Sterile neutrinos ?

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The present ICARUS Collaboration: to be extended

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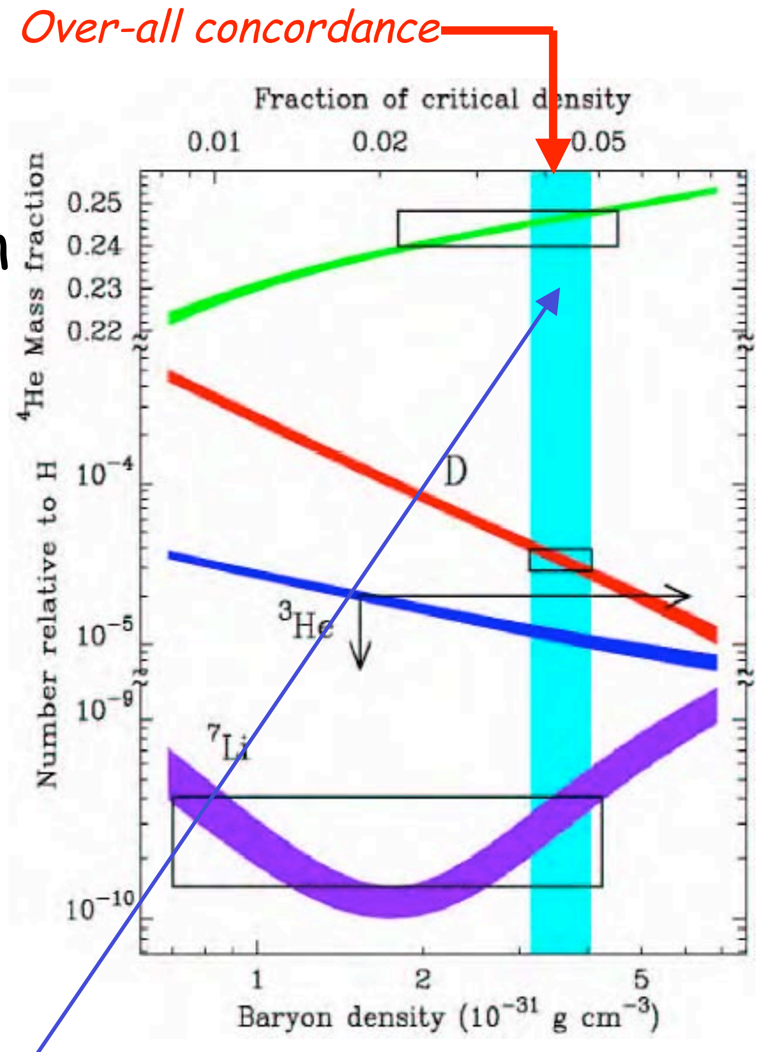
From optical astronomy to Astro-Particle physics

- Luminous matter accounts for only a tiny fraction of the total mass density of the Universe and only about a tenth of the ordinary matter (baryons).
- Stars are very interesting and pretty to look at — and without them, astronomy wouldn't be astronomy and we wouldn't exist — they represent a tiny fraction of the cosmic mass budget, only about 0.5 % of the total energy and mass of the Universe.
- As we have known for several decades, the bulk of the constituents of the Universe are dark and only indirectly observable through induced effects.
- In order to know more, the scientific activity of optical Astronomy needs to be extended in a variety of ways.
- Particle physics provides attractive solutions both with *accelerator and non accelerator experiments,* which have recently transformed the early phases of the Universe from philosophy to an experimental science.

Ordinary matter: Big Bang Nucleo-synthesis (BBN)

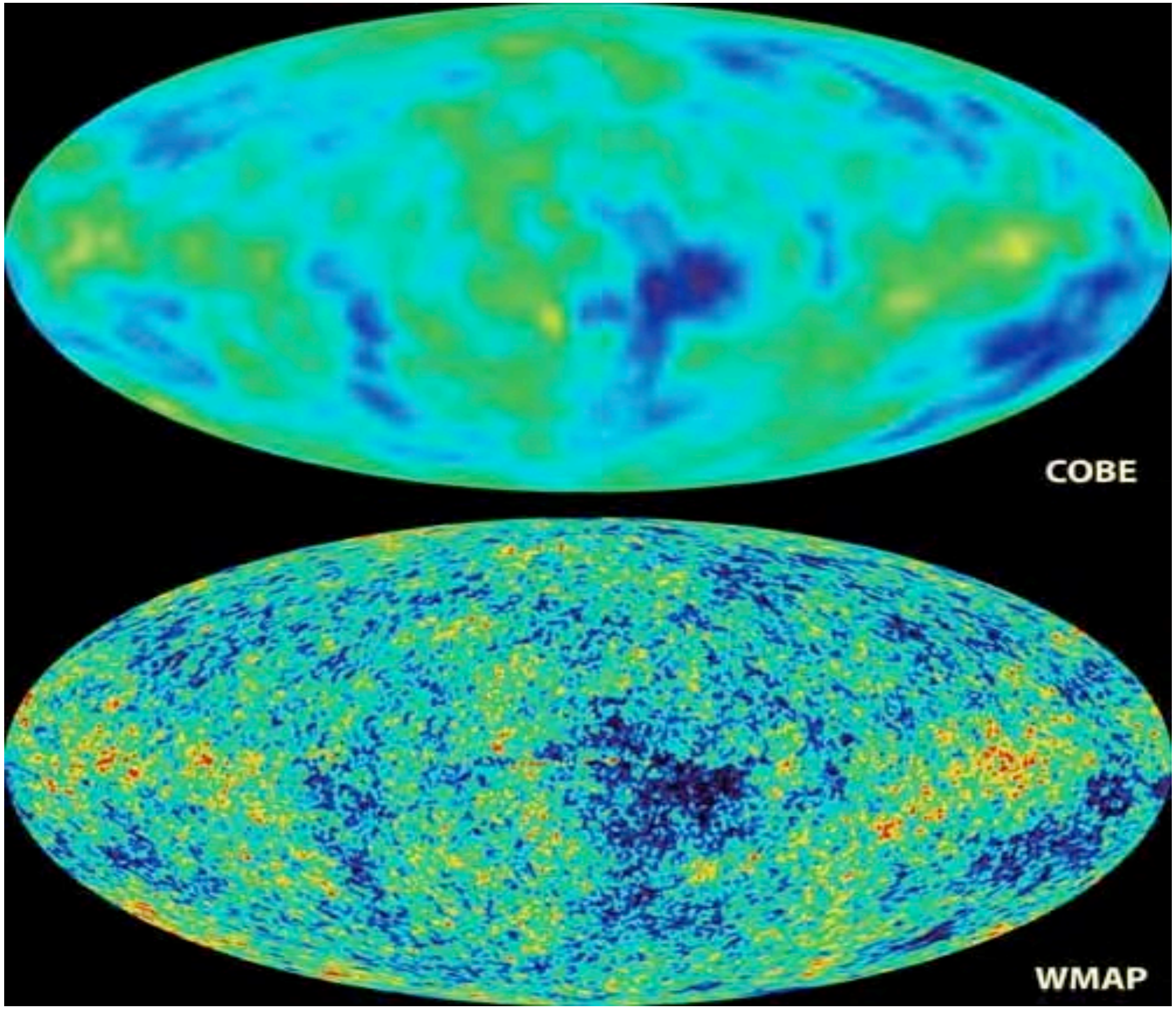
- The big-bang nucleo-synthesis has provided for more than twenty years a key test of the baryon density Ω_B.
- The situation has greatly improved when Burles and Tytler clarified matters, based on the deuterium abundance measured in four high-red shift hydrogen clouds, seen in absorption against distant QSOs.
- The measurement turned the previous factor 3 into a 10% determination of baryon density : $\Omega_B h^2 = 0.02 \pm 0.002$.
- BBN depends on the baryon/photon ratio: from the observed number of photons we can constrain the baryon density.



$\Omega_{BBN} = 0.044 \pm 0.004$

The oldest image of the Universe (CMB)

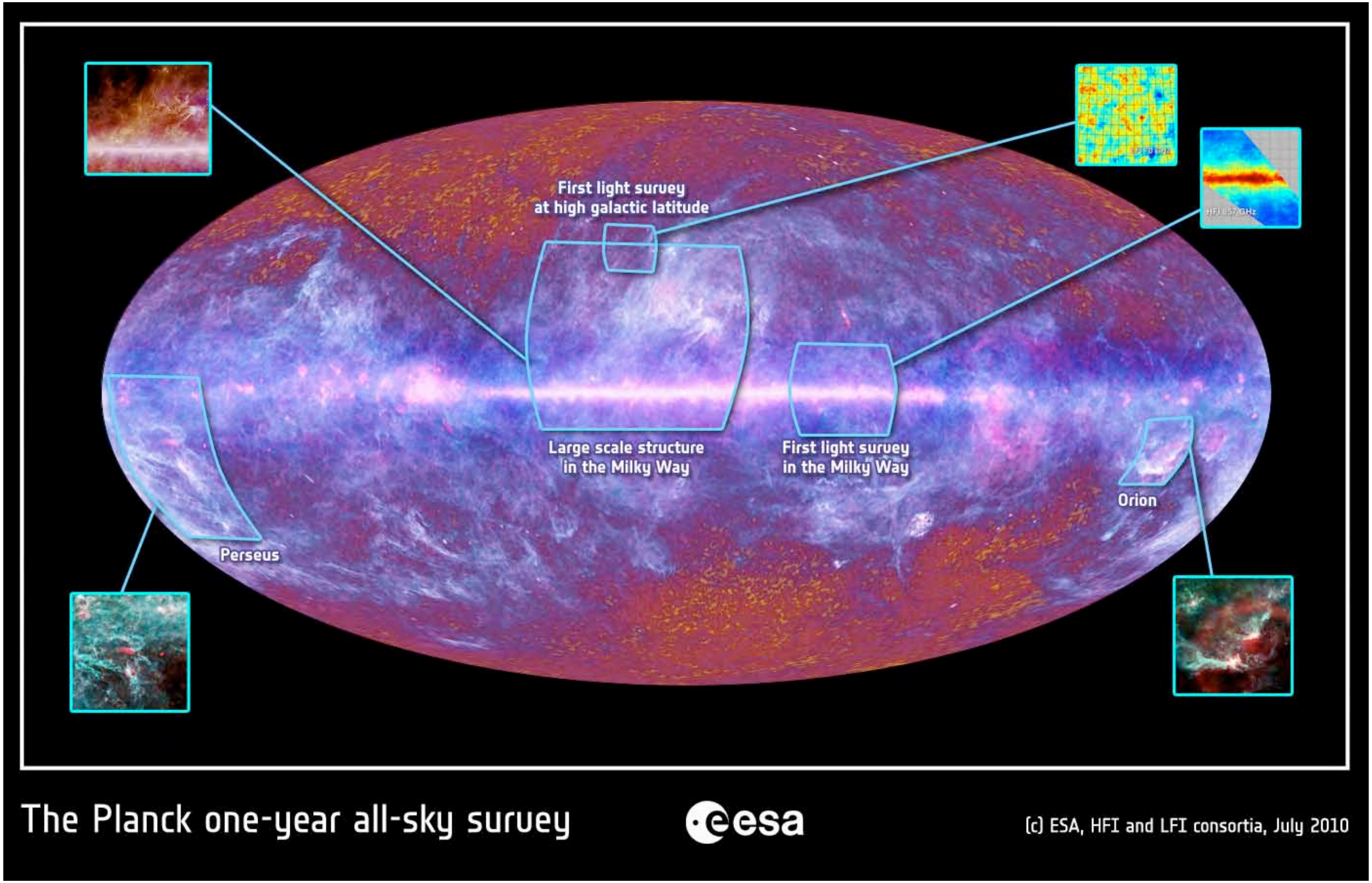
When it originated, some 300,000 years after the Big Bang, the temperature of the Universe was about 3,000 K. Since then, the temperature of the radiation has dropped by a factor of roughly 1100, due to the expansion of the Universe.



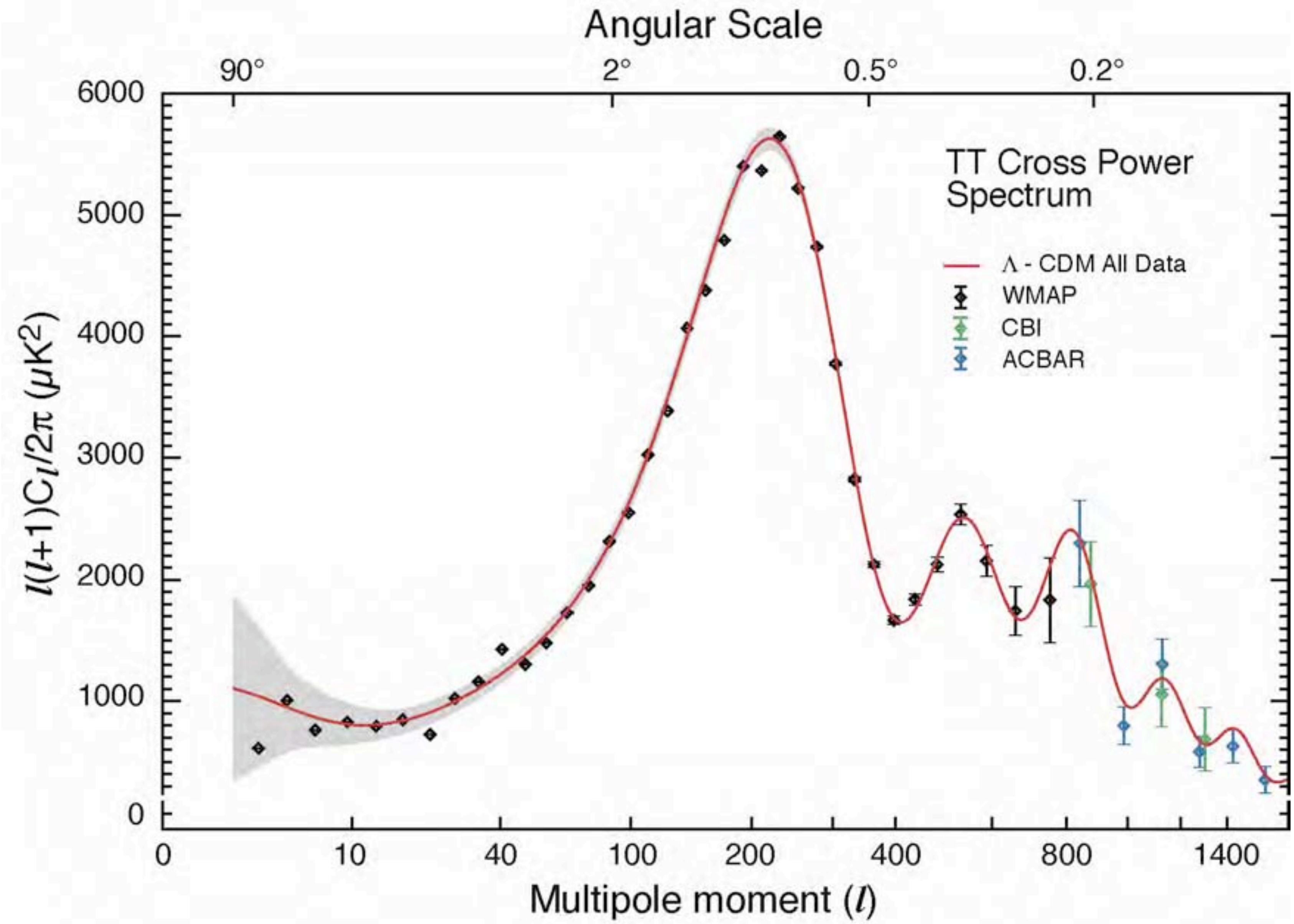
COBE

WMAP

The Planck satellite

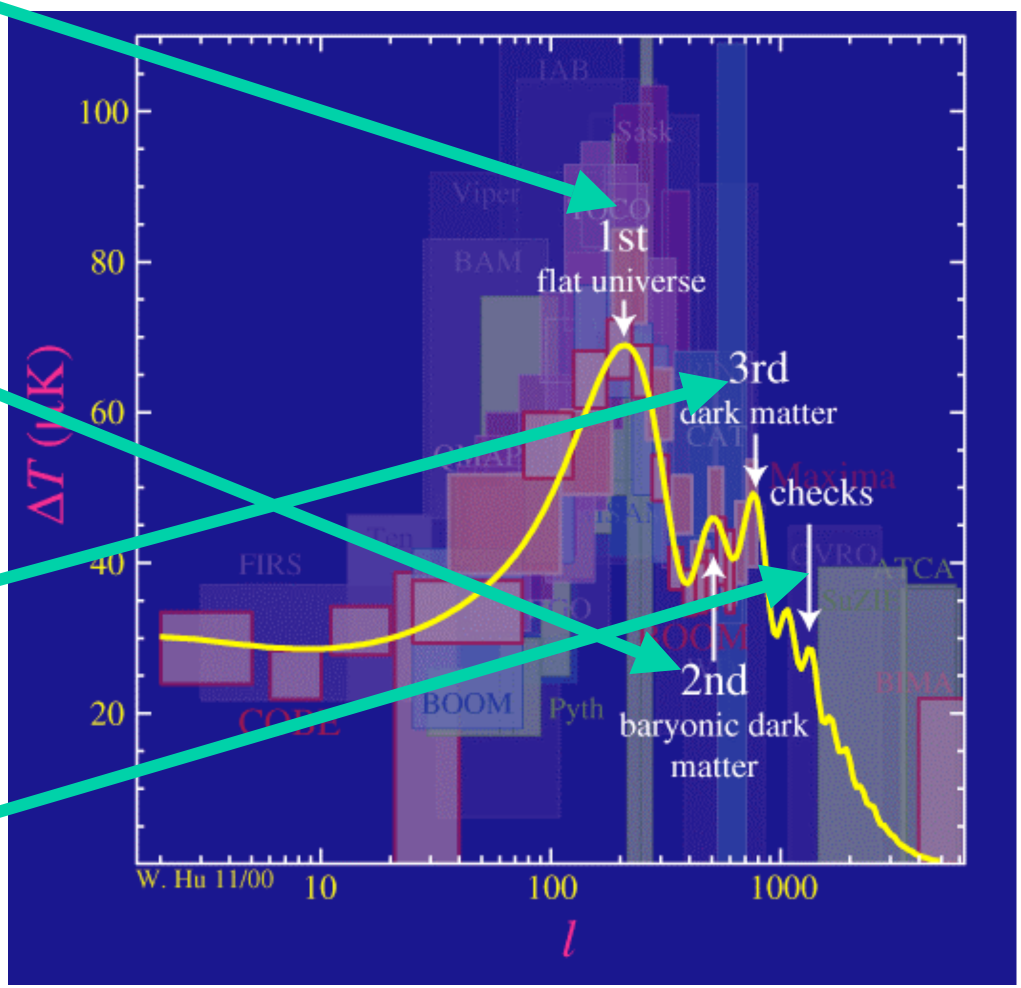


WMAP power spectrum vs. dipole moment



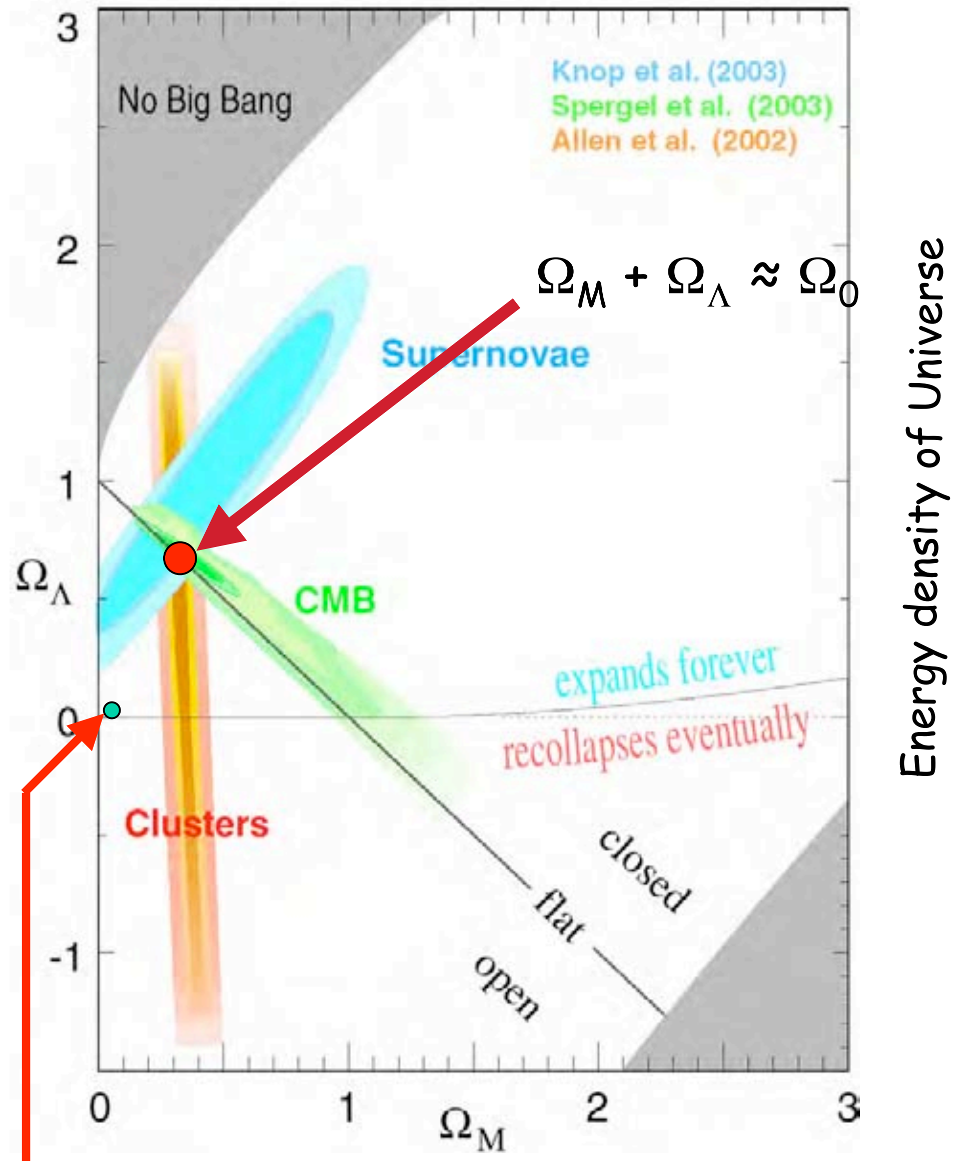
Direct cosmological measurements from WMAP

- First peak shows the universe is close to spatially flat. Shape and position are in beautiful agreement with predictions from standard cosmological models
- Constraints on the second peak indicate substantial amounts of baryonic matter
- Third peak will measure the physical density of the overall dark matter
- Damping tail will provide consistency checks of underlying assumptions



The over-all Cosmic concordance.

- We are witnessing today a turning point in Cosmology as important as in 1964, when the Cosmic Background Radiation (CBR) was discovered.
- With the recent discovery of an invisible energy component in the empty space, about as large as the total matter of the Universe multiplied by c^2 (e.g. the non zero value of Ω_Λ) we have now for the first time a credible model for structure formation that is consistent with all the data at hand.

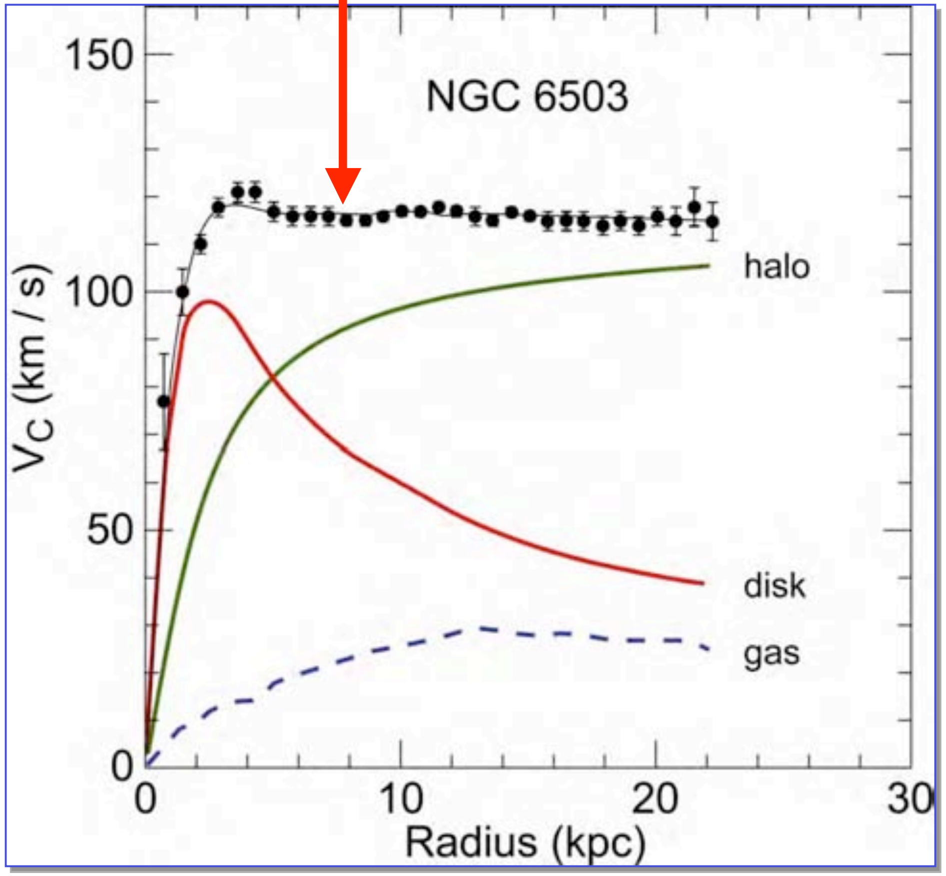


Nucleosynthesis: Ω_{BBN} = 0.044 ± 0.004

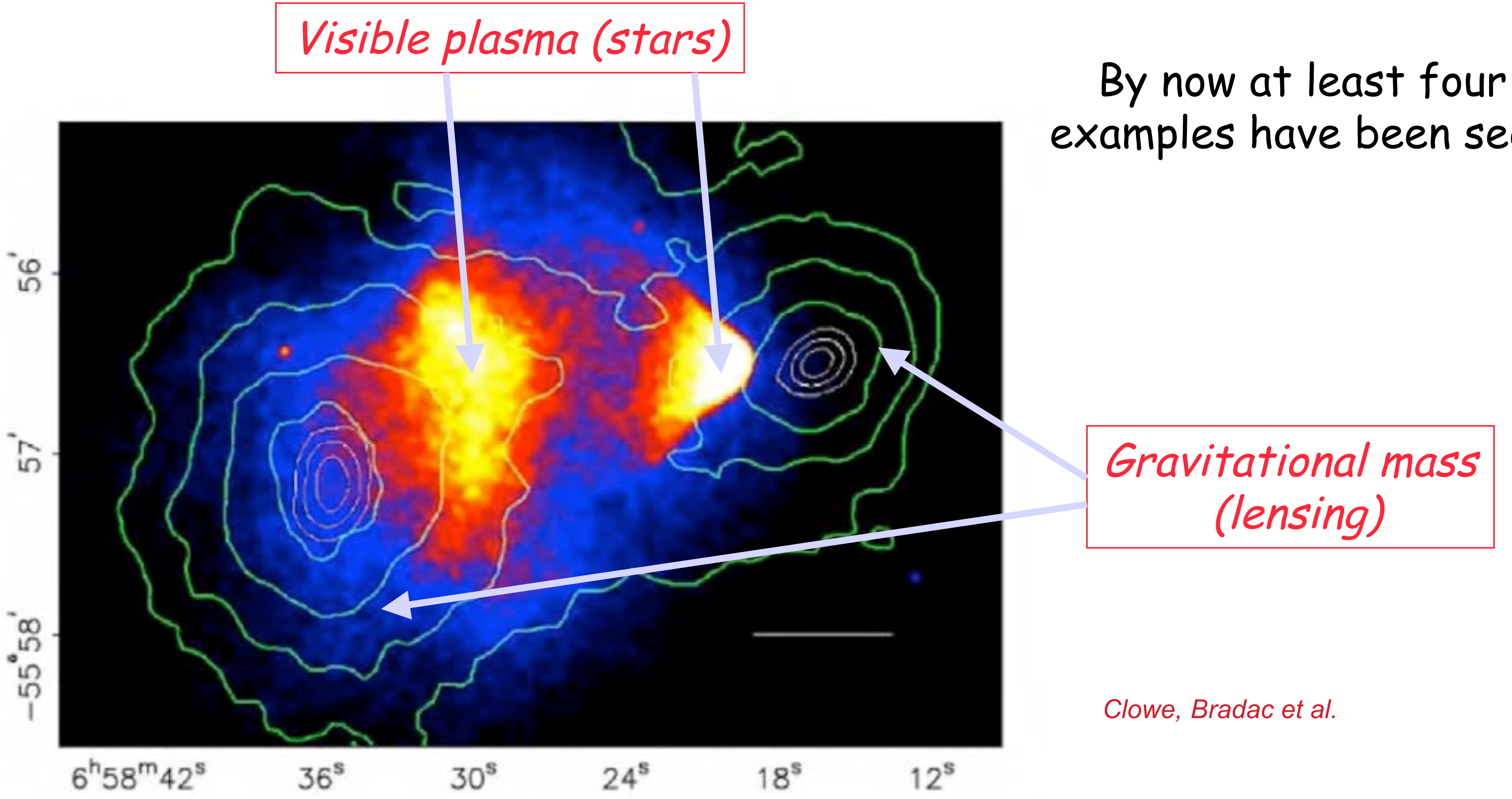
Experimental evidence for Dark matter: Galactic rotation

- A classic example: Doppler measurements in spiral galaxies.
  - Observe: v(r)
  - if v is constant, then: M ≈ r
  - **Needs "dark matter"**

Major disagreement with "naïve" Kepler's laws



Separation of dark and luminous matter in colliding galaxies



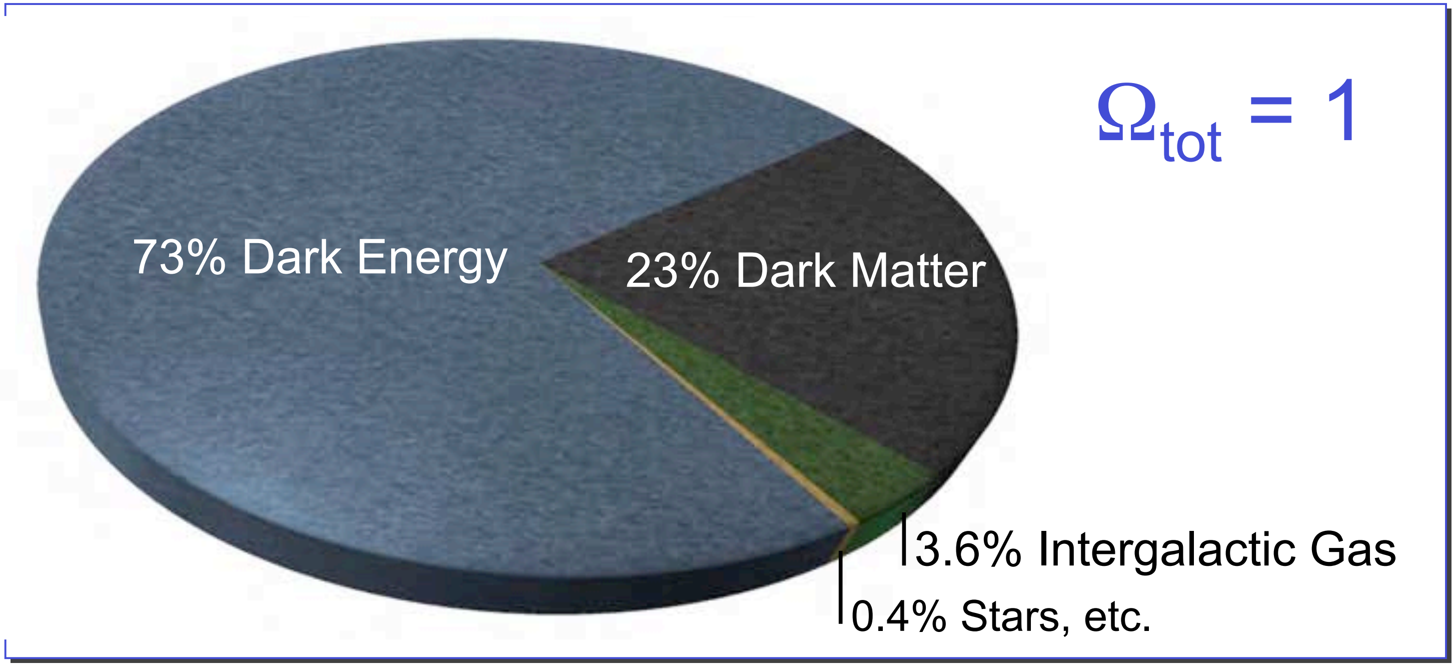
By now at least four examples have been seen

Clowe, Bradac et al.

- The gravitational potential does not trace the plasma distribution, the dominant baryonic mass component; the majority of the matter in the system is unseen.

A first conclusion: unknown non hadronic matter exists

- Only about 4 % of the Universe is made of ordinary, hadronic matter (inanimate and living), of which we are made of and that we perceive.
- The remaining 96% is invisible and so far completely unknown.



This is a major result of immense experimental consequences

A detectable Dark Matter signal in the laboratory ?

- Gravitational evidence has therefore proven that **dark matter** is the dominant form of mass in the Universe, well above ordinary baryonic matter
- Dark matter does not interact with the electromagnetic and strong force, thus making it transparent and hard to detect, despite the fact that dark matter must permeate the galaxy.
- Despite the impressive amount of astrophysical evidence, the exact nature of Dark Matter is still unknown.
- Dark matter must have participated to the evolution of the Universe, presumably in a comparable, but different way than ordinary matter. Indeed dark matter, because of its share of mass has been a main driving force throughout its evolution.
- The experimental search in the laboratory for a such new forms of matter outside of the Standard Model is an extremely exciting programme.

Will LHC find the keys ?

- Central to the Standard Model is the experimental observation of the Higgs boson, for which a very strong predictions for a relatively low mass comes from the remarkable findings of LEP and of SLAC.
- In the case of an *elementary* Higgs, while fermion masses are "protected", the Higgs mass becomes quadratically divergent due to higher order fermion corrections. This would move its physical mass near to the limit of quantum mechanics.
- Therefore in order to "protect" the mass of the Higgs, we need an extremely precise graph cancellation in order to compensate for the divergence of known fermions.
- SUSY is indeed capable of ensuring such a symmetric cancellation, with a SUSY partner yet to be discovered for each and every ordinary particle. *But SUSY masses must be quite near the resulting Higgs mass value*.

The case of superconductivity

- In the old Lindau-Ginzberg theory superconductivity was due to the presence of an hypothetical neutral scalar particle.
- In reality the phenomenon of superconductivity is generated by the presence of the so called Cooper pairs, i.e. a *dynamic* scalar through the formation of electron pairs.
- In the case of the Higgs particle similar alternatives may be conceivable:
  - If *Higgs is elementary*, the super-symmetric cancellation is today the only reasonably known explanation.
  - If *Higgs is the complex resultant* for instance of fermions or other combinations there is no compelling reason for the presence of SUSY and related cancellation.
- There is no obligation for super-symmetry unless Higgs is a genuine elementary particle.

SUSY also as the source of non-baryonic matter ?

- A discovery of a "low mass" *elementary* Higgs may become an important hint to the existence of an extremely rich realm of SUSY physics, *a real blessing for LHC*.
- BUT, the relation between Dark Matter and SUSY is far from being immediate: the fact that such SUSY particles may also eventually account for the non baryonic dark matter is therefore either *a big coincidence or a big hint*.
- However in order to be the origin of dark mass, the lowest lying neutral SUSY particle must be able to survive the 13.7 billion years of the Universe.
- The lifetime of an otherwise fully "permitted" SUSY particle decay is typically $\approx 10^{-18}$ sec ! We need therefore to postulate some strictly conserved quantum number (R-symmetry) capable of an almost absolute conservation, with a forbidness factor well in excess of *$(13.7 \times 10^{+9}$ years$)/(10^{-18}$ sec$) = 4 \times 10^{35}$* !!!

WIMPS without SUSY ?

- Kaluza-Klein DM inUED
- Kaluza-Klein DM in RS
- **Axion**
- Axino
- Gravitino
- Photino
- SM Neutrino
- Sterile Neutrino
- Sneutrino
- Light DM
- Little Higgs DM
- Wimpzillas
- Q-balls
- Mirror Matter
- Champs (charged DM)
- D-matter
- Cryptons
- Self-interacting
- Superweakly interacting
- Braneworls DM
- Heavy neutrino
- **NEUTRALINO**
- Messenger States in GMSB
- Branons
- Chaplygin Gas
- Split SUSY
- Primordial Black Holes

- Despite the impressive amount of astrophysical evidence, the exact nature of Dark Matter is still unknown.
- All present evidence *is now limited to gravitational effects*.
- Other types of interactions may be also connected to DM. A key question is the presence of a *electro-weak coupling to ordinary matter*.
- Massive Neutrinos ? Neutrino/nucleons ≈ $10^9/1$

Neutrinos: a golden field for astro-particle physics

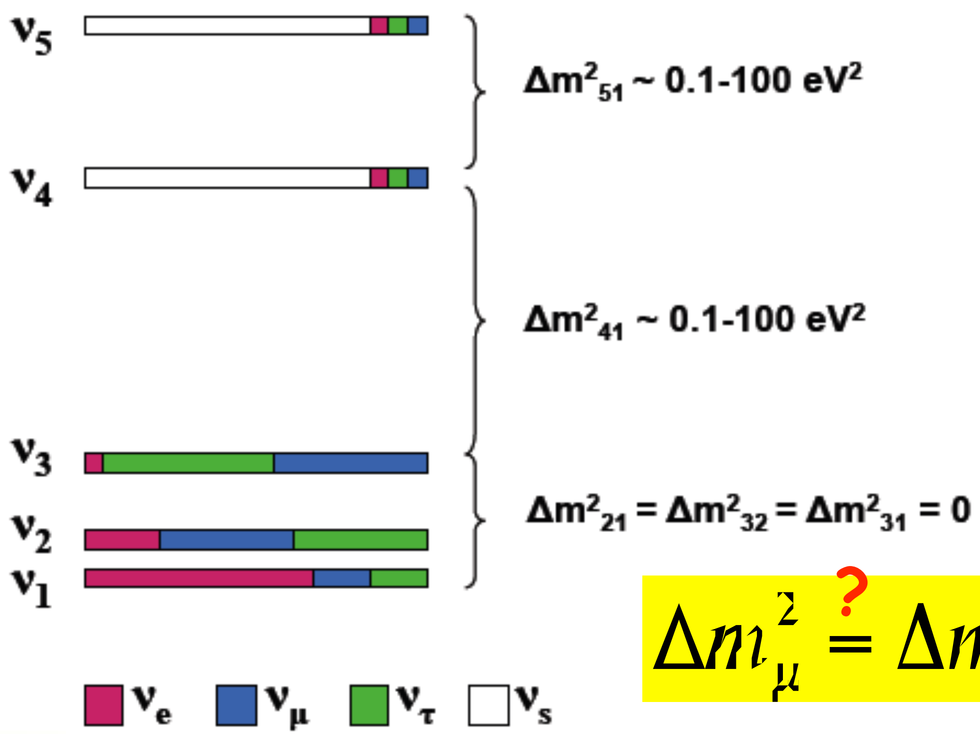
- Over the last several years, neutrinos have been the origin of an impressive number of “Surprises”:
- *Are neutrino a simple “carbon copy” repetition of quarks?*
  - Masses, once zero “by ignorance”, are actually important
  - Oscillations extend and complete the C+KM quark mixing
  - Oscillations due to matter exist, due to neutral currents
- But this is’t all ! Important discoveries may be ahead:
  - CP violation in the lepton sector (CPT ?)
  - Majorana or Dirac ν’s;ν-less β-decay,ν-masses
  - Sterile neutrino and other “surprises”
  - Right handed neutrinos and see-saw mechanisms
- Of course the astronomical importance of neutrinos from space is immense, so is their role in the cosmic evolution.

Neutrinos anomalies ?

- The sum of the strengths of the coupling of different ν is very close to 3. But only assuming that neutrinos in similarity to charged leptons, have unitary strengths that we conclude that the *resulting number of neutrino kinds is 3.*
- The experimentally measured weak coupling strengths are only poorly known, leaving lots of room for alternatives.
- Neutrino oscillations have established a picture consistent with the mixing of three physical neutrino ν_e, ν_μ and ν_e with mass eigenstates ν_1, ν_2 and ν_3.
- In particular the mass differences turn out to be relatively small $\Delta m^2_{31} \approx 2.4 \times 10^{-3}\ eV^2$ and $\Delta m^2_{21} \approx 8 \times 10^{-5}\ eV^2$.
- There are however a number of *"anomalies"* which, if confirmed experimentally, could be due to the presence of an additional, larger squared mass differences in the framework of neutrinos with mixing or of other effects.

Can the anomalies indicate a more complicated picture?

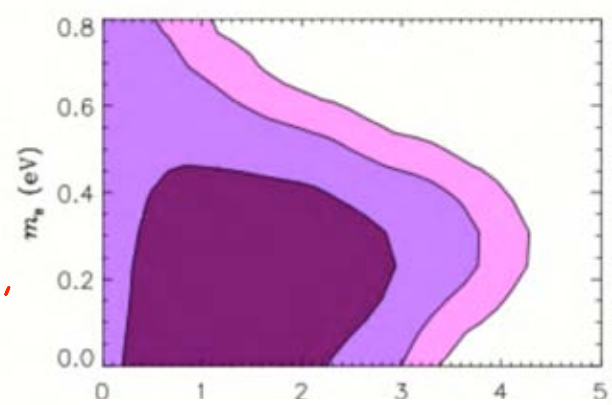
- Sterile neutrino models
- 3+2 next minimal extension to 3+1 models
- 2 independent Δm^2
- 4 mixing parameters
- 1 Dirac CP phase allowing difference between neutrinos and antineutrinos



$$\Delta m^2_{\mu} \stackrel{?}{=} \Delta m^2_{\bar{\mu}}$$

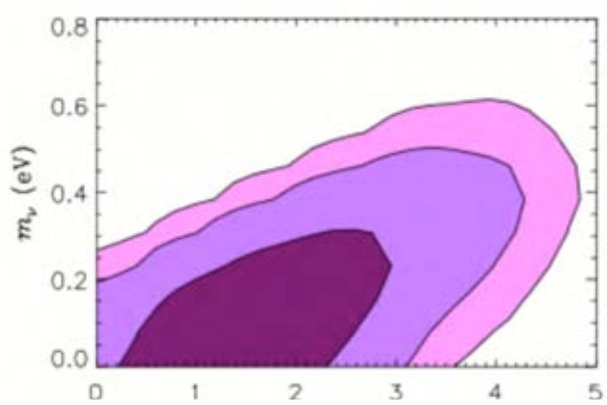
From cosmology

CMB + LSS + ΛCDM
Ns= 1.6 ± 0.9
Hamann, Hannestad, Raffelt, Tamborra, Wong, PRL 105 (2010) 181301



Number of sterile neutrinos

BBN:
Ns= 0.64 ± 0.4
Izotov, Thuan, ApJL 710 (2010) L67



Number of sterile neutrinos

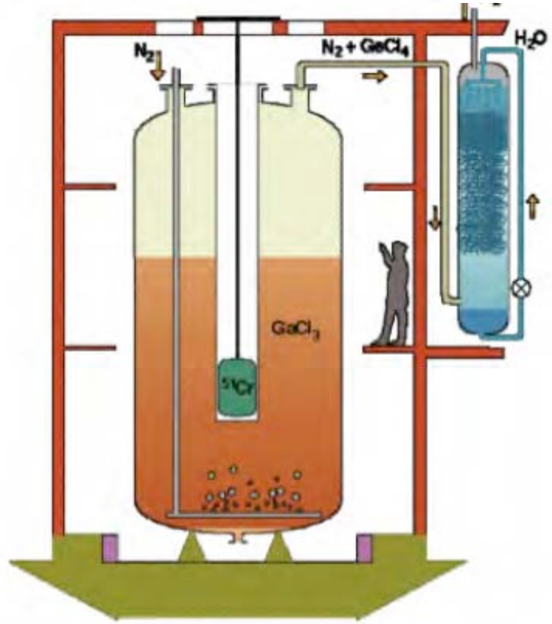
Sterile neutrinos

- The possible presence of oscillations into sterile neutrinos was proposed by B. Pontecorvo, but so far without conclusion.
- Two distinct classes of anomalies have been analyzed, namely
  - the apparent *disappearance signal* in the anti-ν_e events detected from near-by nuclear reactors and from the from Mega-Curie k-capture calibration sources in the Gallium experiments to detect solar ν_e
  - observation for *excess signals* of ν_e electrons from neutrinos from particle accelerators (LNSD/MiniBooNE)
- These experiments may all point out to the possible existence of at least one fourth non standard neutrino state driving oscillations at a small distances, with typically $\Delta m^2_{new} \geq 1\ eV^2$ and relatively large mixing angle with $\sin^2(2\theta_{new}) \approx 0.1$.
- The existence of additional neutrino states may be also hinted — or at least not excluded — by cosmological data

The Gallium anomaly

- 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 ± 0.05), about 2.7σ from R=1

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



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 $\sin^2(2\theta_{new}) \approx 0.3$.

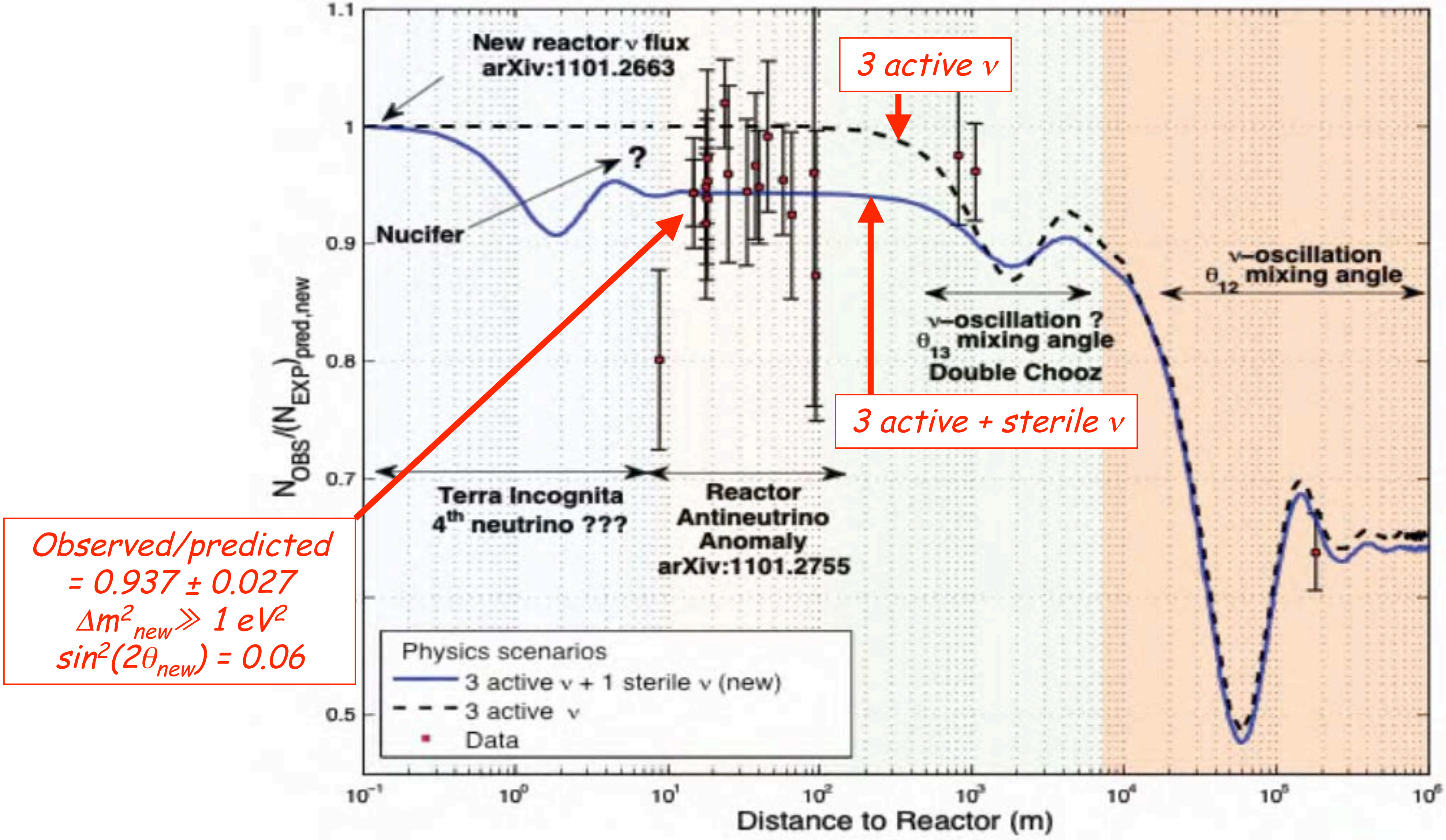
The reactor (anti)-neutrino disappearance anomaly

- Recently a re-evaluation of all the reactor antineutrino spectra has increased the flux by about 3%. With such a new flux evaluation, the ratio R between the observed and predicted rates is decreased to R = 0.937 ± 0.027 , leading to a deviation of 2.3 σ from unity (98.4 % confidence level).
- Reactor experiments all explore distances which are far away from the perspective oscillatory region with $\Delta m^2_{new} \approx 2\ eV^2$, with perhaps the exception of the ILL experiment (at ≈ 9 m) which had unfortunately a very modest statistical impact (68% confidence level). The disappearance rate is given by the well known formula

$$R = 1 - \sin^2(2\theta^2_{new})\sin^2\left(1.27\frac{\Delta m^2_{new}[eV^2]L[m]}{E_{\nu e}[MeV]}\right)$$

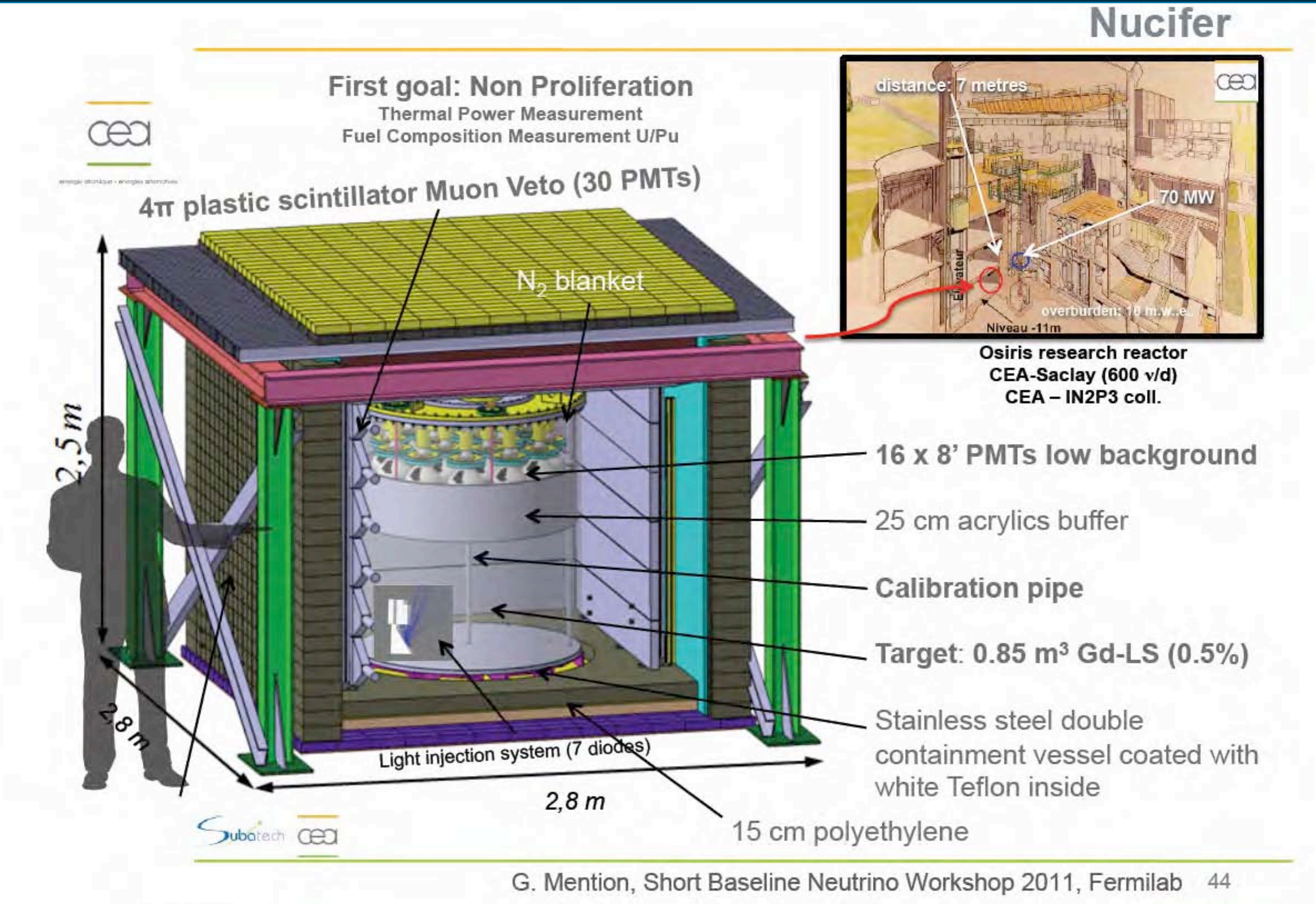
At $\Delta m^2_{new} = 2\ eV^2$ and E = 2 MeV the first predicted minimum of R occurs at 1.23 m

Short baseline reactor antineutrino anomaly

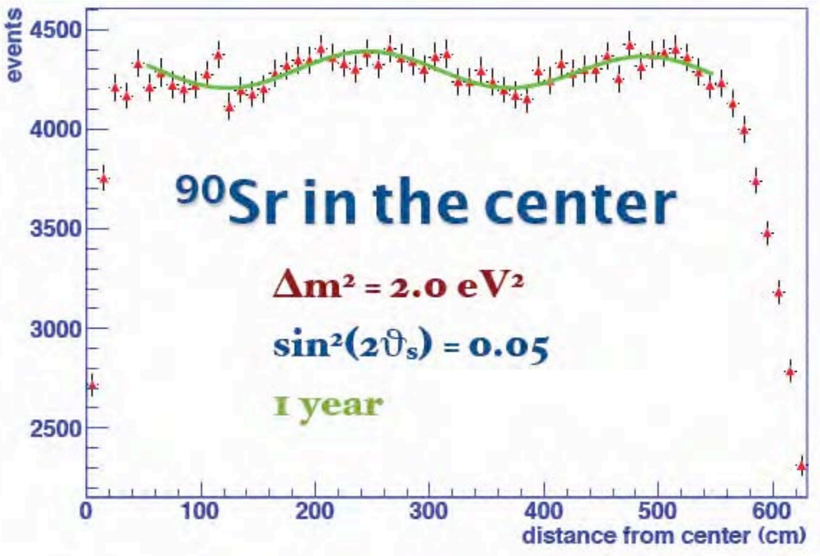


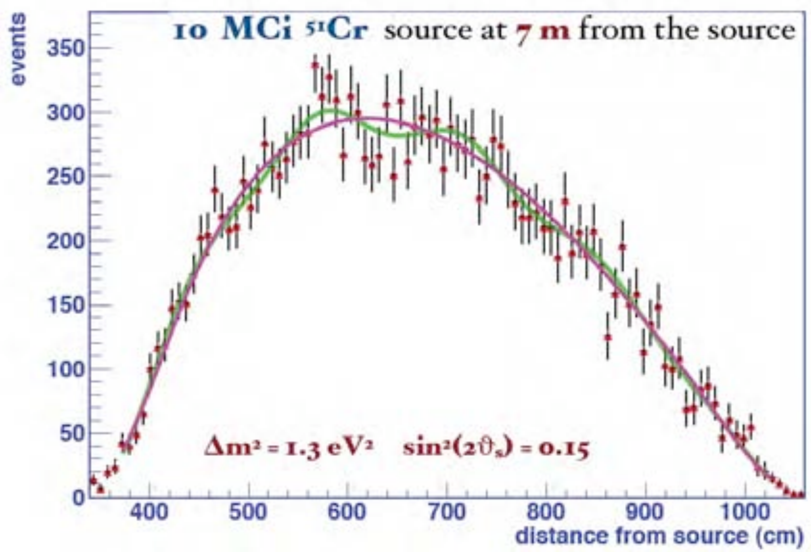
From G. Mention et al. arXiv:1101.2755v1 [hep-ex]

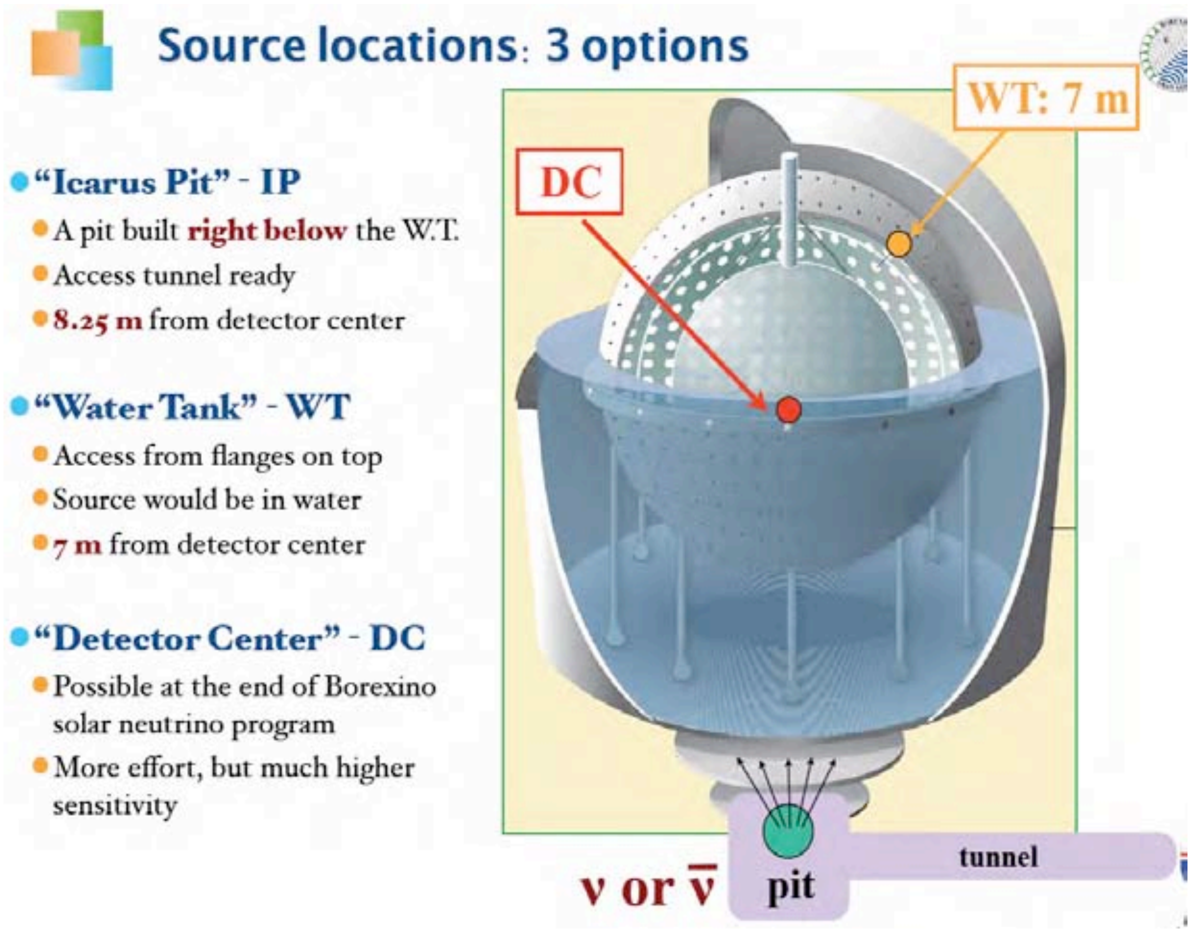
Lucifer Reactor ?



Borexino with 10 Million Curie sources ?







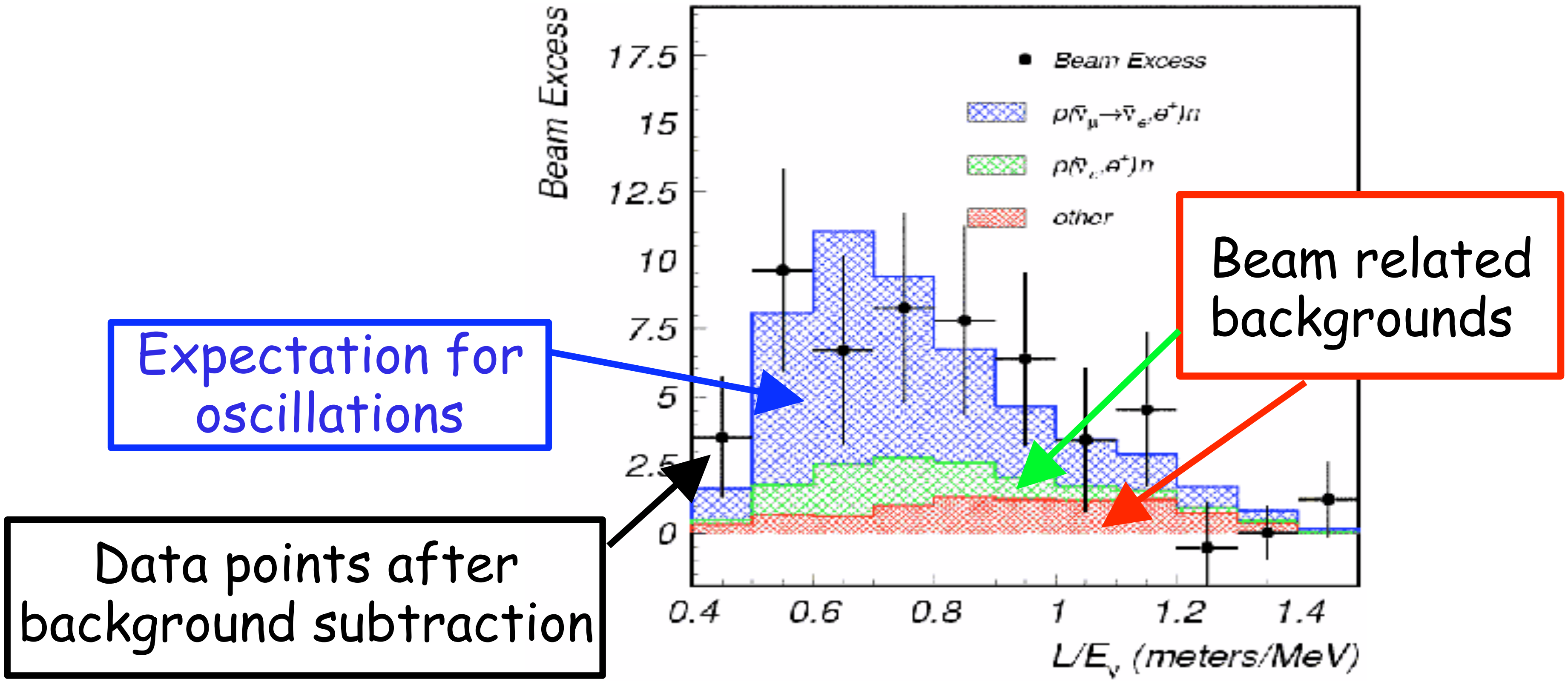
Marco Pallavicini
Borexino Collaboration
FNAL, May 12th-14th, 2011

The LNSD like anomalies ($\nu_\mu \rightarrow \nu_e$)

- As well known, the LNSD signal with anti-neutrino oscillations from an accelerator would imply an additional mass-squared difference largely in excess of the Standard Model's values.
- The LSND signal (87.9 ± 22.4 ± 6.0) represented a 3.8 σ effect at L/E distances of about 0.5 – 1.0 m/MeV.
- The MiniBooNE experiment has used a horn focused neutrino beam from 8 GeV protons of the FNAL Booster, to verify the observation of an anti- ν_e anomaly of the LNSD experiment
- While the LSND like anomaly seems to be absent in the neutrino data, a new "anomaly" appears at much smaller values of the neutrino energy.
- A possible explanation has been described by Giunti & Laveder taking into account that the overall normalization factors of the incoming events is as large as 1.21 ± 0.24.

LSND: Evidence for $(\nu_\mu \rightarrow \nu_e)$

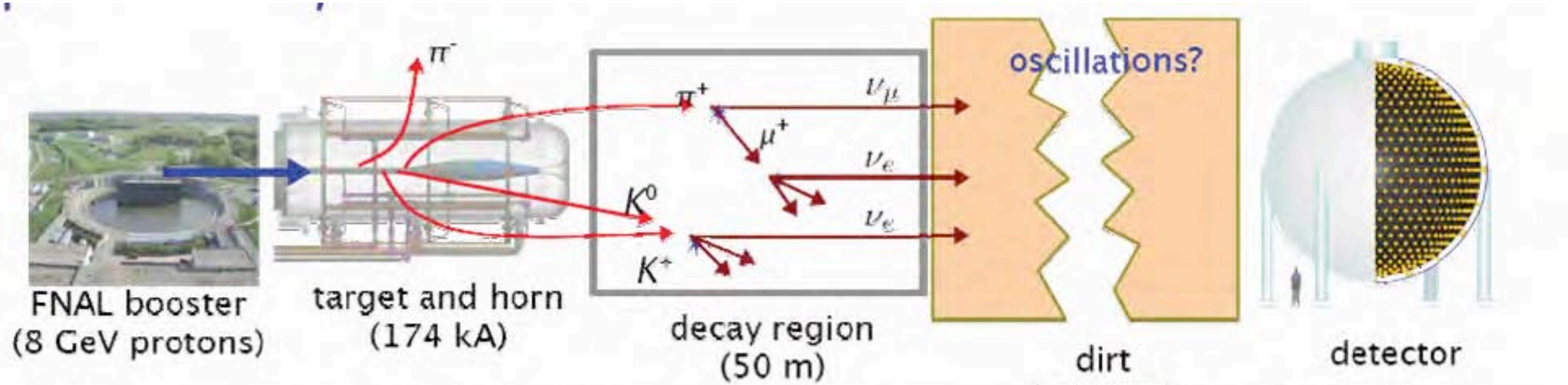
Excess of events: 87.9 ± 22.4 ± 6.0

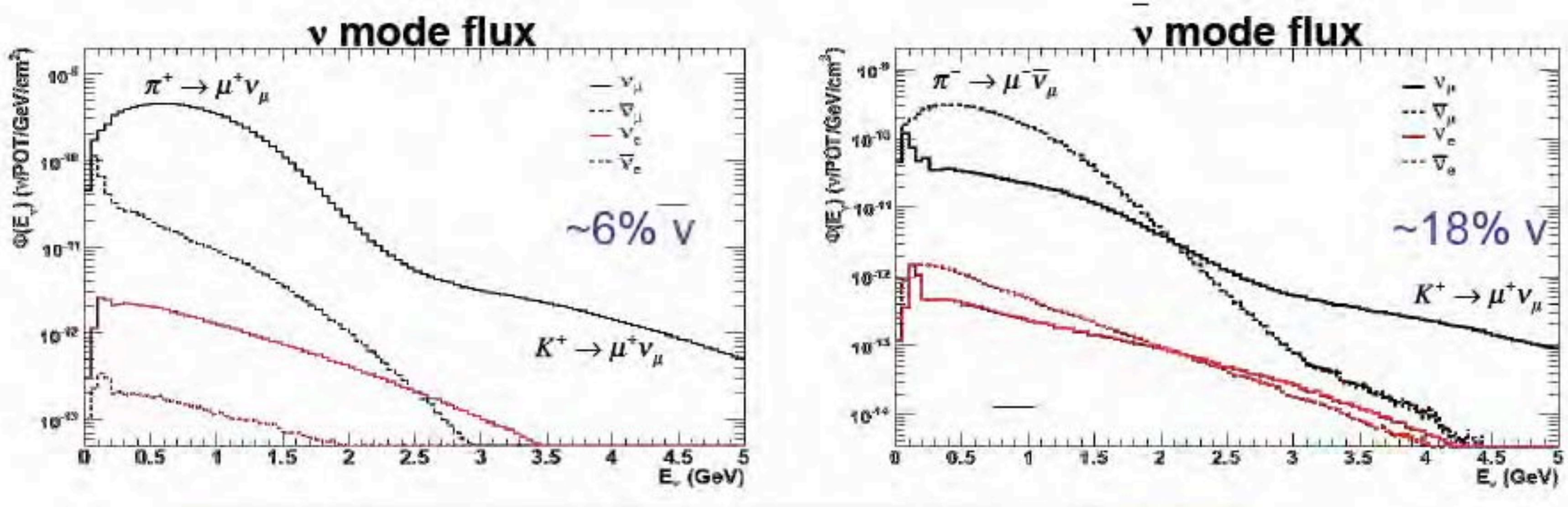


- The experimental evidence is very strong, namely 3.8 s.d.
- The experimental result so far has not been challenged experimentally

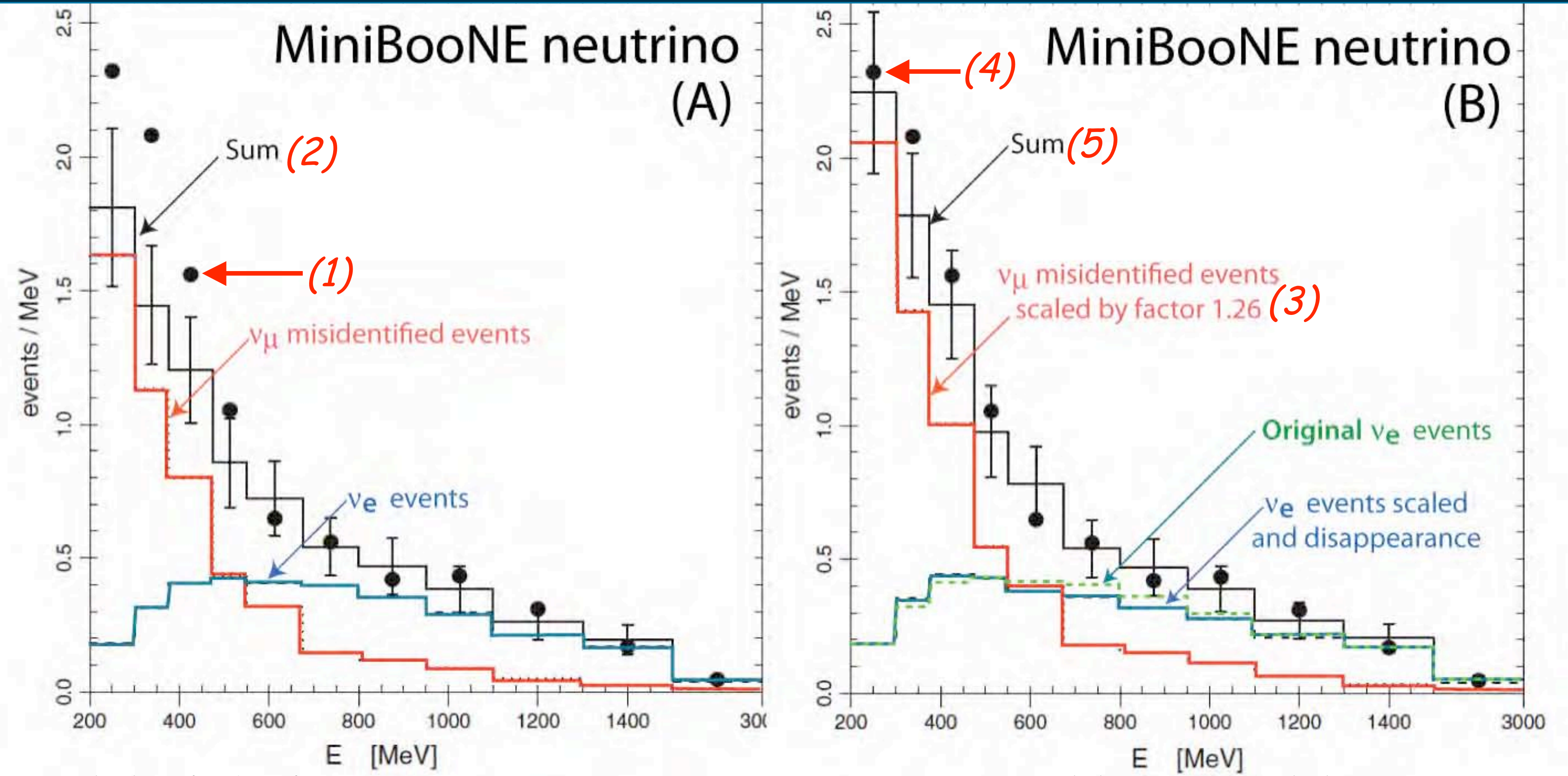
MiniBooNE experiment at FermiLab

- MiniBooNE looks for an excess of electron neutrino events in a predominantly muon neutrino beam



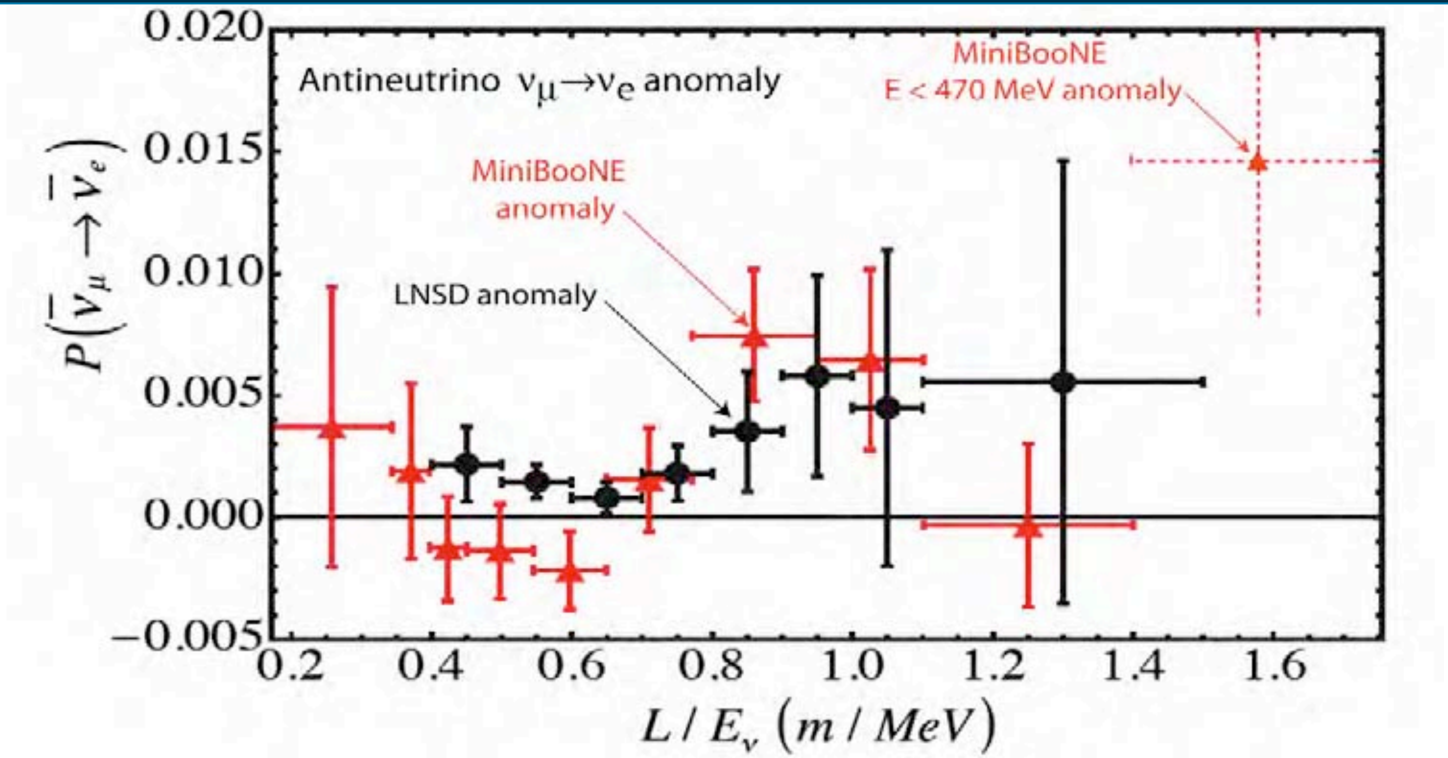


The MiniBooNE neutrino run



- (A) Slight low energy disagreement between data*(1)* and sum*(2)* prediction, incompatible with LNSD data and dominated by misidentified events.
- (B) Scaling of misidentified ν_μ events*(3)* by an allowed factor 1.26 ensures perfect agreement of data*(4)* and predictions*(5)* with no LNSD anomaly.

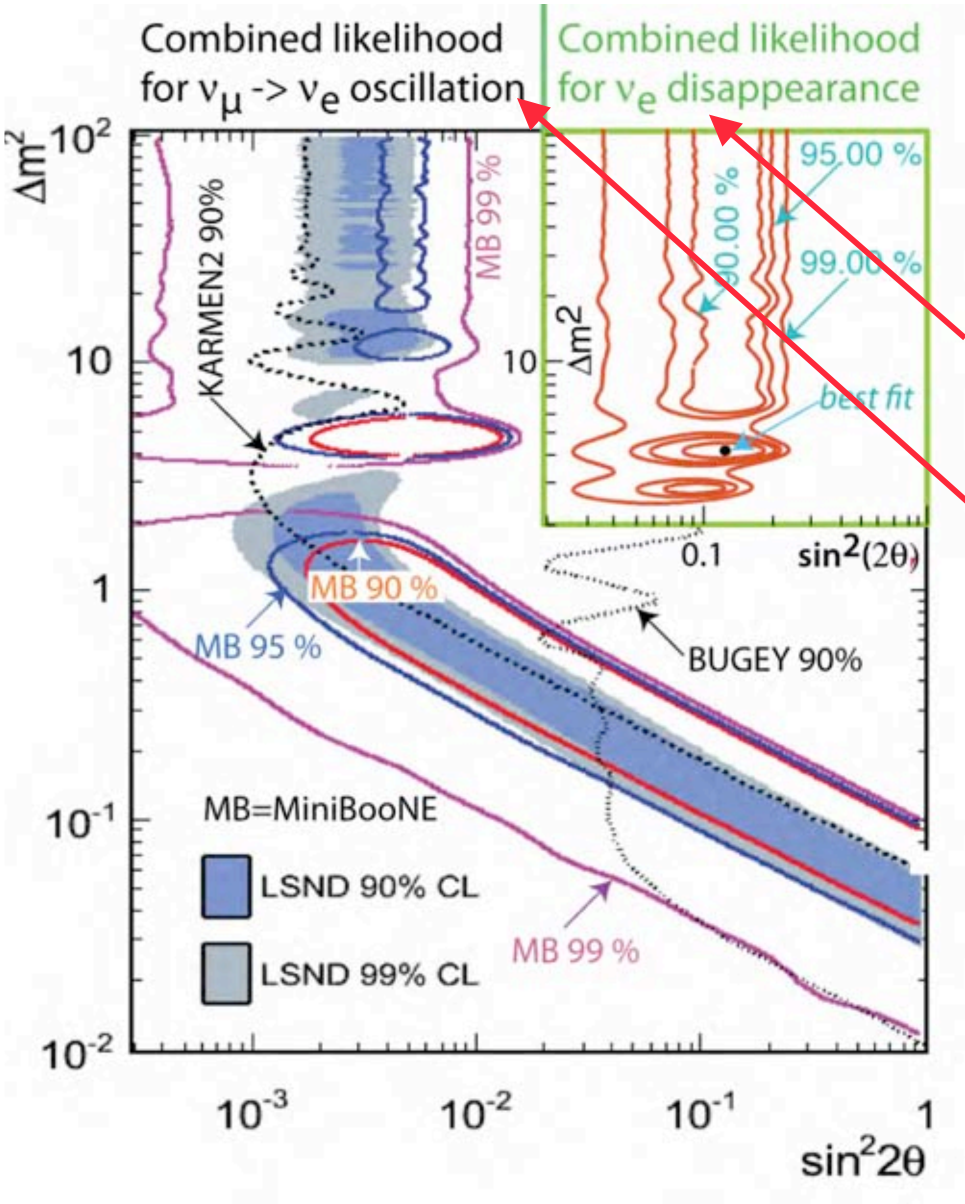
The MiniBooNE anti-neutrino run



F.Mills, ICHEP, July 2010

- The more recent MiniBooNE antineutrino run has shown the direct presence of a LSND like anomaly for neutrino energies > 430 MeV. The result is compelling with respect to the ordinary two-neutrino fit, indicating a 99.4% probability for an anomalous excess in ν_e production.
- The reported effect is broadly compatible with the expectation of LNSD experiment, which, as well known, was originally dominant in the antineutrino channel.

Anomalies: an unified approach ?



Allowed regions in the plane for combined results:

the νe disappearance rate (right) (reactors and Gallium sources)

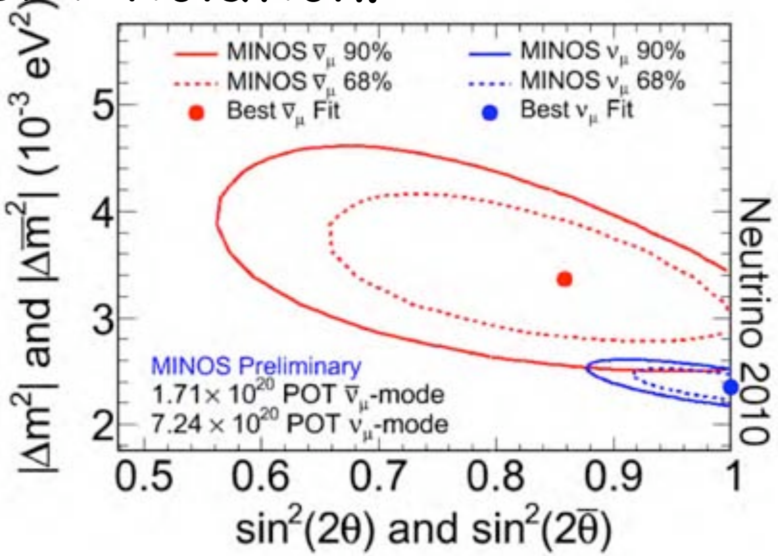
the LSND /MiniBooNE anti-νe accelerator driven anomaly (left).

While the values of Δm^2_{new} may indeed have a common origin, the different values of $\sin^2(2\theta_{new})$ may reflect within the four neutrino hypothesis the structure of $U_{(4,k)}$ mass matrix, with k = μ and e.

CPT violations ?

- While reactions and cross sections are different between ν and anti-ν, CPT invariance ensures identity of oscillations.
- The "tension" between the neutrino and antineutrino MiniBooNE + LNSD data seems to indicate a difference of the effective mixing angles in the neutrino and antineutrino channels.
- Such a difference, if confirmed could be due to some unknown mechanism, or perhaps even to CPT violation.

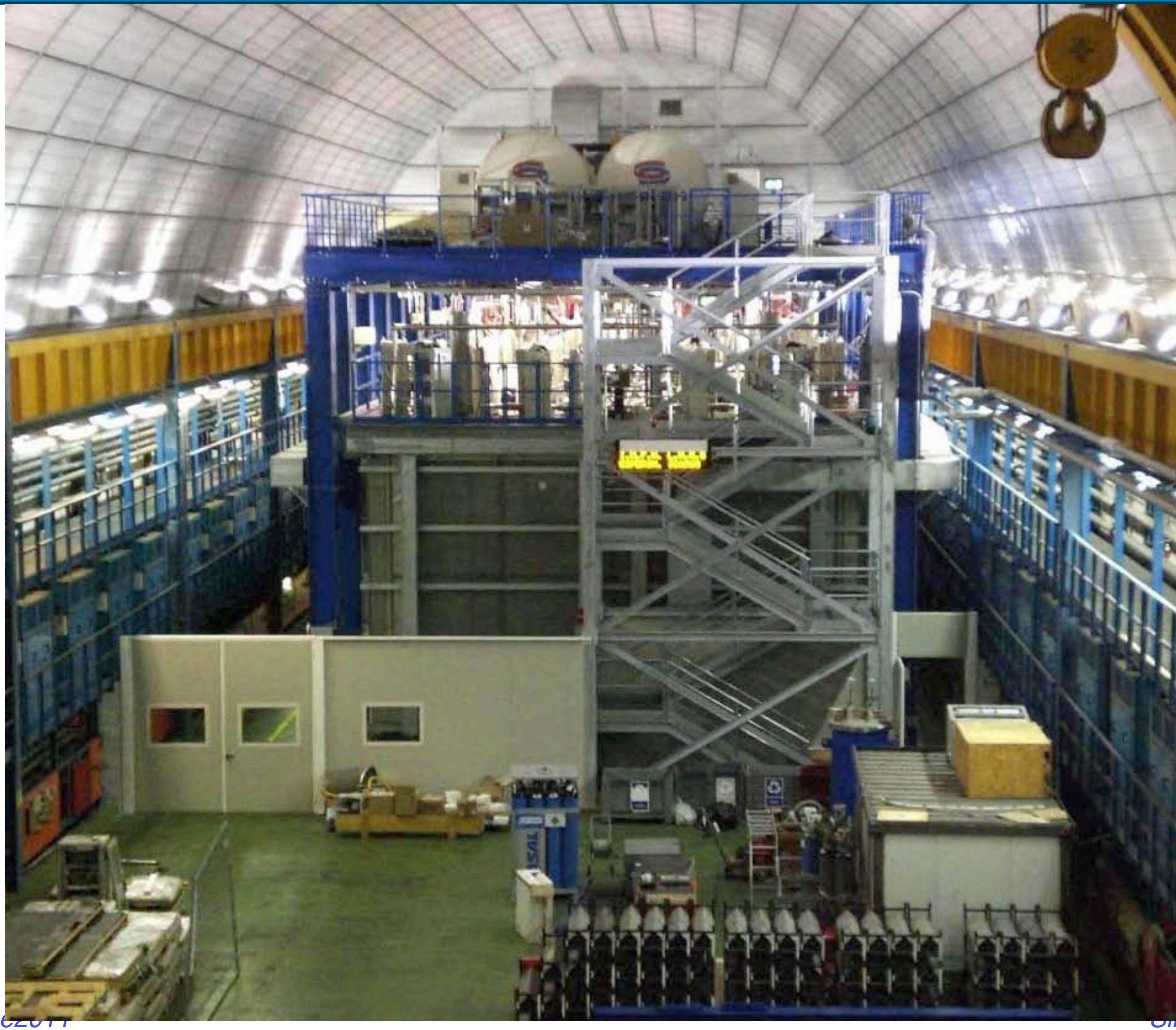
MINOS experiment has recently pointed out a possible difference (2 σ) between the effective mixing ν and anti-ν in the long-baseline channels.



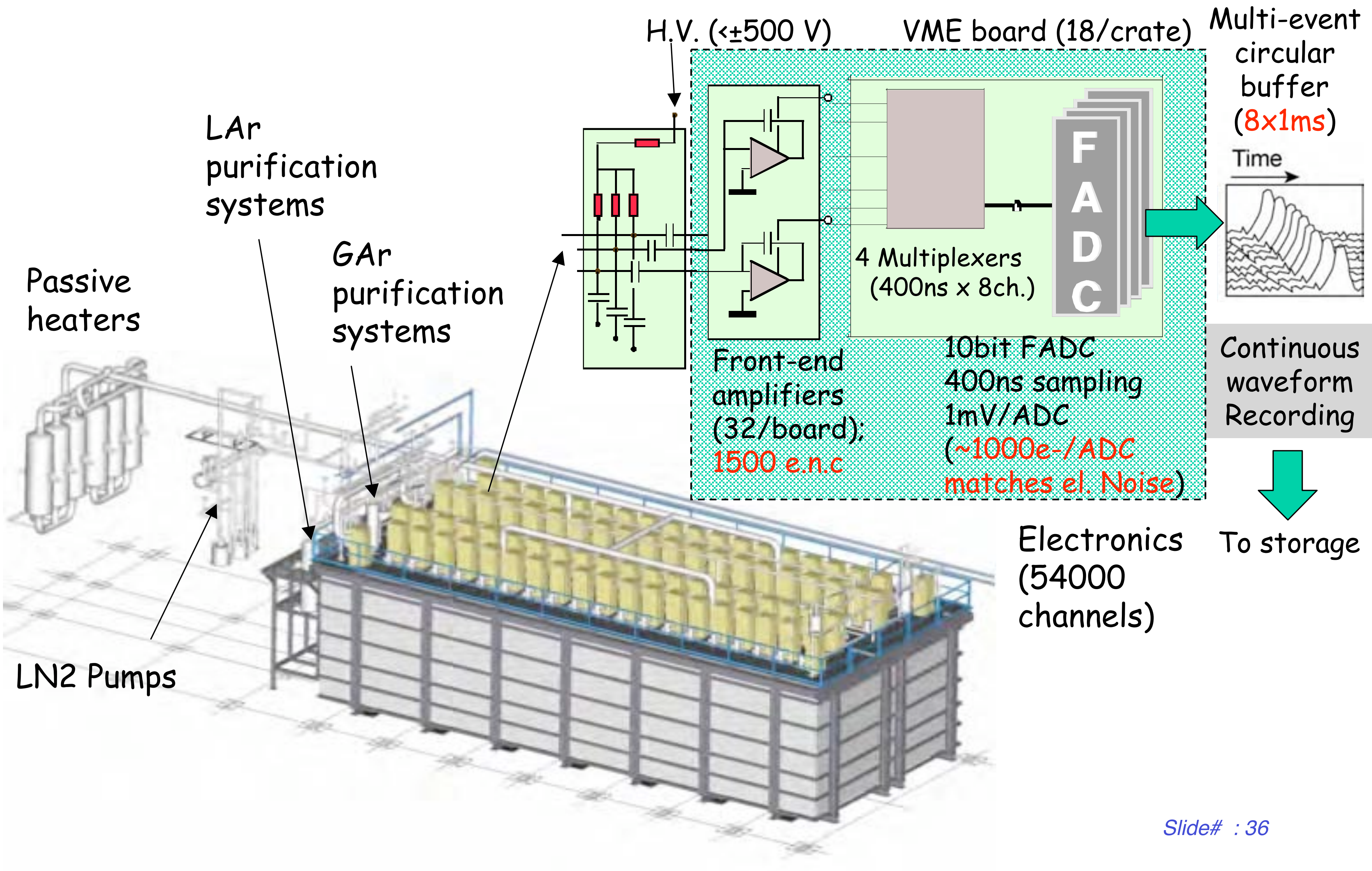
Fates of secular conservation laws !

Parity	Fallen 1956
Charge Conjugation	Fallen 1956
CP	Fallen 1964
T	Fallen 1999
Lepton Number	Still viable ($0\nu\beta\beta$?)
Baryon Number	Still viable
CPT	Still viable

The ICARUS detector in underground Hall B of LNGS



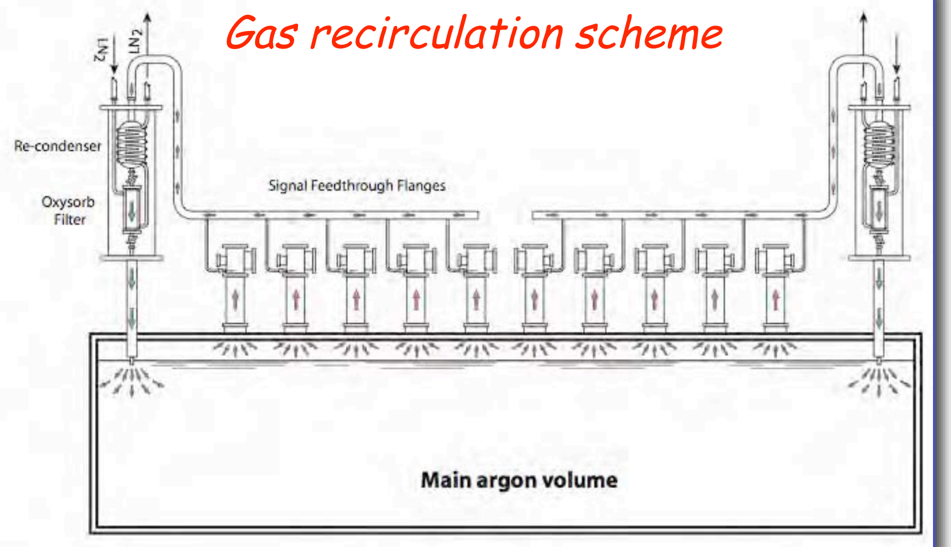
ICARUS Cryogenics and Electronics



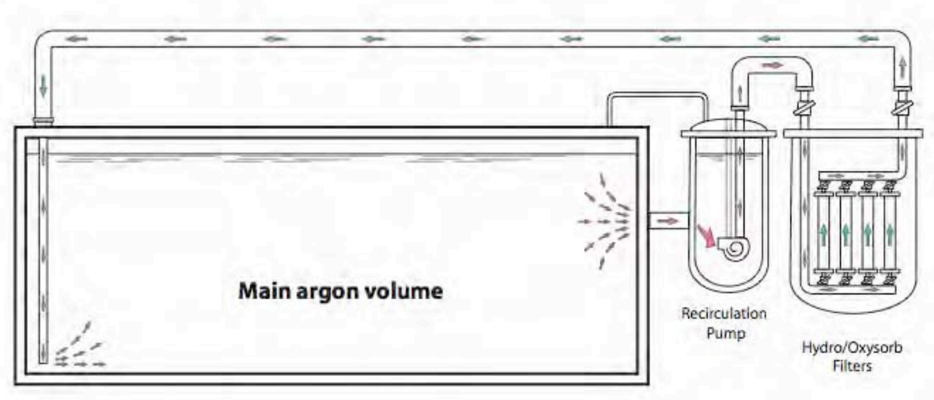
LAr Purification in T600

- The presence of electron trapping polar impurities attenuates the electron signal as $\exp(-t_D/\tau_{ele})$
- τ_{ele} ~ 300 μs / ppb (O_2 equivalent).
- Because of temperature (87 K) most of the contaminants freeze out spontaneously. Main residuals: O_2, H_2O, CO_2.
- Recirculation/purification (100 Nm^3/h) of the gas phase (~40 Nm^3) to block the diffusion of the impurities from the hot parts of the detector and from micro-leaks on the openings (typically located on the top of the device) into the bulk liquid.
- Recirculation/purification (4 m^3/h) of the bulk liquid volume (~550 m^3) to efficiently reduce the initial impurities concentration (can be switched on/off).

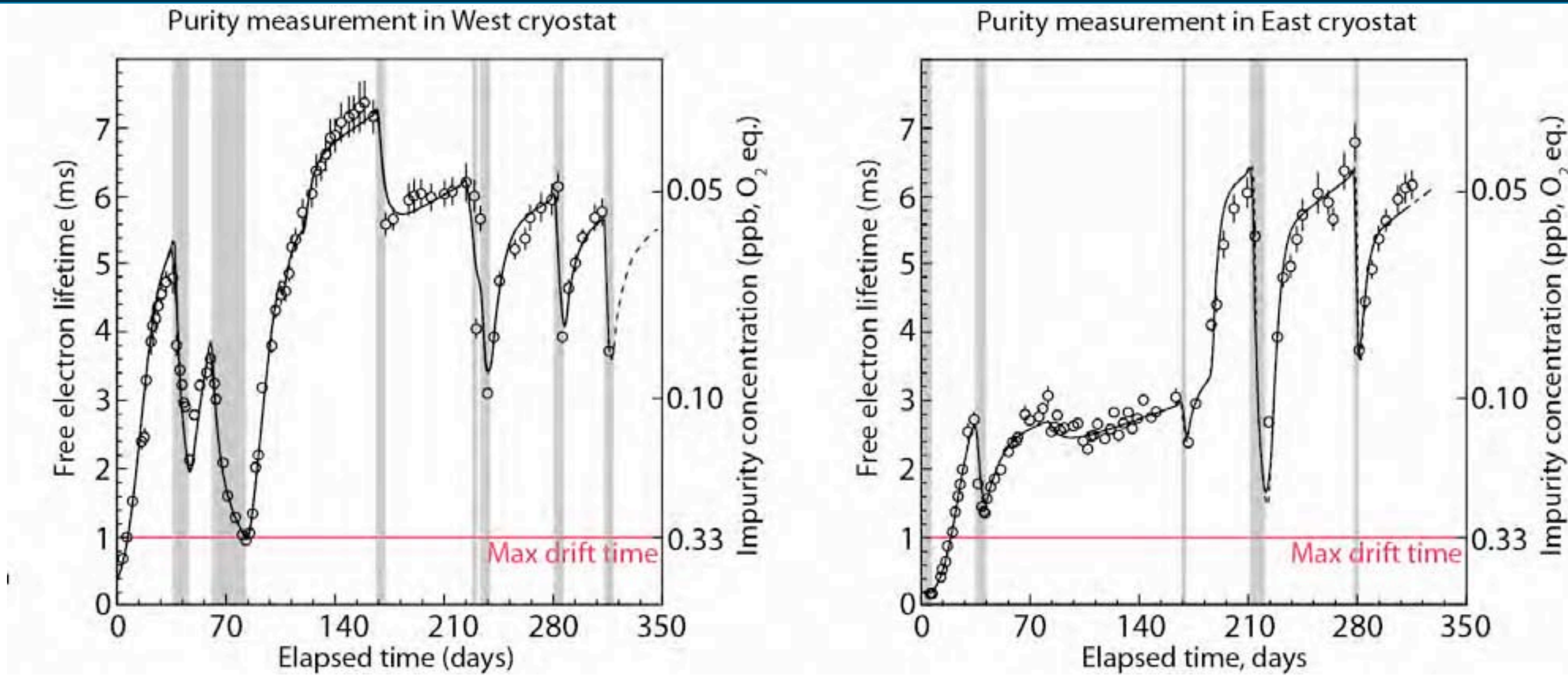
Gas recirculation scheme



Liquid recirculation scheme



LAr purity time evolution



Simple model: uniform distribution of the impurities, including internal degassing, decreasing in time, constant external leak and liquid purification by recirculation.

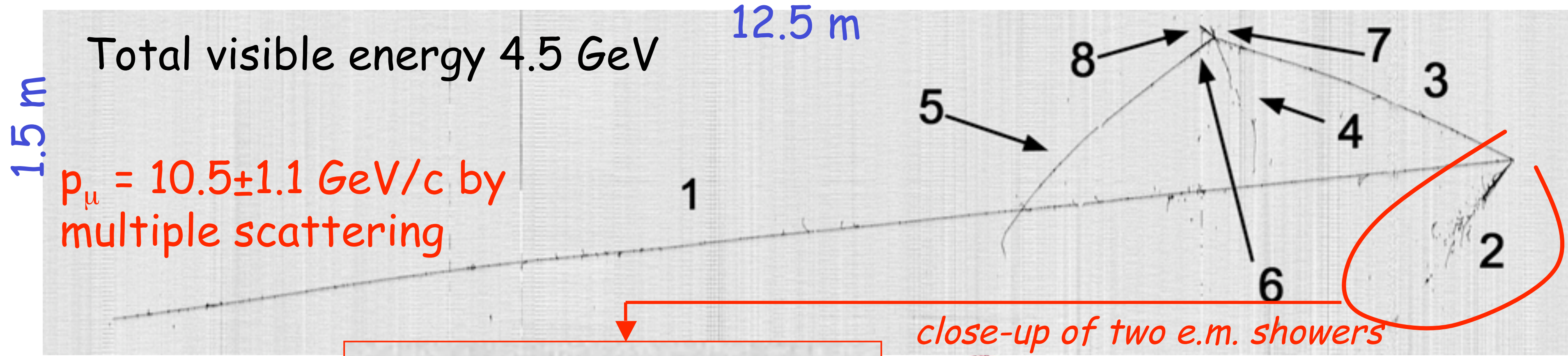
τele [ms] = 0.3 / N[ppb O2 equivalent]

$$dN/dt = -N/\tau_R + k + k_I \exp(-t/\tau_I)$$

τR: recirculation time for a full detector volume
kI and τI : related to the total degassing internal rate
k : related to the external leaks

τR: 2 m³/h corresponding to ≈ 6 day cycle time

LAr-TPC: powerful technique. Run 9927 Event 572

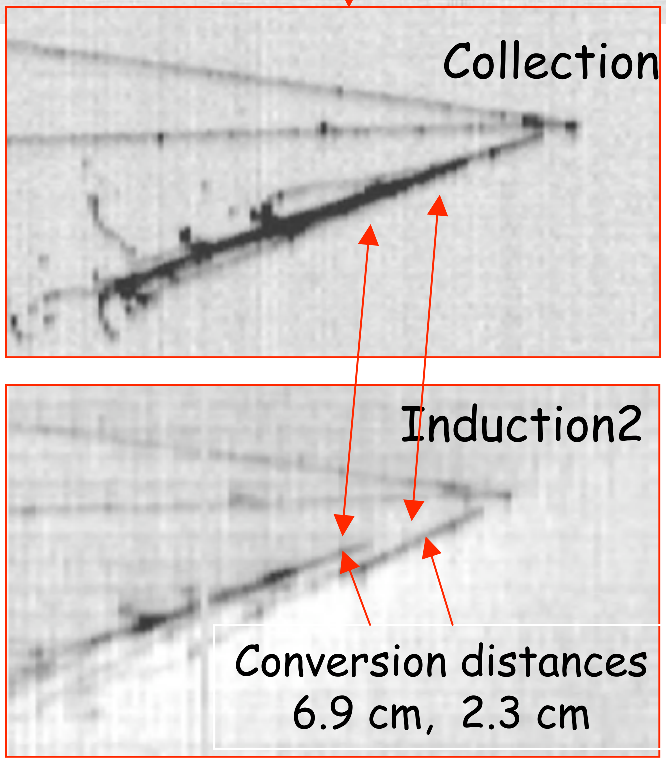


Primary vertex (A)

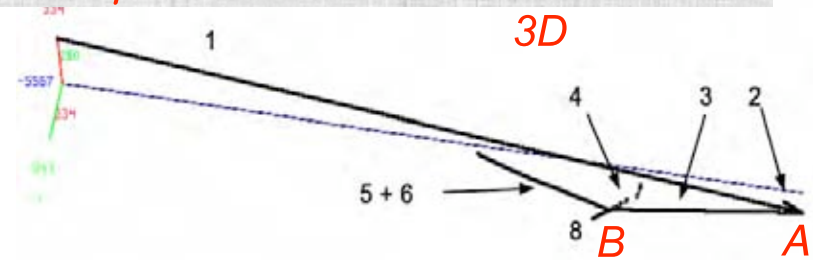
very long μ (1), e.m. cascade(2), pion (3).

Secondary vertex (B)

The longest track (5) is a μ coming from stopping k (6).
- μ decay is observed.

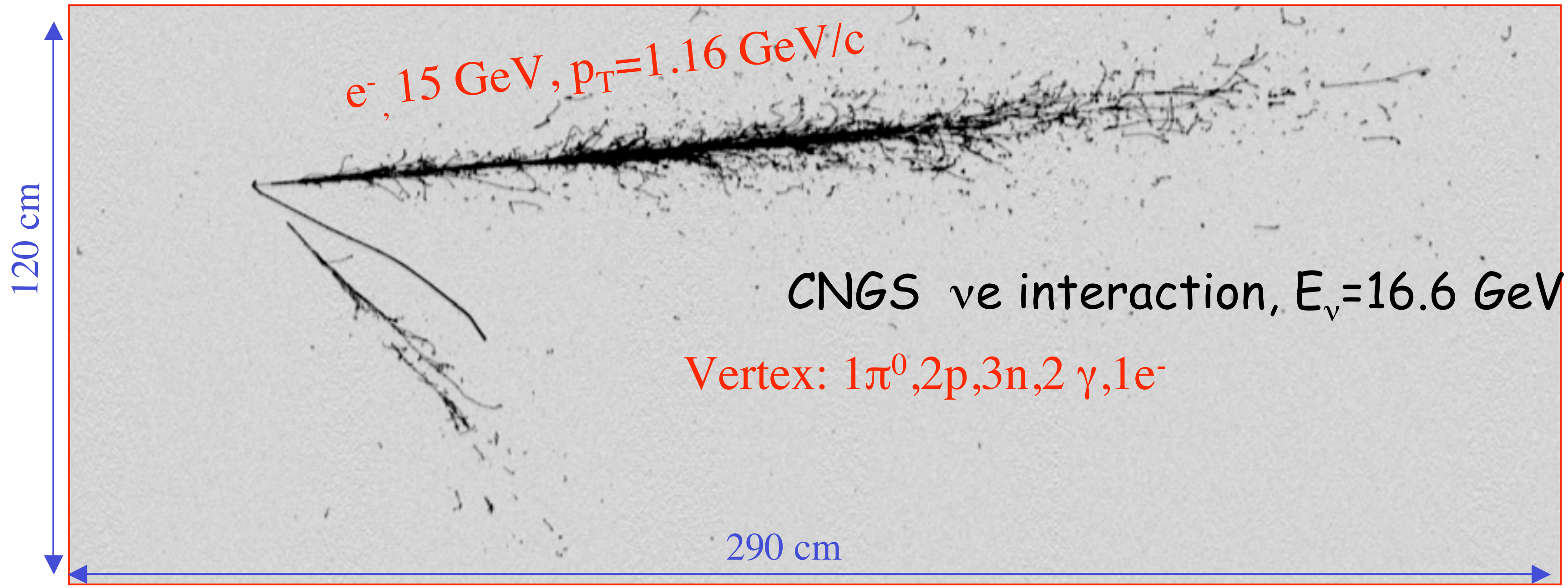


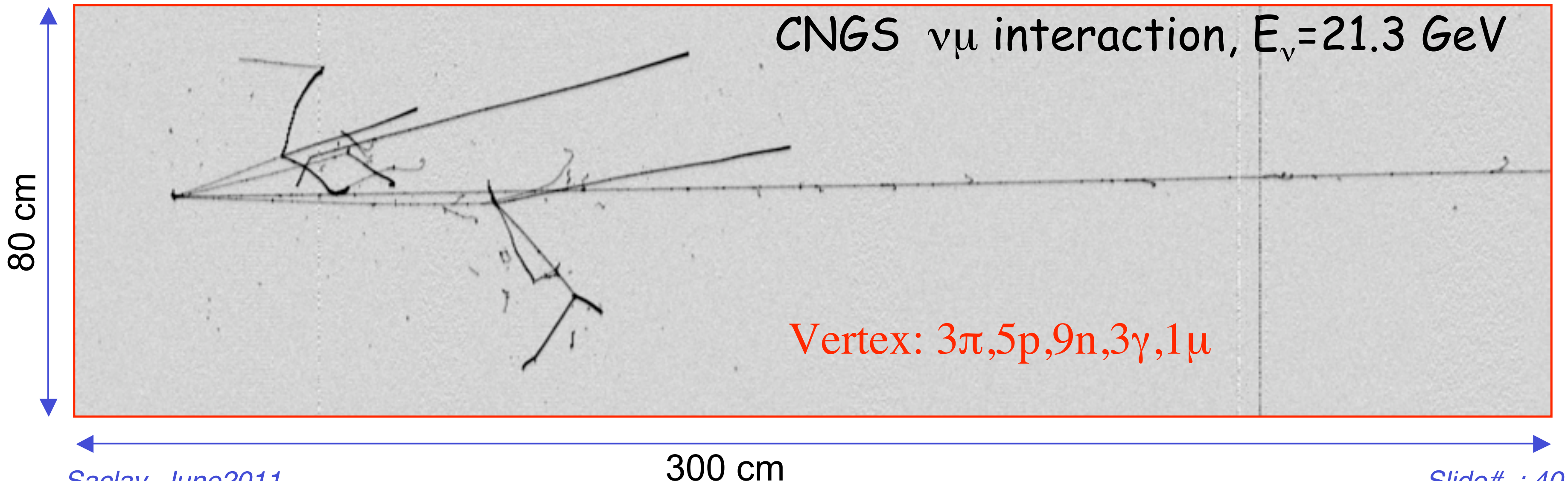
$M^*_{\gamma\gamma}$ = 125±15 MeV/c²



Track	E_{dep}[MeV]	cosx	cosy	cosz
1 (μ)	2701.97	0.069	-0.040	-0.997
2 (π^0)	520.82	0.054	-0.420	-0.906
3 (π)	514.04	-0.001	0.137	-0.991
Sec.vtx	797.			
.	76.99	0.009	-0.649	0.761
4	313.9			
5 (μ)	86.98	0.000	-0.239	-0.971
6 (K)	35.87	0.414	0.793	-0.446
7	283.28	-0.613	0.150	-0.776
8				

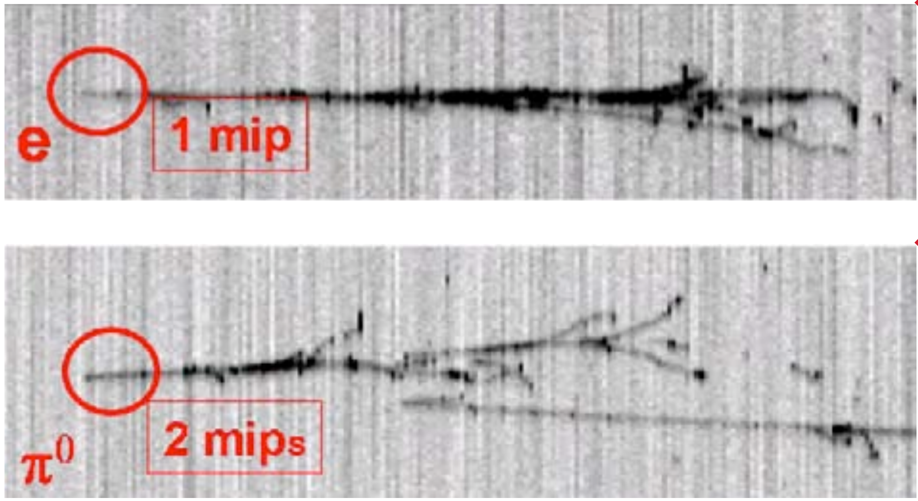
Reconstructed CC events in T600

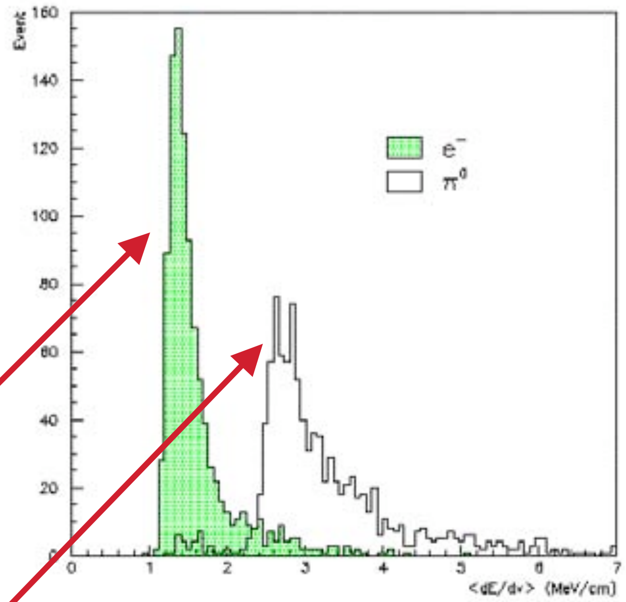


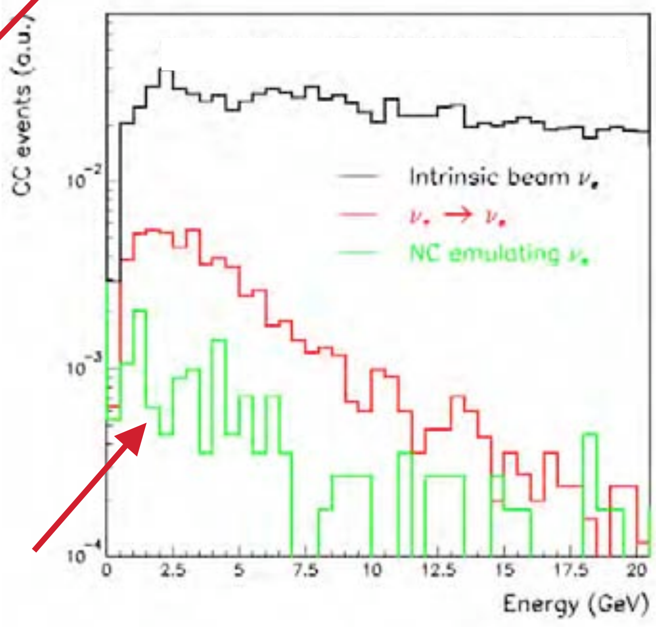


Electron – π^0 separation

- NC in LAr suppressed by:
  - topology (γ conversion from vertex)
  - reconstruction of π^0 mass
  - electron/photon separation (dE/dx)
- Electron identification eff. = 90 %
- Residual misidentification < 0.1%

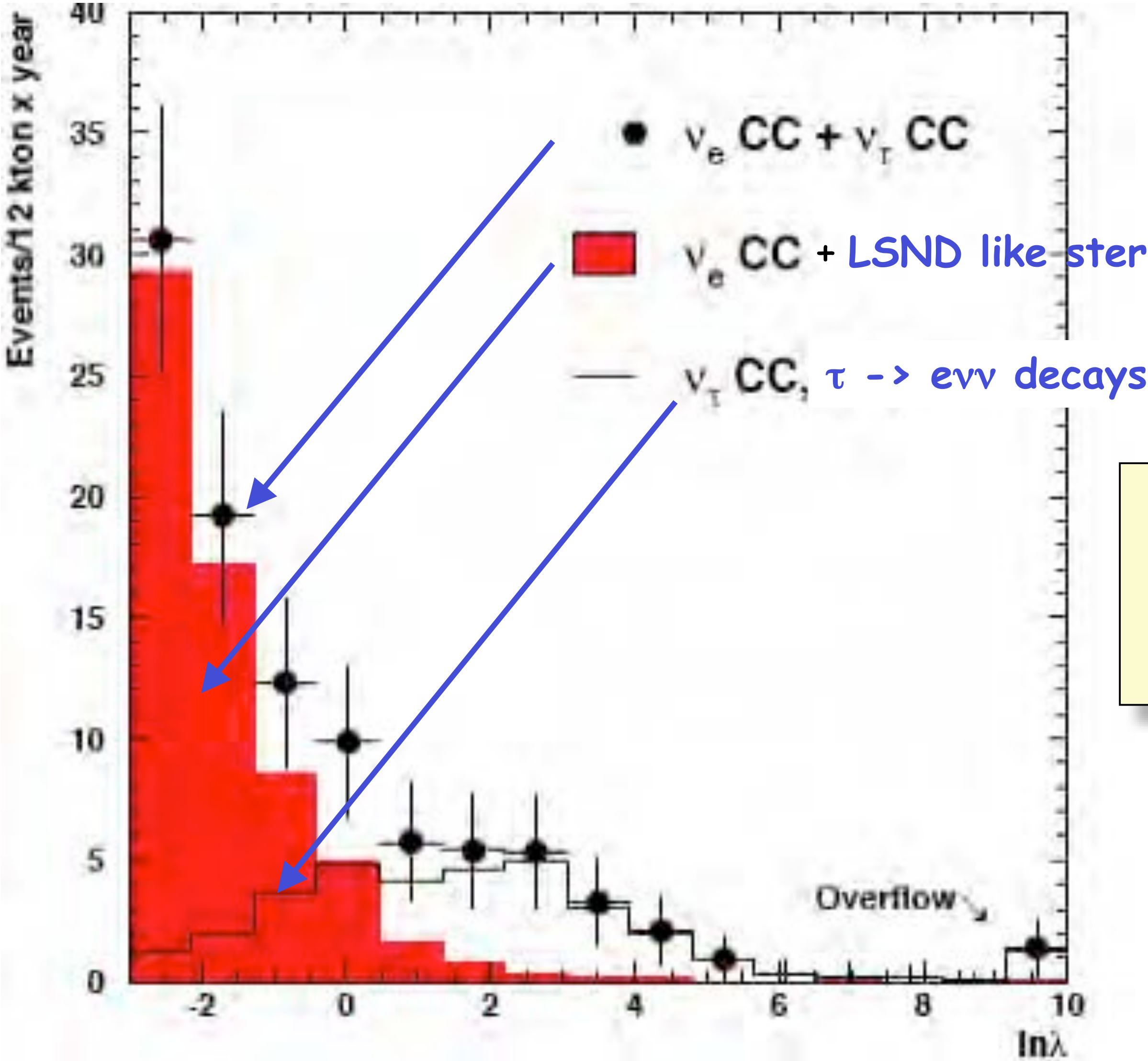






NC-e background

ν–e balanced events and ν–tau decays

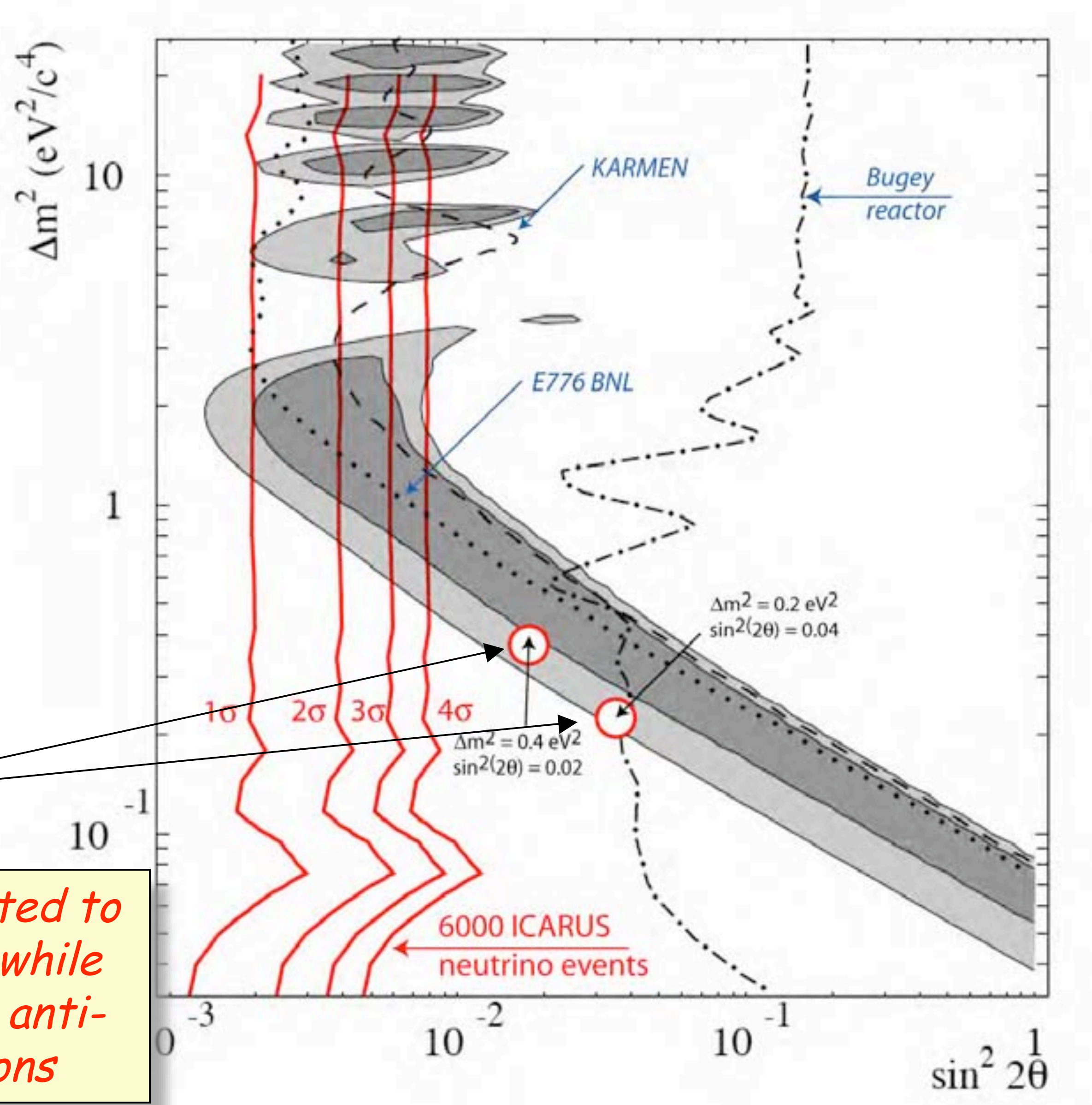


Likelihood weight

Likelihood distributions may separate an hypothetical LSND excess from the expected presence of $\tau \to \varepsilon\nu\nu$ decays

LNSD ν_e search at T600 with events from CERN to LNGS

- Sensitivity region, in terms of Standard Deviations σ, for 6000 raw CNGS neutrino events. The potential signal is above the background generated by the intrinsic νe beam contamination, in the deep inelastic interval 10-30 GeV.
- The Δm^2 distribution extends widely beyond the LNSD and MiniBoone regions.
- Two indicated points are reference values of MiniBoone proposal



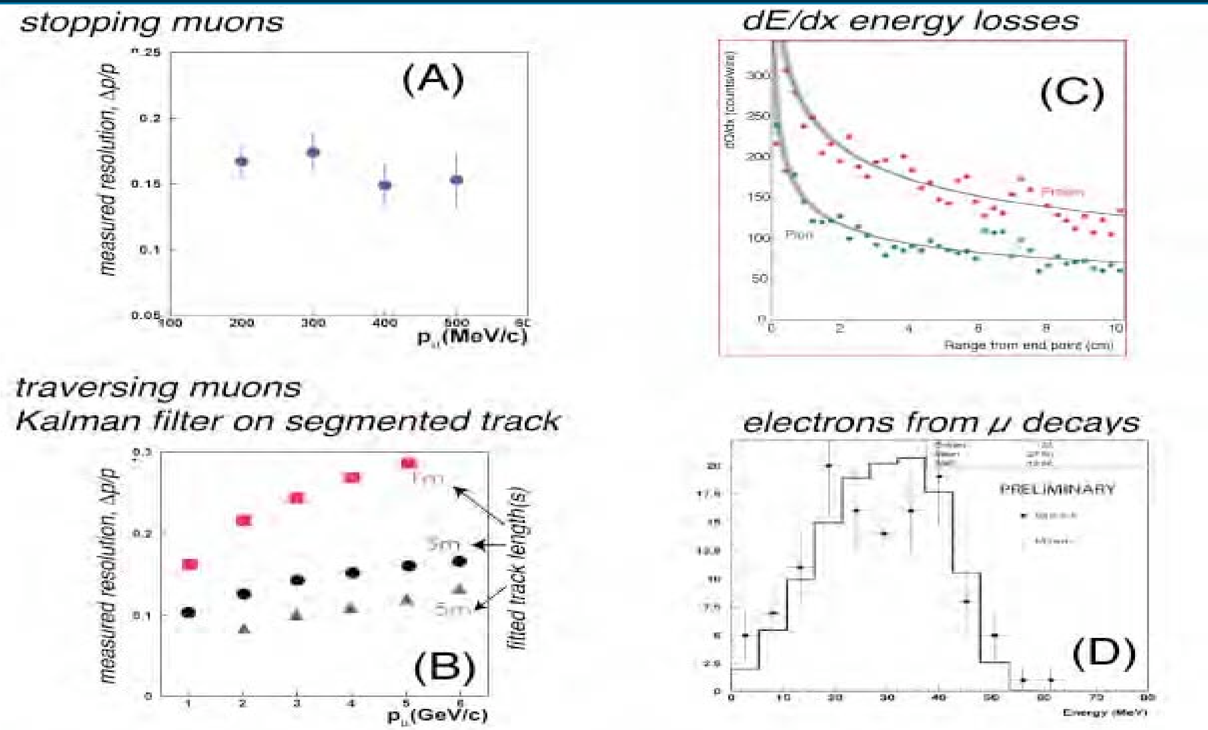
T600 at the CNGS is most likely limited to neutrino (compatibility with Opera) while the present interest is now towards anti-neutrino and apparent CPT violations

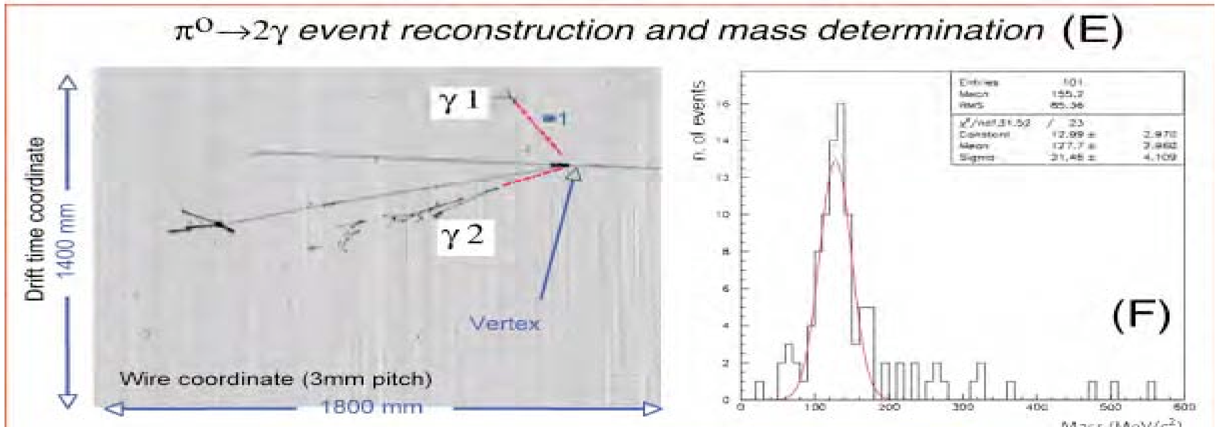
A direct, new approach to sterile oscillations at CERN/PS

- The direct, unambiguous measurement of an oscillation pattern requires necessarily the (simultaneous) observation at several different distances. It is only in this way that the values of Δm^2 and of $sin^2(2\theta)$ can be separately identified.
- The CERN-PS experiment introduces important new features, *which should allow a definitive clarification of all the above described "anomalies"*:
  - L/E oscillation paths lengths to ensure appropriate matching to the Δm^2 window for the expected anomalies.
  - "Imaging" detector capable to identify unambiguously <u>all</u> reaction channels with a *"Gargamelle class" LAr-TPC*
  - Interchangeable ν and anti-ν focussed beams
  - Very high rates due to large masses, in order to record relevant effects at the % level (>10^6 νμ, ≈10^4 νe)
  - Both initial νe and νμ components cleanly identified.

LAr-TPC performance at low (few GeV) energies

- (A) momentum resolution of stopping muons;
- (B) momentum resolution of traversing muons with the Kalman filter method;
- (C) dE/dx energy loss for slow pions (green) and protons (red);
- (D) Michel electron decay spectrum from $\mu \rightarrow e$ decays;
- (E) $\pi^0 \rightarrow 2\gamma$ reconstruction and mass determination;
- (F) mass spectrum of 230 interactions with $\gamma\gamma$ candidates.

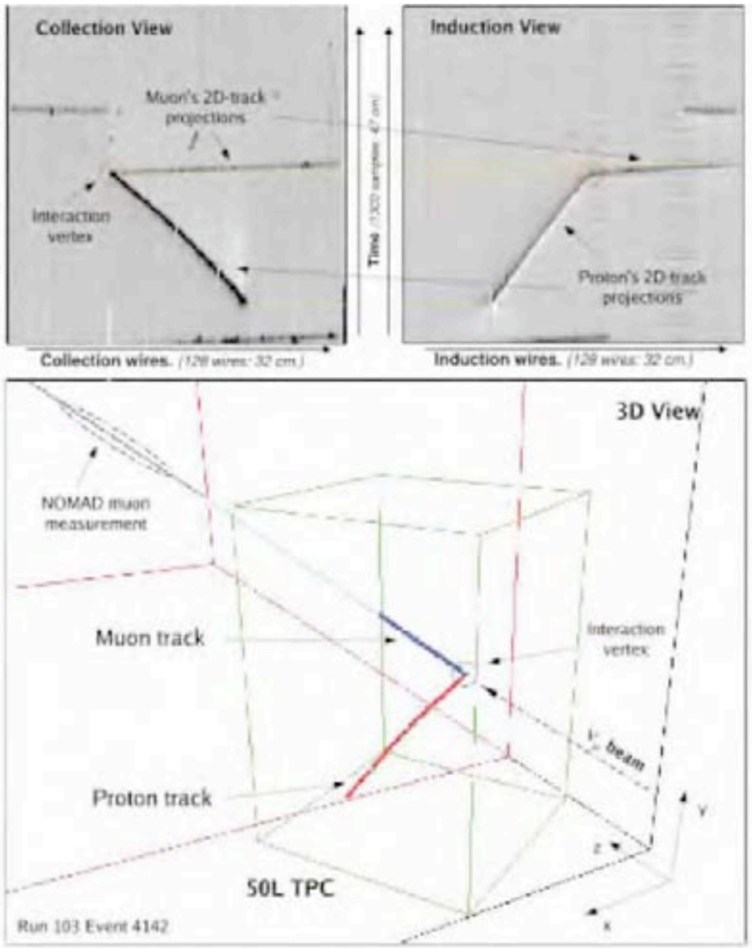




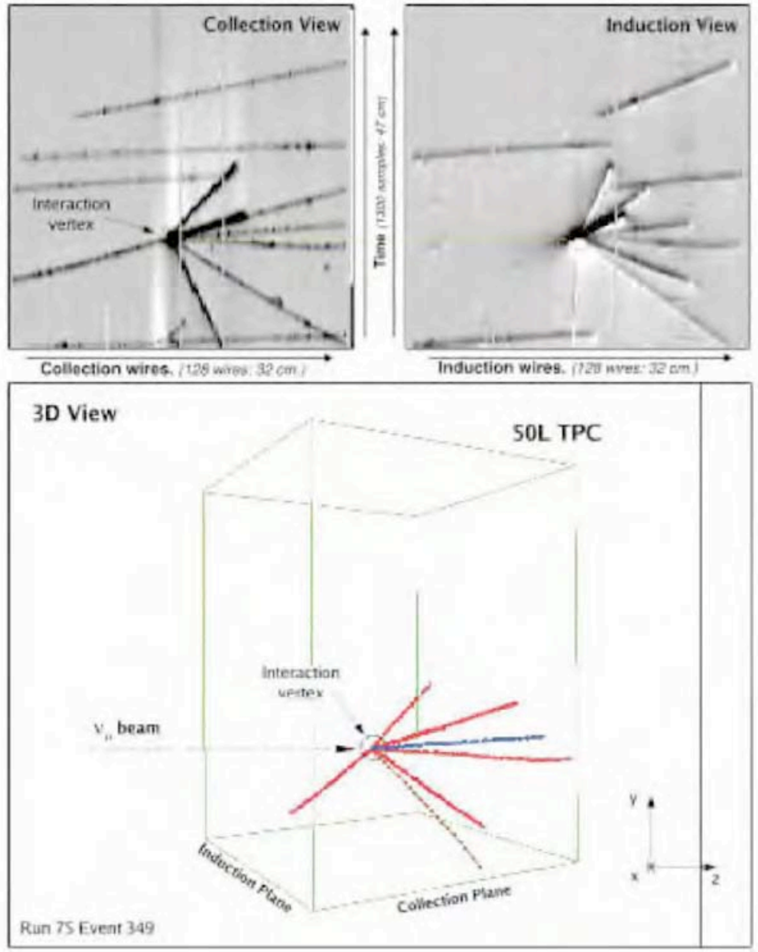
$m_{\gamma\gamma} = 133.4 \pm 3.0(stat) \pm 4.0(sys)\mathrm{MeV/c^2}$

neutrino events recorded in the LAr-TPC

- Quasi-elastic events reconstructed @ CERN WANF:
  - ➤ quasi-elastic event with a muon and a proton recoil track (A)
  - ➤ a multi-prong neutrino event reconstructed in 3D (B)



(A)

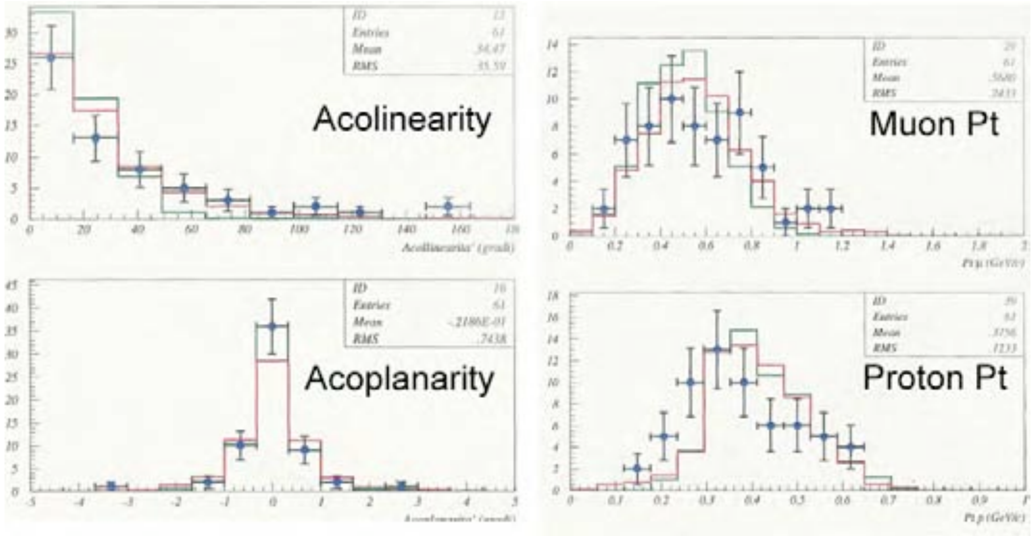


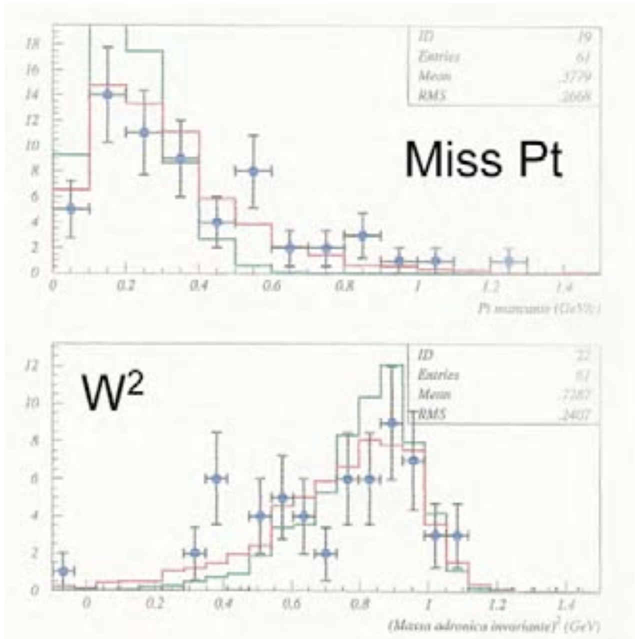
(B)

200 quasi elastic final states with one proton T_P>50 MeV

- Quasi-elastic neutrino events in LAr have been reconstructed in the 50 litre ICARUS LAr-TPC exposed to the CERN-WANF beam in coincidence with the NOMAD experiment.

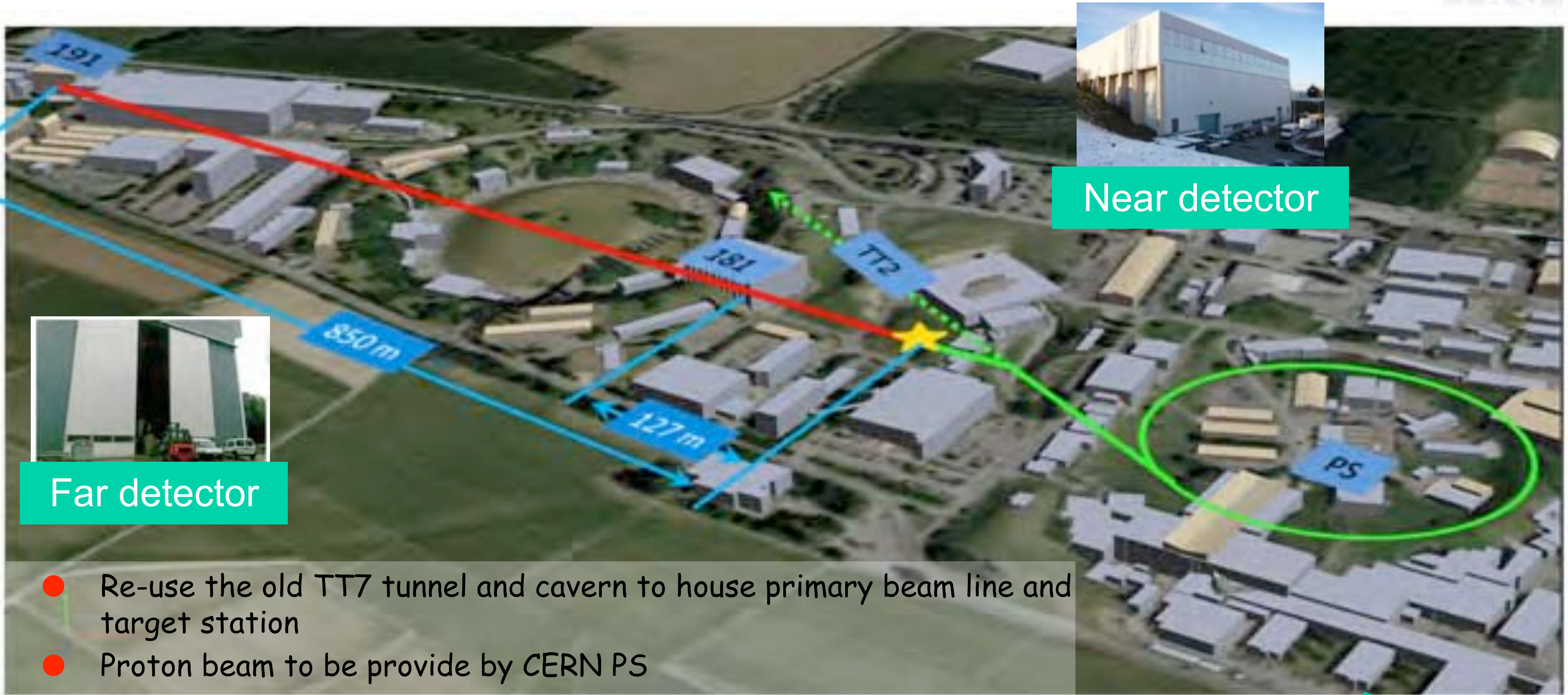
- Simulations, accounting for Nuclear Fermi motion and re-interactions in nuclei, are found in good agreement with a 200 pure lepton-proton final state events with 1 proton TP > 50 MeV (range > 2 cm) and any number protons TP< 50 MeV.





The Proposed Lay-out at CERN-PS

Rende Steerenberg, CERN Switzerland

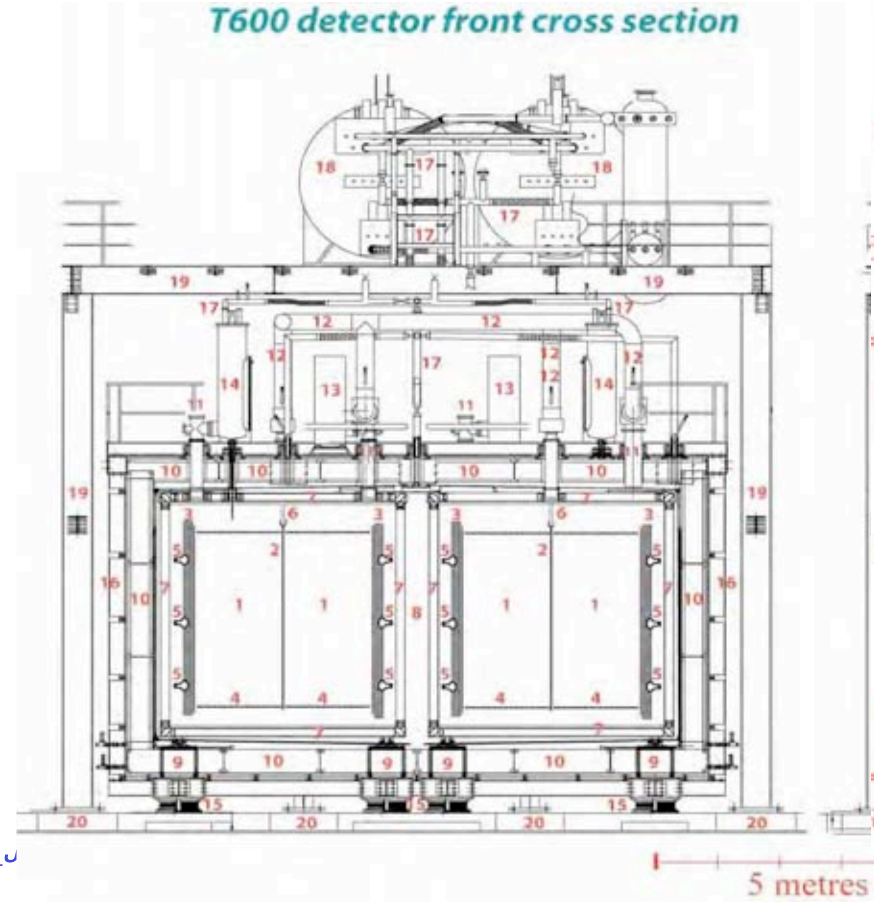


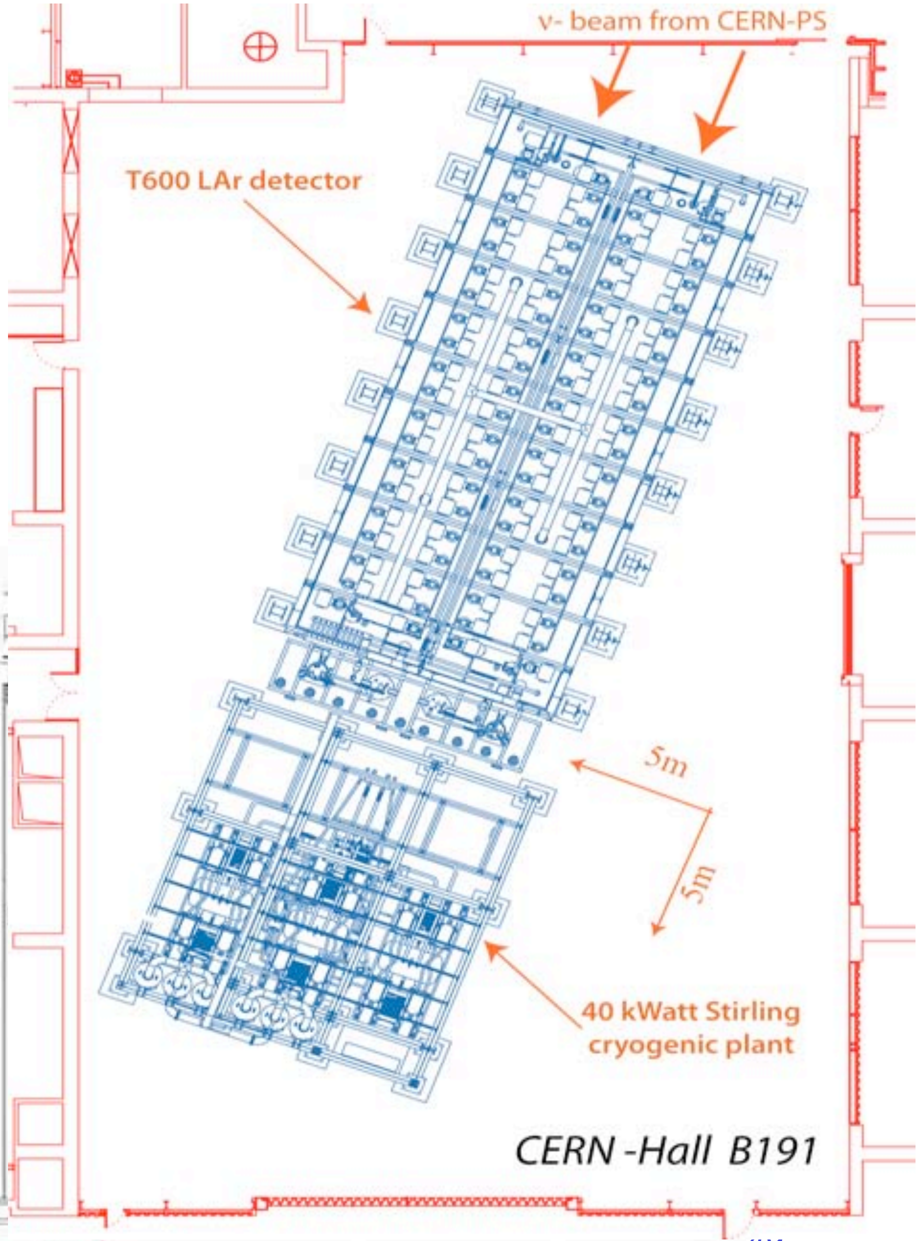
- 150t liquid argon TPC near detector in building 181
- 600t liquid argon TPC far detector in building 191

T600 ICARUS detectors

The ICARUS T600 as "Far" detector in Hall B191

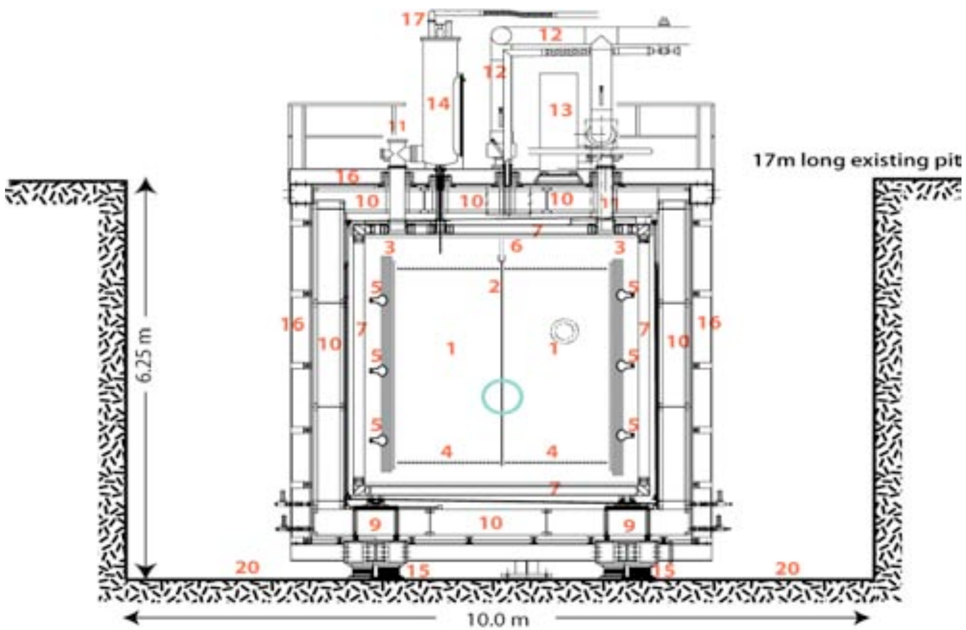
- The T600 detector could be moved and operated at CERN in the old BEBC experimental hall (Hall 191) without major modifications

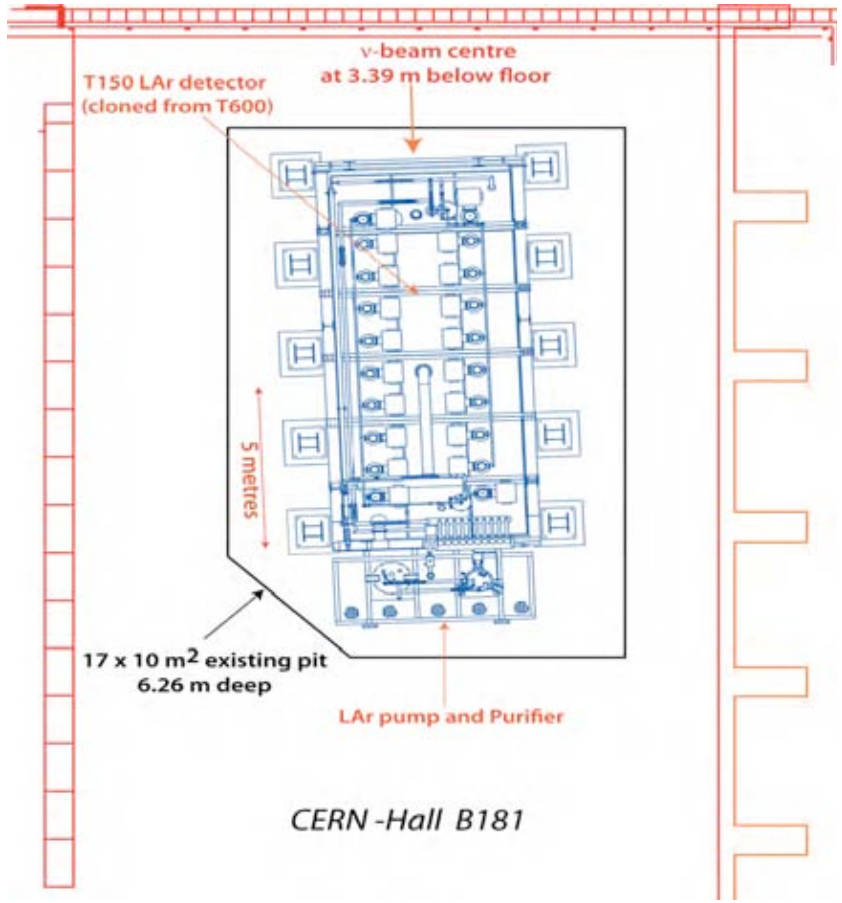




The additional T150 detector (to be constructed)

- Maximum of similarity with Far: a clone of a single semi-module, length reduced by a factor 2 (about 12 m) keeping untouched the inner detector layout (TPC structure) with a mass of 150 t.
- Near detector dimensions (1 m passive insulation): 13 x 6 m^2 with 6 m height. It fits perfectly the existing basement pit of Hall 181, previously used for neutrino exps.

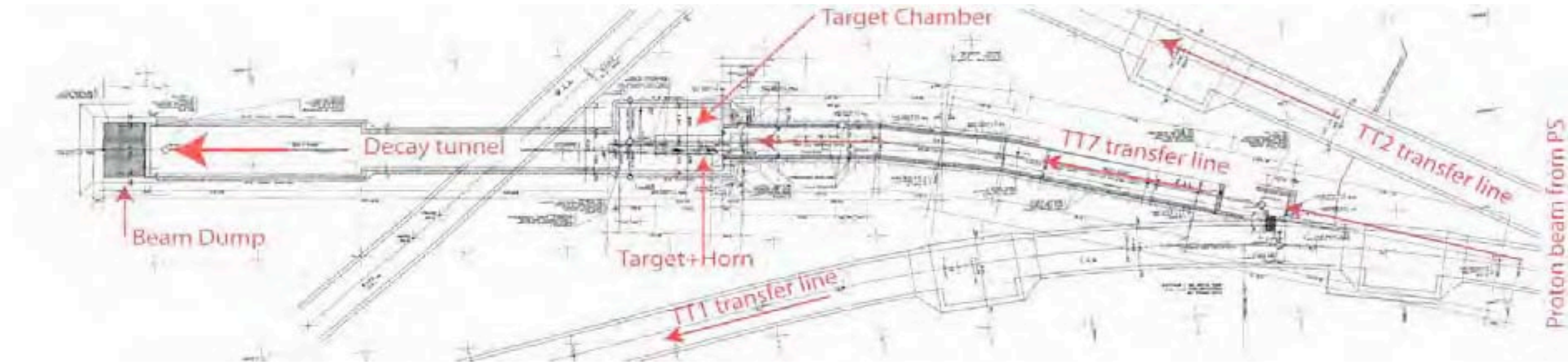




Refurbishing the old line used by BEBC

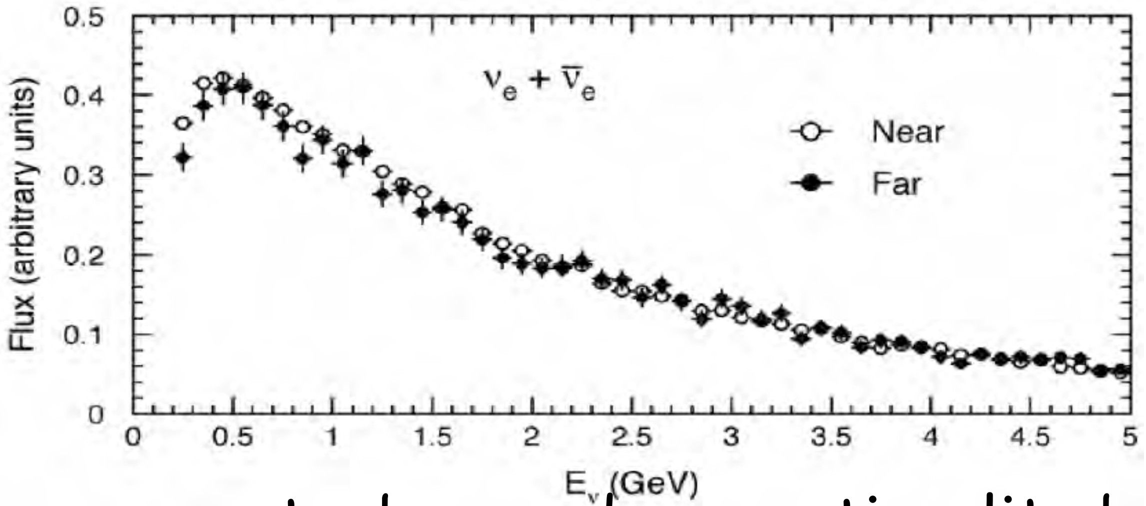
- The PS proton beam at 19.2 GeV/c is extracted via TT2, TT1 and TT7
- The magnetic horn is designed to focus particles of momentum ≈ 3GeV/c
- The decay tunnel is about 50 m long, followed by an iron beam stopper

PS-180 $\nu\mu \rightarrow \nu e$ (BEBC)



Unique features of the CERN PS beam

- The present proposal is a search for spectral differences of electron like specific signatures in *two identical detectors* but at two different neutrino decay distances.
- *In absence of oscillations*, apart some beam related small spatial corrections, the two spectra are a precise copy of each other, *independently of the specific experimental event signatures and without any Monte Carlo comparisons*.



Precise identity of ν-e events in the near and far positions

- Therefore an exact, observed proportionality between the two ν_e spectra implies directly the absence of neutrino oscillations over the measured interval of L/E.

Basic features of the proposed experiment

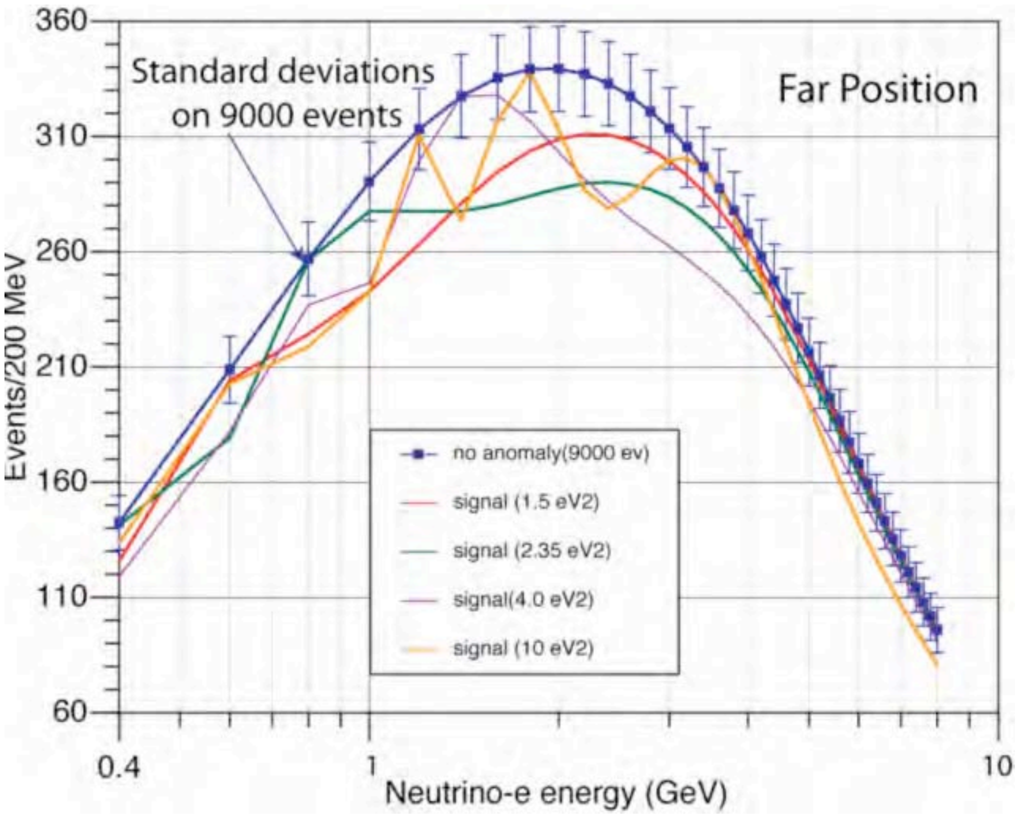
- Our proposed experiment, collecting a large amount of data both with neutrino and antineutrino focussing, may be able to give a likely definitive answer to the 4 following queries:
  - the LSND/+MiniBooNe both antineutrino and neutrino $\nu\mu \rightarrow \nu e$ oscillation anomalies;
  - The Gallex + Reactor oscillatory disappearance of the initial ν–e signal, both for neutrino and antineutrinos
  - an oscillatory disappearance maybe present in the ν–μ signal, so far unknown.
  - Accurate comparison between neutrino and antineutrino related oscillatory anomalies, maybe due to CPT violation.
- In absence of these "anomalies", the signals of the detectors should be a precise copy of each other for all experimental signatures and without any need of Monte Carlo comparisons.

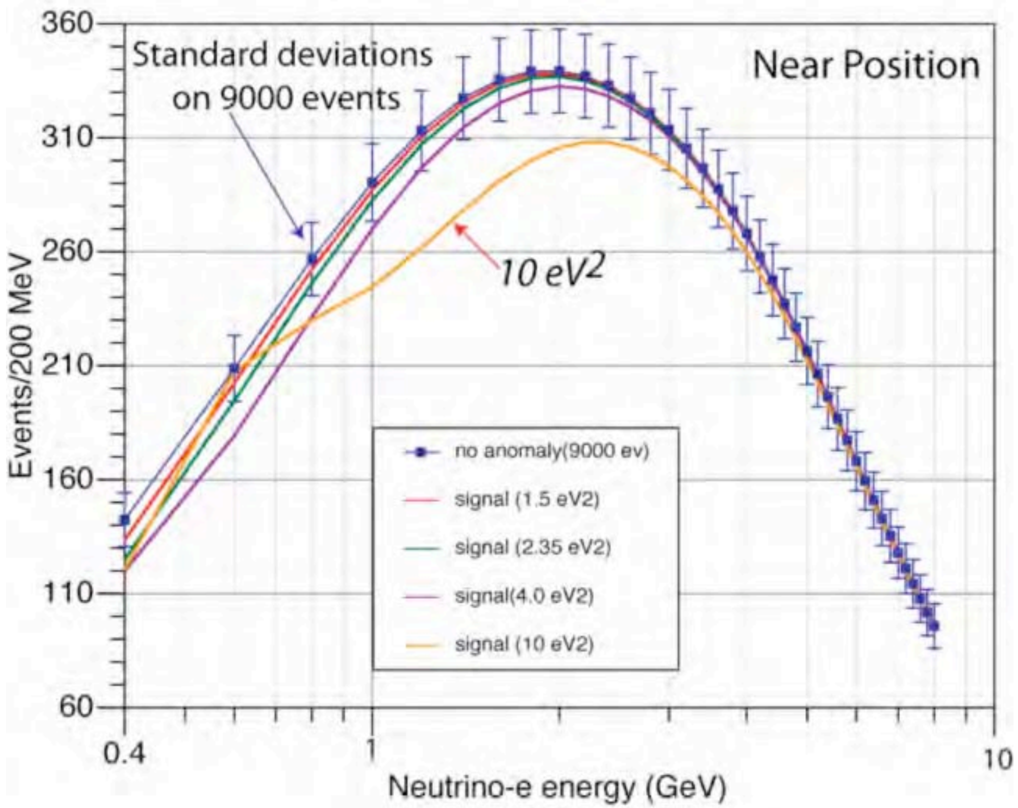
Expected signal for LSND/MiniBooNE anomalies

- Event rates for the near and far detectors given for 2.5 10^{20} pot (30 kW beam power) for E_ν < 8 GeV. The oscillated signals are clustered below 3 GeV of visible energy.

	ν focus		$\bar{\nu}$ focus	
	FAR	NEAR	FAR	NEAR
Fiducial mass	500 t	150 t	500 t	150 t
Distance from target	850 m	127 m	850 m	127 m
ν_μ interactions (or $\bar{\nu}_\mu$ for $\bar{\nu}$ focus)	1.2×10^6	18×10^6	2.0×10^5	2.3×10^6
QE ν_μ (or $\bar{\nu}_\mu$) interactions	4.5×10^5	66×10^5	87000	
Events/Burst	0.17	2.5	0.03	0.3
Intrinsic $\nu_e + \bar{\nu}_e$ from beam	9000	120000	2000	29000
Intrinsic $\nu_e + \bar{\nu}_e$ ($E_\nu < 3$ GeV)	3900	54000	880	13000
ν_e oscillations:				
$\Delta m^2 = 2.\ eV^2;\ sin^2 2\theta = 0.002$	1194	1050	230	58
$\Delta m^2 = 0.4\ eV^2;\ sin^2 2\theta = 0.02$	2083	2340	330	115
$\Delta m^2 = 0.064\ eV^2;\ sin^2 2\theta = 0.96$	3350	1250	465	140
$\Delta m^2 = 4.42\ eV^2;\ sin^2 2\theta = 0.0066$	2980	25050	490	3220

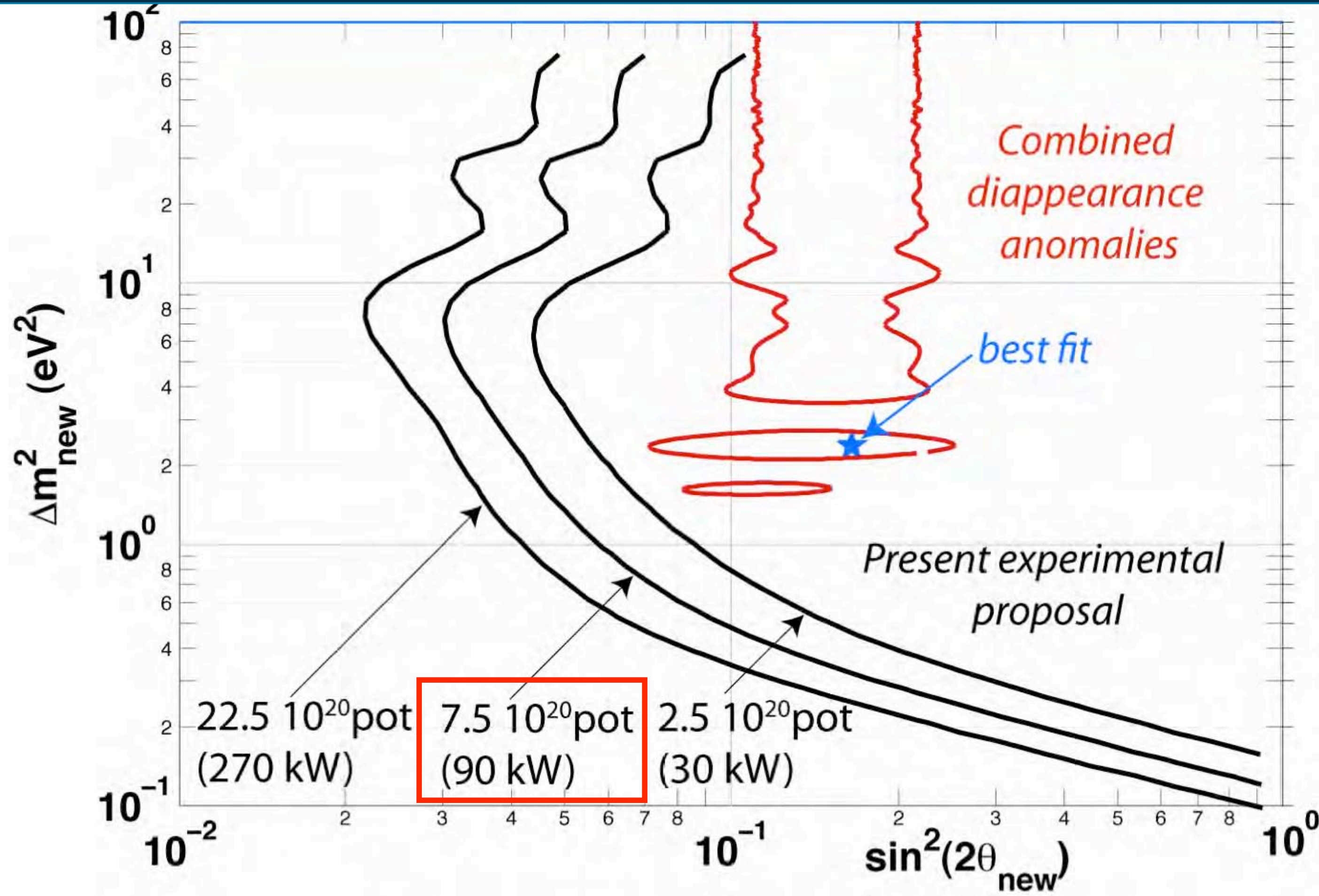
Sensitivity to νe (and νμ) disappearance signals





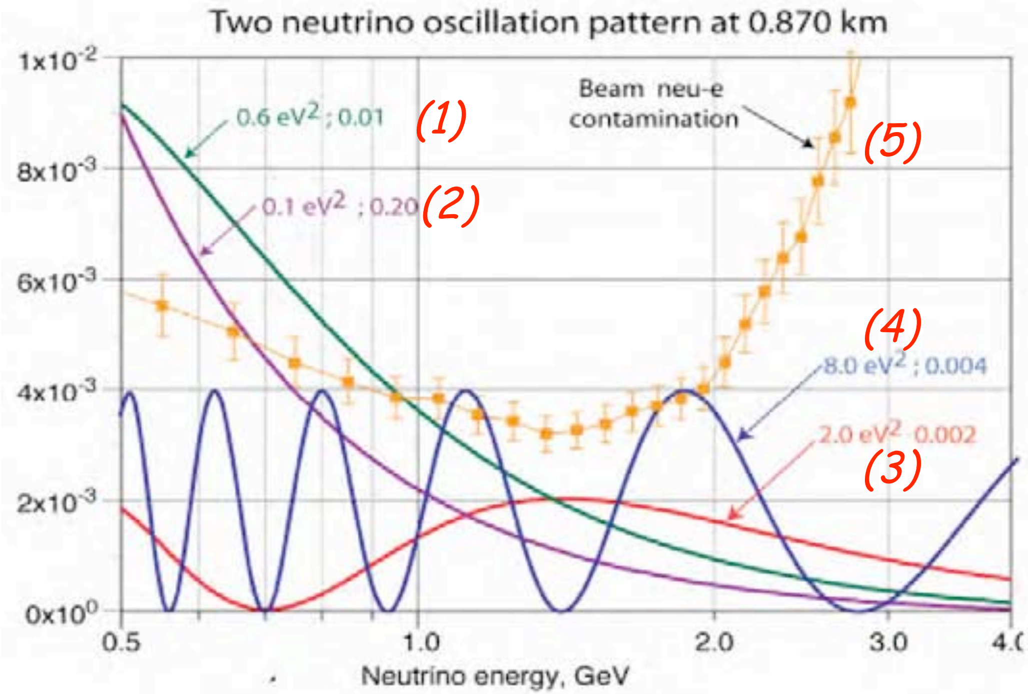
The energy distributions of the electron neutrino events is shown in (a) and (b)respectively for the "Far" and "Near" and a number of possible values in the region of $\Delta m^2 > 1eV^2$ and $\sin^2(2\theta) \approx 0.16$.
If confirmed without any doubt such a large mass difference will have an important role in the explanation of the existence of the Dark Mass in the Universe.

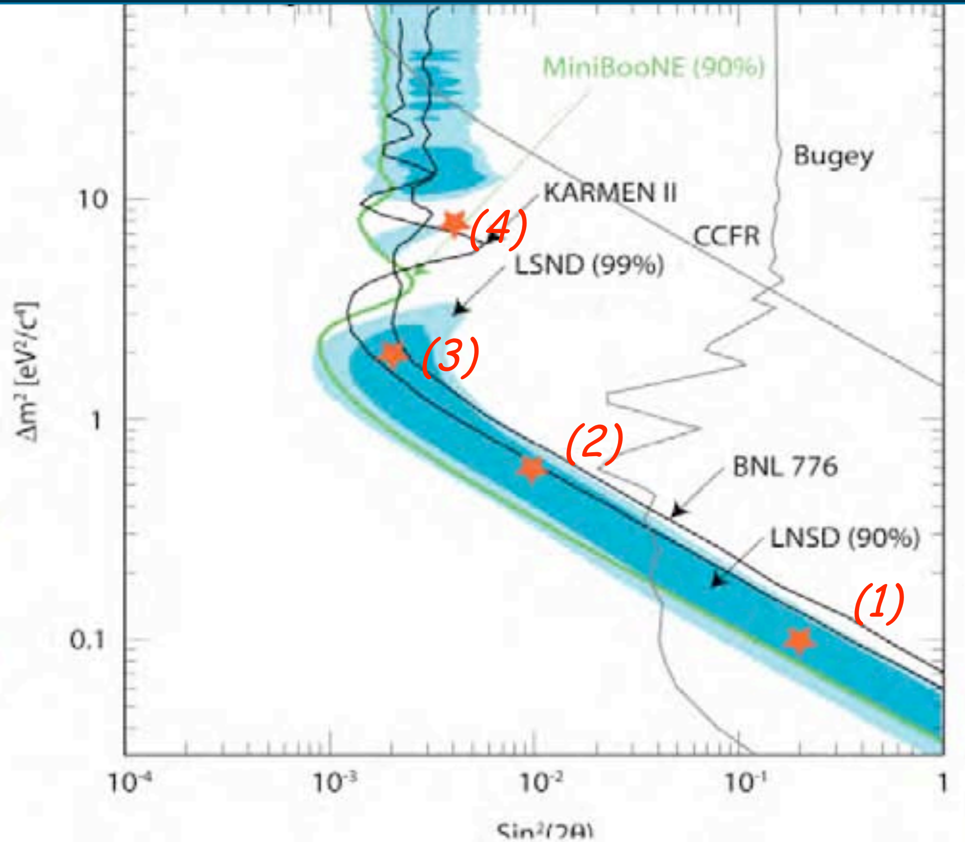
Sensitivity to disappearance anomalies



- Sensitivities (90% CL) in the $\sin^2(2\theta_{new})$ vs. Δm^2_{new} for an integrated intensity of (a) at the 30 kWatt beam intensity of the previous CERN/PS experiments, (b) the newly planned 90 kWatt neutrino beam and (c) a 270 kWatt curve. They are compared (in red) with the "anomalies" of the reactor + Gallex and Sage experiments. A 1% overall and 3% bin-to-bin systematic uncertainty are included (for each 100 MeV bins).

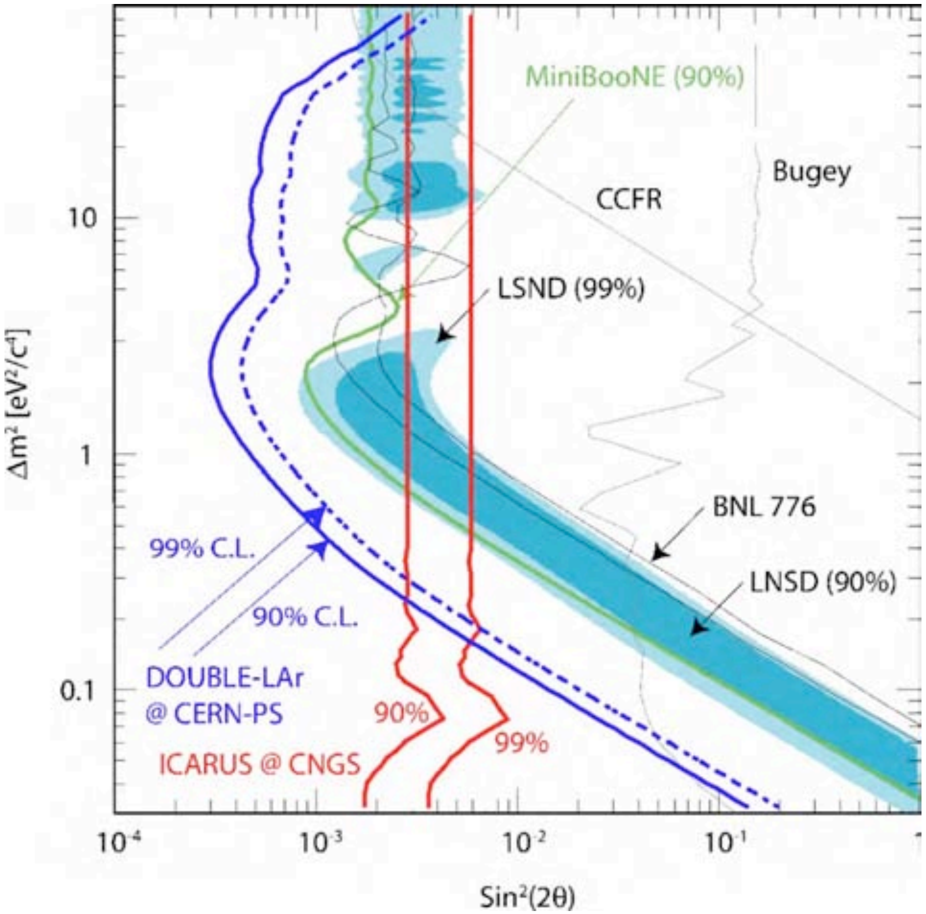
LSND direct determination of mass and mixing angle

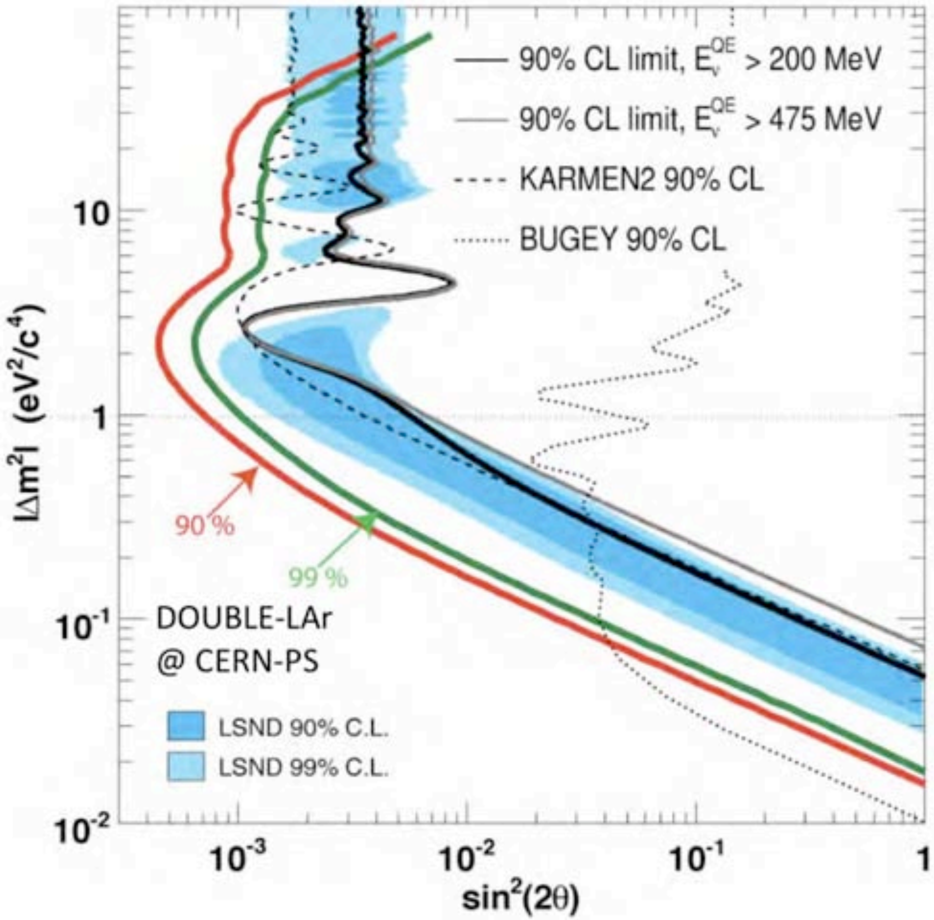




- The present method, unlike LNSD and MiniBooNE, determines both the mass difference and the value of the mixing angle.
- Very different and clearly distinguishable patterns (1-4) are possible, depending on the values in the (Δm^2 – $\sin^2 2\theta$) plane.
- The intrinsic ν - e background (5) is also shown.

Comparing LNSD like sensitivities *(arXiv:0909.0355)*





Expected sensitivity for the proposed experiment exposed at the CERN-PS neutrino beam (left) for 2.5 10^{20} pot and twice as much for anti-neutrino (right) . The LSND allowed region is fully explored both for neutrinos and antineutrino. The expectations from one year of ν at CNGS2 are also shown.

Status of advancement of the Proposal

- A Memorandum has been sent to the CERN-SPS-C dated on March 9th describing a possible continuation of the ICARUS programme at the CERN-PS, with the following three major new steps:
  - the construction, or better the reconstruction of a CERN-PS horn focussed neutrino beam;
  - the enlargement and the reformulation of the collaboration to a wider international team; and
  - the formulation and approval of a formal proposal to the SPS-C, ensuring the availability of appropriate human and financial resources.
- The response of the Research Board (June 7th) has been positive on all three issues, namely
  - *CERN recognises the physics motivation and the opportunity offered by the ICARUS technology and availability.*
  - *The SPS-C will review the project once a detailed proposal is available.*
  - In addition *CERN is prepared, within its available resources, to study the re-building of the neutrino beam*.
- Therefore requirements are now fulfilled in order to move ahead towards the detailed proposal.

F.Mills,
July 2010

" *** LSND effect rises from the dead… "


Thank you !