Recent results of KamLAND

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Tohoku University
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14th Neutrino Workshop

Contents

- KamLAND detector
- Reactor neutrino observation
- Search for electron anti-neutrino from the sun
- Future plan

KamLAND : Kamioka Liquid scintillator Anti-Neutrino Detector

Physics Motivation

→ **Reactor electron anti-neutrinos**

Geo electron anti-neutrinos

→ **Solar anti-neutrinos**

7Be solar neutrinos

Other anti-neutrino sources

SN neutrinos

Relic neutrinos

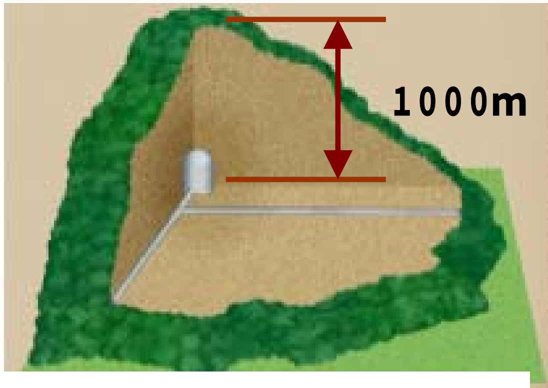
KamLAND advantage:

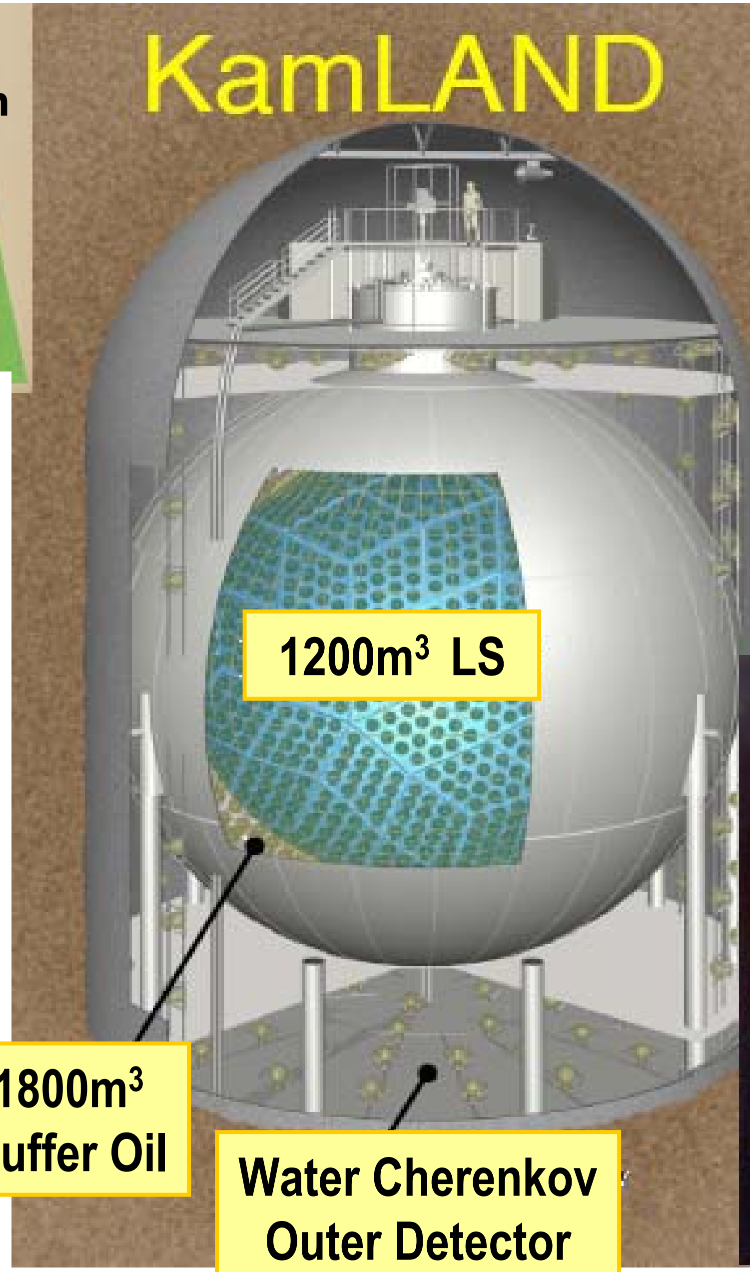
- high energy resolution
- low threshold ~0.9MeV
  ~0.3MeV (in the future)
- low background condition

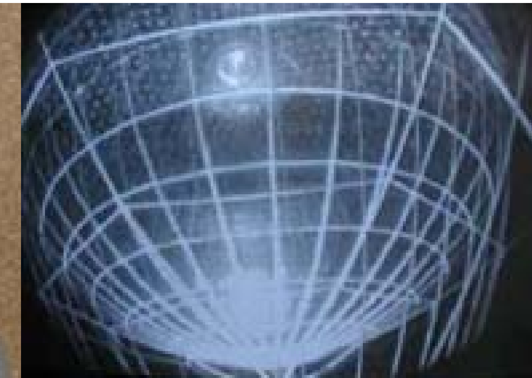
KamLAND Collaboration

- **Tohoku University:** K.Eguch, S.Enomoto, K.Furuno, J.Goldman, H.Hanada, H.Ikeda, K.Ikeda, K.Inoue, K.Ishihara, W.Itoh, T.Iwamoto, T.Kawaguchi, T.Kawashima, H.Kinoshita, Y.Kishimoto, M.Koga, Y.Koseki, T.Maeda, T.Mitsui, M.Motoki, K.Nakajima, M.Nakajima, T.Nakajima, H.Ogawa, T.Sakabe, I.Shimizu, J.Shirai, F.Suekane, A.Suzuki, K.Tada, O.Tajima, T.Takayama, K.Tamae,H.Watanabe
- **University of Alabama:** J.Busenitz, Z.Djurcic, K.McKinny, D-M.Mei, A.Piepke, E.Yakushev
- **LBNL Berkeley:** B.E.Berger, Y.D.Chan, M.P.Decowski, D.A.Dwyer, S.J.Freedman, Y.Fu, B.Fujikawa, K.M.Heeger, K.T.Lesko, K-B.Luk, H.Murayama, D.R.Nygren, C.E.Okada, A.W.Poon, H.M.Steiner, L.A.Winslow
- **California Institute of Technology:** G.A.Horton-Smith, R.D.McKeown, J.Ritter, B.Tipton, P.Vogel
- **Drexel University:** C.E.Lane, T.Miletic
- **University of Hawai Manoa:** P.W.Gorham, G.Guilian, J.G.Leanned, J.Maricic, S.Matsuno, S.Pakvasa
- **Louisiana State University:** S.Dazeley, S.Hatakeyama, M.Murakami, R.C.Svoboda
- **University of New Mexico:** B.D.Dieterle, M.DiMauro
- **Stanford University:** J.Detwieler, G.Gratta, K.Ishii, N.Tolich, Y.Uchida
- **University of Tennessee:** M.Batygov, W.Bugg, H.Cohn, Y.Efremenko, Y.Kamyshkov, A.Kozlov, Y.Nakamura
- **TUNL/ NCSU:** L.De Braeckeleer, C.R.Gould, H.J.Karwowski, D.M.Markoff, J.A.Messimore, K.Nakamura, R.M.Rohm, W.Tornow, A.R.Young
- **IHEP Beijing:** Y-F.Wang

KamLAND experiment







LS

80% dodecane
20% pseudocumene
(1,2,4 Trimethylbenzene)
1.52g/l PPO
(2,5-Diphenyloxazole)

$\rho = 0.78 \text{g/cm}^3$

8,000 photons/MeV

$\lambda \sim 10\text{m}$

BO

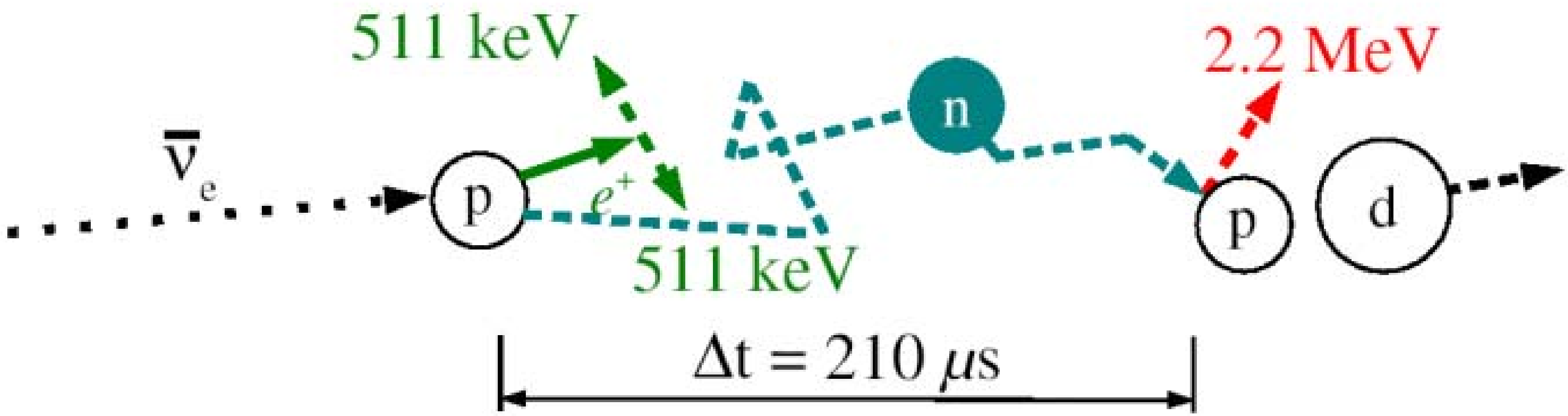
50% dodecane
50% isoparaffin

$\rho_{LS} / \rho_{BO} = 1.0004$

1325 17” photo-tubes
22% photo-coverage

- $\overline{\nu}_e$ detection in liquid scintillator

$$\overline{\nu}_e + p \rightarrow n + e^+$$



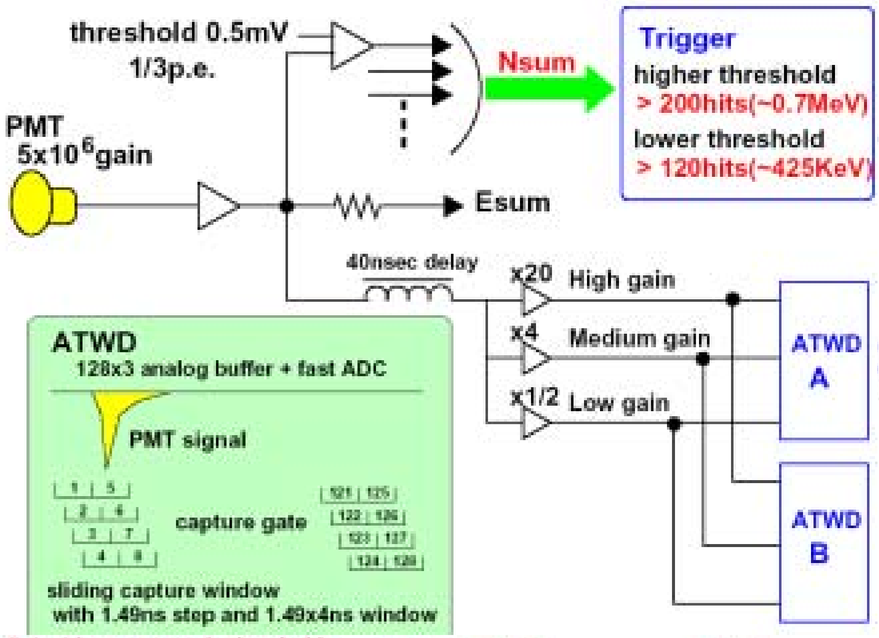
- prompt part : e^+

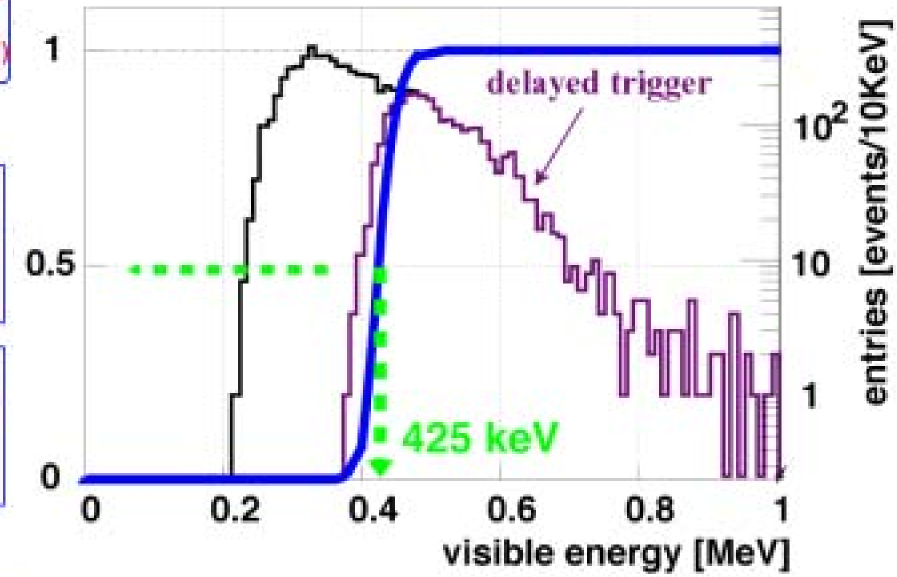
$$E_{vis} = E_{\nu e} - (\Delta m_{np} + m_e) - T_n(\theta) + 2m_e$$
$$= E_{\nu e} - 0.782\text{MeV} - T_n(\theta)$$

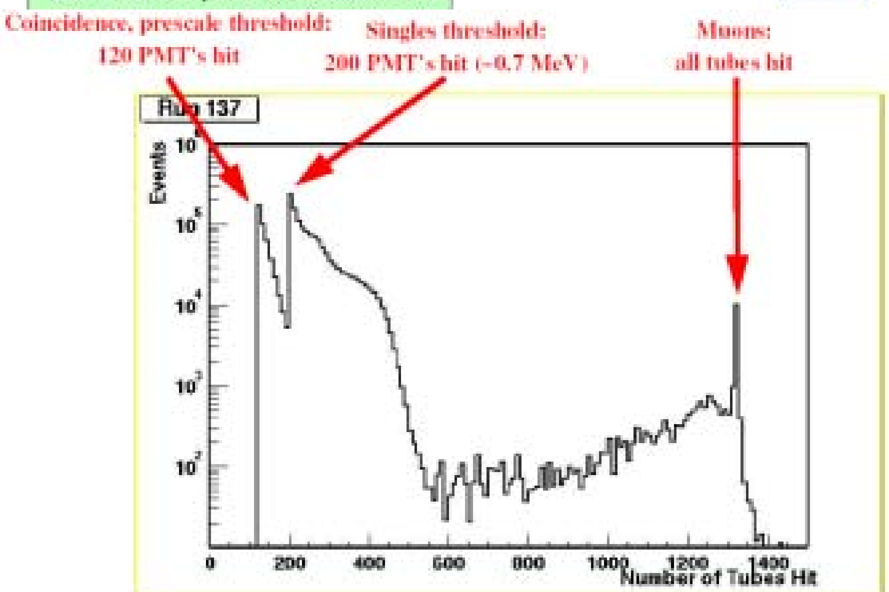
- delayed part : γ (2.2MeV)

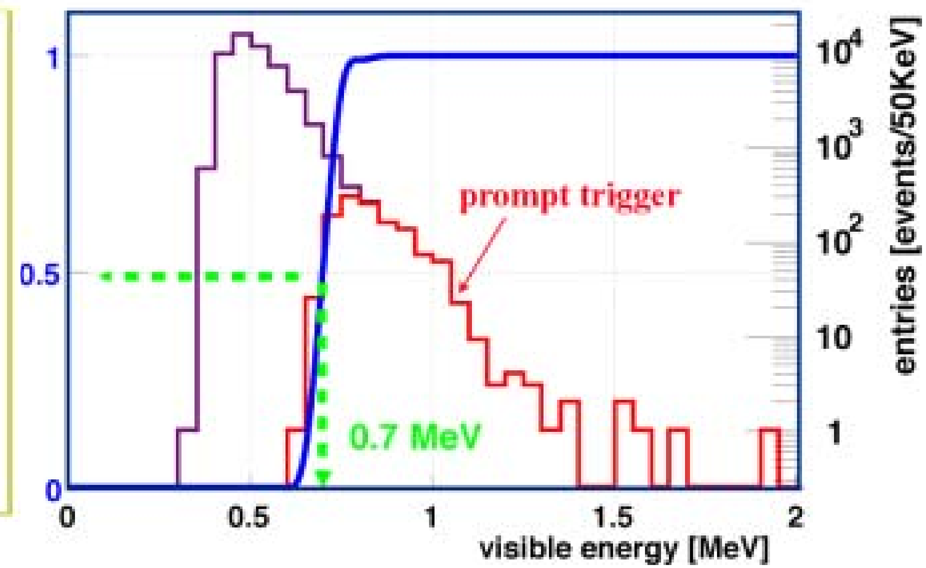
Reduce the background
Powerfully !

- The Front-end Electronics

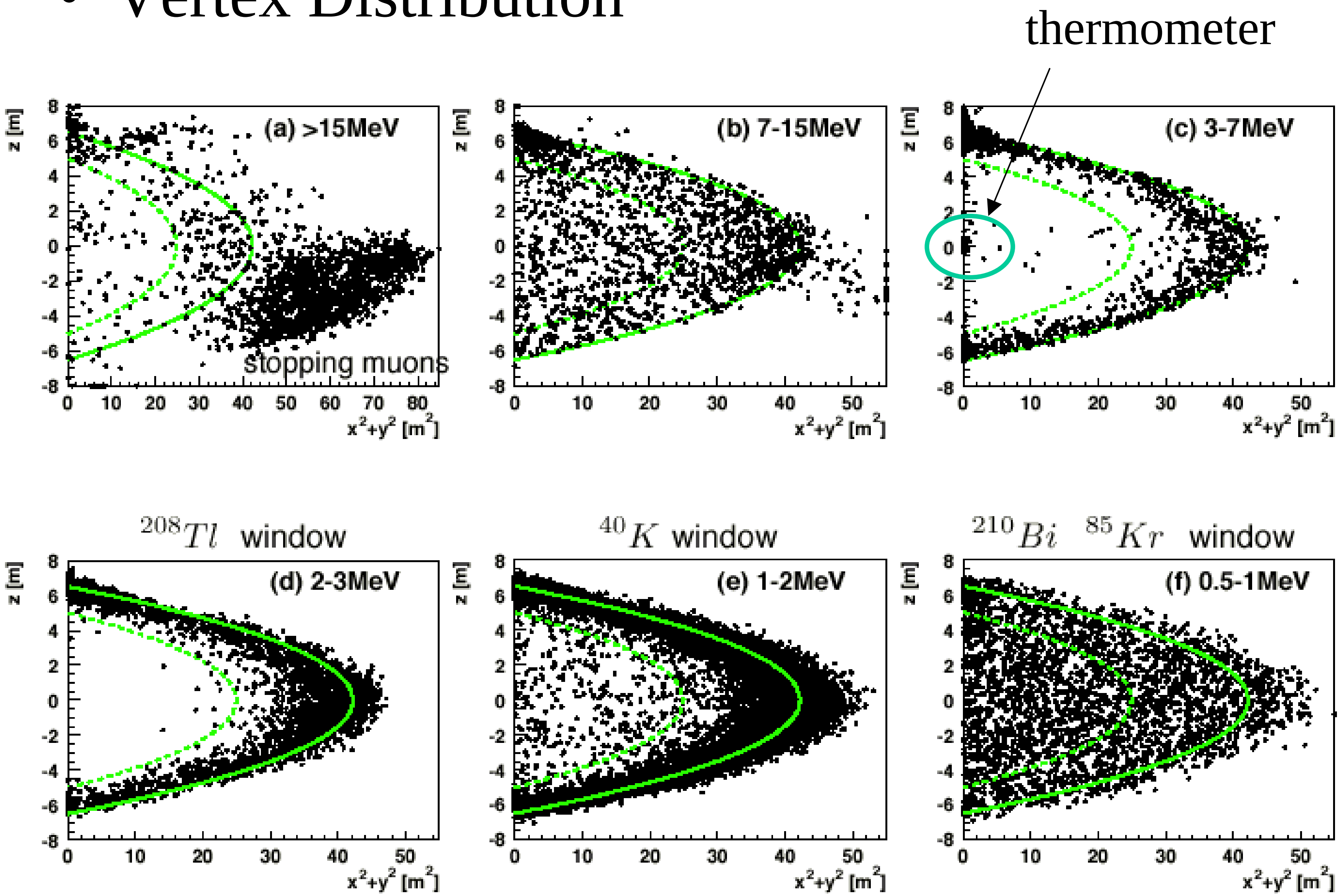




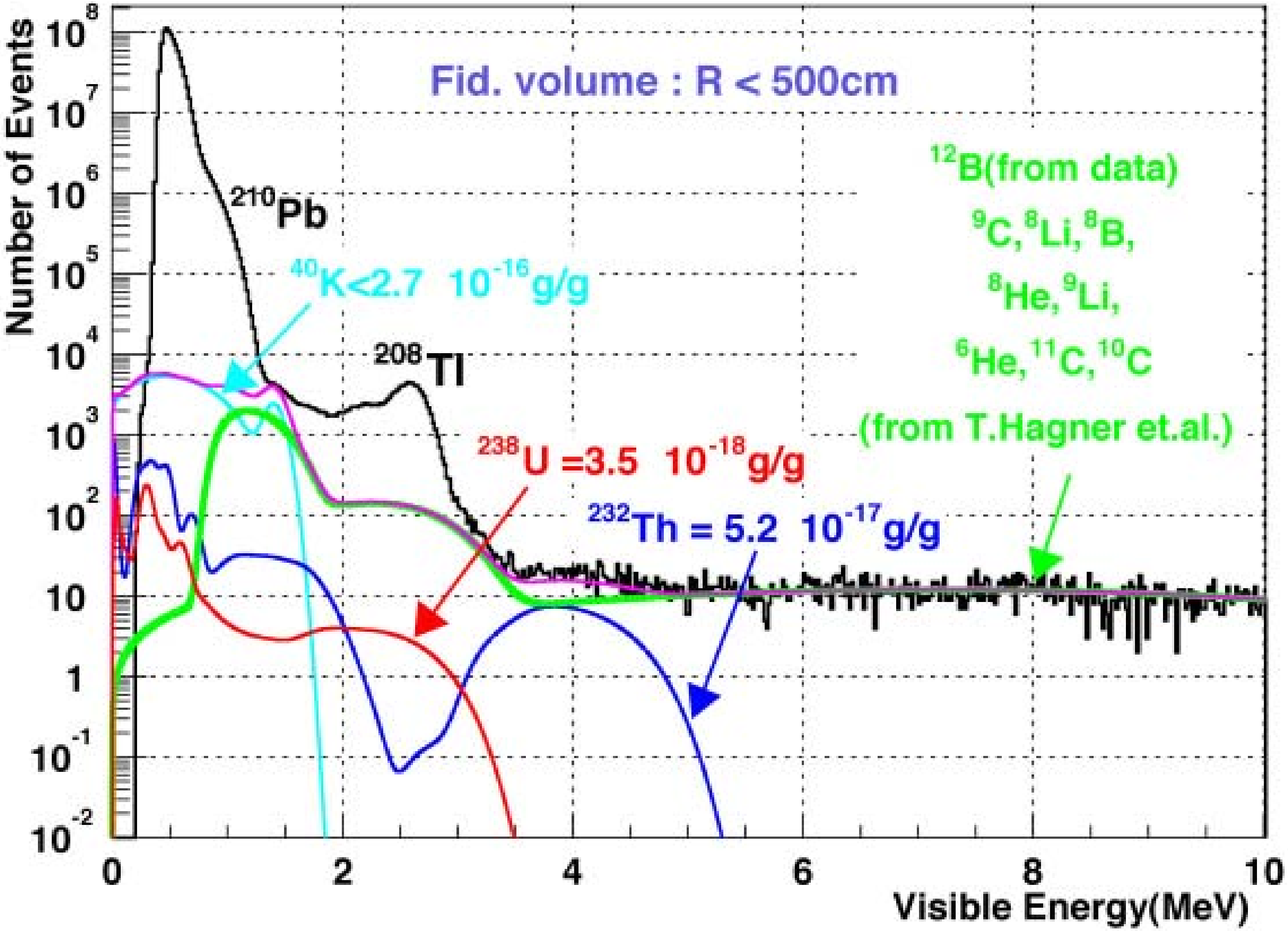




- Vertex Distribution



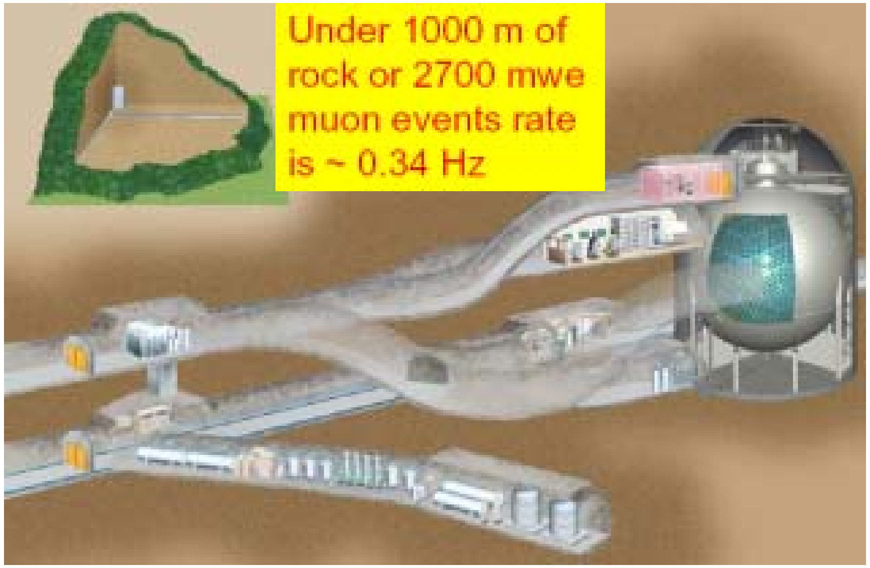
• Liquid Scintillator Impurity

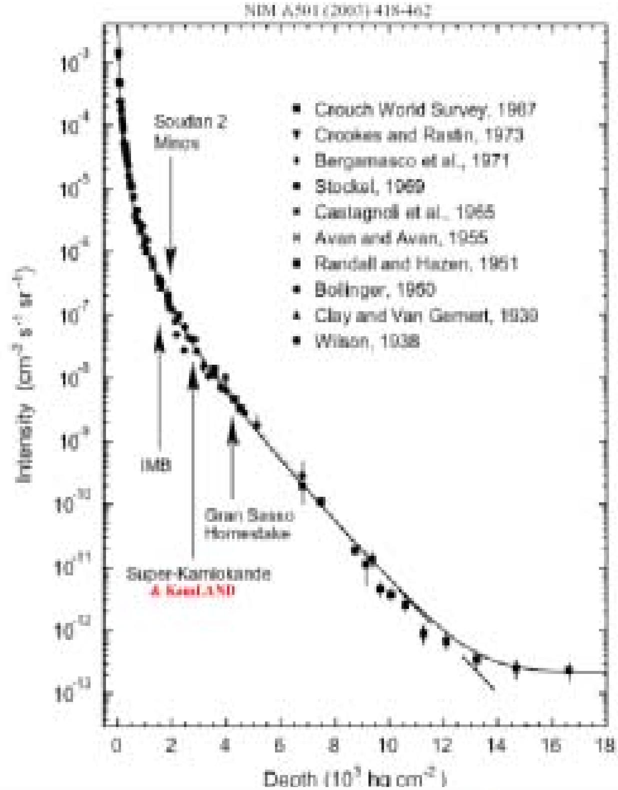


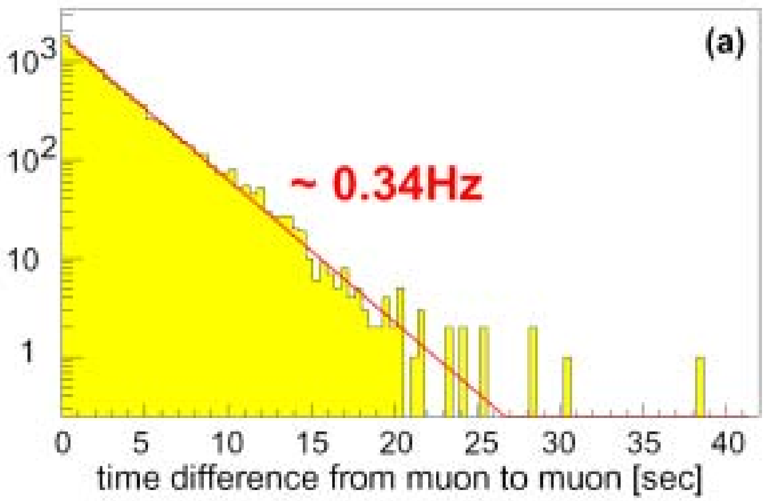
Impurities in the LS			Requirements Reactor	 Solar
^{222}Rn	$0\ 03\ \mu Bq\ \ m^3$	$^{214}Bi \rightarrow ^{214}Po\ (\tau = 237\ \mu s\ \ \ )$		
^{238}U	$(3\ 5\ \ \ \ 0\ 5) \times 10^{-18} g\ \ g$	assume equilibrium	$10^{-13} g\ \ g$	$10^{-16} g\ \ g$
^{232}Th	$(5\ 2\ \ \ \ 0\ 8) \times 10^{-17} g\ \ g$	$^{212}Bi \rightarrow ^{212}Po\ (\tau = 0\ 431\ \mu s\ \ \ )$	$10^{-13} g\ \ g$	$10^{-16} g\ \ g$
^{40}K	$< 2 \times 10^{-16} g\ \ g$	single rate	$10^{-14} g\ \ g$	$10^{-18} g\ \ g$
^{85}Kr	$\sim 1\ Bq\ \ m^3$	single rate/delayed coincidence		$1\ \mu Bq\ \ m^3$
^{210}Pb	$\sim 100\ mBq\ \ m^3$	single rate		$1\ \mu Bq\ \ m^3$

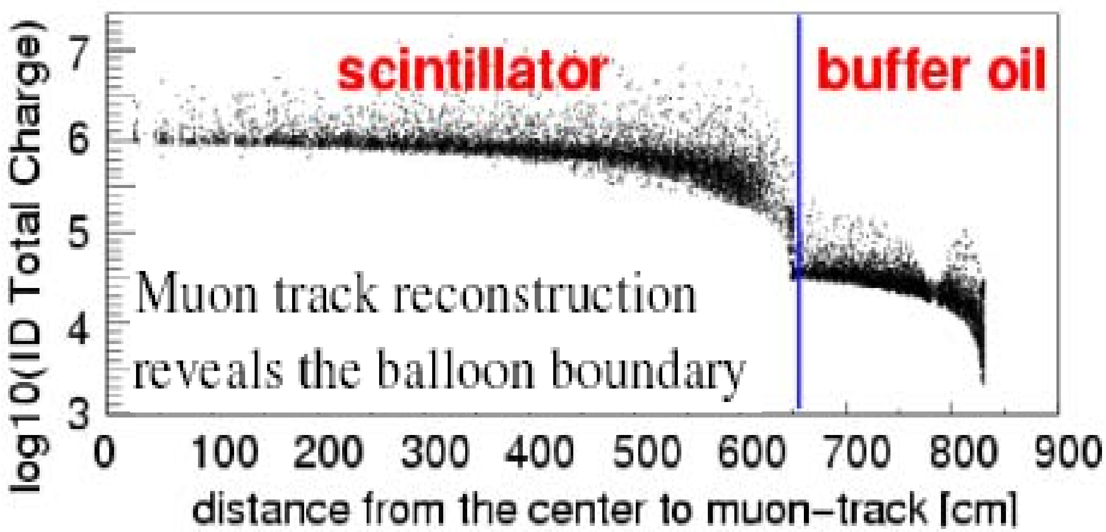
Impurities on the Balloon		
$^{222}Rn\ \ 4\ 0 \times 10^{-4}\ Bq$	$^{238}U\ \ \ 3\ 1 \times 10^{-8}\ g$ ~0.9g mine dust	$^{232}Th\ \ \ 9\ 7 \times 10^{-4}\ Bq$ ~0.1g mine dust

- Cosmic ray muon

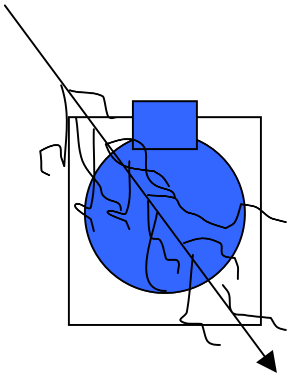


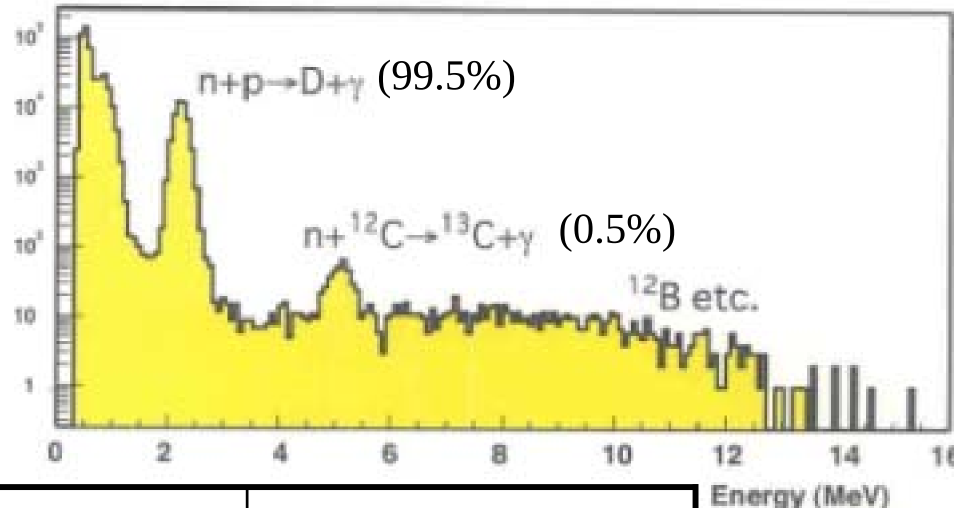






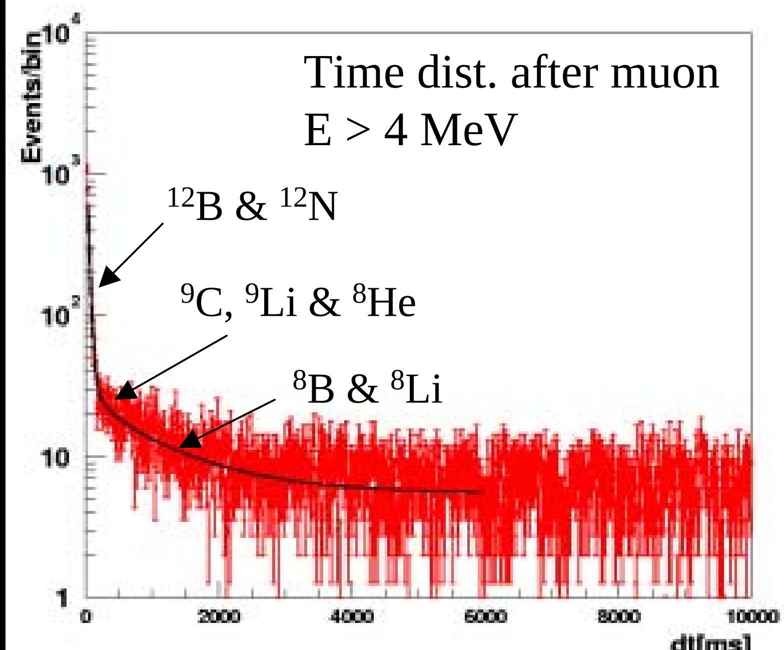
- Spallation events after muon





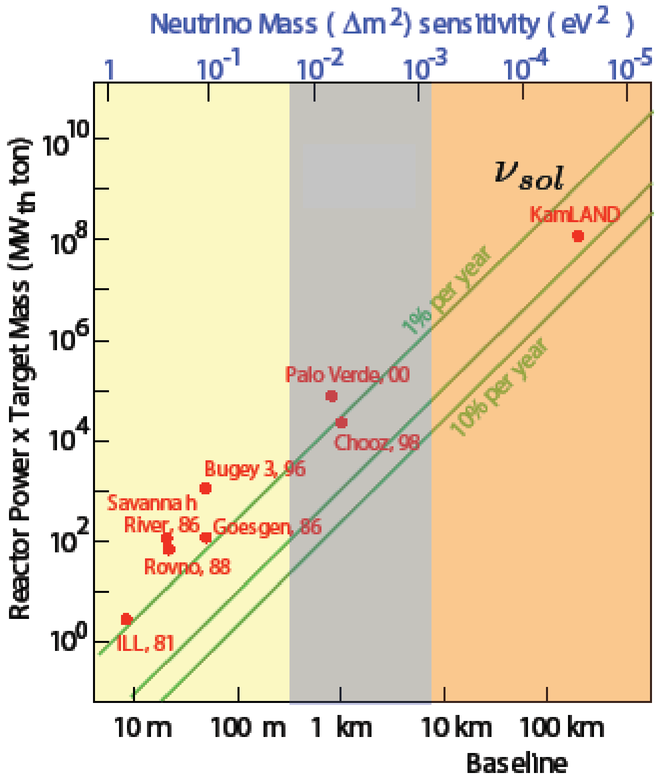
BG of neutrino event
^{9}Li & ^{8}He
energy calibration
p capture (2.224MeV)
^{12}C capture (4.947MeV)
^{12}B beta decay
vertex calibration
p capture
^{12}B beta decay

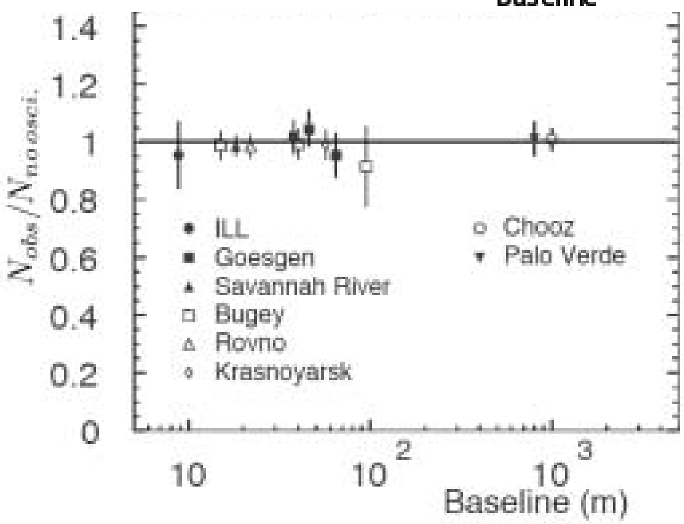
Isotopes	$T_{1/2}$	E_{max} (KeV)
^{12}B	20.2 ms	13369(β^-)
^{12}N	11.0 ms	17338(β^+)
^{11}Li	8.5 ms	20610(β^-)
^{9}Li	173.8 ms	13606(β^- n) ←
^{8}He	119.0 ms	10653(β^- n) ←
^{9}C	126.6 ms	16498(β^+)
^{8}Li	838.0 ms	16006(β^-)
^{6}He	806.7 ms	3508(β^-)
^{8}B	770.0 ms	17979(β^-)



Reactor neutrino observation

• Past reactor experiment





- Many different experiments
  - Baselines up to 1km
  - No evidence for ν disappearance

More than 100km baseline is necessary to explore the LMA solution

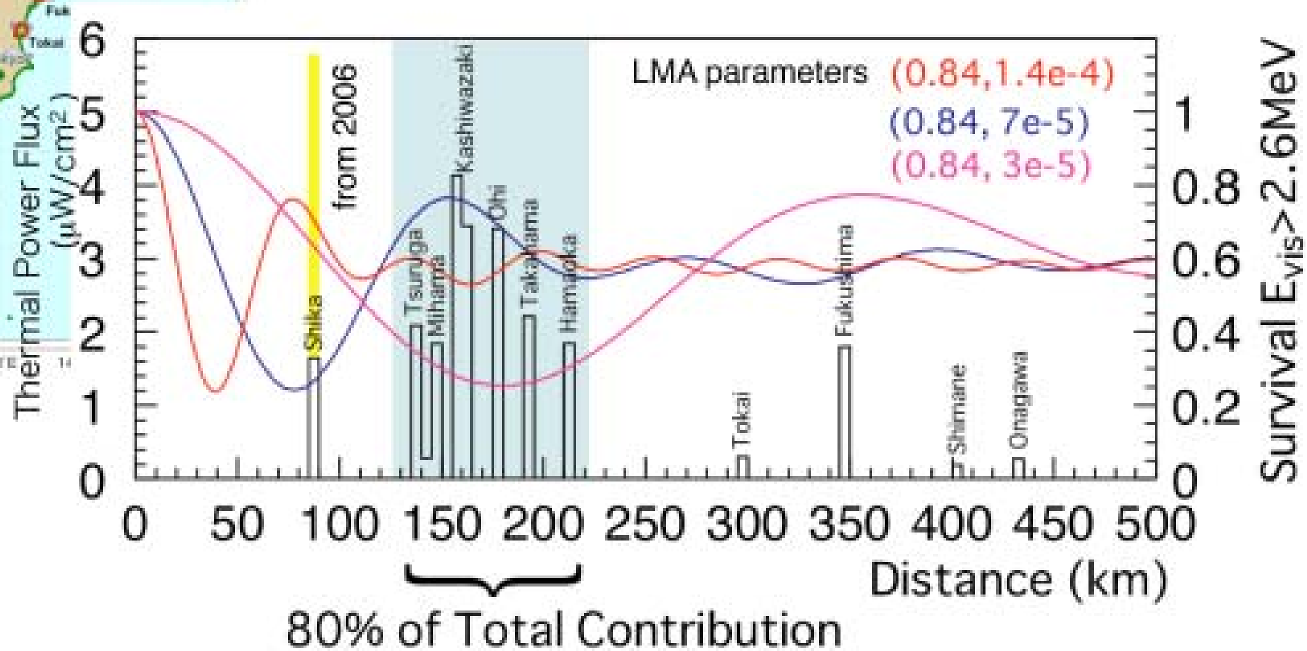
Powerful reactor,
Big detector,
Deep underground

- Kamioka location

70 GW (7% of world total) is generated at 130-240 km distance from Kamioka.

Reactor neutrino flux, $\sim 5 \times 10^6/cm^2/sec$ requires O(kiloton) underground detector.

There is a former Kamiokande cavity at 1000 m (2700 mwe) underground.



~97% from Japan
~2.5% from Korea

- Event selection

(1) fiducial cut $R < 5\,m$ 3.46×10^{31} free protons

(2) timing correlation $0.5 < dT < 660\,\mu sec,\ \tau = 212\,\mu sec$

(3) vertex correlation $|r_{prompt} - r_{delayed}| < 1.6\,m$

(4) delayed energy $1.8 < E < 2.6\,MeV$

(5) thermometer cut $\sqrt{x^2 + y^2} > 1.2\,m$

detection efficiency 78.3%

(6) spallation cut

all vol. $(dQ > 10^6\,p.e.)$ or $L < 3\,m$ $(dQ < 10^6\,p.e.)$ VETO for $2\,sec$

dead time 11.4 %

(7) energy threshold $E_{vis} > 2.6\,MeV$

Endpoint energy of geo-$\bar{\nu}_e$ event is 2.5 MeV.

• Systematic errors

	0.9MeV	2.6MeV		
Thermal Power	2.0	2.0	Reactor related 3.4%	Japanese reactors contribute ~97% of neutrino flux.
Korean Reactors	0.25	0.25		Only electric power is known but contribution is ~2.5%.
Other Reactors	0.35	0.35		Contribution is only 0.7%.
Burn-up effect	1.0	1.0		fraction of U235/U238/Pu239/Pu241
Long-life Nuclei	0.5	0.002		contribution of Ru106 and Ce144
Time-lag of beta decay	0.3	0.3		<1 day time lag for an equilibrium
Neutrino Spectra	2.3	2.5		PLB160(1985)325, PLB218(1989)365, PRC24(1981)1543
Cross section	0.2	0.2		PRD60(1999)053003, PRC67(2003)035502
Total LS mass	2.1	2.1	Detector 5.5%	$1171 \pm 25\ m^3$
Fiducial Volume Ratio	4.1	4.1		vertex distribution of spallation neutron
Energy Threshold	-	2.1		position 1.4%, time 0.6%, quench 1.02%, dark 0.4% ->1.91%
Efficiency of Cuts	2.1	2.1		capture time, space correlation, energy window
Live Time	0.07	0.07		
Total	6.0%	6.4%		

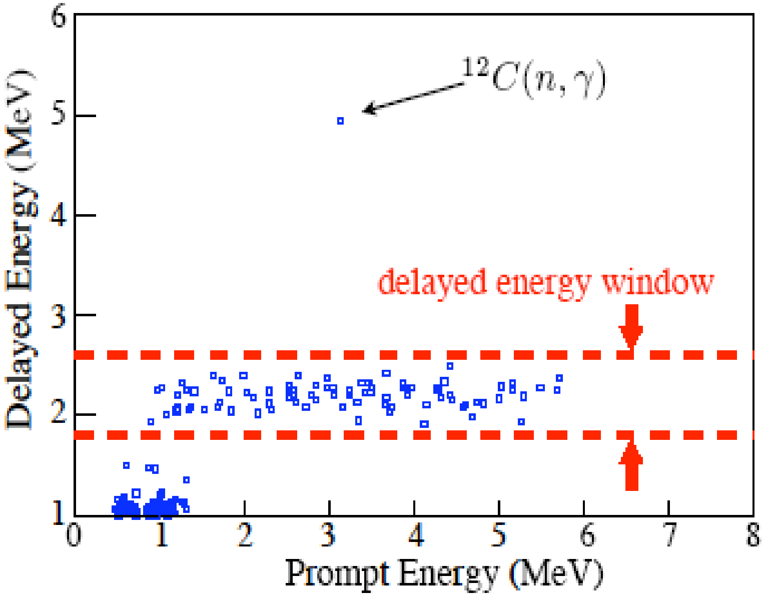
- Reactor neutrino analysis result

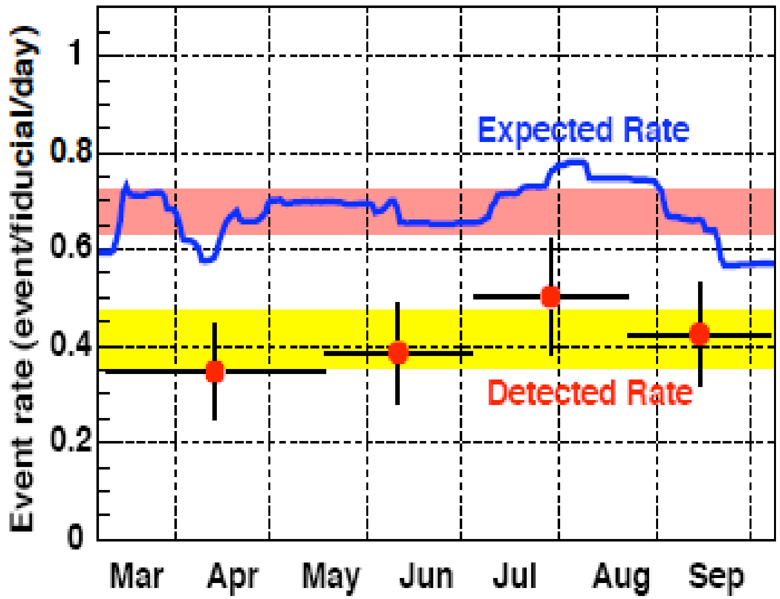
4 Mar. – 6 Oct. 2002   145.1 live days (162 ton-year exposure)

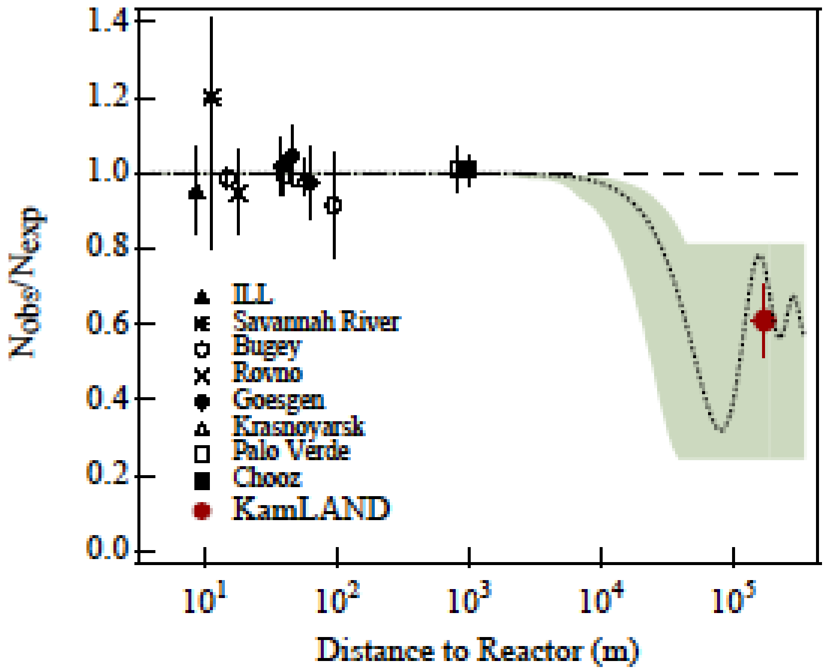
Analysis threshold	2.6MeV	0.9MeV
Expected signal	86.8±5.6	124.8±7.5
BG	1±1	2.9±1.1 (+9 geo neutrino)
Observed	54	86

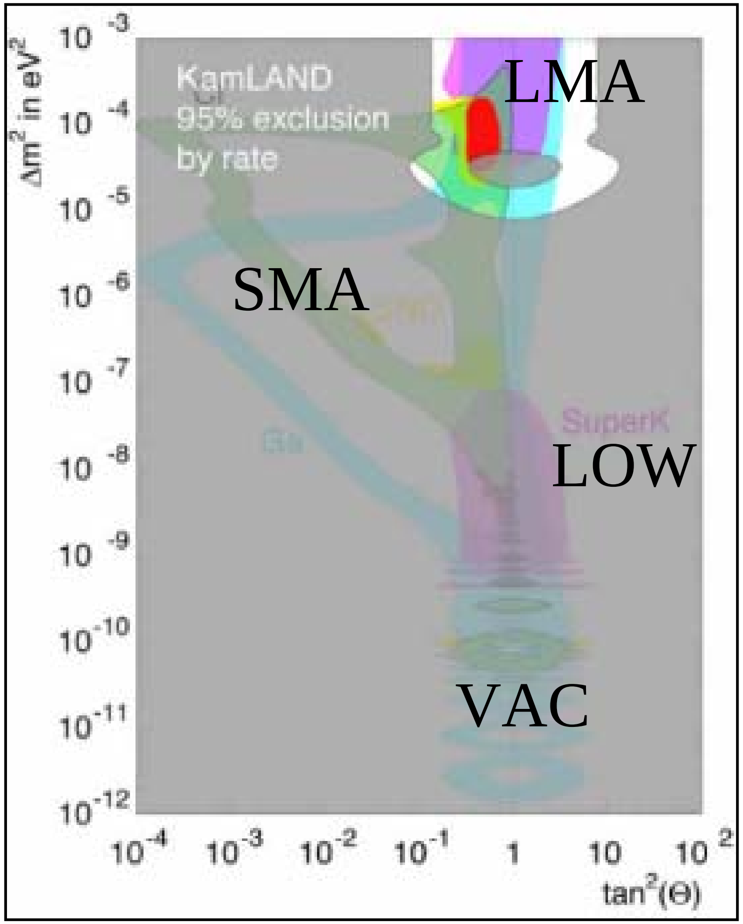
neutrino disappearance 99.95C.L.

R=0.611±0.085(stat)±0.041(sys)







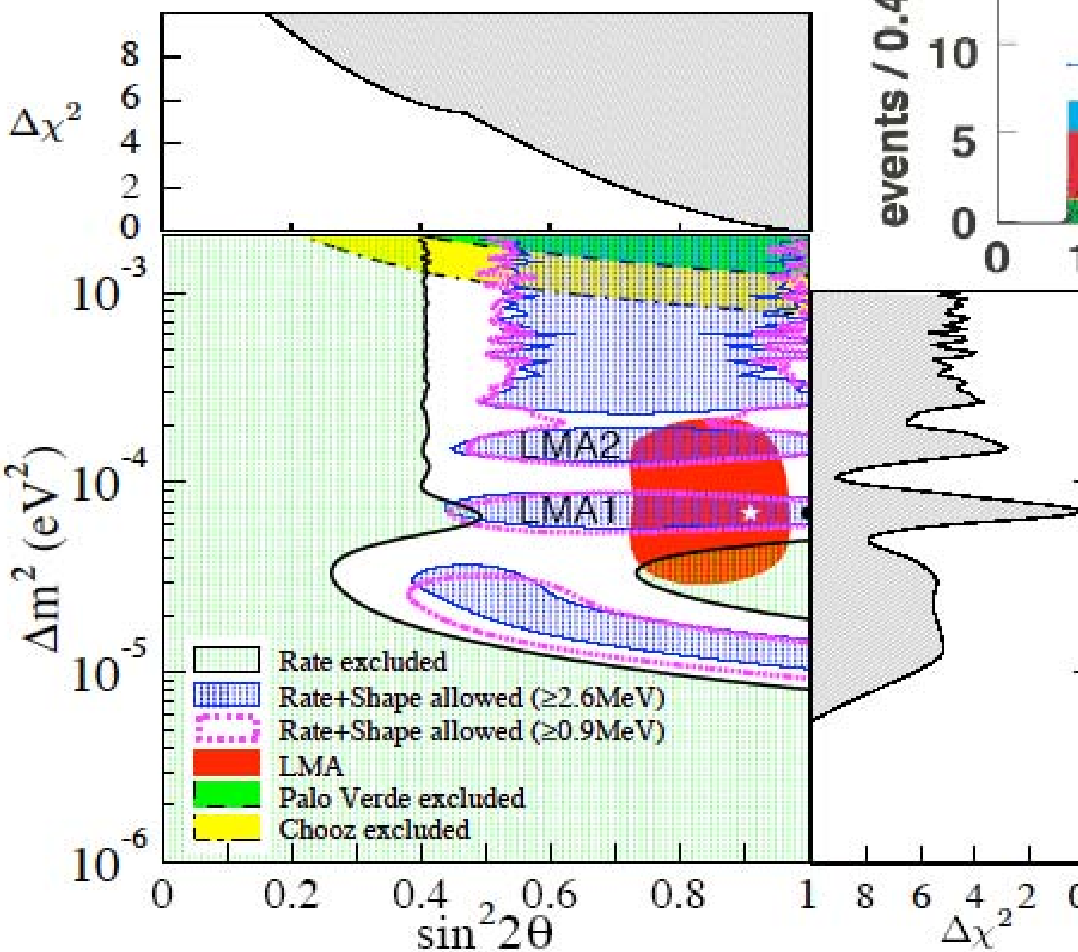


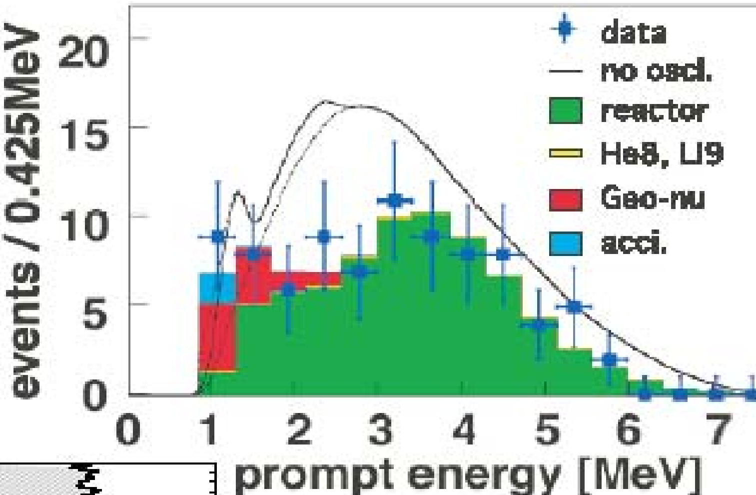
Assuming CPT invariance :

exclude except LMA

exclude RSFP solution too.

Rate + Shape Analysis





Best Fit E > 2.6 MeV

$$\sin^2 2\theta = 1.0$$

$$\Delta m^2 = 6.9 \times 10^{-5} eV^2$$

Best Fit E > 0.9 MeV

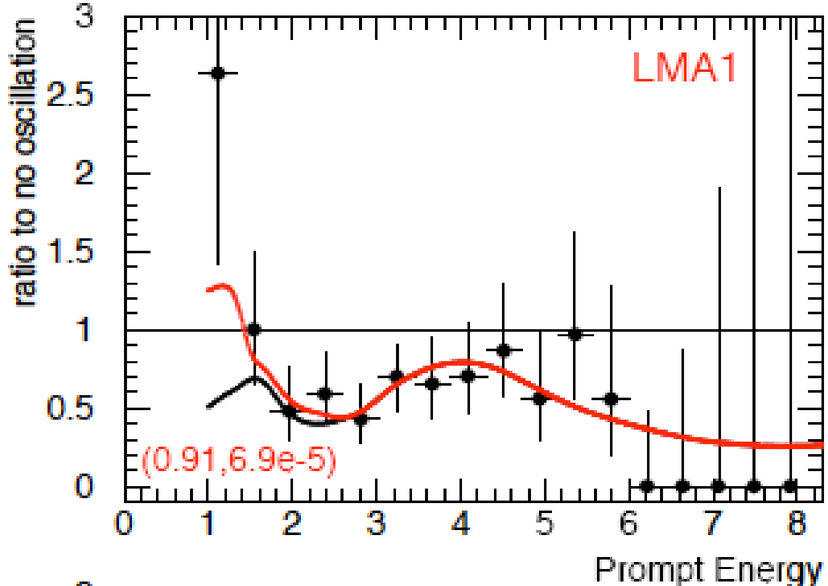
$$\sin^2 2\theta = 0.91$$

$$\Delta m^2 = 6.9 \times 10^{-5} eV^2$$

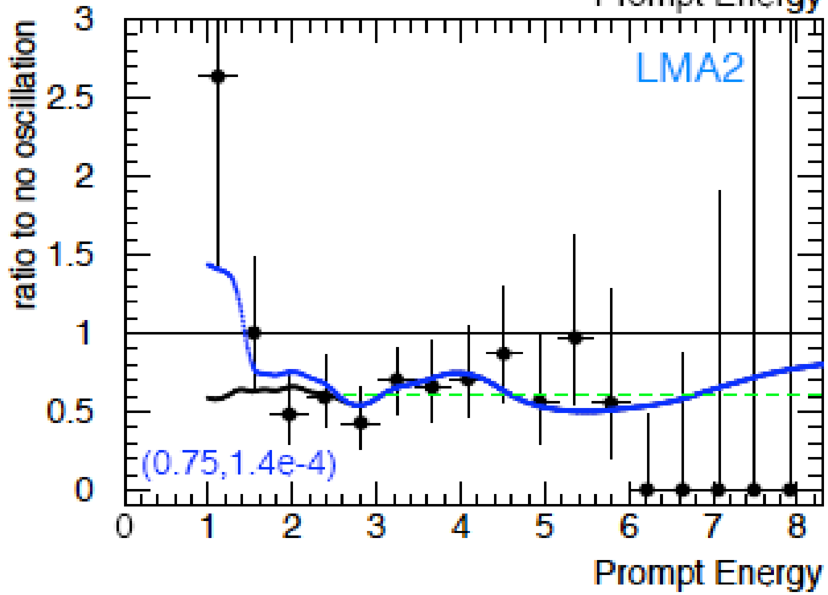
$$\bar{\nu}_{geo}(^{238}U) = 4$$

$$\bar{\nu}_{geo}(^{232}Th) = 5$$

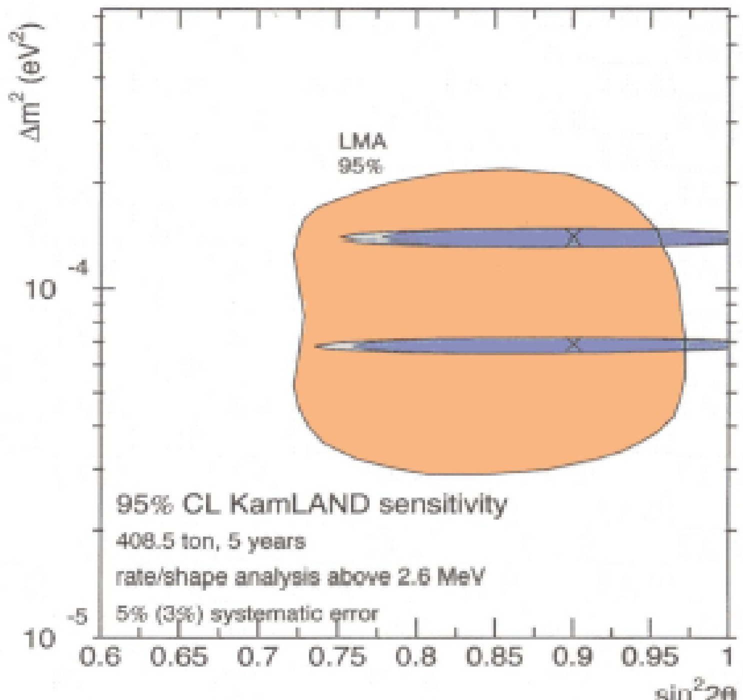
hint of geo-nu,
but consistent with 0 at 95% CL



BG is subtracted
and
Geo-neutrinos with
a model (16 TW)
are included.

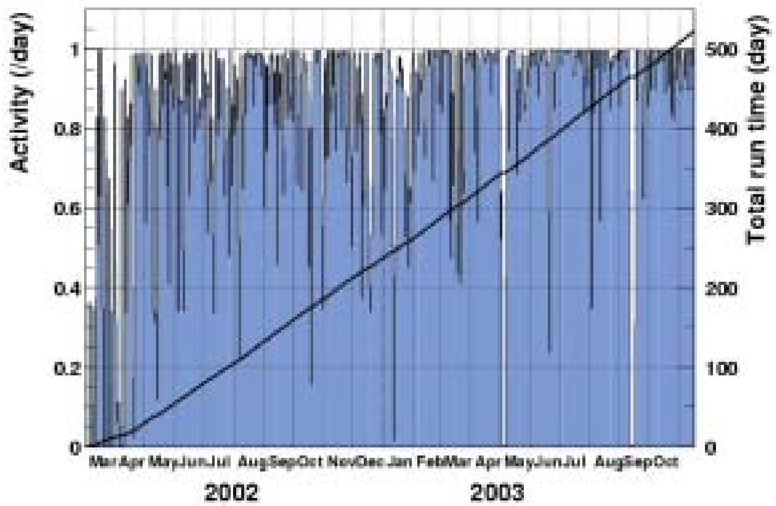


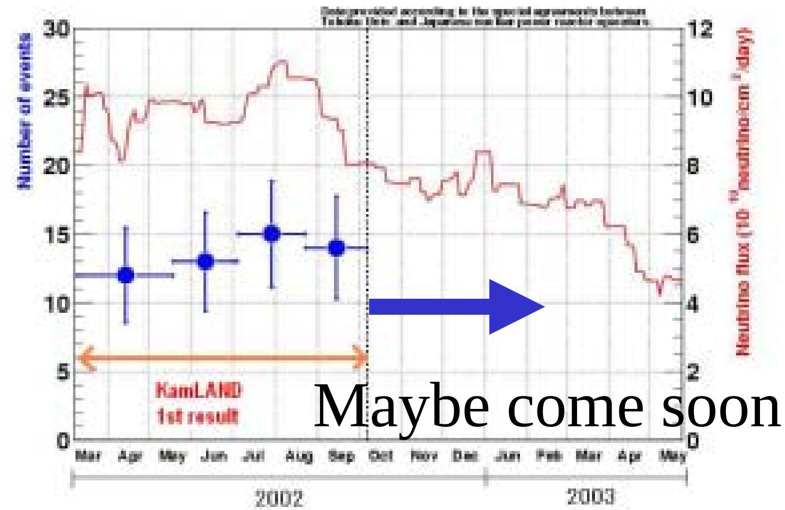
Constant suppresion
is also consistent at
53% confidence for
now.



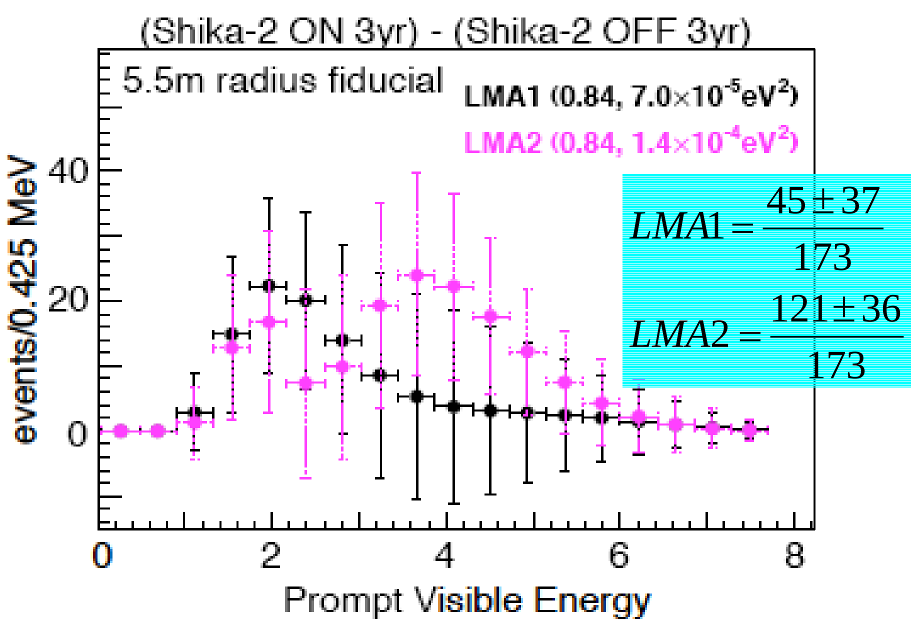
Without big changes,
KamLAND will pinpoint Δm^2_{21} .

- # Future
  - Analysis data update : seasonal variation

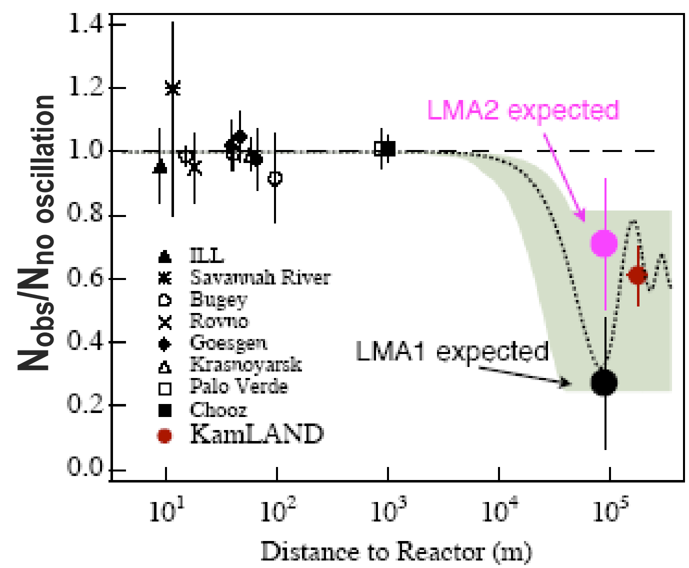




- Shika2 reactor will work at 88km –2006 : LMA1 or LMA2



Oscillatory pattern may be seen as an evidence for oscillation.



- Reactor neutrino observation summary

KamLAND has observed an evidence for reactor neutrino disappearance at ~180km distance with 99.95% C.L.

$$R = \mathbf{0.611 \pm 0.085 \pm 0.041}$$

Assuming CPT invariance, only the LMA solution is compatible with the deficit.

KamLAND is running on stable condition. KamLAND will give high sensitivity data to survey the LMA region.

Search for electron anti-neutrino from the sun

- How make solar anti-neutrino ?

ν_e with a non-zero transition magnetic moment can evolve into $\overline{\nu}_\mu$, $\overline{\nu}_\tau$ while propagating through intense magnetic fields in the sun.

$$
i\frac{d}{dt}\begin{pmatrix}\nu_e\\ \nu_\mu\\ \overline{\nu}_e\\ \overline{\nu}_\mu\end{pmatrix}=\begin{pmatrix}\frac{G}{\sqrt{2}}(2N_e-N_n) & \frac{\Delta m^2}{4E}\sin 2\theta & 0 & \mu B\\ \frac{\Delta m^2}{4E}\sin 2\theta & -\frac{G}{\sqrt{2}}N_n+\frac{\Delta m^2}{2E}\cos 2\theta & -\mu B & 0\\ 0 & -\mu B & -\frac{G}{\sqrt{2}}(2N_e-N_n) & \frac{\Delta m^2}{4E}\sin 2\theta\\ \mu B & 0 & \frac{\Delta m^2}{4E}\sin 2\theta & -\frac{G}{\sqrt{2}}N_n+\frac{\Delta m^2}{2E}\cos 2\theta\end{pmatrix}\begin{pmatrix}\nu_e\\ \nu_\mu\\ \overline{\nu}_e\\ \overline{\nu}_\mu\end{pmatrix}
$$

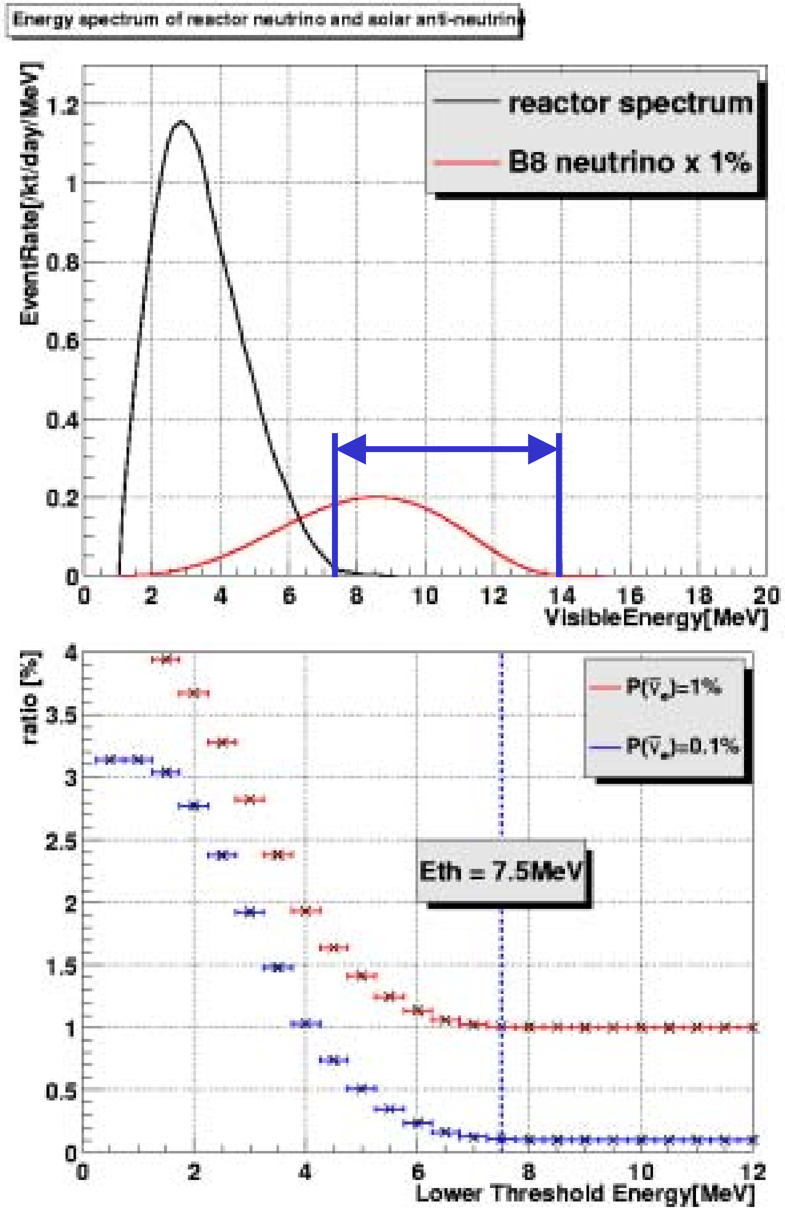
: MSW effect

: spin-flavor presession

conversions : $\nu_{eL} \rightarrow \overline{\nu}_{\mu R} \rightarrow \overline{\nu}_{eR}$ or $\nu_{eL} \rightarrow \nu_{\mu L} \rightarrow \overline{\nu}_{eR}$

→ depend to magnetic field model

• Energy region for solar anti-neutrino



✓Avoid BG by reactor

✓Near of the ^{8}B neutrino endpoint

$7.5 < E_{e+} < 14 MeV$

$$8.3 < E_{\bar{\nu}_e} < 14.8 MeV$$

- Event selection

Data: 4. Mar. – 1. Dec. 2002
Livetime: 185.5 days

Event selection criteria

spallation cut $t < 2$sec for $dQ > 10^6$ p.e.
$t < 2$sec, dr(from muon track) < 3 m for $dQ > 10^6$ p.e.
dead time 11.5%

vertex cut $R_p < 550$ cm, $R_d < 550$ cm (no thermometer cut)

vertex correlation $dL < 160$ cm

timing correlation $0.5 < dt < 660\mu s$

energy cut delayed: $1.8 < E < 2.6$MeV
detection efficiency 84.1%

energy cut prompt: $7.5 < E < 14.0$ MeV

- Systematic errors

✓Detection efficiency (ε) : 1.6 %

space correlation R<550cm, dL<160cm	: 1.6%
time correlation 0.5 < dt < 660 μs	: 0.4%
delayed energy 1.8 < E_d < 2.6 MeV	: 0.1%

✓Cross section (σ) : 0.2 %

✓Number of target proton : 4.3 %

total volume error 1171 +/- 25 m^3	: 2.2%
fiducial volume ratio R<550 cm	: 3.7%

✓Energy threshold : 4.3 %

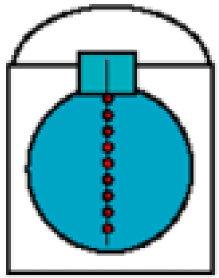
energy calibration is done by ^{12}B beta decay

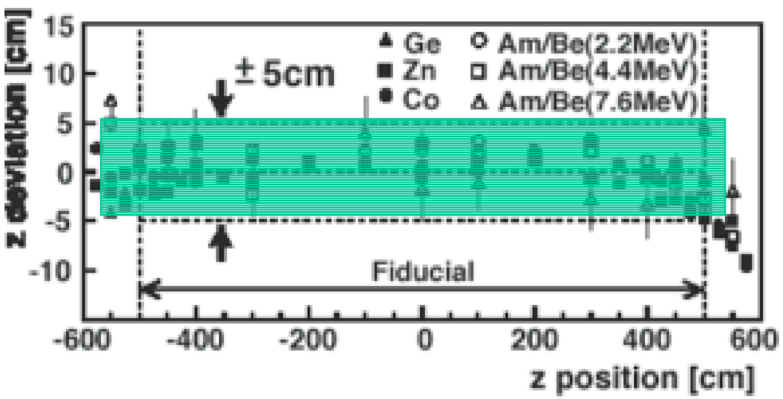
✓Livetime (T) : 0.07 %

✓Total : 6.3 %

- # Vertex calibration

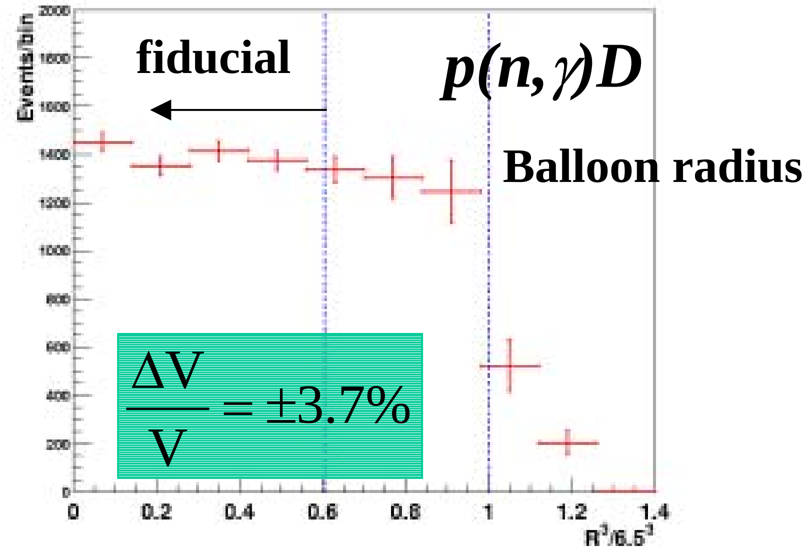
with radioactive sources

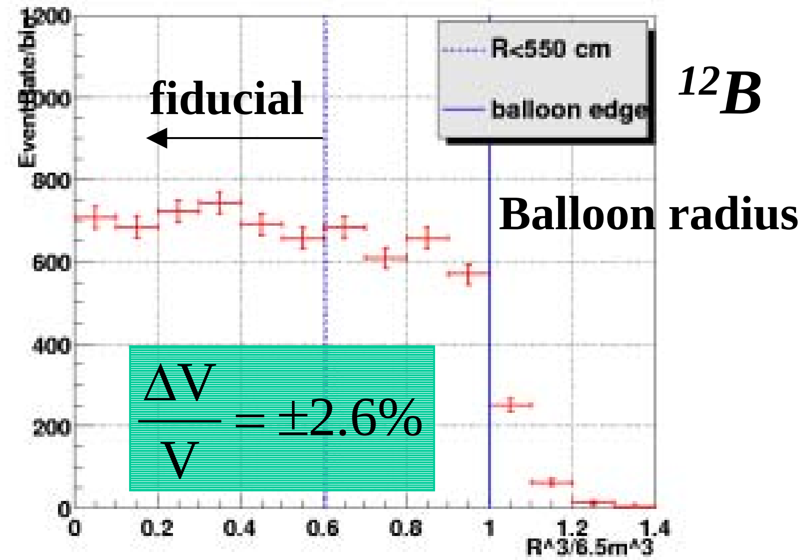




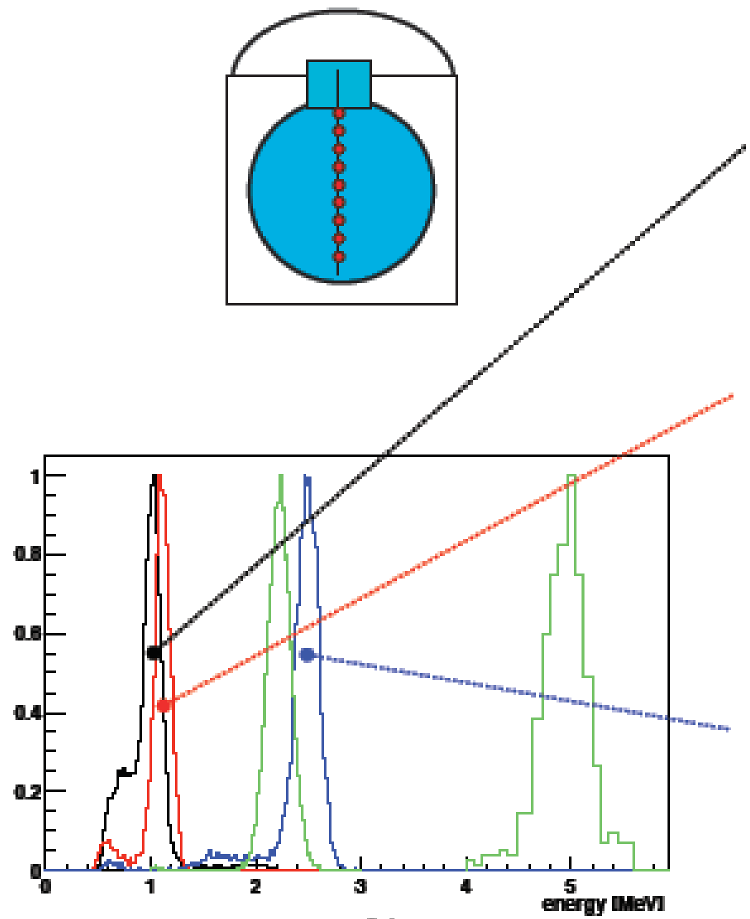
$$\sigma_{xyz} \sim \frac{30\,cm}{\sqrt{E}}$$

with spallation events

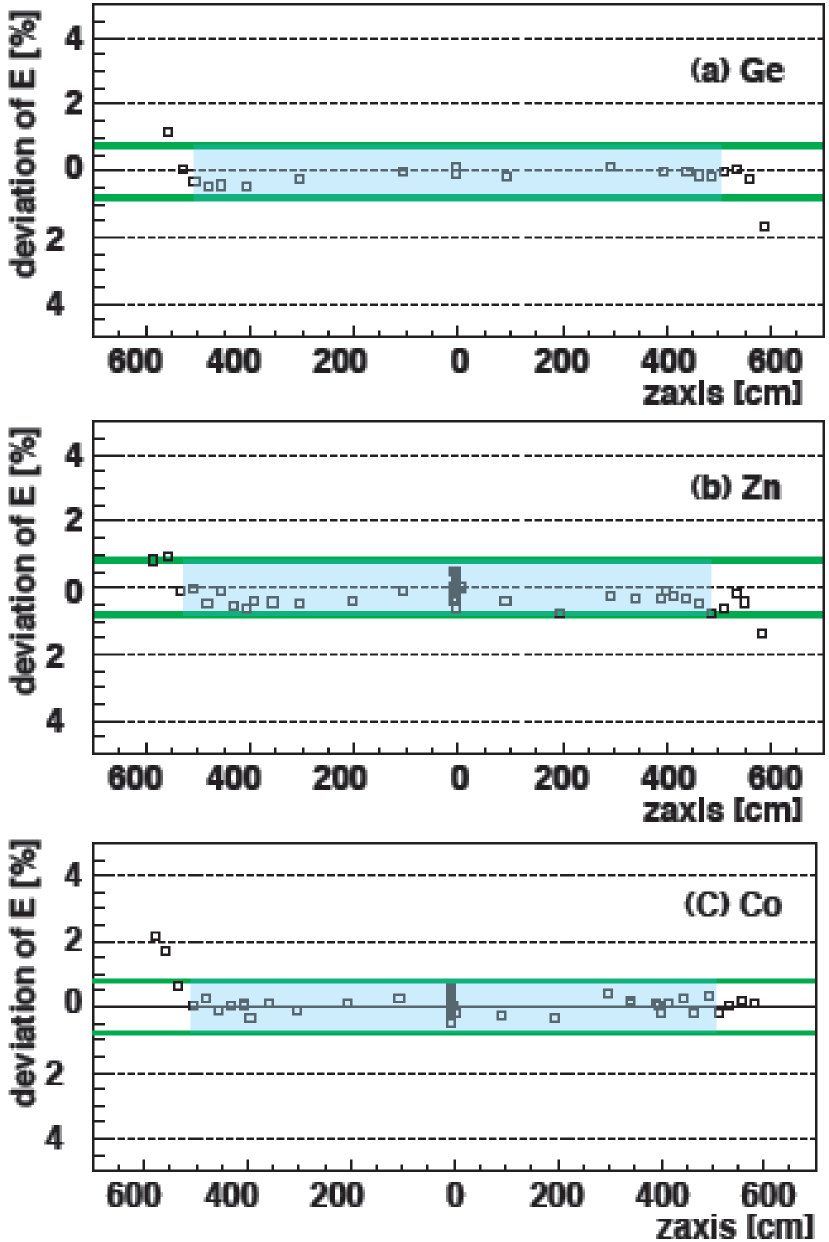




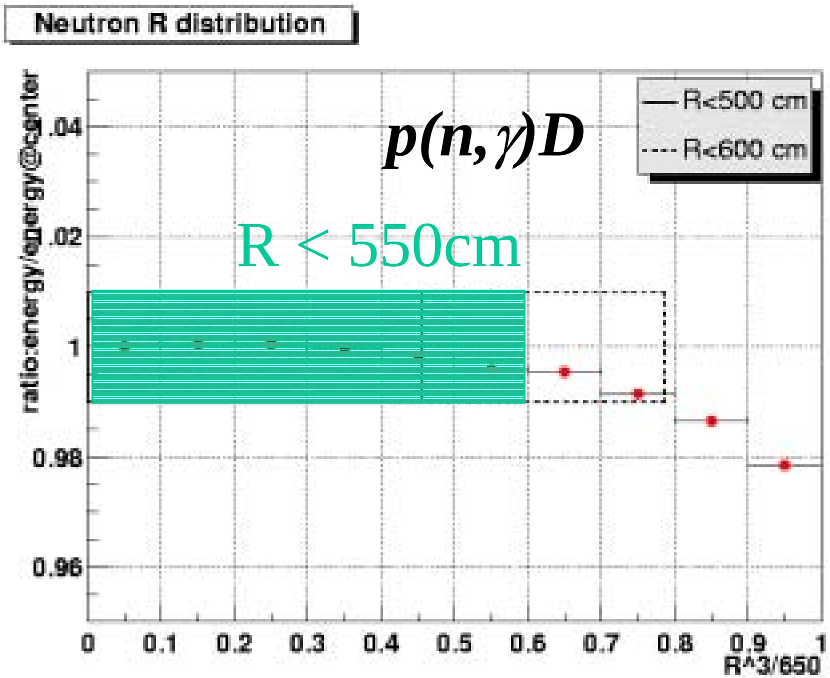
Energy Calibration with Radioactive Sources

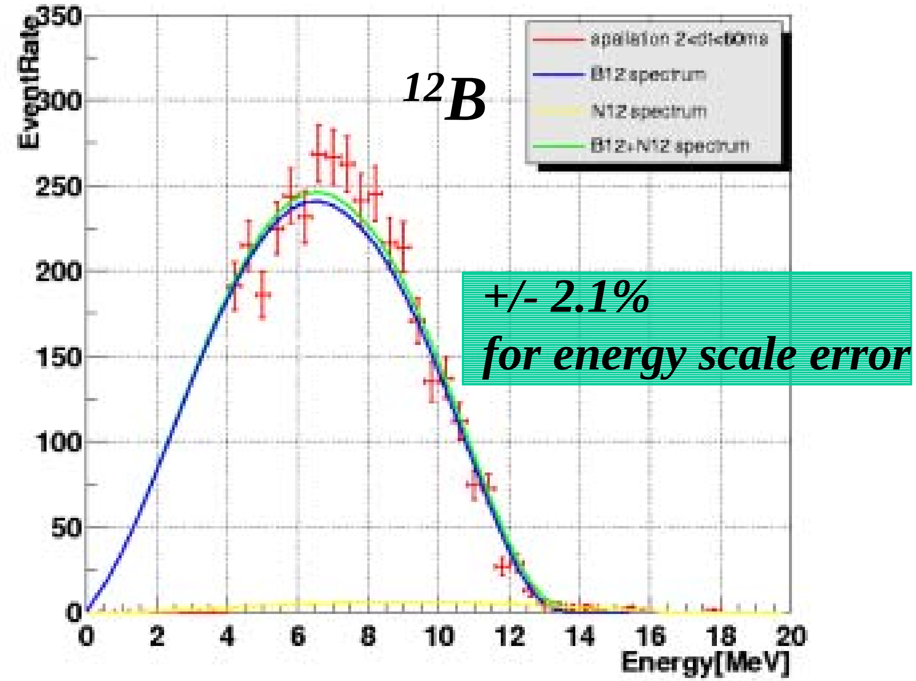


$$\frac{\sigma}{E} \sim \frac{7.5\%}{\sqrt{E}}$$



Energy calibration with muon spallation





Assuming ^{8}B neutrino shape : 4.3% error @ 7.5MeV threshold

- Expected background

  - ✓ Reactor neutrino : 0.2 +/- 0.2

    Ep > 7.5MeV, LMA region

  - ✓ Atmospheric neutrino : 0.001

    T.K. Gaisser Phys. Rev. Lett. 1985

  - ✓ Fast neutron : 0.3 +/- 0.2

    OD inefficiency 8% + passing rock event

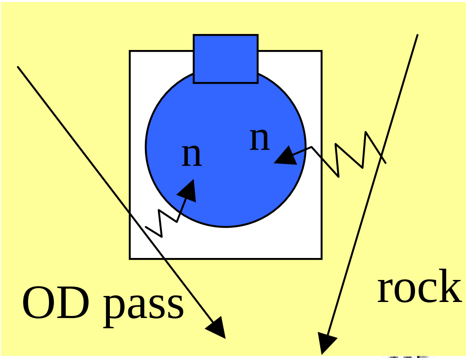
  - ✓ Accidental coincidence : 0.02

    pick up the off-timing events 1 < dt < 10 sec

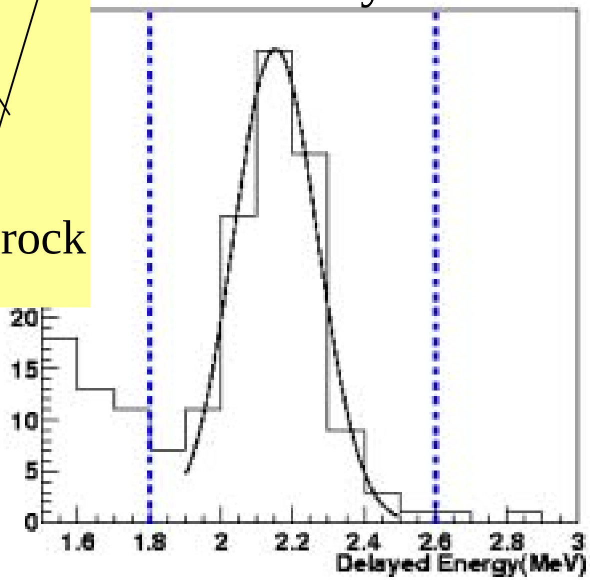
  - ✓ ^{8}He & ^{9}Li : 0.6 +/- 0.2

  - ✓ Total : 1.1 +/- 0.4

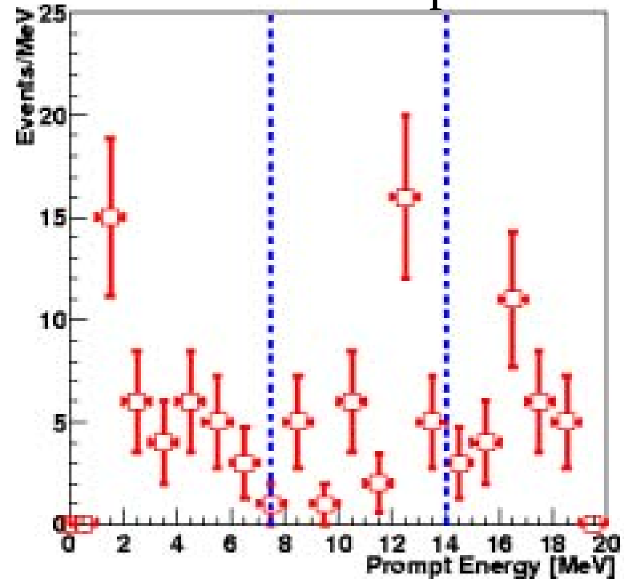
- Fast neutron

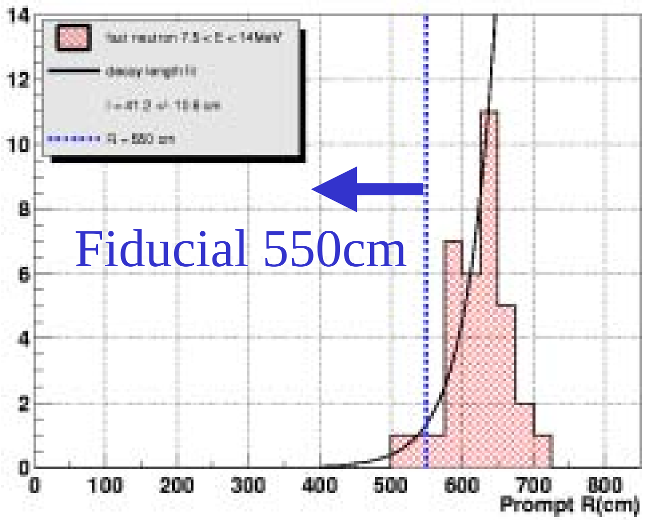


Delayed event



Prompt event





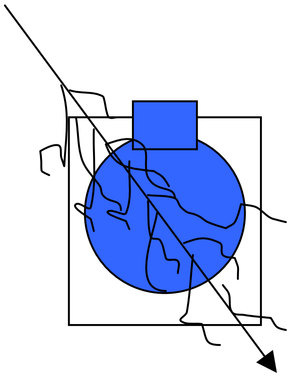
For $7.5 < E_p < 14$MeV, fiducial

$N_{OD\text{-}muon} = 0.1 \pm 0.1$

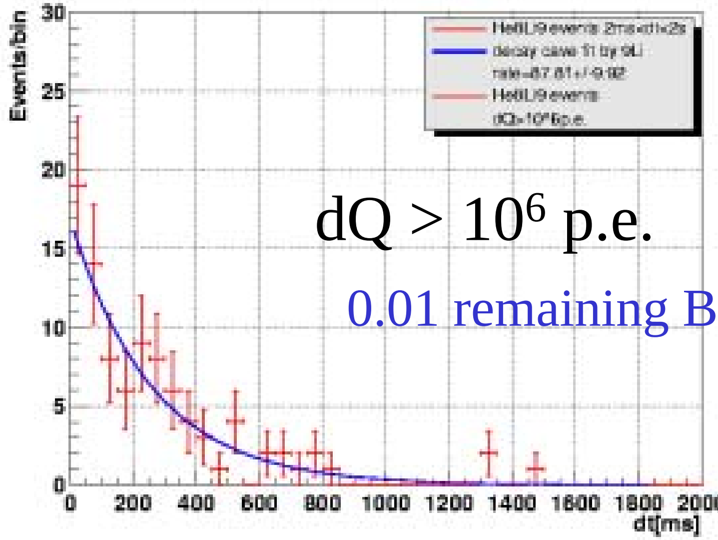
$N_{rock} = 0.2 \pm 0.2$

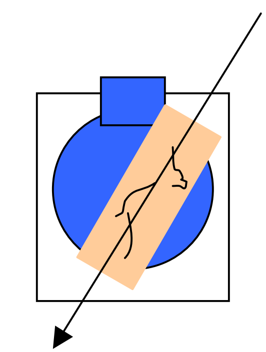
Total = 0.3 +/- 0.2

- ^{8}He & ^{9}Li

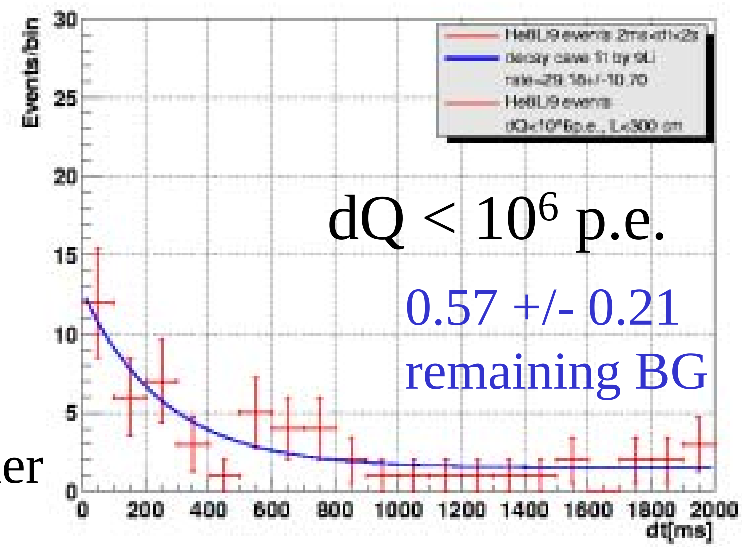


2sec VETO
for all volume



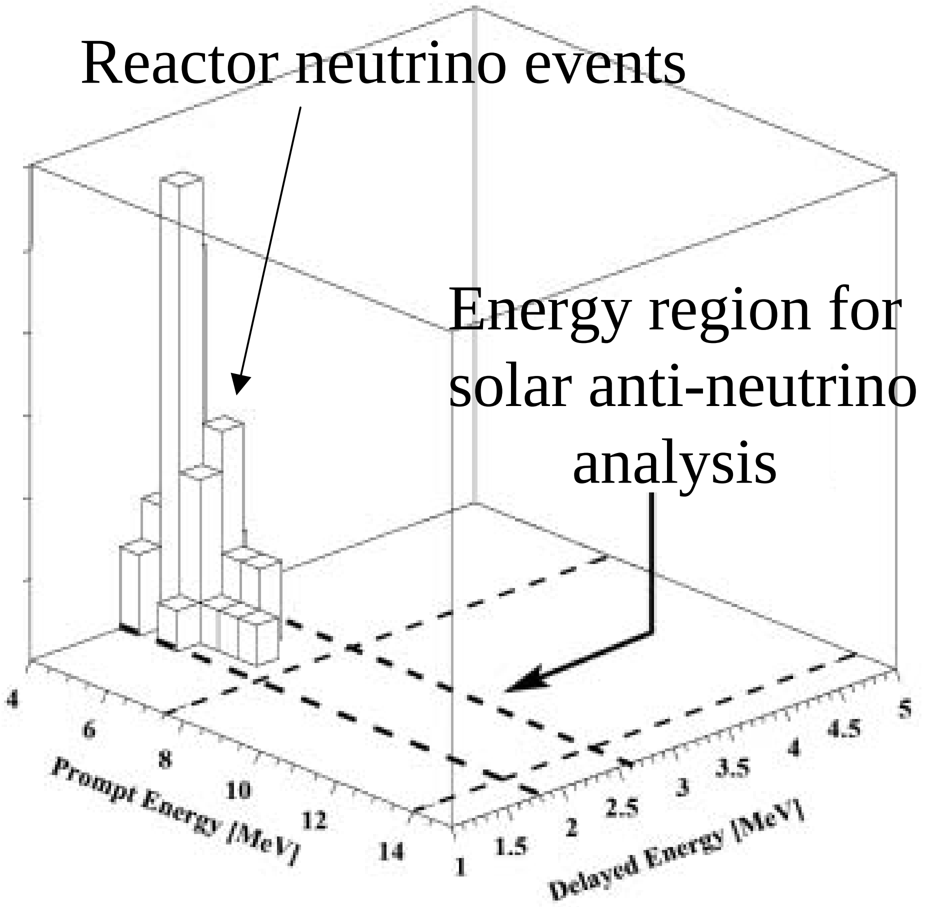


2sec VETO
for 6mϕ cylinder
93.6% eff.



Total remaining BG
= 0.6 +/- 0.2
for 7.5 < Ep < 14MeV

- Analysis result



No observed event !

- The ν_e flux over the energy range 8.3-14.8 MeV (7.5 – 14 MeV for E_p)

N_{signal}=1.58 : using the Feldman-Cousins method
G.J.Feldman & R.D.Cousins, Phys. Rev. D57,3873(1998)

$$\Phi_{\bar{\nu}_e} = \frac{N_{signal}}{\bar{\sigma} \times \bar{\varepsilon} \times T \times \rho_p \times f_v}$$

$$\bar{\sigma} = 6.88 \times 10^{-42}\,\mathrm{cm}^2$$
$$\bar{\varepsilon} = 0.841$$
$$T = 1.60 \times 10^{7}\,s$$
$$\rho_p \times f_v = 4.61 \times 10^{31}$$: number of target protons

$$< 3.7 \times 10^2\ \mathrm{cm}^{-2}\mathrm{s}^{-1}\ (90\%\ \mathrm{C.L.})$$

Normalize to ^{8}B solar neutrino flux

This energy window is containing 29.5% of the total flux of

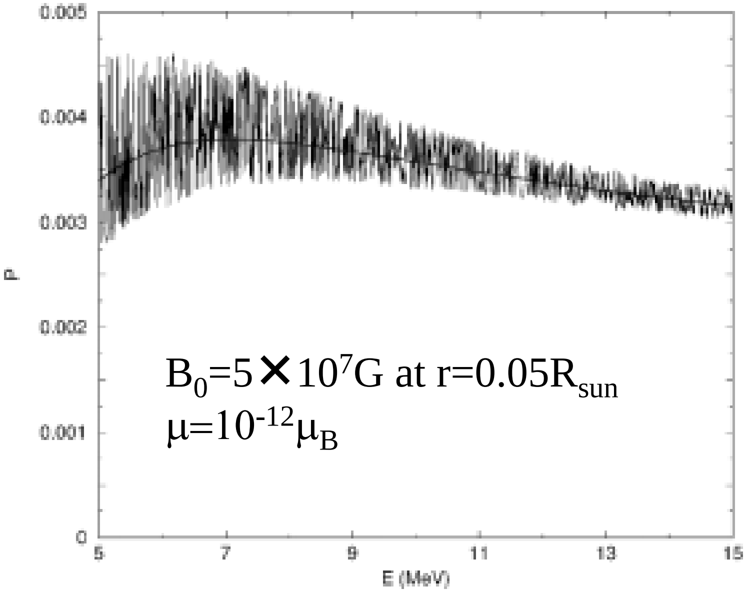
$$5.05^{+1.01}_{-0.81} \times 10^6\ \mathrm{cm}^{-2}\mathrm{s}^{-1}\ \ (\mathrm{BP2000})$$

Neutrino conversion probability < 2.8×10^{-4} (90% C.L.)

X30 improvement of the previous best measurement !

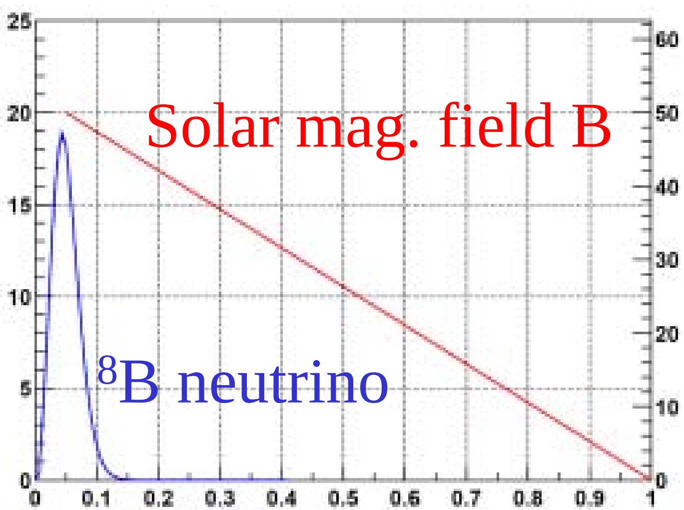
hep-ex/0310047

- Interpretation by spin-flavor precession (1)



$$P(\nu_{eL} \to \bar{\nu}_{eR}) \simeq 1.8 \times 10^{-10} \sin^2 2\theta \left[\frac{\mu}{10^{-12}\mu_B} \frac{B_\perp(0.05\,R_\odot)}{10\,\mathrm{kG}} \right]^2$$

Physics Letters B 553 (2003) 7–17



Our result :

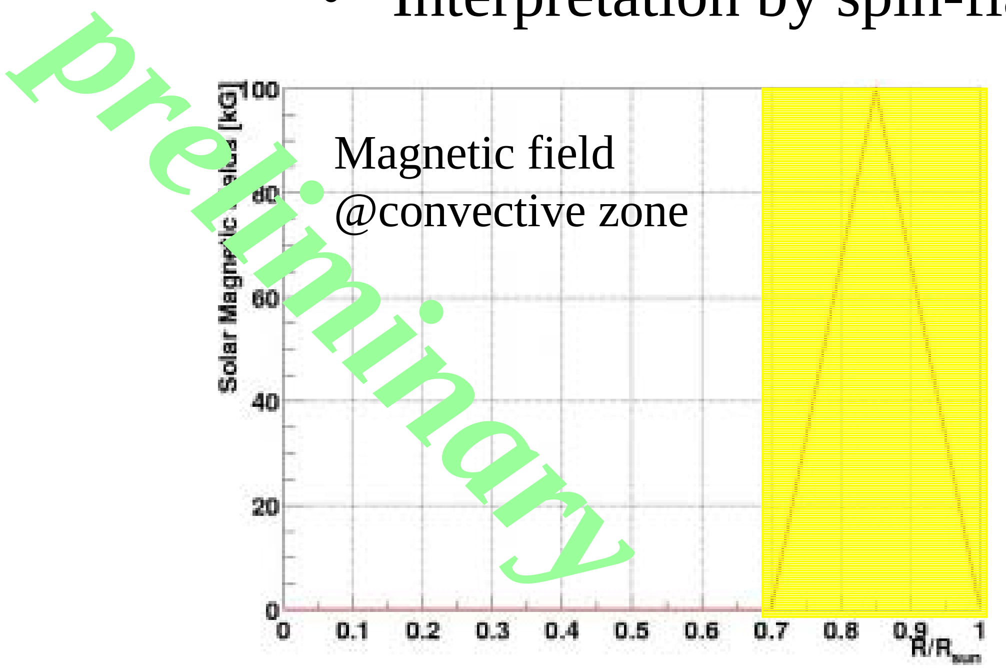
$$\frac{\mu}{10^{-12}\mu_B} \frac{B_T(0.05R_{sun})}{10kG} < 1.3 \times 10^3$$

If B_T=300kG, $\mu_\nu < 4.3 \times 10^{-11} \mu_B$

MUNU experiment :

$$\mu_{\bar{\nu}_e} < 1.0 \times 10^{-10} \mu_B (90\% C.L.)$$

- Interpretation by spin-flavor precession (2)



J.Pulido, hep-ph/0106201

B_{core}<2MG

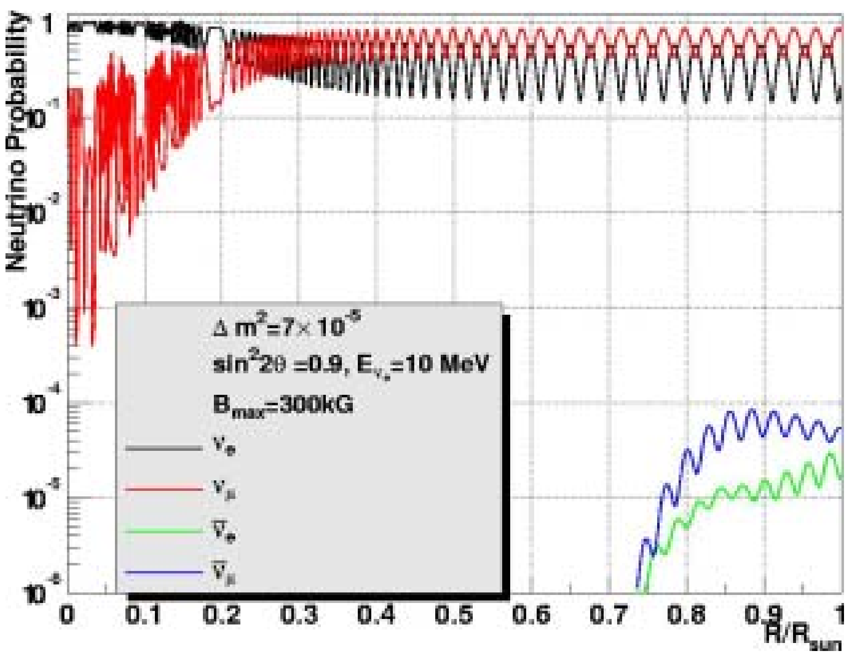
S.Chandrasekar & E.Fermi, Astrophys.J.188(1953)116

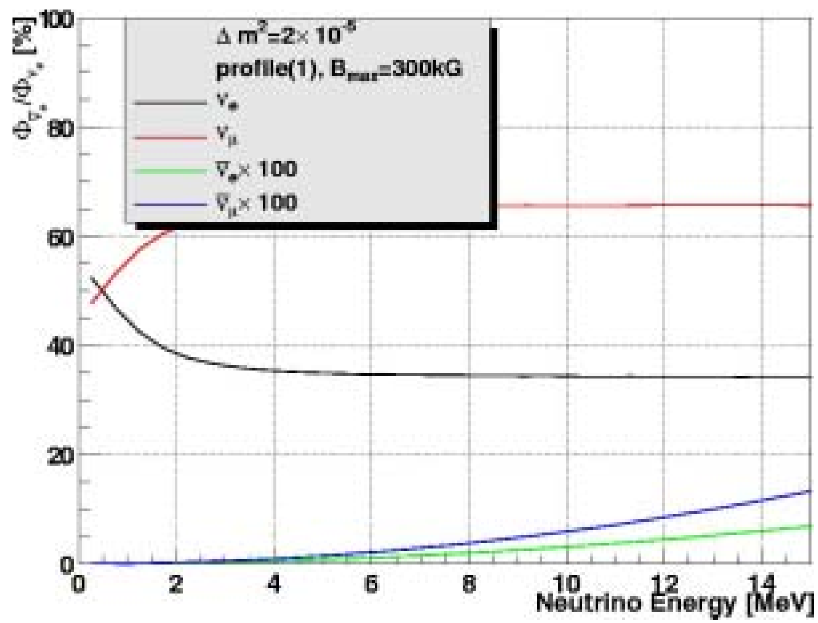
B_{core}<7MG

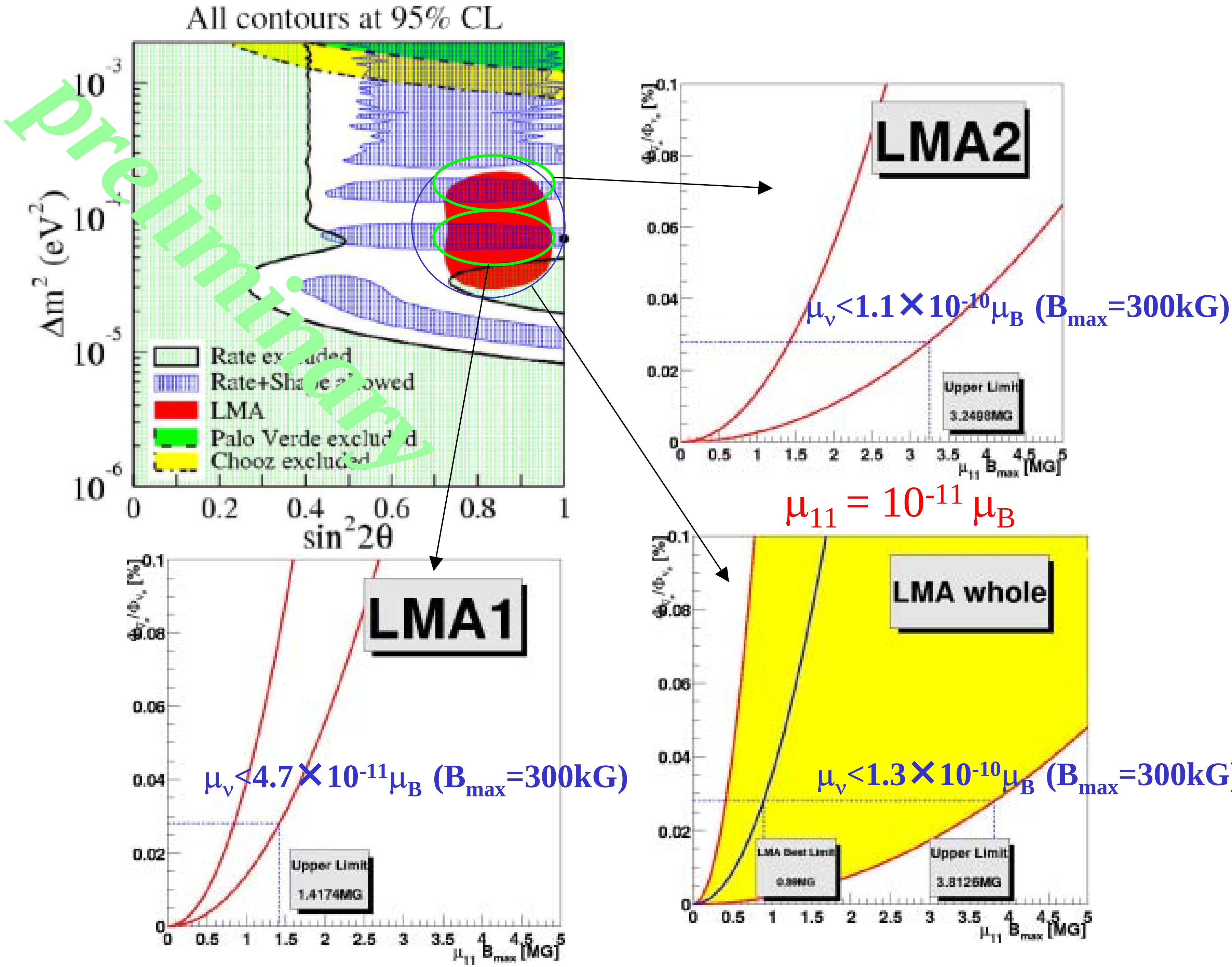
A.Friedland & A.Gruzinov, astro-ph/0211377

$B_{convective}$<300kG

H.M.Antia et. Al., astro-ph/0005587






All contours at 95% CL
preliminary
Δm² (eV²)
sin²2θ
Rate excluded
Rate+Shape allowed
LMA
Palo Verde excluded
Chooz excluded
LMA2
μν<1.1×10⁻¹⁰μB (Bmax=300kG)
Upper Limit
3.2498MG
μ11 B max [MG]
μ11 = 10⁻¹¹ μB
LMA1
μν<4.7×10⁻¹¹μB (Bmax=300kG)
Upper Limit
1.4174MG
LMA whole
μν<1.3×10⁻¹⁰μB (Bmax=300kG)
LMA Best Limit
0.99MG
Upper Limit
3.8126MG

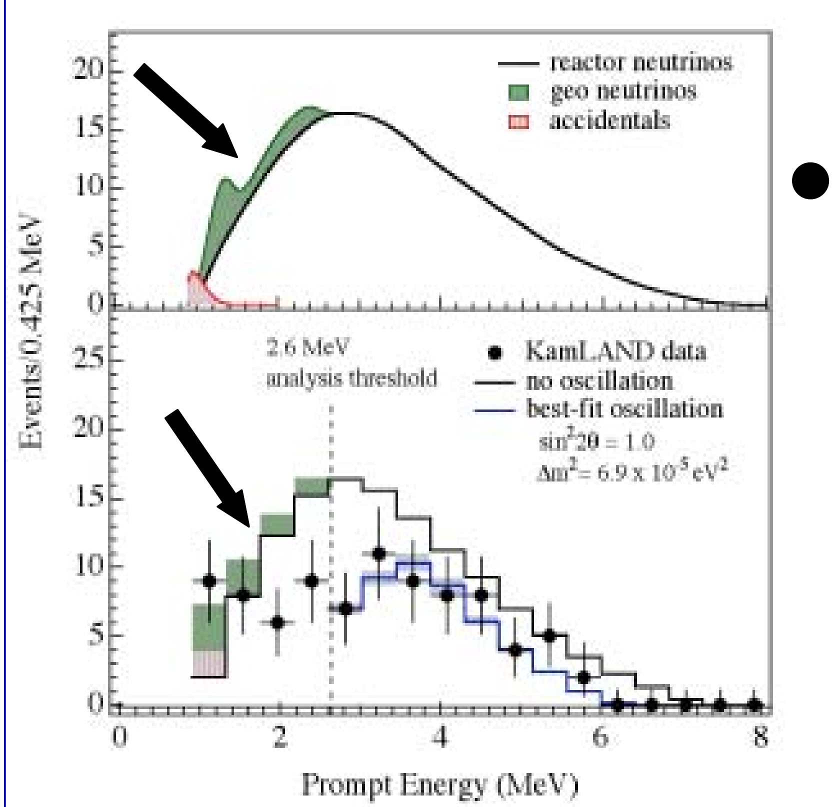
- Solar anti-neutrino summary

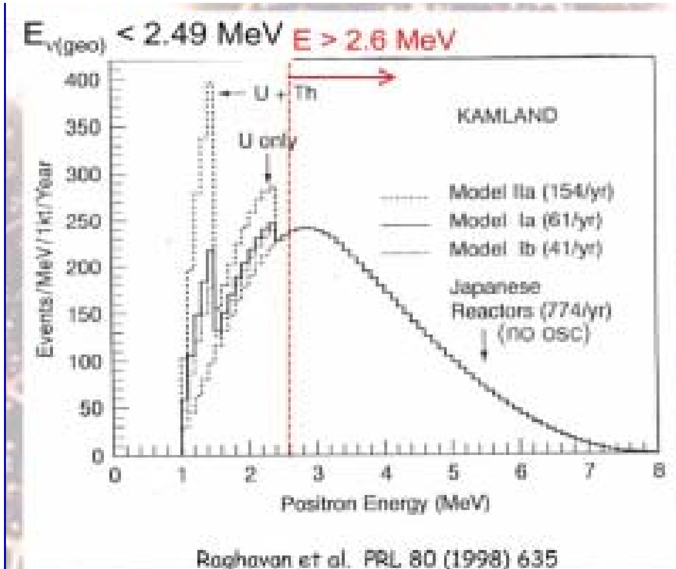
We got a anti-neutrino flux upper limit in the energy range 8.3 – 14.8 MeV $< 3.7 \times 10^2$ **cm^{-2}s^{-1} (90% C.L.)**

This correponds to **2.8×10^{-4}** for BP2000 ^{8}B neutrino flux

Future study

• Geo neutrino





A model

crust	U	1.8 ppm
mantle	U	0.01 ppm
Th/U		3.6

→ 16 TW heat flow
~9 events in our data

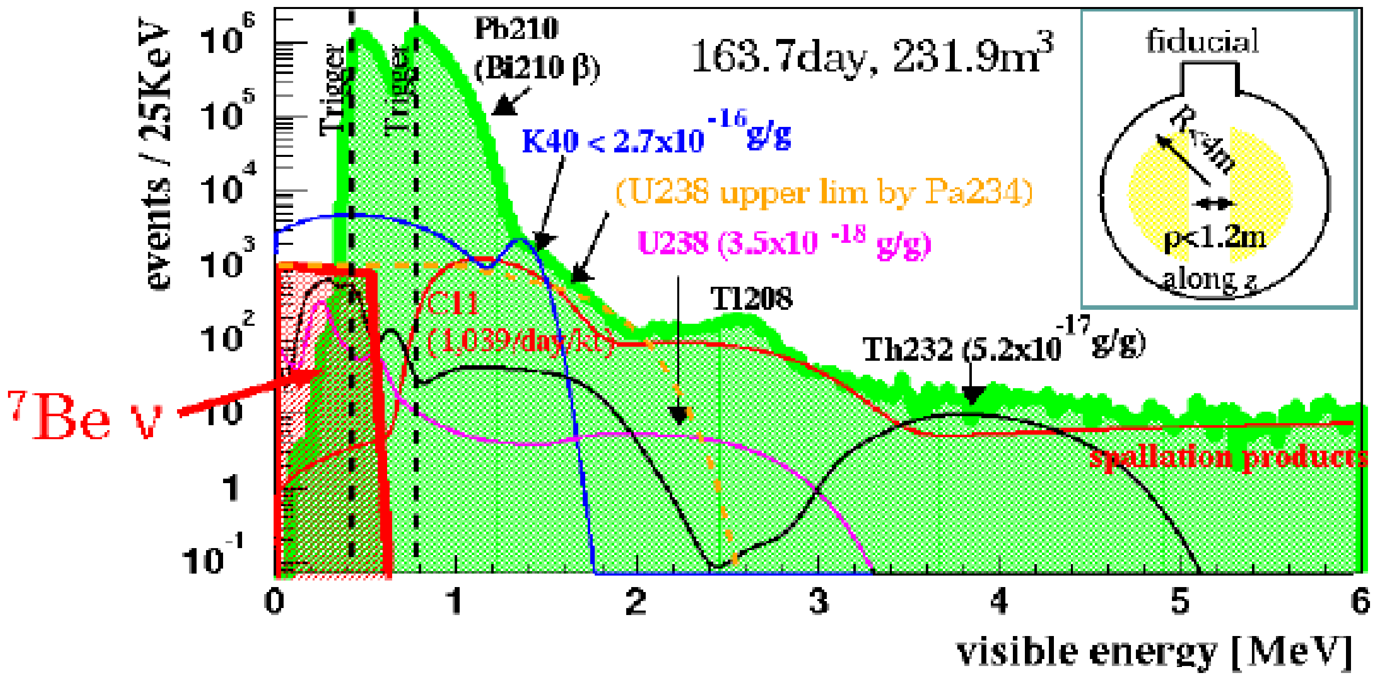
Best fit with 0.9 MeV rate + shape analysis (0.91, 6.9e-5)

U 4 events
Th 5 events

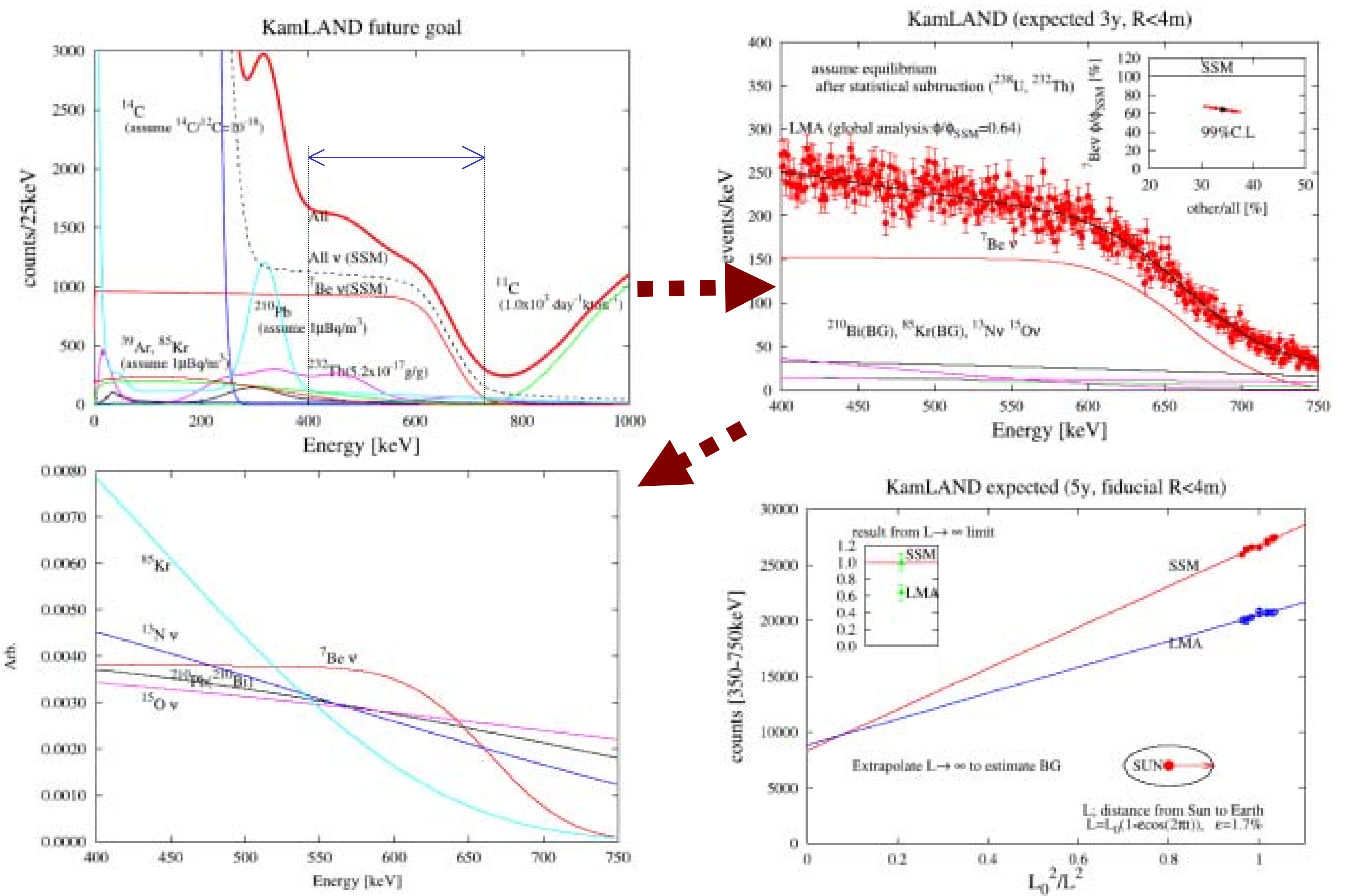
⇒ ~40 TW
consistent with 16 TW at 1 sigma
0~110 TW at 95% C.L.

Total : 9+/-6 events

- Toward ^{7}Be solar neutrino detection



We need the purification again!

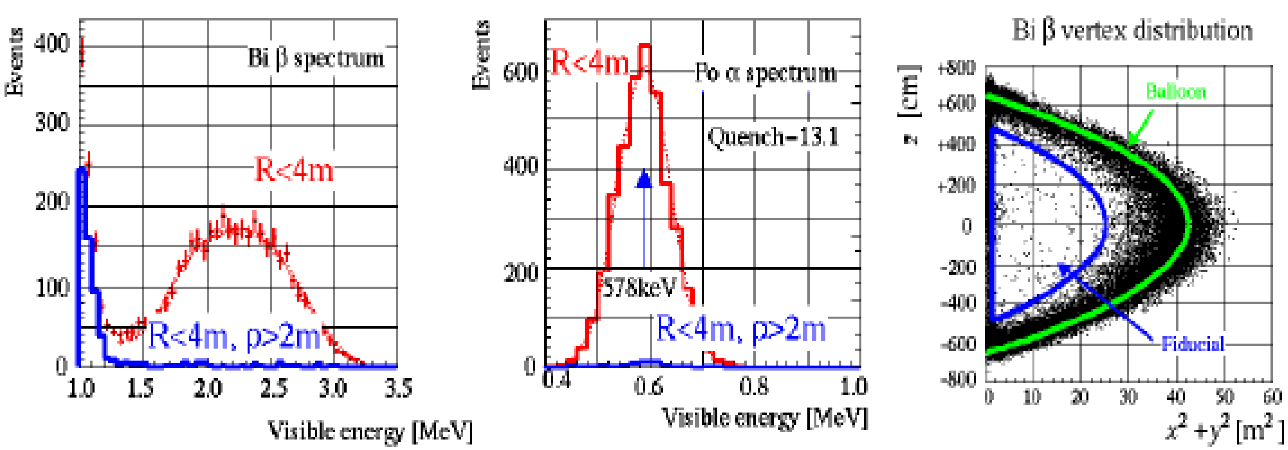

KamLAND future goal
counts/25keV
Energy [keV]
All
All ν (SSM)
7Be ν(SSM)
14C
11C
210Pb
39Ar, 85Kr
KamLAND (expected 3y, R<4m)
assume equilibrium
LMA (global analysis:φ/φSSM=0.64)
events/keV
7Be ν
SSM
99%C.L.
other/all [%]
Energy [keV]
Arb.
85Kr
13N ν
7Be ν
15O ν
Energy [keV]
KamLAND expected (5y, fiducial R<4m)
result from L→∞ limit
SSM
LMA
counts [350-750keV]
Extrapolate L→∞ to estimate BG
SUN
L; distance from Sun to Earth
ε=1.7%

Impurities in LS

(^{238}U: 3.5×10^{-18}g/g, ^{232}Th: 5.2×10^{-17}g/g)

	^{238}U	^{232}Th
decay mode	^{214}Bi $\xrightarrow{\beta}$ ^{214}Po $\xrightarrow{\alpha}$ ^{210}Pb Q=3.3MeV, $T_{1/2}$=164μs, Q=7.8MeV	^{212}Bi $\xrightarrow{\beta(64\%)}$ ^{212}Po $\xrightarrow{\alpha}$ ^{208}Pb Q=2.3MeV, $T_{1/2}$=0.3μs, Q=9.0MeV
Fiducial	R < 4m, ρ > 2m	R < 4m, ρ > 2m
$\Delta T(\Delta L \leq 1\text{m})$	5 - 1,000μs	0.4 - 1.0μs
prompt E_β	1.3MeV $\leq$	1.0 - 2.0MeV
delayed E_α	0.3 - 1.0MeV	0.3 - 1.0MeV

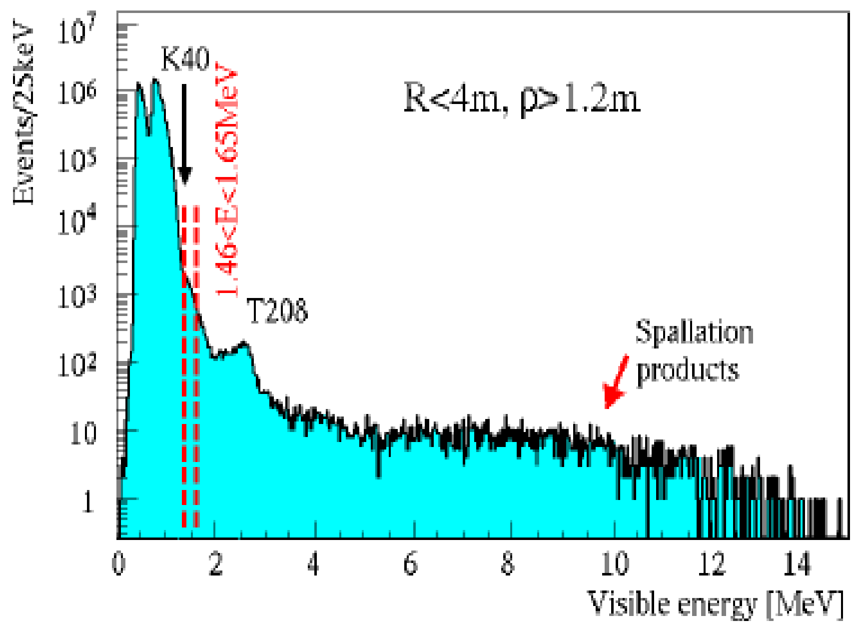
^{214}Bi-^{214}Po coincidence



Impurities in LS

(^{40}K: $< 2.7 \times 10^{-16}$g/g, ^{210}Pb: $\sim 1 \times 10^{-20}$g/g)

	^{40}K	^{210}Pb
decay mode	^{40}K $\xrightarrow{EC}$ ^{40}Ar* $\xrightarrow{\gamma\ 1.46\text{MeV}}$ ^{40}Ar Q=2.3MeV, 10.7%	^{210}Pb ($T_{1/2}$=22.3y) $\xrightarrow{\beta,\ Q=63.5\text{keV}}$ ^{210}Bi ($T_{1/2}$=5.0d) $\xrightarrow{\beta,\ Q=1.2\text{MeV}}$ ^{210}Po ($T_{1/2}$=138d) $\xrightarrow{\alpha,\ Q=5.3\text{MeV}}$ ^{206}Pb (Stable)
Fiducial	$R < 4.0$m, $\rho > 1.2$m	$R < 4.0$m, $\rho > 1.2$m
Energy cut	1.46 - 1.65MeV	0.9 - 1.3MeV



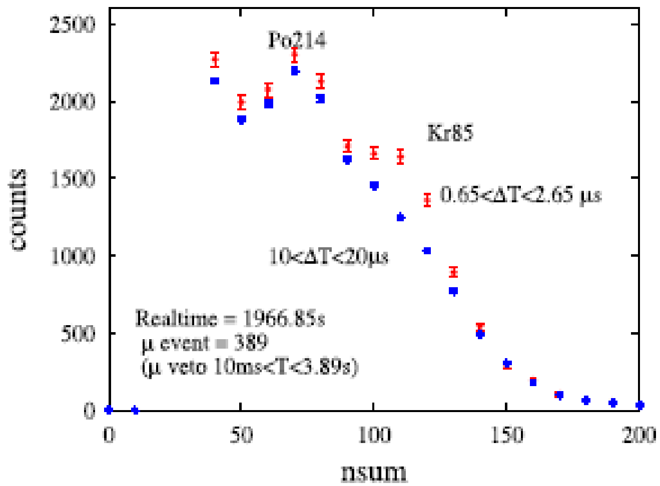
Impurities in LS (^{85}Kr: 0.7Bq/m^3)

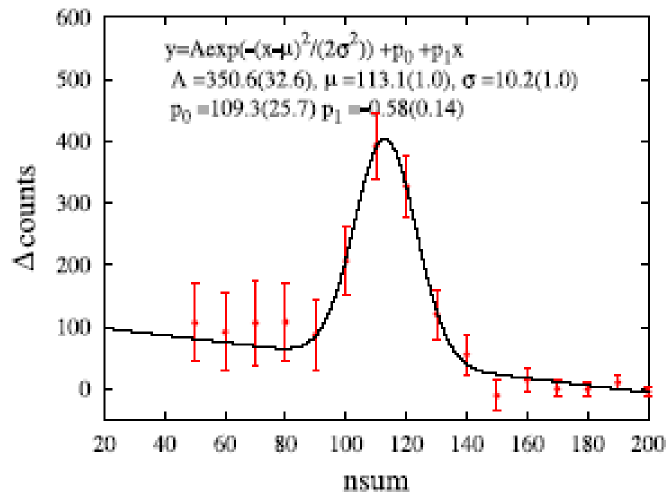
^{85}Kr $\xrightarrow{\beta\ (173\text{keV})}$ ^{85}Rb* $\xrightarrow{\gamma\ (514\text{keV})}$ ^{85}Rb

Q=687keV 0.434% $T_{1/2}$=1.0μs

$T_{1/2}$=10.8y

prompt $78 \leq E_\beta \leq 162$keV[*], $0.65 \leq \Delta T \leq 2.65\mu s$ in whole balloon





[*] Analyzed with the sum of hit PMTs

- How reduce the impurity?

Background	now	goal
^{238}U(by Bi-Po)	3.5×10^{-18}g/g	**OK!!**
^{238}U(by ^{234}Pa)	$\mathbf{O}(10^{-15}$g/g)(Max.)	10^{-18}g/g
^{232}Th (by Bi-Po)	5.2×10^{-17}g/g	**OK!!**
^{40}K	2.7×10^{-16}g/g(max.)	$< 10^{-18}$g/g
^{210}Pb	$\sim 10^{-20}$g/g	5×10^{-25}g/g $\sim 1\mu$Bq/m^3
^{85}Kr, ^{39}Ar	^{85}Kr =0.7Bq/m^3	1μBq/m^3
^{222}Rn (after purification)	^{238}U $= 3.5 \times 10^{-18}$g/g $= 3.3 \times 10^{-8}$Bq/m^3	**OK!!** (1μBq/m^3)
^{222}Rn (during purification)		1mBq/m^3 ^{210}Pb $= 0.5\mu$Bq/m^3 after decay

For ^{210}Pb & ^{40}K : water extraction update
distillation

For ^{85}Kr & ^{39}Ar : nitrogen purge system update

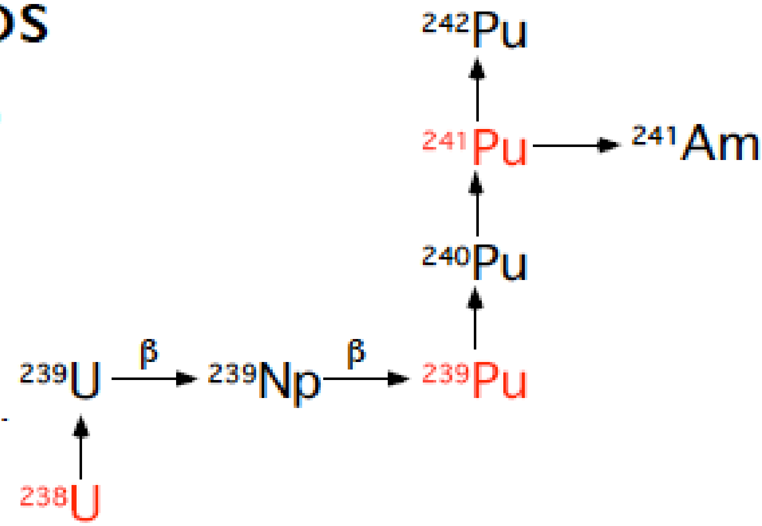
For Rn protection : acryl cover for system
main guard + fresh air blow

We start R&D for detection ^{7}Be solar neutrinos on KamLAND !

Other study

Reactor Neutrinos

- Only 4 fissile nuclei (U235,U238,Pu239,Pu241) are important. The others contribute only 0.1% level.
- Fission fragments repeat beta-decay and emit anti-electron-neutrinos (electron-neutrino contamination is ~10ppm level above 1.8 MeV).
- Fission rate is strongly correlated with thermal power output (measurable at much better than 2% accuracy).



$$^{235}U : 201.7 \pm 0.6,\ ^{238}U : 205.0 \pm 0.9,\ ^{239}Pu : 210.0 \pm 0.9,\ ^{241}Pu : 212.4 \pm 1.0 MeV$$

M.F.James, J.Nucl.Energy 23(1969)517

- One fission causes ~6 neutrino emission in average. Thus, neutrino intensity is $\sim 2 \times 10^{20}\, \bar{\nu}_e / GW_{th} / sec$.
- Fission spectra reach equilibrium within a day above ~2 MeV. Except only a few cases such as;

$$^{106}Ru \xrightarrow{T_{1/2}=372 days} Rh \xrightarrow[E_{max}=3.541 MeV]{} Pd$$

$$^{144}Ce \xrightarrow{T_{1/2}=285 days} Pr \xrightarrow[E_{max}=2.996 MeV]{} Nd$$

V.I.Kopeikin et al., Physics of Atomic Nuclei, 64-5(2001)849

Neutrino Spectra

U235, Pu239, Pu241

Beta spectra were measured with a spectrometer irradiating thermal neutrons at ILL.

Fitting with 30 hypothetical beta branches and convert each branches to neutrino spectrum.

K.Schreckenbach et al., Phys.Lett.B160(1985)325
A.A.Hahn et al., Phys.Lett.B218(1989)365

U238

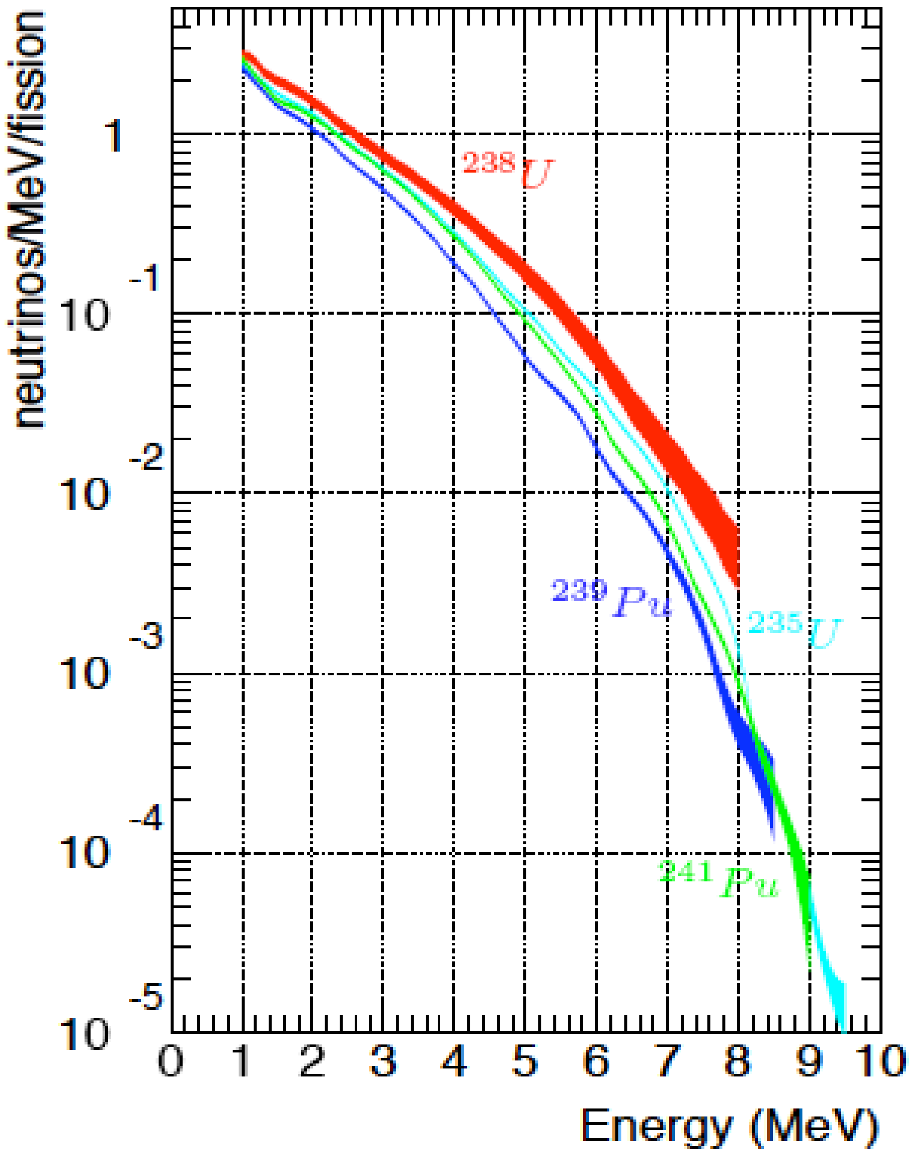
No fission with thermal neutrons

Theoretical calculation tracing 744 unstable fission products

Error is larger, but small contribution ~8%

P.Vogel et al., Phys. Rev. C24(1981)1543

Knowing time evolution of fuel composition, error from spectra calculation is ~2.3%.

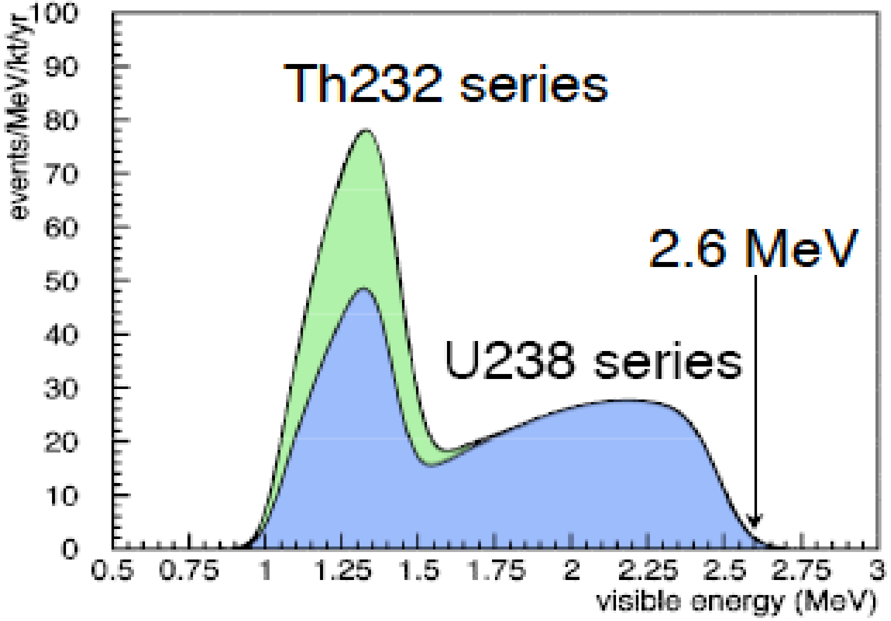


Background

(in 162 ton-yr sample)

	0.9 MeV	2.6 MeV
Total B.G.	2.9 ± 1.1	1 ± 1

Another important B.G.



A guess (16 TW)

~9 events (0.9 MeV)

~0.04 events (2.6 MeV)

$\bar{\nu}_e$ from the earth has never been observed, before.

If observed, it opens a new field of "Neutrino Geo-physics."

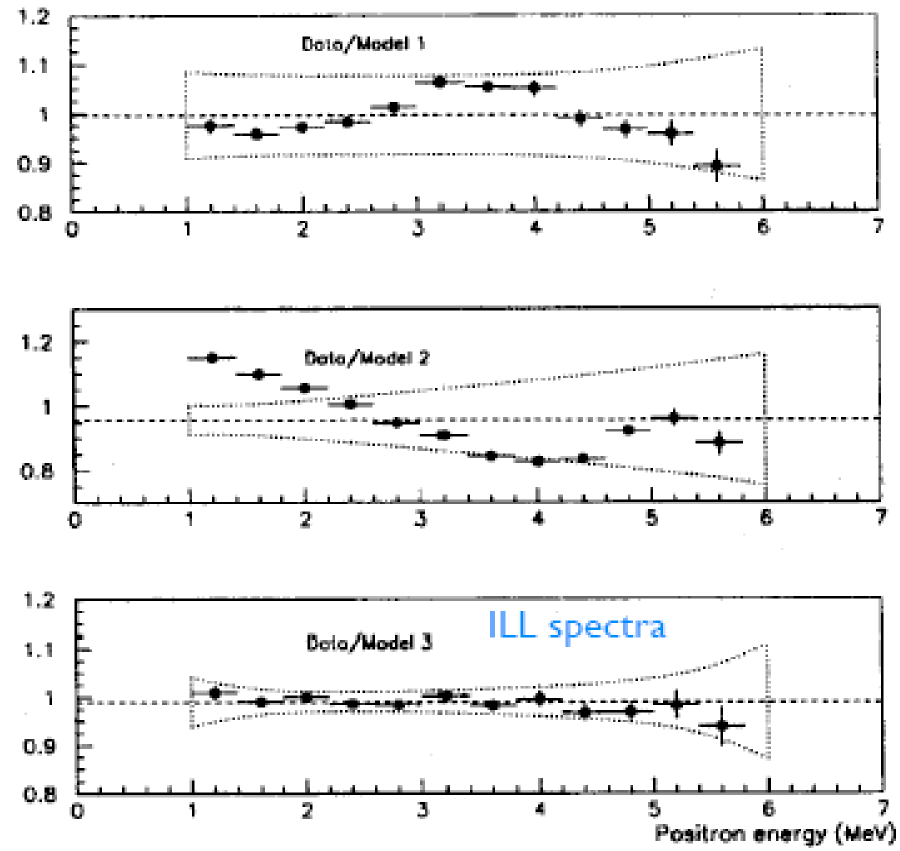
Validity of Spectra & Cross-section Calculation

Bugey measured an overall reaction rate with 1.4% accuracy and is in good agreement with the calculation.

Y.Declais et al., Phys.Lett.B338(1994)383

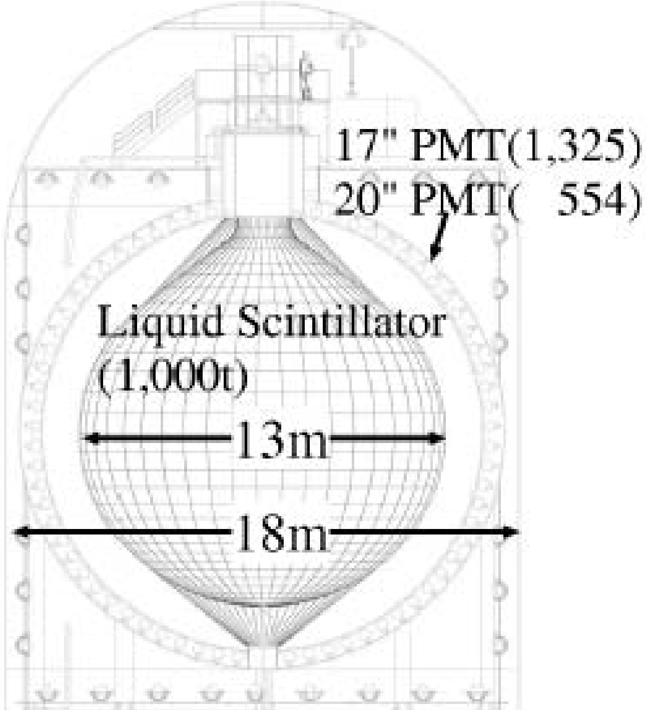
$$\sigma_f = 5.750 \times 10^{-43} cm^2/fission \pm 1.4\%$$
$$\sigma_{V-A} = 5.824 \times 10^{-43} cm^2/fission \pm 2.7\%$$

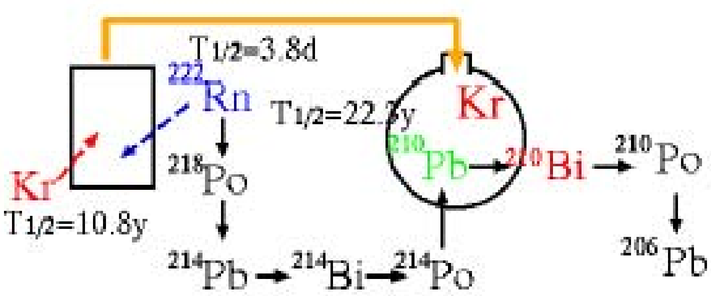
$$\sigma_f/\sigma_{V-A} = 0.987 \pm 1.4\% \pm 2.7\%$$



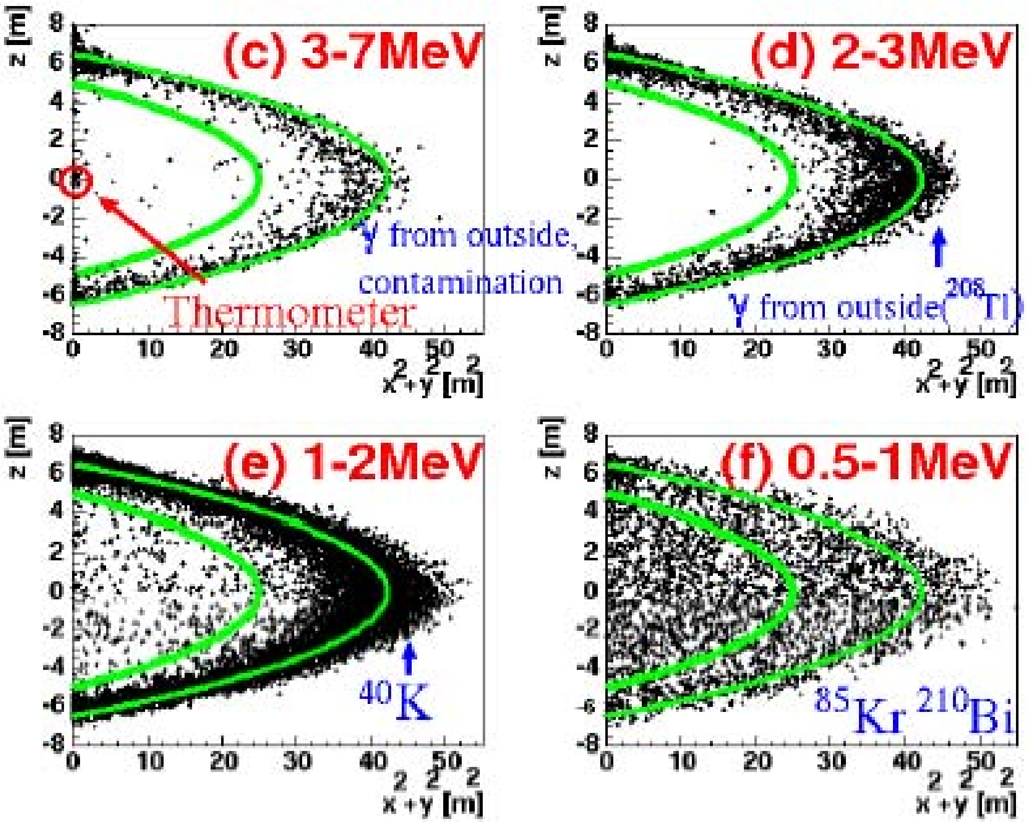
Bugey-3 tested models of neutrino spectra and the ILL spectra shows excellent agreement. B.Achkar et al., Phys.Lett.B374(1996)243

A few % precision is achievable without near detector for flux normalization.





(2ms veto after muon)



Rn protection

SAMMARY

Rn activity in the mine = 2×10^3 Bq/m^3

↓

Mine guard + Fresh Air Blow
Rn activity = 30-50 Bq/m^3

Cost = 28,000,000 [Yen] + 35,000,000(?)[Yen]

Water proof
(Water springing from the rock contains a lot of Rn. (2×10^4 Bq/m^3))

Replace new packings

Cost = 1,400[Yen/one-piece (40A)]
+ Labors cost 2,000[Yen/one-piece]
x ~350 [piece] (LS only)

Acryl cover
reduction < 1/100 (~1/200)

Cost = 40,000-60,000[Yen/piece]
+ Labors cost 5,000 [Yen/piece]
x 200 [peices]

Stainless + Epoxy resin
reduction =1/100 or more
(to be tested)

Cost < 100,000 [Yen]
+ Labors cost (?)[Yen]

Leakage
from New packings
2×10^{-5} [Rn/s]

number of fittings =1000
leak = 10 ml/s
Rn activity = 40 Bq/m^3

Leakage from valves
4×10^{-4} [Rn/s]

number of valves =200
leak = 10 ml/s
Rn activity = 40 Bq/m^3
reduction = 1/100

Note !! (See Japanese Industrial Standard)
Leak rate of valves= 0.01ml/s x ϕ (@0.6MPa)
= 1.7 x10 ml/s x ϕ (@1atm)

Rn might sneak into LS/MO from valves.
We have to check ALL valves.

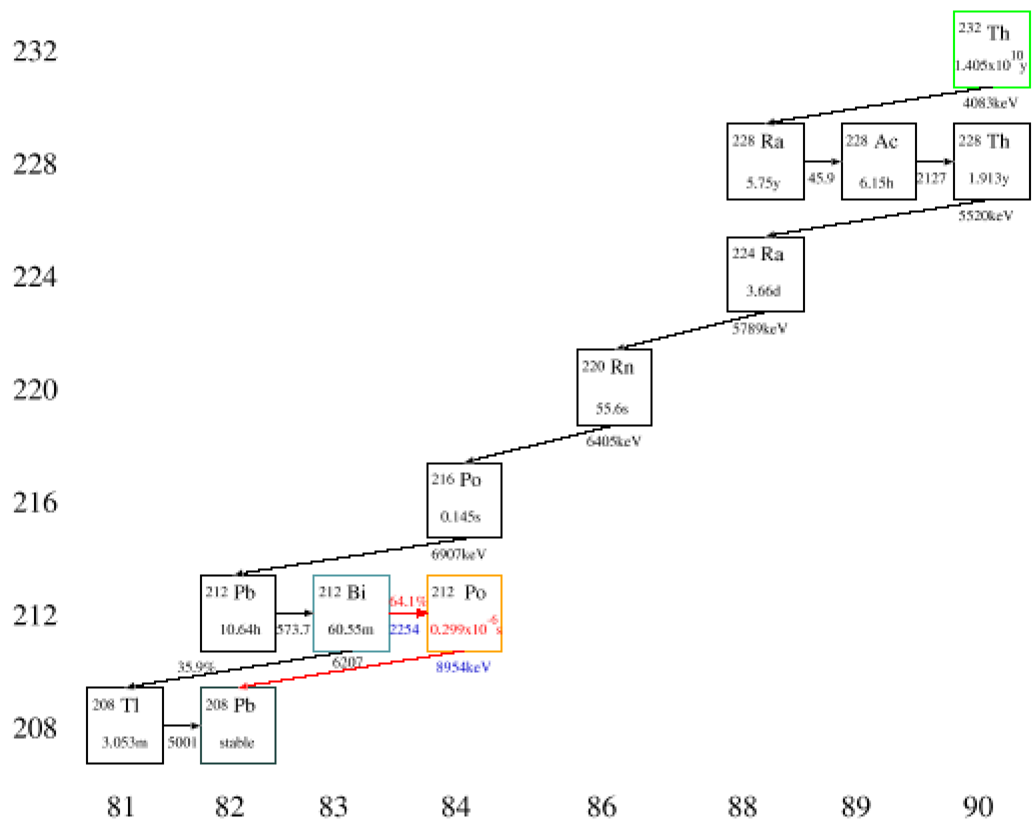
Leakage from fittings
8×10^{-4} [Rn/s]

number of fittings =100
leak = 10 ml/s
Rn activity = 40 Bq/m
reduction = 1/100

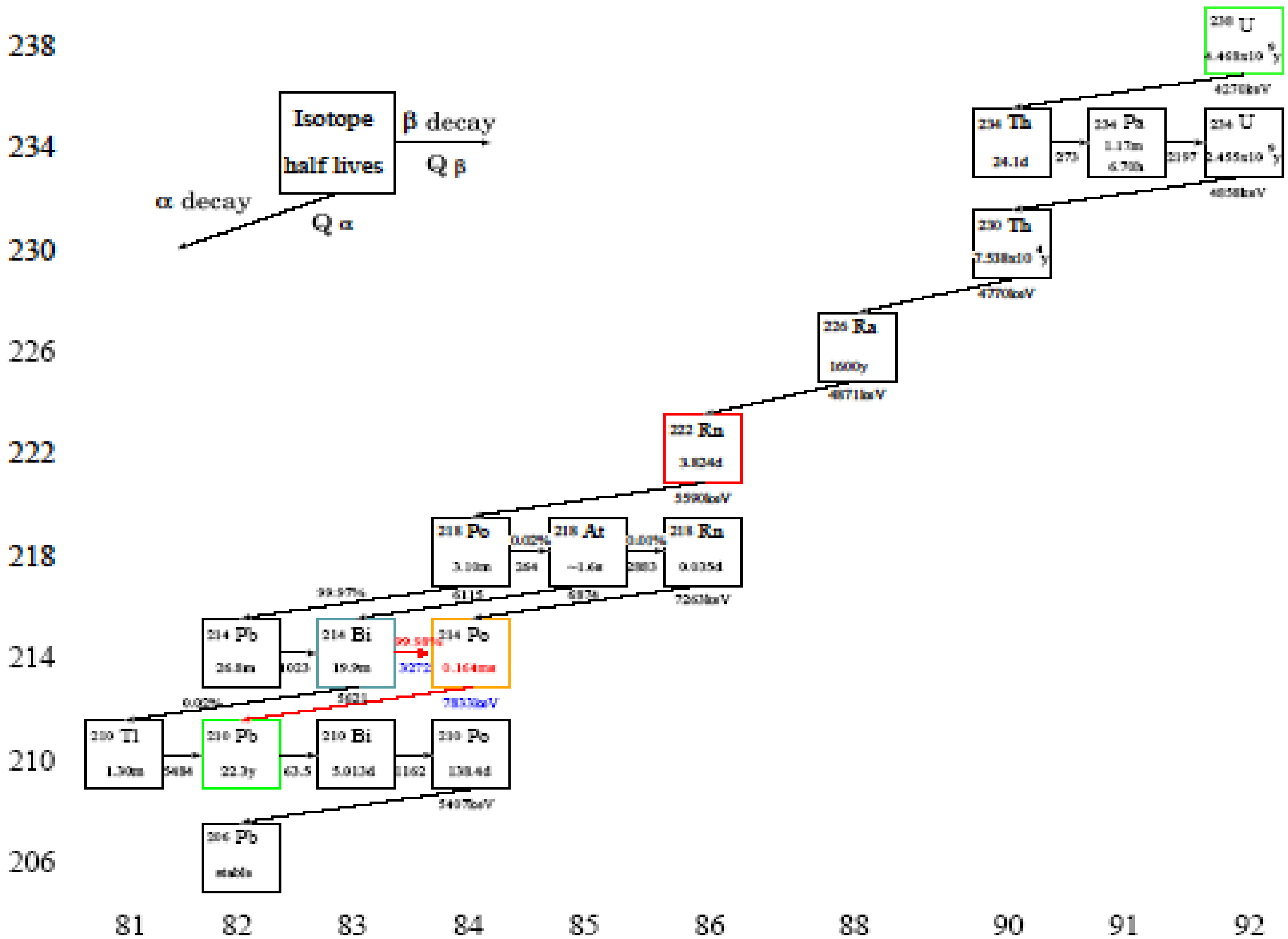
Cf; Our Goal=100-150Rn/m^3
=6-8x10^{-2} Rn/s (Q=2m^3/h)

revised 26 Feb., 2003

Th-series


232
228
224
220
216
212
208
232 Th
1.405x10 10 y
4083keV
228 Ra
5.75y
45.9
228 Ac
6.15h
2127
228 Th
1.913y
5520keV
224 Ra
3.66d
5789keV
220 Rn
55.6s
6405keV
216 Po
0.145s
6907keV
212 Pb
10.64h
573.7
212 Bi
60.55m
64.1%
2254
212 Po
0.299x10 -6 s
35.9%
6207
8954keV
208 Tl
3.053m
5001
208 Pb
stable
81
82
83
84
86
88
89
90

U-series



238
234
230
226
222
218
214
210
206
Isotope
half lives
β decay
Q β
α decay
Q α
238 U
4.468x10 9 y
4270keV
234 Th
24.1d
273
234 Pa
1.17m
6.70h
2197
234 U
2.455x10 5 y
4858keV
230 Th
7.538x10 4 y
4770keV
226 Ra
1600y
4871keV
222 Rn
3.824d
5590keV
218 Po
3.10m
0.02%
264
218 At
~1.6s
0.01%
2883
218 Rn
0.035s
99.97%
6115
6874
7263keV
214 Pb
26.8m
1023
214 Bi
19.9m
99.98%
3272
214 Po
0.164ms
0.02%
5621
7833keV
210 Tl
1.30m
5484
210 Pb
22.3y
63.5
210 Bi
5.013d
1162
210 Po
138.4d
5407keV
206 Pb
stable
81
82
83
84
85
86
88
90
91
92