European Physical Society – EPS Historic Site

The neutrino experiment at MTA Atomki

Using a cloud chamber located in this building, in 1956 J. Csikai and A. Szalay photographed beta-decay events. In some cases the angle between the tracks of the electron and the residual nucleus implied the emergence of an undetected third particle in the decay. Thus confirming the existence of the neutrino, the Debrecen neutrino experiment laid a brick of the foundation of modern physics.

Európai Fizikai Társulat – EPS történelmi emlékhely

A neutrínókísérlet, MTA Atomki

1956-ban Csikai Gyula és Szalay Sándor ebben az épületben béta-bomlási eseményeket fényképezett le egy ködkamrában. Az elektron és a maradékmag pályájának szöge azt mutatja, hogy a bomlásban keletkezik egy nem detektált harmadik részecske is. A neutrínó létezését így megerősítve, a kísérlet hozzájárult a modern fizika megalapozásához.

Debrecen
2013

(A few) Modern neutrino detectors

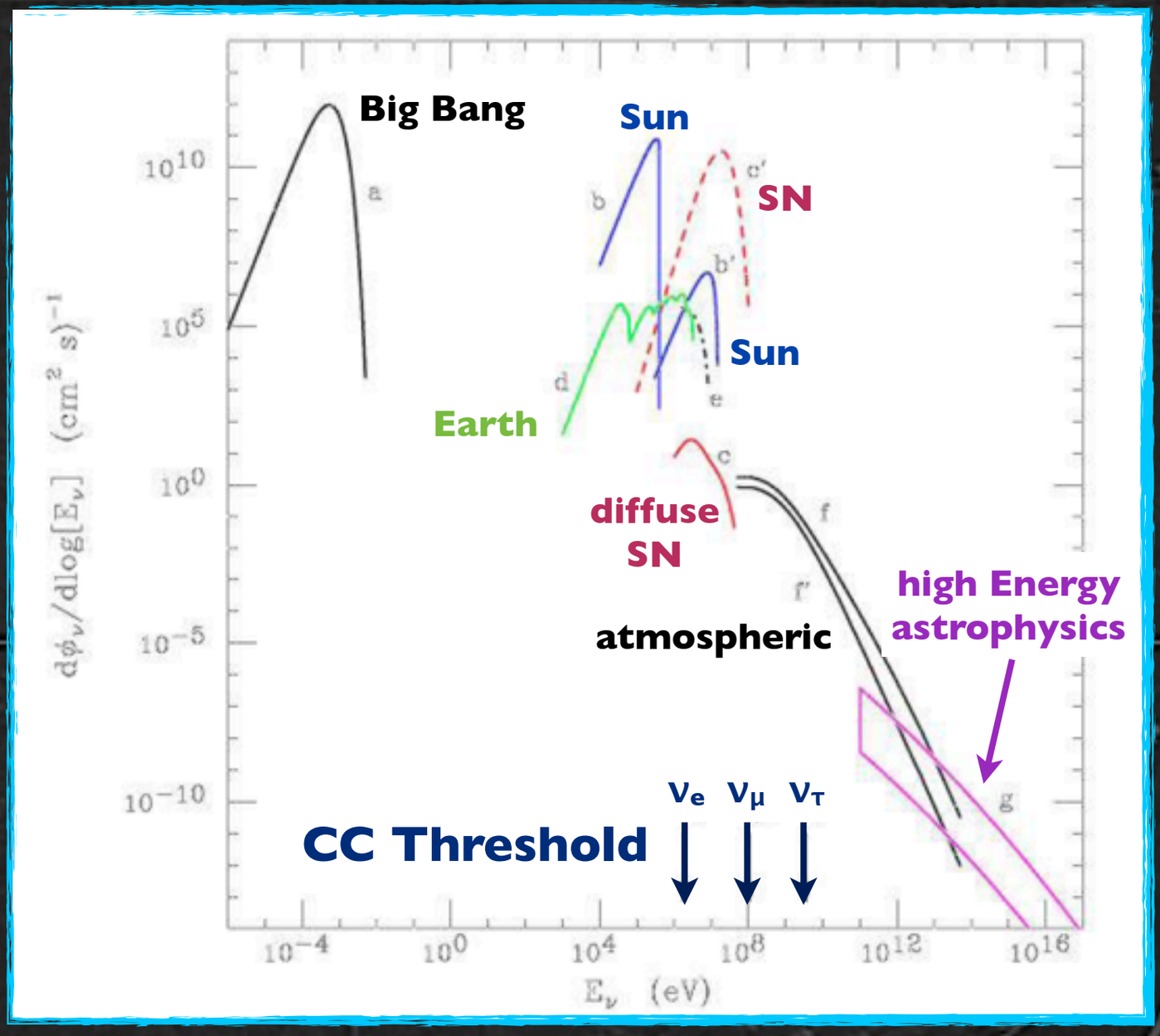
(and some results)

EPS Historic site celebration
DEBRECEN, Oct. 25th, 2013

Marco Pallavicini
Università di Genova e INFN Genova (Italia)

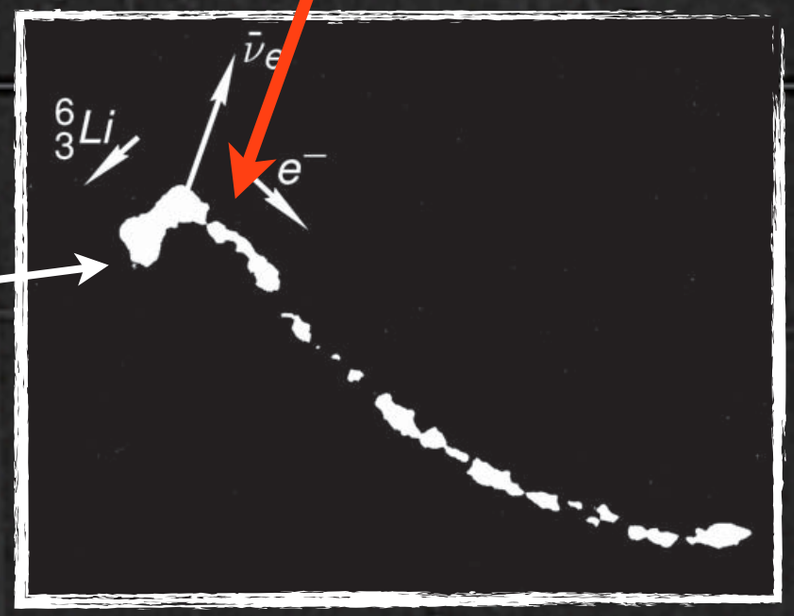
WHY NEUTRINO DETECTORS ?

- **Since the early times, neutrino physics has changed significantly**
  - **From discovery of neutrinos to fundamental physics and astronomy by means of neutrinos**
    - **Fundamental physics**
    - **Astronomy and Astrophysics**
    - **Cosmology**
    - **Geophysics**



DETECTION AND DETECTORS

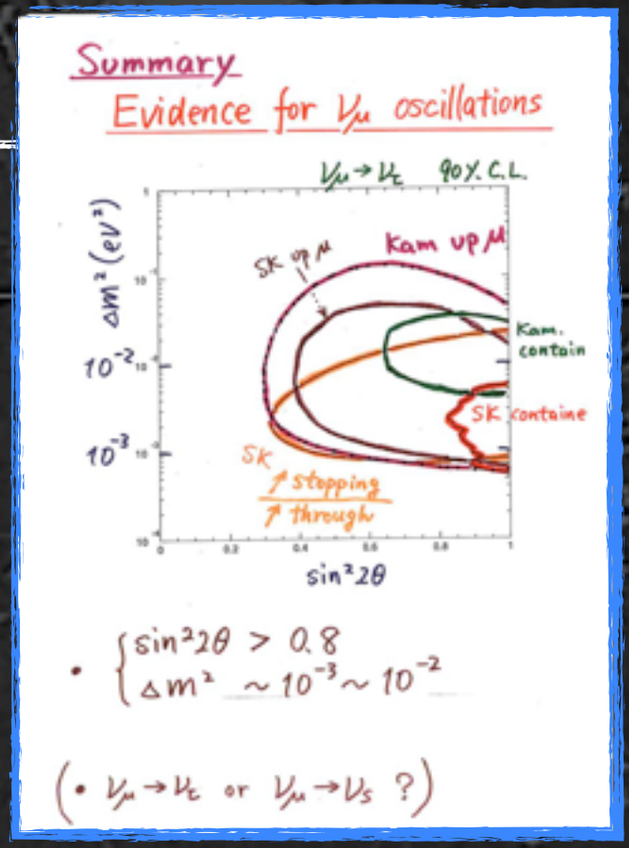
Many modern studies reverse Debrecen result!

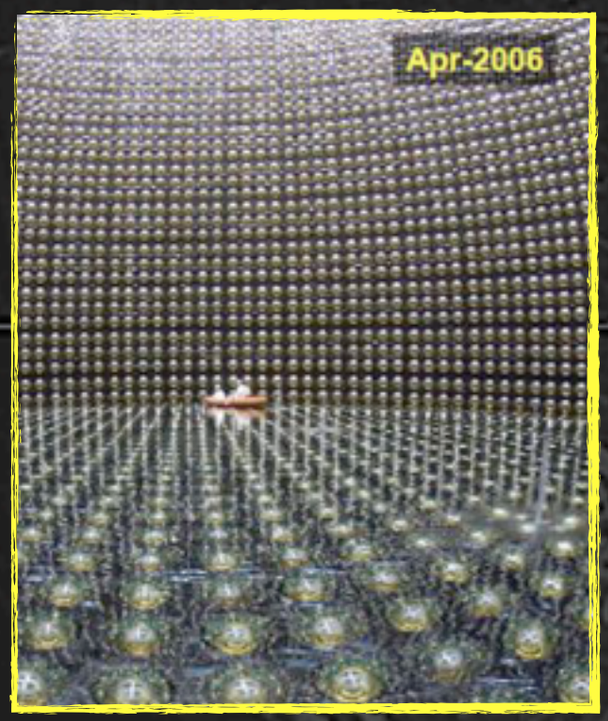


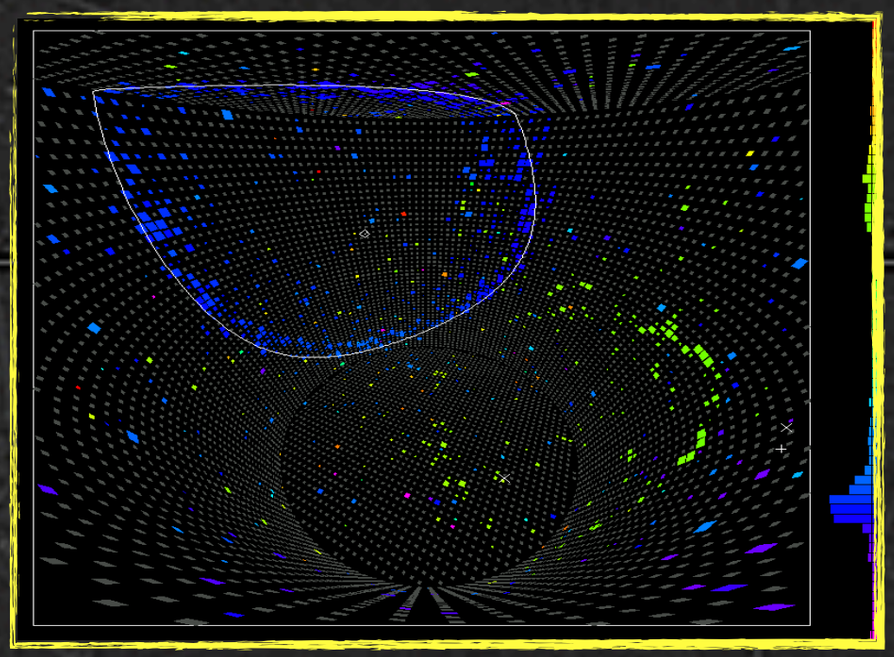
- **Neutrino detection principles**
  - **Inverse beta-decay**
  - **Charge current interactions on nuclei**
  - **Elastic scattering on electrons**
  - **Neutral current interactions**
- **A few (among many) existing neutrino detectors**
  - **Water: Super-Kamiokande, SNO**
  - **Water in the Sea or Ice at the South Pole: Antares, Km3Net, Ice Cube**
  - **Liquid scintillators: Borexino, KamLAND, Double-Chooze, Daya-Bay,…**
  - **Long Base Line detectors: Opera, Minos, T2K**
  - **Liquid Argon detectors: Icarus**
- **The future: INO, Memphis, Glacier, Lena, Juno, HyperK, LBNE, SNO+, ….**

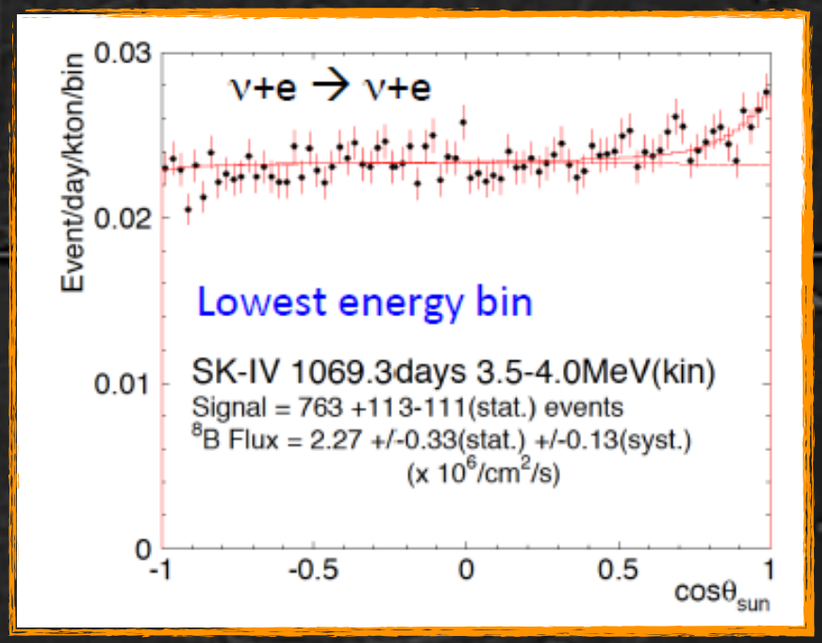
(SUPER)-KAMIOKANDE DETECTOR

- **Largest water Cherenkov detector ever built**
  - **Kamiokande: 198x-199y, SK since 1996, 260 kton/y**
  - **Detection method: CC interactions or elastic scattering**
- **Major discoveries**
  - **First direct detection of Super Nova neutrinos (SN1987A)**
  - **Existence of oscillations through atmospheric neutrinos (1998)**
  - **T2K evidence of $\vartheta_{13} \neq 0$ (2001)**
  - **Fundamental contribution to the solution of the solar neutrino problem**





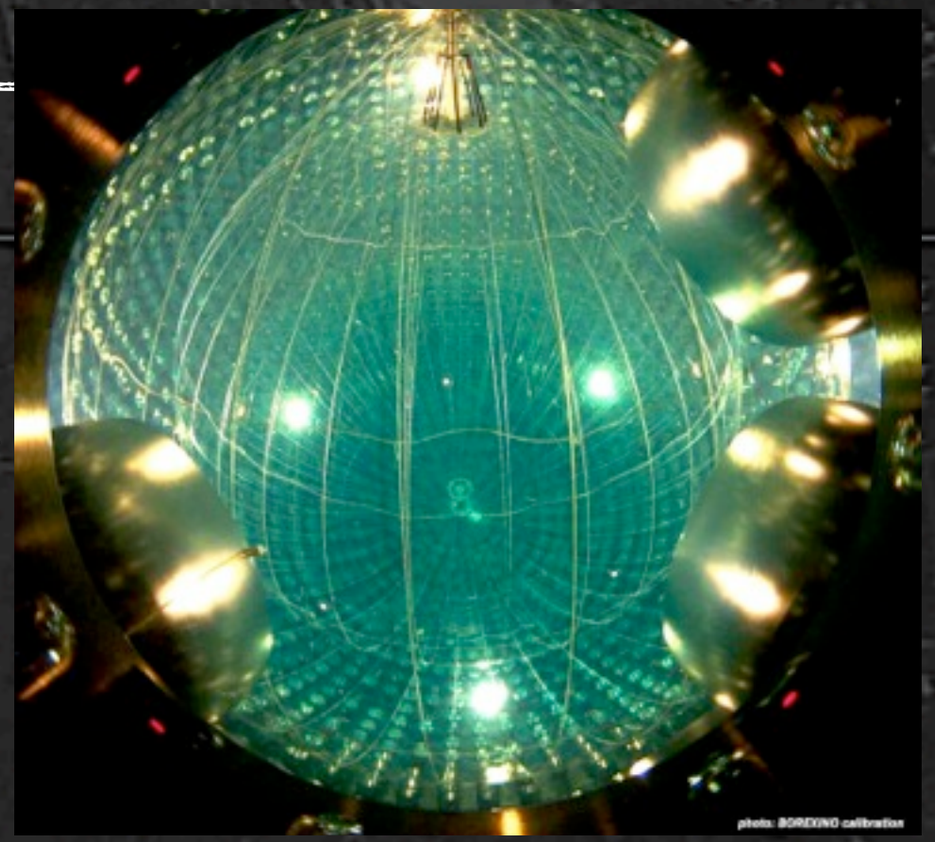


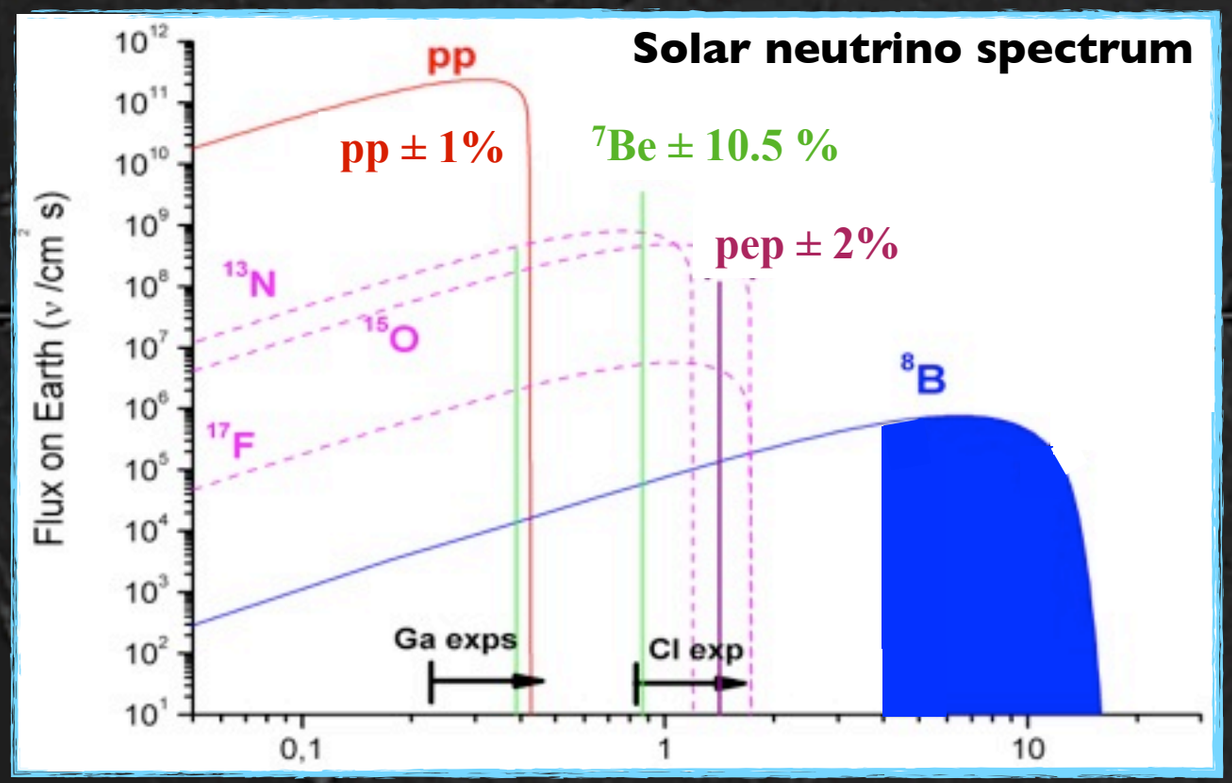


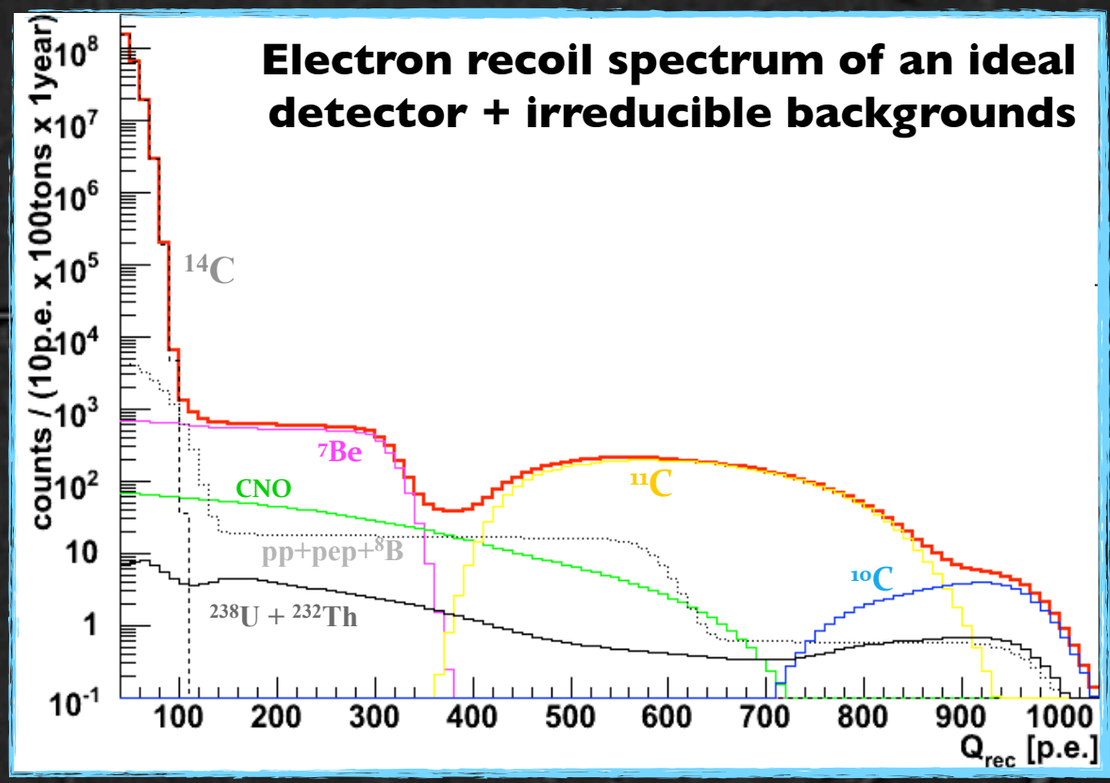
11129 PMTs 40% coverage

BOREXINO

- **Mainly, a <u>solar ν experiment:</u>**
  - **$\nu + e^- \rightarrow \nu + e^-$ in liquid scintillator**
    - **Ultra-low radioactive background obtained via selection, shielding, and purifications**
    - **Low energy threshold, good resolution, spatial reconstruction, and pulse shape ID**
  - **But also:**
    - **<u>Geo-neutrinos,</u> search for rare events**







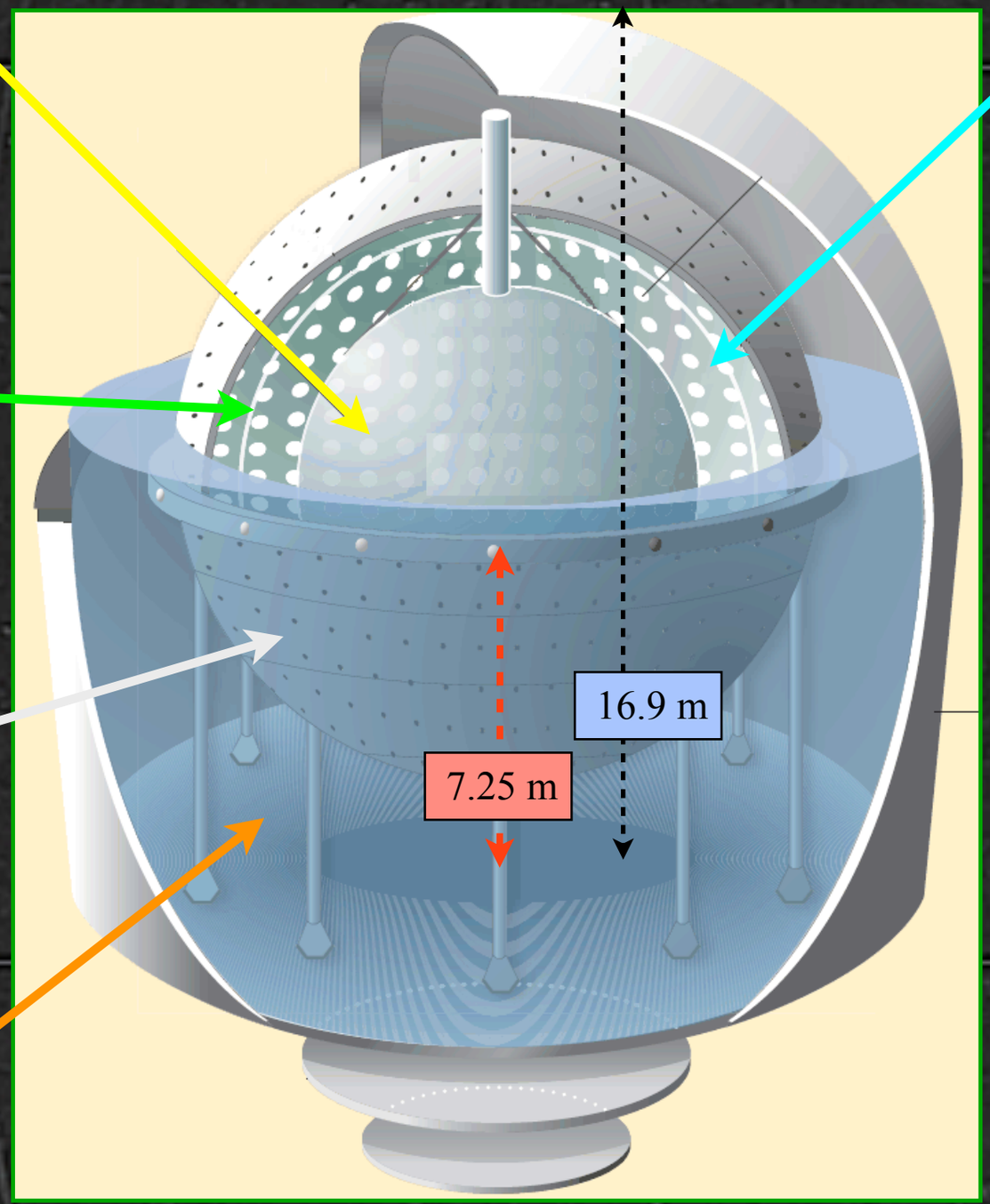
BOREXINO DETECTOR

Scintillator:
270 t PC+PPO (1.5 g/l) in 150 μm thick nylon vessel (R = 4.25 m)

Outer nylon vessel:
R = 5.50 m
(^{222}Rn barrier)

Stainless Steel Sphere:
R = 6.75 m
2212 PMTs

Water Tank:
γ and n shield
μ water Č detector
208 PMTs in water



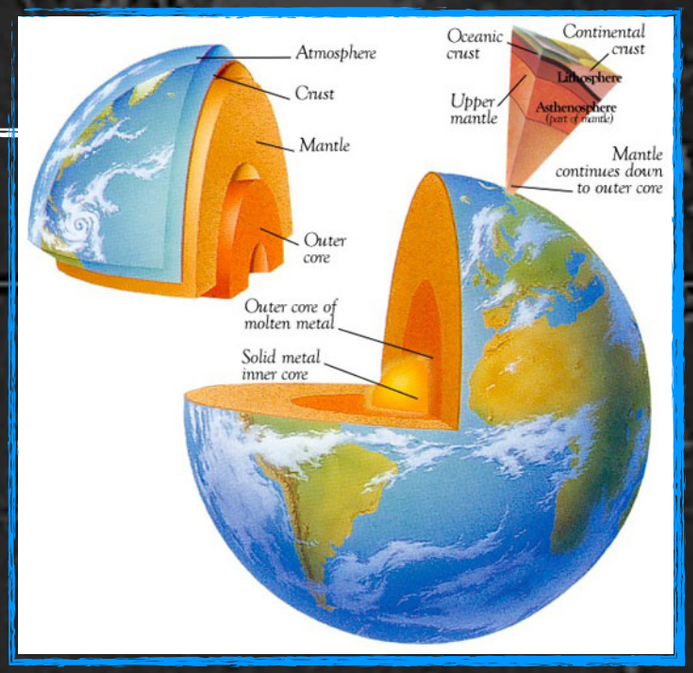
Buffer region:
PC+DMP quencher
4.25 m < R < 6.75 m

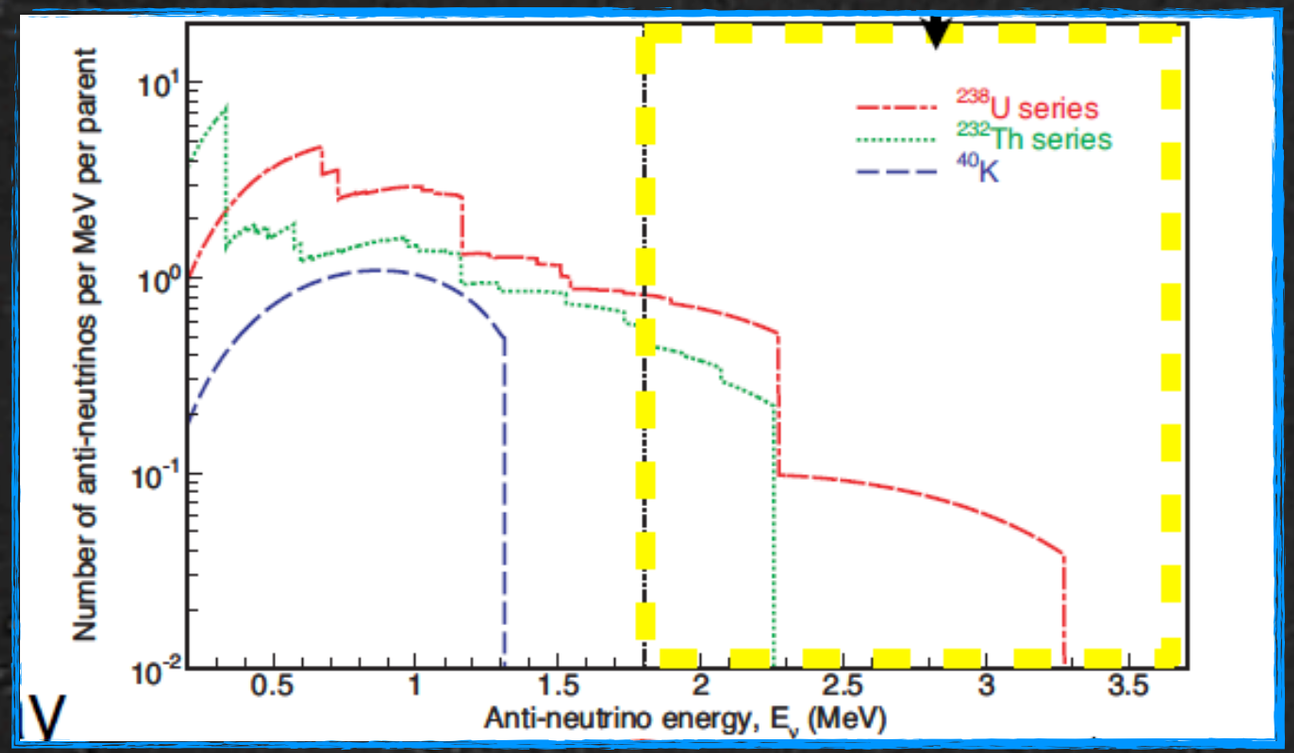
The principle of graded shielding: materials more and more pure moving toward center.

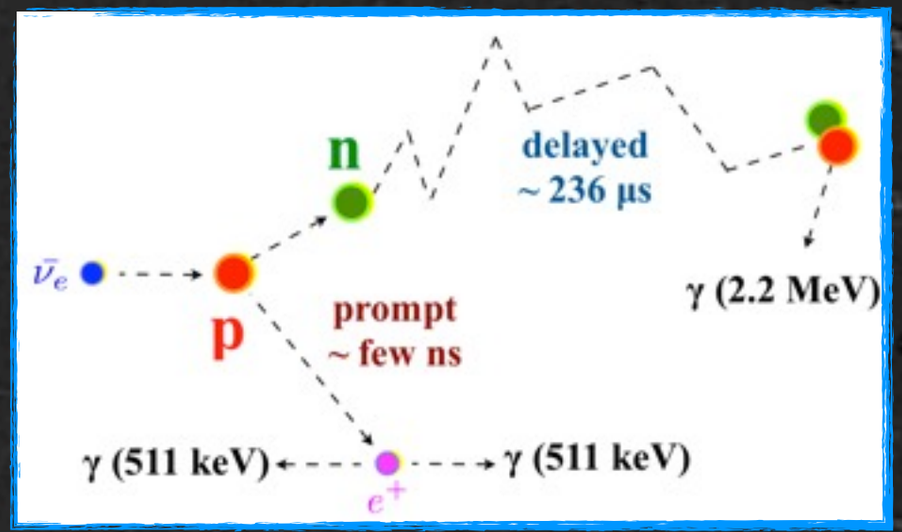
Borexino core is the less radioactive place on Earth: 9-10 orders of magnitude less than good mineral water

GEO-NEUTRINOS

- **Anti-neutrinos emitted by Earth radioactivity**
  - **First detected by KamLAND and Borexino**





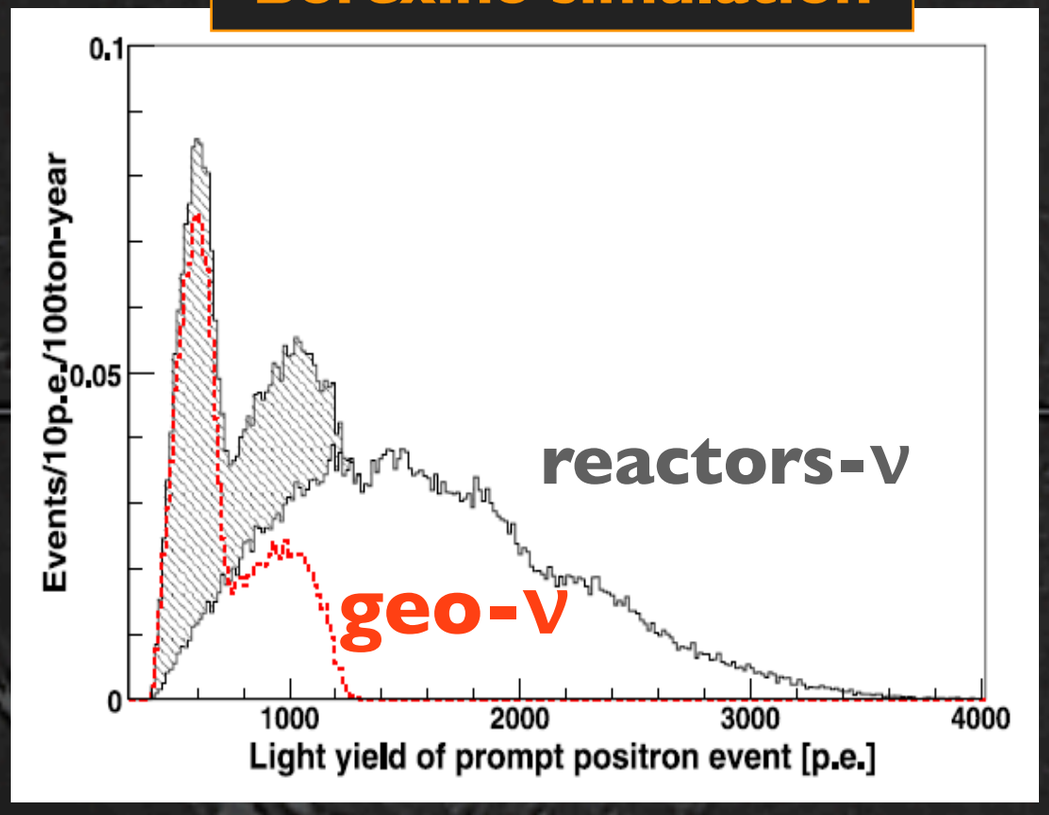


- **Very low flux (3 orders less than solar neutrinos)**
  - **Clean anti-neutrino signature**
  - **Only background: reactors (much bigger at KamLAND site)**

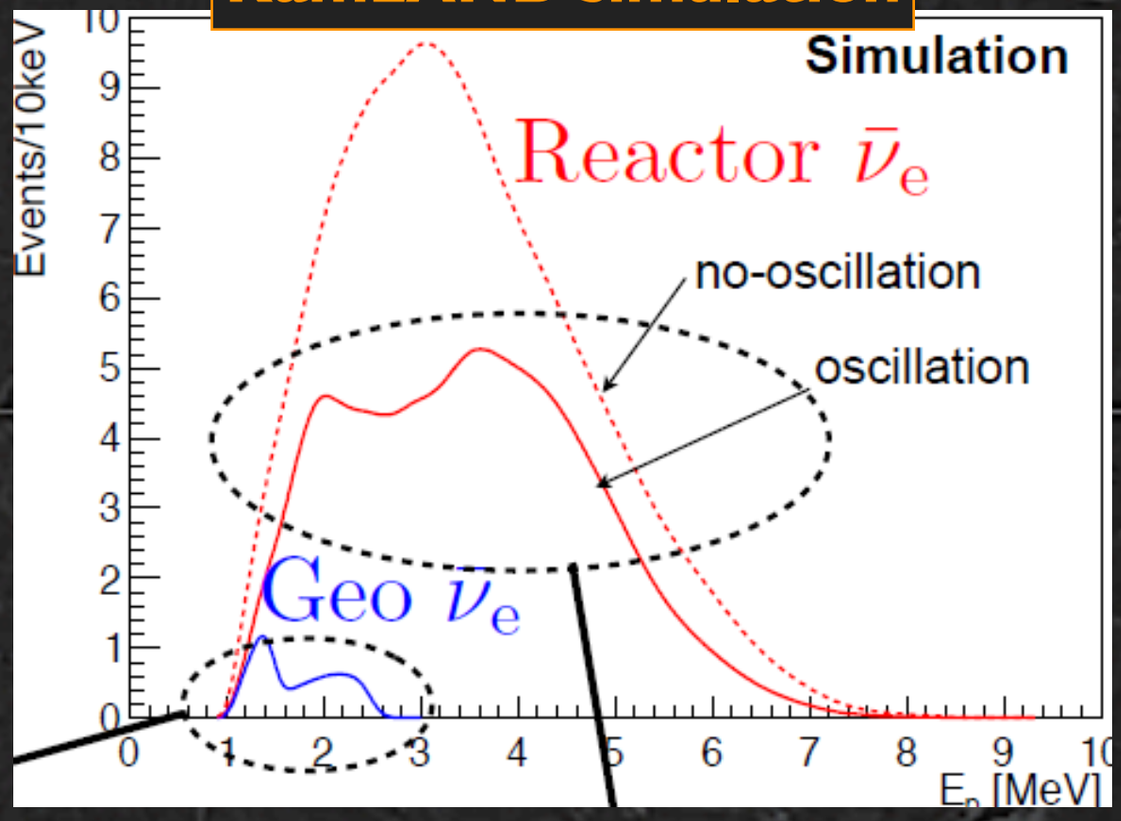
GEO-NEUTRINOS

- **Expected signal differ between KamLAND and Borexino**
  - **Reactor background very different**
    - **No reactors in Italy, several in Japan around KamLAND site**
  - **Continental crust for Borexino, partially oceanic in Japan**

Borexino simulation

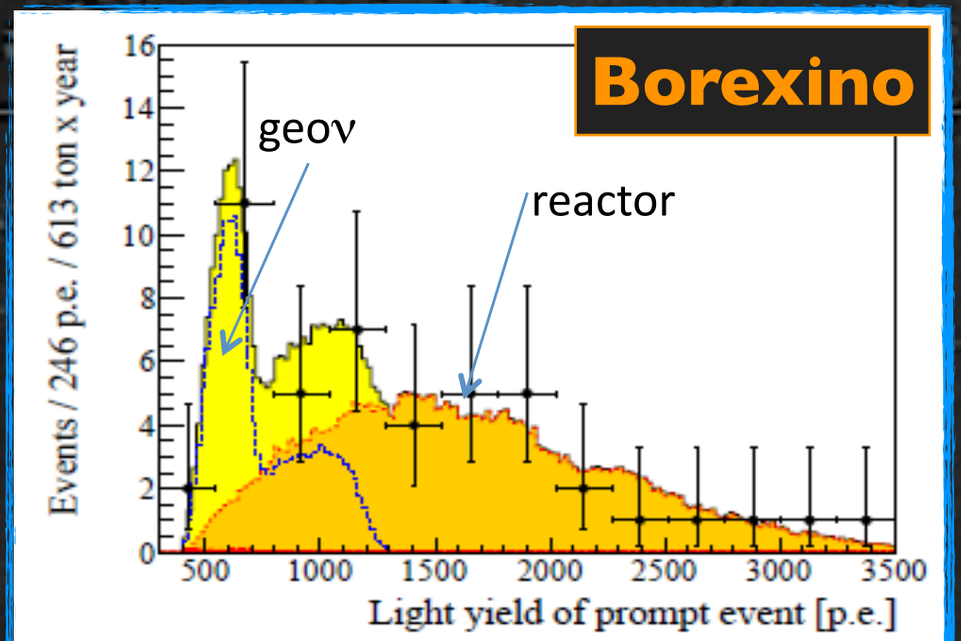


KamLAND simulation



BOREXINO AND KAMLAND RESULTS

Borexino

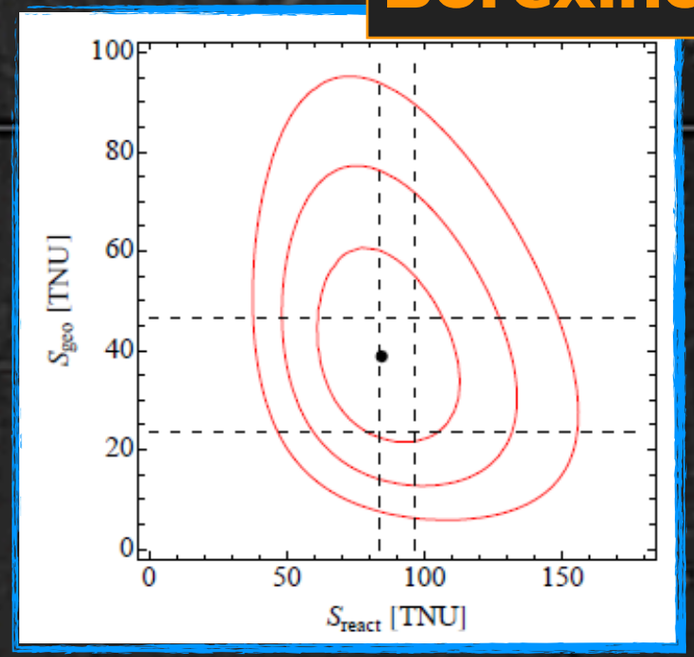


No geoν signal: rejected at 4.5 σ C.L.

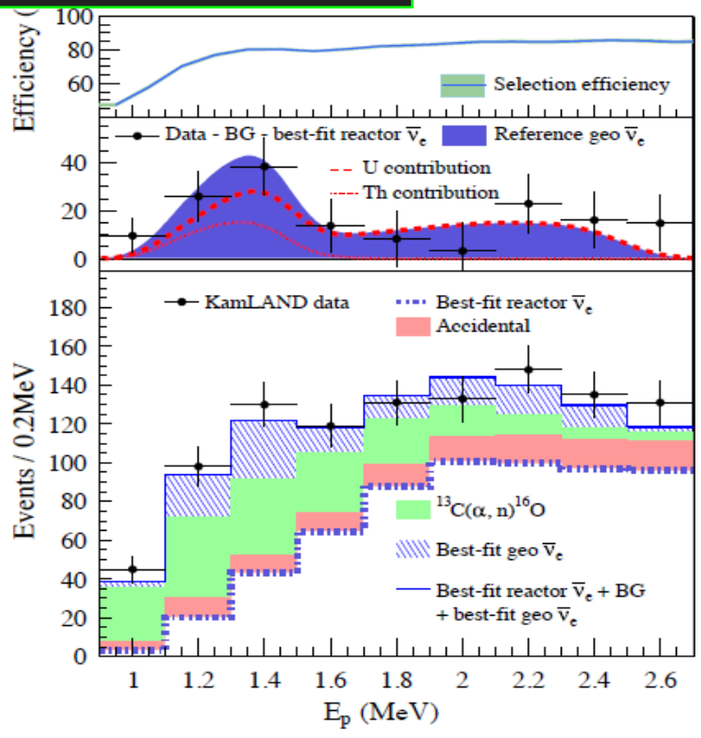
N_{geo} = 14.4 ± 4.4 events = = 38.8 ± 12.0 TNU

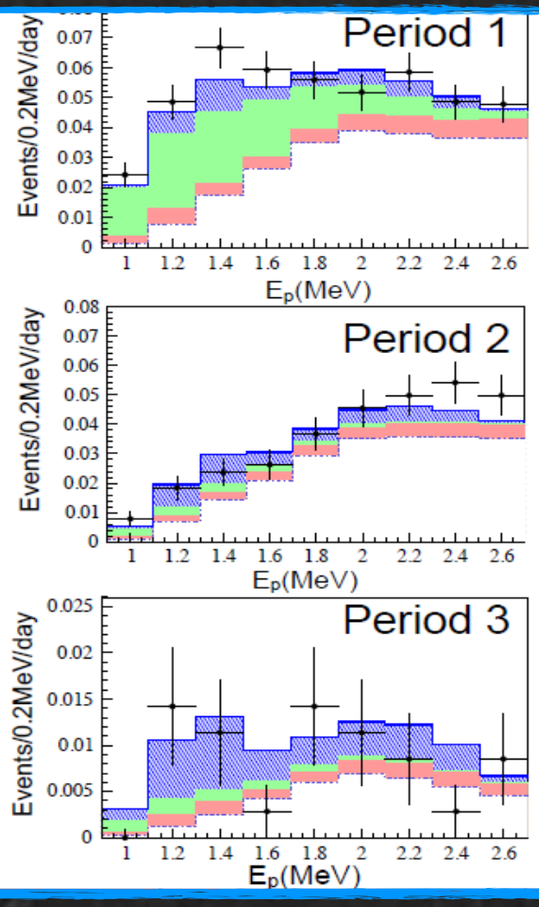
Reactor events consistent with neutrino oscillations

Borexino



KamLAND





H. Watanabe Neutrino Geoscience 2013

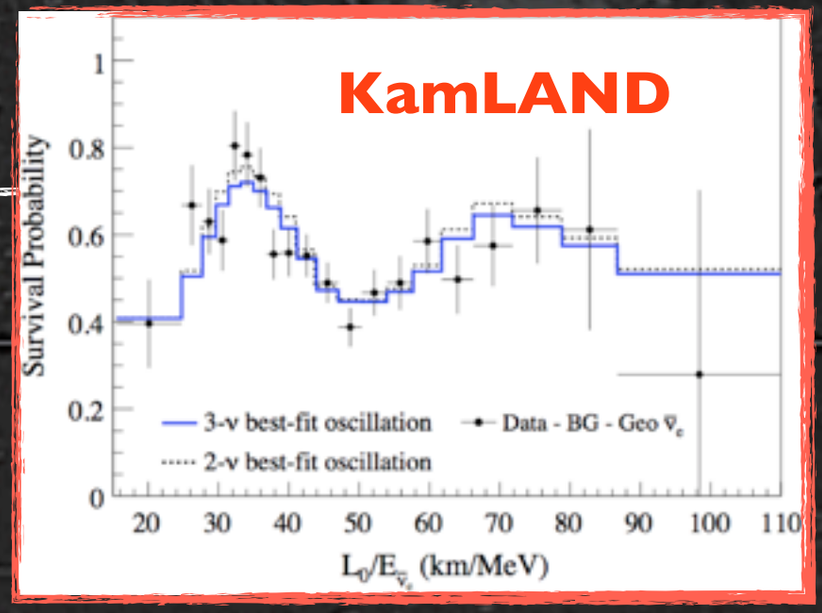
KamLAND

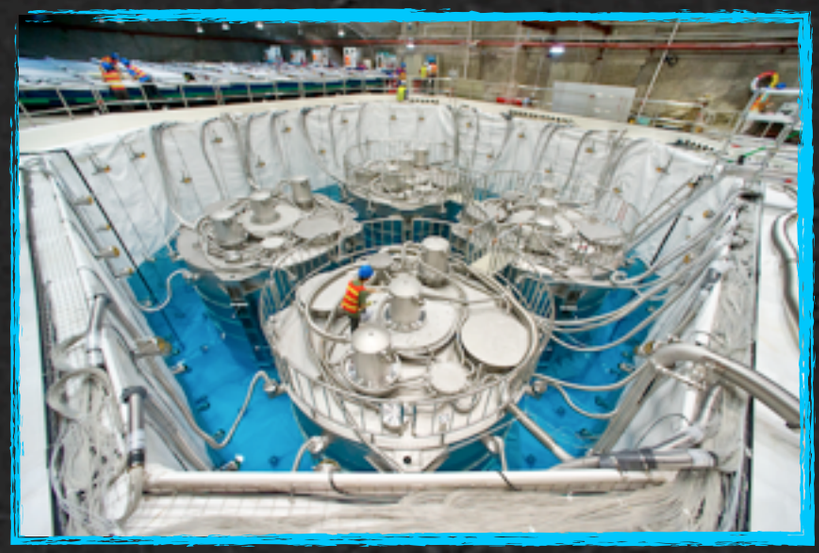
N_{geo} = 31.1 ± 7.3 TNU

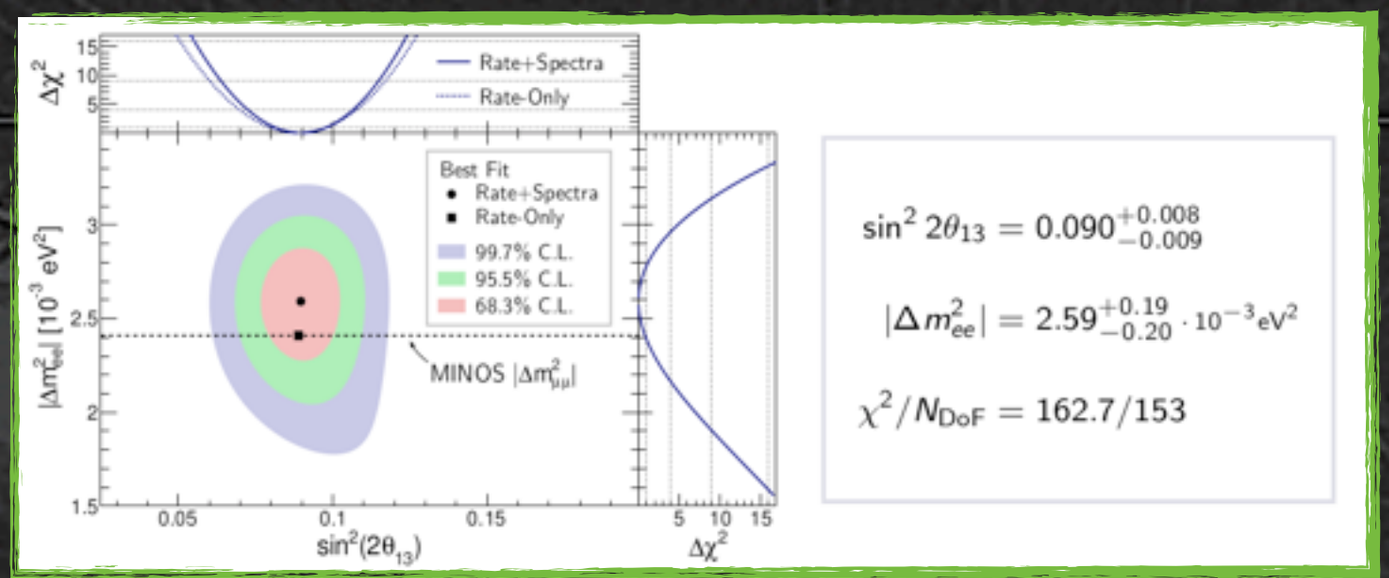
Low background period gave consistent results

NEUTRINOS FROM REACTORS

- **Two major discoveries from reactors in recent years:**
  - **Confirmation of ν_e-ν_μ oscillations (KamLAND 2002)**
  - **Discovery of $\vartheta_{13} \neq 0$ (evidence from T2K, discovery of Daya-Bay and Reno (previous hint from Double Chooz)**
- **All reactor detectors use Reines-Cowan process with liquid scintillators**
  - **Disappearance experiments**







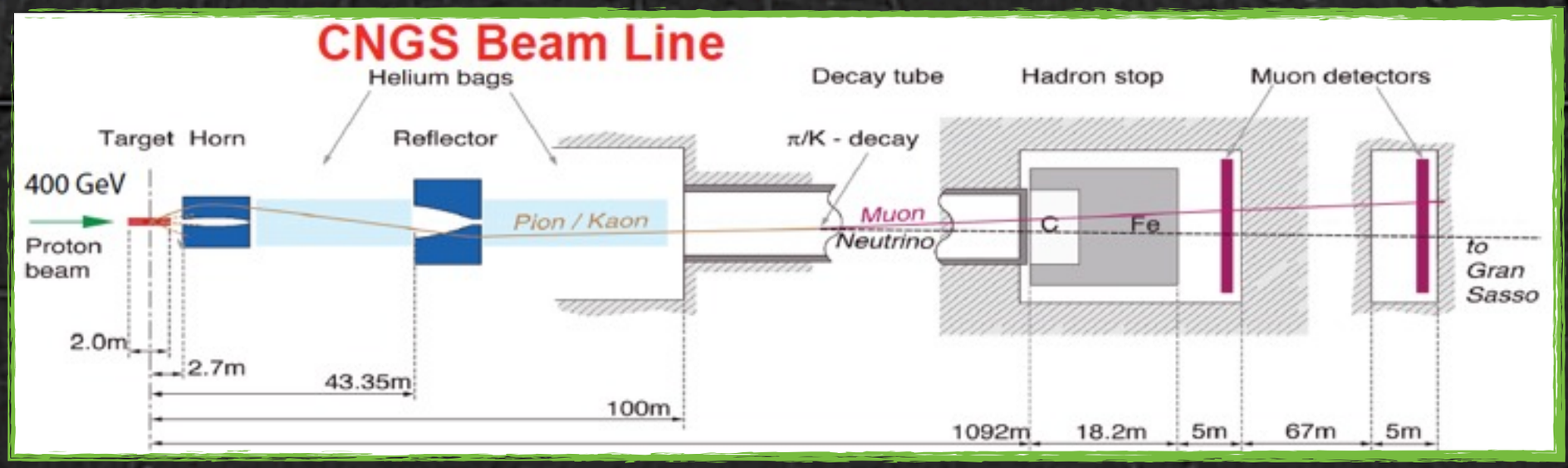
$$\sin^2 2\theta_{13} = 0.090^{+0.008}_{-0.009}$$

$$|\Delta m^2_{ee}| = 2.59^{+0.19}_{-0.20} \cdot 10^{-3}\text{eV}^2$$

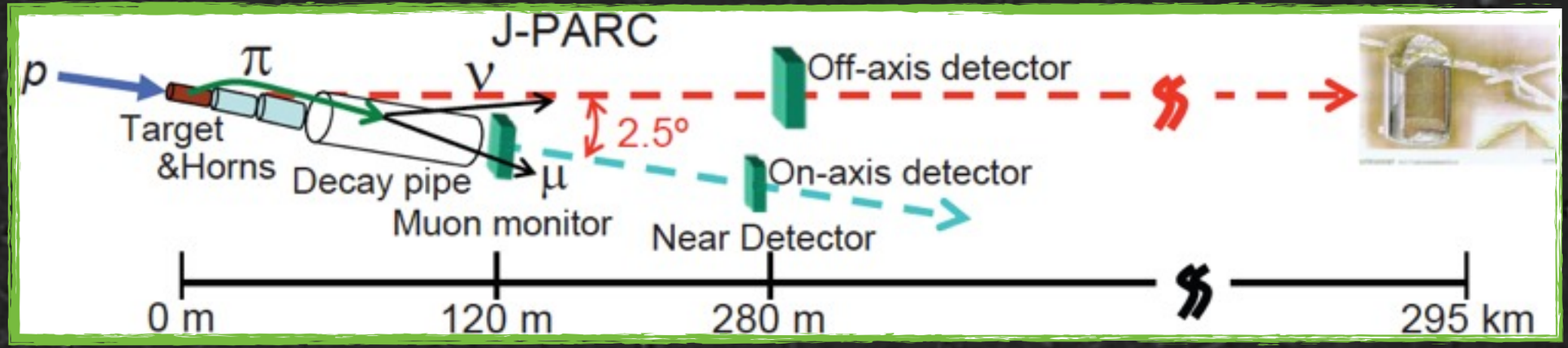
$$\chi^2/N_{\text{DoF}} = 162.7/153$$

NEUTRINOS FROM ACCELERATORS

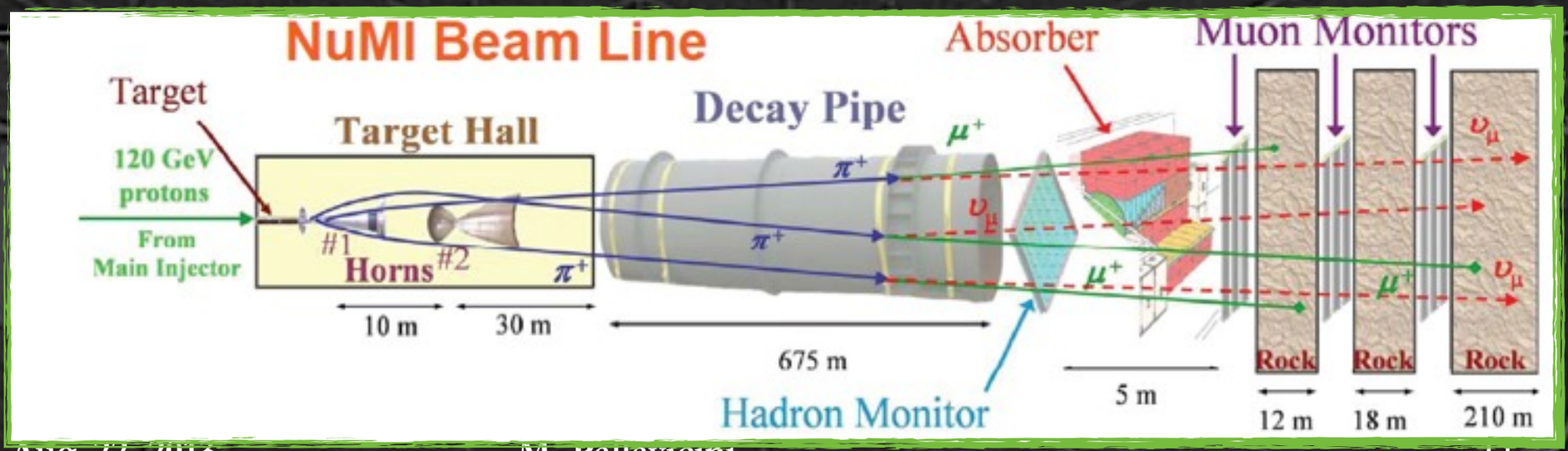
CERN-
Gran Sasso
~730 km
Opera, Icarus



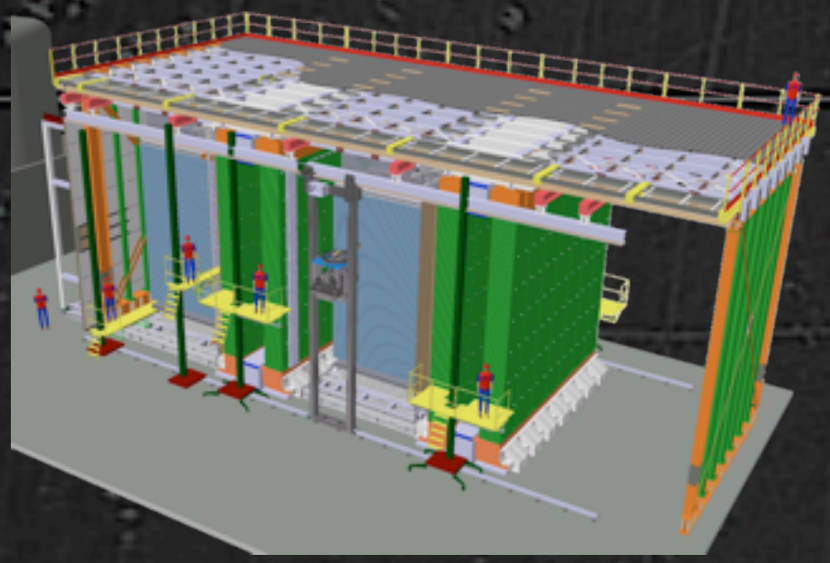
KEK-SuperK
~295 km
T2K



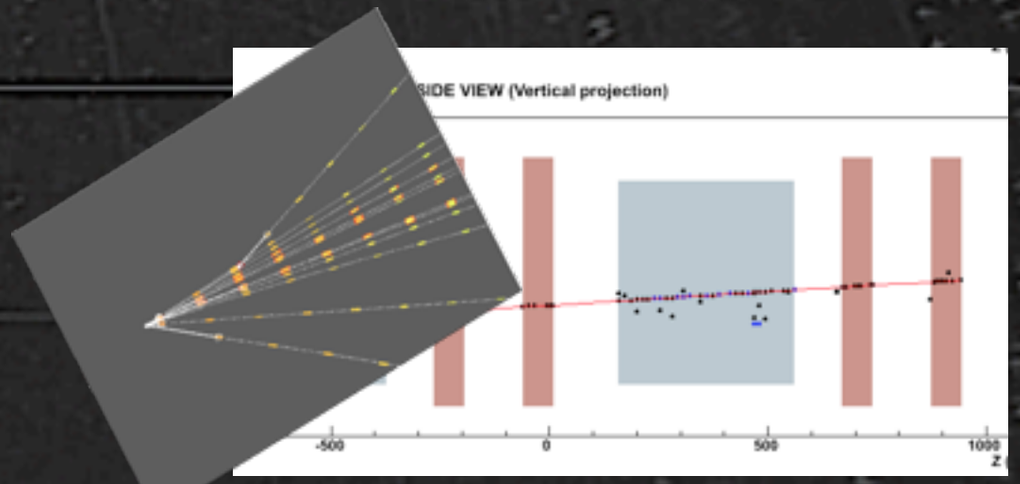
Fermilab-
Minnesota
~730 km
MINOS, NOVA



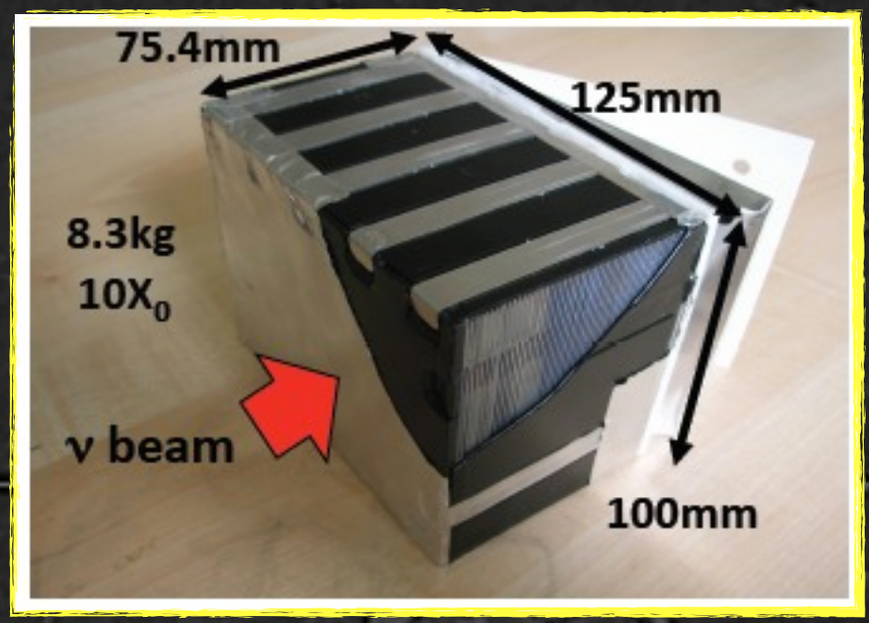
OPERA : NEUTRINO TAU APPEARANCE

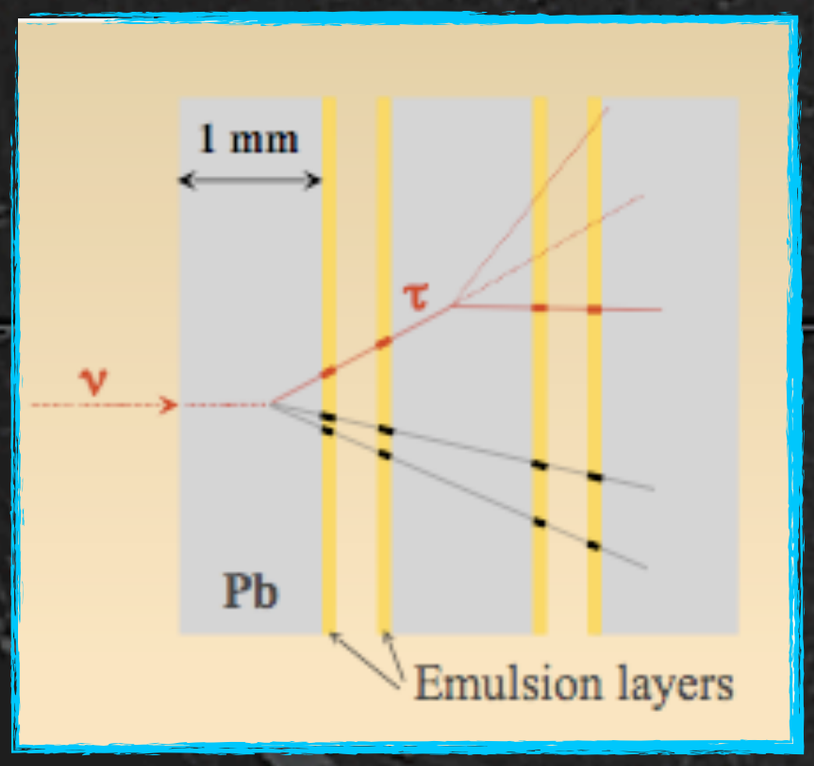


“Ibrid” detector:
emulsions and electronic chambers



A charm candidate



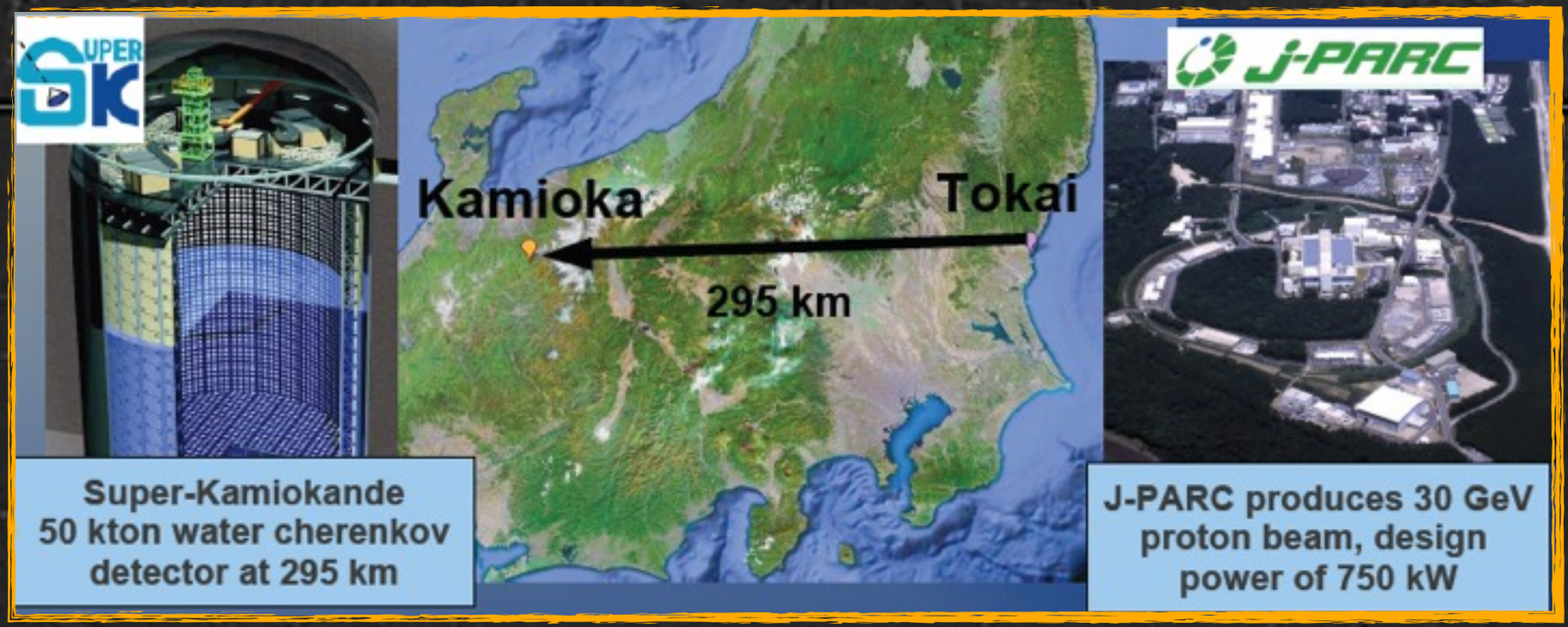


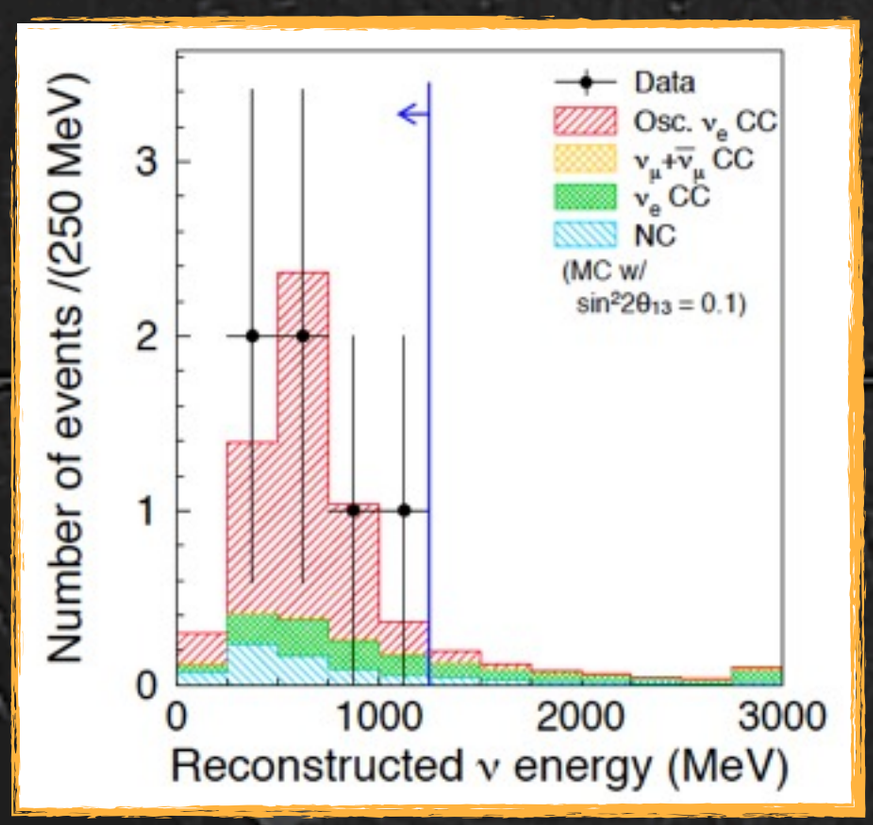
3 events
detected in data set 2008-2012

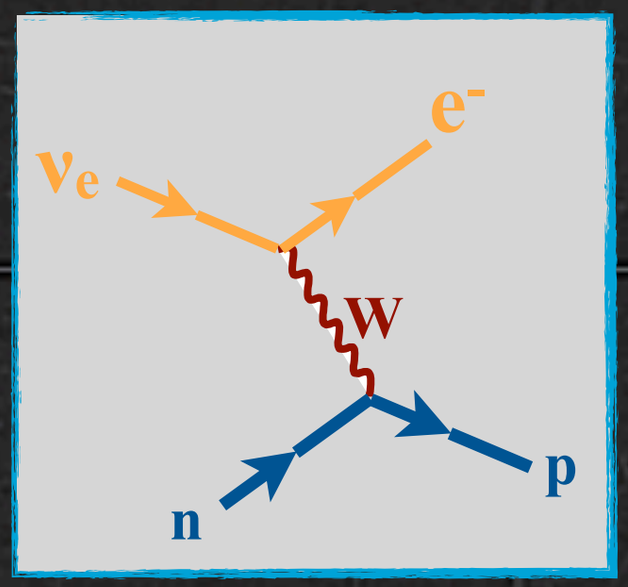
Run finished

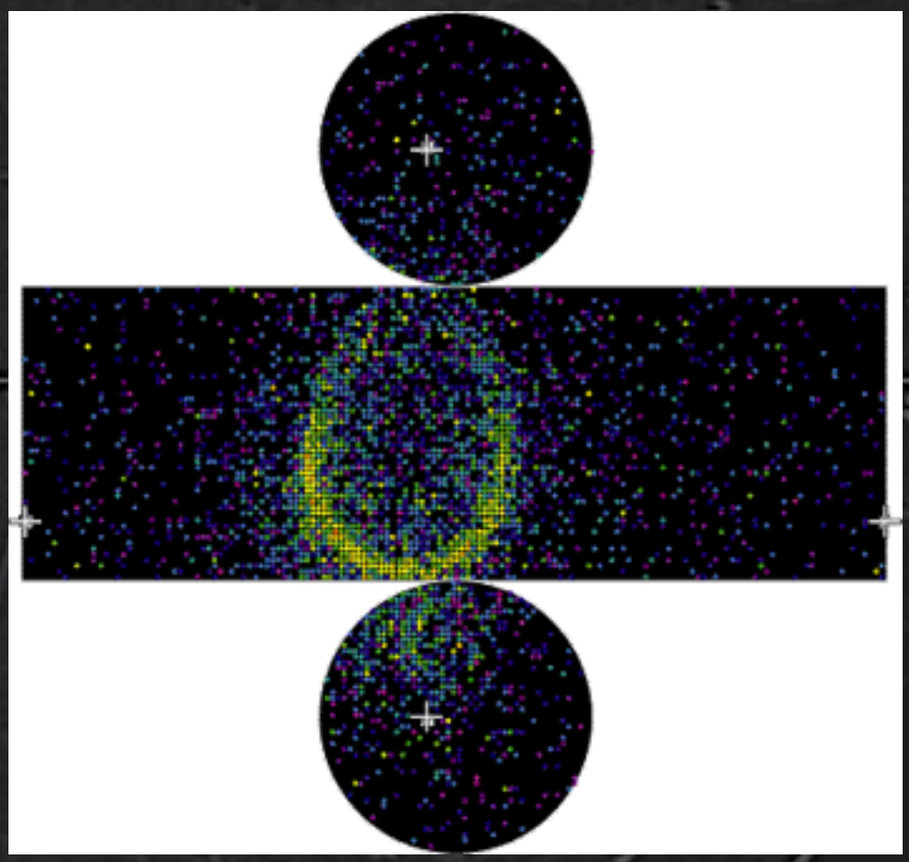
Analysis still in progress

T2K


Kamioka
Tokai
295 km
Super-Kamiokande
50 kton water cherenkov
detector at 295 km
J-PARC produces 30 GeV
proton beam, design
power of 750 kW

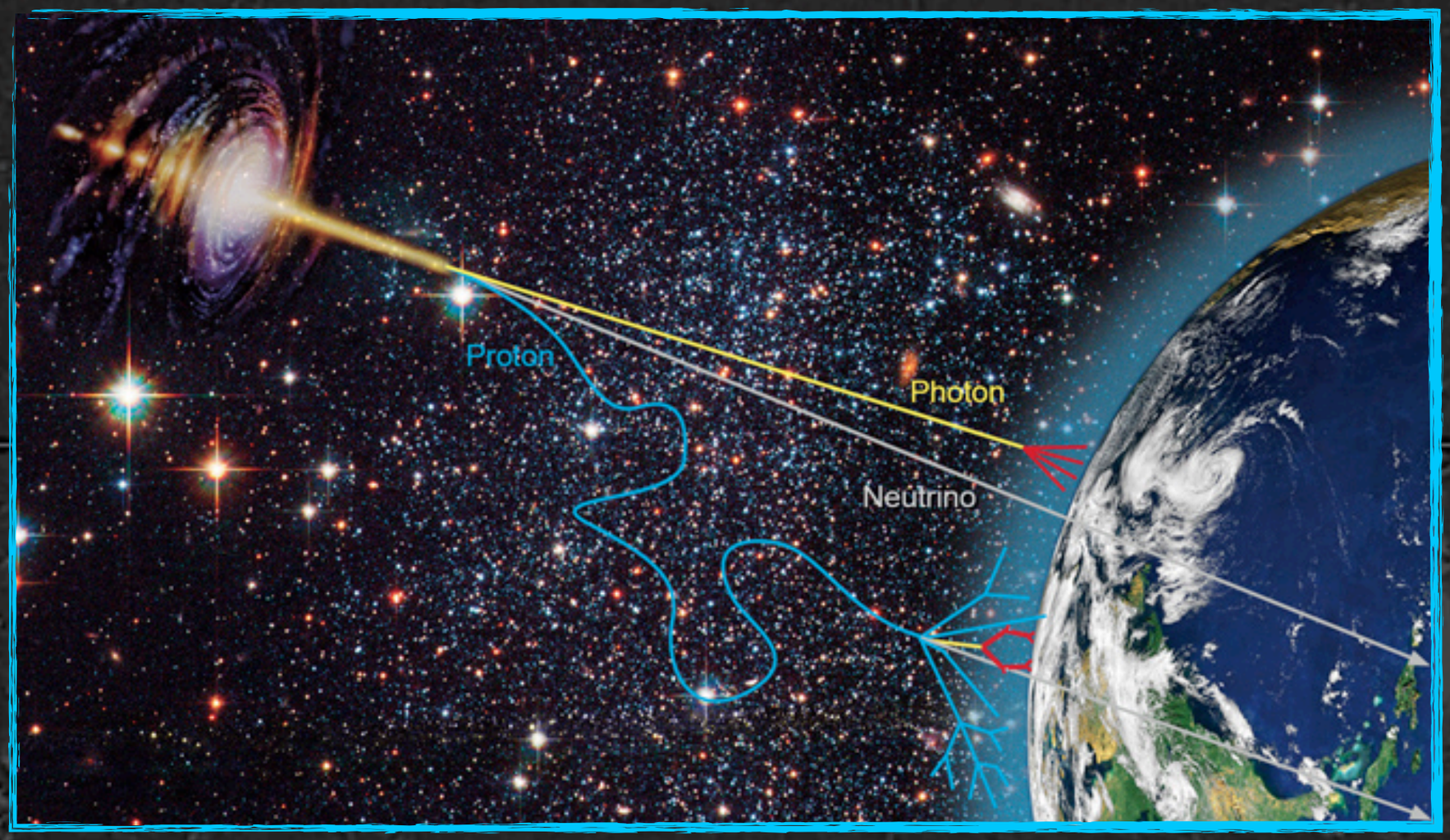

Data
Osc. ν_e CC
$\nu_\mu+\bar{\nu}_\mu$ CC
ν_e CC
NC
(MC w/
$\sin^2 2\theta_{13} = 0.1$)
Number of events /(250 MeV)
Reconstructed ν energy (MeV)
0
1000
2000
3000
1
2
3


ν_e
e^-
W
n
p



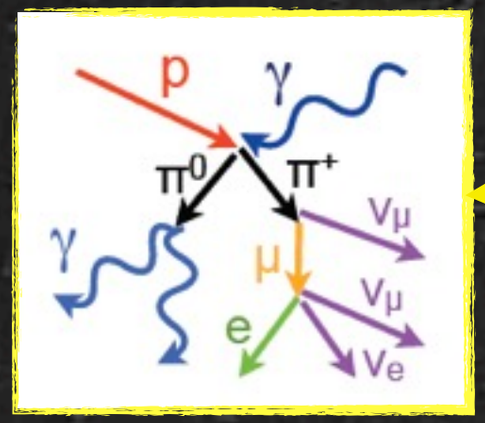
WHY NEUTRINO ASTRONOMY ?

- **Neutrinos are unique probes**
  - ***Neutral:*** **directionality not affected by poorly known galactic and inter-galactic magnetic fields**
  - ***Weakly interacting:*** **deliver information from inaccessible regions, such as star cores, accreting regions, supernova cores, dense environments**
  - ***Coupled to hadrons:*** **neutrino detection is a smokegun for adronic processes**



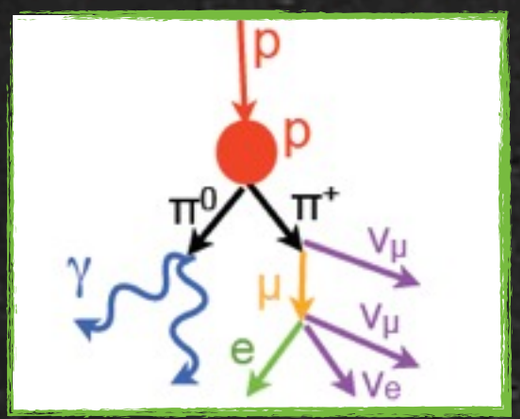
WHY NEUTRINO ASTRONOMY ?

Photo-pion Production



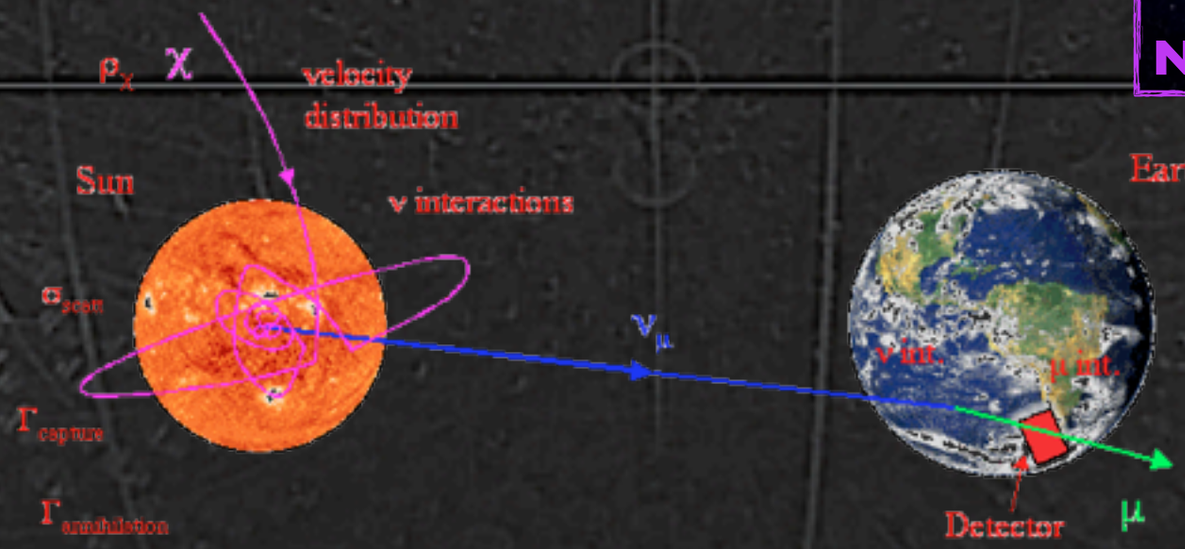
Neutrinos probe hadronic interactions

Neutrinos from core collapse SNe



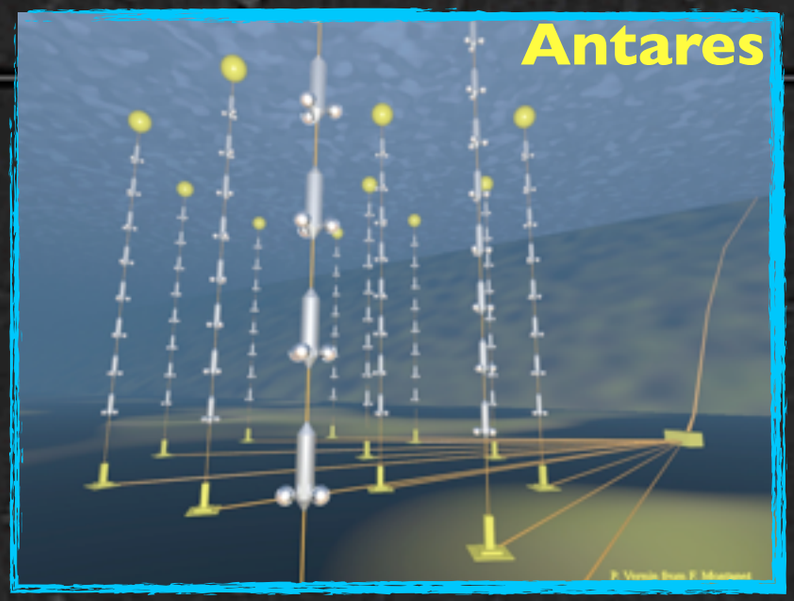
Proton-Proton Interactions

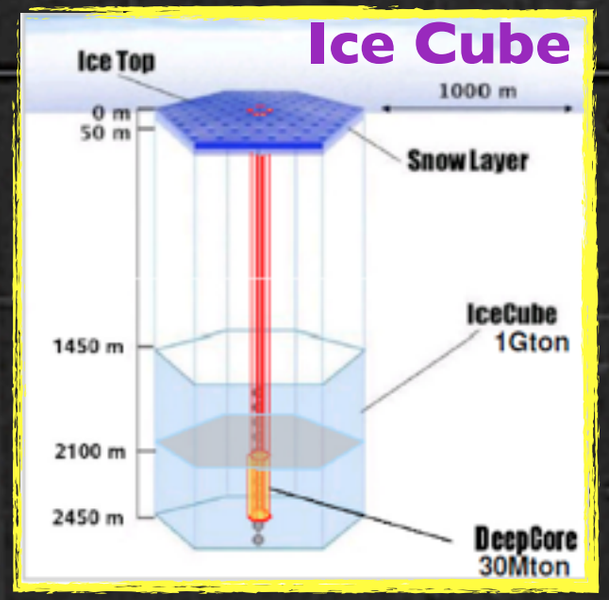
Solar Neutrinos, neutrinos from Dark Matter annihilation in the Sun



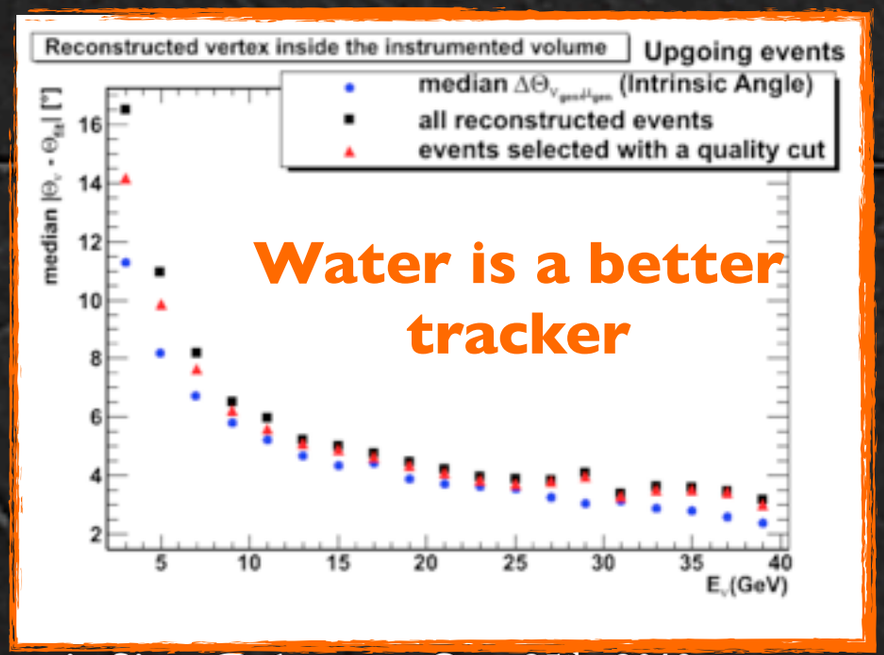
Neutrinos from AGNs

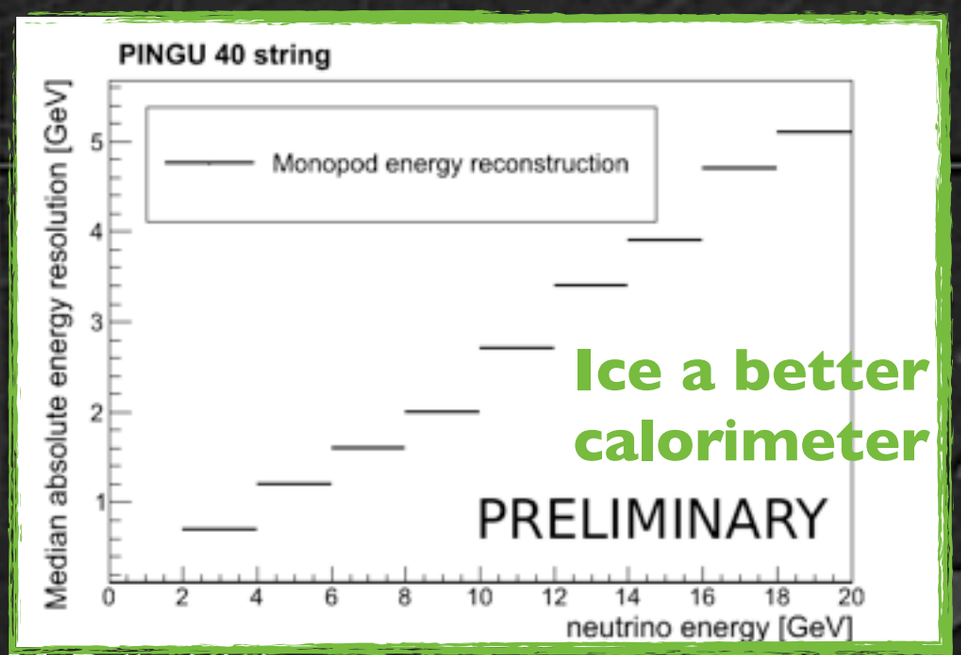
Neutrino telescopes in water and ice





- **Original goal: astronomy with very high energy neutrinos**
- **Recent ideas: high density cores ("Pingu" and "Orca") for high precision atmospheric neutrinos studies**

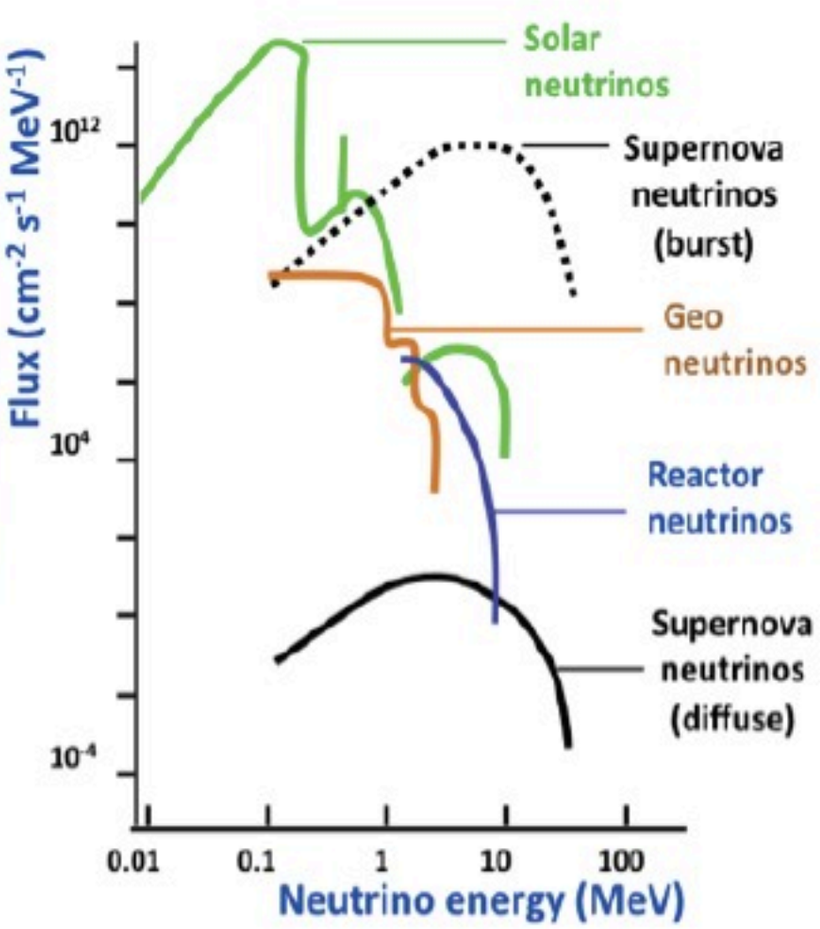




SOME FUTURE IDEAS (AMONG MANY MANY....)

- **Lena (from Oberauer 2012)**

Emphasize LENA (low energy neutrino astronomy) – scintillator detector of the European LAGUNA-LBNO consortium

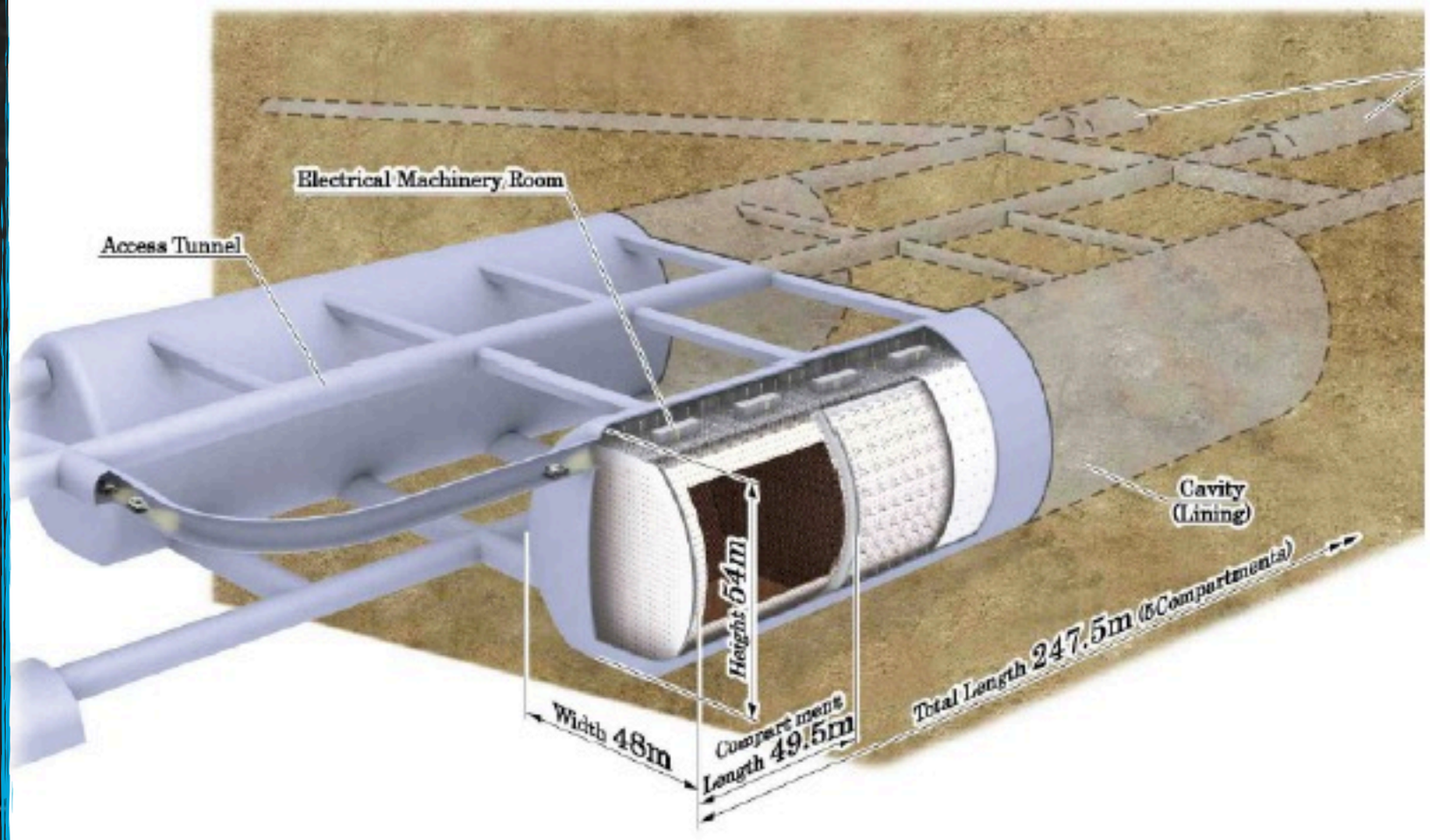


Neutrino Sources	Rates
▪ Galactic Supernova neutrinos	10^4/SN
▪ Diffuse Supernova neutrinos	10/yr
▪ Solar neutrinos	10^4/d
▪ Geoneutrinos	10^3/yr
▪ Reactor neutrinos	$10^{3\text{-}4}$/yr
▪ Neutrino oscillometry	10^4/Mci
▪ Pion decay-at-rest beam	
▪ Indirect dark matter search	

5

THE FUTURE OF WATER DETECTORS

- **Hyper-Kamiokande (C. Walter, TAUP 2013)**



- 560 kton fiducial mass
- 99000 PMTs 20% coverage
- Outer veto detector

- Sensitivity studies scale SK result to large exposure, i.e. assume the same detector performance

Running SK for another 10 years will get us 85% of 1 HK year.

- Uses an upgraded JPARC beam
- Sent to Hyper-K 1 Mton water Cherenkov detector in Kamioka

Conclusions

- **Neutrino physics, since the pioneer times we are celebrating today, has gone a long way**
  - **The still play a crucial role**
  - **They are fundamental tools for astronomy, astrophysics, cosmology, geo-physics**

- **Next missions**
  - **Discover Majorana or Dirac nature**
  - **Measure mass hierarchy**
  - **Discover CP violation**
  - **Are there sterile neutrinos ?**

- **Stay tuned for more surprizes !**

Köszönöm!