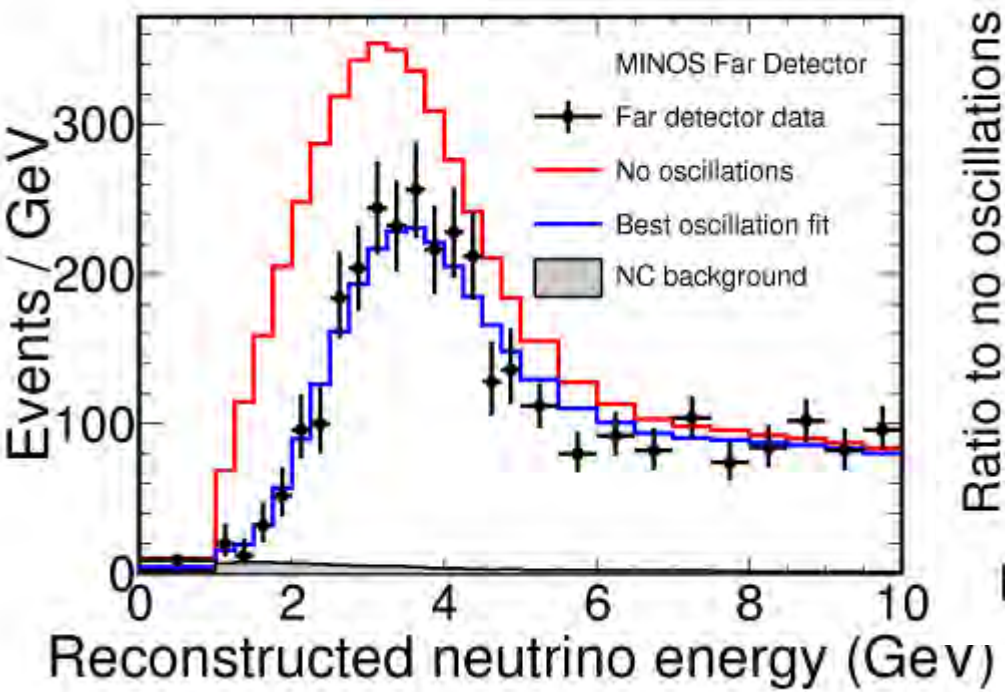
Neutrinophysik: Status und Ausblick

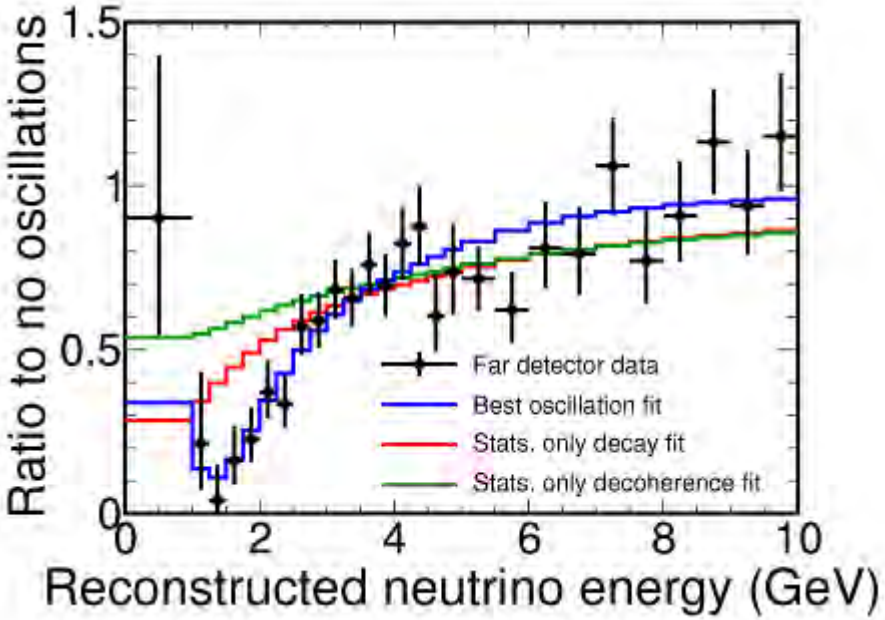
Caren Hagner, Universität Hamburg

- Neue Ergebnisse der Experimente mit Neutrinostrahlen an Beschleunigern (MINOS und OPERA)
- Neue Ergebnisse im Bereich der Sonnenneutrinos (BOREXINO)
- T2K, MINOS und Double Chooz Ergebnisse zu θ_{13}
- LAGUNA-LBNO
- Zusammenfassung

MINOS Results: ν_μ Dissappearance

for $7.25 \cdot 10^{20}$pot



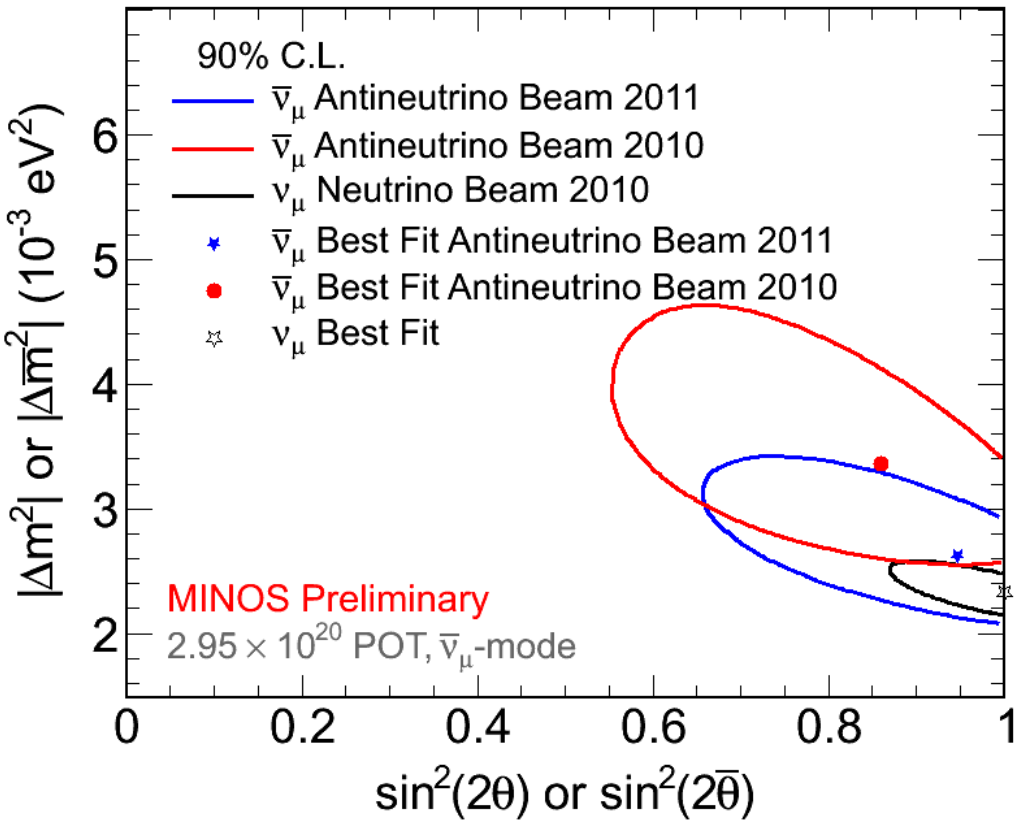


$$\left|\Delta m^2_{32}\right| = 2.32^{+0.12}_{-0.08} \times 10^{-3}\,\mathrm{eV}^2 \quad (90\%\mathrm{CL})$$

$$\sin^2 2\theta_{23} > 0.90 \quad (90\%\mathrm{CL})$$

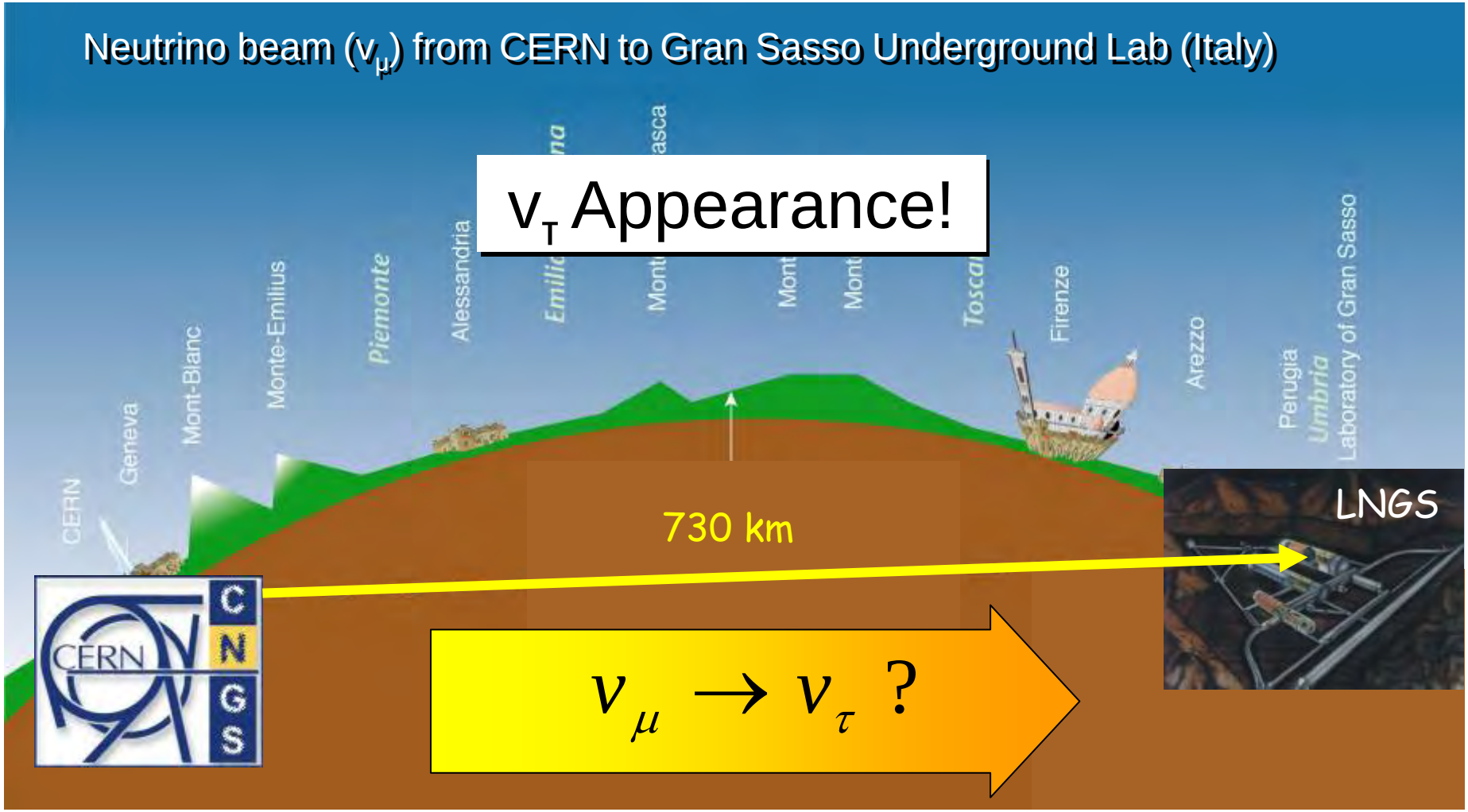
"Measurement of the neutrino mass splitting and flavor mixing by MINOS "
MINOS Coll., Phys.Rev.Lett.106:181801,2011 (arXiv:1103.0340)

Comparison between Neutrino and Anti-Neutrino Results



Alte Auswertung (2010) „Tension“ zwischen Neutrino und Antineutrino Resultat
Neue Auswertung (2011) mit 2.95 10^{20} pot: Gute Übereinstimmung

OPERA:
Oscillation Project with Emulsion tRacking Apparatus

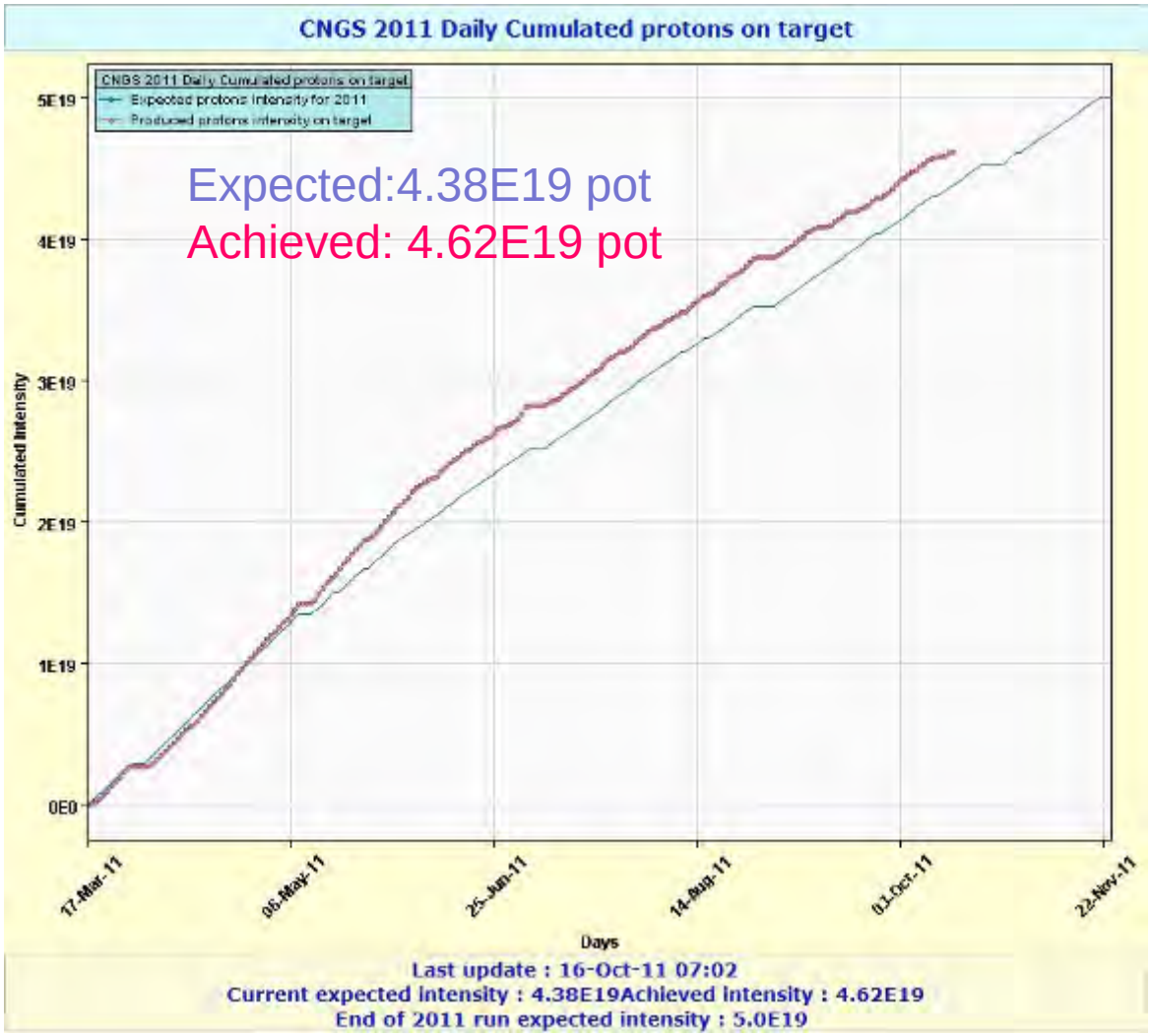


Physics runs: 2008, 2009, 2010, 2011 completed

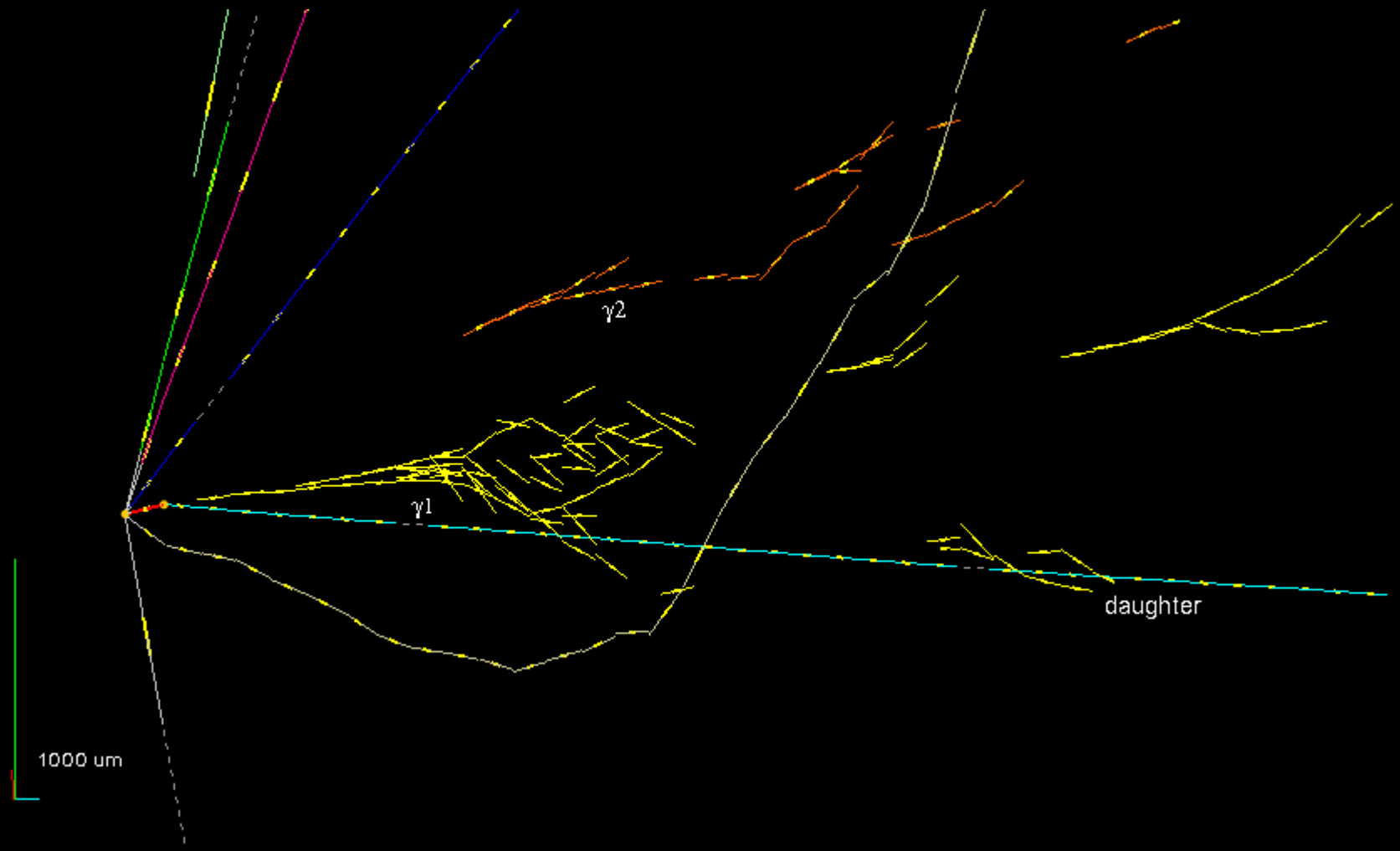
Total Integrated Beam Intensity since CNGS Start in 2006

Bis zum 16.10.2011

Protons on target/year	
2006	0.08 E19
2007	0.08 E19
2008	1.78 E19
2009	3.52 E19
2010	4.04 E19
2011	4.62E19
Total	**14.12 E19**



reconstructed ν_T candidate event



Interpretation of the event: $\tau \rightarrow \rho\,(\pi\,\pi^0)\,\nu_\tau$

- Invariant mass of $\gamma\,\gamma$ system compatible with π^0 mass value.
- Invariant mass of the $\pi\,\gamma\,\gamma$ system compatible with ρ (770)

π^0 mass	ρ mass
$120 \pm 20 \pm 35$ MeV	$640\ ^{+125}_{-80}\ ^{+100}_{-90}$ MeV

OPERA collaboration:
„Observation of a first ν_τ candidate event in the OPERA experiment…”,
Phys. Lett. B 691 (2010) 138.

Analyse der 2008, 2009 Daten:

2738 events analysiert (92% der Daten aus 2008 und 2009)

Decay channel	Number of signal events expected for 22.5×10^{19} p.o.t.	Analysed sample	Interaction vertex location efficiency
$\tau \to \mu$	1.79	0.39	0.54
$\tau \to e$	2.89	0.63	0.59
$\tau \to h$	2.25	0.49	0.59
$\tau \to 3h$	0.71	0.15	0.64
Total	7.63	1.65	

Table 3: Expected numbers of observed signal events for 22.5×10^{19} p.o.t. and for the analysed sample of the data accumulated in the 2008 and 2009 runs. Updated efficiencies for locating interaction vertices appear in the last column

0.05

0.16

background

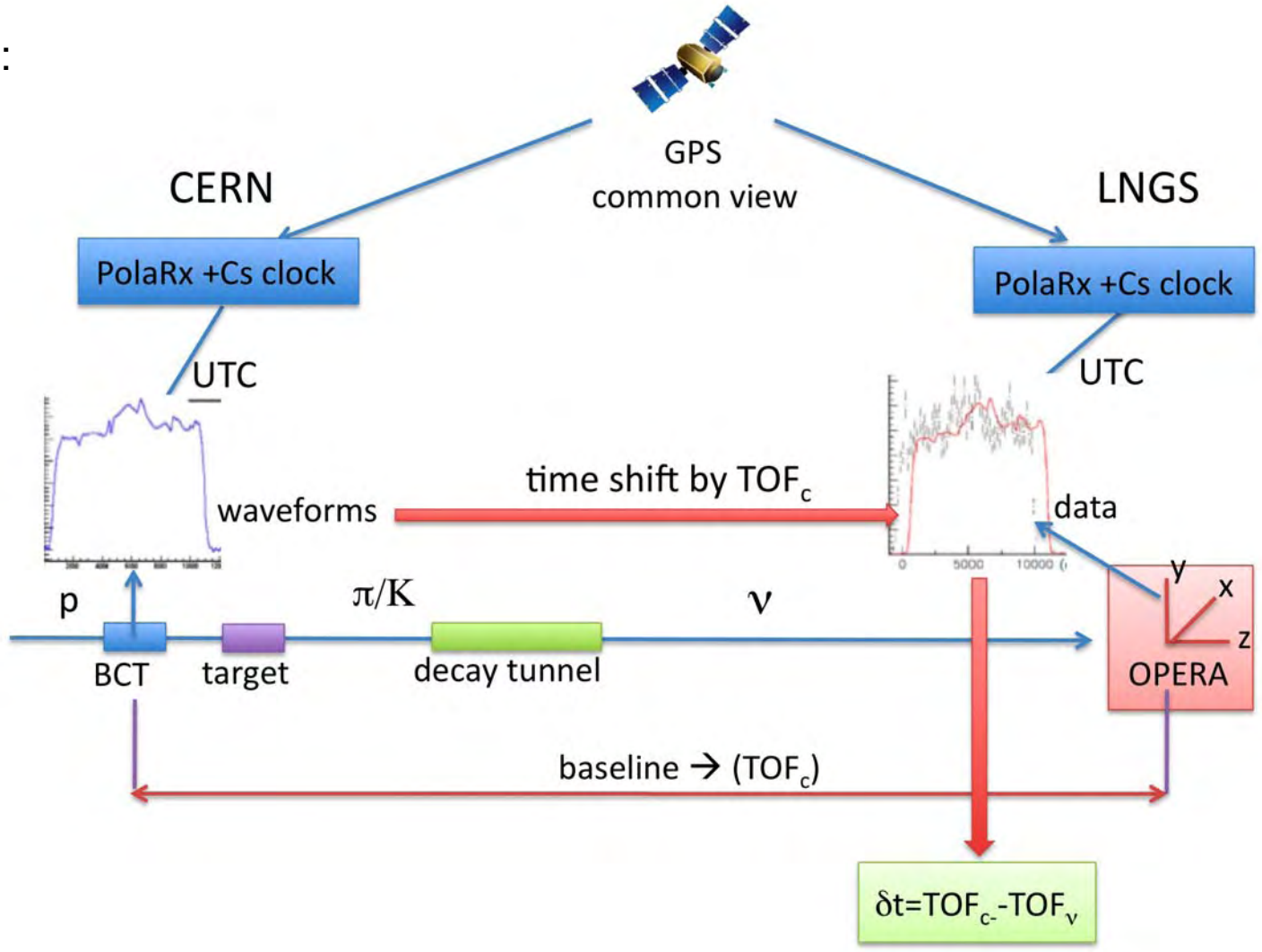
Compare to 1 event observed

Tau – hadron channel: Probability that event is not a background fluctuation: 95%
All channels: probability that event is background: 15%

Opera Coll., “Search for vmu - vtau oscillation with the OPERA experiment in the CNGS beam” arXiv:1107.2594v1 submitted to Phys.Lett.B

Neutrino Geschwindigkeit: Methode

Methode:



Neutrino Geschwindigkeit: Ergebnis

Neutrinos kommen früher an als erwartet (für v=c) um:

$$57.8 \pm 7.8(\text{stat})^{+8.3}_{-5.9}(\text{sys})\ \text{nsec}$$

Dies entspricht einem Geschwindigkeitsunterschied (v - c)/c:

$$\left(2.37 \pm 0.32(\text{stat})^{+0.34}_{-0.24}(\text{sys})\right) \times 10^{-5}$$

Baseline 730.085km

OPERA coll., „Measurement of the neutrino velocity with the OPERA detector in the CNGS beam" arXiv:1109.4897, submitted to JHEP yesterday

Alternative Analyse (Fit mit einzelnen Proton Pdfs) ergibt

$$54.5 \pm 5.0(\text{stat})^{+9.6}_{-7.2}(\text{sys})\ \text{nsec}$$

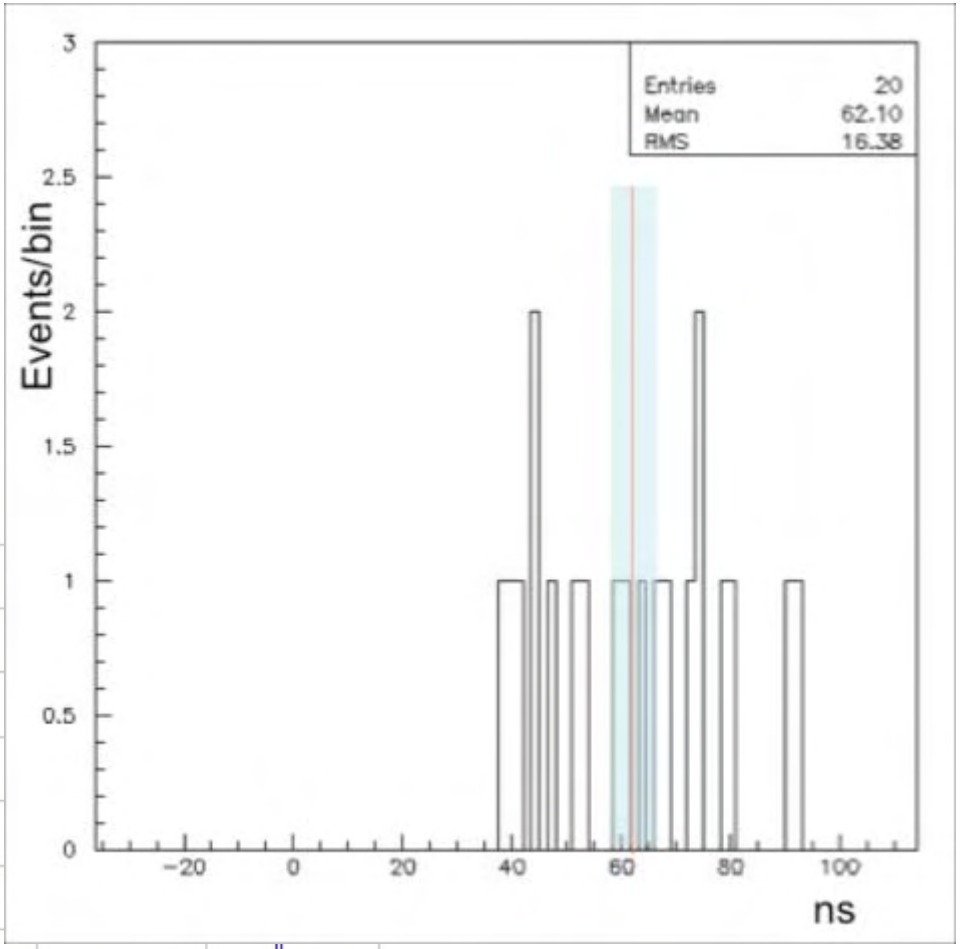
OPERA: Bunched Beam Test

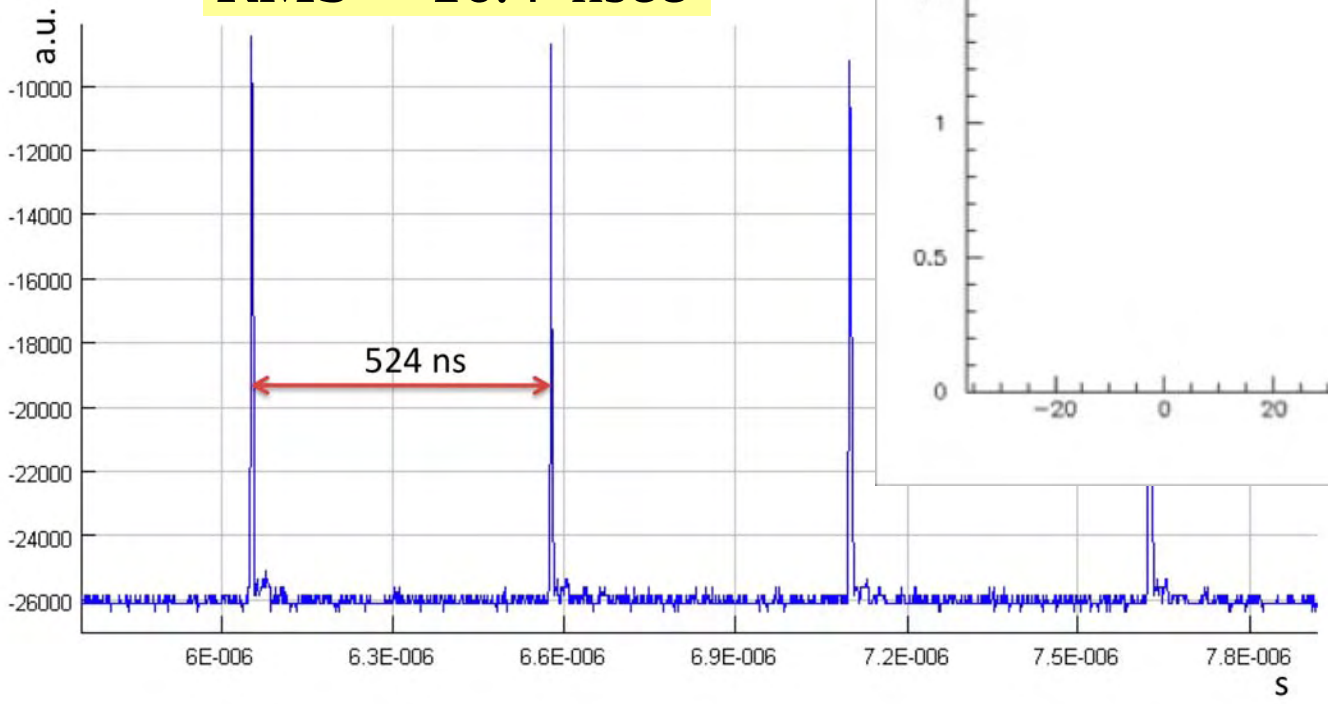
CERN provided „bunched beam“:
22.Oct – 6. Nov 2011, 4×10^{16}pot
20 events registered

Result agrees with standard analysis:

$$(62.1 \pm 3.7)\text{nsec}$$

$$\text{RMS} = 16.4 \text{ nsec}$$





Vergleich mit anderen Messungen

OPERA 2011 (Myonneutrinos, 17GeV) (v – c)/c :

$$\left(2.37 \pm 0.32\,(\text{stat})^{+0.34}_{-0.24}\,(\text{sys})\right) \times 10^{-5}$$

MINOS (Myonneutrinos, 2 GeV)

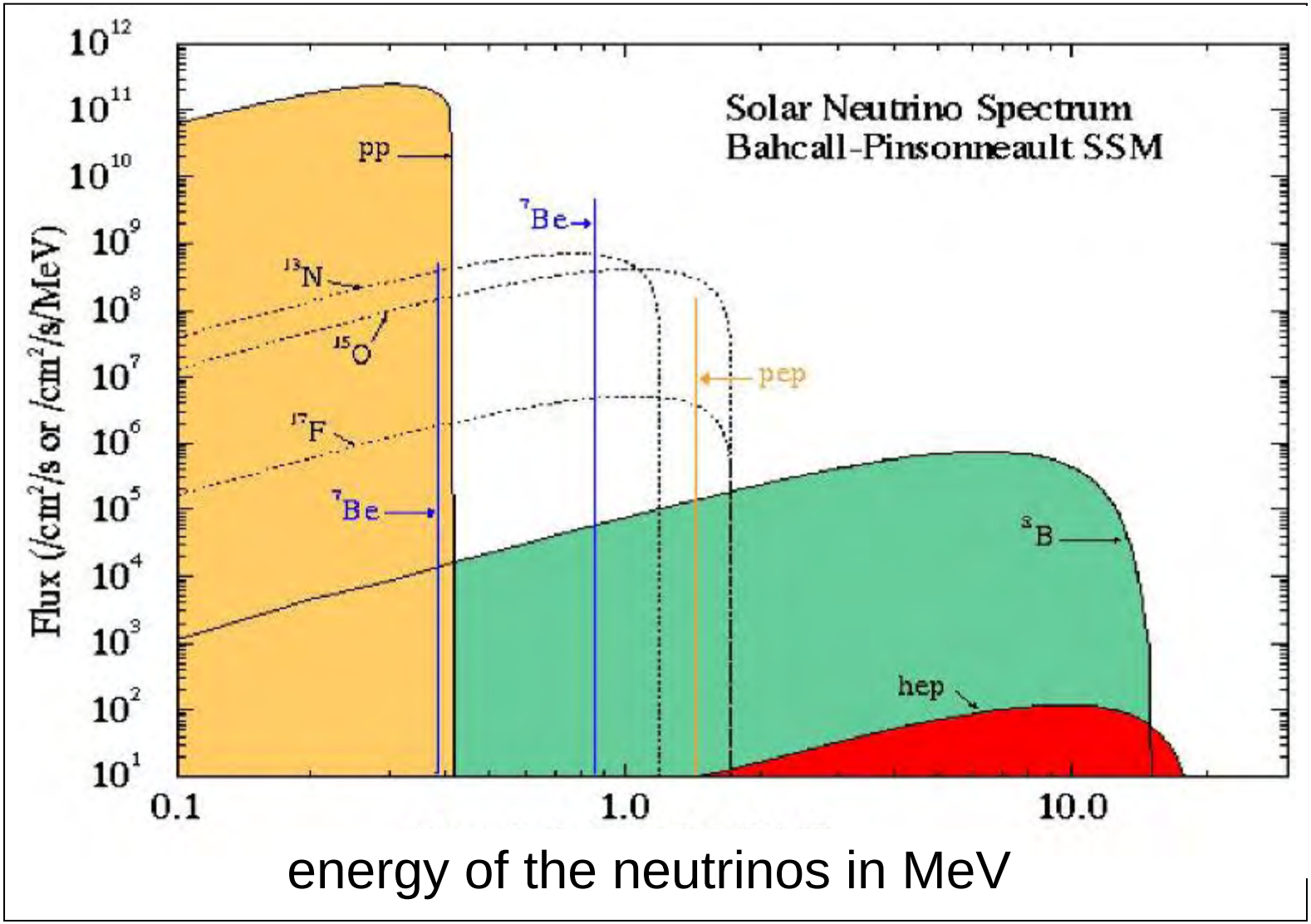
$$\left(5.1 \pm 2.9\right) \times 10^{-5}$$

SN 1987A (Anti- Elektronneutrinos, E einige 10MeV)

$$< 2 \times 10^{-9}$$

Ausblick:
Messung von v mit anderen LNGS Experimenten (Borexino, Icarus, LVD) sowie MINOS, T2K

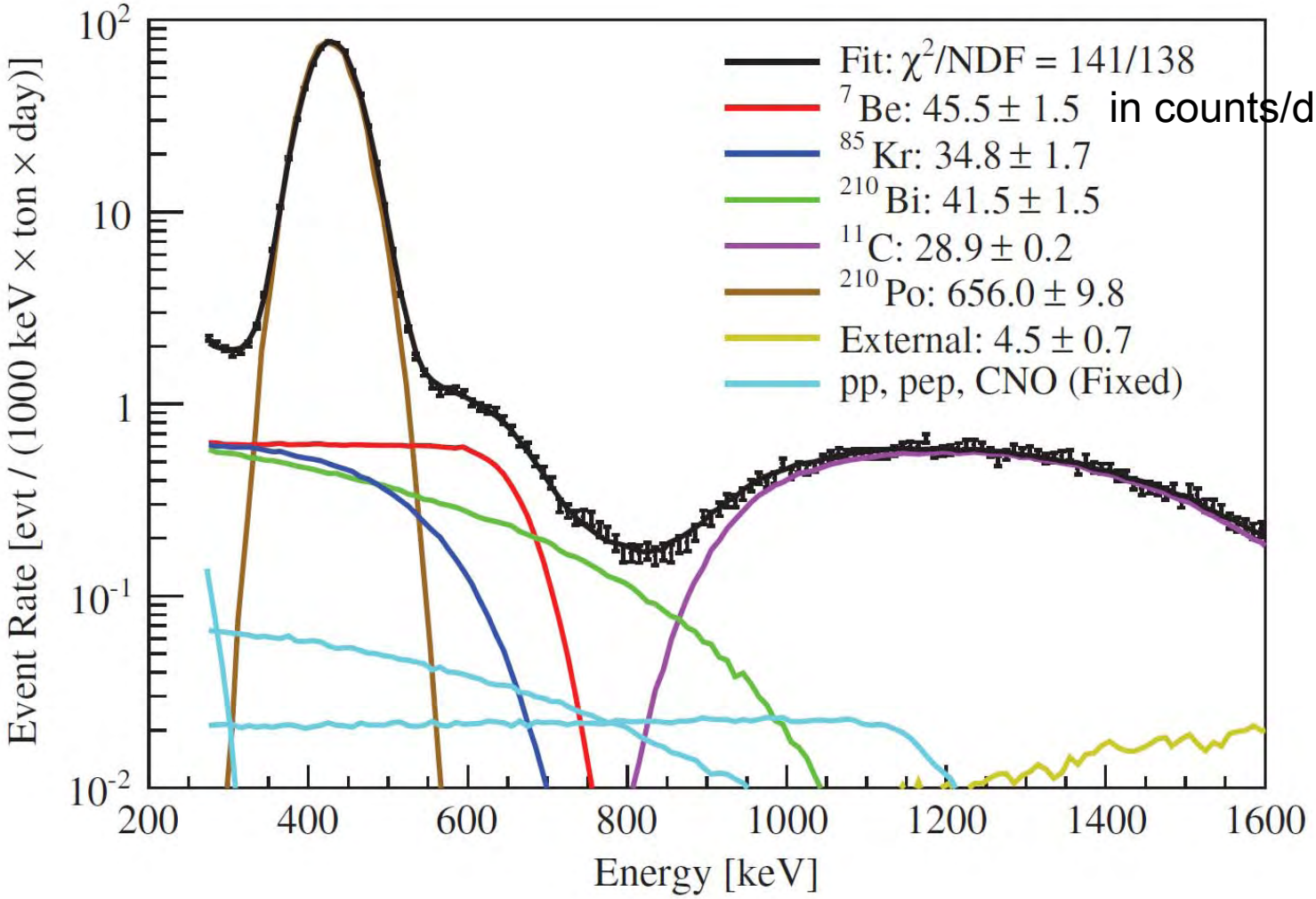
The new generation of solar neutrino experiments



Borexino:
300t Liquid Scintillator

Signal:
elastische Neutrino – Elektron Streuung

Main Borexino Result: Flux of 7Be Neutrinos



in counts/day/100t

Borexino Coll. „precision measurement of the 7Be solar neutrino interaction rate in Borexino“, PRL 107, 141301 (2011)

Was bedeutet das Borexino Ergebnis?

46 ± 1.5stat ± 1.6sys cpd/100 t

Prediction of standard solar model:

No oscillation	74 ± 5	cpd/100 t
Oscillation (LMA):		
„high metalicity“	47 ± 3	cpd/100t
„low metalicity“	44 ± 4	cpd/100 t

„No-Oscillation“ is excluded from BOREXINO alone with more than 4.9 sigma.

$$\phi(^7\mathrm{Be}) = (4.84 \pm 0.24) \times 10^9\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$$

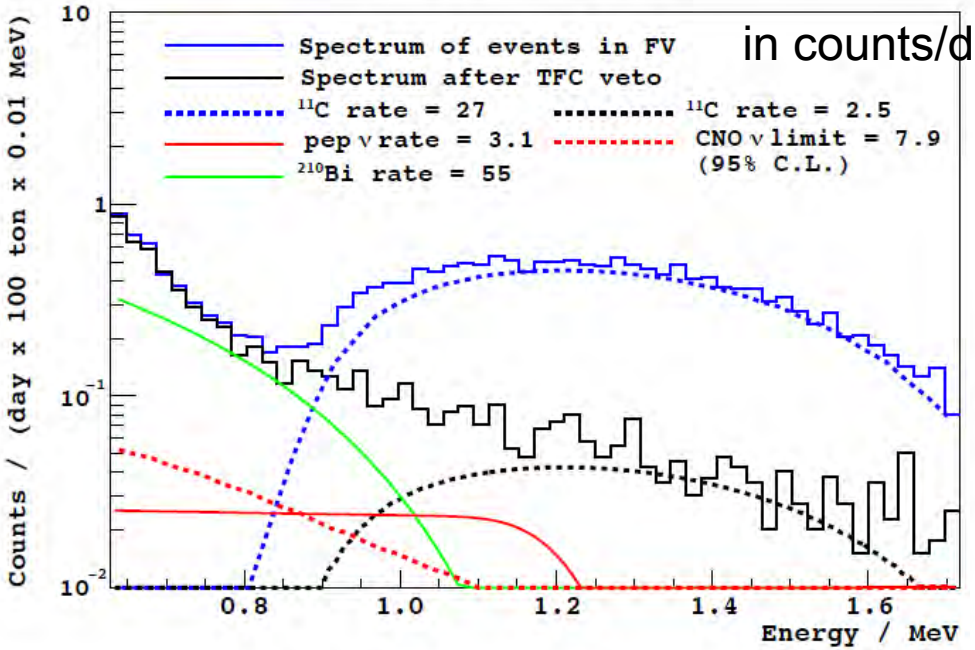
$$f(^7\mathrm{Be}) = \phi(^7\mathrm{Be}) / \phi_{\mathrm{SSM}} = 0.97 \pm 0.09$$

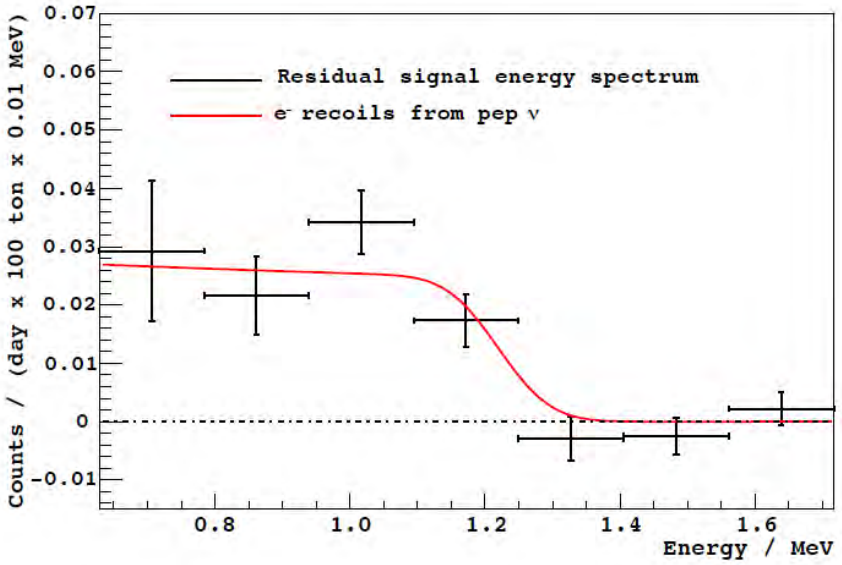
$$f(\mathrm{pp}) = 1.013^{+0.003}_{-0.010}$$

$$\text{Contribution of CNO} < 1.7\%\,(95\%\mathrm{CL})$$

New, first time! Measurement of pep Neutrinos

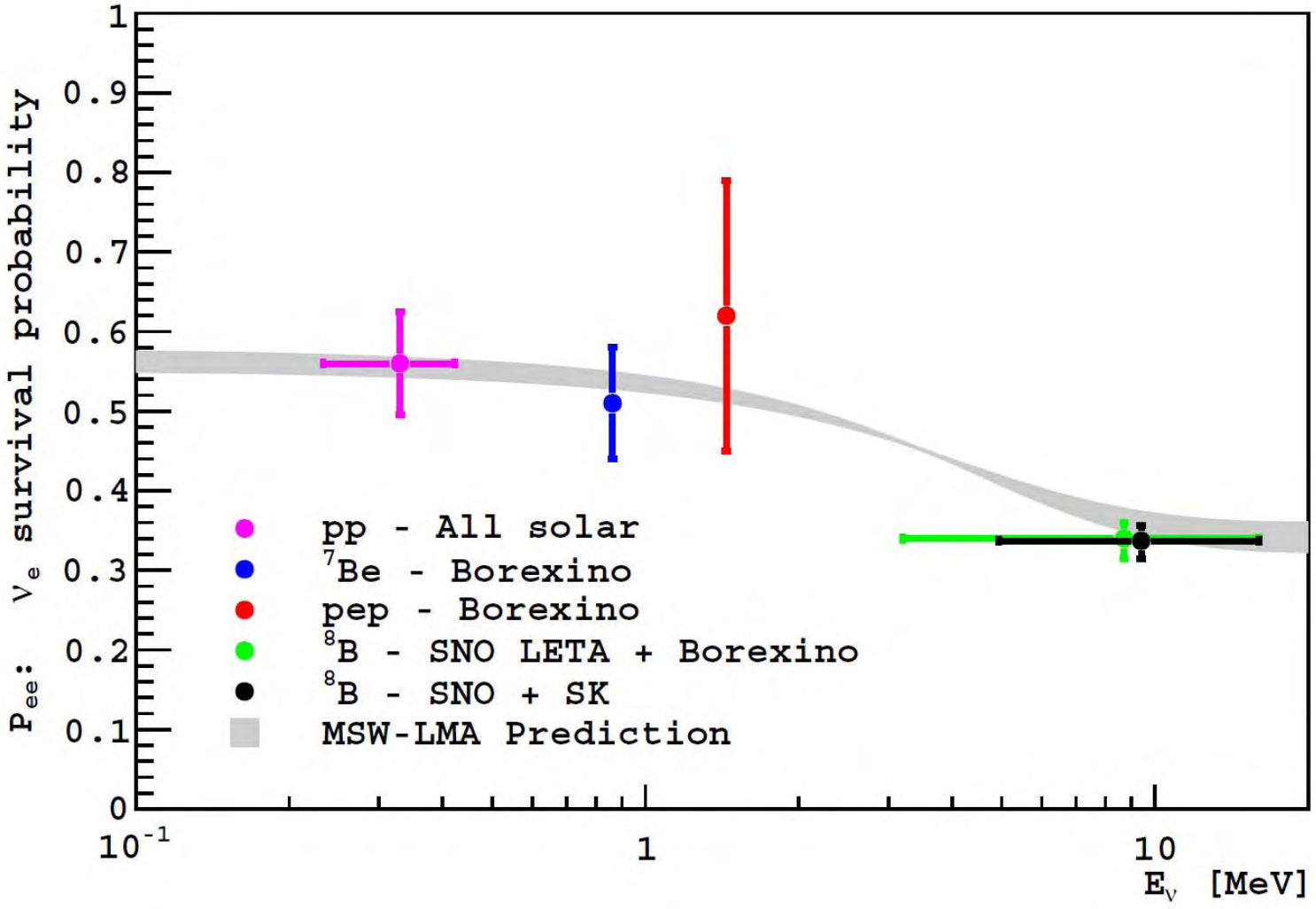
pep neutrinos: monoenergetic E = 1.4 MeV, „compton-like“ edge at 1.2 MeV



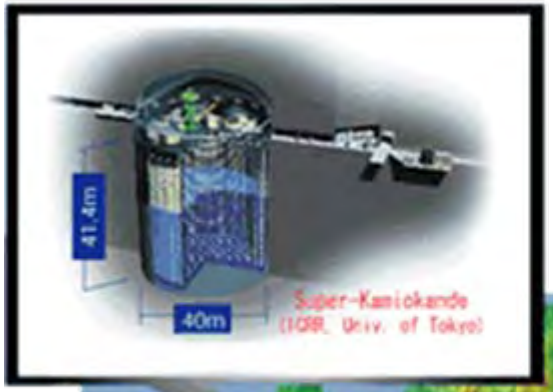


Borexino Coll. „First evidence of pep solar neutrinos by direct detection in Borexino“, arXiv:1110.3230v1 (2011)

Testing the MSW hypothesis:



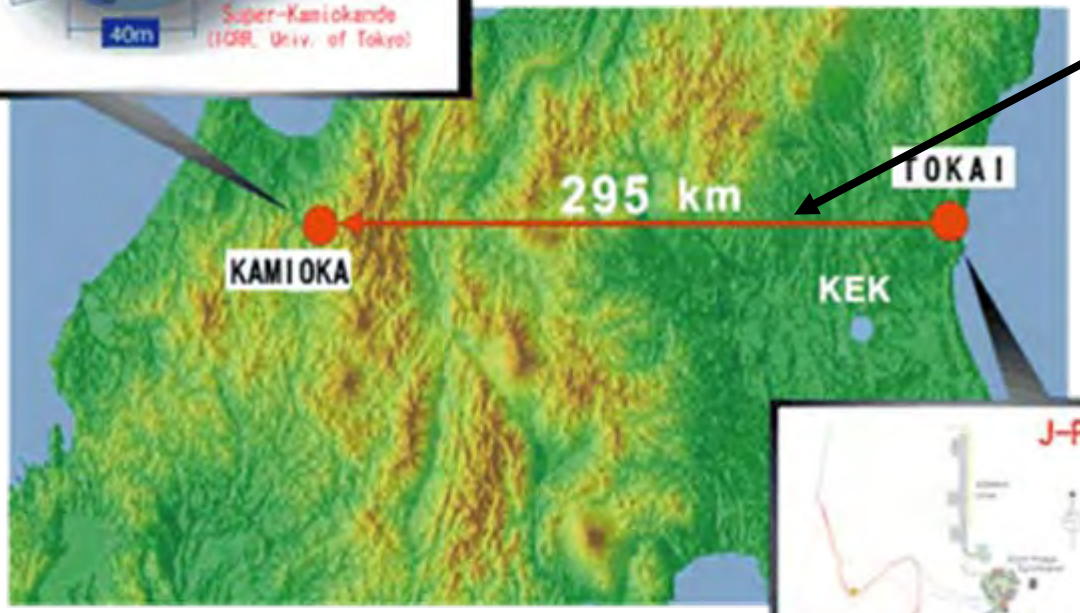
T2K (Tokai to Kamioka)



First neutrinos produced on April 23rd 2009

Off-Axis Detector Superkamiokande

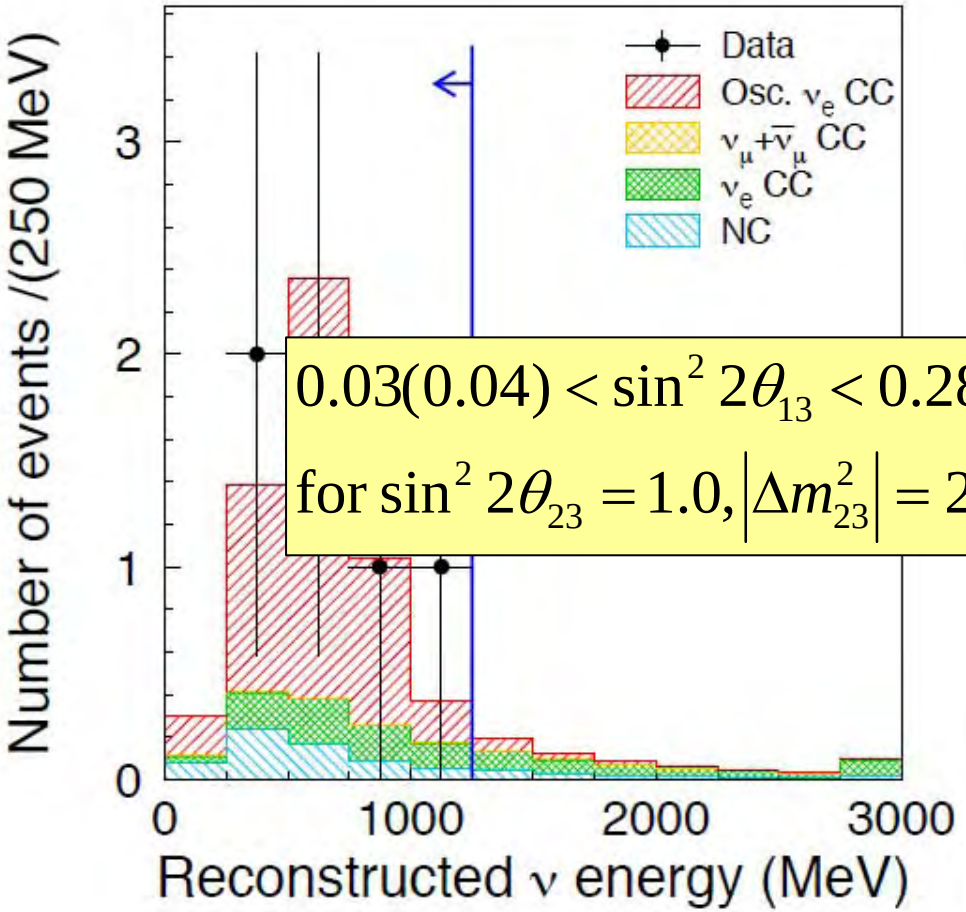
Neutrino Super Beam



Proton driver

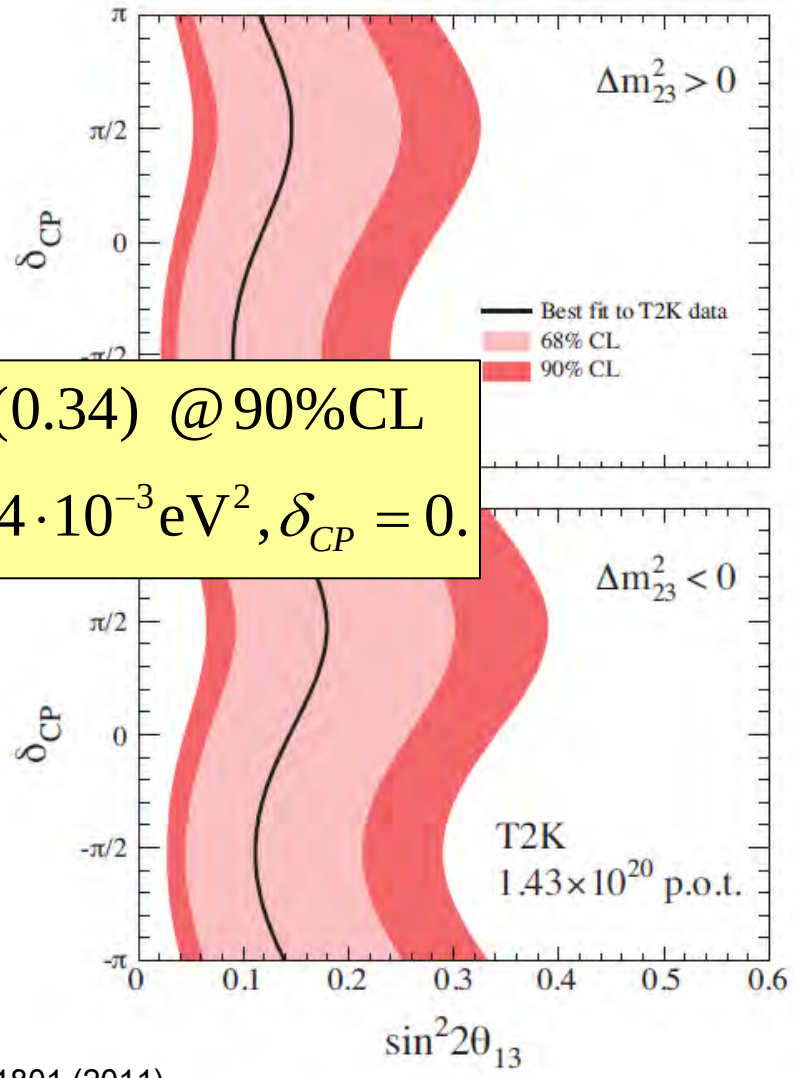
Stop due to earthquake and tsunami in march 2011 (infrastructure damaged)
Restart accelerator 1.12.2011

T2K: Appearance of ν_e in ν_μ Beam!



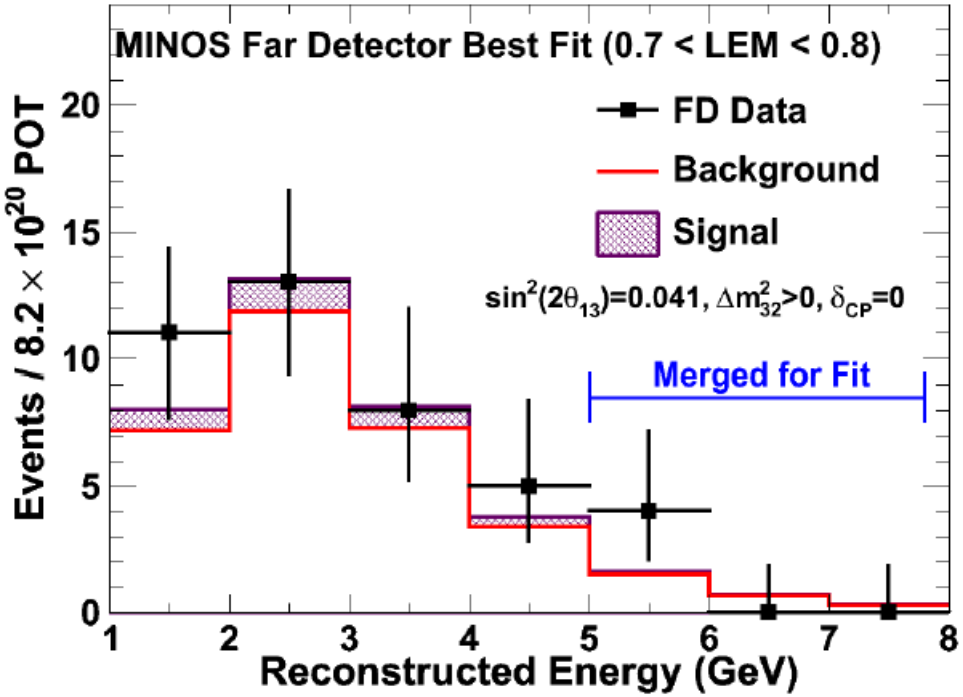
$$0.03(0.04) < \sin^2 2\theta_{13} < 0.28(0.34) \ @\,90\%\text{CL}$$

$$\text{for } \sin^2 2\theta_{23} = 1.0, \left|\Delta m^2_{23}\right| = 2.4 \cdot 10^{-3}\text{eV}^2, \delta_{CP} = 0.$$



T2K Coll., "Indication of Electron Neutrino Appearance from an Accelerator-produced Off-axis Muon Neutrino Beam", PRL 107, 041801 (2011)

MINOS ν_e appearance

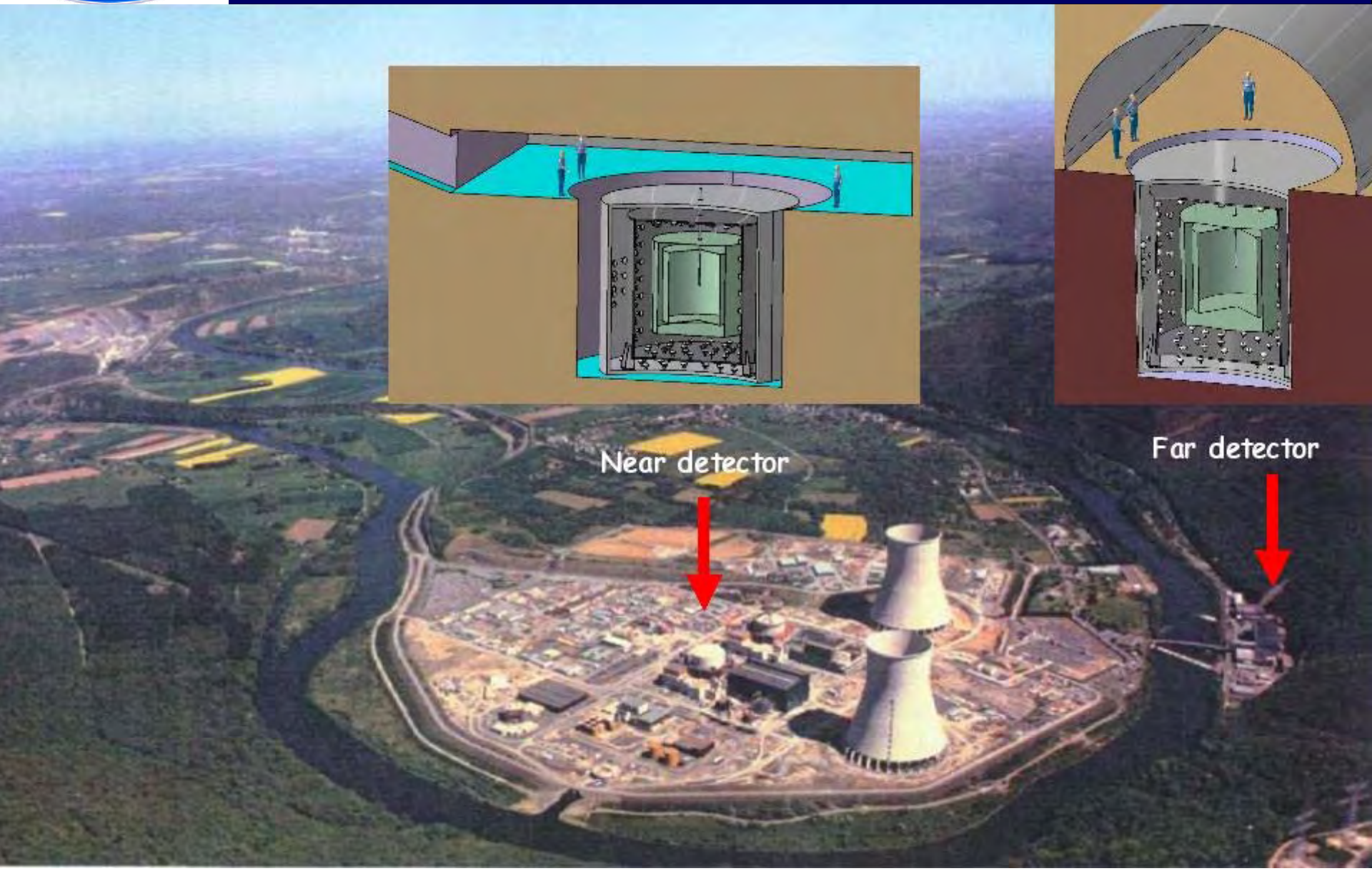


Expected background (θ_{13}=0):
49.6 +- 2.7 (syst) +- 7.0 (stat)

Observed data: **62**

Phys. Rev. Lett. 107, 181802 (2011)

Double-CHOOZ



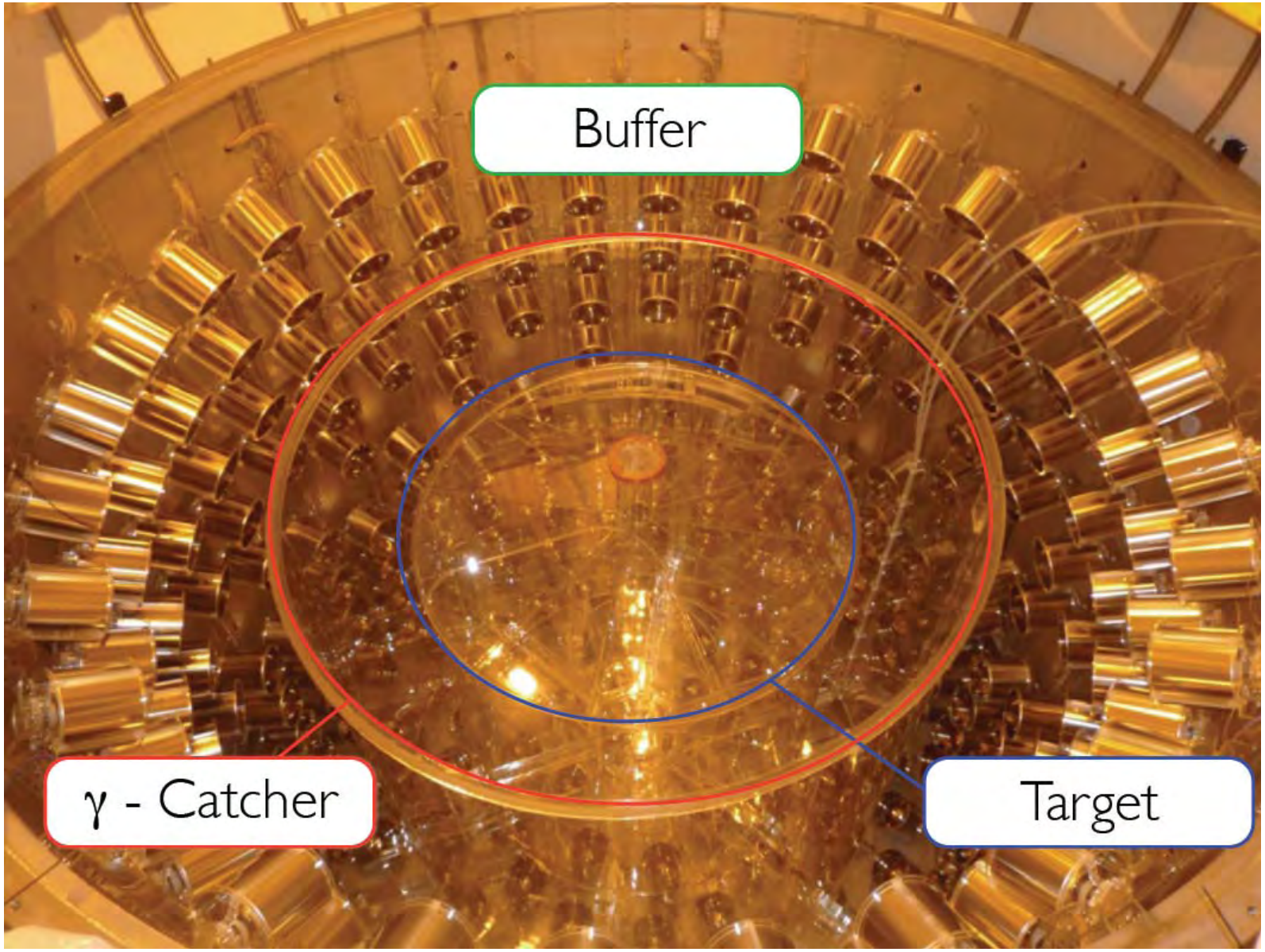
Double Chooz Milestones

- Mai 2008 - Oktober 2010: Aufbau ferner Detektor
- Dezember 2010: Ferner Detektor gefüllt
- April 2011: Start Data Taking mit fernem Detektor
- November 2011: Erste Analyse der Neutrinodaten

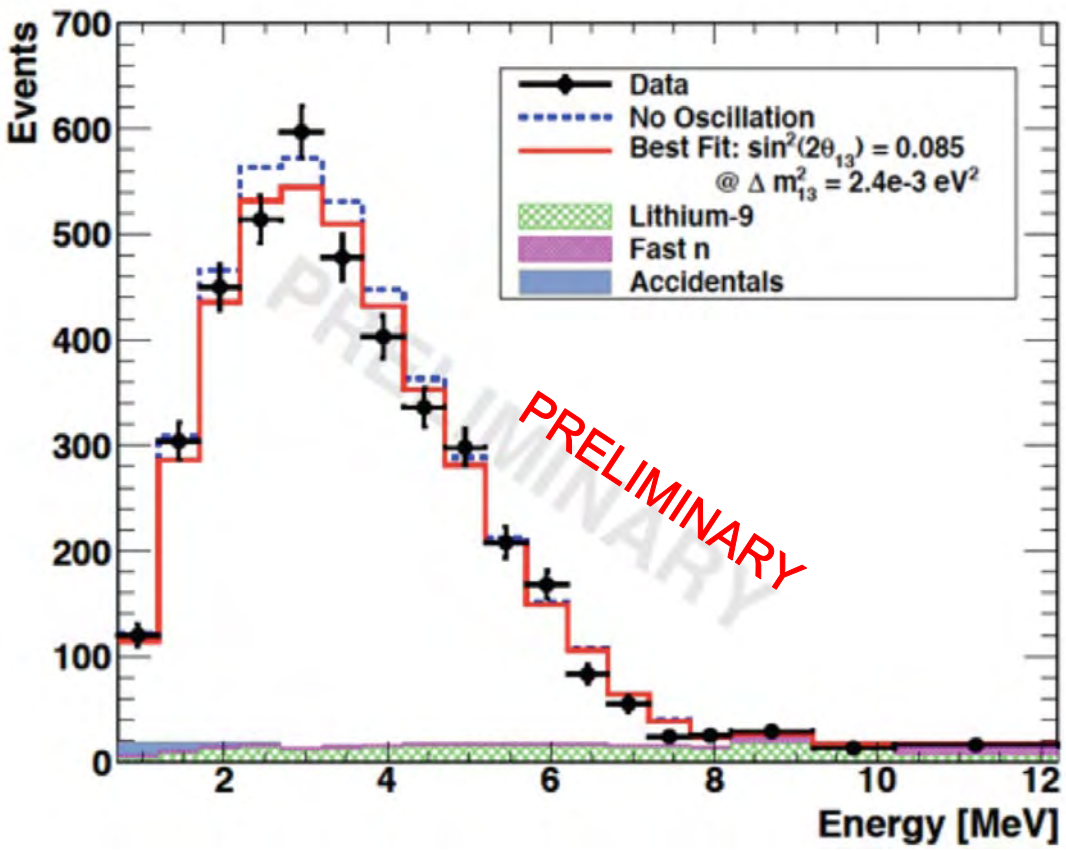
- April 2011: Bau des Labors für nahen Detektor begonnen
- Juni 2012: Labor naher Detektor fertig
- Beginn 2013: Naher Detektor fertig

Datennahme mit beiden Detektoren

Double Chooz Detector



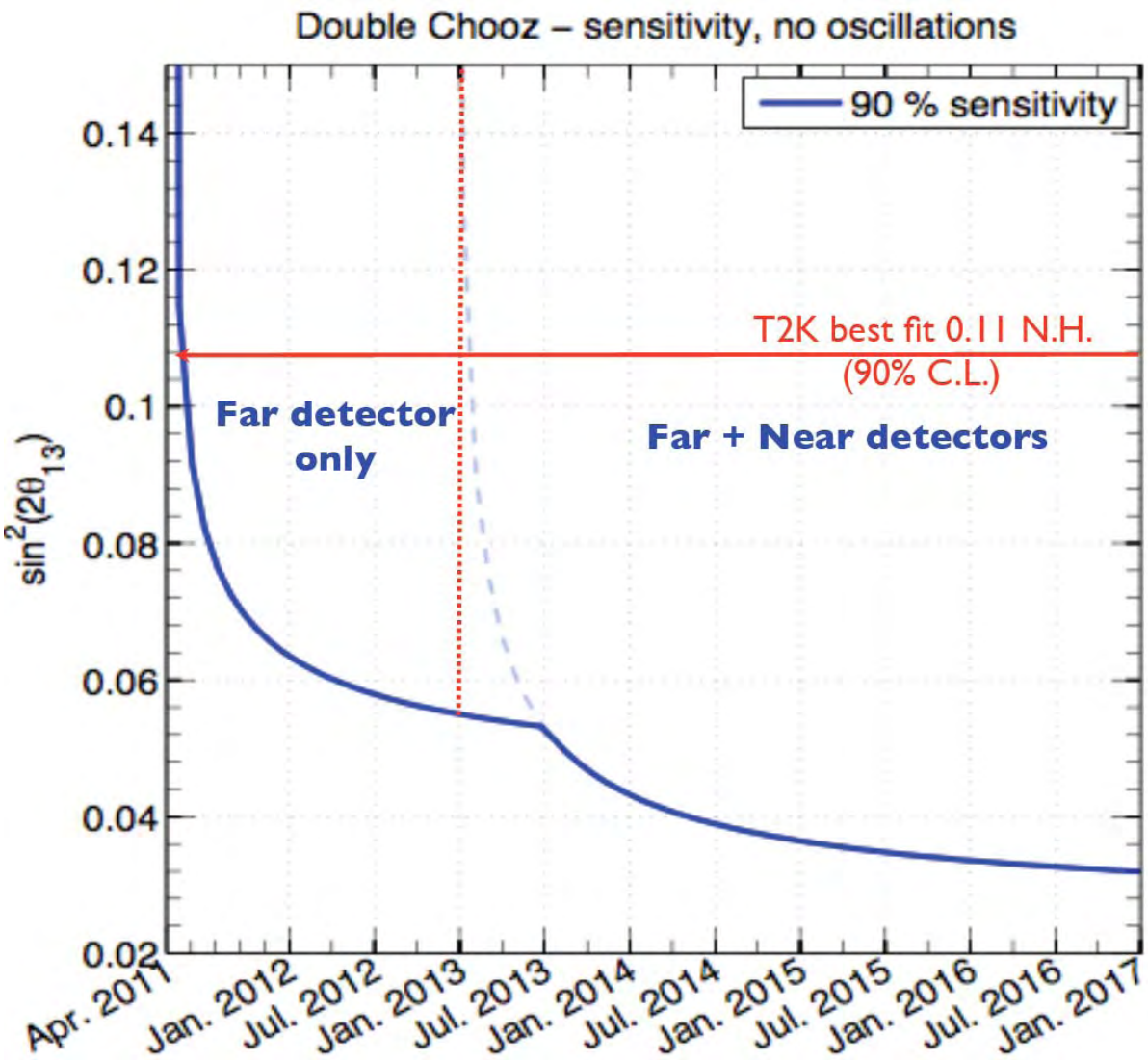
Double Chooz Preliminary Result



Presented by H. Kerret at LowNu 2011 (Seoul) last week (9.11.2011)

$$\sin^2(2\theta_{13}) = 0.085 \pm 0.029(\text{stat}) \pm 0.042(\text{syst}) \text{ at } 68\%\text{CL}$$

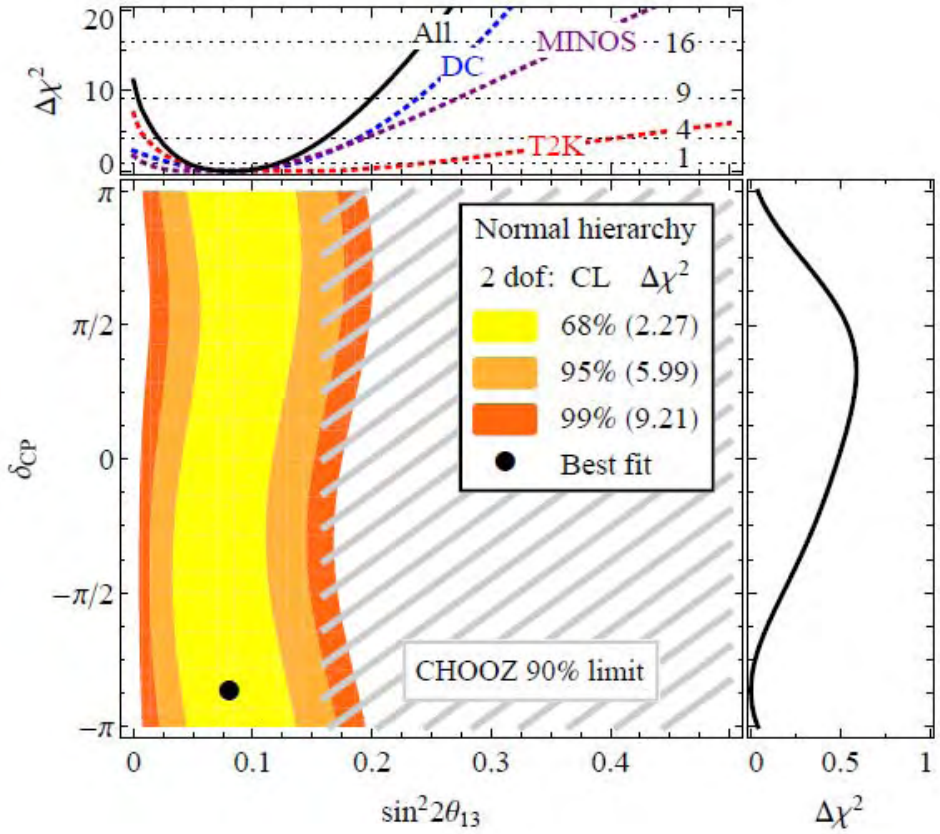
Double Chooz Ausblick

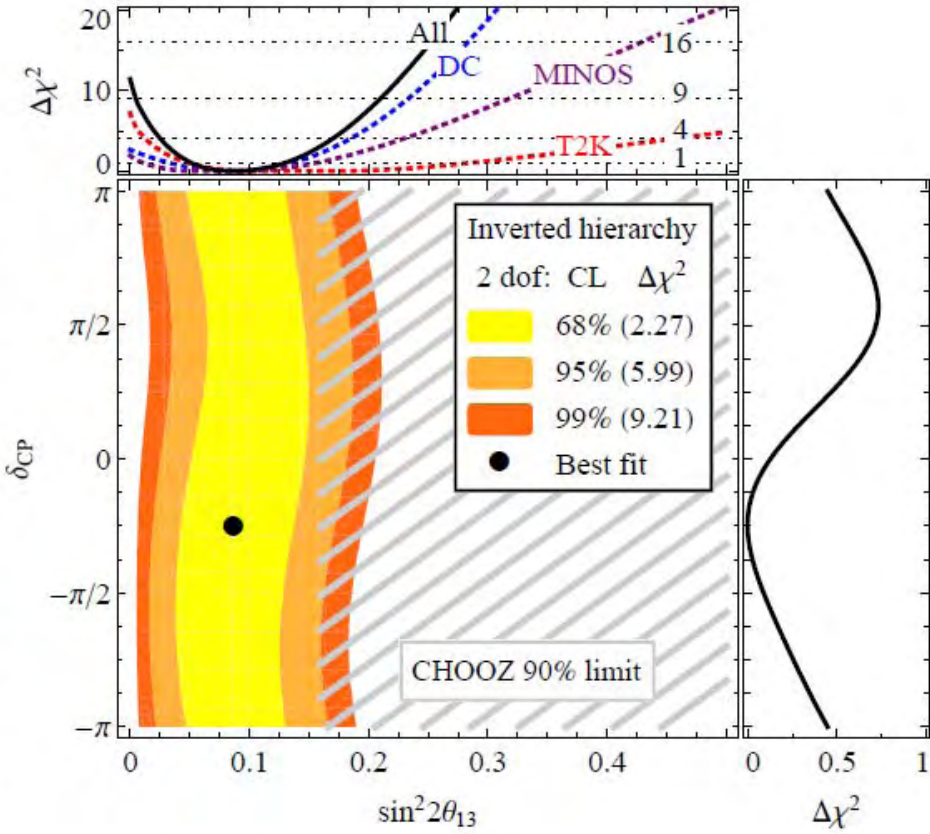


The Competitors:
- Daya Bay (China) Started August 2011
- Reno (S. Korea) Started August 2011
- Plan to have first results in 2012

Combined Analysis θ_{13}: MINOS, T2K, DCHOOZ

"Combining Accelerator and Reactor Measurements of theta13 -The First Result", Machado et al., arXiv:1111.3330v1





$$\text{normale Hierarchie (95\% CL)}: \; 0.023 < \sin^2(2\theta_{13}) < 0.16$$

$$\text{inverse Hierarchie (95\% CL)}: \; 0.027 < \sin^2(2\theta_{13}) < 0.17$$

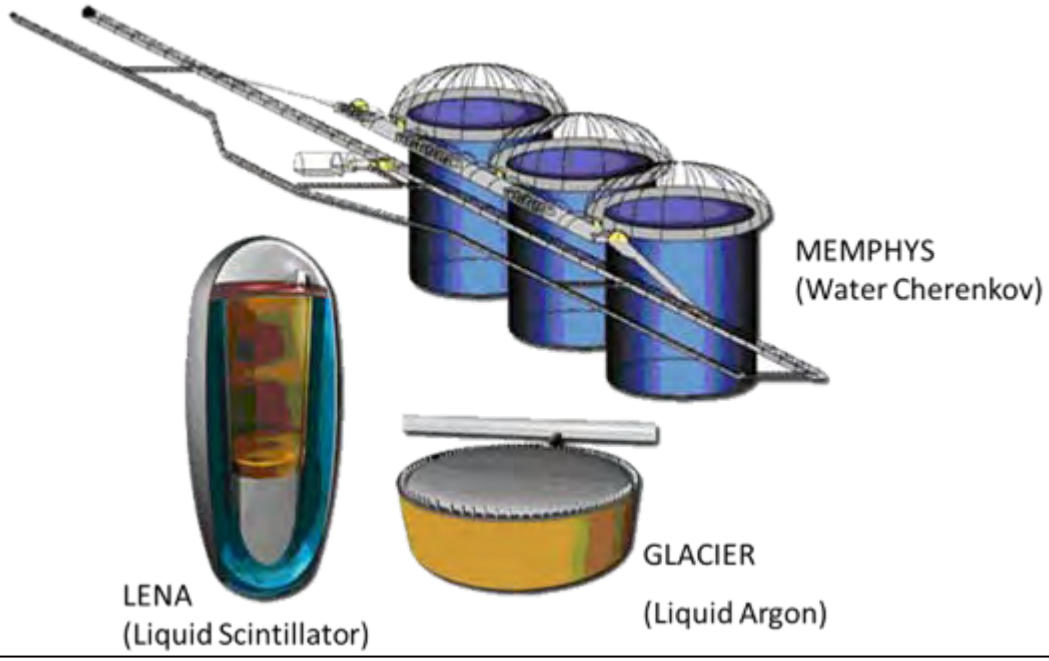
„sin2(θ_{13}) = 0 excluded at 3,36σ CL for both hierarchies"

LAGUNA

- **Large Apparatus for Grand Unification and Neutrino Astrophysics**

- **FP7 funded Laguna Design Study (2008-2011)**

- **Investigate feasibility of deep underground megaton scale detector, 7 european sites, 3 detector technologies:**
  - **Water Cerenkov**
  - **Liquid Argon**
  - **Liquid Scintillator**



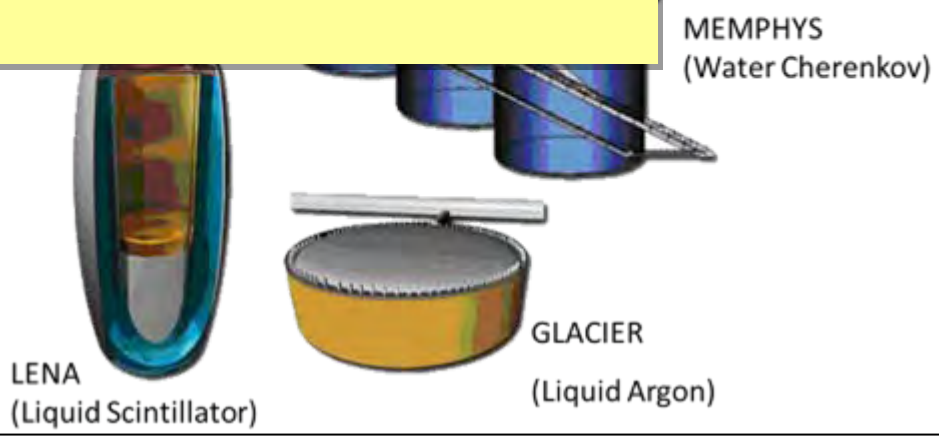
LAGUNA

- **Large Apparatus for Grand Unification and Neutrino Astrophysics**

- **FP7 funded Laguna Design Study (2008-2011)**

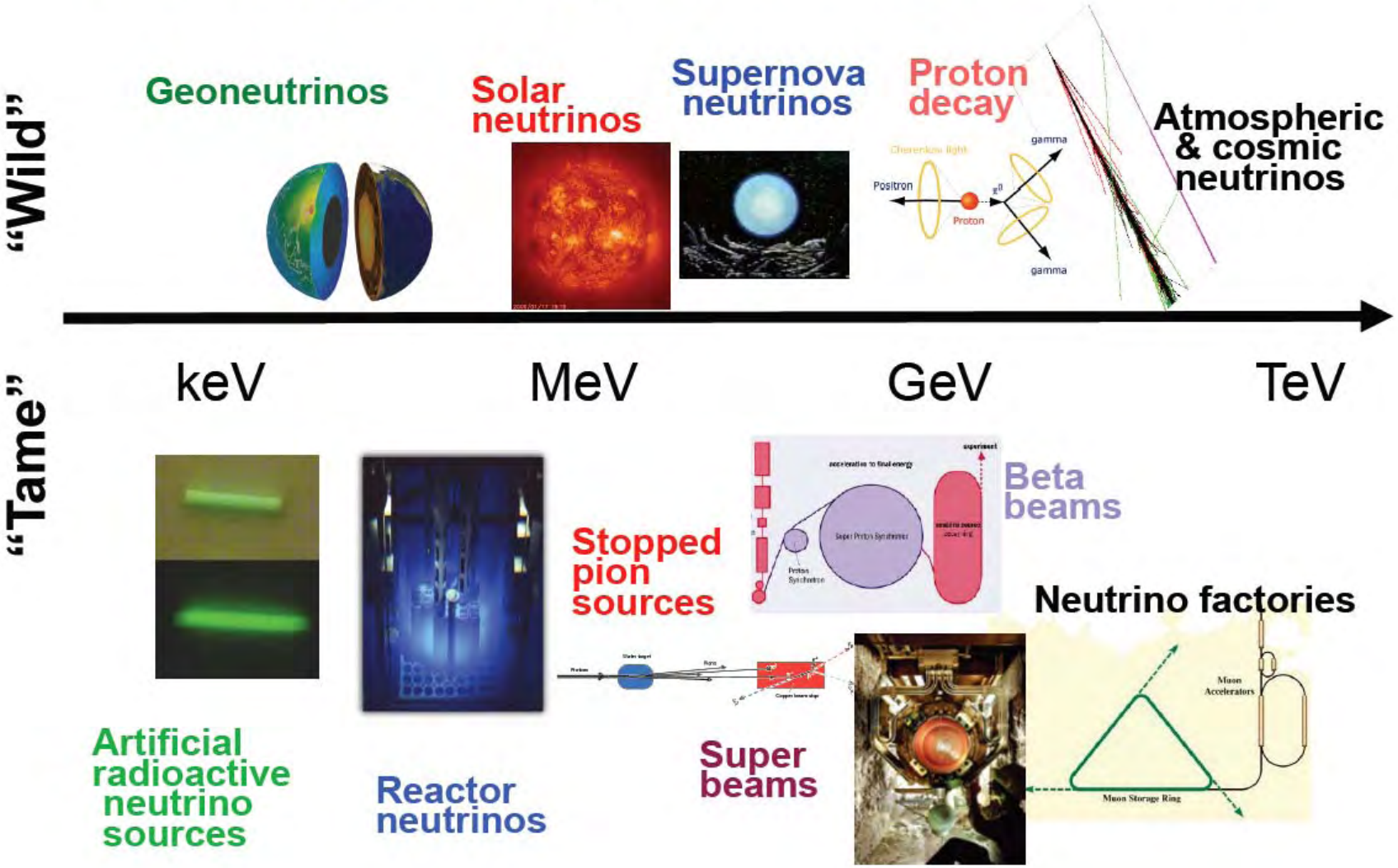
- **Investigate feasibility of deep underground megaton scale detector, 7 european sites, 3 detector technologies:**
  - **Water Cerenkov**

Outcome:
- Caverns technologically feasible (no show stoppers)
- Cavern construction not the dominant cost (10%-20%)
- Physics determines site selection



Underground Physics for the Next Decades

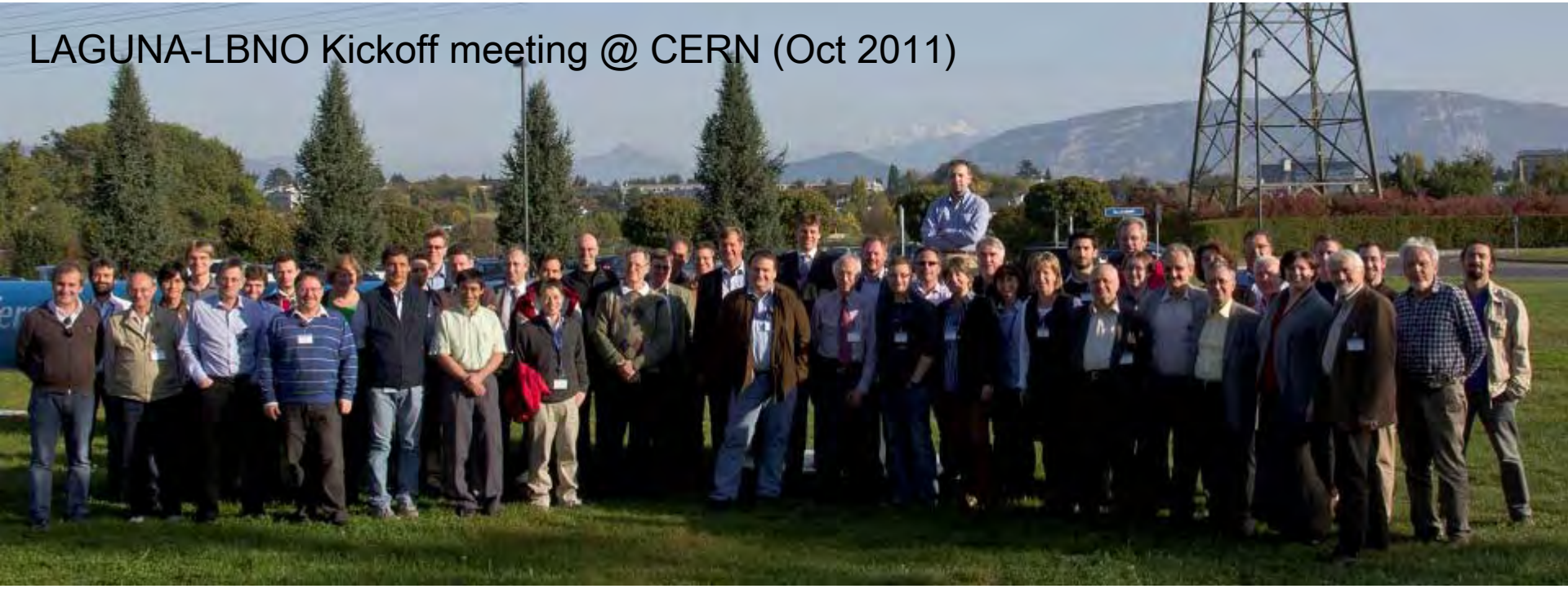
Wide range of energy scales & technical issues



(Slide from Kate Scholberg @ TAUP2011)

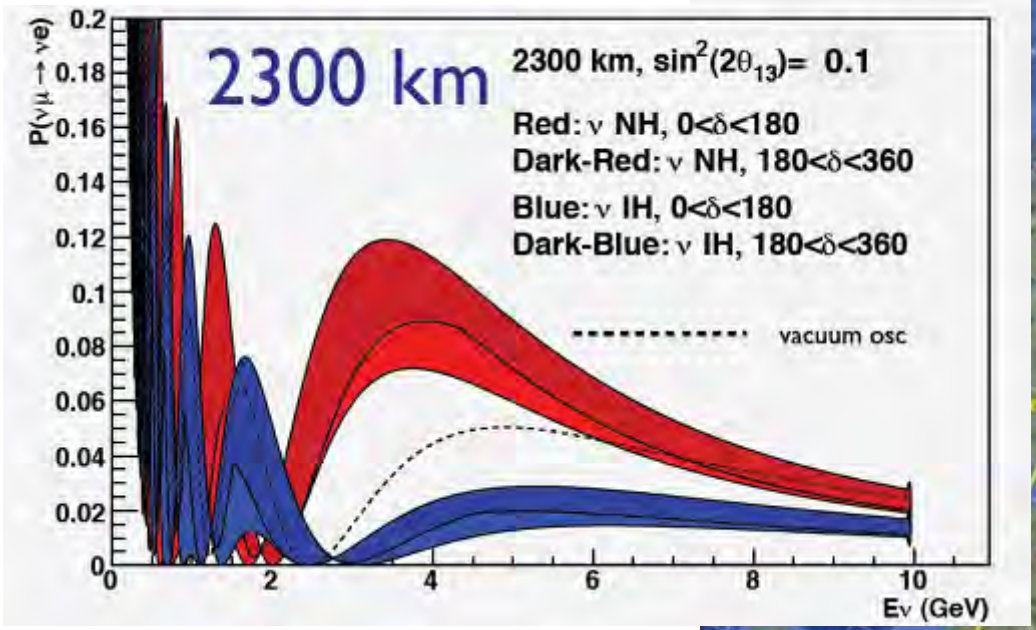
LAGUNA-LBNO

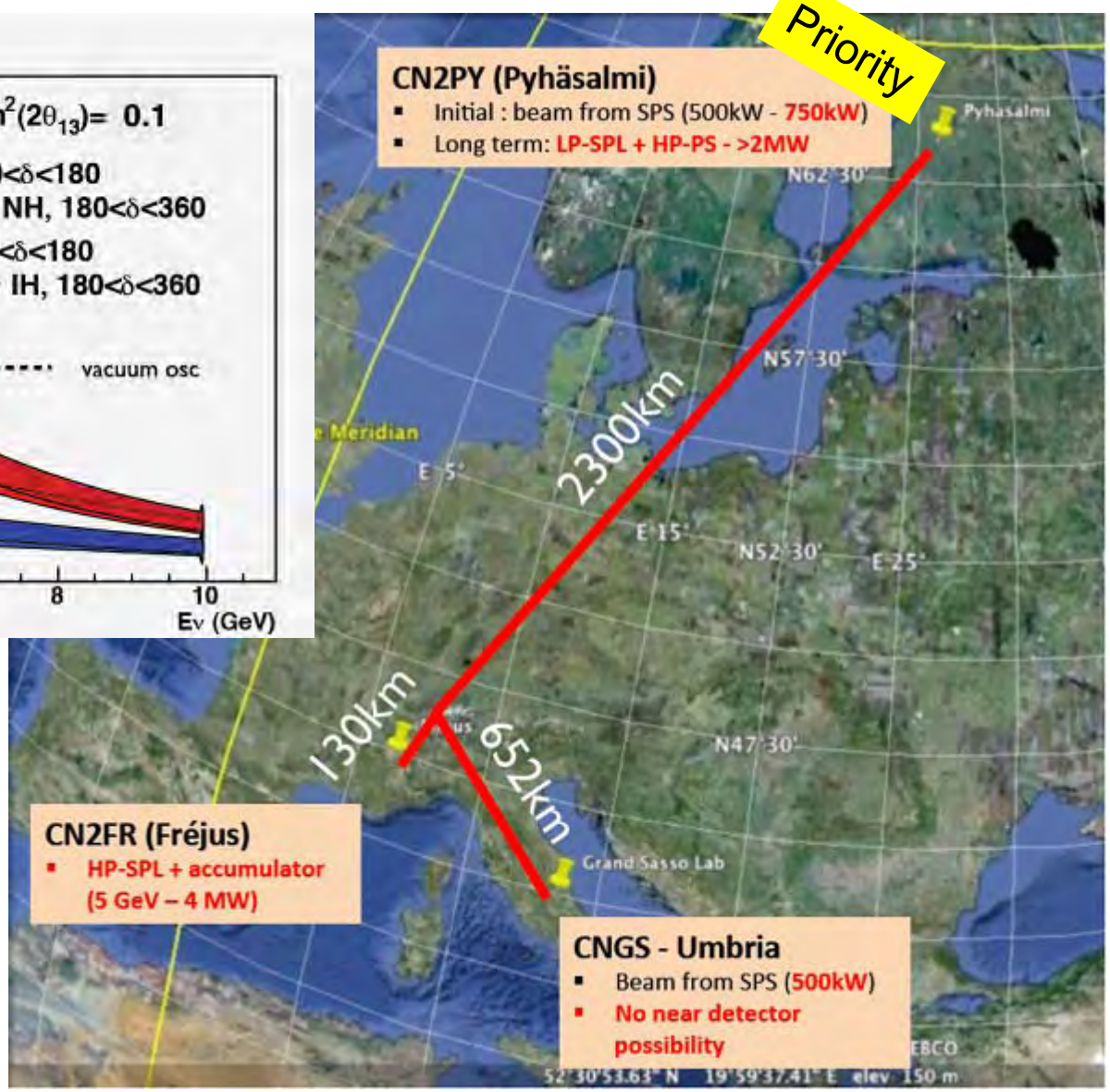
- **Large Apparatus for Grand Unification and Neutrino Astrophysics and Long Baseline Neutrino Oscillation**
- **FP7 funded Laguna-LBNO Design Study (2011-2014)**
- **300 members, 13 countries, 45 institutions**
- **Includes new industrial and academic beneficiaries (Cern, KEK, Russian institutes)**



LAGUNA-LBNO Options

Example for Glacier (Liquid Argon)



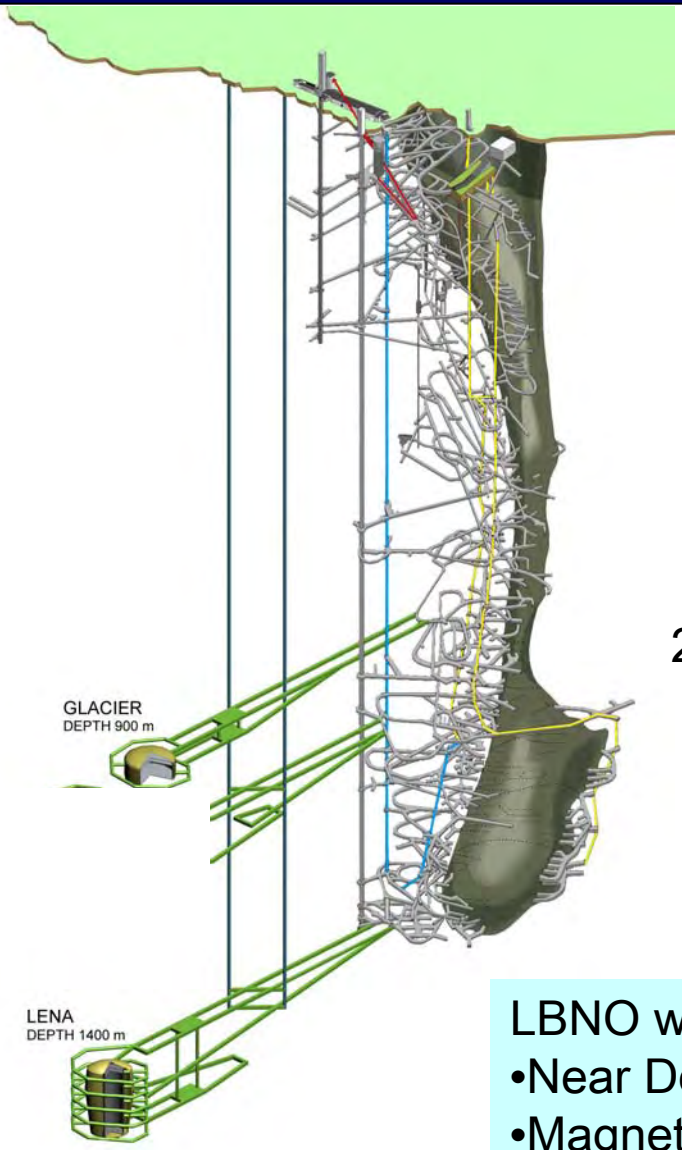


Priority: Pyhäsalmi Site with Liquid Argon and Liquid Scintillator Detectors

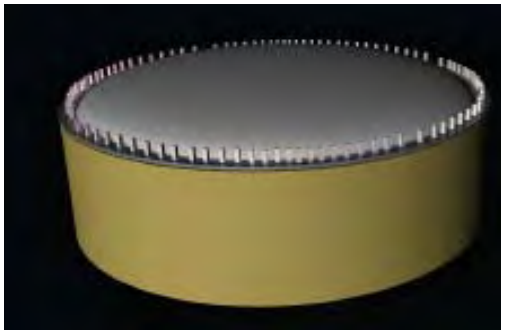
„LENA“ (Depth: 1400m)

50kt Liquid Scintillator

Low Energy Neutrinos (MeV)
Astroparticle Physics
Proton Decay (K channel)
Tracking investigated



„GLACIER“
(Depth: 900m)



20kt-100kt Liquid Argon

Excellent tracking
for neutrino beam

LBNO would require additional
•Near Detector @ Cern
•Magnetized detector @ PY

Zusammenfassung und Ausblick

- Neutrino-Oszillationen sind mit hoher Präzision vermessen:
  Δm_{12}, Δm_{23}, θ_{12}, θ_{23}.
  Neutrinomischung hat andere Struktur als Quarkmischung.

- Hinweise, dass $\Theta_{13} > 0$ von Double Chooz, T2K und MINOS sind zusammen genommen nun bei 3σ.

- Hinweise auf sterile Neutrinos?
  - MiniBoone & LSND: Überschuss von Anti-Elektronneutrinos
  - Reaktorneutrino Anomalie

- Unerwartetes:
  - OPERA Messung der Neutrinogeschwindigkeit (?)

- Offene Fragen:
  Antineutrino = Neutrino?, Masse des leichtesten Neutrinos?, CP-Verletzung?, Massenhierarchie?,…

- LAGUNA-LBNO setzt Priorität auf CN2PY mit Liquid Argon und Liquid Scintillator Detektoren