The NUCIFER experiment

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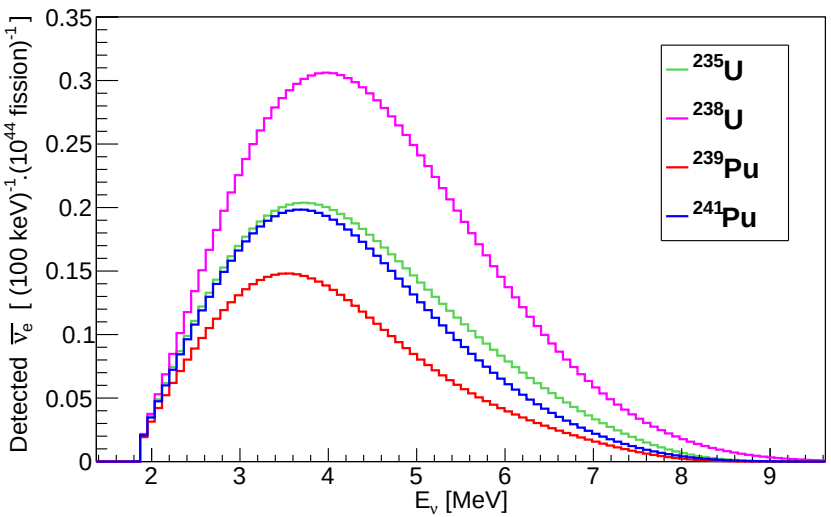
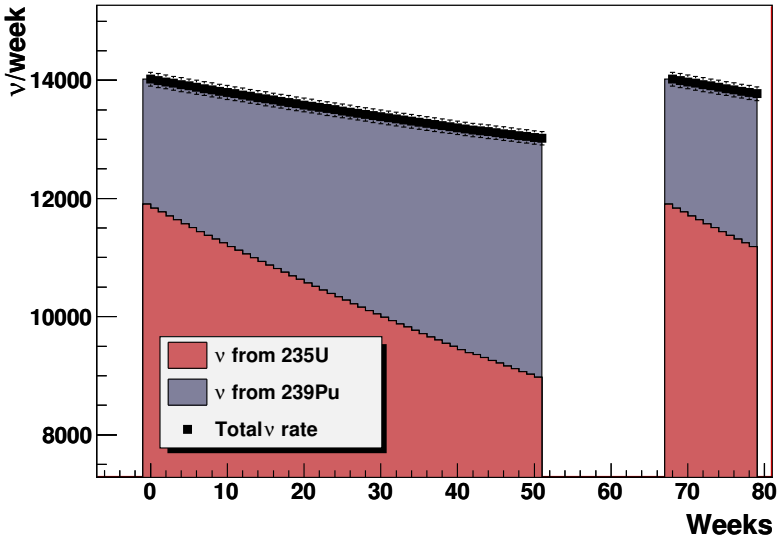
Antineutrinos for the non-proliferation

- Nuclear reactors are pure and intense sources of $\bar{\nu_e}$: $1.9 \times 10^{20}\ \overline{\nu_e}/\mathrm{s}/\mathrm{GW_{th}}$
  $\Rightarrow$ compact and small detector at short baseline is possible.
- Neutrino emission depends on the fuel composition and on the core power :

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





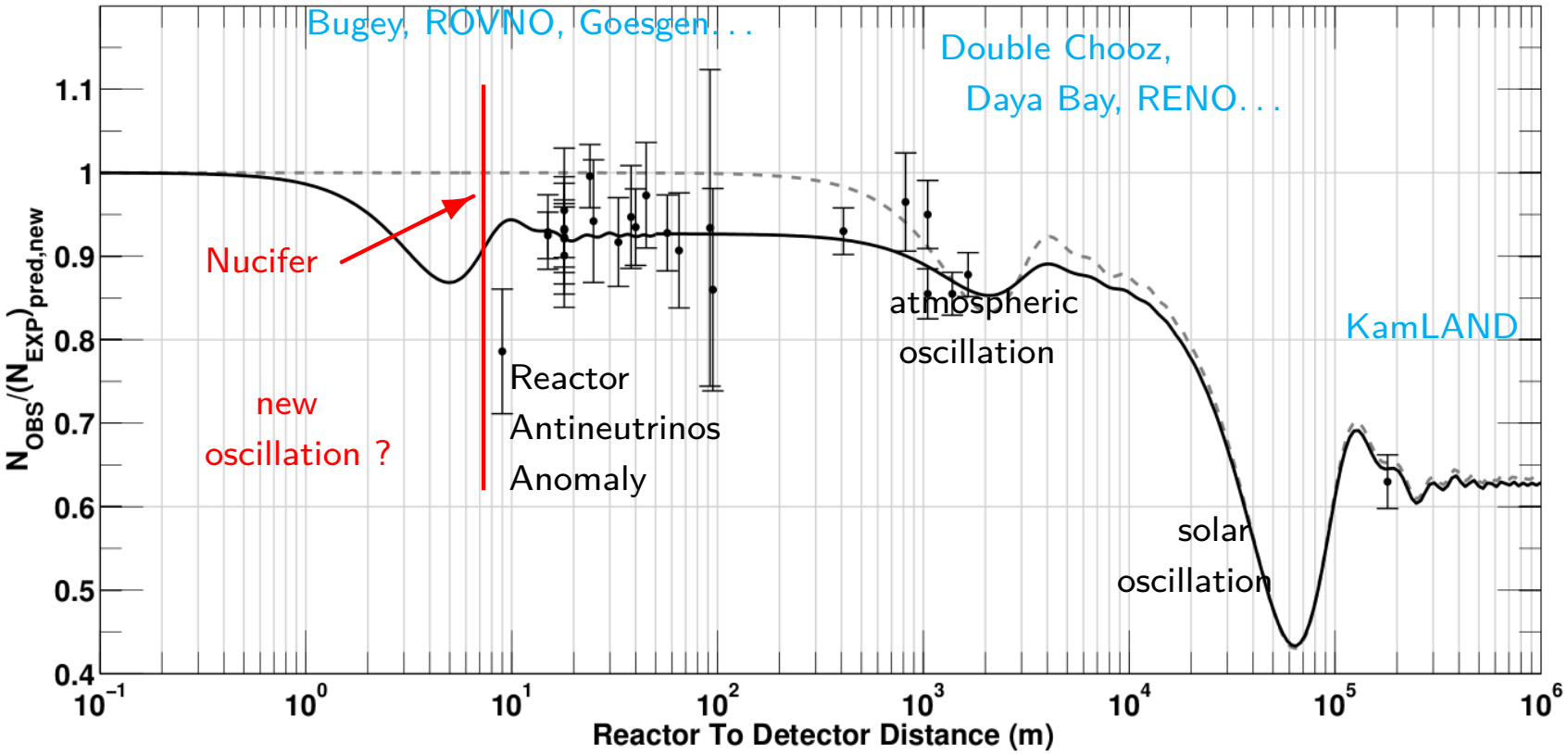
- Direct real time informations on reactor operation.
- Complementary method to know total burnup reactor.

  $\Rightarrow$ IAEA interest for surveillance of reactors.

Reactor antineutrinos anomaly

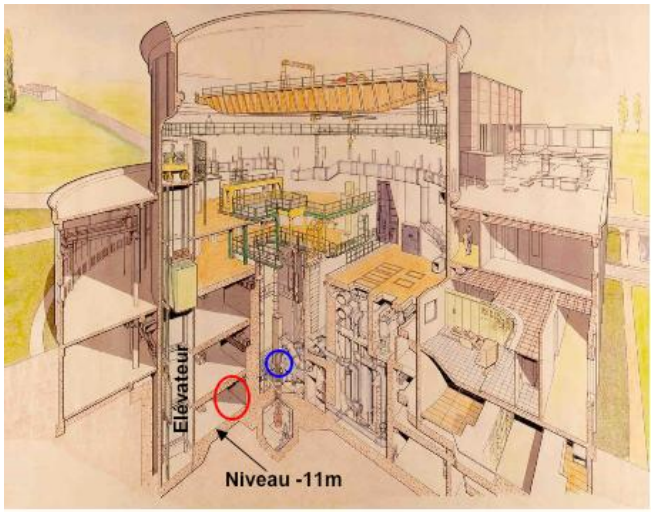
- Reevaluation of reactor $\bar{\nu}_e$ spectra, Th. A. Mueller et al., Phys.Rev.C 83, 054615 (2011)
- Reanalysis of short baseline experiments $\Rightarrow$ deficit of 6% (2013 update)

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



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

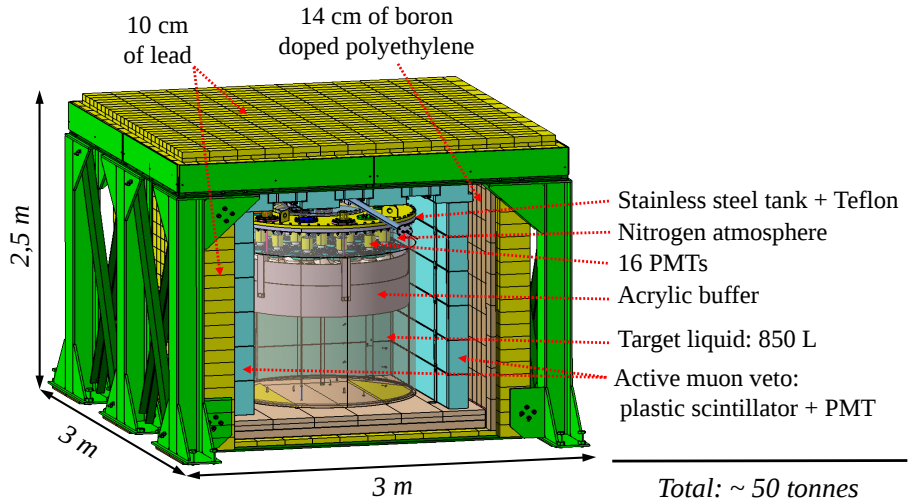
OSIRIS site and detector caracteristics



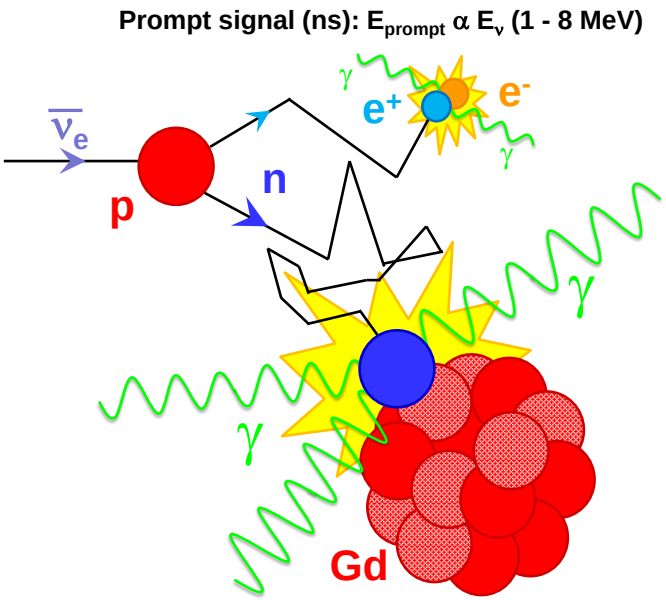
- 70 MW_{th} "pool type" research reactor,
- $\sim$7 m from the reactor core,
  $\Rightarrow$ high gamma flux.
- Low overburden
  $\Rightarrow$ muon flux attenuation = 2.7.

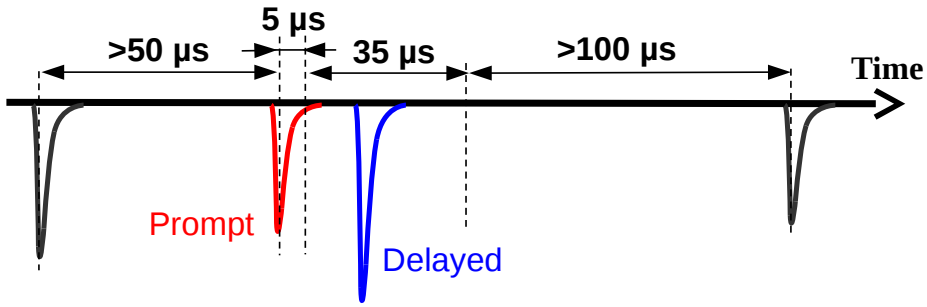
Main caracteristics of NUCIFER :

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



Detection principle



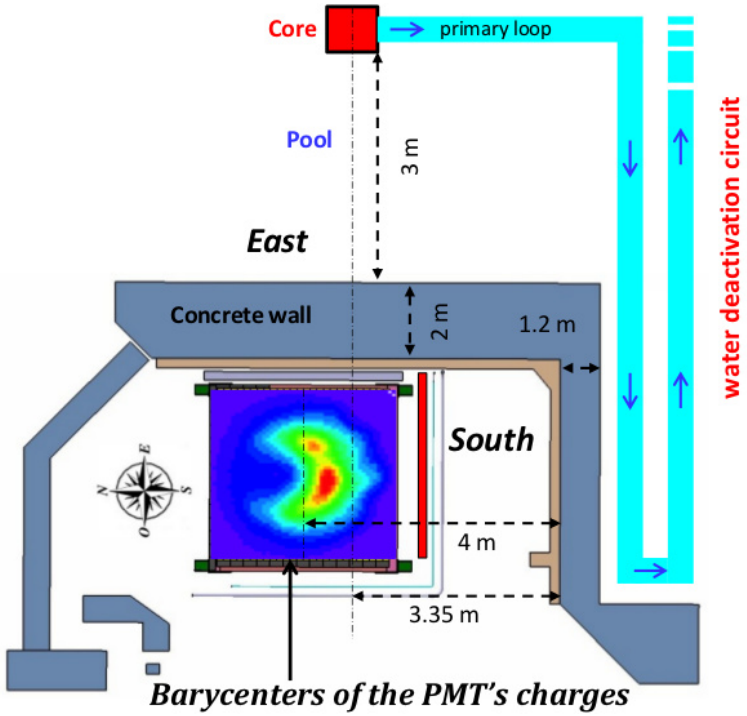


- Old energy cuts :
  - $2 < \mathrm{E_{prompt}} < 6$ MeV
  - $6 < \mathrm{E_{delayed}} < 10$ MeV
- New energy cuts :
  - $2 < \mathrm{E_{prompt}} < 7.1$ MeV
  - $4.2 < \mathrm{E_{delayed}} < 9.6$ MeV

  $\Rightarrow$ 2 times more detected neutrinos with slightly improved $S/\sqrt{B}$.
- Time cut :
  - $5 < \Delta t < 40$ µs

Nucifer integration

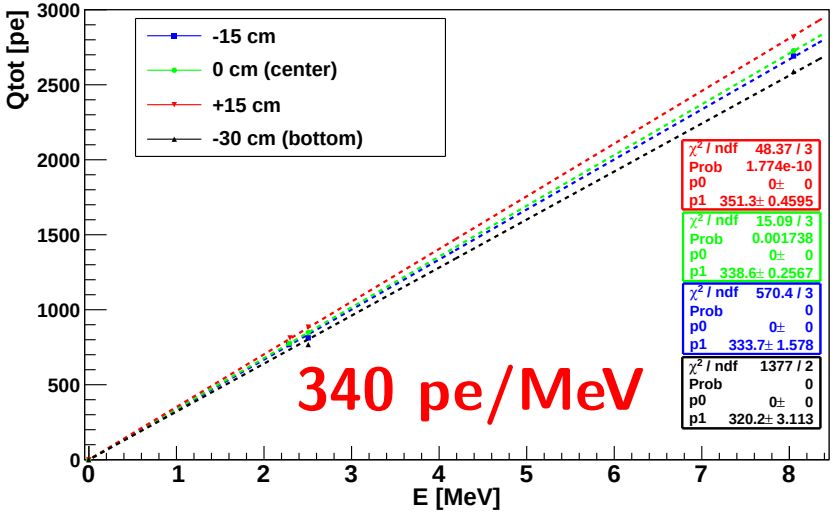
- First data at Osiris, May 2012.
- Liquid change, November 2012.
- Installation of south wall, March 2013.
- Two reactor cycles before long shut down, April-May 2013.



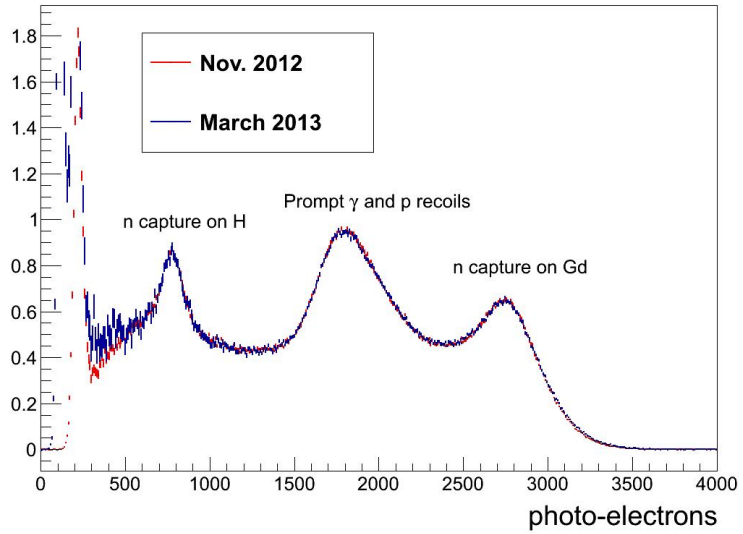
Liquid calibration

- Use of 4 radioactive sources (Co, Cs, Na and AmBe) at 4 points of the detector.

Energy calibration



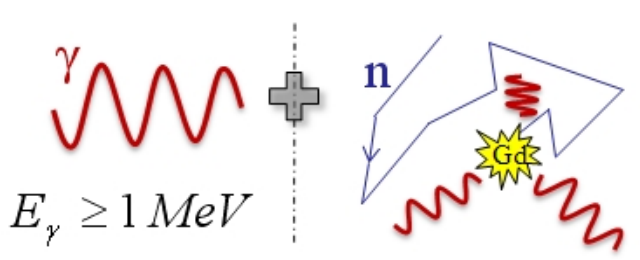
Liquid stability



- Detector response linear and stable,
- ±10% dependence on vertex elevation dominated by optical absorption on vessel walls.

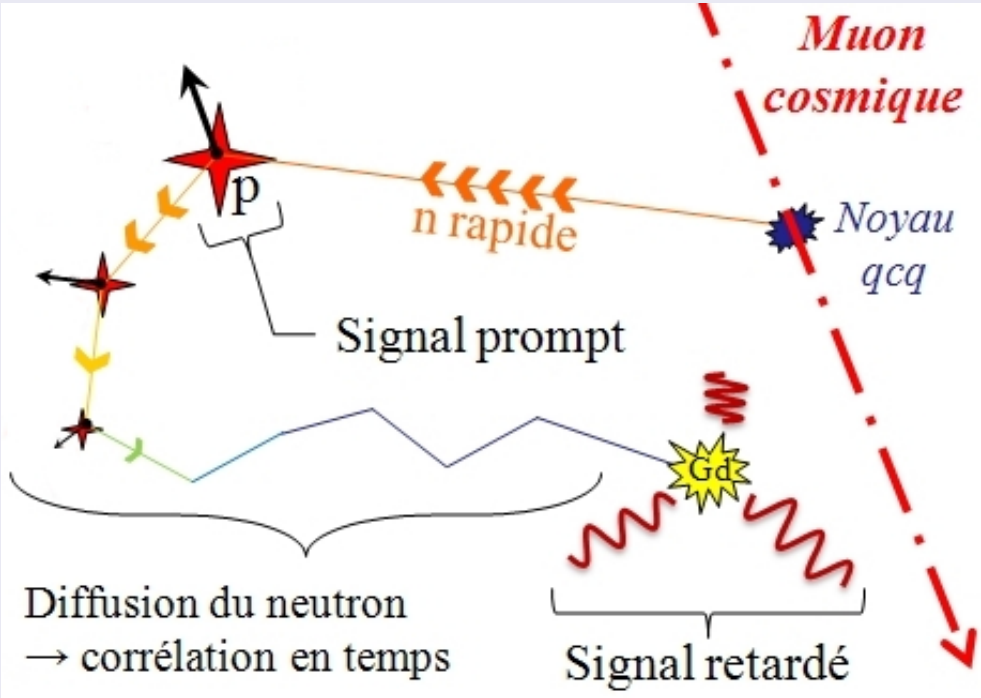
Expected backgrounds

Accidental background



- Random coincidence between a gamma and a neutron capture.
- Measured reactor ON and subtracted.

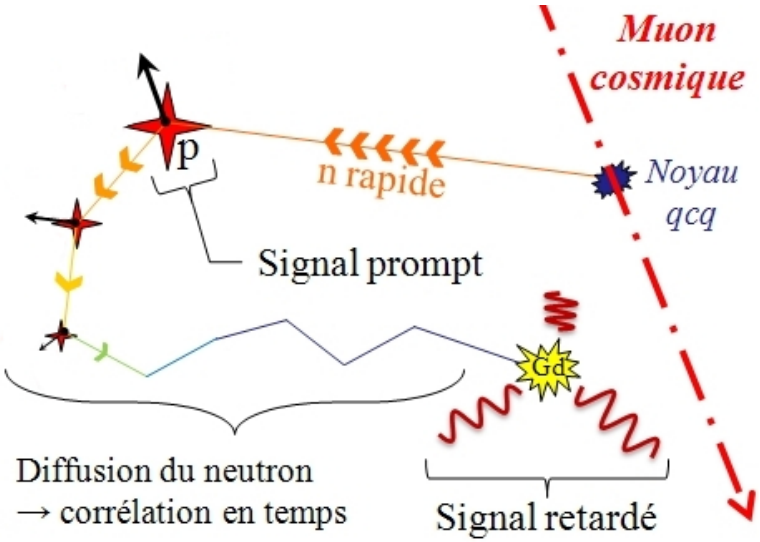
Correlated background

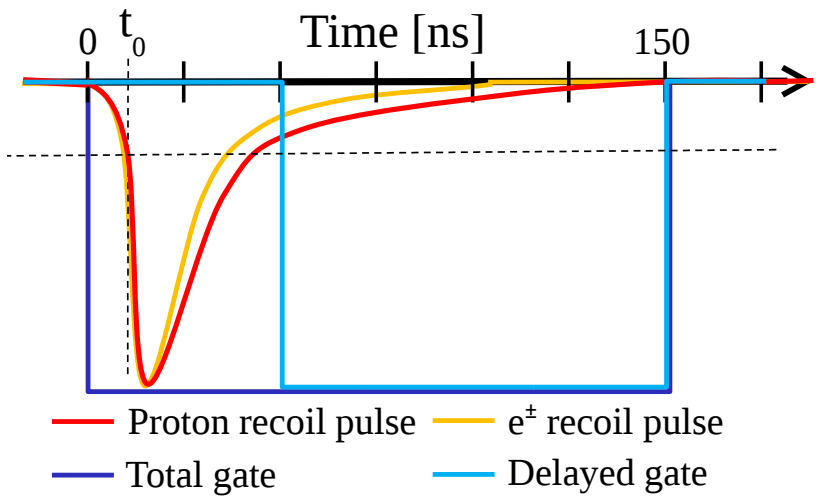


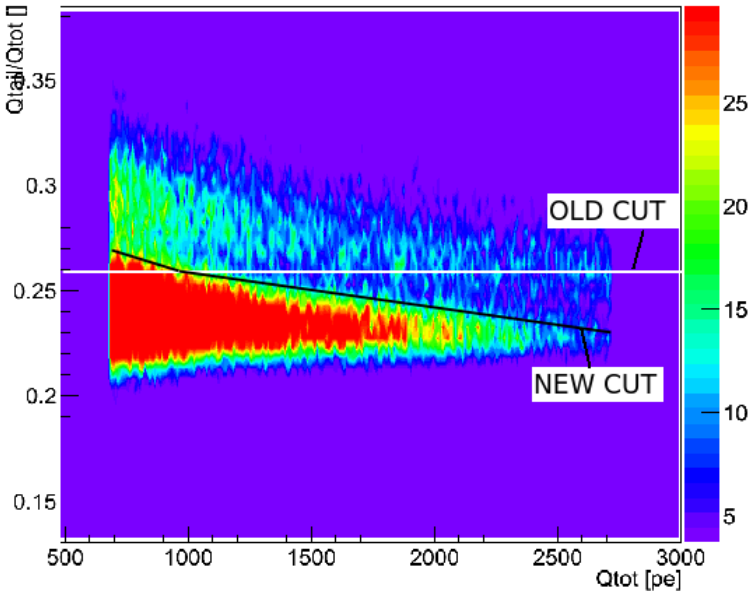
- Cosmic $\mu^{\pm}$ ⇒ fast n ⇒ correlated signal.
- Decreased by overburden and quenching.
- Measured reactor OFF and subtracted.

⇒ **Measured neutrino count rate:** $N_{\bar{\nu}_e} = N^{ON}_{corr} - N^{ON}_{acc} - (N^{OFF}_{corr} - N^{OFF}_{acc})$.

Background rejection with Pulse Shape Discrimination

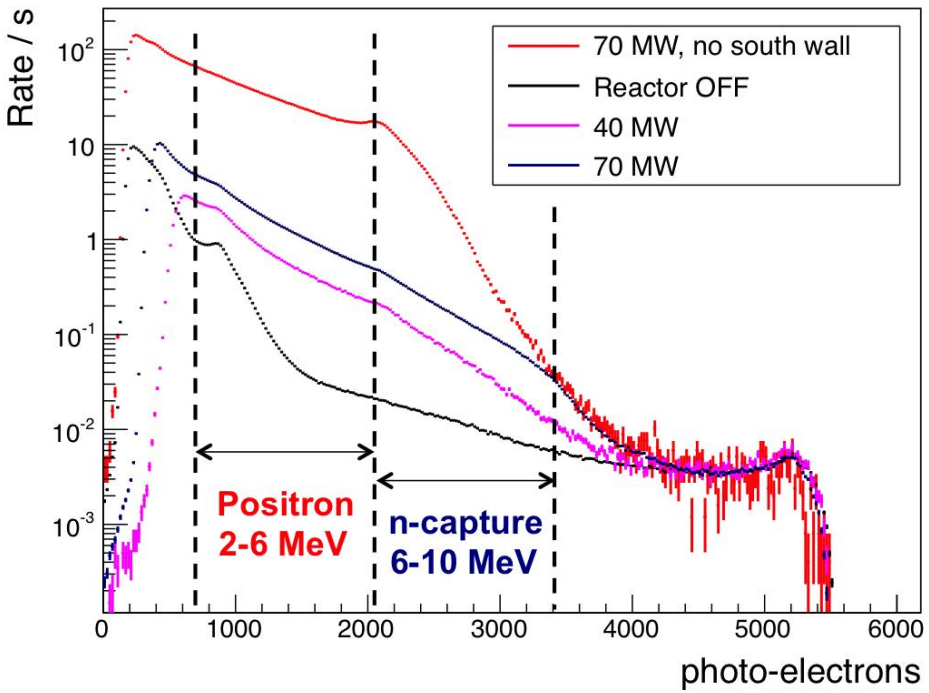


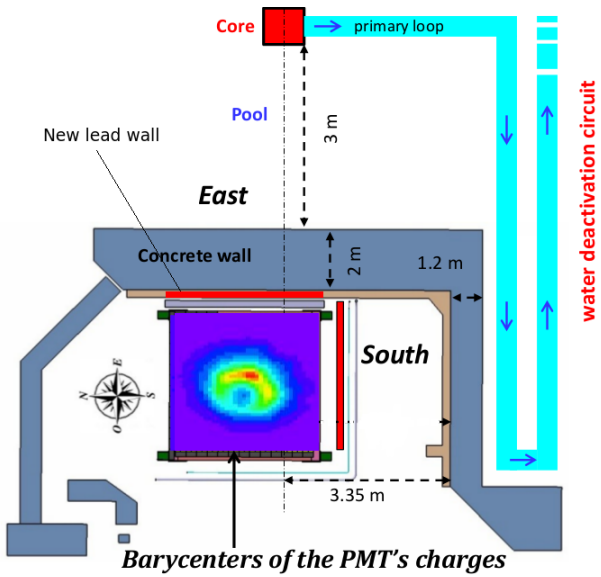




- $\bar{\nu}$ prompt, γ, (n,γ) $\Rightarrow$ low Q_{tail}/Q_{tot} ratio.
- Fast neutron prompt only $\Rightarrow$ p recoil $\Rightarrow$ *high* Q_{tail}/Q_{tot} ratio.
- PSD $\Rightarrow$ Online rejection of the correlated background before substraction of the correlated events.

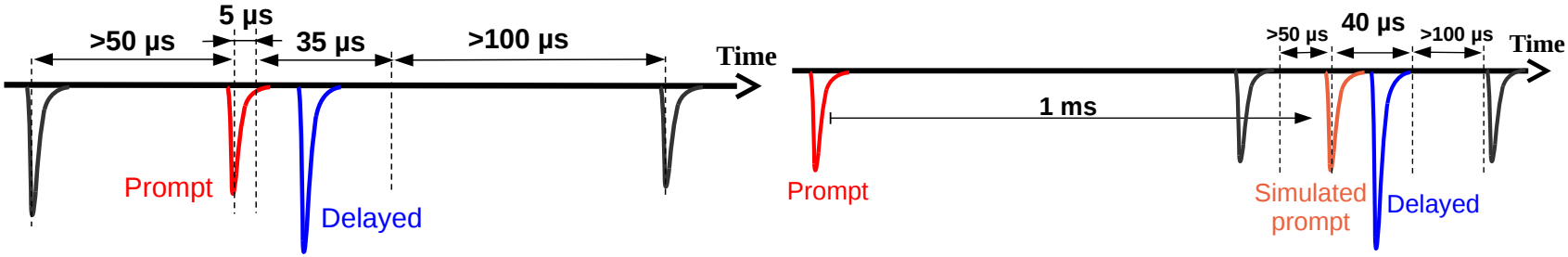
Reactor spectrum





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

Results (PRELIMINARY)



- Results with the old energy cuts (ON : 22 days, OFF : 5 days):

	Accidental rate	Correlated rate
Reactor OFF	(33.9 ± 0.3) /day	(124 ± 6) /day
Reactor ON	(3131 ± 2) /day	(259 ± 14) /day

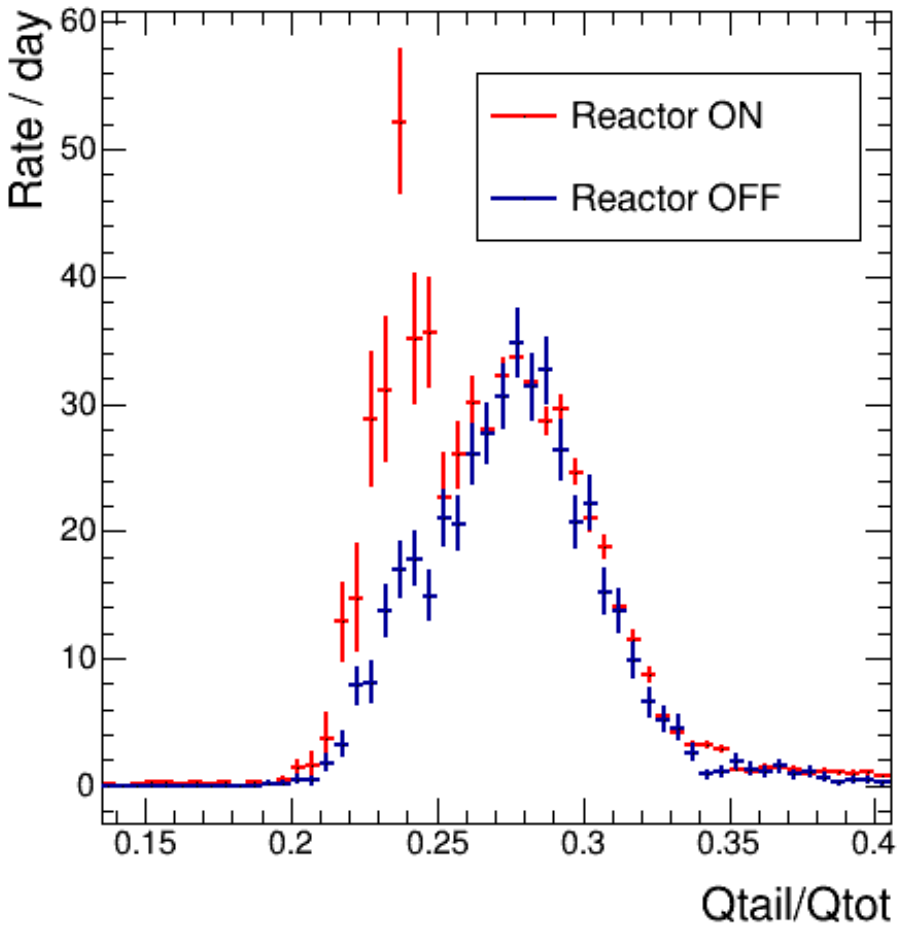
$\Rightarrow 135\ \overline{\nu_e}$/day $\pm$ 15.

- PRELIMINARY reanalysis with the new cuts (ON : 46 days, OFF : 43 days):

	Accidental rate	Correlated rate
Reactor OFF	(57.2 ± 0.2) /day	(216 ± 3) /day
Reactor ON	(8596 ± 15) /day	(459 ± 15) /day

$\Rightarrow 243\ \overline{\nu_e}$/day $\pm$ 15.

Results (PRELIMINARY)



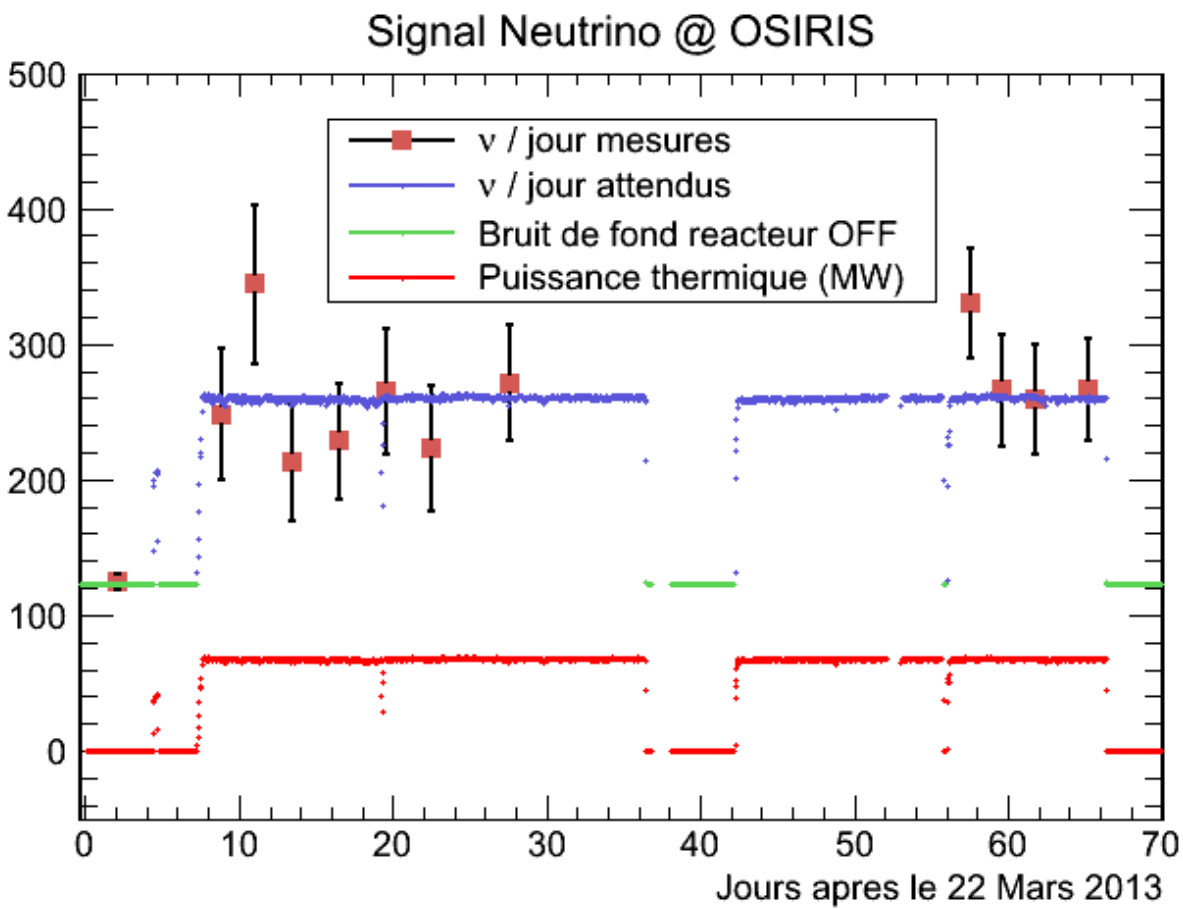
Correlated events excess = fast neutrons coming from the core ?

- 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.

Results (PRELIMINARY)



- Still work to estimate systematics errors :
  - Survey of Osiris site,
  - Simulation of detector efficiency.

Conclusion

- Nucifer sees neutrinos: (243 ± 15) /day (stat. only).
- Still work to get proper systematics.
- Last upgrade planned: add lead to reduce accidental background (S/AccB $\simeq 1$).
- Next reactor cycle scheduled for December.
- One full year of data taking with background close to the specifications.

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

Back-up