# Short baseline neutrino and anti-neutrino oscillation studies at the CERN-SPS

**Maximiliano Sioli** (Bologna University and INFN)
*on behalf of the NESSiE Collaboration*

36th ICHEP, Melbourne, July 4-11, 2012

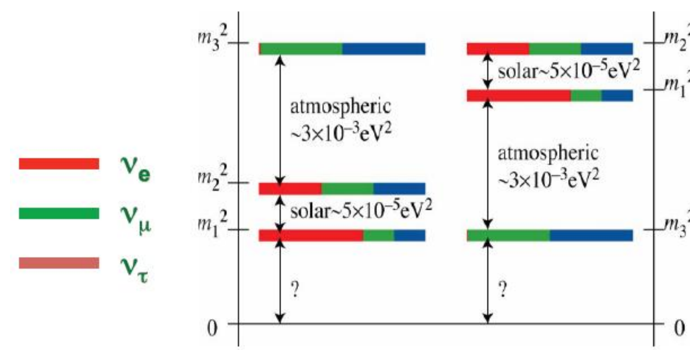
# Outline

- Theoretical motivation
- Experimental motivation
- A conclusive experiment
  - Where: CERN
  - How: LAr + spectrometers
  - When: now!
- Conclusions

# Theoretical motivations

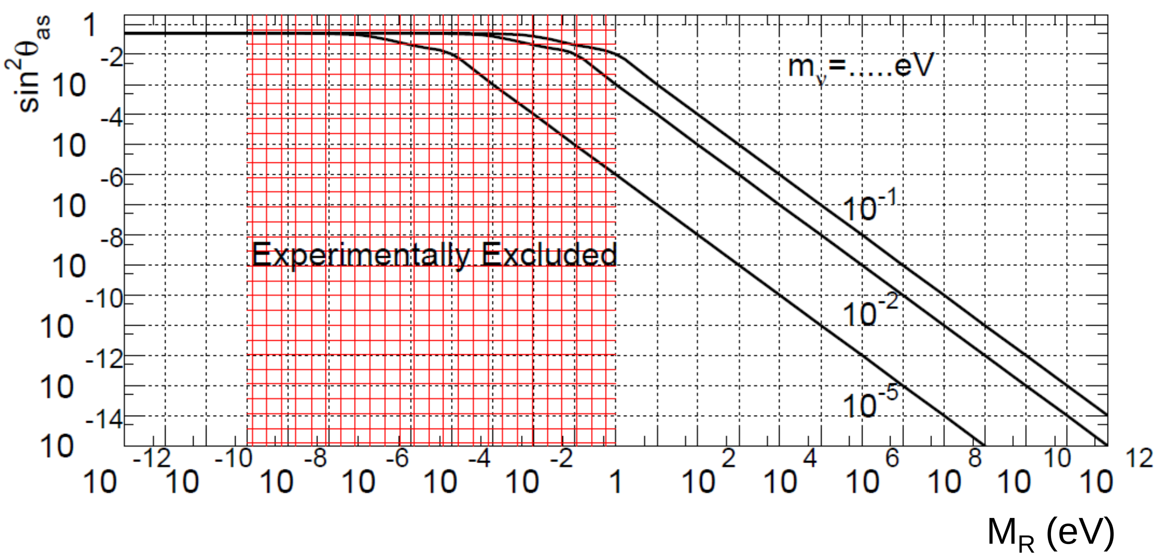
- State of the art of (standard) neutrino physics (btw, beyond the SM!)
  - There are 3 species of (light) neutrinos, with $m \leq m_Z/2$ (from LEP)
  - They oscillate, so they have mass and mix (flavor basis ≠ mass basis)
- We know
  - 3 mixing angles $\theta_{12}$, $\theta_{23}$, $\theta_{13}$
  - 2 mass square differences $\Delta m^2_{12}$, $\Delta m^2_{23} \sim \Delta m^2_{13}$
- We do not know
  - Mass hierarchy
  - $\delta$ phase (CPV)
  - Mass absolute values
  - Neutrino nature (Dirac vs Majorana)

*Present and future physics*



# Theoretical motivations

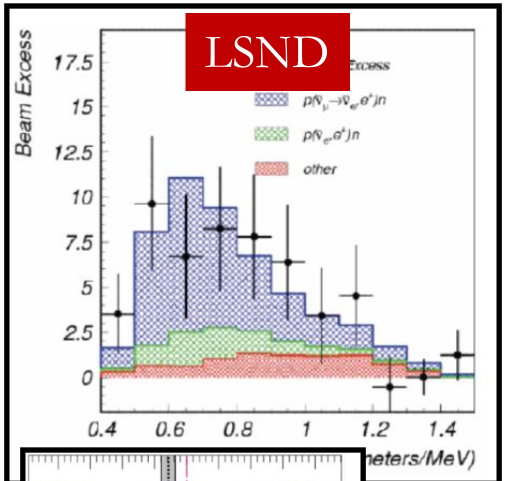
- Besides this solid scenario the quest for sterile neutrinos never stopped
- A sterile neutrino is a neutral lepton without direct EW coupling (only through mixing with active states)
- A sterile neutrino is nothing but an exotic particle
  - SM automatically introduces sterile neutrino states through mass generation
  - See-saw mechanism introduces "adjustable" neutrino-mass scale

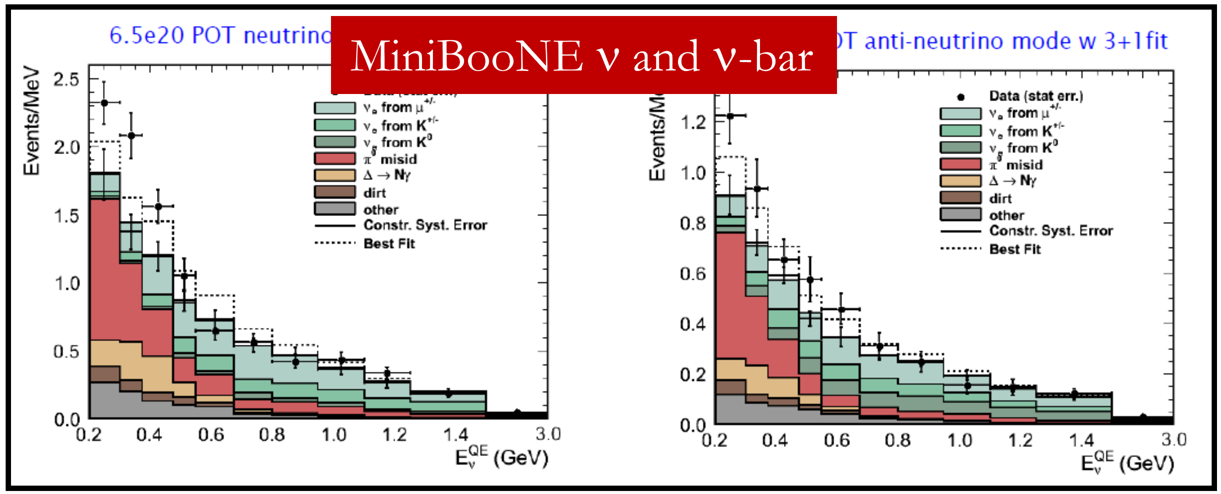


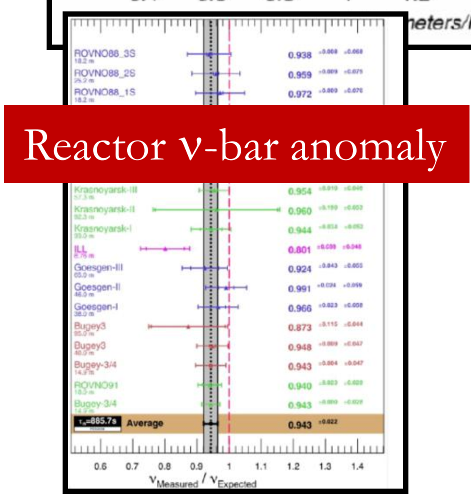

*Active-sterile mixing as a function of the right-handed neutrino mass $M_R$ for different values of active neutrino masses $m_\nu$*

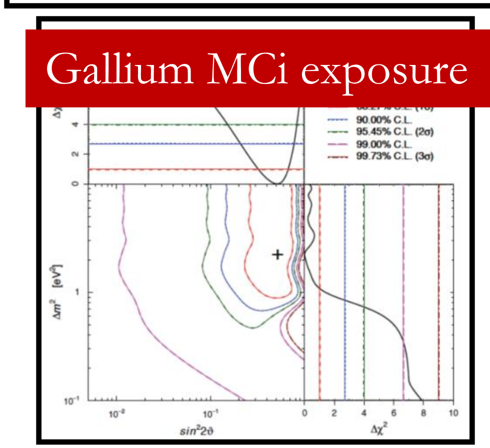
# Experimental motivations

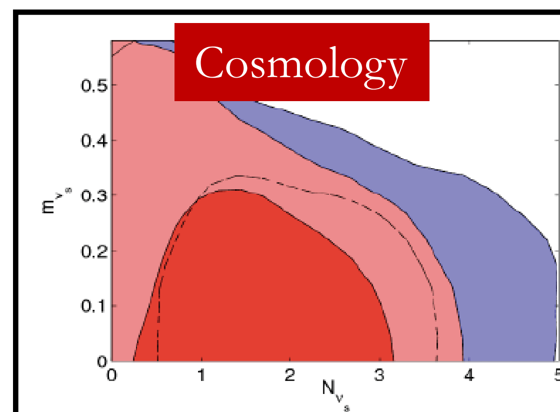
- In the last decade a set of experimental results challenged the 3 ν framework
  → no one conclusive, but all pointing toward the same direction



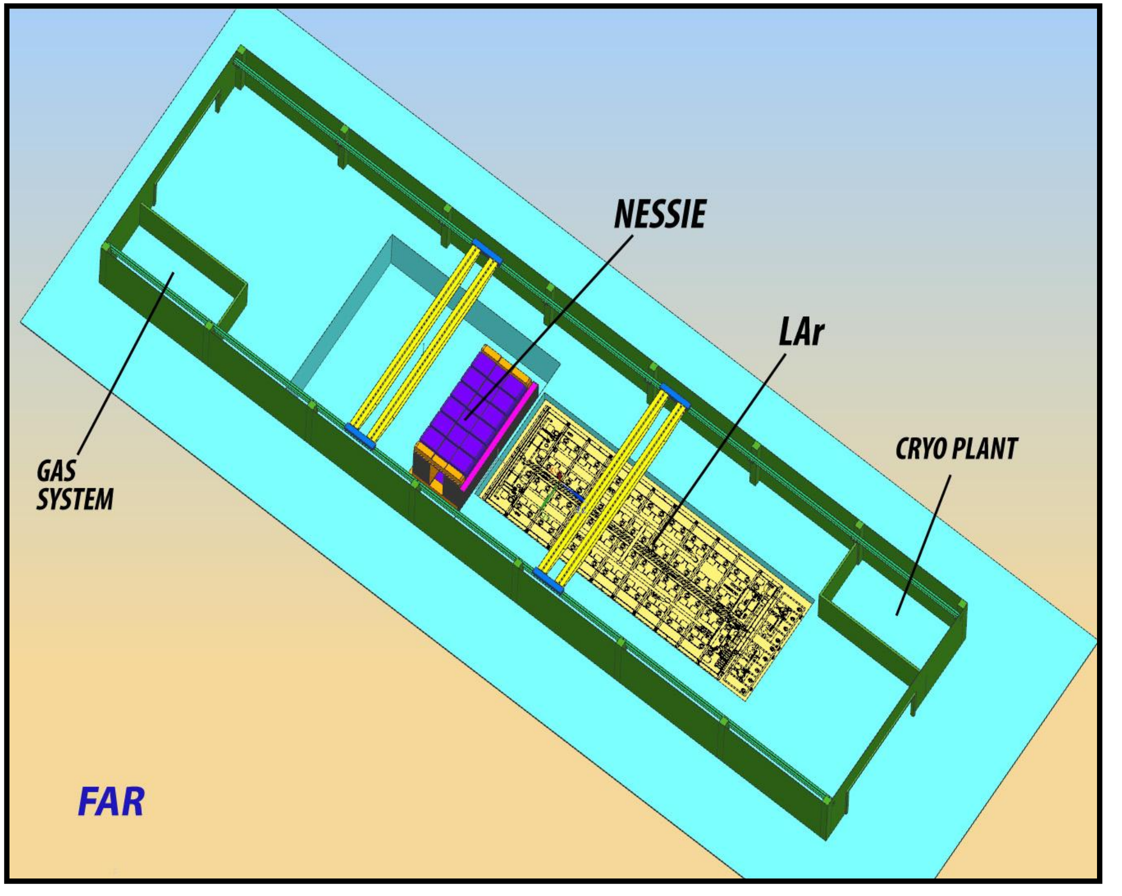



# A conclusive experiment

A coupled system of LAr detector + muon spectrometer for

- Observation of all reaction channels ($\nu_\mu$, $\nu_e$; CC, NC) through the unique LAr-TPC imaging capabilities
- Charge separation and muon momentum extension with a magnetized iron spectrometer
- Different sites near (300 m) + far (1600 m)

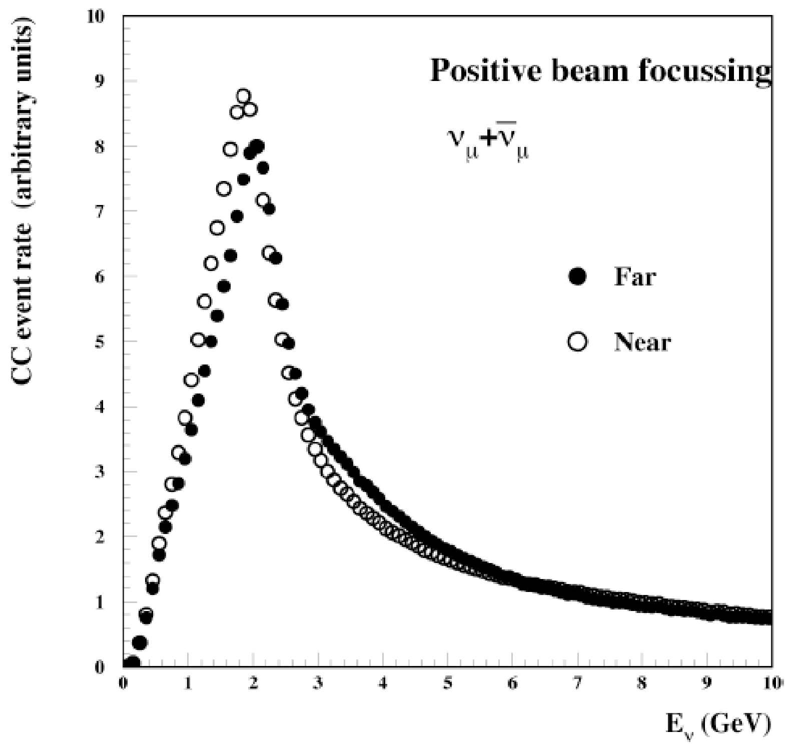


# Where: CERN North Area

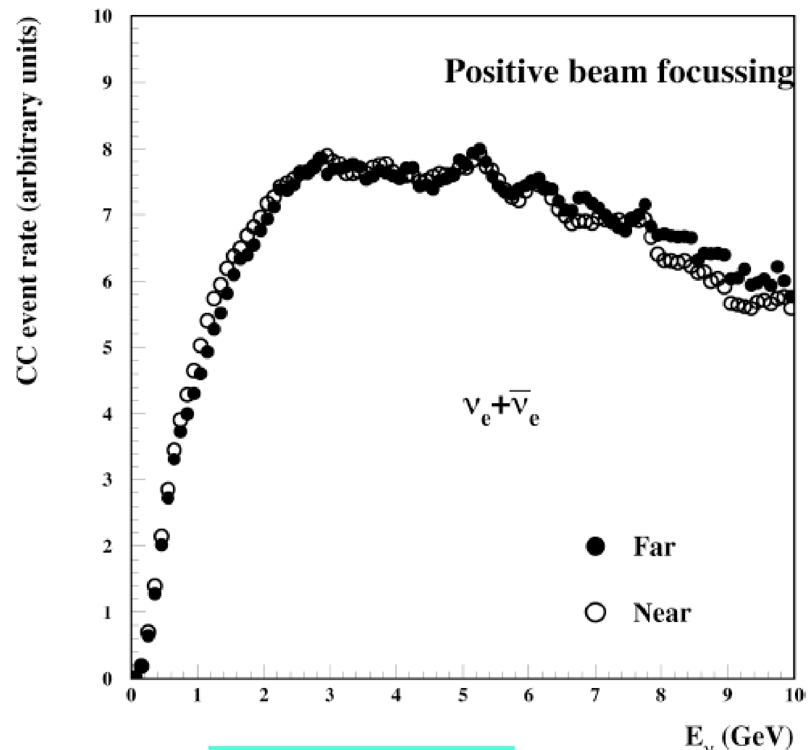

- 100 GeV primary beam fast extracted from SPS
- Target station next to TCC2
- Decay pipe: $L$ =100 m, ø = 3 m
- Beam dump: 15 m of Fe with graphite core, followed by μ stations
- Neutrino beam angle: pointing upwards, at -3m in the far detector, ~5 mrad slope

# The new SPS neutrino beam

- 100 GeV protons, on-axis, fast extraction (10.5 μs), CNGS intensity (conservative)
- Sharing scenario: 2 years of ν-bar followed by 1 year of ν




CC muons

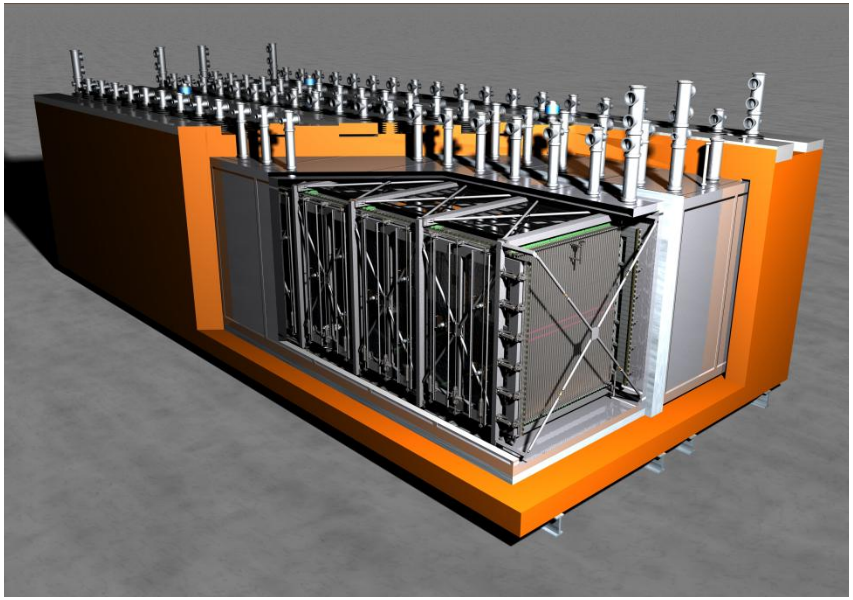



CC electrons

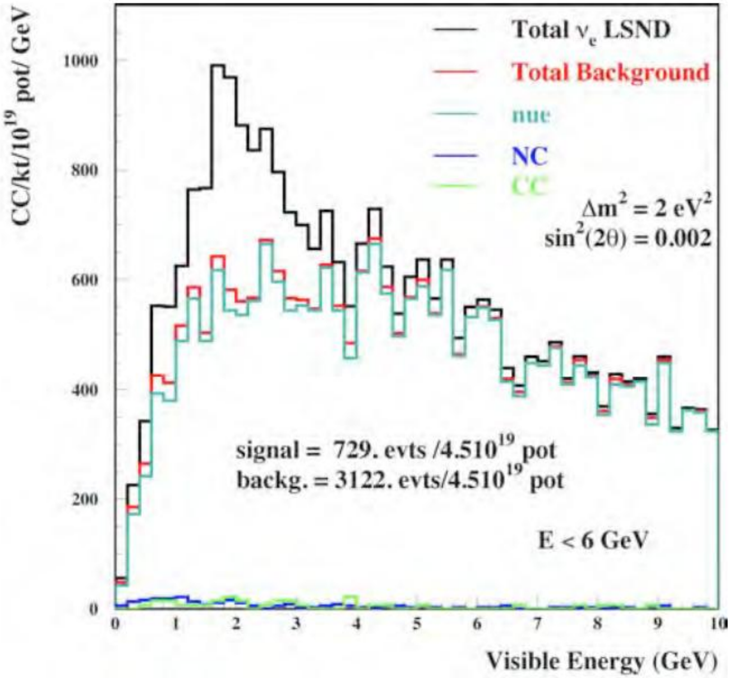
# Lar-TPC imaging detectors

- Near location: **T150** (basic structure of T600 already operating at LNGS)
- Far location: **T600** (transportation from LNGS)

T600 inside new insulation



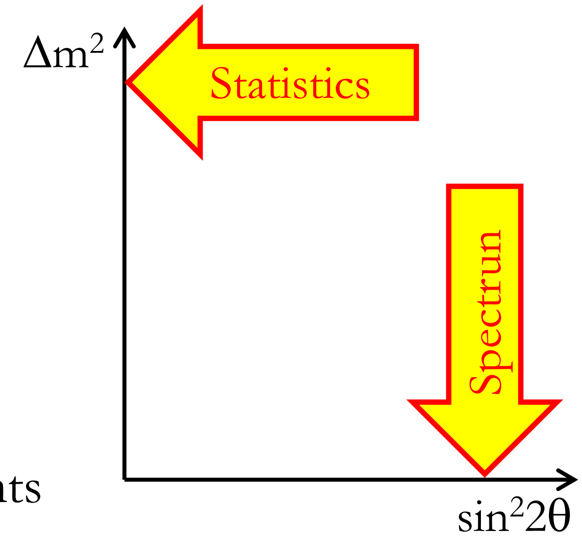
LAr performance shown for a particular testpoint



# NESSiE detector concept

NESSiE (Neutrino Experiment with SpectrometerS in Europe)

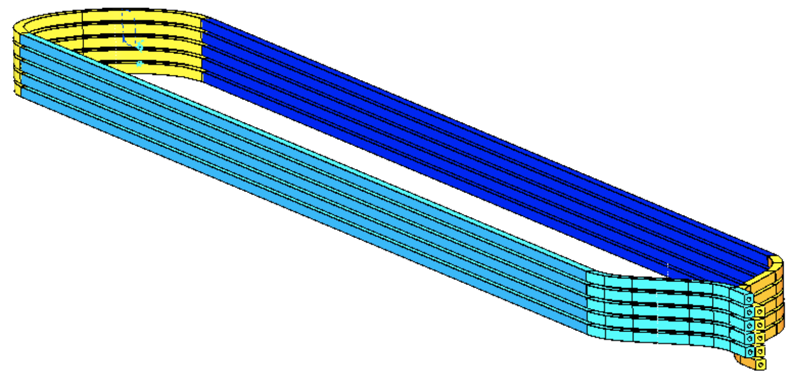
- Goal:
  - Allow charge separation and momentum measurement of as many muons as possible escaping from LAr
    (large statistics ↔ low $\sin^2 2\theta$)
  - Go as low as possible in muon momentum
    (low momenta ↔ low $\Delta m^2$)
  - Possibility to also study (NESSiE) internal events
    (coarser resolution w.r.t. LAr)

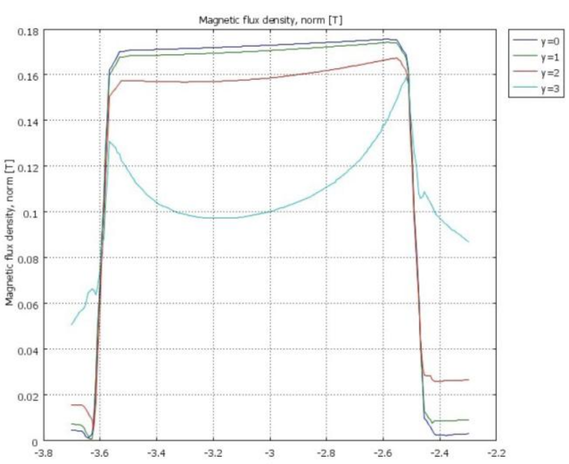


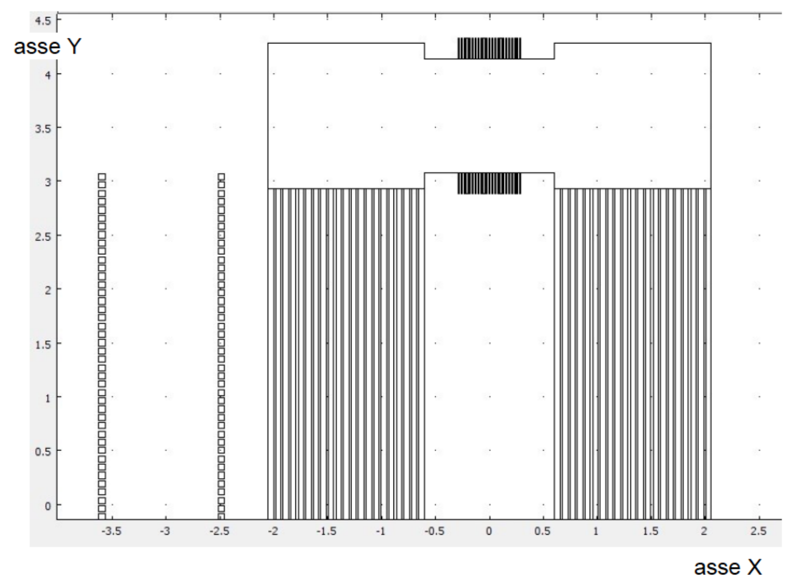

- Solution:
  - Air-core magnets for low momentum muons escaping from LAr
    ($E_\mu$ < 0.5 GeV/c in NESSiE ↔ $\langle E_\nu \rangle$ < 1 GeV in LAr)
  - Downstream massive iron dipolar magnets for higher momenta extension

# Air-core magnet

- New concept for a large transverse area magnetic field in air (~40 $m^2$)
- B = 0.15 T
- Power < 2 MW
- To be coupled to a mm detector (different possibilities under study)

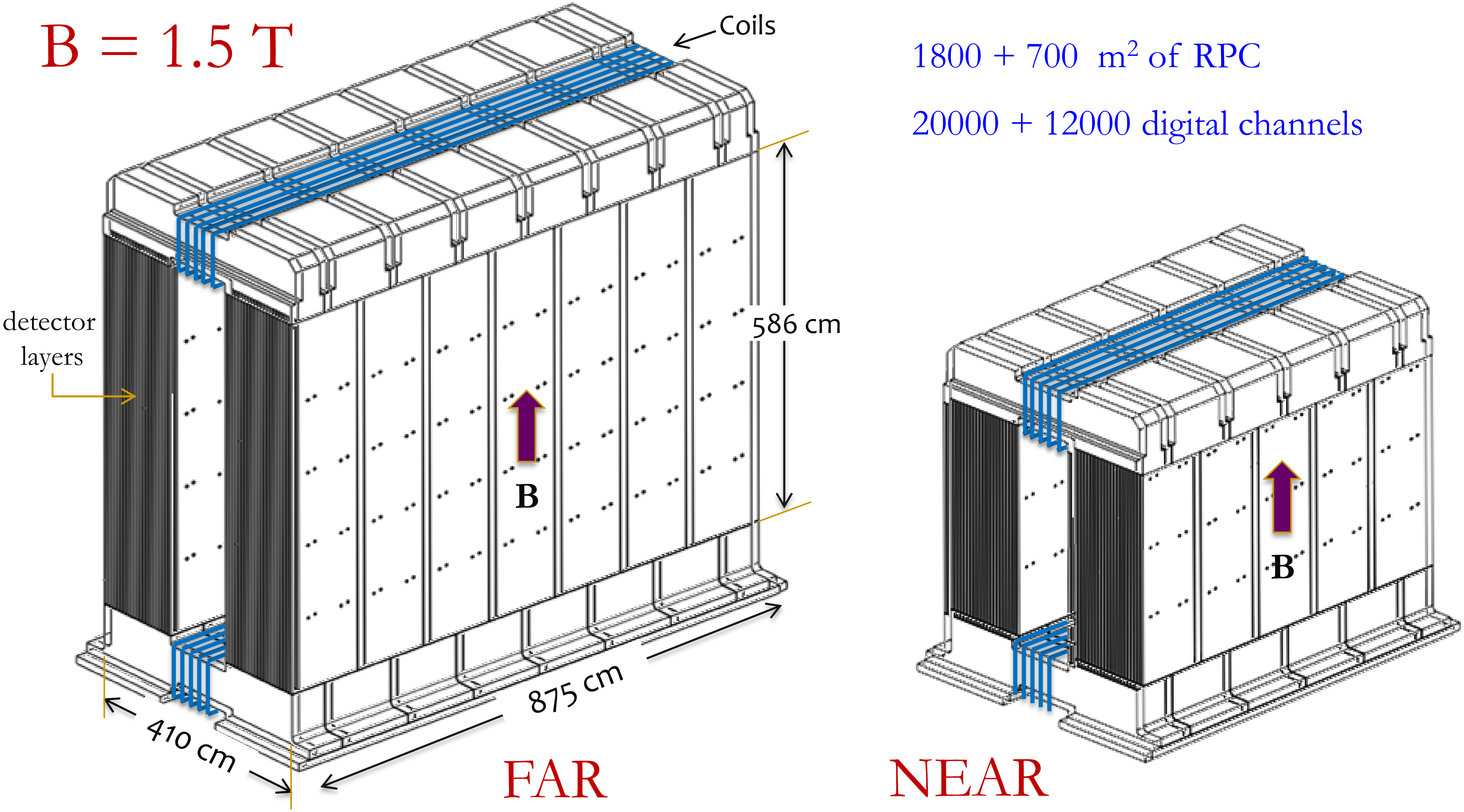




# NESSiE iron dipolar magnets

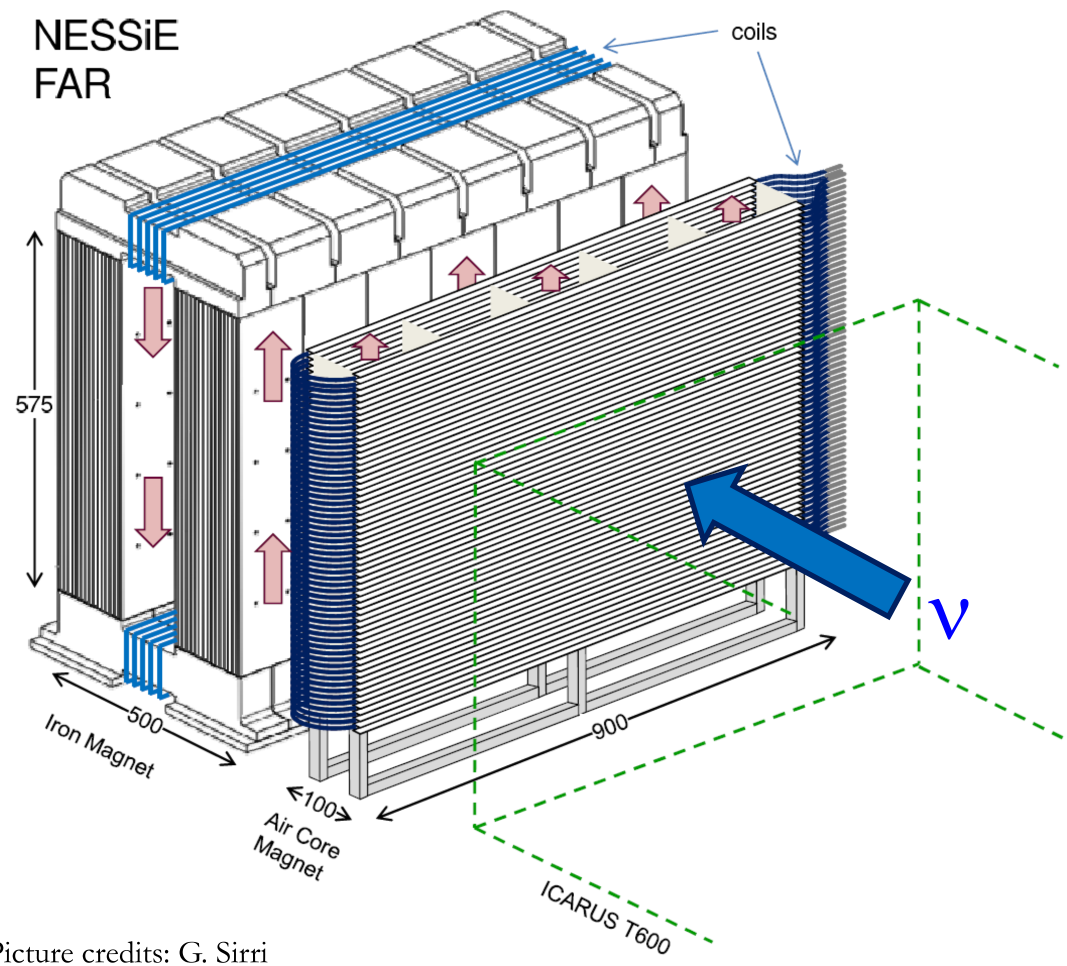
B = 1.5 T

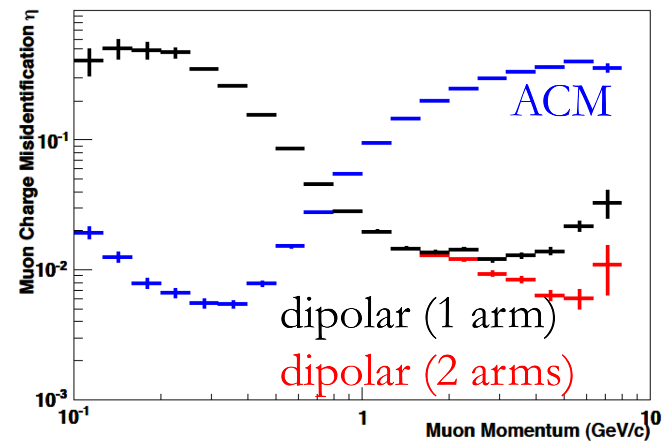



1800 + 700 $m^2$ of RPC

20000 + 12000 digital channels

# Detector configuration (far position)




Charge mis-reconstruction at few percent level in all dynamical range of interest (full simulation including selection, efficiency and recontruction)

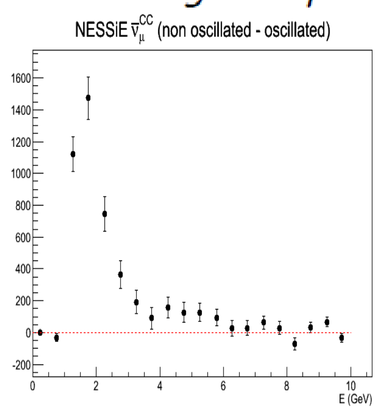
Picture credits: G. Sirri

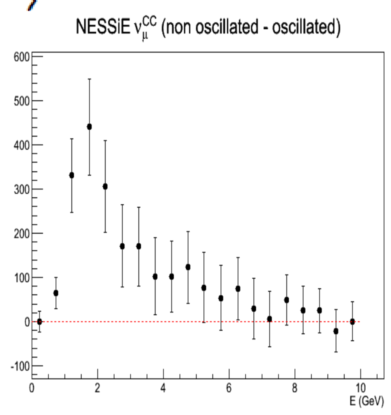
# Expected signal rates

| | | 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 |
| | $\nu_\mu + \bar{\nu}_\mu$ (LAr) | 2030 K | 5250 K | 270 K | 670 K |
| | Appear. test point | 590 | 1900 | 360 | 914 |
| | | | | | |
| *detected* | $\nu_\mu$ (LAr+NESSiE) | 230 K | 1200 K | 21 K | 110 K |
| | $\nu_\mu$ (NESSiE) | 1150 K | 3600 K | 94 K | 280 K |
| | $\bar{\nu}_\mu$ (Lar+NESSiE) | 370 K | 56 K | 33 K | 6.9 K |
| | $\bar{\nu}_\mu$ (NESSiE) | 1100 k | 300 K | 89 K | 22 K |
| | Disappear. test point | 1840 | 4700 | 1700 | 5000 |

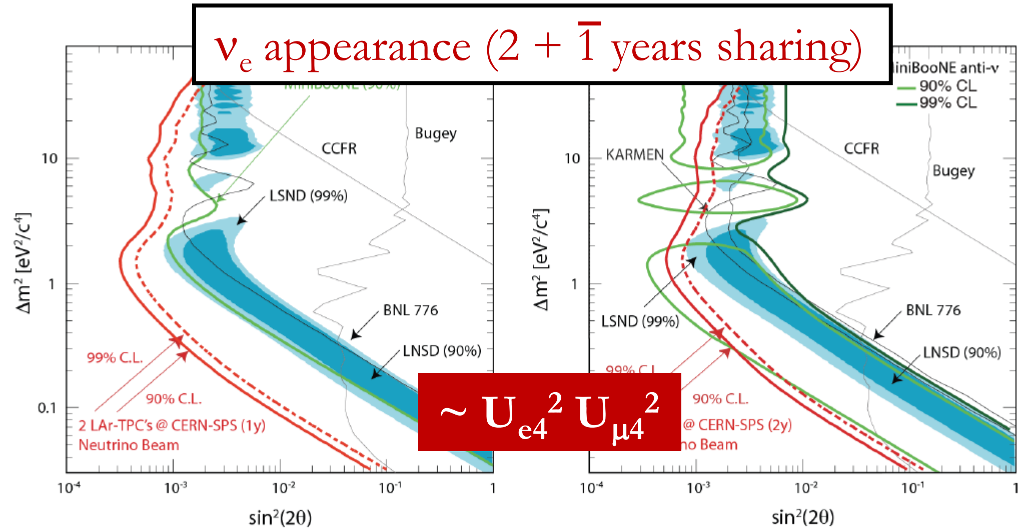
*NOTE: $\nu$ "contamination" in anti-$\nu$ negative polarity beam*

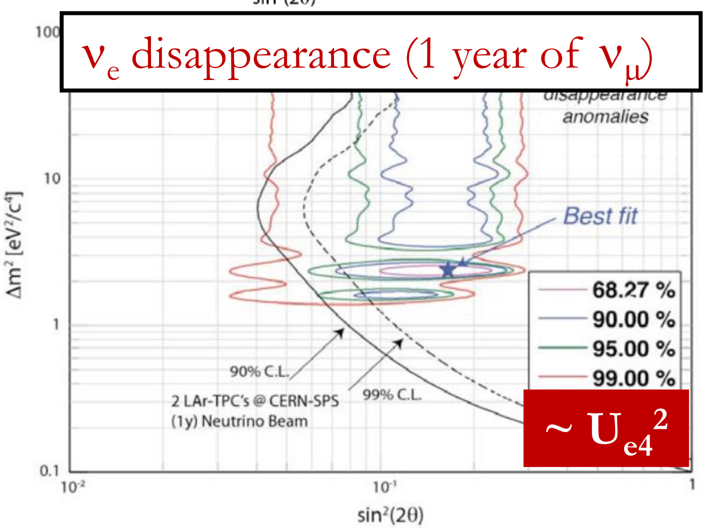
- Expected rates for near and far detectors given for $4.5\times10^{19}$ pot
- Signal test point fixed at 2 $eV^2$ shown as example

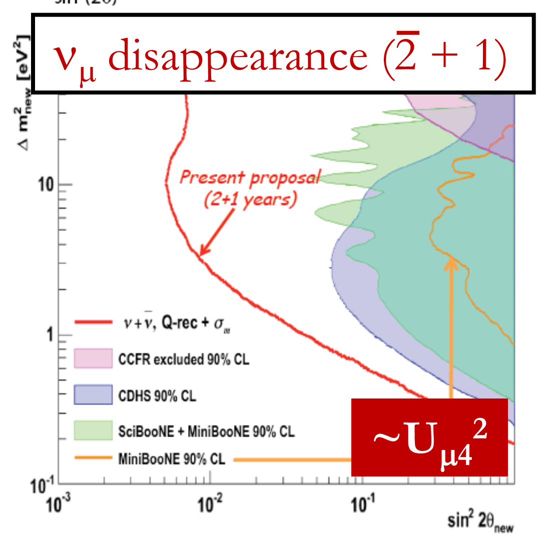


# Physics reach of the project



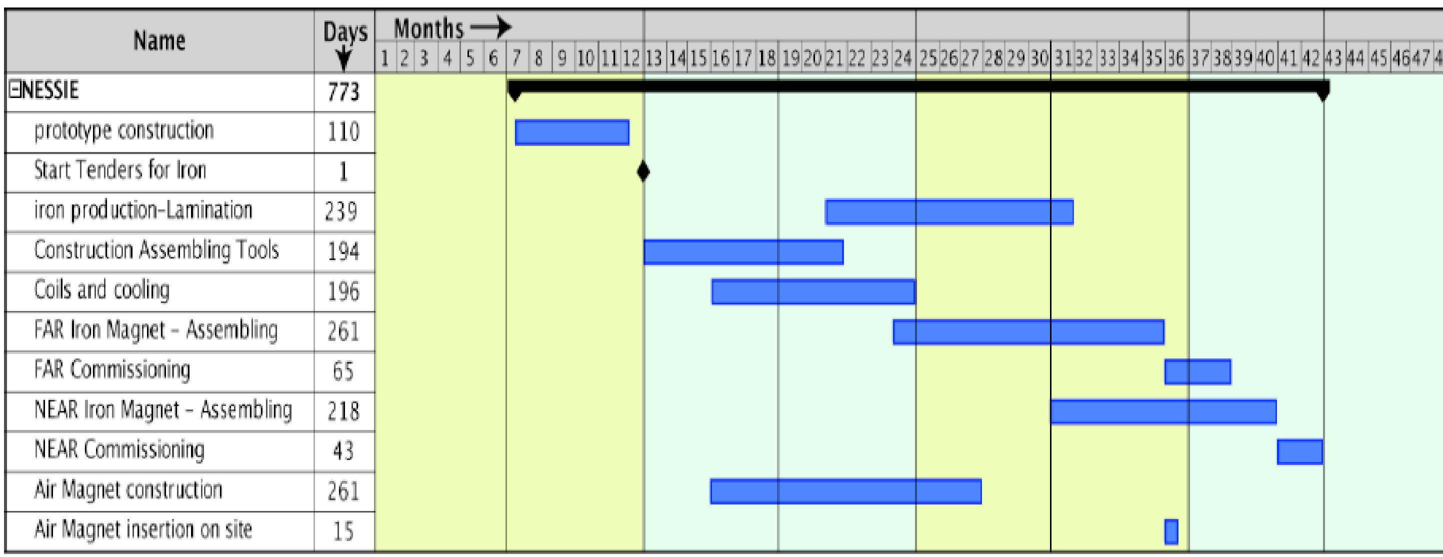




- $\nu_e$ appearance and disappearance signals may share the same $\Delta m^2_{new}$ and different mixing angles in a 3+1 scenario
- A two year run with ν-bar would to address CPV in one shot with NESSiE

# NESSiE time schedule

- Physics proposal submitted to SPSC in Oct 2011 [arXiv: 1111.2242v1]
- In the meanwhile:
  - Request to switch PS ↔ SPS
- Joint technical proposal submitted to SPSC in March 2012 [arXiv:1203.3432]
- From green-light, we expect 3 years of prototyping and construction
  → run in 2016



# Conclusions

- The search for sterile neutrino states has profound theoretical and experimental motivations
- We need an ultimate experiment to
  - Finally get rid of several long-standing anomalies OR
  - Discover the existence of a light sterile neutrino state → enormous consequences for our understanding of physics BSM
- We are proposing an high-luminosity experiment
  - On a short time-scale if compared to other proposals
  - Ancillary to other LBL neutrino experimental proposals
- The NESSiE spectrometers would complement a LAr target experiment
  - To extend $p_\mu$ range and to address charge separation
  - To better assess the role of systematics in the $\nu_\mu$ disappearance channel