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Search for Sterile Neutrinos in the CC ν_μ mode at the new CERN-SBLNF

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SPSC-P-347

SPSC-P-347

Outline

- Physics Potential and Motivations
- The new CERN Neutrino Facility (CENF)
- ICARUS LAr & NESSIE spectrometers
- Project Schedule

Neutrino Physics

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 isn'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.

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Fitting all together?

there are three classes of data:

$\nu_e \to \nu_e$ disappearance $\sin^2 2\theta_{ee}$
$\nu_\mu \to \nu_\mu$ disappearance $\sin^2 2\theta_{\mu\mu}$
$\nu_\mu \to \nu_e$ appearance $\sin^2 2\theta_{\mu e}$

- each combination of two sets is consistent (they depend on different mixing parameters)
- BUT: strong tension if all three of them are combined

3+1 SBL oscillations

$$\boxed{\sin^2 2\theta_{\mu e} \approx \frac{1}{4} \sin^2 2\theta_{ee} \sin^2 2\theta_{\mu\mu}}$$

$\nu_\mu \to \nu_e$ app. signal requires also signal in both, ν_e and ν_μ disappearance (appearance mixing angle quadratically suppressed)

How to disentangle all the anomalies

Short Base Line Neutrino Beam

Measure at L/E corresponding at $\Delta m^2 \sim 1\ eV^2$

with ≥ 2 sites

ν_μ AND $\overline{\nu}_\mu$

in Apppearance (ν_e)

AND

in Disappearance (ν_μ)

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- ✓ **Measure Electrons and Muons in a wide range (0.2 – 2 GeV)**
- ✓ **Measure Charge-Id**
- ✓ **Low systematics**
- ✓ **High rate capability (for both beams and detectors)**

Search for "anomalies" from neutrino and anti-neutrino oscillations at $\Delta m^2 \approx 1eV^2$ with muon spectrometers and large LAr–TPC imaging detectors.

Technical proposal.

(CERN-SPSC-2012-010 and SPSC-P-347)

2 collaborations
30 institutions
~140 people

(arXiv:1203.3432

ICARUS Collaboration

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(a) Contact Person

NESSiE Collaboration

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(b) Contact Person

CERN Neutrino Facility

Letter of Intent for the New CERN Neutrino Facility

Draft 0 - v1.

January 11, 2013

Neutrinos CERN Community

ABSTRACT:
The nature and characteristics of neutrinos still represent one of the most intriguing questions of modern particle physics. This Letter of Intent presents a plan to build at CERN a Short Baseline Neutrino Facility capable to meet this challenge. The new beam line will make use of the SPS beam, it will be located in the CERN North Area of the Prevessin site and will comprise in a first step 2 experimental halls (far and near) which will host the detector facilities. The beam layout will be compatible with a long neutrino baseline which might be constructed in a second stage.

KEYWORDS: Neutrino, Short-baseline, Long-baseline, Sterile Neutrinos, ICARUS, NESSIE, LAGUNA, LBNO, CERN.

Leader Project:
Marzio Nessi (Cern)

Deputy:
Rende Steerenberg (Cern)

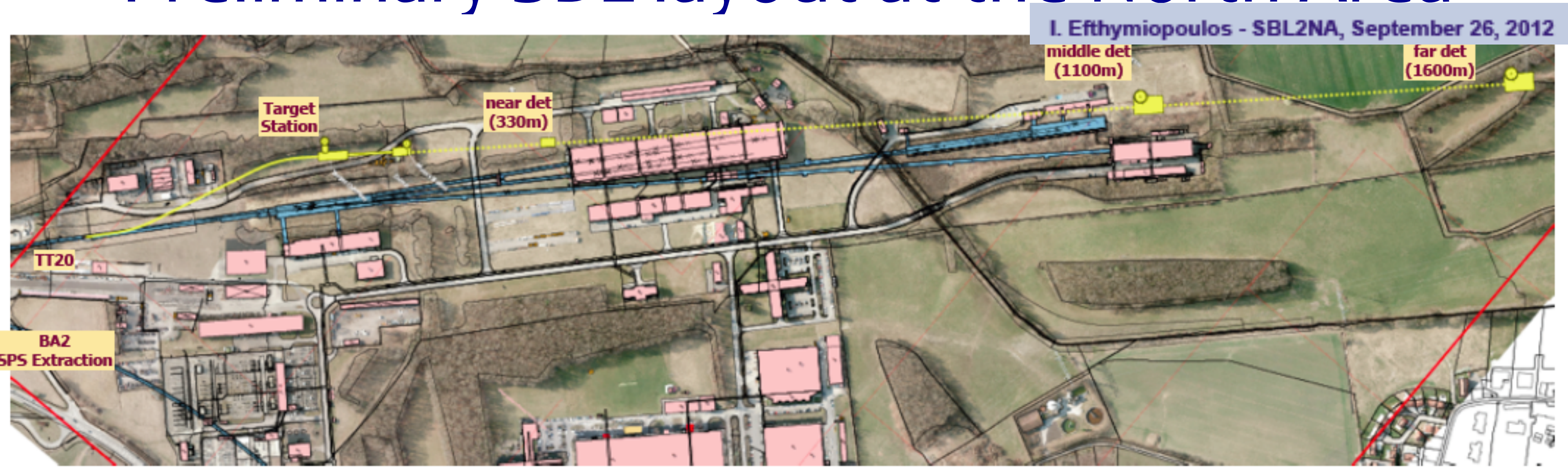
- **200 pages for 5 Work-Packages,**
- **a TDR for Beam, Infrastructures and Experiments**

The ICARUS-NESSiE P-347 proposal at the CERN-SPS

SPSC-P-347 (arXiv:1203.3432)

- L/E oscillation path lengths to ensure appropriate matching to the Δm^2 window for the expected anomalies
- NEAR and FAR sites
- "Imaging" LAr-TPC detector capable of identifying unambiguously all reaction channels
- Magnetic spectrometers to determine muon charge and momentum
- Interchangeable ν + anti-ν beams
- High rates due to detector large masses , in order to record relevant effects at the percent level ($>10^6$ ν_μ , ~ 10^4 ν_e)
- Both initial ν_e and ν_μ components cleanly identified.

Preliminary SBL layout at the North Area



Near site L ~300 m (sufficient to shield from μ)

Far site L ~ 1600 m (still within CERN properties)

SPS p beam: 100 GeV ν beam ~ 2 GeV

$4.5 \cdot 10^{19}$ pot/year (~stably achieved for CNGS)

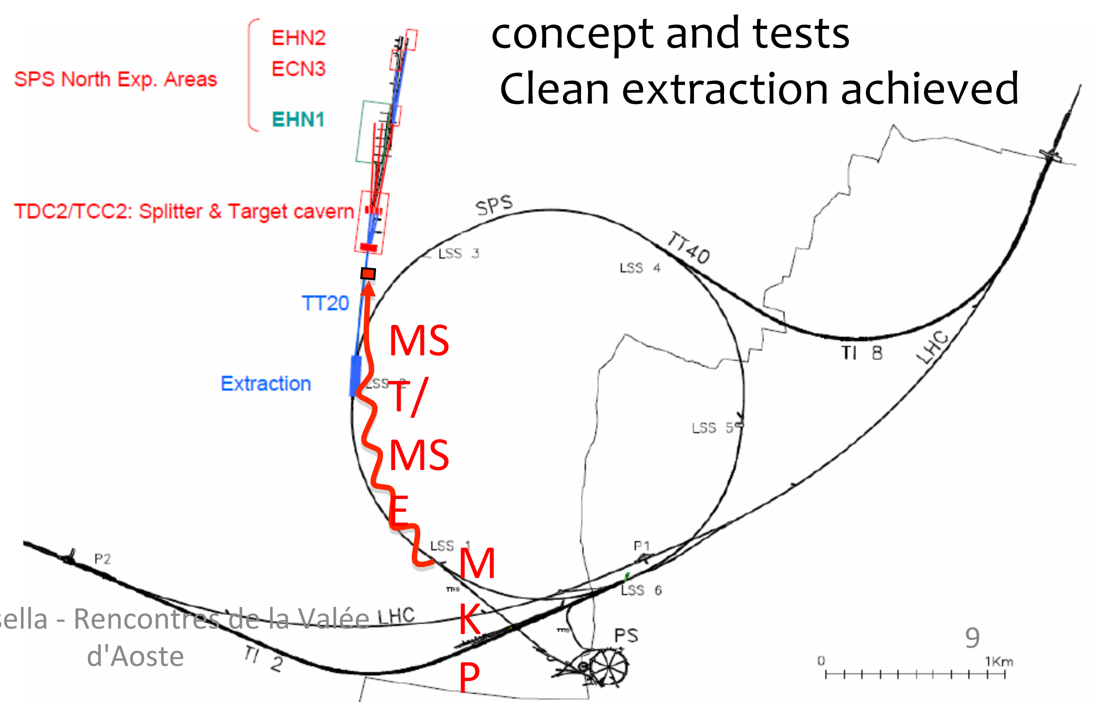
target station ~ 11 m underground

ν-beam pointing upwards (5 mrad slope, -3 m at far)

interactions/spill = 5 / 0.65 at near /far ($2 \cdot 10^{13}$ p/spill with "+" polarity)

SPS ``non local extraction'': concept and tests

Clean extraction achieved



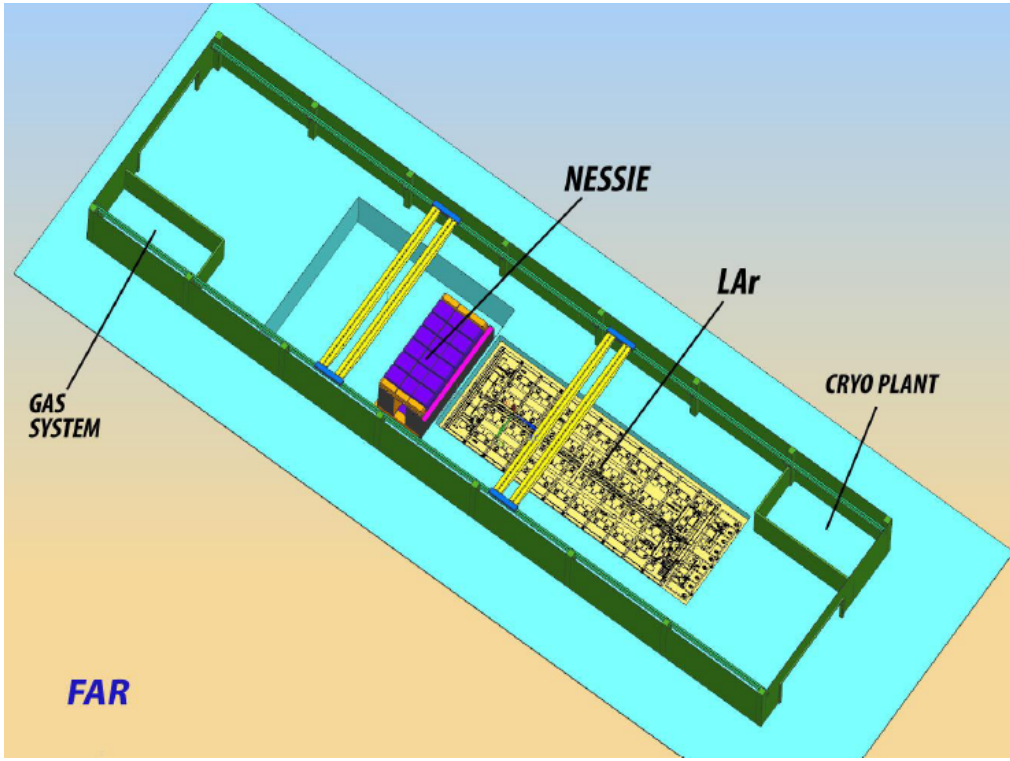
ICARUS-NESSiE

A coupled system of LAr detector and muon Spectrometers

NEAR SITE @300 m :
LAr mass = 119 t
Iron magnet mass = 840 t
5 interactions/spill

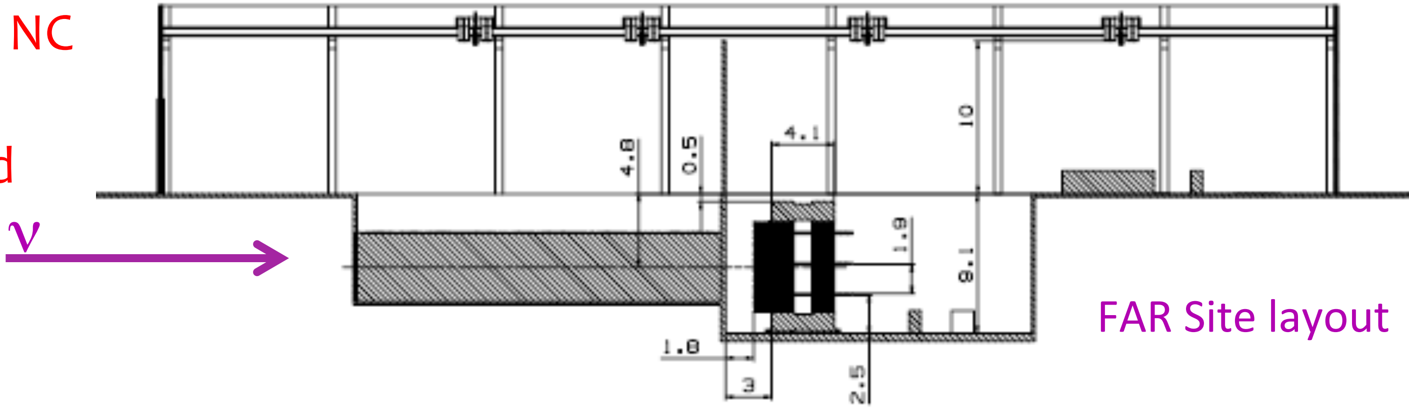
$2 \cdot 10^{13}$ p/spill (with "+" polarity)

FAR SITE @1600 m:
LAr mass = 476 t
Iron magnet mass = 1515 t
0.65 interactions/spill



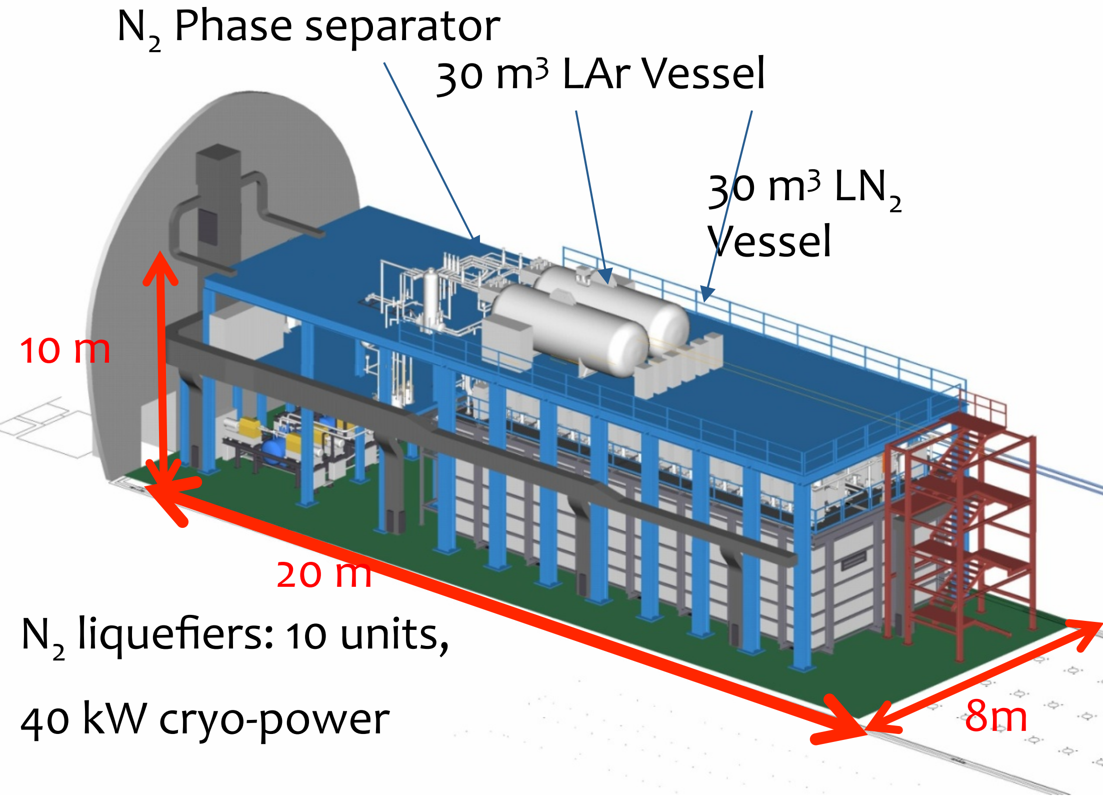
Observation ν_μ, ν_e CC, NC channels

Charge separation and muon momentum



FAR Site layout

ICARUS T600 at LNGS : LAr TPC status of the art



N_2 liquefiers: 10 units,

40 kW cryo-power

Two identical modules

- 3.6 x 3.9 x 19.6 ~ 275 m^3 each
- Liquid Ar active mass: ~ 476 t
- Drift length = 1.5 m (1 ms)
- HV = -75 kV   E = 0.5 kV/cm
- v-drift = 1.55 mm/µs

4 wire chambers:

- 2 chambers per module
- 3 R/O wire planes per chamber at 0, ±60°
- 54000 wires, 3 mm pitch, 3 mm plane spacing

20+54 PMTs , 8" Ø, for scintillation light:

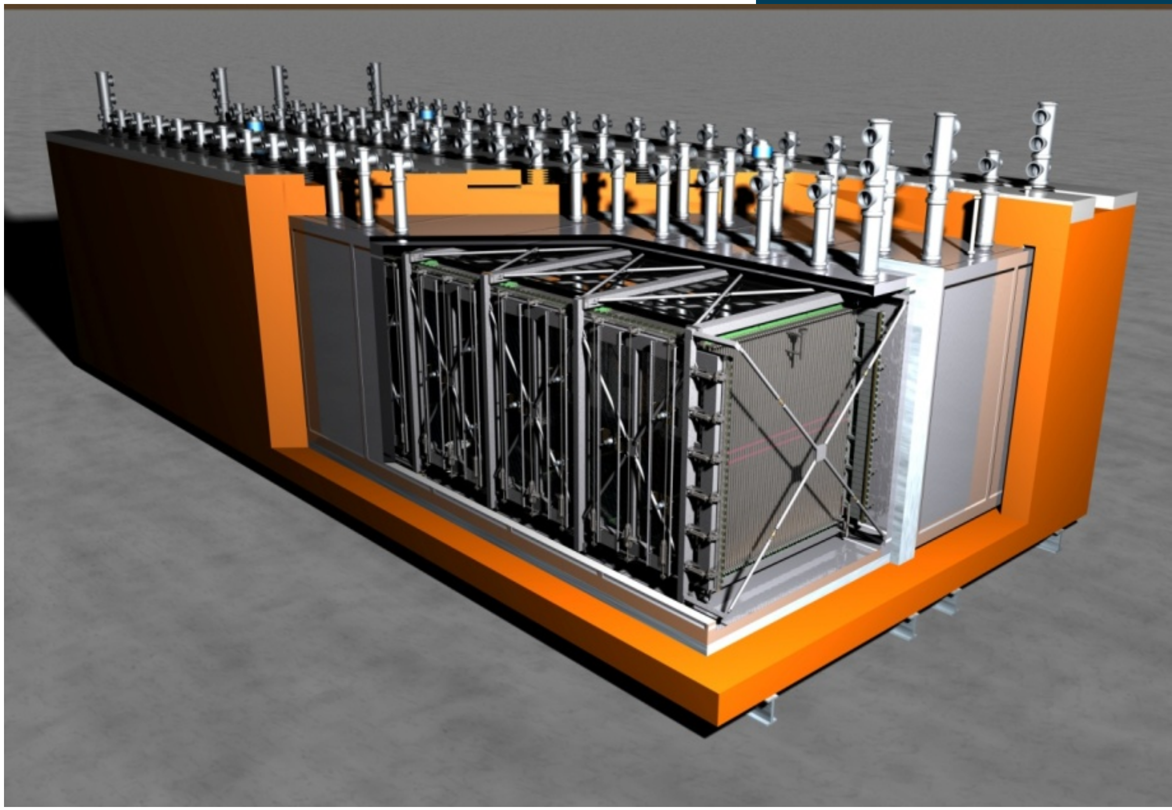
VUV sensitive (128nm) with wavelength shifter

ICARUS Collab courtesy

The ICARUS T600 as "Far" detector

- T600 will be transported to CERN in 2013, after decommissioning at LNGS, ensuring the new experiment operation again in 2016
- A large number of components will be disassembled and transported: inner detectors, electronics, ancillary systems, LN_2 liquefaction system

ICARUS Collab Courtesy



TPC's will be inserted in new vessels of extruded Al, vacuum-tight < 10^{-5} mbar l s^{-1} standing up to 1 bar internal overpressure

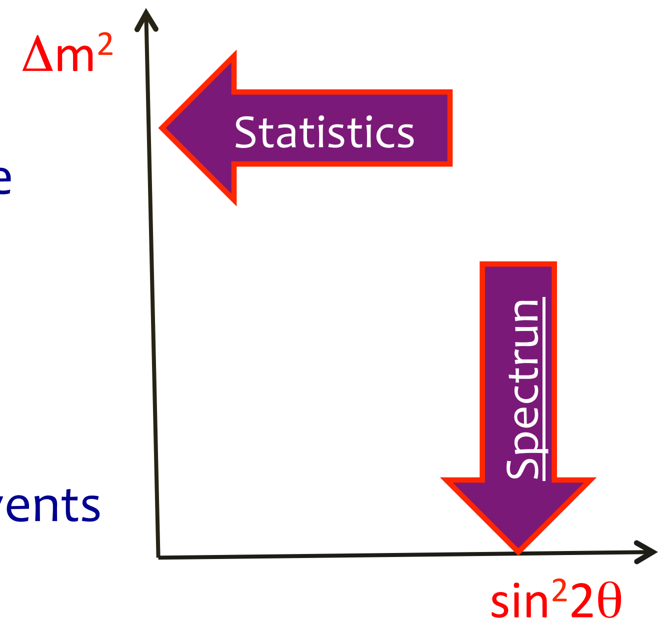
New external insulation based on industrial membrane tank concept: better performance and full spill containment. Expected heat loss: 6.6 kW (T600).

NESSiE

(Neutrino Experiment with SpectrometerS in Europe)

- **Goals:**
  - Allow charge separation and momentum measurement of as many muons as possible escaping from LAr

    (large statistics ↔ low $\sin^2 2\theta$)
  - Go as low as possible in muon momentum (low momenta ↔ low Δm^2)
  - Possibility to also study (NESSiE) internal events (coarser resolution w.r.t. LAr)

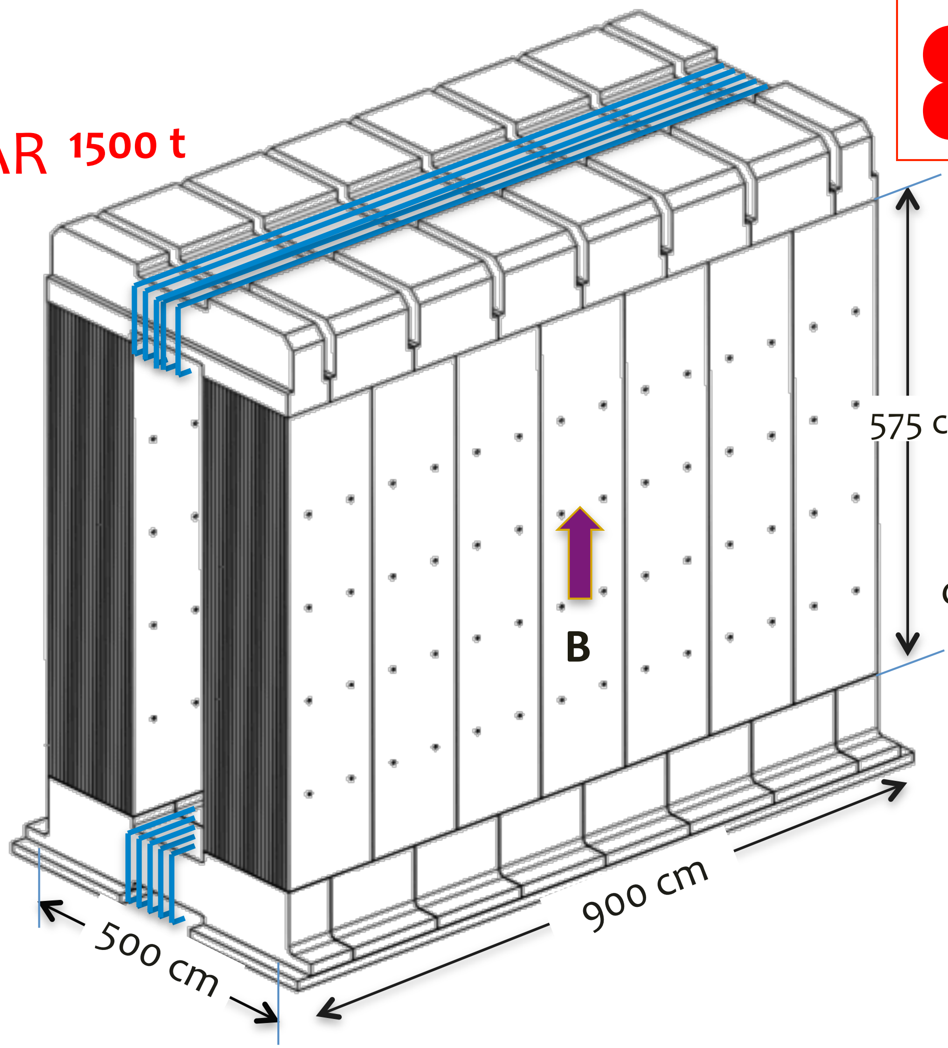


- **Solution:**
  - Air-core magnets for low momentum muons escaping from LAr (P_μ < 0.5 GeV/c in NESSiE ↔ $\langle E_\nu \rangle$ < 1 GeV in LAr)
  - Downstream massive iron dipolar magnets for higher momentum extension

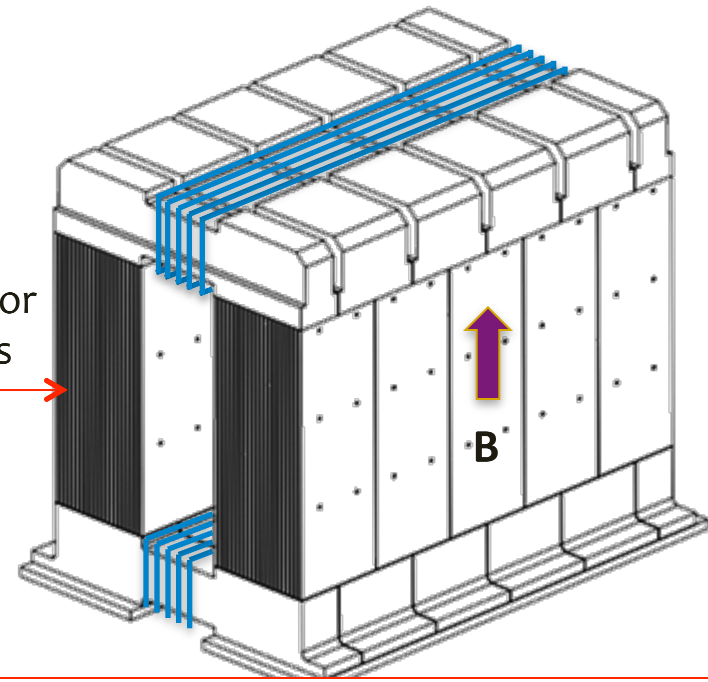
Iron dipolar magnets (OPERA-like)

- design, construction/operation expertise acquired with OPERA
- digital RPC read-out
- Same design scheme for electronics

FAR 1500 t



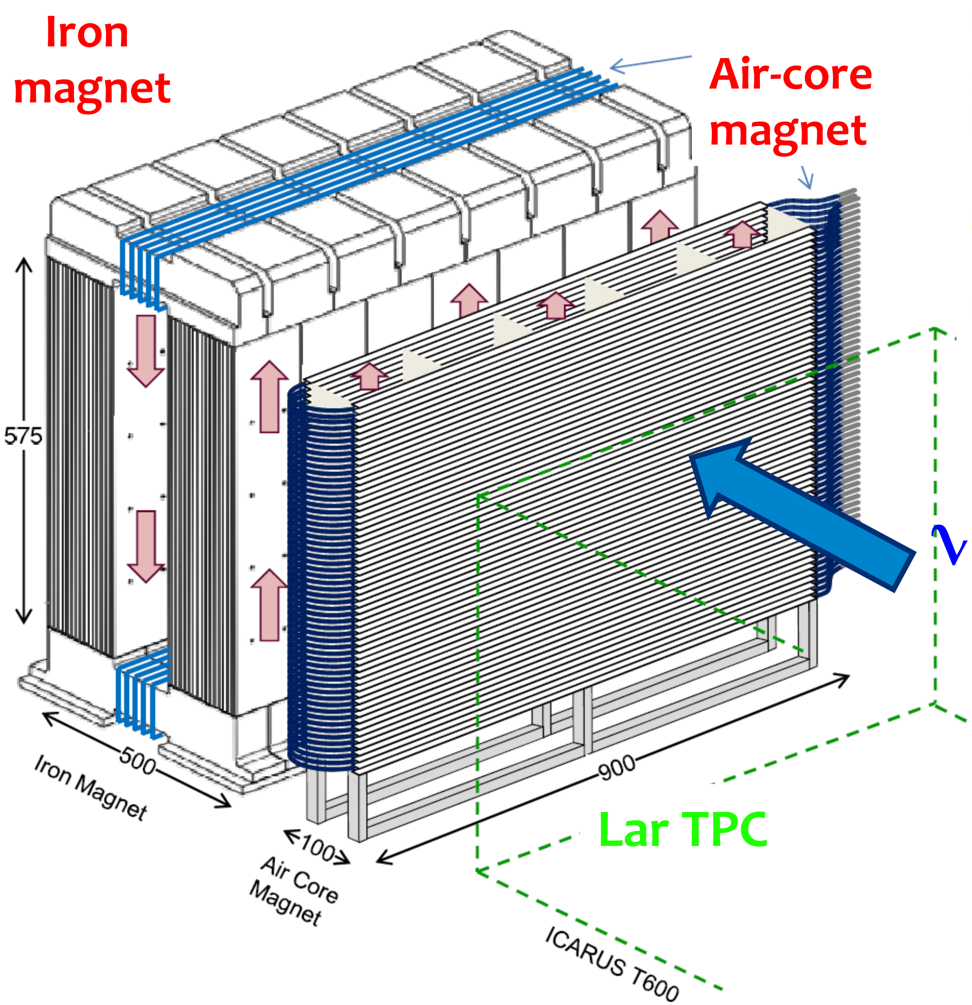
NEAR 840 t

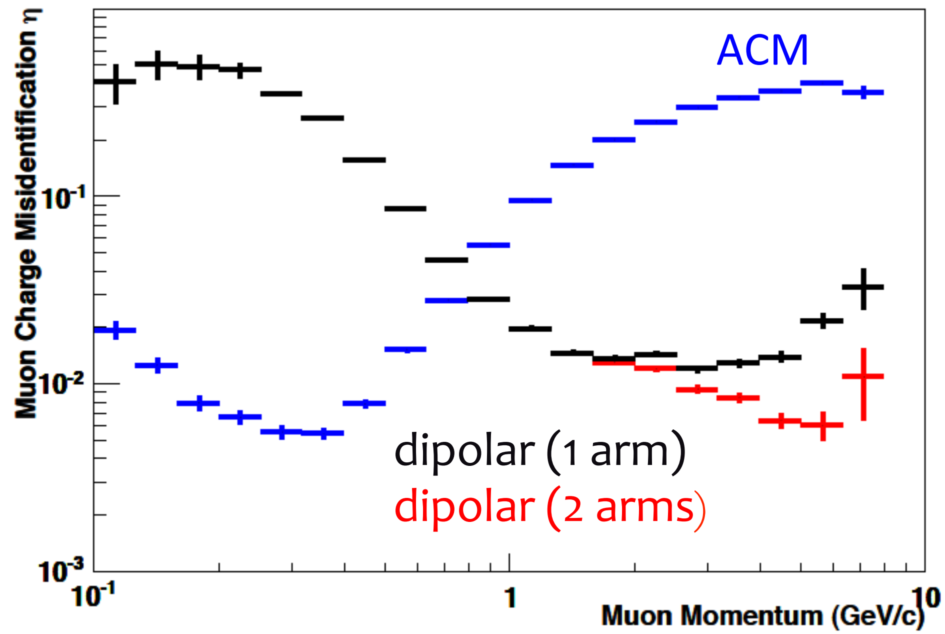


- 1800 + 700 m² of RPC (11 planes/arm)
- 20000 + 12000 digital channels
- Bending in 1.5 T uniform B-field and with range for stopping muons (~50%)

A massive instrumented target itself

NESSiE Detector configuration
(@ Near and Far locations)



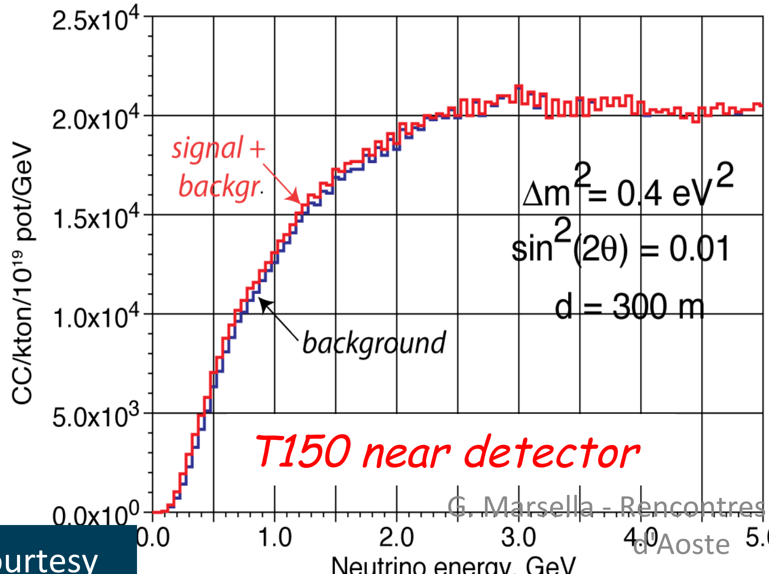


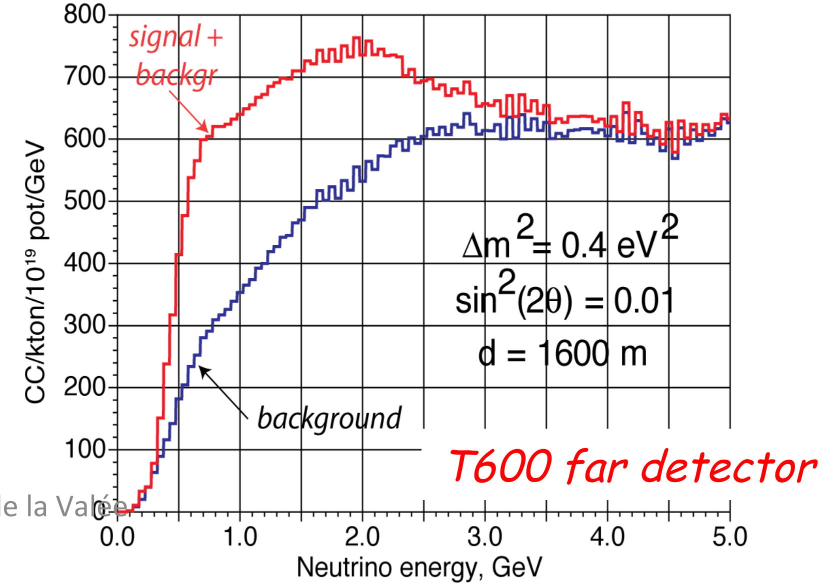
Charge mis-reconstruction at few % level in 0.5 -10 GeV range

(full simulation including selection, efficiency and reconstruction)

A possible expectation of LSND mass and mixing angle

- Our dual method, unlike LNSD and MiniBooNE, determines both the mass difference and the value of the mixing angle.
- Events rates are hereby, shown both for [background] and [oscill.+background] at d=300 m and d=1600 m and the optimal "predictions" from ICARUS et al. $\Delta m^2 = 0.4\ eV^2$, $\sin^2(2\theta) = 0.01$
- For d=1600 m, $E\nu$ < 5 GeV and 4.5 10^{19} pot (1 y) a ν_e oscillation signal of ≈1200 events is expected above 5000 backgr. events

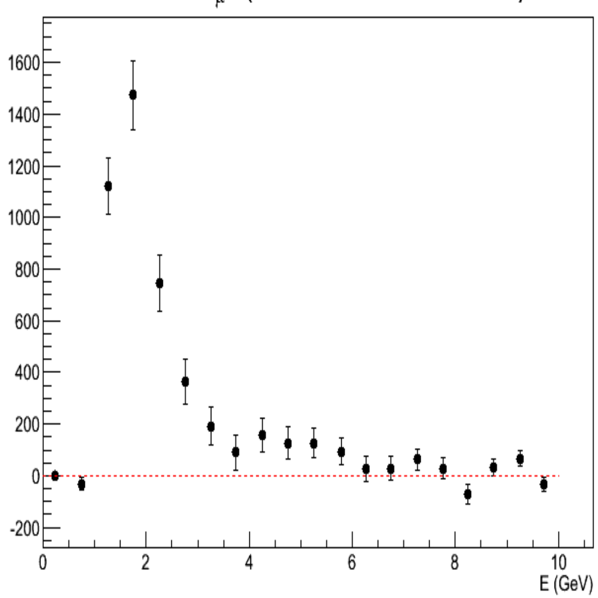




ICARUS Collab Courtesy

		NEAR (ν–bar)	NEAR(ν)	FAR(ν–bar)	FAR(ν)
produced	$\nu_e + \nu_e$–bar (LAr)	35 K	54 K	4.2 K	6.4 K
	$\nu_\mu + \nu_\mu$–bar (LAr)	2000 K	5250 K	270 K	670 K
	Appear. test point	590	1900	360	910
detected	ν_μ (LAr+NESSiE)	230 K	1200 K	21 K	110 K
	ν_μ (NESSiE)	1150 K	3600 K	94 K	280 K
	ν_μ–bar (Lar+NESSiE)	370 K	56 K	33 K	6.9 K
	ν_μ–bar (NESSiE)	1100 K	300 K	89 K	22 K
	Disappear. test point	1800	4700	1700	5000

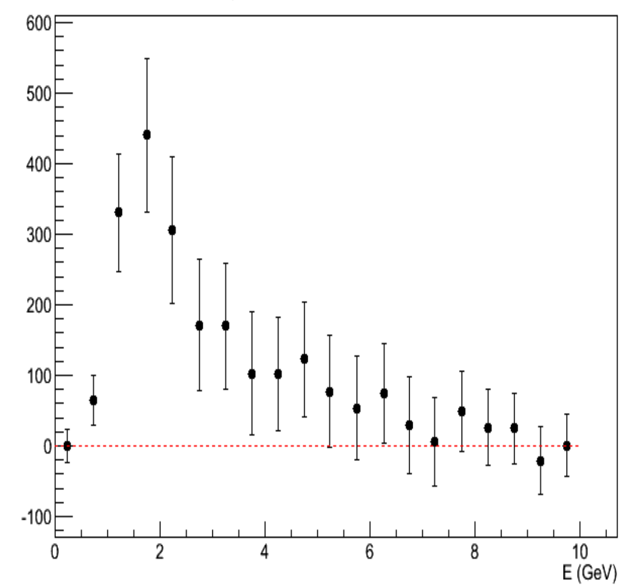
NESSiE $\bar{\nu}_\mu^{CC}$ (non oscillated - oscillated)



1 year of anti-ν run $4.5\cdot10^{1}$
pot (negative polarity)

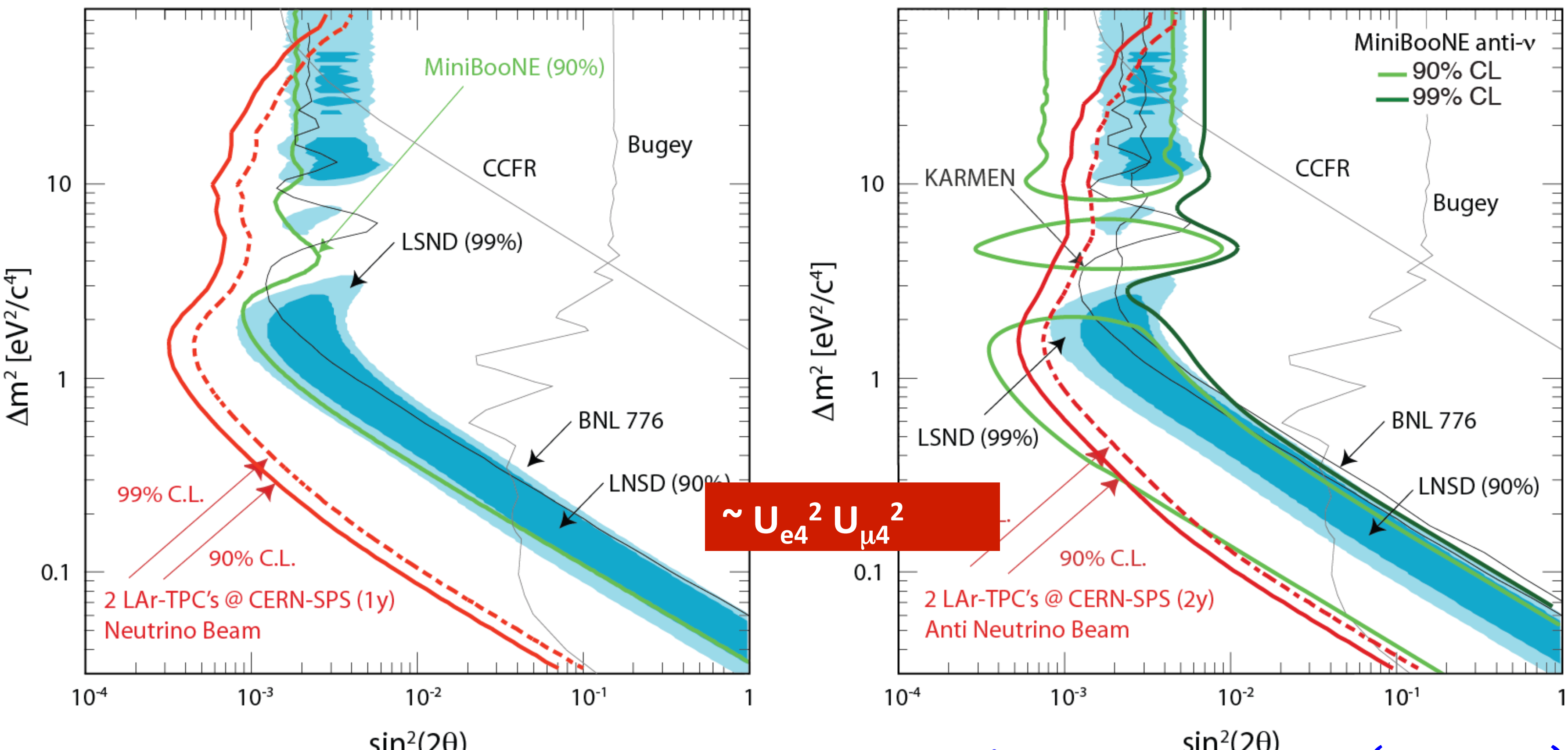
Disappearance signals

NESSiE ν_μ^{CC} (non oscillated - oscillated)



Physics reach: all channels explored

ν_e appearance



ν_μ - $4.5\cdot10^{19}$ pot (1 year)

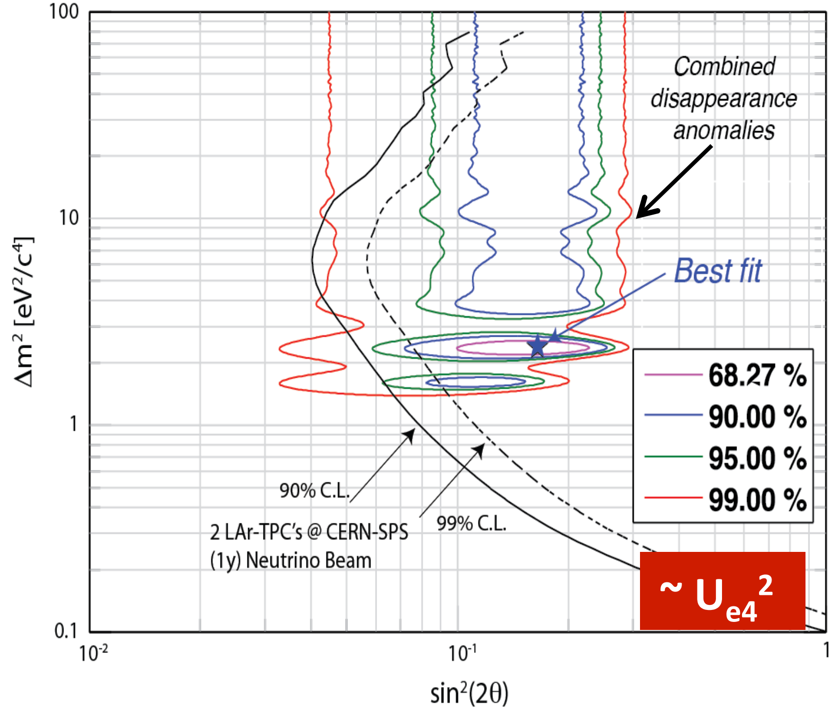
anti-ν_μ – 9 $\cdot10^{19}$ pot (2 years)

3% syst. uncertainty on ν energy spectrum.

LSND allowed region is fully explored in both cases

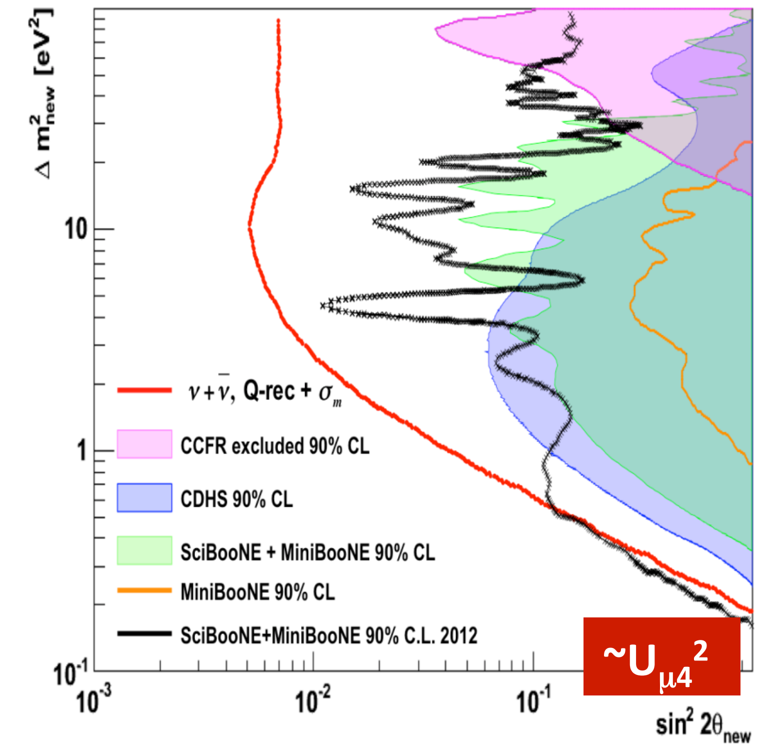
ν_e, ν_μ Disappearance

ν_e disappearance (1 year of ν_μ)



The reactor/Gallium anomalies fully addressed

ν_μ disappearance (2 + 1)



2 year run (*) with ν-bar would address CPV in one shot with NESSiE+LAr

(*) $4.5 \cdot 10^{19}$ pot (1 year)

Status of approval and foreseen

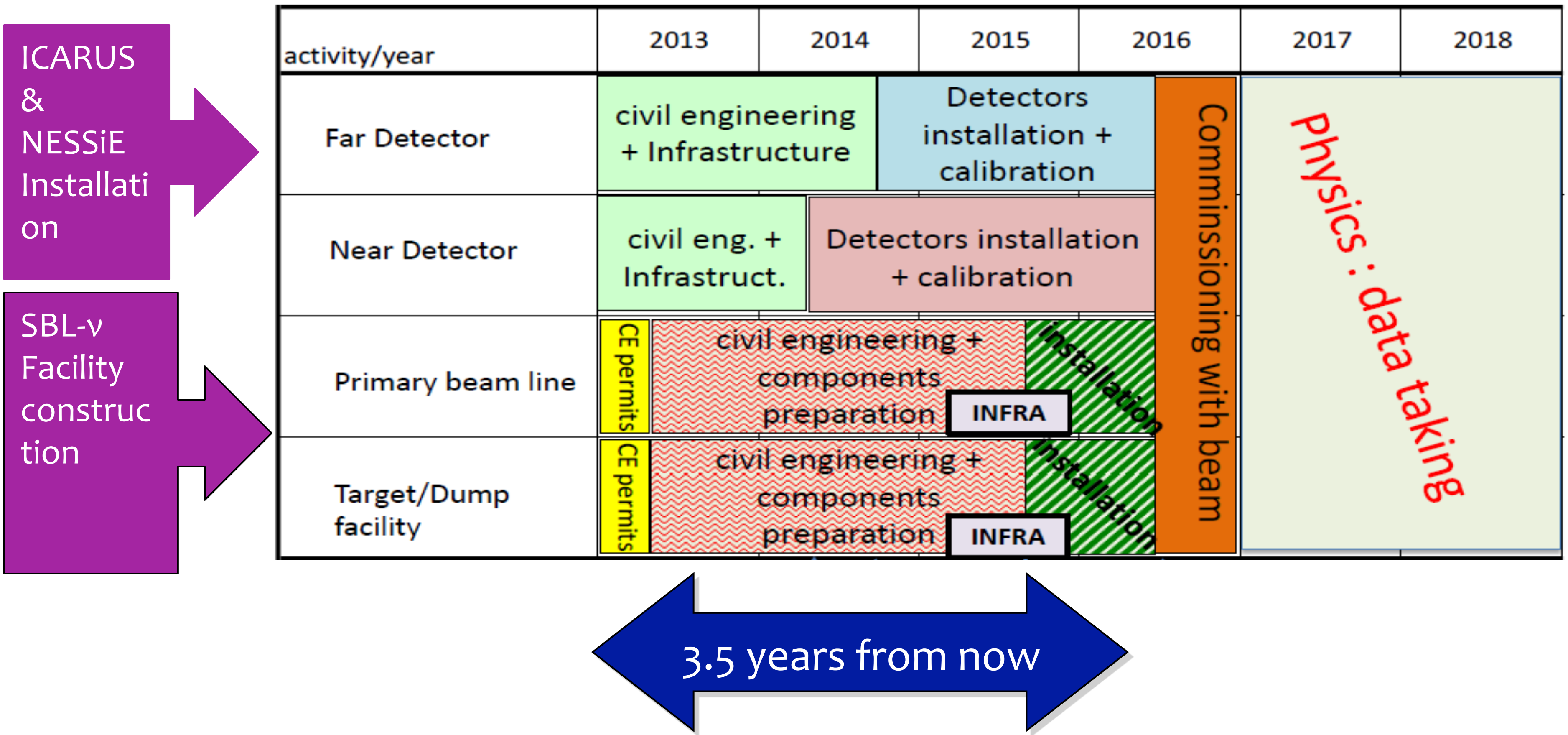
At CERN

- Group established by CERN in order to realize SPS based new short-baseline ν beam in the North Area (project leader M. Nessi)
- Scientific Approval (SPSC) middle of January 2013
- Feasibility document submitted to CERN Directorate on February 7^{th} 2013
- Resource Approval (Research Board) on March 4^{th} 2013
- Final Approval (CERN Council) in June 2013

INFN: Currently Major contributor to the experiments (not beam)

- Scientific approval
- Next step: evaluation by the Technical Scientific Commitee (CTS) as for costs, manpower
- In-Kind contribution of Opera Spectrometers

Time schedule: neutrino beam by June 2016



Conclusions

Possibility of exciting discoveries of BSM Physics with vast consequences or, at least, a complete clarification of present anomalies.

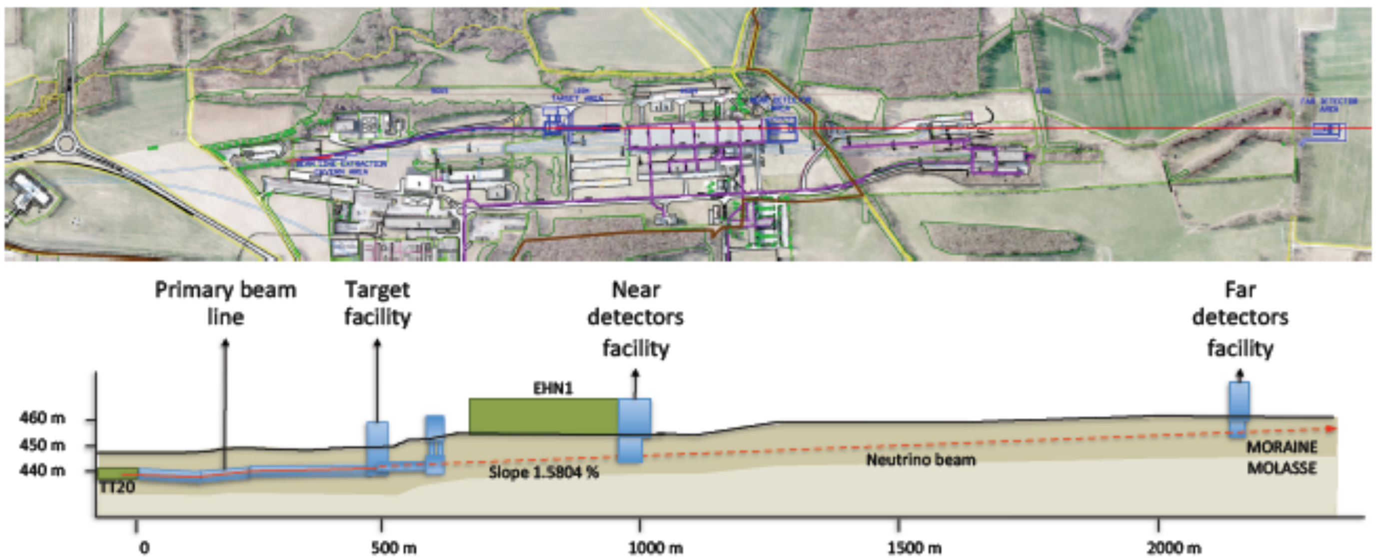
Favorable time scale thanks to the use of existing/ running detectors (or reasonable extensions).

Opportunity for a revival of neutrino activity in Europe.

Large room for contributions !

BACKUP SLIDES

CERN Neutrino Facility (CENF)



Layout of the facility at CERN. Bottom: Vertical cut showing the TT20, the EHN1 and the main components of the facility

Effective SBL Oscillation Probabilities in 3+1 Schemes

$$P_{\nu_\alpha \to \nu_\beta} = \sin^2 2\vartheta_{\alpha\beta} \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$

$$\sin^2 2\vartheta_{\alpha\beta} = 4|U_{\alpha 4}|^2 |U_{\beta 4}|^2$$

(no CP violation)

$$P_{\nu_\alpha \to \nu_\alpha} = 1 - \sin^2 2\vartheta_{\alpha\alpha} \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$

$$\sin^2 2\vartheta_{\alpha\alpha} = 4|U_{\alpha 4}|^2 \left(1 - |U_{\alpha 4}|^2\right)$$

coupled measurements !!

Perturbation of 3ν Mixing

$$|U_{e4}|^2 \ll 1\,, \quad |U_{\mu 4}|^2 \ll 1\,, \quad |U_{\tau 4}|^2 \ll 1\,, \quad |U_{s4}|^2 \simeq 1$$

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} \end{pmatrix}$$

SBL

$$\sin^2 2\vartheta_{\alpha\alpha} \ll 1$$

$$\Downarrow$$

$$|U_{\alpha 4}|^2 \simeq \frac{\sin^2 2\vartheta_{\alpha\alpha}}{4}$$

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Effective SBL Oscillation Probabilities in 3+2 Schemes

$$\phi_{kj} = \Delta m^2_{kj} L / 4E$$

$$\eta = \arg[U^*_{e4} U_{\mu 4} U_{e5} U^*_{\mu 5}]$$

$$P_{\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e} = 4|U_{e4}|^2 |U_{\mu 4}|^2 \sin^2\phi_{41} + 4|U_{e5}|^2|U_{\mu 5}|^2 \sin^2\phi_{51} + 8|U_{\mu 4} U_{e4} U_{\mu 5} U_{e5}| \sin\phi_{41} \sin\phi_{51} \cos(\phi_{54} \overset{(+)}{-} \eta)$$

$$P_{\overset{(-)}{\nu}_\alpha \to \overset{(-)}{\nu}_\alpha} = 1 - 4(1 - |U_{\alpha 4}|^2 - |U_{\alpha 5}|^2)(|U_{\alpha 4}|^2 \sin^2\phi_{41} + |U_{\alpha 5}|^2 \sin^2\phi_{51}) - 4|U_{\alpha 4}|^2 |U_{\alpha 5}|^2 \sin^2\phi_{54}$$

- More parameters: 7 *many coupled measurements !!*
- CP violation

[Sorel, Conrad, Shaevitz, PRD 70 (2004) 073004; Maltoni, Schwetz, PRD 76 (2007) 093005; Karagiorgi et al, PRD 80 (2009) 073001; Kopp, Maltoni, Schwetz, PRL 107 (2011) 091801; Giunti, Laveder, PRD 84 (2011) 073008; Donini et al, arXiv:1205.5230]

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3+1 SBL oscillations

appearance

$$P_{\mu e} = \sin^2 2\theta_{\mu e} \sin^2 \frac{\Delta m^2_{41} L}{4E} \qquad \sin^2 2\theta_{\mu e} = 4|U_{e4}|^2 |U_{\mu 4}|^2$$

disappearance ($\alpha = e, \mu$)

$$P_{\alpha\alpha} = 1 - \sin^2 2\theta_{\alpha\alpha} \sin^2 \frac{\Delta m^2_{41} L}{4E} \qquad \sin^2 2\theta_{\alpha\alpha} = 4|U_{\alpha 4}|^2 (1 - |U_{\alpha 4}|^2)$$

$$\boxed{\sin^2 2\theta_{\mu e} \approx \frac{1}{4} \sin^2 2\theta_{ee} \sin^2 2\theta_{\mu\mu}}$$

$\nu_\mu \to \nu_e$ app. signal requires also signal in both, ν_e and ν_μ disappearance (appearance mixing angle quadratically suppressed)

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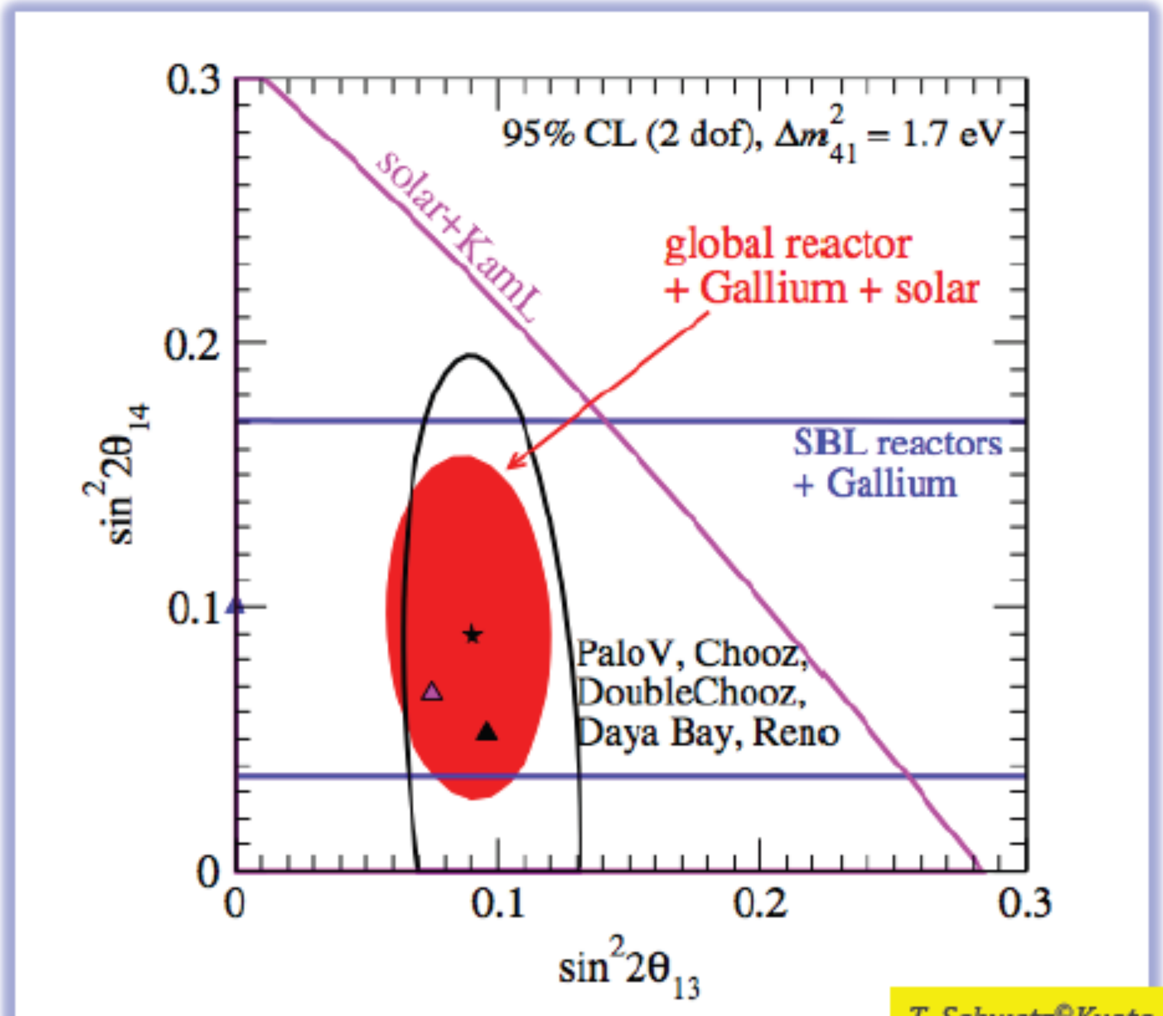
TENSIONS also for the 3+2 scheme, due to disappearance bounds, particularly for ν_μ
On top of that, coupling to standard 3-flavour scenario is weak :



TENSIONS...

it is a game to play VERY carefully !

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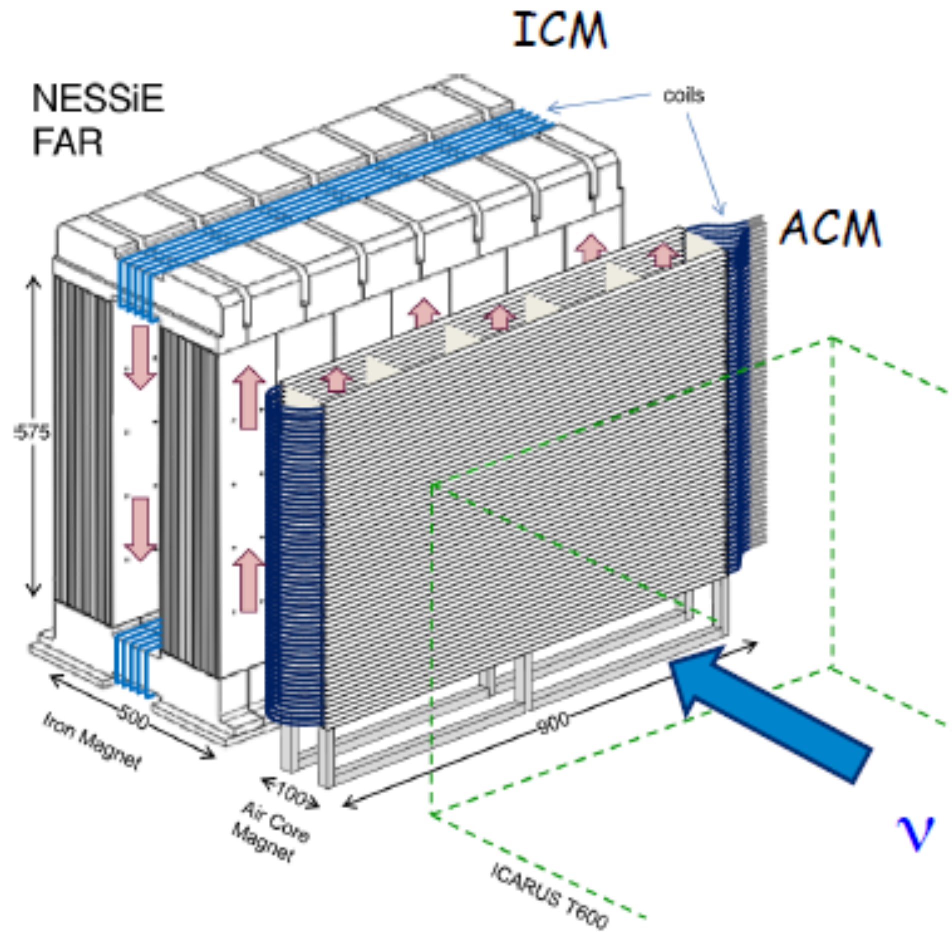
Nessie main facts

- Two Iron spectrometers (**ICM**),
  1500 + 800 t, composed by:
- 48 yoke blocks, , 4.5 x 0.6 x 1 m, 25t
- 480 slabs, 2 – 3 t, 1.25m x 3.5–6 m
- 1800 + 700 m^2 of RPC
- «sandwich style» assembly to be made in situ, one piece per time
- 20,000+12,000 digital channels
- Two **ACM** preassembled and installed in one shot
- Precision Trackers preassembled and installed in one shot
- Near Nessie movable aside on air-pad
- 1 + 0.5 MW , 10 kA, power (summed up for ACM and ICM)

Optimized ! Reduced by almost a factor of 2 !!!



Useful ICARUS-NESSiE Refs

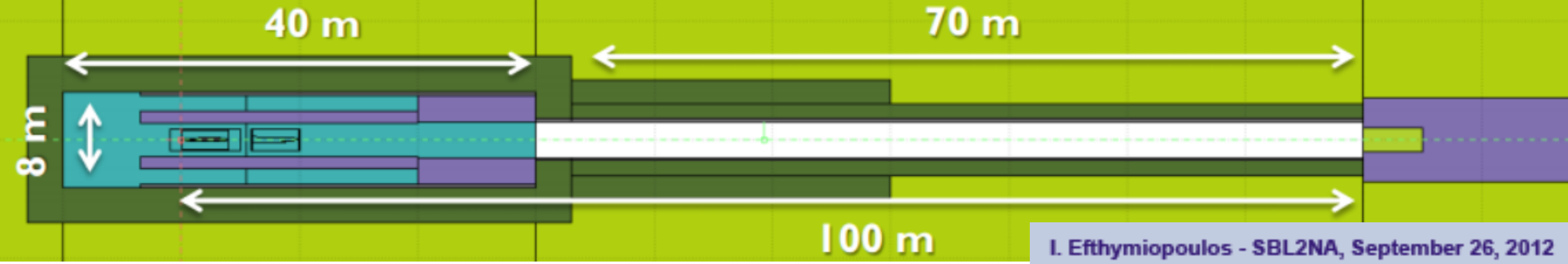
- C. Rubbia et al., ICARUS/CNGS2 Coll., Physics Programme for ICARUS after 2012 SPSC-M-773 09/03/2011

- C. Rubbia et al., ICARUS/CNGS2 Coll., A comprehensive search for "anomalies" from neutrino and anti-neutrino oscillations at large mass differences ($\Delta m^2 \approx 1eV^2$) with two LAr–TPC imaging detectors at different distances from the CERN-PS SPSC-P-345 14/10/2011

- P. Bernardini et al., NESSiE Coll. Prospect for Charge Current Neutrino Interactions Measurements at the CERN-PS SPSC-P-343 11/10/2011 arXiv:1111.2242v1

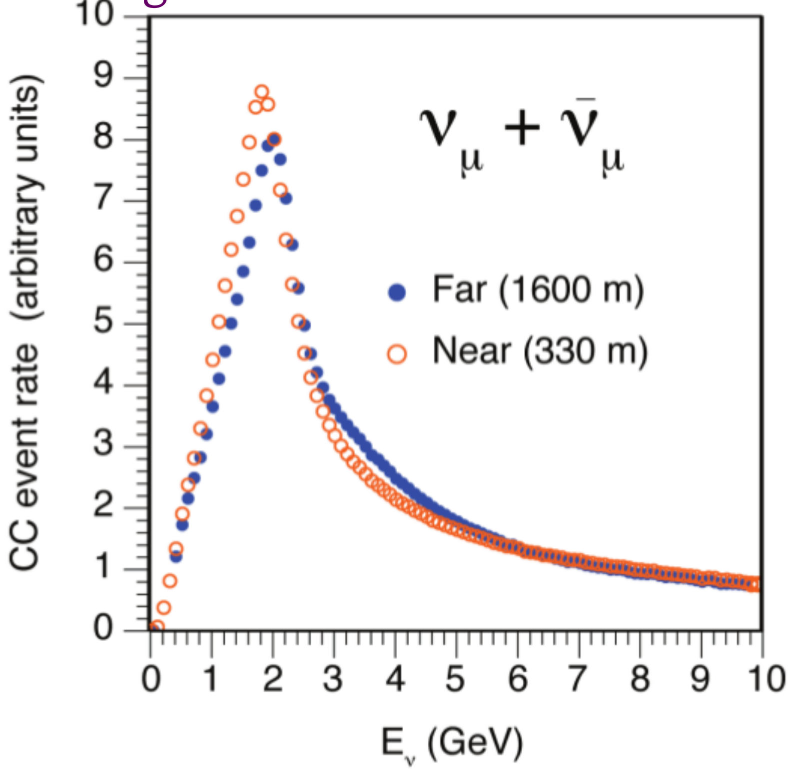
- M. Antonello et al. ICARUS-NESSiE Coll. Search for "anomalies" from neutrino and anti-neutrino oscillations at $\Delta m^2 \approx 1eV^2$ with muon spectrometers and large LAr-TPC imaging detectors. Technical proposal. SPSC-P-347 arXiv:1203.3432

- M. Antonello et al. ICARUS-NESSiE Coll. Search for anomalies in the neutrino sector with muon spectrometers and large LArTPC imaging detectors at CERN. Contribution to the European Strategy for Particle Physics. Krakow 10-12 September 2012. 28/09/2012 arXiv: 1208.0862v2

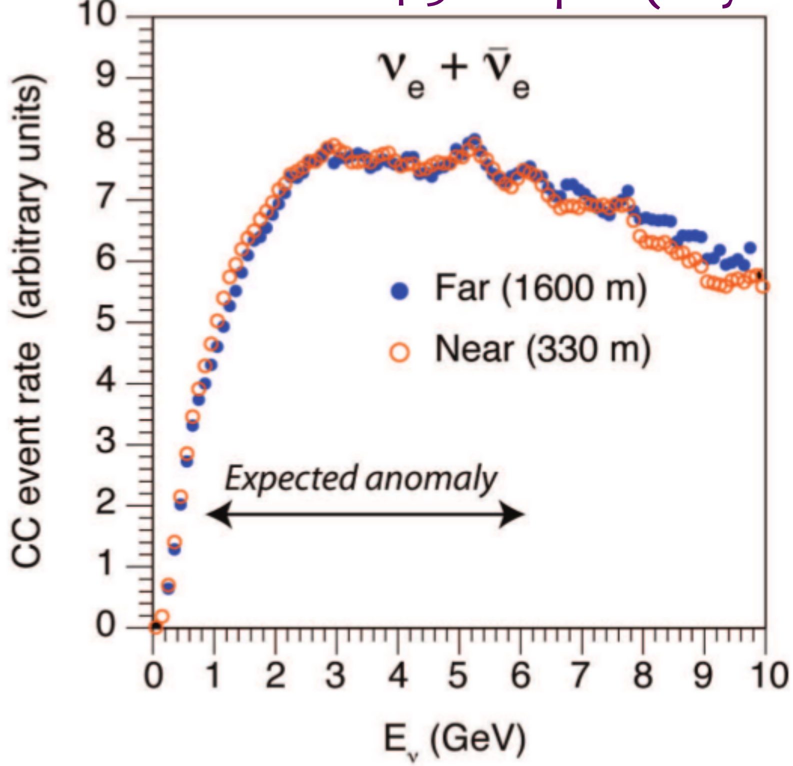


Tentative beam-line and ν CC spectra

On-axis configuration



Event rates 4.5 10^{19} pot (≈1 year)



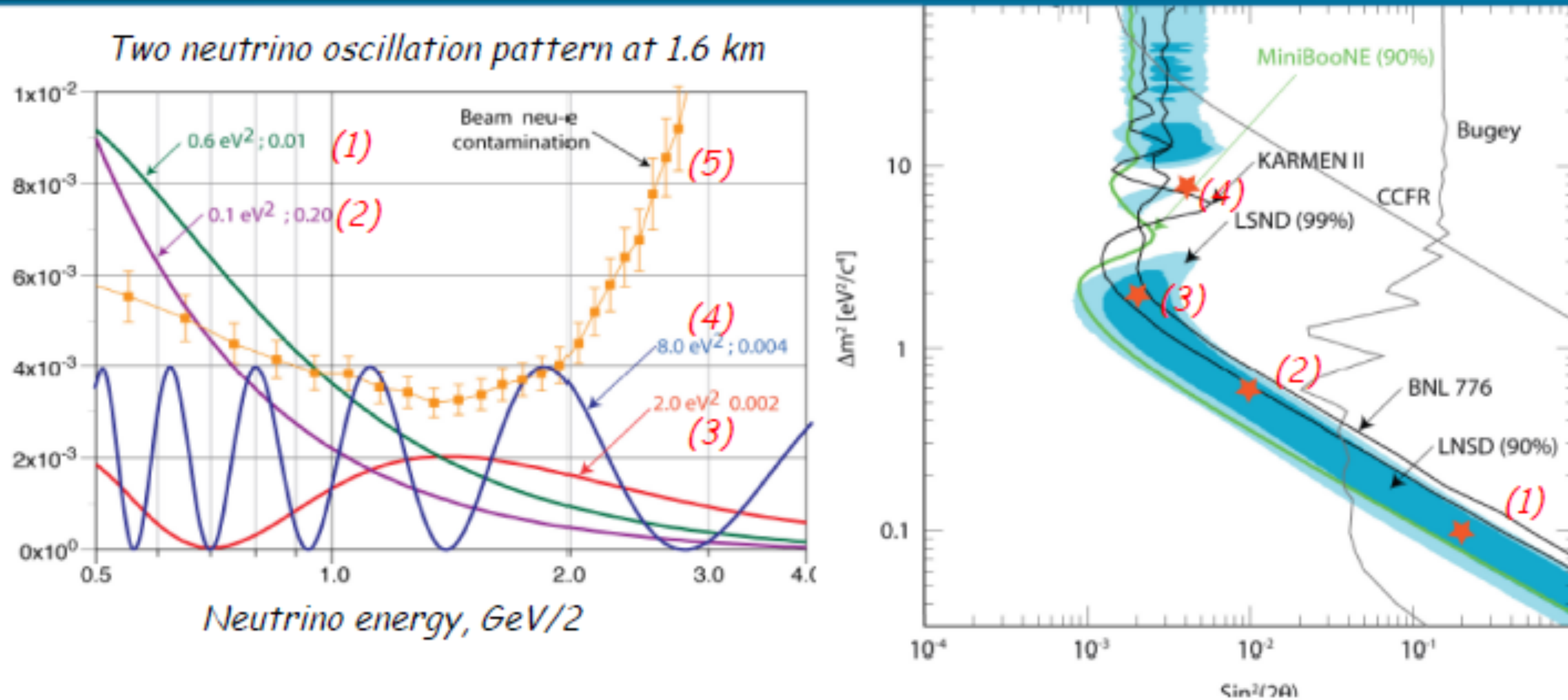
Unoscillated ν_e fluxes are ~ identical → N/F deviations = oscillations

The oscillated signals are clustered below 6 GeV of visible energy

LAr-TPC and Spectrometer Trigger

- Expected ν event rate in each LAr-TPC in FAR position : 0.18 (0.10) per 10.5 μs spill (2 10^{13} pot) for positive (negative) focusing.
- Additional beam related events: 0.15 (0.08)/spill/TPC. In spill Cosmic ray: ~0.11 μ/spill/TPC easily recognized by the different event topology.
- Coincidence of PMT signals within SPS p-spill gate will be used to trigger event acquisition separately on each T600-TPC.
- In T150 p-spill signal will be used to trigger data collection, due to multiple neutrino interactions (5 (2.5) events/spill/TPC).
- Moreover PMT signals & charge deposition in TPC wires (SuperDaedalus boards) will also be used for event localization/ data reduction.
- Spectrometer: few (several tens) events/spill in FAR (NEAR), triggerless mode within spill gate, events are time-stamped, DAQ transmission in inter-spill time.

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.