Neutrino physics - today and tomorrow

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FCAL Collaboration Meeting, 13.02.2006

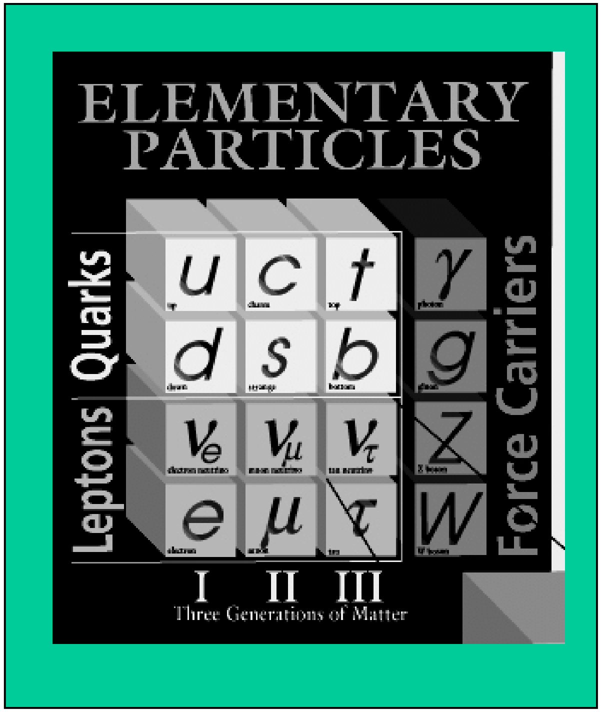
Neutrino oscillations

Absolute masses of neutrinos

Dirac or Majorana particle

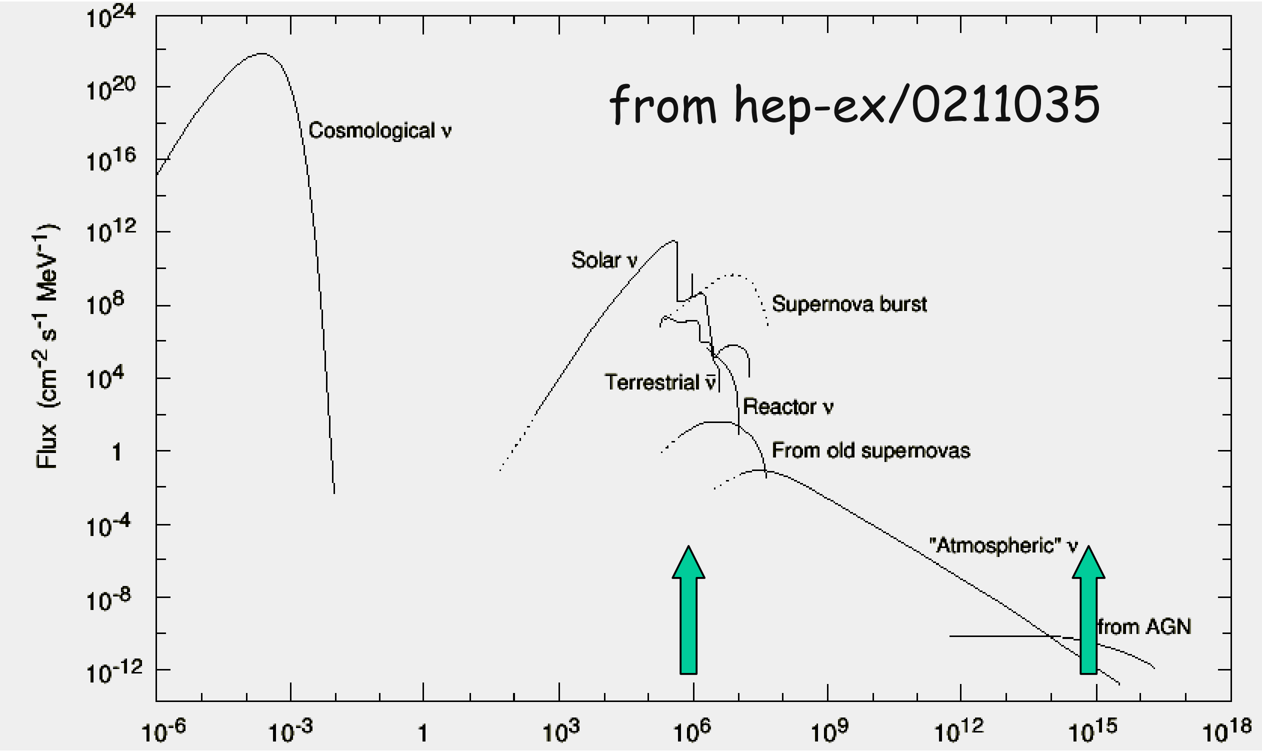
Astrophysical UHE neutrinos

Neutrino basics



Three light active neutrinos: ν_e, ν_μ, ν_τ - result from LEP, if others then sterile

Oscillations: studied with solar, reactor, atmospheric and accelerator neutrinos



from hep-ex/0211035

Neutrino oscillations – one page summary

1998 - 2002 - romantic era of great discoveries

1998 SuperKamiokande - atmospheric anomaly explained
by the ν_μ -> ν_τ oscillations
2002 confirmed by the long base accelerator experiment K2K
2001-2002 SNO solves the 35 years old solar neutrino puzzle
by the ν_e -> $\nu_{\mu,\tau}$ transmissions
Dec 2002 KamLAND shows that reactor anti-ν_e's oscillate like solar ν_e's

from 2003 onwards - realistic era of precise measurements

- precise determination of the oscillation parameters and neutrino mixing matrix elements
- solving mass hierarchy problem

LBL accelerator (on-, off-axis) and reactor expts, superbeams, niu-factories, β-beams, bigger and improved detectors for all kinds of neutrino experiments

Neutrino oscillations primer

In the two-neutrino oscillation scheme with two flavour eigenstates α and β and two mass eigenstates 1 and 2, the probability that neutrino of flavour α transforms into neutrino of flavour β:

$$P(\nu_\alpha \to \nu_\beta) = \sin^2 2\theta \sin^2\left(1.27\Delta m^2 \frac{L}{E}\right)$$

Appearance experiment:

$$P\left(\nu_\alpha \to \nu_\beta\right) \geq 0$$

Disappearance experiment:

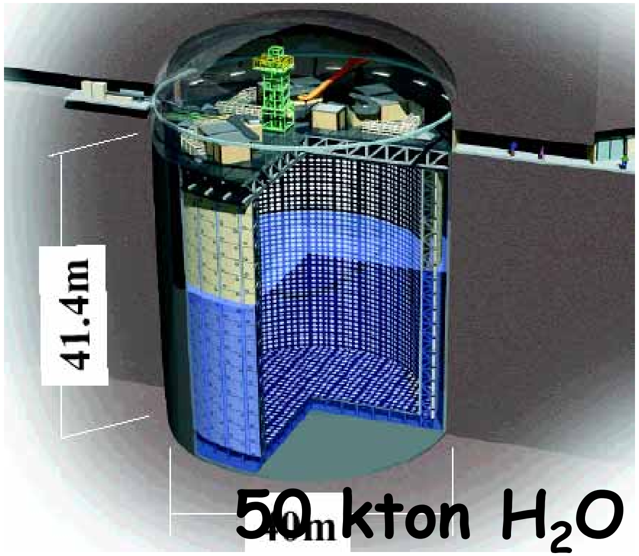
$$P\left(\nu_\alpha \to \nu_\alpha\right) \leq 1$$

Matter effects: the same formulae for probabilities like for vacuum oscillations but effective masses and effective mixing angles

Neutrinos are born in weak interactions as flavour eigenstates but propagate in vacuum or matter as mass eigenstates

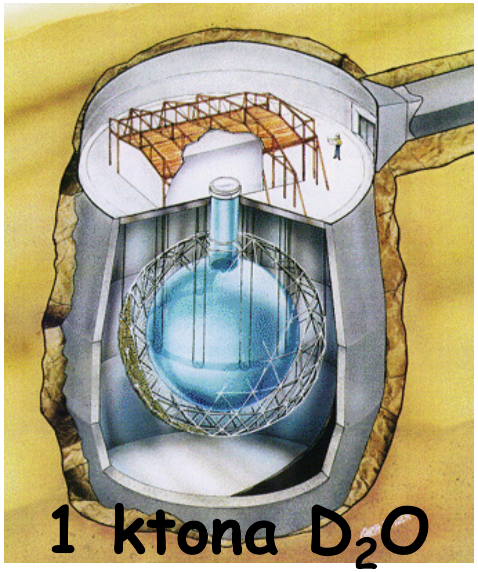
Heros of the period 1998-2002

- Solid experimental evidence for neutrino oscillations coming from the SuperKamiokande, K2K, SNO and KamLAND experiments



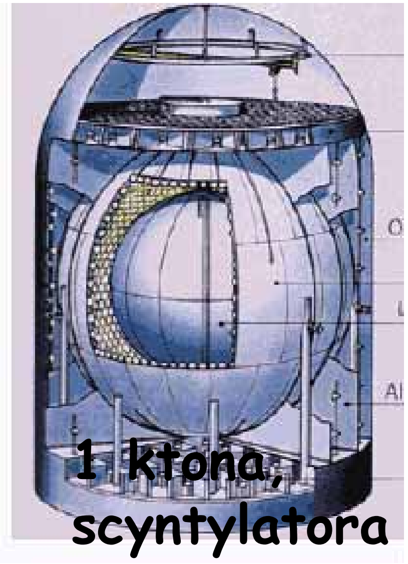
50 kton H_2O

SuperKamiokande



1 ktona D_2O

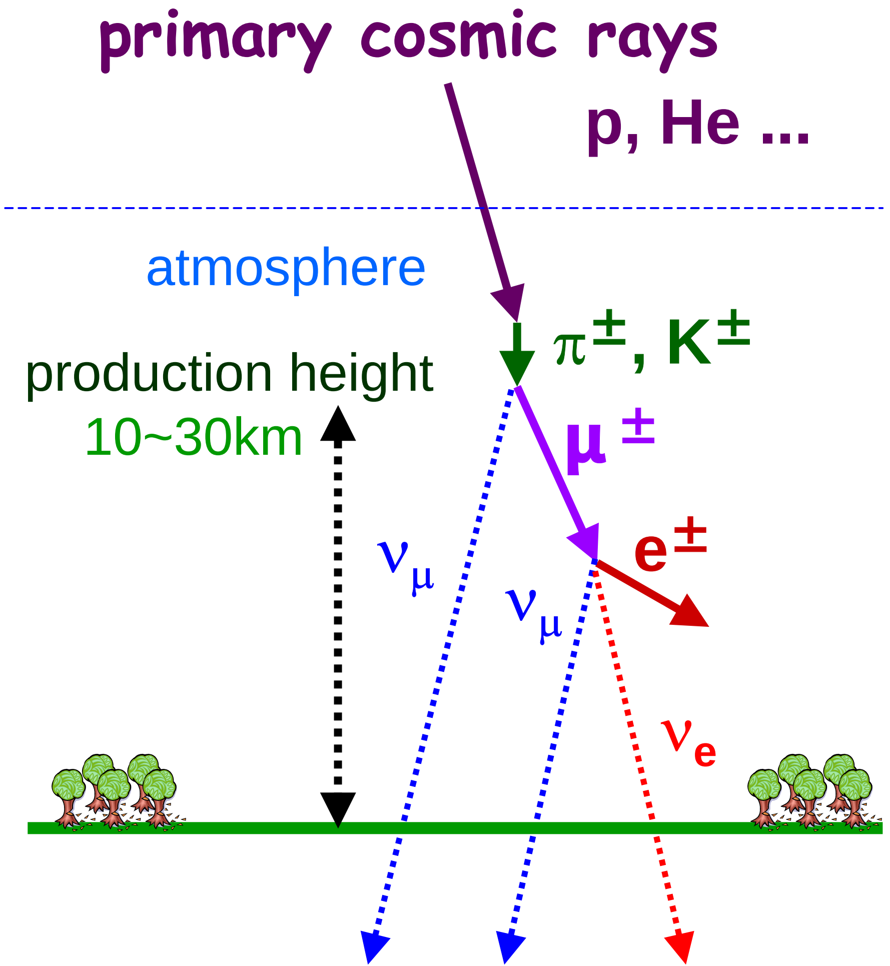
SNO



1 ktona, scyntylatora

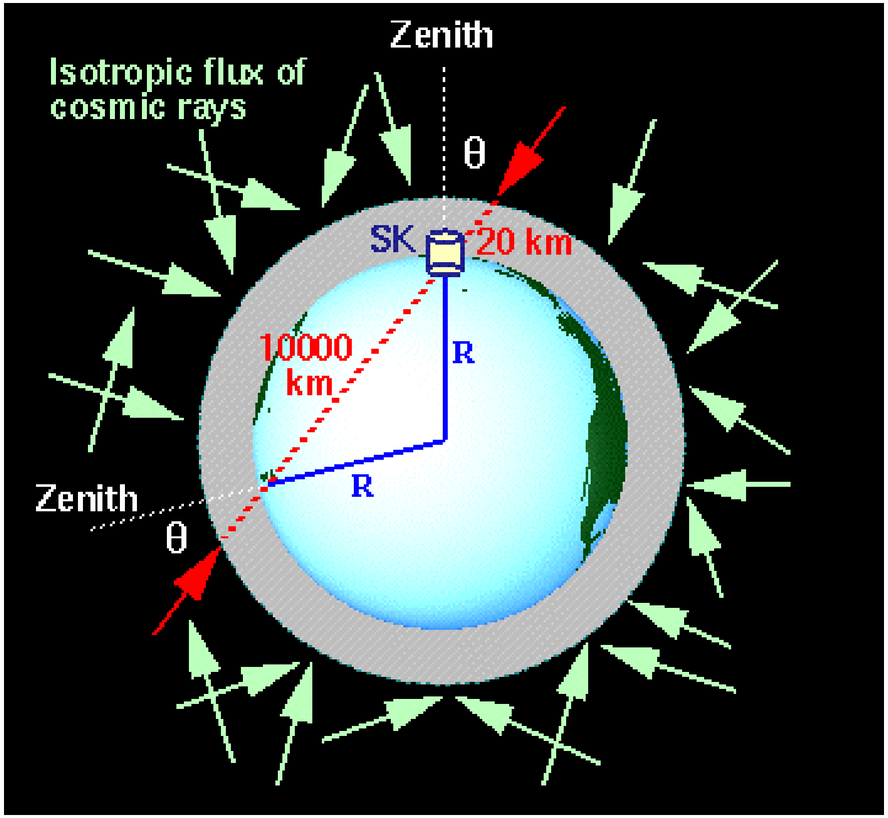
KamLAND

Atmospheric neutrinos primer



$$\frac{\phi(\nu_\mu+\overline{\nu}_\mu)}{\phi(\nu_e+\overline{\nu}_e)}\begin{cases}\sim 2(\text{for } E_\nu<1\text{GeV})\\ >2(\text{for } E_\nu>1\text{GeV})\end{cases}$$

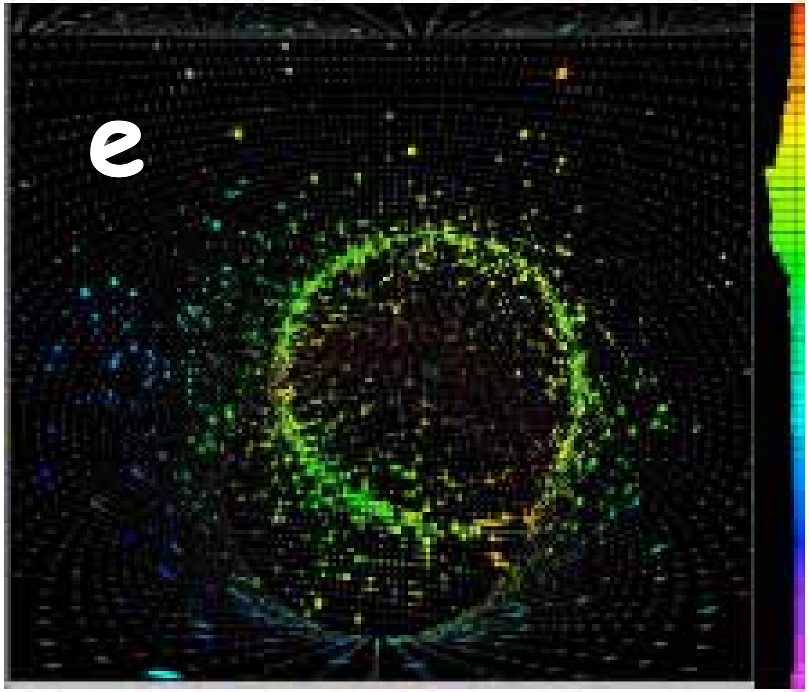
For E_ν > a few GeV,
(Up-going / down-going) $\mu \sim 1$



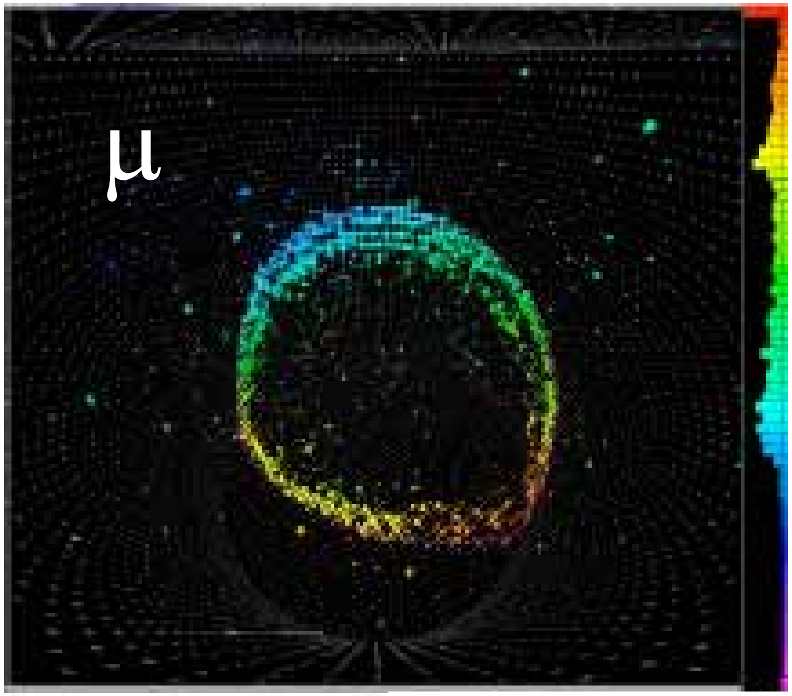
Can't measure E_ν or L_ν, but can look at $\cos\theta_{zenith}$ in bins of E_{lepton}

SuperKamiokande golden channels

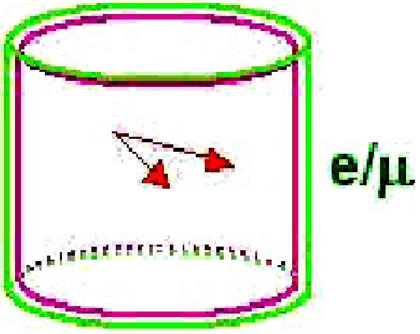
$$\nu_\mu(\nu_e)+n\rightarrow\mu^-(e^-)+p$$



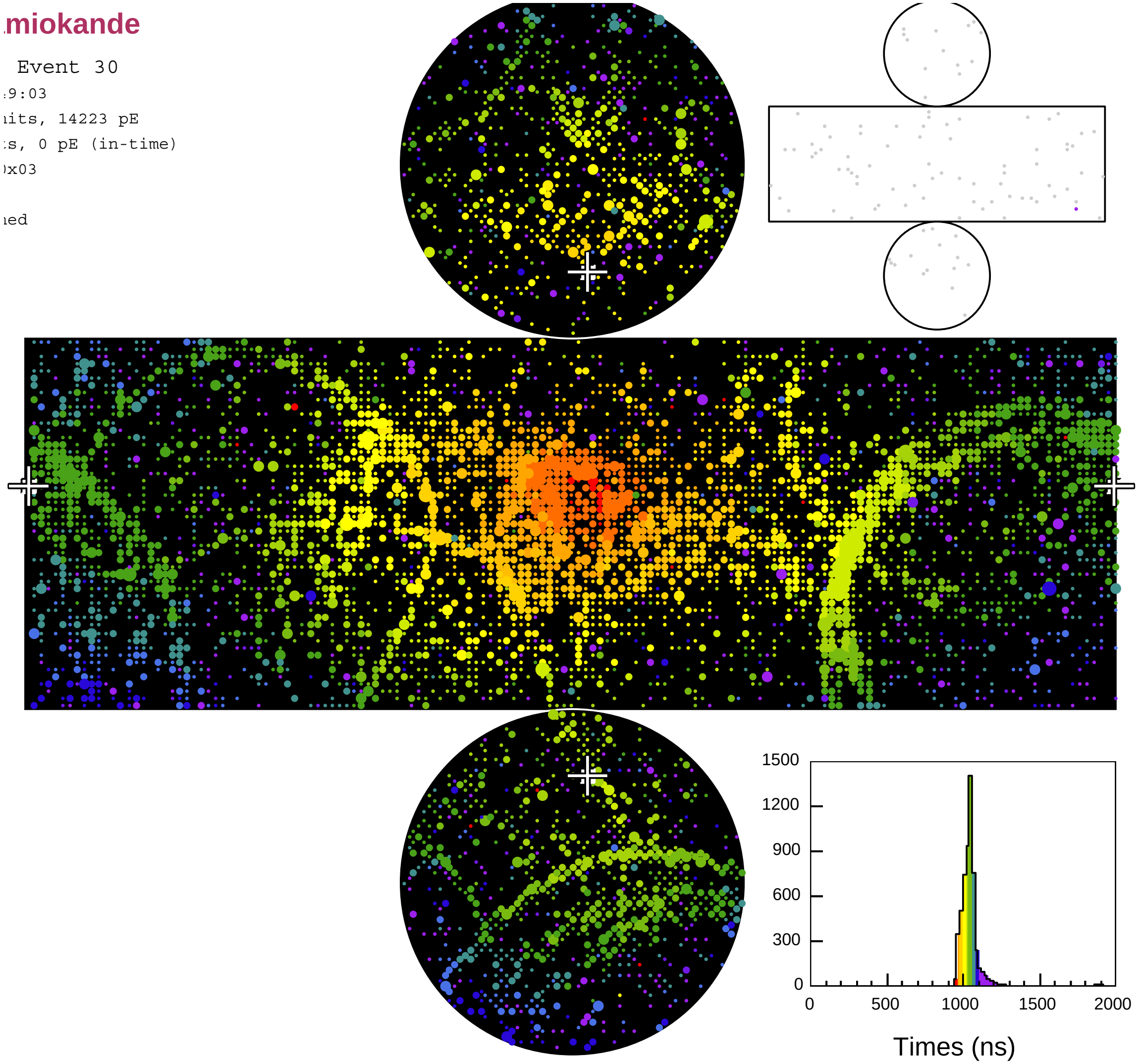
$$\bar{\nu}_\mu(\bar{\nu}_e)+p\rightarrow\mu^+(e^+)+n$$



Energies and directions of μ and e are measured, about 20000 atmospheric neutrino interactions collected in 1996-2005 (SKI – till the accident in 2001, SKII – since December 2002)

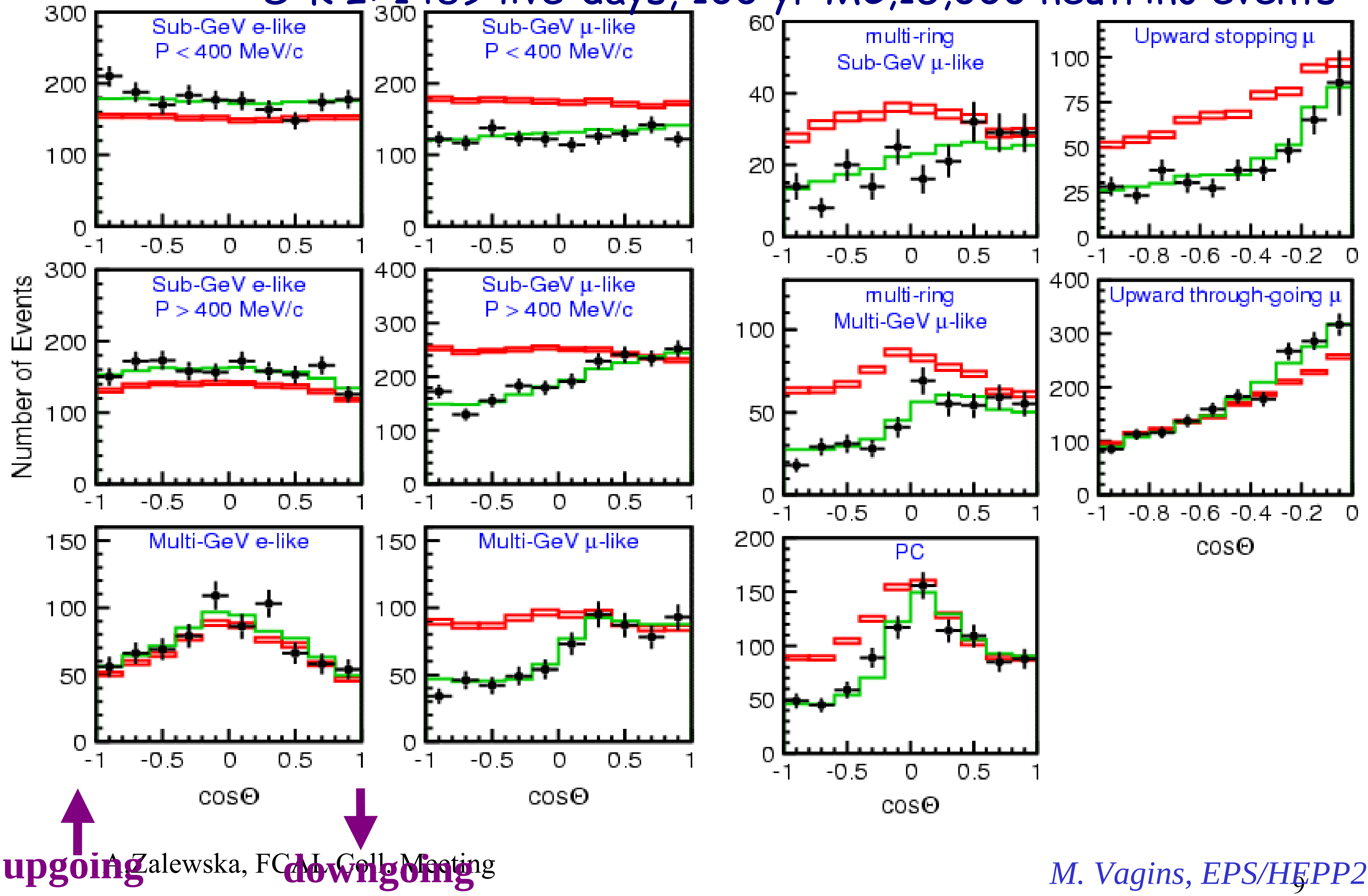


SuperK - multi-ring event



➢Zenith angle distributions showing ν_μ disappearance

S-K I: 1489 live-days, 100 yr MC,15,000 neutrino events

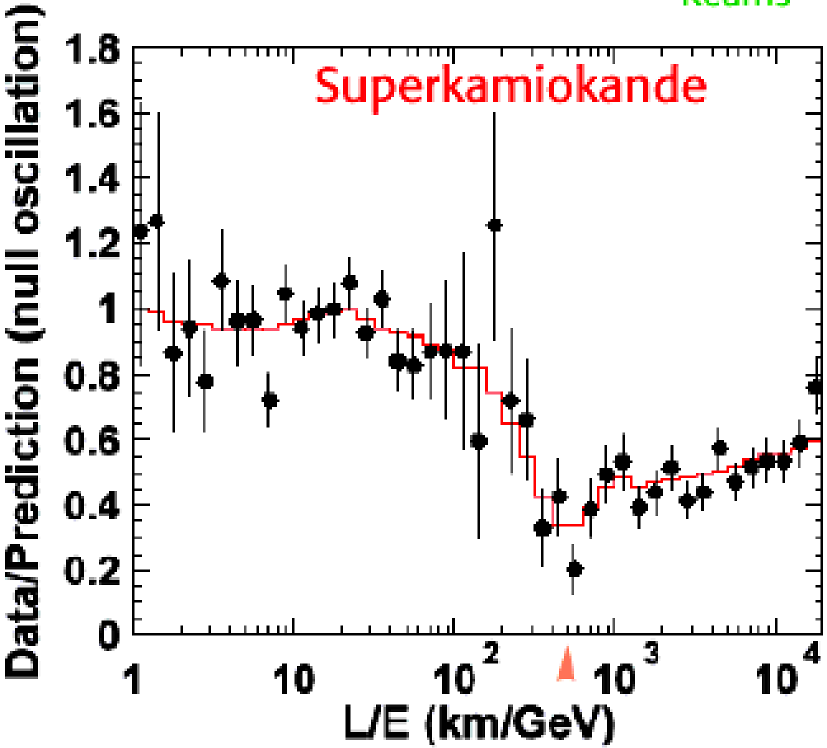


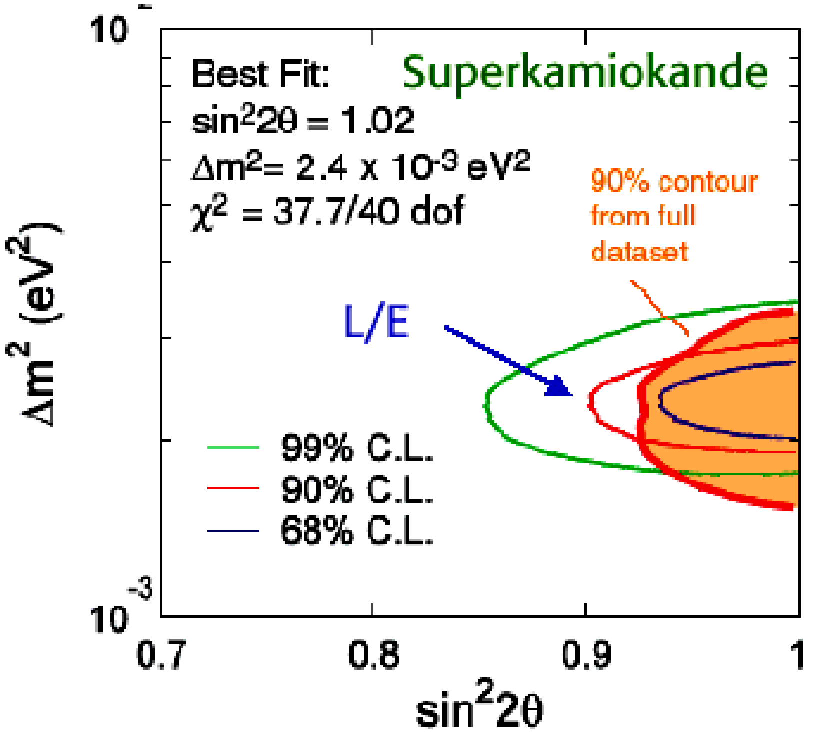
M. Vagins, EPS/HEPP2005

SuperKamiokande – L/E dependence

L/E dependence – direct test for oscillations

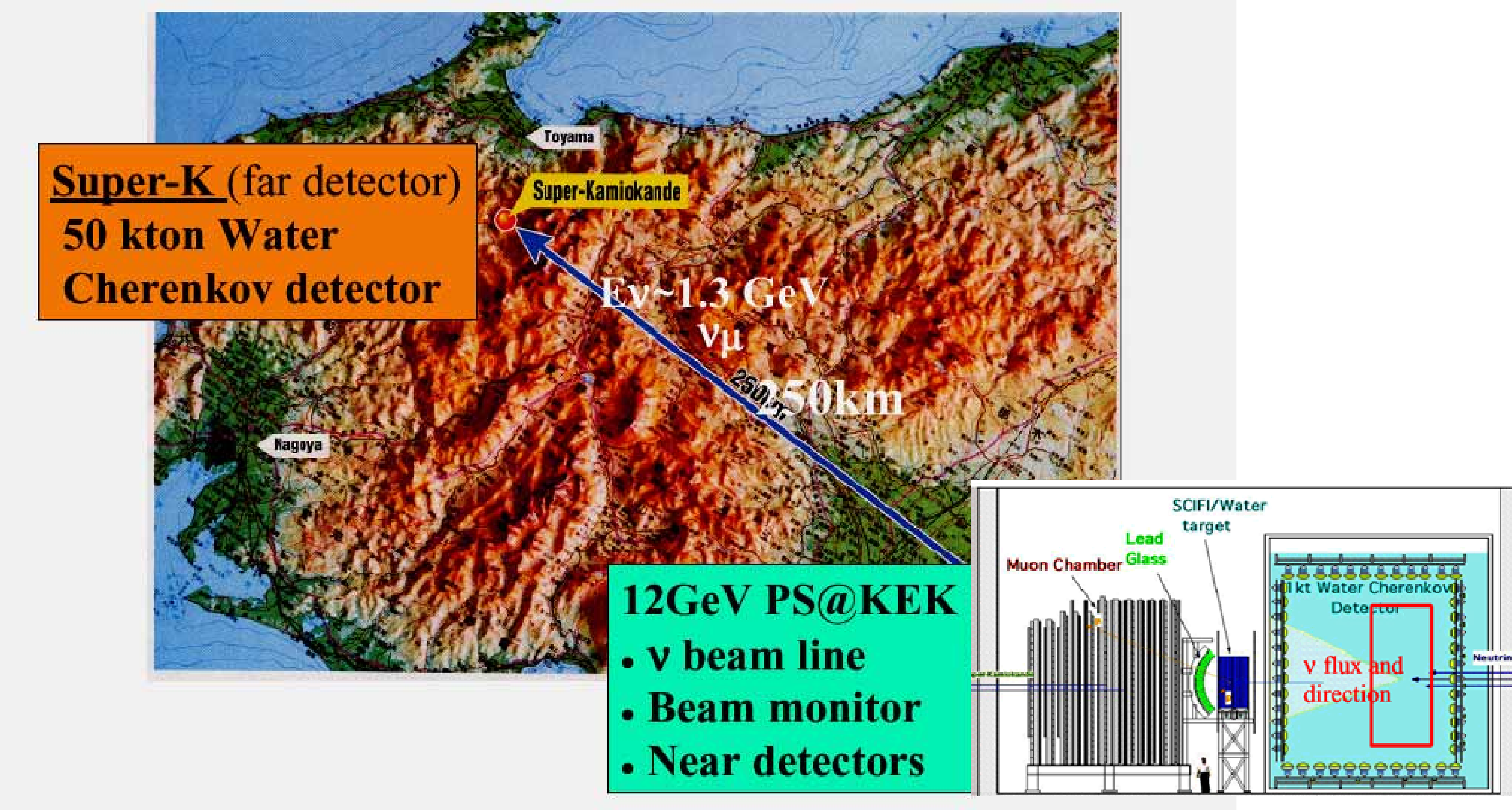
Kearns





SuperK measurements point to the $\nu_\mu \leftrightarrow \nu_\tau$ oscillations

K2K - first LongBaseLine accelerator experiment



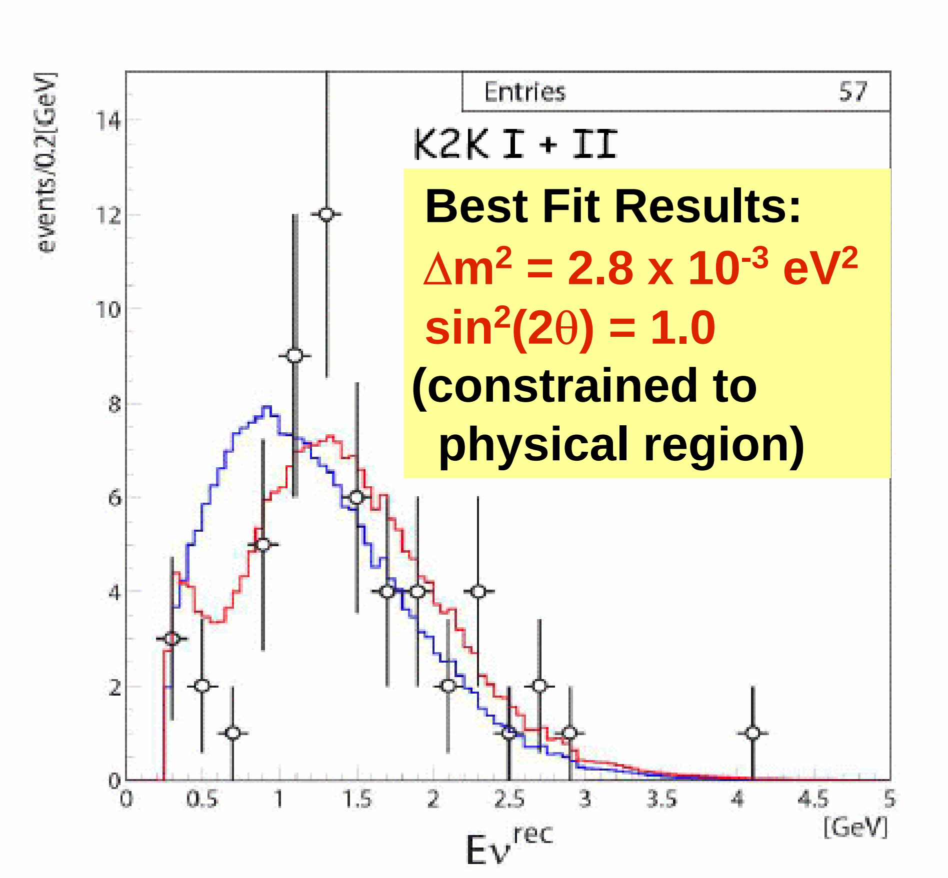
Super-K (far detector)
50 kton Water Cherenkov detector

12GeV PS@KEK

- **ν beam line**
- **Beam monitor**
- **Near detectors**

$< E_\nu > \sim 1.3$GeV
almost pure $\nu_\mu (\sim 98\%)$

➢ K2K Long Baseline Accelerator (KEK to Kamioka)

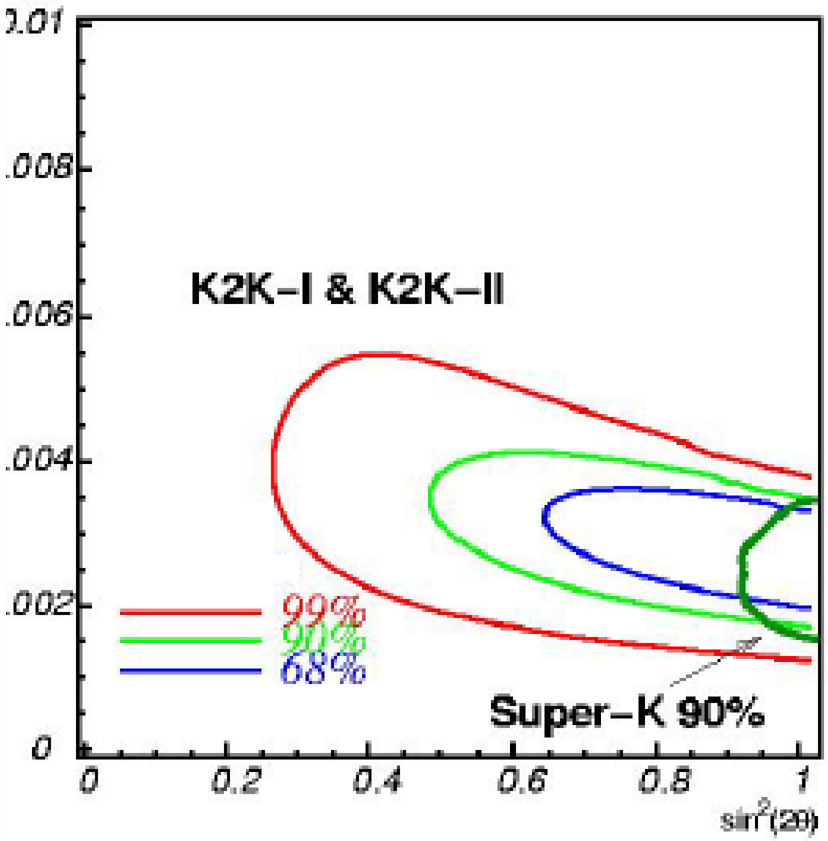


Best Fit Results:

$\Delta m^2 = 2.8 \times 10^{-3}$ eV^2

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

(constrained to physical region)



K. Scholberg, WIN05

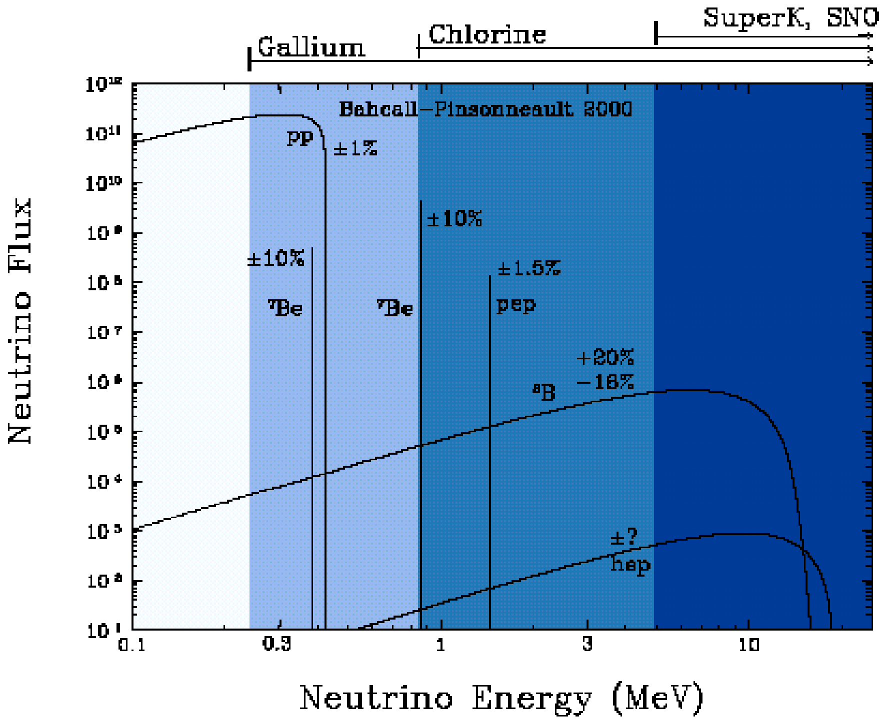
Single-ring μ-like events

Total 107 beam events observed; expect 149.7

No-oscillation excluded at >4σ

Consistent with SK atmospheric ν's

Solar neutrinos primer



Most of the solar neutrinos in pp cycle

$$4p \rightarrow {}^4\mathrm{He} + 2e^+ + 2\nu_e + 2\gamma$$

Experiments (since 1969) measure the reactions:

$\nu_e + n \rightarrow p + e^-$ All

In particular:

$\nu_e + {}^{37}\mathrm{Cl} \rightarrow {}^{37}\mathrm{Ar} + e^-$

$\nu_e + {}^{71}\mathrm{Ga} \rightarrow {}^{71}\mathrm{Ge} + e^-$

$\nu_\ell + e^- \rightarrow \nu_\ell + e^-$ SuperK, SNO

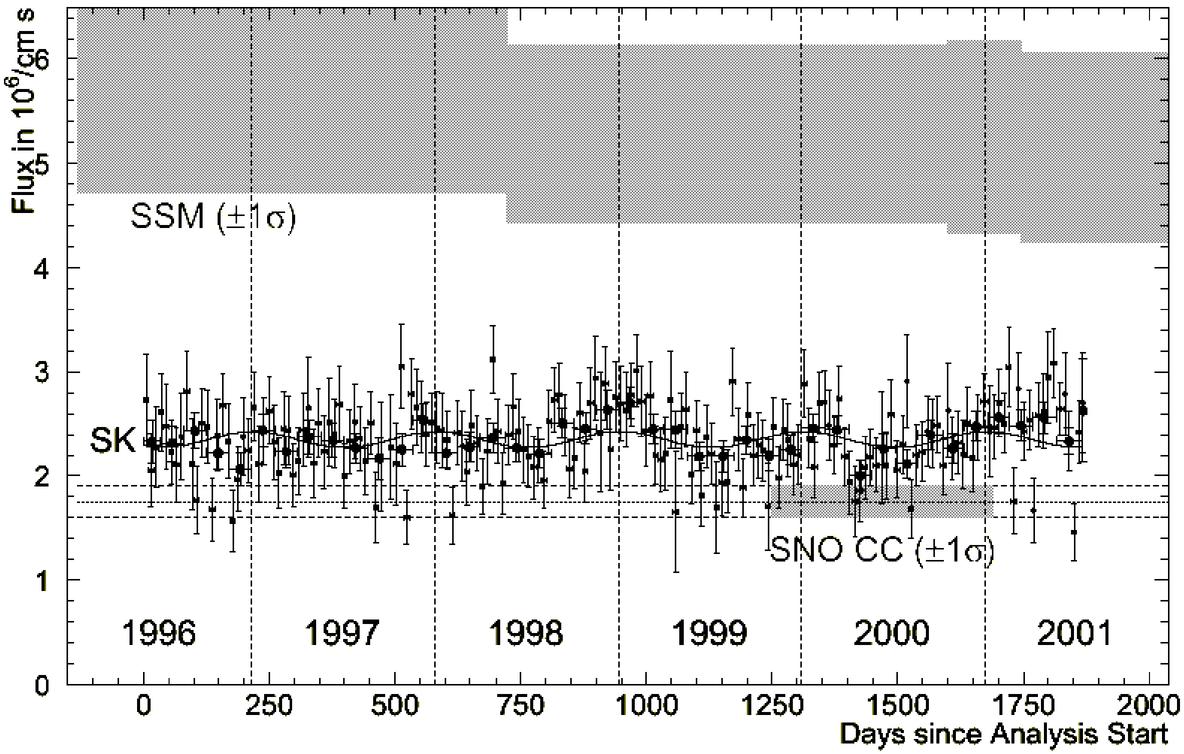
$\nu_\ell + n \rightarrow \nu_\ell + n$ SNO

-- Solar ν_e are produced in the Sun center

-- A lack of the solar neutrinos w.r.t. to the Solar Model was observed for more than 30 years

-- It has been partially explained by the SuperKamiokande experiment and fully by the SNO experiment in terms of the oscillations $\nu_e \leftrightarrow \nu_{\mu,\tau}$

SuperKamiokande - solar neutrinos flux modulation in time

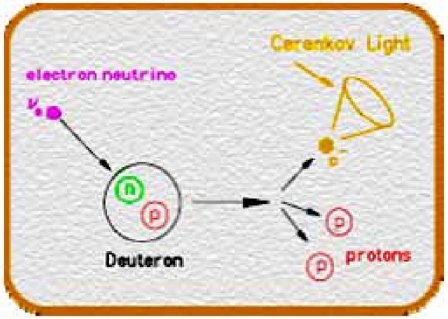


The annual flux changes are in agreement with the expectations based on the annual changes of the distance Sun-Earth

→ the matter effects insde Sun are responsible for the neutrino flavour changes

Processes measured in the SNO experiment

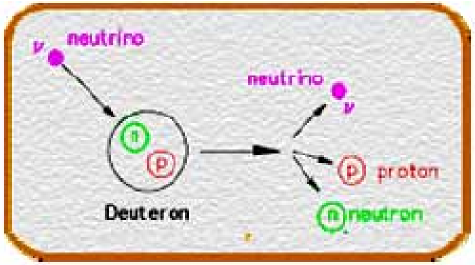
CC $\nu_e + d \Rightarrow p + p + e^-$



Only ν_e, good measurement of ν_e energy, weak dependence on the neutrino direction 1-1/3cosθ

E_{th}=1.4MeV

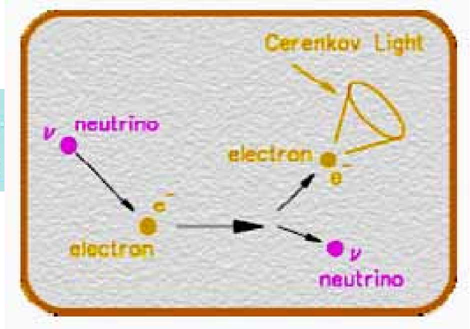
NC $\nu_x + d \Rightarrow p + n + \nu_x$



All three flavours with the same cross section, measurement of the total neutrino flux

E_{th}=2.2MeV

ES $\nu_x + e^- \Rightarrow \nu_x + e^-$



Mostly sensitive to ν_e, very sensitive to the neutrino direction, relatively small cross section

Reaction measured also in SuperK

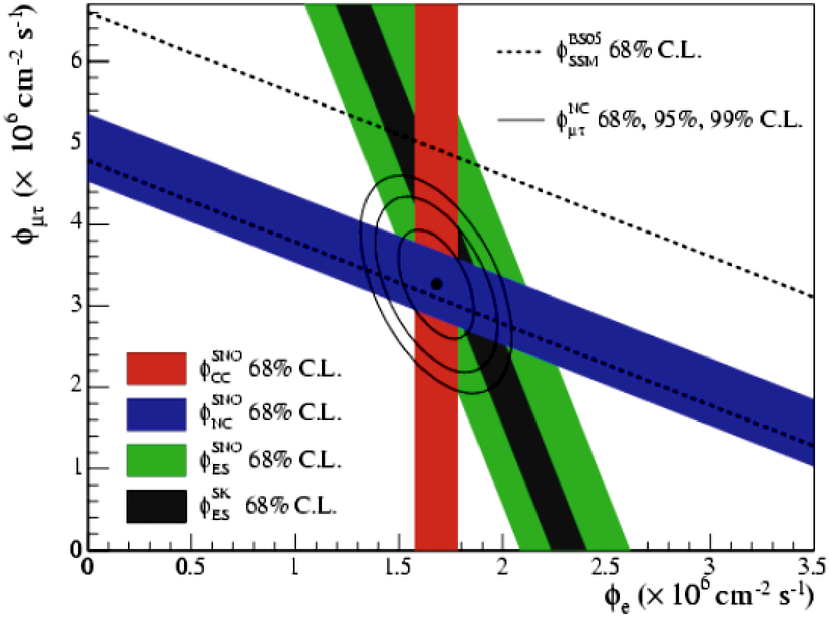
Three phases of the experiment (now the third one) – goals: high efficiency and low background measurement of the neutron capture reaction (→ precise measurement of the total neutrino flux)

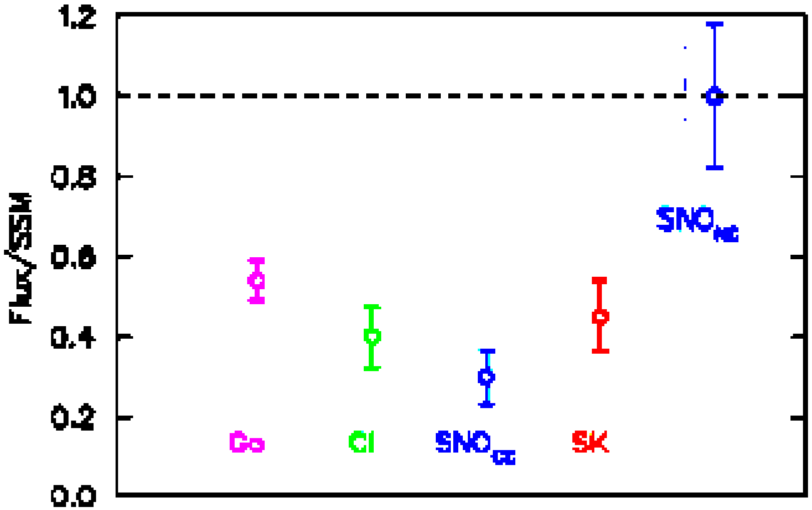
SNO - results

2002 $\Phi_{ssm} = 5.05^{+1.01}_{-0.81}$ $\Phi_{sno} = 5.09^{+0.44\,+0.46}_{-0.43\,-0.43}$

2005

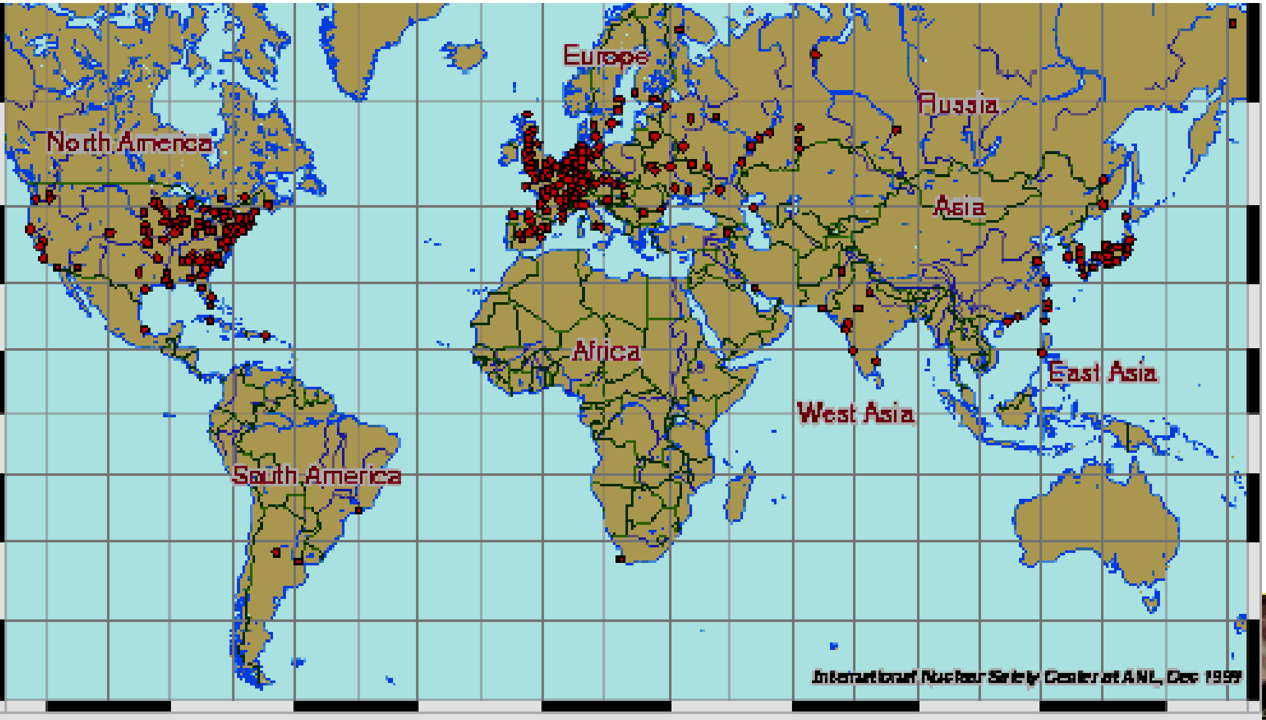
Flavor content of solar flux.





The total neutrino flux is in agreement with the Solar Model, a lack of ν_e's is due to their transfer into $\nu_{\mu,,\tau}$ inside Sun, matter effects play the essential role in it

Reactor antineutrinos



International Nuclear Safety Center at ANL, Dec 1999

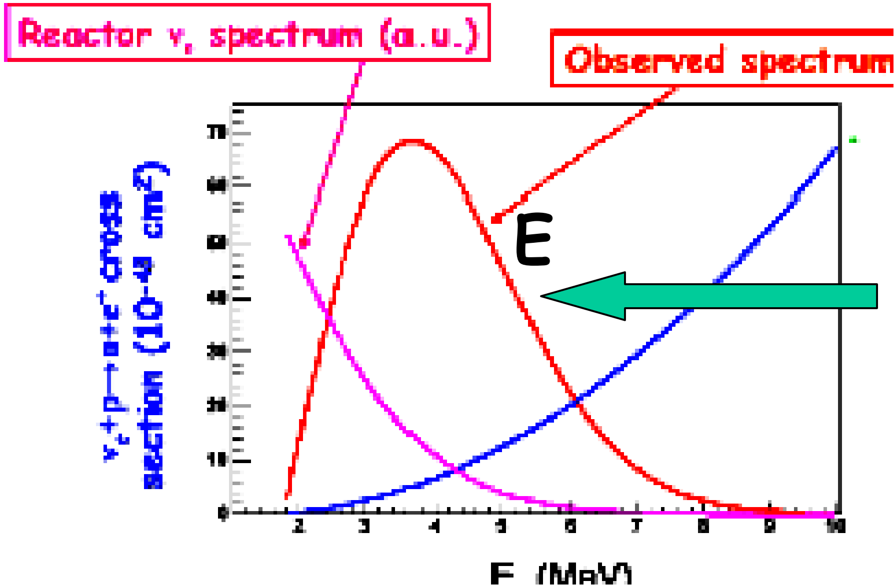
Long tradition, started by the first observation of neutrino interactions by Reines and Cowan

Typical power station gives $6\text{x}10^{20}$ anty-ν/s and 3GW of power

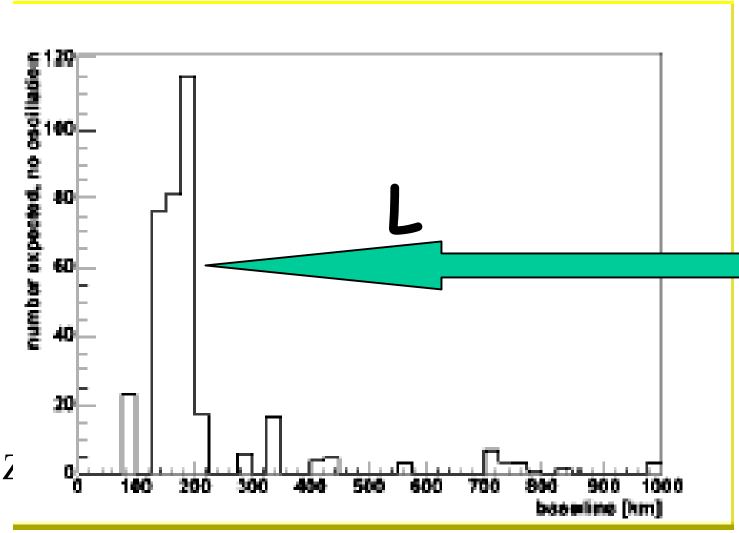
The Palo Verde reactor experiment

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

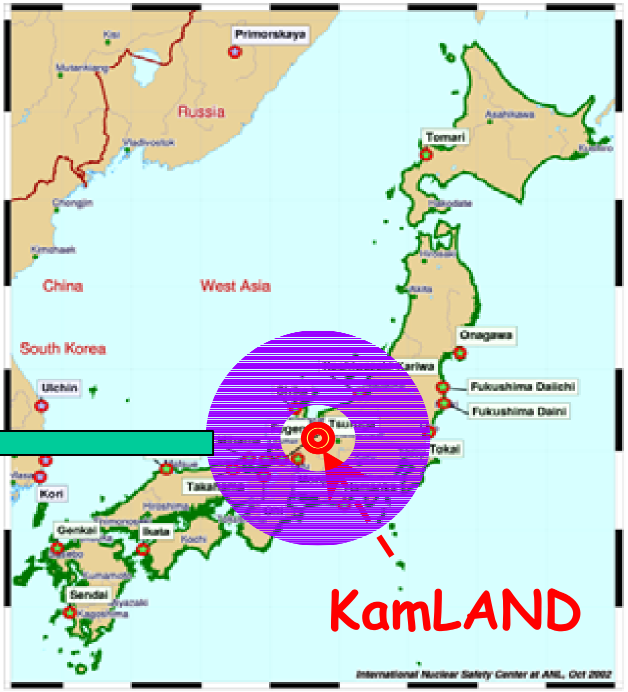
KamLAND – energies of anti-ν_e's and bases L



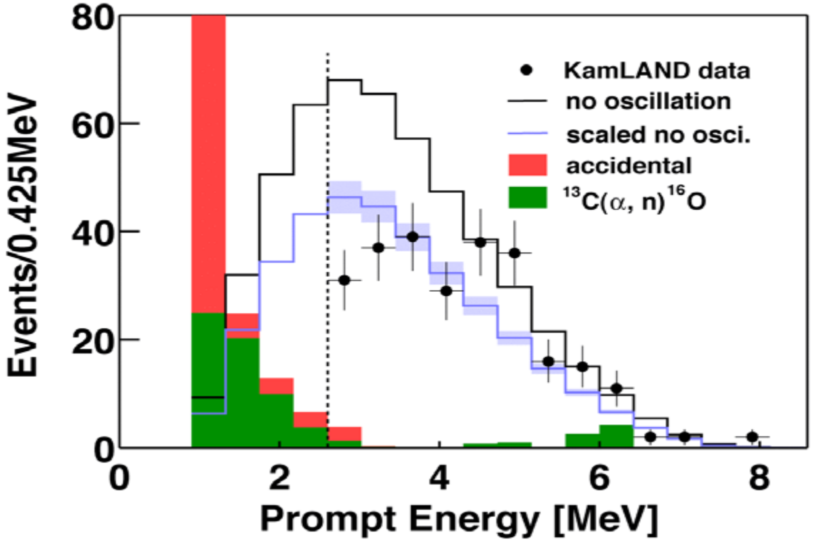
The observed neutrino energy spectrum in KamLAND is a convolution of the energy spectrum of neutrinos produced in reactors and the cross section for their interactions in the detector

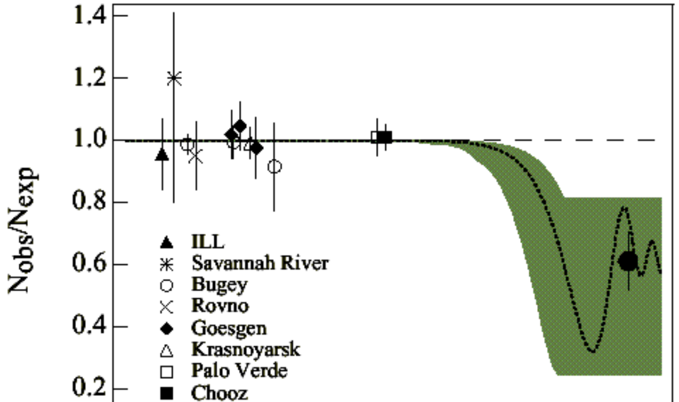


A.Z



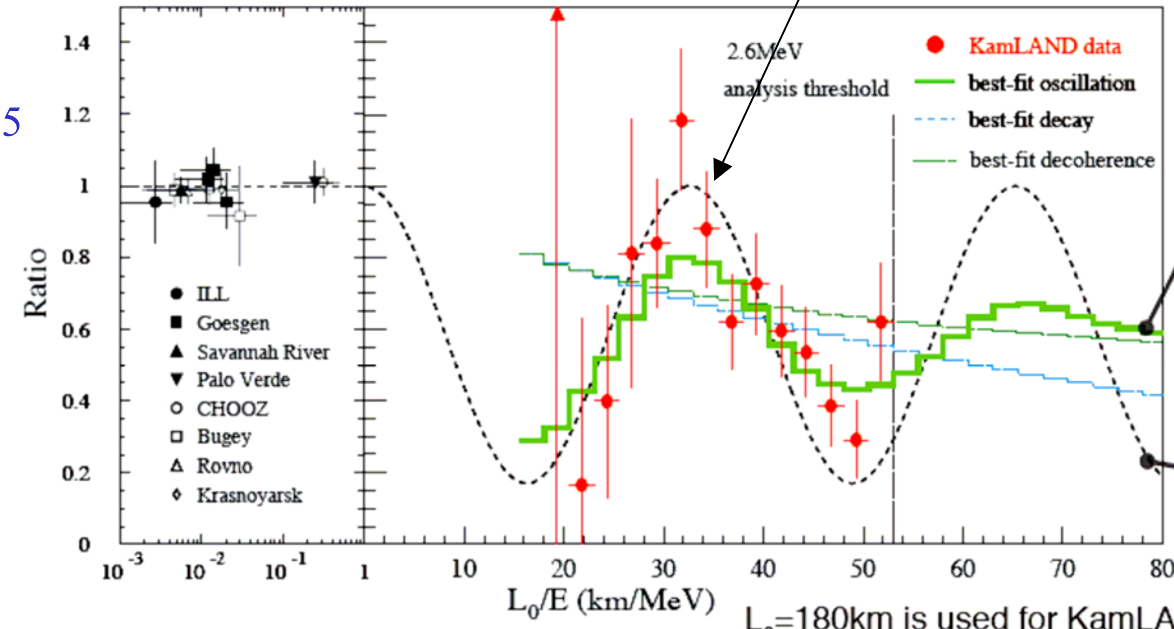
KamLAND: Testing the Model with L/E Behavior





$$P_{\upsilon_e \to \upsilon_e} = 1 - \sin^2 2\theta_{12} \sin^2\left(\frac{1.27\Delta m_{12}^{2} L}{E}\right)$$

KamLAND, PRL 94, 2005
J.Klein, EPS HEP2005



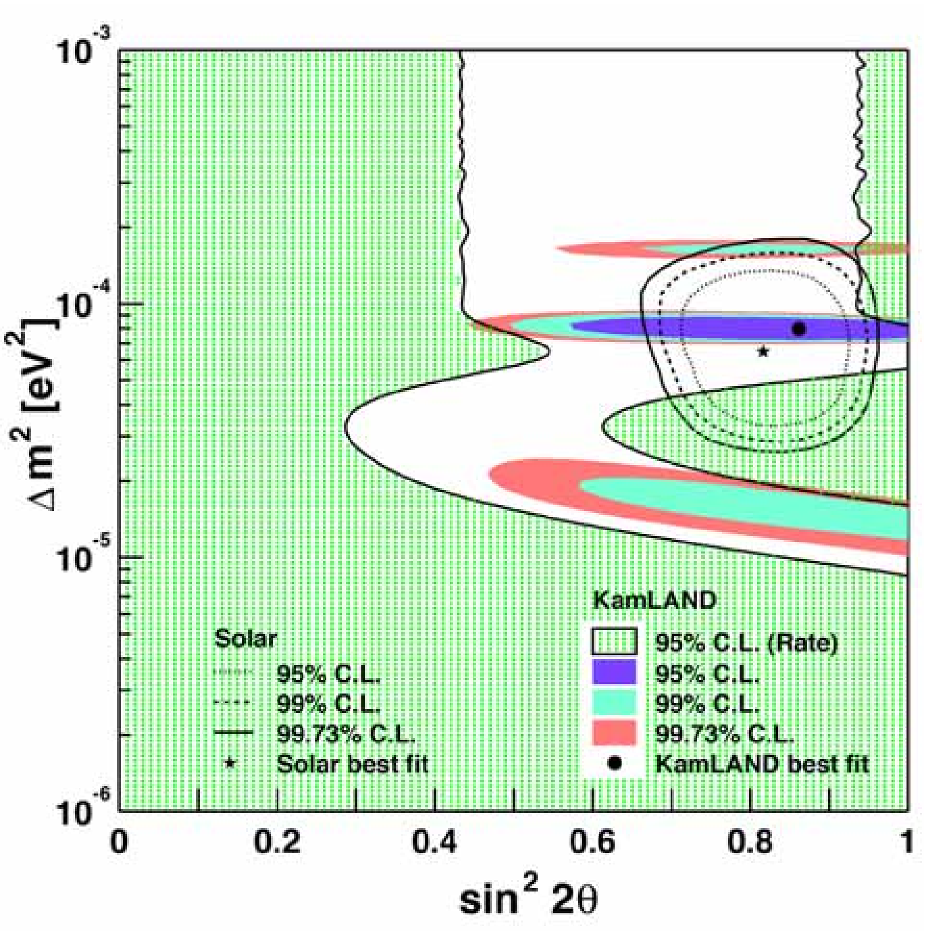
with real reactor distribution

ideal oscillation pattern

A.Zalewska, FCAI

L_0=180km is used for KamLAND

➢ KamLAND+SNO: Testing the Model



	Reactor	**Solar**
E	**2-10 MeV**	**0.1-15 MeV**
L	**150 km**	**1.5 x 10^8 km**
MSW	**No**	**Yes**
ν	**Anti-ν_e**	ν_e

KamLAND, PRL 94, 2005
J.Klein, EPS HEP2005

Three neutrino mixing

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Oscillation parameters: 3 mixing angles, 2 differences of mass squares, 1 phase
If neutrino is the Majorana particle, 2 additional phases

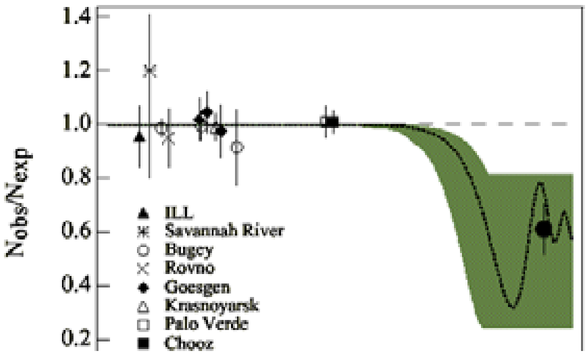
Atmospheric neutrinos

CP phase

solar neutrinos

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

connects solar and atmospheric regions



If $\delta \neq 0, \pi, 2\pi \ldots$ then CP is violated for leptons (like for quarks), θ_{13} is a gateway to a measurent of δ

Oscillation parameters

The most probable values:

$\theta_{23} = 45^0$ (maximal mixing), $\theta_{12} = 33^0$ (large), $\theta_{13} < 10^0$ (small),

$\Delta m^2_{23} \approx 2.5 \times 10^{-3}$ eV^2, $\Delta m^2_{12} \approx 8 \times 10^{-5}$ eV^2,

$| \Delta m^2_{13} | = | \Delta m^2_{23} - \Delta m^2_{12} |$

Why this scheme of mixing angles is so much different from the scheme for quark mixing?

Is CP violated for neutrinos?

Neutrino oscillations

Two oscillation regions with a very solid experimental evidence:

atmospheric region

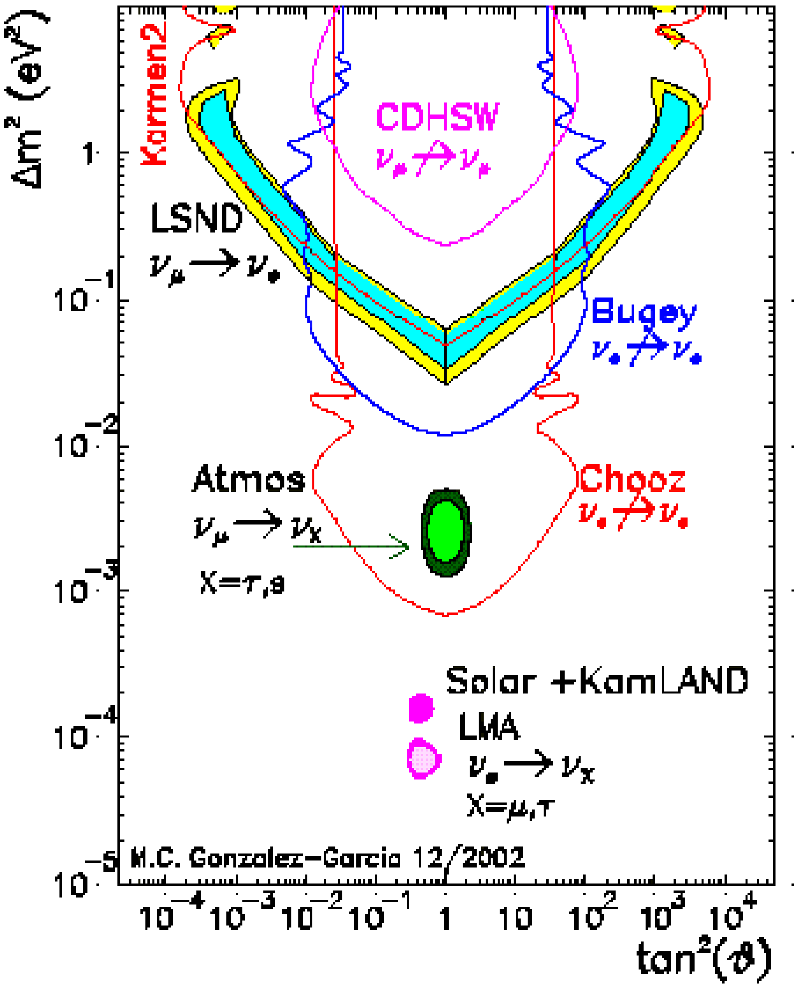
solar region

Third region:

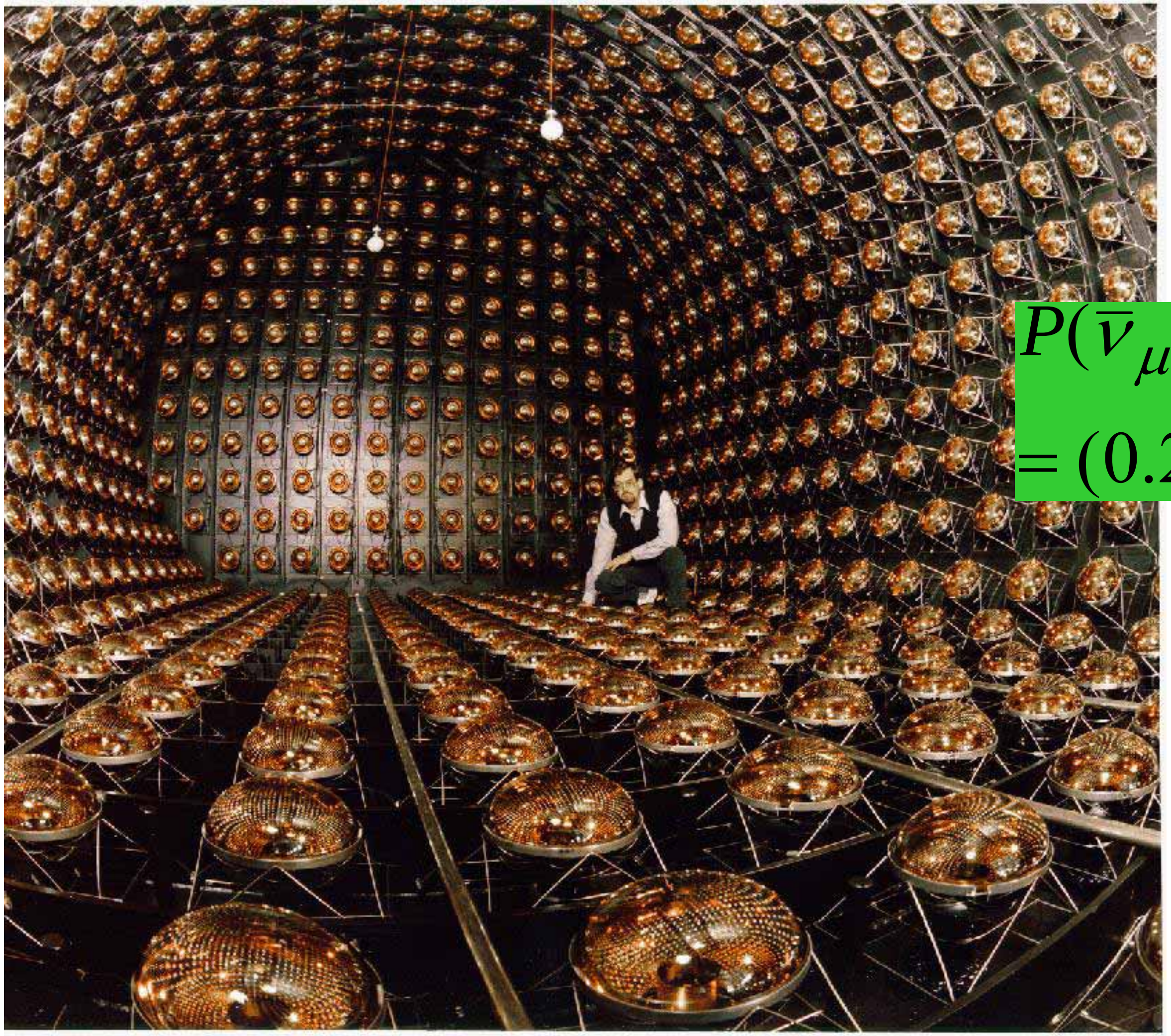
LSND

being checked by the dedicated MiniBooNE experiment

Note: three differences of mass squares cannot be built up with three neutrino masses; the fourth neutrino is needed if LSND effect is confirmed



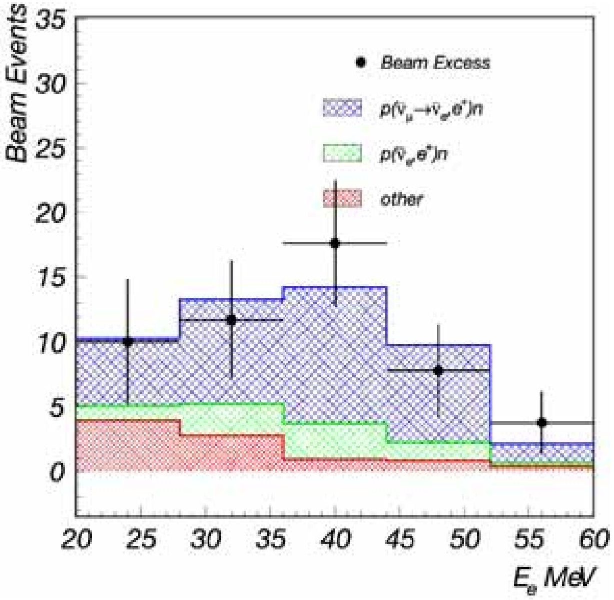
LSND effect



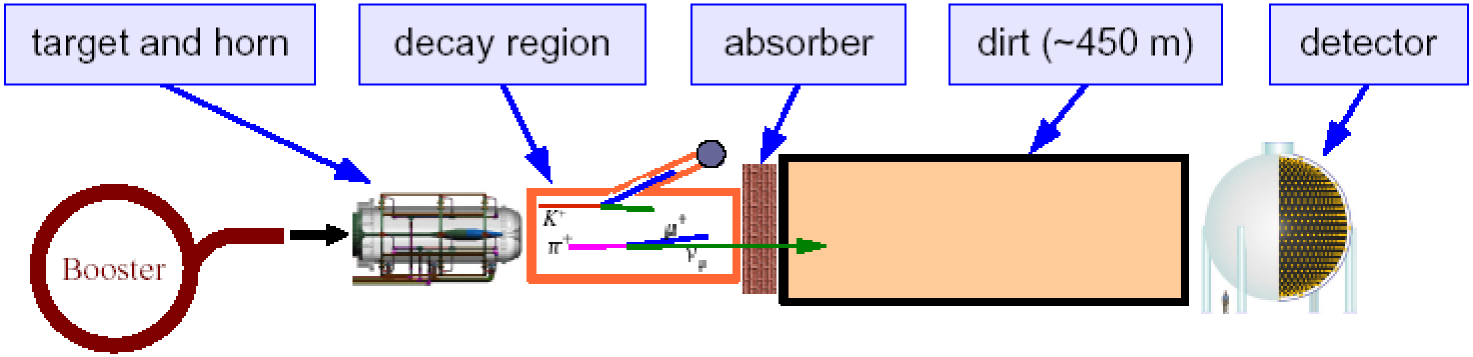
Excess of positrons above background interpreted as anty-ν_e appearance due to oscillations

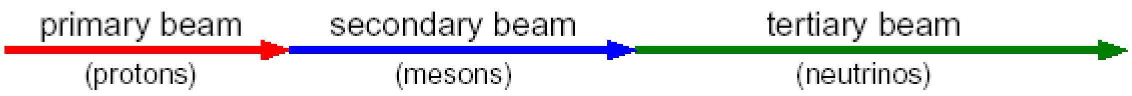
$$P(\overline{\nu}_\mu \rightarrow \overline{\nu}_e)$$

$$= (0.264 \pm 0.067 \pm 0.045)\%$$



➢ MiniBooNE – checking the LSND effect





Ú 8 GeV protons from the Fermilab booster neutrino beam of energy about 1 GeV

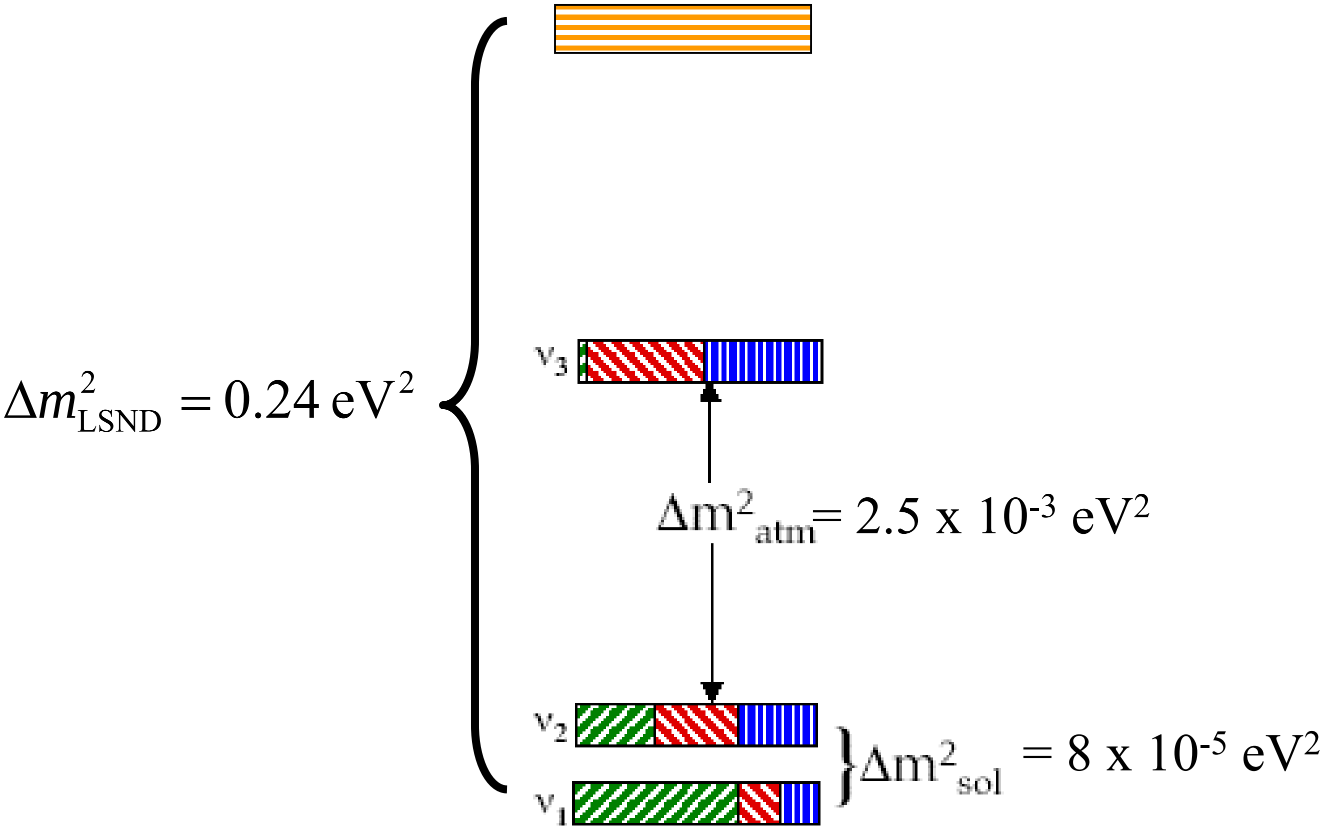
Ú detektor at a distance of 500 m from the target

Ú 10^{21} p.o.t. to confirm/exclude the LNSD effect

$$P(\nu_\mu \to \nu_e) = \sin^2 2\theta \sin(\frac{1.27\Delta m^2 L}{E})$$

Results expected around summer 2006

If LSND confirmed ... revolution !



$\Delta m^2_{\mathrm{LSND}} = 0.24\ \mathrm{eV}^2$

$\Delta m^2_{\mathrm{atm}} = 2.5 \times 10^{-3}\ \mathrm{eV}^2$

$\Delta m^2_{\mathrm{sol}} = 8 \times 10^{-5}\ \mathrm{eV}^2$

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \\ \nu_s \\ \nu_{s'} \\ \vdots \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} & U_{e5} & \cdots \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} & U_{\mu 5} & \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} & U_{\tau 5} & \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} & U_{s5} & \\ U_{s'1} & U_{s'2} & U_{s'3} & U_{s'4} & U_{s'5} & \\ & & \cdots & & & \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \\ \nu_4 \\ \nu_5 \\ \vdots \end{pmatrix}$$

Future oscillation experiments

Assuming three neutrinos, future oscillation experiments should answer the following important questions:

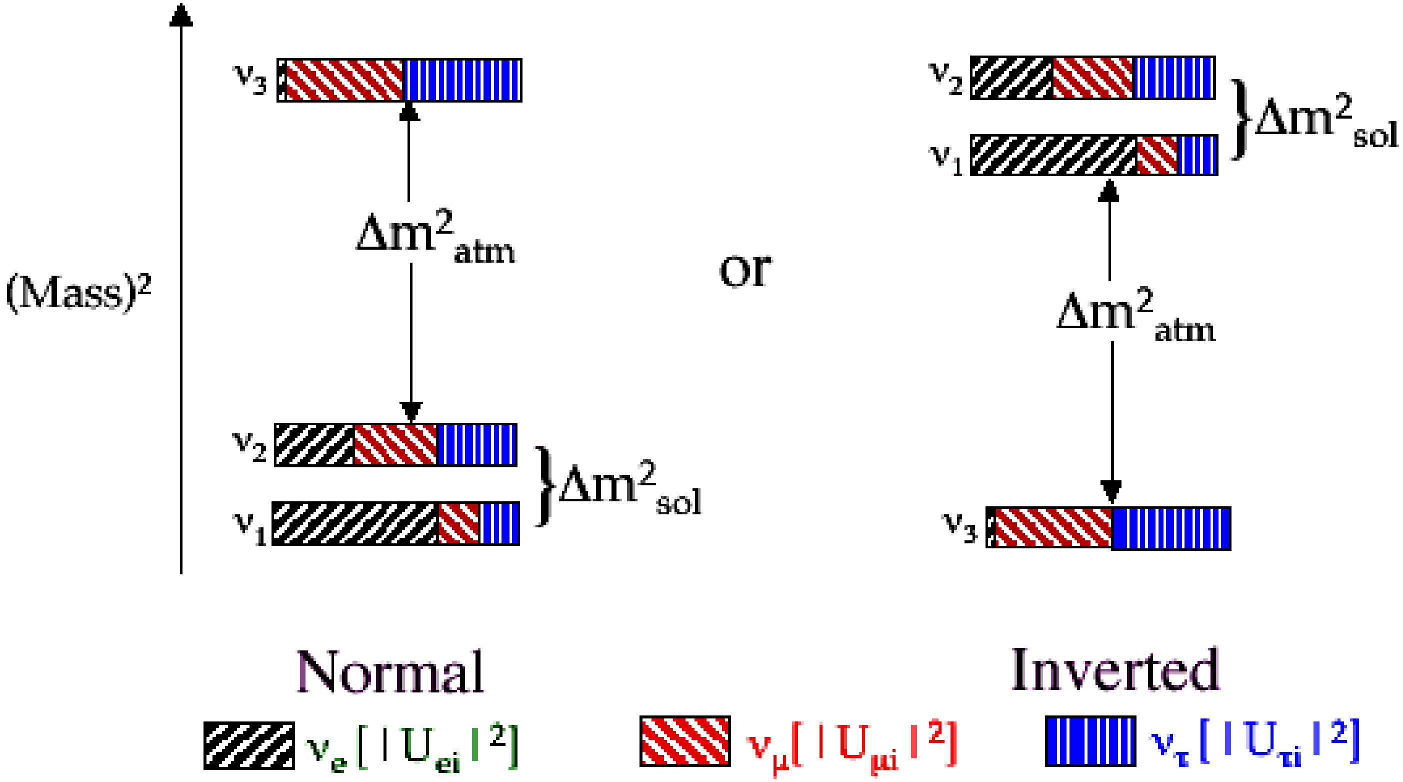
Is θ_{23} really maximal?

How small is θ_{13}?

Is CP violated for neutrinos?

Mass hierarchy – normal or inverted?

Neutrino mass hierarchies for three neutrinos



Two important questions:

How far from zero the whole picture is?

Normal or inverted hierarchy of neutrino masses?

Three phases of experiments

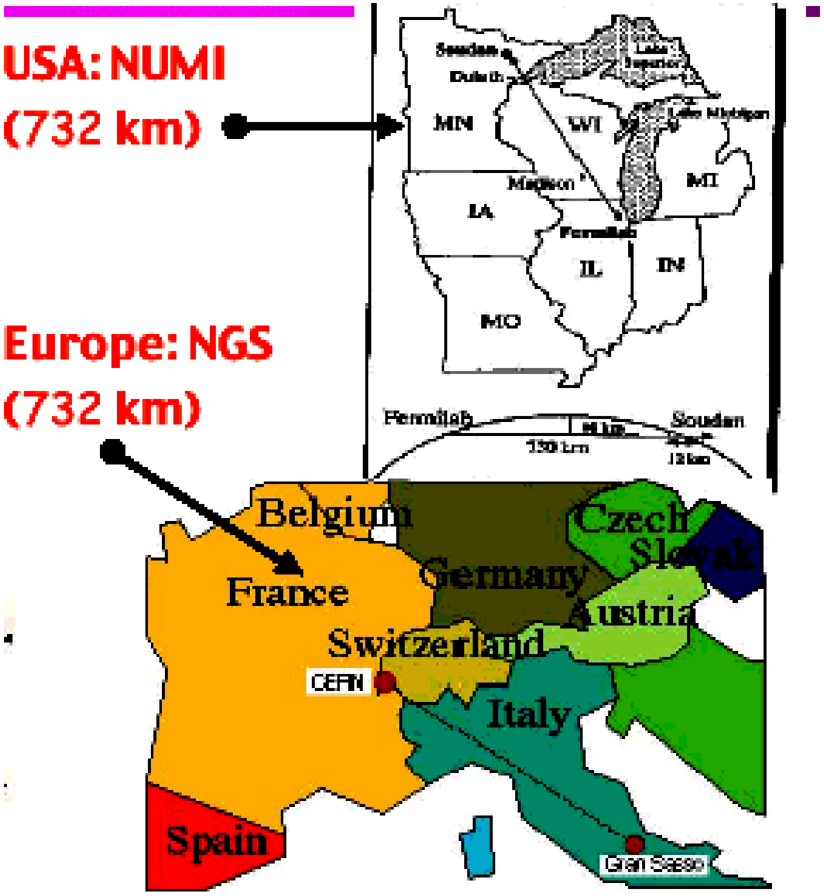
Phase I (years 2005-2010):
- MINOS experiment on the NuMi beam
- OPERA (ICARUS) experiment on the CNGS beam
- Double-CHOOZ reactor experiment

Phase II (approved experiments – years 2010-2015):
- T2K off-axis experiment (Tokai to Kamioka) on the Japonese superbeam
- NOνA off-axis experiment on the superbeam NuMi
- More sophisticated reactor experiments?

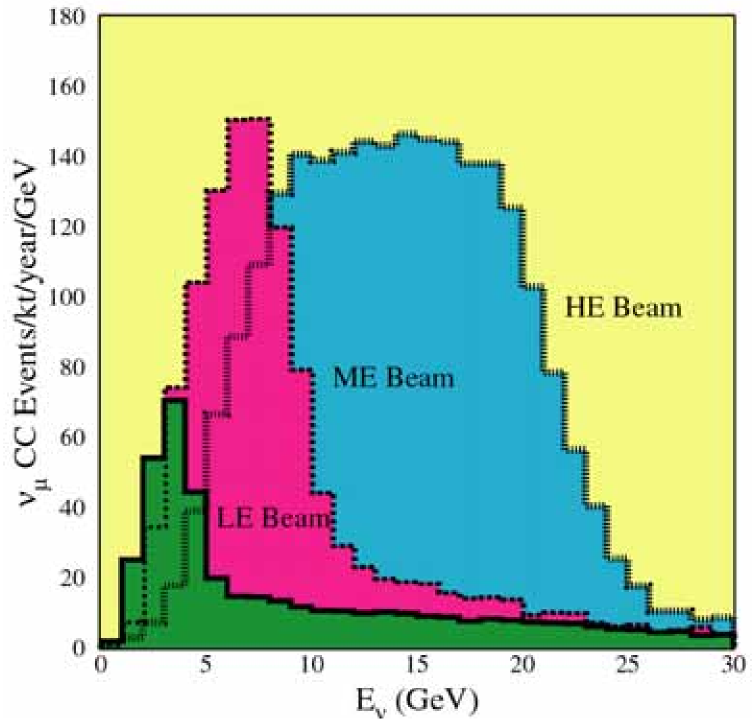
Phase III (now only R&D programs) ~ 2020 ?
- New neutrino sources: neutrino factories, β beams, ???
- Huge detectors: 1 Mton water Cherenkov, large scintillator detector, 100 ktons Liquid Argon, ???

PhaseI - Long BaseLine accelerator projects

- ♦ NuMi - neutrino beam from FNAL to the MINOS detector in the Soudan mine, started in January 2005, near and far detector, ν_μ disappearance
- ♦ CNGS - neutrino beam from CERN to Gran Sasso, far detector OPERA (ICARUS), start in 2006, ν_τ appearance

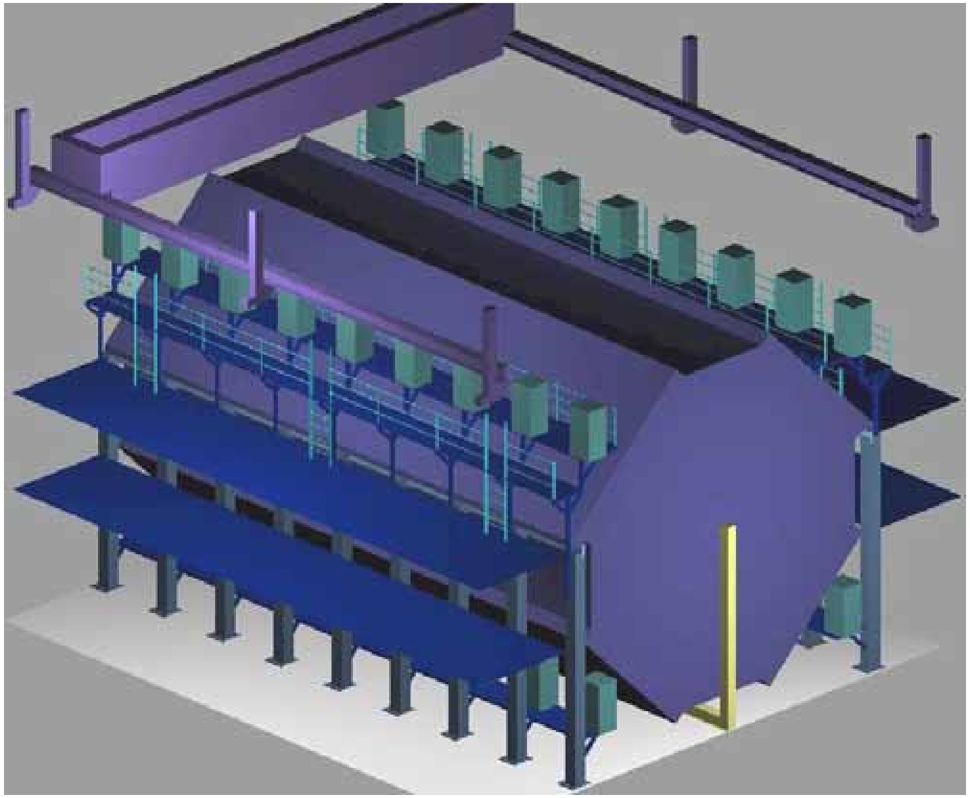


MINOS experiment



NuMi beams

Taking data since January 2006, first results expected soon

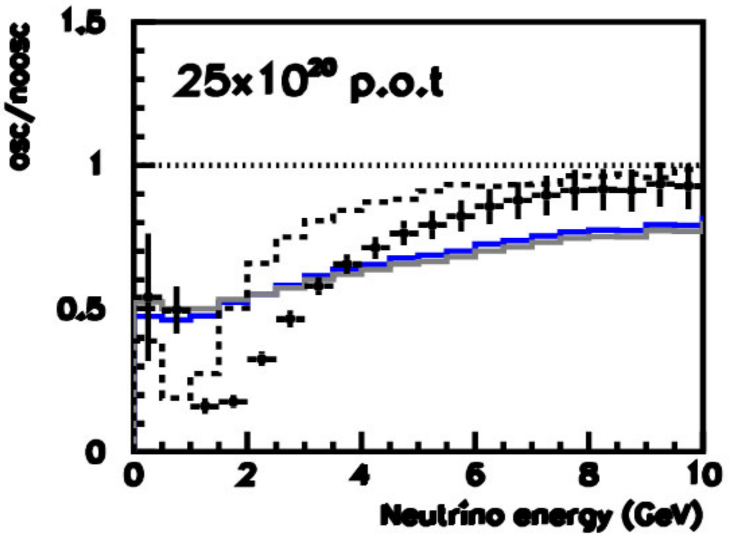


- 5.4kt in total, calorimetric detector
  - 484 planes in two ~14.5m long "super modules", each plane 8m octagon
  - 2.54cm Fe, 1cm Scintillator
  - ~1.5T Magnetic field

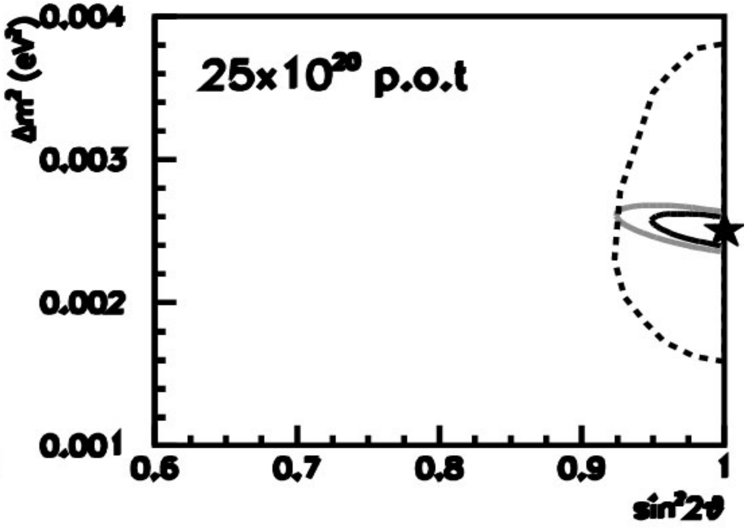
MINOS experiment

5 years of data taking - 25 x 10^{20} p.o.t

oscillation pattern



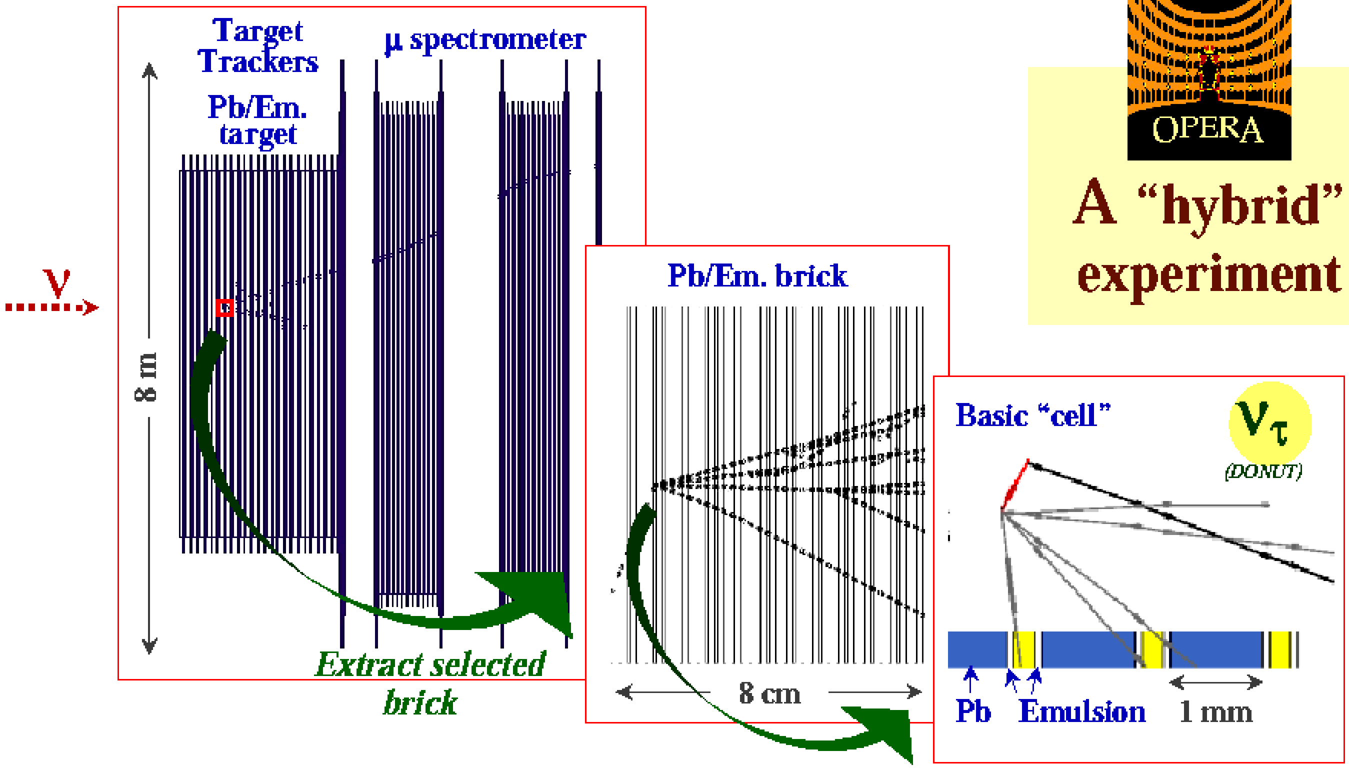
improved Δm^2_{23}



Will improve the CHOOZ limit on θ_{13} by a factor 2

CNGS – the OPERA experiment

High energy neutrino beam, optimized for ν_τ appearance
The OPERA experiment: emulsions + magnetic spectrometer, small signal with no background



OPERA

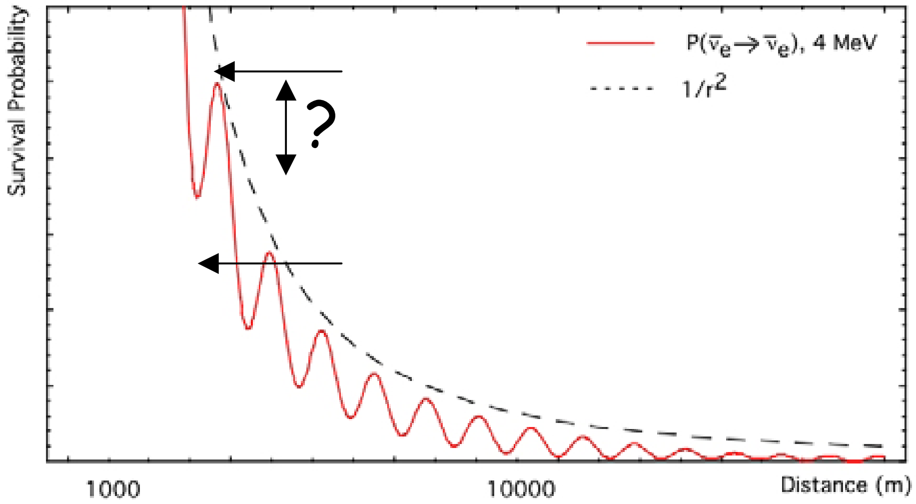
A "hybrid" experiment

Electronic detectors
→ select ν interaction brick
→ μ ID, charge and p

Emulsion scanning
→ vertex search
→ decay search
→ e/γ ID, kinematics

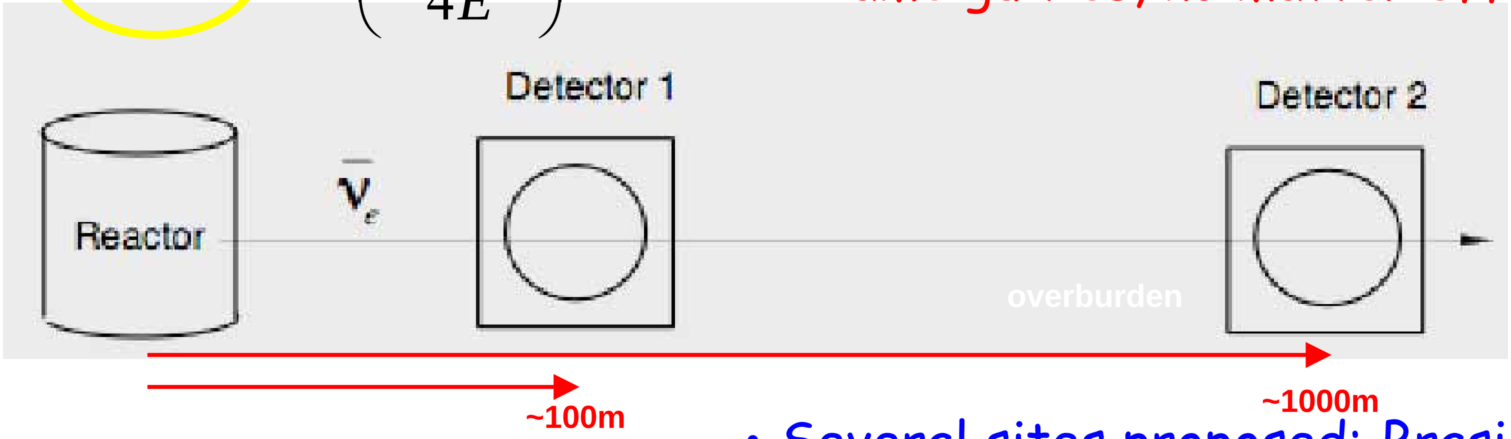
Reactor experiments for θ_{13} measurements

- Long Baseline (~1 km from source)
- Disappearance $\bar{\nu}_e \rightarrow \bar{\nu}_e$
- Use near detector to measure reactor flux, spectrum and detector efficiency to cancel "all systematics"
- Look for small deviation from $1/r^2$ with plenty of reactor signal



$$1-P_{\bar{e}\bar{e}} \cong \boxed{\sin^2 2\theta_{13}} \sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right) + O(\alpha^2)$$

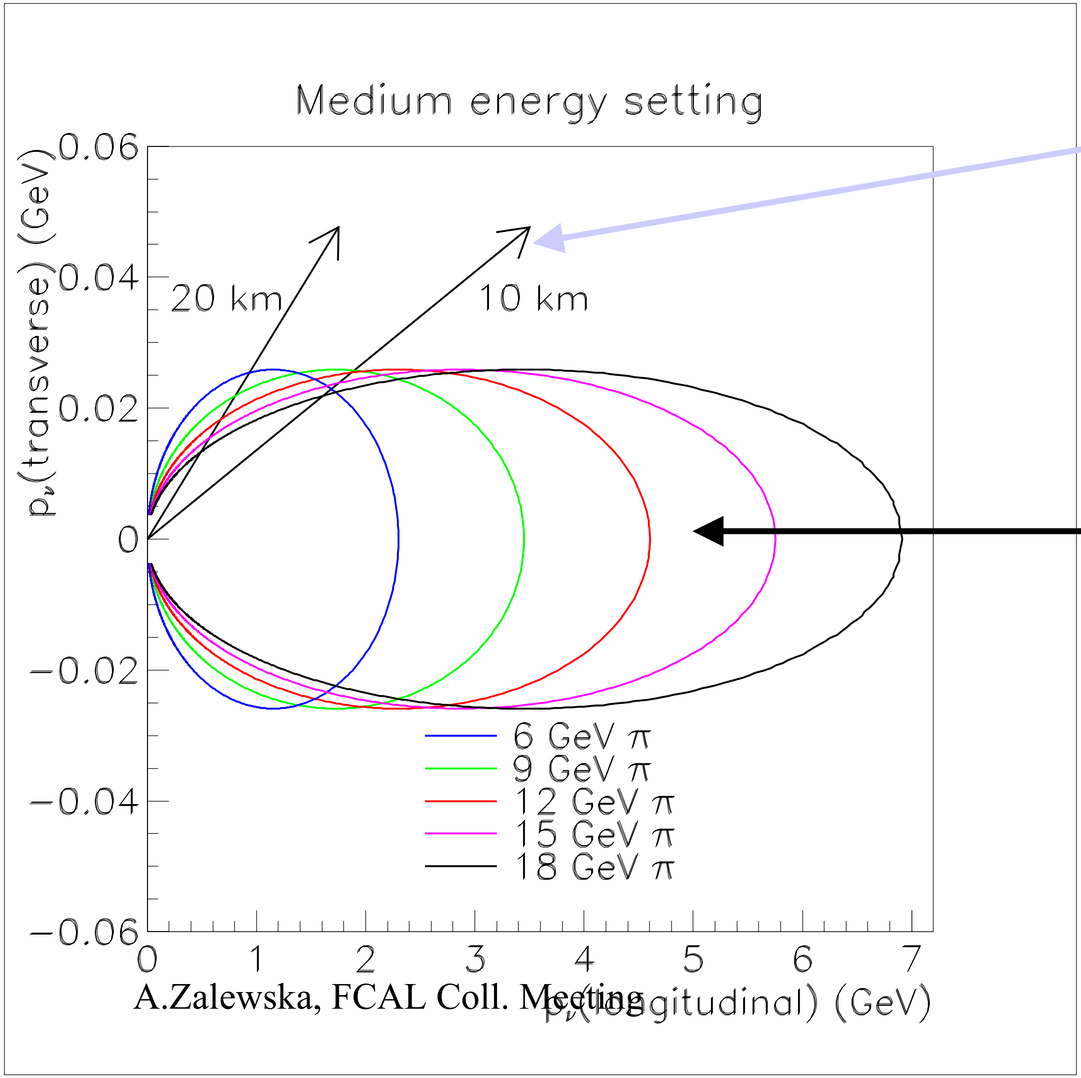
- Very clean θ_{13} measurement (no ambiguities, no matter effects)



- Several sites proposed: Brasil, China, France, Japan, Russia, Taiwan, USA

Phase II - off-Axis principle

Two body decay kinematics



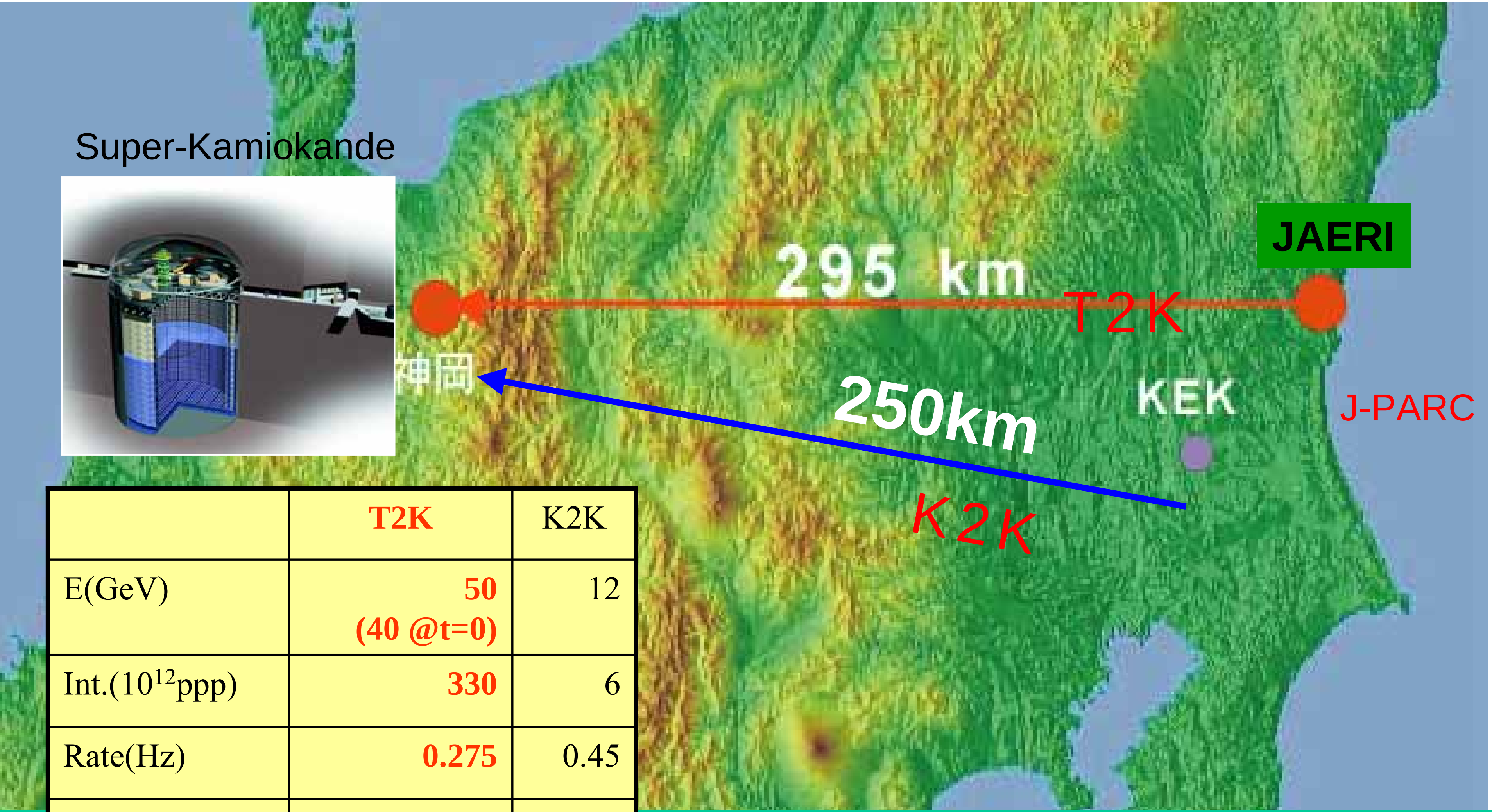
At an angle of 15 mrad, the energy of produced neutrinos is 1.5-2 GeV for all pion energies ➔ very intense, narrow band beam

'On axis': $E_\nu = 0.43 E_\pi$

$$p_L = \gamma(p^* \cos\theta^* + \beta E^*)$$
$$p_T = p^* \sin\theta^*$$

T2K (Tokai to Kamioka) experiment

From Kajita-son presentation



	T2K	K2K
E(GeV)	**50** **(40 @t=0)**	12
Int.(10^{12}ppp)	**330**	6
Rate(Hz)	**0.275**	0.45
Power(MW)	**0.75**	0.0052

C China, France, Italy, Japan, Korea, Poland, Russia, Spain, Switzerland, UK, USA

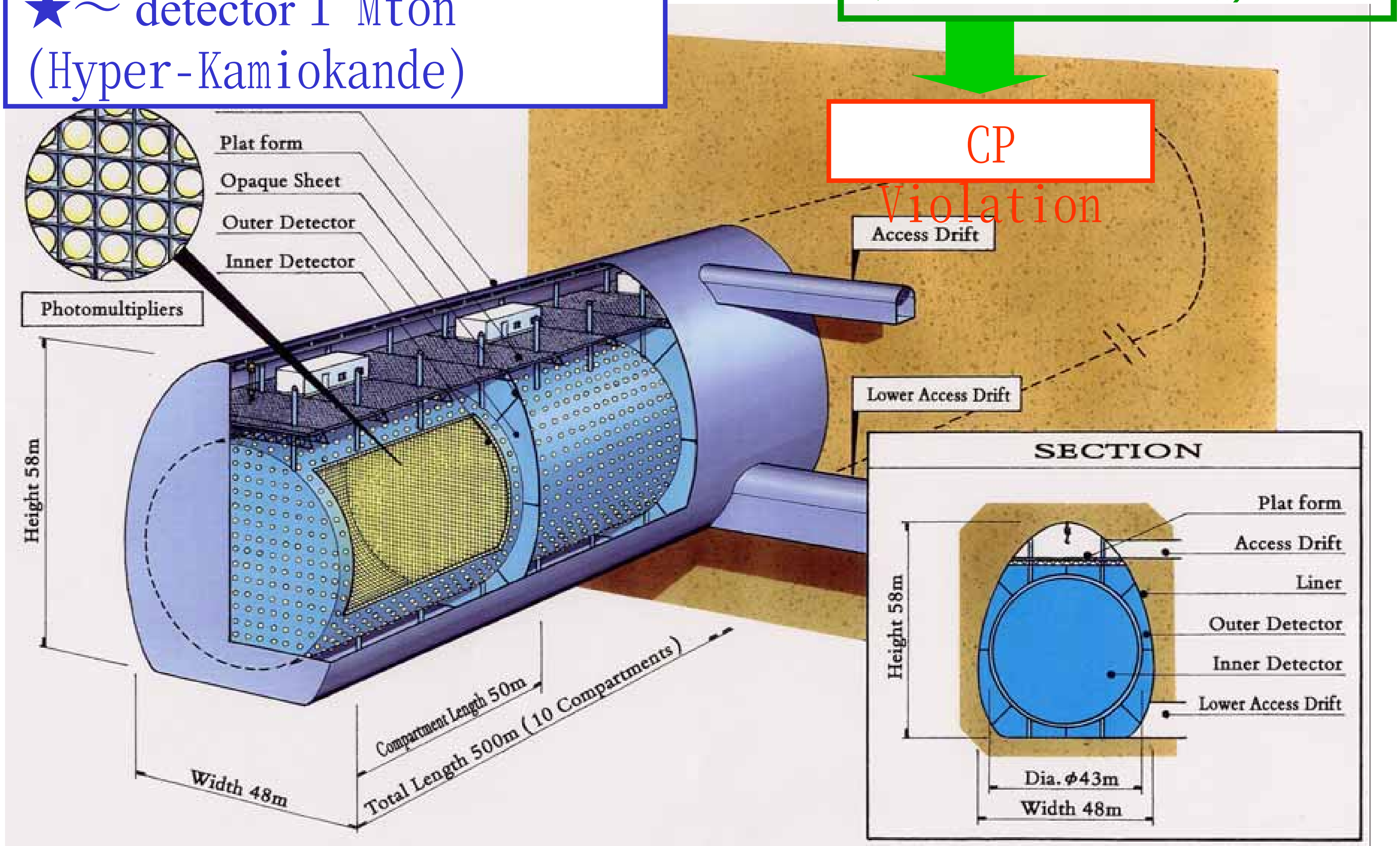
T2K (T2KJ) - further future

★0.77 → 4 MW

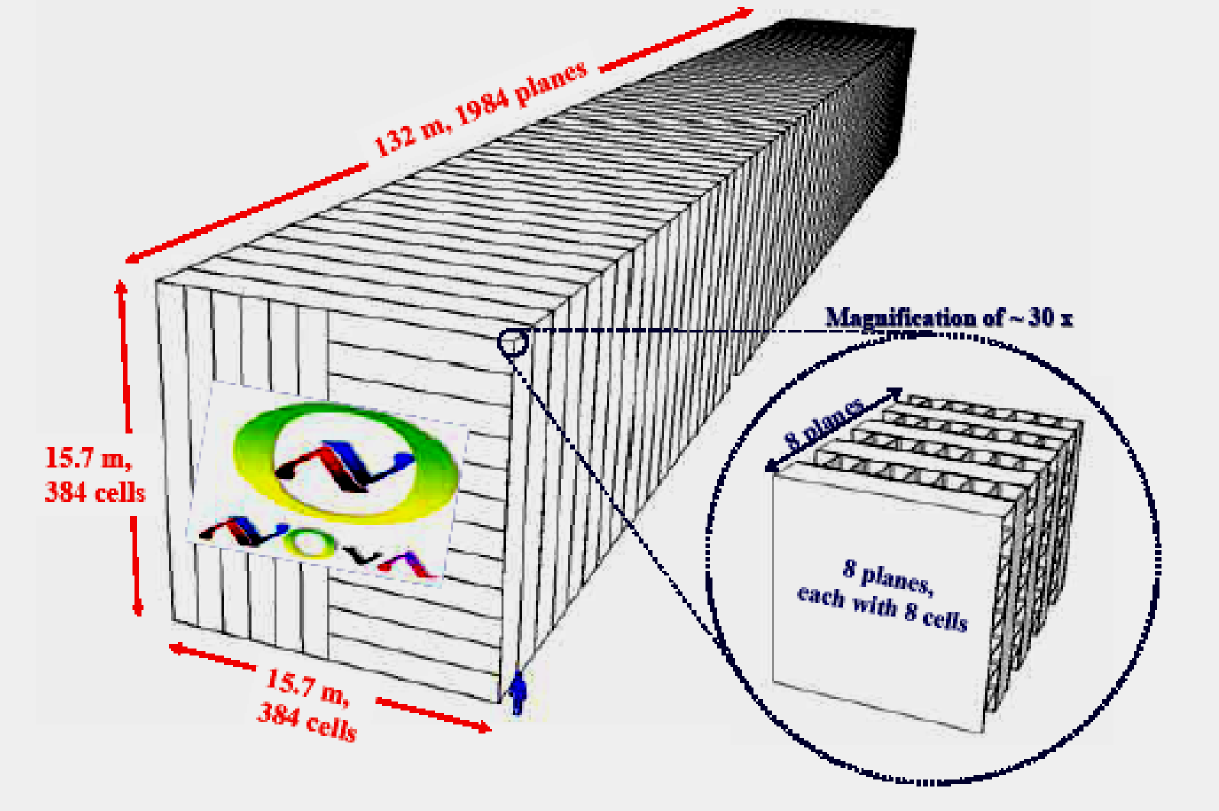
★~ detector 1 Mton (Hyper-Kamiokande)

10^6 przypadków (ν_μ and anti-ν_μ)

CP Violation



NOνA experiment

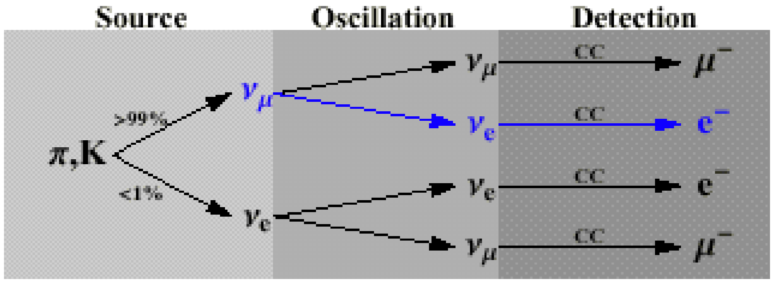


- 30 ktons in total, 80% of mass in a form of liquid scintillator i.e. active medium (5% for MINOS), individual cells are 3.9 cm wide, 6 cm deep and 15.7 m long
- Design optimized for the identification of ν_e-type events, longitudinal sampling of 0.15% (1.5% for MINOS)

- Detector will be placed at a shallow depth at a distance ~900 km from the NuMi target, 12 km off-axis

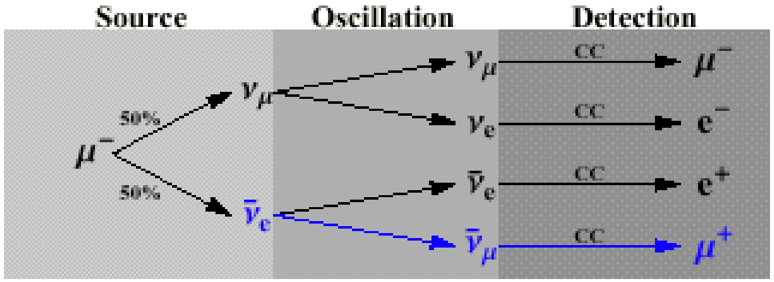
Phase III – new sources of neutrinos

Superbeams



Conventional beams
of ν_μ from π decays.
but of very high intensity

Neutrino Factories

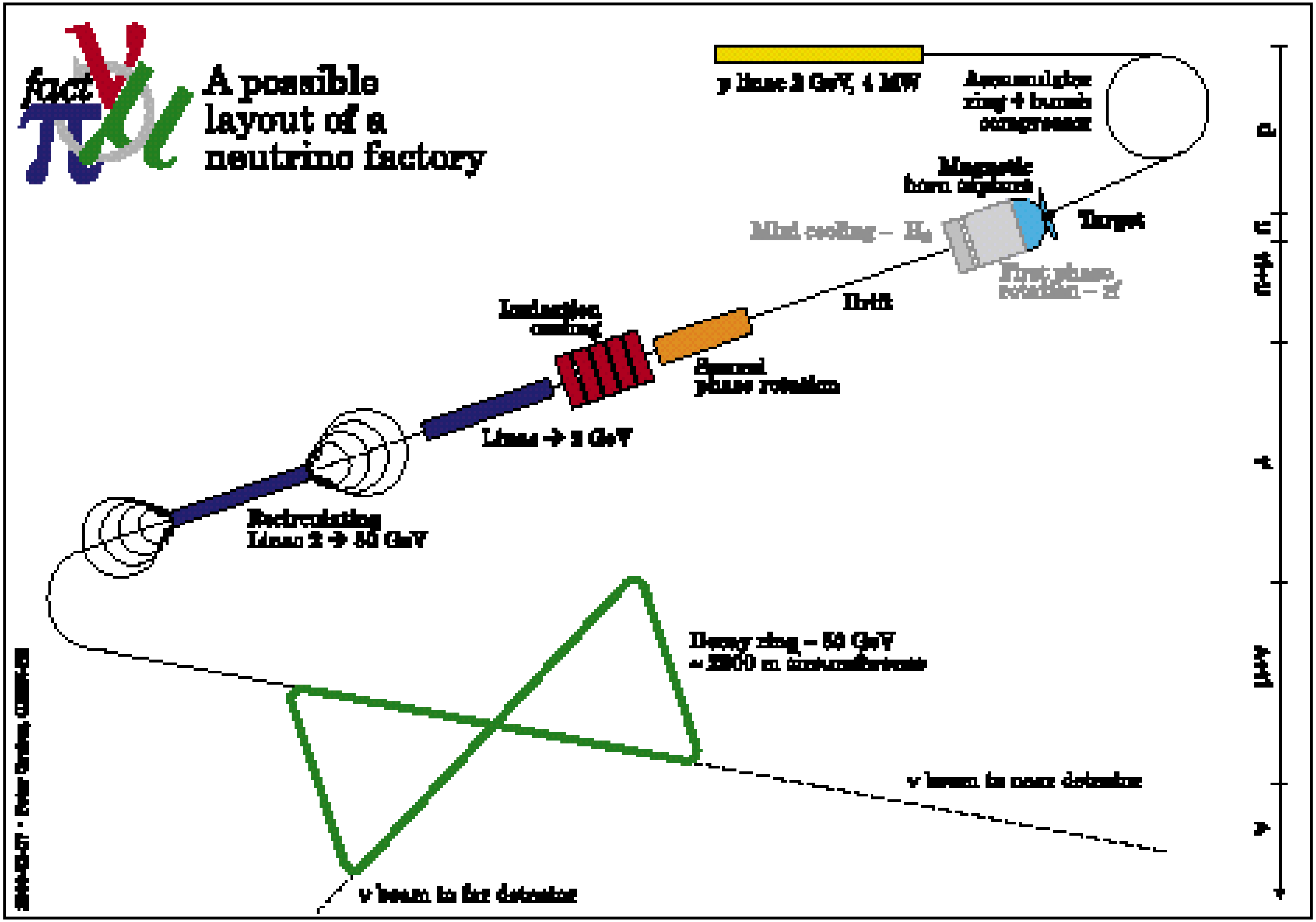


New type of accelerator:
neutrinos from decays of
accelerated muons

β beams
very fresh idea

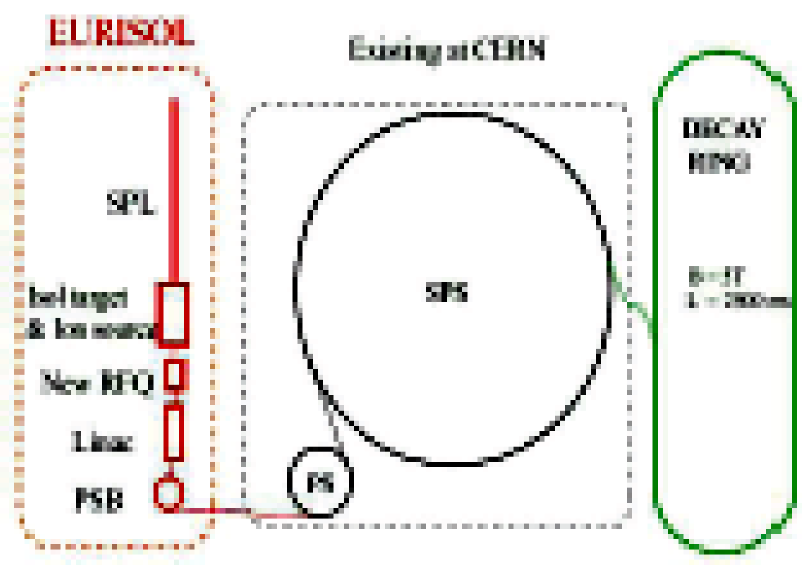
New type of accelerator:
neutrinos (antineutrinos)
from accelerated ^{18}Ne (^{6}He)

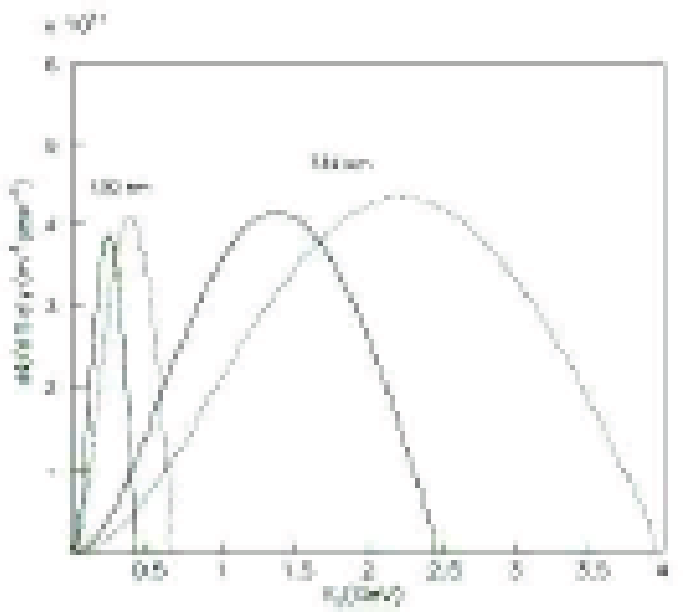
CERN concept of the neutrino factory



β beam concept

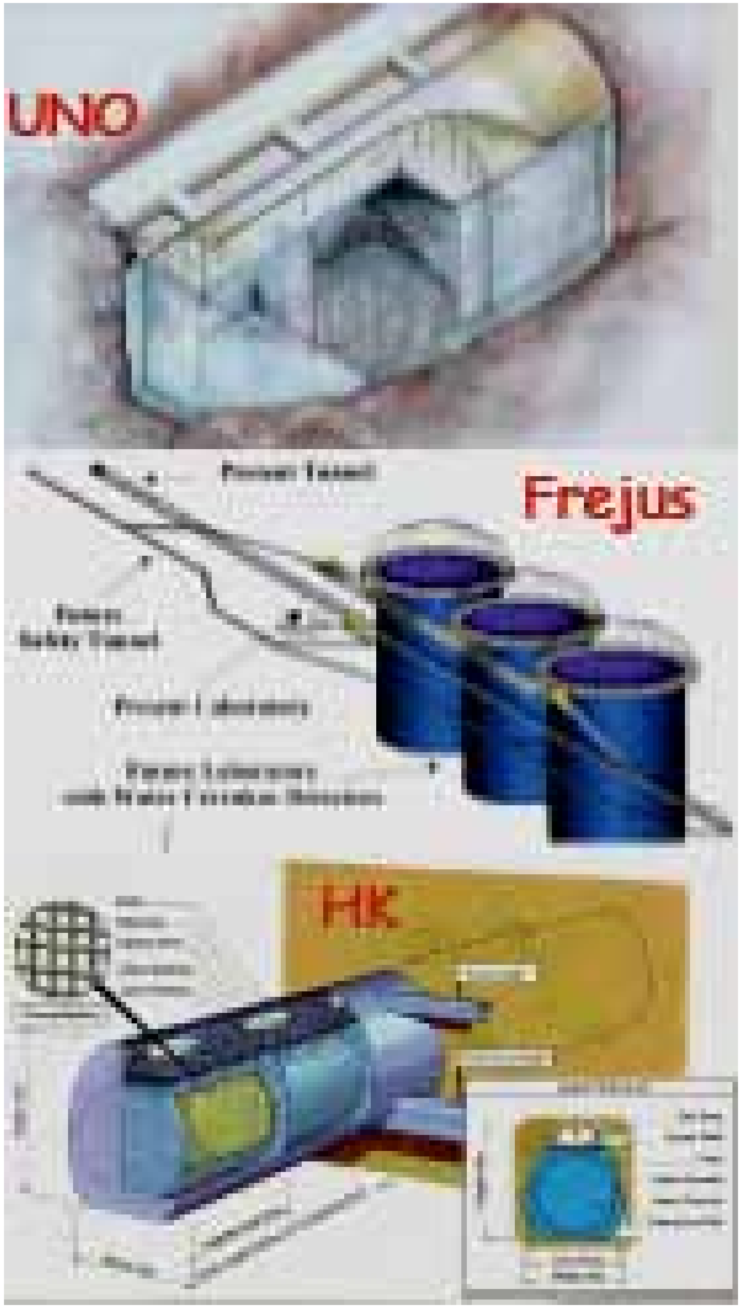
- β beams have been introduced in 2001 by P.Zucchelli.
- the idea is to generate a pure ν_e ($\bar{\nu}_e$), precisely known E spectrum, with accelerated radioactive ions (^{18}Ne, ^{6}He).
- Studies with several γ factors and baselines.
- Design study in relation to the EURISOL facility at CERN.



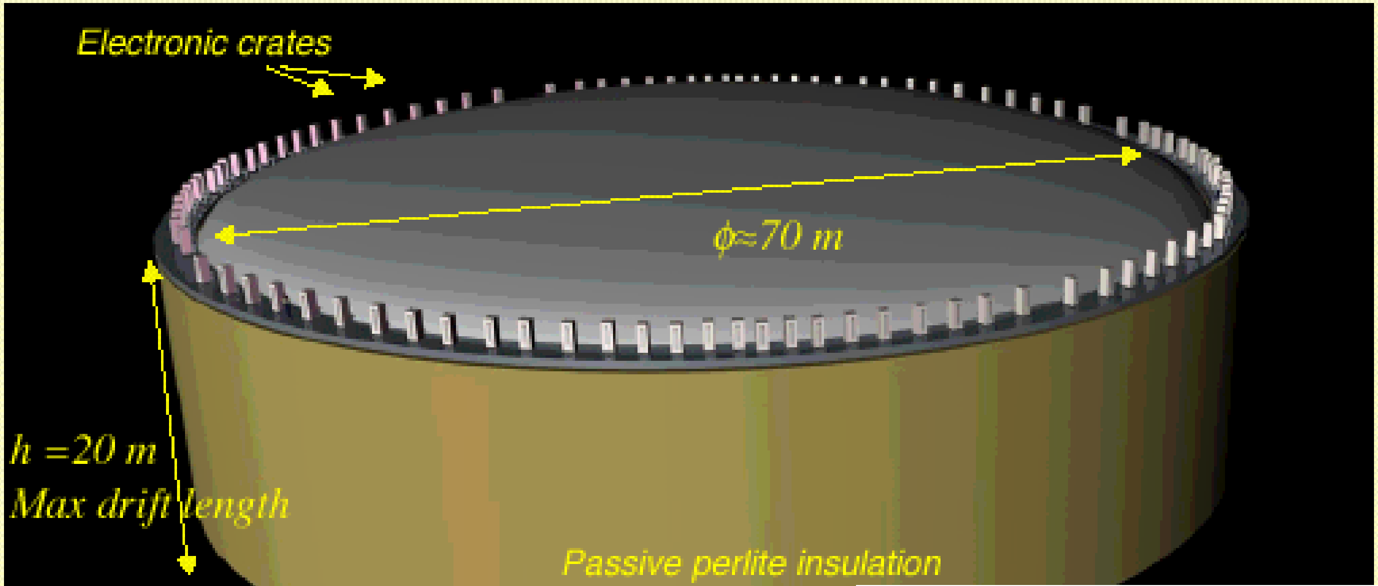


Future detectors ?

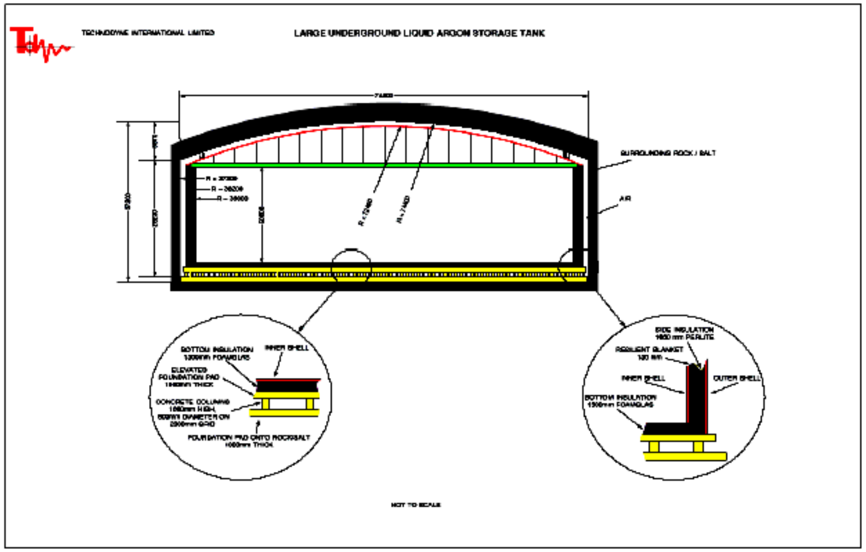
What about 1 Mton of water?



A 100 kton liquid Argon TPC detector



Technodyne baseline design



From A.Rubbia presentation at the TPC conf., Paris 2004

Absolute mass determination

Direct measurements based on the end-point of electron energy spectra in beta decays

The best measurement from the end-point of the tritium beta decay

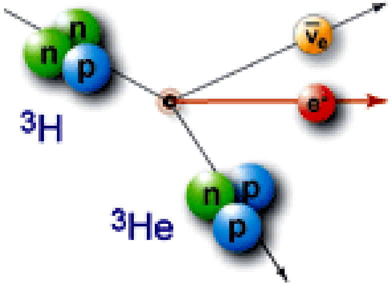
Cosmological limits

Resent cosmic microwave background measurements by the Wilkinson Microwave Anisotropy Probe (WMAP) together with different survey experiments give low upper limits for a sum of masses of different neutrino species but they are model dependent

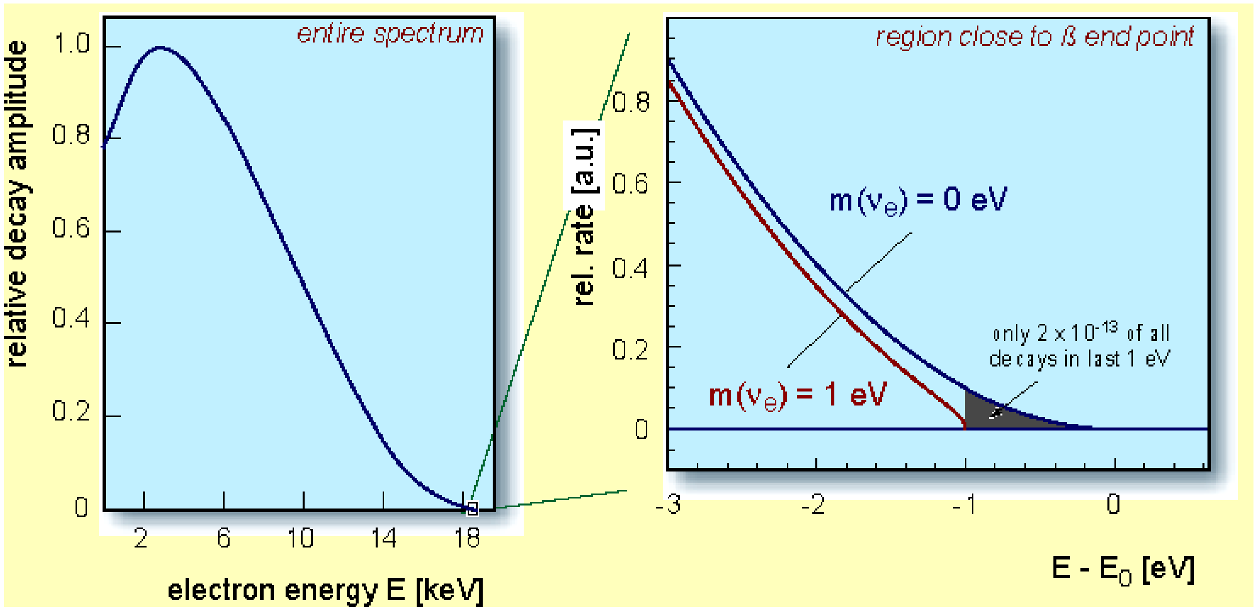
Based on the lifetime measurements for the neutrinoless double beta decays

Potentially the most sensitive method but neutrino must be the Majorana particle

Measurement based on the tritium β decay

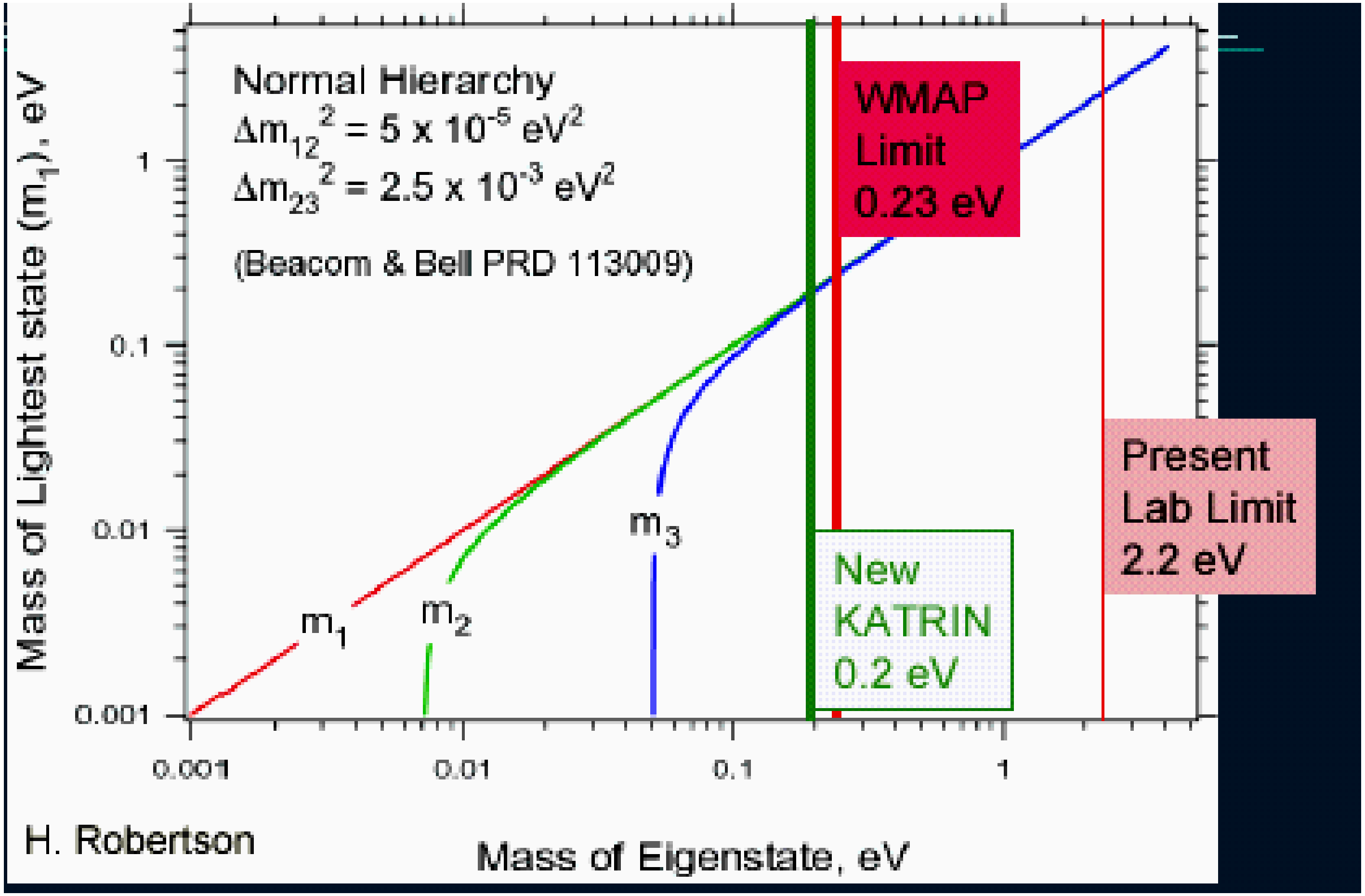


$$E_0 = M(^3H) - M(^3He) - m_e$$
$$= 18.6\ keV$$
$$\tau_{1/2} = 12.3\ years$$



Present limit $m(\nu_e)<2.2$ eV – from the Mainz i Troitsk experiments
The future eksperiment KATRIN (will start up w 2008) should achieve the limit of 0.2 eV → 1000 times less events in the tail
→ experiment sensitivity must increase 1000 times

Neutrino mass hierarchies



Effective neutrino mass in tritium beta decay as a function of the lightest neutrino mass

Cosmological limitations for a sum of ν masses

Authors	**Σm_ν/eV (limit 95%CL)**	**Data / Priors**
Spergel et al. (WMAP) 2003 [astro-ph/0302209]	0.69	WMAP, CMB, 2dF, σ_8, HST
Hannestad 2003 [astro-ph/0303076]	1.01	WMAP, CMB, 2dF, HST
Tegmark et al. 2003 [astro-ph/0310723]	1.8	WMAP, SDSS
Barger et al. 2003 [hep-ph/0312065]	0.75	WMAP, CMB, 2dF, SDSS, HST
Crotty et al. 2004 [hep-ph/0402049]	1.0 0.6	WMAP, CMB, 2dF, SDSS & HST, SN
Hannestad 2004 [hep-ph/0409108]	0.65	WMAP, SDSS, SN Ia gold sample, Ly-α data from Keck sample
Seljak et al. 2004 [astro-ph/0407372]	0.42	WMAP, SDSS, Bias, Ly-α data from SDSS sample

Halzen, 2005

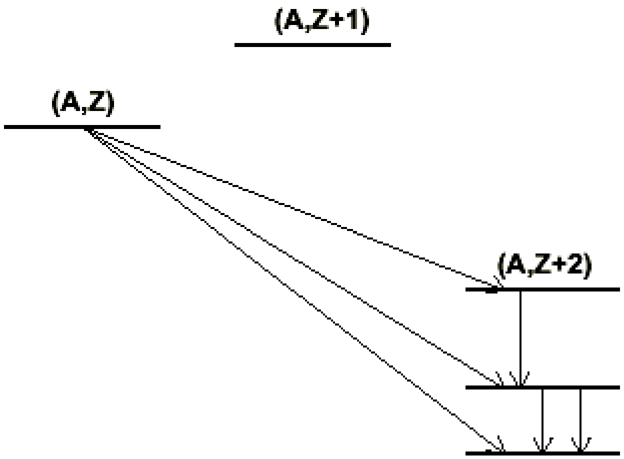
Double beta decay primer

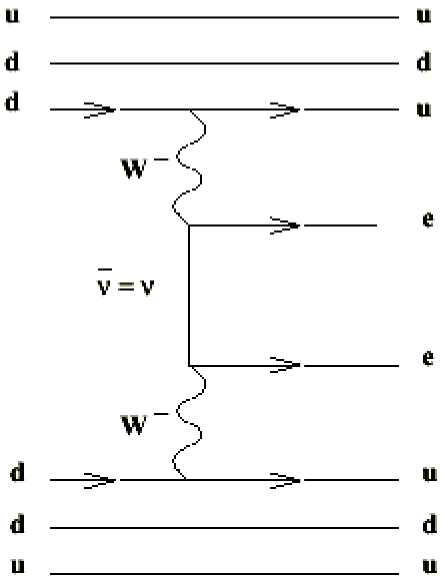
For some even-even nuclei the decay chain

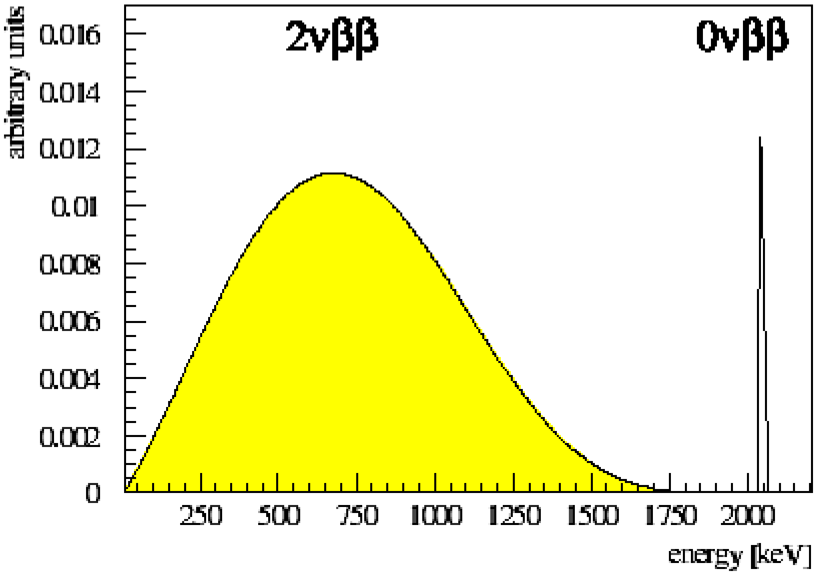
$$(A,Z) \rightarrow \quad (A,Z+1) + e^- + \overline{\nu}_e$$
$$\hookrightarrow (A,Z+2) + e^- + \overline{\nu}_e$$

is forbidden by energy conservation and one could have

$$(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\overline{\nu}_e$$
$$(A,Z) \rightarrow (A,Z+2) + 2e^-$$







Double beta decay

$$[T^{0\nu}_{1/2}]^{-1} = G^{0\nu}|M^{0\nu}|^2\langle m_\nu\rangle^2$$

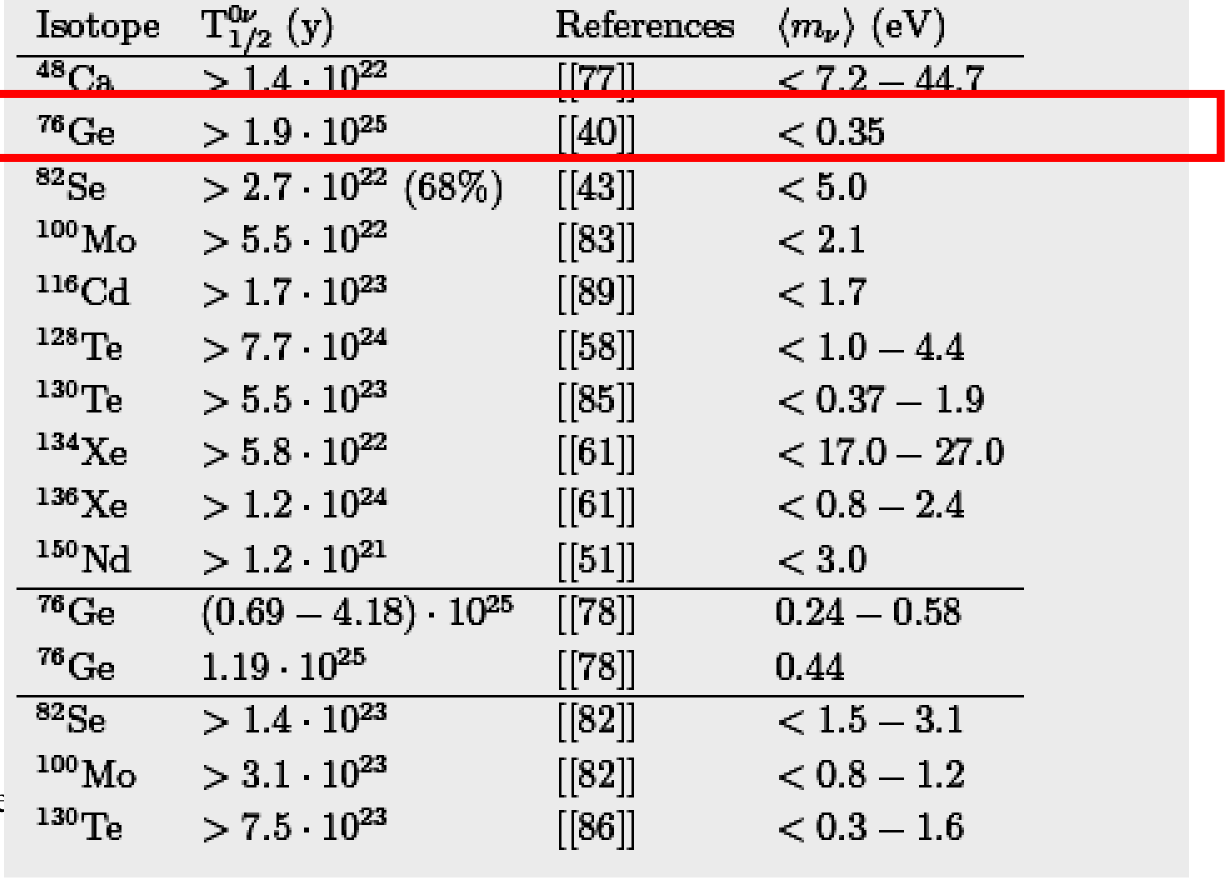
$|M^{0\nu}|^2$ The nuclear matrix element

$\langle m_\nu\rangle^2$ effective neutrino mass $\langle m_\nu\rangle = \sum_k \phi_k m_k U^2_{e,k}$

nucl-ex/0410029

Ultimate goal of experiments: sensitivity ~10 meV

Many sophisticated experiments in preparation

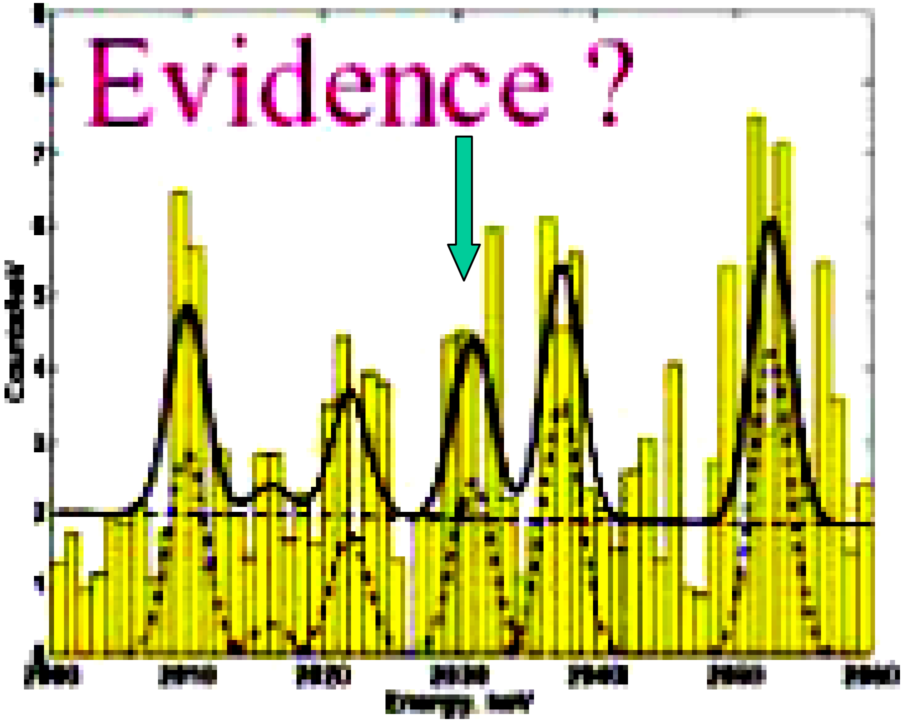


Isotope	$T^{0\nu}_{1/2}$ (y)	References	$\langle m_\nu\rangle$ (eV)
^{48}Ca	$> 1.4 \cdot 10^{22}$	[[77]]	$< 7.2 - 44.7$
^{76}Ge	$> 1.9 \cdot 10^{25}$	[[40]]	< 0.35
^{82}Se	$> 2.7 \cdot 10^{22}$ (68%)	[[43]]	< 5.0
^{100}Mo	$> 5.5 \cdot 10^{22}$	[[83]]	< 2.1
^{116}Cd	$> 1.7 \cdot 10^{23}$	[[89]]	< 1.7
^{128}Te	$> 7.7 \cdot 10^{24}$	[[58]]	$< 1.0 - 4.4$
^{130}Te	$> 5.5 \cdot 10^{23}$	[[85]]	$< 0.37 - 1.9$
^{134}Xe	$> 5.8 \cdot 10^{22}$	[[61]]	$< 17.0 - 27.0$
^{136}Xe	$> 1.2 \cdot 10^{24}$	[[61]]	$< 0.8 - 2.4$
^{150}Nd	$> 1.2 \cdot 10^{21}$	[[51]]	< 3.0
^{76}Ge	$(0.69 - 4.18) \cdot 10^{25}$	[[78]]	$0.24 - 0.58$
^{76}Ge	$1.19 \cdot 10^{25}$	[[78]]	0.44
^{82}Se	$> 1.4 \cdot 10^{23}$	[[82]]	$< 1.5 - 3.1$
^{100}Mo	$> 3.1 \cdot 10^{23}$	[[82]]	$< 0.8 - 1.2$
^{130}Te	$> 7.5 \cdot 10^{23}$	[[86]]	$< 0.3 - 1.6$

0νββ signal in the Moskow-Heidelberg experiment?

First announcement in 2002, new publication in 2004, based on the data collected between 1990 and 2003

Klapdor-Kleingrothaus Phys. Lett. B586 (2004) 198



Maximum at 2039 keV

$T_{1/2}$ = 0.6-8.4x10^{25}lat

→ m_ν = 0.17-0.63 eV

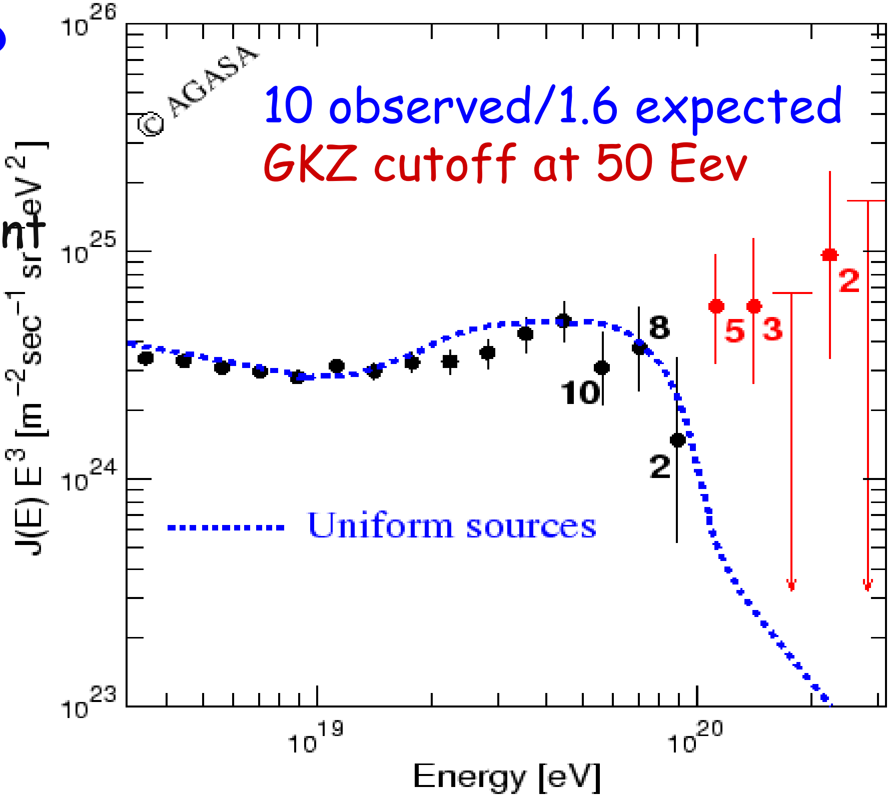
This result must be verified by another experiment, e.g. NEMO3 should achieve the required sensitivity in a few years

Extremely High Energy neutrinos

Do they exists?

Where do they come from?

Boosted by the observation of EHE cosmic rays in the AGASA experiment



10 observed/1.6 expected

GKZ cutoff at 50 Eev

It is a part of the experimental program realized with big volume detectors (up to 1 km^3)
based on a detection of Cherenkov radiation in ice

Amanda, Icecube

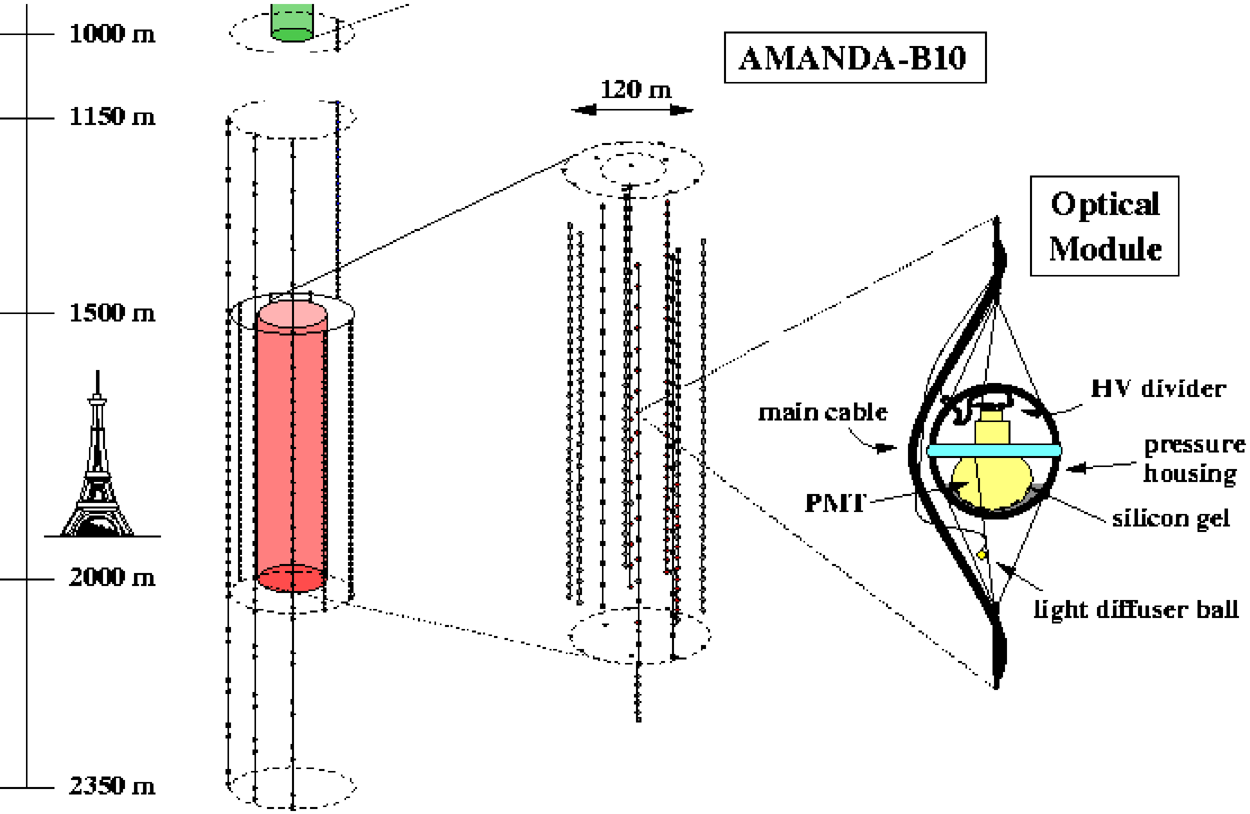
or deeply in a sea or lake water

Antares, Nestor, (pioneered by Baikal)

AMANDA/ICECUBE - Antarctic experiments

- 80 Strings
- 4800 PMTs
- 1 km^3
- 2004 - 2010

Neutrino Telescope in the Ice



AMANDA as of 2000
Eiffel Tower as comparison
(true scaling)

zoomed in on
AMANDA-A (top)
AMANDA-B10 (bottom)

zoomed in on one
optical module (OM)

<u>1997:</u>

AMANDA-B10

302 OMs on 10 Strings

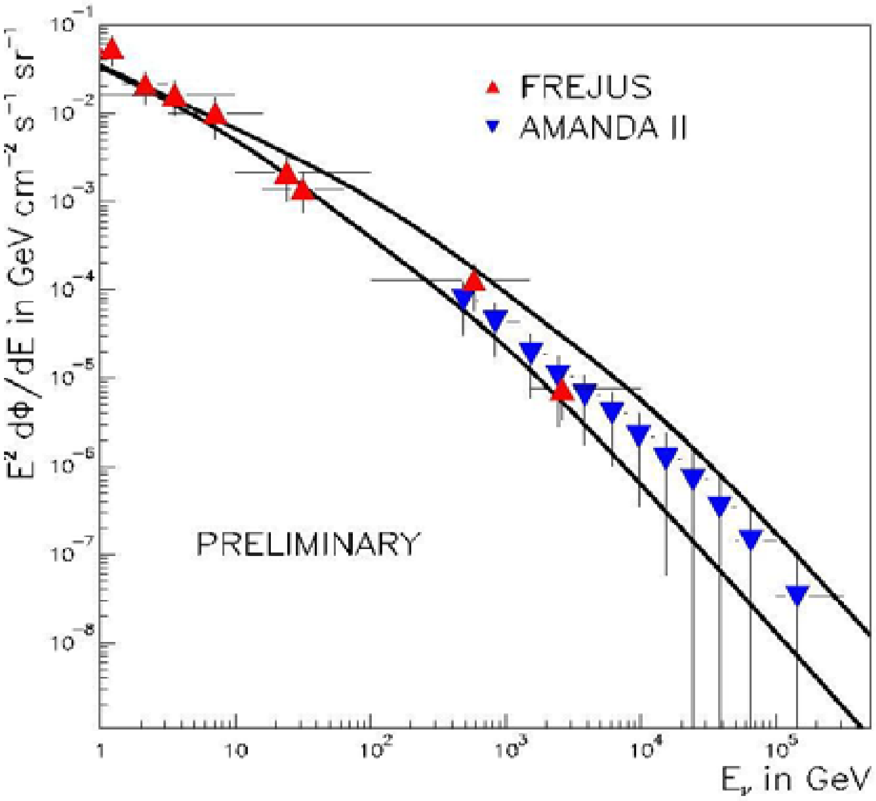
<u>2000:</u>

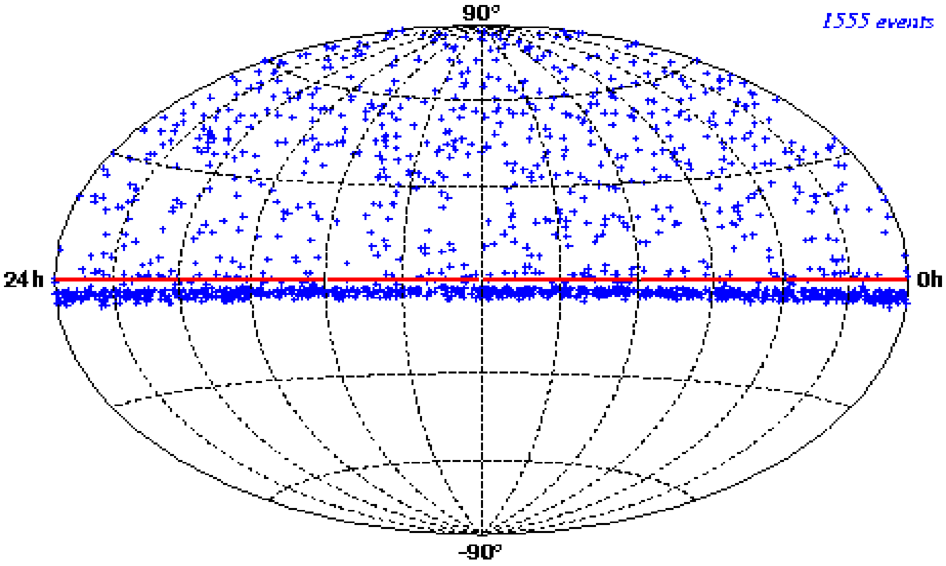
AMANDA-II

677 OMs on 19 Strings

First results from AMANDA

Atmospheric neutrino spectrum



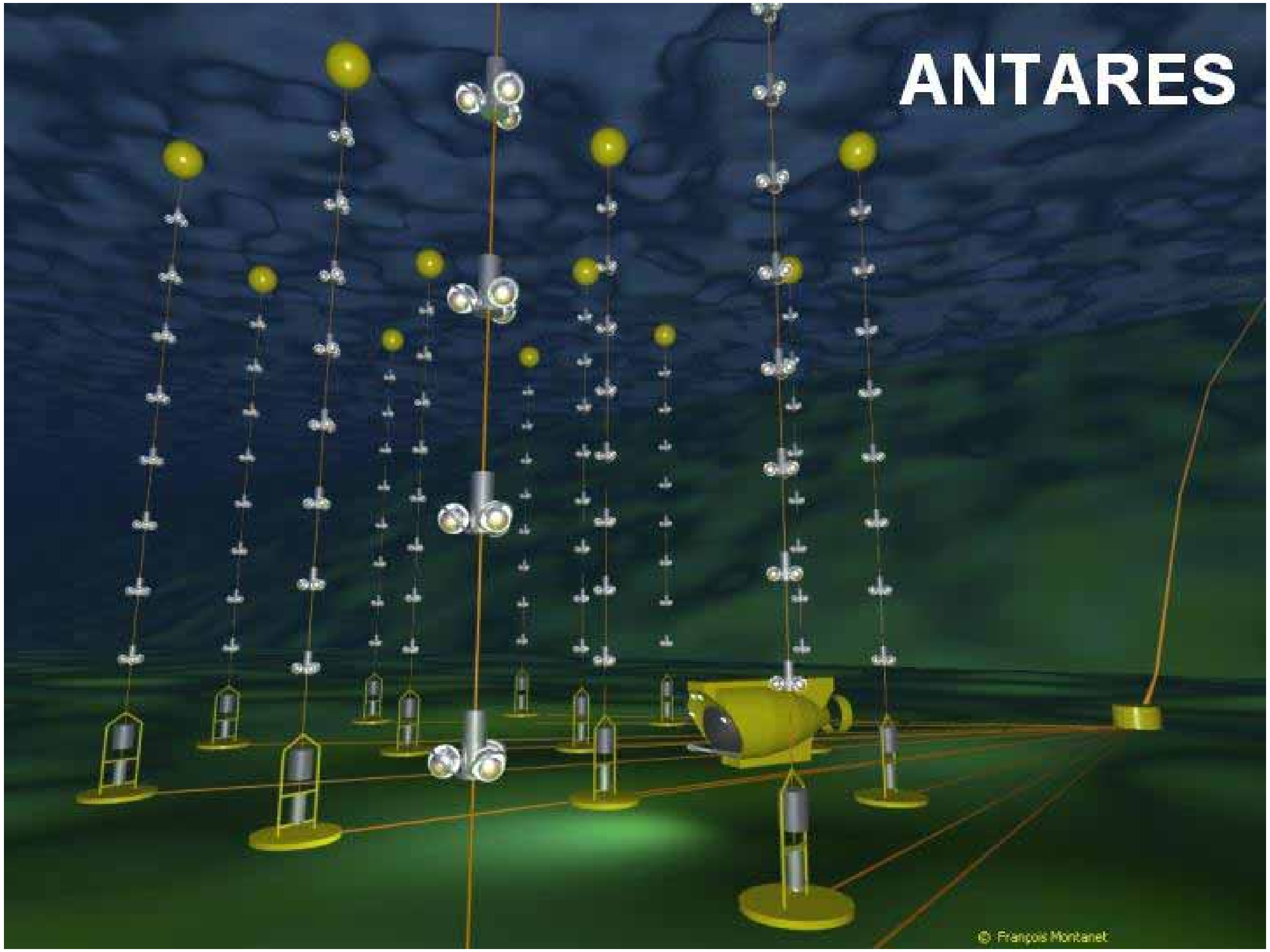


Search for extraterestial point sources

ICRC 2003: Geenen for AMANDA

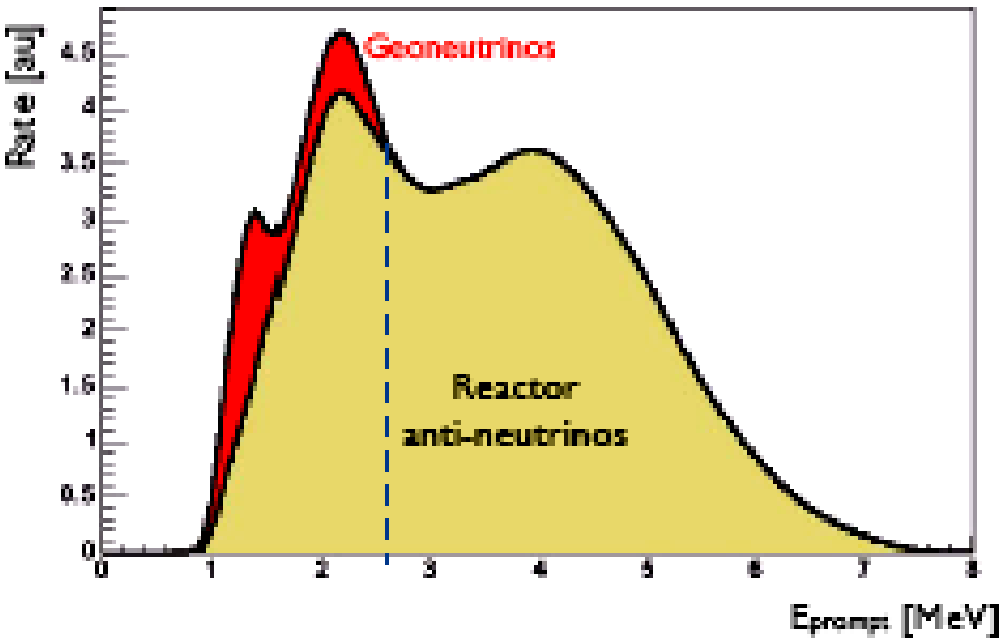
Deep water neutrino telescopes

Close to Toulon, at a death of 2400 m., successful first tests, problems with bioluminescence



Geoneutrinos in KamLAND

- Antineutrinos from ^{238}U, ^{232}Th and ^{40}K allow to study the mechanism of heat generation inside Earth
- KamLAND is the first experiment sensible enough to measure neutrinos from U and Th decays



The present limit from KamLAND-u on a heat from radioactive decays ff U and TH < 60 TW (as compared to the estimate of 31+-1 TW)

T.Araki et al., Nature 436 (2005) 467

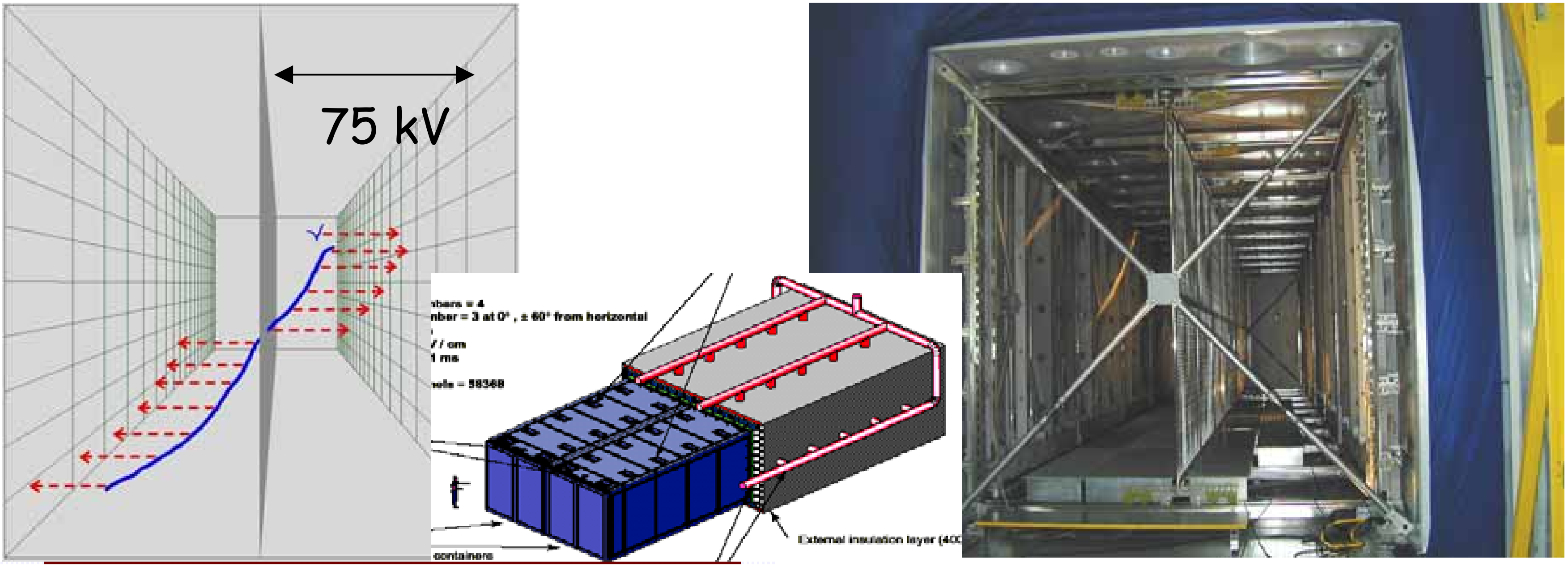
Instead of conclusions

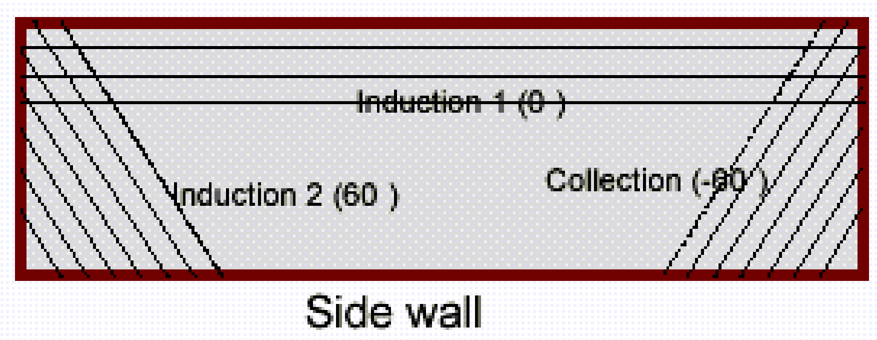
The modern electronics, informatics and telecommunication are based on 1 eV of the energy gap in Si

Does the tiny neutrino mass (probably much smaller than 1 eV) reflect the existance of particles with masses unaccessible to studies at accelerators and of the yet undiscovered laws of Nature?

LAr TPC - principle of operation

Ionization electrons drift (msec) over large distances (meters) in a volume of highly purified liquid Argon (0.1 ppb of O_2) under the action of an E field. With a set of wire grids (traversed by the electrons in ~ 2-3 μs) one can realize a massive, continuously sensitive electronic "bubble chamber".





Single "bubble" 3x3x0.6 mm^3
no signal multiplication, about
8000 e^--ion pairs per mm

T600 - data quality