The NESSiE concept for Sterile Neutrinos

The Sterile Neutrino Issue
with SPS beam at CERN

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for the NESSiE collaboration

IFAE 2013 - April 5, 2013

INFN Istituto Nazionale di Fisica Nucleare

Università degli Studi di Padova

Proposal SPSC-P347 (March 2012)

OUTLINE

1. Physics ground & different scenarios
2. SPSC-P347 proposal
3. Latest beam & new simulation
4. Spectrometers
5. Performances

The 3ν oscillation paradigm

- ν-oscillations: the first physics BSM → ν are massive!
- decades of experiments → mixing of 3 active ν, PMNS unitary matrix

BUT

- Some observations are in tension with the 3ν scheme, pointing to a new $\Delta m^2 \sim eV^2$ (predominantly from single detector experiments…)
- LEP Z invisible decay width $N_{active} = 3$ (with $m_\nu < M_Z/2$), the extra state does not couple to Z/W
- **The extraordinary consequence of a possible sterile neutrino discovery calls for a conclusive experimental search**

Sterile neutrinos

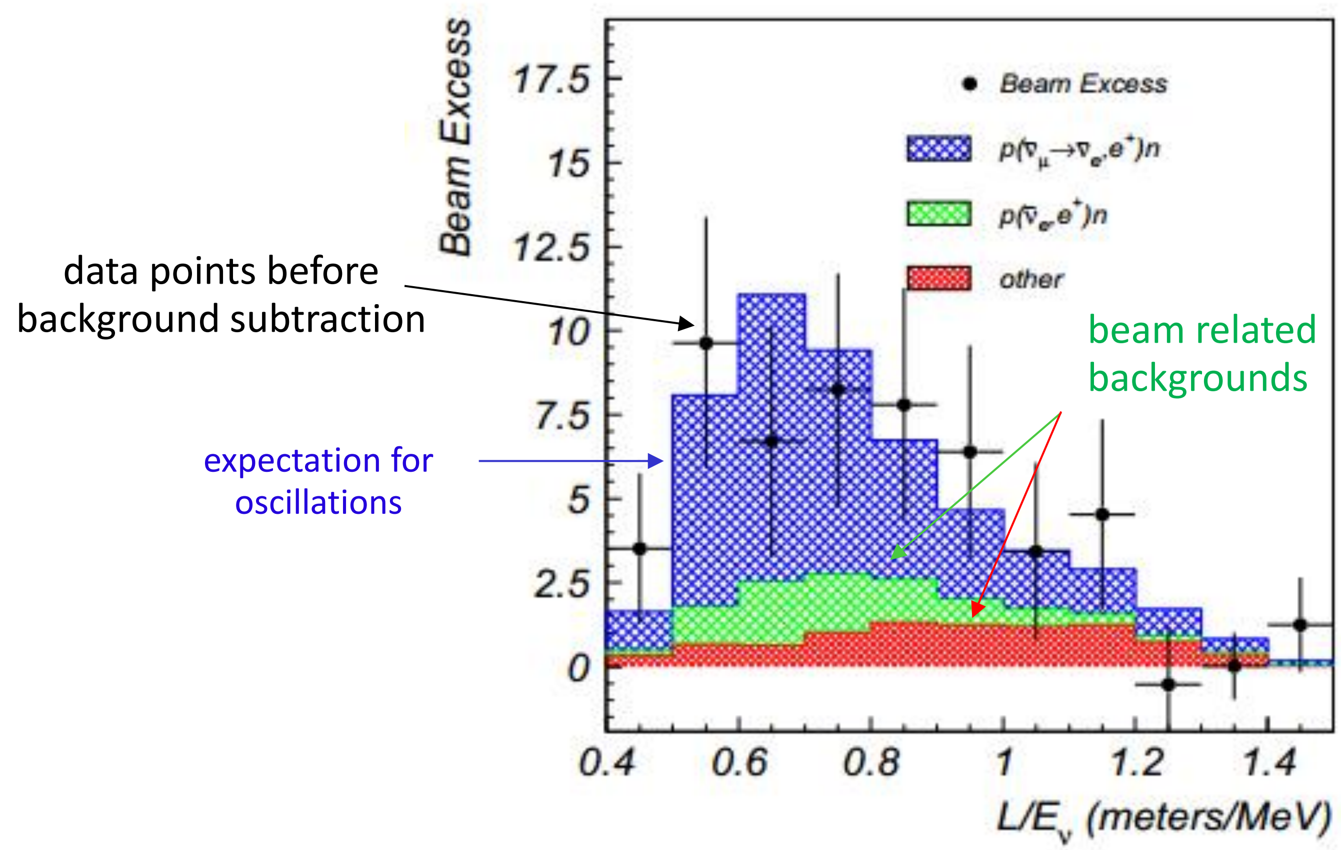
- Neutrino are special: the only neutral fermions in the SM
- SM extensions: SM singlet $L_L\phi$ can couple to a new BSM singlet chiral fermion field ν_R (i.e. think to light $anti\text{-}\nu_R$ which can oscillate with "active" ν)
- Light anti-ν_R are called sterile neutrinos
- Examples of light ν_R: see-saw, SUSY, extra dim. (KK), mirror world.
- "Sterile" = no SM interactions
- But (ν_e, ν_μ, ν_τ) can mix with sterile neutrinos (ν_s)

- Two distinct classes of anomalies have been analyzed, namely:
  - the apparent disappearance signal in the anti-ν_e/ν_e events detected from
    - (1) near-by nuclear reactors
    - (2) from MCi calibration sources in the Gallium experiments to detect solar ν_e
  - observation for appearance signals of anti-ν_e from anti-ν_μ from particle accelerators (LNSD/MiniBooNE) (but no ν_e excess signal from ν_μ -> ν_e)

- Observables:
- Smoking Gun: Neutral Current Deficit (also disappearance of active neutrinos)
- Counterchecked Smoking Gun: NC/CC ratios
- At least a fourth non-standard neutrino state can oscillate at small distances, $\Delta m^2_{new} \approx 1$ eV^2 (➔ **SHORT BASELINE projects)**

LSND: «evidence» of $anti\, \nu_\mu \rightarrow anti - \nu_e$

- L ~ 30m, 20 < E < 200 MeV
- source: $anti\text{-}\nu_\mu$ beam
- detection: $anti\text{-}\nu_e + p \rightarrow e^+ + n$ (2.2 MeV γ)



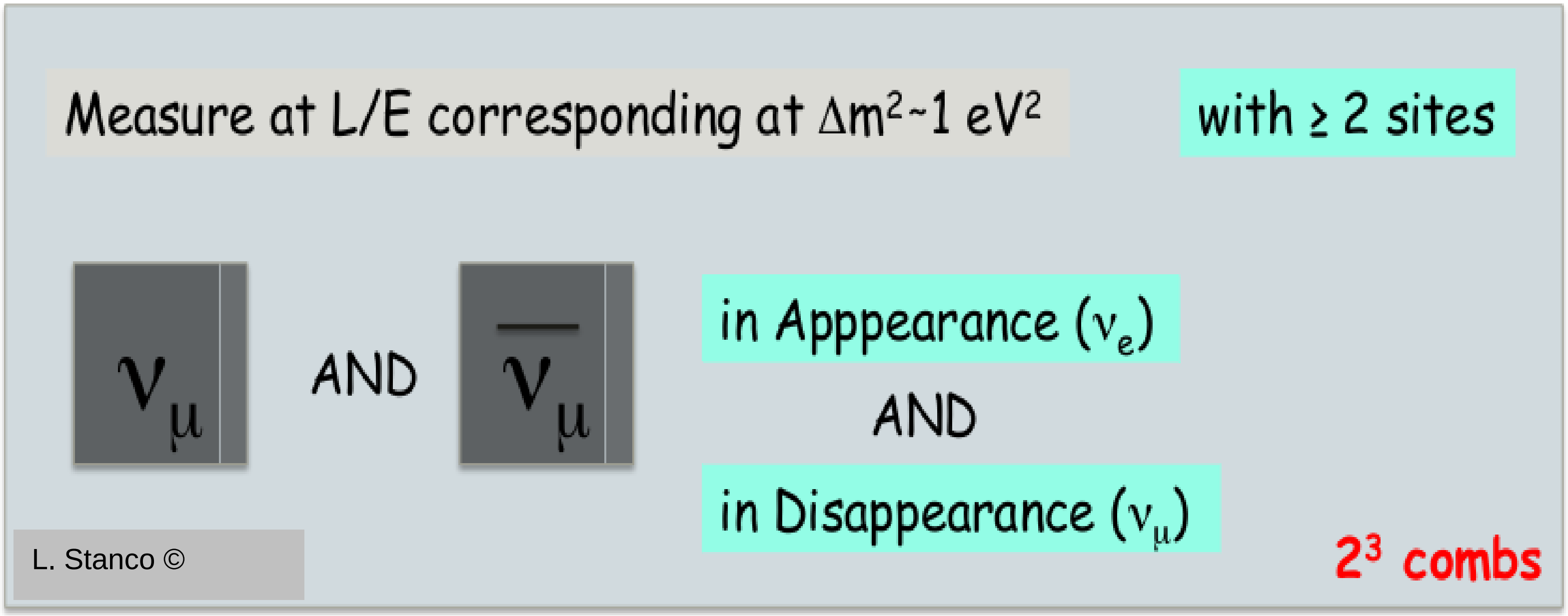
anti-ν_e excess:
87.9 ± 22.4 ± 6.0
(3.8 σ not very strong)

PRL 75 (1995) 2650; PRC 54 (1996) 2685;
PRL 77 (1996) 3082; PRD 64 (2001) 112007

- the experimental result so far has not been challenged experimentally

Approach at the CERN SPS

A direct unambiguous measurement of an oscillatory pattern requires necessarily the (simultaneous) observation at several different distances: the only way to identify both Δm^2 and $sin^2 2\theta$



We need a Superior Class Experiment: 3 kton Fe + 1 kton LAr

- ICARUS imaging detector unambiguous identification of ALL channest w. a LAr-TPC
- NESSiE magnetic spectrometers to determinate μ charge and momentum

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

M. Benettoni[5], P. Bernardini[26,27], A. Bertolin[5], C. Bozza[31], R. Brugnera[4,5], A. Cecchetti[6], S. Cecchini[25], G. Collazuol[5,6], P. Creti[27], F. Dal Corso[5], I. De Mitri[26,27], G. De Robertis[23], M. De Serio[23], L. Degli Esposti[25], D. Di Ferdinando[25], U. Dore[29,30], S. Dusini[5], P. Fabbricatore[3], C. Fanin[5], R. A. Fini[23], G. Fiore[27], A. Garfagnini[4,5], G. Giacomelli[24,25], R. Giacomelli[25], G. Grella[31], C. Guandalini[25], M. Guerzoni[25], U. Kose[5], G. Laurenti[25], M. Laveder[4,5], I. Lippi[5], F. Loddo[23], A. Longhin[6], P. Loverre[29,30], G. Mancarella[26,27], G. Mandrioli[25], A. Margiotta[24,25], G. Marsella[27,28], N. Mauri[6], E. Medinaceli[4,5], A. Mengucci[6], M. Mezzetto[5], R. Michinelli[25], M. T. Muciaccia[22,23], D. Orecchini[6], A. Paoloni[6], A. Pastore[22,23], L. Patrizii[25], M. Pozzato[24,25], R. Rescigno[31], G. Rosa[29], S. Simone[22,23], M. Sioli[24,25], G. Sirri[25], M. Spurio[24,25], L. Stanco[5,b], S. Stellacci[31], A. Surdo[27], M. Tenti[24,25], V. Togo[25], M. Ventura[6] and M. Zago[5].

(b) Contact Person

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 and $anti$-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.

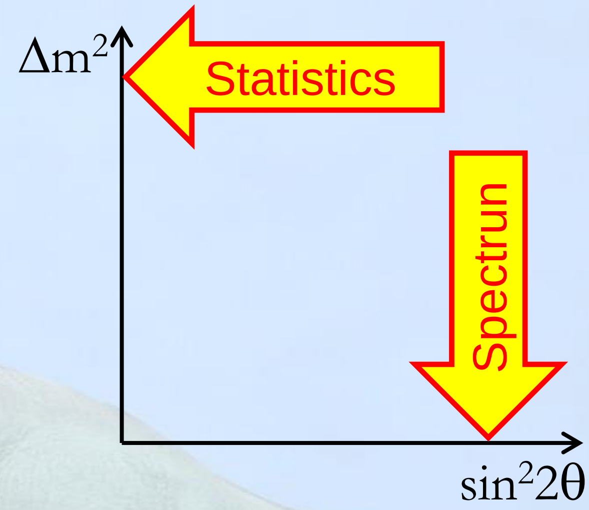
Scientific Approval (CERNS' SPSC) middle of January 2013!!!

NESSiE (Neutrino Experiment with Spectrometers in Europe)

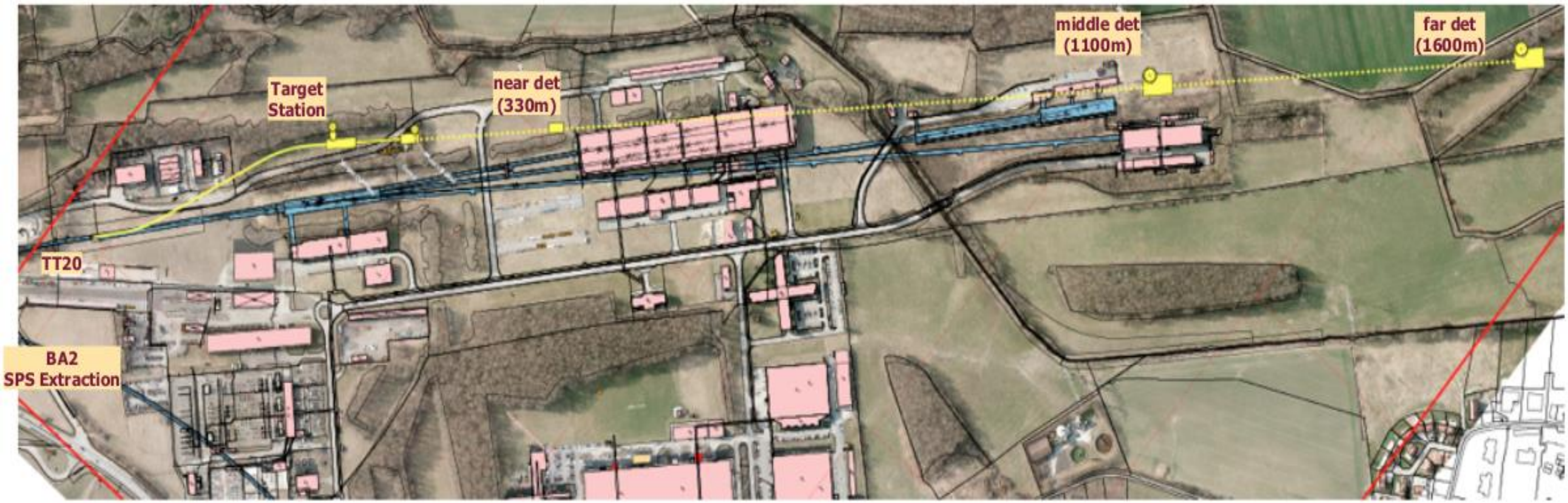
charge and momentum measurements in
the CC neutrino interactions

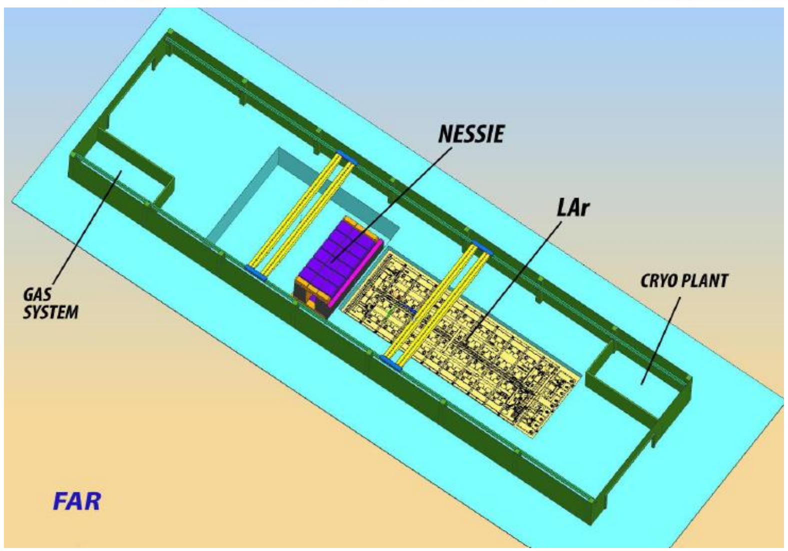
Fundamental because:

- Increase the Δm^2 range (low P → low Δm^2)
- Measure precisely ν_μ dissapearance in a wide energy range
- Large statistics → low $sin^2 2\theta$
- Separate ν_μ from $anti$- ν_μ
- Measure the ϕ_ν the near detector, to keep systematics as low as possible
- Normalize NC/CC



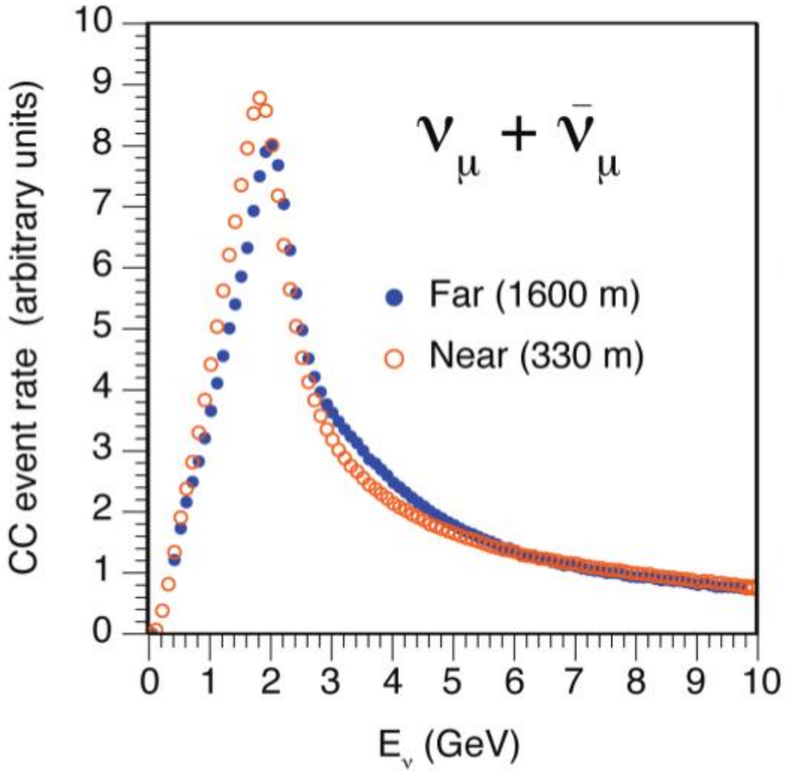
Preliminary SBL layout at the CERN's North Area

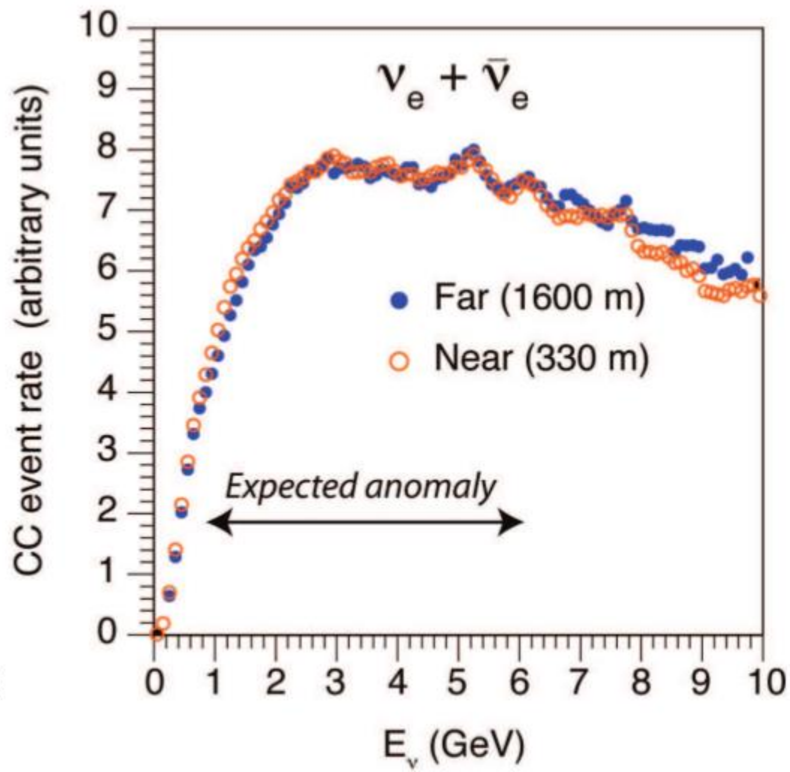




- Near site L = 300m
- Far site L = 1600m
- SPS p beam: 100 GeV → 2 GeV ν beam
- Luminosity: $4.5 \cdot 10^{19}$ pot/year (CNGS)
- Interactions/spill = 5 / 0.65 at near / far

Latest beam studies at SPS





Un-oscillated ν_e fluxes are ~ identical
→ N/F deviations = oscillations
The oscillated signals are clustered below 6 GeV of visible energy

Scenario **defined** for DATA Taking:
2 years of $anti\text{-}\nu$ followed by 1 year ν

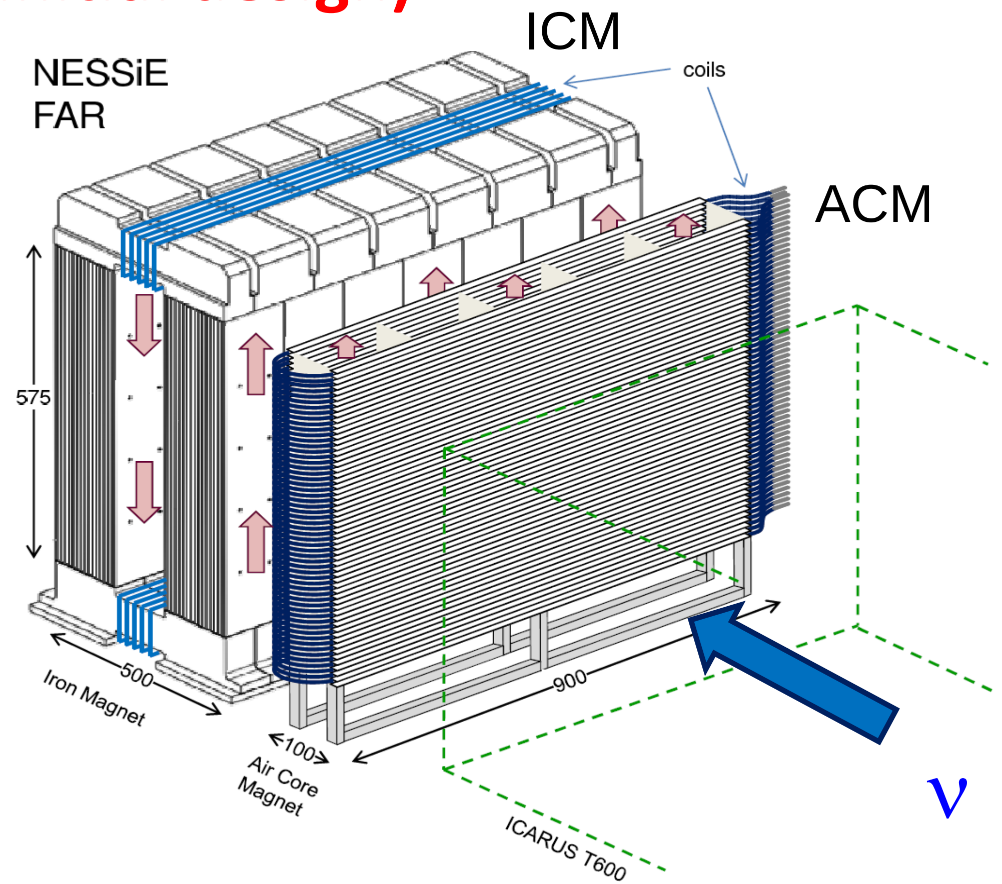
NESSiE (initial design)

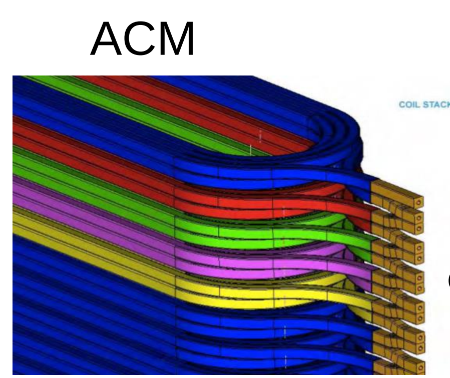
IRON CORE MAGNETS

- Two Iron spectrometers (**ICM**), FAR 1500 t (LAr 476 t) + NEAR 800 t (LAr 119 t), instrumented with:
  - 1800 + 700 m^2 of RPC
  - «sandwich style» assembly to be made in situ, one piece per time
- 20 000 + 12 000 digital channels

AIR CORE MAGNETS

- Two Air Core Magnets (**ACM**) pre-assembled and installed in one shot
  - B = 0.17 T
- Precision Trackers preassembled and installed in one shot



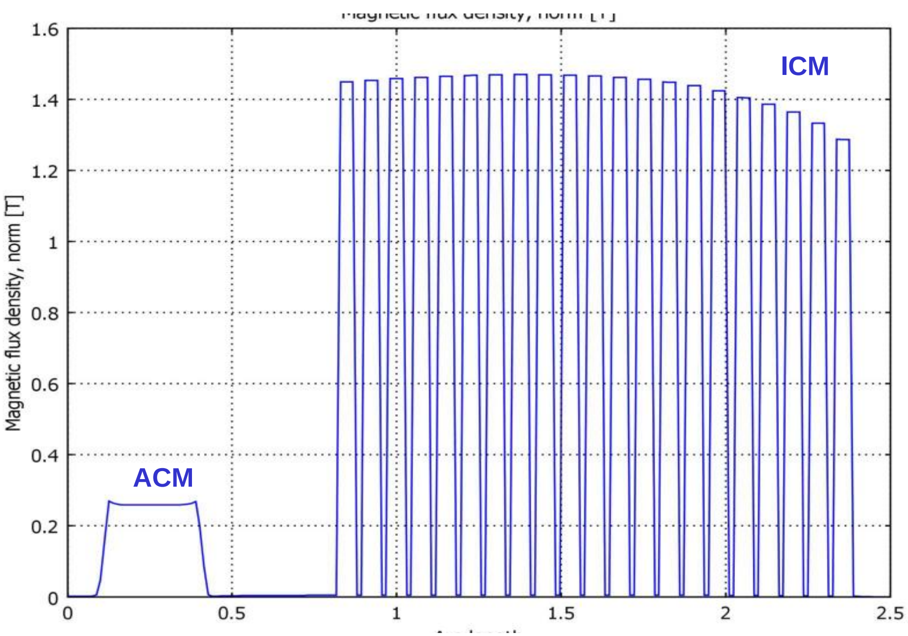


Cross section of the Al coils with circular water cooling channel (~ LHCb)

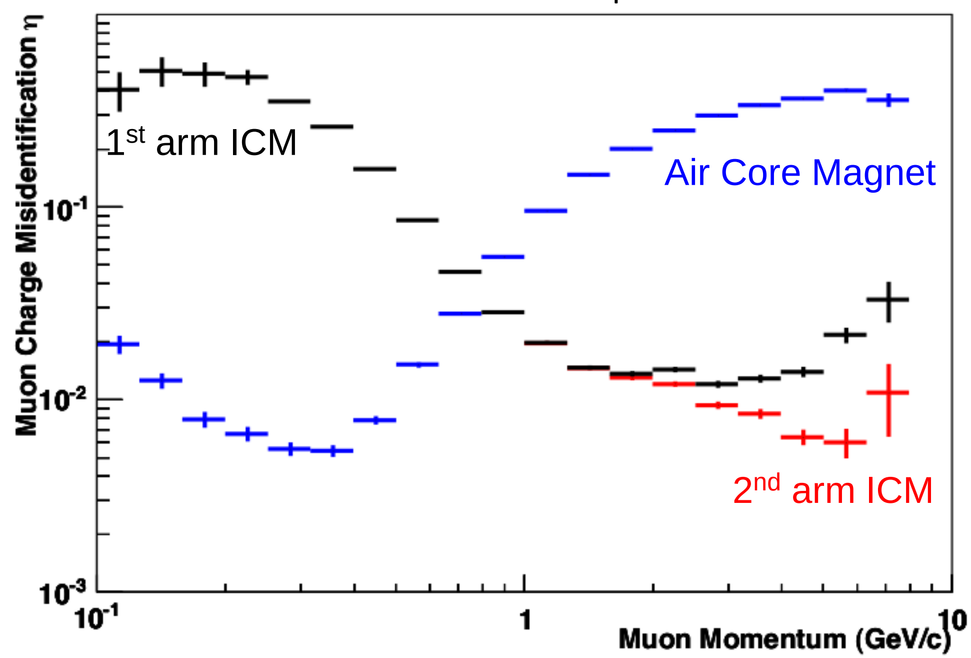
NESSiE performances

Complementary of NESSiE spectrometers in the low (<1 GeV) and high energies domanis

Transverse profile of the global magnetic field (iron + air)



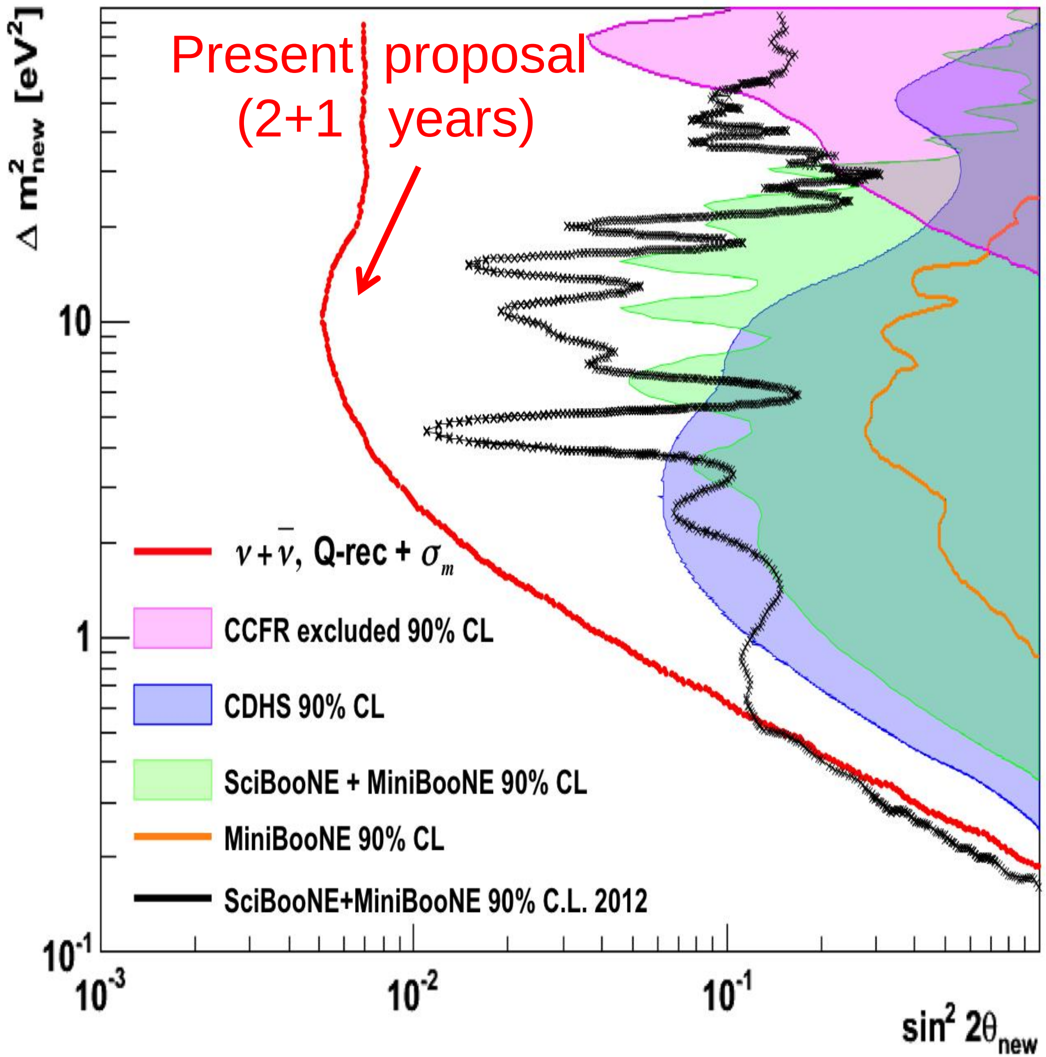
Charge missidentification percentage
including selection, efficiency and reconstruction proceadures



Sensitivity to ν_μ disappearance

NESSiE can disentangle ν_μ $anti$-ν_μ (interplay of diff. oscillation scenarios)

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



Conclusions

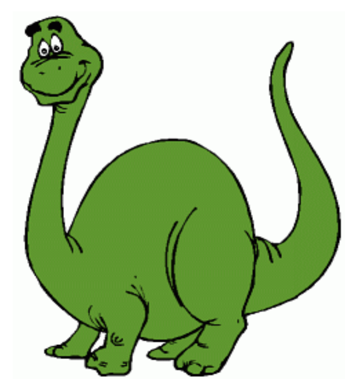
Possibility of exciting discoveries of BSM Physics with vast consequences or a complete clarification of present anomalies.

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

Opportunity for a revival of neutrino activity in Europe.

Possible synergies with the other 3ν and R&D programs.

Large room and availability for contributions in NESSiE



Backup slides

Status of approval and further

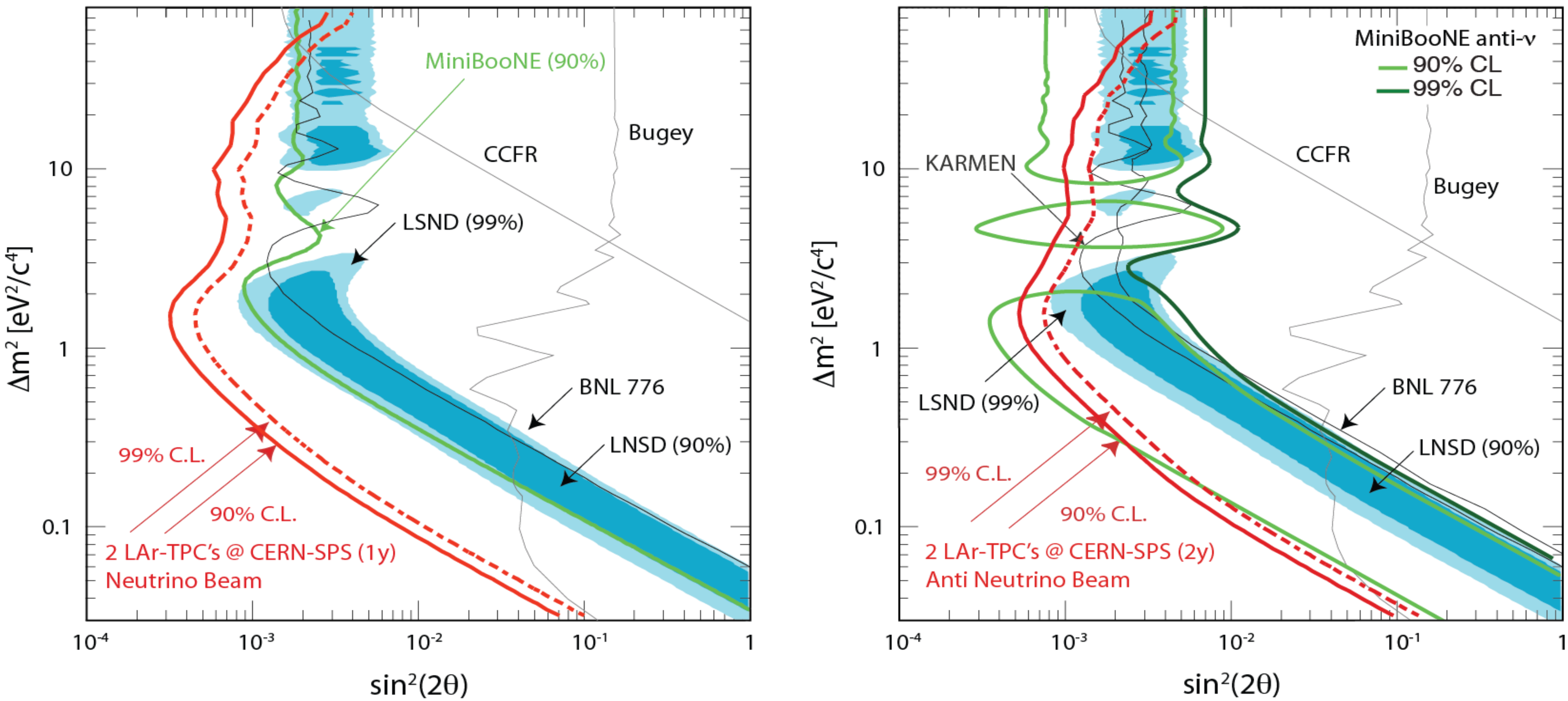
CERN

- 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 7th 2013
- Research Board evaluation on March 4th 2013
- SPC
- CERN Council

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

- Scientific approval
- Under evaluation by the Technical Scientific Committee (CTS) as for costs, manpower
- In-Kind contribution of Opera Spectrometers

ν_e / $anti$-ν_e appearance sensibility



ν_μ - 4.5·10^{19} pot (1 year)

$anti$-ν_μ - 9.0·10^{19} pot (2 years)

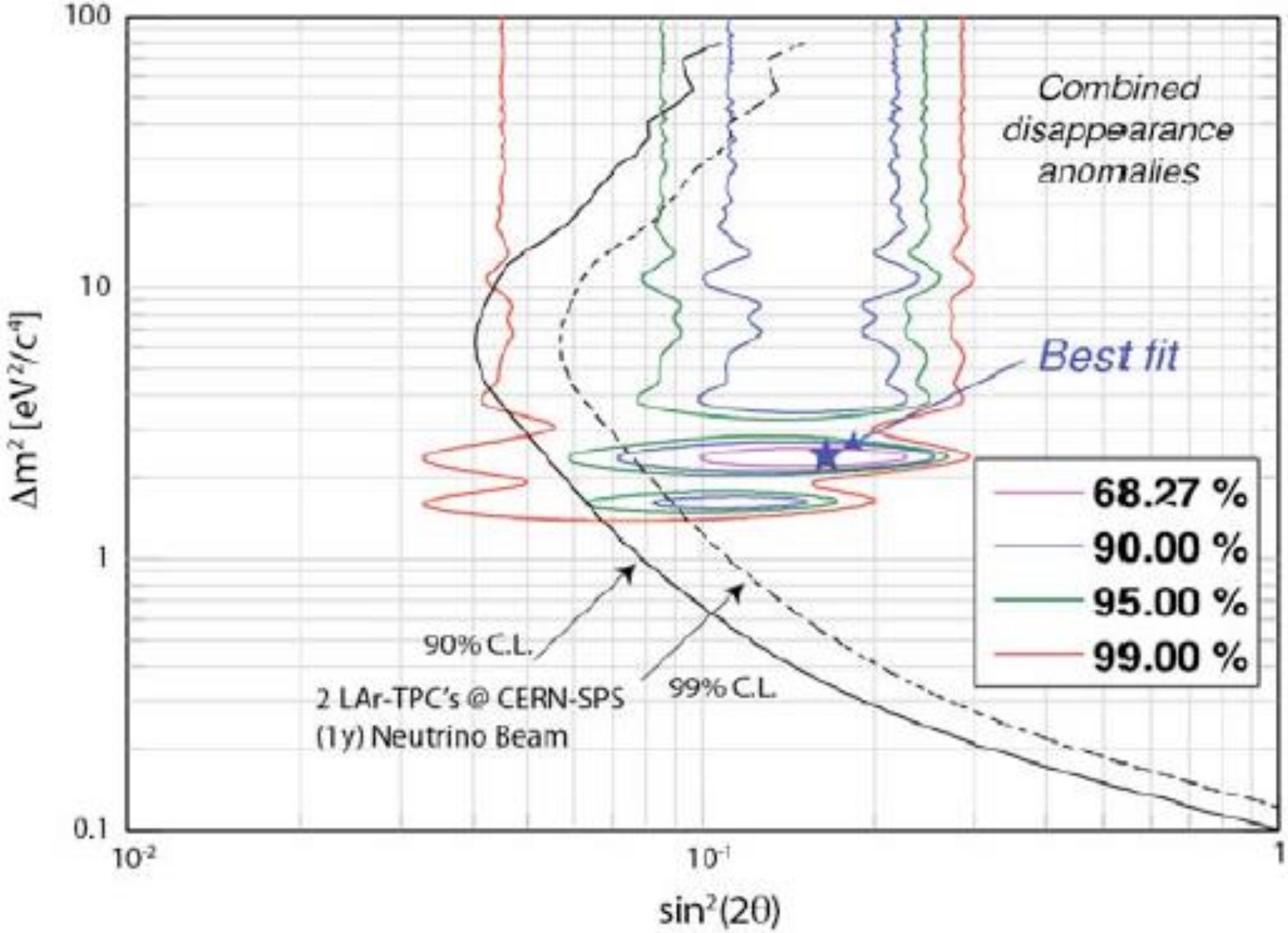
2 LAr-TPCs at CERN-SPS

LSND allowed region is fully explored in both cases

ν_e disappearance

ν_μ 4.5· 10^{19} pot
(1 year)

2 LAr-TPCs at CERN-SPS



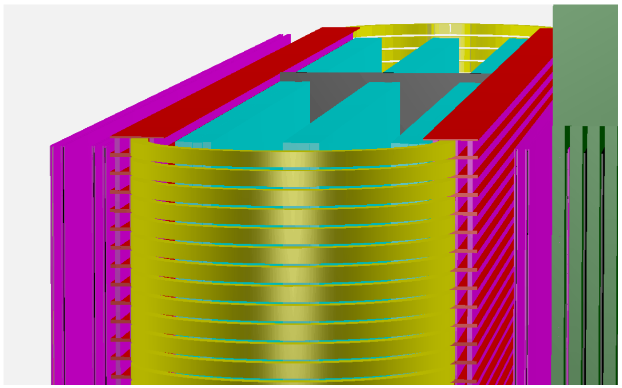
The reactor/Gallium anomalies can be fully addressed

Possible Instrumentation, ACM

Precision Trackers

- to be placed inside the Air Core Magnet
- several open options for detector technology. Under study: triangular scintillator bars with SiPM analog R/O, drift tubes, TPC, wire chambers, analog RPC …
- room for new ideas and collaborators

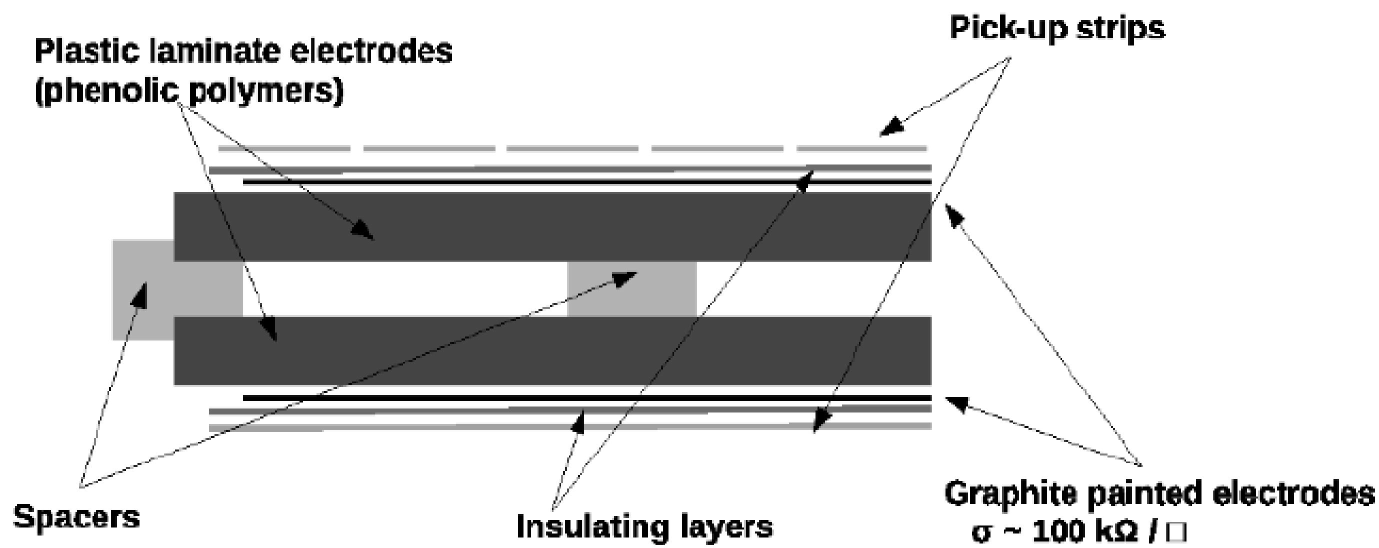
Average muon momentum at vertex ~ 4 GeV



e.g. 3 drift tube layers inside (example), RPCs outside

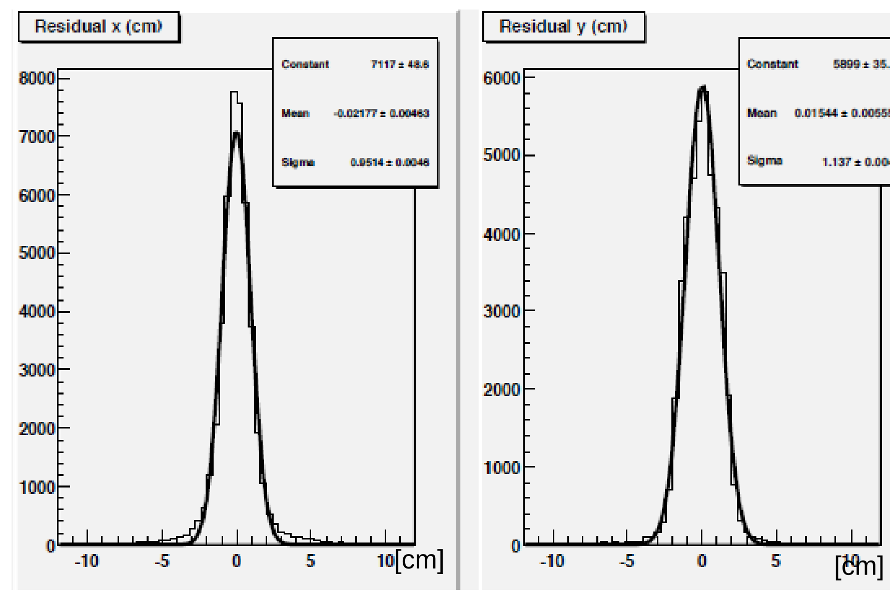
@ spectrometer entrance

Resistive Plate Chambers RPC, ICM

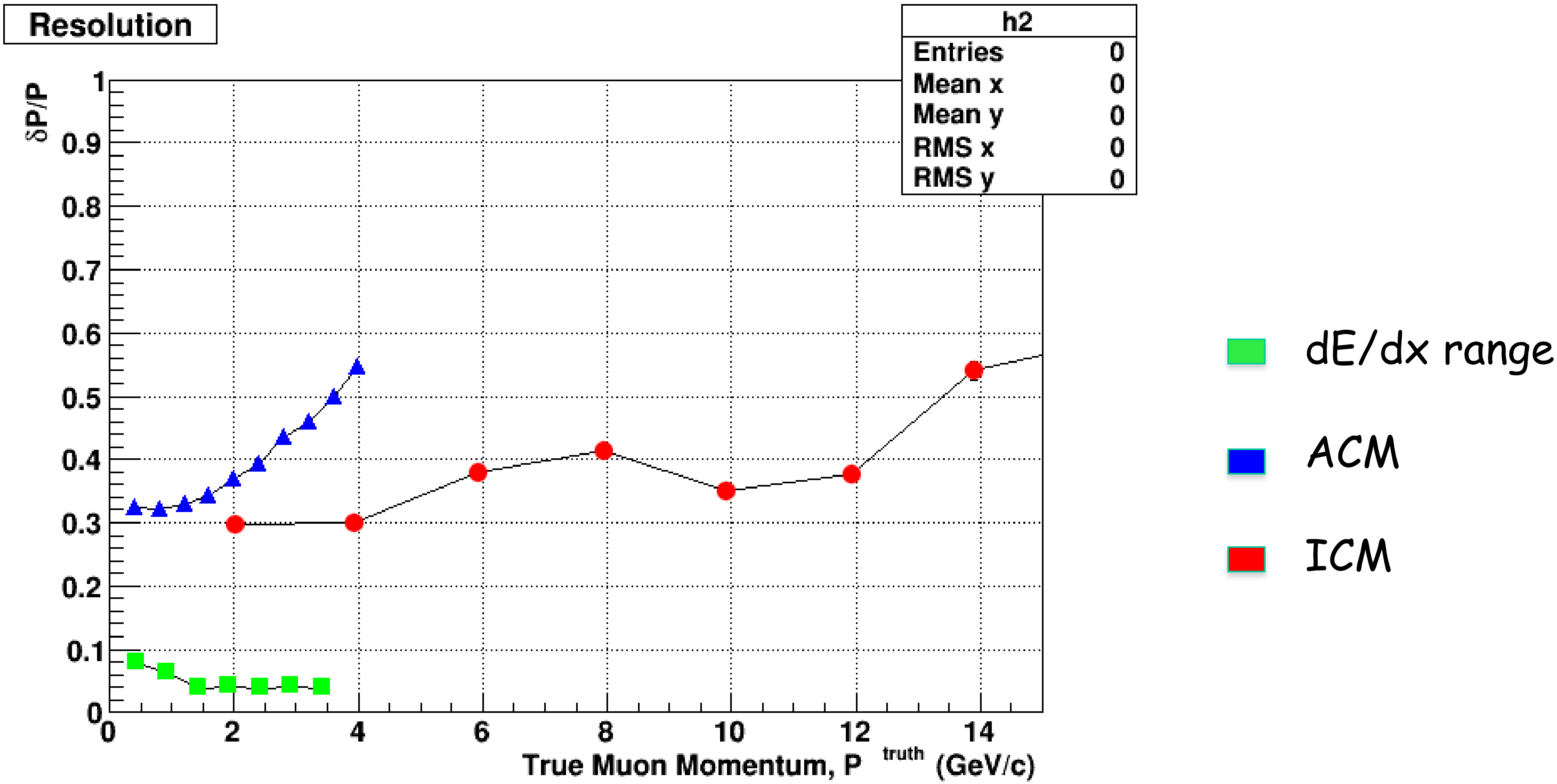


<u>Fe magnets:</u> **operation V = 5.8 kV (I < 100 nA/m^2)**
resolution position ~ 1 cm, time ~ ns
gas mixture Ar / $C_2H_2F_4$ / I-C_4H_{10} / SF_6
digital read-out
NEAR: exposed surface ~ 20 m^2
240 internal chambers
40 layers (2 columns x 3 rows)
FAR: exposed surface ~ 50 m^2
600 internal chambers
40 layers (3 columns x 5 rows)

RPC resolution (digital read-out)

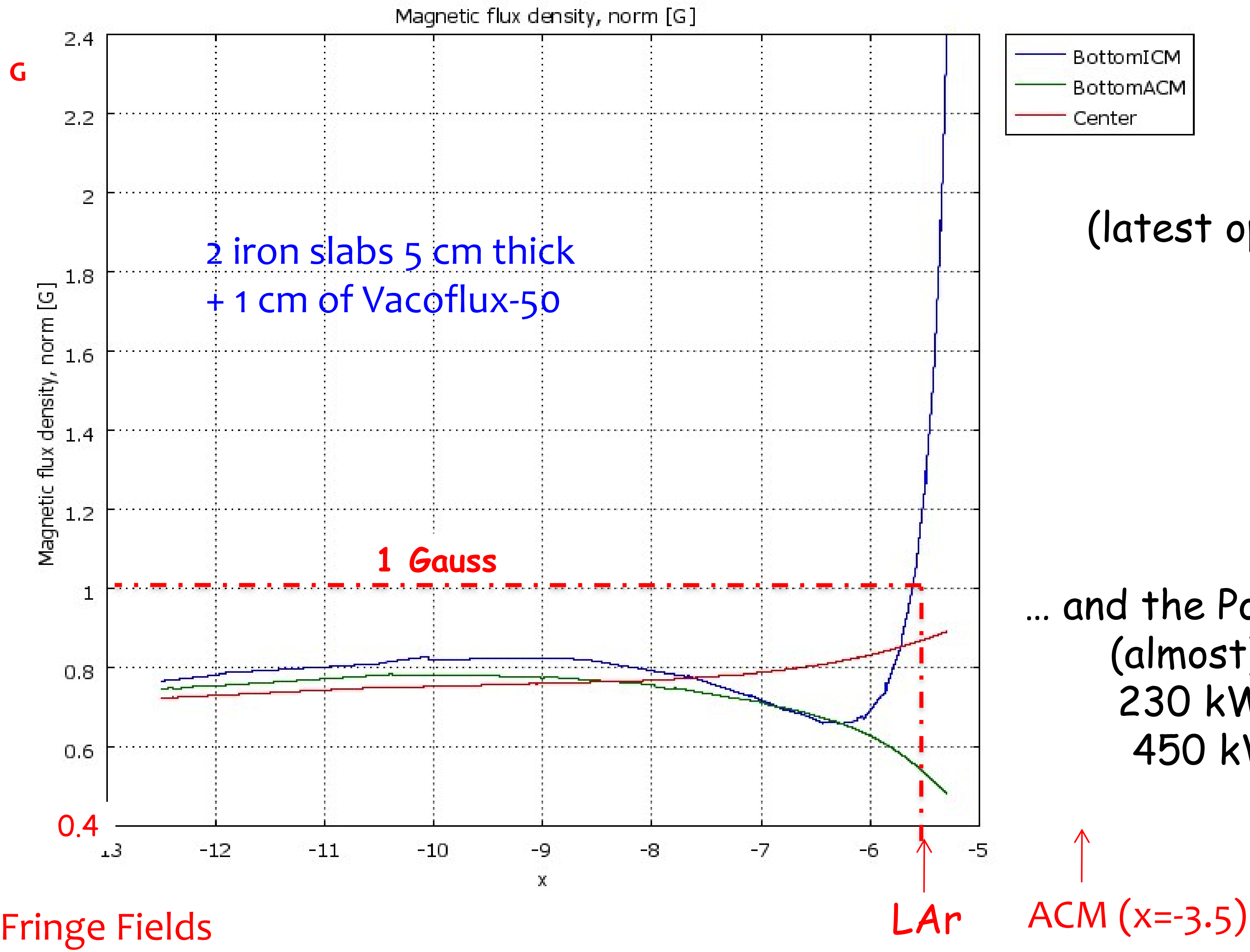


Momentum measurement at 4% with dE/dx up to 3.5 GeV
At 30% with Prec.Tracker above 3 GeV
At 30% with ACM below 1.5 GeV



Latest configuration (OPERA-2), algorithms not optimized …

… and the fringe field is under control



(latest optimization)

… and the Power Supplies (almost) as well:
230 kW (Near)
450 kW (Far)

Fringe Fields

e.g. Expected events in 1 year of running (ν_μ)

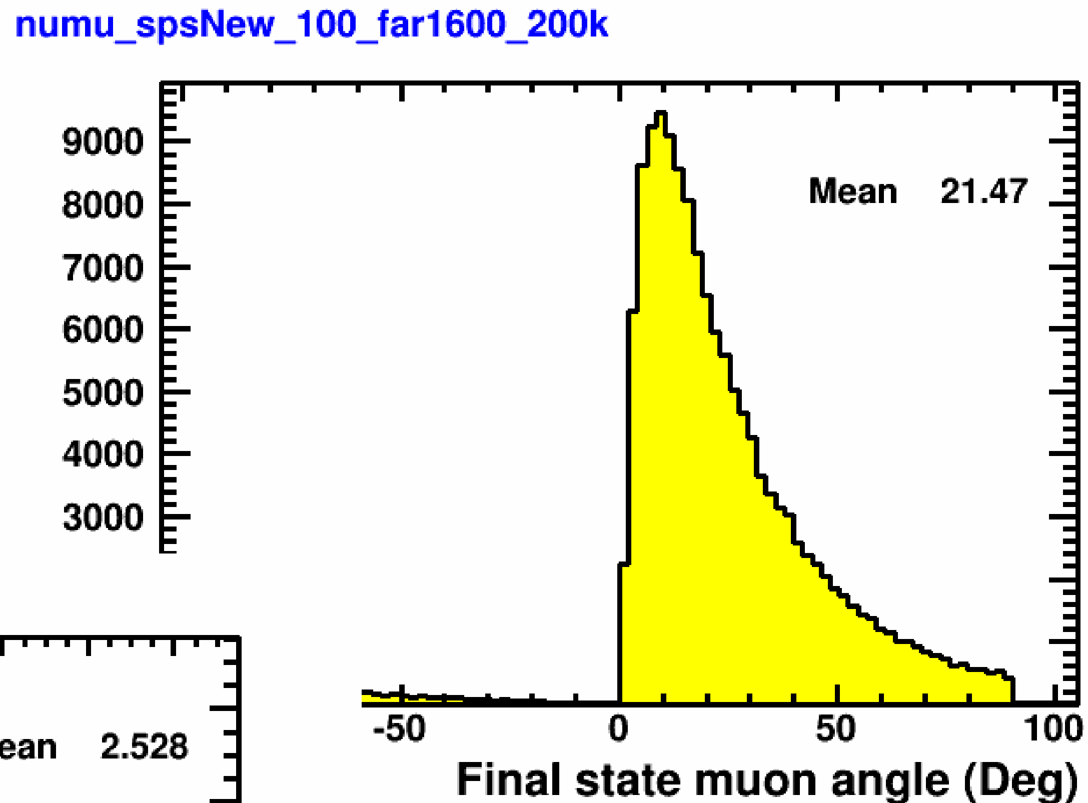
To reconstruct: 5.3 M muons in LAr (Near), 0.67 M muons in Lar (Far)
pos. foc. 5.2 M muons in Nessie (Near), 0.42 M in Nessie (Far)
(with factor 2 in overhead of triggers, positive focussing)

		NEAR (anti-ν)	NEAR(ν)	FAR(anti-ν)	FAR(ν)
produced	ν_e + anti-ν_e (LAr)	35 K	54 K	4.2 K	6.4 K
produced	ν_μ + anti-ν_μ (LAr)	2000 K	5250 K	270 K	670 K
produced	Appear. test point	590	1900	360	910
	"NESSiE" = fiducial volume of 241 t (N) and 661 t (F)				
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	anti-ν_μ (Lar+NESSiE)	370 K	56 K	33 K	6.9 K
detected	anti-ν_μ (NESSiE)	1100 K	300 K	89 K	22 K
detected	Disappear. test point	1800	4700	1700	5000

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

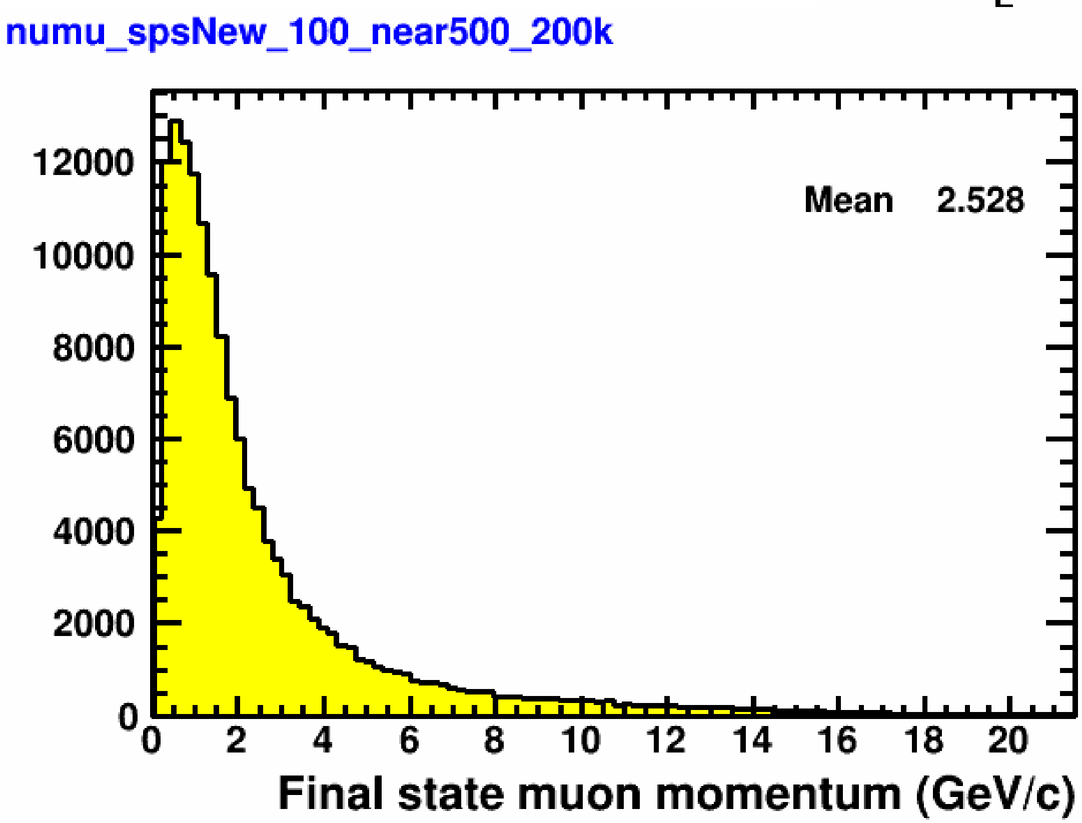
- Values for Δm^2 (sterile model) around 2 eV^2 are reported as example

Muons' distributions



Muon angle

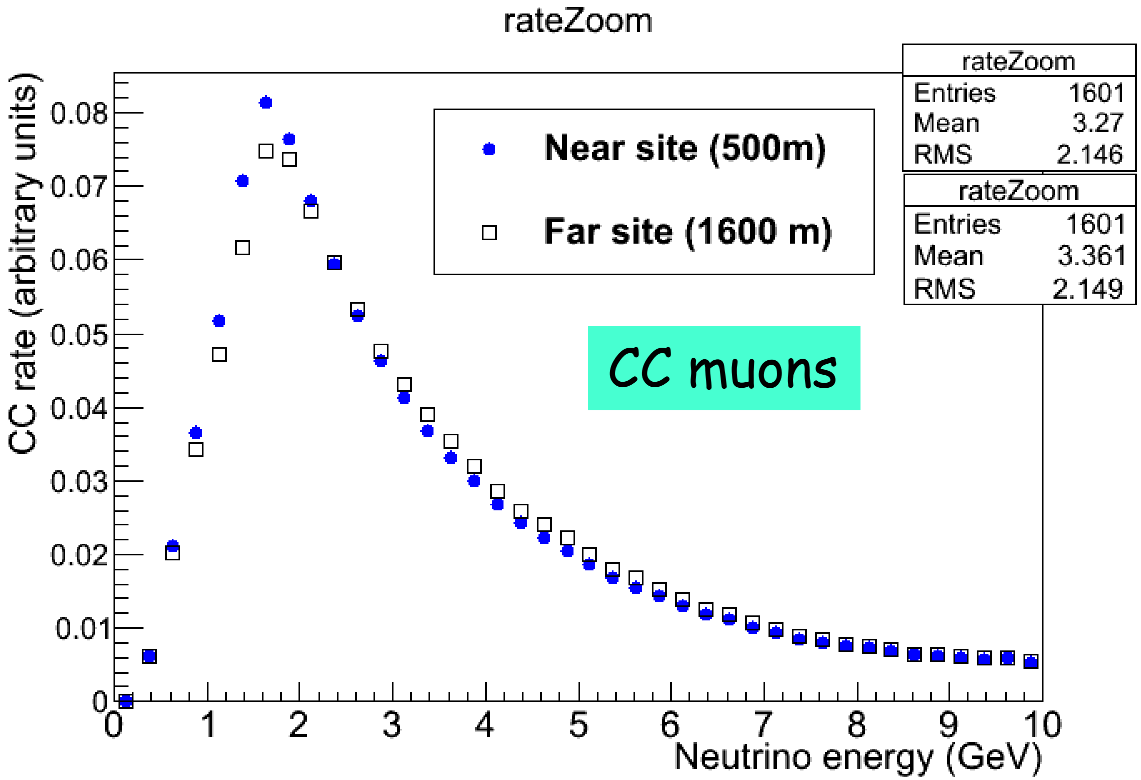
Muon momentum



Latest Beam Studies at SPS

- 100 GeV proton, Fast Extraction (10.5 μs), Luminosity as at CNGS

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

Scenario **defined** for DATA Taking: 2 years of anti-ν followed by 1 year ν

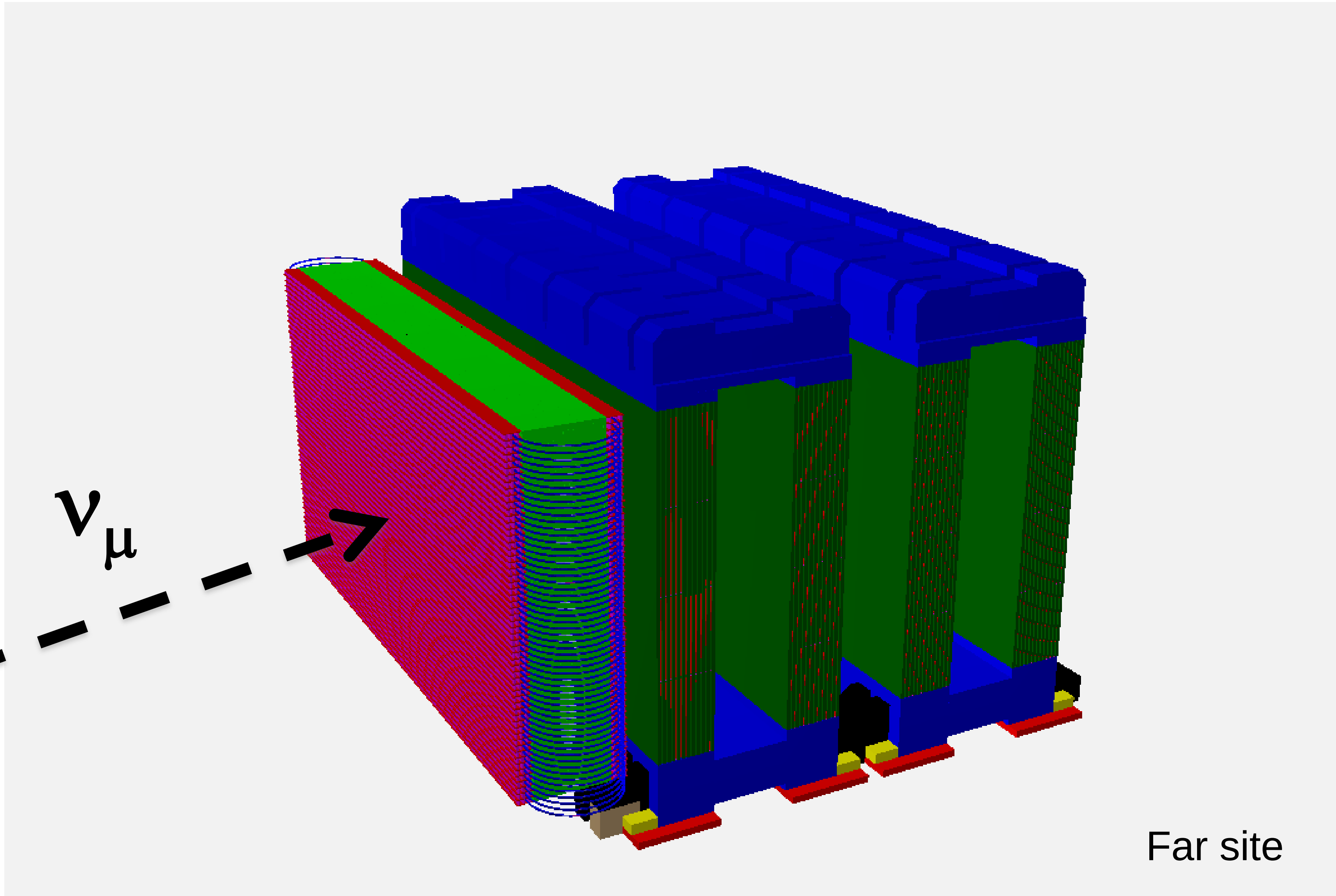
Opera re-use

- 2 Spectrometers “available”, with Detectors and Servicing
- Possibility to full re-use for Far and Near ICM
- Need two new sets of Yokes (Top & Bottom)
  new Electronics for RPC
  Mechanical Tools
  PT detectors
  Scintillators
- Other: ACMs

T0 availability for dismantling
and transportation at CERN: Autumn 2014

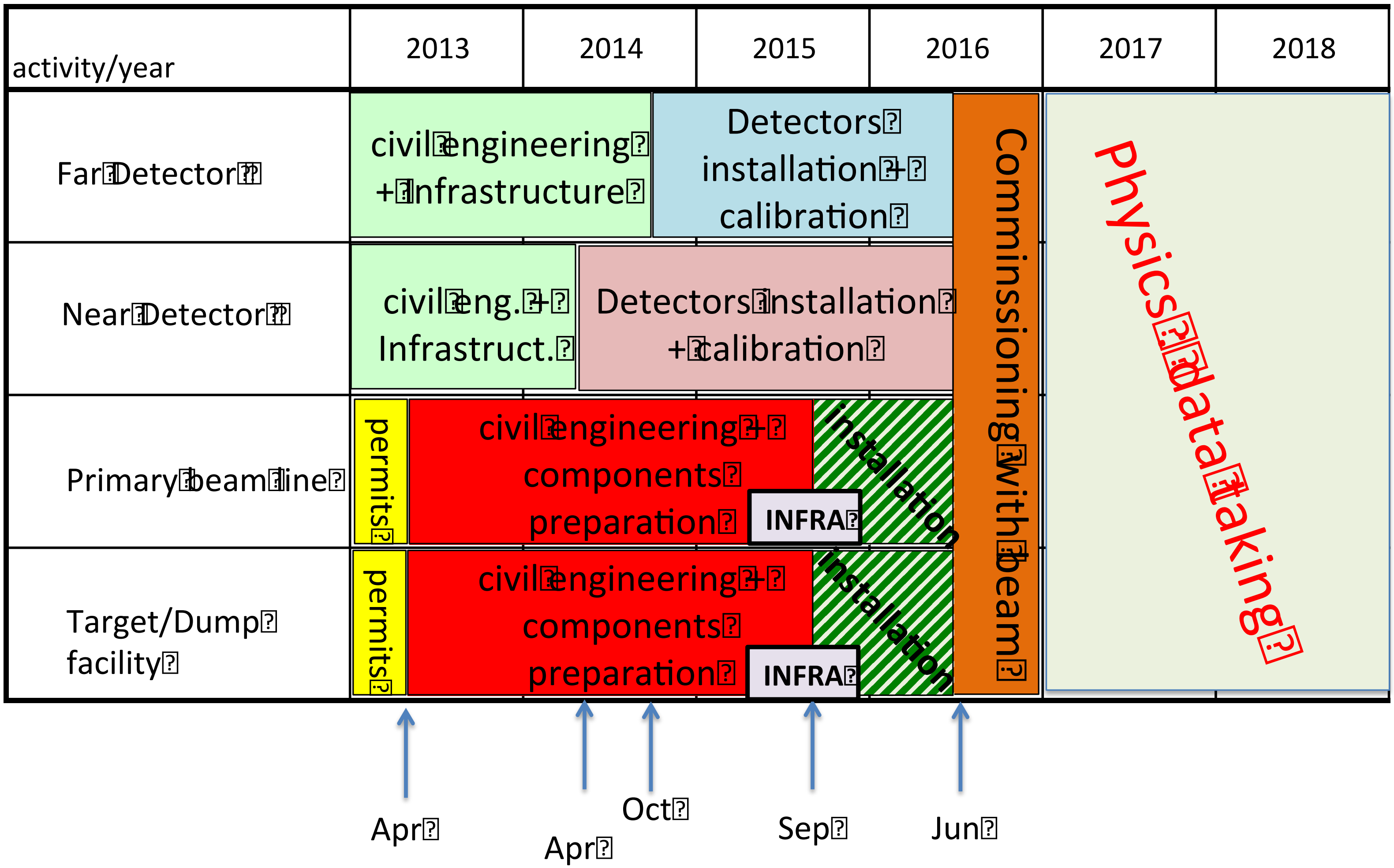
OPERA discussion:
possible start dismantling July-December 2014

Arrangement with OPERA Spectrs.



CERN Schedule

Overall Planning Proposal (nord area)



Nessie Schedule

2013:	ACM prototype construction, iron SM, ACM, HPT and ancillaries design
2013 - end:	start tenders process
2014 - early:	issue tenders for production/modification (copper. yokes, slabs, rpc, strips, tools/frames)
2014:	parts and tools production/modification
2014 – end:	first deliveries at Cern (copper coils, yokes, slabs, strips, tools/frames, RPC)
2015 - early:	start assembly
2016 - mid:	finish assembly
2016 – fall:	commissioning and start of data taking

MONEY estimation

Iron magnets: in-kind value 5940 K€ (from OPERA)
Cost for transportation to CERN and refurbishing: 3000 K€
In-kind value of Precision Tracker: 1900 K€
possible refurbishing: 700 K€
In-kind value of Scintillators: 1900 K€
possible refurbishing: 300 K€
Cost ACM: 700 (Near) + 1800 (Far)

TOTAL: 3+1+1+2 = 7 M€

→ might be staged at 2nd phase (after LS2)

Spare slides

The Gallium anomaly: ν_e disappearance

Acero, Giunti, Laveder, 0711.4222
Giunti, Laveder, 1006.3244

~MCi ν_e EC calib. sources:

$e^- + {}^{51}Cr \rightarrow {}^{51}V + \nu_e$

$e^- + {}^{37}Ar \rightarrow {}^{37}Cl + \nu_e$

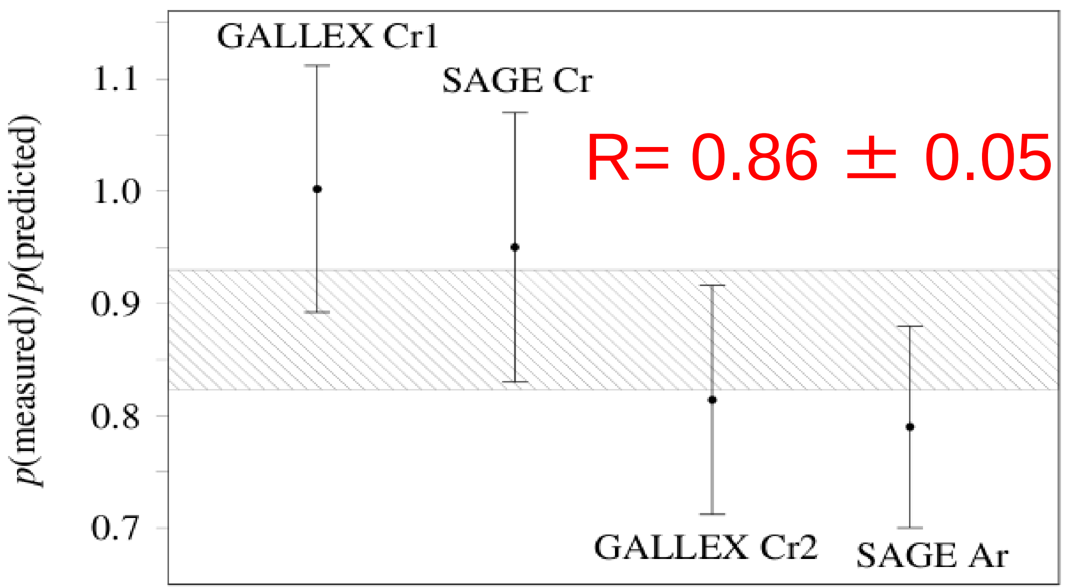
E ~ 0.7 MeV

$\langle L_{SAGE} \rangle = 0.6$ m
$\langle L_{GALLEX} \rangle = 1.9$ m

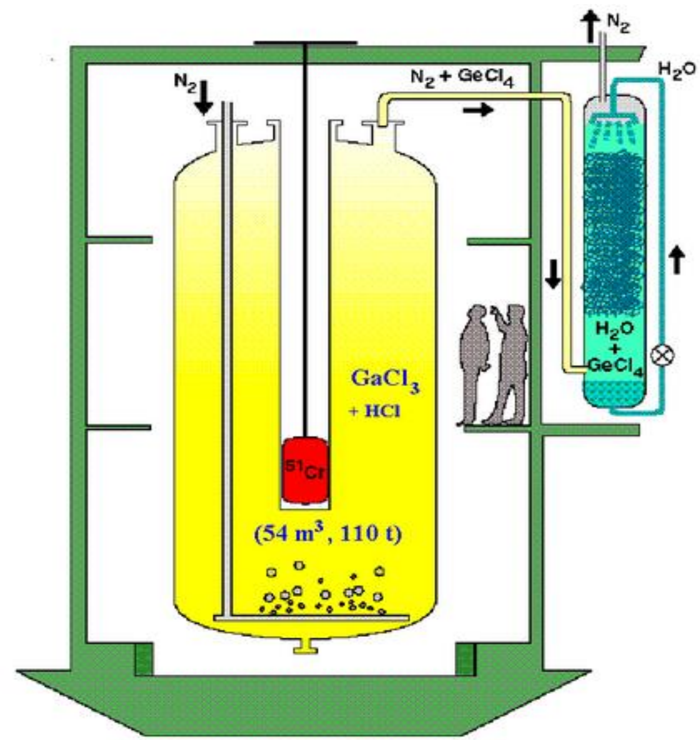
Radiochemical detection

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

5-20% deficit in the ν_e



R= 0.86 ± 0.05 (2.8σ)

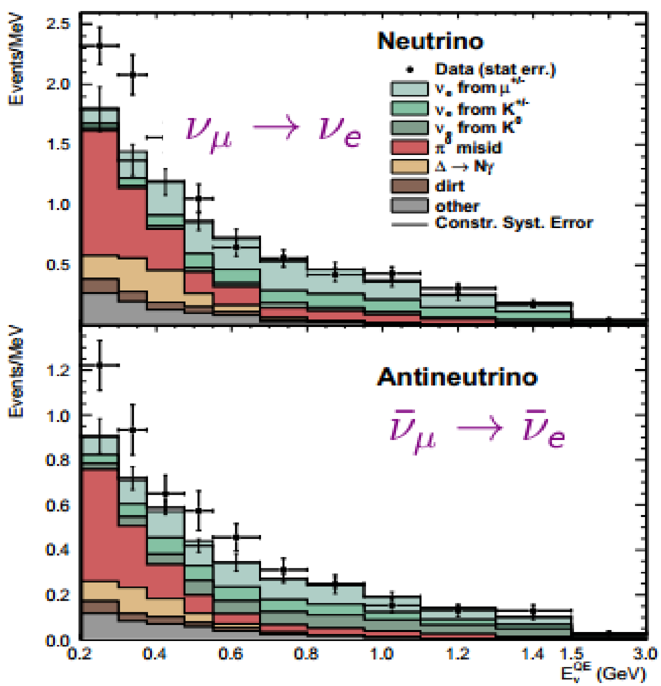


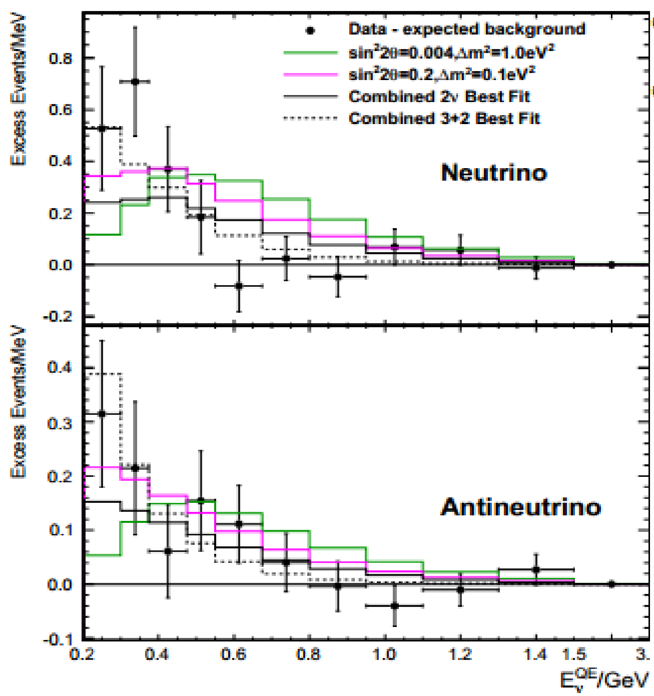
SAGE, PRC 73 (2006) 045805, nucl-ex/0512041]

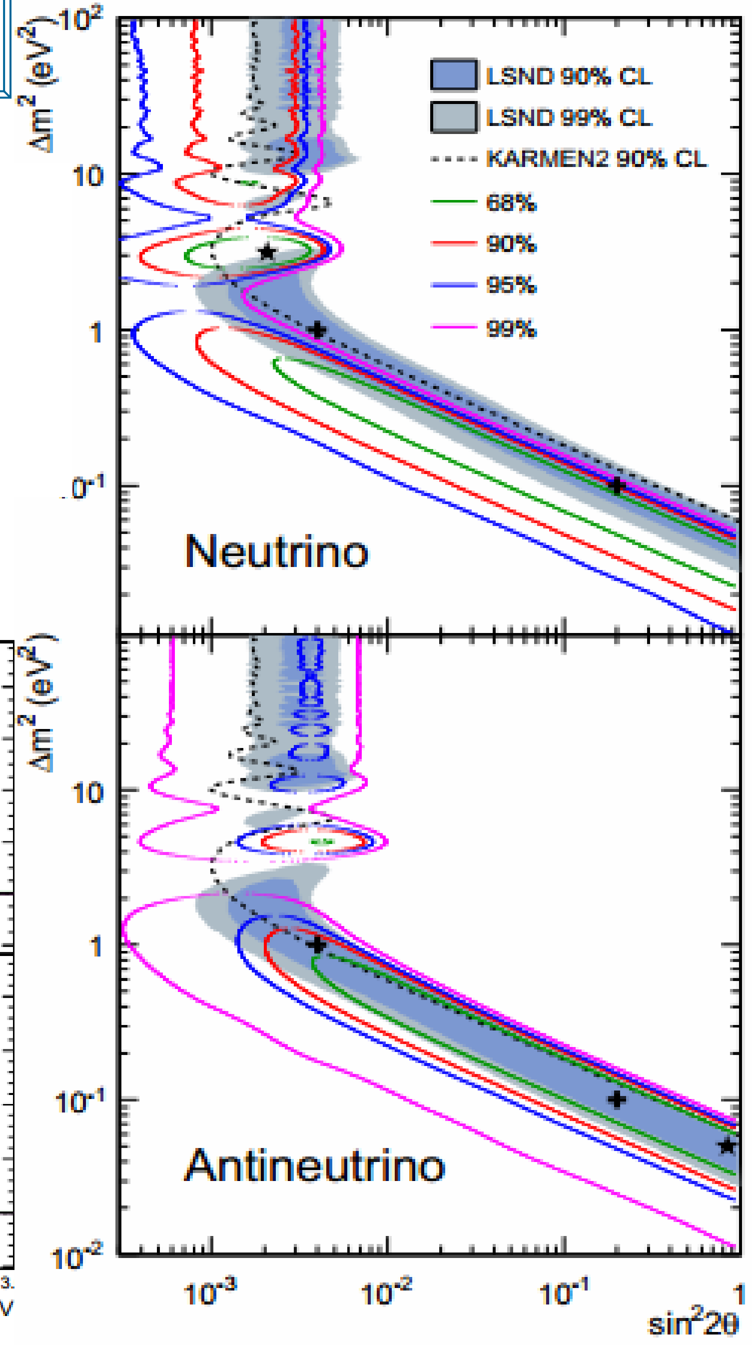
MiniBooNE: SBL ν_e/anti-ν_e appearance

arXiv:1207.4809v2

- LSND L/E with higher L, E
- L ~ 541 m, 0.2 < E < 3 GeV
- n and anti- n data looks more similar than in the past. The (low-energy) excess (240±35±53 events, 3.8 σ!) is hardly (especially for n) compatible with the LSND excess (which should occur at higher E).







Galium and Reactors anomalies

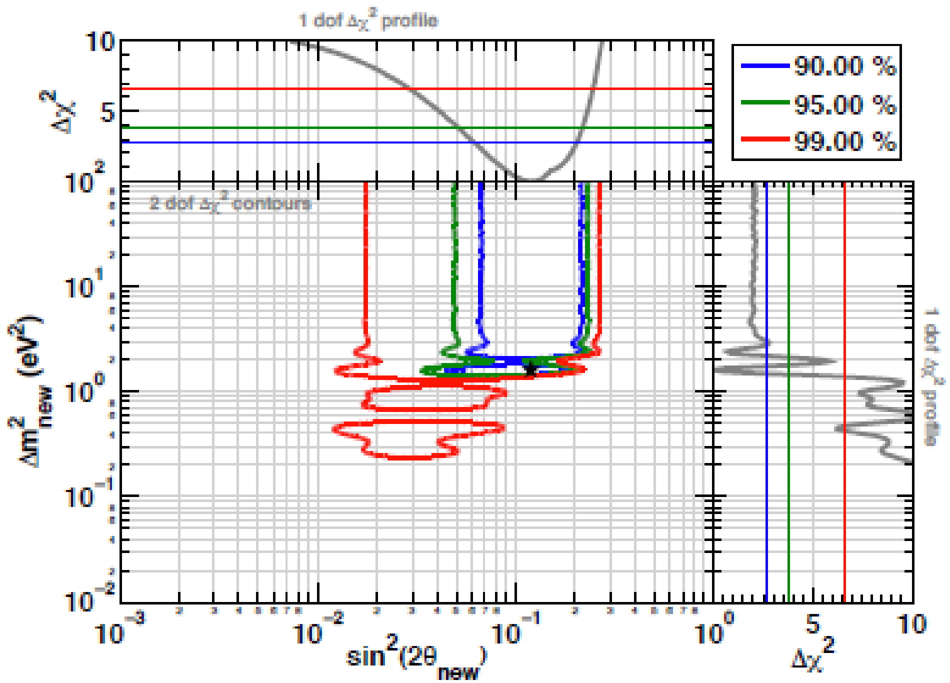
- $\sim$6% deficit in the $\bar{\nu}_e$ reactor rates, given the recent and carefully recomputed fluxes (3.0σ)
- 5-20% deficit in the ν_e rates from intense calibration source in Gallium experiments (2.7σ)

Combining Gallium and reactor anomalies: compatible phase space regions

$\Delta m^2_{new} \approx \text{eV}^2$,

$\sin^2(2\theta_{new}) \approx 0.1$

arXiv:1101.2755v4



LSND: «evidence» of $anti\ \nu_\mu \rightarrow anti - \nu_e$

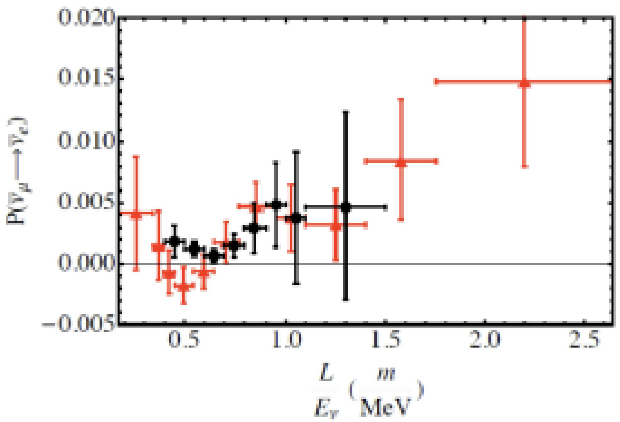
LSND: first piece of evidence in favor of *beyond 3ν* oscillations (3.8σ)

- appearance of $\bar{\nu}_e$ from $\bar{\nu}_\mu$, interpreted as oscillation with $\Delta m^2 \sim 1$ eV^2

MiniBooNE tested LSND parameter region

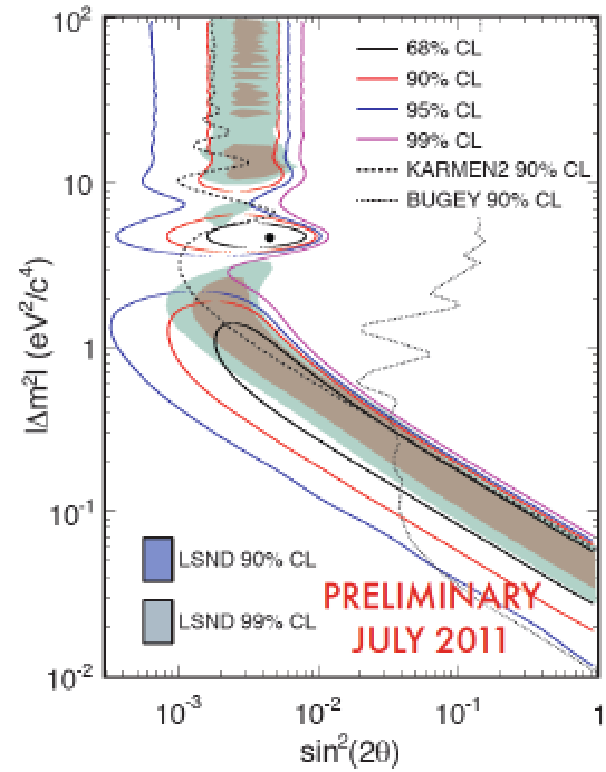
- (ν-mode) result: incompatible
- ($\bar{\nu}$-mode) result: compatible

$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ probability

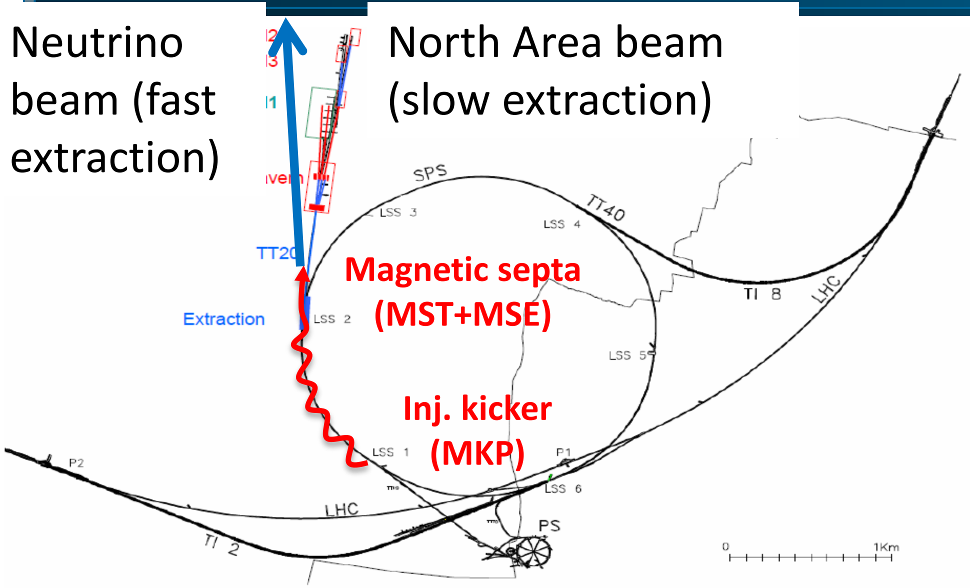


Black: LSND; Red: MiniBooNE

Allowed parameter space



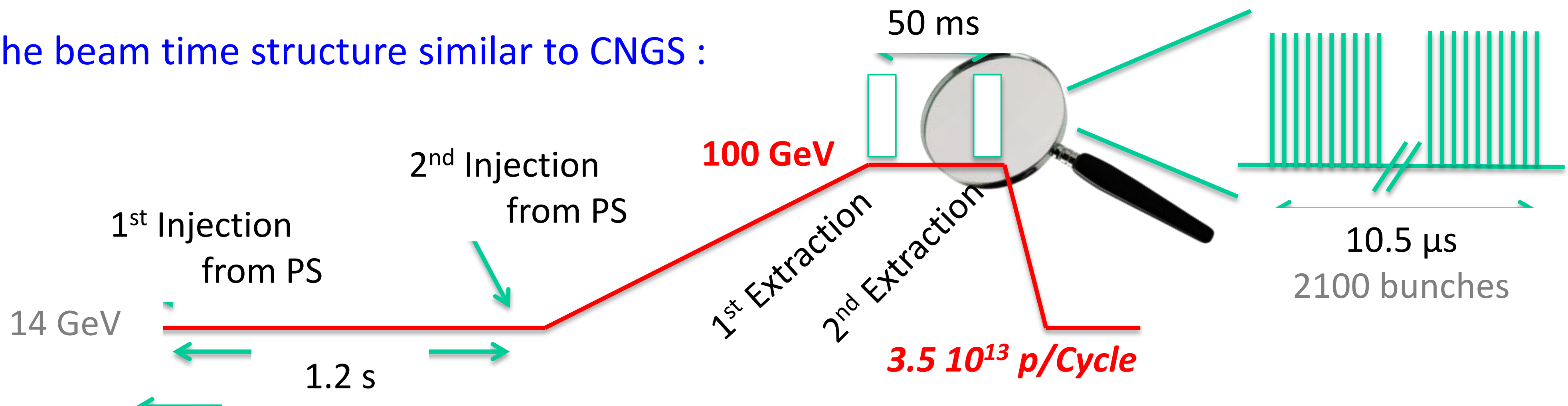
Which type of beam can CERN offer?



Fast extraction

- Beam excitation via injection kicker in LSS1 + extraction in LSS2 via existing septa *(incompatibility with simultaneous north area slow extracted beam !)*
- *Solution tested for low intensities during recent beam tests*

The beam time structure similar to CNGS :



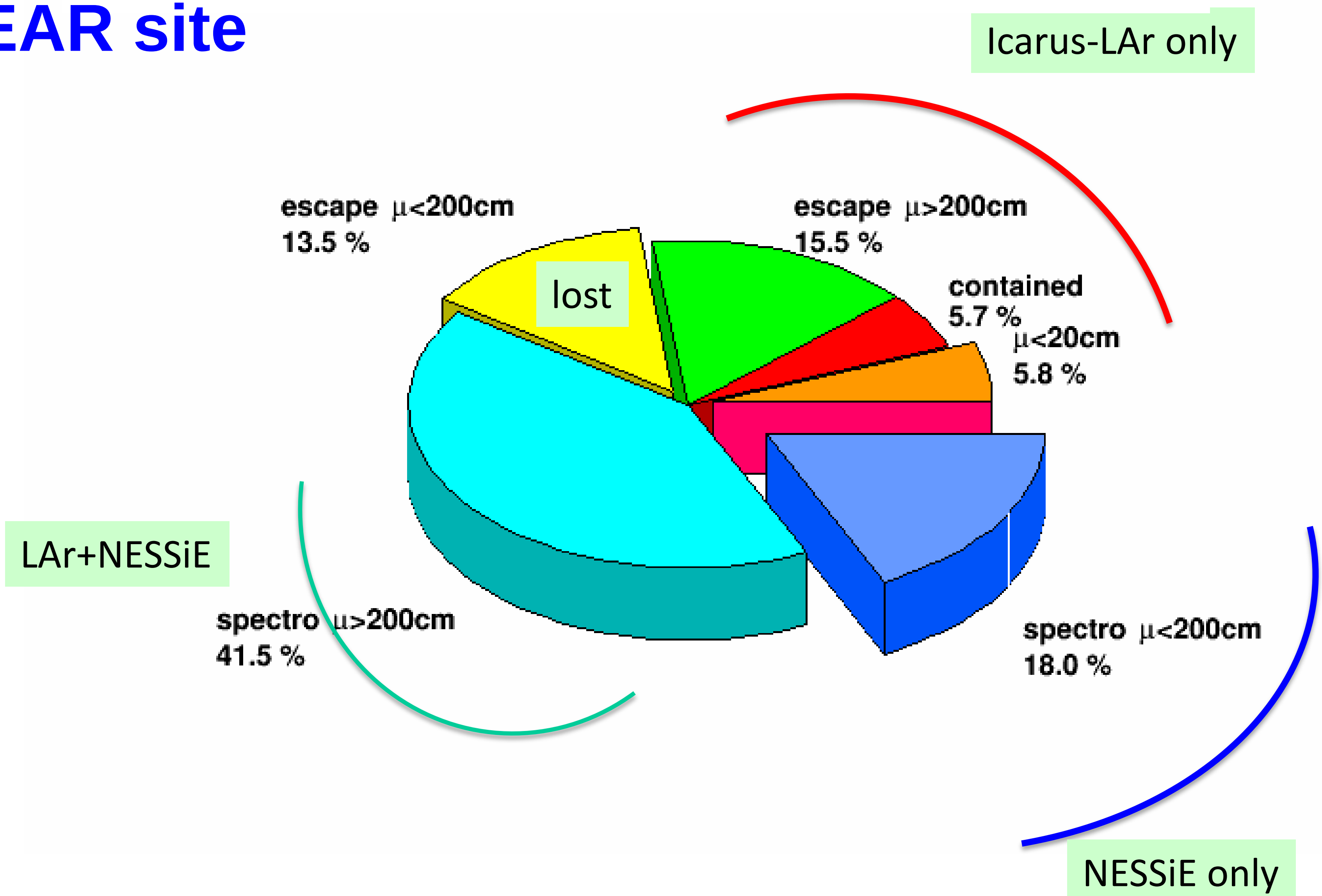
Cycle / Pulse 3.6 sec. (every 6 seconds)

→ **4.5×10^{19} pot/yr**

Neutrino Interactions in the Liquid Argon

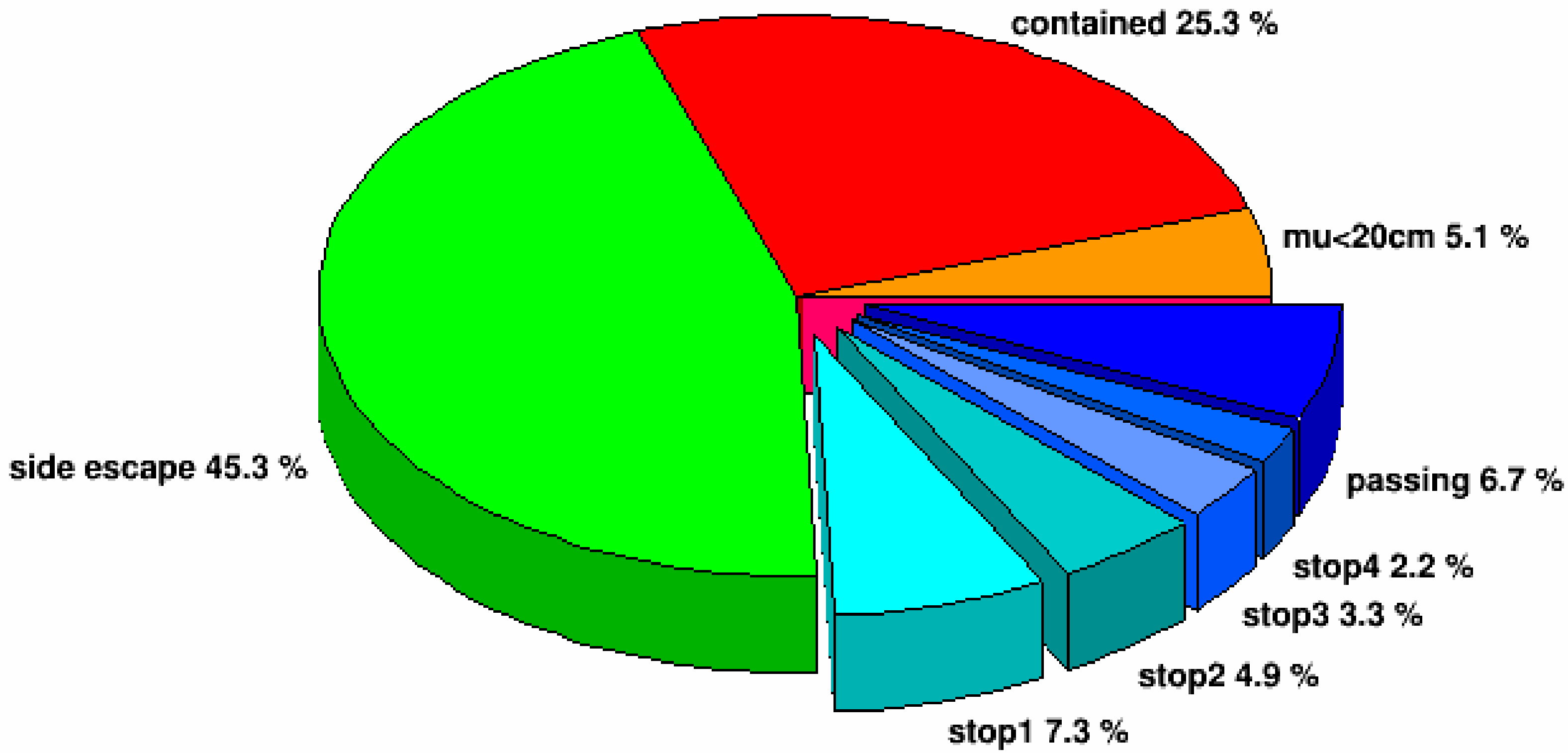
(accepatances)

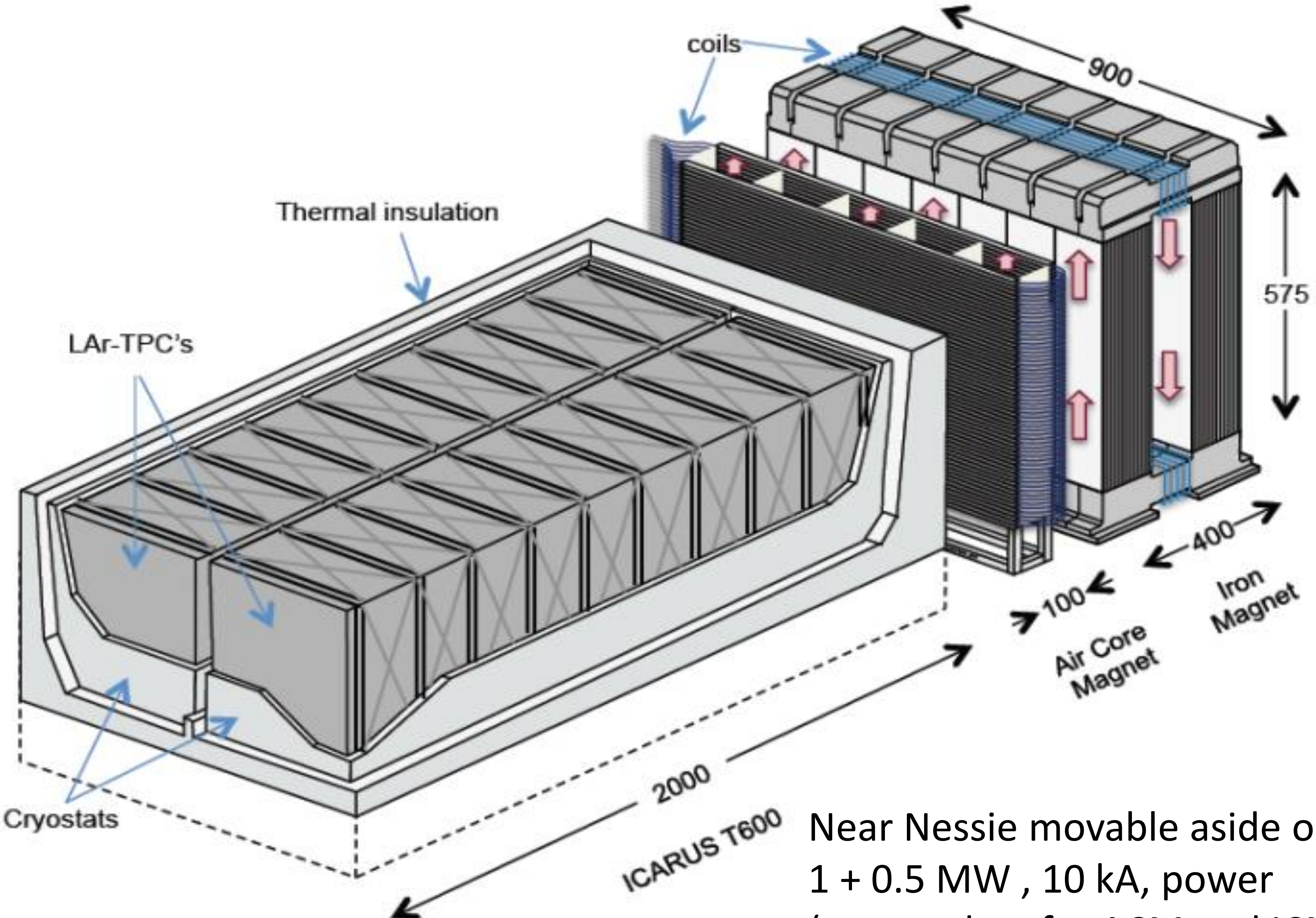
NEAR site



muon stopping in the iron spectrometer

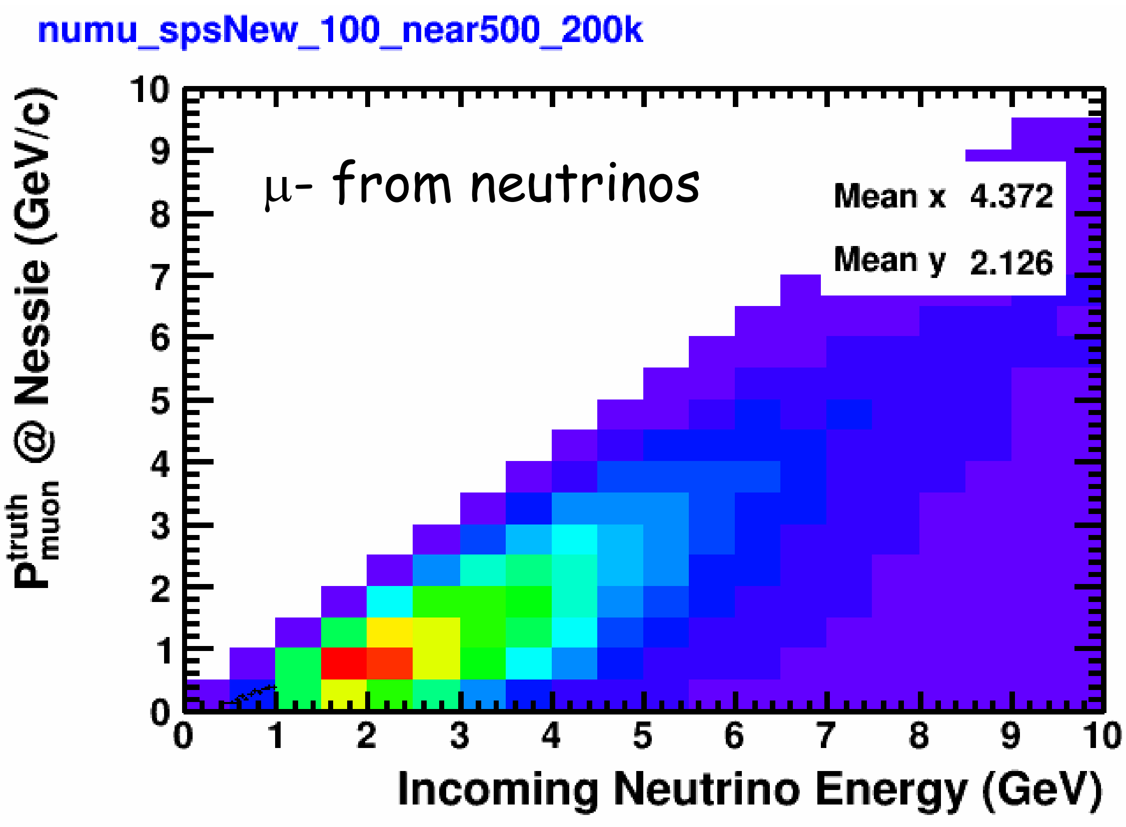
FAR site

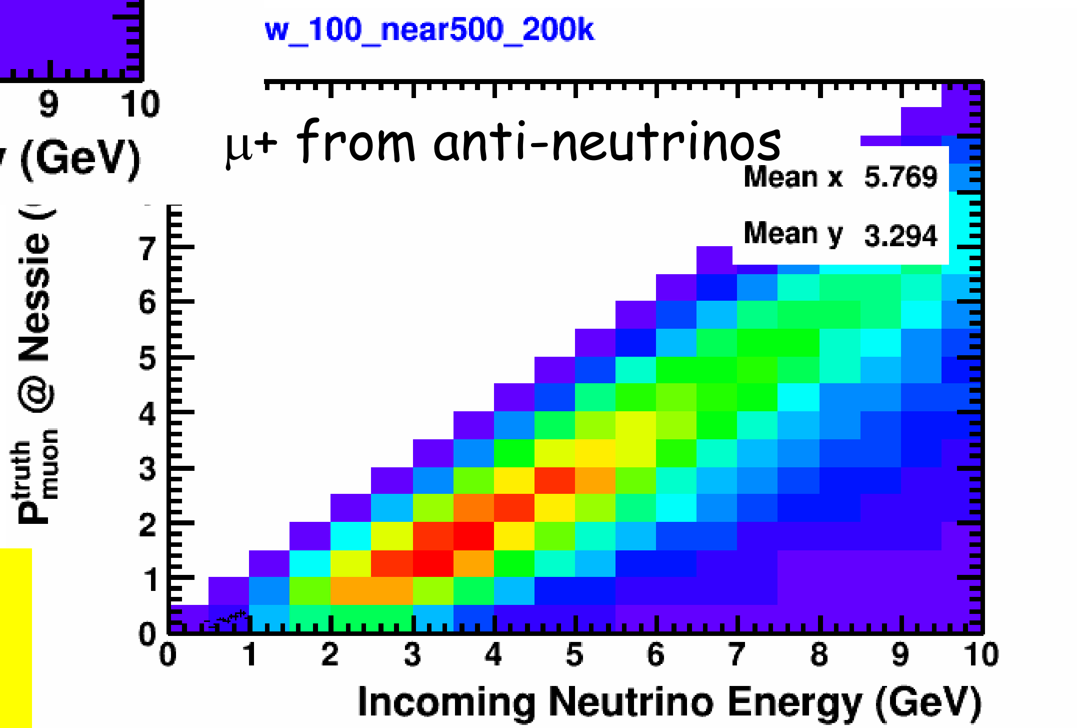




Near Nessie movable aside on air-pad
1 + 0.5 MW , 10 kA, power
(summed up for ACM and ICM)

POSITIVE FOCUSSING





up to 30% ν_μ in anti-ν_μ beam (negative focussing)