The STEREO experiment, a search for sterile neutrino at ILL

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on behalf of the STEREO collaboration

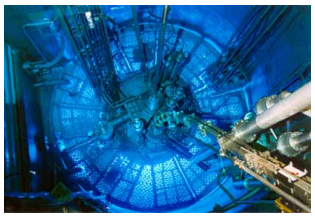
supported by

GDR Neutrino - 12th of june 2018

Motivation

The Reactor Antineutrino Anomaly (RAA)

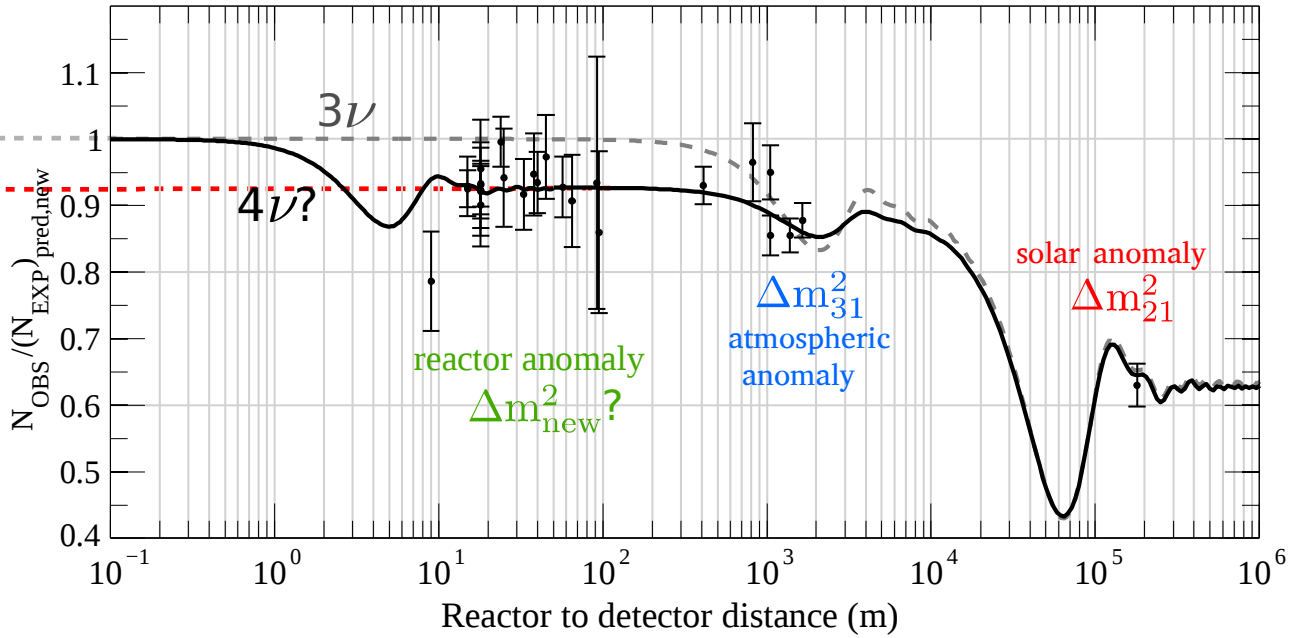
Phys.Rev.D83:073006 (2011)



2011: reevaluation of the $\bar{\nu}_e$ reactor flux prediction
$\rightarrow$ **Reactor Antineutrino Anomaly**

~ 6 % deficit

- **Sterile neutrino ?**
- Wrong prediction ?



$$P_{\overline{\nu}_e \rightarrow \overline{\nu}_e}(E_{\overline{\nu}_e}, L) = 1 - \sin^2(2\theta_{new}) \sin^2\left(1.27 \frac{\Delta m^2_{new}[eV^2] L[km]}{E_{\overline{\nu}_e}[MeV]}\right)$$

$\sim$ 1eV sterile neutrino

$\rightarrow$ **Need dedicated measurements**

Experimental site

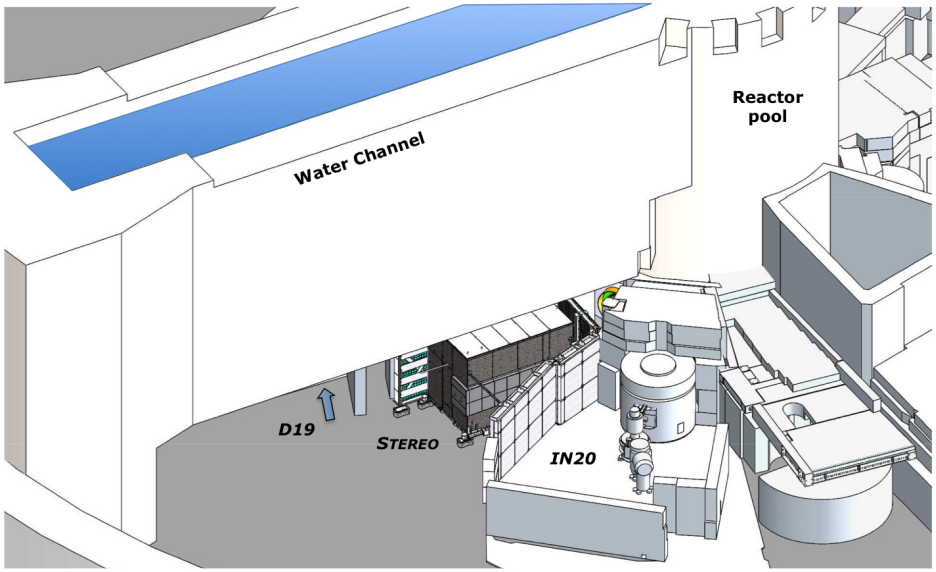
ILL research facility, Grenoble, France

Research reactor core $\sim 50\,\mathrm{MW}_{th}$
$\rightarrow 10^{19}\ \bar{\nu}_e\ s^{-1}$

✓ **Compact** core (40cm ∅)

✓ **Highly** ^{235}**U** enriched

✓ **Short baseline** measurement:
$8.9\mathrm{m} < \mathrm{L}_{core} < 11.1\mathrm{m}$

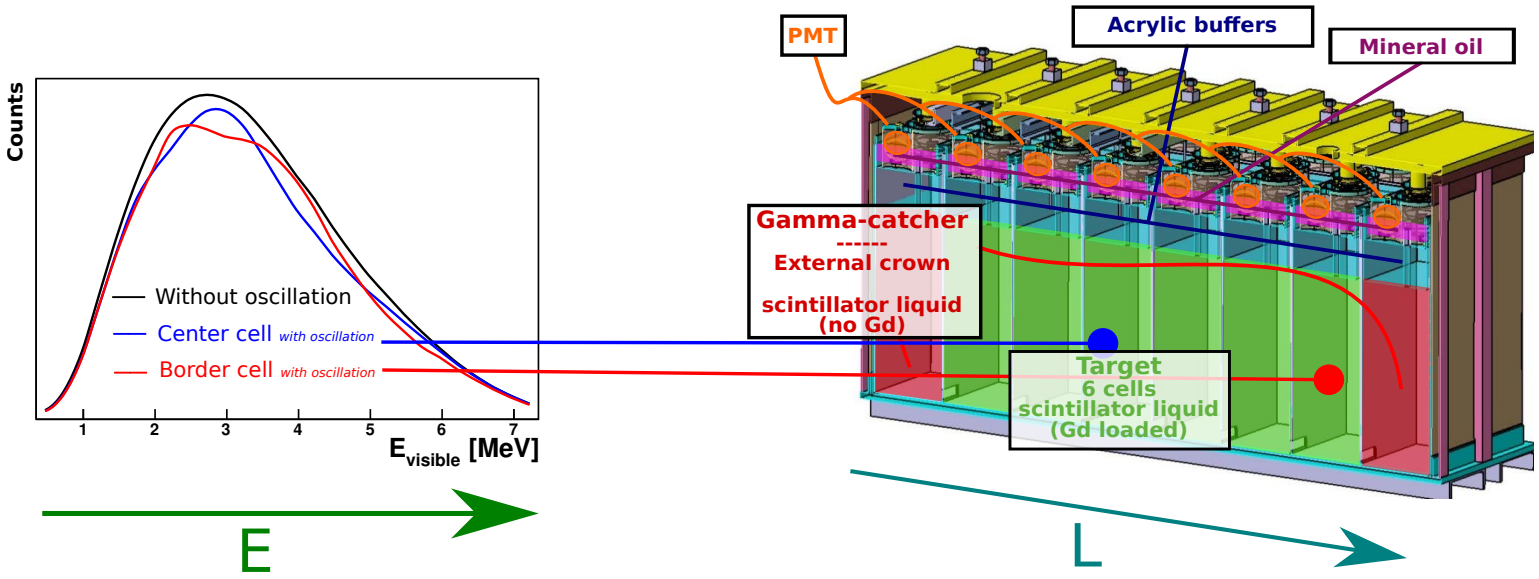


- **Surface-level** experiment
- γ **and neutron background** from neighboring experiments

The STEREO experiment

arXiv:1804.09052 (2018)

Designed to probe the Reactor Antineutrino Anomaly region



- ✓ **Segmented** target filled with Gd-doped liquid scintillator
- ✓ **Gamma-catcher** as active shielding

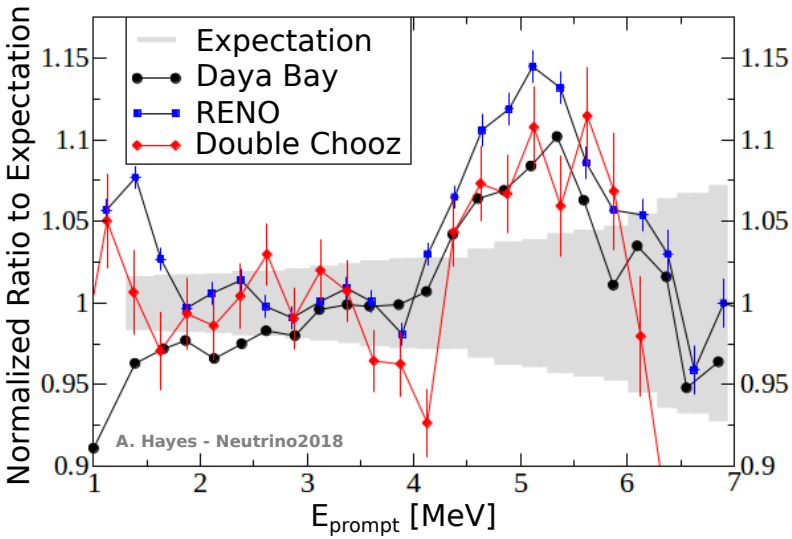
- ✓ Oscillation hypothesis test: measuring **relative distortions** of the $\bar{\nu}_e$ energy spectrum

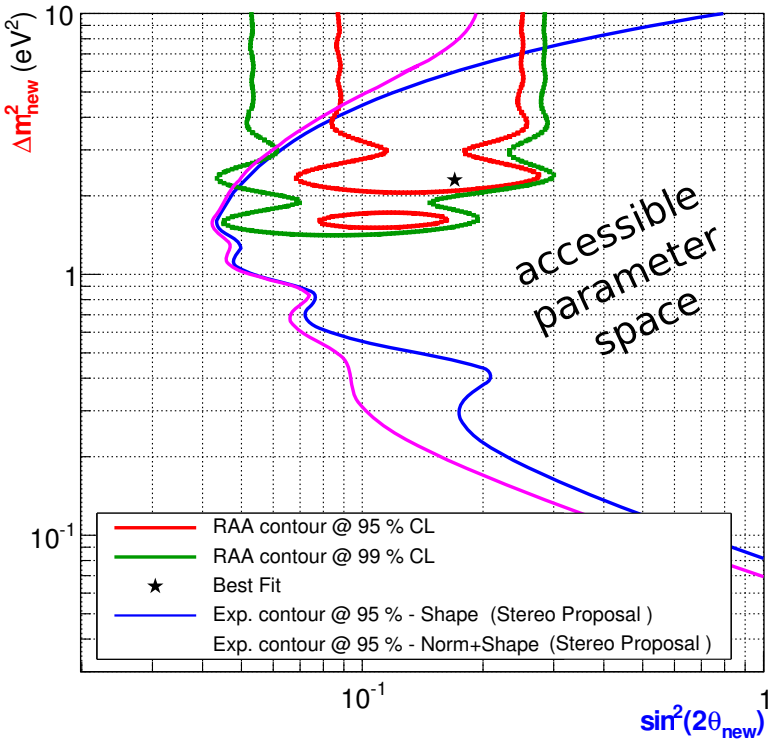
The STEREO experiment

arXiv:1804.09052 (2018)

Designed to probe the Reactor Antineutrino Anomaly region

- Designed to probe the RAA region
- First approach: **relative distortions** → independent from predicted energy spectrum (norm. + shape)

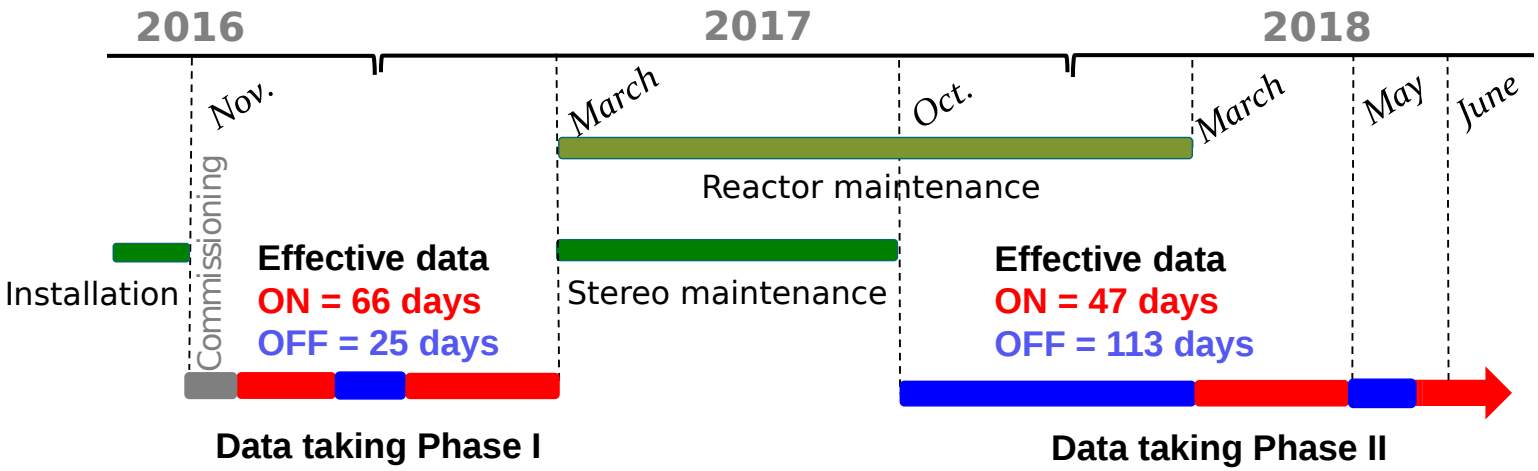




- Measurement of a **pure ^{235}U $\bar{\nu}_e$ energy spectrum**

Data taking

STEREO is running since nov. 2016



Phase-I:

- Loss of optical coupling between PMTs and target for one target and on GC cell
- Evolving light cross-talks between cells

  $\rightarrow$ repaired during summer 2017

Phase-II:

- Stable conditions

Physics runs: $\sim$ **95% of data taking time**

Detector response

Calibration

arXiv:1804.09052 (2018)

- **Monitoring of liquids/electronics:**
  Automatic daily **LED measurement**: PMT gain, liquid stability, electronics linearity

- **Monitoring of the energy response:**
  On a weekly basis: internal and external calibrations using **radioactive sources**

- **Monitoring of the neutron capture:**
  Using dedicated AmBe source

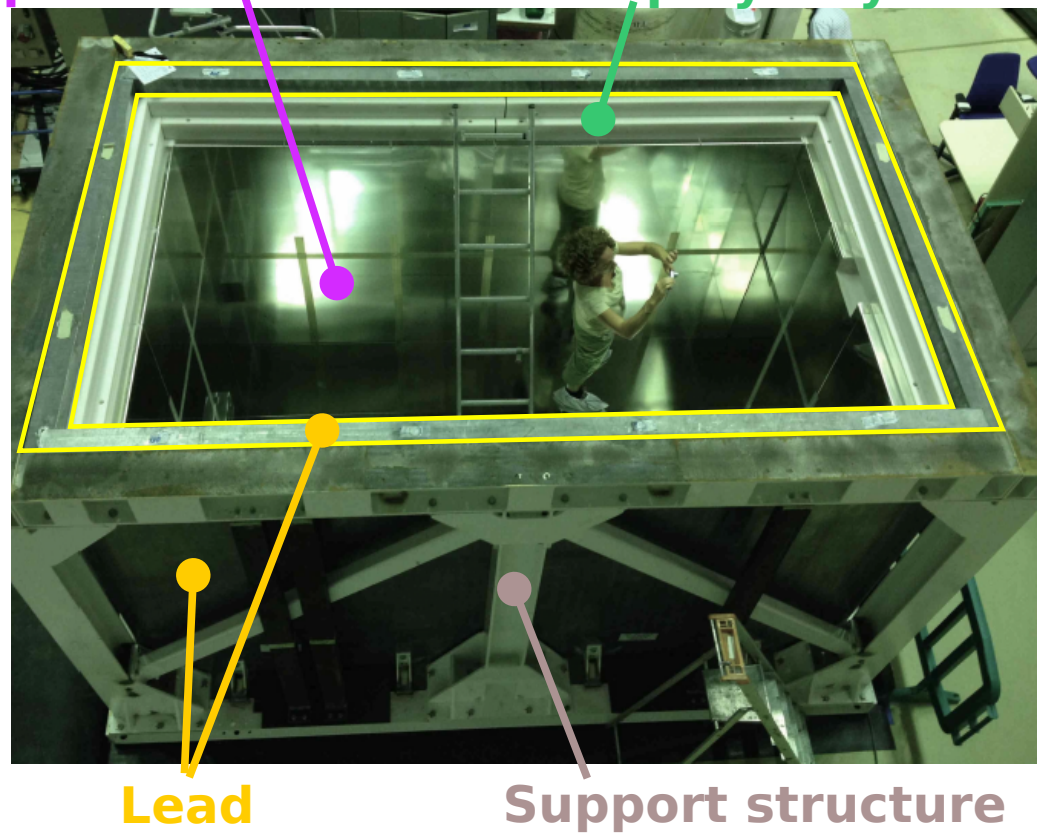
Tuning of the MC simulation of the detector: optical surfaces, liquid properties

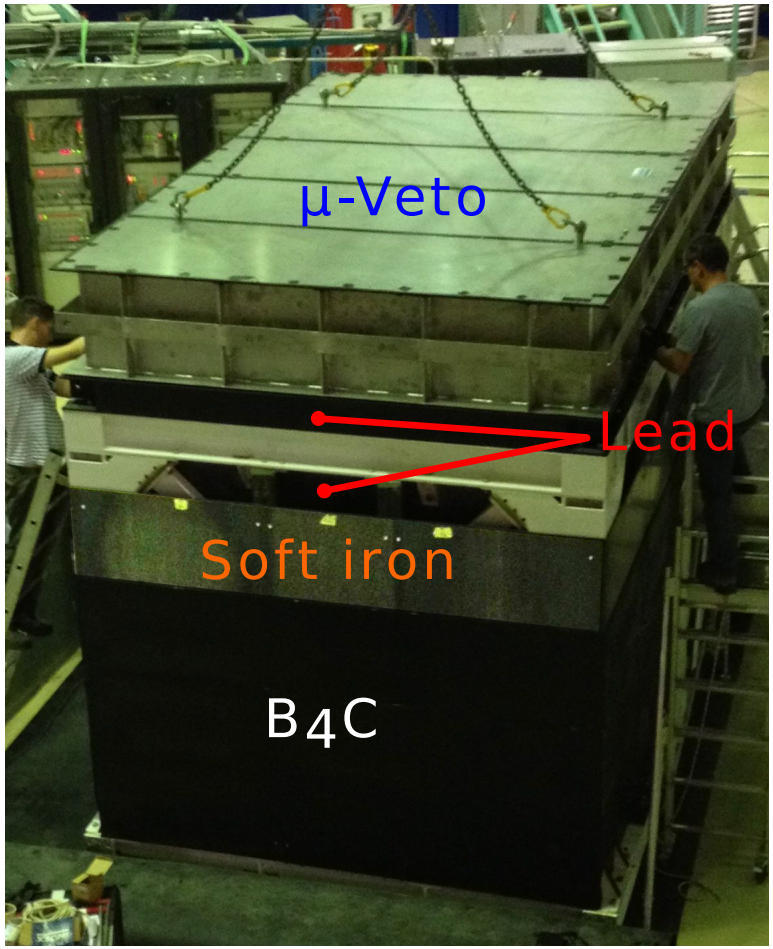
	Cell-to-cell correlated	Uncorrelated
Energy scale σ_j^{Escale}	0.35 %	1.10 %
Normalization σ_j^{Norm}	-	1.70 %

→ Details in this afternoon session (16:40):
Energy calibration in the STEREO experiment - V. Sergeyeva (LAPP)

Shielding against background

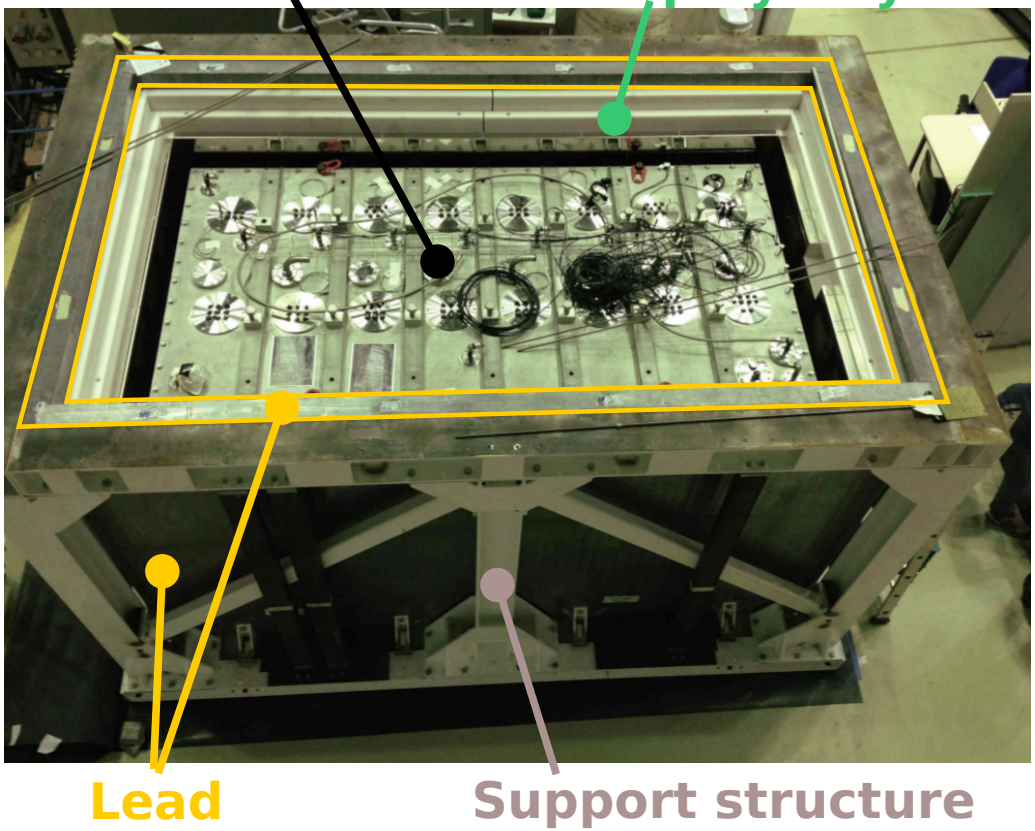
Passive and active shieldings

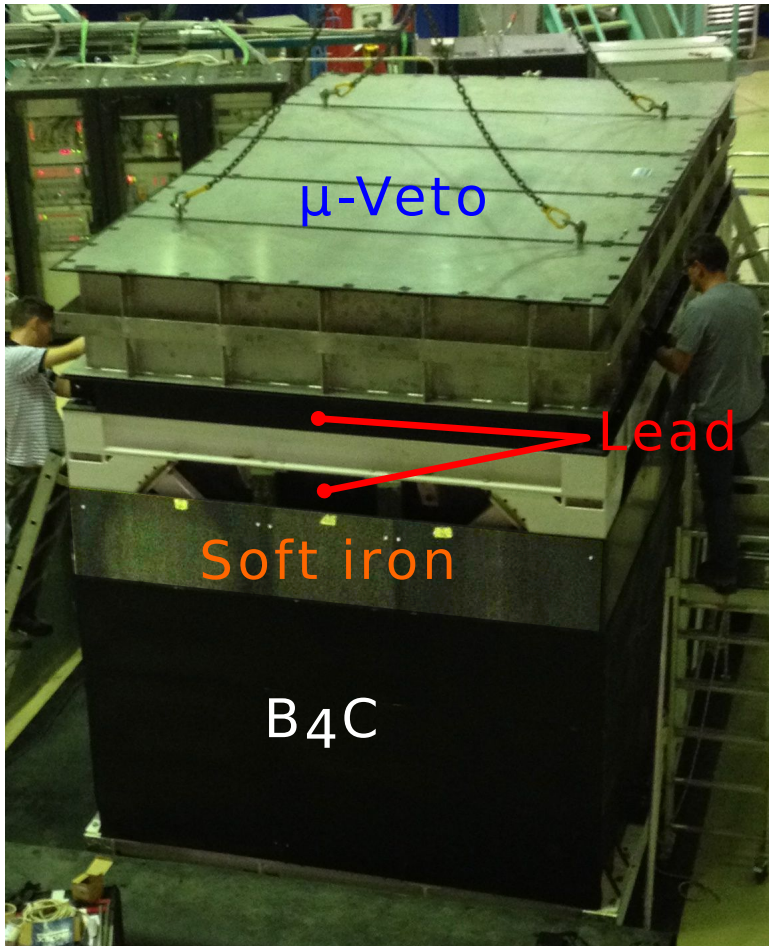




Shielding against background

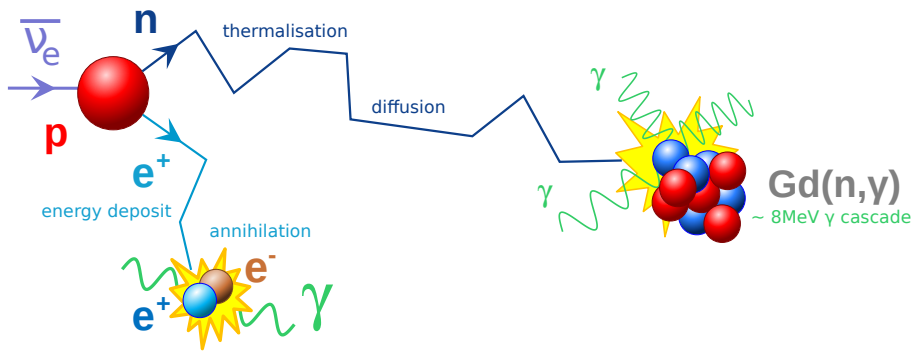
Passive and active shieldings

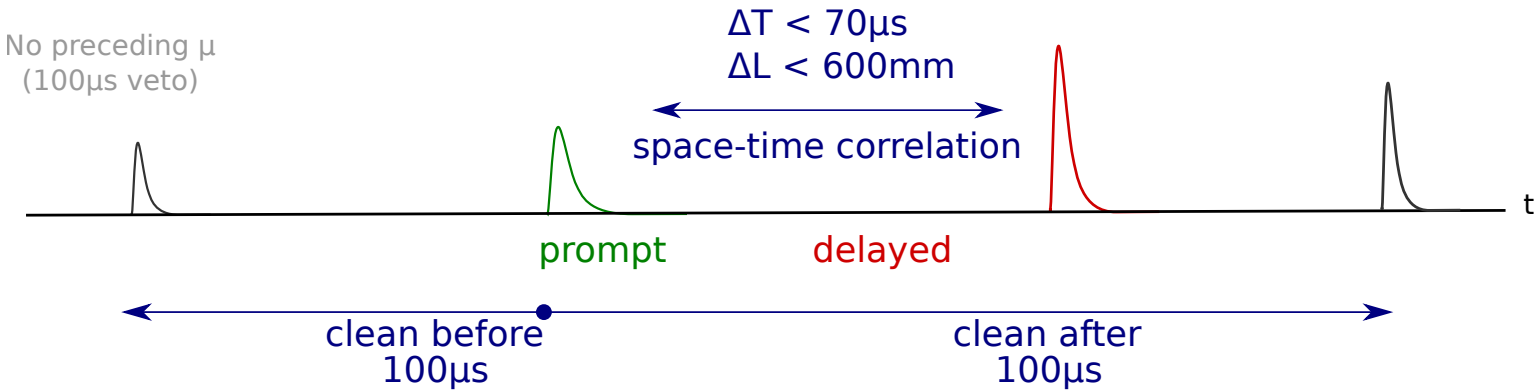




$\bar{\nu}_e$ signal selection

Inverse Bêta Decay reaction





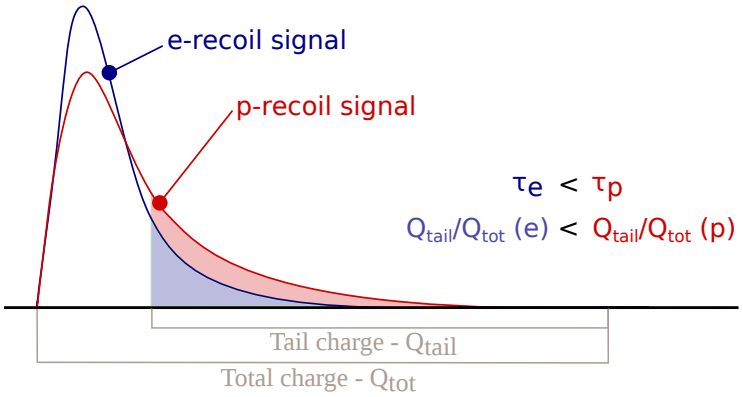
$1.6 < E_{prompt} < 7.1\,MeV$ $\quad$ $4.5 < E_{delayed} < 10\,MeV$

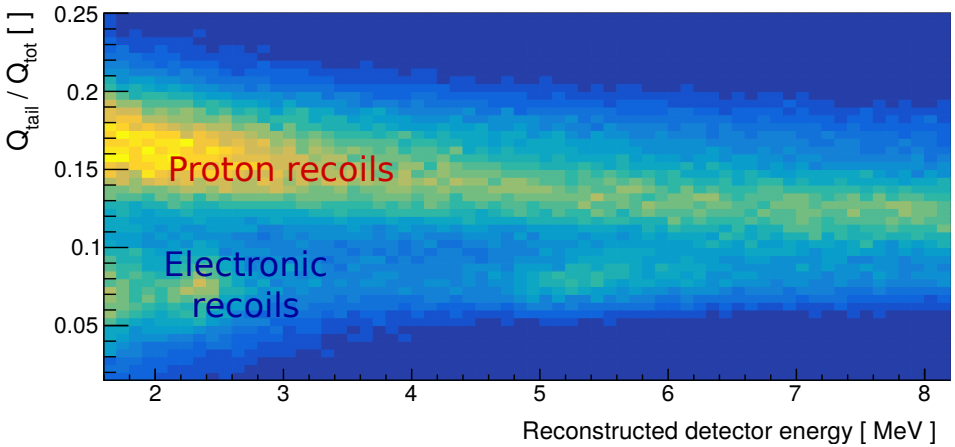
Prompt contained in one cell

Correlated background

Pulse Shape Discrimination

Pulse Shape Discrimination for prompt signal





Neutron induced reactions:

- **Fast neutrons**
  Prompt: n_{fast} recoil
- **Multiple neutron captures**
  Prompt: 2.2 MeV γ or a 8 MeV γ cascade from n-cap
- **^{12}C(n,n'γ)^{12}C** reactions
  Prompt: **mixing** between 4.4 MeV γ and n_{fast} recoil

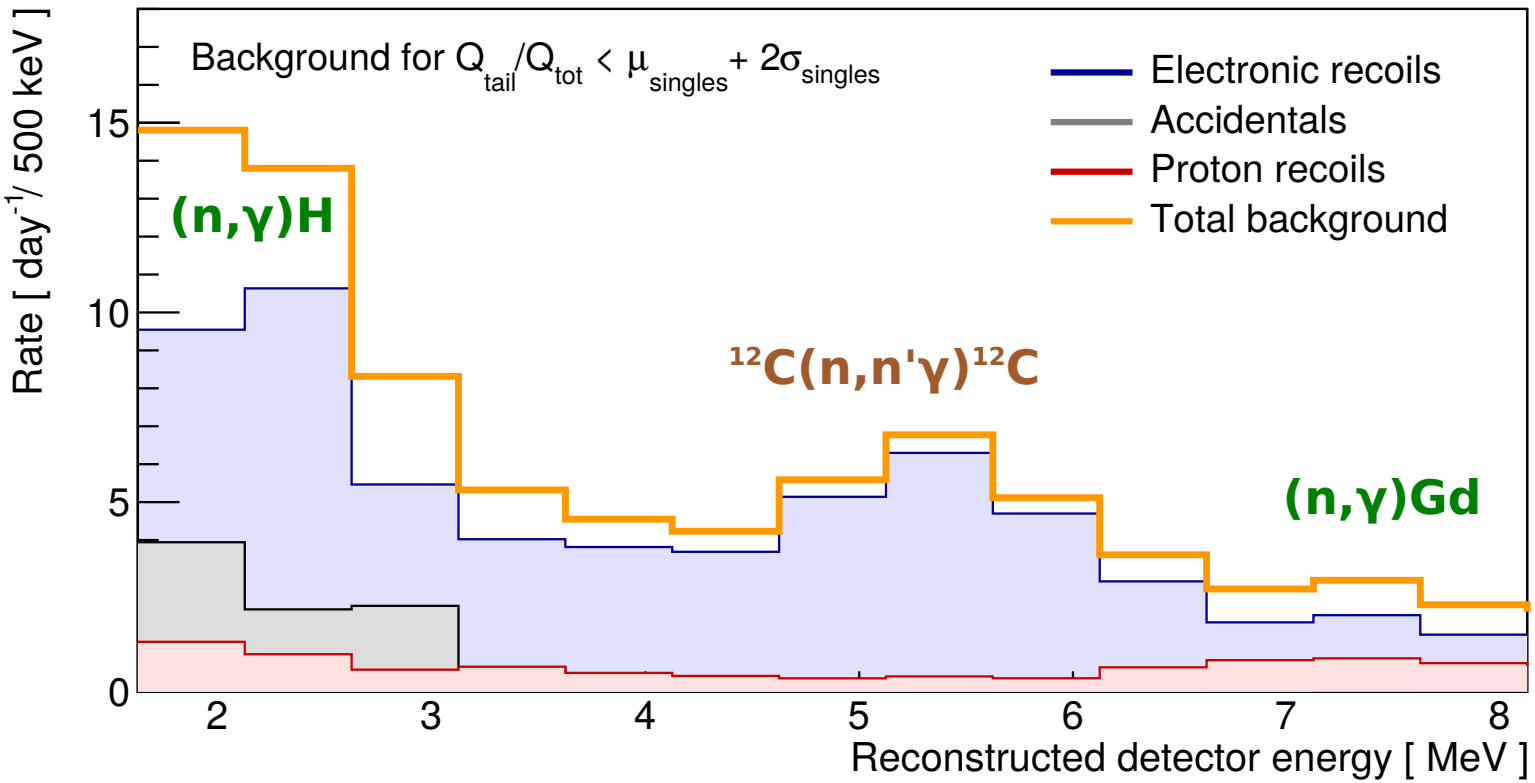
(Delayed are Gd capture)

Stopping muons:
Prompt: μ stop
Delayed: Michel $e^{+/-}$
Asymmetry based rejection

Correlated background

Reactor-OFF prompt energy spectrum

Reactor-OFF prompt energy spectrum in the region of interest

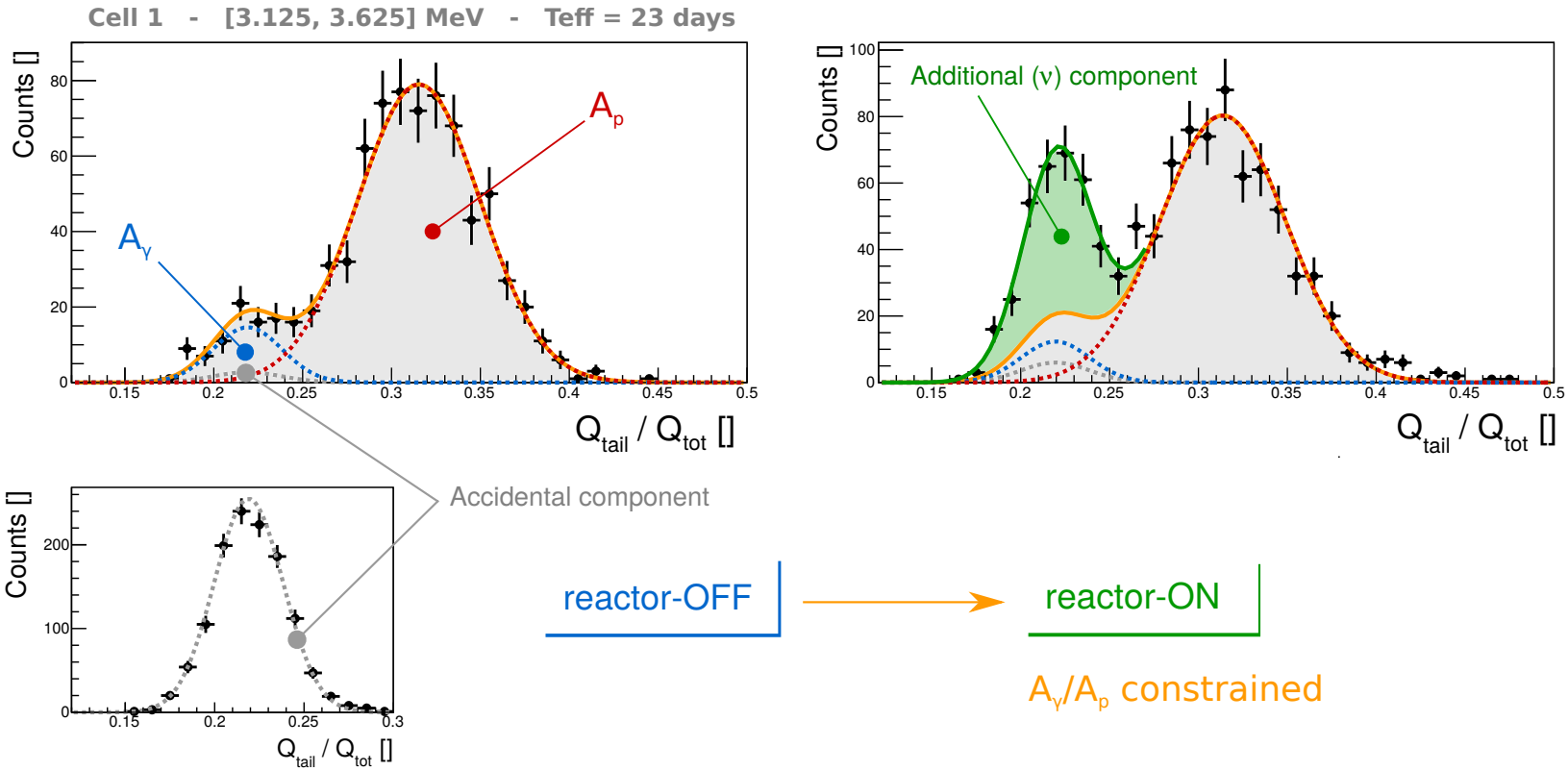


$\langle S/B \rangle \sim 0.9$

$\bar{\nu}_e$ signal selection

Extraction of the $\bar{\nu}_e$ rates from PSD distributions

Multi-Gaussian background model for each cell/energy/time bin PSD:



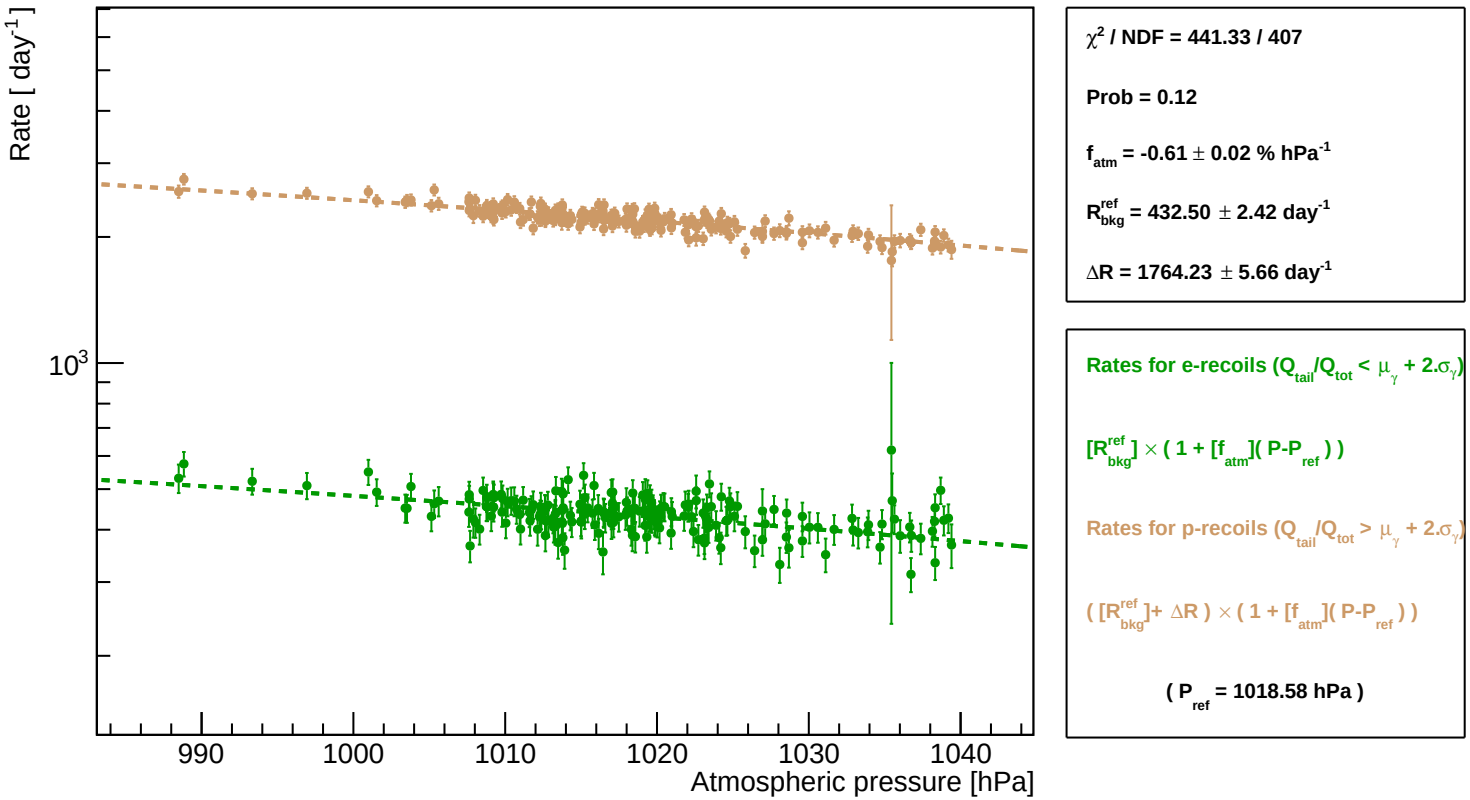
Self-consistent method to estimate background under $\bar{\nu}_e$ component:

- Adapt to PSD variations (temperature sensitivity)
- Local rescaling to global norm (pressure sensitivity)

$\bar{\nu}_e$ signal selection

Extraction of the $\bar{\nu}_e$ rates from PSD distributions

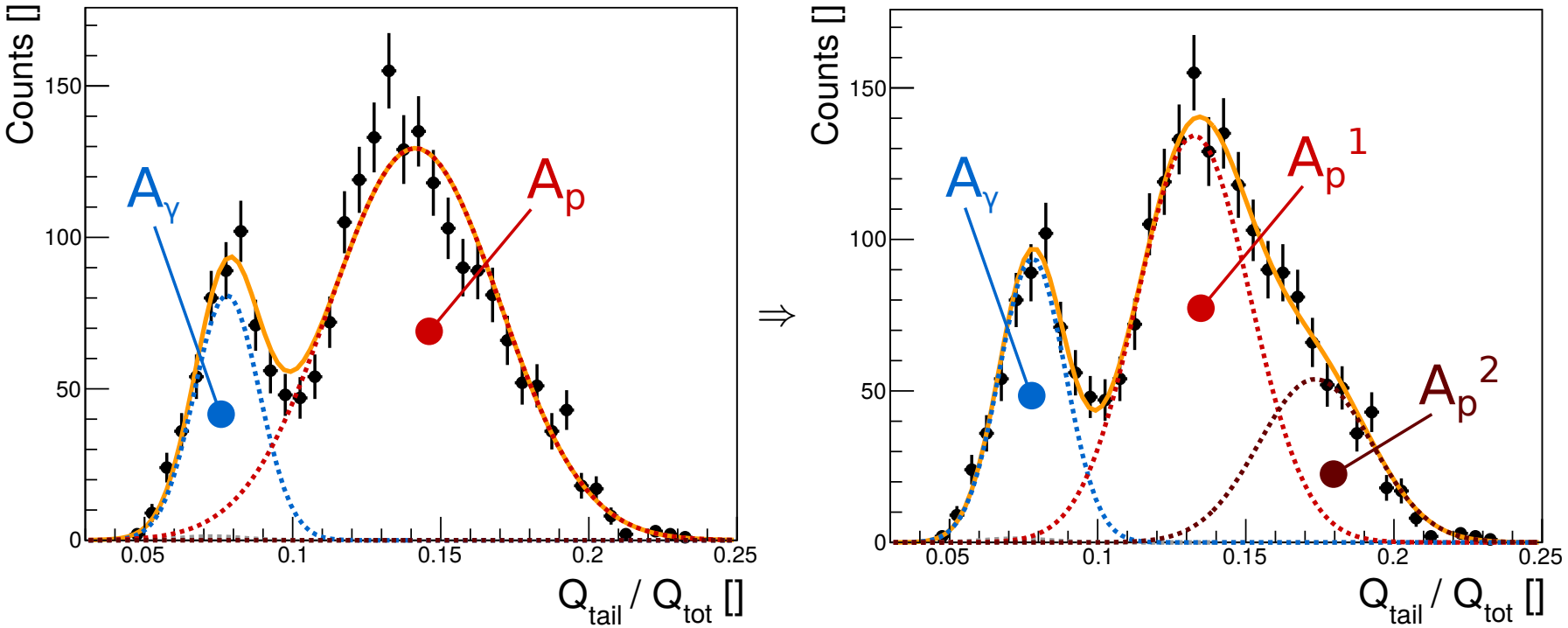
- $\mathcal{A}_\gamma/\mathcal{A}_p$ **compatible with a constant** in all cell/energy bin
- Same correlation with atmospheric pressure for **e-recoils rates** and **p-recoils rates**



$\bar{\nu}_e$ signal selection

Extraction of the $\bar{\nu}_e$ rates from PSD distributions

Phase-II: 84 days (effective time) with **stable** conditions
$\rightarrow$ Updated background model with increased statistics



Second component for p-recoils, anchored **relatively** to the first one
Possible physical origin: multiple proton recoils (under study)

Ratio method

arXiv:1806.02096 (2018)

Relative comparison of energy distributions

Oscillation test using **ratio of energy distributions - cell 1 taken as reference**

- Reduced systematics
- Unsensitive to absolute flux normalization
- Unsensitive to spectrum shape

$$R_{i,j}^{\text{Data}} = \frac{\text{Data}_{i,j}}{\text{Data}_{i,ref=1}} \quad \text{compared with} \quad R_{i,j}^{\text{MC}} = \frac{\text{MC}_{i,j}}{\text{MC}_{i,ref=1}}$$

MC takes into account cells differences, detection efficiencies etc.

$$\chi^2 = \sum_{i=1}^{N_{\text{Ebins}}} \left(\overrightarrow{R_i^{\text{Data}}} - \overrightarrow{R_i^{\text{MC}}}(\alpha) \right)^t V_i^{-1} \left(\overrightarrow{R_i^{\text{Data}}} - \overrightarrow{R_i^{\text{MC}}}(\alpha) \right) + \sum_{j=1}^{N_{\text{Cells}}} \left(\frac{\alpha_j^{\text{Norm}}}{\sigma_j^{\text{Norm}}} \right)^2 + \sum_{j=0}^{N_{\text{Cells}}} \left(\frac{\alpha_j^{\text{Escale}}}{\sigma_j^{\text{Escale}}} \right)^2$$

V_i is the **covariance matrix** of the 5 ratios (common reference for each cell) for the energy bin i

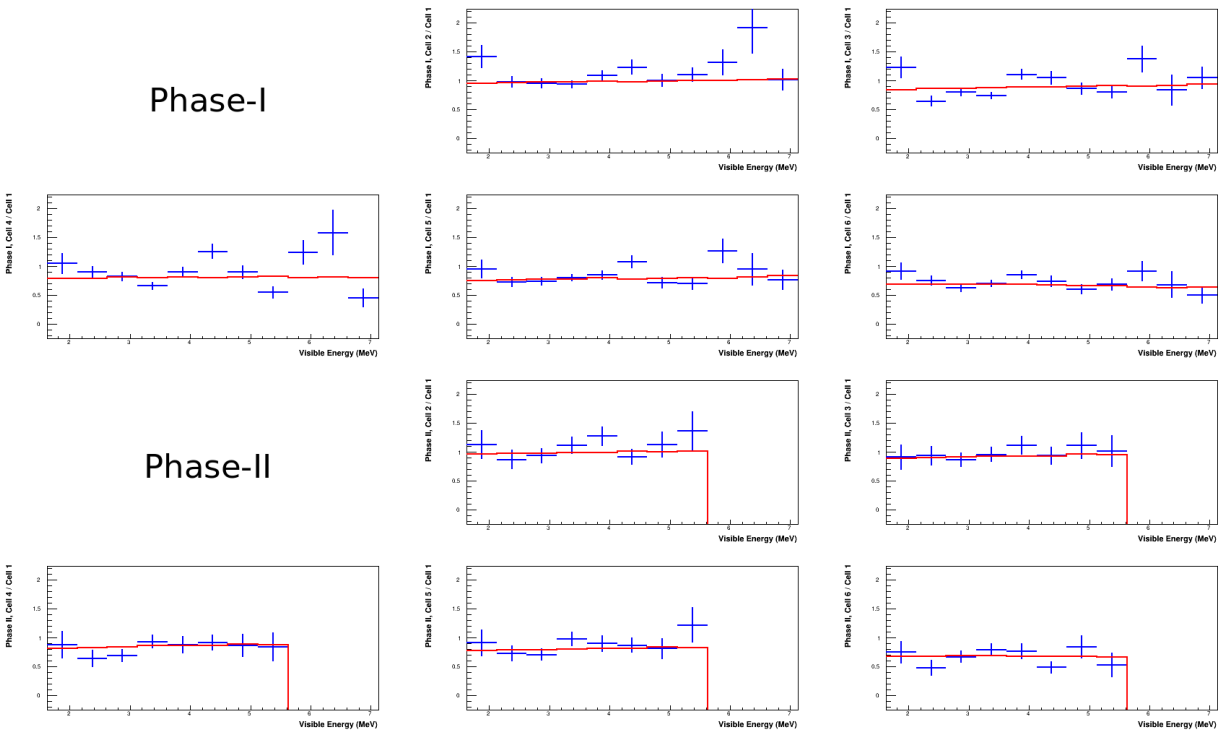
$\{\alpha\}$ are pull-terms to take into account estimated **systematics**

Ratio method

Non-oscillation hypothesis

arXiv:1806.02096 (2018)

Ratio method: cell 1 taken as reference



Measured ratios for the cells from 2 to 6 (blue) compared to the null oscillation hypothesis model (red)

- **Measured ratios**
- **Non-oscillation prediction**

- Minimized pull terms stay within $\pm 1\,\sigma$

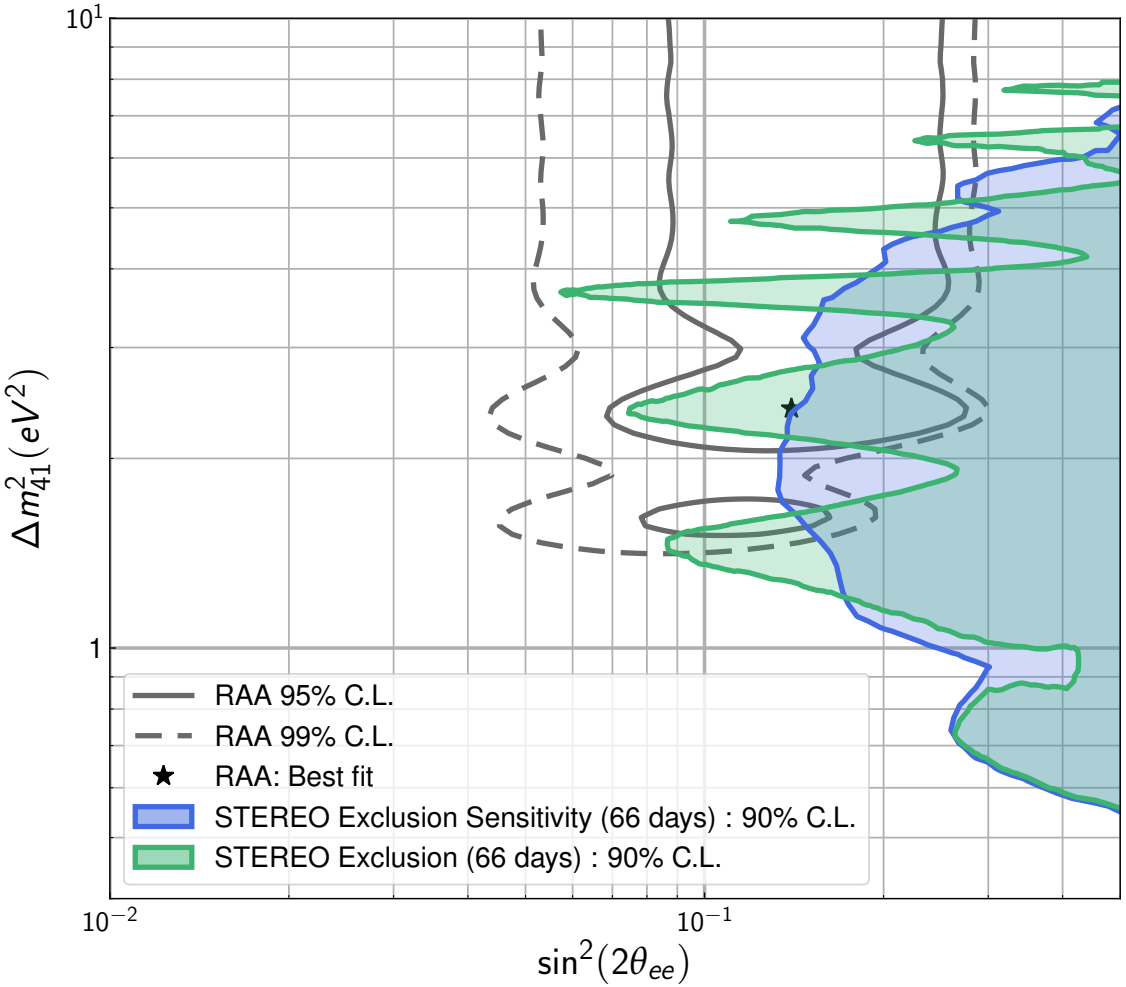
- **Non-oscillation hypothesis (H_0) not rejected:**
  p-value = 34 % (40 %)
  for phase-I (phase-I+II)

Ratio method

arXiv:1806.02096 (2018)

Exclusion contours - Phase I

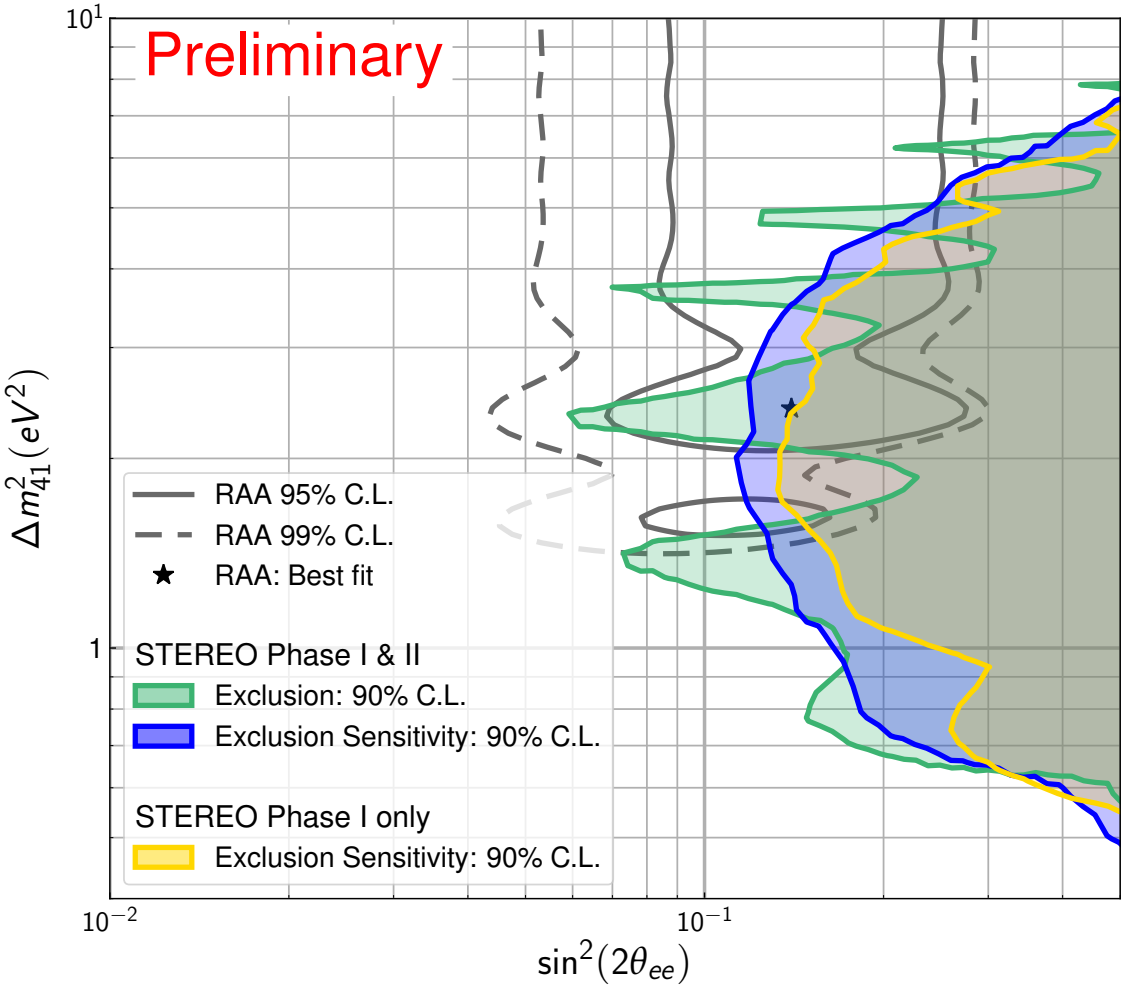
- **Phase-I results**
  66 days reactor(ON)
  $396 \pm 4\ \bar{\nu}_e$ day^{-1}
- **Raster-scan** method
  $\Delta\chi^2$ distributions estimated by MC pseudo experiments
- Best-fit value of the **RAA rejected at 97.5 % C.L.**



Ratio method

Exclusion contours - Phase I+II combined

- **Phase-I + Phase-II combined results**
  (66+47) days reactor-ON
- Considered as two **independent measurements**:
  $\chi^2 = \chi^2_I(\overrightarrow{\alpha_I}) + \chi^2_{II}(\overrightarrow{\alpha_{II}})$
  $\overrightarrow{\alpha_I} \neq \overrightarrow{\alpha_{II}}$
- Best-fit value of the **RAA rejected at 98 % C.L.**



Conclusions and perspectives

- STEREO is now running under **very stable conditions**
  Data taking will continue until end 2019, reaching **300 days of reactor-ON data**
- The **correlated background understanding improves** using reactor-OFF periods
- Exclusion contour obtained using the **robust ratio method**
  arXiv:1806.02096 (2018)
- Improved results are coming soon, with a **pure ^{235}U spectrum**

Thanks for your attention !