Recent Results in Neutrino Physics : Highlights

- Overview
- Highlights in Neutrino Oscillation Results from Atmospheric, Solar, Accelerator and Reactor Neutrino Experiments
- Future Directions & Projects
- TEXONO Research Program (if time permits)
- Outlook

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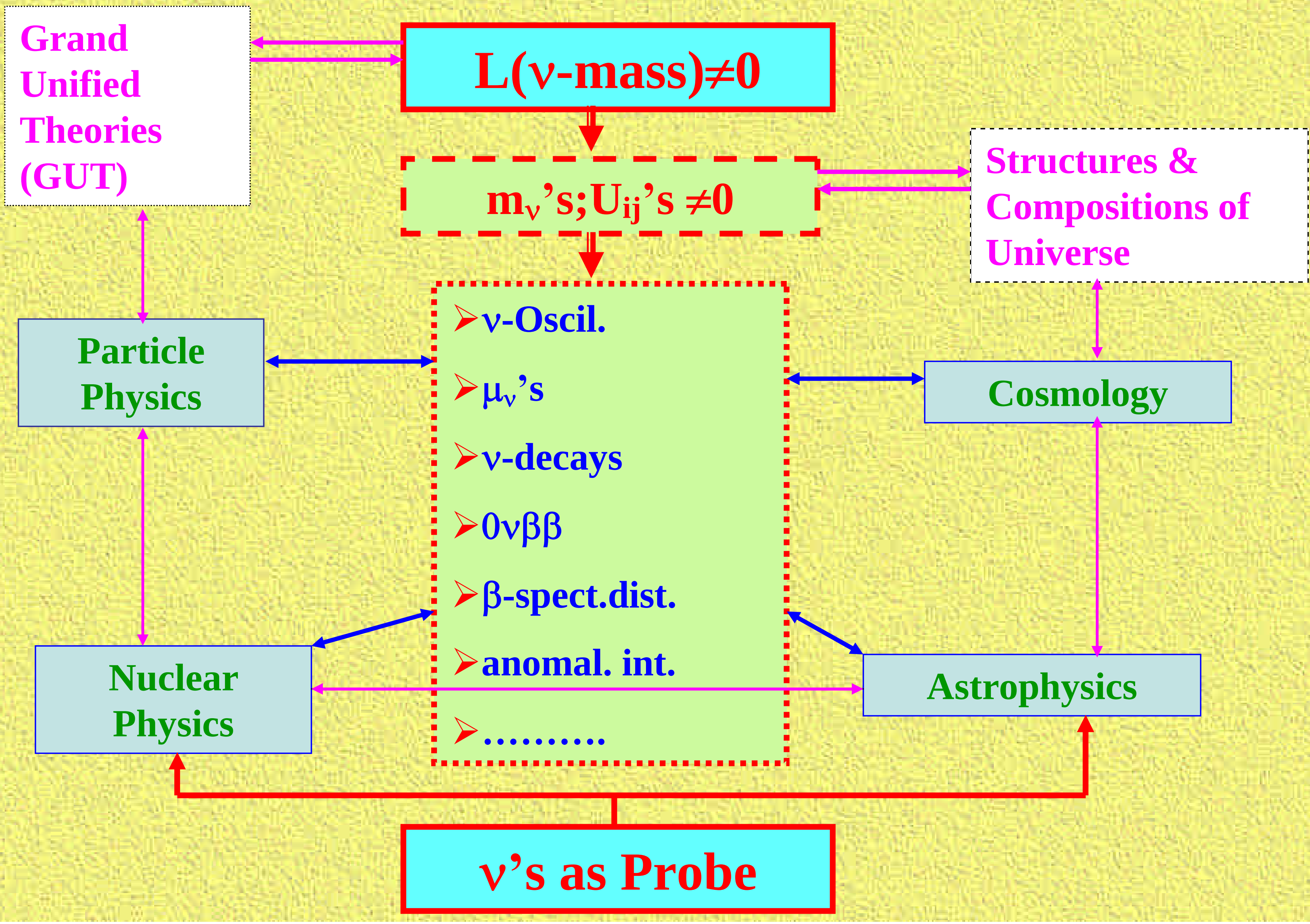
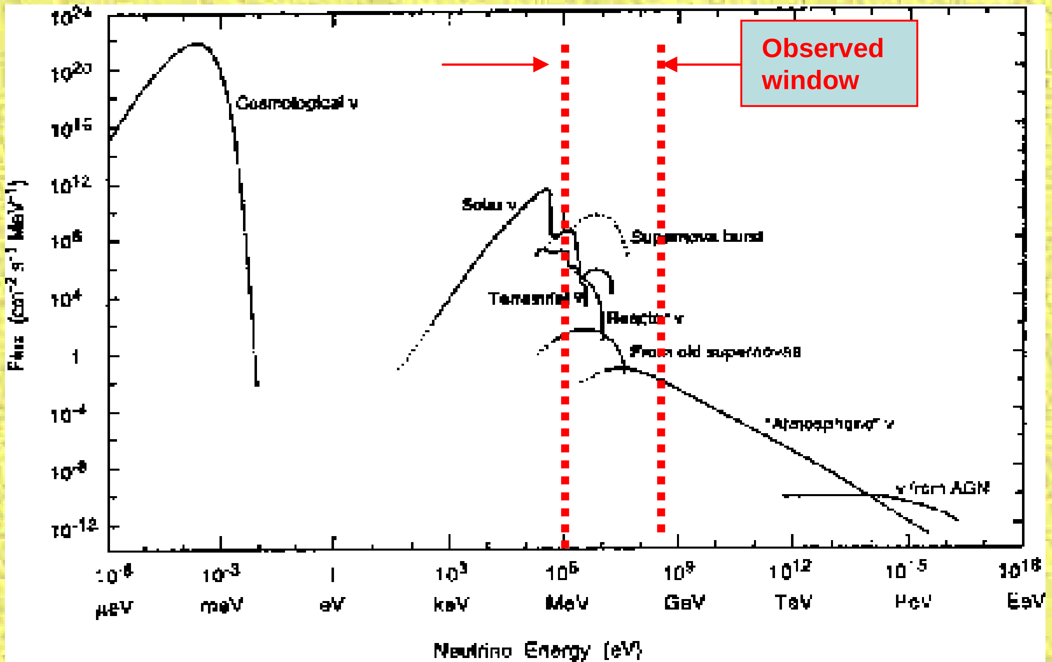
KIAS-APCTP-DMRC Workshop on
"The Dark Side of the Universe"
May 24(Tue)~26(Thu) KIAS, Seoul, Korea

Neutrino Physics Road-Map



Neutrino Sources



- ν's everywhere:

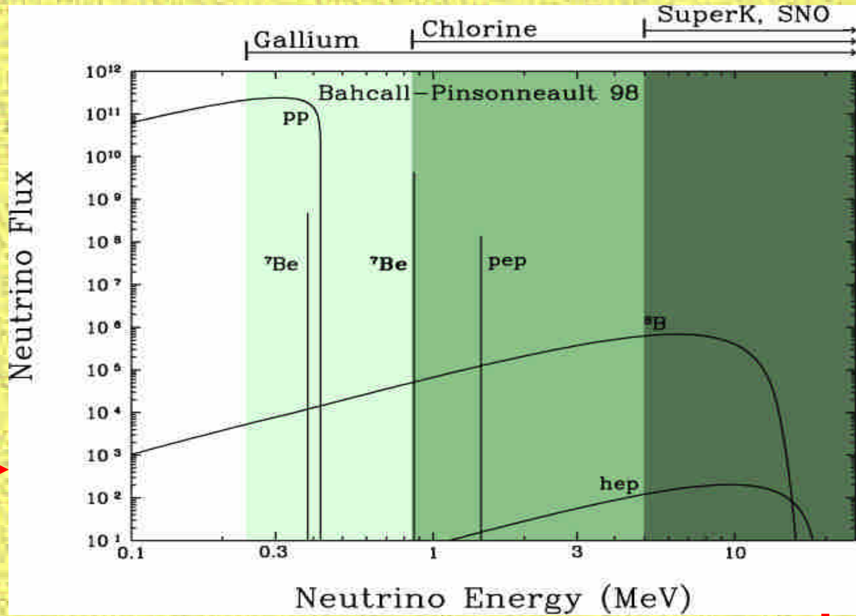
  ≈300 per c.c.

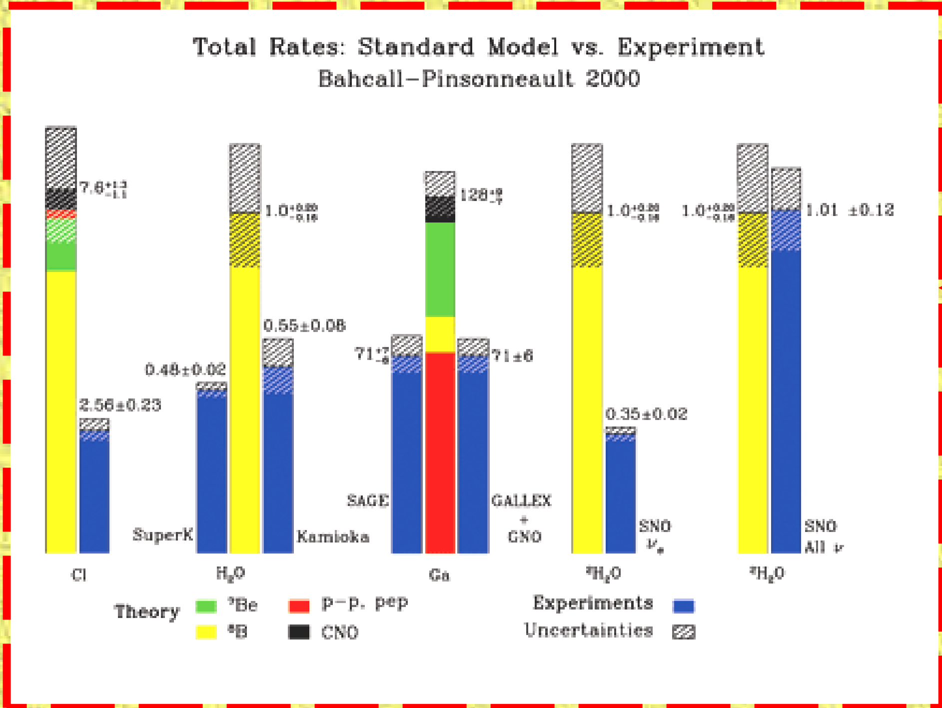
- from sun, supernovae, cosmic rays, reactors, accelerators, astrophysical sources, & relic Big Bang …

Solar Neutrinos

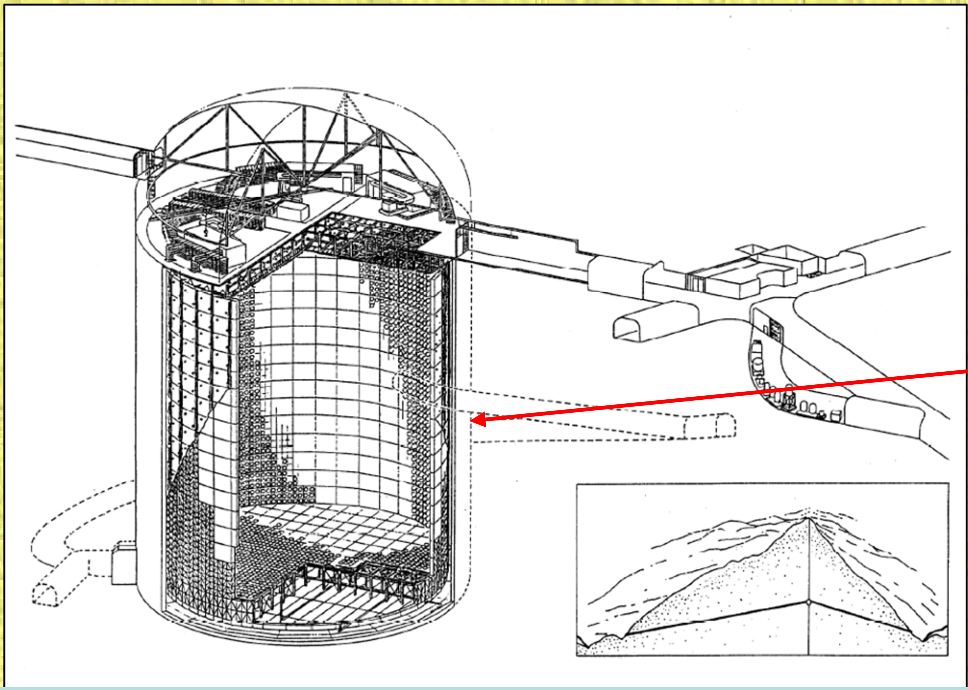
REACTION	TERM (%)	ν ENERGY (MeV)
$p+p \rightarrow {}^2H+e^+ +\nu_e$	(99.96)	≤ 0.423
or		
$p+e^- +p \rightarrow {}^2H+\nu_e$	(0.44)	1.445
${}^2H+p \rightarrow {}^3He+\gamma$	(100)	
${}^3He+{}^3He \rightarrow \alpha+2p$	(85)	
or		
${}^3He+{}^4He \rightarrow {}^7Be+\gamma$	(15)	
${}^7Be+e^- \rightarrow {}^7Li+\nu_e$	(15)	{0.863 90% {0.385 10%
${}^7Li+p \rightarrow 2\alpha$		
or		
${}^7Be+p \rightarrow {}^8B+\gamma$	(0.02)	
${}^8B \rightarrow {}^8Be^*+e^+ +\nu_e$		< 15
${}^8Be^* \rightarrow 2\alpha$		
or		
${}^3He+p \rightarrow {}^4He+e^+ +\nu_e$	(0.00003)	< 18.8

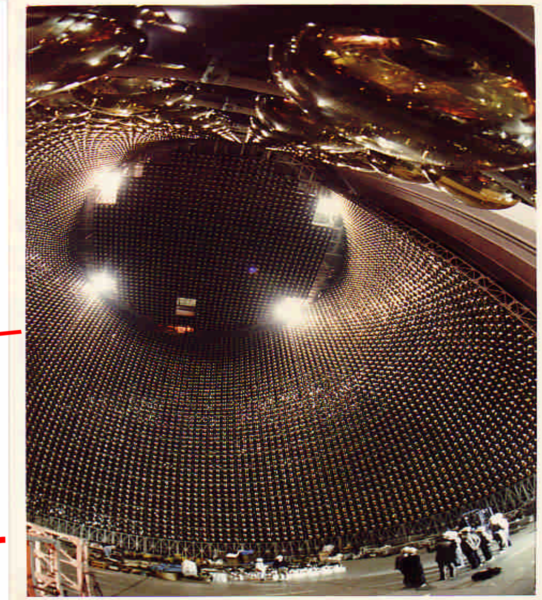
Neutrino terminations from BP2000 solar model. Neutrino energies include solar corrections: J. Bahcall, Phys. Rev. C, 56, 3391 (1997).

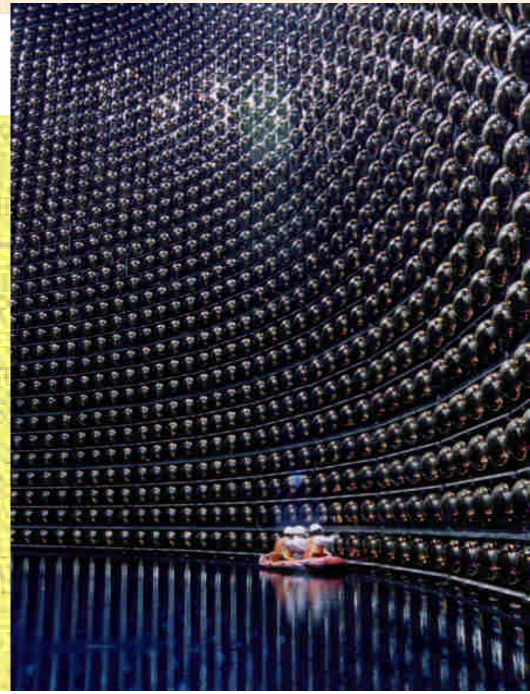




Super-Kamionkande







※ **Water Cerenkov detector:** **50k tons, viewed by $11,000^{+}$ Φ=50 cm PMTs in 1000 m underground site in central Japan**

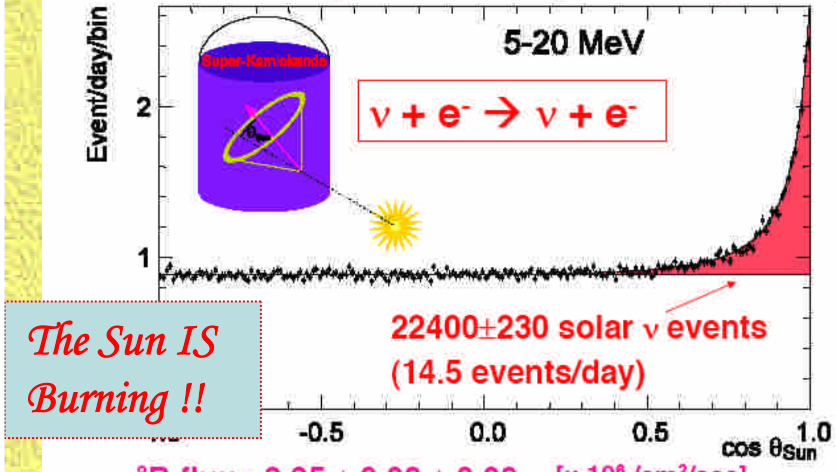
※ **Physics:** **solar ν, atmospheric ν , long baseline accelerator ν, proton decays ..**

※ **Accidents (PMTs imploded) Nov 01,**

- **50% PMT data again end of 02 !!**
- **No major deterioration in data quality**

Super-Kamiokande-I solar neutrino data

May 31, 1996 – July 13, 2001 (1496 days)

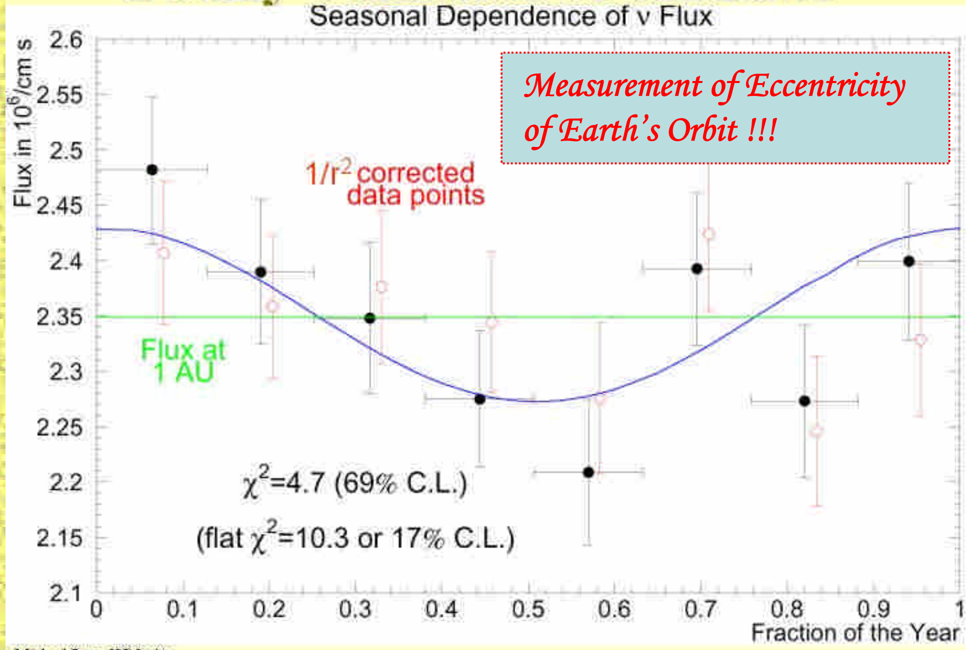


^{8}B flux : 2.35 ± 0.02 ± 0.08 [x 10^6 /cm^2/sec]

$$\frac{\text{Data}}{\text{SSM(BP2004)}} = 0.406 \pm 0.004 \begin{matrix} +0.014 \\ -0.013 \end{matrix}$$

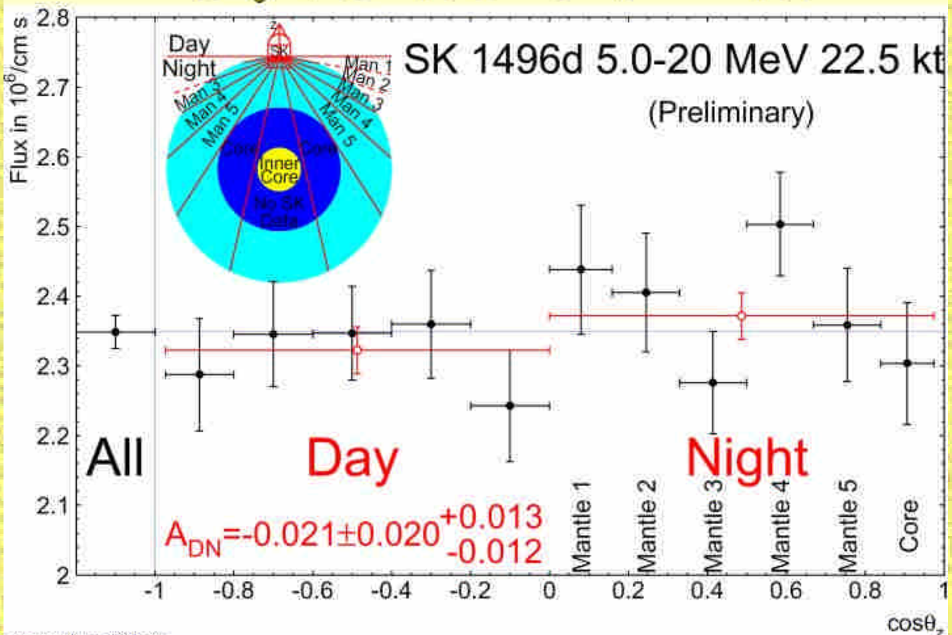
(Data/SSM(BP2000) = 0.465 ±0.005 +0.016/-0.015)

Yearly Variation of SK Rate



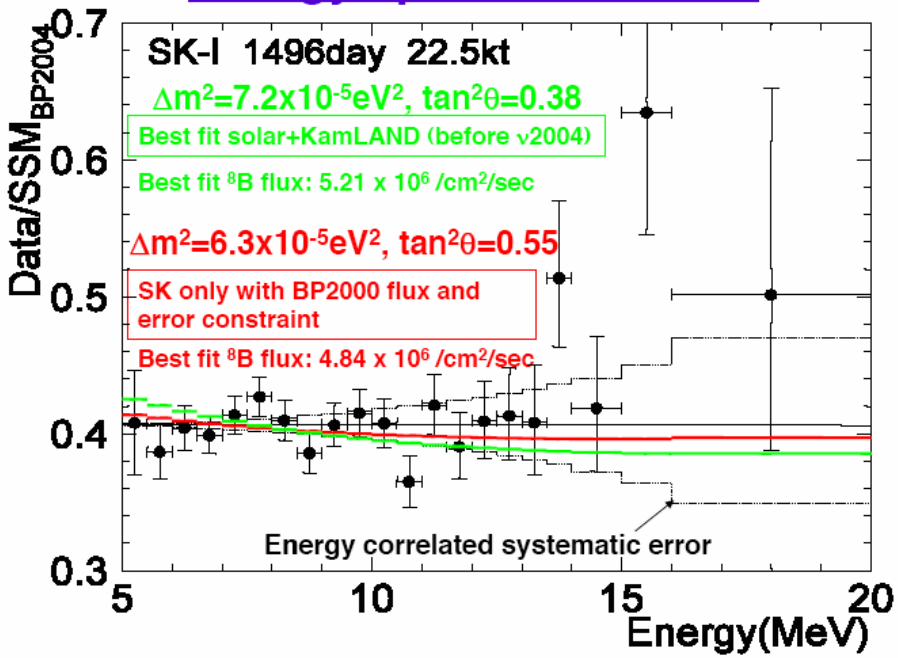
Michael Smy, UC Irvine

Daily Variation of SK Rate

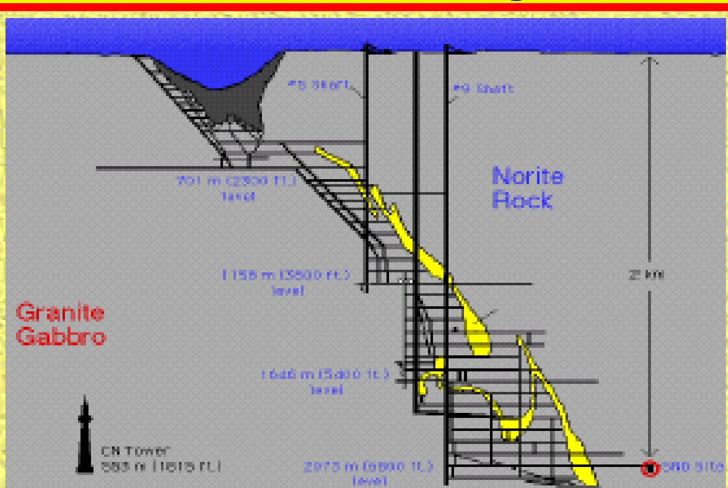


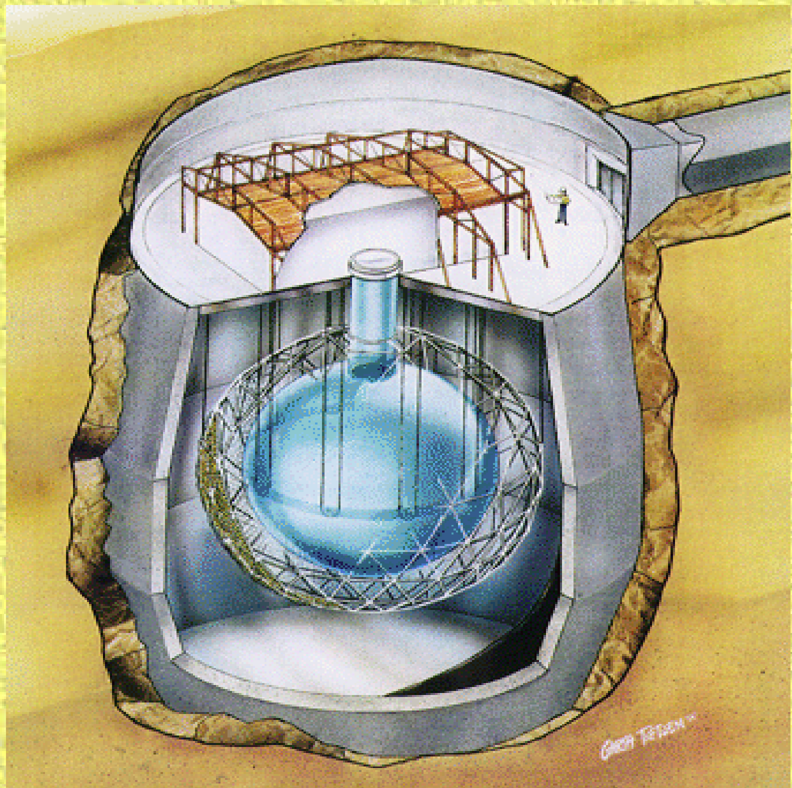
Michael Smy, UC Irvine

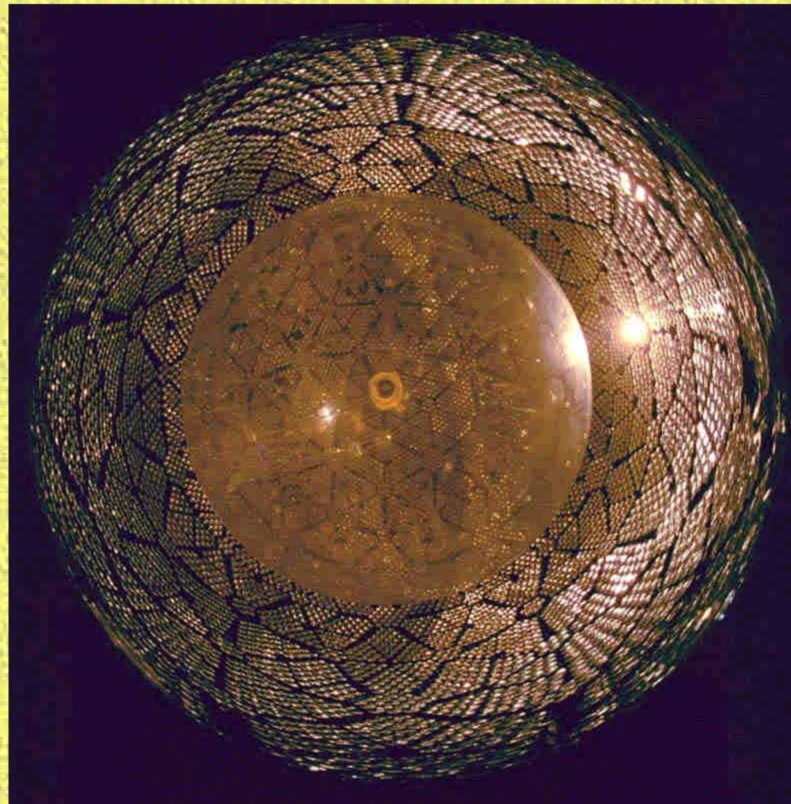
Energy spectrum of SK-I



Sudbury Neutrino Observatory (SNO)







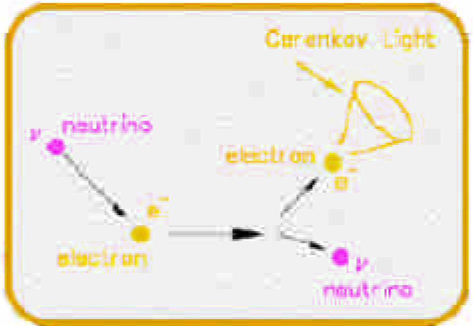
※ **1 kton Heavy Water Cerenkov detector:**

shielded by 7k ton of water viewed by 9456 PMTs located 2000 m underground in Canada.

※ **Physics: Solar ν …**

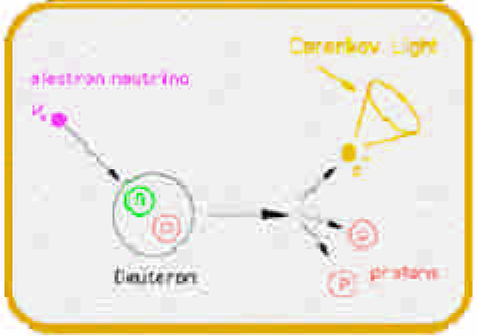
Signals in SNO

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



- Strong directional sensitivity

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

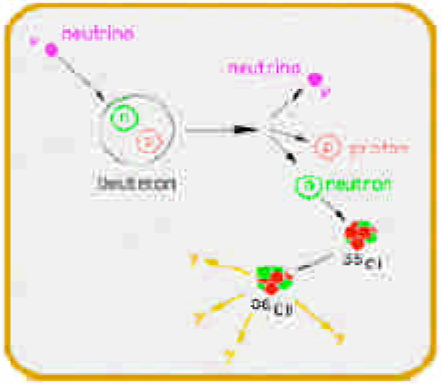


- Good measurement of ν_e energy spectrum

- Weak directional sensitivity $\propto$ 1-1/3cos(θ)

- ν_e ONLY

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



- Measure total ^8B ν flux from the sun.

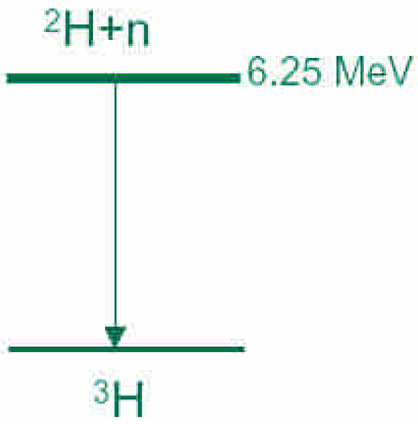
- Equal cross section for all ν types

SNO - 3 neutron detection methods

Phase I (D_2O)

Nov. 99 - May 01

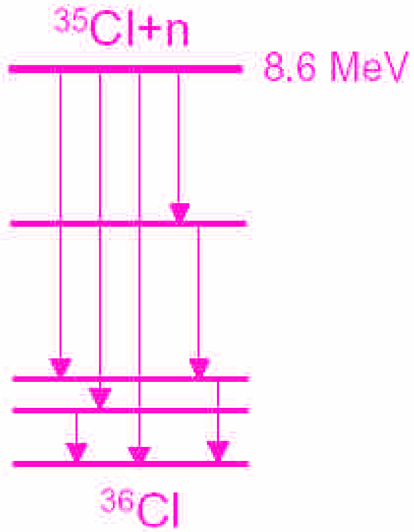
n captures on
$^2H(n, \gamma)^3H$
$\sigma = 0.0005$ b
Observe 6.25 MeV γ
PMT array readout
Good CC



Phase II (salt)

July 01 - Sep. 03

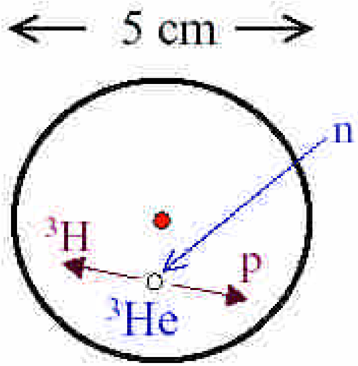
2 t NaCl. n captures on
$^{35}Cl(n, \gamma)^{36}Cl$
$\sigma = 44$ b
Observe multiple γ's
PMT array readout
Enhanced NC



Phase III (^3He)

Summer 04 - Dec. 06

40 proportional counters
$^3He(n, p)^3H$
$\sigma = 5330$ b
Observe p and ^3H
PC independent readout
Event by Event Det.



$n + {}^3He \rightarrow p + {}^3H$

ν Reactions in SNO

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

-Good measurement of ν_e energy spectrum
-Weak directional sensitivity ∝ 1-1/3cos(θ)
- ν_e only.

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

- Equal cross section for all ν types
- Measure total ^8B ν flux from the sun.

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

-Low Statistics
-Mainly sensitive to ν_e, some sensitivity to ν_μ and ν_τ
-Strong directional sensitivity

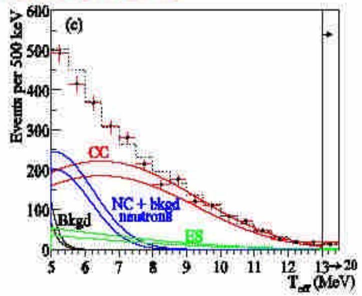
Actual measurements : only detect e- (a burst of light) : deconvolute the channels

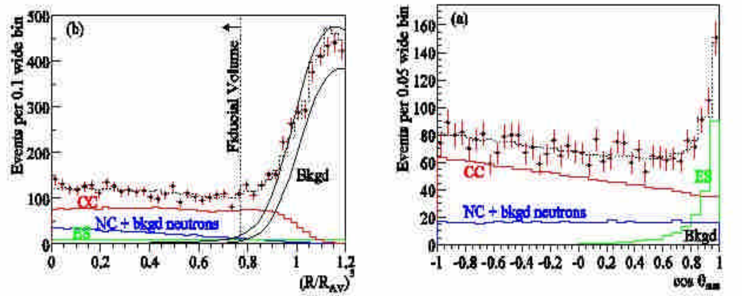
Pure D_2O Phase

Shape Constrained Signal Extraction Results

#EVENTS

CC	$1967.7^{+61.9}_{-60.9}$
ES	$263.6^{+26.4}_{-25.6}$
NC	$576.5^{+49.5}_{-48.9}$





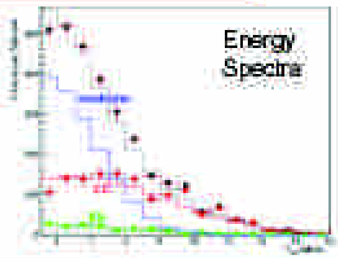
Event Distributions (PRL 92, 181301, 2004)

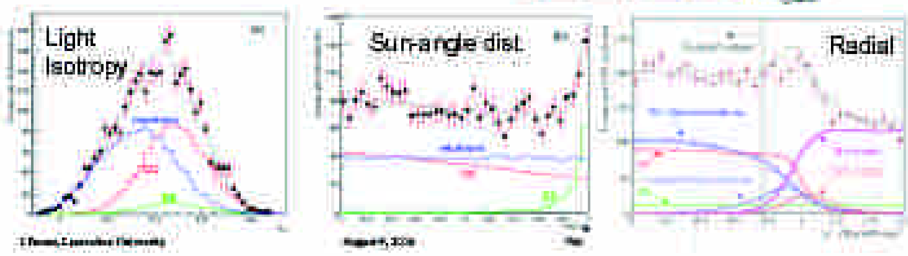
Salt Phase

[illegible]

#EVENTS

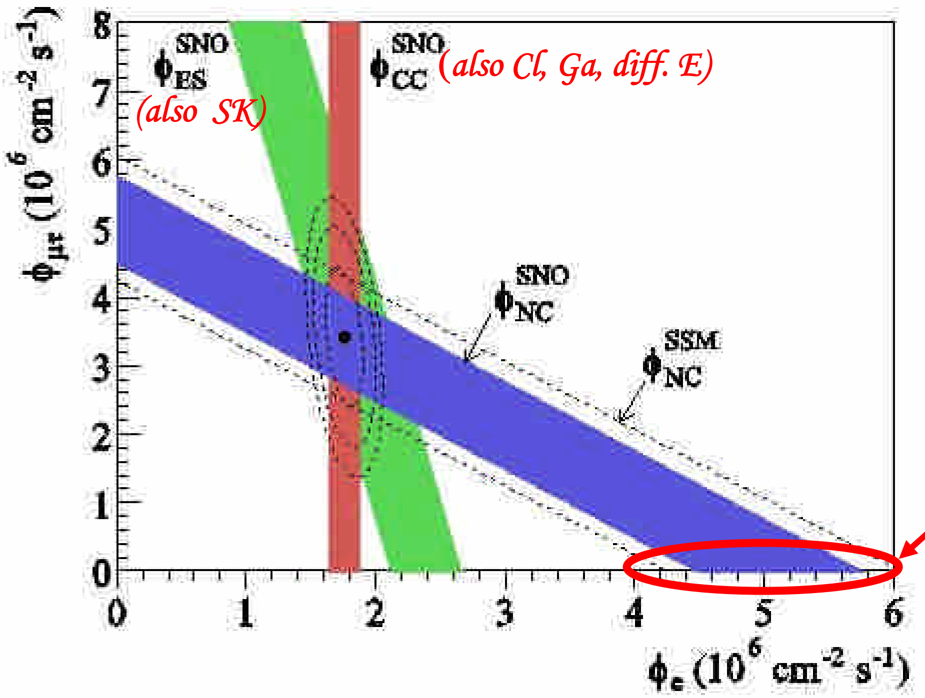
CC	1339.6 [illegible]
ES	170.3 [illegible]
NC	1344.2 [illegible]





Physics Implication Flavor Content

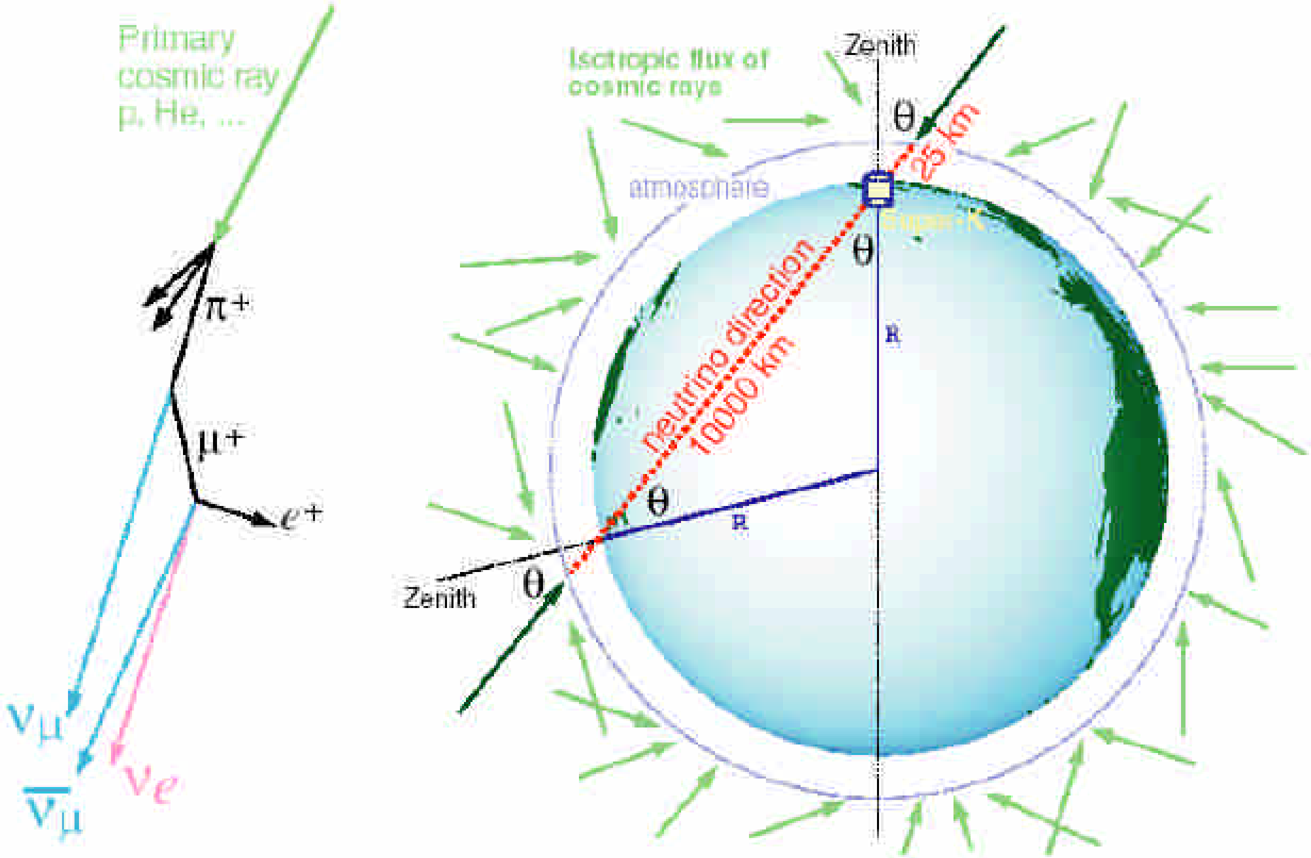
$\Phi_{ssm} = 5.05^{+1.01}_{-0.81}$ $\Phi_{sno} = 5.09^{+0.44+0.46}_{-0.43\,-0.43}$



Standard Solar Model + Standard Particle Physics Model

Strong evidence of flavor change (5σ effect)

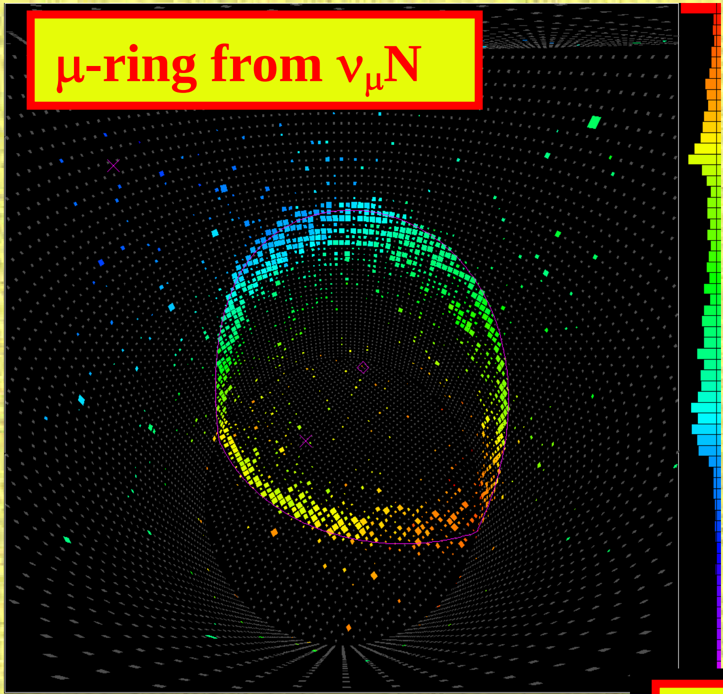
Atmospheric neutrinos

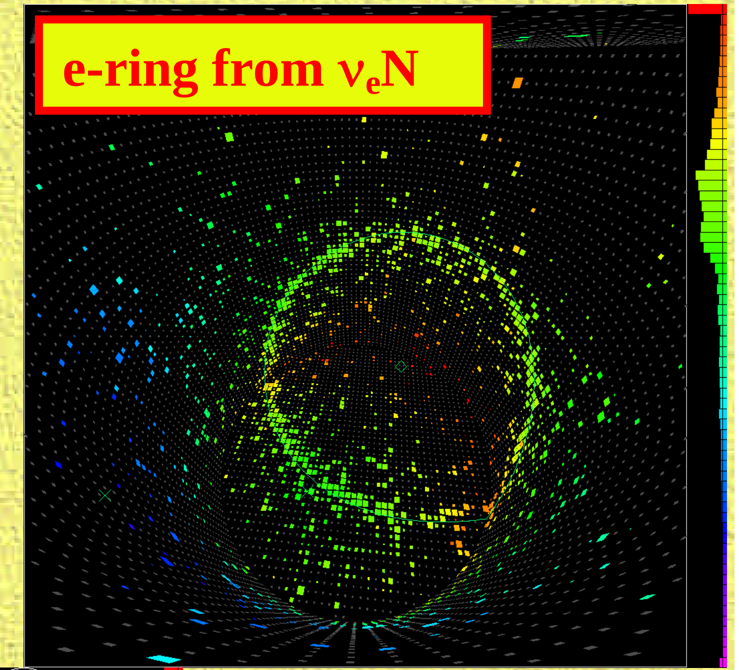


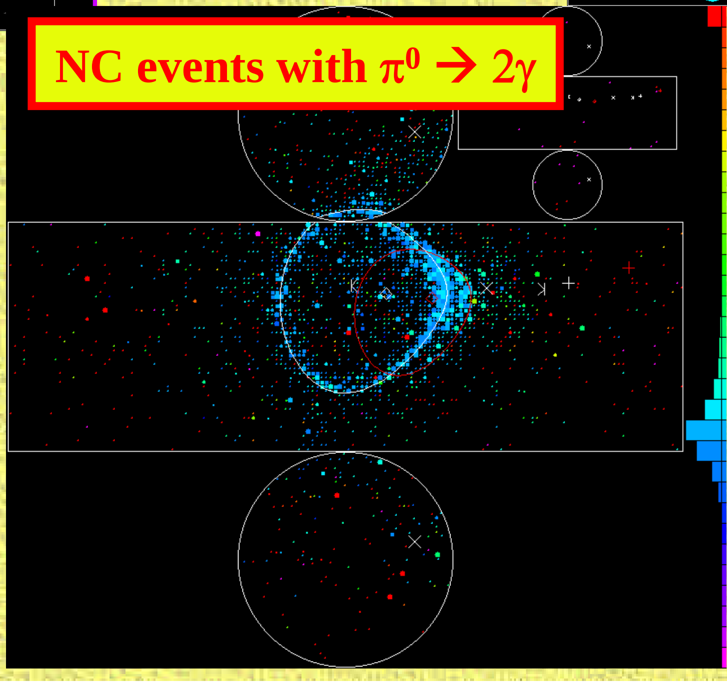
Ratio of ν_μ/ν_e ~ 2
(for E_ν < few GeV)

Up/Down Symmetric Flux
(for E_ν > few GeV)

SK sub-GeV events from atmospheric ν interactions



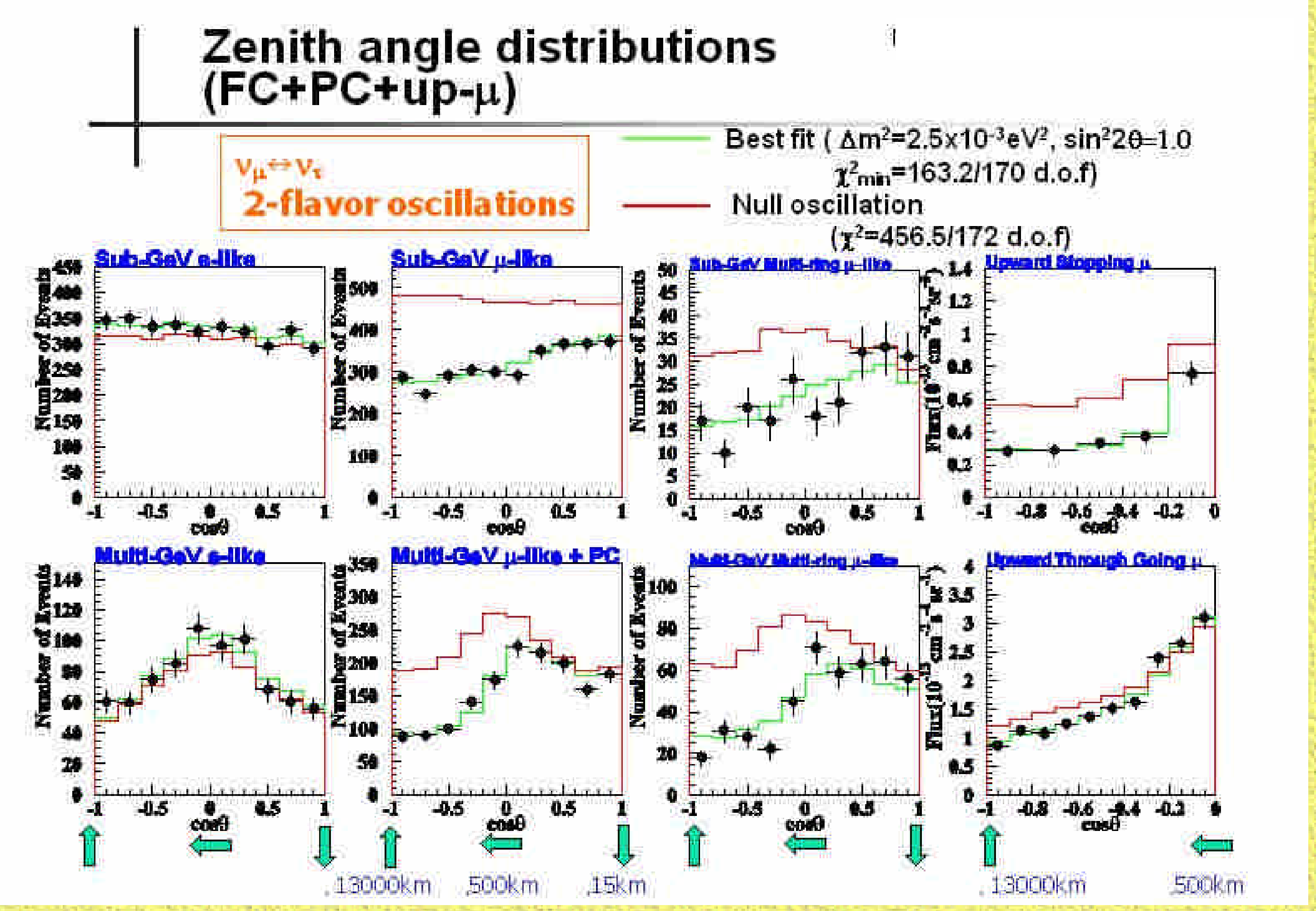




Atmospheric Neutrinos

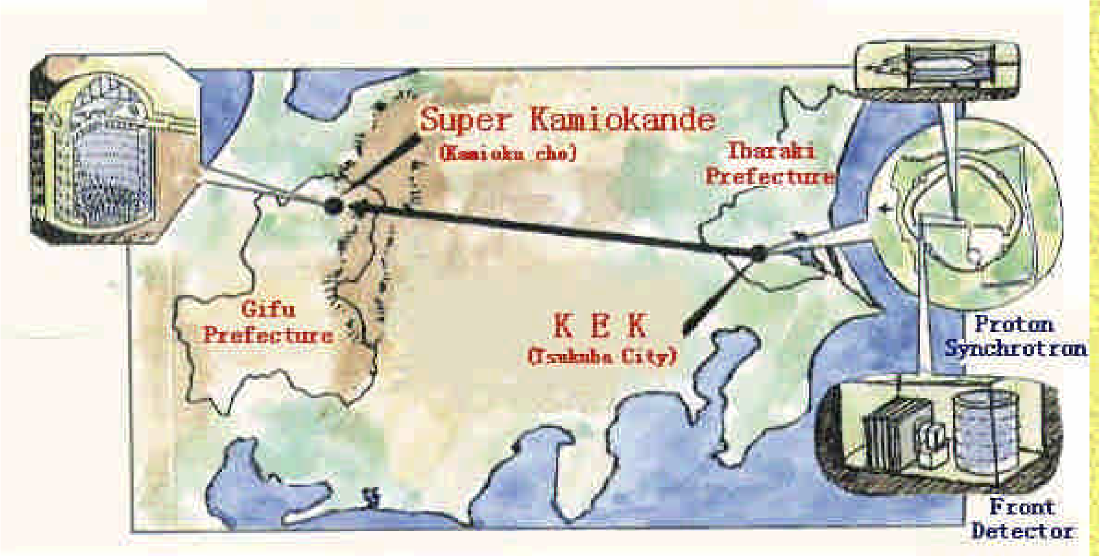
Up-Down Asymmetry & Deficit

- ν_μ **disappearing,** ν_e **OK,**
- **Strong evidence : > 15σ**
- **Better fits for ν_τ appearing**



KEK-SuperK (K2K)

Accelerator ν Flight path 250 km



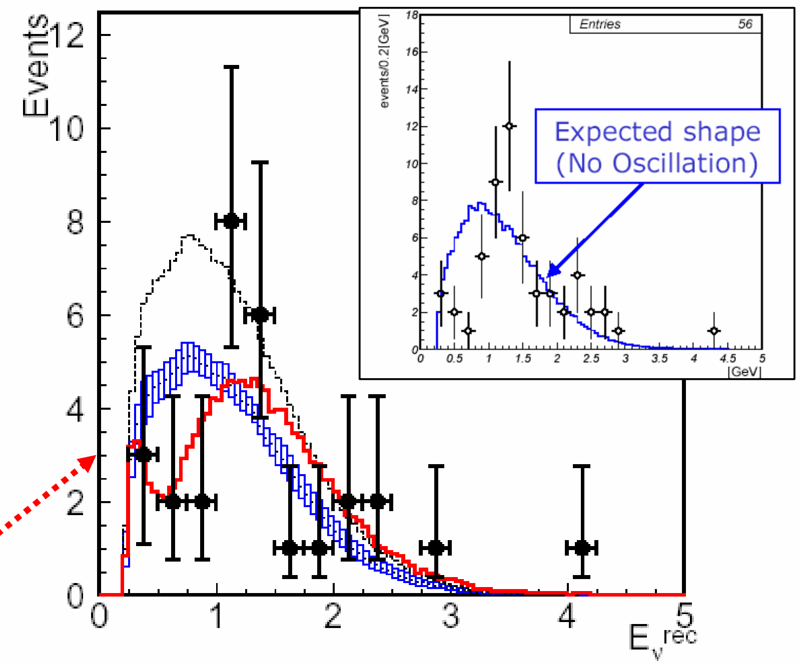
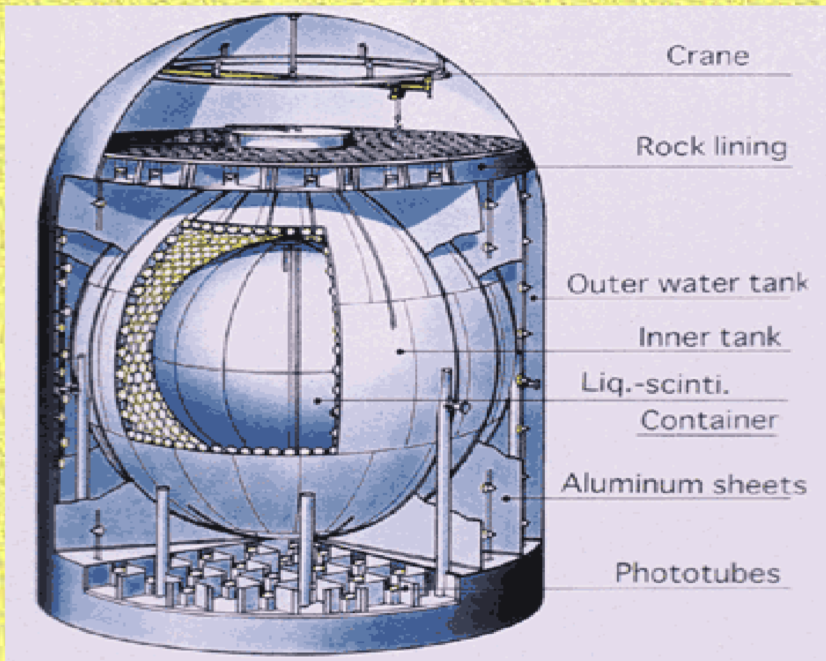


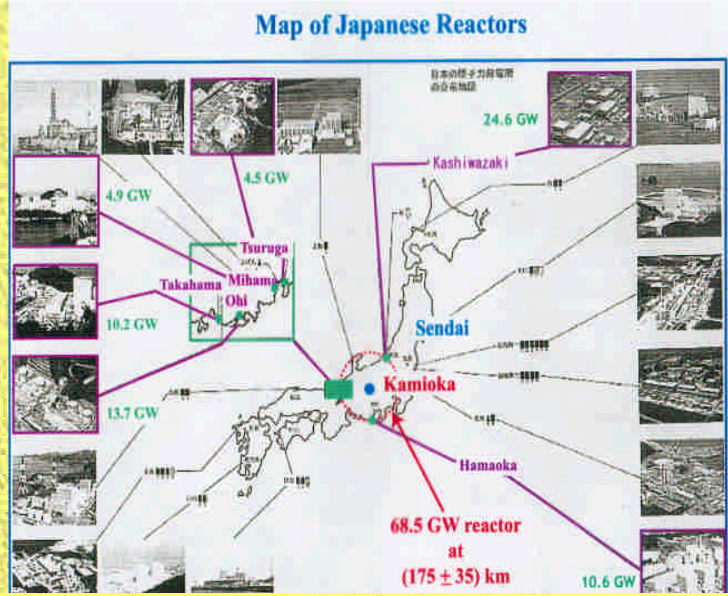
FIG. 2: The reconstructed E_ν distribution for $1R\mu$ sample (from method 1). Points with error bars are data. Box histogram is expected spectrum without oscillations, where the height of the box is the systematic error. The solid line is the best fit spectrum. These histograms are normalized by the number of events observed (29). In addition, the dashed line shows the expectation with no oscillations normalized to the expected number of events (44).

Deficit of ν_μ at far detector

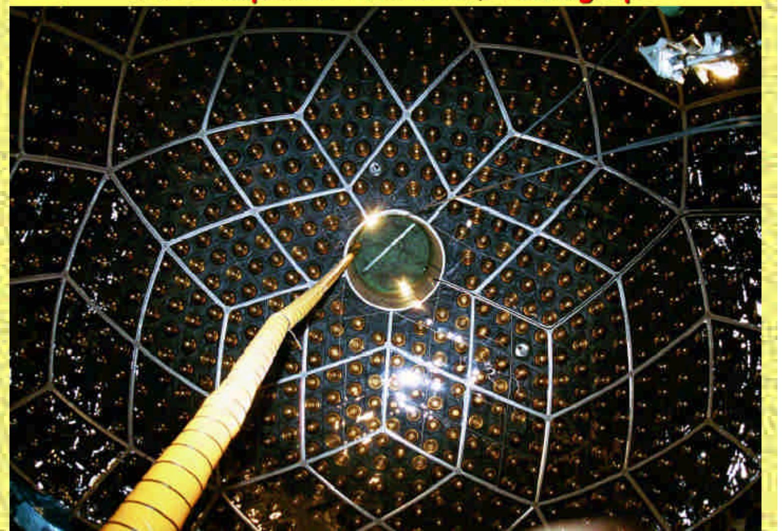
⊕ spectral distortion

KamLAND





The completed detector, looking up



- **Long Baseline Reactor ν**
  - ♥ **(sensitive to 20% of world's reactors !)**
- **ave. flight path of 160 km**
- **1 kton liquid scintillator in old Kamiokande site**
- **probe "LMA" for solar ν**
- **historical results only 5 years from approved !!!!**

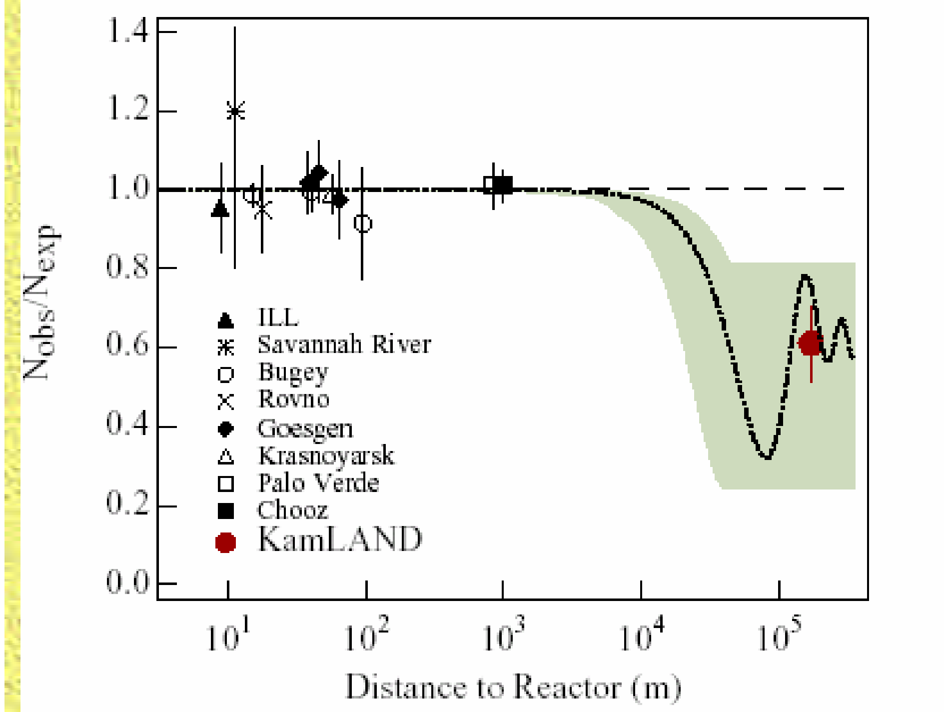
A specific signature is provided by the inverse-β reaction

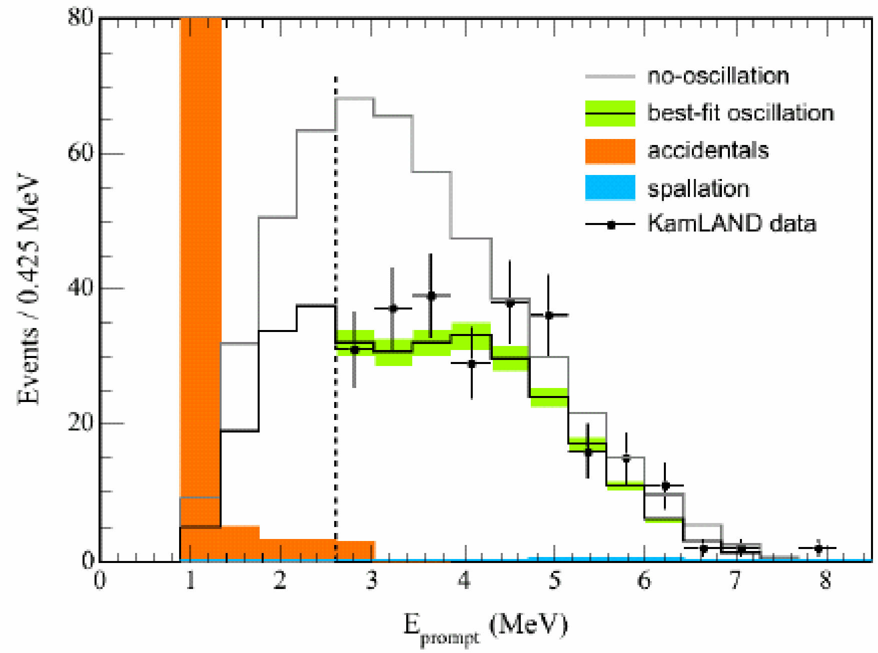
$$\overline{\nu}_e + p \rightarrow e^+ + n$$

$$\tau \approx 200\ \mu s$$

$$p + n \rightarrow d + \gamma(2.2\ MeV)$$

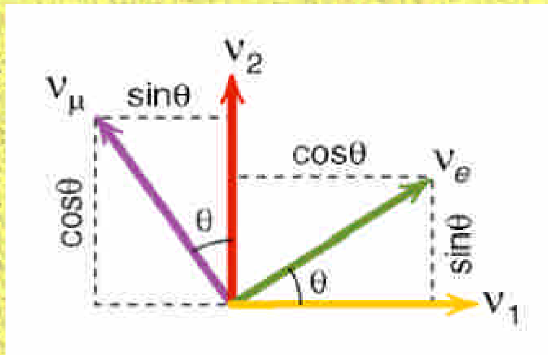
Event tagging by coincidence in time, space and energy of the neutron capture

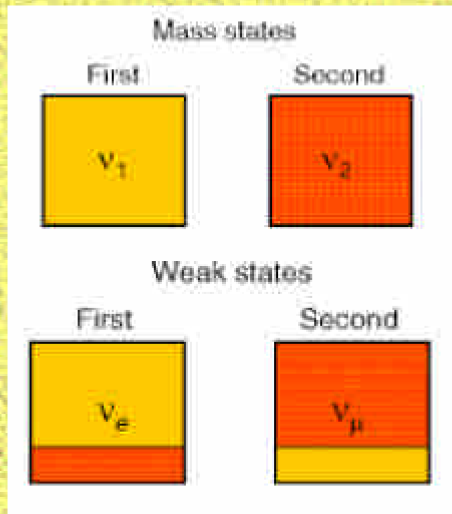




Neutrino Oscillations *(in 2-family language)*

- **Neutrinos produced & detected as ν_e, ν_μ , ν_τ ("flavor eigenstates")**
- **Propagate as ν_1 , ν_2 ("mass eigenstates")**





$$\begin{pmatrix} \nu_e \\ \nu_\mu \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \end{pmatrix} = U \begin{pmatrix} \nu_1 \\ \nu_2 \end{pmatrix}$$

3 families

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

- **Probability of producing ν_e & detecting as ν_e :**

$$P_{ee} = 1 - \sin^2 2\theta \ \sin^2 \left[\frac{1.27 \ \Delta m^2 \, (eV) \, L \, (m)}{E \, (MeV)} \right]$$

- **⊕ Matter Effect : Origin – ν_e+e (CC+NC) Vs ν_μ +e(NC)**

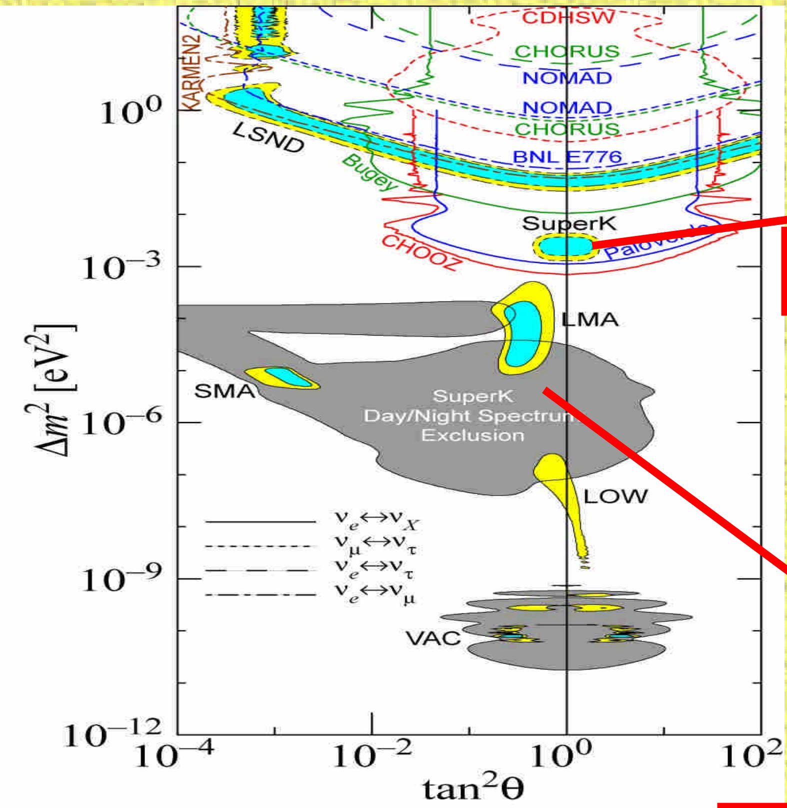
$$\sin^2 2\tilde{\theta} = \frac{(\Delta m^2)^2 \sin^2 2\theta}{(\Delta m^2 \cos 2\theta - A)^2 + (\Delta m^2)^2 \sin^2 2\theta} = 1$$

$$if \ \Delta m^2 \cos 2\theta = \pm\sqrt{2} E G N_e$$

at resonance

$\Delta m^2 - \theta$: Summary

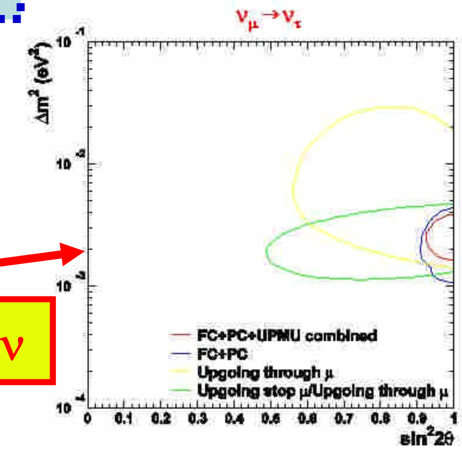
PDG 2000:



2002

May-2002 Neutrino2002 @ Munich

Combined allowed regions



$\nu_\mu \leftrightarrow \nu_\tau$ oscillations

Best fit($\Delta m^2 = 2.5\times10^{-3}, \sin^2 2\theta = 1.0$

$\chi^2_{min} = 163.2/170$ d.o.f)

No oscillation

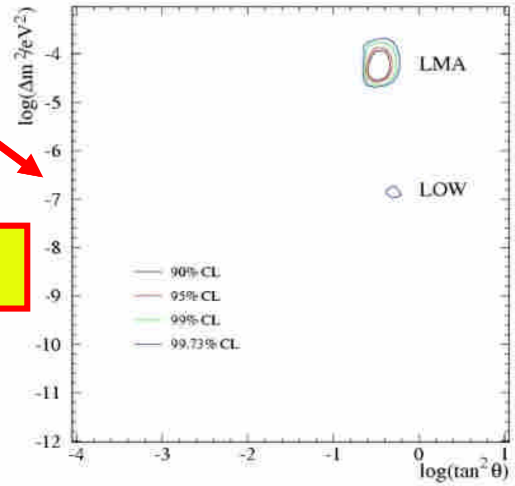
(χ^2 $= 456.5/172$ d.o.f)

$\Delta m^2 = (1.6\sim3.9)\times10^{-3}$eV^2

$\sin^2 2\theta > 0.92$ @ 90%CL

SK atm. ν

Global Fit with total SNO spectrum



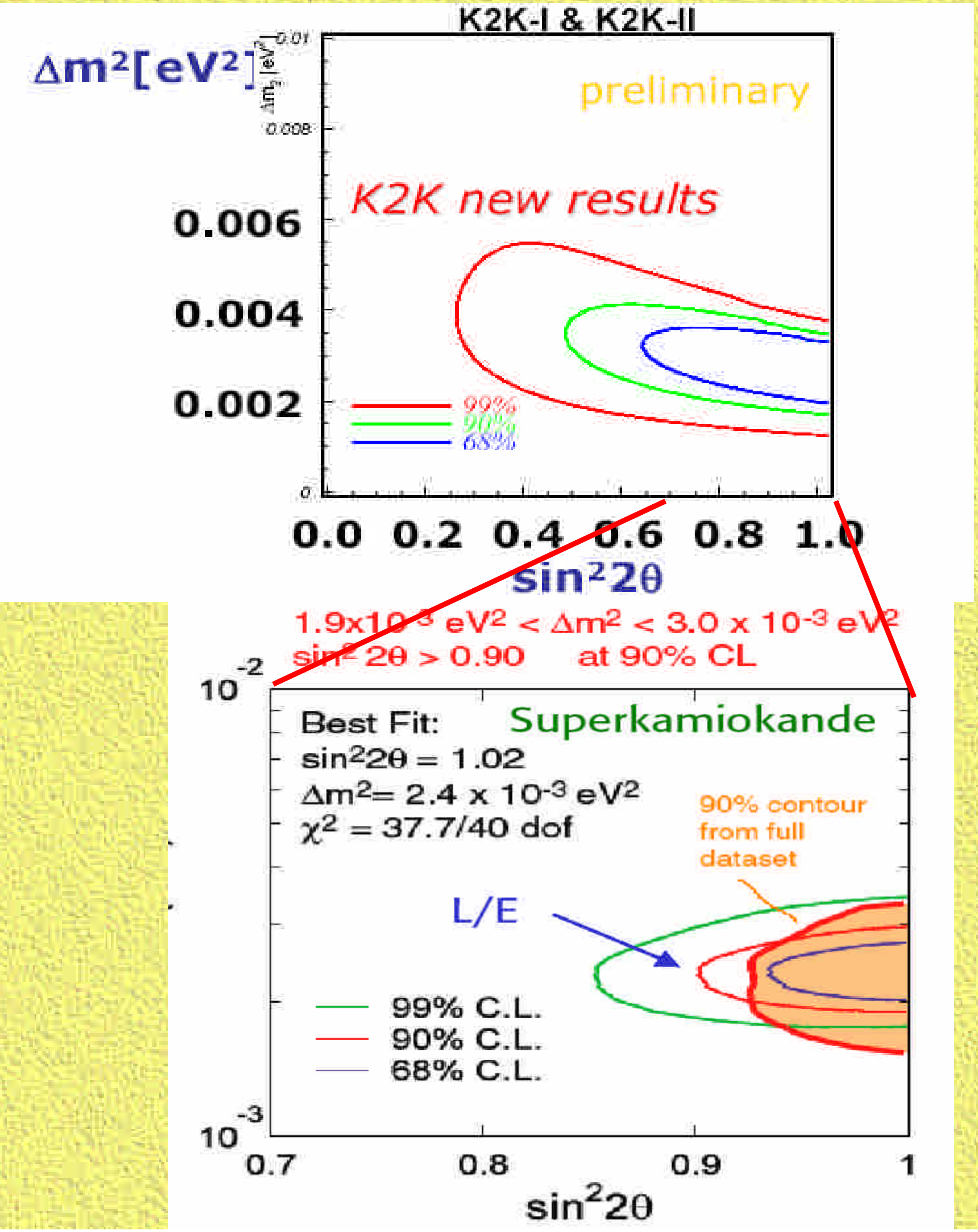
without separate day and night spectra

most of the MSW model constraints comes from SNO CC/NC!

SNO solar ν

2004

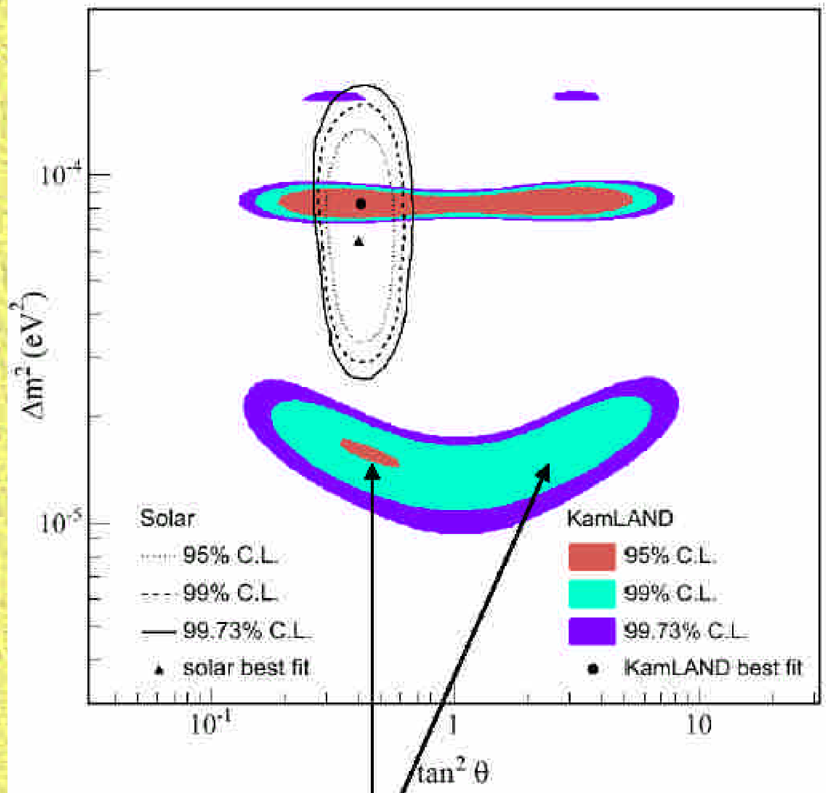
K2K : Consistent Checks to atm. ν



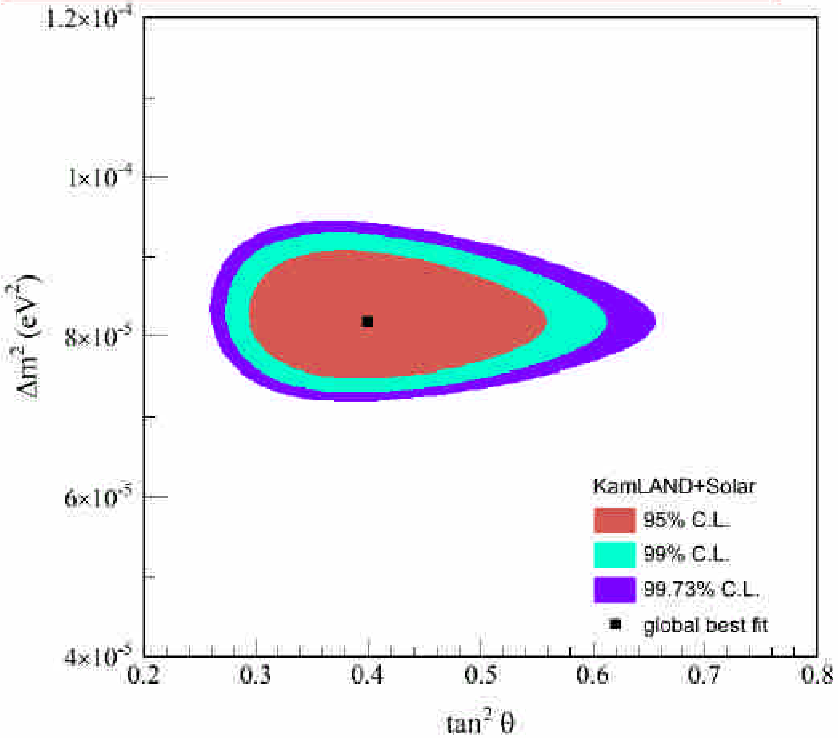
Combined solar ν – KamLAND 2-flavor analysis

$$\Delta m^2_{12} = 8.2^{+0.6}_{-0.5} \times 10^{-5}\, eV^2$$

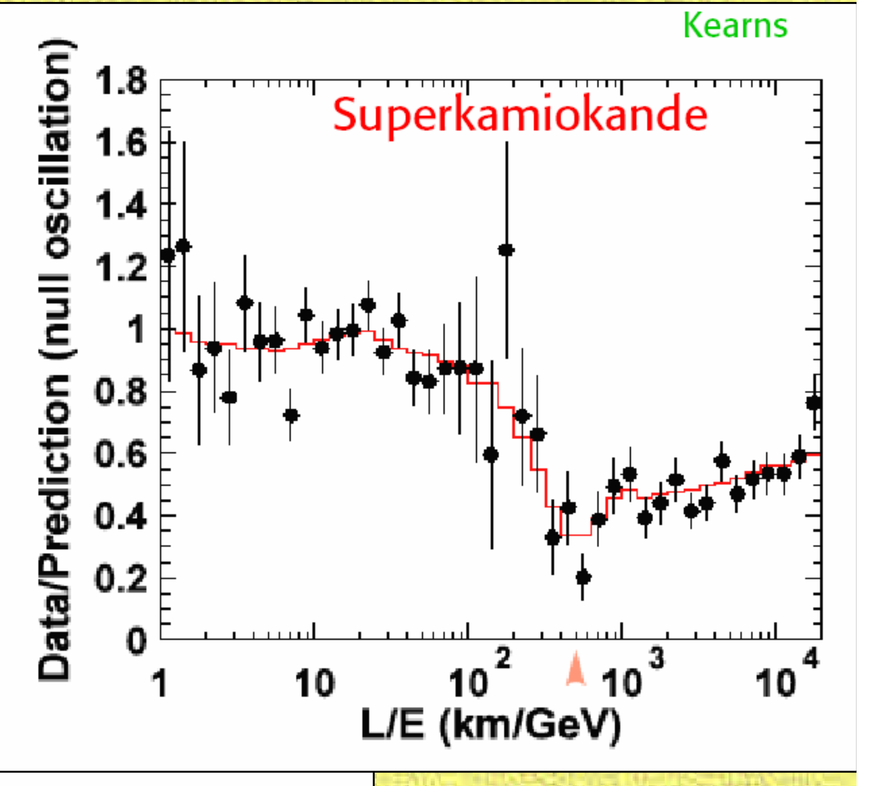
$$\tan^2\theta_{12} = 0.40^{+0.09}_{-0.07}$$

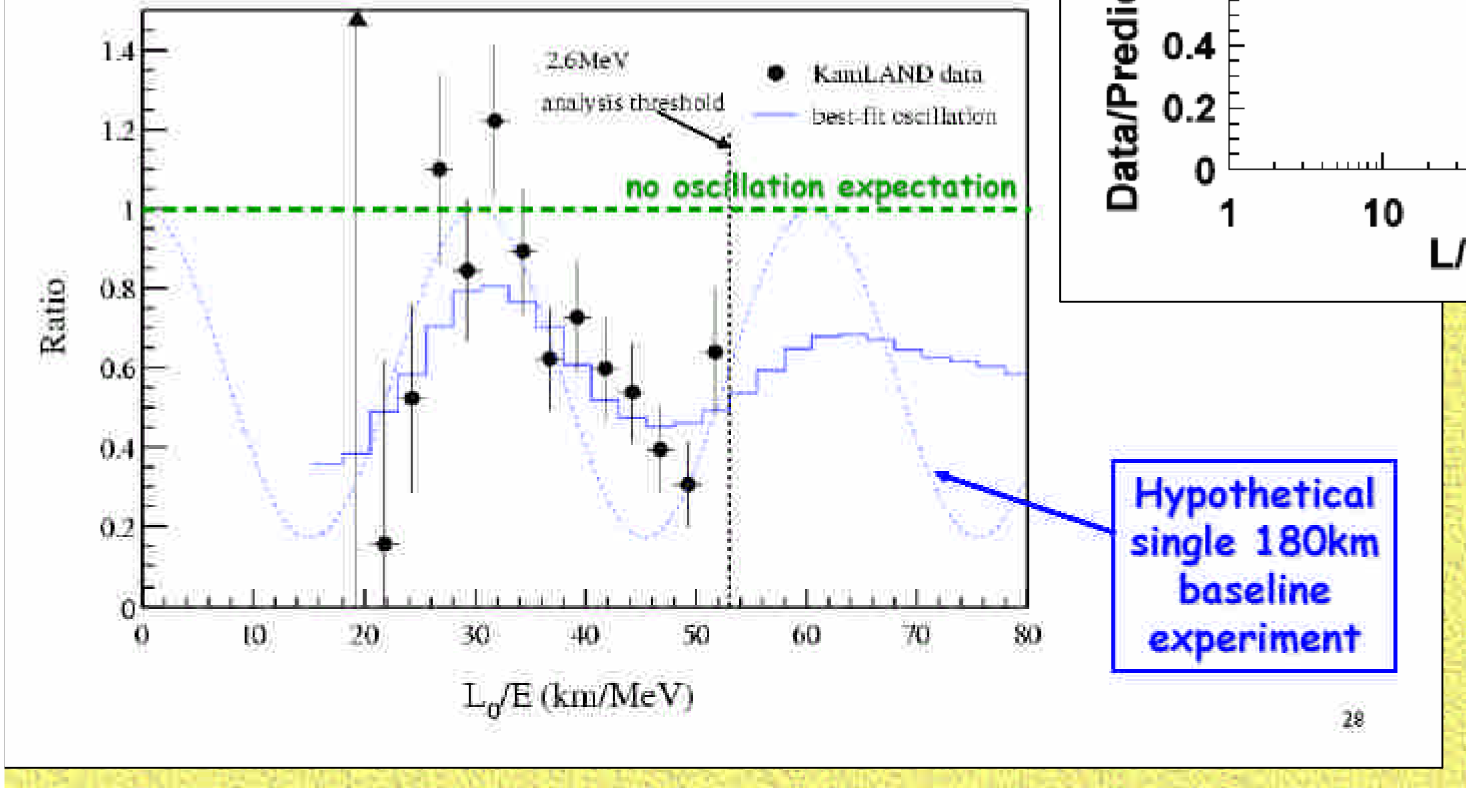


Includes (small) matter effects



+ **observations of L/E oscillation signatures from SK atm-ν & KamLAND** *(averaged)*…..





Three Families of Neutrino Mixing

The *Maki-Nakagawa-Sakata* (MNS) matrix :

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}$$

$$= \underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix}}_{} \times \overbrace{\begin{pmatrix} \cos\theta_{13} & 0 & e^{-i\delta_{CP}}\sin\theta_{13} \\ 0 & 0 & 0 \\ -e^{i\delta_{CP}}\sin\theta_{13} & 0 & \cos\theta_{13} \end{pmatrix}}^{\text{Dirac phase}} \times \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \times \overbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & e^{i\alpha/2} & 0 \\ 0 & 0 & e^{i\alpha/2+i\beta} \end{pmatrix}}^{\text{Majorana phases}}$$

?

atmospheric, K2K	reactor and accelerator	SNO, solar SK, KamLAND	0νββ
$\theta_{23} = \sim 45°$	$\tan^2\theta_{13} < 0.03$ at 90% CL	$\theta_{12} \sim 30°$	
maximal	*small … at best*	*large*	

Θ_{13} : crucial unknown towards CP-studies

Possible CP Violation in ν Sector:

$$P(\nu_e \to \nu_\mu) - P(\bar{\nu}_e \to \bar{\nu}_\mu) = 16\, s_{12} c_{12} s_{13} c_{13}^2 s_{23} c_{23}$$

$$\sin\delta \,\sin\left(\frac{\Delta m_{12}^2}{4E} L\right) \sin\left(\frac{\Delta m_{13}^2}{4E} L\right) \sin\left(\frac{\Delta m_{23}^2}{4E} L\right)$$

Neutrinos all mixed up

$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = \begin{bmatrix} \\ U_{\alpha j} \\ \\ \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}$$

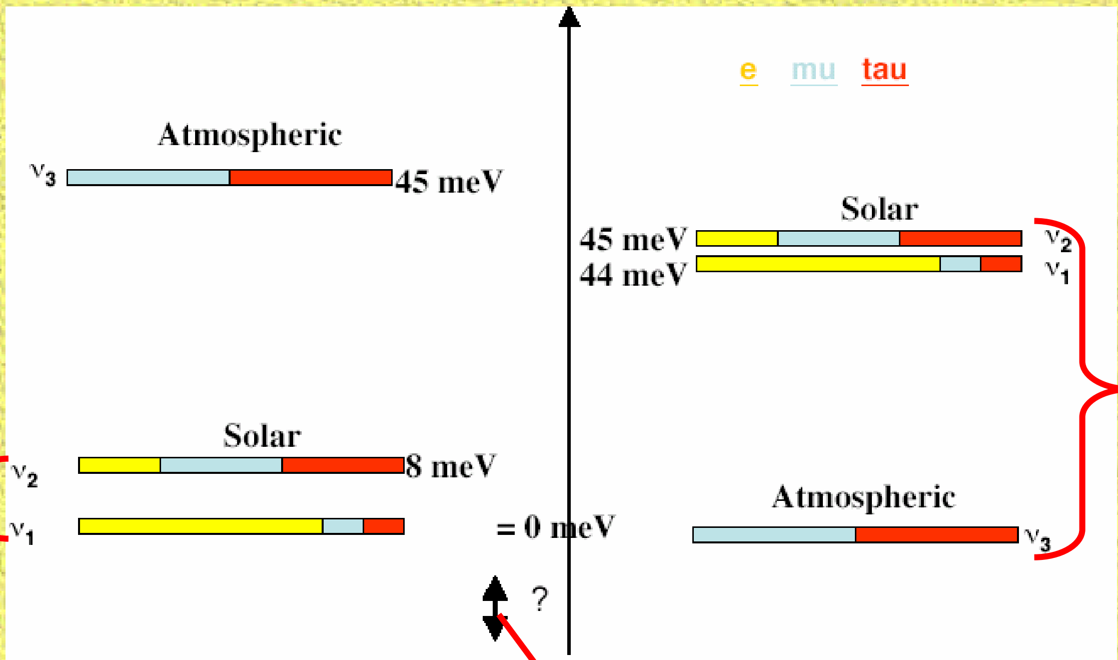
$$[U] \simeq \begin{bmatrix} \cos\theta_{solar} & \sin\theta_{solar} & \sin\theta_{13} \\ -\sin\theta_{solar}/\sqrt{2} & \cos\theta_{solar}/\sqrt{2} & 1/\sqrt{2} \\ \sin\theta_{solar}/\sqrt{2} & -\cos\theta_{solar}/\sqrt{2} & 1/\sqrt{2} \end{bmatrix}$$

$$\theta_{atm} \simeq 45^\circ, \qquad \theta_{solar} \simeq 35^\circ, \qquad \theta_{13} \leq 10^\circ$$

Neutrino Mass Structures :

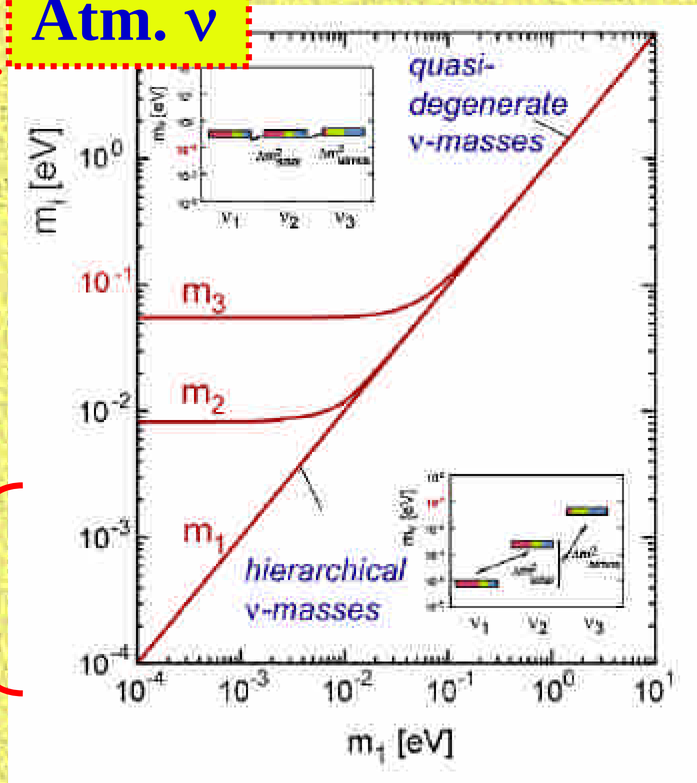
- Normal Vs Inverted Hierarchy ??
- Quasi-Degenerate Vs Hierarchical ??
- Dirac Vs Majorana ??

Δm^2



Solar ν

Atm. ν



※ absolute scale unknown

Deeper Physical Questions ……….

Physics at high mass scales, physics of flavor, and unification:

- Why are neutrino masses so small?
- Why are the mixing angles *large, maximal, and small*?
- Is there CP violation, T violation, or CPT violation in the lepton sector?
- Is there a connection between the lepton and the baryon sector?

θ_{13}

$$U_{MNSP} = \begin{pmatrix} big & big & small? \\ big & big & big \\ big & big & big \end{pmatrix} \quad \longleftrightarrow ? \quad V_{CKM} = \begin{pmatrix} big & small & tiny \\ small & big & tiny \\ tiny & tiny & big \end{pmatrix}$$

- Understanding the role of neutrinos in the early Universe

In particular :

- Is $\theta_{12} + \theta_{Cabbibo} = \pi/4$?
- Is $\theta_{23} = \pi/4$?
- Is $\theta_{13} = 0$?
- ……..

Mixing angles may reveal deeper/higher energy scale & symmetry principles

neutrino mass structures may reveal GUTs scale physics *(e.g. See-Saw Mechanisms)* :

A very natural and appealing explanation:

ν's are nearly massless because they are Majorana particles and get masses through L non conserving interactions suppressed by a large scale $M \sim M_{GUT}$

$$m_\nu \sim \frac{m^2}{M}$$

$m \sim m_t \sim v \sim 200$ GeV

M: scale of L non cons.

Note:

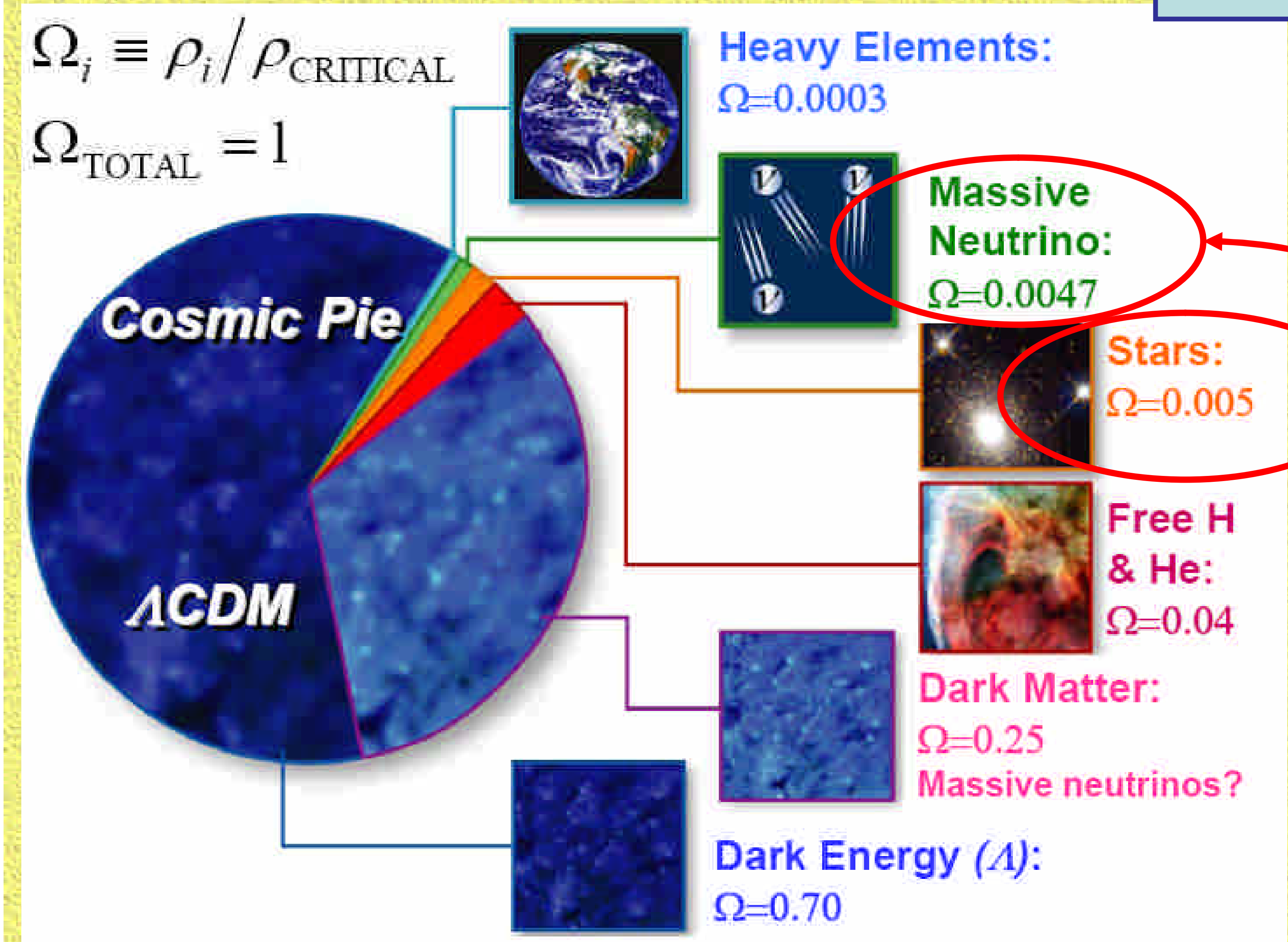
$m_\nu \sim (\Delta m^2_{atm})^{1/2} \sim 0.05$ eV

$m \sim v \sim 200$ GeV

$M \sim 10^{15}$ GeV

Neutrino masses are a probe of physics at M_{GUT} !

at least as much neutrinos by mass as visible matter !

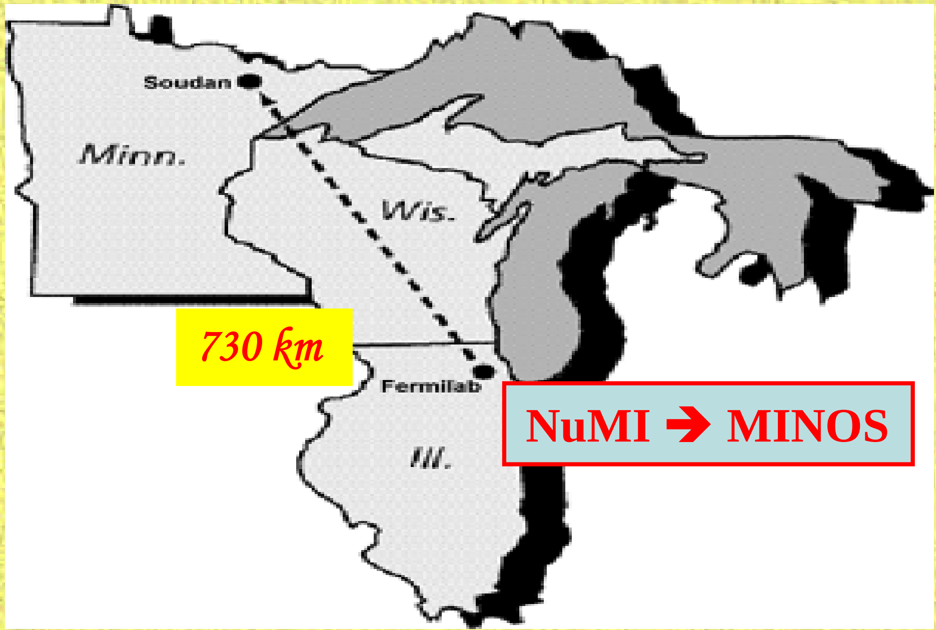


Future Experimental Projects

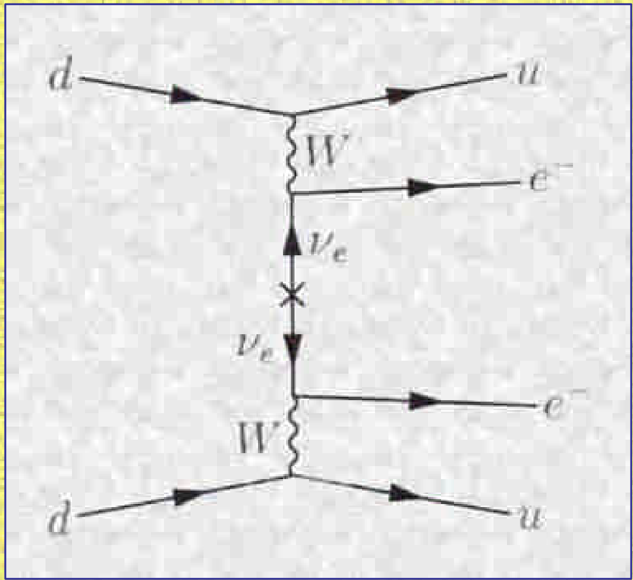
What / How	Absolute mass scale	Majorana Nature	Hierarchy	θ_{13}	δ	α's
β-decay /cosmology	×					
ββ-decay	×	×	×			×
Oscillations			×	×	×	

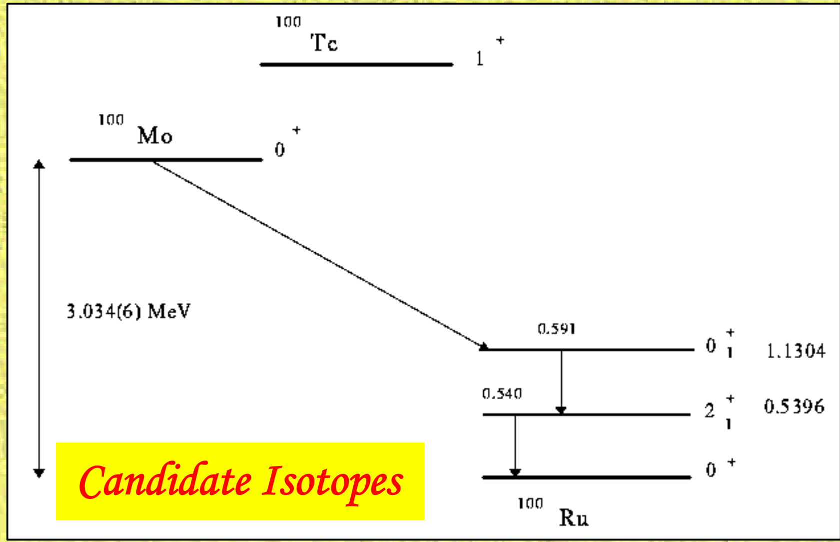
- **Long baseline accelerator/reactor experiments (NuMI, CNGS, T2K, q13 ……)**
  - ※ *Detailed studies of mixing matrices by oscillation studies*
- **0νββ experiments**
  - ※ *Distinguish mass hierarchy, fix absolute mass scales*
- **Direct mass searches in β-decay**
  - ※ *Probe degenerate mass structures*
- **Neutrino properties (e.g. magnetic moments studies…)**
  - ※ *How neutrino interacts/couples with outside world*
- **Neutrino from sky and earth**
  - ※ *do astronomy/earth science with neutrino sources, understand roles of neutrinos in astrophysics/geophysics*

Long Baseline Accelerator Neutrino Projects :

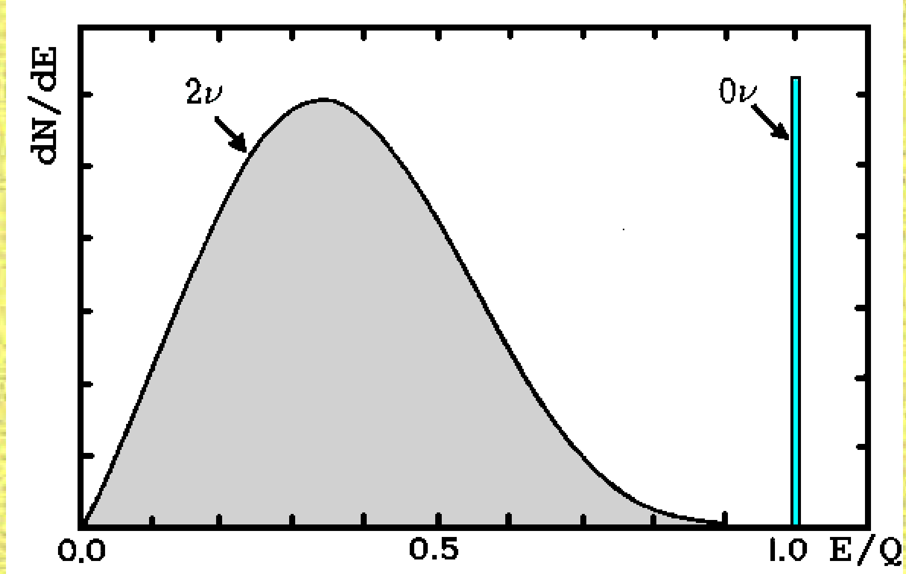


0νββ





$$\Gamma_{0\nu} = G_{0\nu} |M_{0\nu}|^2 \langle m_{\beta\beta} \rangle^2$$



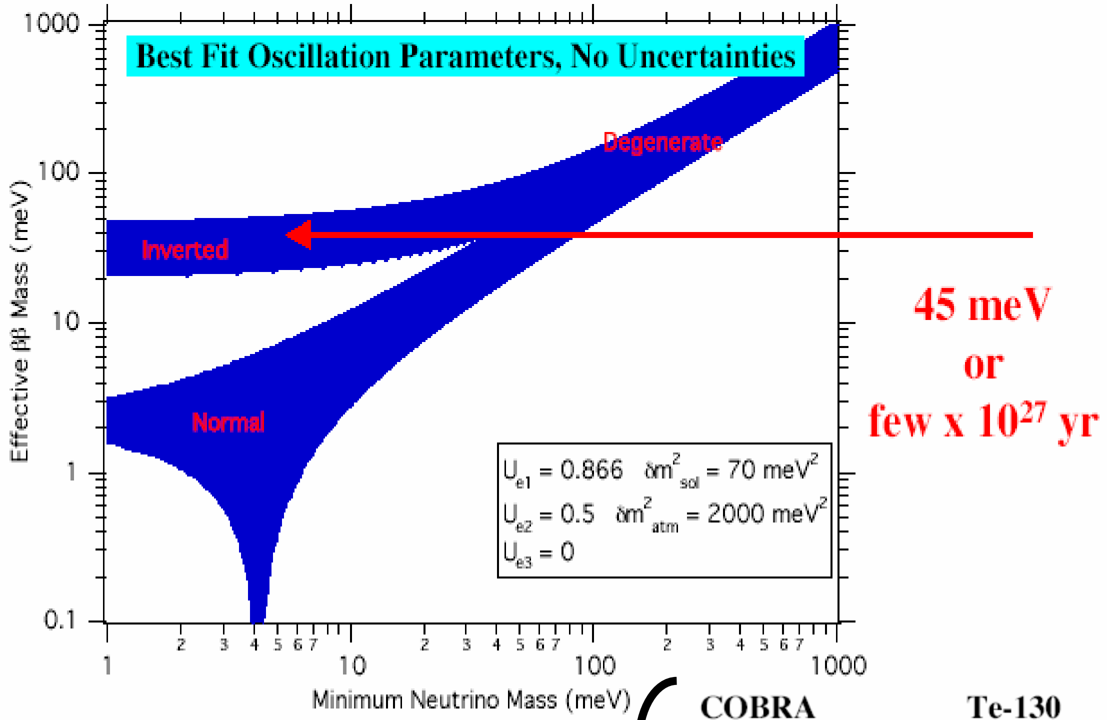
G are calculable phase space factors.

$G_{0\nu} \sim Q^5$

|M| are nuclear physics matrix elements.

Hard to calculate.

$$\langle m_{\beta\beta} \rangle = \left| |U_{e1}|^2 m_1 + e^{i\beta} |U_{e2}|^2 m_2 + e^{i\alpha} |U_{e3}|^2 m_3 \right|$$



0νββ: *probe*

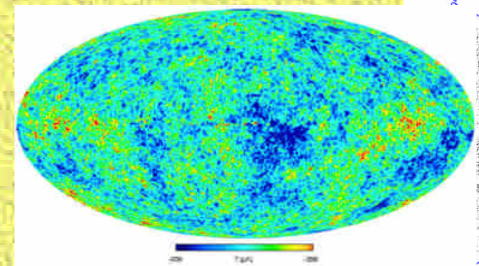
- ν_M/ν_D
- m_ν hierachy
- m_ν scale

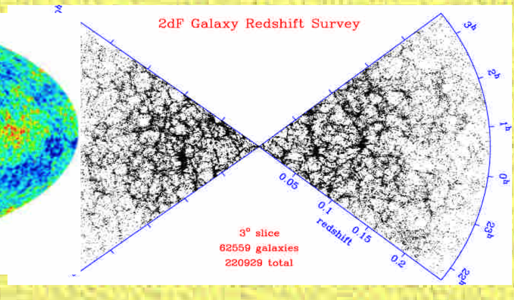
0νββ Projects:

COBRA	Te-130	10 kg CdTe semiconductors
DCBA	Nd-150	20 kg Nd layers between tracking chambers
NEMO	Mo-100, Various	10 kg of ββ isotopes (7 kg of Mo)
CAMEO	Cd-116	1 t $CdWO_4$ crystals
CANDLES	Ca-48	Several tons CaF_2 crystals in liquid scint.
CUORE	Te-130	750 kg TeO_2 bolometers
EXO	Xe-136	1 ton Xe TPC (gas or liquid)
GEM	Ge-76	1 ton Ge diodes in liquid nitrogen
GENIUS	Ge-76	1 ton Ge diodes in liquid nitrogen
GSO	Gd-160	2 t Gd_2SiO_5:Ce crystal scint. in liquid scint.
Majorana	Ge-76	500 kg Ge diodes
MOON	Mo-100	Mo sheets between plastic scint., or liq. scint.
Xe	Xe-136	1.56 t of Xe in liq. Scint.
XMASS	Xe-136	10 t of liquid Xe

Neutrino Mass Measurements

cosmology & structure formation

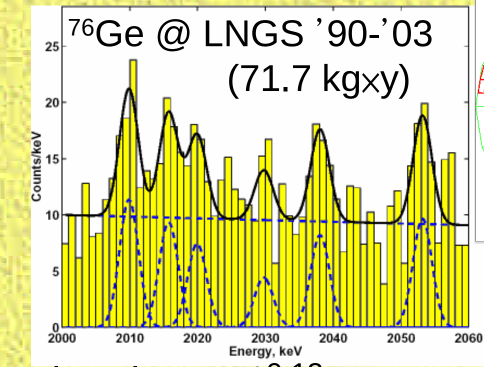


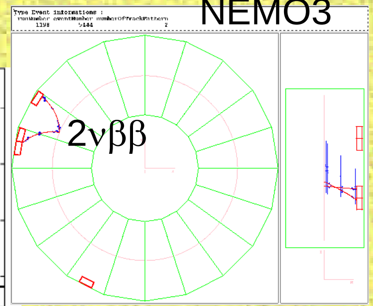


D.N. Spergel et al: $\Sigma m_\nu < 0.69$ eV (95%CL)

S.W. Allen et al: $\Sigma m_\nu = 0.56$ eV (best fit)

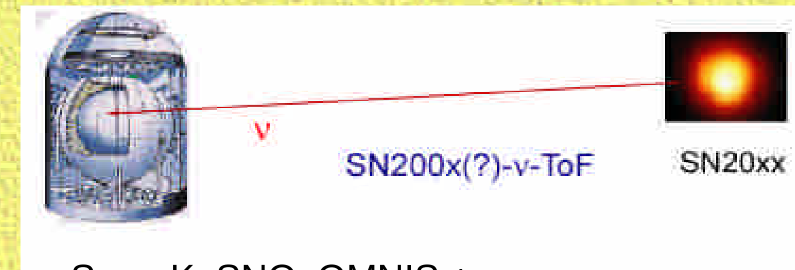
$0\nu\beta\beta$ decay:





$|m_{ee}| = 0.44^{+0.13}_{-0.2}$ eV

astrophysics: SN ToF measurements



SuperK, SNO, OMNIS + grav.waves:

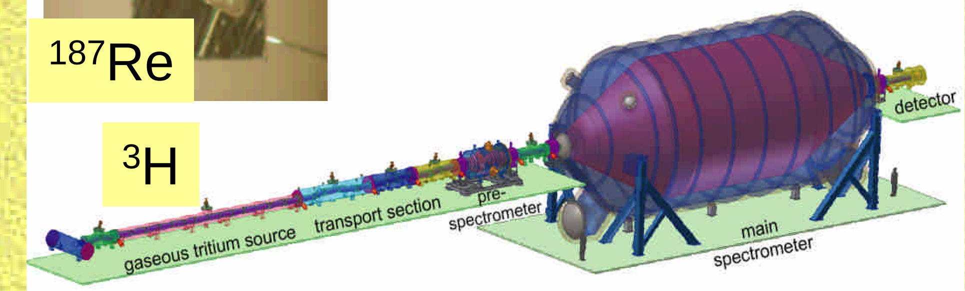
potential for ~1eV sensitivity?

β decay kinematics:

microcalorimeters

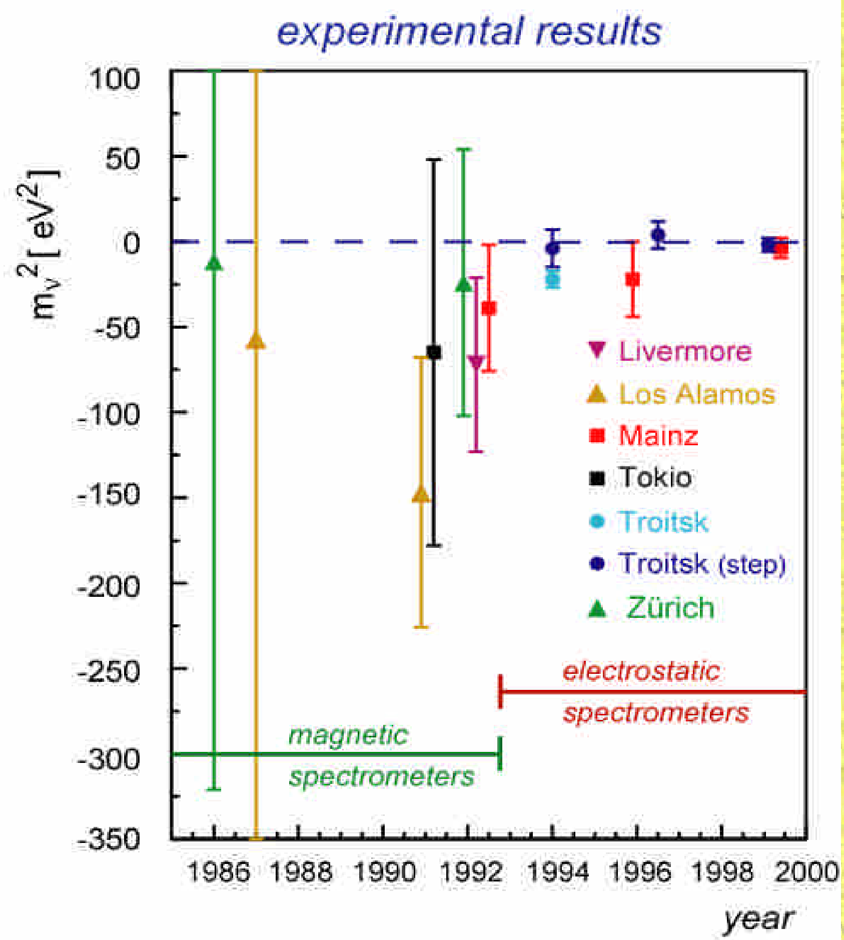
MAC-E spectrometers

^{187}Re



^{3}H

Experiment	m_ν
ITEP *T_2 in complex molecule* *magn. spectrometer (Tret'yakov)*	17-40 eV
Los Alamos *gaseous T_2 - source* *magn. spectrometer (Tret'yakov)*	< 9.3 eV
Tokio *T - source* *magn. spectrometer (Tret'yakov)*	< 13.1 eV
Livermore *gaseous T_2 - source* *magn. spectrometer (Tret'yakov)*	< 7.0 eV
Zürich *T_2 - source impl. on carrier* *magn. spectrometer (Tret'yakov)*	< 11.7 eV
Troitsk (1994-today) *gaseous T_2 - source* *electrostat. spectrometer*	< 2.2 eV
Mainz (1994-today) *frozen T_2 - source* *electrostat. spectrometer*	< 2.2 eV



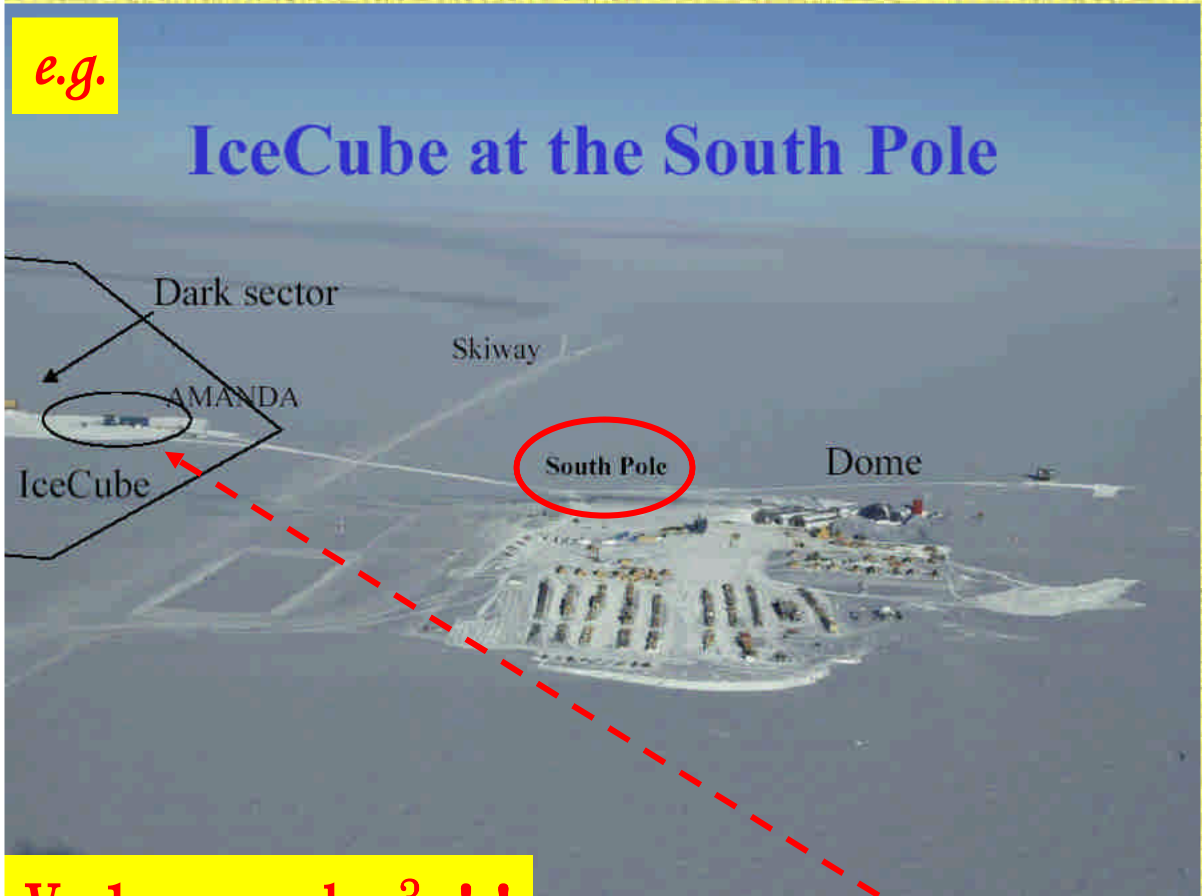
New Project :

KATRIN
Karlsruhe Tritium Neutrino Experiment

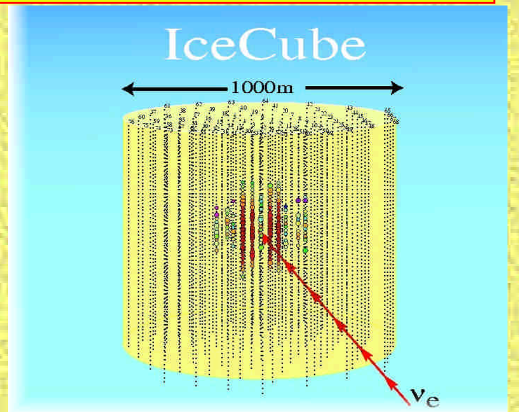
Sensitivity : m_ν < 0.2eV (90%CL)

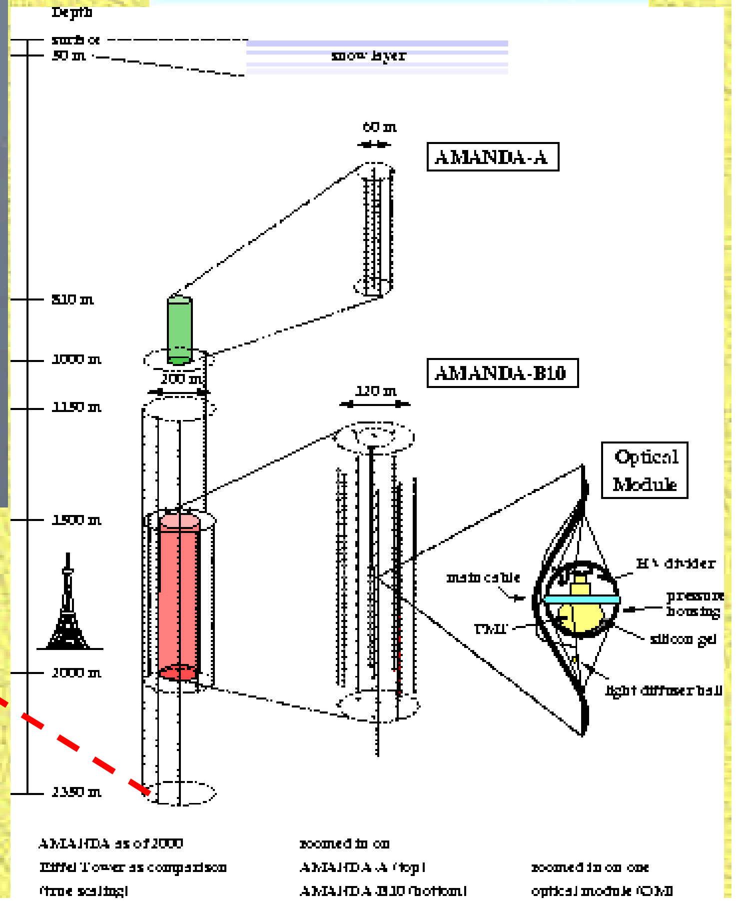
IceCube High Energy Neutrino Telescope

e.g.



Volume ~km^3 !!





TEXONO Collaboration

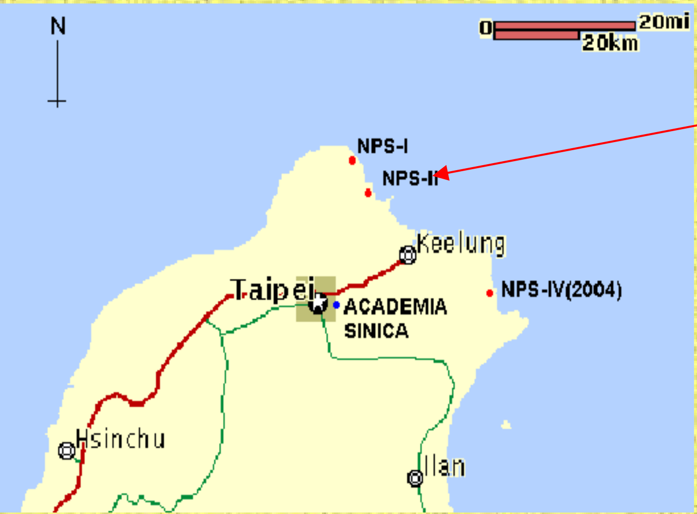
Collaboration : **Taiwan (AS, INER, KSNPS, NTU) ; China (IHEP, CIAE, THU, NJU) ; Turkey (METU) ; USA (UMD)**

Program: **Low Energy Neutrino & Astroparticle Physics**

- **Kuo-Sheng (KS) Reactor Neutrino Laboratory**
  - reactor : high flux of low energy electron anti-neutrinos
  - oscillation expts. ⇒ $m_\nu \neq 0$ ⇒ anomalous ν properties & interactions
  - ν physics full of surprises , need intense ν-source
    - ※ study/constraint new regime wherever experimentally accessible
    - ※ explore possible new detection channels
- **Diversified R&D Projects**

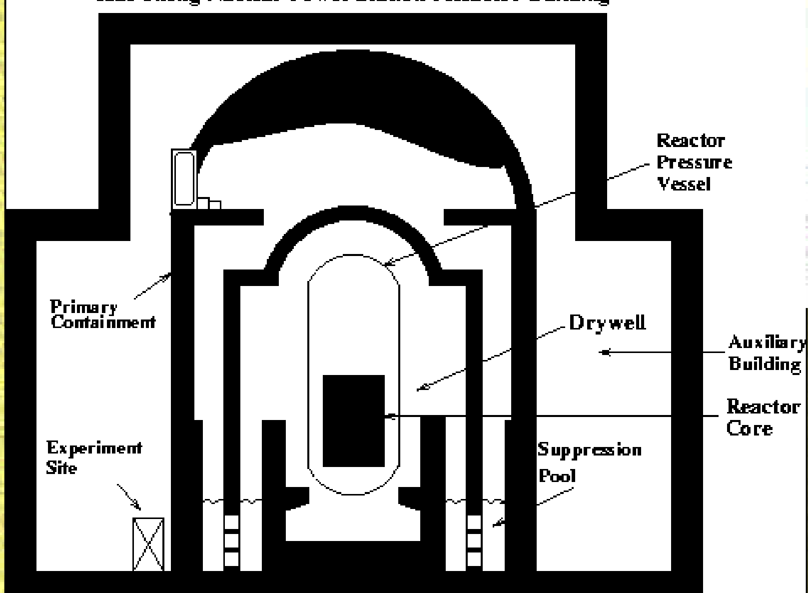
Kuo-Sheng Nuclear Power Plant

KS NPS-II : 2 cores × 2.9 GW



Powerful collaboration. Scientists from Taiwan and mainland China are studying neutrino emissions from this nuclear power plant outside Taipei.

KS ν Lab: 28 m from core#1



Kuo Sheng Reactor Neutrino Laboratory

Front Gate

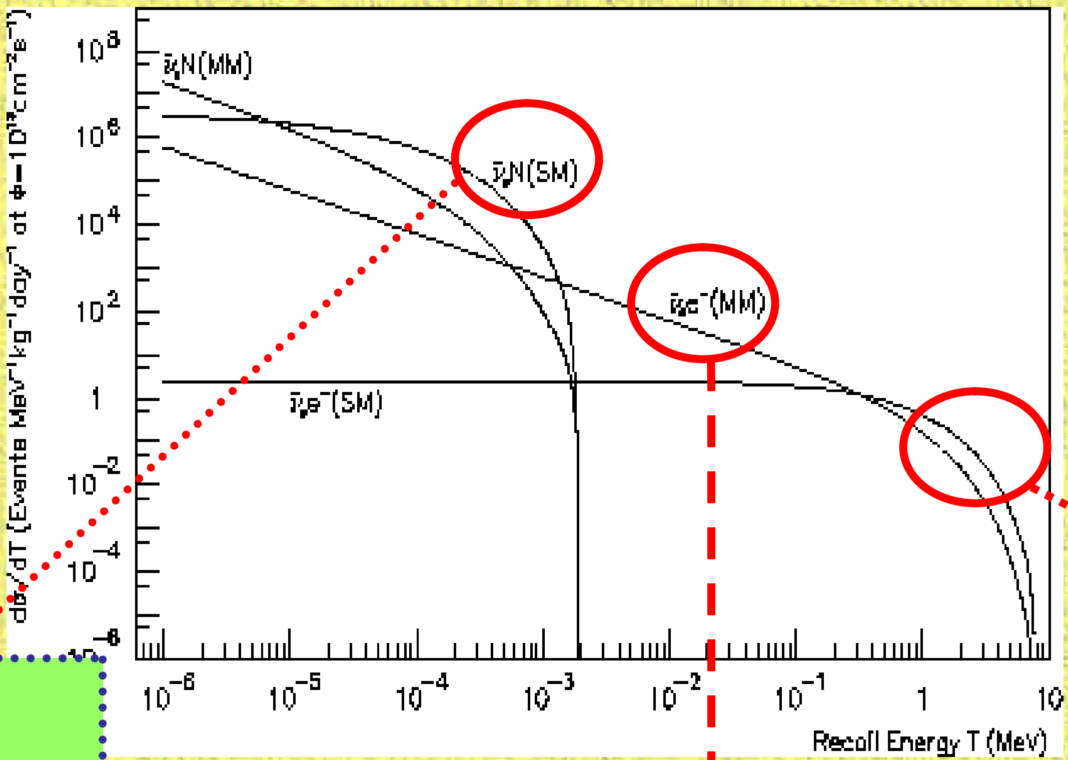
Front View *(cosmic vetos, shieldings, control room …..)*

Inner Target Volume

Configuration: **Modest yet Unique**

Flexible Design: **Allows different detectors conf. for different physics**

Reactor Neutrino Interaction Cross-Sections



R&D :

- **Coh. (νN)**
- **T < 1 keV**

Results & More Data:

- **$\mu_\nu(\nu_e)$**
- **T ~ 1-100 keV**

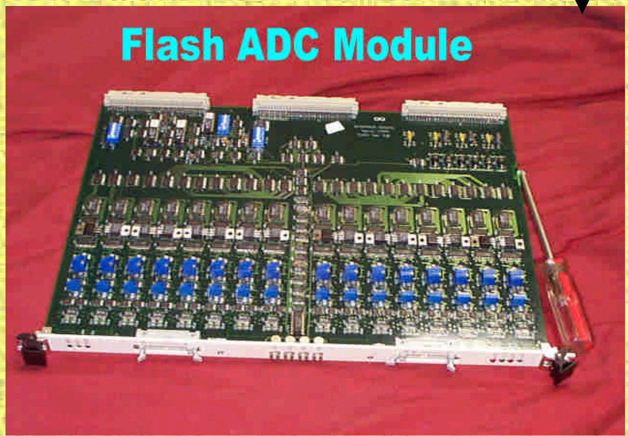
On-Going Data Taking:

- **SM $\sigma(\nu e)$**
- **T > 2 MeV**

KS Expt: Period I Detectors

ULB-HPGe [1 kg]

CsI(Tl) [46 kg]



FADC Readout

[16 ch., 20 MHz, 8 bit]

Multi-Disks Array [600 Gb]

- **TEXONO data (4712/1250 hours ON/OFF)** **[PRL 90, 2003]**
- **comparable bkg level to underground CDM experiment at 10-20 keV :**

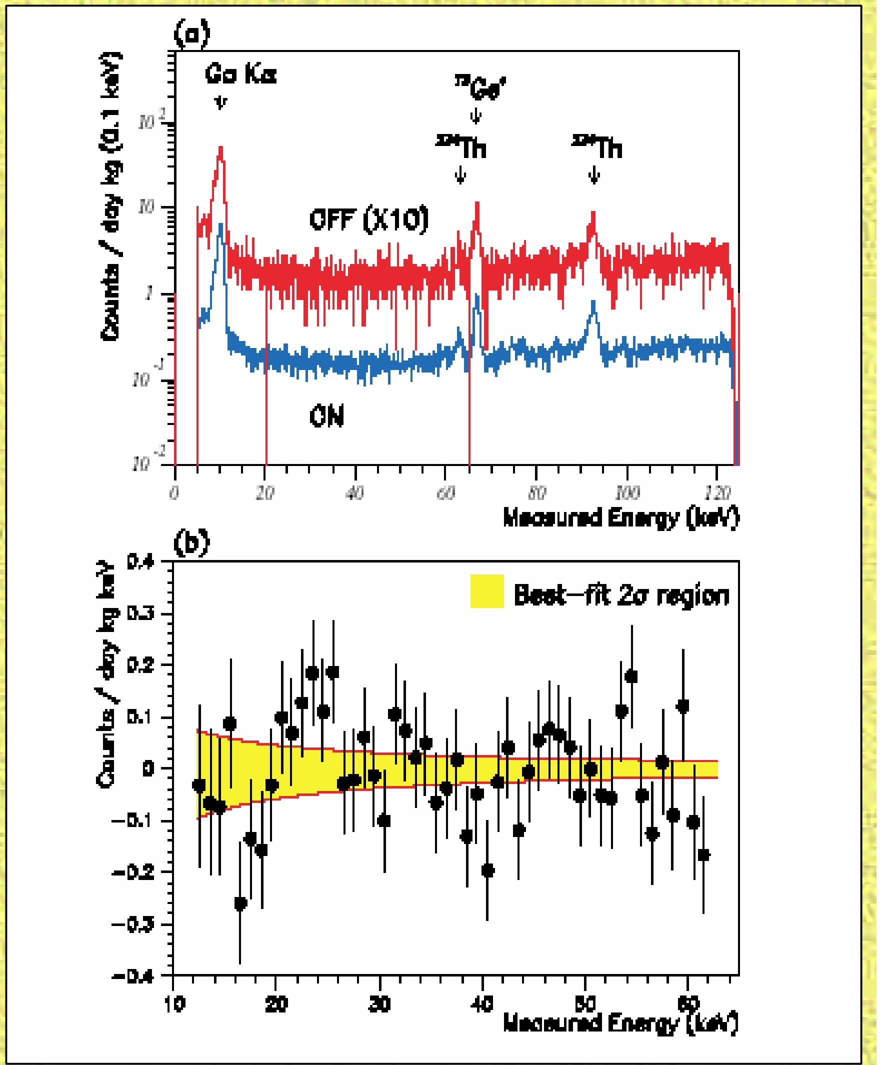
  ~ 1 $day^{-1}keV^{-1}kg^{-1}$ (cpd)

- **analysis threshold 12 keV**
- ***No excess*** **of counts ON/OFF comparison**
- **Limit:**

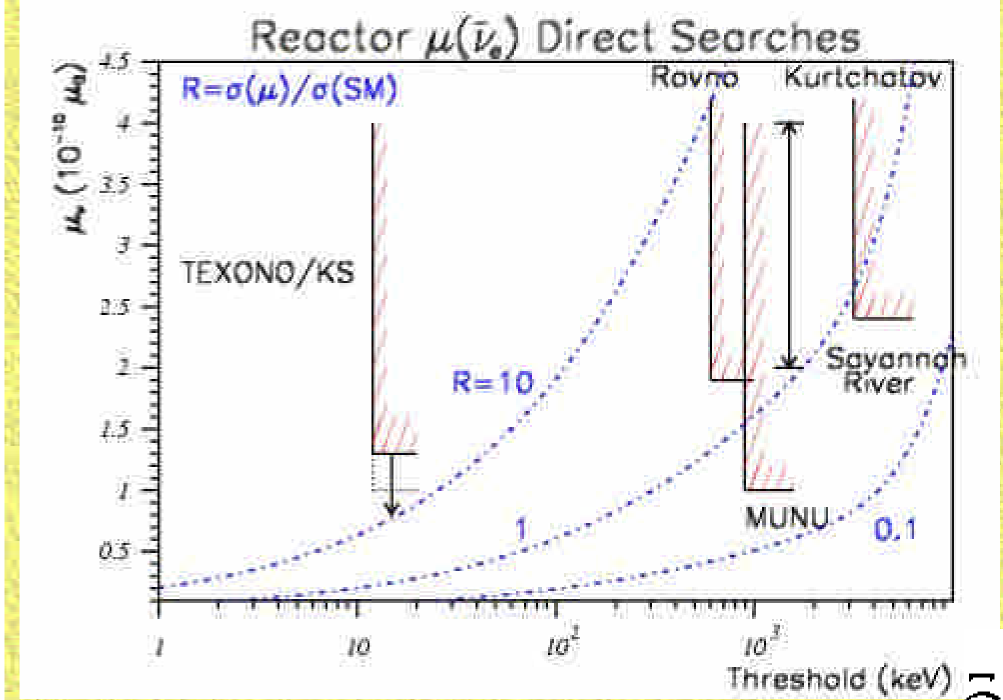
  $\mu_\nu(\nu_e) < 1.3 \times 10^{-10}\ \mu_B$ (90% CL)

- **more data/improvement to get to sensitivity range**

  $\mu_\nu(\nu_e) \rightarrow 0.8 \times 10^{-10}\ \mu_B$



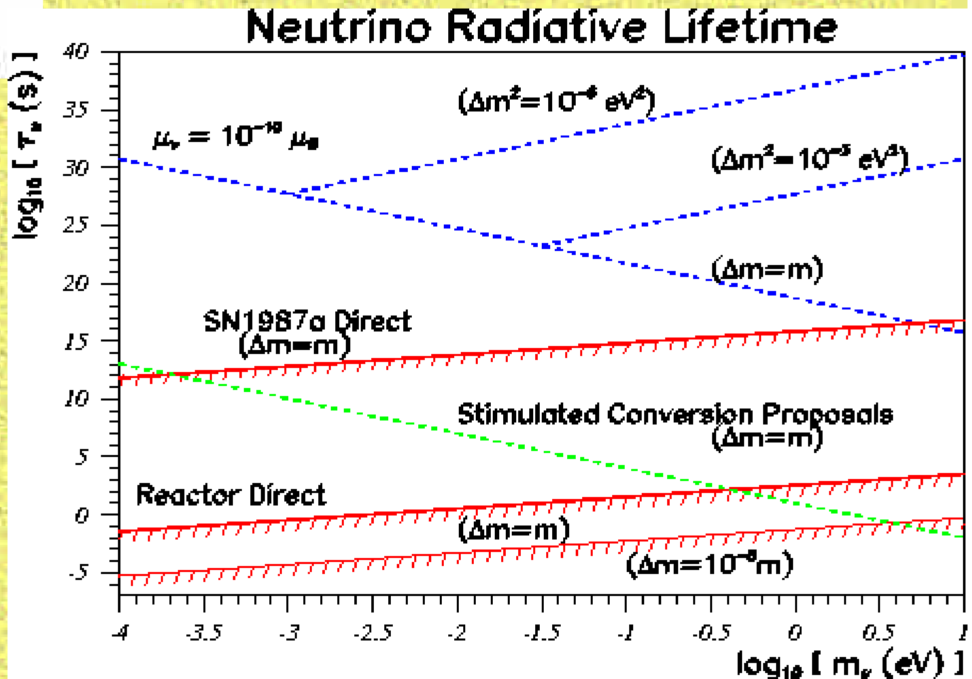
Reactor $\mu_\nu(\nu_e)$ Sensitivities



μ_ν

Γ_ν Sensitivities

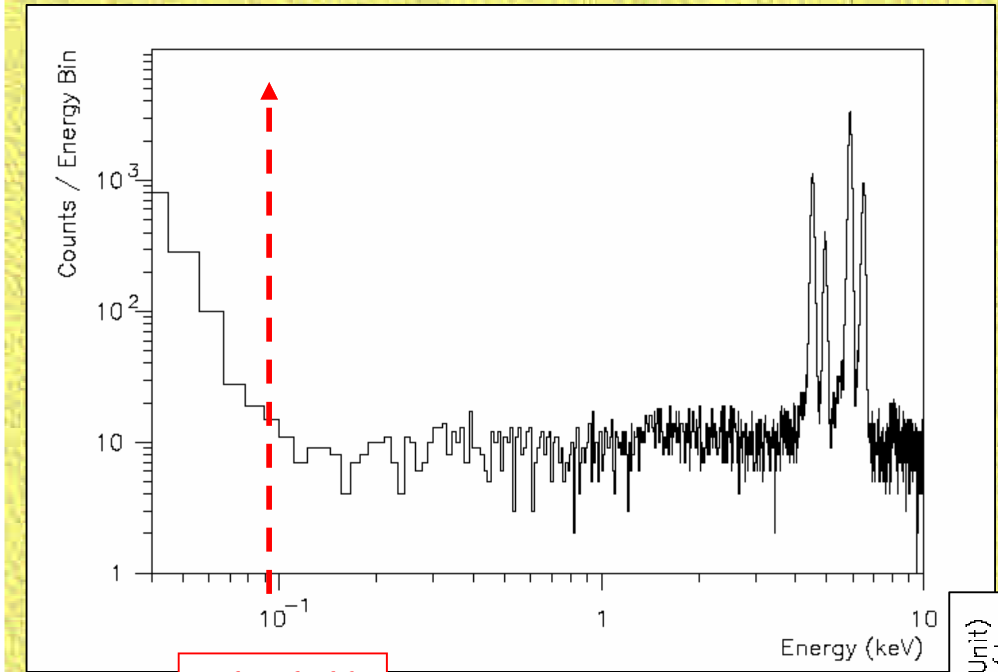
Γ_ν



"Ultra-Low-Energy" HPGe Prototype

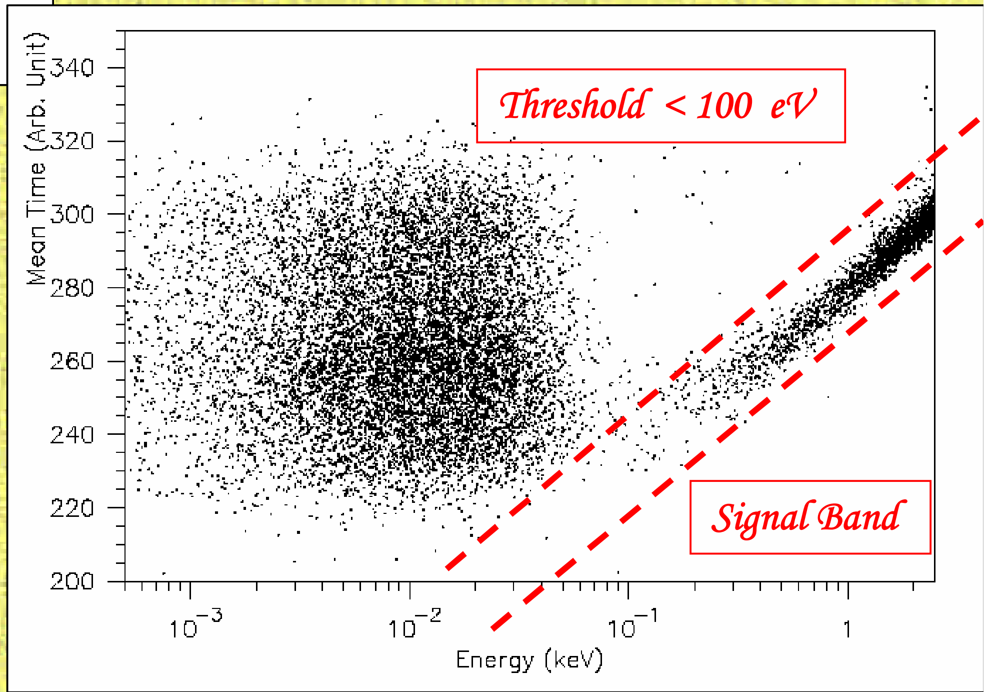
- **mass 5 g ; can be constructed in multi-array form**
- **threshold <100 eV after modest PSD** *(lowest achieved for bulk radiation detectors)*
- **background measurement at KS & Y2L**
- **study applications in νN coherent scattering and Dark Matter searches**

ULE-HPGe Prototype Results



Threshold ~ 100 eV

PSD Cut

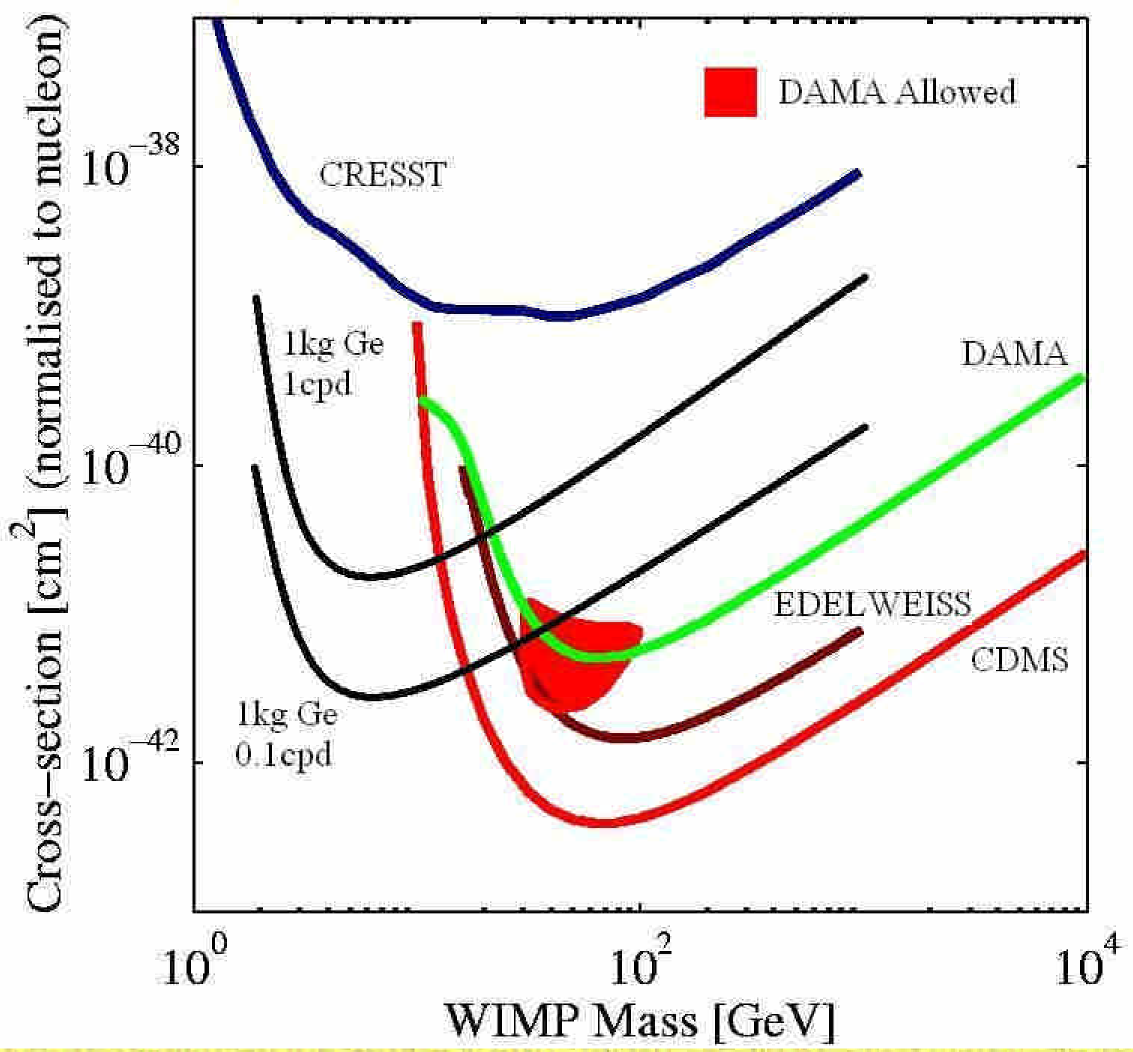


TEXONO ⊕ *KIMS* @ *Y2L*

- **Install 5 g ULB-ULEGe at Y2L on January 2005**
- **Study background and feasibility for CDM searches**
- **may evolve into a full-scale (1 kg) CDM experiment**

Yangyang（襄陽）Lab (Y2L)
min. 700 m of rock overburden

Sensitivity Plot for CDM-WIMP search with 1 kg ULEGe at 100 eV threshold ………



Summary & Outlook

- **Neutrinos are important** *but* **strange objects**

  history of ν physics full of surprises !

- **Strong evidence***s* **of massive ν's & finite mixings**

  Physics Beyond the Standard Model !

- **More experiments & projects coming up**

  EVEN MORE EXCITEMENT !

Neutrinos *may* (?) also be avenue to Dark Matter Problem ⇒ *physics-wise or experimentally*