The NUCIFER and STEREO experiments

Search for light sterile neutrino state at short baseline

Maxime Péquignot
on behalf of the Nucifer and Stereo collaborations

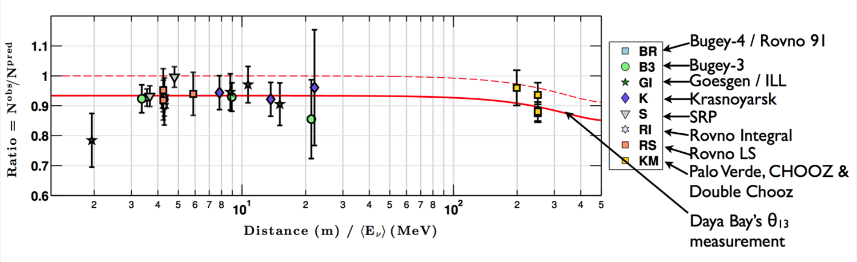
CEA Saclay - IRFU/SPhN

December 15, 2014

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, $\sin^2(2\theta) \sim 0.1$)

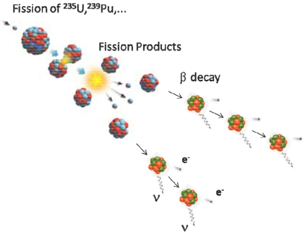
Reactor antineutrinos and detection

- Beta decay of the fission products :

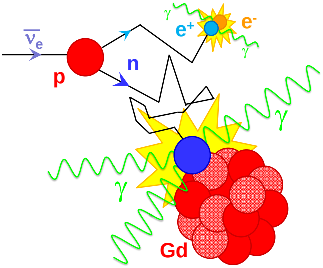
$$n \rightarrow p + e^{-} + \bar{\nu}_e$$

- Intense and pure production of electronic antineutrinos

$\rightarrow \sim 1{,}9 \times 10^{20}\ \overline{\nu_e}/s/GW_{th}$



Prompt signal (ns): $E_{prompt} \propto E_\nu$ (1 - 8 MeV)

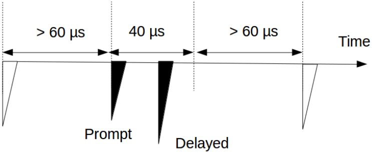


Delayed signal (µs): $E_{delayed} \sim 8$ MeV on Gadolinium

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

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

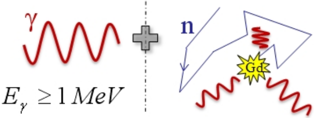
- Selection of the events with time and energy



Background

ACCIDENTALS

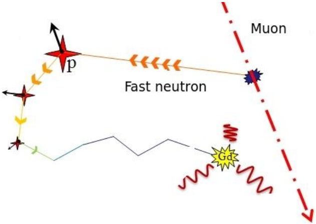
- Random coincidence between two independent events :
  - Gamma + neutronic capture
  - Gamma + high energy gamma



- Lead and polythene shieldings
- Reactor ON measurement and subtraction

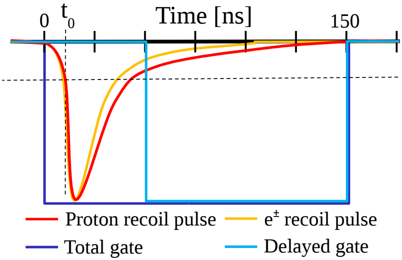
CORRELATED

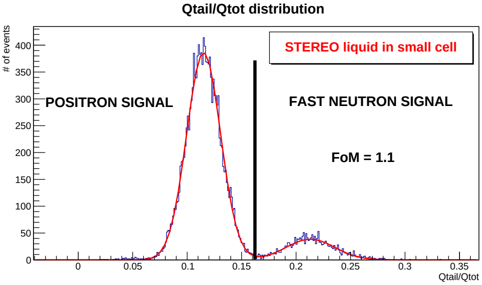
- Coincidence because of a same event
  - Cosmic muon → fast neutron



- 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}

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

- Fast neutron prompt : proton recoil

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

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

The Nucifer experiment

at the Osiris reactor (Saclay)

Nucifer

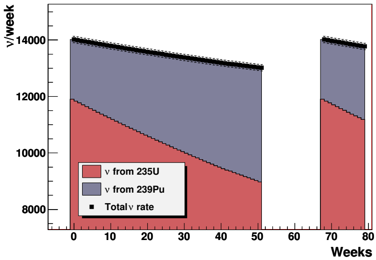
DE LA RECHERCHE À L'INDUSTRIE cea

Subatech

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Irfu CEA - Saclay

Motivations and detector caracteristics



- Design for reactor monitoring :

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

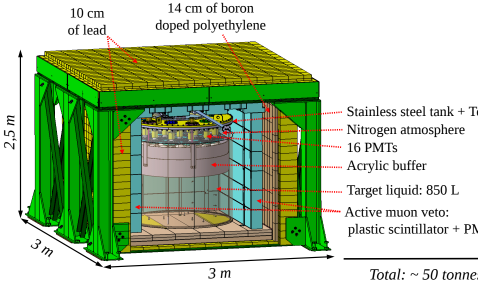
with $k(t)$ function of the fuel composition.

- Direct real time informations on reactor operation.

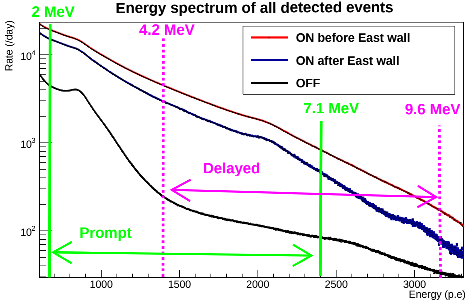
$\Rightarrow$ IAEA interest for non-proliferation.

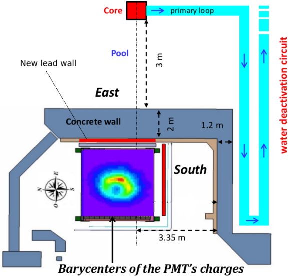
Main caracteristics of NUCIFER :

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



Energy spectrum for all detected events





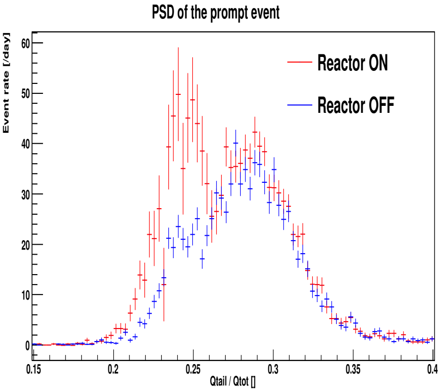
- Installation on site since April 2012.
- Liquid scintillator change in November 2012.
- Shielding upgrades to mitigate the reactor induced background.
- Since July 2014 $\frac{S}{B_{acc}} \sim \frac{1}{12}$, $\frac{S}{B_{corr}} \sim \frac{1}{3}$ (without PSD cut).

Results (November 2014)

- Results (November 2014) :

	Accidental rate	Correlated rate
Reactor OFF	(75 ± 1) /day	(1063 ± 10) /day
Reactor ON	(3793 ± 1) /day	(1384 ± 15) /day

$\rightarrow$ **321 $\pm$ 18 ν/day**



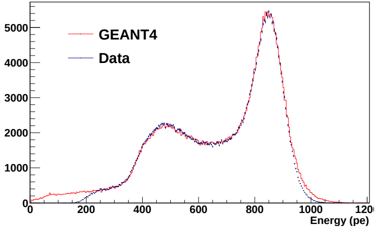
Correlated events excess = fast neutrons coming from the core ?

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

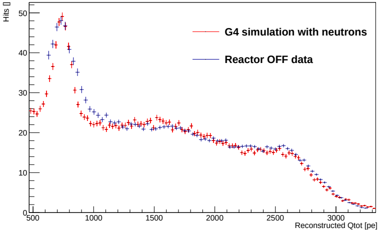
  $\Rightarrow$ excess at low Qtail/Qtot is due to neutrinos.

Nucifer simulation with GEANT4

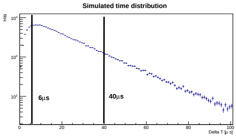
Cobalt source at the center of the detector

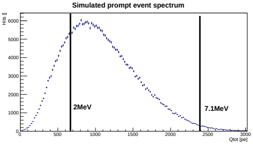


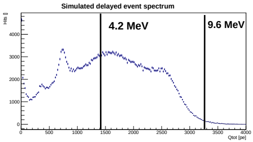
Neutron captures in target and shieldings



- Detector efficiency with optimized analyse cuts :







$\Rightarrow$ Detection efficiency : $\epsilon(\text{detection}) = \mathbf{0.31} \pm \mathbf{0.02}$

Prediction of the neutrino rate

- Interaction rate in the detector :

$$N_{int} = \frac{1}{4.\pi.L^2} \int \sigma(E) * S(E) dE * N_p * \frac{P_{th}}{< E_{^{235}U} >}$$

$\rightarrow N_{int} =$ 989.4 interactions per day

- Detection rate : $N_{det} = N_{int} * \epsilon(\text{detection}) = 307$ detected neutrinos per day

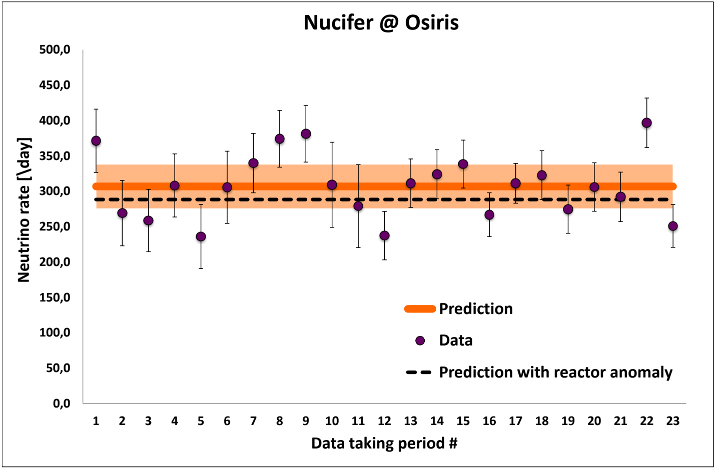
  Dominant uncertainties :

  - $\delta E_{scale} = 6.7\%$ based on largest local distortions.
  - $\delta\ \epsilon_{multiplicity} = 6.5\%$: cut efficiency $= 0.92 \pm 0.02$ but uncertainty amplified by ON-OFF subtraction.
  - $\delta L = 4\%$: analysis of reactor site survey in progress.

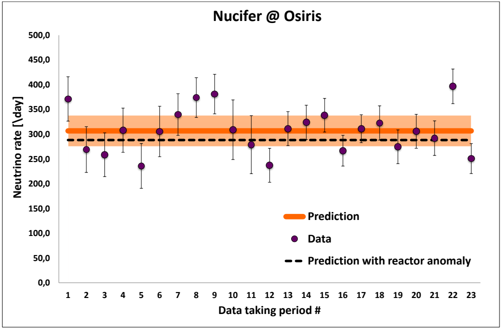
$\Rightarrow N_{det} = \mathbf{307} \pm \mathbf{32}$ detected neutrinos per day.

Results (PRELIMINARY)

- 105.4 days of data taking from May 2013 to December 2014.
- Each point represents ∼4.5 days of data taking.



Results (PRELIMINARY)



- Mean value = **306 ± 9 ν/day**.
- Predicted value = 307 ± 32 ν/day.

- Data taking will continue till the end of 2015.
- Clear neutrino signal but high background level of the Osiris site requires an accurate determination of all selection cuts. Ongoing effort on the reduction of the systematics.

  On-going work :
- Application of PSD cut to decrease the correlated background.

The Stereo experiment

at the ILL reactor (Grenoble)

DE LA RECHERCHE À L'INDUSTRIE
cea

LPSC Grenoble

lapp

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

ill
NEUTRONS FOR SCIENCE

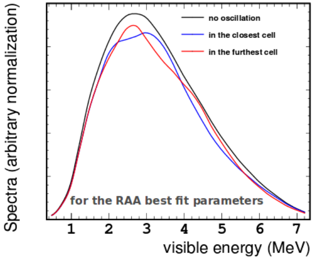
جامعة الحسن الثاني - الدار البيضاء
UNIVERSITE HASSAN II - CASABLANCA

Motivation and specifications of the Stereo experiment

MOTIVATION :

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

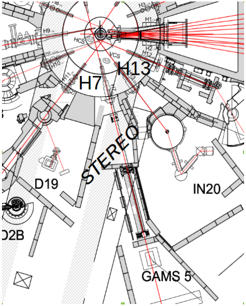
Oscillation phase shift between 2m apart cells



SPECIFICATIONS :

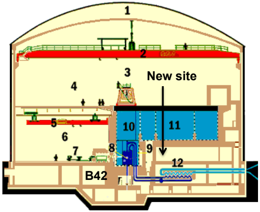
- Close to a compact and high flux nuclear reactor core : 10 m from the **ILL reactor**.
- Relative distortions among identical detector cells : **independent from reactor normalization** and history (pure ^{235}U spectrum).
- Accurate detector response : **mature technology of Gd-Loaded liquid scintillators**.

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).

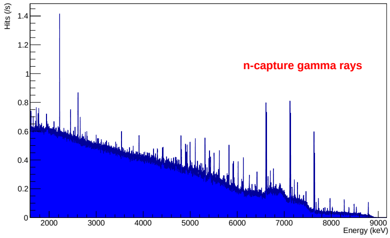


DRAWBACK :

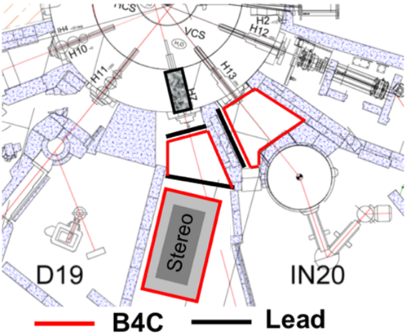
- High neutron and gamma flux because of experimental beam lines.

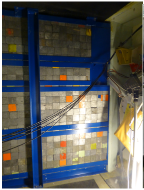
  → **Requires heavy shielding**.

Shieldings against muons, gammas and neutrons



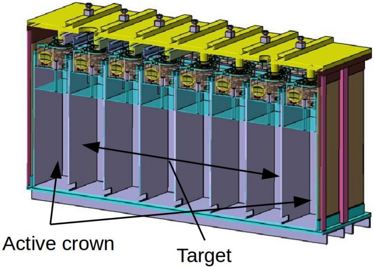
- Front wall shielding and H13 reinforcement :
  - Dedicated beam plug.
  - Additional lead wall.
  - Additional neutron shielding : B_4C.
- Shielding surrounding the target :
  - 10 cm thick lead.
  - 15 cm thick polyethylene.
  - 30 cm thick surrounding crown.
- "On-site" protection :
  - Water channel.

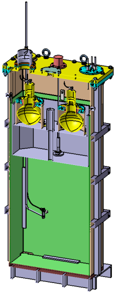




Detector design

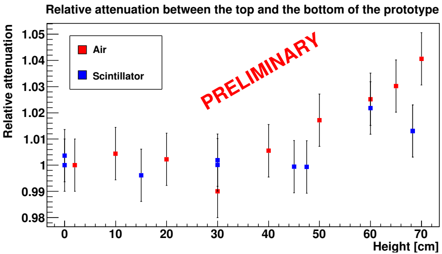
- Six cells (40x90x90) cm^3 filled with Gd-loaded liquid scintillator.
- Surrounding crown filled with unloaded liquid scintillator.
  - Containment of energy leakage
  - Active veto of external background
- Light collection :
  - Four PMTs per cell and acrylic buffer.
  - Acrylic walls and optical segmentations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





Prototype

- Installation last week in Saclay.
- One cell filled with unloaded liquid scintillator.
- Two LEDs for light injection :
  - one fixed for the single photo-electron.
  - one movable for the calibration at different positions.
- Reflections on the walls have no impact on the energy resolution.



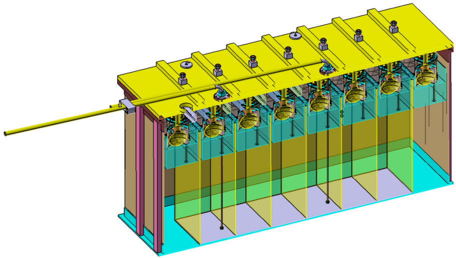
Calibration system

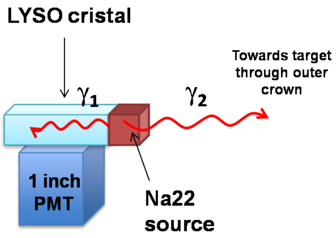
OBJECTIVES :

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

TOOLS :

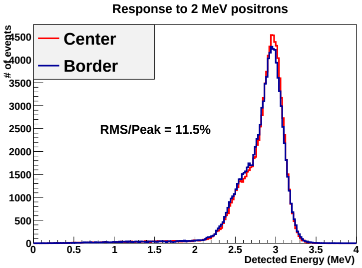
- Gamma and neutron sources :
  - Inside cells along vertical axis.
  - Underneath the detector vessel.
  - Around the detector vessel.
- Tagged source :
  - Circulated around the detector vessel at different Z.
  - Absolute calibration at 511 keV.

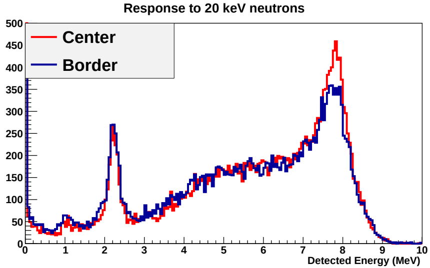




Positron and neutron response

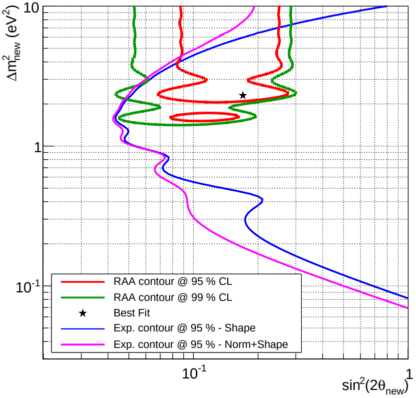
- Complete GEANT4 model to simulate the detector response.





- 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

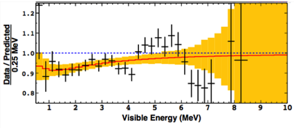
- Now in its final configuration after two major shielding upgrades.
- About 300 neutrinos per day are detected ($\sim$31% of efficiency).
- The accuracy is limited by the accidental rate of high energy γ-rays.
- The detector performances would be enhanced in the case of deployment at a nuclear power station (no gammas from the core).

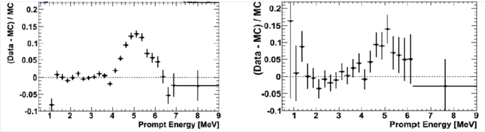
STEREO

- The sensitivity covers the contour of the reactor anomaly.
- Accurate measurement of pure ^{235}U spectrum (high statistic and good control of detector response).
- Several prototypes are under test to validate the detector response.
- Challenging mitigation of reactor induced background.
- Beginning of data taking at the end of 2015.

Back-up

- 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.