

Reactor antineutrinos at short baseline

The NUCIFER and STEREO experiments

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Neutrino history

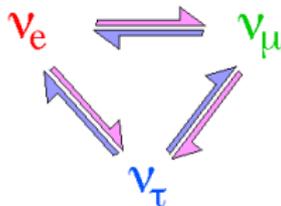
- 1930 : hypothesis of "neutrons" by Pauli to explain the β -decay spectrum :



- Coupling only with weak interaction \rightarrow hard to detect but ...
- ... 1956 : first detection of electronic antineutrinos by Reines and Cowan with a detector close to a nuclear reactor !
- 1968 : solar neutrino deficit \rightarrow less detected neutrinos than expected ...
- Pontecorvo idea : neutrino oscillations.
- 1998 : oscillation observation by Super-Kamiokande.

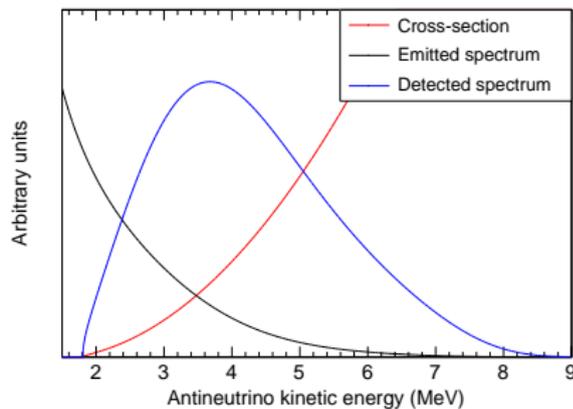
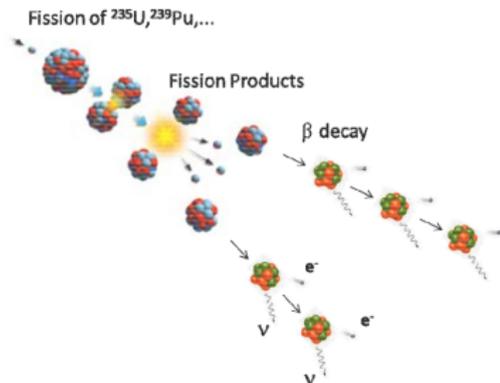
$$P_{\nu_e \rightarrow \nu_e} = 1 - \sin^2(2\theta) \sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

- Three kind of neutrinos observed : electron, muon and tau.



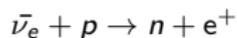
Reactor antineutrinos

- Nuclear reactors are pure and intense sources of $\bar{\nu}_e$: $1.9 \times 10^{20} \bar{\nu}_e/\text{s}/\text{GW}_{\text{th}}$
⇒ small detector at short baseline is possible despite of the small cross-section.

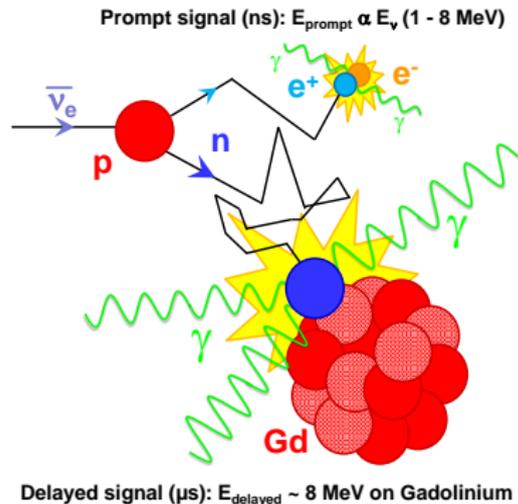
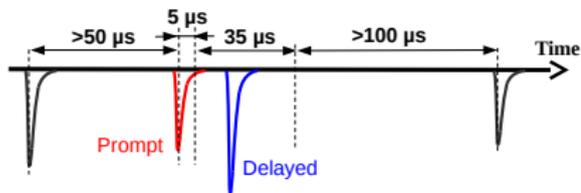


Neutrino detection principle

- Inverse β -decay utilisation :

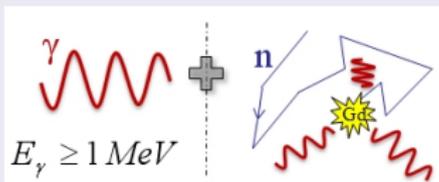


- in Gd-loaded liquid scintillator.
- Very small cross-section $\sim 10^{-43}$ cm²
- Prompt and delayed events in coincidence.



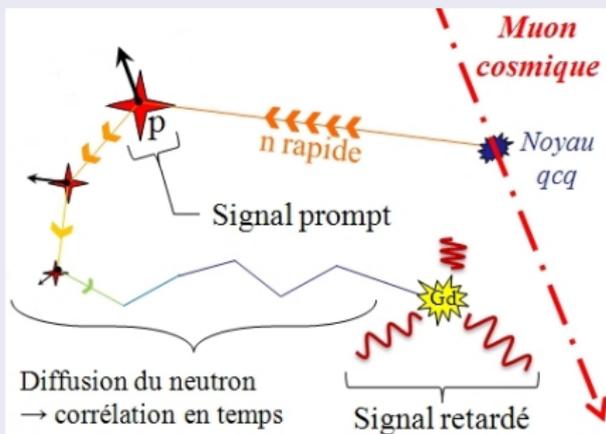
Expected backgrounds

Accidental background



- Random coincidence between a gamma and a neutron capture or another energetic gamma.
- Shielding to stop them.
- Measured reactor ON and subtracted.

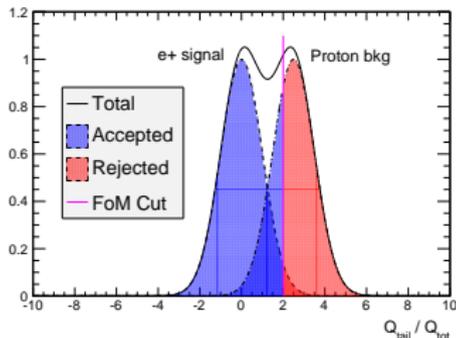
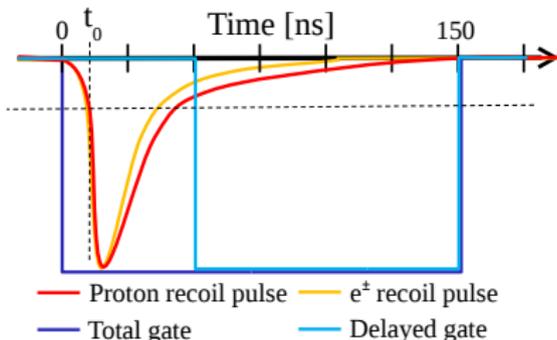
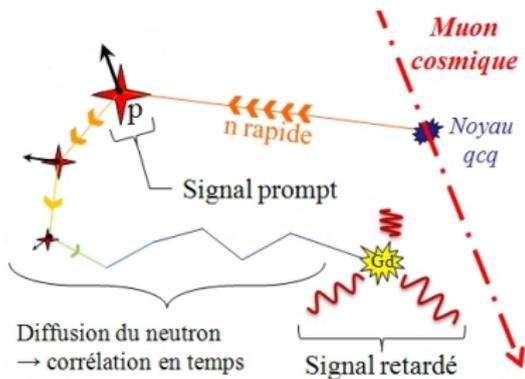
Correlated background



- Cosmic $\mu^\pm \Rightarrow$ fast $n \Rightarrow$ correlated signal.
- Decreased by overburden and the muon veto.
- PSD rejection.
- Measured reactor OFF and subtracted.

\Rightarrow Measured neutrino count rate: $N_{\bar{\nu}_e} = N_{\text{corr}}^{\text{ON}} - N_{\text{acc}}^{\text{ON}} - (N_{\text{corr}}^{\text{OFF}} - N_{\text{acc}}^{\text{OFF}})$.

Background rejection with Pulse Shape Discrimination



- $\bar{\nu}$ prompt, γ , $(n, \gamma) \Rightarrow$ low Q_{tail} / Q_{tot} ratio.
- Fast neutron prompt only \Rightarrow *p* recoil \Rightarrow high Q_{tail} / Q_{tot} ratio.
- PSD \Rightarrow Online rejection of the correlated background before subtraction of the correlated events.

The Nucifer experiment



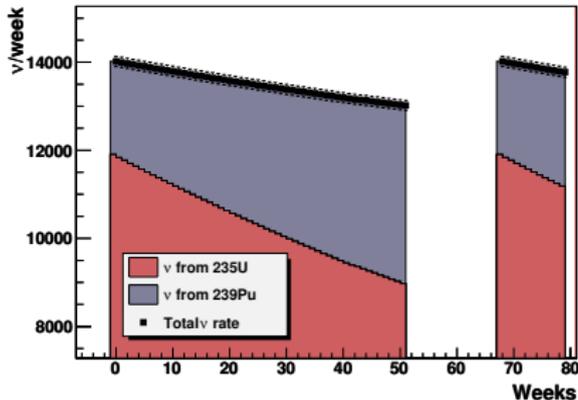
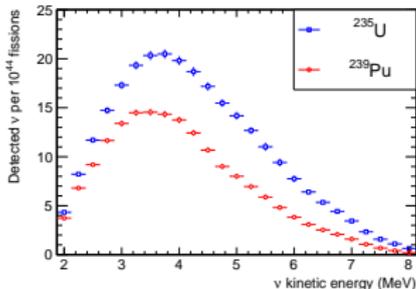
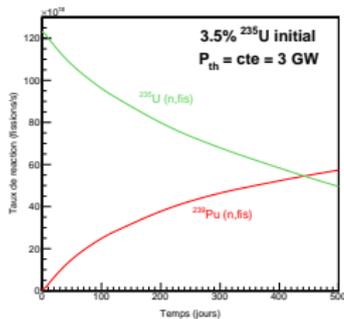
Nucifer



Antineutrinos for the non-proliferation

- Neutrino emission depends on the fuel composition and on the core power :

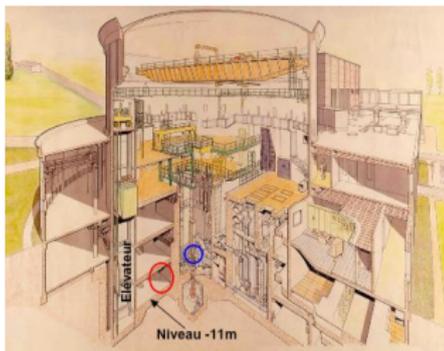
$$N_{\bar{\nu}_e} = \alpha * P_{th} * (1 + k(t))$$
 with $k(t)$ function of the fuel.



- Direct real time informations on reactor operation.
- Complementary method to know total burnup reactor.

⇒ IAEA interest for surveillance of reactors.

OSIRIS site and detector characteristics



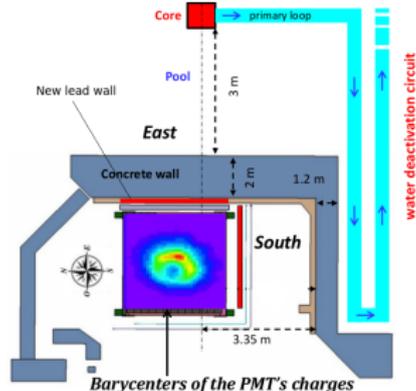
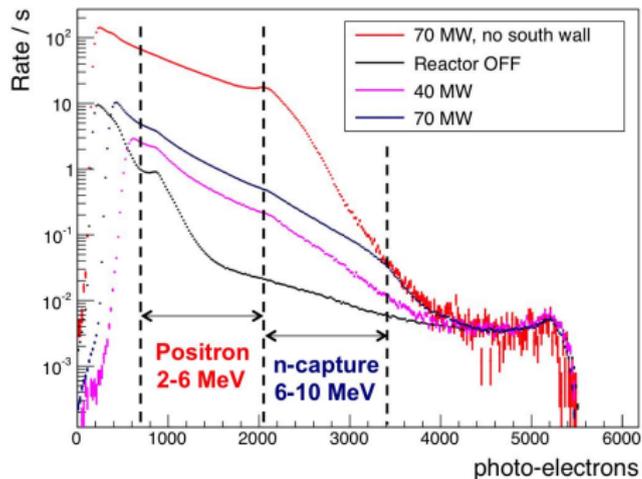
- 70 MW_{th} “pool type” research reactor,
- ~ 7 m from the reactor core,
⇒ high gamma flux.
- Low overburden
⇒ muon flux attenuation = 2.7.

Main characteristics of NUCIFER :

- 850 L of Gd-loaded (0.2%) liquid scintillator (MPIK scintillator),
- 16 PMTs fixed on an acrylic buffer,
- central calibration tube.

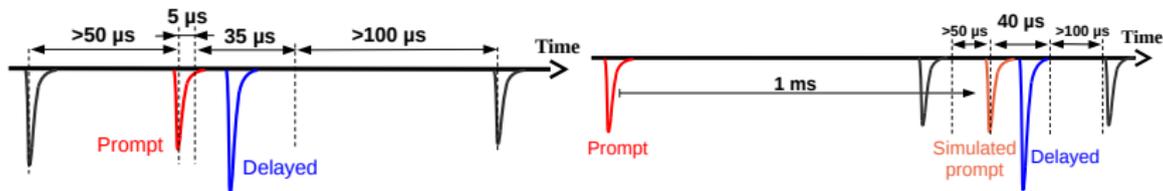


Reactor spectrum



- Single rate ~ 200 Hz above 2 MeV, on expectation, but leakage of high energy gammas in E_{delayed} window \Rightarrow too much accidental background.
- A lead wall will be added to bring the background on specifications (factor ~ 30).

Results (PRELIMINARY)



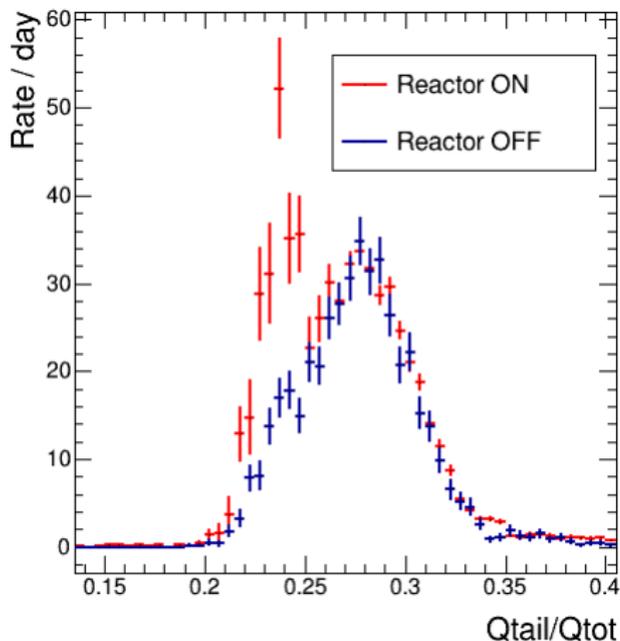
- Results (ON : 22 days, OFF : 5 days):

	Accidental rate	Correlated rate
Reactor OFF	$(33.9 \pm 0.3) / \text{day}$	$(124 \pm 6) / \text{day}$
Reactor ON	$(3131 \pm 2) / \text{day}$	$(259 \pm 14) / \text{day}$

$\Rightarrow 135 \bar{\nu}_e / \text{day} \pm 15.$

- Optimized cuts $\rightarrow 293 \bar{\nu}_e / \text{day}$, publication in preparation.

Results (PRELIMINARY)

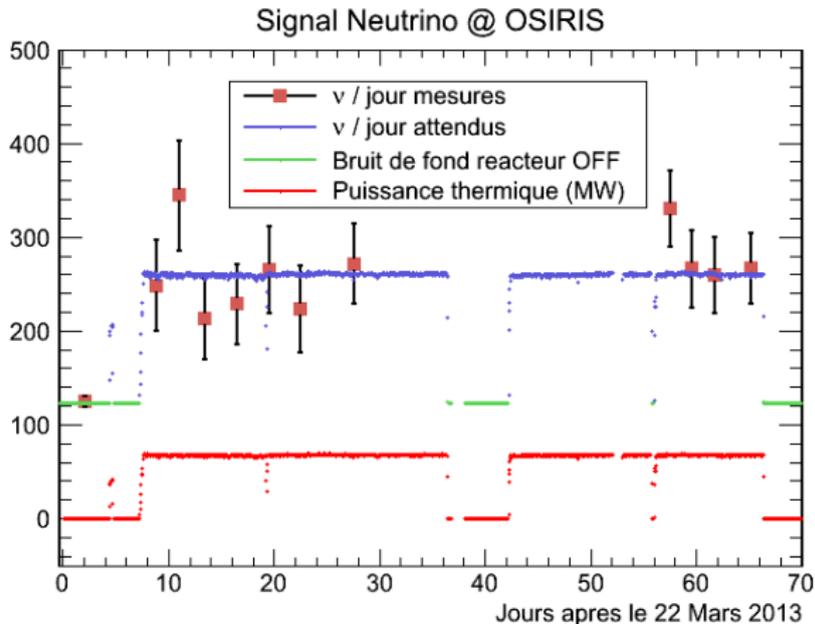


Correlated events excess = fast neutrons coming from the core ?

- High Q_{tail}/Q_{tot} : fast neutrons.
- Low Q_{tail}/Q_{tot} : γ , neutrino.
- No more fast neutrons when the reactor is ON than when it is OFF

\Rightarrow excess at low Q_{tail}/Q_{tot} is due to neutrinos.

Results (PRELIMINARY)



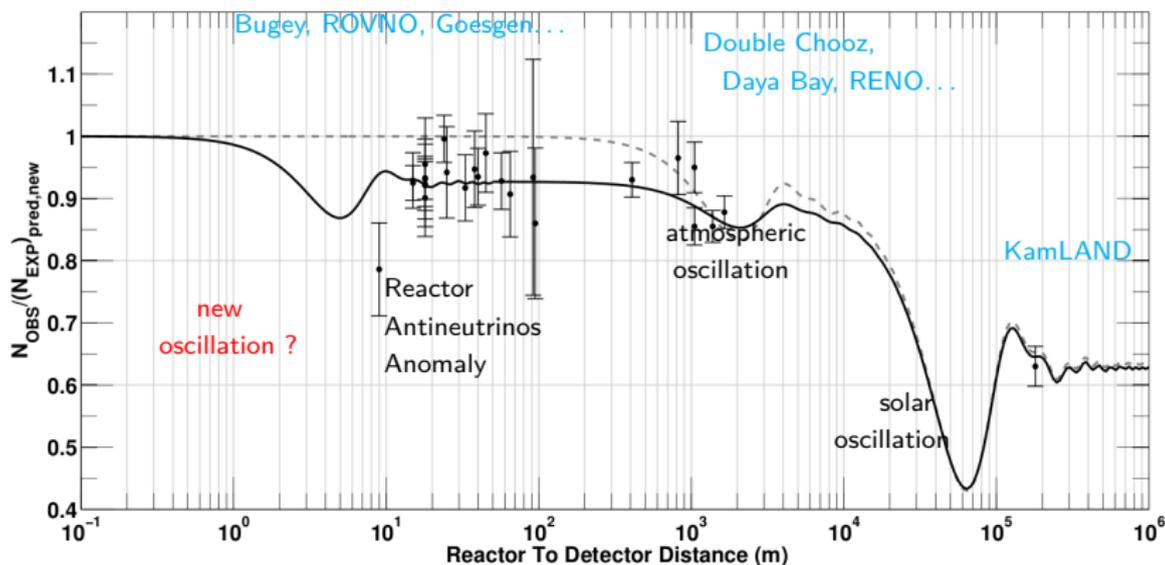
The Stereo experiment



Reactor antineutrinos anomaly

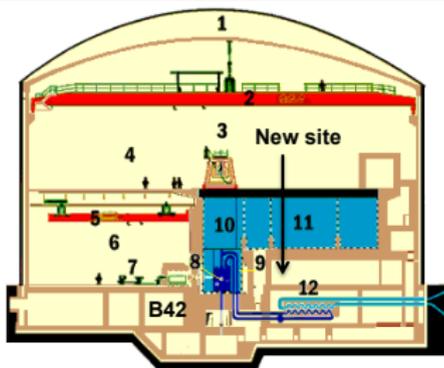
- Reevaluation of reactor $\bar{\nu}_e$ spectra, Th. A. Mueller et al., Phys.Rev.C 83, 054615 (2011)
- Reanalysis of short baseline experiments \Rightarrow deficit of 6% (2013 update)

G. Mention et al., Phys. Rev. D 83, 073006 (2011)



New oscillations toward a sterile neutrino at very short baselines ($\Delta m^2 \gtrsim 1 \text{ eV}^2$).

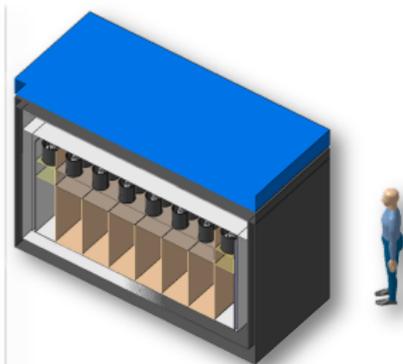
ILL site and detector design



- 58 MW_{th} “pool type” research reactor,
- ~10 m from the reactor core.
⇒ High gamma and neutron flux.
- Efficient overburden provided by the water channel (muon attenuation : 4).
⇒ Low muon induced.

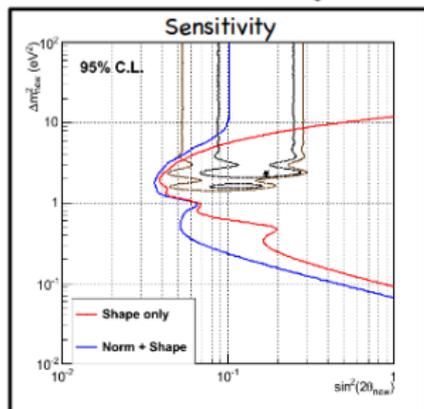
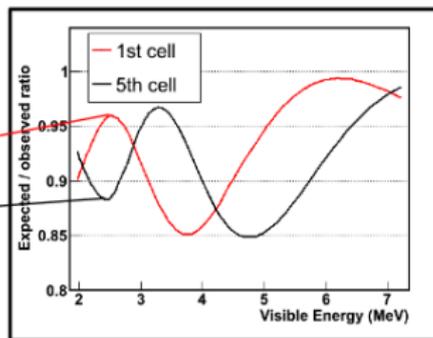
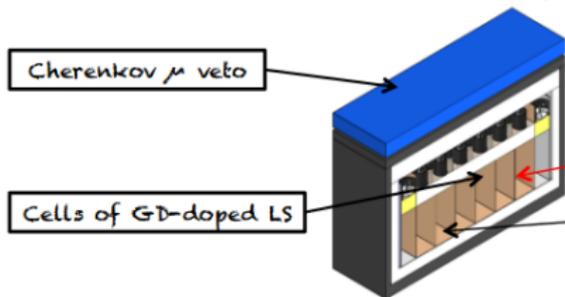
Main characteristics of STEREO :

- 6 independent target cells with 4 PMTs,
- a gamma catcher with 24 PMTs.



STEREO motivation

Motivation : to detect a new oscillation pattern in E and L.



- Experimental contour covers the 99% C.L. contour of the reactor anomaly.
- It includes the best fit at 5σ .

Liquid scintillator choice

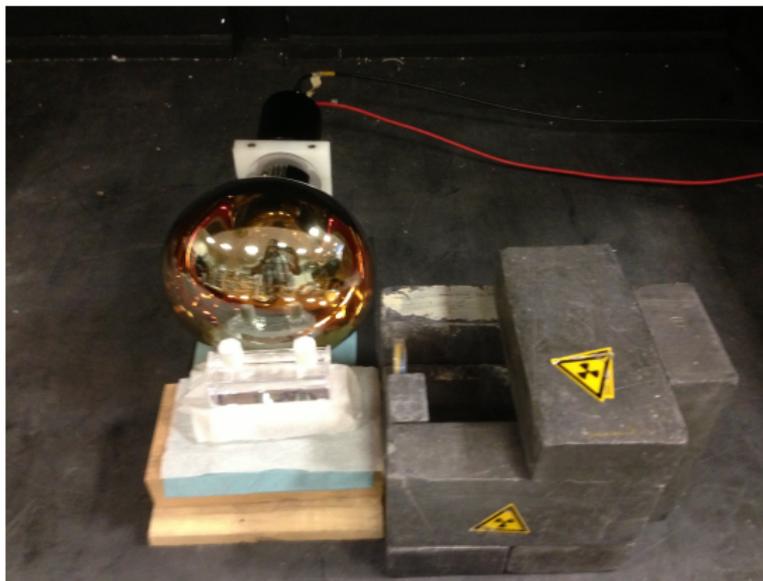
- Different liquid scintillators are studied based on Petrelad and PXE.

Requested properties :

- Attenuation length $> 4\text{m}$ in the range of PMTs sensibility ($\sim 430\text{nm}$).
- Stable for several years and compatible with detector materials.
- Good light yield i.e quantity of photons for one MeV.
- Good pulse shape discrimination for background rejection.

Light yield determination

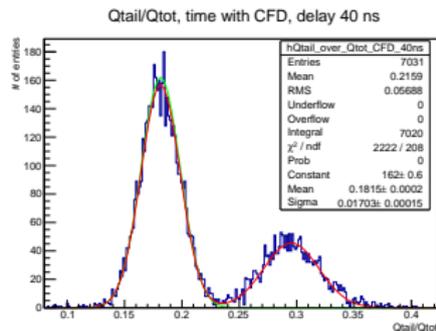
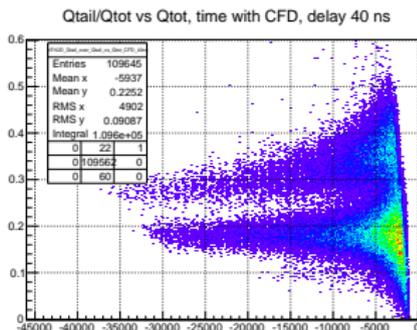
- Utilisation of a ^{60}Co source : 2 γ rays (1.15 MeV and 1.35 MeV).
- Rought calibration using the high E edge of the ^{60}Co spectrum.



- All tested liquids have comparable light yields ($\sim 7500\text{-}8000$ photon/MeV).

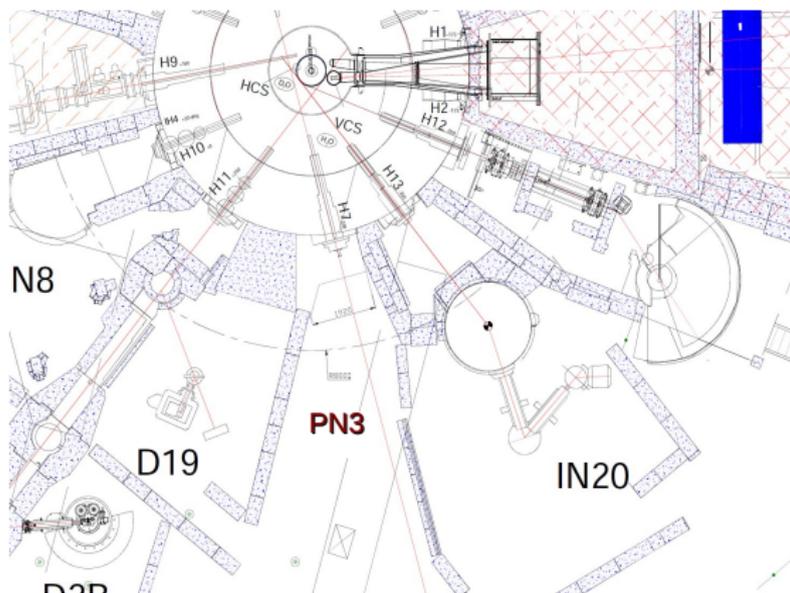
PSD determination

- Same set-up with a ^{252}Cf source (fast neutrons and gammas).



- Very good separation achieved in test cells.
- Provides margin for an efficient online rejection in the detector..

Site presentation



Background specifications for STEREO :

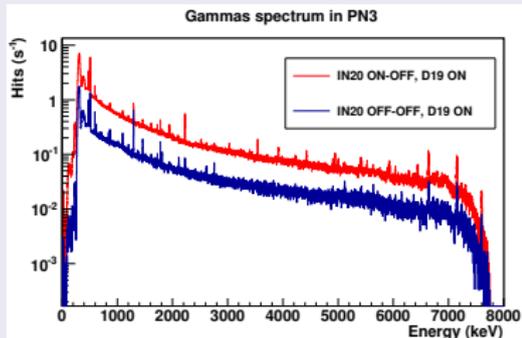
- 200 Hz for prompt events ($E > 2\text{MeV}$)
- 1 Hz for delayed events ($E > 5\text{MeV}$)

Thermal neutrons and gammas

Detection of thermal neutrons with a helium tube.

- High thermal neutron ambience due to neighbour neutron beam lines.
- Hotspots close to the wall IN20/PN3.
⇒ Efficient reduction with B4C plate (validated on-site).

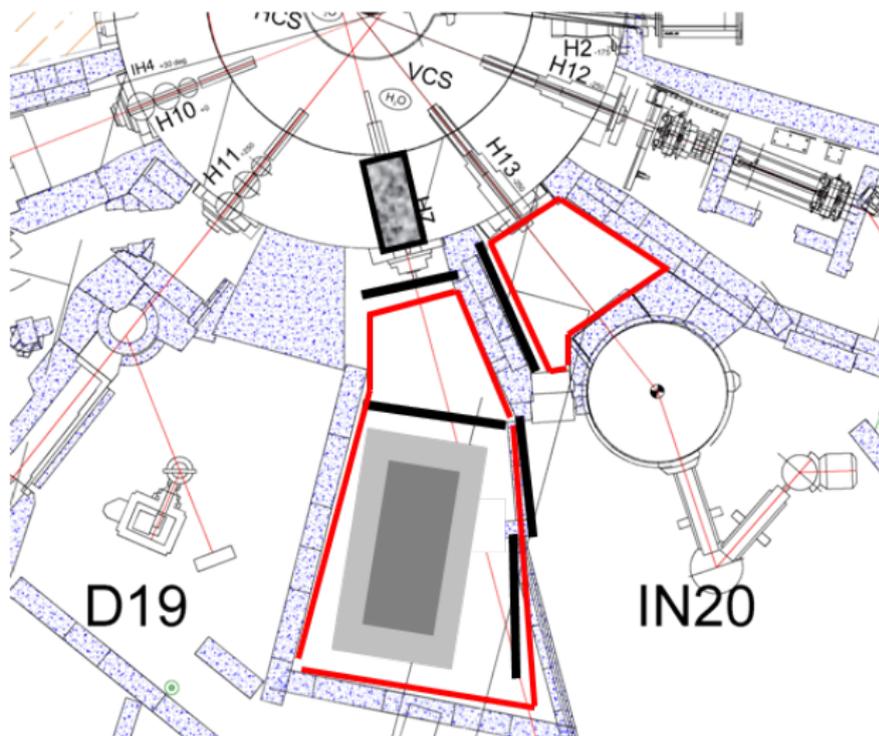
Detection of gamma with a HPGe.



- (IN20 ON) spectrum is 4 times higher than (IN20 OFF) spectrum
- 80% of gamma comes from IN20.
⇒ Addition of lead.

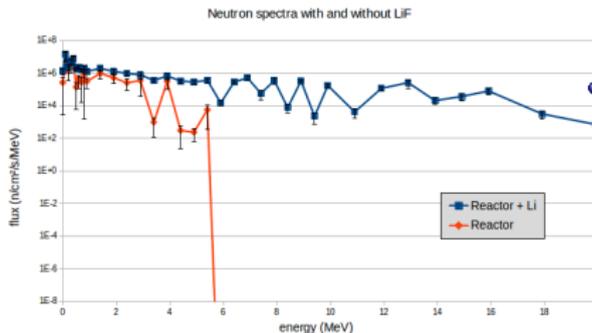
Neutrons and gammas shielding

Addition of B4C in PN3 and IN20 + lead in PN3.

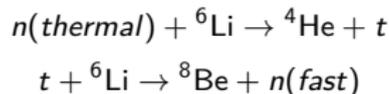


What about fast neutrons ?

- Measurements were done with a PEHD shielding around the helium tube.
 ⇒ Identification of two main sources : IN20 casemate and H7 neutron tube.
- MCNPX simulations were done to prove that neutron with an energy higher than 6 MeV can not come from the reactor :

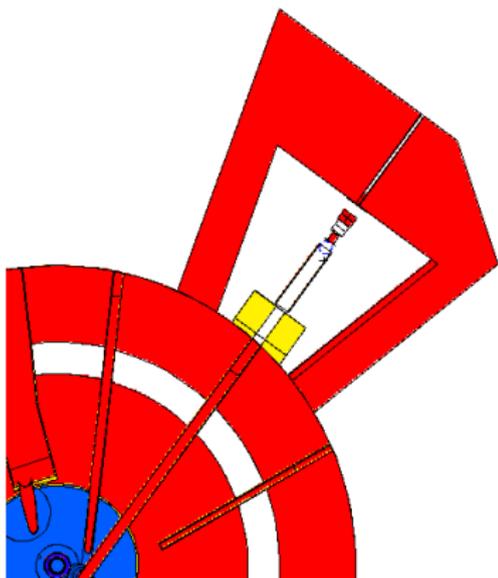


- ${}^6\text{Li}$ produces fast neutrons by the following reaction :

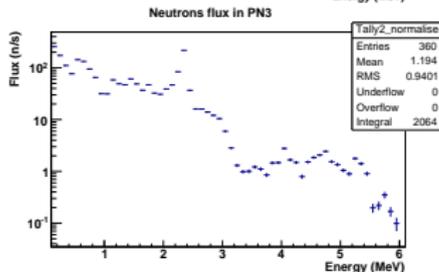
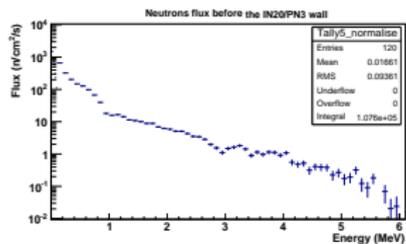
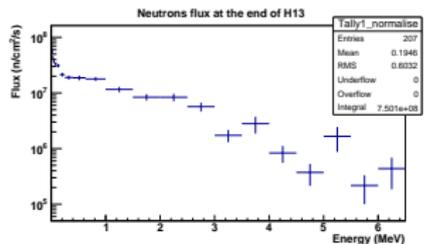


⇒ ${}^6\text{Li}$ will be removed and the plug will stop these fast neutrons coming from H7.

What about fast neutrons from IN20 ?



- Addition of CH2 around the IN20 collimators to provide enough margin of background reduction.



What are the next steps ?

- November 2013 : decommissioning of GAMS5 and H7.
- February 2014 : shielding installation in H13 casemate.
- Mai 2014 : H7 plug installation.
- June 2014 : shielding installation in Stereo casemate.
- June-July 2014 : background measurements.
- September-October 2014 : detector installation.
- November 2014 : Stereo commissioning.

Conclusions

- Nucifer sees neutrinos with high stat significance, data from 3 Osiris cycles on disk.
- Publication in preparation.
- Last upgrade of lead shielding planned to reduce accidental background.
- One full year of data taking with background close to the specifications.

- Complete on site background studies, shielding structures being designed.
- Prototype cell expected early next year to validate the response of the inner detector.
- Sequential background cross-checks after reactor restart in July 2014, detector commissioning November 2014.

**Toward an applied antineutrino physics...
... and a sterile neutrino ?**

Back-up

MCNPX Simulations

