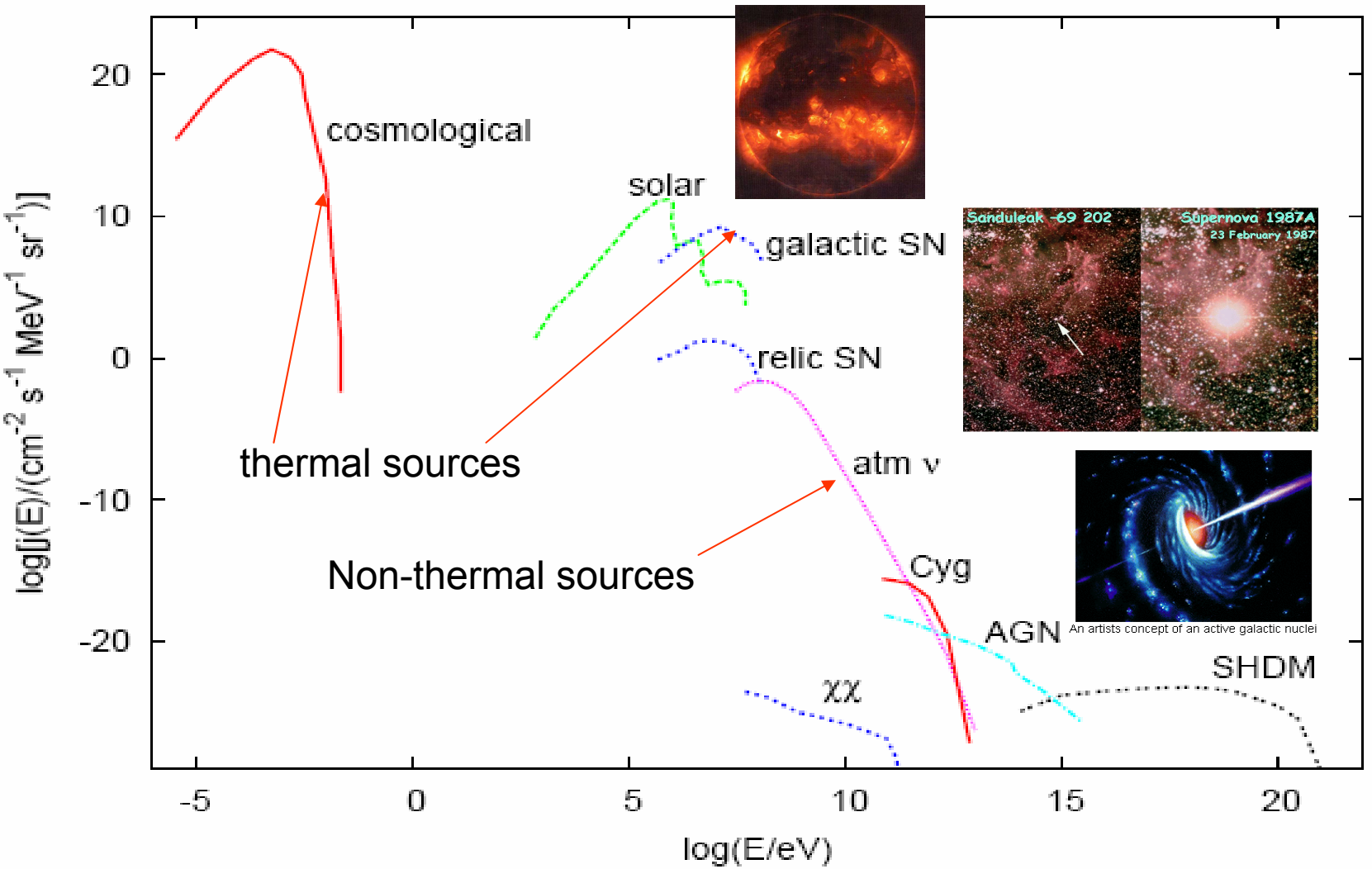
Astrophysical Neutrinos

Neutrinos as probes

HQL, Munich, October 16th-20th, 2006

L. Oberauer, TU Munich

Energy Spectra of Astrophysical Neutrinos



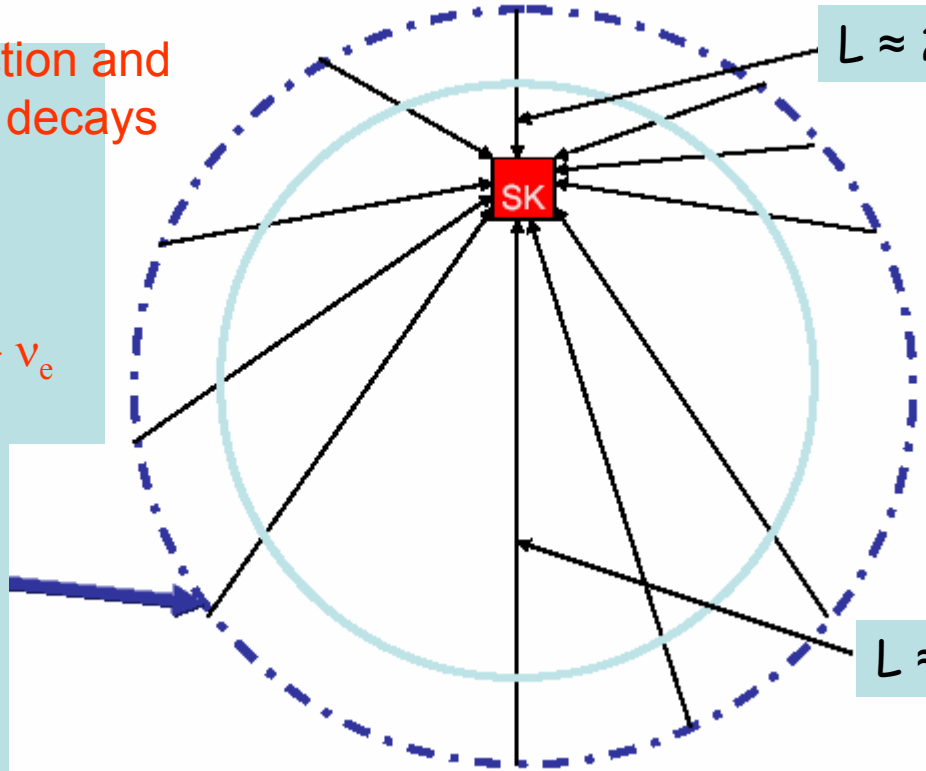
Oscillations and Atmospheric Neutrinos

Pion production and subsequent decays (incl. muon)

$\pi \rightarrow \mu + \nu_\mu$

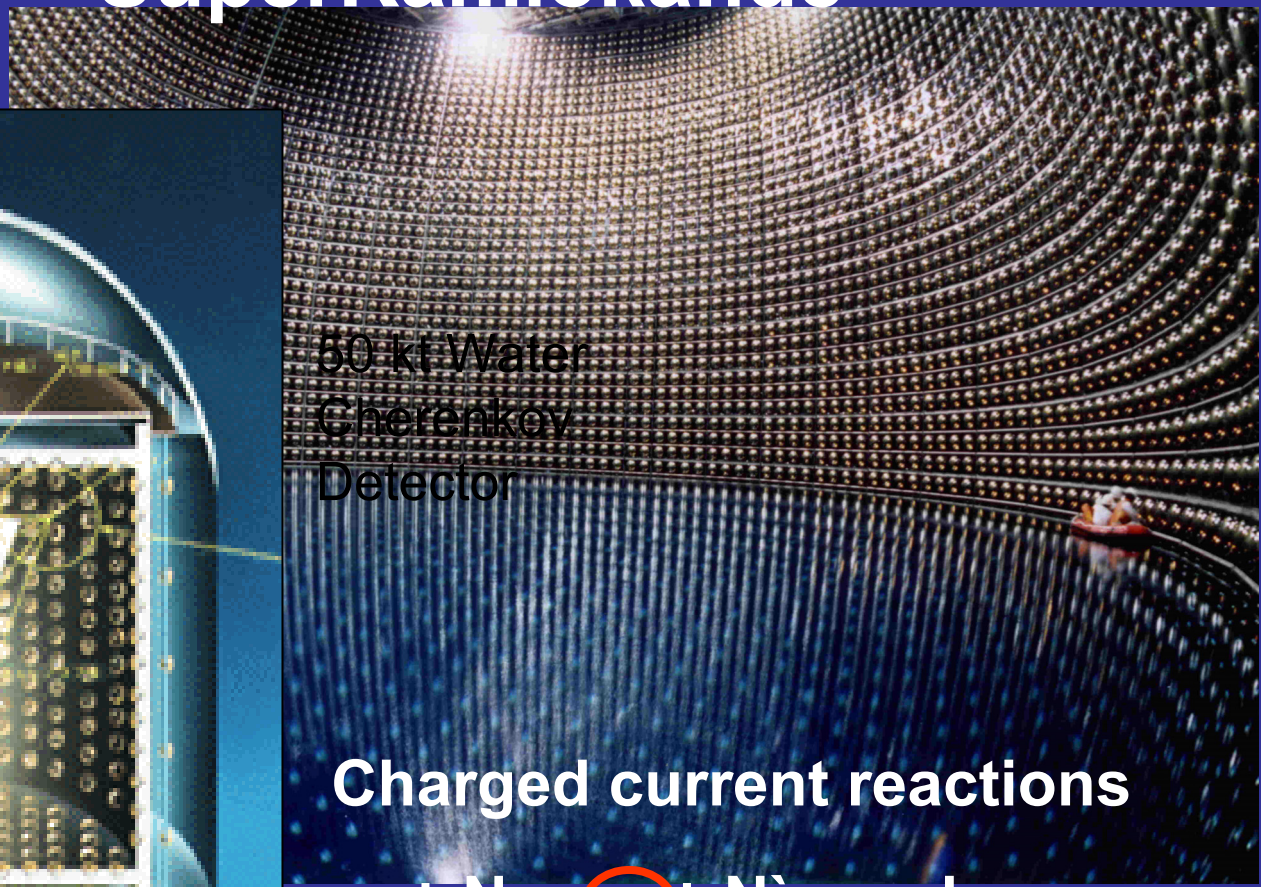
$\mu \rightarrow e + \nu_\mu + \nu_e$

atmospheric neutrinos: $E_\nu \sim$ GeV



$$P(\nu_\mu \rightarrow \nu_x) = \sin^2 2\theta_{atm} \sin^2\left(\frac{1.27\Delta m^2_{atm} L}{E_\nu}\right)$$

Atmospheric Neutrinos and SuperKamiokande



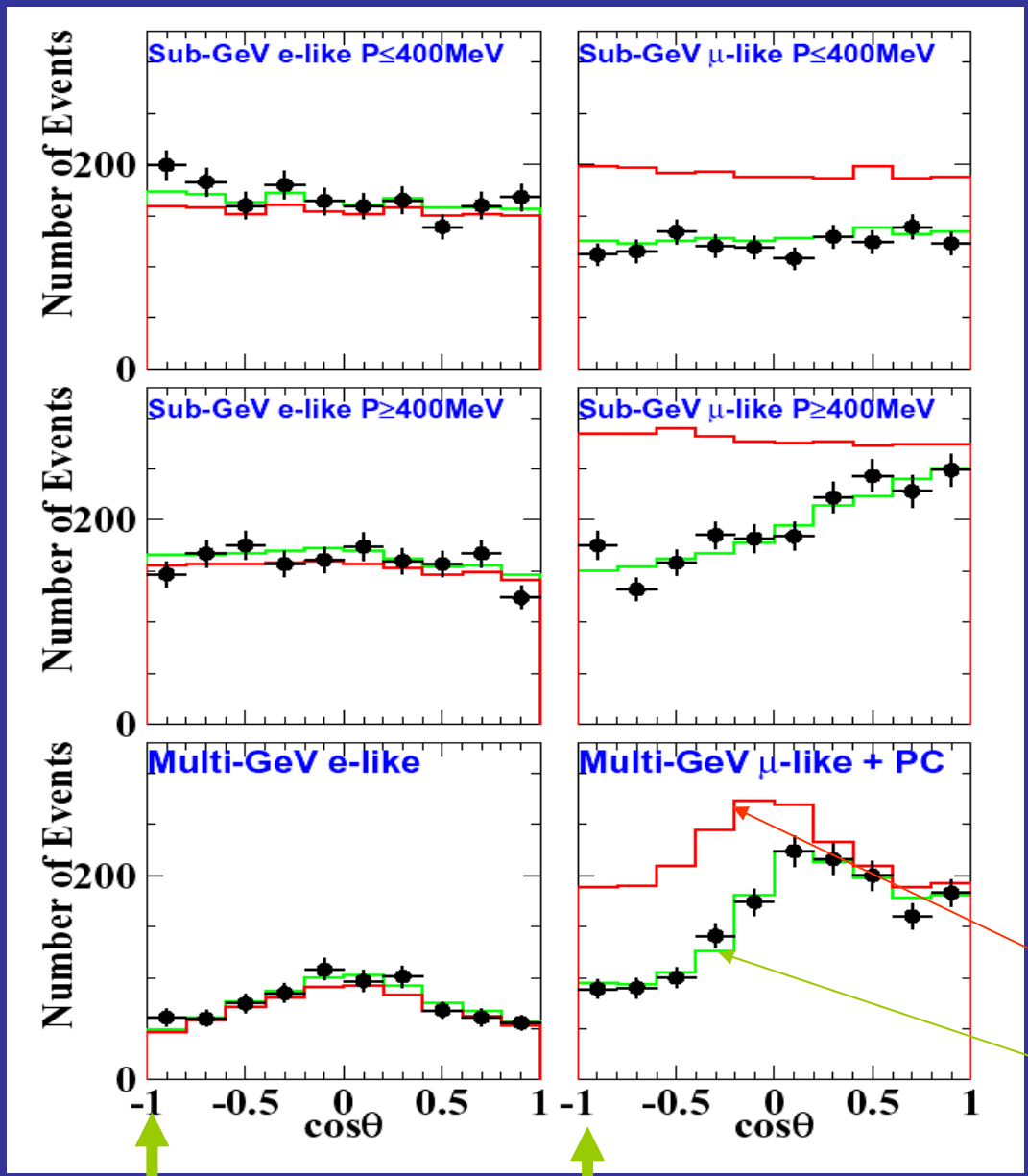
Charged current reactions

$\nu_\mu + N \rightarrow \mu + N'$ and

$\nu_e + N \rightarrow e + N'$

Electron events

Muon events



ν_e

e

ν_μ

μ

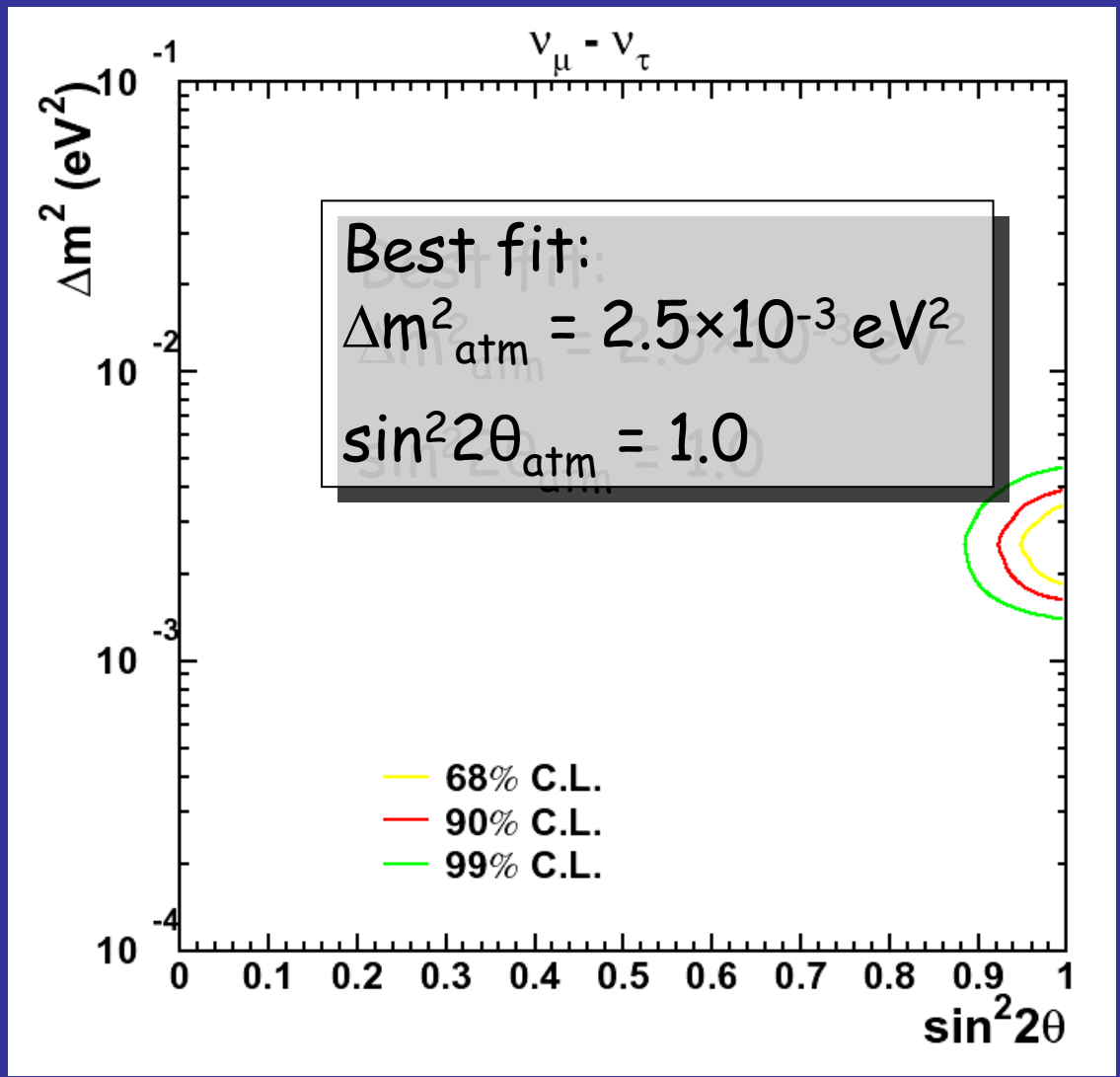
No-oscillation

Oscillation

Up going

Up going Neutrinos

Result atmospheric Neutrino-Oscillations

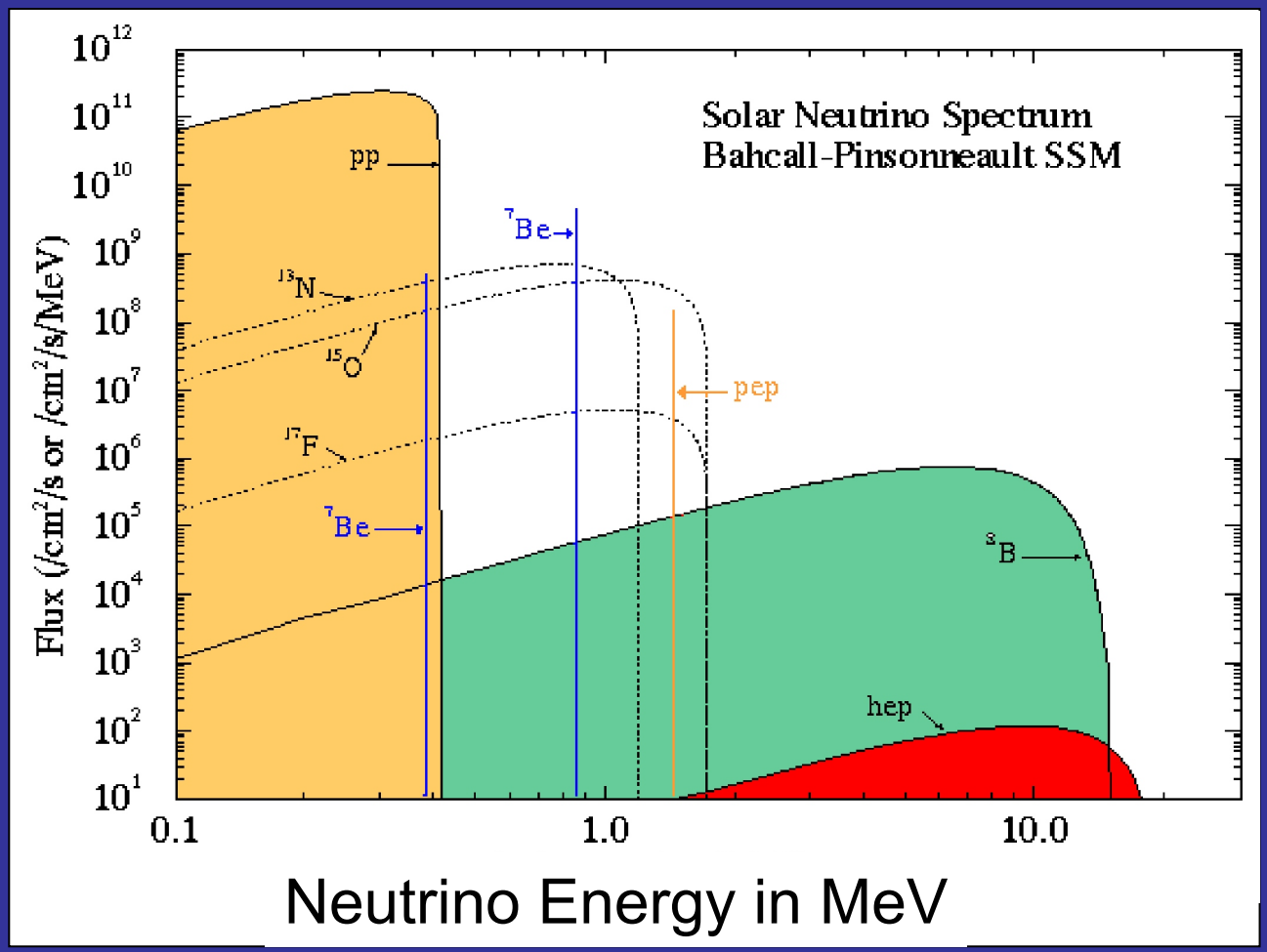


Confirmed by

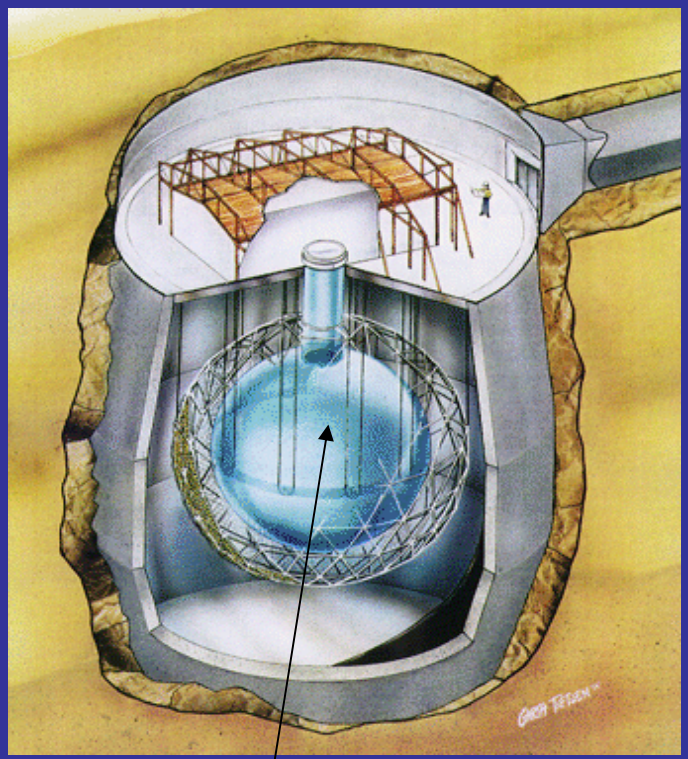
- **MACRO (Gran Sasso)**
- **Soudan (USA)**
- **K2K accelerator long baseline (250 km) experiment**
- **MINOS (USA) acc. exp. in 2006**

Oscillations and Solar Neutrinos

$$4p \rightarrow \mathrm{He}^4 + 2e^+ + 2\nu_e + 26.7\,\mathrm{MeV}$$



Sudbury Neutrino Observatory
SNO



1kt Cherenkov Detector with ***heavy*** water

- charged current interaction (cc)

$$\nu_e + D \rightarrow p + p + e$$

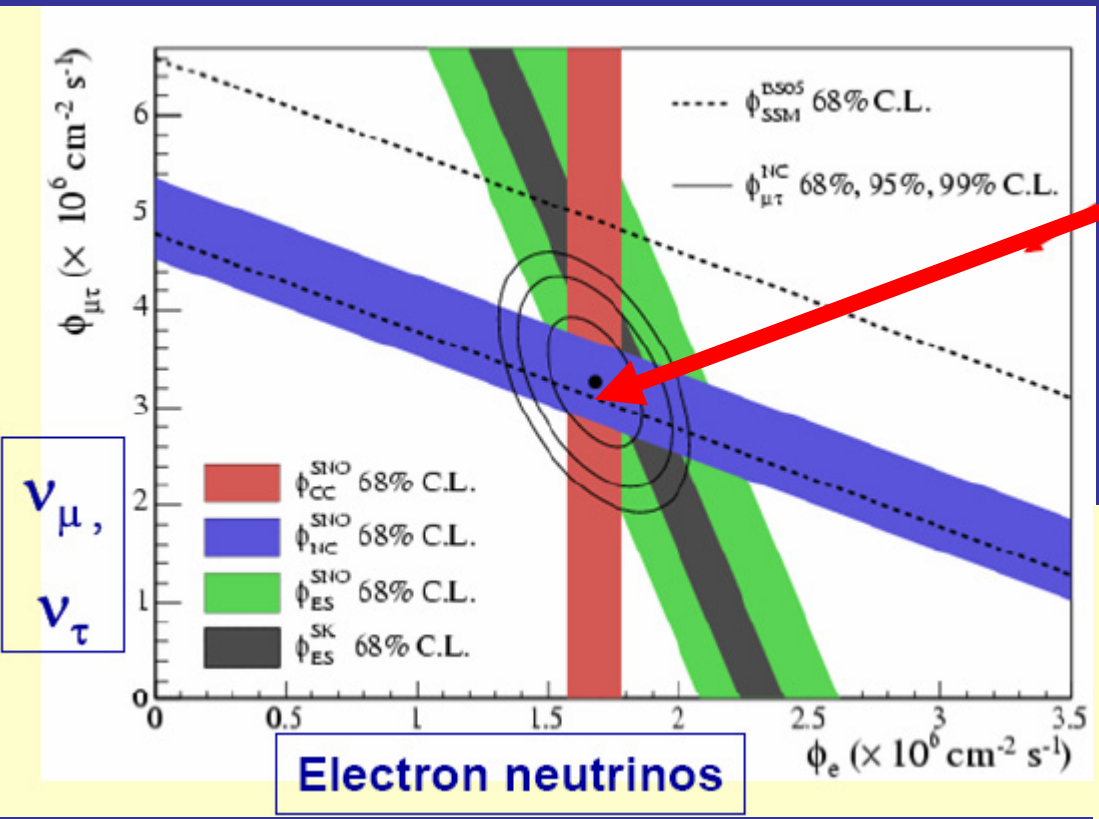
- neutral current interaction (nc)

$$\nu_x + D \rightarrow \nu_x + p + n$$

- elastic Neutrino-Electron scattering (cc + nc)

$$\nu_x + e \rightarrow \nu_x + e$$

SNO Result



- Flavour transition discovered: 7 sigma !
- Reasonable agreement with solar model

$$\phi_{CC} = 1.68\ ^{+0.06}_{-0.06}(\text{stat.})^{+0.08}_{-0.09}(\text{syst.})$$

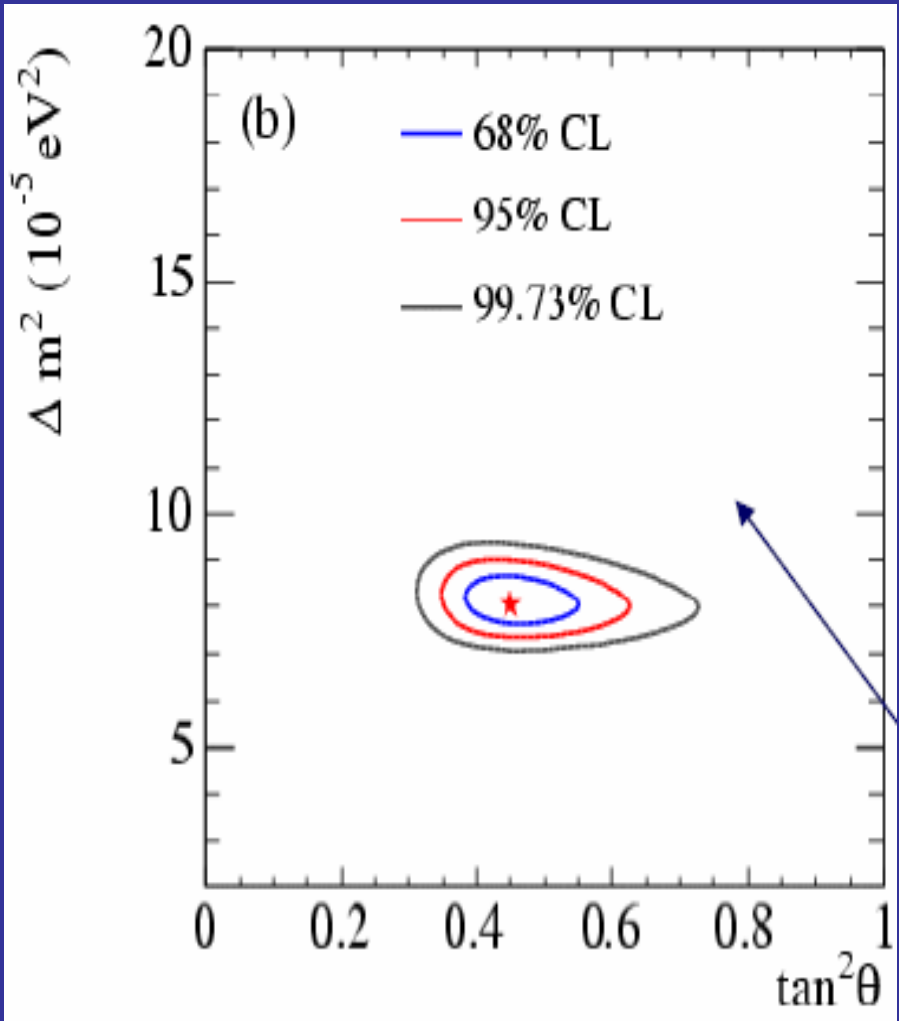
$$\phi_{NC} = 4.94\ ^{+0.21}_{-0.21}(\text{stat.})^{+0.38}_{-0.34}(\text{syst.})$$

$$\phi_{ES} = 2.35\ ^{+0.22}_{-0.22}(\text{stat.})^{+0.15}_{-0.15}(\text{syst.})$$

(In units of $10^6\,\text{cm}^{-2}\text{s}^{-1}$)

Neutrinos from the Sun (ν_e) transform into ν_μ or ν_τ !

Solar Neutrino Oscillation



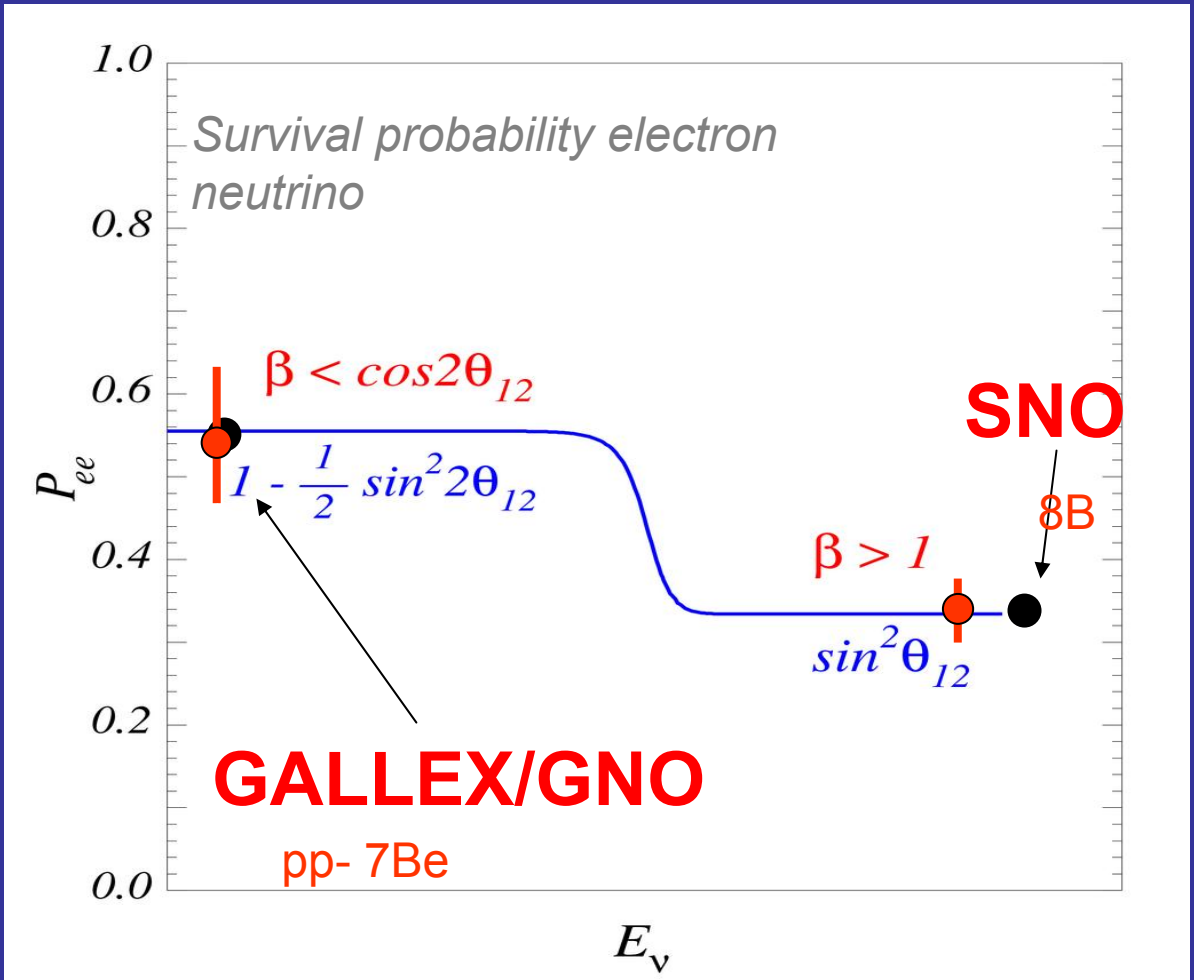
- Determination of

  $\Theta_{12} \sim 34^0$

  $\nu_e \longrightarrow \nu_{\mu,\tau}$

  $\Delta m^2 \sim 8 \times 10^{-5}$ eV^2
- Confirmation by reactor experiment **KamLAND**

The solar matter effect – evidence by GALLEX/GNO



- Evidence for matter effect inside the Sun
- **$m_2 > m_1$**
- Why are neutrino masses so small?
- GUT
- Leptogenesis

Future of Solar Neutrino Spectroscopy: low energies

- Monoenergetic ^{7}Be
- CNO, pep

Why?

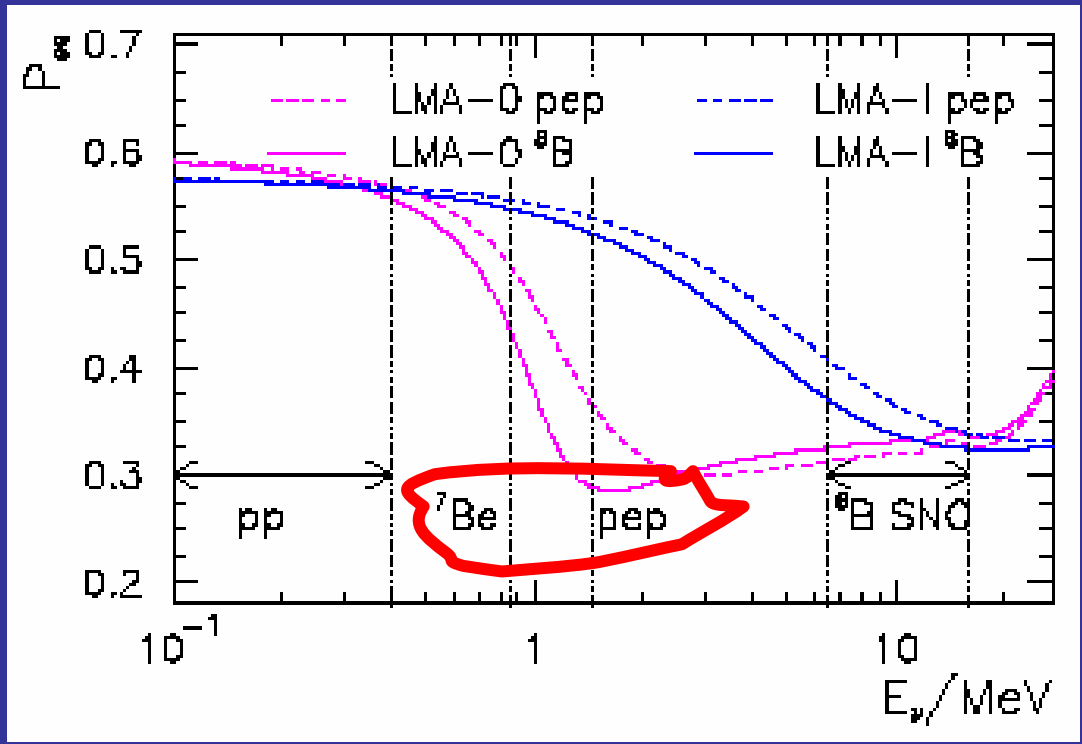
- Accurate Measurement of thermo nuclear fusion processes:

  $^{7}Be \sim 10\% \Rightarrow pp \sim 1\%$!
- CNO important for star development

The MSW Effect and new Physics ?

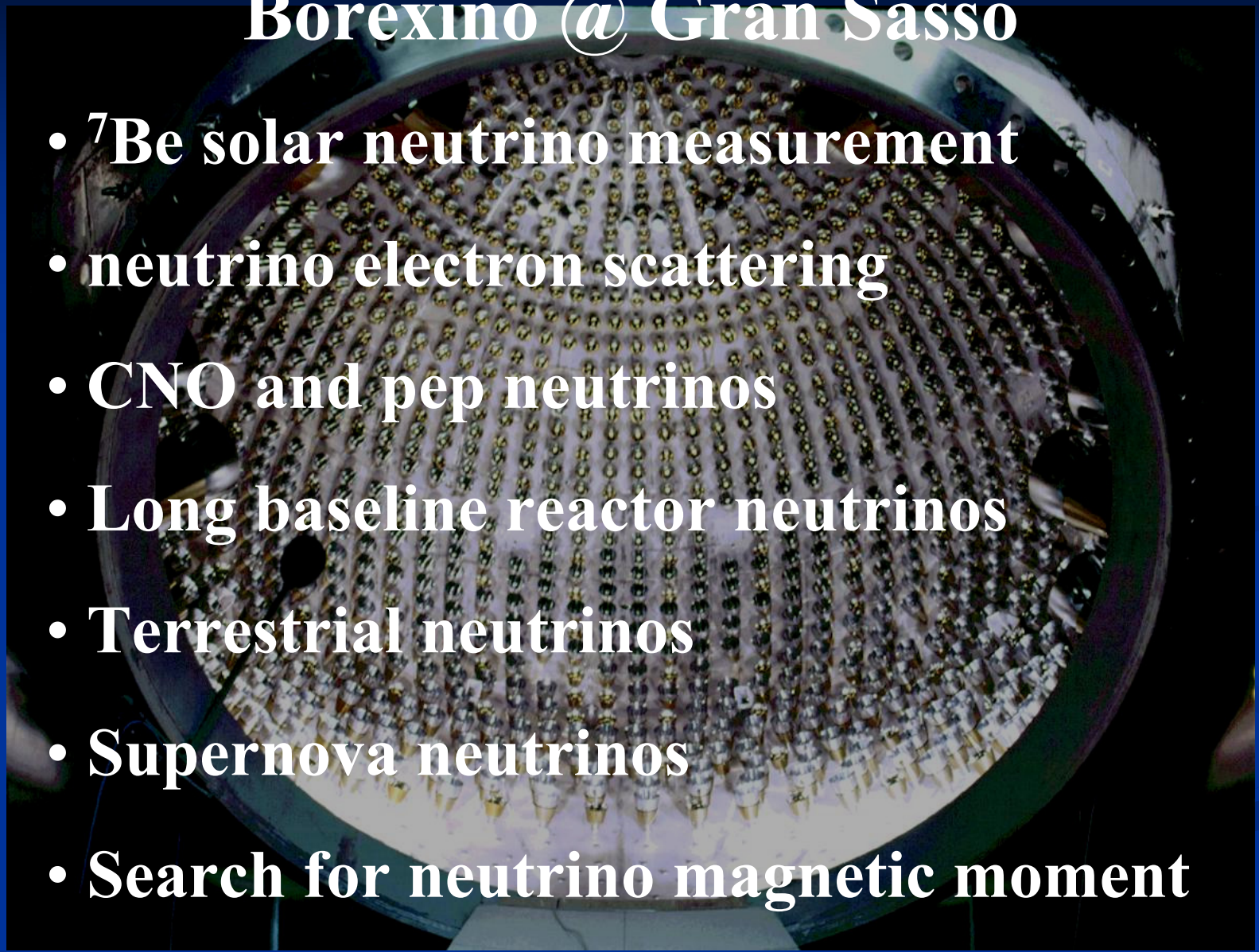
The MSW effect as filter

- Θ_{13}
- sterile Neutrinos?
- magnetic Neutrino moment?
- new interactions ?



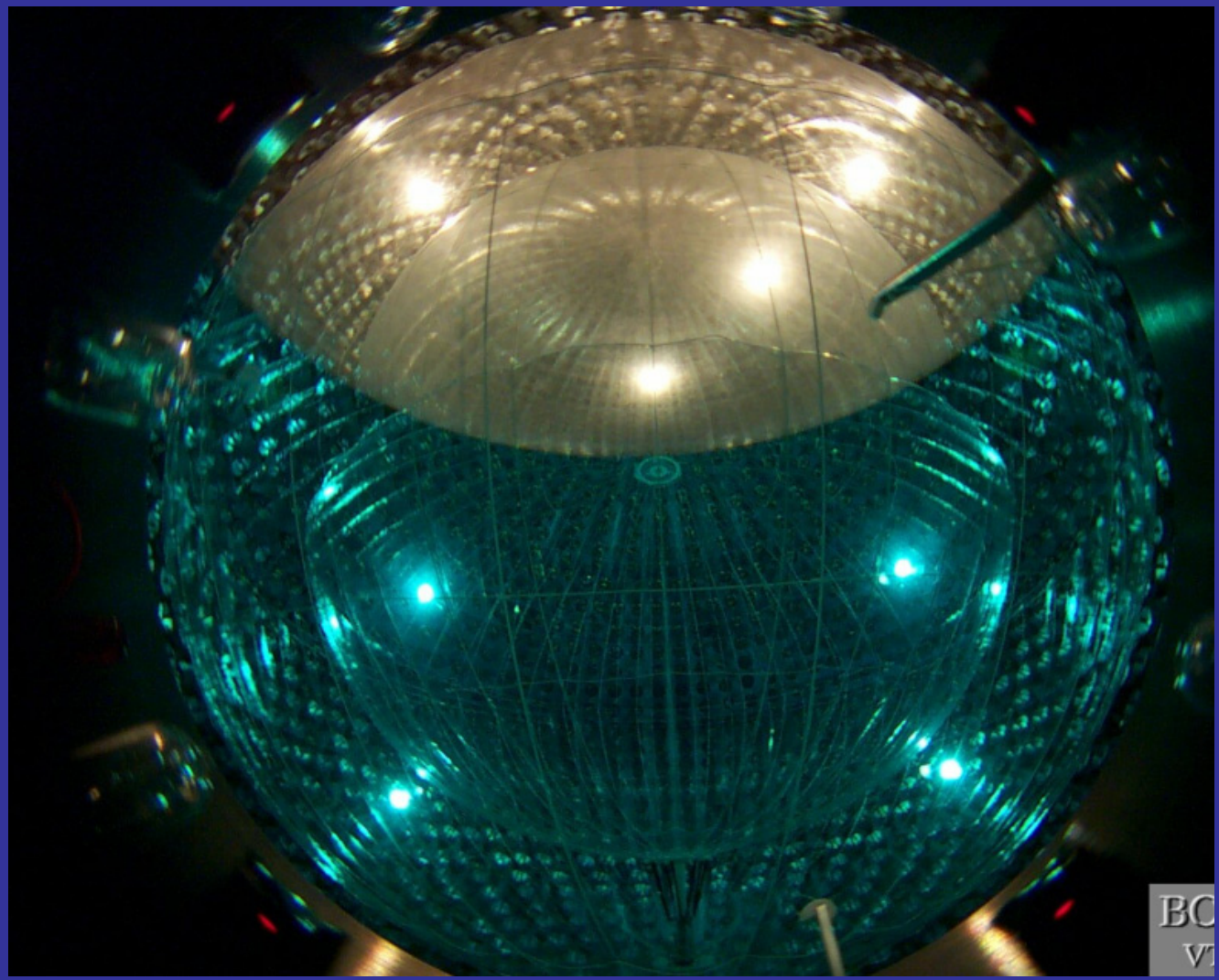
Friedland, Lunardini, Peña-Garay, hep-ph/0402266

Borexino @ Gran Sasso

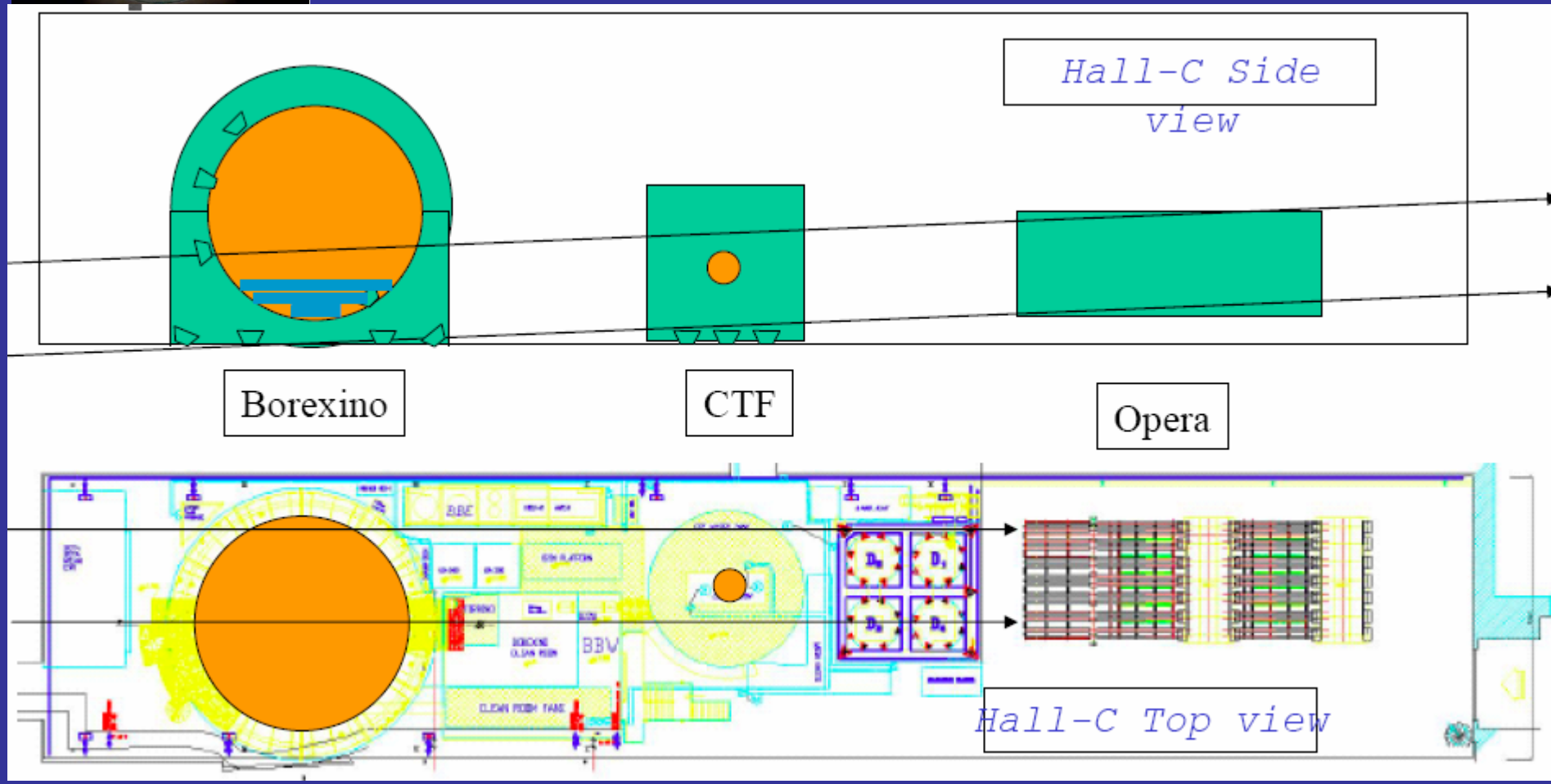


- ^{7}Be solar neutrino measurement
- neutrino electron scattering
- CNO and pep neutrinos
- Long baseline reactor neutrinos
- Terrestrial neutrinos
- Supernova neutrinos
- Search for neutrino magnetic moment

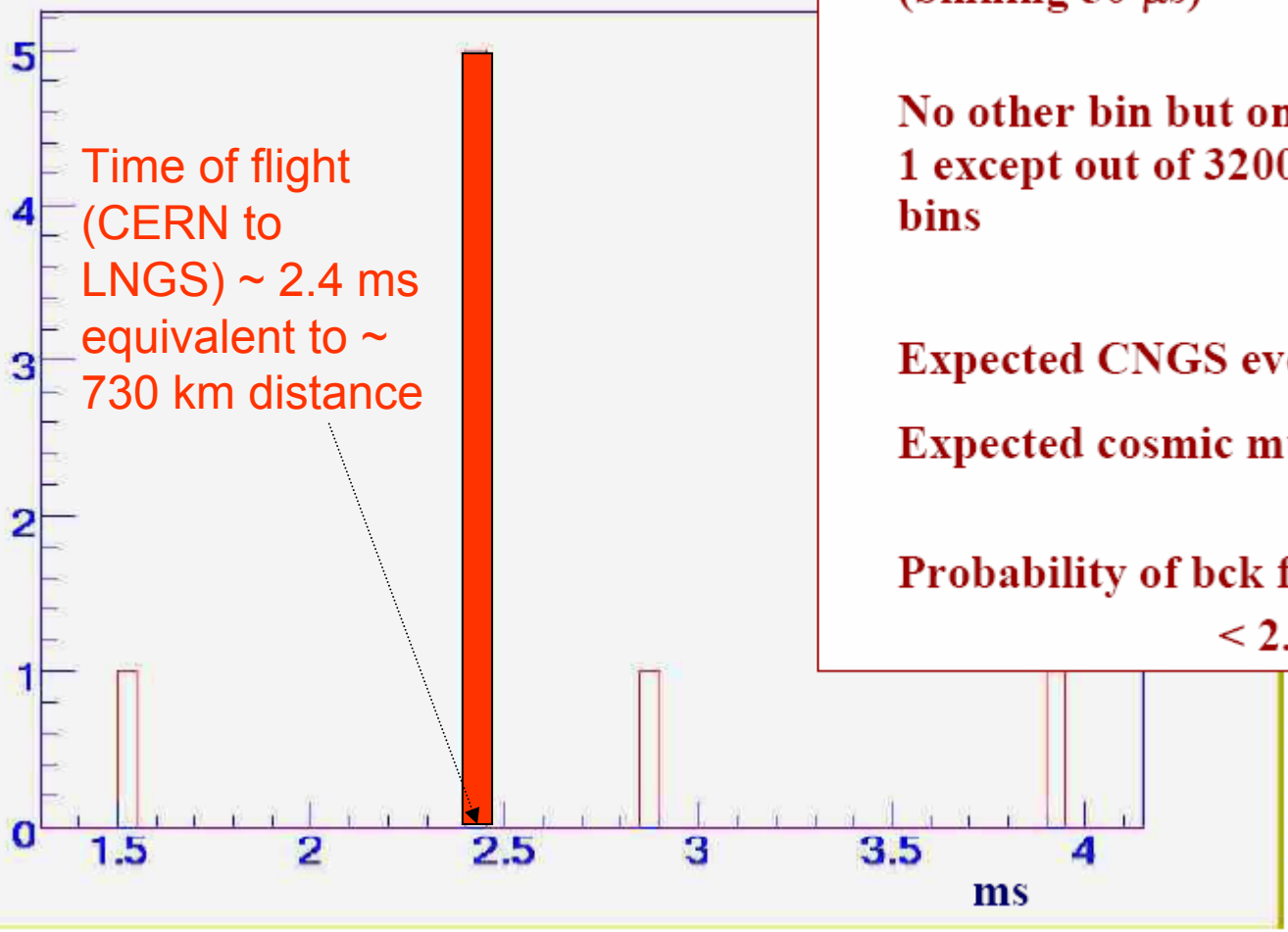
Water filling started in August 2006



BOREXINO sees neutrinos from CERN (August 2006) !



First neutrino events in BOREXINO



5 events at 2.4 ms delay

(binning 50 μs)

No other bin but one has more than 1 except out of 3200 events in 8000 bins

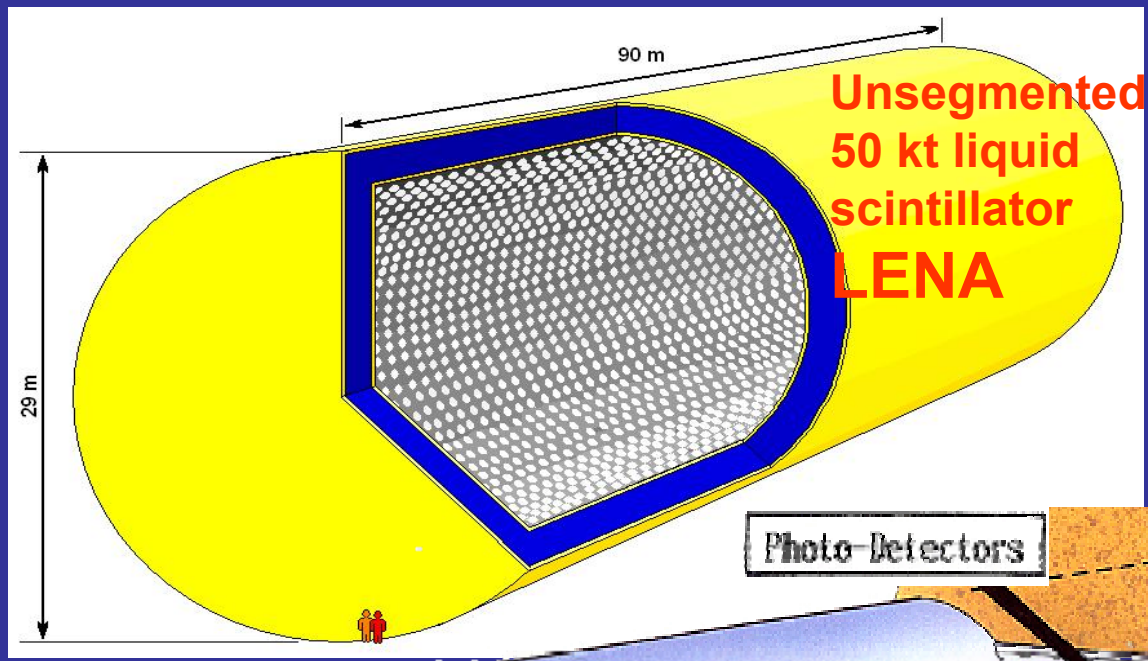
Expected CNGS events: 5

Expected cosmic muons: ~ 2000

Probability of bck fluctuation:

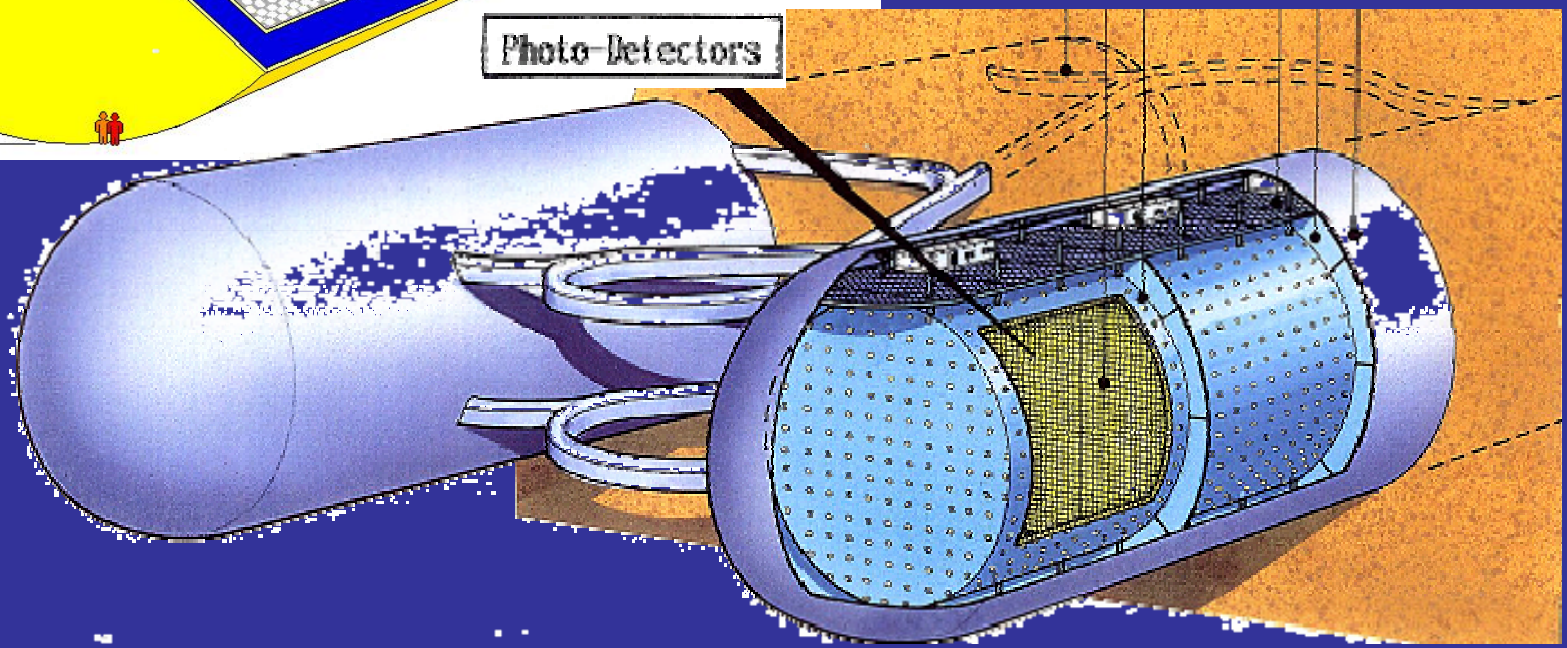
$< 2.\ 10^{-5}$

Future Neutrino Observatories



…Liquid Argon ~100 kt TPC

HyperKamiokande (1 Mt Water Cherenkov)



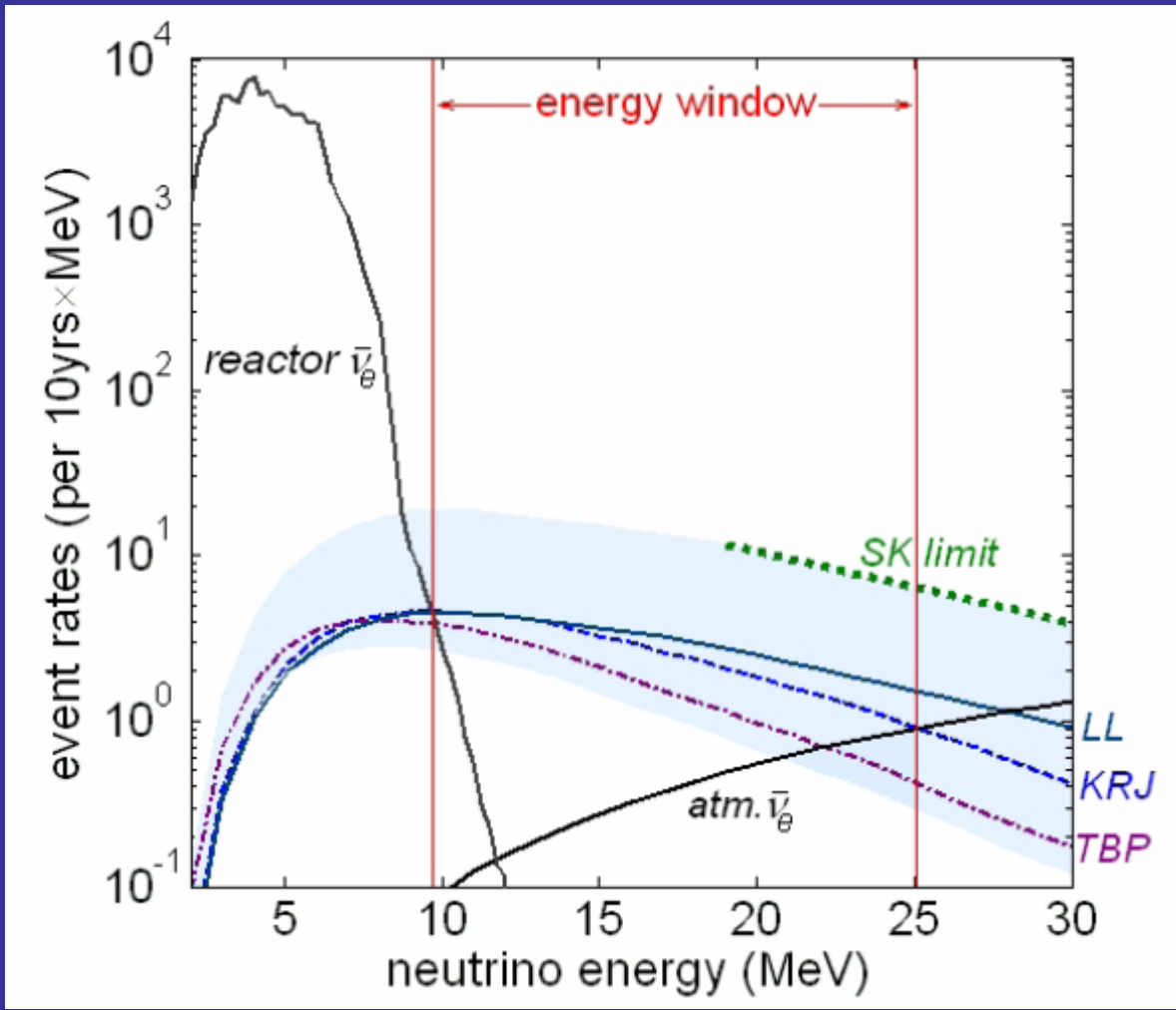
LAGUNA

- Large Aparatus for Grand Unification and Neutrino Astronomy
- European initiative (France, Germany, Italy, Switzerland, UK, Poland, Finland)
- Aim: Design studies for all 3 kinds of detectors (water Ch, scintillator, liquid argon) until ~ 2010

Physics goals of future Neutrino Observatories

- Gravitational collapse
- Star formation rate in the early universe
- Thermonuclear fusion reactions
- Baryon number violation (Proton decay)
- Leptonic CP – violation
- Geophysics
- Indirect search for Dark Matter
- Active Galactic Nuclei – UHE Neutrinos

One example for **LENA**: Detection of the Diffuse Supernova Neutrino Background (DSNB) ?

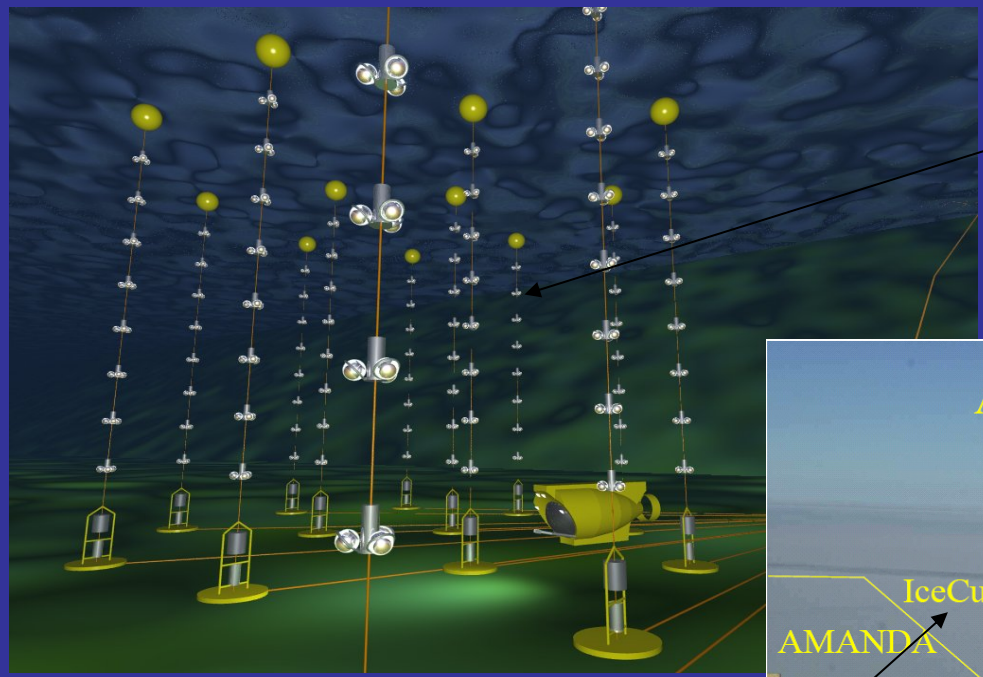


- up to now only limits
- flux and spectral shape depend on

Star formation rate

Gravitational collapse model

Extremely Large Observatories



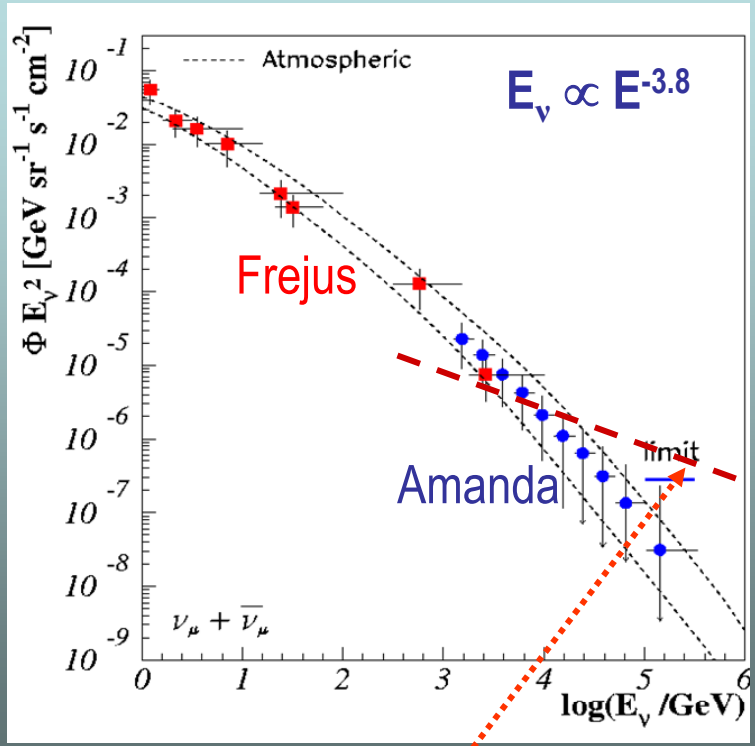
Km^3 Cherenkov detector in the mediterranian sea

Km^3 Cherenkov detector at the South Pole (Ice Cube)

= 2π

= 00-03 combined

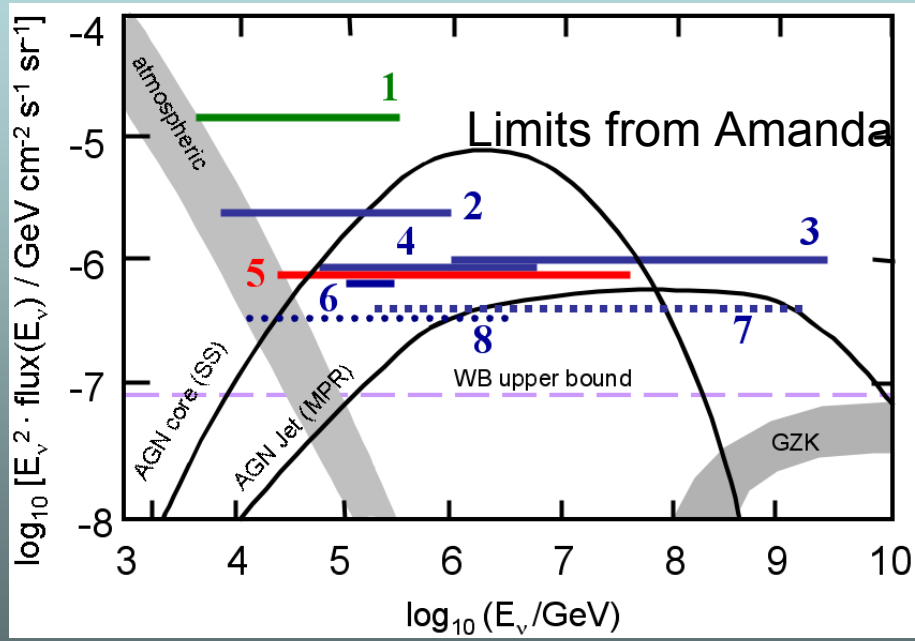
Atmospheric neutrino



A change in the slope would indicate a non-atmospheric component

Waxmann-Bahcall limit:

Model-independent upper bound



Ice-Cube ~ 3 10^{-9}

Conclusions

- Neutrino physics very successfull in the last decade
- Neutrino masses and mixing established
- Physics beyond the standard model
- New window to astrophysical observations