TAUP07 Conference

Topics in Astroparticle and Underground Physics

Sendai, September 11-15, 2007

- **Neutrino Physics**

  Borexino, Miniboone,
  Minos, Opera, and status of current experiments

- Dark Matter

- ν et γ Astronomy

- gravitational waves

- Cosmic rays

Neutrino physics: introduction

$$\underbrace{\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix}}_{\substack{\textbf{Flavour} \\ \text{eigenstates}}} = \underbrace{\begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}}_{\substack{\text{Mixing} \\ \text{matrix}}} \underbrace{\begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}}_{\substack{\textbf{Mass} \\ \text{eigenstates}}}$$

Oscillation probability:

$$P_{\nu\alpha \leftrightarrow \nu\beta} = \sin^2 2\theta \sin^2\left[1.27\left(\frac{L}{E_\nu}\right)\Delta m^2\right]$$

L: oscillation distance
E_ν: neutrino energy
θ: mixing angle
Δm^2: mass differences

Study on solar and atmospheric neutrinos, then on accelerator and reactor neutrinos

$\Delta m^2_{12}=7.59\times10^{-5}$ eV^2
$\tan^2\theta_{12}=0.49$

$\Delta m^2_{23}=2.4\times10^{-3}$ eV^2
$\sin^2 2\theta_{23}=1.0$

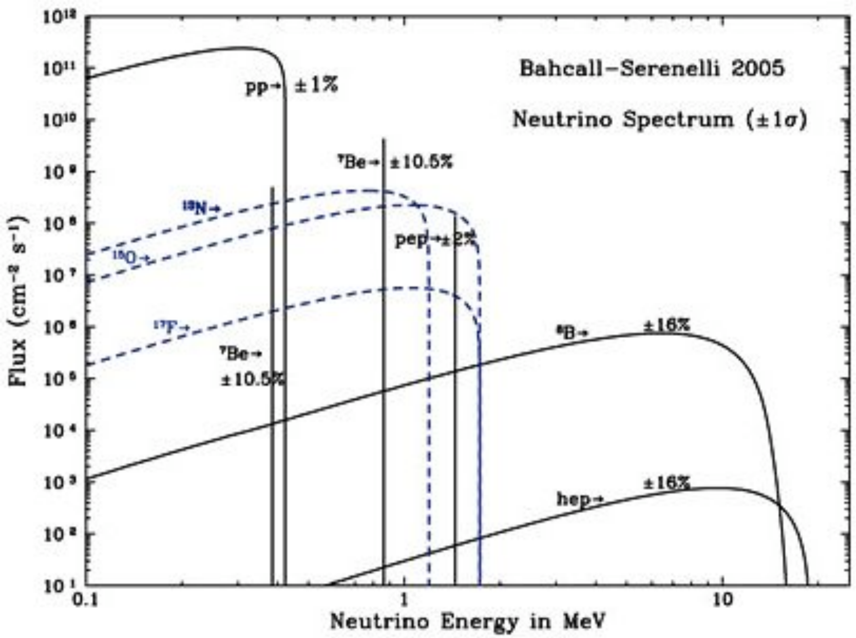
$\sin^2 2\theta_{13}<0.14$

Borexino

Gianpaolo Bellini - University and INFN Milano

- **1st real time detection of ^{7}Be ν (0,862 MeV)**

  1st measurement of sub-MeV solar ν
- The ^{7}Be ν_e contribute for 10% of the ν_e solar flux



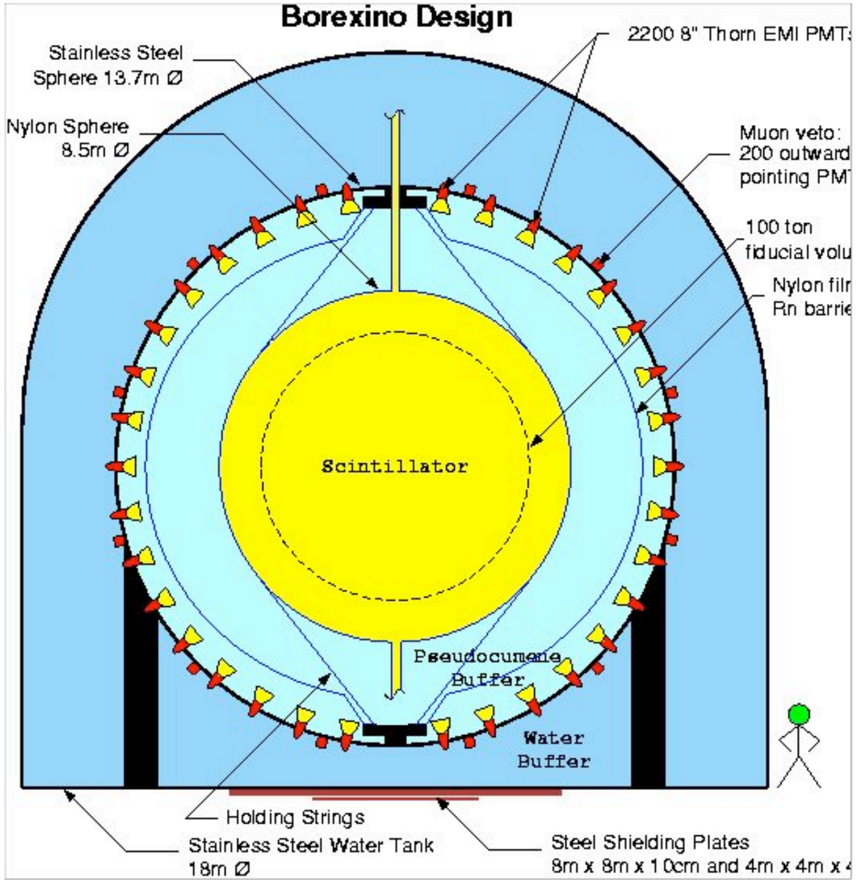
Detection:

Liquid scintillator that produces sufficient light to observe low energy neutrino events via elastic scattering by electrons.

The recoil electron profile for a mono-energetic neutrino is similar to that of Compton scattering of a single γ-ray.

Borexino

Impossible to distinguish neutrino scattered electrons from electrons due to natural radioactivity
⇒ Very low radioactive contamination



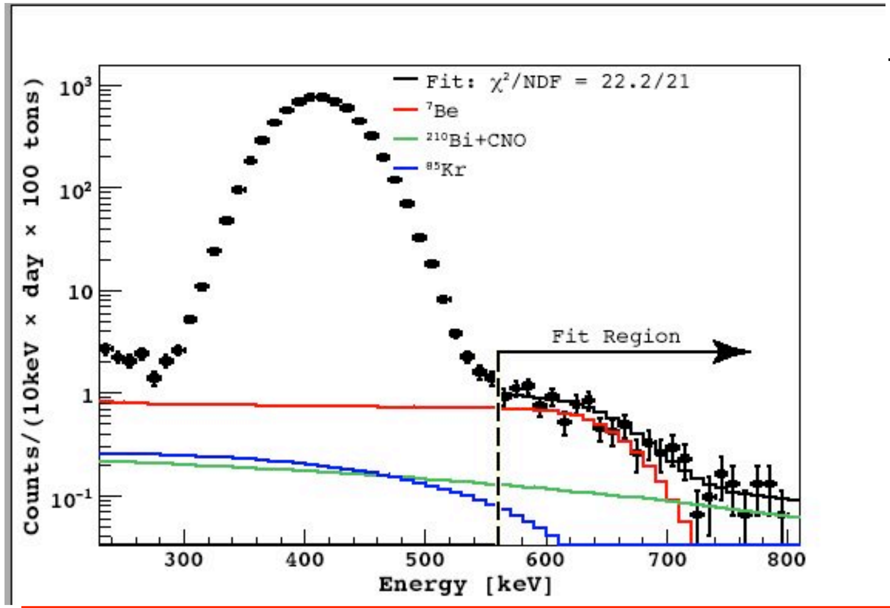
- Hall C, Gran Sasso

- Scintillator: pseudocumene doped with PPO
Background: γ < 0,5 count/(day.100 ton)
in the region 250-800 keV

- Graded shielding with the scintillator at the center

Signal signature: recoil electron profile with a clear Compton edge at 665 keV.

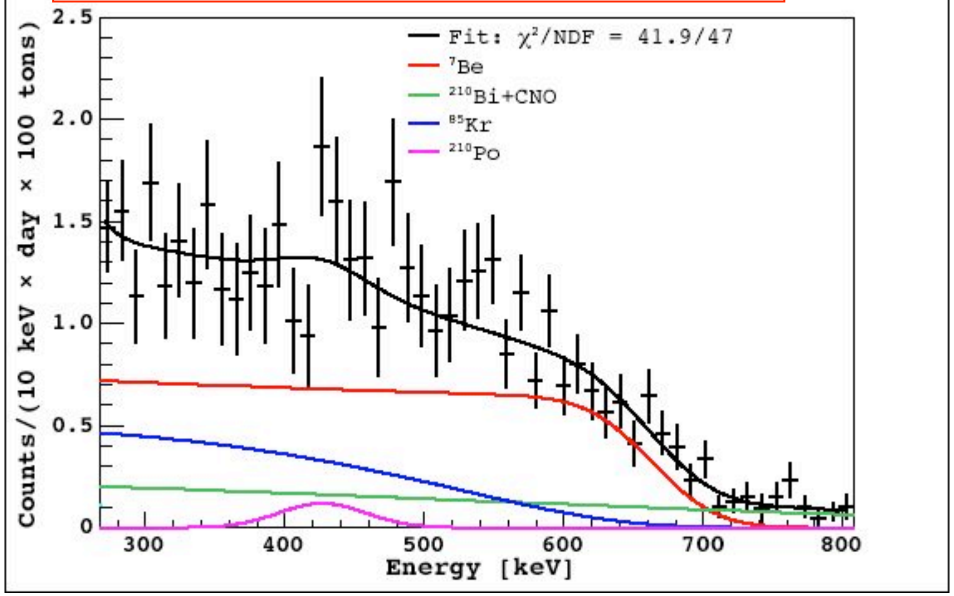
Borexino



<u>2 steps</u>:
1st fit in 250-800 keV with ^{210}Po, ^{85}Kr, CNO+^{210}Bi, ^{7}Be as free parameters.

2nd fit in 560-800 keV with only ^{7}Be, and CNO+^{210}Bi as free parameters.

After subtraction of the ^{210}Po peak.
Fit in the region 270-800 keV



<u>Result</u>:

$47 \pm 7_{stat} \pm 12_{sys}$ counts/(day.100 ton)

Consistent with Standard Solar Models and Neutrino oscillations with LMA-MSW parameters

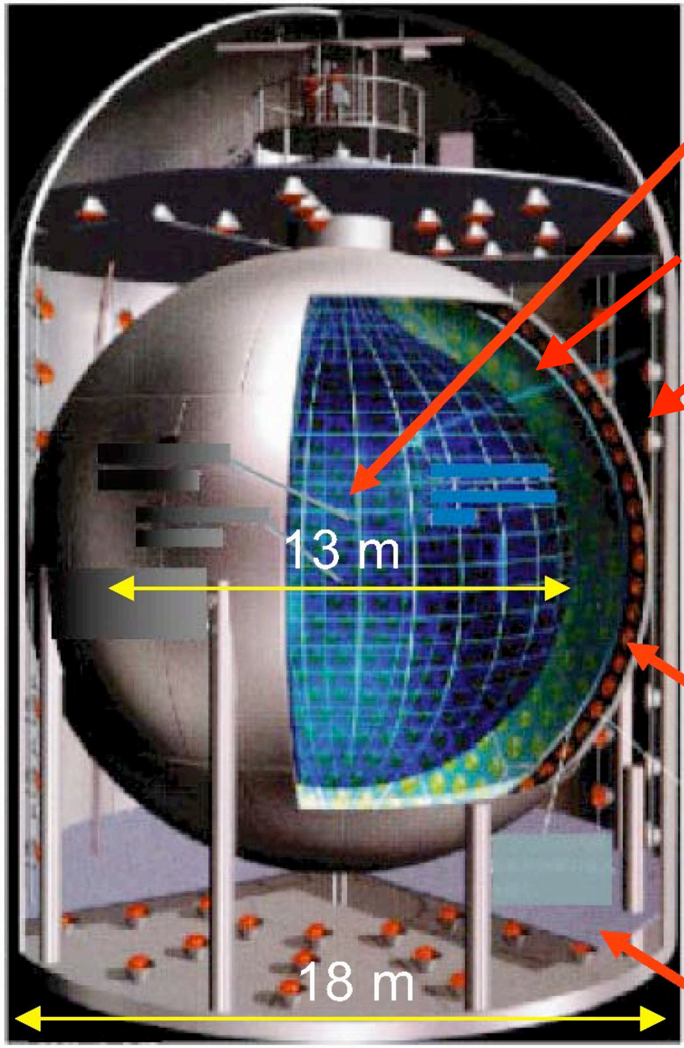
<u>Uncertainties</u>:

- Exact knowledge of ^{85}Kr contamination in the scintillator
- Fiducial mass determination
- 47.4 live days of data taking.

arXiv:0708.2251v2 [astro-ph]

KamLand - *Kamioka Liquid Scintillator Anti-Neutrino Detector*

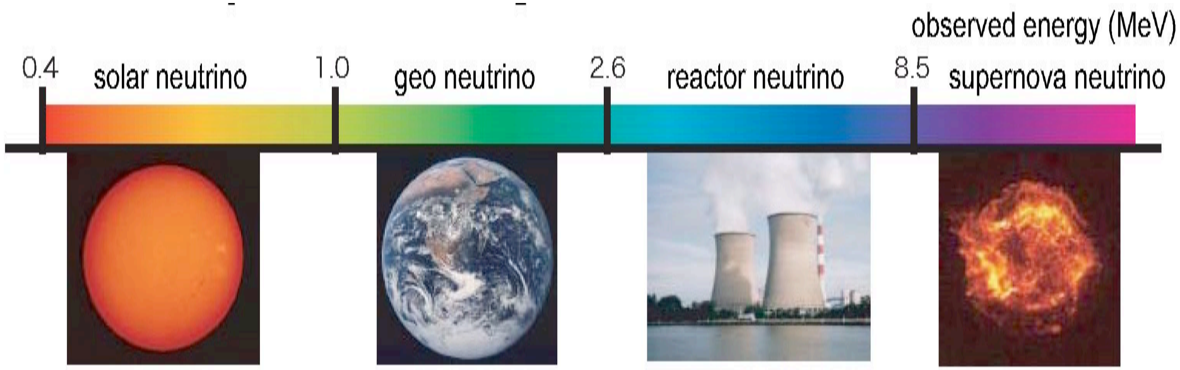
Yasuhiro Kishimoto - Tohoku University



1,000 ton Liquid Scintillator

1,325 17 inch + 554 20 inch PMTS

Water Cherenkov Outer Detector



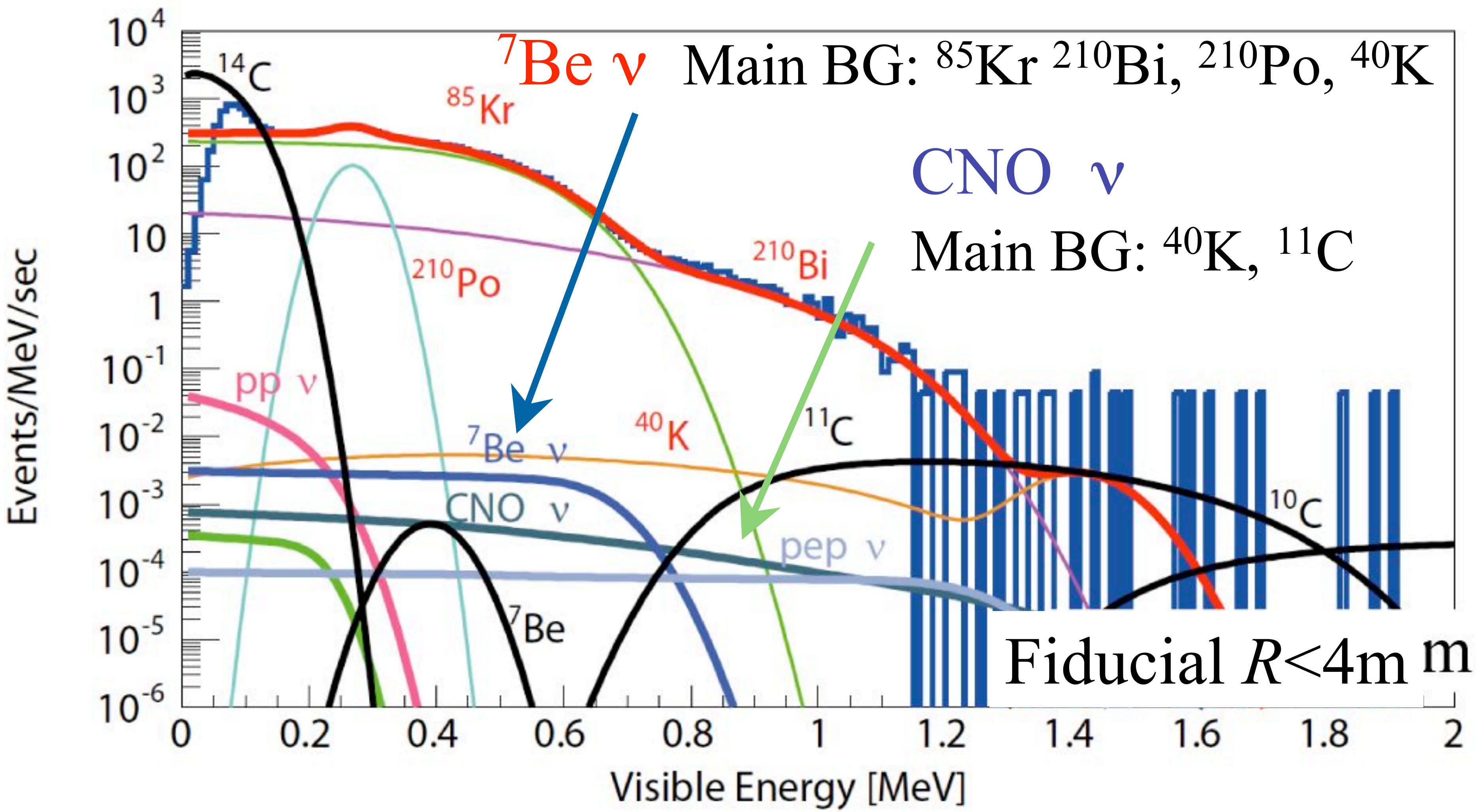
$N(U+Th)=25^{+19}_{-18}$

LMA solution
$\tan^2\theta_{12}=0.56$

Next target

$\Rightarrow$ Decrease the energy threshold to measure ^{7}Be and CNO ν.

KamLand

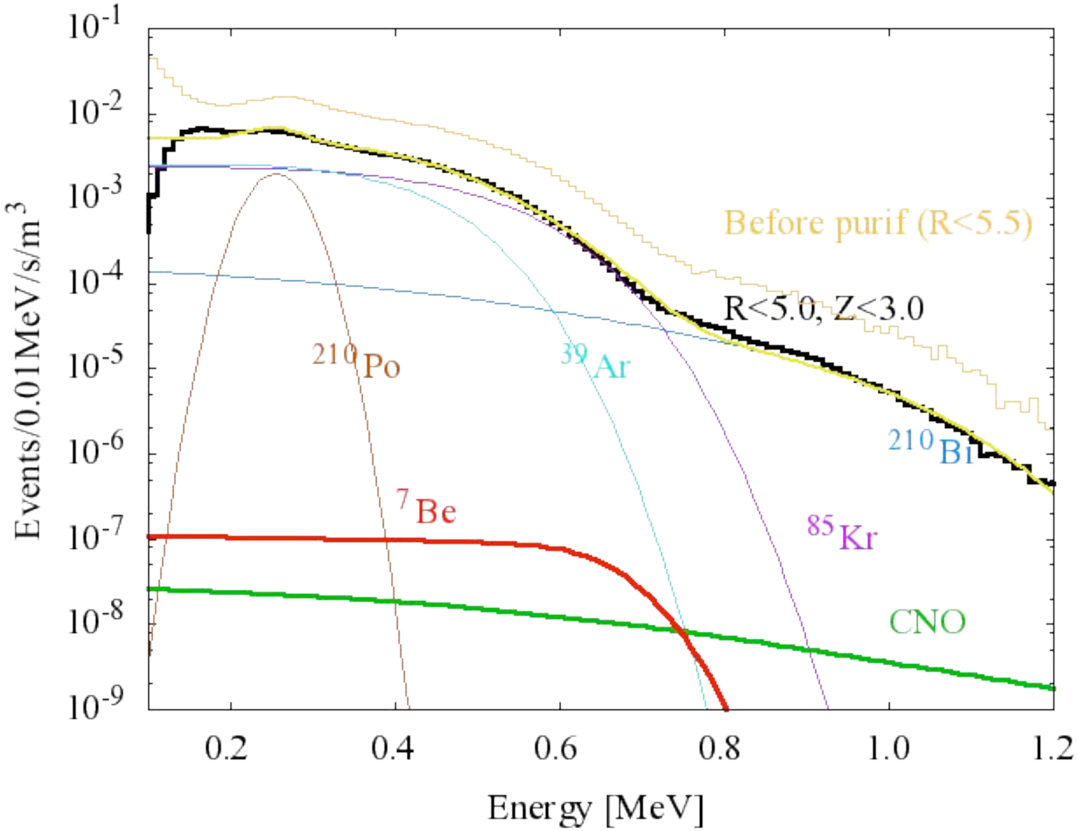


⇒ Purification: - distillation against metals and ions
- N_2 purge against Kr, Ar and Rn

Goal: 10^5-10^6 reduction

KamLand

<u>Status after purification</u>:



The activity are still high for ^{7}Be and CNO ν, but ^{210}Po reduction helps reactor and geo ν measurement a lot because of lower (α, n) background.

⇒ 2nd purification will start in spring of next year.

<u>Another goal</u>: measurement of $\beta\beta0\nu$ with ^{150}Nd

SNO - Sudbury Neutrino Observatory

Mark Chen - Queen's University

- 1000 tones of D_2O (phase 1) + salt (phase2) + ^3He counters (phase3)
- Direct measurement of the averaged survival probability of ^8B solar ν

$$\frac{\phi_{CC}}{\phi_{NC}} = 0.340 \pm 0.023^{+0.029}_{-0.031}$$

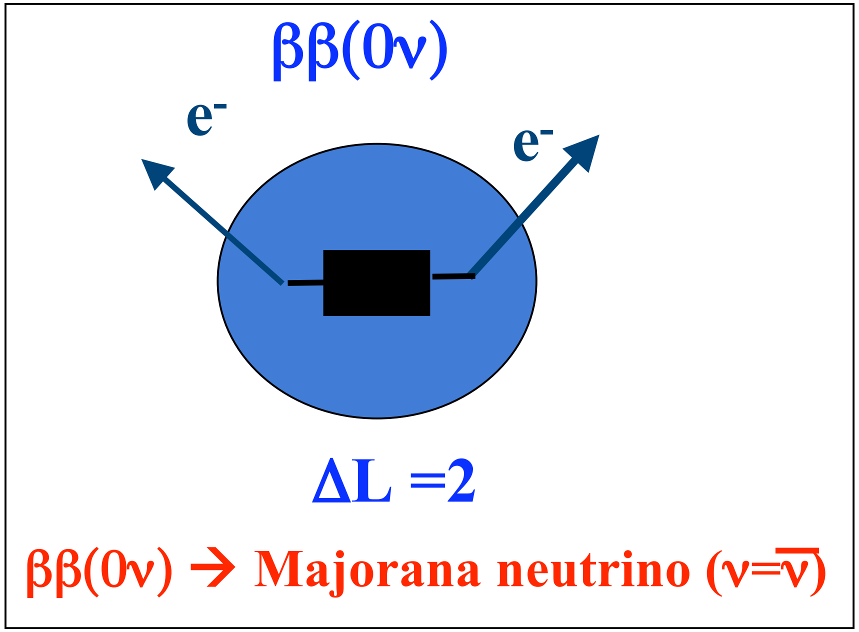
<u>Next phase</u>:

SNO+: Fill the detector with liquid scintillator with low radioactivity contamination to lower the threshold.

<u>Goal</u>: measurement of pep and CNO solar ν, geoneutrinos, reactor ν oscillations, supernovae neutrinos, $\beta\beta 0\nu$ with ^{150}Nd.

Neutrinoless double beta decay (ββ0ν)

Fabrice Piquemal - CENBG, Université Bordeaux I



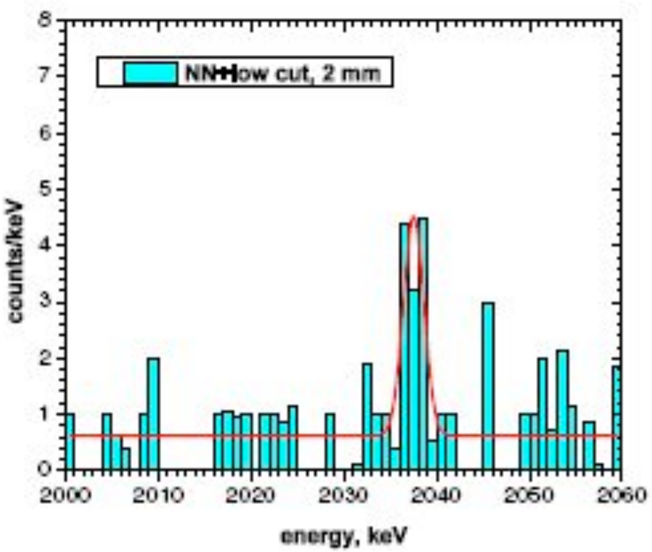
$$T_{1/2}^{-1} = F\left(Q_{\beta\beta}^{5}, Z\right)\left|M^{0\nu}\right|^{2}\left\langle m_{\nu}\right\rangle^{2}$$

General interest for ^{150}Nd because $Q_{\beta\beta}$=3667 keV

- **Today experiments have a mass of enriched source ~10 kg**
- **To reject inverted hierarchy mass scenario, enriched source mass ≥ 1 ton**
- **All projects have this goal but it is unrealistic to plan to go directly from 10 kg to 1 ton scale (understanding and control of the background)**
- **Intermediate step at 100 kg scale is needed (as proposed by each project)**

$\beta\beta0\nu$ with ^{76}Ge

Claim of Heidelberg-Moscow experiment, signal at 6σ



$$T_{1/2} = 2.23^{+0.44}_{-0.31} \quad 10^{25} \text{ yr}$$

$$\langle m\nu \rangle = 0.32 \pm 0.03 \text{ eV}$$

GERDA experiment:

PHASE I: 17.9 kg of enriched ^{76}Ge (from HM and IGEX)

In 1 year of data if $B=10^{-2}$ cts/keV/kg/yr (check of Klapdor's claim)

Start 2009 at Gran Sasso, results 2010 $T_{1/2} > 3\ 10^{25}$ yr $\langle m_\nu \rangle < 250$ meV

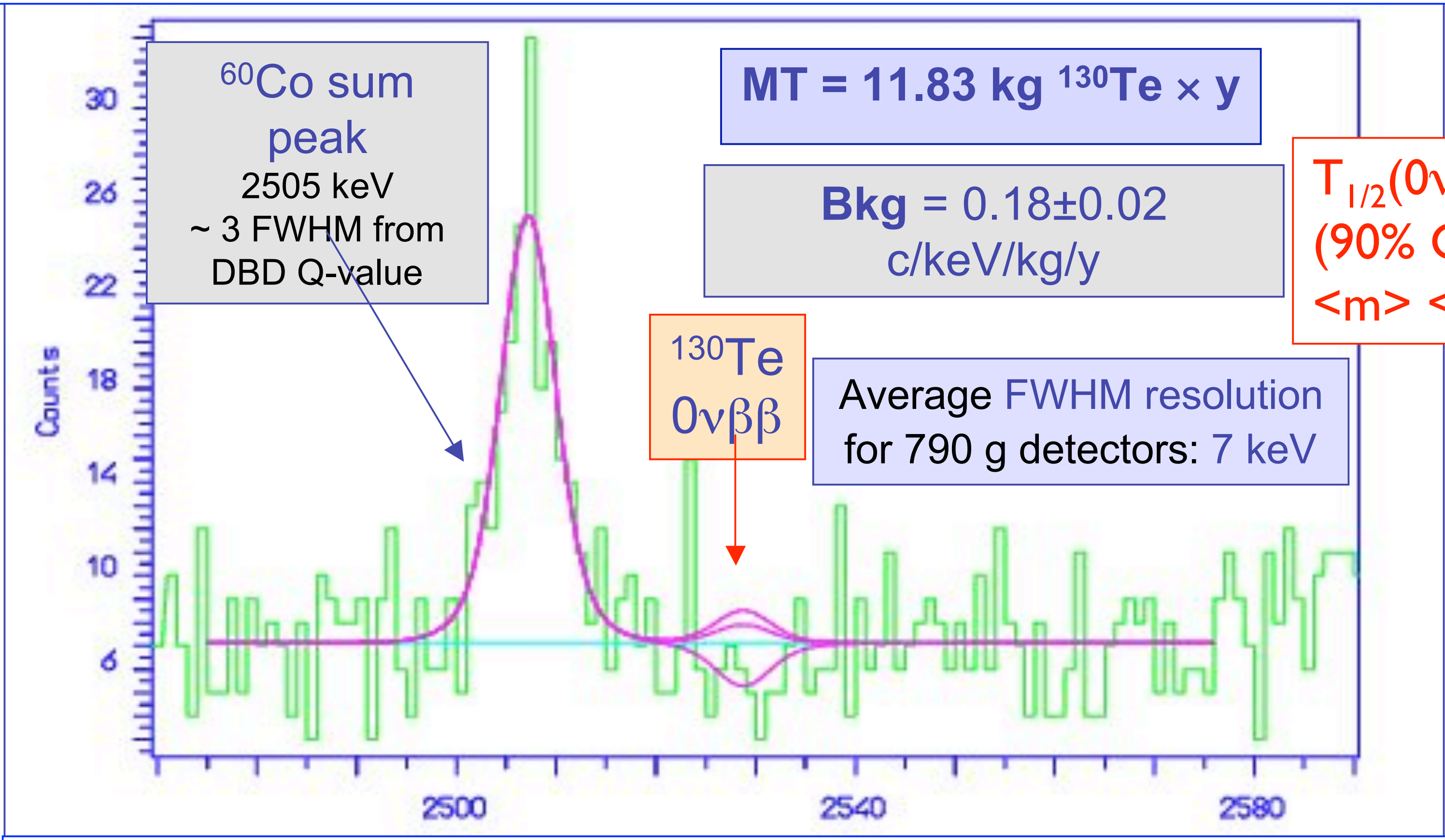
Use of liquid nitrogen or argon for active shielding - Segmentation

Improvement of Pulse Shape Analysis

CUORICINO - CUORE

Andrea Giuliani - University of Insubria

CUORICINO = tower of 13 modules,
11 modules x 4 detector (790 g) each, 2 modules x 9 detector (340 g) each
M = ~ 41 kg ⇒ ~ 5 x 10^{25} ^{130}Te nuclides



$T_{1/2}(0\nu)>3.0\times10^{24}$ yr (90% C.L.)
<m> <0.20-0.98 eV

CUORE: 1000 crystals are fully funded by INFN and DoE
The first tower will be assembled in 2008 and operated in 2009. Data in 2011

NEMO3-SUPERNEMO

Tracko-calo detector

Central source foil (~50 μm thickness)

Tracking detector (6180 drift cells)

Calorimeter (1940 plastic scintillators + PMTs)

Efficiency 8 %

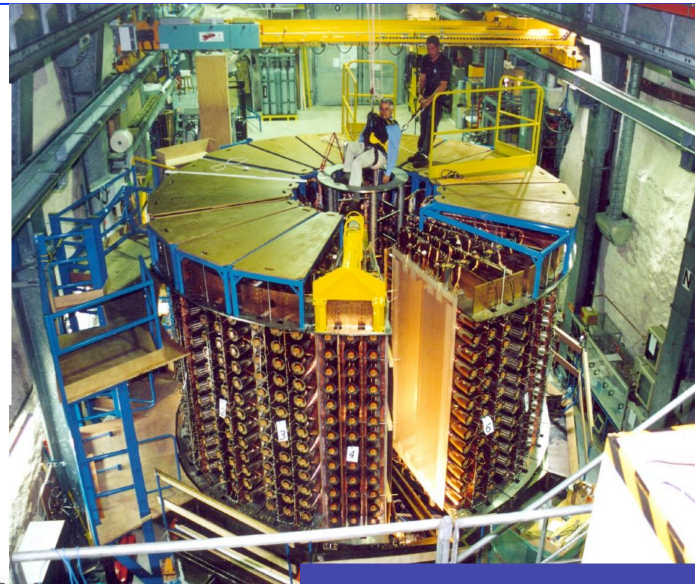
Running at Modane Underground lab since 2003

Multi-isotopes (7 kg of ^{100}Mo, 1 kg of ^{82}Se,…)

Identification of electrons

Very good bckg rejection ($< 10^{-3}$ cts/keV/kg/yr)

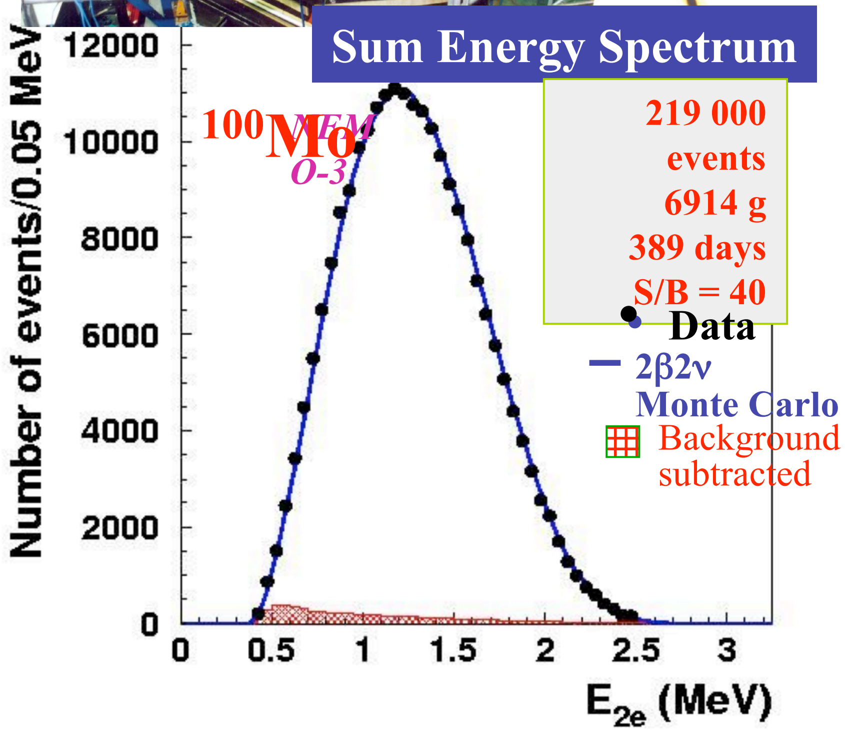
Angular distribution and single electron energy



$T_{1/2}(\beta\beta0\nu) > 5.8\ 10^{23}$ yr (90 % C.L.)

$<m_\nu> < 0.6 – 1.3$ eV

$T_{1/2}(\beta\beta2\nu)$ for ^{48}Ca, ^{82}Se, ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{130}Te, ^{150}Nd



SUPERNEMO: 100 kg of ^{82}Se or ^{150}Nd

R&D funded by France, UK and Spain

MiniBooNE

Mike Shaevitz - Columbia University

- MiniBoone was prompted by the positive LSND results.
- LSND observed a (~ 3.8 σ) excess of $\bar{\nu}_e$ events in a pure $\bar{\nu}_\mu$ beam: 87.9 ± 22.4 ± 6.0 events at the $\Delta m^2 \sim 1 eV^2$
- The Karmen Exp. did not confirm the LSND oscillations but had a smaller distance

- LSND in conjunction with the atmospheric and solar oscillation results needed more than 3 ν's

$\Rightarrow$ Models developed with 2 sterile ν's

or

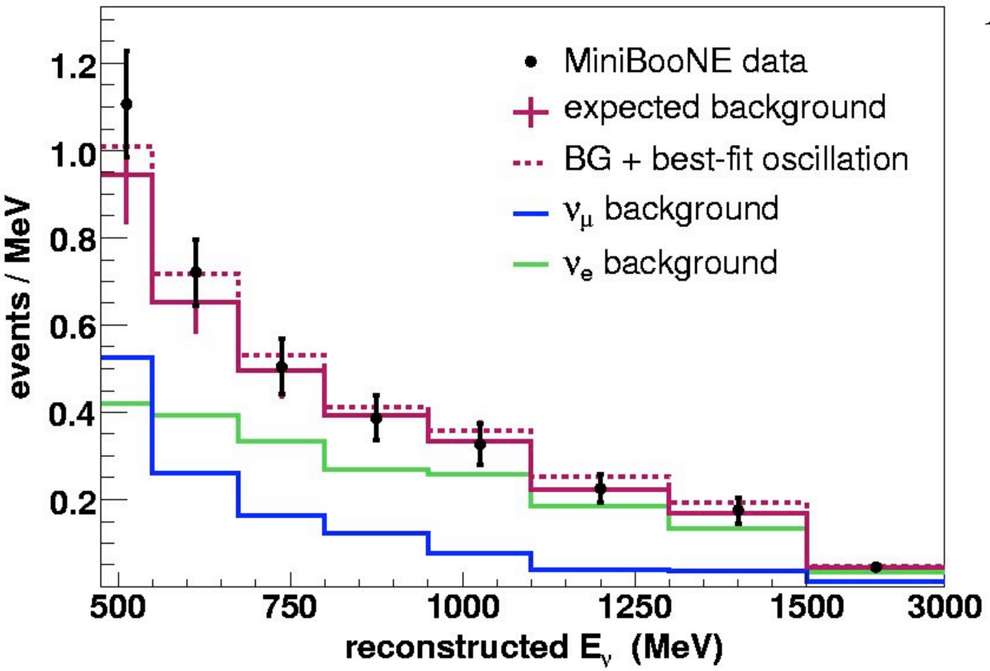
$\Rightarrow$ Other new physics models

MiniBooNE experiment: Fermilab Booster ν beam

- Baseline: 451 meters
- 800 tons of pure mineral oil (CH_2)

Charged particles passing through the oil can emit both directional Cherenkov light and isotropic scintillation light - distinction ν_μCC and ν_eCC

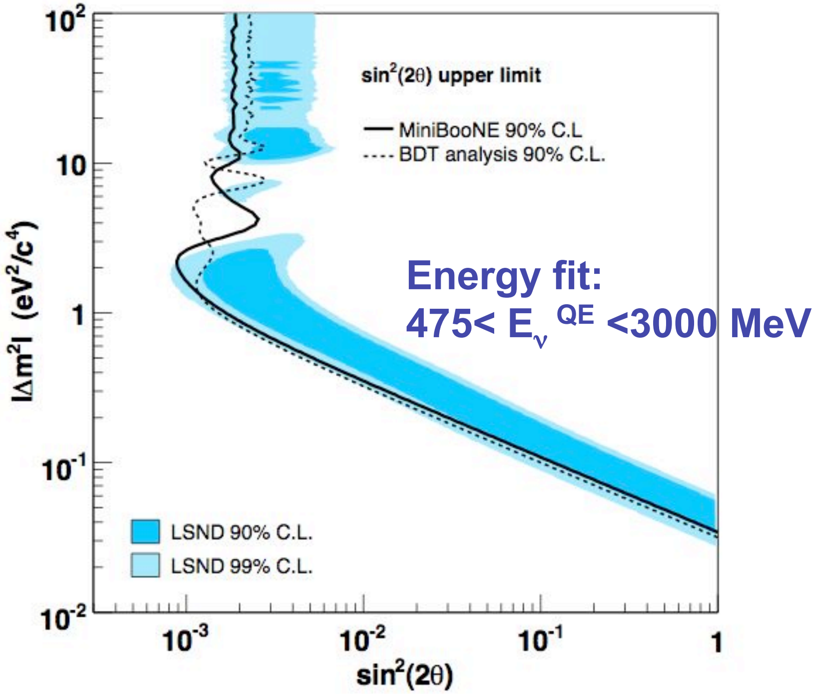
MiniBooNE



Data consistent with expected background
⇒ No indications of oscillations

Oscillation Search Region
$475 < E_\nu < 1250$ MeV

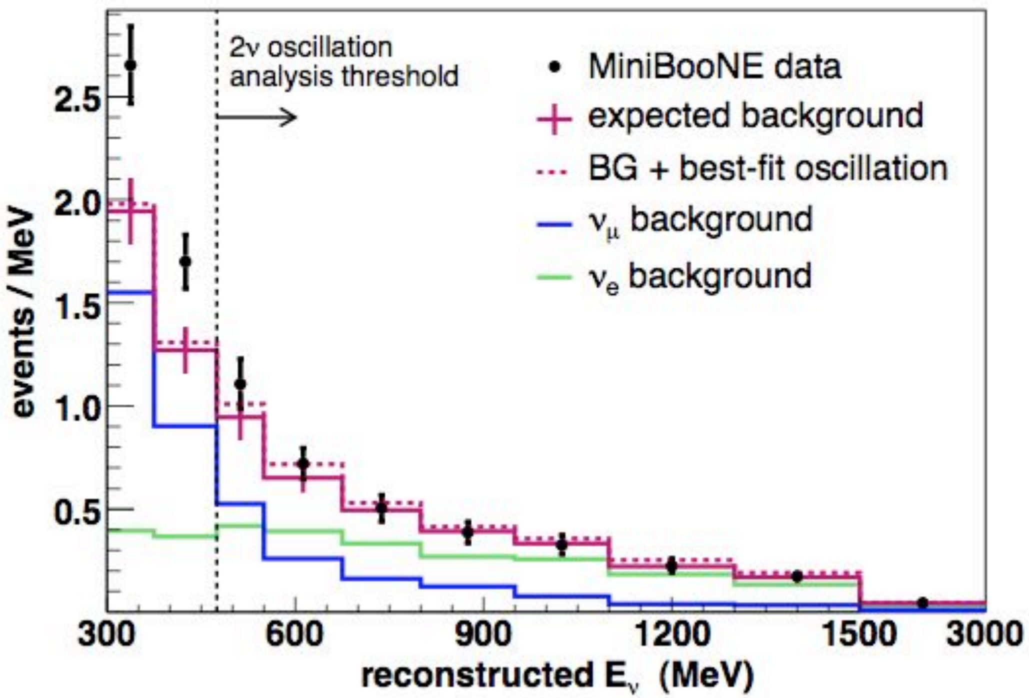
data: 380 ± 19 (stat) events
expectation: 358 ± 35 (sys) events
significance: 0.55 σ



Phys. Rev. Lett. 98, 231801 (2007),
arXiv:0704.1500 [hep-ex]

MiniBooNE

But, an excess of events observed below 475 MeV!



96 ± 17 ± 20 events above background, for $300 < E_\nu^{QE} < 475$MeV

Deviation: 3.7 σ

- Excess distribution inconsistent with a 2-neutrino oscillation model
- Could be a background, they are currently working on this with high priority

… or perhaps new physics

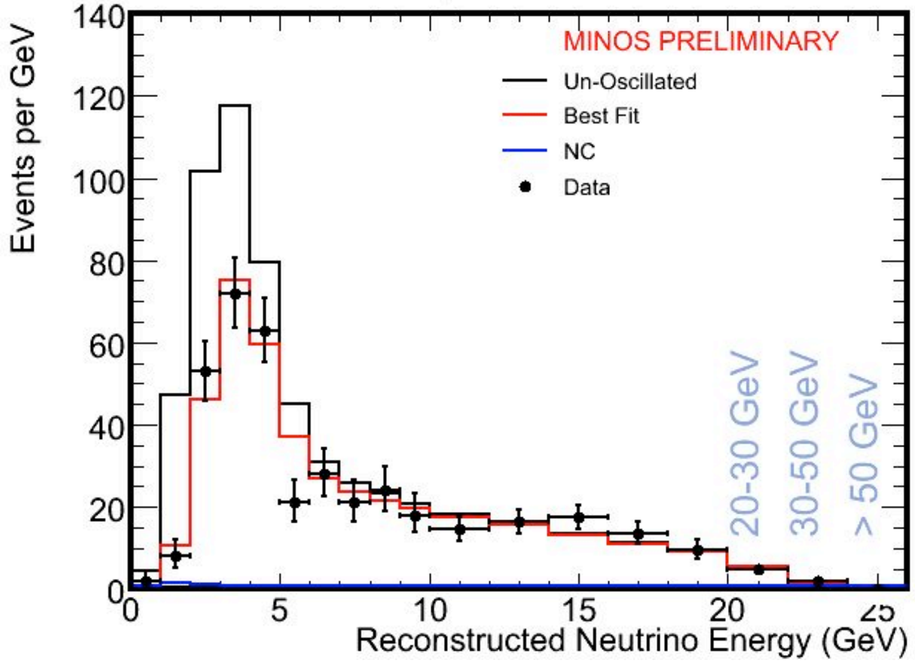
MINOS

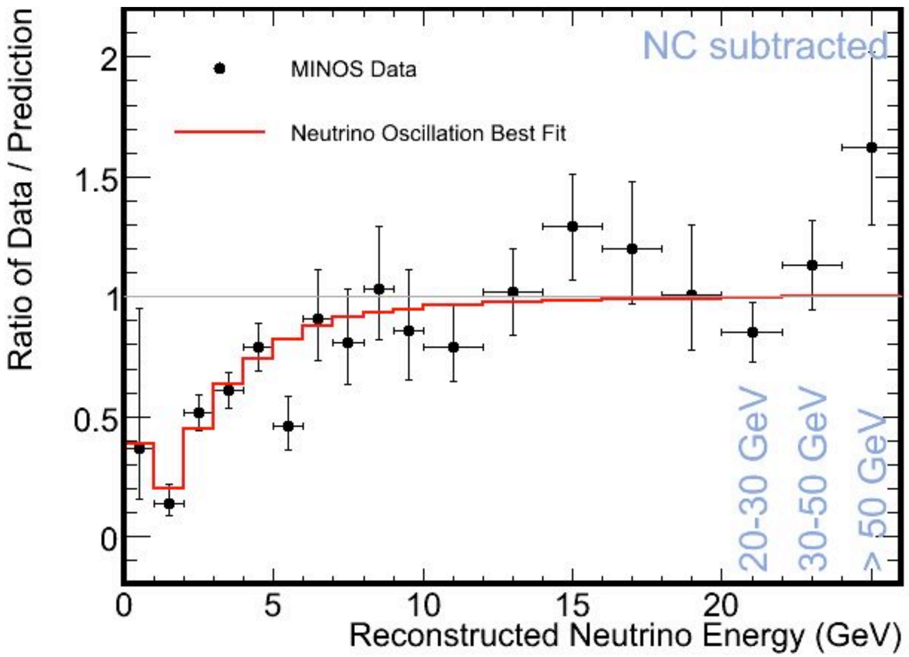
Andy Blake - Cambridge University

The MINOS Experiment

- **Accelerator beam of muon neutrinos produced by NuMI facility at Fermilab.**
- **Near Detector at Fermilab to measure spectrum and composition of beam.**
- **Far Detector at Soudan mine to study neutrino disappearance in beam.**

PRELIMINARY OSCILLATION RESULTS FOR 2.5×10^{20} POTs DATA.





The minimum of the ratio gives the value of Δm^2

MINOS

Data sample	Observed	Expected (no osc.)	Observed / Expected
ν_μ(all E)	563	738 ± 30	0.74 (4.4σ)
ν_μ (<10 GeV)	310	496 ± 20	0.62 (6.2σ)
ν_μ(<5 GeV)	198	350 ± 14	0.57 (6.5σ)

Best fit values:

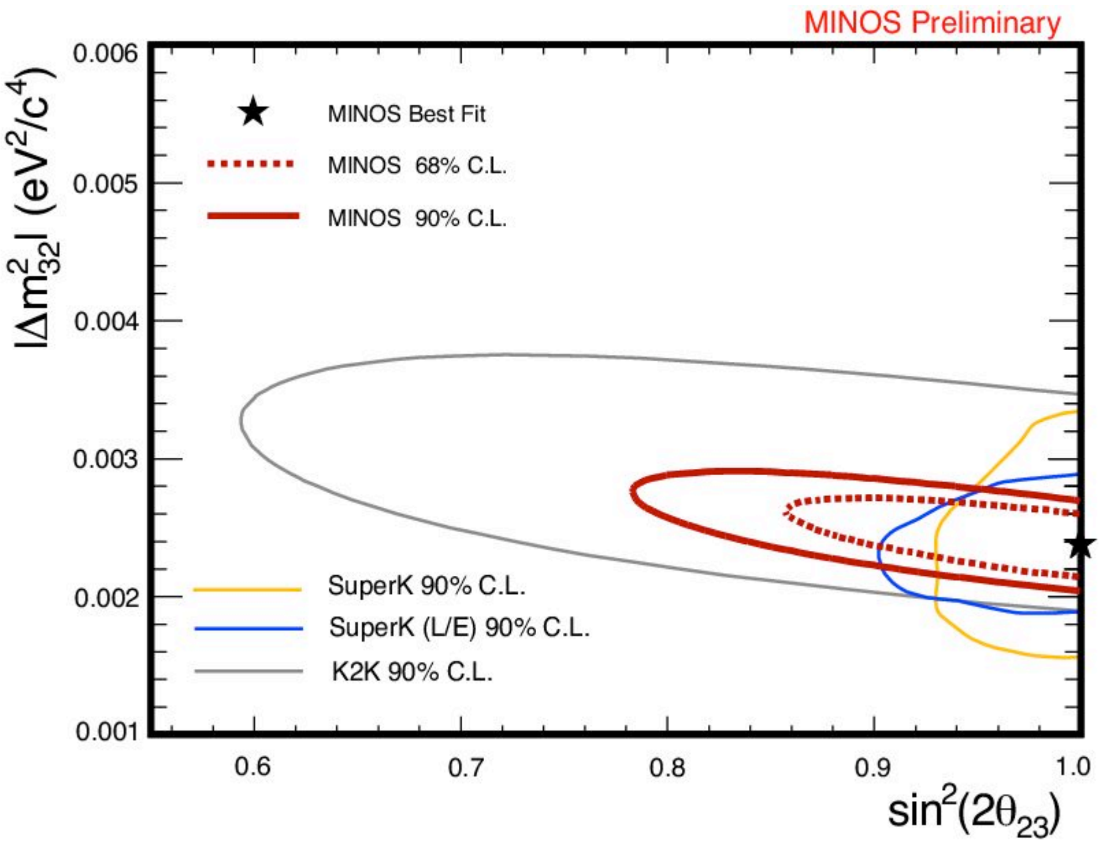
$$\left|\Delta m^2_{32}\right| = 2.38^{+0.20}_{-0.16} \times 10^{-3}\ \mathrm{eV}^2$$

$$\sin^2 2\theta_{23} = 1.00_{-0.08}$$

$$\chi^2 / N_{DoF} = 41.2/32$$

Accelerator experiments:
Energy very well known
⇒precise measurement of Δm^2

Atmospheric experiments:
Flux very well known
⇒precise measurement of θ

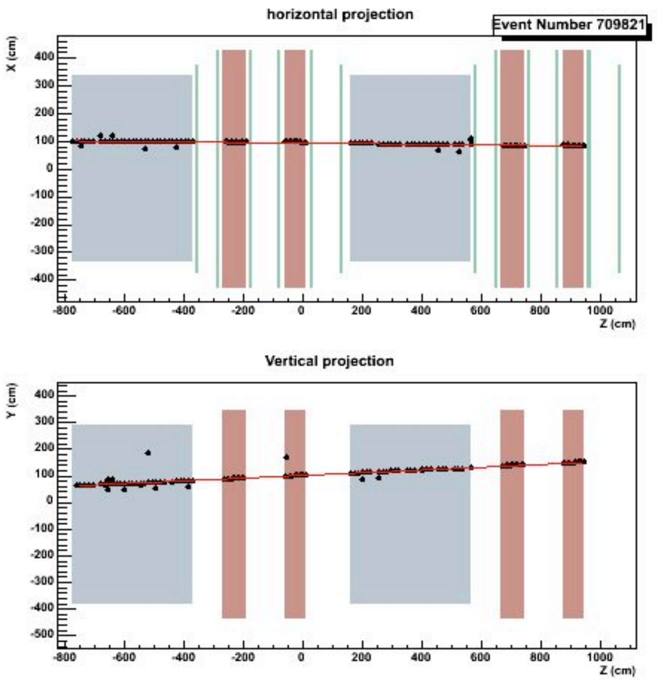


OPERA: 1st CNGS run - August 2006

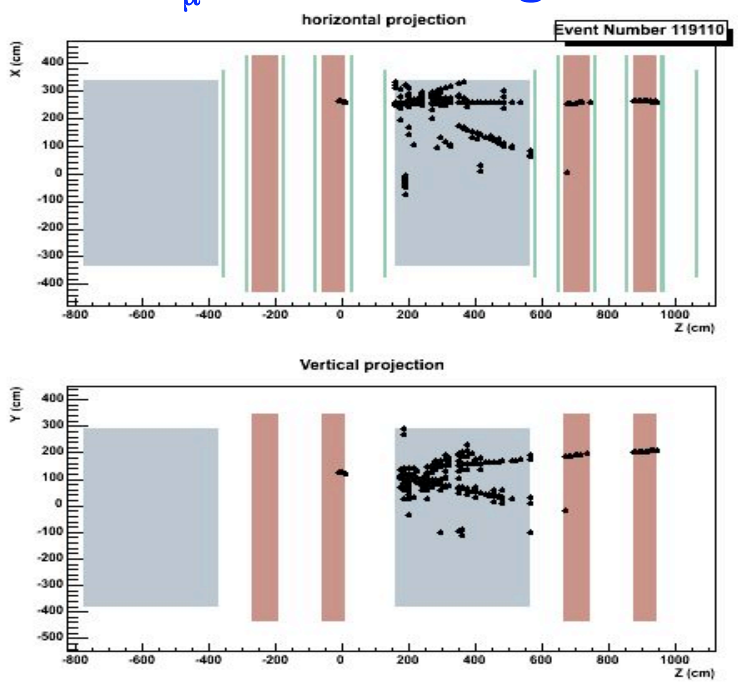
Direct search for the $\nu_\mu \rightarrow \nu_\tau$ oscillation by looking at the appearance of ν_τ in a pure ν_μ beam

- 121 hours of real beam operation
- 70% of nominal intensity $\rightarrow$ 1.7×10^{13} pot/extraction
- Time selection (CNGS and OPERA synchronized by GPS)
- 319 beam events collected:
  - 3/4 external events (interaction in the rock)
  - 1/4 internal events (interaction in the detector, but there was no brick)

ν_μCC in rock (rock muons)



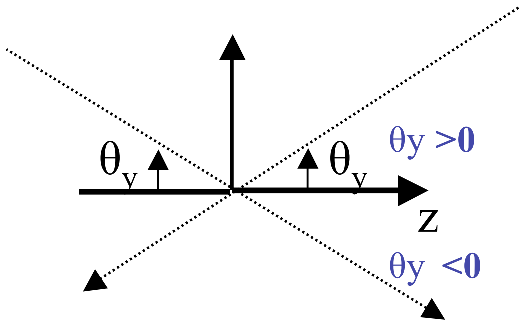
ν_μCC in the magnet

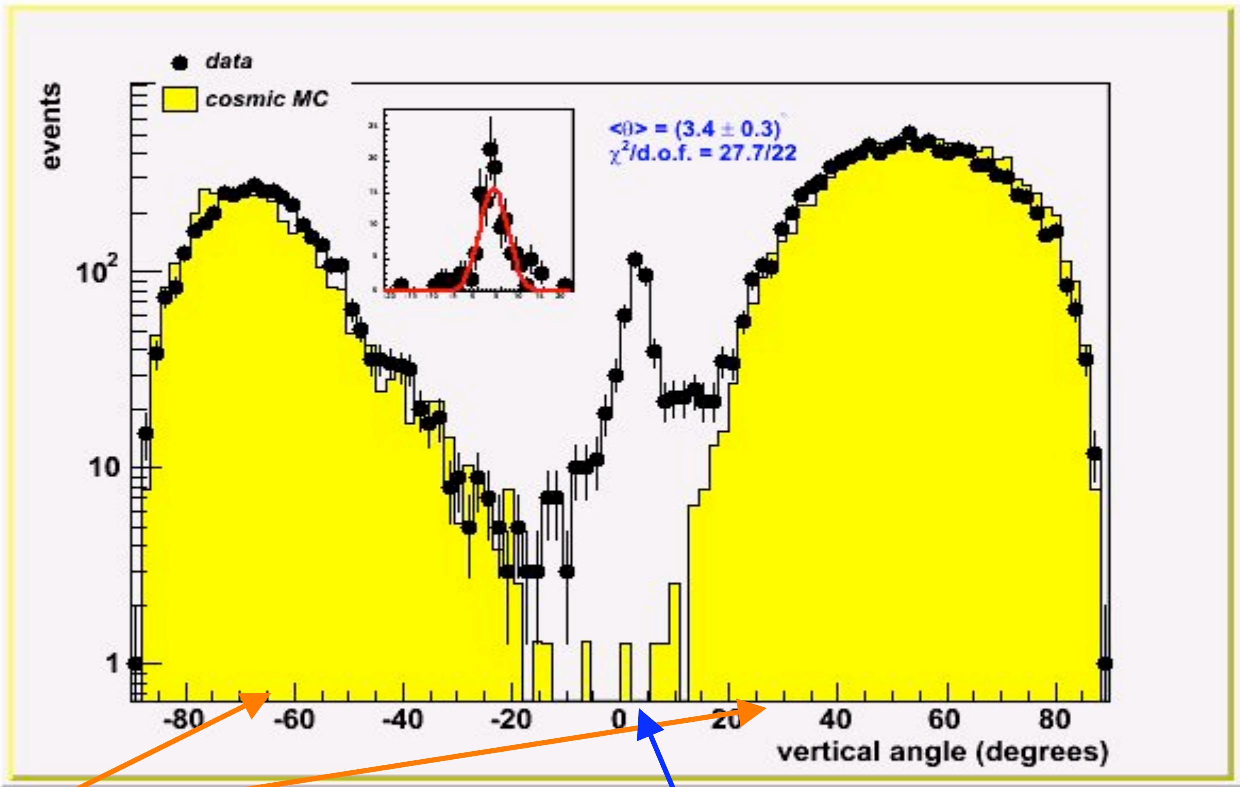


OPERA

Events direction:

Zenith angle of muon track:





Cosmic ray
MC simulation from MACRO parametrization

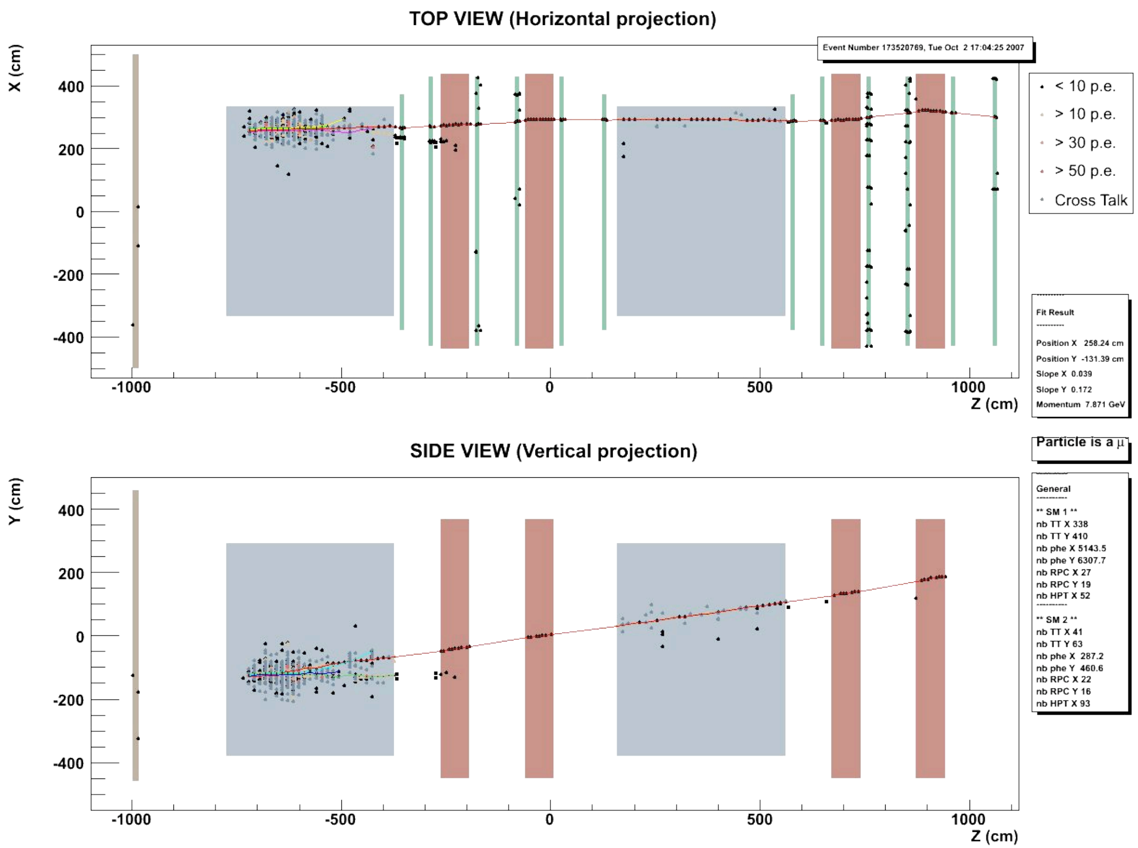
Beam events:
$<\Theta_y> = 3.4 \pm 0.3°$ *(as expected)*
(statistically dominated)

"First events from the CNGS neutrino beam detected in the OPERA experiment"
R. Acquafredda et al., New J. Phys.8 (2006) 303

OPERA

- CNGS run in 2007 (beginning 18 September):
  - 6 weeks of CNGS commissioning and physics run
  - 70% of nominal intensity: 1.7×10^{13} pot/extraction
  - 505 tons (~59000 bricks) at the start of the run
  - 616 tons (~72000 bricks) at the end of the run

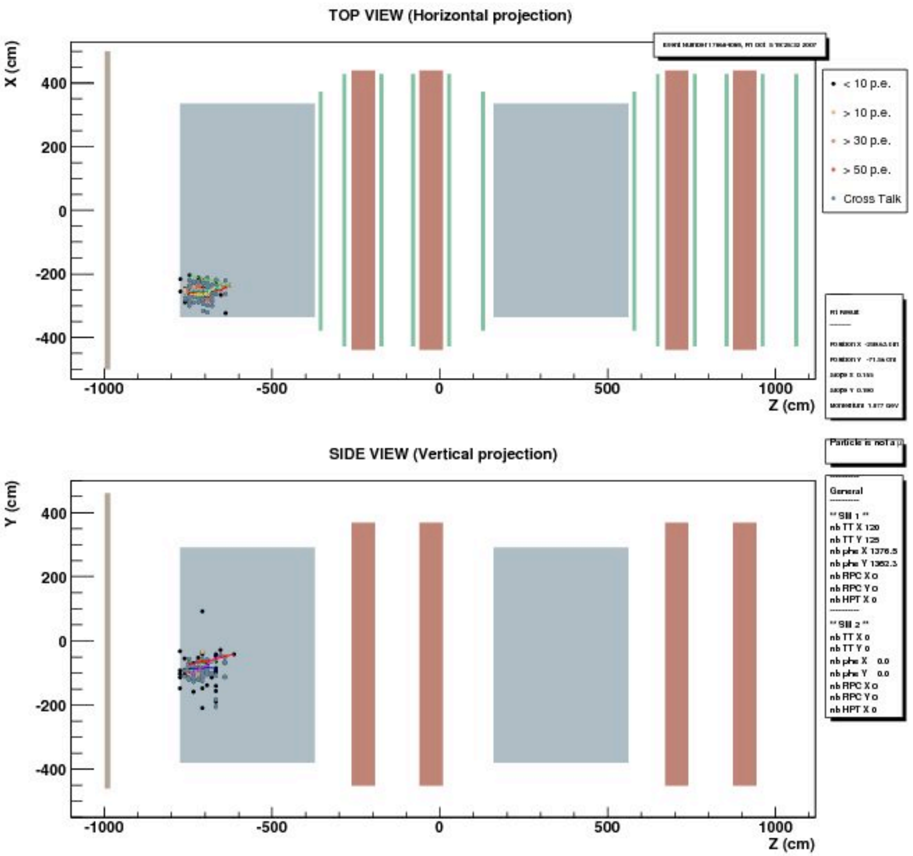
First interactions in the OPERA bricks!



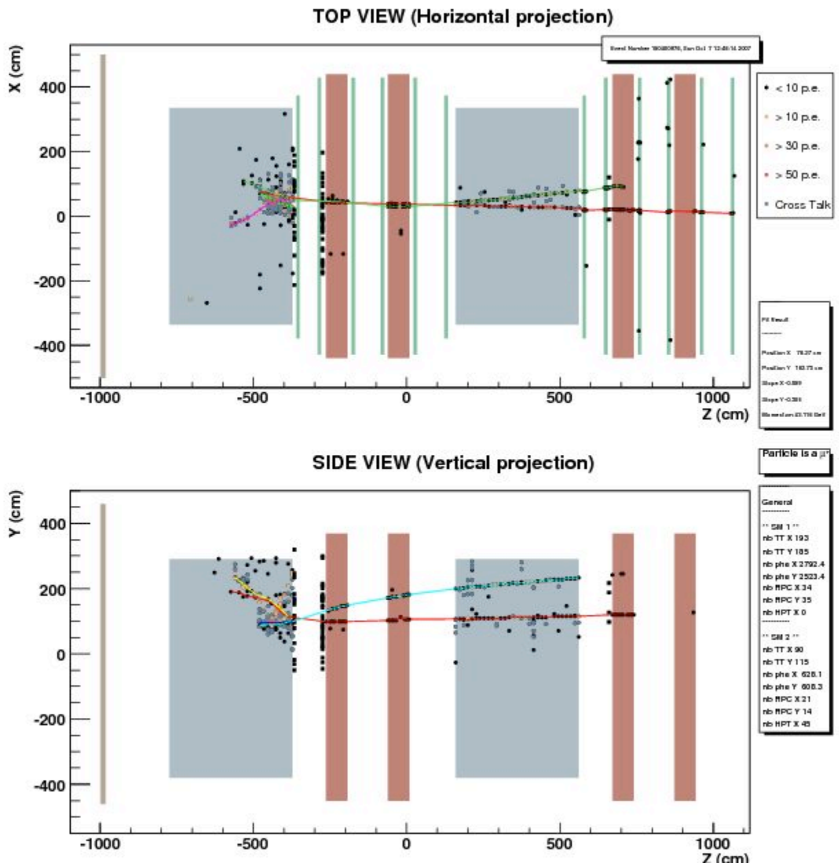
ν_μCC event

OPERA

Neutral Current event



Di-muon event



At now, 8 CC events, and 2 NC events.
Bricks will be extracted

Conclusions

- New measurement of Borexino
- Detectors conversion to decrease energy threshold
- No confirmation of LSND result
- Precise measure by MINOS
- First ν_μCC events in the OPERA bricks

- Many technologies developed and focused for the dark matter detection (cryogenic, liquid noble gaz, inorganic scintillators)

- Several Gravitational waves detectors have started common data taking and coherent analysis.
- Big steps forward in the interferometers technology. They reached design sensitivity above 100 Hz.