DOUBLE-LAr: Sterile neutrinos with the CERN PS

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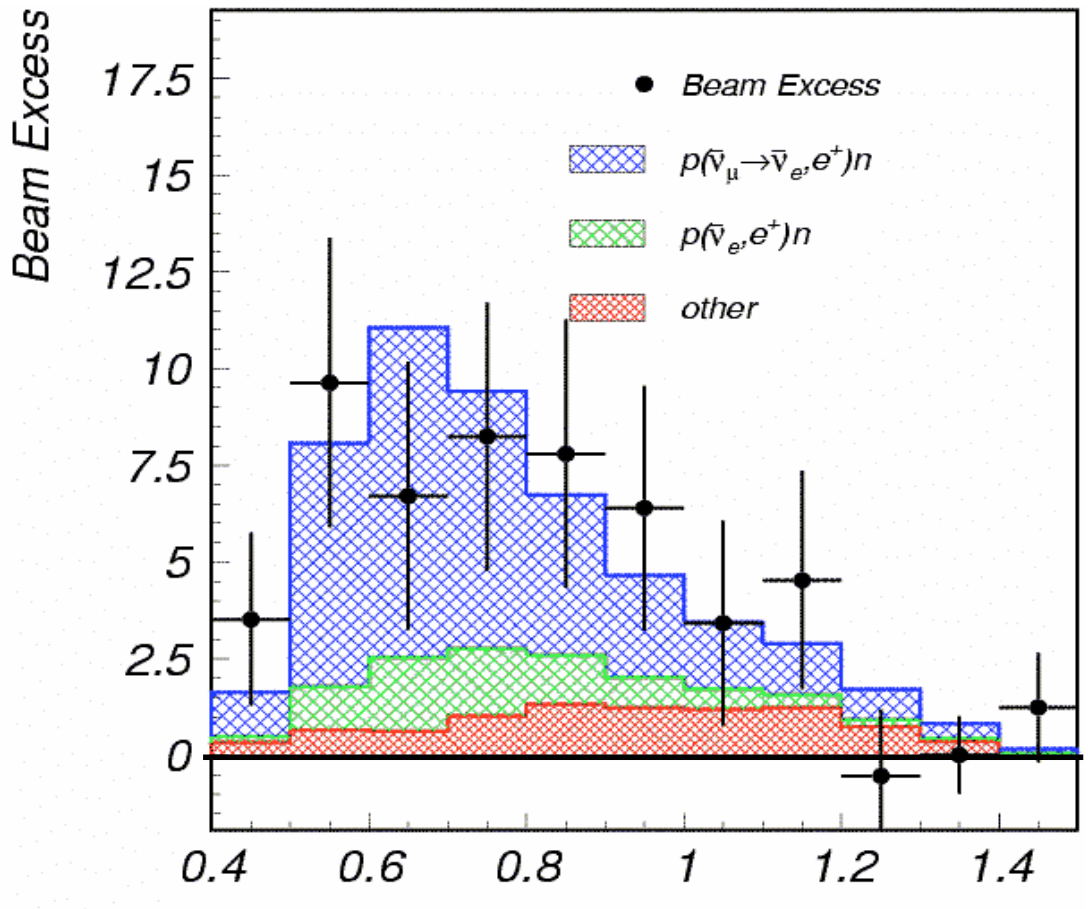
Persisting neutrino anomalies

beyond the standard model…

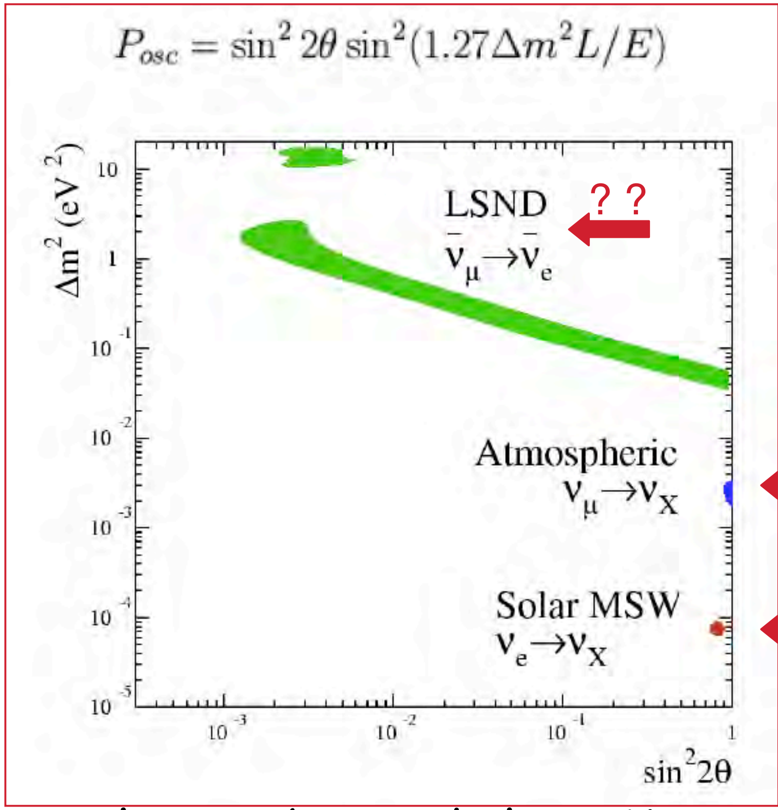
The LSND Experiment: antineutrino oscillations ?

LSND has observed an excess of $\bar{\nu}_e$ events in a $\bar{\nu}_\mu$ beam, 87.9 ± 22.4 ± 6.0 **(3.8σ)**



LSND Collab, PRD 64, 112007

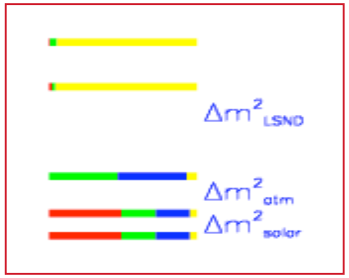
Points -- LSND data
Signal (blue)
Backgrounds (red, green)



- 3 oscillation signals, if confirmed, require new physics beyond the SM

Many theoretical hypothesis…..

3+2 Sterile Neutrinos — Sorel, Conrad, & Shaevitz (PRD70(2004)073004)



← Additional, sterile neutrinos ?

← Standard neutrinos

MaVaNs & 3+1 — Hung (hep-ph/0010126)

Sterile Neutrino — Kaplan, Nelson, & Weiner (PRL93(2004)091801

CPT Violation & 3+1 Sterile Neutrino — Barger, Marfatia, & Whisnant (PLB576(2003)303)

Quantum Decoherence — Barenboim & Mavromatos (PRD70(2004)093015)

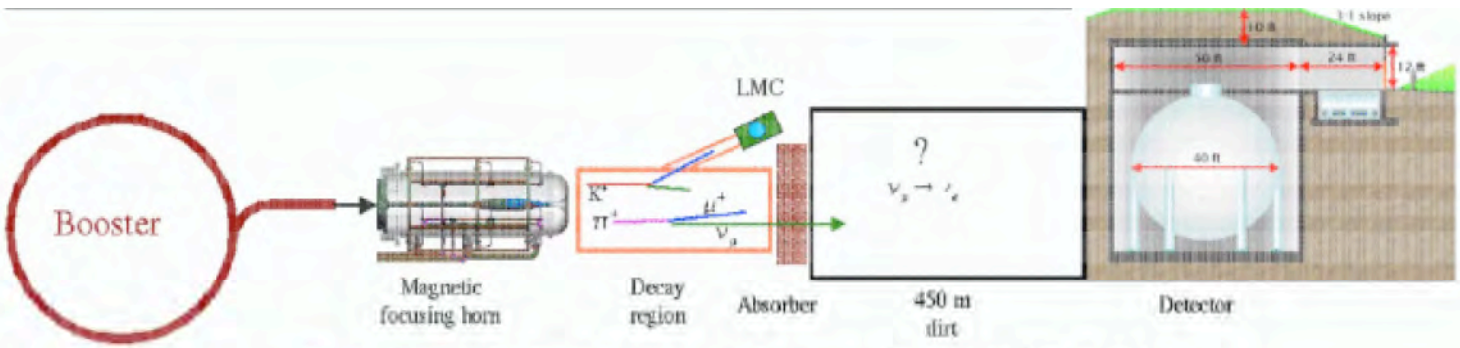
Lorentz Violation — Kostelecky & Mewes (PRD70(2004)076002)
Katori, Kostelecky, Tayloe (hep-ph/0606154)

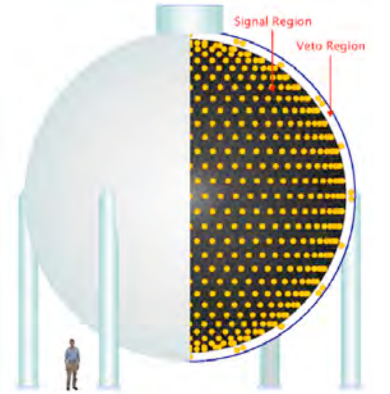
Extra Dimensions — Pas, Pakvasa, & Weiler (PRD72(2005)095017)

Sterile Neutrino Decay — Palomares-Ruiz, Pascoli, & Schwetz (JHEP509(2005)48)

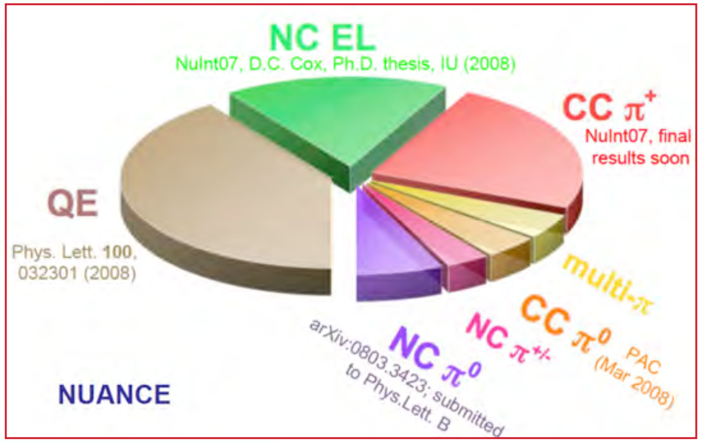
And so on….

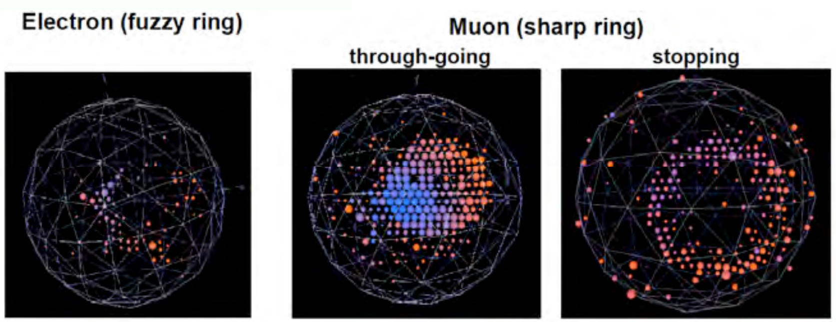
The MiniBooNE experiment at FNAL (1998-today)





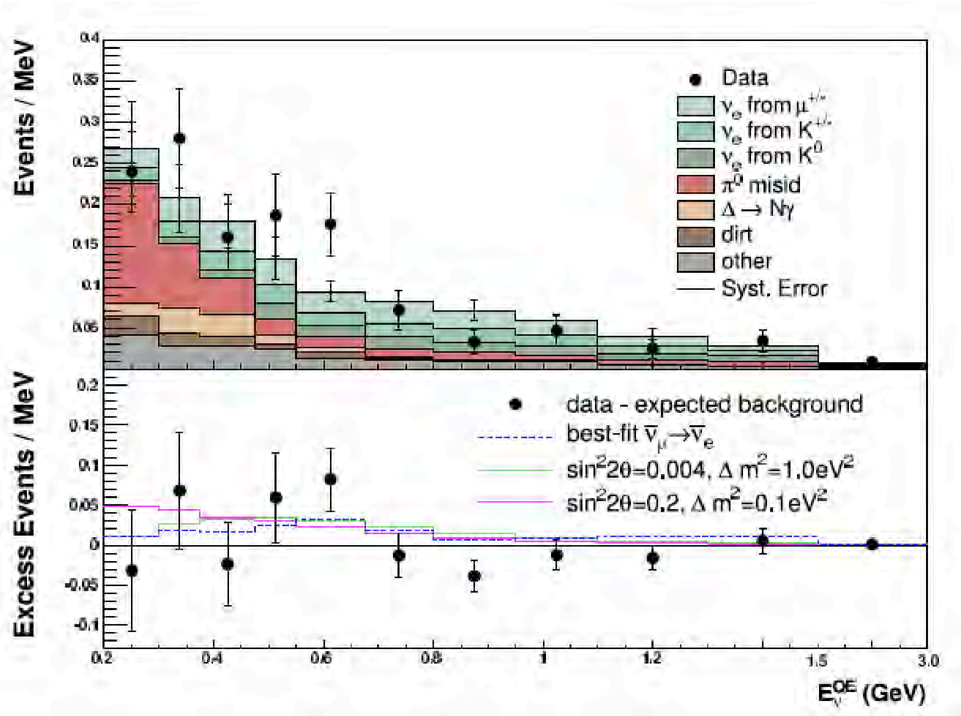
- Booster - 8 GeV proton beam (5 x 10^{20} POT/y)
- Target - 71 cm Be
- Horn - 5 Hz, 170 kA, 143 µs, 2.5 kV, 10^8 pulses/y
- Decay Pipe - 50 m (adjustable to 25 m)
- Neutrino Distance - ~ 0.5 km
- $\langle E_\nu \rangle$ ~ 1 GeV
- (ν_e / ν_μ) ~ 5×10^{-3}
- Detector - 40' diameter spherical tank
- Mass - 800 (450) tons of mineral oil
- PMTs - 1280 detector + 240 veto, 8" diameter



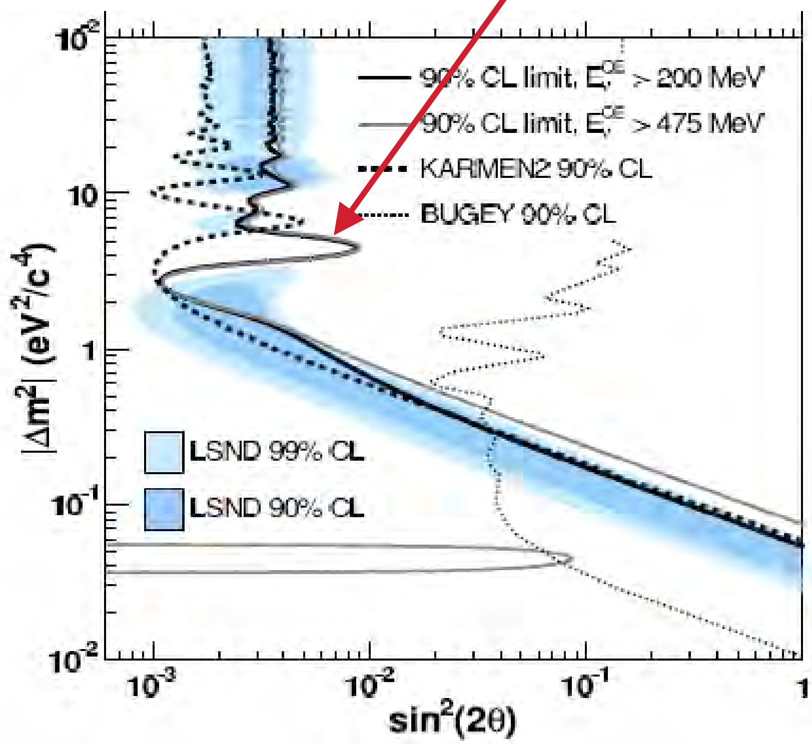


MiniBooNE experiment: antineutrino data

- MiniBooNE result for anti-neutrino events, the direct analog of LSND, is based on 3.39 x 10^{20} POT.
- The result is inconclusive with respect to the LNSD result.
- LSND is still alive and well.

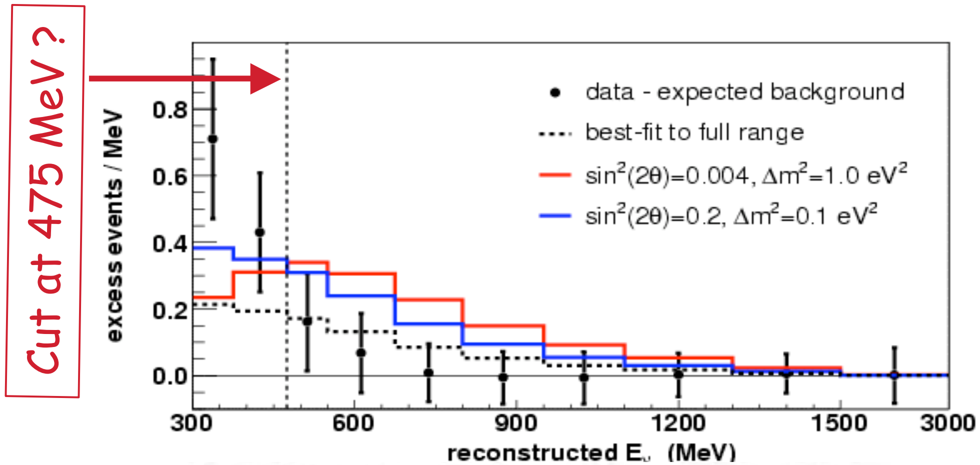


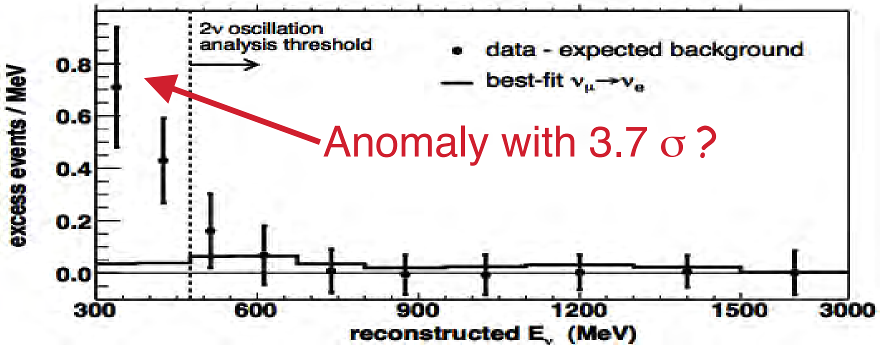
MiniBooNE limit at 90 %

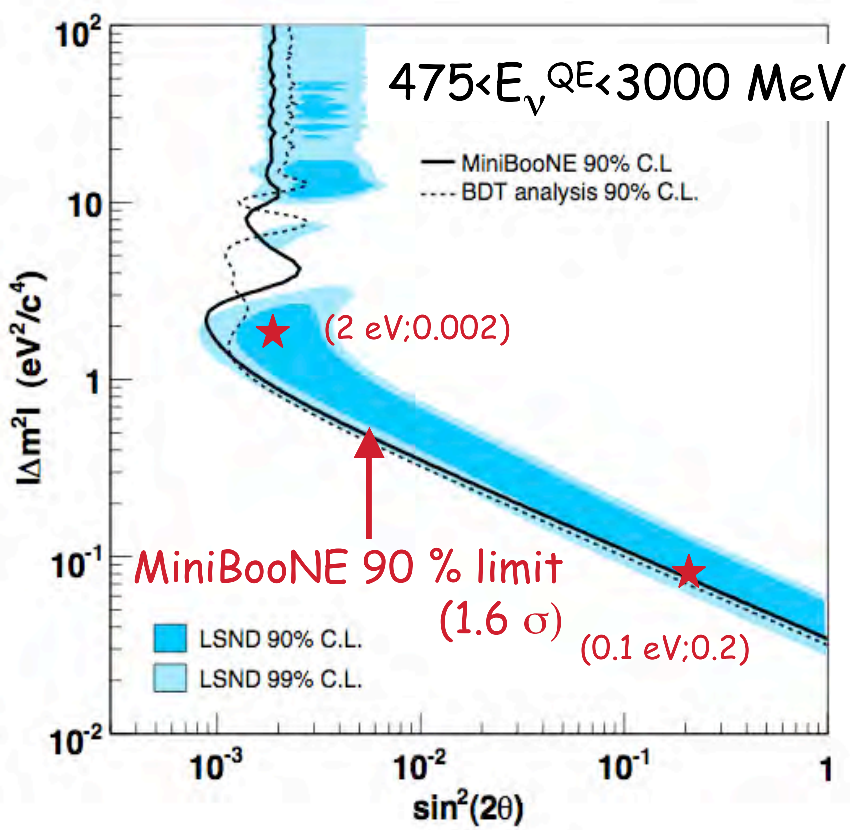


MiniBooNE experiment: neutrino data

- MiniBooNE result for neutrino events is based on 6.46 x 10^{20} POT, corresponding to 1.5x10^{5} $\nu\mu$ CC-QE events
- We expect 375 νe CC-QE intrinsic background events. with a possible LSND signal of ~200 νe CC-QE events
- 96±17±20 events above background, for 300 < E_{ν}^{QE} < 475MeV:



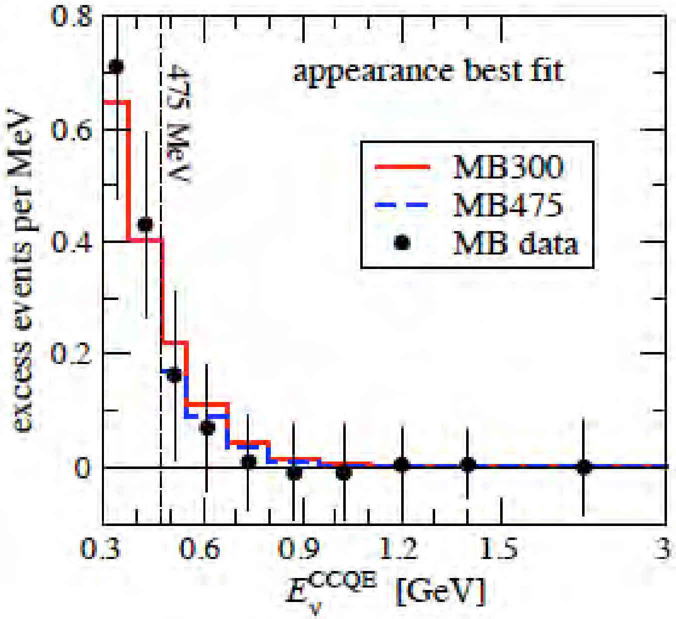




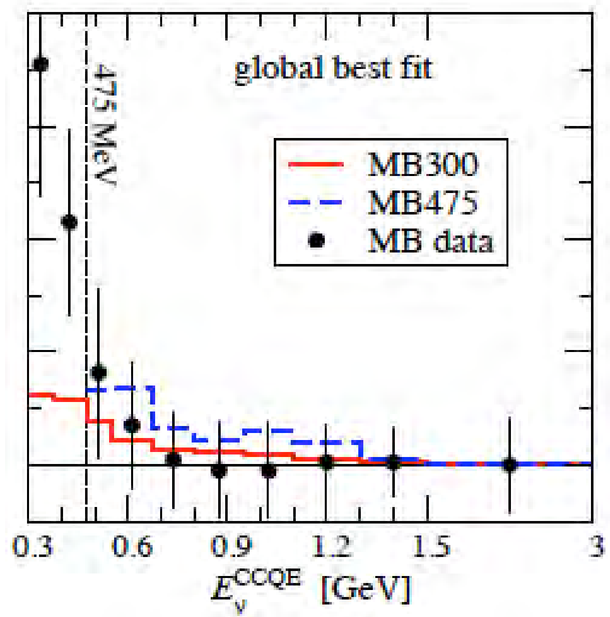
Theoretical considerations: a signal with 5 neutrinos ?

- In models with more than one sterile neutrino (see for instance Maltoni and Schwetz, Phys. Rev. D 76, 093005 (2007)) MiniBooNE results are in perfect agreement with the LSND appearance evidence.
- However, if all other disappearance data are taken into account (3+2) oscillations are no longer in full agreement.

Fit to LSND, KARMEN, NOMAD, MB



Global fit to all experimental data



The search for sterile neutrinos

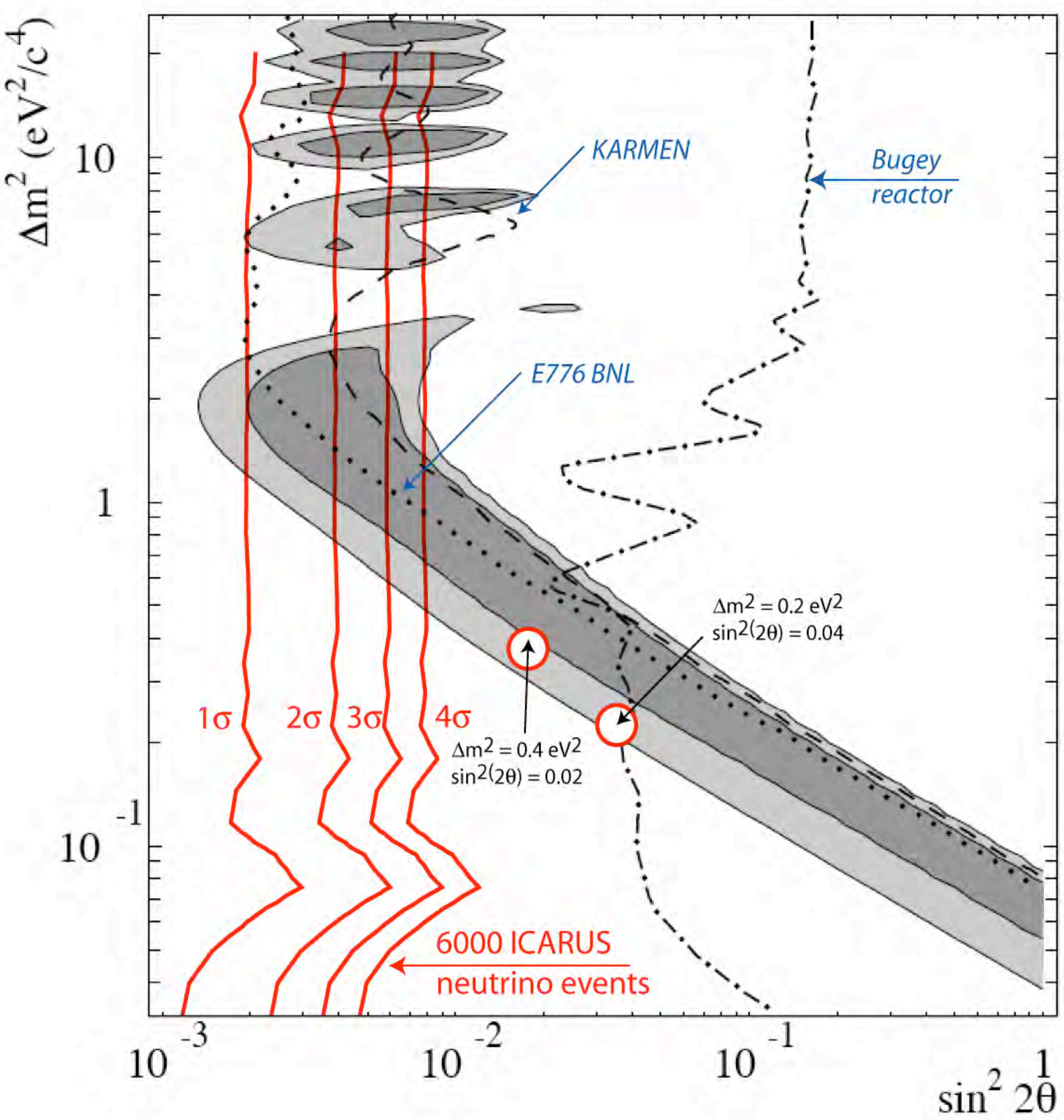
is continuing:

future experimental searches (3)

The ICARUS experiment at LNGS

Sterile neutrino search with CNGS2 (ICARUS)

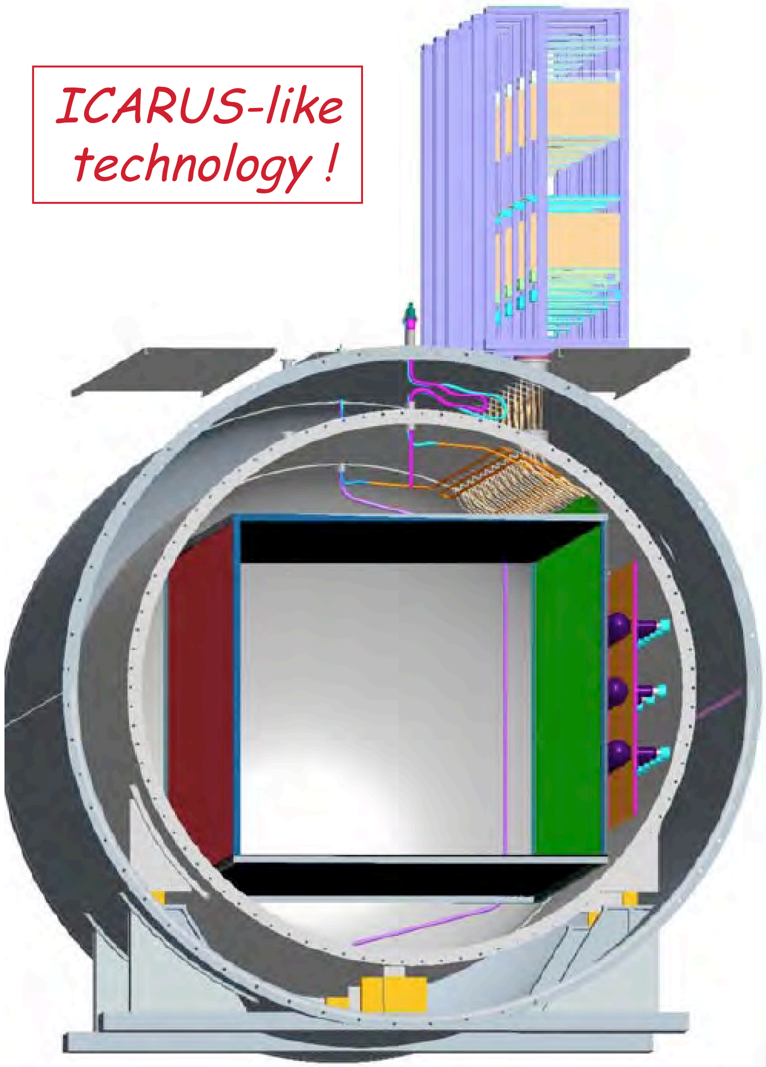
- The $\sin^2(2\theta)$-Δm^2 explored region covers most of LNSD allowed areas and extends to lower values of Δm^2
- Two indicated points are reference values of MiniBooNE proposal and of previous slides
- Data taking will be enough to exclude $\sin^2(2\theta)$ values > 5 10^{-3} at 3 σ with ν (!)
- Smaller $\sin^2(2\theta)$ are not explored. *An additional LAr experiment at PS is proposed for ν and ν-bar.*



Newly proposed experiments : MicroBooNE at FNAL

- The LNSD search is continuing at FNAL.
- Present MiniBooNE relies heavily on Montecarlo simulations (NUANCE) based on the extremely scarce neutrino events from 40 years old bubble chambers.
- MicroBooNE is a new LArTPC detector from the Booster designed to advance LAr R&D in the US in collaboration with ICARUS and to determine whether the MiniBooNE low-energy excess is due to electrons or photons.
- A 70-ton fiducial volume detector, located near MiniBooNE.
- Received Stage-1 approval at Fermilab and initial funding from DOE and NSF.
- It may begin data taking as early as 2012.

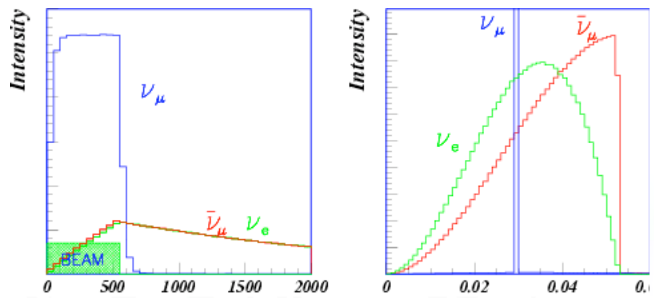
ICARUS-like technology !

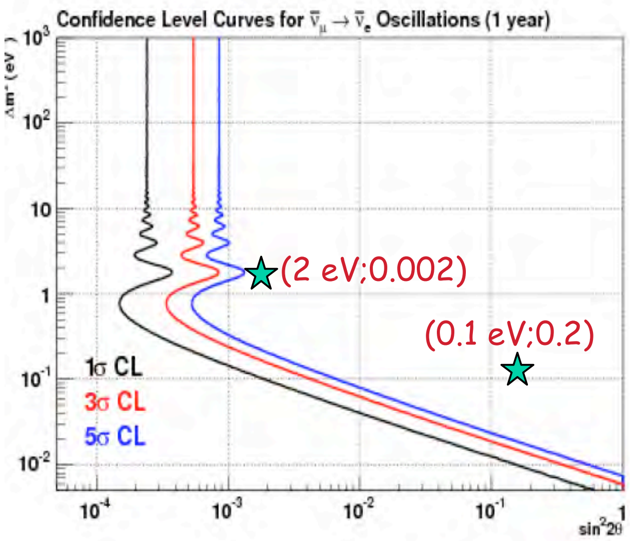


Are 70 tons of LAr at one single location sufficient to settle definitively ν and ν-bar signals?

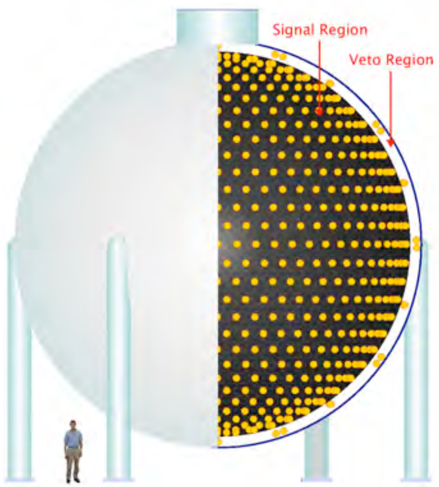
Newly proposed experiments : OscSNS at ORNL

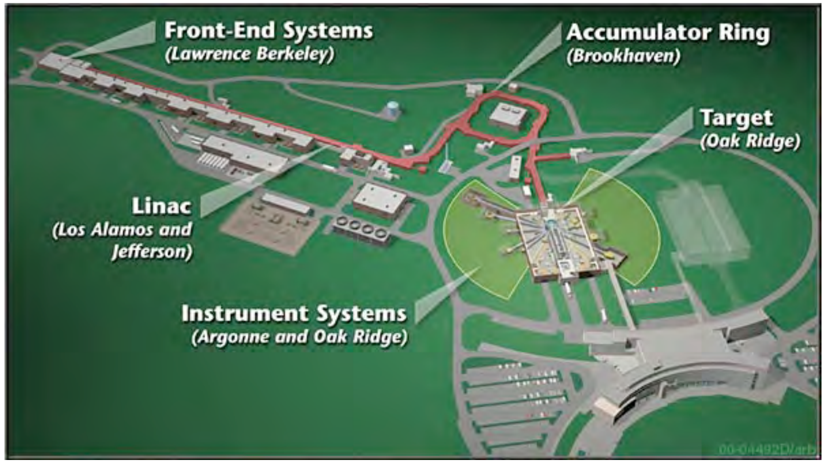
- A new experiment with pions at rest, similar to LSND but with a higher intensity spallation source (1.4 MW) planned at SNS.
- A "MiniBooNE-like" detector (800 t) with higher PMT coverage at a distance of ~60 m from the SNS beam stop at ORNL.





MiniBooNE Detector





One year of "nominal" SNS intensity

Distance to detector	Disappearance ($\nu_\mu \rightarrow$ sterile)	Appearance intrinsic background (anti-ν_e + X $\rightarrow$ e)	Appearance signal (anti-$\nu_\mu \rightarrow$ anti-ν_e with 0.26% oscillation probability)
60 m	6,322 ± 81	79 ± 24	253 ± 3

LSND result was based on 87.9 events !

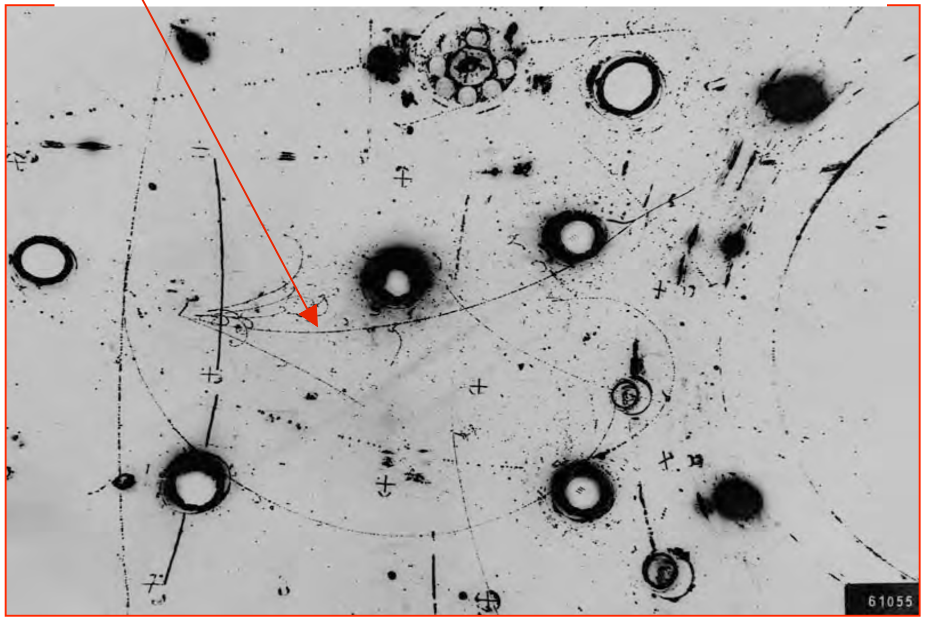
A definitive determination of the sterile neutrino anomaly puzzle with LAr at the CERN-PS ?

(LOI)

The LAr electronic chamber

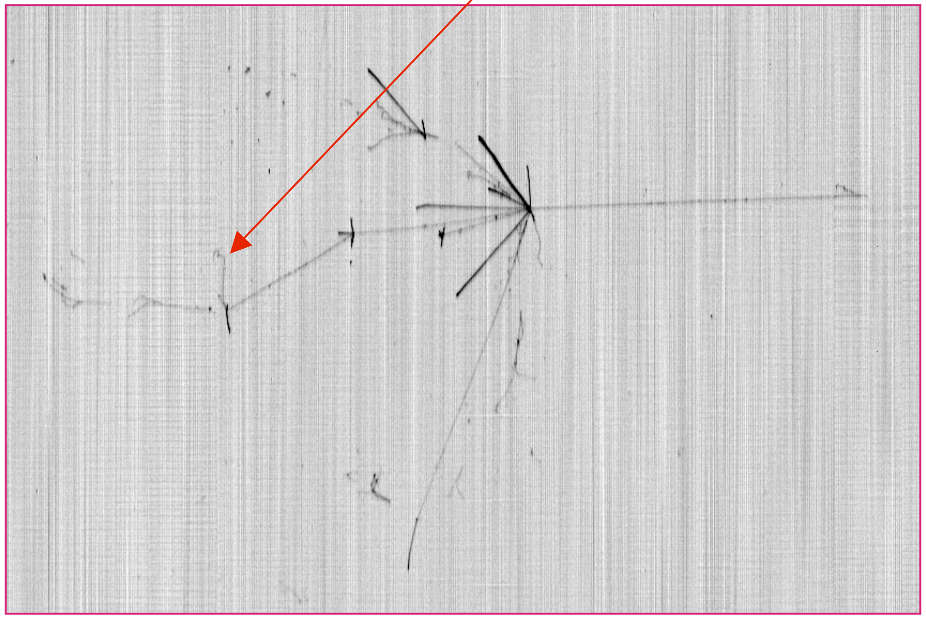
Bubble diameter ≈ 3 mm (diffraction limited)

Gargamelle bubble chamber



Bubble size ≈ 3x3x0.2 mm^3

ICARUS electronic chamber



Medium	*Heavy freon*	
Sensitive mass	3.0	ton
Density	1.5	g/cm^3
Radiation length	11.0	cm
Collision length	49.5	cm
dE/dx	2.3	MeV/cm

≈ 3 tons (pulsed)

Medium	*Liquid Argon*	
Sensitive mass	Many ktons	
Density	1.4	g/cm^3
Radiation length	14.0	cm
Collision length	54.8	cm
dE/dx	2.1	MeV/cm

ICARUS 600 t Now commissioned at LNGS (CNGS2)

Liquid Argon TPC properties

- High density, heavy ionization medium
  - r = 1.4 g/cm^3, X_0=14 cm, l_{int} = 80 cm
- Very high resolution detector
  - 3D image 3 x 3 x 0.6 mm3 (400 ns sampling)
- Continuously sensitive
- Self-triggering or through prompt scintillation light
- Stable and safe
  - Inert gas/liquid
  - High thermal inertia (230 MJ/m3)
- Relatively cheap detector
  - Liquid argon is cheap, it is only "stored" in the experiment
  - TPC: # of channels proportional to surface

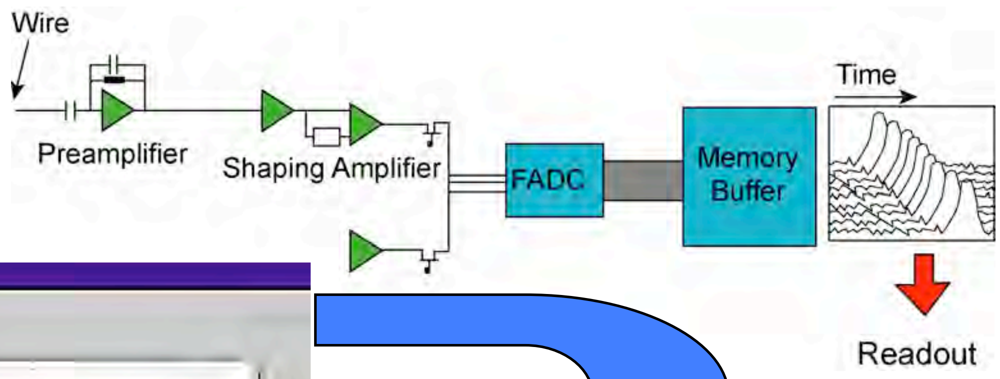
- Cryogenic temperature
  - T = 88 K at 1 bar
- High purity required for long-drift time
  - 30 ppt of O2 equivalent for 10 ms drift
- No signal amplification in liquid
  - 1 m.i.p. over 3 mm yields 20000 electrons
  - equivalent noise charge 1200 electrons

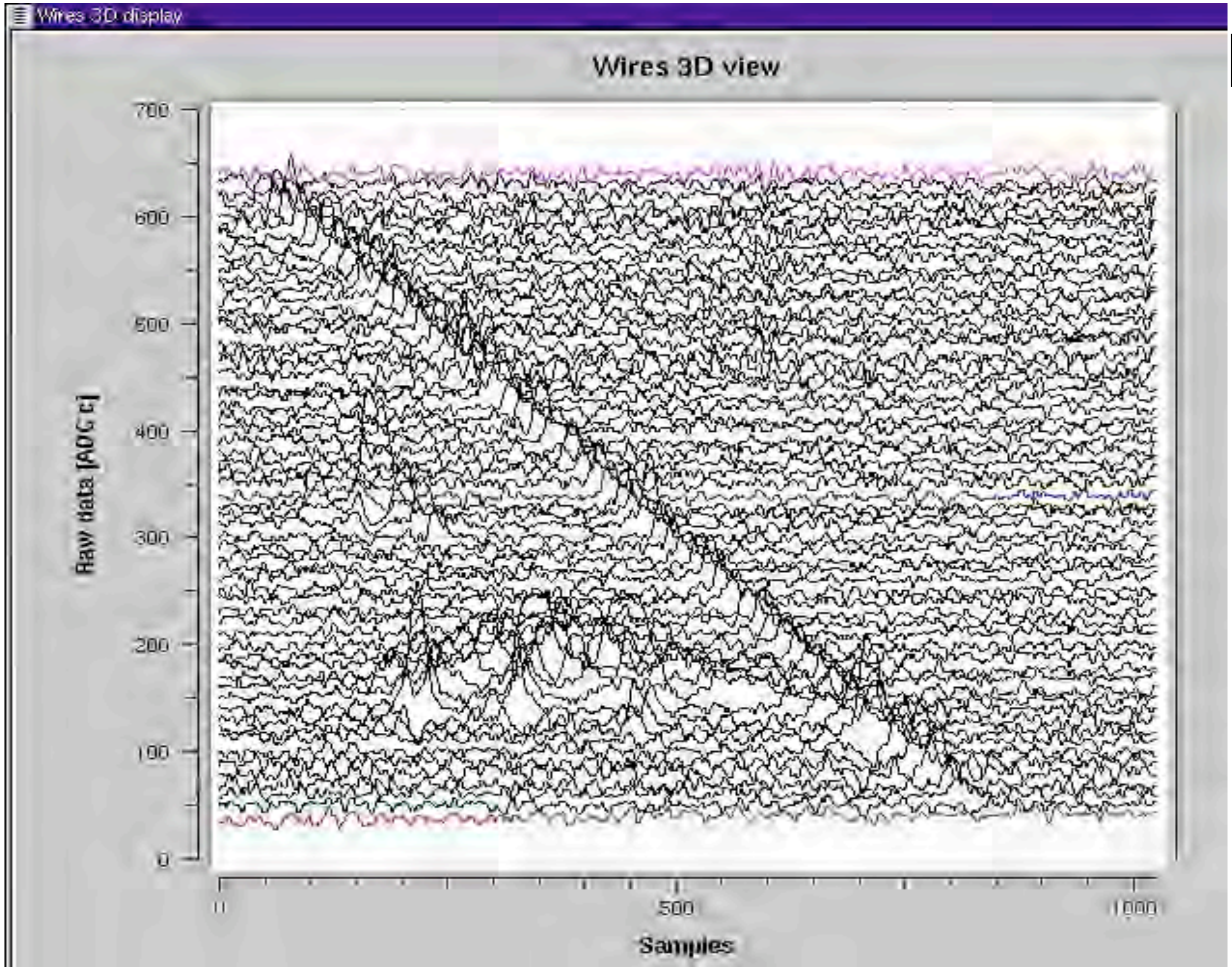
← Cryogenic plant

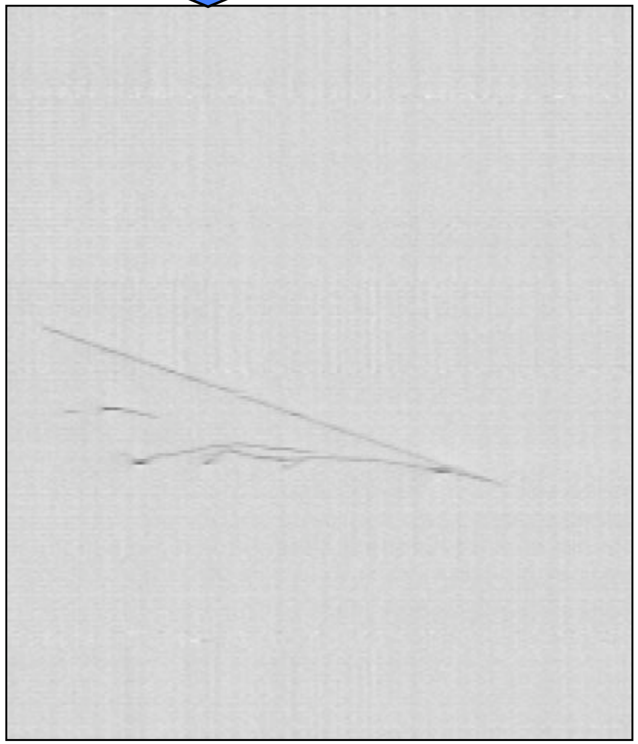
← Argon purification

← Low noise electronics

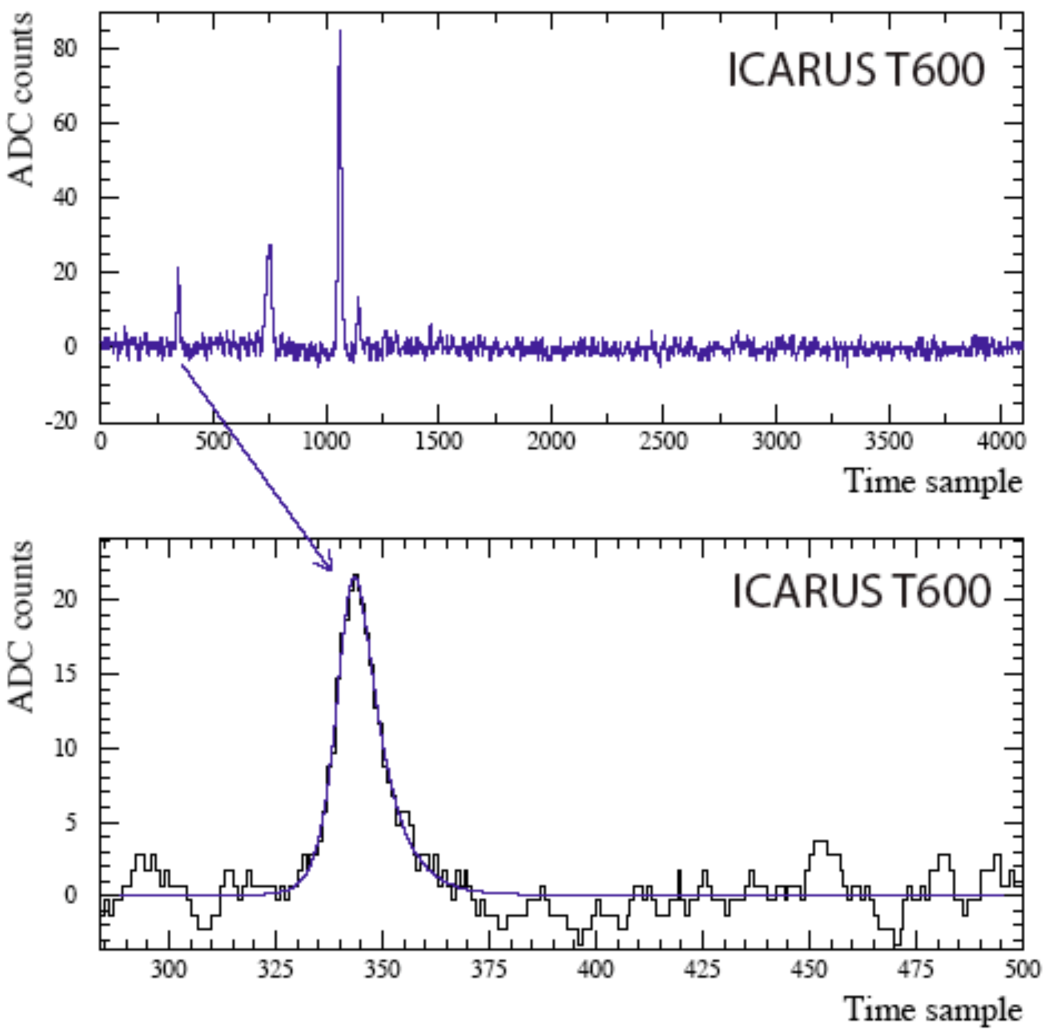
Principle diagram of signal recording







Single wire signal

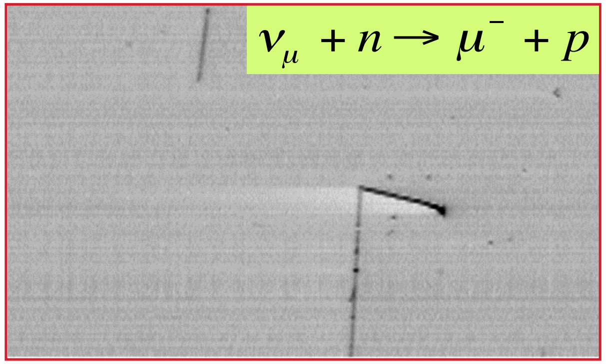


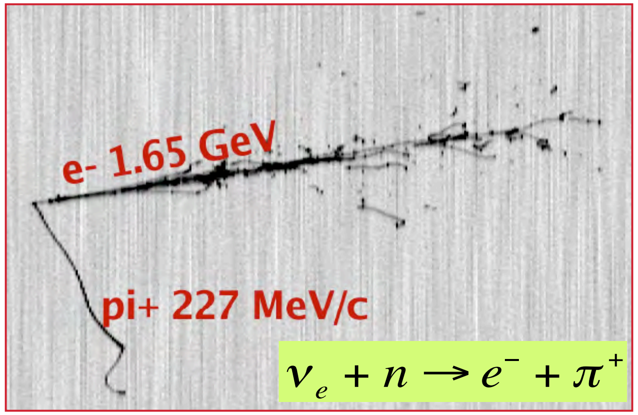
Fit function:

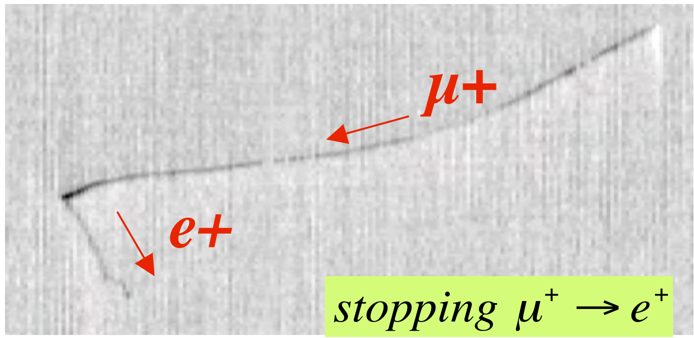
$$f(t) = B + A\frac{e^{-\frac{t-t_0}{\tau_1}}}{1+e^{-\frac{t-t_0}{\tau_2}}}$$

Summary of performances

- Tracking device
  - Precise event topology
  - Momentum via multiple scattering
- Measurement of local energy deposition dE/dx
  - e / γ separation (2%X_0 sampling)
  - Particle ID by means of dE/dx vs range measurement
- Total energy reconstruction of the events from charge integration
  - Full sampling, homogeneous calorimeter with excellent accuracy for contained events







RESOLUTIONS

Low energy electrons: σ(E)/E = 11% / √ E(MeV)+2%

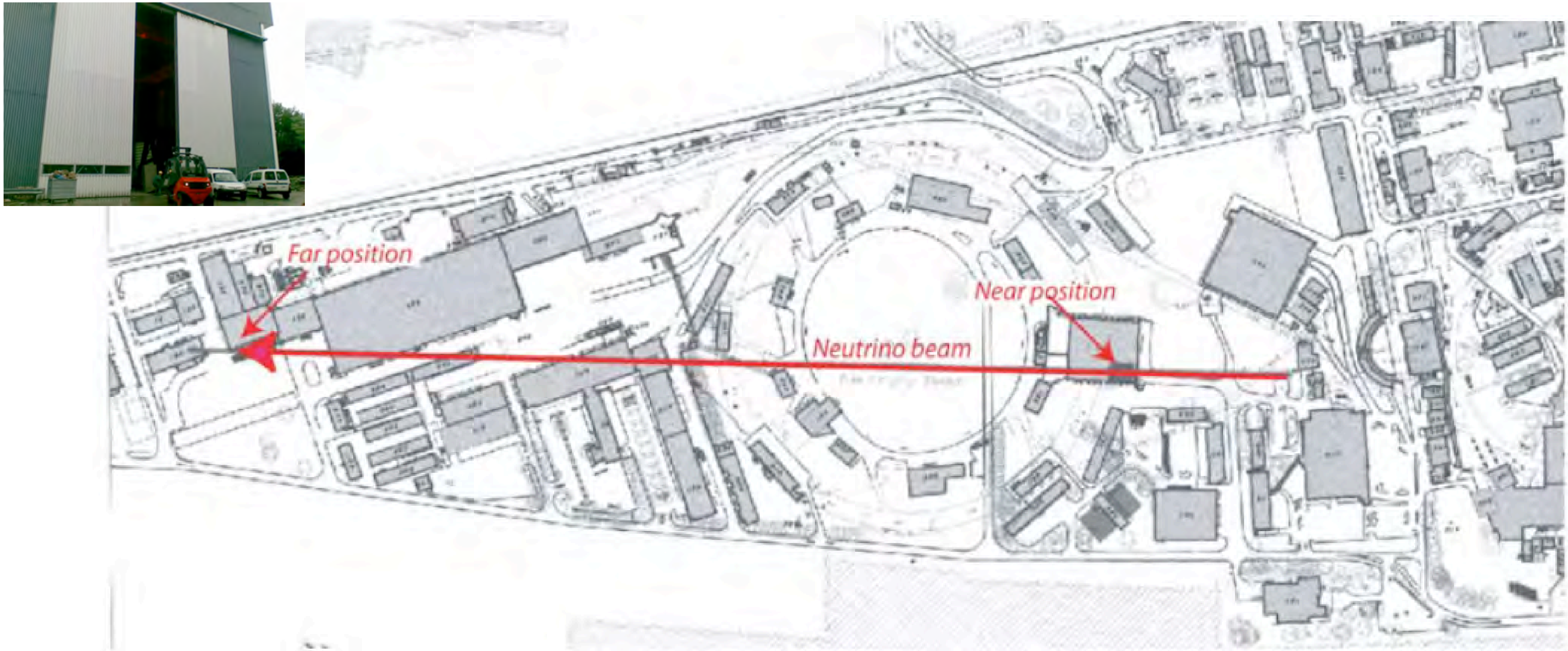
Electromagn. showers: σ(E)/E = 3% / √ E(GeV)

Hadron shower (pure LAr): σ(E)/E ≈ 30% / √ E(GeV)

Hadron shower (+TMG): σ(E)/E ≈ 17% / √ E(GeV)

The CPS neutrino beam

- The PS proton beam at 19.2 GeV/c is extracted from the PS via TT2, TT1 and TT7. The magnetic horn is designed to focus particles of momentum around 2 GeV/c.
- The decay tunnel is about 50 m long, followed by an iron beam stopper. There are two positions for the detection of the neutrinos.
- The far (main) location is at 850 m from the target; a secondary location is foreseen at a distance of 127 m from the target. MiniBooNE was at 550 m from the target.



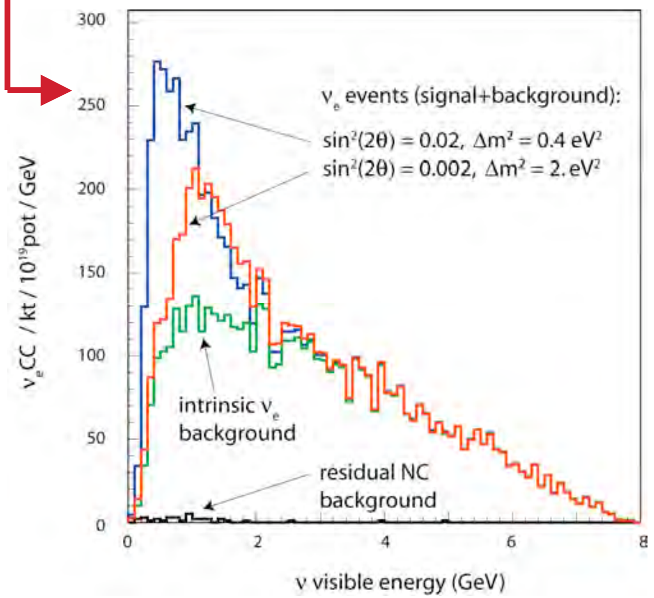
The DOUBLE-LAr

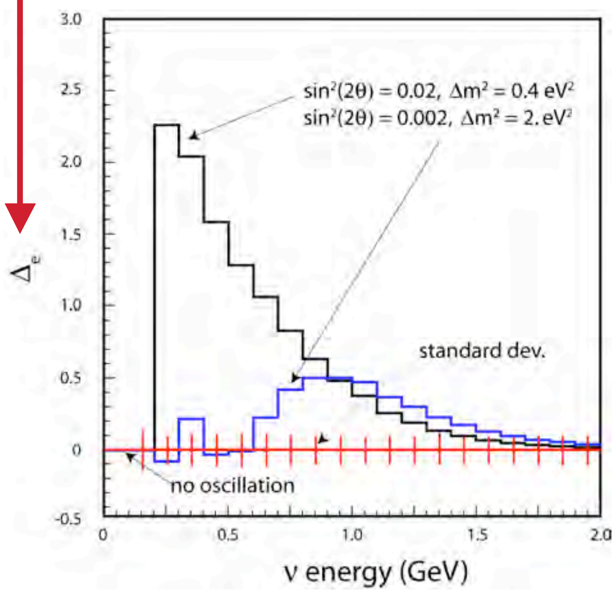
- Expected effect due to $\nu\mu \to \nu e$ oscillation at the far location and for typical LSND-like oscillation paths.
- Two identical detectors located at different distances in order to separate out the $\nu_\mu \leftrightarrow \nu_e$ oscillation dependence from all other effects

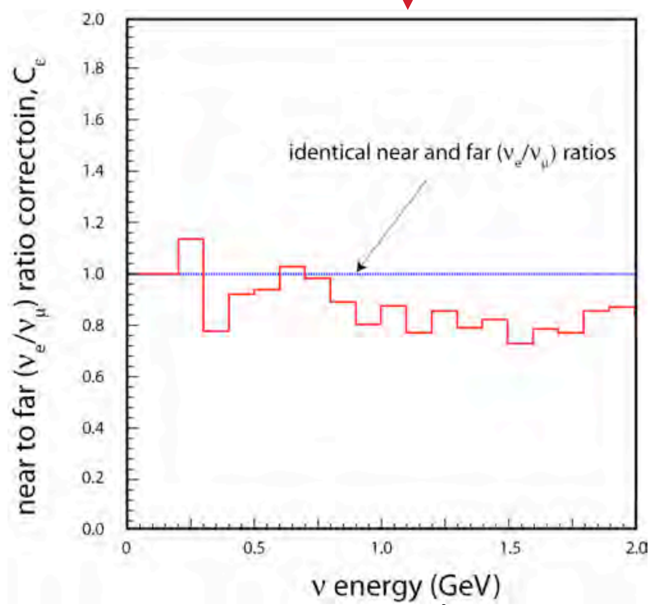
Purely oscillation dependent effect

$$\Delta_e = \left(\frac{N_e}{N_\mu}\right)^{far} - C_e \left(\frac{N_e}{N_\mu}\right)^{close}$$

different spectral shapes of close and far positions



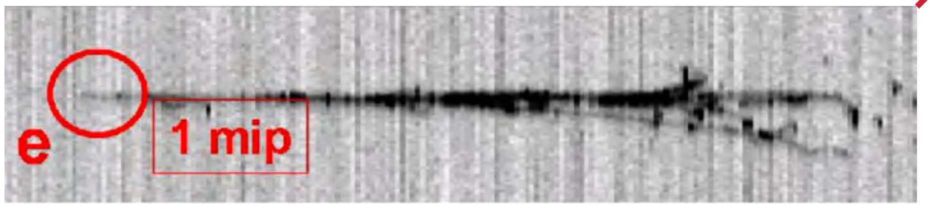


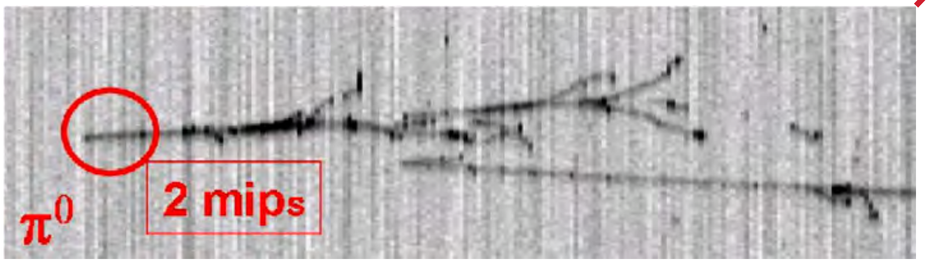


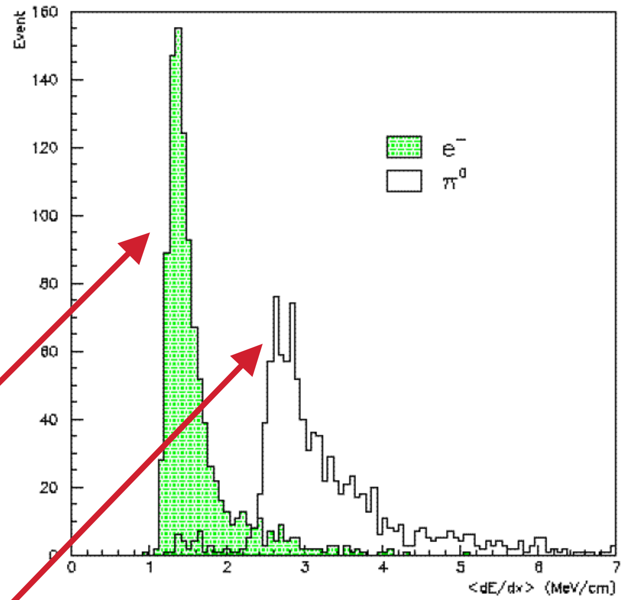
- In absence of neutrino oscillations, after C_e correction, ratios cancel, $\Delta_e=0$
- No neutrino and/or nuclear cross sections and no detector related effects.

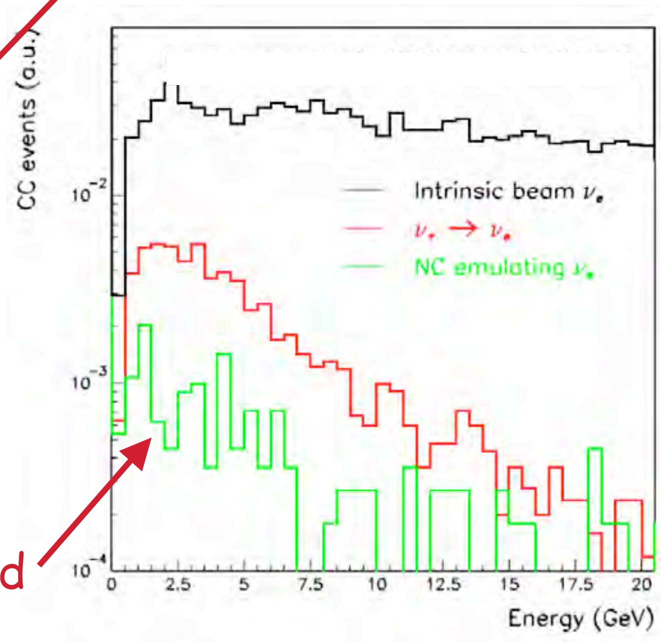
π^0 backgrounds

- 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%





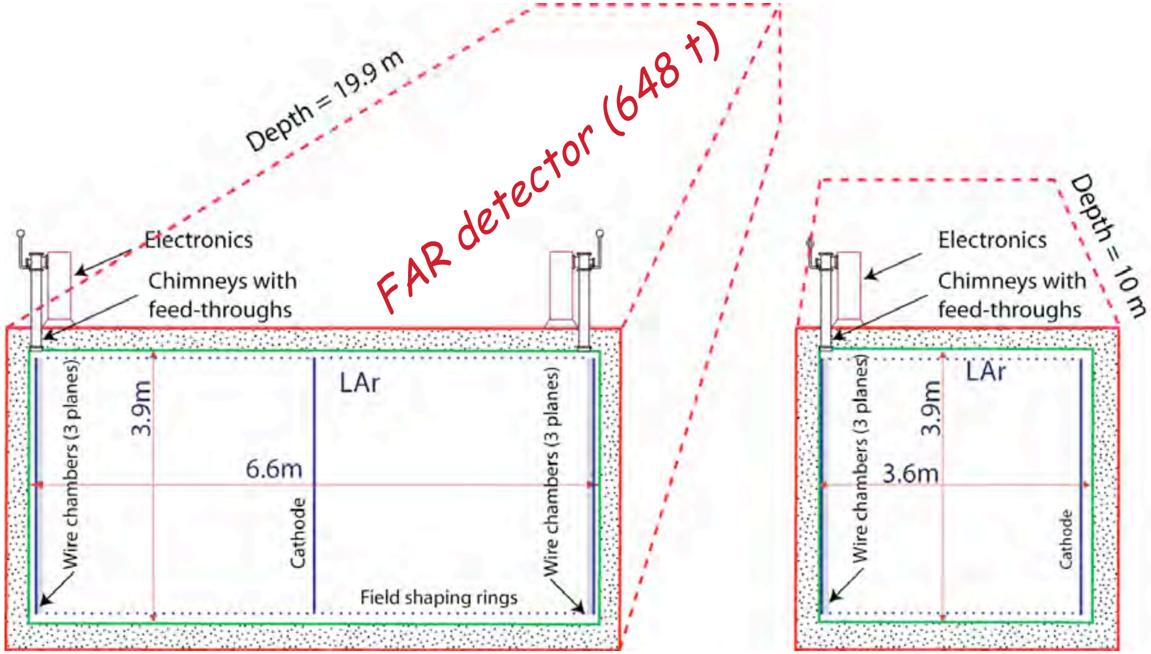




NC-e background

LAr twin detectors

- Two separate containers
- inner volume FAR: **6.6 x 3.9 x 18 m³**
- inner volume NEAR: **3.6 x 3.9 x 8 m³**
- 4 wire chambers with 3 readout planes at 0°, ±60°
- Total number wires ≈ 10'000
- Maximum drift = 3.6 m
- HV = -180 kV @ 0.5 kV/cm

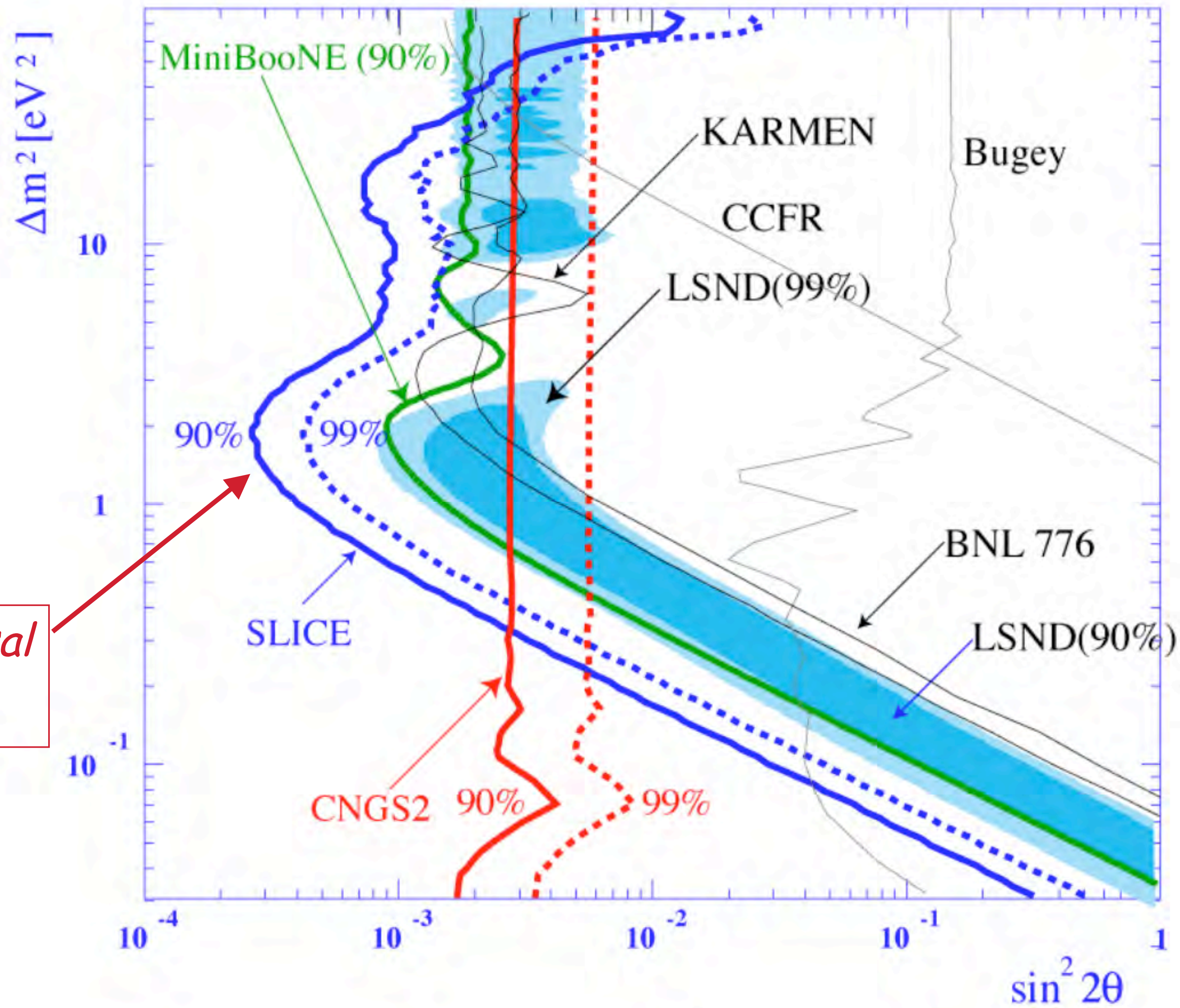


NEAR detector (112 t)

	FAR	NEAR
Integrated protons on target	$2.5\ 10^{20}$	
Fiducial mass	500 t	10 t
Distance from target, m	850	127
ν_μ interactions	1.2×10^6	1.2×10^6
QE ν_μ interactions	4.5×10^5	4.4×10^5
Events/burst	0.17	0.17
Intrinsic ν_e from beam	9000	8000
Intrinsic ν_e from beam ($E_\nu < 3$ GeV)	3900	3600
ν_e oscillations: $\Delta m^2 = 2.\ eV^2;\ sin^2 2\theta = 0.002$	1194	70
ν_e oscillations: $\Delta m^2 = 0.4\ eV^2;\ sin^2 2\theta = 0.02$	2083	156

- Set-up heavily simplified with respect to ICARUS
- Cheaper, cryogenic vessel with ≈ 1 m thick perlite walls
- Wire chamber mechanics, purification system and readout electronics "cloned" from the ICARUS set-up
- Very quick construction schedule.

Neutrino data



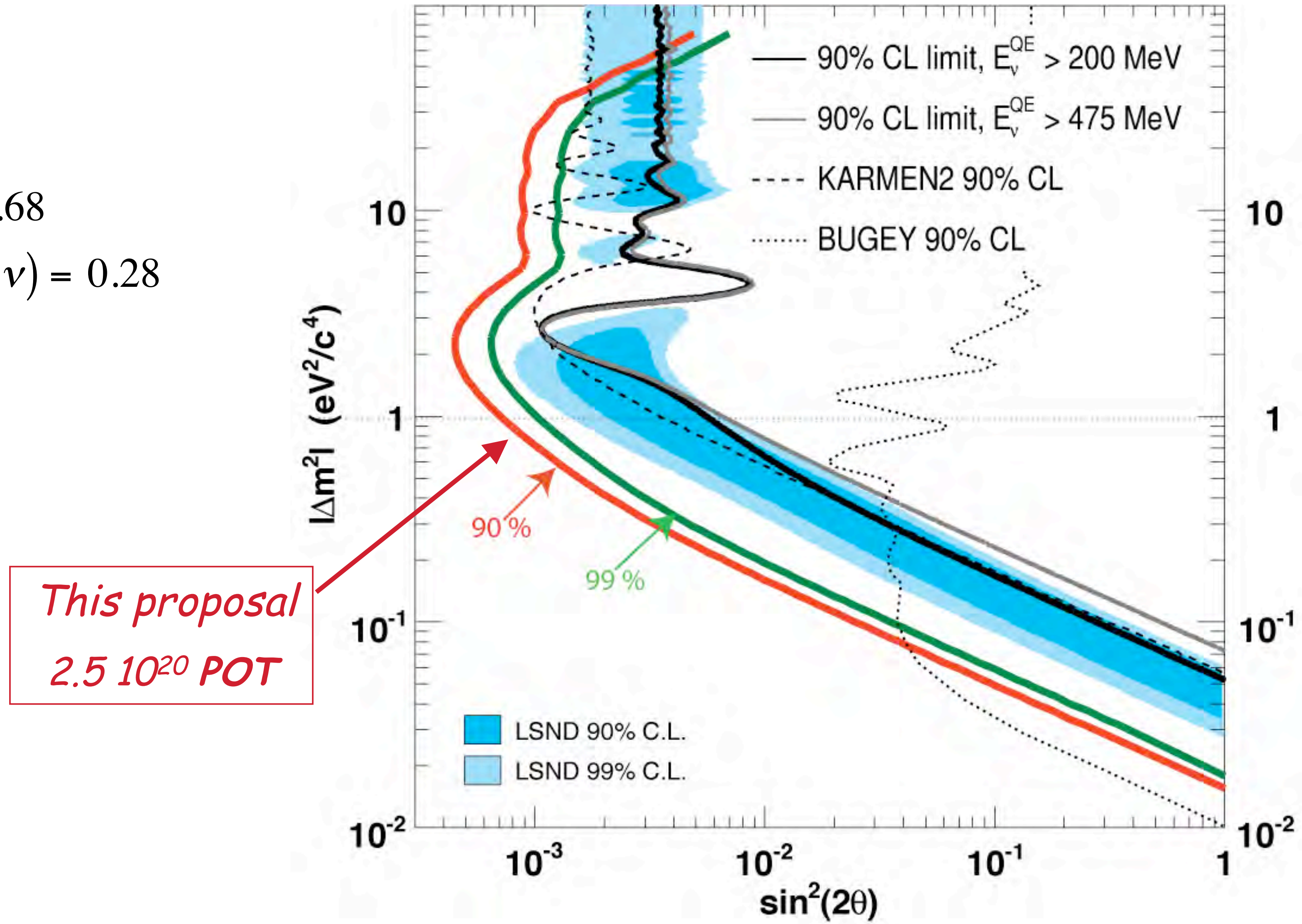
This proposal

2.5 10^{20} POT

Anti-neutrino data

$\phi_{\bar{\nu}} / \phi_{\nu} = 0.68$

$N(\bar{\nu}) / N(\nu) = 0.28$



A first cost estimate

1.	**Main outer dewar with perlite insulation**		**1725**
	a. Engineering design	200	
	b. Perlite with external walls	150	
	c. Extruded Aluminium box and liquid N2 circulation	850	
	d. Control process	75	
	e. Chemical purifiers, both for the liquid and for the gaseous	350	
	f. Inner structures to ensure uniform circulation of LAr	100	
2.	**Wire planes and other electron signal collecting structures**		**2150**
	a. Engineering design	150	
	b. Construction and commissioning	2000	
3.	**H.V. supply to about 200 kV, including race track structures**		**165**
	a. Engineering design	15	
	b. Construction and commissioning	150	
4.	**Light collecting photomultipliers**		**400**
	a. Costs of the PM and associated hardware'	300	
	b. Construction and commissioning	100	
5.	**Initial purification studies without vacuum**		**60**
	a. Small scale models and tests	30	
	b. Hydrodynamic calculations	30	
6.	**Readout electronics (6 mm pitch)**		**750**
	a. Development costs	50	
	b. Construction	700	
7.	**Final installation in the test site (CERN)**		**200**
8.	**Contingency and miscellanea (20%)**		**1090**
IVA (at 20%)			**1308**
Total (kEuro)			**7848**

Thank you !