Chasing the Light Sterile Neutrino: Status of the STEREO Experiment

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on Behalf of the STEREO Collaboration

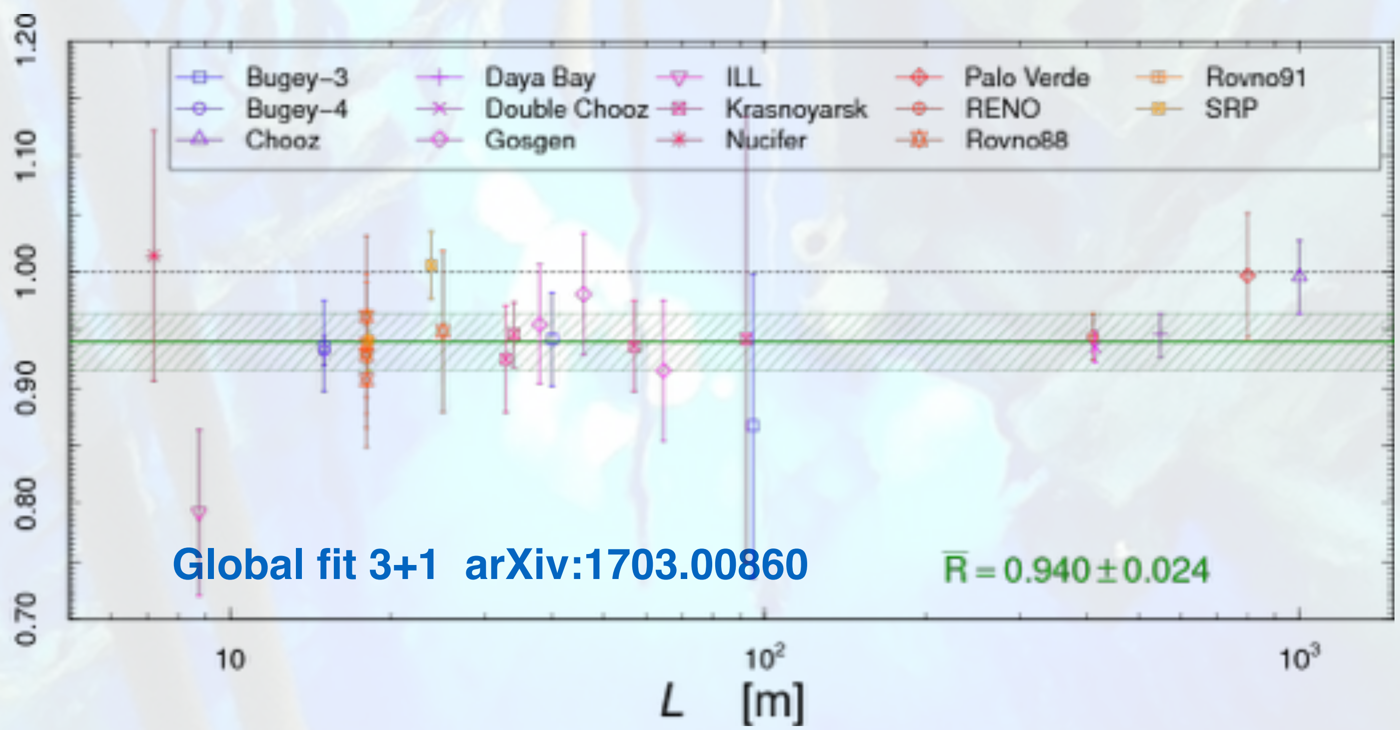
CNNP 2017 - Catania

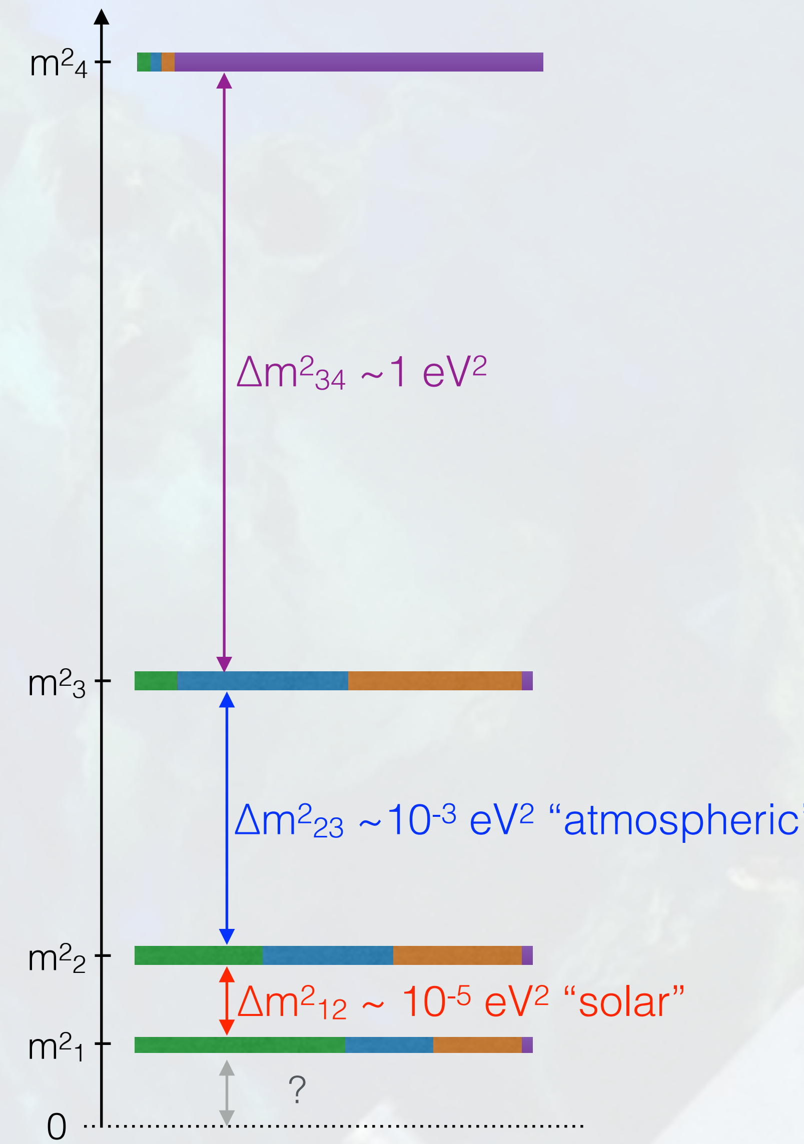
Reactor Antineutrino Anomaly

- Estimation of reactor $\bar{\nu}_e$ spectrum → **~2.6 σ rate excess** wrt short baseline measures

Phys.Rev.D83, 073006 (2011)

~ 6%





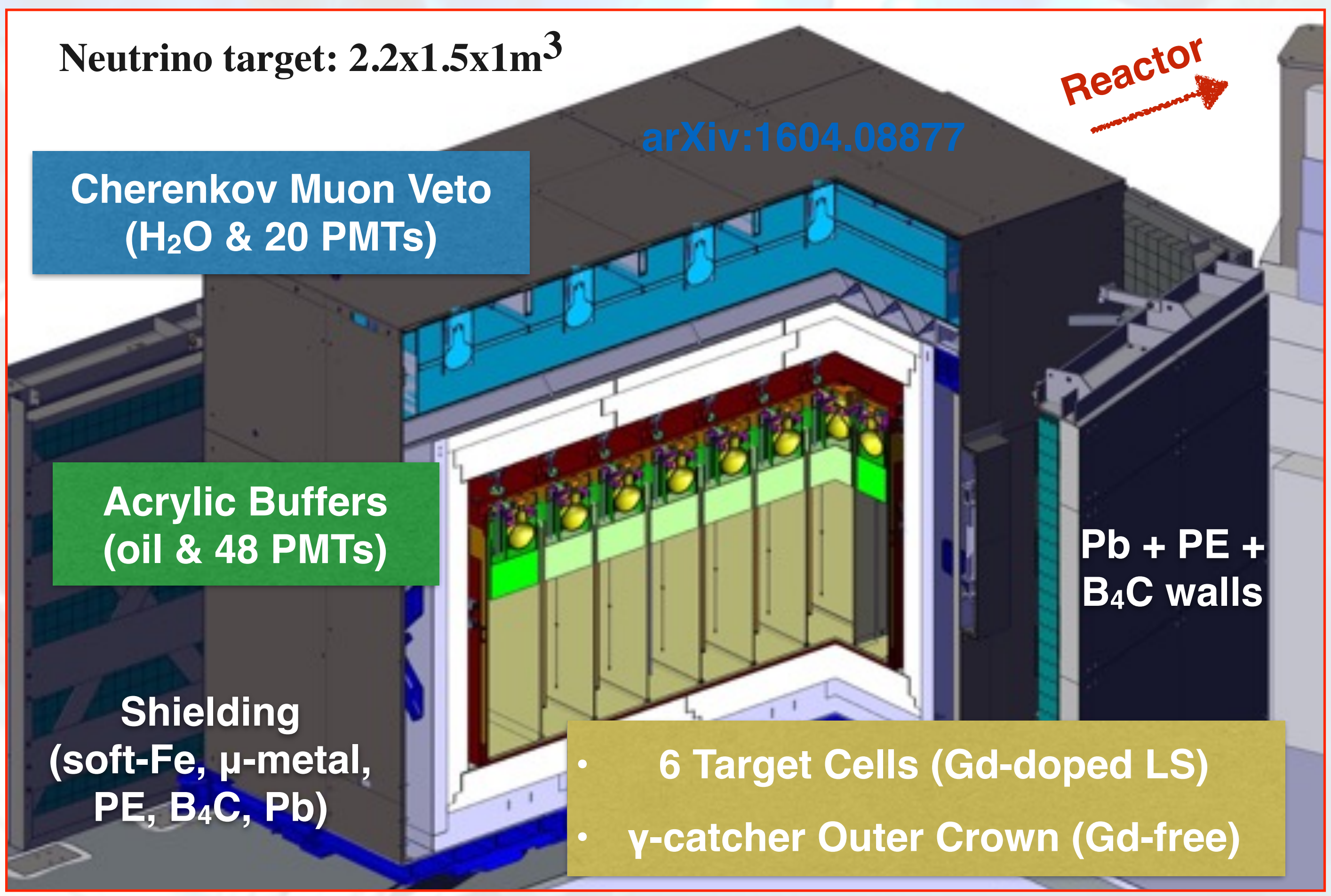
- Explained by **oscillation involving extra sterile neutrino**(s) with Δm^2 **~ 0.1-1 eV**

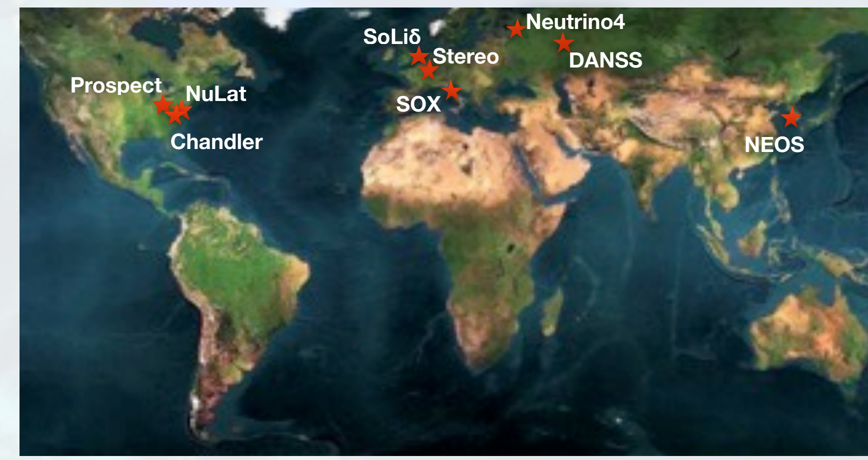
$$P_{\bar{\nu}_e\to\bar{\nu}_e}(L \lesssim 10^2 m) \simeq 1 - \sin^2(2\theta_{ee})\sin^2(1.27\Delta m^2_{14} L/E_{\bar{\nu}_e})$$

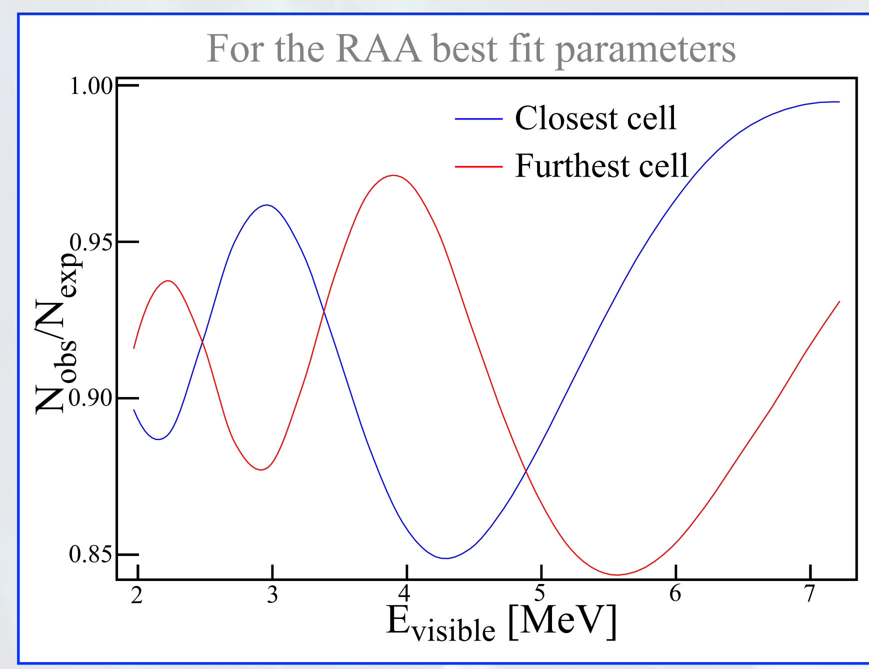
new parameters

The STEREO experiment

- STEREO detector: **9 m from** ILL research reactor **core** (⌀ = 37 cm, 93% ^{235}U, 58.3 MW_{th})
- **Compare 6 target cells** to measure oscillation-driven **distortion in the $E_{\bar{\nu}_e}$ spectrum**
- Main challenges: surface level, reactor noise
  ...and competition

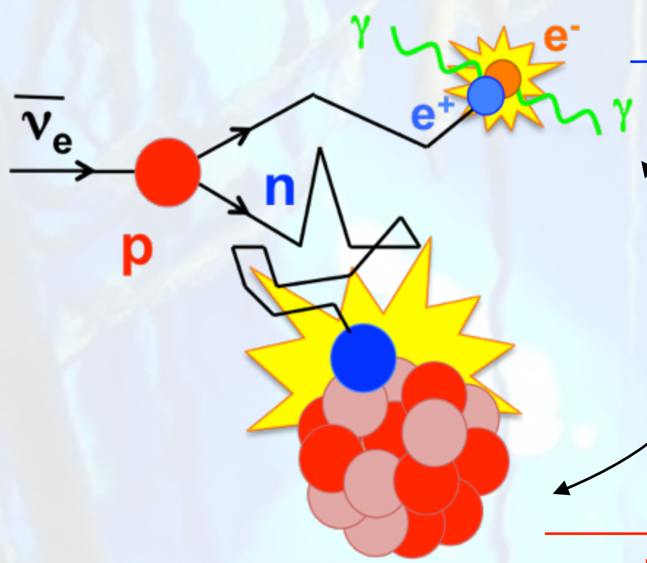






Signal and Background

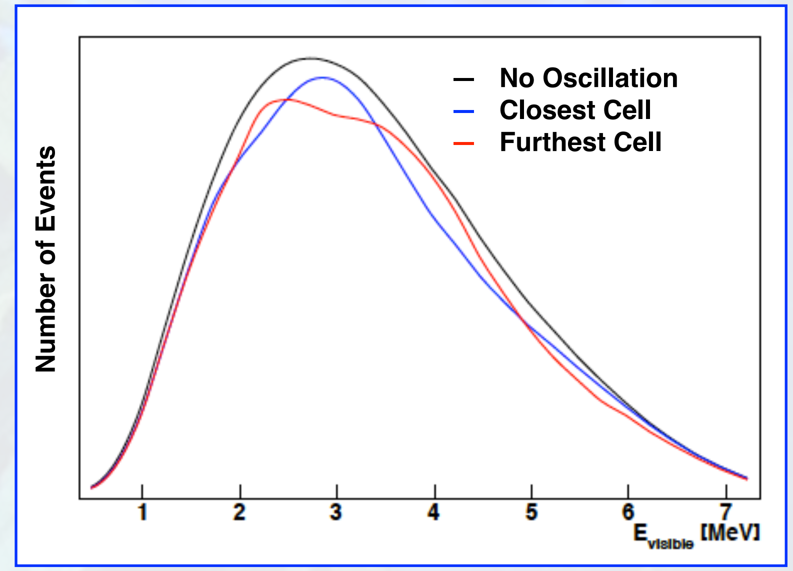
- Signal: **I**nverse **B**eta **D**ecay $\bar{\nu}_e\, p \rightarrow e^+\, n$



Prompt

Two-fold coincidence

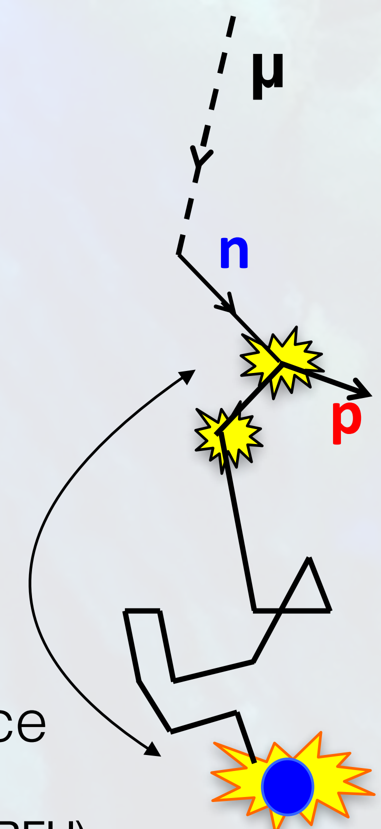
Delayed



$E_\nu \simeq E_{e+} + 0.8\, MeV$

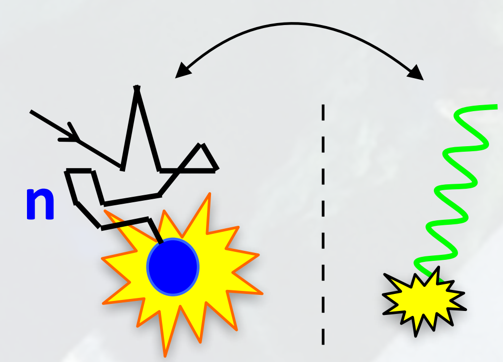
$n + Gd \rightarrow Gd^* + \gamma\text{'s}\ (8\ MeV)$

- Background
  - Cosmic induced (fast n, n-γ from μ spallation)
  - Reactor-induced (accidental coincidences between $n_{\rm th}$ leakage, high-E γ's from n-capture on metals)



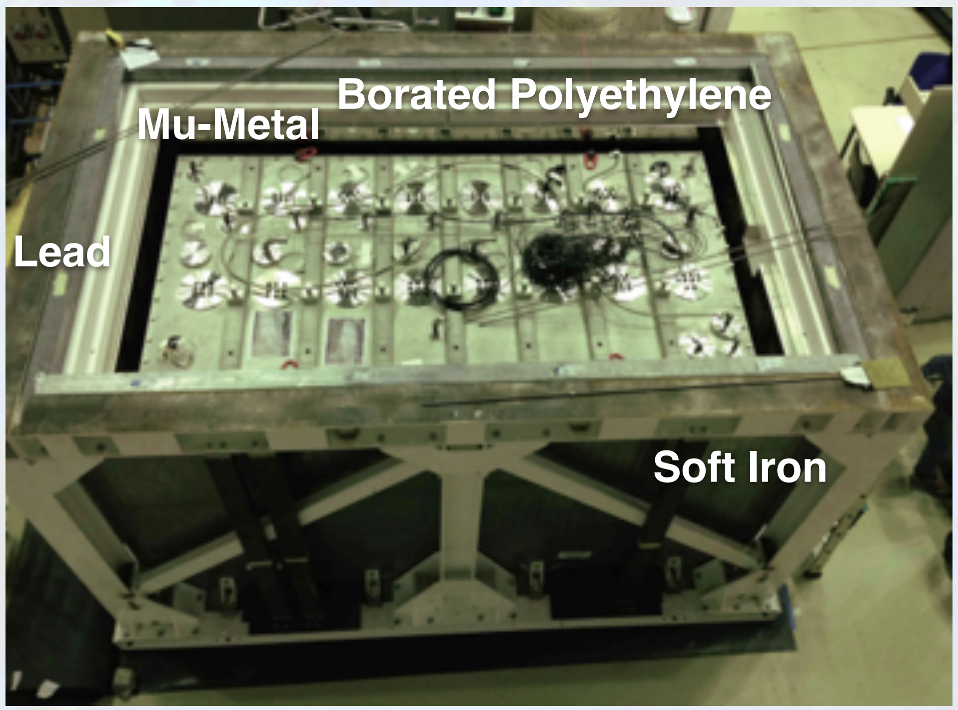
Physical coincidence

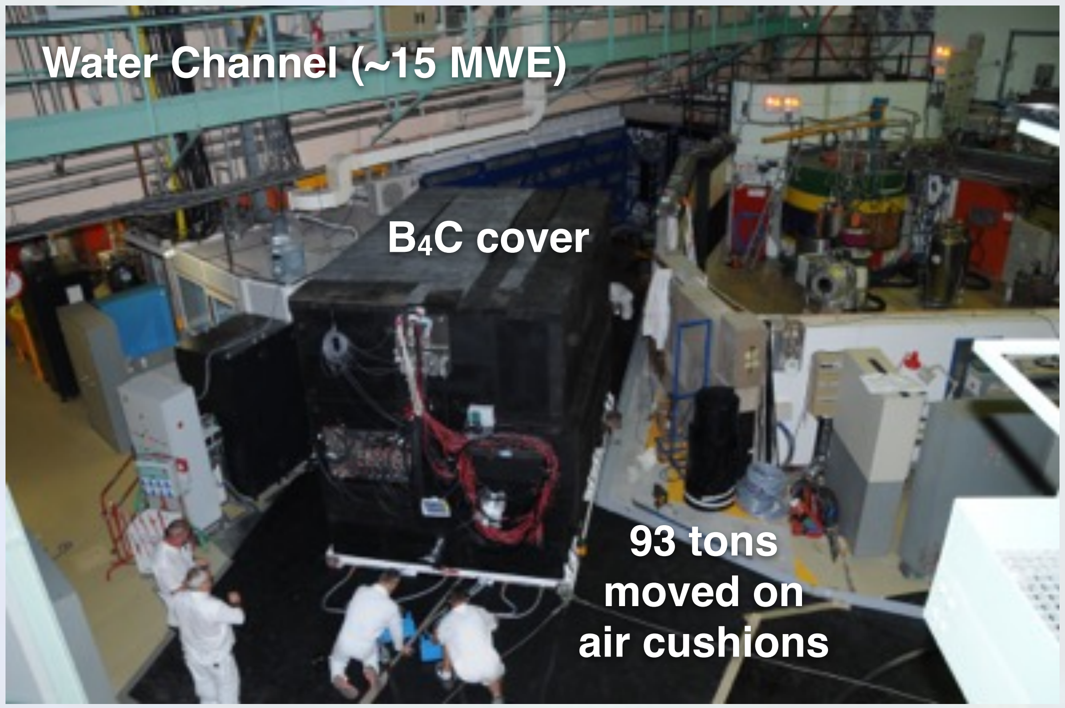
Accidental coincidence

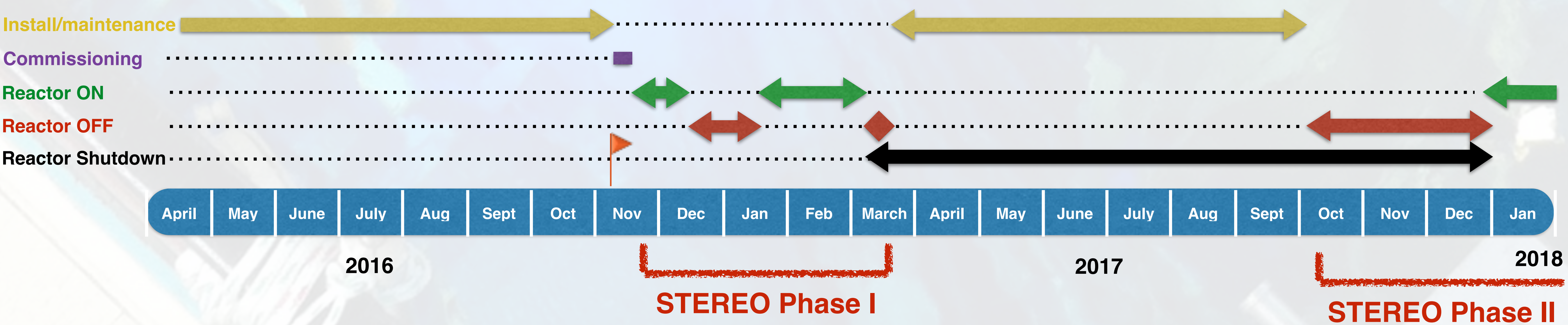


STEREO Timeline and Data Taking

- Phase I (from Nov 2016): **70 days reactor ON** (~1.5 cycles), **25 days OFF**
- Phase II (from 4 Oct 2017): expecting 7 additional cycles in 2018-19

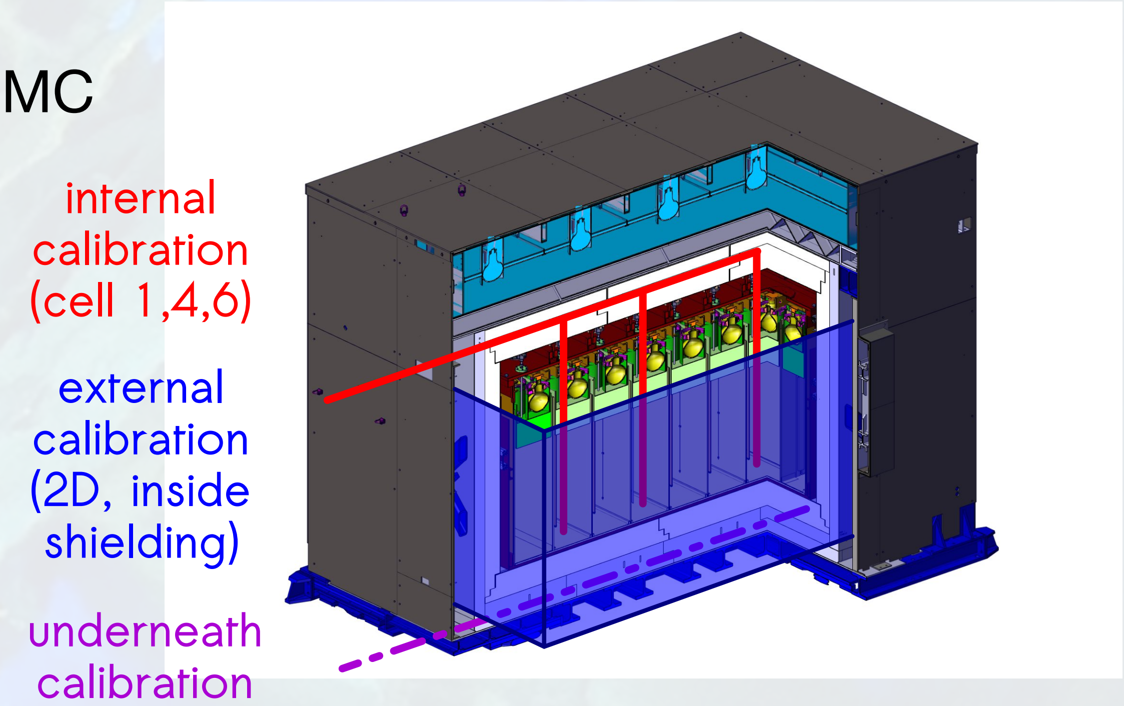


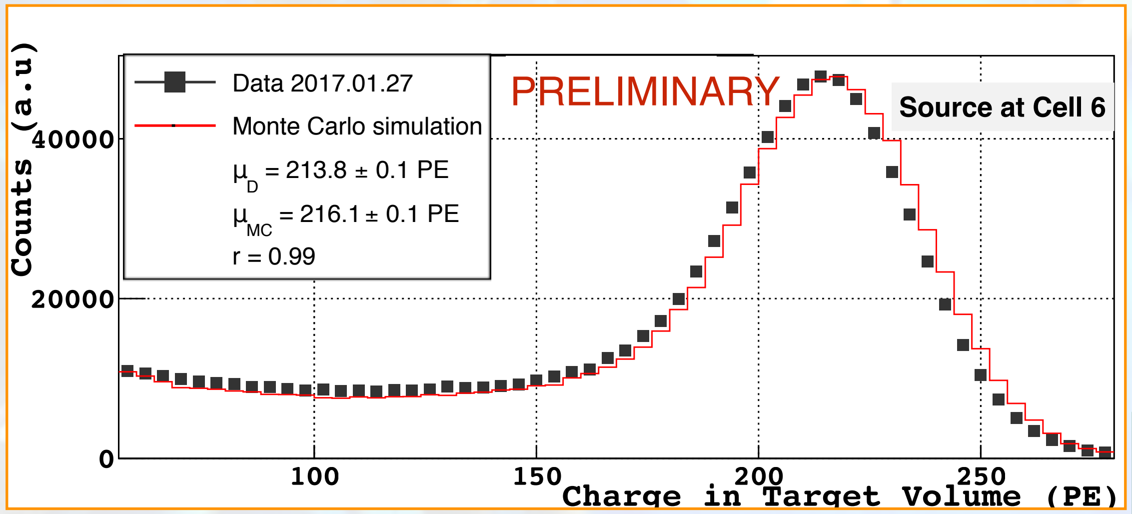


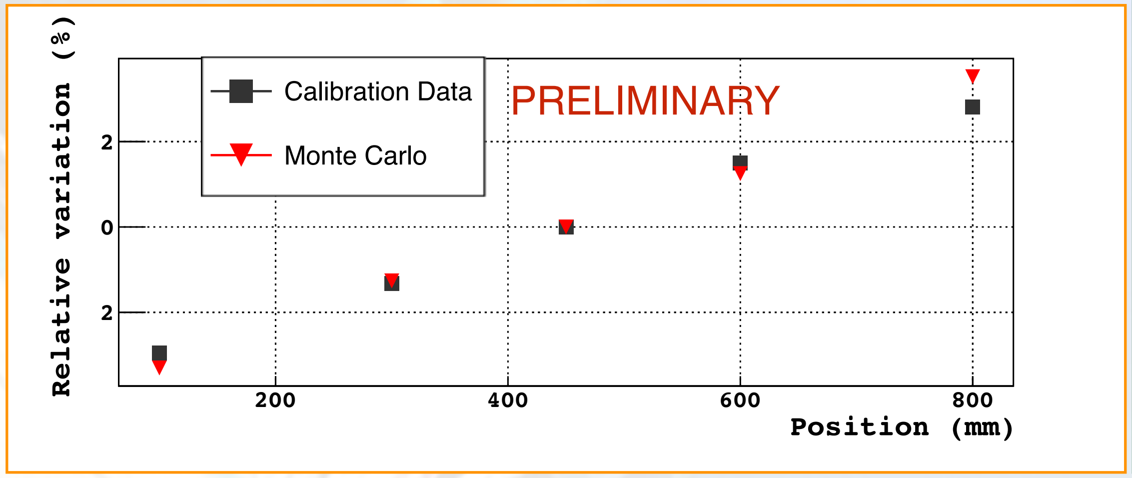


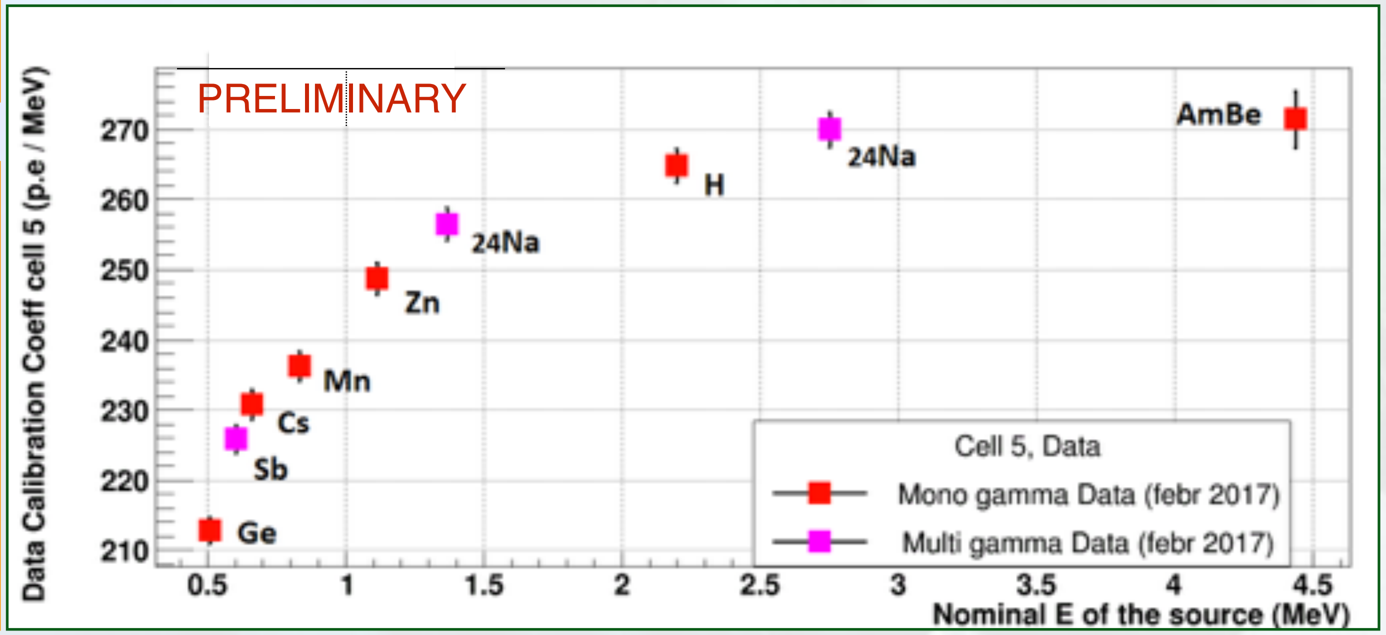
Calibration: γ Peaks

- STEREO detector **calibrated** regularly with γ and n sources using **3 independent systems**
- Energy peaks: low z-dependence, reproduced by MC









Energy Reconstruction

- Deposited energy is obtained from charges collected in each cell (matrix inversion)

$$Q_i = \alpha_i^{\mathrm{geom}} \sum_{j=\mathrm{cells}} E_j^{\mathrm{dep}}\, c_j\, L_{ji}$$

Charge collected cell i

Photon acceptance cell i

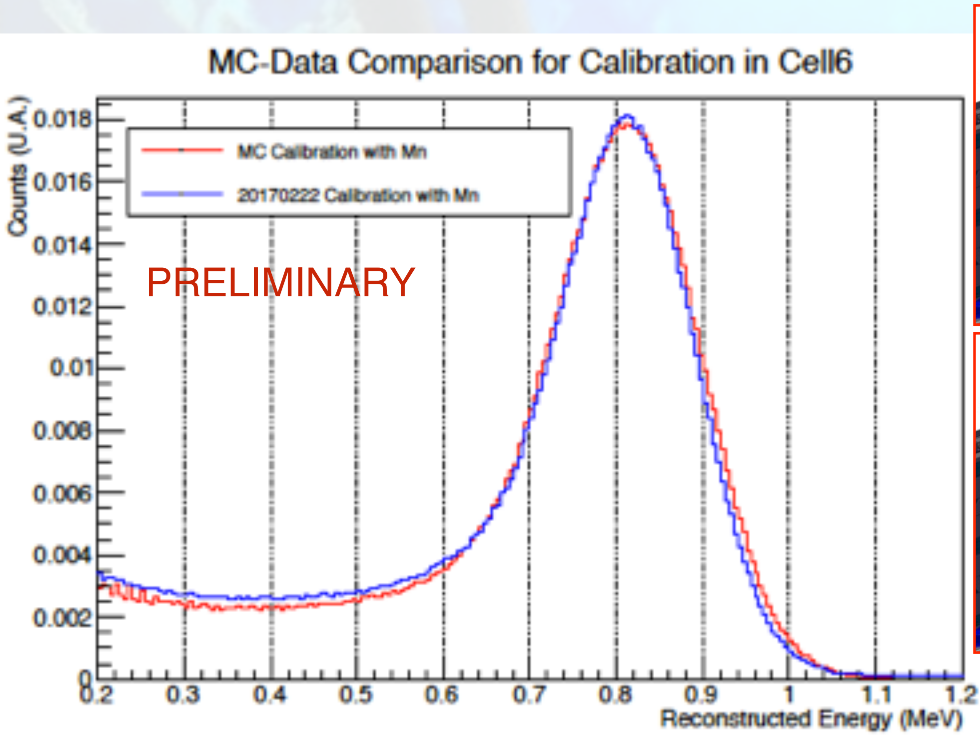
Energy deposit cell j

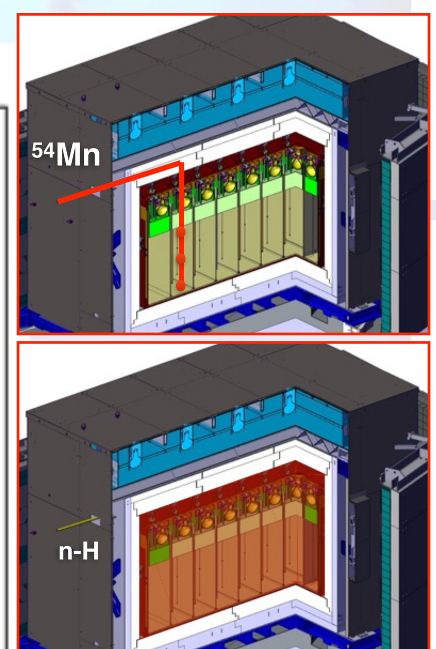
Photons/MeV in cell i (from ^{54}Mn calibration)

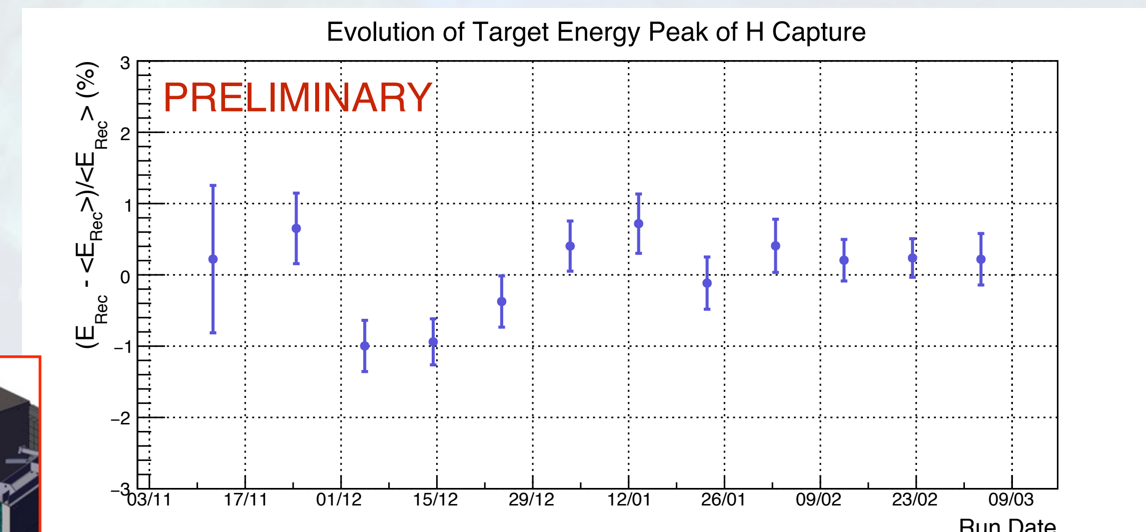
Cross-talk cells i and j (from ^{54}Mn, μ's)

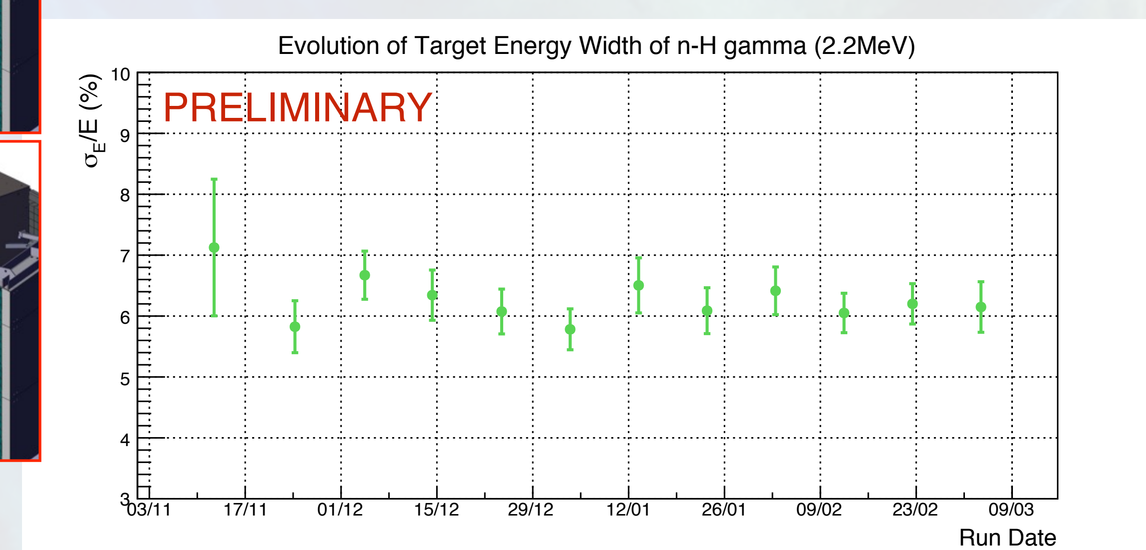
- Very good data-MC agreement on ^{54}Mn peak

- Validation with n-H capture peak stability



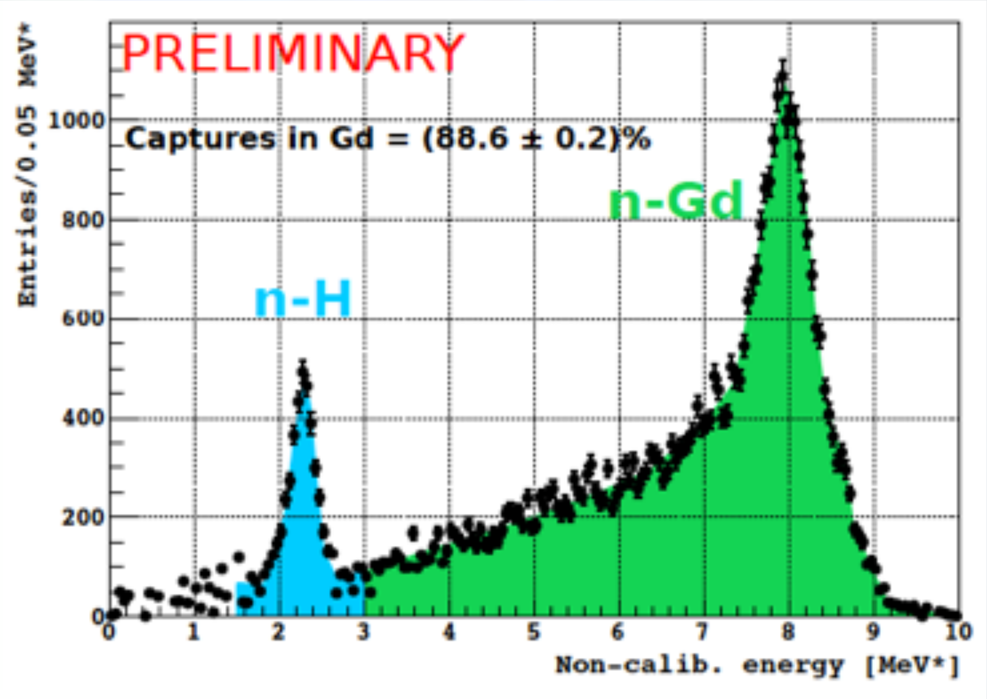


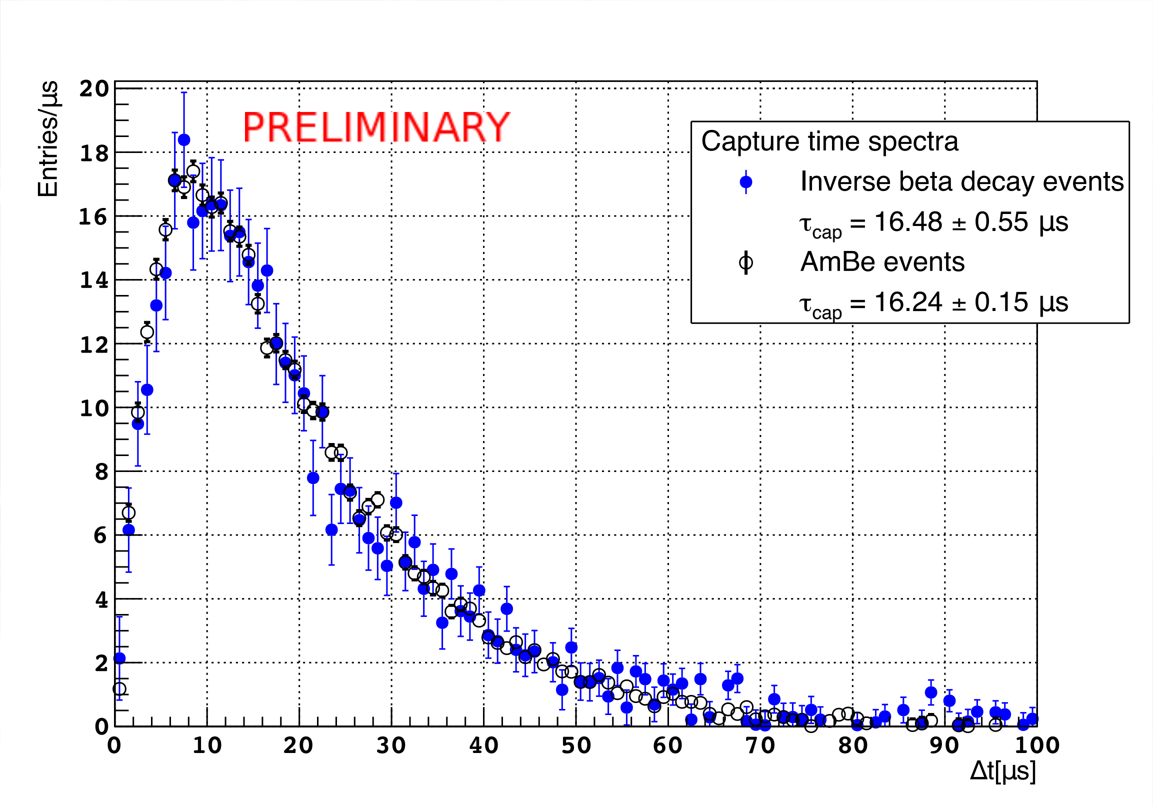


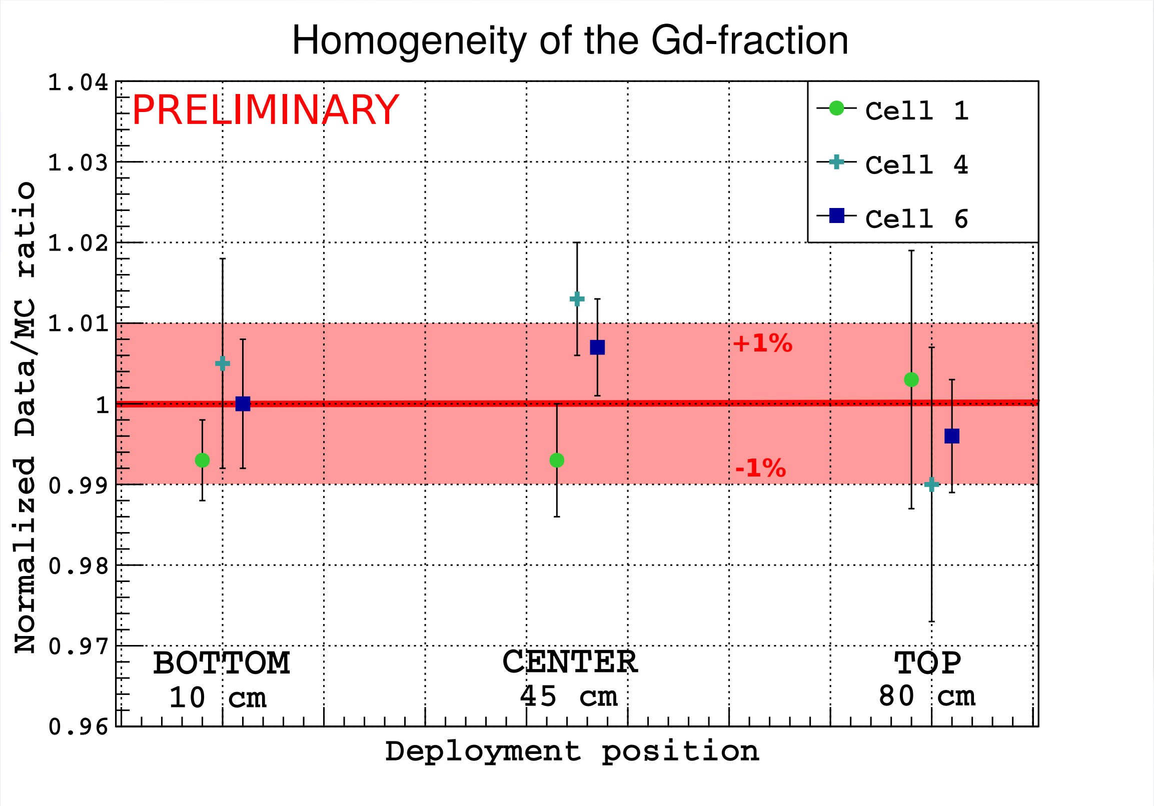


Calibration: Detection Efficiency

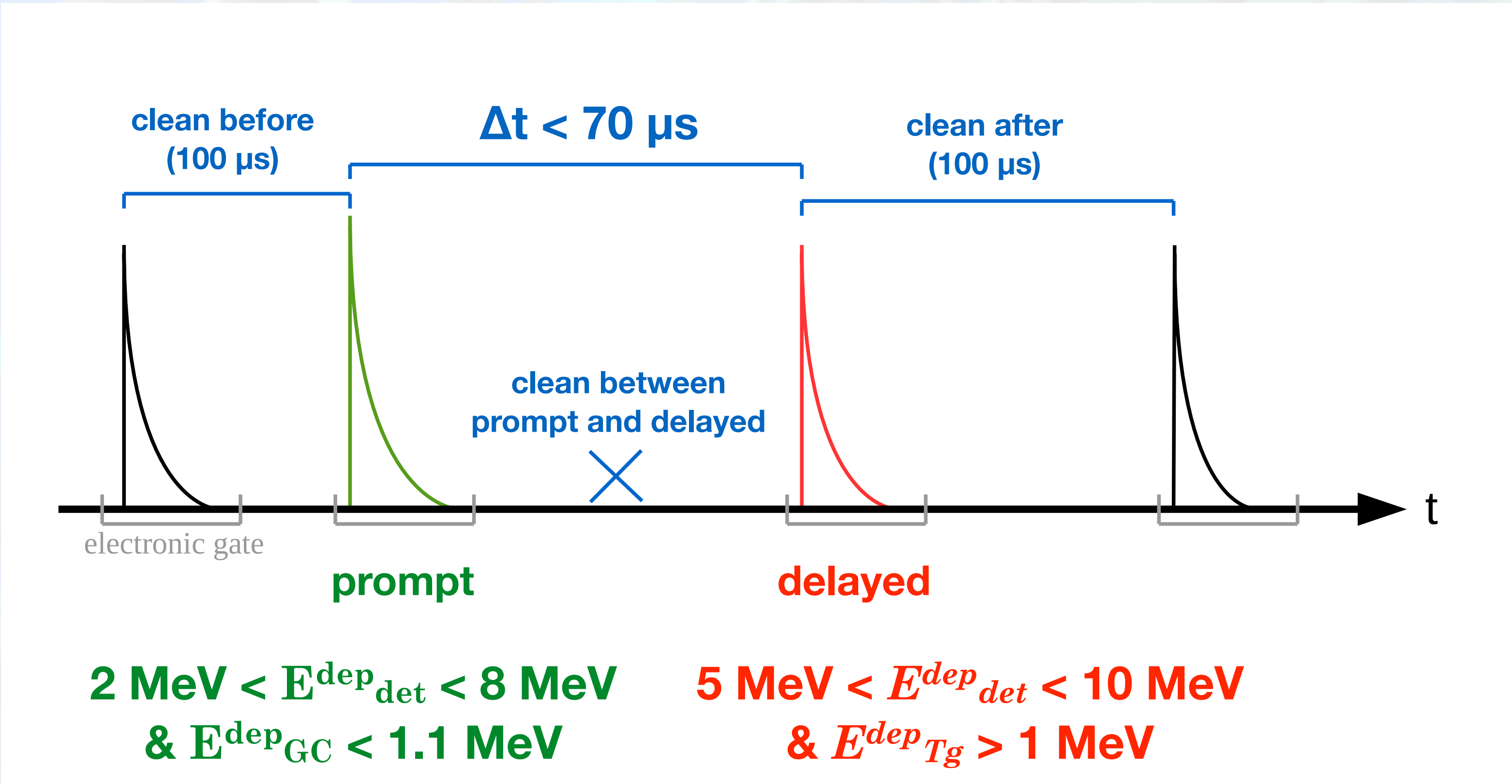
- Neutron calibration using AmBe coincidences
- n-capture time in agreement with IBD candidates
- Correction factor for Gd-capture fraction in MC
  → **MC validation** for global **n-capture efficiency** calculation

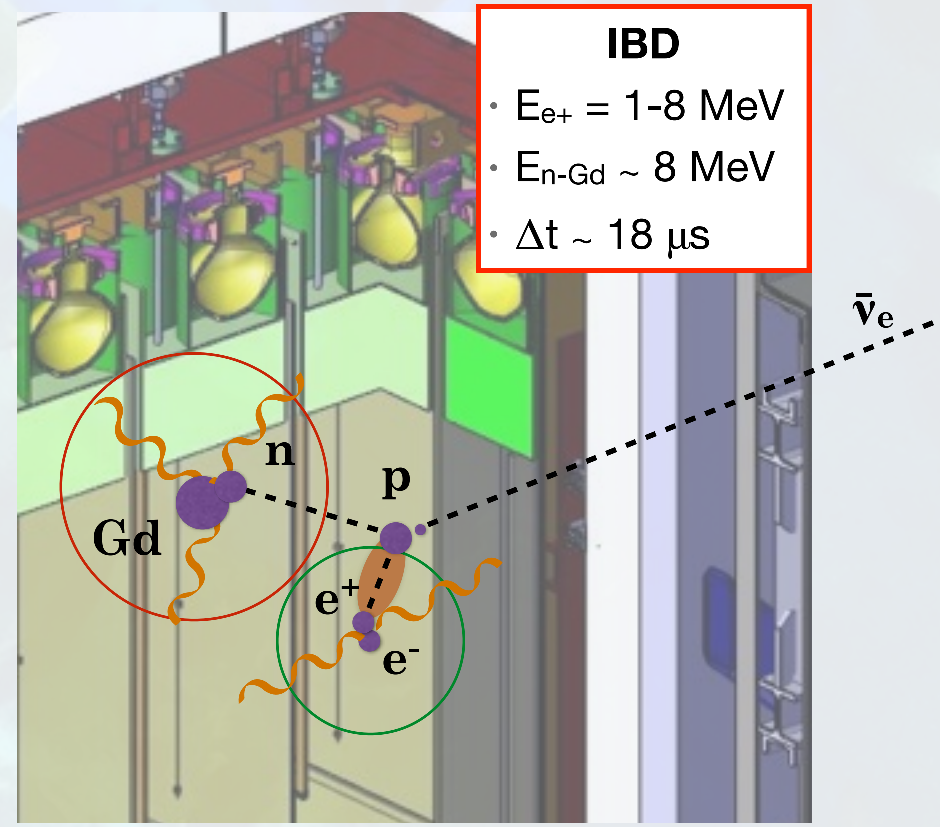




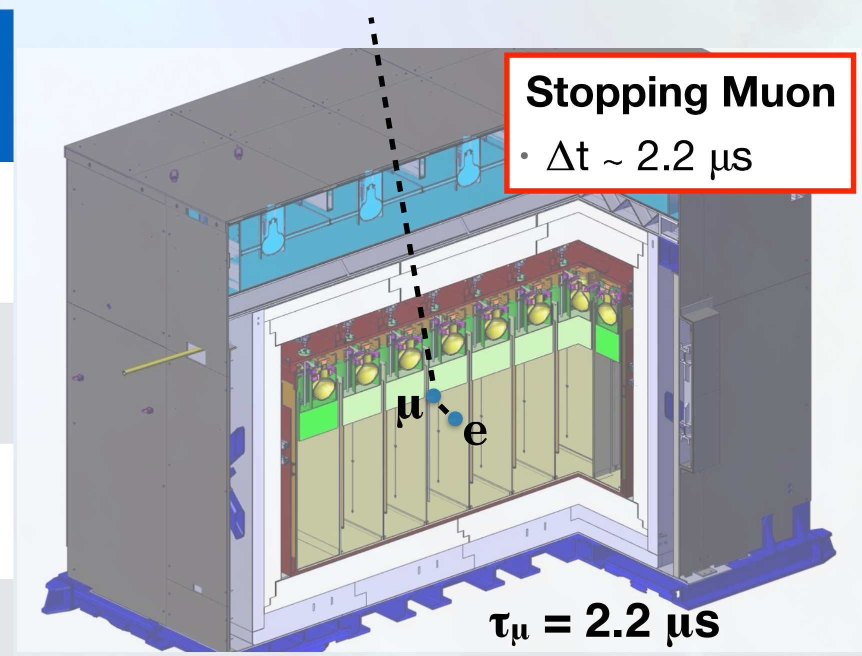


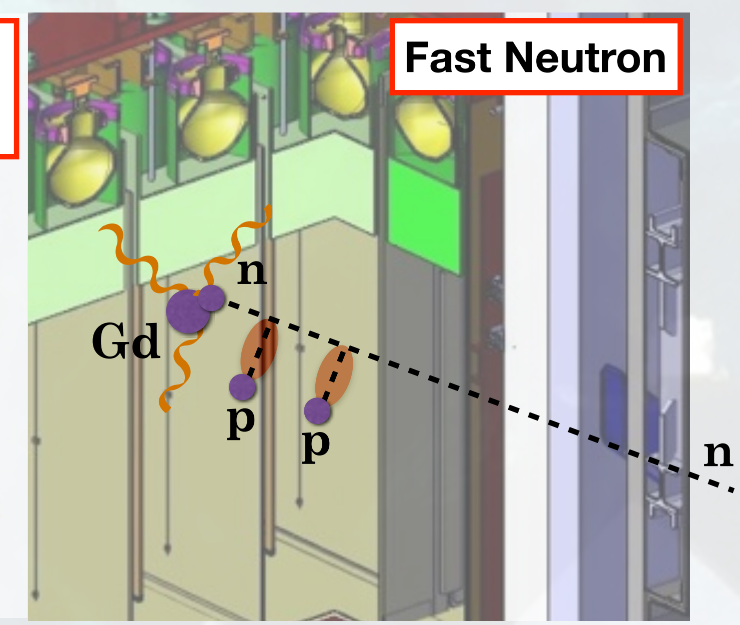
Neutrino Selection and Cuts





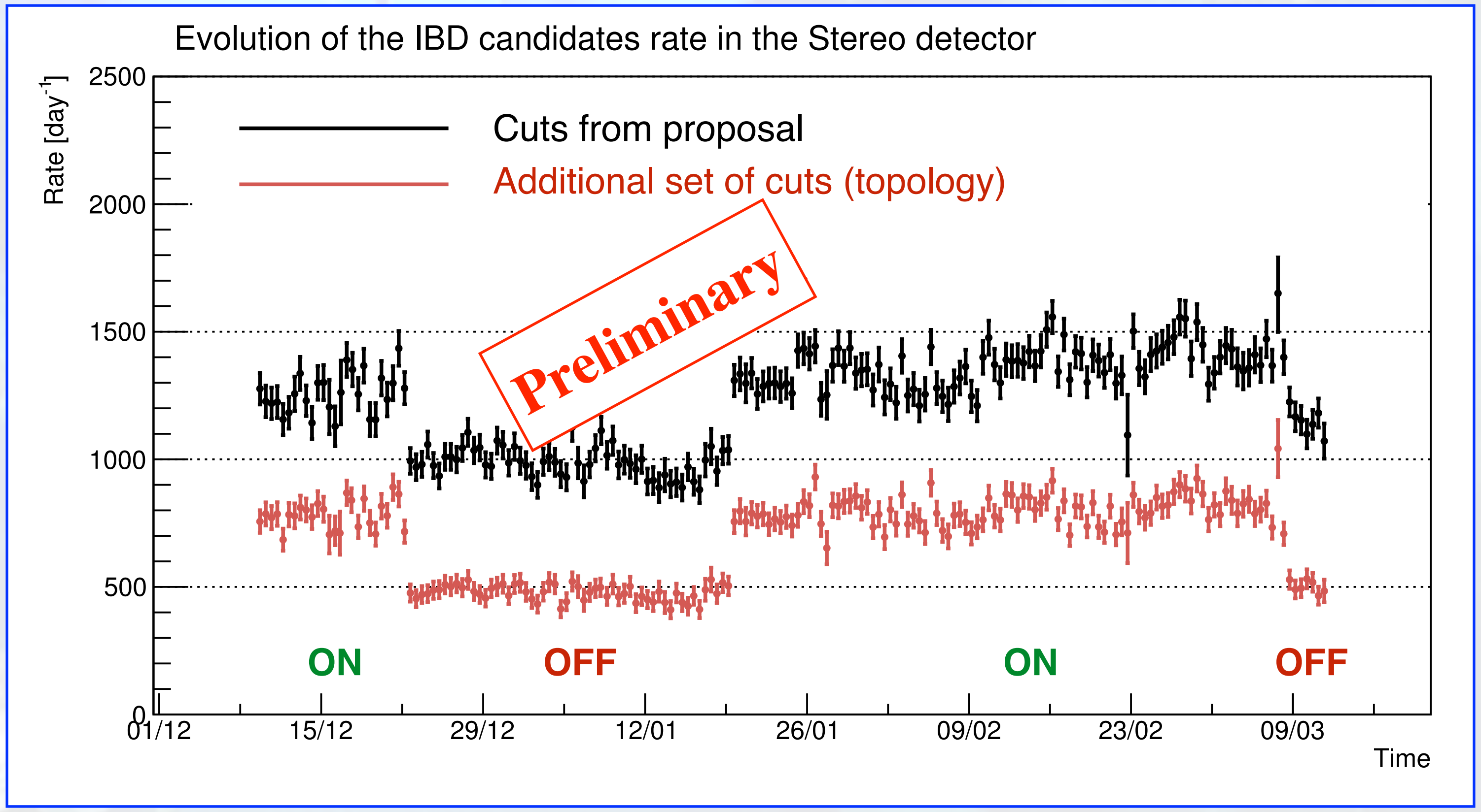
Cuts	Fast Neutrons	Stopping Muons	Neutrino efficiency
100 µs after-µ veto	✘		~6.5 % deadtime
PMT charge homogeneity		✘	98 %
PSD (Q_{tail}/Q_{tot})	✘	✘	98 % with 2σ cut
Cell multiplicity	✘		>99 %





Neutrino Rate

- Accidental coincidences measured online using multiple off-time windows and subtracted
- After all cuts applied and atmospheric pressure correction: neutrino efficiency >95%, **neutrino rate ~300 /day**
- Next analysis steps: refine cuts, define systematics for reactor-OFF subtraction, finalise energy reconstruction for spectral analysis



Thank you for your attention

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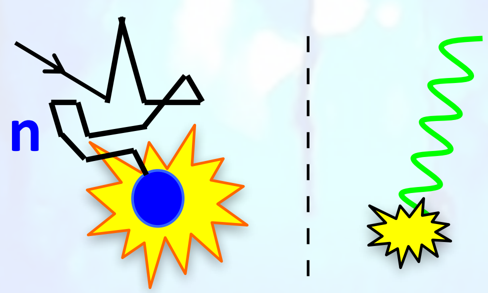
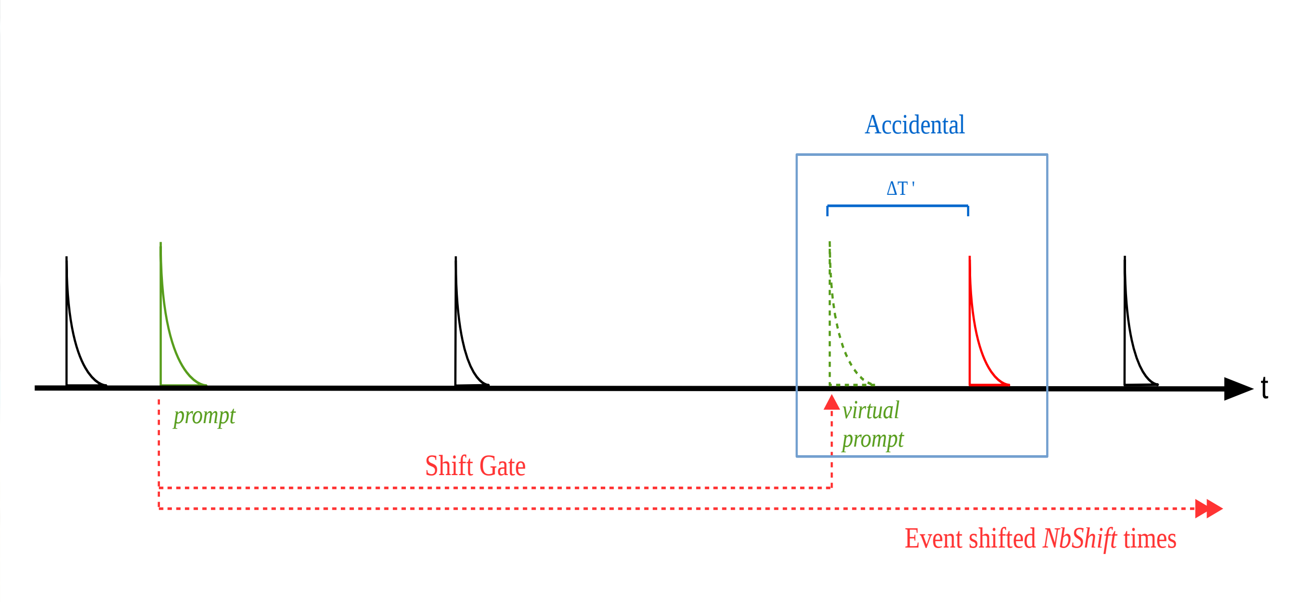
STEREO *is a collaboration of* CEA, ILL NEUTRONS FOR SCIENCE, LAPP Laboratoire d'Annecy-le-Vieux de Physique des Particules, LPSC Grenoble Laboratoire de Physique Subatomique et de Cosmologie, MAX-PLANCK-INSTITUT FÜR KERNPHYSIK *supported by* Enigmass, ANR

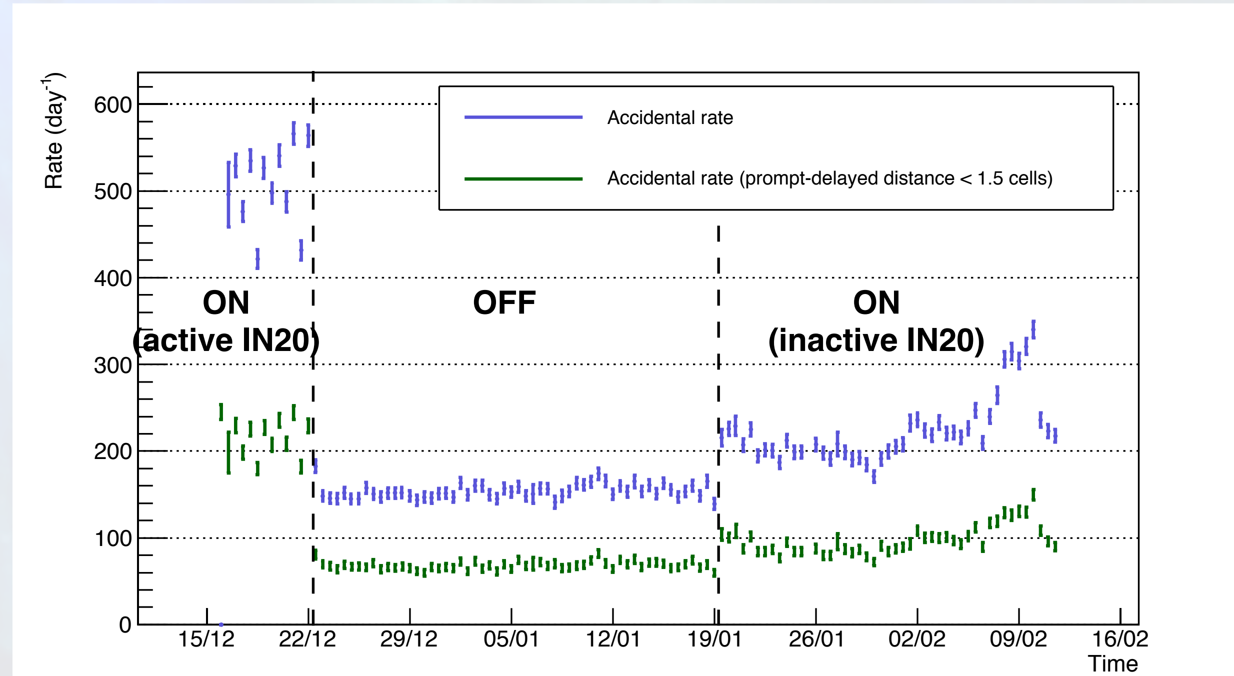

Backup

Accidental Coincidences

- Accidental γ's/n's coincidences (reactor-induced, influenced by neighbouring experiments)
- Remaining accidentals **measured online** & **subtracted statistically** with off-time windows
- Prompt-delayed vertices strongly correlated for IBD → cut on spatial distance

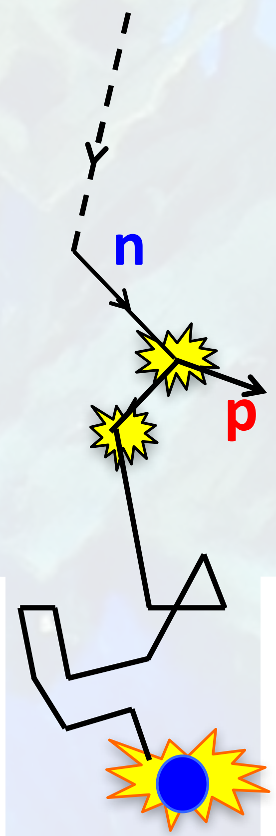


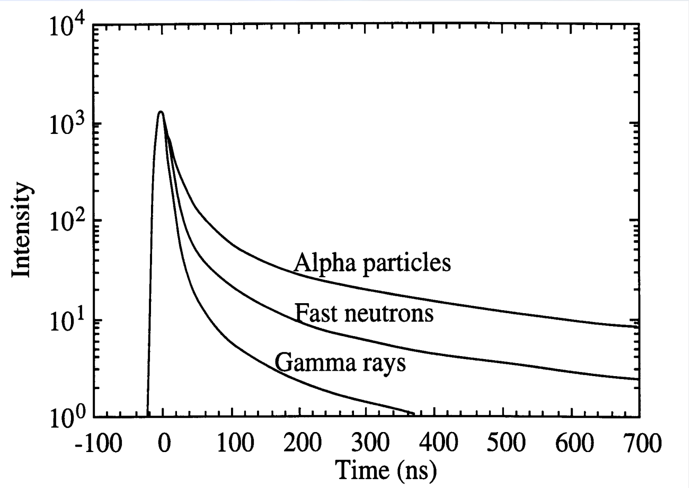


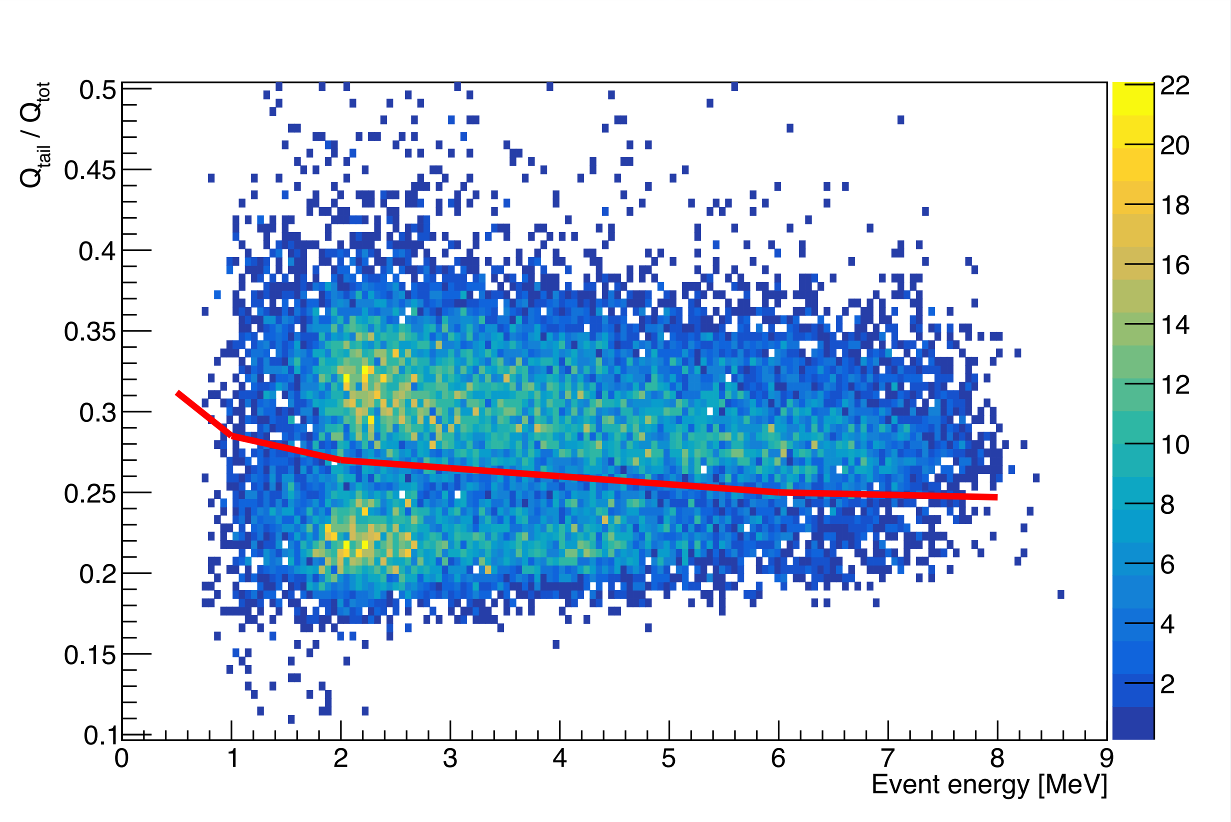


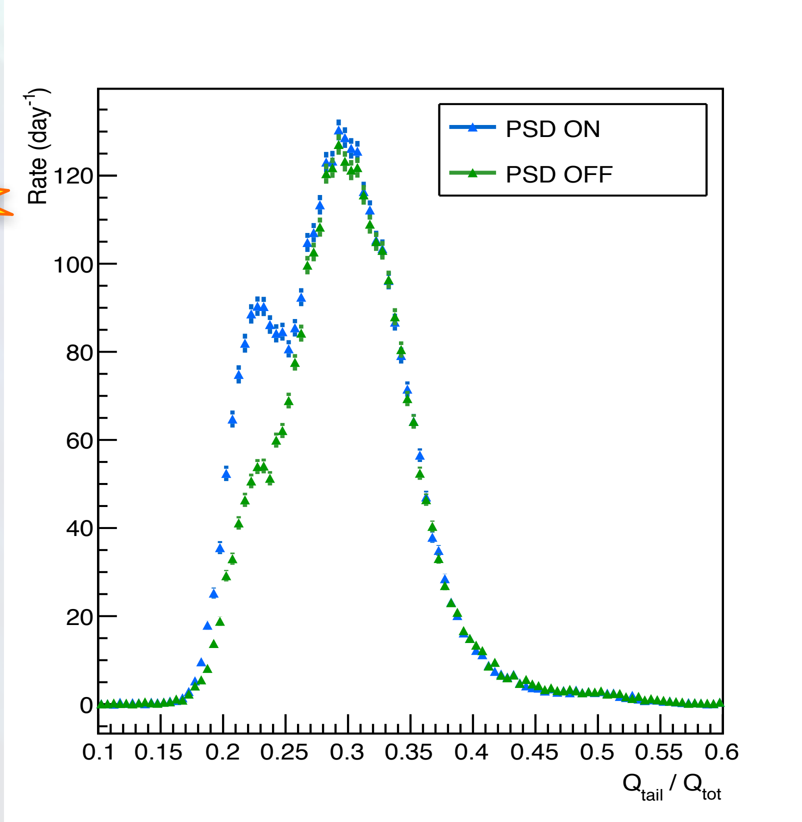
Pulse Shape Discrimination

- **P**ulse **S**hape **D**iscrimination: disentangle particles with large $\mathrm{dE/dx}$ (recoil protons, low-energy decaying μ's)
- Intrinsic property of LS
- Use Q_{tail}/Q_{tot} ratio (@ read-out)



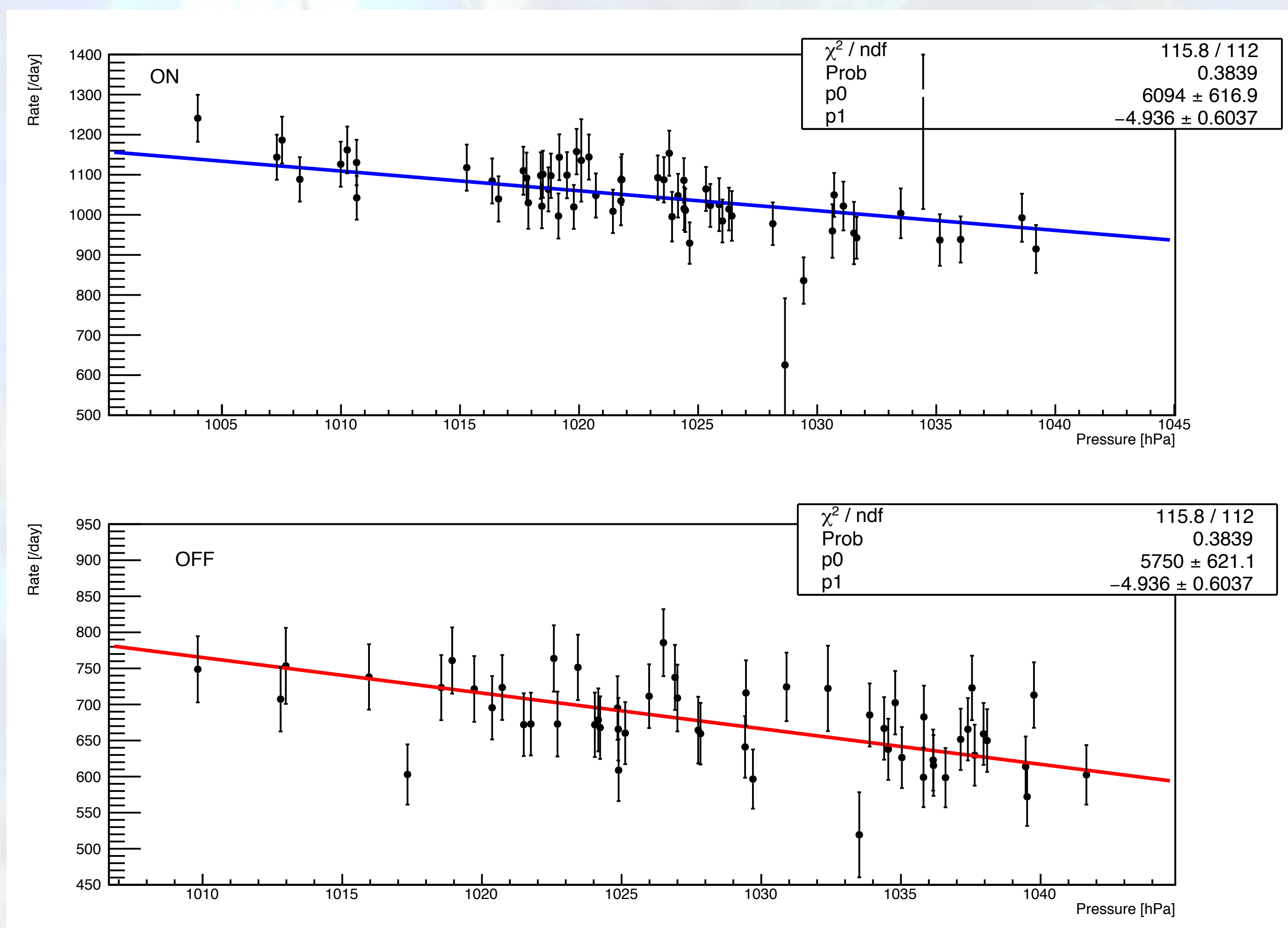






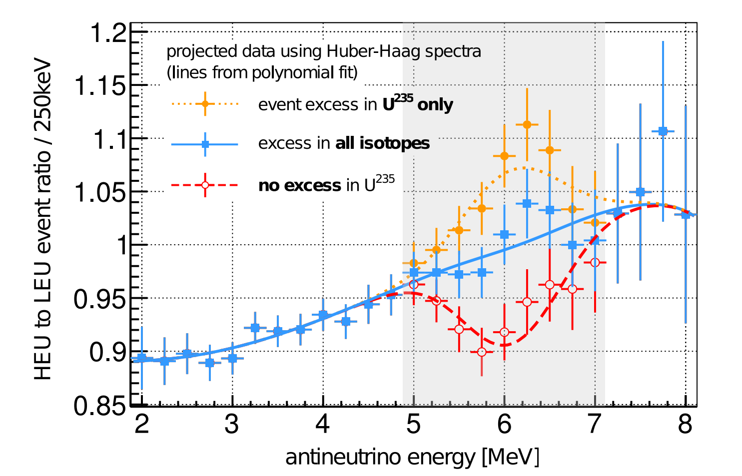
Correlated Rate Variation with Atmospheric Pressure

- **Residual cosmic background** is measured during **reactor off**
- Subtraction must take into account differences in μ rates between on and off periods
- **Correction for μ rate variation** with atmospheric pressure $\mathbf{p_{atm}}$ is made by extracting the dependency (on-off combined fit) and **re-normalising to a** $\mathbf{p_{ref}}$



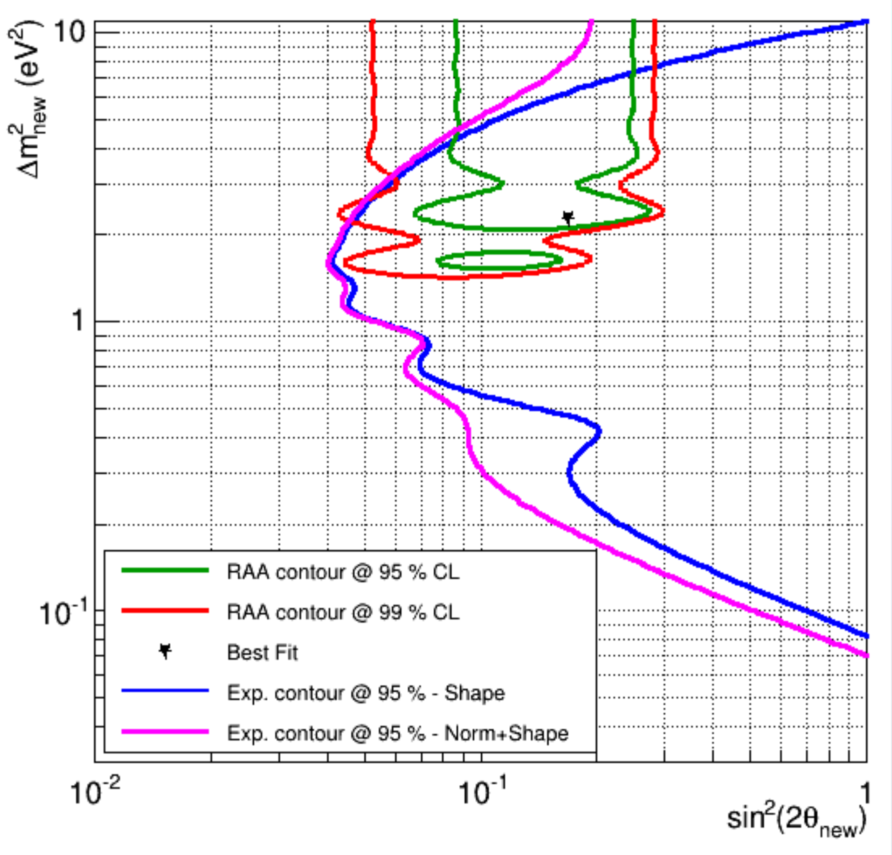
STEREO Sensitivity & the 5 MeV Distortion

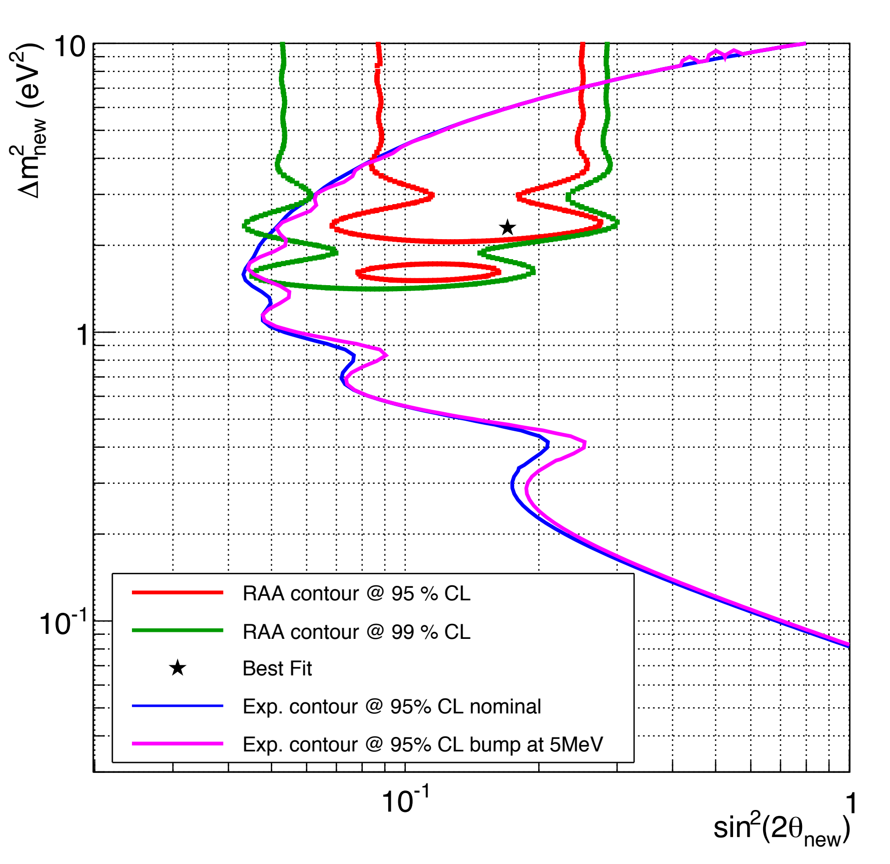
- STEREO will provide a new reference measurement of pure ^{235}U ν spectrum ⇒ isolate source of the distortion, constrain models



arXiv:1512:xxx
C. Buck, A.P. Collin, J. Haser, M. Lindner

- Sensitivity after 300 days reactor ON, not reduced by distortion
    - 400 ν/day in 300 days - **S/B = 1.5**
    - E_{e+} > 2 MeV, E_n > 5 MeV - ε_{det} = 60%
    - δ**E$_{scale}$ = 2%**, $\delta\Phi_\nu$ = 4%





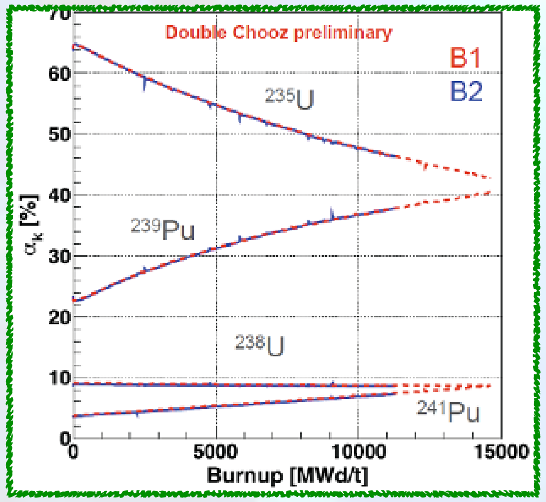
Antineutrino Spectrum Estimation

- In LEU facilities the fuel evolution (burnup) involves mostly ^{235}U and ^{239}Pu

$$N_{\rm IBD}^{\rm exp}(E_{\bar\nu},t) = \frac{N_p \epsilon}{4\pi L^2} \times \frac{P_{th}(t)}{\langle E_f\rangle(t)} \times \langle\sigma_f\rangle(E_{\bar\nu},t)$$

Average E released per fission

$$\langle E_f\rangle = \sum_k \alpha_k \langle E_F\rangle$$



Average Cross Section per fission

$$\langle\sigma_f\rangle_k = \int dE\, S_k(E)\, \sigma_{\rm IBD}(E)$$

Neutrinos per fission per MeV (prediction)

CS (theoretical + corrections)

k = isotope (^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu)

- Single $\bar\nu$ spectra $S_k(E)$ not available, obtained from β spectrum
- Model currently most used: Mueller (^{238}U) - Huber (^{235}U, Pu)

Mueller et al., Phy. Rev. C 83.5 (2011): 054615

Huber P., Phys. Revi. C 84.2 (2011): 024617

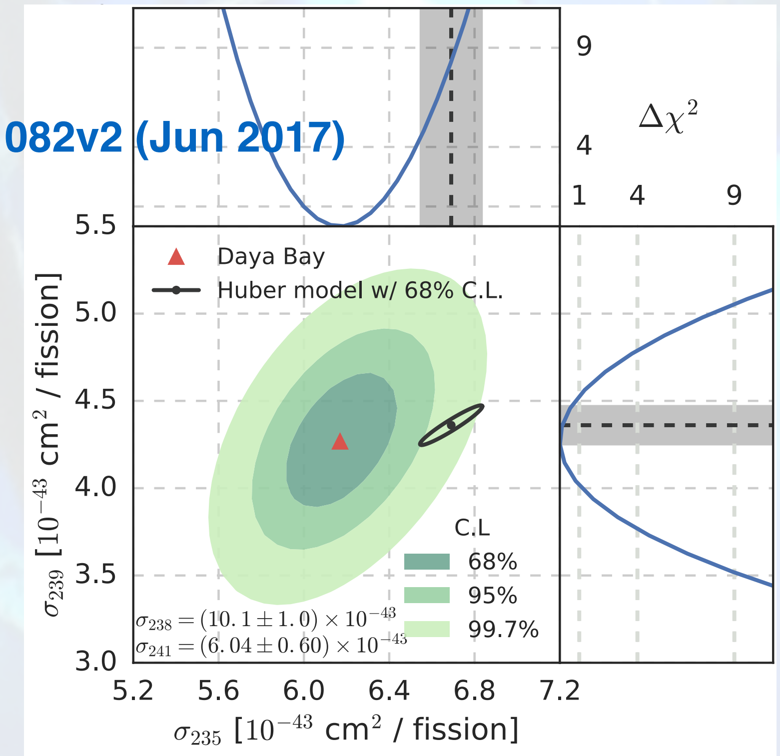
Light Sterile Search @ Reactors

	Core P_{Th}	Core Size	Overburden	Segmentation	Baseline	Material
Chandler	72 MW (^{235}U)	⌀ = 50 cm	~10 mwe	6.2 cm (3D)	5.5 m	PS + Li layer
DANSS	3 GW (LEU)	h = 3.6 m ⌀ = 3.1 m	~50 mwe	5 cm (2D)	10.7-12.7 m	Gd-doped PS
NEOS	2.8 GW (LEU)	h = 3.7 m ⌀ = 3.1 m	~20 mwe	-	23.7 m	Gd-doped LS
Neutrino4	90 MW (^{235}U)	35x42x42 cm^3	few mwe	22.5 cm (2D)	6-12 m	Gd-doped LS
NuLat	40/1790 MW (^{235}U/LEU)		few mwe	6.35 cm (3D)	4.7/24 m	Li-doped PS
Prospect	85 MW (^{235}U)	h = 0.5 m ⌀ = 0.2 m	few mwe	15 cm (2D)	7 m	Li-doped LS
SoLiδ	72 MW (^{235}U)	⌀ = 0.5 m	~10 mwe	5 cm (3D)	5.5 m	PS + Li layer
Stereo	58 MW (^{235}U)	⌀ = 37 cm	~15 mwe	25 cm (1D)	8.9 m	Gd-doped LS

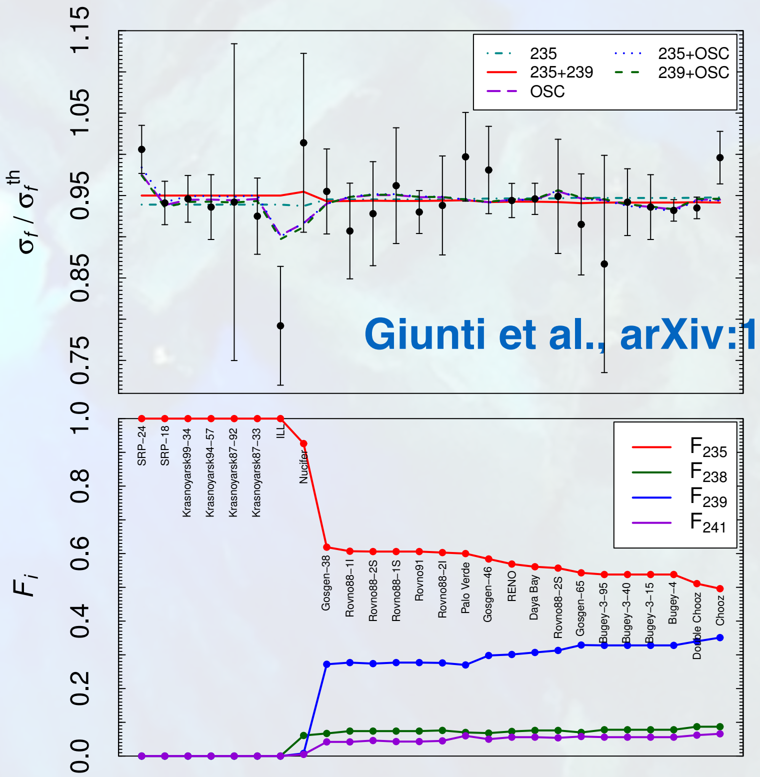
Sterile Neutrino vs Flux Normalisation

- Daya Bay slightly favours ^{235}U $\bar{\nu}_e$ flux suppression over sterile hypothesis
- Situation is reversed for other experiments (flux deficit independent from fuel composition)
- ^{235}U and ^{239}Pu fluxes are normalised on separate "vintage" β-spectrum measurements @ ILL

arXiv:1704.01082v2 (Jun 2017)



Giunti et al., arXiv:1708.01133v1 (Aug 2017)



- Daya Bay (but also DANSS and NEOS) are LEU experiments (mixed fuel)
- **Need results from short baseline HEU experiments to solve the conundrum**

The Global Picture

- If we include NEOS and DANSS recent results in the game, the sterile hypothesis cannot still be rejected
- This is mainly due to (matching) features in the experimental spectra, reflected in the exclusion plot, that prefer oscillation rather than scaling
- **A global analysis from multiple experiments can discriminate whether these are fluctuations or there is an oscillatory pattern**

Gentler et al., arXiv:1709.04294v1 (Sep 2017)