The STEREO detector

Search for a light sterile neutrino at ILL

Stephane Zsoldos
LPSC / IN2P3 CNRS

STEREO Collaboration

LPSC Grenoble
Laboratoire de Physique
Subatomique et de Cosmologie

lapp
Laboratoire d'Annecy-le-Vieux
de Physique des Particules

DE LA RECHERCHE À L'INDUSTRIE
cea

MAX-PLANCK-INSTITUT
FÜR KERNPHYSIK

ill
NEUTRONS FOR SCIENCE®
Institut Laue-Langevin

جامعة الحسن الثاني - الدار البيضاء
UNIVERSITE HASSAN II - CASABLANCA

Reactor Antineutrino Anomaly

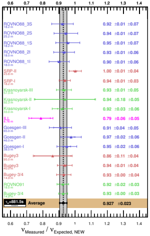
Surviving probability of a flavor state

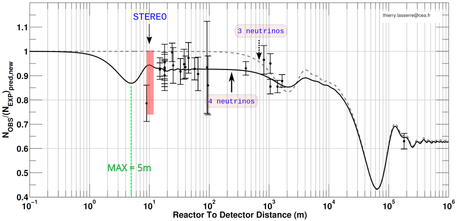
$$P_{\alpha\to\alpha} = 1 - \sin^2(2\theta_m)\sin\left(1.27\cdot\Delta m^2_{ij}\frac{L}{E}\right)$$

- Reevaluation of reactor $\bar{\nu}_e$ spectra (Mueller *et al*, **Phys Rev C83 054615**)
- Reanalysis of short baseline reactor experiments (Mention *et al*, **Phys Rev D83 073006)**

$P_{\bar{\nu}_e\to\bar{\nu}_e}$ = 0.924±0.023

$\Rightarrow$ **2.7**σ deviation from 1





New oscillation towards sterile state ? With $\Delta m^2_{\text{new}} \approx 1$ eV^2 $\sin^2 2\theta_{\text{new}} \approx 0.13$

Up-to-date on competition at Δm^2_{new}

- Adapted from T. Laserre 2014 **arXiv:1404.7352** and J. Lamblin 2015

Name	P_{th} (MW)	L (m)	Depth (m.w.e)	M_{target} (Tons)	Tech	Seg	Mov	Start
Nucifer	70	7	13	0.8	Gd	x	x	2014
NEOS far	2700	25	16-23	1	Gd	x	x	2015
NEOS near	15	5	23	1	Gd	x	x	2016
STEREO	57	9-11	18	1.75	Gd	✓	✓	2016
SoLiδ	70	5.5-10	10	2.9	^{6}Li	✓	x	2016
DANSS	3000	9.7-12.2	50	0.9	Gd	✓	✓	2016
Neutrino-4	100	6-12	10	1.5	Gd	x	✓	2016
Prospect	85	7-18	few	1-10	Gd+^{6}Li	✓	✓	2017
NuLat	85	3-8	few	1	^{6}Li+^{10}B	✓	✓	2017

Recent update

- NEOS : Installation on-site (far detector) during **summer 2015**
- SoLiδ : 1 ton detector will be installed on-site **summer 2016**

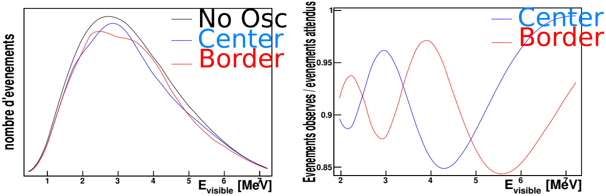
The STEREO Experiment

Goal

Observe a new oscillation measuring $\bar{\nu}_e$ energy vs distance

- Close to a compact reactor : ILL (Grenoble)
  - ⊘ core : 40 cm
  - Highly Enriched in ^{235}U $\Rightarrow$ small evolution of $\bar{\nu}_e$ flux
- Relative distorsion of $\bar{\nu}_e$ rates vs $E_{\bar{\nu}_e}$ among cells
  $\Rightarrow$ Measurements independant from reactor normalisation
- Absolute rate measurements with small dependance on core evolution

Energy spectrum between center and border cell



The STEREO Collaboration

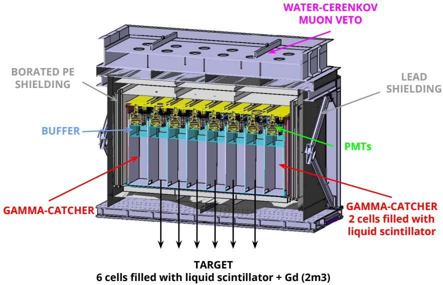
An International Collaboration

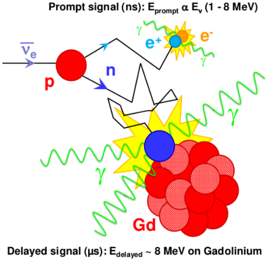
20 researchers, 5 PhD students

- LPSC Grenoble — Laboratoire de Physique Subatomique et de Cosmologie: Muon veto, electronics, simulation, daq and monitoring, light injection system
- CEA — De la recherche à l'industrie: Inner detector design, cell prototype, simulation
- LAPP — Laboratoire d'Annecy-le-Vieux de Physique des Particules: Calibration system, simulation, shieldings
- ILL — Neutrons for Science, Institut Laue-Langevin: Security, shieldings, background measurements
- Max-Planck-Institut für Kernphysik: Liquid scintillator, PMTs, PMTs mechanics

The STEREO detector

- Detection with **inverse β-decay** in liquid scintillator + Gd : $\bar{\nu}_e + p \rightarrow e^+ + n$
  $\Rightarrow$ Coincidence signal from e^+ and delayed n capture (8 MeV γ-cascade)
  $\Rightarrow$ Measuring $E_{e^+} \rightarrow E_{\bar{\nu}_e}$
- Segmented detector of 6 identical cells and surrounded by an external gamma-catcher located between 9-11m from ILL nuclear reactor (Grenoble)





- Cell size : 90 $\times$ 90 $\times$ 40 cm^3
- Detection volume : $\approx$ 2 m^3

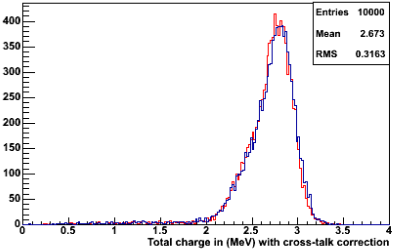
Simulation of detector response

Goal

Minimise asymmetries among cells

- Résolution $\approx$ 12% (RMS for 2 MeV positrons)
- Neutron efficiency $\approx$ 60% with a delayed signal above 5 MeV
  - Only 4% difference on neutrons response between center and border cells

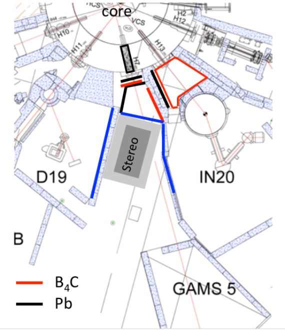
Simulation T=2 MeV positrons in center and border cells



Background at ILL Site

Specifications

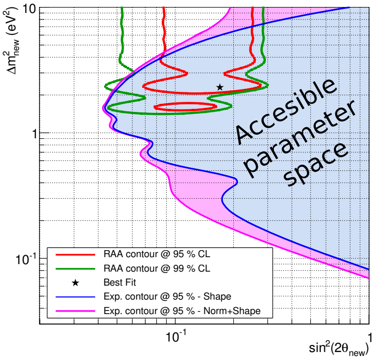
- 57 MW reactor
- Compact core
- 10.2 m from reactor to STEREO
- Water Channel $\rightarrow$ shield against cosmic muons
- Possibility to move the detector by 1.1m ($\approx$ 3 cells width) $\Rightarrow$ systematics studies



Drawbacks

- Background from nearby experiments :
  - γ and neutrons (D19, IN20) $\rightarrow$ measured on-site ✓
  - $\vec{B}$-Field (IN20) $\rightarrow$ measured on-site ✓
- Need of large heavy shieldings $\rightarrow$ Lead, B_4C and Polyethylene

Sensitivity and discovery potential

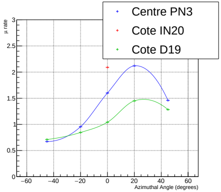


- 400 $\bar{\nu}$ per day during 300 days
- Signal/Background $\simeq$ 1.5
- Realistic detection and reconstruction effects (simulation)
- Systematics effect
  $\Rightarrow$ Uncertainties on $\bar{\nu}$ flux
  $\Rightarrow$ Uncertainties on neutron lifetime
- Cut off
  $\Rightarrow$ E_{e^+} > 2 MeV
  $\Rightarrow$ E_{neutron} > 5 MeV $\rightarrow$ Eff 60%
- $\delta E_{\text{scale}} \simeq$ 2% (calibration)

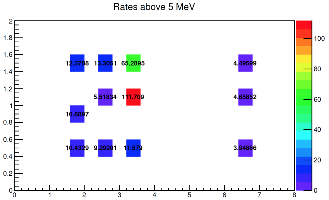
On-site background measurements : γ, n, μ and $\vec{B}$-field

- γ, n : Extensive mapping of STEREO area using Ge, NaI and He3 detectors
- μ : Measurements with a *cosmic wheel* : rates VS zenith angle
- $\vec{B}$-field : Mapping with a 3-axis fluxgate

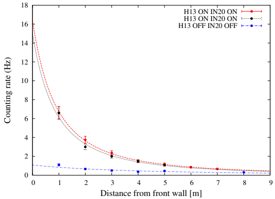
μ rates vs zenith angle



γ spectrum



n rates vs distance



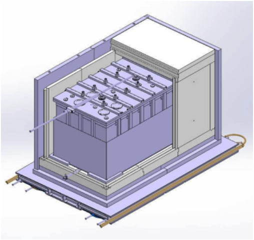
Conclusion

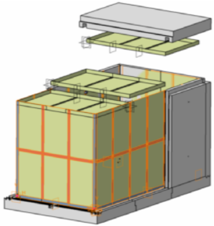
- Main sources **identified**
- Design and **validation** of extra protection

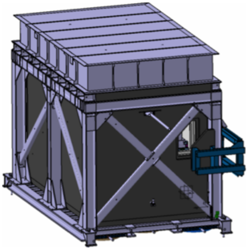
Description of internal shieldings

- Informal validation by ASN

Internal shieldings | Magnetic shieldings | Overview







- Lead $\approx$ 65 T $\Rightarrow$ against γ
- Polethylene $\approx$ 6 T $\Rightarrow$ against fast neutrons
- B_4C $\approx$ 1T $\Rightarrow$ against thermal neutrons
- Soft Iron + μMetal $\Rightarrow$ shield $\vec{B}$-field

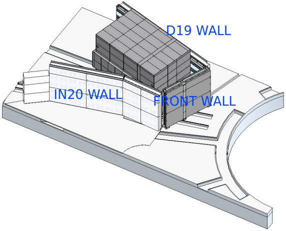
Calendar

- Delivery : **April 2016**

Description of external shieldings

- D19 Wall : 10 cm of lead
- Front Wall : 10 cm of lead + 10 cm of polyethylene **delivered** ✓
- IN20 Wall : 15 cm of lead + 10 cm of borated polyethylene

Location at ILL



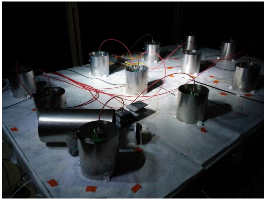
Front wall installation Sep 2015

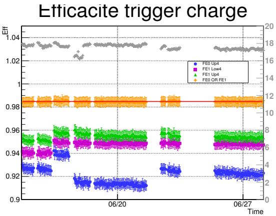
Calendar

- D19 + IN20 Walls : delivery **Jan 2016**

Results from muon veto prototype

- Water-Cerenkov detector
  - $4 \times 2.6 \times 0.25$ m^3 water + wavelength shifter (4MU)
  - 20 PMTs on the top
  - Tyvek diffuser





Results from prototype

- Excellent overall efficiency **98.5%** and stable through time
- PMTs mapping to reduce sensitivity to γ

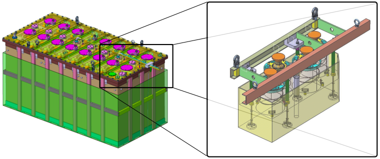
  $\Rightarrow$ Delivery final detector **Nov 2015**

Design of inner detector

- Double steel tank ⇒ Protection from liquid scintillator
- Acrylic buffer between PMTs and Cell ⇒ Diffuse light for better resolution
- Design **validated** and order **placed** : under construction

Detector Vessel

Zoom on a buffer



Calendar

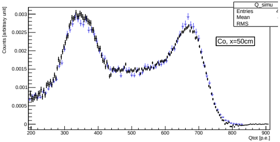
- Buffer : delivery **Nov 2015**
- Tank : delivery **Feb 2016**
- Integration at LPSC, transportation at ILL **April 2016**

Results from cell prototype

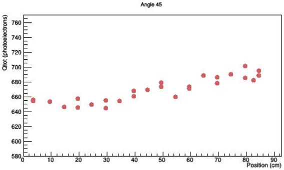
- Specific separators between cells and GC to enhance reflectivity
  $\Rightarrow$ *Sandwich* of 2mm acrylic + 100μm air gap + VM2000 foil $\rightarrow$ **97%** reflectivity
- Minimize Z-dependancy

Cell Prototype

Response to ^{60}Co



Light Z-dependancy

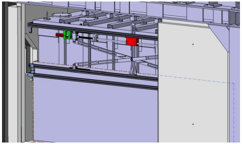


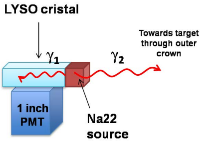
First Results

- Validation of the light and energy response
- Confirmation of the expected bottom-up effect of $\pm$5%

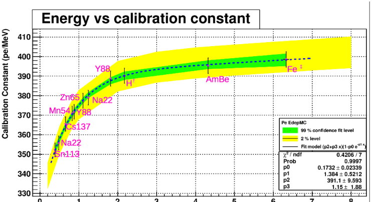
Calibration system

- Automated circulation of sources around and underneath the detector + internal calibration tubes
  - γ sources : energy scale
  - AmBe sources : neutron efficiency and PSD
  - Z dependance = tagged ^{22}Na with LYSO cristal





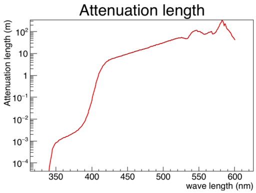
- Prototype under test

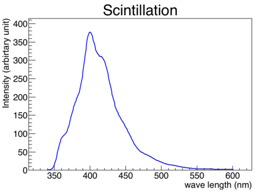


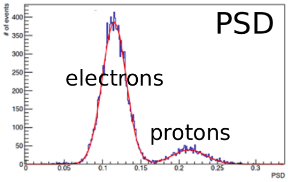
Systematic on $< E_{\gamma}^{Fe} >$ to be evaluated

Scintillation Liquid

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





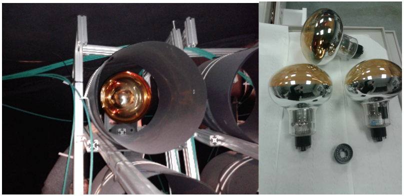


- All components already **delivered** ✓

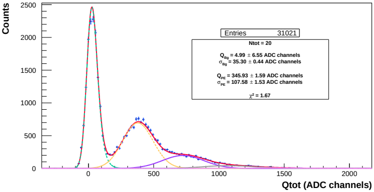
PMTs

- Detector photomultipliers : New Hamamatsu R5912-100
  $\Rightarrow$ Better Gain 10^7
  $\Rightarrow$ Better QE $\approx$ 30% at 420 nm
- Tests are handled by MPIK Heidelberg in their Faraday lab
- New PMTs basis with decoupling system **delivered**

Benchmark Tests



Photoelectron response

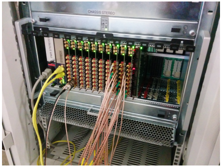


- All components already **delivered** and **tested** ✓

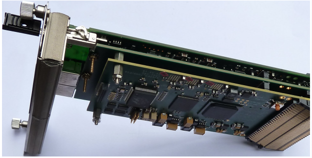
Electronics

- Dedicated electronics hosted in μTCA crate
- Front-end boards are already tested and **validated**
  - 8-channel FADC 14 bits 250 MHz sampling
  - Q_{tot}, Q_{tail}, t_{CFD} and pulse
  - Gain x1 and x20 for single PE
  - First level programmable trigger (FPGA) $\Rightarrow$ **validated** with muon veto
- Trigger board $\Rightarrow$ Second level programmable trigger (FPGA) taking into account the 3 detectors : cells, GC, veto
- LED driver for light calibration

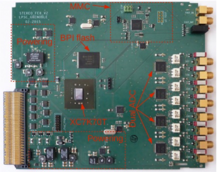
μTCA crate



Trigger board



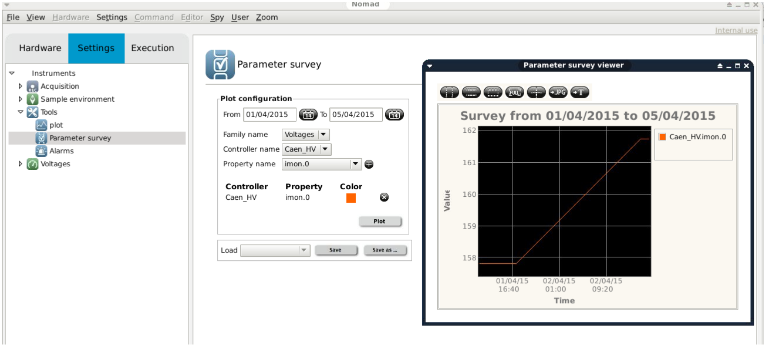
Front-end



- All cards already **delivered** and **tested** ✓

Data Acquisition

- Configuration and data collection **done** using standard ILL software NOMAD
- Development of low level driver **done** at LPSC fully operationnal
- Slow-control, monitoring under development



Conclusion

- Sensitivity contours cover the Reactor Anomaly
- First Shieldings already installed
- Final design validated by prototypes and seismic studies
- All parts of detector under fabrication or already delivered
- Integration at LPSC Feb 2016

First data in **June 2016**