Short Baselines and Sterile Neutrino

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After this presentation there will be two other related talks on Sterile Neutrinos, namely by

Peter Wilson on "Short-Baseline Program at Fermilab" and

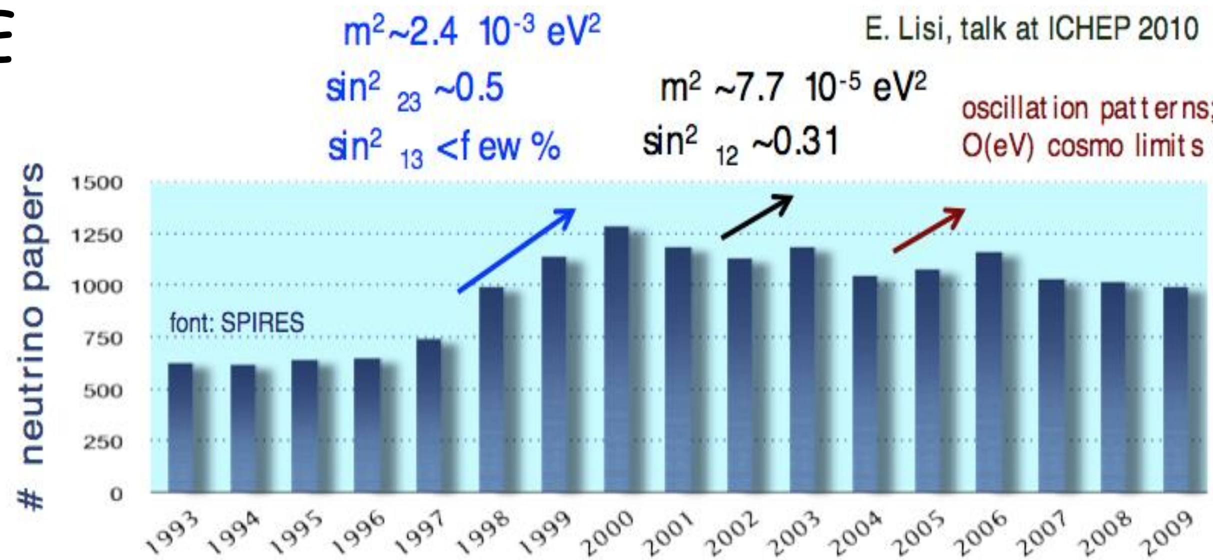
Marco Pallavicini: on "Sterile neutrino searches, sources/reactors"

The new frontier

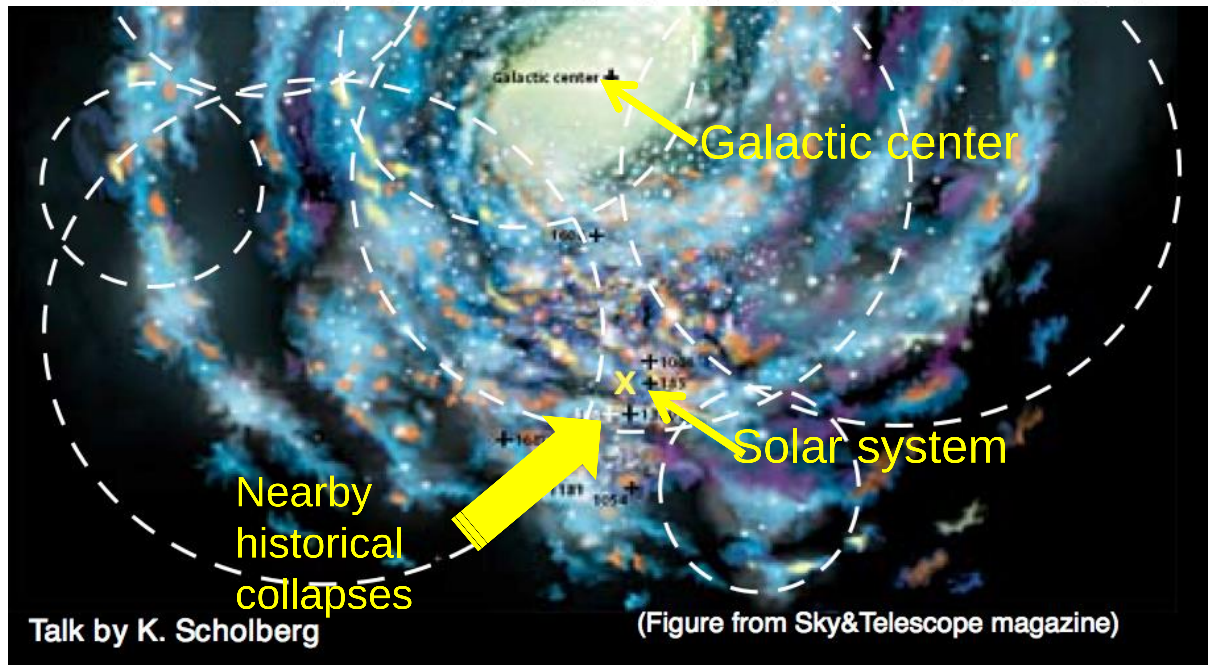
- The discovery of Higgs boson at CERN/LHC has crowned the success of the Standard Model (SM). It will now call for the verification of the couplings to gauge bosons and to fermions.
- However, being sofar the only elementary fermions whose basic properties are still largely unknown, neutrinos must naturally be one of the main priorities to complete our knowledge of the SM.
- No doubt, neutrino masses and oscillations represent today one of the main experimental potentials for novel physics beyond the Standard Model.
- Albeit still unknown precisely, the incredible smallness of the finite neutrino rest masses, compared to those of other elementary fermions points to some specific scenario, awaiting to be elucidated.
- The astrophysical importance of neutrinos is immense, so has been their cosmic evolution.

From the Universe to the laboratory

- According to the inSPIRE database, 2,900 neutrino papers were produced in 2012, compared to about 2,400 papers concerning the Higgs boson.



- Neutrinos are key actors both of the Universe and of the laboratory.
- For instance, over the Milky Way, about 2000 neutrino induced stellar collapses have been recorded.

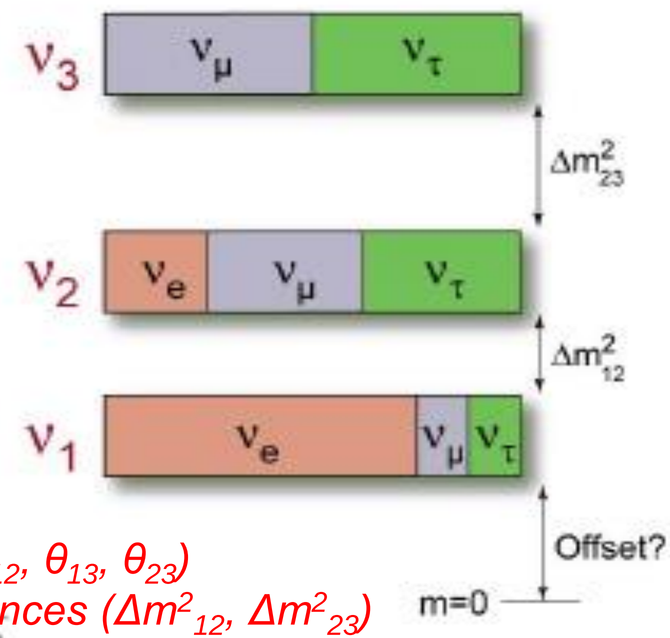


Contributions due to neutrino masses

- A priori, neutrinos, which are massive, could be excellent cosmological DM candidates since we are certain that they exist, in contrast with other hypothetical particles or fields.
- So far oscillation experiments are insensitive to the absolute scale of neutrino masses, since the experimental knowledge of Δm^2_{21} and Δm^2_{31} that incidentally have relatively low differences, leaves the values of their actual masses unconstrained.
- However, according to standard convictions, neutrino mass contributions are probably far too small to provide a significant contribution to the mass of the Universe.
- Indeed, in order to saturate the Dark Mass with neutrinos, their mass values should be of the order of a few eV, unlikely, though still compatible with the experimental data where $m \lesssim 1.5\ eV/c^2$.
- However the situation could be dramatically changed by the existence of one or more massive "sterile" neutrino like objects on which there are today growing experimental hints.

The standard neutrino picture

- The sum of the strengths of the electro-weak coupling to all ν's states has been observed from Z_0 decays and found very close to 3. However the number of neutrino-like objects is so far undefined.
- Neutrino oscillations have established a picture consistent with the mixing of three physical neutrino νe, νμ and ντ with the help of three mass eigenstates ν1, ν2 and ν3.
- The unknown masses of the 3 neutrino may be arbitrarily chosen with its lowest mass = 0, from which the other values become 0.009 eV and 0.05 eV from Δm^2 values.
- In the ΛCDM (Lambda Cold Dark Matter) model, the density fractions are $\Omega\Lambda$ =0.70, Ωb =0.05 and $\Omega cdm=1-\Omega\Lambda-\Omega b-\Omega\nu$ =0.25.



- ✓ *Three angles (θ_{12}, θ_{13}, θ_{23})*
- ✓ *Two mass differences (Δm^2_{12}, Δm^2_{23})*
- ✓ *One unkown common offset from m = 0*

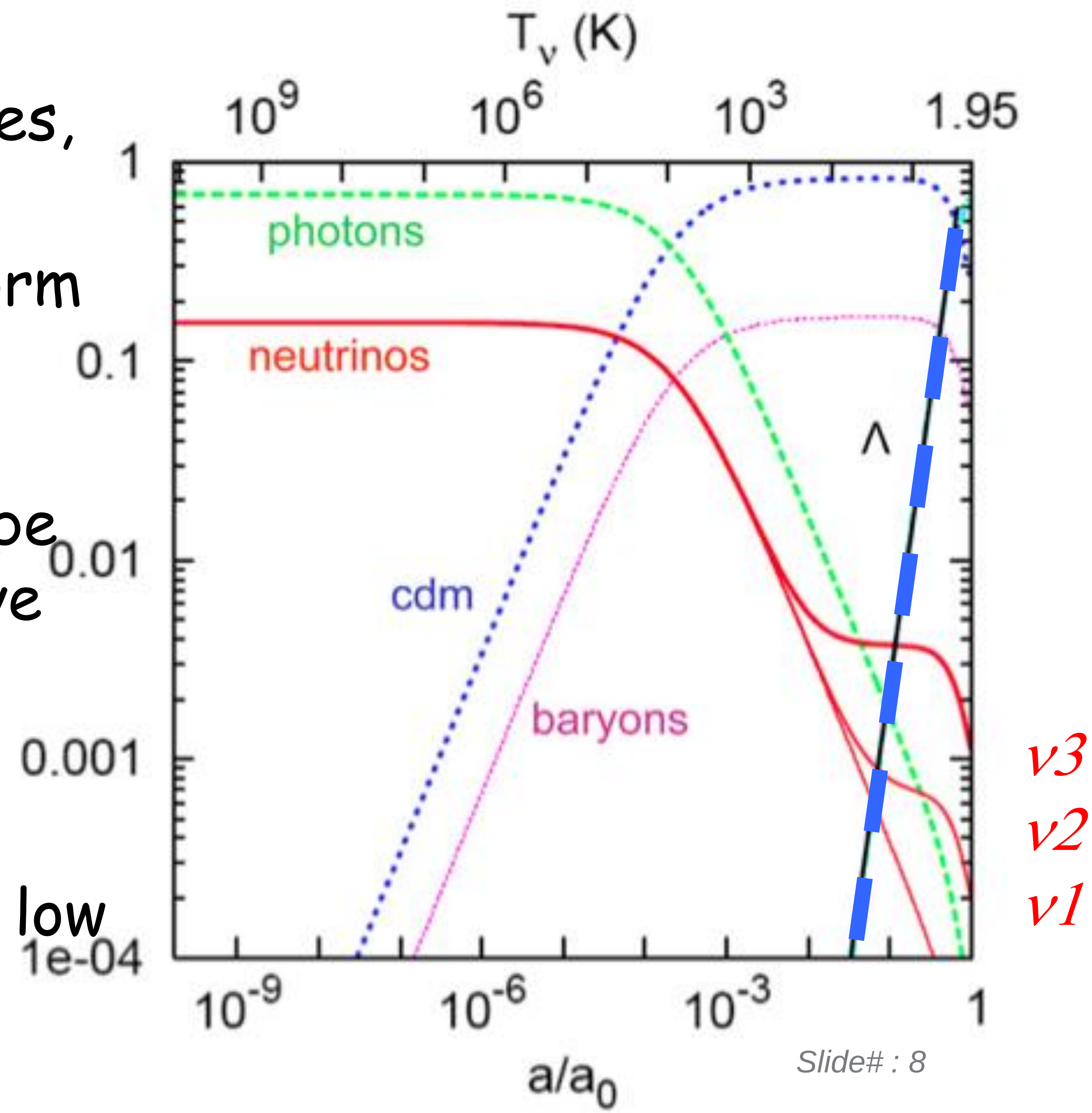
The relic neutrino background

- Nowadays the existence of dark matter (DM), as dominant non-baryonic component in the Universe, is well established.
- The existence of a relic sea of neutrinos is a generic feature of the standard Big Bang model, each one in number only slightly below that of relic photons that constitute the cosmic microwave background (CMB).
- This cosmic neutrino background (CNB) has not been detected yet, but its presence is indirectly established by the accurate agreement between the calculated and observed primordial abundances of light elements, as well as from the analysis of the power spectrum of CMB and other observables.
- Neutrinos have interacted with other particles only during the early part immediately after the Big Bang. But already from $T_\nu \lesssim 1$ MeV they have proceeded independently.

Cosmic evolution

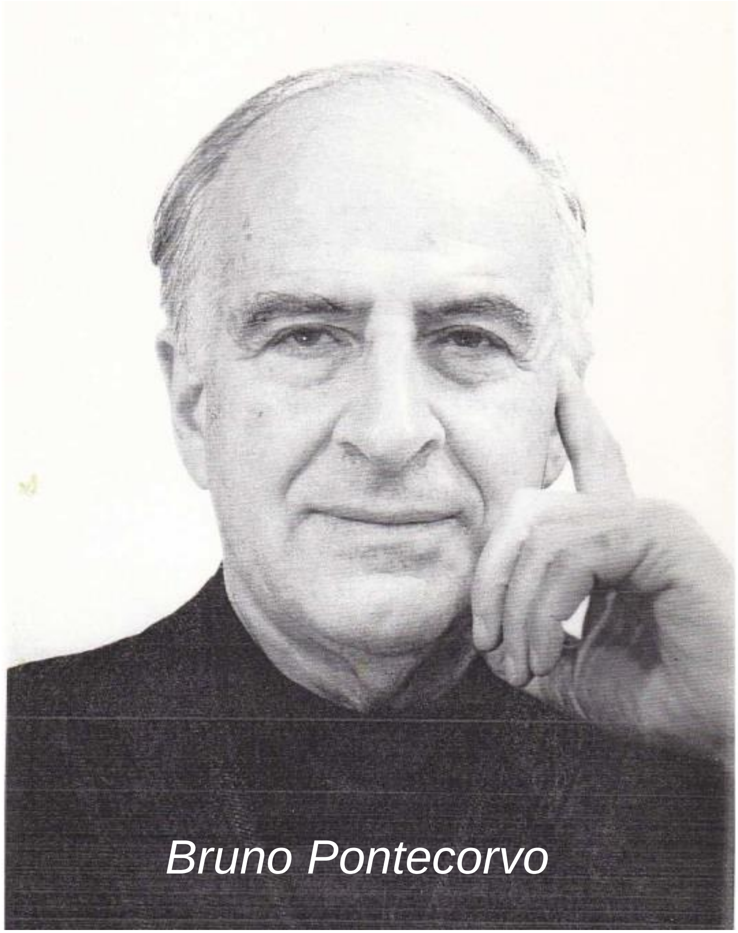
- The density fractions $\Omega i \equiv \rho i/\rho 0$ are shown, where it is easy to see which of the Universe component dominates, fixing its expansion rate:
  1. first, radiation in the form of photons and neutrinos (radiation domination);
  2. then matter, which can be CDM, baryons and massive neutrinos at late times (matter domination);
  3. finally, the cosmological constant Λ takes over at low z (typically z < 0.5).

a(t) is normalized to a(now) = 1 and related to the redshift z as a = 1 (1 + z)



What are “sterile” neutrinos ?

- Sterile neutrinos are a hypothetical type of neutrinos that do not interact via any of the fundamental interactions of the Standard Model except gravity.
- The name was coined in 1957 by Bruno Pontecorvo, who hypothesized their existence in a seminal paper.
- Since per se they would not interact electromagnetically, weakly, or strongly, they are extremely difficult to detect.
- If they are heavy enough, they may also contribute to cold dark matter or warm dark matter.



Bruno Pontecorvo

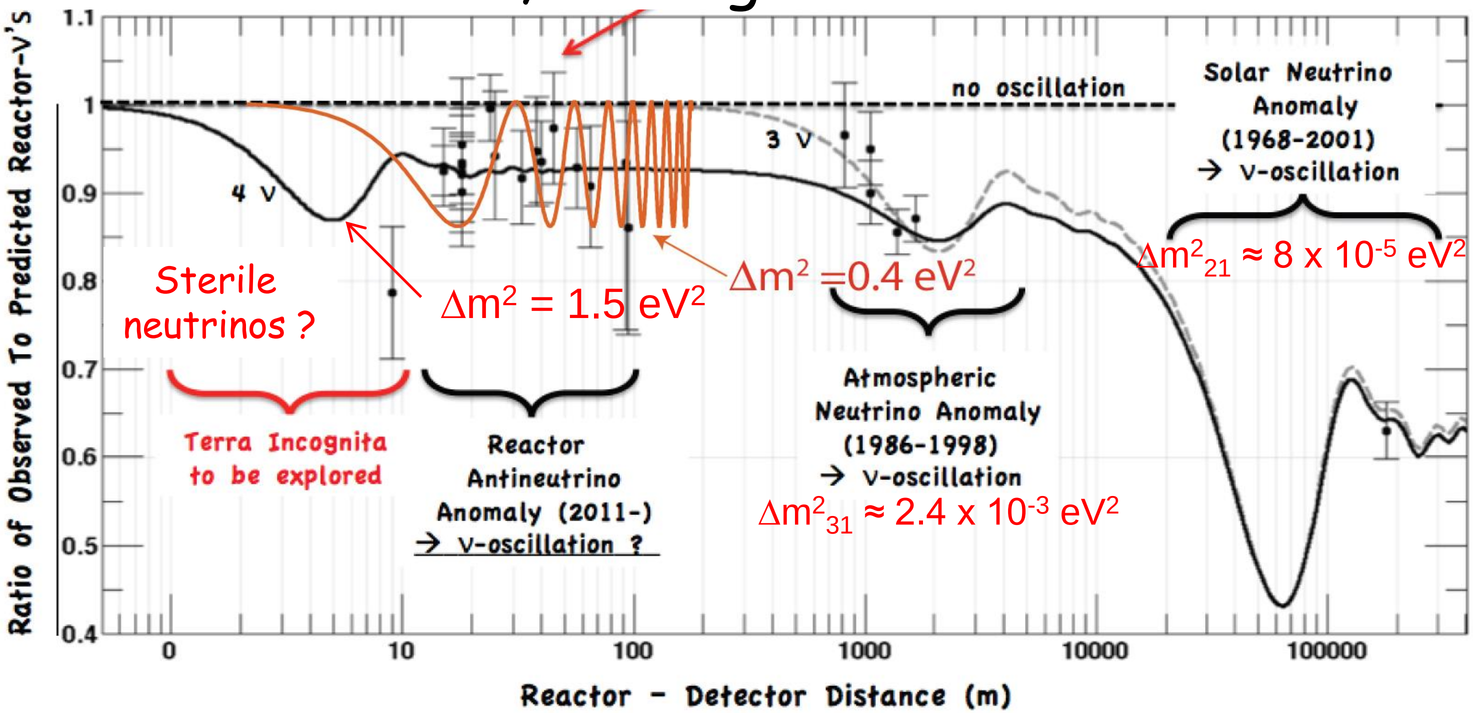
- Sterile neutrinos may mix with ordinary neutrinos via a mass term. Evidence may be growing from several anomalies.

Persisting anomalies in the neutrino detection

- Three, so far independent anomalies have been reported:
  - the apparent *disappearance signals* in the anti-ν_e events detected (1) from near-by nuclear reactors and (2) from Mega-Curie k-capture calibration sources in the experiments to detect solar ν_e.
  - (3) observation of presumed *excess signal* of ν_e electrons from muon neutrinos from particle accelerators (the LSND effect);
- The most popular common direction is the one of one or more *"sterile neutrinos"* although other alternatives may be possible
- These independent signals may all point out to the possible existence of at least a fourth, non standard and heavier neutrino-like state, driving additional oscillations at a much smaller distances, with Δm^2_{new} of the order of $\approx 1\ eV^2$ and relatively small $\sin^2(2\theta_{new})$ mixing angles.

1,-The reactor (anti)-neutrino disappearance anomaly

- A recent re-evaluation of all the reactor antineutrino spectra has increased the expected flux: the ratio R between observed and predicted rates of previous experiments has been decreased to $R = 0.938 \pm 0.023$, leading to a deviation of 2.7 σ from unity

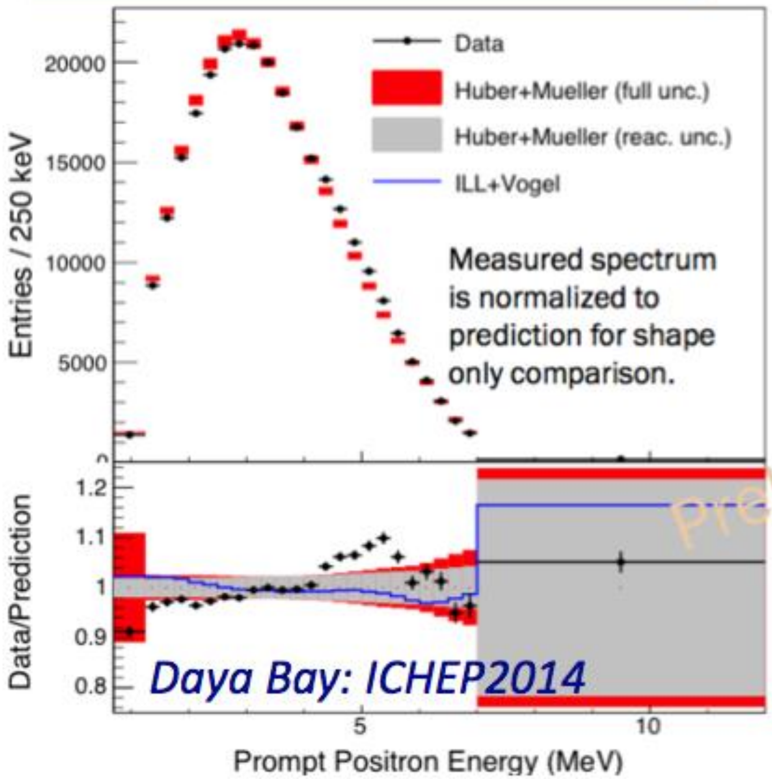


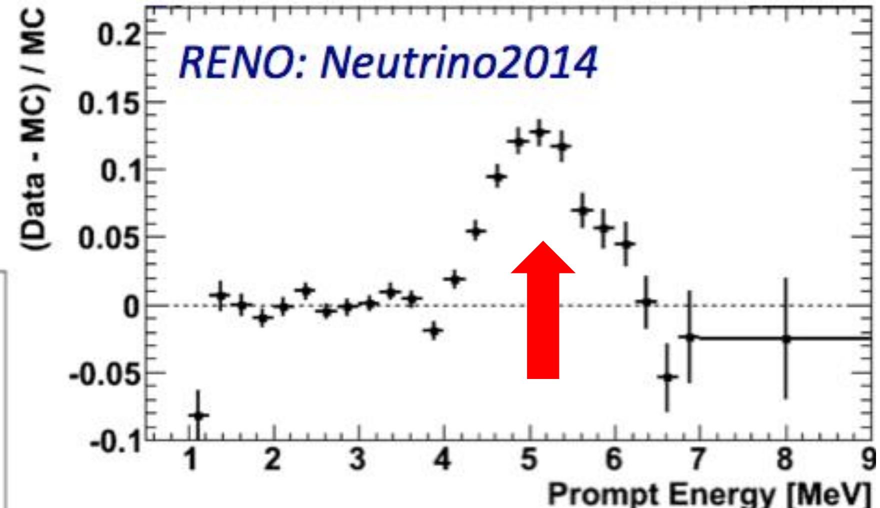
- Reactor ~~experiments explo~~re distances generally far away from the perspective oscillation regions related to sterile neutrinos, giving therefore only an asymptotic value and Δm^2 greater than $\approx 0.1\ eV/c^2$

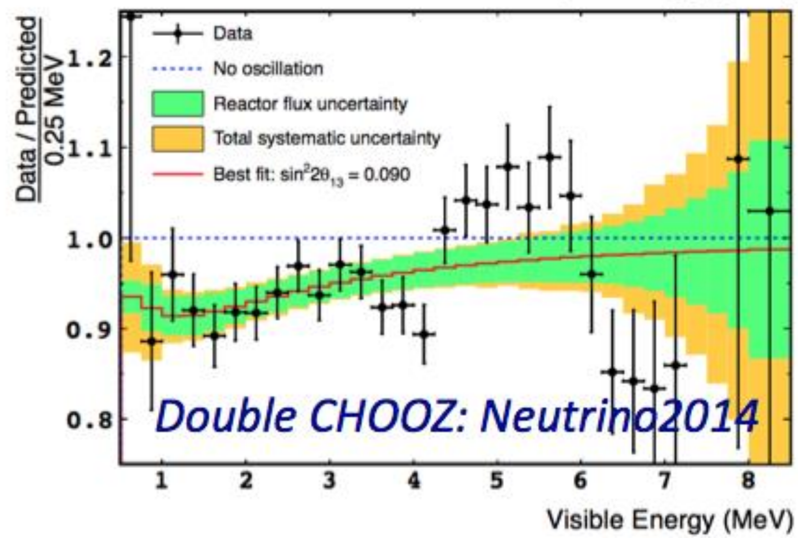
Spectra and experimental data are not in perfect agreement

- A rate excess is observed over Montecarlo flux predictions at about 5 MeV

Recent $\overline{\nu}_e$ measurements also disagree with BILL-derived spectra.



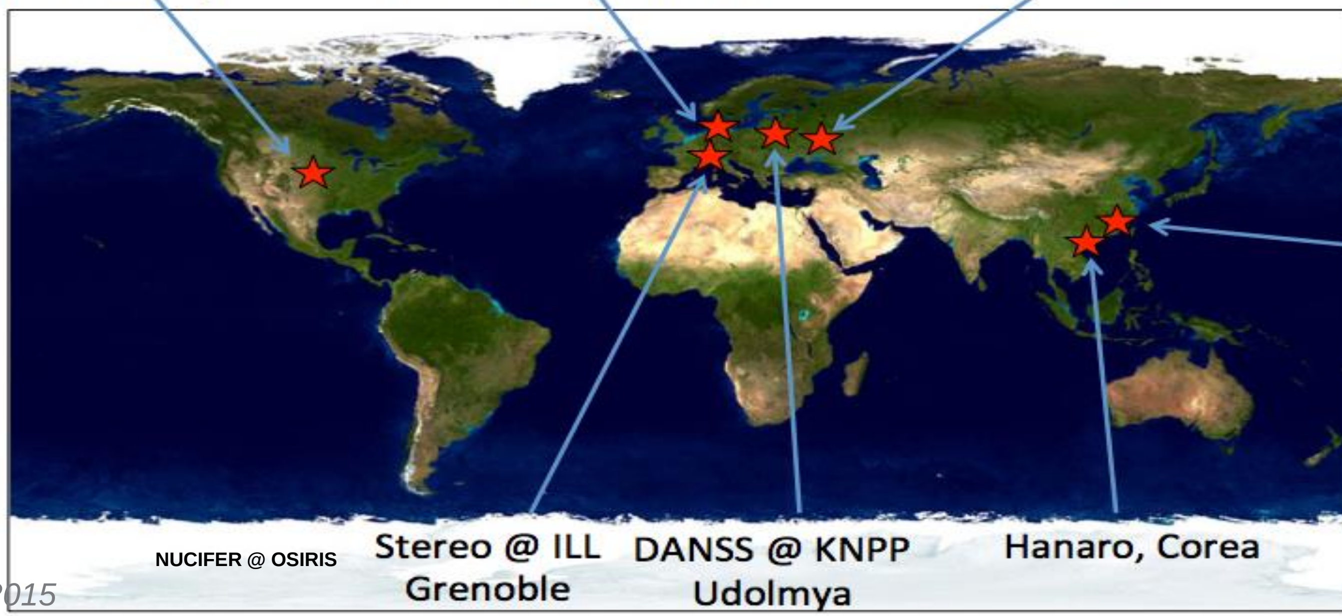




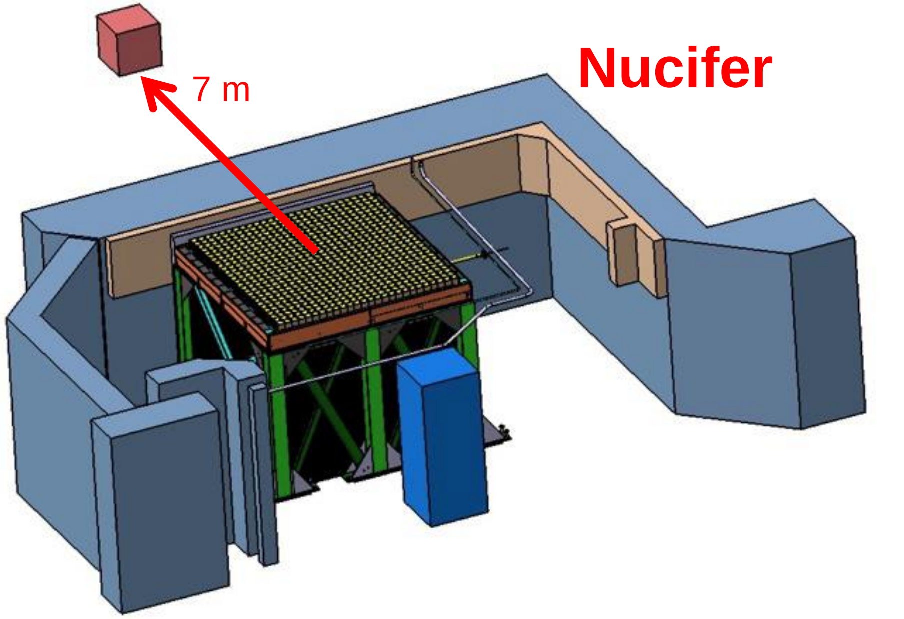
Several new very short baseline reactor experiments

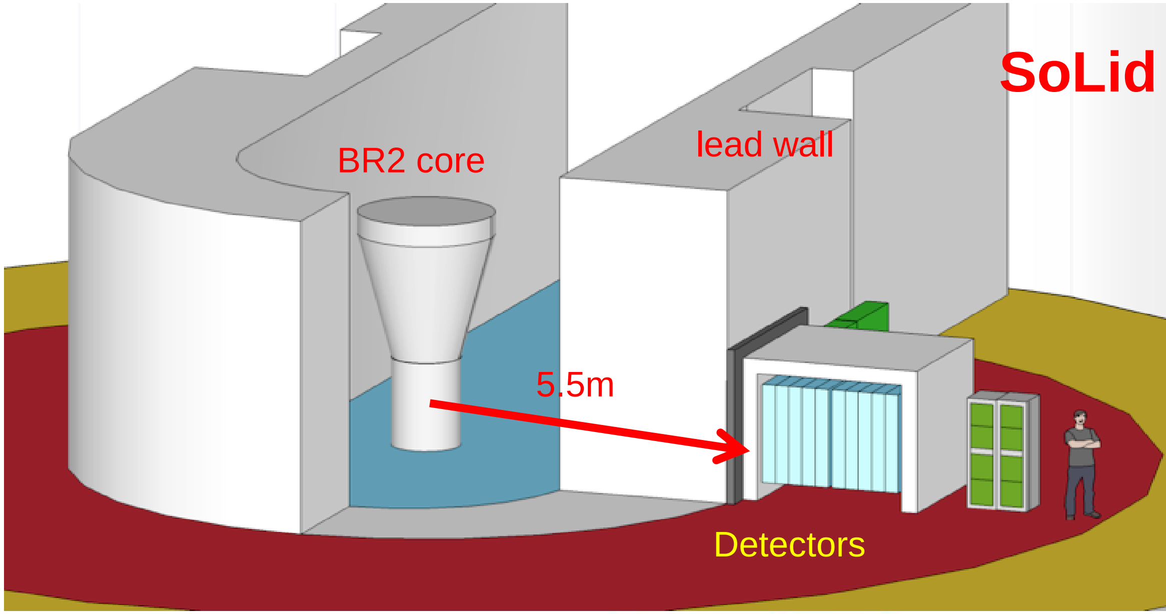
- Compact, intense sources and very short baselines are used in order to determine oscillation patterns within the detector
- High statistics ~100 evts/day/t
- Challenging reactor-induced backgrounds (©and n)

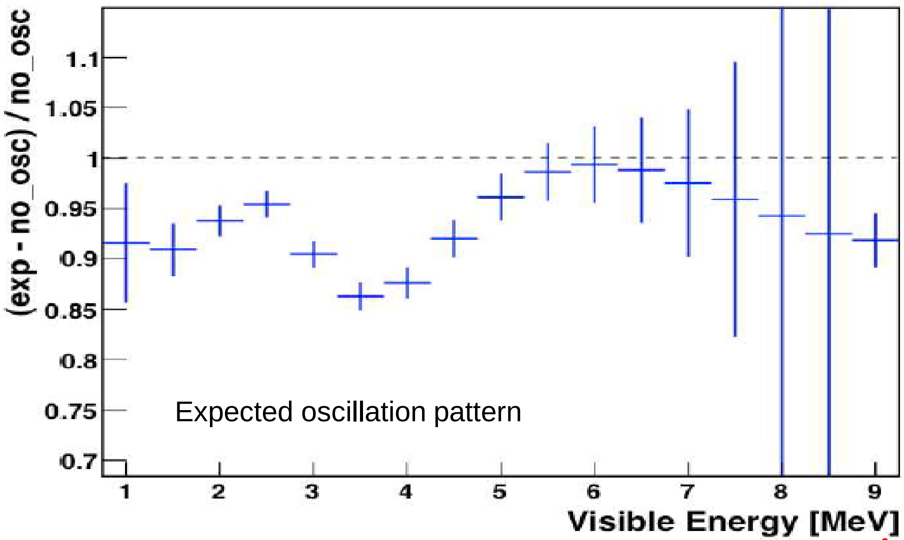
Projects	Ref	P_{th} (MW)	M_{target} (tons)	L (m)	Depth (m.w.e.)
Nucifer	[22]	70	0.75	7	13
Stereo	[23]	50	1.75	[8.8-11.2]	18
Neutrino 4	[24]	100	2.2	[6-12]	few
DANSS	[25]	3	0.9	[9.7-12.2]	50
Solid	[26]	[45-80]	3	[6-8]	10
Hanaro		30	0.5	6	few
US project	[27]	20-120	1 & 10	4 & 18	few
CARR	[28]	60	-	7 & 15	few

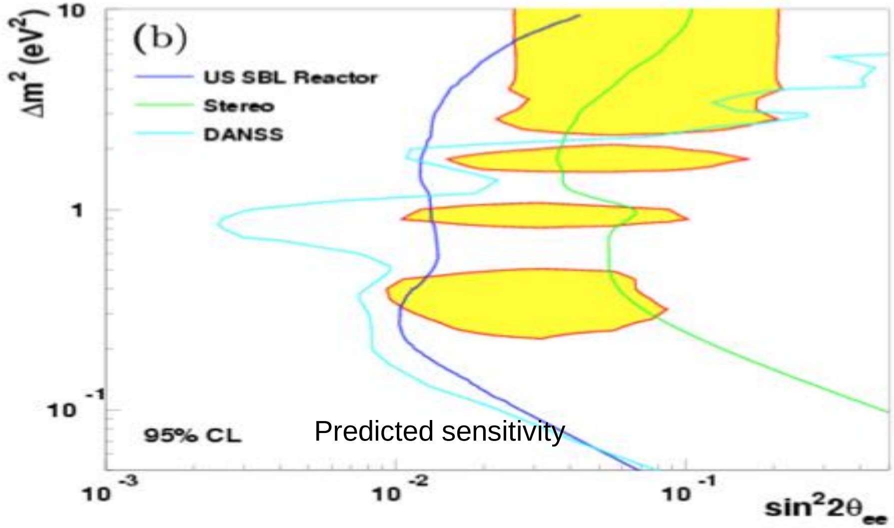


Some future reactor experiments







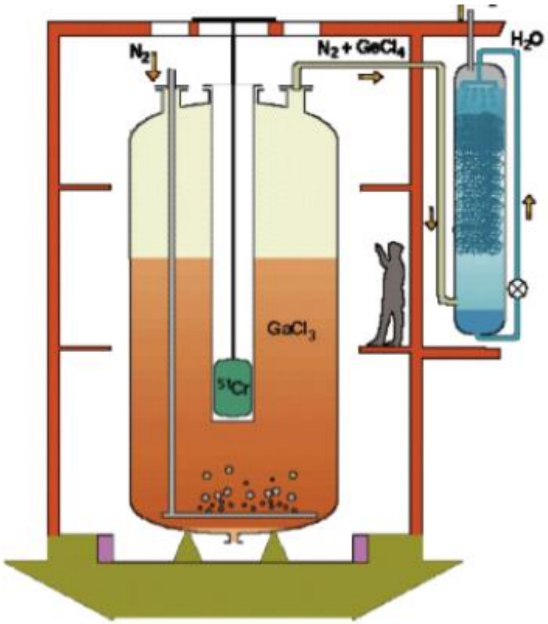


- *Some experiments may plan to initiate data taking by 2016.*

2.-The Gallium disappearance anomaly

$$^{71}\mathrm{Ga} + \nu_e \rightarrow {}^{71}\mathrm{Ge} + e^-$$

- SAGE and GALLEX experiments recorded the calibration signal produced by intense artificial k-capture sources of ^{51}Cr and ^{37}Ar.
- The averaged result of the ratio R between the source detected and predicted neutrino rates are consistent with each other, giving R=(0.86 $\pm$ 0.05), about 2.7σ from unity



30.3 tons of Gallium
in an aqueous solution : $GaCl_3$ + HCl

- These best fitted values may favour the existence of an undetected sterile neutrino with an evidence of 2.3σ and a broad range of values centred around $\Delta m^2_{new} \approx 2\ eV^2$ and $\sin^2(2\theta_{new}) \approx 0.3$.

Future experiments

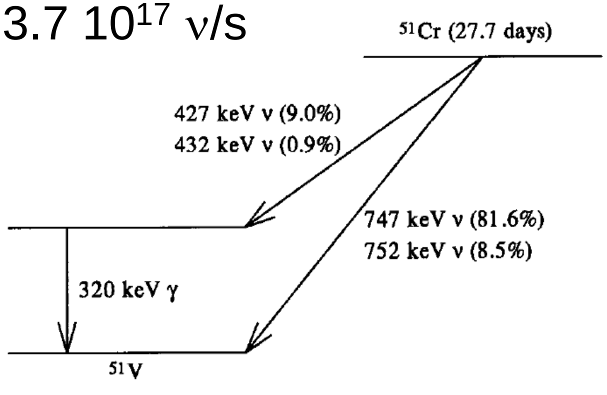
- Aiming at recording the L/E oscillation pattern within the detector using an intense ν source:
  - Existing (Borexino, KamLAND, Daya-Bay) or future (SNO+, LENS, JUNO) liquid scintillator detectors;
  - Future experiments based on other techniques (RICOCHET, BEST)

First data available by 2016

Many processes have been studied

^{51}Cr: 750 KeV ν; 40 d

3.7 10^{17} ν/s

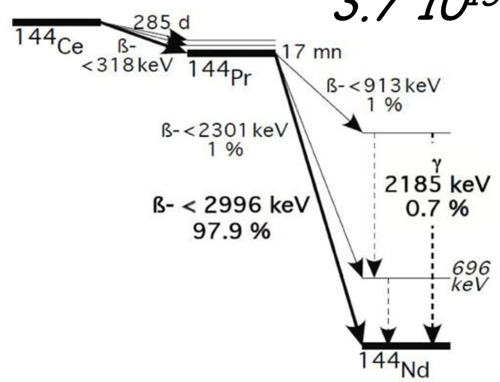


Decay scheme of ^{51}Cr to ^{51}V through electron capture.

- Production: thermal neutrons on ^{50}Cr; n-capture x-sect ~17 b
- Advantages: 320 KeV γ emitted by the source not difficult to handle; Enriched Cr still available from Gallex.
- Disadvantages: radioctivity is a serious bkg for ν+e→ν+e- detection.

^{144}Ce: <2.99 MeV $\bar{\nu}$; 411 d

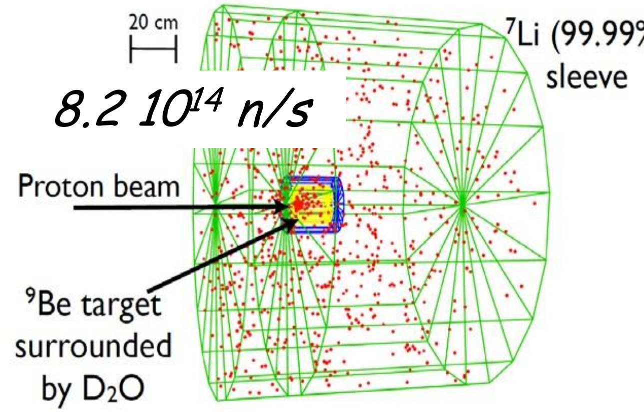
3.7 10^{15} n/s



- Production: extracted from exhausted nuclear fuel (Russia)
- Advantages: detecting reaction anti-□+p->n+e+ has very little bkg; long source lifetime.
- Disadvantages: □s (E=2.2 MeV) emitted by the source are difficult to handle.

^{8}Li: <13 MeV $\bar{\nu}$; 868 ms

8.2 10^{14} n/s



- Production: IsoDAR, Isotropic Decay At Rest (prototype by 2016): 60 MeV p on ^{9}Be tgt -> n moderated and multiplied by D_2O shield -> ^{8}Li produced in surrounding sleeve of ^{7}Li
- Advantages: long data taking possible; high Eν.
- Disadvantages: flux known at ~5%; Prod. of ^{8}Li not point-like (~150 cm).

Some examples of different detectors

Borexino detector: SOX

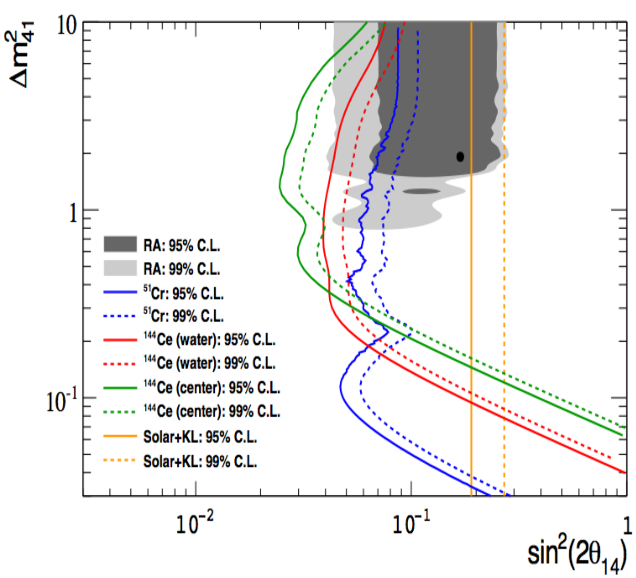
75 kCi ^{144}Ce and 10MCi ^{51}Cr placed outside/
in water tank/
in inner Scintill.:

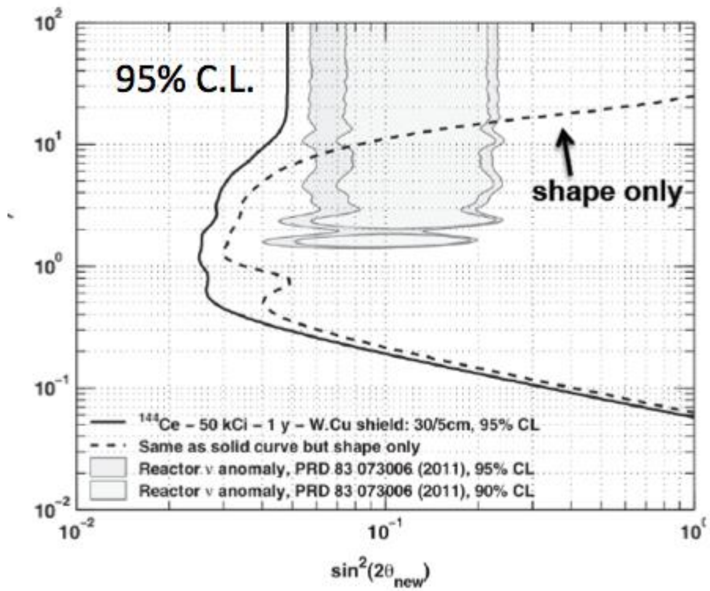
Kamland: CeLAND

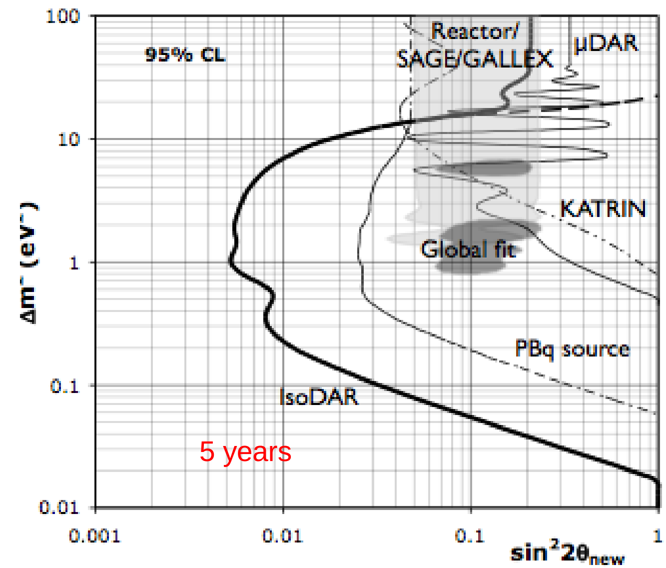
Phase 1 (2015): 75 kCi ^{144}Ce in outer detector
Phase 2 (2016, if feasible): 50 kCi ^{144}Ce at center of LS

IsoDAR:

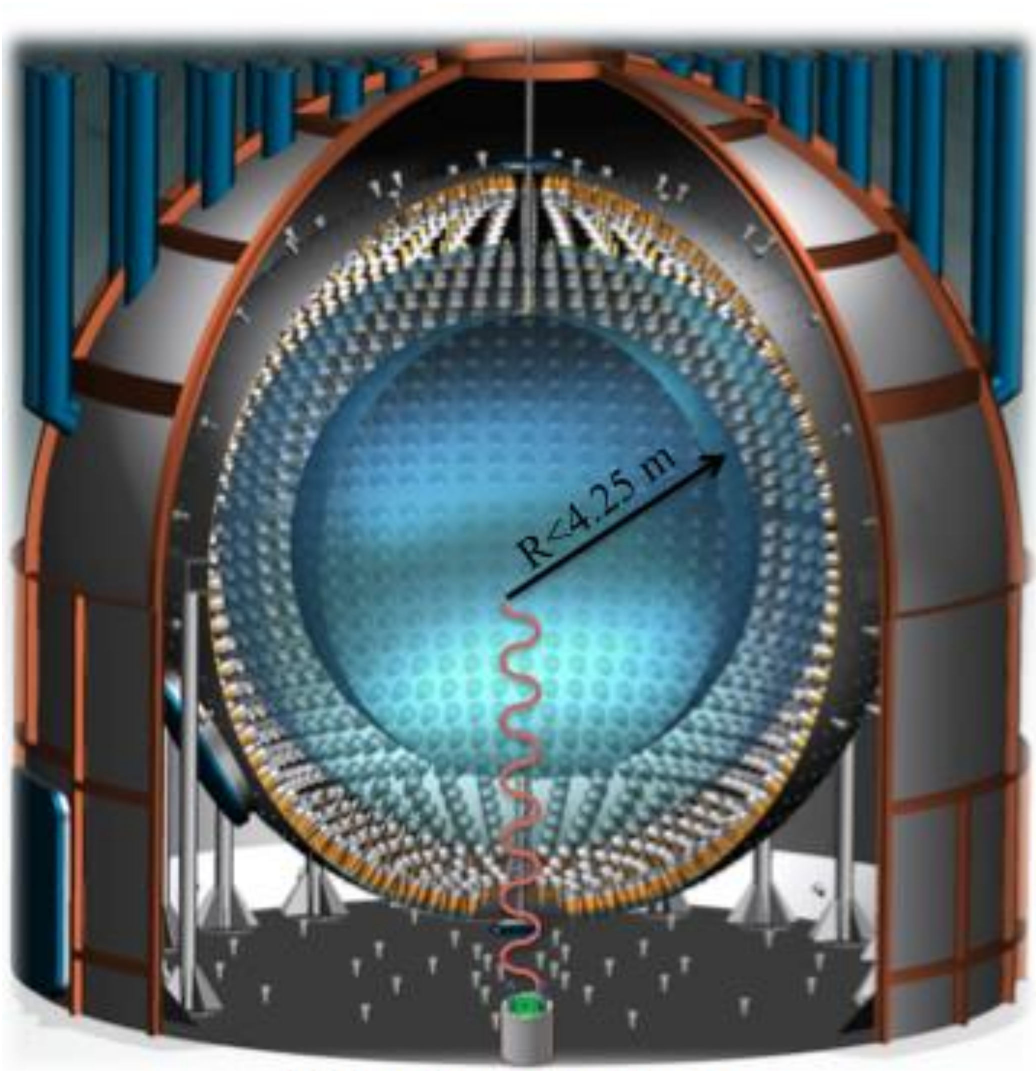
R&D proposal to place high-power low-energy cyclotron (DAEdALUS project) in the Kamioka mine to search for an oscillation pattern in Kamland



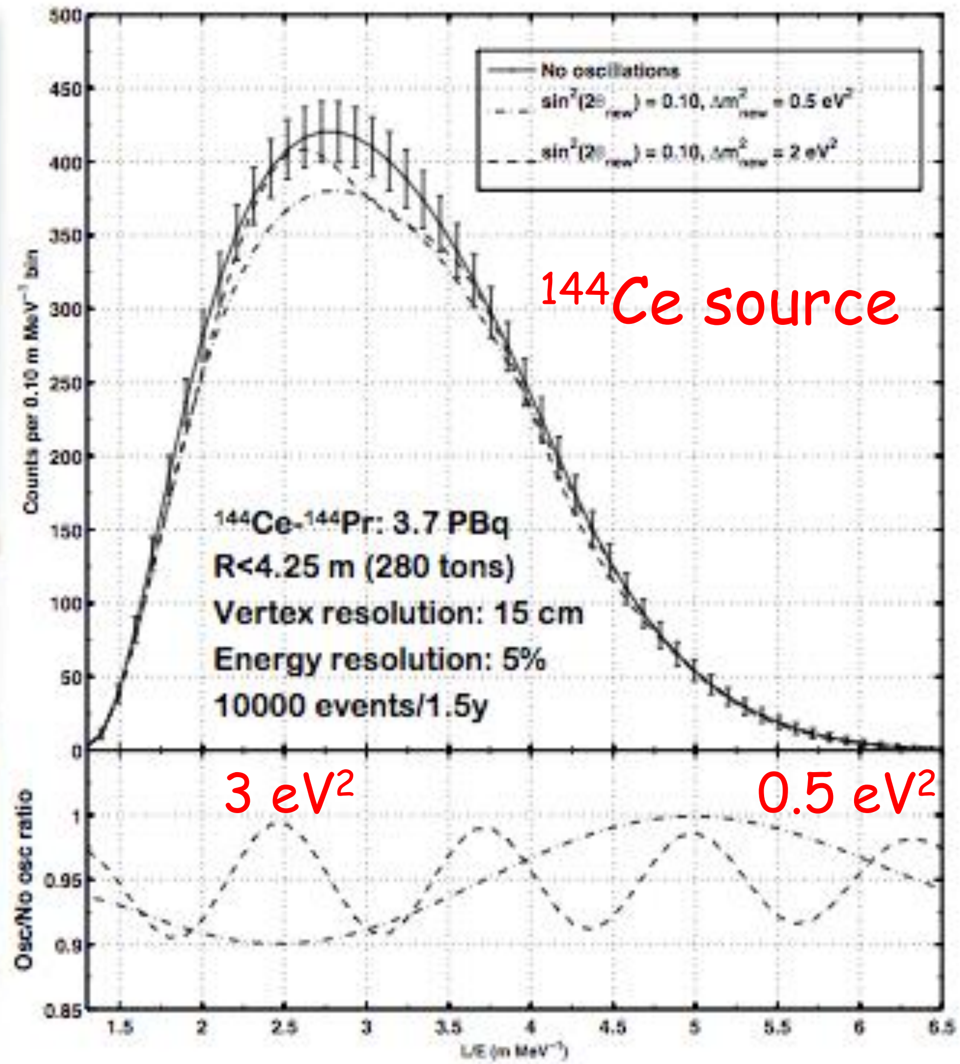




An example:Borexino experiment at LNGS



8.3 m from Bx Center

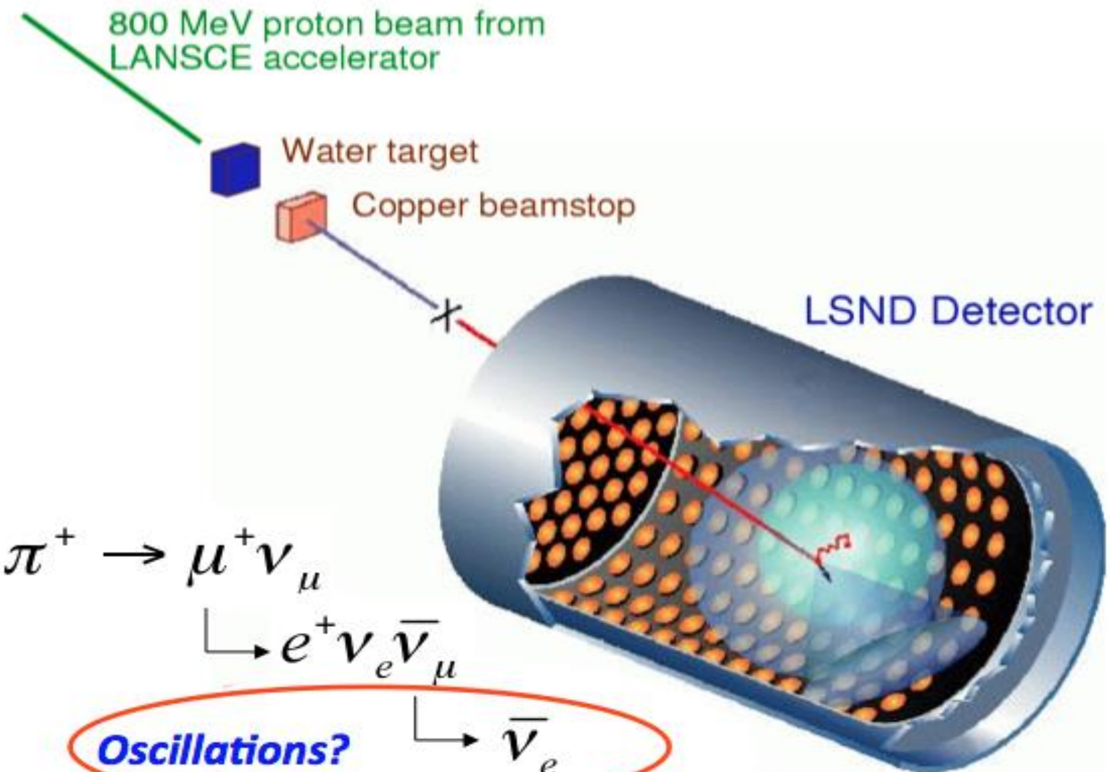


Expected disappearances from present reactor measurements

Transport of the ^{144}Ce source from Russia to LNGS

- **IAEA Regulations for the Safe Transport of Radioactive Material**
- **Train / Dedicated Boat/ Truck: 3 weeks (5% activity loss)**

3.-The LSND anomaly (appearance of νμ -> νe events)



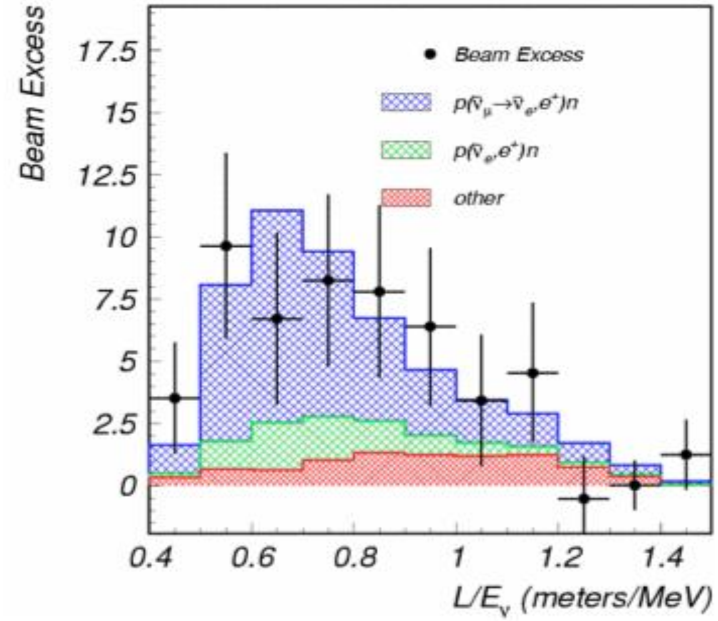
$\pi^+ \rightarrow \mu^+ \nu_\mu$

$\hookrightarrow e^+ \nu_e \bar{\nu}_\mu$

Oscillations? $\hookrightarrow \bar{\nu}_e$

Signal: $\bar{\nu}_e \rightarrow e^+ n$

$\hookrightarrow n\,p \rightarrow d\,\gamma(2.2\text{MeV})$



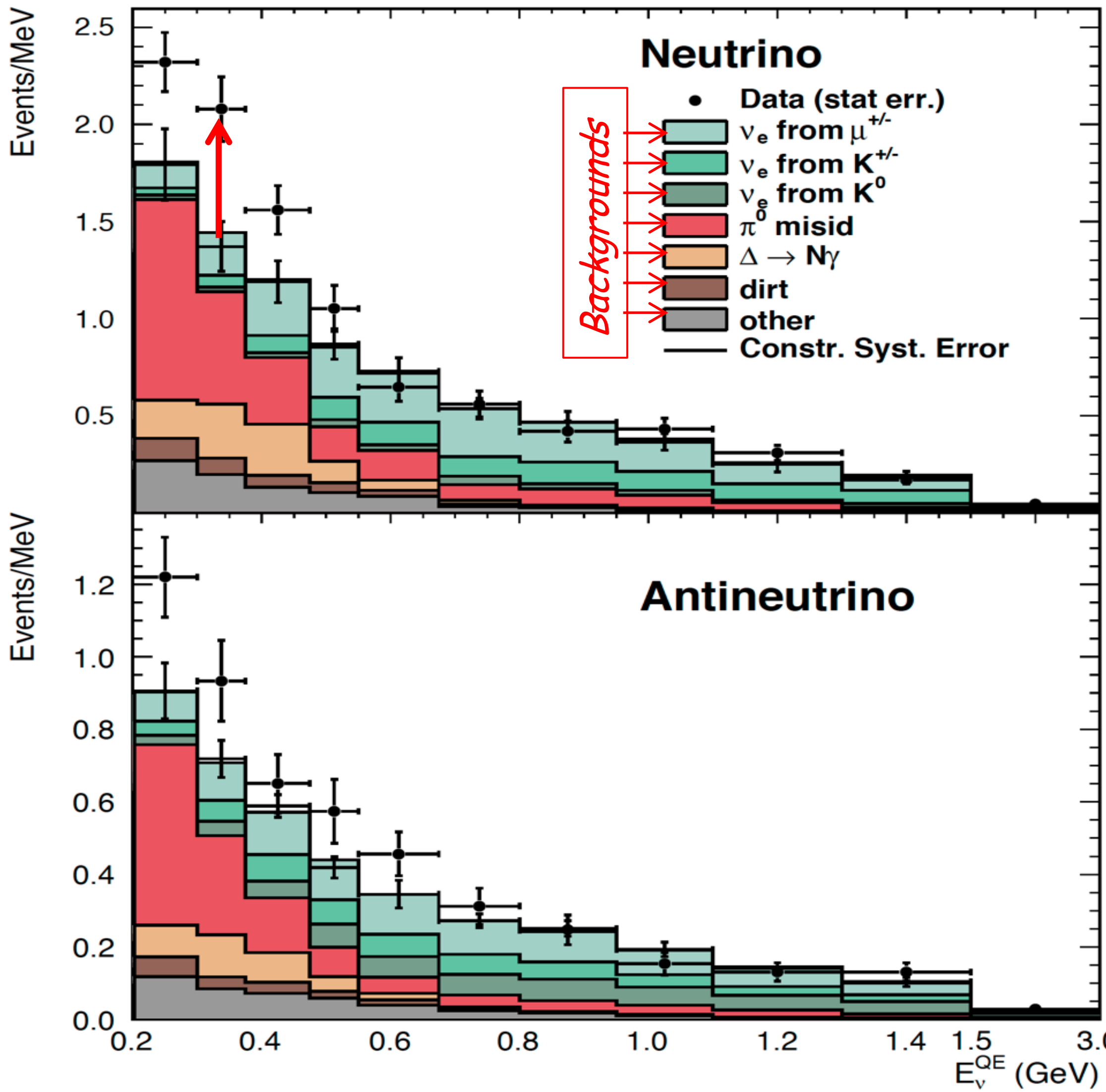
Saw an excess of $\bar{\nu}_e$:
87.9 ± 22.4 ± 6.0 events.

With an oscillation probability of (0.264 ± 0.067 ± 0.045)%.

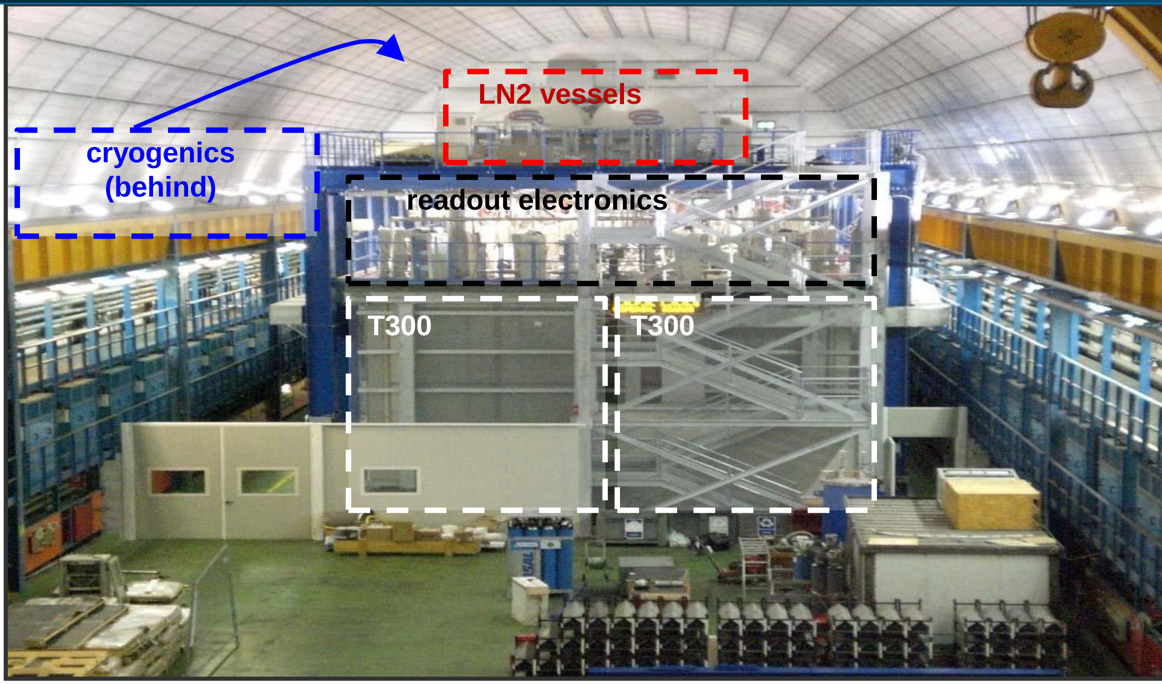
3.8 σ evidence for oscillation.

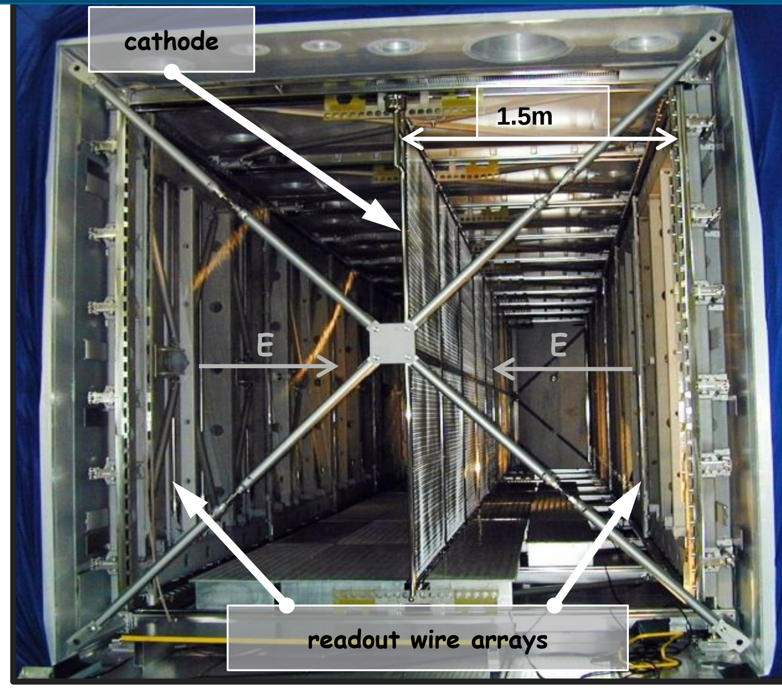
Beyond the LSND anomaly: the MiniBooNe experiment

- MiniBooNE looked for νe excess at L/E ≈ 1 km/GeV in both ν, anti-ν beams, Eν≈ 0.8 GeV.
- The LSND anomaly not been entirely clarified, but a new possible excess at low energy was observed for both ν and anti-ν
- The effect, maybe either due to electrons or gamma will have to be searched by MiniBooNe with the LAr-TPC



The advent of the LAr-TPC: the ICARUS-T600 detector



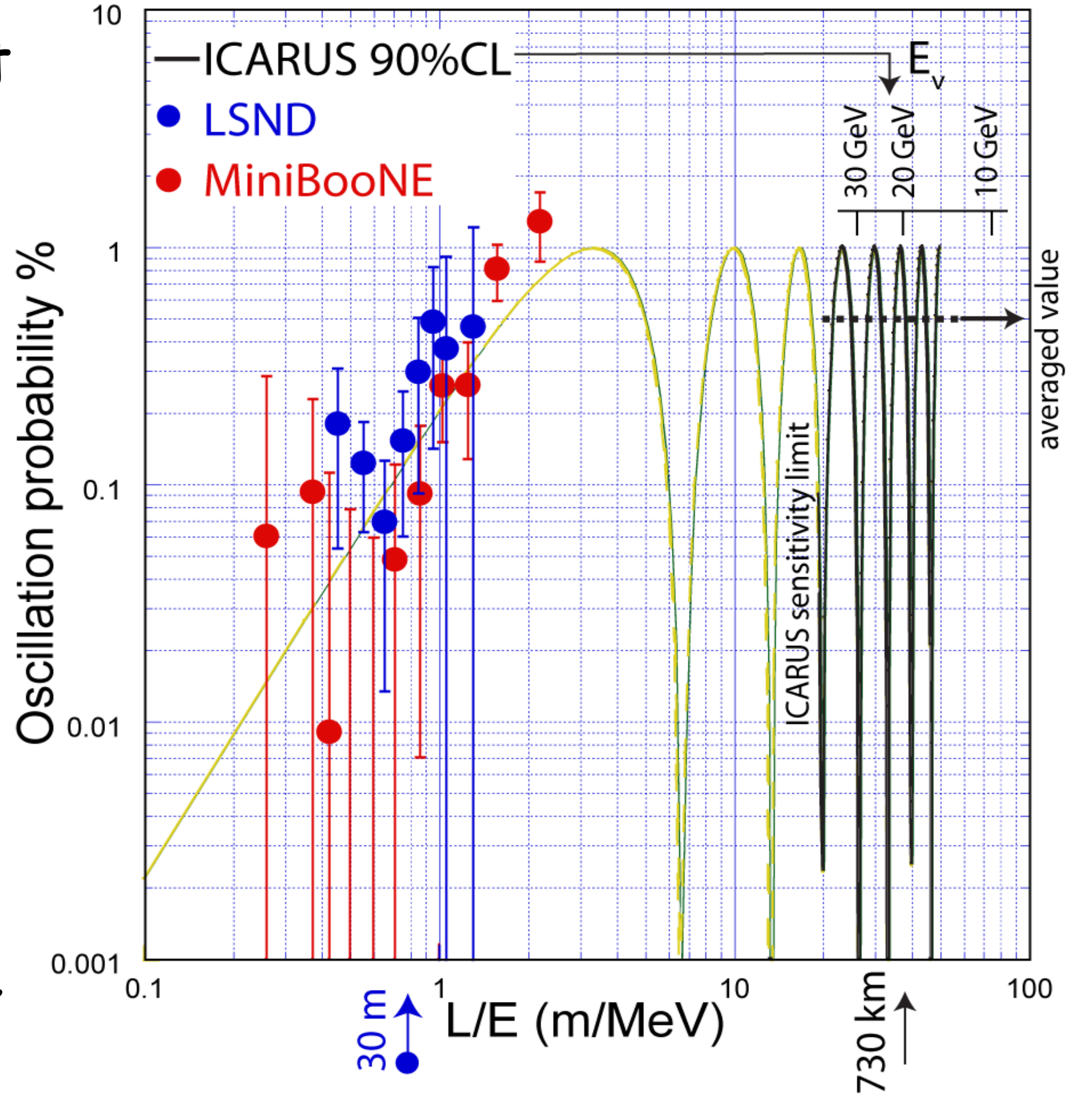


- Two identical modules (T300)
  - 3.6x3.9x19.6 = 275 m3 each
  - Liquid Ar active mass: ~476 t
  - Drift length = 1.5 m (1 ms)
  - HV = -75 kV; E = 0.5 kV/cm
  - drift velocity = 1.55 mm/μs
  - Sampling time 0.4 μs (sub-mm resolution in drift direction)
- 4 wire chambers
  - 2 chambers per module
  - 3 "non-distructive" readout wire planes per chamber wires at 0, ±60° (ind1, ind2, coll view)
  - ~ 54000 wires, 3 mm pitch and plane spacing
  - Charge measurement on collection plane
- 20+54 8" PMTs for scintillation light detection
  - VUV sensitive (128nm) with TPB wave shifter

Improving with ICARUS the location of sterile LNSD anomaly

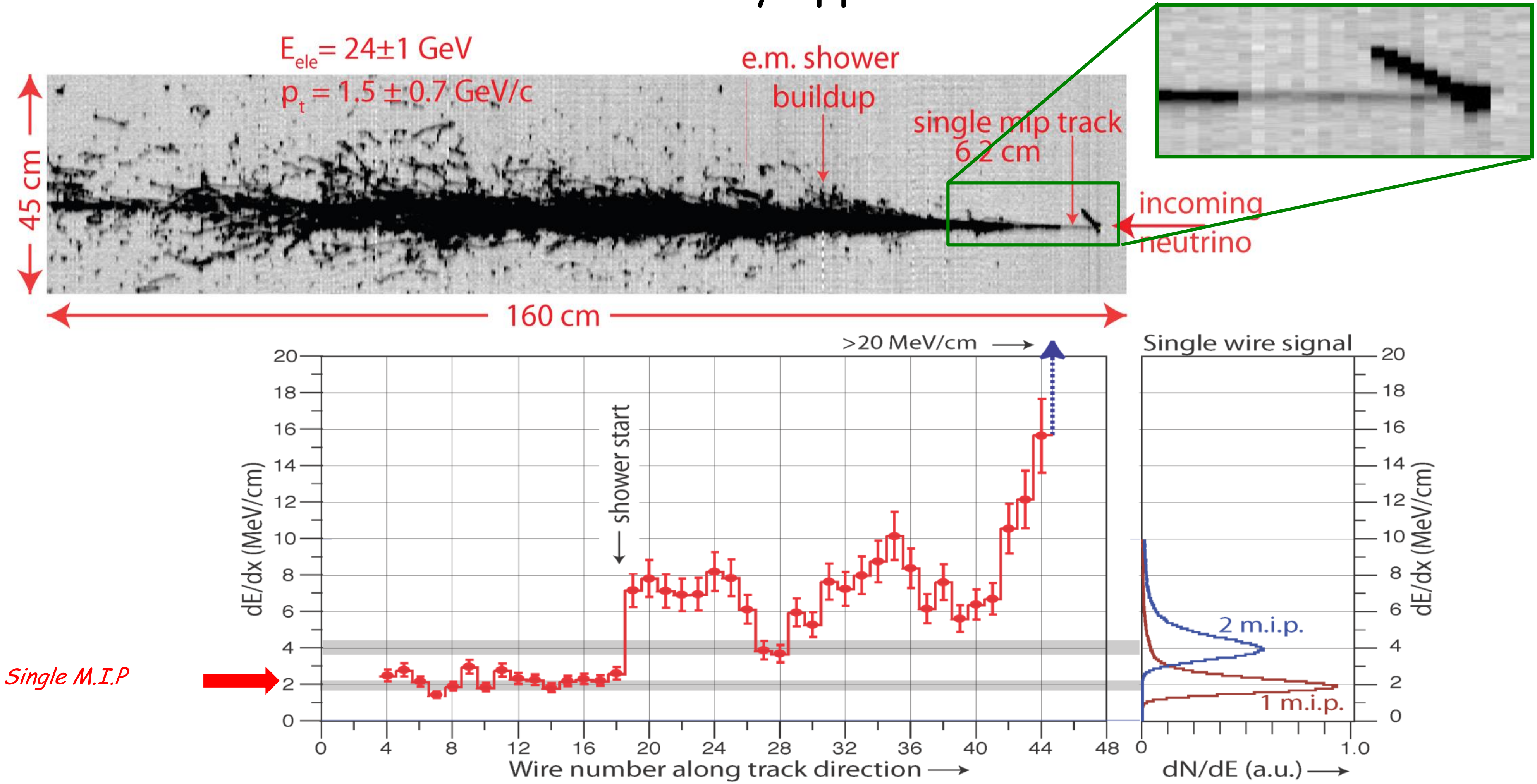
- Most of the subsequent experiments are or will be based on the LAr-TPC technology, originally developed at LNGS/INFN with the ICARUS detector.
- The searches from neutrinos from CERN have been performed at the CNGS facility with an almost pure νμ beam in 10-30 GeV Eν range (beam associated νe ~1%) at a distance L=732 km from target.
- ICARUS has concluded a very successful, long duration run with its T600 detector at the LNGS underground laboratory taking data both with the CNGS neutrino beam and with cosmic rays.
- ICARUS searched for ⎨ e excess related to a LSND-like anomaly,with the observation of νe events on the ⎨ ⌠ CNGS beam and L/E⎨ ~36.5 m/MeV.
- Unique detection properties of LAr-TPC technique allow to identify unambiguously individual e-events with high efficiency.

- There are main differences between ICARUS and LSND:
  - L/E_ν ~1 m/MeV at LSND, but
  - L/E_ν ≈36.5 m/MeV at CNGS
  - a LSND -like short distance signal averages far away to $\sin^2(1.27\Delta m^2_{new} L/E) \sim 1/2$ and $\langle P \rangle_{\nu\mu\to\nu e} \sim 1/2 \sin^2(2\theta_{new})$
- When compared to other long baseline results (MINOS and T2K) ICARUS because of its higher energies operates in a L/E_ν region in which contributions from standard ν oscillations [mostly $\sin(\theta_{13})$] are not yet too relevant.



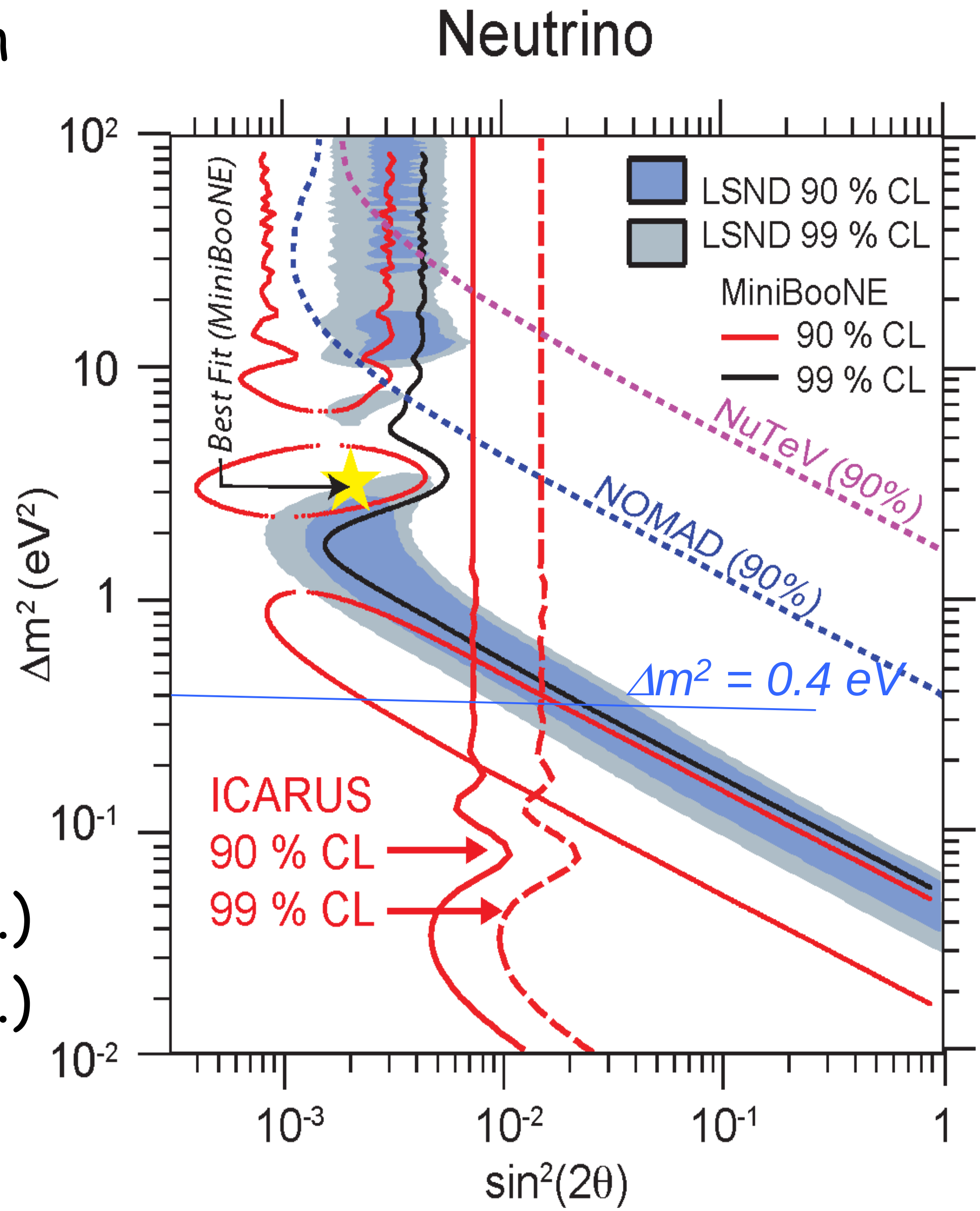
The ICARUS LAr-TPC result with 2450 ν interactions

- Event with a clear electron signature found in the sample of 2450 ν interactions (7.23 10^{19} pot).
- The evolution of the actual dE/dx from a single track to an e.m. shower for the electron shower is clearly apparent from individual wires.



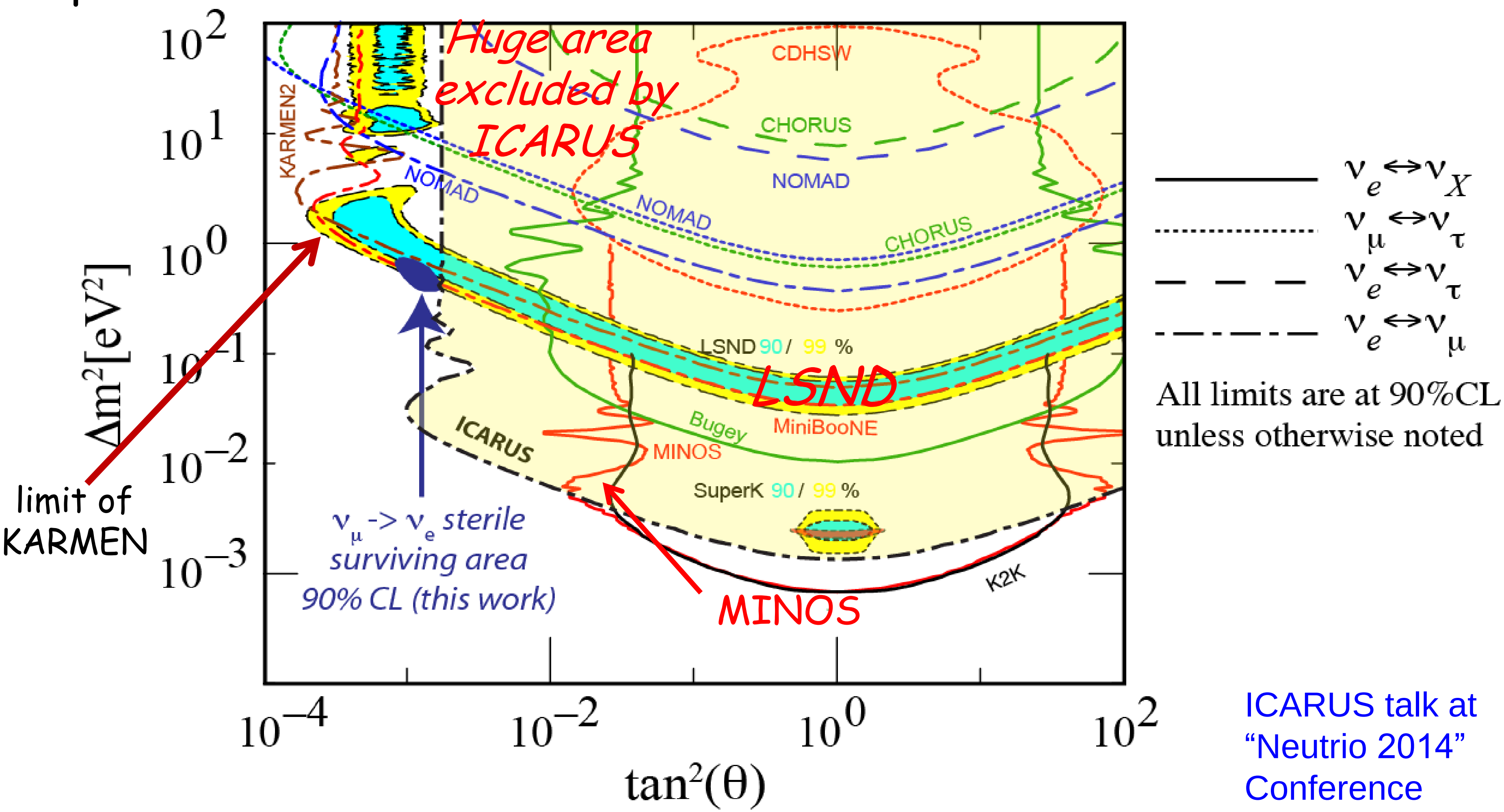
ICARUS result on the search of the LSND-anomaly

- 6 ν_e events have been observed in agreement with the expectations 7.9 ± 1.0 due to the conventional sources (the probability to observe ≤ 6 ν_e events is ~33%).
- Weighting for the efficiency, ICARUS limits on the number of events due to LSND anomaly are: 5.2 (90 % C.L.) and 10.3 (99 % C.L.).
- These provide the limits on the oscillation probability:
  - $P(\nu_\mu \rightarrow \nu_e) \leq 3.85 \times 10^{-3}$ (90 % C.L.)
  - $P(\nu_\mu \rightarrow \nu_e) \leq 7.60 \times 10^{-3}$ (99 % C.L.)
- Opera has also confirmed this result



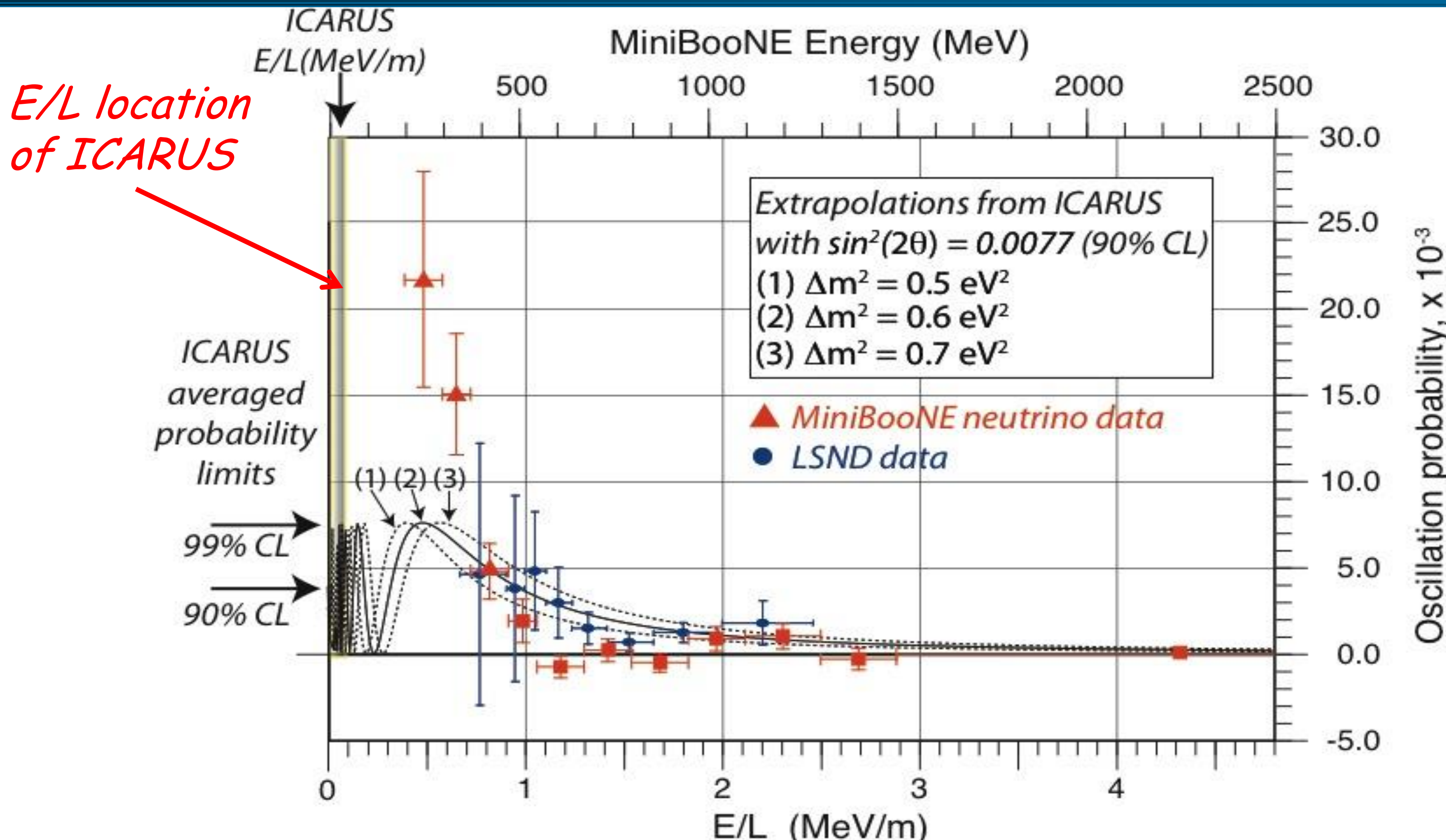
LSND-like search by the ICARUS experiment at LNGS

- ICARUS and OPERA results indicate a very narrow region of the parameter space (⊗m^2 ≈ 0.5 eV^2, sin^2(2∇) ≈ 0.005) where all experimental results can be accommodated at 90% CL.



ICARUS talk at “Neutrio 2014” Conference

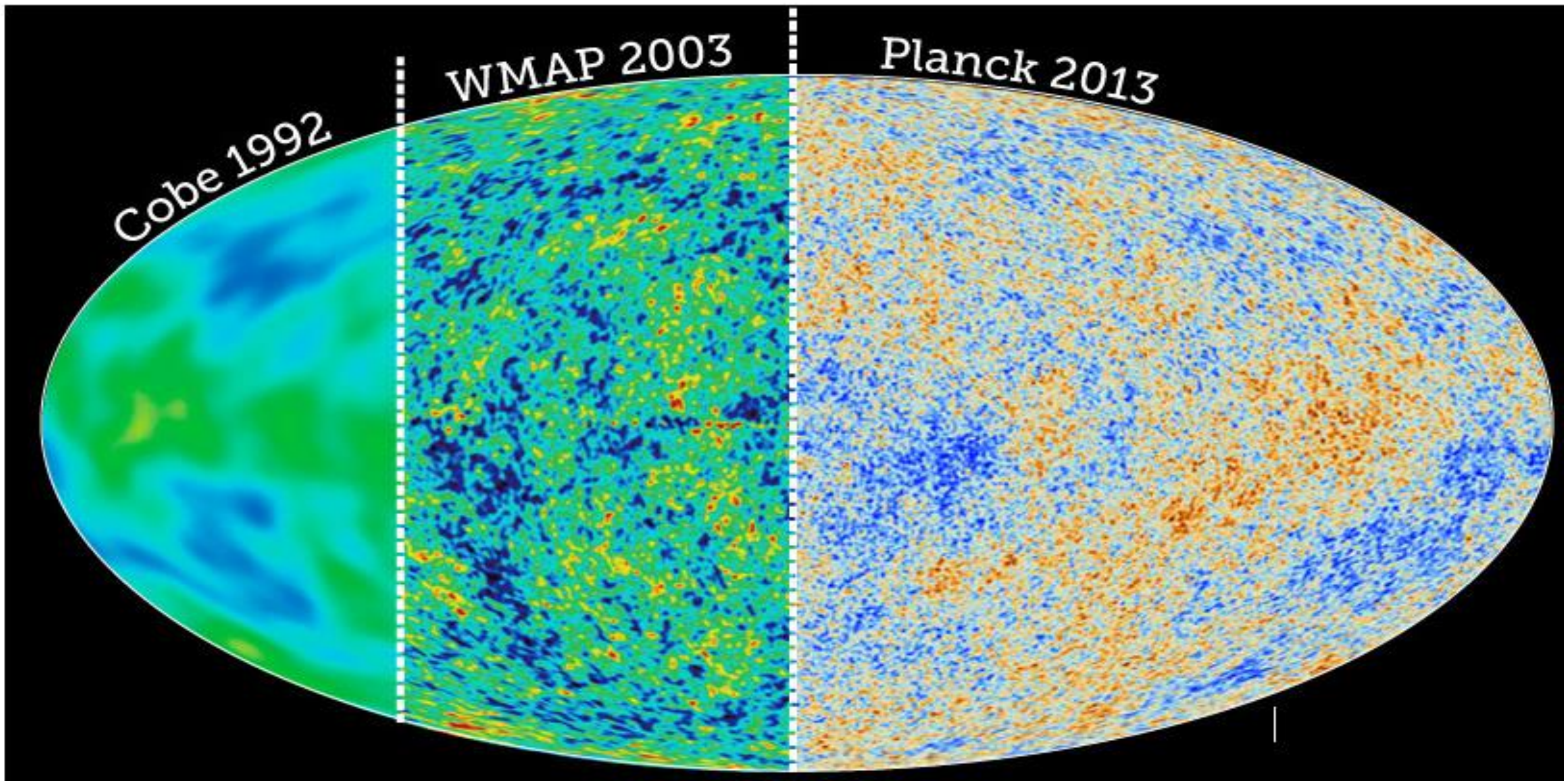
A ICARUS search of the low energy MiniBooNE effect



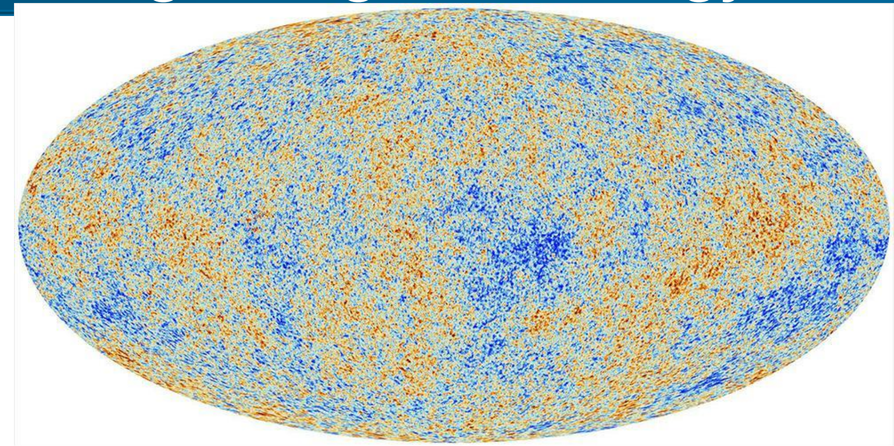
- ICARUS has also excluded the low energy sterile neutrino peak reported by MiniBooNE in the neutrino channel. This result has also been confirmed by OPERA.

Predictions from the Microwave Anisotropy probes

- A view of the cosmic microwave background collected by three major satellites over the last 20 years. The heat map of the cosmos was imprinted on the sky when the universe was just 380,000 years old.



Number of neutrino families from Big Bang cosmology

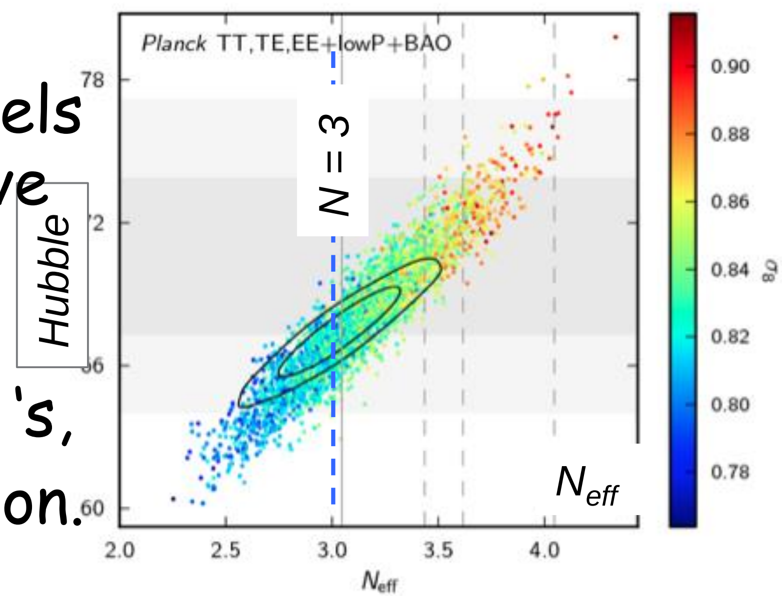


- A cosmologic search for neutrino-like relativistic particles beyond the three families of neutrinos (N_{eff}> 3) of the standard model has been reported by the Planck collaboration.

$$N_{\rm eff} = 3.13 \pm 0.32 \quad \textit{Planck}\ \text{TT+lowP};$$
$$N_{\rm eff} = 3.15 \pm 0.23 \quad \textit{Planck}\ \text{TT+lowP+BAO};$$
$$N_{\rm eff} = 2.99 \pm 0.20 \quad \textit{Planck}\ \text{TT, TE, EE+lowP};$$
$$N_{\rm eff} = 3.04 \pm 0.18 \quad \textit{Planck}\ \text{TT, TE, EE+lowP+BAO}$$

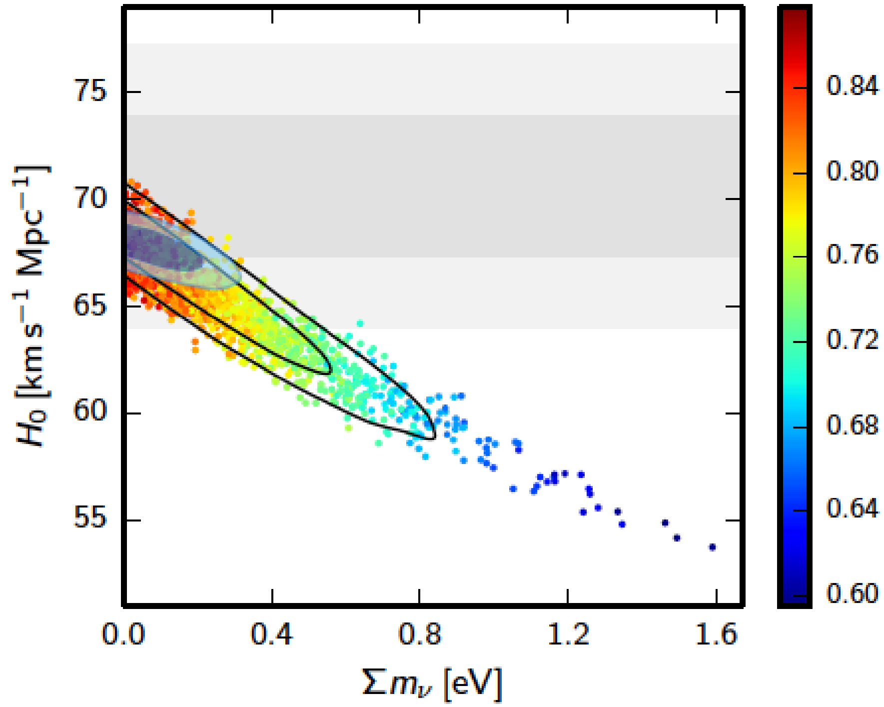
$$\rho = N_{\rm eff}\,\frac{7}{8}\left(\frac{4}{11}\right)^{4/3}\rho_\gamma$$

- Specific fully-thermalized particle models with one additional massless particle give different ΔN_{eff} according to actual decoupling
  - ➢ ΔN_{eff} = 0.57 if at the same time as ν 's,
  - ➢ ΔN_{eff}= 0.39 if before muon annihilation.



Sum of neutrino masses prediction from Cosmology

$$\sum m_\nu < 0.72 \text{ eV} \quad \textit{Planck}\ \text{TT+lowP};$$
$$\sum m_\nu < 0.21 \text{ eV} \quad \textit{Planck}\ \text{TT+lowP+BAO};$$
$$\sum m_\nu < 0.49 \text{ eV} \quad \textit{Planck}\ \text{TT, TE, EE+lowP};$$
$$\sum m_\nu < 0.17 \text{ eV} \quad \textit{Planck}\ \text{TT, TE, EE+lowP+BAO}$$



- Strong dependence of sum of neutrino like masses on the actual value of the Hubble Constant
- Two main predictions from Planck:
  1. The value of N_{eff} at 68% confidence is consistent with three standard active neutrinos eventually coexisting with one possible additional low mass species.
  2. The sum of the neutrino-like masses has a upper bound of the order of a fraction of eV

A "naïve expectation" for the short baseline program

- Let us combine the appearance (LSND) and the disappearances (neglecting oscillations into ν_τ and direct $\nu\mu \leftrightarrow \nu e$) as coming from an unique sterile neutrino signature with a 4 x 4 matrix U_{ik}.
- The general formula in the (3+1) model is then:

$$P_{\nu a \to \nu b} = \delta_{ab} - 4|U_{a4}|^2 \left(\delta_{ab} - |U_{b4}|^2\right) \sin^2\left(\frac{\Delta m_{41}^2 L}{4E}\right)$$

- where Δm_{41}^2 is the squared mass difference with respect to the fourth heavier neutrino
- Let us assume LSND and $\sin^2(2\theta_{e\mu}) = 4|U_{e4}|^2|U_{\mu 4}|^2 \approx 1.5\ 10^{-3}$
- This implies disappearances of both νe and νμ, since $\sin^2(2\theta_{ee}) = 4|U_{e4}|^2 (1-|U_{e4}|^2)$ and $\sin^2(2\theta_{\mu\mu}) = 4|U_{\mu 4}|^2 (1-|U_{\mu 4}|^2)$.
- Reactors now claim $\sin^2(2\theta_{ee}) \approx 0.12$, hence $|U_{e4}|^2 = 0.03$.
- Let us assume in addition also muon-electron Universality, such that νe and νμ disappearances are identical.
- Then we expect $\sin^2(2\theta_{ee}) = \sin^2(2\theta_{\mu\mu}) \approx 0.08$, still in reasonable agreement within present observations.

Cancellations between disappearance and appearance

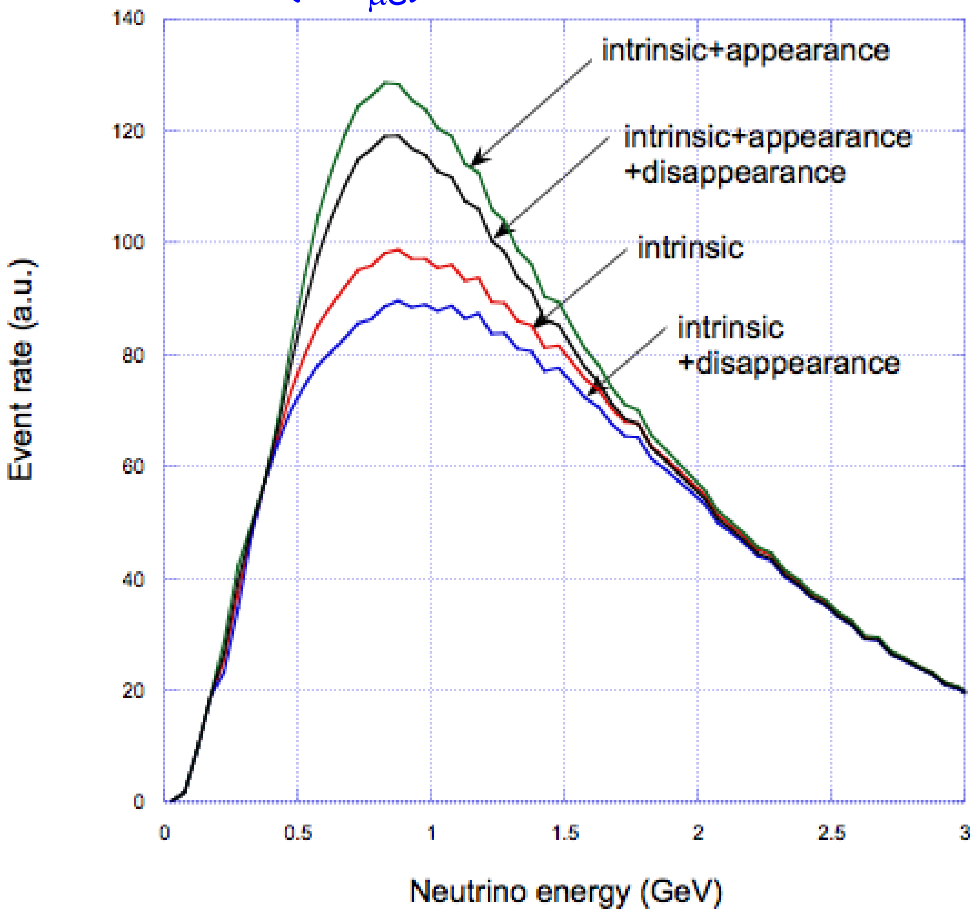
- There is an important difference between the original LSND and the future FermiLab programs.
- This is due to the fact that νe events are now produced both from a $R_{\nu\mu}(E)$ generated LSND $\nu\mu \to \nu e$ effect and from a $R_{\nu e}(E)$ "intrinsic" νe source with about 0.5% of the muon rate.
- Attenuation, in analogy with the case of nuclear reactors, must occur also for the "intrinsic" beam produced ve source
- Therefore cancellation between this and LSND generated $\nu\mu \to \nu e$ conversion are expected in the detected νe signal $S_{\nu e}$:

$$S_{\nu e} = [R_{\nu\mu}(E)\sin^2(2\theta_{e\mu}) - R_{\nu e}(E)\sin^2(2\theta_{ee})]\sin^2(1.27\,\Delta m_{41}^2\,L/E)$$

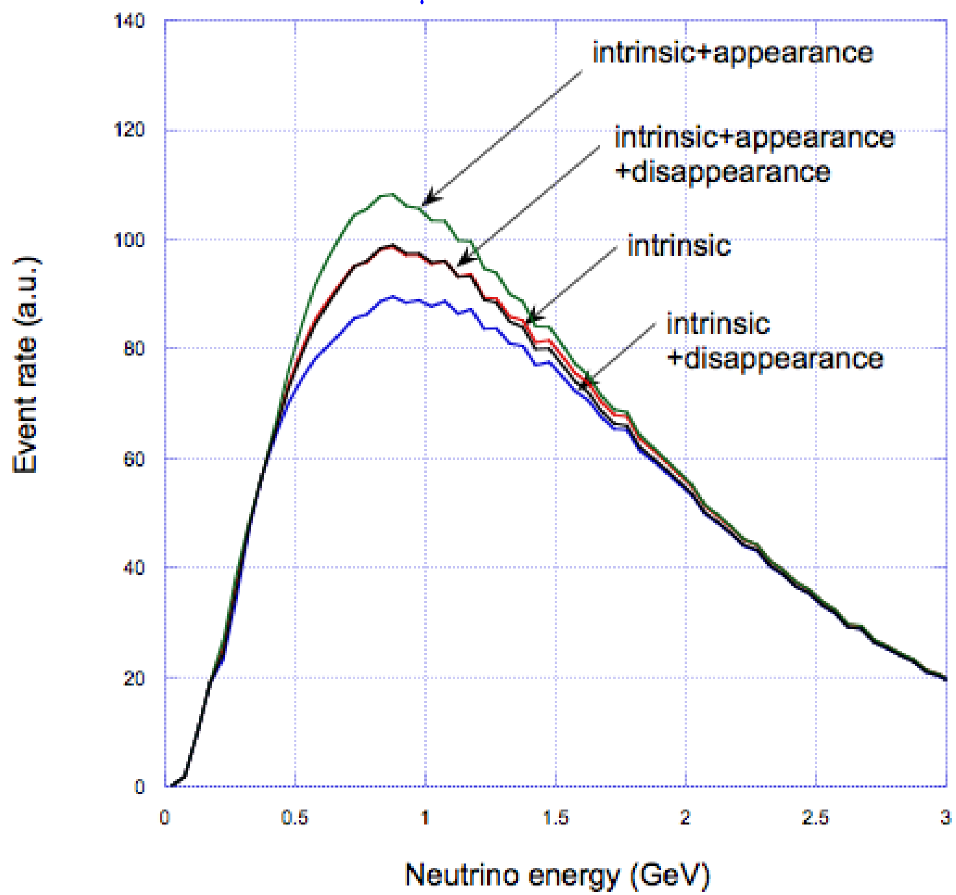
- where Δm_{41}^2 ,the squared mass difference with respect to the fourth heavier neutrino is a common factor as a function of mass difference and L/E.

Examples of electron neutrino spectra

Giunti Laveder best fit:
$\Delta m^2 \sim 1.5\ eV^2$;
$\sin^2(2\theta_{\mu\mu}) = 0.05$;
$\sin^2(2\theta_{ee}) = 0.1$;
$\sin^2(2\theta_{\mu e}) = 1.25 \times 10^{-3}$

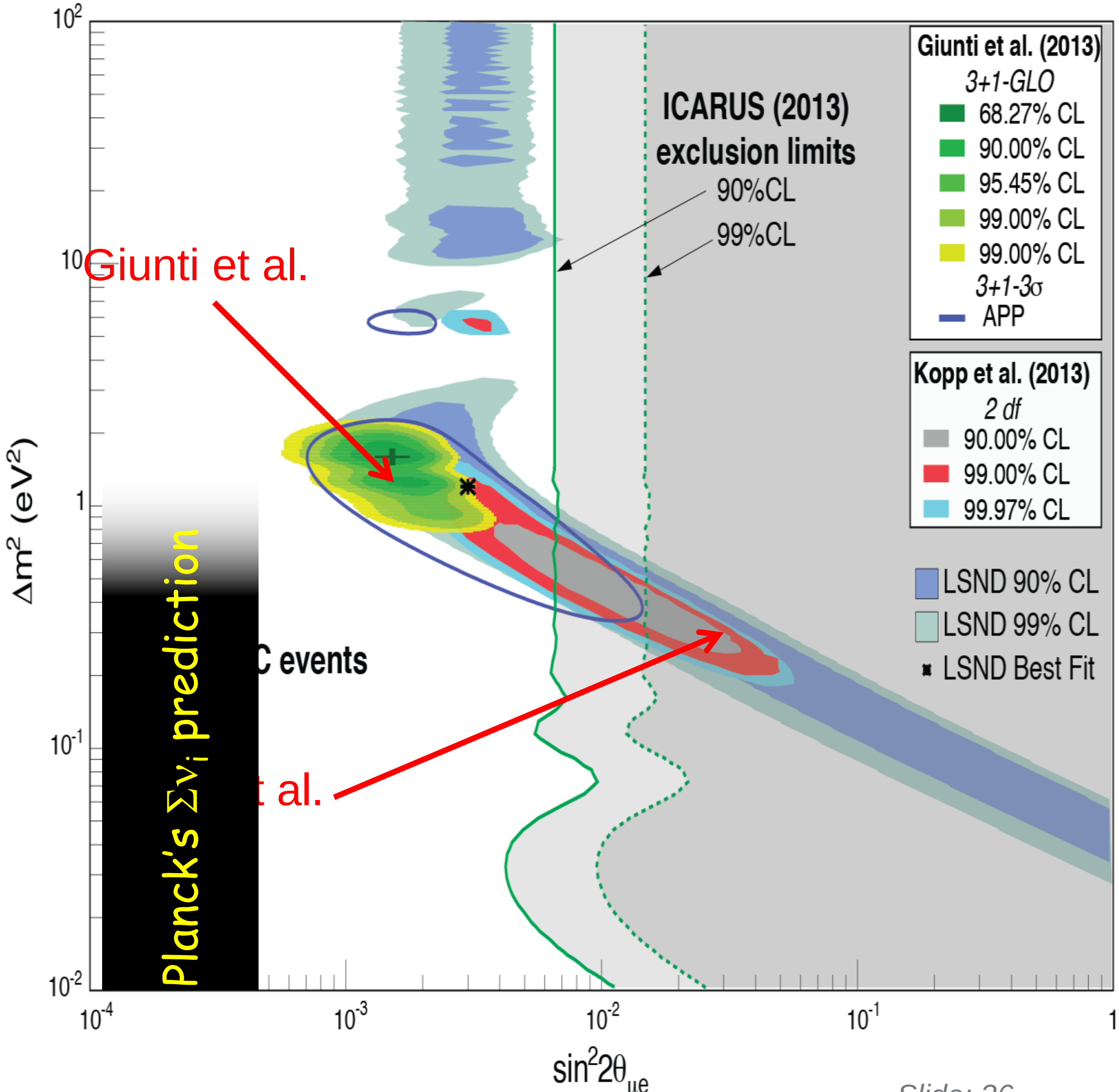


Extreme case of full cancellation
$\Delta m^2 \sim 1.5\ eV^2$;
$\sin^2(2\theta_{\mu\mu}) = 0.016$;
$\sin^2(2\theta_{ee}) = 0.1$;
$\sin^2(2\theta_{\mu e}) = 0.4 \times 10^{-3}$



Global fits of the sterile neutrino anomalies

- Recent global fit of $\sin^2\theta_{\mu e}$ and Δm^2 performed by Giunti et al., including all the available data is in poor agreement with the analysis of Kopp et al.
- The new ICARUS exclusion value strongly limits the LSND's window.
- Large values of Δm^2 are in poor agreement with cosmological predictions of the sum of neutrino like masses from Planck .



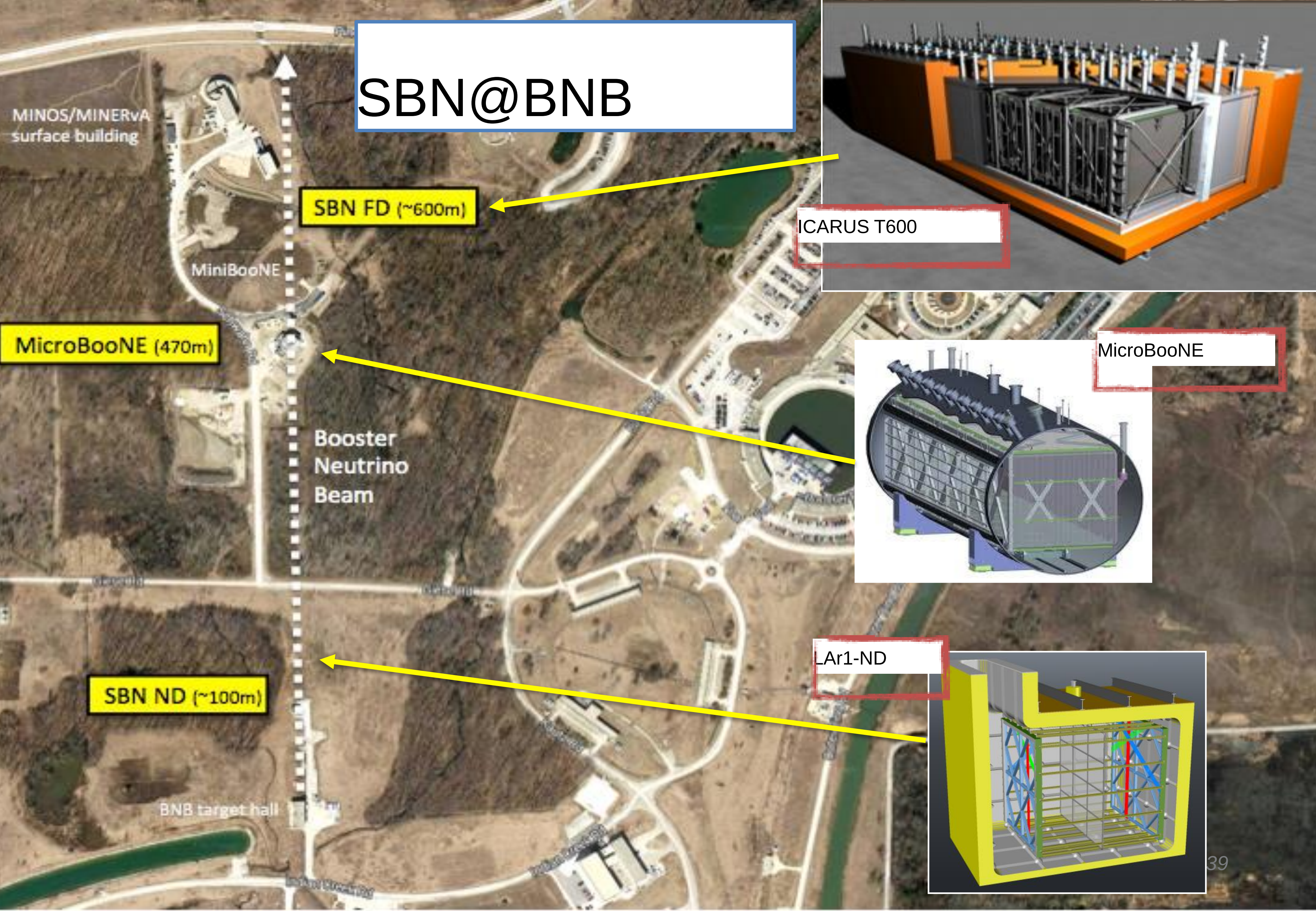
Sterile oscillations searches with LAr-TPC

- A highly sensitive search for $\nu_\mu - \nu_e$ oscillation in the appearance mode was proposed in 2009 by the ICARUS Coll. to test at CERN the LSND claim (arXiv:0909.0355, SPSC-P-345, SPSC-P-347)
- A dual detector at two different (near and far) locations to separately identify the Δm^2 and $sin^2(2\theta)$ by the (simultaneous) observation at different distances of neutrino interactions with :
  - appropriate L/E oscillation path lengths to ensure appropriate matching to the Δm^2 window for the expected anomalies;
  - "Imaging" detector capable to identify unambiguously <u>all</u> channels with the novel *LAr-TPC;*
  - Very high rates due to large LAr mass, nearing in total 1 kt, in order to record relevant effects at the % level (>10^6 ν_μ, ≈10^4 νe events);
  - Both initial ν_e and ν_μ components cleanly identified;
- The already approved experiment SPSC-P-347 was cancelled by the CERN management decision of not pursuing neutrino beams in Europe.
- The alternate, dual detector experiment has then been proposed by a collaborative, international program at FNAL's BNB with three detectors at different baselines (near: Lar1-ND, mid: MicroBooNE, far: ICARUS).

Basic features of the proposed Fermilab program

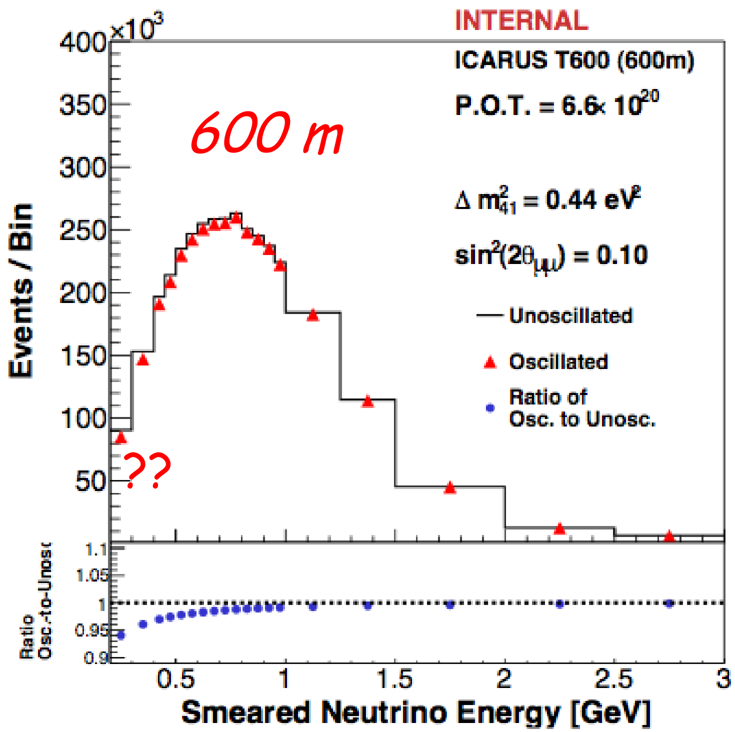
- The proposed experiment, collecting a large amount of data, may be able to give a *definitive* answer to the 3 following queries :
  - the LSND/MiniBooNE appearance of the $\nu_\mu \rightarrow \nu_e$ oscillation anomalies;
  - The Gallex + Reactor oscillatory disappearance of the initial ν_e signal;
  - an oscillatory disappearance maybe also be present in the ν_μ signal, so far unknown.
- In absence of any of these "anomalies", the signals of the detectors should be a closer copy of each other for all experimental signatures.
- However presence of a relatively large rate of intrinsic ν_e events, absent in the original LSND experiment, may introduce a significant correlation between appearance and disappearance signals.

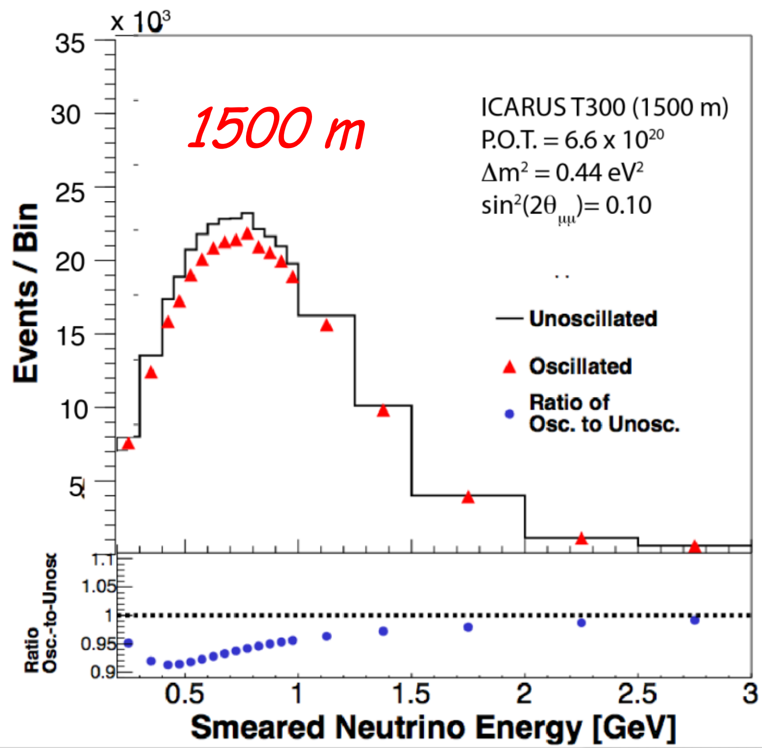
SBN@BNB


MINOS/MINERvA surface building
SBN FD (~600m)
ICARUS T600
MiniBooNE
MicroBooNE (470m)
MicroBooNE
Booster Neutrino Beam
SBN ND (~100m)
LAr1-ND
BNB target hall

Expected Δm^2 of the disappearance signals ?

- According to the predictions from Big Bang Cosmology, the mass difference Δm^2 may be small. Assume $\Delta m^2 \approx< 0.4\ eV^2$,
- The $\nu\mu$ disappearance effect at 600 m will be seriously limited to the lowest neutrino bin energies 0.2-0.4 GeV.
- *As a second phase* and in order to amplify the effect, we may have to move a LAr-TPC to a distance of the order of 1500 m.





Conclusions

- Over the last several years, neutrinos have been already the origin of an impressive number of "Surprises":
  - Masses, once zero "by ignorance", are actually important
  - Oscillations extend and complete the C+KM quark mixing
  - Oscillations due to matter exist, due to neutral currents
- *Are neutrino a simple "carbon copy" repetition of quarks?*
- Important discovery potentials may be ahead:
  - CP violation in the lepton sector (CPT ?)
  - Majorana or Dirac ν' s;ν-less β-decay,ν-masses
  - Right handed neutrinos and see-saw mechanisms
- There also is a small but realistic probability that sterile neutrinos and other "anomalies" may be confirmed.
- *A neutrino-like object with $m \approx 1$ eV/c^2 could be a fundamental new discovery and be a major source for the Dark Mass !*


Thank you !