The STEREO experiment

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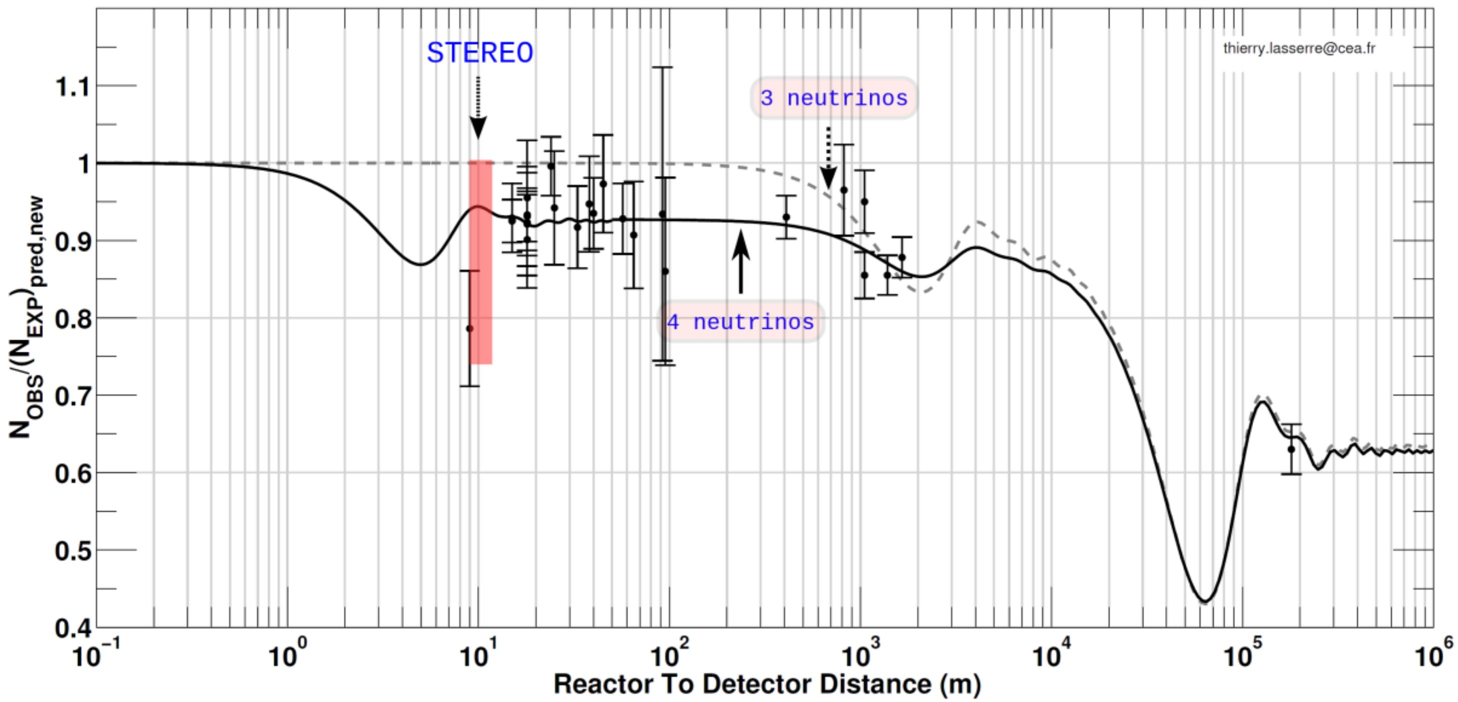
Reactor Antineutrino Anomaly

- Reevaluation of reactor ν_e spectra (Mueller *et al*, **Phys Rev C83 054615**)
- Reanalysis of short baseline reactor experiments (Mention *et al*, **Phys Rev D83 073006)**



$P(\nu_e \rightarrow \nu_e) = 0.924 \text{ +- } 0.023$
⇒ **3σ** deviation from 1

Compatible with **Gallium** anomaly ⇒ **>3σ** deviation

New oscillation towards sterile state ?

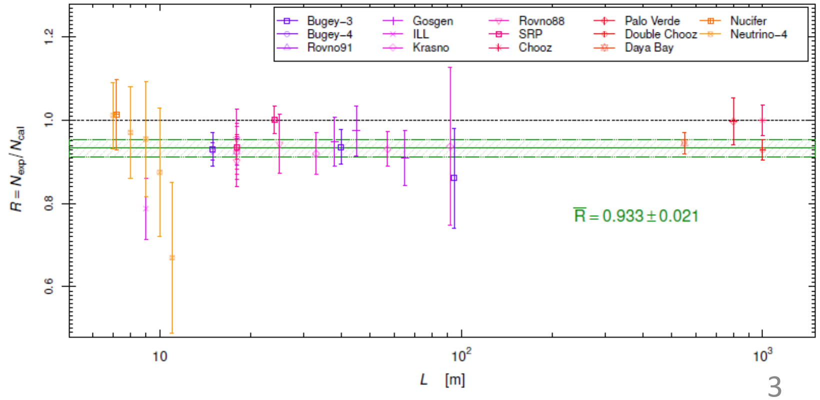
$\Delta m^2 = 1eV \; \sin^2(2\theta) = 0.17$

Up-to-date on competition at $\Delta m^2 = 1eV$

NAME	P_{th} (MW)	L (m)	Depth (m.w.e)	Mtarget (tons)	Tech	Seg	Mov
Nucifer	70	7	13	0.8	Gd	X	X
NEOS	2700	25/5	16/23	1	Gd	X	X
Neutrino-4	100	6-12	10	1.5	Gd	X	✓
DANSS	3000	9.7-12.2	50	0,9	Gd	✓	✓
STEREO	**57**	**9-11**	**18**	**1.75**	**Gd**	✓	✓
SoLiD	70	5.5-10	10	2.9	^6Li	✓	✓
PROSPECT	85	7-18	few	1-10	Gd+^6Li	✓	✓
NuLat	85	3-8	few	1	^6Li+^{10}B	✓	✓

Recent update : Neutrino-4 Results :

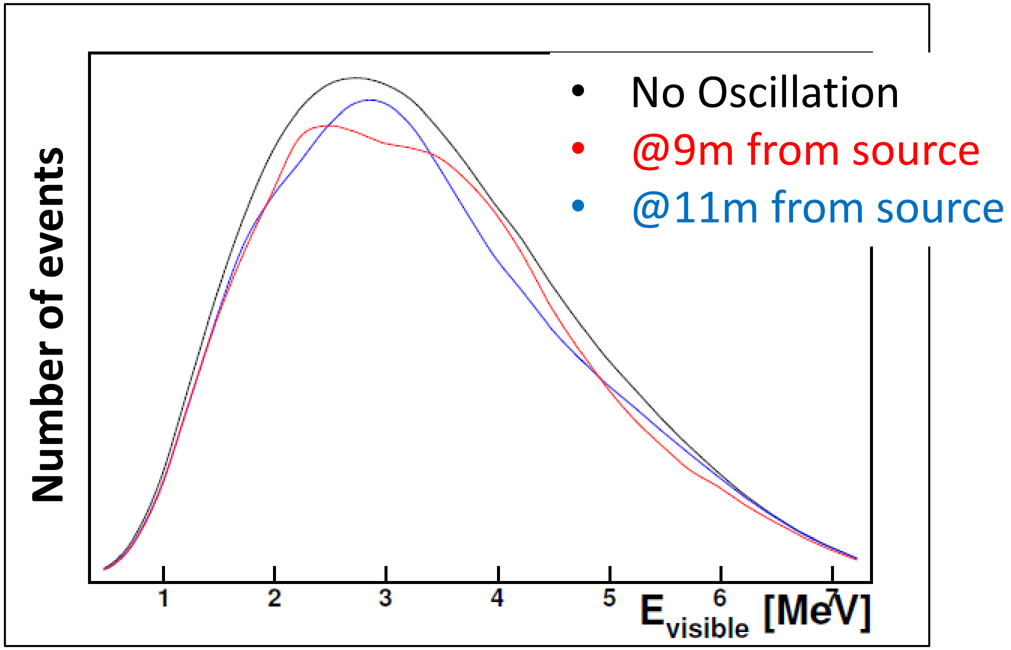
- New measurements at very short distance!
- High systematics…



The STEREO experiment : aim

Goal : *Observe a new oscillation measuring ν_e energy vs distance*

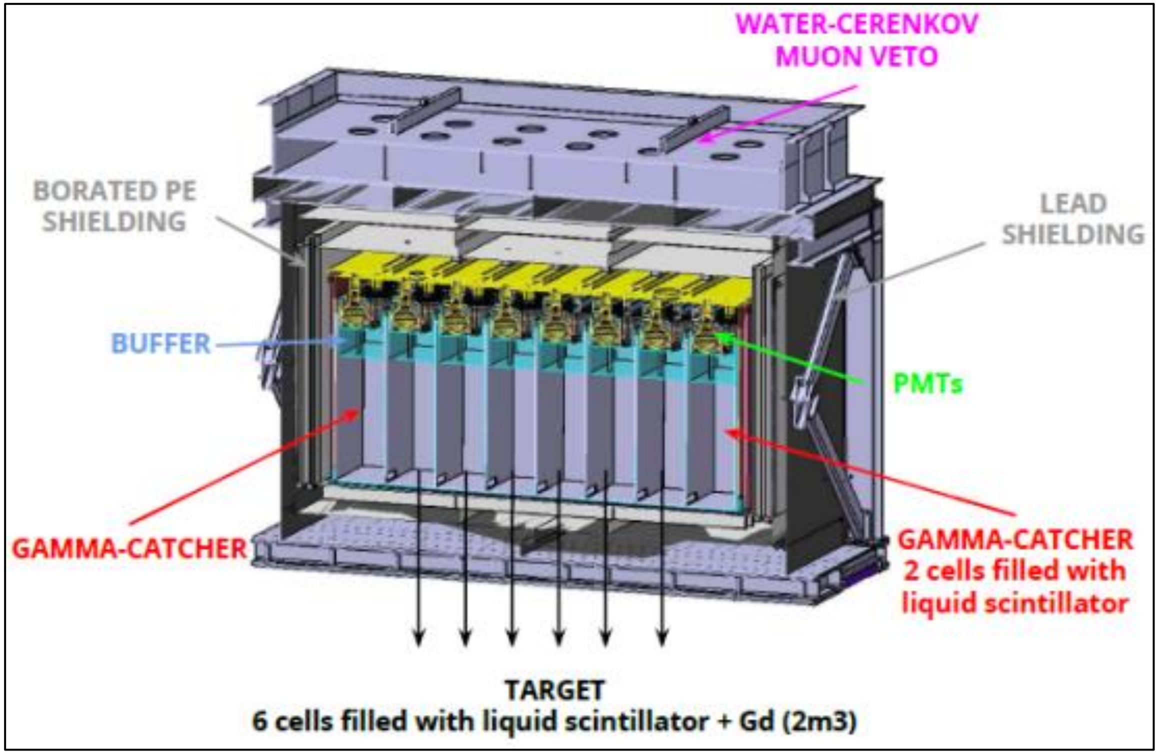
- Close to a compact reactor : ILL (Grenoble)
  - ⇒ Core : 40 cm diameter, 80 cm high
  - ⇒ Highly enriched fuel (^{235}U) and small evolution of ν_e flux
- Relative distorsion of ν_e rates vs $E_{\nu e}$ among cells
  - ⇒ Measurements independant from reactor nomalisation
- Absolute rate measurements with small dependance on core evolution



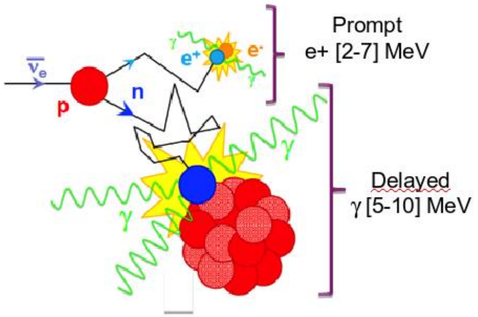
Energy resolution is **crucial !**

The STEREO experiment : detector

Goal : *Observe a new oscillation measuring ν_e energy vs distance*



Detection with **IBD** in
Liquid scintillator + Gd



- Segmented detector of 6 identical cells fill with LS+Gd
- Surrounded by an external **gamma-catcher** fill with LS (**no** Gd)

BACKGROUND

γ	200 Hz
n thermal	10 Hz
N fast	1 Hz

- Accidentals : $\gamma+\gamma$, $\gamma+n$, n_H+n_{Gd}
- Correlated : $n_{fast}+ p \rightarrow p + n_{Gd}$

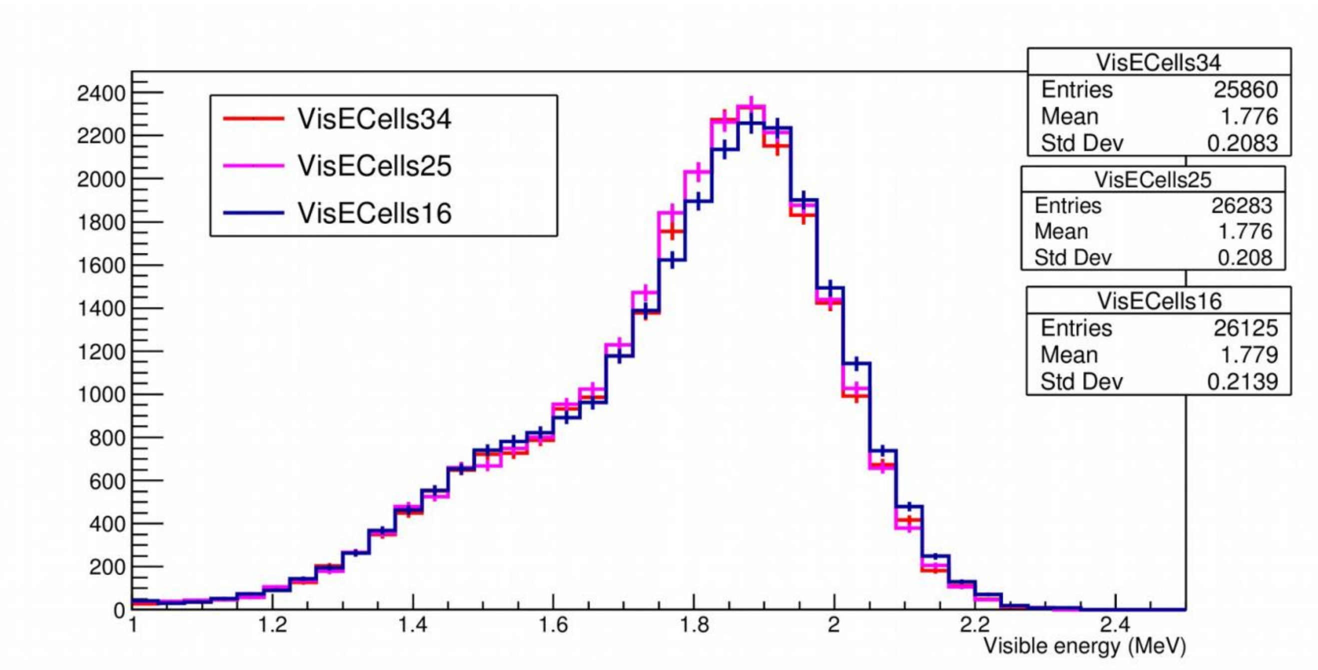
  ⇒ **Passive shieldings**

Background control is **crucial !**

Simulation of detector response

Goal : *Minimise asymmetries among cells*

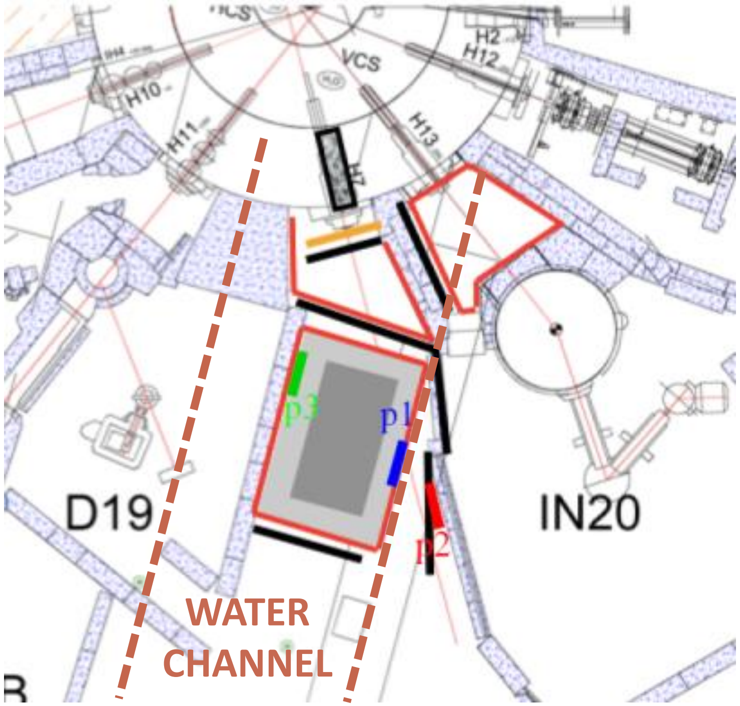
- Simulated E resolution of **12%** for positrons at 2 MeV
  ⇒ Small differences between cells
- Neutron efficiency of 60% with a delayed signal above 5 MeV
  ⇒ Only **4%** difference on neutron response between cells



STEREO site at the ILL reactor

SPECIFICATIONS

- 57MW and compact core reactor
- [8.9-11.1]m from reactor to STEREO
- Water Channel ⇒ Shield against cosmic muons
- Possibility to move the detector by 1.1m (approx 3 cells width)
  ⇒ **Systematics studies**



DRAWBACKS

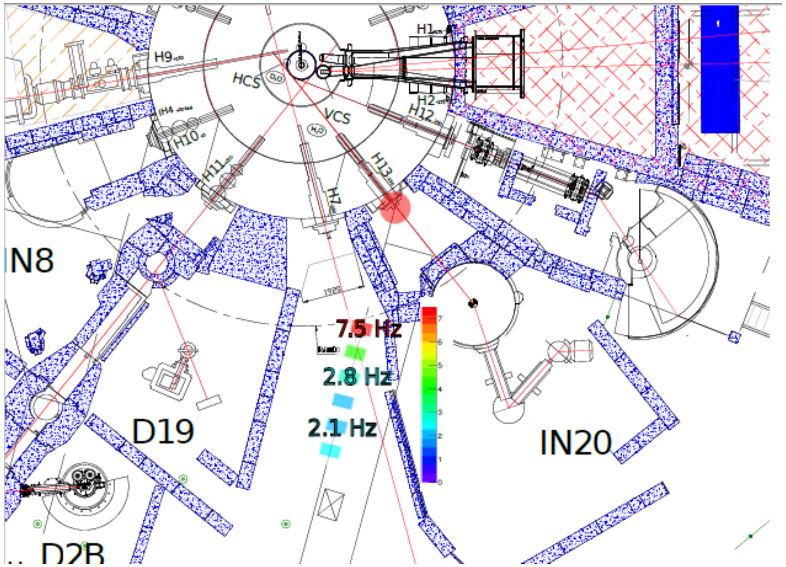
- Background from nearby experiments :
  ⇒ Gammas and neutrons, B-Field
- Nead of large heavy shieldings
  ⇒ Lead, B4C, Polyethylene, Soft Iron and µMetal

Background analysis on site

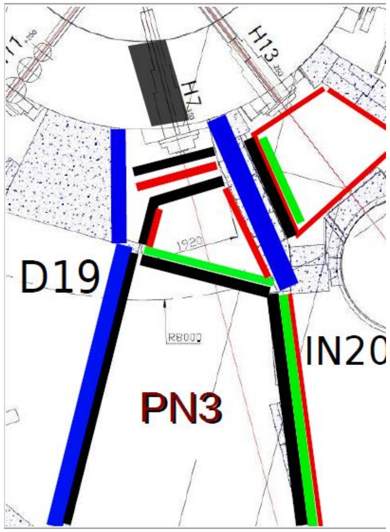
Many measurement campaigns for background on site
- Ge and NaI for gammas
- ^{3}He for neutrons

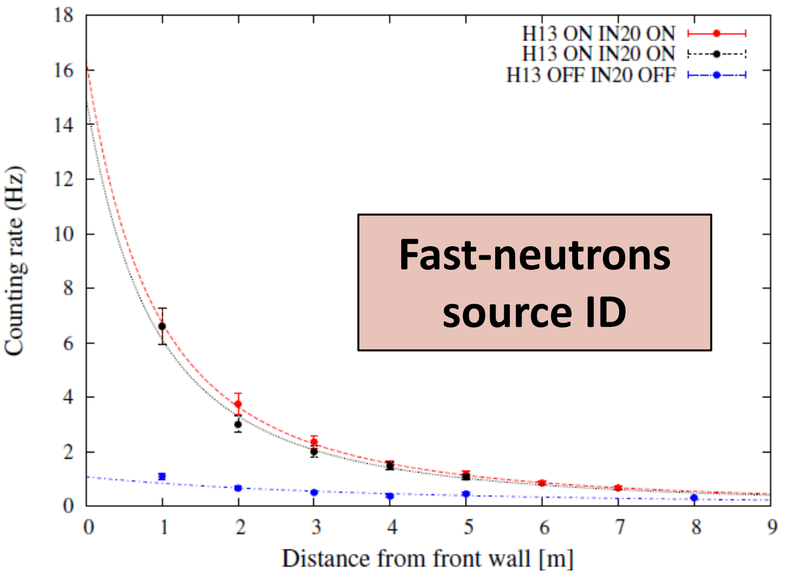
Neutrons and Gammas analysis :
- Identification of hot spots
- Impact on shielding design
- Nearby experiments contribution

B-Field analysis :
- Design magnetic shielding for detector and muon veto



- Blue : **Concrete**
- Red : **Lead**
- Green : **PE**



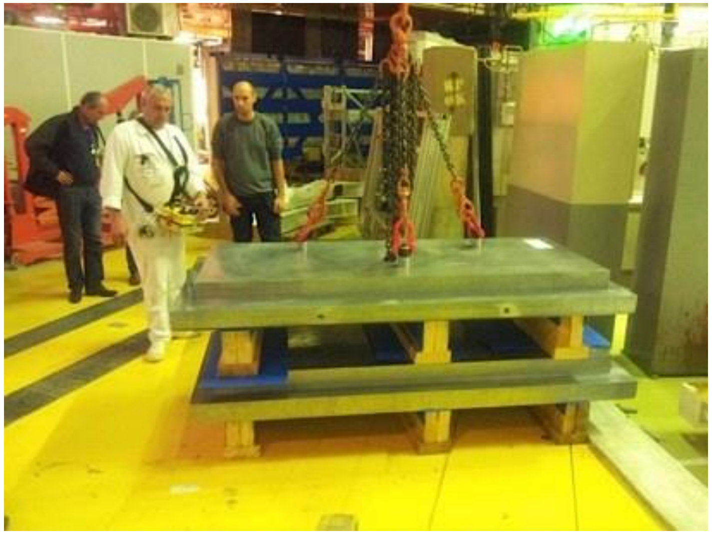


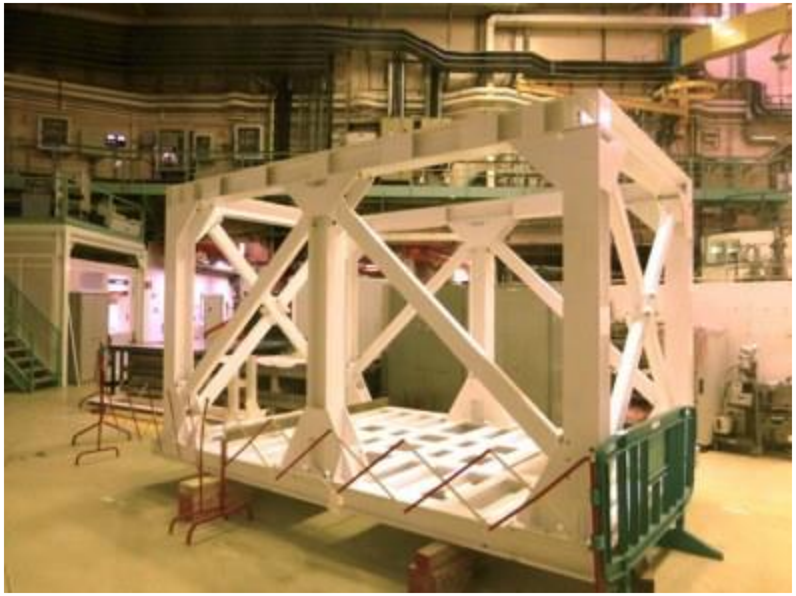
INSTALLATION COMPLETED

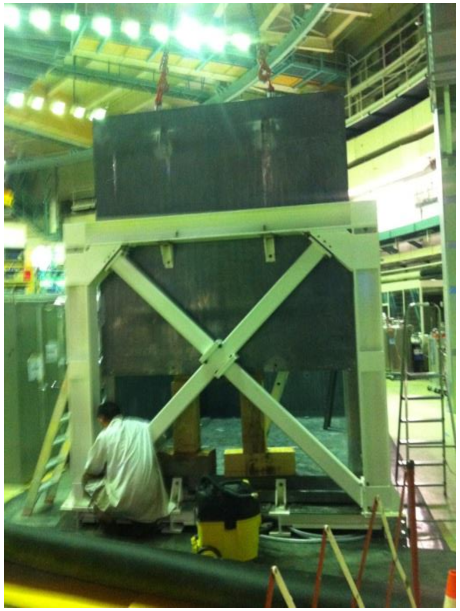
Internal shielding

- Magnetic shielding (soft iron + µMetal)
- 6 tons of polyethylene
- 65 tons of lead

INSTALLATION On-going

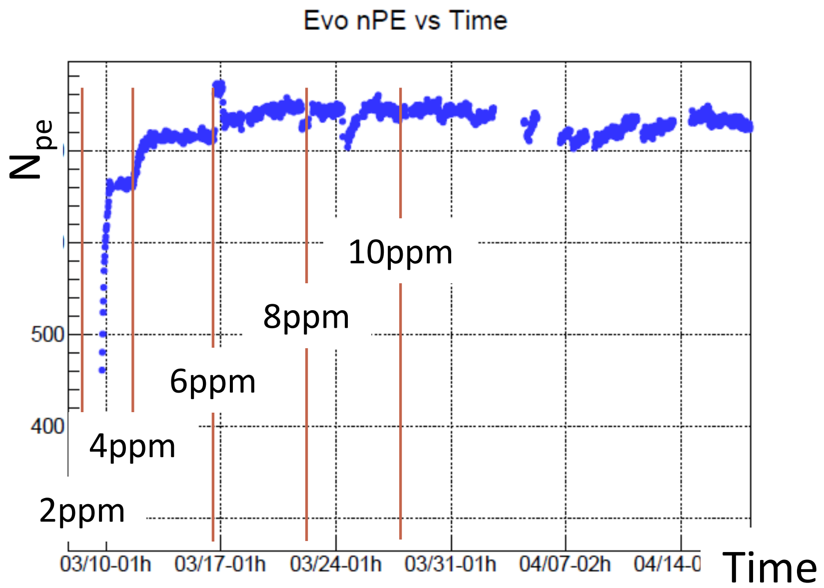






Muon veto system

- Volume of water : 2500L
- Pure water + wavelength shifter
- 20 PMTs
- Tyvek sheets for reflectivity
- 12 optical fibers for light calibration

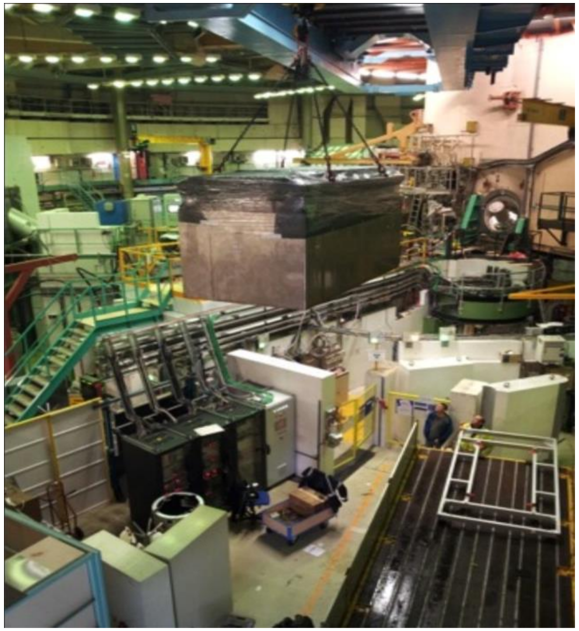


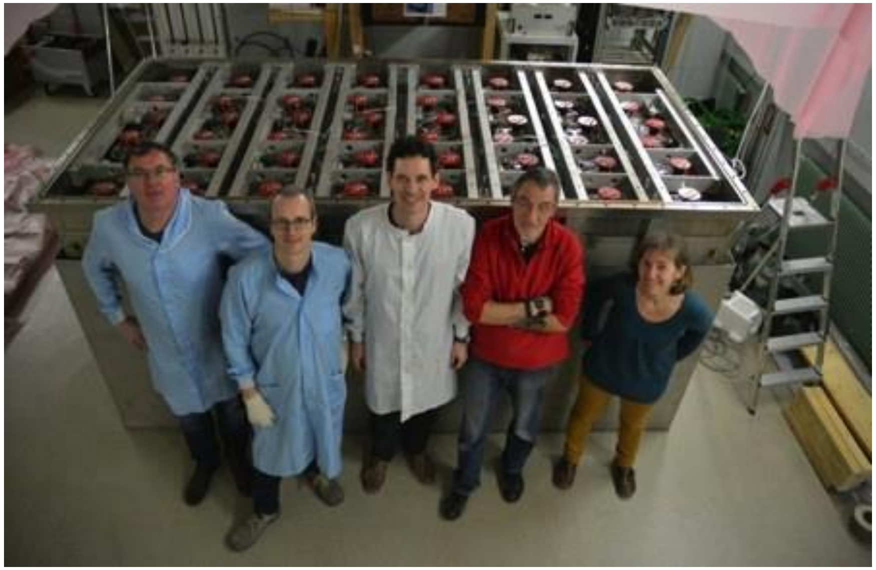
- Several prototypes tested before final instrument
- Simulation studies of the design
  ⇒ Minimizing geometrical effect

INSTALLATION COMPLETED

Inner detector

- Double stainless steel vessel
- Acrylic buffer between PMTs and LS
- Sandwich of VM2000 foils in cell walls
- 48 8'' PMTs hemispherical

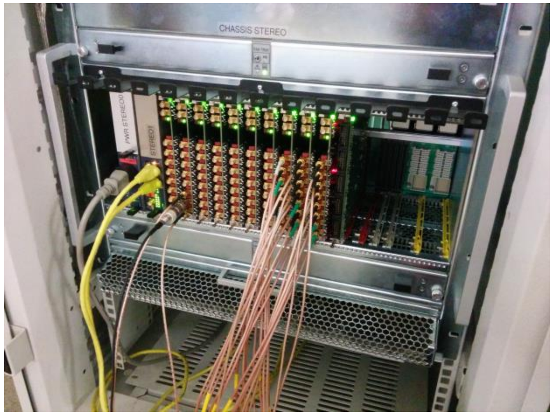




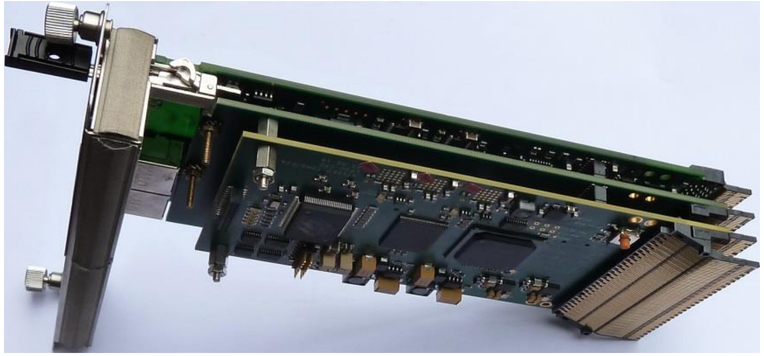
Electronics

- Dedicated electronics hosted on µTCA crate
- Front-end boards
  - 8-channel FADC 14 bits 250 MHz sampling
  - Qtot, Qtail, tCFD and pulse
  - Gain x1 and x20 for single PE
  - First level programmable trigger (FPGA)
- Trigger board ⇒ Second level programmable trigger (FPGA) taking into account the 3 detectors : cells, GC and veto
- LED driver for light calibration

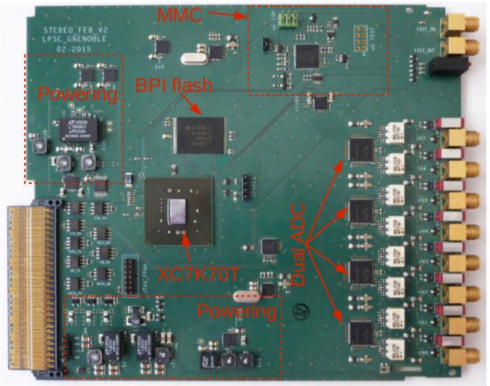
INSTALLATION COMPLETED



µTCA Crate



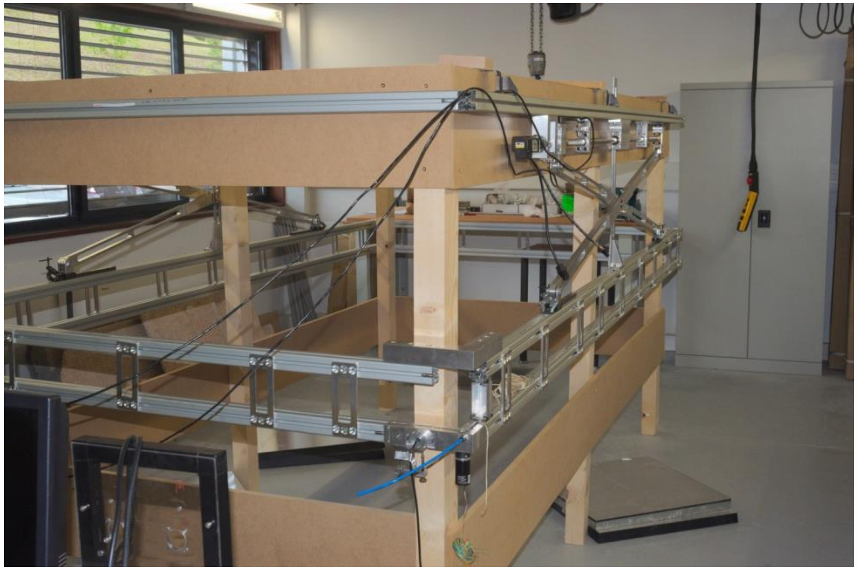
Trigger board

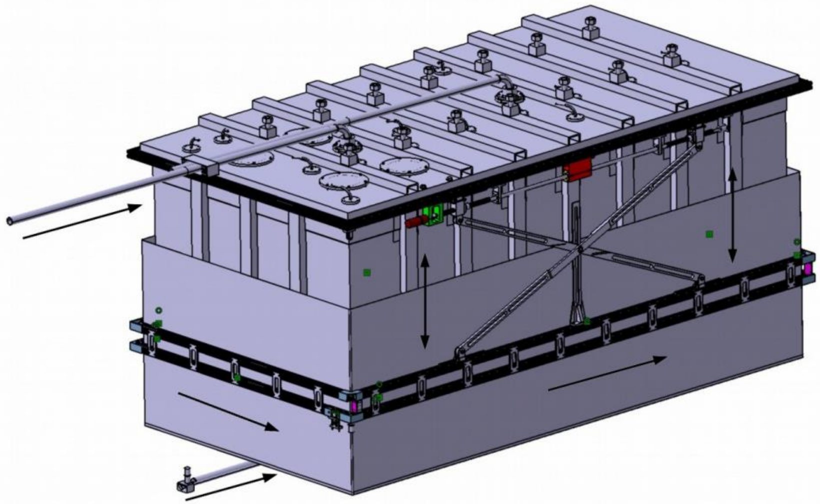


Front-end board

Calibration System

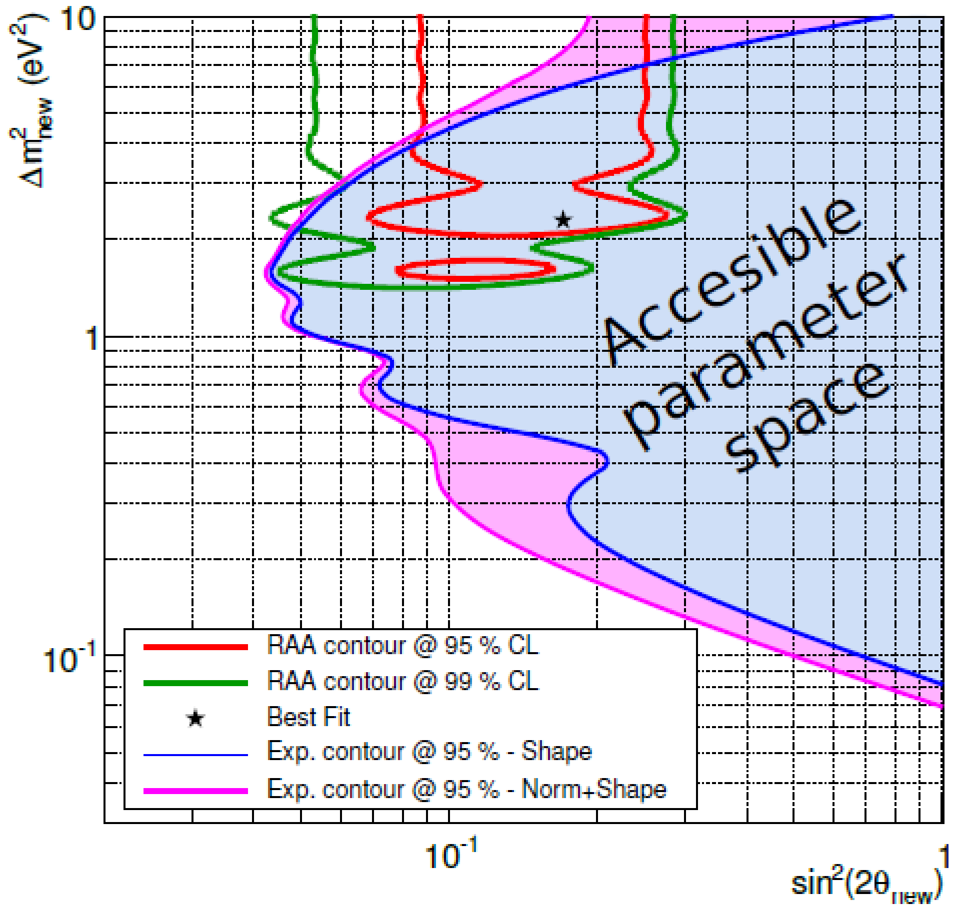
- 3 subsytems :
  - Automated circulation around detector ⇒ **Energy scale**
    (each cell independently + GC + vertical dependance with collimation)
  - Automated movement under detector ⇒ **n capture efficiency** inter-calibration
    (1 reference point in each cell)
  - 3 manual calibration tubes ⇒ Energy scale + n capture efficiency + vertical dependence (2 central and one bordel cell)





Sensitivity and discovery potential

- 400 ν per day during 300 days
- S/B = 1.5
- Realistic detection and reconstruction effects from simulation
- Systematics effect
  - ⇒ Flux uncertainties
  - ⇒ Neutron lifetime uncertainties
- Cut
  - ⇒ Positron > 2 MeV
  - ⇒ Neutron > 5 MeV -> Eff 60%
- Escale = 2% (calibration)



Conclusions

- Most items **delivered** at ILL
- STEREO site **ready** (shielding, floor …)
- Detector **tested** and **ready** to be inserted
- Detector **filling** ⇒ **End 09/2016**
- Objective : **commissioning** in **10/2016**

  ⇒ **100 days** of data taking before **03/2017**

  ⇒ ***First physics results***

Stay Tuned !

BACKUP

The STEREO collaboration

20 researchers, 3 postdocs, 5 PhD

LPSC Grenoble – Laboratoire de Physique Subatomique et de Cosmologie: Muon veto, electronics, simulation, DAQ and monitoring, light injection system

CEA: Inner detector design, cell prototype, simulation

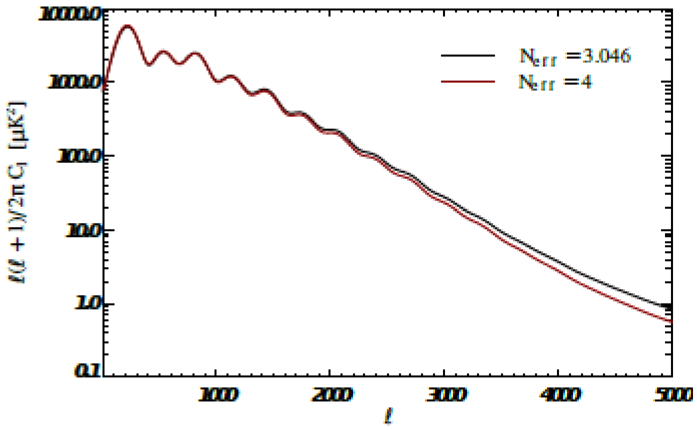
ILL – Institut Laue-Langevin: Security, shieldings, background measurements

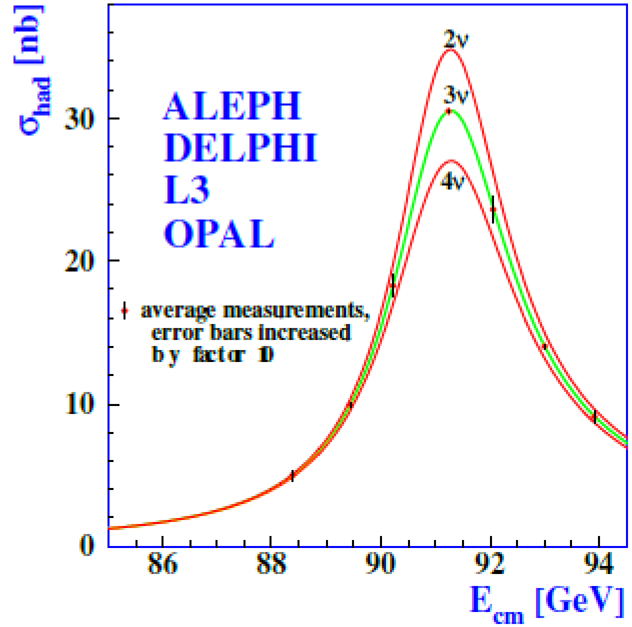
LAPP – Laboratoire d'Annecy-le-Vieux de Physique des Particules: Calibration system, simulation, shieldings

Max-Planck-Institut für Kernphysik: Liquid scintillator, PMTs, PMTs mechanics

Neutrinos Beyond Standard Model

- 3 neutrinos flavors from Z^0 decay width measurements and cosmology (LSS)
- Neutrinos oscillates ⇒ **non-zero mass**





- Several mechanism to provide masses to neutrinos
  - Dirac : $-m(\nu_L\bar{\nu}_R + \bar{\nu}_L\nu_R)$
  - Majorana :$-\frac{1}{2}m(\nu_L\bar{\nu}^C{}_L + \nu_L\bar{\nu}^C{}_L)$

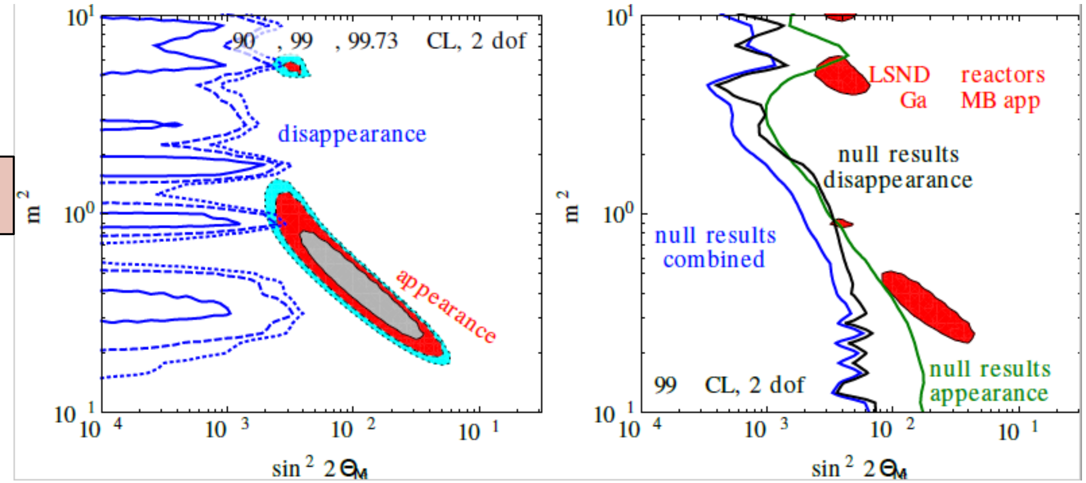
- **Light sterile neutrinos ?** ν_R
- **Heavy Majorana sterile neutrino ?** ⇒ $\nu_L\bar{\nu}^C{}_L$

Seesaw mechanism

Neutrino oscillation anomalies and sterile fits

Based on J. Kopp analysis

10.1007/JHEP05(2013)050



New oscillation towards sterile state ?

Tension about the global 3+1 picture

- Gallium + RAA ⇒ **>3σ**
- Combined with ν_μ appearance ?
  ⇒ **NO overlap** at 99%

Appearance incompatible with disappearance observation

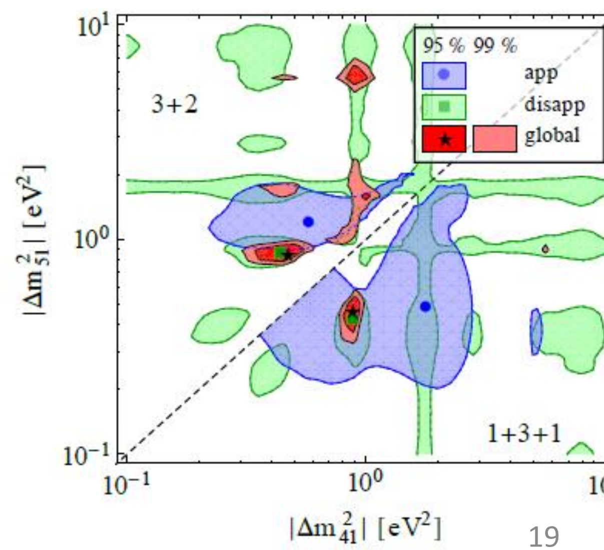
- Quadrically suppress by non-disparition of ν_μ

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

« Release » tension by adding second sterile state

2 options : 3+2 or 1+3+1

- Tension between appearance and disappearance remain severe
- 1+3+1 scenario most favorable



Remove MiniBooNE appearance ? C. Giunti analysis

10.1016/j.nuclphysb.2016.01.013

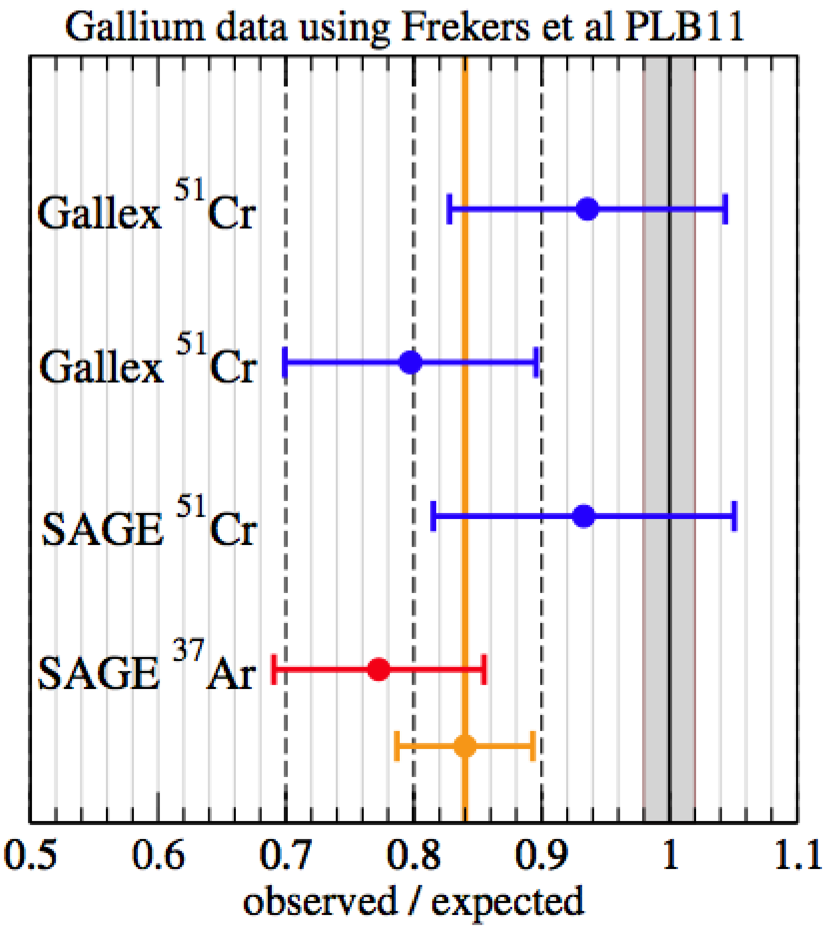
Gallium anomaly

- A β^+ emitter (51Cr or 37Ar) is placed inside a 71Ga solar neutrino detector for calibration
- Neutrinos are detected through 71Ga + ve -> 71Ge + e-

$P(\nu_e \rightarrow \nu_e) = 0.86 \pm 0.15$
⇒ **2,7σ** deviation from 1

New oscillation towards sterile state ?

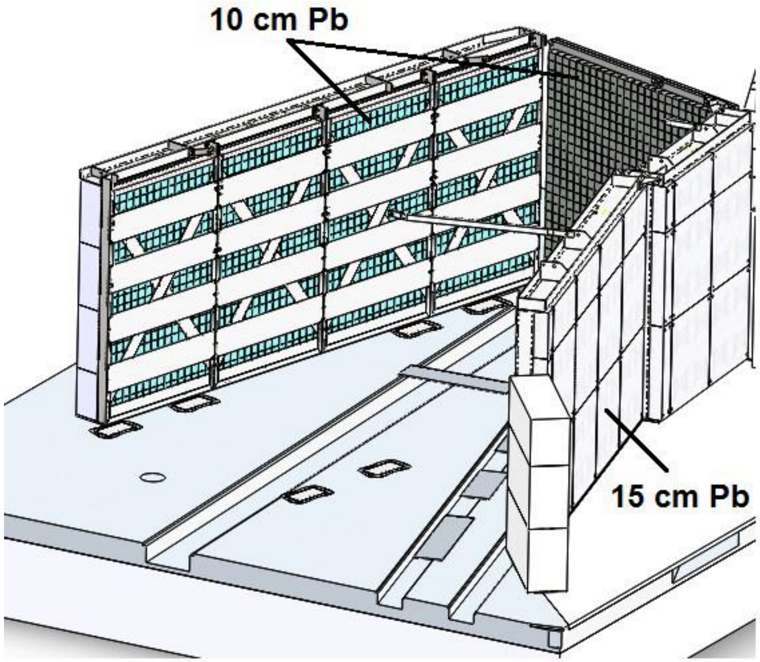
$\Delta m^2 = 2.24\text{eV}\ \sin^2(2\theta) = 0.50$

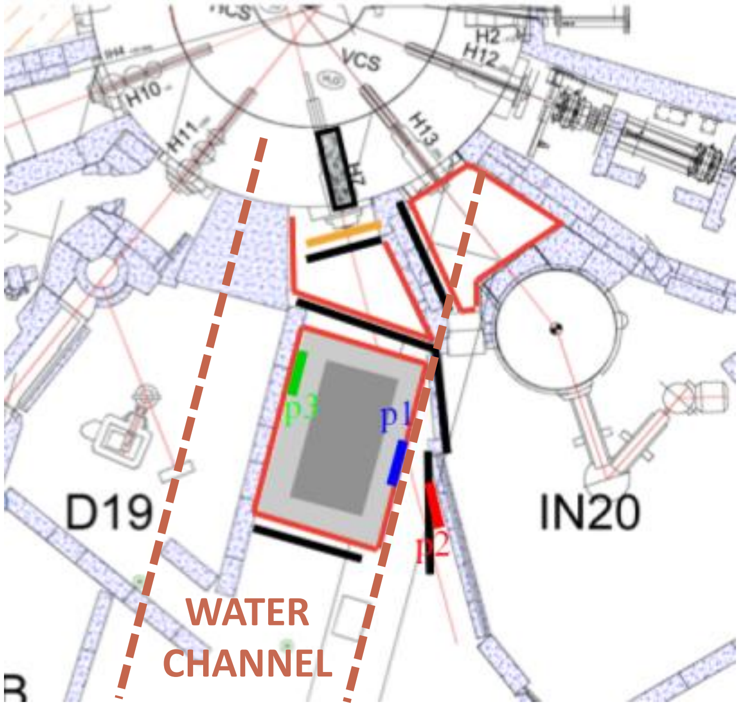


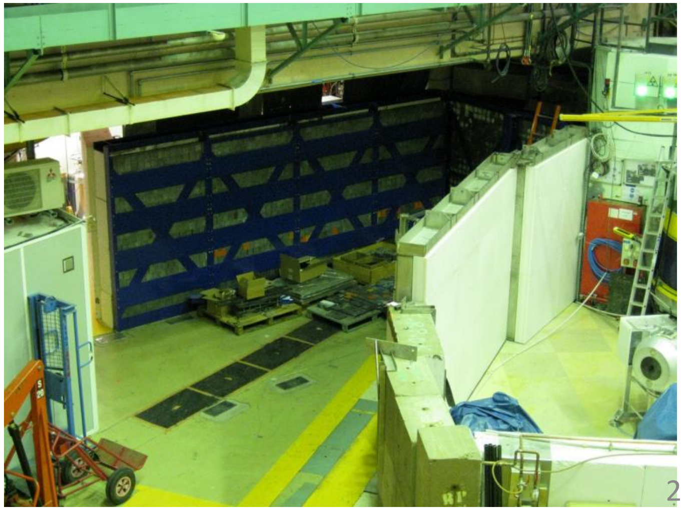
External shielding

- **D19** : 10cm of lead + B4C
- **Front wall** : plug in H7 tube + 10cm of polyethylene + 10cm of lead
- **IN20** : 10cm of borated polyethylene + 15cm of lead + B4C

INSTALLATION COMPLETED







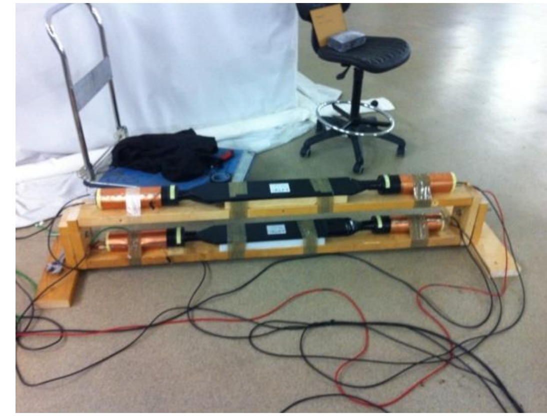
Muon-induced background

- Muons are the most source of background
  - MIP : 2MeV/cm and cell height 90cm ⇒ 180 MeV dE

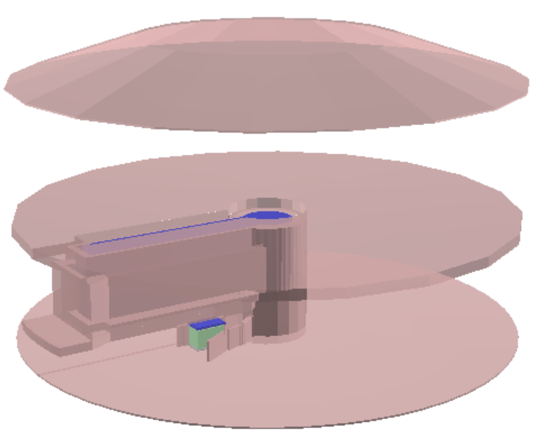
  ⇒ **Saturation of the PMT** will affect **E reconstruction**
- Create fast neutrons by **spallation**

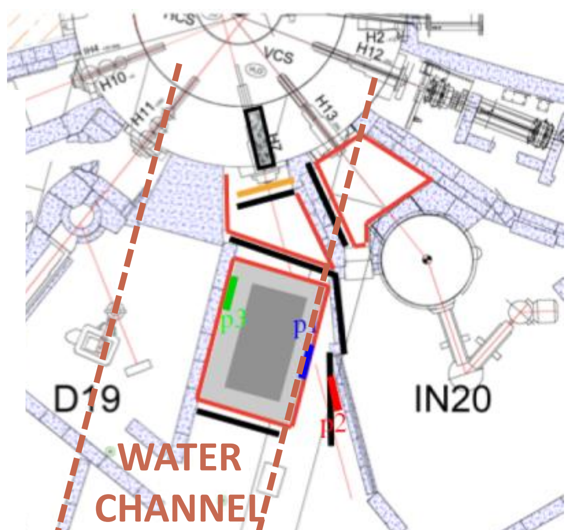
  ⇒ **Irreducible correlated background**

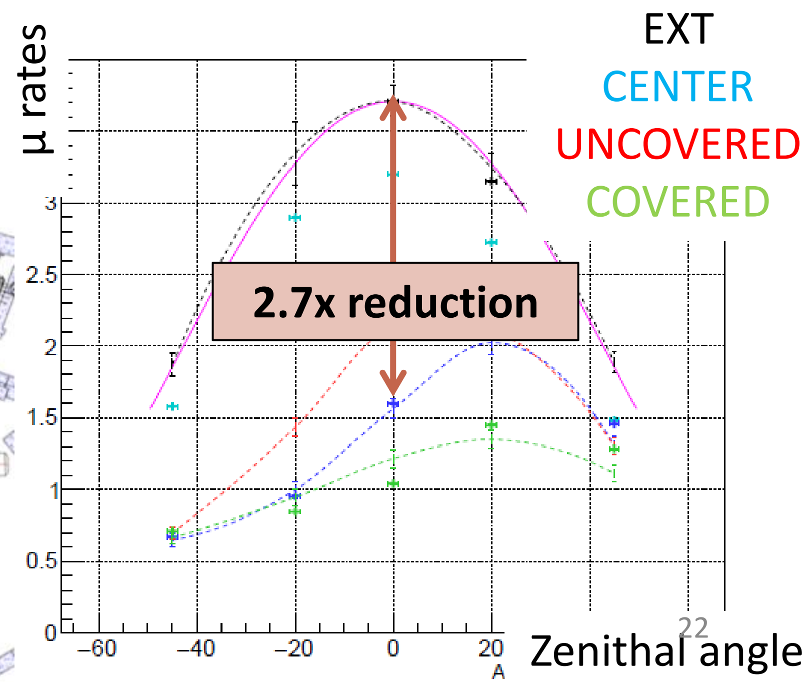
Construction of a **transportable detector** to measure **muon rates** vs **zenithal angle**



Simulation of the setup with CRY and estimation of muon rates

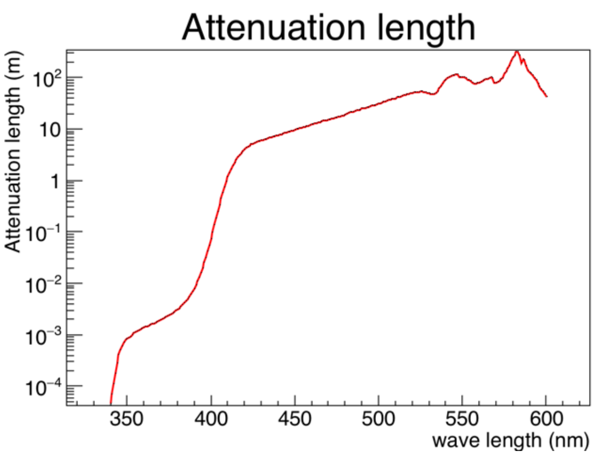


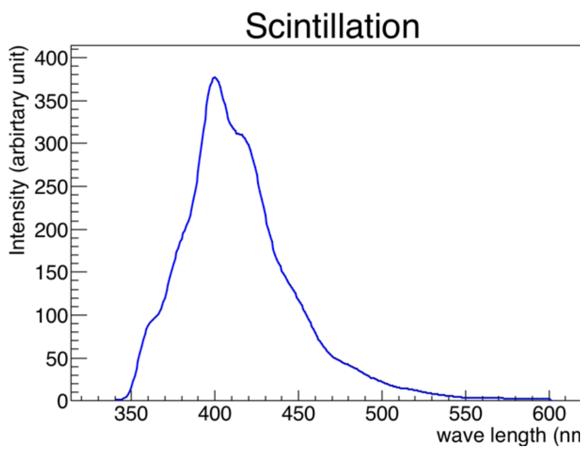


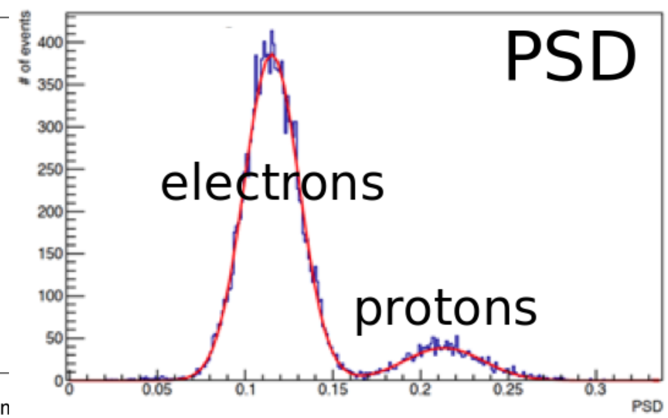


Scintillation liquid

- Composition of the scintillation liquid definitive
  - LAB : 75% ⇒ protons target
  - PXE : 20% ⇒ scintillation
  - DIN : 5% ⇒ enhance pulse shape discrimination
  - Gd-complex 0.2% + 1% THF ⇒ neutron capture
  - PPO + bis-MSB ⇒ wavelength shifters
- STEREO sample stable after 2 years





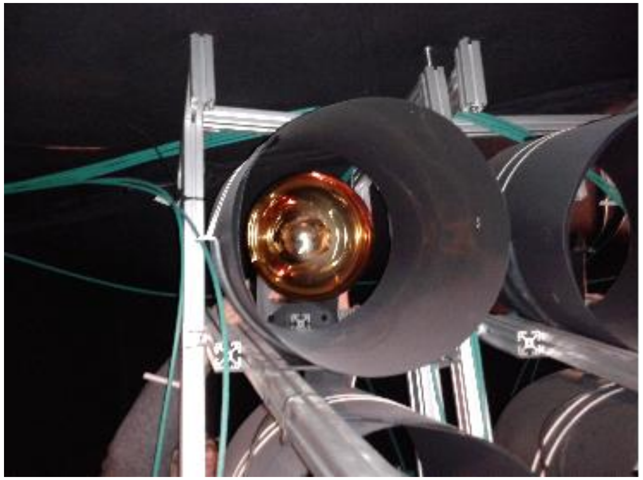


- Light yield ⇒ **6000 photons/Mev**
- Attenuation length **> 5m** in final mixture

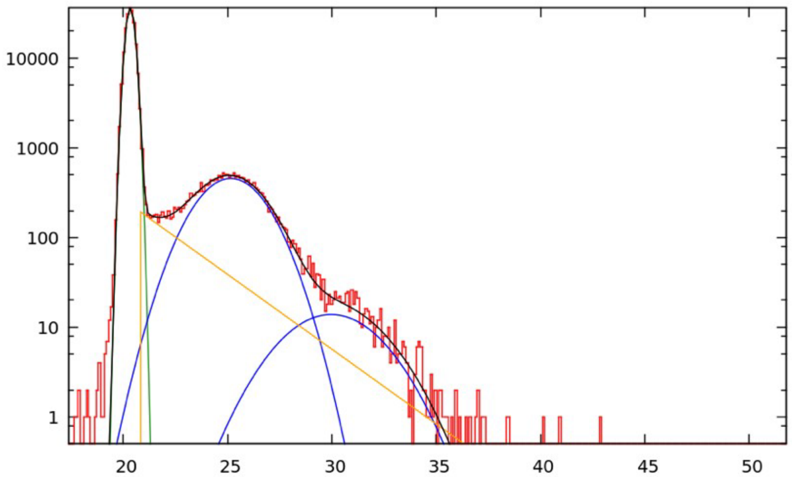
DEVELOPMENT COMPLETED

PMTs

- Detectors photomultipliers : New Hamamatsu RS5912-100
  - Better Gain ⇒ 10^7
  - Better QE ⇒ approx 30% at 420nm
- Tests handled by MPIK Heidelberg in their Faraday lab
- PMTs basis with decoupling system



PMTs during tests at MPIK

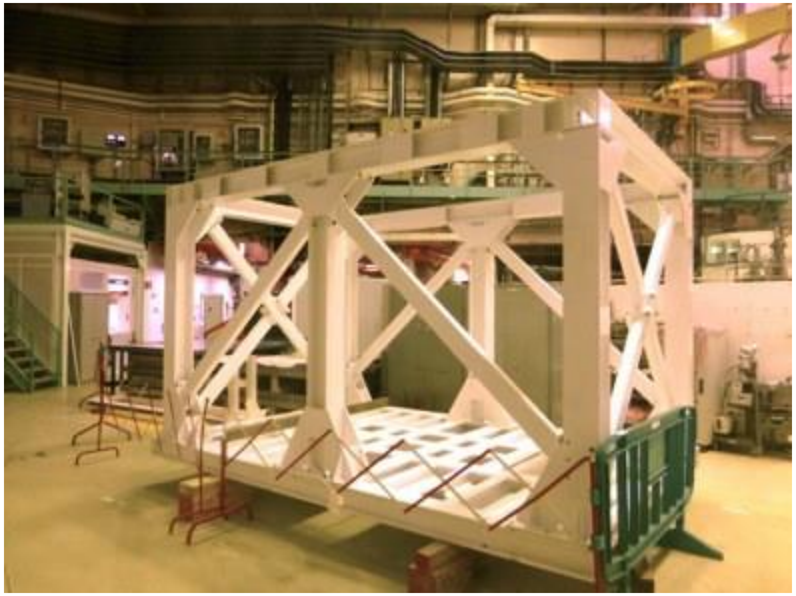


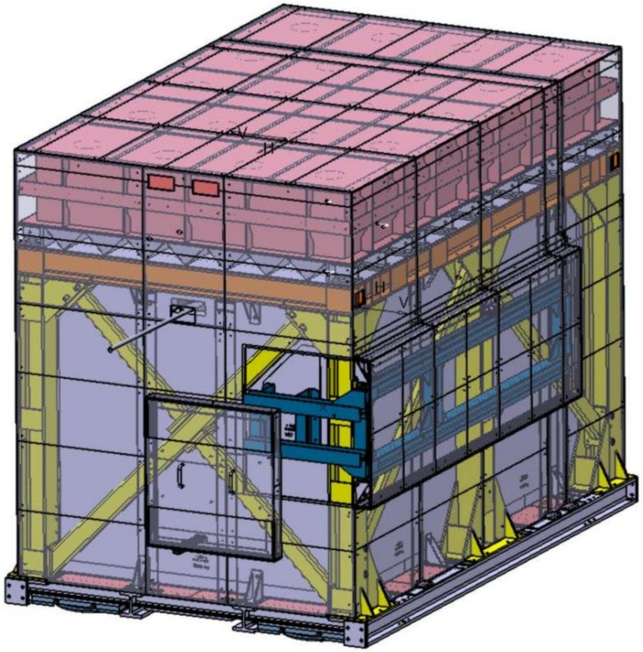
Photoelectron fits

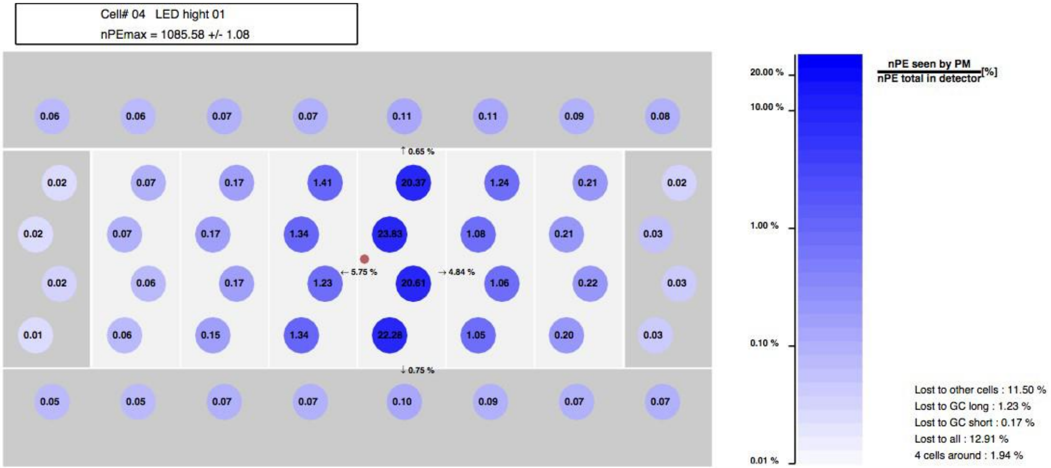
INSTALLATION COMPLETED

Installation status

- Tested detector and acquisition with LEDs in air
  - ⇒ Fine tuning of simulation
- Mounting of support structure ongoing
- Filling STEREO with LS : **september 2016**



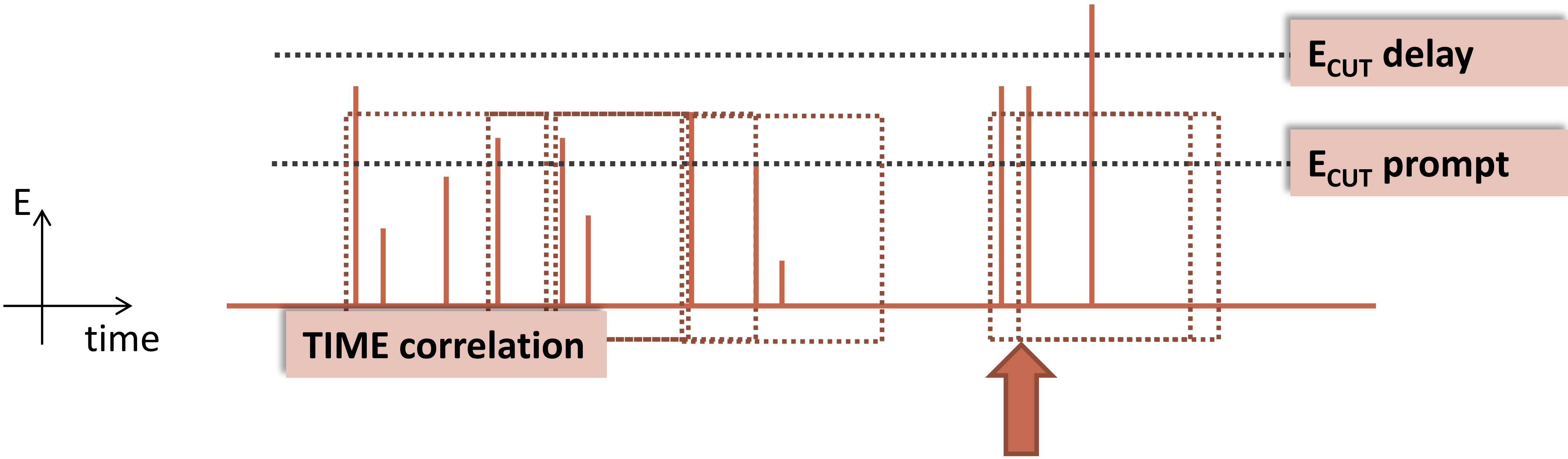




Neutrino analysis

Analysis strategy to identify antineutrino candidates

- Identify muon events : **muon veto** or **dE in detector > 10 MeV**
  - ⇒ Then remove following event in range **< [100-1000]µs**
- Identify prompt candidates with $\mathbf{E_{cut}}$ **= [2-8]MeV**
- Identify delay event with $\mathbf{E_{cut}}$ **= [5-10]MeV** and **time correlation < 50 µs**



Event topology

- Vtx calculation : Q barycenter
- Multivariate analysis