A proposal for short baseline neutrino "anomalies" with innovative LAr imaging detectors coupled with large muon spectrometers

SPSC P347

(ICARUS + NESSIE)

April 3, 2012

Are neutrino a simple "carbon copy" repetition of quarks?

- Over the last several years, neutrinos have been the origin of an impressive number of "Surprises":
  - Mass differences, once zero "by ignorance", are important
  - Large mixing oscillations
  - 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, following the $\theta_{13} >> 0$ result
  - Majorana or Dirac ν's ?; ν-less β-decay
  - Actual values of ν-masses
  - Right handed neutrinos and see-saw mechanisms
  - Sterile neutrino and other "surprises"
- Of course the astronomical importance of neutrinos in space is immense, so is their role in the cosmic evolution.
- Just a few eV neutrino may be the source of the dark mass.

Neutrinos anomalies ?

- Neutrino oscillations have established a beautiful picture, consistent with the mixing of three physical neutrino ν_e, ν_μ and ν_τ and mass eigenstates ν_1, ν_2 and ν_3.
- The two observed mass differences turn out to be relatively small $\Delta m^2_{31} \approx 2.4 \times 10^{-3}\ eV^2$ and $\Delta m^2_{21} \approx 8 \times 10^{-5}\ eV^2$.
- The sum of the strengths of the ν's has been found very near to 3. But it is possible that neutrinos are something very different than just a neutral counterpart of charged leptons, leaving room for additional neutrinos which do not see fully the ordinary electro-weak interactions but still introduce mixing oscillations with ordinary neutrinos.
- Indeed there are a number of *"anomalies"* which, provided they are confirmed experimentally, might be due to the presence of larger squared mass differences related to additional neutrino states with presumably some kind of "sterile" nature.

Sterile neutrinos

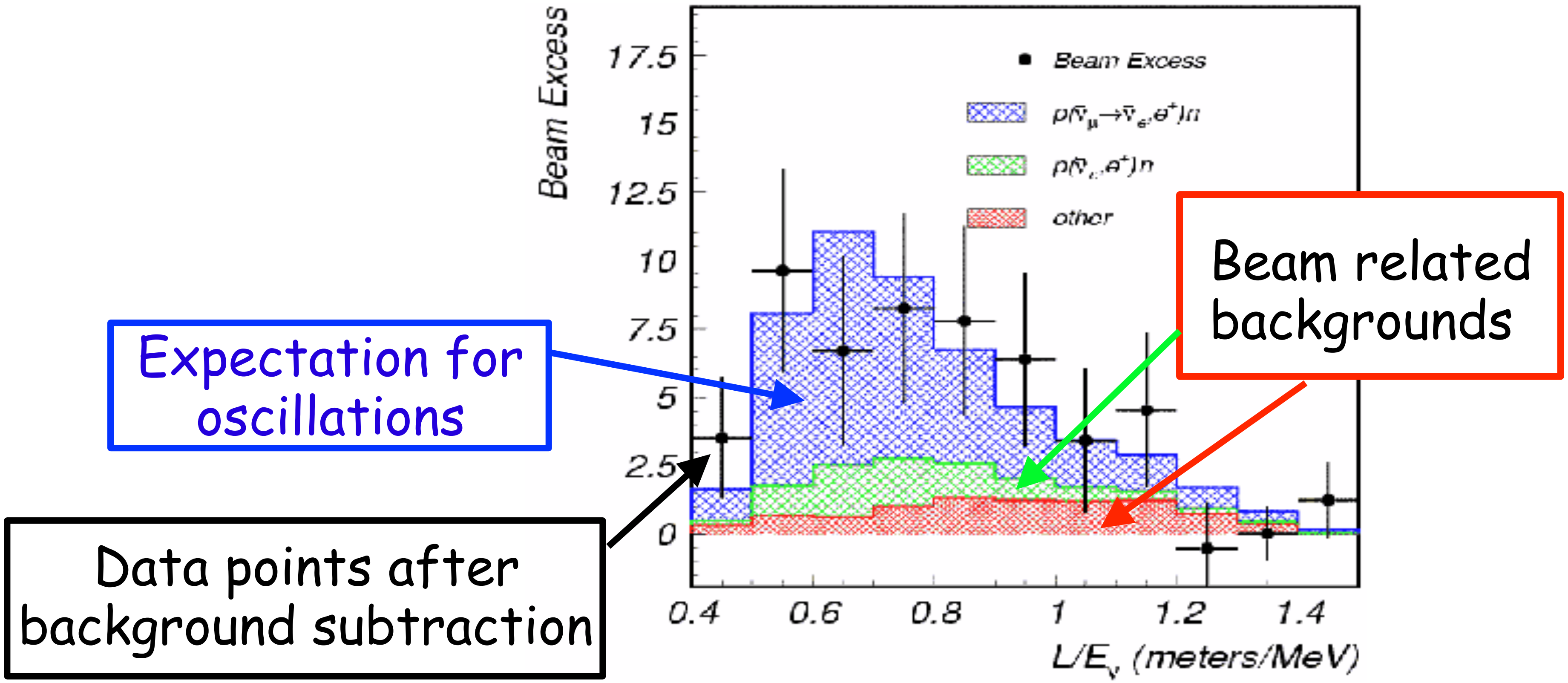
- The possible presence of oscillations into sterile neutrinos was proposed by B. Pontecorvo, but so far without conclusion.
- Two distinct classes of anomalies have been reported, although not in an entirely conclusive level, namely:
  - observation of *excess* ν_e electrons originated by initial anti-ν_μ events from accelerators (LNSD/MiniBooNE)
  - the apparent *disappearance signal* in the anti-ν_e events detected from (1) near-by nuclear reactors and (2) from Mega-Curie k-capture calibration sources in the Gallium experiments which detect solar ν_e
- 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 angles.
- The existence of additional neutrino states may be also hinted — or at least not excluded — by cosmological data

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.

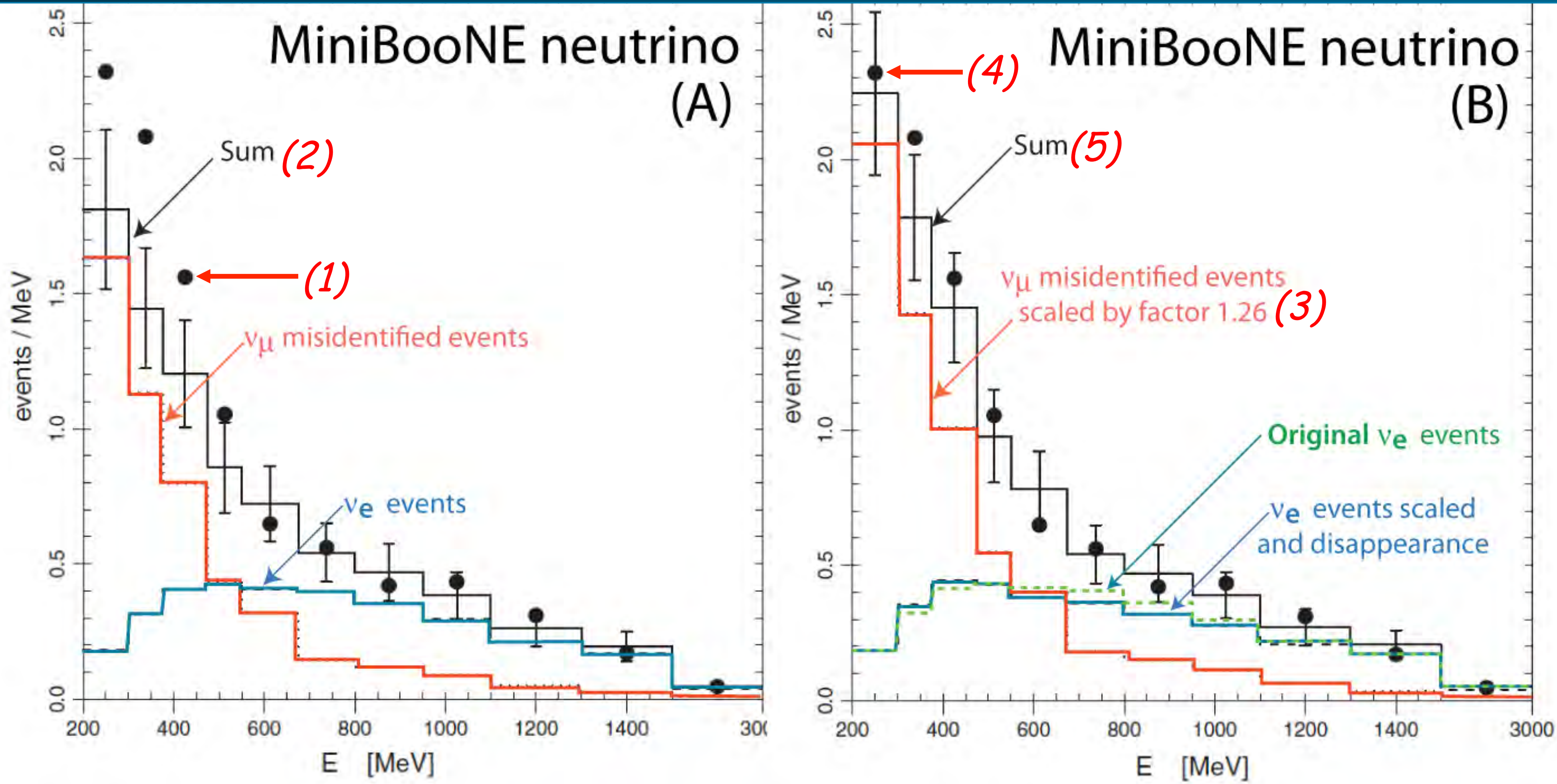
LSND: Evidence for $(\nu_\mu \rightarrow \nu_e)$

Excess of events: 87.9 ± 22.4 ± 6.0



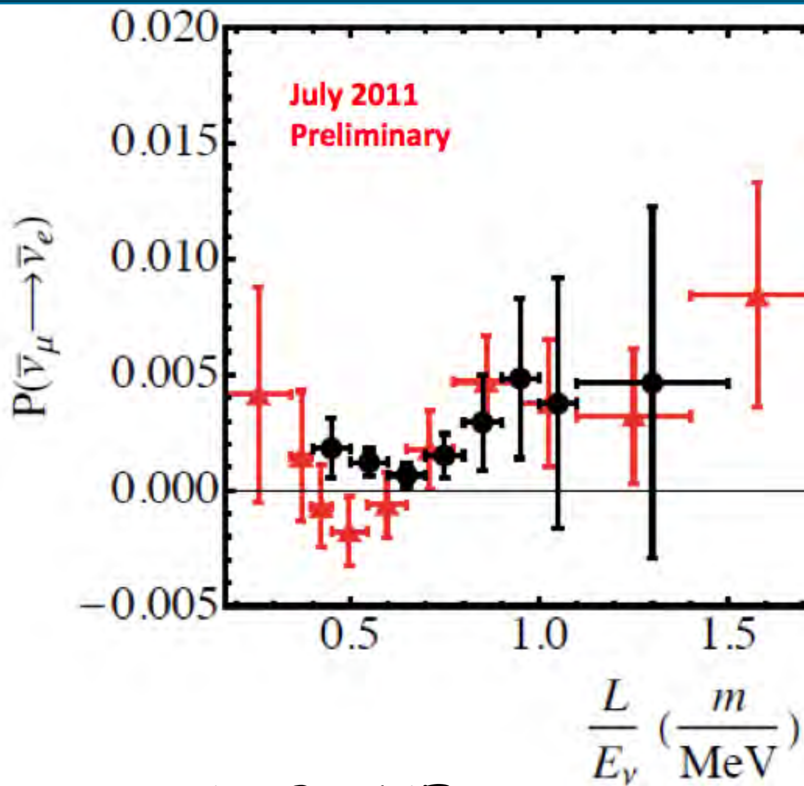
- The experimental evidence is very strong, namely 3.8 s.d.
- The experimental result so far has not been challenged experimentally

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 νμ 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

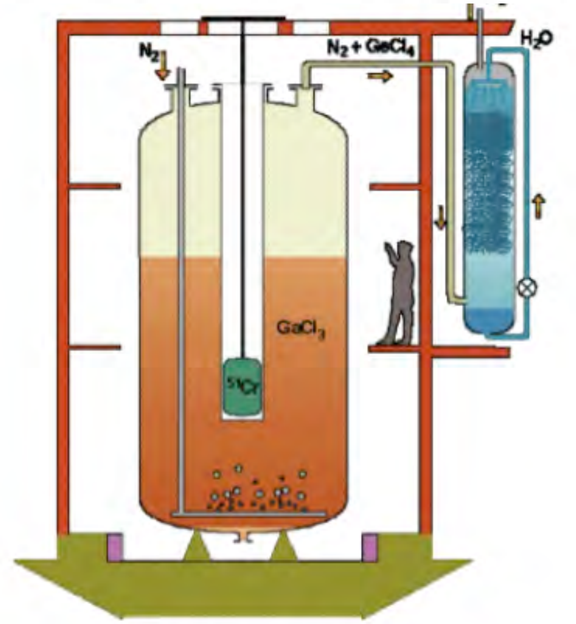


- The more recent MiniBooNE antineutrino run has shown the direct presence of a LSND like anomaly for neutrino energies > 430 MeV. The result is compelling with respect to the ordinary two-neutrino fit, indicating a 99.4% probability for an anomalous excess in ν_e production.
- The reported MiniBooNE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

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

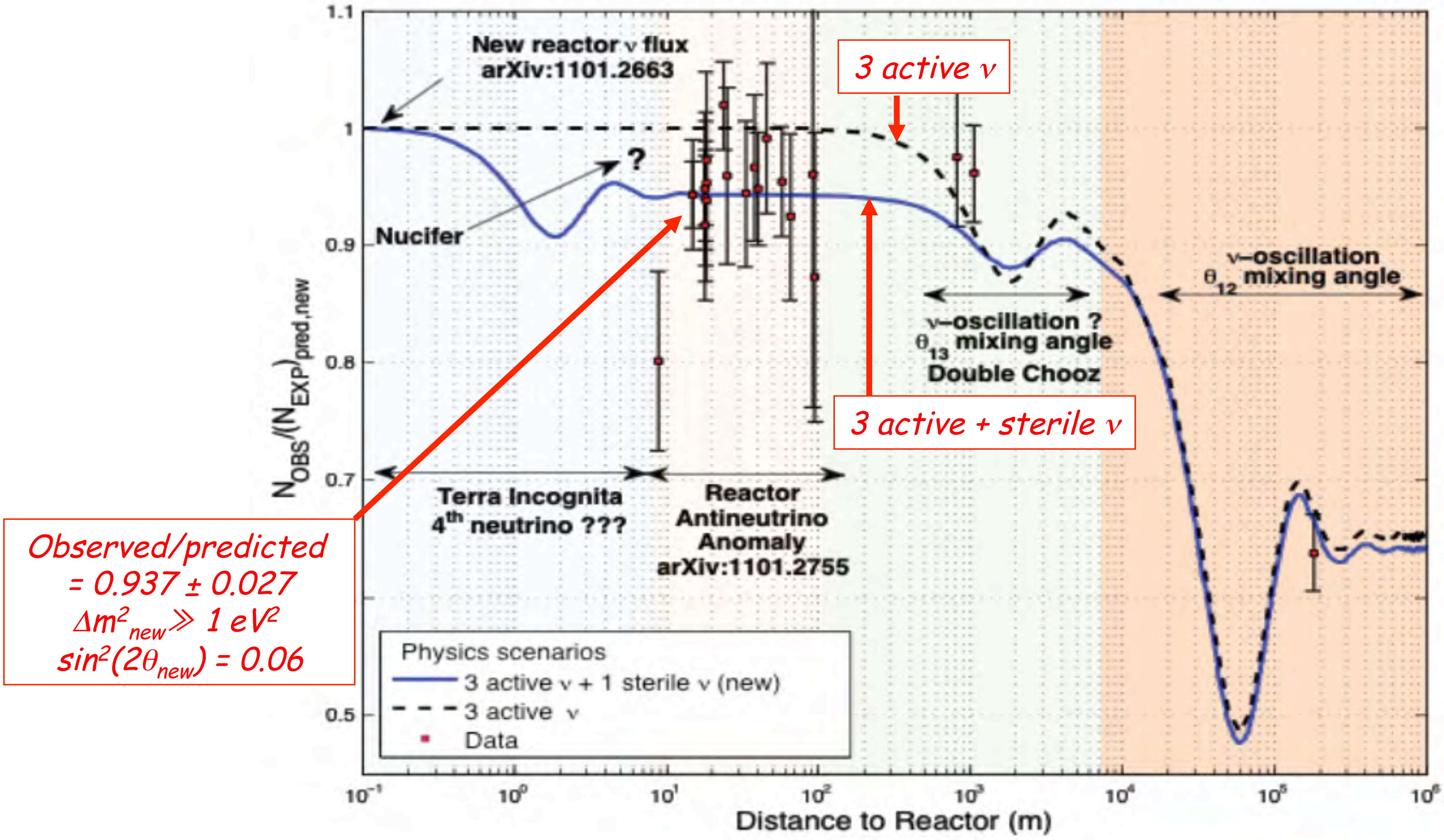
The reactor (anti)-neutrino disappearance anomaly

- 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

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

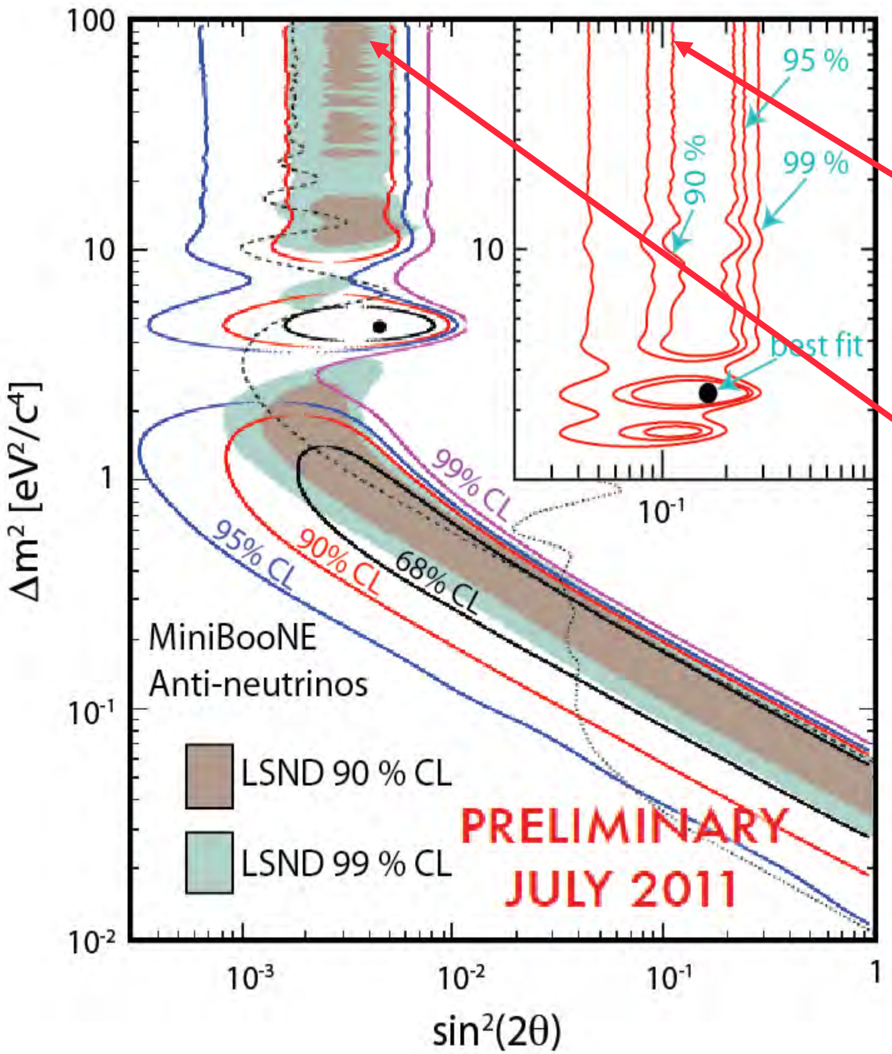
At $\Delta m^2_{new} = 2\ eV^2$ and E = 2 MeV the first predicted minimum of R occurs at 1.23 m

Short baseline reactor antineutrino anomaly



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

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.

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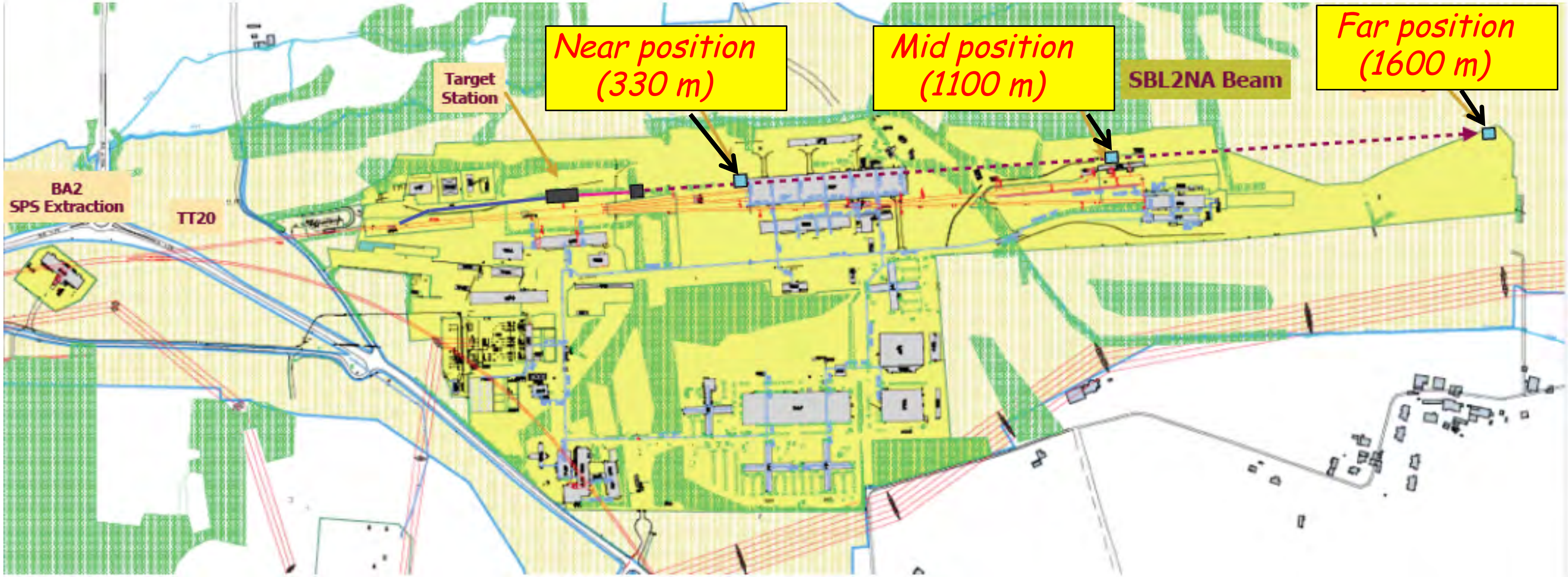
Related documentation to SPSC

- Relevant documents sent to SPS Committee by the ICARUS and NESSiE Collaborations:
  - a Memorandum from the ICARUS collaboration (SPSC-M-773) of March 9, 2011
  - Proposal "A comprehensive search for <<"anomalies>>" from neutrino and anti-neutrino oscillations at large mass differences ($Dm^2 \approx 1eV^2$) with two LAr–TPC imaging detectors at different distances from the CERN-PS" (SPSC-P-345) of Oct. 14th, 2011;·
  - Proposal "Prospect for Charge Current Neutrino Interactions Measurements at the CERN-PS" with two magnetic spectrometers for measuring CC neutrino interactions (SPSC-P-343) of Oct. 11th, 2011;
  - Joint Technical proposal: "Search for "anomalies" from neutrino and anti-neutrino oscillations at $Dm^2 \approx 1eV^2$ with muon spectrometers and large LAr–TPC imaging detectors" (SPSC-P-347) of March 15th, 2012.

New Neutrino Facility in the CERN North Area



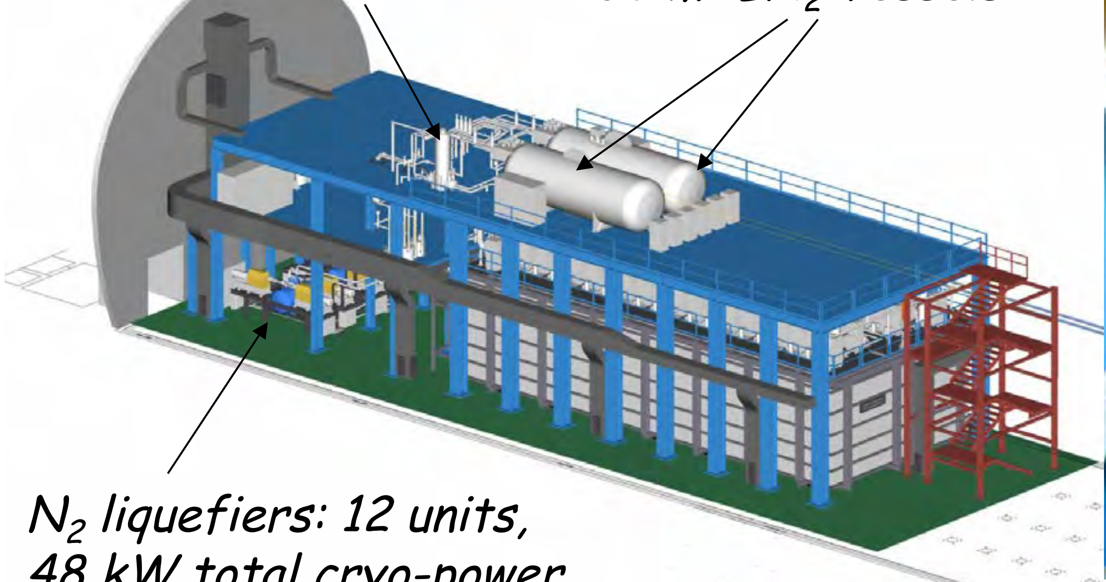
100 GeV primary beam fast extracted from SPS; target station next to TCC2; decay pipe l =100m, ø = 3m; beam dump: 15m of Fe with graphite core, followed by μ stations.

Neutrino beam angle: pointing upwards; at -3m in the far detector ~5mrad slope.

ICARUS-T600 @LNGS: 0.77 kton LAr-TPC

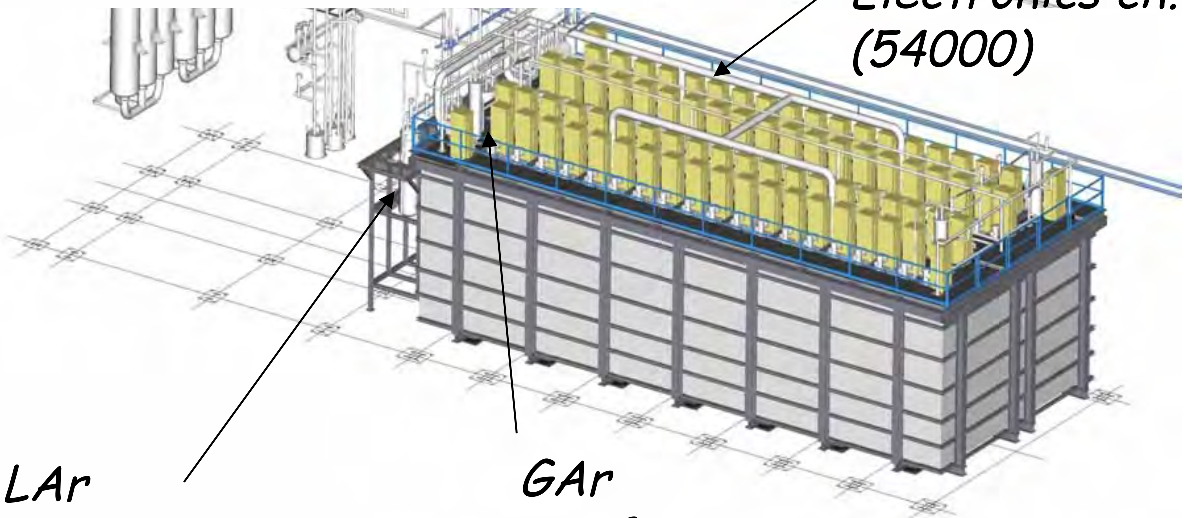
N2 Phase separator

30 m^3 LN$_2$ Vessels



N$_2$ liquefiers: 12 units,
48 kW total cryo-power

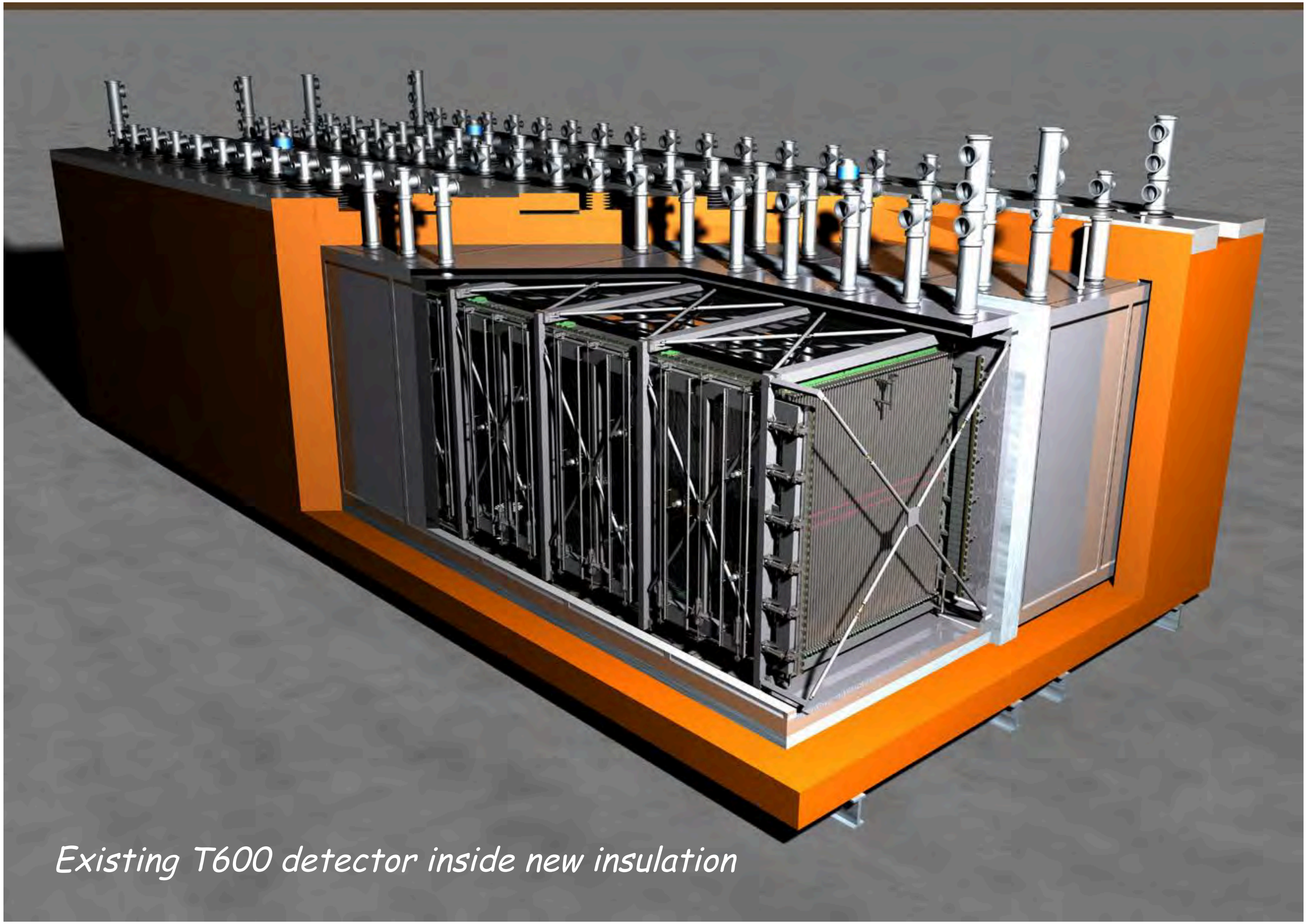
Electronics ch. (54000)



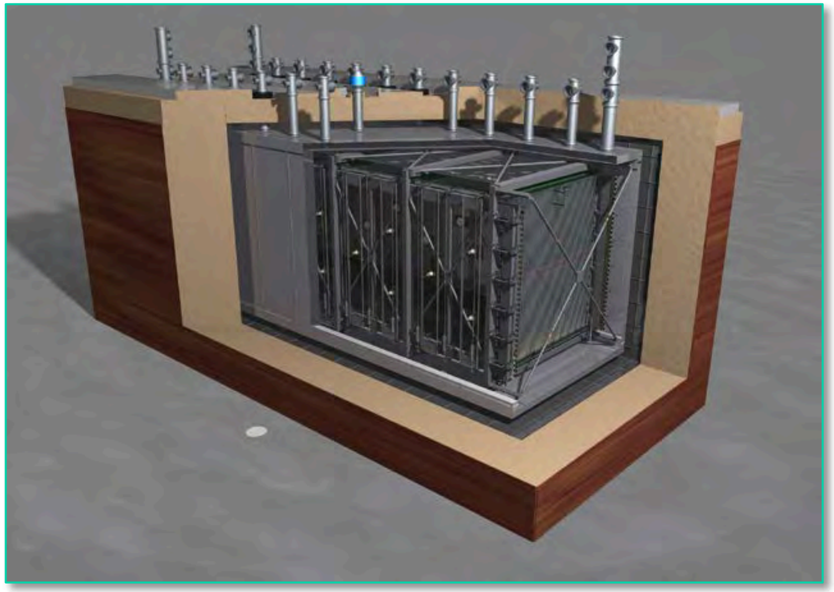
LAr purification systems

GAr purification systems

T600 layout in the CERN-SPS

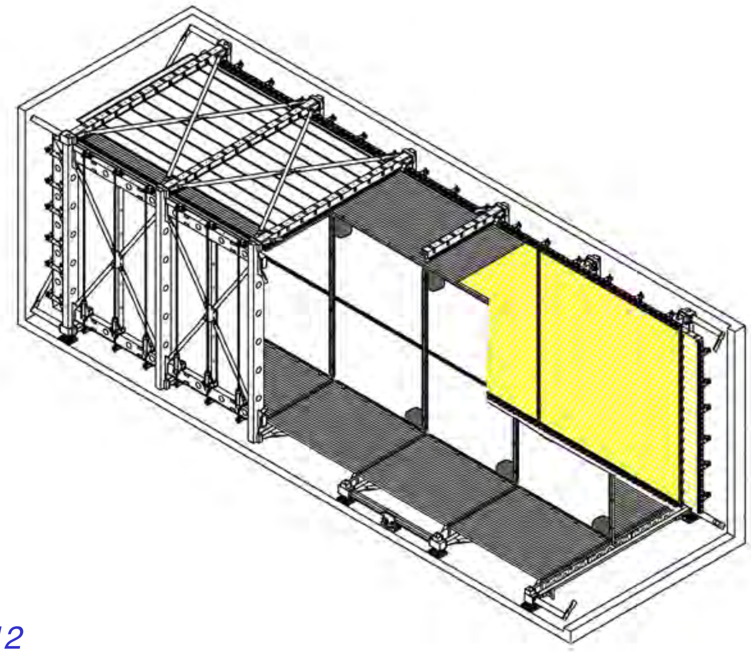


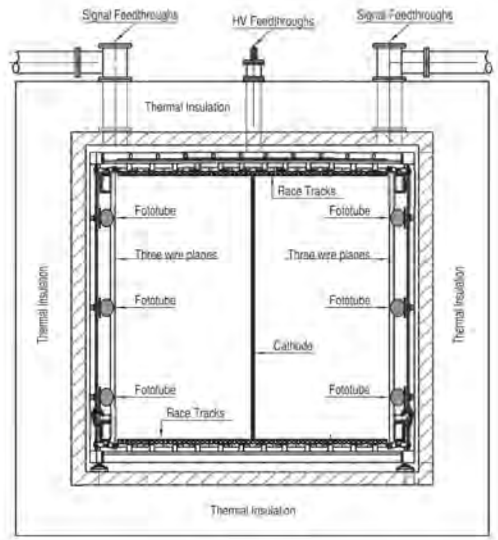
New T150 LAr-TPC



The present design of the T600 is extended to the basic structure of the T150 module. The module contains a high precision, high stability stainless steel structure independent of the container that supports two wire chambers, with three read-out planes each, the field shaping electrodes and one cathode, separating the two 1.5 m drift regions.

Most of the solutions already successfully adopted for the T600 at LNGS will be used. Existing equipment will be conveniently re-used (wiring tables, cleaning tools, etc.).

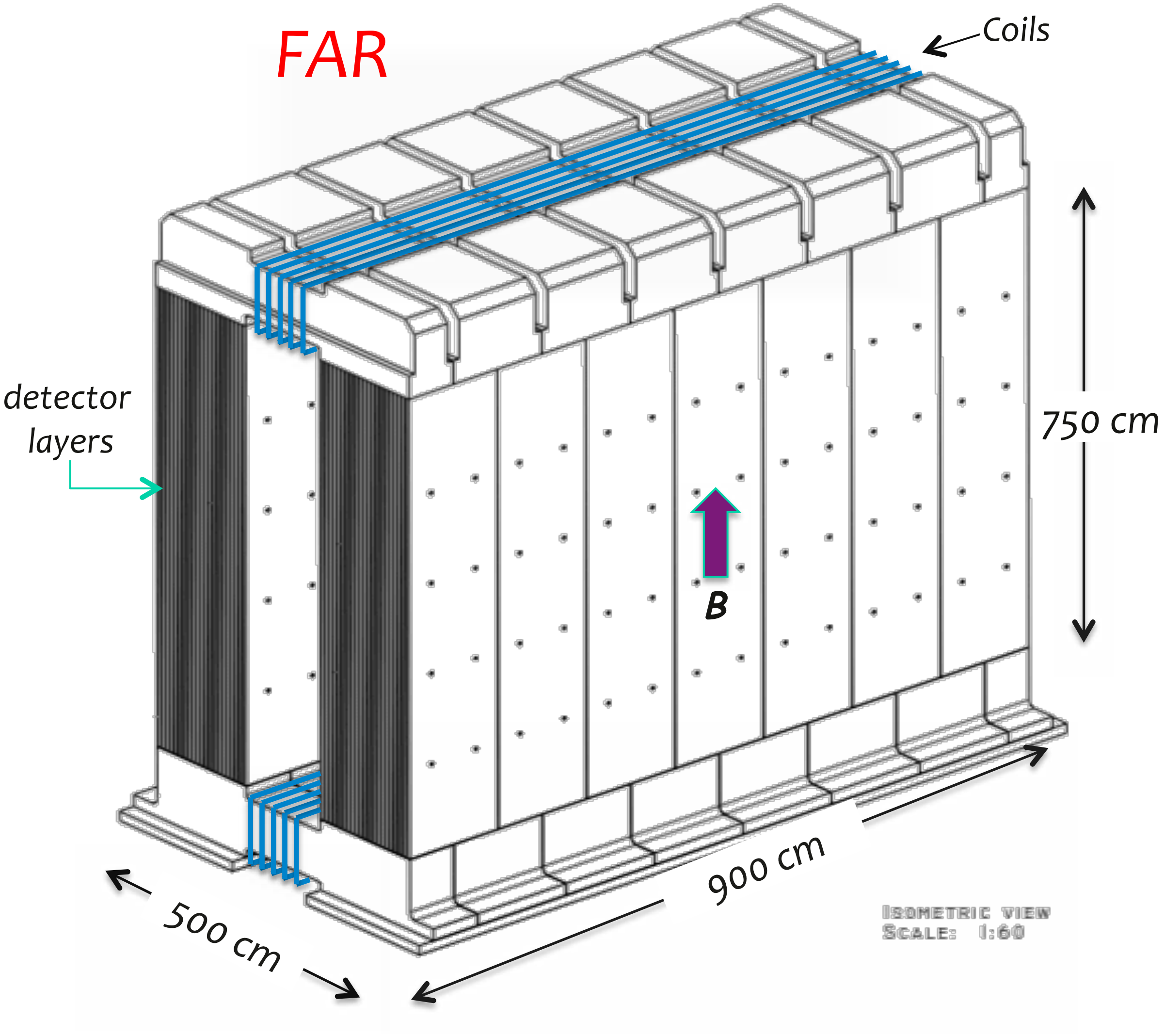


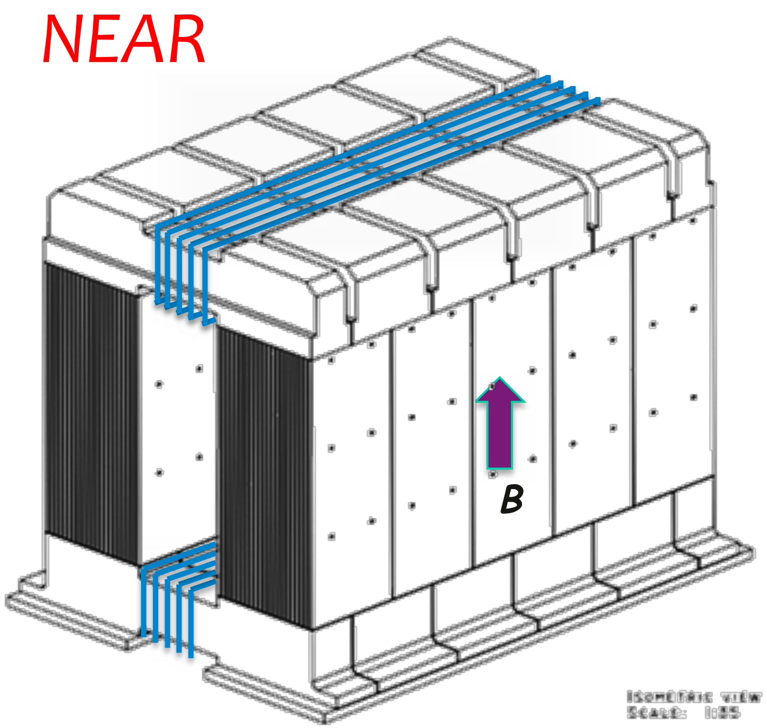


⇨ TWO Spectrometers

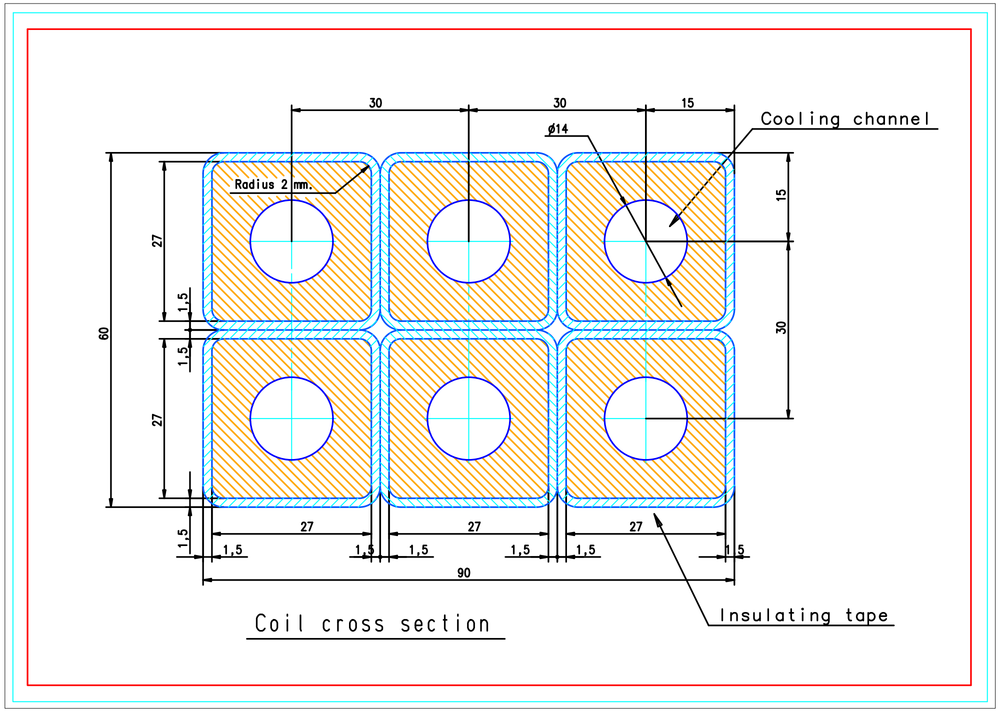
PLUS Air-Magnet Coils

1800 + 700 m² of RPC
20,000+12,000 digital channels
Precision Trackers



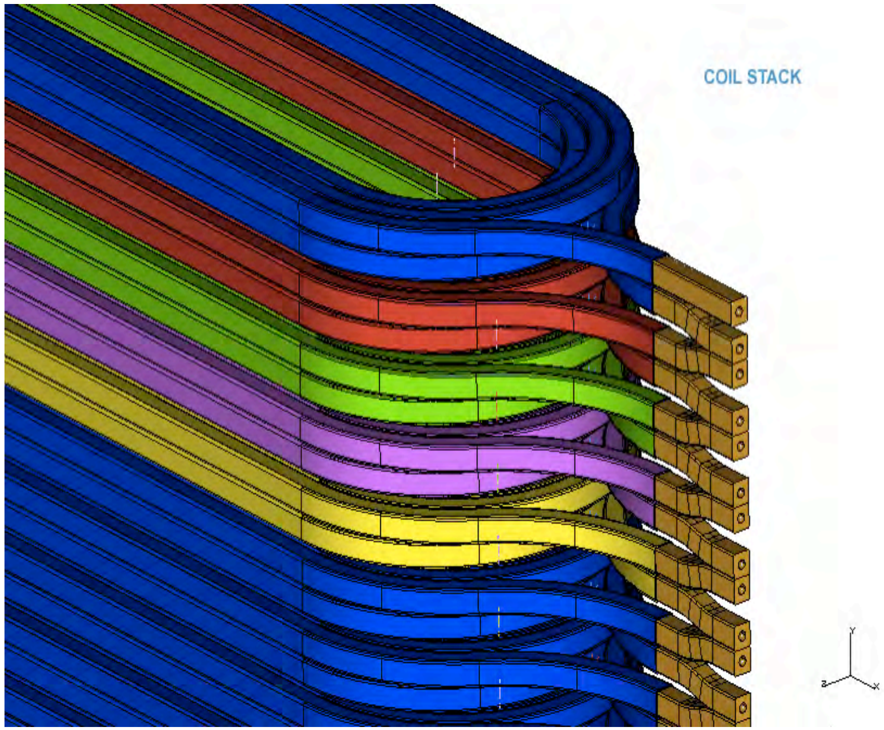


Fully new concept of a 40 m2 transverse area magnet field in air



Aluminium coils with internal cooling

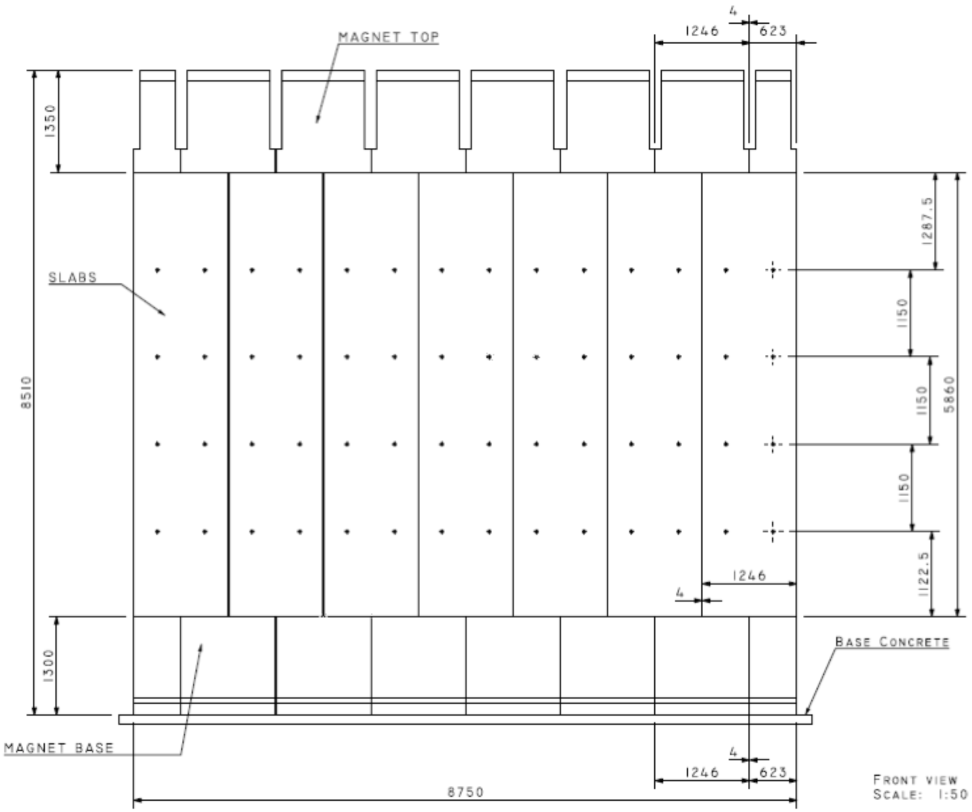
The air-magnet single coil structure.

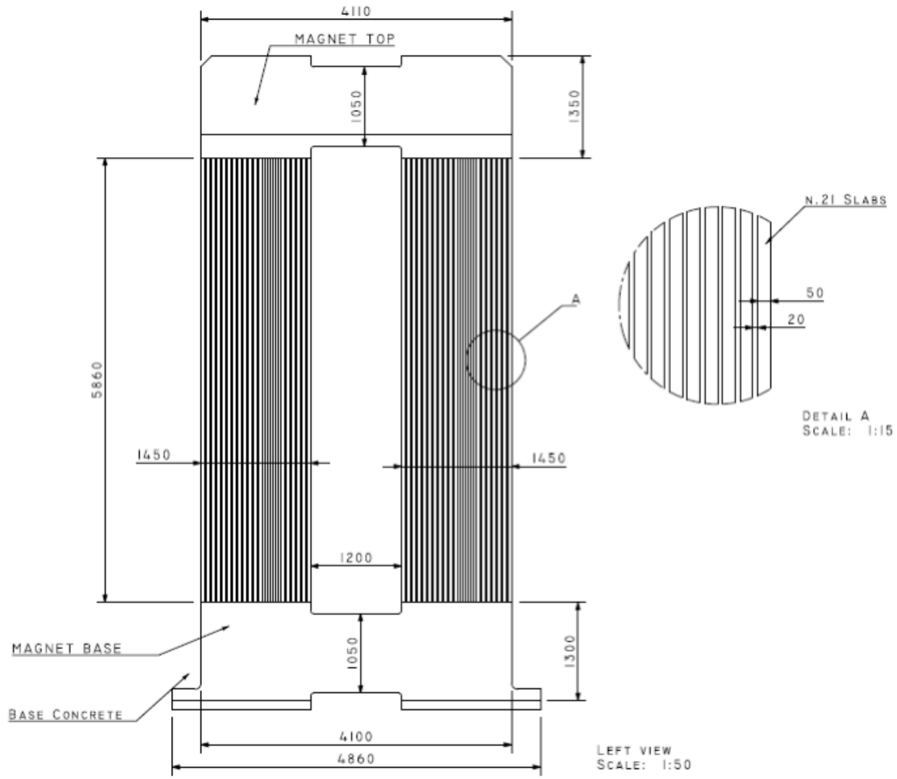


The air-magnet coil ("pancake") structure

Iron-Magnets

Transverse and longitudinal views of the FAR site iron magnet.

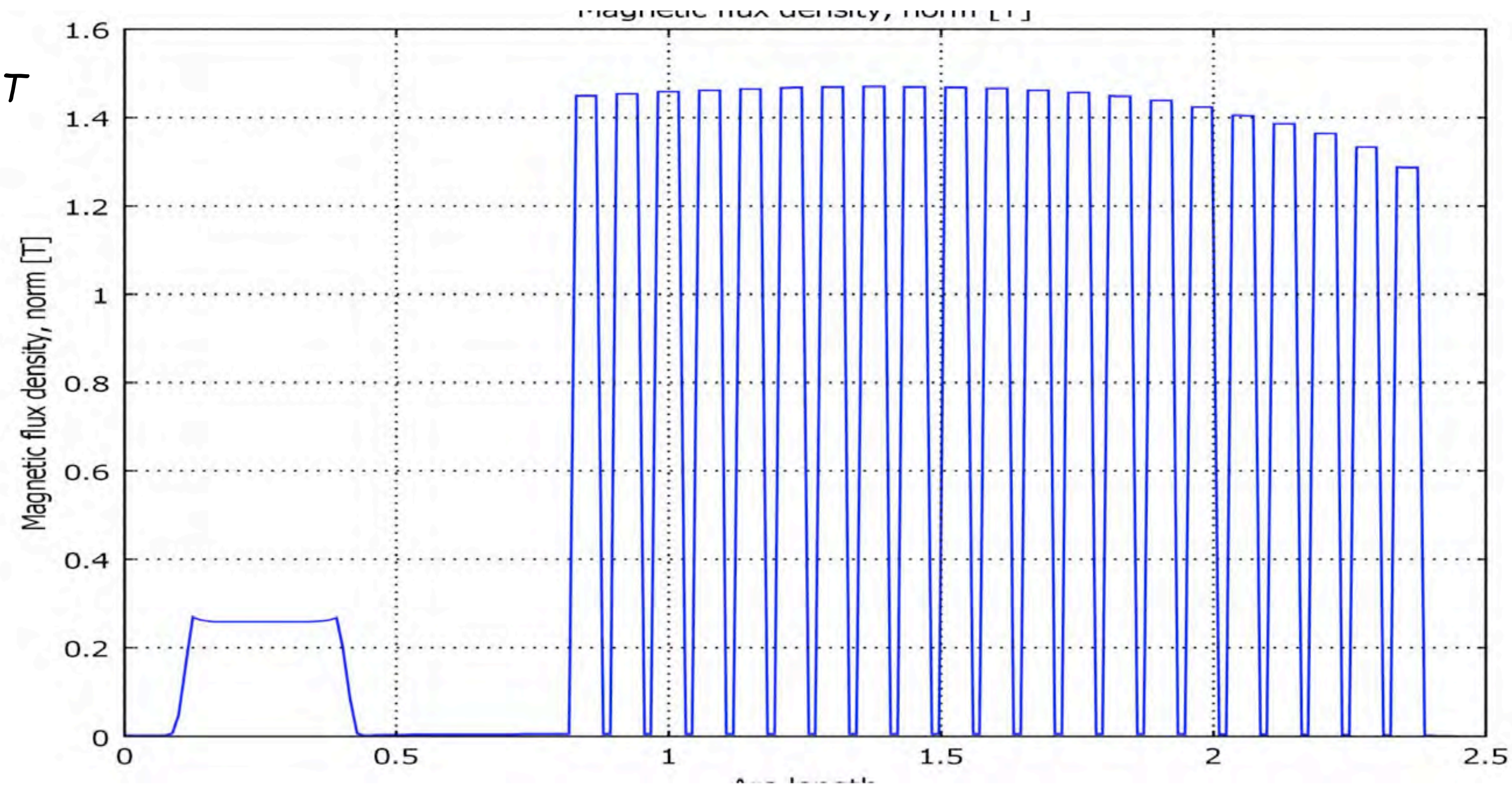




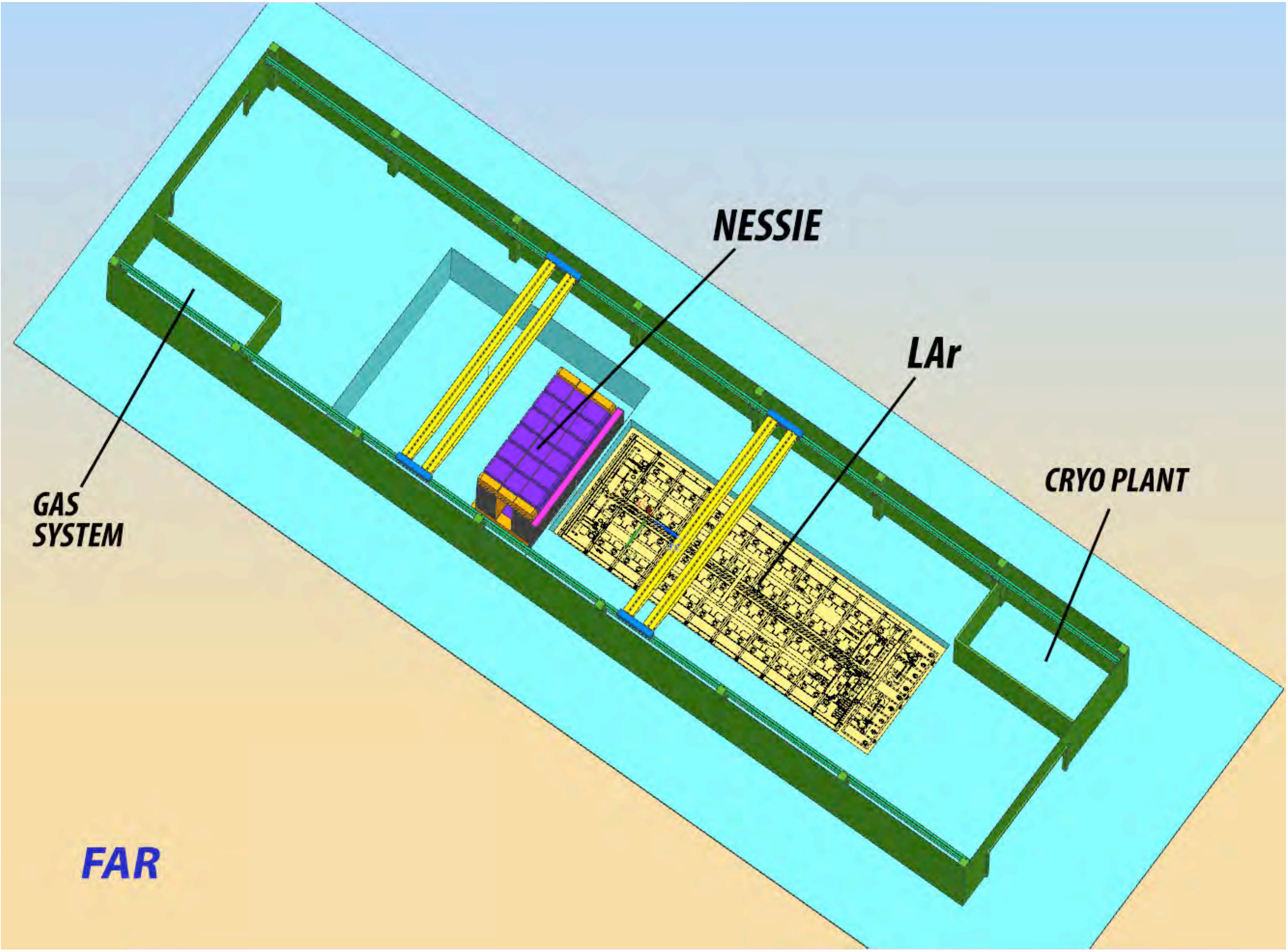
Magnetic Fields

The transverse profile of the global (air plus iron) magnetic fields

1.6 T



Installation at CERN

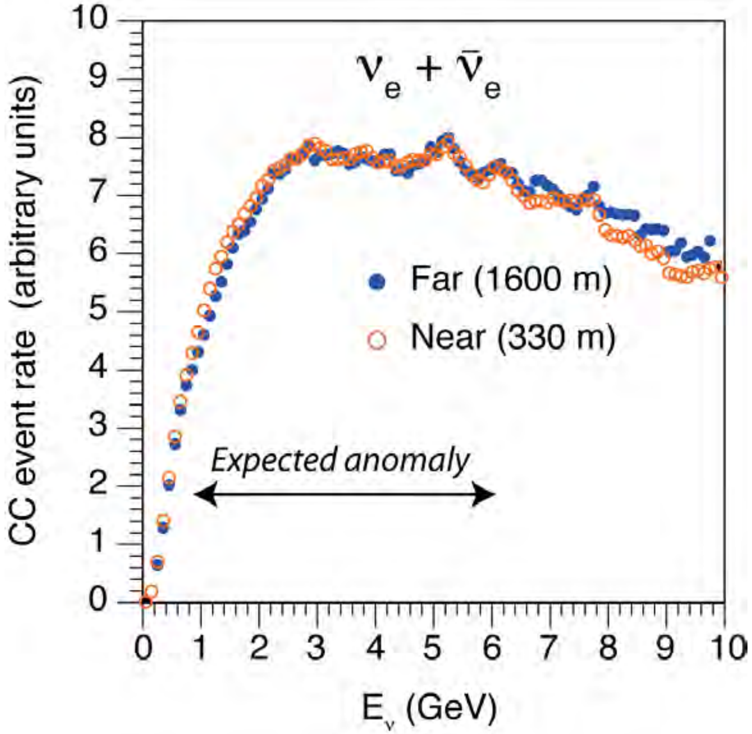


A direct, new approach to sterile oscillations at CERN/SPS

- 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 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*
  - Magnetic spectrometers to determine muon charge and p
  - 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.

Unique features of the CERN 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*.
- 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.



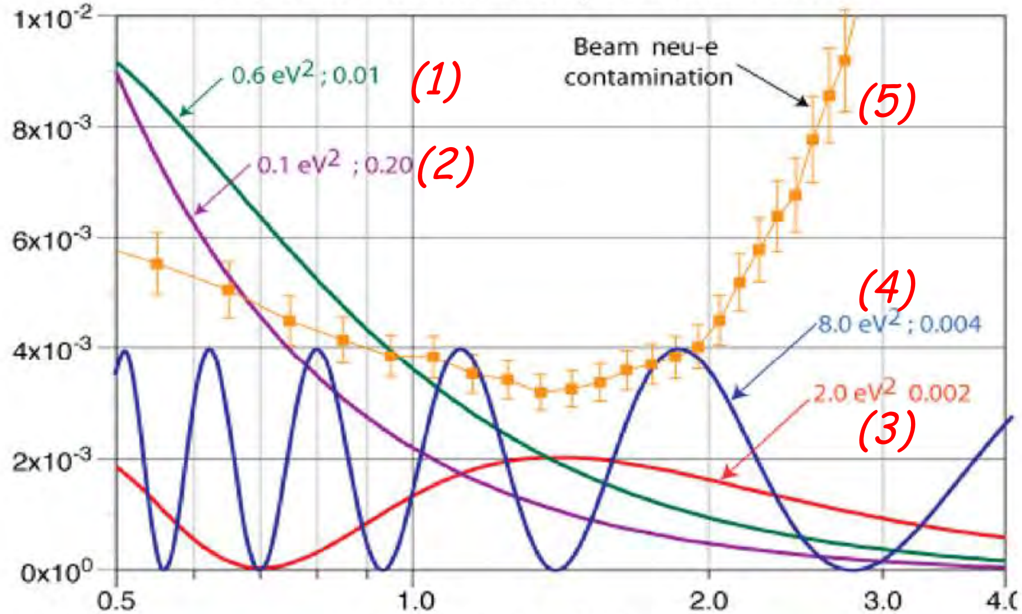
Precise identity of ν-e events in the near and far positions

Basic features of the proposed experiment

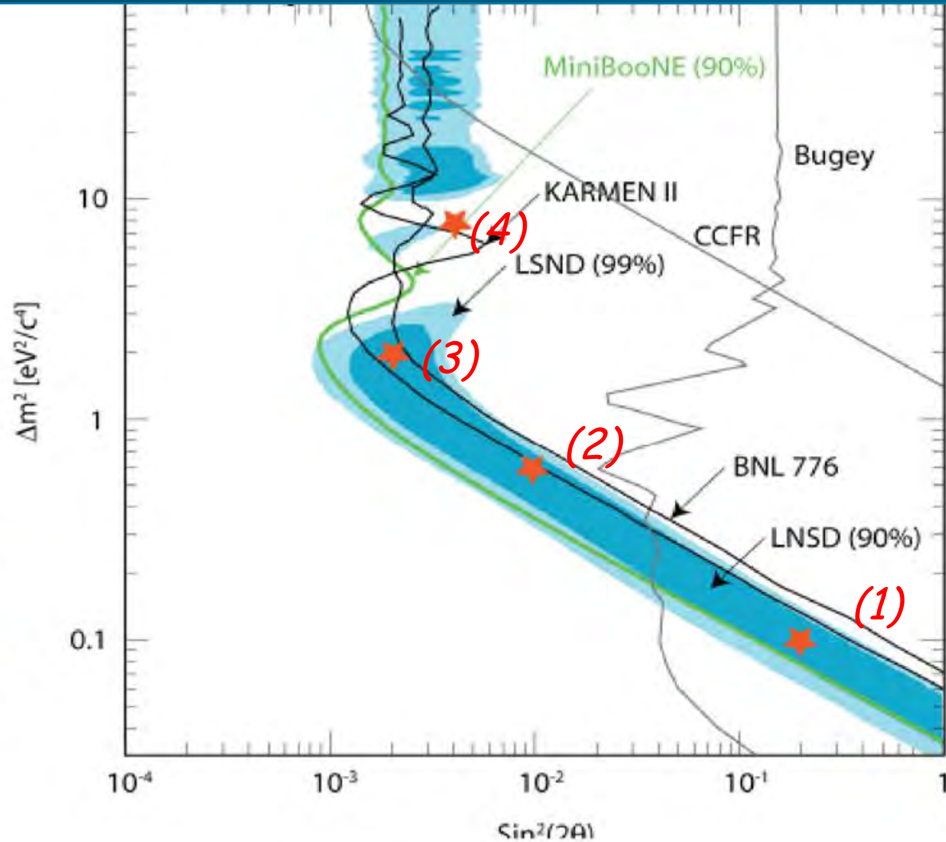
- Our proposed experiment, collecting a large amount of data both with neutrino and antineutrino focussing and muon momentum determination may be able to give a likely definitive answer to the 4 following queries:
  - the LSND/+MiniBooNe both antineutrino and neutrino $\nu\mu \rightarrow \nu e$ oscillation 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.

LSND direct determination of mass and mixing angle

Two neutrino oscillation pattern at 1.6 km

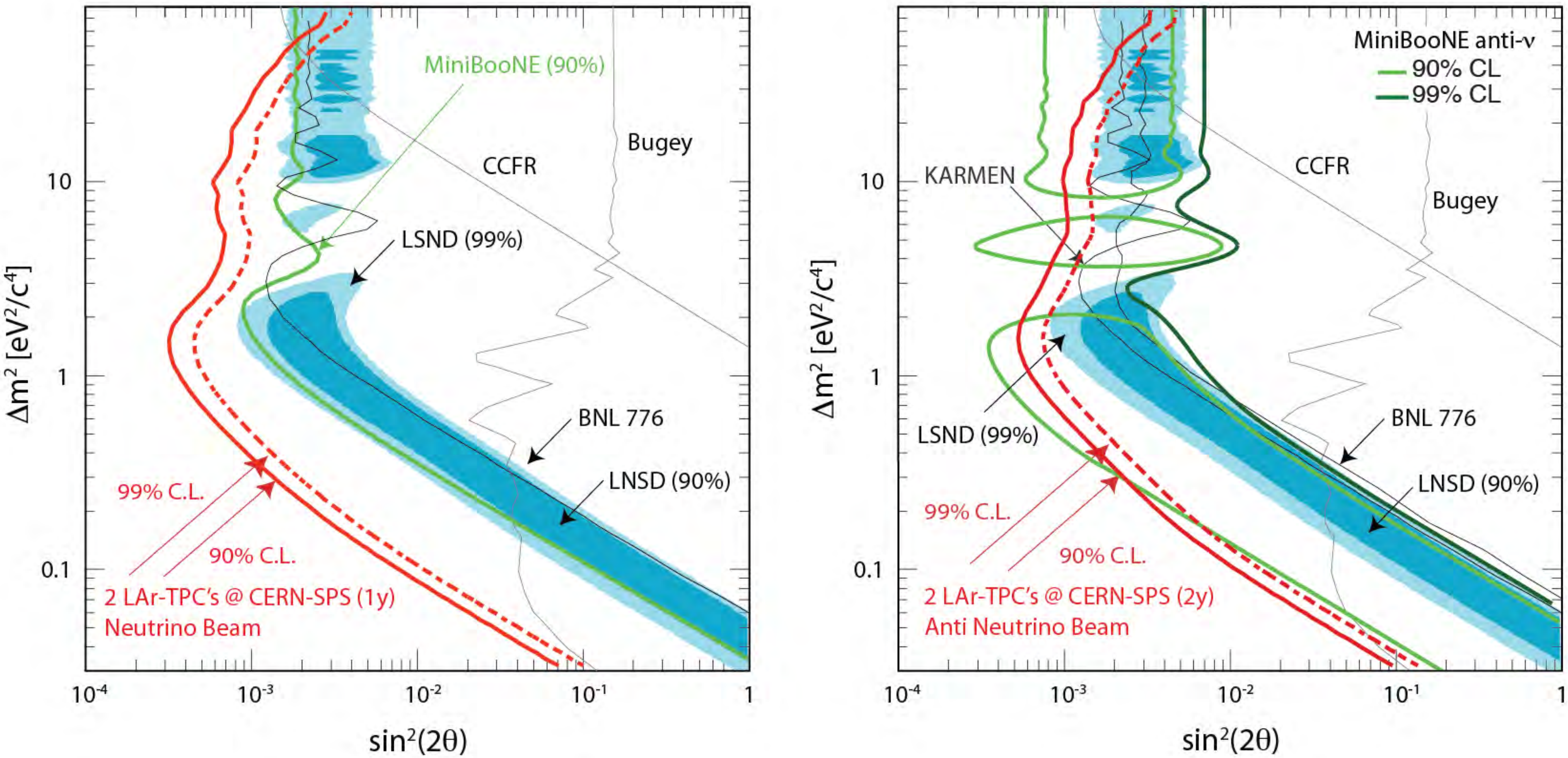


Neutrino energy, GeV/2



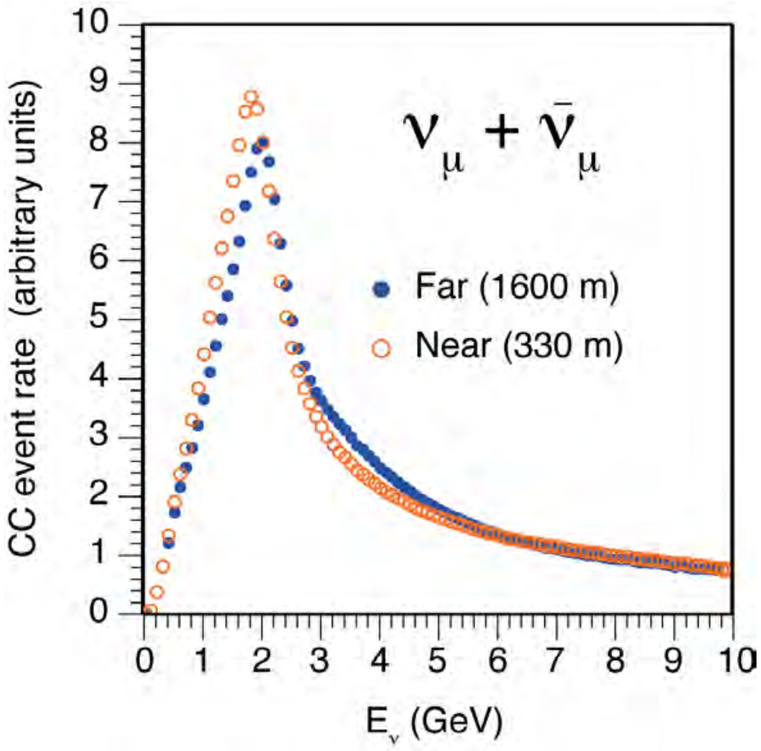
- The present method, unlike LNSD and MiniBooNE, determines both the mass difference and the value of the mixing angle.
- Very different and clearly distinguishable patterns (1-4) are possible, depending on the values in the (Δm^2 – $\sin^2 2\theta$) plane.
- The intrinsic ν -e background (5) is also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

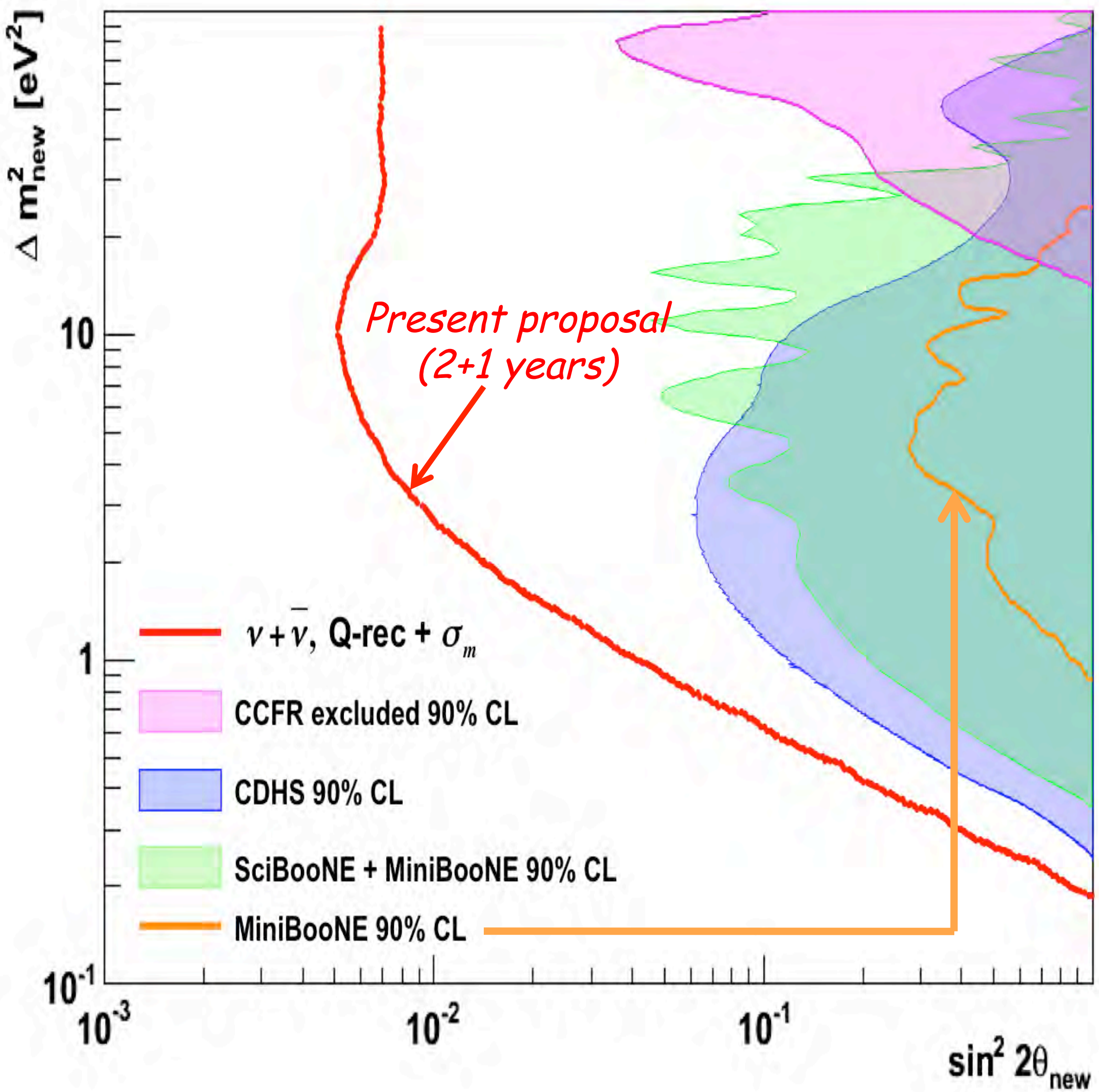
Comparing LSND sensitivities



Expected sensitivity for the proposed experiment: ν_μ beam (left) and anti-ν_μ (right) for 4.5 10^{19} pot (1 year) and 9.0 10^{19} pot (2 years) respectively. LSND allowed region is fully explored in both cases.

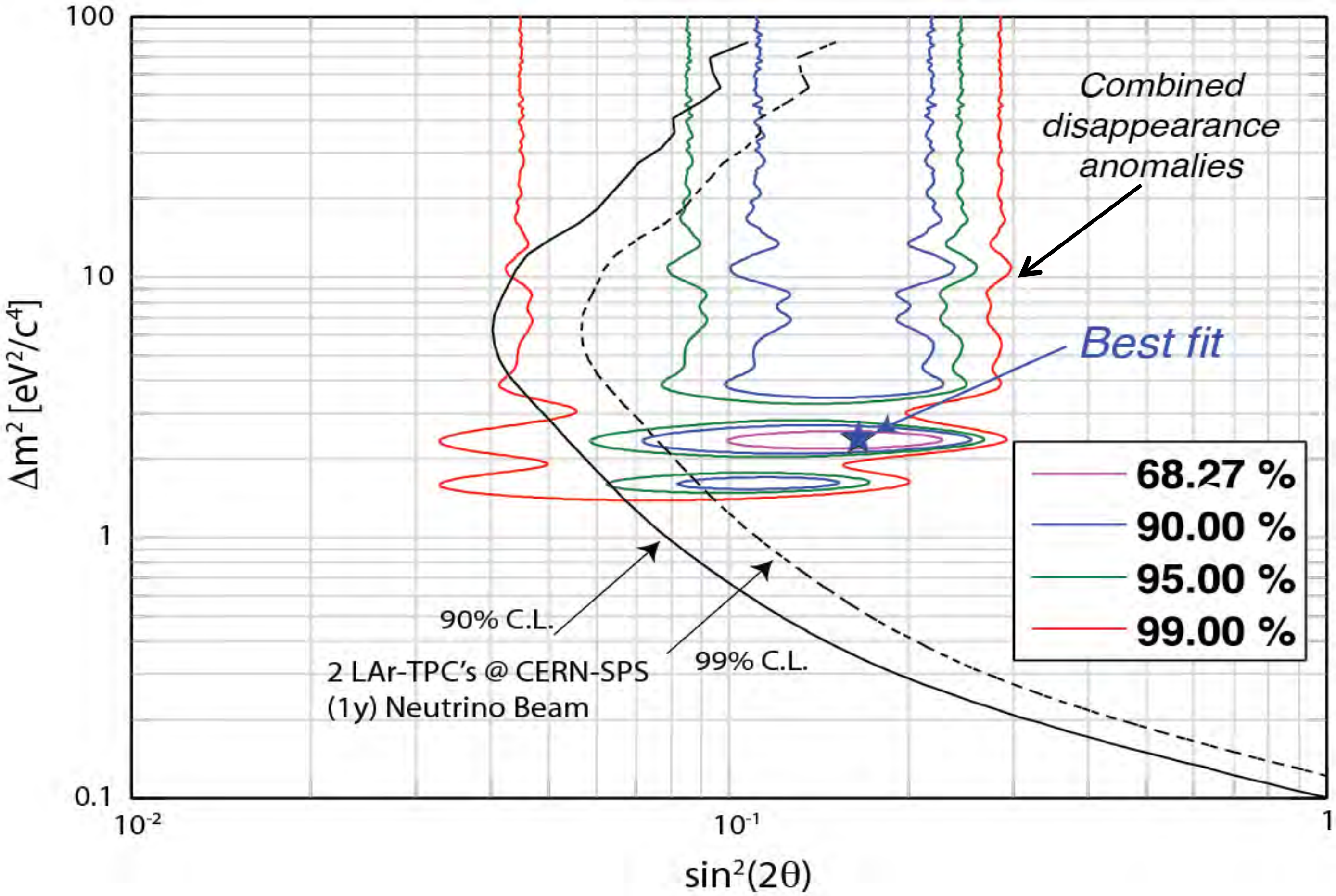
Sensitivity to νμ disappearance





90% C.L. sensitivity for 2 years anti-ν + 1 year ν. Exclusion limits : CCFR, CDHS, SciBooNE + MiniBooNE

Sensitivity to ν_e disappearance anomalies



- *Oscillation sensitivity in $\sin^2(2\theta_{new})$ vs. Δm^2_{new} distribution for CERN-SPS neutrino beam (1 year). A 3% systematic uncertainty on energy spectrum is included. See also combined "anomalies" from reactor neutrino, Gallex and Sage experiments.*

Expected signals for LSND/MiniBooNE anomalies

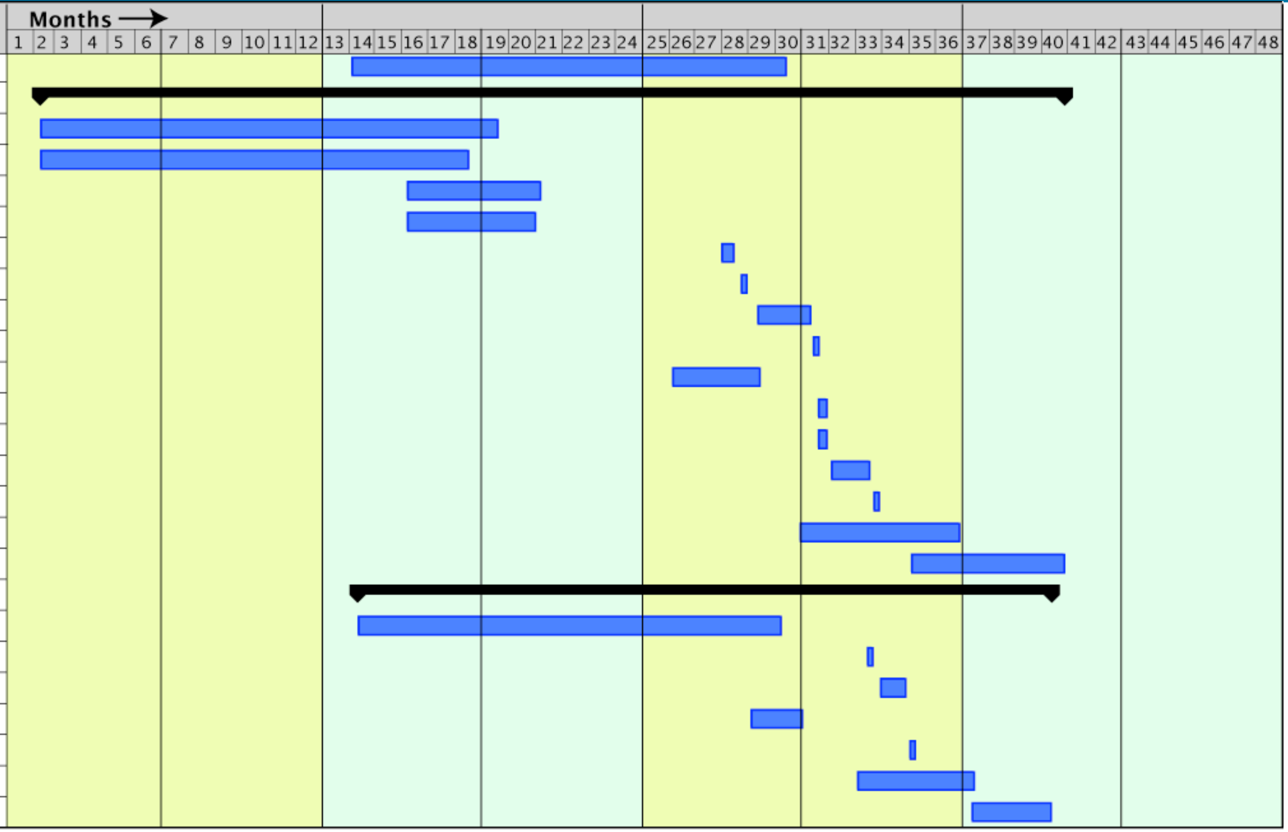
- Event rates for the near and far detectors given for 4.5 10^{19} pot. The oscillated signals are clustered below 3 GeV of visible energy
- Values for: $\sin^2(2\theta) = 0.002$, $\Delta m^2 = 2\ eV^2$ are reported as example

		NEAR (neg. foc.)	NEAR (pos. foc.)	FAR (neg. foc.)	FAR (pos. foc.)
produced	$\nu_e + \bar{\nu}_e$ (LAr)	35 K	54 K	4.2 K	6.4 K
produced	$\nu_\mu + \bar{\nu}_\mu$ (LAr)	2030 K	5250 K	270 K	670 K
	Appear. test point	590	1900	360	914
detected	ν_μ (LAr+NESSiE)	230 K	1200 K	21 K	110 K
detected	ν_μ (NESSiE)	1150 K	3600 K	94 K	280 K
detected	$\bar{\nu}_\mu$ (Lar+NESSiE)	370 K	56 K	33 K	6.9 K
detected	$\bar{\nu}_\mu$ (NESSiE)	1100 k	300 K	89 K	22 K
detected	Disappear. test point	1840	4700	1700	5000

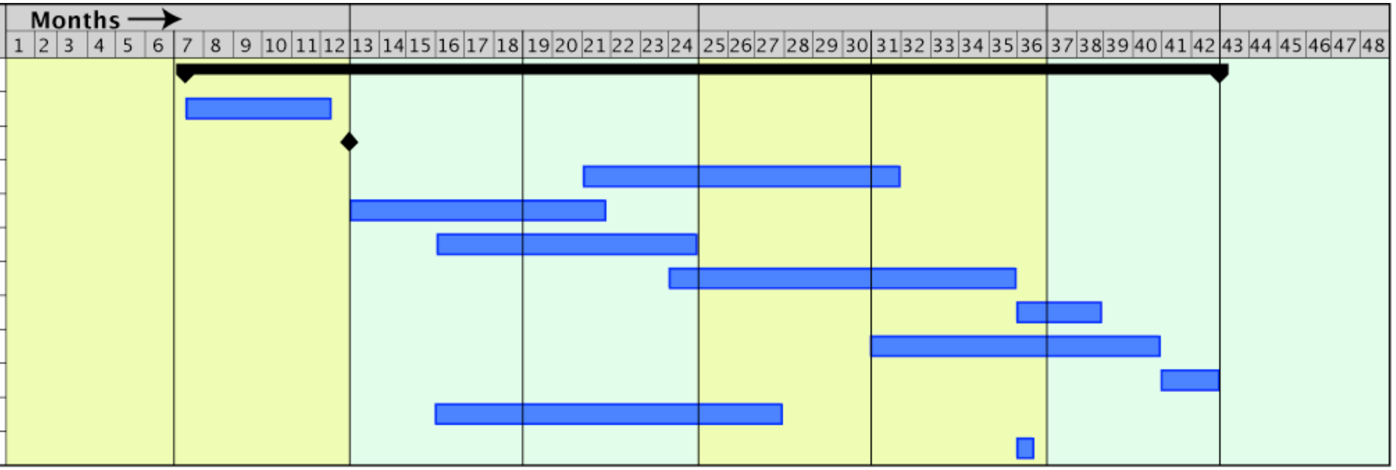
NOTE: ν "contamination" in anti-ν negative polarity beam

Time Schedule

Name	Days
Buildings in NA: preparation-erection	356
⊟**T600**	**833**
Vessels, thermal Isolation: design, orders...	373
Transport frame: design, order, constructio...	349
Working area equipment...	111
T600 decommissiong & disassembly...	106
T600 first vessels delivery...	11
T600 first TPC transport to CERN	6
T600 First module assembly	46
T600 First module tranport in NA	6
T600 thermal isolation erection...	73
T600 second vessels delivery	10
T600 second TPC transport to CERN	9
T600 second module assembly	35
T600 second module tranport in NA	6
T600 plant assembly...	131
T600 final tests, commissioning, filling...	125
⊟**T150**	**566**
T150 TPC order, construction, delivery	346
T150 vessel delivery	6
T150 cryostat assembly	24
T150 thermal isolation erection	45
T150 transport in NA	6
T150 plant assembly	97
T150 final tests, commissioning, filling...	66



Name	Days
⊟**NESSIE**	**773**
prototype construction	110
Start Tenders for Iron	1
iron production-Lamination	239
Construction Assembling Tools	194
Coils and cooling	196
FAR Iron Magnet - Assembling	261
FAR Commissioning	65
NEAR Iron Magnet - Assembling	218
NEAR Commissioning	43
Air Magnet construction	261
Air Magnet insertion on site	15



Future sterile neutrino searches elsewhere

- **Radioactive sources** (EC, fission fragments) plus low energy detectors to search for ν_e, anti-ν_e disappearance. Elastic Scattering: Daya Bay, Borexino, SNO+Cr; Charged Current: LENS, Baksan, Ce-LAND, Borexino; Neutral Current: RICOCHET. Most use existing detectors.
- **Reactors.** Several ideas for new reactor experiments. Some, piggy-backing on safe guards measurements are under construction: Nucifer, SCRAAM, Stereo. Need to be very close to reactor core. Small cores advantageous.
- **Stopped π Beams:** (Direct test of LSND anomaly): OscSNS: Improved LSND (Off beam axis, lower duty factor, gadolinium?); LSND-Reloaded: Gd-loaded Super-K plus cyclotron. What if LSND is new physics but not oscillations?
- **Decay in Flight Beams:** MicroBooNE, BooNE, LArLAr, VLENF: the CERN idea of a two-detector experiments is now also considered in order to clarify the MiniBooNE/LSND anomaly.

(visit http://cnp.phys.vt.edu/white_paper/)

Conclusive Studies

Oscillation	*Neutrinos*	*Experiments*
θ_{12}	ν_e(solar, reactors)	SNO, SK, Borexino, Kamland
θ_{23}	ν_μ (atmospheric, accelerators)	SK, Minos, T2K
θ_{13}	ν_e(reactors)	Daya Bay, Reno, Double Chooz
θ_{14}	ν_e(reactors, radioactive sources)	SBL Reactors, Gallex, Sage, Daya Bay, **This Proposal**
θ_{24}	ν_μ (accelerators)	CDHS, Miniboone. **This Proposal**


Thank you !