カムランド実験と太陽ニュートリノ

三井唯夫
(東北大ニュートリノ科学研究センター(RCNS))

「宇宙ニュートリノ研究会」
2006年7月6日　東京大学宇宙線研究所

Neutrino 2006 Santa Fe

Session IV — Thursday, June 15

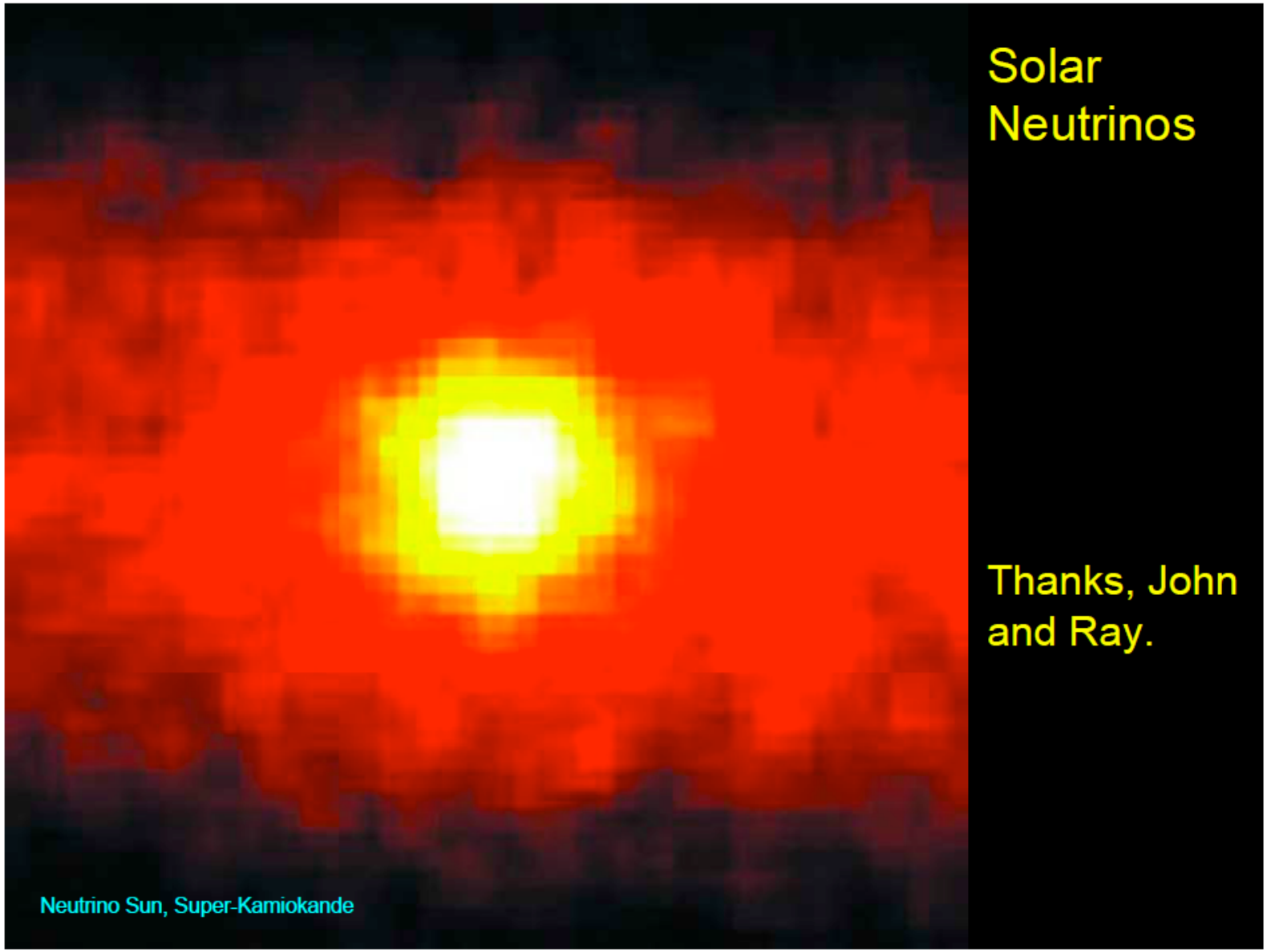
Neutrino Mixing - Solar Neutrinos

10:40-11:10 am	**What We Know and Don't Know about Neutrino Production in Stars** - Sylvaine Turck-Chieze
11:10-11:40 am	**MSW Oscillations - LMA and Subdominant Effects** - Alex Friedland
11:40-11:55 am	**Evidence for sterile neutrinos from solar neutrino flux modulation** - David Caldwell
11:55 am-12:15 pm	**Low-energy Cross Section Measurements** - Roberto Menagazzo (LUNA collaboration)
12:15-1:45 pm	**LUNCH**
1:45-2:10 pm	**Radiochemical Solar Neutrino Experiments** - Vladimir Gavrin (SAGE collaboration)
2:10-2:40 pm	**Active Solar Neutrino Experiments** - Andrew Hime (SNO collaboration)
2:40-3:10 pm	**Future Experiments and Goals** - Bruce Vogelaar (Borexino collaboration)
3:10-3:40 pm	Break

Session V — Thursday, June 15

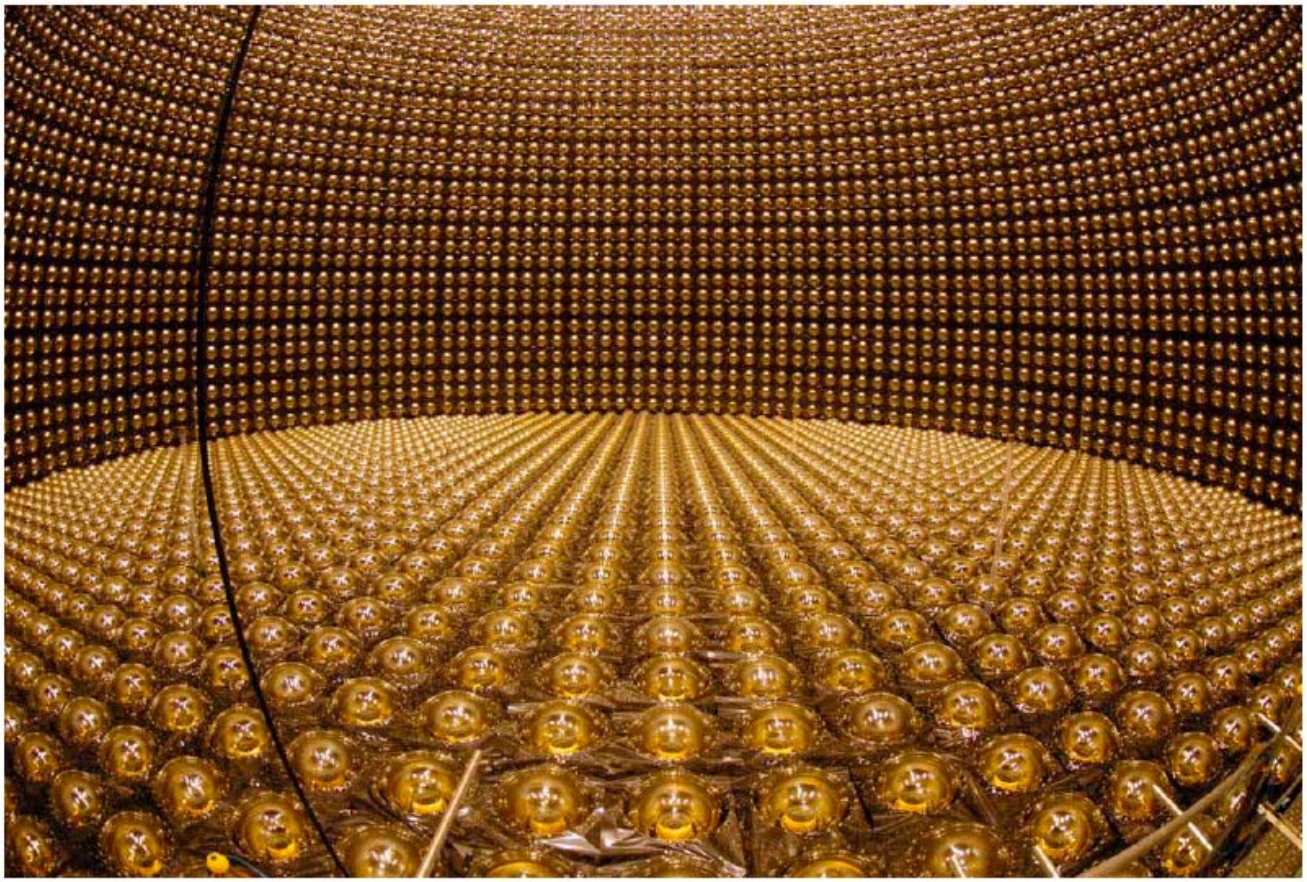
Neutrino Mixing and Other Physics - Reactor Neutrinos

3:40-4:00 pm	**Results and future plans for MuNu** - Zornita Daraktchieva (MuNu collaboration)
4:00-4:25 pm	**KamLAND results and future** - Tadao Mitsui (KamLAND collaboration)
4:25-4:55 pm	**Overview of Future theta13 Reactor Experiments** - Karsten Heeger
4:55-5:15 pm	**Status and Plans for Double Chooz** - David Reyna (Double Chooz collaboration)
5:15-5:40 pm	**The Future for Geoneutrinos** - Raju Raghavan
5:40-6:00 pm	**Neutrino Applications in Reactor Monitoring** - Michel Cribier



Slide by H. Robertson (neutrino 2006) http://neutrinosantafe06.com/

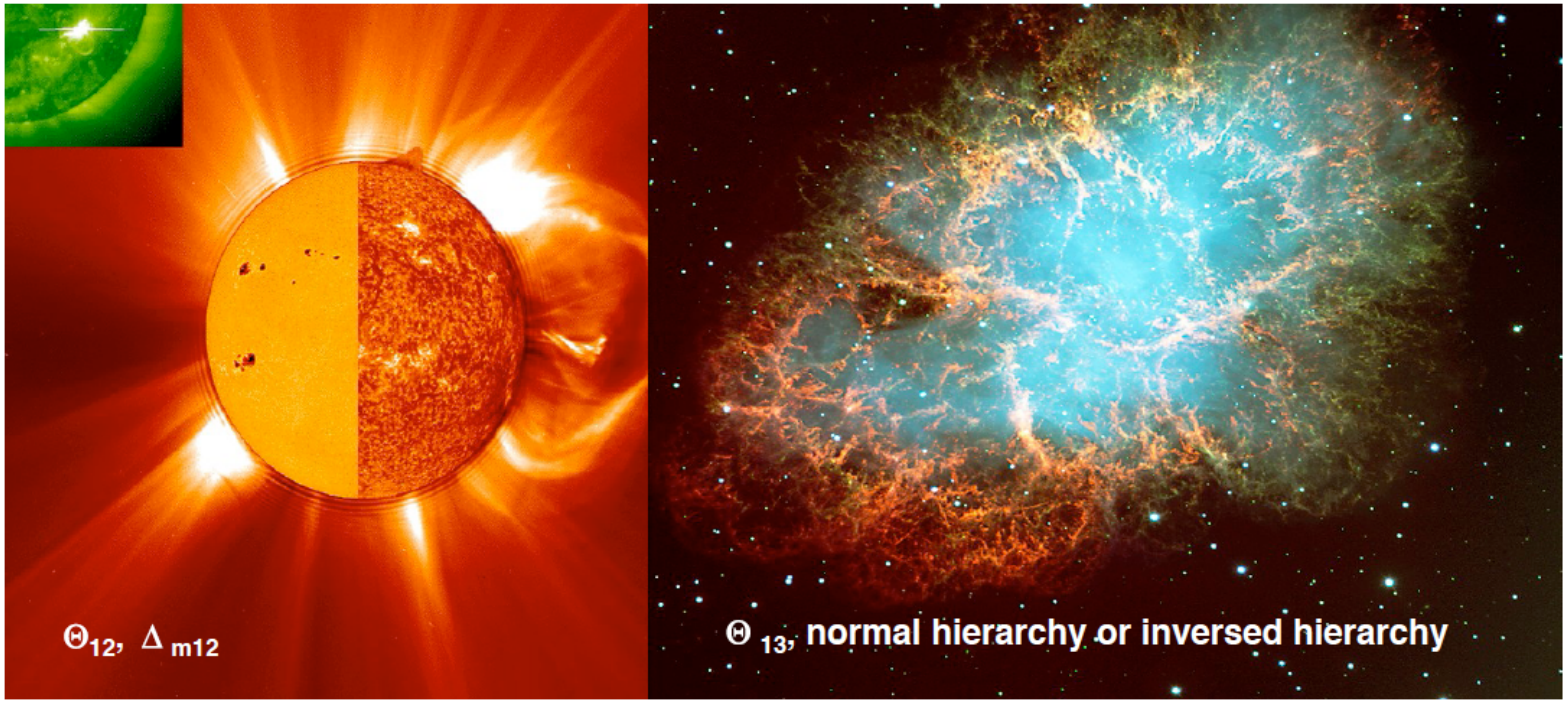
SK-III: 40% PMT Coverage



Full Recovery April 2006

Slide by A. Hime (neutrino 2006)
(from Super-K)

http://neutrinosantafe06.com/



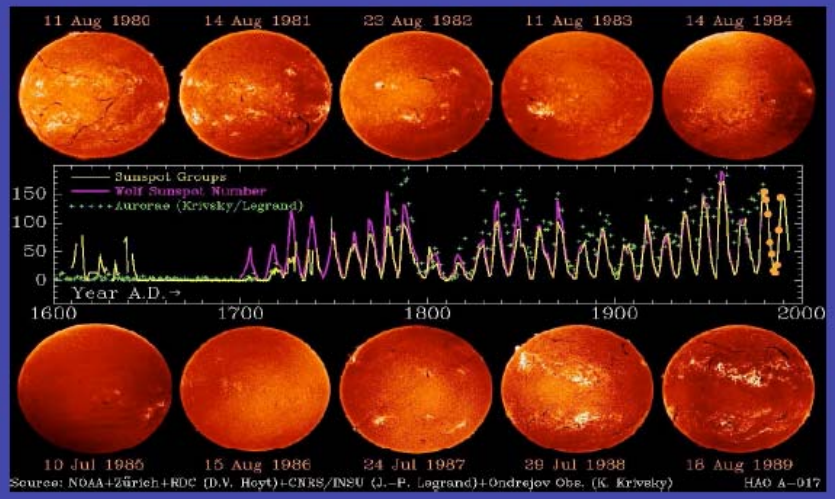
What we know and don't know about Neutrino production in stars ?

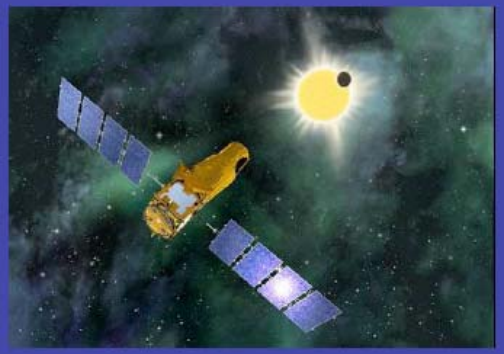
Sylvaine TURCK-CHIEZE Santa Fe June 15th 2006

Slide by S. Turck-Chieze (neutrino 2006) http://neutrinosantafe06.com/

Solar and stellar Perspectives

We are preparing a new step in solar (stellar) modelling where effects of rotation and magnetic fields will be introduced





Space Projects PICARD 2008 then DynaMICS to study the real influence of the Sun on the Earth

COROT launch October 2006, development of asteroseismology,

Then KEPLER

Sylvaine TURCK-CHIEZE Santa Fe June 15th 2006

Slide by S. Turck-Chieze (neutrino 2006) http://neutrinosantafe06.com/

MSW Oscillations - LMA and Subdominant Effects

Alexander Friedland

Theoretical Division, T-8
Los Alamos National Lab

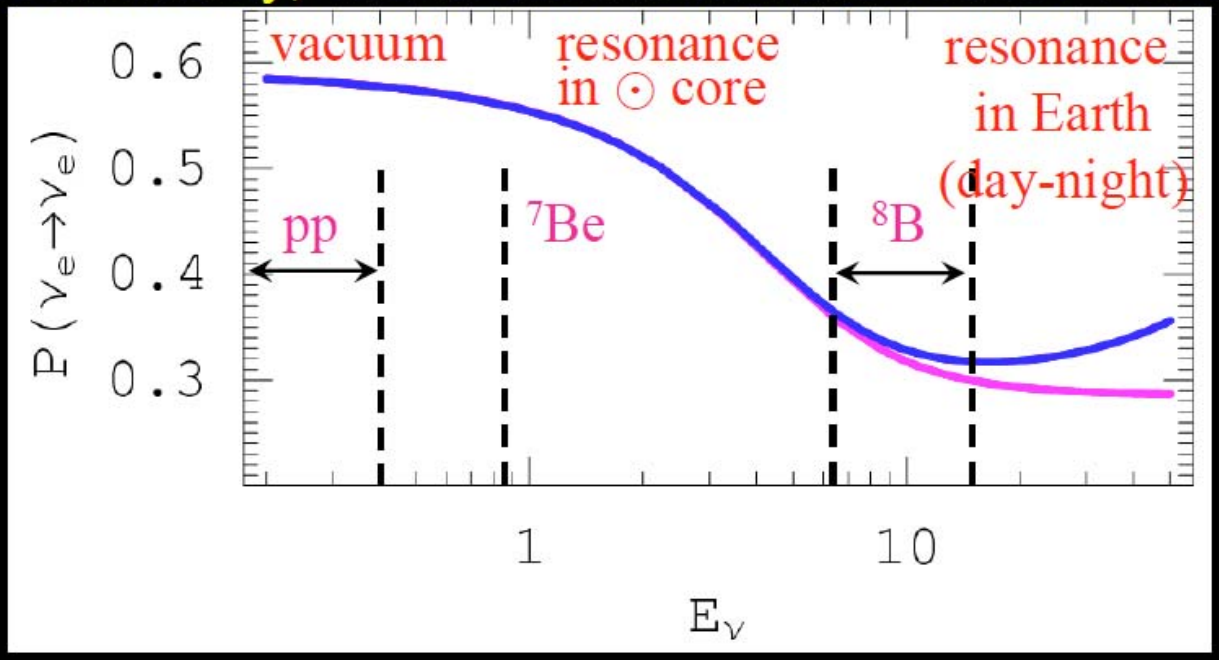
Neutrino 2006, Santa Fe

June 15

Slide by A. Friedland (neutrino 2006) http://neutrinosantafe06.com/

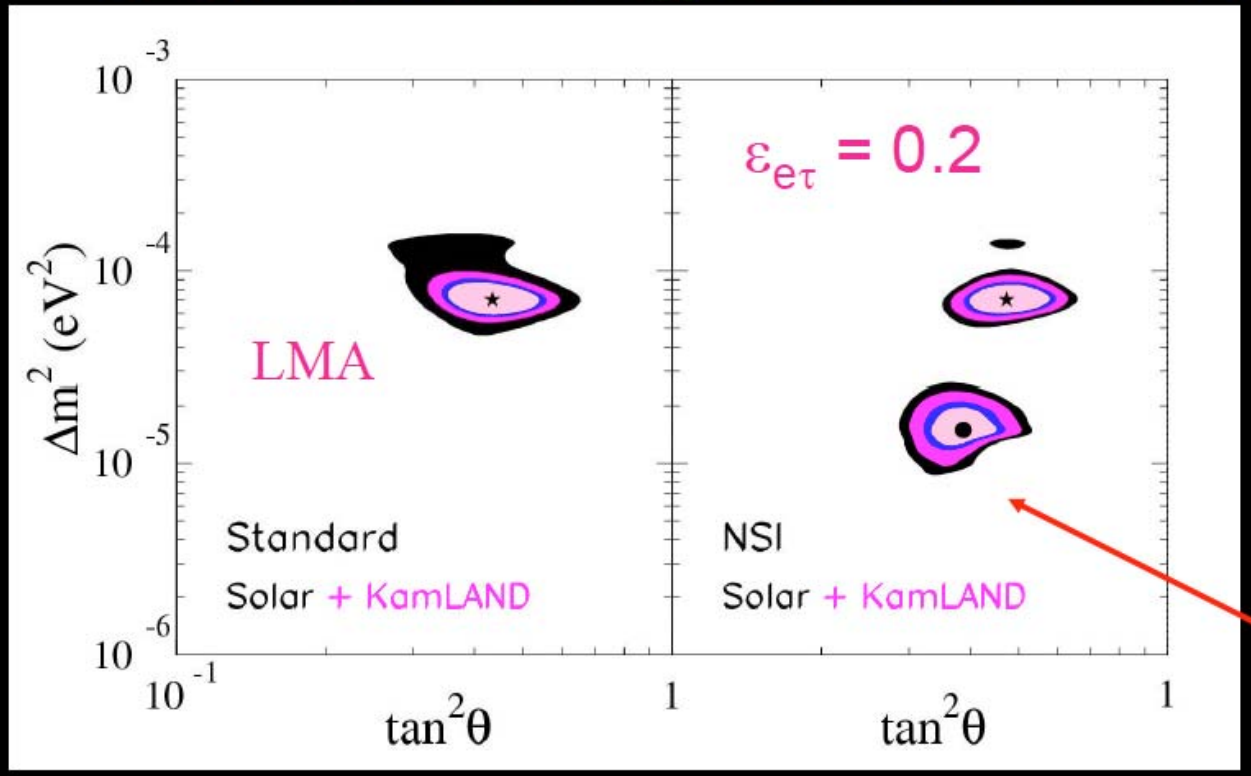
Designing LMA

- Fine-tune Δm^2 such that the transition between the regimes occurs at the intermediate solar energies
  $\Delta m^2 \sim G_F N_\odot (10^6 eV) \sim$ a few $\times 10^{-5}$ eV^2
- Remarkably, checks with KamLAND reactor ν osc.!



Slide by A. Friedland (neutrino 2006) http://neutrinosantafe06.com/

More radical effects on solar ν's



Friedland, Lunardini, Peña-Garay, Phys. Lett. B594, 347 (2004);

Guzzo, de Holanda, Peres, Phys.Lett. B591, 1 (2004);

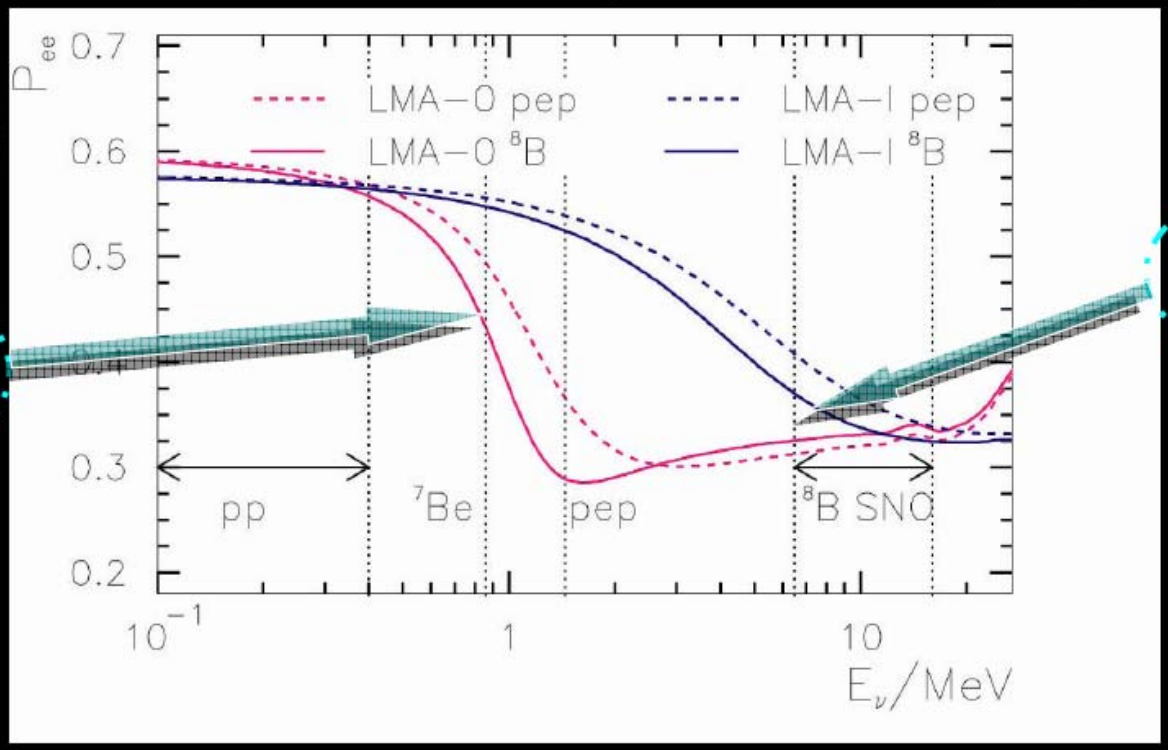
Miranda, Tortola, Valle, hep-ph/0406280

Slide by A. Friedland (neutrino 2006) http://neutrinosantafe06.com/

Survival probability for LMA-0

Phys. Lett. B594, 347 (2004)

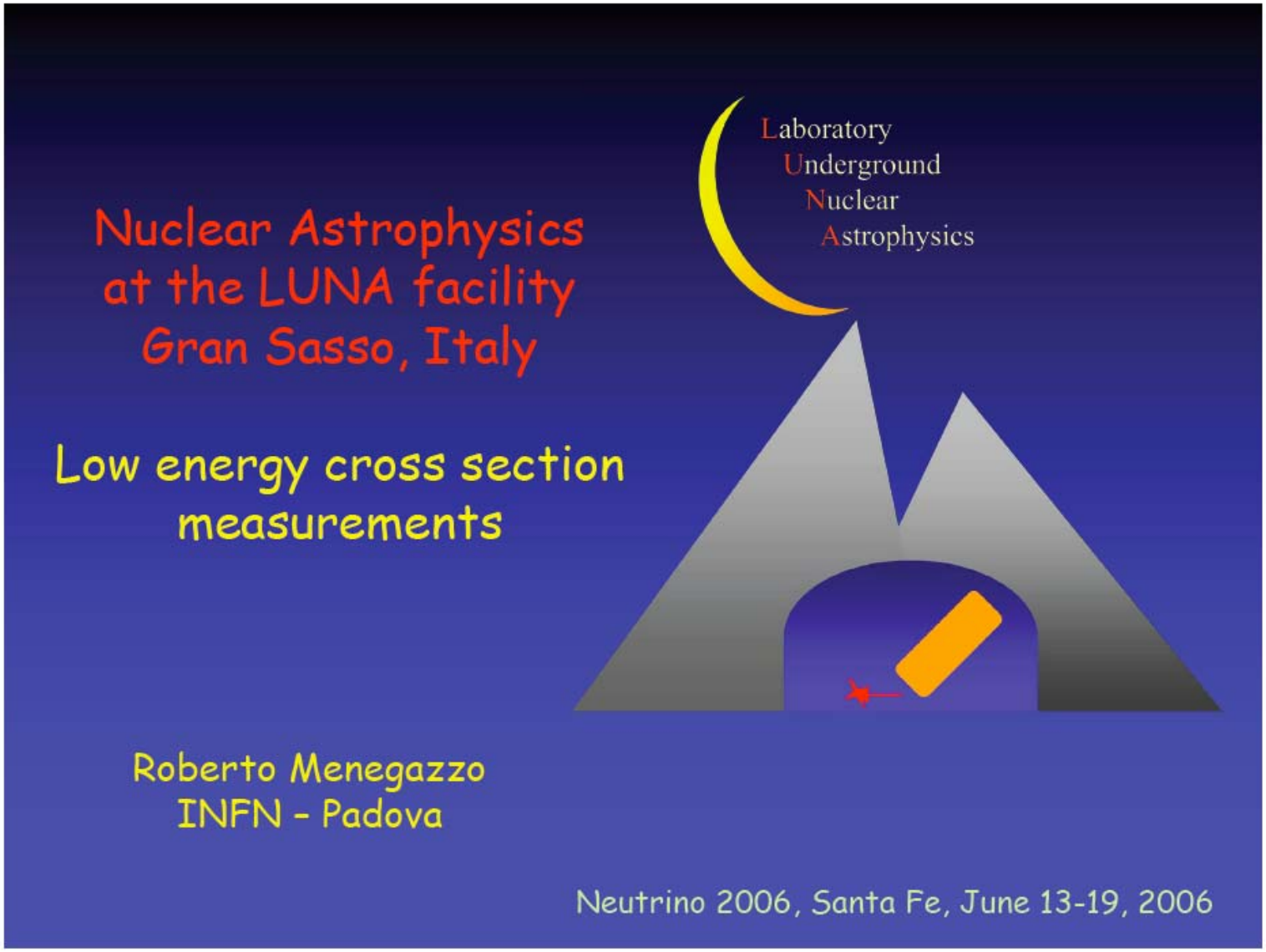
Distinct predictions



Borexino

SNO

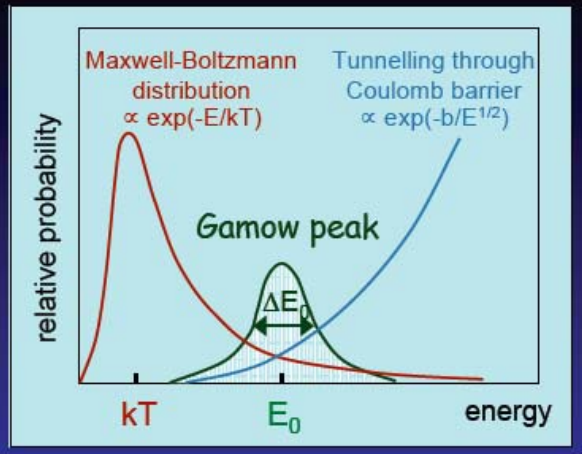
Slide by A. Friedland (neutrino 2006) http://neutrinosantafe06.com/



Slide by R. Menegazzo (neutrino 2006) http://neutrinosantafe06.com/

Stellar burning rates

$$\langle \sigma v \rangle = \int \sigma(E) \cdot E \cdot \exp(-E/kT)\, dE$$



ASTROPHYSICAL S(E)-FACTOR

$$\sigma(E) = E^{-1} \exp(-2\pi\eta)\, S(E)$$

non-nuclear origin — STRONG energy dependence

nuclear origin — WEAK energy dependence

$2\pi\eta = 31.29\, Z_1 Z_2 (\mu/E)^{\frac{1}{2}}$ Gamow factor

μ in amu and E_{cm} in keV

Energy available from thermal motion

$kT \sim 8.6 \times 10^{-8}\, T[K]$ keV

T ~ 15x10⁶ K (e.g. our Sun) ⇒ kT ~ 1 keV

T ~ 10¹⁰ K (Big Bang) ⇒ kT ~ 2 MeV

Maximum reaction rate at E_0

$$E_0 = \left(\frac{bkT}{2}\right)^{3/2} = 0.122\left(Z_1^2 Z_2^2 A\right)^{1/3} T_9^{2/3} \text{ MeV}$$

$$\Delta E = \frac{4}{\sqrt{3}}\sqrt{E_0 kT} = 0.237\left(Z_1^2 Z_2^2 A\right)^{1/6} T_9^{5/6} \text{ MeV}$$

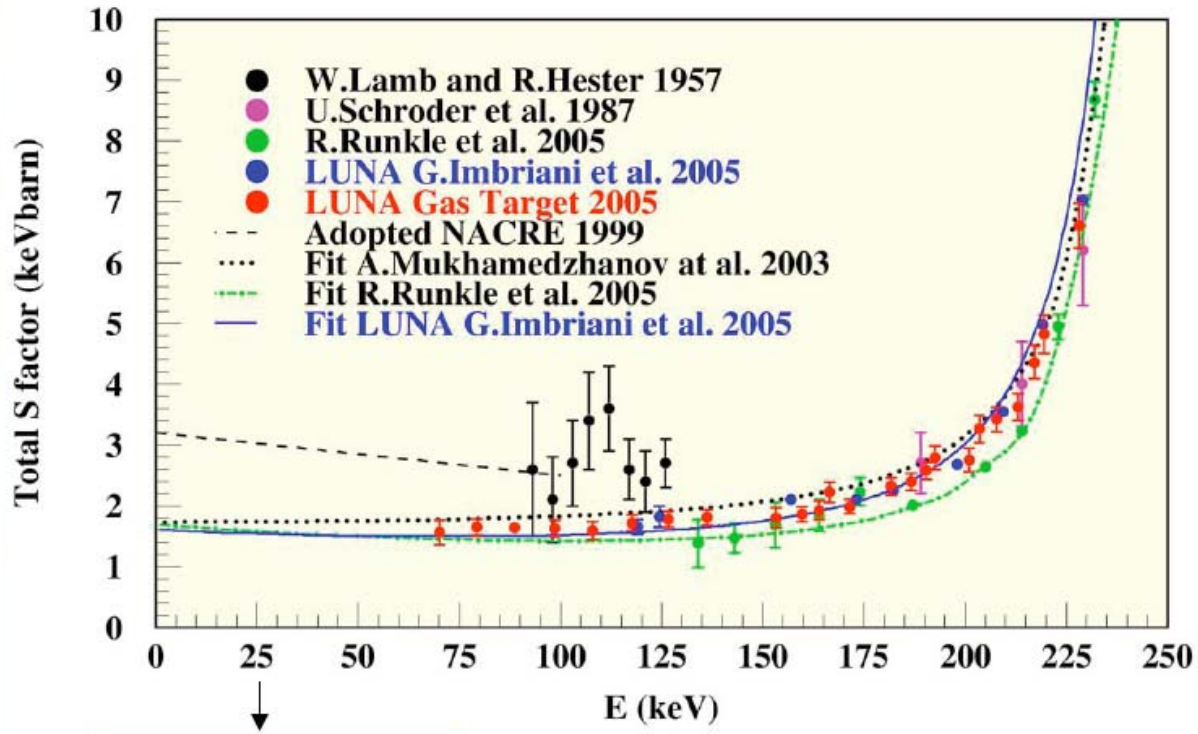
Data EXTRAPOLATION down to astrophysical energies is NEEDED !

... but very DANGEROUS !

Slide by R. Menegazzo (neutrino 2006) http://neutrinosantafe06.com/

$^{14}N(p,\gamma)^{15}O$: total S- factor

A. Lemut et al., Phys. Lett B 643, 483 (2006)



Slide by R. Menegazzo (neutrino 2006) http://neutrinosantafe06.com/

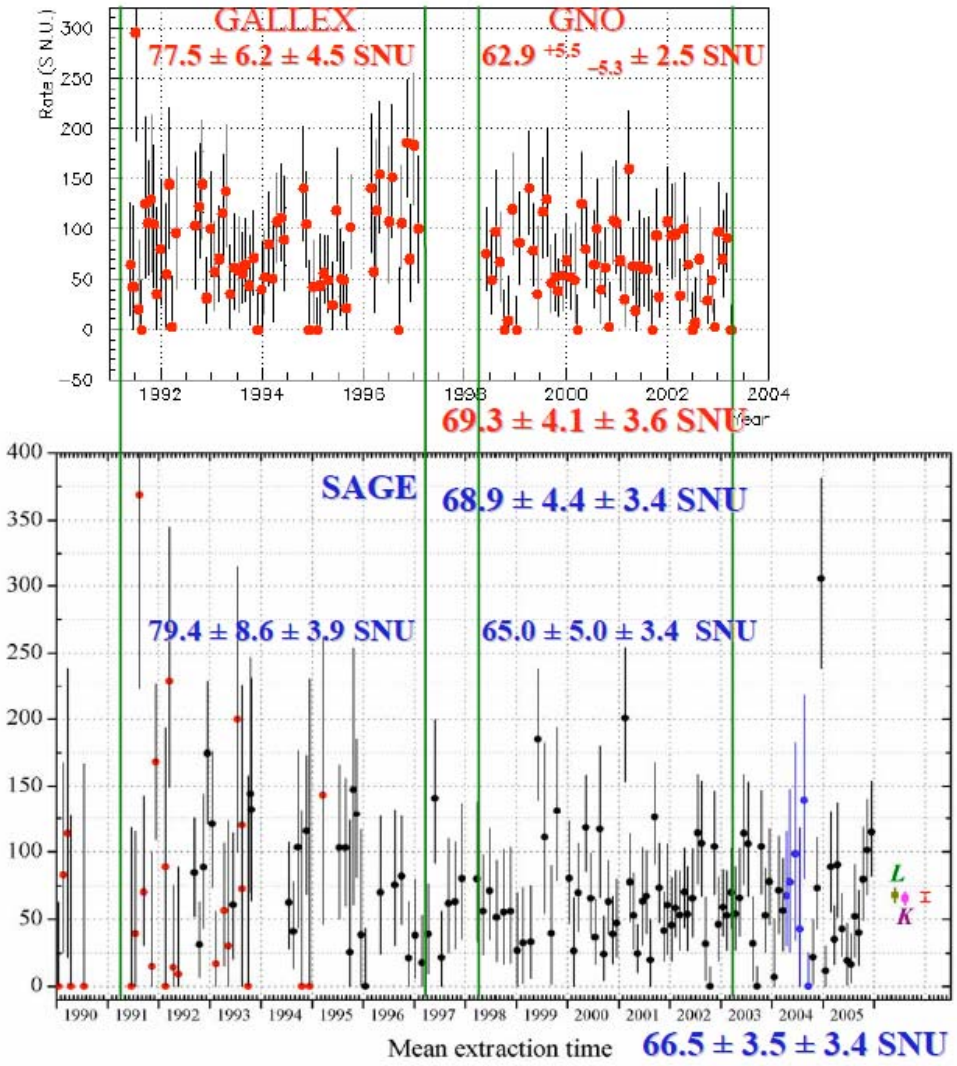
LUNA: future with the 400 kV facility and even more...

reaction	Q- value (MeV)	Gamow energy (keV)	Lowest meas. Energy (keV)	LUNA limit (keV, estimate)
$^{12}C(\alpha,\gamma)^{16}O$	7.16	300	950	500
$^{22}Ne(\alpha,n)^{25}Mg$	-0.47	470-700	850	630
$^{13}C(\alpha,n)^{16}O$	2.21	170-250	270	200
$^{2}H(\alpha,\gamma)^{6}Li$	1.47	50-300	700 (direct) 50 (indirect)	50
$^{15}N(p,\gamma)^{16}O$	12.13	10-300	130	50
$^{17}O(p,\gamma)^{18}F$	5.6	35-260	300	65
$^{18}O(p,\gamma)^{19}F$	8.0	50-200	143	143
$^{23}Na(p,\gamma)^{24}Mg$	11.7	100-200	240	138
$^{22}Ne(p,\gamma)^{23}Na$	8.8	50-300	250	68
$^{15}N(\alpha,\gamma)^{19}F$	4.01	364	536	364

Red: feasible at LUNA2; Blue: LUNA3 required; Green: LUNA3 desireable

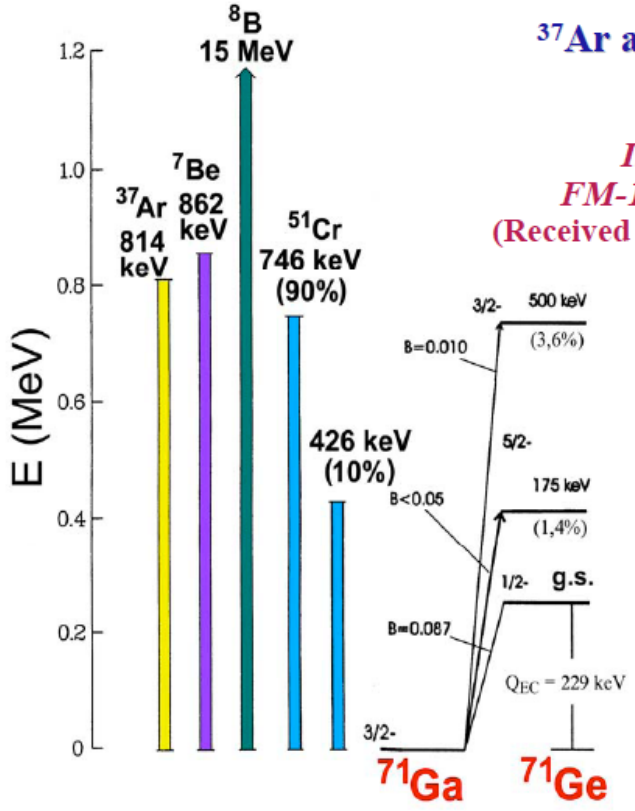
Slide by R. Menegazzo (neutrino 2006) http://neutrinosantafe06.com/

Slide by V.N. Gavrin (neutrino 2006) http://neutrinosantafe06.com/



Slide by V.N. Gavrin (neutrino 2006) http://neutrinosantafe06.com/

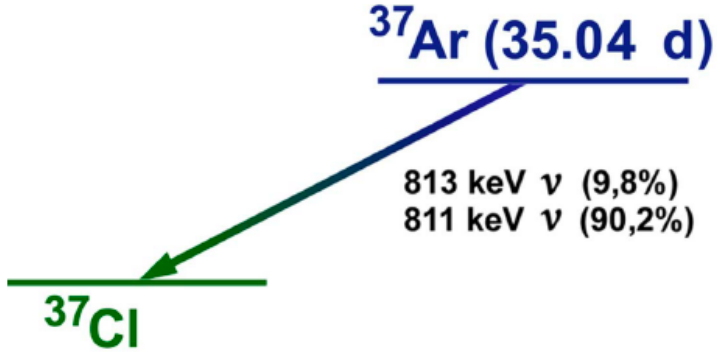
PHYSICAL REVIEW C VOLUME 38, NUMBER 5 NOVEMBER 1988



^{37}Ar as a calibration source for solar neutrino detectors

W.Haxton
Institute for Nuclear Theory, Department of Physics,
FM-15, University of Washington, Seattle Washington 98195
(Received 18 July 1988; revised manuscript received 12 September 1988)

I discuss the possibility that a high-intensity 811-keV ^{37}Ar neutrino source, produced by neutron capture on separated ^{36}Ar , could be used to calibrate the ^{7}Be solar neutrino capture cross sections of ^{71}Ga, ^{127}I, and other detectors…



The advantages of a ^{37}Ar source compared to a ^{51}Cr source

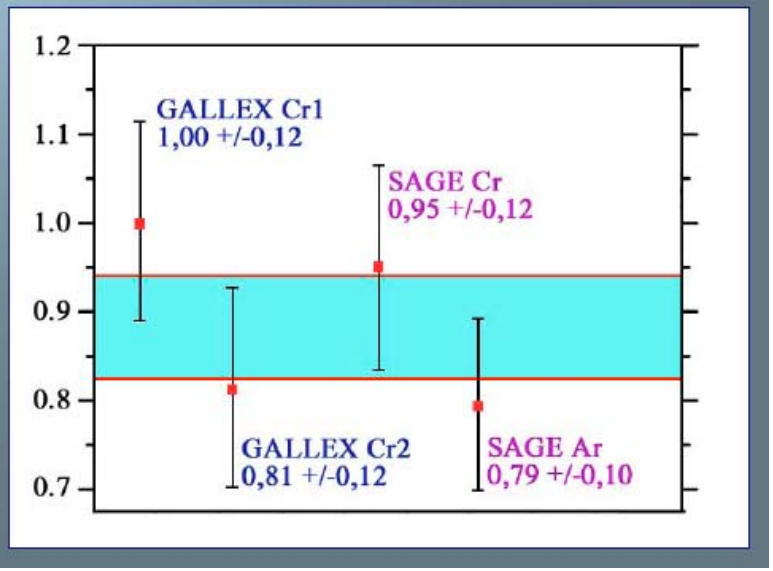
1. Practically free of radioactive impurities.
2. Half-life longer (35 d compared to 27 d).
3. The neutrino energy is greater (811 keV compared to 747 keV).
4. The decay is purely to the ground state (100% compared to 90%).

Slide by V.N. Gavrin (neutrino 2006) http://neutrinosantafe06.com/

Comparison of source experiments with Ga

Item	GALLEX Cr1[2, 3]	GALLEX Cr2 [2,3]	SAGE ^{51}Cr [1]	SAGE ^{37}Ar
Source production				
Mass of reactor target (kg)	35.5	35.6	0.512	330
Target isotopic purity	38.6% ^{50}Cr	38.6% ^{50}Cr	92.4% ^{50}Cr	96.94% ^{40}Ca
Source activity (kCi)	1714 +30/-43	1868 +89/-57	516.6 ± 6.0	409 ± 2
Specific activity (kCi/g)	0.048	0.052	1.01	92.7
Gallium exposure				
Gallium mass (tones)	30.4 ($GaCl_3$:HCl)	30.4 ($GaCl_3$:HCl)	13.1 (Ga metal)	13.1 (Ga metal)
Gallium density (10^{21} ^{71}Ga/cm^3)	1.946	1.946	21.001	21.001
Measured production rate ρ (^{71}Ge/d)	11.9 ±1.1 ±0.7	10.7 ±1.2 ±0.7	14.0 ±1.5 ±0.8	11.0 +1.0/-0.9 ±0.6
R=P(measured)/P(predicted)	1.00 +0.11/-0.10	0.81 ±0.10	0.95 ±0.12	0.79 +0.09/-0.10

The weighted average value of *R*, the ratio of measured to predicted ^{71}Ge production rates, is 0.88 ± 0.05, more than two standard deviations less than unity.



Slide by V.N. Gavrin (neutrino 2006) http://neutrinosantafe06.com/

Active Solar Neutrino Experiments

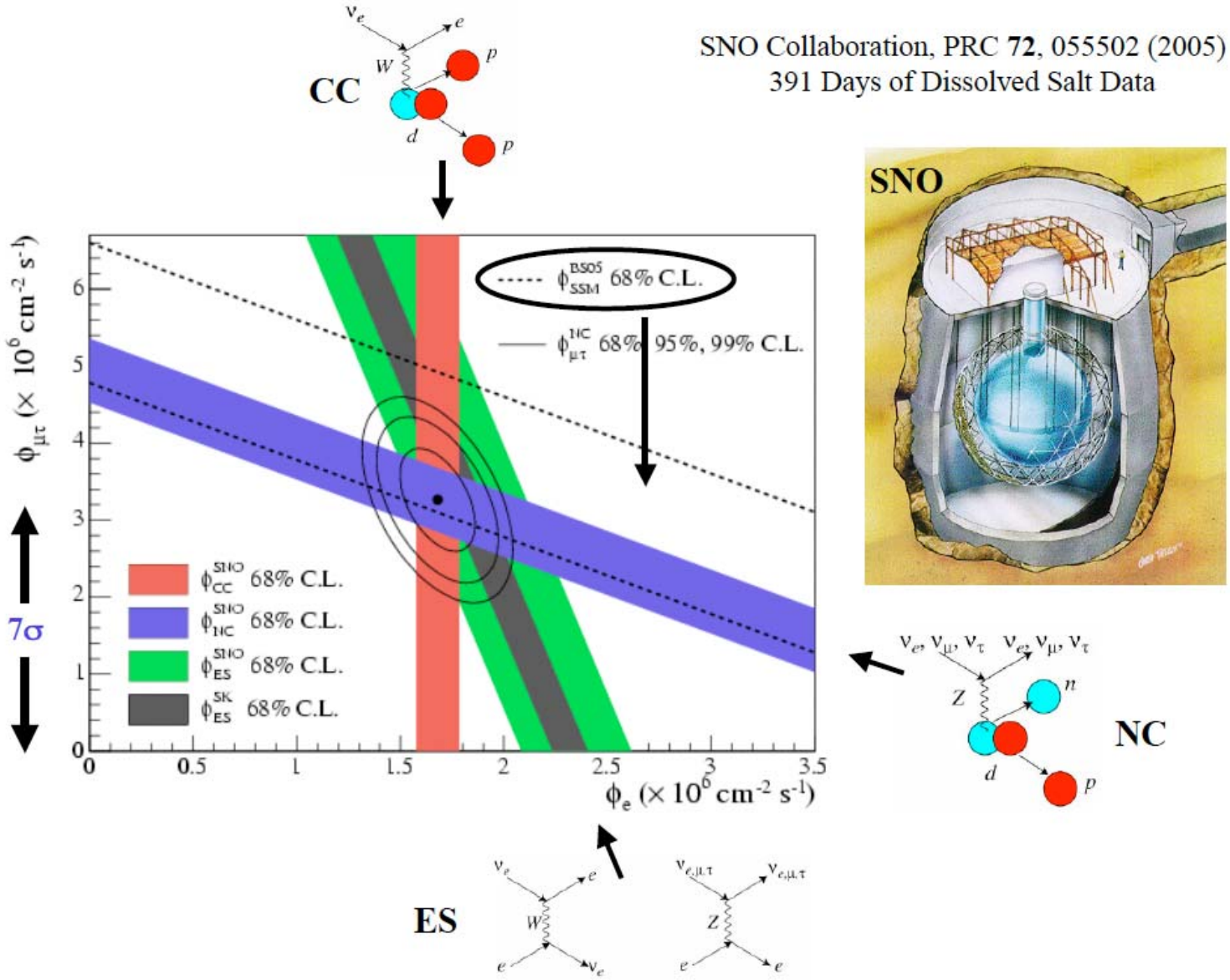
[Results & Prospects for Solar Neutrinos at SNO & SK]

- Update Results on Fluxes, Spectral Distortions, D/N-Asymmetries
- Temporal Modulations & Flux Periodicities
- New Search for hep Solar Neutrinos
- Future Prospects for ^{8}B Solar Neutrinos

Andrew Hime
Physics Division, Los Alamos National Laboratory

Neutrino 2006, Sante Fe, New Mexico

Slide by A. Hime (neutrino 2006) http://neutrinosantafe06.com/



Slide by A. Hime (neutrino 2006) http://neutrinosantafe06.com/

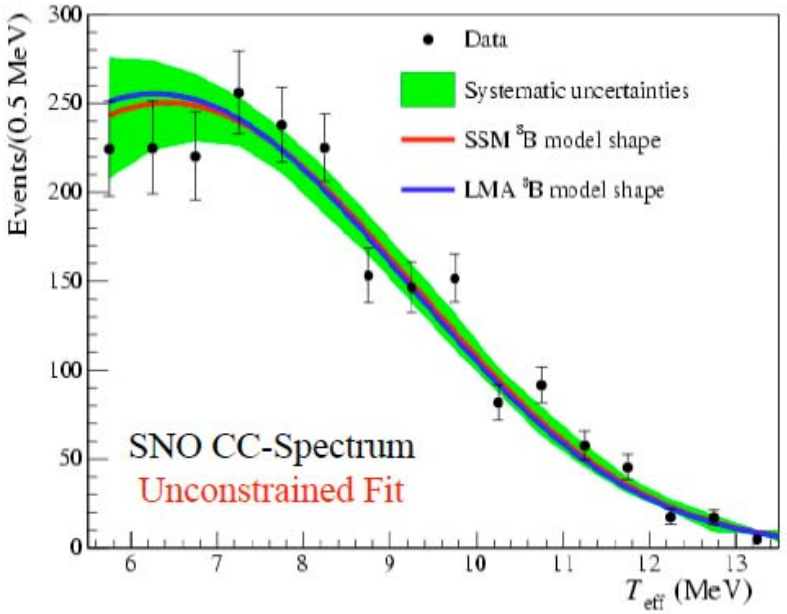
SNO Collaboration, PRC **72**, 055502 (2005)
391 Days of Dissolved Salt Data

$$\phi_{CC} = 1.68\ ^{+0.06}_{-0.06}(\text{stat.})^{+0.08}_{-0.09}(\text{syst.})$$

$$\phi_{NC} = 4.94\ ^{+0.21}_{-0.21}(\text{stat.})^{+0.38}_{-0.34}(\text{syst.})$$

$$\phi_{ES} = 2.35\ ^{+0.22}_{-0.22}(\text{stat.})^{+0.15}_{-0.15}(\text{syst.})$$

x 10^6 cm^{-2} s^{-1}



$$A_{DN} = \frac{\text{(Night-Day)}}{\text{(Day+Night)/2}}$$

$$A_{\text{salt} + D_2O} = 0.037 \pm 0.040$$

(assuming $A_{NC} = 0$)

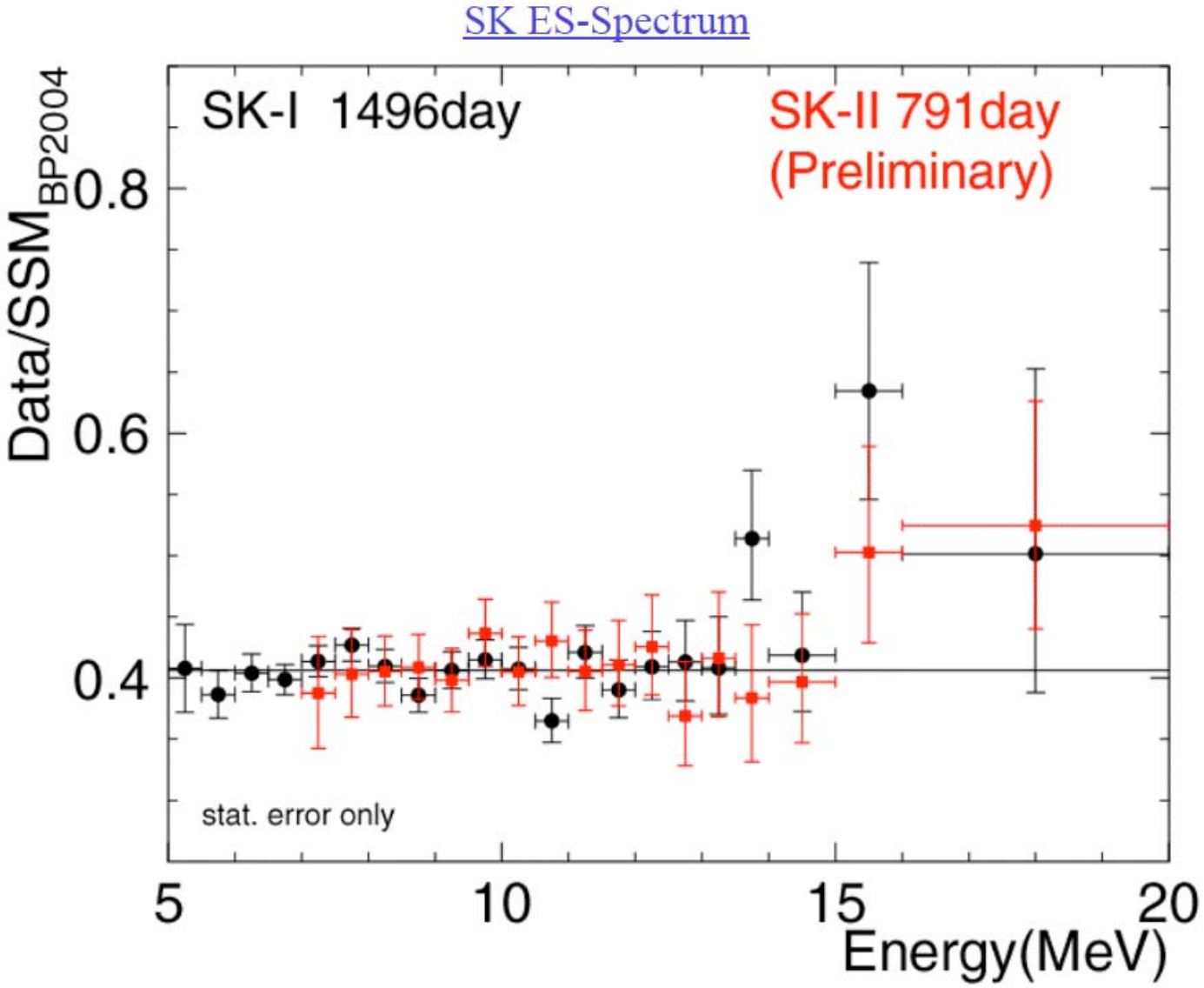
Statistical Limitation for Observing "Small" Day-Night Asymmetry

➔ Combined "Low-Energy Threshold" Analysis of D2O & Salt-Phase Data Sets

➔ Break CC-NC Correlation with Neutral-Current-Detectors (NCDs)

➔ Ultimately Combine Data from all Phases

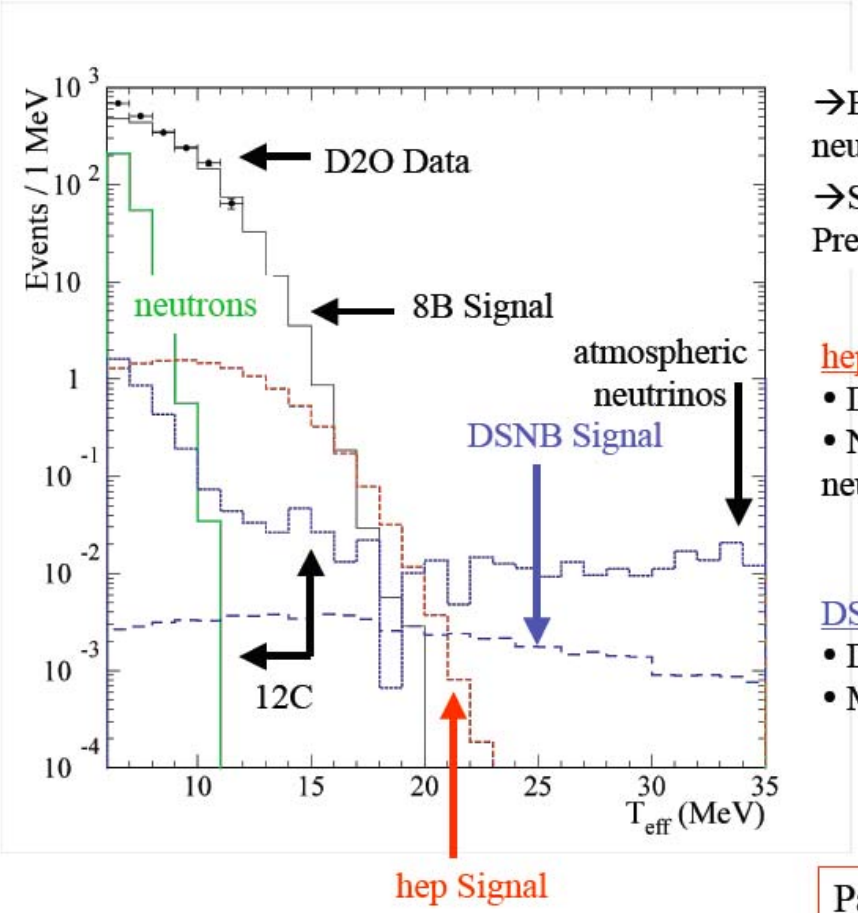
Slide by A. Hime (neutrino 2006) http://neutrinosantafe06.com/



Slide by A. Hime (neutrino 2006)
(from Super-K)

http://neutrinosantafe06.com/

Preliminary Results from Analyzing SNO (Phase-I) D_2O Data Set
in Search of hep Solar Neutrinos & the Diffuse Supernovae Neutrino Background (DSNB)



→Both signals lie in the region between 8B solar neutrinos and atmospheric neutrinos …

→Search by counting number of events within a Predefined energy window or signal box …

hep neutrinos
- Dominant BGND is 8B solar neutrinos
- Normalize with low-energy fit with account for neutrino oscillations ($6 < T_{eff} < 12$ MeV)

DSNB neutrinos
- Dominant BGND is atmospheric neutrinos
- Michel Electrons

Paper on hep & DSNP is forthcoming …
… focus on hep solar neutrinos here …

Slide by A. Hime (neutrino 2006) http://neutrinosantafe06.com/

SNO Preliminary Results for hep Solar Neutrinos

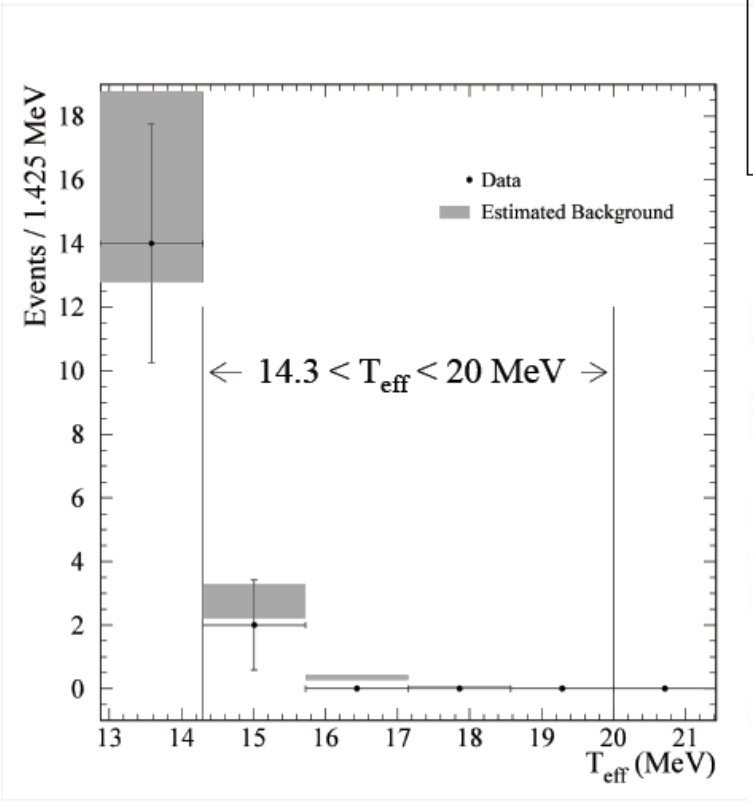
SNO: $\phi_{hep} < 2.3 \times 10^4$ cm^{-2} s^{-1} (90% C.L.)

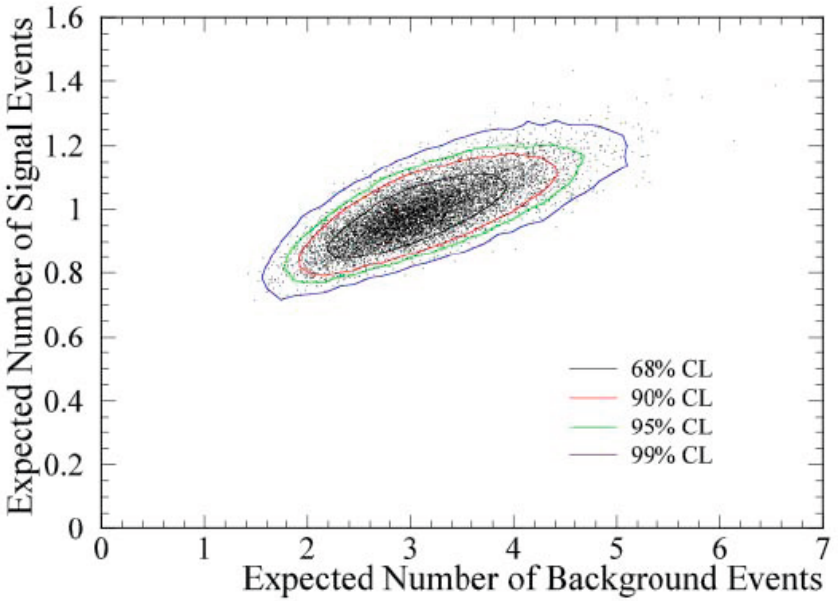
X 6.5

All Flavors

SK: $\phi_{hep} < 7.3 \times 10^4$ cm^{-2} s^{-1} (90% C.L.)

SK: $\phi_{hep} < 1.5 \times 10^5$ cm^{-2} s^{-1} (90% C.L.)





Expect 3.1 ± 0.6 BGND Events

Expect 0.99 ± 0.09 Signal Events

We Observe 2 Events in the Signal Box

Slide by A. Hime (neutrino 2006) http://neutrinosantafe06.com/

SOLAR NEUTRINOS

Extraordinary Neutrino Beam Free of Charge

For NEUTRINO PHYSICS:

- WELL DEFINED HIGHEST FLUX (~10^{11}cm^{-2}s^{-1})
- PURE FLAVOR SOURCE - ν_e only
- LONGEST BASELINE (10^8 km)
- HIGH DENSITY UP TO 160 g/cm^3; ~ 10^{11} g/cm^2 path
- LOWEST ENERGIES (keV to MeV)
- PRESENCE OF HIGH MAGNETIC FIELDS
- FULL SPECTRUM: ENERGY DEPENDENT EFFECTS

Best tools for investigating neutrino flavor phenomena in Vacuum and in Matter

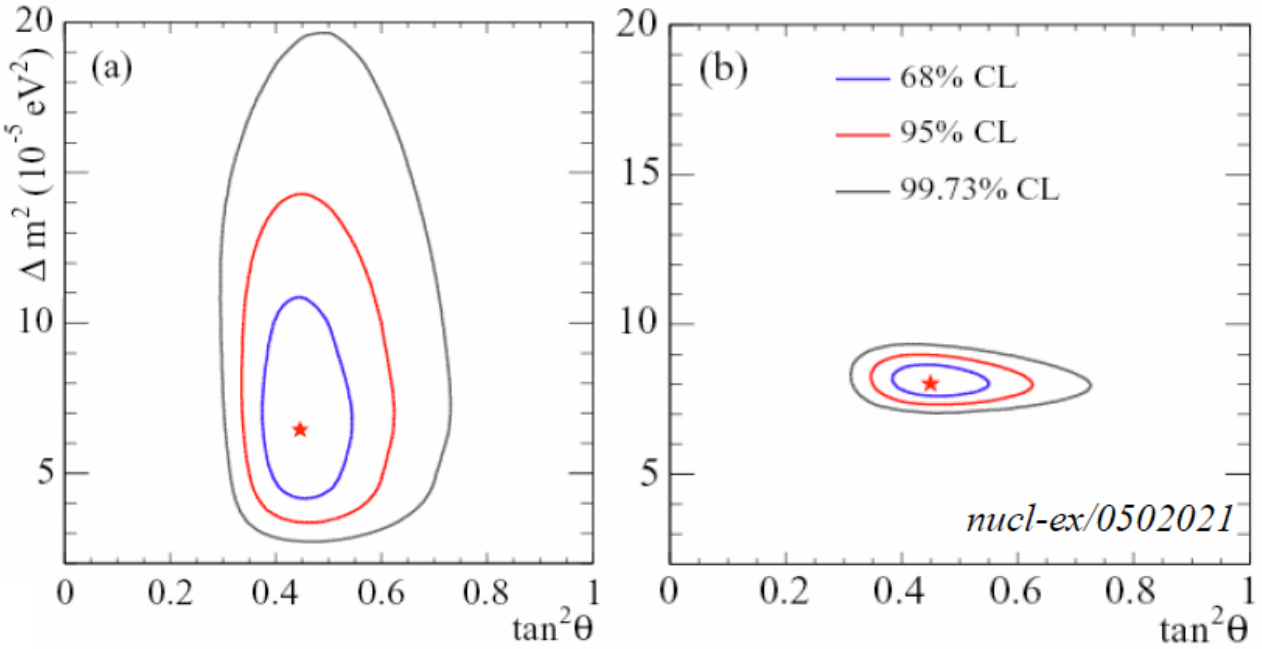
For ASTROPHYSICS

Best tool for unprecedented look at how a real Star works
- in the past, present and future

Slide by R.B. Vogelaar (neutrino 2006) http://neutrinosantafe06.com/

Neutrino Oscillation Explanation

MSW explanation: resonant conversion at ^{8}B energies



Solar data: Δm_{12}^2, θ

add anti-neutrinos (KamLAND) (assumes CPT): Δm_{12}^2, θ

MSW-LMA is based on the *combined* results from many complementary experiments

Slide by R.B. Vogelaar (neutrino 2006) http://neutrinosantafe06.com/

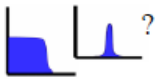
This program will *individually* measure:

- pp flux 3% (CC); 1.5% (ES)
- ^{7}Be flux 4% (CC); 3% (ES)
- pep flux 15% (CC); 3% (ES)
- CNO flux 8% (CC); ?

this is the best and perhaps only way probe the extremely fertile solar ν parameter space to:

Slide by R.B. Vogelaar (neutrino 2006) http://neutrinosantafe06.com/

Summary

Experiment	mono-energetic ν response	Solar ν Sensitivity	%pp 5 yr	%^{7}Be 5 yr	Status
Borexino		^{7}Be, pep?		5	results in a few years
KamLAND		^{7}Be, CNO?		5	results in a few years
LENS		pp ⇔ CNO	3	5	ready to prototype
MOON		pp ⇔ CNO			r&d only (for now)
CLEAN		pp ⇔ ^{7}Be	1	< 3	ready to prototype
HERON		pp ⇔ ^{7}Be	1.5	5	r&d only (for now)
TPC		pp ⇔ ^{7}Be			r&d
XMass		pp, ^{7}Be			100 kg prototype
SNO+		^{7}Be, pep	1.5(pep)		TDR Fall 06, construct 07

Slide by R.B. Vogelaar (neutrino 2006) http://neutrinosantafe06.com/

KamLAND Results and Future

Tadao Mitsui
(Research Center for Neutrino Science, Tohoku U.)
for the KamLAND Collaboration

The XXII International Conference on
Neutrino Physics and Astrophysics
June 13-19, 2006, Santa Fe

KamLAND collaboration

T. Araki, S. Enomoto, K. Furuno, Y. Gando, K. Ichimura, H. Ikeda, K. Inoue, Y. Kishimoto, M. Koga, Y. Koseki, T. Maeda, T. Mitsui, M. Motoki, K. Nakajima, K. Nakamura, H. Ogawa, M. Ogawa, K. Owada, J.-S. Ricol, I. Shimizu, J. Shirai, F. Suekane, A. Suzuki, K. Tada, S. Takeuchi, K. Tamae, Y. Tsuda, H.Watanabe, J. Busenitz, T. Classen, Z. Djurcic, G. Keefer, D. S. Leonard, A. Piepke, E. Yakushev, B. E. Berger, Y. D. Chan, M. P. Decowski, D. A. Dwyer, S. J. Freedman, B. K. Fujikawa, J. Goldman, F. Gray, K. M. Heeger, L. Hsu, K. T. Lesko, K.-B. Luk, H. Murayama, T. O'Donnell, A.W. P. Poon, H. M. Steiner, L. A. Winslow, C. Jillings, C. Mauger, R. D. McKeown, P. Vogel, C. Zhang, C. E. Lane, T. Miletic, G. Guillian, J. G. Learned, J. Maricic, S. Matsuno, S. Pakvasa, G. A. Horton-Smith, S. Dazeley, S. Hatakeyama, A. Rojas, R. Svoboda, B. D. Dieterle, J. Detwiler, G. Gratta, K. Ishii, N. Tolich, Y. Uchida, M. Batygov, W. Bugg, Y. Efremenko, Y. Kamyshkov, A. Kozlov, Y. Nakamura, H. J. Karwowski, D. M. Markoff, R. M. Rohm, W. Tornow, R. Wendell, M.-J. Chen, Y.-F. Wang, F. Piquemal

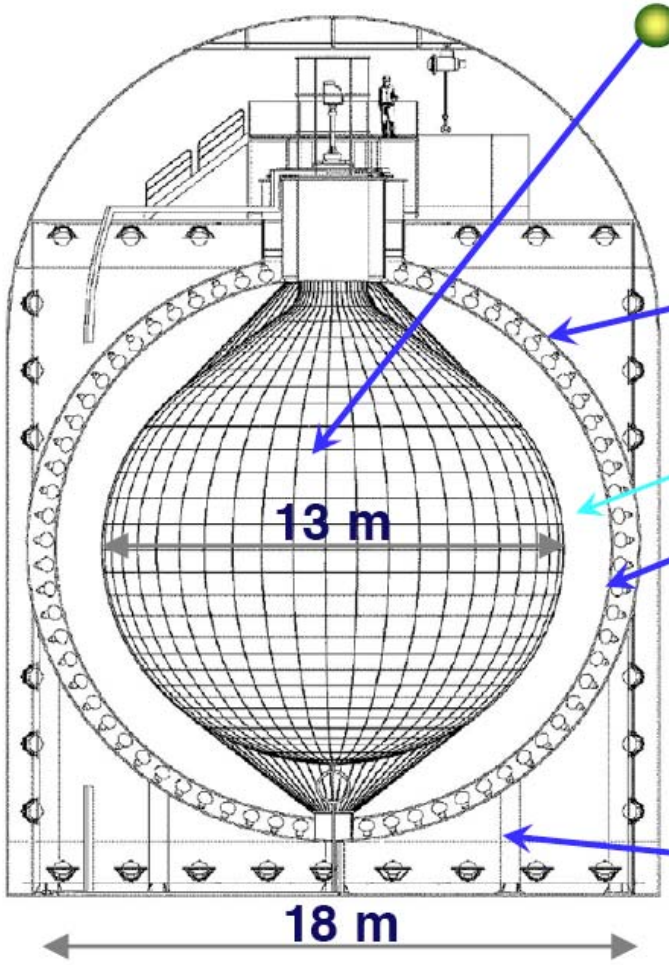
@Laforet Zao Resort & Spa (Oct. 8, 2005)

KamLAND results and future

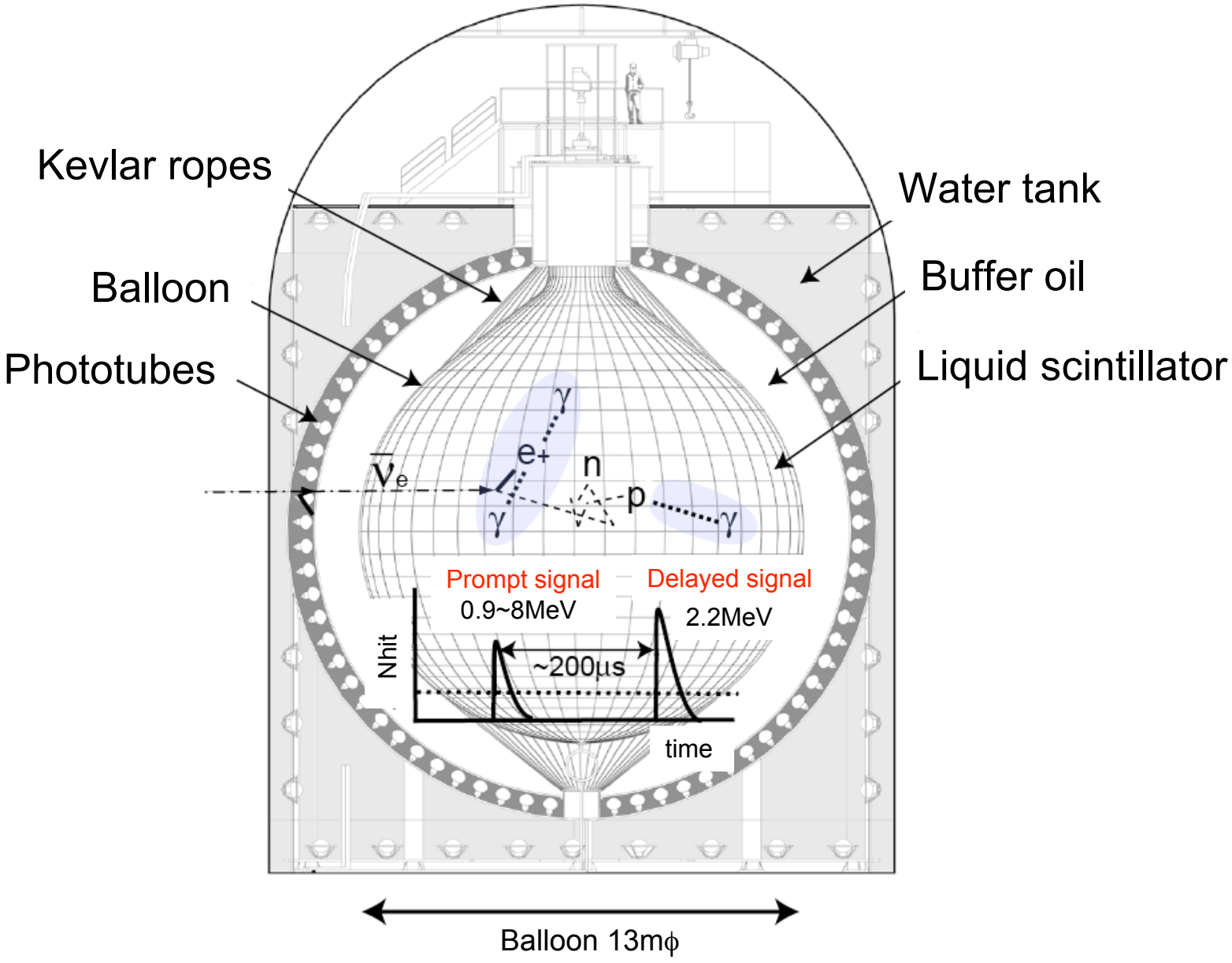
- Reactor results and future
- Geoneutrino results and future
- Solar neutrino future
  - ^{7}Be
  - pep, CNO, low-energy ^{8}B
- Other physics
  - Solar $\overline{\nu}_e$, supernova, and other high energy $\overline{\nu}_e$
  - Invisible decay of neutron

KamLAND Detector

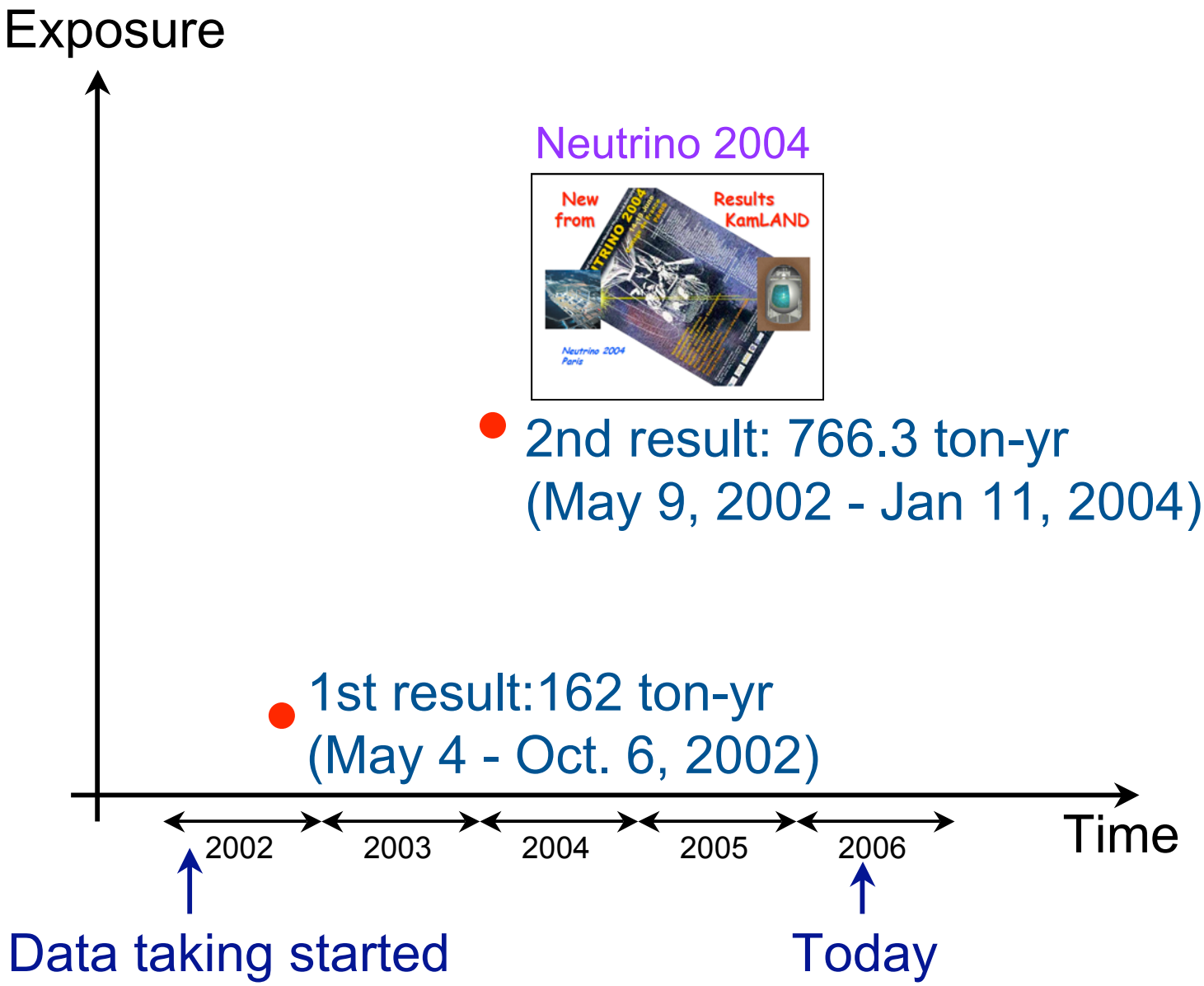
- detector location: old Kamiokande site
  : 2700 m.w.e.
- 1000 ton liquid scintillator
  : 80% (dodecane) + 20% (pseudocumene)
  + 1.52 *g/l* PPO
  : housed in spherical plastic balloon
- 3000 m^3 stainless steel vessel
  : filled with a mixture of paraffin oil and dodecane ($\Delta\rho$ = 0.04%)
- 1325 17-inch + 554 20-inch PMT's
  commissioned in February, 2003
  photocathode coverage : 22% → 34%
  energy resolution at 1 MeV : 7.3% → 6.3%
- water Cerenkov outer detector



Kamioka Liquid *Antineutrino* Detector

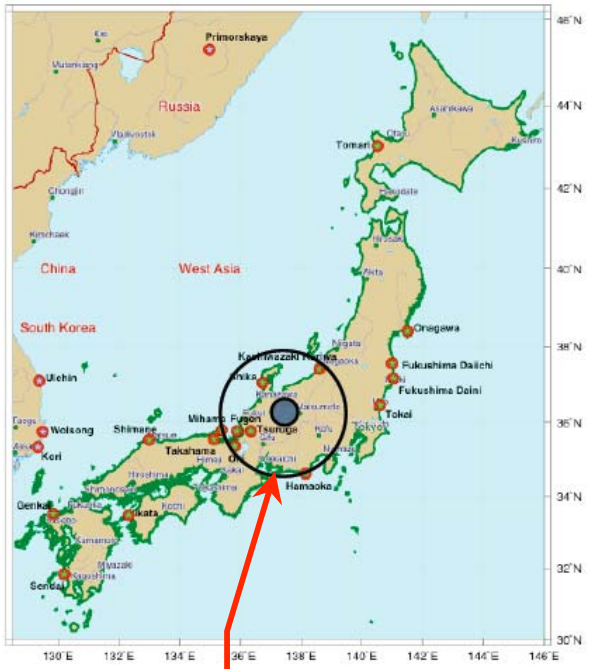


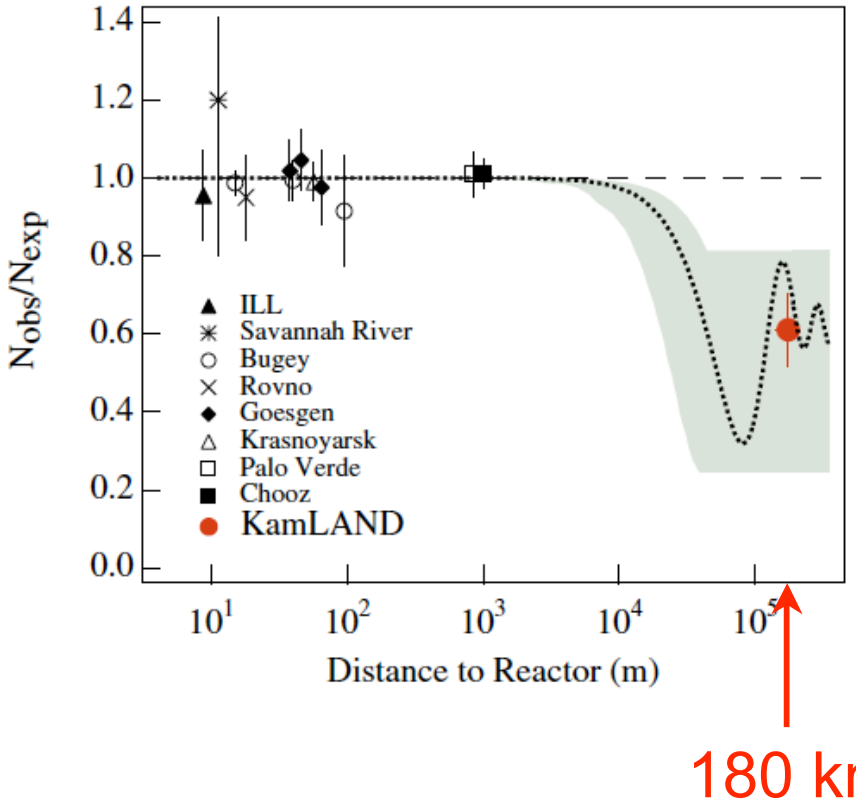
Reactor results



First result: reactor neutrino disappearance

Phys. Rev. Lett. 90 (2003) 021802

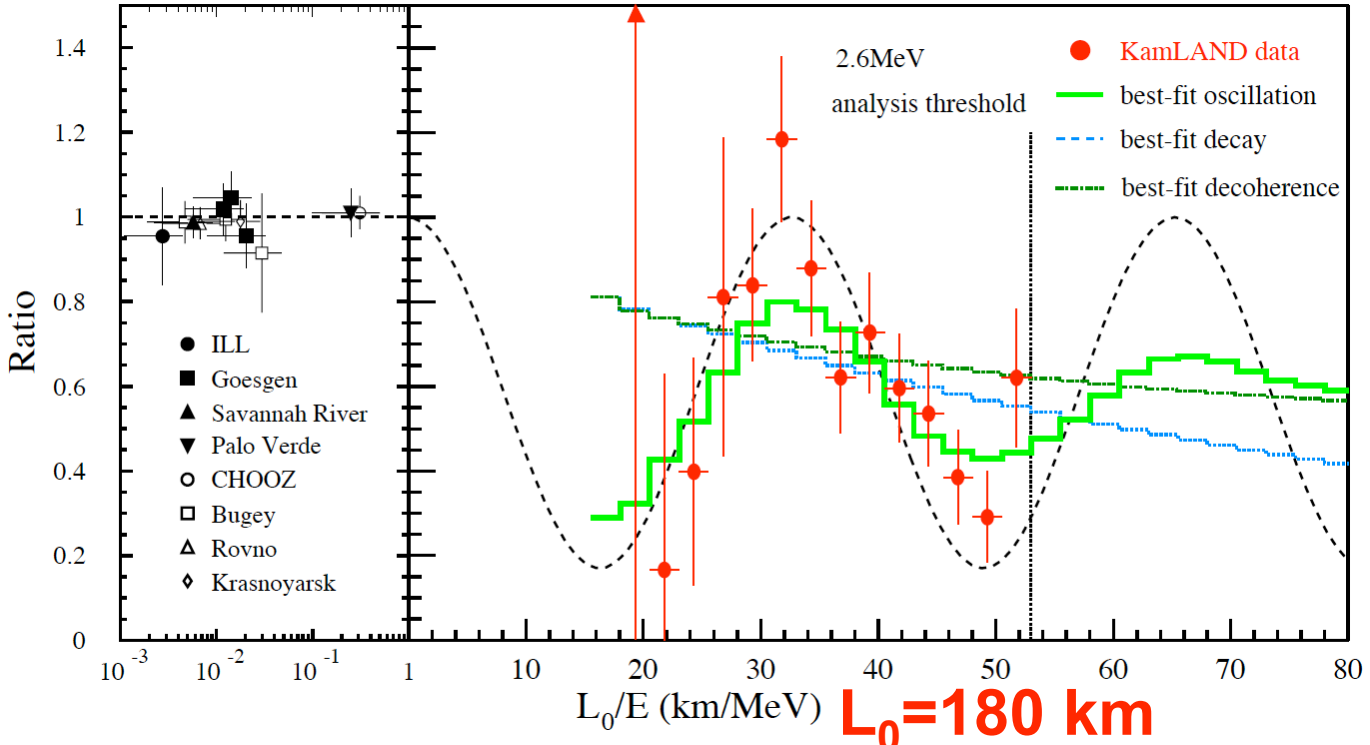


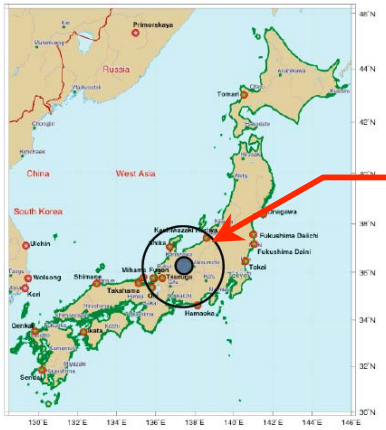


Disappearance: 99.95%C.L.

2nd result: spectral distortion

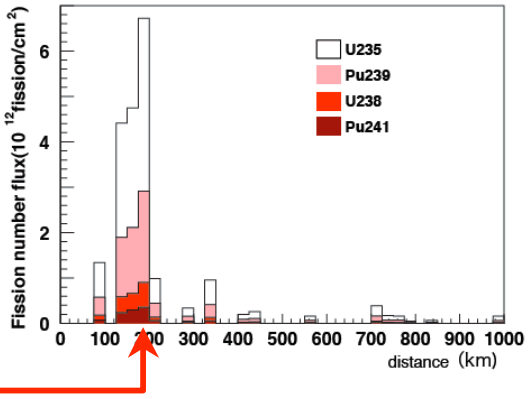
Phys. Rev. Lett. 94 (2005) 081801





L_0

L_0



Determination of solar neutrino solution
Precise measurement of Δm_{12}^2

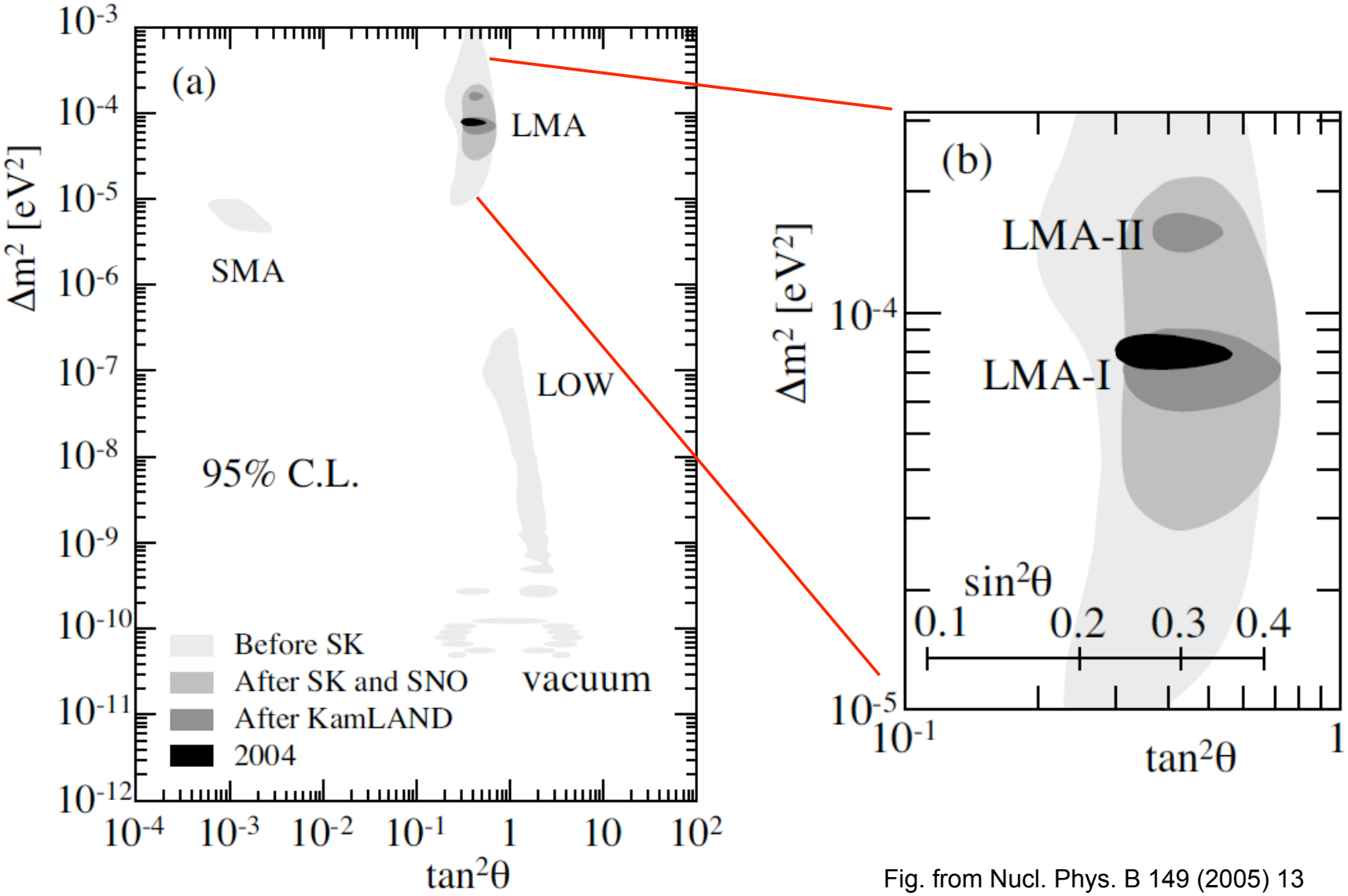


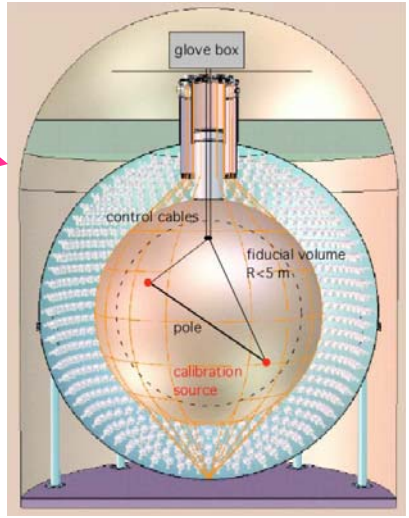
Fig. from Nucl. Phys. B 149 (2005) 13

Reactor future

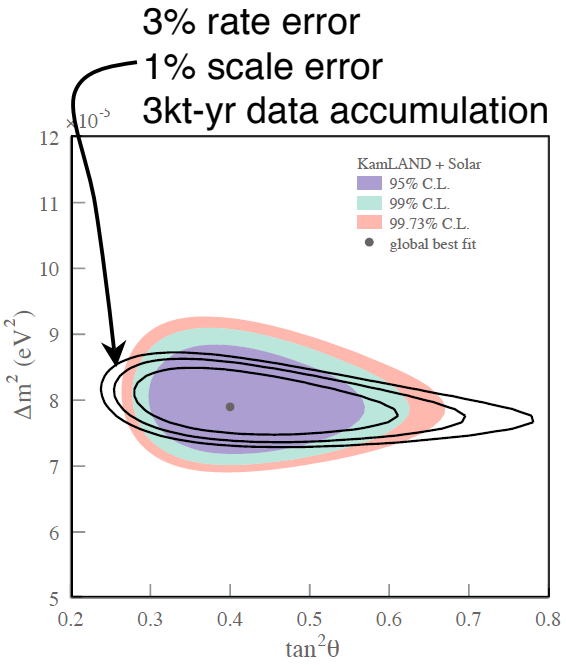
- Keep taking data: (statistical error) ∝ (time)$^{-1/2}$
- Reduction of the systematic error to keep (total error) ~∝ (time)$^{-1/2}$
  - All volume calibration instead of only along the vertical axis: from July 2006, the "4π system"
  - Better understanding of the detector, improving analysis tools
- See also posters
  - #56 T. Classen for energy scale
  - #57 D. Dwyer for oscillation analysis
  - #60 L. Hsu for Monte Carlo

Systematic	%
Fiducial volume	4.7
Energy threshold	2.3
Efficiency of cuts	1.6
Livetime	0.06
Reactor power	2.1
Fuel composition	1.0
$\bar{\nu}_e$ spectra	2.5
Cross section	0.2
Total	6.5

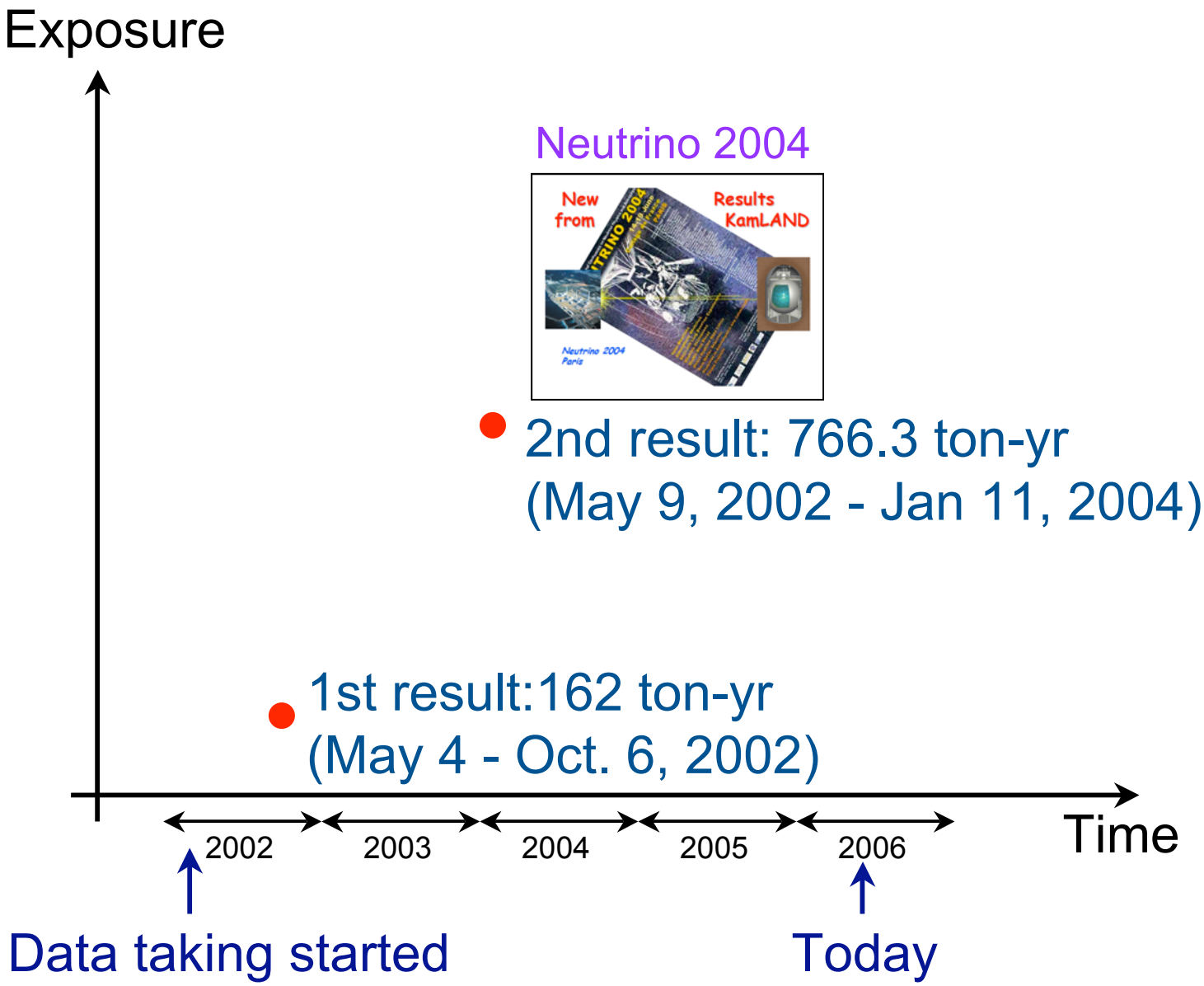
improve



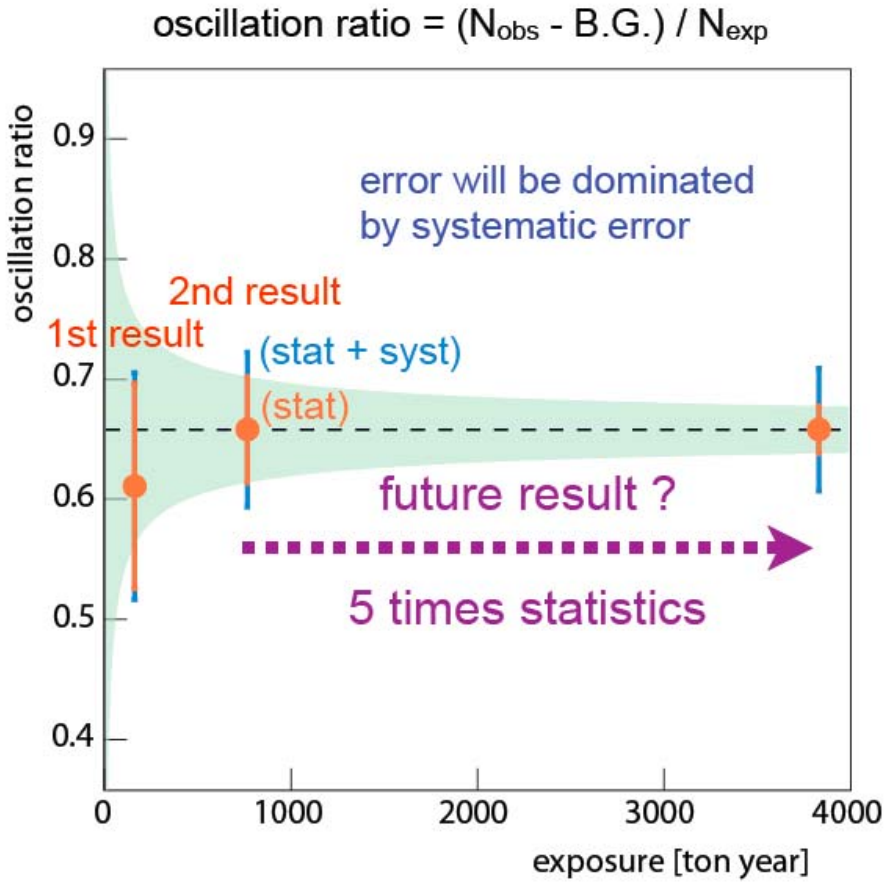
"4π system"



Reactor results



Reactor Future Prospect



Systematic	%
Fiducial volume (dominant)	4.7
Energy threshold	2.3
Efficiency of cuts	1.6
Livetime	0.06
Reactor power	2.1
Fuel composition	1.0
$\bar{\nu}_e$ spectra	2.5
Cross section	0.2
Total	6.5

Fiducial volume uncertainty will be reduced by full volume calibration (now planing)

full volume caliburation → systematic uncertainty ~ 4%

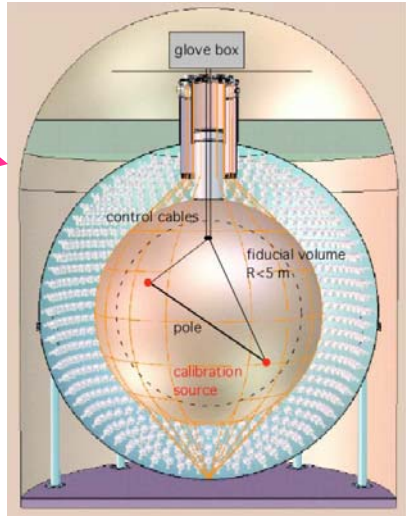
Slide by A. Shimizu (COE symposium Tohoku, Sendai)

Reactor future

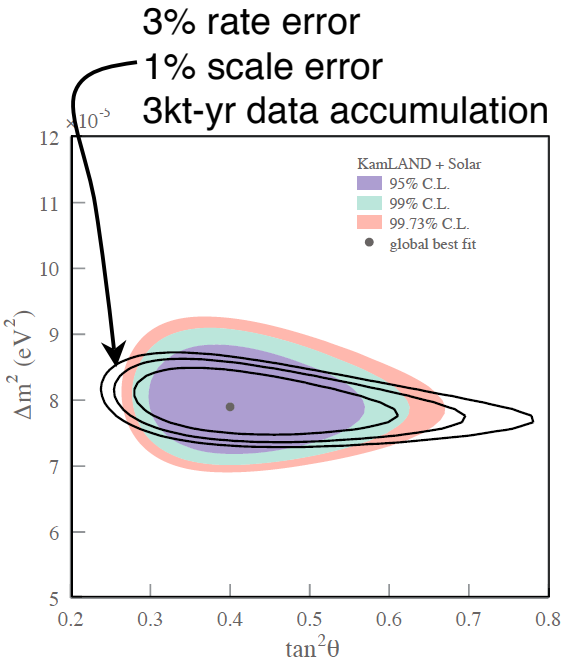
- Keep taking data: (statistical error) ∝ (time)$^{-1/2}$
- Reduction of the systematic error to keep (total error) ~∝ (time)$^{-1/2}$
  - All volume calibration instead of only along the vertical axis: from July 2006, the "4π system"
  - Better understanding of the detector, improving analysis tools
- See also posters
  - #56 T. Classen for energy scale
  - #57 D. Dwyer for oscillation analysis
  - #60 L. Hsu for Monte Carlo

Systematic	%
Fiducial volume	4.7
Energy threshold	2.3
Efficiency of cuts	1.6
Livetime	0.06
Reactor power	2.1
Fuel composition	1.0
$\bar{\nu}_e$ spectra	2.5
Cross section	0.2
Total	6.5

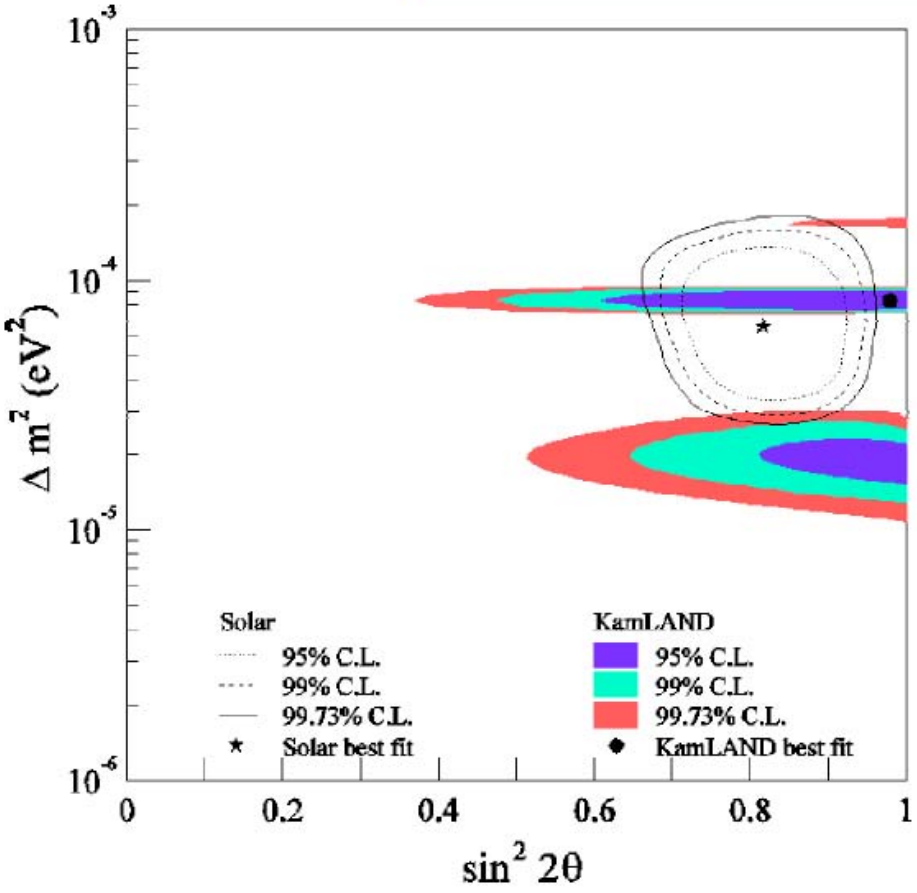
improve



"4π system"



A shape-only fit gives similar results



$\Delta m^2 = 8.3 \cdot 10^{-5}$ eV^2

$\sin^2 2\theta = 0.98$

Neutrino 2004

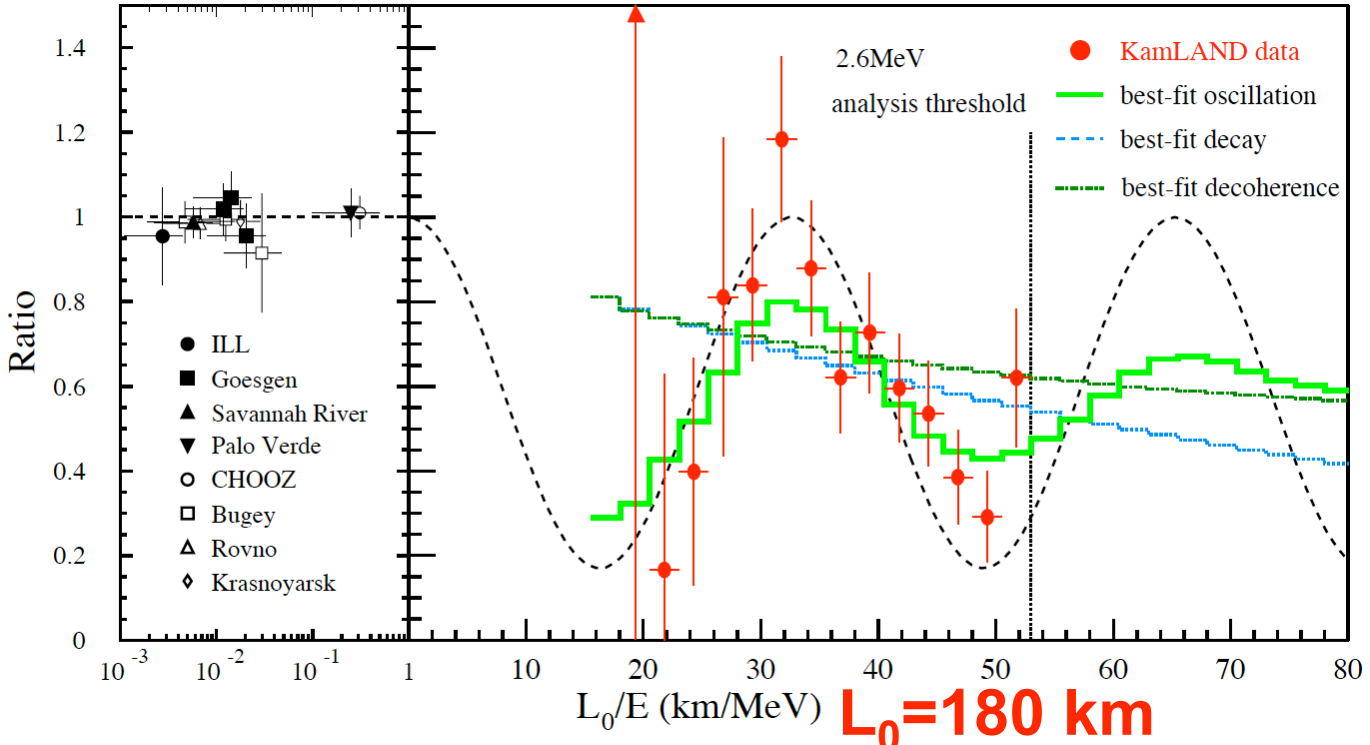
New Results from KamLAND

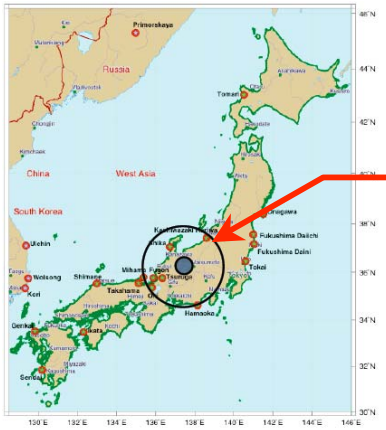
Note: alpha-n B.G. is not Included in this analysis

Slide by G. Gratta (neutrino 2004)

2nd result: spectral distortion

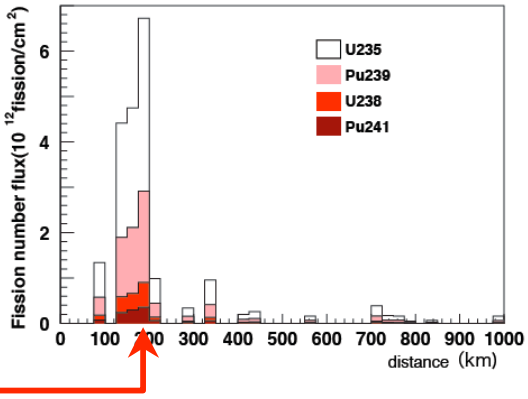
Phys. Rev. Lett. 94 (2005) 081801





L_0

L_0



Possible source of “fake distortion”

Shimized p185

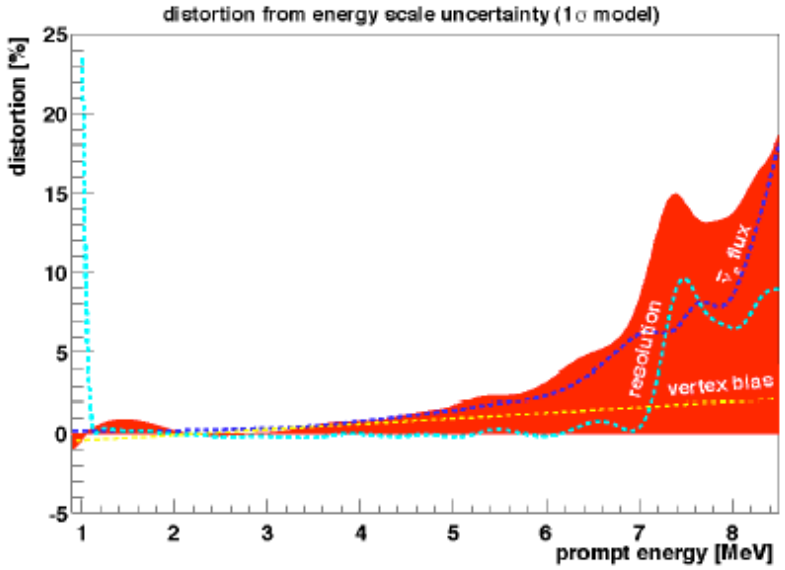
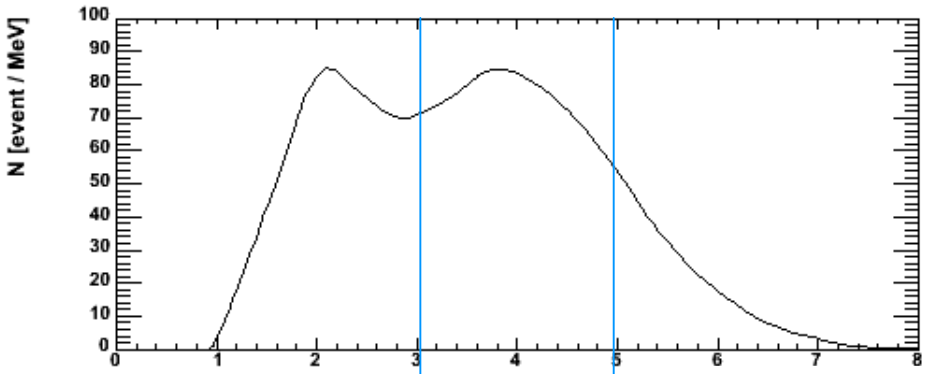
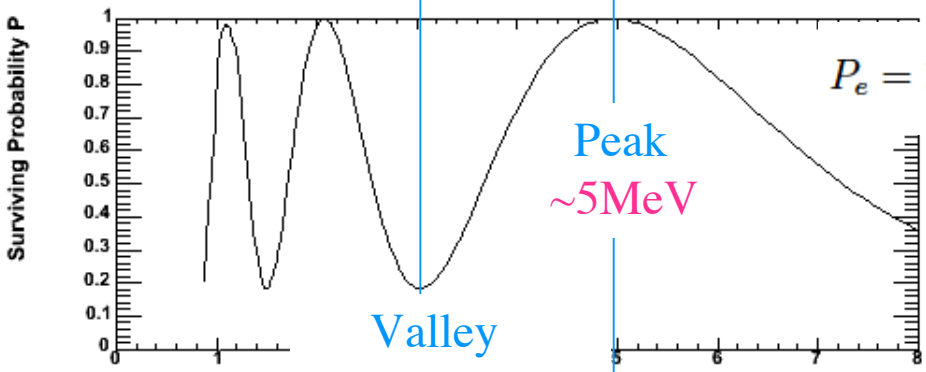


Figure 6.2: Distortion from the energy scale uncertainty in the case of no oscillation. The red shaded curve indicates the effect of varying one of the energy nonlinearity parameters in the model at 1σ. Other distortion components, such as $\bar{\nu}_e$ flux uncertainty, wider resolution (1.2 times of expected resolution conservatively) and a vertex bias (2.7%), are also shown with dashed lines. Each component is normalized at 2.2 MeV to show the contribution to the distortion. For technical reasons (economy with computing time), other distortion components are incorporated in the energy scale uncertainty in the $\bar{\nu}_e$ shape distortion analysis.



Reactor ν for $\Delta m^2 = 7.9 \times 10^{-5} eV^2$

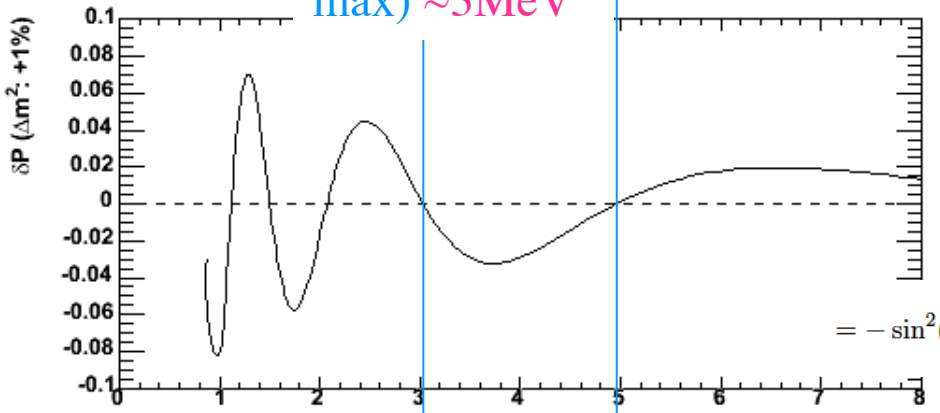


$$P_e = 1 - \sin^2(2\theta)\sin^2\left(1.27\Delta m^2 \frac{180 \times 10^3[\mathrm{m}]}{E_{real} + 0.8[\mathrm{MeV}]}\right)$$

Peak ~5MeV

Valley (disapparance max) ~3MeV

Surviving probability Pe

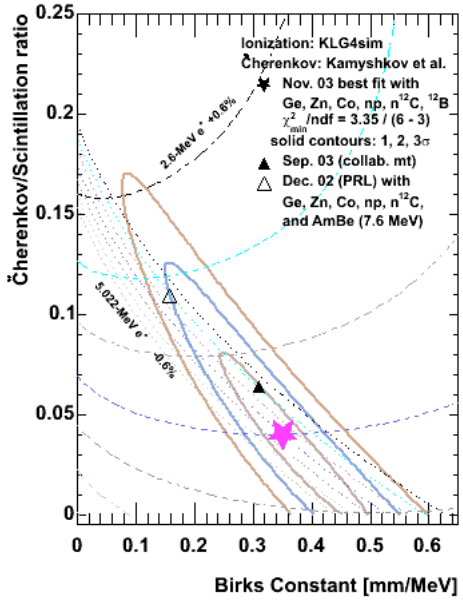


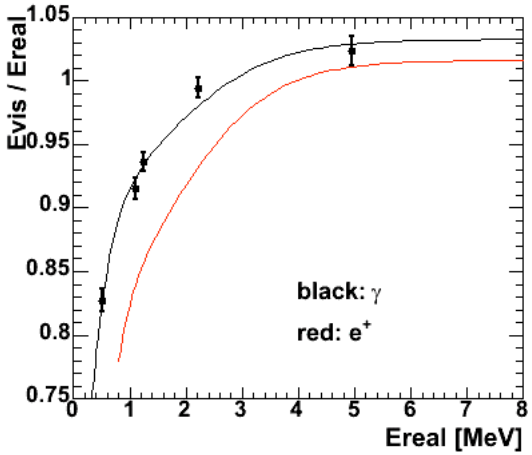
Spectral difference for $\delta\Delta m^2$

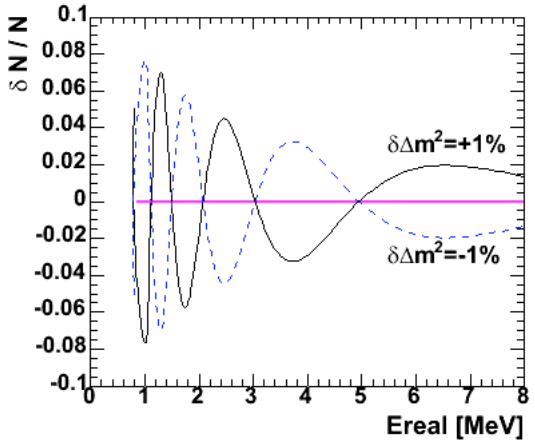
$$\frac{\delta N}{N} = \frac{1}{N}\frac{dN}{d\Delta m^2}\delta\Delta m^2 = \frac{dP_e}{d\Delta m^2}\delta\Delta m^2$$

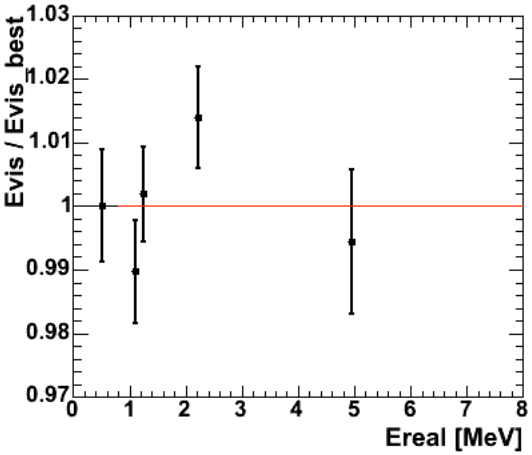
$$= -\sin^2(2\theta)\sin\left(2 \times 1.27\Delta m^2 \frac{180 \times 10^3[\mathrm{m}]}{E_{real} + 0.8[\mathrm{MeV}]}\right) \times 1.27\frac{180 \times 10^3[\mathrm{m}]}{E_{real} + 0.8[\mathrm{MeV}]}\delta\Delta m^2$$

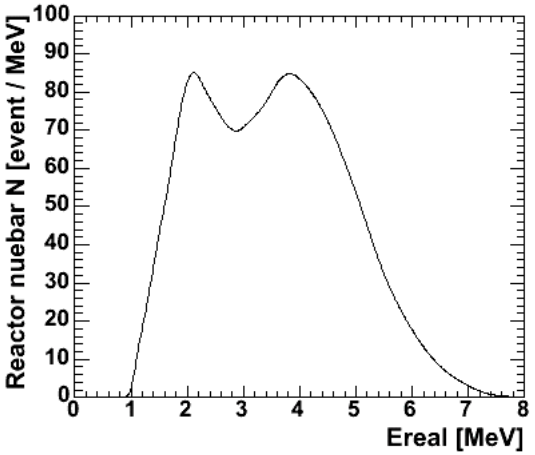
Nov. 2003 Berkeley meeting version











エネルギースケールの系統誤差の扱い

- 実際の解析:
  - すべて考慮したスペクトル(原子炉分布、時間変化、検出器分解能、中性子反跳)に対して、エネルギースケールを変化させて”observed spectrum” を計算し、用いたエネルギースケールごとに、”pull-up chi square” を加える。
- 定性的理解のため:
  - スペクトルを単純
  - 実際にどうゆがむか、delta-m square がずれた場合と、ゆがみ方の違いを確認。

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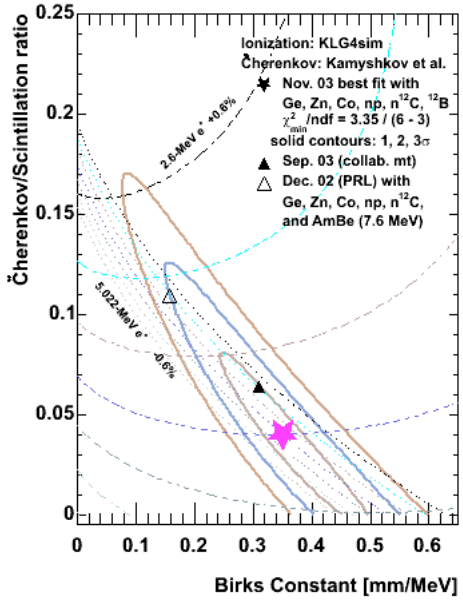

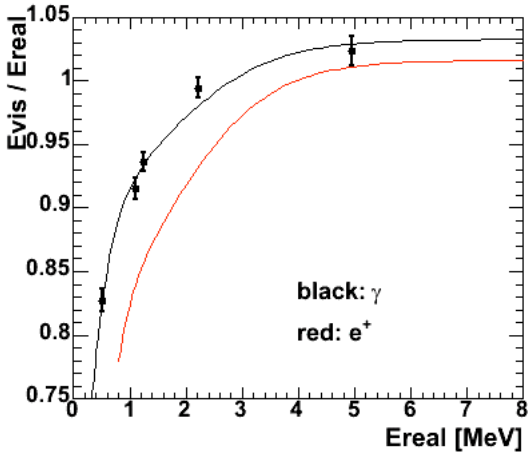

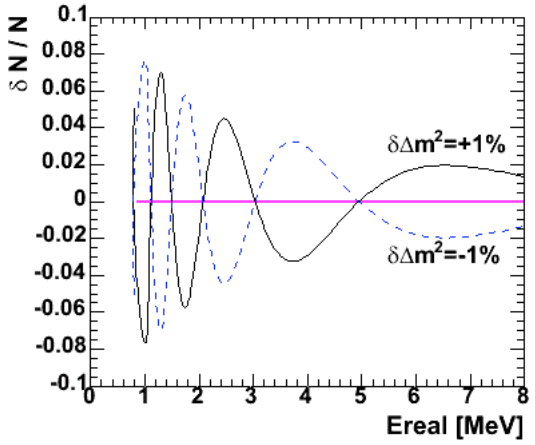

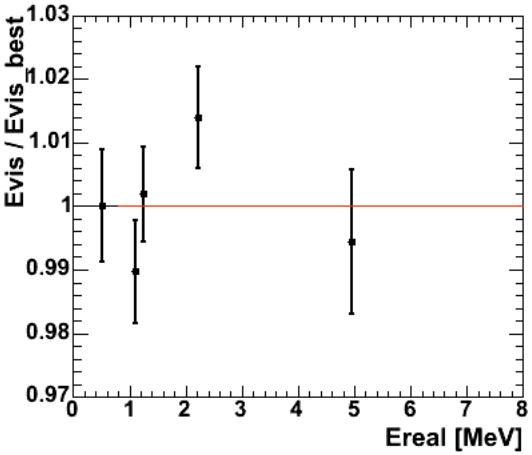

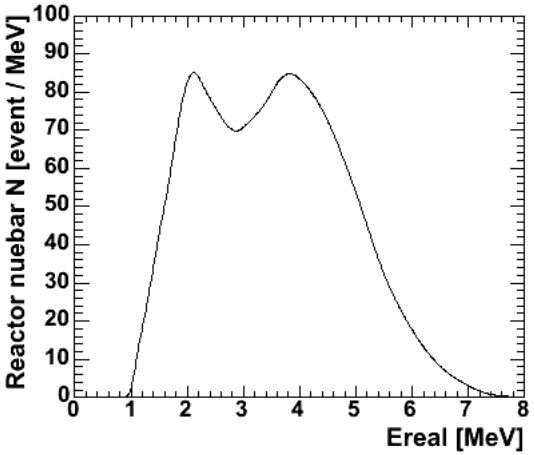

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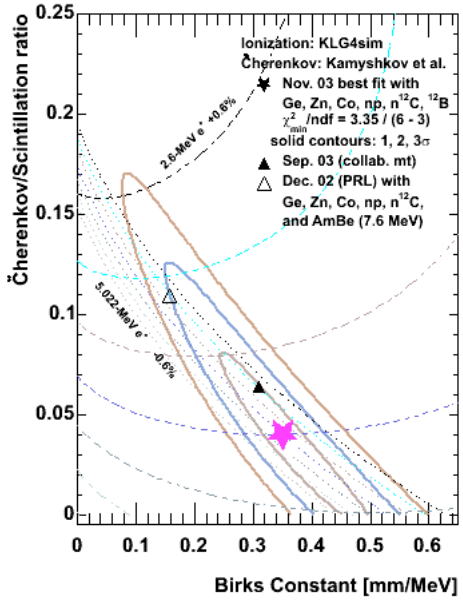

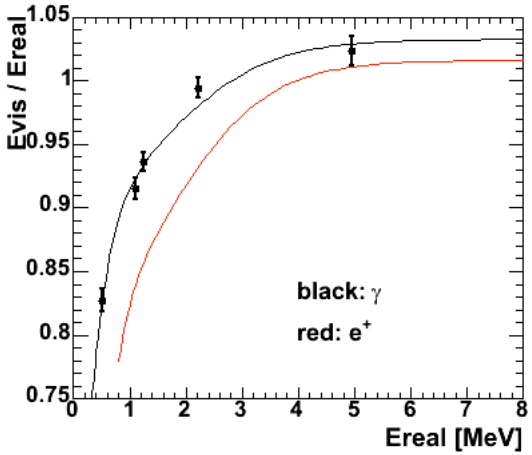

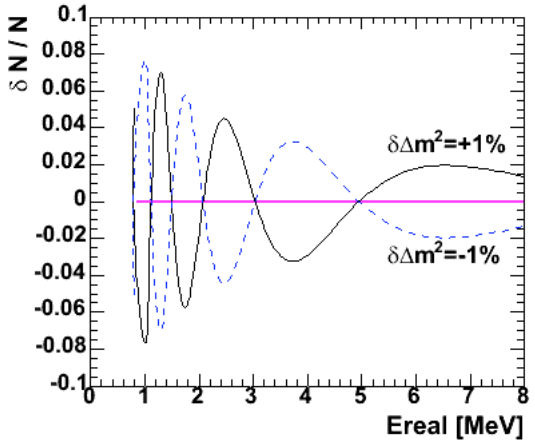

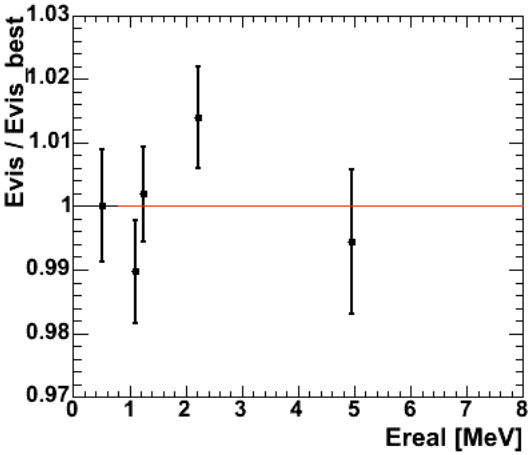

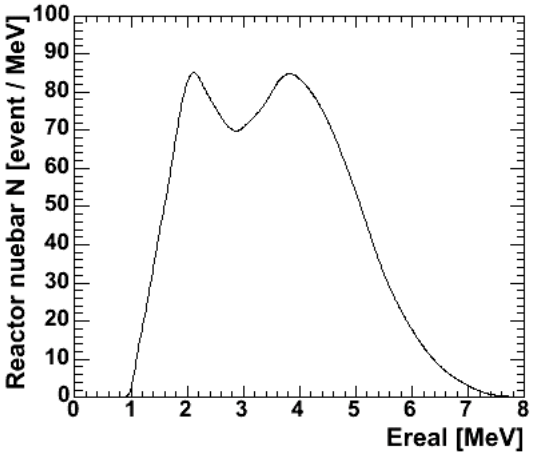

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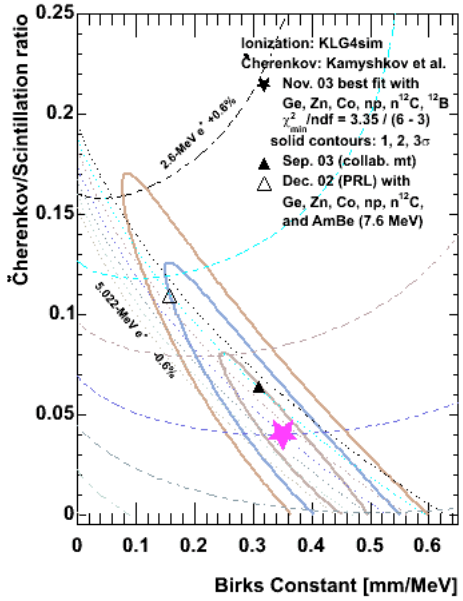

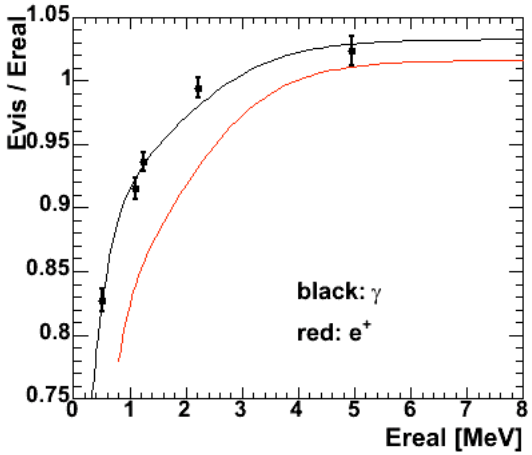

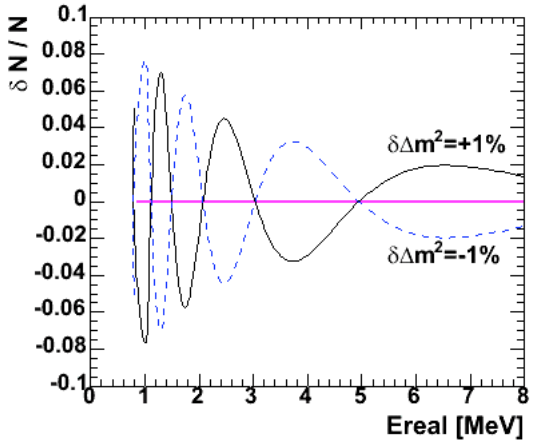

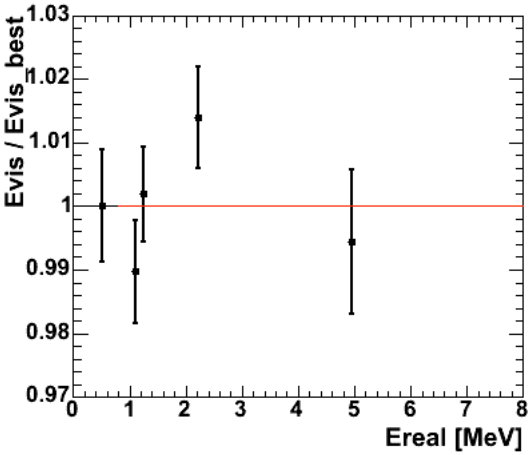

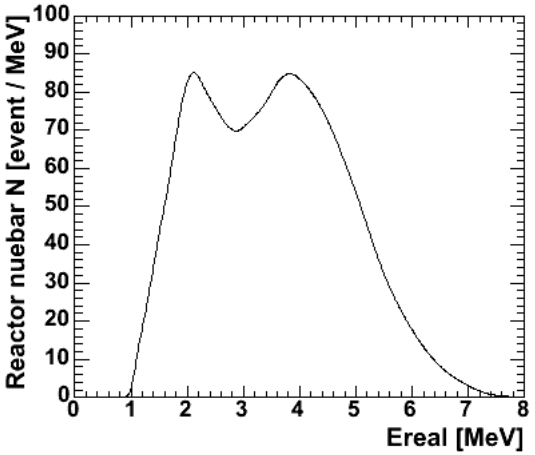

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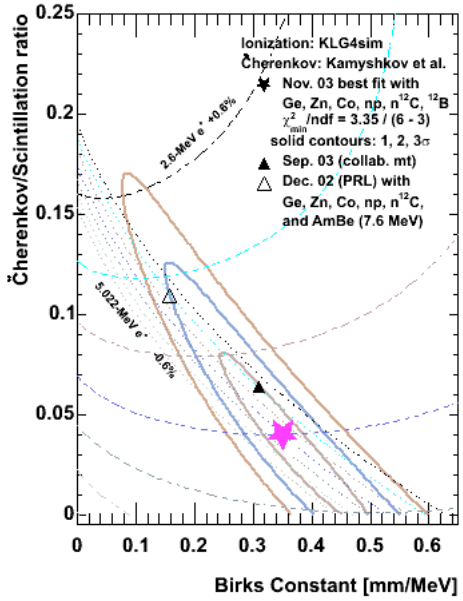
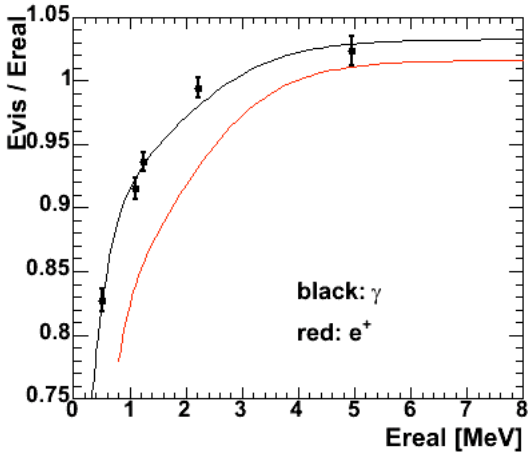
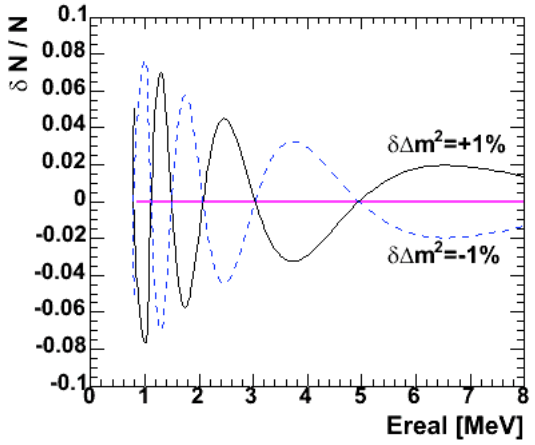
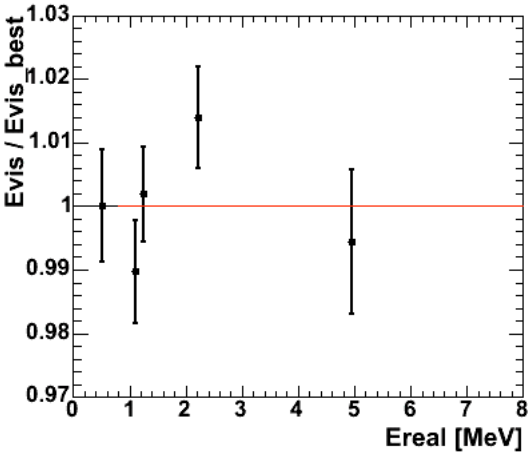
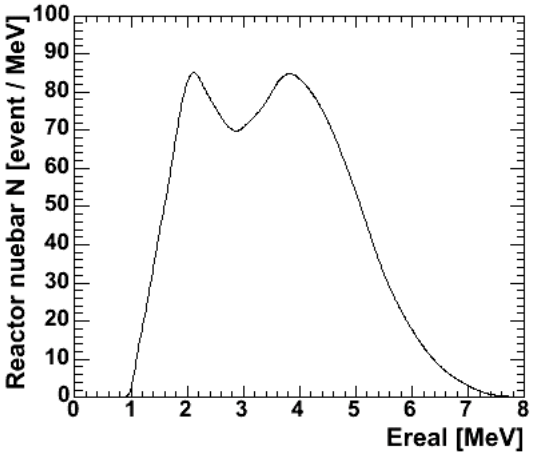
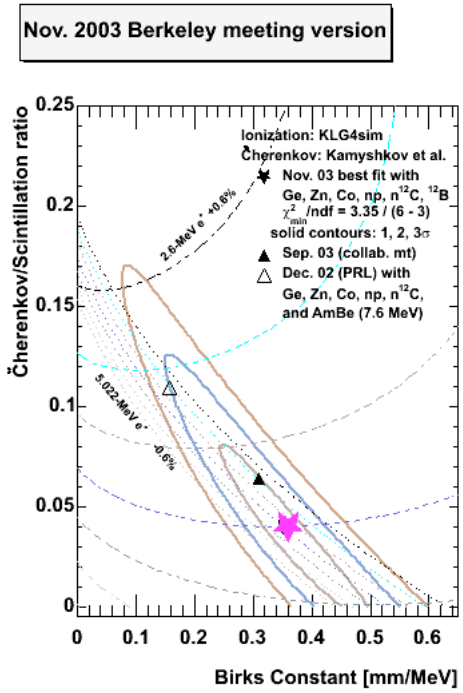


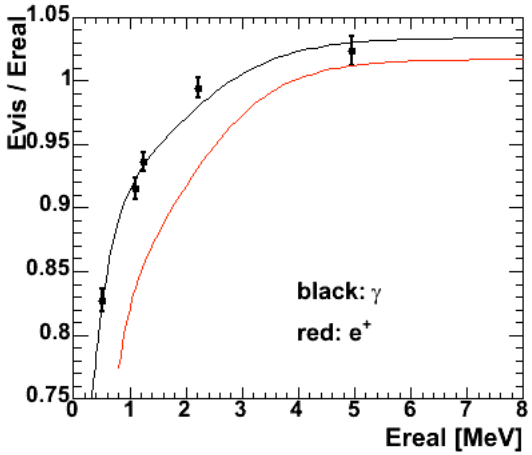


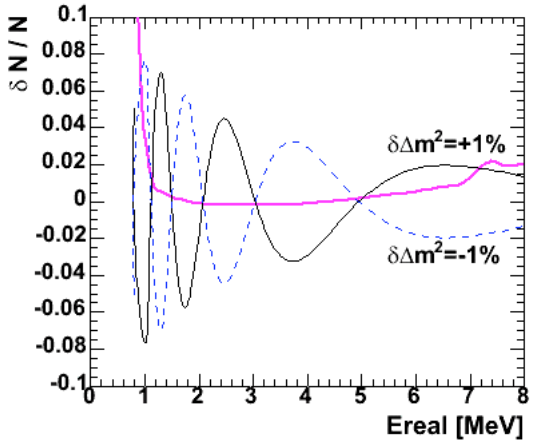


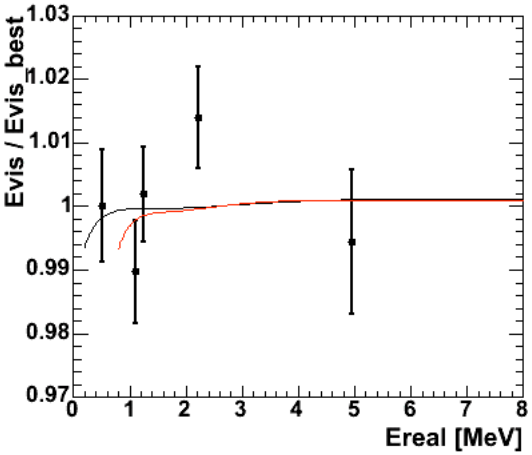


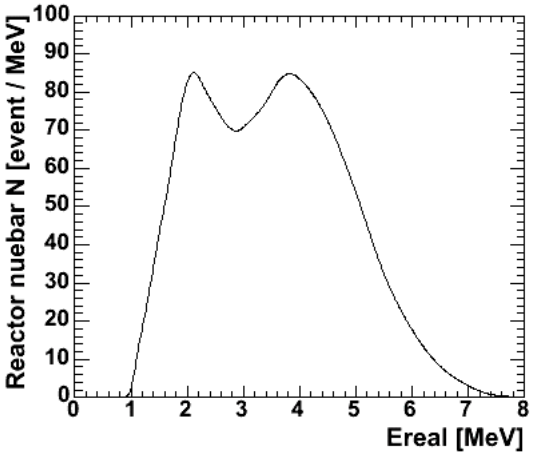


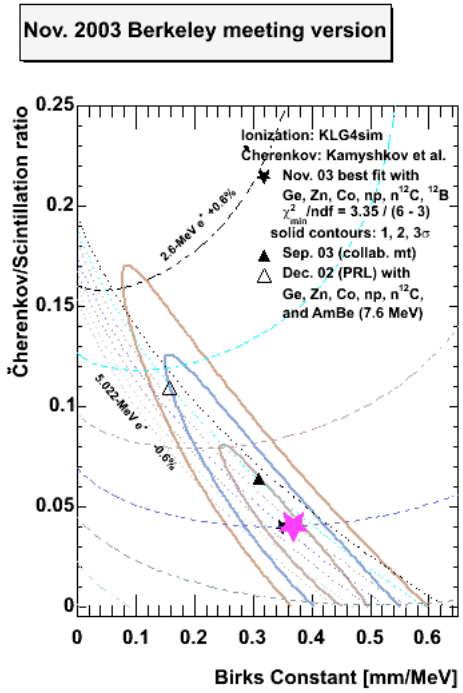

Nov. 2003 Berkeley meeting version
Ionization: KLG4sim
Cherenkov: Kamyshkov et al.
Nov. 03 best fit with
Ge, Zn, Co, np, n12C, 12B
χ2min /ndf = 3.35 / (6 - 3)
solid contours: 1, 2, 3σ
Sep. 03 (collab. mt)
Dec. 02 (PRL) with
Ge, Zn, Co, np, n12C,
and AmBe (7.6 MeV)
2.6-MeV e+ +0.6%
5.022-MeV e+ -0.6%
Čherenkov/Scintillation ratio
Birks Constant [mm/MeV]

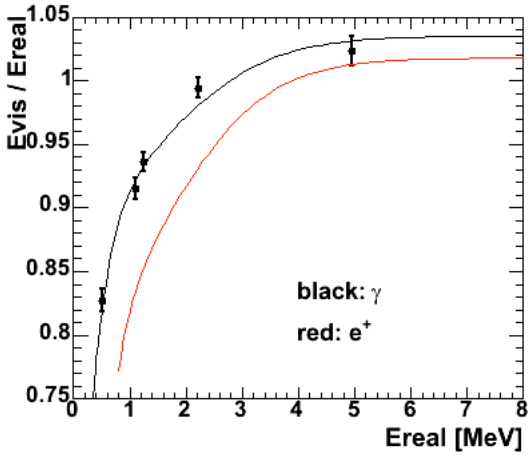

Evis / Ereal
black: γ
red: e+
Ereal [MeV]

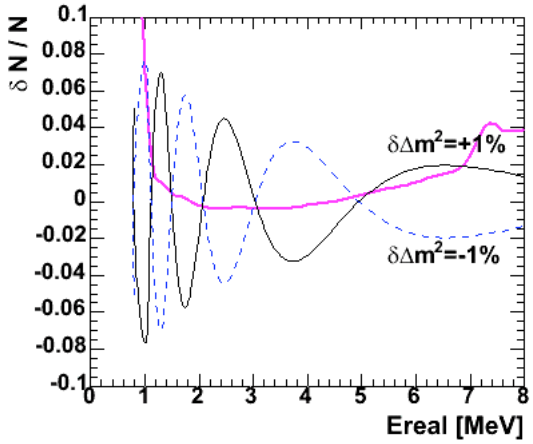

δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]

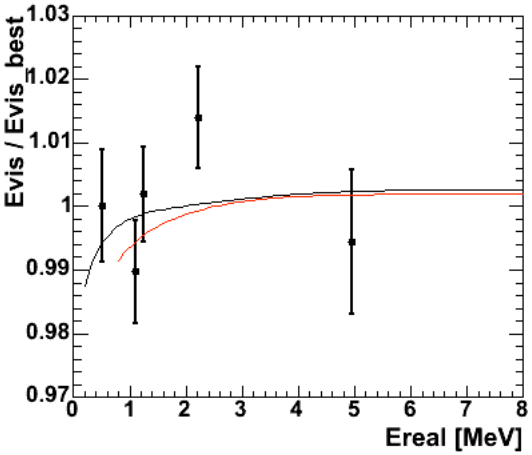

Evis / Evis_best
Ereal [MeV]

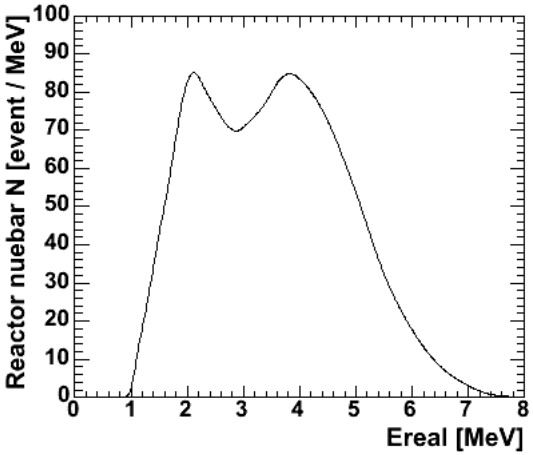

Reactor nuebar N [event / MeV]
Ereal [MeV]

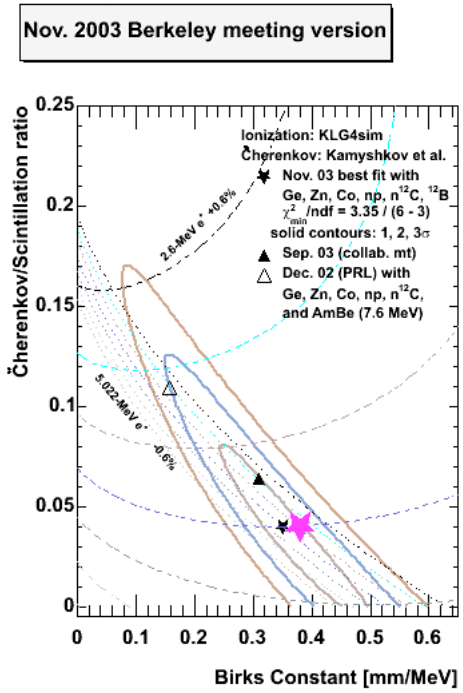

Nov. 2003 Berkeley meeting version
Ionization: KLG4sim
Cherenkov: Kamyshkov et al.
Nov. 03 best fit with
Ge, Zn, Co, np, n12C, 12B
χ2min /ndf = 3.35 / (6 - 3)
solid contours: 1, 2, 3σ
Sep. 03 (collab. mt)
Dec. 02 (PRL) with
Ge, Zn, Co, np, n12C,
and AmBe (7.6 MeV)
2.6-MeV e+ +0.6%
5.022-MeV e+ -0.6%
Čherenkov/Scintillation ratio
Birks Constant [mm/MeV]


Evis / Ereal
black: γ
red: e+
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]


Nov. 2003 Berkeley meeting version
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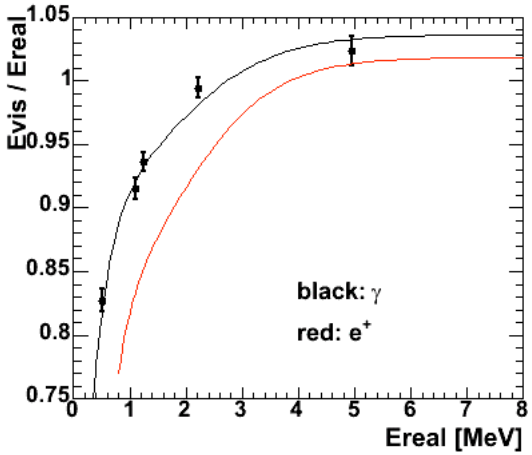
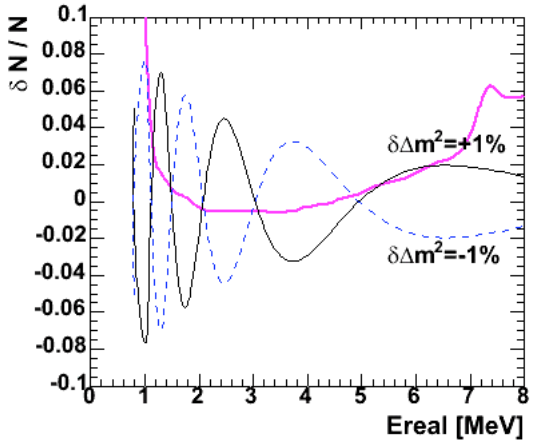
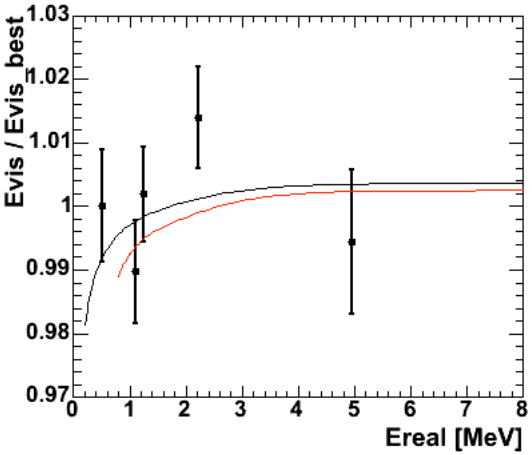
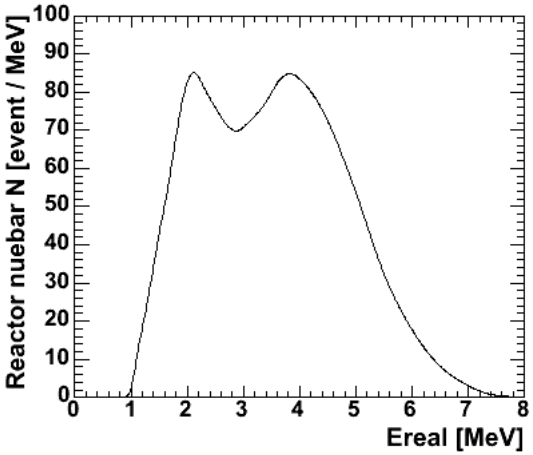
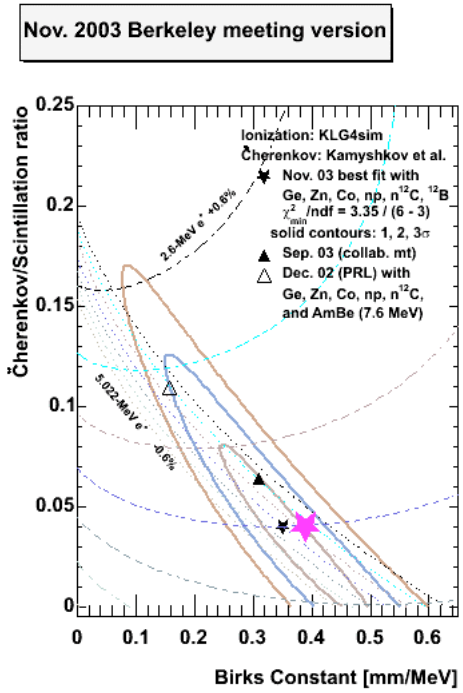
Birks Constant [mm/MeV]


Evis / Ereal
black: γ
red: e+
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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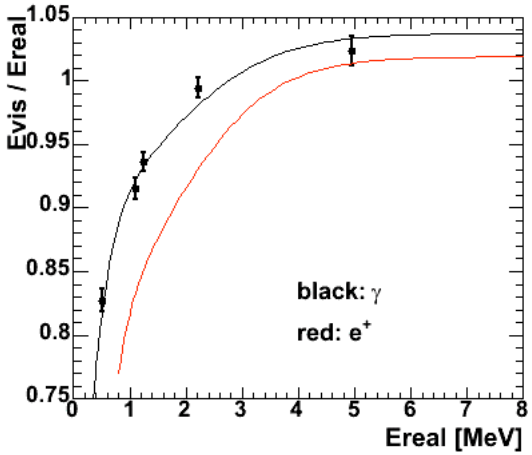
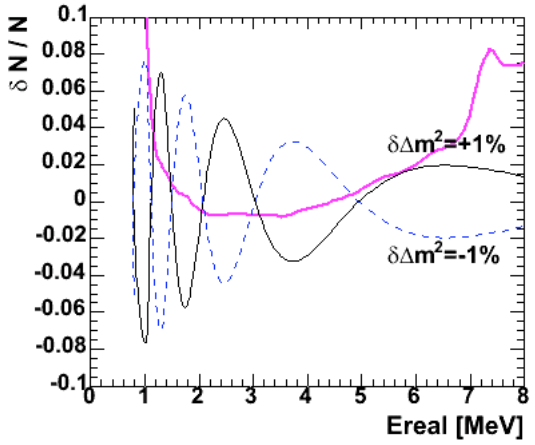
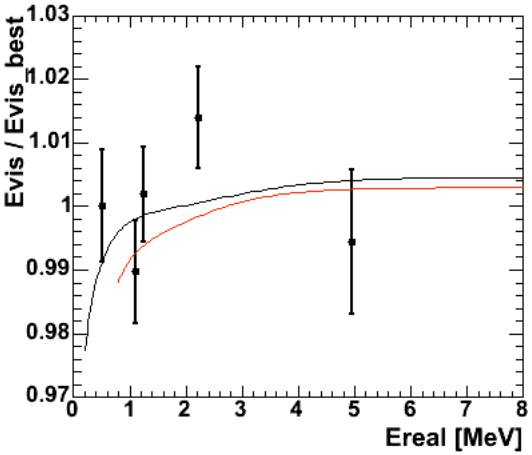
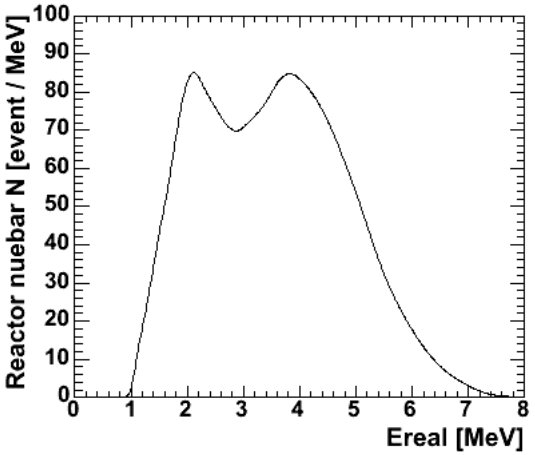
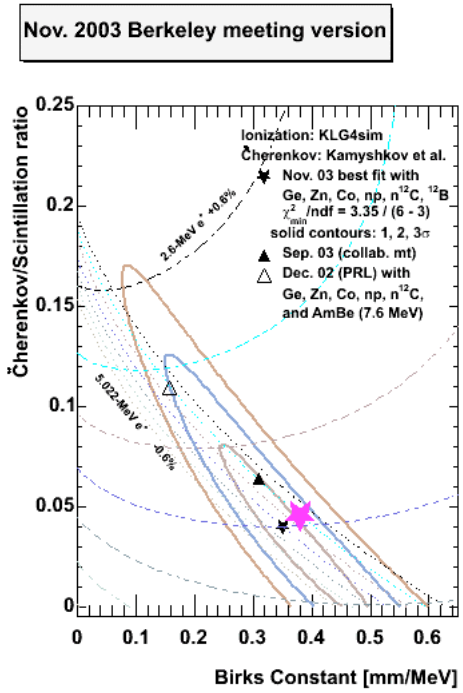

Evis / Ereal
black: γ
red: e+
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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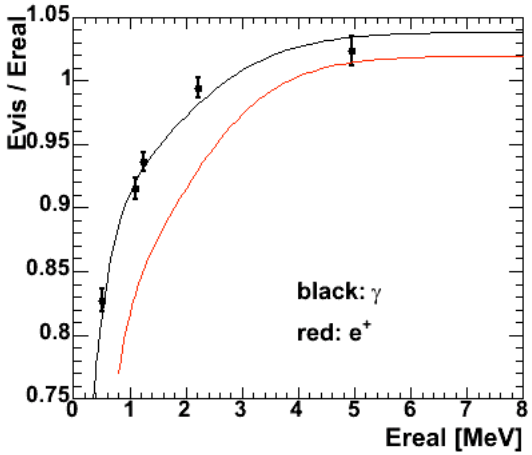
Evis / Ereal
black: γ
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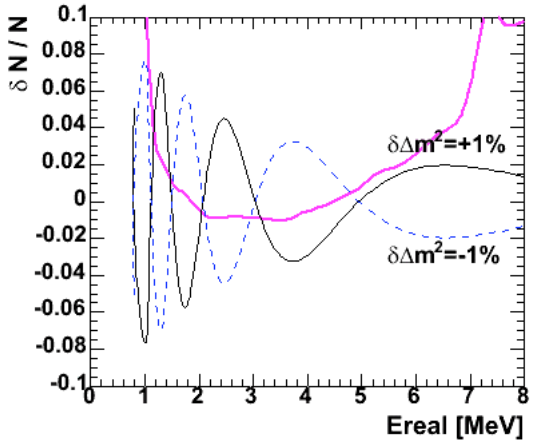
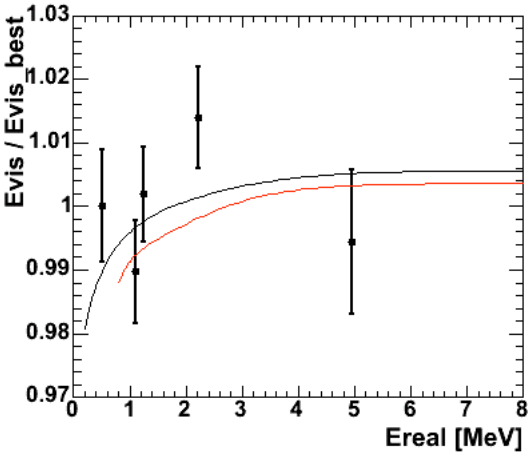
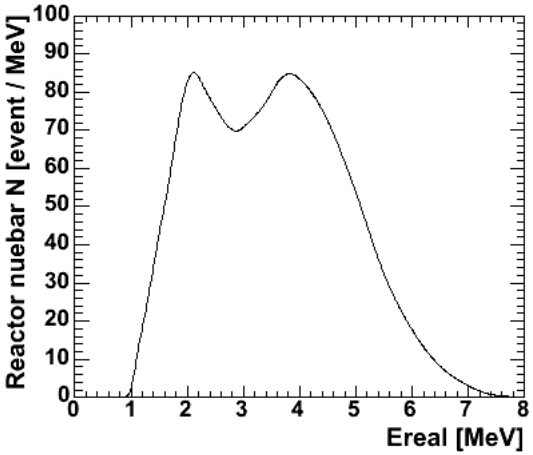
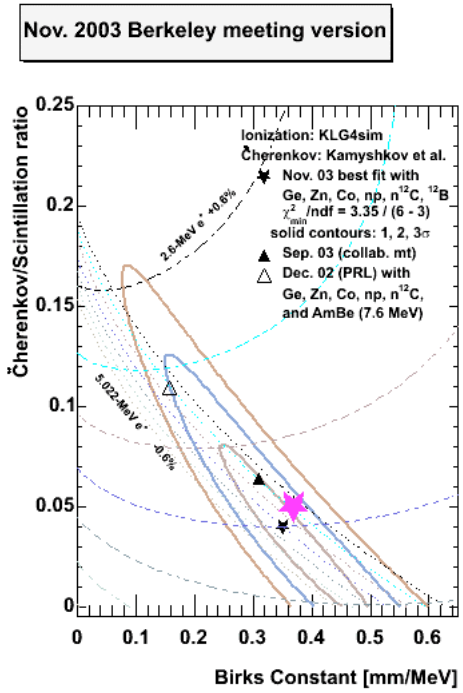
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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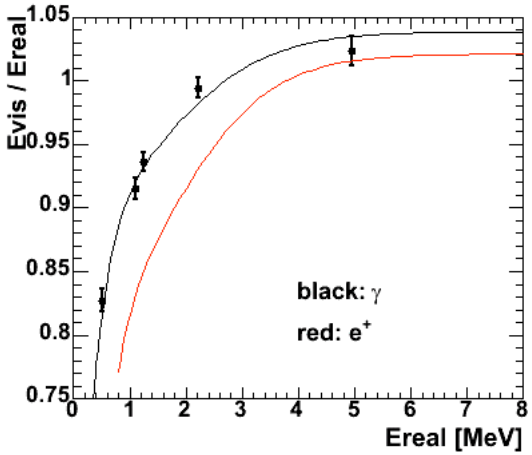
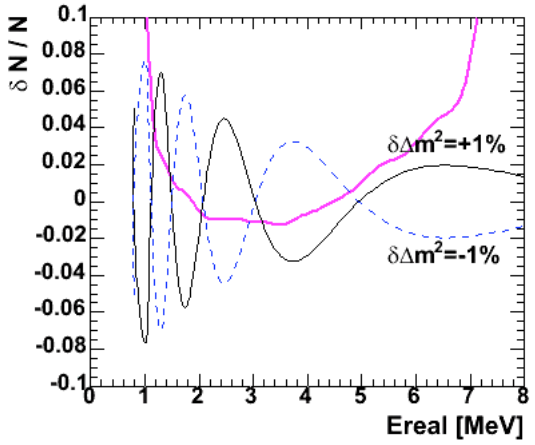
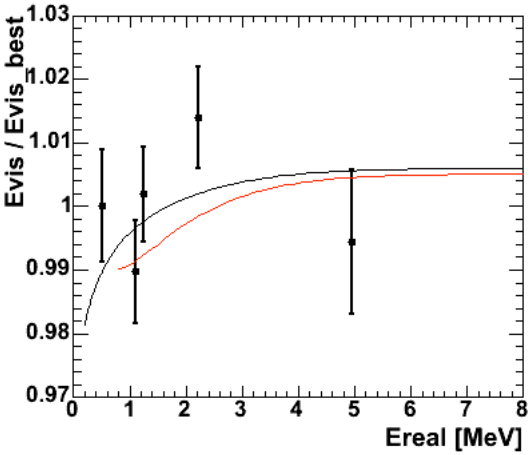
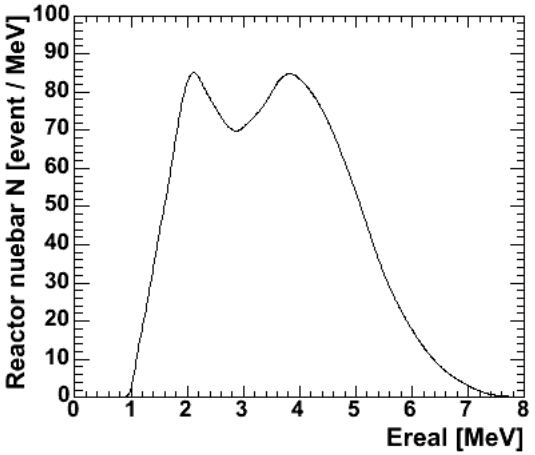
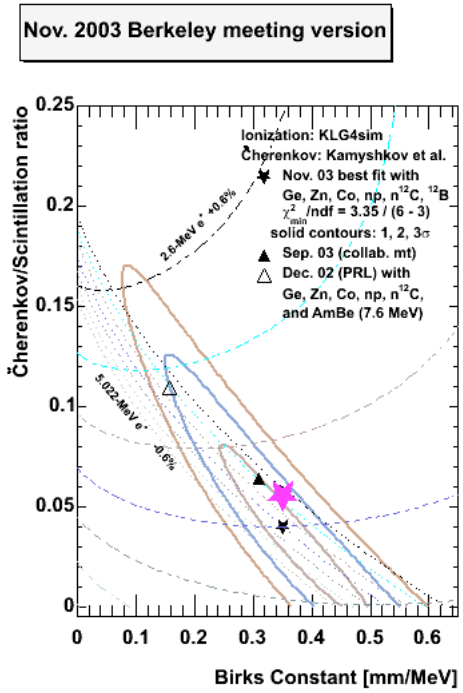

Evis / Ereal
black: γ
red: e+
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]


Nov. 2003 Berkeley meeting version
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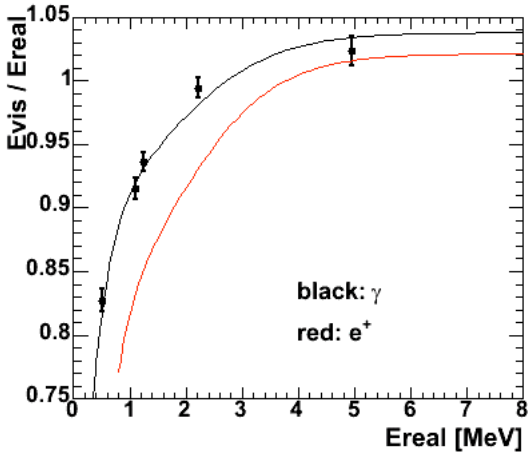
Evis / Ereal
black: γ
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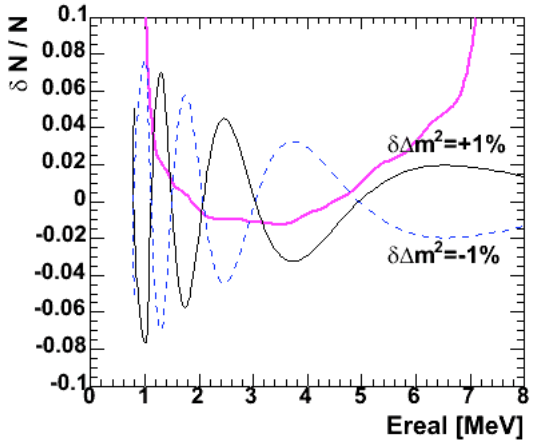
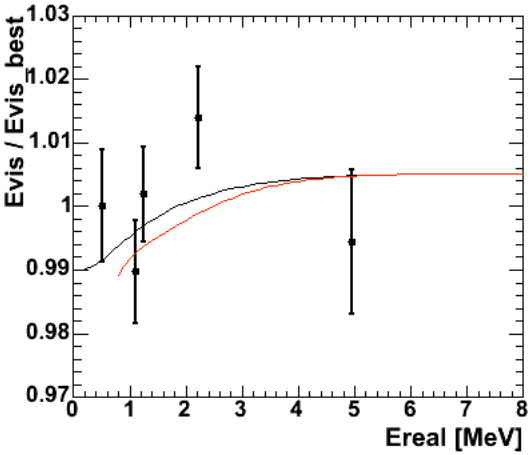
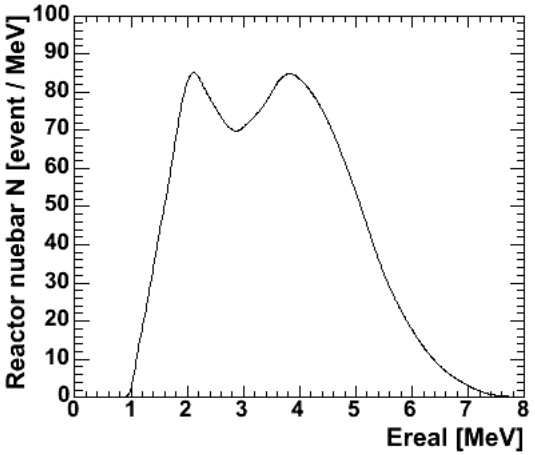
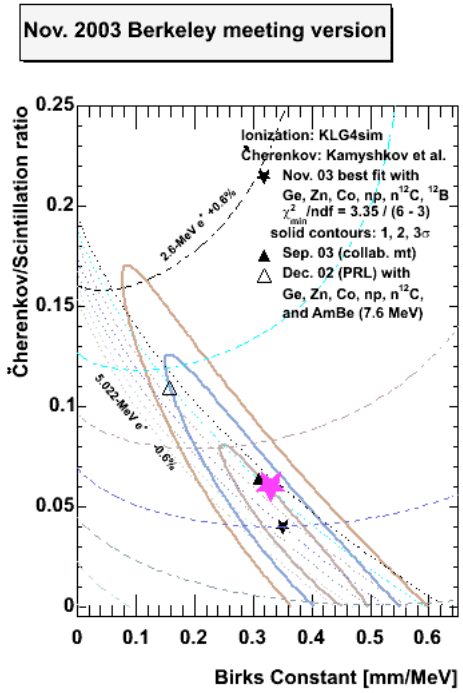

δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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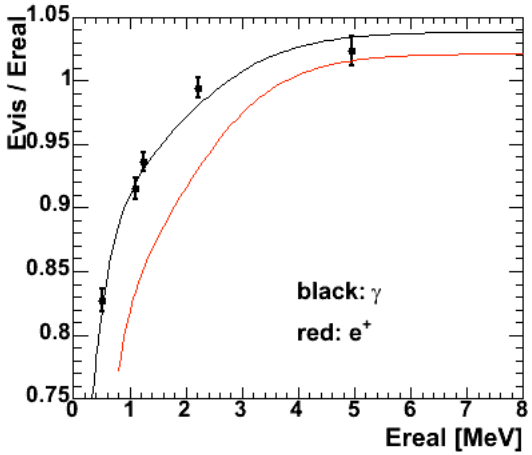
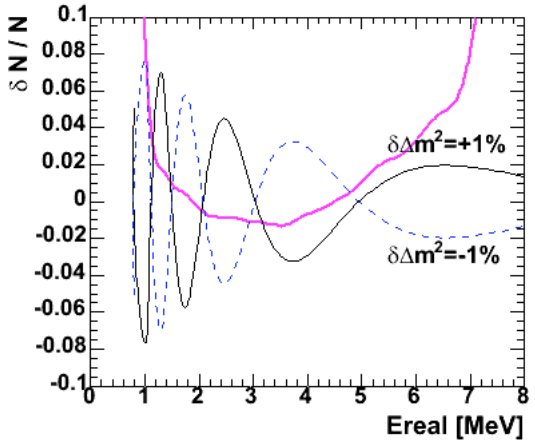
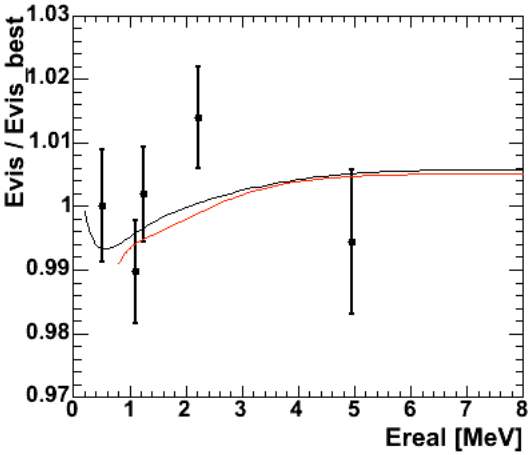
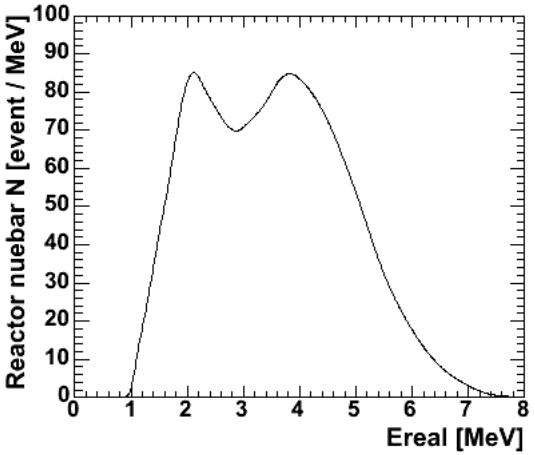

Evis / Ereal
black: γ
red: e+
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
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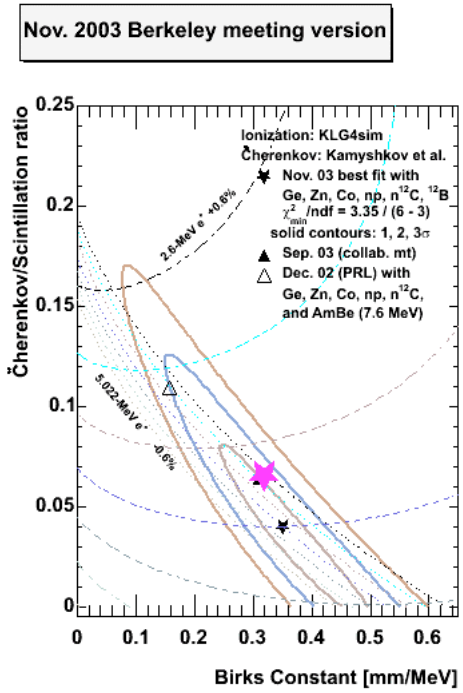
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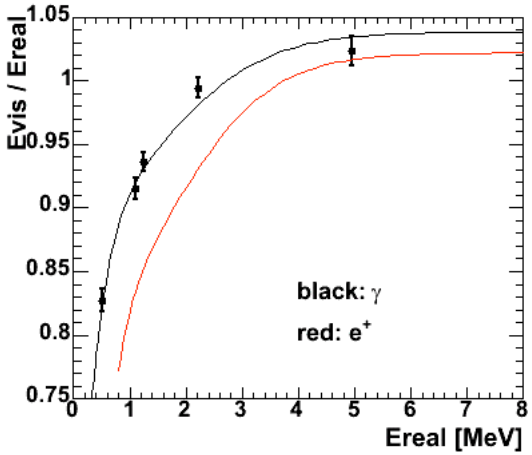
Evis / Ereal
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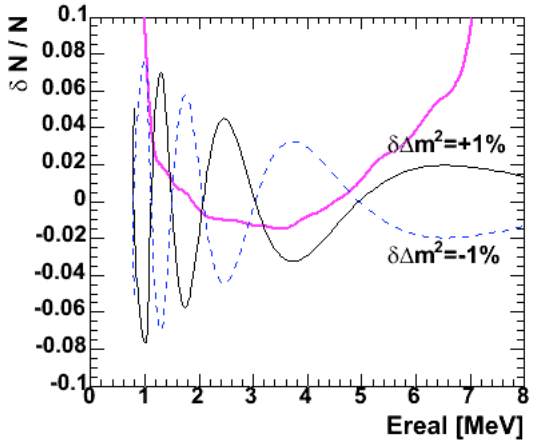
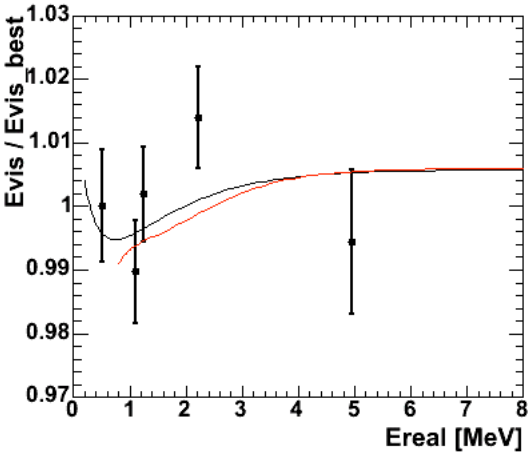
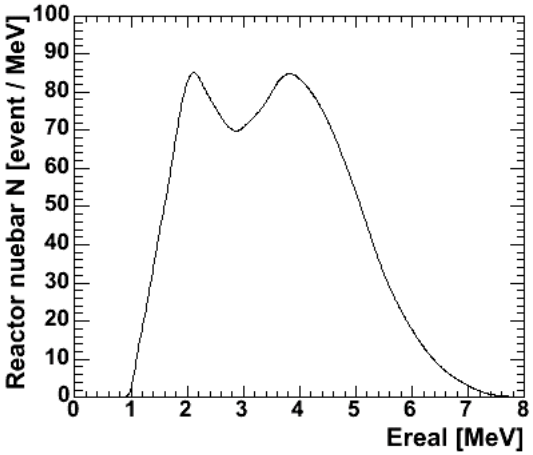
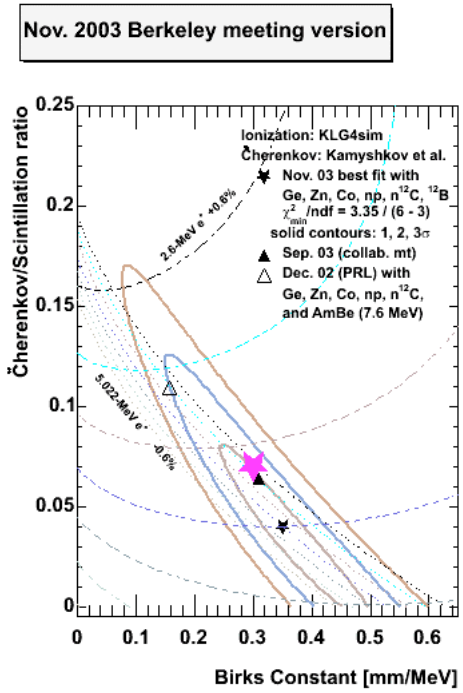
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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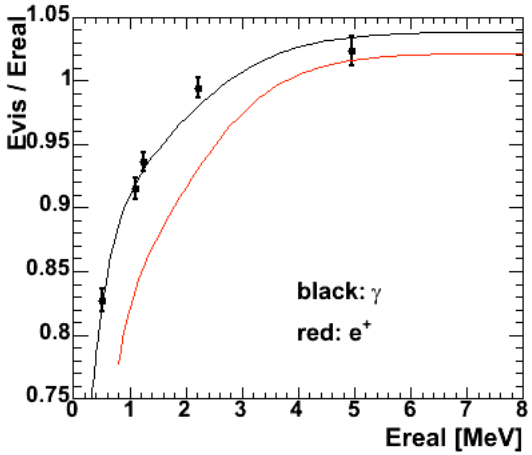
Evis / Ereal
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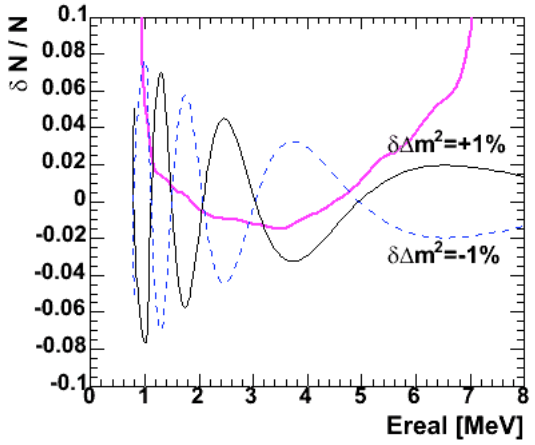
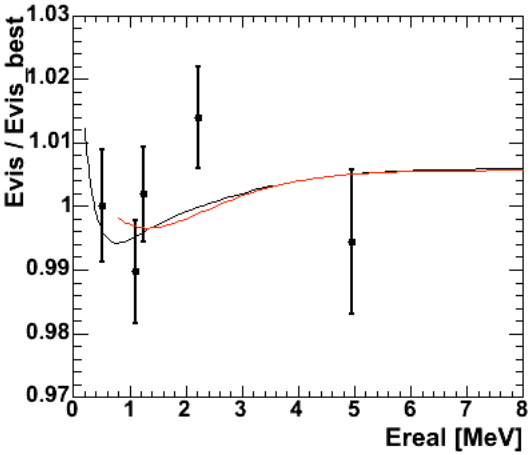
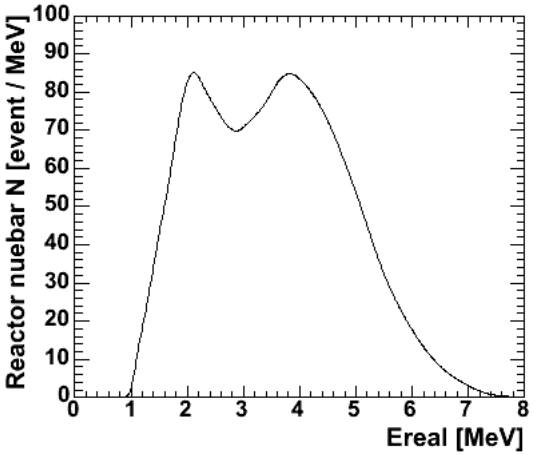
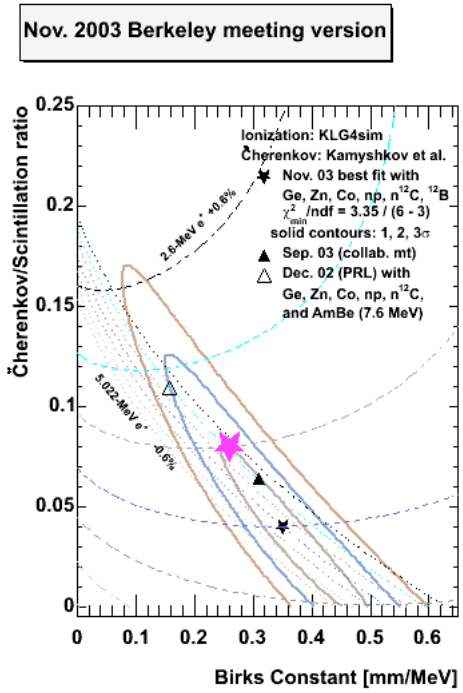
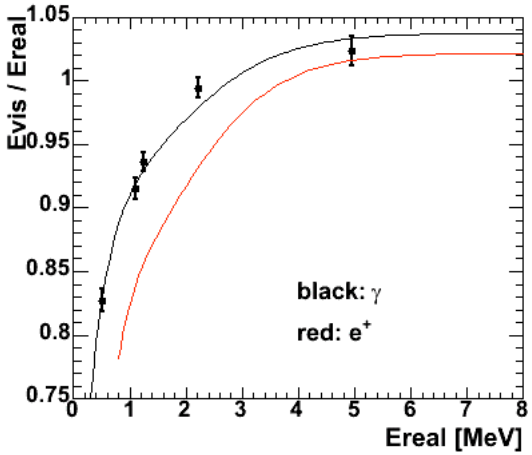
red: e+
Ereal [MeV]

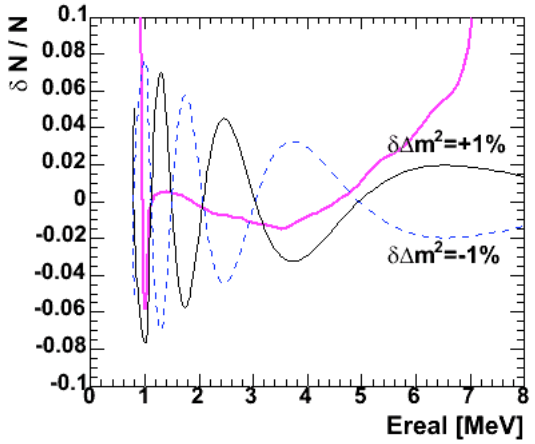

δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]

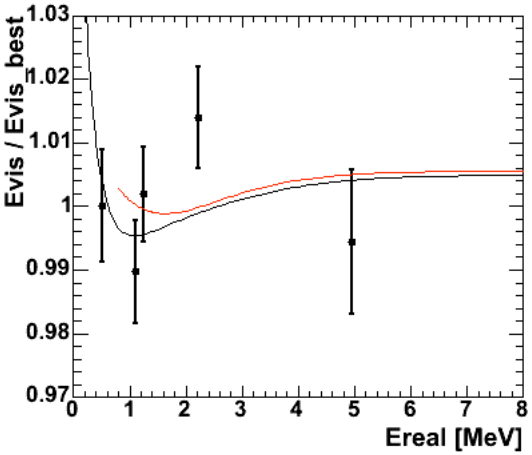

Evis / Evis_best
Ereal [MeV]

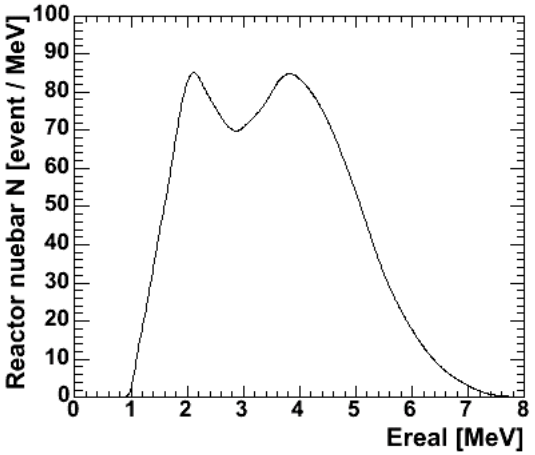

Reactor nuebar N [event / MeV]
Ereal [MeV]

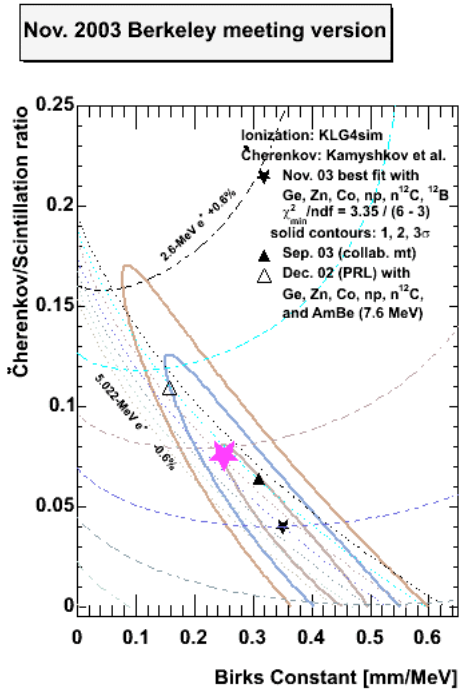

Nov. 2003 Berkeley meeting version
Ionization: KLG4sim
Cherenkov: Kamyshkov et al.
Nov. 03 best fit with
Ge, Zn, Co, np, n12C, 12B
χ2min /ndf = 3.35 / (6 - 3)
solid contours: 1, 2, 3σ
Sep. 03 (collab. mt)
Dec. 02 (PRL) with
Ge, Zn, Co, np, n12C,
and AmBe (7.6 MeV)
2.6-MeV e+ +0.6%
5.022-MeV e+ -0.6%
Čherenkov/Scintillation ratio
Birks Constant [mm/MeV]


Evis / Ereal
black: γ
red: e+
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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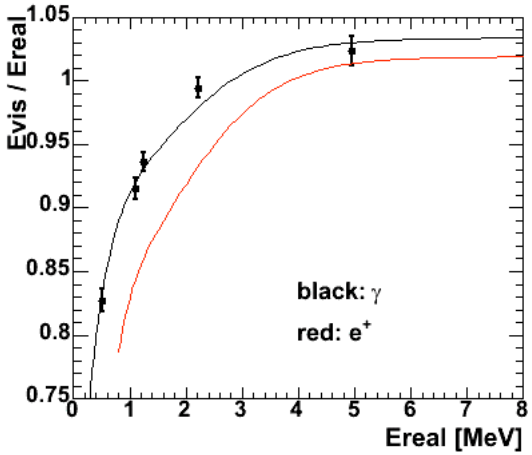
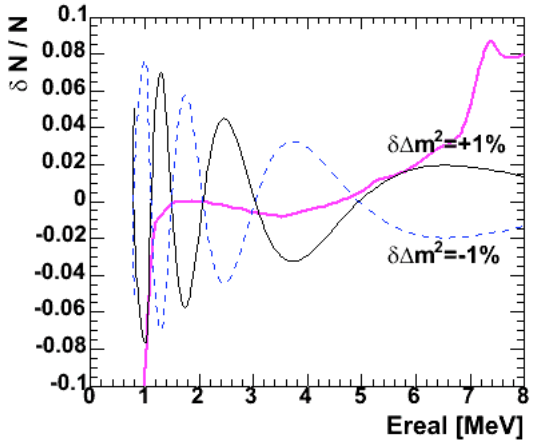
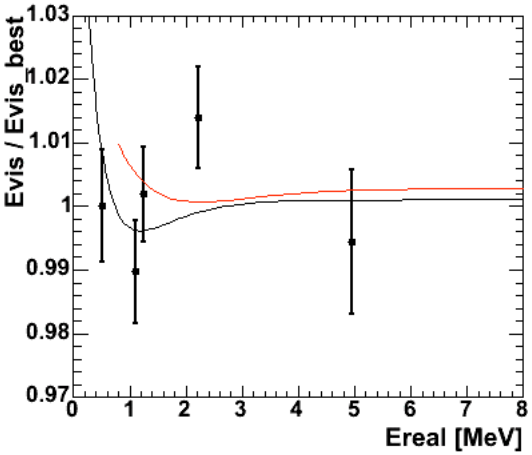
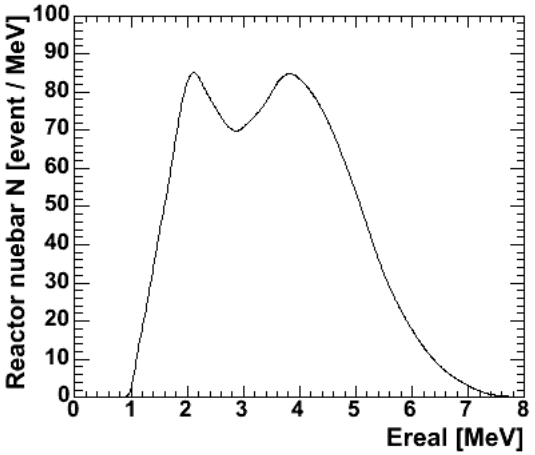
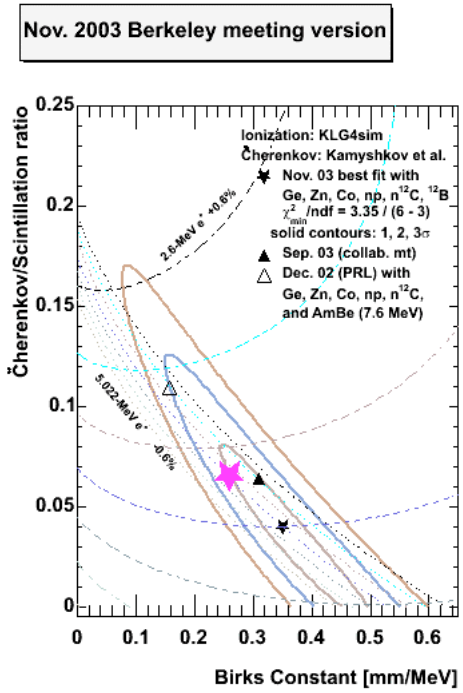
Birks Constant [mm/MeV]


Evis / Ereal
black: γ
red: e+
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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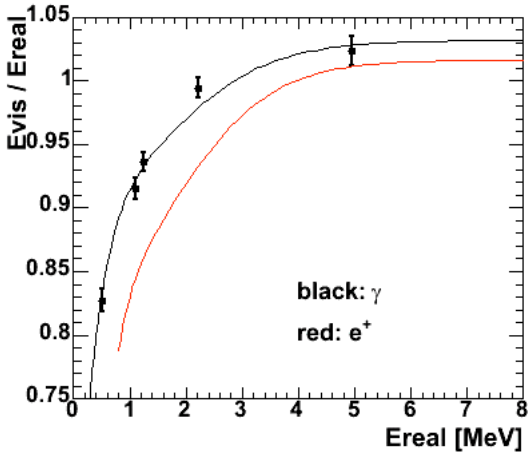
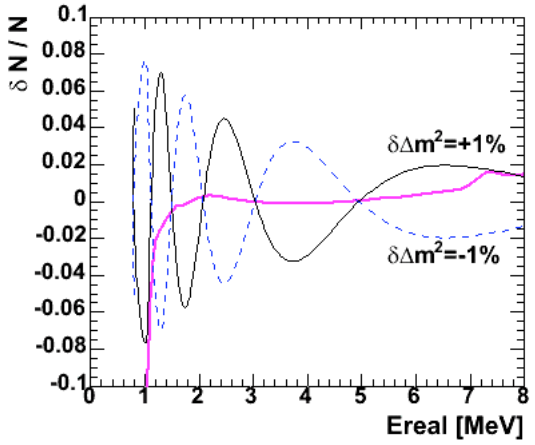
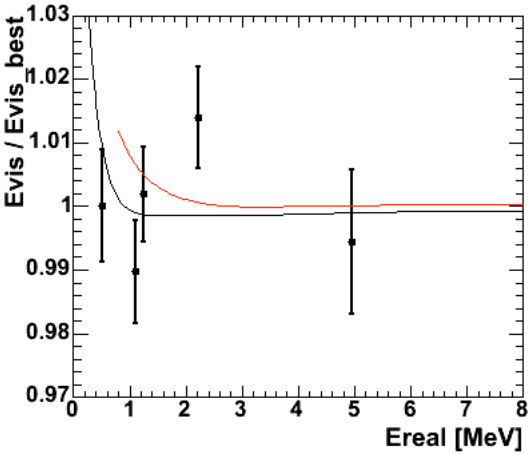
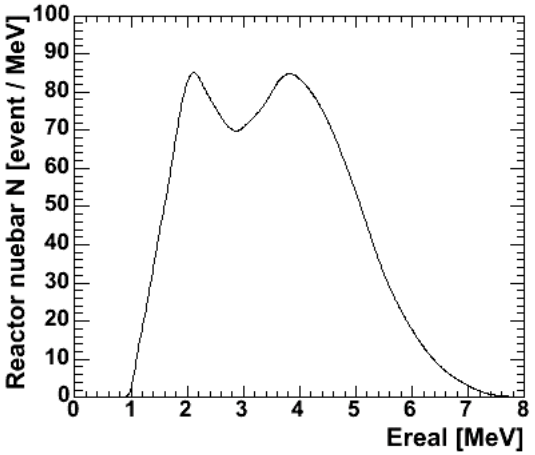
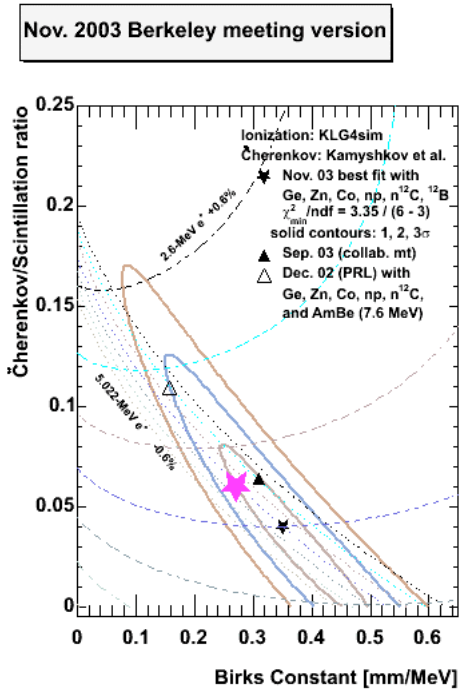

Evis / Ereal
black: γ
red: e+
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]


Nov. 2003 Berkeley meeting version
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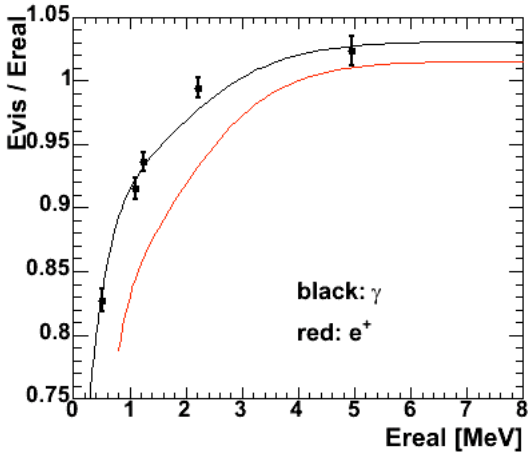
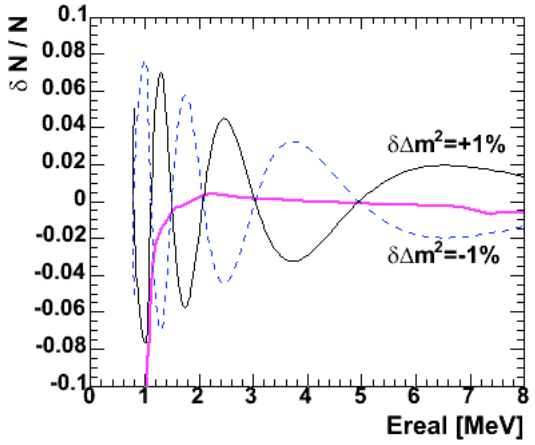
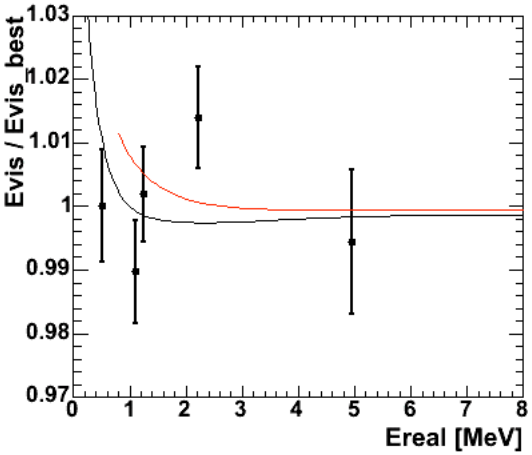
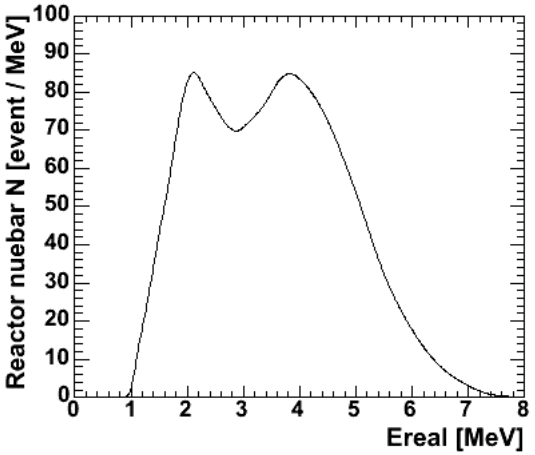
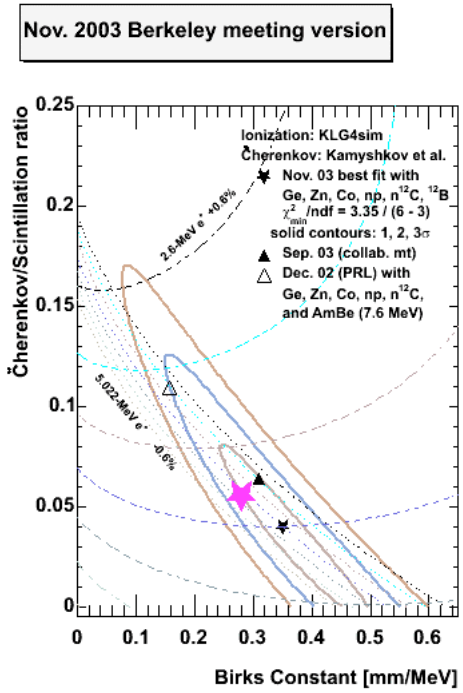

Evis / Ereal
black: γ
red: e+
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]


Nov. 2003 Berkeley meeting version
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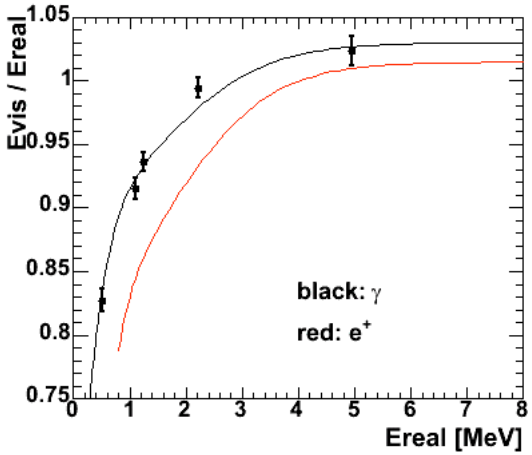
Evis / Ereal
black: γ
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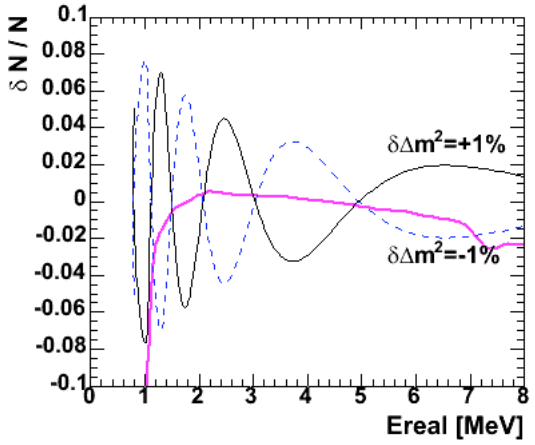
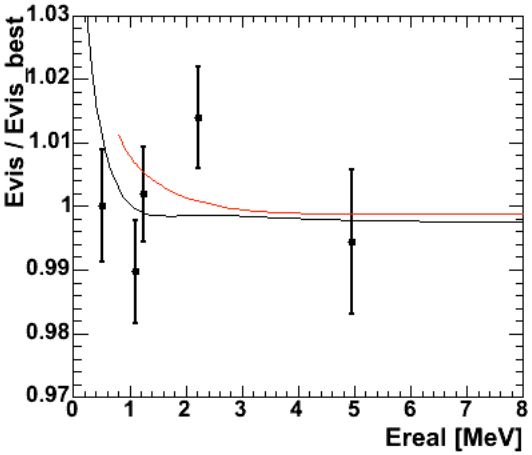
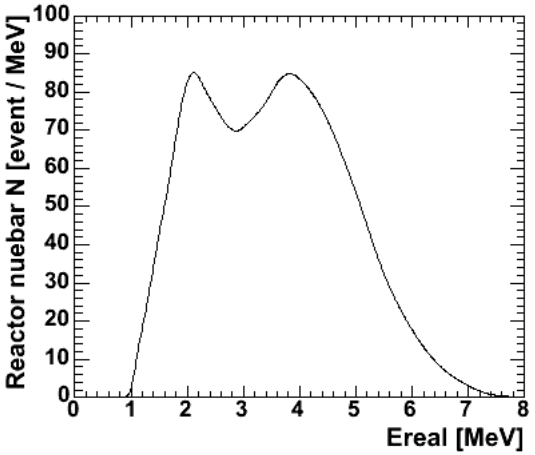
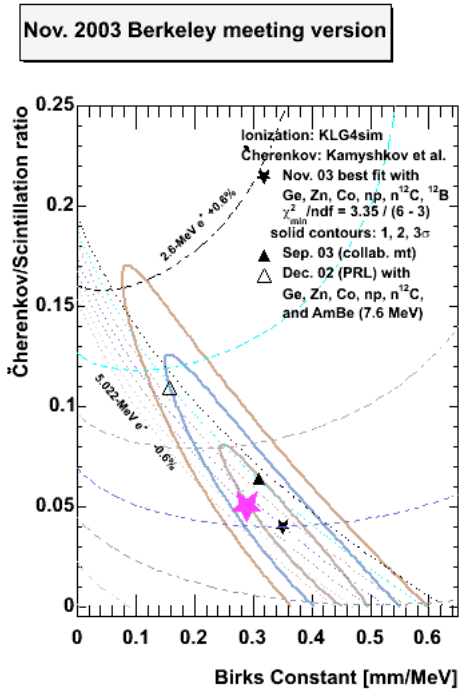
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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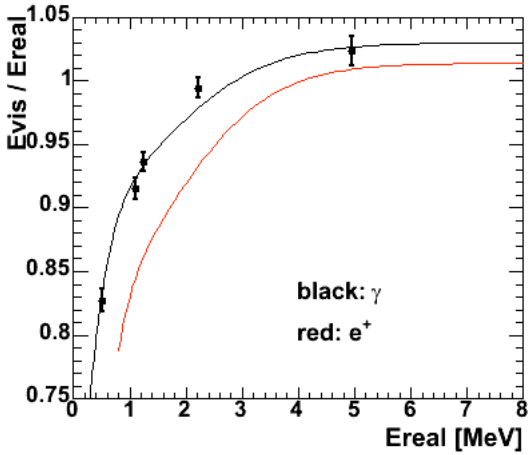
Evis / Ereal
black: γ
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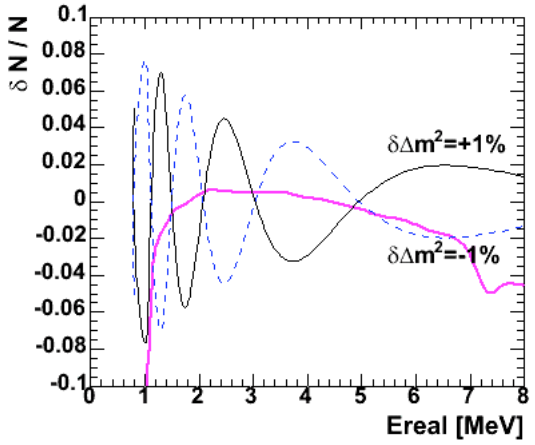
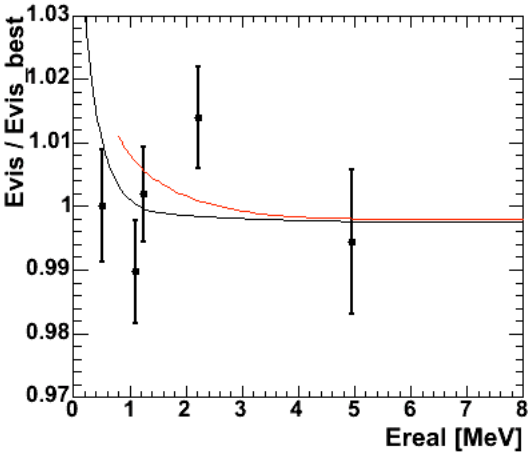
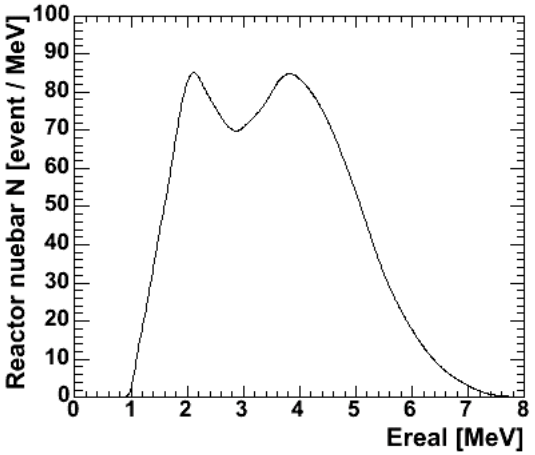
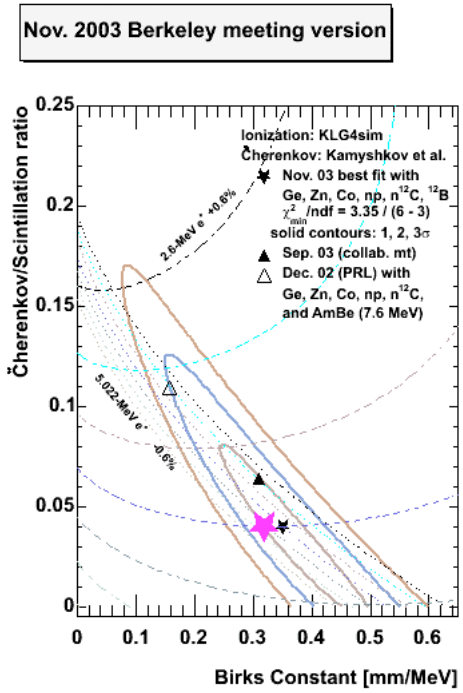

δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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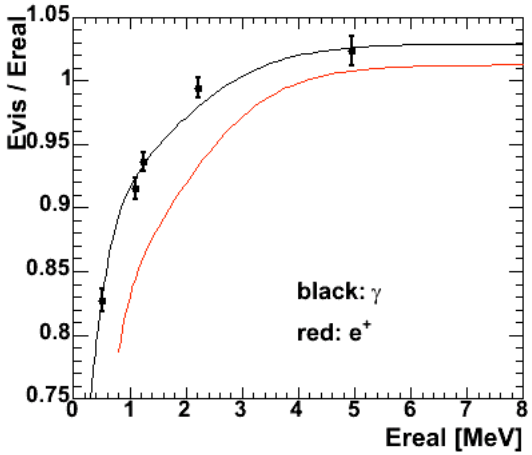
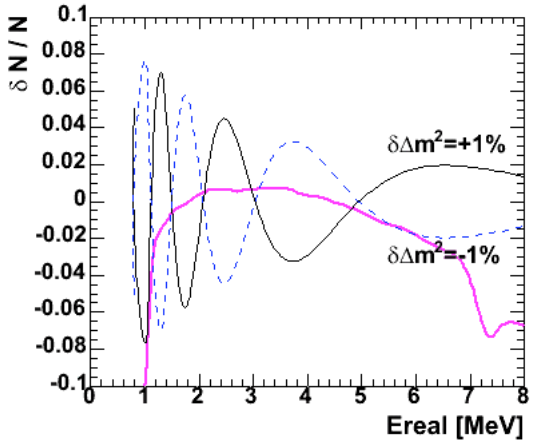
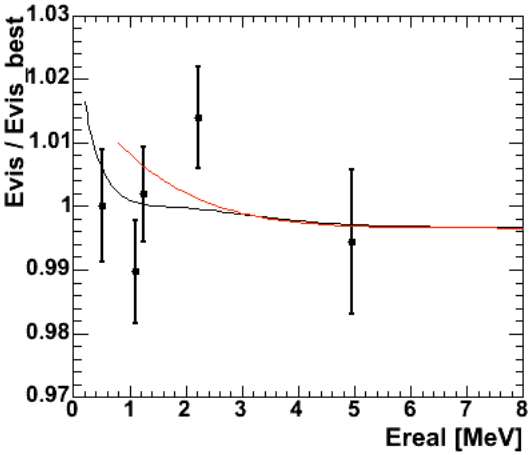
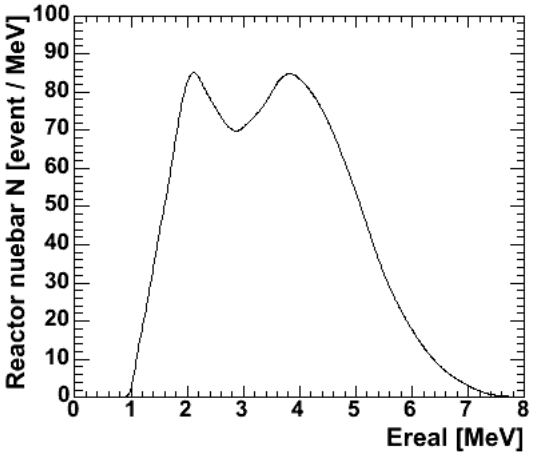

Evis / Ereal
black: γ
red: e+
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
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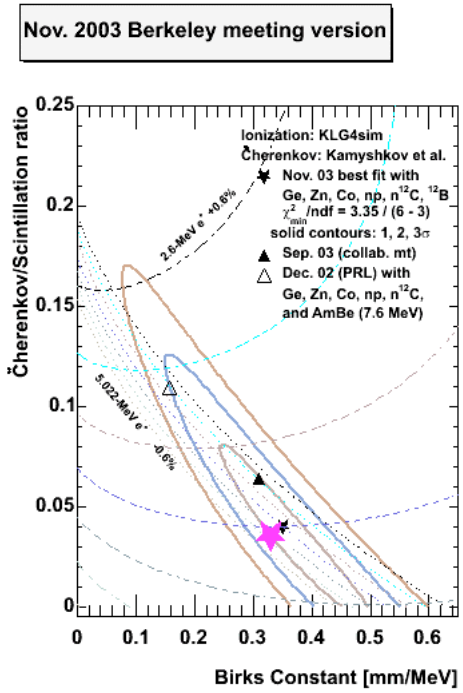
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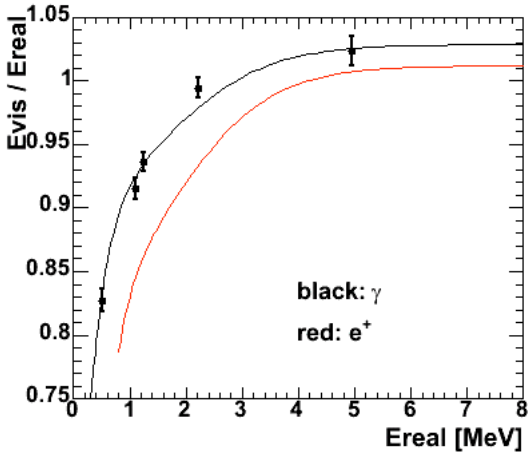
Evis / Ereal
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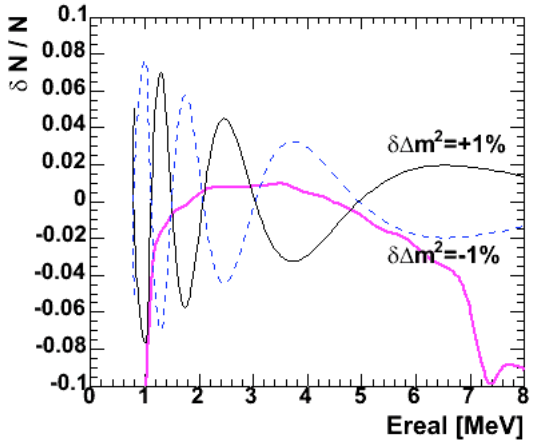
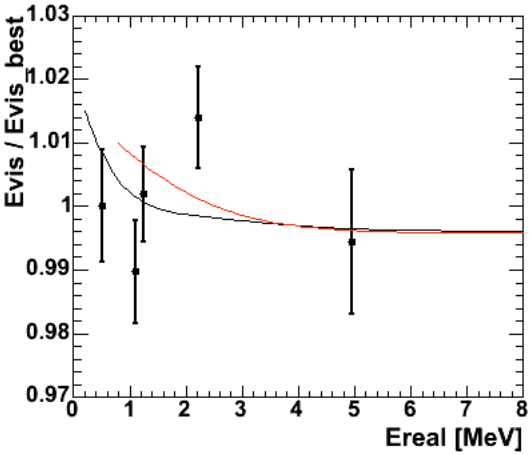
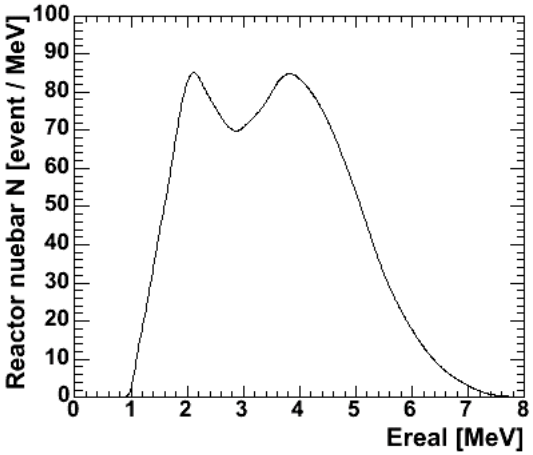
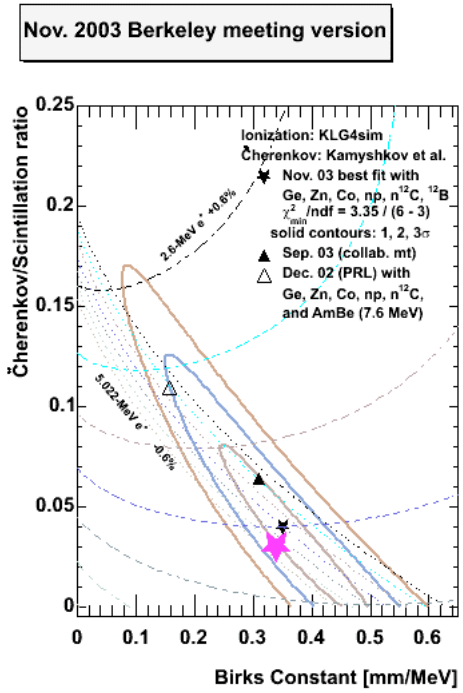
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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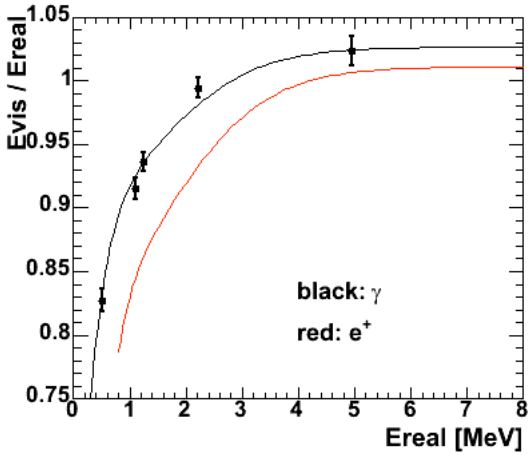
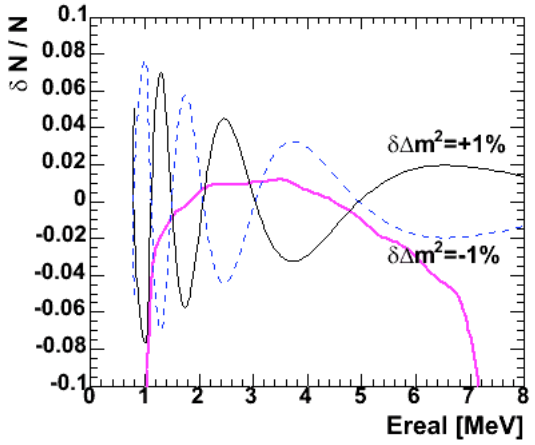
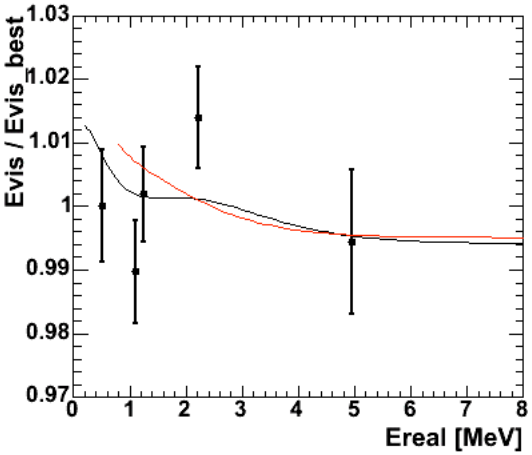
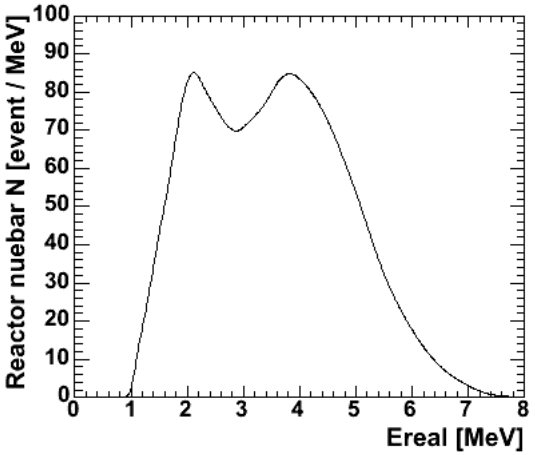
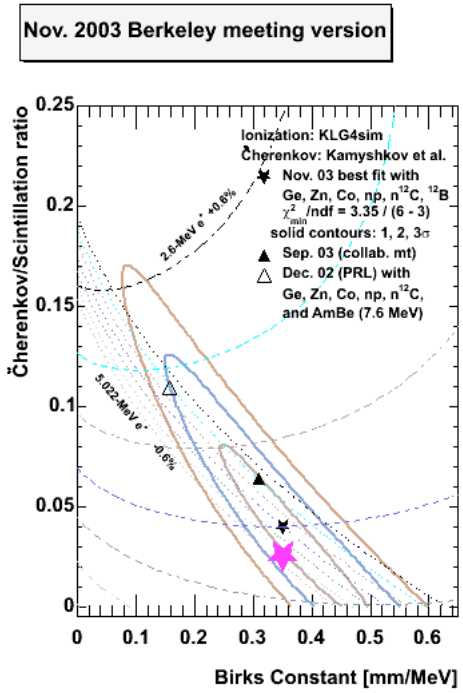

Evis / Ereal
black: γ
red: e+
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]


Nov. 2003 Berkeley meeting version
Ionization: KLG4sim
Cherenkov: Kamyshkov et al.
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Ge, Zn, Co, np, n12C, 12B
χ2min /ndf = 3.35 / (6 - 3)
solid contours: 1, 2, 3σ
Sep. 03 (collab. mt)
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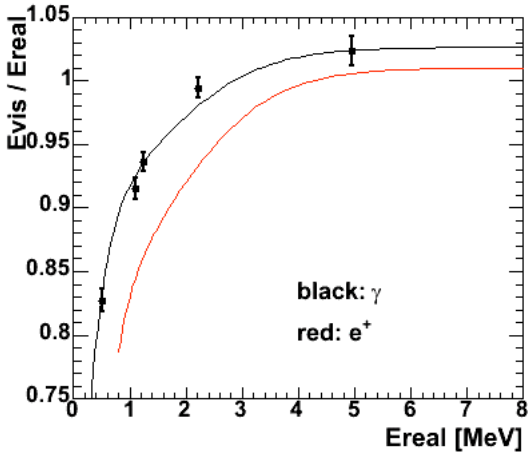
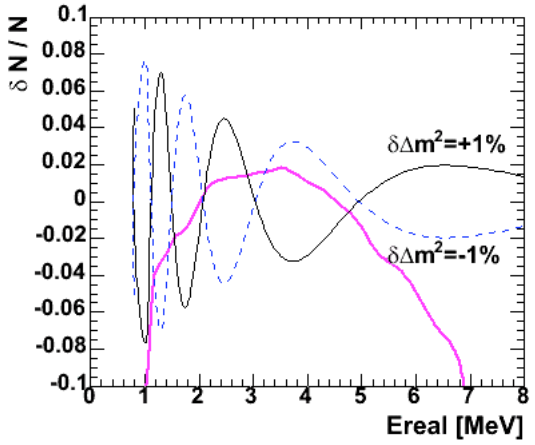
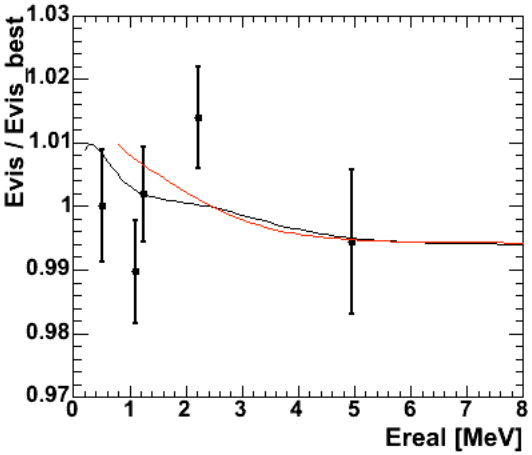
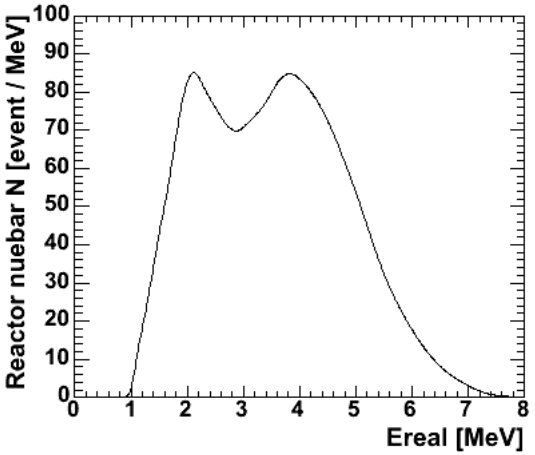
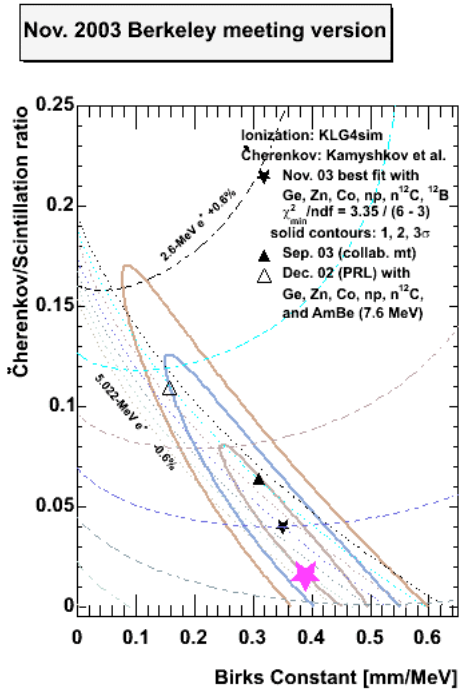
Ge, Zn, Co, np, n12C,
and AmBe (7.6 MeV)
2.6-MeV e+ +0.6%
5.022-MeV e+ -0.6%
Čherenkov/Scintillation ratio
Birks Constant [mm/MeV]


Evis / Ereal
black: γ
red: e+
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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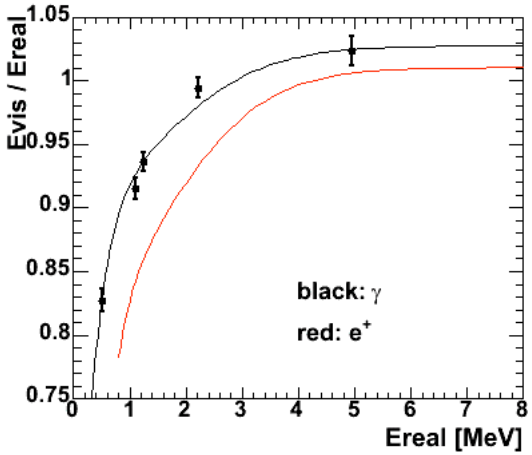
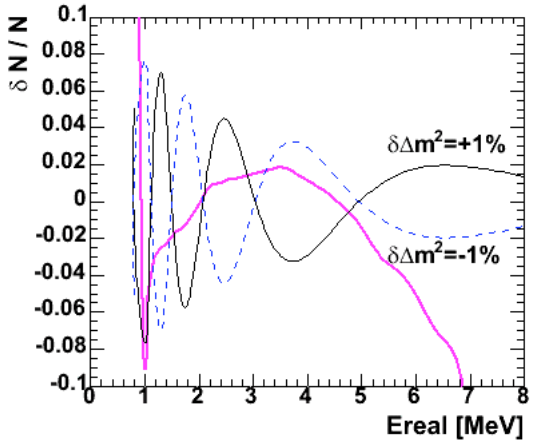
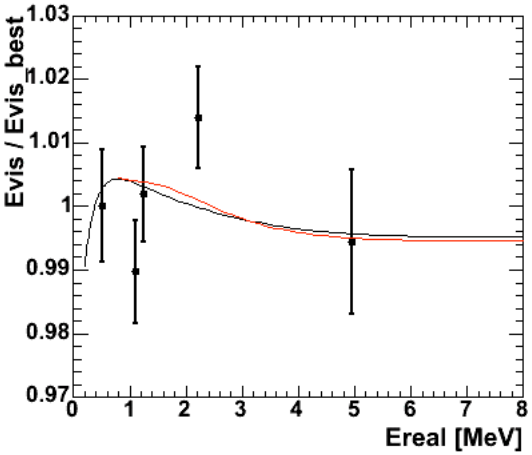
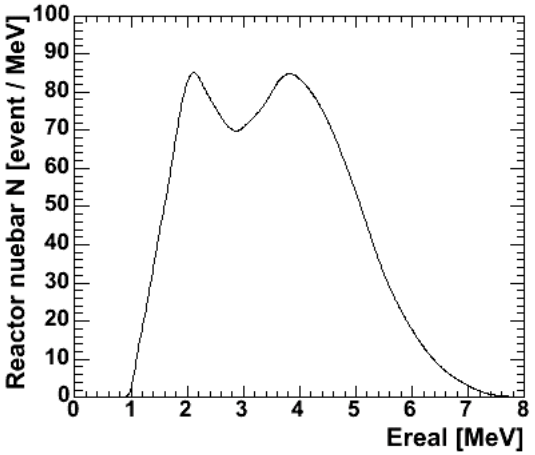
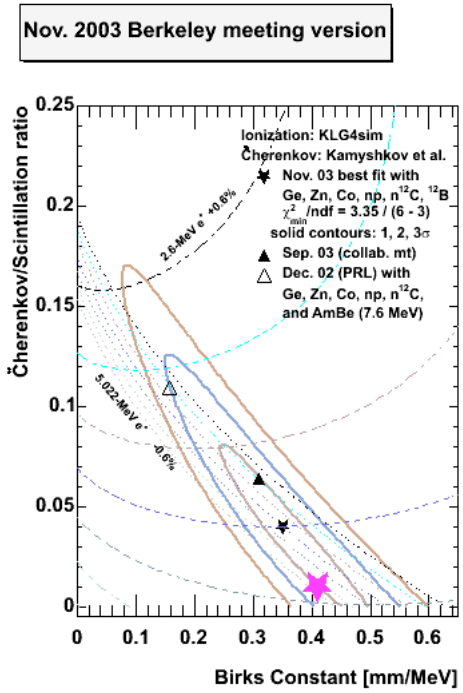

Evis / Ereal
black: γ
red: e+
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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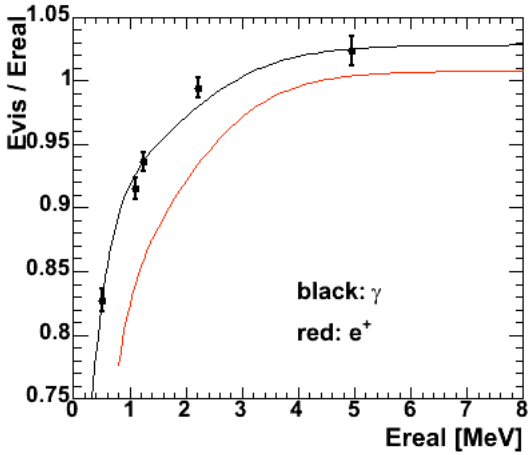
Evis / Ereal
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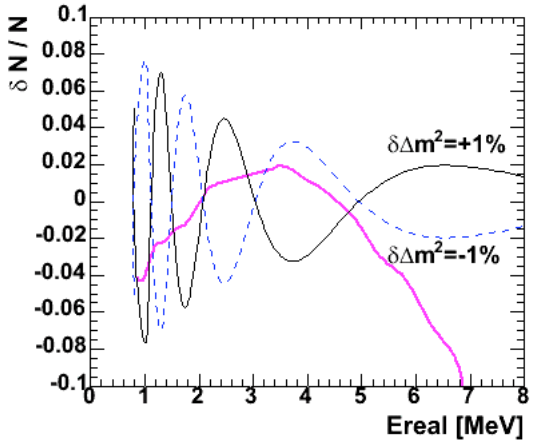
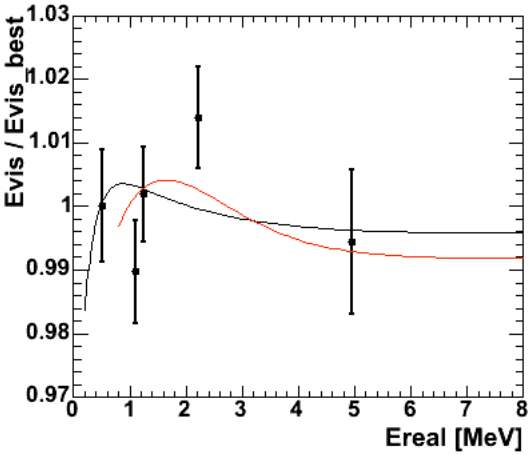
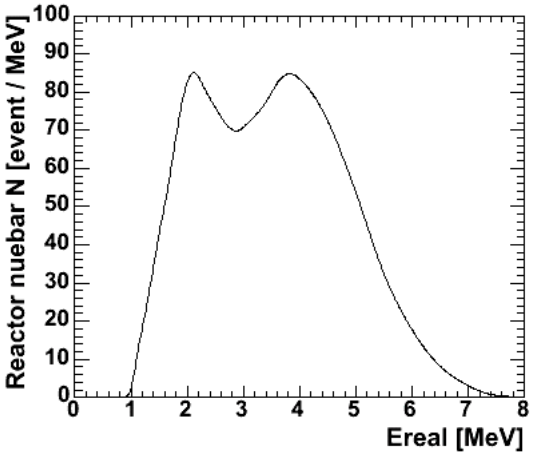
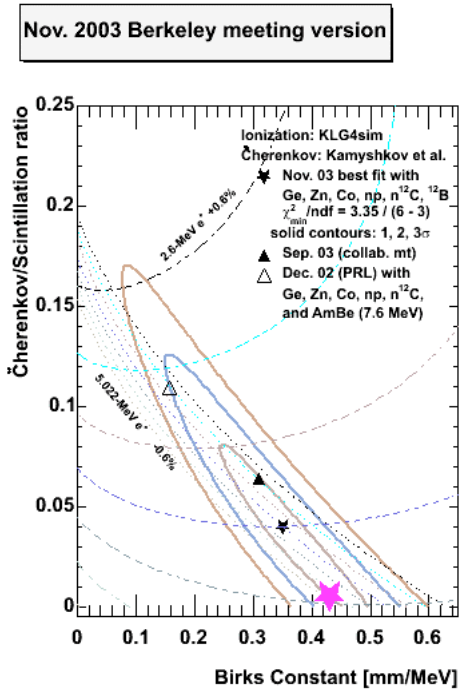
red: e+
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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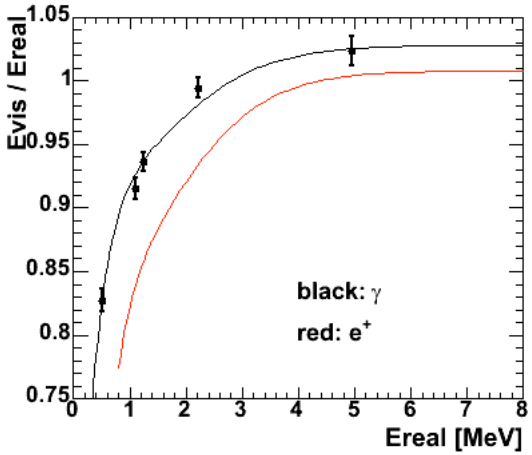
Evis / Ereal
black: γ
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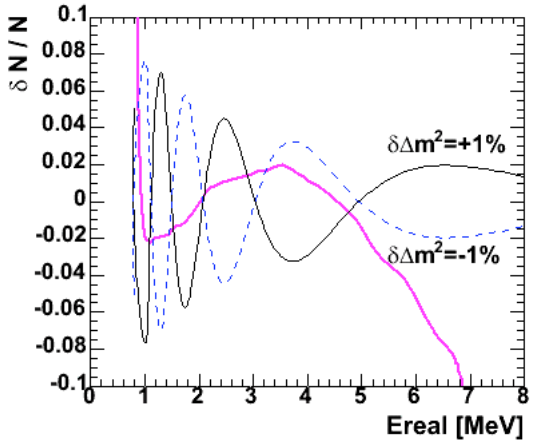
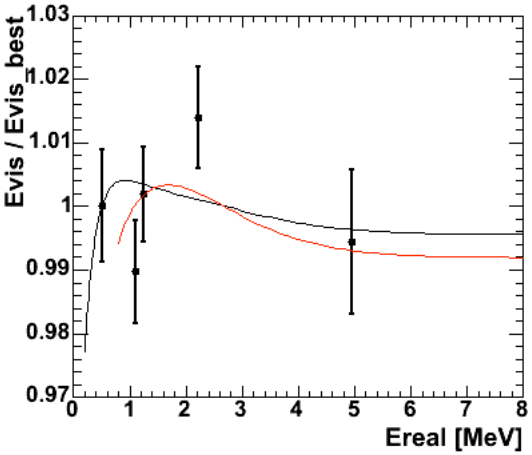
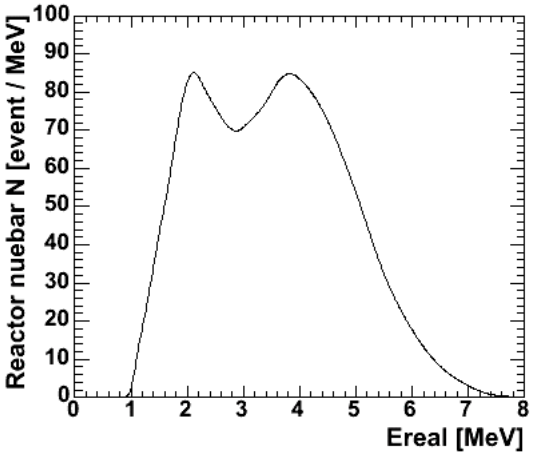
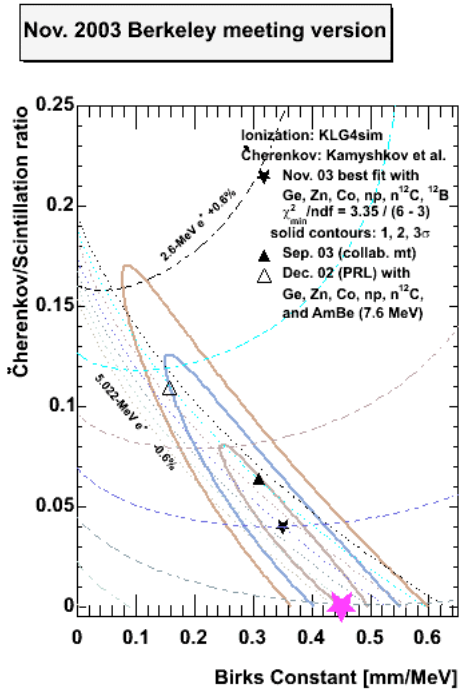
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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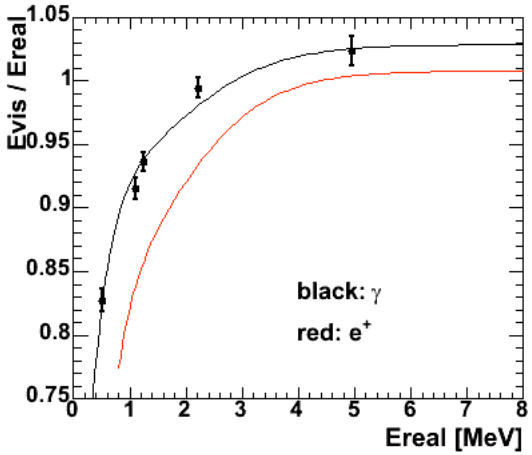
Evis / Ereal
black: γ
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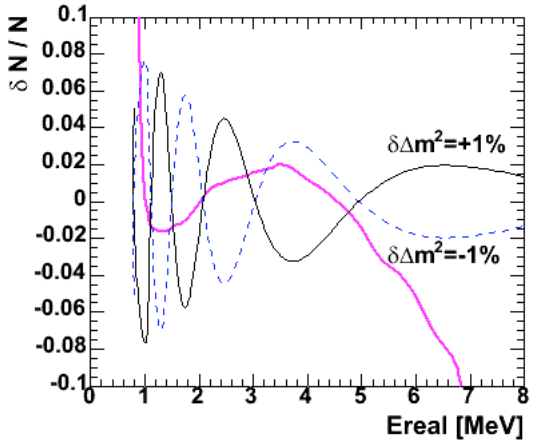
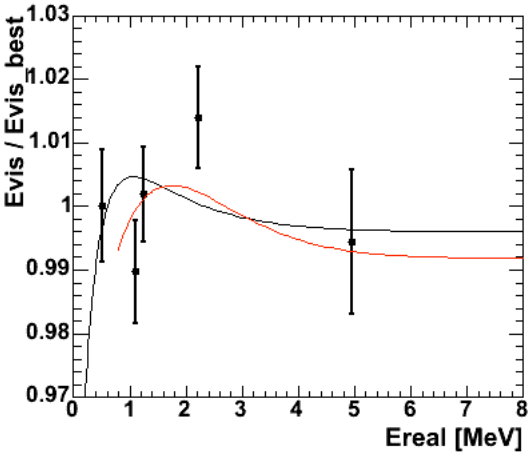
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
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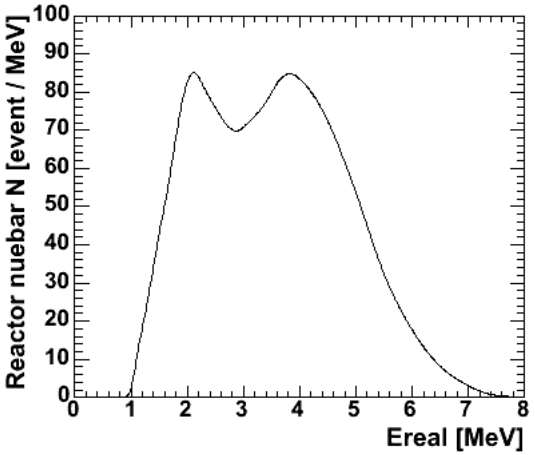
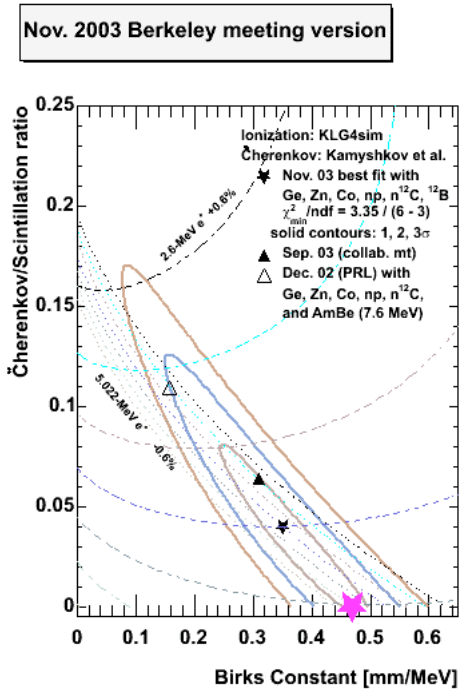

Reactor nuebar N [event / MeV]
Ereal [MeV]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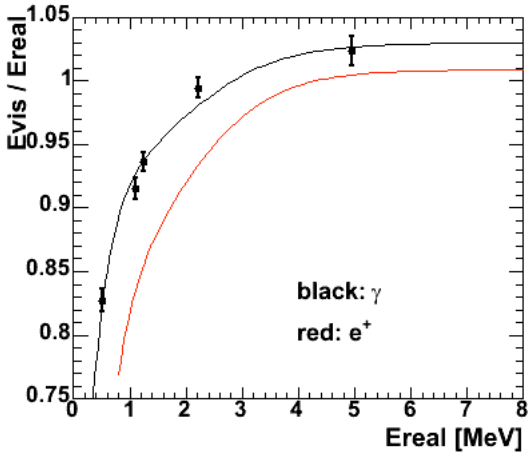
Evis / Ereal
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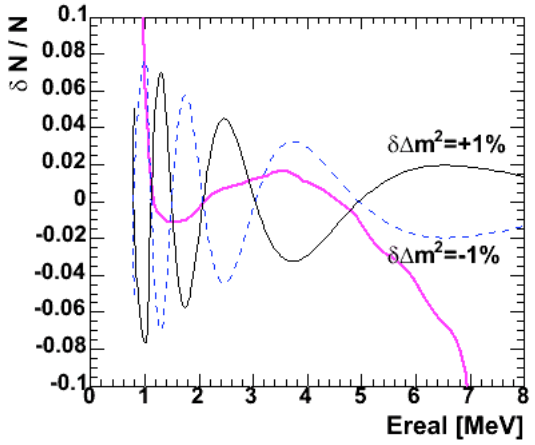
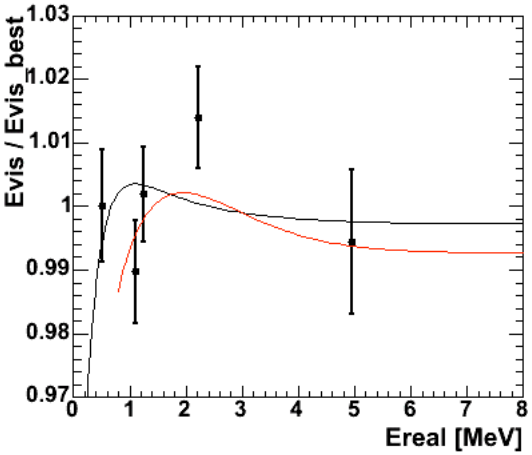
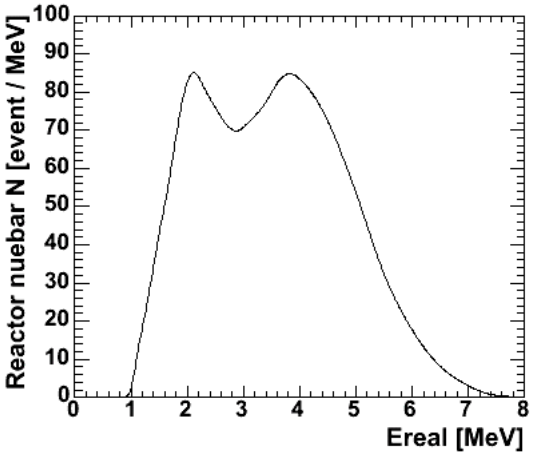
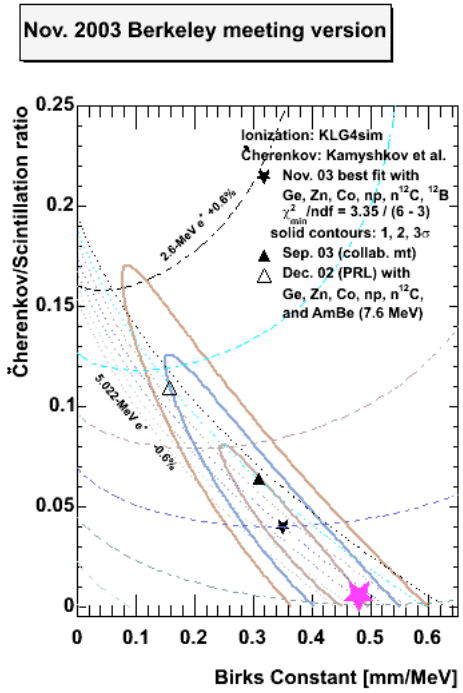

δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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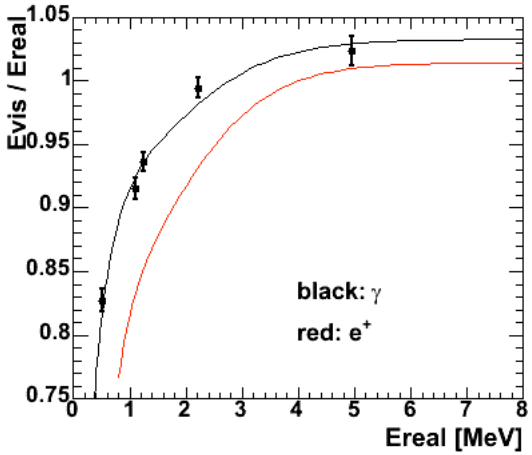
Evis / Ereal
black: γ
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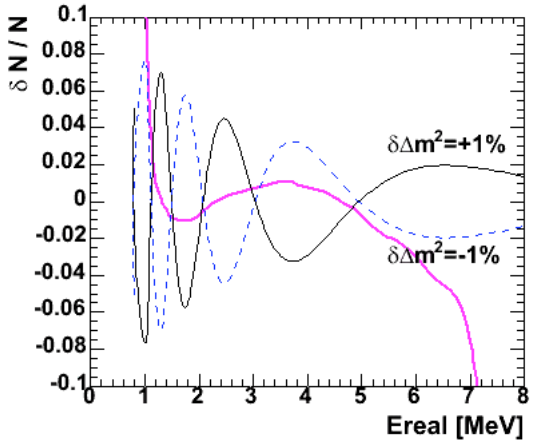
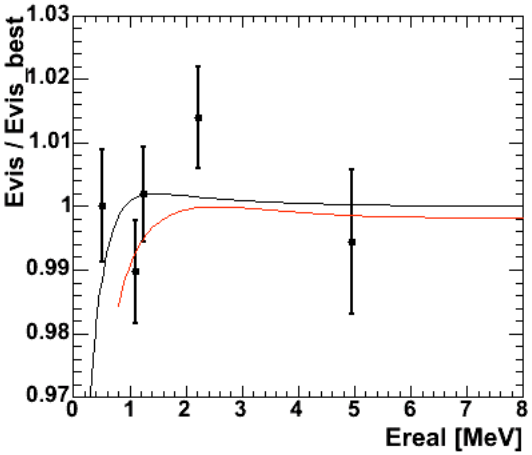

δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
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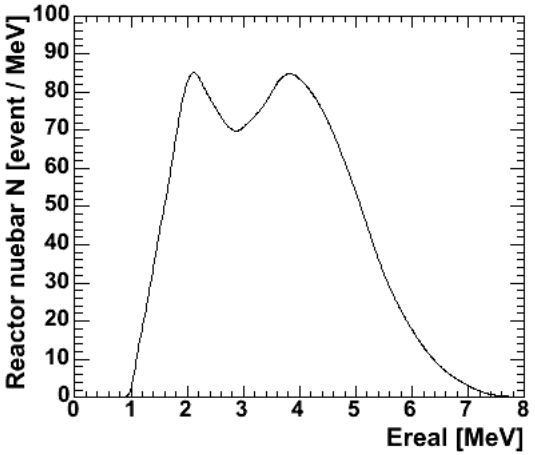
Reactor nuebar N [event / MeV]
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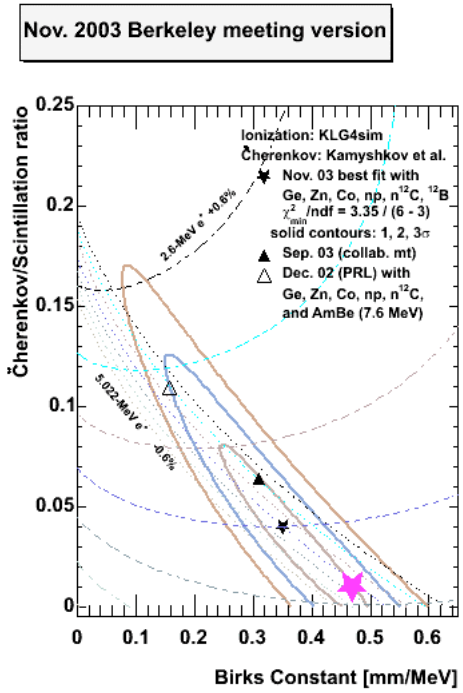
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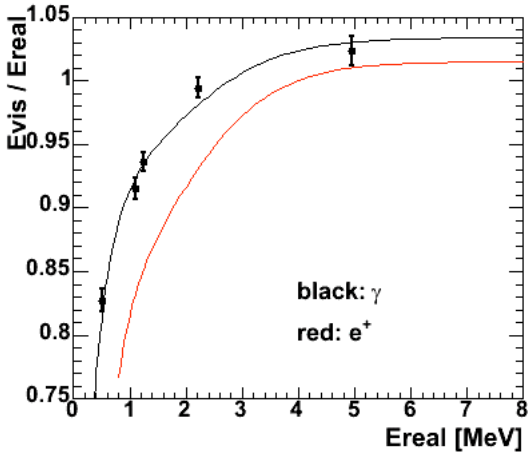
Evis / Ereal
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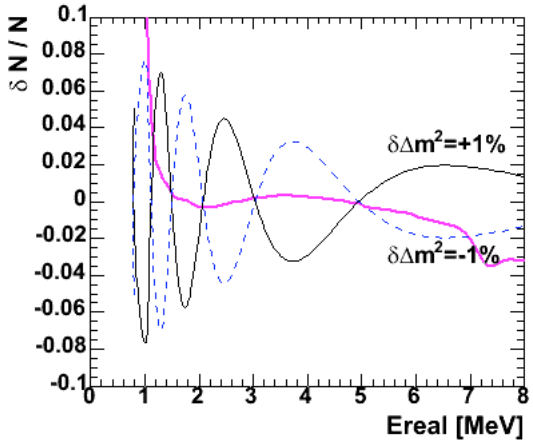
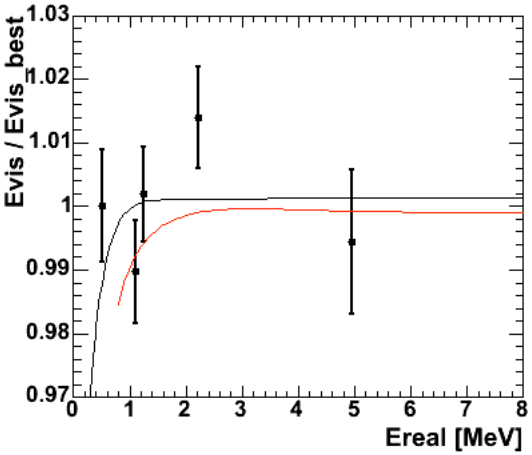
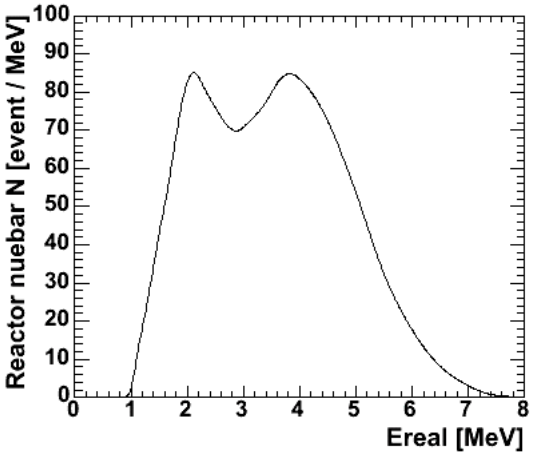
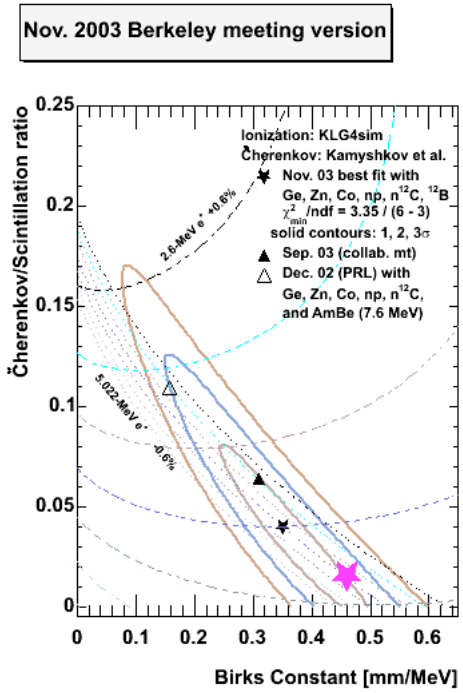
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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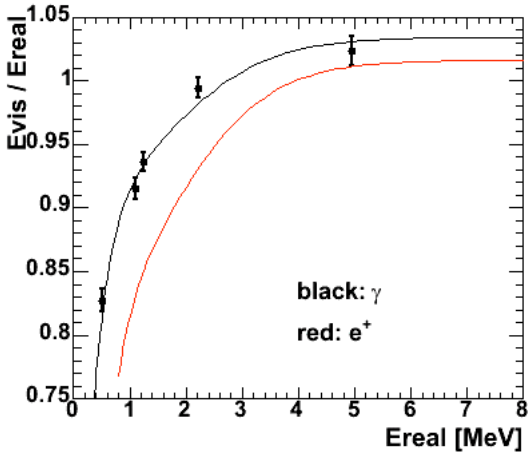
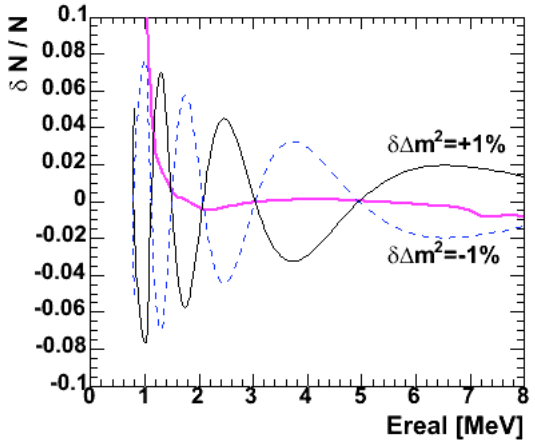
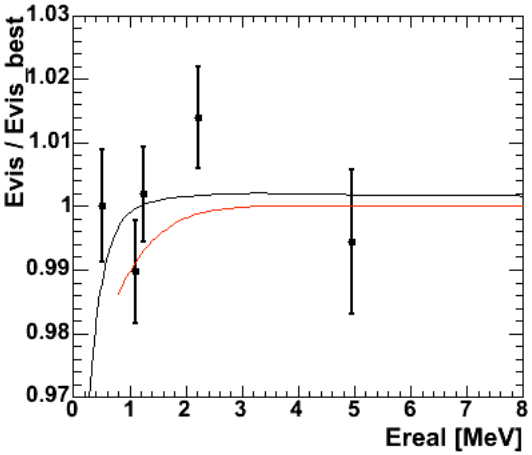
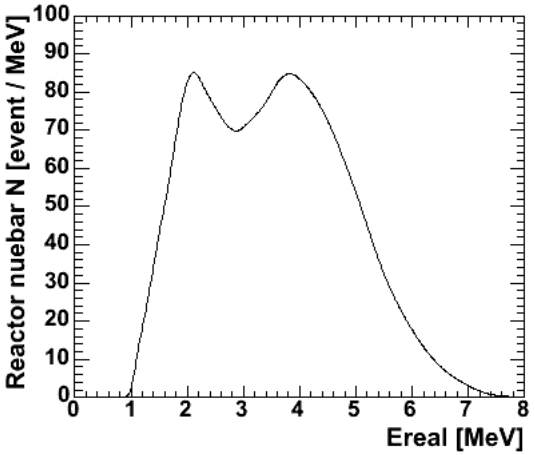
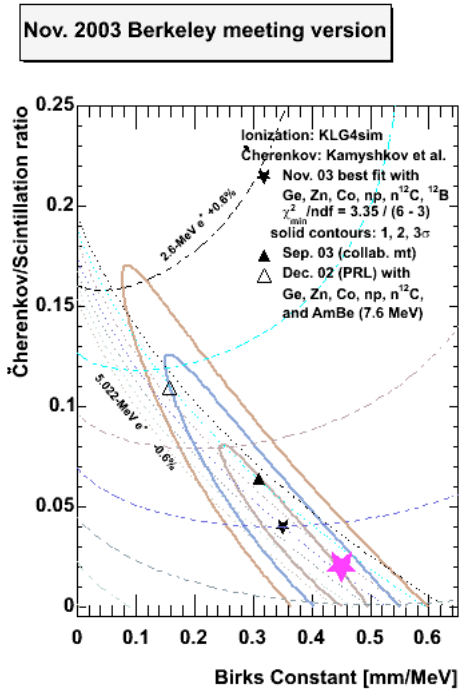

Evis / Ereal
black: γ
red: e+
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]


Nov. 2003 Berkeley meeting version
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Cherenkov: Kamyshkov et al.
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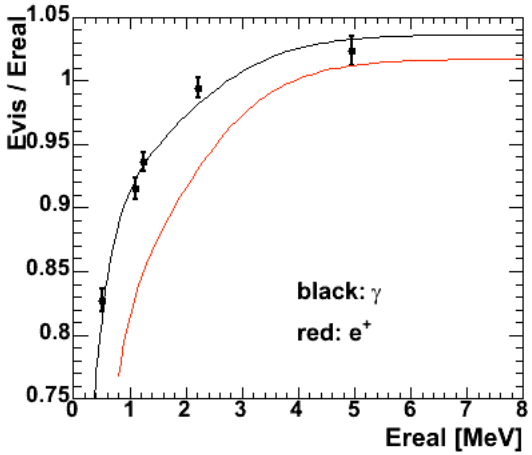
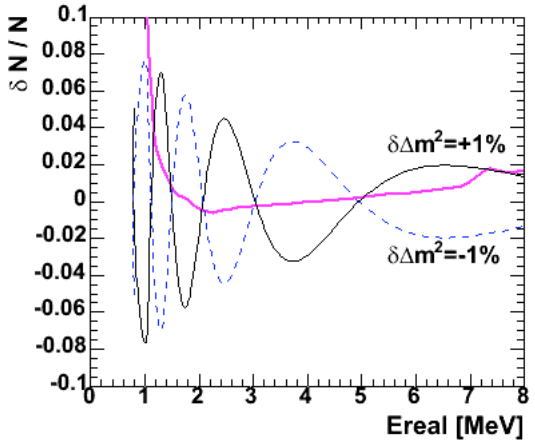
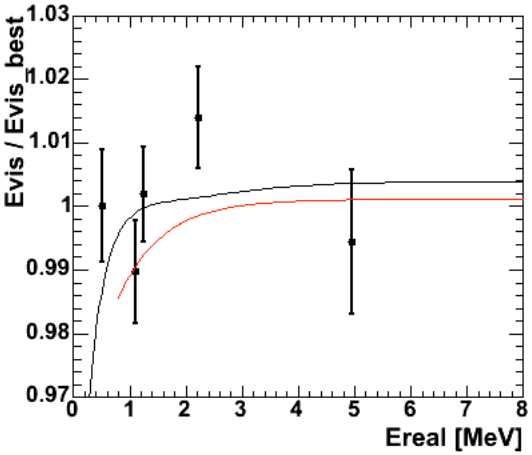
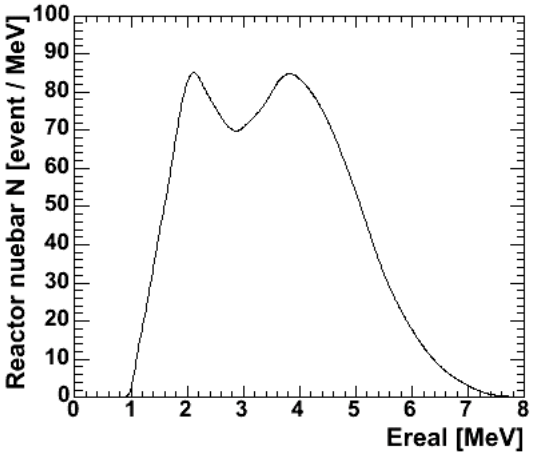
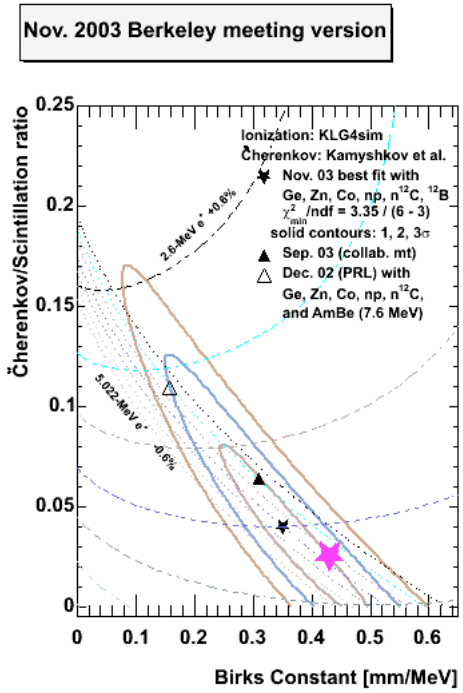
Ge, Zn, Co, np, n12C, 12B
χ2min /ndf = 3.35 / (6 - 3)
solid contours: 1, 2, 3σ
Sep. 03 (collab. mt)
Dec. 02 (PRL) with
Ge, Zn, Co, np, n12C,
and AmBe (7.6 MeV)
2.6-MeV e+ +0.6%
5.022-MeV e- -0.6%
Čherenkov/Scintillation ratio
Birks Constant [mm/MeV]


Evis / Ereal
black: γ
red: e+
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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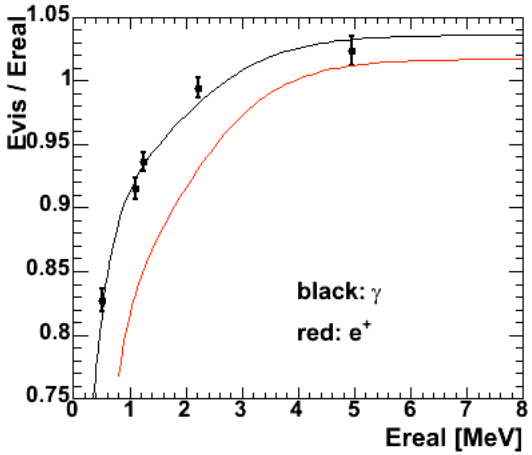
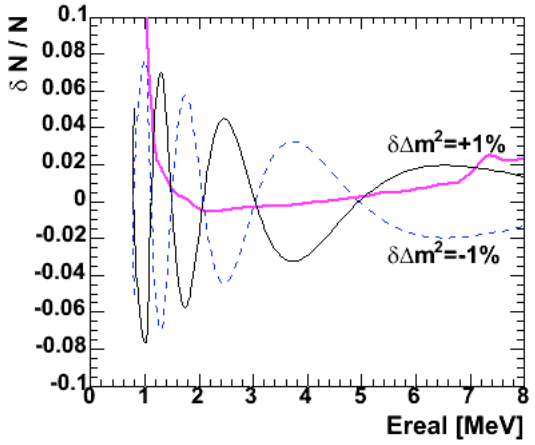
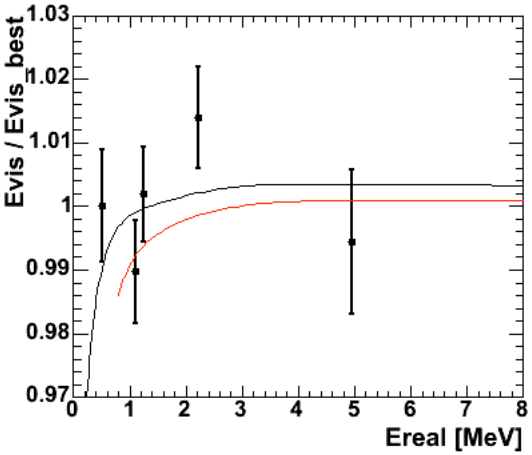
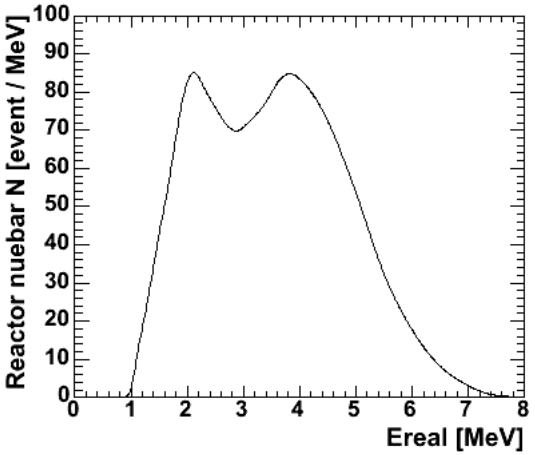
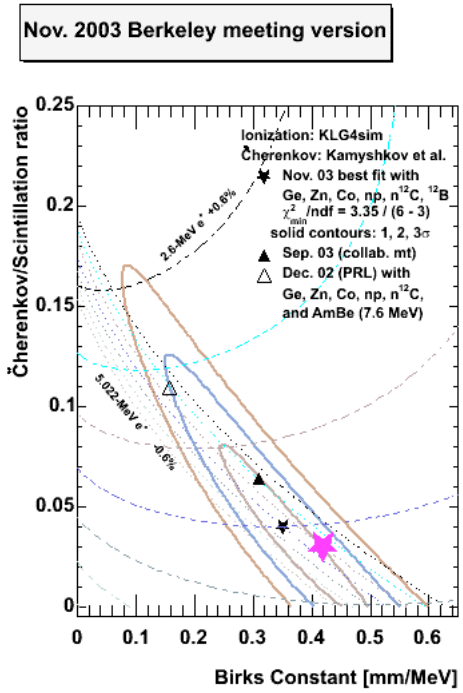
Birks Constant [mm/MeV]


Evis / Ereal
black: γ
red: e+
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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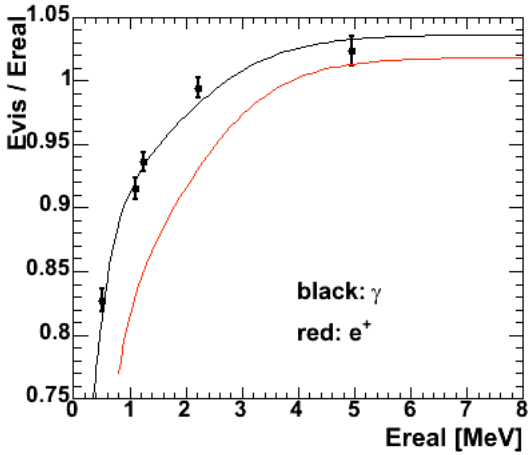
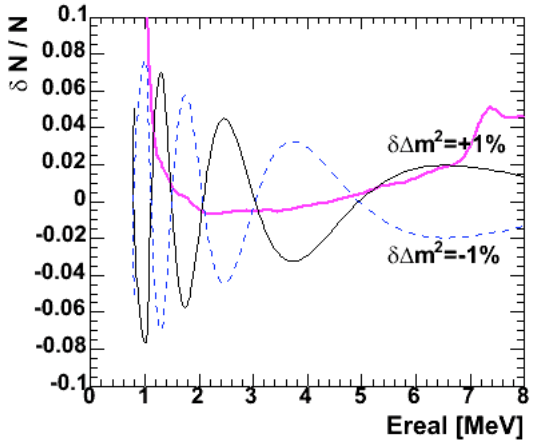
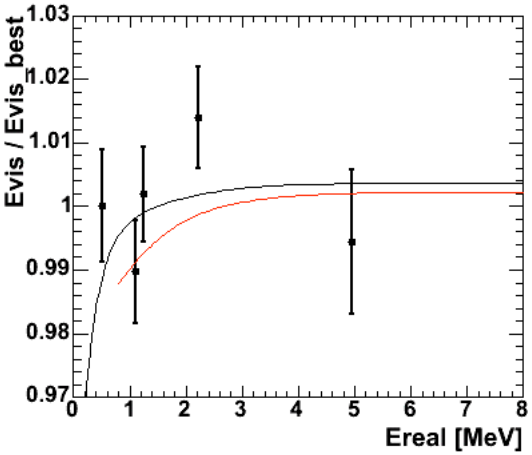
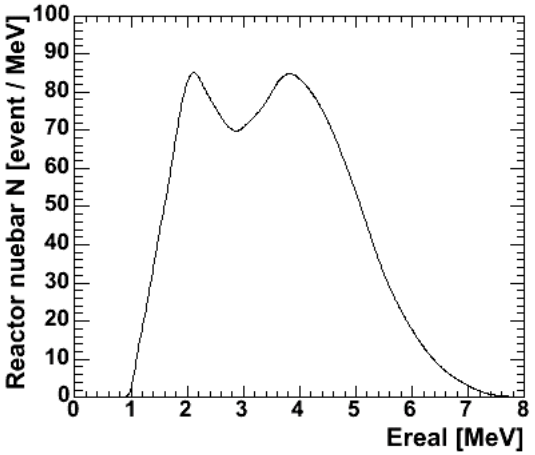
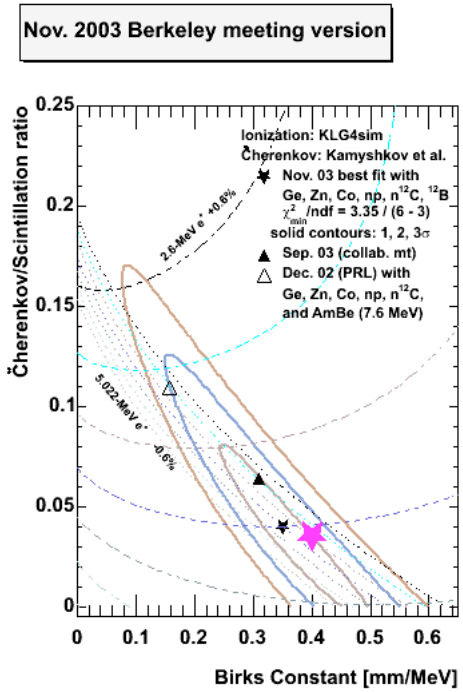

Evis / Ereal
black: γ
red: e+
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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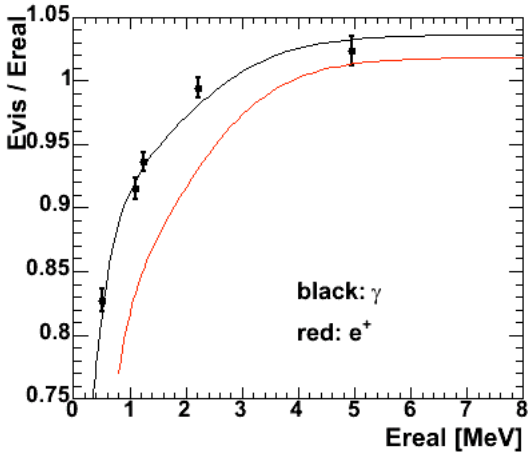
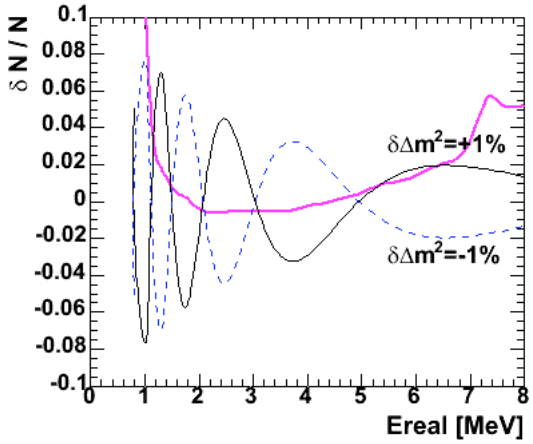
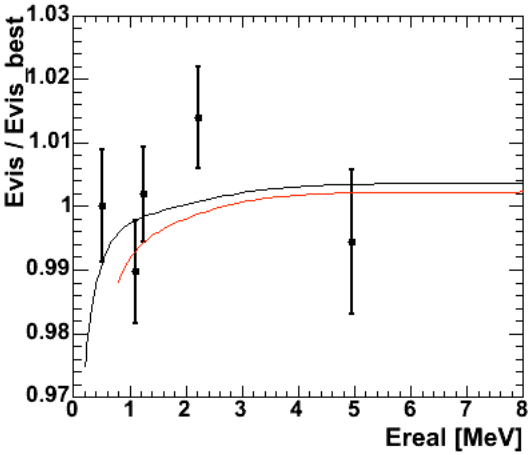
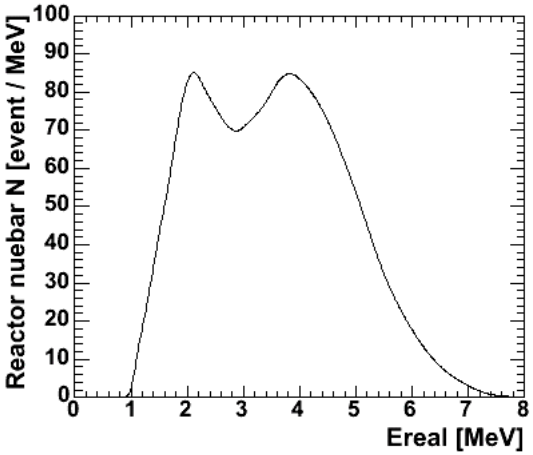
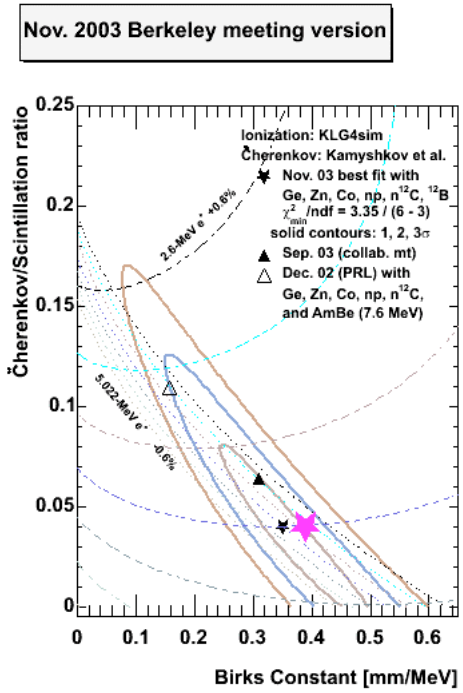

Evis / Ereal
black: γ
red: e+
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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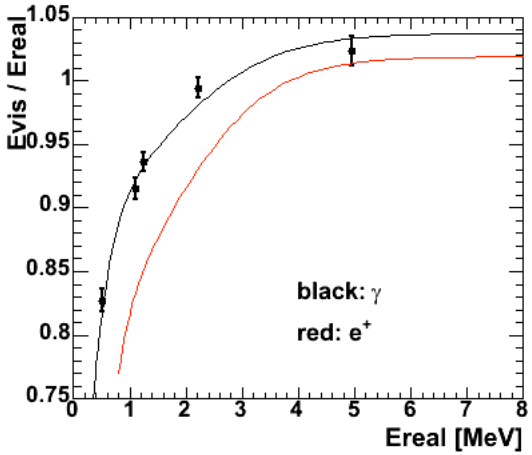
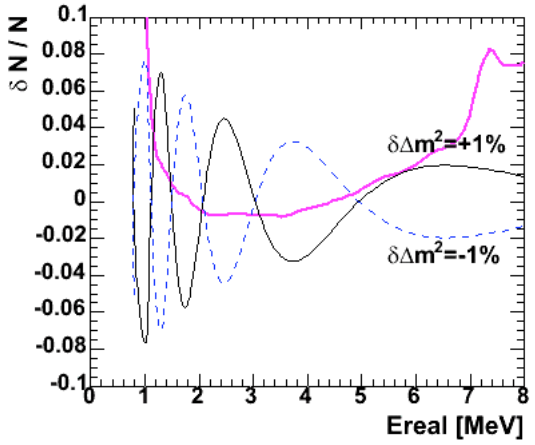
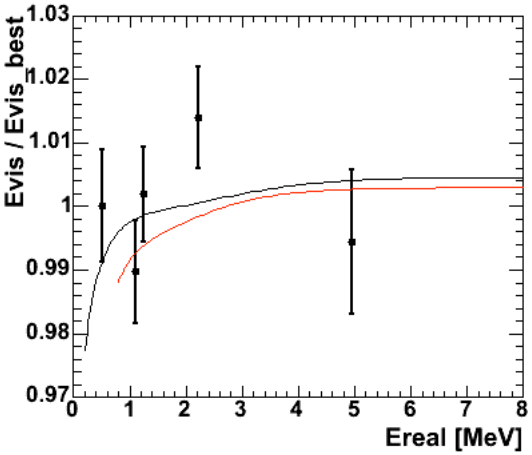
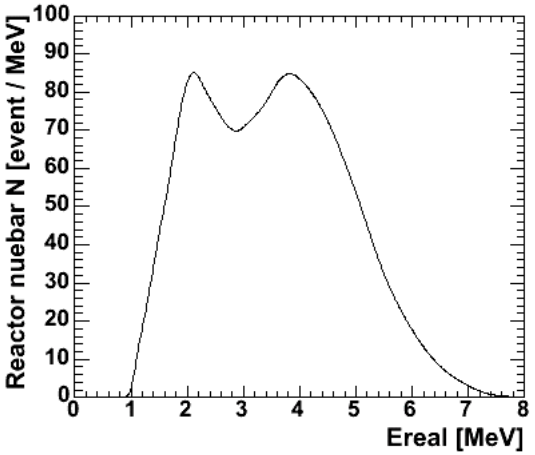
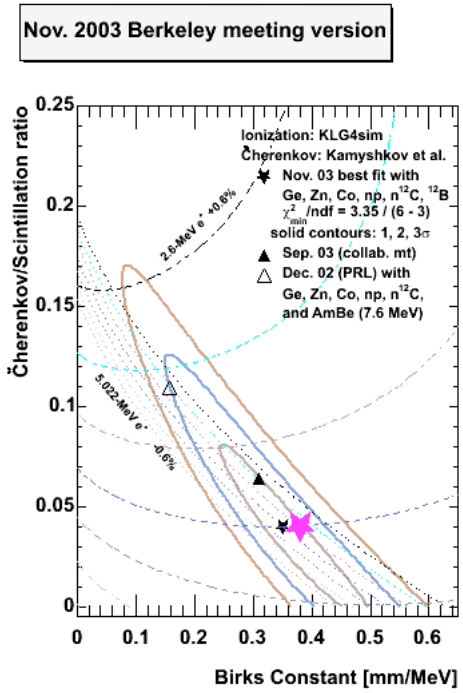

Evis / Ereal
black: γ
red: e+
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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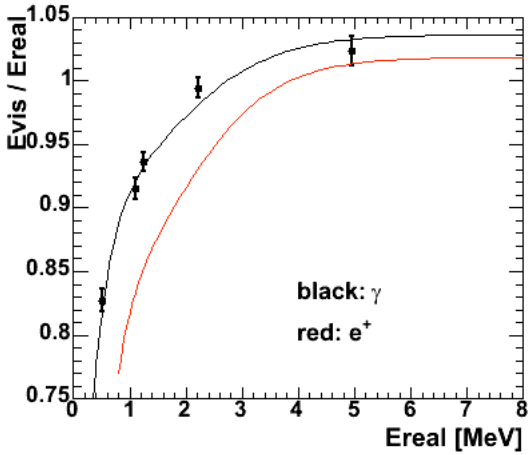
Evis / Ereal
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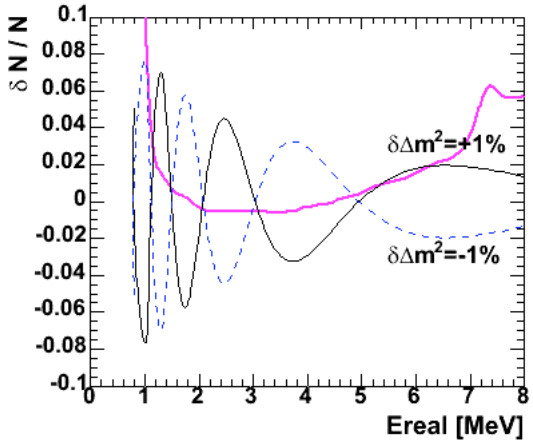
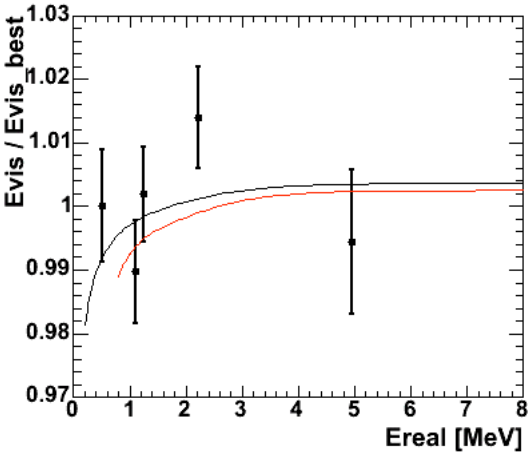
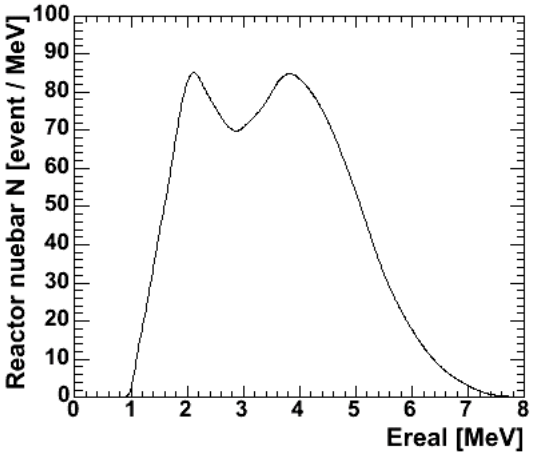
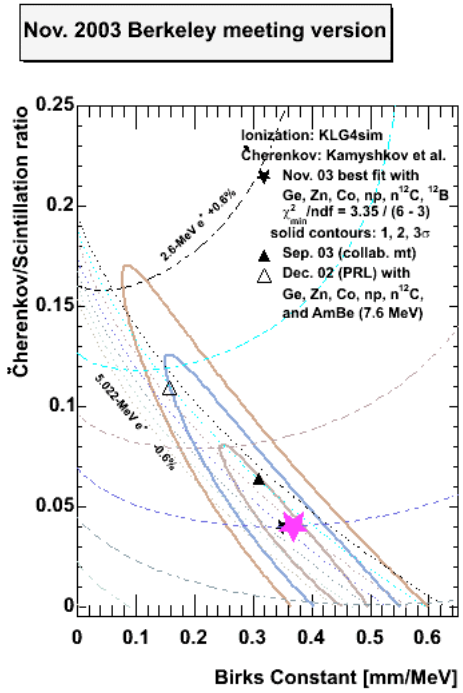

δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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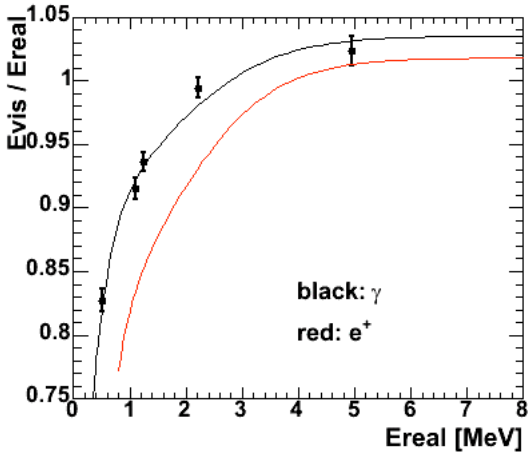
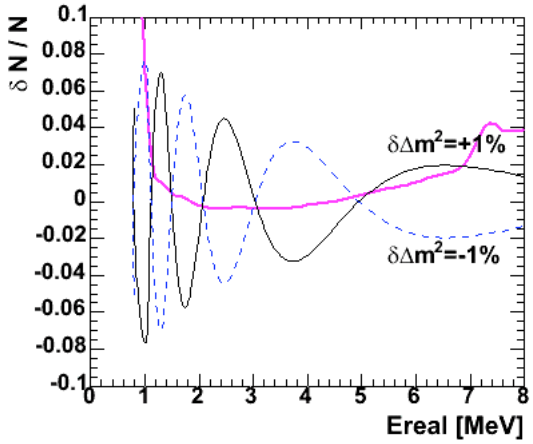
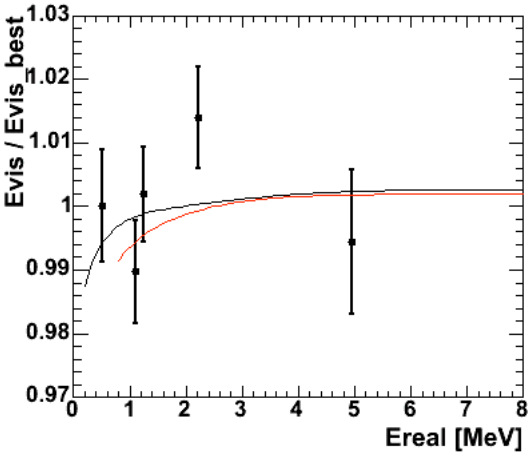
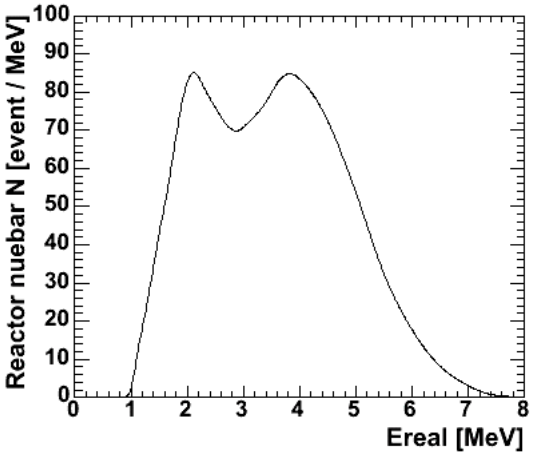
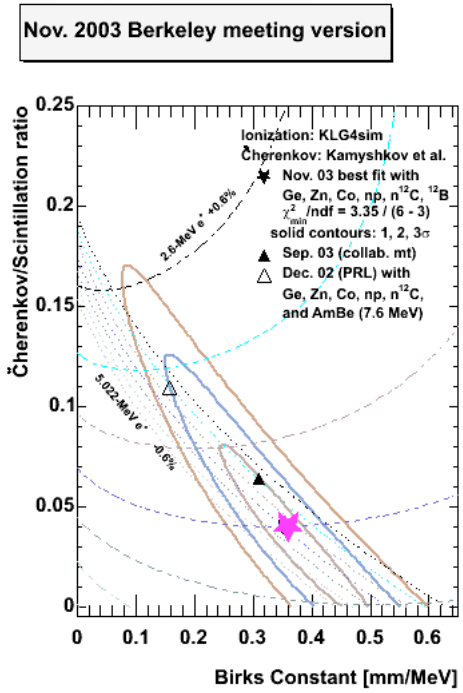

Evis / Ereal
black: γ
red: e+
Ereal [MeV]


δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]


Evis / Evis_best
Ereal [MeV]


Reactor nuebar N [event / MeV]
Ereal [MeV]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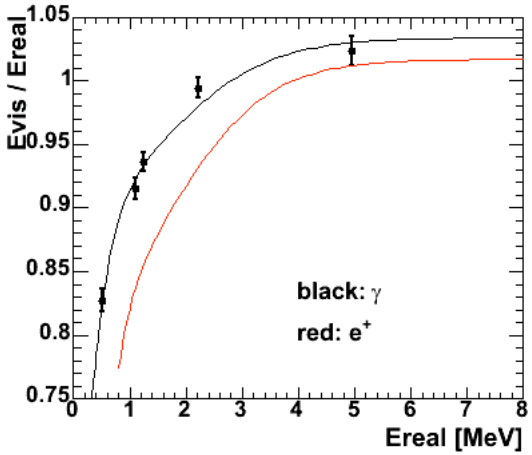
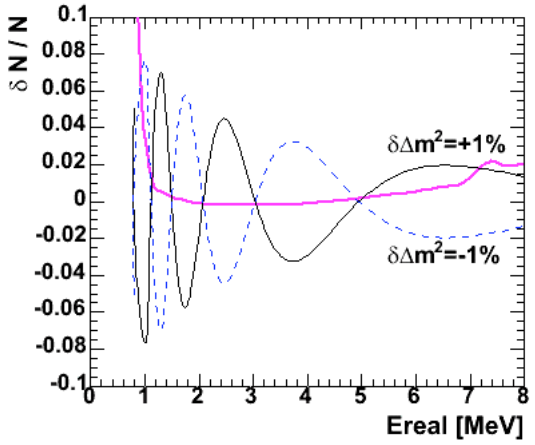
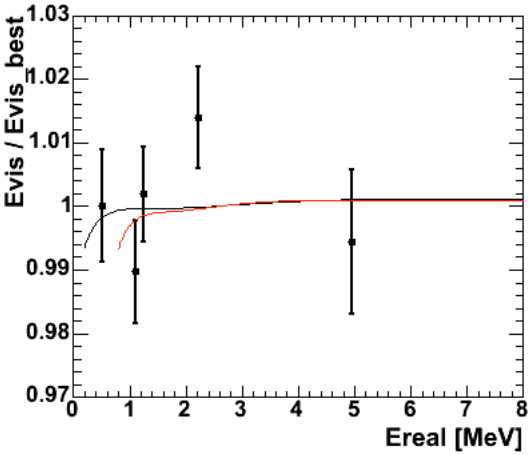
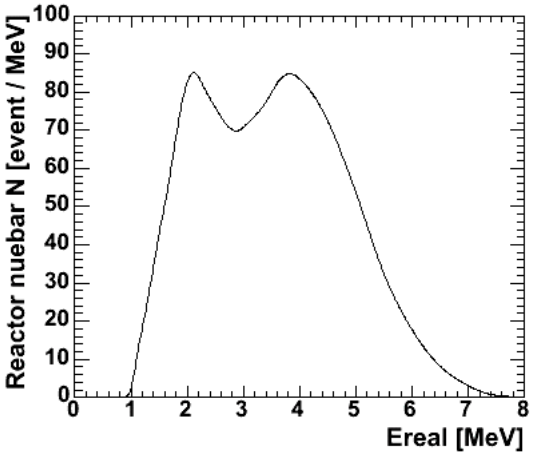
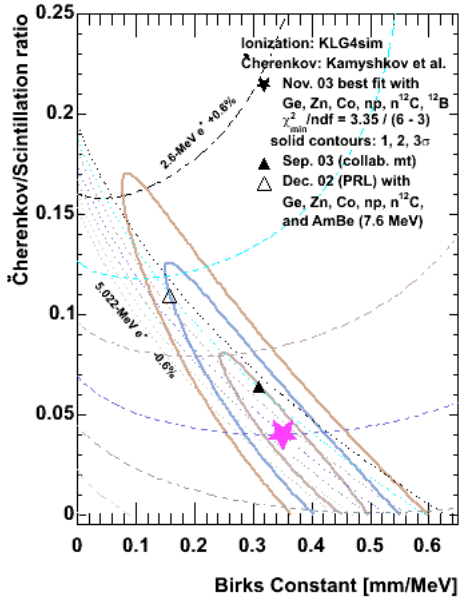

Evis / Ereal
black: γ
red: e+
Ereal [MeV]

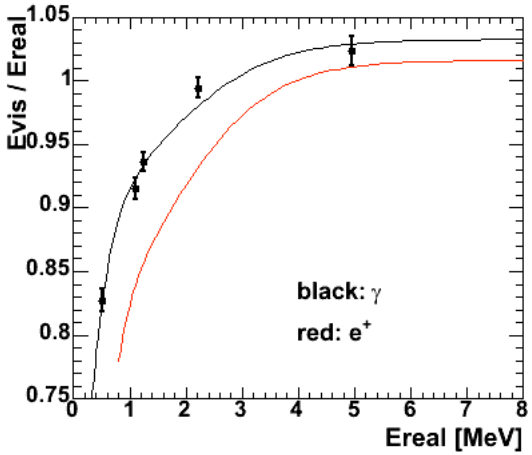

δ N / N
δΔm2=+1%
δΔm2=-1%
Ereal [MeV]

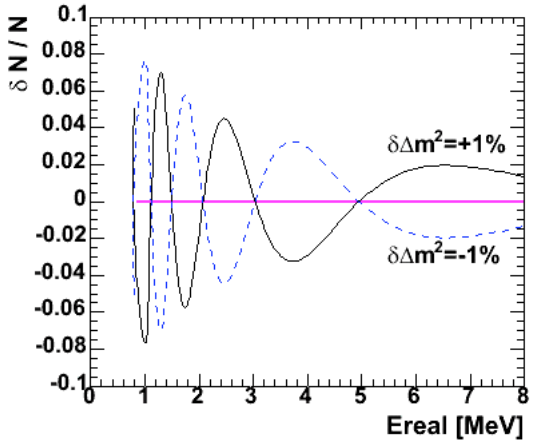

Evis / Evis_best
Ereal [MeV]

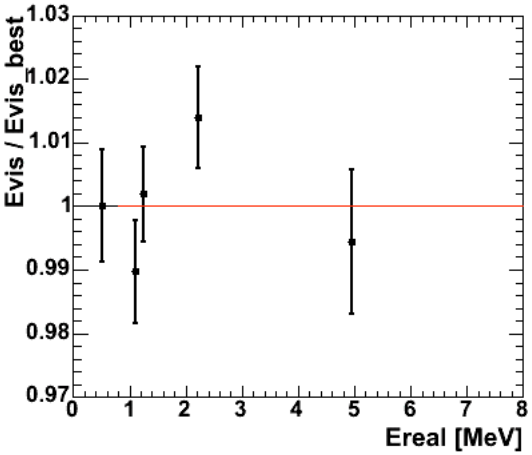

Reactor nuebar N [event / MeV]
Ereal [MeV]

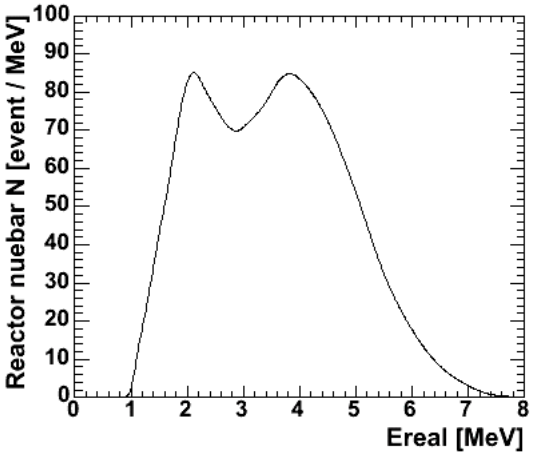
Nov. 2003 Berkeley meeting version



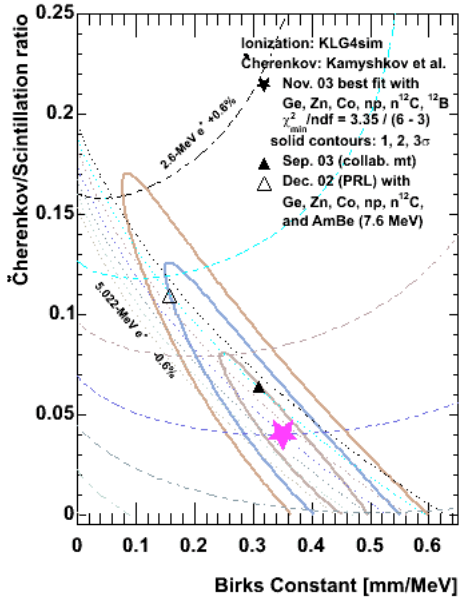


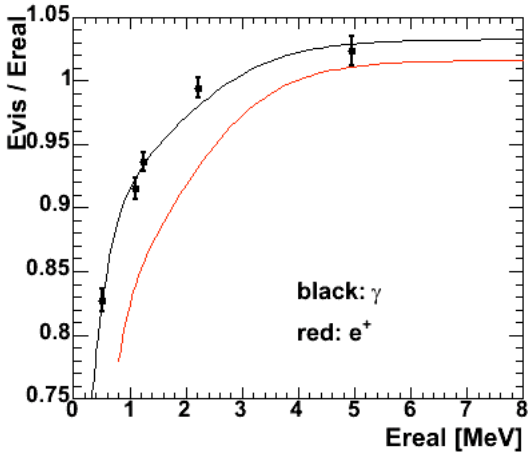


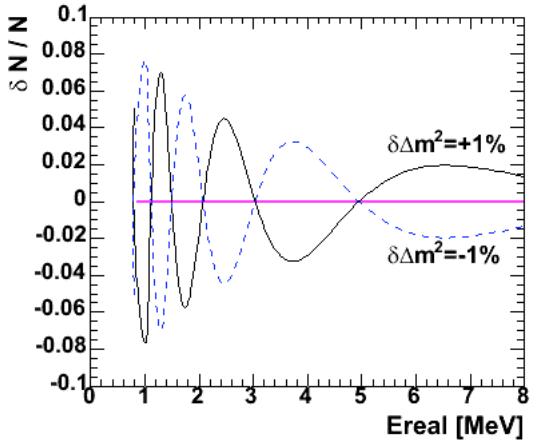


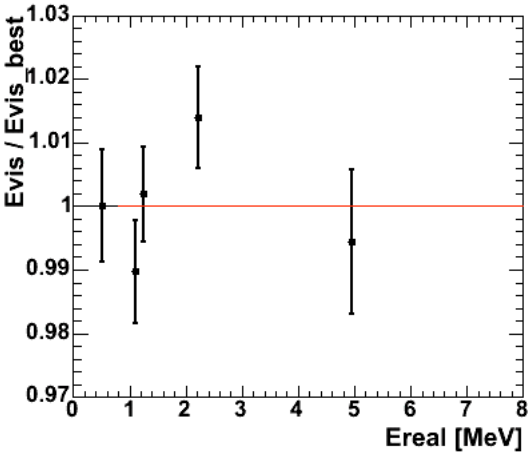


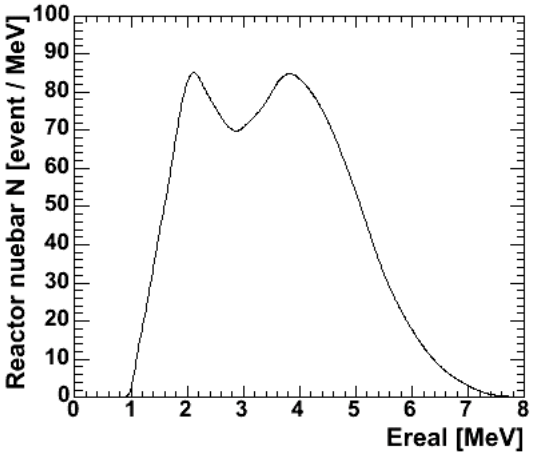
Nov. 2003 Berkeley meeting version











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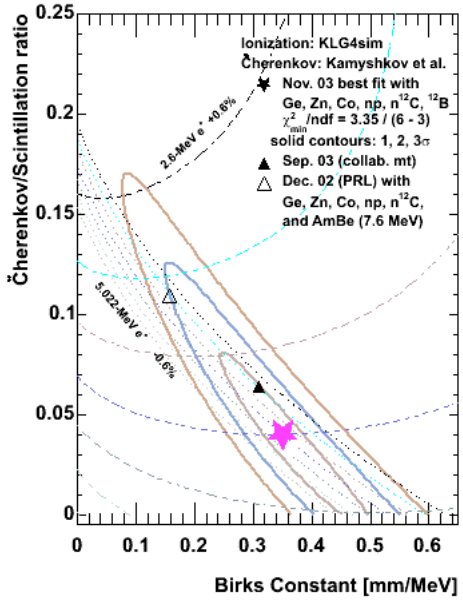

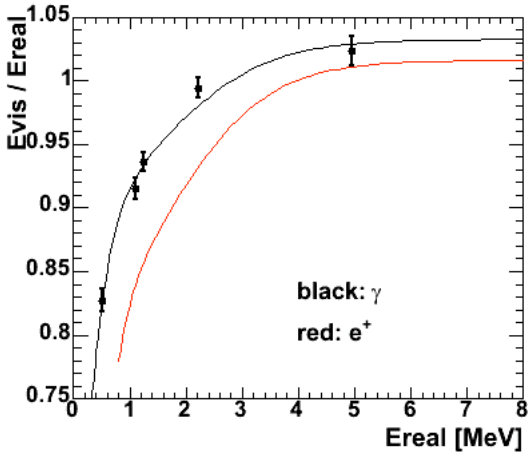

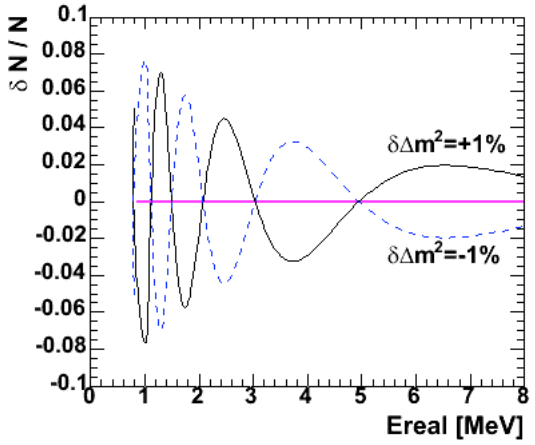

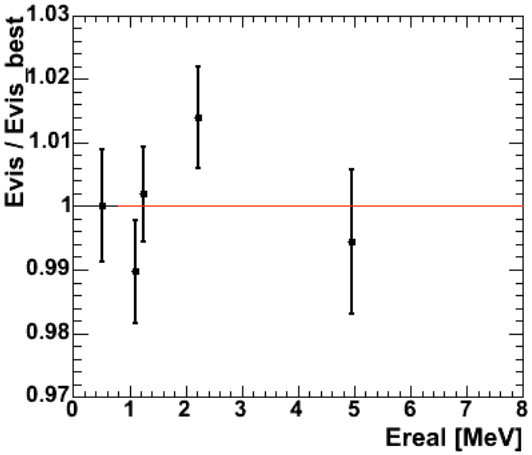

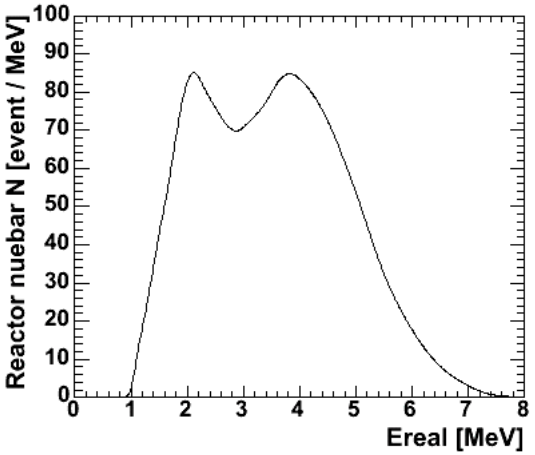

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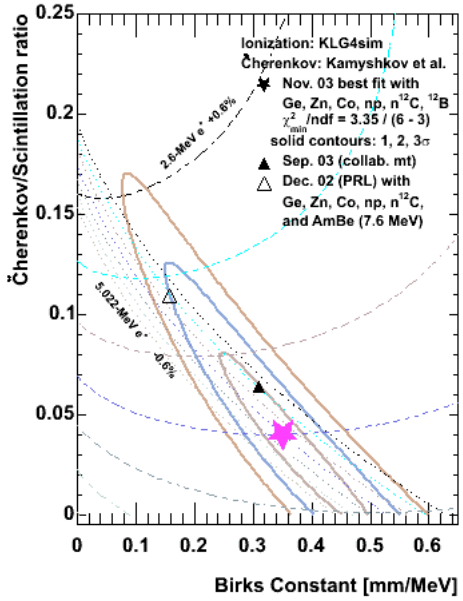
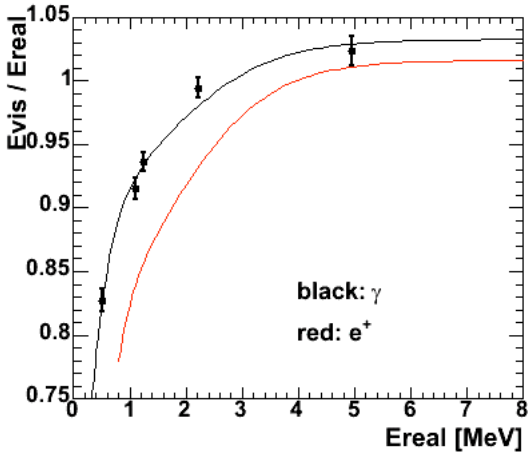
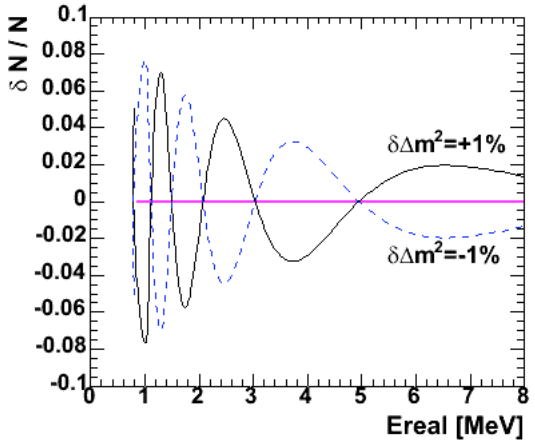
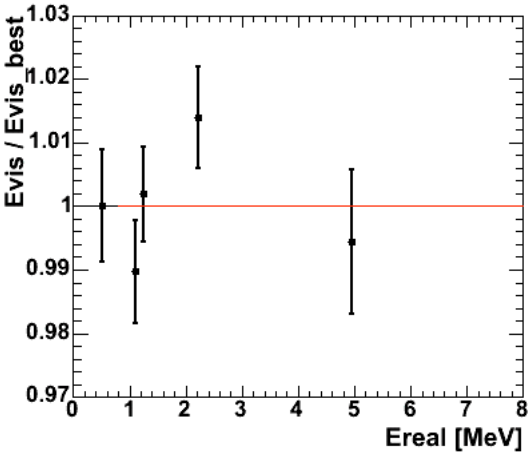
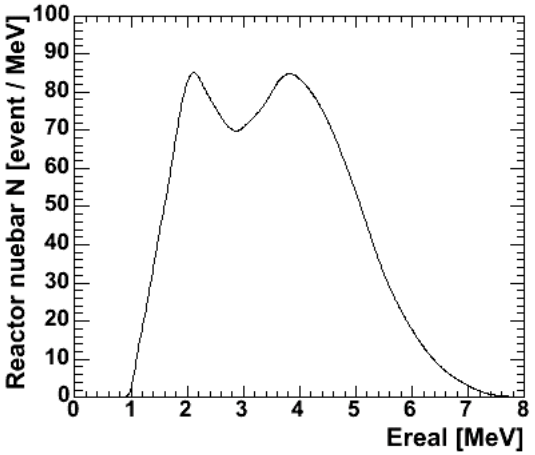


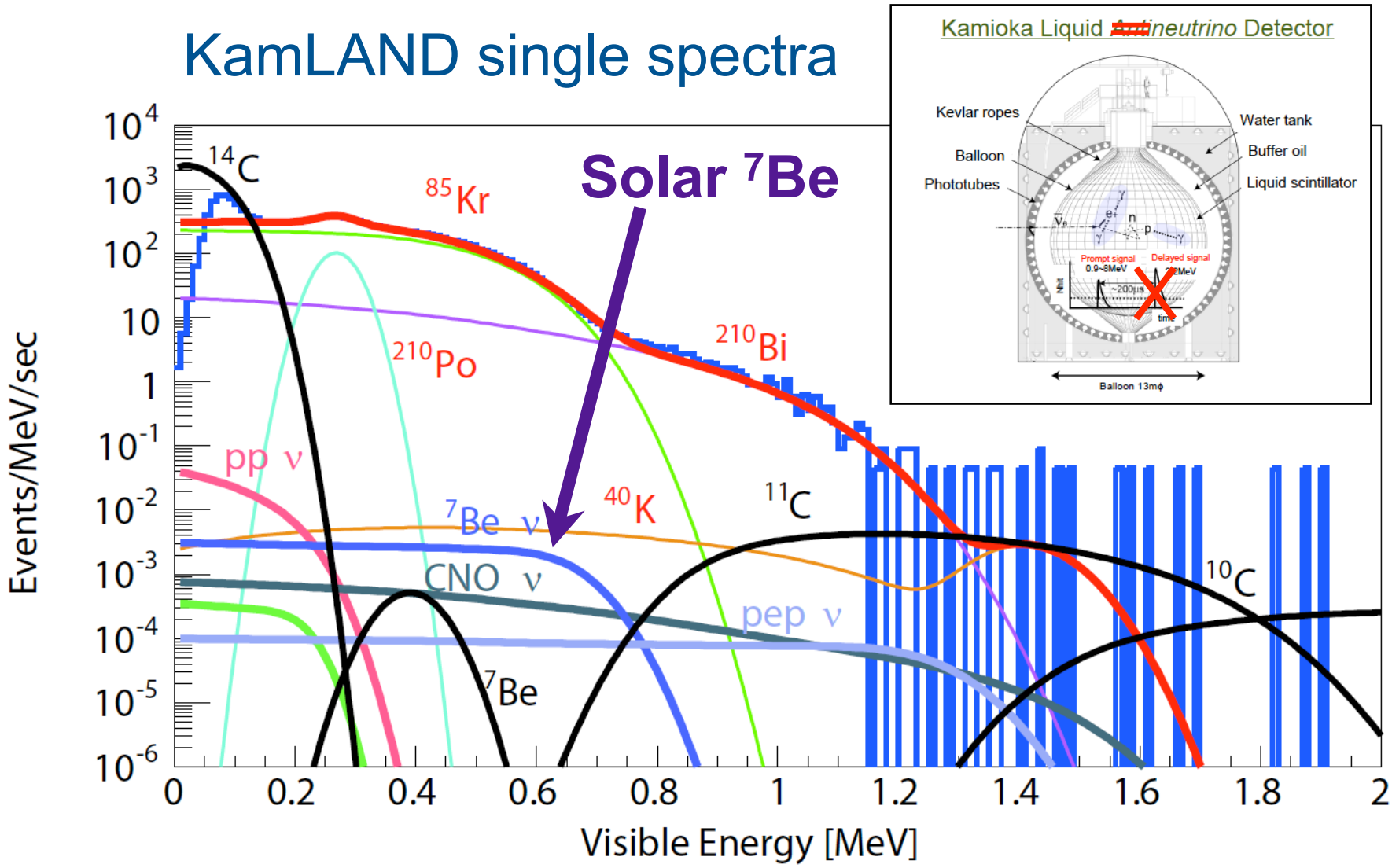






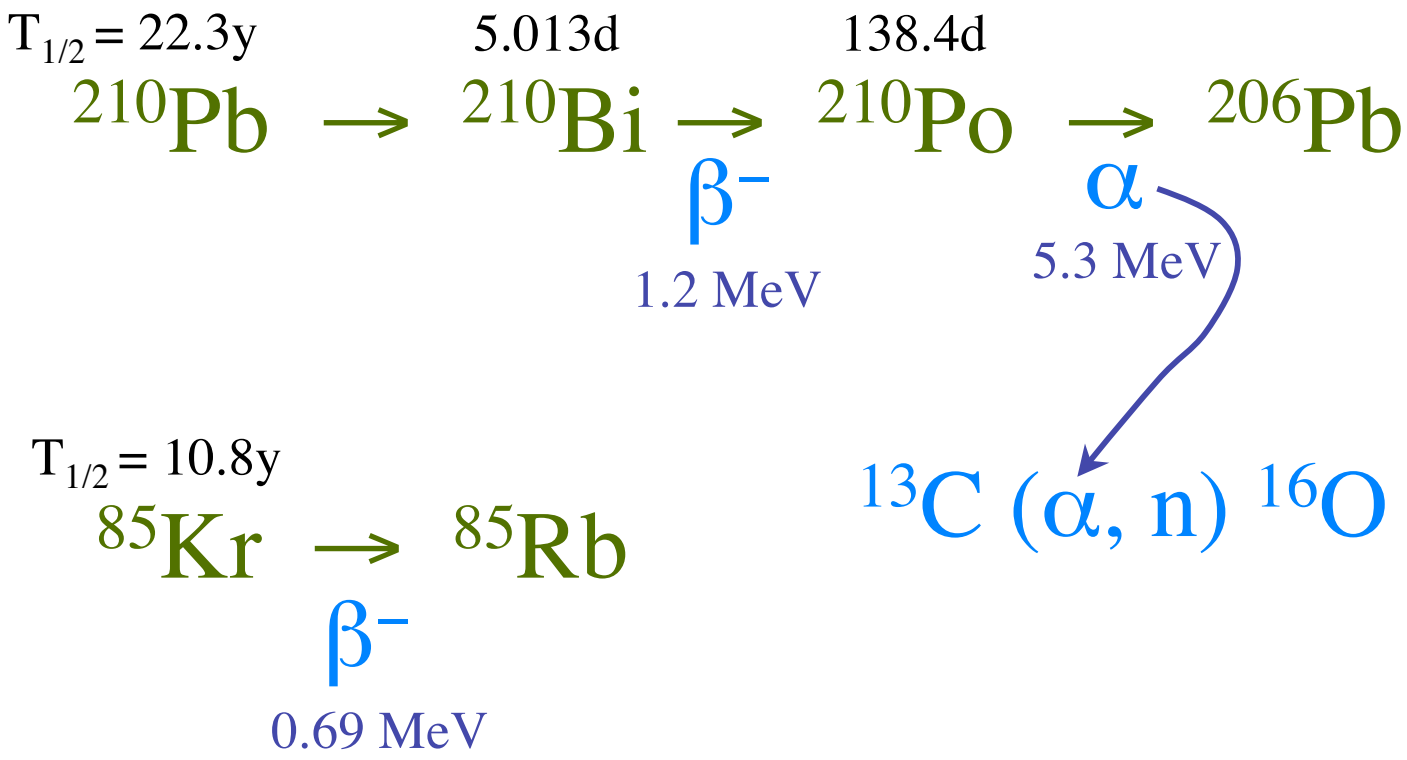


Solar neutrino future



Reduction of ^{210}Pb, ^{85}Kr by 10^{-5}

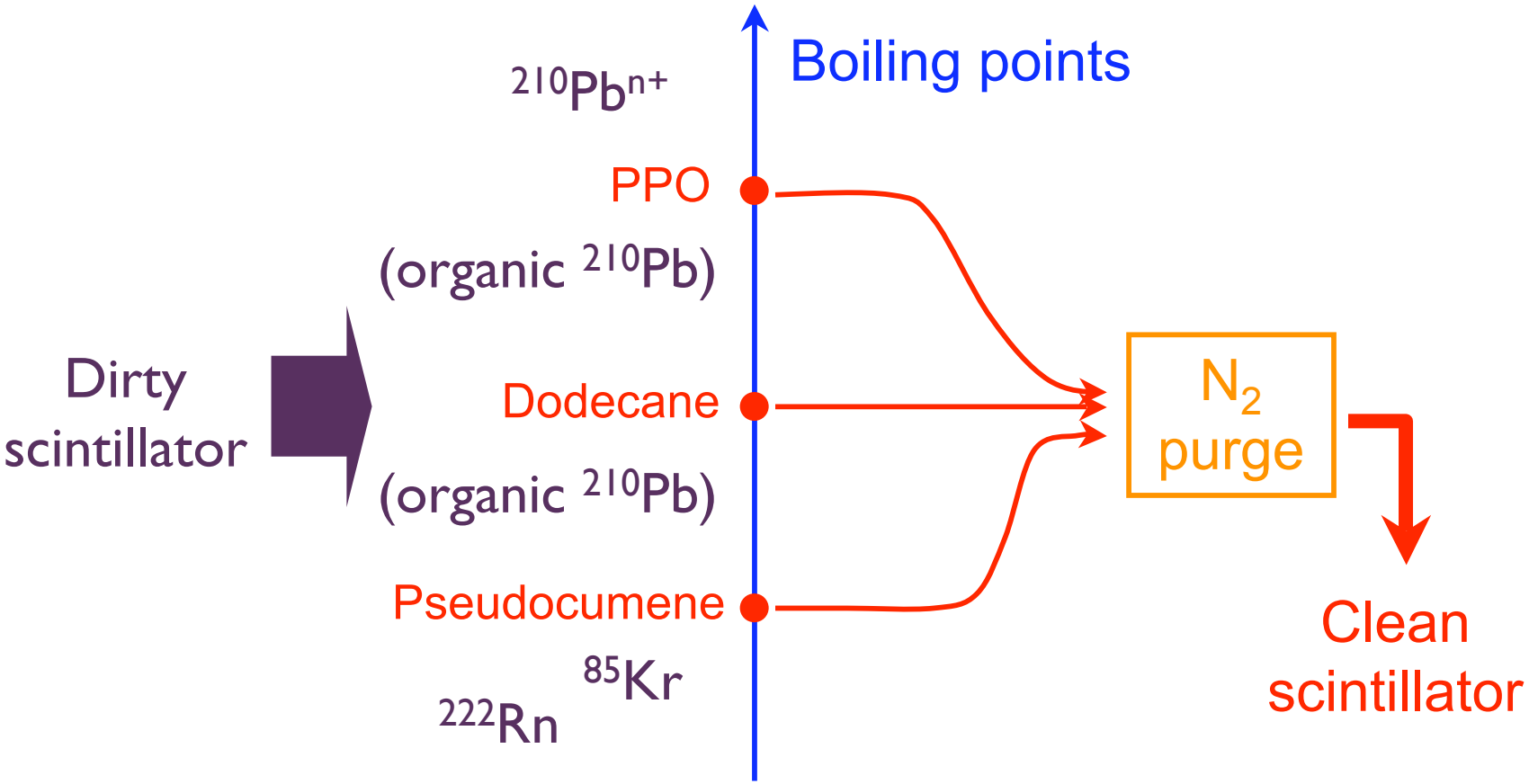
→ KamLAND "solar ν phase"



- Obstacles for solar ^{7}Be (^{210}Bi, ^{85}Kr, ^{210}Po), and antineutrino (reactor and geoneutrino) physics (^{210}Po)

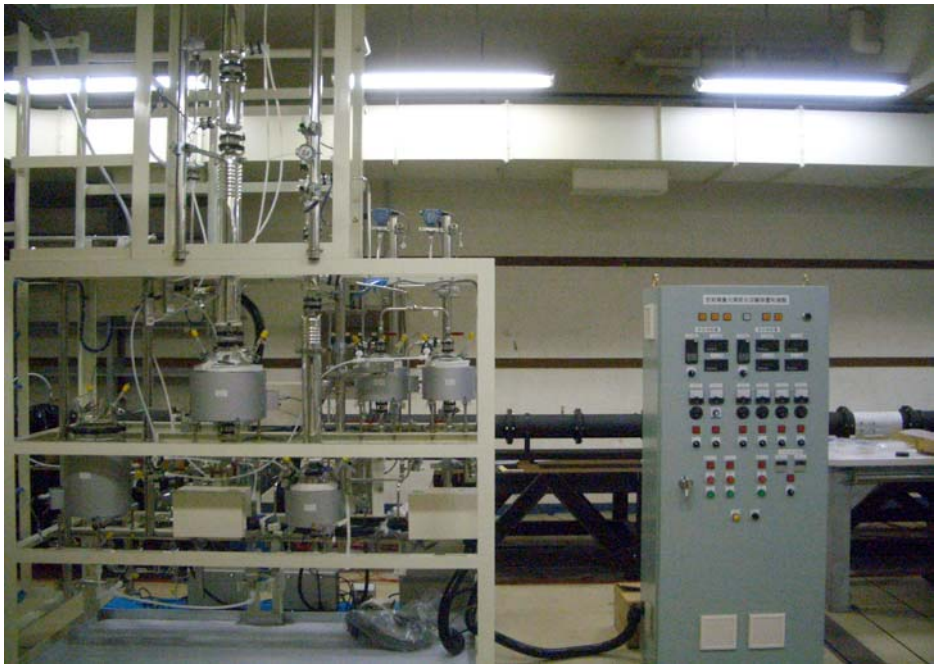
Distillation + N_2 purge

- KamLAND scintillator:
  - 80% dodecane ($C_{12}H_{26}$)
  - 20% pseudocumene (1,2,4-$(CH_3)_3$-C_6H_3),
  - 1.5-g/l PPO (2,5-Diphenyloxazole, 2,5-$(C_6H_5)_2$-C_3HNO)



Distillation–R&D since 2004

~ milli-liter system



~ liter system

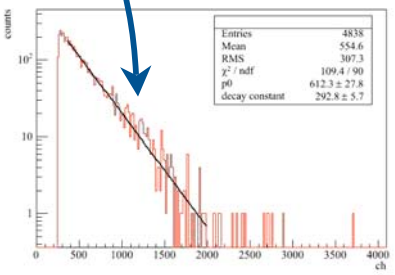
Real system:

~ 1.5 kilo-liter / hr (design flow rate)

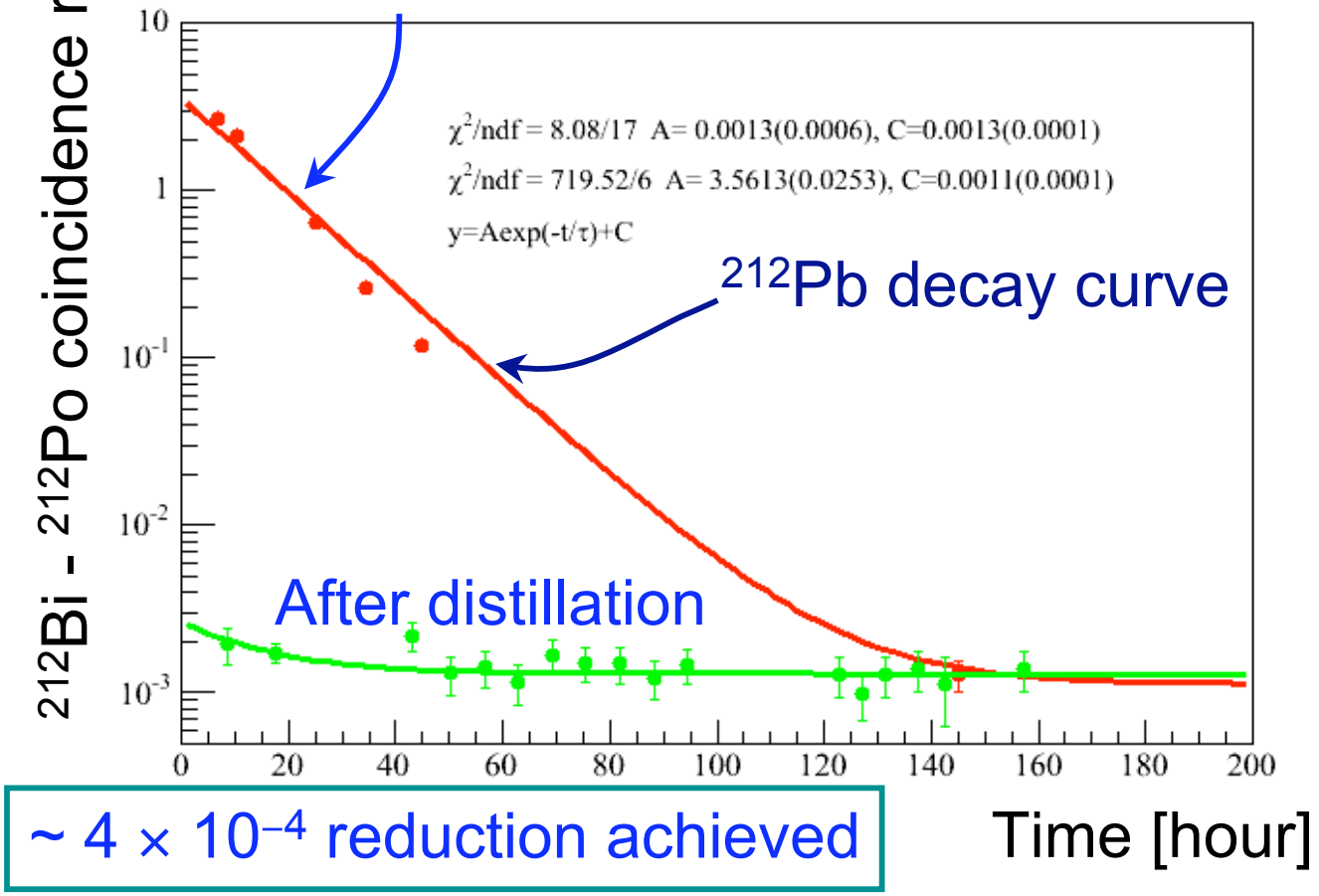
Construction starting August, 2006

R&D using ^{212}Pb instead of real ^{210}Pb

- *In KamLAND*: ^{222}Rn → ^{218}Po → ^{214}Pb → ^{214}Bi → ^{214}Po → ^{210}Pb → ^{210}Bi → ^{210}Po → ^{206}Pb
- *Pb removal R&D*: ^{220}Rn → ^{216}Po → ^{212}Pb → ^{212}Bi → ^{212}Po → ^{208}Pb
- ^{212}Pb is tagged by ^{212}Bi-^{212}Po ($T_{1/2}$ = 299 ns)
- ^{212}Pb decay curve ($T_{1/2}$ = 10.6 hr)
- Both ^{212}Pb and ^{210}Pb are Po daughter:
  → molecular forms in the scintillator are expected to be similar



Example of PPO distillation



~ 4 × 10^{-4} reduction achieved

~10^{-4} ~10^{-5} reduction has been achieved
also for dodecane, and pseudocumene distillation

* See also poster #28 G. Keefer

Toward "solar ν phase"

- Excavation of a new mine tunnel for the distillation system
  (completed: Fall, 2005)
- New computer system for data acquisition and storage of larger data
  (installed: Winter, 2005)
- New electric power ~ 1MW for the distillation system
  (power line construction going on: June, 2006)
- Design of the distillation system
  (almost done: June, 2006)
- Construction of the N_2 generator and purge system
  (partly done, will complete in September 2006)
- Construction of distillation system
  (August - September, 2006)
- Construction of "miniLAND" (1-ton detector to measure ^{222}Rn level after purification, down to ~1 mBq/m^3 ($\approx$ μBq/m3 for ^{210}Pb))
- Construction of Kr detector (see also poster #30 C. Mauger)

Toward "solar ν phase" (continued)

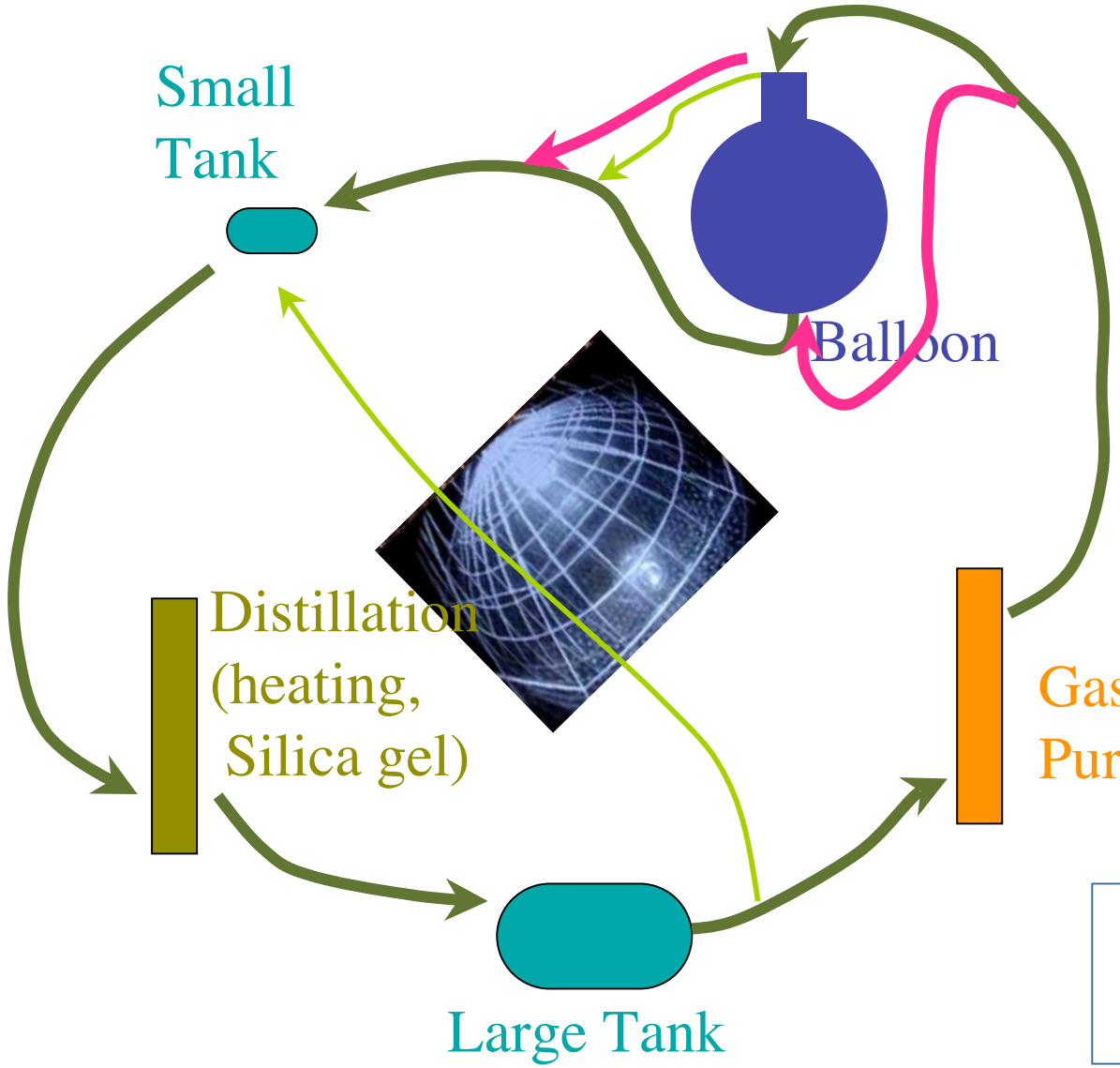
- Engineering run of the distillation system
- Real purification of the KamLAND scintillator
  (this will take a few months …)
- Observation of the solar ^{7}Be neutrinos

Control room for the distillation system in the newly excavated mine tunnel

純化されたシンチレータを汚いものと混ぜない

- 蒸留後の暖かい（軽い）ものを上から入れる。
- 窒素置換の経験。（密度差が違う？、拡散係数は）
- バルーンが汚れているとしたら、むしろ混ぜる、という方法もある。

Flow Plan I

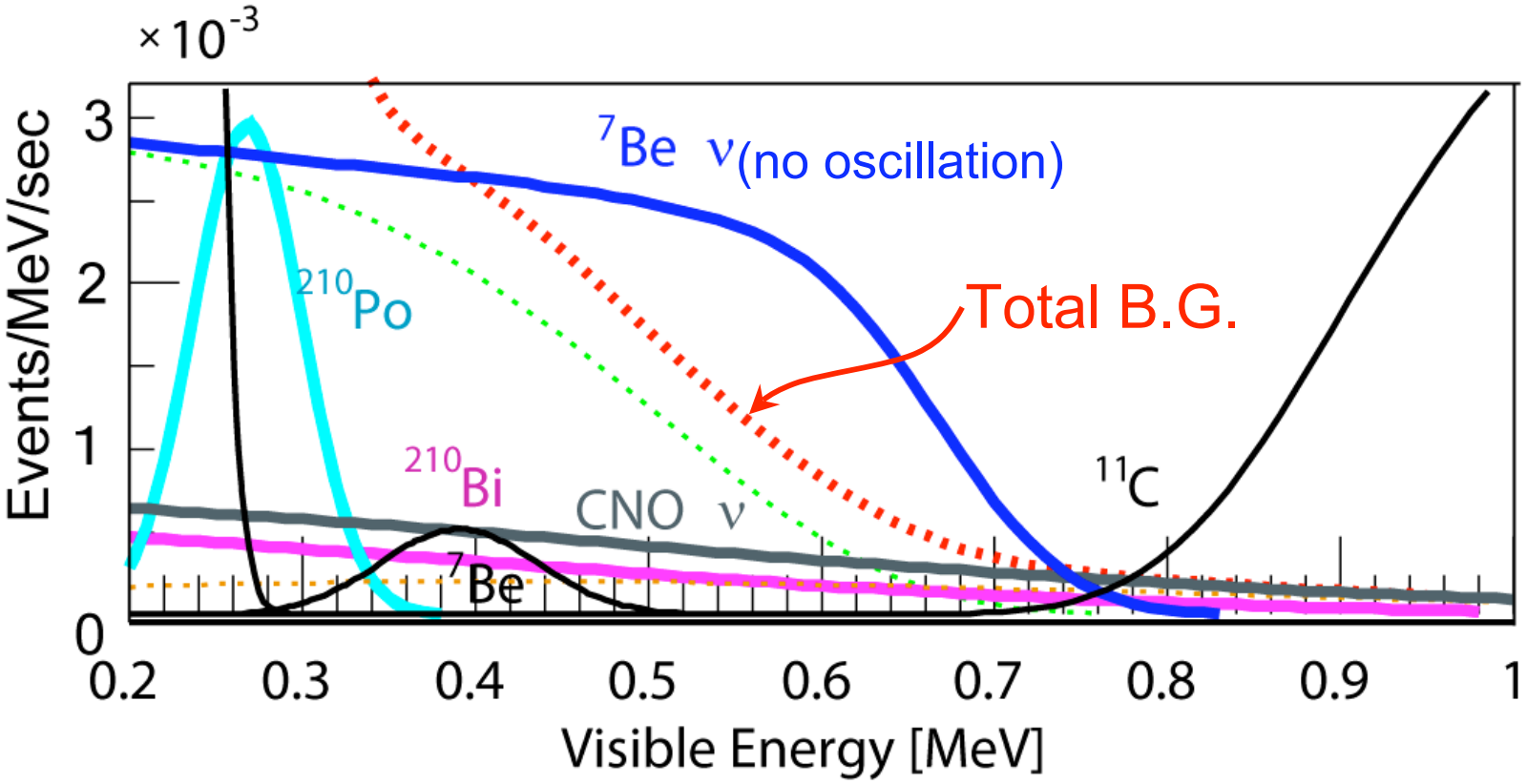


High temperature
from the top **bottom**
→ "Laminar **convective**
purification"
Level control by
overflow is the
same as up-going
circulation

Main flow
Control flow

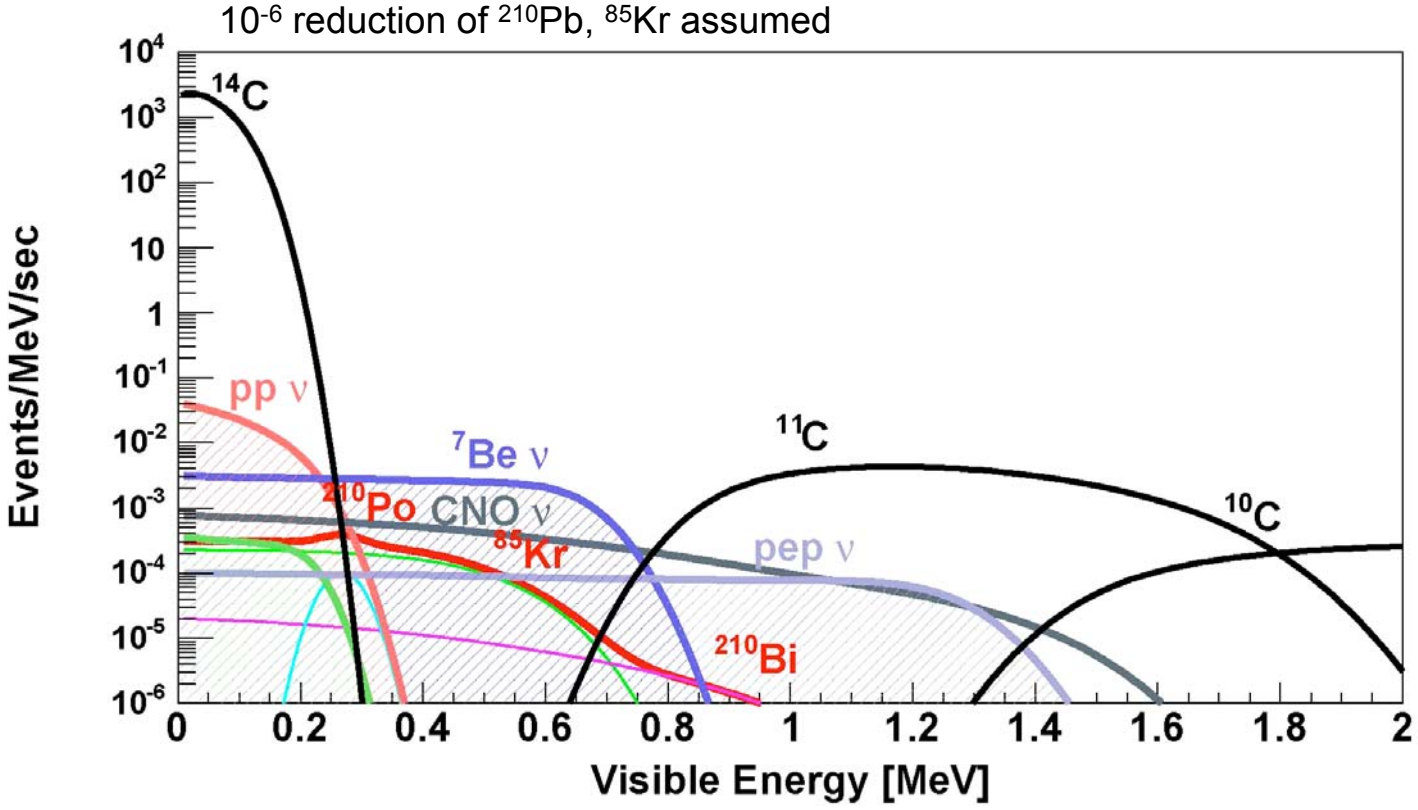
Solar neutrino future

- After ~3×10^{-5} reduction of ^{210}Pb and ^{85}Kr



pep and CNO neutrinos

- Even after successful ^{210}Pb, ^{85}Kr reduction, at KamLAND depth 2,700 m.w.e., spallation ^{11}C($T_{1/2}$ = 20.4 min.) is a serious background …



^{11}C off-line rejection

muon + neutron tagging (Galbiati et al., hep-ph/0411002)

Most of ^{11}C are created by

$$\boxed{^{12}\mathrm{C} + \mathrm{X} \rightarrow {}^{11}\mathrm{C} + n + \mathrm{Y} + \cdots}$$

$$\mathrm{X} = \gamma, n, p, \pi^-, \pi^+, e, \mu$$

~ 95% of ^{11}C reaction produce neutrons

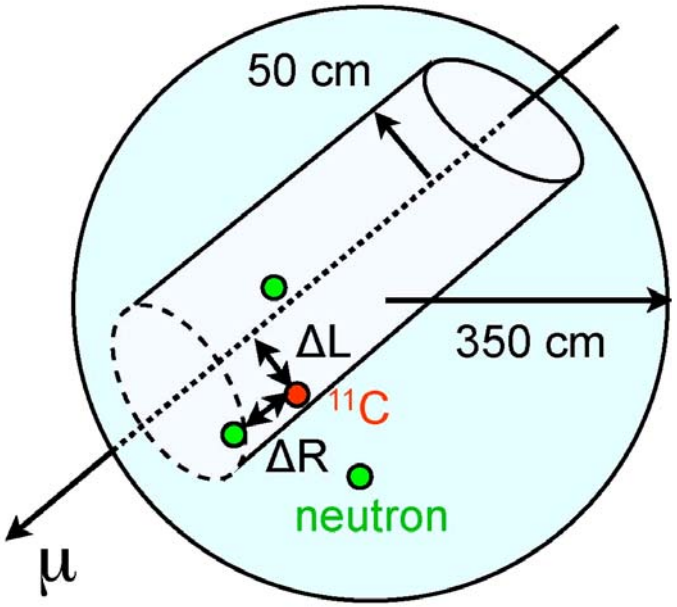
3-fold coincidence

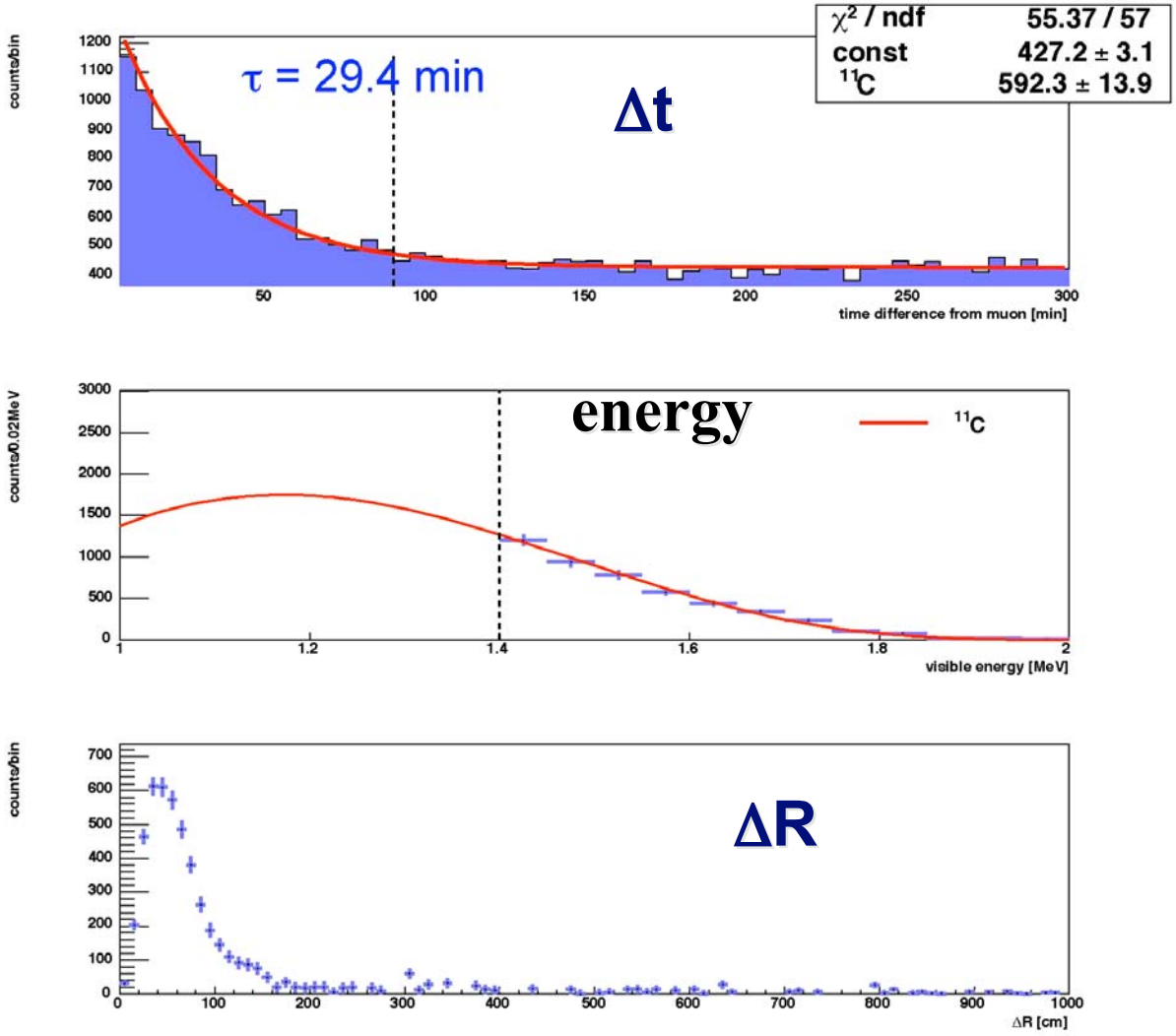
(1) muon - (2) neutron (capture time ~ 210 μsec)

- (3) ^{11}C (lifetime = 29.4 min)

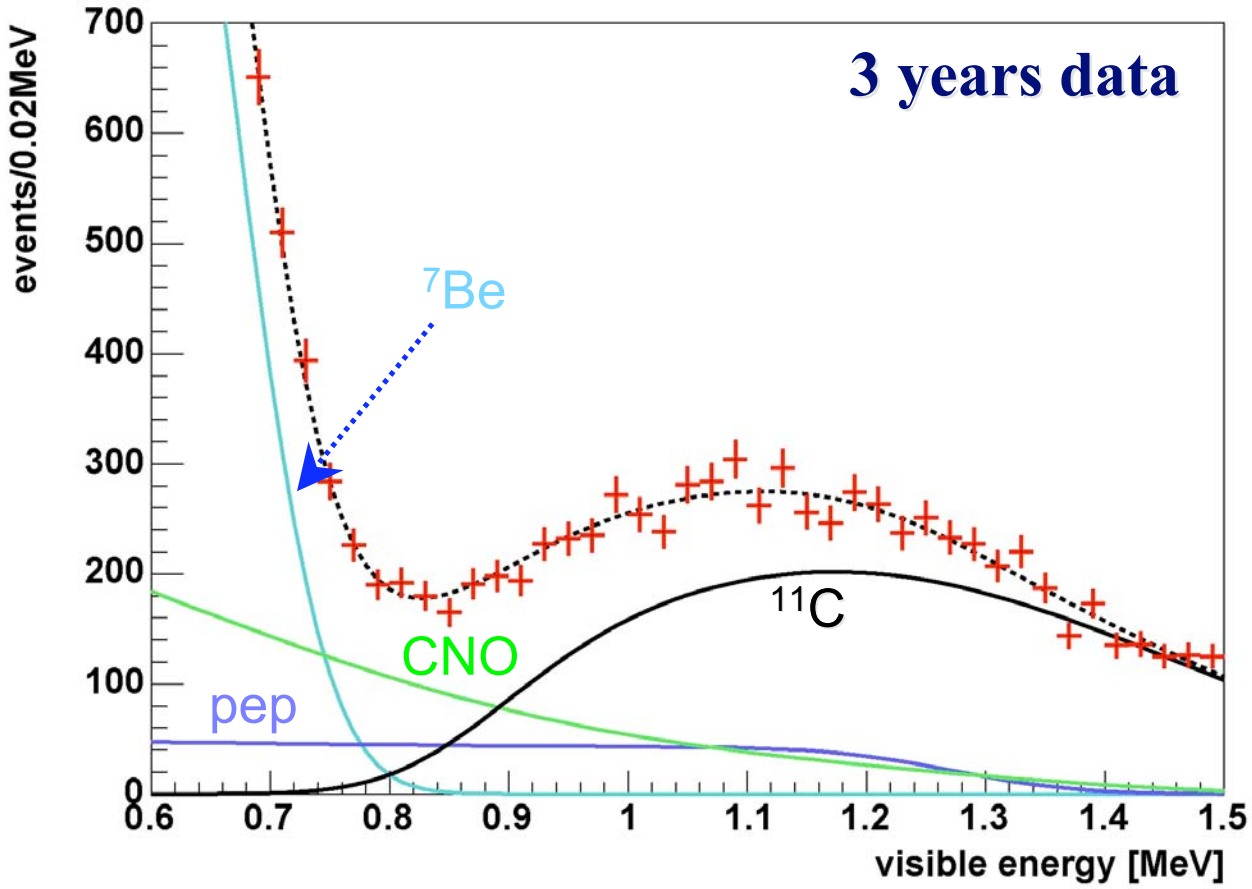
μ–n–^{11}C events in KamLAND data

($\Delta L < 50$ cm, #$n_{detected} > 0$)





pep CNO future

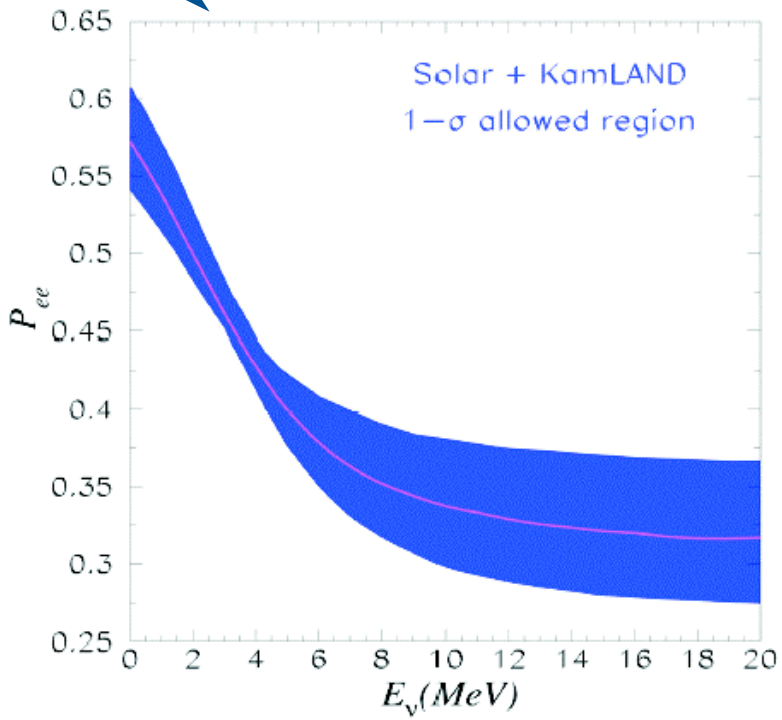


- Problem: electronics dead time after large μ signal → missing neutrons
- ^{11}C without neutrons (5%)
- Veto by μ only? → better μ fitter with better understanding of μ events
- See also poster: #55 L. Winslow for muon tracker

Low-energy ^{8}B neutrino–MSW distortion

- If ^{208}Tl (β + γ, Q = 5 MeV) reduced enough
- $\rightarrow$ ^{232}Th reduction needed (distillation works?)

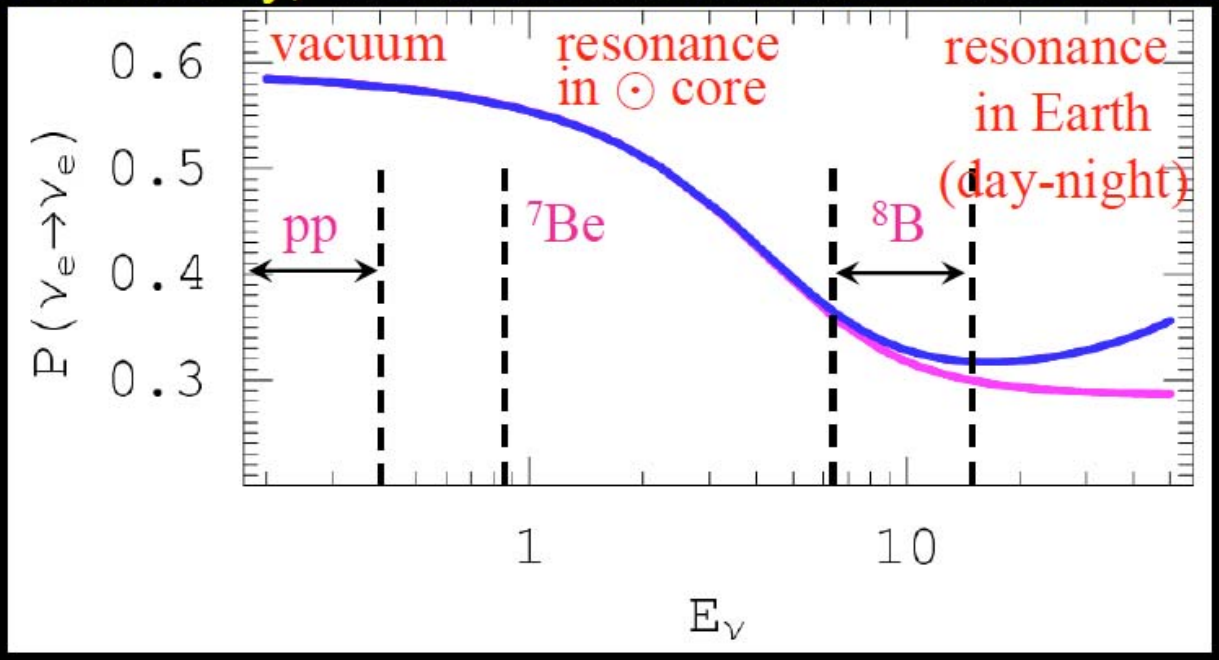
KamLAND: low-energy frontier



from Pena-Garay

Designing LMA

- Fine-tune Δm^2 such that the transition between the regimes occurs at the intermediate solar energies
  $\Delta m^2 \sim G_F N_\odot (10^6 eV) \sim$ a few $\times 10^{-5}$ eV^2
- Remarkably, checks with KamLAND reactor ν osc.!



Slide by A. Friedland (neutrino 2006) http://neutrinosantafe06.com/

Solar $\overline{\nu}_e$, other high energy $\overline{\nu}_e$

PRL 92 (2004) 071301
see also talk by A. Friedland (this morning)

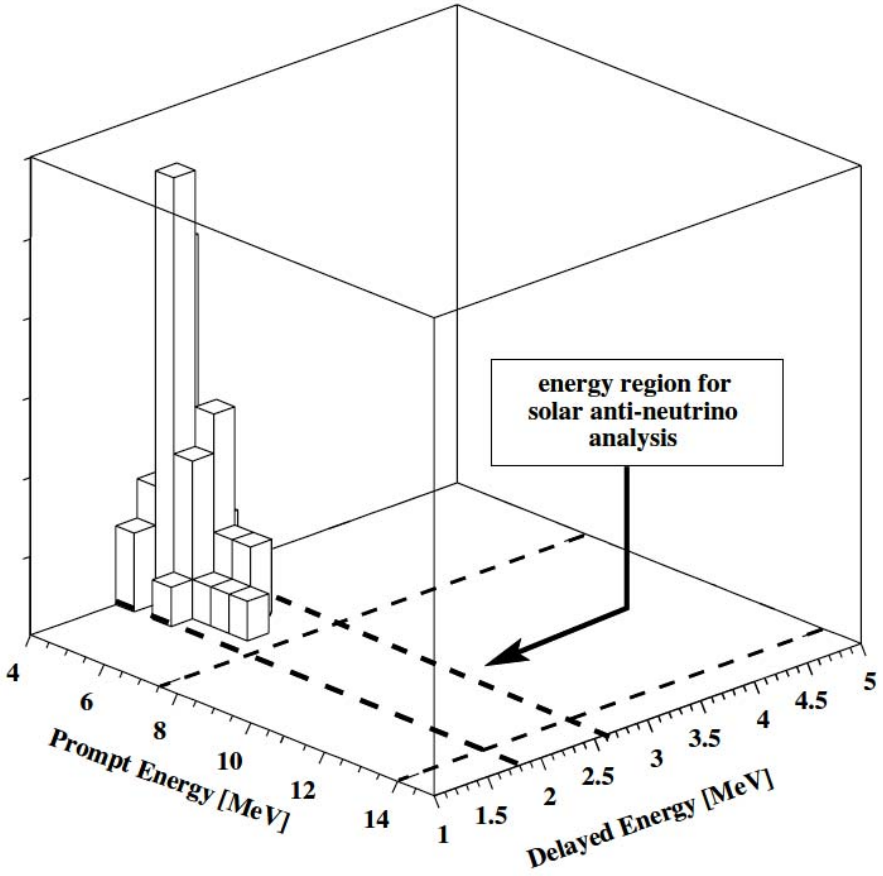


FIG. 2. Energy distribution of the final event candidates. The tail from reactor $\bar{\nu}_e$ events is visible below 8 MeV.

- ν_e / SSM-^{8}B
  $< 2.8 \times 10^{-4}$
  (90 % C.L.)
- Supernova search: almost no B.G.
- See also poster #111 K. Ishii for supernova search

Summary

- Reactor neutrino:
  - Data taking is going well and will continue
  - All volume calibration is starting soon
- Geoneutrino:
  - Efforts to reduce systematic error of B.G.
- Solar neutrino:
  - Toward “solar ν phase” (^{210}Pb, ^{85}Kr reduction by 10^{-5})
  - Distillation will start in September 2006
- Thank you very much and please keep encouraging KamLAND