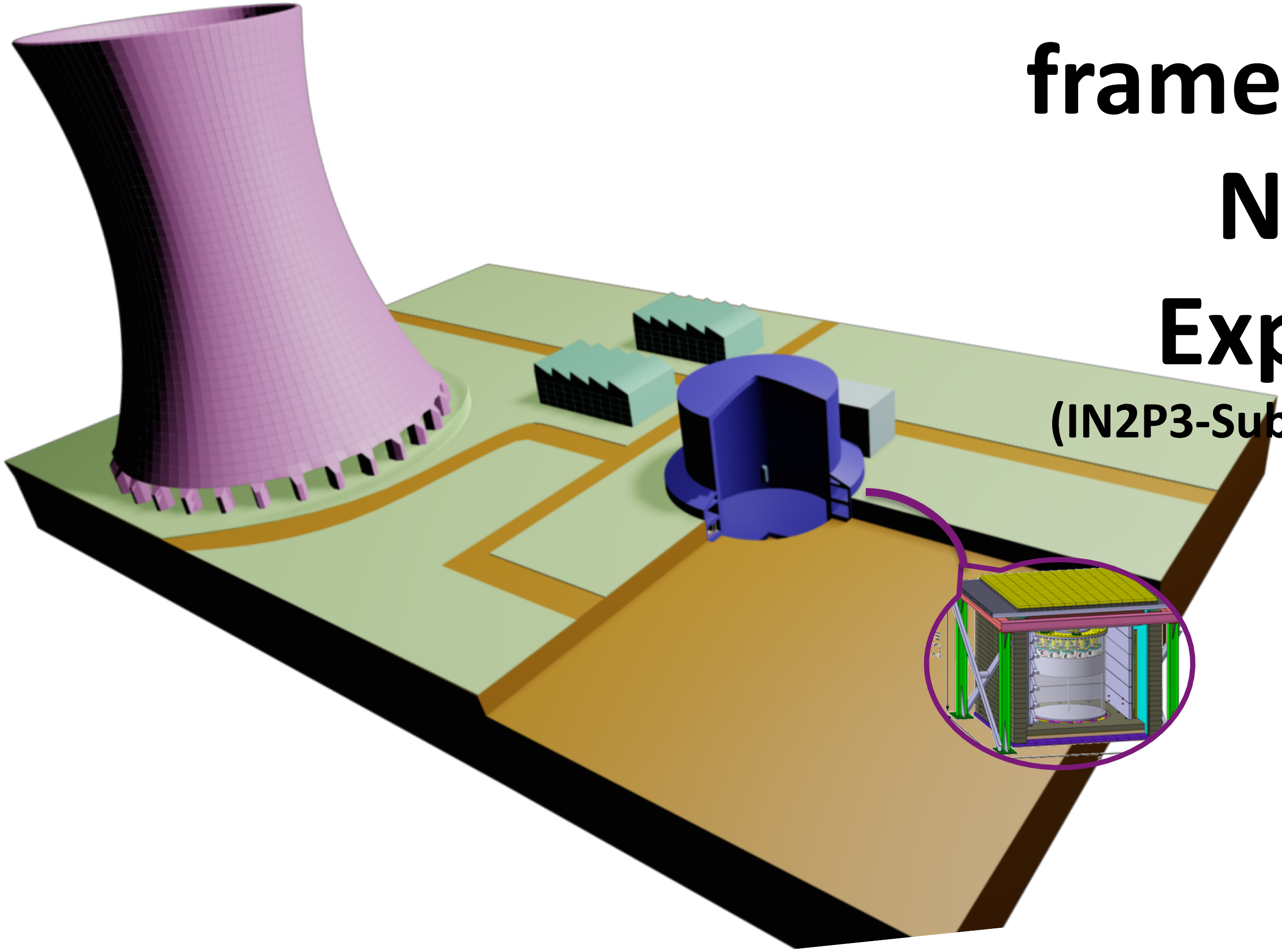
R&D in the framework of the NUCIFER Experiment

(IN2P3-Subatech; CEA/DSM/Irfu; CEA/DAM)



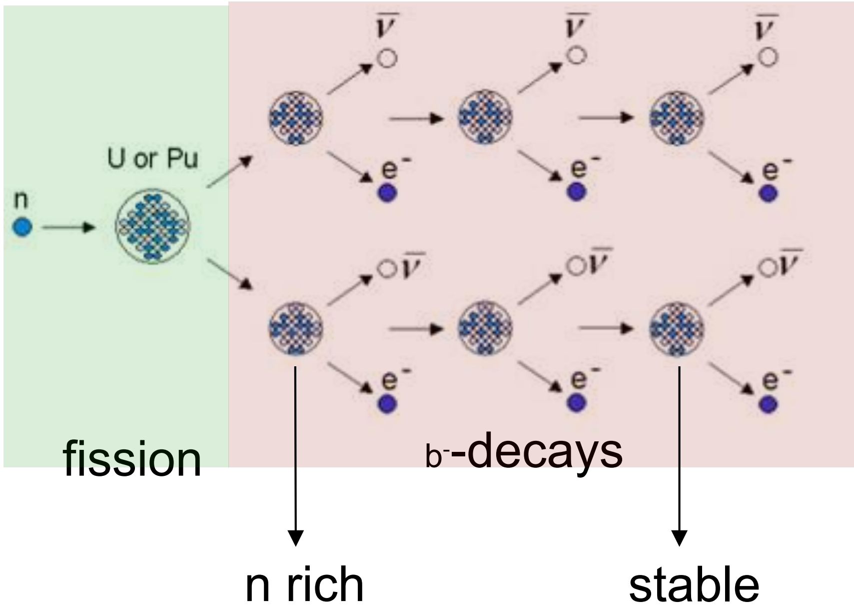
for the Nucifer Subatech Group:

V.M. Bui, A. Cucoanes, M. Fallot, A. Porta, F. Yermia

Reactor neutrino emission and detection

Emission: β-decay of fission products

- ~ 6 $\overline{\nu}_e$ / fission
- ~10^{21} $\overline{\nu}_e$ /s for a 1 GW_{el} reactor

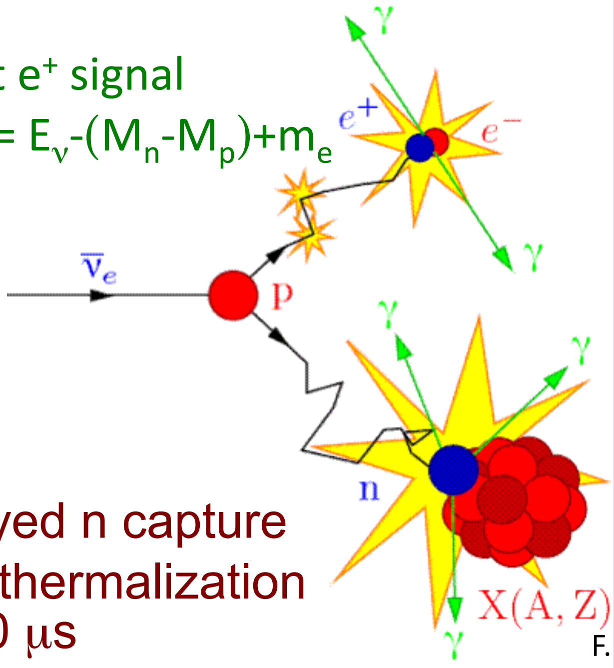


Detection: $\overline{\nu}_e + p \rightarrow e^+ + n$

Threshold: $M_n - M_p + M_e = 1.8$ MeV

Prompt e^+ signal

$E_{prompt} = E_\nu - (M_n - M_p) + m_e$



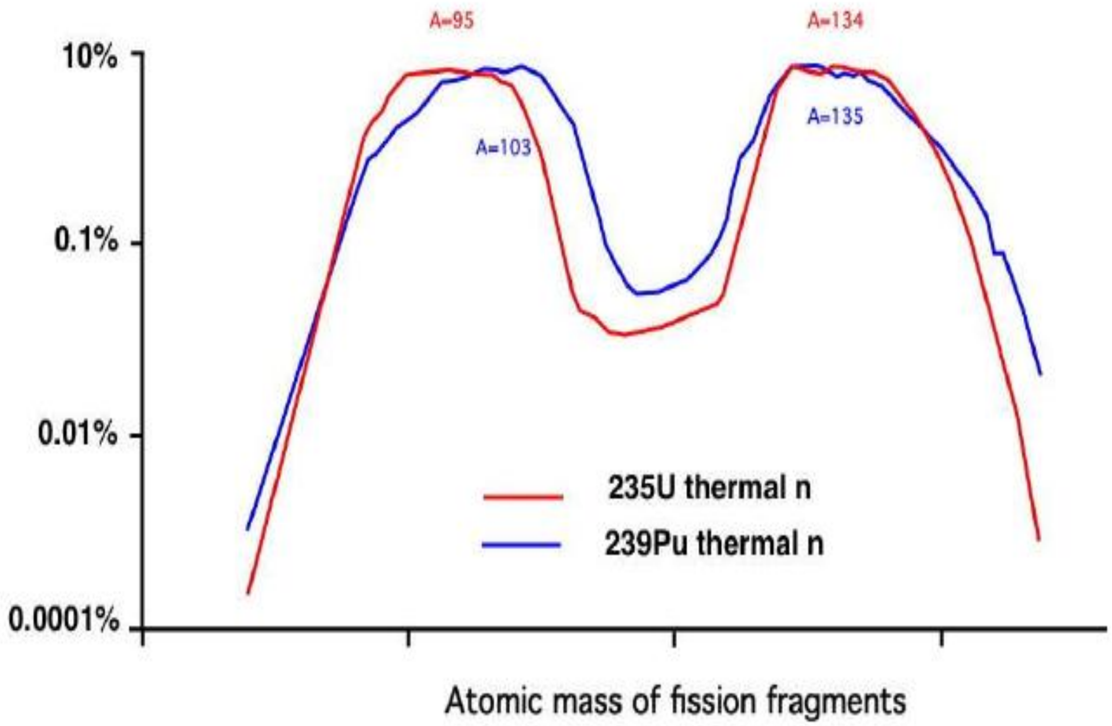
Delayed n capture after thermalization t ~ 30 μs

Detection reaction cross section ~10^{-43} cm^2
→ typical ν detector masses: many 10 tons - some ktons

1ton target @ **25m** of **$1GW_{el}$** reactor gives
~**4600 int./day** ➡ **1% stat** within **5 days**

Miniature ν detector and high statistical precision

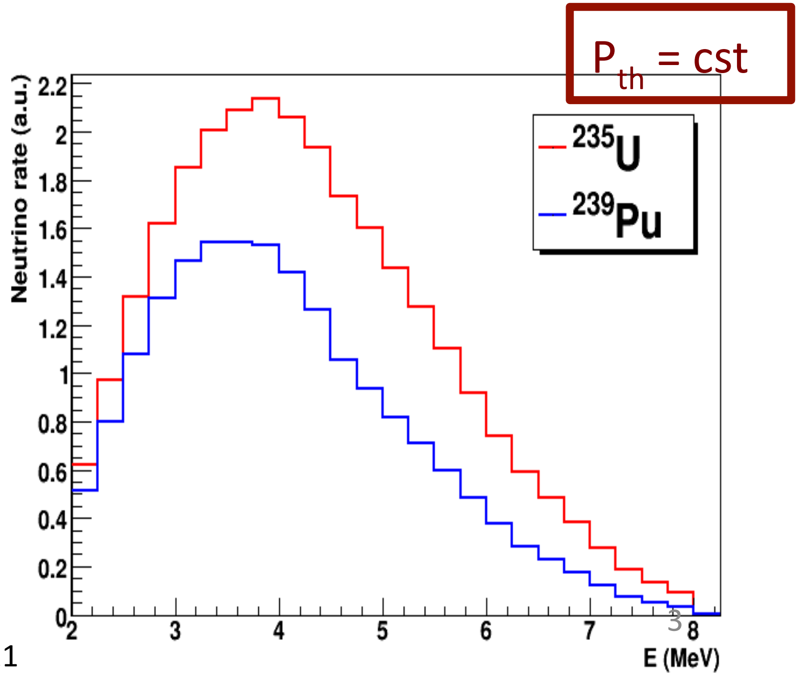
Dependence of neutrino flux on fuel composition.



	^{235}U	^{239}Pu
E / fission *	193.5 MeV	198.9 MeV
$< E_\nu >$ (E_ν>1.8 MeV)	2.94 MeV	2.84 MeV
ν / fission (E_ν>1.8 MeV)	1.92	1.45
$< \sigma_{\nu\ int} >$	≈ 3.2 10^{-43} cm^2	≈ 2.76 10^{-43} cm^2

* $E=E_{dep}-E_n$

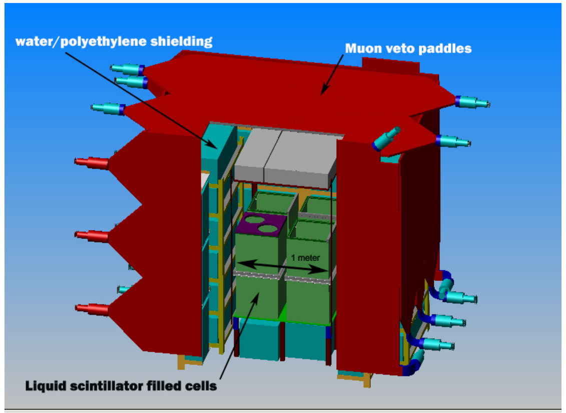
→ For the same released thermal power, one expects to detect **60% less neutrinos from pure ^{239}Pu fissions than from pure ^{235}U**



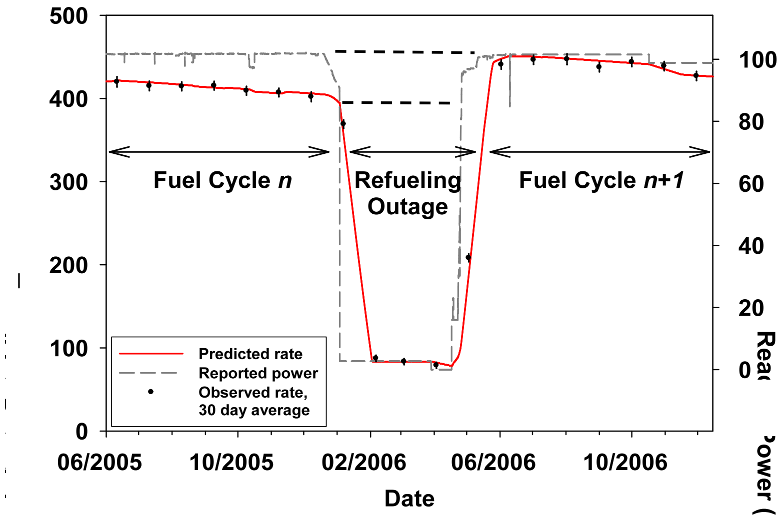
The detection of these neutrinos would give a remote and real time image of the core composition.

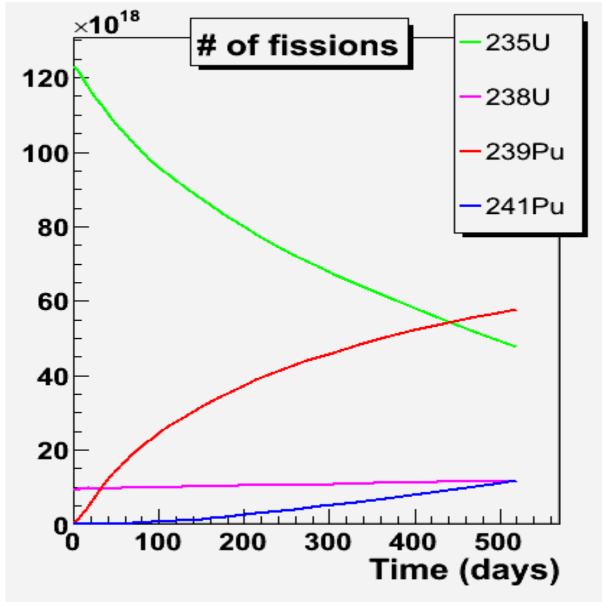
Evolution of neutrino rate

Data from San Onofre



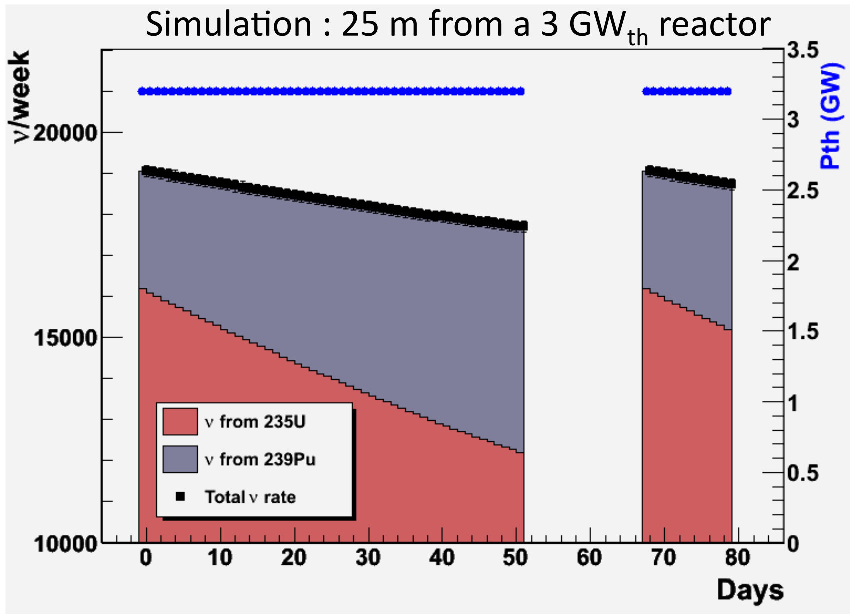
Removal of 250 kg ^{239}Pu, replacement with 1.5 tons of fresh ^{235}U fuel





➔ Sensitive to fuel composition and burn-up

Expected rate in Nucifer



Nucifer & IAEA guidelines

The IAEA asked for a feasibility study to determine whether antineutrino detection methods could provide practical safeguard tools for selected applications (dedicated working group).

- **IAEA Detector Design Guidelines:**
  - –"Small" → 3 m x 3 m x 2,5 m maximum
  - –Do not induce additional safety risk to the power plant
  - –Remote & Easy Operation by Inspectors not trained as neutrino physicists
  - –Reliable for remote operations
  - – **cheap !**

- **Main Challenges of Nucifer for integration into safeguard regime:**
  - ▪Effort to simplify the state-of-the-art design and run close to surface while keeping detector performances

    Attempt: **50% detection efficiency**
  - ▪Proceed to the 'industrialization' of neutrino science

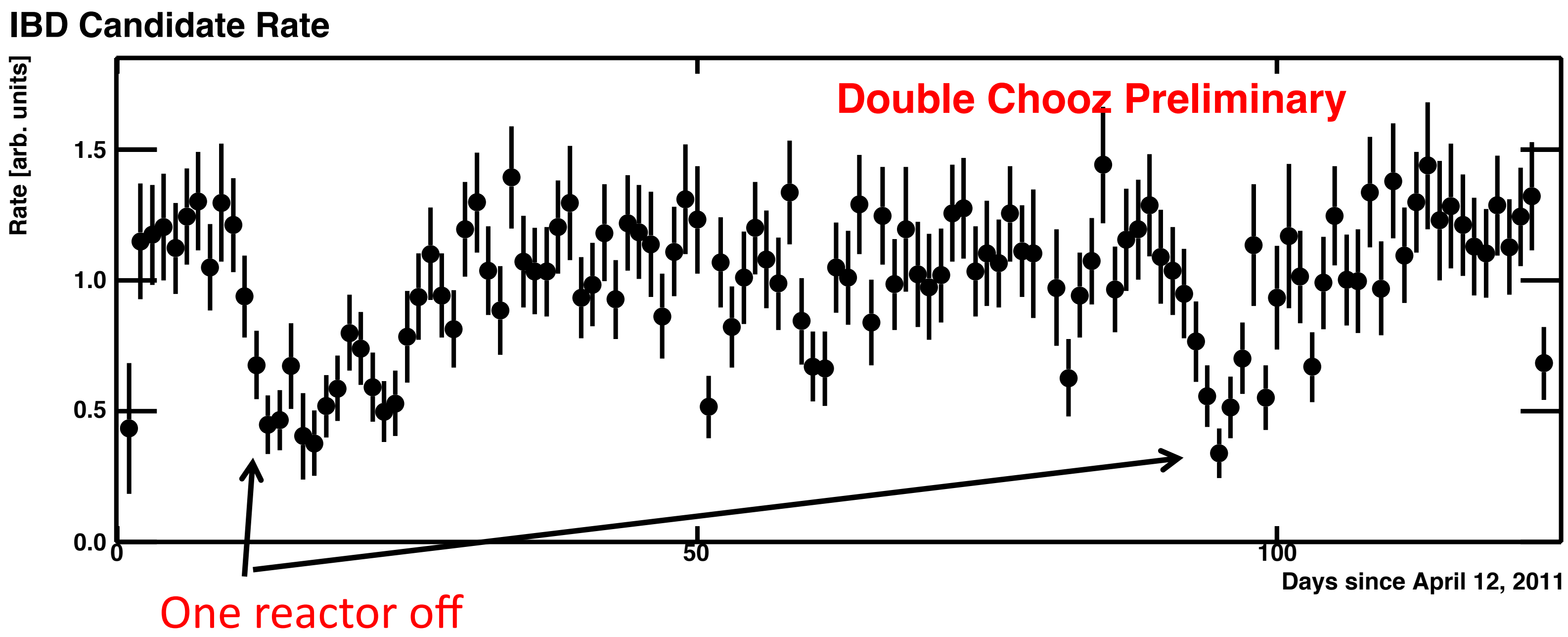
    Using the state-of-the art known technology (Double Chooz synergy)

Synergy with Double Chooz

Calculations to improve antineutrino spectra predictions: Th. Mueller et al., PRC 83 (2011) 054615 and P. Huber, PRC 84 (2011) 024617.

Synergy with Double Chooz

Nucifer's big brother is watching neutrinos since April 2011
More than 4000 accumulated by early September.

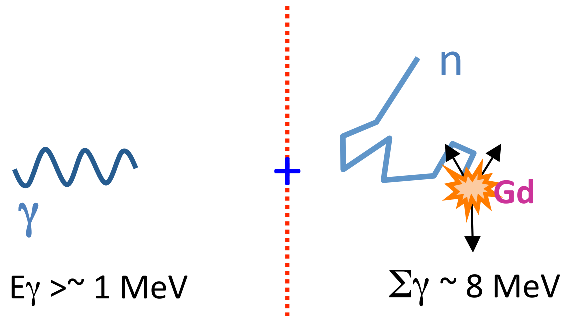


Accurate spectra in the next few Double Chooz, RENO and Daya Bay near detectors!

Backgrounds

Close to surface ➔ big background induced by cosmic ray muons

Accidental background

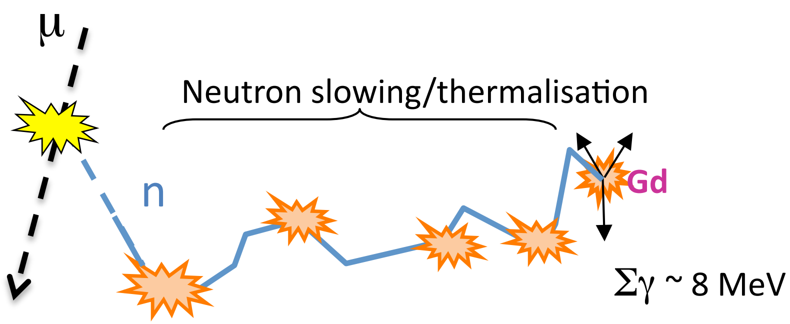


- Natural radioactivity
- Neutrons and gammas from reactors

Rejection:

- Shielding
- Low radioactivity materials
- Random background, ≠ Δt and E spectra, measured online

Correlated background



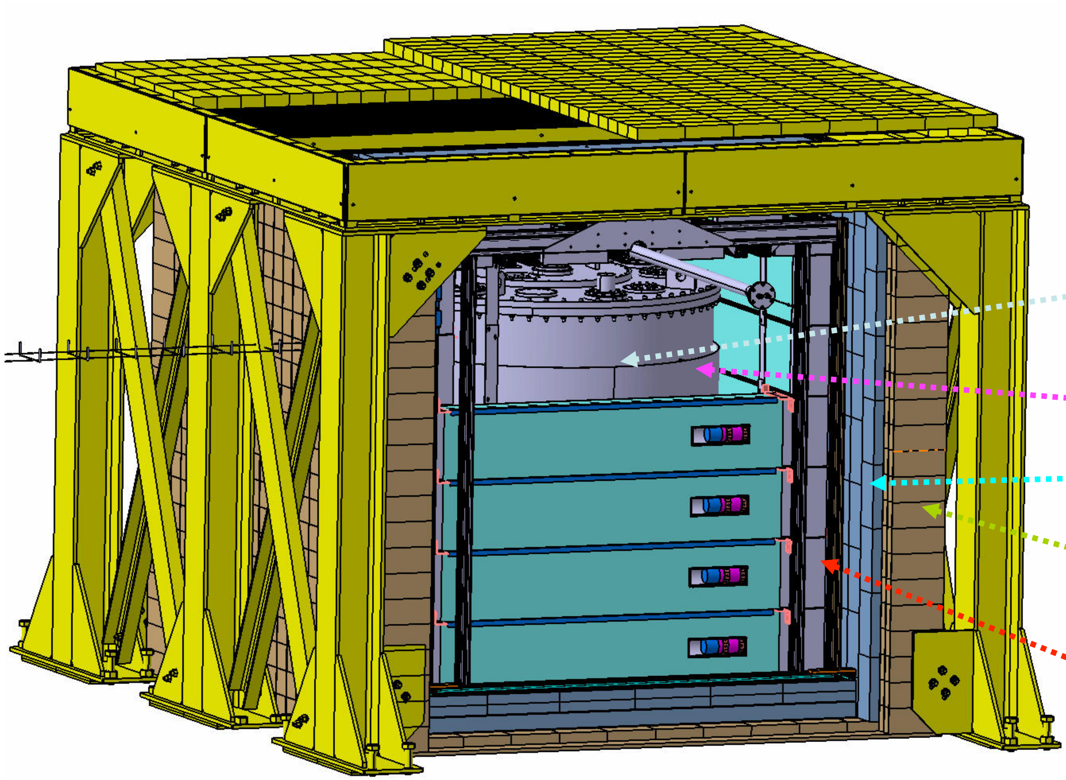
- Muon induced neutrons

Pass E and ΔT ν cuts!

Rejection:

- Overburden (few m.w.e) **+ Active μ veto**
- **Pulse Shape Discrimination (CEA study)**
- Reactor off data

The NUCIFER detector

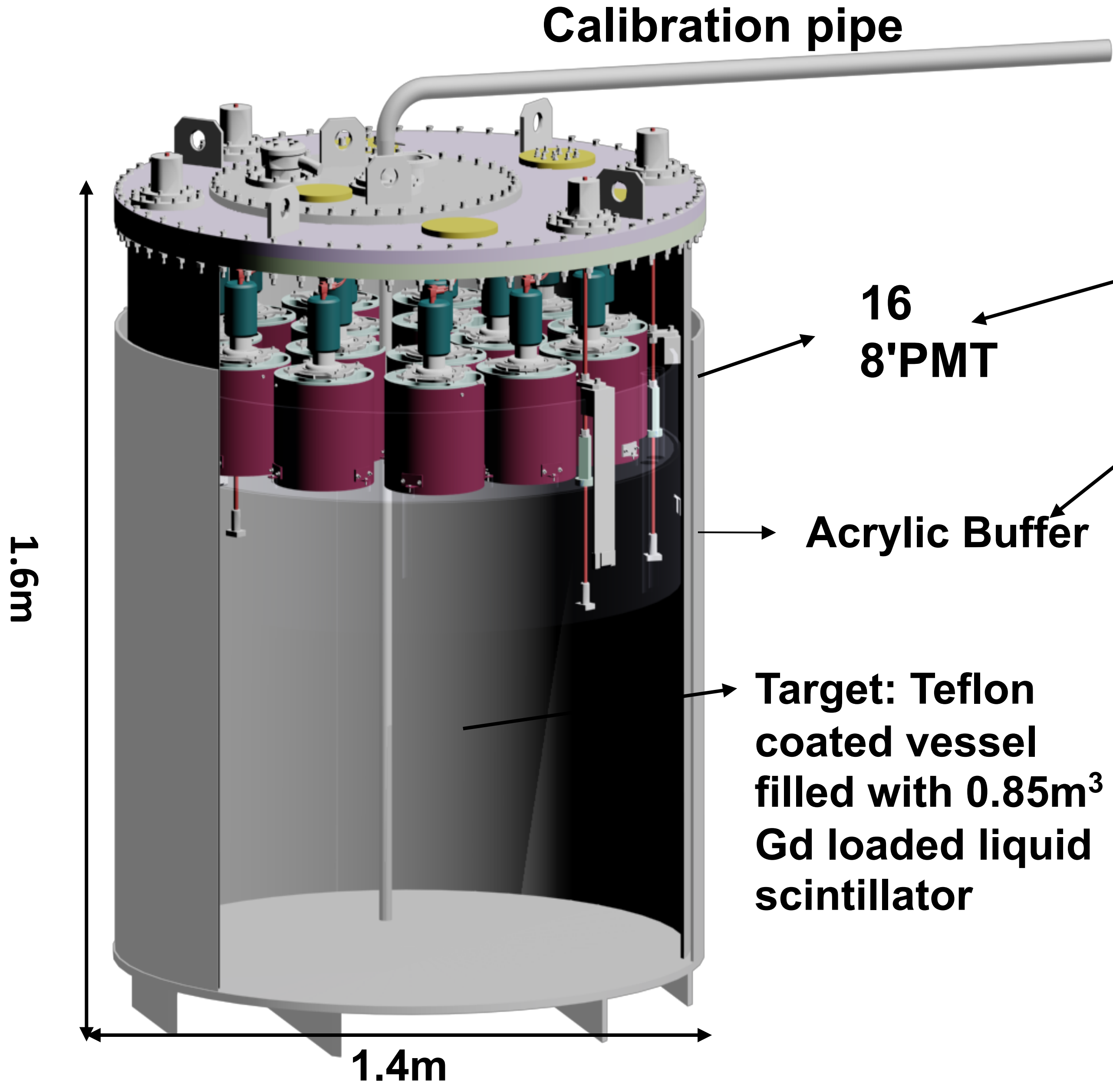


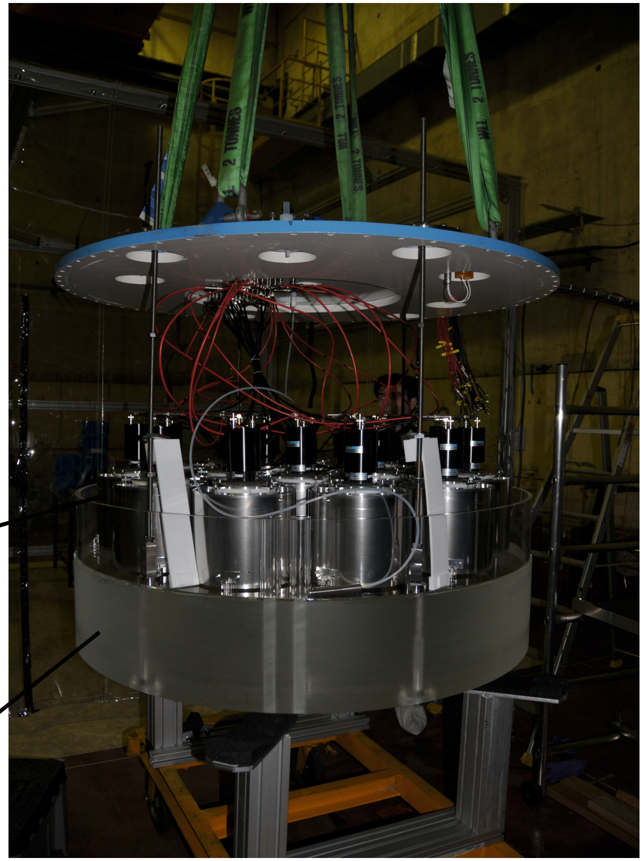
- ➢ **Detector (2.8x2.8m2): monolithic, simple, with 16 PMTs on the top surface:**
  - Target : ~1 m^3 of liquid scintillator doped with Gadolinium
  - Steel tank + internal reflecting paint
  - 14 cm of polyethylene shielding against neutrons
  - 10 cm of lead shielding against gammas
  - Muon veto (5 cm thick plastic scintillators)

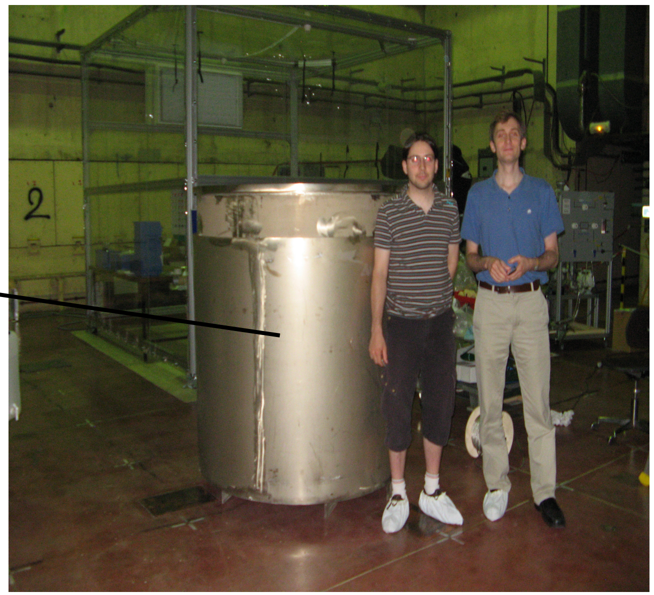
Installation at Osiris research reactor(CEA-Saclay, France, P=70MW_{th})
in autumn 2011: 7 m form reactor core,

Final test at Nuclear Power Plant (2013)

The neutrino detector



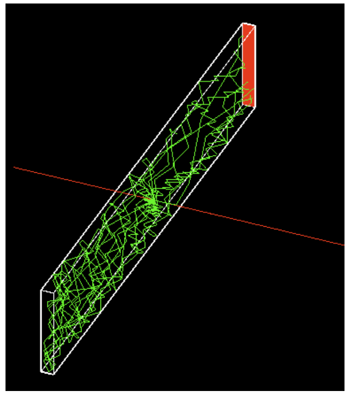


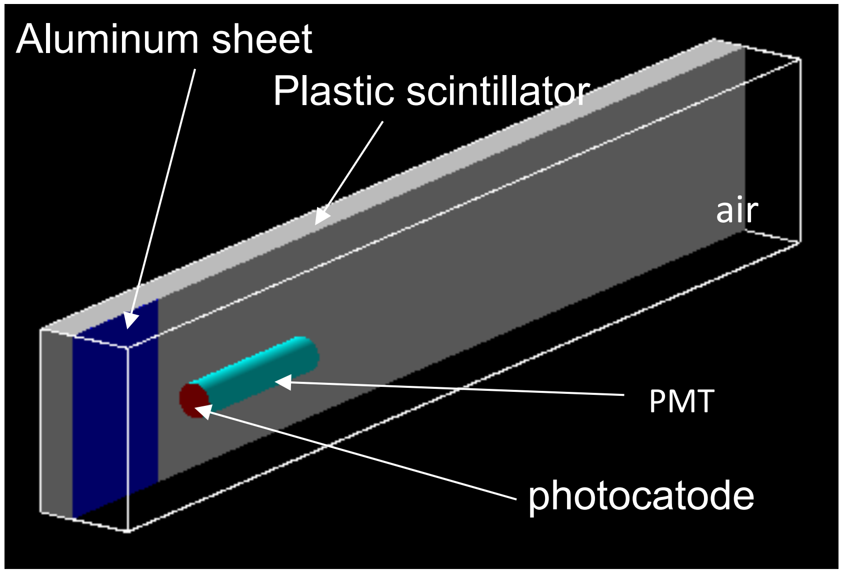


Background Reduction: Muon Veto I

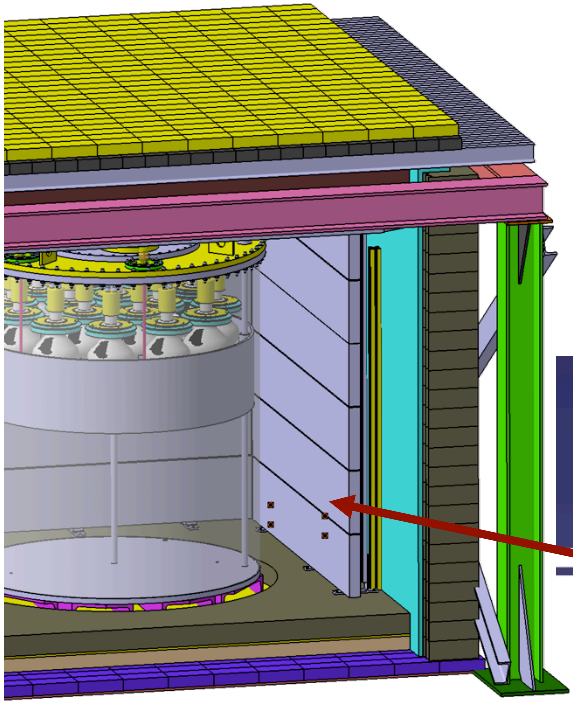
- Near the surface
- ➔ a few kHz of Muons expected (Osiris : 73Hz/m2)
- **Inside the shielding** because of high gamma ray background level close to research reactors (5kHz reactor OFF/5MHz reactor ON, energy distribution up to 10MeV), studied with GEANT4
- Surrounds 5/6th of the target

- Technology: 31 modules : **5cm thick Layer of Plastic Scintillator**
(to avoid Triggering on Ambient Gamma Rays)
viewed by 1 decoupled PMT in a reflective mirror aluminium box
- The response uniformity is ensured by an aluminium sheet placed on the scintillator part in front of the PMT
- applying a threshold to select muons w.r.t gammas
(Design optimization by using **GEANT4 and Litrani simulations**, as light collection studies) ➔

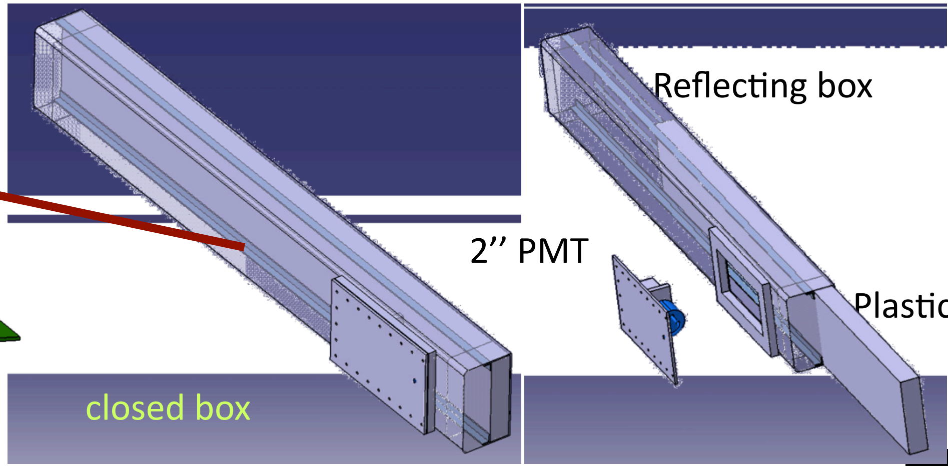


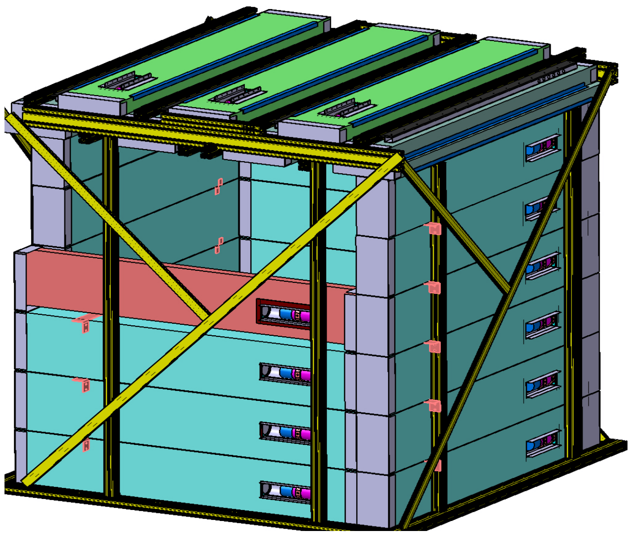


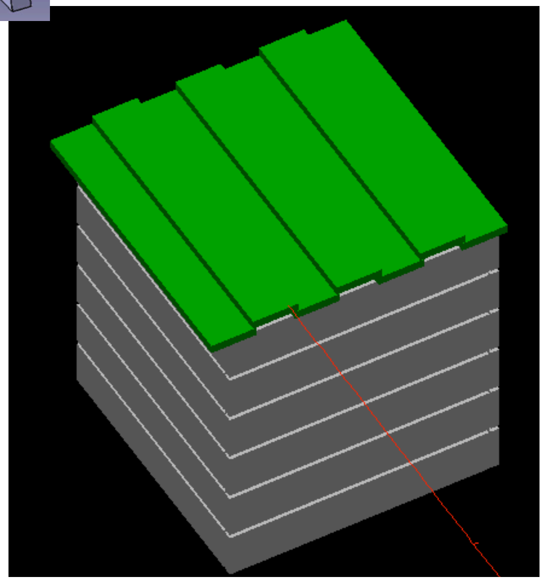
Background Reduction: Muon Veto II



tested concept: 30x180x5cm^3 slats located in a hermetic and reflecting box with one PMT: diffusion in air gap to maximize the response uniformity as a function of the muon crossing position / PMT position

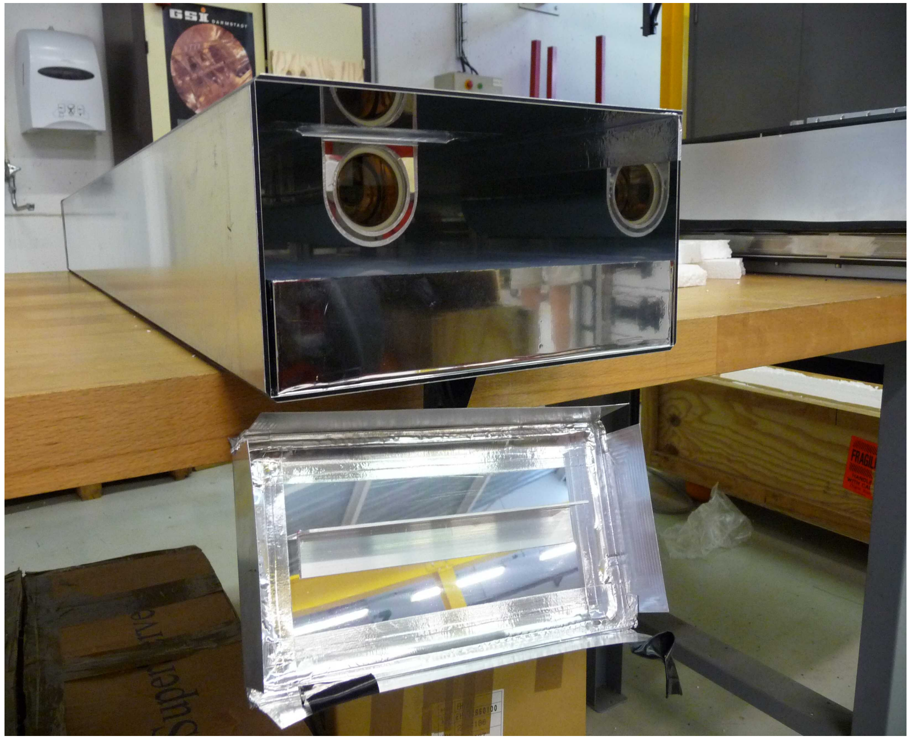


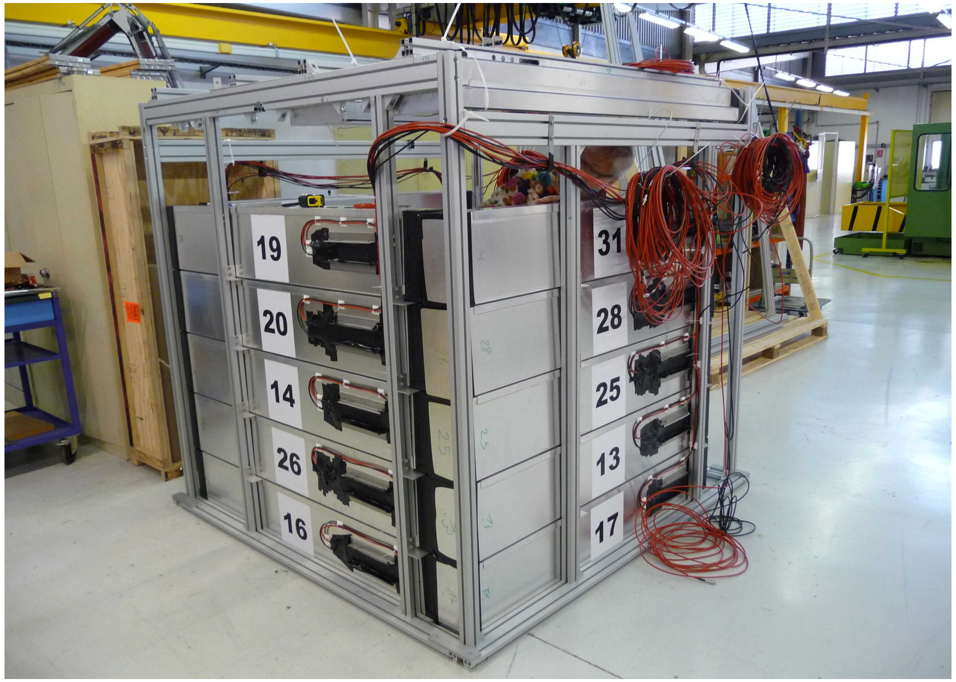




Muon veto performances

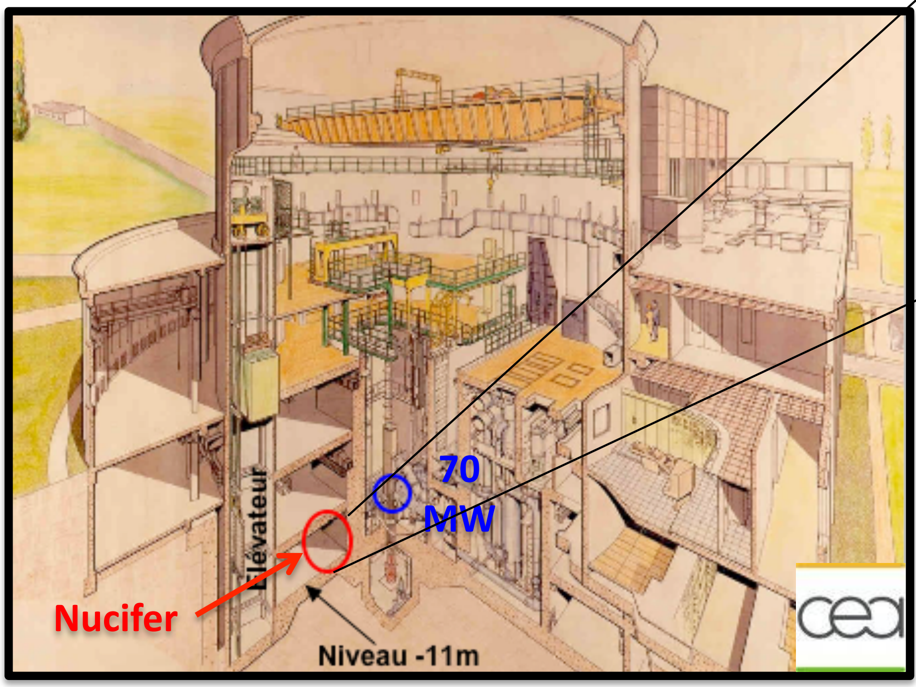
- Test measurements with radioactive sources (Ambe: 4.4 MeV prompt gammas and Co: 1.2 and 1.3 MeV gammas), muon signal and at Orisis research reactor
- Comparison with simulation results
- Muon detection efficiency for each module > 95%
- Maximal non uniformity response factor 2.5
- Energy threshold higher than 2 MeV

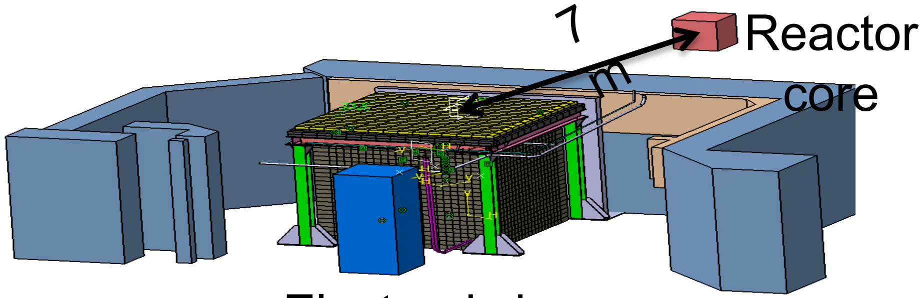




Nucifer @ Osiris

Osiris research reactor at CEA Saclay





- **70 MW reactor**
- **Nucifer 7 m from the core**
- 15 mwe overburden

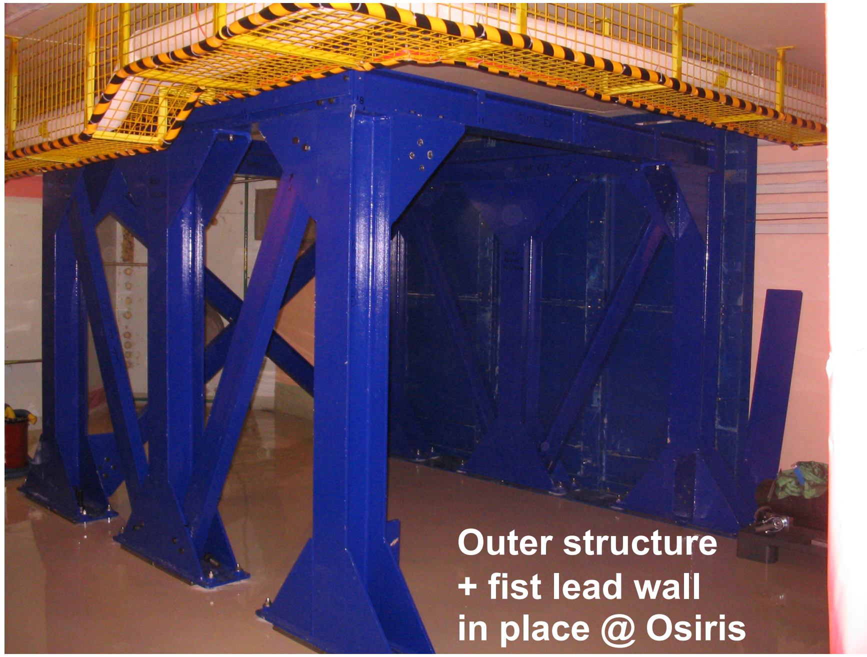
650 ν/day expected
Assuming 50% det efficiency

What we can learn:

- **Limit on sensitivity to reactor neutrino flux measurement (with Nucifer detector performances, i.e. efficiency, resolution…)**
- **Test of our background knowledge and suppression capabilities**
- **Comparison with reactor core and scenario simulation results**
- **Very short baseline oscillation study**

Nucifer installation @ Osiris

First neutrinos expected by the end of 2011.

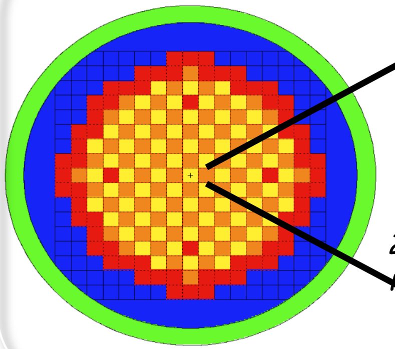


Outer structure
+ fist lead wall
in place @ Osiris

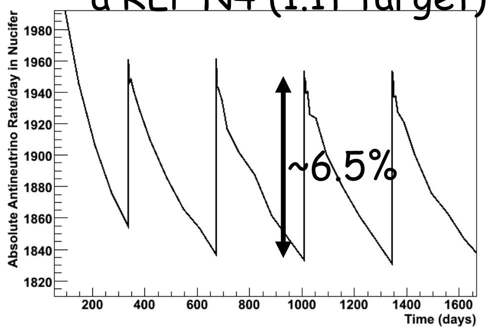
Non proliferation scenario studies

Complex reactor simulations to compute antineutrino emission associated to diversion scenarios, taking into account accurately reactor physics

French N4 PWR full core

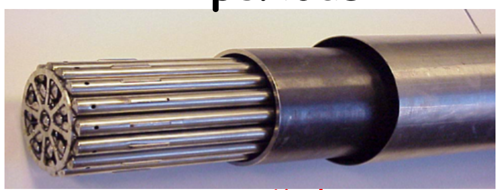


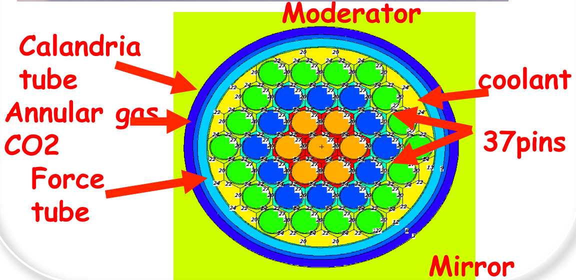
Flux detected in Nucifer at 25m of a REP N4 (1.1t target)



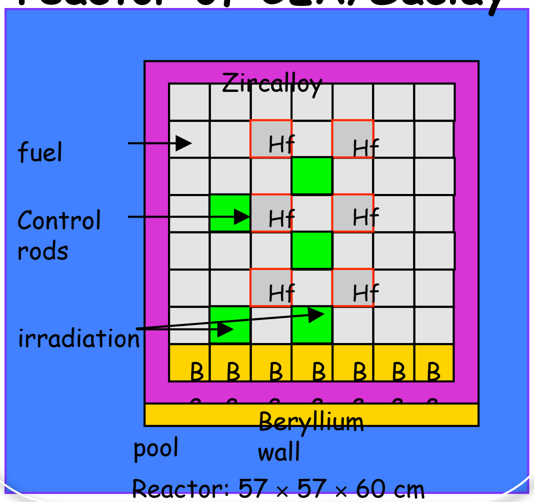
MCNP **U**tility for **R**eactor **E**volution O. Méplan et al. ENC Proceedings (2005) Developped by CNRS/IN2P3/IPNO and LPSC for Generation IV reactor simulations

CANDU 600 channels with different refueling periods

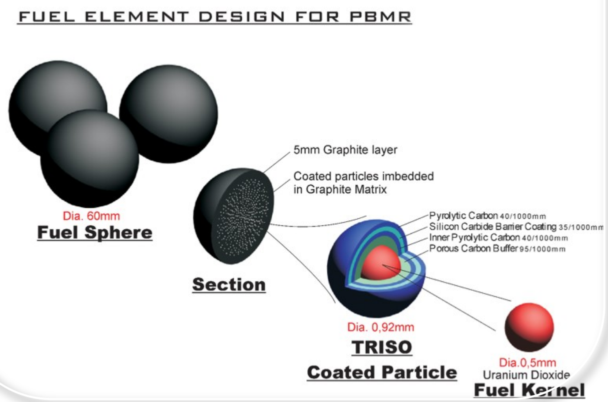




OSIRIS research reactor of CEA/Saclay



VHTR pebbles and full core (on-going)



Conclusions

Neutrino detection is a promising method for reactor survey:

- The challenge is a small ν detector close to the earth surface

  ➔ If we go at some 10 m from reactor core with a 1 ton detector we can have a good statistic within few days

  ➔ Optimization of background shielding and background rejection methods

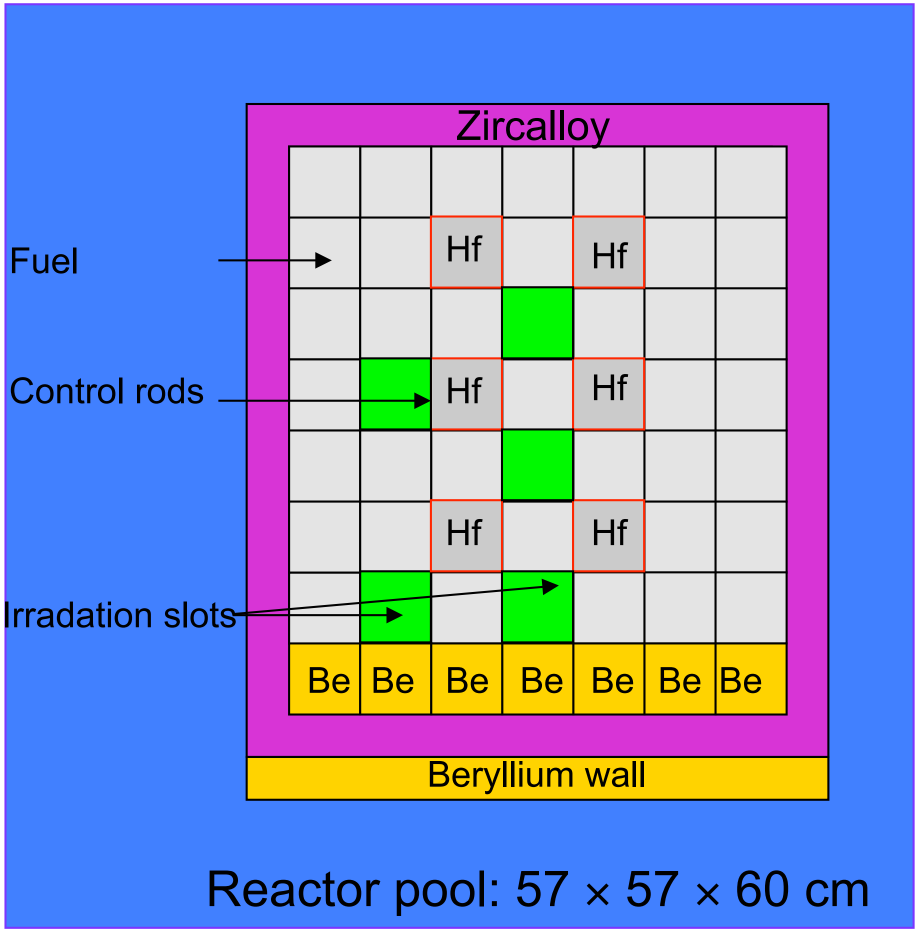
  ➔ Detector has to respect IAEA requirements

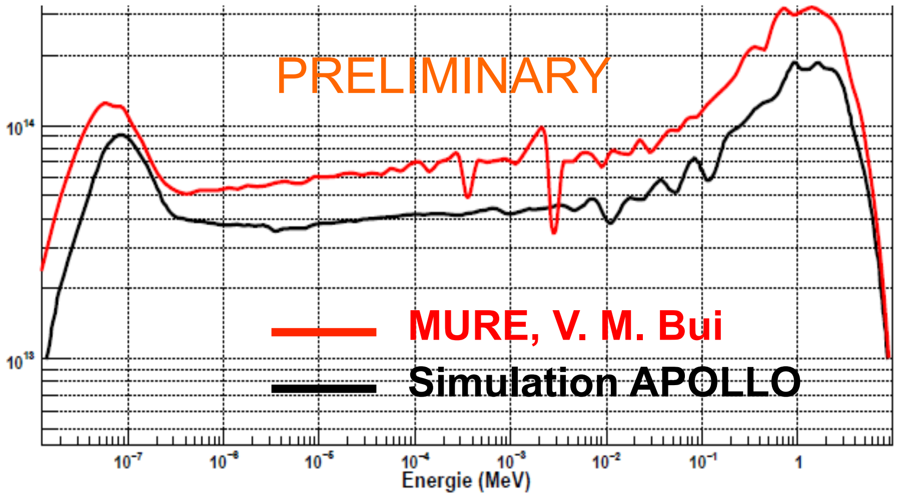
  ➔ Possible hint of 4th neutrino without affecting future non-proliferation potential.

- We are installing Nucifer @ 7 m from the Osiris research reactor core.

- First neutrino event expected for start 2012

Osiris reactor simulation with MURE





Simulated without taking into account real reactor core operation history yet
➔ differences in absolute normalization and presence of resonances

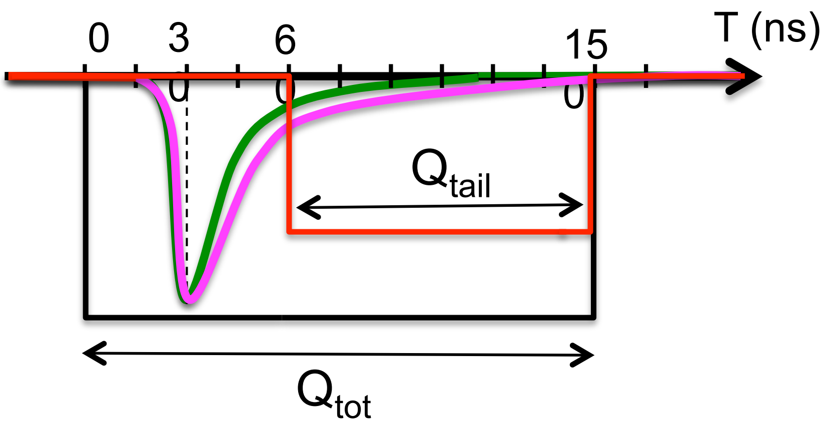
1 fuel element:22 slats U_3Si_2Al

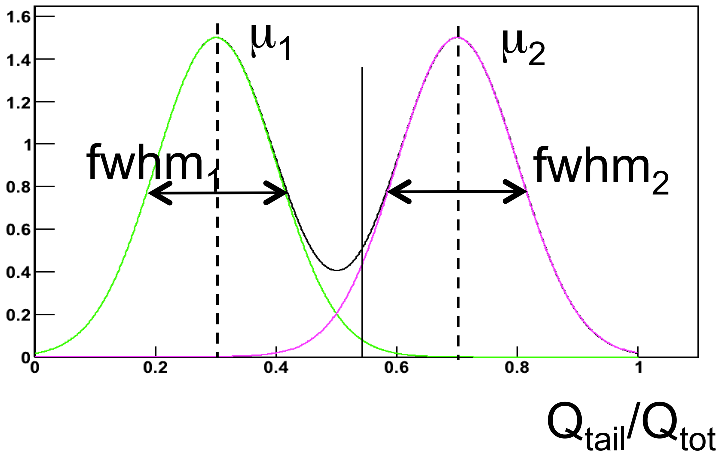
Pulse Shape Discrimination

PSD in organic liquid scintillators: due to long-lived decay of scintillator light caused by high dE/dx particles

e-like signal

recoil-proton signal

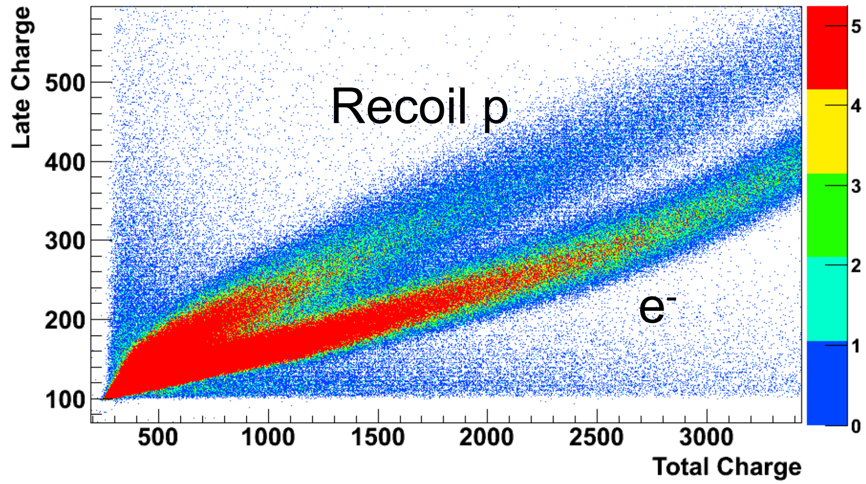


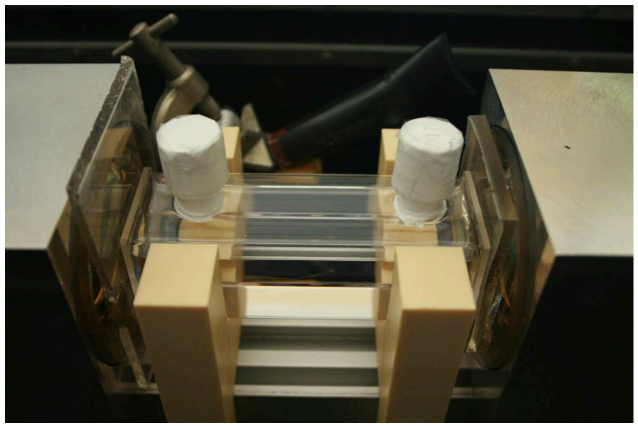


$$\text{Figure Of Merit} = \frac{\mu_2 - \mu_1}{fwhm_1 + fwhm_2}$$

In this example FoM = 0.85

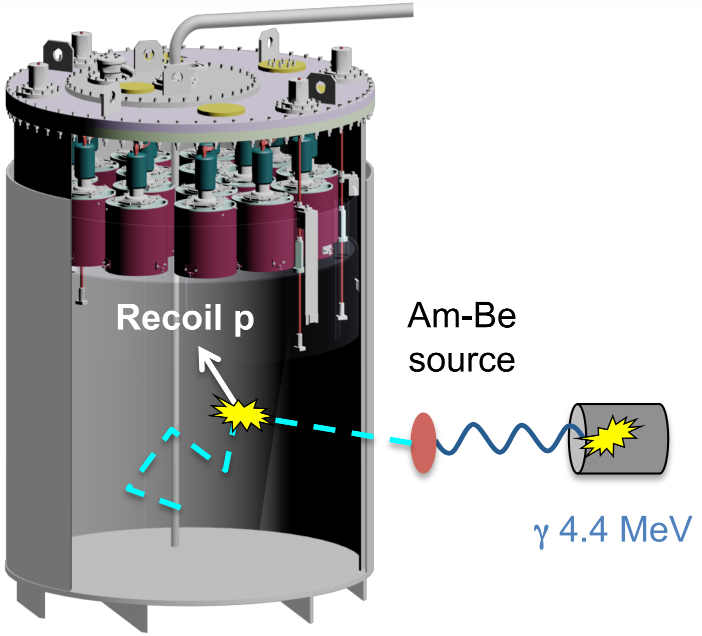
PSD of Eljen-331 liquid in 100 ml test cell



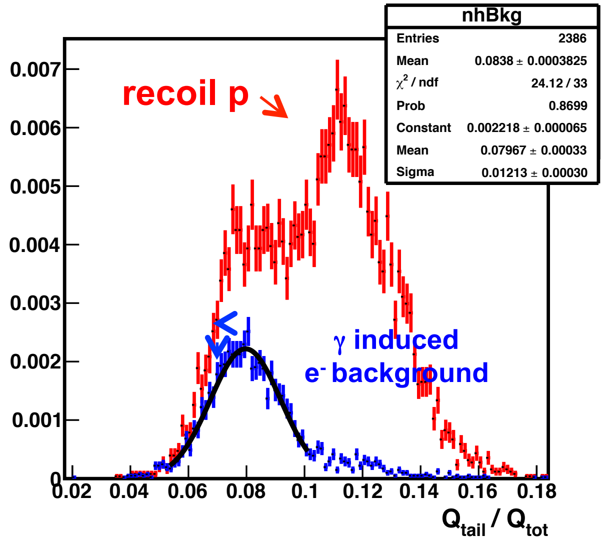


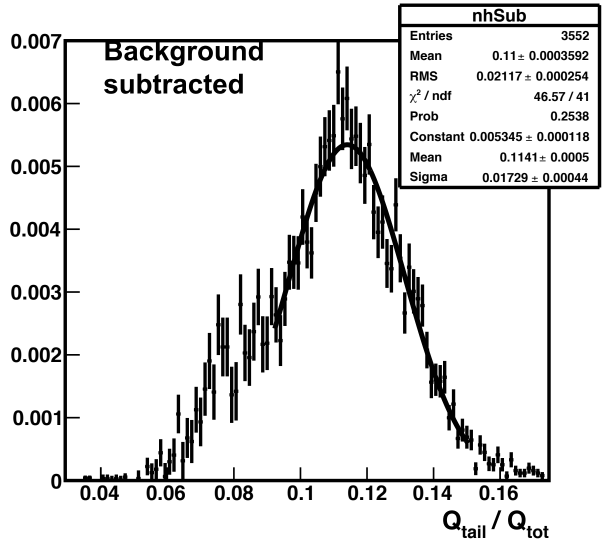
Measured FoM:
- Lab+PPO: 0.55
- EJ-331: 1.1

PSD in Nucifer detector

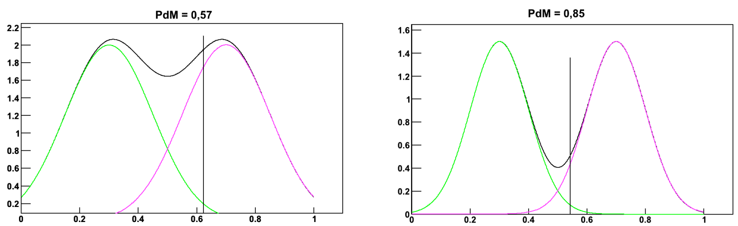


In Nucifer : FoM of LAB+PPO ~ 0.50





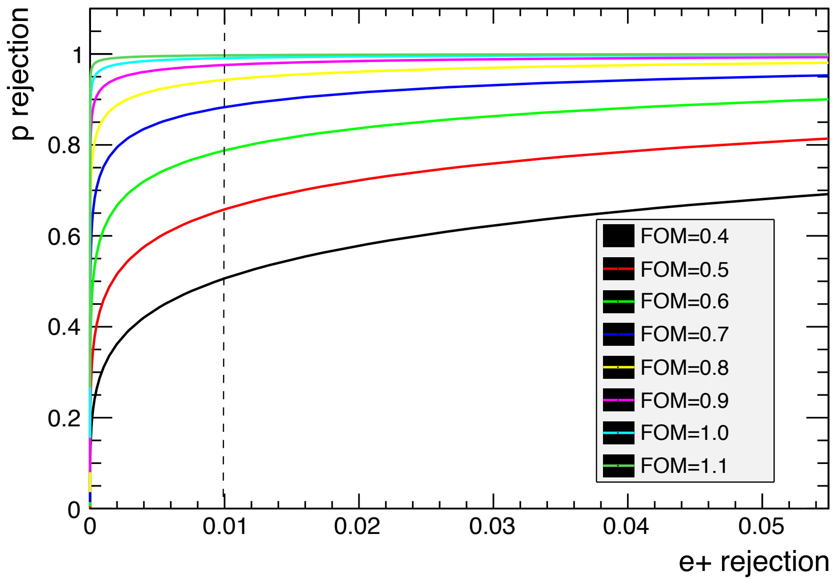
→ configuration of the Nucifer vessel preserves an e-p separation at quasi same level than in small test cell.



Requiring 99% signal efficiency:

- 50% rejection measured with test liquid
- ~90% rejection expected with final liquid

Chart of fast neutron reiection



Remote control

- Remote control of acquisition system, PMT high voltage setting and monitoring, run start and slow control.
- The data output and possible alarms can be also monitored on-line by a simple understanding display.
- The detector stability and linearity are monitored at the 1% level using 4 independent LEDs.