THE SEARCH FOR EV STERILE NEUTRINOS WITH THE STEREO EXPERIMENT

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ON BEHALF OF THE STEREO COLLABORATION

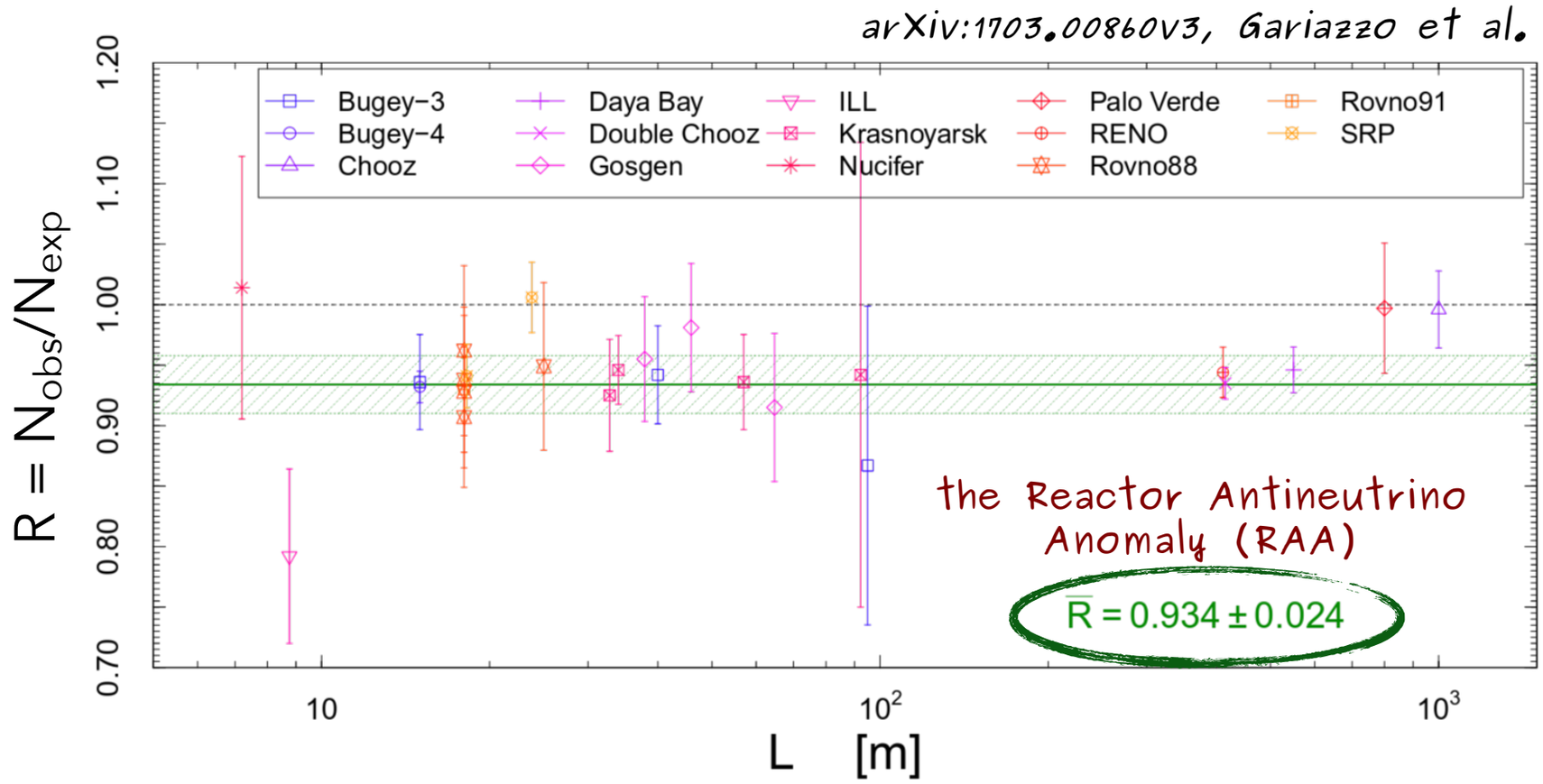
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

HEIDELBERG

REACTOR ANTINEUTRINO ANOMALY

2011

Global 6% **deficit** observed after the re-evaluation of the N_{exp} $\bar{\nu}_e$ from the nuclear reactor in **several experiments** at different **baselines**



→ **inaccurate prediction?**

inaccuracies in the beta-converted/*ab initio* $\bar{\nu}_e$ flux model of **^{235}U, ^{239}Pu, ^{241}Pu / ^{238}U**

! Talk on Wednesday
Leendert Hayen

! Next Talk
Joel Kostensalo

→ **new physics?**

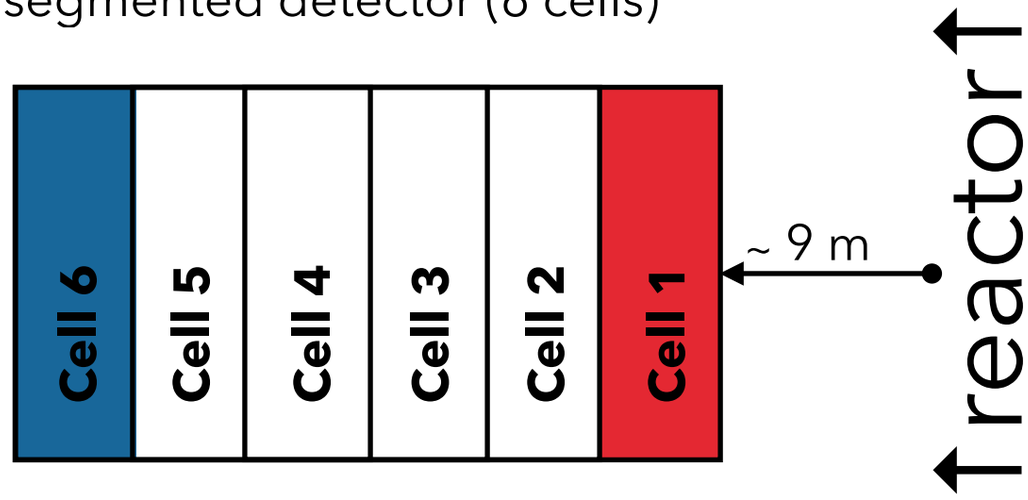
existence of ~ 1 eV **sterile neutrino** could explain also other anomalies (*GALLIUM*, LSND)

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

new **oscillation angle** and **mass splitting**

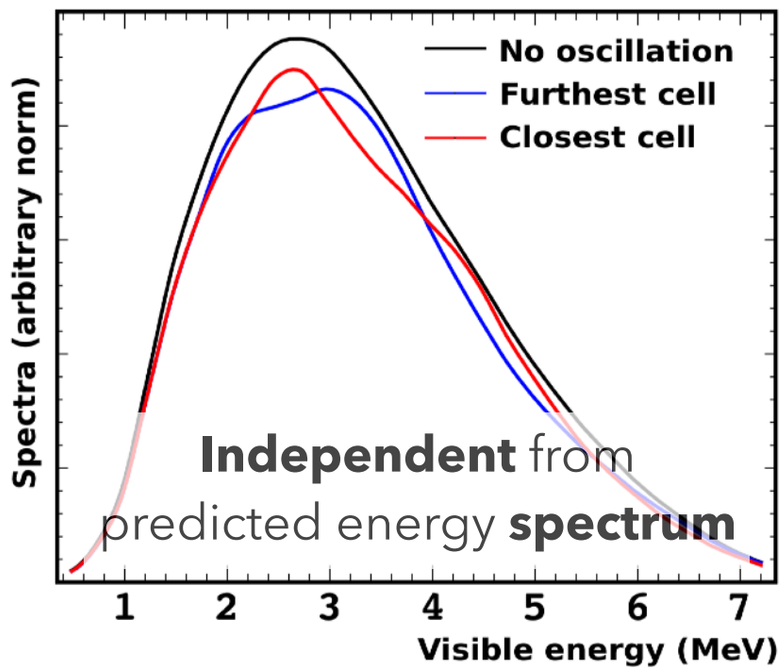
MOTIVATION OF STEREO EXPERIMENT

segmented detector (6 cells)



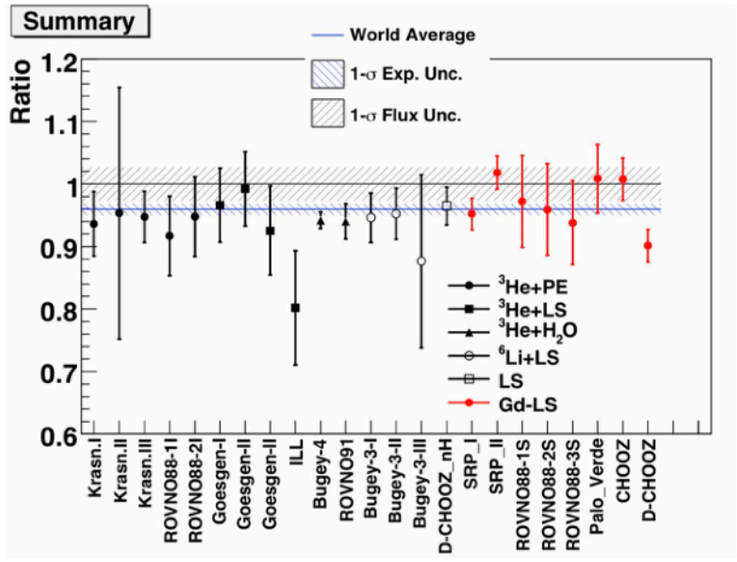
sterile neutrino hypothesis

relative **distortions** of the $\bar{\nu}_e$ energy spectrum as a function of the distance [9-11m]



flux absolute normalization studies

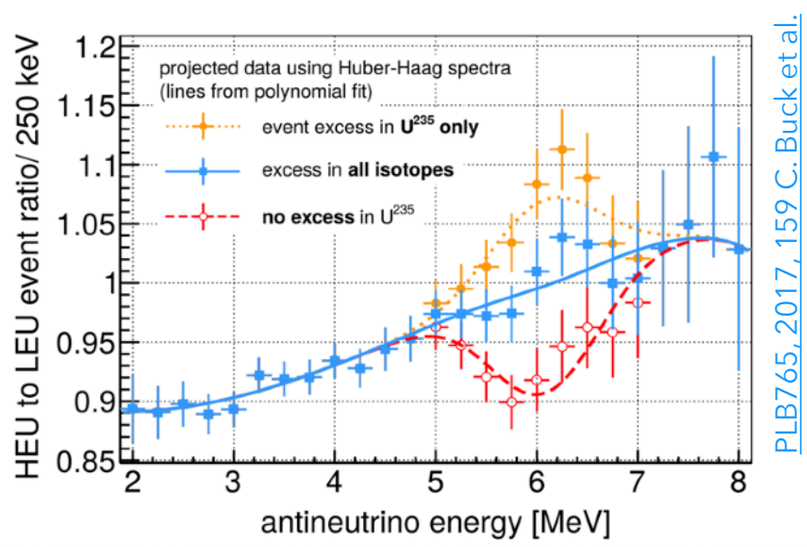
Measurement of abs. rate of. $\bar{\nu}_e$ from a HEU reactor



10.1103/PhysRevD.87.073018

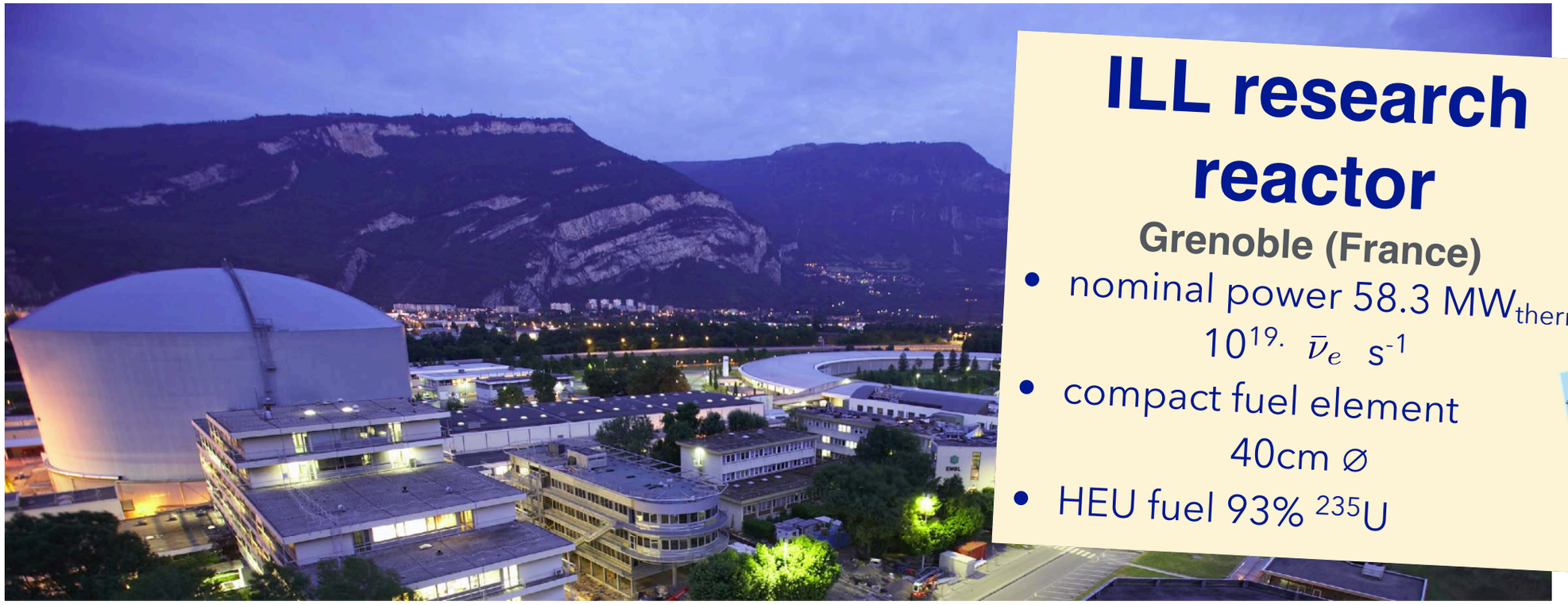
additional spectral shape studies

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



PLB765, 2017, 159 C. Buck et al.

EXPERIMENTAL SITE – ILL



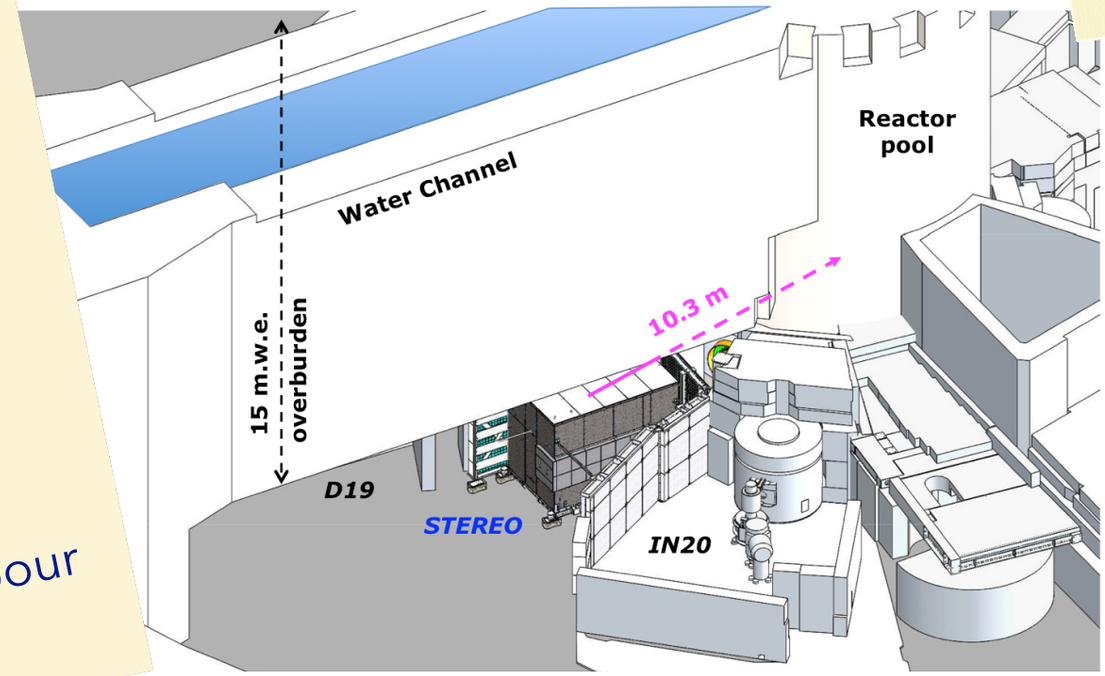
ILL research reactor

Grenoble (France)

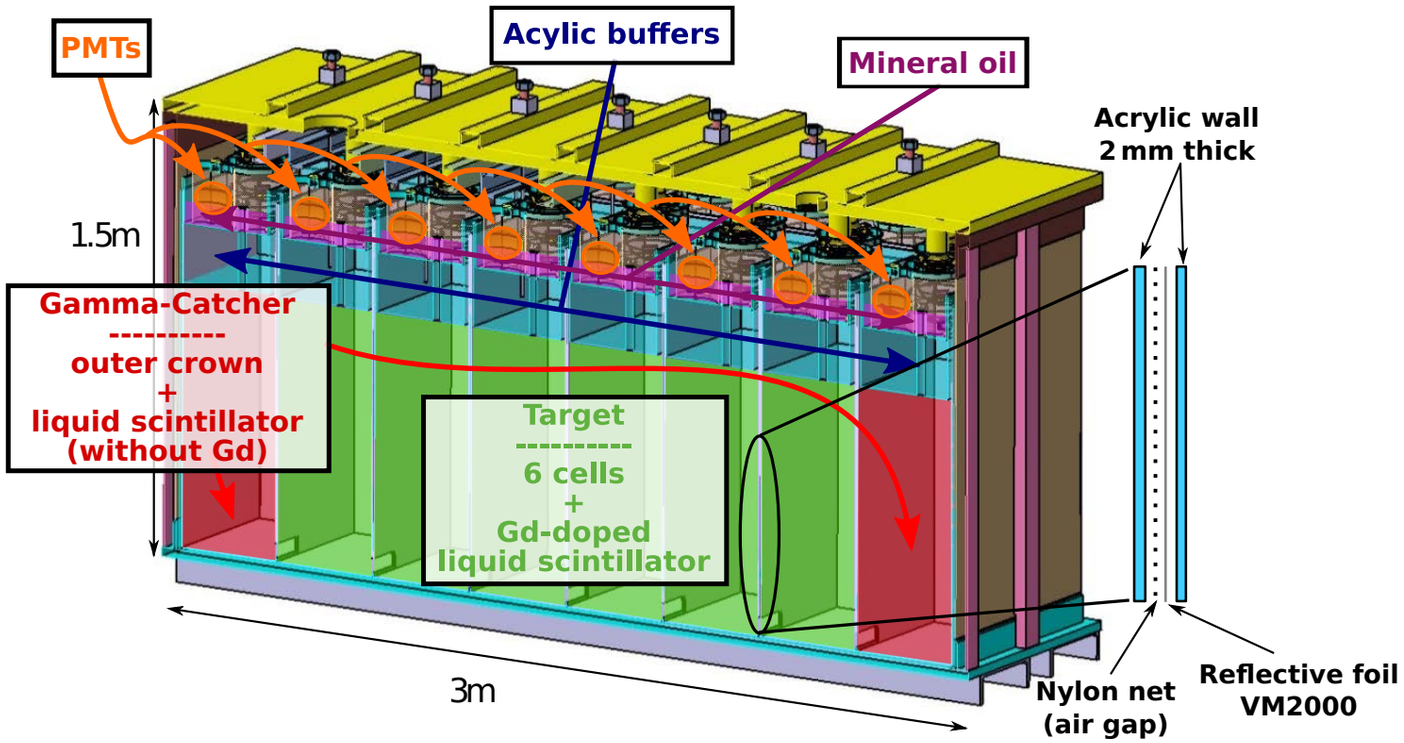
- nominal power 58.3 MW_{therm}
  $10^{19.}$ $\bar{\nu}_e$ s^{-1}
- compact fuel element
  40cm ⌀
- HEU fuel 93% ^{235}U

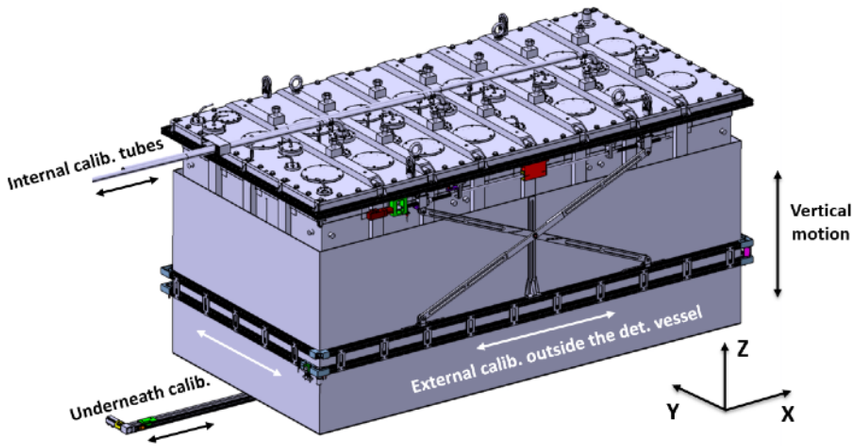
Experimental site

- taking data since nov. 2016
- short baseline experiment
  9.4m < L < 11.1m
- ground-level experiment
- gamma and neutron background from neighbour experiments

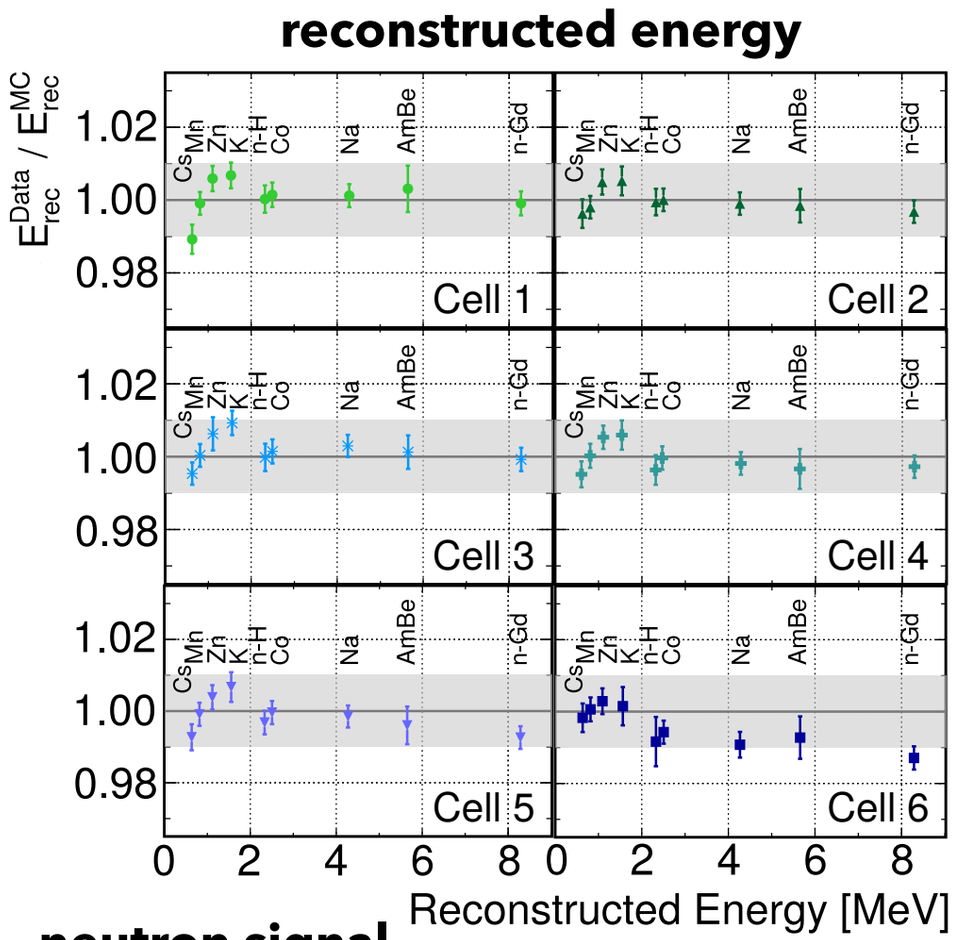


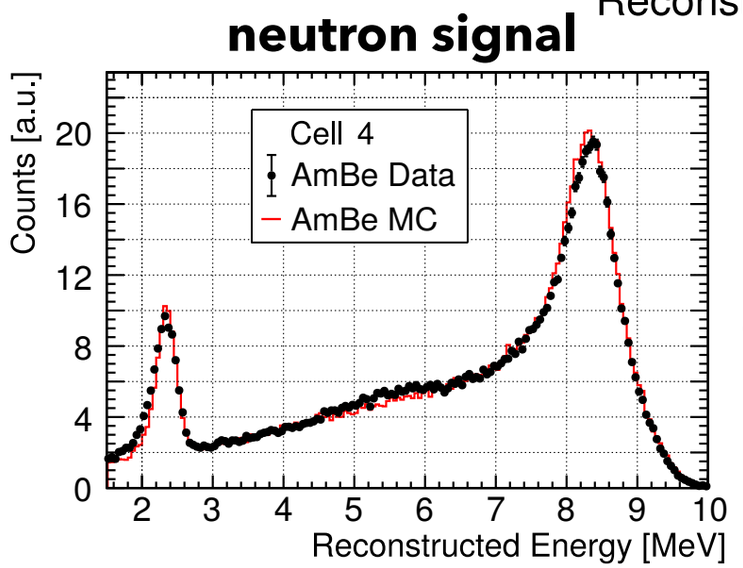
STEREO DETECTOR, CALIBRATION AND RESPONSE





Good detector **response**, and
agreement between **DATA** and **MC**





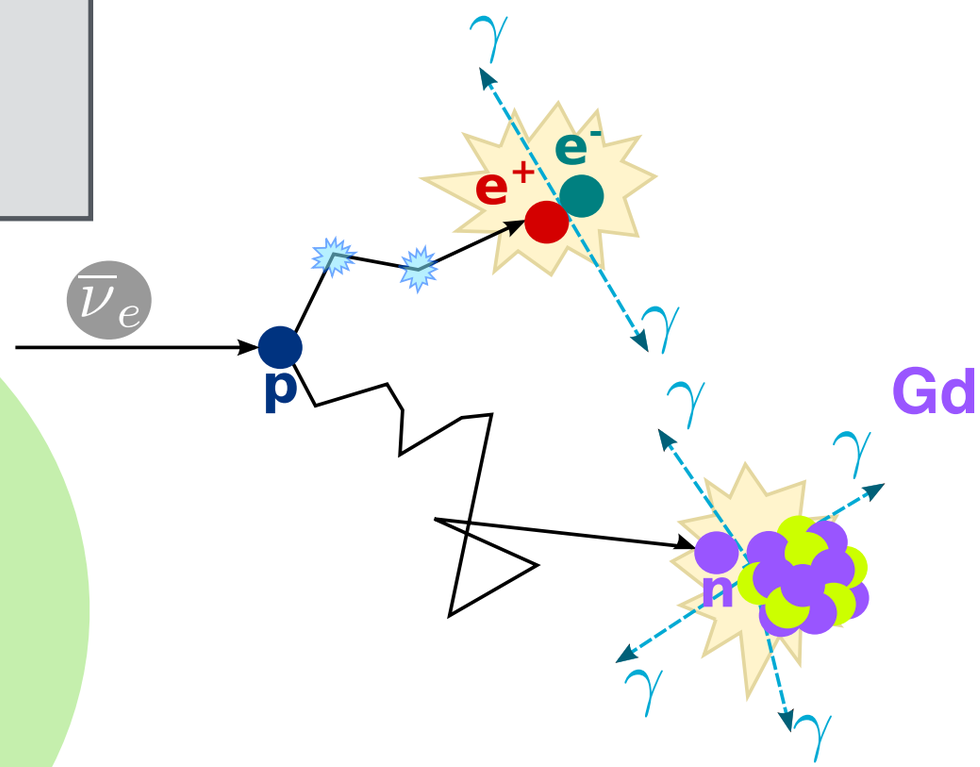
! improvement of the MC gamma cascade after a n-capture in Gd with FIFRELIN in STEREO
Eur. Phys. J. A (2019) 55:183.

arXiv:1912.06582

NEUTRINO SIGNAL AND SELECTION

Inverse Beta Decay

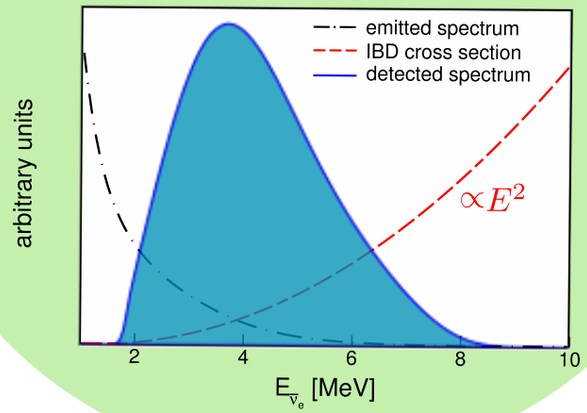
$$\overline{\nu}_e + p \rightarrow e^+ + n$$



1. Prompt Event

positron

$$E_{vis,e^+} \simeq E_{\overline{\nu}_e} - 0.8MeV$$



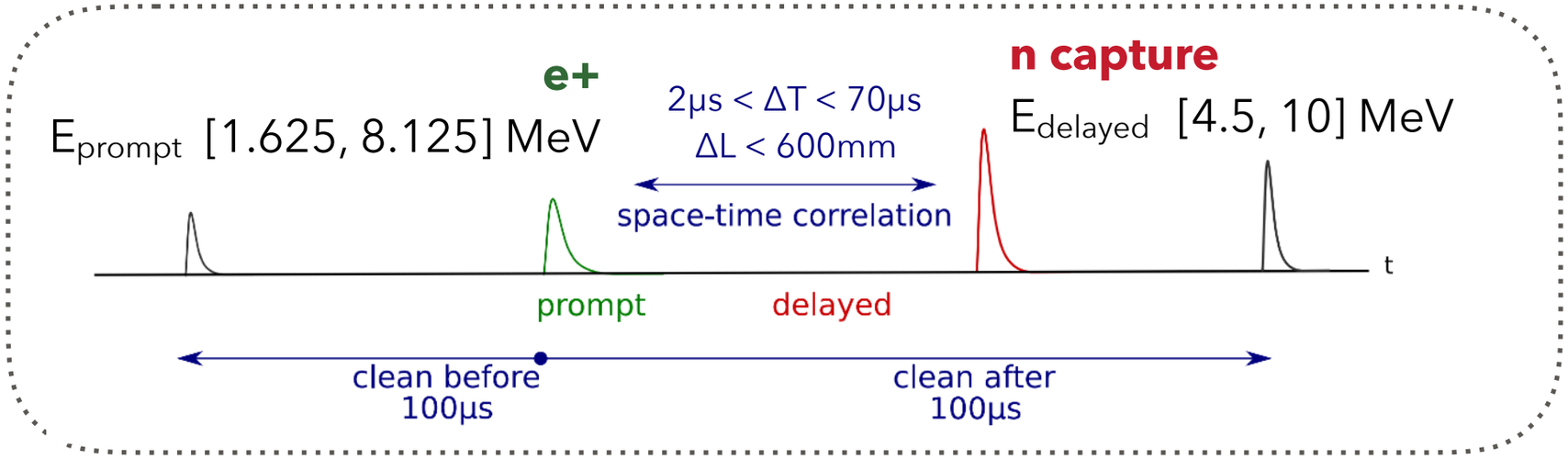
2. Delayed Event

neutron capture

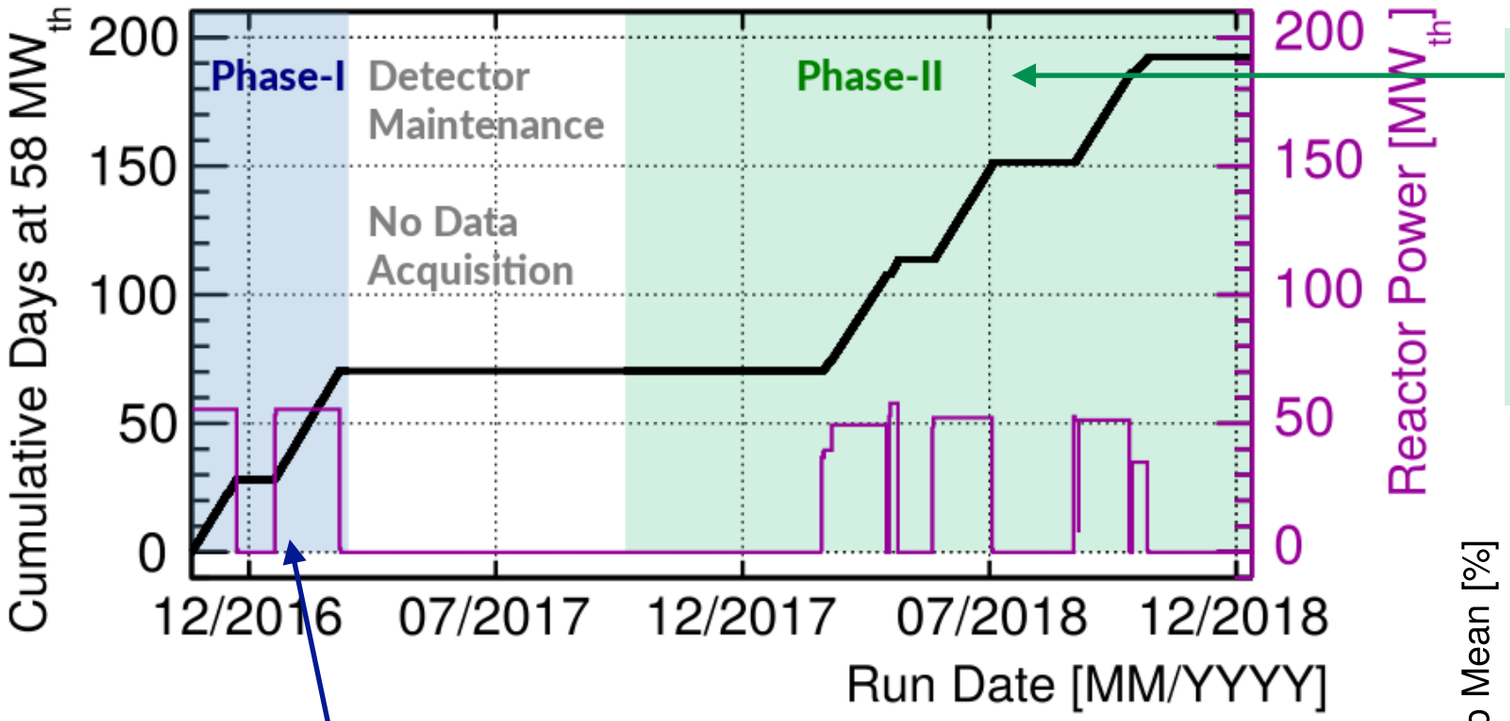
- Gd nuclei
  $\sum_i E_{\gamma,i} \sim 8MeV$
- H nuclei
  $E_\gamma \sim 2.2MeV$

! more details about correlated selection cuts in arXiv:1912.06582

Correlated IBD selection



ANALYZED DATA – TIME LINE



Phase-II

119 ON - 211 OFF

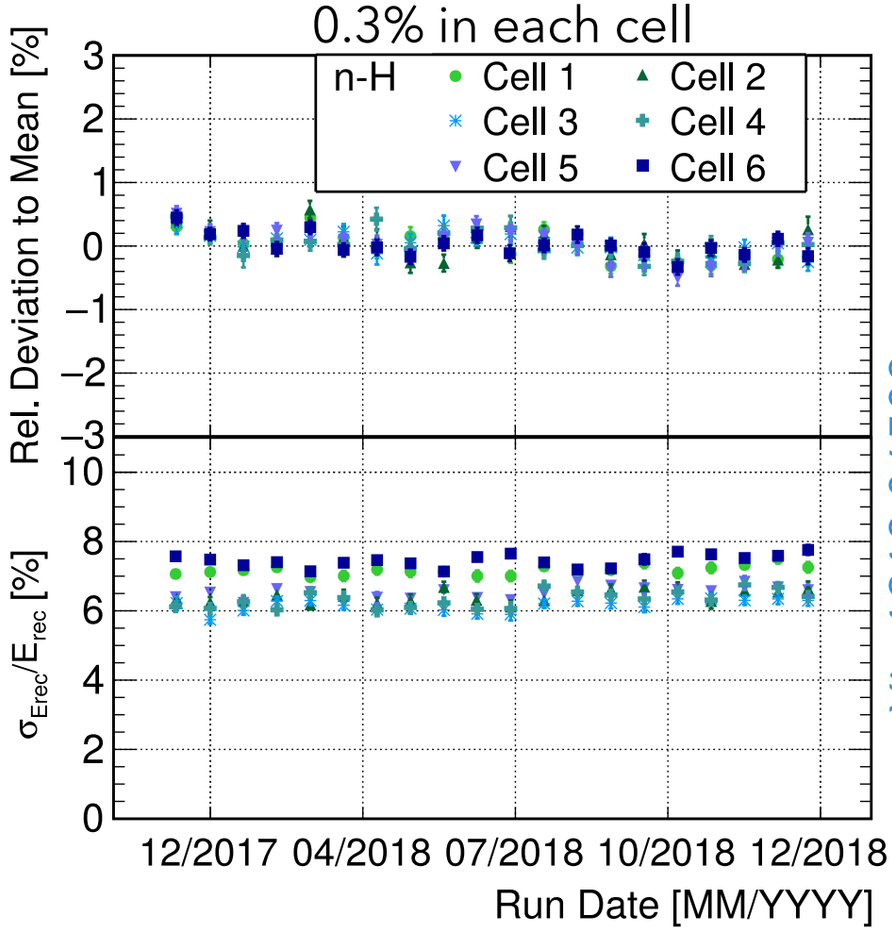
- Stable conditions
  ~ **98.5% of data taking time**

Phase-I

61 ON - 24 OFF

- Loss of optical coupling between PMTs and two different cells
- Evolving light cross-talks between cells
  → **repaired during Summer 2017**

energ. reco. stable at the 0.3% in each cell

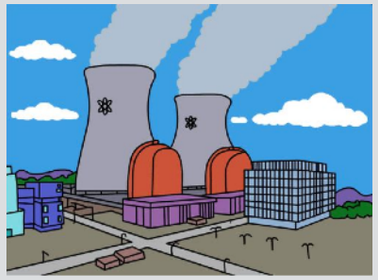


arXiv:1912.06582

BACKGROUND AND SHIELDING IN STEREO

REACTOR ON

Reactor Induced

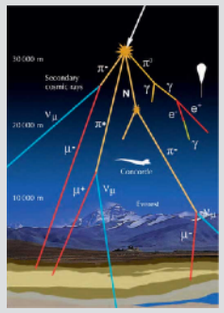


- neutrons
- gamma radiation from n-capture

Environmental Radioactivity

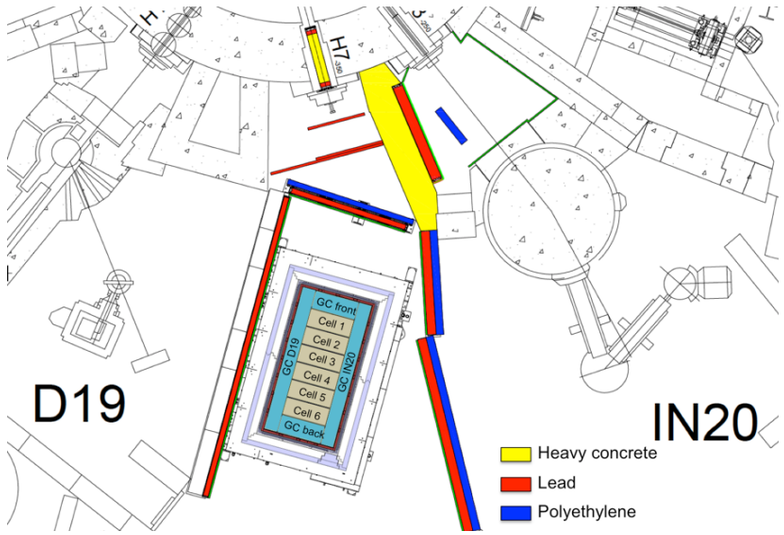
- Example: Thorium/ Uranium, Radon

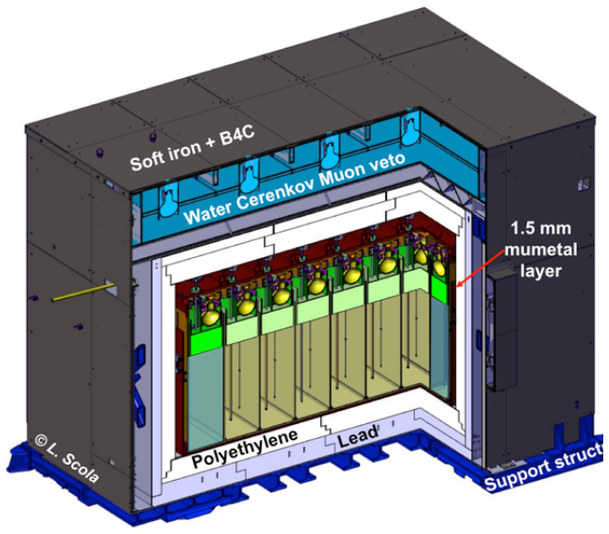
Muon induced

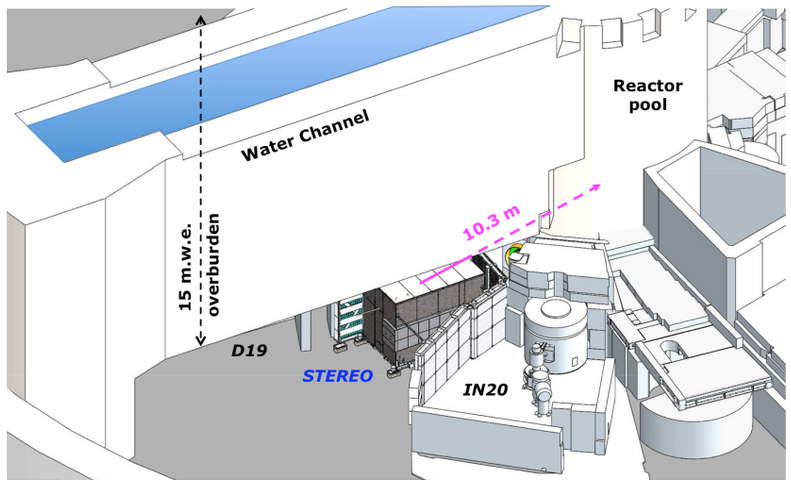


- spallation neutrons (in shielding)
- stopping muons

REACTOR OFF



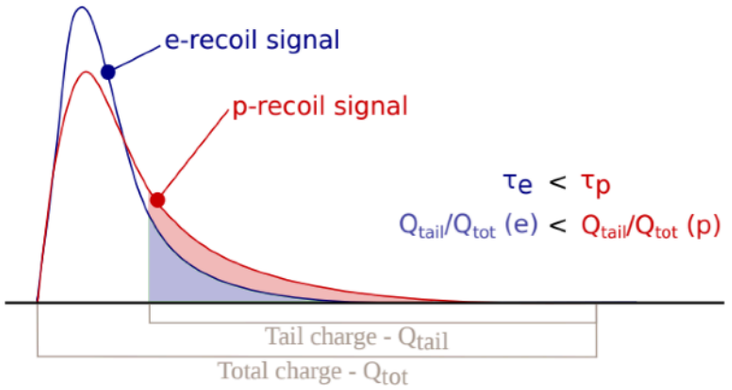


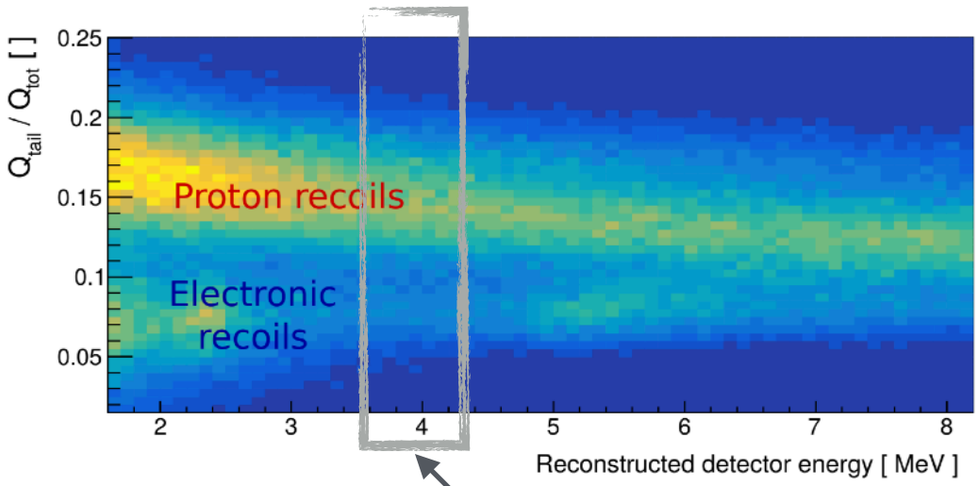


passive shielding, active veto and water pool

CORRELATED BACKGROUND: PULSE SHAPE DISCRIMINATION

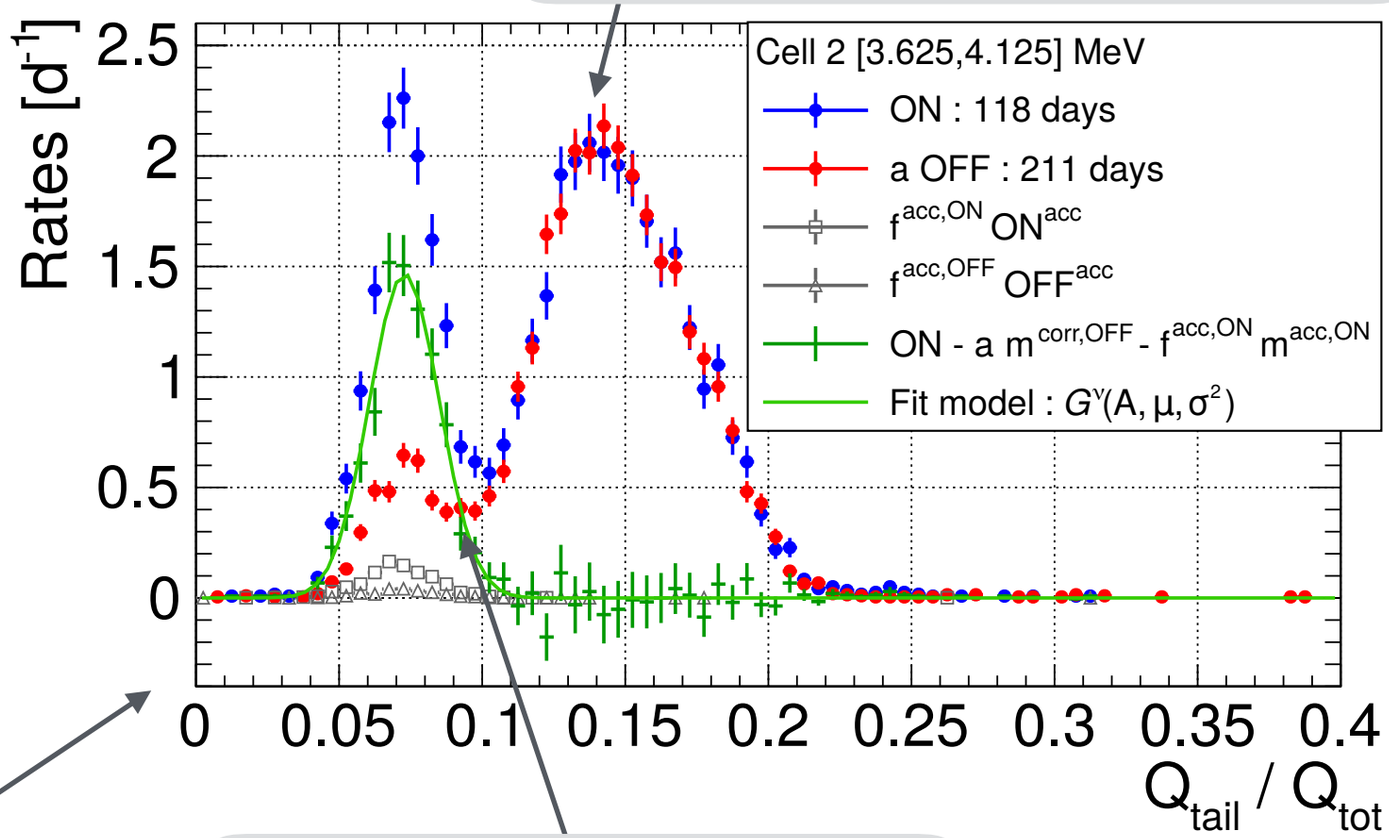
Correlated background still present on selected events ⟶ **PULSE SHAPE DISCRIMINATION**





Neutrino candidates extracted per **cell** and **energy bin**

Background model measured from **reactor OFF data**



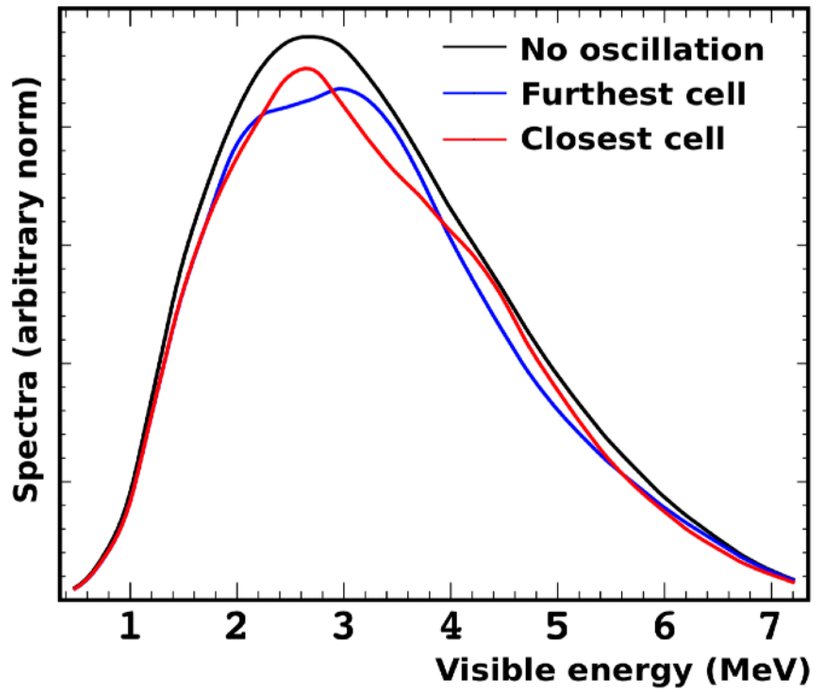
Use normal distribution to ***fit neutrino spectrum*** simultaneously in all spectra

Self-consistent method to estimate **NEUTRINO** and **BACKGROUND** events at the same time

arXiv:1912.06582

STERILE NEUTRINO OSCILLATION ANALYSIS

Prediction independent method that **studies relative distortions** of the positron energy spectrum between cells following a $\Delta\chi^2$ formalism



measured spectra in each cell, energy bin

Φ is a free parameter for each energy bin but common for all the cells

$$\chi^2 = \sum_{l}^{N_{Cells}} \sum_{i}^{E_{Bins}} \left(\frac{D_{l,i} - \phi_i M_{l,i}}{\sigma_{l,i}} \right)$$

simulated spectra in each cell

$$M_{l,i} \equiv M_{l,i}(sin^2(2\theta_{ee}), \Delta m^2_{41}, \vec{\alpha})$$

$$+ \sum_{l}^{N_{cells}} \left[\left(\frac{\alpha_l^{Norm}}{\sigma_l^{Norm}} \right)^2 + \left(\frac{\alpha_l^{E-scale}}{\sigma_l^{E-scale}} \right)^2 \right] + \left(\frac{\alpha^{E-scale}}{\sigma^{E-scale}} \right)^2$$

uncorrelated — correlated

Systematic effects parametrized by α **nuisance parameters**

Determine $\Delta\chi^2$ in each Δm^2 bin by MC pseudo experiments

STERILE NEUTRINO OSCILLATION ANALYSIS

Prediction independent method that **studies relative distortions** of the positron energy spectrum between cells following a $\Delta\chi^2$ formalism

$$\chi^2 = \sum_{l}^{N_{Cells}} \sum_{i}^{E_{Bins}} \left(\frac{D_{l,i} - \phi_i M_{l,i}}{\sigma_{l,i}} \right)$$
$$+ \sum_{l}^{N_{cells}} \left[\left(\frac{\alpha_l^{Norm}}{\sigma_l^{Norm}} \right)^2 + \left(\frac{\alpha_l^{E-scale}}{\sigma_l^{E-scale}} \right)^2 \right] + \left(\frac{\alpha^{E-scale}}{\sigma^{E-scale}} \right)^2$$

uncorrelated | correlated

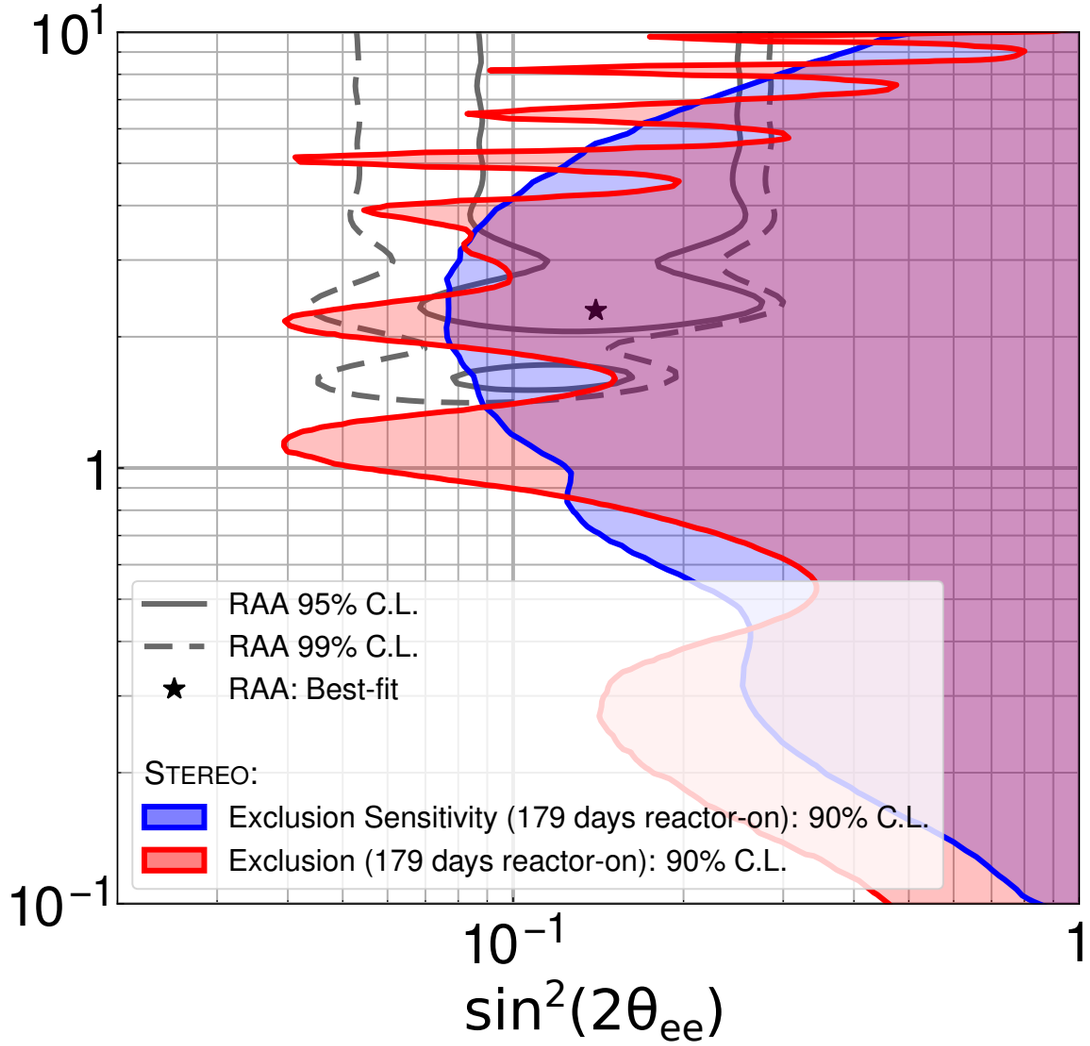
PHASE I + II Analysis

$$\chi^2_{\mathrm{PI+PII}} = \chi^2_{\mathrm{PI}}(sin^2(2\theta_{ee}), \Delta m^2_{41}, \vec{\alpha}_{\mathrm{PI}}, \phi_i, A)$$
$$+\chi^2_{\mathrm{PII}}(sin^2(2\theta_{ee}), \Delta m^2_{41}, \vec{\alpha}_{\mathrm{PII}}, \phi_i)$$

Determine $\Delta\chi^2$ in each Δm^2 bin by MC pseudo experiments

with A correction coeff. to compare phases

EXCLUSION CONT. Phase I + II Analysis

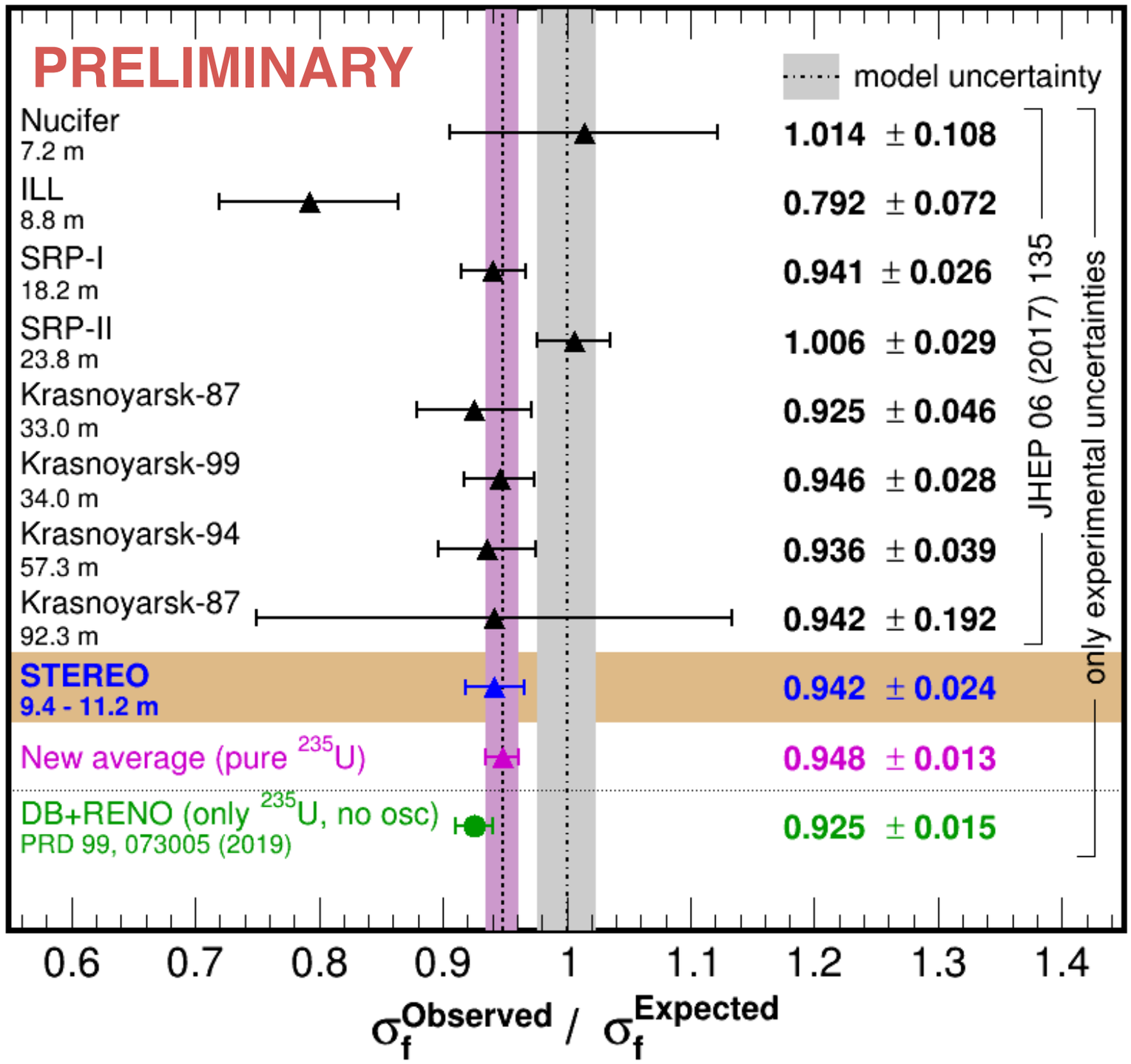


Best-fit value of the **RAA (2011)** **rejected at > 99.9% C.L.**

ABSOLUTE NORMALIZATION STUDIES new!

- Total **extracted rate** of 364 ± 5 ($\bar{\nu}_e$ /day) compared to **expected rate**
- Achieved a **good control** of the **uncertainties**
- Most **accurate measurement** of the **neutrino flux** from pure **^{235}U** nuclear fuel
- In **agreement** with **world average**

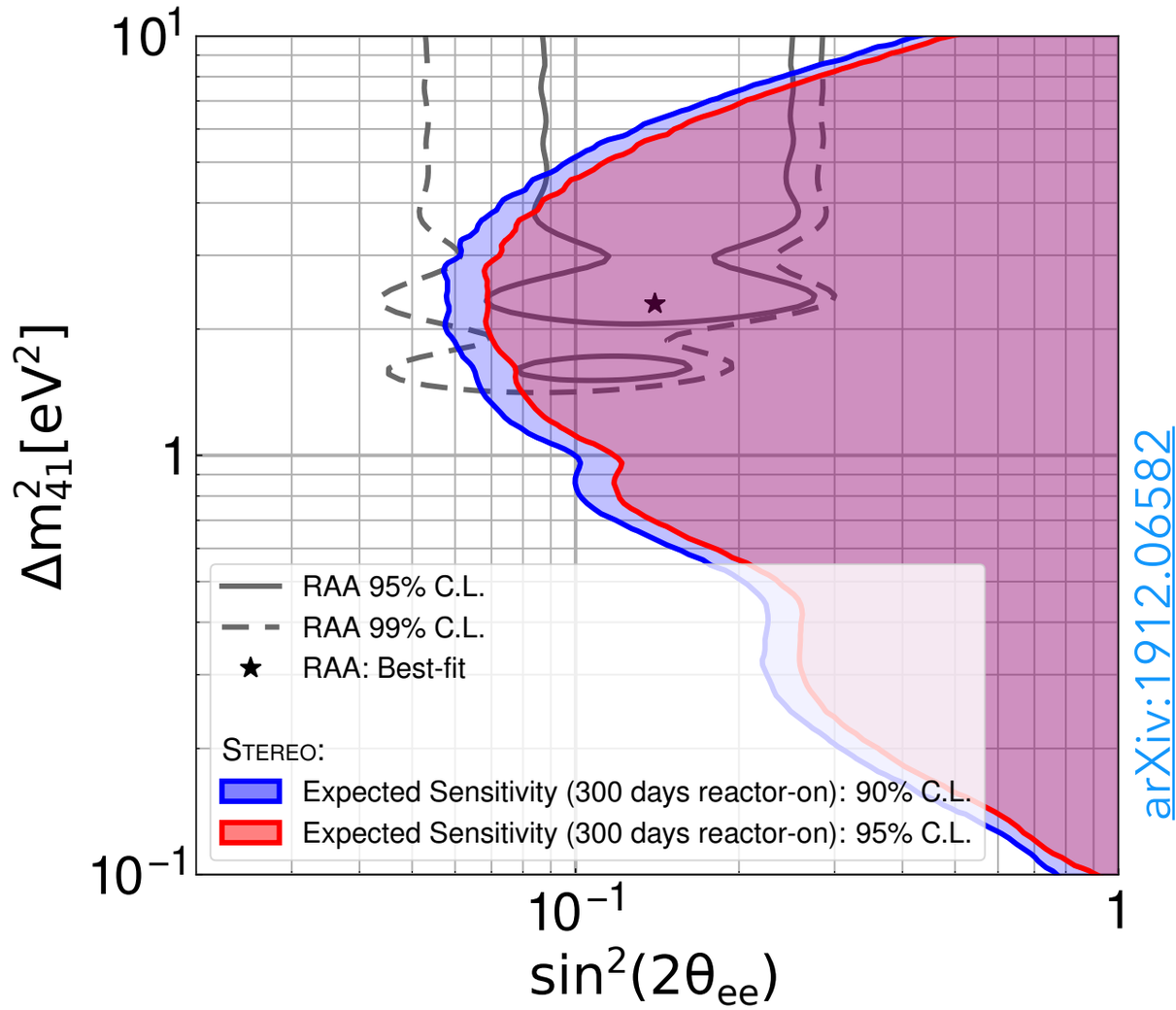
Rate Measurement - Phase II Analysis



SUMMARY

- STEREO is running under **stable** conditions.
- The **understanding** of the **correlated background** improves using reactor-OFF periods
- Exclusion contour obtained using a robust prediction independent method, **rejects** the original **RAA best fit value** is at **99.9% CL**.
- **Detailed methods and current results** submitted in Dec. 2019, arXiv:1912.06582
- **Improved** description of the **Gd neutron capture gamma cascade** with FIFRELIN published in EPJA Eur. Phys. J. A (2019) 55:183.
- Publication on **absolute normalization** under preparation
- **Further data taking** until end of **2020**, covering a total of 300 days of reactor on with **Phase III.**

EXP. STEREO SENSITIVITY with Phase-I+II+III



thanks for your attention

Stay tuned!

Photo: S. Schoppmann

The STEREO Collaboration

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Photo: ILL