The NUCIFER and STEREO experiments

Search for light sterile neutrino state at short baseline

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on behalf of the Nucifer and Stereo collaborations

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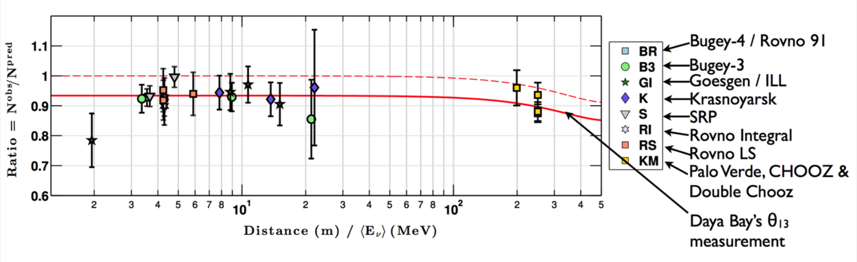
Reactor antineutrino anomaly

- Reevaluation of reactor $\bar{\nu}_e$ spectra, Th. A. Mueller et al., Phys. Rev.C 83, 054615.
- Reanalysis of short baseline experiments, G. Mention et al., Phys. Rev. D 83, 073006

$\Rightarrow$ **neutrino deficit of 6.5%**



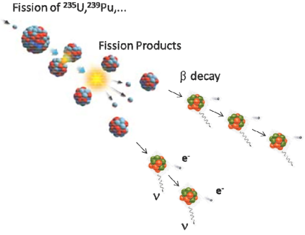
- Error on the flux prediction ?
- New oscillations toward a sterile neutrino ? ($\Delta m^2 \gtrsim 0.5$ eV^2, $\sin^2(2\theta) \sim 0.1$)

Reactor antineutrinos and detection

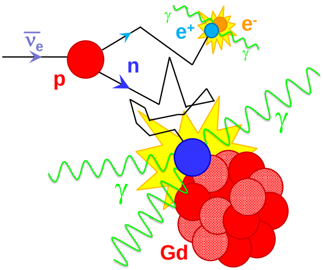
- Beta decay of the fission products :

$$n \rightarrow p + e^- + \bar{\nu}_e$$

- Intense and pure production of electronic antineutrinos
  $\rightarrow \sim$ 1,9 x 10^{20} $\overline{\nu_e}/s/GW_{th}$



Prompt signal (ns): E_{prompt} α E_ν (1 - 8 MeV)



Delayed signal (μs): $E_{delayed}$ ~ 8 MeV on Gadolinium

- Detection with the inverse beta decay reaction in a liquid scintillator :

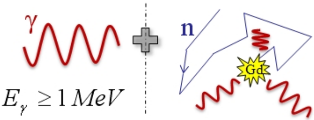
$$\bar{\nu}_e + p \rightarrow e^+ + n$$

- Selection of the events with time and energy
- Very small cross-section :
  $\sim 10^{-43}$ cm^2 at 1 MeV

Background

ACCIDENTALS

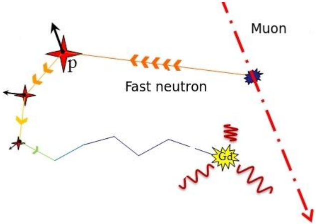
- Random coincidence between two independent events :
  - Gamma + neutronic capture
  - Gamma + high energy gamma



- Lead and polythene shieldings
- Reactor ON measurement and subtraction

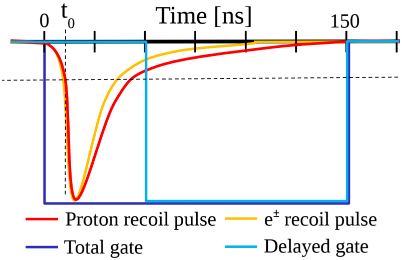
CORRELATED

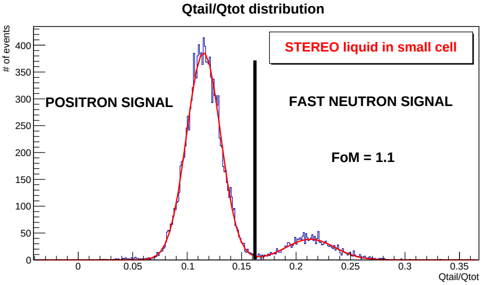
- Coincidence because of a same event
  - Cosmic muon → fast neutron



- Decreased by overburden and an active muon veto
- Reactor OFF measurement and subtraction
- Online pulse shape discrimination (PSD)

Pulse shape discrimination





- Neutrino prompt signal : positron ionisation and annihilation

  $\Rightarrow$ small Q_{tail}/Q_{tot}

- Fast neutron prompt : proton recoil

  $\Rightarrow$ high Q_{tail}/Q_{tot}

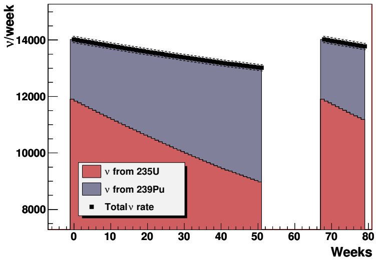
$$\Rightarrow FoM = \frac{\mu_2 - \mu_1}{2.35 * (\sigma_1 + \sigma_2)}$$

- Correlated background subtraction with the PSD (before the offline subtraction)

The Nucifer experiment

at the Osiris reactor (Saclay)

Motivations and detector caracteristics



- Design for reactor monitoring :

$$N_{\bar{\nu}_e} = \alpha * P_{\text{th}} * (1 + k(t))$$

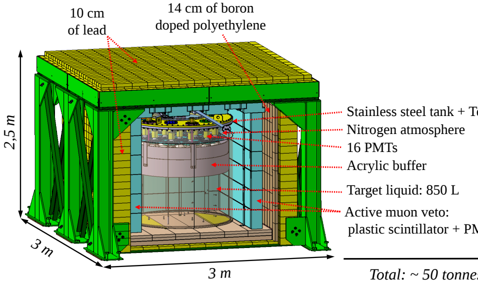
with $k(t)$ function of the fuel composition.

- Direct real time informations on reactor operation.

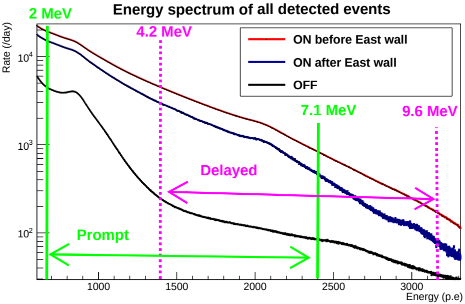
$\Rightarrow$ IAEA interest for non-proliferation.

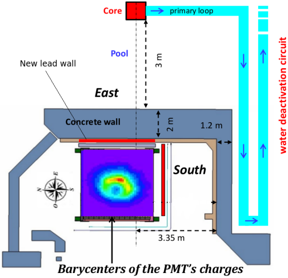
Main caracteristics of NUCIFER :

- 850 L of Gd-loaded (0.2%) liquid scintillator (MPIK scintillator),
- 16 PMTs fixed on an acrylic buffer,
- central calibration tube,
- $\sim$7 m from a 70 MW_{th} "pool type" research reactor.



Energy spectrum for all detected events





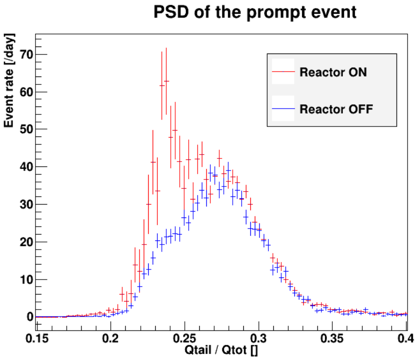
- Installation on site since April 2012 - Four runs of $\sim$3 weeks in 2013.
- Liquid scintillator change in November 2012.
- Shielding upgrades to mitigate the reactor induced background.
- Since July 2014 $\frac{S}{B_{acc}} \sim \frac{1}{10}$, $\frac{S}{B_{corr}} \sim \frac{1}{1}$.

Results (april-may 2013)

- Results (april-may 2013) :

	Accidental rate	Correlated rate
Reactor OFF	(66 ± 1) /day	(360 ± 8) /day
Reactor ON	(8511 ± 3) /day	(665 ± 28) /day

$\rightarrow$ **305 $\pm$ 29 ν/day**



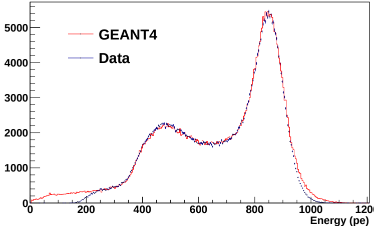
Correlated events excess = fast neutrons coming from the core ?

- High Qtail/Qtot : fast neutrons.
- Low Qtail/Qtot : γ, neutrino.
- No more fast neutrons when the reactor is ON than when it is OFF

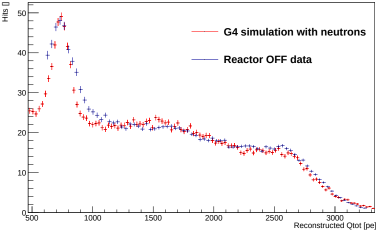
  $\Rightarrow$ excess at low Qtail/Qtot is due to neutrinos.

Nucifer simulation with GEANT4

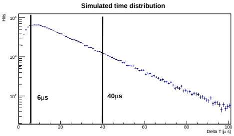
Cobalt source in the detector centre

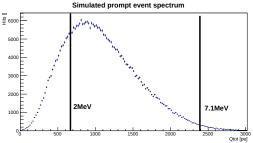


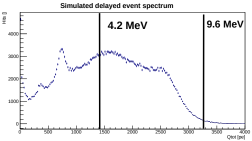
Neutron captures in target and shieldings



- Detector efficiency with optimized analyse cuts :

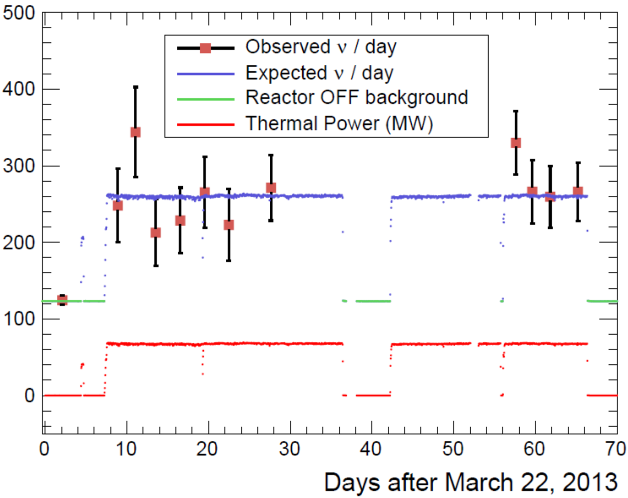






$\Rightarrow$ Efficiency determination : $\epsilon(\text{detection}) = 0.31 \pm 0.02$

Results (PRELIMINARY)



- Still work to get a more accurate prediction of the neutrino rate
- Need a good precision measurement for the distance from the core

The Stereo experiment

at the ILL reactor (Grenoble)

DE LA RECHERCHE À L'INDUSTRIE
cea

LPSC Grenoble

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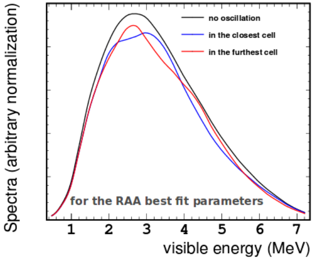
Motivation and specifications of the Stereo experiment

MOTIVATION :

- Observe an **unambiguous** new oscillation pattern **in energy and distance**.

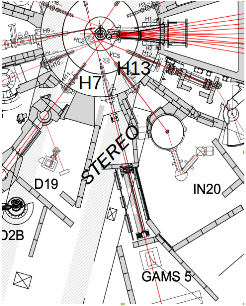
Oscillation phase shift between 2m apart cells



SPECIFICATIONS :

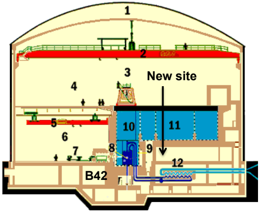
- Close to a compact and high flux nuclear reactor core : 10 m from the **ILL reactor**.
- Relative distortions among identical detector cells : **independent from reactor normalization** and history (pure ^{235}U spectrum).
- Accurate detector response : **mature technology of Gd-Loaded liquid scintillators**.

ILL site



ADVANTAGES :

- 58 MW research reactor.
- High ^{235}U enrichment and compact core.
- Overburden with the transfer water channel.
- Strong structure of floor (500 t /slab).

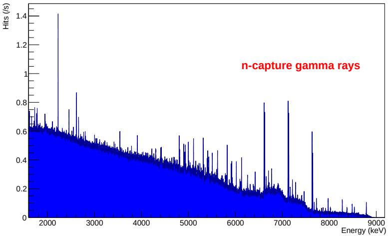


DRAWBACK :

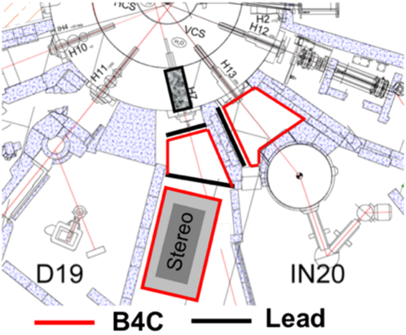
- High neutron and gamma flux because of experimental beam lines.

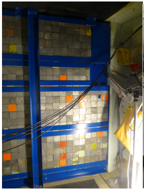
  $\rightarrow$ **Requires heavy shielding**.

Shieldings against muons, gammas and neutrons



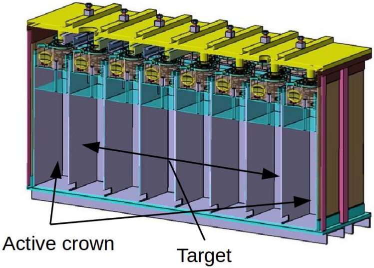
- Front wall shielding and H13 reinforcement :
  - Dedicated beam plug.
  - Additional lead wall.
  - Additional neutron shielding : B_4C.
- Shielding surrounding the target :
  - 10 cm thick lead.
  - 15 cm thick polyethylene.
  - 30 cm thick surrounding crown.
- "On-site" protection :
  - Water channel.

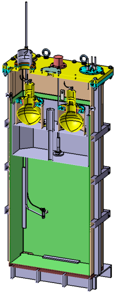




Detector design

- Six cells (40x90x90) cm^3 filled with Gd-loaded liquid scintillator.
- Surrounding crown filled with unloaded liquid scintillator.
  - Containment of energy leakage
  - Active veto of external background
- Light collection :
  - Four PMTs per cell and acrylic buffer.
  - Acrylic walls and optical segmentations with VM200.
- Validation with prototype in September 2014.





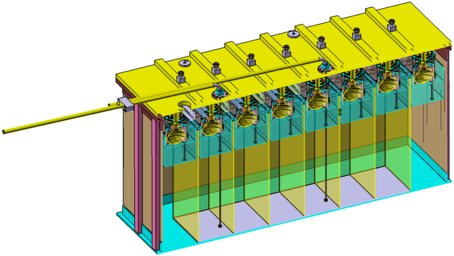
Calibration system

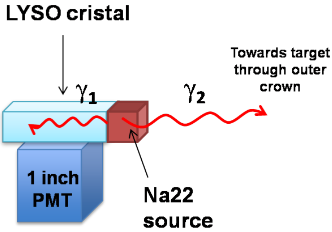
OBJECTIVES :

- Energy scale and neutron efficiency.
- Fine-tuned simulation.

TOOLS :

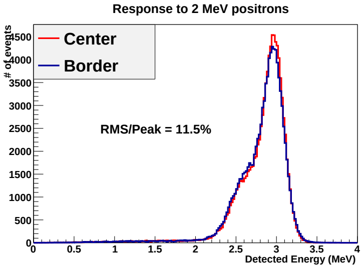
- Gamma and neutron sources :
  - Inside cells along vertical axis.
  - Underneath the detector vessel.
  - Around the detector vessel.
- Tagged source :
  - Circulated around the detector vessel at different Z.
  - Absolute calibration at 511 keV.

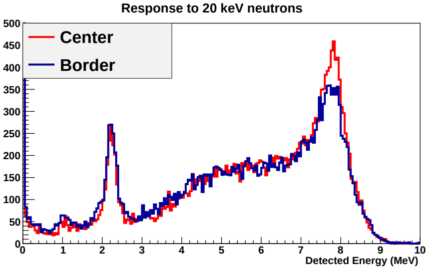




Positron and neutron response

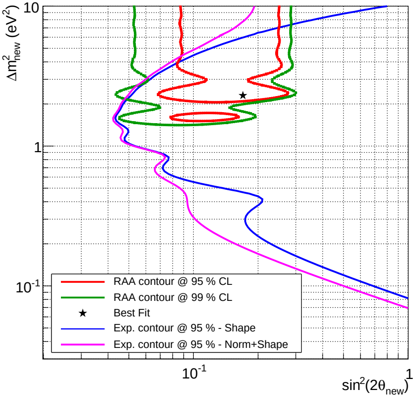
- Complete GEANT4 model to simulate the detector response.





- Similar response between center and border cell :
  - RMS/Peak(center cell) = 11.5%
  - RMS/Peak(border cell) = 11.7%.
- Neutron efficiency above 5 MeV :
  - 64.5% $\pm$ 0.5% for center cell
  - 60.1% $\pm$ 0.5% for border cell.

Stereo contours



- 300 days data taking (6 reactor cycles)
- Energy reconstruction systematics : $\delta E_{scale} = 2\%$
- Systematics of the emitted neutrino spectra included
- Normalisation : 4%
- Signal / background = 1.5
- Prompt signal energy > 2 MeV
- Delayed signal energy > 5 MeV
- Expected detection rate = 410 $\overline{\nu}_e$ / day

Conclusions

NUCIFER

- Now in its final configuration after two major shielding upgrades
- About 300 neutrinos per day are detected ($\sim$30% of efficiency)
- The accuracy is limited by the accidental rate of high energy γ-rays

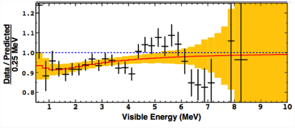
STEREO

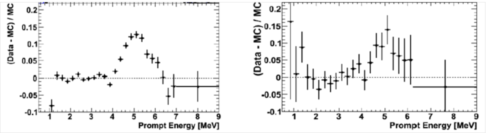
- The sensitivity covers the contour of the reactor anomaly
- Several prototypes are under test to validate the detector response
- Challenging mitigation of reactor induced background
- Beginning of data taking in Spring 2015

Back-up

Bump at 5 MeV

- Neutrino excess at 5 MeV in several experiments : DC, RENO, Chooz, Rovno ...





- Scale with reactor power so
  - bias in the conversion procedure ?
  - bias in the reference electron spectrum ?
  - another neutrino interaction ?

- Which impact on Stereo sensibility ?
- Bump amplitude = 10% of neutrino signal.
- Incertainty = 50% of bump amplitude. → No significative impact on the contour.