Vietnam Flavour Physics Conference 2022

Recent results and plans for the future of the DANSS experiment

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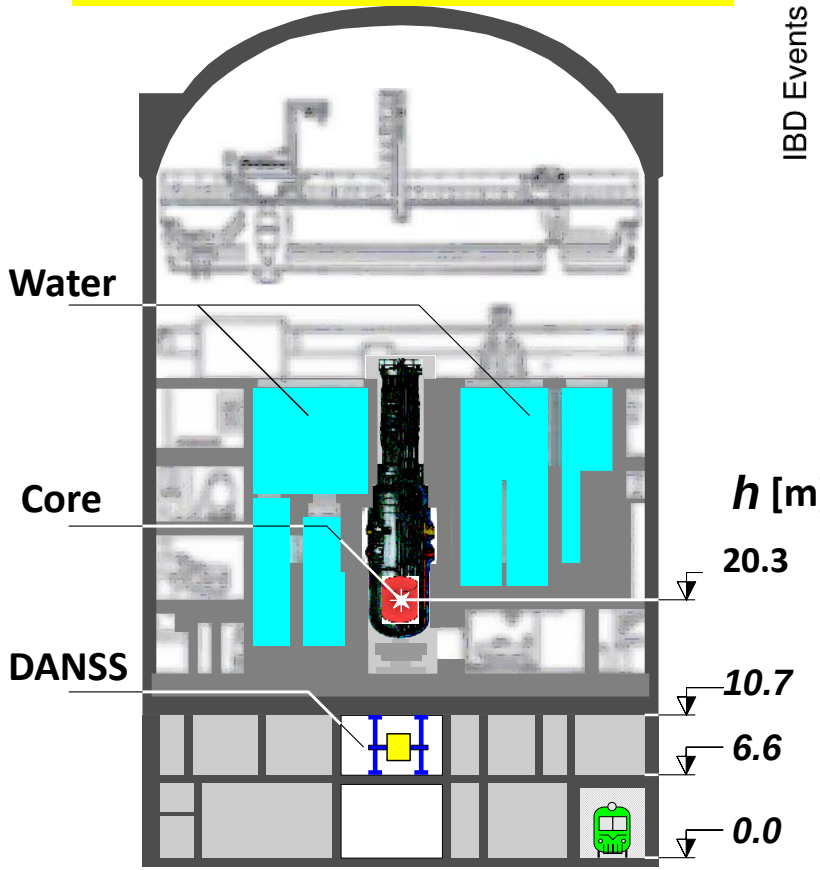
Reasons to search for sterile neutrino with $\Delta m^2 \sim 1\ \mathrm{eV}^2$

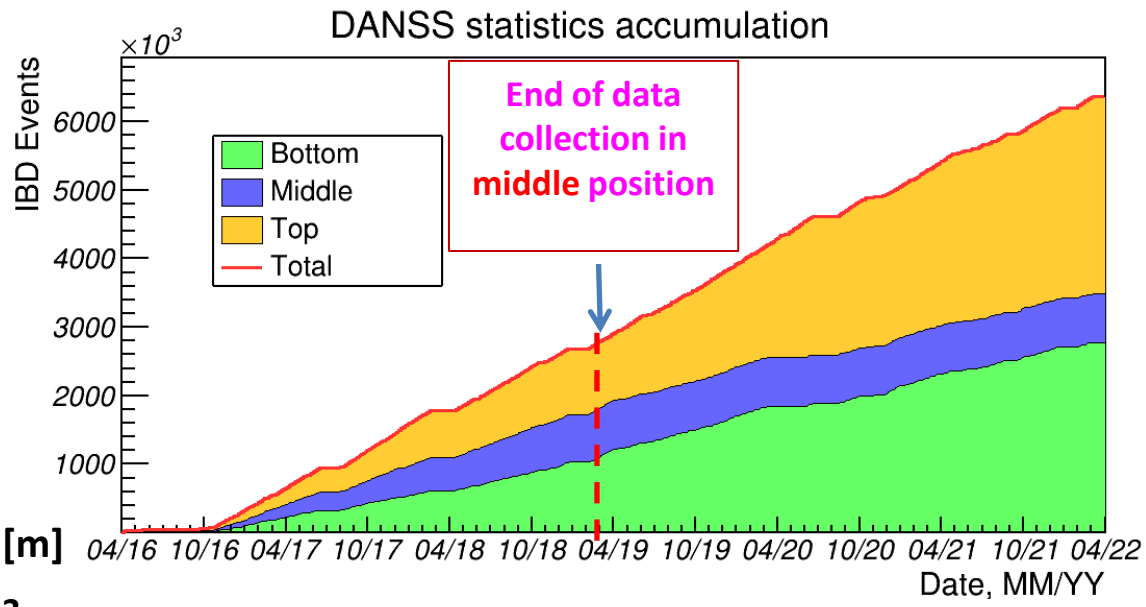
- Gallium anomaly (GA) – deficit of ν_e in Ga experim.
- Experiments: SAGE, GALLEX and BEST.
- Reactor antineutrino anomaly (RAA) - $\bar{\nu}_e$ deficit from reactors. Experiments: KI, DayaBay and RENO.
- Appearance of ν_e in ν_μ beams.
- Experiments: LSND and MiniBoone.
- Neutrino-4 claim of sterile neutrino observation.

3+1ν model: $P_{\nu_\alpha \to \nu_\beta} \simeq \sin^2 2\theta_{\alpha\beta} \sin^2\left(\frac{\Delta m^2_{14} L}{4E}\right)$;

DANSS experiment

Detector arrangement:





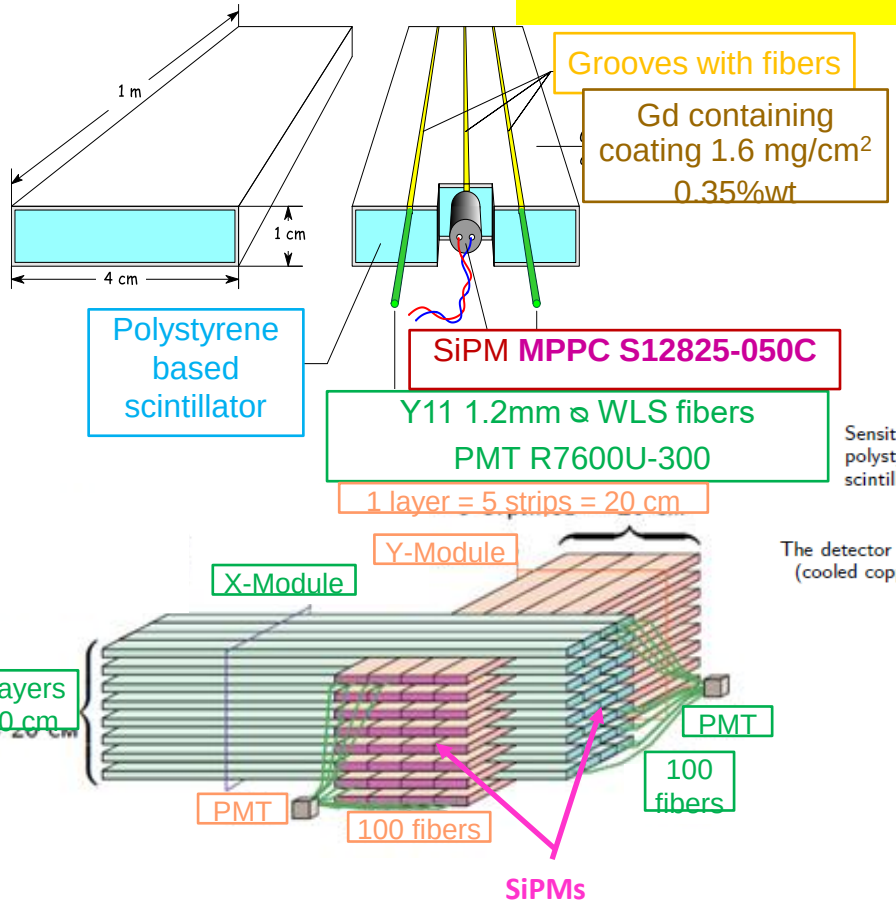
Total statistics accumulated is 6M IBD-events in 6 years and 4 reactor off periods

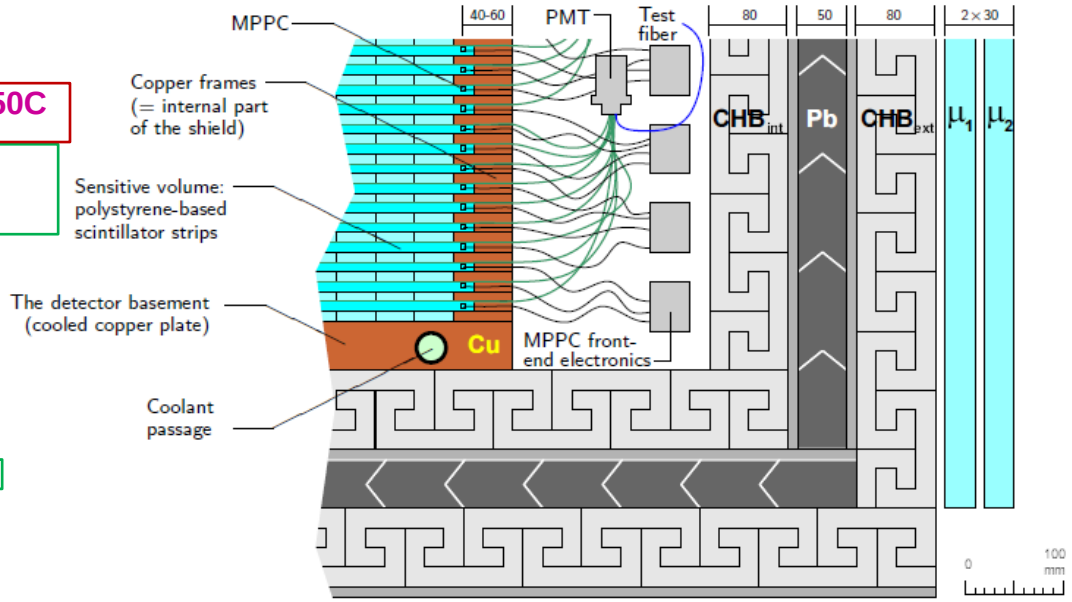
IBD reaction: $\tilde{\nu}_e + p \rightarrow n + e^+$

DANSS is installed on a movable platform under 3.1 GW WWER-1000 reactor (Core: h=3.7m, ∅=3.1m) at Kalinin NPP.
Detector distance from reactor core 10.9-12.9m (center to center) is changed 2-3 times a week

DANSS Detector design

JINST 11(2016)no11,P11011

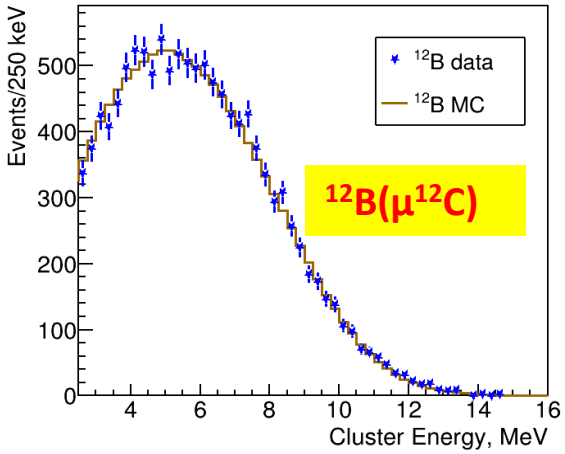


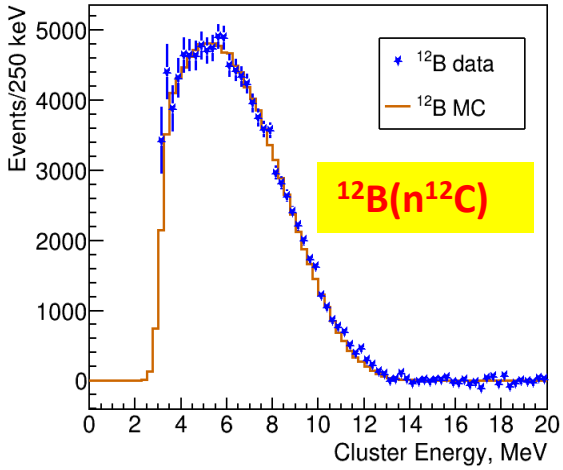


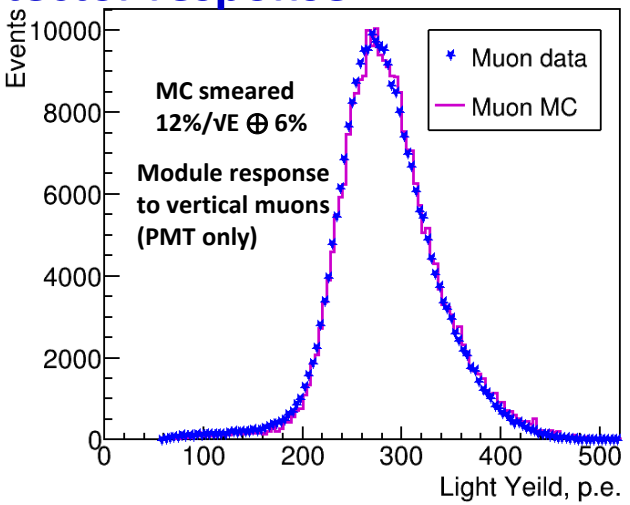
- **2500 scintillator strips with Gd containing coating for neutron capture**
- **Light collection with 3 WLS fibers**
- **Central fiber read out with individual SiPM**
- **Side fibers from 50 strips make a bunch of 100 on a PMT cathode = Module**
- **Two-coordinate detector with fine segmentation – spatial information**
- **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**

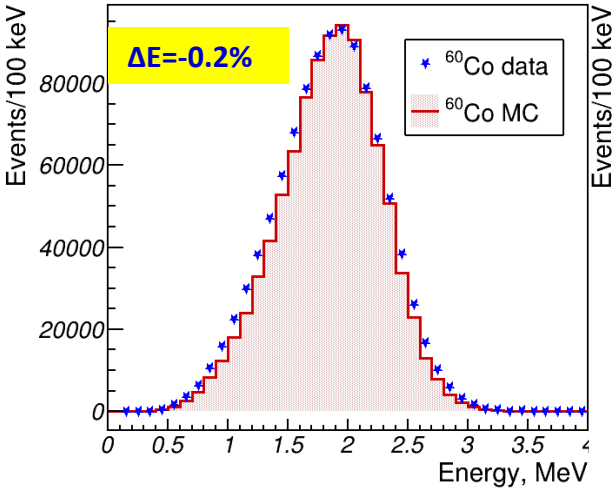
Calibration

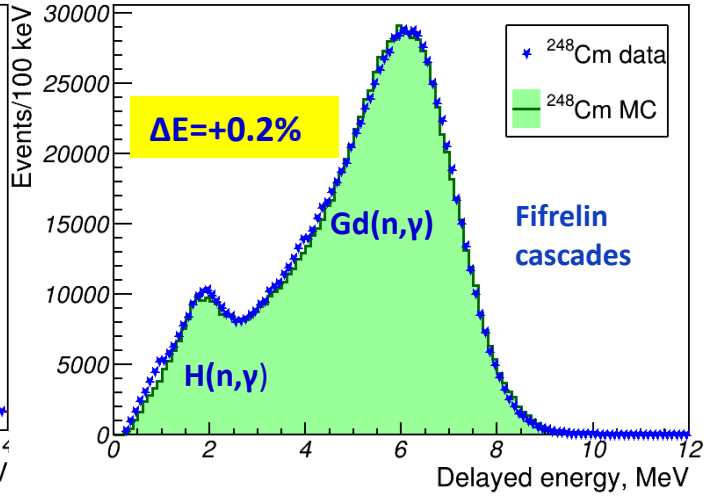
2500 SiPM gains and X-talks are calibrated every 30-40 min.
All 2550 channels are calibrated every 2 days using cosmic muons
Several calibration sources are used to check the detector response

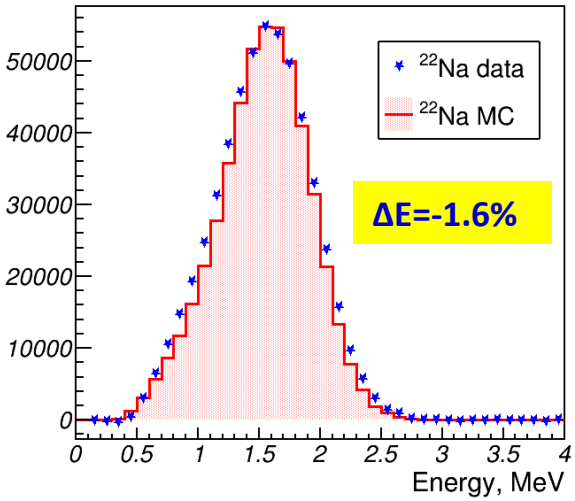












Systematic error on E scale of +/-2% was added due to ^{22}Na disagreement

Test statistics

$$\chi^2 = \min_{\eta,k} \sum_{i=1}^{N} \begin{pmatrix} Z_{1i} & Z_{2i} \end{pmatrix} \cdot W^{-1} \cdot \begin{pmatrix} Z_{1i} \\ Z_{2i} \end{pmatrix} + \sum_{i=1}^{N} \frac{Z_{1i}^2}{\sigma_{1i}^2} + \sum_{j=1,2} \frac{(k_j - k_j^0)^2}{\sigma_{kj}^2} + \sum_{l} \frac{(\eta_l - \eta_l^0)^2}{\sigma_{\eta l}^2}$$

3 position data — 2 position data — Nuisance parameters (systematics and efficiency)

i – energy bin (36 total) in range 1.5–6 MeV;

$Z_j = R_j^{\text{obs}} - k_j \times R_j^{\text{pre}}(\Delta m^2,\ \sin^2 2\theta,\ \eta)$ for each energy bin,

$R_1 = Bottom/Top, R_2 = Middle/\sqrt{Bottom \cdot Top}$, where

$Top,\ Middle,\ Bottom$ – absolute count rates per day for each detector position,

k – relative efficiency, $k^0=1$ $\eta^0=0$

η – nuisance parameters;

W – covariance matrix;

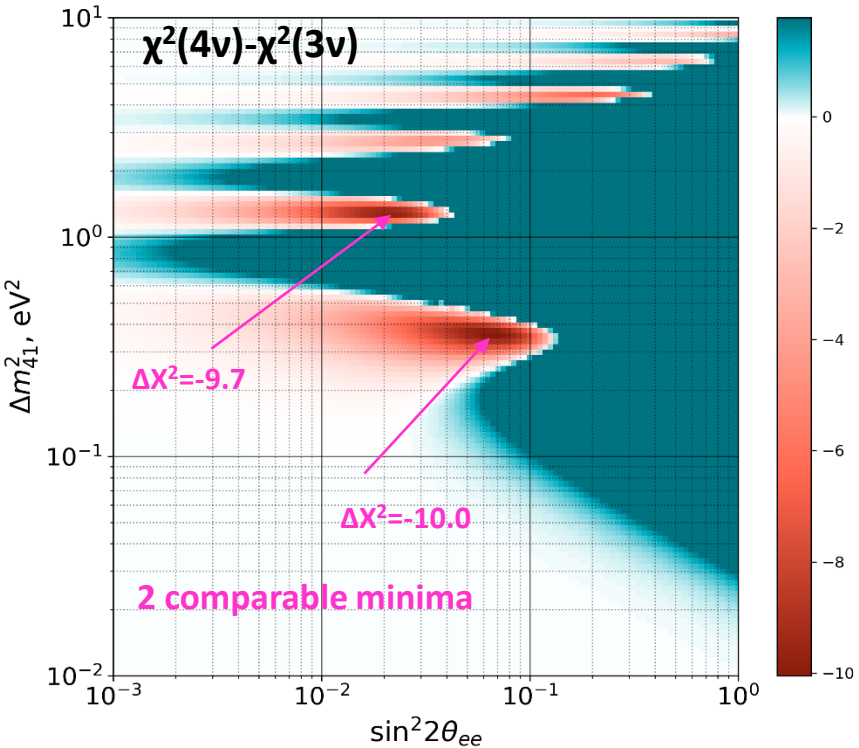
Difference in χ^2 between 4ν and 3ν hypotheses

Red - $\chi^2(4\nu)<\chi^2(3\nu)$,

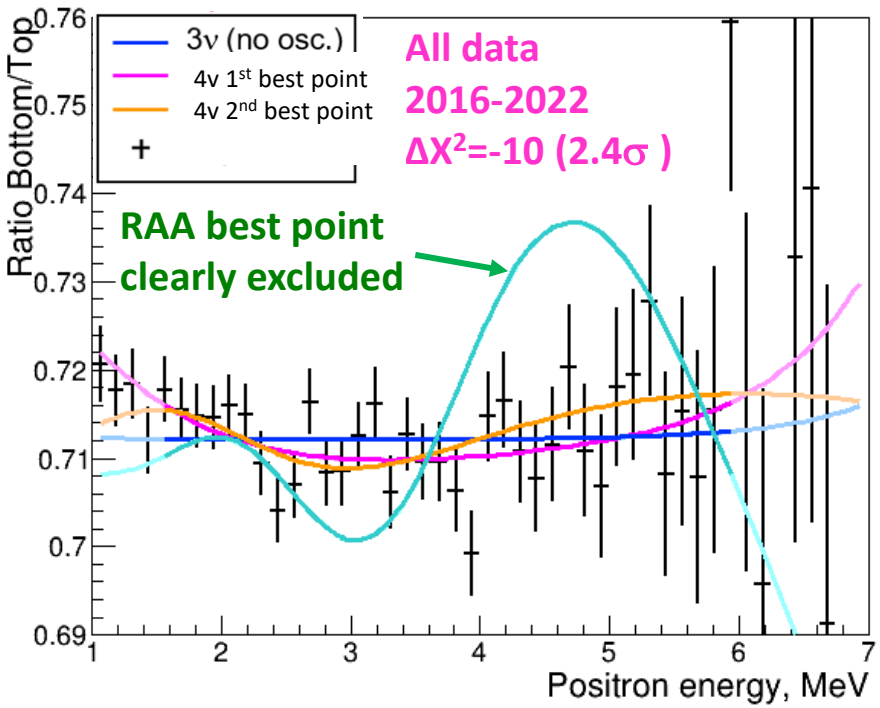
Blue – $\chi^2(4\nu)>\chi^2(3\nu)$,

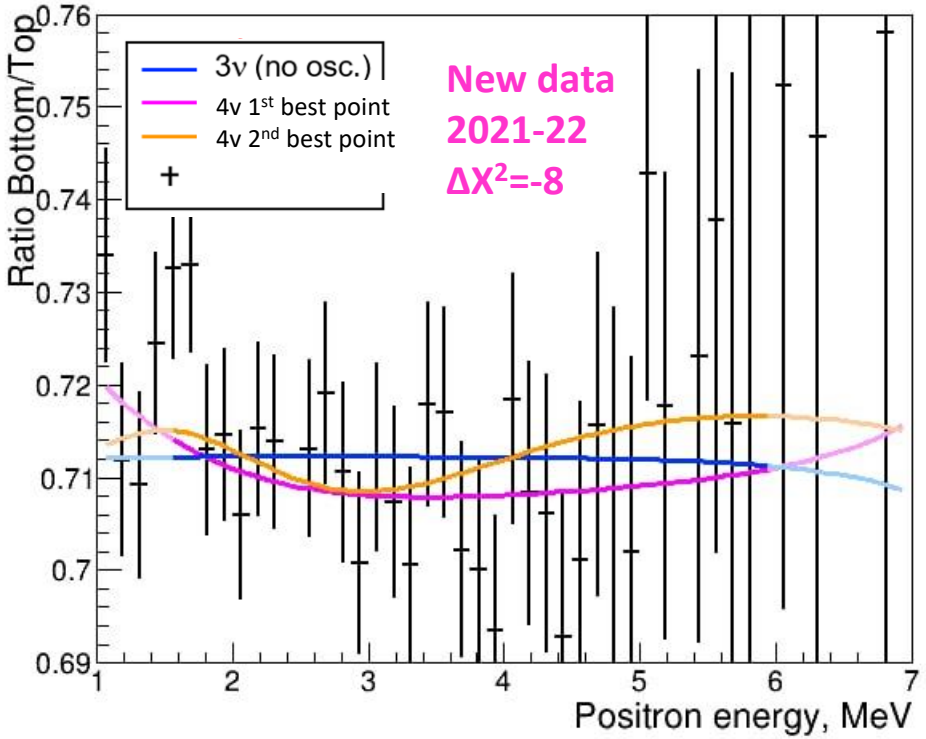
Dark blue region is excluded at 3σ CL in case of χ^2 distribution with 2 DoF $(\chi^2(4\nu)-\chi^2_{min})=11.8$

This assumption is not valid ➔ we use Gaussian CLs method to get limits



Ratio of positron spectra





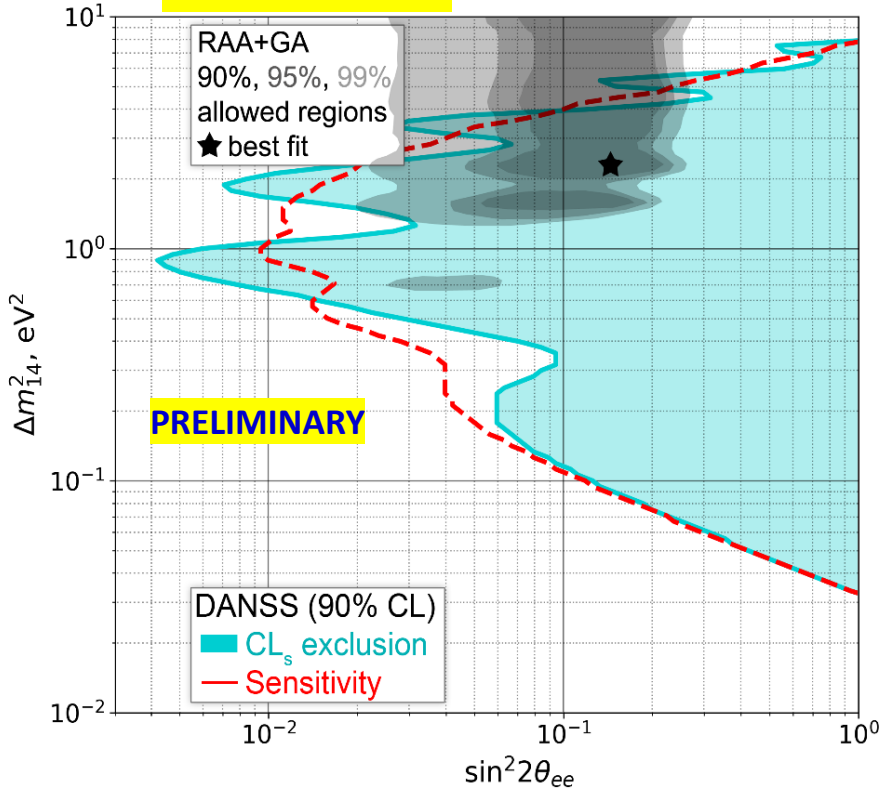
- Fit in 1.5-6 MeV range (to be conservative).
- 2016-2020 data – no statistically significant indication of 4ν(ΔX^2=-5.6, 1.5 σ)
- 2021-2022 data - weak, statistically not significant hint of 4ν (ΔX^2=-8.0, 2.0 σ)
- Using current statistics 2016-2022 (~4.4 million IBD events with 1.5 MeV<E<6MeV) we see statistically not significant hint of 4ν signal:

  ΔX^2=-10 (2.4σ) for 4ν hypothesis best point Δm^2=0.35 eV², $\sin^2 2\theta$=0.067

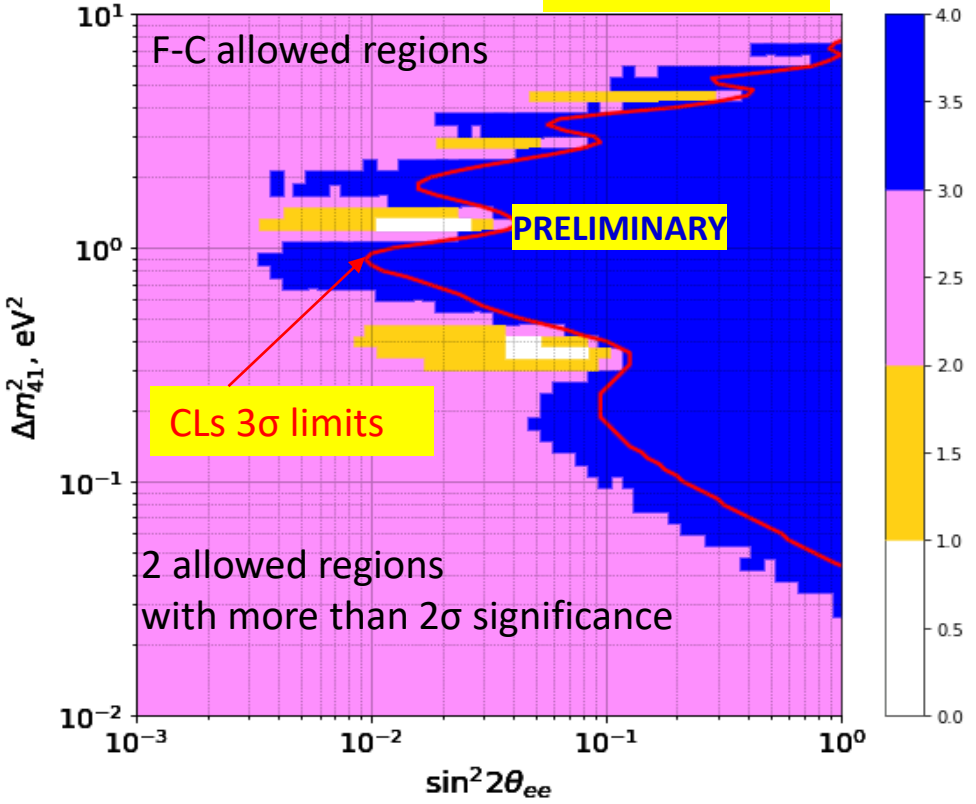
  ΔX^2=-9.7 for 4ν hypothesis second best point Δm^2=1.26 eV², $\sin^2 2\theta$=0.02
- RAA was excluded by DANSS with more than 5σ already in 2018 (Phys. Lett. B, Vol. 787, no.10, p.56-63)

The DANSS results

CLs method



F-C method



Exclusion region was calculated using Gaussian CLs method for E_{e+} in 1.5-6 MeV region

A very interesting part of 4ν parameters is excluded.

The most probable point of RAA is excluded at >5σ confidence level

There are two F-C allowed regions with more than 2σ significance

However even the best one (2.4σ) is not significant enough to claim indication of 4ν

Temperature and barometric effects on cosmic muons

Reasons for:

1. **Muon variations are major background for some dark matter or Sun researches.**
2. **Unique conditions of the detector – thick reactor with water vessels above and only walls from the sides.**

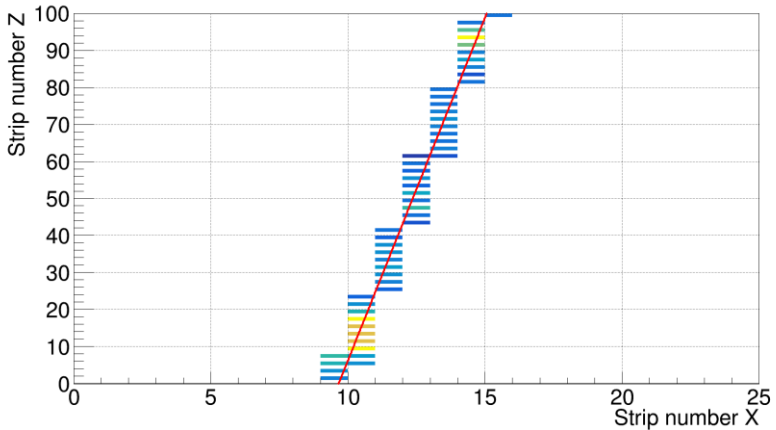
Sum of both effects:

$$\frac{I-\langle I\rangle}{\langle I\rangle} = \alpha\frac{T_{eff}-\langle T_{eff}\rangle}{\langle T_{eff}\rangle} + \beta(P-\langle P\rangle);$$

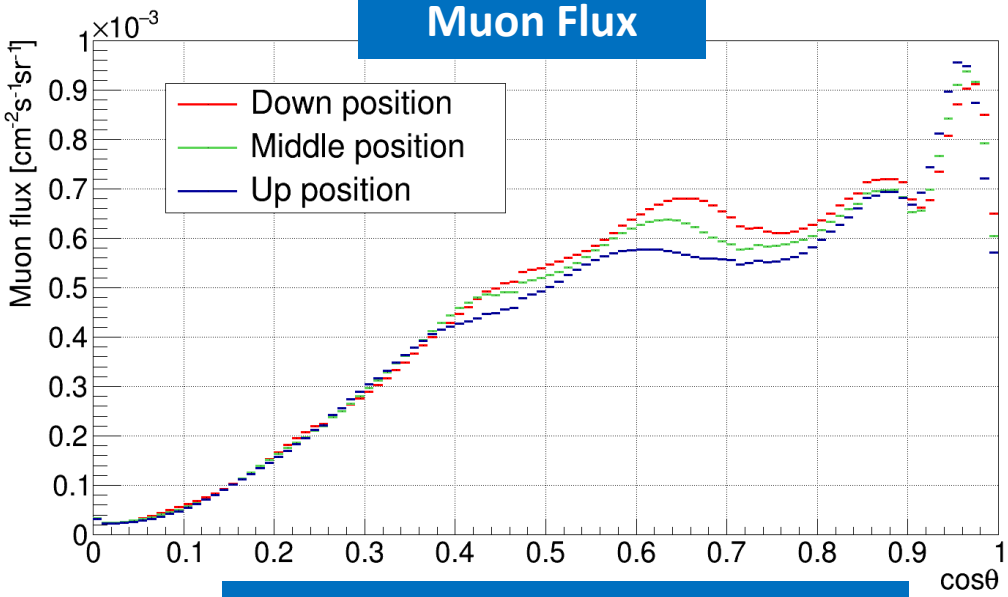
β(<Ethr>) – barometric cor. coefficient

α(<Ethrcosθ>) – temperature cor. coefficient

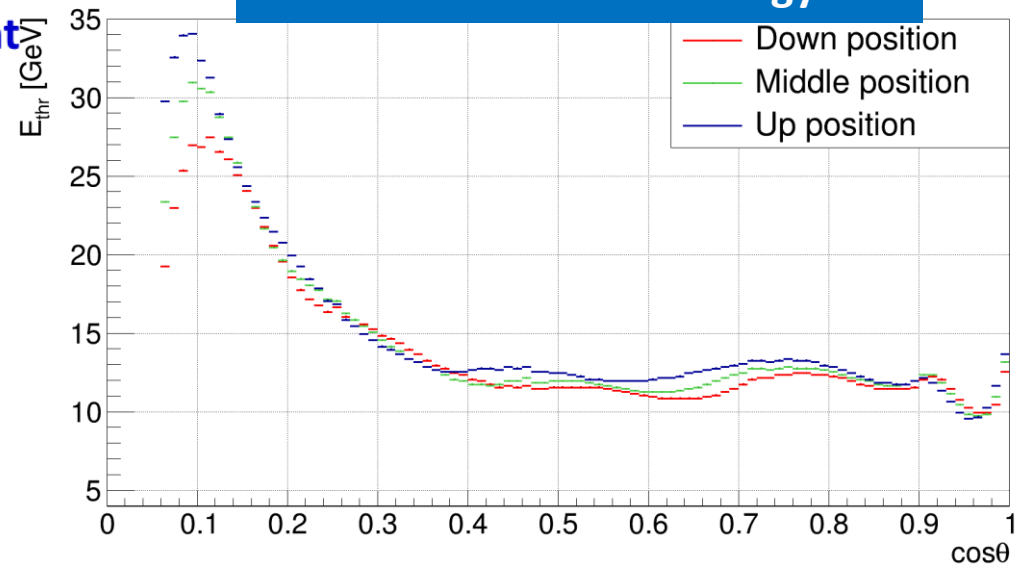
Ethr – muon threshold energy



Muon Flux



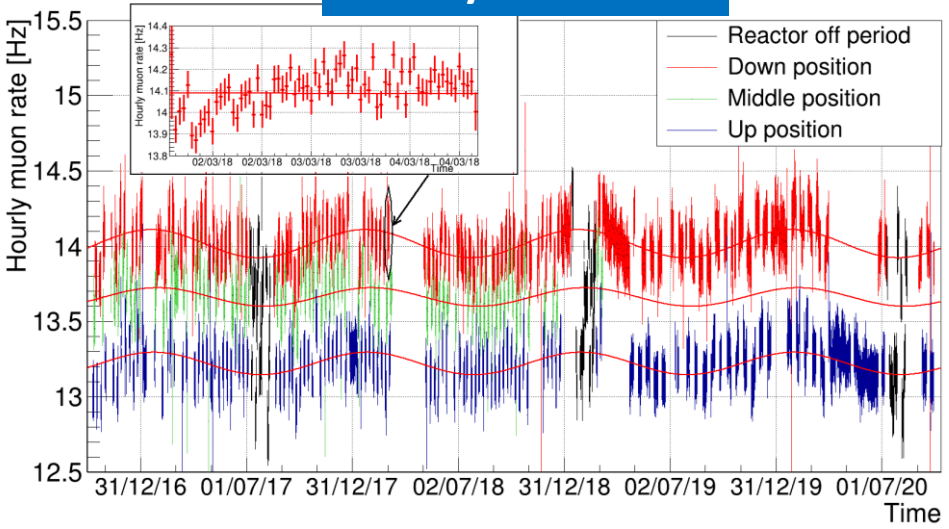
Muon Threshold Energy



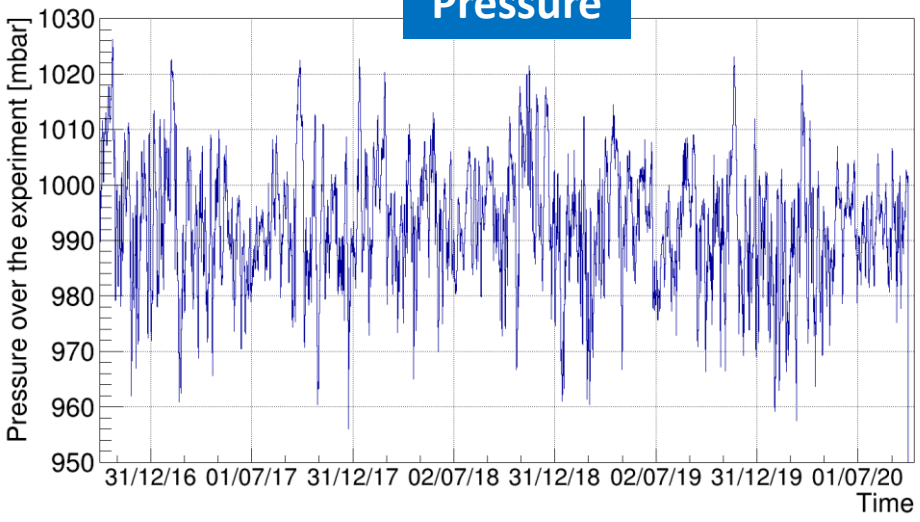
Atmospheric and muon data

- 4 years of muon statistic are used in analysis;
- First time in such researches climate model ERA5 is used;
- Seasonal variations are clearly seen for muon rate and T_{eff}, and are not observed for pressure.

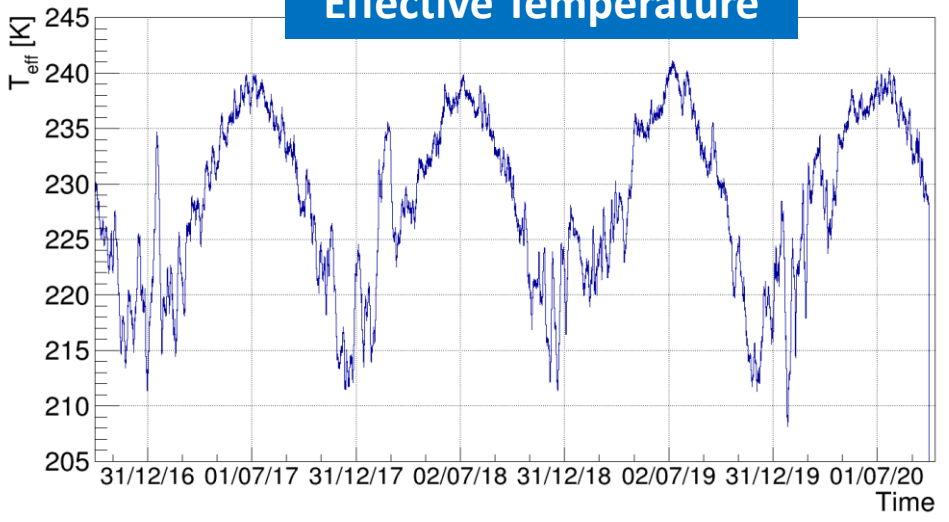
Hourly muon rate



Pressure



Effective Temperature

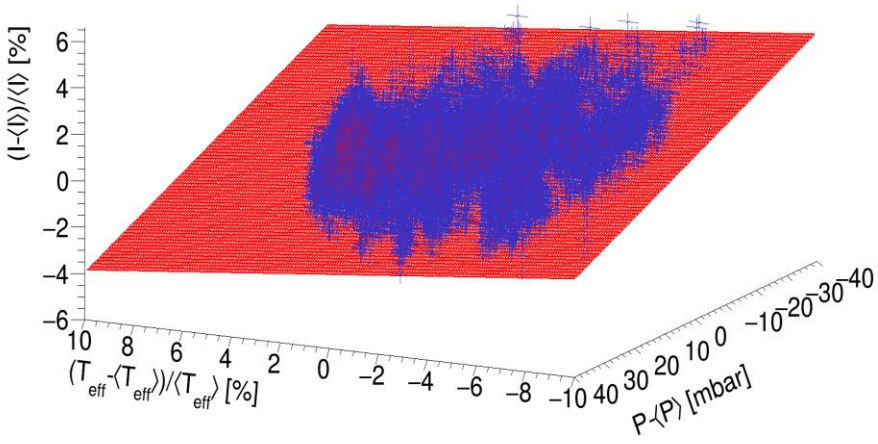


Correlation analysis

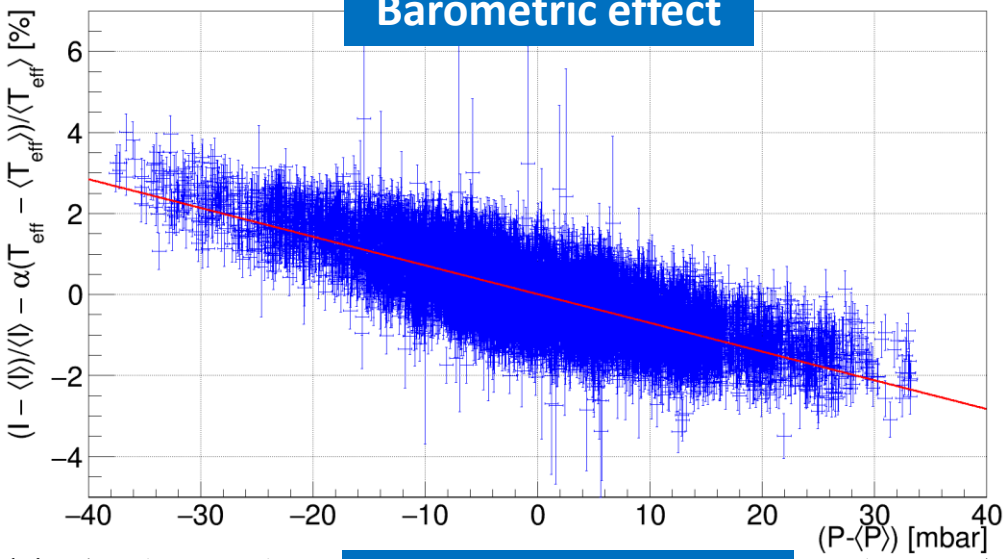
Muon rate dependency on pressure and effective temperature:

$$\frac{I-\langle I\rangle}{\langle I\rangle} = \alpha\frac{T_{eff}-\langle T_{eff}\rangle}{\langle T_{eff}\rangle} + \beta(P-\langle P\rangle);$$

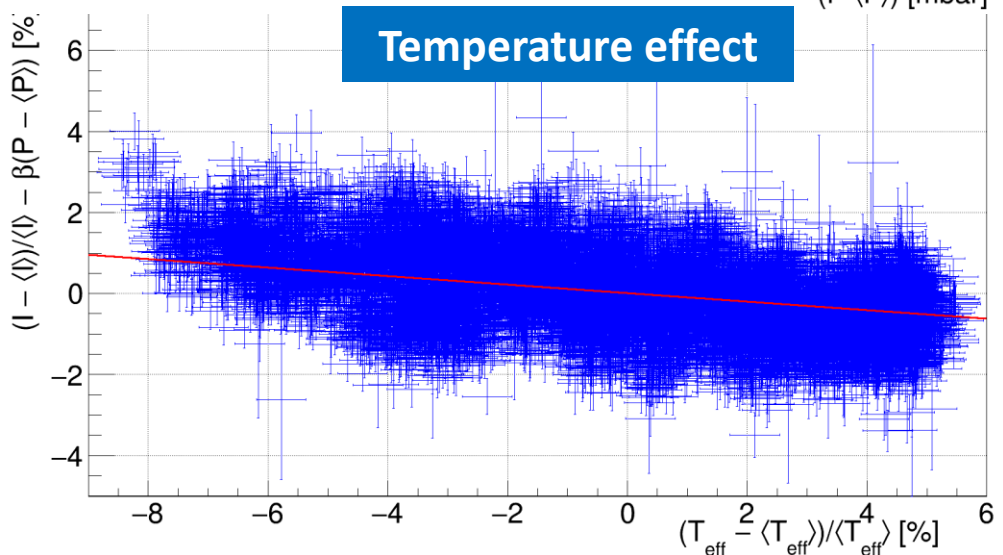
3-dimentional distribution



Barometric effect



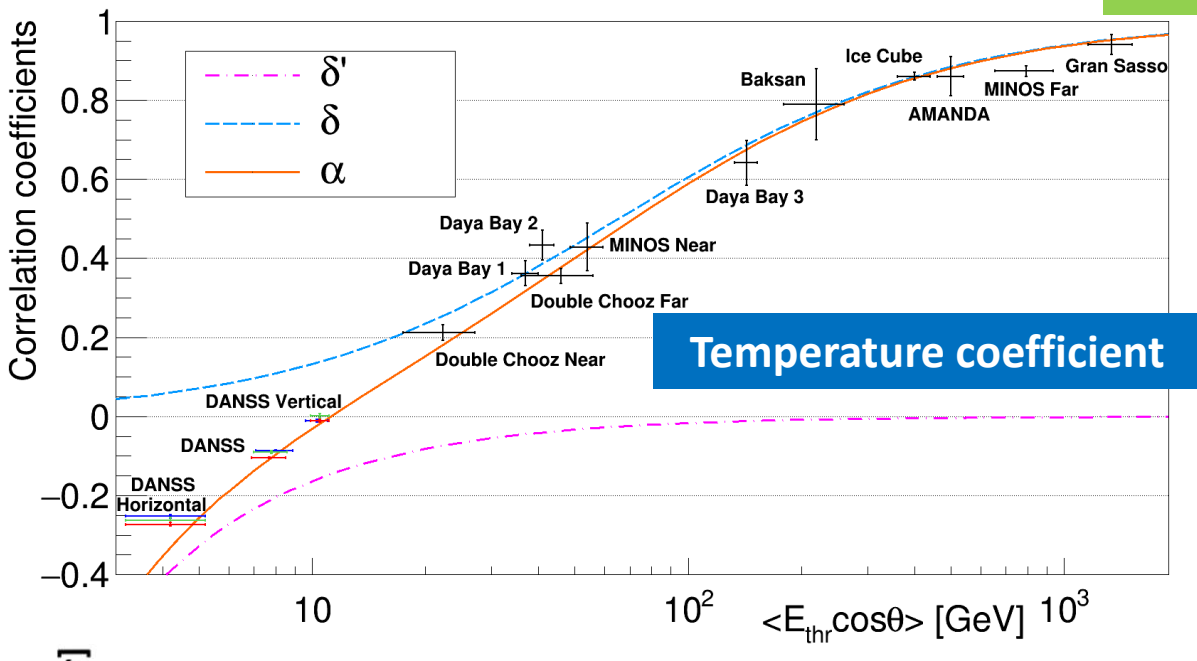
Temperature effect

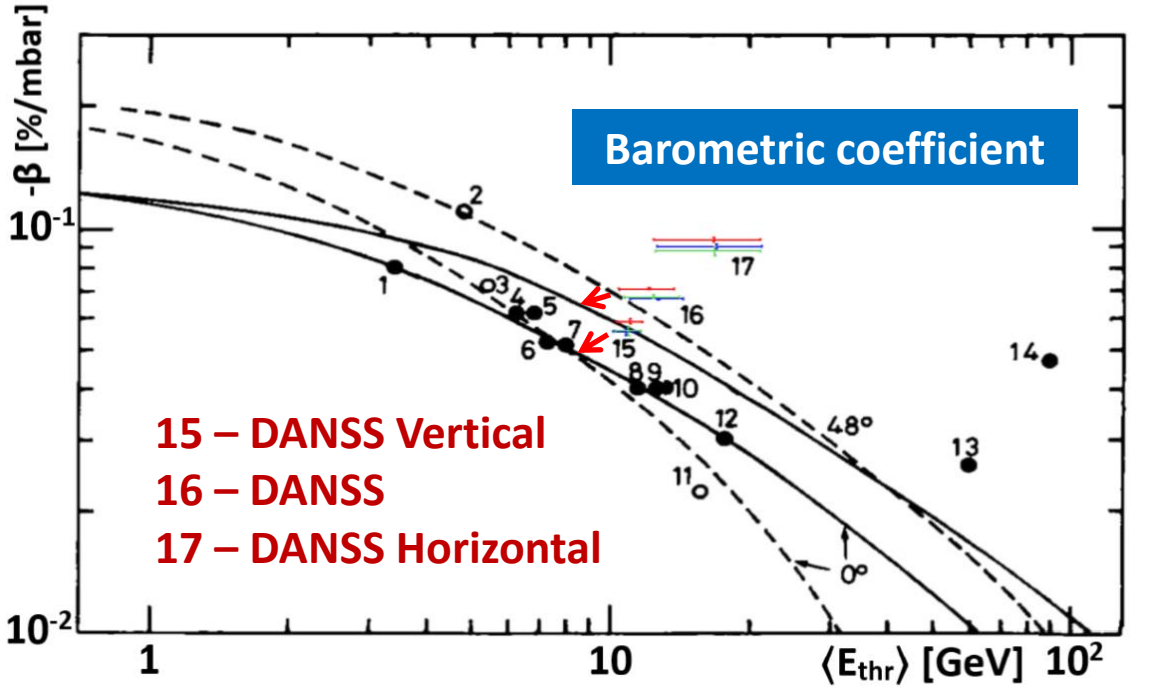


Comparison with theory and other experiments

Eur. Phys. J. C (2022) 82: 515

- 9 values of α and β was calculated – for each detector position, and for each angular area;
- All values of α are in perfect agreement with theory curve;
- β values are ~30% above model predictions!





Plans for the DANSS upgrade

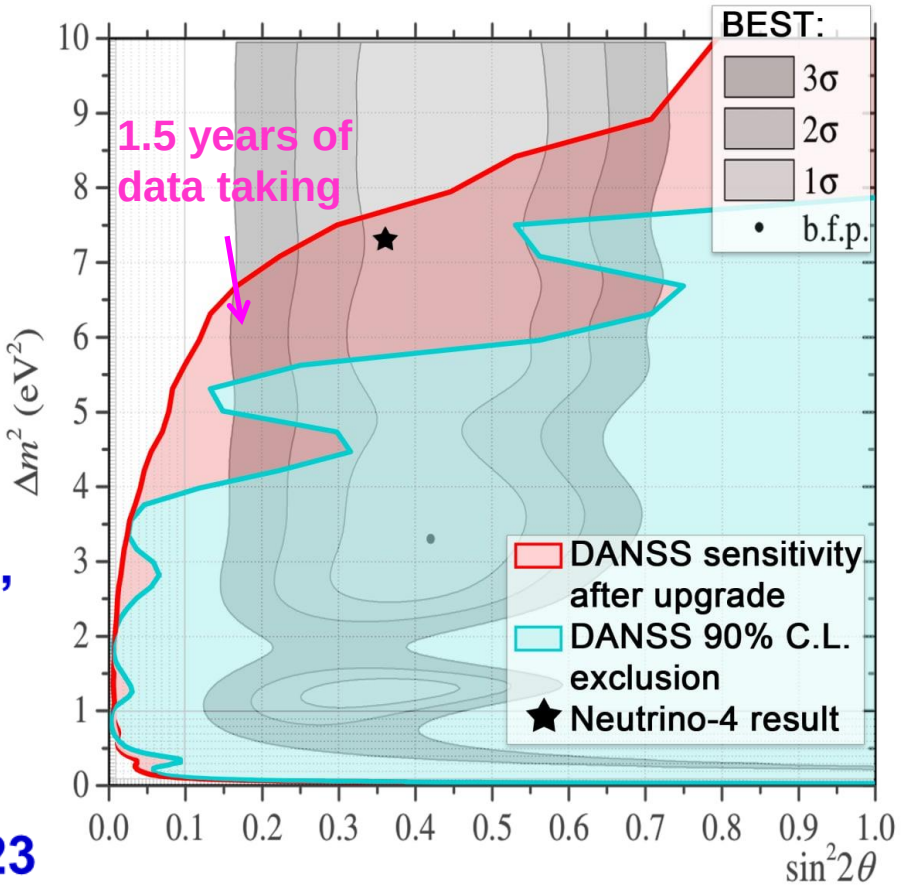
Main goal is to reach energy resolution $12\%/\sqrt{E}$ (now it only $34\%/\sqrt{E}$)

New design:

- Same passive shielding;
- Same lifting system;
- Same digitizing system;
- No PMT readout;
- New strips – 2x5x120 cm,
- with 2-side 4SiPM readout;
- New structure: 60 layers x 24 strips, sensitive volume – 1.7 m^3;
- Gd-contained film between layers;

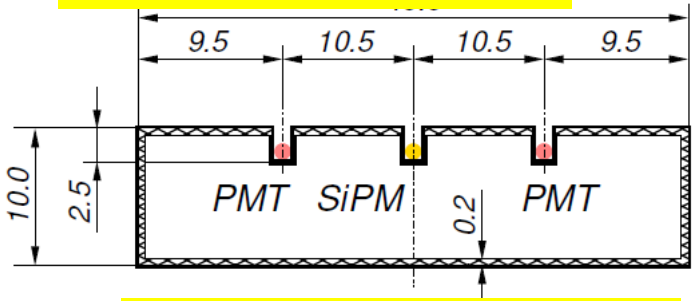
Upgrade planned to be finished in 2023

DANSS sensitivity after the upgrade

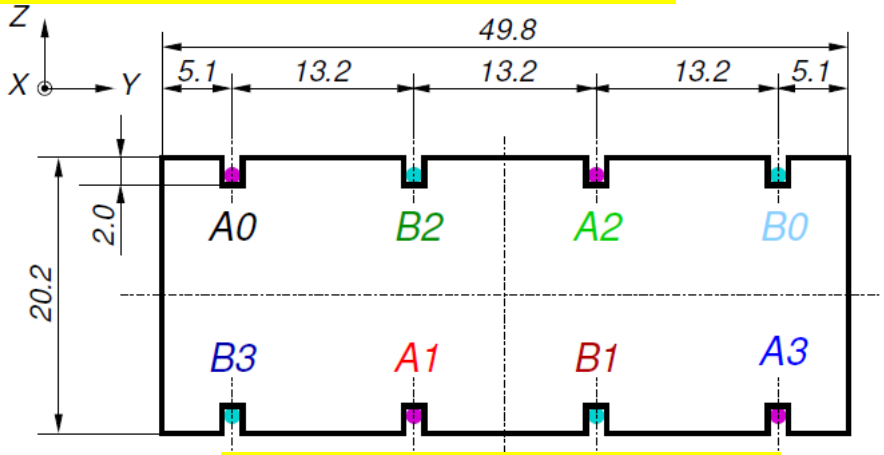


New strip design

JINST 17(2022) P04009



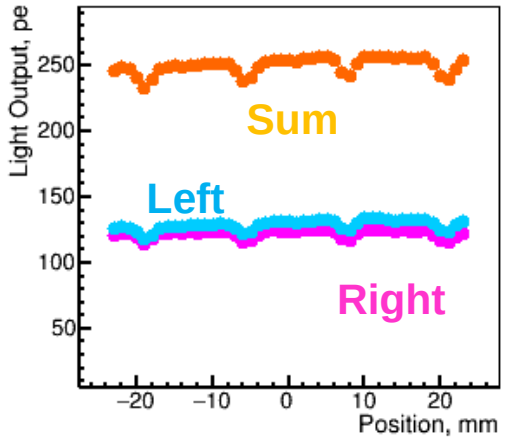
Old strip



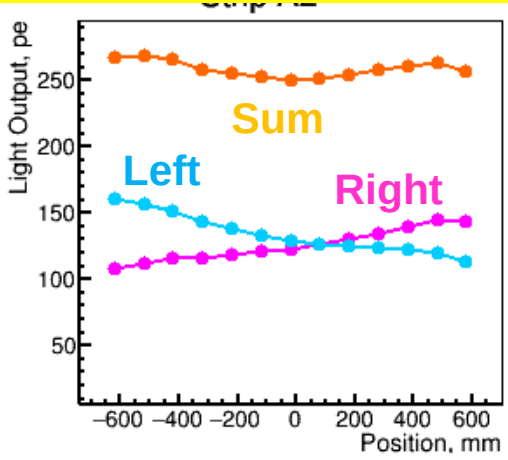
New strip

Size: 1x4x100 cm
3 grooves for fibers
Coating with Gd
Coating with TiO_2
One side readout
Y11 WSF

Size: 2x5x120 cm
8 grooves for fibers
Gd-contained film between layers
Chemical foaming
Two side readout
New WSF (JINST 17 P01031, 2022)



Strip scanning on π-beam:
Transverse profile
Longitudinal profile



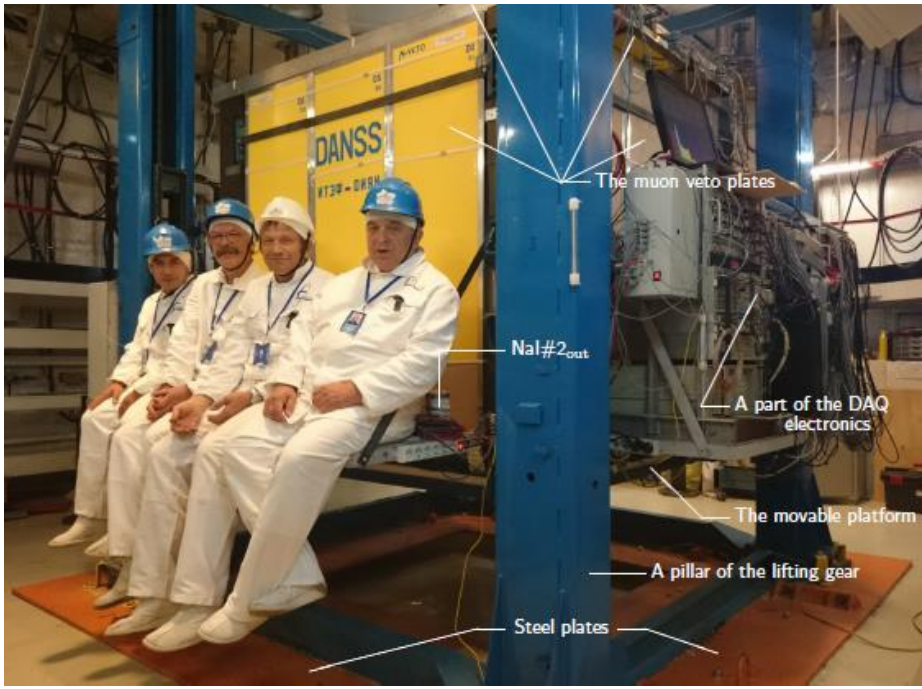
Summary

- DANSS collects more than 6M of IBD events;
- Big part of the RAA+GA region was excluded;
- With new data weak hint on sterile neutrino has appeared – two close points:

ΔX^2=-10 for Δm^2=0.35 eV^2, $\sin^2 2\theta$=0.067

ΔX^2=-9.7 for Δm^2=1.26 eV^2, $\sin^2 2\theta$=0.02

- But these results are not statistically significant (2.4 σ) to claim the indication of the sterile neutrino;
- Temperature and barometric correlation coefficients for cosmic muon flux were measured in new area of the overburden parameters;



Our plans:

To take data for a few more months

To upgrade detector in 2023