Status of the Stereo experiment : search of a sterile neutrino

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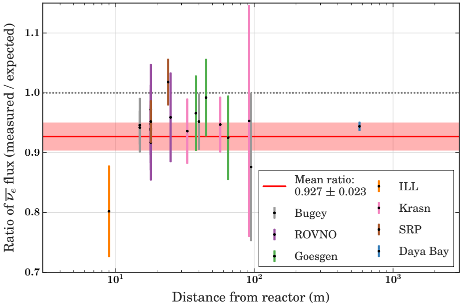
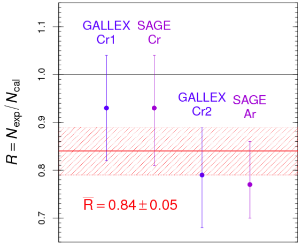
Short distance neutrino anomalies



Reactor anomaly : $\overline{\nu_e}$ deficit at 3 σ
$\overline{\nu_e}$ flux measured by several experiments at less than 100 m from reactor



"Gallium" anomaly : ν_e deficit at 2.7 σ measured by SAGE and GALEX with calibration sources deployed in the center of their solar neutrino detectors

Possible explanations :

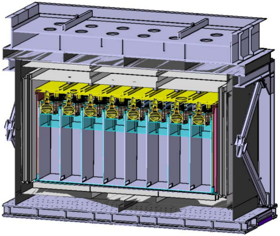
- Error in the predicted ν fluxes
- New ν flavor inducing short distance oscillation : a sterile neutrino

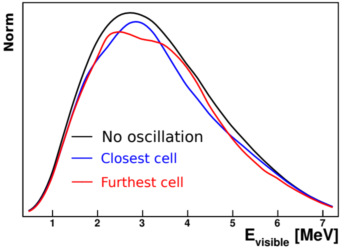
Stereo experiment

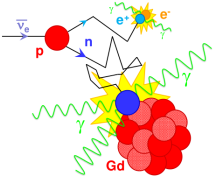
Objective : Probe sterile neutrino parameters space $(\Delta m^2_{st}, \sin^2(2\theta_{st}))$

- Measure the distortion of the $\overline{\nu_e}$ spectrum for different distances at about 10m from ILL core
- Measure a reference of (quasi) pure ^{235}U neutrino spectrum

Segmented detector







Detection with IBD reaction :

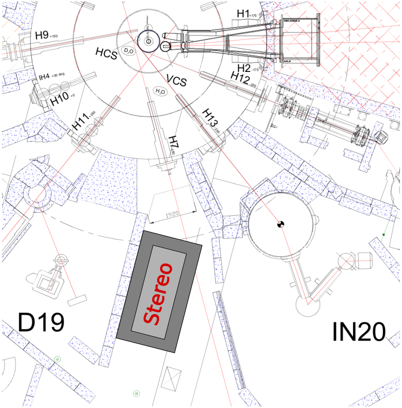
Prompt - positron $\Rightarrow E_{vis} = E_\nu - 0.782\,MeV$

Delayed - n-capture on gadolinium (Gd) few μs after prompt

Stereo site at ILL

Reactor :

- Nominal reactor power $\sim$ 57 MW
- Highly ^{235}U enriched at 93%
- Compact core (diameter = 37 cm) prevent oscillation signal being washed out



Detector position :

- Stereo covers $[8.9 - 11.1]$m from core with a possible extension to 12.3 m ($\sim$ 3 cells width)
- Overburden of water channel (15 m.w.e.) $\Rightarrow$ shielding against muons

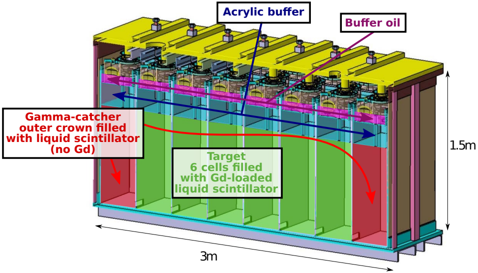
Drawbacks :

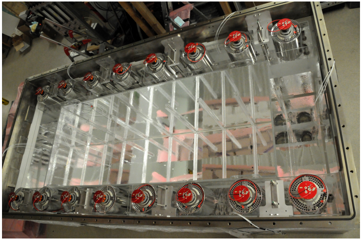
- High level of background (n, γ) from neighboring experiments

Stereo detector

Two sub-volumes :

Target (for IBD) segmented in 6 identical cells
Gamma-catcher to collect escaping gamma, improve efficiency and energy resolution





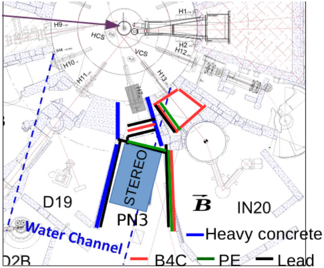
- 48 PMTs : 4 PMTs per Target cell and 4 or 8 PMTs per Gamma-catcher cell
- Cell separation by acrylic wall with multi-layer of VM2000 and air for total reflection $\Rightarrow$ improved light collection

Detector assembled in spring 2016 and tested without liquid !

Neutron and γ background measurement :

- Fast n from reactor and beam tubes
- Thermal n from neighboring experiments
  $\Rightarrow$ n-capture causing γ emission

External shielding :



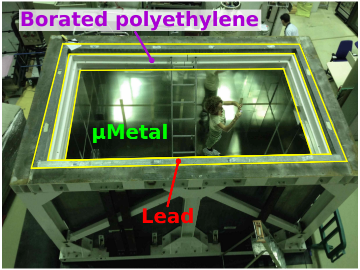
- Magnetic field from IN20 $\Rightarrow$ gain variation of PMTs over time
- μ rate and distribution measurement

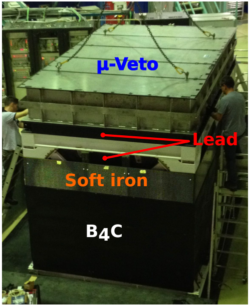
Simulation of the γ, n, μ and magnetic field backgrounds
$\Rightarrow$ design and validation of the detector shielding

Background and shielding

Detector shielding :

- 6 tons of borated polyethylene
- 65 tons of lead
- B_4C sheet all around the detector structure
- Magnetic shielding (soft iron + μMetal)

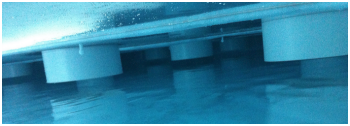




August 2016 : Assembly of the shielding and the detector complete
September 2026 : Detector moved to its data-taking position !

Muon veto

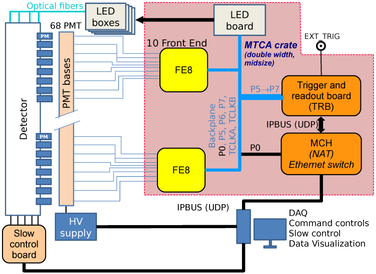
Muon veto : Water Cerenkov tank to detect muons with 20 PMTs and Tyvek sheets for reflectivity



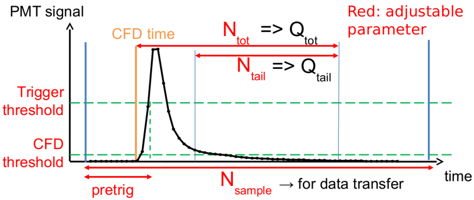
Studies :

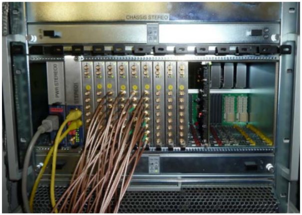
- Several prototypes tested before final instrument
- Geometrical effect vs μ efficiency
- Lower γ sensitivity with 4 PMTs charge trigger

Electronics

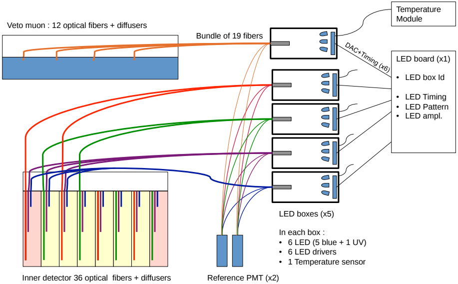


- Dedicated electronics hosted in a single μ-TCA crate
- Two programmable levels of trigger (FPGA) :
  - 1st level per front-end board $\Rightarrow$ trigger on single PMT, sum 4 or 8 PMTs
  - 2nd level on the trigger board $\Rightarrow$ trigger between the different sub-detectors (target, gamma-catcher, veto)
- 1kHz without deadtime
- Debug mode : save pulse on disk but with a large deadtime





Calibration system



LED System :

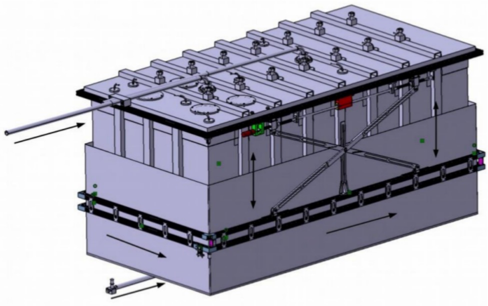
- Photo-electron calibration
- Charge linearity measurement
- Monitoring : gain, light collection
- UV LED for liquid properties

Calibration in energy with radioactive sources (γ, n), deployed by two external systems ... :

- Pantograph system : around the detector
- Rail system : under the detector

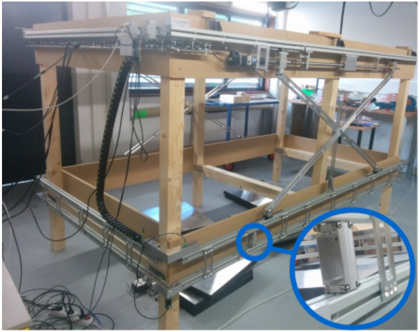
... and one internal system :

- 3 tubes in 3 different cells

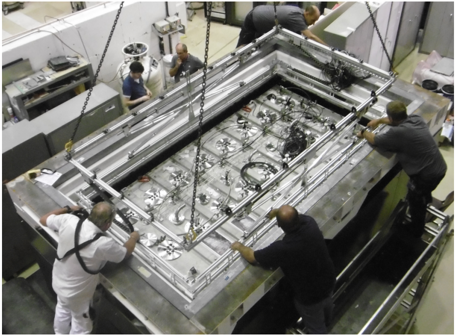


Installation of the pantograph system

Test of the pantograph at LAPP

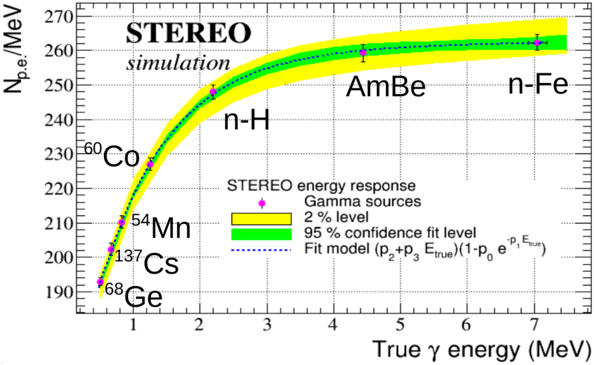


Insertion of the pantograpth at ILL



Since August :

- Installed around the detector vessel
- Tested and currently working with calibration source



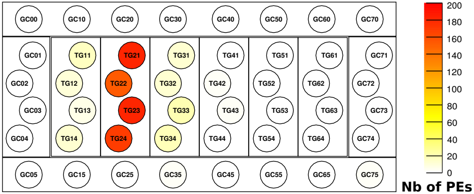
Different sources of calibration :

- Gamma sources : energy scaling, efficiency
- Neutron sources : Pulse Shape Discrimination (PSD) efficiency and n-efficiency

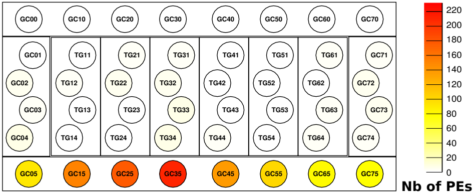
10th November 2016:

- ASN gave its authorization for the Stereo experiment
- Detector filled with liquid scintillator and buffer oil

Event of prompt neutrino candidate :

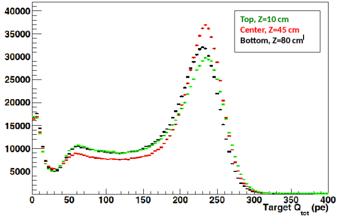


Event of background in Gamma-catcher :



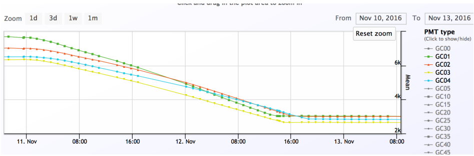
First source calibration done :

- ∼280 PEs/MeV in Target cells as expected
- Small top-bottom effect on the detector response : 2% of differences



Buffer leak in cell 4 and one short gamma-catcher cell :

- Decrease by a factor 2.5 of the light collection
- LS and buffer oil chemically compatible



Related systematics under studies

Data taking already started : after 10 days of commissioning

- Acquisition rate of ~ 3 kHz with $\sim 1.8\%$ deadtime at ∼250 keV threshold
- Single rate in neutrino window (2 MeV $< E_{vis} <$ 8 MeV) : ∼14 Hz

Conclusion

- Stereo detector fully installed and filled with liquid scintillator, since the 10th November 2016 !
- Stereo started **taking data** after 10 days of commissioning
- First data taking period until March 2017, with 80 days reactor ON
- **First result expected in 2017 !**

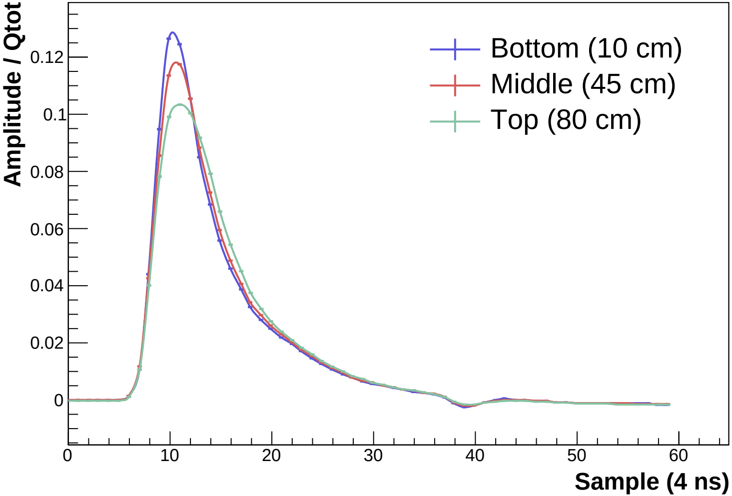
Thanks for your attention !

funded by :

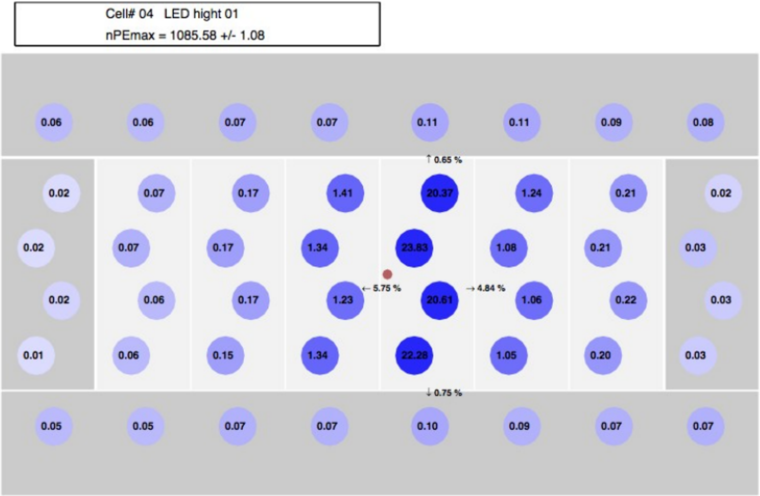
Backup

Gamma pulse shapes and z-dependence

Pulse shape of gamma using a Mn source at different high in a cell



Light leaks with empty detector

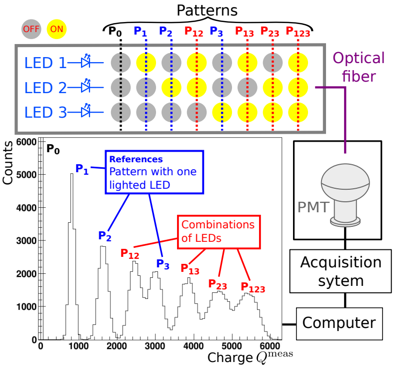


Measurements : with **empty** detector ⇒ ∼ 10% light leaks

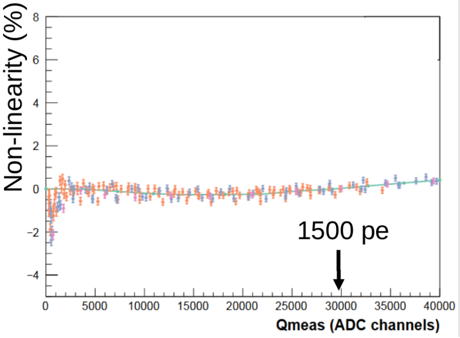
PMT charge linearity

Good PMT charge linearity needed for energy measurement !

- Use light injection system with 4 LEDs triggered simultaneously according to all possible combinations



- Use single LED charge to compute expected charge of LED combinations



< 1% of non-linearity !

Muon background

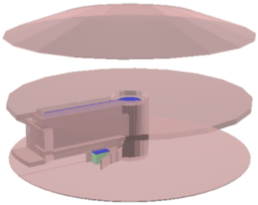
- Muons are the strongest souce of bacground
  - MIP : 2MeV/cm and cell height 90cm ⇒ 180 MeV dE

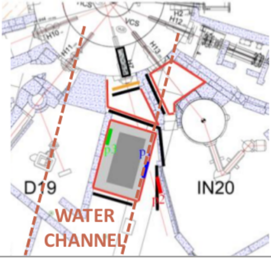
  ⇒ **Saturation of the PMT** will affect **E reconstruction**
- Create fast neutrons by **spallation**

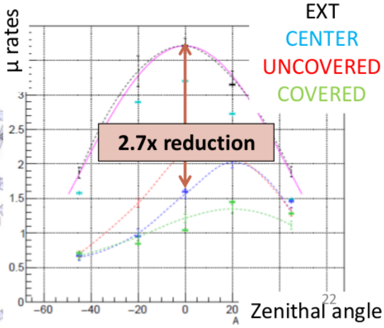
  ⇒ **Irreducible correlated background**

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

Simulation of the setup with CRY and estimation of muon rates





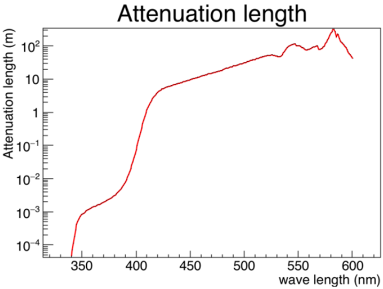


Liquid scintillator and PMTs

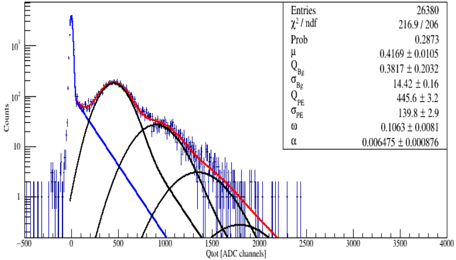
Liquid scintillator :
75% LAB + 20% PXE + 5% DIN

Light yield $\simeq$ 6000 photons / MeV

Attenuation length $>$ 5 m

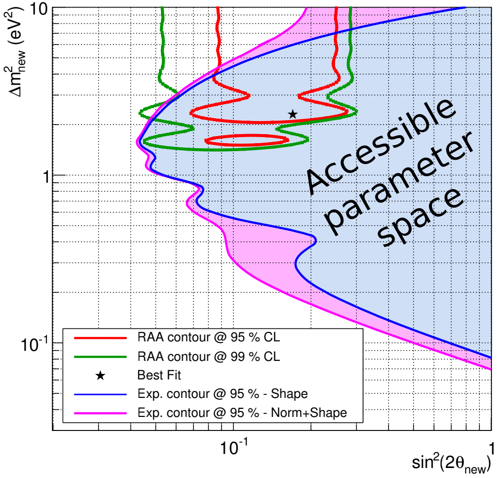


68 PMT HAMAMATSU
R5912-100 (8")
Quantum efficiency $\simeq$ 30%
Dark rate: 3000 Hz
Transit time spread: 3.5 ns



All PMTs have been tested and installed into the detector and the muon veto

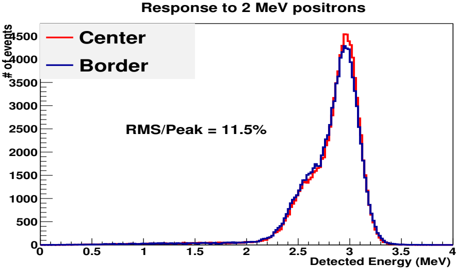
Expected sensitivity

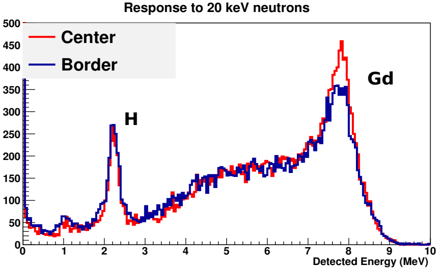


- 300 days of data acquisition
- 400 ν per day :
  - $E_{prompt} > 2$ MeV, Eff $= 79\%$
  - $E_{delayed} > 5$ MeV, Eff $= 60\%$
  - Deadtime $= 5\%$
  - $L_{Reactor} \sim 10$ m
- S / B = 1.5
- Systematic uncertainties :
  - Energy scale = 2% (by cell)
  - Spectrum shape = [0.7% - 4%]
  - Norm = 3.7% (correlated)
  - Norm = 2% (uncorrelated by cell)

Detector response

- Complete GEANT4 model to simulate the detector response





- Similar response between center and border cell :
  - RMS/Peak(center cell) = 11.5%
  - RMS/Peak(border cell) = 11.7%
- Neutron efficiency (Evis > 5 MeV) :
  - 64.5% ± 0.5% for center cell
  - 60.1% ± 0.5% for border cell

Optimization of the energy resolution and the similarity of response between cells