External background and exotic physics at the T2K near detectors

JENNIFER **WP3** - task **3.2** and **3.3**

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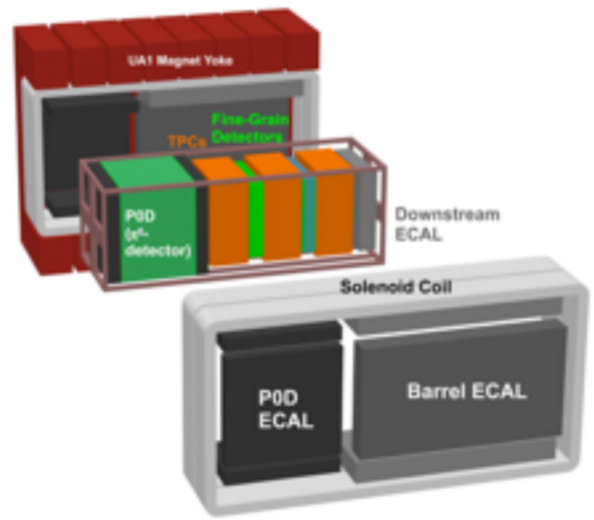
JENNIFER Consortium General Meeting
Roma, June 10-12

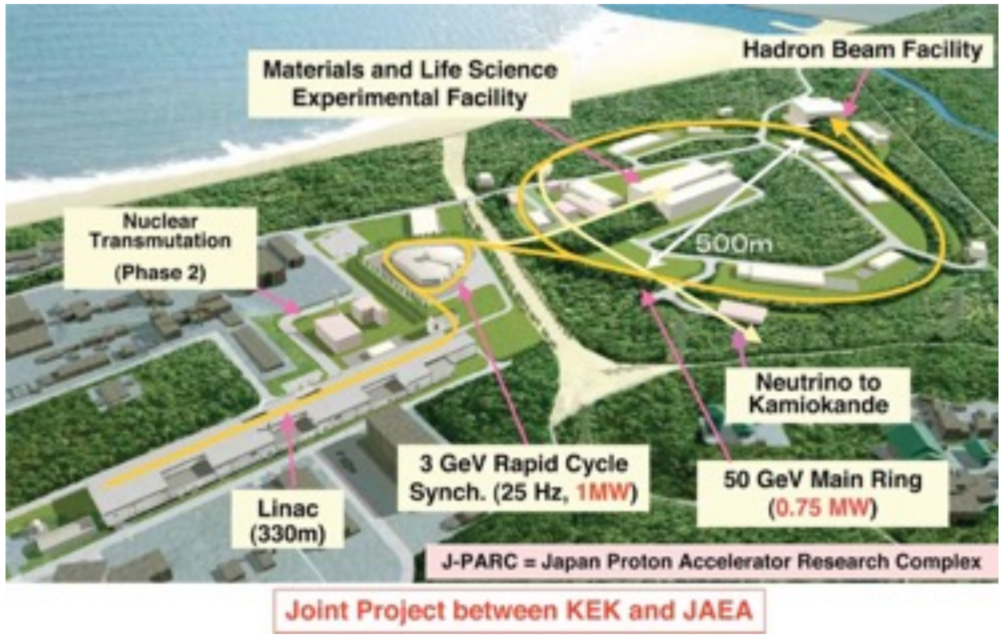
The T2K experiment

- Long baseline neutrino oscillation experiment in Japan (Tokai to Kamioka)
- Muon (anti-)neutrino beam produced from a 30 GeV proton beam (JPARC)
- Neutrinos detected at 2 points :
  - the near detector (**ND280**) at 280 m
  - the far detector (**Super-Kamiokande**) at 295 Km

Japan Proton Accelerator Research Complex **(JPARC)**

Far Detector
(~300Km)





Near Detector
(@~280m)

Plan of the talk

- External background at ND280

  deliverable: report on anti neutrino analysis; **EMD:24**

- Exotic physics

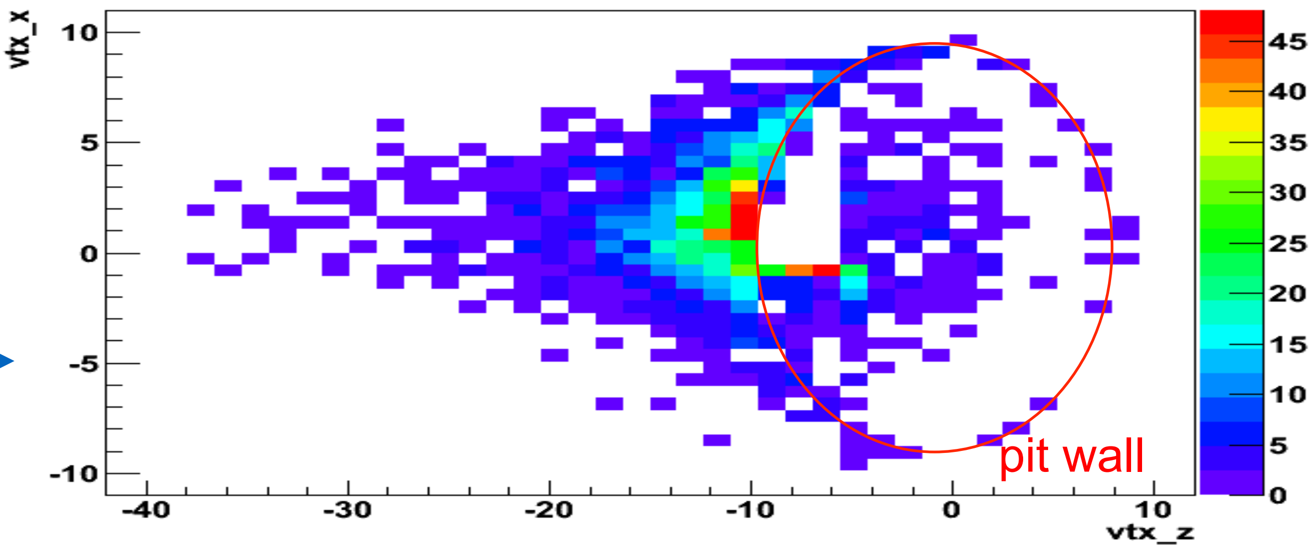
  deliverable: combined muon and electron neutrino oscillation analysis report; **EMD: 48**

External background

- External background: interactions on the sand surrounding the detector and in the structures inside the detector pit
- A large number of particles enter in the detector, even from interaction at long distance
  - low energy photons and neutrons (most abundant)
  - muons

top view, 1e^{17} POT

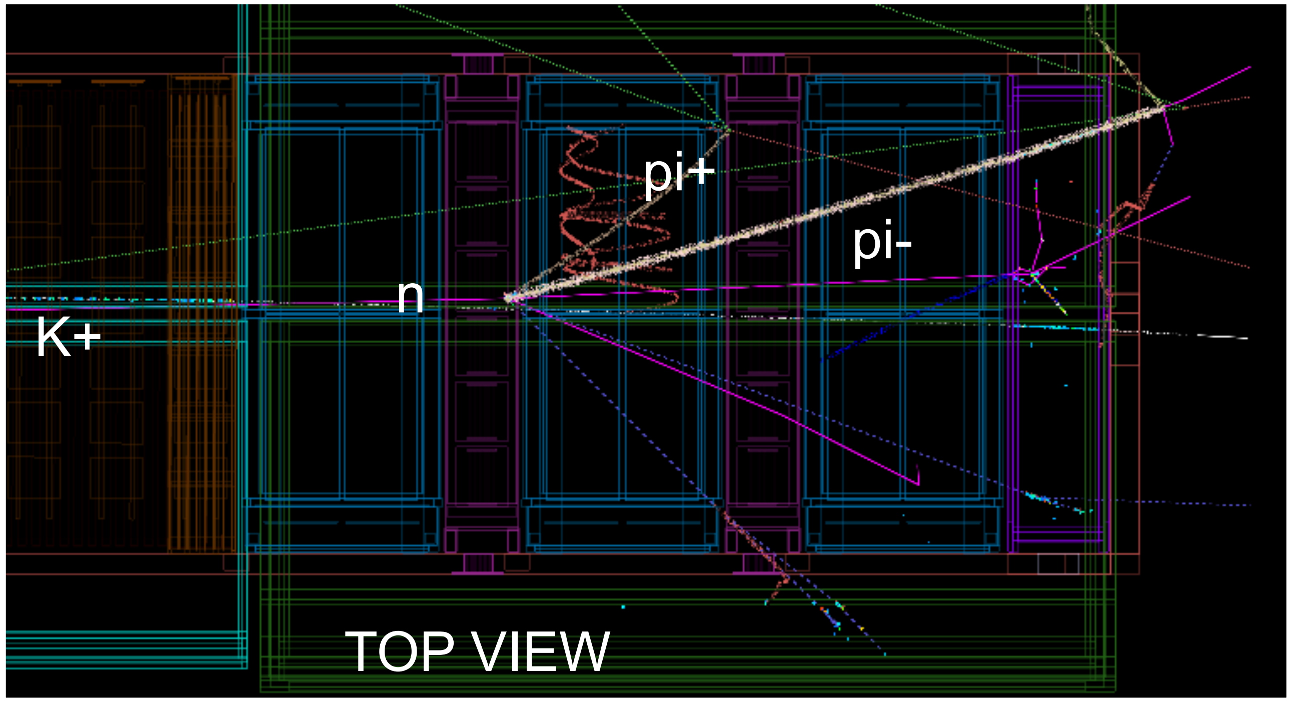
neutrino interaction vertices for which the muon enter in the detector



External background

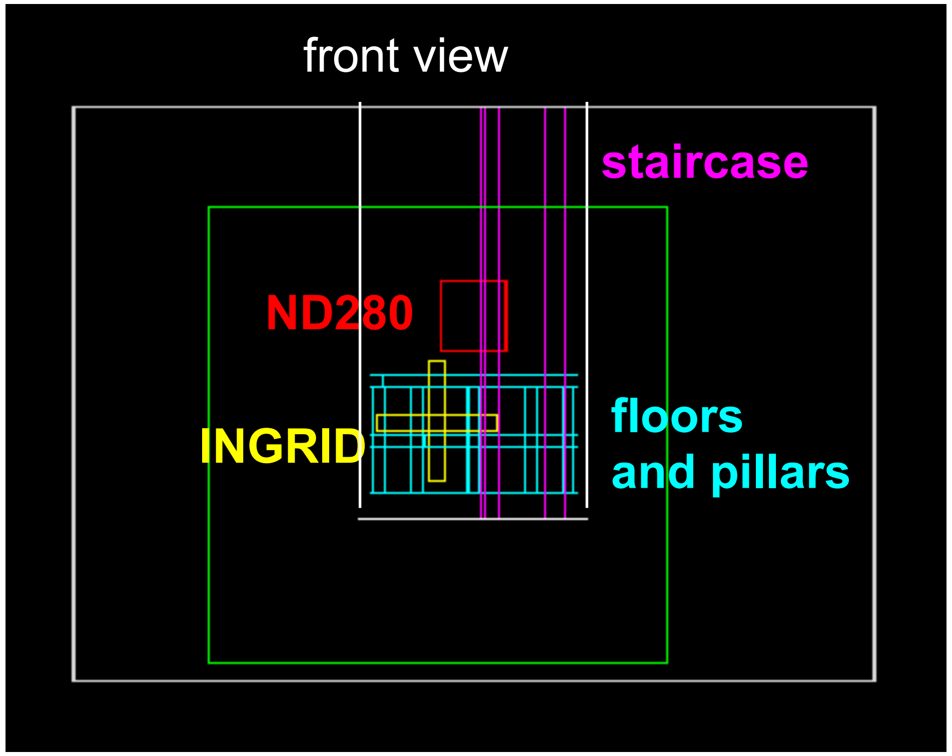
- Charged particles entering the detector can be identified and vetoed (unless reconstruction error occurs)
- Neutral particles can re-interact inside active volume of the detector : **Out of Fiducial Volume events**
- Sand muon contamination is ~1% for ND280 samples used on the oscillation analysis

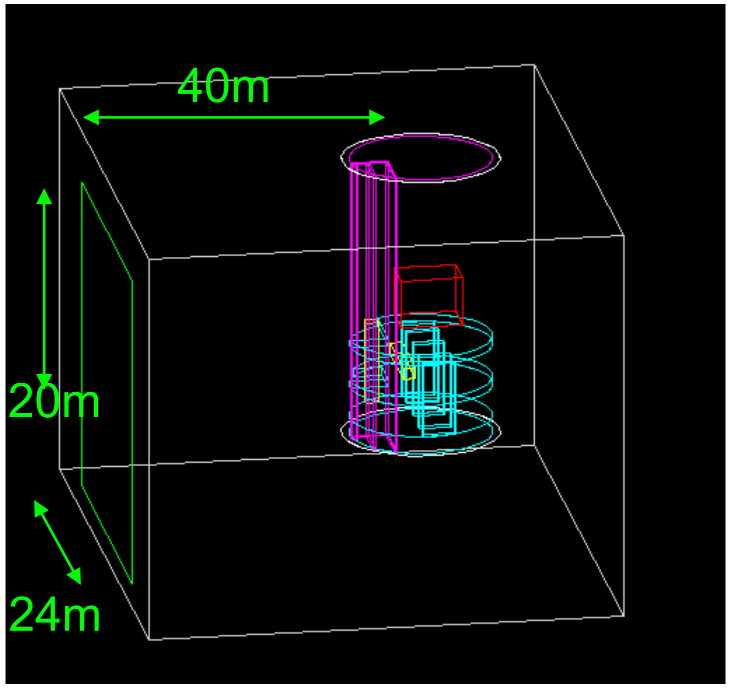
neutron re-interacts in FGD1, the produced negative pion is selected as muon candidate



MC simulation

- Simulation developed in 2012, never revised
- Model partially realistic (dimension of the pit and detector boxes) but with some simplifications
  - pit structures (no INGRID nor stairs in the simulation)
  - no information on the sand: density and chemical composition assumed
  - low energy particles not reaching the detector are not tracked





Data/MC comparison

- Study of the sand MC simulation using a sample enriched in sand interaction: charged tracks with starting point in the first few layers of the P0D
- Rate in data: sand interactions + interaction in detector walls and coil

ν mode

- data/MC ratio ~1.1
- 10% accuracy is *good enough*
- set as systematic uncertainty for the sand contamination to selected signal samples

$\bar{\nu}$ mode

- data/MC ratio slightly worse
  - pretty good agreement for positive particles
  - big discrepancy for negative particles (~30% excess in data)

    → investigation ongoing

Improvements and new ideas

- Optimisation of cuts (tested with neutrino beam MC only)
- Check of the influence of the sand density
- Modification of physics models used in GEANT propagation through the sand (neutron interactions)
- Modification of the pit geometry – add more structures (stairs, Ingrid)

Some ideas :

- Can sand muons be used as beam monitoring?
  - much higher rate than from interaction in P0D or FGD detectors
  - sand muon typical **rate** is **220 tracks/10^{17} POT**, with a **precision** of about **0.58%**
- Sand muons probe different energy range than events selected in the tracker
  - they can be used to **determine** the fraction of **wrong sign** neutrino in the beam
  - can they be used to constrain the flux ?

External Background : outlook

- Tuning of the sand MC:
  - in the next months new sand MC productions with changed models/parameters
  - computer cluster in Warsaw will be used for production (software installed and tested)

- Sand muons as beam monitoring tool:
  - basic study and documentation will be ready by the end of the year → work strongly connected to J. Lagoda’s work (deadline at end of 2015)
  - improvements will then be possible using the tuned MC

Exotic physics

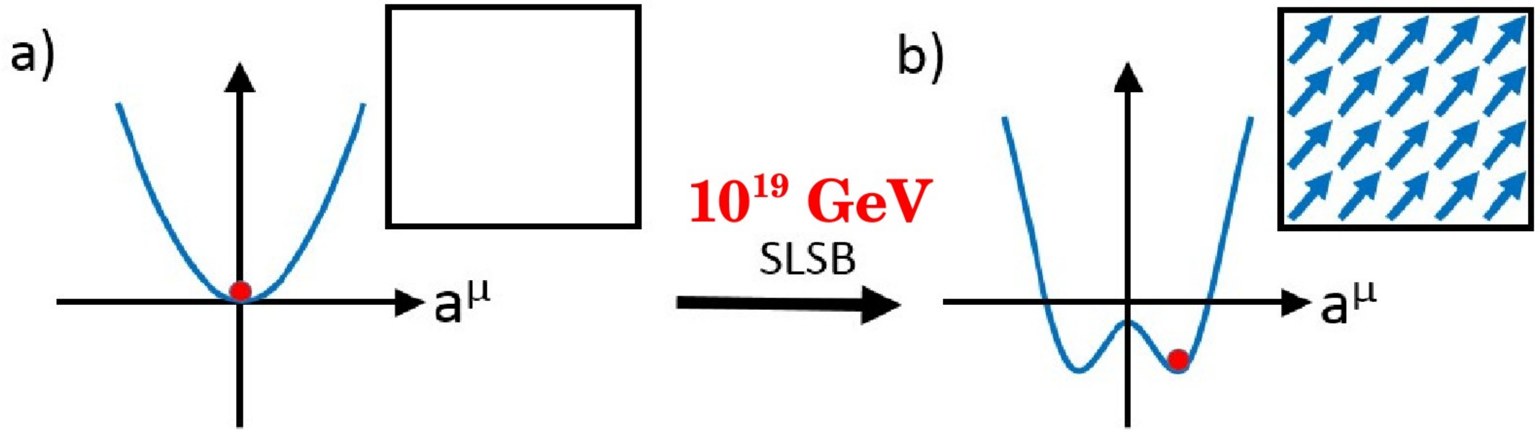
- Lorentz violation at INGRID
- Sterile neutrinos at ND280

Lorentz violation

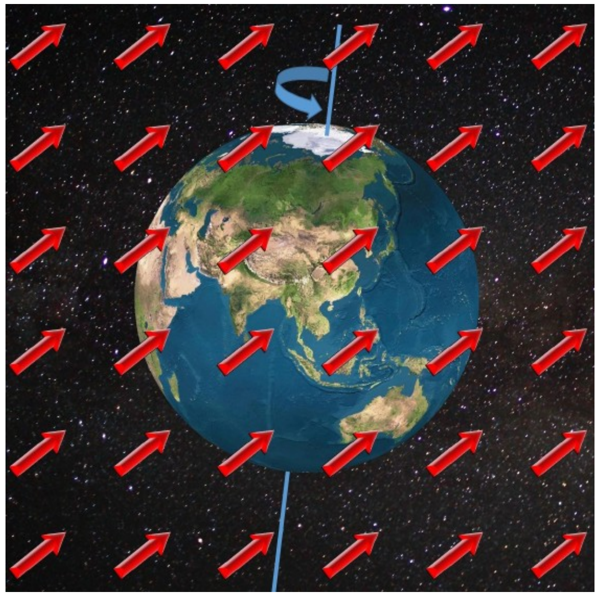
- Predicted in most of the theories beyond the Standard Model
- Consequence of merging SM w/ gravity (Plank scale ~10^{19} GeV)
- Effective theory:

Standard Model Extension (SME) = **SM Lagrangian** + all terms allowing a **Lorenz violation** **spontaneous symmetry breaking**

Example of a vector field → Preferential direction



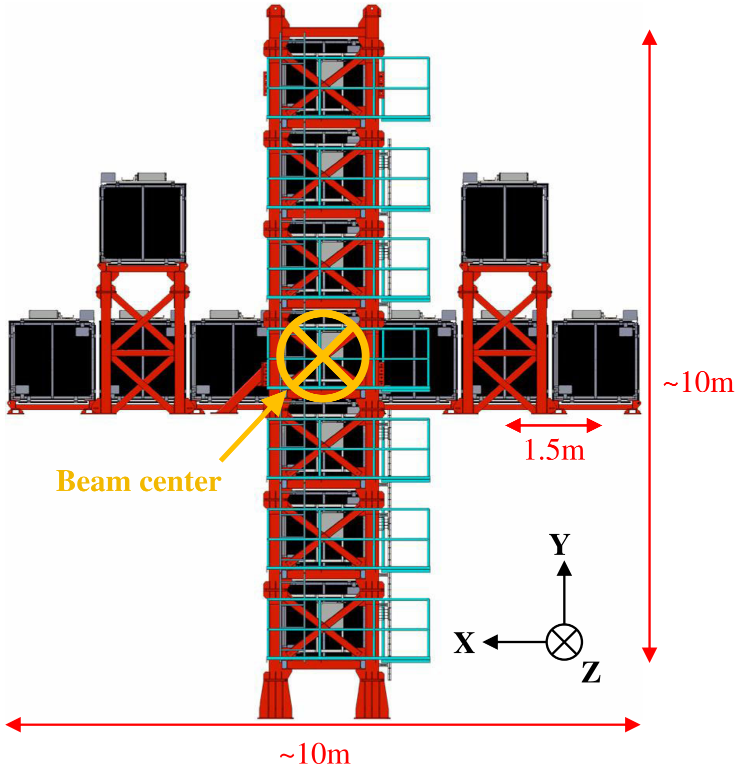
Physics change w/ direction →

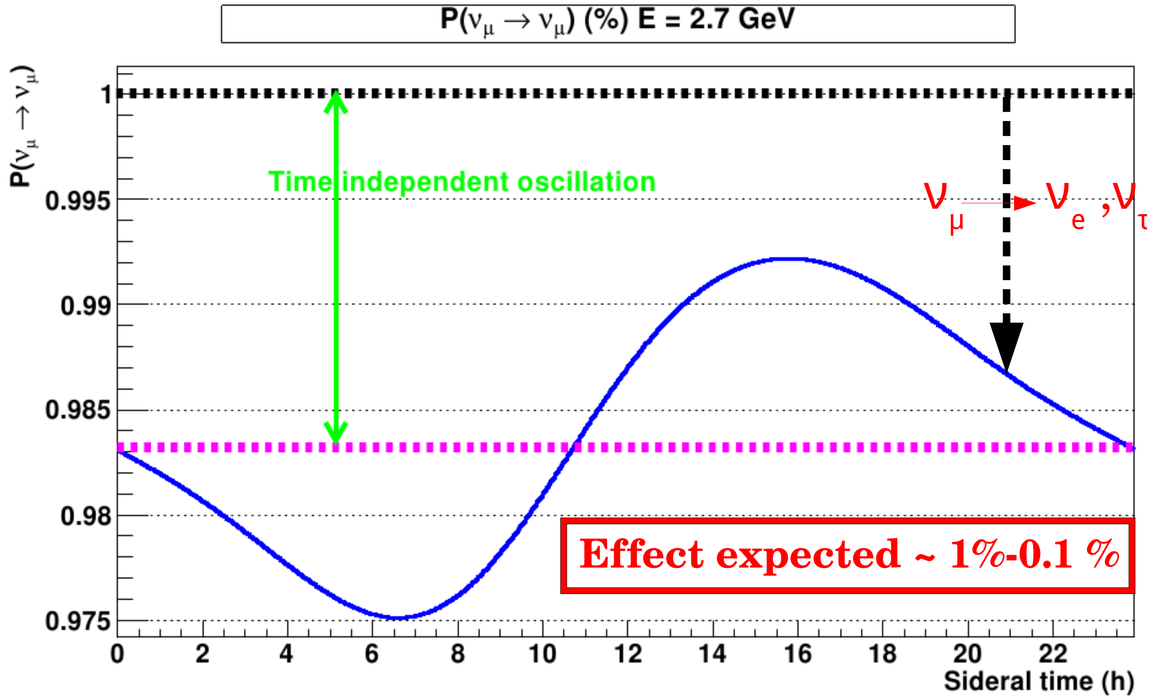


from B. Quilain, talk at Blois 2015

Lorentz violation

- Search for Lorentz violation looking for interference with neutrino oscillations at **INGRID**
  - Oscillations depends on the alignment of the baseline w/ the absolute LV direction
  - Focusing on ν_μ disappearance (high statistics)
  - Selection based on the e - μ particle identification





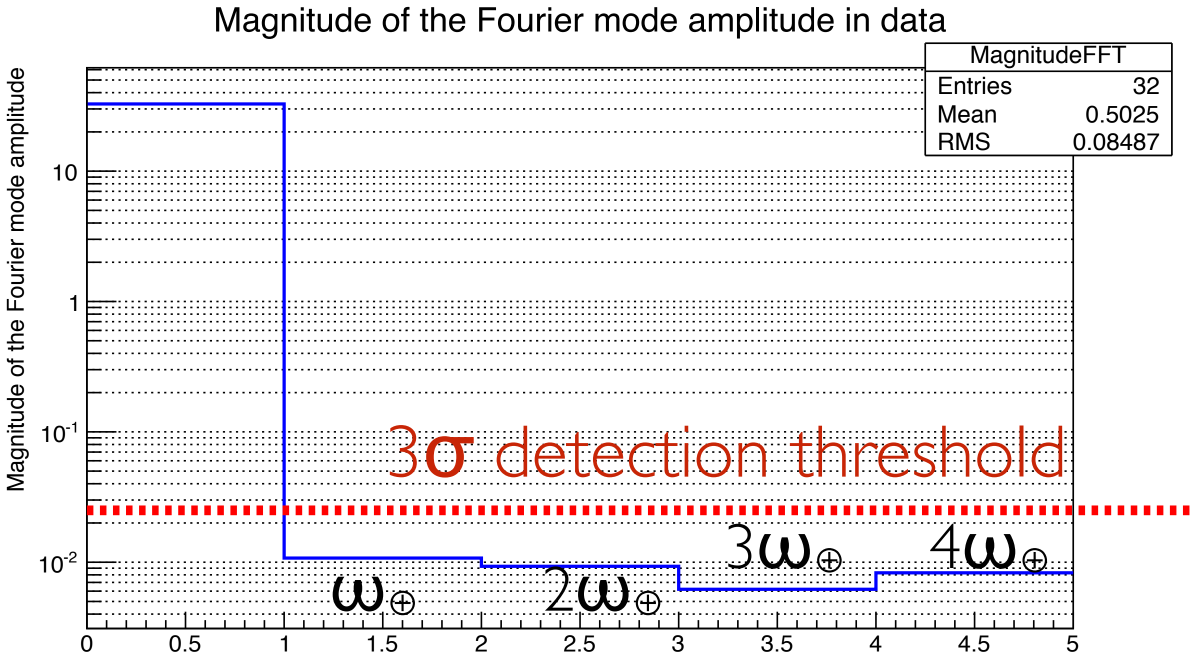
Lorentz violation results

$$P_{\nu_\mu \to \nu_x} = \left(\frac{L}{hc}\right)^2 \left|(C_{\mu x}) + (A_s)_{\mu x} \sin(\omega_\oplus T_\oplus) + (A_c)_{\mu x} \cos(\omega_\oplus T_\oplus) + (B_s)_{\mu x} \sin(2\omega_\oplus T_\oplus) + (B_c)_{\mu x} \cos(2\omega_\oplus T_\oplus)\right|^2$$

$T_\oplus$: sideral time

$\omega_\oplus$:sideral angular phase

- Two analyses:
  - **Fast Fourier Transformation :** frequencies clearly identified



Conclusion:

- No evidence for LV
- Compatible with a flat signal within 3σ

Lorentz violation results

$$P_{\nu_\mu \to \nu_x} = (\frac{L}{hc})^2 |(C_{\mu x}) + (A_s)_{\mu x} \sin(\omega_\oplus T_\oplus) + (A_c)_{\mu x} \cos(\omega_\oplus T_\oplus) + (B_s)_{\mu x} \sin(2\omega_\oplus T_\oplus) + (B_c)_{\mu x} \cos(2\omega_\oplus T_\oplus)|^2$$

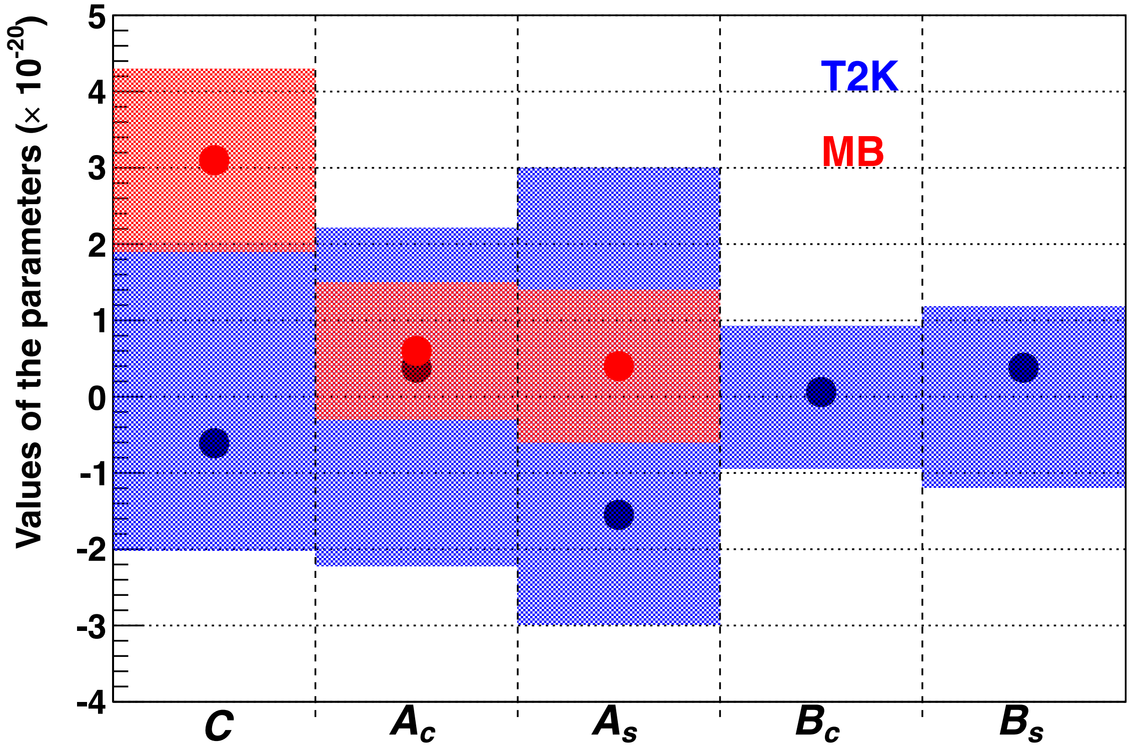
$T_\oplus$: sideral time

$\omega_\oplus$:sideral angular phase

- Two analyses:
  - **Fast Fourier Transformation :** frequencies clearly identified
  - **Binned likelihood method:** takes into account correlations between SME parameters

Conclusion:

- No evidence for LV (no hint > 1σ)
- Better sensitivity than MB



LV : Outlook

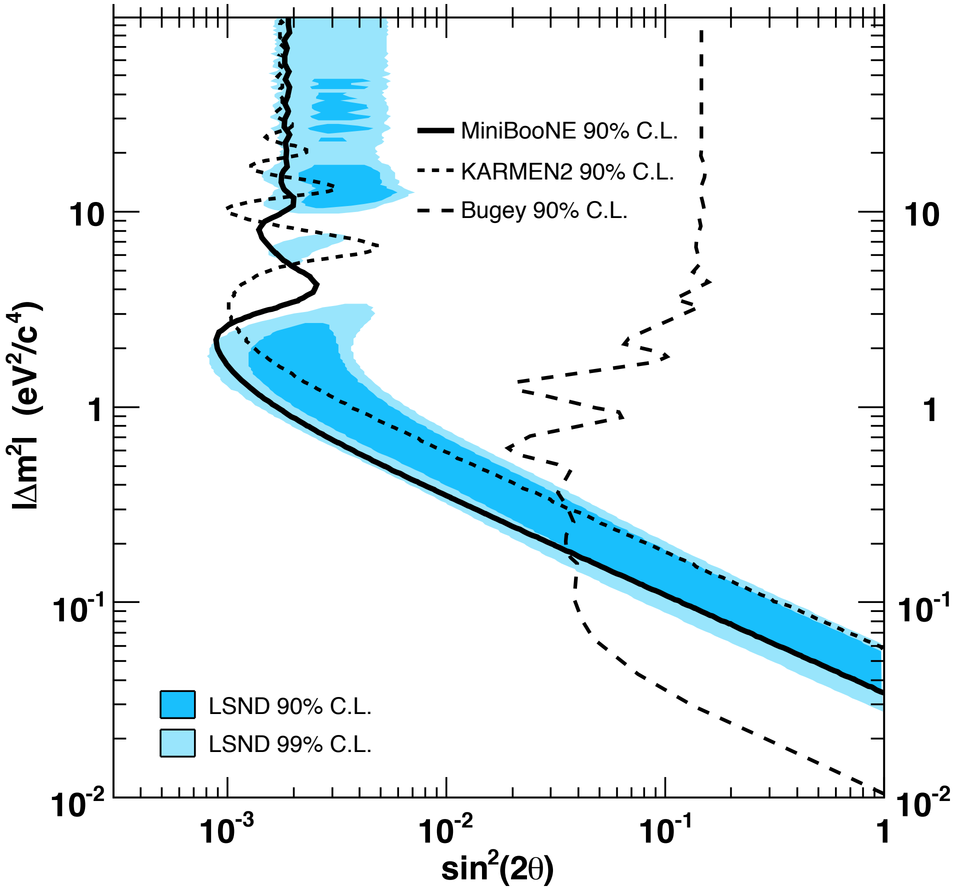
- Analysis with data in neutrino mode achieved
- Results presented for the first time at a conference (Blois 2015)
- Paper under preparation

- Analysis with more data is foreseen

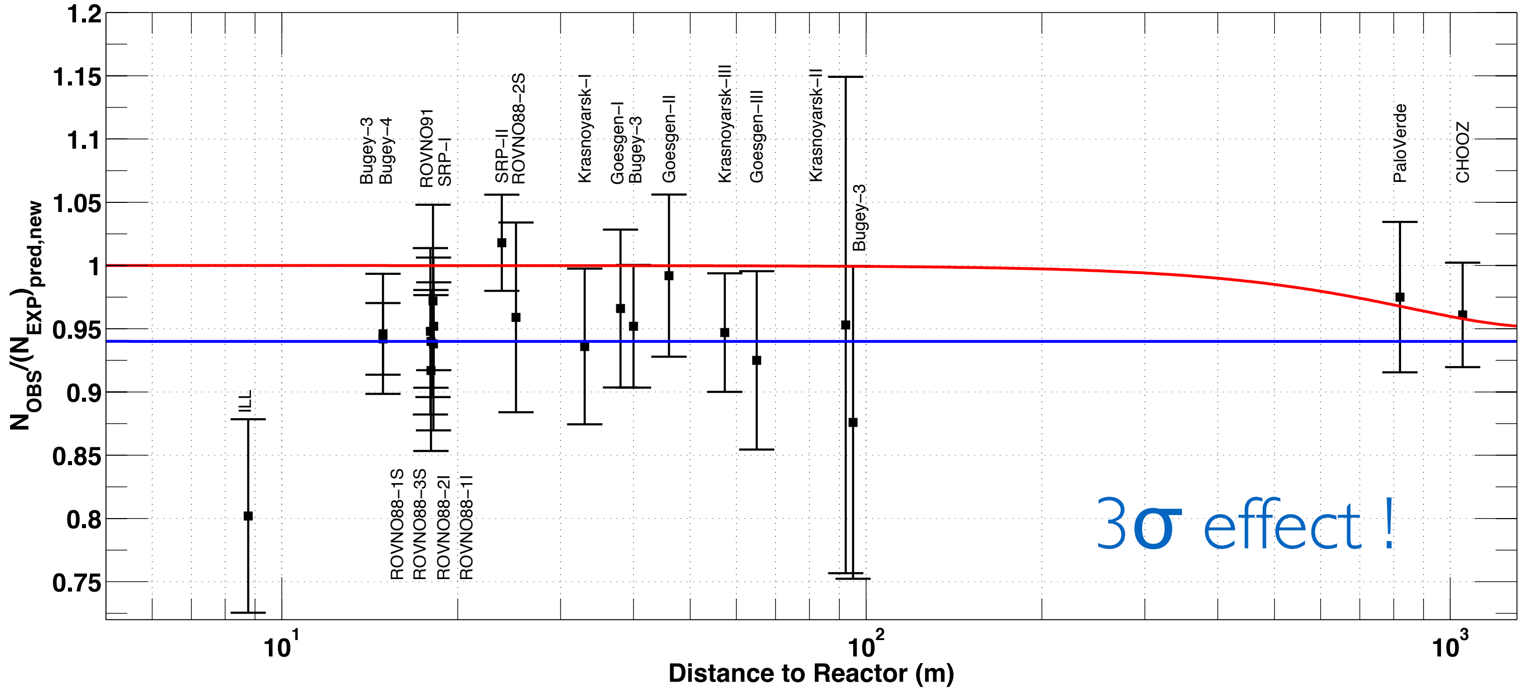
Anomalies to the 3 neutrino paradigm

- LSND : excess observed in $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$
- KARMEN : no excess seen
- MiniBooNE : excess observed in $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ but *not* in $\nu_\mu \rightarrow \nu_e$
- A depletion of the expected ν_e events observed by nuclear reactors

Phys.Rev.Lett. **98** 231801 (2007)



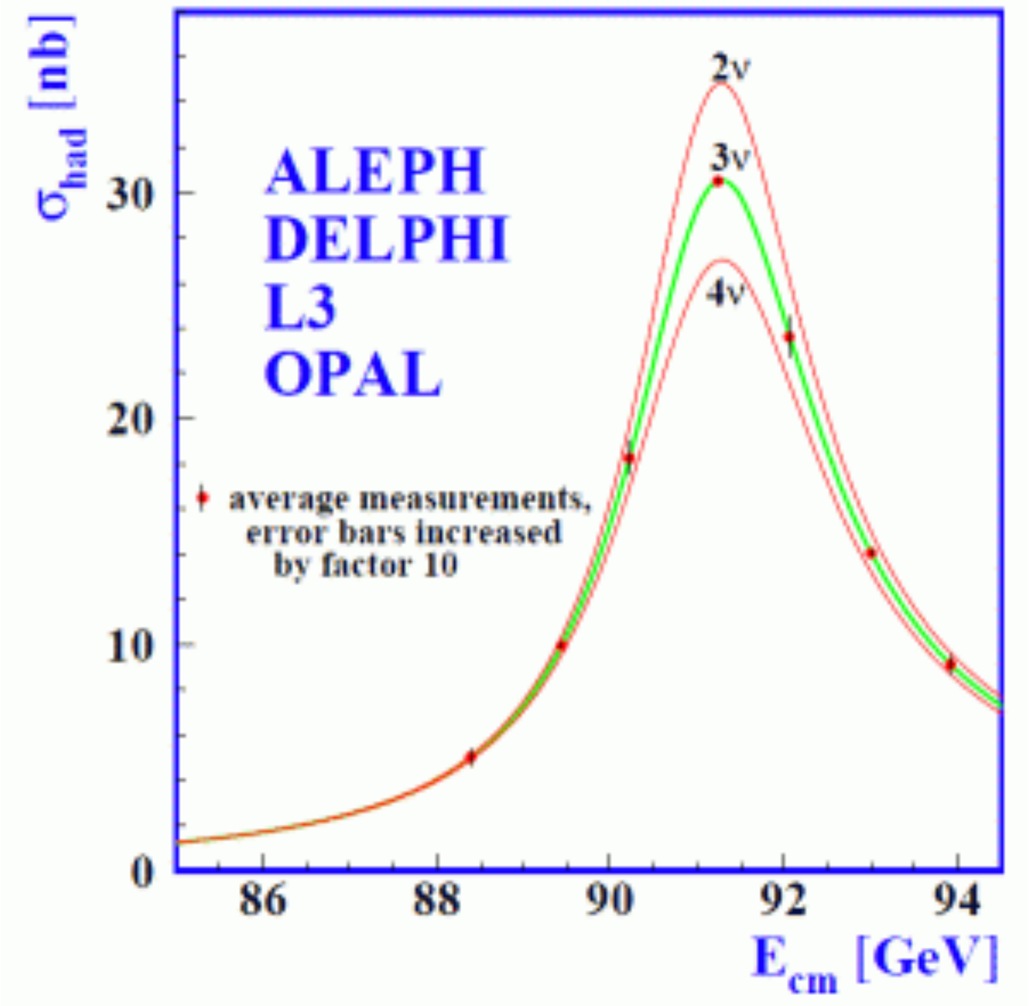
Phys.Rev.D **83** 073006 (2011)



3σ effect !

Why sterile neutrinos ?

- Anomalies may be explained by introducing one (or more) neutrino with mass of the order of 1 eV^2
- Number of active neutrino measured at LEP
- Neutrinos must be sterile : do not interact via weak force



$$e^+ e^- \rightarrow Z^0 \rightarrow f \bar{f}$$

$$N_\nu = 2.9840 \pm 0.0082$$

Number of weak interacting neutrinos

Introducing sterile neutrinos

- 3 (active)+1 (sterile) model is the simplest extension
- Because of the large mass of the sterile neutrino, the masse states for active neutrinos are degenerate : 2 neutrino approximation
- Other models exist (3+2, 1+3+1..) but seem not to be favoured by observations

The 3+1 model

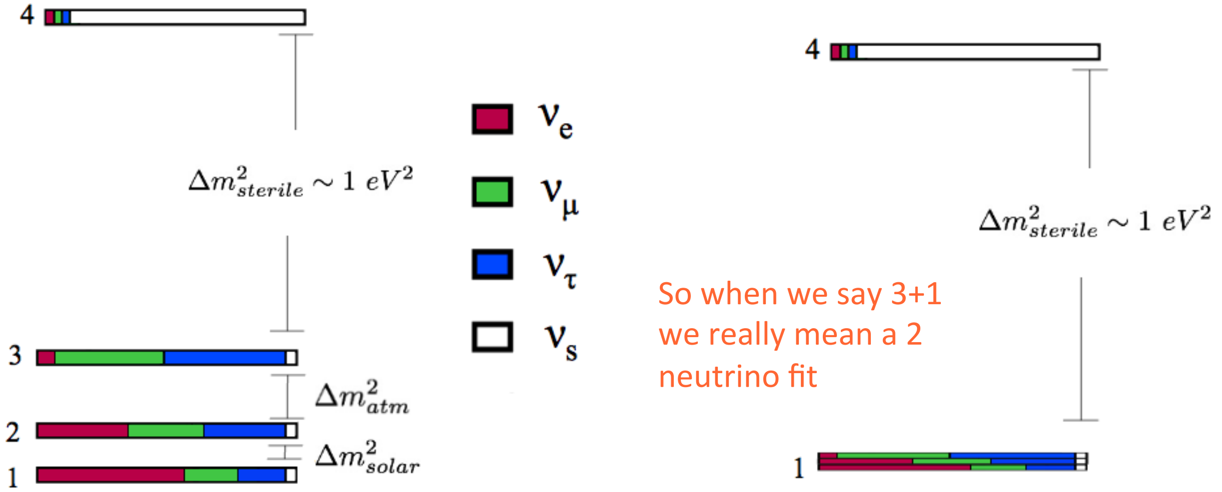
$$\text{Appearance: } P(\nu_\alpha \to \nu_{\beta\neq\alpha}) = \sin^2 2\theta_{\alpha\beta}\sin^2(1.27\Delta m^2\frac{L}{E})$$

$$\text{Disappearance: } P(\nu_\alpha \to \nu_\alpha) = 1-\sin^2 2\theta_{\alpha\alpha}\sin^2(1.27\Delta m^2\frac{L}{E})$$

$$\sin^2 2\theta_{\mu e} = 4U_{e4}^2U_{\mu4}^2$$

$$\sin^2 2\theta_{\mu\mu} = 4U_{\mu4}^2(1-U_{\mu4}^2)$$

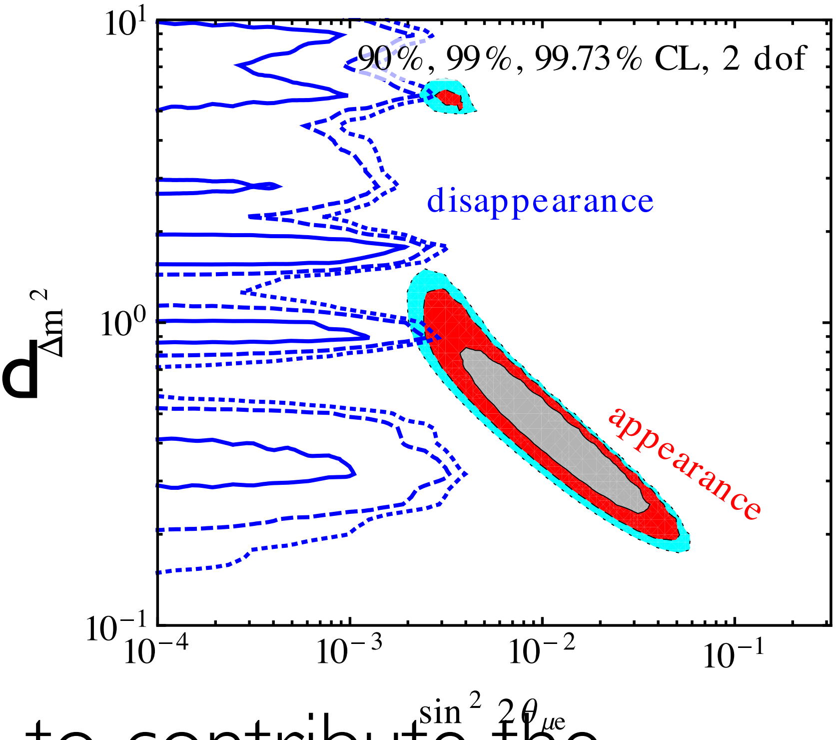
$$\sin^2 2\theta_{ee} = 4U_{e4}^2(1-U_{e4}^2)$$



So when we say 3+1 we really mean a 2 neutrino fit

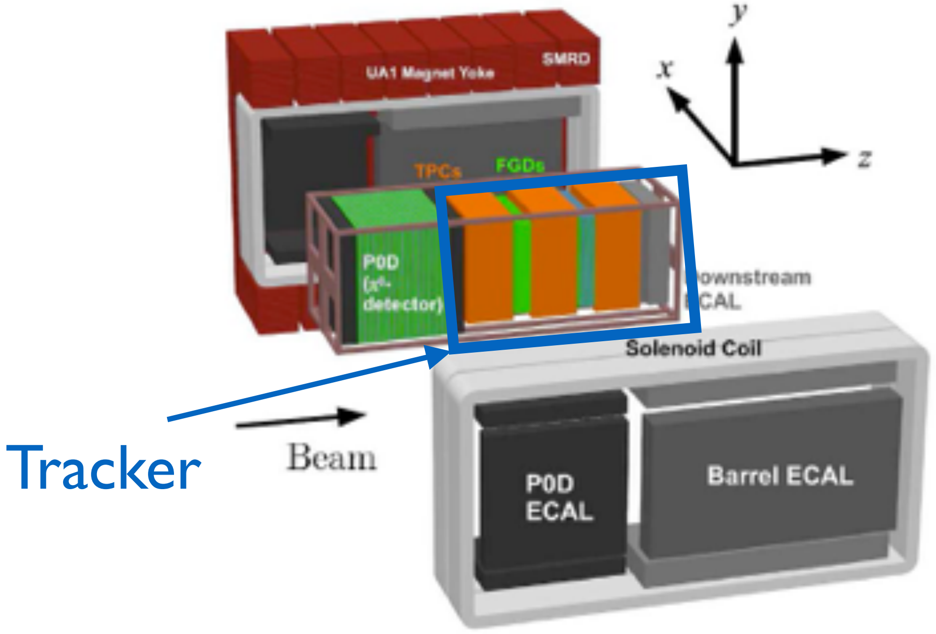
Sterile neutrino searches at T2K

- **No observation of ν_μ disappearance** so far
- **Tensions** between some measurements
- Puzzling scenario, **more measurements are needed**



- ND280 with its **280m baseline** has good conditions to contribute the searches for SBL oscillations
  - Event selection based on tracker information
  - 3+1 model
  - binned likelihood fit to the neutrino energy

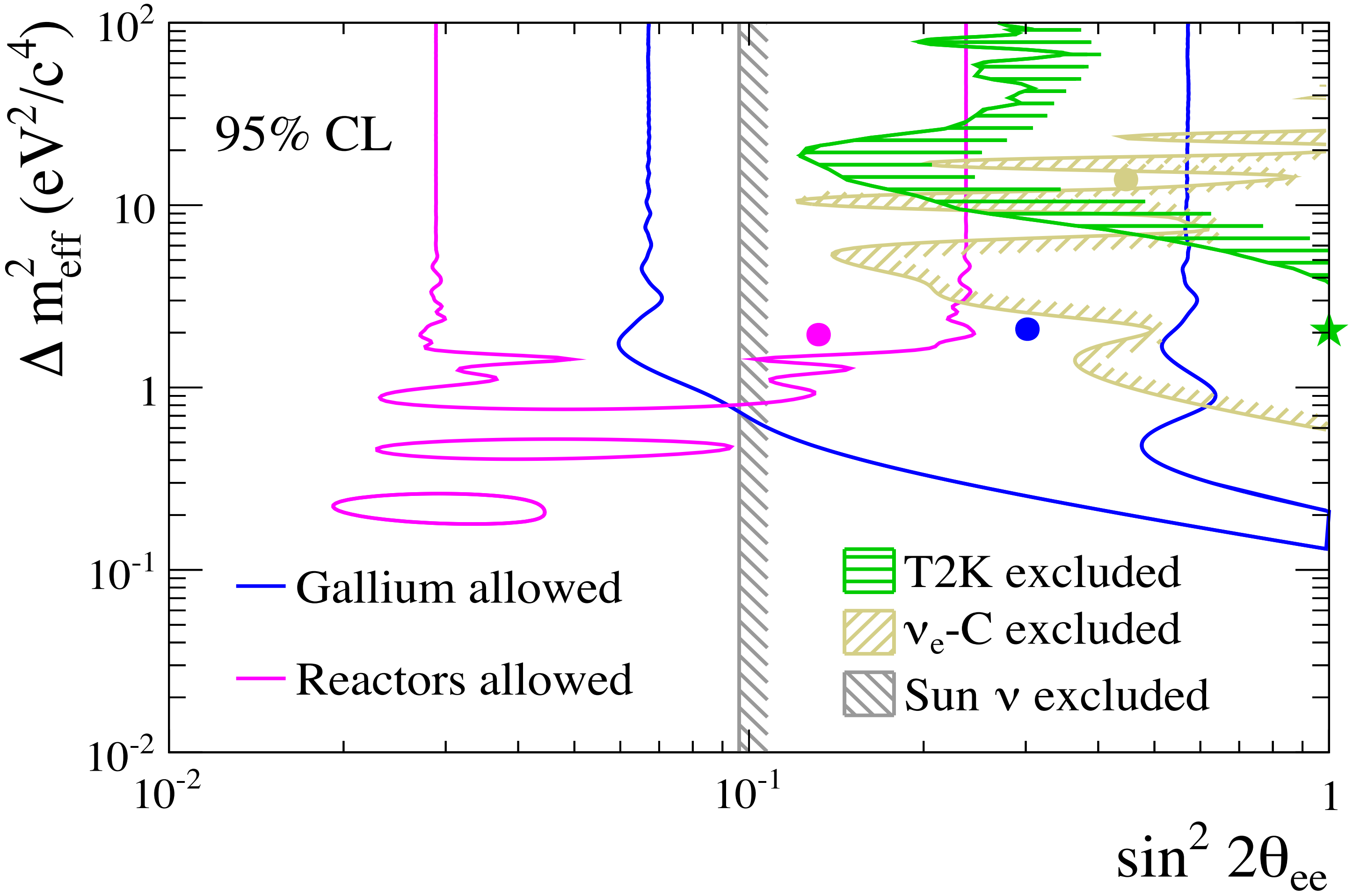
- Measurements on the three channels
  - ν_e disappearance (published)
  - ν_μ disappearance (on-going)
  - joint fit (near future)



ν_e disappearance

- ν_e sample (67% purity) selected from the contamination (1%) of the ν_μ beam
- Selection based on the ECal and TPC particle identification
- Sample of γ-conversion to constrain the main bkg (DIS and NC with π^0)

Analysis published: Phys. Rev. D. 91 051102 (2015)



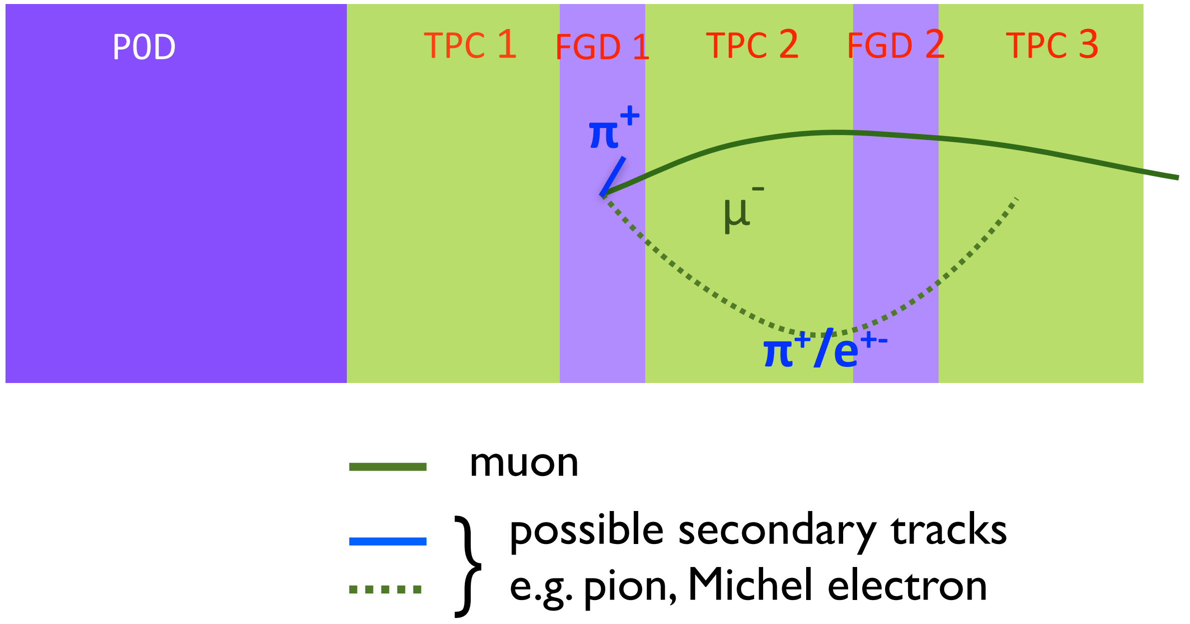
6×10^{20} POT

best fit point :

$\sin^2 2\vartheta_{ee} = 1$, $\Delta m^2_{eff} = 2.05$ eV^2

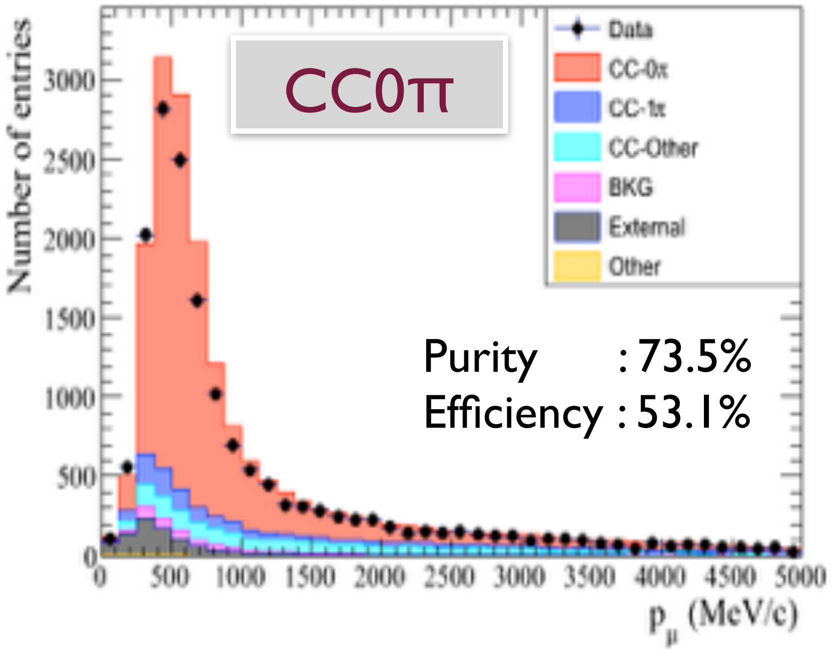
ν_μ disappearance: selection

- Simple selection done using information coming from the tracker (FGD and TPCs)
- Selected events classified into three topologies depending on the number of pions in the final state
  - CC0π → CCQE
  - CC1π$^+$ → Resonant pion production
  - CCOth → mainly DIS

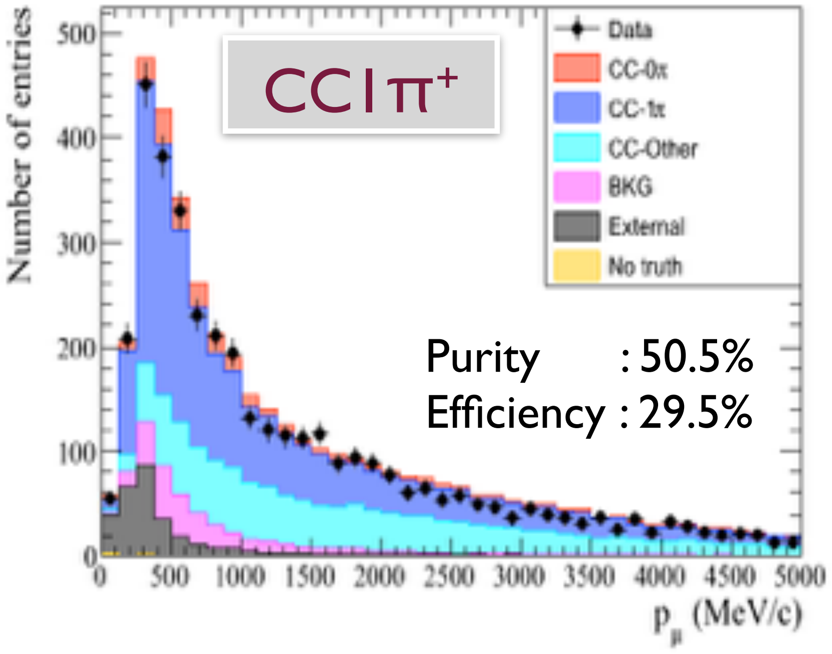


muon

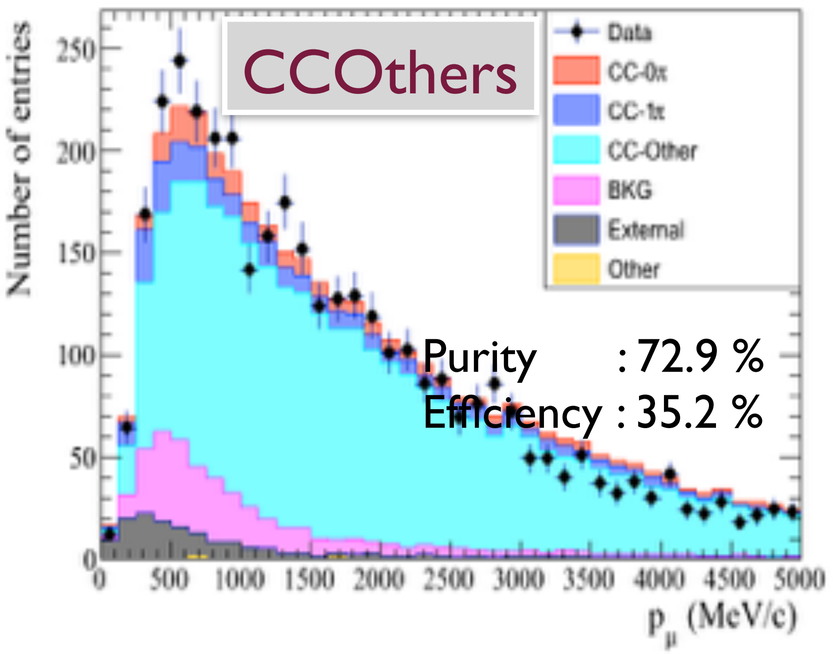
possible secondary tracks
e.g. pion, Michel electron



Purity : 73.5%
Efficiency : 53.1%

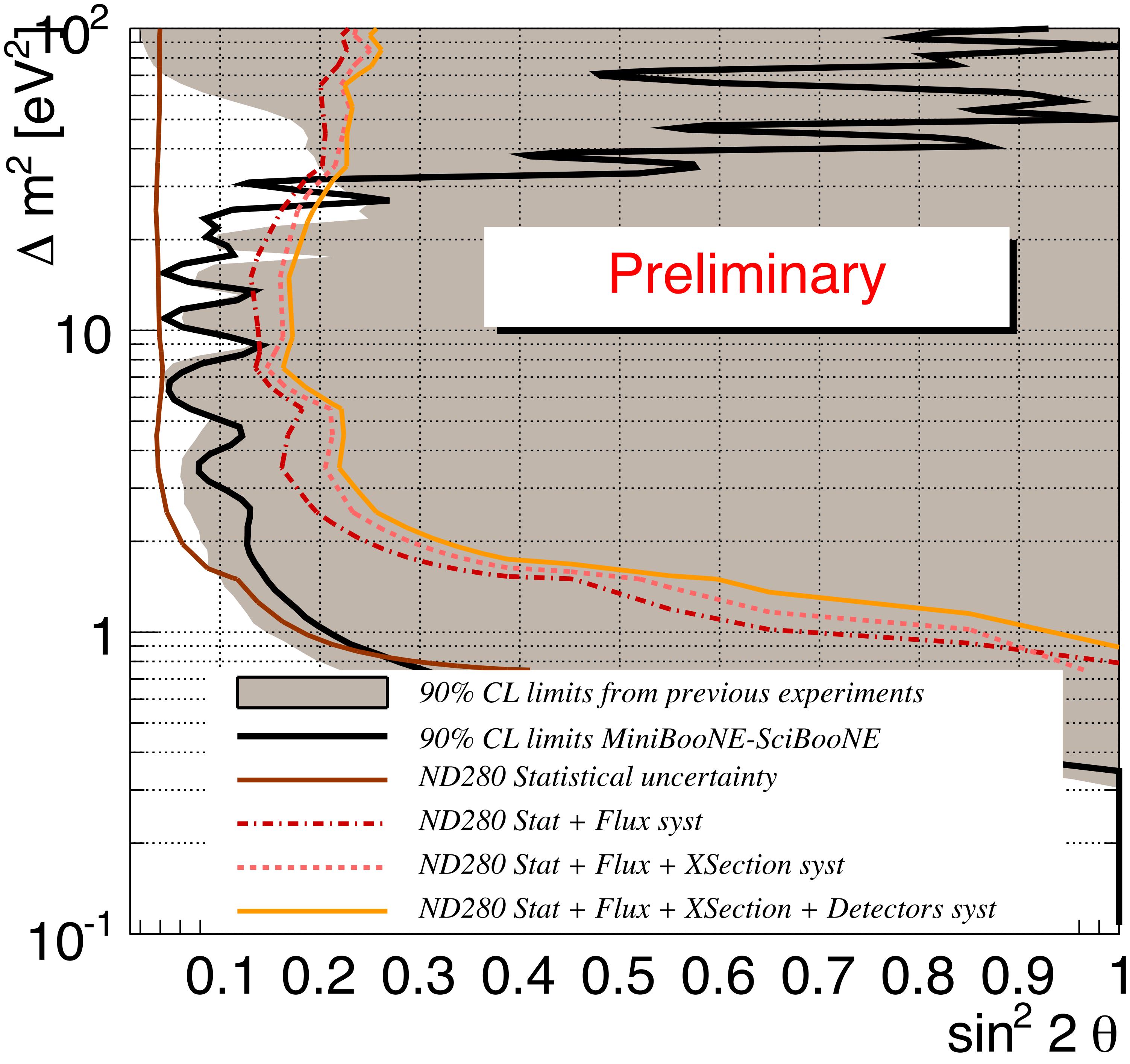


Purity : 50.5%
Efficiency : 29.5%



Purity : 72.9 %
Efficiency : 35.2 %

ν_μ disappearance: sensitivity study



sensitive to:

$\sin^2 2\vartheta_{\mu\mu} > 0.2$, $\Delta m^2_{eff} > 2$ eV^2

SBL : Outlook

Toward the joint ν_e - ν_μ fit :

- ν_e disappearance published in early 2015
- ν_μ disappearance analysis being finalised for fall 2015

- Analyses developed both the same framework
- Exploration of the feasibility to use new computing technology (GPU) to reduce the computing time
- Parallel (independent) study of the nuPRISM appearance sensitivity: joined ν_e - ν_μ constraints look very promising!