Searches for New Physics in the DANSS Experiment

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For the DANSS Collaboration

Kalininskaya NPP, Udomlya
300 km from Moscow

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There are several indications in favor of existence of the 4th neutrino flavor - “sterile” neutrino seen in short distance oscillations

LSND + MiniBooNE – **appearance anomaly**: appearance of ν_e ($\bar{\nu}_e$). **6.1σ** combined result.

MiniBooNE, PRL **121**, 221801 (2018)

MicroBooNE – doesn’t confirm MiniBooNE, but doesn’t exclude.

MicroBooNE, PRL **128**, 241802 (2022)

MicroBooNE – no excess, but 2.4σ shortage of ν_e events.

MicroBooNE, arXiv:2412.14407

GALEX (Gran Sasso) and SAGE (Baksan) – **Gallium Anomaly (GA)**: deficit of ν_e from neutrino source in gallium detectors calibration. Phys. Rev. C **80**, 015807 (2009)

Recent results from BEST demonstrate event larger deficit of neutrinos.
The combined significance >5σ Phys. Rev. D **105**, L051703 (2022)

Reactor antineutrino anomaly (RAA) – deficit of ν_e (5.7%) in combined analysis of reactor experiments. G. Mention et al. Phys. Rev. D **83**, 073006 (2011)

Much smaller (3.7%): M. Estienne et al. PRL **123**, 022502 (2019)

No anomaly (0.6%): V. Kopeikin et al. Phys. Rev. D **104**, L071301 (2021)

^{235}U yield measurements by Daya Bay and RENO

Neutrino-4: 2.7σ @ $\Delta m^2 \sim 7 eV^2$ $\sin^2 2\theta \sim 0.35$ A.P. Serebrov et al., Phys. Rev. D **104**, 032003 (2021)

Criticism of the Neutrino-4 analysis: M. Danilov et al. JETP Lett. **112** no. 7, 452 (2020)
C. Giunti et al. *Phys. Lett. B* 816, 136214 (2021)

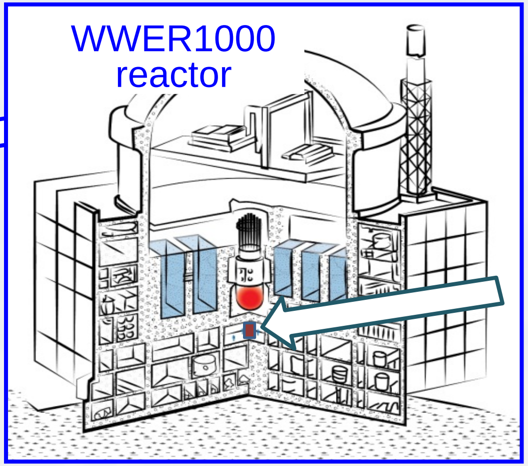
Neutrino-4 best fit point has some tension with results of PROSPECT
M. Andriamirado et al., arXiv:2406.10408

Neutrino-4 preferred parameter space is excluded by KATRIN’s first five measurement campaigns
H. Acharya et al., arXiv:2503.18667

Another explanation of disappearance anomalies (GA and RAA) could be Large Extra Dimensions (LED)

Nevertheless, these are one of the statistically strongest indications of the New Physics

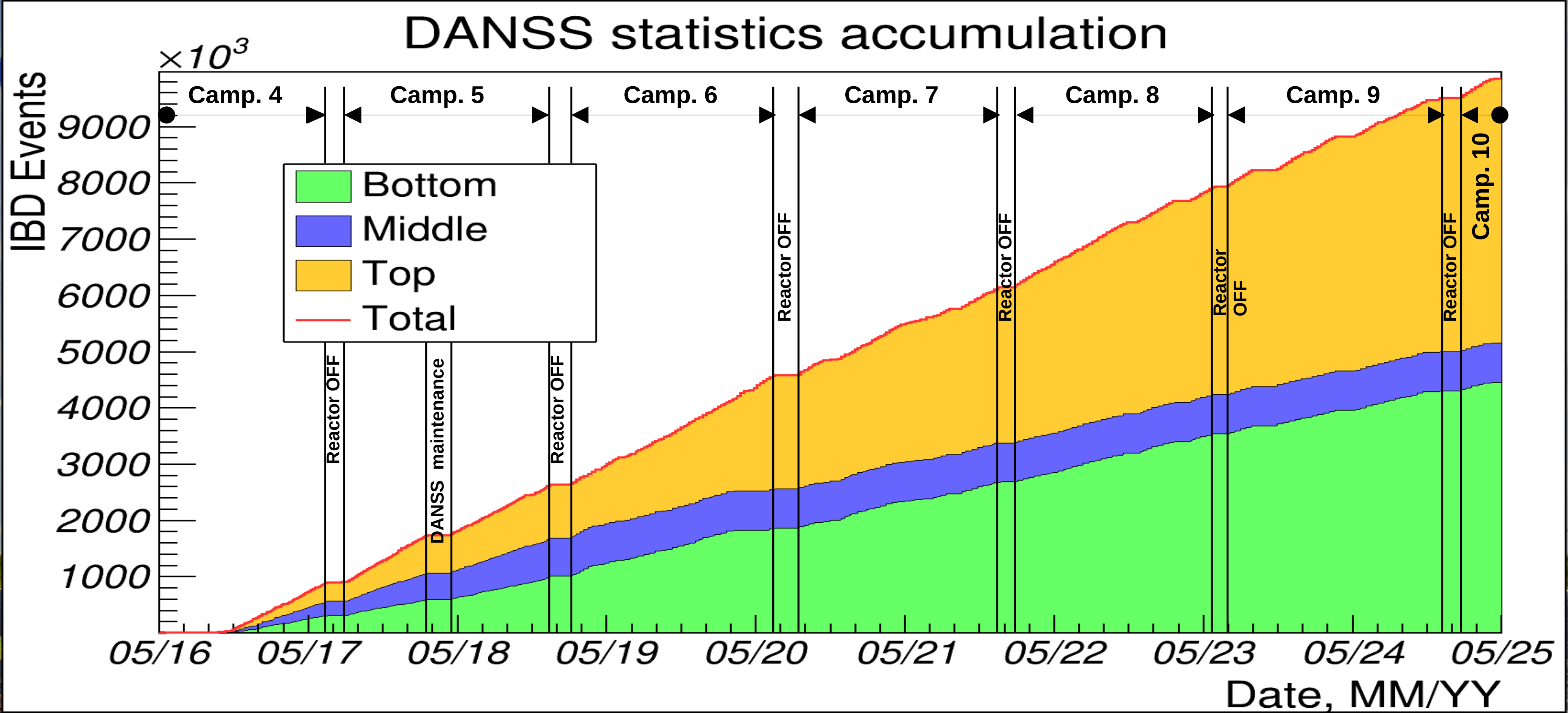
Kalininskaya Nuclear Power Plant, Russia, ~300 km NW from Moscow



Below 3.1 GW_{th} commercial reactor ~$5\cdot10^{13}$ $\nu\cdot cm^{-2}c^{-1}$@11m

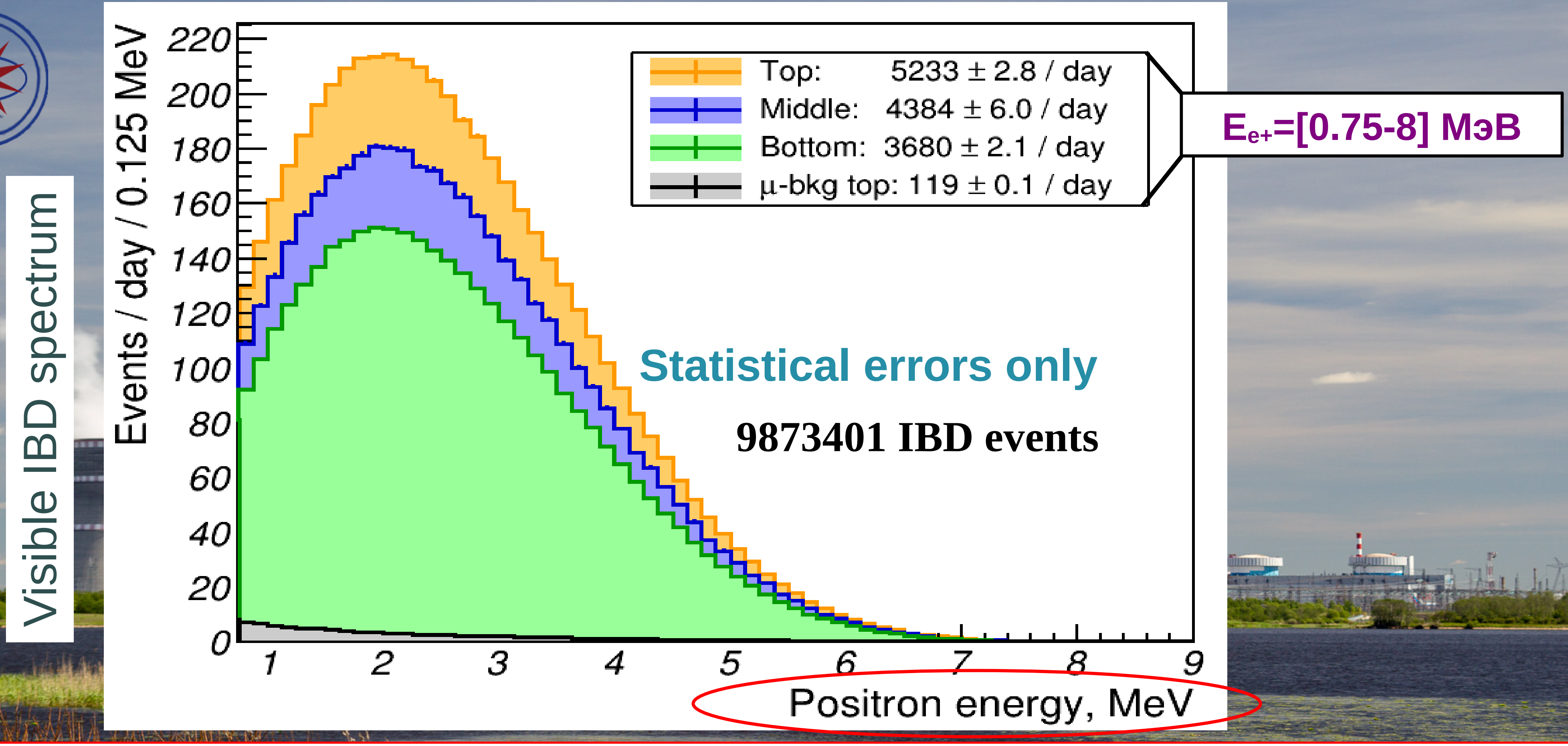
DANSS on a lifting platform
Two week cycle of up/down position

- Detector of the reactor AntiNeutrino based on Solid-state Scintillator - no flammable or dangerous materials – can be put just after reactor shielding
- Inverse Beta-Decay (IBD) to measure antineutrinos: $\bar{\nu}_e + p \to e^+ + n$
- Reactor fuel and body with cooling pond and other reservoirs provide overburden ~50 m w.e. for cosmic background suppression
- Lifting system allows to change the distance between the centers of the detector and of the reactor core from 10.9 to 12.9 m on-line
- The setup details: JINST 11 (2016) no.11, P11011
- The first results: Phys.Lett. B787(2018)56 – one year of running



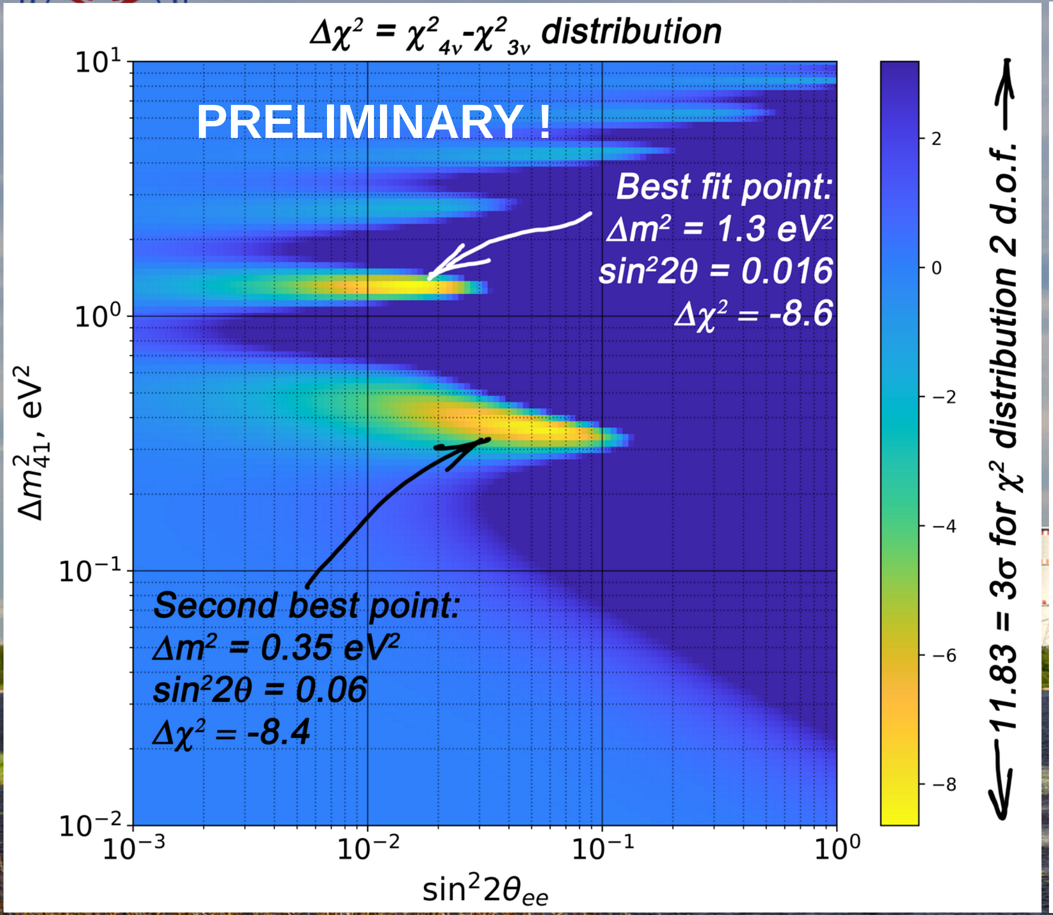
- ✓ **5 full reactor cycles ! 6 reactor off periods !**
- ✓ **We present data till May 25.**
- ✓ **Previous analysis (2024):** I.G. Alekseev, Physics of Atomic Nuclei in press.

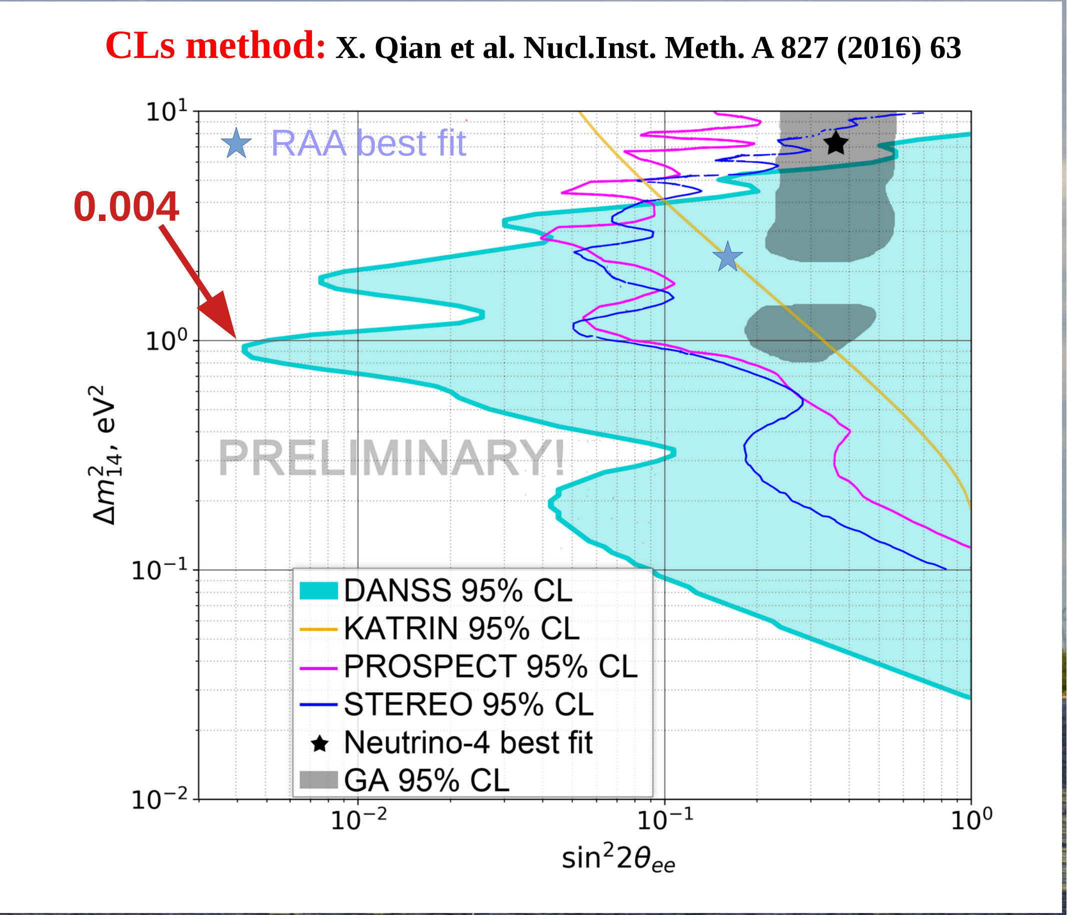
Talk by D. Svirida Aug 27, 2025, 3:20 PM



- ✓ All backgrounds subtracted
- ✓ Neighbor reactors at 160 m, 334 m, and 478 m, 0.6% of neutrino signal at top position, subtracted
- ✓ For E_{e+}=[1.5-6] MeV background = 1.75% in top position: S/B > 50 !

Sterile neutrino search





- ✓ 7.2 M IBD events 1.5 MeV < E < 7 MeV (conservative approach)
- ✓ $\Delta\chi^2$=-8.6 (2.5σ) – No statistically significant hint of 4ν oscillations
- ✓ The RAA best point is deep inside the exclusion region (5σ level reached in 2018 [I. Alekseev et al., PLB **787** (2018) 56])

Using absolute counting rates

$$\chi^2_{abs} = \chi^2_{rel} + ((N_{top} + N_{mid} + N_{bottom})^{obs} - (N_{top} + k_2 \cdot \sqrt{k_1} \cdot N_{mid} + k_1 \cdot N_{bottom})^{pre})^2/\sigma^2_{abs}$$

χ^2_{rel} — χ^2 using counts ratios only, $N_{top/mid/botom}$ — total counts in the corresponding detector positions

σ_{abs} — systematic uncertainty taken as **7%** (very conservative)

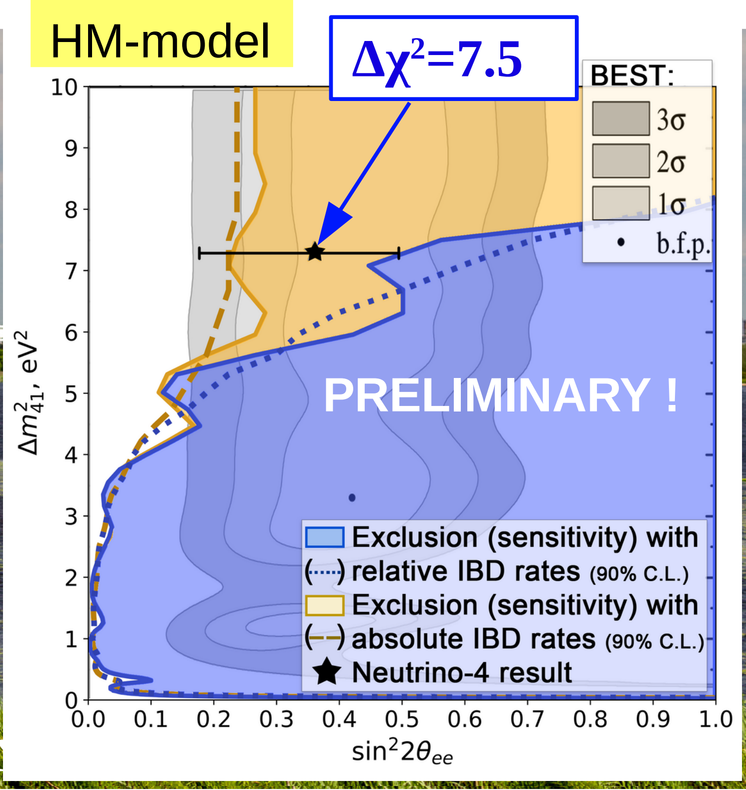
Exclusions for large Δm^2_{41} are consistent with previous results (Daya Bay, Bugey-3, Katrin …)

Our preliminary results exclude the dominant fraction of BEST expectations [Phys.Rev.Lett.128, 232501] as well as best fit point of Neutrino-4 experiment [Phys. Rev. D 104, 032003].

Systematic uncertainties

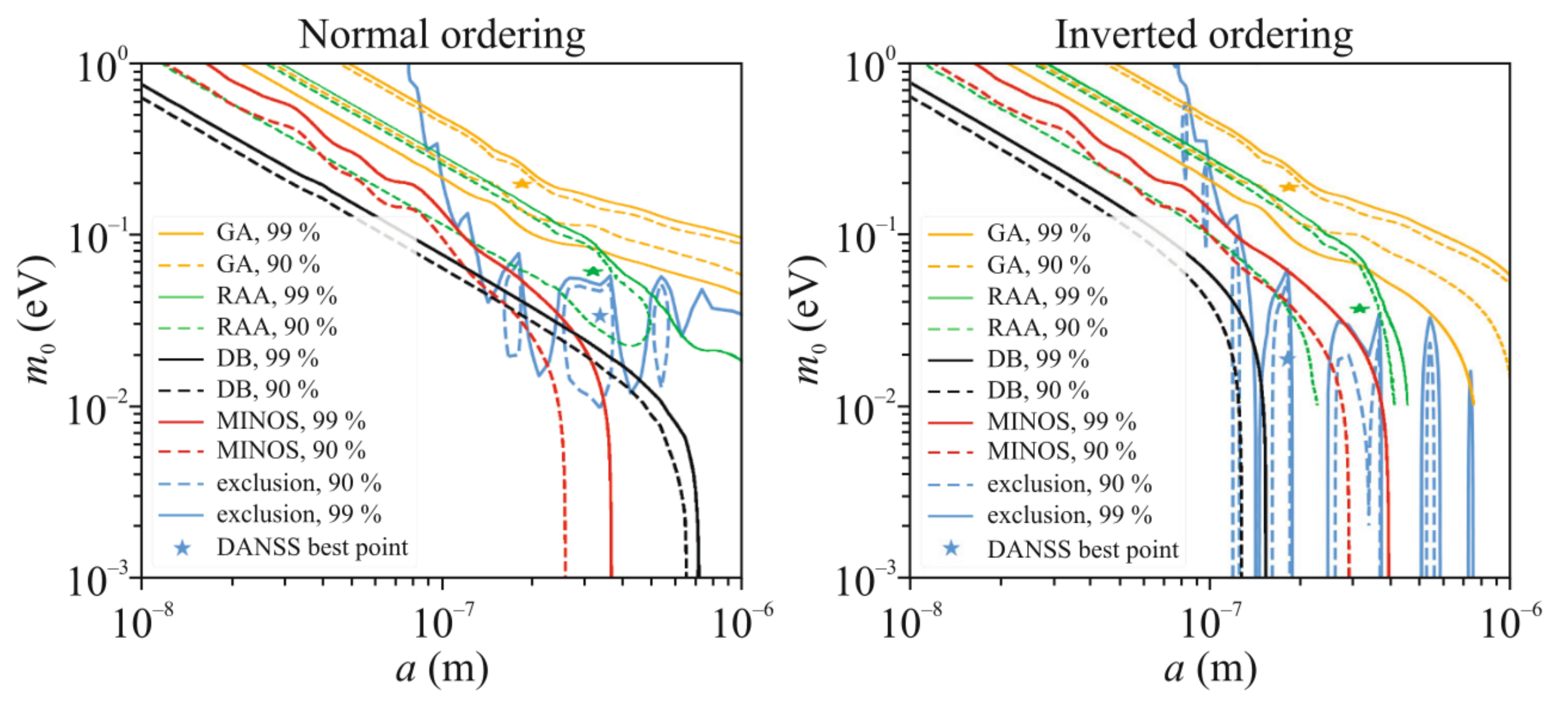
Source	Uncertainty
Number of protons	2%
Selection criteria	2%
Geometry (distance and fission points distribution)	1%
Fission fractions (from KNPP)	2%
Average energy per fission (PRC **88**, 014605)	0.3%
Reactor power (from KNPP)	1.5%
Backgrounds	0.5%
Total without flux predictions	**4%**
Flux predictions	2-**5%**
Total	5-**7%**

KI model exclusions are slightly stronger



Large extra dimensions

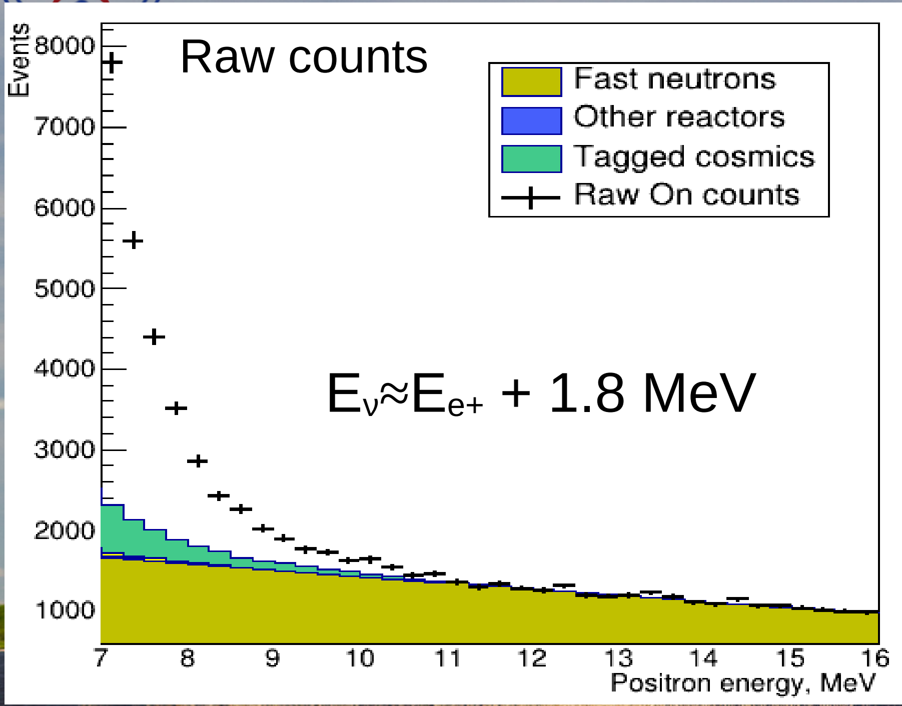
I.G. Alekseev et al., JETP Letters 122 (2025) 1

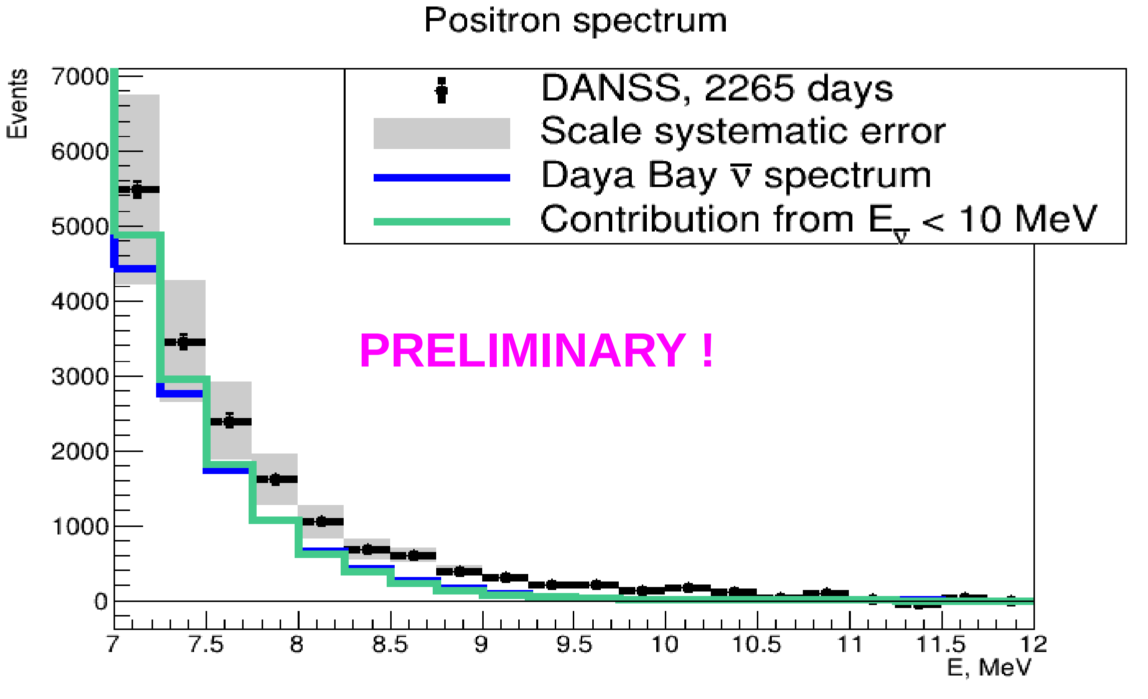


- Model-independent analysis – we use DOWN/UP ratio only
- Using Wilks' theorem to be compatible with other plots
- 5.8 M IBD events
- E_{e+}=[1.5-7] MeV

- Another way to solve RAA and GA — oscillation to large extra dimensions.
- The analysis is similar to sterile neutrino search, but different L/E pattern.
- No statistically significant evidence for LED. The best point significance is 2σ [NO] and 1.8σ [IO] only.
- We exclude large and interesting region preferred by GA and RAA.
- GA best point is excluded at > 5σ level, RAA at 4.2σ.

High energy antineutrinos





Background subtraction is based on 6 “reactor off” periods

DANSS observes antineutrino with energy > 10 MeV: **1797 ± 169$_{stat}$ ± 189$_{sys}$ ev. (7.1σ)**

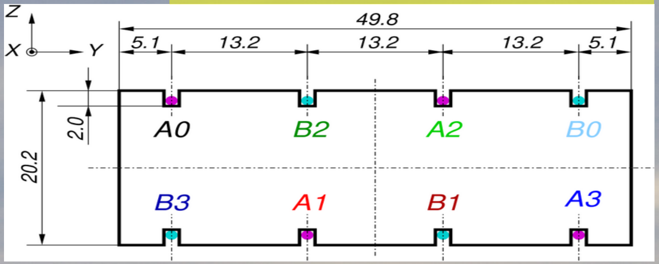
Fraction of IBD events with antineutrino energy > 10 MeV: $(1.48 \pm 0.14_{stat} \pm 0.16_{sys}) \cdot 10^{-4}$

Scale uncertainty of 2% makes the largest contribution to the systematic error

Fraction of high energy events is somewhat larger than at Daya Bay **[PhysRevLett.129.04180]**

DANSS upgrade

JINST 17 (2022) P04009

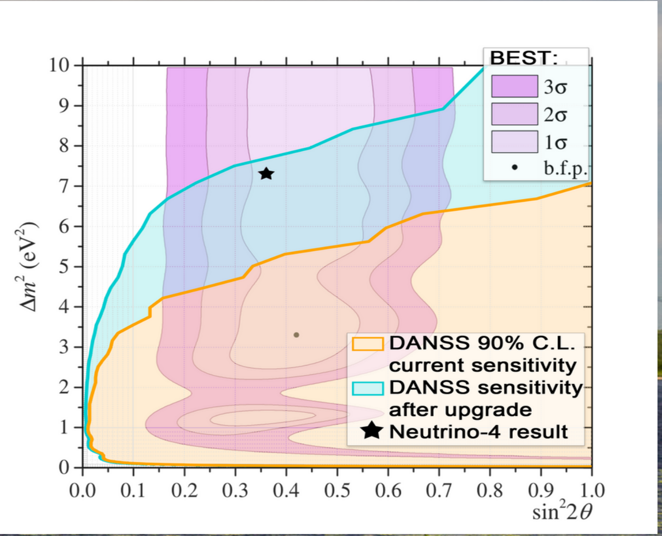


Counter cross section

Main goal of the upgrade is to improve energy resolution:

34%/√E --> 12%/√E

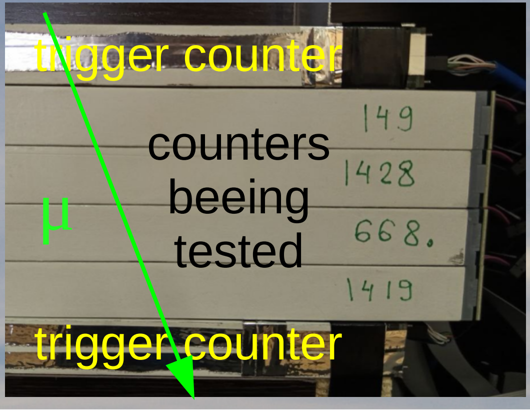
- ✓ New scintillation counters from bulk polystyrene: **20x50x1200** mm^3;
- ✓ 60 layers x 24 counters — cube (120 cm)^3 → **1.7** times larger fiducial volume;
- ✓ **No PMT** – SiPM readout from both sides of each WLS;
- ✓ **8** grooves with WLS, **16 SiPM** per strip to get high light yield and uniformity;
- ✓ Time to get longitudinal coordinate in each counter. Faster (**4.0** ns decay time) WLS fiber KURARAY **YS-2**; **JINST 17 (2022) P01031**
- ✓ Chemical whitening of counters – no large dead layer with titanium and gadolinium;
- ✓ Gadolinium in polyethylene film between layers;
- ✓ New front end electronics – low power inside passive shielding. Cool SiPMs to 10^{o}C to reduce noise;
- ✓ Keep platform, passive shielding and digitization.
- ✓ Triggerless readout.



DANSS sensitivity after upgrade – 1.5 years of running and current setup – 4.5 years of running

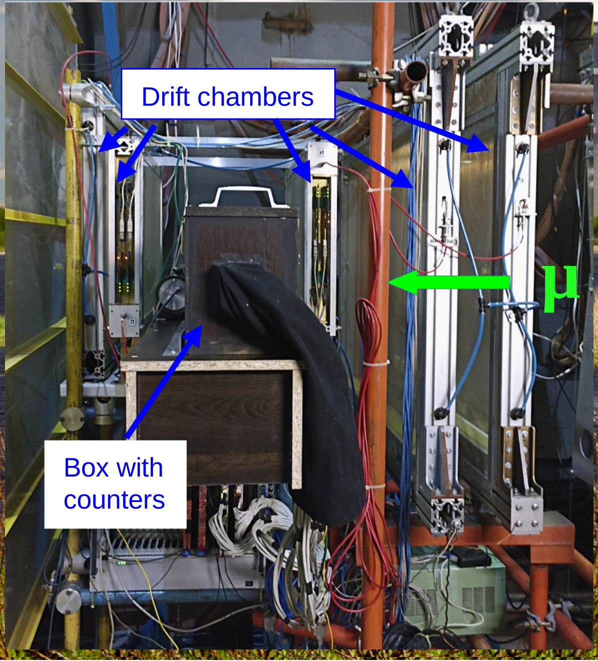
Upgrade Status & Plans

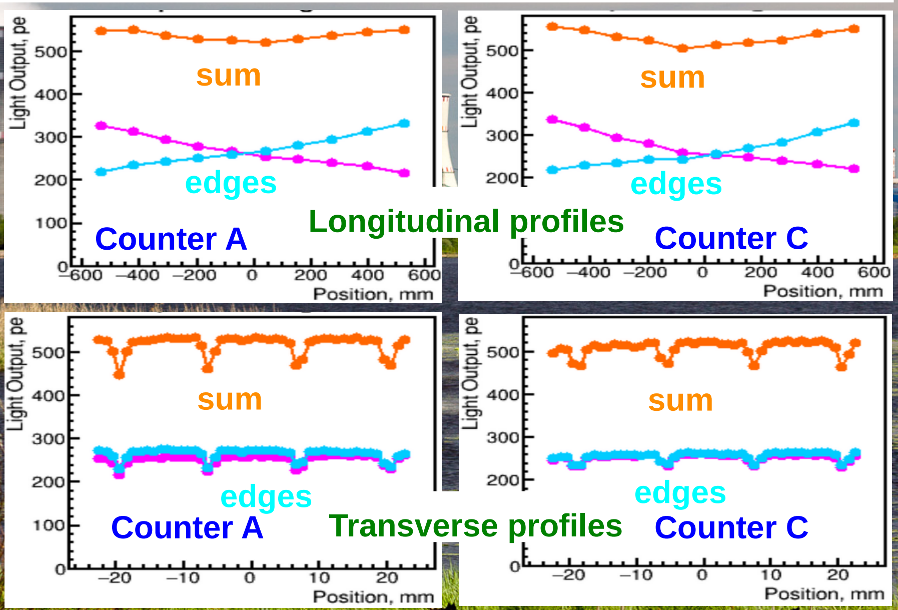
- ✔ New scintillation counters developed. Mass production has been started.
- ✔ DANSS decommissioning is scheduled early 2026.
- ✔ 10M events will be accumulated – the largest statistics in the world.
- ✔ DANSS-II assembly will start after DANSS disassembly.
- ✔ **DANSS-II commissioning is expected in the second part of 2026.**

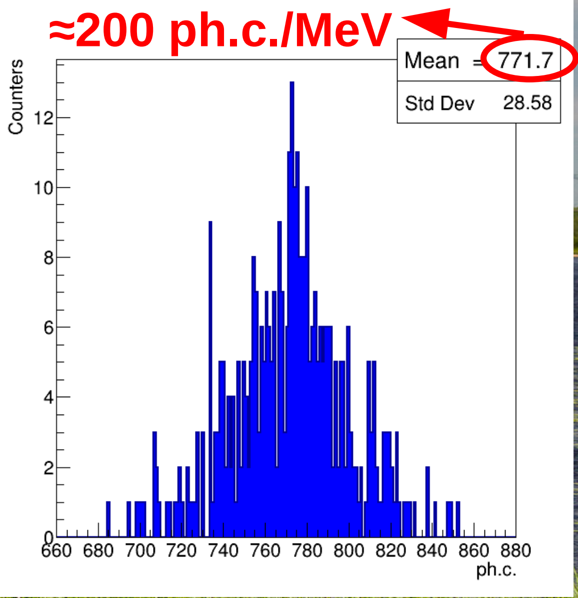


Mass production counter test with atmosphere muons

New scintillation counters test (16 SiPM per counter) with μ-beam at U-70 (Protvino)







Conclusions

- DANSS recorded the first data in April 2016 and is running now. Nearly 10 million IBD events collected. The experiment is still running. Will stop data collection early next year.
- We record more than 5 thousand antineutrino events per day in the closest position. Signal to background ratio is > 50.
- A search for sterile neutrinos done using relative counts only (model-independent approach). Two best points observed:

  Δm^2=1.3 eV^2, $\sin^2 2\theta$=0.016: $\Delta\chi^2$=-8.6 (2.5σ in Feldman-Cousins analysis)

  Δm^2=0.35 eV^2, $\sin^2 2\theta$=0.06: $\Delta\chi^2$=-8.4

  This is not statistically significant (2.5σ) to claim an indication of sterile neutrino.
- We use relative counts at top and bottom positions to search for large extra dimensions (LED). A large exclusion region set covering a very interesting part of LED parameters space, preferred by gallium and reactor anomalies. DANSS best points:

  Normal ordering: a=0.335 μm, m_0=0.034 eV (2.0σ)

  Inverted ordering: a=0.180 μm, m_0=0.017 eV (1.8σ)

  The statistical significance is low => no evidence of LED oscillations. GA best point is excluded with significance more than 5σ and RAA best point is excluded at the level of 4.2σ.
- DANSS observes antineutrino with energy > 10 MeV: $1797 \pm 169_{stat} \pm 189_{sys}$ (7.1σ).
- Our analysis plans are to finalize the energy calibration and to include larger E_{e+} range in the analysis.
- In parallel to data collection we are working on detector upgrade aimed to reach 12% resolution @ 1 MeV and increase sensitive volume by 70%. We plan to finish operation of the current setup early 2026 and commission DANSS-II in the fall 2026.

Thank you !

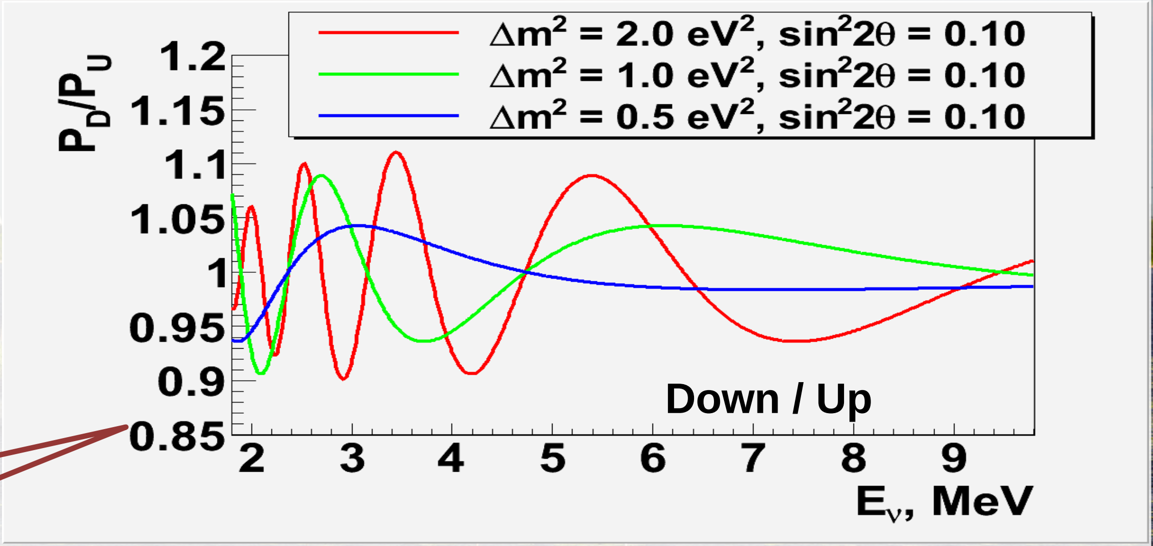
RSF grant https://rscf.ru/en/project/23-12-00085/

In a simple model with the 4th neutrino survival probability of electron antineutrino from the reactor is given by the formula:

$$P_{ee}^{2\nu}(L) = 1 - \sin^2(2\theta_i)\sin^2\left(1.27\frac{\Delta m_i^2[\mathrm{eV}^2]L[\mathrm{m}]}{E_{\bar{\nu}_e}[\mathrm{MeV}]}\right)$$

DANSS: Measure ratio of neutrino spectra at different distance from the reactor core – both spectra are measured in the same experiment with the same detector. No dependence on the theory, absolute detector efficiency or other experiments.

Naïve ratio without smearing by reactor and detector sizes and the resolution



Inverse Beta-Decay (IBD)

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

H. Bethe and R. Peierls 1934.
F. Reines and C. L. Cowan 1953-56

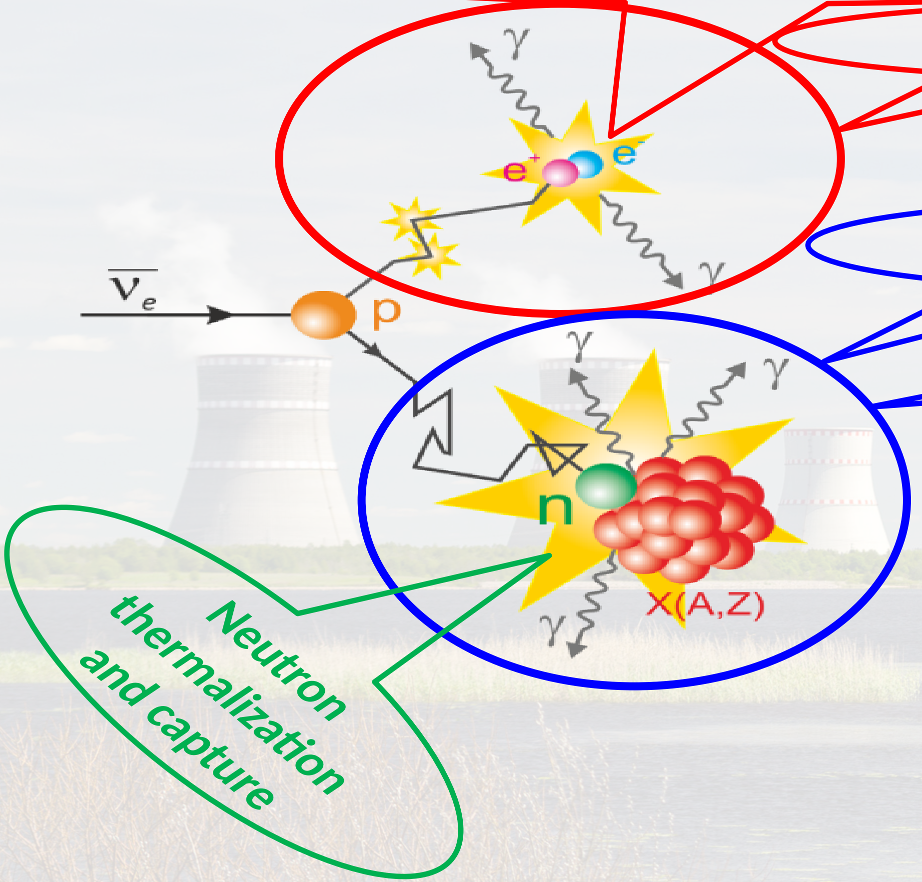
Continuous ionization cluster

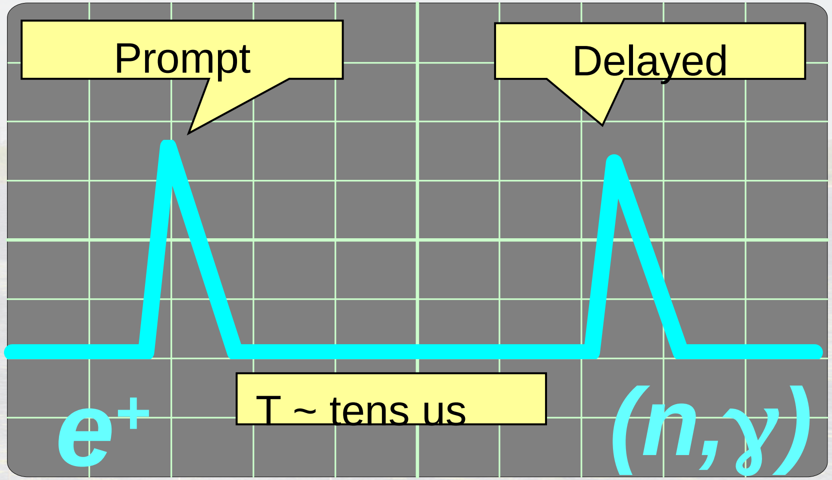
Fast (prompt) signal

$E_e \approx E_\nu$ – 1806 MeV

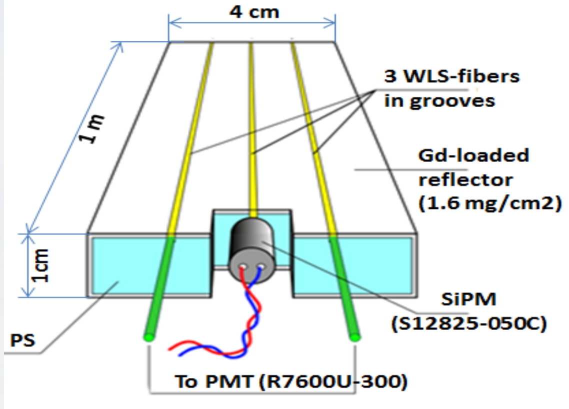
Delayed signal

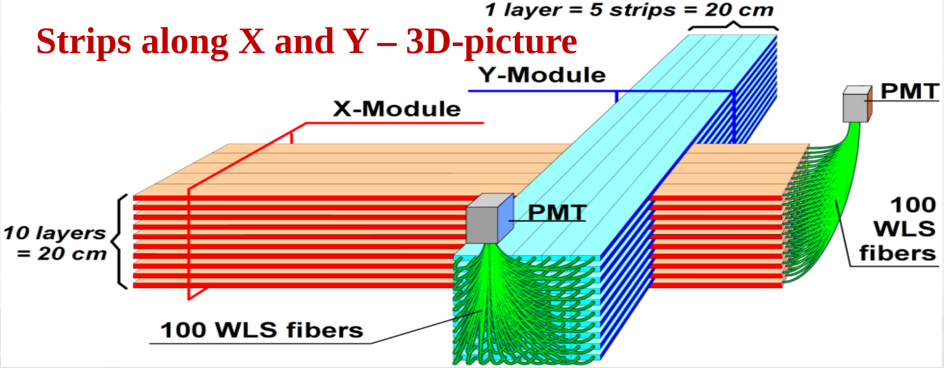
Gamma flush in the whole detector

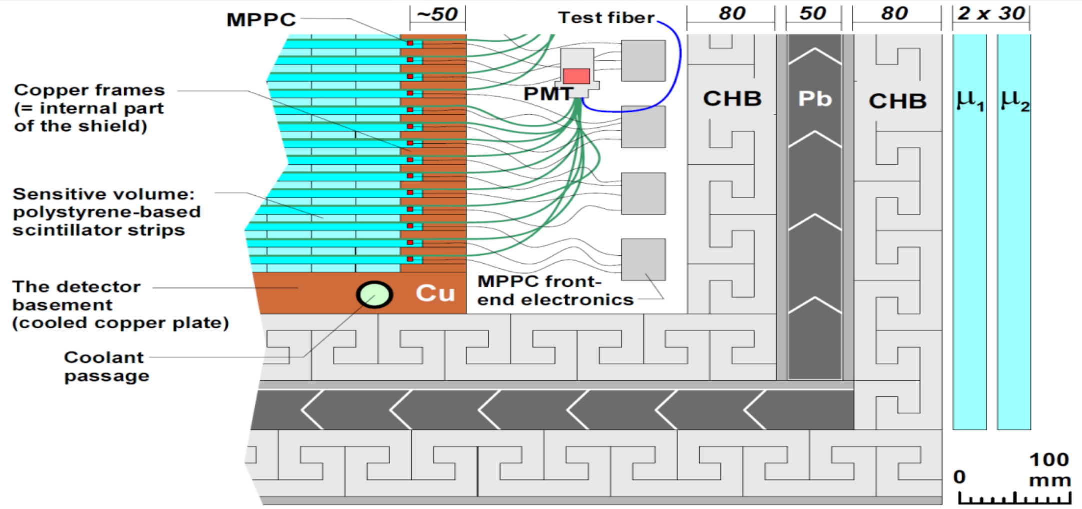




Detector of the reactor AntiNeutrino based on Solid-state Scintillator





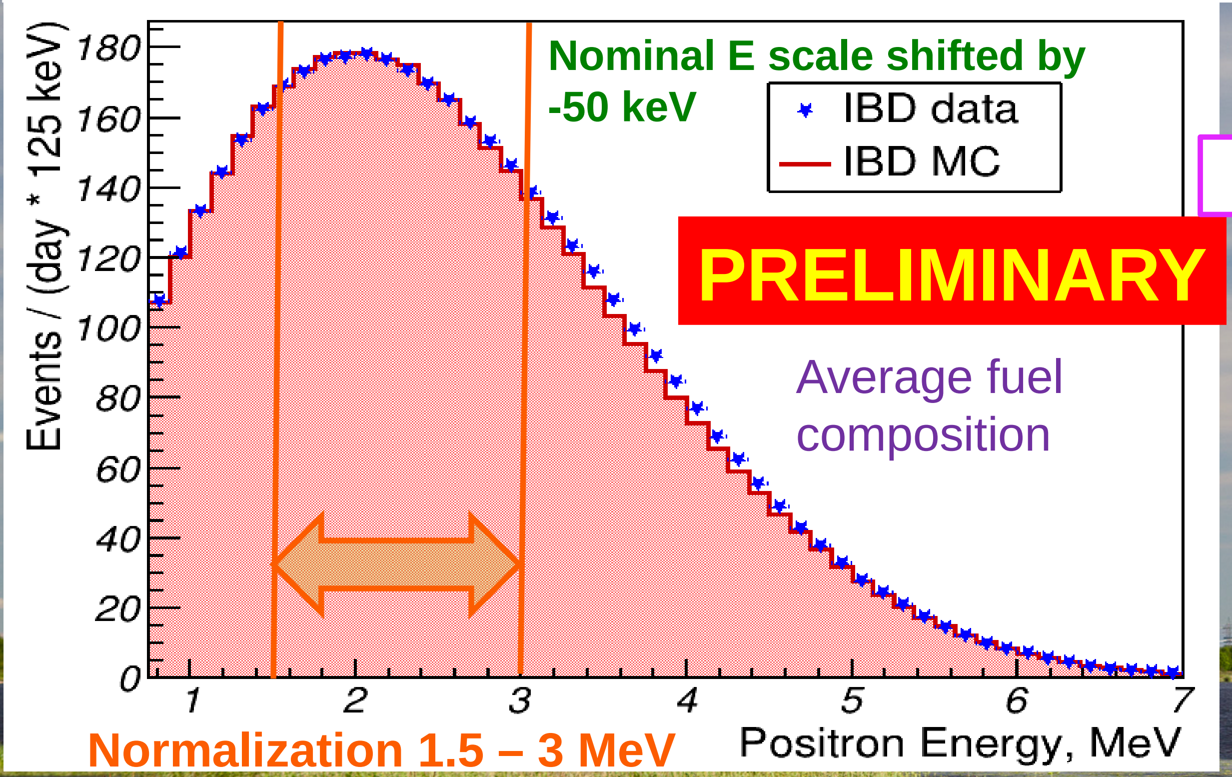


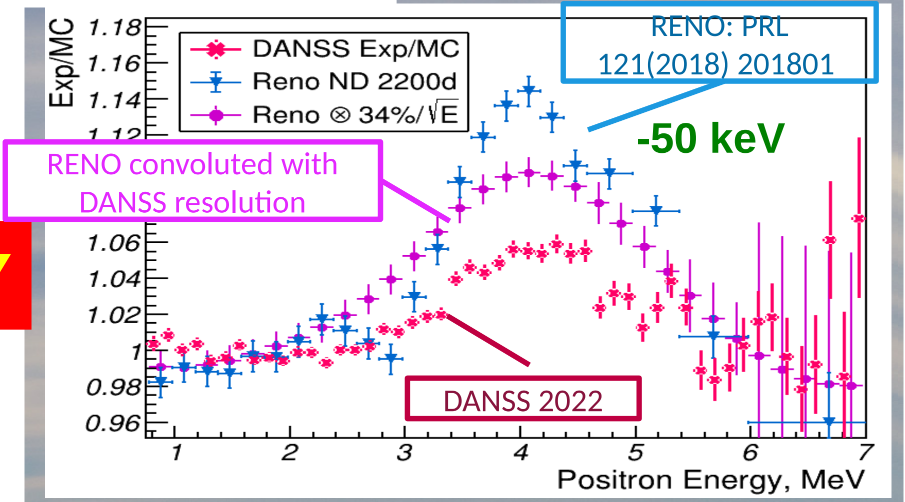
- Multilayer closed passive shielding: electrolytic copper frame ~5 cm, borated polyethylene 8 cm, lead 5 cm, borated polyethylene 8 cm
- 2-layer active μ-veto on 5 sides
- Dedicated WFD-based DAQ system
- Total 46 64-channel 125 MHz 12 bit Waveform Digitisers (WFD)
- System trigger on certain energy deposit in the whole detector (PMT based) or μ-veto signal
- Individual channel selftrigger on SiPM noise (with decimation)

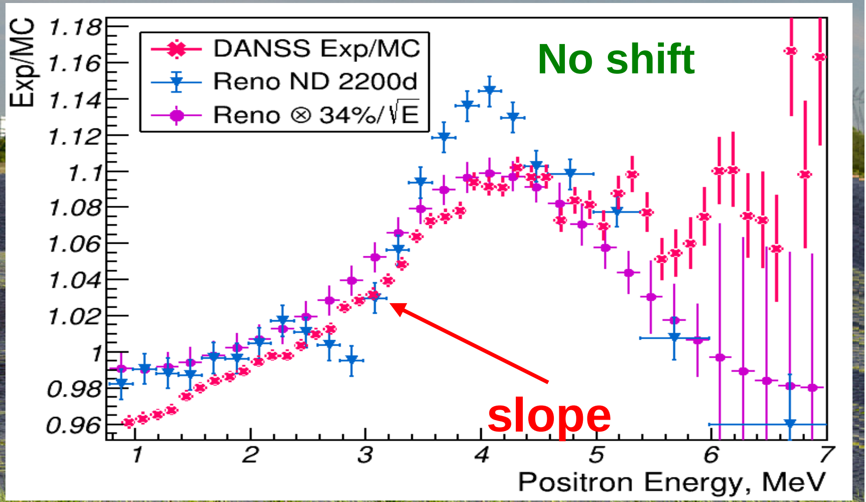
- Scintillation strips 10x40x100 mm³ with Gd-dopped coating (0.35%wt)
- Double PMT (groups of 50) and SiPM (individual) readout
- SiPM: 18.9 p.e./MeV & 0.37 X-talk
- PMT: 15.3 p.e./MeV
- 2500 strips = 1 m³ of sensitive volume

JINST 11 (2016) no.11, P11011

Positron spectrum comparison to H-M model







- New energy calibration
- Strong dependence on energy shift and scale
- Effect (if does exist) looks twice smaller than expected from other measurements

χ^2_{rel}

$$\chi^2_{rel} = \min_{\eta} \sum_{bins} \frac{(R^{obs}_{bt} - R^{pre}_{bt}(\Theta, \eta))^2}{\sigma^2}$$

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

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

$\Theta = \{\Delta m^2_{41}, \sin^2 2\theta_{ee}\}$
- sterile neutrino parameter space

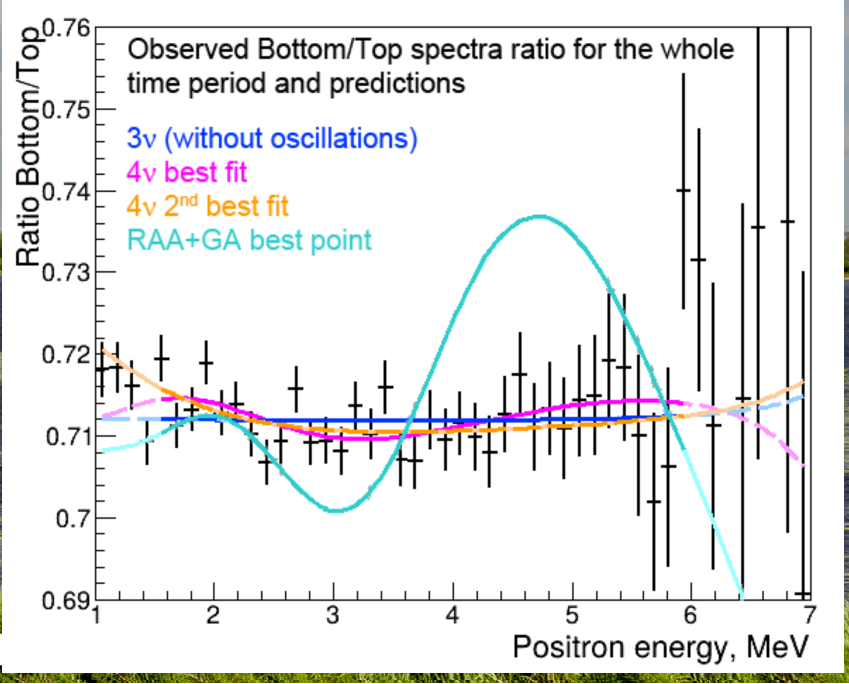
Data taking in two positions
$R_{bt} = Bottom/Top$,

Data taking in three positions
$R_{mbt} = Middle/\sqrt{Bottom \cdot Top}$,
W – covariance matrix,

Penalty terms
$\eta(\eta^0)$ – nuisance parameters (and their nominal values)

1σ values used in the penalty terms (changes with respect to nominal values):

- relative detector efficiencies at different distances (0.4%)
- distance to the fuel burning profile center (5 cm)
- correlated backgrounds (35%)
- additional smearing in energy resolution $(6\%/\sqrt{E} \oplus 2\%)$
- energy scale (2%)
- energy shift (50 keV)



LED

- Neutrino oscillations (case of n=1, other are much smaller if exist)
  - Right neutrinos ν_R (and $\bar{\nu}_L$) being $SU(2)$ singlets can oscillate to LED.
  - An amplitude for survival probability for $\bar{\nu}_{ee}$ is given by

$$A_i \approx \left(1 - \frac{\pi^2}{6} m_i^2 a^2\right) \exp\left(i \frac{m_i^2 L}{2E}\right) + 2 m_i^2 a^2 \exp\left(i \frac{m_i^2 L}{E}\right) \sum_{n=0}^{\infty} \frac{\exp\left(i \frac{n^2 L}{2ea^2}\right)}{n^2}, a m_i \ll 1$$

where m_i is a mass of i-th neutrino state and $\frac{n}{a} = m_n^{KK}$ - mass of n-th Kaluza-Klein state [1]

$$\bar{S}_{MC} = \sum_{L\,(r_d, r_r)} \left(\left| Amplitude\left(\frac{E_{\bar{\nu}}}{L}, a, m_0\right) \right|^2 \cdot profile(r_r) \cdot spectra(E_{\bar{\nu}}) \cdot \frac{1}{L^2} \right) @M_{response}$$

Oscillations to LED — Distribution of fission points — $\bar{\nu}$ energy spectrum — Geometric flux attenuation — Modelled matrix of detector's response

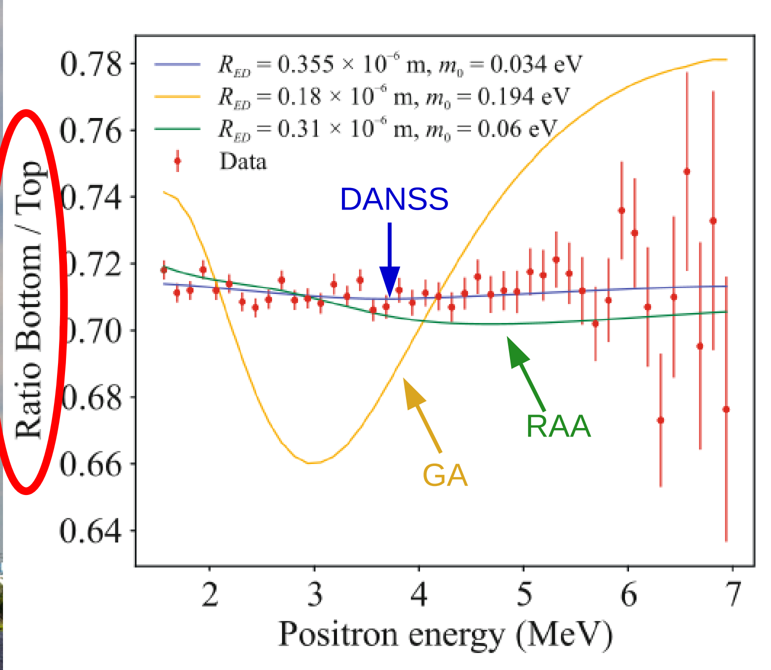
Test statistics

$$\chi^2 = \sum_{bins} \frac{(R_i^{MC}(\eta) - R_i^{Data})^2}{\sigma_i^2} + \sum_{syst} \frac{(\eta - \eta_0)^2}{\sigma_\eta^2}$$

- R – ratio of spectra in Bottom and Top position
- σ – experimental error
- η – systematic parameter:

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

Best fit points (NO)



- P.A.N. Machado et al., PRD 85, 073012 (2012)
- D.V. Forero et al., PRD 106, 035027 (2022)

High energy antineutrinos

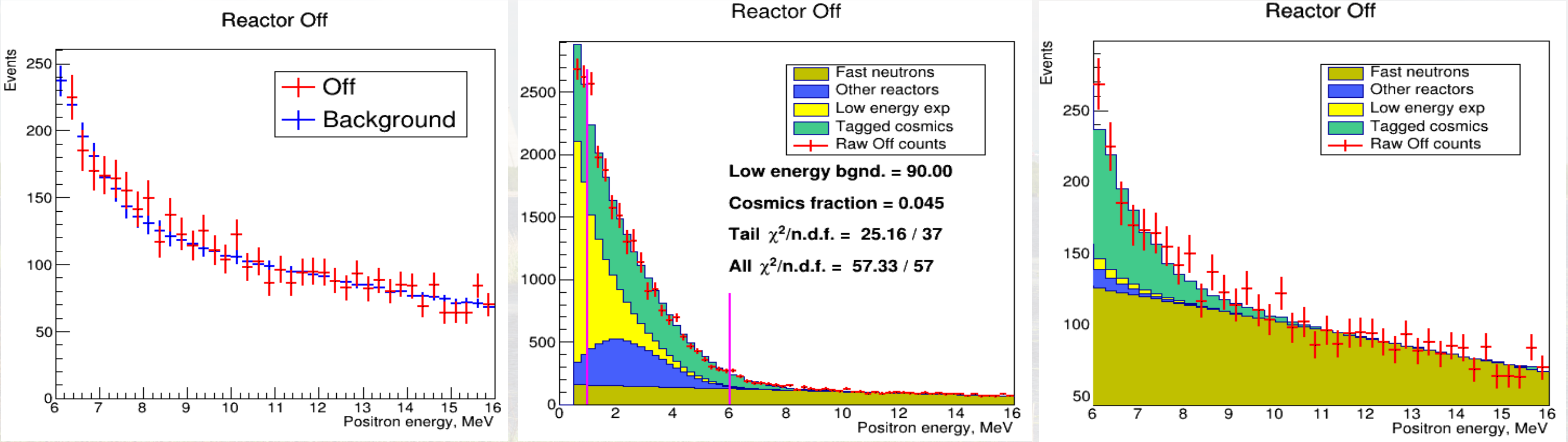
Reactor off background subtraction

Fast neutron background is a line extrapolation from 11-16 MeV.

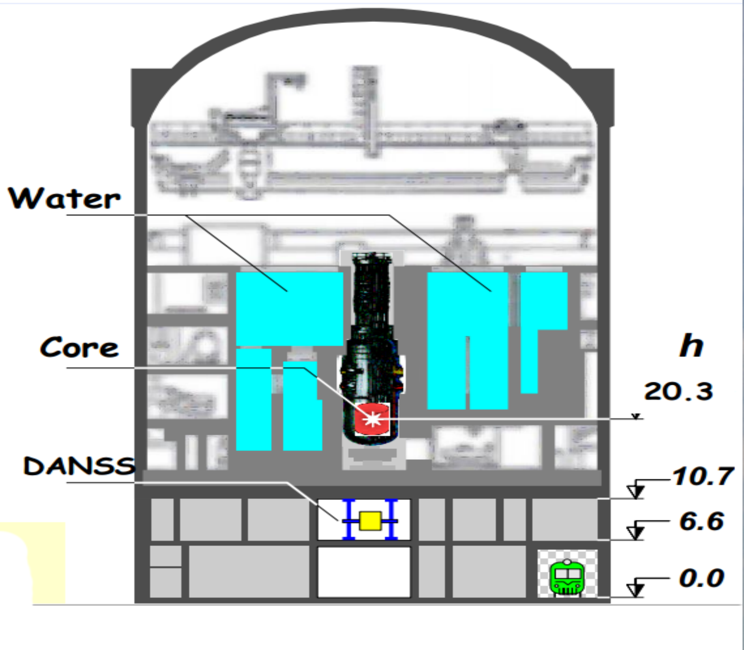
Neutrinos from the adjacent reactors — 0.6 % of the top position counts at reactor on.

Background from VETO inefficiency (missed muons) is from and approximation of reactor off spectrum above 6 MeV by scaling spectrum from tagged muon background events.

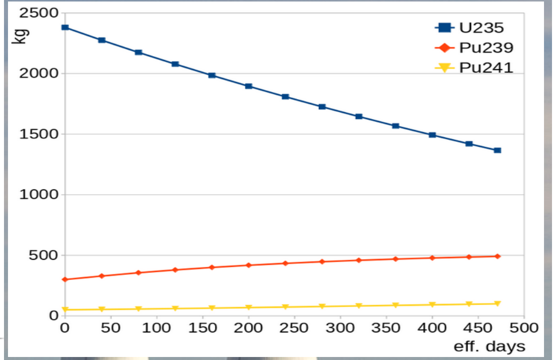
The residual background at low energies is apprximized by the function $e^{-(E/1.0\ \text{МэВ})}$. The contribution is optimized using reactor off data. It is small at high energies.



Reactor WWER-1000: 3.1GW$_{th}$

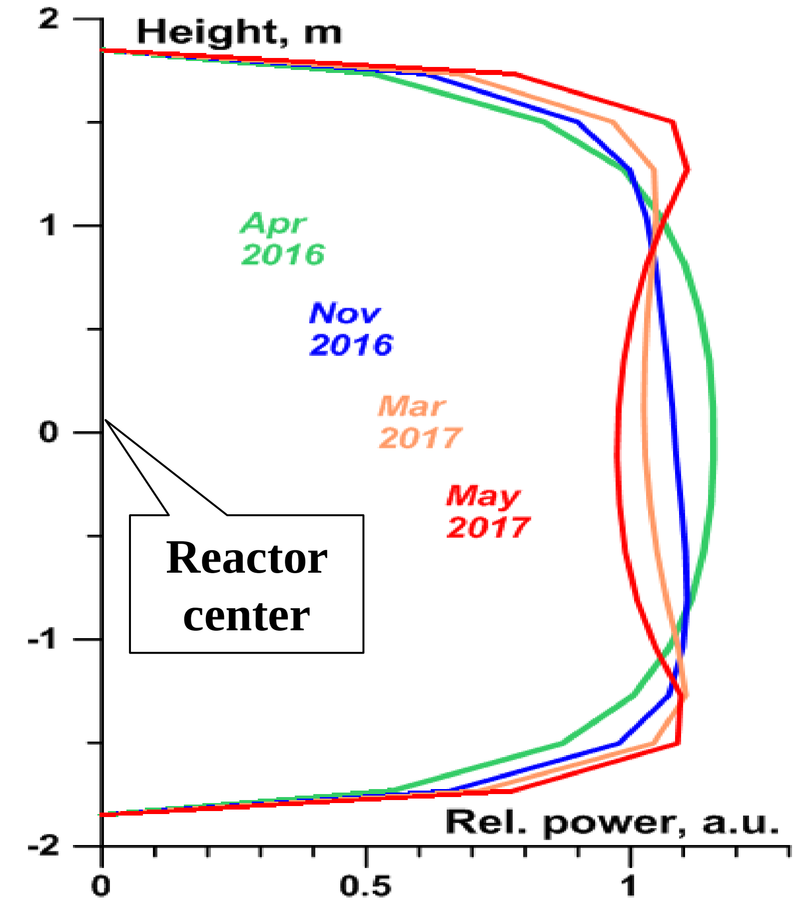


Main fuel nuclei



+70 t ^{238}U

Reactor vertical burning profile for 100% power during the campaign 4



Fission fractions

	Begin 4	End 4	Begin 5	End 5	Begin 6	End 6	Begin 7
^{235}U	63.5%	44.1%	65.8%	43.9%	66.3%	45.6%	68.7%
^{238}U	6.7%	7.8%	6.9%	7.8%	6.5%	7.3%	6.7%
^{239}Pu	26.7%	39.3%	24.9%	39.4%	24.8%	38.6%	22.8
^{241}Pu	2.7%	8.6%	2.2%	8.6%	2.3%	8.6%	1.7%