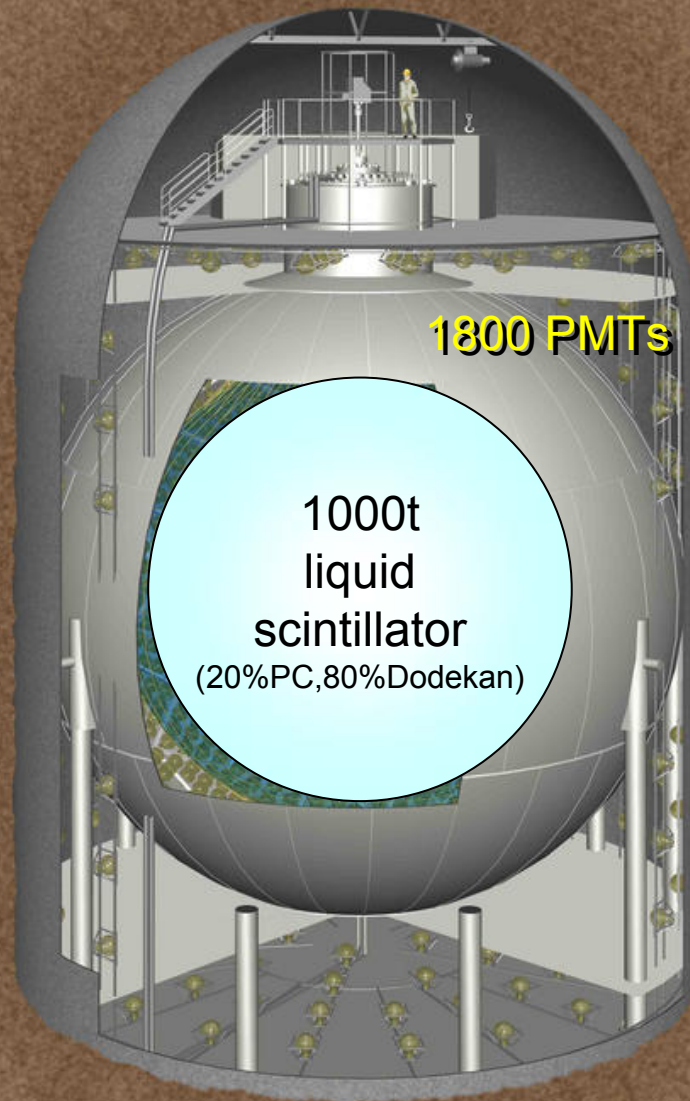


KAMLAND



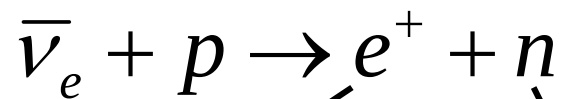
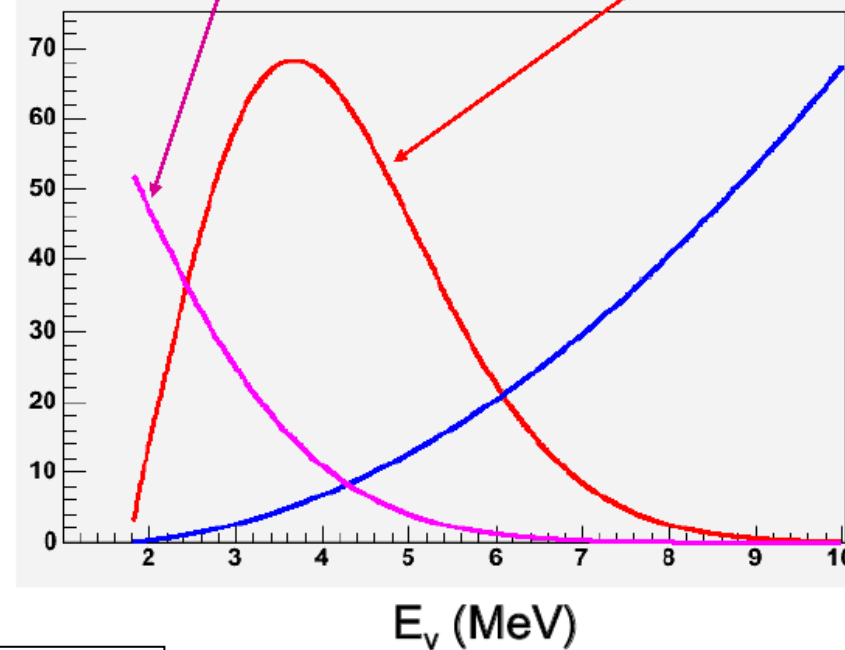
Kamioka Liquid Scintillator Anti-Neutrino Detector

How to detect reactor neutrinos

Reactor $\bar{\nu}_e$ spectrum (a.u.)

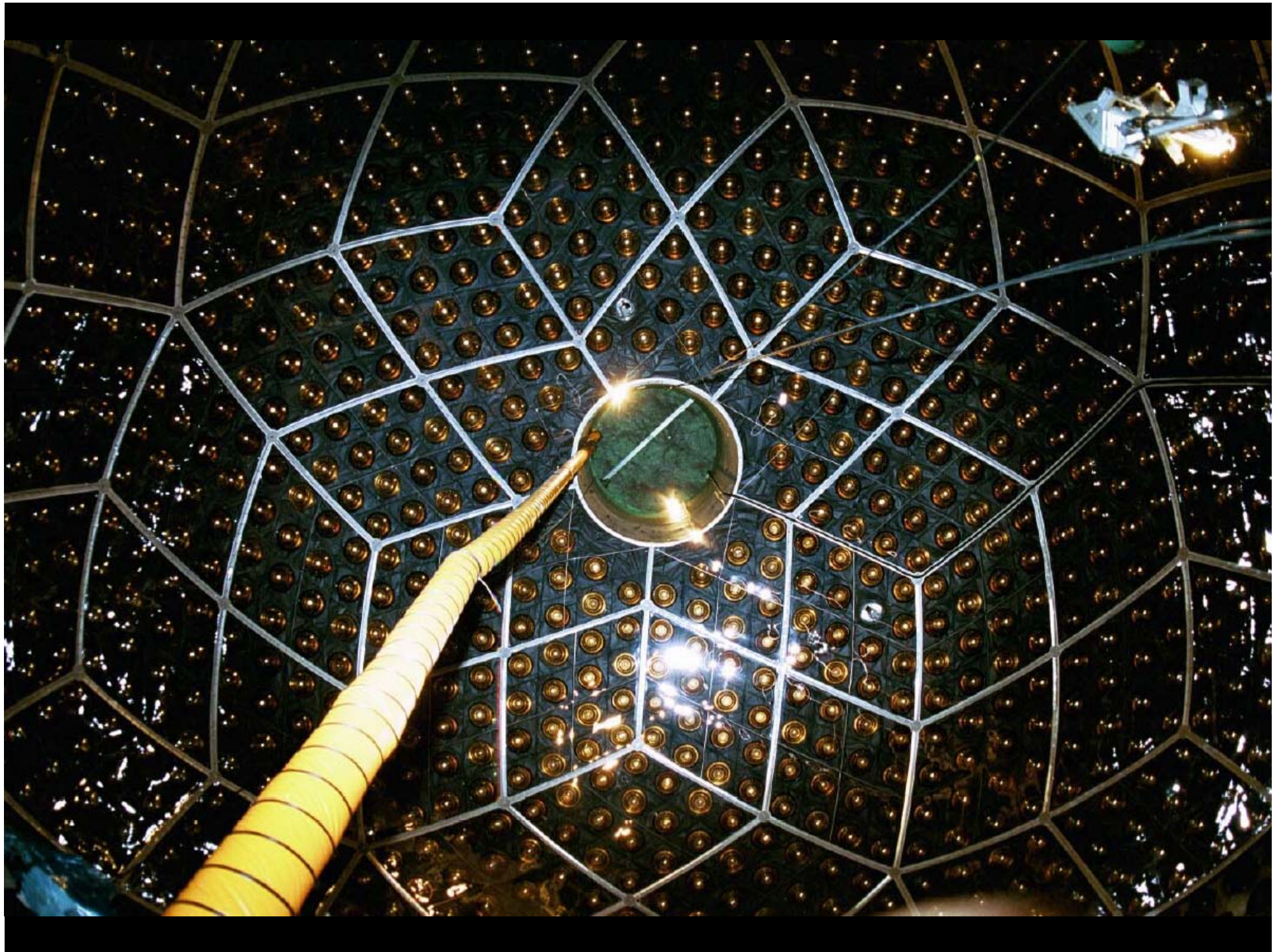
Observed spectrum (a.u.)

$\bar{\nu}_e + p \rightarrow n + e^+$ cross
section (10^{-43} cm^2)



prompt signal
 $E_\nu - 0.8 \text{ MeV}$

delayed signal
 $n + p \rightarrow d + \gamma(2.2 \text{ MeV})$

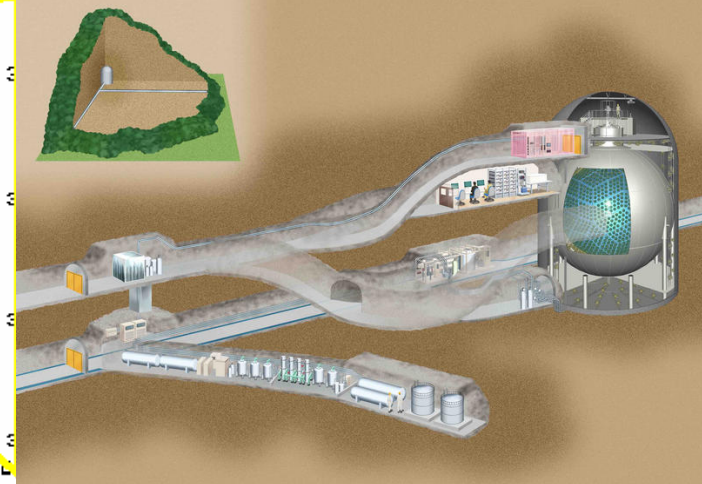


Reactor distances & event rates

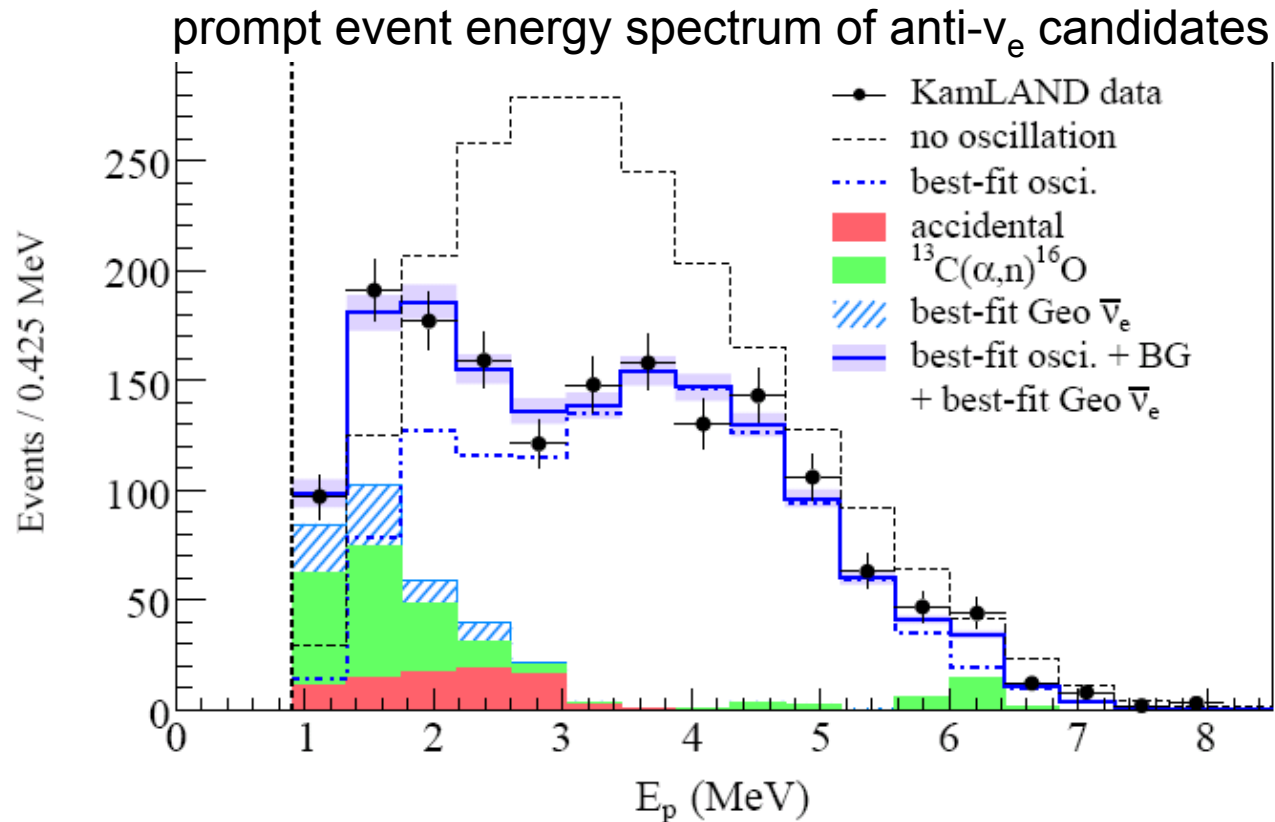
Average distance of reactors from Kamland: 180km



Site	Dist (km)	Rate noosc* (yr ⁻¹ kt ⁻¹)
Kashiwazaki	160	254.0
Ohi	179	114.3
Takahama	191	74.3
Tsuruga	138	62.5
Hamaoka	214	62.0
Mihama	146	62.0
Sika	88	55.2
Fukushima1	349	31.1
Fukushima2	345	29.5
Tokai2	295	10.1
Onagawa	431	9.3
Simane	401	6.3
Ikata	561	5.1
Genkai	755	4.8
Sendai	830	2.1
Tomari	783	1.4



KamLAND result (2008)



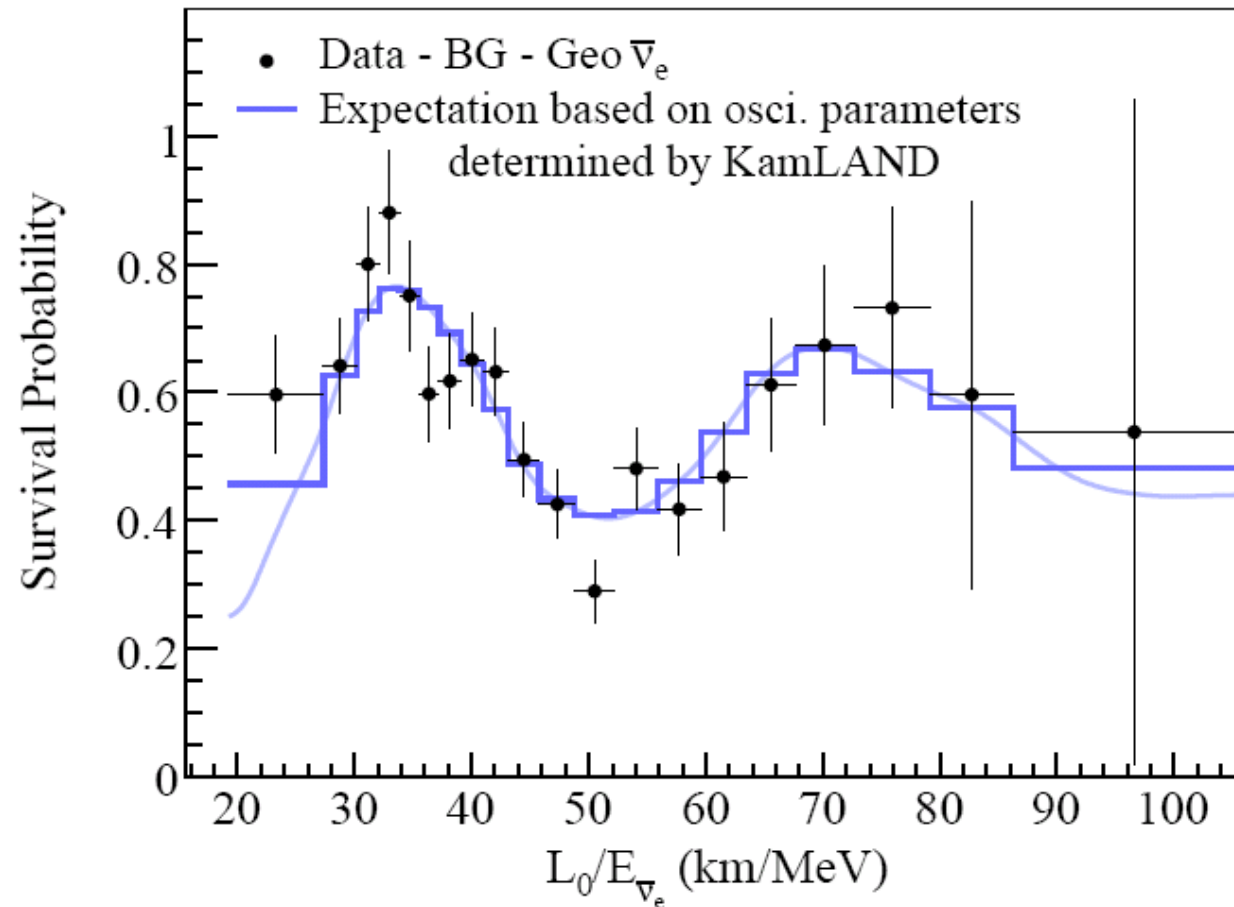
best fit: $\Delta m_{21}^2 = 7.58_{-0.13}^{+0.14}(\text{stat})_{-0.15}^{+0.15}(\text{syst}) \times 10^{-5} \text{ eV}^2$

$\tan^2 \theta_{12} = 0.56_{-0.07}^{+0.10}(\text{stat})_{-0.06}^{+0.10}(\text{syst})$

„Precision Measurement of Neutrino Oscillation Parameters with KamLAND“, Phys.Rev.Lett.100:221803,2008

KamLAND result (2008)

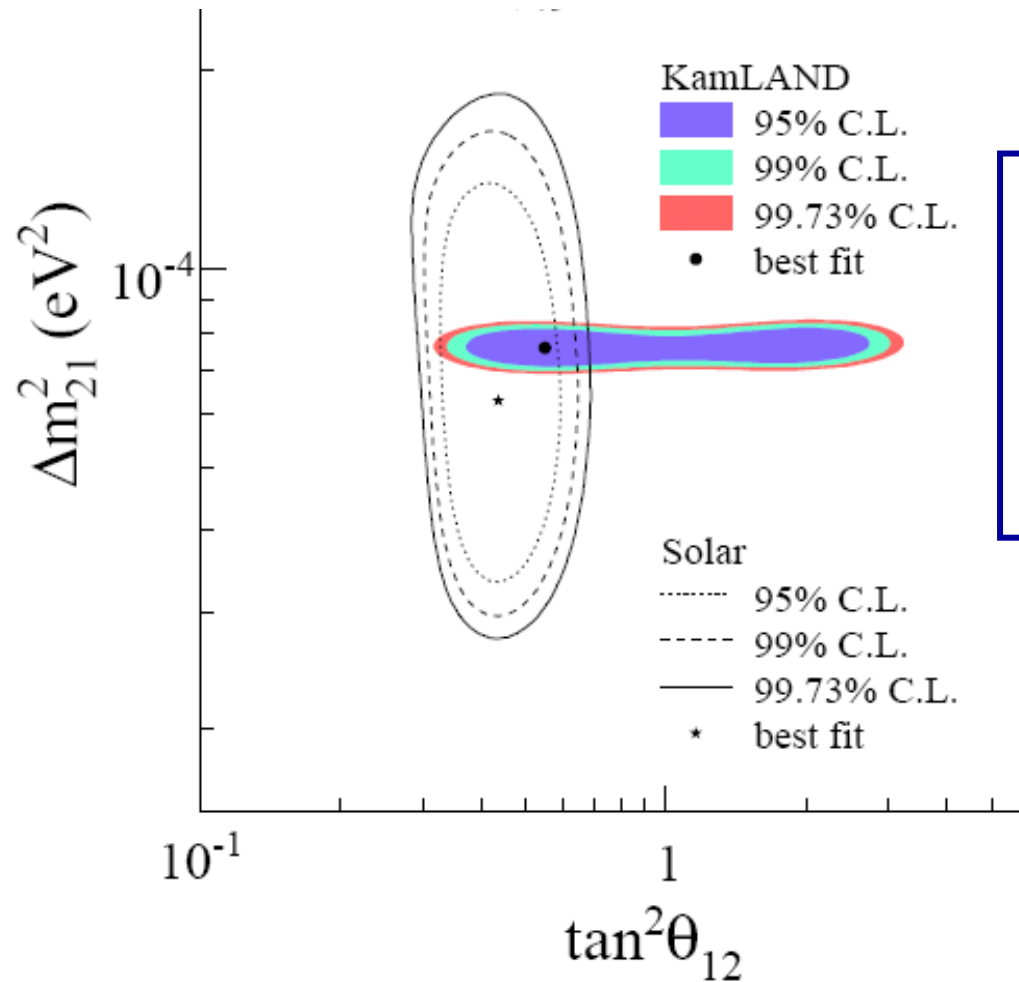
„Precision Measurement of Neutrino Oscillation Parameters with KamLAND“, Phys.Rev.Lett.100:221803,2008



L_0 is the „effective“ baseline = flux-weighted average of distance = 180km

KamLAND result (2008)

„Precision Measurement of Neutrino Oscillation Parameters with KamLAND“, Phys.Rev.Lett.100:221803,2008



KamLAND + solar:

$$\Delta m_{21}^2 = 7.59^{+0.21}_{-0.21} \times 10^{-5} \text{ eV}^2$$

$$\tan^2 \theta_{12} = 0.47^{+0.06}_{-0.05}$$

Neutrino Oscillations: the unknown sector

Lecture 1

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

?

Methods to measure θ_{13} , CPV:

neutrino super beams: appearance of ν_e in ν_μ beam

$$\begin{aligned}
 P(\nu_\mu \rightarrow \nu_e) \approx & \sin^2 \theta_{23} \frac{\sin^2 2\theta_{13}}{(\hat{A} - 1)^2} \sin^2((\hat{A} - 1)\Delta) \\
 & + \alpha \frac{\sin \delta_{CP} \cos \theta_{13} \sin 2\theta_{12} \sin 2\theta_{13} \sin 2\theta_{23}}{\hat{A}(1 - \hat{A})} \sin(\Delta) \sin(\hat{A}\Delta) \sin((1 - \hat{A})\Delta) \\
 & + \alpha \frac{\cos \delta_{CP} \cos \theta_{13} \sin 2\theta_{12} \sin 2\theta_{13} \sin 2\theta_{23}}{\hat{A}(1 - \hat{A})} \cos(\Delta) \sin(\hat{A}\Delta) \sin((1 - \hat{A})\Delta) \\
 & + \alpha^2 \frac{\cos^2 \theta_{23} \sin^2 2\theta_{12}}{\hat{A}^2} \sin^2(\hat{A}\Delta)
 \end{aligned}$$

nuclear reactors: disappearance of anti- ν_e

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - \sin^2 2\theta_{13} \sin^2 \Delta - \alpha^2 \Delta^2 \cos^4 \theta_{13} \sin^2 2\theta_{12}$$

$$\alpha = \Delta m_{21}^2 / \Delta m_{31}^2 \ll 1$$

$$\Delta = \Delta m_{31}^2 L / 4E$$

matter dependent quantities :

$$\hat{A} = 2VE / \Delta m_{31}^2$$

$$V = \sqrt{2}G_F n_e, \text{ with electron density } n_e \text{ (assumed constant)}$$

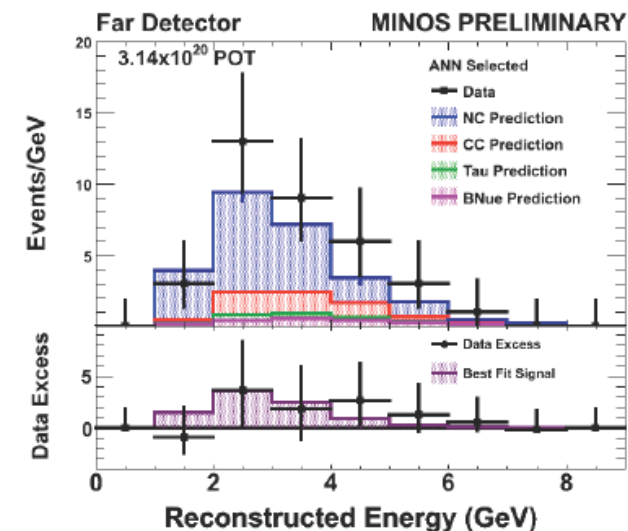
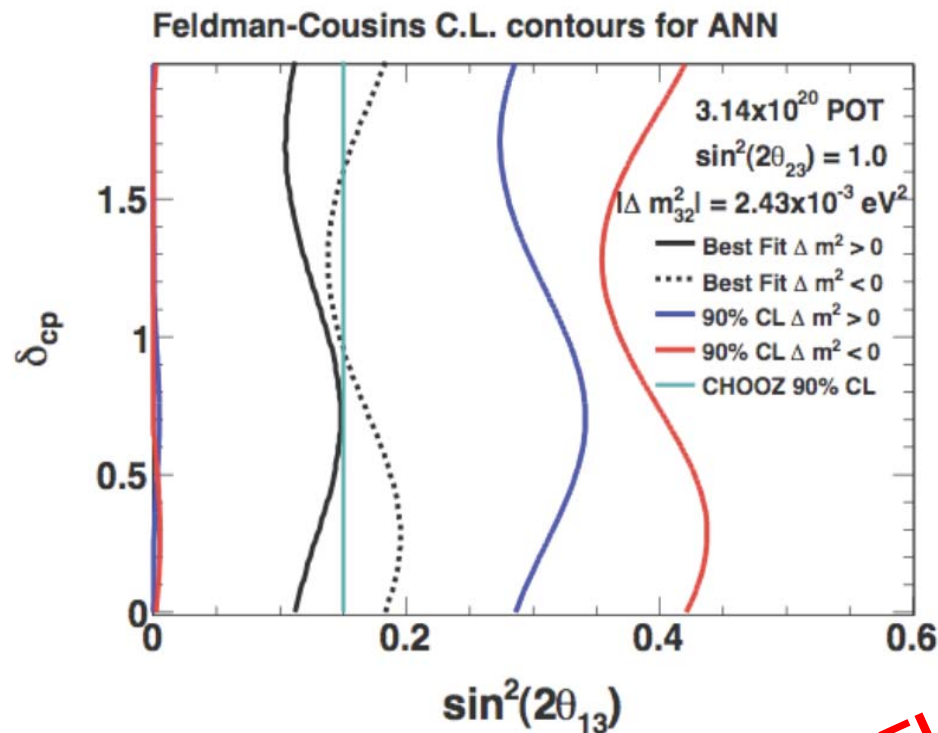
synergies



NEW! MINOS: ν_e appearance

35 events found in signal region, expected background: $27 \pm 5(\text{stat}) \pm 2(\text{sys})$

$\sin^2 2\theta_{13} < 0.29$ (90% CL) for $\delta_{\text{CP}} = 0$ and normal hierarchy



PRELIMINARY

From „Recent Results from the MINOS experiment“, M. Diwan @ Neutrino Telescopes Venice March 2009, arXiv:0904.3706

Global analysis: Hints of $\theta_{13} > 0$ (II)

„SNO, KamLAND and neutrino oscillations: θ_{13} “, Fogli, Lisi, Marrone, Palazzo, Rotunno, arXiv:0905.3549

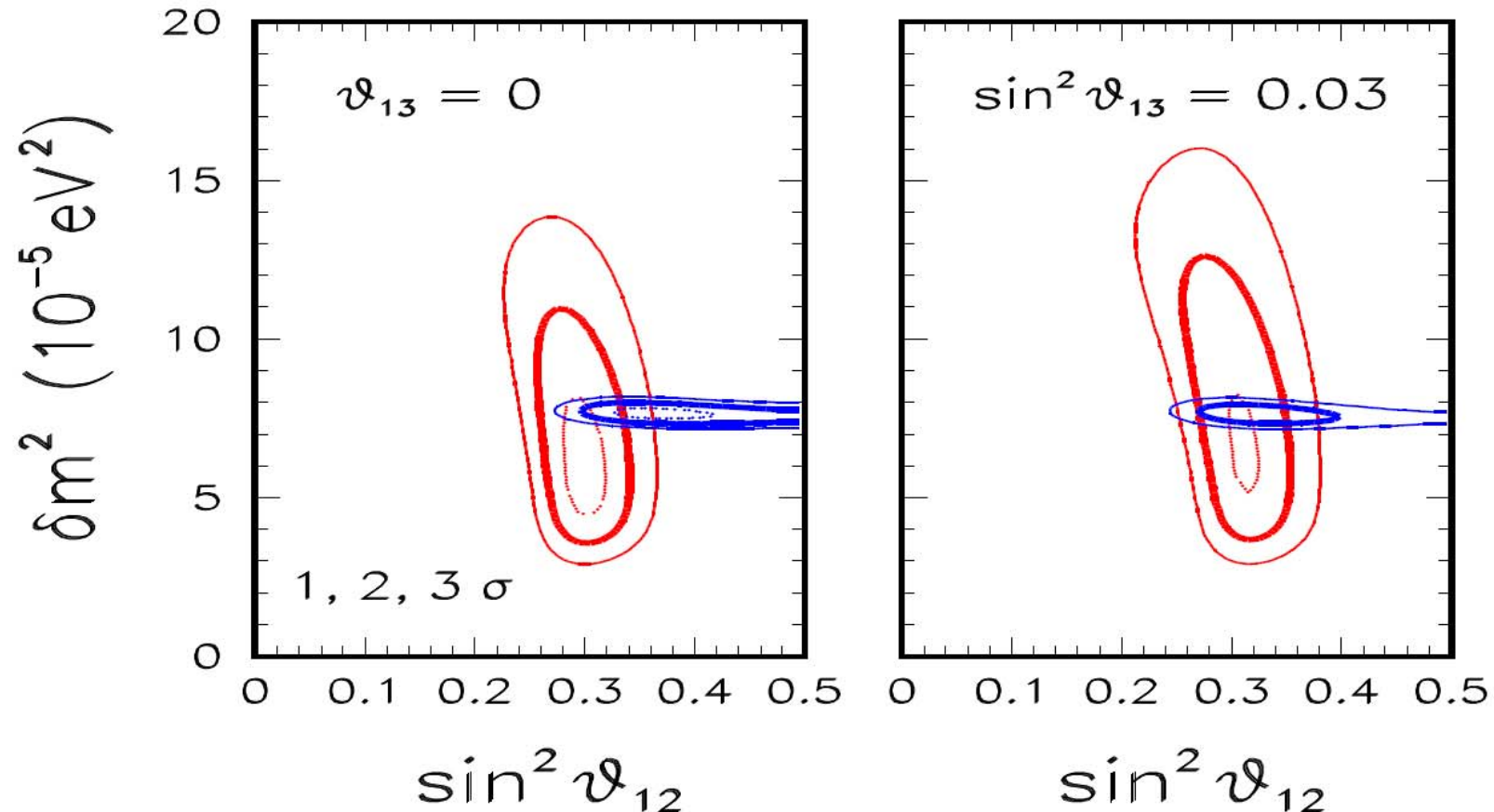
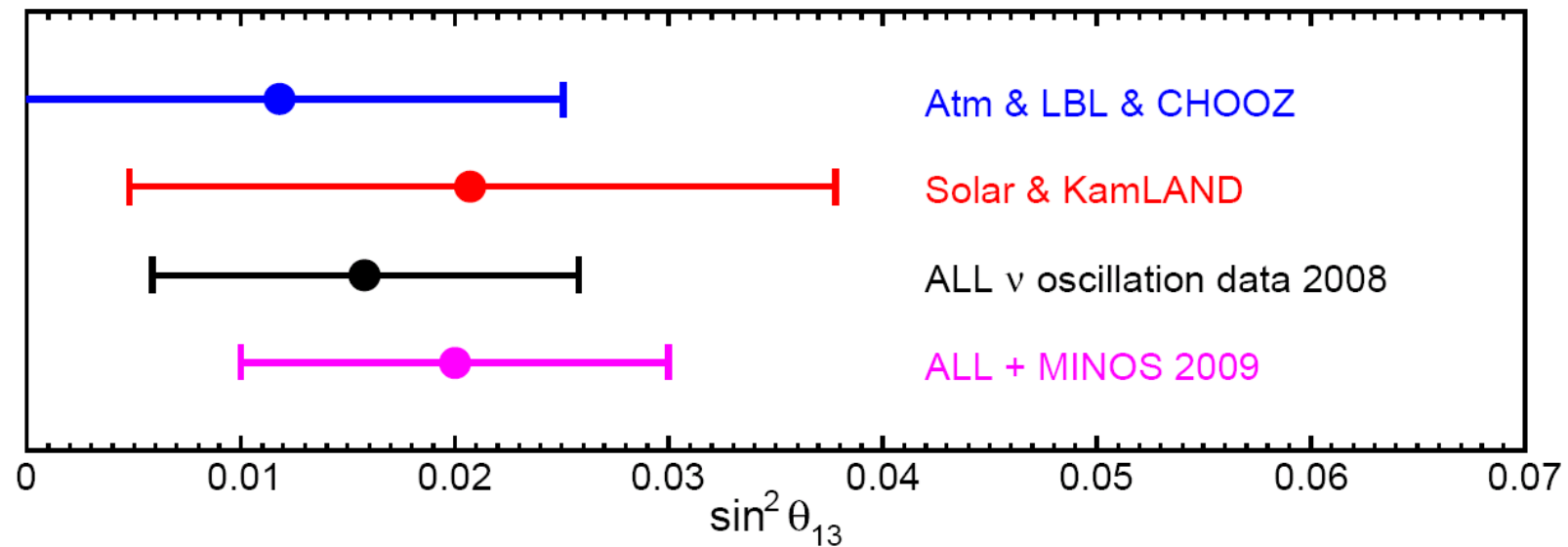


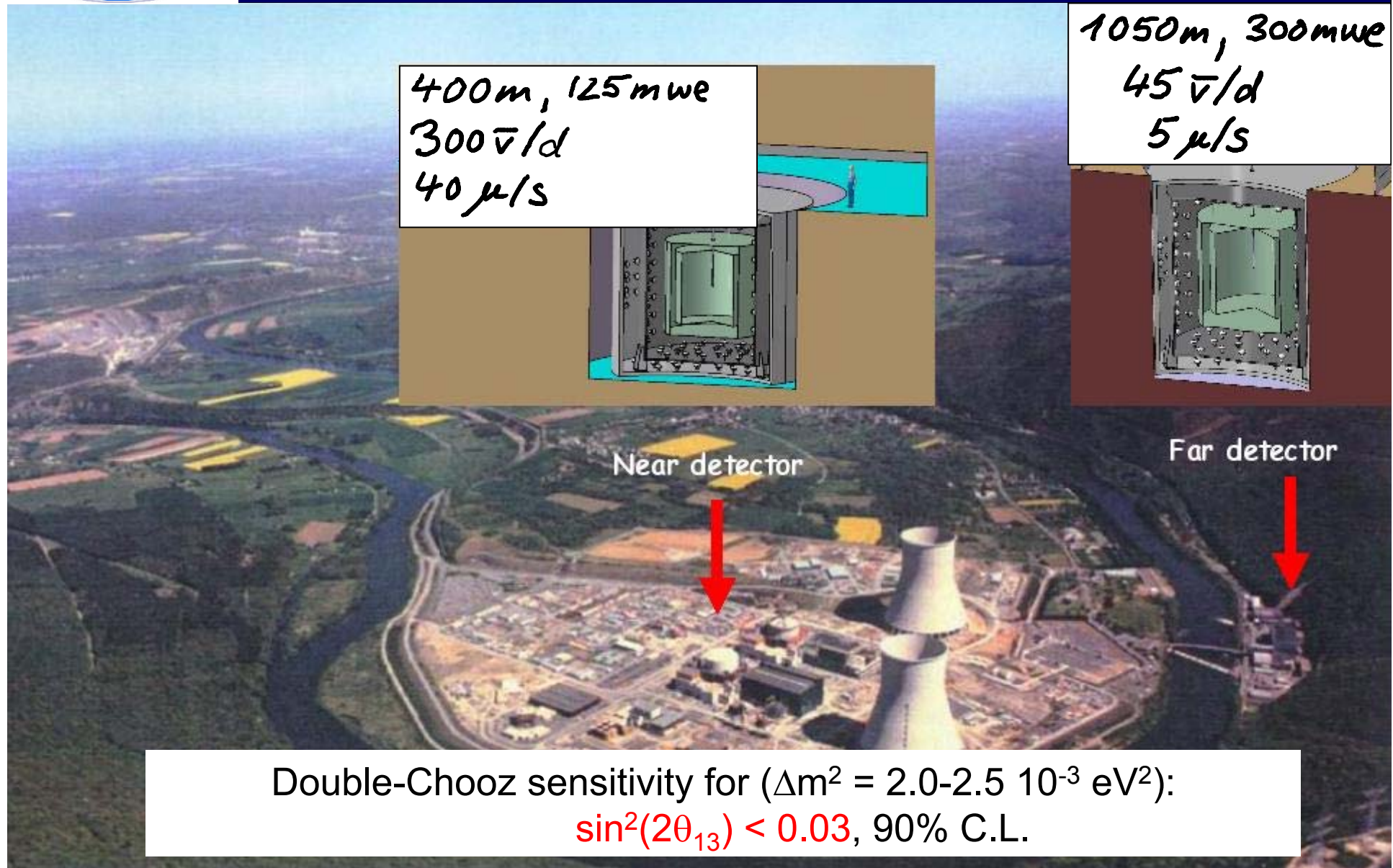
Figure 1: Comparison of n - σ regions allowed by the latest (2008) solar and KamLAND data in the $(\delta m^2, \sin^2 \theta_{12})$ plane, for two fixed values of θ_{13} .

Global analysis: Hints of $\theta_{13} > 0$ (III)

„SNO, KamLAND and neutrino oscillations: θ_{13} “, Fogli, Lisi, Marrone, Palazzo, Rotunno, arXiv:0905.3549

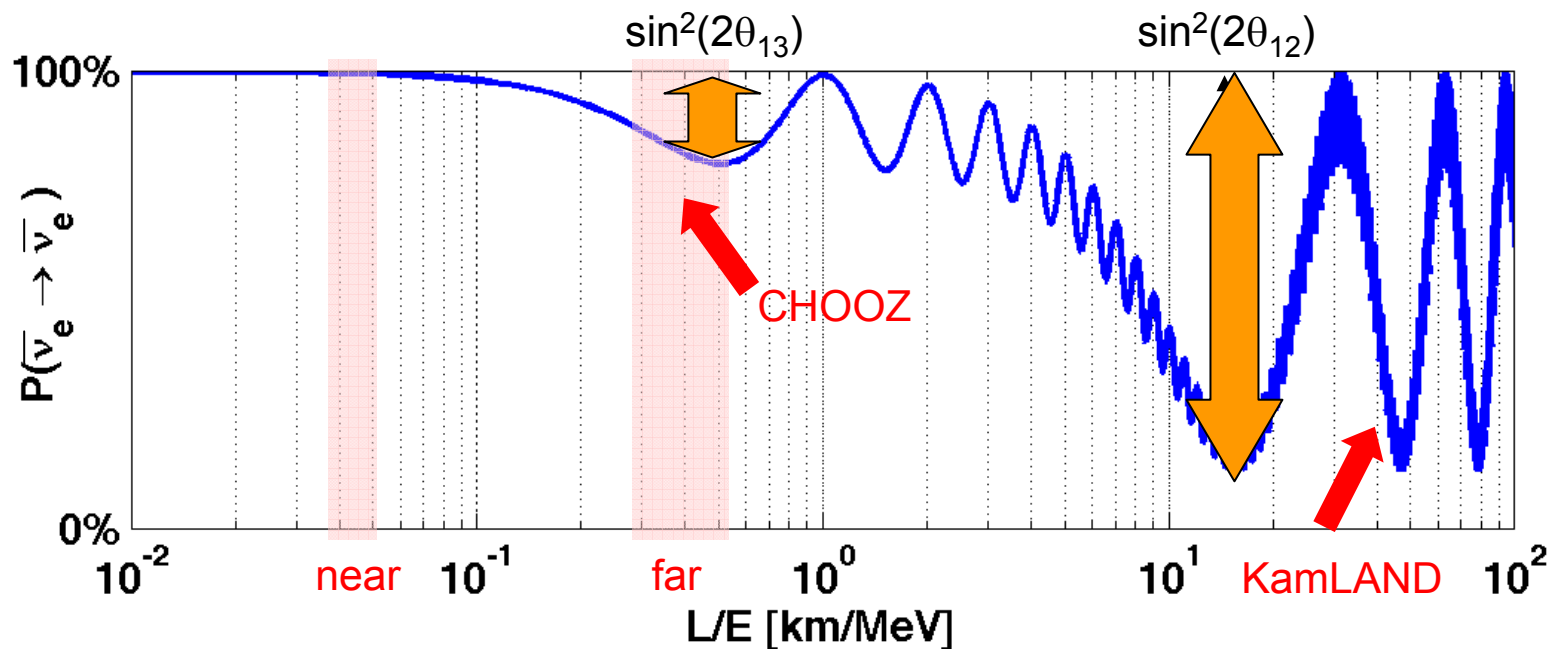


Double-CHOOZ



Oscillations of reactor neutrinos and θ_{13}

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) \approx 1 - \sin^2 2\theta_{13} \sin^2 \frac{\Delta m_{31}^2 L}{4E_{\bar{\nu}}} - \cos^4 \theta_{13} \sin^2 2\theta_{12} \sin^2 \frac{\Delta m_{21}^2 L}{4E_{\bar{\nu}}}$$



- max. sensitivity on θ_{13} : $E_{\nu} \sim 4 \text{ MeV}$, $\Delta m_{\text{atm}}^2 \rightarrow L_{\text{osc}}/2 \sim 1.5 \text{ km}$

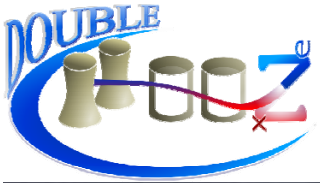


Double Chooz

How can one reduce the systematic uncertainty to $<1\%$?

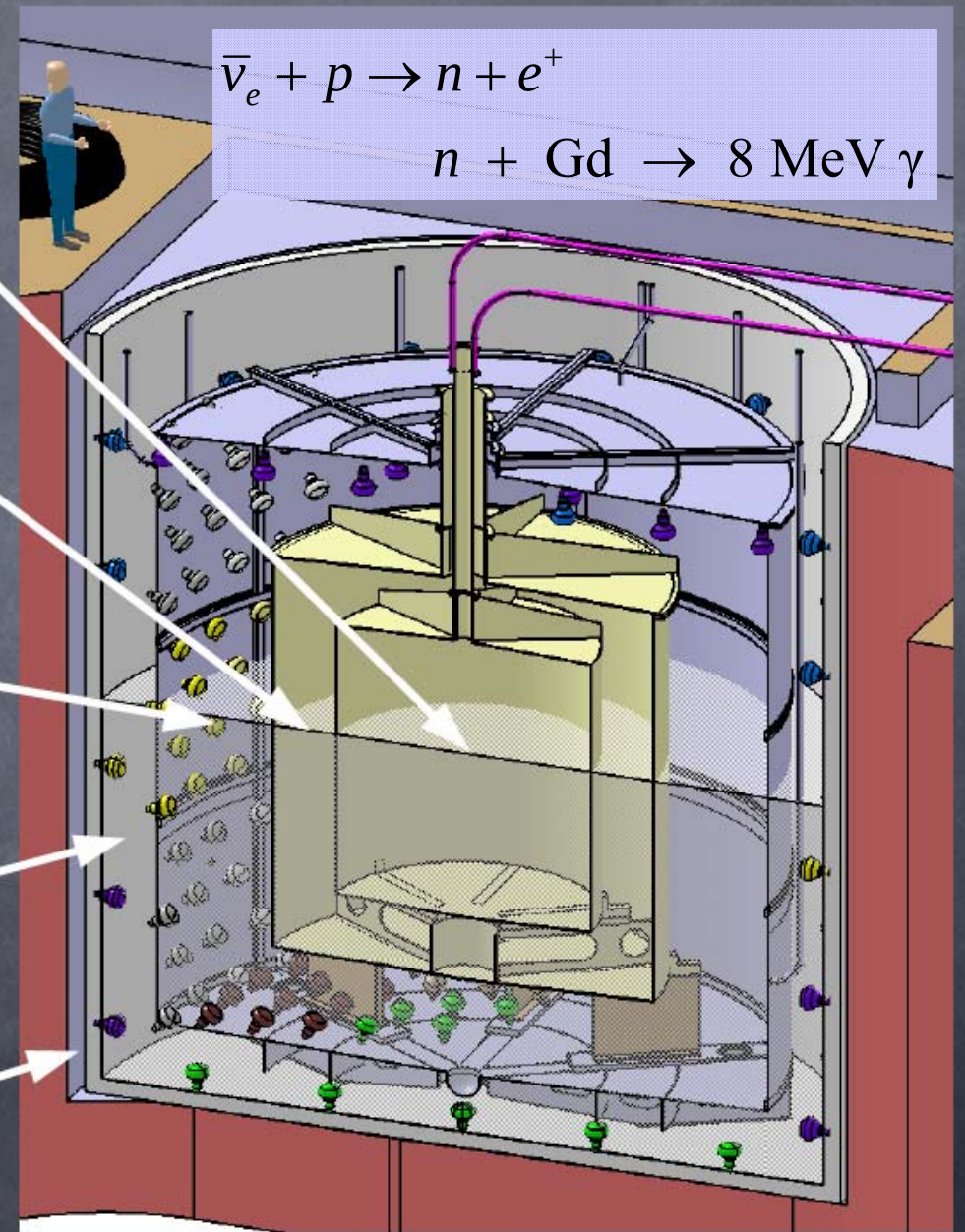
- comparison of (almost identical) **near and far detector**: many uncertainties cancel, e.g. neutrino flux and -spectra.
- Larger target (increased from 5 to 10m^3) and longer measurement (5 years), **higher statistics**.
- **Improved detector design** and special choice of materials (radioactive purity) based on experience from CHOOZ.

	CHOOZ	Double Chooz
Reactor fuel cross section	1.9%	—
Reactor power	0.7%	—
Energy per fission	0.6%	—
Number of protons	0.8%	0.2%
Detection efficiency	1.5%	0.5%
TOTAL	2.7%	0.6%



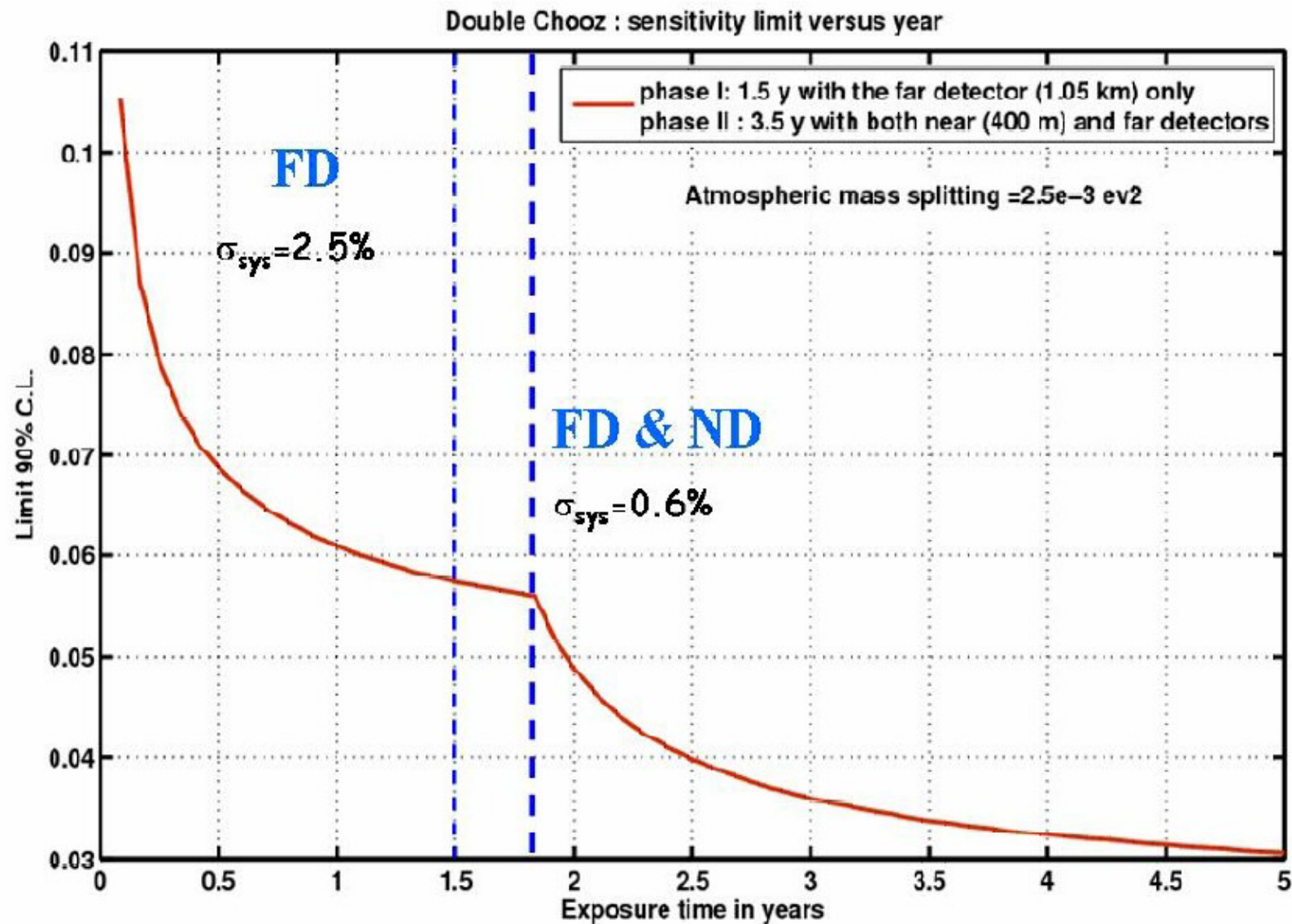
Double CHOOZ Detector

- Inner Detector design:
 - **target**: ~8t of Gd-doped scintillator in acrylics vessel
 - **γ -catcher**: 55 cm wide undoped scintillator in acrylics vessel
 - **buffer**: 105 cm wide, mineral oil in stainless steel vessel
 - **inner veto**: 50 cm wide, undoped scintillator in painted steel vessel
 - **shield**: 17 cm of steel slideable on top





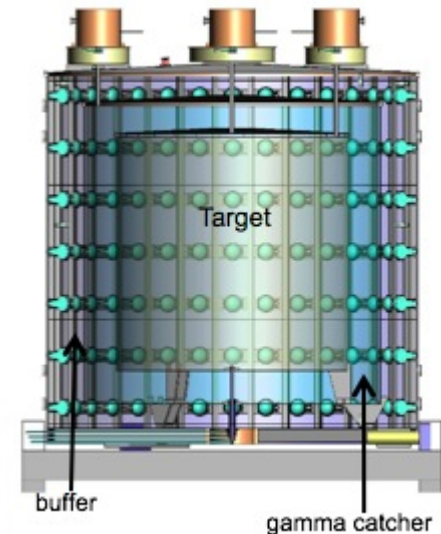
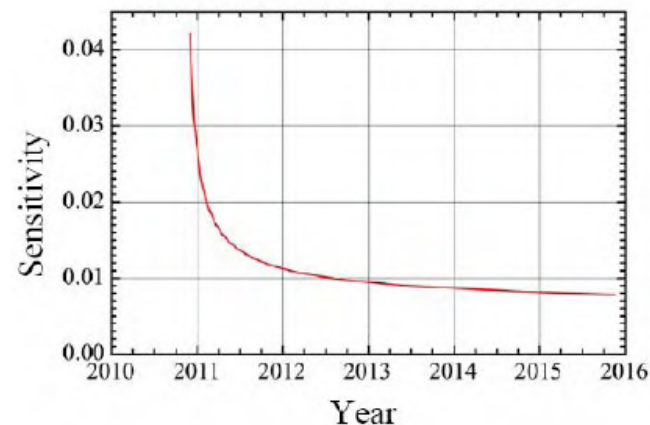
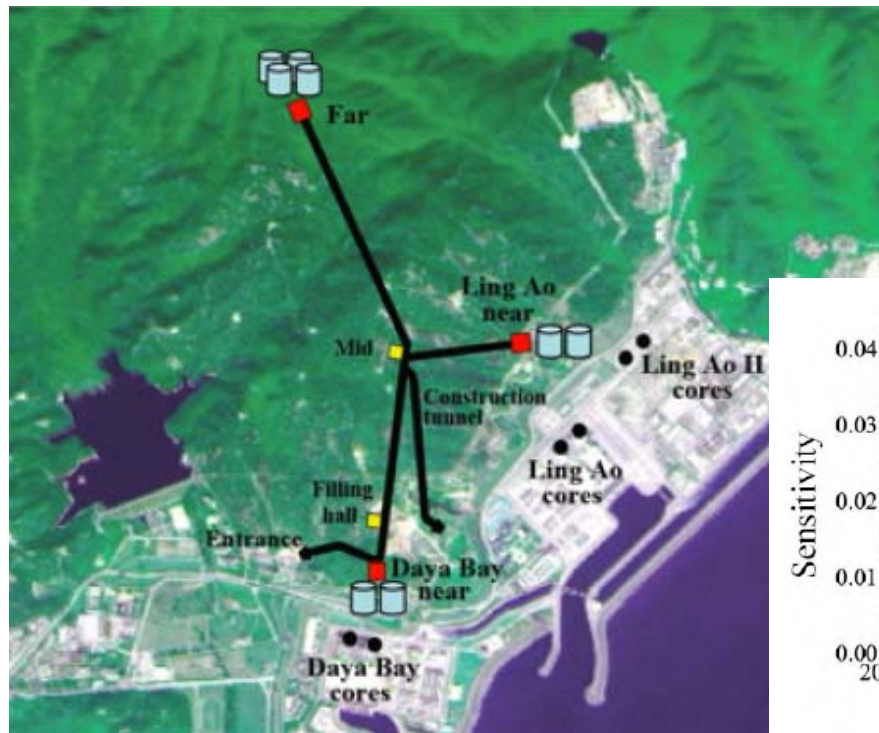
Double CHOOZ sensitivity



Daya Bay Experiment (USA & China)

Guangdong Daya Bay nuclear power station:

$P_{th} = 11.6$ GW (now), 17.4 GW(2011) 6th most powerful worldwide



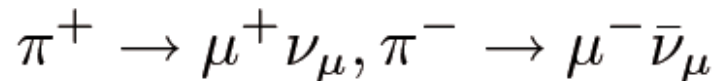
Goal: sensitivity on $\sin^2 2\theta_{13} < 0.01$

Commissioning of the detectors in 1st hall in 2009.

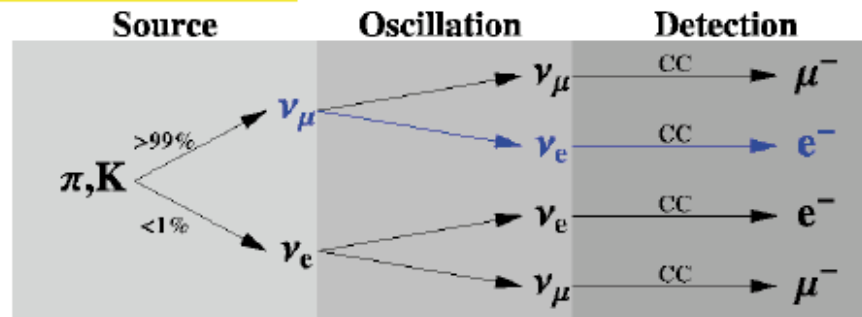
Construction will last about two years, installation of the last detector in 2010.

New neutrino beams

Pion Decays

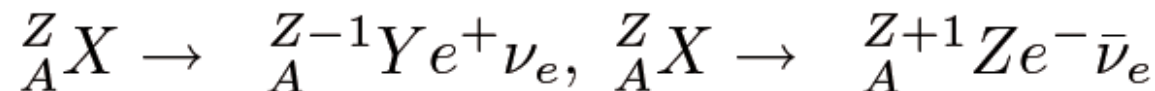


Superbeam



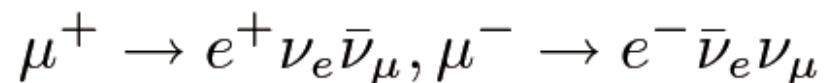
$\nu_\mu \rightarrow \nu_e$ oscillation most interesting
 ν_e contamination $\Leftrightarrow$ off-axis
 good electron detection efficiency
 good NC background rejection
 near detector
 $\bar{\nu}$ -beam $\simeq$ different experiment

Beta Decays

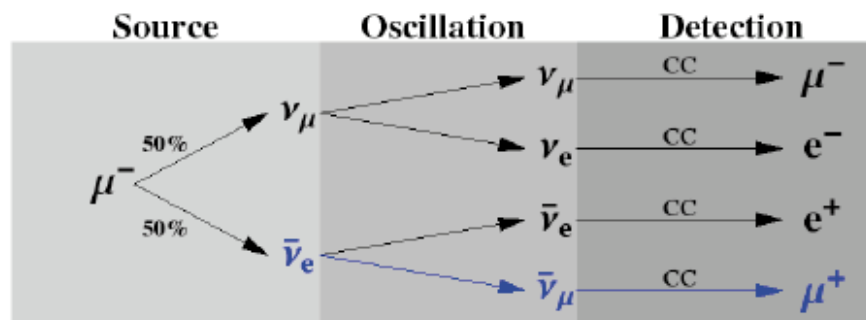


Beta Beam

Muon Decays

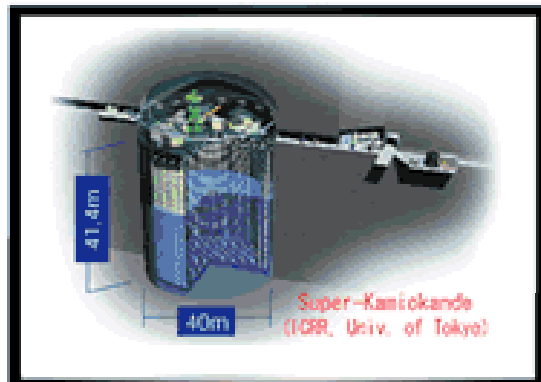


Neutrino Factory



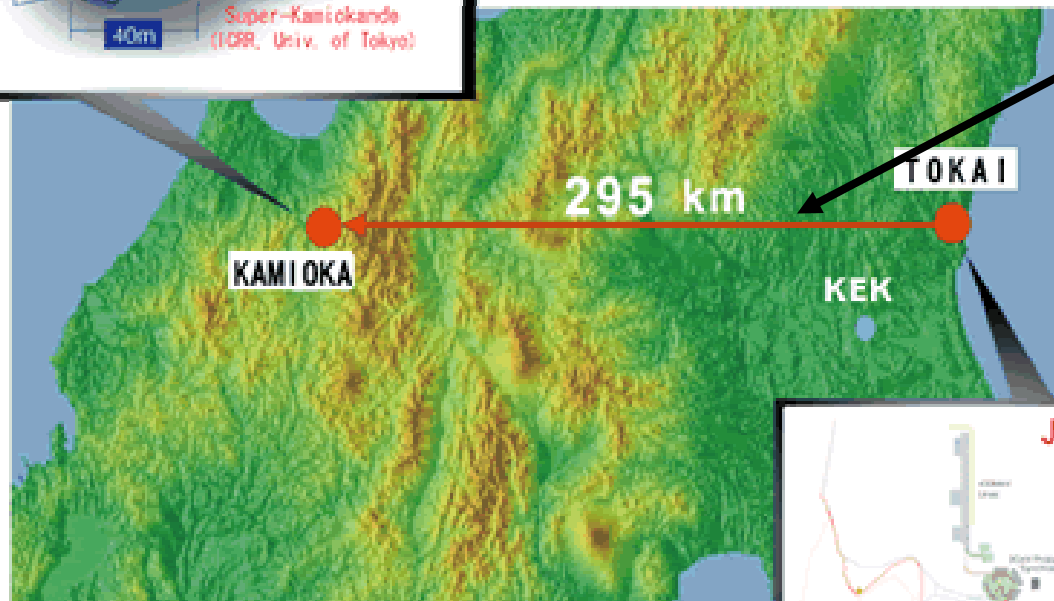
$\bar{\nu}_e \rightarrow \bar{\nu}_\mu$ oscillation most interesting
 excellent beam properties
 very good charge ID required
 good NC background rejection
 μ^+ mode very symmetric

T2K (Tokai to Kamioka)

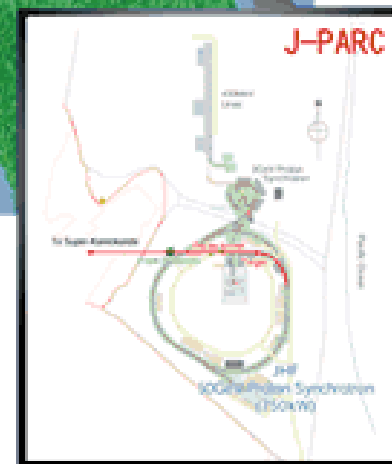


First neutrinos produced on April 23rd 2009!

Off-Axis Detector Superkamiokande

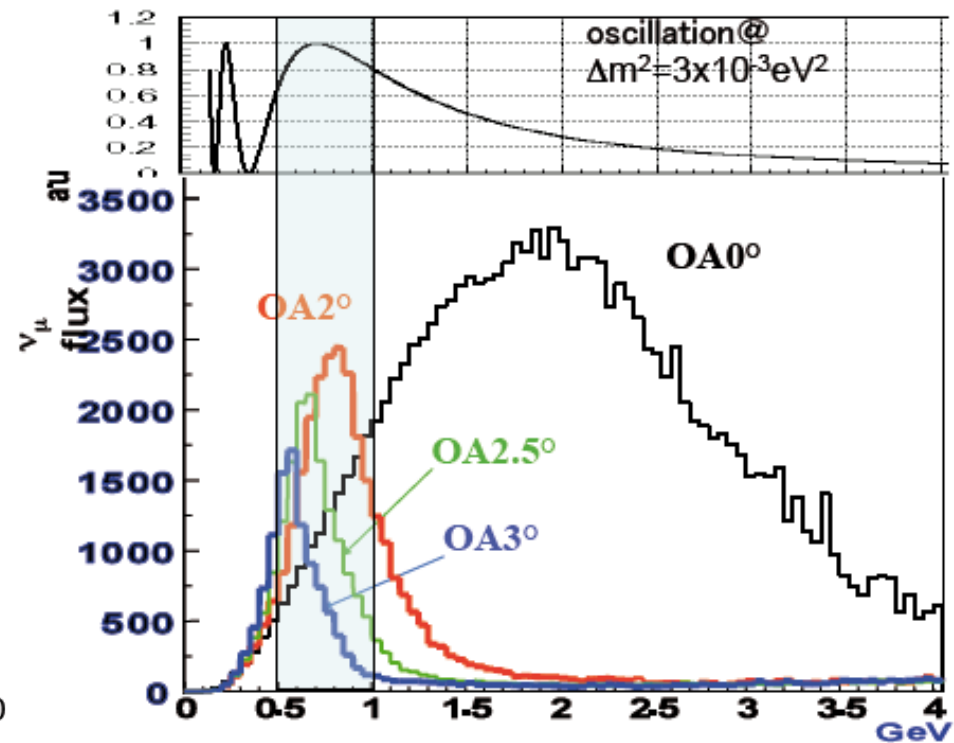
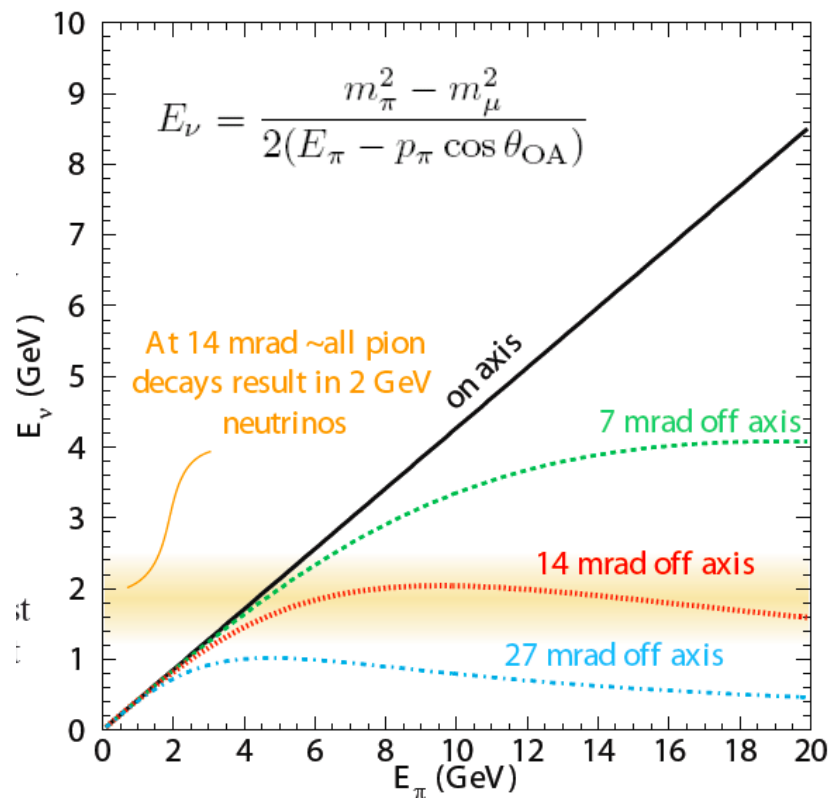
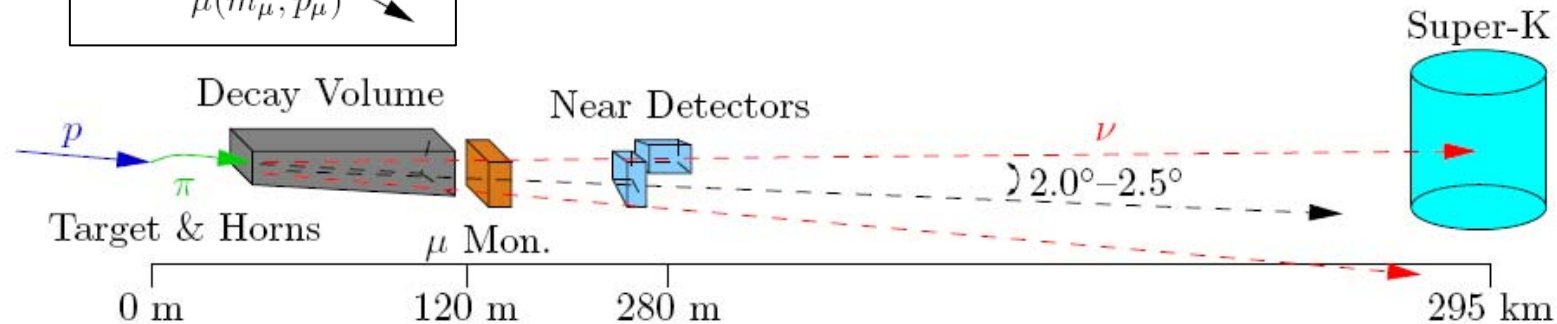
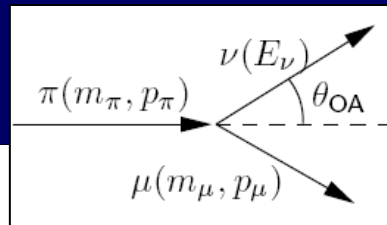


Neutrino Super Beam

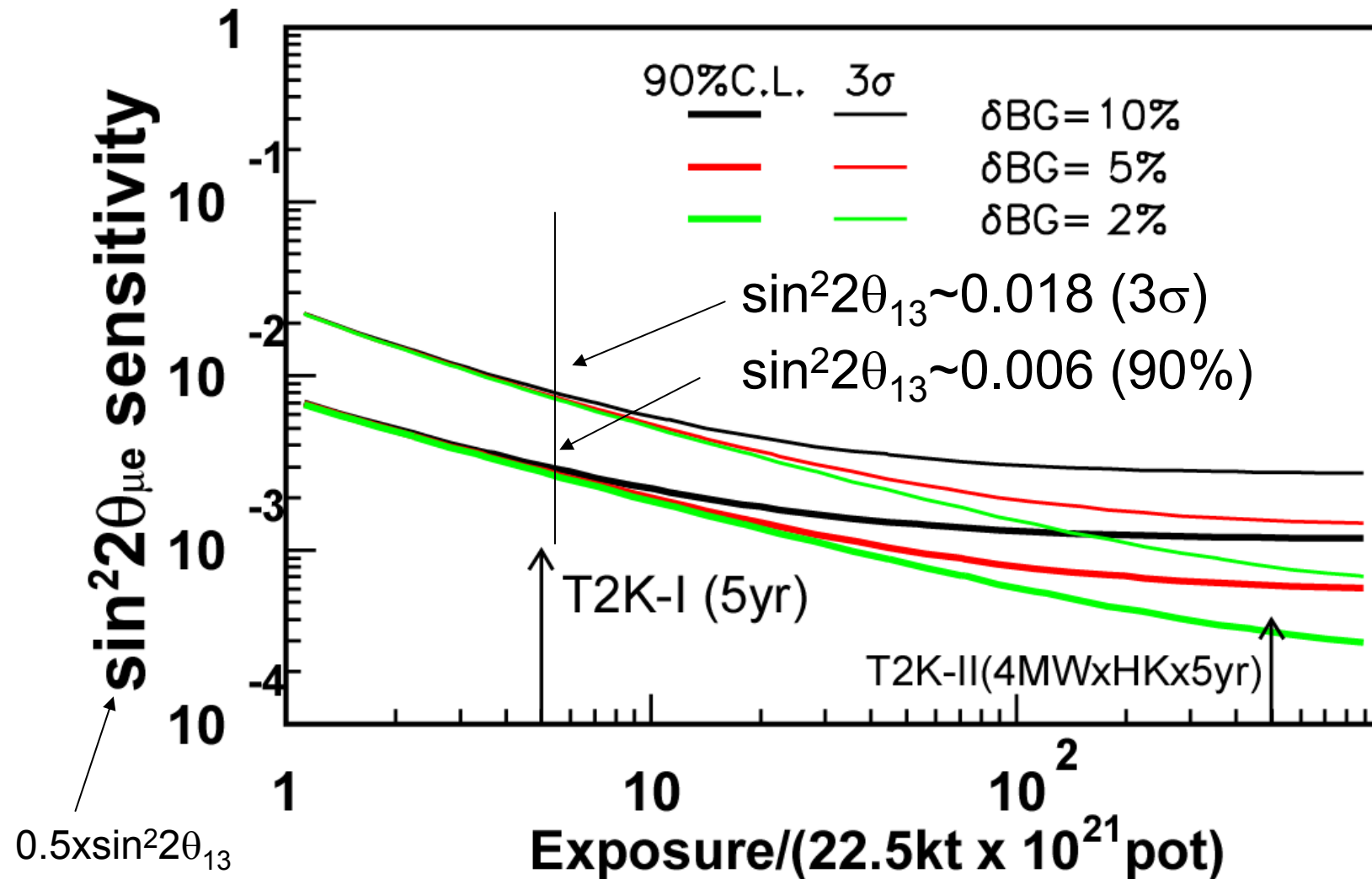


Proton driver

Off axis beams



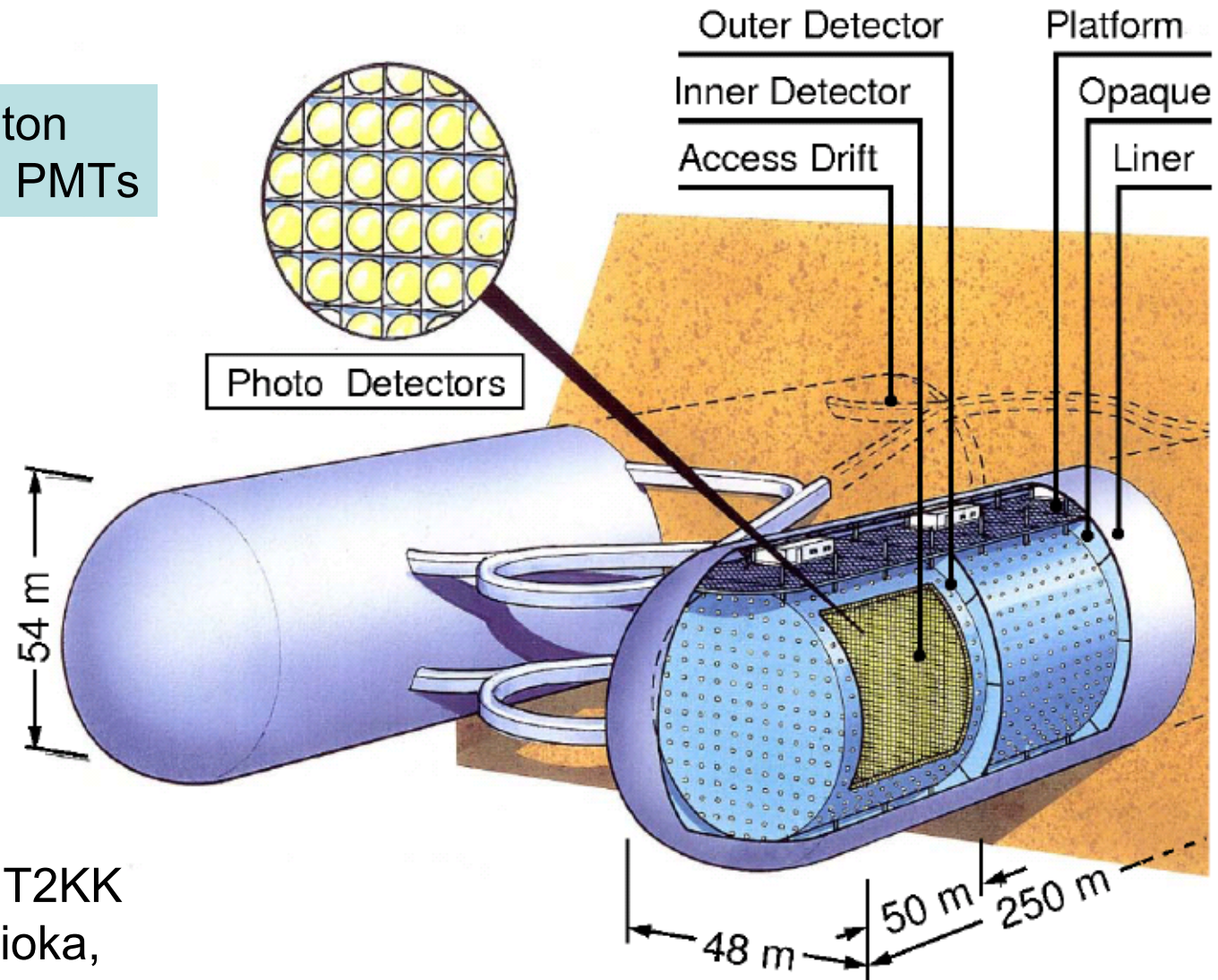
T2K: Sensitivity for θ_{13}



$\sin^2 2\theta_{13} < 10^{-3}$ can be searched if syst err $\sim$ few %

Future plans to upgrade T2K: Hyper-Kamiokande

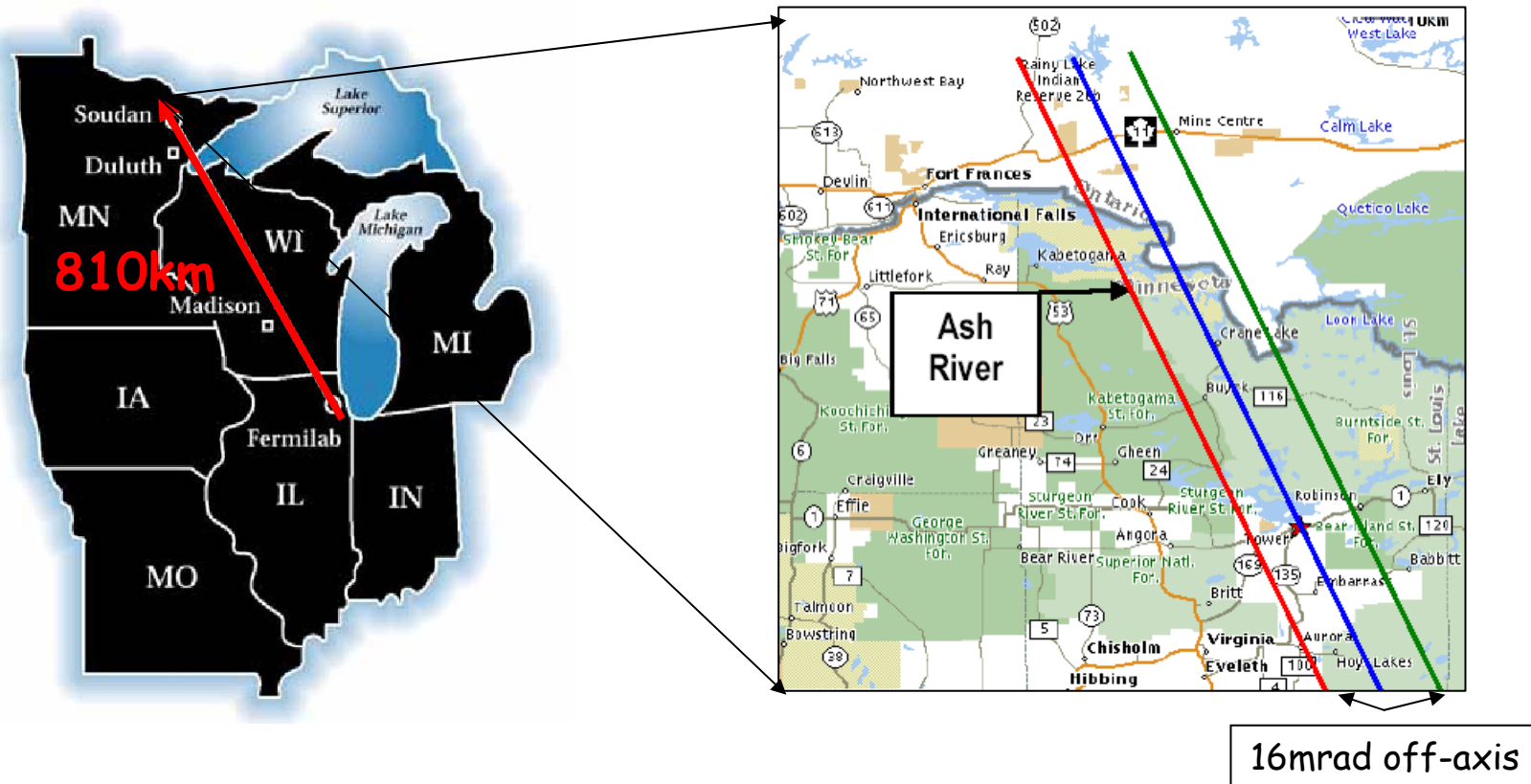
1 Megaton
200000 PMTs



Possible project: T2KK
1 HyperK in Kamioka,
1 HyperK in Korea ($L=1000\text{km}$, $\text{OA}=2.5^\circ$)

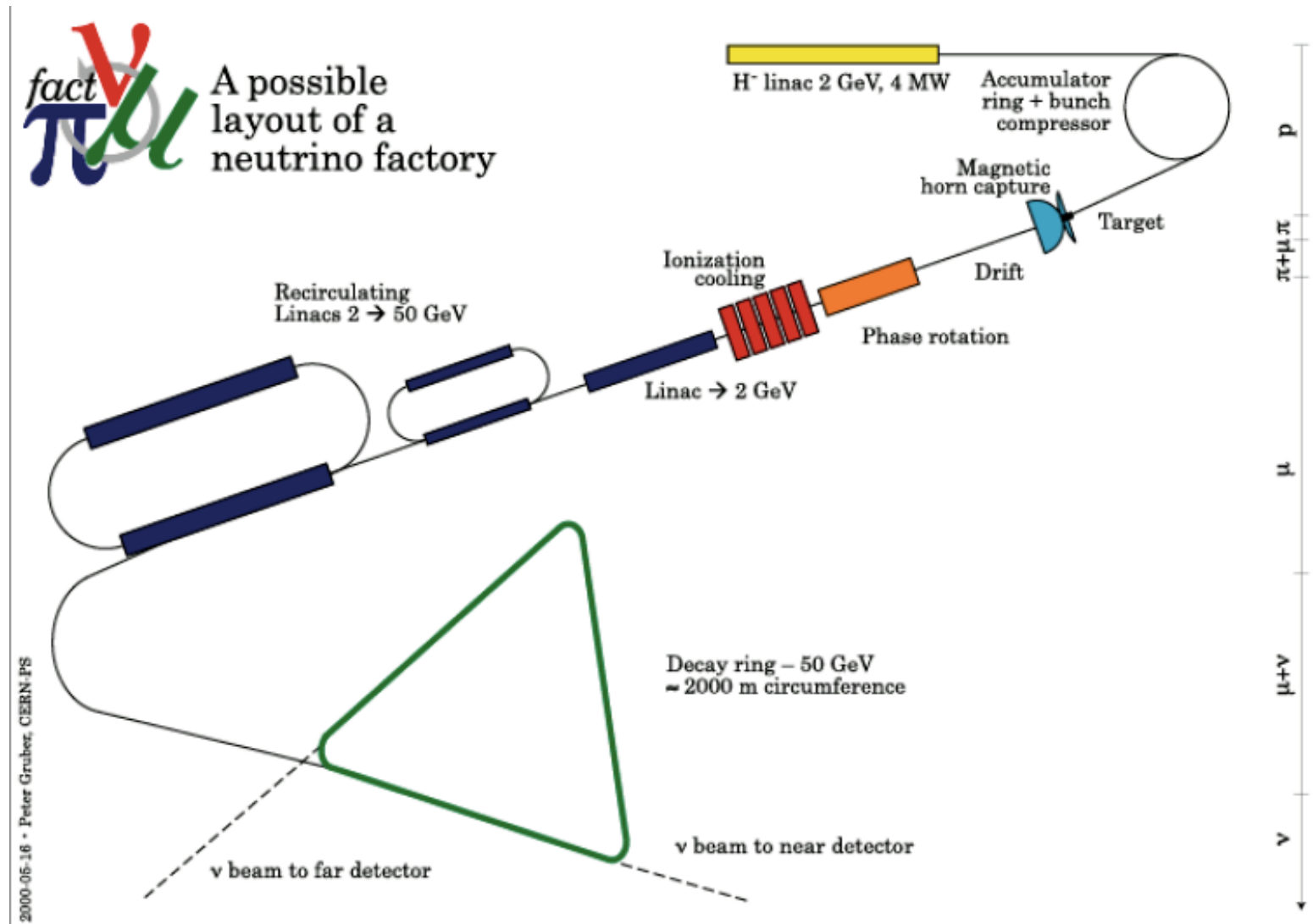


NOvA



@Fermilab: increase beampower from 400kW to 700kW
far detector: 15 kton liquid scintillator (groundbreaking jan 09)
construction complete in 2014, 6 years measurement.

Neutrino factories



Neutrino factories



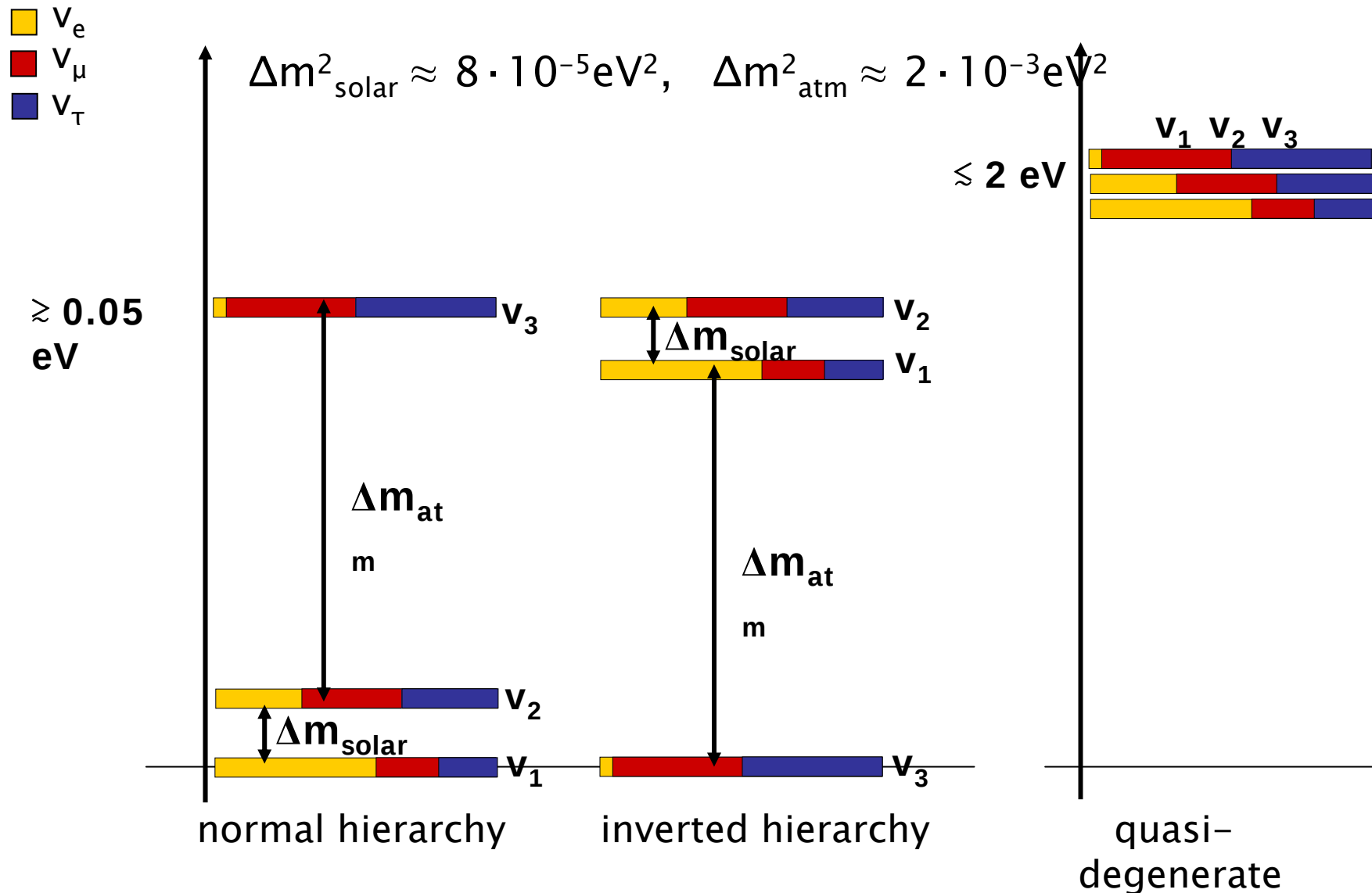
12 Oscillation Processes in a Neutrino Factory

12 Oscillation Processes from (simultaneous) beams of positive and negative muons in a neutrino Factory.

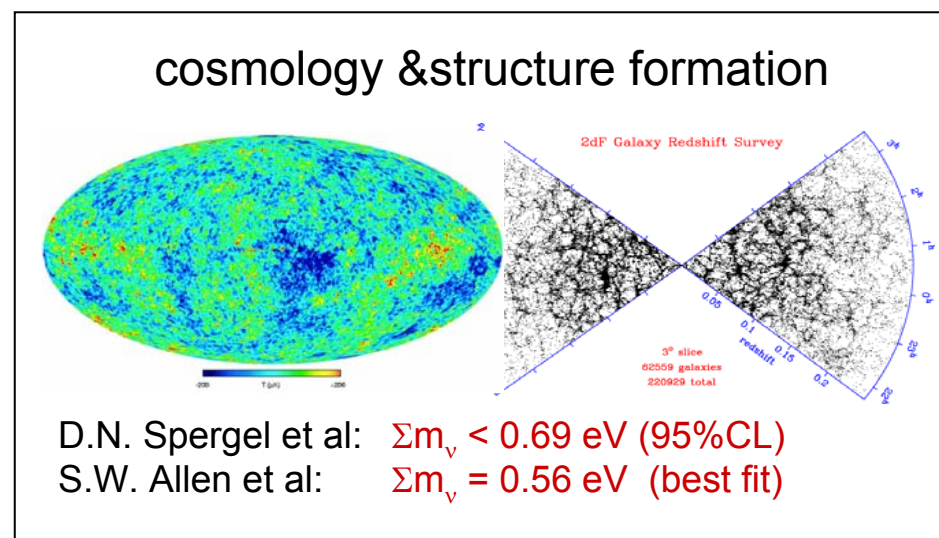
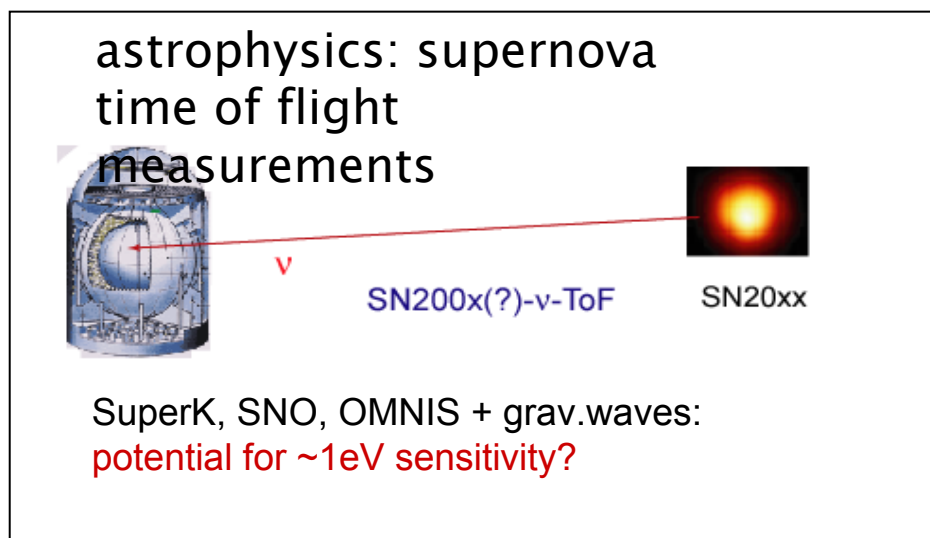
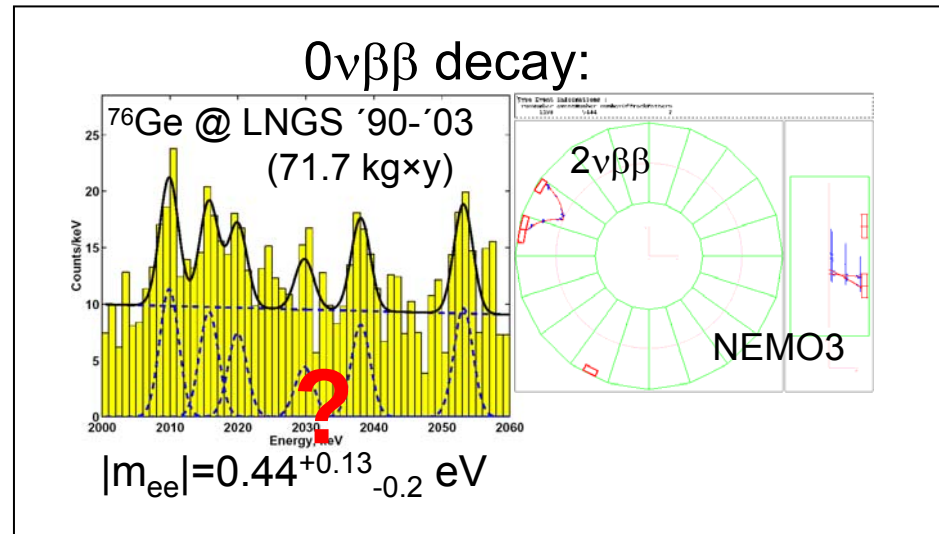
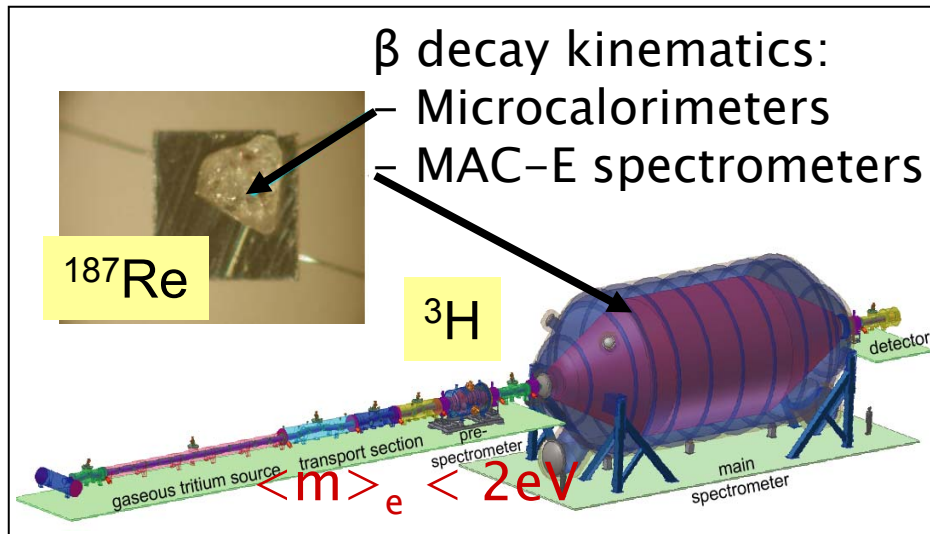
$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$	$\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$	
$\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$	$\nu_\mu \rightarrow \nu_\mu$	disappearance
$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	$\nu_\mu \rightarrow \nu_e$	appearance (challenging)
$\bar{\nu}_\mu \rightarrow \bar{\nu}_\tau$	$\nu_\mu \rightarrow \nu_\tau$	appearance (atm. oscillation) platinum
$\nu_e \rightarrow \nu_e$	$\bar{\nu}_e \rightarrow \bar{\nu}_e$	disappearance
$\nu_e \rightarrow \nu_\mu$	$\bar{\nu}_e \rightarrow \bar{\nu}_\mu$	appearance: “golden” channel golden
$\nu_e \rightarrow \nu_\tau$	$\bar{\nu}_e \rightarrow \bar{\nu}_\tau$	appearance: “silver” channel silver

What do we know about neutrino masses?

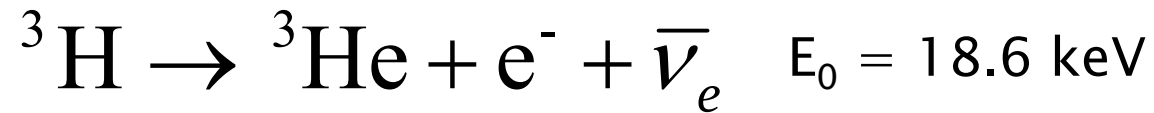
Lecture 1



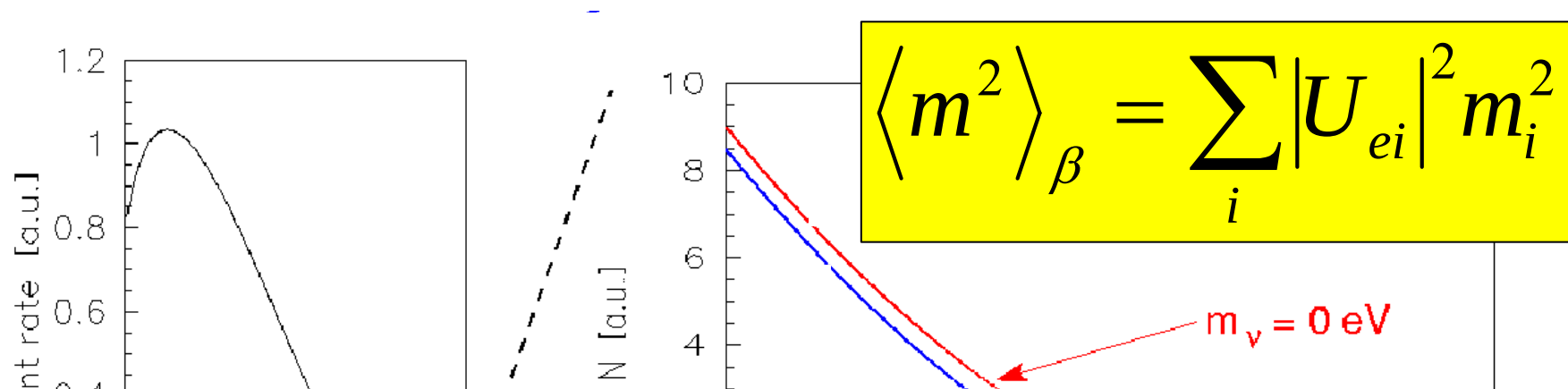
Neutrino Mass Measurements Strategies



Tritium β -Decay: Mainz/Troitsk



$$dN/dE = K \times F(E,Z) \times p \times E_{\text{tot}} \times (E_0 - E_e) \times [(E_0 - E_e)^2 - \mathbf{m}_\nu^2]^{1/2}$$



$$\langle m^2 \rangle_\beta = \sum_i |U_{ei}|^2 m_i^2$$

Mainz Data (1998,1999,2001)

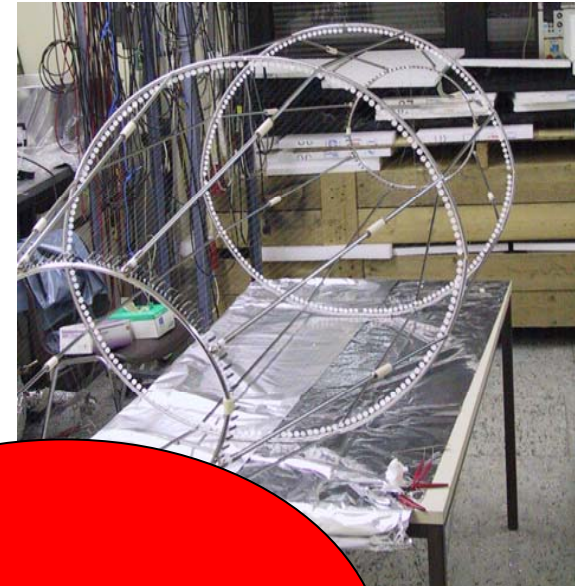
$$\langle m^2 \rangle_\beta = -1.2 \pm 2.2 \pm 2.1 \text{ eV}^2 \Rightarrow \langle m \rangle_\beta < 2.2 \text{ eV (95\%CL)}$$

KATRIN Main Spectrometer

- stainless steel vessel ($\varnothing=10\text{m}$ & $l=22\text{m}$) on HV potential
- minimisation of bg $\rightarrow$ UHV: $p \leq 10^{-11}$ mbar
 $\rightarrow$ „massless“ inner electrode system



UHV requirements:
 outgassing $< 10^{-13}$ mbar l/s
 inner surface $\sim 800\text{m}^2$
 volume to pump $\sim 1500\text{m}^3$



goal:
 $\langle m \rangle_{\beta} < 0.20 \text{ eV}$

KATRIN: delivery of vacuum vessel



Majorana Particles



Because neutrinos carry no electric charge
(and no color charge), there is the possibility:

particle $\equiv$ anti-particle

Majorana particle

particle ψ

anti-particle (charge conjugate

field): Majorana particle $\psi_M^c = \pm \psi_M$

$$\psi^c = C \bar{\psi}^T$$

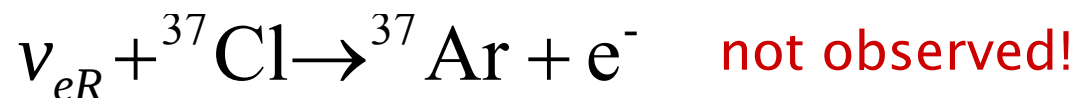
But what about experiments?

Neutrinos

(solar):

Anti-

neutrinos(reactor):

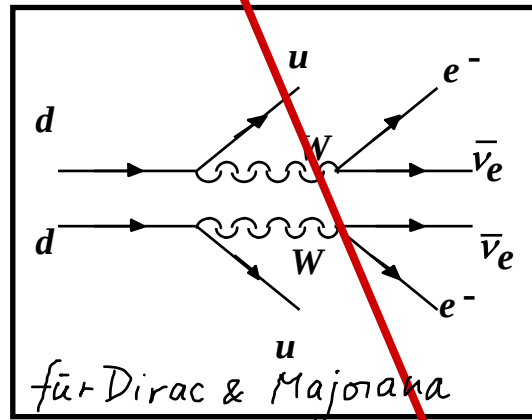


There are two different states per flavor

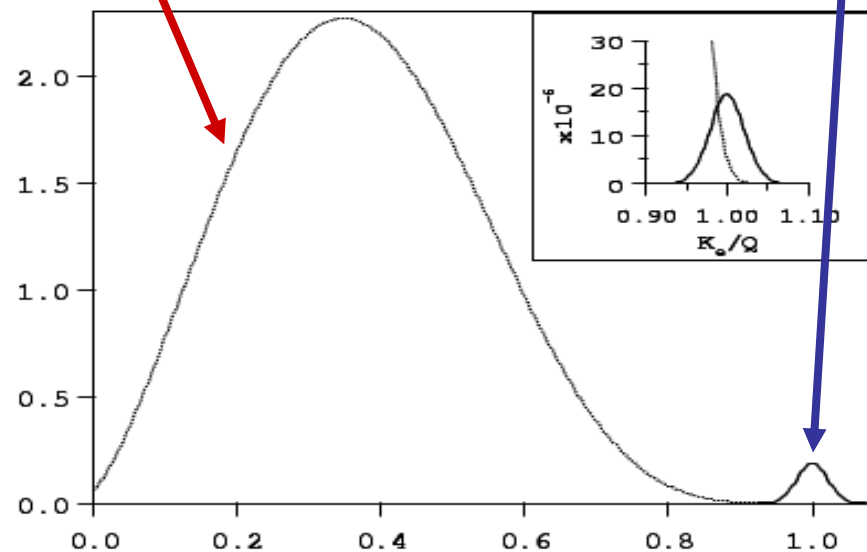
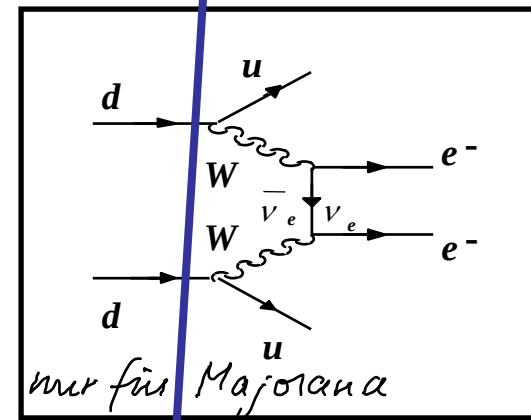
but the difference could be due to left-handed and right-handed states!

2v and 0v double beta – decay

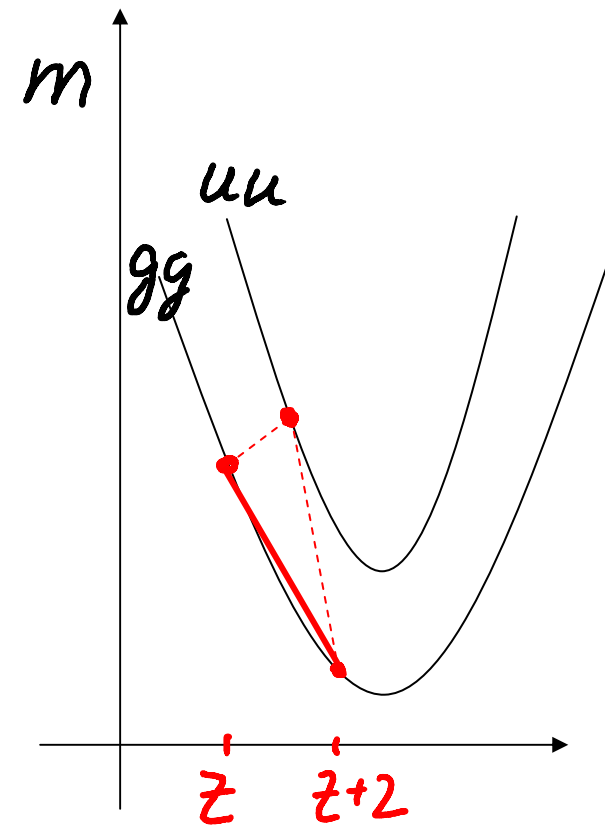
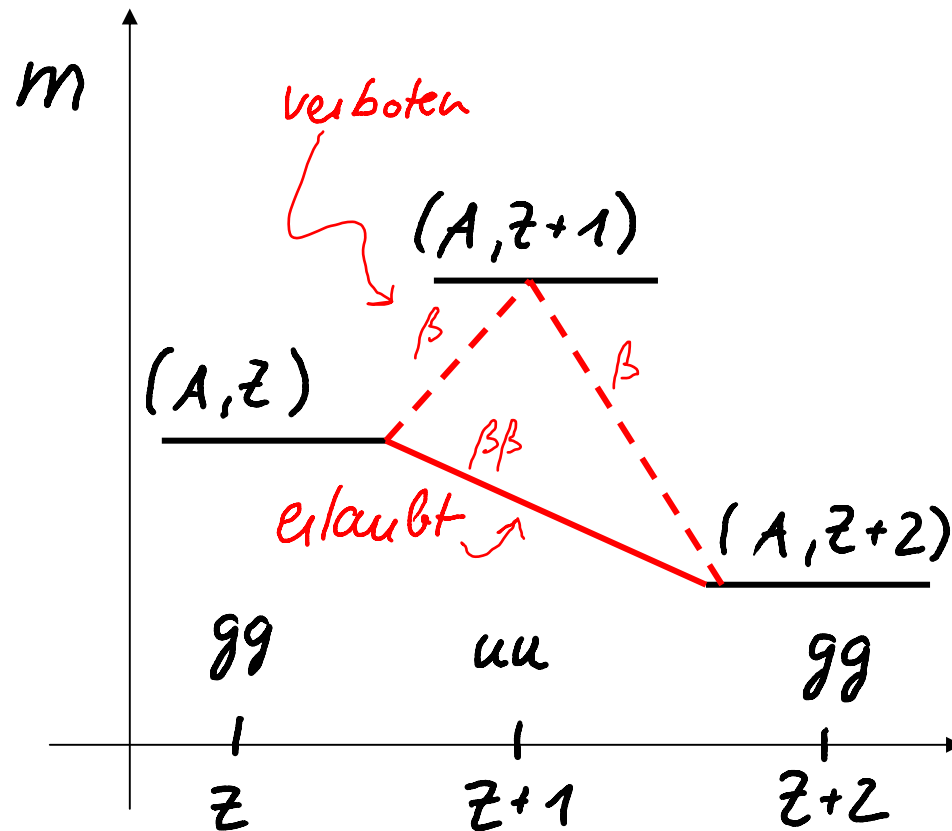
2v - $\beta\beta$ decay 1987 erstmals beobachtet



0v - $\beta\beta$ decay



Which isotopes undergo $\beta\beta$ -transition?



z.B. ^{76}Ge , ^{100}Mo , ^{130}Te , ^{150}Nd , ^{116}Cd

Neutrinoless Double Beta Decay

$$[T_{1/2}^{0\nu}]^{-1} = \underbrace{G^{0\nu}(E_0, Z)}_{\text{Phase space factor}} \underbrace{\left| M_{GT}^{0\nu} - \frac{g_V^2}{g_A^2} M_F^{0\nu} \right|^2}_{\text{Transition matrix element}} \underbrace{\langle m_\nu \rangle_{\beta\beta}^2}_{\text{Effective neutrino mass}}$$

Effective neutrino mass in $0\nu\beta\beta$ -decay:

$$\langle m \rangle_{\beta\beta} \equiv \left| \sum_{i=1}^3 m_i U_{ei}^2 \right|$$

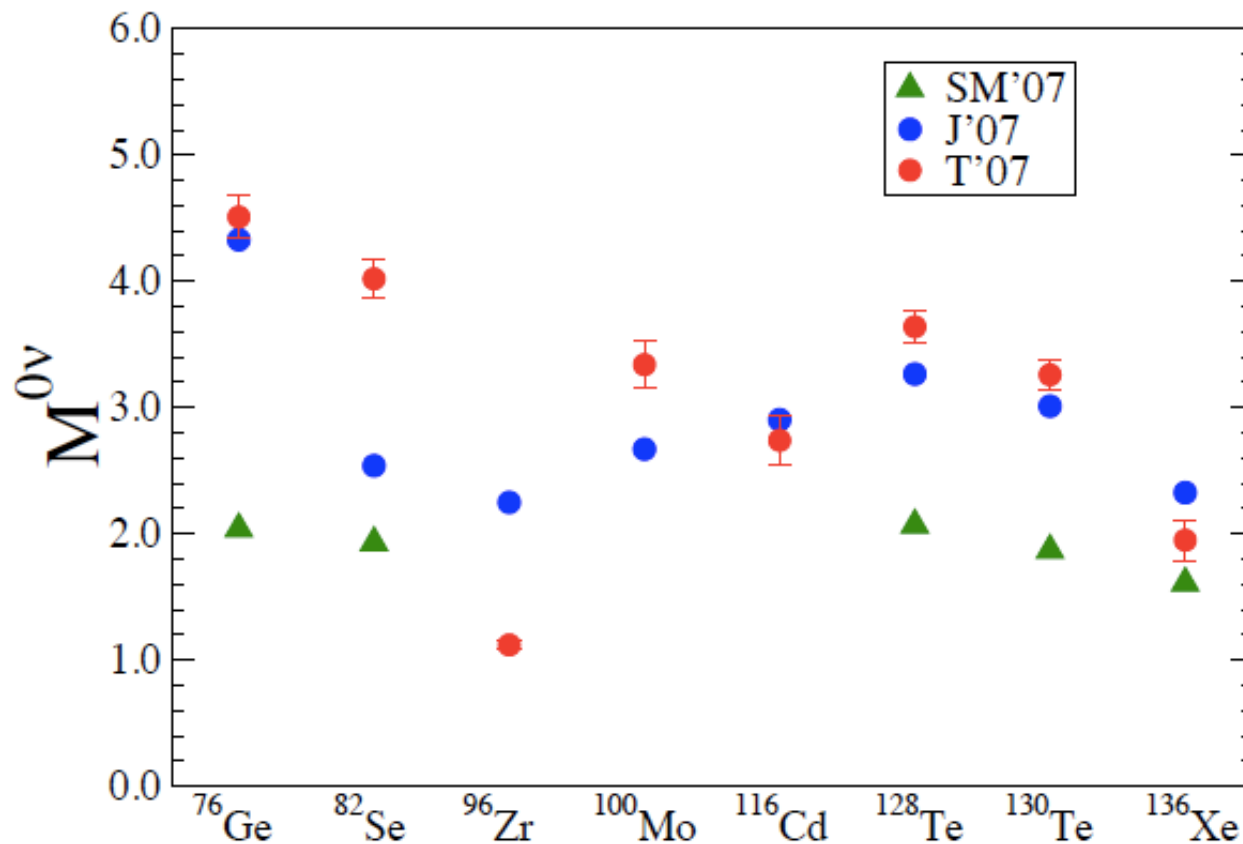
Compare to β -decay:

$$\langle m^2 \rangle_{\beta} = \sum_i m_i^2 |U_{ei}|^2$$



Problem: transition matrix elements

Must be calculated, still large uncertainties



Complex phases in the mixing matrix

Dirac CP-Phase

Majorana CP-Phases

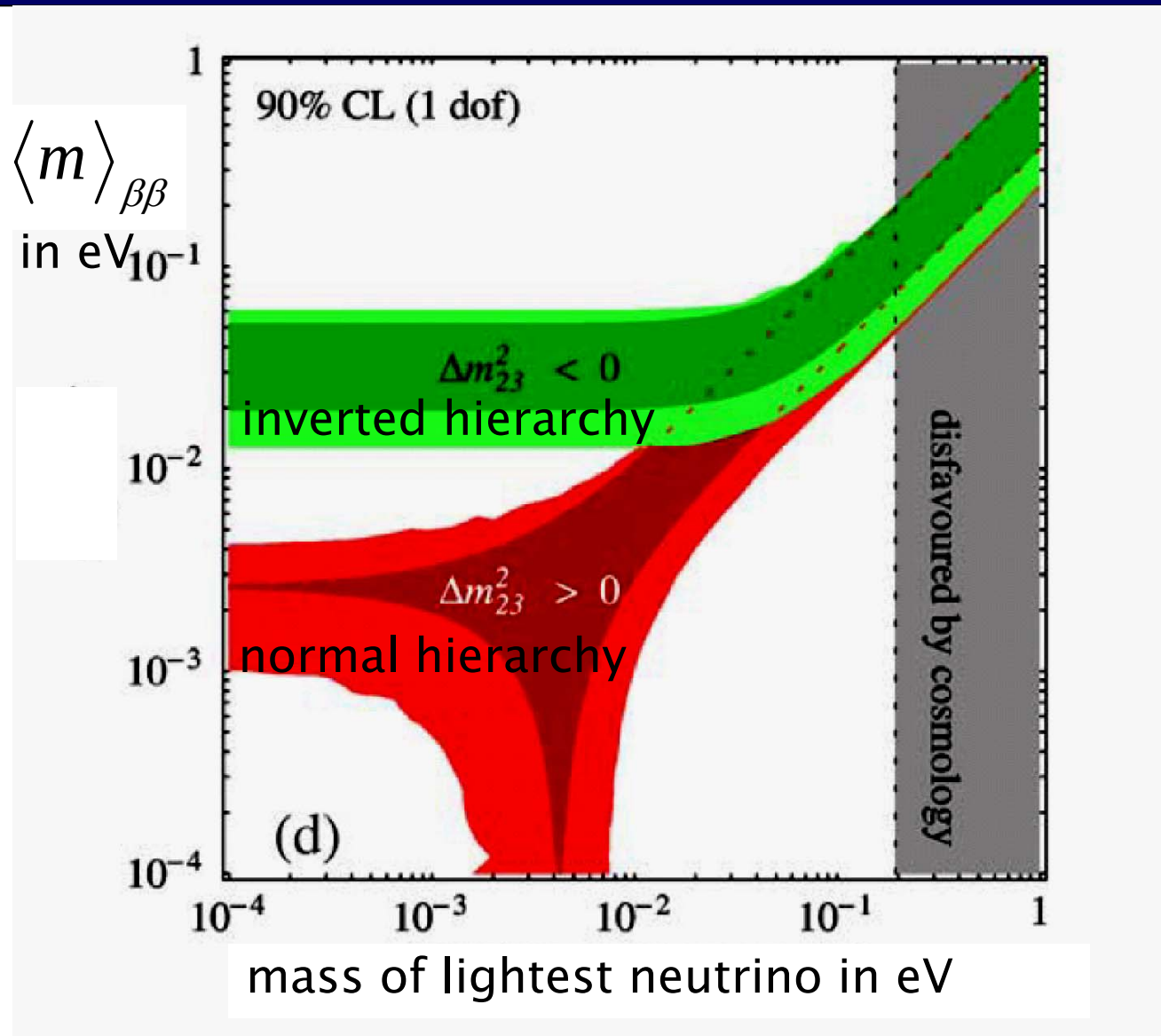
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13}e^{i\alpha_1} & s_{13}e^{-i\delta}e^{i\alpha_2} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & [c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta}]e^{i\alpha_1} & s_{23}c_{13}e^{i\alpha_2} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & [-c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta}]e^{i\alpha_1} & c_{23}c_{13}e^{i\alpha_2} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

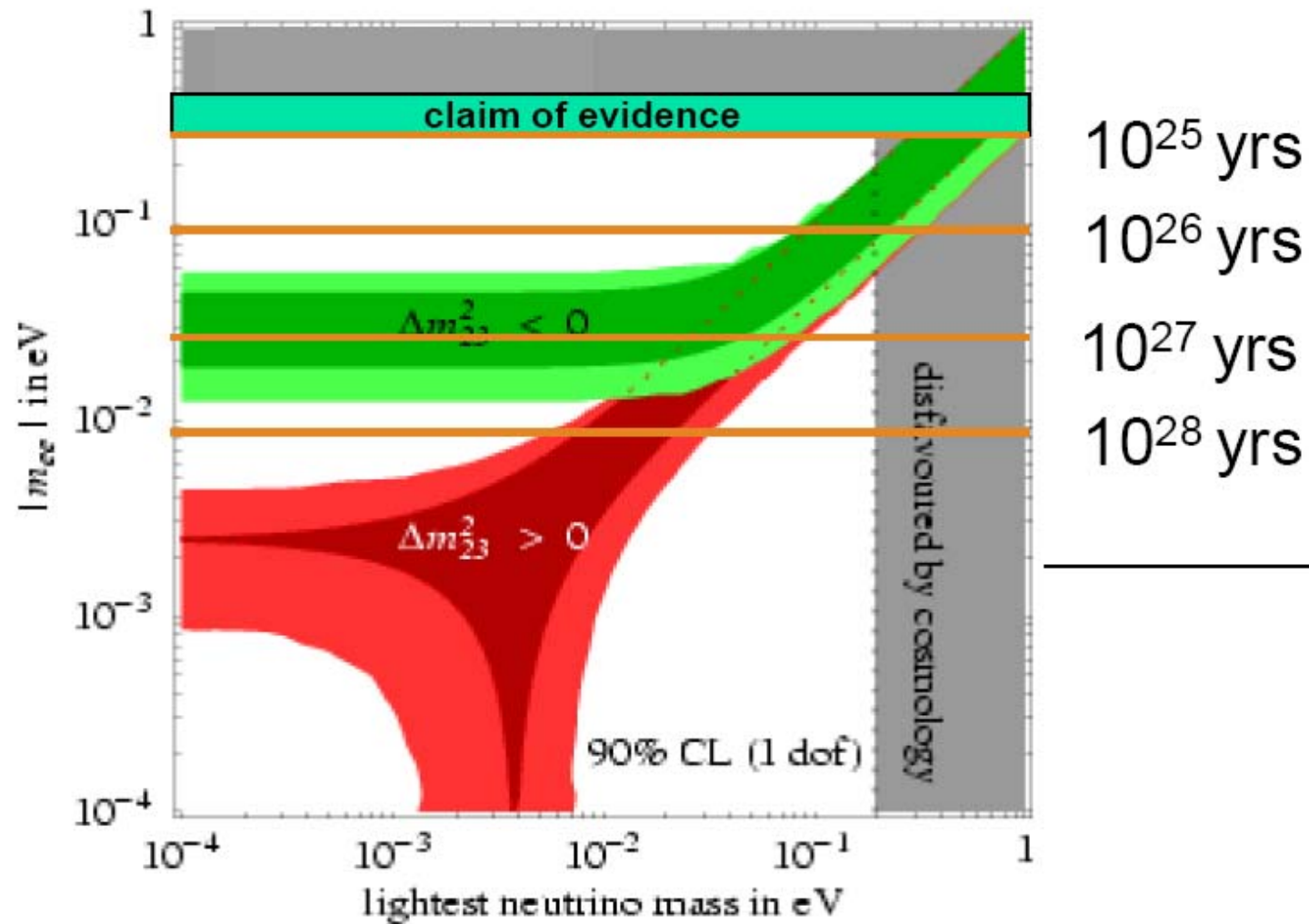
$$\langle m \rangle_{\beta\beta} \equiv \left| \sum_{i=1}^3 m_i U_{ei}^2 \right| = \left| m_1 U_{e1}^2 + m_2 U_{e2}^2 e^{i\alpha_1} + m_3 U_{e3}^2 e^{i\alpha_2} \right|$$

Cancellation
possible!

What does $\beta\beta$ -decay tell about mass of lightest neutrino?

Lecture 1





0ν Doppel-Beta experiments: results

$$\langle m \rangle_{\beta\beta} < 0.35 \text{ eV (90\% CL)}$$

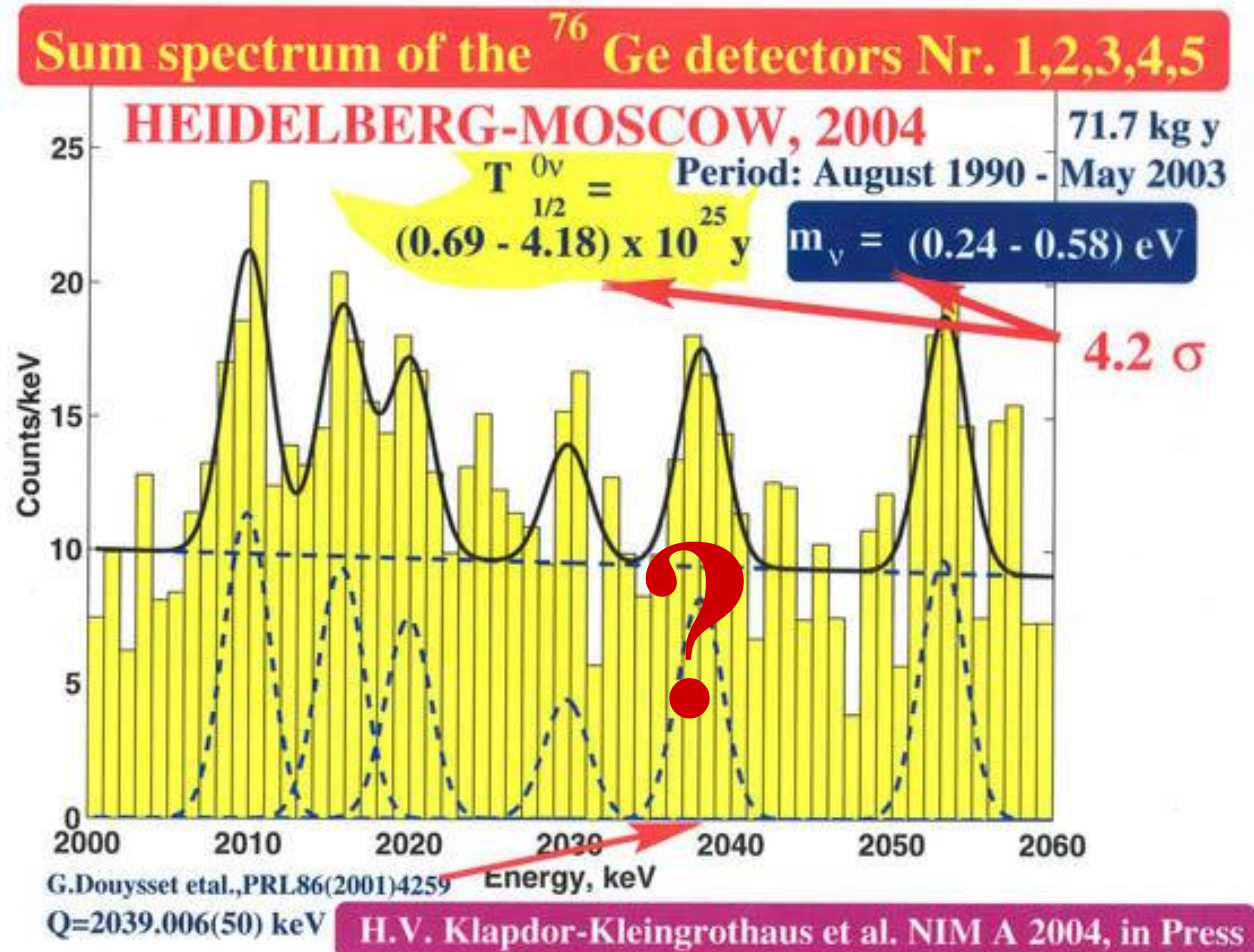
Heidelberg-Moskau Collaboration, Eur.Phys.J. A12 (2001) 147

IGEX Collaboration, hep-ex/0202026, Phys. Rev. C59 (1999) 2108

Isotope	$T_{1/2}^{0\nu}$ (y)	$\langle m_\nu \rangle$ (eV)
^{48}Ca	$> 9.5 \times 10^{21}$ (76%)	< 8.3
^{76}Ge	$> 1.9 \times 10^{25}$ HM-K	< 0.35
	$> 1.6 \times 10^{25}$ IGEX	$< 0.33 - 1.35$
^{82}Se	$> 2.7 \times 10^{22}$ (68%)	< 5
^{100}Mo	$> 5.5 \times 10^{22}$	< 2.1
^{116}Cd	$> 7 \times 10^{22}$	< 2.6
^{128}Te	$> 7.7 \times 10^{24}$	$< 1.1 - 1.5$
^{130}Te	$> 2.1 \times 10^{23}$	$< 0.85 - 2.1$
^{136}Xe	$> 4.4 \times 10^{23}$	$< 1.8 - 5.2$
^{150}Nd	$> 1.2 \times 10^{21}$	< 3

all 90%CL

But: Part of HdM collaboration has published evidence for 0ν double – beta decay!



($Q = 2039 \text{ keV}$ for ^{76}Ge)

Heidelberg-Moskau Experiment (HDM)



5 Ge-Detektoren
(angereichert mit ^{76}Ge)
„Die Detektoren zerfallen!“

Future Projects

Experiment	Isotope	Experimental approach
CANDLES	^{48}Ca	Several tons of CaF_2 crystals in Liquid scintillator
CARVEL	^{48}Ca	100 kg $^{48}\text{CaWO}_4$ crystal scintillators
COBRA	$^{116}\text{Cd}, ^{130}\text{Te}$	420 kg CdZnTe semiconductors
→ CUORE	^{130}Te	750 kg TeO_2 cryogenic bolometers <i>Cuoricino (bis Juni 08)</i>
DCBA	^{150}Nd	20 kg Nd layers between tracking chambers
EXO	^{136}Xe	1 ton Xe TPC (gas or liquid)
→ GERDA	^{76}Ge	~ 40 kg Ge diodes in LN_2 , expand to larger masses
GSO	^{160}Gd	2t $\text{Gd}_2\text{SiO}_3:\text{Ce}$ crystal scintillator in liquid scintillator
MAJORANA	^{76}Ge	~ 180 kg Ge diodes, expand to larger masses
MOON	^{100}Mo	several tons of Mo sheets between scint.
→ SNO++	^{150}Nd	1000 t of Nd-loaded liquid scint.
→ SuperNEMO	^{82}Se	100 kg of Se foils between TPCs <i>NEMO-3</i>
Xe	^{136}Xe	1.56 t of Xe in liquid scint.
XMASS	^{136}Xe	10 t of liquid Xe

Aus K. Zuber, Acta Polonica B 37, 1905 (2006)

GERDA @ LNGS

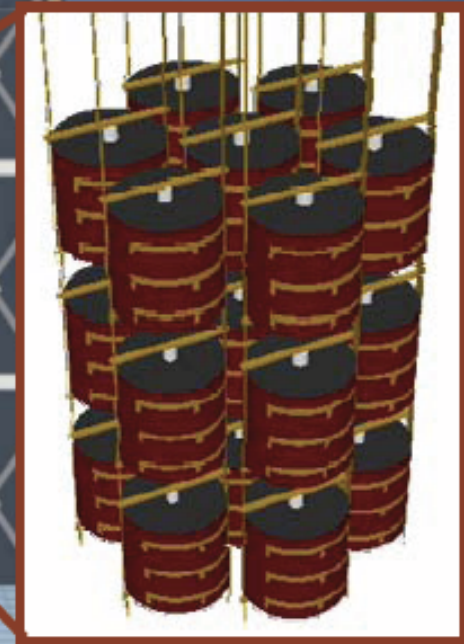
➤ Place array of naked HPGe-detectors enriched in ^{76}Ge in the center of a stainless cryostat filled with LAr.

Phase I: 20kg enriched (86%) ^{76}Ge , like HDM

Phase II: 100 kg*years, 0.1 – 0.3 eV

Phase III: O(1t) enriched ^{76}Ge , 10meV

Detector array



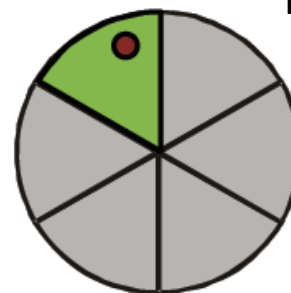
Status GERDA



GERDA Detectors

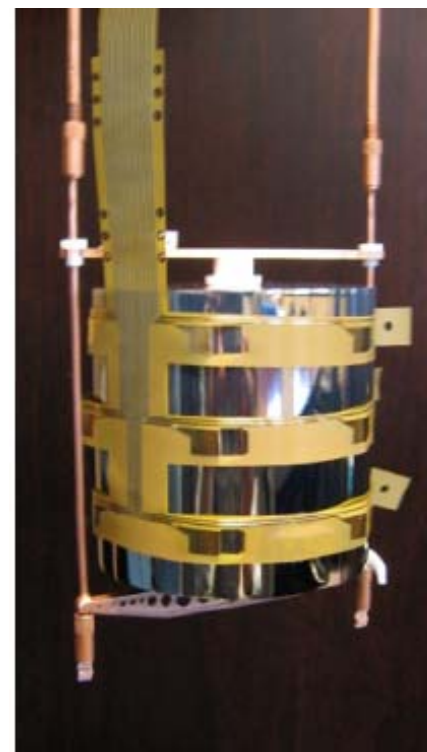
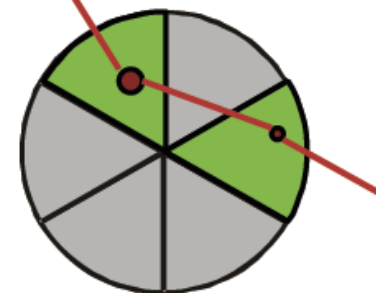


Signal:



Phase II:

Background:



18 fold
segmented
detector to
run in LAr



CUORICINO $\rightarrow$ CUORE

2v double beta with ^{130}Te ($Q=2529$ keV)

18 crystals $3 \times 3 \times 6$ cm³ + 44 crystals

$5 \times 5 \times 5$ cm³

40.7 kg of TeO_2

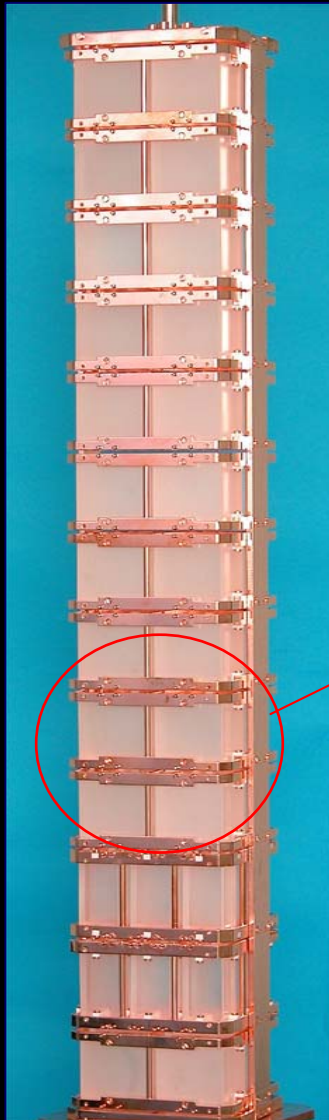
from 2003–2008

$\rightarrow 750$ kg TeO_2
 $\rightarrow 203$ kg ^{130}Te

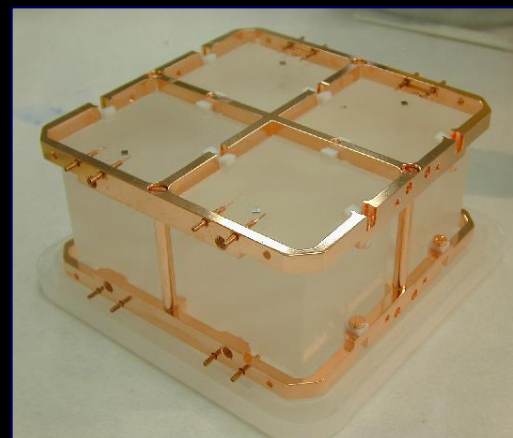
search for 0v double beta:

$T_{1/2}^{0\nu} (^{130}\text{Te}) > 7.5 \times 10^{23}$ y

$\langle m_\nu \rangle < 0.3 - 1.6$ eV



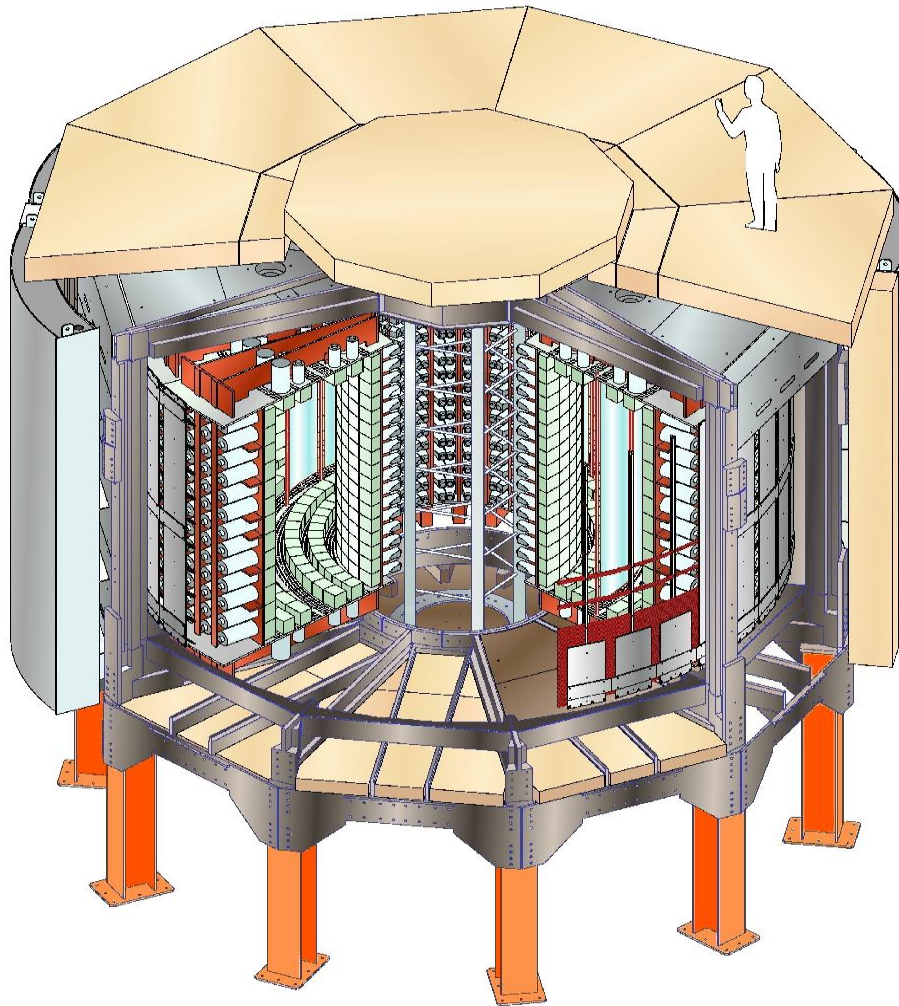
2 modules, 9 detector each,
 crystal dimension $3 \times 3 \times 6$ cm³
 crystal mass 330 g
 $9 \times 2 \times 0.33 = 5.94$ kg of TeO_2



11 modules, 4 detector each,
 crystal dimension $5 \times 5 \times 5$ cm³
 crystal mass 790 g
 $4 \times 11 \times 0.79 = 34.76$ kg of TeO_2



NEMO-3 @ Frejus Lab



Source: 10 kg of $\beta\beta$ isotopes
cylindrical, $S = 20 \text{ m}^2$, $e \sim 60 \text{ mg/cm}^2$

Tracking detector:

drift wire chamber operating
in Geiger mode (6180 cells)

Gas: He + 4% ethyl alcohol + 1% Ar + 0.1% H₂O

Calorimeter:

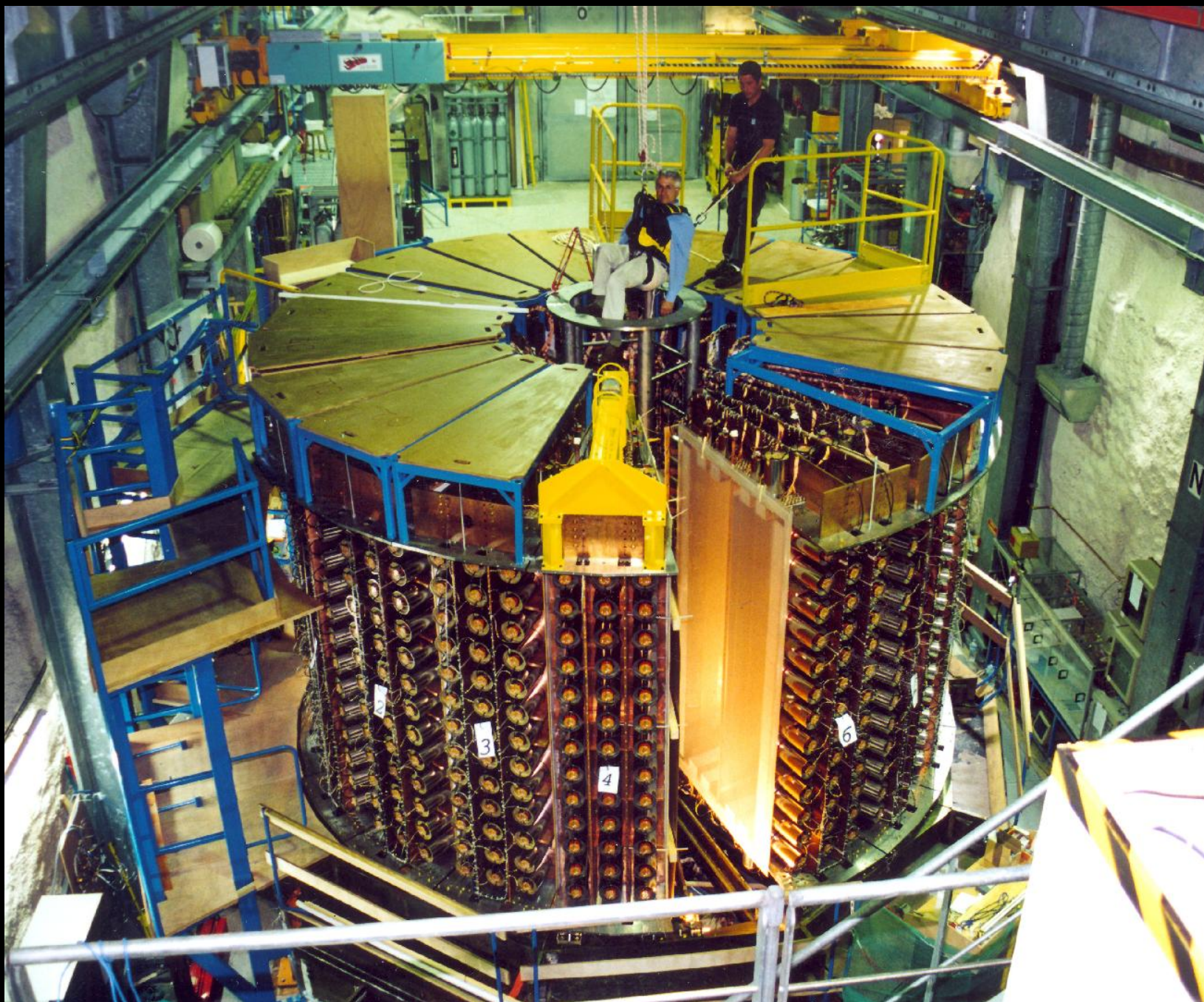
1940 plastic scintillators
coupled to low radioactivity PMTs

Magnetic field: 25 Gauss

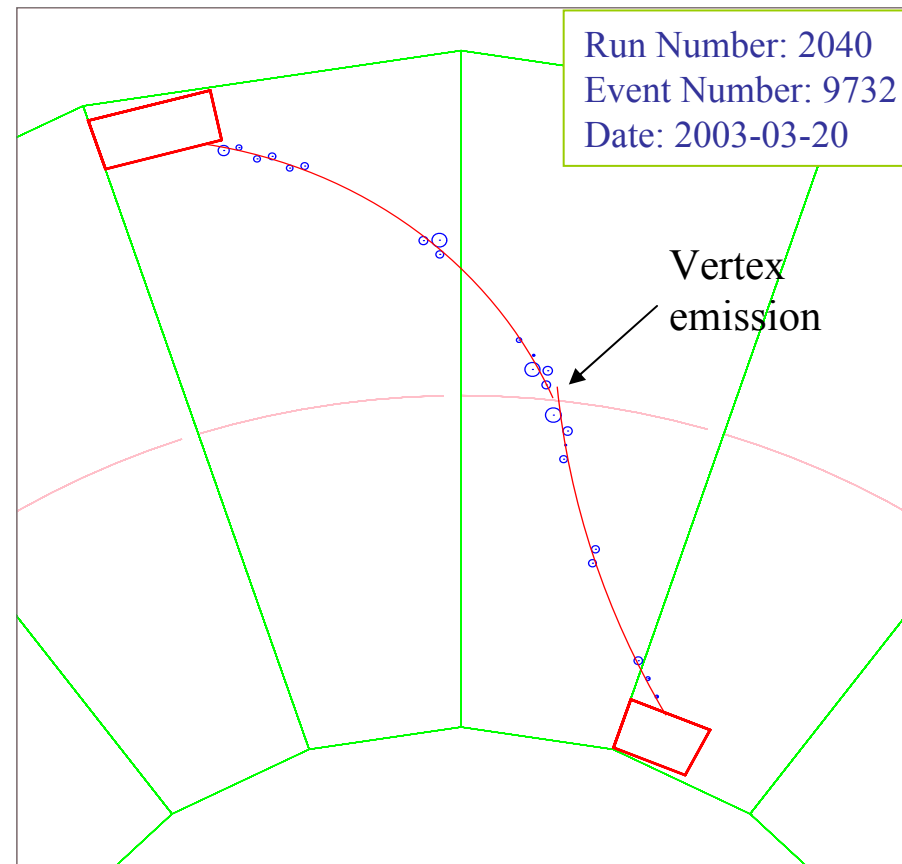
Gamma shield: Pure Iron ($e = 18 \text{ cm}$)

Neutron shield: 30 cm water (ext. wall)

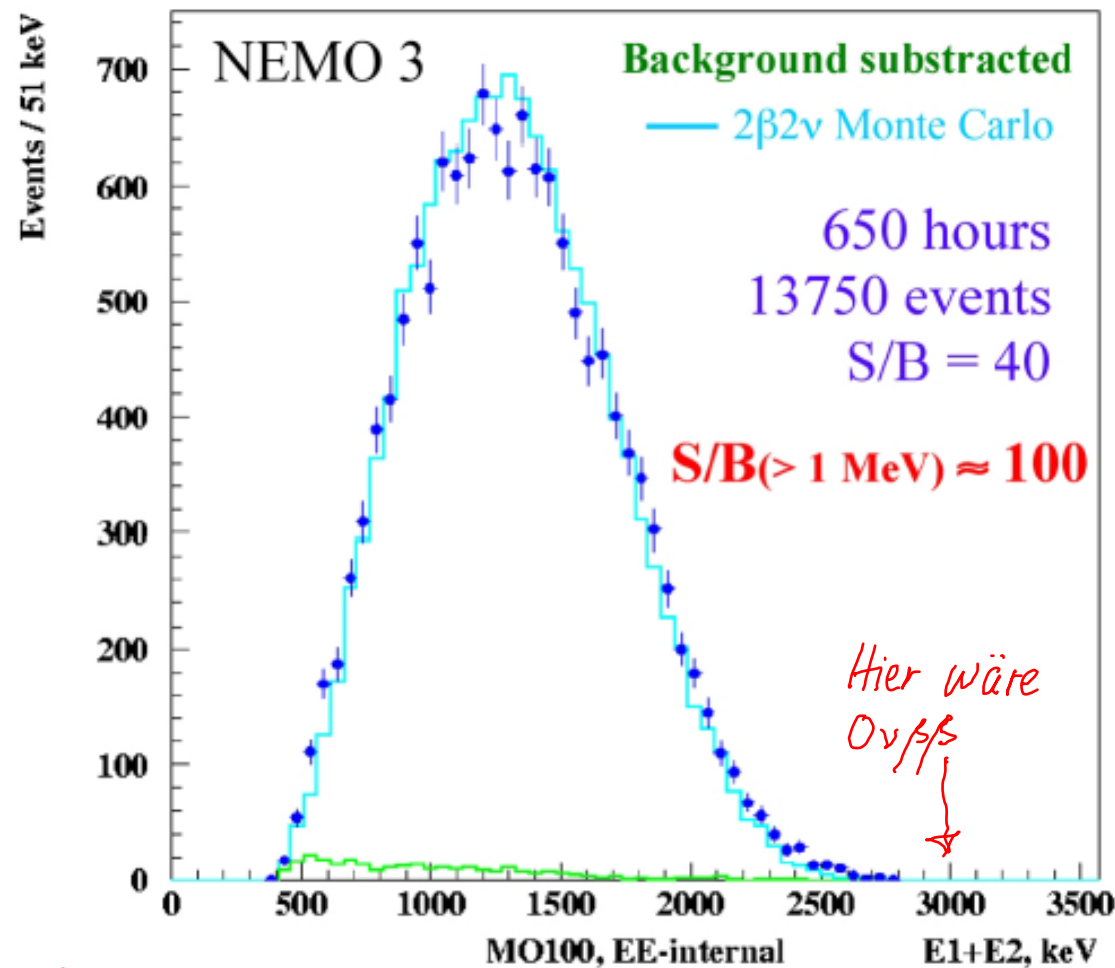
40 cm wood (top and bottom)
(since march 2004: water + boron)



^{100}Mo : $2\nu\beta\beta$ -event in NEMO-3

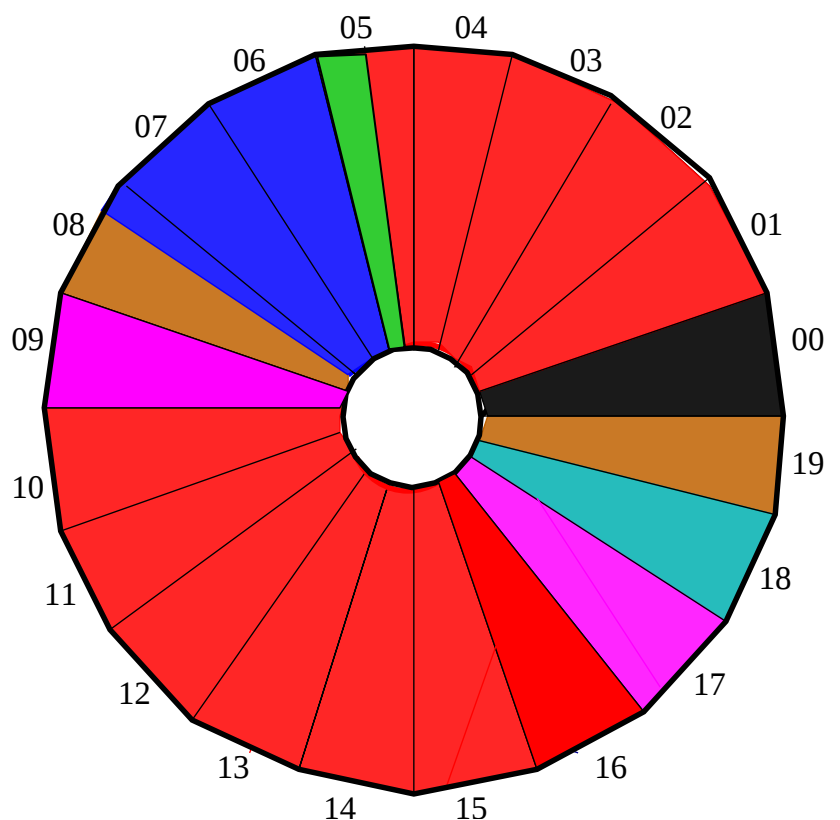


$2\nu\beta\beta$ -decay of ^{100}Mo in NEMO-3



Abgeleitete Grenze
für $0\nu\beta\beta$: $\langle m_\nu \rangle_{ee} < 0.7 - 1.2 \text{ eV}$

Overview Isotopes in NEMO-3



^{100}Mo 6.914 kg
 $Q_{\beta\beta} = 3034 \text{ keV}$

^{82}Se 0.932 kg
 $Q_{\beta\beta} = 2995 \text{ keV}$

$\beta\beta 0\nu$ search

$\beta\beta 2\nu$ measurement

^{116}Cd 405 g
 $Q_{\beta\beta} = 2805 \text{ keV}$

^{96}Zr 9.4 g
 $Q_{\beta\beta} = 3350 \text{ keV}$

^{150}Nd 37.0 g
 $Q_{\beta\beta} = 3367 \text{ keV}$

^{48}Ca 7.0 g
 $Q_{\beta\beta} = 4272 \text{ keV}$

^{130}Te 454 g
 $Q_{\beta\beta} = 2529 \text{ keV}$

$^{\text{nat}}\text{Te}$ 491 g

Cu 621 g

**External bkg
measurement**

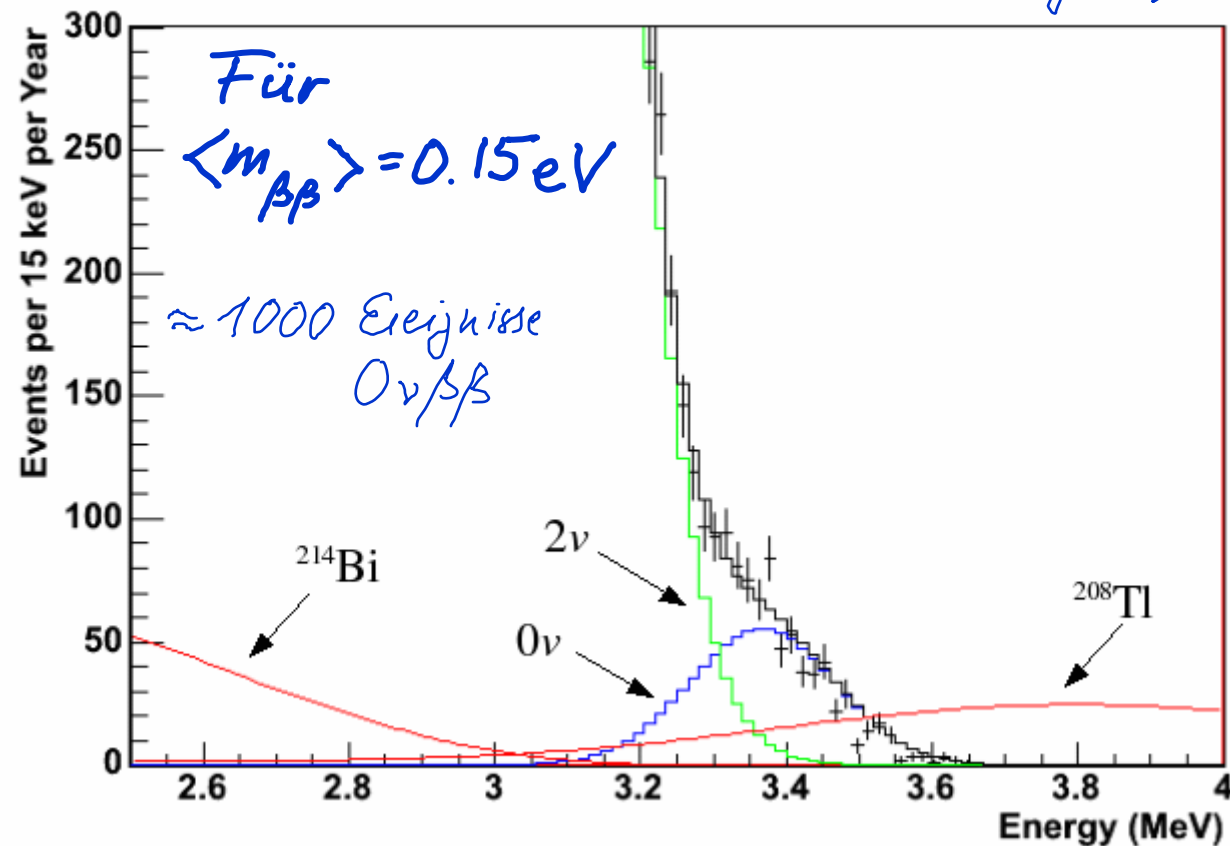
(All the enriched isotopes produced in Russia)

SNO+

D_2O wird durch Flüssig-Scintillator ersetzt
↳ Beladung mit Nd

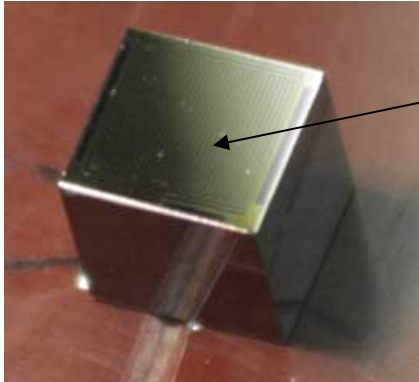
The Simulated Spectrum of Double Beta Decay Events

(1 Jahr)



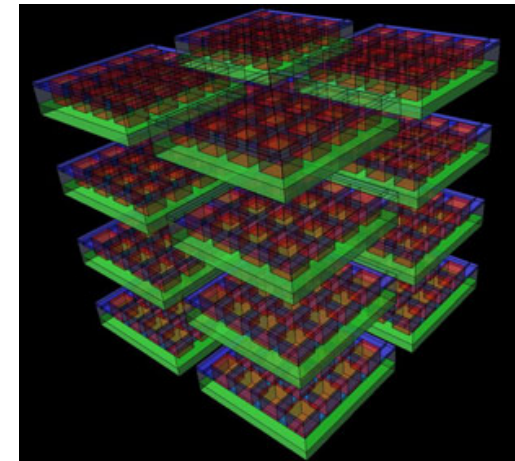
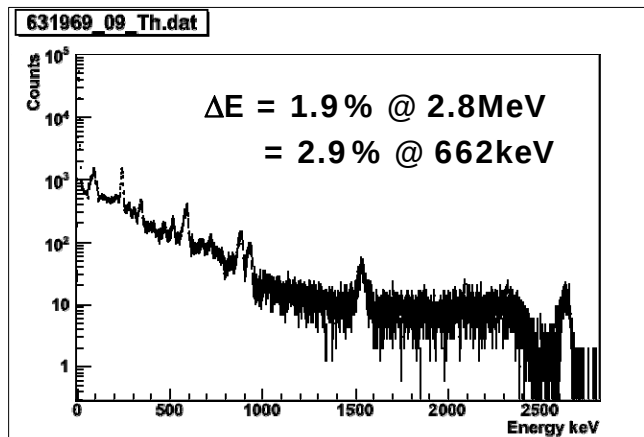
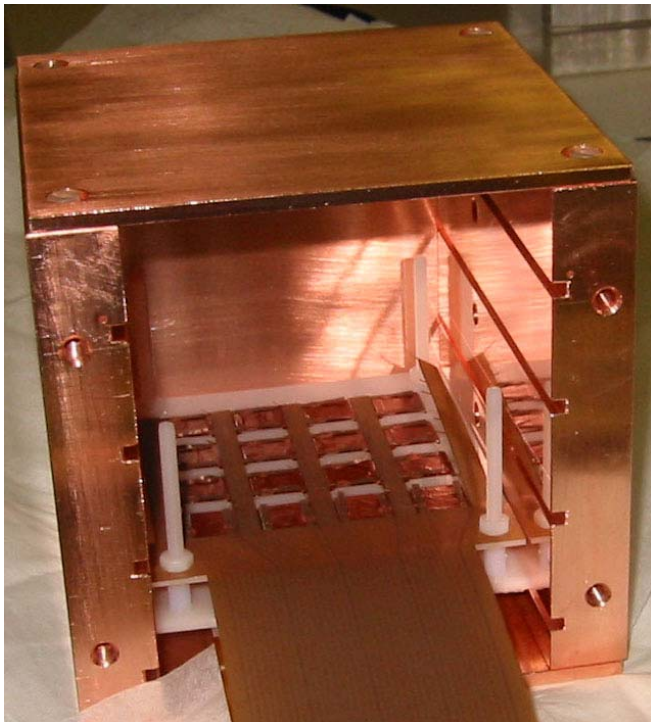


COBRA experiment



Uses CdZnTe (Cadmium Zinc Telluride) detectors

- Source = detector
- Semiconductor (Good energy resolution, clean)
- Room temperature
- Modular design (Coincidences)
- different isotopes possible
- Industrial development of CdTe detectors
- ^{116}Cd above 2.614 MeV
- Tracking („Solid state TPC“)





COBRA experiment

	isotope	nat. ab. (%)	Q (keV)	Decay mode
	Zn70	0.62	1001	β - β -
	Cd114	28.7	534	β - β -
→	Cd116	7.5	2809	β - β -
	Te128	31.7	868	β - β -
→	Te130	33.8	2529	β - β -
	Zn64	48.6	1096	β + /EC
→	Cd106	1.21	2771	β + β +
	Cd108	0.9	231	EC/EC
	Te120	0.1	1722	β + /EC

