The DANSS upgrade. Status and perspectives

I.Zhitnikov (JINR)
on behalf of the DANSS collaboration

22nd Lomonosov Conference on Elementary Particle Physics

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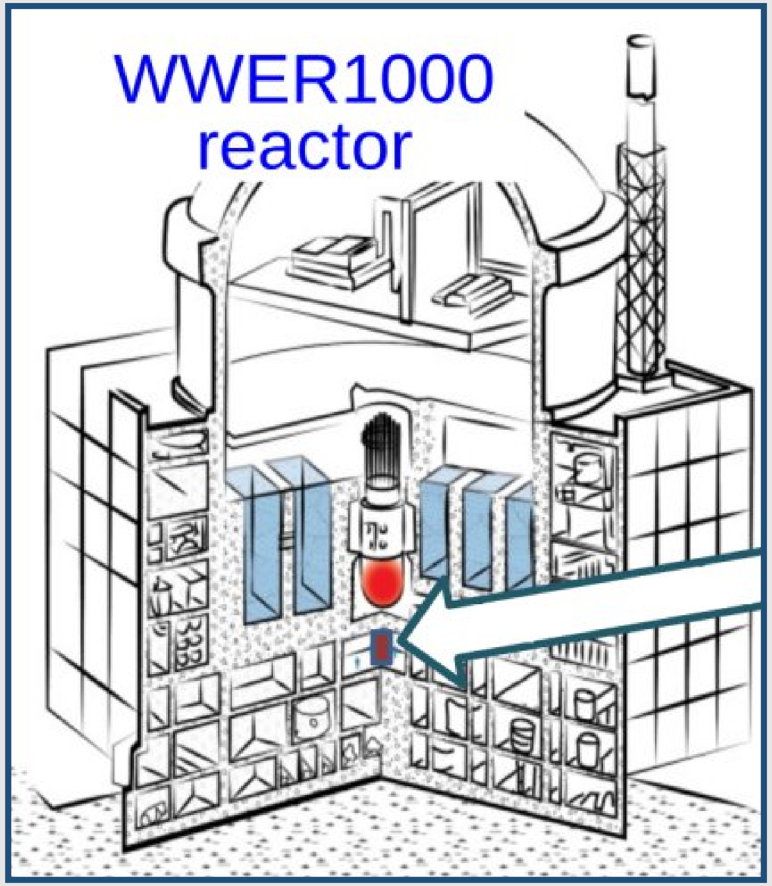
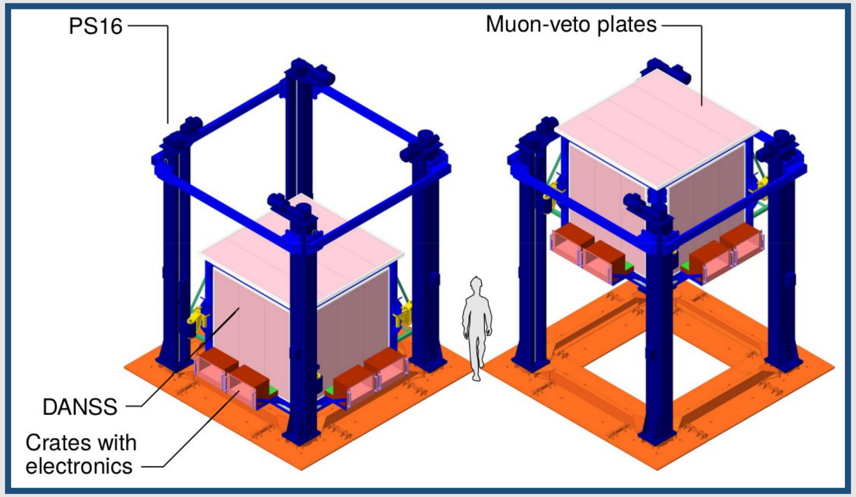
DANSS

Detector of the reactor AntiNeutrino based on Solid-state Scintillator

- Short-baseline reactor antineutrino experiment
- Located below 3.1 GW_{th} commercial reactor
  (4th Unit at KNPP, Udomlya, Russia)
  ~$5{\cdot}10^{13}$ $\nu{\cdot}cm^{-2}c^{-1}$@11m
- 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
- Fuel: ^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu (other components < 0.1%). Fission fractions change during campaign
- Reactor fuel and body with cooling pond and other reservoirs provide overburden
- ~50 m w.e. for cosmic background suppression



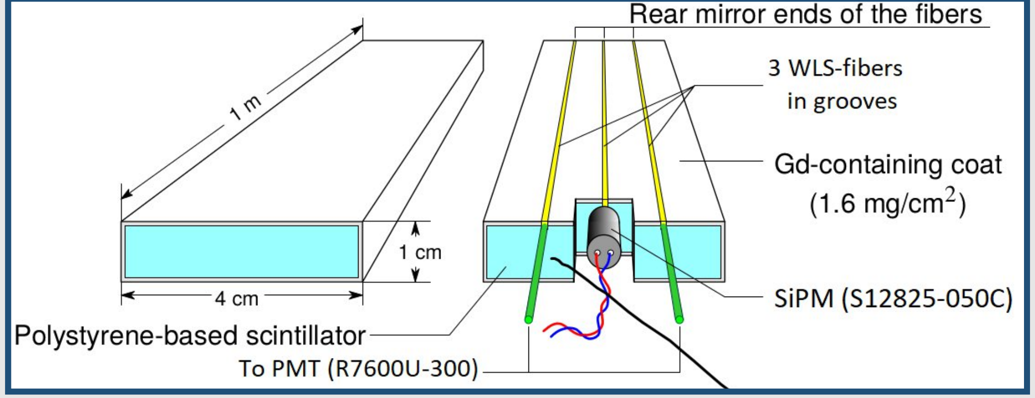


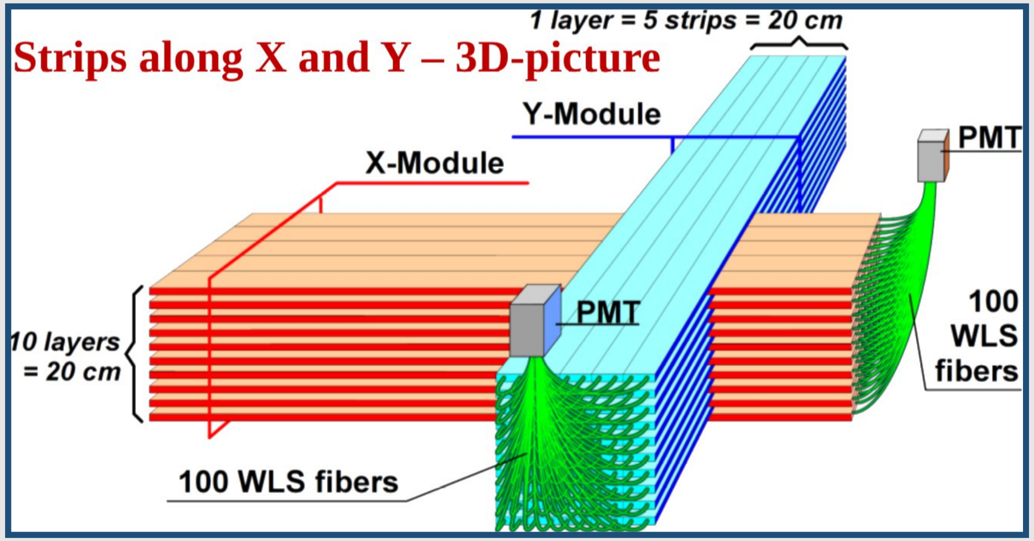
DANSS Motivation

- Physics beyond Standard Model: sterile neutrino search, large extra dimensions etc.
  (see P.Gorovtsov talk “Searches for physics beyond the SM at DANSS”)
- Reactor monitoring using antineutrinos
- High energy reactor antineutrino spectrum
  (important for CEvNS research at reactors)
- Nature of the bump/shoulder at reactor antineutrino spectrum

DANSS Detector

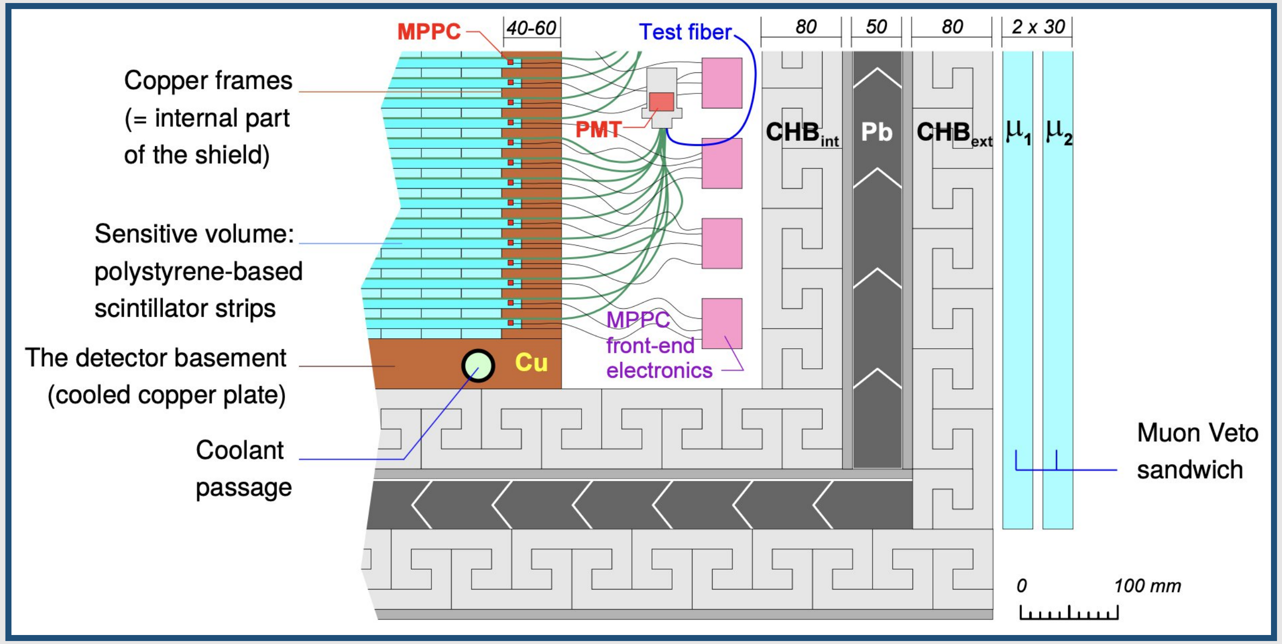
- IBD ($\bar{\nu}_e + p \rightarrow e^+ + n$) reaction is used
- 2500 scintillation counters with Gd-doped coating (0.35%wt) = 1 m^3 of sensitive volume
- Double PMT (50 groups of 50 strips each) and SiPM (individual, 2500 total) readout
- SiPM: 18.9 p.e./MeV & 0.37 X-talk
- PMT: 15.3 p.e./MeV
- Energy resolution: $\sigma/E = 34\%/\sqrt{E}$
- 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, E_{total} > 0.5 MeV) or μ-veto signal
- Individual channel selftrigger on SiPM noise (with decimation)

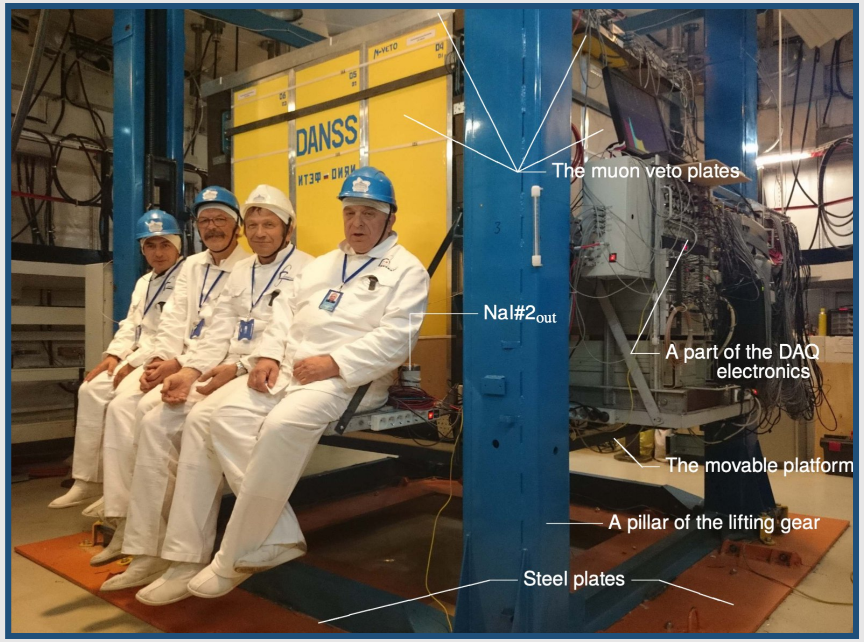




[JINST 11 (2016) no.11, P11011]

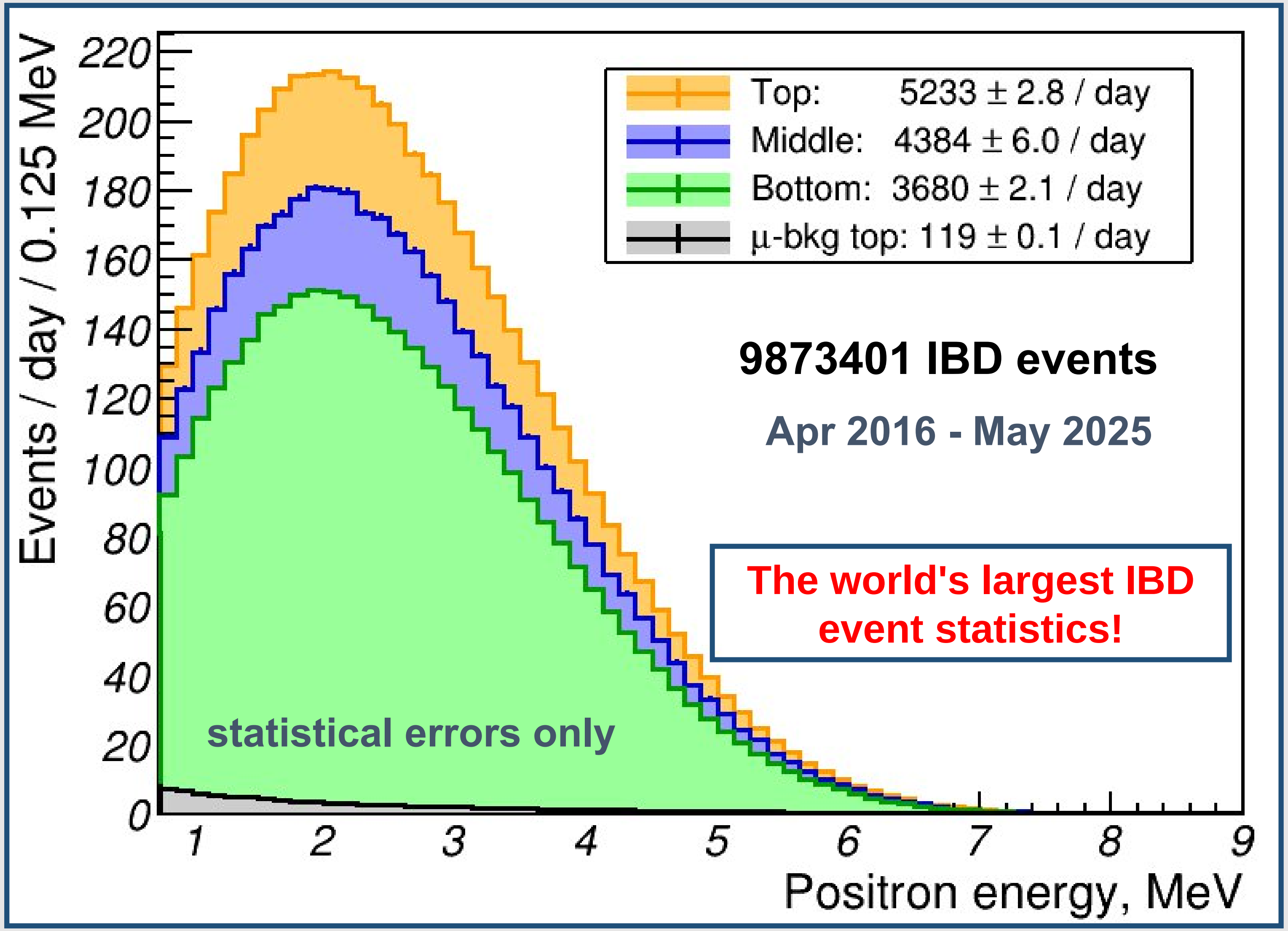
DANSS Detector





[JINST 11 (2016) no.11, P11011]

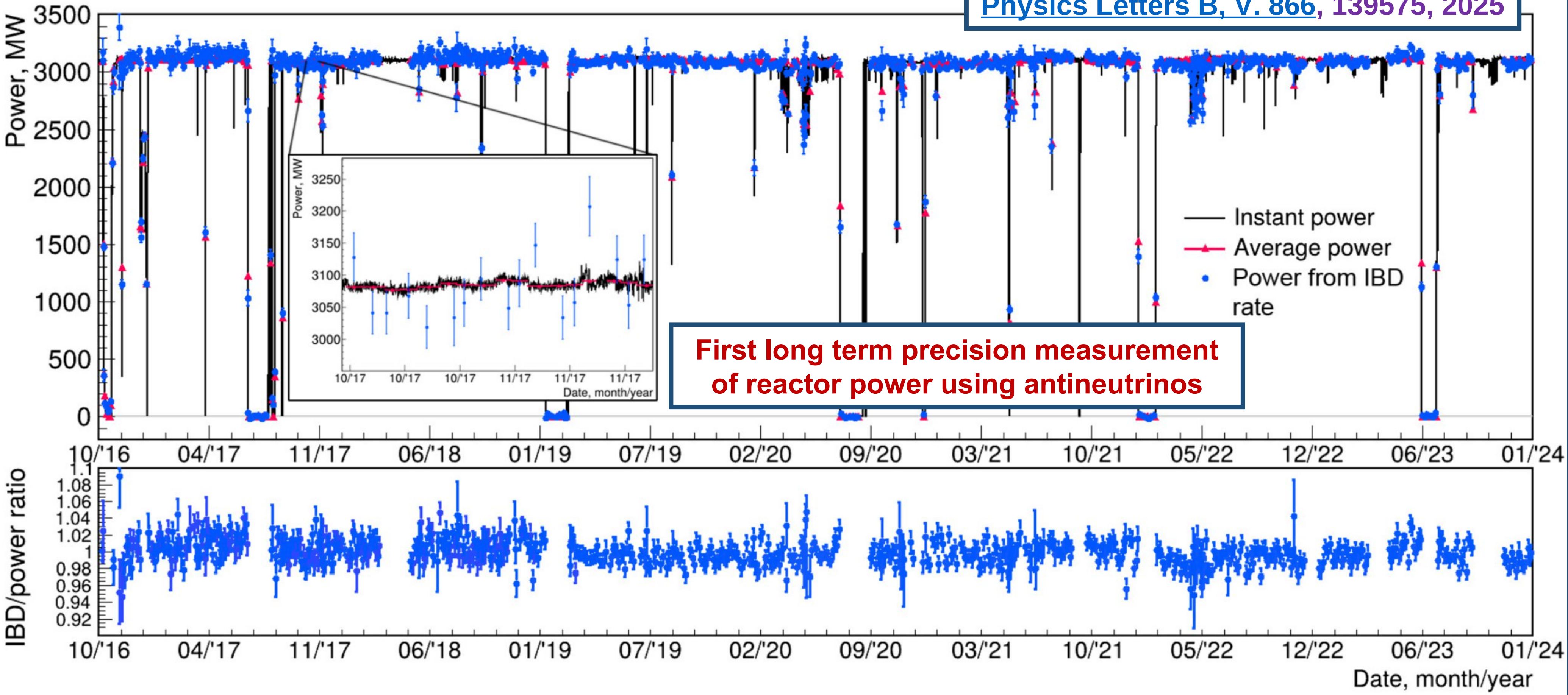
Positron spectrum of IBD-signal



- 3 detector positions
- Pure positron kinetic energy (annihilation photons not included)
- All backgrounds subtracted
- Neighbor reactors background at 160m, 334m and 478 m subtracted(0.6% of neutrino signal at top position)
- For E_{e+}=[1.5-6] MeV background = 1.75% in top position: **S/B > 50**.

Long term remote reactor power and fuel composition monitoring using neutrinos

Physics Letters B, V. 866, 139575, 2025



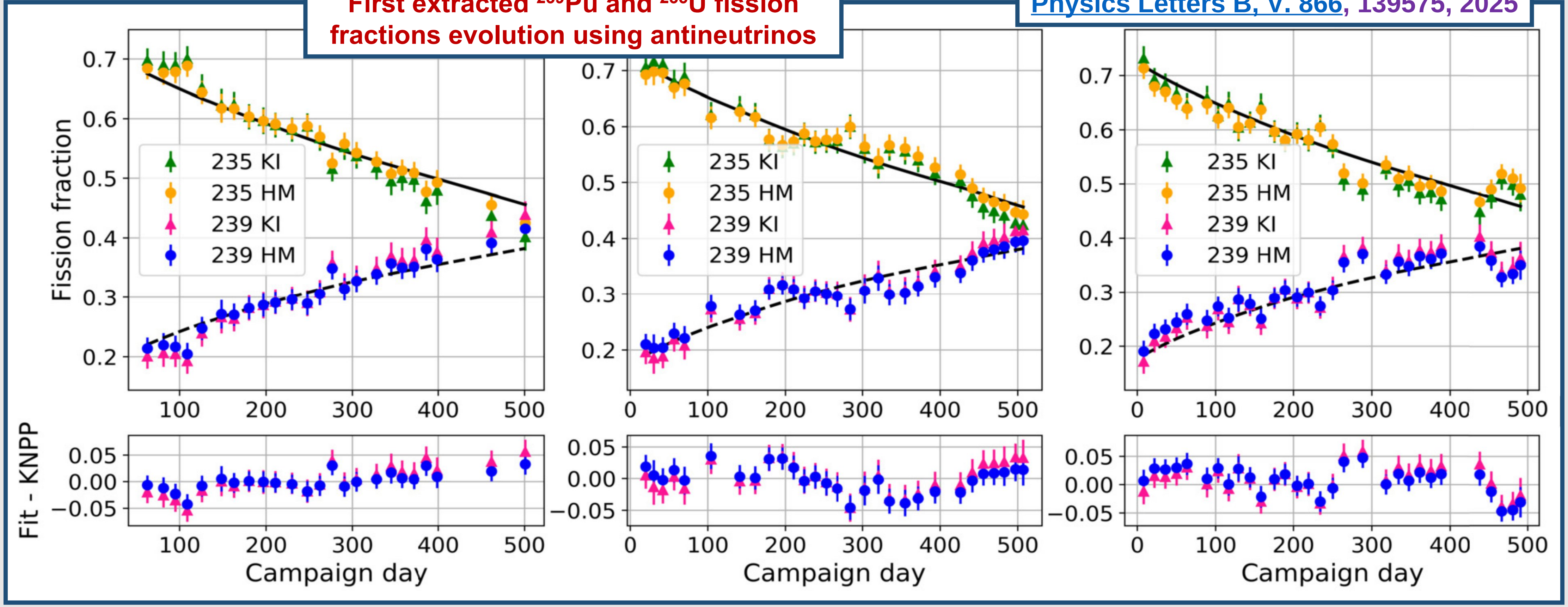
First long term precision measurement of reactor power using antineutrinos

Reactor power is measured using $\tilde{\nu}$ with σ = 1%/week during last 7 years

Long term remote reactor power and fuel composition monitoring using neutrinos

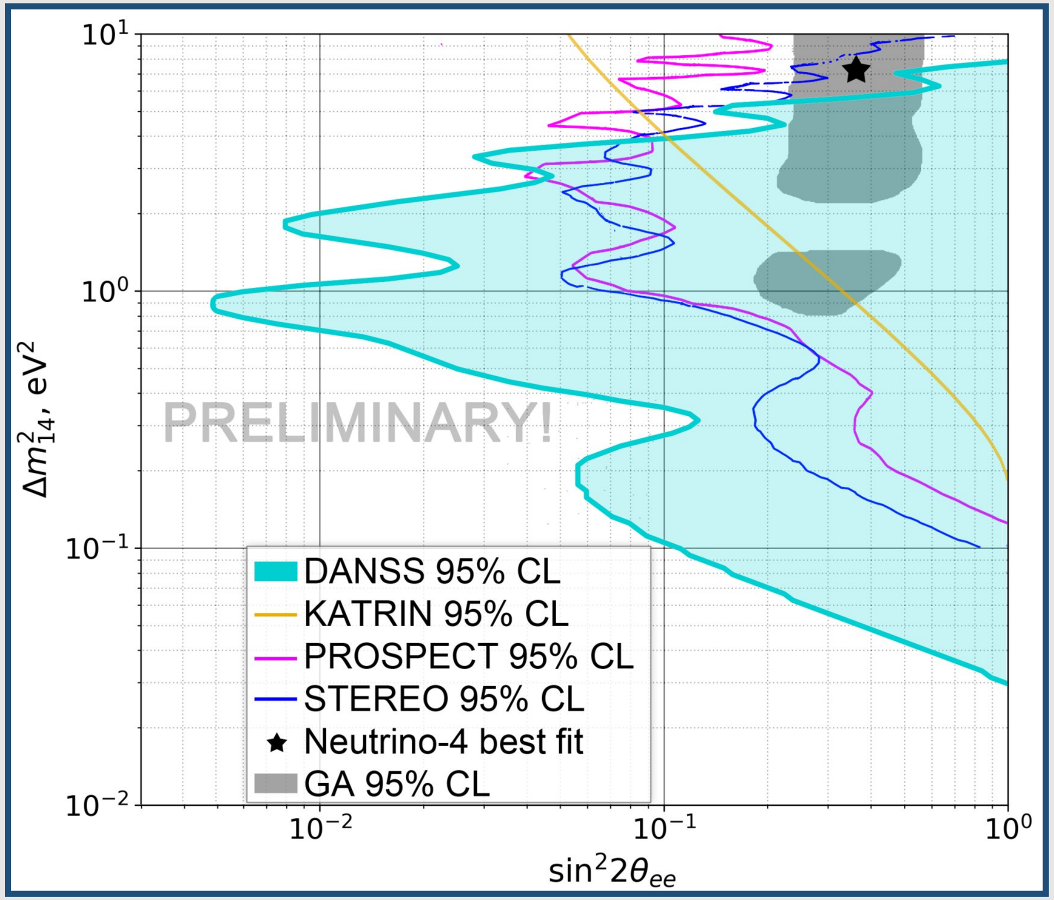
First extracted ^{239}Pu and ^{235}U fission fractions evolution using antineutrinos

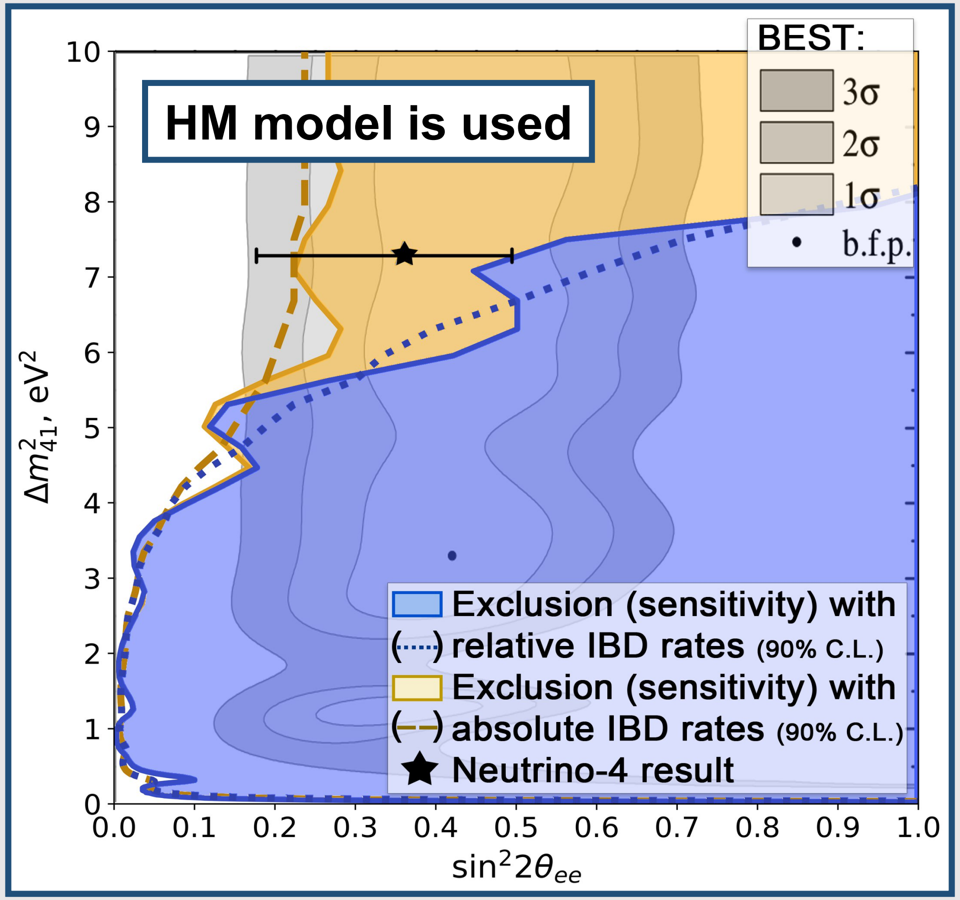
Physics Letters B, V. 866, 139575, 2025



^{239}Pu and ^{235}U fission fractions were measured using IBD spectra. Results are in excellent agreement (better than 3%) with calculations based on neutron flux simulation in the reactor.

Sterile neutrino search



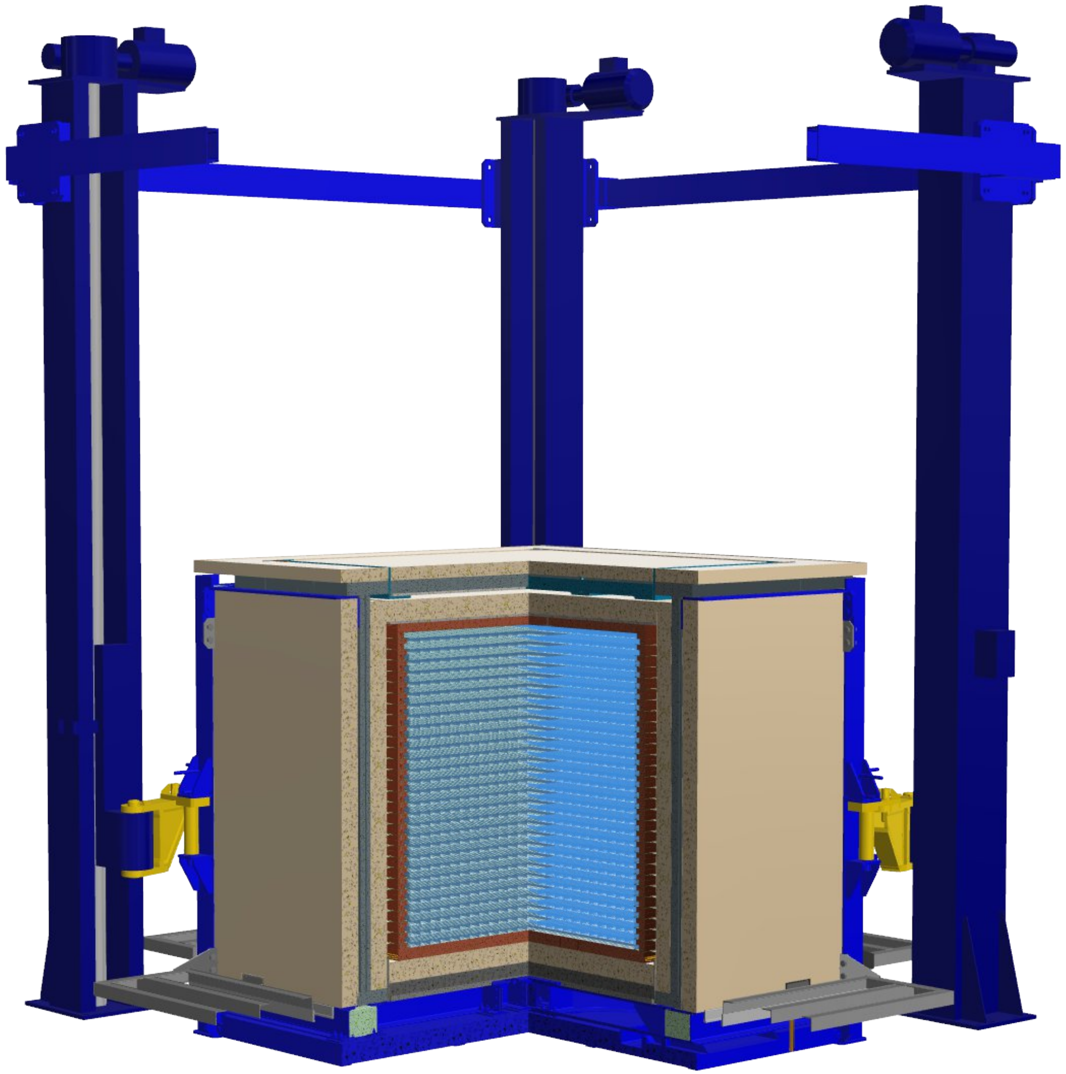


Analysis using relative counting rates excludes a large and the most interesting fraction of sterile neutrino parameter space using only ratio of e+ spectra at 3 distances (**7.2 mln IBD events at [1.5-7] MeV energy range**)
Exclusions are calculated using Gaussian CL_s method

Analysis using absolute counting rates depends on the predictions of the flux from reactors, for which we assumed to a total conservative uncertainty of 7%. Results excludes practically all sterile parameter space preferred by BEST **[Phys.Rev.Lett.128,232501]** and the best fit point of Neutrino-4 **[Phys. Rev. D 104, 032003]** experiment

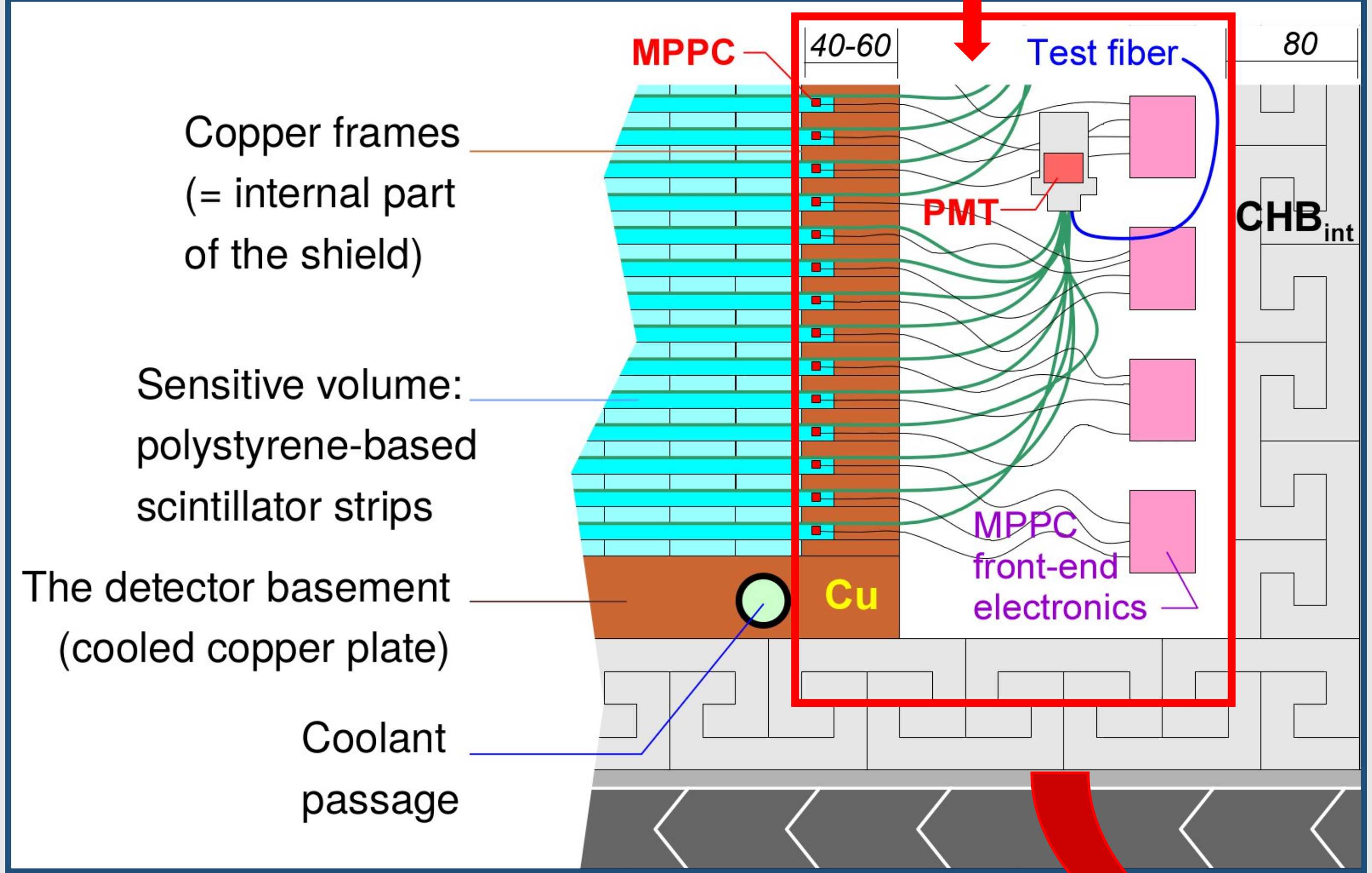
DANSS upgrade overview

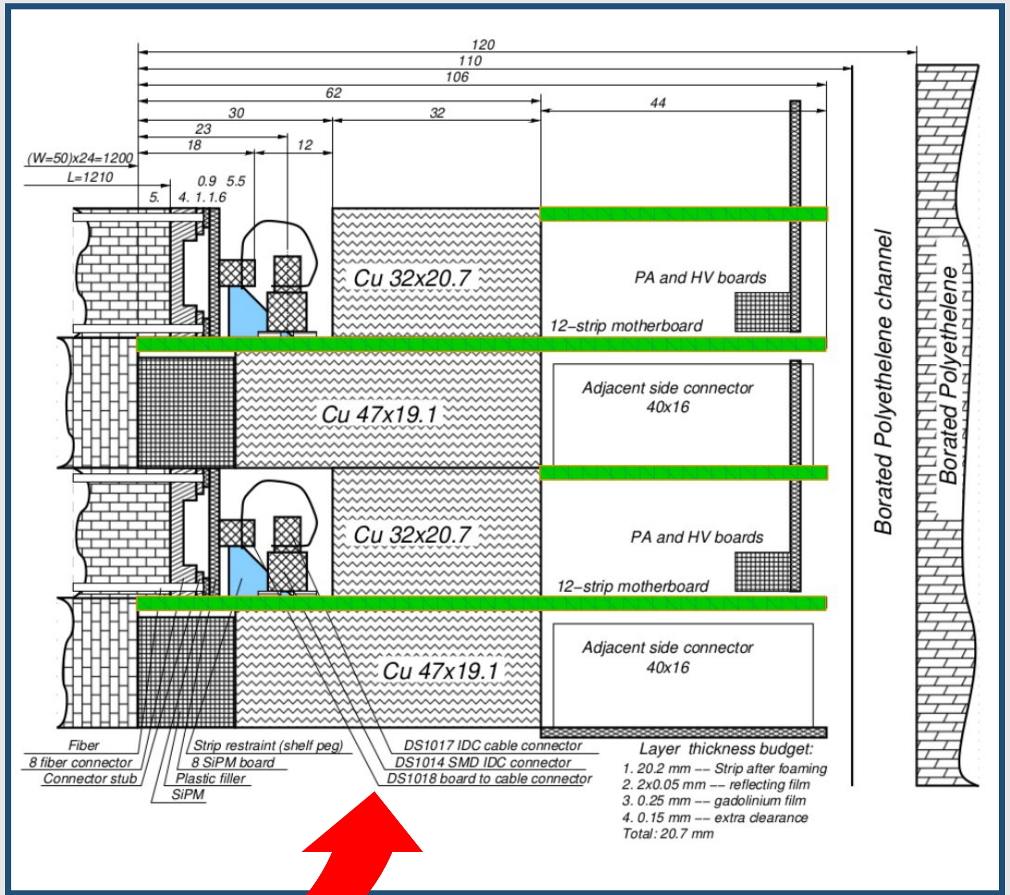
- **Main goal of the upgrade is to improve detector sensitivity for sterile neutrino search with model independent way analysis**
- **Better energy resolution**: $34\%/\sqrt{E} \rightarrow 12\%/\sqrt{E}$
- **New scintillation counters**: $20x50x1200mm^3$
- 60 layers x 24 strips – **1.7 times larger fiducial volume**
- No PMT – SiPM readout from both sides
- 8 grooves with WLS, 16 SiPM per strip get high light yield and uniformity
- Time to get longitudinal coordinate in each strip. Faster (4.0 ns decay time) WLS fiber KURARAY YS-2 **[JINST 17 (2022) P01031]**
- Chemical whitening of strips – no large dead layer with titanium and gadolinium
- Gadolinium in polyethylene film between layers
- New front-end electronics – low power inside passive shielding. Cool SiPM to 10°C
- Keep platform, passive shielding and digitization.



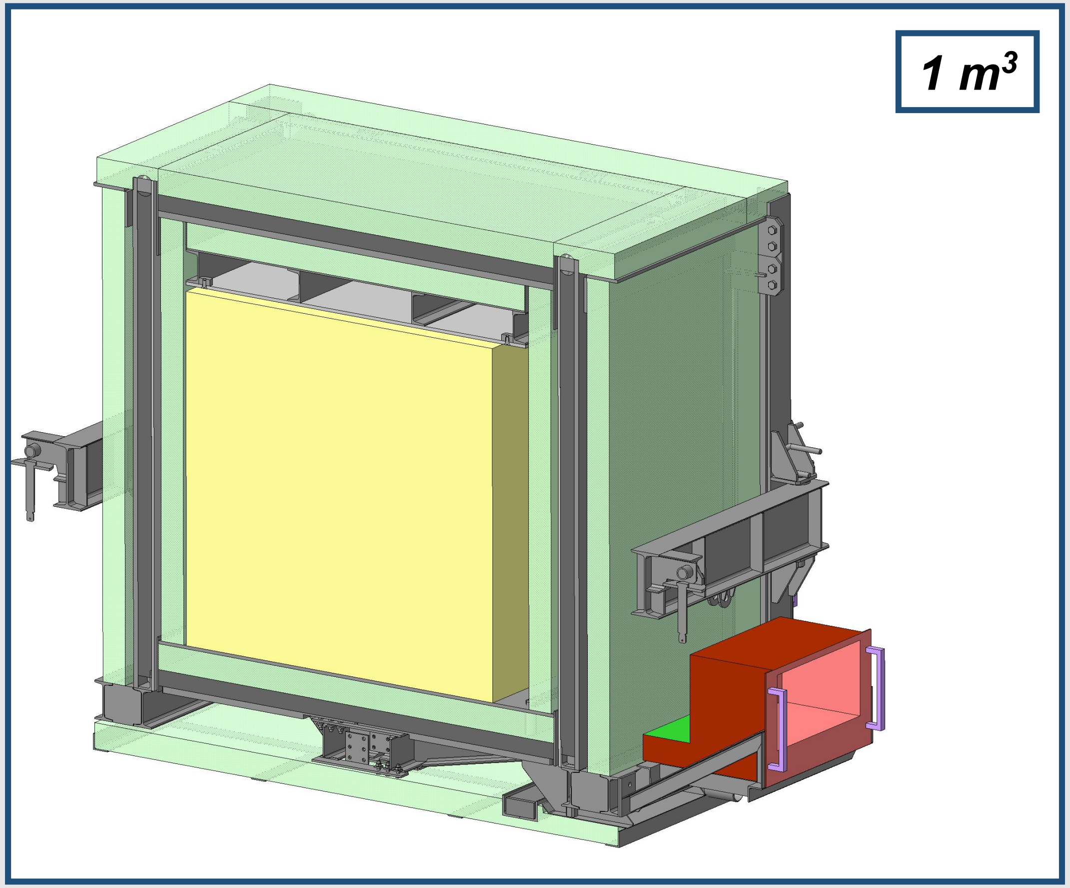
Larger fiducial volume

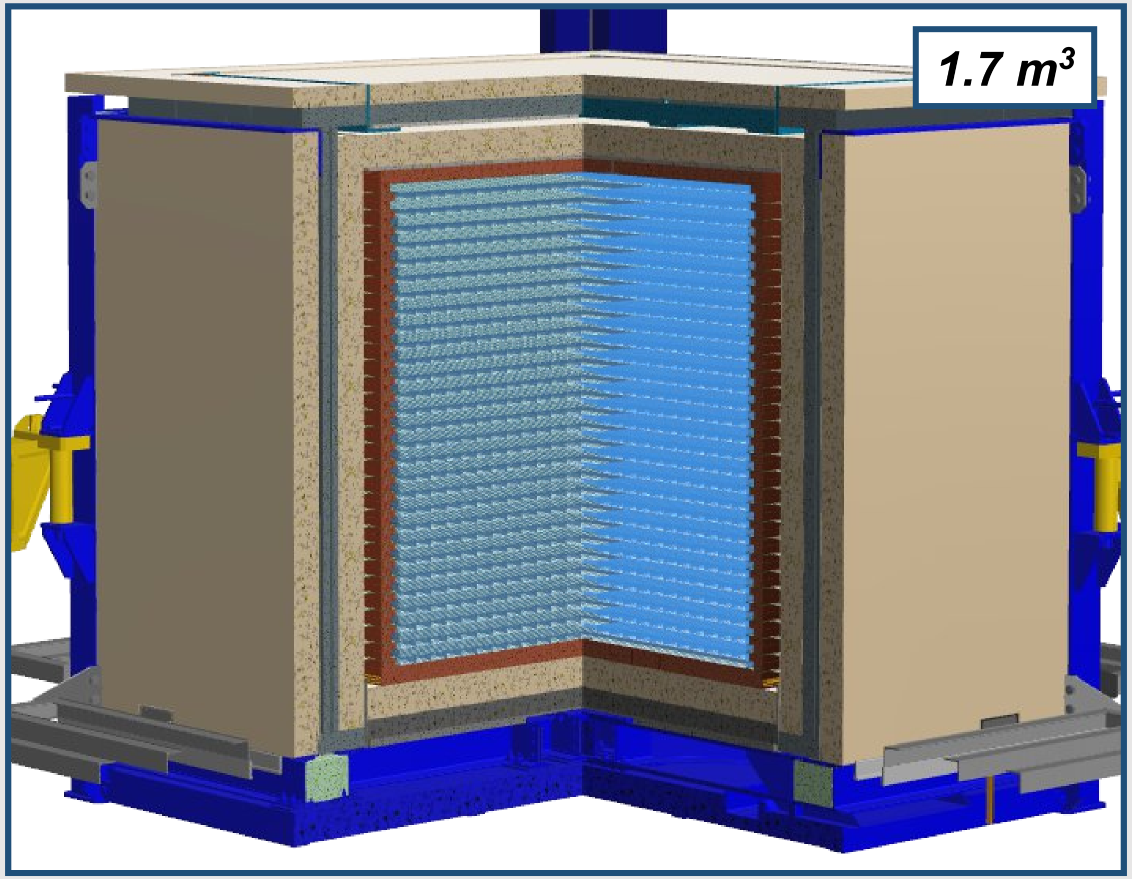
“Empty” space inside of the passive shielding





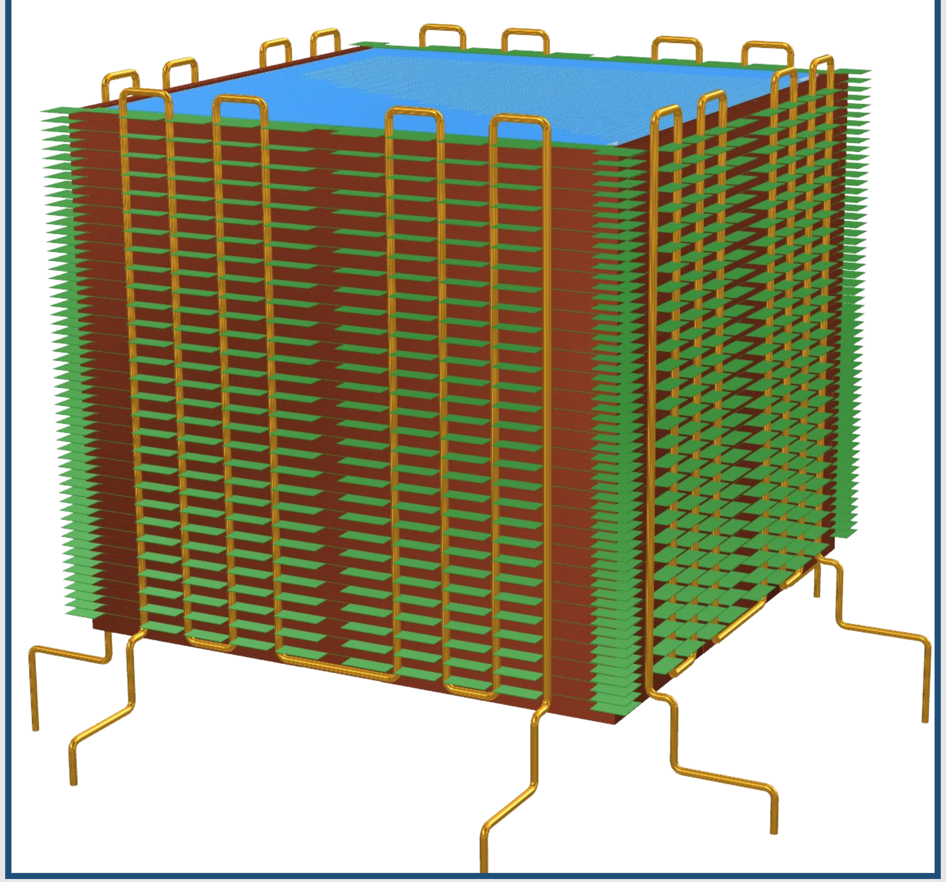
Larger fiducial volume





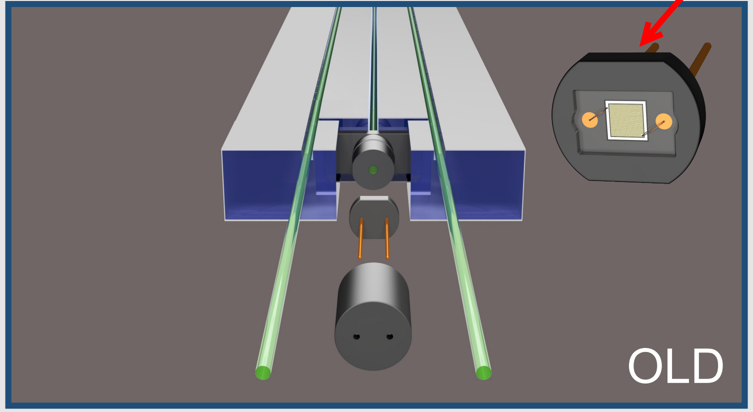
New front-end electronics

- lower heat dissipation inside passive shielding.
- Cool SiPM to 10°C
(instead of 18-22 at DANSS-I): reducing of SiMP noise
- Individual readout for each scintillation counter

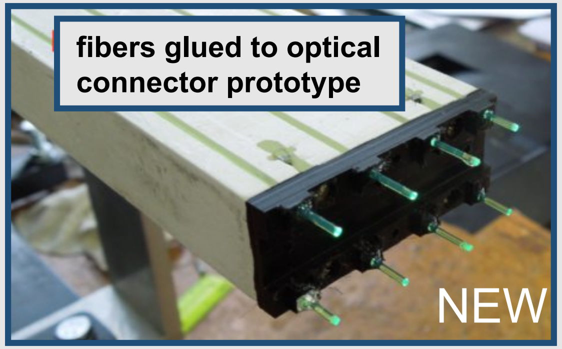


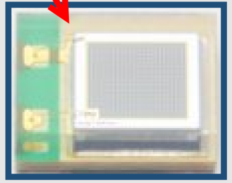
New scintillation counter design

3 fibers, readout from one side,
TiO_2 coating doped Gd, 1 Hamamatsu S12825-050C

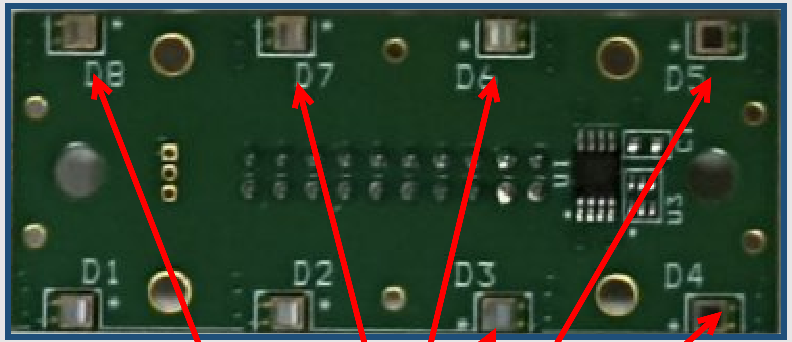


8 fibers, readout from two sides (higher light yield), chemical whitening of strips (less dead layers), films doped Gd between layers of counters,
16 SiPM Hamamatsu S13360-1350PE



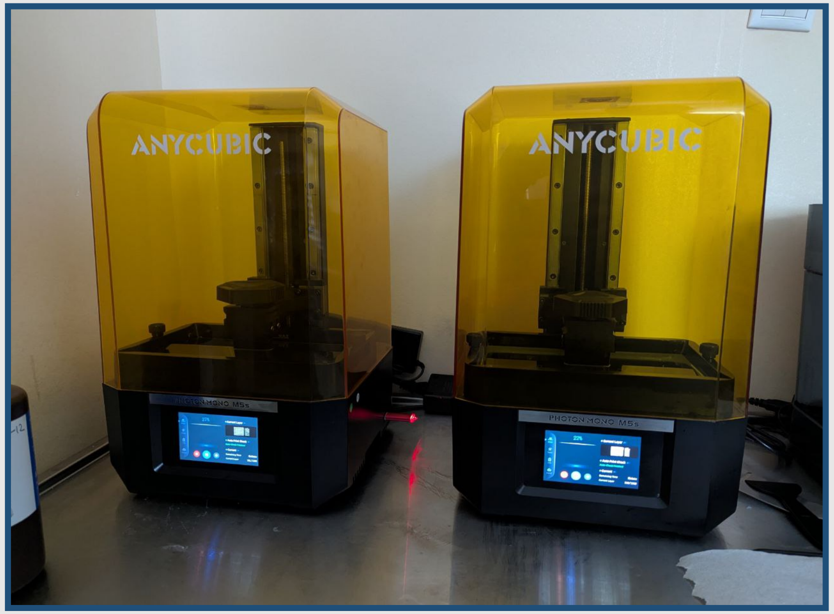


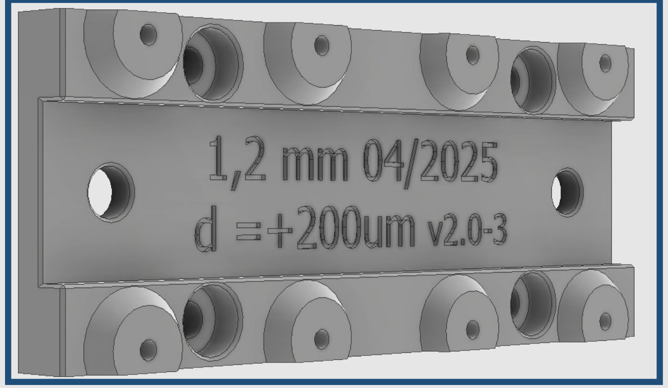
Assembled DANSS-II counters



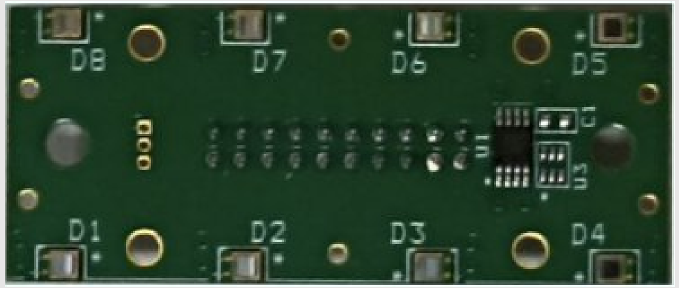
8 SiPM per counter side at single circuit board

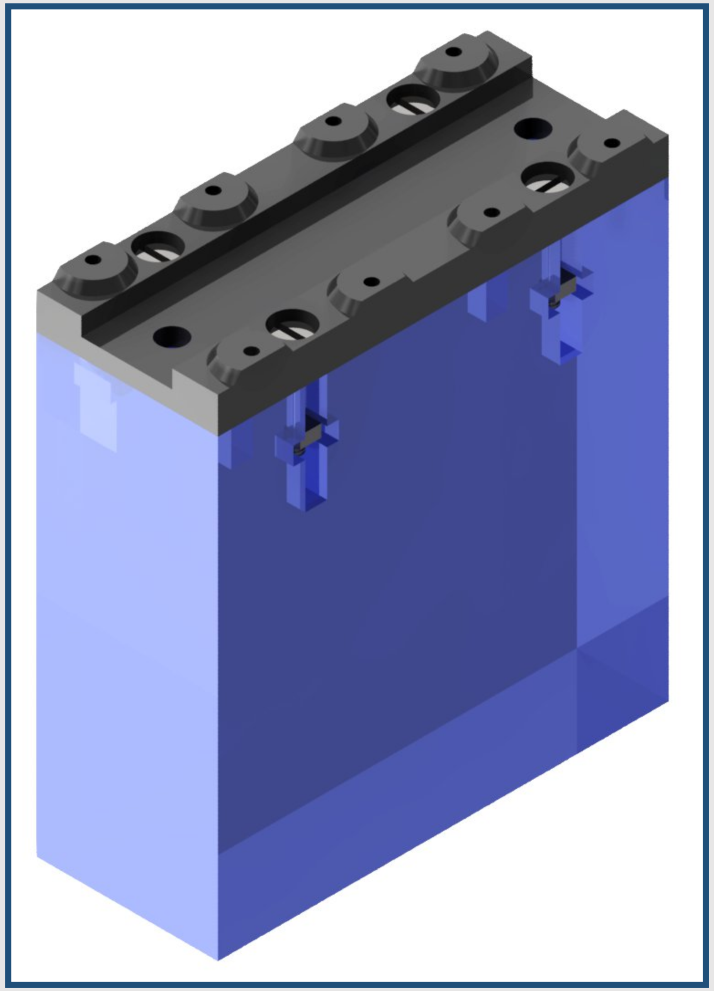
Optical connectors





50 microns precision requirement for point of fiber-SiPM connection

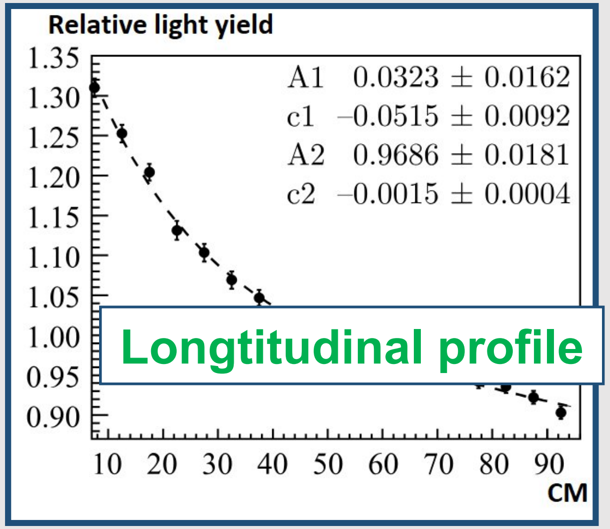




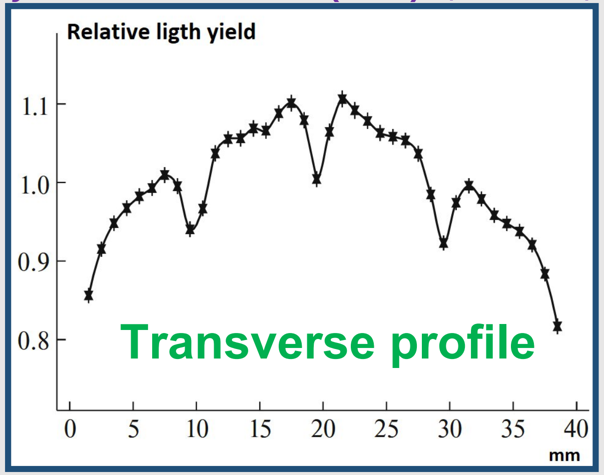
2 LCD photopolymer 3D printers are used for connectors production:

- XY resolution: 16.8 x 24.8 microns
- cheap
- rapid improvements for testing connector designs
- stable result

New scintillation counter design

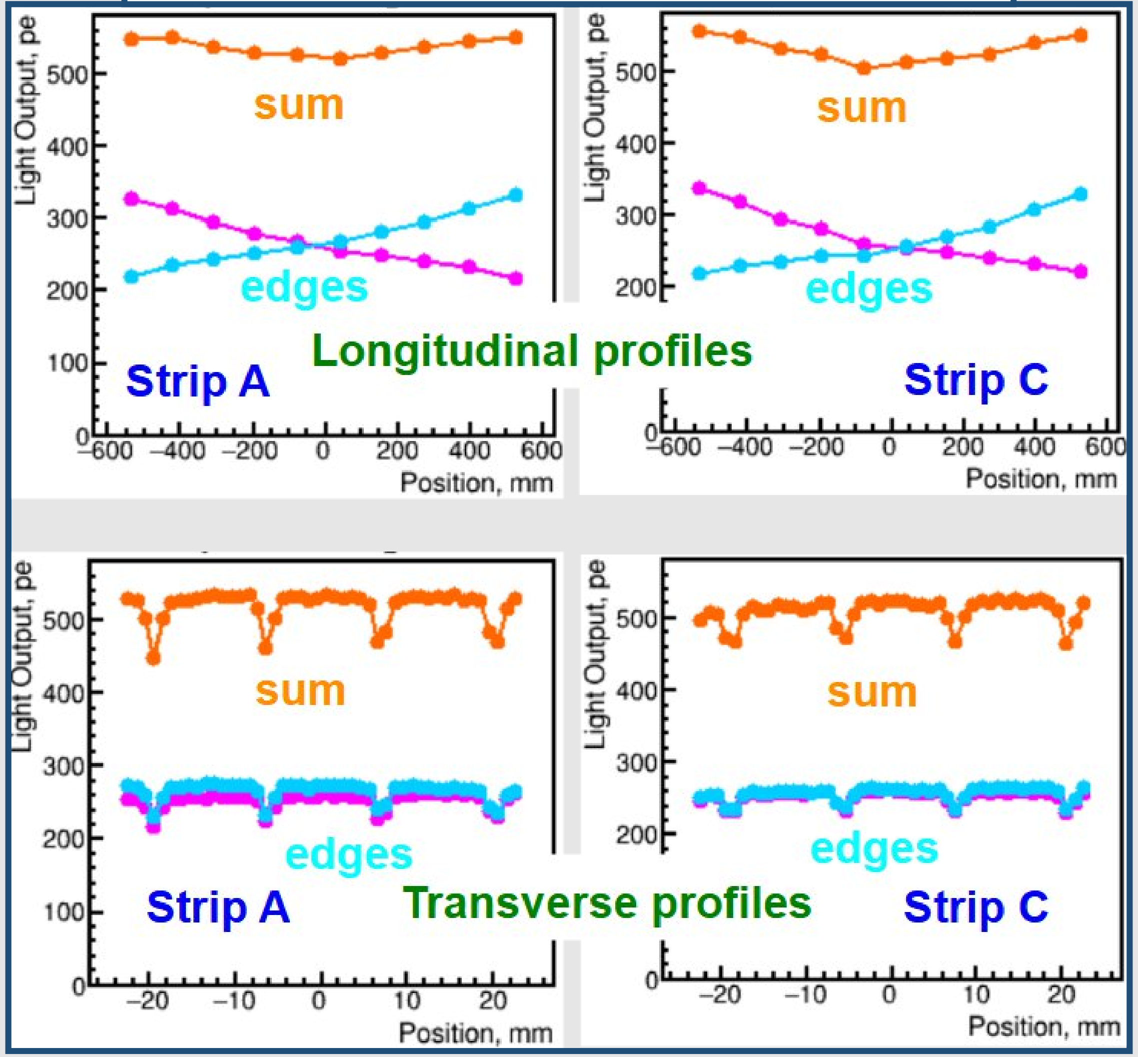


Phys.Part.Nucl.Lett. 15 (2018) 3, 272-283, 2018



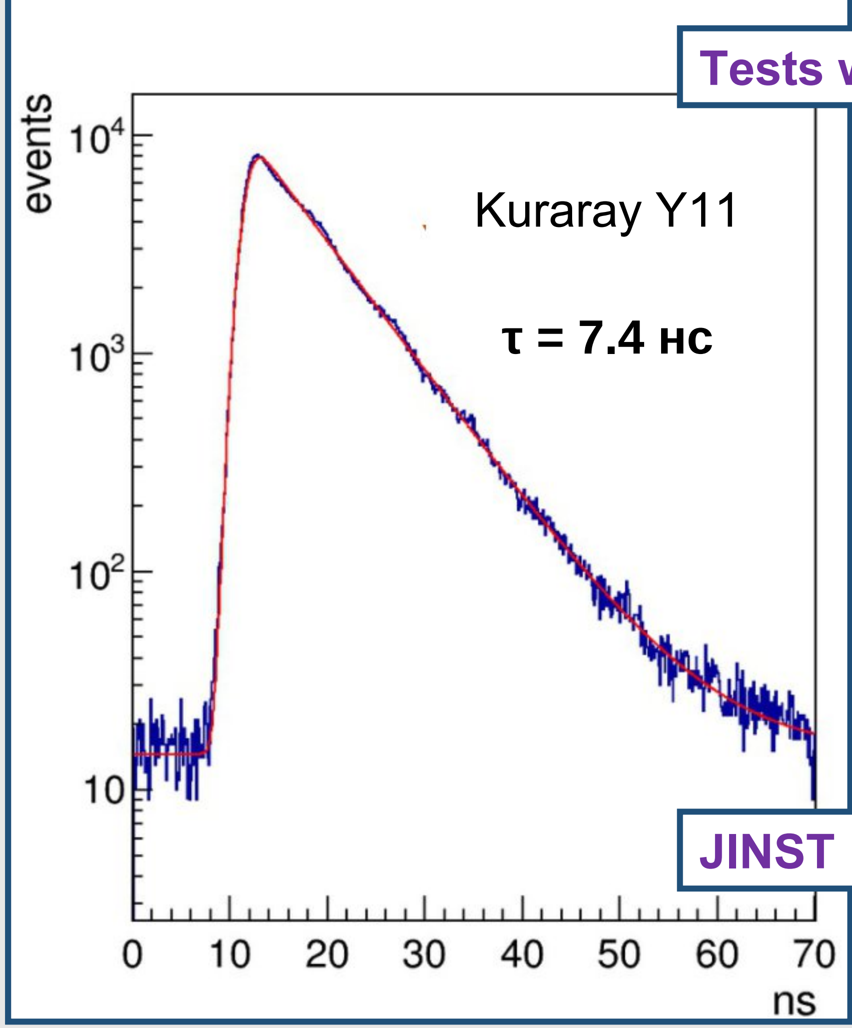
NUCLEAR EXPERIMENTAL TECHNIQUE, Vol.61, No.3, pp 328-331, 2018

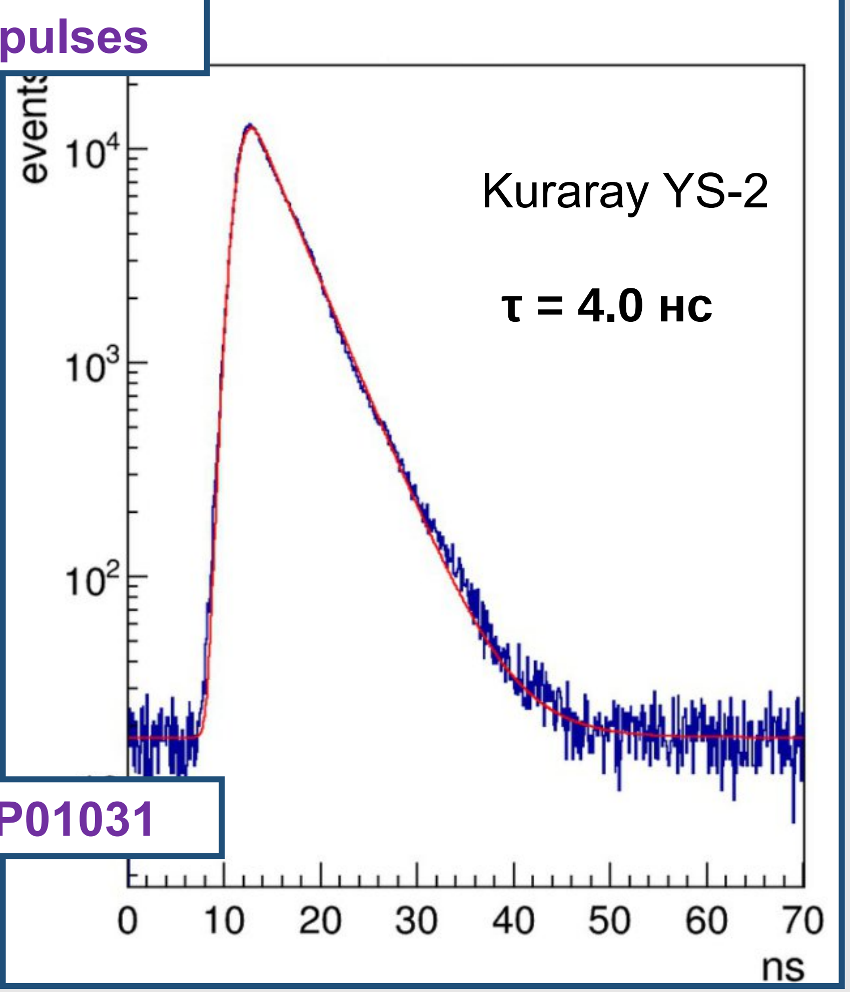
Test with muon beam at U-70 (Protvino)



New optical fibers

Tests with laser pulses



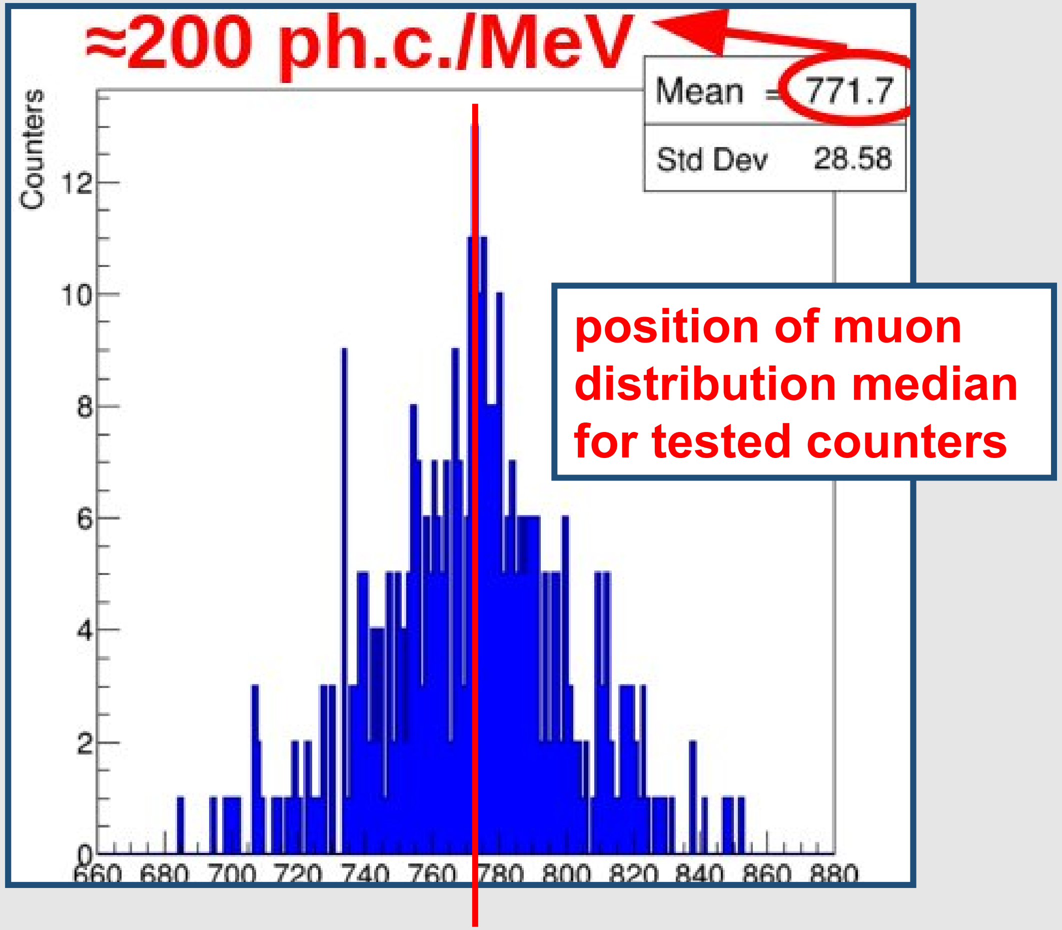


JINST 17 (2022) P01031

Same light yield for scintillation counter and light attenuation. New fibers are twice faster that allows to use a time of event pulses to get longitudinal coordinate in each counter

Mass production tests

Counters tests with atmosphere muons

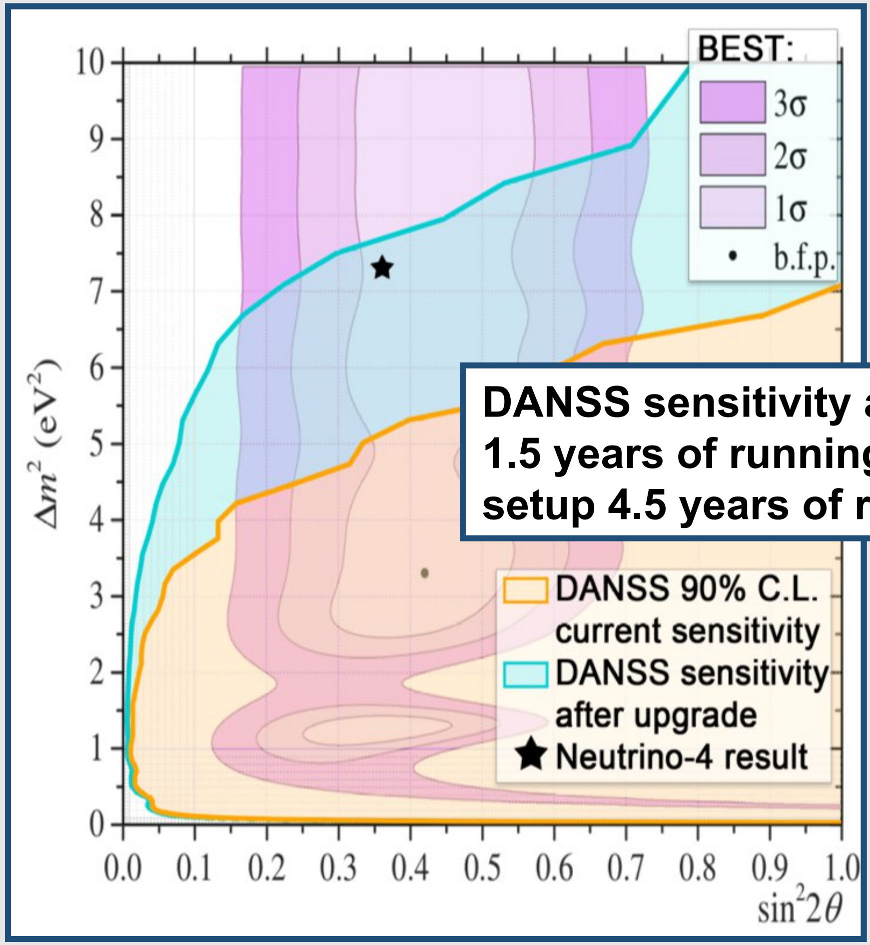


3.85 MeV

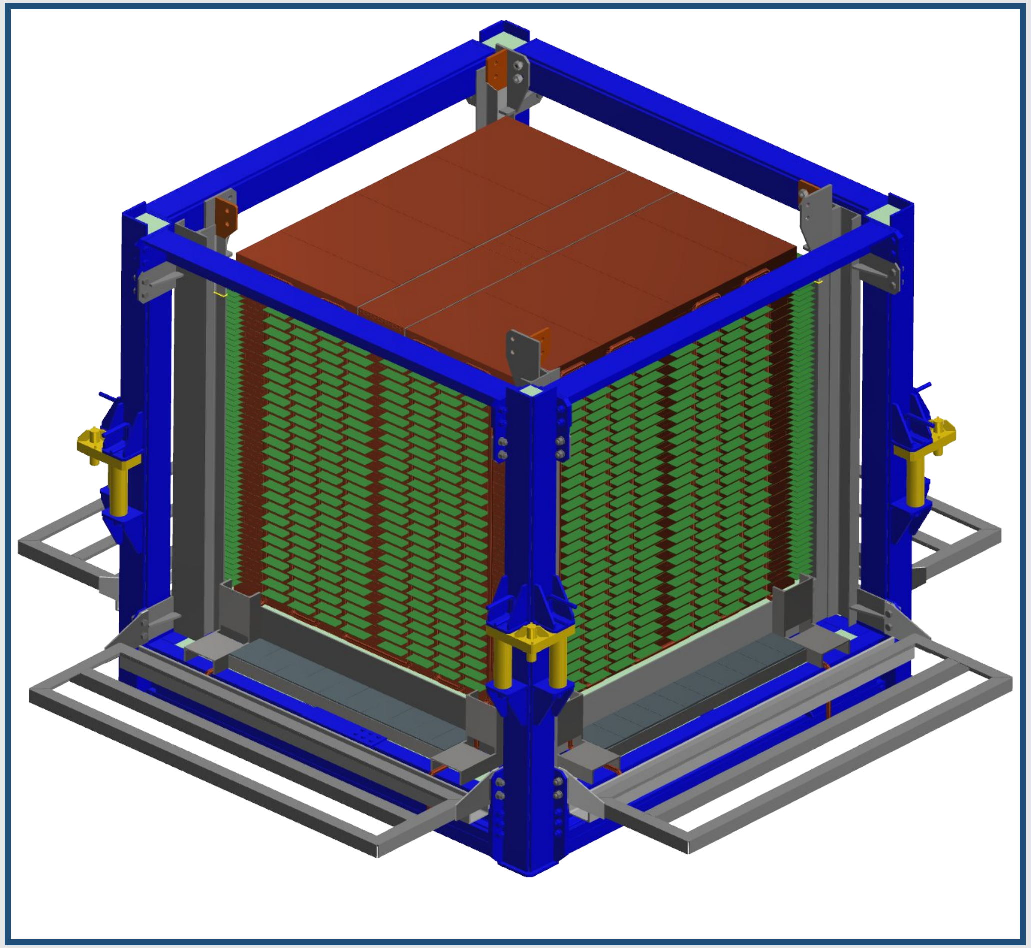
Upgrade status and timeline

- DANSS Upgrade is in progress
- 400 scintillation counters have already been made
- All scintillation counters will be produced to the early of 2026
- The DANSS-I decommissioning is scheduled in early 2026
- The DANSS-II will be assembled at 2026
- The start of the DANSS-II measurements is scheduled for the second part of 2026.

DANSS-II sensitivity

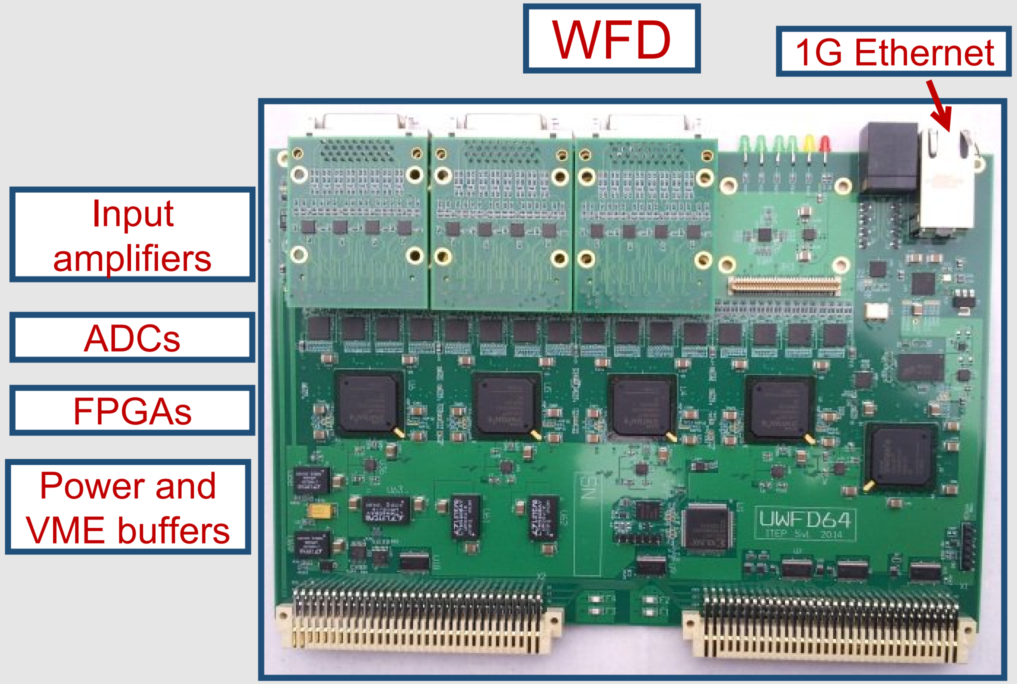


DANSS sensitivity after upgrade 1.5 years of running and current setup 4.5 years of running



Readout electronics

- Total 46 Waveform Digitisers WFD in 4 VME crates on the platform
- WFD: 64 channels, 125 MHz, 12 bit dynamic range, signal sum and trigger generation and distribution (no additional hardware), 1G Ethernet data readout
- Trigger-less DAQ - individual scintillation counter readout with summation signal from both sides higher than 5 SiPM pixels
- 1 dedicated WFDs for μ-veto for trigger production

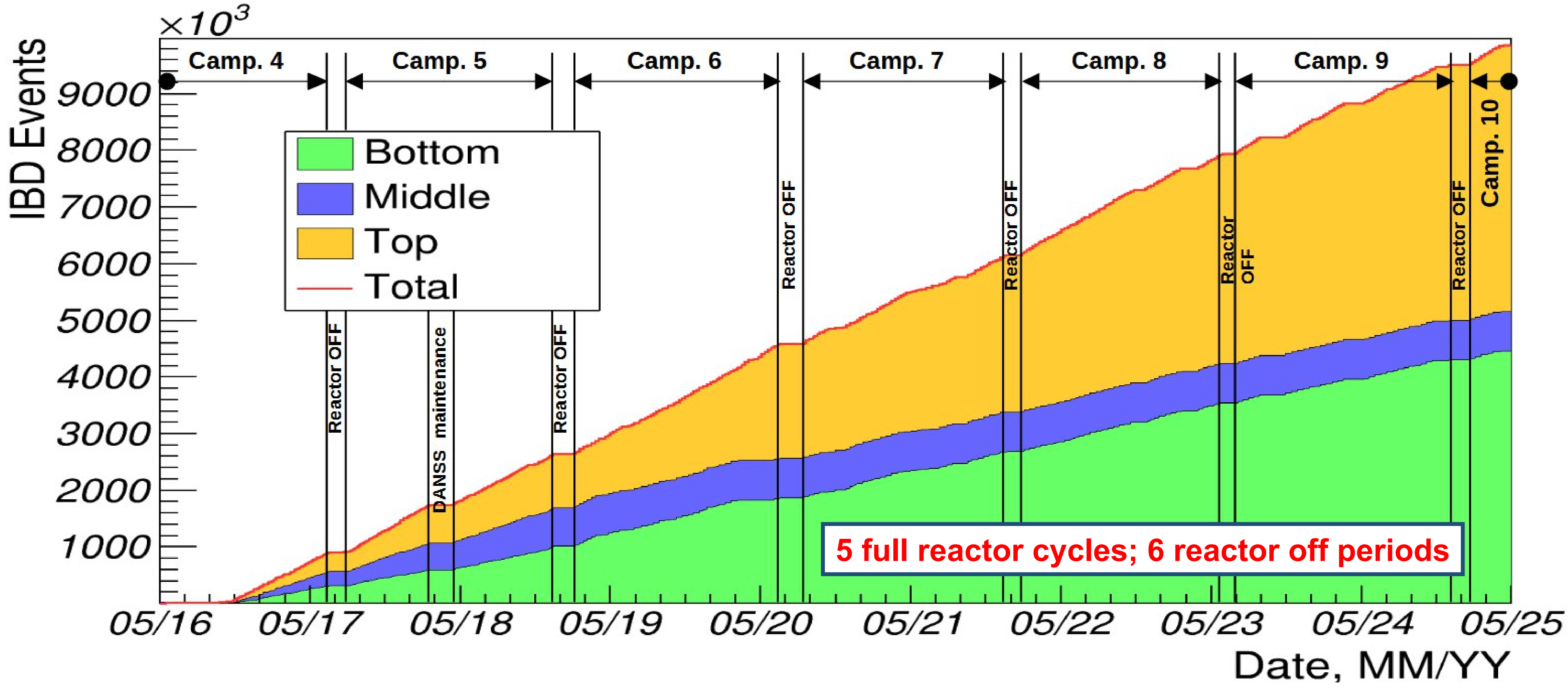


Summary

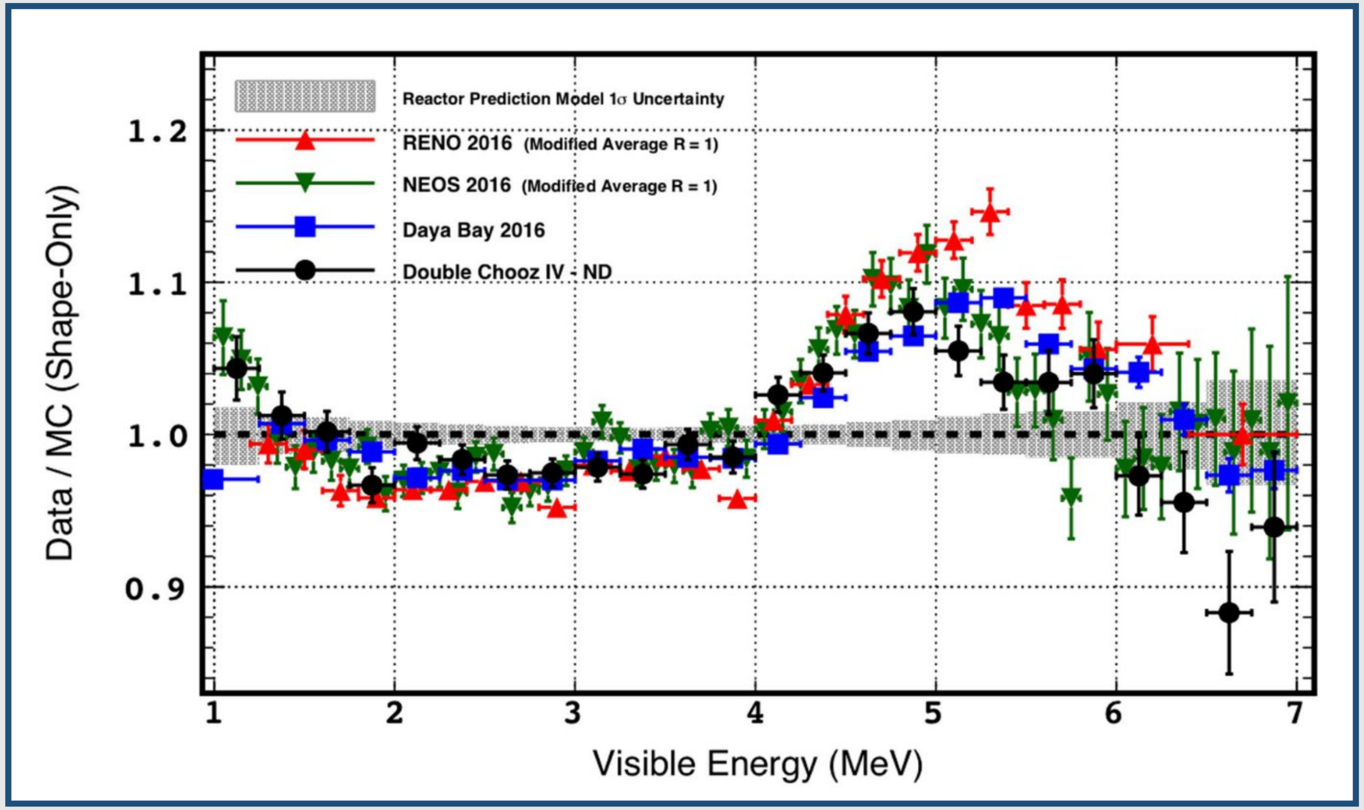
- DANSS upgrade works continue
- DANSS-II will have higher fiducial volume: 1.0 m^3 -> 1.7 m^3
  (5000 IBD events per day -> ~8500-10000 IBD events per day)
- DANSS-II will have much better energy resolution ($\mathbf{34\%/\sqrt{E} \rightarrow 12\%/\sqrt{E}}$)
- New SiPM only readout from both ends of scintillation cells will provide better events geometry reconstruction
- The start of the DANSS-II measurements is scheduled for the end of 2026
- Measurements with new detector will allow scrutinize Neutrino-4 and BEST results with reactor antineutrino model independent analysis
- Upgrade will improve possibilities of reactor monitoring research
- See also P. Gorovtsov talk “Searches for physics beyond the SM at DANSS”

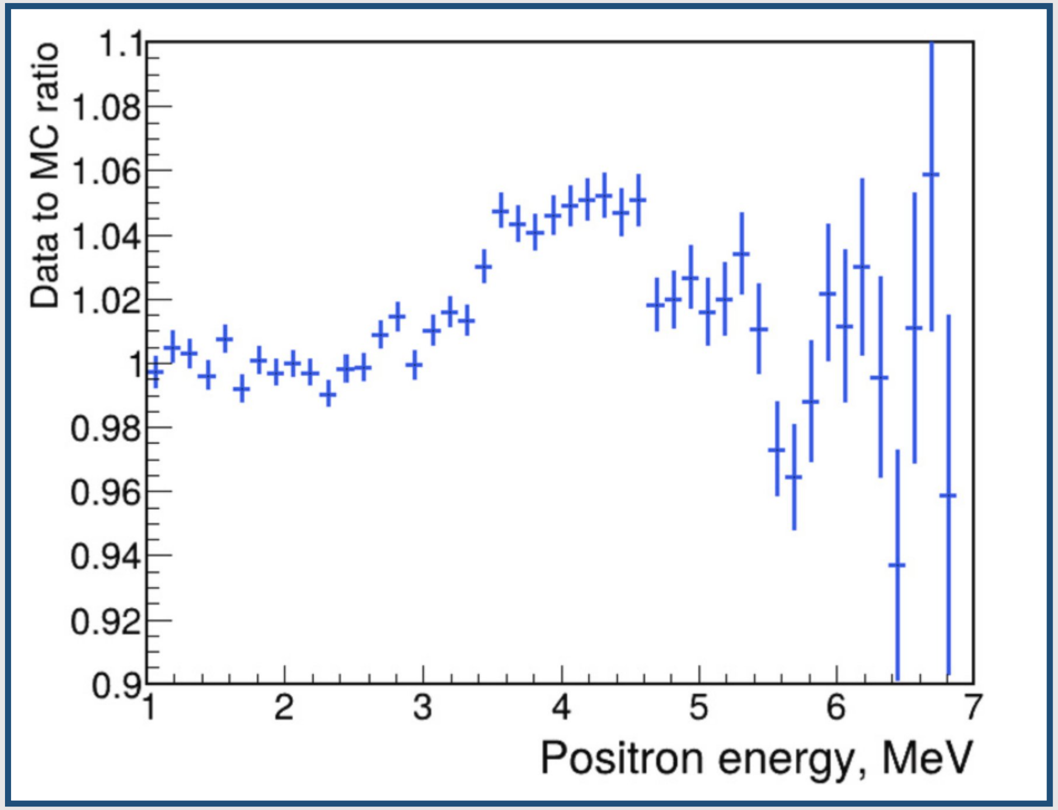
Backup slides

DANSS statistics accumulation



Reactor antineutrino bump





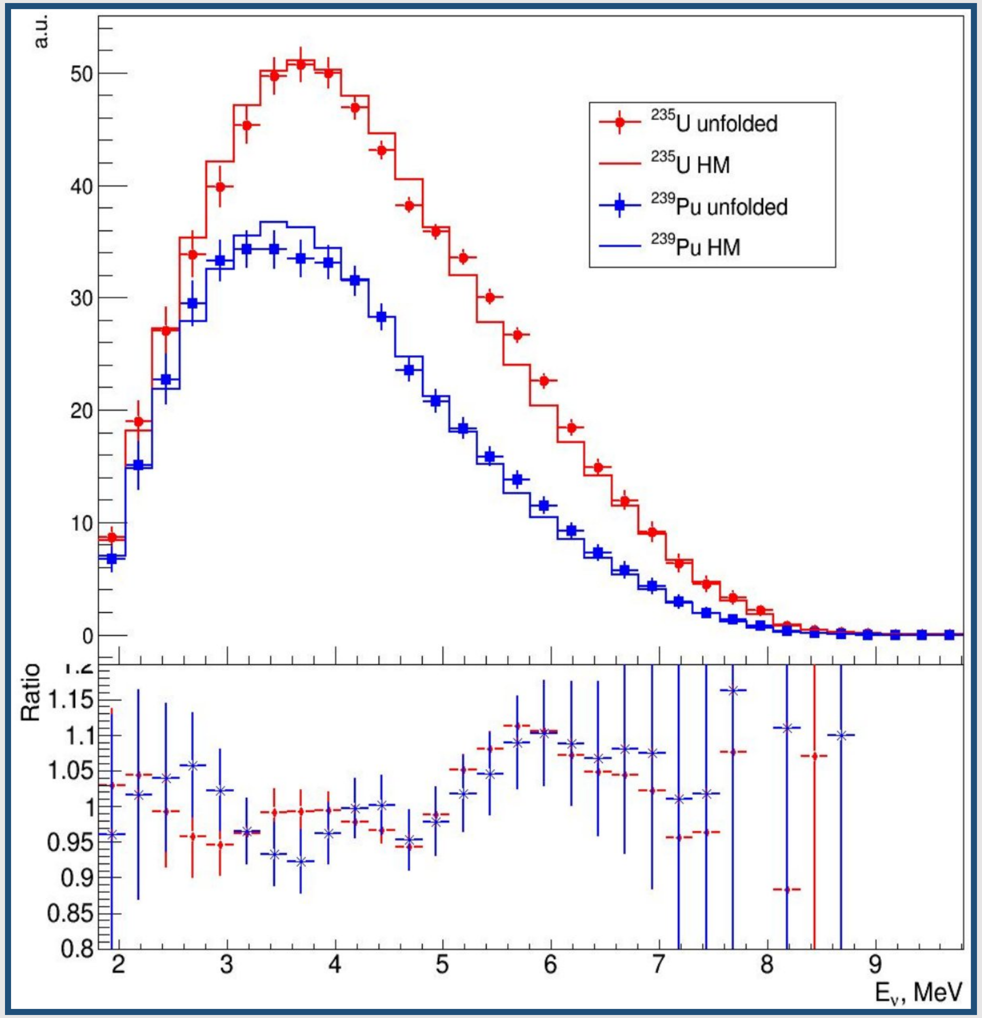
The Double Chooz Collaboration

Double Chooz ϑ_{13} measurement via total neutron capture detection

Nature Physics volume 16, pages 558–564 (2020)

Phys. Lett. B 866, 139575, 2025

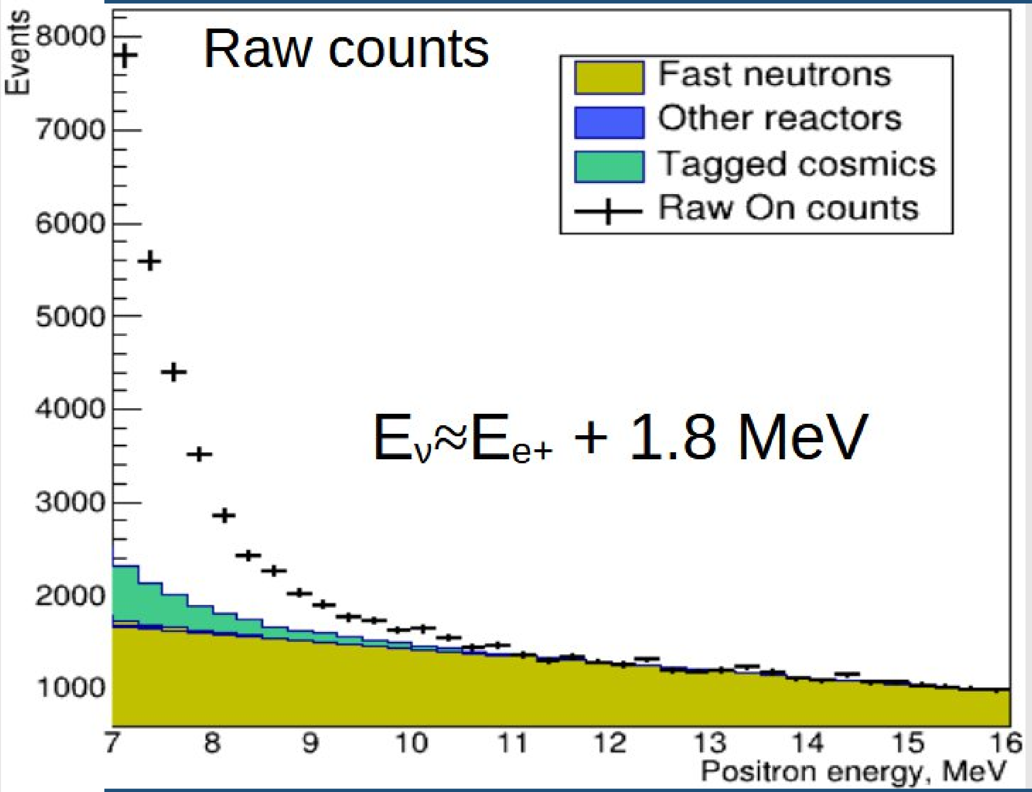
Unfolded ^{235}U and ^{239}Pu antineutrino spectra (and bump)

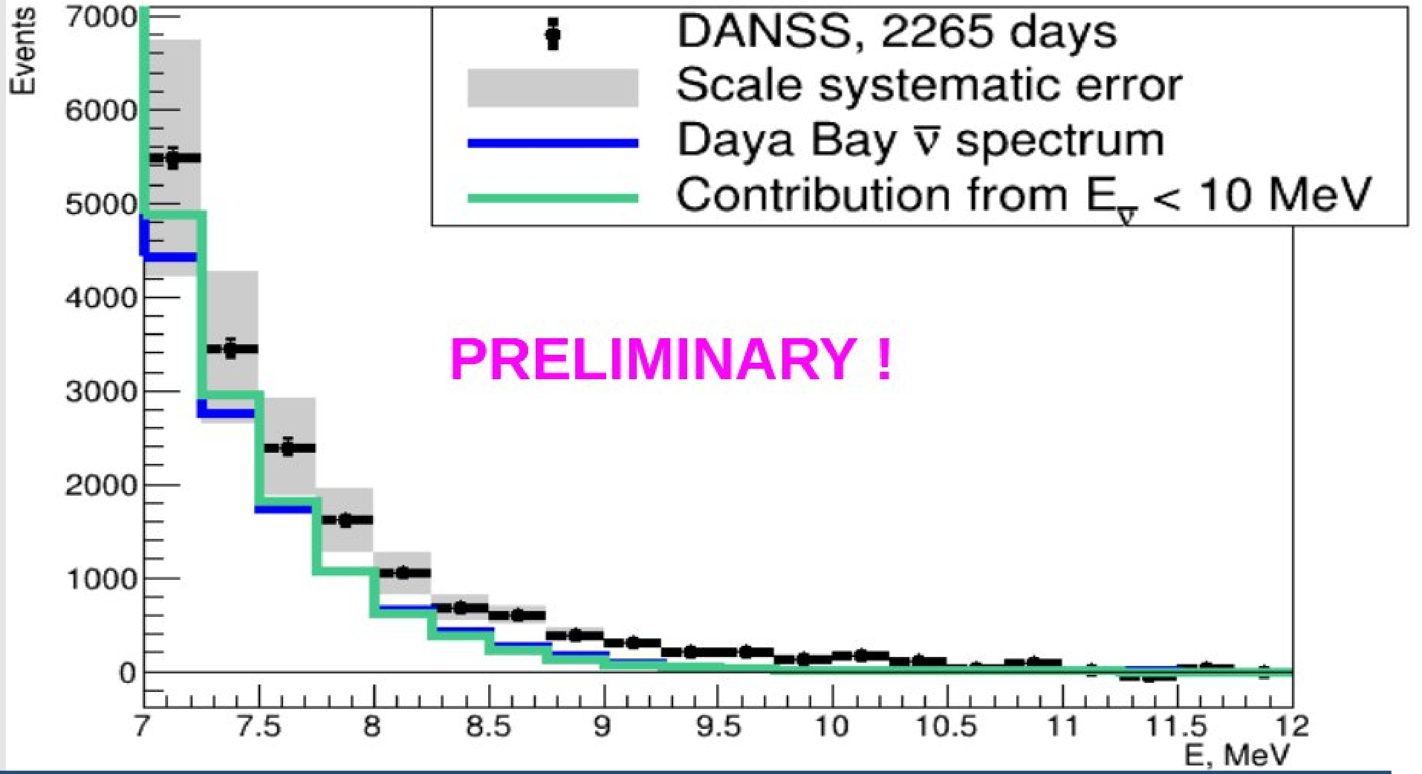


Positron spectra for ^{235}U and ^{239}Pu were reconstructed using IBD rate dependence on ^{239}Pu fission fraction (^{241}Pu and ^{238}U spectra were fixed to HM model)

Neutrino spectra were reconstructed using SVD method

High energy reactor antineutrino spectrum





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 ± 0.14stat ± 0.16sys)·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]