Rapporteur talk on High Energy Phenomena

HE 2.1-5 HE 3.2-4

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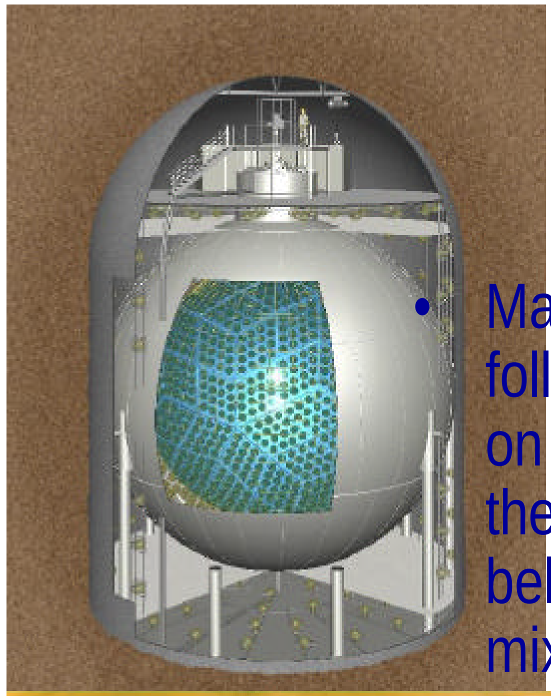
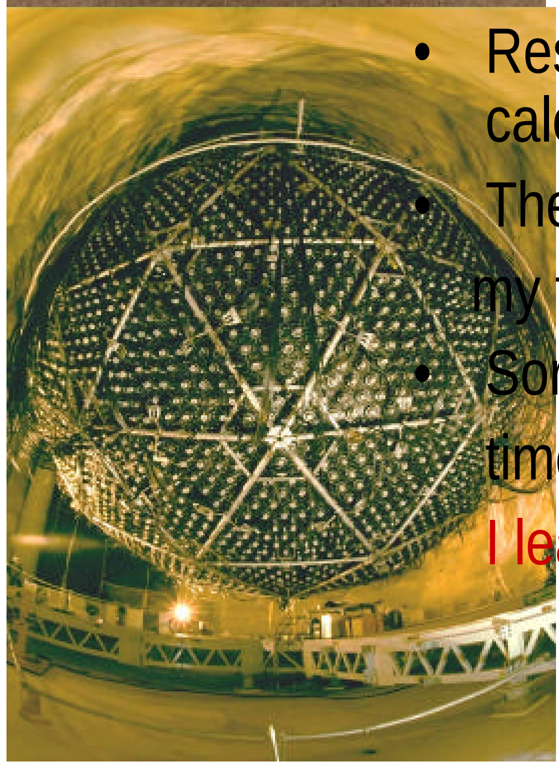
Bari University and INFN

139 papers

Muons and Neutrinos	Interactions, Particle Physics Aspects, Astroparticle Physics and Cosmology
HE 2.1 Muon experiments (23)	HE 3.2 Proton Decay and new phenomena: experiments and theory (3)
HE 2.2 Solar, atmospheric and related neutrino experiments (16)	HE 3.3 Dark Matter, Astroparticle Physics and Cosmology (25)
HE 2.3 Neutrino Telescopes (26)	HE 3.4 Instrumentation and New Projects(7)
HE 2.4 Theory and calculations (31)	
HE 2.5 Instrumentation and New Projects (8)	

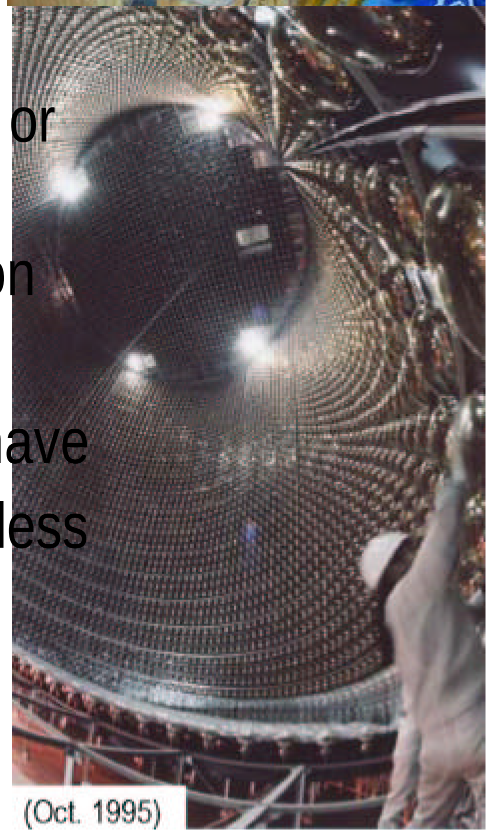
Many thanks to F. Cafagna, I. Sokalski, G. Battistoni, E. Lisi, F. Ronga, P. Lipari, M. Honda, A. Habig





Guidelines

- Many different sessions: this talk will not follow an order depending on Sessions but on subjects and logic connection between them (which often impliesthat works belonging to different sessions will be mixed!)
- Results comparing between experiments or calculations (when possible)
- The order 'unfortunately' often depends on my feelings
- Sorry for all of those works that I do not have time to mention, but from which nevertheless I learnt a lot...



Outline

- **Neutrino oscillations:**

  - **atmospheric n's:** SK updated result $\Delta m^2 = 2 \cdot 10^{-3}$ eV^2, maximal mixing (HE 2.2)
  - **the knowledge of the beam:** atmospheric ν flux calculations (HE 2.4) and μ flux measurements (HE 2.1)
  - **solar n_e oscillations: after the 'Year of n Physics' 2002**

  (19 Apr: DIRECT EVIDENCE for ν flavor transformation from NC in SNO

  8 Oct: Nobel prize to Prof. R. Davis and Prof. M. Koshiba

  4 Dec: K2K LBL observes reduction of ν_μ flux together with distortion of E spectrum

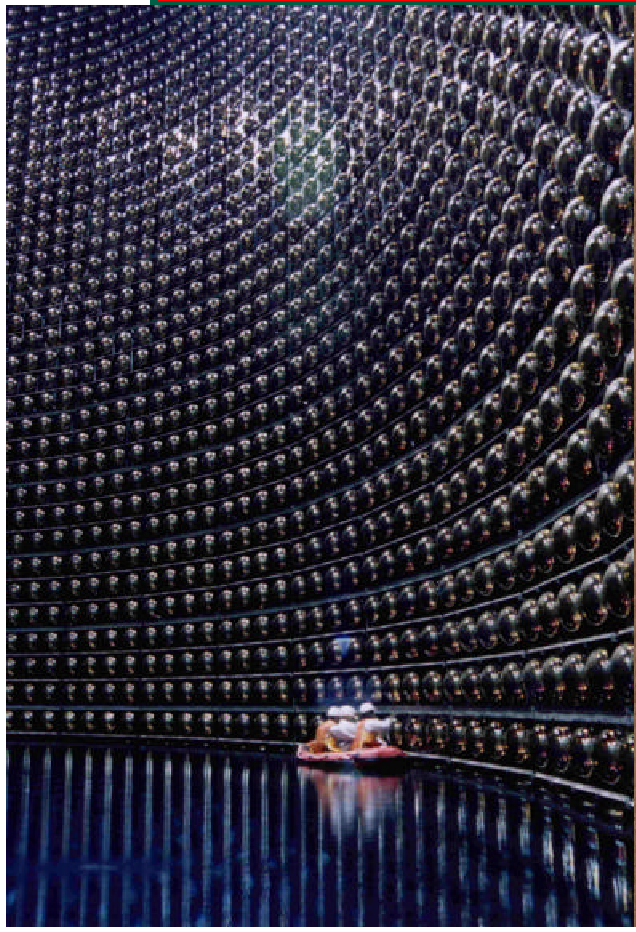
  6 Dec: KamLAND reactor LBL: viable solution to solar ν problem LMA)

  no big news (we have to wait for SNO salt phase results): LMA is well established (Kamland, SK, SNO). **New:** SNO and SK searches for anti-ν_e from the Sun: addresses the <u>fundamental question if ν is Majorana or Dirac</u>

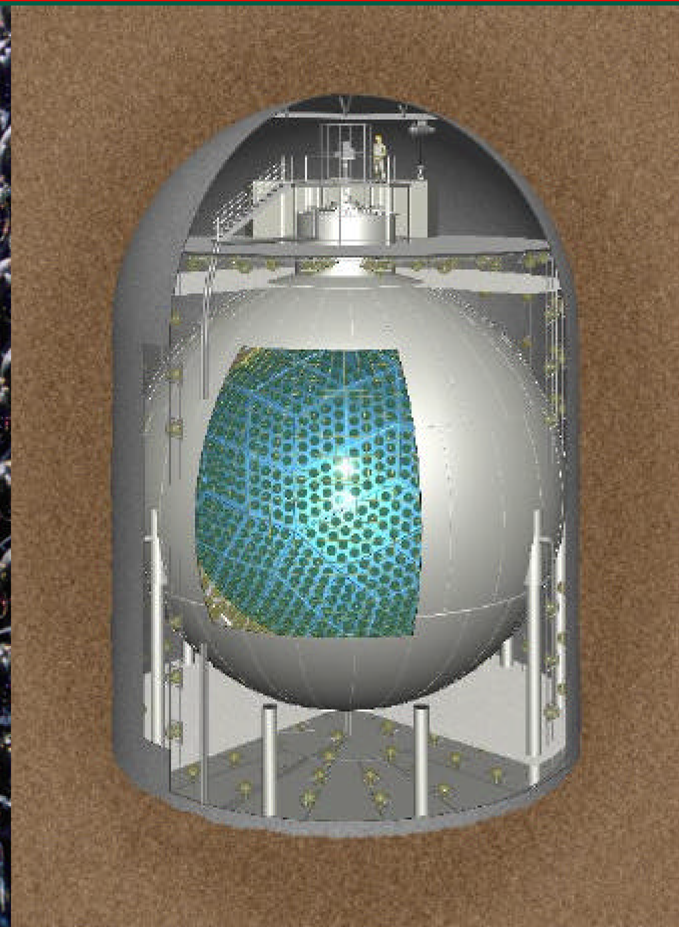
- **Neutrino astrophysics:**
  - **SN neutrinos** **(HE 2.2)**
  - **Neutrino Telescopes** **(HE 2.3): brilliant AMANDA results, Lake Baikal, RICE, ANTARES, NESTOR, ICECUBE**

- **Dark matter (HE 3.4) , New detectors**

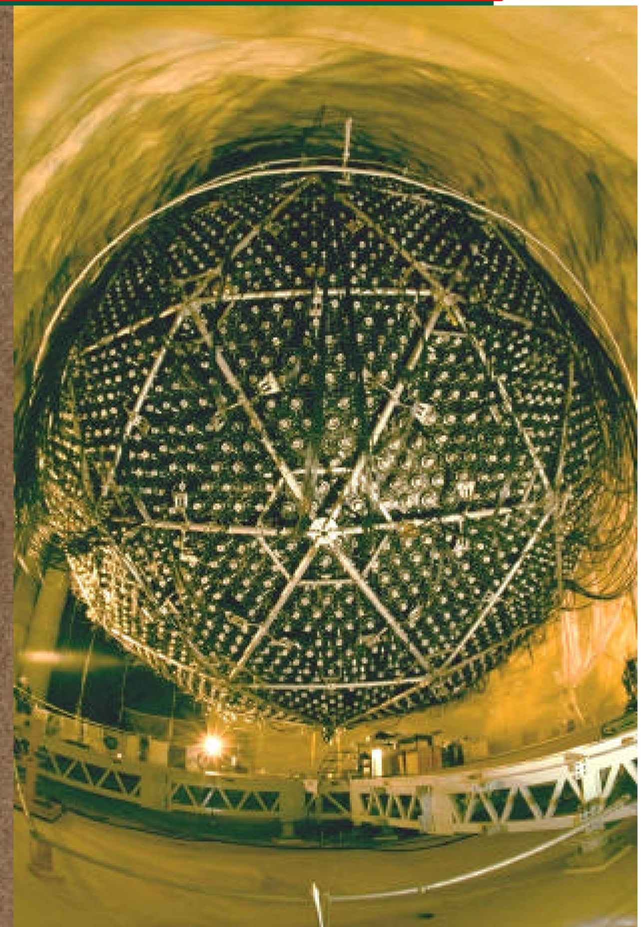
HE 2.2 Solar & atmospheric neutrinos



Super-Kamiokande 7 oral



Kamland 1 oral



Sudbury Neutrino Observatory
1 oral+1 poster

LVD 1 oral + 1 poster

Koshiba & Suzuki highlights

Super-Kamiokande

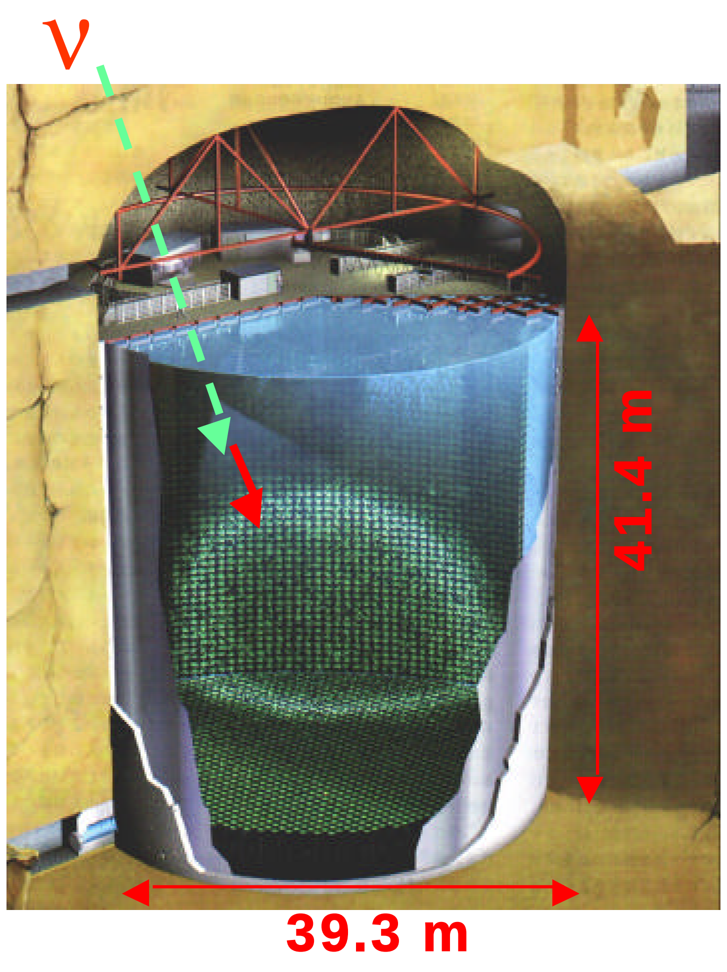
Japan USA

50,000 ultra-pure water ton Cherenkov detector (22,500 ton fiducial volume)
Run time: 1996-2001 (reconstruction finished Dec 2002; Jan, 2003 K2K beam after Nov 2001 ~50% of PMT destruction)

This conference: no new data but atm n reanalysis of 1489 d SK-I data

Atm n results demonstrate $\nu_\mu \to \nu_\tau$ even if oscillatory pattern still not measured, SK measures different topologies in different energy ranges

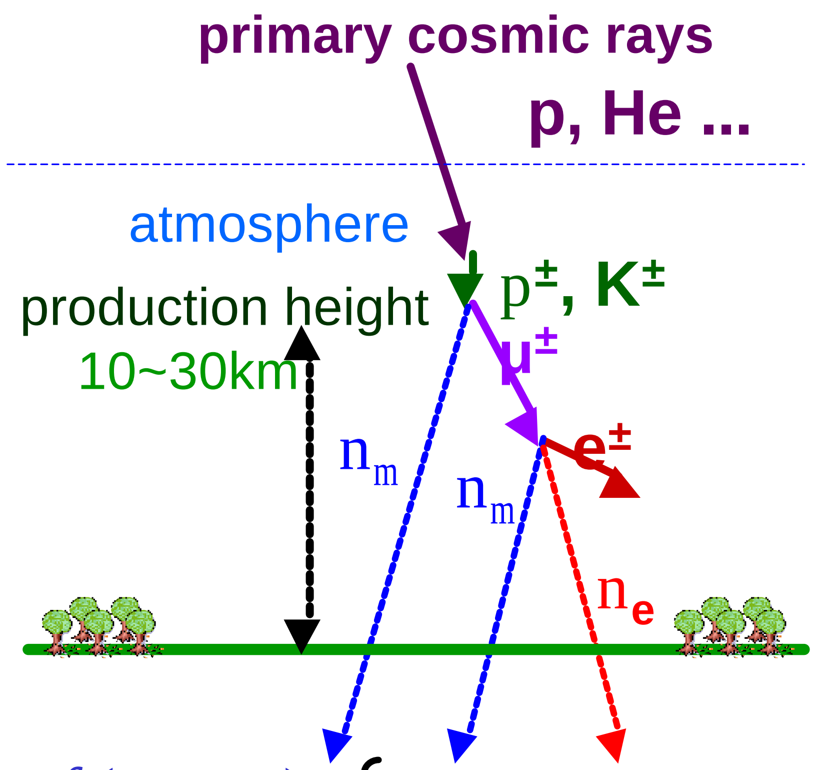
- **Ring selection, Particle ID, multi-ring fits, Up-m reduction automated**
- **New 3D atm n flux (HKKM01)**
- **n interaction generator improved in view** K2K near detector ν interaction data



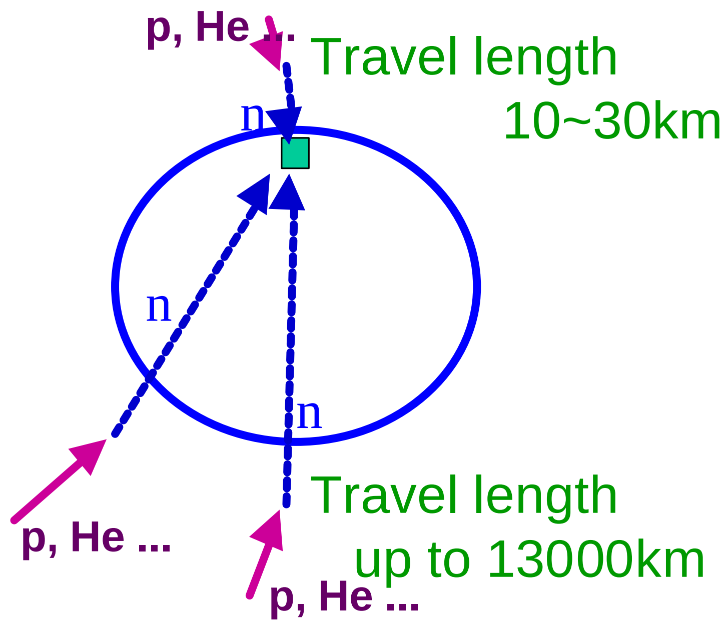
The flavor ratio and the asymmetry

Results based on quantities which have few percent dependence on theoretical uncertainties: Up-down Asymmetry Flavor ratio Angular distribution

Do not depend substantially on absolute normalization of fluxes but **accurate** determination of parameters require also **good knowledge** of the fluxes



$$\frac{f\,(n_m + \bar{n}_m)}{f\,(n_e + \bar{n}_e)} \begin{cases} \sim 2(\text{for } E_\nu < 1\text{GeV}) \\ > 2(\text{for } E_\nu > 1\text{GeV}) \end{cases}$$



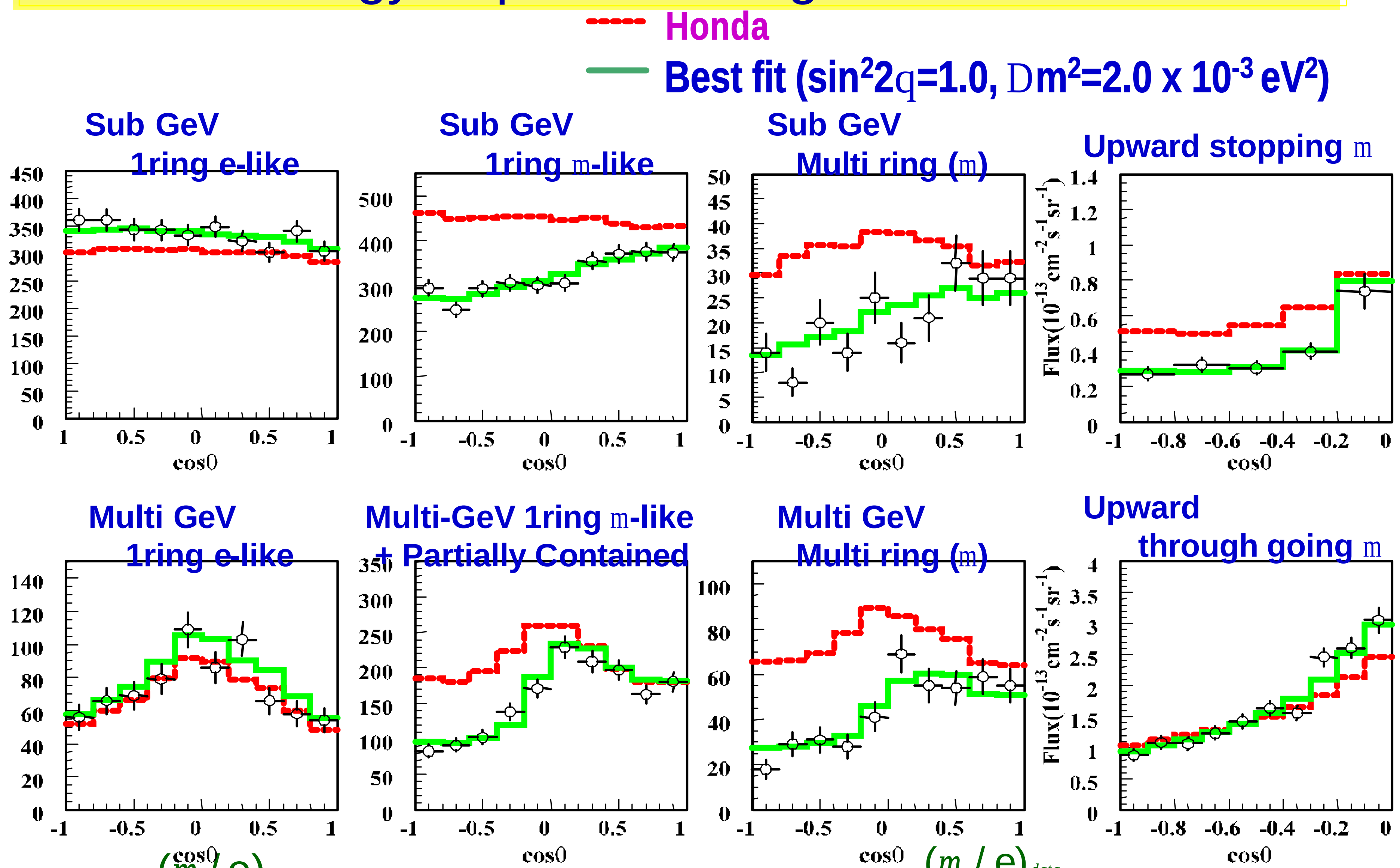
For E_ν > a few GeV,

(Up-going / down-going) ~ 1

Uncertainty of up/down ratio

< a few %

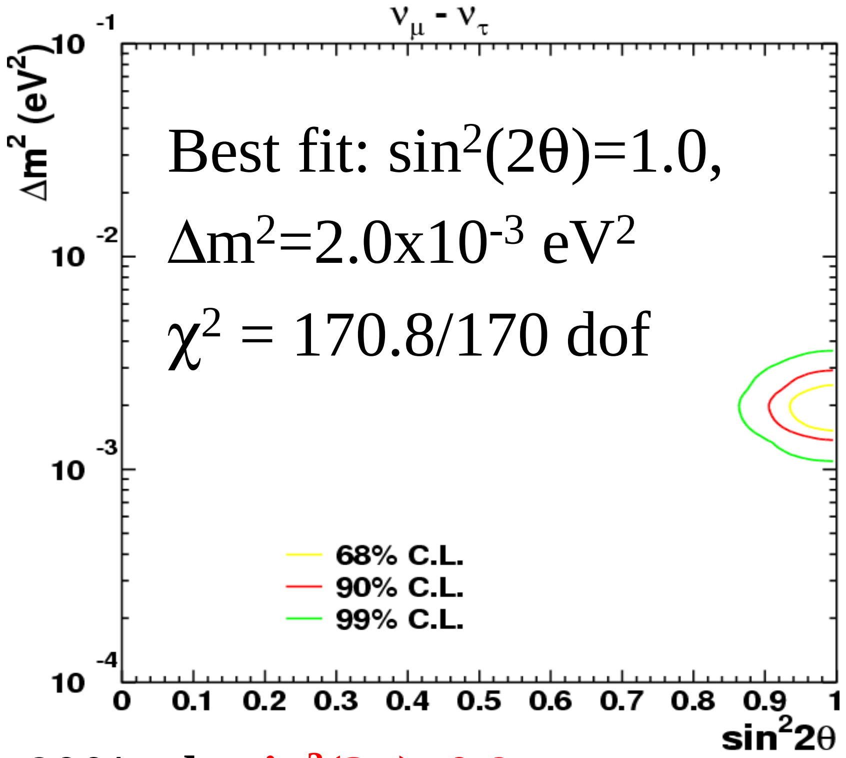
The 'energy-dependent' angular distributions



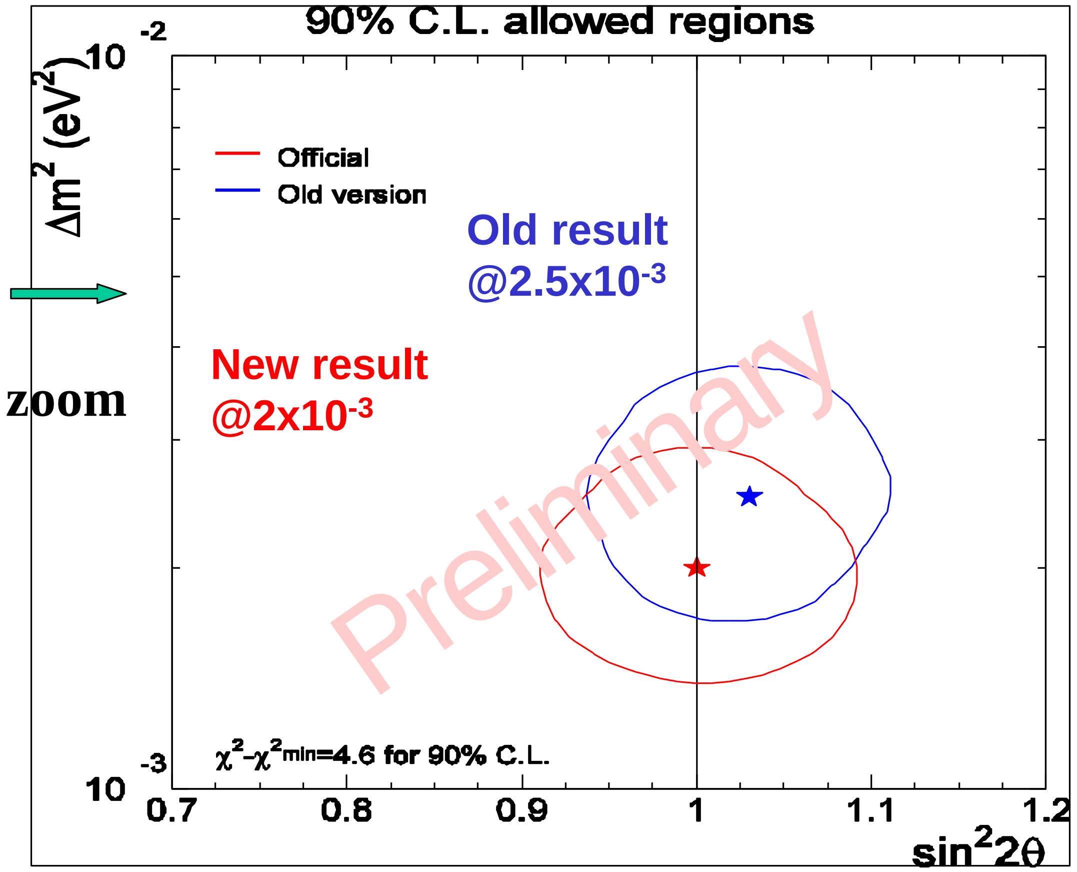
Sub-GeV $\dfrac{(m/e)_{data}}{(m/e)_{MC}} = 0.649 \pm 0.016 \pm 0.051$ Multi GeV+PC $\dfrac{(m/e)_{data}}{(m/e)_{MC}} = 0.699\,^{+0.032}_{-0.030} \pm 0.08$

Observed $A_{\mu\text{-like}}$ 9.5σ from no-oscillation prediction!

$\nu_\mu \leftrightarrow \nu_\tau$ allowed region and oscillation channel



zoom



90% c.l.: $\sin^2(2q)>0.9$

$1.3 < Dm^2 < 3.0\text{x}10^{-3}$ eV^2

The non-observation of NC suppression (HE 2.2.9) disfavors the $\nu_\mu \rightarrow \nu_{sterile}$ scenario: systematic error on π^0 measurement from ~30% to 9% thanks to K2K

τ appearance on statistical basis (HE 2.2.11) 86 exp events $145 \pm 44_{stat} \pm^{11}_{16}\, sys$ (44% eff correction) 3 analysis

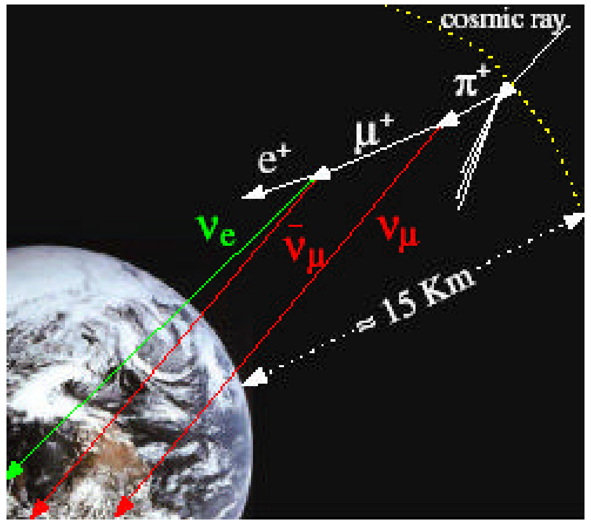
HE 2.4 Theory and Calculations

ATMOSPHERIC NEUTRINO PRODUCTION: high precision 3D calculations, refined geomagnetic cut-off treatment (also geomagnetic field in atmosphere), elevation models of the Earth, different atmospheric profiles, geometry of detector effects

HKKM (HE2.4.2): DPMJET3 FLUKA (1-P-270) 1st 3D, now up to 10 TeV CORSIKA (1-P-271): DPMJETII.5 (hadronic models based on theory driven approaches) BARTOL TARGET2.1 (1-P-272) (tuned on experimental data) Liu et al.: Kalinovsky et al, 89 (parametrized hadronic model)

Many comparison on hadronic models have been done on data and between different calculations.

M. Takita talk: R. Engel et al.(HE 2.1.5) FLUKA2002 introduced as optional model in CORSIKA. GHEISHA based models suspicious



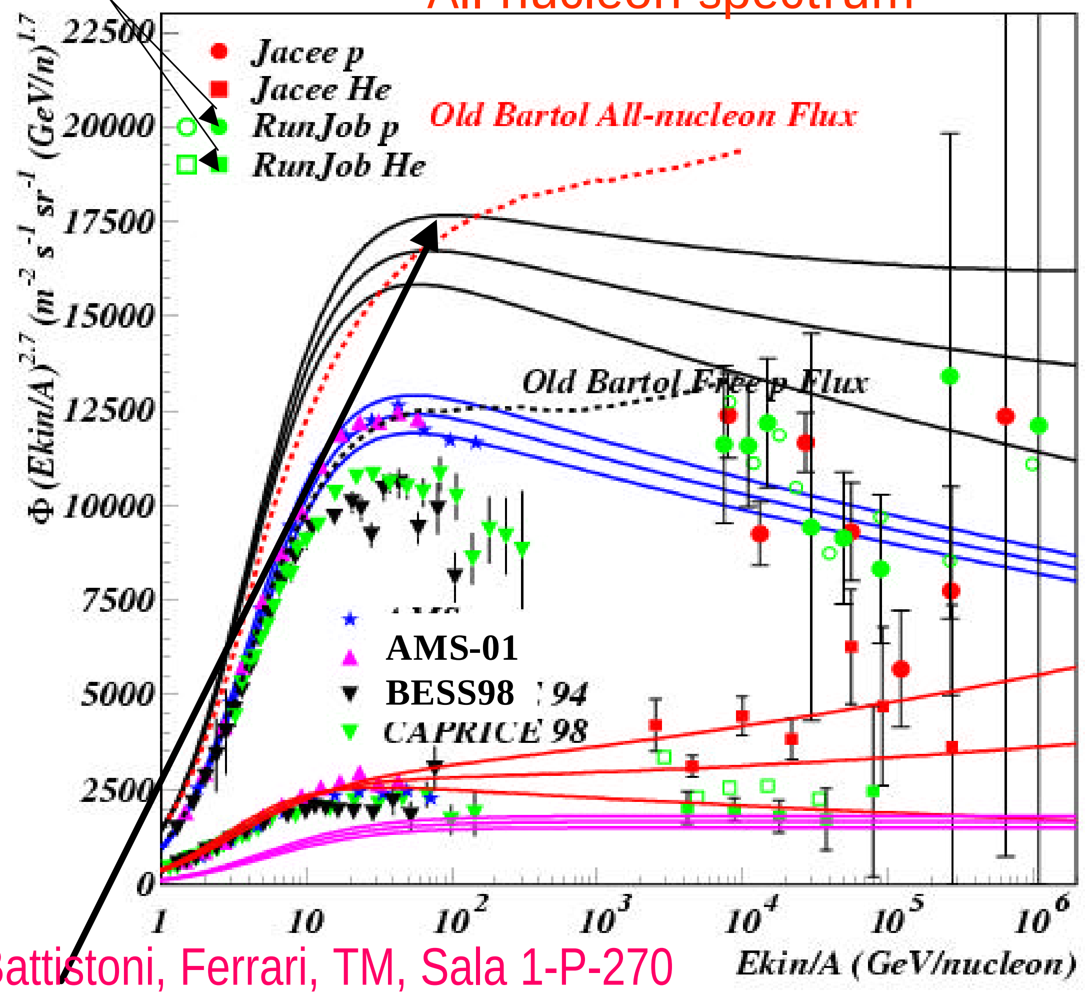
Many benchmarks against m data at ground level and in atmosphere

Neutrino data can say something ON PRIMARY CR?

The primary cosmic ray spectrum

Runjob OG

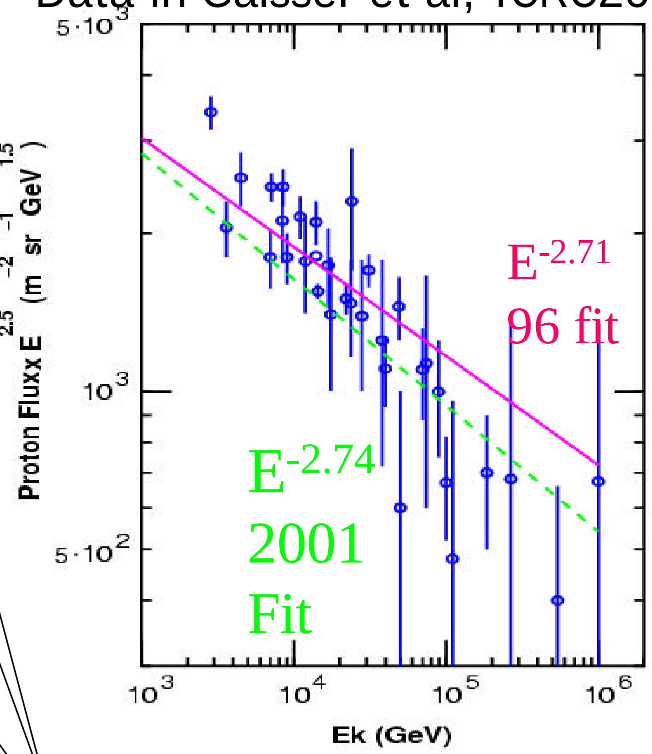
All nucleon spectrum



Battistoni, Ferrari, TM, Sala 1-P-270

M. Honda et al, HE 2.4.2

Data in Gaisser et al, ICRC2001



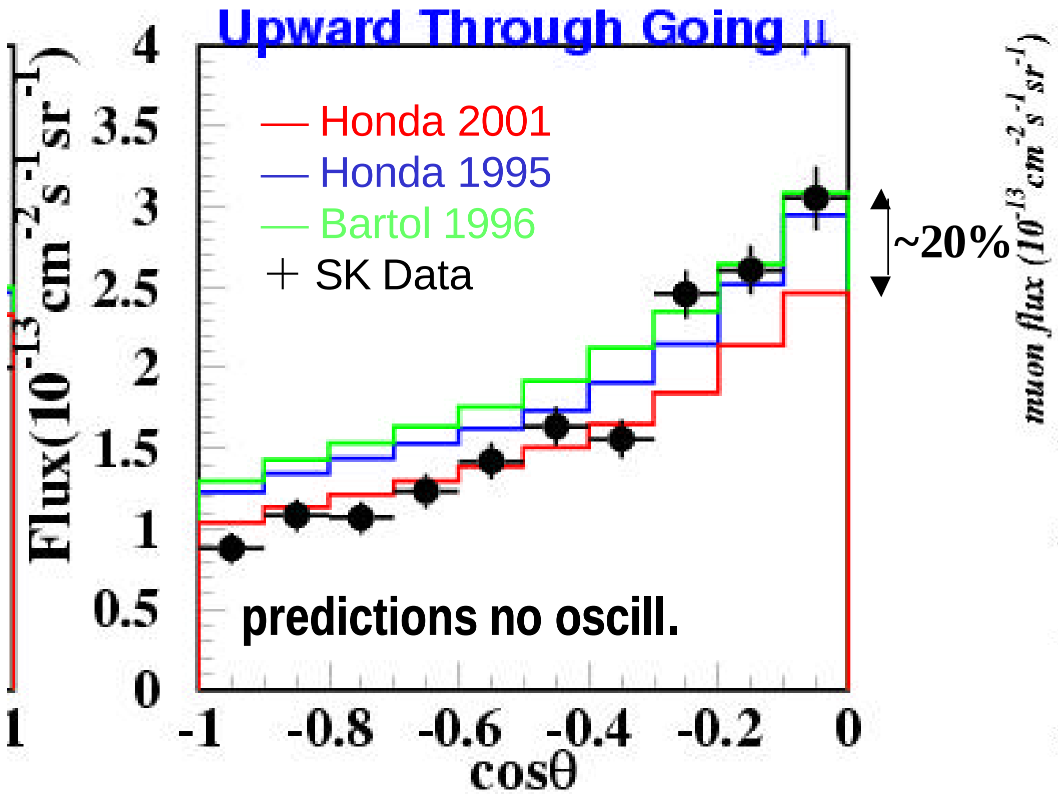
noticeable disagrement on He between RunJob and JACEE

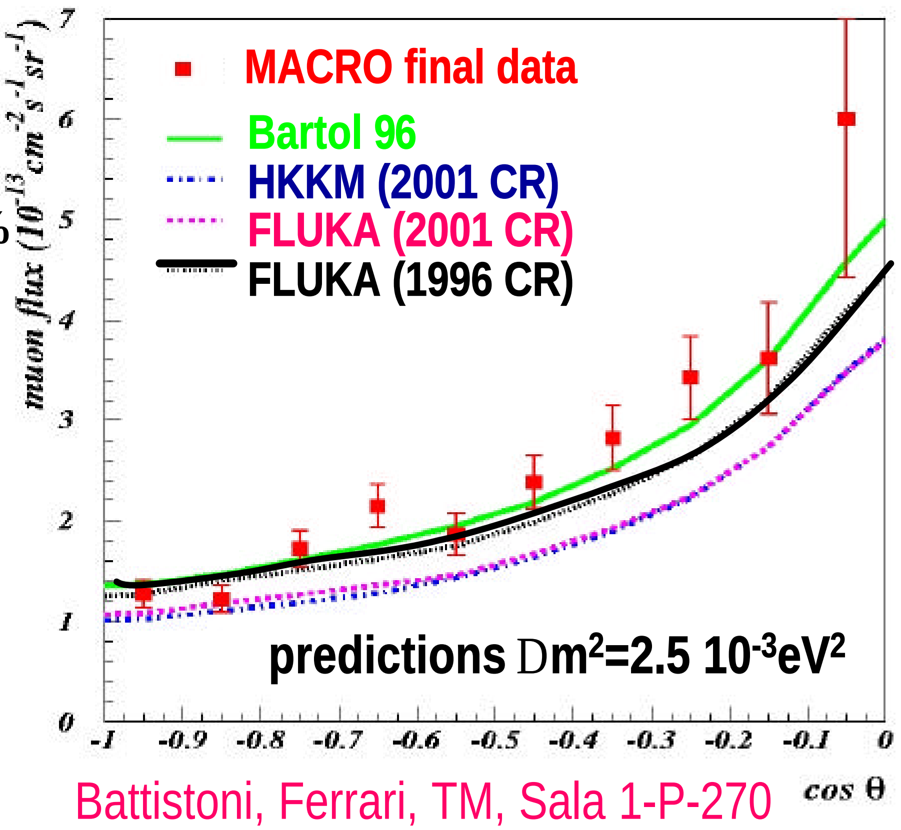
CR Fit 1996 (Bartol group) >> and harder than CR Fit ICRC01 (Gaisser et al.)

R. Battiston talk: Many new relevant results in OG

Some indication (ATIC, EAS-TOP-MACRO,...): CR flux could be harder at HE

The high energy region





Battistoni, Ferrari, TM, Sala 1-P-270

If primary flux form $E^{-2.74}$ to $E^{-2.7}$ >20% enhancement of n flux around 100 GeV

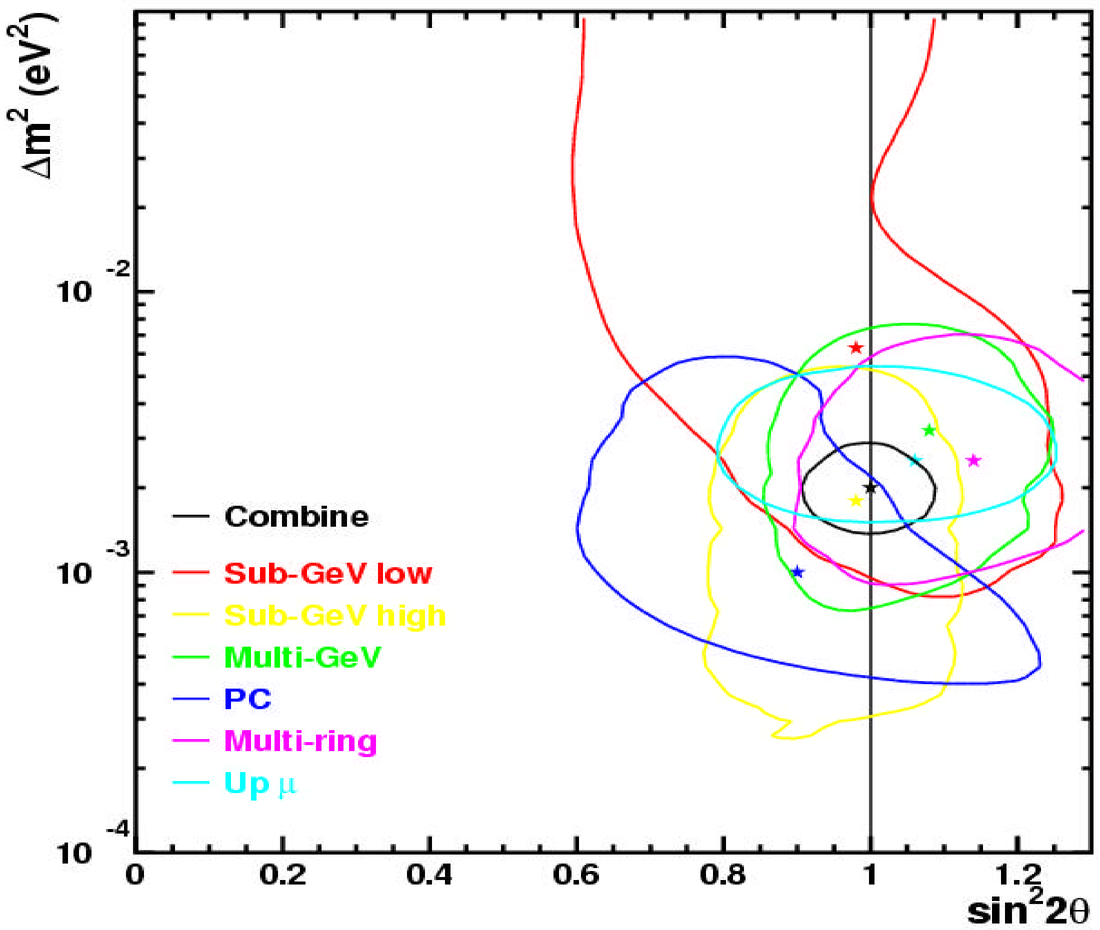
Upward-going through-going μ data $<E_\nu>$ ~ 100 GeV require larger normalization

The data are not well accounted for by the new fit (better the less steep 1996 fit)

SK fit more than 1 parameter on normalization and slope of the flux so it is hard to understand the preferred normalization (MACRO~20-25%)

Parameter knowledge

In a scenario in which atm ν oscillations are well established a better understanding of the CR flux is needed to estimate precisely Δm^2

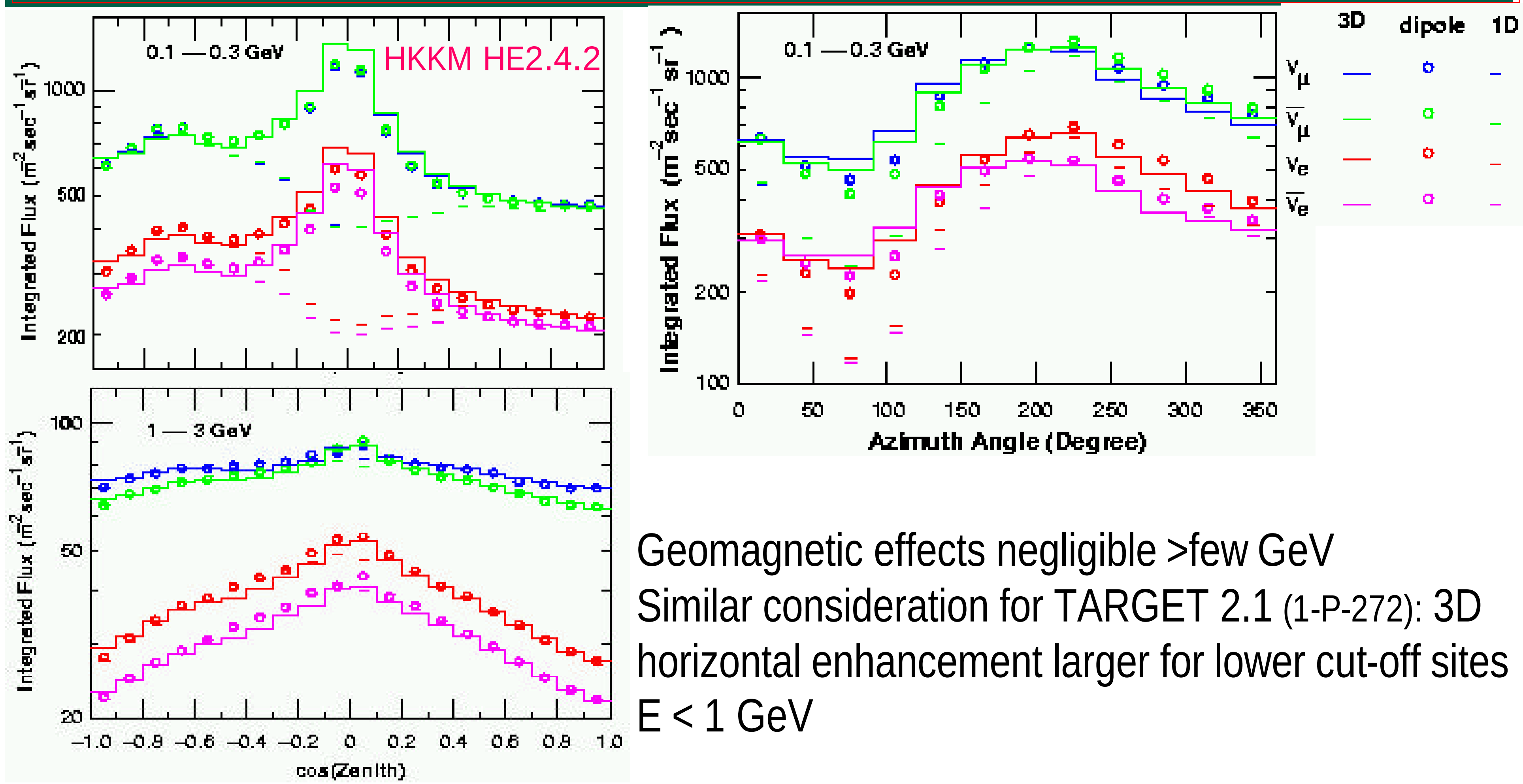


Tsukuba

Combined Systematic Errors

		σ_i	best fit
α	Absolute Normalization Uncertainty	Free	8.70 %
α_L	SubGeV Multi-ring Absolute Normalization Uncertainty	Free	-23.8 %
α_H	MultiGeV Multi-ring Absolute Normalization Uncertainty	Free	-26.1 %
δ	Eν Spectrum Index	0.05	0.005
β_L	SubGeV μ/e Ratio	8 %	-6.1 %
β_H	MultiGeV μ/e Ratio	12 %	-12.5 %
ρ	FC/PC Relative Normalization	8 %	4.3 %
η_L	SubGeV Up/Down Asymmetry	2.4 %	-2.2 %
η_H	MultiGeV Up/Down Asymmetry	2.7 %	-1.1 %
β_1	FC+PC/Stop ↑μ Relative Normalization	7 %	-2.8 %
β_2	Through ↑μ/Stop ↑μ Relative Normalization	7 %	8.2 %
	FC+PC Horizontal/Vertical Uncertainty	4 %	0.2 %
	↑μ Horizontal/Vertical Uncertainty	3 %	1.5 %
	L/E Uncertainty	15 %	-5.8 %

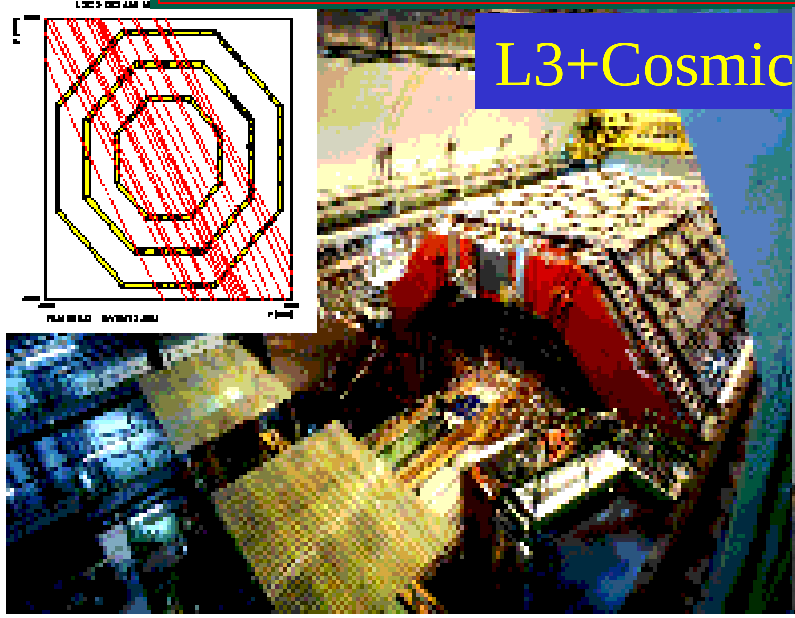
The low energy region: 3D and geomagnetic field



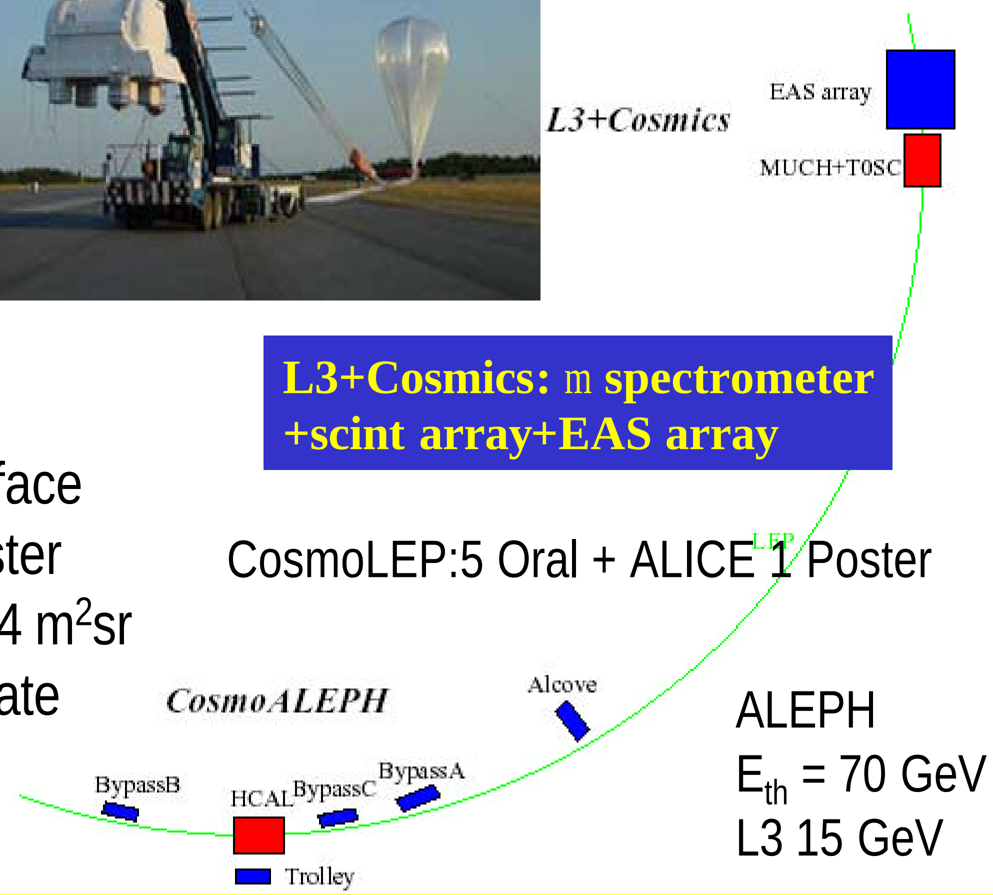
Geomagnetic effects negligible >few GeV
Similar consideration for TARGET 2.1 (1-P-272): 3D horizontal enhancement larger for lower cut-off sites E < 1 GeV

3D effects considerable below ~2 GeV. At 10 GeV even for horizontal directions (angle distribution shrink slower with E than for vertical) νs ~ collinear to primaries

HE 2.1 Muon experiments



BESS:
2 Oral + 1 Poster
HEAT: 1 Oral



LVD: 1 Oral + 1 Poster
Baksan: 2 Poster
DECOR+NEVOD (large acceptance surface detector for horizontal μs): 1 Oral+1 Poster
OKAYAMA: iron magnet spectrometer 24 m^2sr can turn around any direction to investigate geomagnetic effects 1 Oral + 3 Poster
WILLI: 1 Poster
AMANDA II: 1 oral

L3+Cosmics: m spectrometer +scint array+EAS array

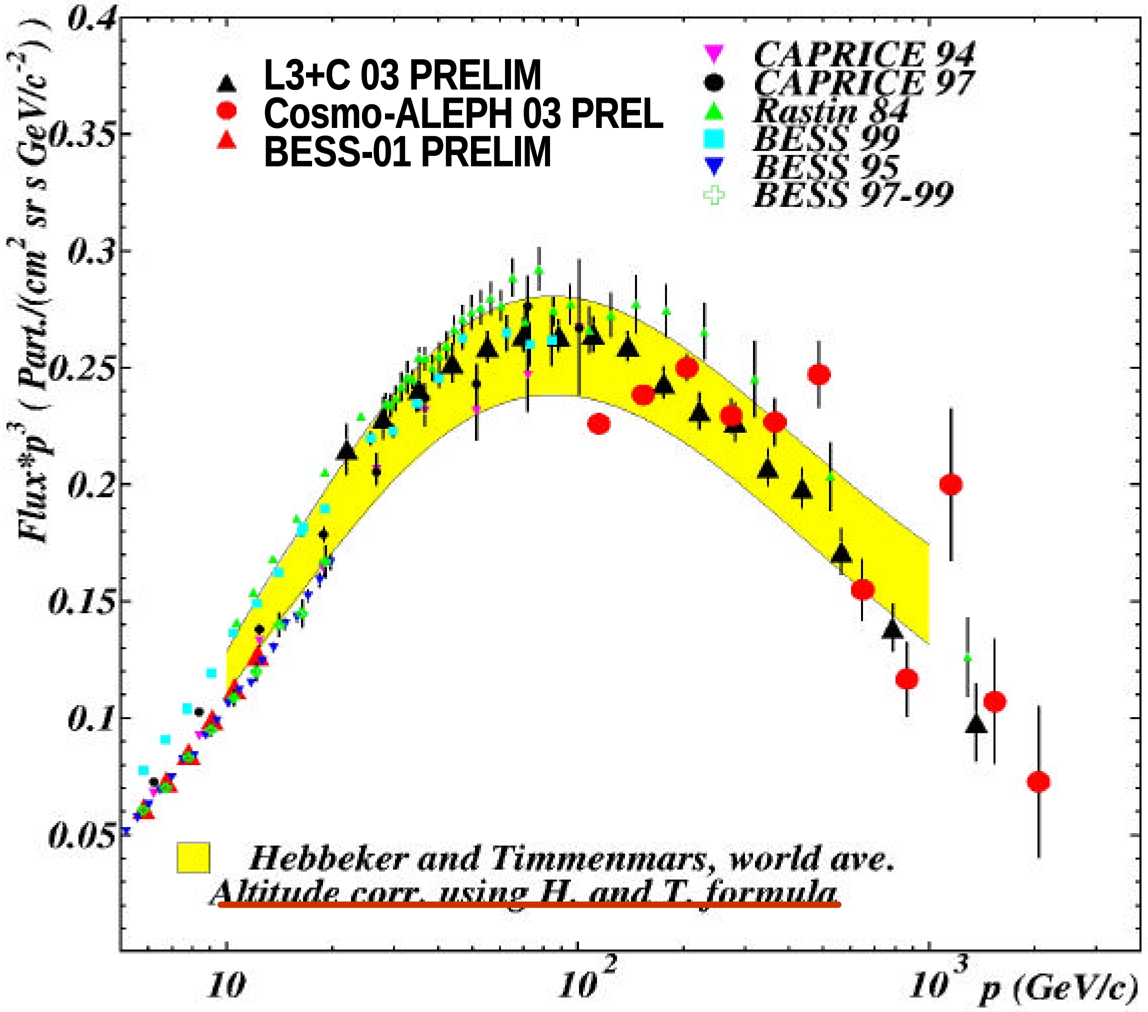
CosmoLEP:5 Oral + ALICE 1 Poster

ALEPH
E_{th} = 70 GeV
L3 15 GeV

CosmoALEPH: ALEPH (h calorimeter+TPC) +5 scint

Vertical Muon Flux at sea level (HE)

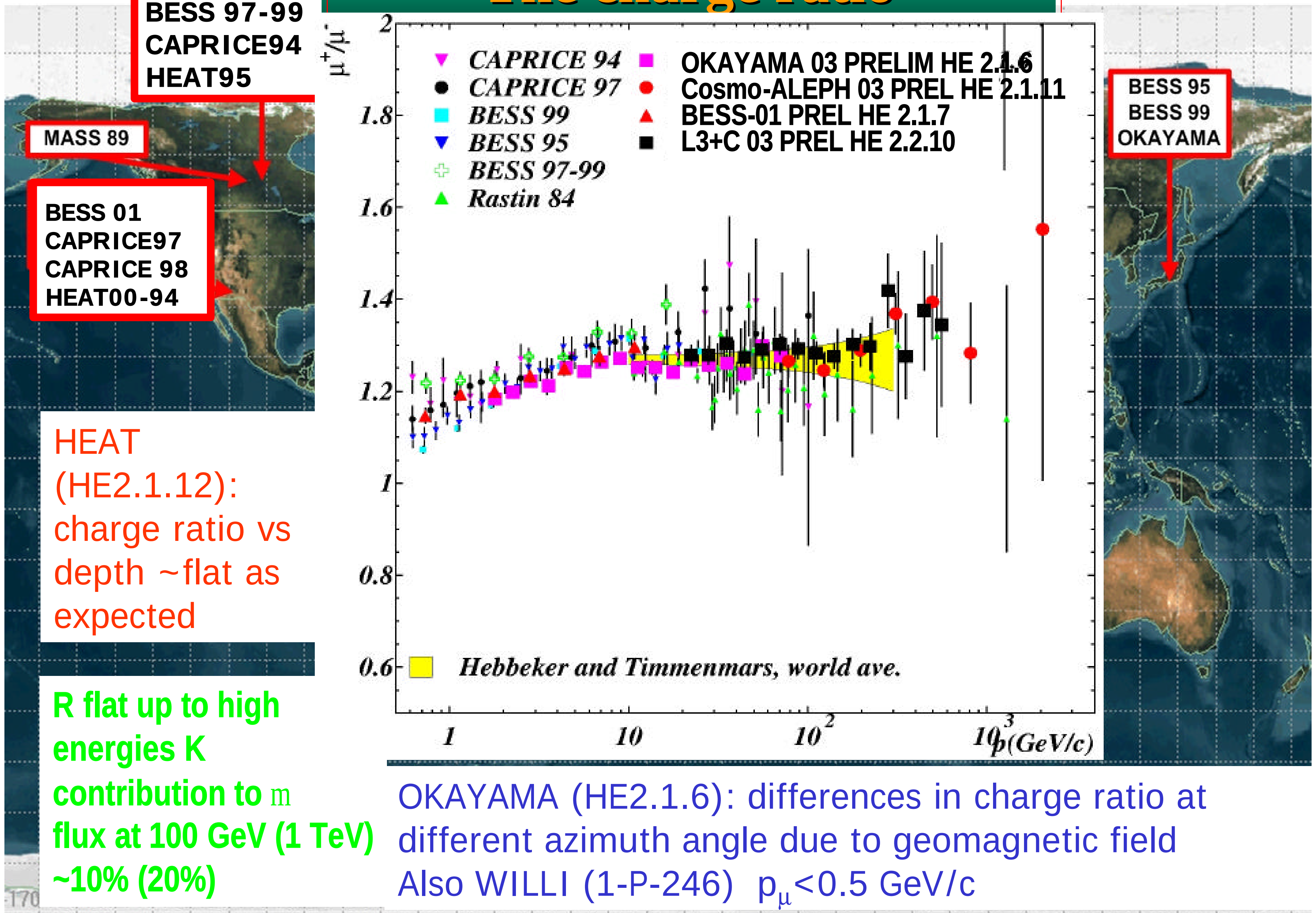
Ground level: large statistics, up to HE. Important constraint to shower development codes and atm ν calculations



L3+C (HE2.1.10): up to 2TeV sys error: 2.6% @ 100 GeV (molasse) 15% @ 2 TeV (rel. mom. res)

Cosmo-ALEPH (HE2.1.11): better knowledge of trigger efficiency needed

The charge ratio

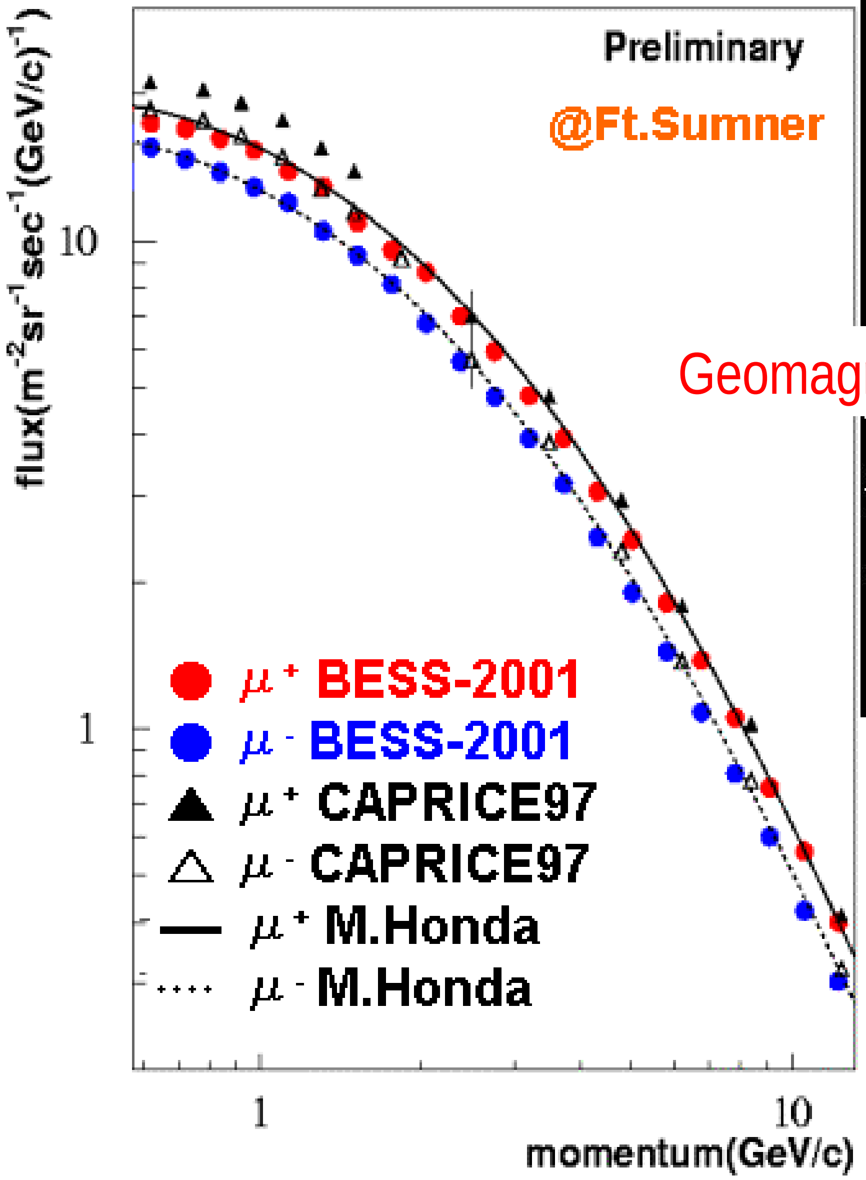


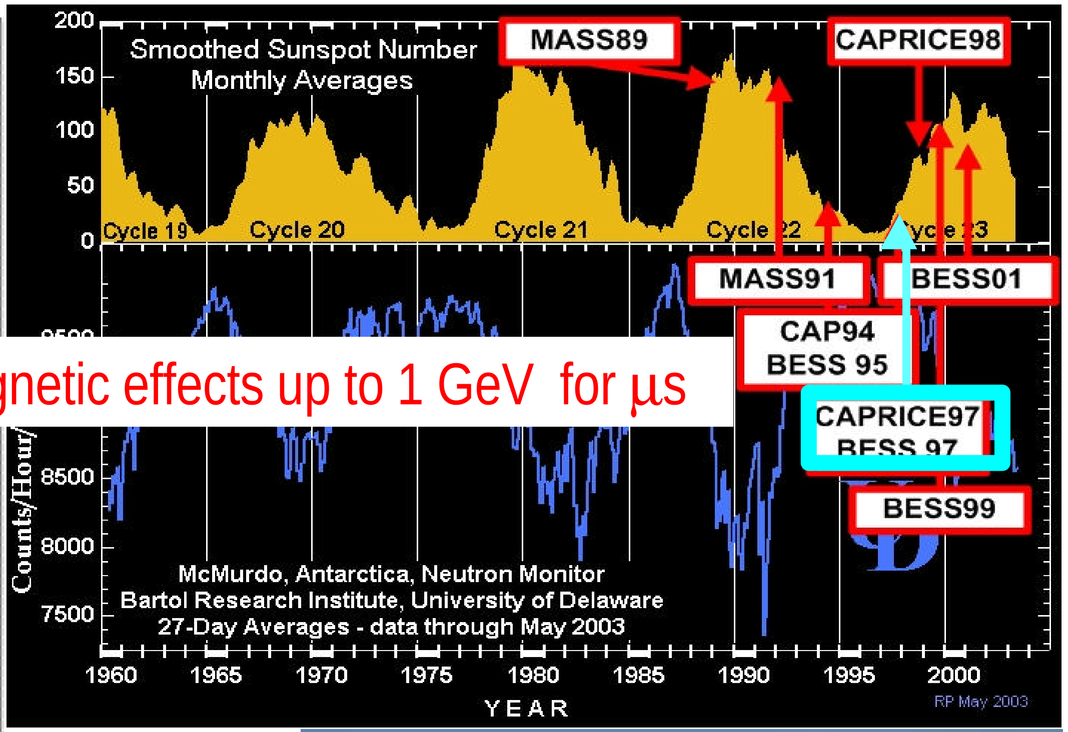
HEAT (HE2.1.12): charge ratio vs depth ~flat as expected

R flat up to high energies K contribution to m flux at 100 GeV (1 TeV) ~10% (20%)

OKAYAMA (HE2.1.6): differences in charge ratio at different azimuth angle due to geomagnetic field
Also WILLI (1-P-246) $p_{\mu}<0.5$ GeV/c

Vertical muon flux at sea level (LE)



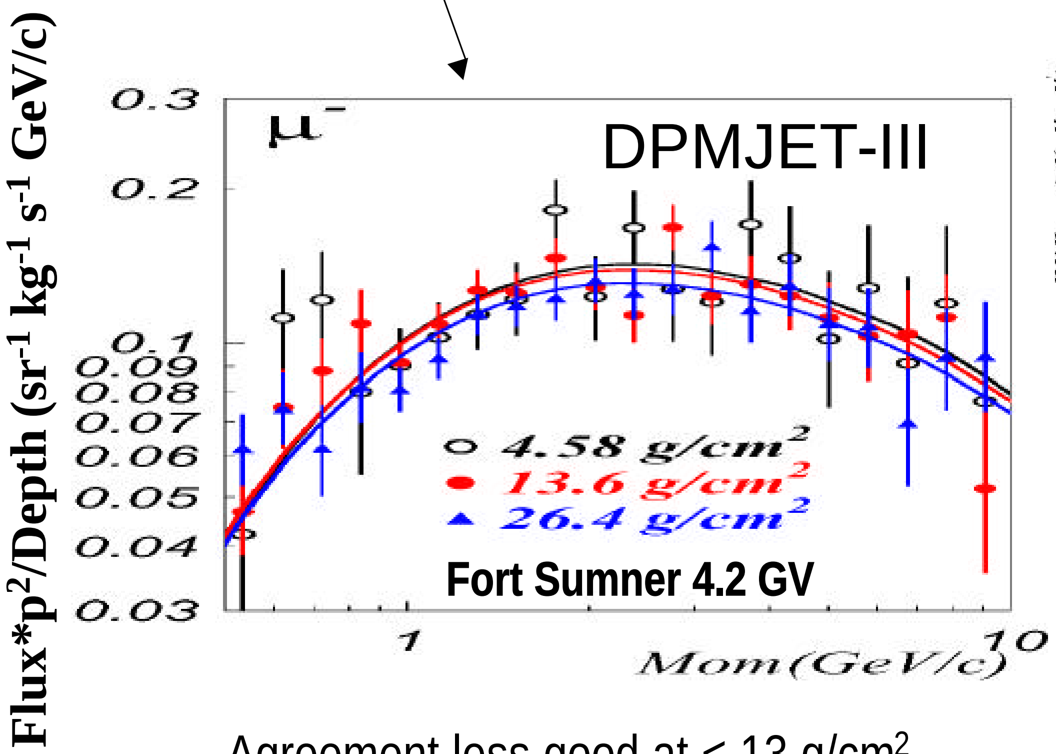


Geomagnetic effects up to 1 GeV for μs

Teresa Montaruli, ICRC2003,

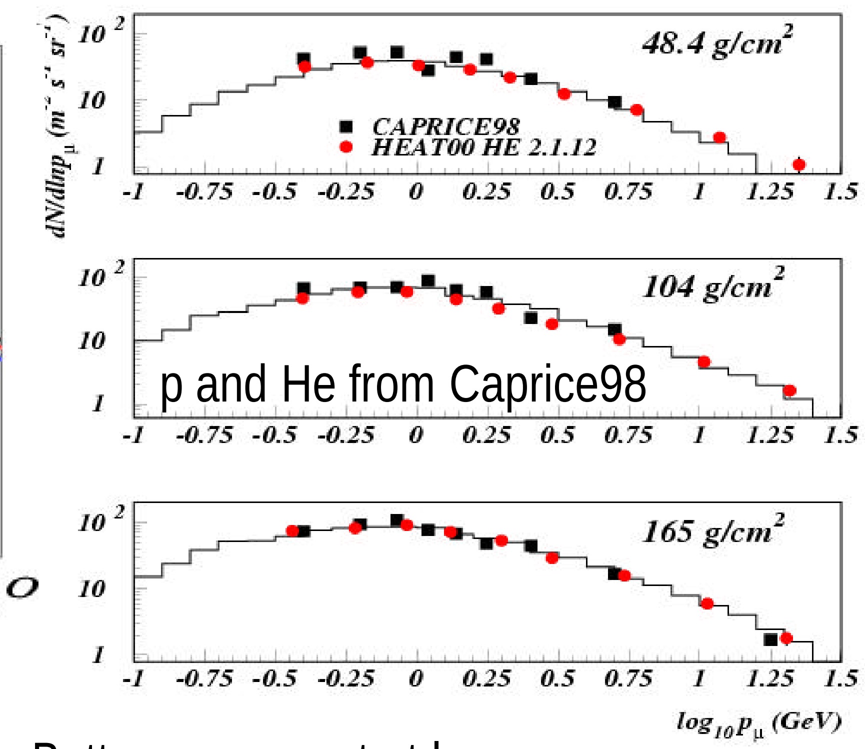
ms in atmosphere: relevant test for hadronic models

Abe et al. (HE2.4.6): at top of the atmosphere (BESS-01 13.5 hrs at 4.5-28 g/cm^2) first interactions ⇒ clean test of hadronic models validate DPMJET-III now used in HKKM (HE2.4.2),



Agreement less good at < 13 g/cm^2

m$^-$ **TARGET2.1 HE 2.4.9 Stanev et al**



Better agreement at low grammage
Hadronic model still needs some refinement
(some overproduction of μ^+ at < 1 GeV/c)

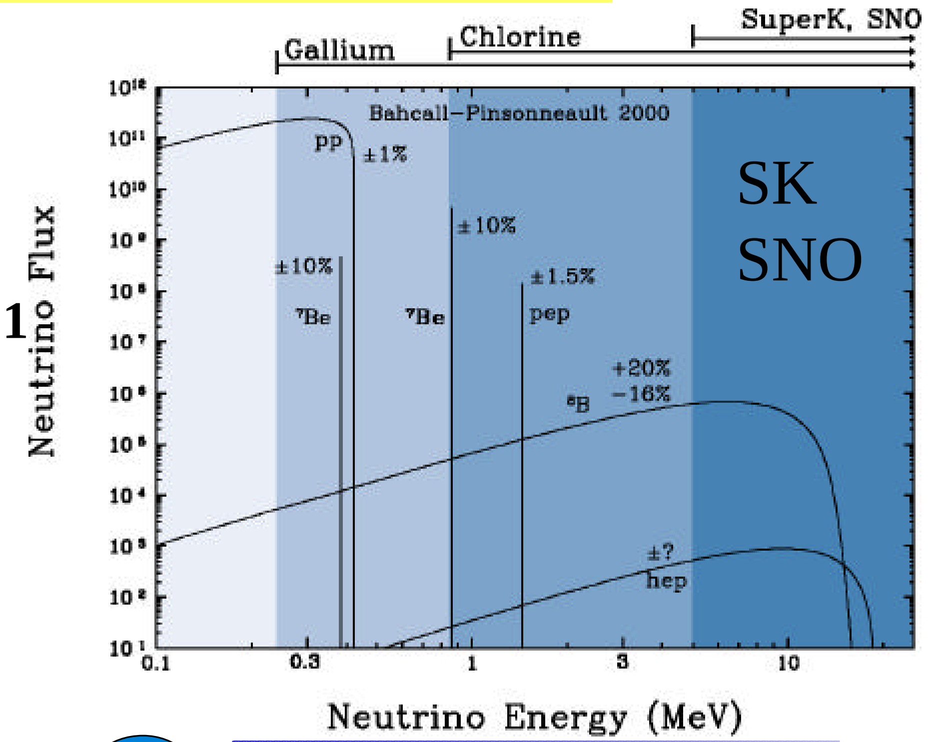
Liu et al, HE 2.4.1: comparison with BESS99 CAPRICE94,97

Solar neutrino observation

4p ? $^4He + 2 e^+ + 2$ n$_e$

Flux, spectrum... are calculated by Standard Solar Model (SSM)

Bahcall et al, 2001, Turck-Chieze et al., 2001



Detectable Reactions in H_2O and D_2O

CC $n_e + d \Rightarrow p + p + e^-$

- **Good measurement of n$_e$ energy spectrum**
- **Weak directional sensitivity µ 1-1/3cos(q)**

$\boxed{\text{- n}_e \text{ ONLY}}$

NC $n_x + d \Rightarrow p + n + n_x$

- **Measure total ^8B n flux from the Sun.**
  - **Equal cross section for all n types**

ES $?_x + e^- \Rightarrow ?_x + e^-$

- **Mainly sensitive to n$_e$, less to n$_m$ and n$_t$**
- **Strong directional sensitivity**

SNO

SK

HE 2.2.4

The Sudbury Neutrino Observatory

Creighton (Ontario) mine 6010 mwe

1 kton D_2O

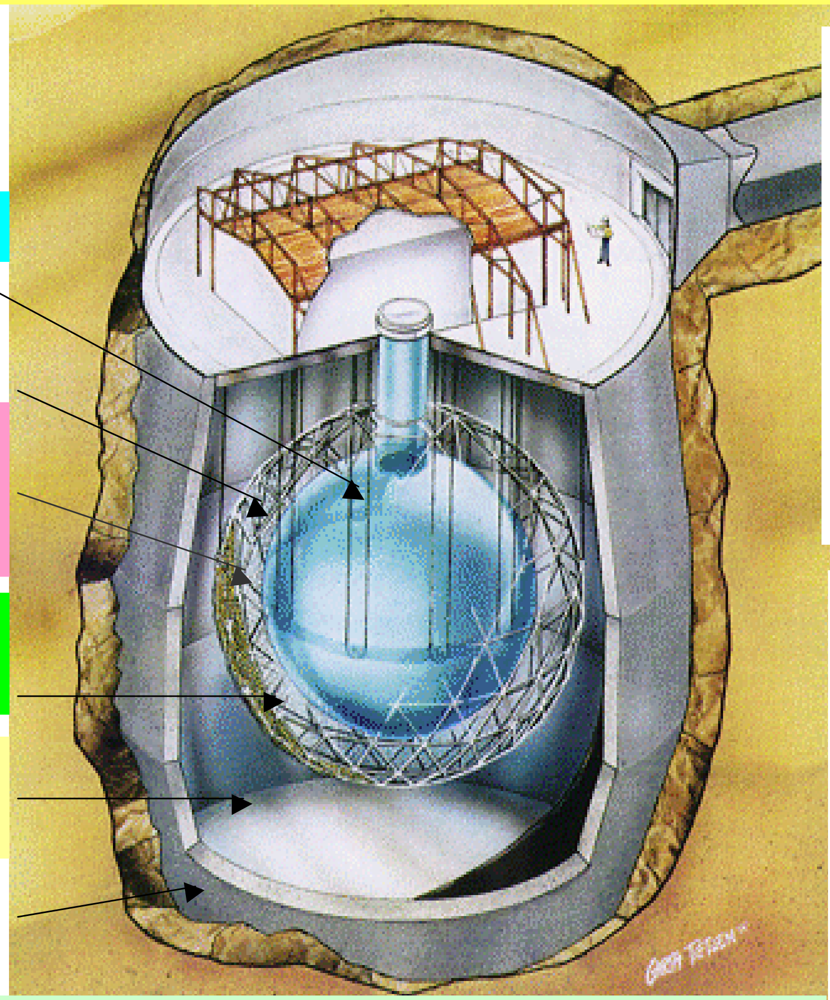
12 m Diameter Acrylic Vessel

Support Structure for 9500 20 cm PMTs, 60% coverage

1.7 kton Inner Shielding H_2O

5.3 kton Outer Shield H_2O

Urylon Liner and Radon Seal



19 Apr 02: direct evidence for n_e transitions, independently of solar models

3 phases: NC detection

- Nov. 1999- May 2001

Pure D_2O:
good CC sensitivity
neutron capture on deuterium

n + **d** ® **t** + g **…** ® **e$^-$**
(E_g = 6.3 MeV)

- Jun. 2001- Mar. 2002

2 tons of Salt in D_2O **to enhance (>3) NC sensitivity n capture on Cl**

n + ^{35}**Cl** ® ^{36}**Cl** + Sg **…** ® **e$^-$**
(E_{Sg} = 8.6 MeV)

- Neutral Current Detectors

^{3}He proportional counters in D_2O, salt removed
Capture on ^{3}He

n + ^{3}**He** ® **p** + **t**

Results from 1st phase: CC: PRL 87 (2001) **Day-Night:** PRL 89 (2002) **NC:** PRL 89 (2002)

SNO results

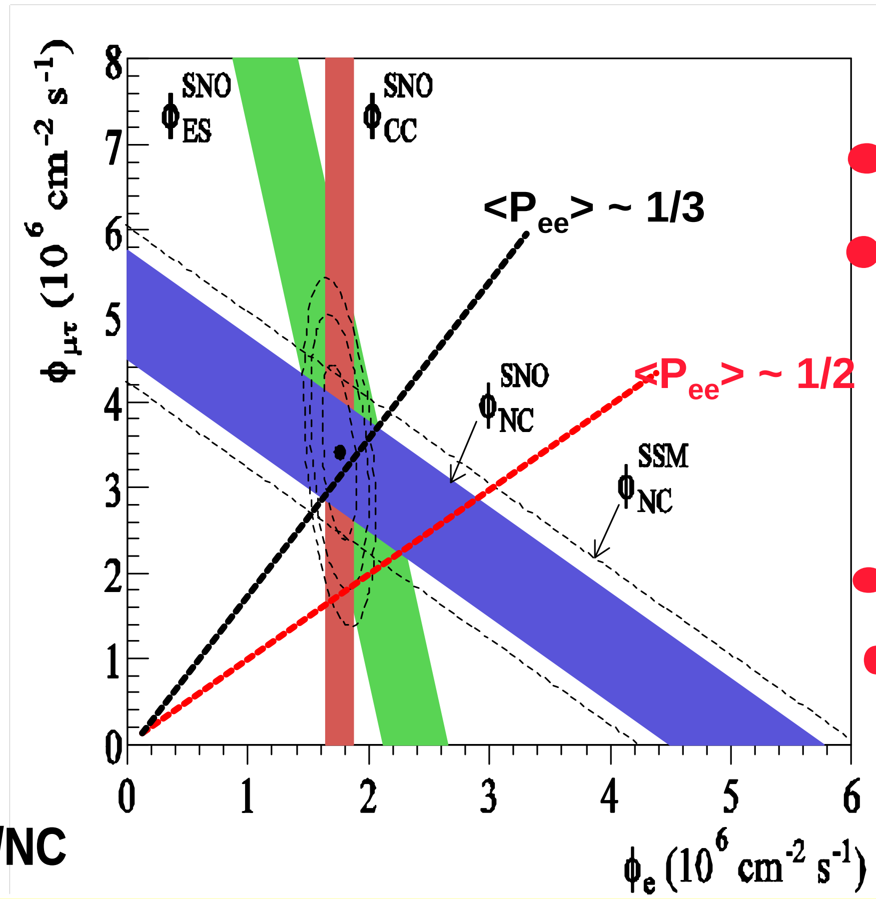
1st evidence from SNO CC+ES compared to SK ES

Fluxes ($\times 10^6$ cm^{-2} sec^{-1})

$$\phi_{CC} = 1.76^{+0.06}_{-0.05}\,(\text{stat.}) \pm 0.09\,(\text{sys.})$$
$$\phi_{ES} = 2.39^{+0.24}_{-0.23}\,(\text{stat.}) \pm 0.12\,(\text{sys.})$$
$$\phi_{NC} = 5.09^{+0.44}_{-0.43}\,(\text{stat.})^{+0.46}_{-0.43}\,(\text{sys.})$$

$F_{ssm} = 5.05^{+1.01}_{-0.81}$ ´ 10^6 cm^{-2} s^{-1}

F_{mt} is 5.3 s from zero



P_{ee} = CC/NC

Null hypothesis of no flavor transformation rejected at 5.3 s

By comparing ES, CC and NC fluxes measured by SNO:

- **extremely good confirmation of SSM**
- **clear evidence of active oscillations**

$F_{CC} < F_{ES} < F_{NC}$

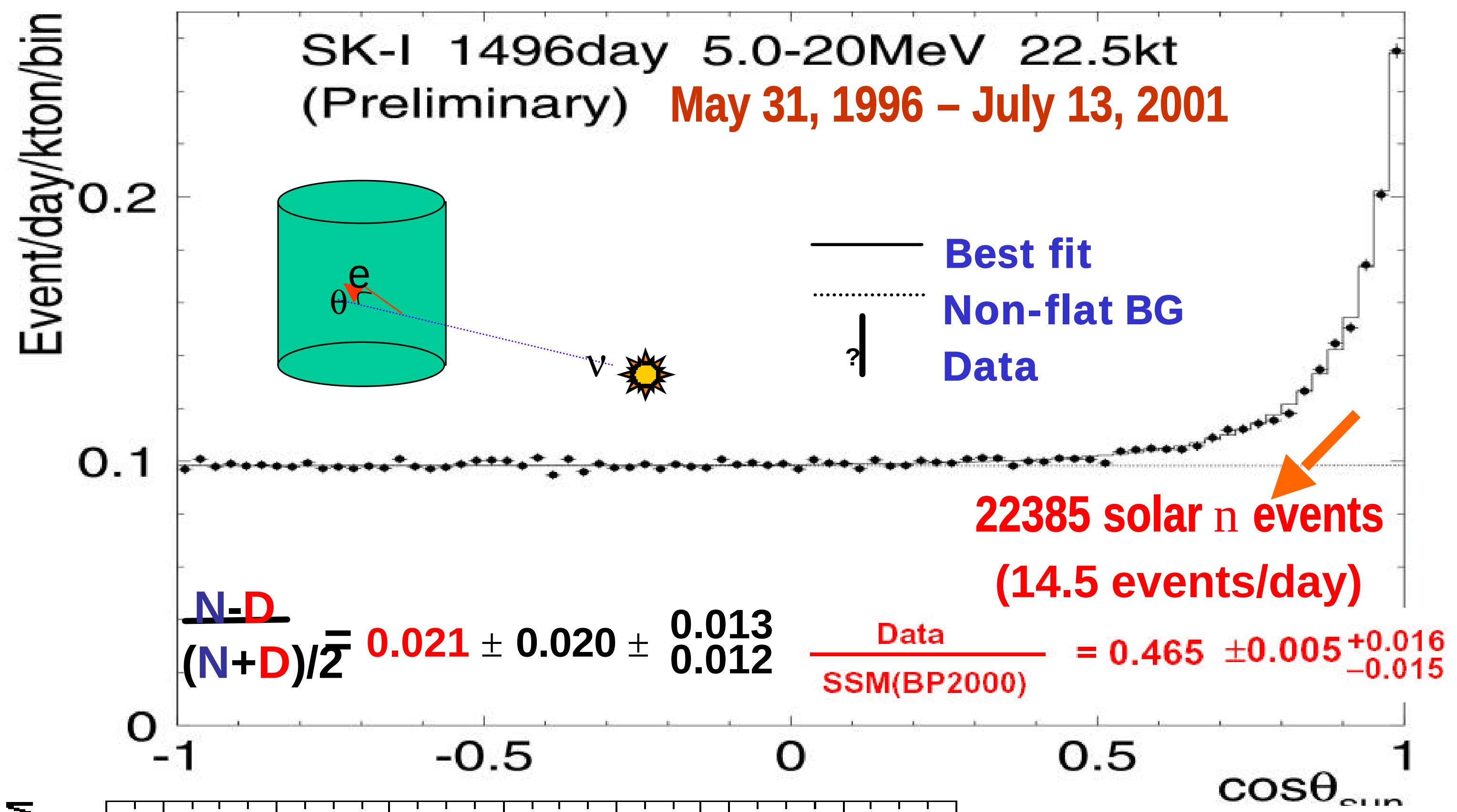
~2/3 of n_e oscillate into active flavors

- **preferred <P_{ee}> ~ 1/3 (matter effects)**
- **2nd phase data fundamental to rule out <P_{ee}> ~ 1/2**

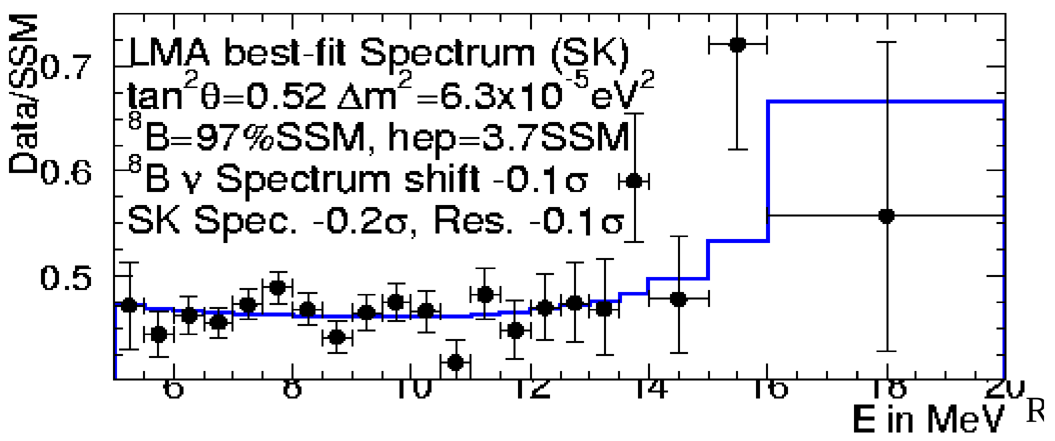
Spectrum and Day-night asymmetry favor MSW

Solar neutrinos in SK

HE 2.2.2
Suzuki
highlight



Time modulation as expected from eccentricity (HE 2.2.5): 80% probability of finding 15 d modulation with 10% (19%) amplitude with 5 d (10 d) binning at 99%c.l.

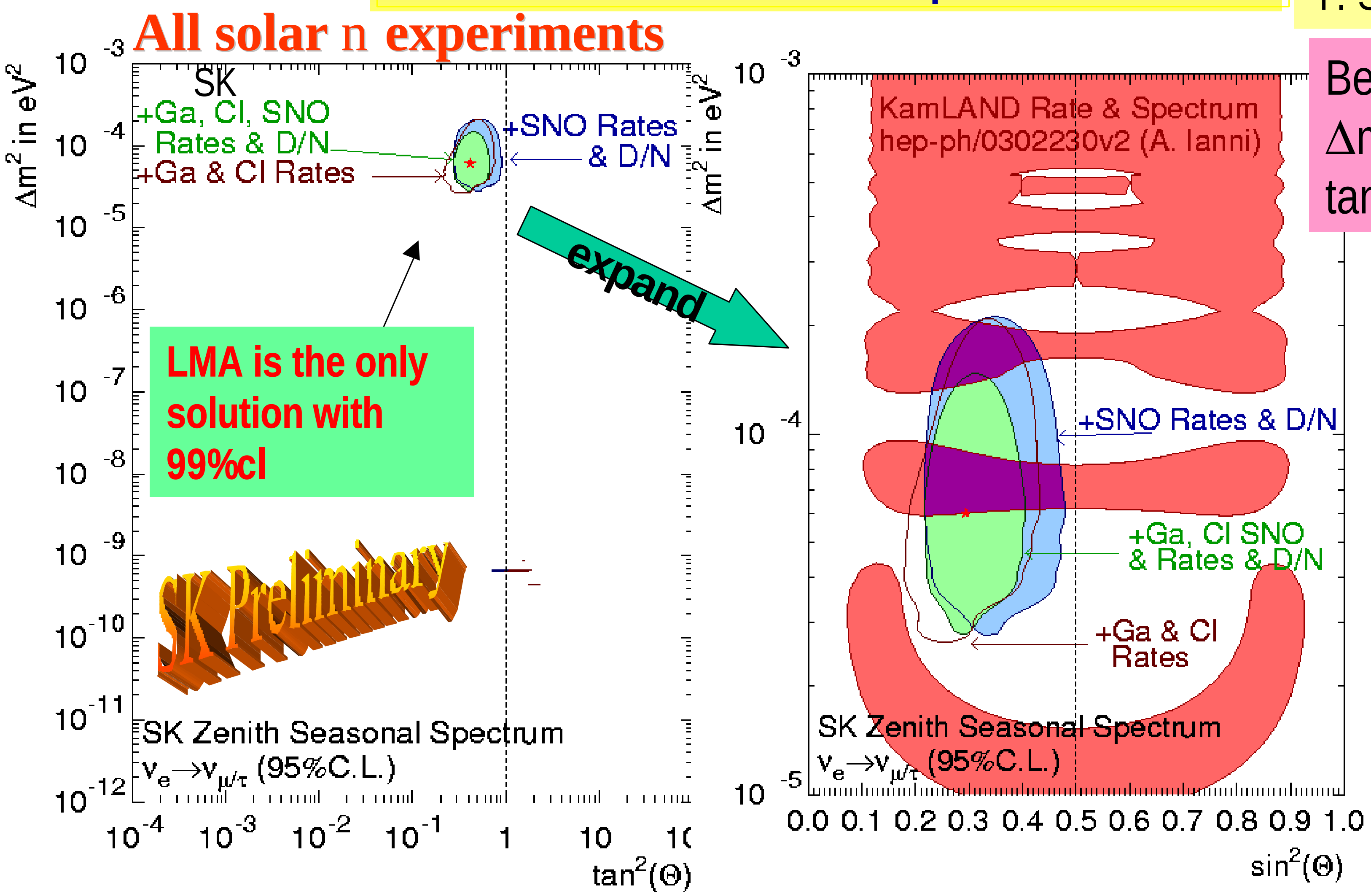


No significant time variation and energy distortion appear
Flux, spectrum and day/night flux differences favor large neutrino mixing at 95%C.L

SK HE 2.2.2
KamLAND HE 2.2.1

SK+SNO+KamLAND
+other solar ν experiments

Kamland results described in Y. Suzuki highlight



Best fit
$\Delta m^2 = 6\ 10^{-5}$ eV^2
$\tan^2\theta = 0.42$

Geo-νs from radioactive elements in KamLAND: E_{th} = 0.9 MeV 9 events from ^{38}U, ^{232}Th allowed range for heat source < 110 TW (95%cl)

SNO: 1-P-252
SK: HE 2.2.3, PRL90(2003)

$\bar{n}_e$ from the Sun?

SNO+SK+ KamLAND: LMA viable solution (if CPT conserved)

If Sun magnetic field and ν magnetic moment large enough ⇒ subdominant Spin Flavor Precession (Lim & Marciano, 1988; Akhmedov, 1988)+oscillations in matter not ruled out: $\nu_e \rightarrow \bar{n}_m, \bar{n}_t$ (SFP) + $\bar{n}_m, \bar{n}_t \rightarrow \bar{n}_e$ (oscillations)

If $\bar{n}_e$ are detected ⇒ ν is Majorana (if Dirac: $n_{eL} \rightarrow n_{eR}$ sterile)

SK: $\bar{n}_e + p \rightarrow e^+ + n$ — e^-/e^+ detection

(2.2 MeV γ from n capture below E_{th})

SNO: $\bar{n}_e + d \rightarrow e^+ + n + n$ — 3-fold coincidence ε =1.1%

2-fold (nn, e^+n) ~ 10%

SK large backgrounds due to spallation (93% contamination)

SNO: 2 candidates <2 exp. background in 306 d (6000 mwe!)

Assuming ^{8}B spectrum: upper limits on $\bar{n}_e$ flux

SK = 0.8% of SSM (E_{th}=8 MeV) after spallation backg subtraction

SNO = 1.02% of SSM (E_{th}=5 MeV) (Previous: 4.5% Kamiokande)

Neutrinos from SN collapse

Neutrinos from Core collapse SN: 99% of binding energy in νs

•*Neutronization*, ~10 ms 10^{51} erg (ν_e) $e^- + p \rightarrow n + \nu_e$

Thermalization: ~10 s 3×10^{53} erg $e^- + e^+ \rightarrow \bar{\nu} + \nu$

Equipartition of energy luminosity between different flavors (Fermi-Dirac spectra)

$\langle E_{\nu_e}\rangle$ = 13 $\langle E_{\bar{\nu}_e}\rangle$ = 16 $\langle E_{\nu_{\mu,\tau}}\rangle$ = 23 MeV (though new results show $\langle E_{\bar{\nu}_e}\rangle \sim \langle E_{\nu_{\mu,\tau}}\rangle$ (Raffelt et al, 2003))

Exp. **SN rate in Galaxy: 2-4/century**

Search for ν bursts: largest yield **I**β $\bar{\nu}_e + p \rightarrow n + e^+$ ~300 e^+/kt

H$_2$O, D$_2$O Detectors:

SK (HE 2.3.3) 4.67yr E_{th} =6.5 MeV <0.49 SN/yr (90%cl) 100% eff in 100 kpc

Expect 3500 events for 10 kpc SN 12M$_{Sun}$ (2% decrease in SK-II due to 1/2 PMTs)

3 fake due to mine blasting In SN Early Warning System (fake< 1/week)

AMANDA II (1-P-258) 677 OMs V_{eff}/OM~400-500 m^3 <4.3 SN/yr (90%c.l.) in Galaxy

90% eff in 9.4 kpc expect 15 fake/yr $\Rightarrow$ SNEWS

Scintillator Detectors:

LVD (HE2.3.9) 10 yr averaged duty cycle: 87% E_{th} = 7 MeV final mass (Jan01): 840 ton

<0.24 SN/yr (90%cl) d < 20 kpc In SNEWS since 98

MACRO: <0.27 SN/yr (90%cl) in Galaxy

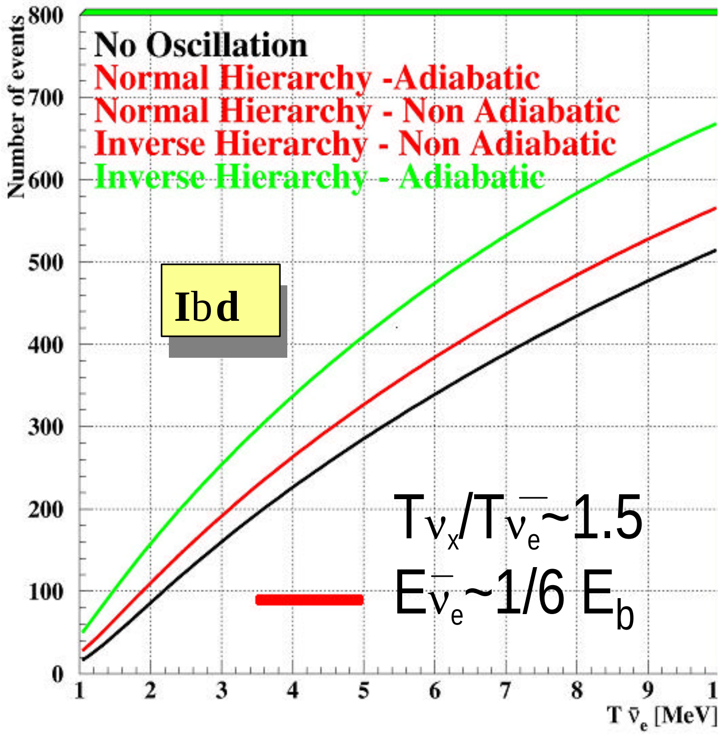
SN neutrinos and oscillations in LVD

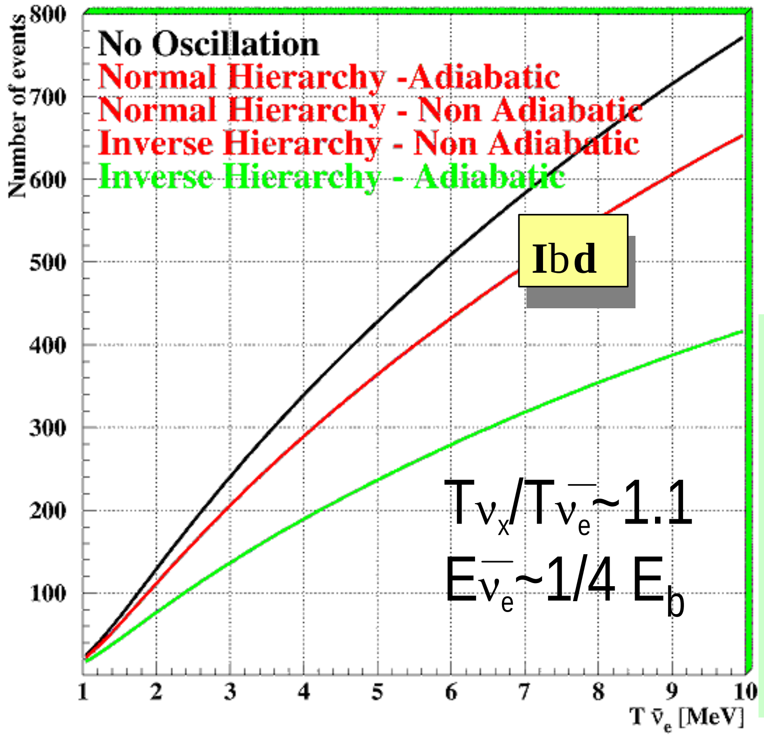
If $\bar{n}_{m,t}$ oscillate in $\bar{n}_e$ (n_e for other detectable reactions on ^{12}C, ^{56}Fe) harder spectra depending on:

- Mass Hierarchy: **normal** $\boxed{\Delta m^2_{32} > 0}$ **/inverted** $\boxed{\Delta m^2_{32} < 0}$
- (non)adiabatic conversion: $|U_{e3}|^2$
- Trajectory: **Earth matter effects**

For M = 1 kt + SN at 10 kpc 2.5 10^{53} erg

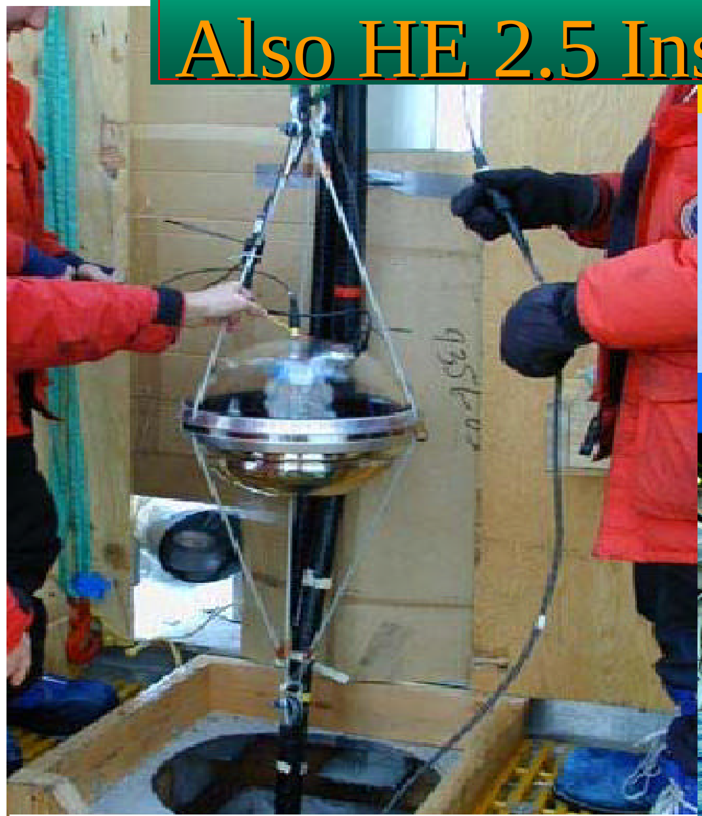
Total exp.events
200 (pessimistic)
450(conservative)
Even with
300 t LVD
observed
the Galaxy

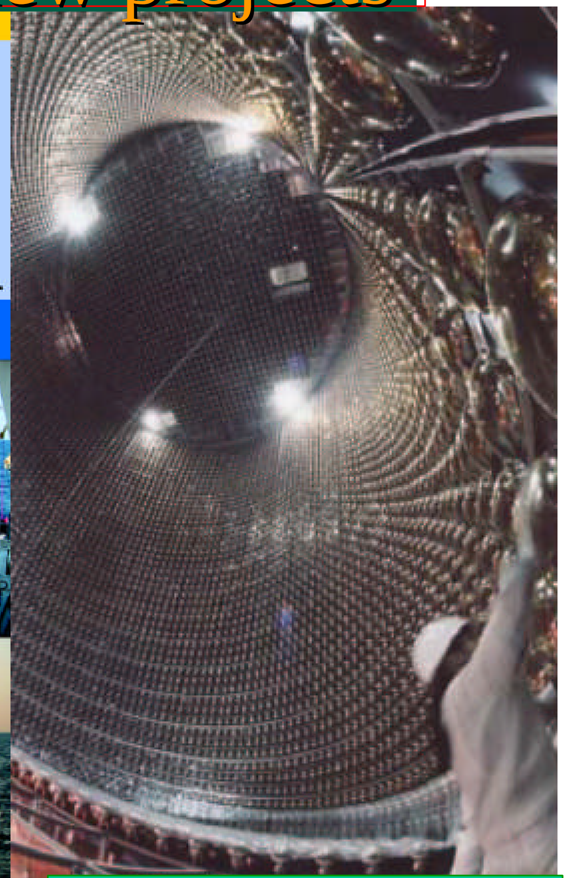




Ando & Sato,HE2.4.5
Resonant Spin
Flavor conversion
efficient in SN
dense environment

HE 2.3 Neutrino Telescopes
Also HE 2.5 Instrumentation and new projects





AMANDA
ANTARCTIC MUON AND NEUTRINO DETECTOR ARRAY
http://amanda.physics.wisc.edu

3 oral + 6 poster

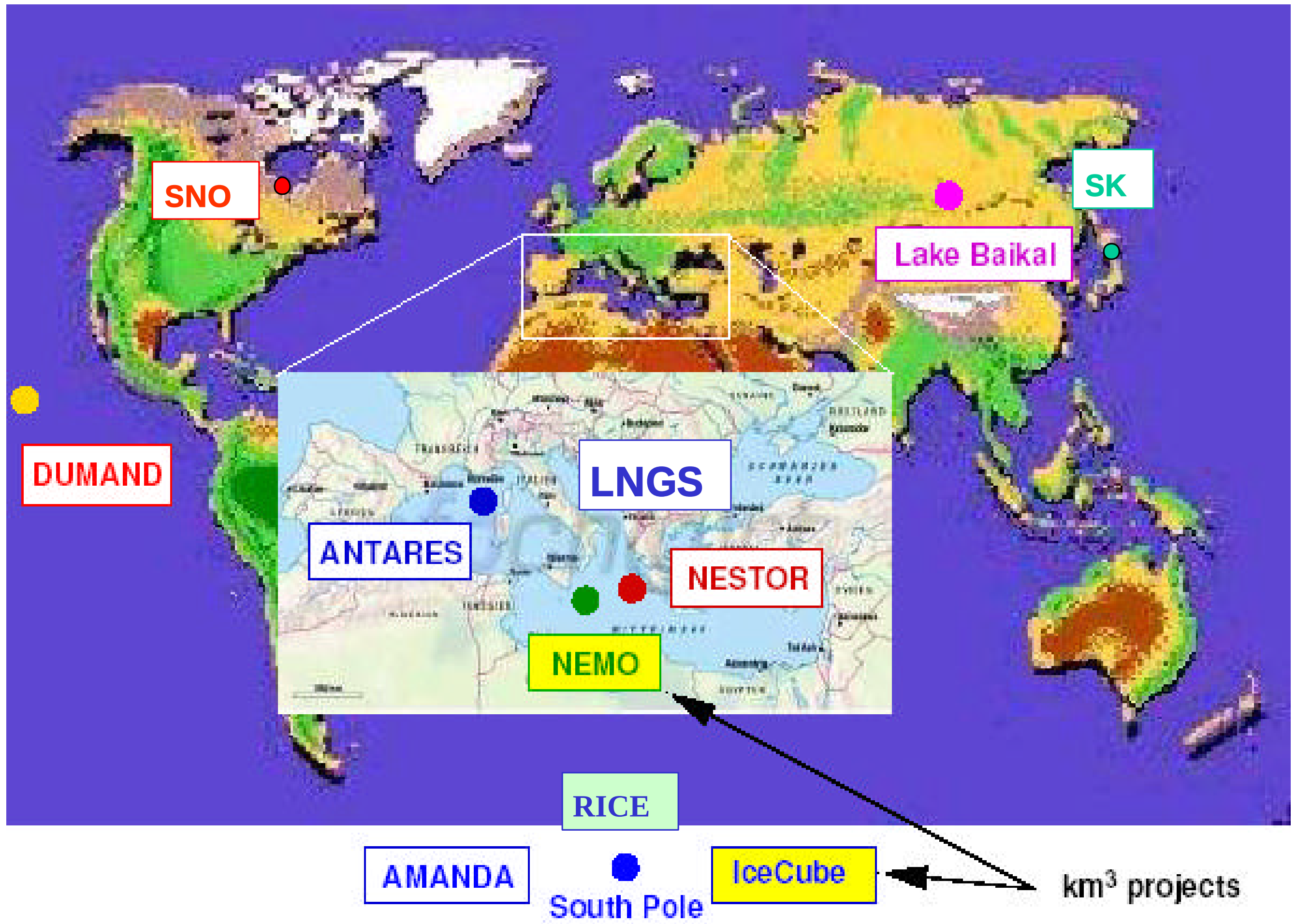
ICECUBE **1 oral**

ANTARES: 3 oral+4 poster

Super - Kamiokande
3 oral + 3 poster

LVD 1 oral + 1 poster
NESTOR 1 poster
Lake Baikal 1 oral
RICE + Radio 1 oral+ 4 poster

The Neutrino Telescope world map



First generation:
$A \sim 10^2$-10^3 m^2
$E_\mu > 1$GeV
underground

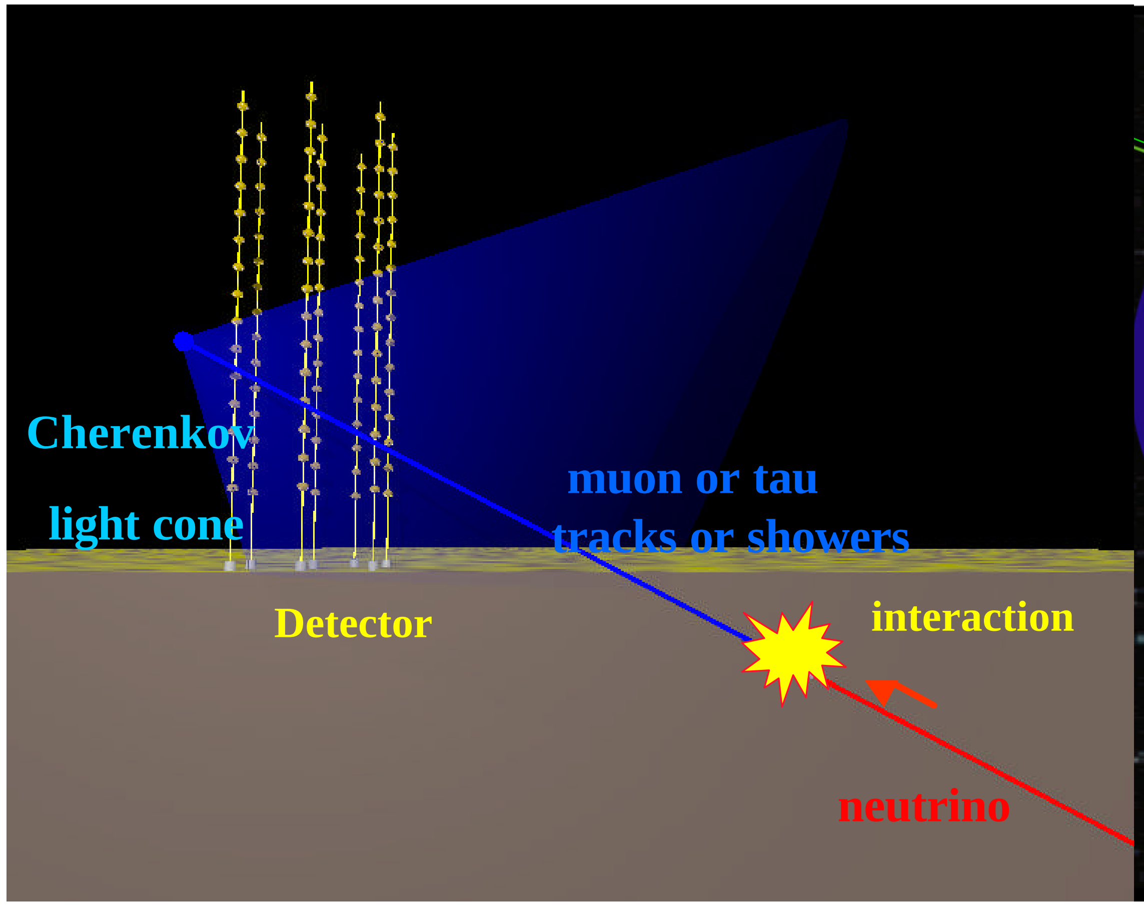
Water Cherenkov:
SK 22.5 kt
SNO $D_2O + H_2O$ 1+1.4kt

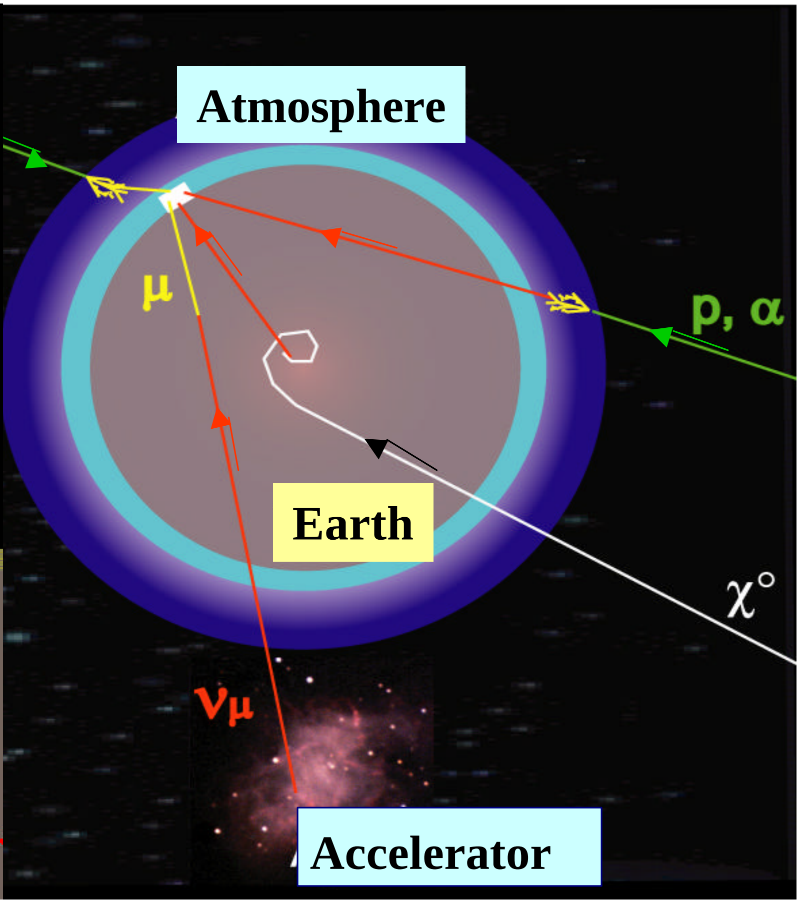
tracking+scintillator:
LVD 1 kt
(MACRO 5.4 kt) } **LNGS**

New generation: A ~ 0.01-1 km^2 underice/water Cherenkov, radio
Lake Baikal > 0.0045 km^2 AMANDA II > 0.03 km^2
ANTARES > 0.05 km^2 IceCube, NEMO > 1 km^2 } $E_\mu > 10$TeV

Physics issues of Neutrino Telescopes

- Cosmic νs (> 1 TeV): upgoing ν induced μs (downgoing > 1 PeV) and 4π cascades ($\nu_e\ \nu_\tau$ NC)
- νs from WIMPs (10 – 1000 GeV)
- atmospheric νs (10 – 100 GeV)
- atmospheric μs
- SN collapse (~10 MeV, ice)



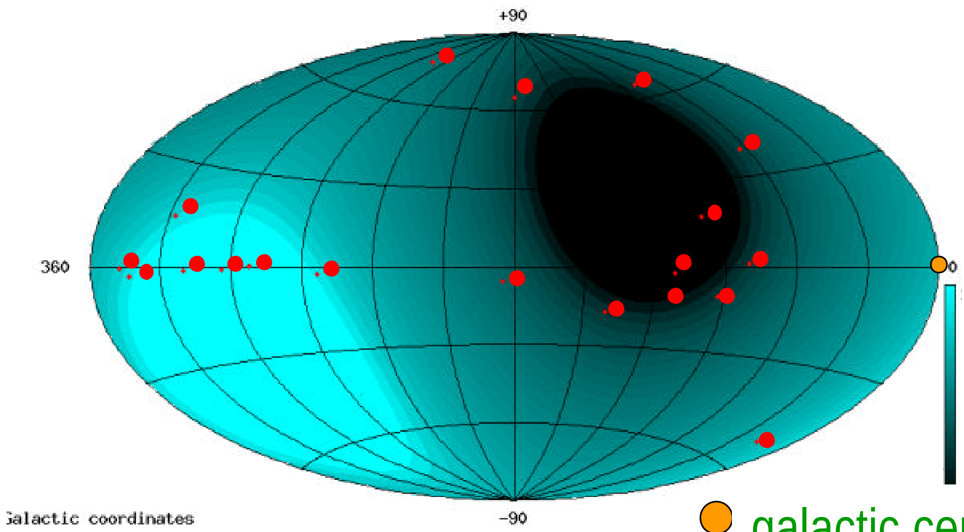


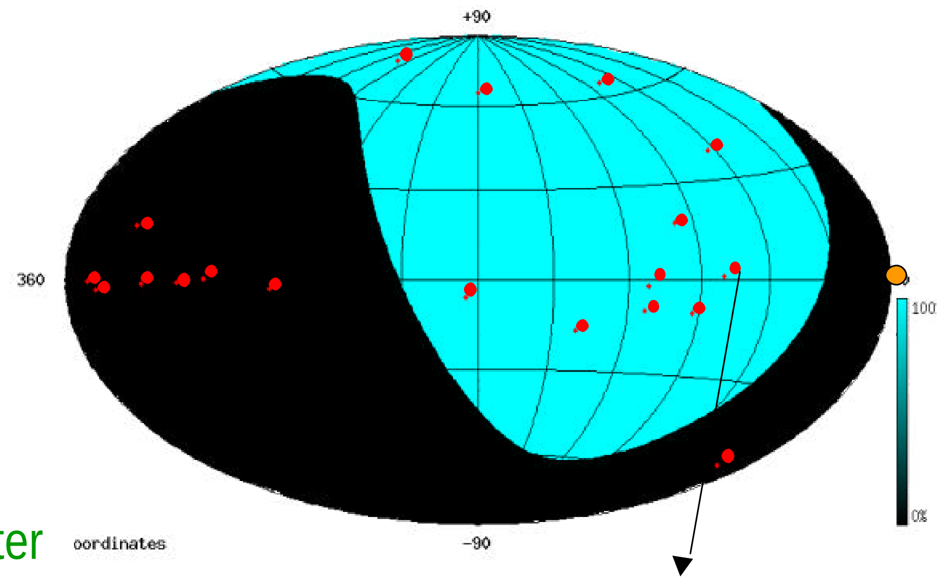
Complementarity

Full sky coverage ⇒ necessity of an undersea Mediterranean km^3 array
Galactic Centre not accessible from South Pole (CANGAROO, Milagro, ICRC2003), Cygnus OB2 (HEGRA)

Mediterranean Sea
Antares, Nestor, NEMO-RD (1 km^3)
Lake Baikal in Siberia

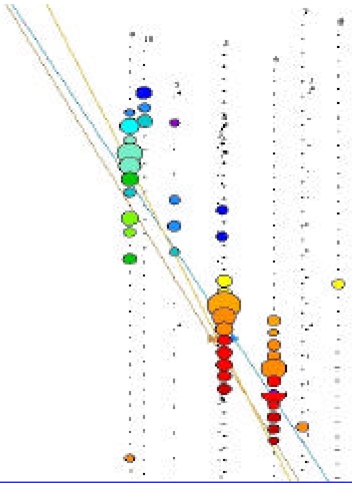
South Pole ice
AMANDA, ICECUBE (1 km^3)





galactic center

red dots: sources observed emitting γ-rays > TeV (plerions, SNRs, Cygnus OB2, BL Lacs)



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http://amanda.physics.wisc.edu

SOUTH POLE

USA Germany
Sweden Belgium
Venezuela

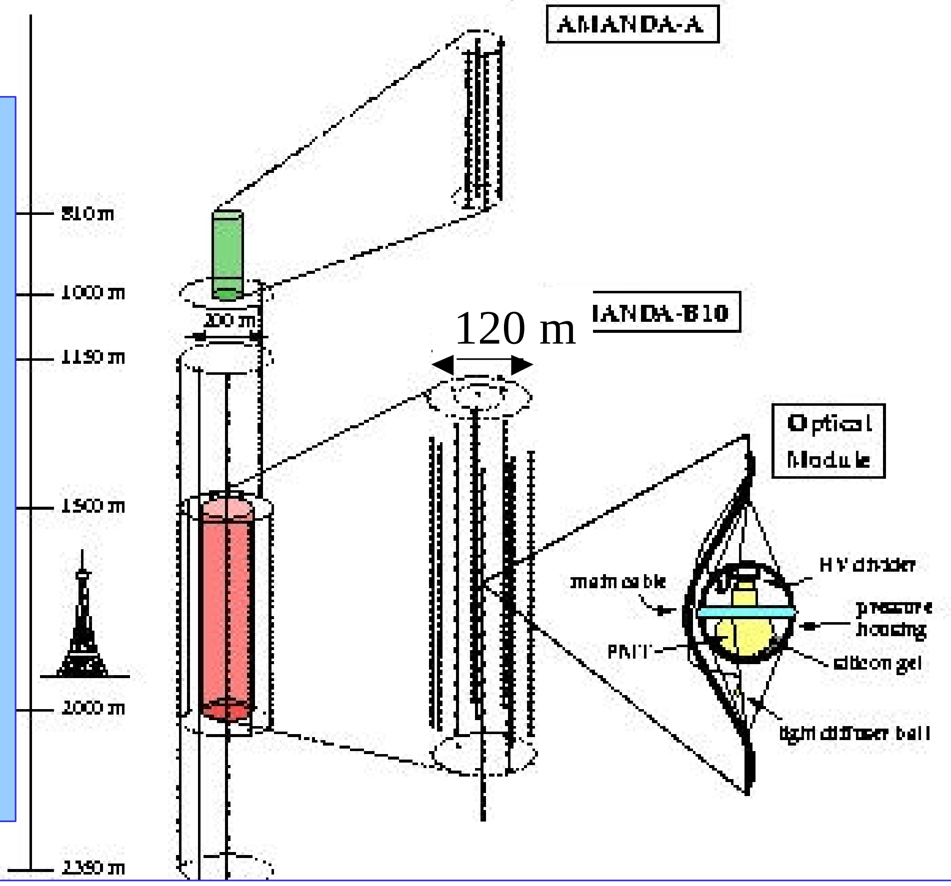
1995-97: AMANDA B-10
302 OM's/10 strings 1500-2000 m
Results recently published: atm ν's, diffuse muon fluxes, cascades, WIMPs, SNs

This conference: <u>first results AMANDA-II</u>

677 OMs/19 strings about factor of 4 and larger acceptance at horizon

Ang. resolution for μs 3.9° $\Rightarrow$ 2.3°

Effective area E_μ>10 TeV > $2\cdot10^4$ m^2

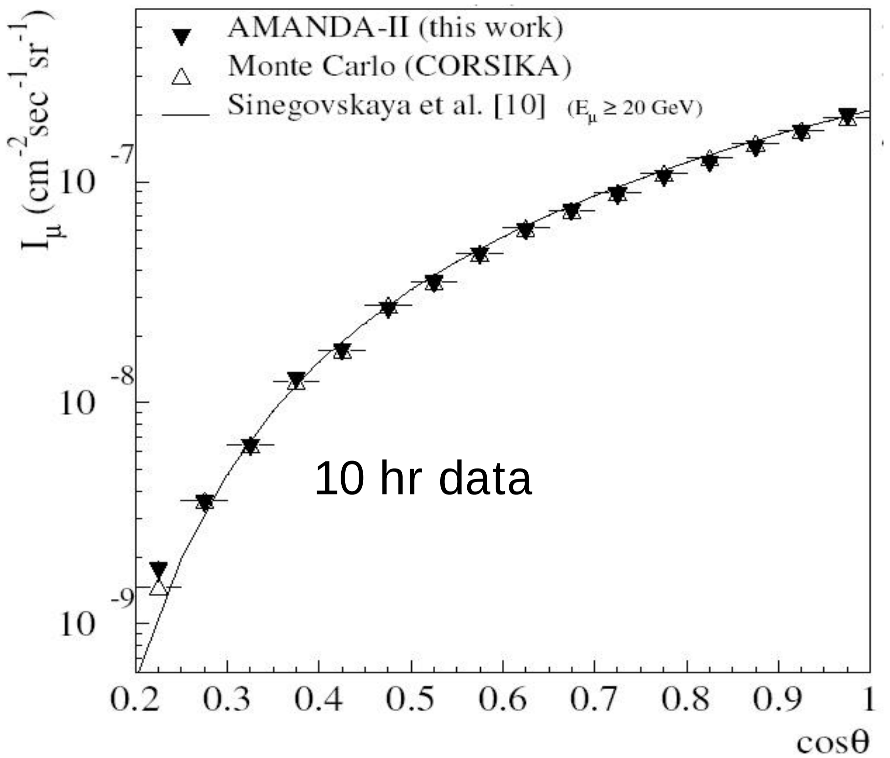


Energy (calibrations in situ)/vertex/ angular resolution for cascades:
σ(log10(E/TeV)) = 0.1-0.2 /5 m /30°-40°

Atmospheric muons in AMANDA-II

Huge statistics allow study of systematics: ~25% mainly due to OM sensitivity, ice optical properties, drill-bubbles

1-P-265: data reduced by 30% but shape in agreement with CORSIKA (QGSJET)



HE 2.1.13: first indirect measurement of CR spectrum from a Neutrino Telescope

$$\Phi(E)=\Phi_0(E/TeV)^{-\gamma}$$

1.5-200 TeV/n for QGSJET generator:

γ(H) = 2.70 ± 0.02

Φ_0 (H) = 0.106 ± 0.007 (m^{-2}s^{-1}sr^{-1}TeV^{-1})

Independent on ice properties, OM sensitivities, detector configuration changements

Spectral index g compatible with direct measurements, error competive

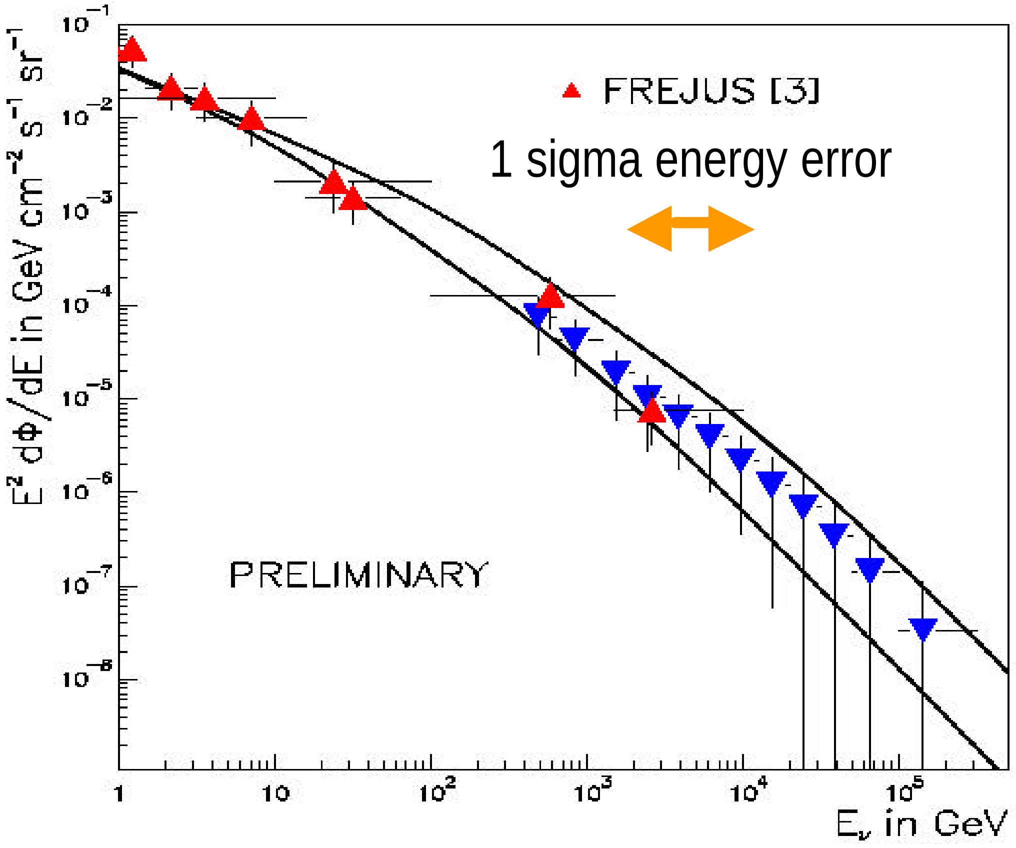
Upgrades: analogue PMT readout ⇒ new DAQ with digital conversion, WFD, dynamic range extended by factor 100, negligible dead time (1-P-264)

Atmospheric neutrinos in AMANDA-II

Atmospheric ν spectrum 570 events (350 upgoing muons/yr)
agreement with Frejus up to 100 TeV
NN energy reconstruction method $\sigma(\log_{10}E)$~0.4-0.6 in 500 GeV-5 PeV
(detector saturation)

γ=3.56±0.20_{stat}
Frejus:
2.66±0.05_{stat}

HE 2.3.6



HE 2.3.11

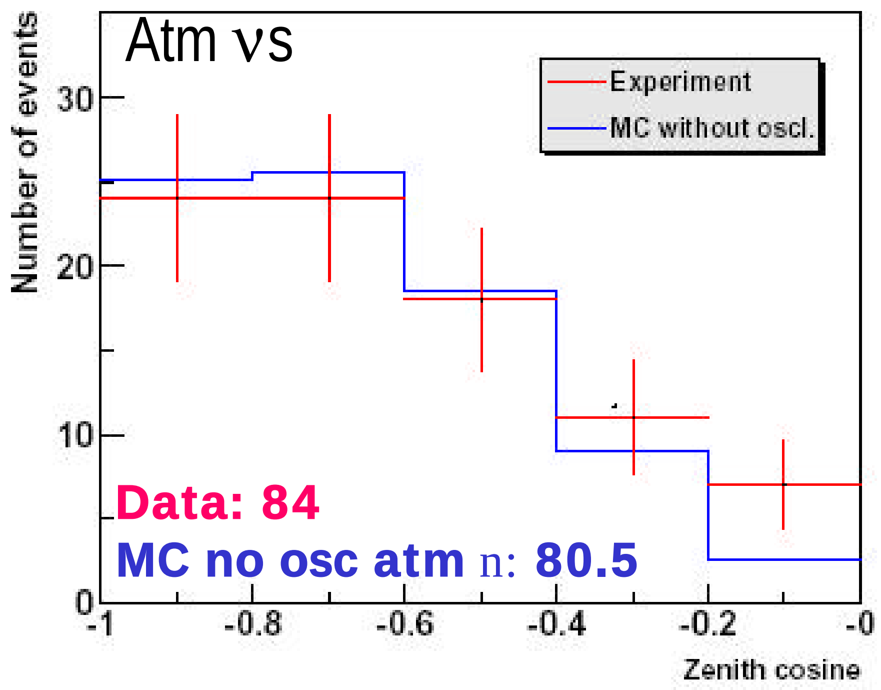
Baikal Neutrino Telescope

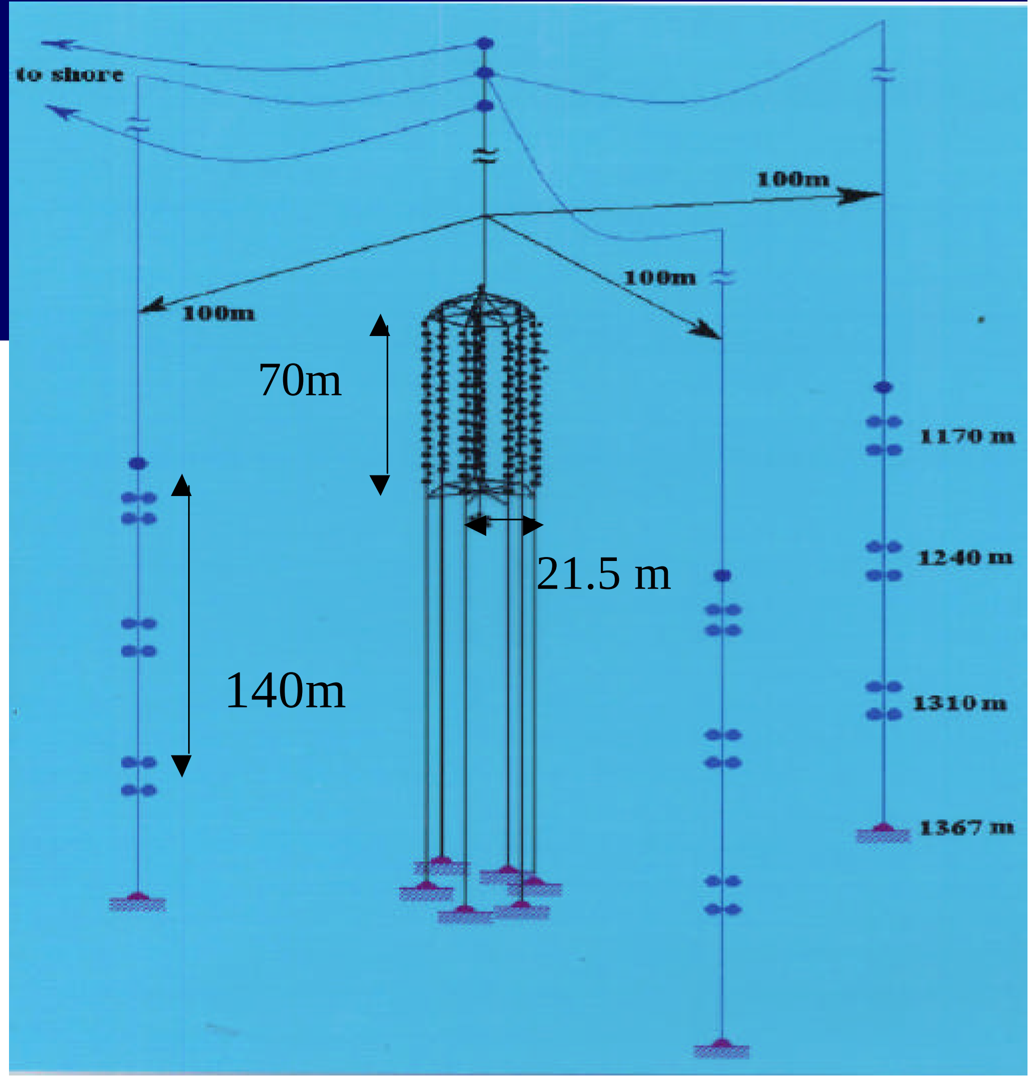
Russia
Germany

1100 m depth in Siberian Lake 3.6 km off-shore, ice platform

192 OMs on 8 strings Ang. res 3° $E\mu_{th}$ ~10-15 GeV
1996-98: 70d NT96 + 234 d NT200 this conference 268 d

Upgrade NT200+: factor 4 sensitivity respect to NT200 to cascades
Mar 03: prototype string with 4 OMs each 70 m





1-P-266

NESTOR

http://www.nestor.org.gr
online measurements

28 km electro-optical cable @ 4000 m depth repaired in Jan 02, counting room fully operational (Pylos)

Basic element: hexagonal floor Φ = 32m rigid arms in titanium, 2 up-down looking 15 inch PMTs

Deployment from ship, all connections in air

1 tower: 12 floors vertically spaced by 30 m

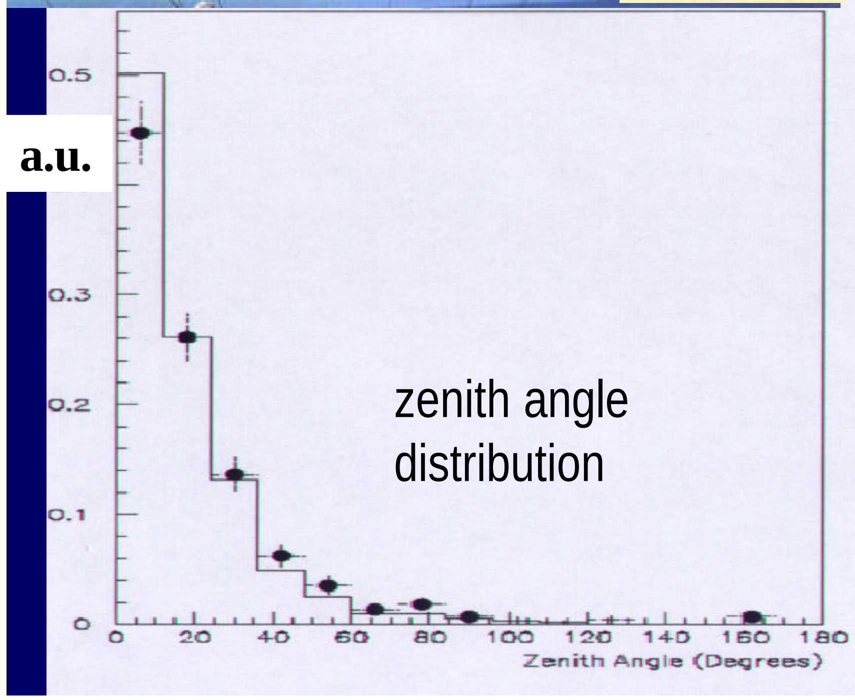
Mar 03: deployed 12 PMT floor Φ = 12m

Time calibrations FWHM < 8 ns

Measured rate ($\geq$ 4-fold coinc. 0.25 pe):

2.61 Hz ± 0.02

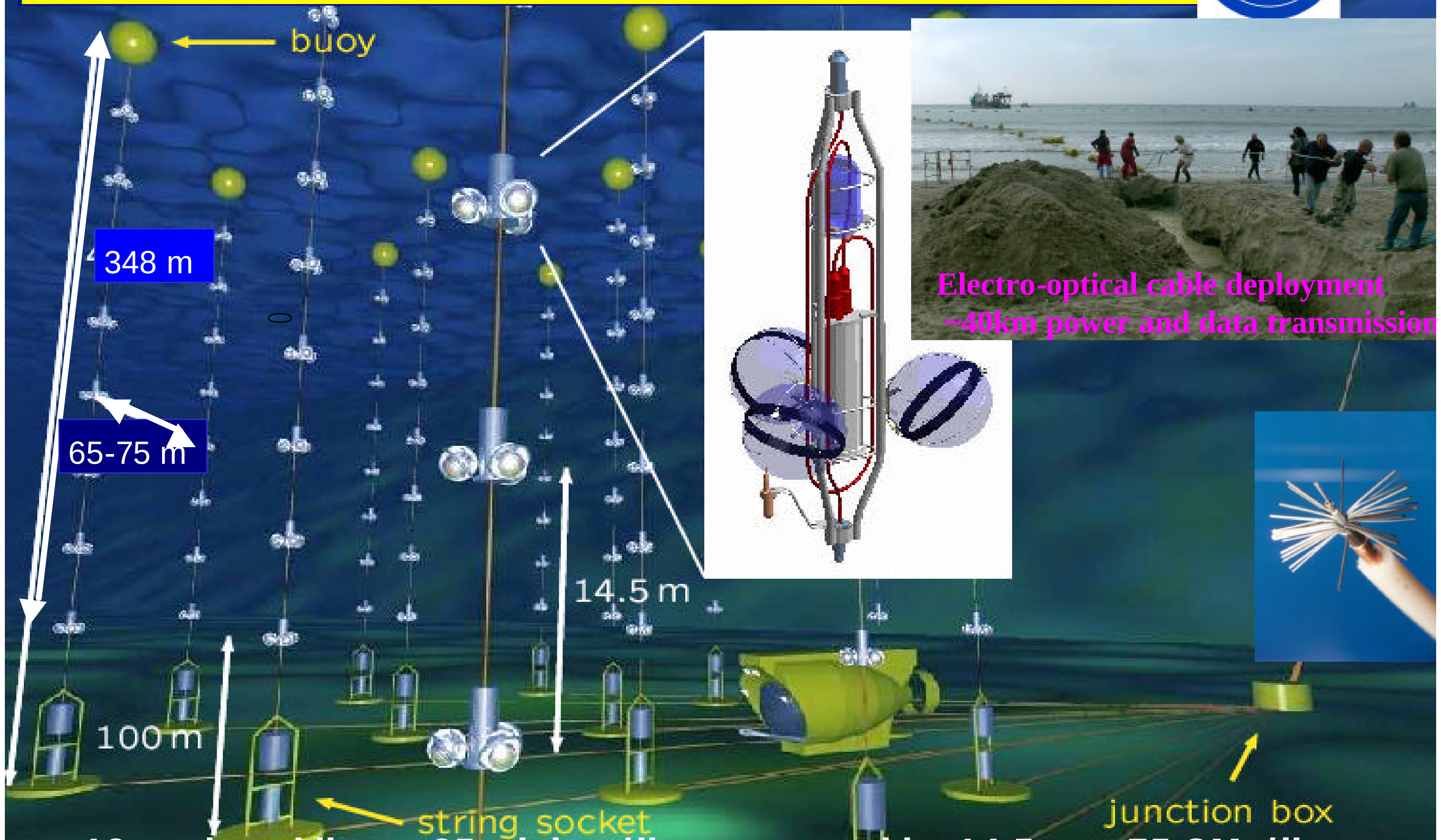
Shape of atmospheric muon cos(zenith) distribution in agreement with expectations



Greece
Switzerland
Germany USA

1-P-270

The ANTARES Neutrino Telescope



12 equipped lines   25 triplets/line separated by 14.5 m Þ 75 OMs/line

900 optical modules containing 10” Hamamtsu PMTs (1-P-291)

Time calibration goal: relative timing between OMs s ~0.5 ns (1-P-292)

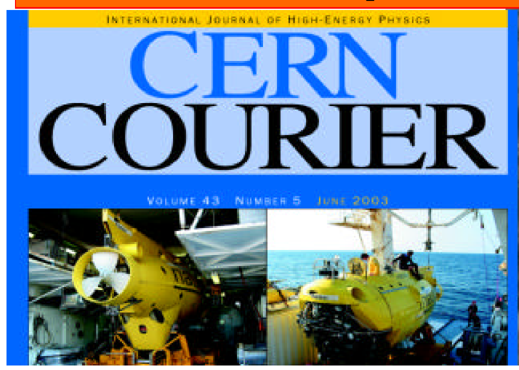
Prototype lines

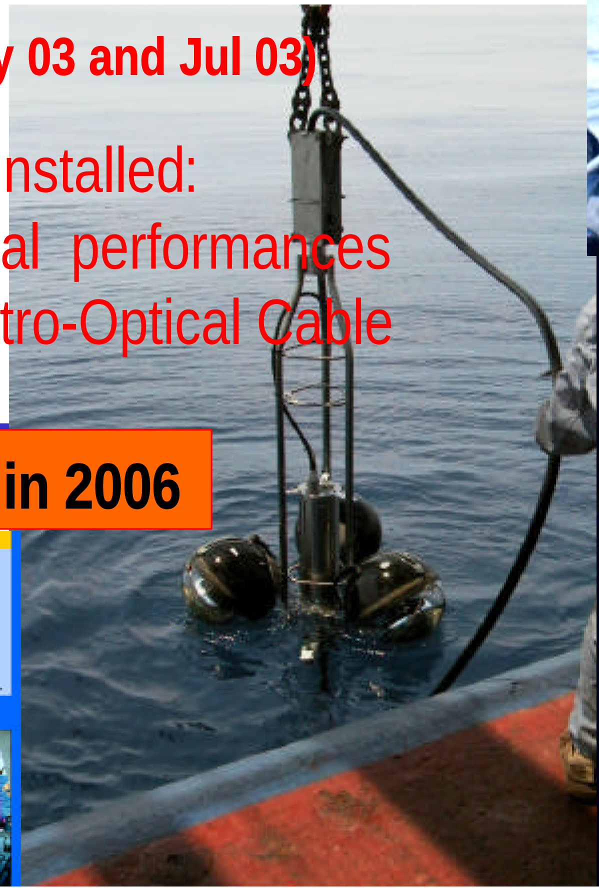
France, Germany, Italy, Russia, Spain, The Netherlands, The United Kingdom

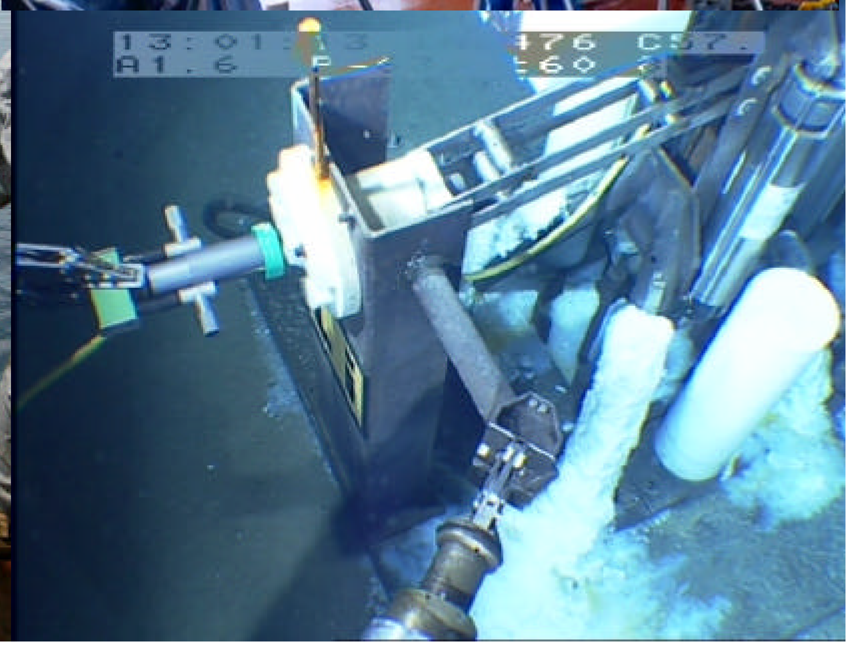
Very successful operations for:

- 2 prototype lines deployment **(Dec 2002 and Feb 2003)**
- submarine cable connections **(Mar 2003)**
- lines recovery **(May 03 and Jul 03)**
- Final components installed: junction box (optimal performances since **Dec 2002),** Electro-Optical Cable **(Oct 2001)**

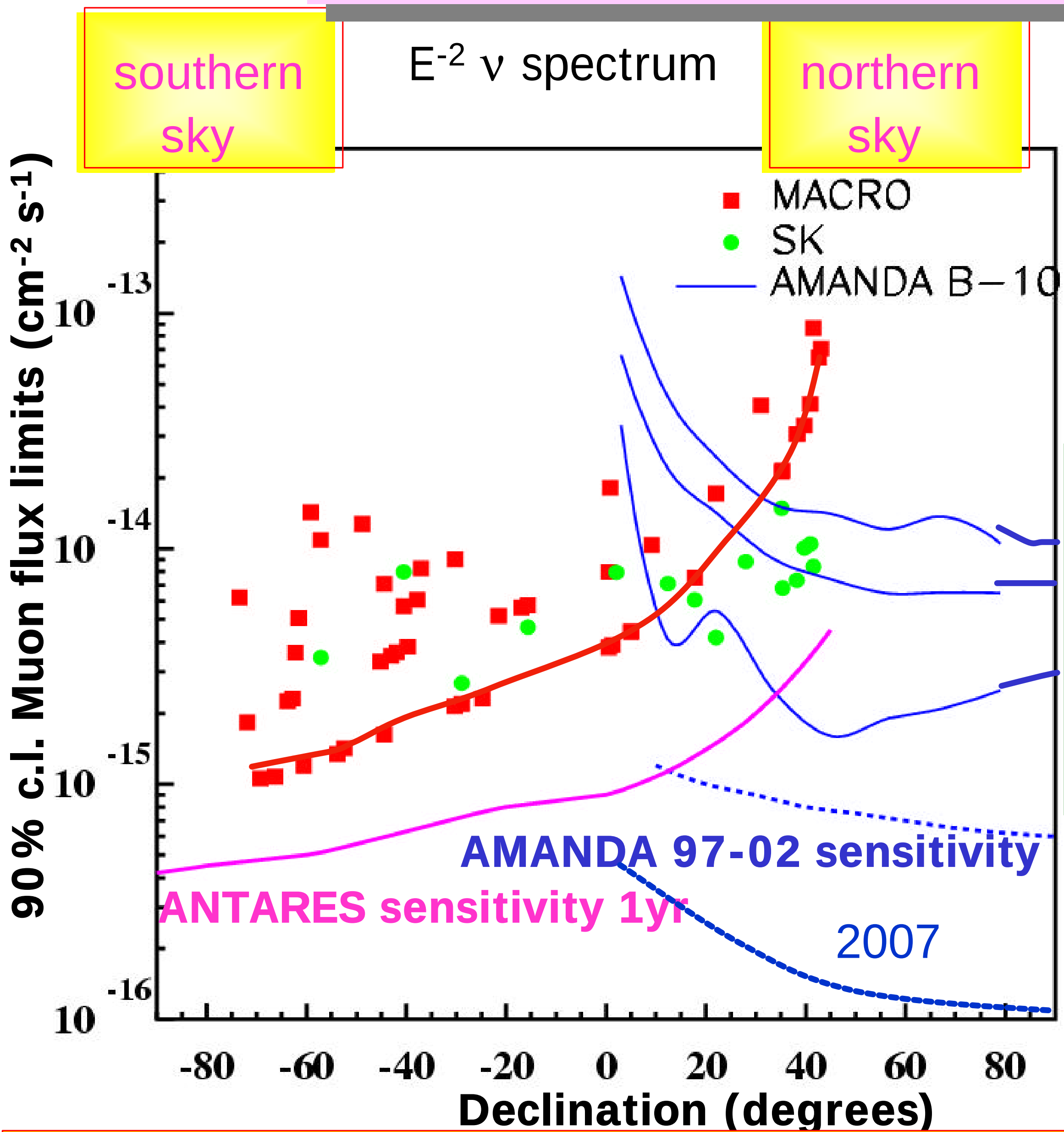
Detector complete in 2006







Point-like sources



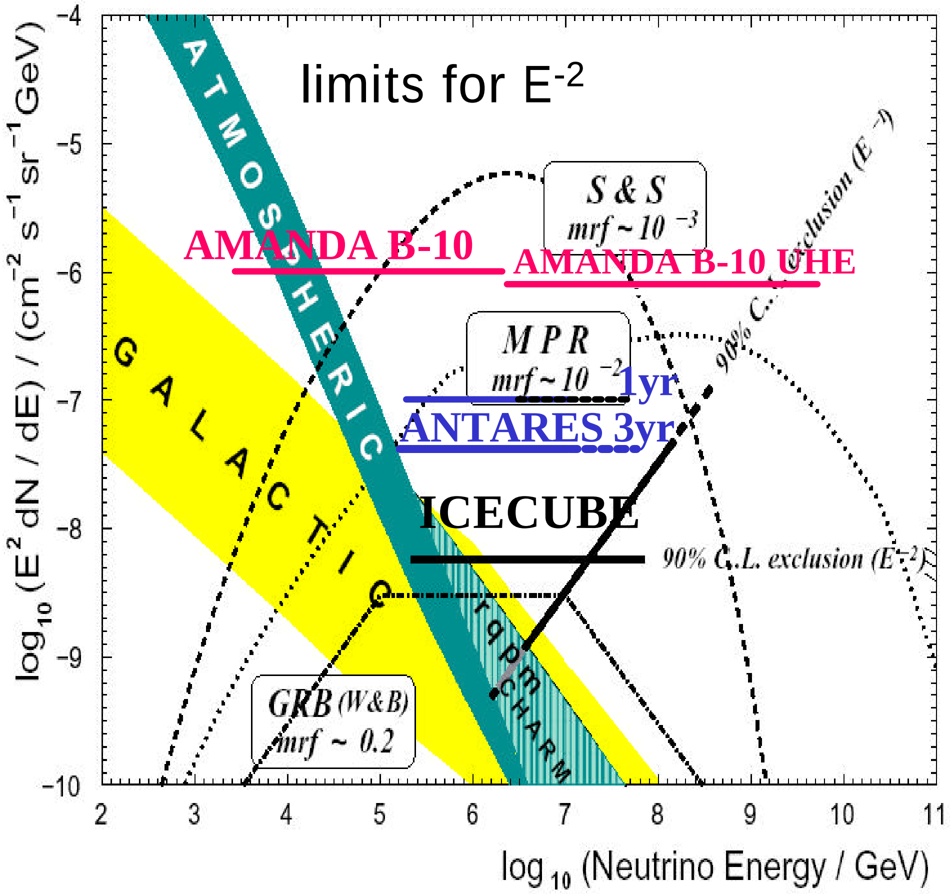
AMANDA II (HE 2.3.5) 197 d
q_{mn}~2.3° 699μ↑ 300 bin grid
(Δδ = 6-10°)
Sensitivity ~flat with d
AMANDA B-10 **(ApJ 583 (2003))**
130 d ang res ~ 3.9°
154 bin grid (Δδ = 8-11°)

SK 2369 μ↑ <Eμ> >3 GeV
4.6 yr 4° half-width cone
ang res ~2° **(HE 2.3.1 HE3.3.5)**
Selects showering sample
354 <En> ~ 1 TeV (354)

ANTARES (HE 2.3.7)
ang. res. 0.15° E_n >10 TeV
const backg grid
Larger potential discovery
for LR unbinned method
compared to binned ones

Final MACRO: 1388 m- <E_m> >1.5 GeV ~6 yrs 3° half-width ang res <1°

Diffuse limits on n_m fluxes (90%c.l.)



ANTARES (HE 2.3.8): E>125 TeV
$3.8\ 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1} (3 yr)

ICECUBE (HE 2.3.12): (USA, Germany, Japan, Belgium,The Netherlands, Sweden,New Zeland, Great Britain, Venezuala)
in 3 yr $4.2\ 10^{-9}$ GeV cm^{-2} s^{-1} sr^{-1}
4800 OMs/80 strings
60 OM/string spaced by 17 m
Instrumented V = 1 km^3
Depth: 1400-2400 m in polar ice
Construction 2004/5 for 6yrs
16/season

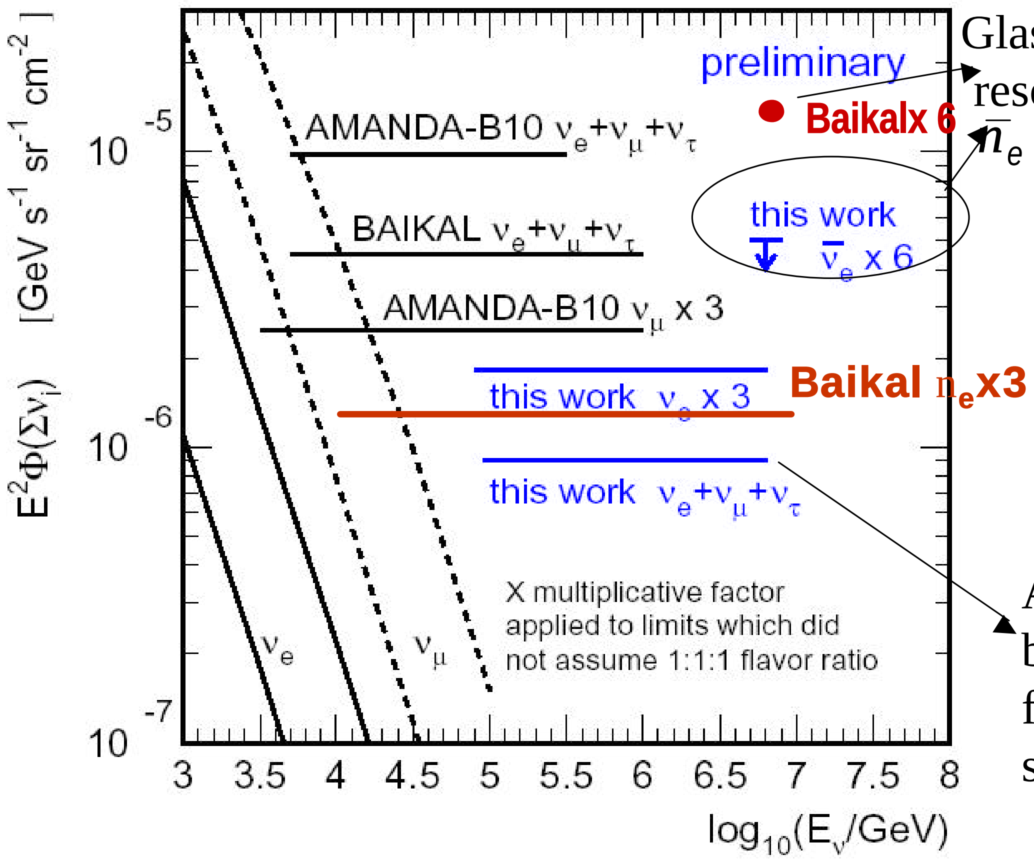
AMANDA B-10 (n_m) (1-P-257): 130 d 6 TeV-1PeV $8.4\ 10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1}
AMANDA UHE (1-P-256): no track required (could also be taus for E >10 PeV R_t >500 m!), only horizontal events not absorbed
134 d 2.5 PeV-5.6 EeV data: 6 Expected Atm m: 8.3 Þ $7.2\ 10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1}
AMANDA II sensitivity:10^{-7} GeV cm^{-2} s^{-1} sr^{-1}

Neutrino astronomy with cascades

Cosmic ν's at surce: ν_e:ν_μ:ν_τ = 1:2:0 (if μ's decay) ⇒ oscillations with atm ν parameters and L > Mpc ⇒ ν_e:ν_μ:ν_τ = 1:1:1 not only a ν_μ astronomy!

AMANDA II 197d (HE 2.3.4): AMANDA-B10 5-300 TeV Þ 80 TeV-7 PeV
better atm m + n rejection data = 2, exp 0.45± 0.5 (atm ms) + 0.1±0.05 (atm ns)
Baikal (HE 2.3.11): 4 ·10^{-7} cm^{-2} s^{-1} sr^{-1} GeV (n_e)

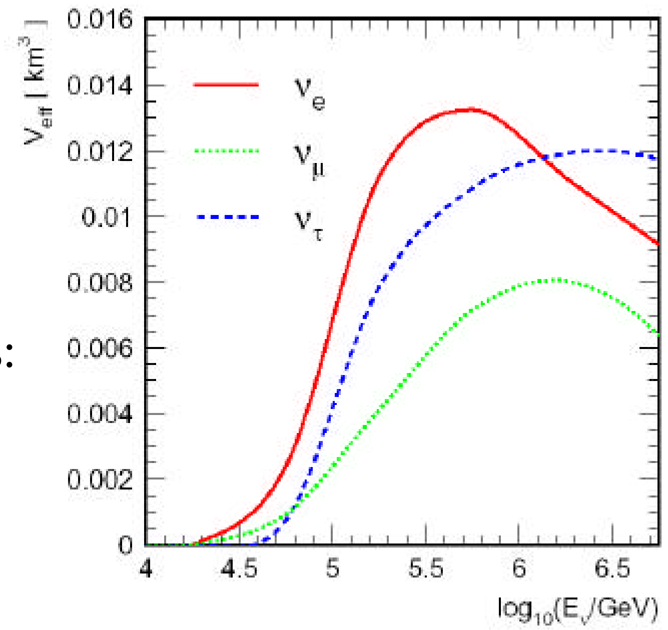
Cascades: em/h showers from ν_e, ν_τ CC and NC



Glashow resonance

$\bar{n}_e + e^- \to W^- \to \bar{n}_e + e^-$

All flavors: better than factor of 2 sensitivity



HE 2.3.10

RICE

USA

Concept: $n_{e,t}$ induce em cascades producing a few ns radio pulses with power concentrated around Cherenkov angle (Askarian effect, 1962)

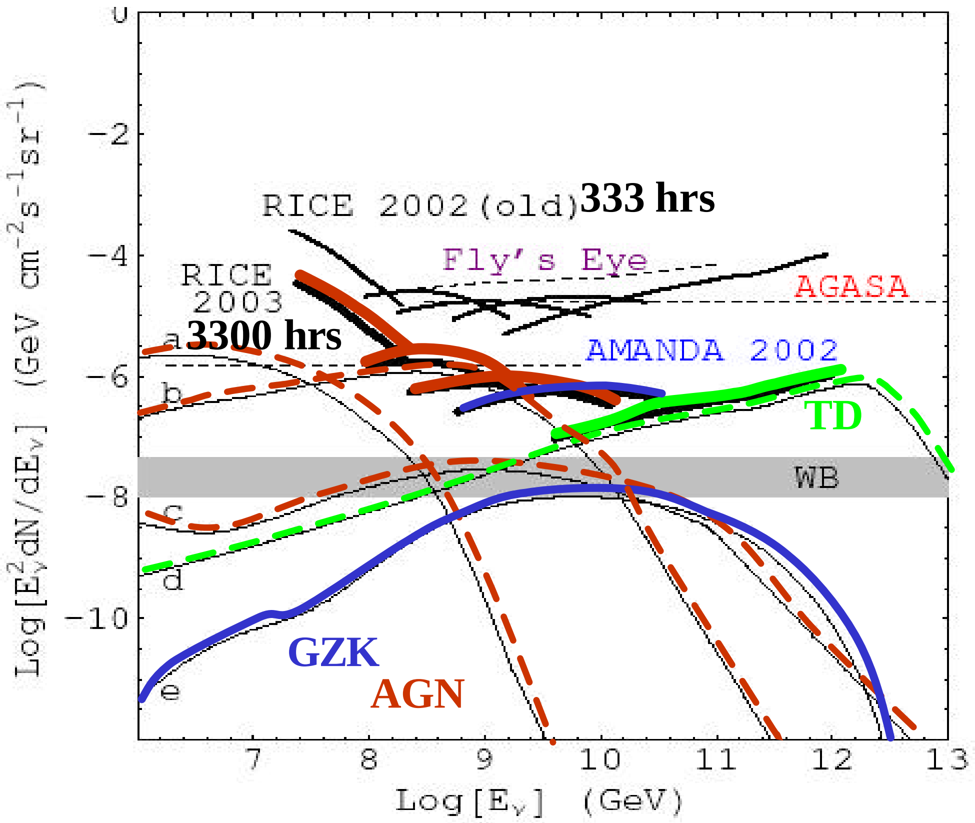
16 radio receivers in (200m)³ at 100-300 m depths in AMANDA holes

Frequency bandpass ~200-500 MHz (VHF) **Attenuation length > 1 km**

Tests and data since 1996

5 candidates pass quality cuts: spurious hits are rejected through scanning Þ close to surface (anthropogenic activity)

VERY COST EFFECTIVE TECHNIQUE! CAN BE EXTENDED TO LARGE VOLUMES!



It would be a pity to miss the opportunity to install receivers in ICECUBE holes!

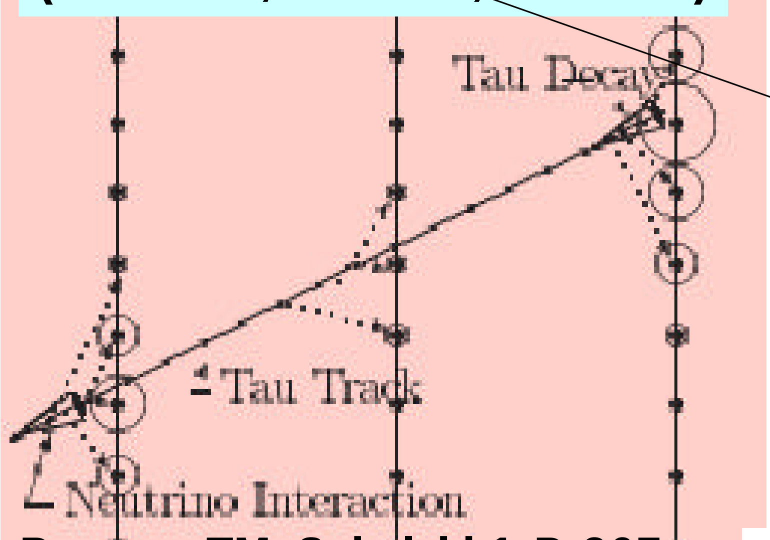
1-P-260: in situ calibrations: spectral index vs depth (ICRC2001 only predicted)

Attractive media: Antartic ice (RICE, ANITA) or geological salt domes (SalSa), few outer meters of Moon surface (GLUE)

HE 2.3-2.4 UHE n_t observation

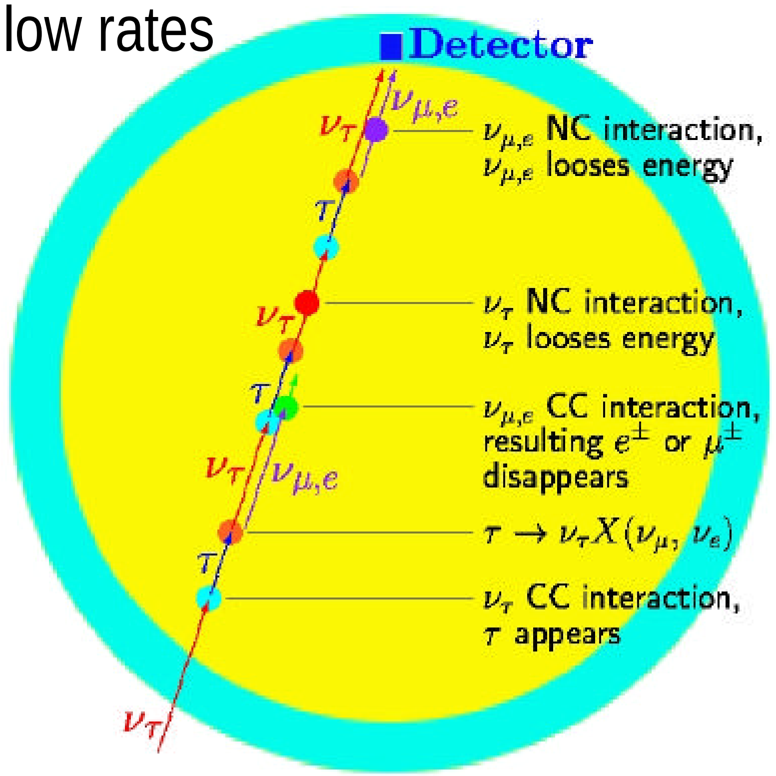
- Motivation: ν_μ absorption and ν oscillations
- ν_τ regeneration process thanks to τ decay
- Flux of τ leptons remarkably larger than μ ones at vertical due to absorption, but larger energy losses than for horizon $\Rightarrow$ pile-up at lower energies where τ decay length small (~50 m @ 1 PeV) and larger atm ν background, downgoing events dominate
- Secondary contribution small for typical spectra (GZK & Z-burst νs, AGNs, E^{-2})
- Background free topology of double-bang low rates

Double Bang ~2-5 /yr/km^3
(Protheroe, 97 blazar, MPR limit)



Bugaev, TM, Sokalski 1-P-267

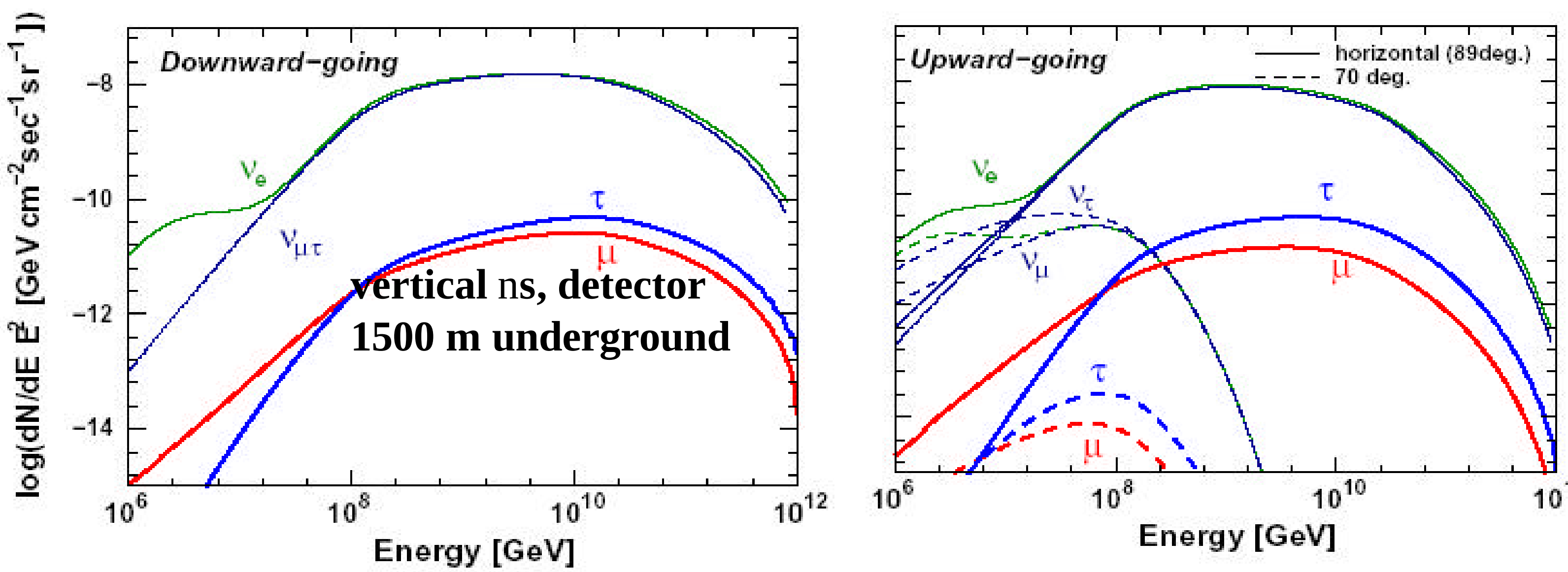
n_m, n_e secondaries contribute 57% at vertical, 2% at horizon



HE 2.3-2.4 EHE m and t observation

Yoshida (1-P-282): GZK ν spectrum, propagation including $\nu_\tau \rightarrow \tau \rightarrow \nu_\tau\ \nu_\mu\ \nu_e$ energy losses and showers from stochastic processes, also heavy lepton pair production ($\mu \rightarrow \tau^+\tau^-$)

$N_{\mu,\tau}$ (E>0.1 EeV) ~ 1-50/yr/km^3



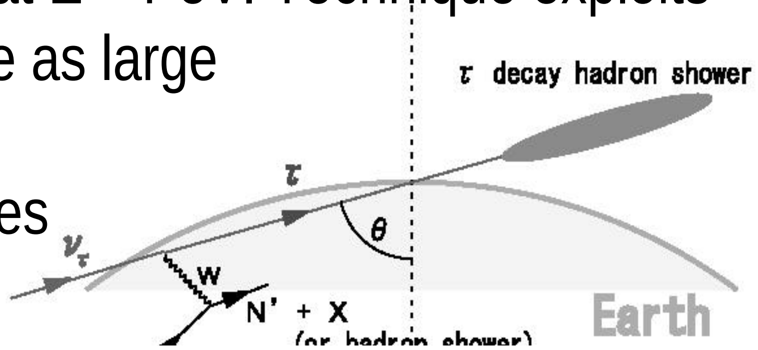
Spectra of GZK ns and secondary m an t produced in the Earth Downgoing dominate

Dutta et al (1-P-276): electron contribution from from τ decay negligible > 10^8 GeV compared to ν_e CC. Relevant for radio detectors (RICE, ANITA at 10^6-10^8 GeV have small effective volume)

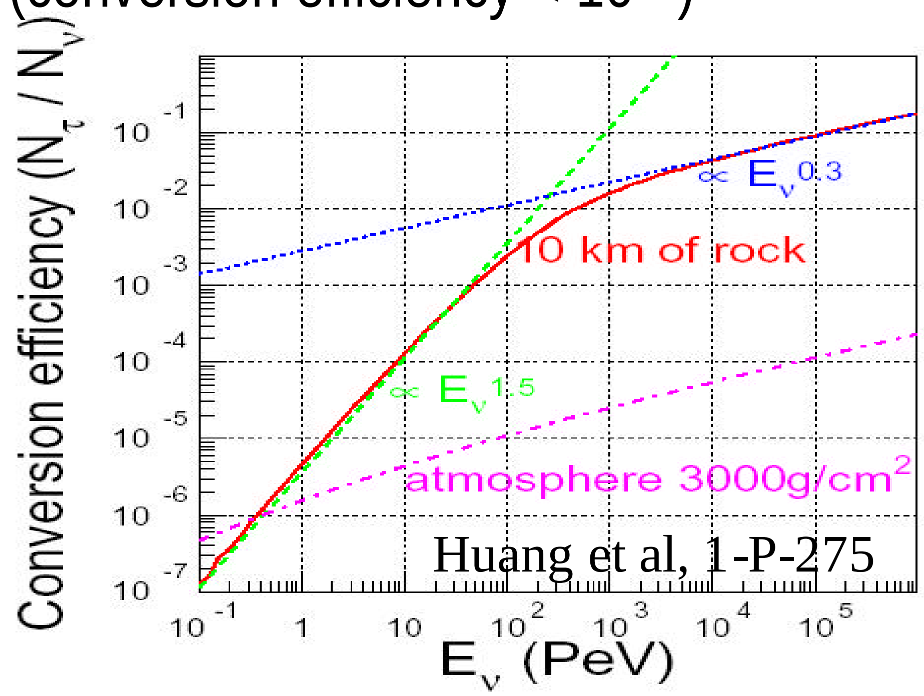
Earth skimming t leptons from UHE n_t

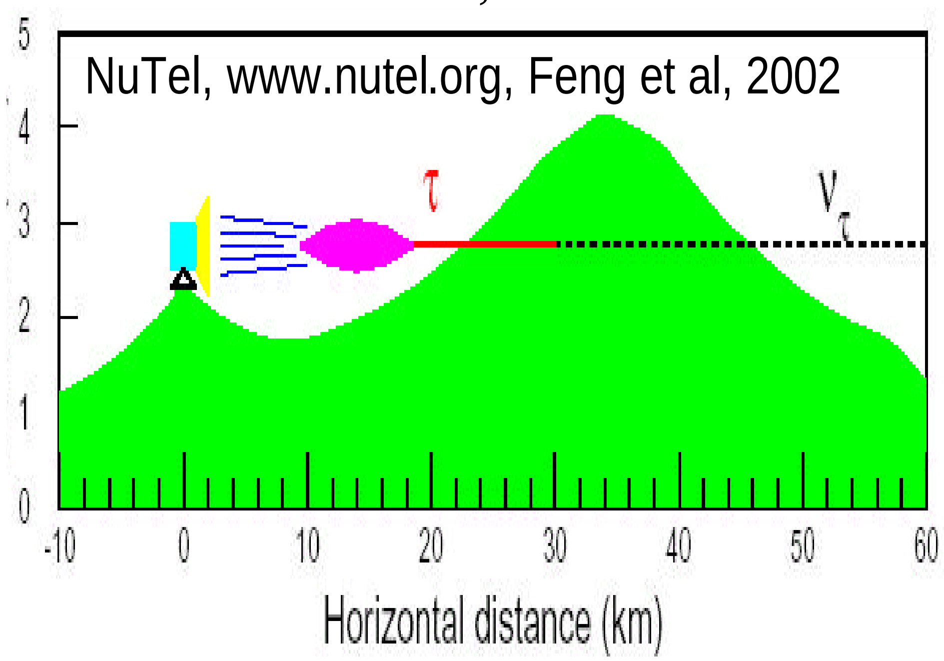
UHE νs: E > 10^8 GeV L_{int} < 2000 km we ⇒ only horizontal or downgoing νs

Earth skimming τ leptons (Huang et al, 1-P-275, Athar et al, HE 2.4.3): cords of length ~L_{int} convert ν_τ to τs that travel ~10 km in Earth at E > PeV. Technique exploits Earth as large volume converter and atmosphere as large volume detector. ν's emerging from mountains (Cao et al, HE 2.3.13): >1PeV: 10-20 km rock reduces CR background+more efficient than atmosphere (conversion efficiency < 10^{-3})



ASHRA, HE3.4.5





HE 3.3 Dark Matter, Astroparticle Physics and Cosmology

Indirect search for dark matter: annihilation of WIMPs leads to $\bar{p}$, $\bar{D}$, e^+ , γ's (satellites, balloons, Cherenkov) and ν's (neutrino telescopes)

Best candidate: LSP in MSSM $c = a\tilde{g} + b\tilde{Z} + c\tilde{H}_1^0 + d\tilde{H}_2^0$

Signatures: excess respect to secondary fluxes

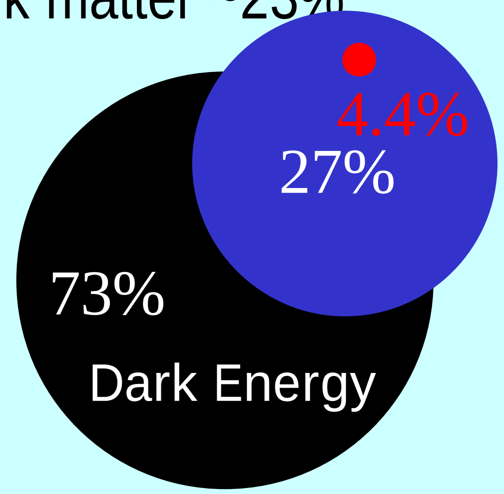
$\bar{p}$: Excess < 1GeV or > 10 GeV
$\bar{D}$: excess < 1 GeV
e^+ : Structure in Spectra above few GeV
γ : Energy Spectra differ from "power laws", or monoenergetic lines detection $\chi^0{}_1\chi^0{}_1 \rightarrow \gamma\gamma,\ Z\gamma$

For diffuse fluxes secondary background critical in scenarios where DM is not clumpy

AMS (HE3.4.1, HE3.4.2, R. Battiston talk): only experiment that should measure all channels up to hundreds of GeV

The picture after WMAP

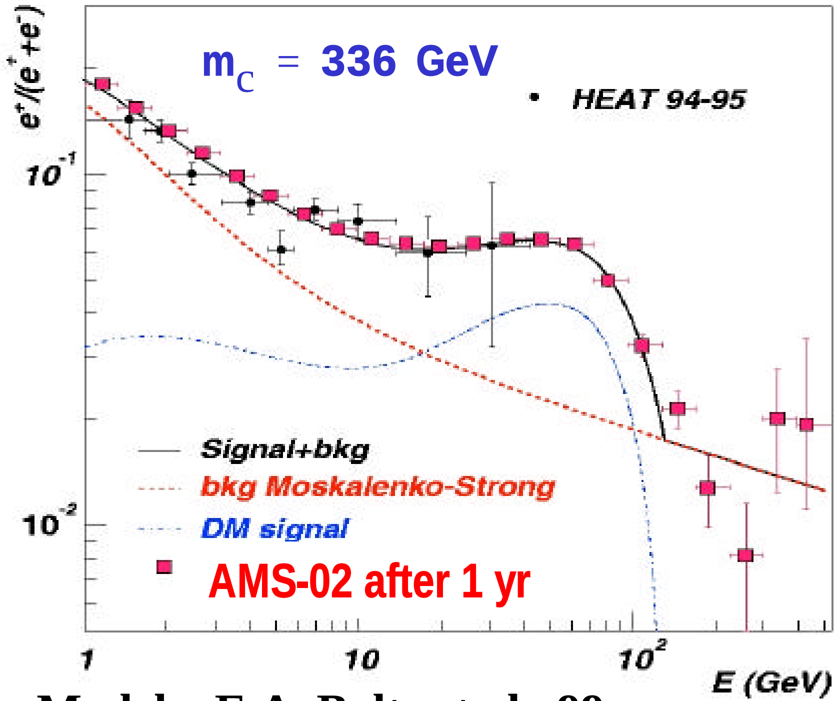
Matter
Baryonic 4.4 (agreement with BBN)
νs < 0.15% (95%cl)
Cold Dark matter ~23%



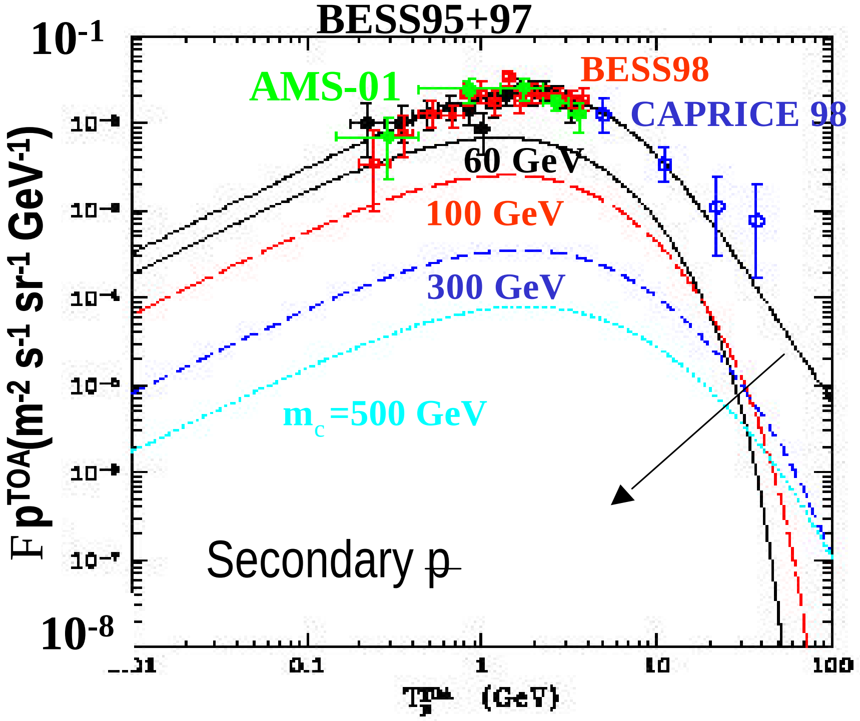
Turner highlights

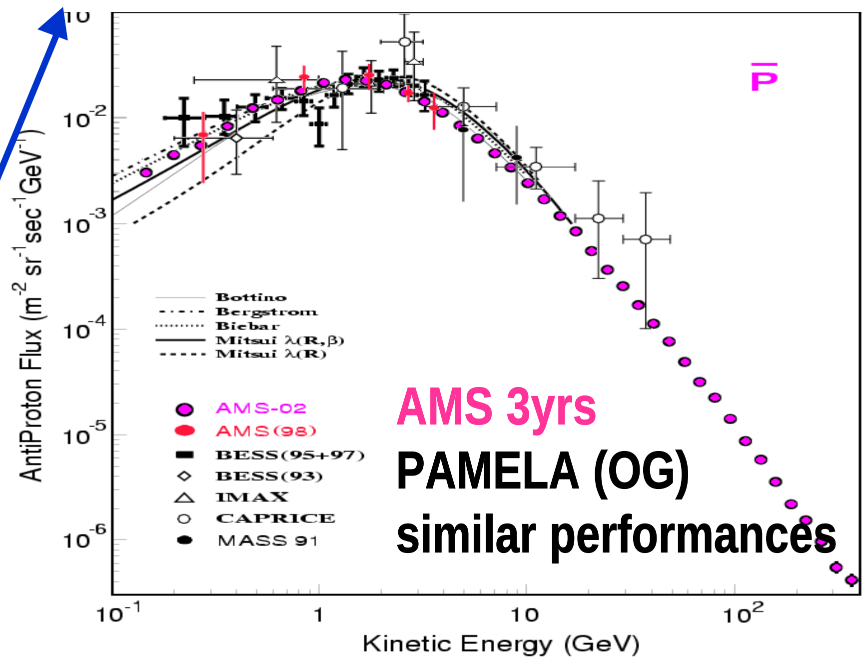
Dark matter with e^+ and $\bar{p}$

HEAT 94-95 : a bump in energy at 7 GeV no standard astrophysical interpretation of e+/e- energy distribution



Models: E.A. Balts et al., 99





Donato et al., 2-P-290: calculations of primary flux spectra including contribution from χ annhilation in Galaxy. Critical detection among background

DM Searches with g's

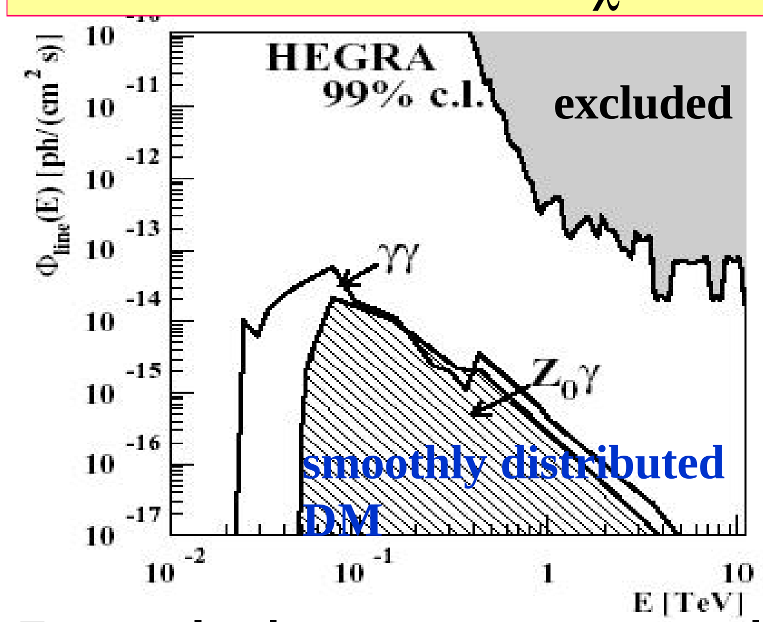
Photons: **diffuse γ radiation in Galaxy from π^0 (CR interactions in interstellar medium) + decay, inverse Compton and bremsstrahlung**

WIMP annihilation in Galactic halo: **similar spectrum but sharp cut-off for** $E_\gamma \sim m_\chi$; also **monoenergetic lines** $\chi\chi \rightarrow 2\gamma$ **and** $\chi\chi \rightarrow \gamma Z$

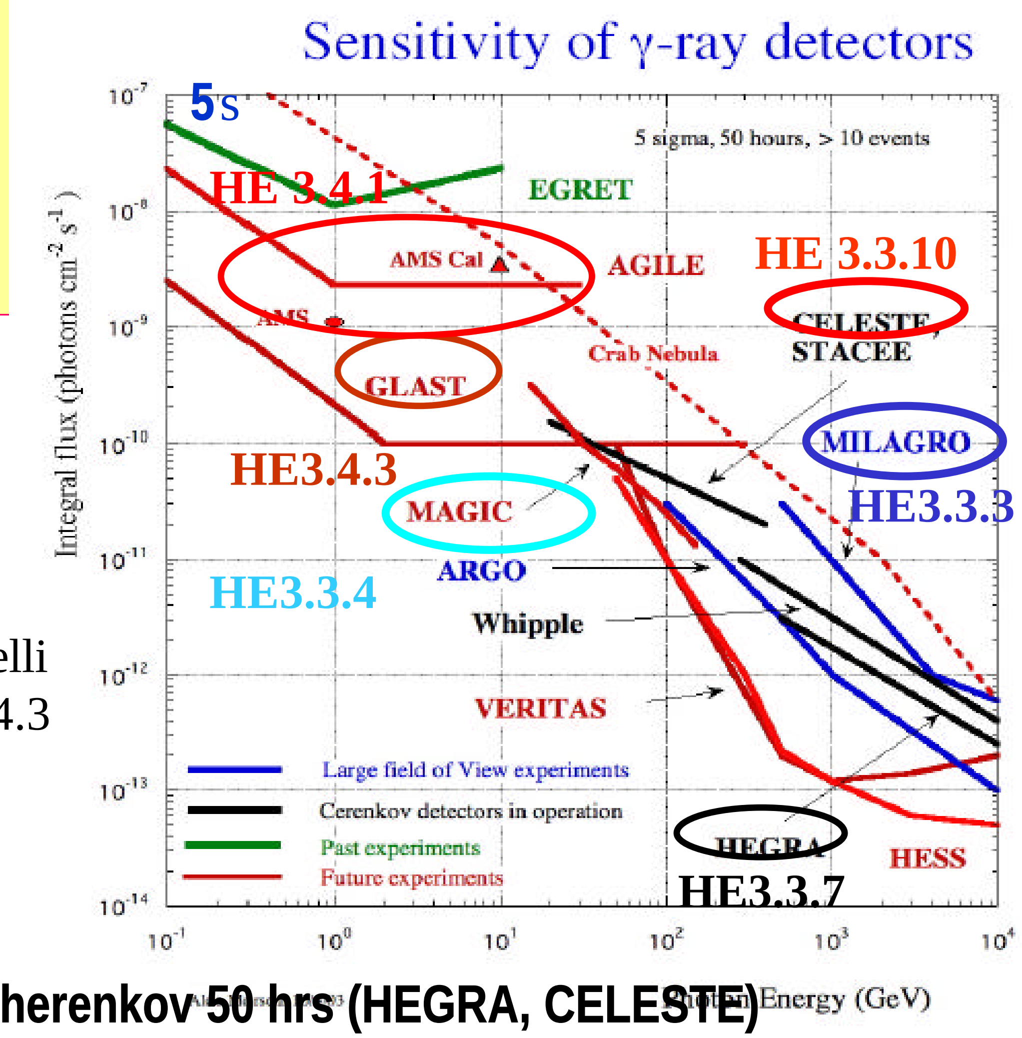
HEGRA (HE 3.3.7) E_{th} = 500 GeV

DE/E=10%: limits for M31

Milagro (HE3.3.3) limits for near-solar enhancement of χ density



Morselli HE3.4.3

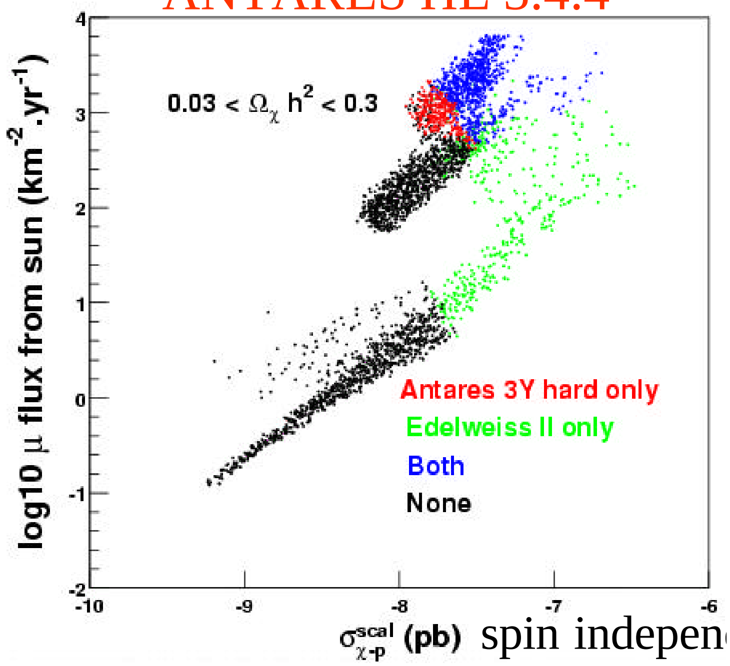


Extra-galactic source average sensitivity

Large FoV (GLAST, Milagro, AMS): 1 yr, Cherenkov 50 hrs (HEGRA, CELESTE)

Indirect DM with ns

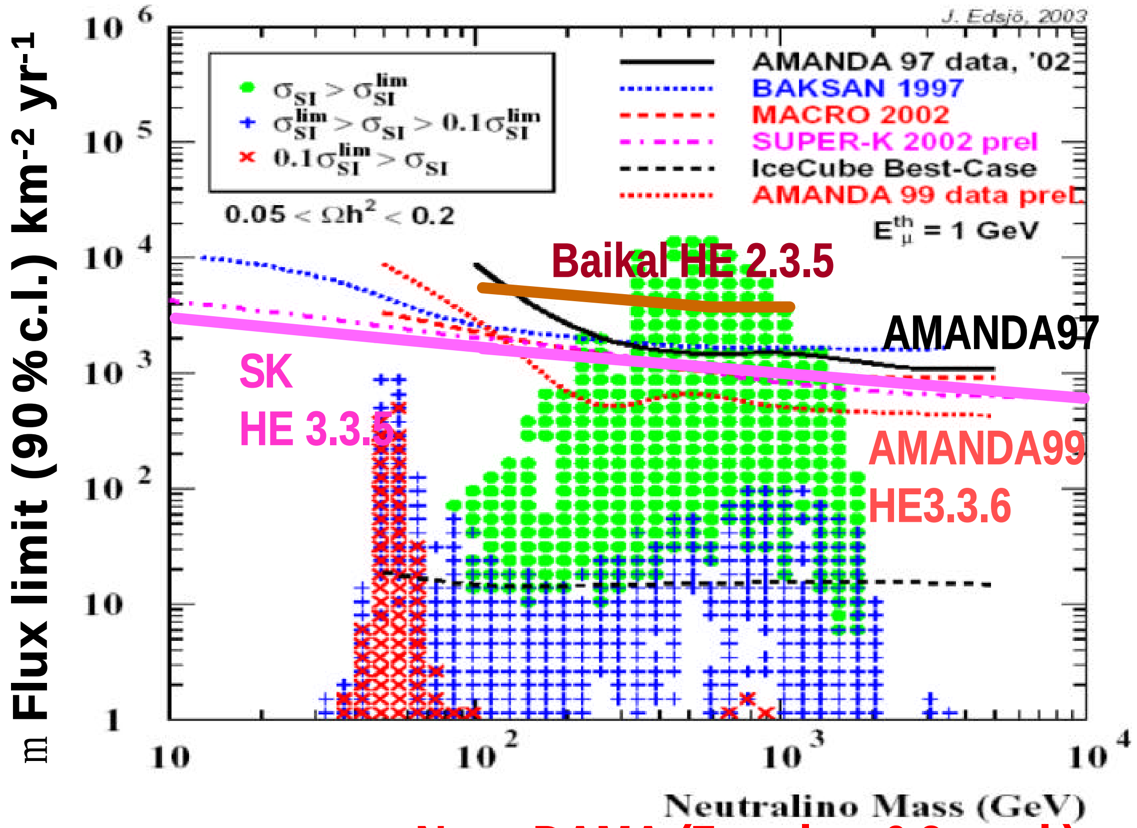
ANTARES HE 3.4.4



spin indepen

$\Omega_\chi^2 h^2$<~0.15 ecluded by WMAP

Neutralinos in Earth



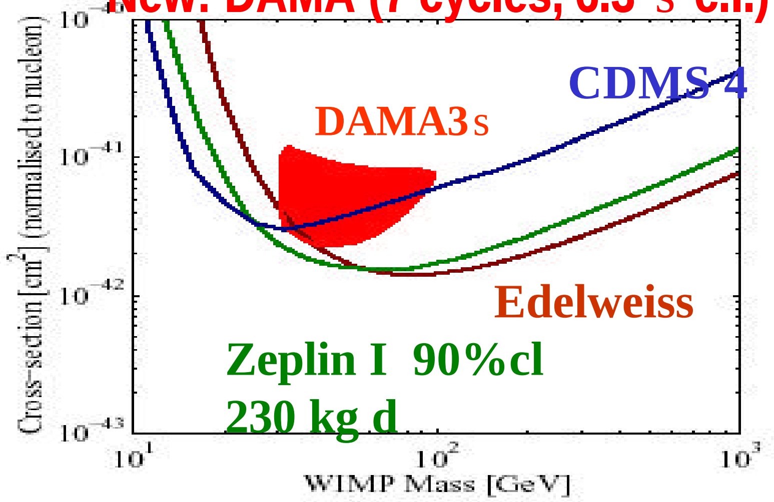
Direct searches (nucleon recoil in low backgr experiments) complementary parameter space

3 running detectors at Bulby Mine (HE 3.3.9)

NaI Advanced Detectors, ZEPLIN (LXe)

DRIFT TPC: directional WIMP signature

New: DAMA (7 cycles, 6.3 s c.l.)



HE 2.5.2

HE 2.5 New projects: ICARUS

Imaging Cosmic And Rare Underground Signals

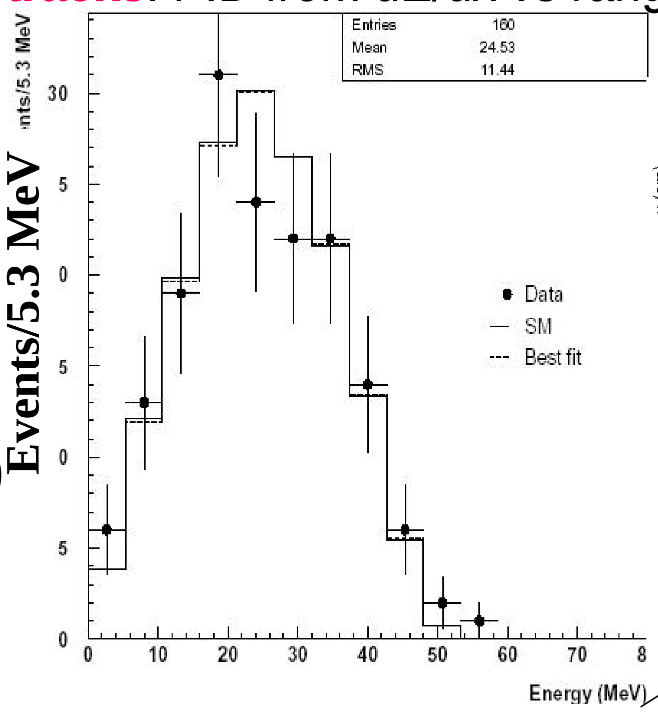
ITALY
SWITZERLAND
CHINA
POLAND
USA
SPAIN

LAr TPC technique: continuously sensitive modular ‘bubble chamber’+ electronic readout: ionization e^- drift in noble gas (msec) over large distances (meters) in highly purified LAr in E field

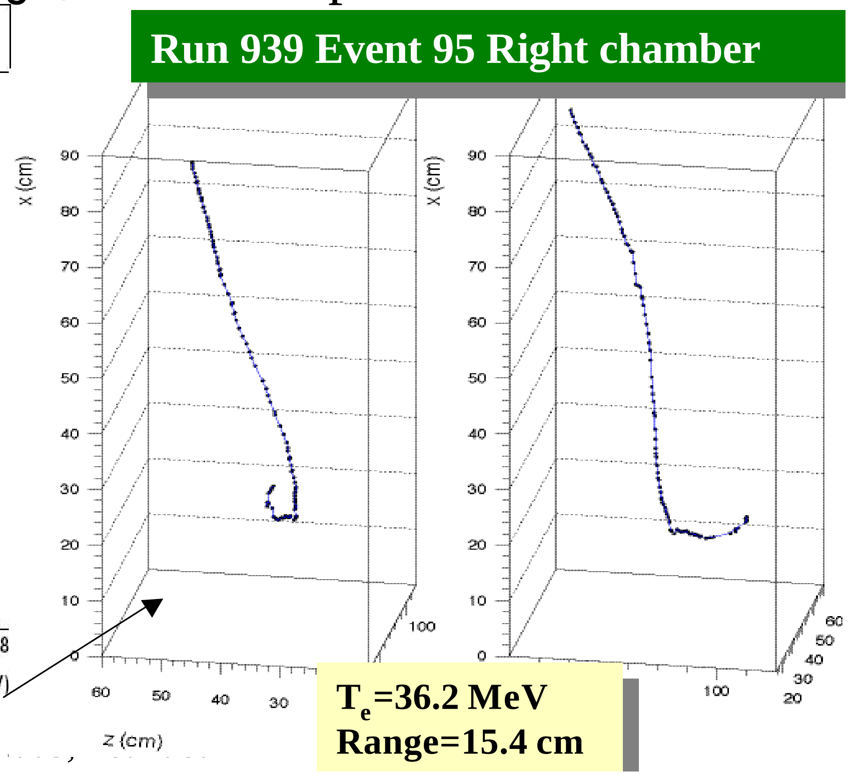
3D imaging: drift time+readout planes; scintillation light on PMTs: t_0+ trigger

Final goal: 3 kton at LNGS 2 T1200+T600+ μ spectrometer
(T1200+T600 founded) T600 tests in Pavia: 2 ×300 t TPCs, max drift time 1ms (e^- lifetime > 10 ms), 3 readout planes, 54000 wires, 3mm pitch
20m μ tracks. PID from dE/dx vs range, excellent **e/π^0 discrimination**

Physics program
p decay atm+
solar +SN νs
CNGS
ν cross sections
T3000 5 yr: gold channel (τ → e, ρ)
max mix
1.6-2.5· 10^{-3} eV^2
8-18 ν_τ CC



stopping μ and Michel e^-



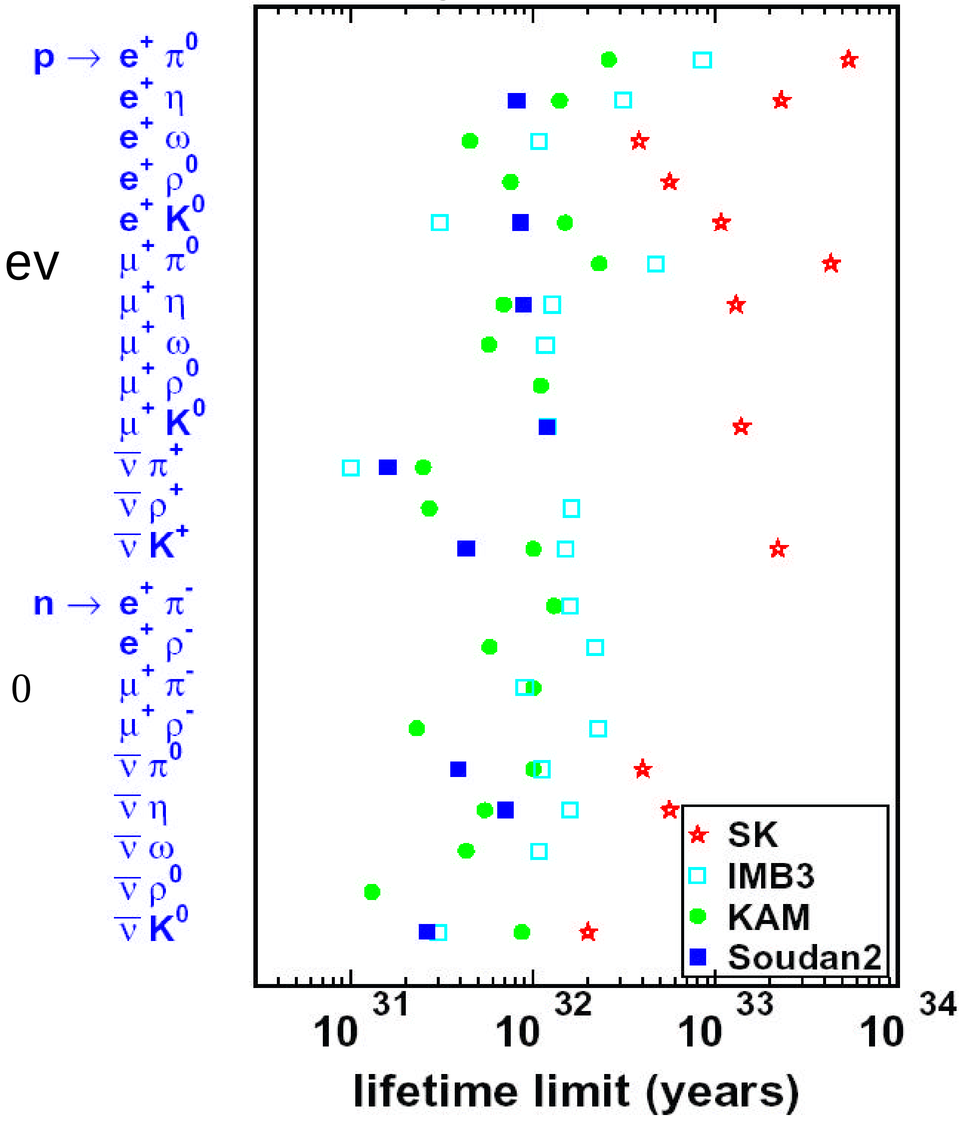
HE 3.2 Proton decay and new phenomena: experiments and theory

Super-Kamiokande, HE 3.2.1

Super-Kamiokande: most sensitive search on nucleon decay
No candidates, background level ~0.1 ev

91.6 kt yr: >5.4 · 10^{33} yr $p \to e^+\pi^0$
>2.2 · 10^{33} yr $p \to \bar{n} K^+$

$m^+ n, p^+ p^0$



Conclusions

- The interest on ν physics is still very high
- After so many interesting results refinements are needed to determine more precisely the parameters governing the atmospheric and solar ν sectors

solar U_{e1}, U_{e2} « q_{12} CHOOZ U_{e3} « θ_{13}

MNSP matrix

atmospheric U_{e3} « q_{13} U_{m3},U_{t3} « q_{23}

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{13}s_{23}e^{i\delta} & c_{12}c_{23} - s_{12}s_{13}s_{23}e^{i\delta} & c_{13}s_{23} \\ s_{12}s_{23} - c_{12}s_{13}c_{23}e^{i\delta} & -c_{12}s_{23} - s_{12}s_{13}c_{23}e^{i\delta} & c_{13}c_{23} \end{pmatrix}$$

- No observation of SN (after Kamiokande and IMB) or astrophysics HE ν sources, but AMANDA has 8×more days.
- ICECUBE deployments starts 2004-5. There is interest in a km^3 array in Mediterranean unifying current efforts (ANTARES, NESTOR, NEMO-RD,...)
- Radio technique is very 'cost effective', needs more investigation but RICE results are promising
- After WMAP results, cosmology entered a precision era. No evidence for CDM particles (neutralinos); only positive signal (modulation signal in DAMA 7 cycles, 6.3 σ c.l.) needs to be understood model independently