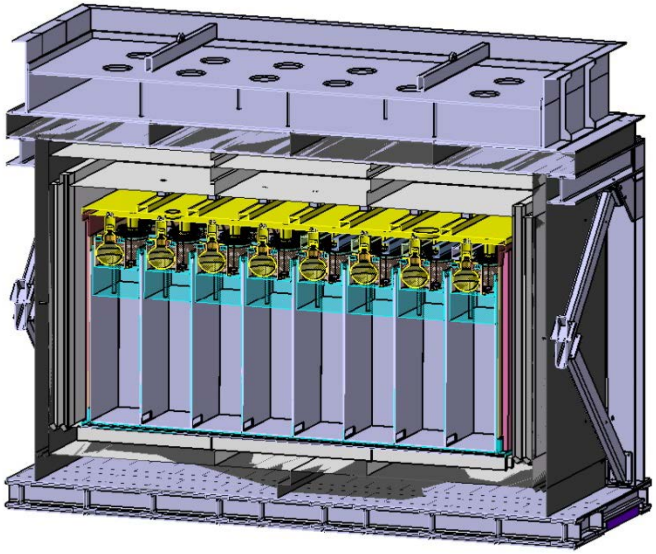
The STEREO experiment: search for a sterile neutrino



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on behalf of the STEREO collaboration

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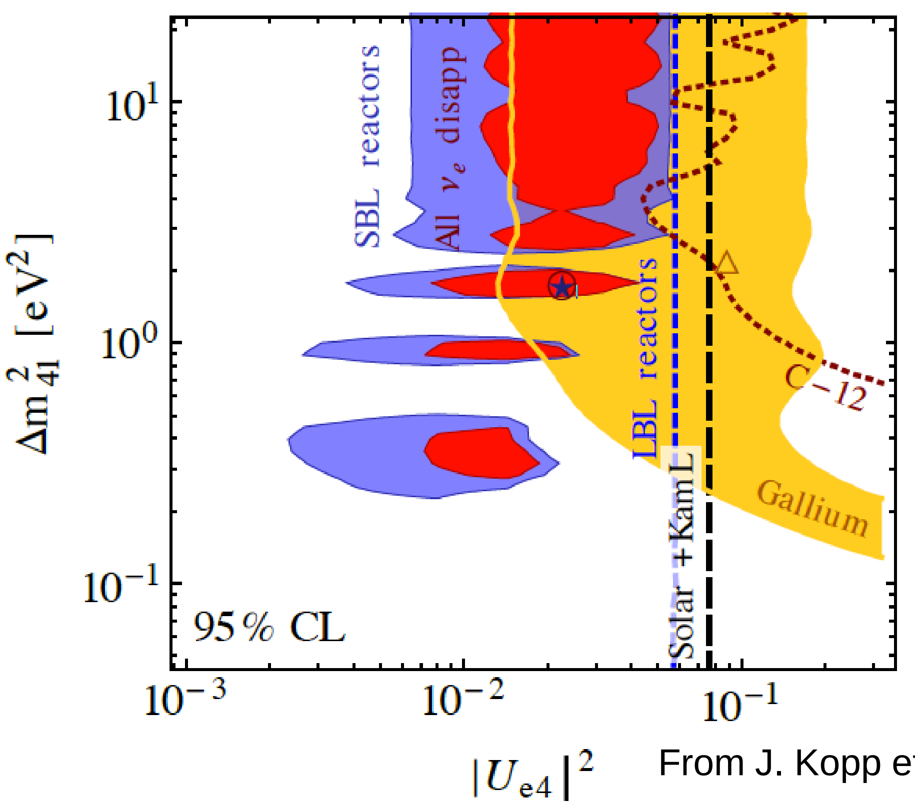
Scientific motivation

Few anomalies in the neutrino oscillation global picture (3 neutrinos):

- LSND/MiniBoone ($\bar{\nu}_\mu \rightarrow \bar{\nu}_e$, $\nu_\mu \rightarrow \nu_e$, accelerators) = excess of ν_e
- «Reactor anomaly» = $\bar{\nu}_e$ deficit (3 σ) at short distance from reactors (5-100 m)
- «Gallium anomaly» = ν_e deficit (3 σ) in gallium solar neutrinos détectors with calibration sources

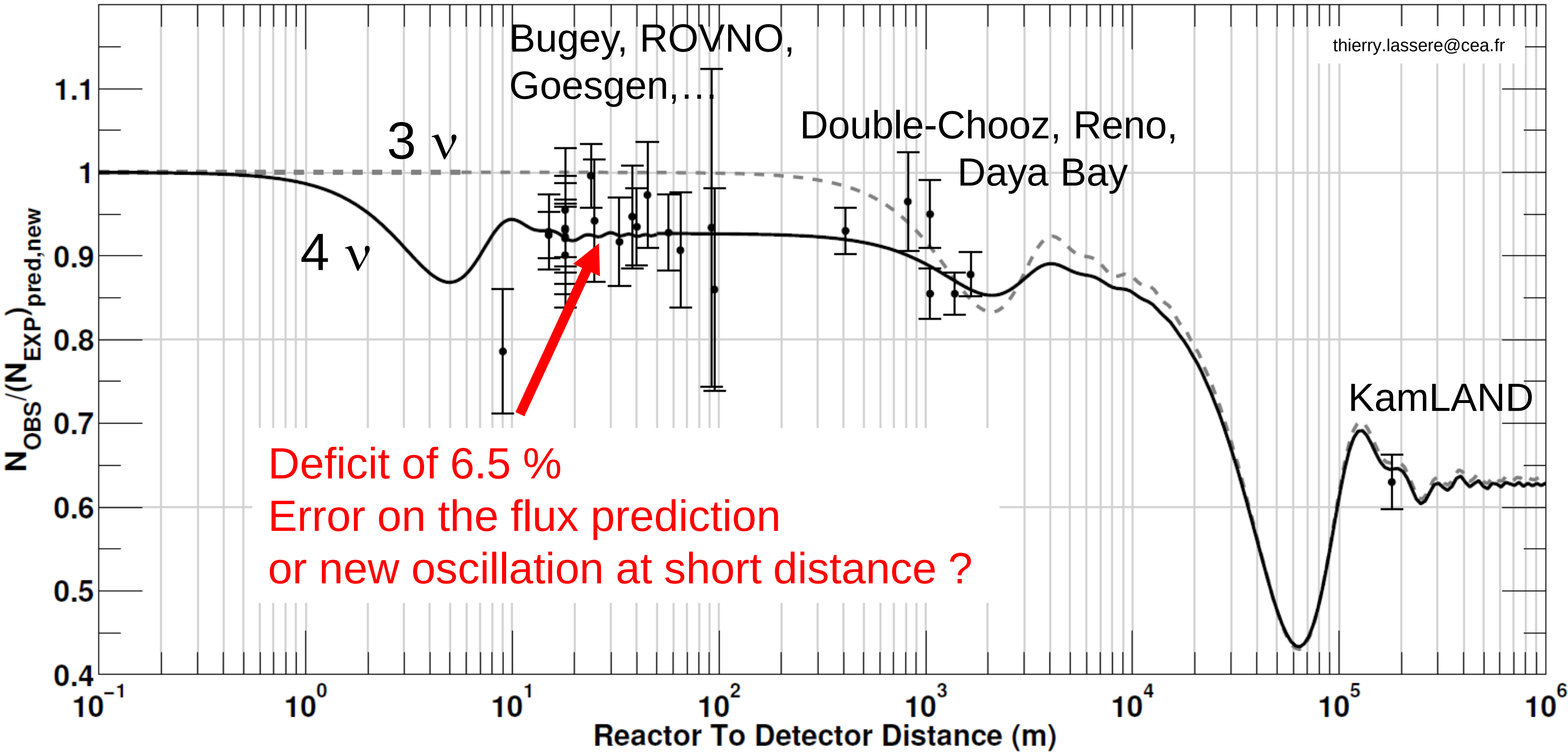


From J. Kopp et al., arXiv:1303.3011

Could be an evidence of one (or more) sterile neutrino at 1eV scale
(although tensions exist when doing a global fit with all experiments)

The Reactor Antineutrino Anomaly

Nuclear reactors as a source of electronic antineutrinos



$$P_{\bar{\nu}_e \to \bar{\nu}_e} = 1 - \boxed{\sin^2 2\Theta_{14} \sin^2\left(1.27\Delta m^2_{41} \frac{L}{E}\right)} - \boxed{c^4_{14} \sin^2 2\Theta_{13} \sin^2\left(1.27\Delta m^2_{31} \frac{L}{E}\right)} - \boxed{c^4_{14} c^4_{13} \sin^2 2\Theta_{12} \sin^2\left(1.27\Delta m^2_{21} \frac{L}{E}\right)}$$

Sterile neutrino search

The basic idea is to measure relative distortions of the $\bar{\nu}_e$ energy spectrum as a function of the distance

Survival probability $$P_{\bar{\nu}_e \to \bar{\nu}_e} = 1 - \boxed{\sin^2 2\Theta_{14} \sin^2 (1.27 \Delta m^2_{41} \frac{L}{E})}$$ Distance Energy

⇒ Independent from the reactor flux normalization

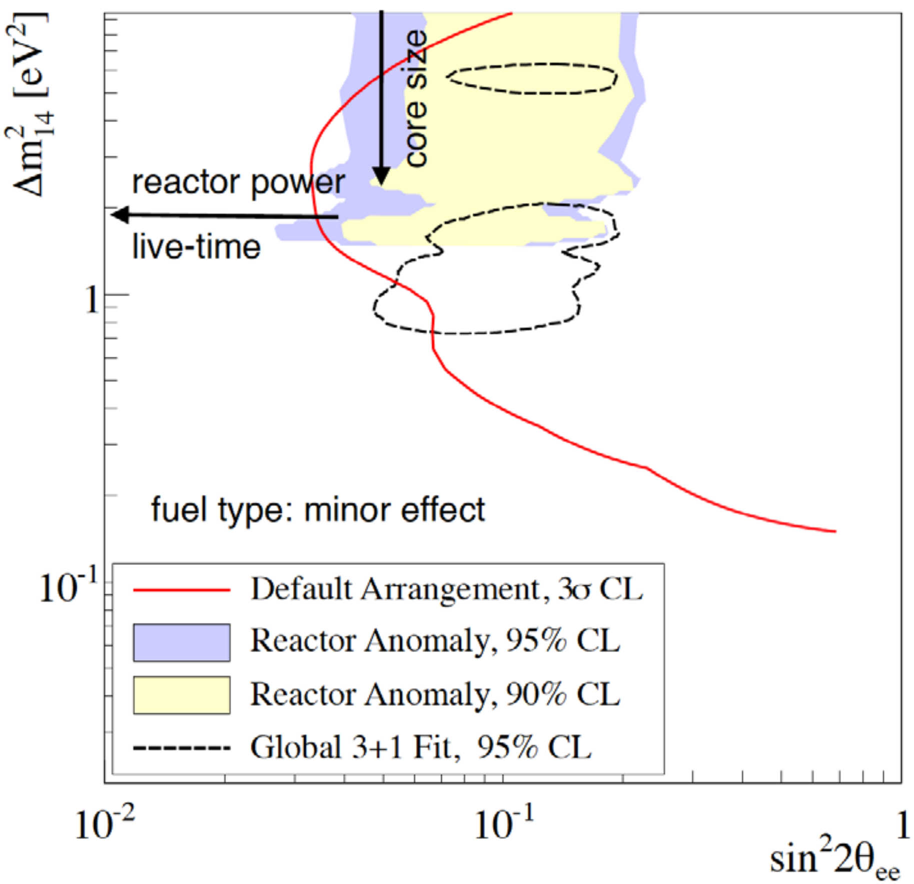
You need:

- a pure source of $\bar{\nu}_e$ (1-10 MeV) = better if compact and powerful

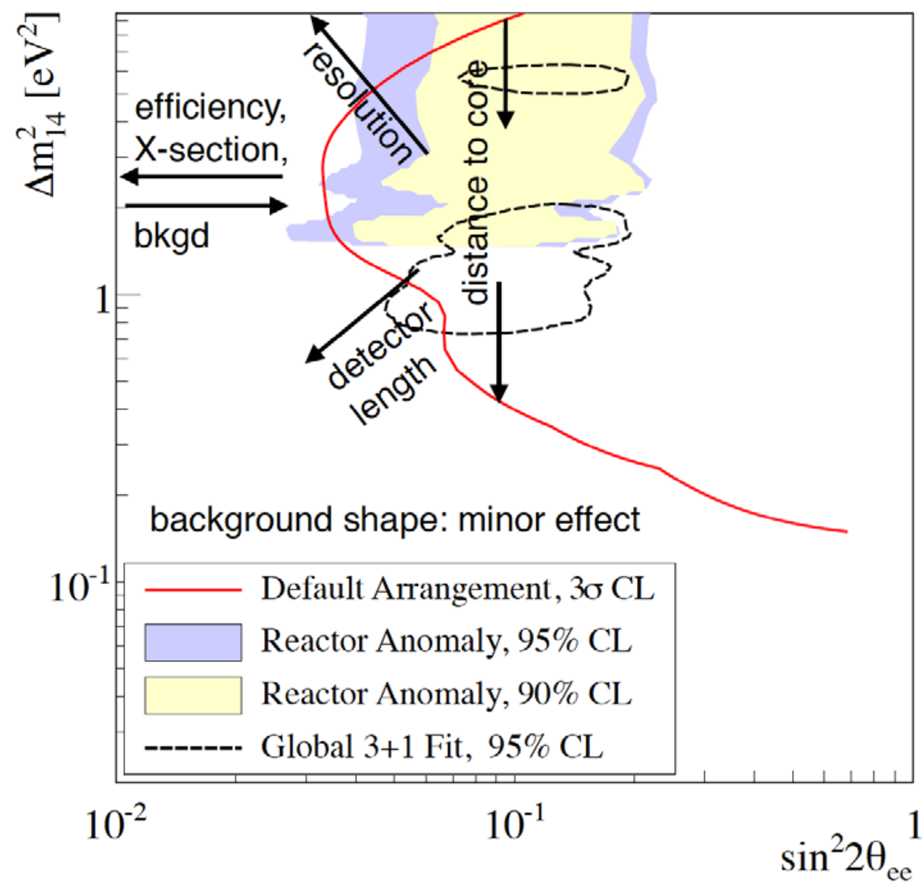
- a detector at short distance (~10 m) able to measure the energy spectrum at several distances (segmented or movable)

Key parameters

Reactor



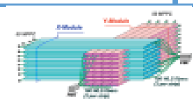
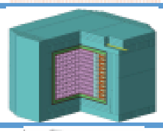
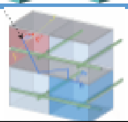
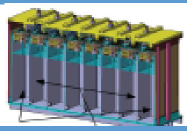
Detector



From K.M. Heeger et al. Arxiv 1212.2182v1

Experiments

From N. Bowden talk @Neutrino2016

Experiment	Reactor Power/Fuel	Overburden (mwe)	Detection Material	Segmentation	Optical Readout	Particle ID Capability
DANSS (Russia) 	3000 MW LEU fuel	~50	Inhomogeneous PS & Gd sheets	2D, ~5mm	WLS fibers.	Topology only
NEOS (South Korea) 	2800 MW LEU fuel	~20	Homogeneous Gd-doped LS	none	Direct double ended PMT	recoil PSD only
nuLat (USA) 	40 MW ^{235}U fuel	few	Homogeneous ^{6}Li doped PS	Quasi-3D, 5cm, 3-axis Opt. Latt	Direct PMT	Topology, recoil & capture PSD
Neutrino4 (Russia) 	100 MW ^{235}U fuel	~10	Homogeneous Gd-doped LS	2D, ~10cm	Direct single ended PMT	Topology only
PROSPECT (USA) 	85 MW ^{235}U fuel	few	Homogeneous ^{6}Li-doped LS	2D, 15cm	Direct double ended PMT	Topology, recoil & capture PSD
SoLid (UK Fr Bel US) 	72 MW ^{235}U fuel	~10	Inhomogeneous ^{6}LiZnS & PS	Quasi-3D, 5cm multiplex	WLS fibers	topology, capture PSD
Chandler (USA) 	72 MW ^{235}U fuel	~10	Inhomogeneous ^{6}LiZnS & PS	Quasi-3D, 5cm, 2-axis Opt. Latt	Direct PMT/ WLS Scint.	topology, capture PSD
Stereo (France) 	57 MW ^{235}U fuel	~15	Homogeneous Gd-doped LS	1D, 25cm	Direct single ended PMT	recoil PSD

The STEREO collaboration

NEUTRONS FOR SCIENCE

Laboratoire d'Annecy-le-Vieux de Physique des Particules

Grenoble

Laboratoire de Physique Subatomique et de Cosmologie

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

~25 physicists

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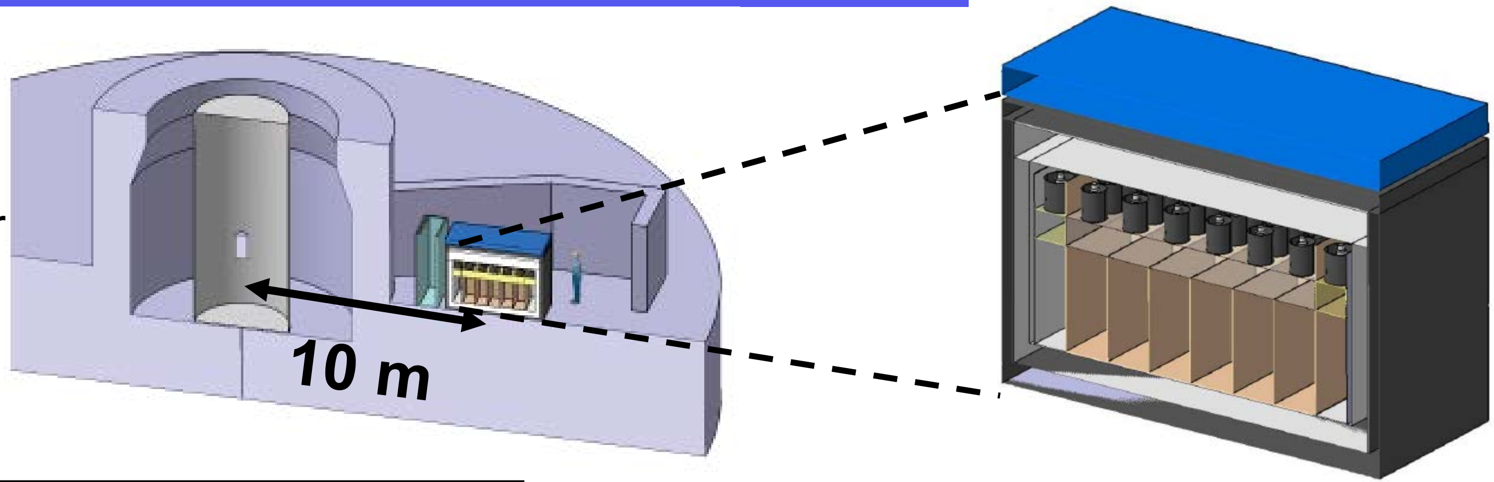
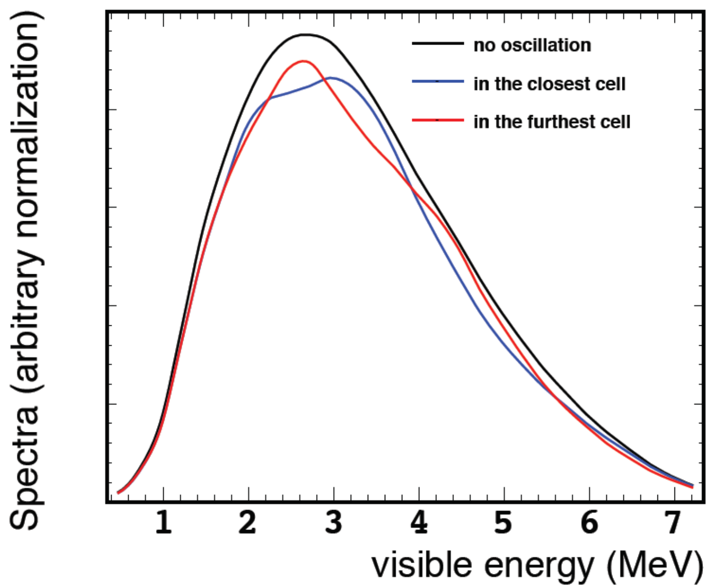
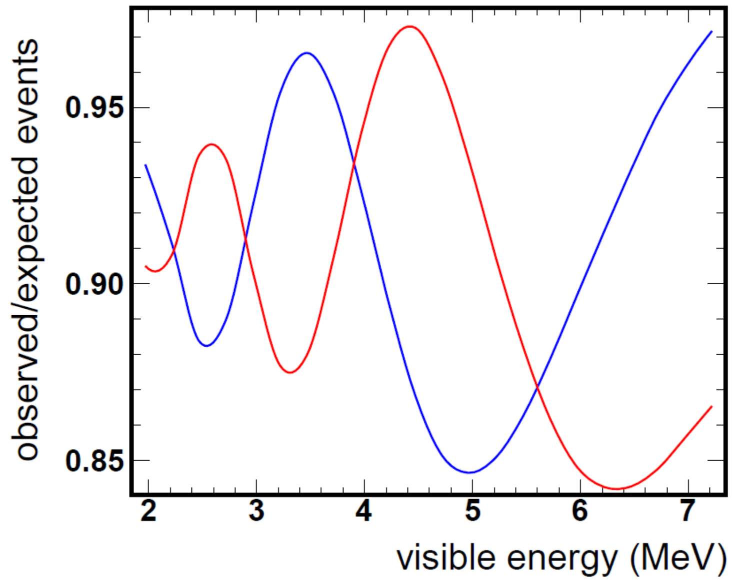
PROJET FINANCÉ PAR L'ANR · ANR · PROJECT FUNDED BY THE ANR

The STEREO experiment

ILL nuclear reactor

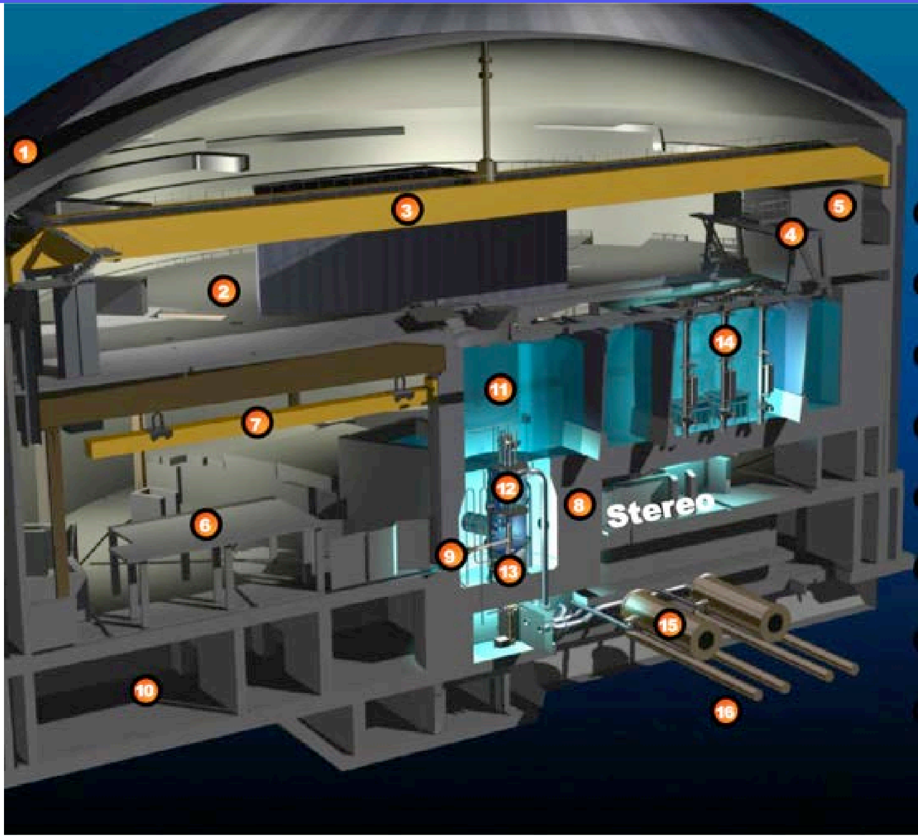


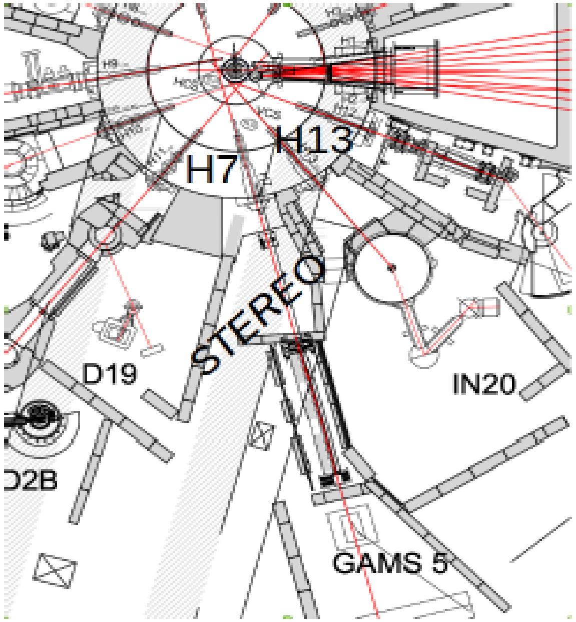




ILL site

- 58 MW research reactor
- High ^{235}U enrichment
- compact core < 1m
- [8.9–11.1] m from core, possible extension to 12.3 m.
- Overburden of water channel (15 mwe)
- 4x50 days cycles each year



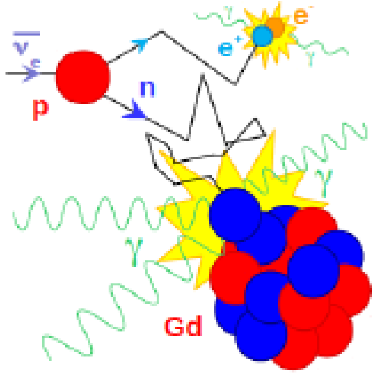


But :

- limited space
- high level of background due to neutron experimental lines

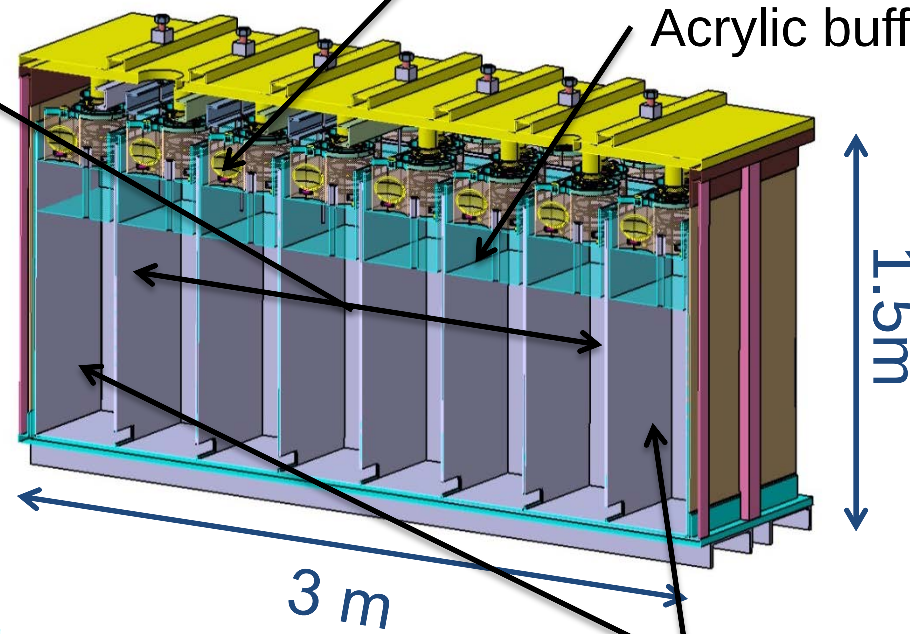
The STEREO detector

6 target cells filled with Gd-loaded liquid scintillator



Readout from top: 4 PMTs per cell

Acrylic buffer



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

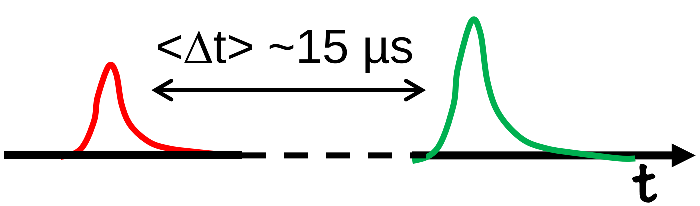
$E_\nu > 1.8$ MeV

$$n + Gd \rightarrow Gd + \gamma s$$

$$e^+ + e^- \rightarrow \gamma\gamma$$

Outer volume filled with liquid scintillator without Gd to reduce edge effects and tag external backgrounds

Signature = time coincidence between a prompt light signal (e^+) and a delayed light signal (n capture).



➡ $E_\nu = E_{prompt} + 0{,}8$ MeV

~ 400 ν_e / day for $E_\nu > 2.8$ MeV

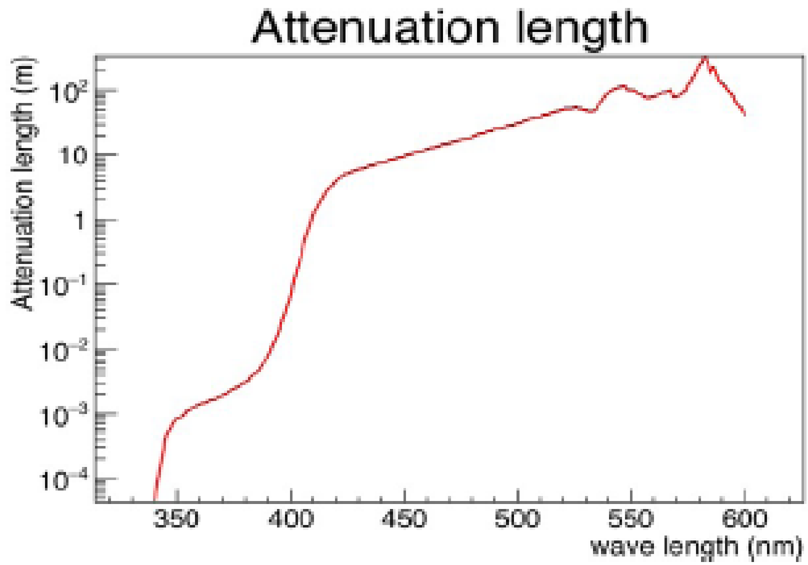
Liquid scintillator and PMTs

Liquid scintillator

75% LAB + 20% PXE + 5% DIN

Light yield ≈ 6000 photons / MeV

Attenuation length > 5 m

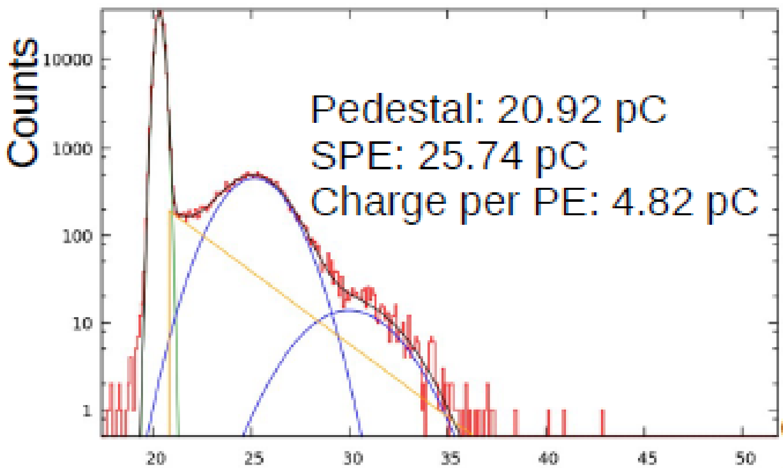


Photomultipliers :

48 PMTs HAMAMATSU R5912-100

Quantum efficiency ≈ 30%

Peak/valley ratio : 2.7

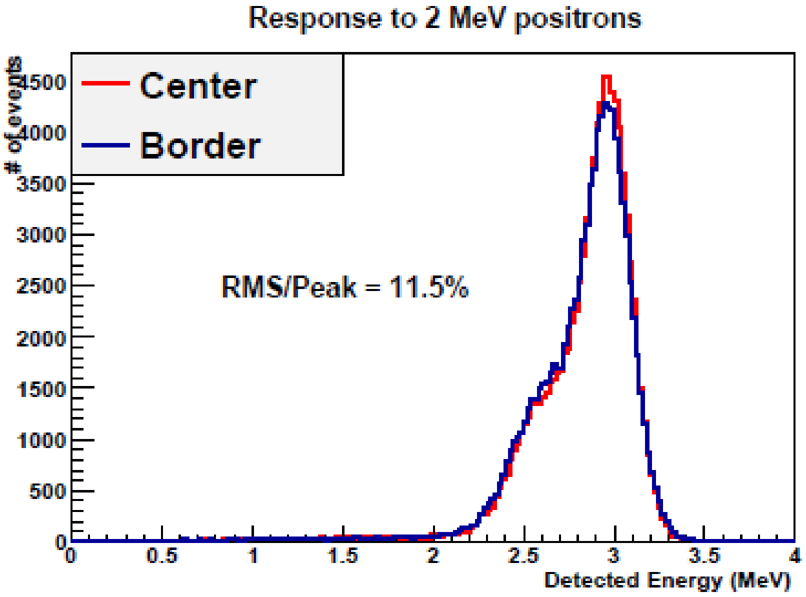


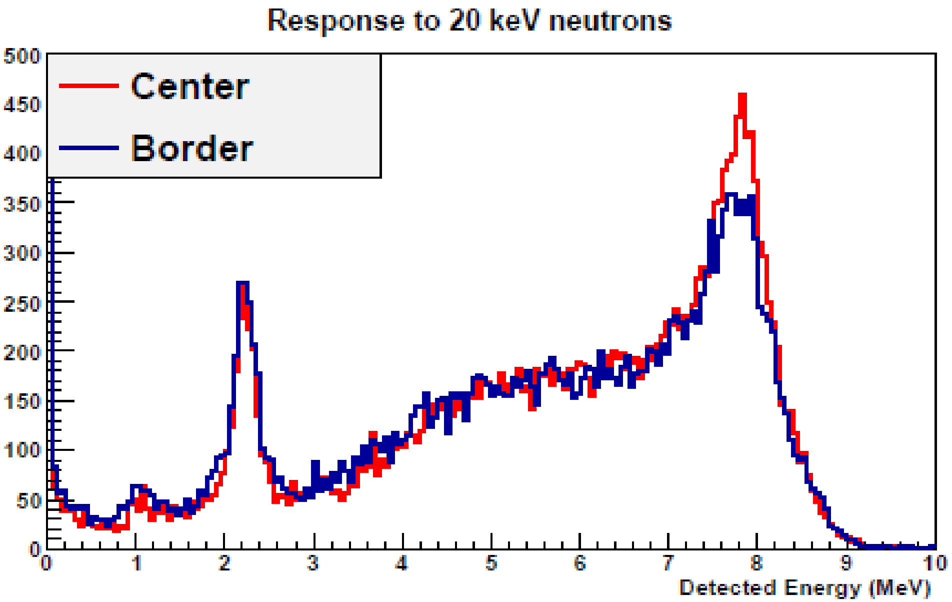
All PMTs have been tested and installed into the detector

Detector response

Energy resolution and similarity between cells are crucial parameters

- Complete GEANT4 model to simulate the detector response.

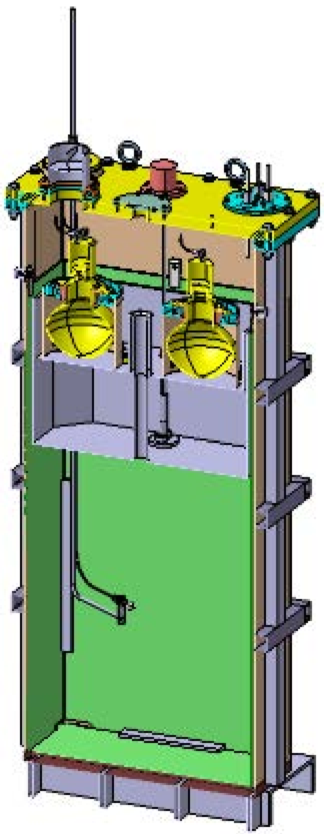


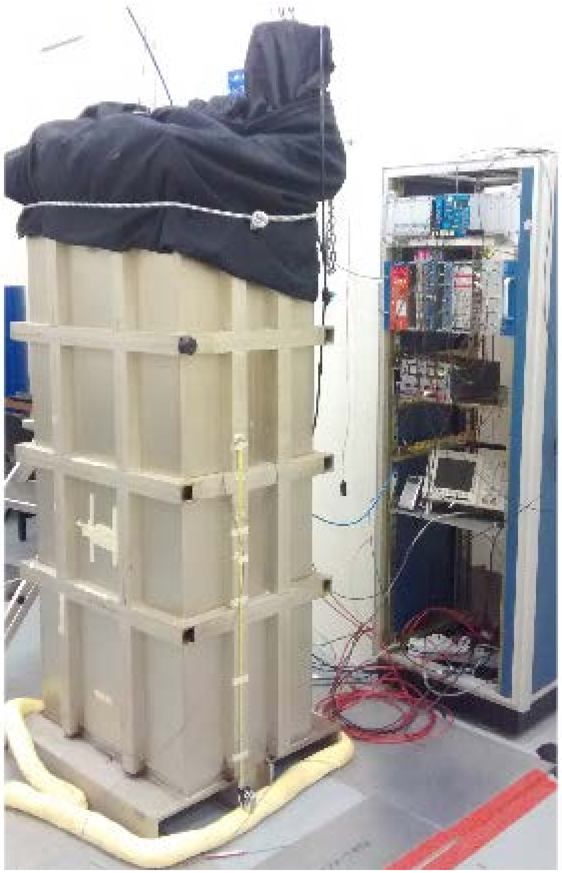


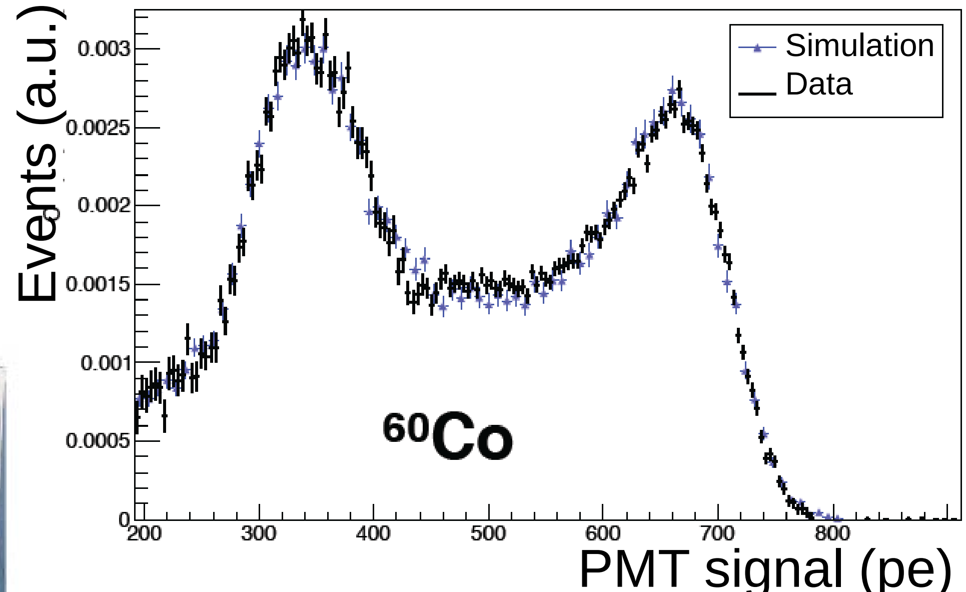
- Similar response between center and border cell :
  - RMS/Peak(center cell) = 11.5%
  - RMS/Peak(border cell) = 11.7%.
- Neutron efficiency above 5 MeV :
  - 64.5% $\pm$ 0.5% for center cell
  - 60.1% $\pm$ 0.5% for border cell.

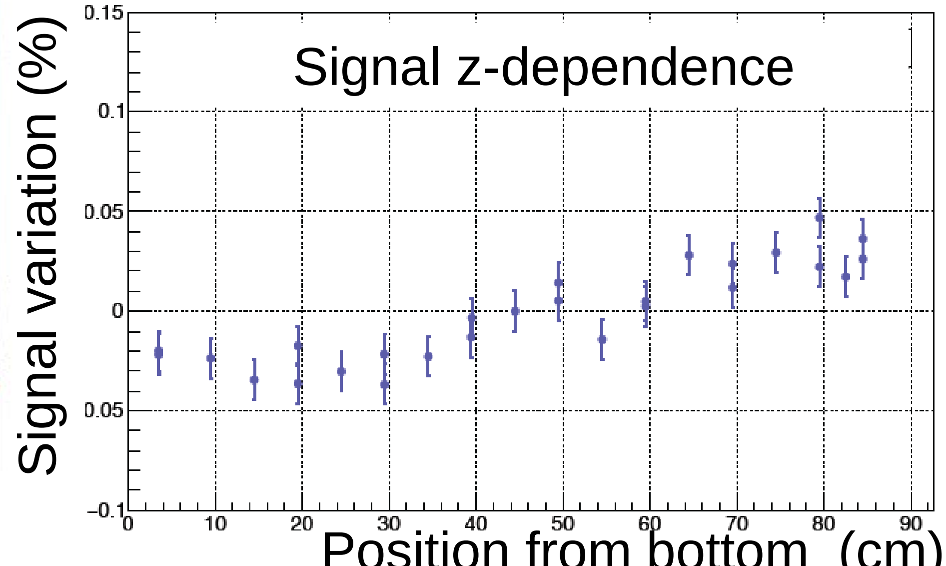
Prototype validation

Prototype = 1 cell with 2 PMTs





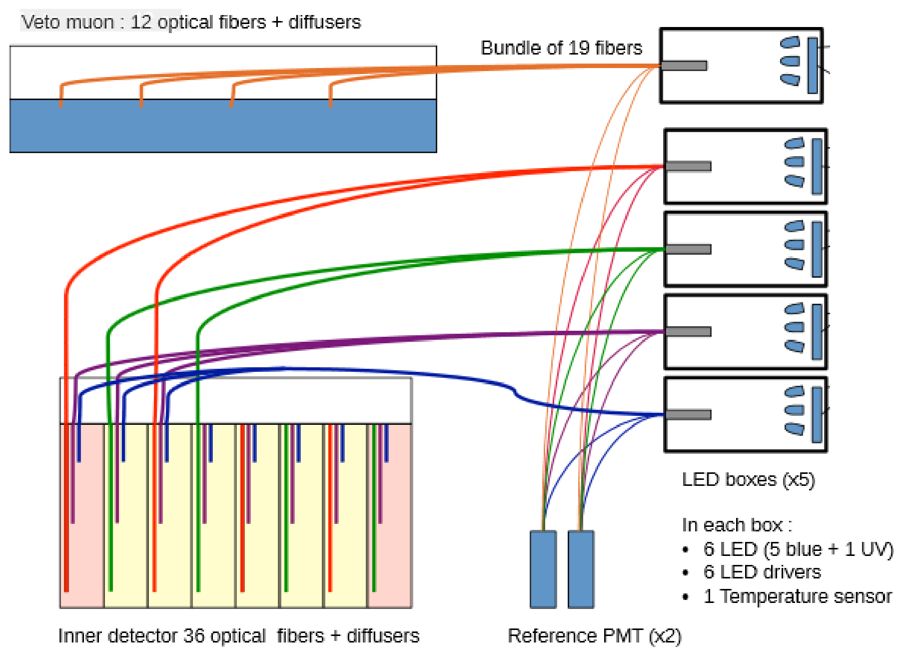




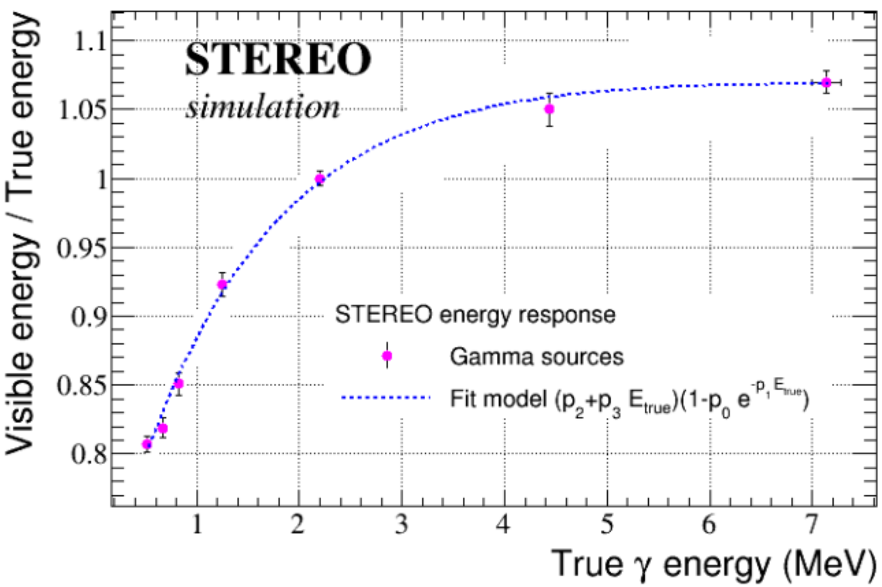
Calibration

LED System = 5 boxes to light on differents parts of the detector

→ PMTs calibration and linearity
→ Light collection study
→ LED UV for liquid properties



Radioactive sources (γ, n) can be deployed at different positions inside and outside the detector cells

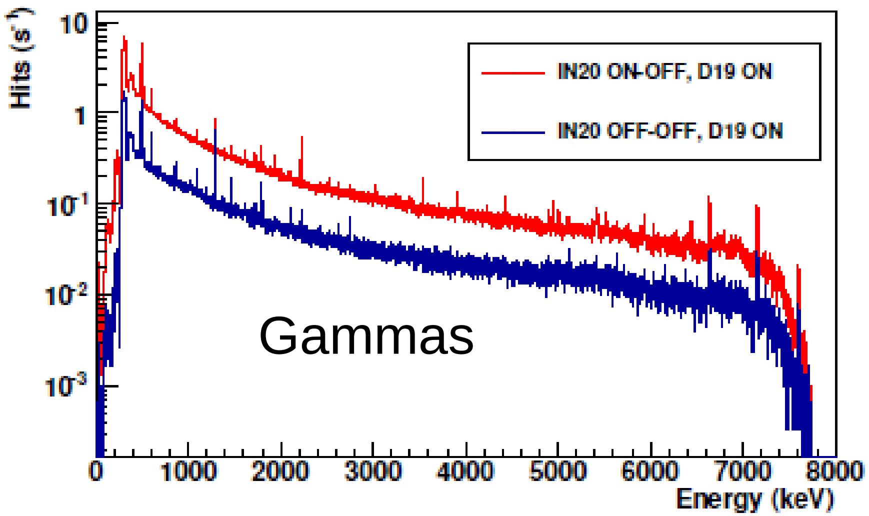


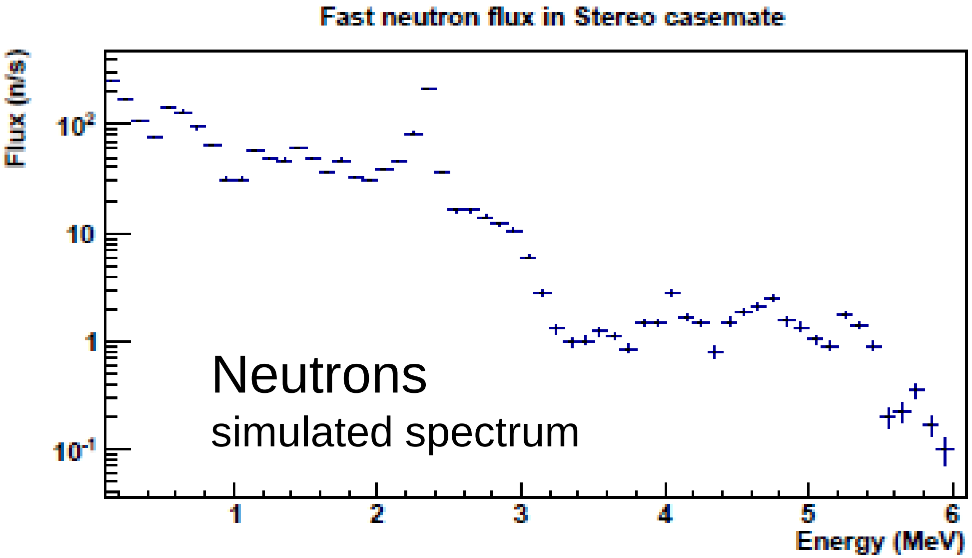
- gammas for energy calibration

- neutrons for efficiency of background rejection and IBD detection

Background

Muon, gamma and neutron background measurements on site have been performed (before any shielding).





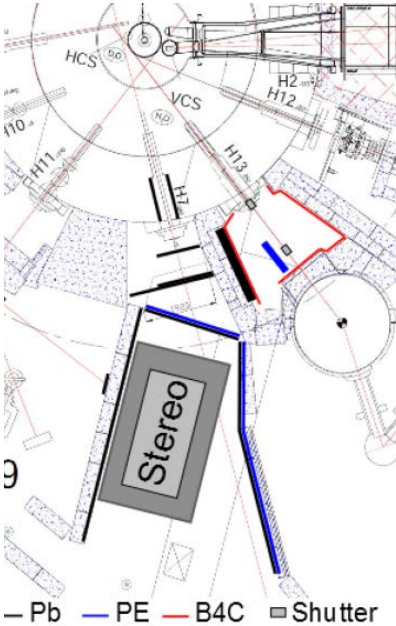
Two kinds of background events which can mimic neutrinos:

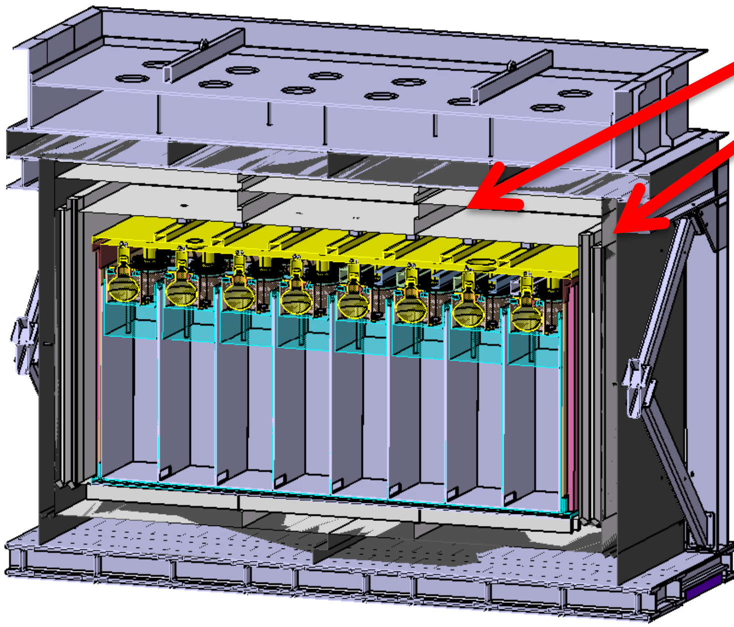
- **accidental coincidences** between γ and/or n_{th}

- **correlated coincidences** = fast neutrons (from reactor or induced by muons) $\rightarrow$ proton recoil + delayed gammas

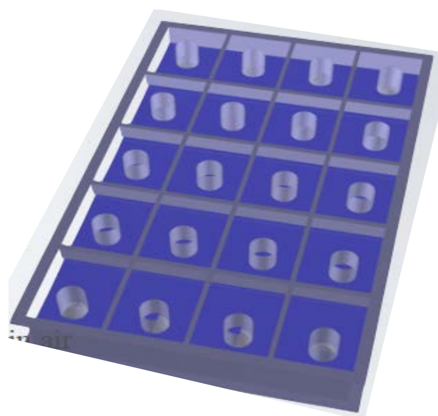
Background shielding

- Water channel above the detector = 15 mwe muon shielding
- Additionnal external walls of lead, PE and B4C to reduce γ and n fluxes from other experiments
- Passive shielding around the detector





- Veto muon = water cerenkov tank
  Muon detection efficiency > 99%

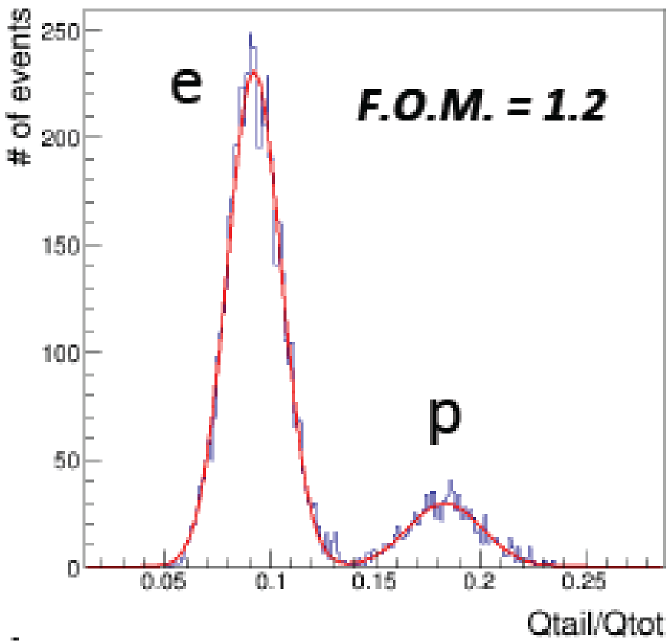


Background discrimination

Shields are not enough to reduce the background at an acceptable level.

In addition, we need to do:

1) An event by event discrimination
using Pulse Shape Discrimination (PSD) on prompt signal to discriminate e^+ (from neutrino interaction) and protons (from fast neutron scattering)



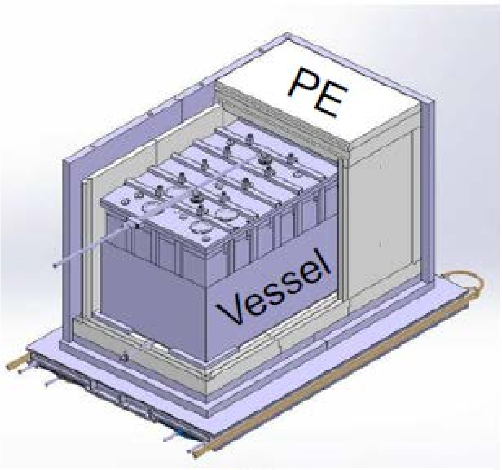
2) Spectrum substraction ON-OFF

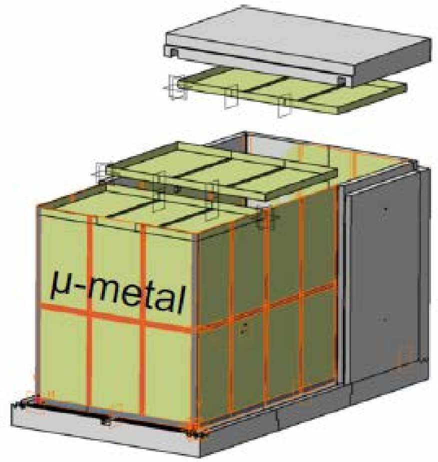
Reactor off periods allow to measure the correlated background from cosmic rays

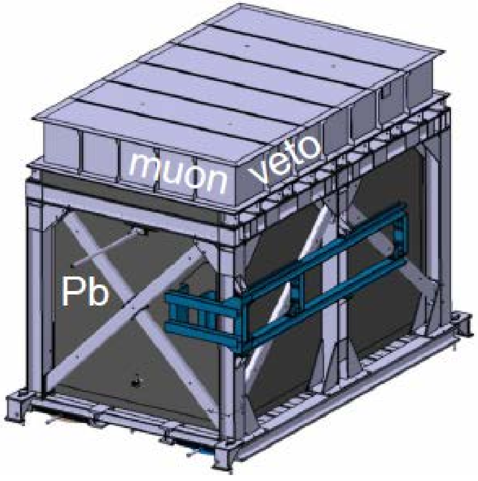
Magnetic shielding

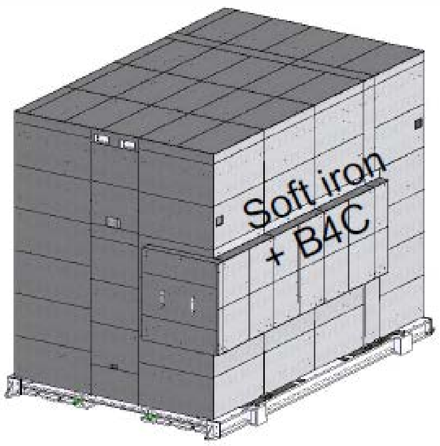
In addition of Lead and PE, µ metal and soft iron are added to shield PMTs against magnetic fields from vicinity experiments (cryomagnets, up to 15T)

→ ~ 1 mT @ STEREO location (before shielding).









Data

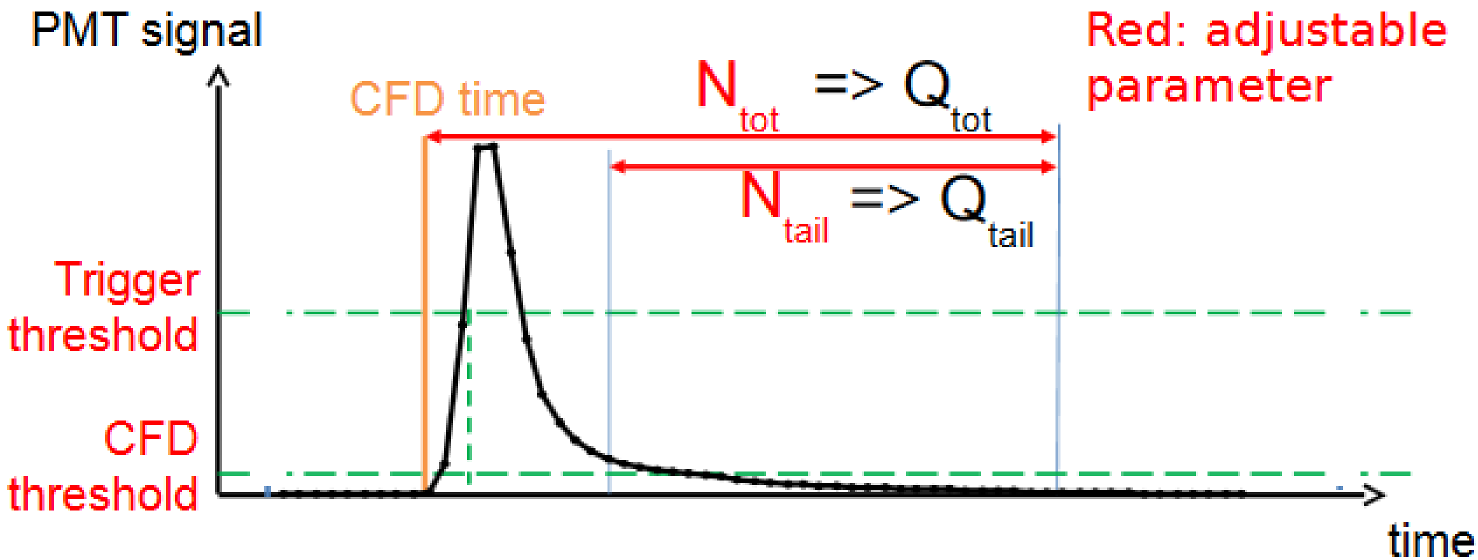
Expected counting rates:

$\mu \sim 500$ Hz, $\gamma \sim$ few 100 Hz, n ~ 1-10 Hz, $\nu_e \sim 400$ /day

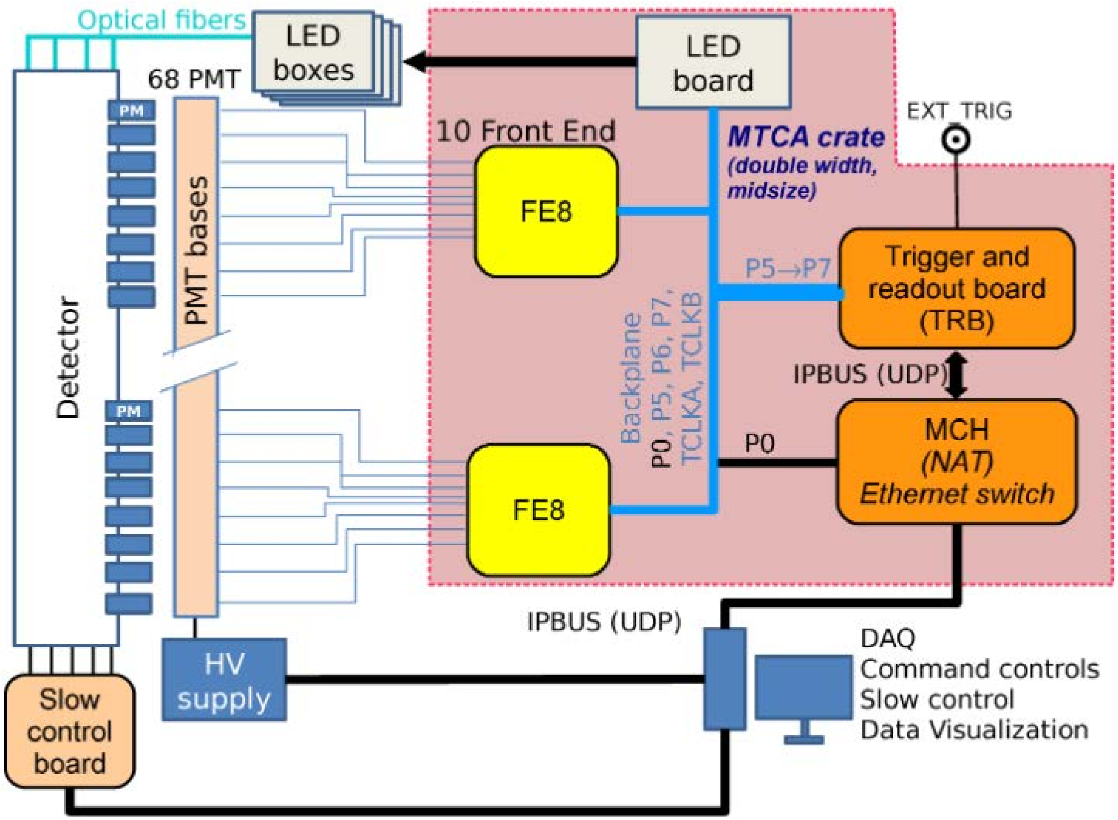
=> Trigger rate up to 1 kHz

=> need computation quantities online:

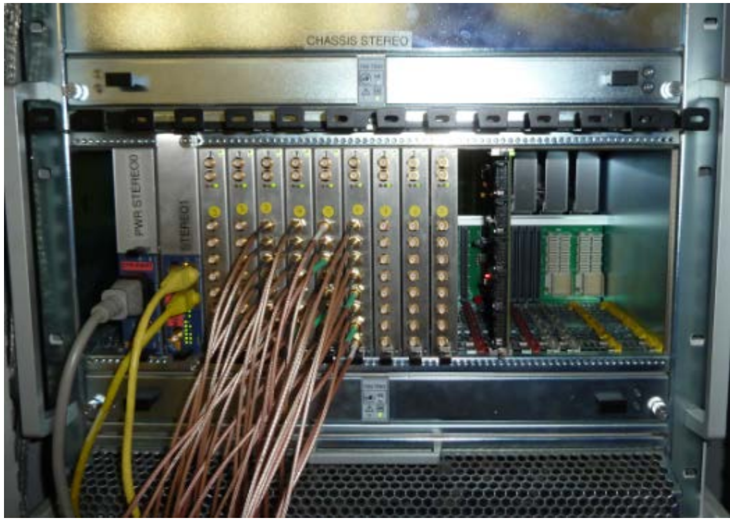
- pulse start time using Constant Fraction Discriminator
- total charge (Qtot) and tail charge (Qtail) for PSD

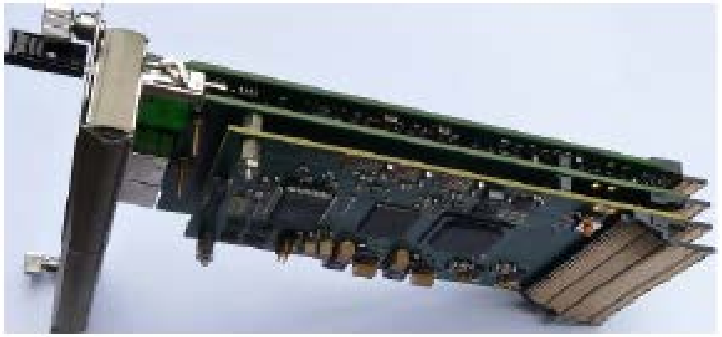


Dedicated electronics have been developed



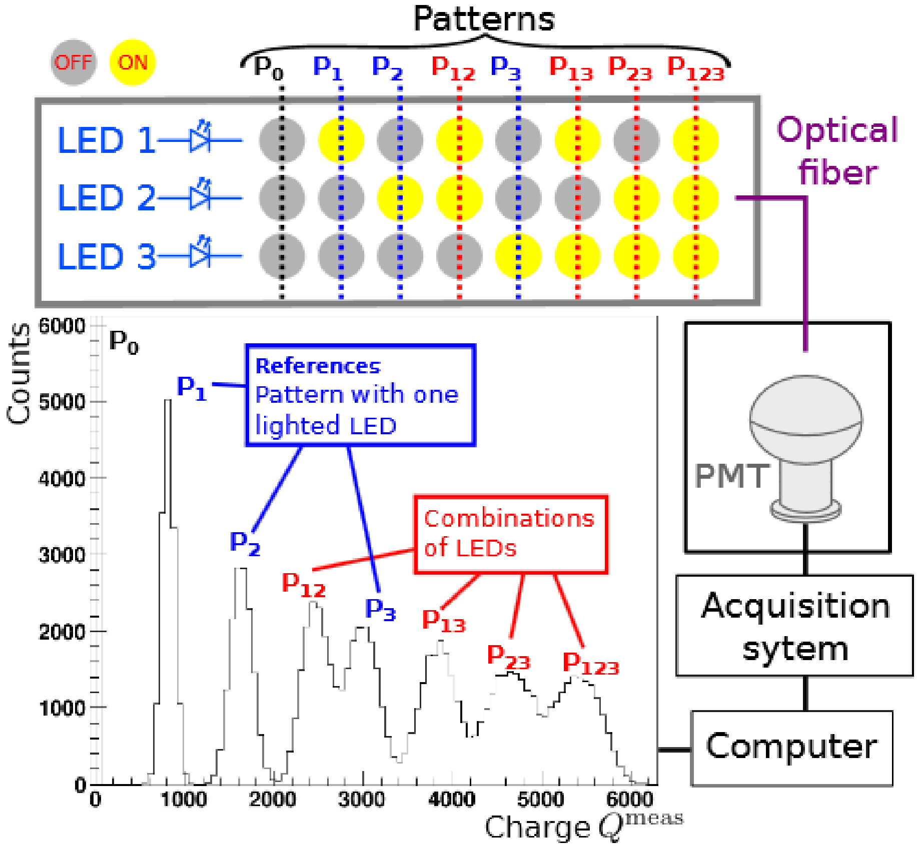
µTCA crate

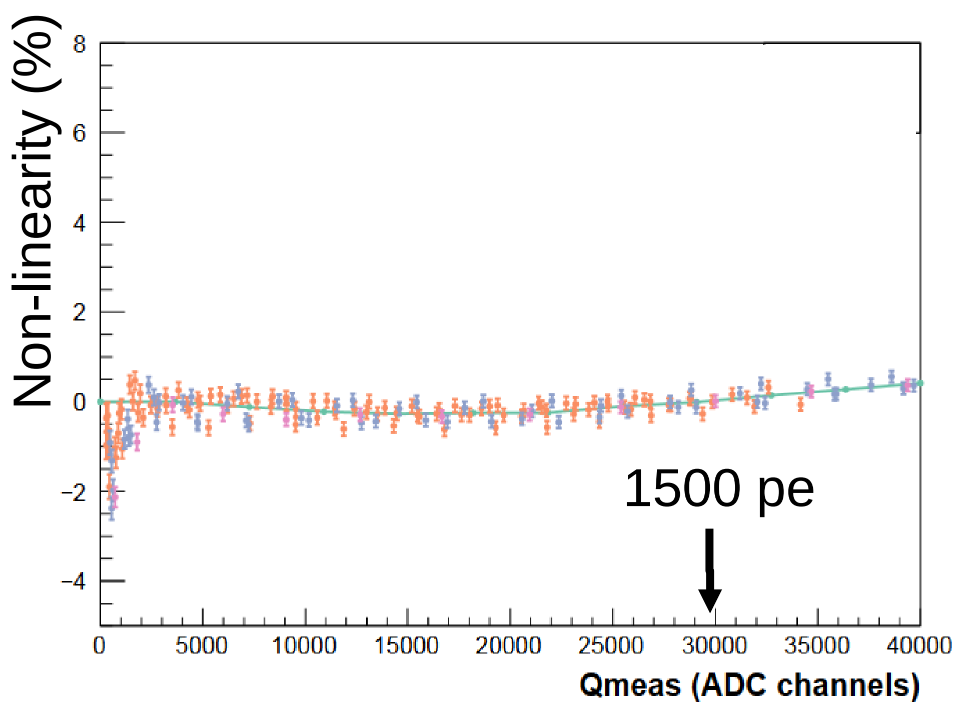




PMT Linearity

Very good energy linearity is required.
PMT linearity is measured using combinations of several LEDs





PMT non-linearity < 1% up to 10 MeV signals

Status and schedule

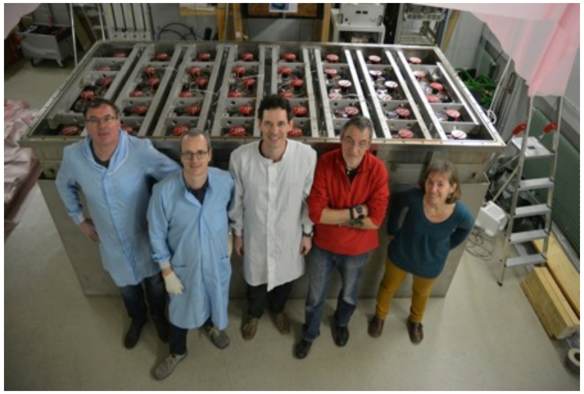
The detector has been fully assembled and tested without liquid scintillator. The detector is now ready.

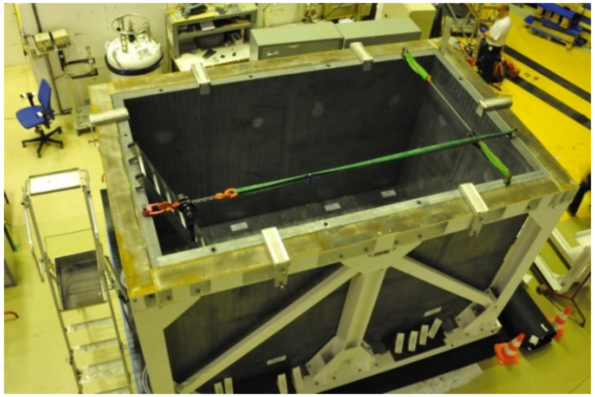
The shield is currently being installed at ILL. Then, the detector will be inserted into the shield, moved to its final location using air cushions and filled with liquid scintillator.

Data taking should start at the end of september.

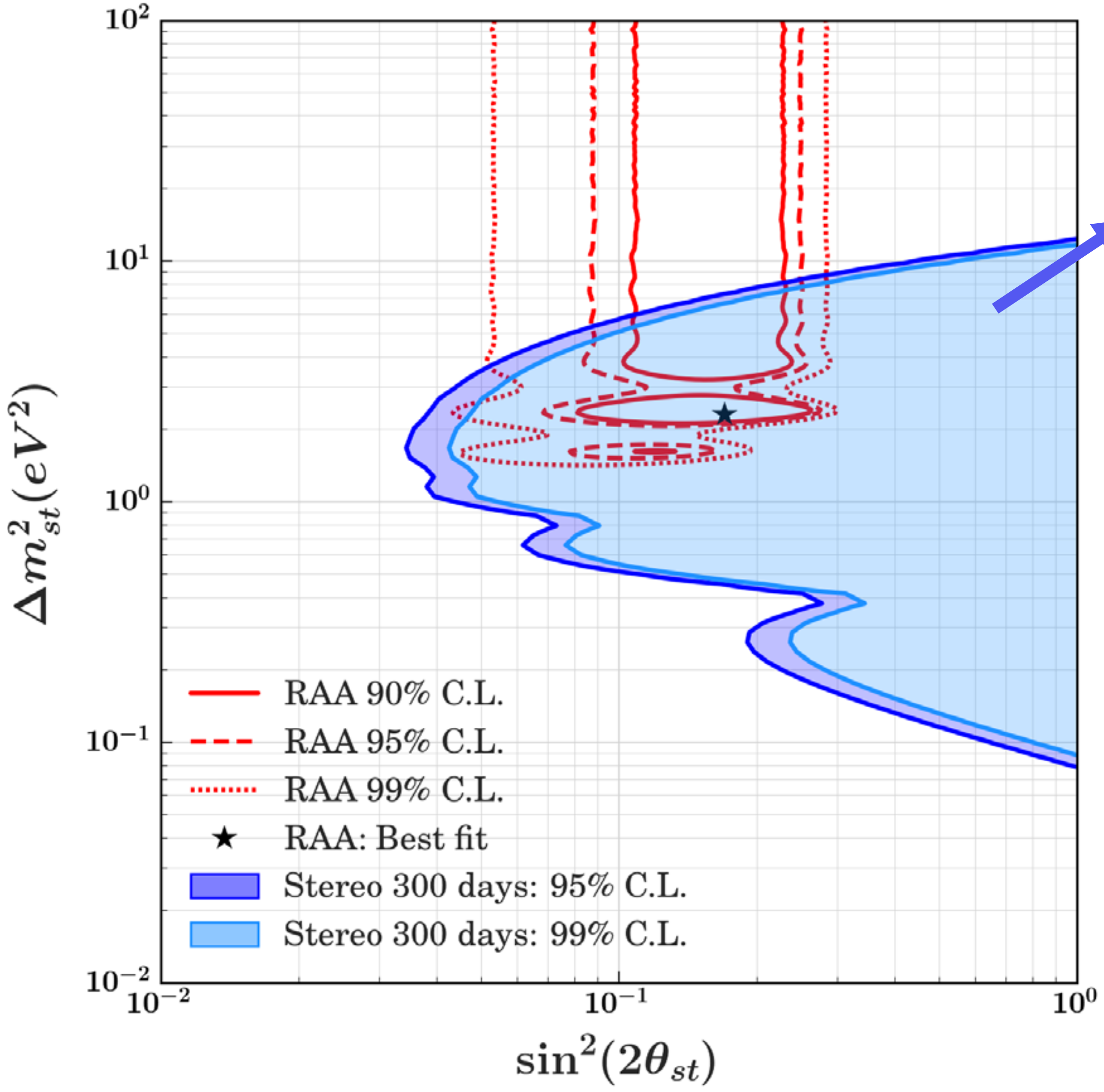
By the end of 2016, we should have about 50 days of reactor ON data.

Experiment will continue to take data at least until 2018 (~ 300 effective days of reactor ON data).





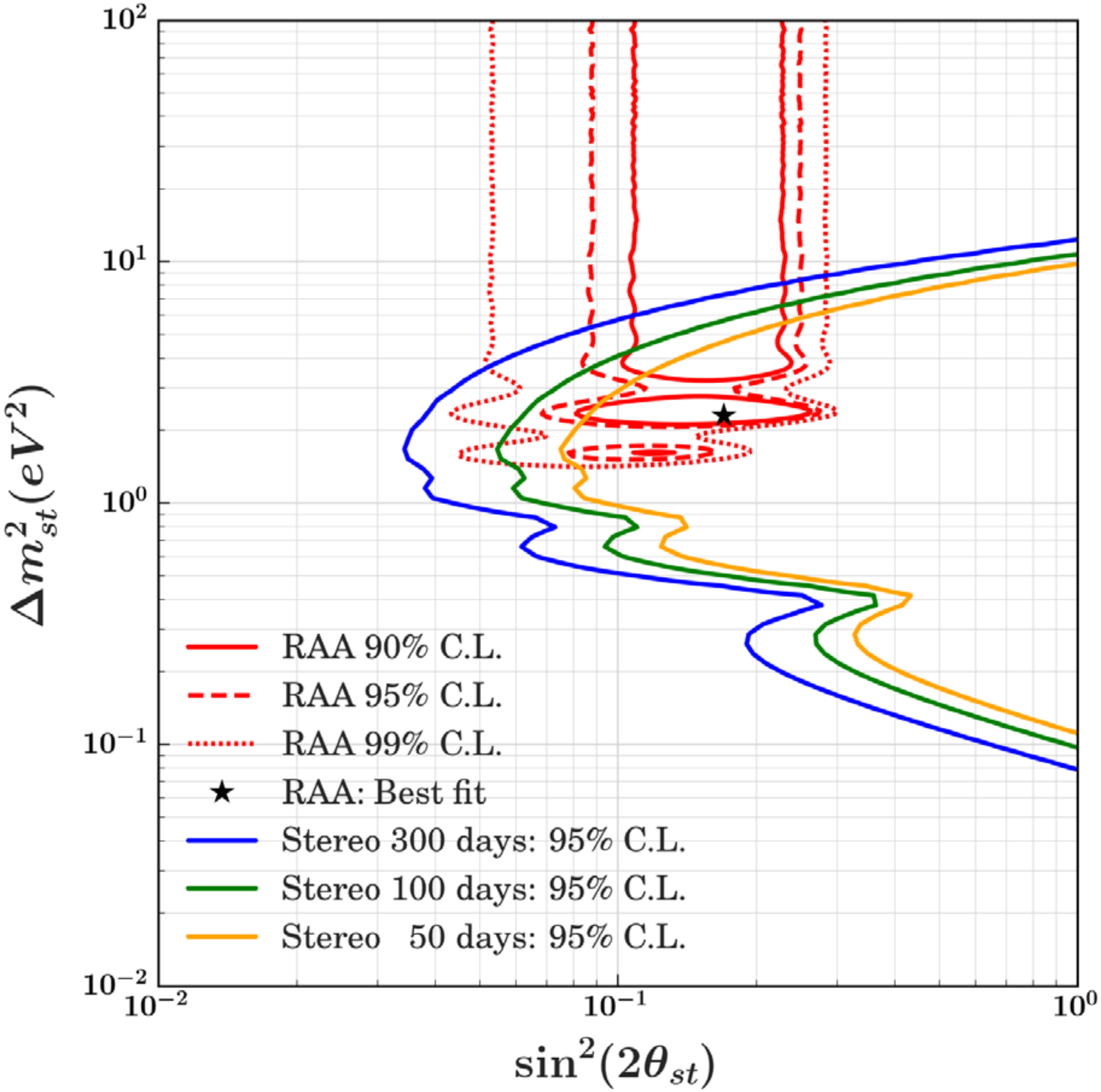
Expected sensitivity



Sensitivity for a shape-only analysis (without normalization on the expected neutrino flux)

- 300 days, ~400ν_e/day
- L_0 = 10 m
- E_{prompt}>2 MeV, $E_{delayed}$>5 MeV
- δE_{scale} = 2%
- $\Delta E/E$ = 12% @ 2MeV
- All syst. of predicted spectra
- S/B = 1.5

Expected sensitivity



First evidence in 2017 ?

Conclusions

- The Reactor Antineutrino Anomaly could be explained either by an error on the flux prediction, either by a mxing with a sterile neutrino
 -> a new measurement at short distance is necessary.

- **The STEREO experiment** is expected to be **sensitive** to the parameter space corresponding **to the RAA**, by looking at relative distortions of the energy spectrum in several detector cells.

- The STEREO detector is being installed at ILL and **will start to take data very soon.**

- **First results are expected for 2017**