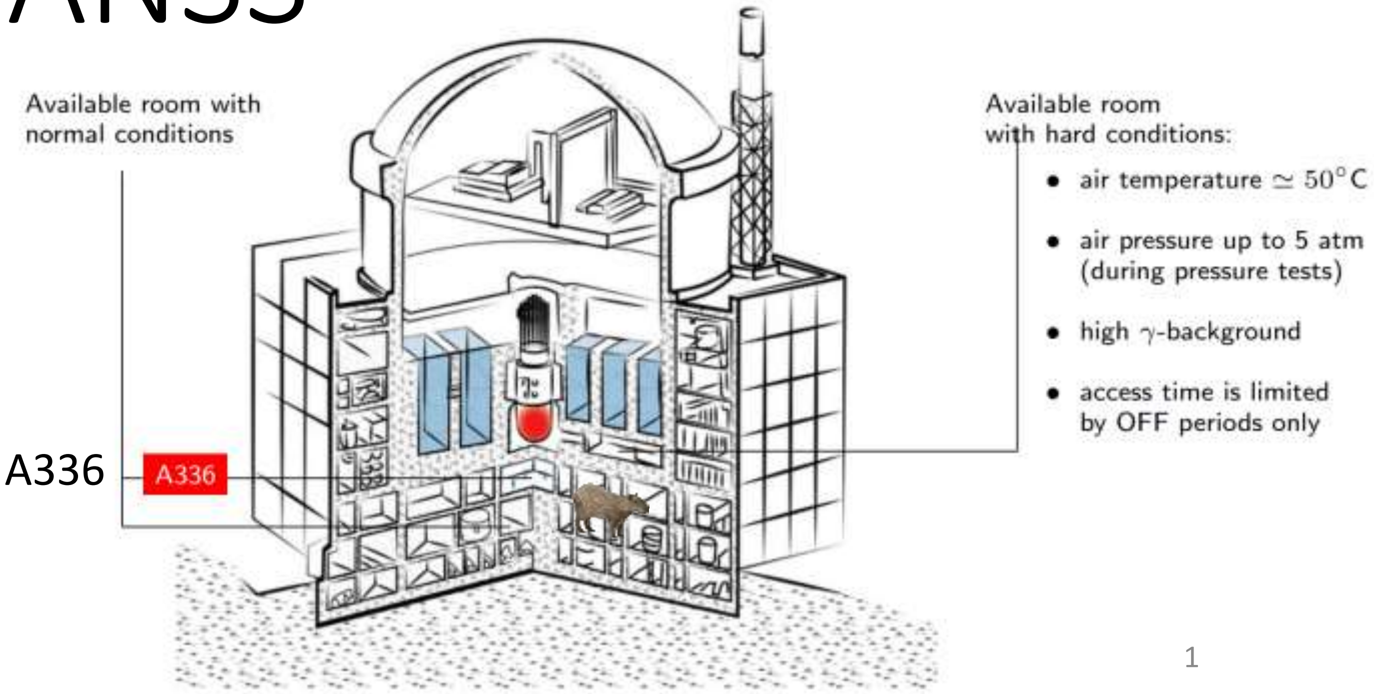
TWENTY-SECOND LOMONOSOV
CONFERENCE August, 21-27, 2025
ON ELEMENTARY PARTICLE PHYSICS
MOSCOW STATE UNIVERSITY

Searches for physics beyond the SM at DANSS



DANSS in A336

Petr Gorovtsov, LPI RAS

On behalf of the DANSS collaboration

Motivation - there are several anomalies in neutrino physics

LSND, MiniBooNE, 29.05.2013, Annual Review of Nuclear and Particle Science vol 63

- LSND & MiniBooNE result: ν_e in the ν_μ beam (6σ): $\Delta m^2 \sim 0.2 - 1\ \mathrm{e}V^2$?
  - MicroBooNE does not confirm this anomaly

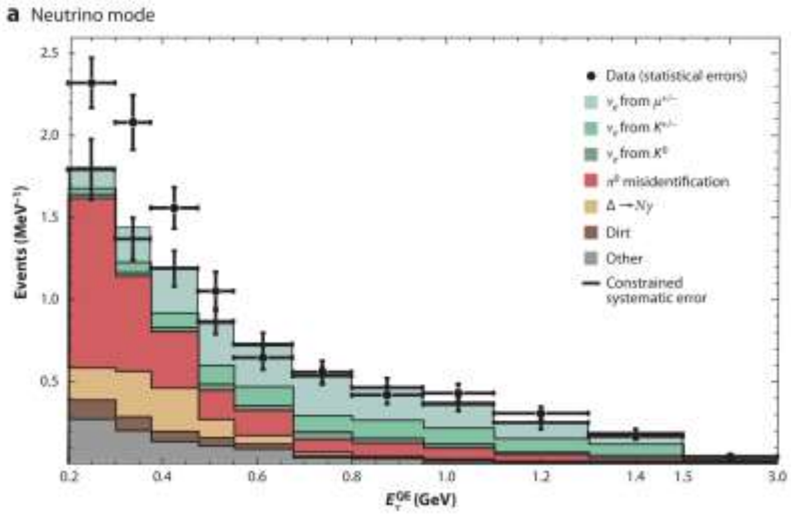
  P. Arbatenko et al., (MicroBooNE), Phys. Rev. Lett. 130, 011801, 2023

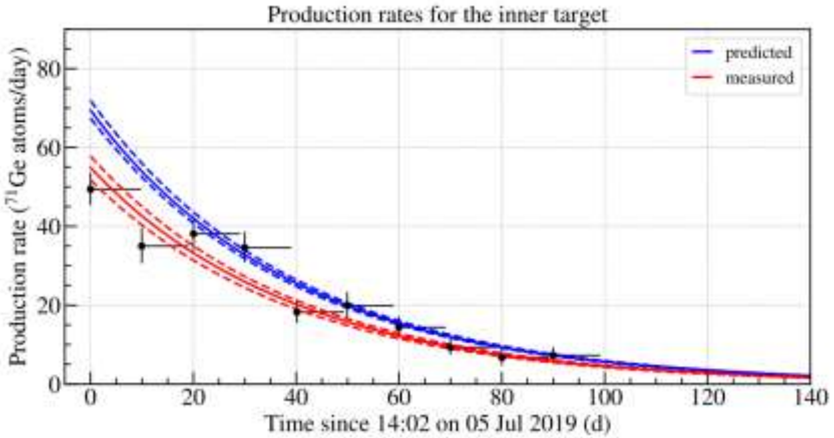
- Gallium anomaly (GA): deficit of ν events in the calibration measurements in gallium experiments SAGE, GALLEX and BEST (5σ)

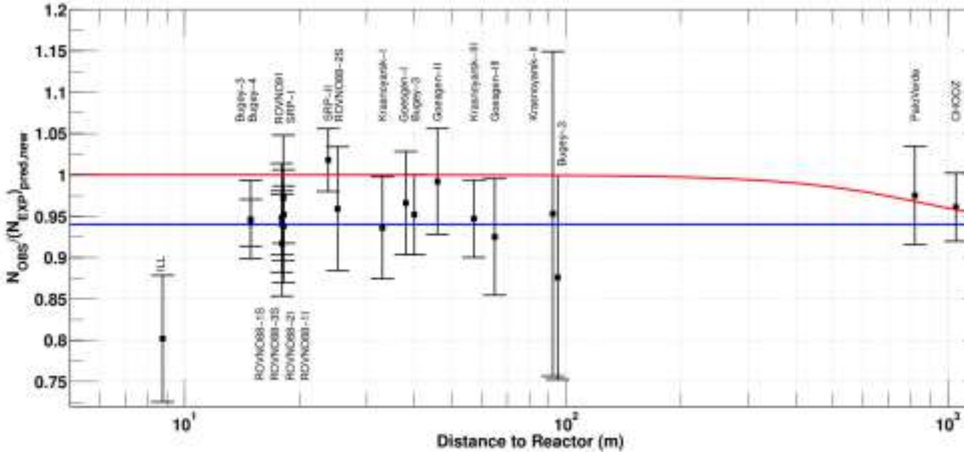
  V.V. Barinov et al, (BEST), Phys. Rev. Lett. 128, 232501, 2022

- Reactor Antineutrino Anomaly (RAA): deficit of $\bar{\nu}_e$ from the reactors in comparison with theoretical predictions (2.8σ)

  G. Mention et al, Phys. Rev. D 83, 073006, 2011







Possible explanations

- Sterile neutrinos: at short distances we can consider only oscillations to sterile state

$$P(\bar{\nu}_e \to \bar{\nu}_e) \approx 1 - \sin^2(2\theta_{ee}) \sin\left(1.267 \frac{\Delta m^2_{41}[eV^2] L[m]}{E[MeV]}\right)$$

$\Delta m^2_{41} \sim 1\ eV^2$

- Large Extra Dimensions (LED) (N. Arkani–Hamed, S. Dimopoulos, G. Dvali, Phys. Let. B, vol 429, issues 3-4, pages 263-272, 1998)
  - Extra dimensions renormalize Planck's mass: $M^2_{Pl} = (M^*_{Pl})^{2+n} a^n$
  - $n \geq 2$ needed for Hierarchy problem but one dimension can be bigger than others. In this approach survival probability for (anti)neutrino: $P(\bar{\nu}_e \to \bar{\nu}_e) = \left|\sum_{flavours} |U_{ei}|^2 A_i\right|^2$

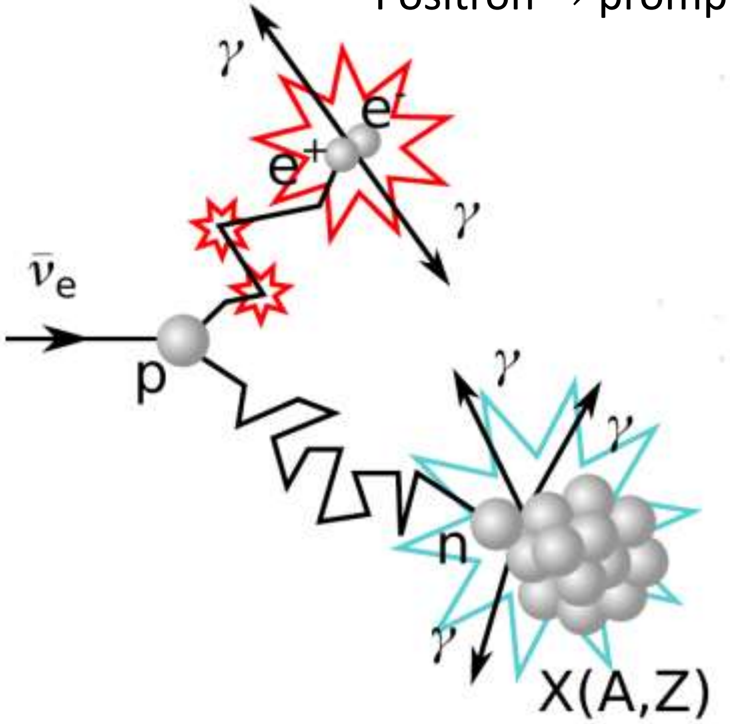
$$A_i = \left(1 - \frac{\pi^2}{6} m_i^2 a^2\right)^2 \exp\left(i \frac{m_i^2 L}{2E}\right) + 2 m_i^2 a^2 \exp\left(i \frac{m_i^2 L}{E}\right) \sum \frac{\exp\left(i \frac{n^2 L}{2Ea^2}\right)}{n^2}, ma \ll 1$$

Absolute mass scale (m_i) — Size of the **dominant** dimension (a) — Kaluza-Klein tower (n)

Detector of AntiNeutrino based on Solid Scintillator

- Detector is placed under the reactor core at Kalinin NPP and consists of safe, nonflammable materials
- The goal is to scrutinize the sterile neutrino hypothesis (and other BSM models)
- A movable platform → spectral ratio analysis not sensitive to detector efficiency and antineutrino spectrum
- Antineutrinos are detected in the IBD reaction:
- The energy of antineutrino is determined by the energy of positron

Positron → prompt signal



Neutron → delayed signal

$$\overline{\nu_e} + p \rightarrow n + e^+$$

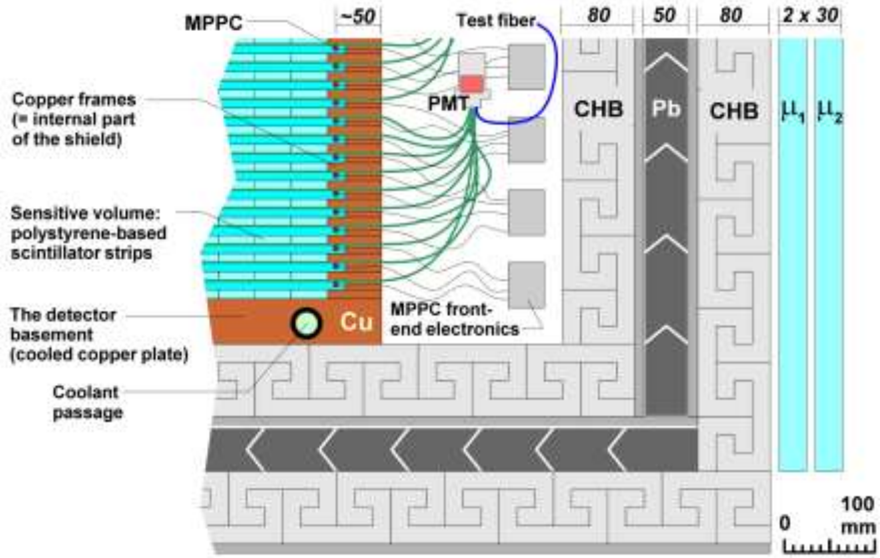
$$E_{\overline{\nu_e}} \approx E_{e^+} + 1.8MeV$$

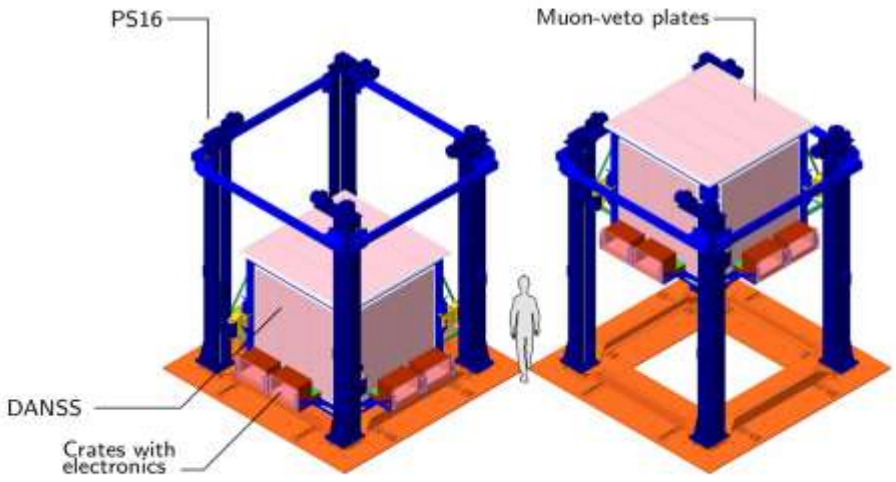
$$\sim 5000\ events/day$$

Largest in the world antineutrino statistics, IBD is used

Design of the detector

- Shielding: muon veto, 8 cm of boron-doped polyethylene, 5 cm of lead, another 8 cm of boron-doped polyethylene, and a 5 cm layer of copper
- 2500 scintillator strips coated with a gadolinium-containing layer for neutron capture. Light is collected with wavelength shifting fibers connected to SiPM and PMT
- Currently the detector’s upgrade is coming: new scintillation counters, more of sensitive volume, better light collection





See the report of I. Zhitnikov

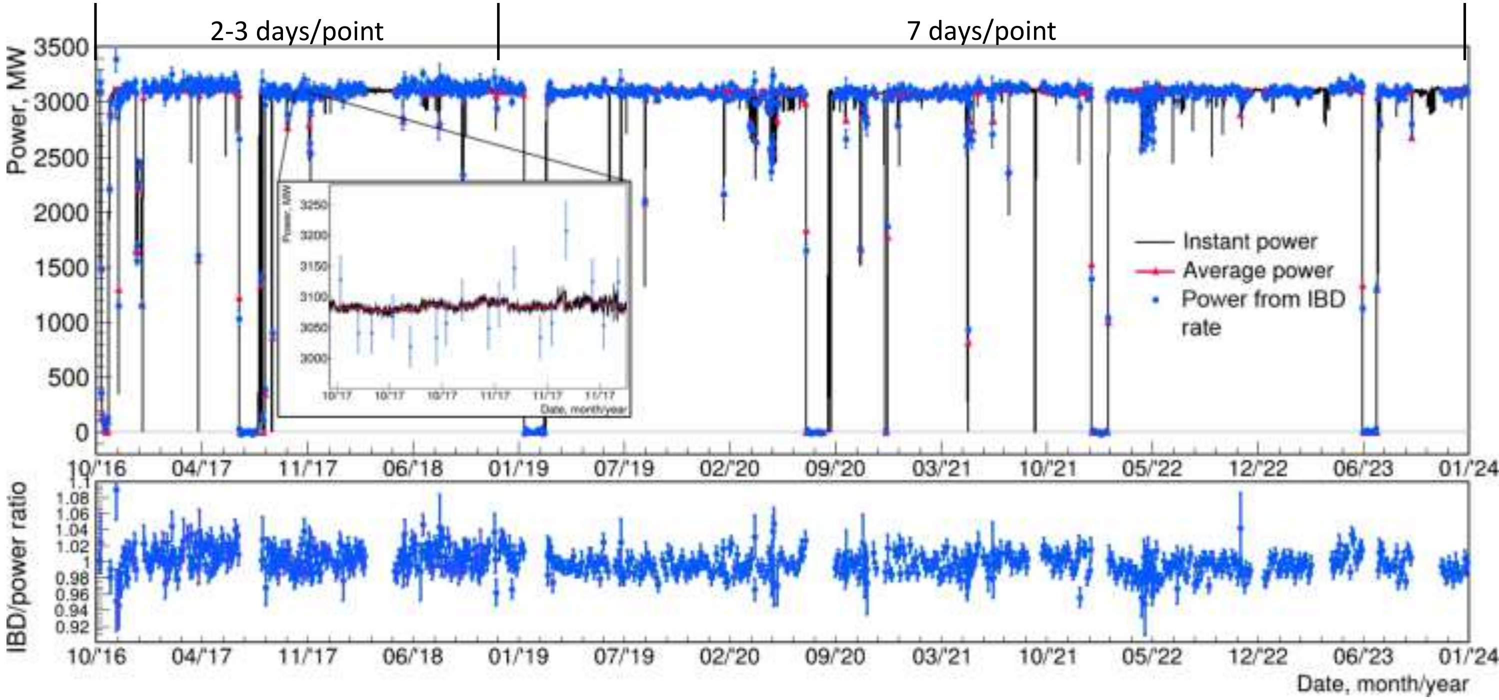
First precise measurement of reactor power with antineutrino

[I. Alekseev et al, (DANSS), Phys. Let. B, vol 866, 139575, 2025](#)

- Antineutrino flux:

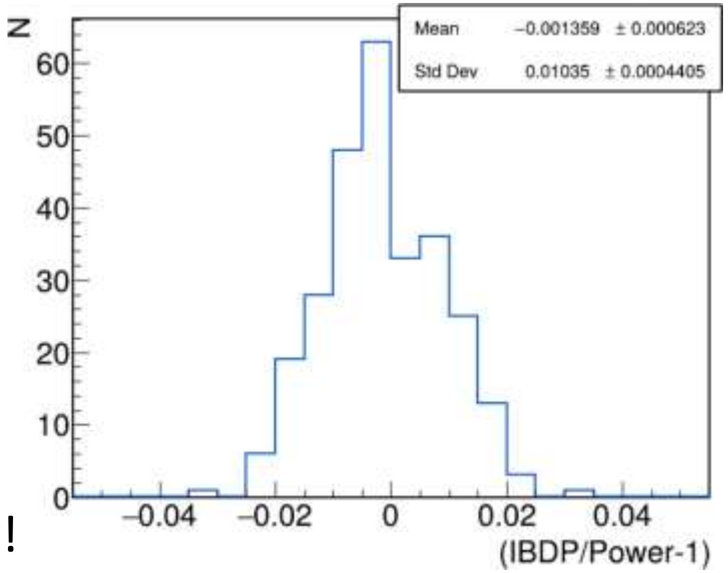
$$\frac{d^2N}{dE_\nu dt} = N_p \sigma(E_\nu)\varepsilon(E_\nu)\frac{d^2\phi}{dE_\nu dt}\frac{1}{4\pi L^2}\mathrm{P}(E_\nu, L)$$

$\mathrm{P}(E_\nu, L) = 1$



- Uncertainty in flux models → normalization to flux during 1 month in 2016
- Corrections applied:
  - Change of the efficiency due to dead channels amount ($< 3\%$)
  - Variation of the dead time due to VETO rate (1%)
  - The fuel evolution (provided by KNPP)

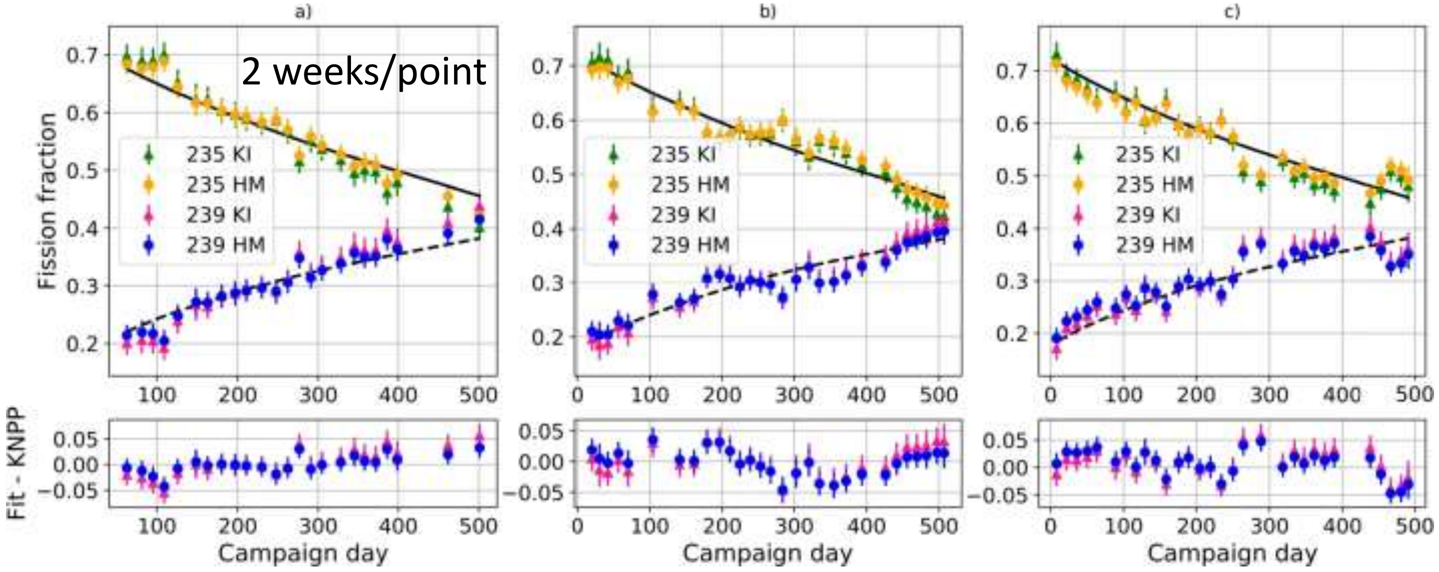
- Excellent agreement between DANSS and KNPP: 1.0% during 7 years
- Statistical accuracy of each point is around 0.7%
- Additional systematic between KNPP and DANSS measurements is 0.79% only!



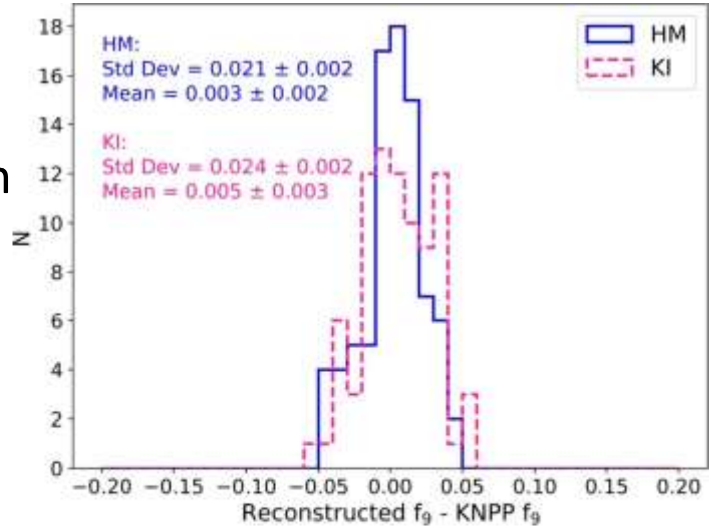
First measurement of fission fractions with antineutrino spectrum

[I. Alekseev et al, (DANSS), Phys. Let. B, vol 866, 139575, 2025]

- The antineutrino spectrum is different for different isotopes



- Correction for efficiency, dead time and neighbouring reactors (0.6%)
- Fit doesn't include $E_{e^+} \in [3; 5{,}5]\ MeV$ due to theoretical uncertainties
- 5th campaign is used to fix energy calibration and ^{238}U and ^{241}Pu fractions (taken from KNPP)
- Statistical error of IBD rate is 0.6%
- $\bar{\nu}_e$ spectra for isotopes are taken from HM or KI model. DANSS shows that results depend weakly on the choice of the model. KNPP data is based on the solving diffusion equation for neutron flux
- Agreement with KNPP is within 2.1% although two methods based on the completely different physical processes



Oscillation analysis

- For different points in parameter space θ spectra ratios R were calculated
  - $\theta = (\sin^2 2\theta_{ee}; \Delta m_{41}^2)$ for sterile neutrino
  - $\theta = (a, m_0)$ for LED searches
- χ^2 statistics is minimized over systematic parameters η
- Gaussian CL$_s$ method or confidence intervals (Wilks theorem assumed) were used

$$\chi^2(\theta,\eta) = \sum_{bins} \frac{\left(R_{bt}^{obs} - R_{bt}^{pre}(\theta,\eta)\right)^2}{\sigma^2}$$

- Data taking in 2 positions

$$R_{bt} = bottom/top$$

$$+ \sum_{bins}\left(R_{bt}^{obs} - R_{bt}^{pre};\ R_{mbt}^{obs} - R_{mbt}^{pre}\right) \cdot W^{-1} \cdot \begin{pmatrix} R_{bt}^{obs} - R_{bt}^{pre} \\ R_{mbt}^{obs} - R_{mbt}^{pre} \end{pmatrix}$$

- Data taking in 3 positions

$$R_{mbt} = middle/\sqrt{bottom \cdot top}$$

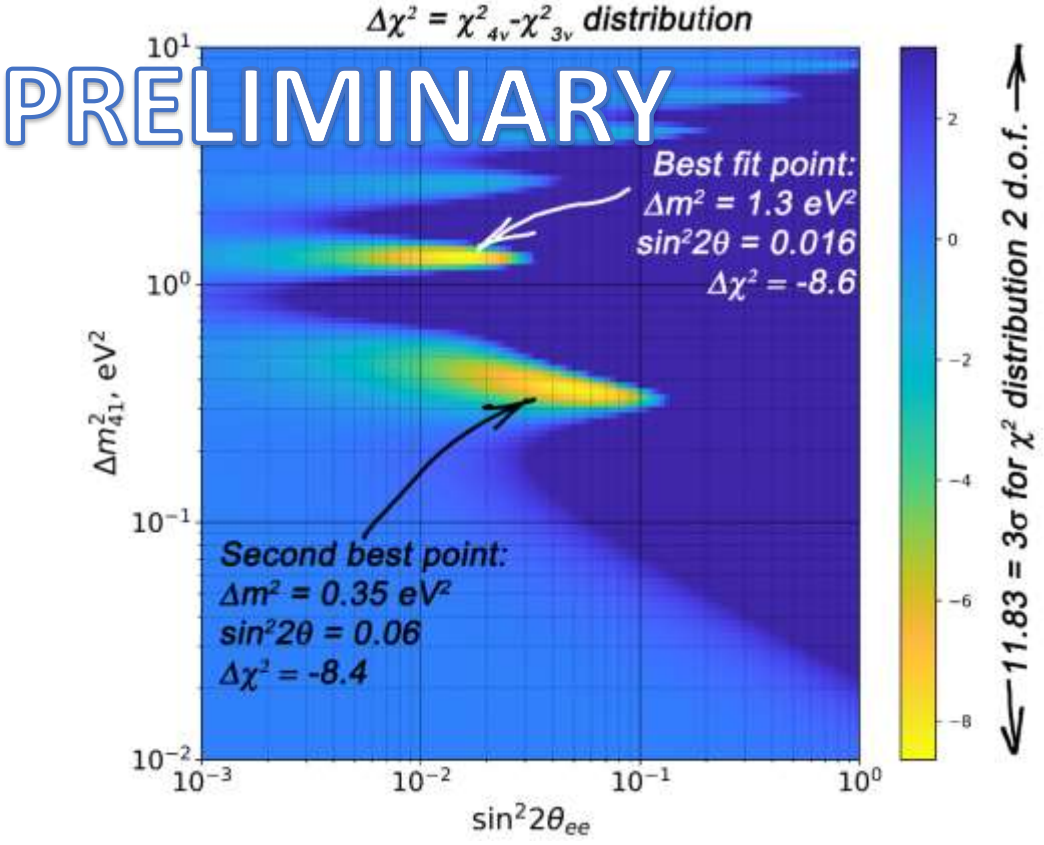
W – covariance matrix

$$+ \sum_{syst} \frac{(\eta - \eta^0)^2}{\sigma_\eta^2}$$

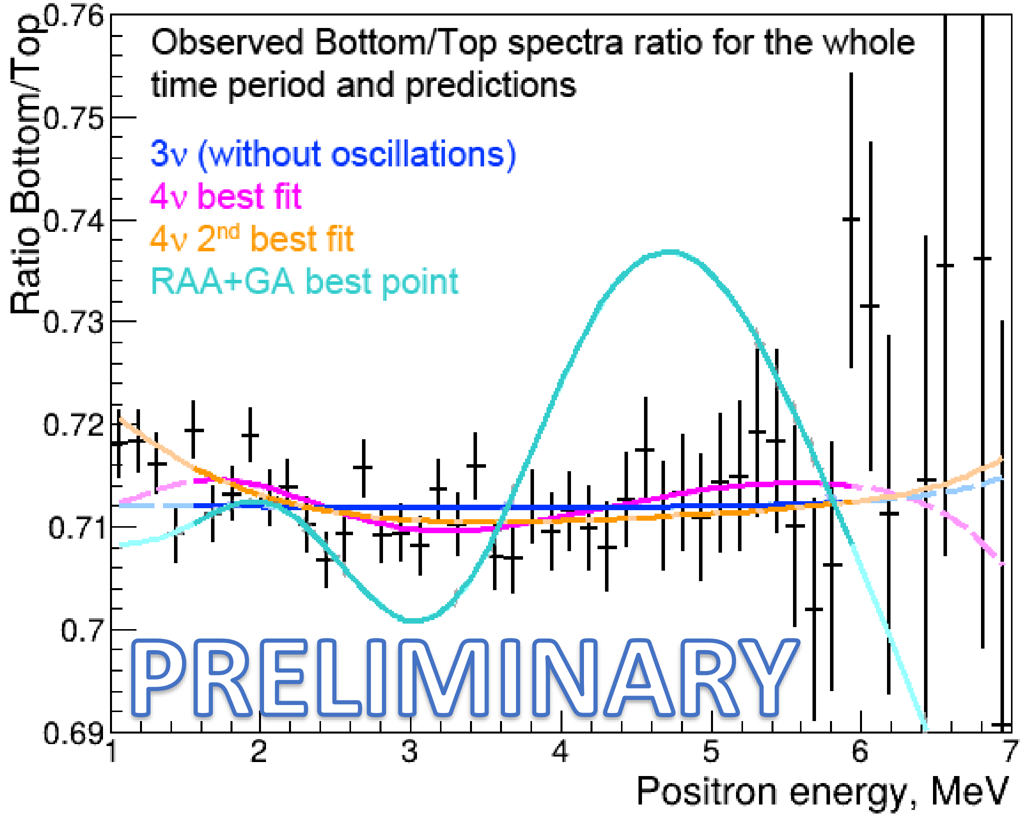
- Penalty term for systematics:
  relative efficiency, background, energy scale, distance to reactor core

Sterile neutrino (only relative counts)

- Color indicates $\chi^2_{4\nu} - \chi^2_{3\nu}$



predicted and observed Bottom/Top ratio

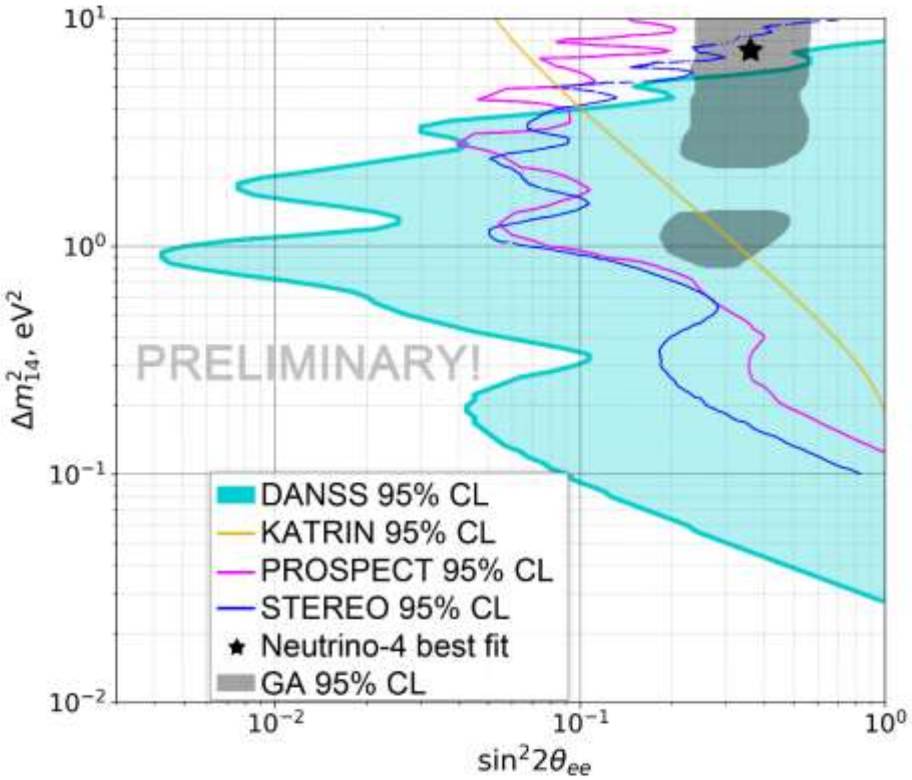


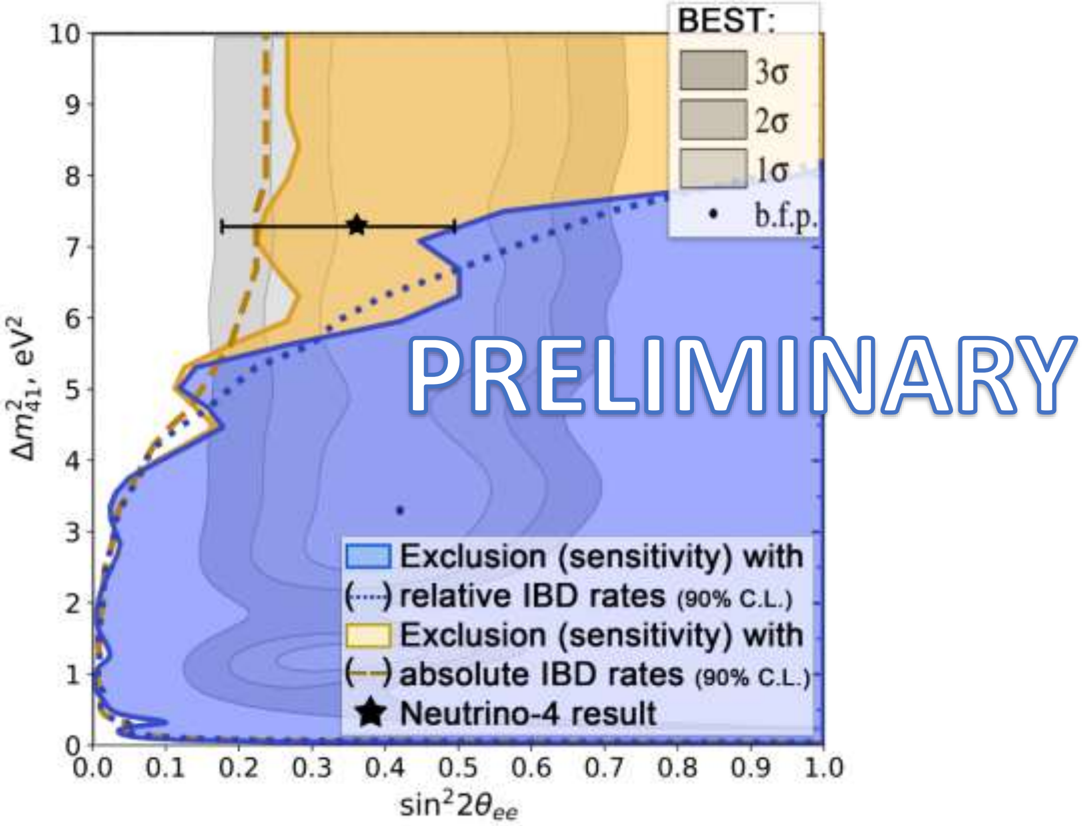
- October 2016 – May 2025, 7.2 mln events in $E_{e^+} \in [1.5; 7]$ MeV
- Best point is $\Delta m^2_{41} = 1.3\ eV^2$; $\sin^2 2\theta_{ee} = 0.016$ with significance of 2.5σ only
- No statistically significant evidence for sterile neutrino

Sterile neutrino

$$\chi^2 += \frac{\left(\left(N_{top}+N_{mid}+N_{bot}\right)^{obs} - \left(N_{top}+k_2\cdot\sqrt{k_1}\cdot N_{mid}+k_1\cdot N_{bot}\right)^{pre}\right)^2}{\sigma^2_{abs}}$$

- With relative counts – independent on model of antineutrino flux and on the uncertainty in the detector efficiency
- With absolute counts – Huber-Mueller model and conservative estimation of systematic uncertainty in the absolute rate

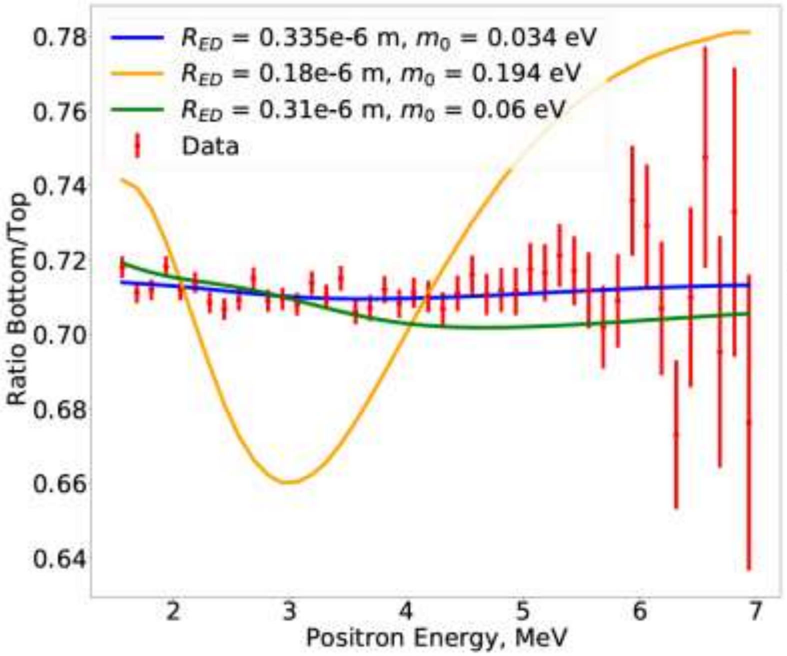




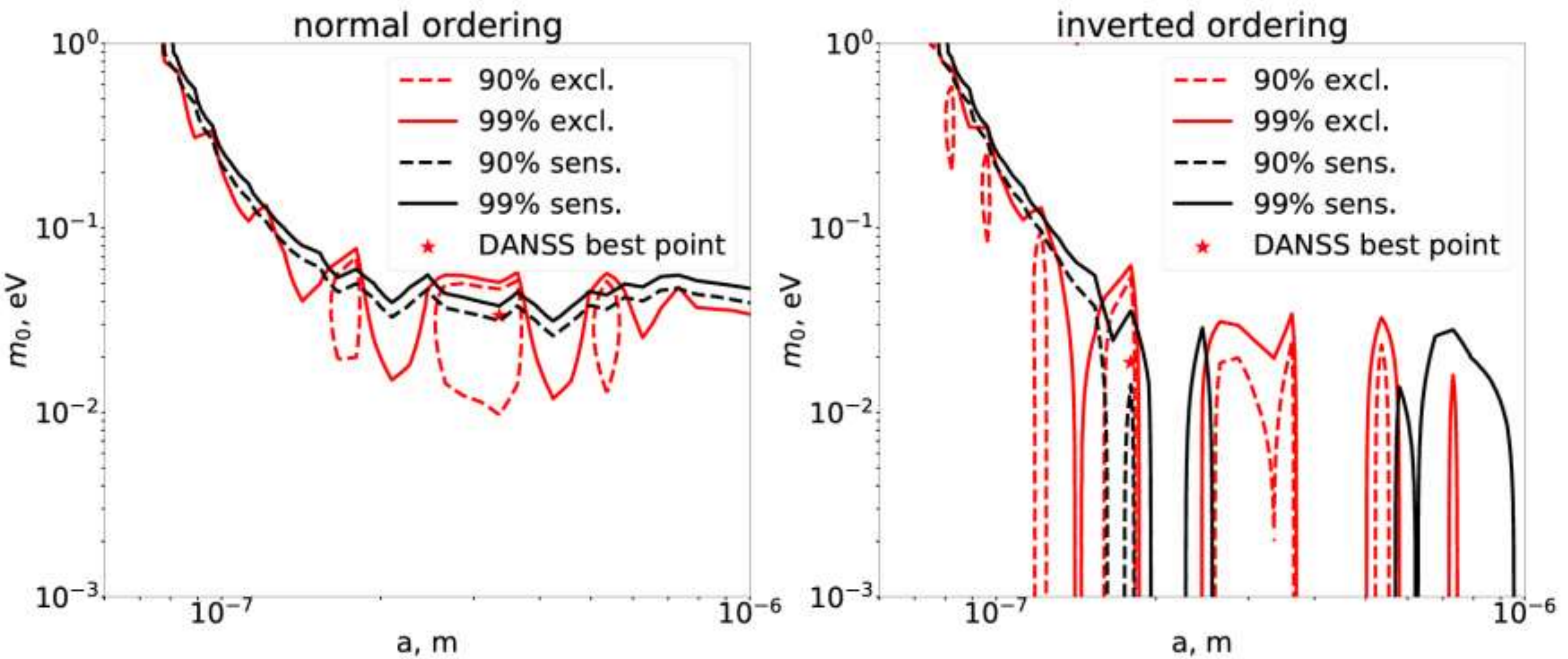
- Absolute counts provide sensitivity to larger Δm^2_{41}
- DANSS exclusions are the best in the world for $\Delta m^2_{41} \in [0.7; 4]\ eV^2$
  - Area preferred by RAA and GA is excluded almost completely including b.f.p (much more than 5σ) in the model-independent analysis
  - Neutrino-4 best point is excluded in the analysis with absolute counts

Search for Large Extra Dimensions

[I. Alekseev et al., DANSS, Letters to JETP, vol 122, issue 1, page 3, 2025]



Observed (red) and predicted for DANSS (blue), GA (orange), RAA (green) b.f.p spectra ratios



- Bottom/Top ratio is used
- October 2016 – January 2024, 5.8 mln events
- Sensitivity is larger for inverted mass ordering

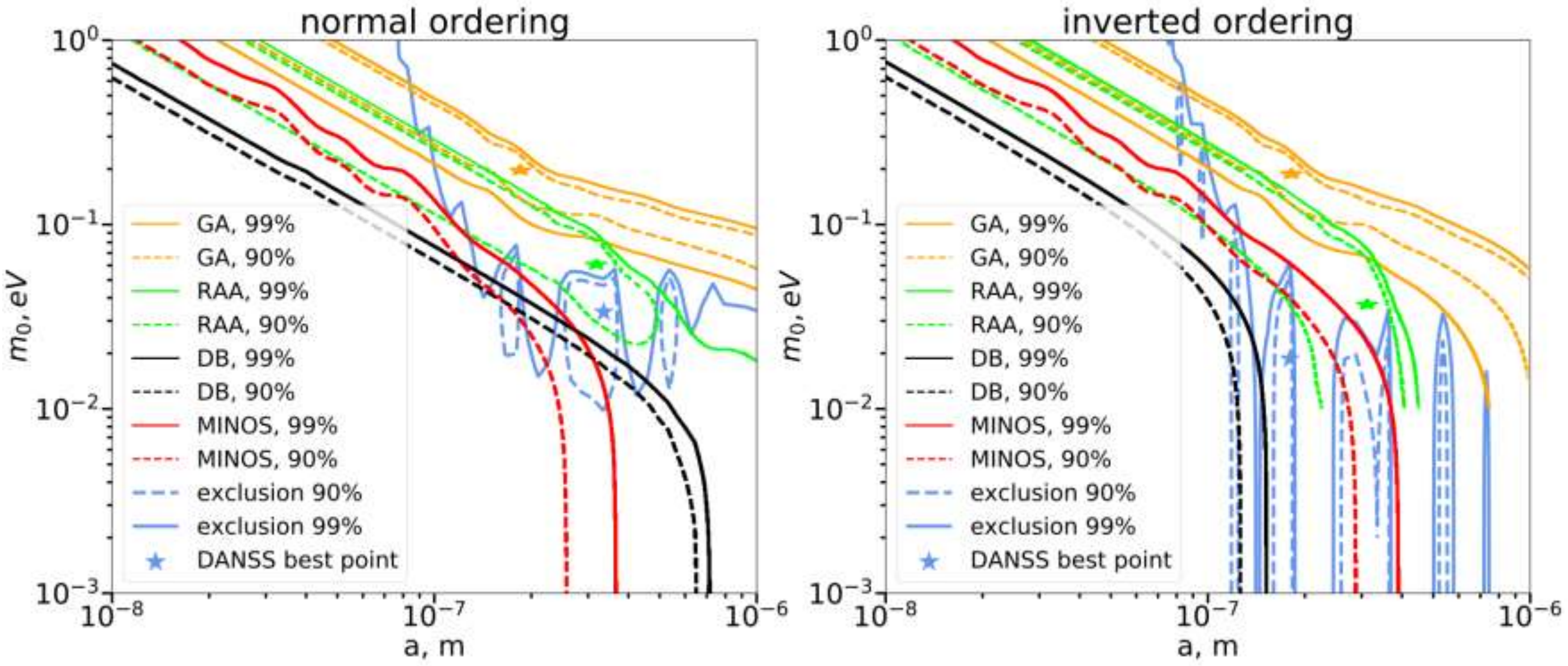
Search for Large Extra Dimensions

I. Alekseev et al., DANSS, Letters to JETP, vol 122, issue 1, page 3, 2025

- CI with Wilks theorem:
  - GA data
  - RAA data
  - DB data
  - MINOS results

From D.V. Forero et al, Phys. Rev. D 106, 035027, 2022

P. Adamson et al, (MINOS), Phys. Rev. D 94, 111101(R), 2016



- GA and RAA can be explained with LED but DANSS excludes corresponding b.f.p. ($> 5\sigma; 4\sigma$) with the most relevant part of parameter space
- Results obtained by DANSS in model-independent analysis contours are the most stringent in the world for some regions with $m_0 \sim 0.01\ eV$ and $a \sim 0.1\ \mu m$

Best points:

$a = 3.4 \times 10^{-7}\ m; m_0 = 0.034\ eV$, 2.0σ (NO)

$a = 1.8 \times 10^{-7}\ m; m_0 = 0.017\ eV$, 1.8σ (IO)

No significant evidence for oscillations to LED

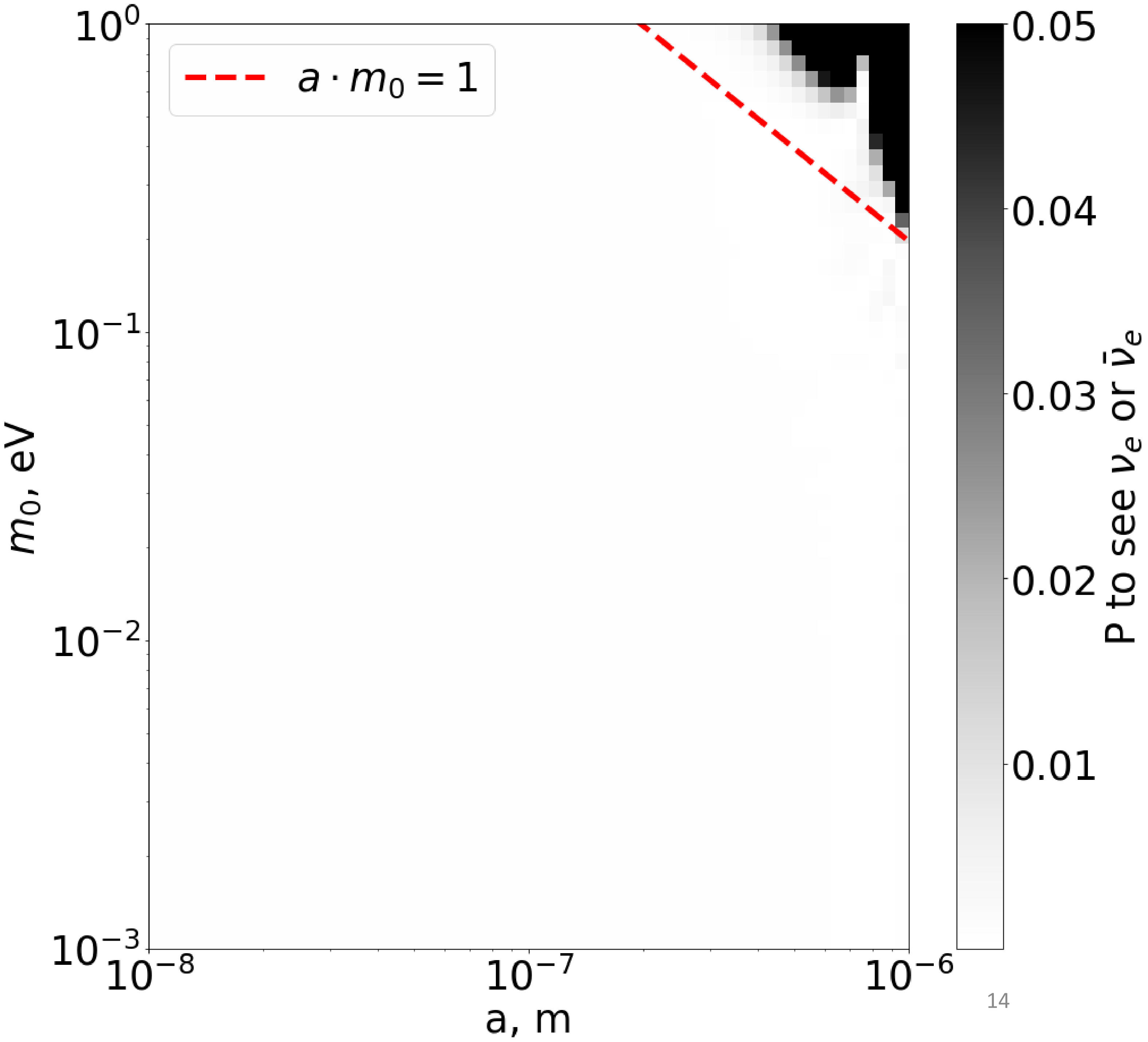
Conclusions

- DANSS acquires around 5000 IBD events per day with S/B ratio > 50
- Measured IBD rate allowed to measure relative reactor power with 1% accuracy in a weak measurements in comparison with traditional methods
- Fission fractions of ^{235}U and ^{239}Pu were determined from the shape of IBD spectrum for the first time with 2.1% precision
- In model-independent analysis DANSS put the most stringent limits on $\sin 2\theta_{ee}$ for $\Delta m_{41}^2 \in [0.7; 4]\ eV^2$
- In the analysis with HM model and conservative estimation of systematic DANSS excludes the best fit point of Neutrino-4
- DANSS excludes the large part of parameter space of LED theory preferred by GA and RAA data and puts the strictest limits for particular regions in (a, m_0) space

- *See the report by I. Zhitnikov about upgrade of the DANSS*

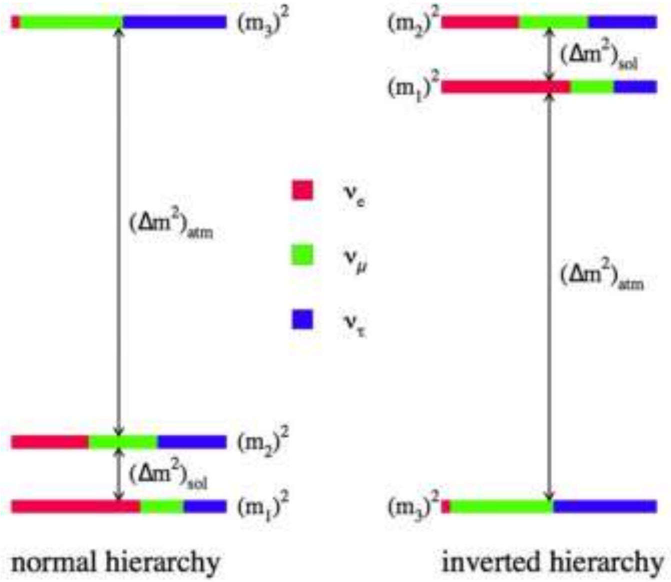
BackUp

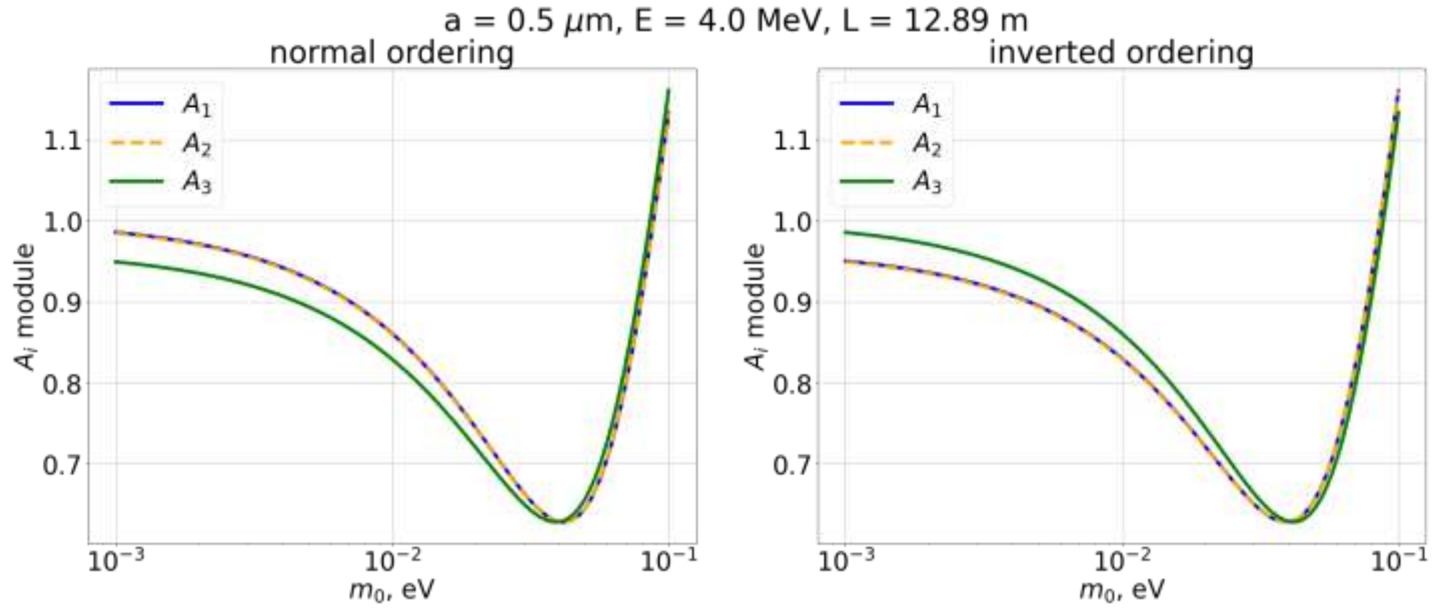
- LSND result with LED
- Probability of appearance is very low



Mass ordering

- For the same m_0 in different ordering values of m_1, m_2, m_3 differ, hence, amplitudes are also different. They have different weights in the total probability





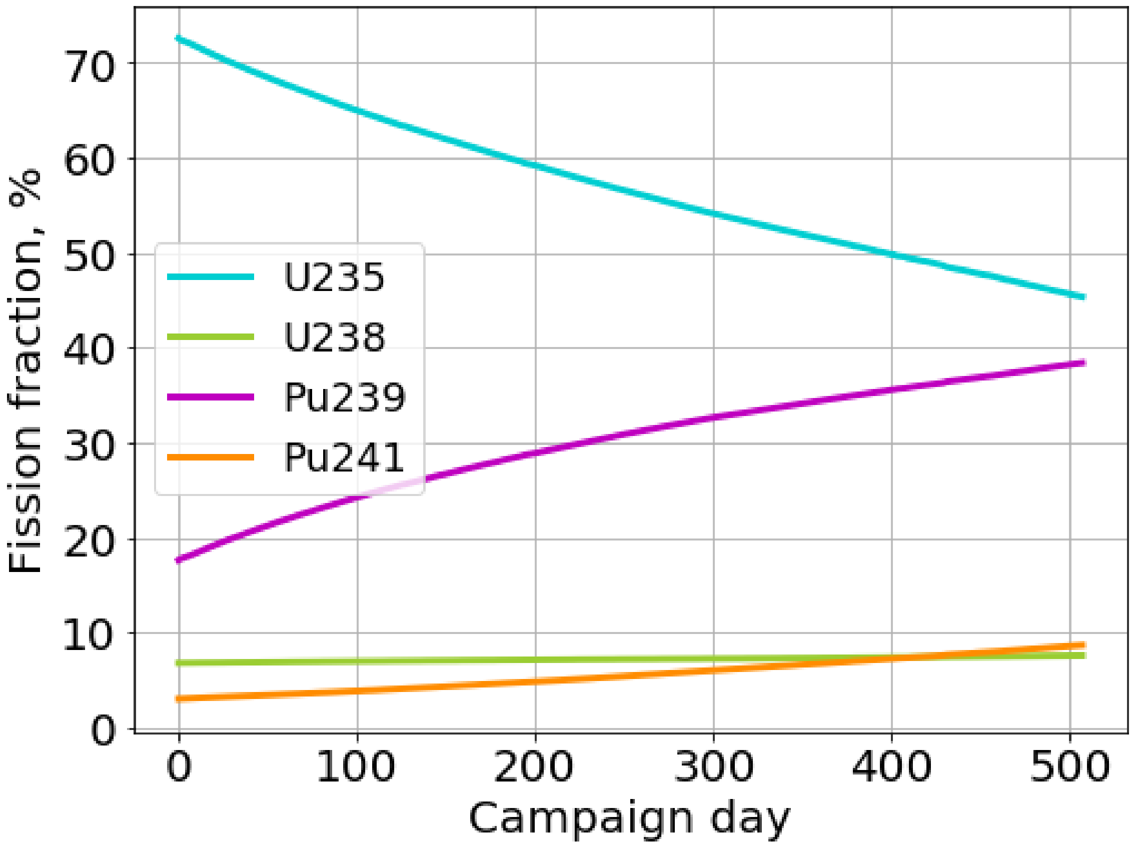
Survival probability:

$$P_{ee} = \left| \sum |U_{ei}|^2 A_i \right|^2$$

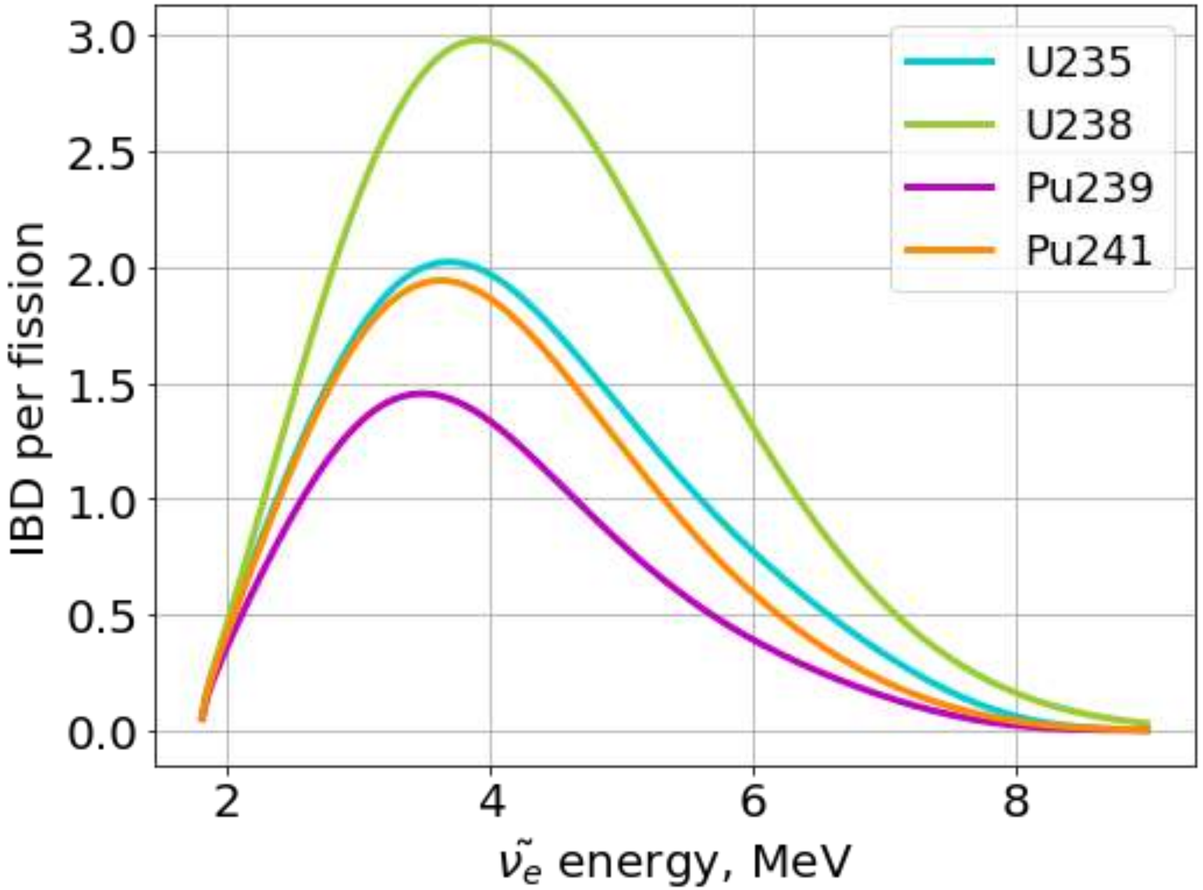
$|U_{e1}| \sim 0.8$
$|U_{e2}| \sim 0.5$
$|U_{e3}| \sim 0.1$

Fission fractions

Fission fraction provided by KNPP



Antineutrino spectra for different isotopes



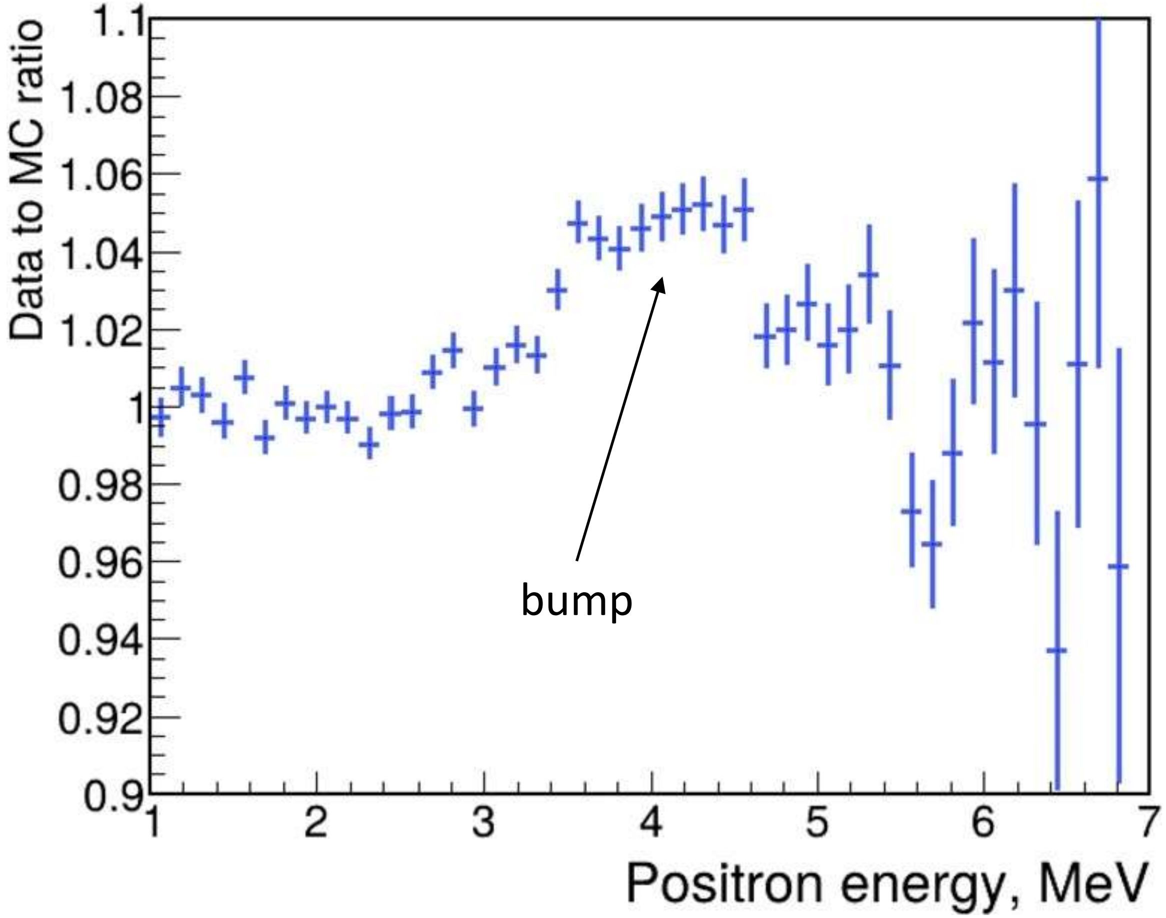
List of systematics

- η_0 - nominal values
- σ_η - standard deviations

η	k	b	K_E	smear	shift, кэВ	move, см
η_0	1	0	1	0	0	0
σ_η	$4 \cdot 10^{-3}$	$7 \cdot 10^{-3}$	0.02	$\frac{6\%}{\sqrt{E}} + 2\%$	50	5

Bump in positron spectra

- Ratio of measured and predicted by HM spectra
- 3-5.5 MeV range is not included

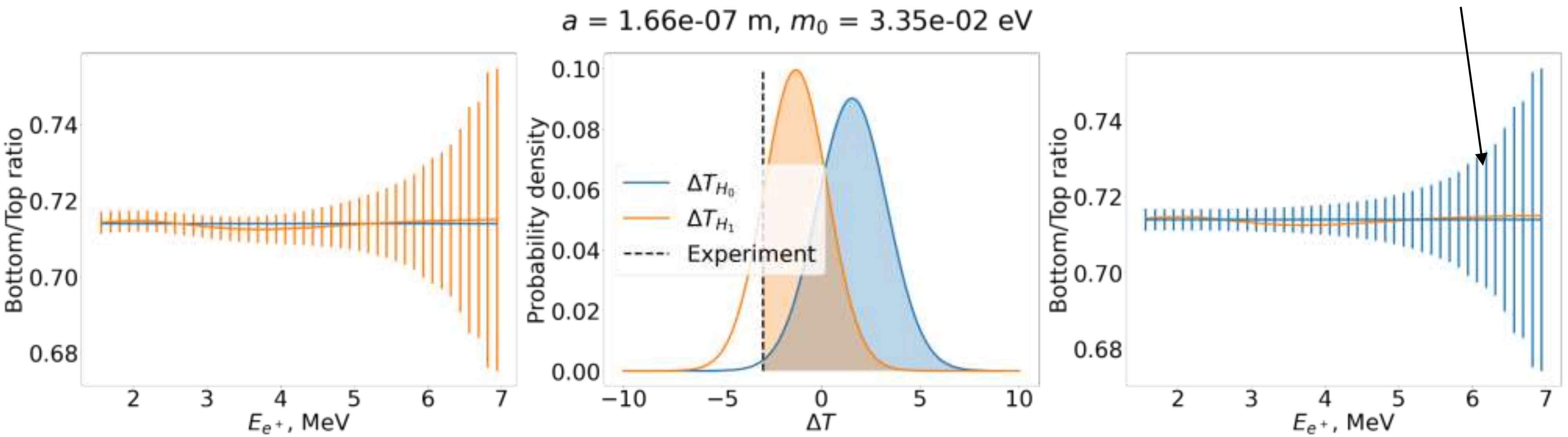


Gaussian CL_s method

Significance of exclusion H_1 in comparison with H_0 without any suggestions on the structure of parameter space. H_0 is assumed to be true.

- $\chi_1^2 - \chi_0^2$ (ΔT) is distributed according to normal distribution with parameters determined from Asimov datasets.
- Confidence level: $CL_s = \frac{1-p_1}{1-p_0}$

Prediction of theory with experimental error



Unfolding of the antineutrino spectrum

- Unfolding with SVD method