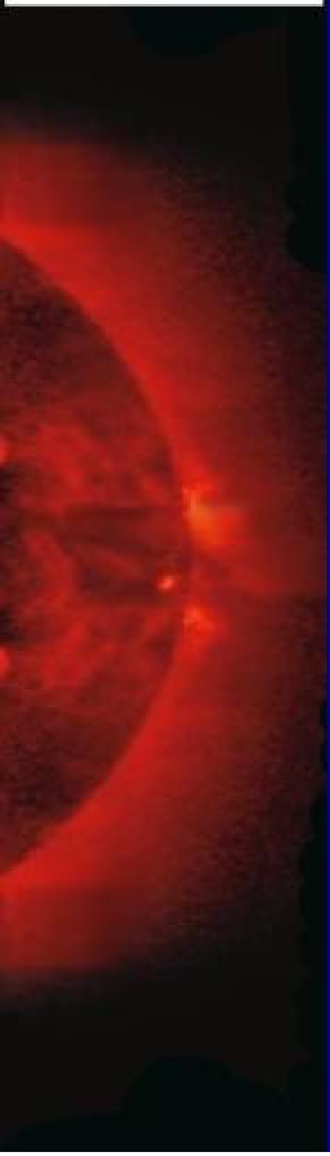


Neutrino 2002 Munich

Neutrino Astronomy
And Neutrino Properties

Where Do We Stand, Where Are We Going? Experiments

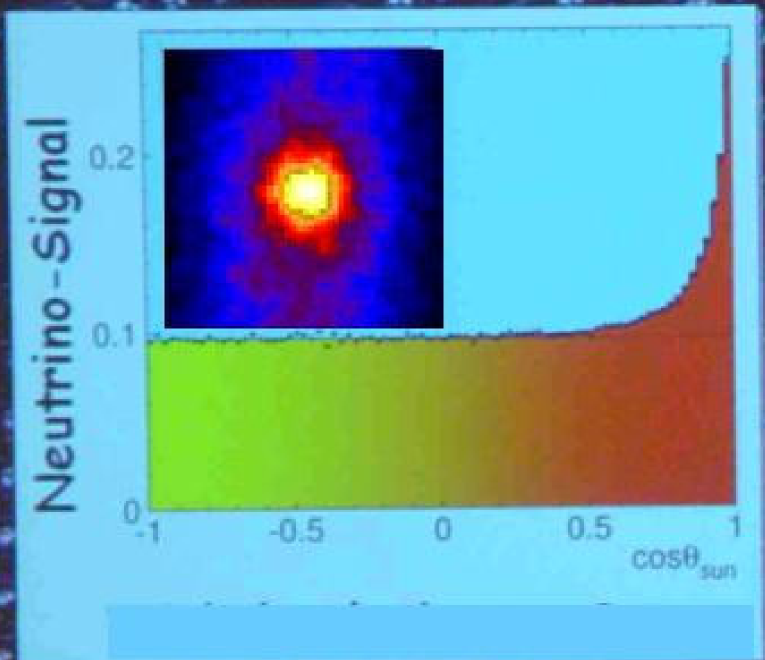
Michel Spiro
CEA Saclay

personal
incomplete
biased
mistakes

with the help of
Tobias Lachenmaier, TUM

could have been
much worse

Solar neutrino astronomy



- ν are a wonderful tool to better understand the sun.

- The understanding of the sun helps to better understand the universe.

Supernovae

- ready to detect SN neutrino bursts in our galaxy (SNO, SK, LVD, OMNIS, KamLand, Borexino, other projects)
- need 1 Megaton detector for the local group
  (factor $\times 2$)
- need 100 Mt detector for Virgo cluster (1/year) $\rightarrow$ need for better ideas

Neutrino astronomy above 100 GeV

Window for the most energetic phenomena in the universe.

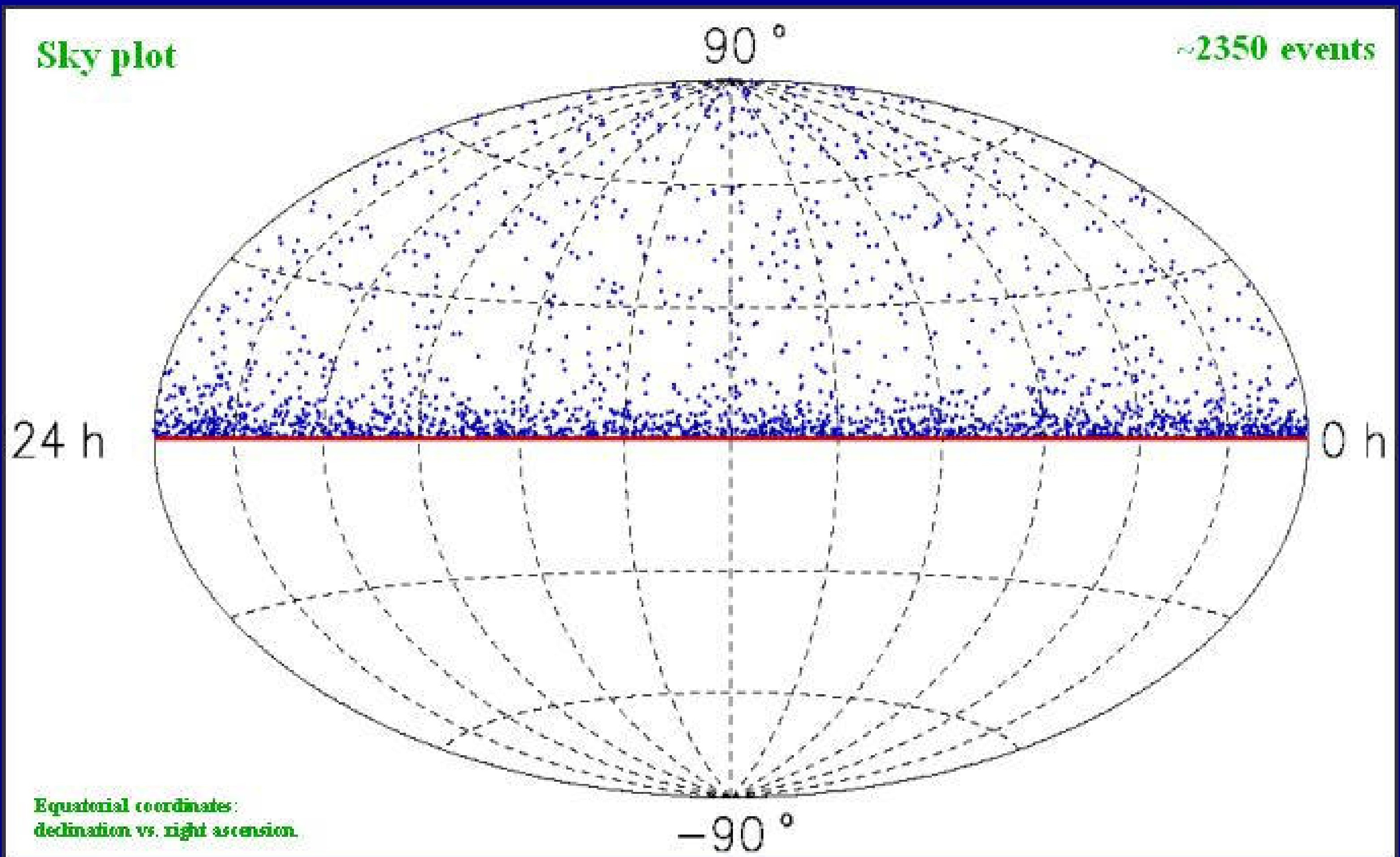
AMANDA ANTARES NESTOR Baikal NEMO

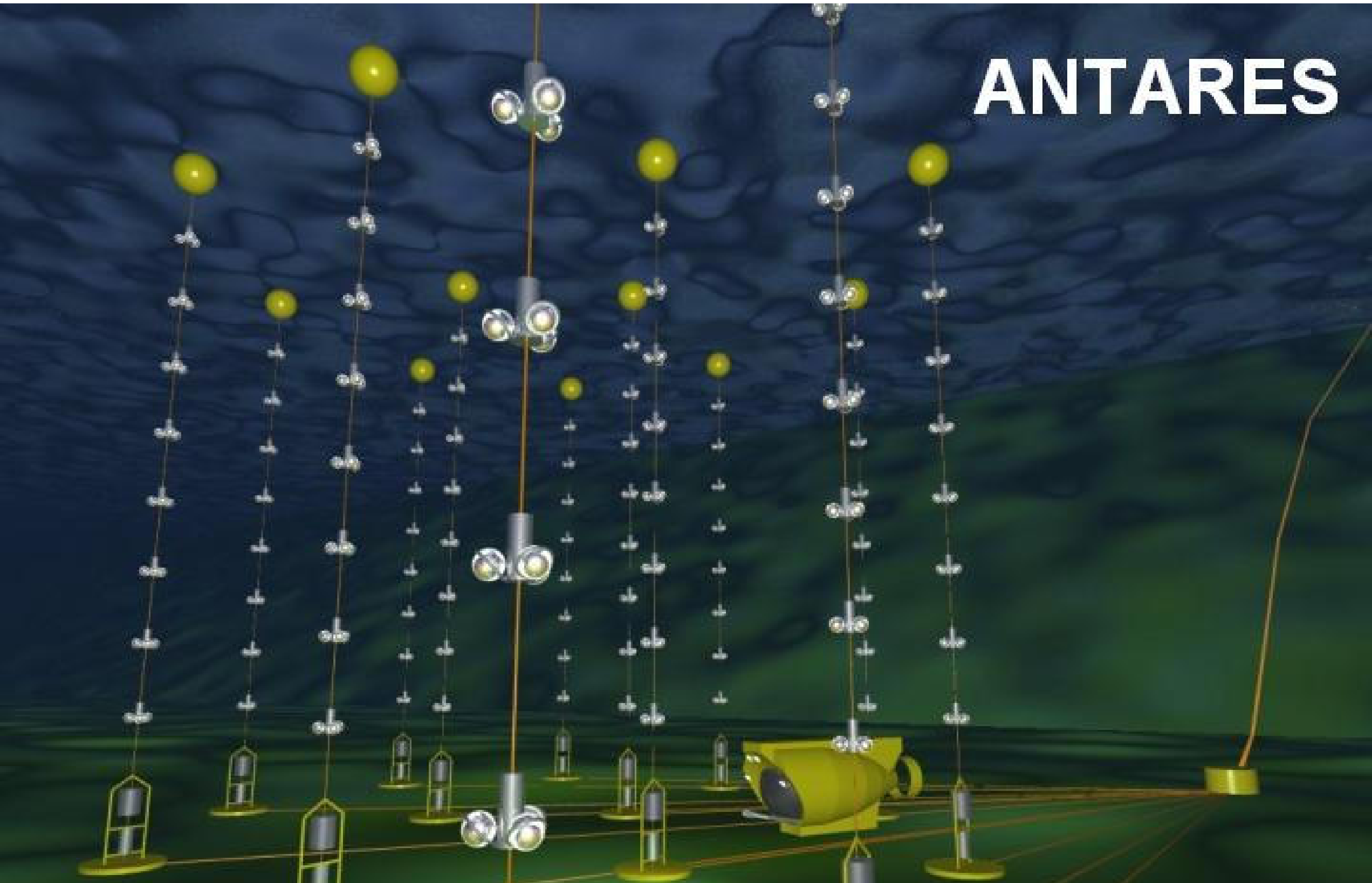
Recommendation of the IUPAP-PANAGIC-HENAP subcommittee:

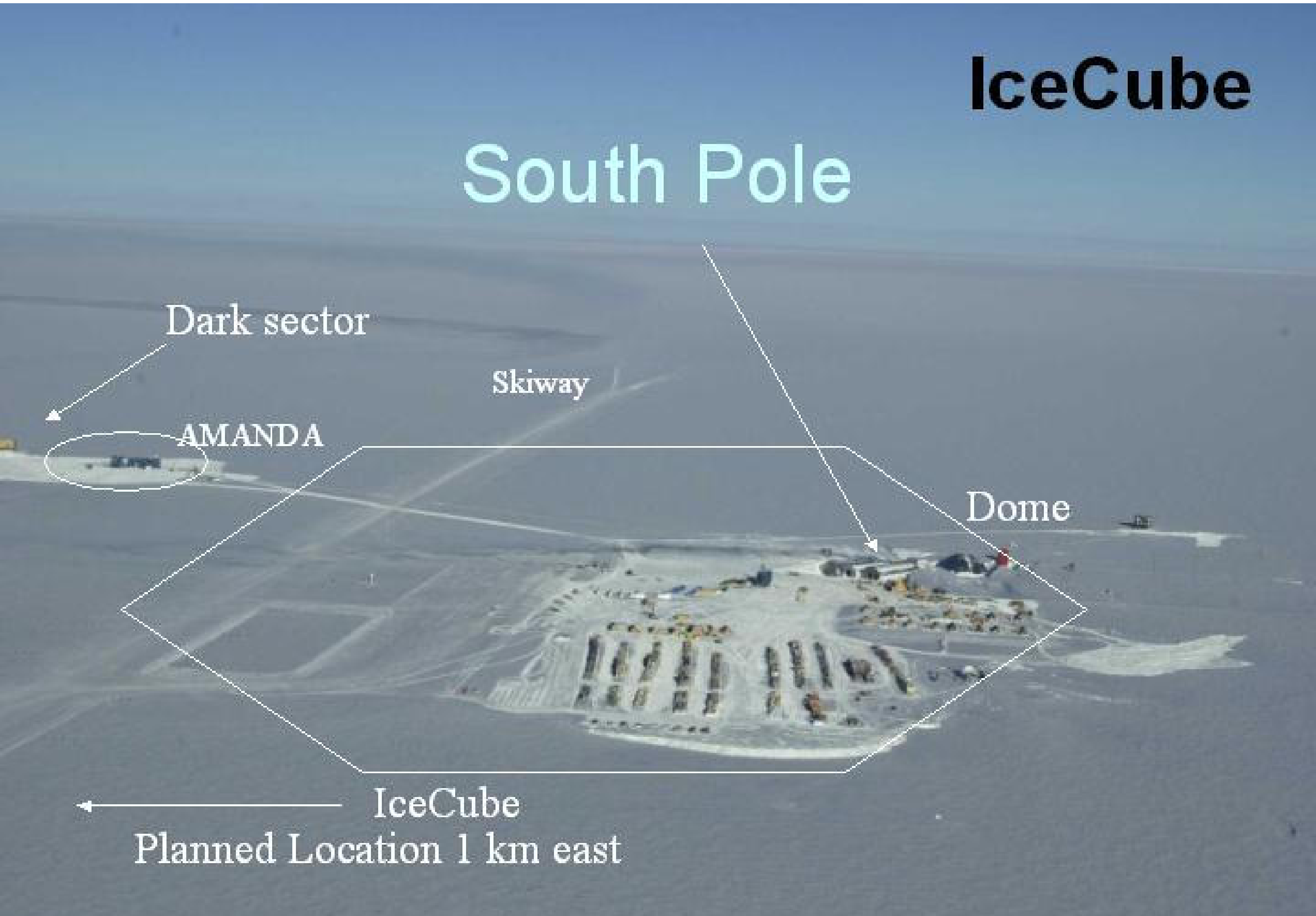
- one 1 km^3 telescope at the south pole (IceCube)
- one (and only one) 1km^3 in the Mediterranean Sea ($\rightarrow$ galactic center)

ice: easy deployment
water: very good angular resolution

AMANDA-II


Sky plot
90 °
~2350 events
24 h
0 h
Equatorial coordinates:
declination vs. right ascension.
−90 °


ANTARES
© François Montanet


IceCube
South Pole
Dark sector
Skiway
AMANDA
Dome
IceCube
Planned Location 1 km east

Neutrino oscillations and properties

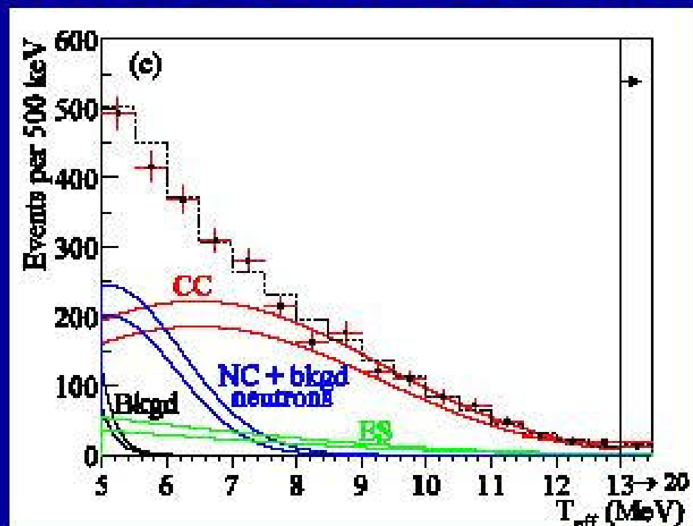
1. $\Delta m^2_{12}, \theta_{12}$	Solar, Reactor
2. $\Delta m^2_{23}, \theta_{23}$	atmospheric, LBL
3. θ_{13}	Reactor, atmospheric, LBL, Superbeams, Megaton
CP violation δ	Superbeams, β beams, neutrino factory
4. m_ν	T, dark matter
5. Mass hierarchy	atmospheric, Reactor, VLBL, neutrino factory, $\beta\beta$
6. Dirac or Majorana	$\beta\beta$ experiments

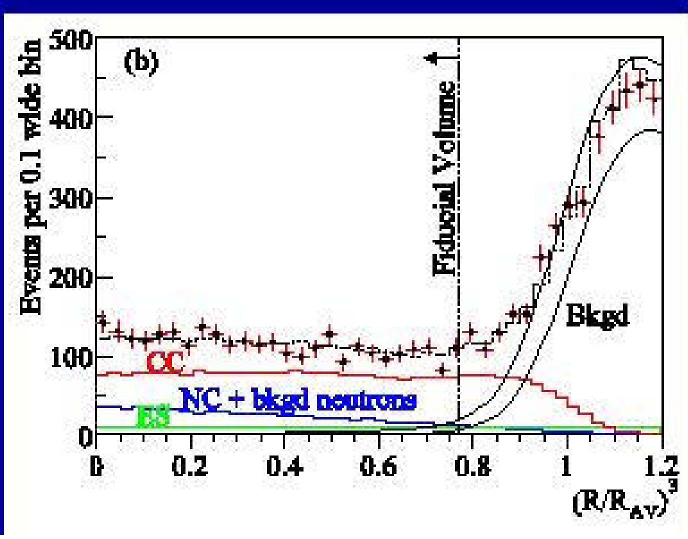
Highlight

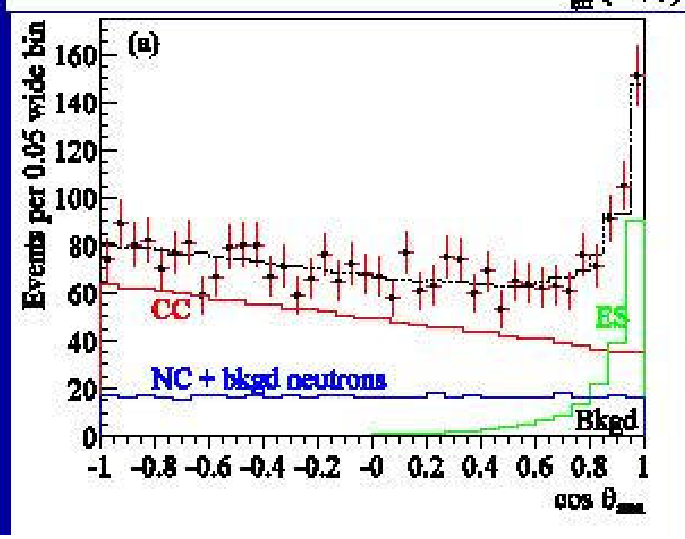
SNO Signal Extraction Results

#EVENTS

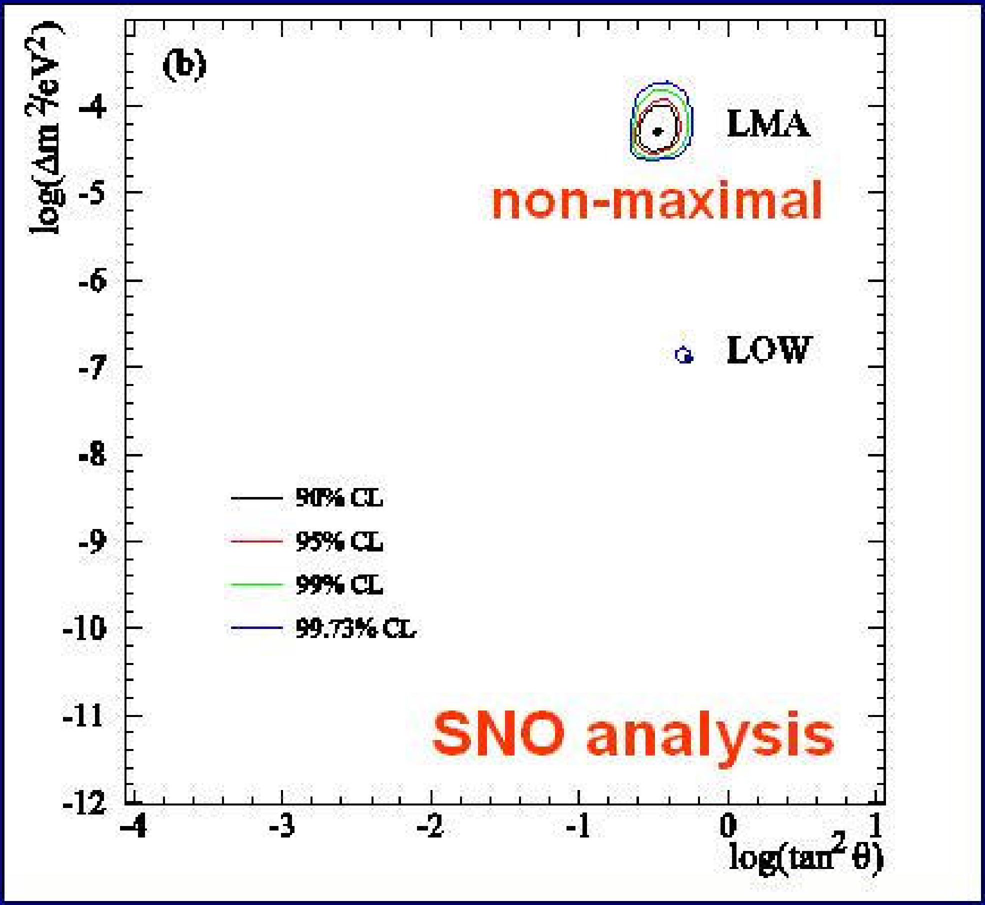
CC	1967.7	+61.9 +60.9
ES	263.6	+26.4 +25.6
NC	576.5	+49.5 +48.9





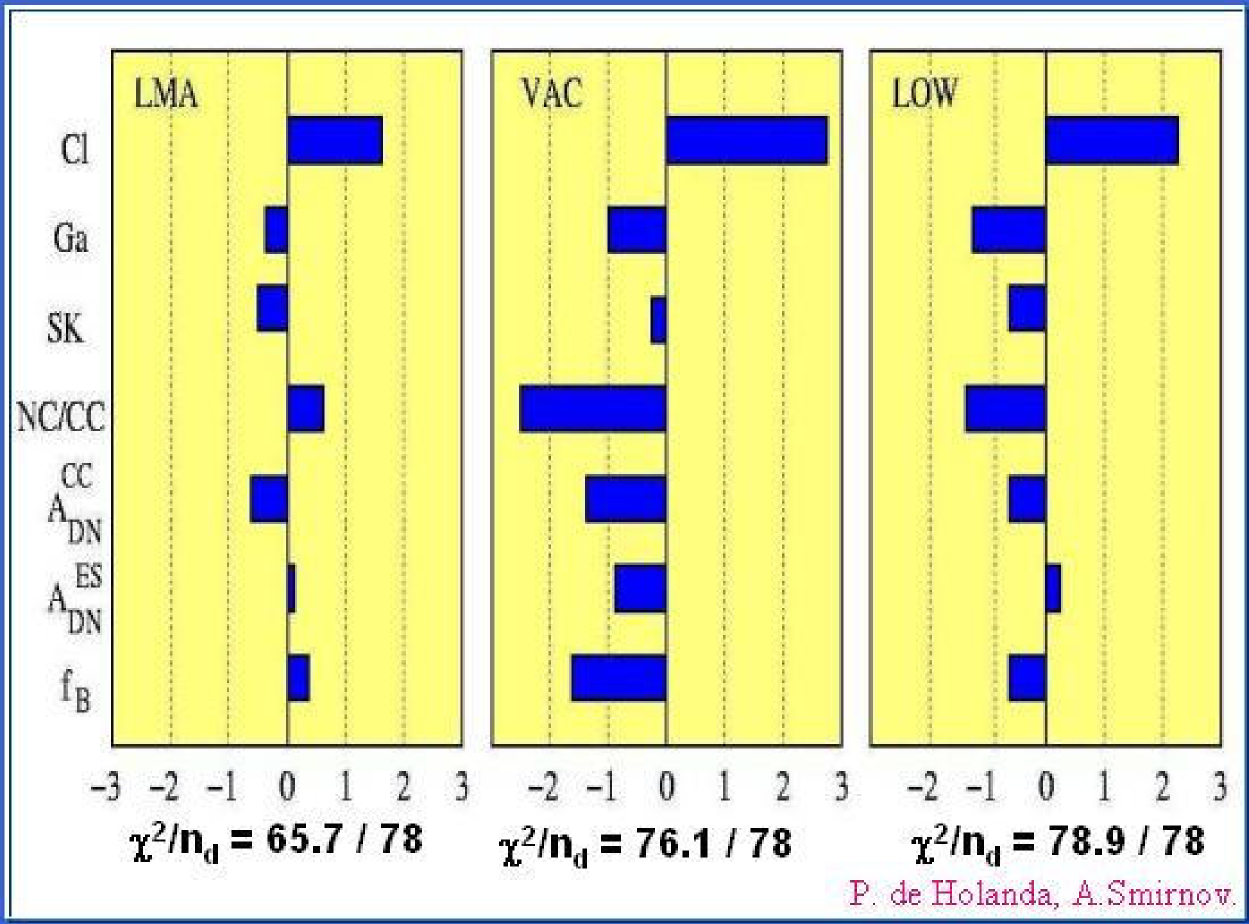


Combining All Experimental and Solar Model Information:



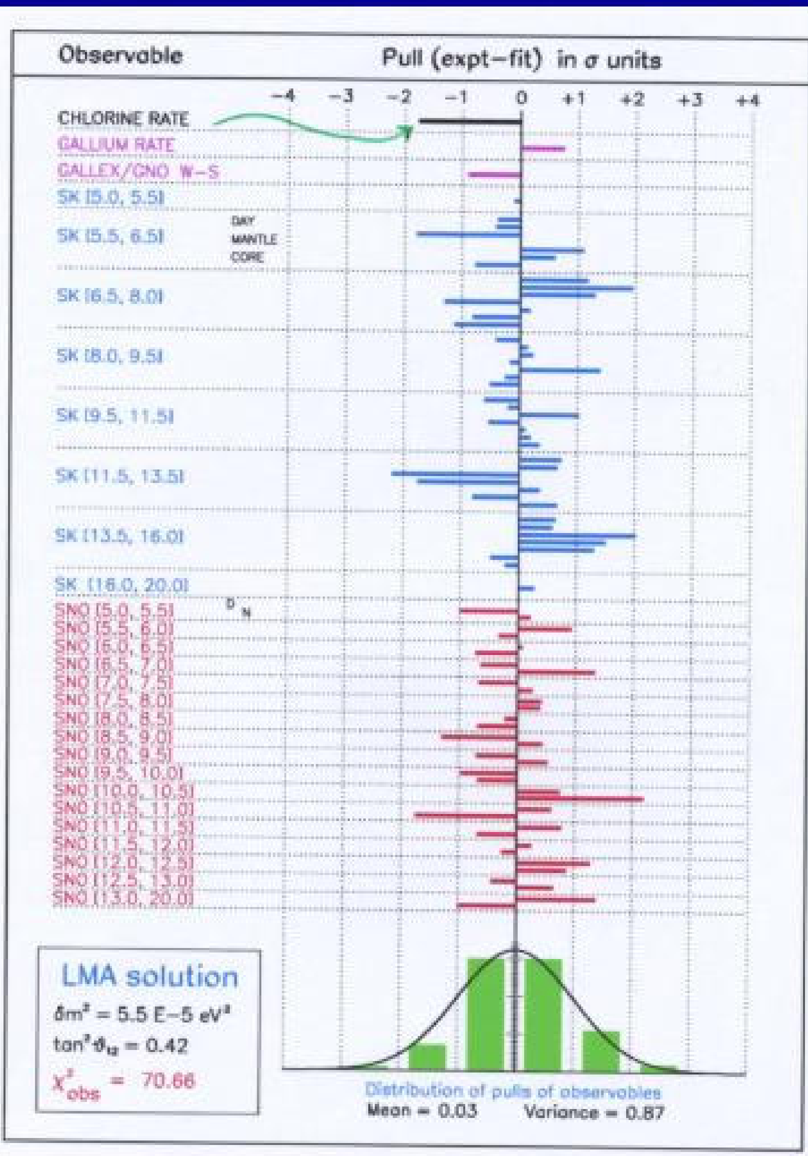
LMA
(and LOW?)

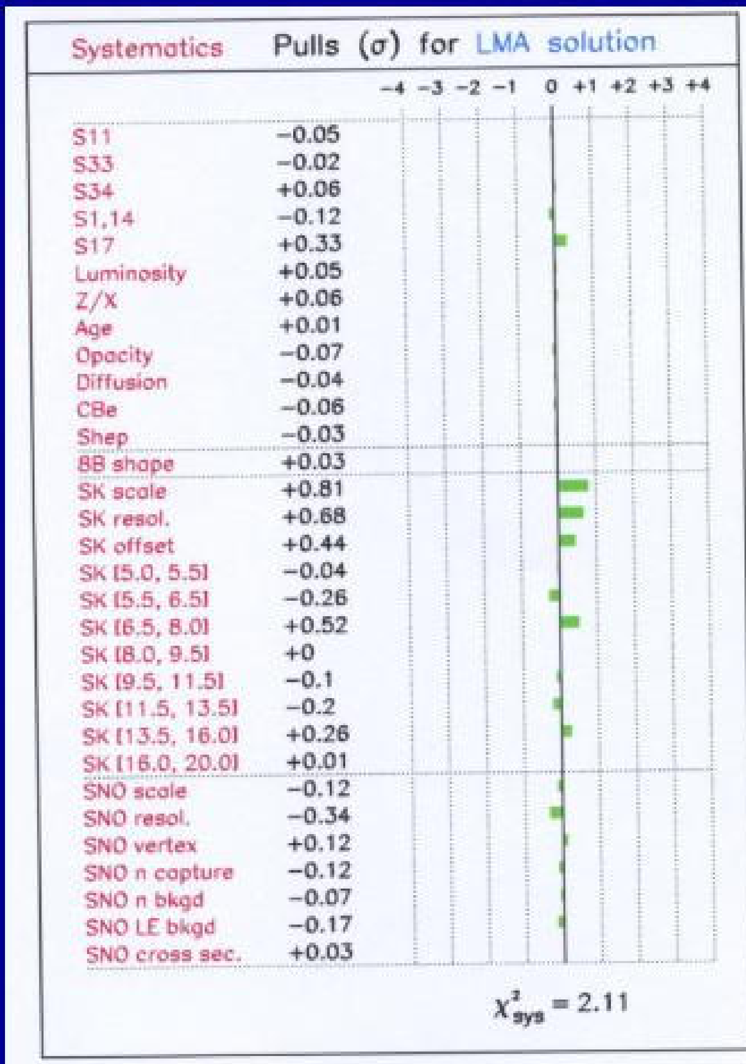
Pull-off diagrams



Personal comments

- many good local minima (LMA almost too good, does the $\Delta\chi^2$ method apply?, need for MC)
- the rate of individual experiments (like Ga or Cl) has no more weight than one single bin in the energy spectrum
- blind analysis and blind solar models would have been desirable
- no way to judge the reliability of the data points in a statistical analysis


Observable
Pull (expt−fit) in σ units
−4 −3 −2 −1 0 +1 +2 +3 +4
CHLORINE RATE
GALLIUM RATE
GALLEX/GNO W−S
SK [5.0, 5.5]
SK [5.5, 6.5]
DAY
MANTLE
CORE
SK [6.5, 8.0]
SK [8.0, 9.5]
SK [9.5, 11.5]
SK [11.5, 13.5]
SK [13.5, 16.0]
SK [16.0, 20.0]
SNO [5.0, 5.5]
D
N
SNO [5.5, 6.0]
SNO [6.0, 6.5]
SNO [6.5, 7.0]
SNO [7.0, 7.5]
SNO [7.5, 8.0]
SNO [8.0, 8.5]
SNO [8.5, 9.0]
SNO [9.0, 9.5]
SNO [9.5, 10.0]
SNO [10.0, 10.5]
SNO [10.5, 11.0]
SNO [11.0, 11.5]
SNO [11.5, 12.0]
SNO [12.0, 12.5]
SNO [12.5, 13.0]
SNO [13.0, 20.0]
LMA solution
δm² = 5.5 E−5 eV²
tan²ϑ₁₂ = 0.42
χ²obs = 70.66
Distribution of pulls of observables
Mean = 0.03
Variance = 0.87


Systematics
Pulls (σ) for LMA solution
−4 −3 −2 −1 0 +1 +2 +3 +4
S11 −0.05
S33 −0.02
S34 +0.06
S1,14 −0.12
S17 +0.33
Luminosity +0.05
Z/X +0.06
Age +0.01
Opacity −0.07
Diffusion −0.04
CBe −0.06
Shep −0.03
8B shape +0.03
SK scale +0.81
SK resol. +0.68
SK offset +0.44
SK [5.0, 5.5] −0.04
SK [5.5, 6.5] −0.26
SK [6.5, 8.0] +0.52
SK [8.0, 9.5] +0
SK [9.5, 11.5] −0.1
SK [11.5, 13.5] −0.2
SK [13.5, 16.0] +0.26
SK [16.0, 20.0] +0.01
SNO scale −0.12
SNO resol. −0.34
SNO vertex +0.12
SNO n capture −0.12
SNO n bkgd −0.07
SNO LE bkgd −0.17
SNO cross sec. +0.03
χ²sys = 2.11

from E. Lisi

Future:

We have 3 approaches:

Solar models flux < 1 MeV	flux > 5 MeV (^{8}B)	Reactor
GNO, SAGE (Cl – ^{8}B)	SNO & SK	Kamland HLMA?
Borexino		
LENS XMASS, ...		

If agreement $\Rightarrow$ better accuracy

If discrepancy $\Rightarrow$ discovery

Future:

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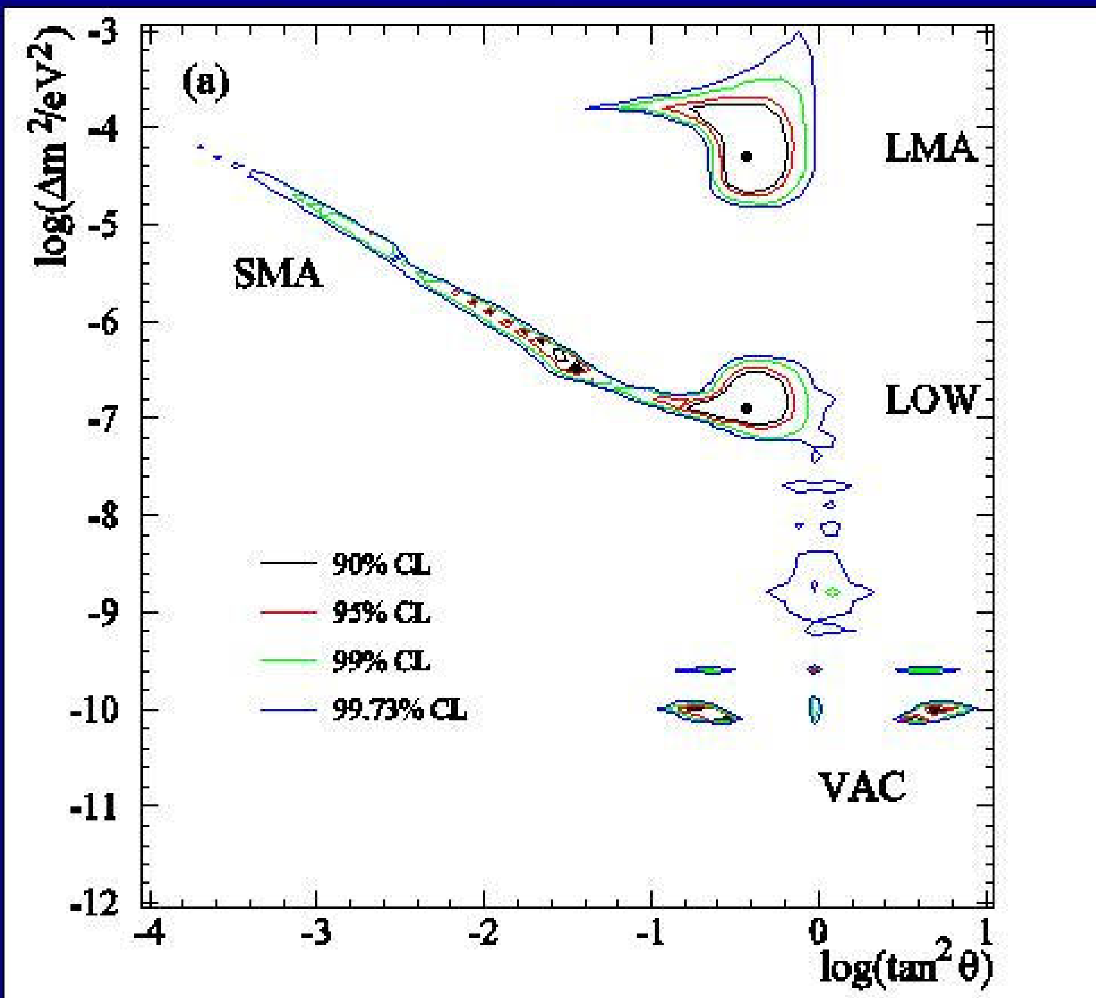
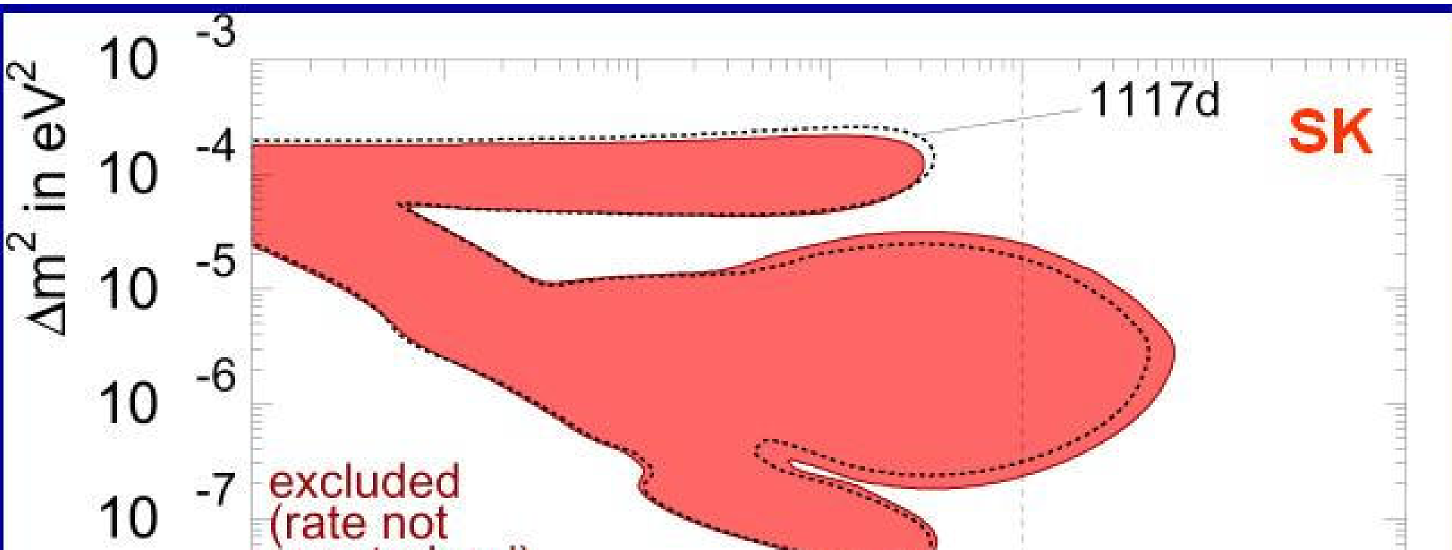
Solar models flux < 1 MeV	flux > 5 MeV (^{8}B)	Reactor
GNO, SAGE (Cl – ^{8}B) ⇓ Borexino ⇓ LENS XMASS, ...	SNO & SK	Kamland HLMA?

If agreement ⇒ better accuracy

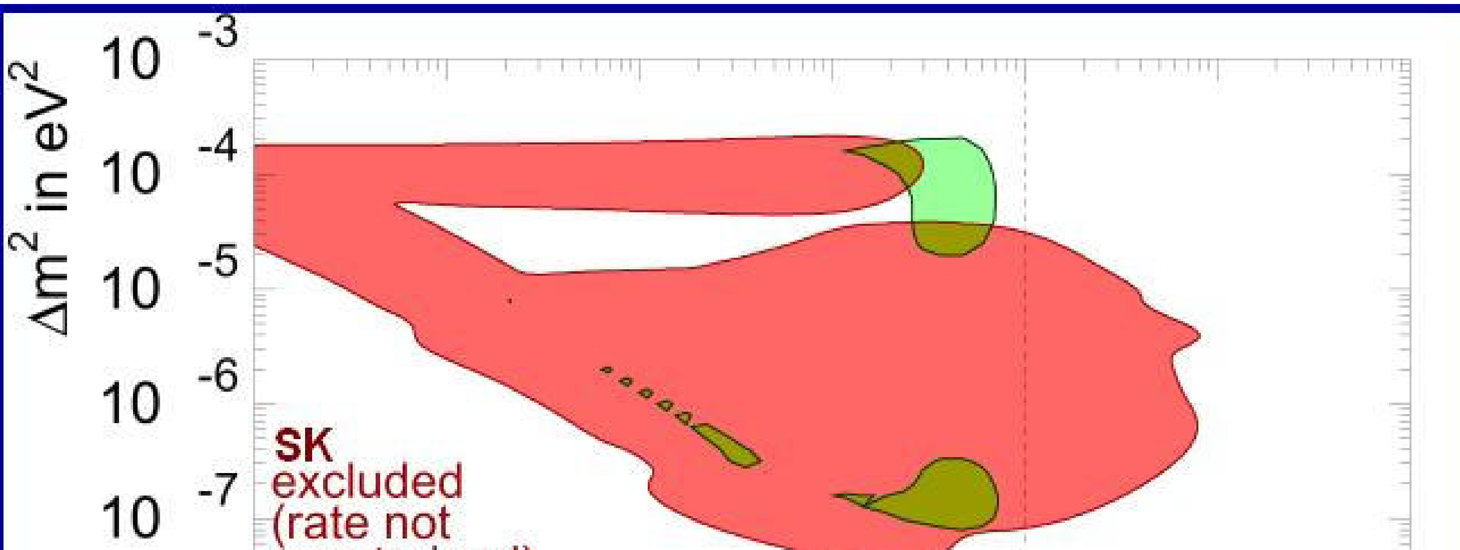
If discrepancy ⇒ discovery

SNO Day and Night Energy Spectra Alone





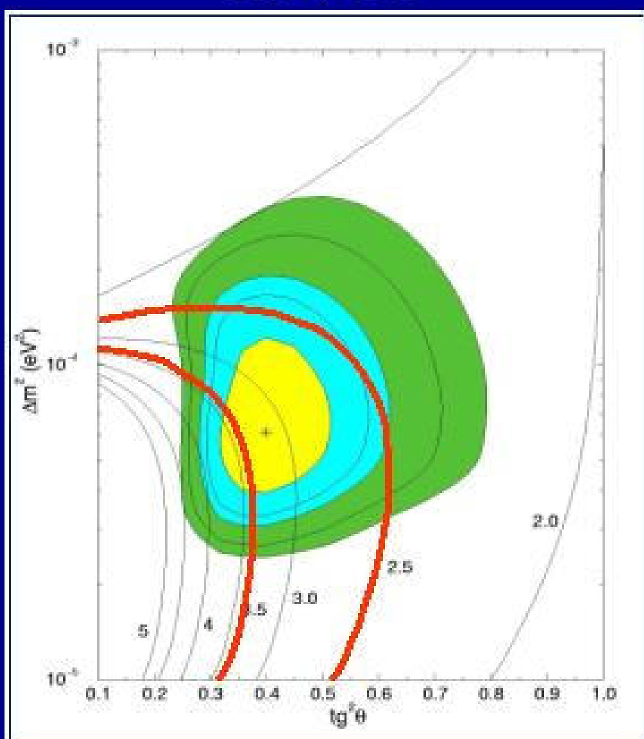
SK
1117d
excluded
(rate not
constrained)
Day/Night Spectrum $\nu_e \rightarrow \nu_{\mu/\tau}$ (95%C.L.)
Δm^2 in eV^2
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
10^{2}
$\tan^2(\Theta)$



Δm² in eV²
SK
excluded
(rate not
constrained)
allowed
(SNO Day/Night
Spectrum)
Zenith Spectrum $\nu_e \rightarrow \nu_{\mu/\tau}$ (95%C.L.)
tan²(Θ)

Grids of predictions

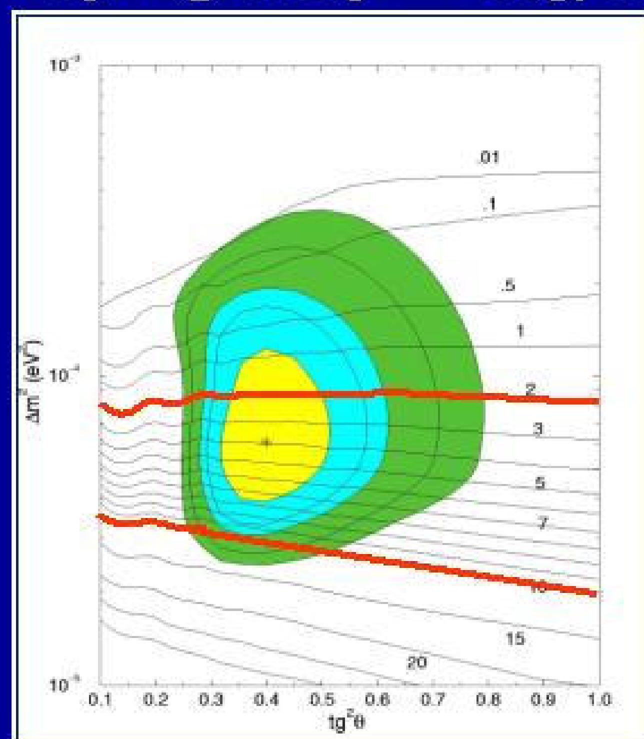
NC / CC



best fit: NC/CC = 3.15
3σ: ~ - (2.0 - 4.5) %

SNO: NC/CC = 2.9 ± 0.4

Day-Night asymmetry, %



best fit: A_{DN}^{CC} = - 3.9 %
3σ: - (~ 0 - 14) %

SNO: A_e = (7.0 ± 5.1) %

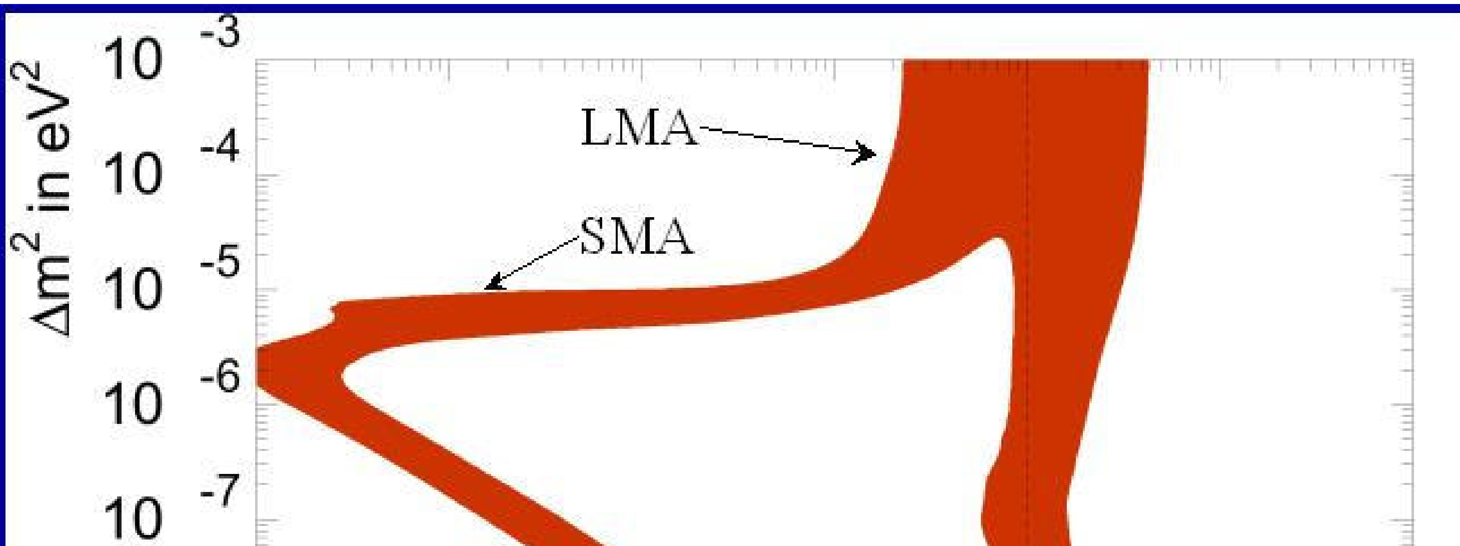
Future:

We have 3 approaches:

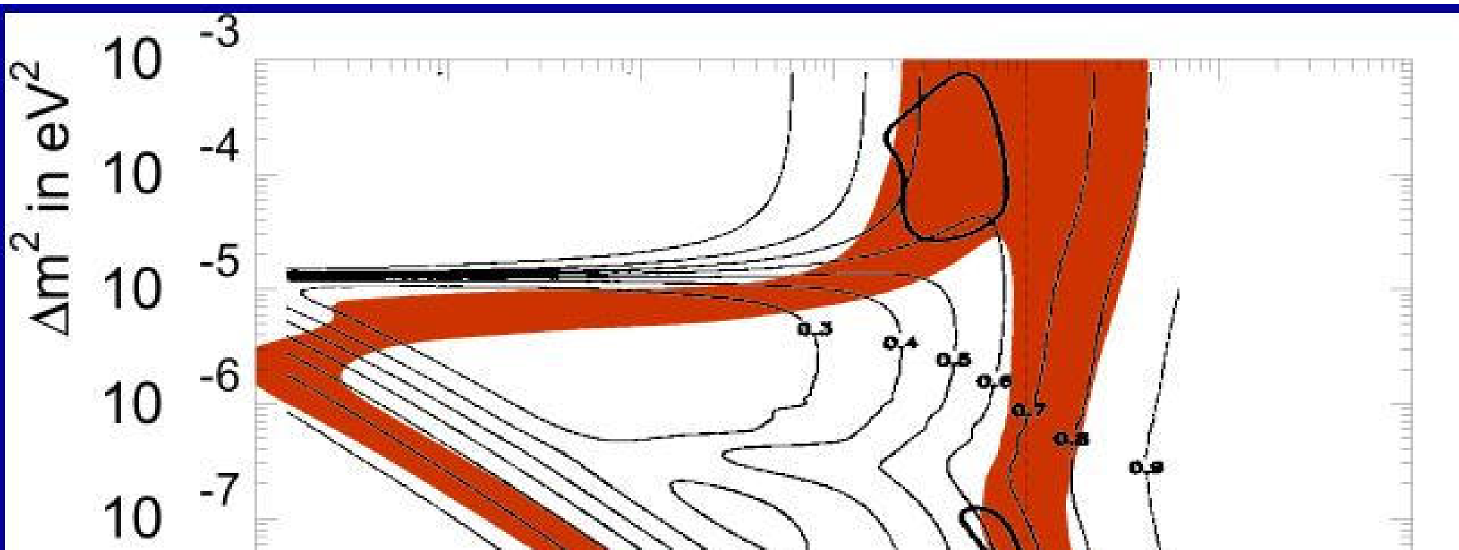
Solar models flux < 1 MeV	flux > 5 MeV (^8B)	Reactor
GNO, SAGE (Cl – ^8B) ⇓ Borexino ⇓ LENS XMASS, ...	SNO & SK	Kamland HLMA?

If agreement ⇒ better accuracy

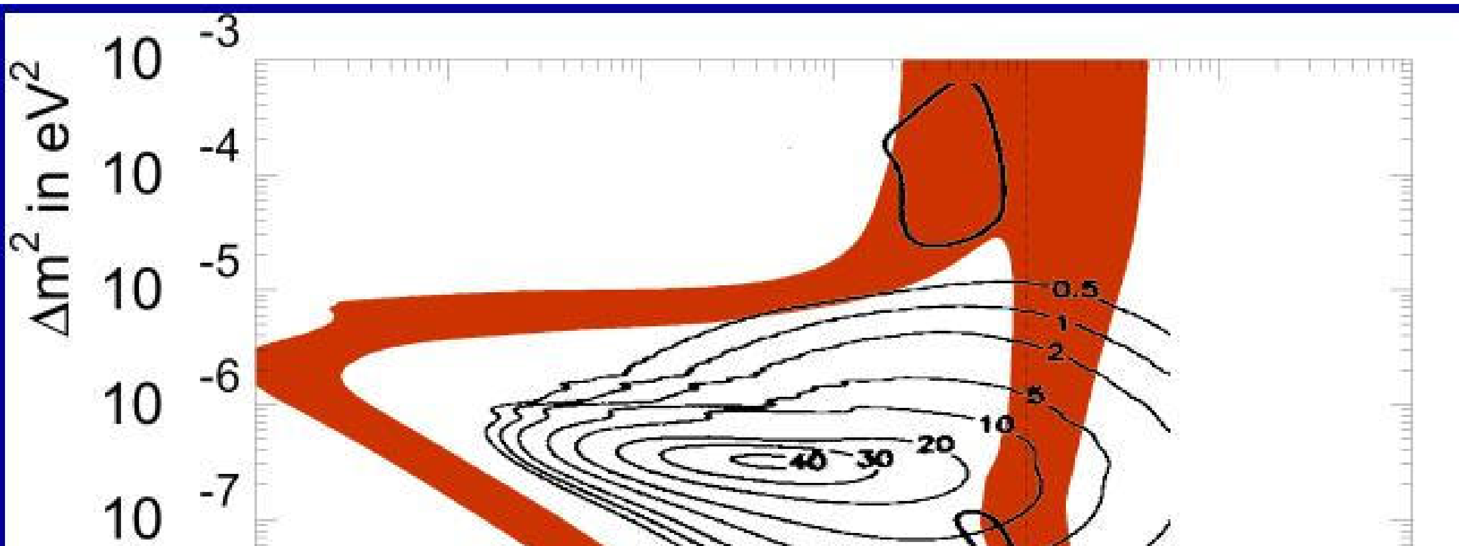
If discrepancy ⇒ discovery



Δm^2 in eV^2
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
LMA
SMA
LOW
VAC
allowed
(Gallium)
$\nu_e \rightarrow \nu_{\mu/\tau}$ (95%C.L.)
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
10^{2}
$\tan^2(\Theta)$



Δm^2 in eV^2
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
0.3
0.4
0.5
0.6
0.7
0.8
0.9
allowed (Gallium)
2 d.o.f.
99.73 % C.L.
+ Borexino rate
$\nu_e \rightarrow \nu_{\mu/\tau}$ (95%C.L.)
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
10^{2}
$\tan^2(\Theta)$



Δm^2 in eV^2
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
allowed
(Gallium)
+ Borexino D/N %
$\nu_e \rightarrow \nu_{\mu/\tau}$ (95%C.L.)
0.5
1
2
5
10
20
30
40
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
10^{2}
$\tan^2(\Theta)$

Future:

We have 3 approaches:

Solar models flux < 1 MeV

GNO, SAGE
(Cl – ^{8}B)
↓
Borexino
↓
LENS
XMASS, ...

flux > 5 MeV (^{8}B)

SNO & SK

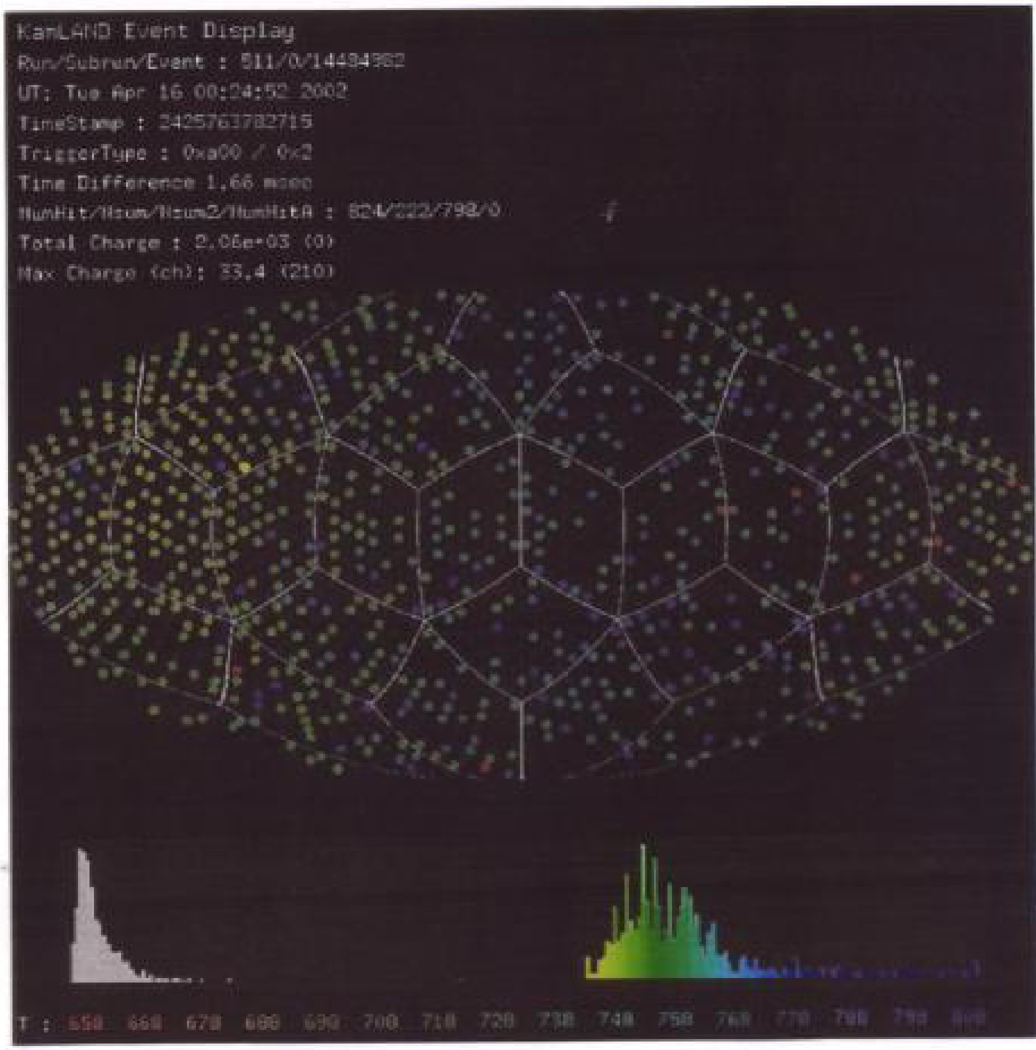
Reactor

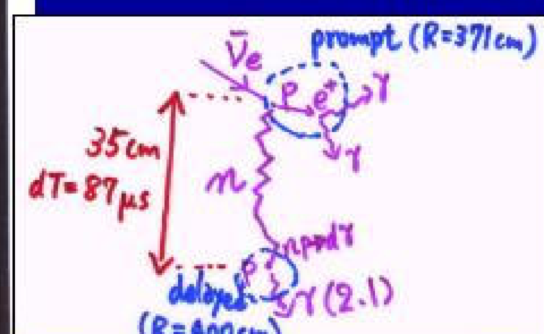
Kamland
HLMA?

If agreement $\Rightarrow$ better accuracy

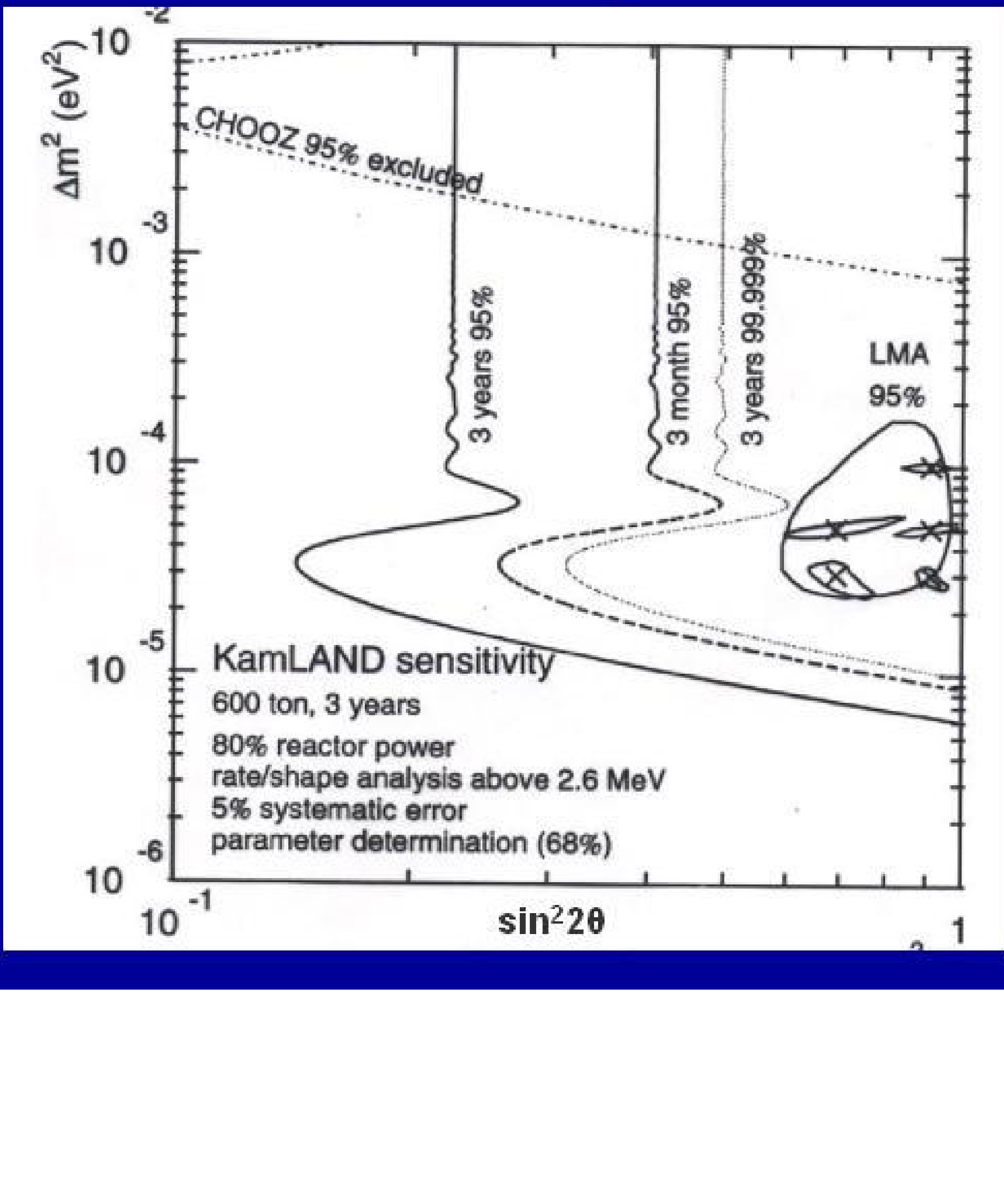
If discrepancy $\Rightarrow$ discovery

KamLAND $\overline{\nu}_e$ candidate (prompt)





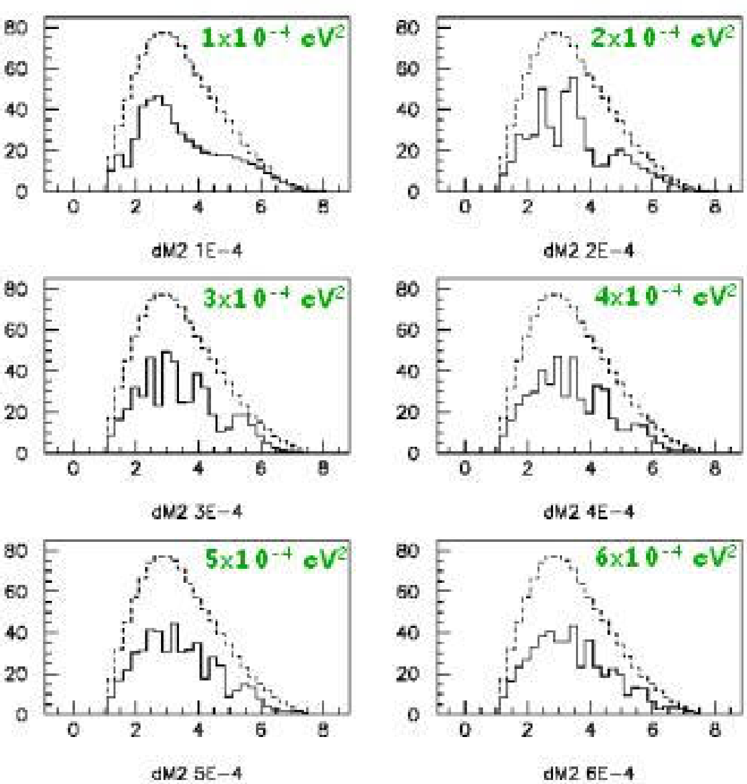
KamLAND sensitivity



Blind analysis desirable!

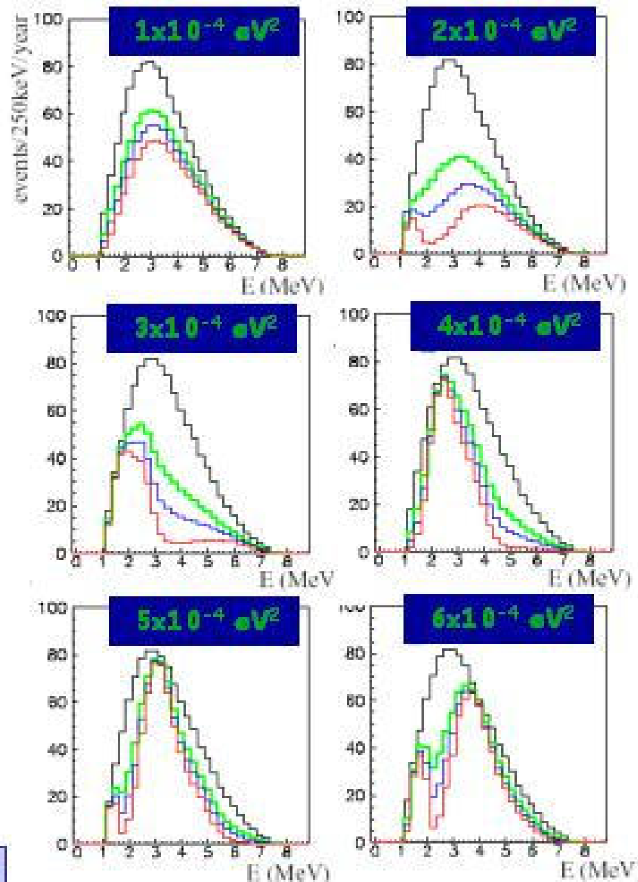
The HLMA region Δm^2 >~ $2x10^{-4}$ eV^2

KamLAND positron spectra ~200km



$sin^2(2\theta)$=1 (red), no energy resolution, 250 keV bins

HLMA @Heilbronn positron spectra ~ 20km



Schoenert, Lasserre, Oberauer, hep-ex/0203013

Neutrino oscillations and properties

1.	Δm^2_{12}, θ_{12}	Solar, Reactor
2.	Δm^2_{23} , θ_{23}	atmospheric, LBL
3.	θ_{13}	Reactor, atmospheric, LBL, Superbeams, Megaton
	CP violation δ	Superbeams, β beams, neutrino factory
4.	m_ν	T, dark matter
5.	Mass hierarchy	atmospheric, Reactor, VLBL, neutrino factory, $\beta\beta$
6.	Dirac or Majorana	$\beta\beta$ experiments

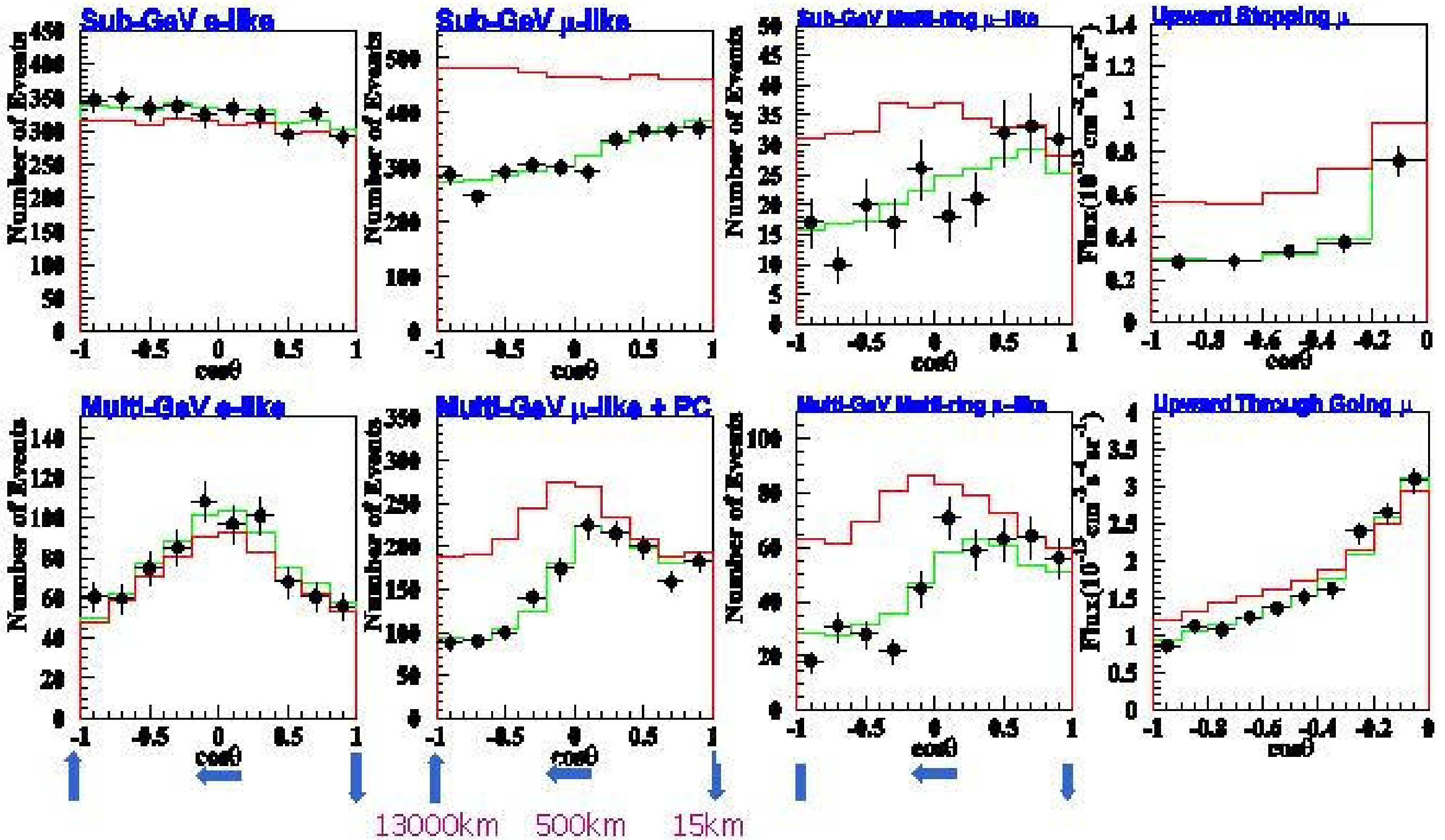
SK Zenith angle distributions (FC+PC+up-μ)

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

2-flavor oscillations

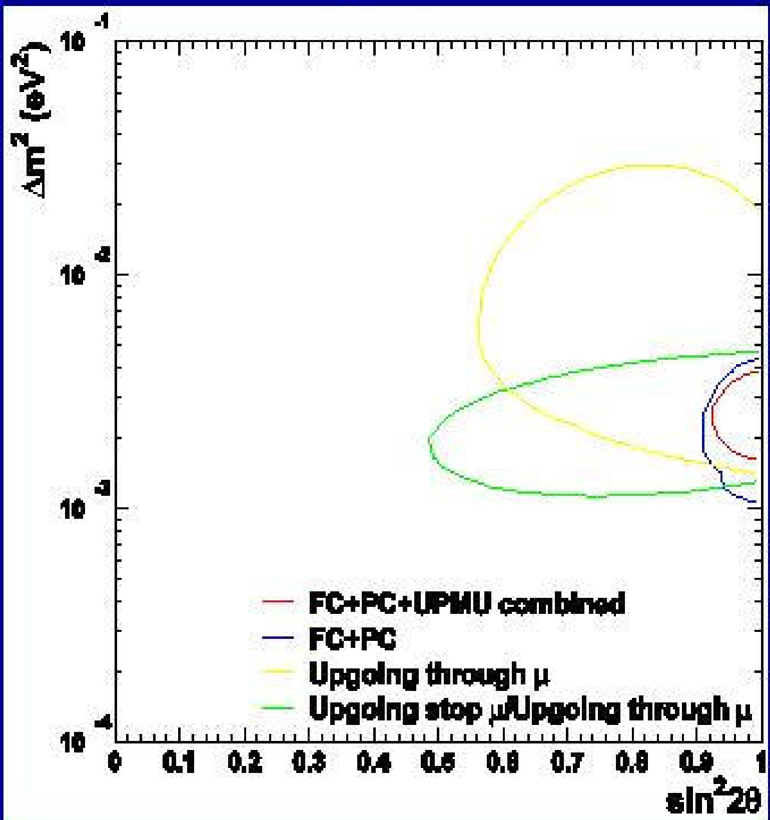
Best fit ($\Delta m^2 = 2.5 \times 10^{-3} eV^2$, $\sin^2 2\theta = 1.0$
$\chi^2_{min} = 163.2/170$ d.o.f)

Null oscillation
($\chi^2 = 456.5/172$ d.o.f)



Super-Kamiokande
Combined allowed regions

$\nu_\mu \rightarrow \nu_\tau$

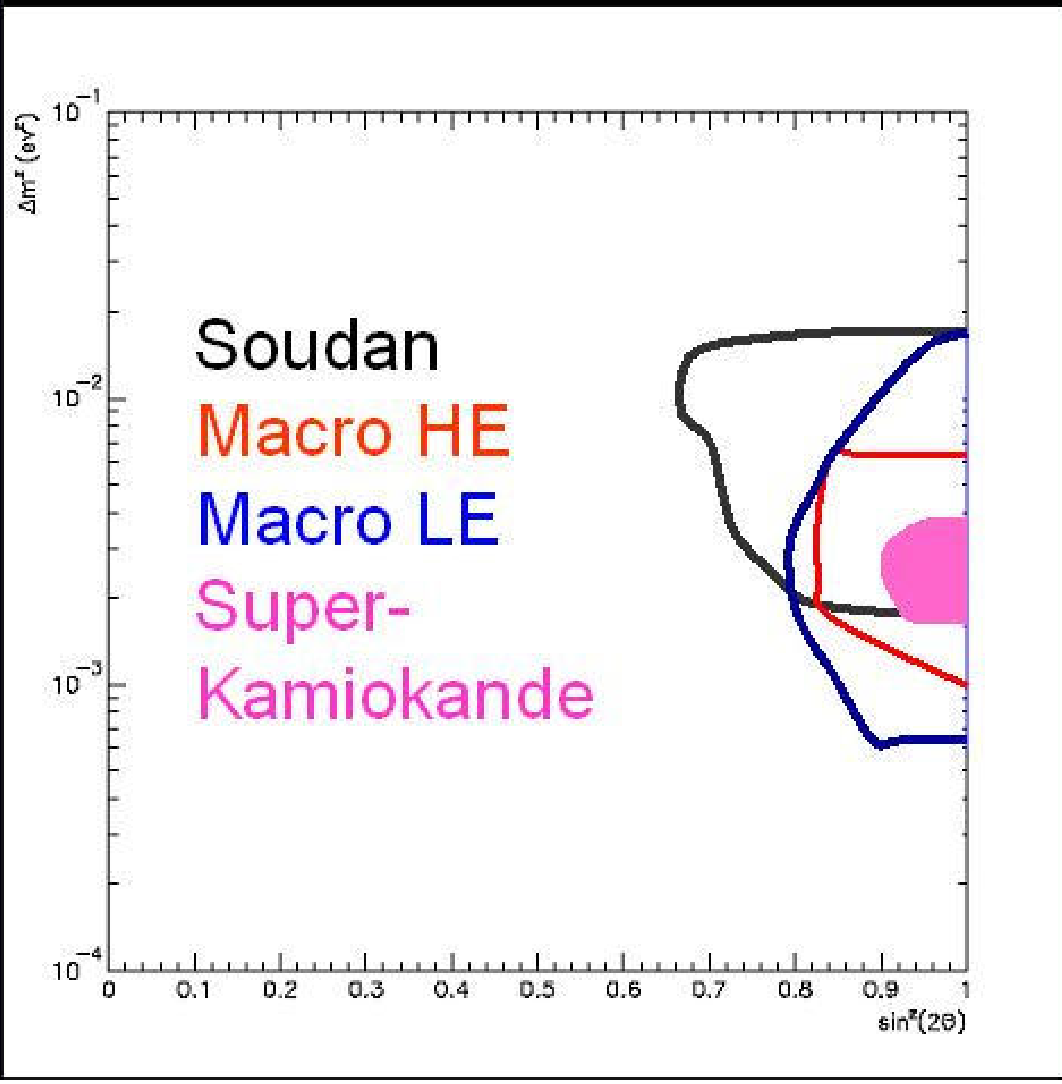


$\nu_\mu \leftrightarrow \nu_\tau$ oscillations

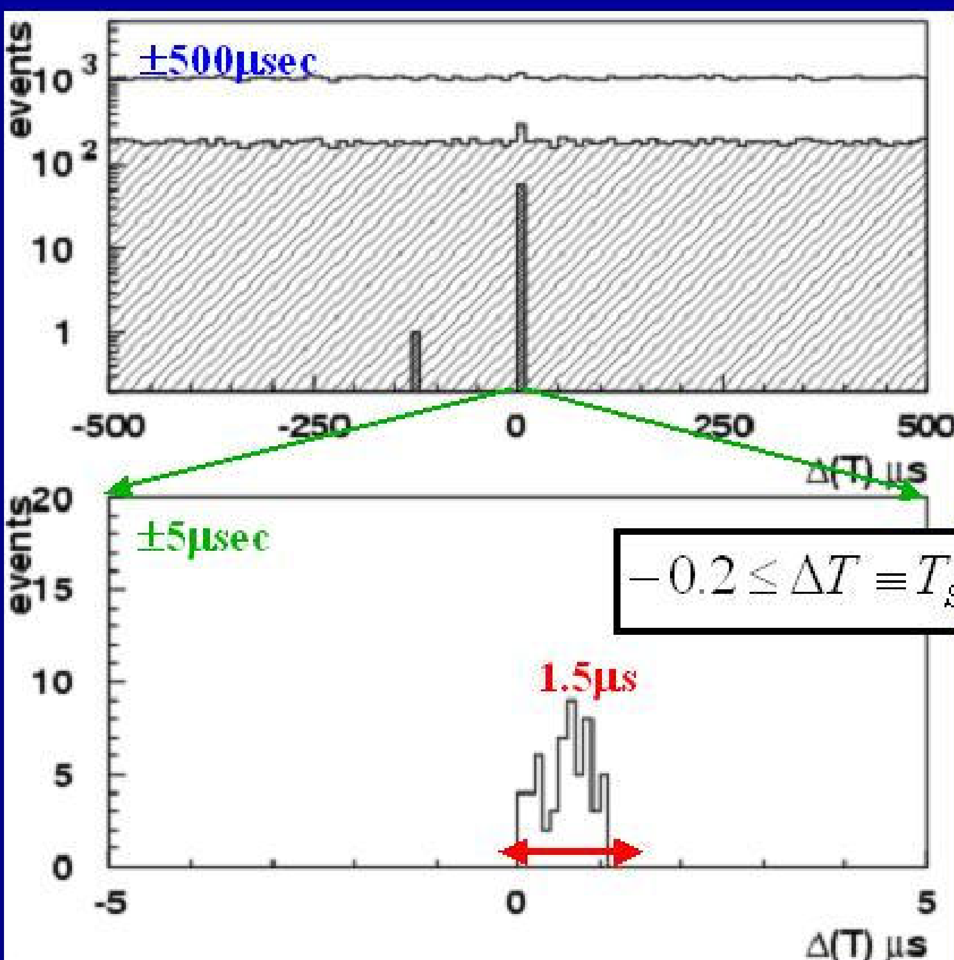
Best fit(Δm^2=2.5x10^{-3},sin^{2}2θ=1.0
χ^2_{min}=163.2/170 d.o.f)
No oscillation
(χ^2 =456.5/172 d.o.f)

Δm^2 = (1.6~3.9)x10^{-3}eV^2
sin^{2}2θ > 0.92 @ 90%CL

Δm^2, $\sin^2(2\theta)$ Comparison

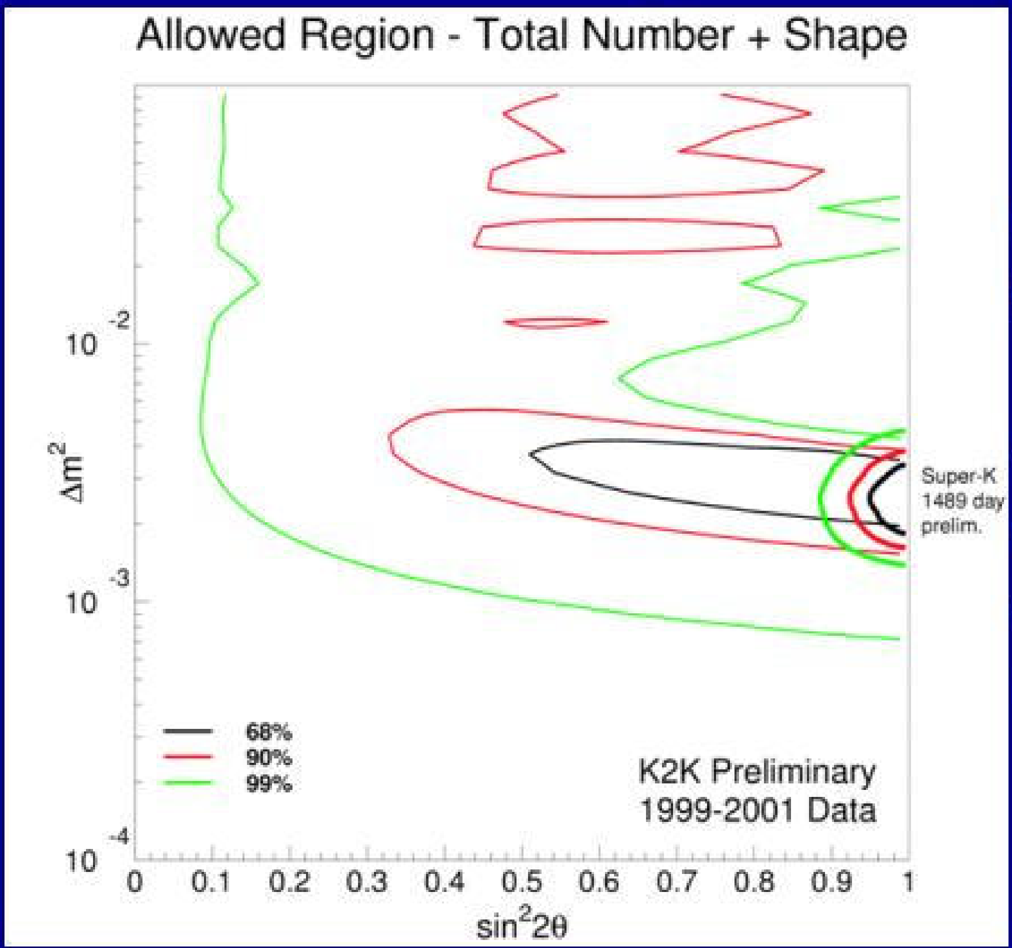


K2K Oscillation analysis on June 99 - July 01 data



$$-0.2 \le \Delta T \equiv T_{SK} - T_{Spill} - \mathrm{TOF} \le 1.3\mu\mathrm{sec}$$

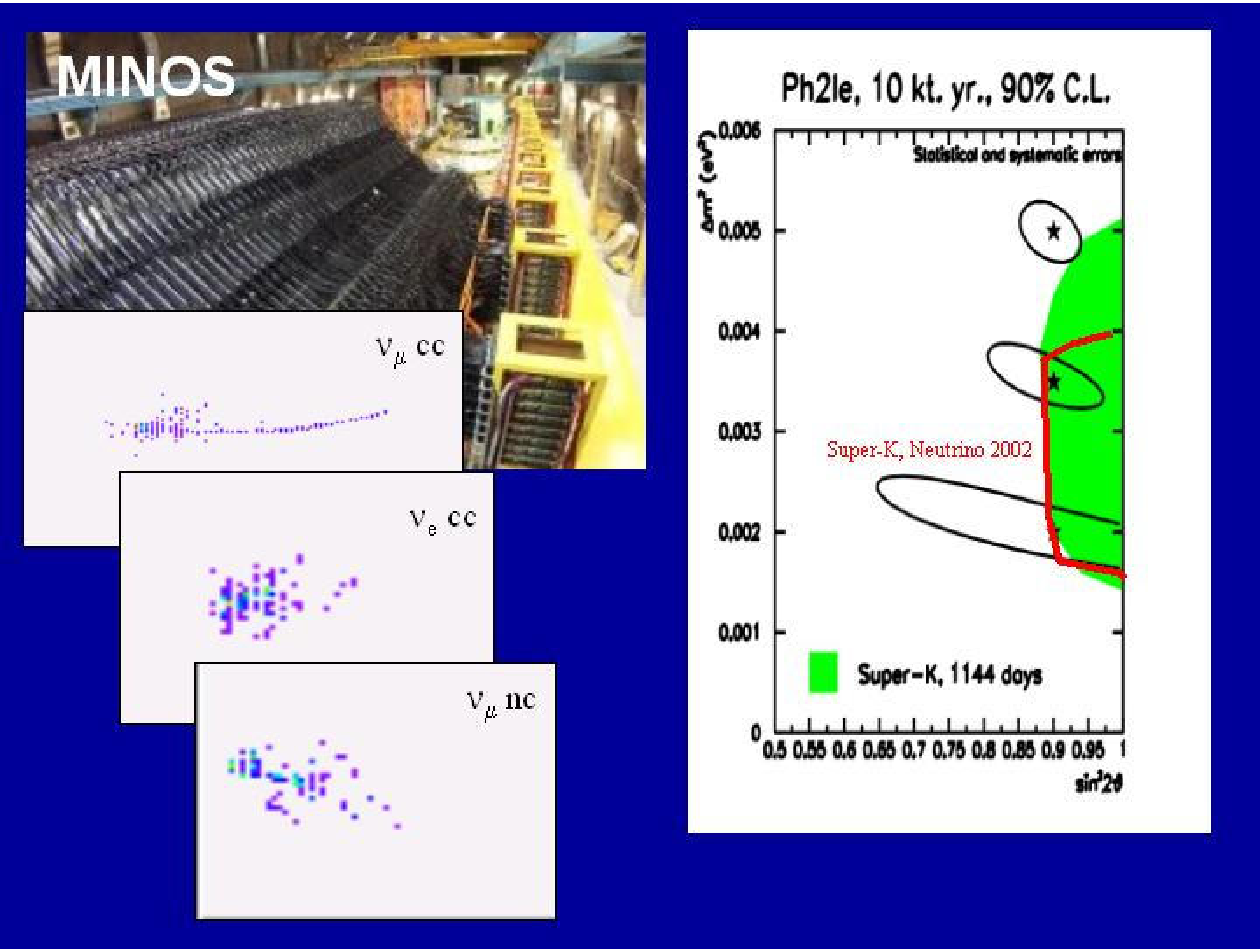
K2K Oscillation analysis on June 99 - July 01 data



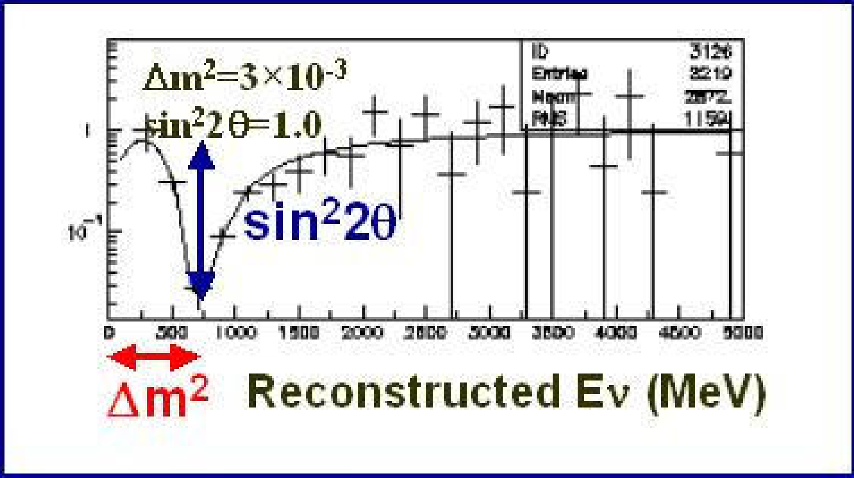
Null oscillation probability < 1% (56 events observed, 80 expected)

$\sin^2 2\theta$, Δm^2 are consistent with atmospheric neutrinos

Data taking will resume within this year.


MINOS
ν_μ cc
ν_e cc
ν_μ nc
Ph2le, 10 kt. yr., 90% C.L.
Statistical and systematic errors
Δm^2 (eV^2)
0.006
0.005
0.004
0.003
0.002
0.001
0
Super-K, Neutrino 2002
Super-K, 1144 days
0.5 0.55 0.6 0.65 0.7 0.75 0.8 0.85 0.9 0.95 1
$\sin^2 2\theta$

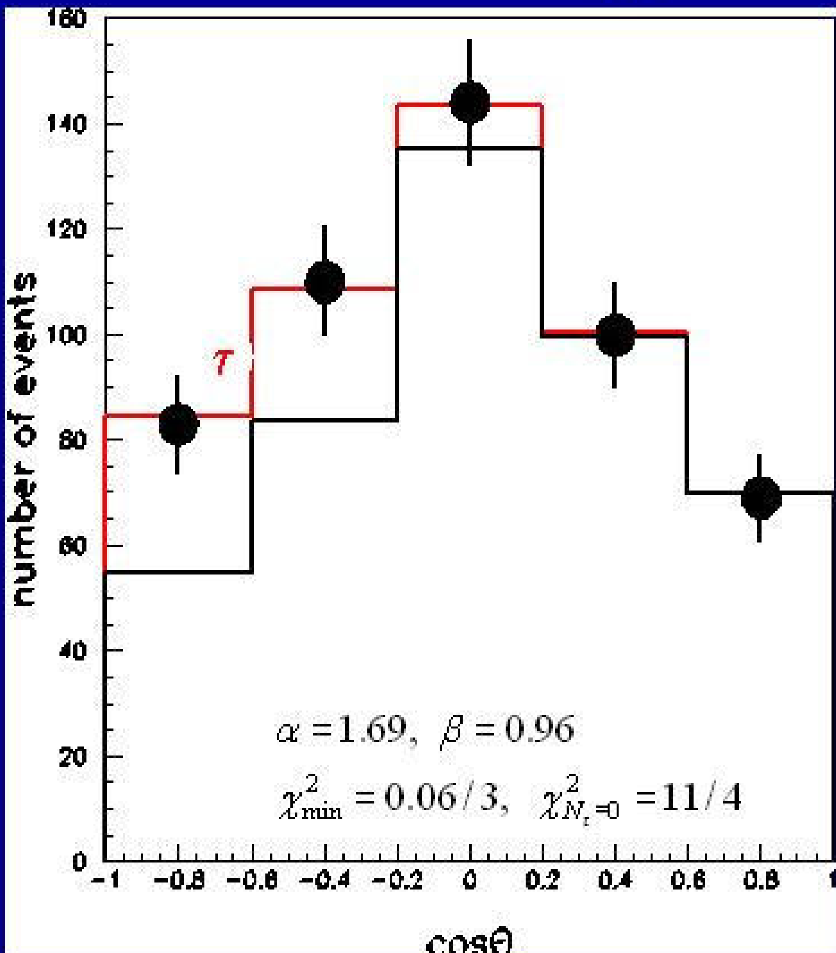
JHF-Kamioka



$\delta \sin^2 2\theta_{23} \sim 0.01$

$\delta \Delta m_{23}^2 \quad < 1\times10^{-4} eV^2$

SK: τ appearance analysis

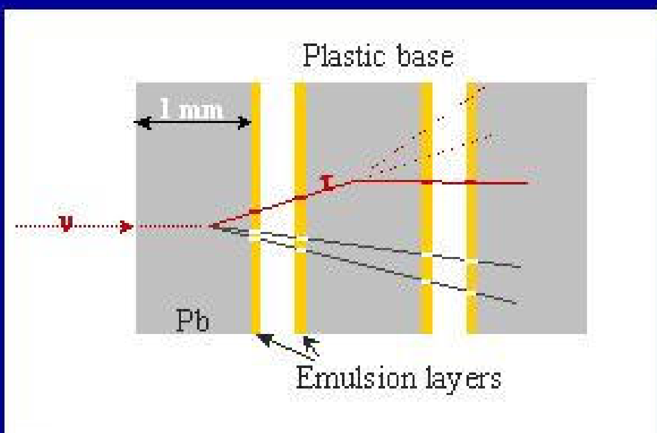


$N^{FC}(\tau) = 145 \pm 44(\text{stat.})$
$+11/-16(\text{sys.})$

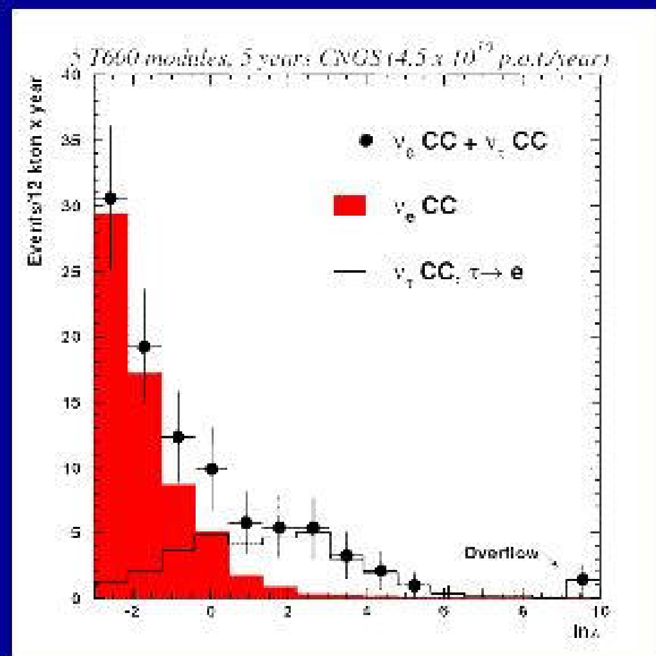
$N_{exp} = 86$

consistent with $\nu_\mu \leftrightarrow \nu_\tau$

OPERA



ICARUS



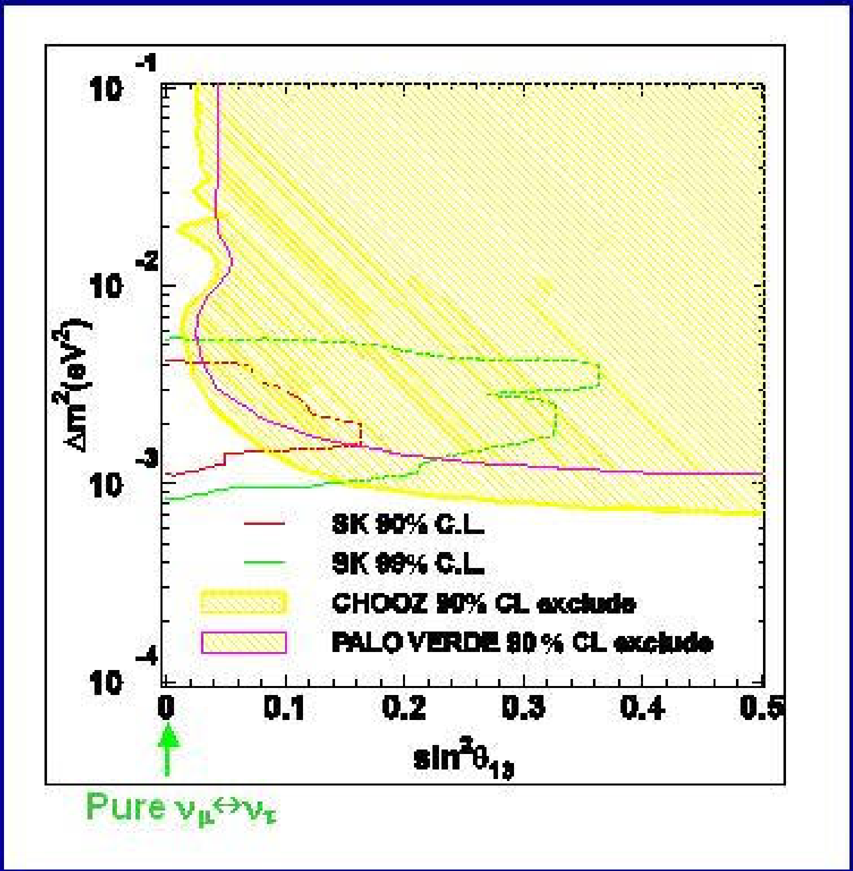
events in 5 years:

Δm^2 =	1.6	2.5	3.0	4.0	$\cdot 10^{-3} eV^2$
events:	5	12	17	30	

Neutrino oscillations and properties

1. Δm^2_{12}, θ_{12}	Solar, Reactor
2. Δm^2_{23}, θ_{23}	atmospheric, LBL
3. θ_{13}	Reactor, atmospheric, LBL, Superbeams, Megaton
CP violation δ	Superbeams, β beams, neutrino factory
4. m_ν	T, dark matter
5. Mass hierarchy	atmospheric, Reactor, VLBL, neutrino factory, $\beta\beta$
6. Dirac or Majorana	$\beta\beta$ experiments

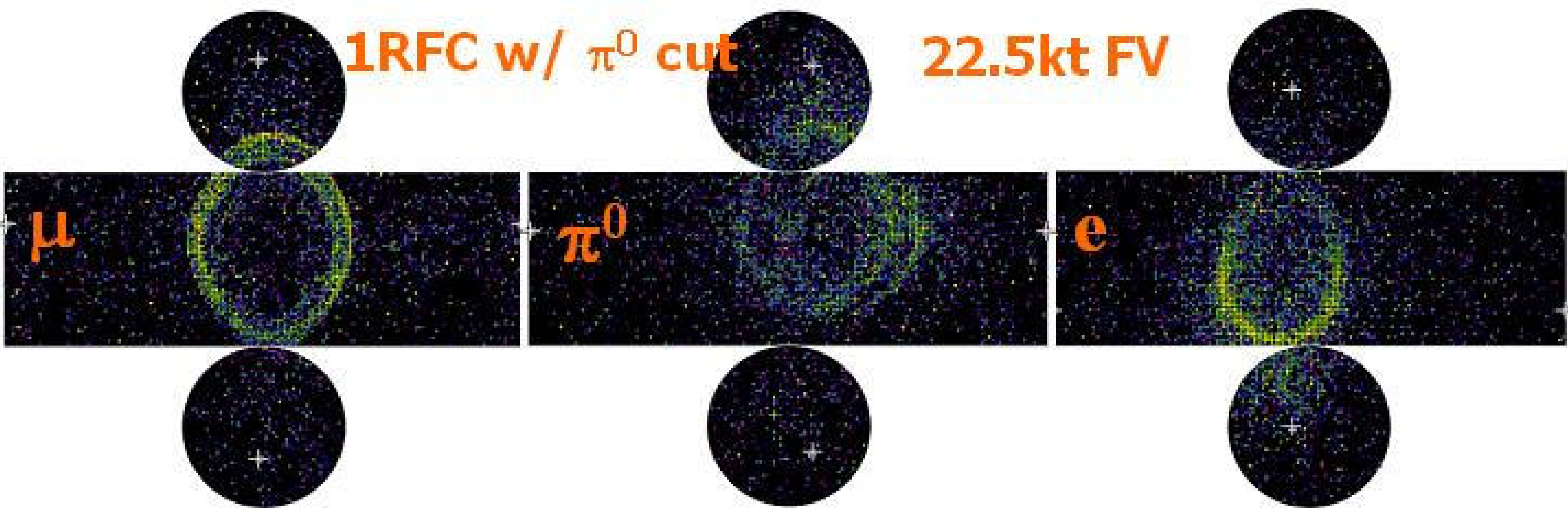
Allowed region for θ_{13}



SK getting close to CHOOZ's limit on θ_{13}

consistent with CHOOZ's excluded region

ν_e appearance in JHF-Kamioka (phase 1)



Backgrounds

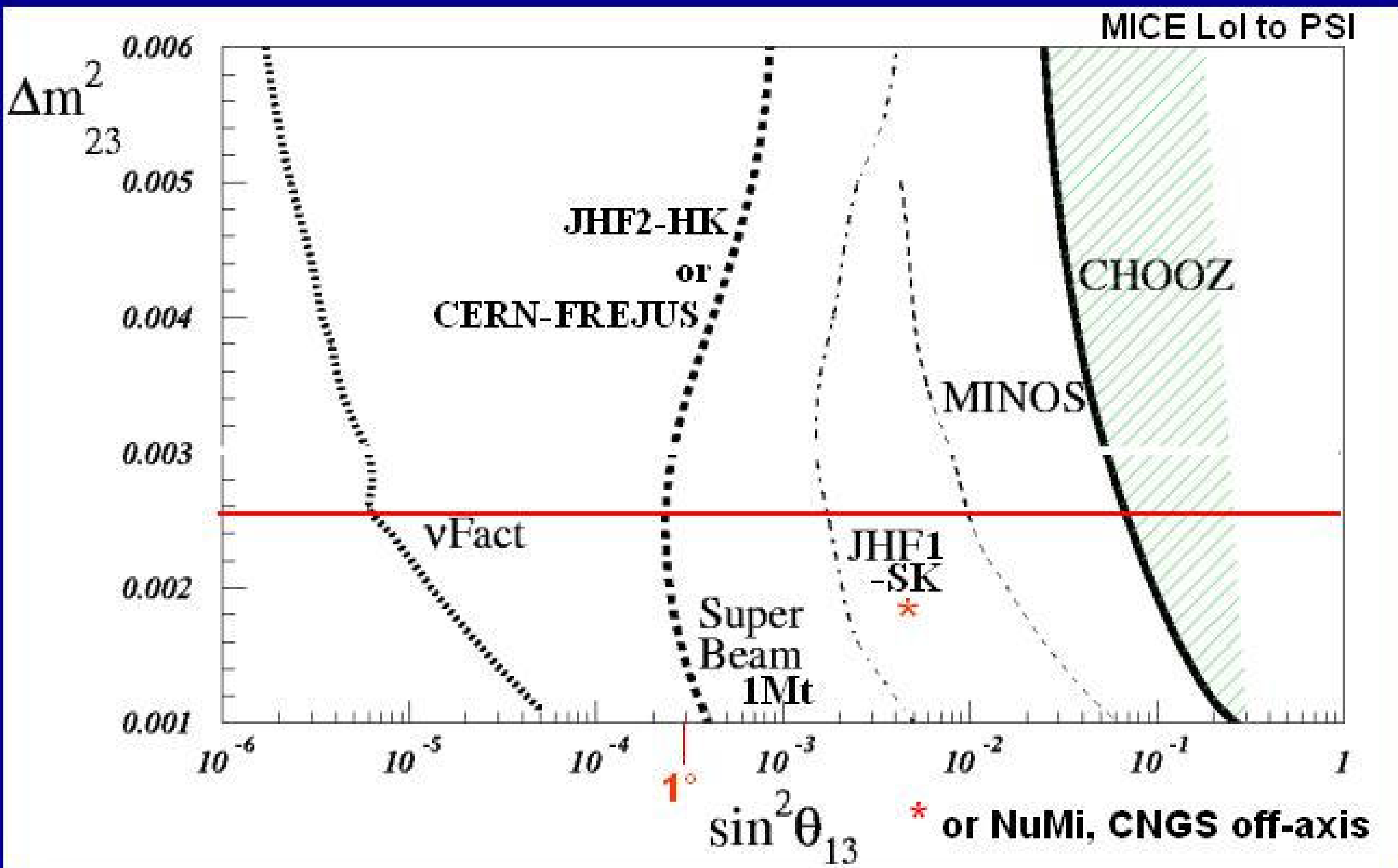
1.8 events	9.3(*) events	11.1 events

Signal

123.2 events @ $\sin^2 2\theta_{13}=0.1$, $\Delta m^2=3\times10^{-3}\text{eV}^2$

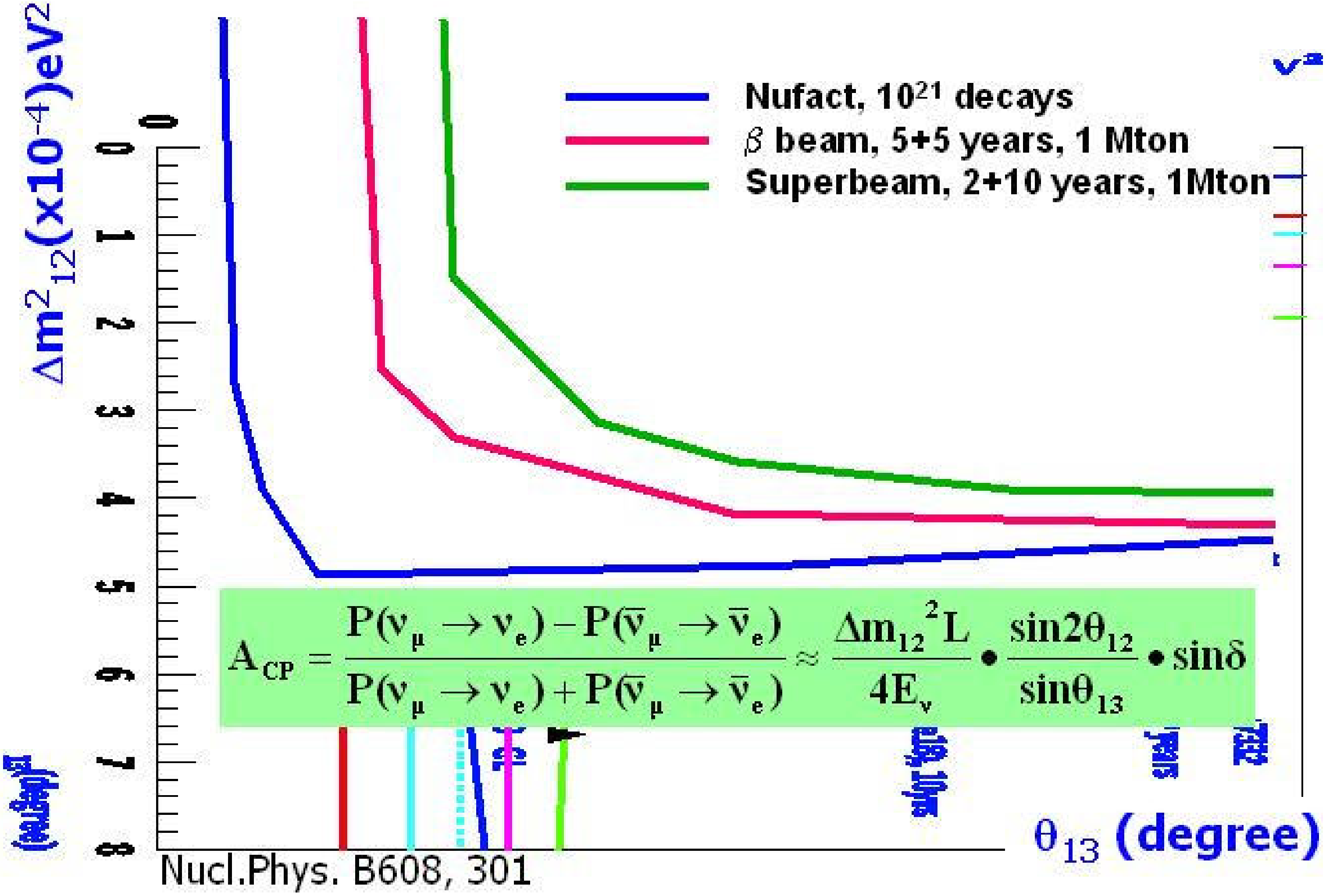
(5 years running)

(*) still can be further improved



year:	2020	2015	2009	2007
G€:	2	1.0	0.2	

sensitivity to maximal CP violation



$$A_{CP} = \frac{P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)} \approx \frac{\Delta m_{12}{}^2 L}{4E_\nu} \bullet \frac{\sin 2\theta_{12}}{\sin\theta_{13}} \bullet \sin\delta$$

Neutrino oscillations and properties

1. Δm^2_{12}, θ_{12}	Solar, Reactor
2. Δm^2_{23}, θ_{23}	atmospheric, LBL
3. θ_{13}	Reactor, atmospheric, LBL, Superbeams, Megaton
CP violation δ	Superbeams, β beams, neutrino factory
4. m_ν	T, dark matter
5. Mass hierarchy	atmospheric, Reactor, VLBL, neutrino factory, $\beta\beta$
6. Dirac or Majorana	$\beta\beta$ experiments

Direct neutrino mass measurement

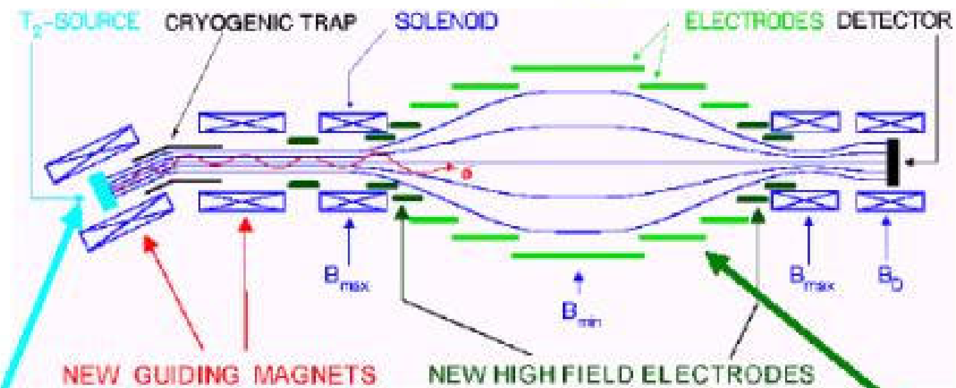
- Neutrinos of galactic supernovae
  - galactic SN only every 30 years
  - not sensitive below 1 eV (uncertainty in time spectrum)

- Tritium β decay
  - at Mainz
  - and Troitsk
  - KATRIN

- ^{187}Re β decay with bolometers

FUTURE sub-eV (KATRIN and ^{187}Re β decay with bolometers)

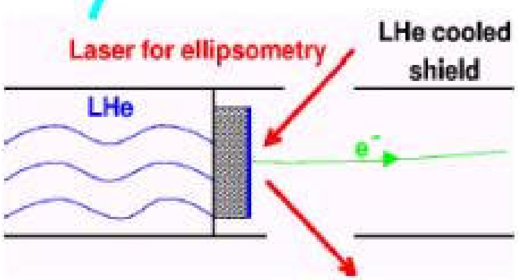
Mainz Neutrino Mass Experiment since 1997



Mainz
ν group
2001:

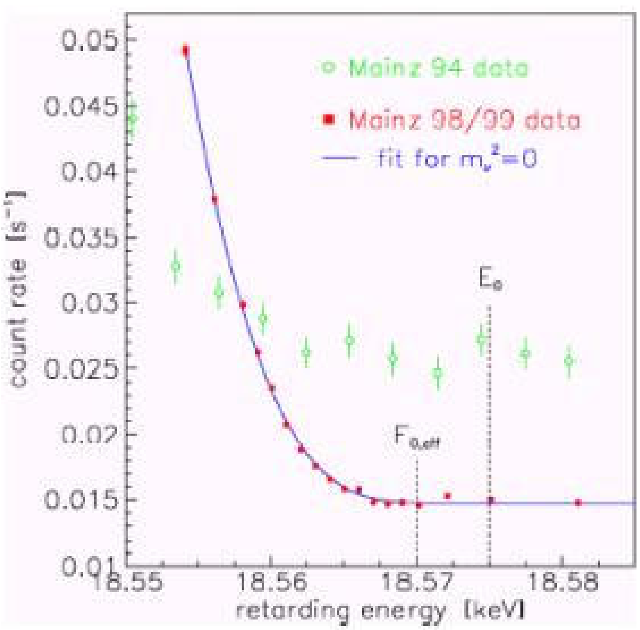
J. Bonn
B. Bornschein*
L. Bornschein
B. Flatt
Ch. Kraus
B. Müller
E.W. Otten
J.P.Schall
Th. Thümmler**
Ch. Weinheimer**

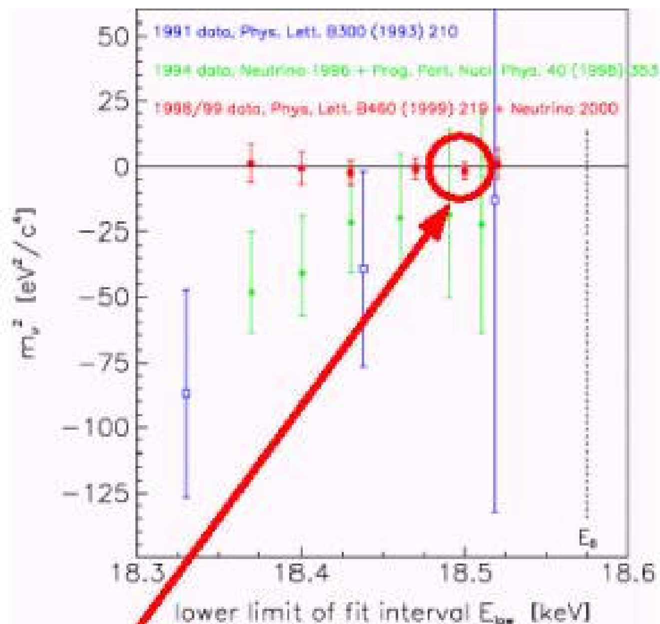
* → FZ Karlsruhe
** → Univ. Bonn



- T_2 Film at 1.86 K
- quench−condensed on graphite (HOPG)
- 45 nm thick (≈130ML), area 2cm²
- Thickness determination by ellipsometry

Mainz data of 1998,1999



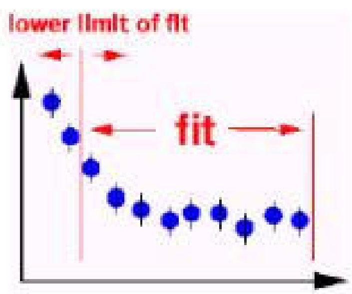


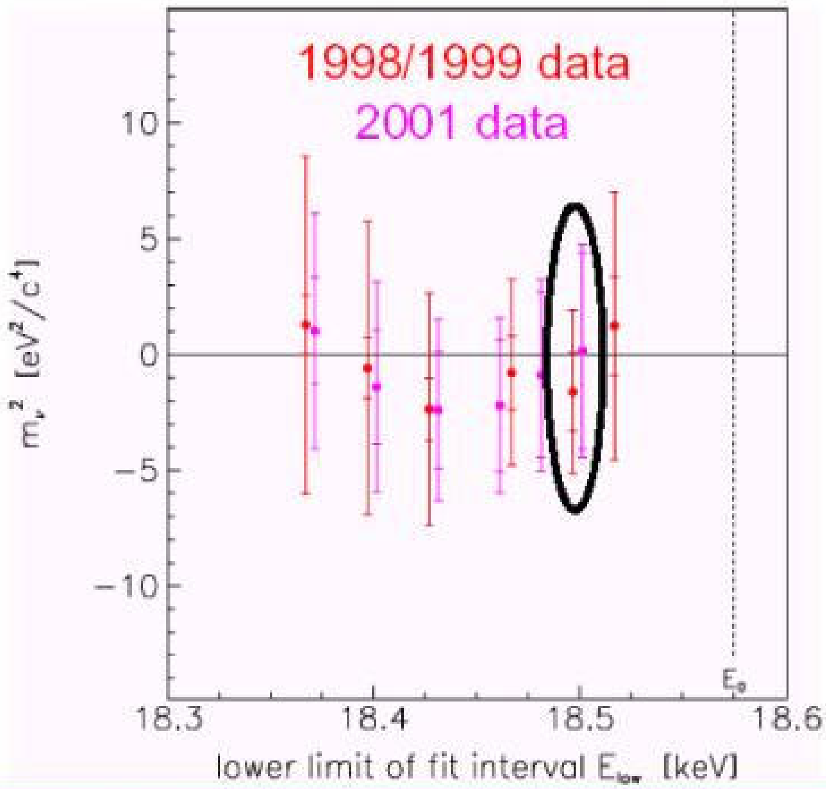
$m^2(\nu) = -1.6 \pm 2.5 \pm 2.1\ eV^2$ (χ^2/d.o.f. = 125/121)

$\Rightarrow$ $m(\nu) < 2.2$ eV (95% C.L.)

(J. Bonn et al., Nucl. Phys. B (Proc. Suppl.) 91 (2001) 273)

Results of 1998/1999, 2001 data





1998/1999: $m^2(\nu) = -1.6 \pm 2.5 \pm 2.1\ eV^2$ $\Rightarrow$ $m(\nu) < 2.2\ eV$ (95% C.L.)

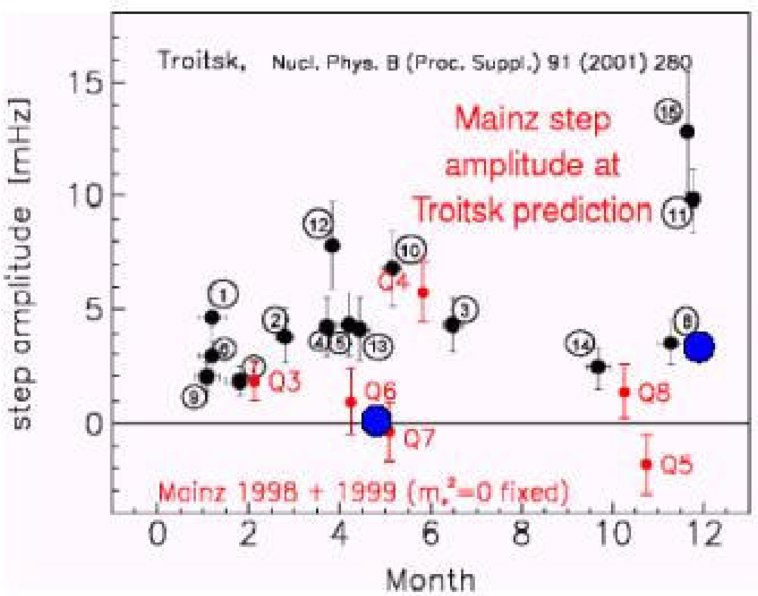
2001: $m^2(\nu) = +0.1 \pm 4.2 \pm 2.0\ eV^2$

1998/1999/2001: $m^2(\nu) = -1.2 \pm 2.2 \pm 2.1\ eV^2$ $\Rightarrow$ $m(\nu) < 2.2\ eV$ (95% C.L.)

$\Rightarrow$ **Mainz sensitivity limit reached**

Status of Troitsk anomaly

Amplitude of anomaly: Troitsk, Mainz



Troitsk 2001/2002:

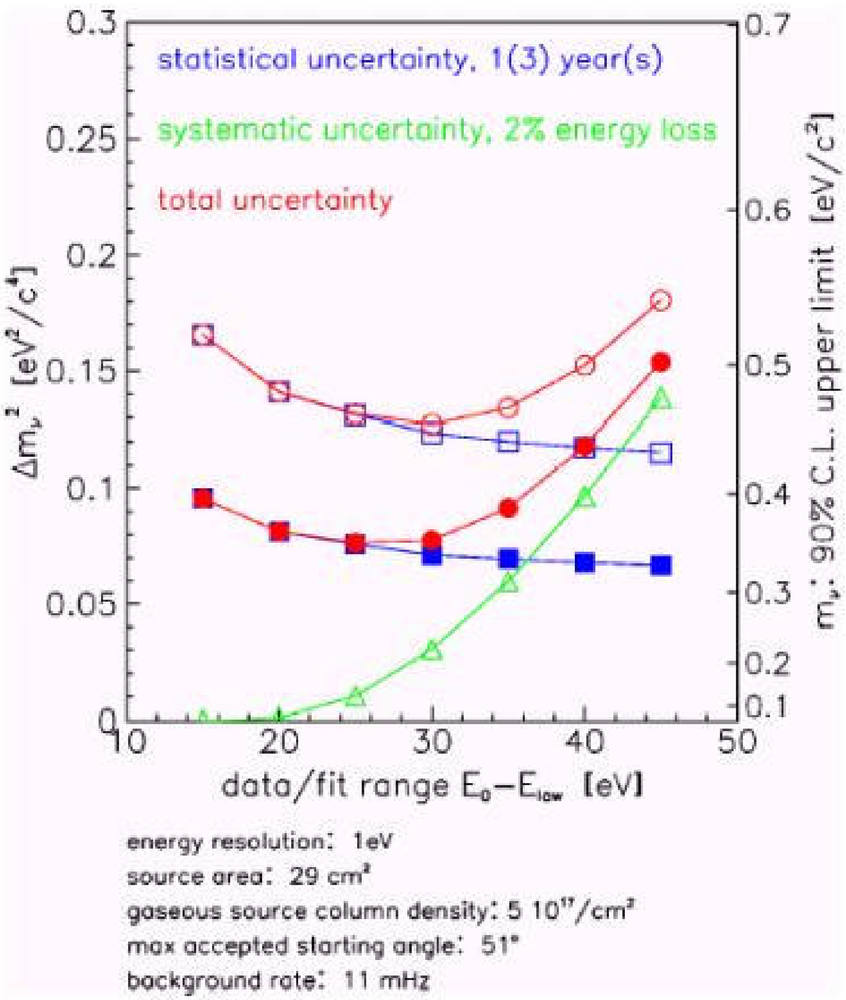
- **No anomaly in May 2001**
- **Only small anomaly in Dec. 2001**

Mainz:

- **Clear contradiction to 0.5 y period**
- Similiar effect observed only once (Q4 1998)
- **Does not show up in in newest Mainz data** of 2000 (Q9,Q10, partially in parallel with Troitsk) and of 2001 (Q11,Q12)

⇒Troitsk anomaly is very likely experimental artefact, which can be avoided (Mainz)

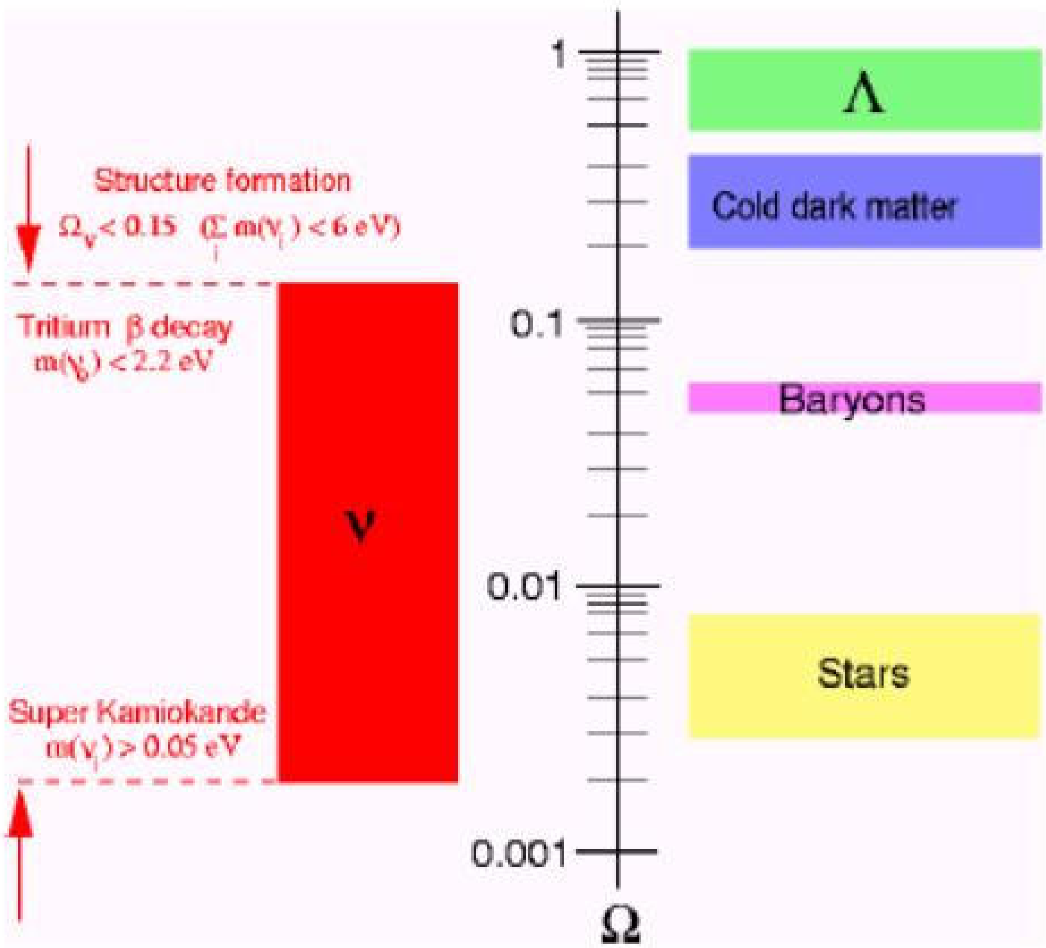
KATRIN Estimation of sensitivity



First simulations with conservative assumptions

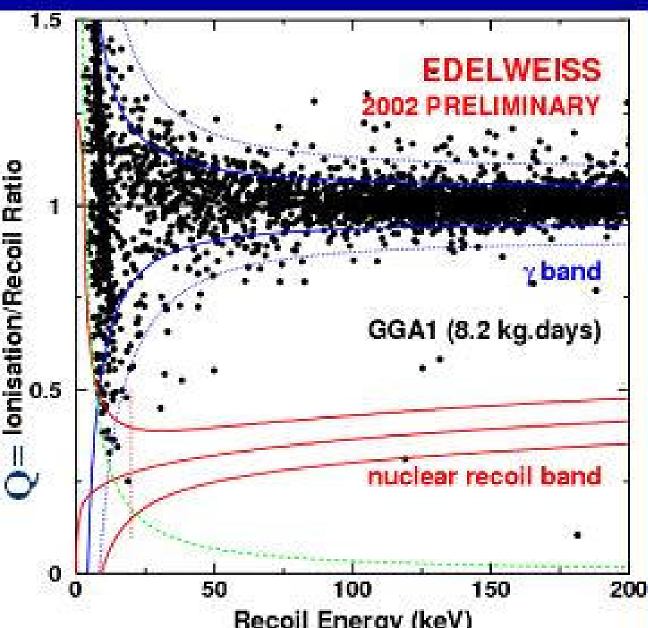
⇒ Sensitivity on $m(\nu_e)$ $\approx 0.35 eV/c^2$

Cosmology and neutrino mass

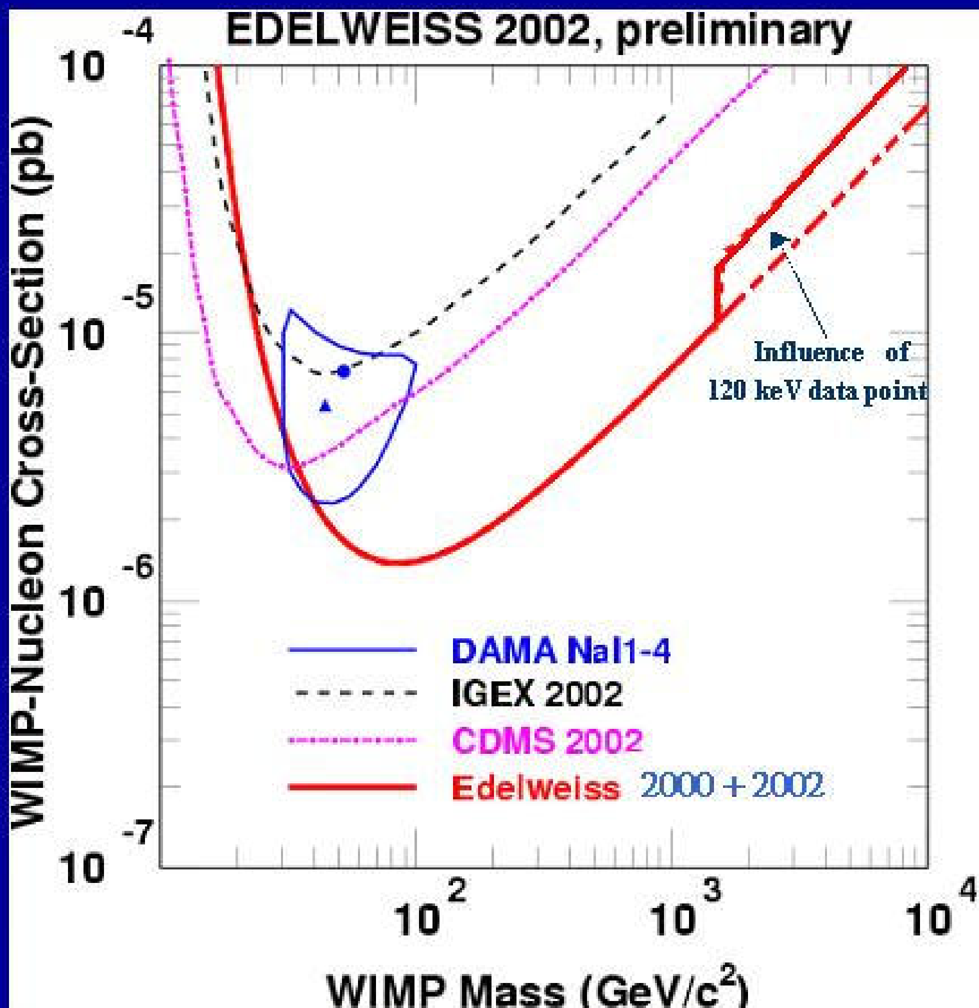


Highlight

EDELWEISS-I



no event in nuclear recoil band



Neutrino oscillations and properties

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2.	Δm^2_{23}, θ_{23}	atmospheric, LBL
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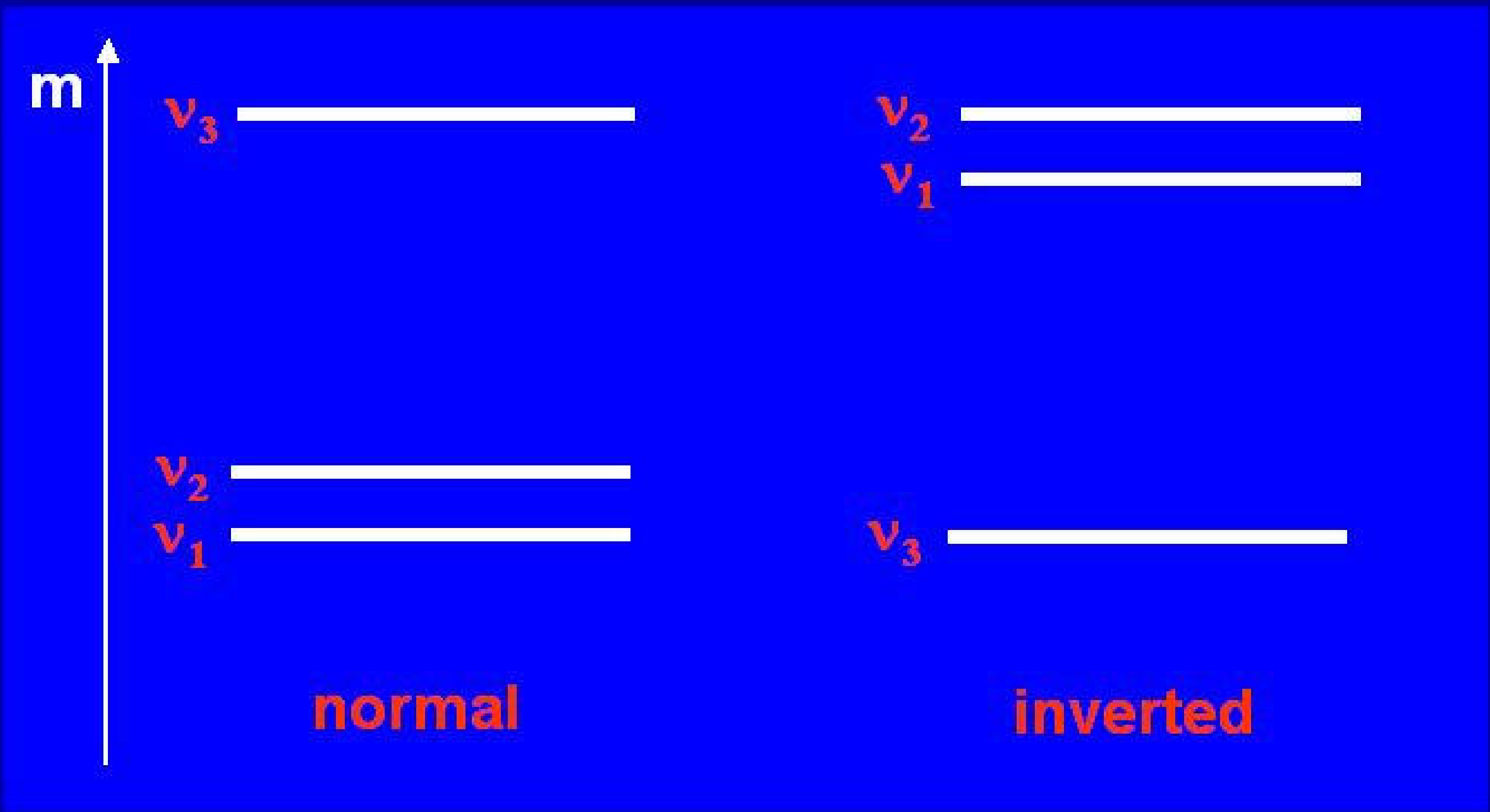
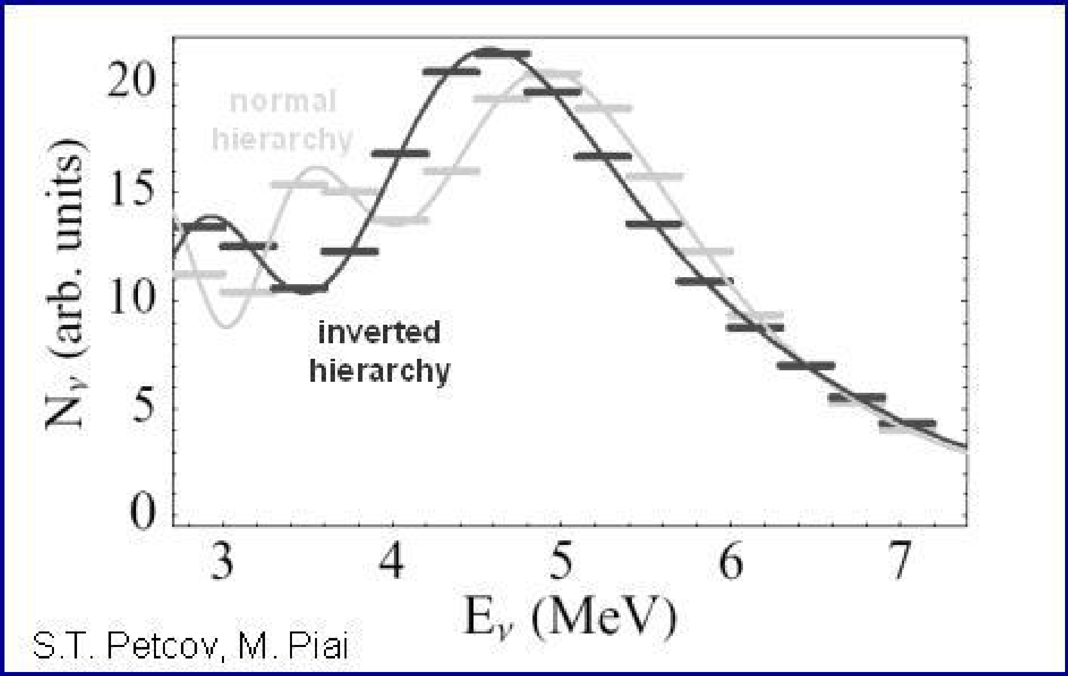
5.	Mass hierarchy	atmospheric, Reactor, VLBL, neutrino factory, $\beta\beta$
6.	Dirac or Majorana	$\beta\beta$ experiments

Mass hierarchy



Reactor $\overline{\nu_e}$ spectrum: sub-leading oscillations by Δm^2_{31} and $\sin^2 2\theta_{13}$



L=20 km

$\Delta m^2_{sol}=2\cdot 10^{-4}$ eV^2 (HLMA)

$\sin^2 2\theta_{sol}=0.8$

$\sin^2 2\theta_{13}=0.05$

$\Delta m^2_{31}=1.3\cdot 10^{-3}$ eV^2

In principle, an alternative to measure the sign of Δm^2_{31}.

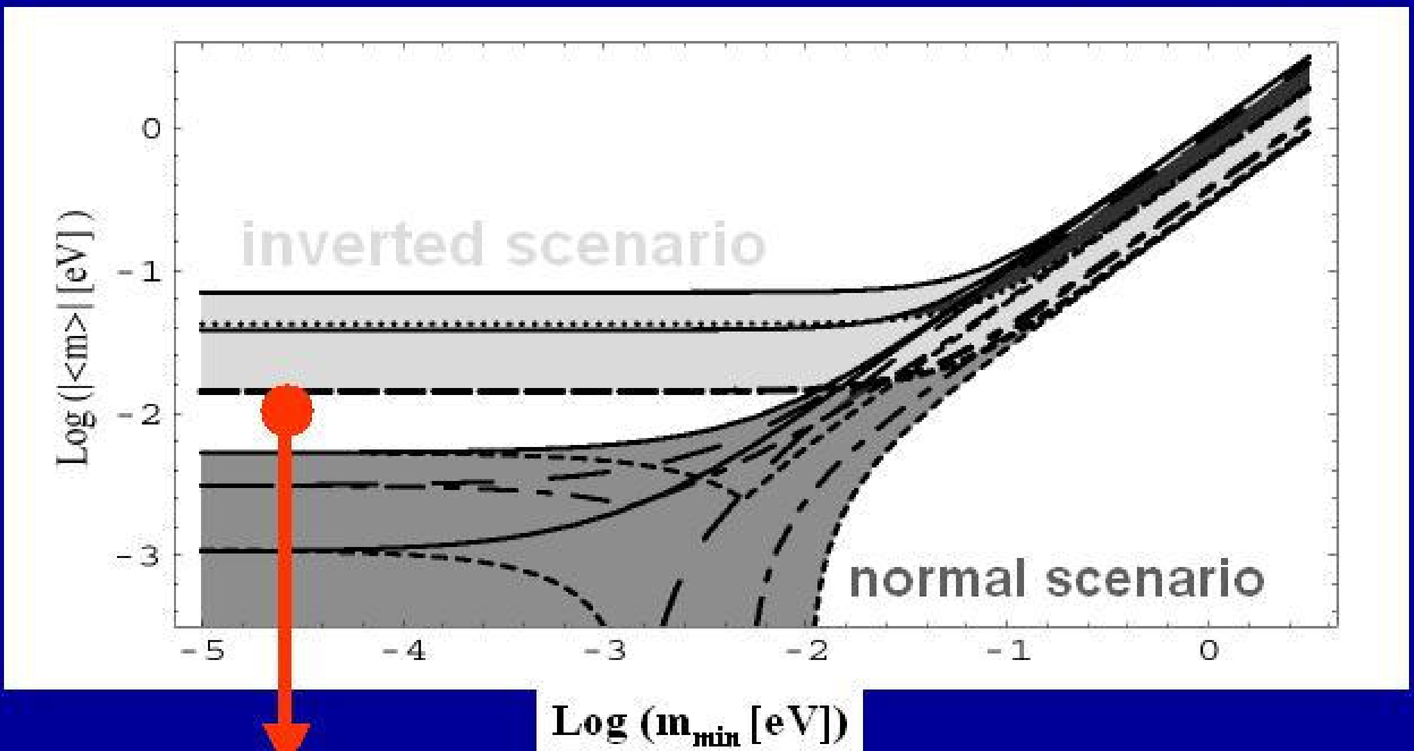
Very Long Baseline Experiments (before ν factory)

BNL LOI is proposed to send ν beam to Homestake at the distance of ~3000km to study matter effect and the sign of Δm^2_{32}.

This is a unique feature of this project, which is not considered in JHF-Kamioka and CERN-SPL-Frejus.

What to expect for $0\nu\beta\beta$ concerning hierarchy?

S. Pascoli, S.T. Petcov



(background-free) detector with 100kg

Neutrino oscillations and properties

1.	Δm^2_{12}, θ_{12}	Solar, Reactor
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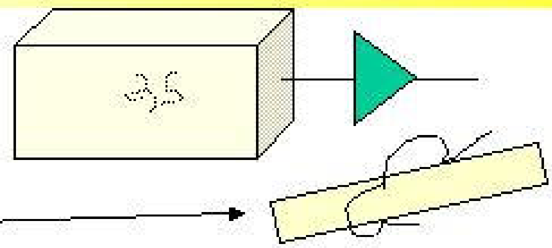
6.	Dirac or Majorana	$\beta\beta$ experiments

$0\nu2\beta$ Experimental Situation

2 main experimental approaches:

- Active Source
- Passive Source



Best $0\nu2\beta$ results involve active source experiments

Experiment	Isotope	$T_{1/2}^{0\nu}$ (y)	$<m_\nu>$ (eV)
You Ke et al. 1998	^{48}Ca	$> 9.5 \times 10^{21}$ (76%)	< 8.3
Klapdor-Kleingrothaus 2001	^{76}Ge	$> 1.9 \times 10^{25}$	< 0.35
Aalseth et al 2002		$> 1.57 \times 10^{25}$	< 0.33 - 1.35
Elliott et al. 1992	^{82}Se	$> 2.7 \times 10^{22}$ (68%)	< 5
Ejiri et al. 2001	^{100}Mo	$> 5.5 \times 10^{22}$	< 2.1
Danevich et al. 2000	^{116}Cd	$> 7 \times 10^{22}$	< 2.6
Bernatowicz et al. 1993	$^{130/128}Te$*	$(3.52 \pm 0.11) \times 10^{-4}$	< 1.1 – 1.5
Bernatowicz et al. 1993	^{128}Te*	$> 7.7 \times 10^{24}$	< 1.1 – 1.5
Mi DBD – ν 2002	^{130}Te	$> 2.1 \times 10^{23}$	< 0.85 – 2.1
Luescher et al. 1998	^{136}Xe	$> 4.4 \times 10^{23}$	< 1.8 – 5.2
Belli et al. 2001	^{136}Xe	$> 7 \times 10^{23}$	< 1.4 – 4.1
De Silva et al. 1997	^{150}Nd	$> 1.2 \times 10^{21}$	< 3
Danevich et al. 2001	^{160}Gd	$> 1.3 \times 10^{21}$	< 26

Heidelberg-Moscow

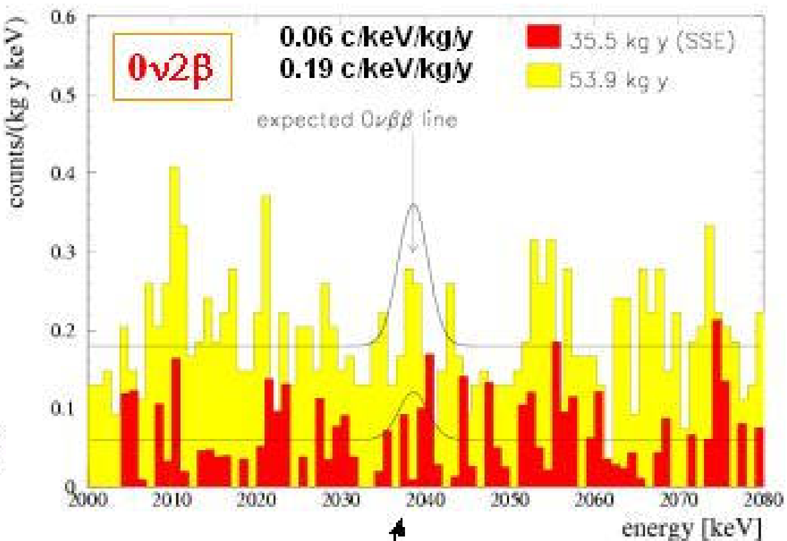
Klapdor-Kleingrothaus HV et al. Eur. Phys. J. 12 (2001) 147

Max-Planck-Institut für Kernphysik
Russian Science Center Kurchatov Institute

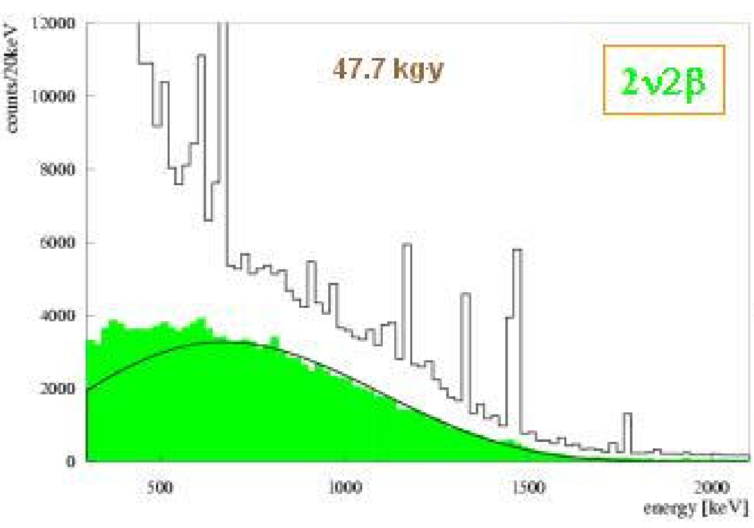
1990-2000

Gran Sasso underground laboratory

- Five Ge diodes (overall mass 10.9 kg) isotopically enriched (86%) in ^{76}Ge
- Lead box and nitrogen flushing of the detectors
- Digital Pulse Shape Analysis (factor 5 reduction)



$T_{1/2}^{0\nu} > 1.9 \times 10^{25}$ (90 % C.L.)
$\langle m_\nu \rangle < 0.35$ (0.3-1.24) eV

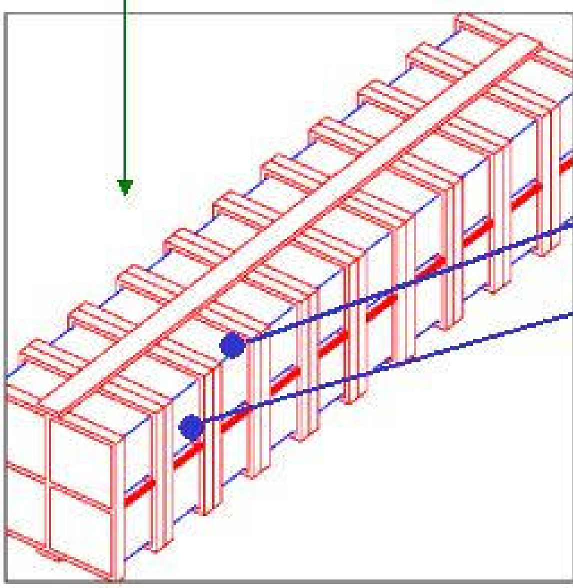


Accurate background model:
$T_{1/2}^{2\nu} > (1.55 \pm 0.01(\text{stat})\ ^{+0.19}_{-0.15}\ (\text{syst})) \times 10^{21}$

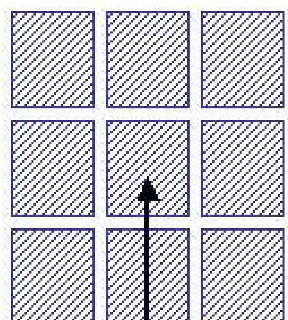
The CUORICINO set-up

CUORICINO = tower of 14 modules, 4 detector (760 g) each
M = 42 kg

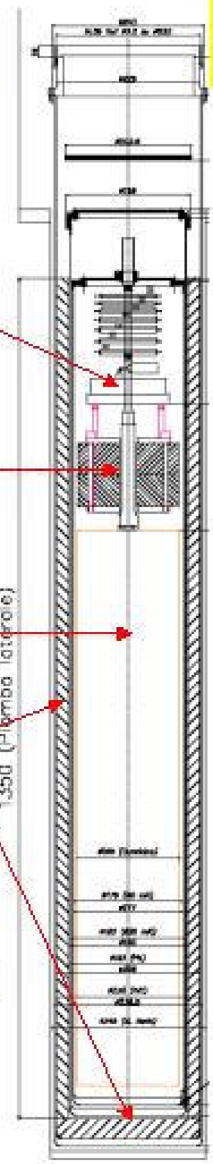
New configuration: 2 planes will consist of 340 g detectors arranged in a 3×3 matrix



Plane section



This detector will be completely surrounded by active materials. Substantial improvement in BKG reduction



Coldest point

Cold finger

Tower

Lead shield

Same cryostat and similar structure as Mi DBD

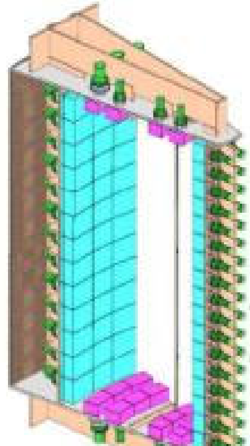
0205006

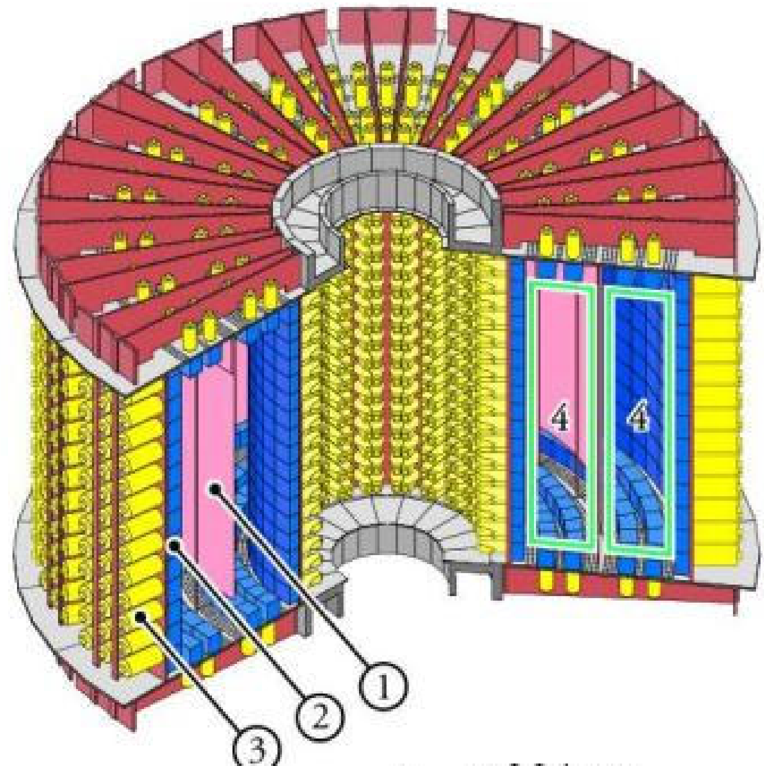
Neutrinoless Experiment with MOlibdenum III or Neutrino Ettore Majorana Observatory

Large Collaboration: 13 groups from Europe, USA and Japan

Passive source - Spectroscopic approach

$0\nu2\beta$ sensitivity:
T ~ 10^{24} y
<mν> ~ 0.1 eV





Detector structure: 20 sectors

1 Source:
up to 10 kg of $\beta\beta$ isotopes
(metal film or powder glued to mylar strips)
cylindrical surface: 20 m^2 x 40-60 mg/cm^2

2 Tracking volume:
open octagonal drift cells (6180)
operated in Geiger mode
(σ_r=0.5 mm, σ_Z=1 cm)

3 Calorimeter:
1940 plastic scintillators coupled to low activity PMs:
FWHM(1 MeV) ~ 11-14.5 %

m_{tot} ~ 36 tons
Low activity materials

Magnetic Field (30 G) + Iron Shield (20 cm) + Neutron Shield (30 cm H_2O)

NEMO 3

D.Lalanne&CS.Sutton contr. pap. ν 2002

Now Operating in the Frejus Underground Laboratory: 4800 m.w.e.

Identification of e^-, e^+, γ, n and delayed-α

- *ββ* events
- source radiopurity → after enrichment and chemical processing
- BKG rejection

by e-γ, e-γ-α coincidences analysis

Enriched sources placed in NEMO3

Isotope	Mass (g)	I.A.	Intended studies	$<m^{5y}_{\nu}>$ (eV)
^{100}Mo	6914	97%	ββ(0ν)	0.2-0.7
^{82}Se	932	97%	ββ(0ν)	0.6-1.2
^{116}Cd	405	93%	ββ(2ν)	
^{130}Te	454	89%	ββ(2ν)	
^{150}Nd	36.6	91%	ββ(2ν)	
^{96}Zr	9.4	57%	ββ(2ν)	
^{48}Ca	7.0	73%	ββ(2ν)	
^{nat}Te	207		Ext. γ bkg	
Cu	621		Ext. γ bkg	

March 2002: start without shielding
Summer 2002: start with full shielding

Future projects

Experiment	Author	Isotope	Detector description	$T^{5y}_{1/2}(y)$	$<m_\nu>^*$
COBRA	Zuber 2001	^{130}Te	10 kg CdTe semiconductors	1×10^{24}	0.71
DCBA	Ishihara et al 2000	^{150}Nd	20 kg enriched Nd layers with tracking	2×10^{25}	0.035
NEMO3	Sarazin et al 2000	^{100}Mo	10 kg of bb(0n) isotopes (7 kg Mo) with tracking	4×10^{24}	0.56
CUORICINO	Arnaboldi et al 2001	^{130}Te	40 kg of TeO_2 bolometers	5×10^{24}	0.32
CUORE	Arnaboldi et al. 2001	^{130}Te	760 kg of TeO_2 bolometers	5×10^{26}	0.032
EXO	Danevich et al 2000	^{136}Xe	1 t enriched Xe TPC	8×10^{26}	0.052
GEM	Zdesenko et al 2001	^{76}Ge	1 t enriched Ge diodes in liquid nitrogen + water shield	7×10^{27}	0.018
GENIUS	Klapdor-Kleingrothaus et al 2001	^{76}Ge	1 t enriched Ge diodes in liquid nitrogen	1×10^{28}	0.015
MAJORANA	Aalseth et al 2002	^{76}Ge	0.5 t enriched Ge segmented diodes	3×10^{27}	0.028
CAMEO	Bellini et al 2001	^{116}Cd	1 t $CdWO_4$ crystals in liquid scintillator	$> 10^{26}$	0.069
CANDLES	Kishimoto et al	^{48}Ca	several tons of CaF_2 crystal in liquid scintillator	1×10^{26}	
GSO	Danevich 2001	^{160}Gd	2 t Gd_2SiO_5:Ce cristal scintillator in liquid scintillator	2×10^{26}	0.065
MOON	Ejiri et al 2000	^{100}Mo	34 t natural Mo sheets between plastic scintillator	1×10^{27}	0.036
Xe	Caccianiga et al 2001	^{136}Xe	1.56 t of enriched Xe in liquid scintillator	5×10^{26}	0.066
XMASS	Moriyama et al 2001	^{136}Xe	10 t of liquid Xe	3×10^{26}	0.086

* Staudt, Muto, Klapdor-Kleingrothaus Europh. Lett 13 (1990) 31

Exploring the neutrino sector

New Chapter of Alice in Wonderland