Latest results of the STEREO sterile neutrino search at ILL

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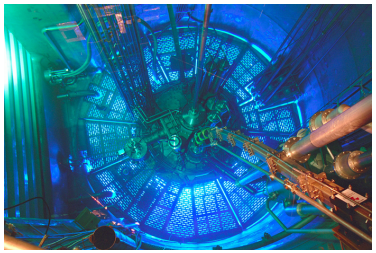
on behalf of the STEREO collaboration

The Reactor Antineutrino Anomaly (RAA)



$\overline{\nu}_e$ — $\nu_{m1}\ \nu_{m2}\ \nu_{m3}$ — $\overline{\nu}_e$?

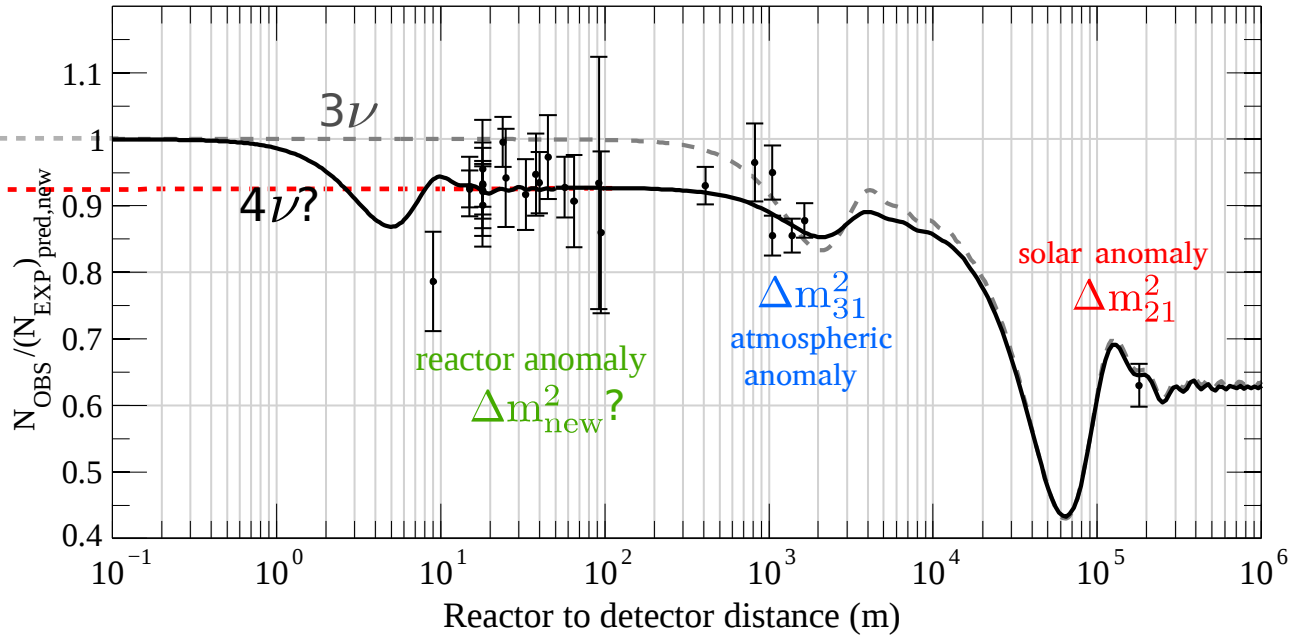
PRODUCTION (flavours) — PROPAGATION (masses) — DETECTION (flavours)

$$P_{survival}(L, E) = 1 - \sin^2(2\theta) \cdot \sin^2(1.27\Delta m^2 \cdot L/E)$$

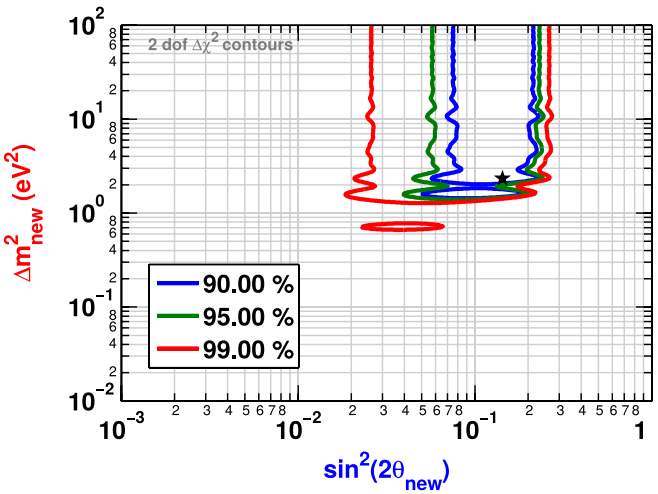
with Δm^2[eV], L[m] and E [MeV]

~ 6 % deficit

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



Motivation of STEREO



- **Oscillation test**

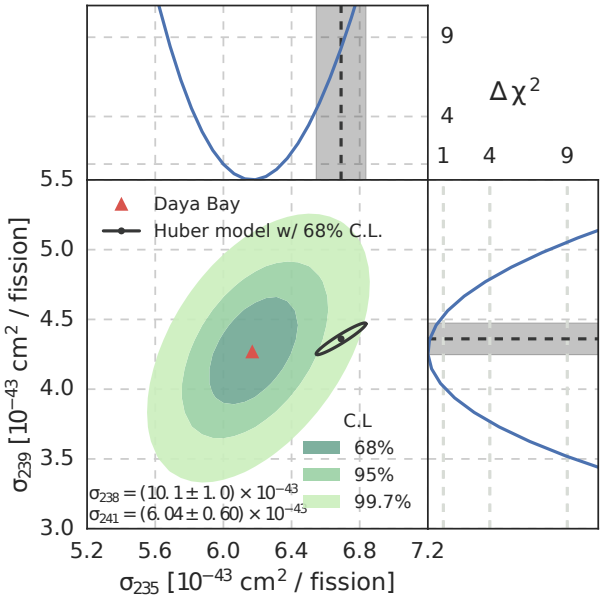
  $L/E \sim 10\,\mathrm{m}/3\,\mathrm{MeV} \rightarrow \sim$ **1eV sterile neutrino**

  Two new parameters: $\sin^2(2\theta_{new})$ and Δm^2_{new}

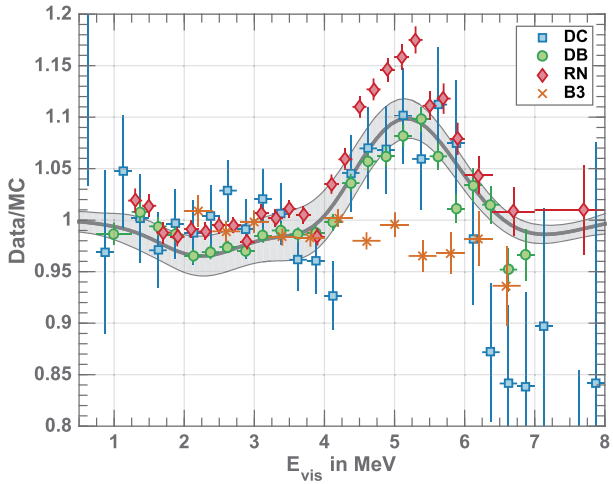
  Physical Review D 83, 073006 (2011), G. Mention et al.

- **absolute flux** normalization studies

- **spectral shape** studies



Phys. Rev. Lett. 118, 251801 (2017)



Physics Letters B 773 (2017)

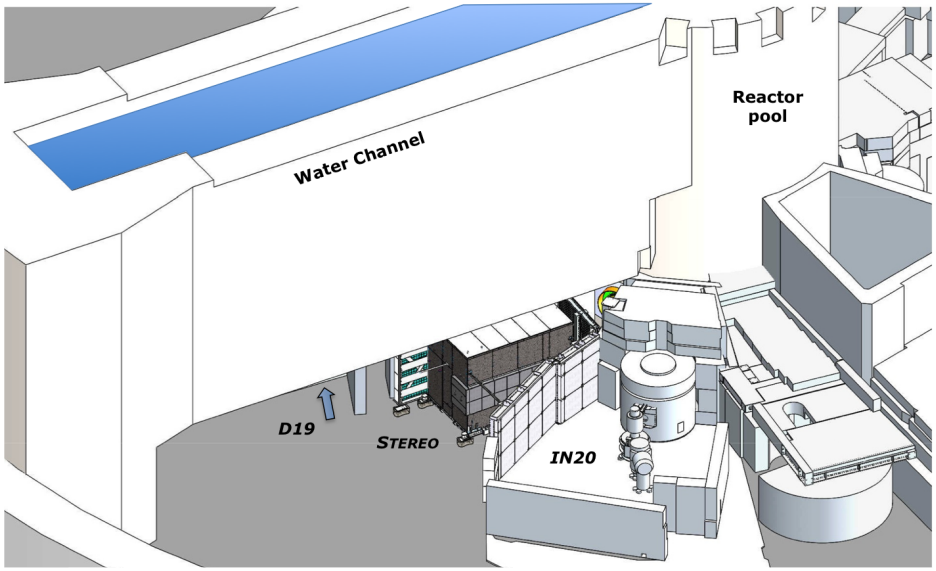
ILL research facility, Grenoble, France

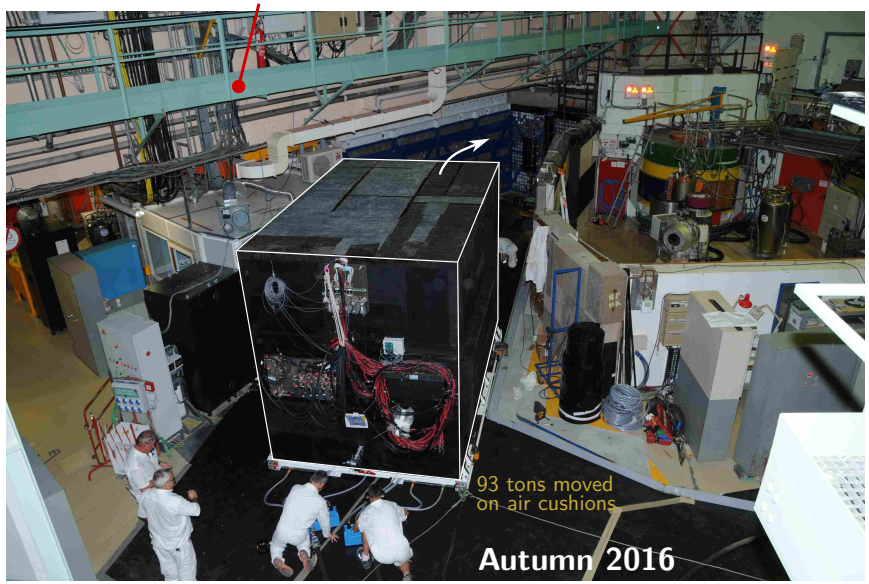
Research reactor core 58 MW_{th}
$\rightarrow 10^{19}\ \bar{\nu}_e\ s^{-1}$

✓ **Compact** core (40cm ∅)

✓ **Highly** ^{235}**U** enriched

✓ **Short baseline** measurement:
$8.9m < L_{core} < 11.1m$

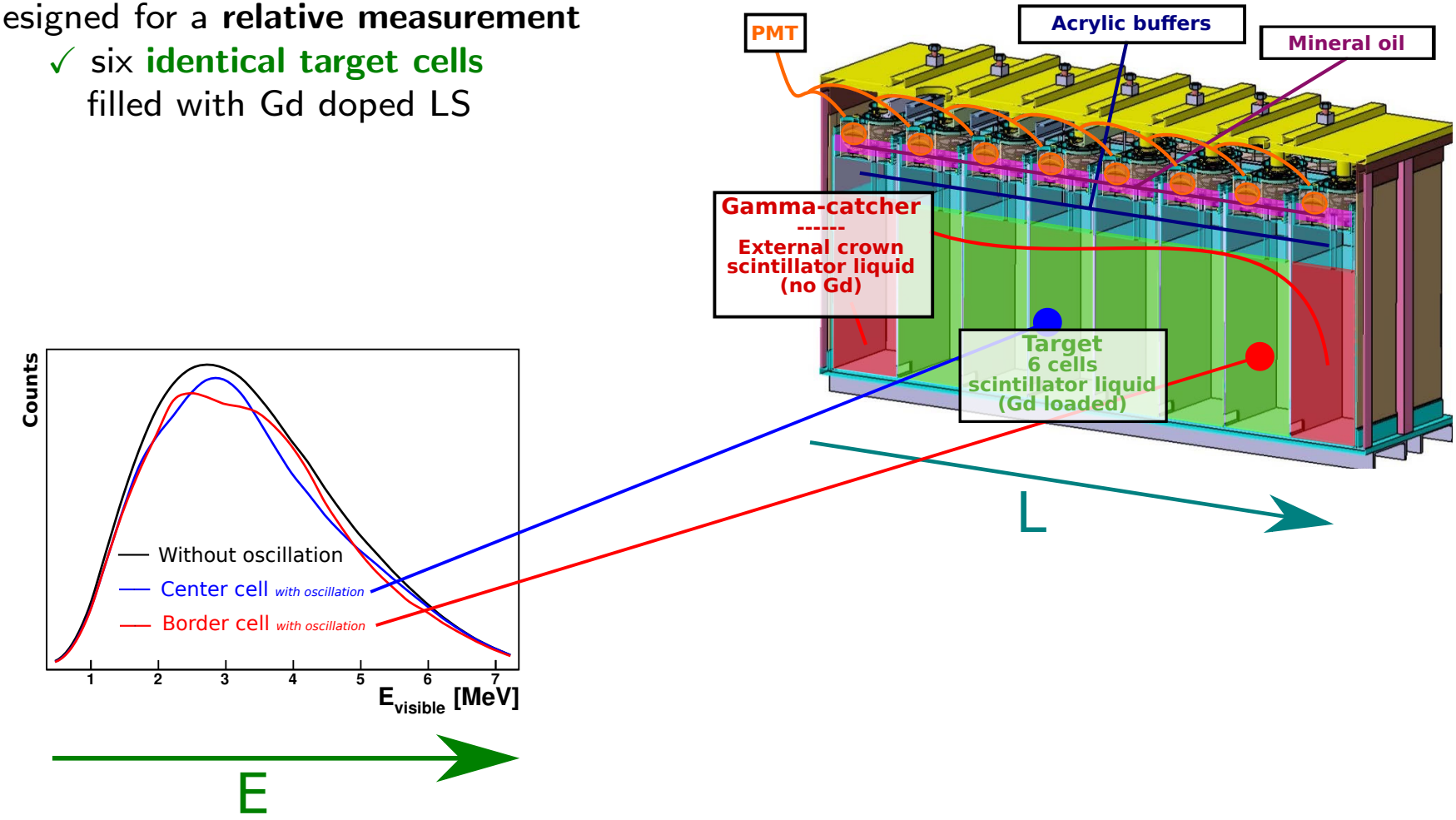




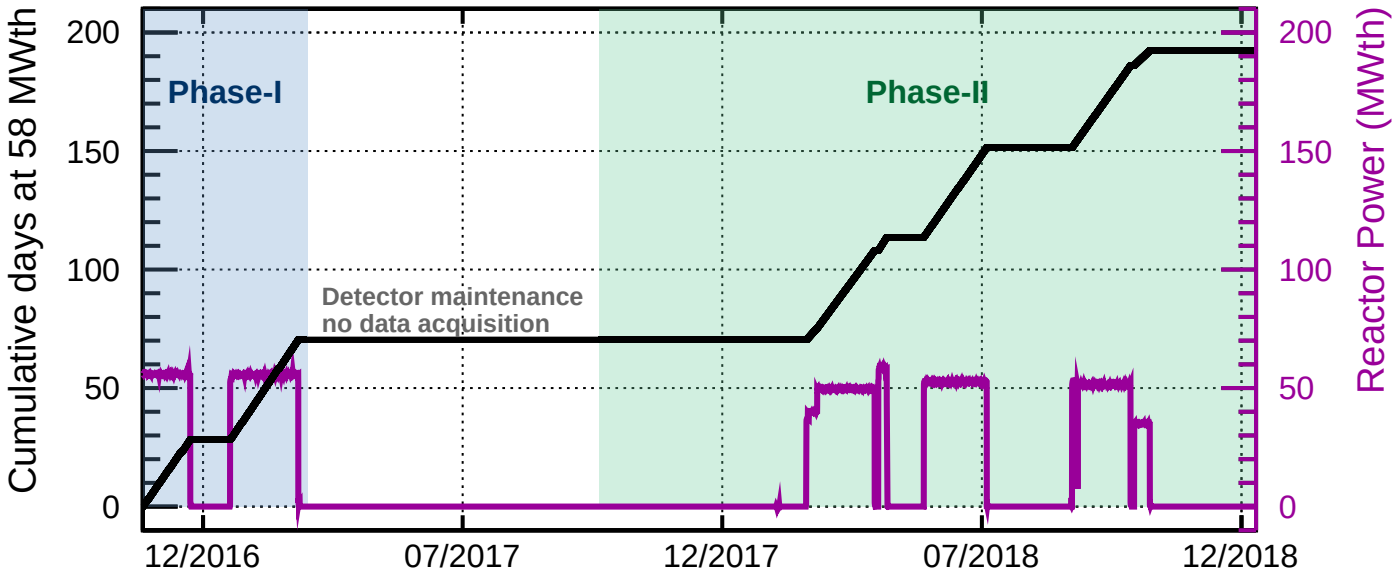
- **Surface-level** experiment
- γ **and neutron background** from neighboring experiments

The STEREO detector

- designed for a **relative measurement**
  - ✓ six **identical target cells** filled with Gd doped LS



Data taking



- Phase-I: 66 days reactor ON – 22 days reactor OFF
- Phase-II: 119 days reactor ON – 211 days reactor OFF

- **Data taking efficiency: 98.5%**
- 14% dead-time after off-line cuts

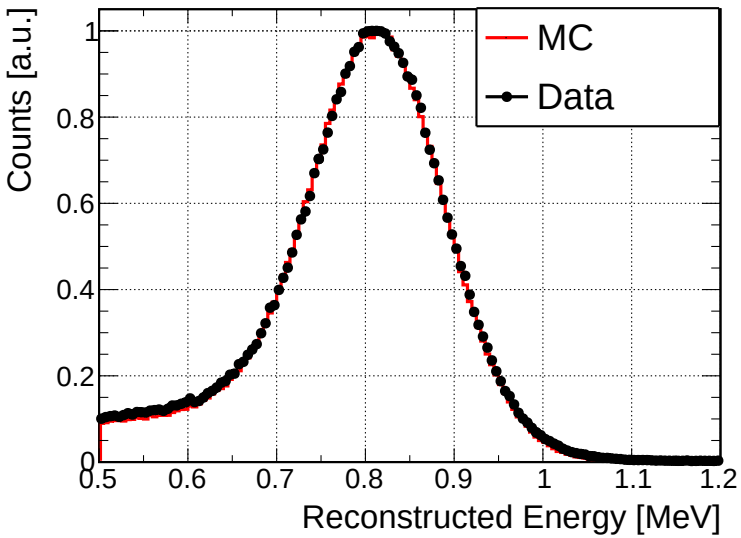
Detector response

$$\overrightarrow{E_{rec}} = M^{-1}\overrightarrow{Q}$$

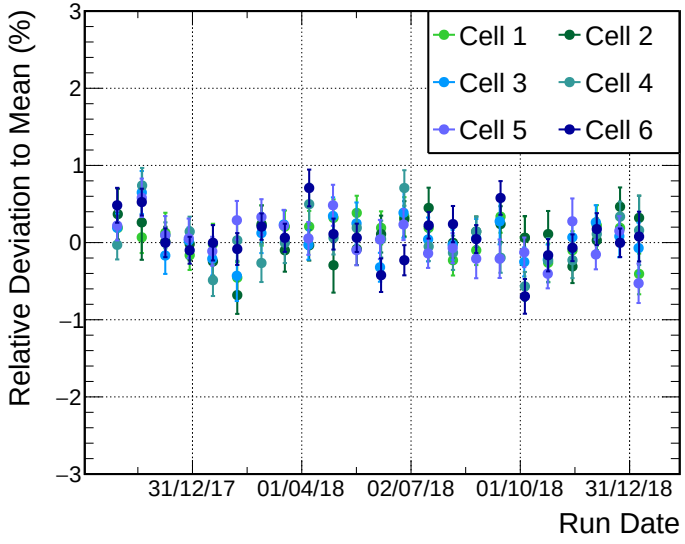
$\overrightarrow{Q}$ are the collected charges

M^{-1} matrix constructed from regular monitoring: $m_{ij} = C_i \cdot L_{ji}$

- C_i calibration coefficients (^{54}Mn radioactive source)
- L_{ji} cross-talks between cells (cosmics)



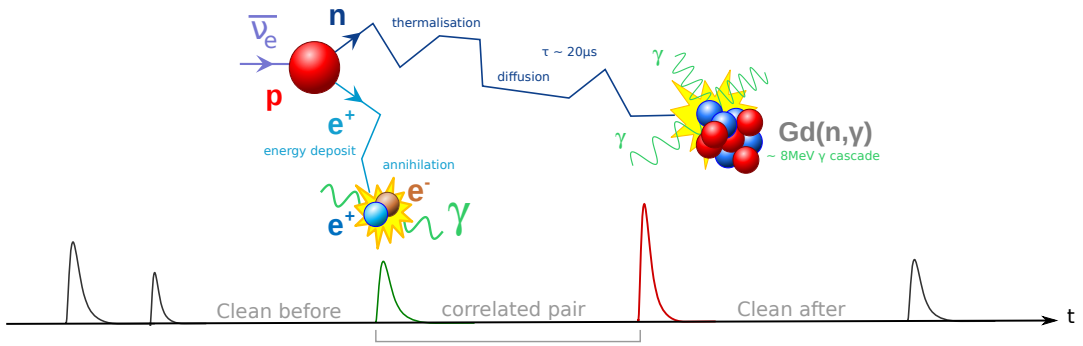
Data/MC agreement of the reconstructed energy distribution for a ^{54}Mn calibration



Stability of the reconstructed energy monitored with cosmogenic events

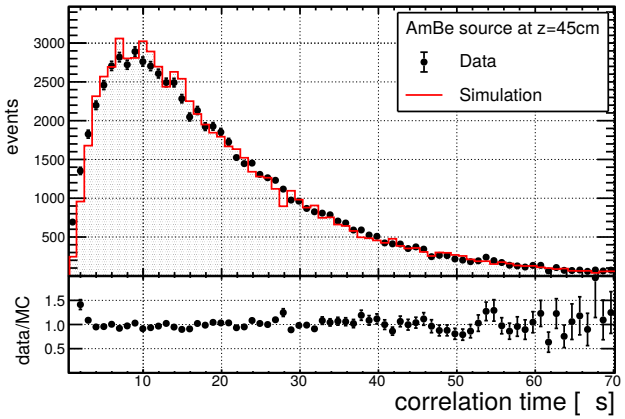
Non-linearity effect (*quenching*) calibrated using a set of γ sources consistency tested over the **whole ROI energy range**

$\bar{\nu}_e$ signal selection and efficiency studies

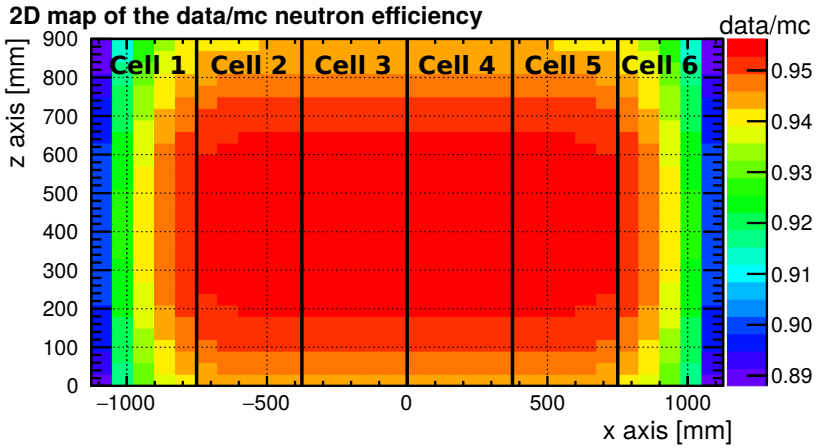


- Mean cut efficiency: 61.4±0.9%
- Uncertainty dominated by **neutron efficiency** (delayed signal)

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

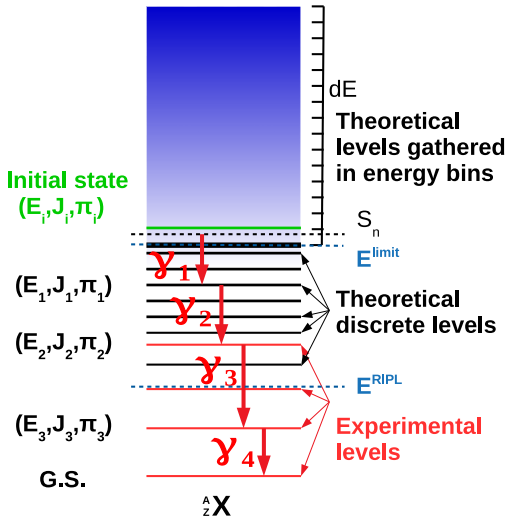


Good agreement with Monte-Carlo in **correlation time**



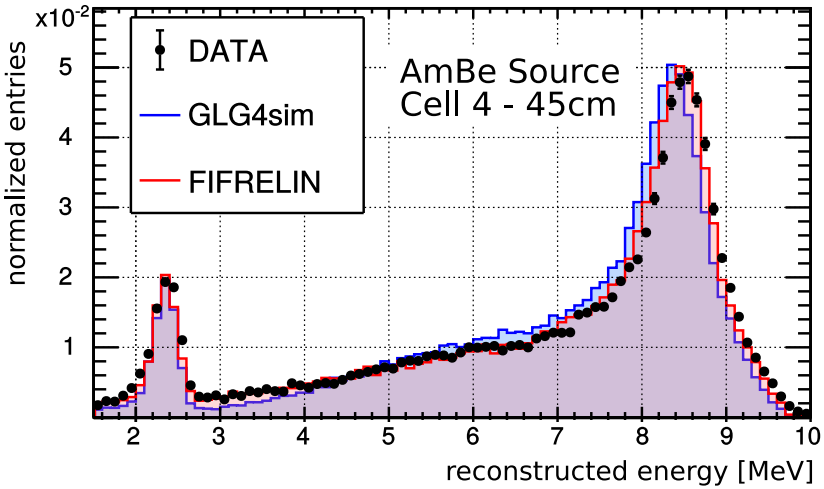
3D model correcting discrepancies between data and MC at the % level

OUTLOOK: Improved Gd Gamma cascade simulation

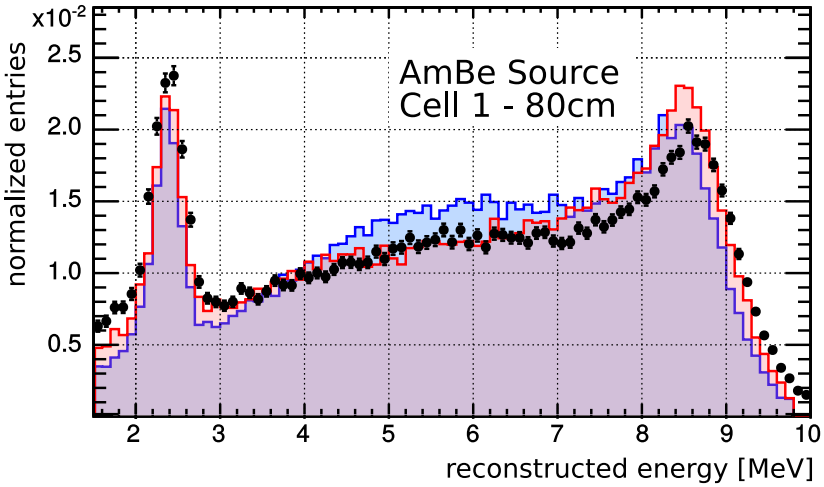


- Delayed signal: **gamma cascade** from (n,γ)Gd $\rightarrow$ correct modelization of primary importance for **small detectors** (low gamma containment)
- **Improved simulation** using **FIFRELIN** deexcitation of Gd isotopes using **experimental data** completed by **nuclear models**

Central position

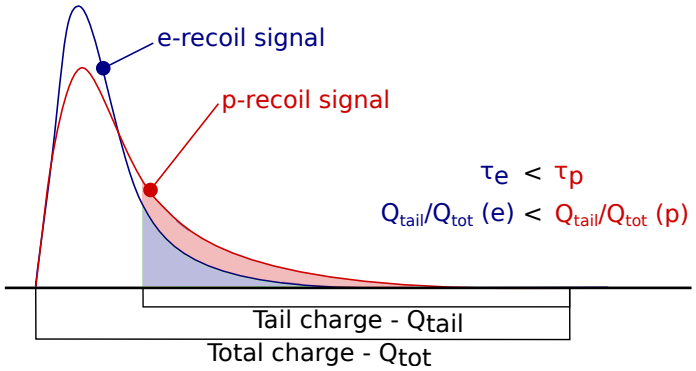


Border position



$\rightarrow$ **arXiv:1905.11967 – 10^7 cascades available on zenodo:2653787**

Correlated background and $\bar{\nu}_e$ extraction



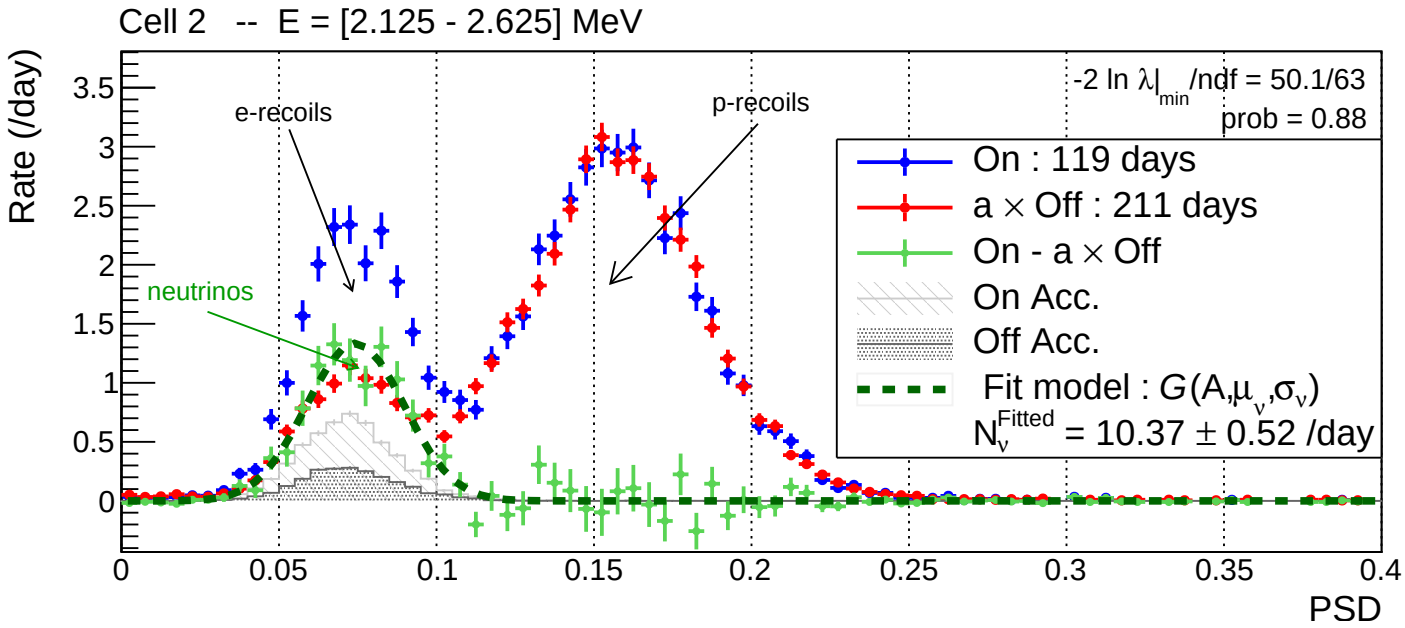
Pulse **S**hape **D**iscrimination (PSD) for prompt signal

- electron recoils (γ, $\bar{\nu}_e$...)
- proton recoils (fast neutrons...)

Correlated background (cosmics):

- rate sensitive to environment
- **stable in shape**

→ build **model from reactor-off data**



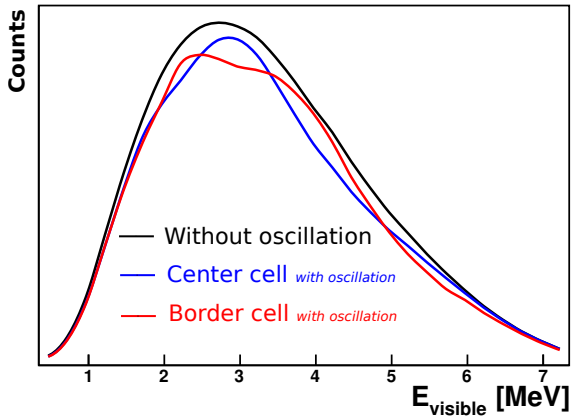
$\bar{\nu}_e$signal extraction from **reactor-on data**,
with **self-consistent background rescaling** for each cell, energy bin

Oscillation analysis

Oscillation test: look for **relative distortions** of the $\bar{\nu}_e$-spectrum between cells

✓ reduced systematics

✓ prediction independent



$$\chi^2 = \sum_{l}^{\text{Ncells}} \sum_{i}^{N_E} \left(\frac{\mathbf{D_{l,i}} - \phi_\mathbf{i} \mathbf{M_{l,i}}(\mu, \sigma, \alpha)}{\sigma_{l,i}} \right) + \sum_{l}^{\text{Ncells}} \left(\frac{\alpha_l^{\text{NormU}}}{\sigma_l^{\text{NormU}}} \right)^2 + \sum_{l}^{\text{Ncells}} \left(\frac{\alpha_l^{\text{EscaleU}}}{\sigma_l^{\text{EscaleU}}} \right)^2 + \left(\frac{\alpha_0^{\text{EscaleC}}}{\sigma_0^{\text{EscaleC}}} \right)^2$$

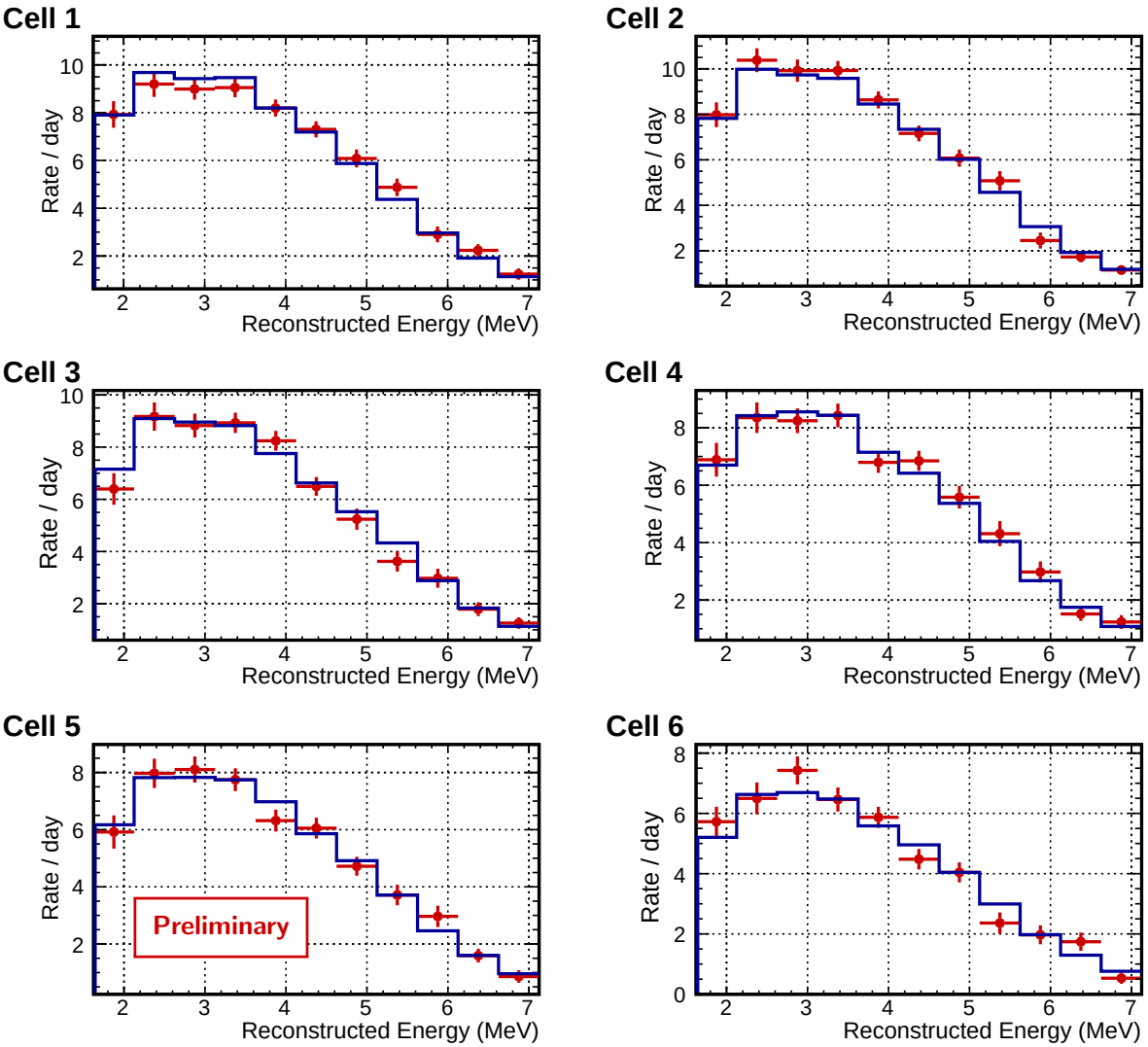
$\mathbf{D_{l,i}}$: measured spectra

$\mathbf{M_{l,i}}$: simulated spectra – takes into account cell differences, detection efficiencies etc.

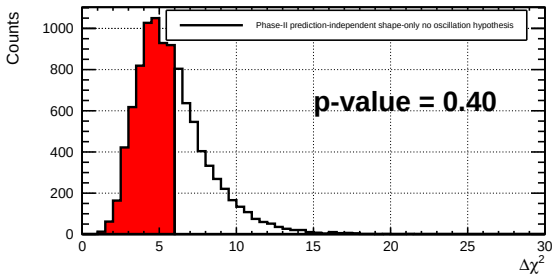
$\phi_\mathbf{i}$: free normalization parameter in energy bin i **common** for all cells

$\{\alpha\}$: nuisance parameters taking account **systematics** (energy scale, uncorrelated norm)

Non oscillation hypothesis

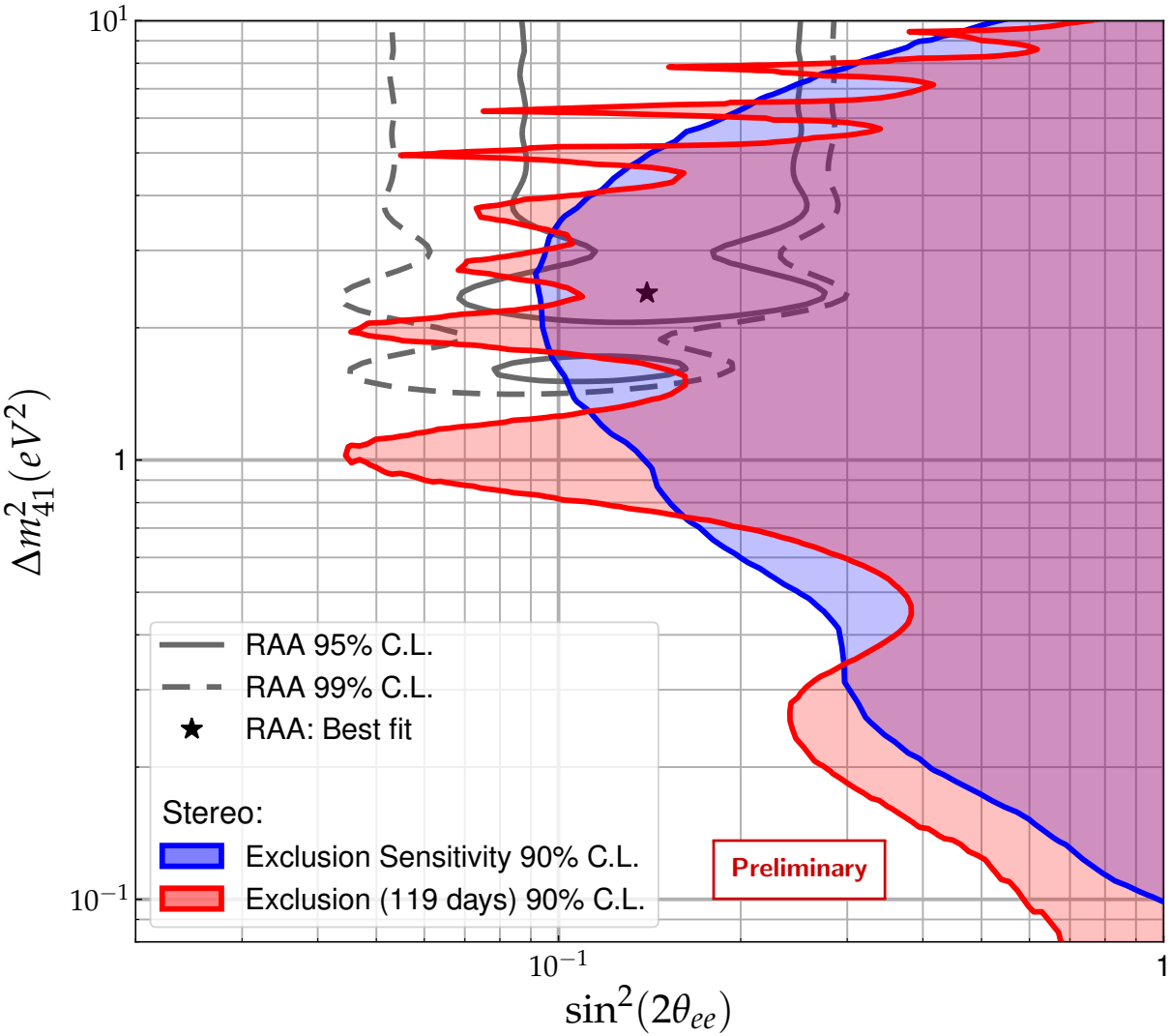


- Very good agreement between **data** and **non-oscillated model**
- **no sterile hypothesis not rejected**



- minimized pull terms stay within $\pm 1\sigma$

Exclusion contours



- **Phase-II results**
- **Raster-scan** method $\Delta\chi^2$ distributions estimated by MC pseudo experiments
- Best-fit value of the **RAA** (2011) **rejected at 99 % C.L.**

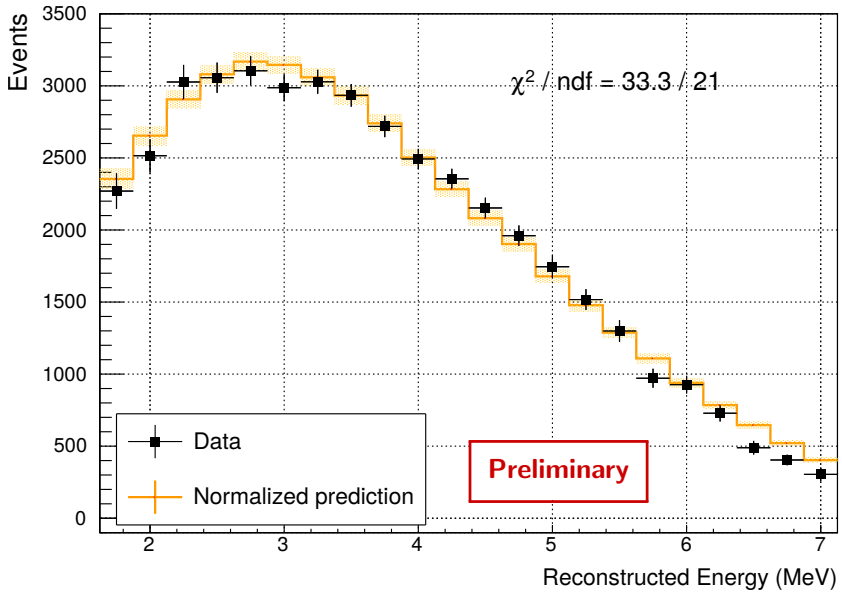
Conclusion and perspectives

STEREO detects $\bar{\nu}_e$ at 10 m from reactor core with high precision

- 43.4 k$\bar{\nu}_e$ detected in phase-II, **65.5k total**
- 185 days ON, 233 days OFF show a very **high stability of the background**
- **Initial RAA contours (2011) now mostly exluded**, best-fit point at 99% C.L., with no signs of cell-to-cell systematics
- **New work on n-Gd γ cascade simulation with FIFRELIN**
  $\rightarrow$ **arXiv:1905.11967** – 10^7 cascades available on **zenodo:2653787**

Stay tuned! Perspectives in the near future:

- Upcoming **oscillation analysis** paper
- Absolute measurement of the **pure ^{235}U antineutrino flux**
- Spectrum **shape**
- Statistics to be doubled by mid-2020



The STEREO Collaboration

Spokesperson:
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Contact:
david.lhuillier@cea.fr

Website:
http://stereo-experiment.org

Photo: ILL

Detector response

$$\overrightarrow{E_{rec}} = M^{-1}\overrightarrow{Q}$$

$\overrightarrow{Q}$ are the collected charges

M^{-1} matrix constructed from regular monitoring: $m_{ij} = C_i \cdot L_{ji}$

- C_i calibration coefficients (^{54}Mn radioactive source)
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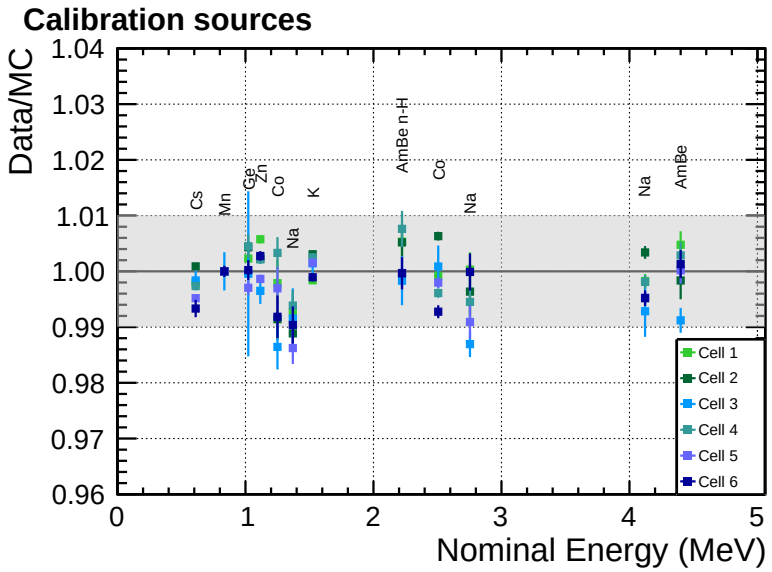
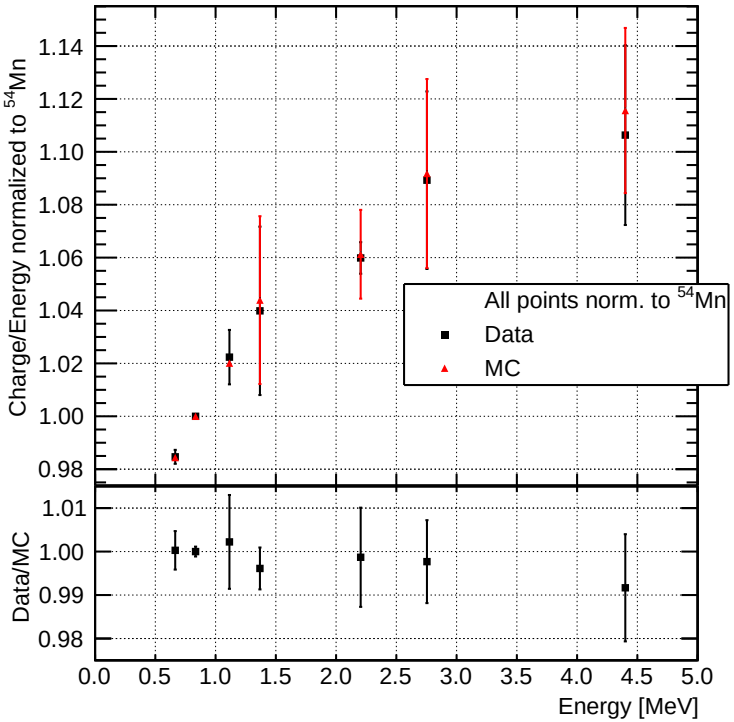


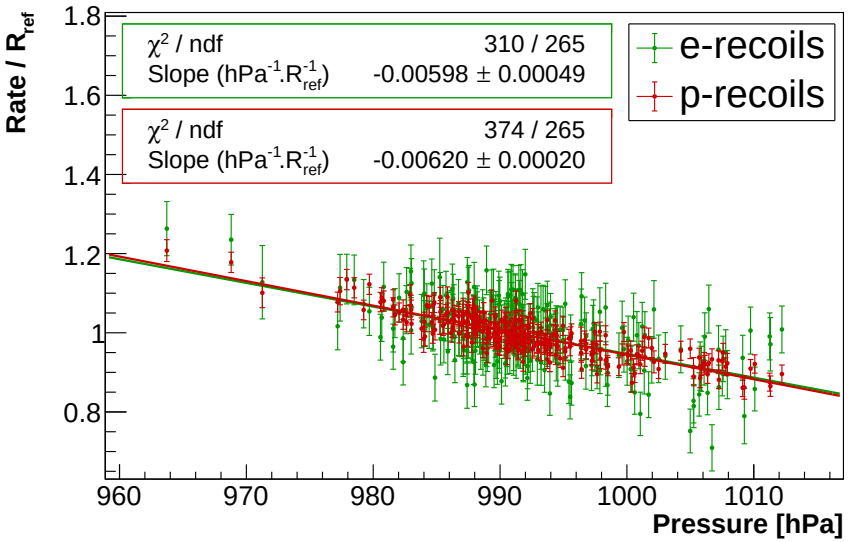
Agreement MC/Data over the whole energy range



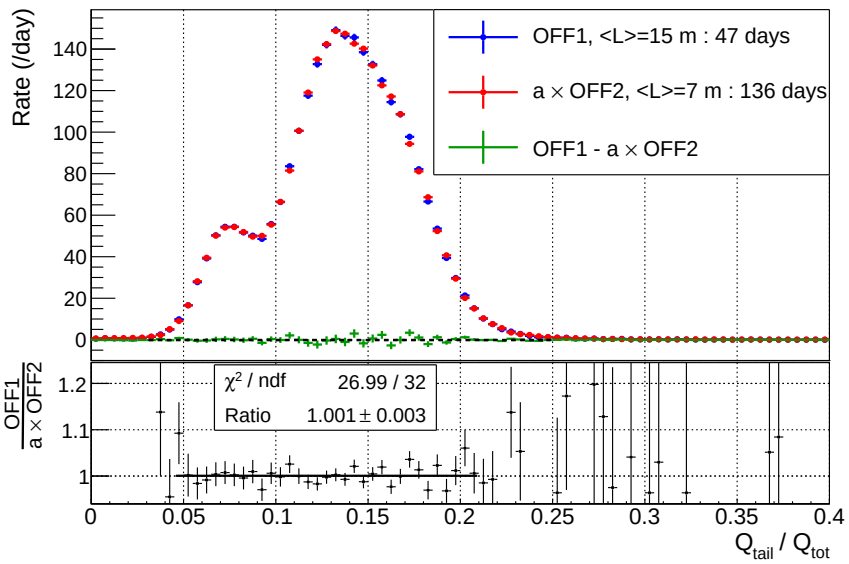
Non linearities calibration at the percent level

Background stability and spectrum

Background measured during **reactor-off periods**.
233 days available $\rightarrow$ high-statistics for stability tests

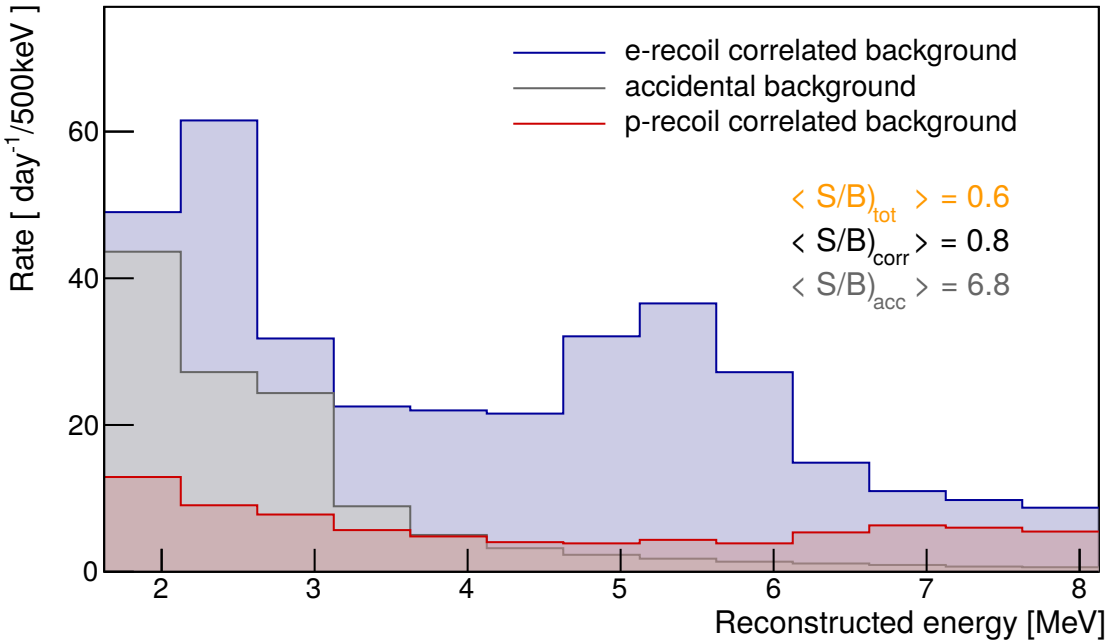


Correlation of the IBD candidates rate **with atmospheric pressure**, for e-recoils et p-recoils



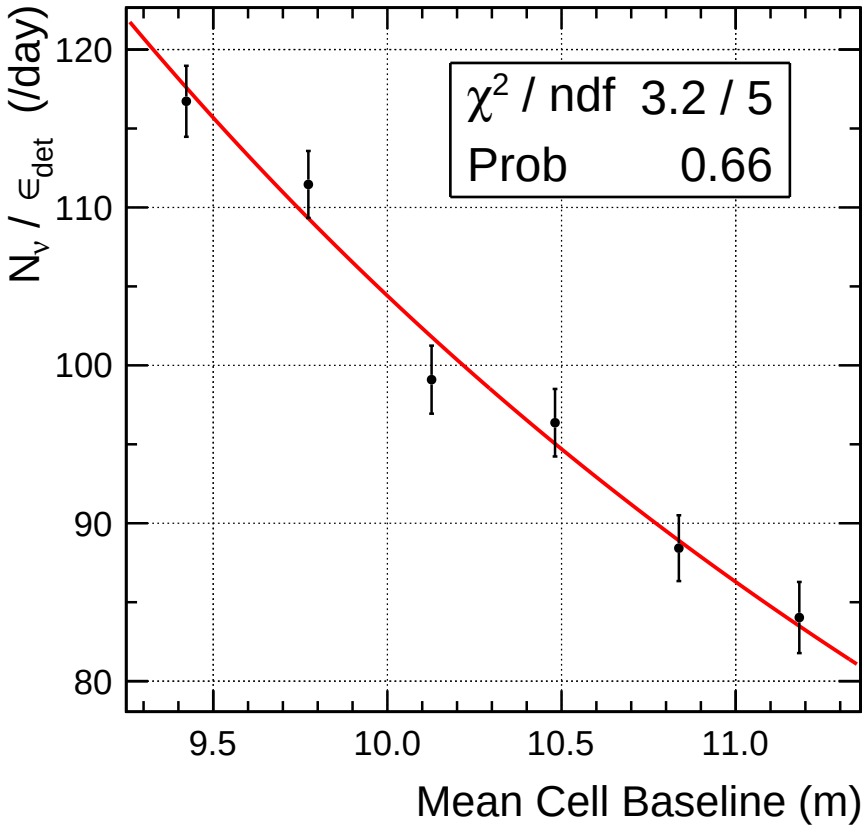
PSD distribution for two independent reactor-off dataset with **different pool water level**

Background shape and S/N ratio



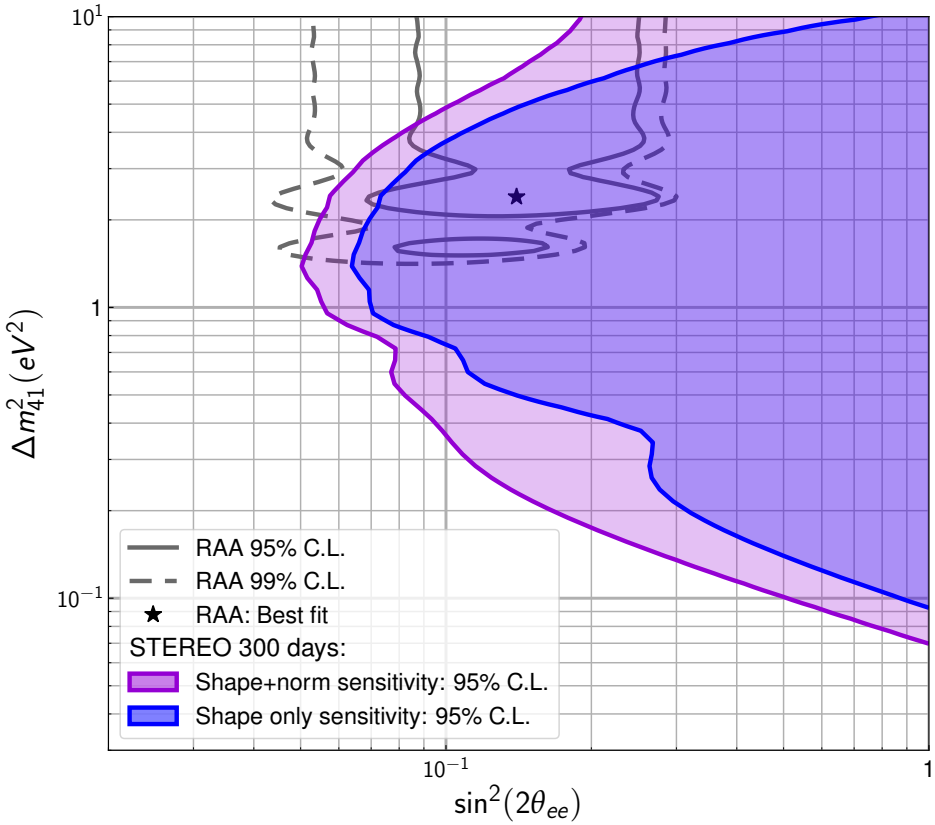
Prompt background energy spectrum,
decomposed into e-recoil, p-recoil and accidental components

$1/L^2$ law



$\bar{\nu}_e$ flux as a function of the reactor distance

STEREO final sensitivity



Expected STEREO sensitivity after 300 days