3rd IAEA Technical Meeting on Nuclear data for antineutrino spectra applications

APR '7

DANSS detector. Status and modernization

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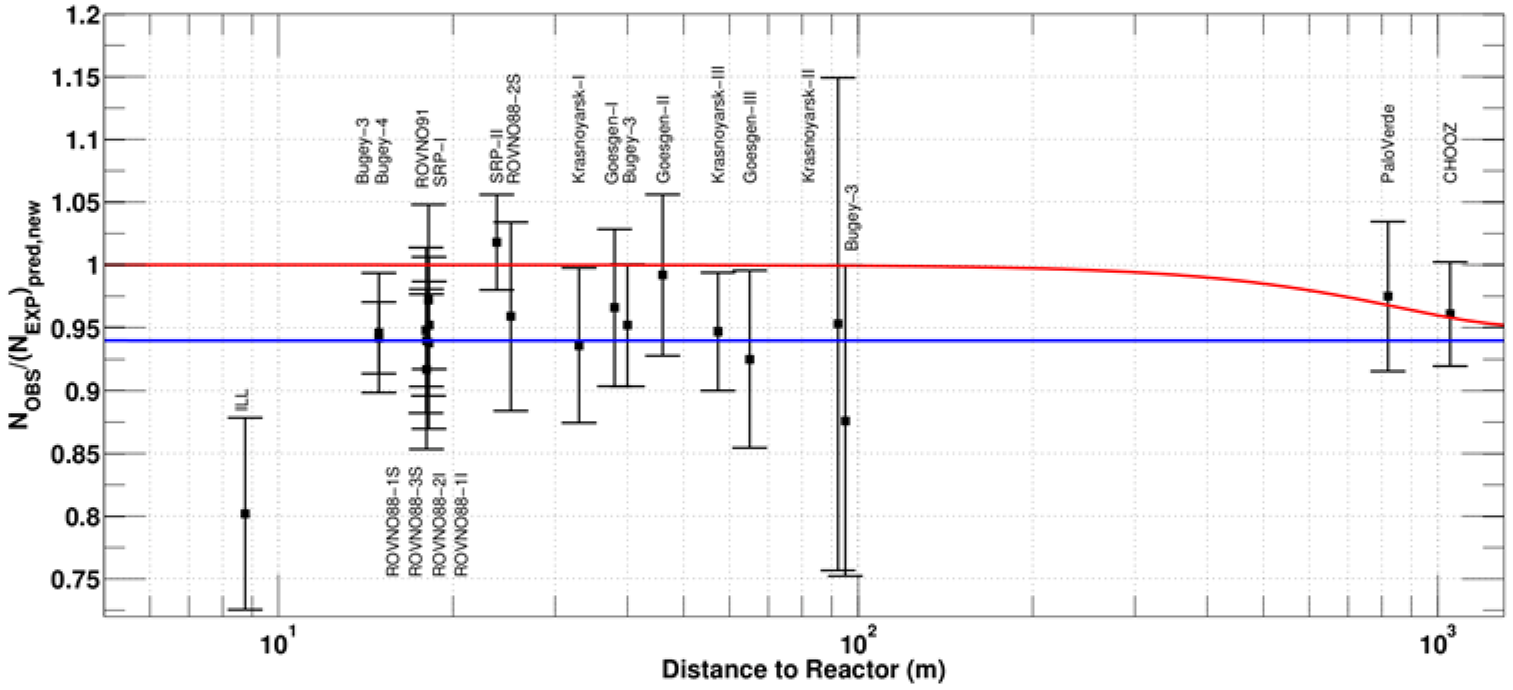
on behalf of DANSS collaboration

ОИЯИ

Motivation (fundamental)

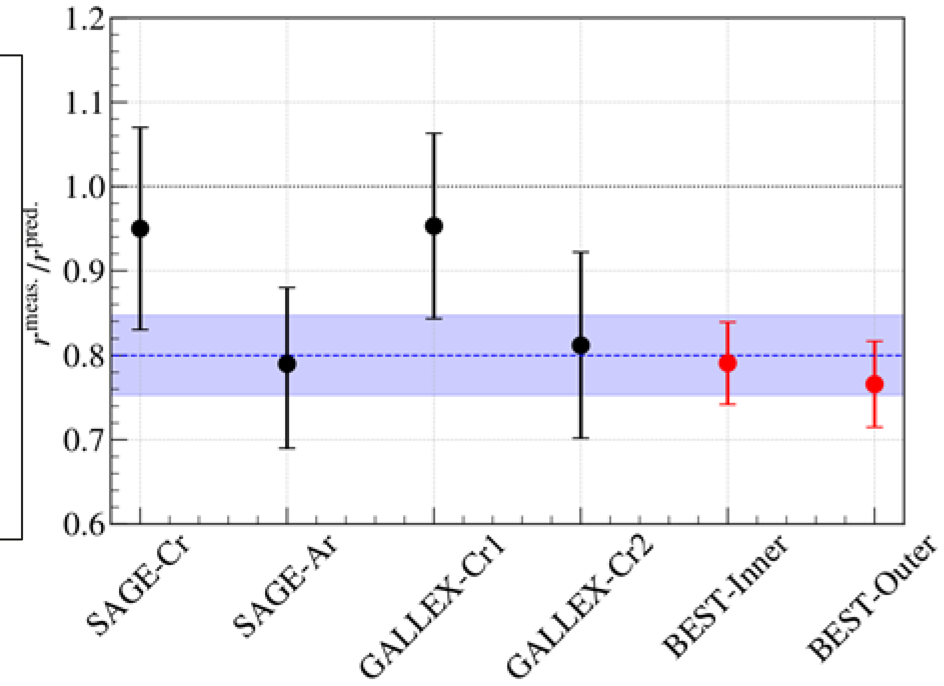
The Reactor Antineutrino Anomaly
[Phys.Rev.D83:073006 (2011)]



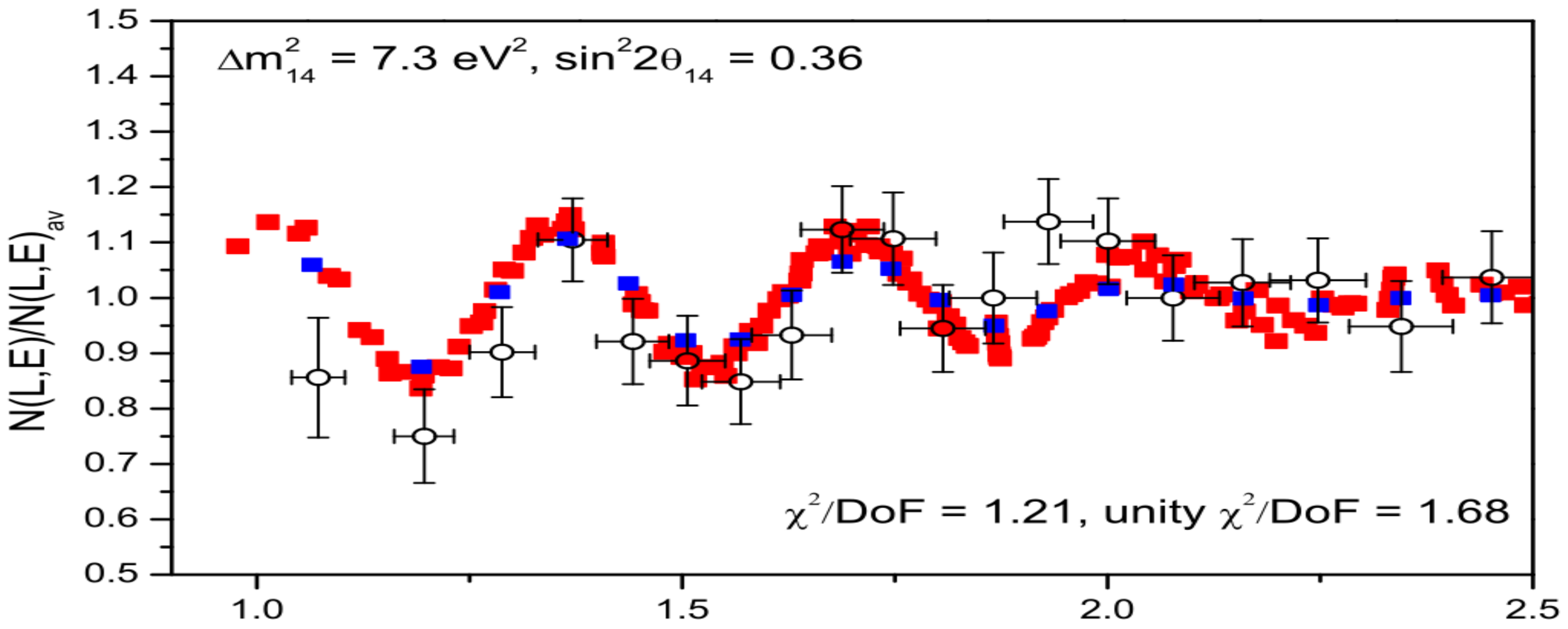
Reactor antineutrino anomaly (RAA): defect in reactor $\tilde{\nu}$ fluxes 3σ (Phys.Rev.C 83 054615).
Probably explained by Kurchatov Institute (KI) (arXiv:2103.01684v1), Daya Bay, RENO results.

Gallium anomaly + new BEST results
[Phys. Rev. C 105, 065502 (2022)]

Galium anomaly (SAGE, GALEX): defecit of ν_e in calibration runs with radioactive sources (Phys.Rev.C 83 065504).
Results from BEST (PhysRevLett.128.232501) confirm GA. Signicance > 5σ



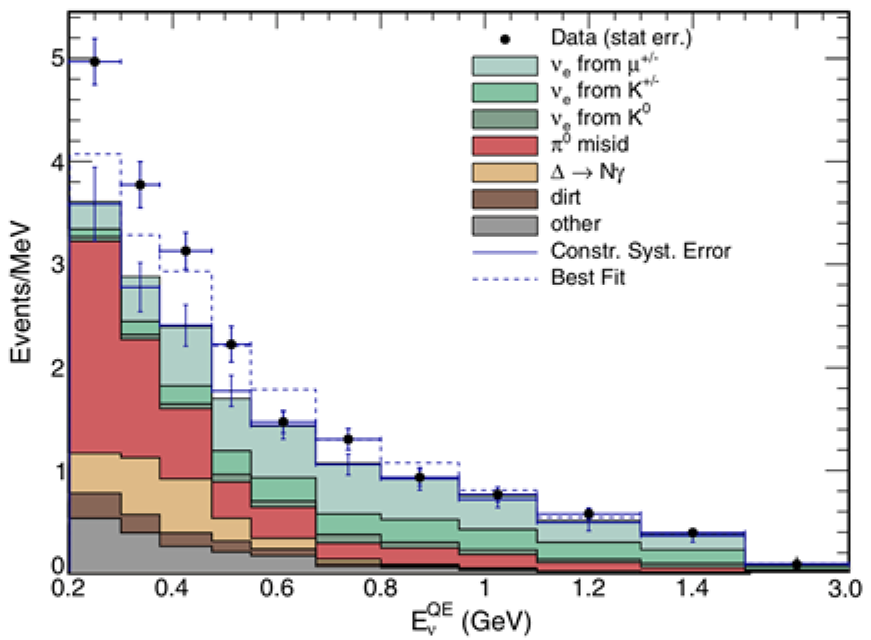
Neutrino-4 results
[Phys. Rev. D 104, 032003 (2021)]



Neutrino4: disappearance of $\tilde{\nu}$ from reactor.
Signicance 2.7σ (Jetp Lett. 109, 213-221 (2019), Phys. Rev. D 104, 032003 (2021)).

Accelerator anomaly
[PRL 128, 221801 (2018)]

LSND and MiniBoone: appearance of $\tilde{\nu}_e$in $\tilde{\nu}_\mu$ beam at short distances.
Signicance – 6σ for combined results.
(Phys.Rev.Lett. 121, 221801 (2018)).
Not conrmed by MicroBoone (arXiv:2110.14054v2) but not excluded



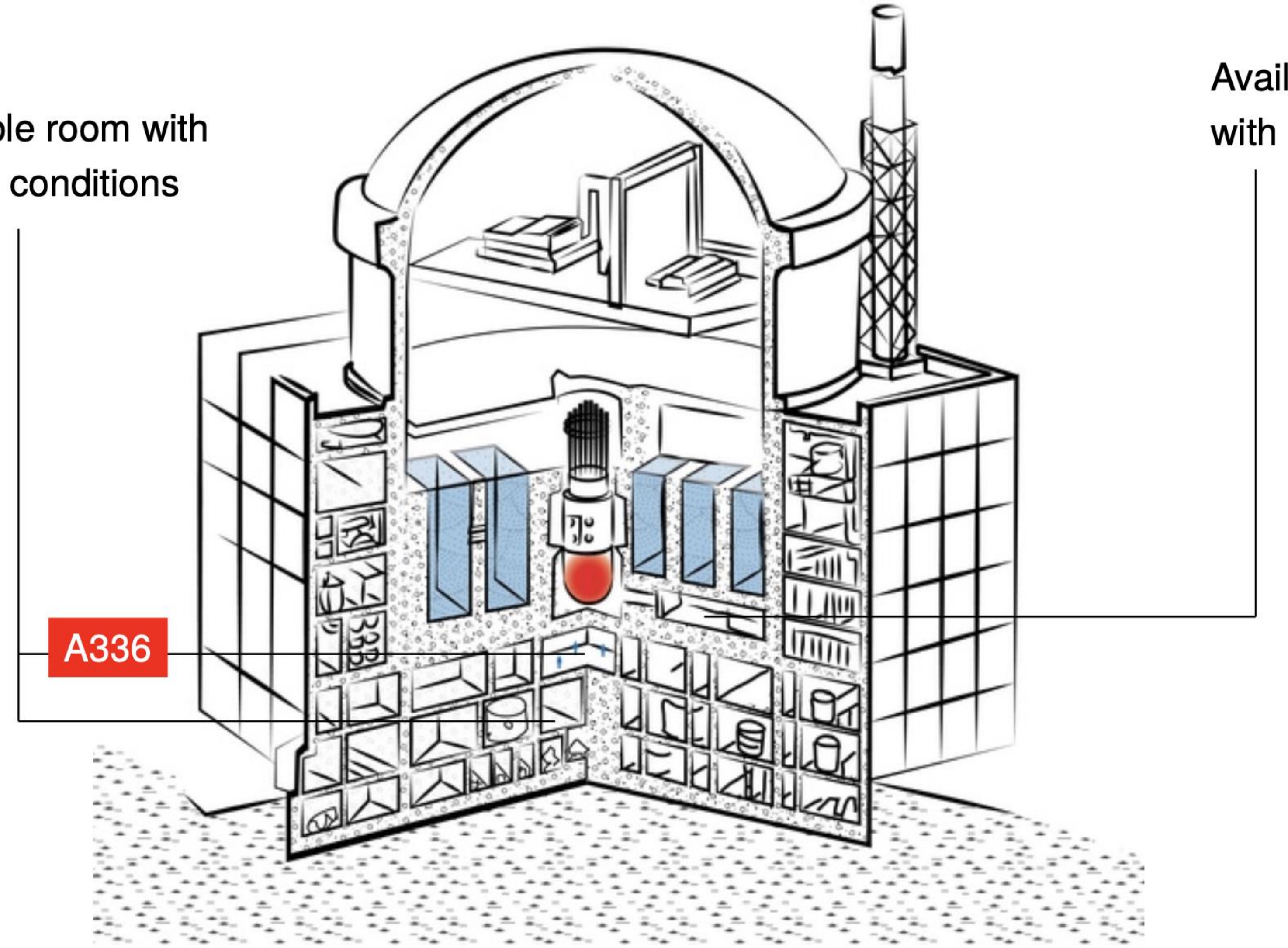
Anomalies can be described by 3+1ν model at short baseline:

$$P_{ee} \approx 1 - sin^2(2\theta_{41})sin^2(1.27\frac{\Delta m^2_{41}[eV^2]L[m]}{E_{\bar{\nu}_e}[MeV]})$$

Motivation (practical)

Reactor antineutrino flux is *almost* proportional to the reactor thermal power:

Available room with normal conditions



Available room with hard conditions:

- air temperature $\simeq 50°$C
- air pressure up to 5 atm (during pressure tests)
- high γ-background
- access time is limited by OFF periods only

$$P(t,T) = F(t)\sum_{i-1}^{4} f_i(T)e_i$$

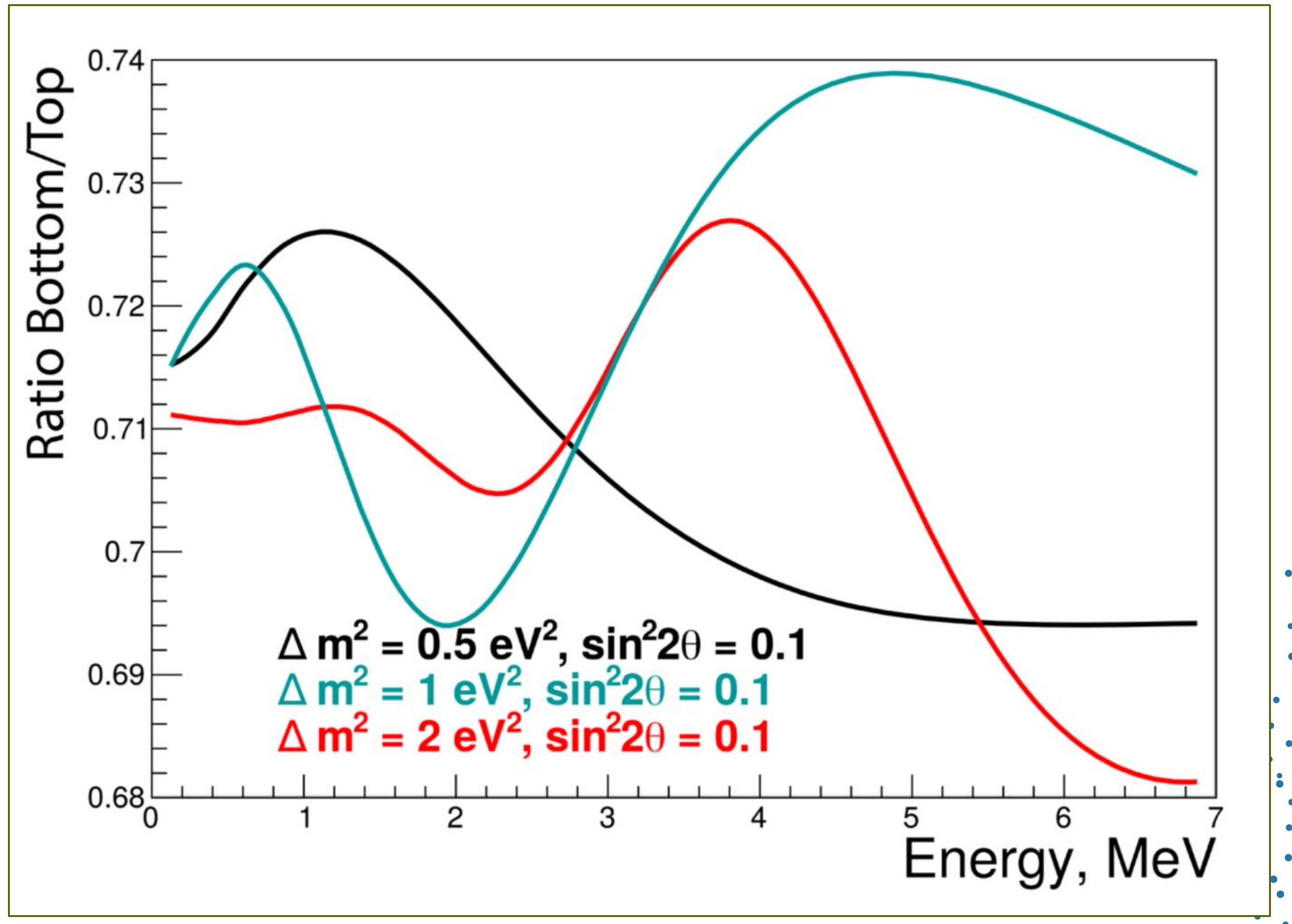
$$C(t,T) = \alpha F(t)\sum_{i-1}^{4} f_i(T)I_i$$

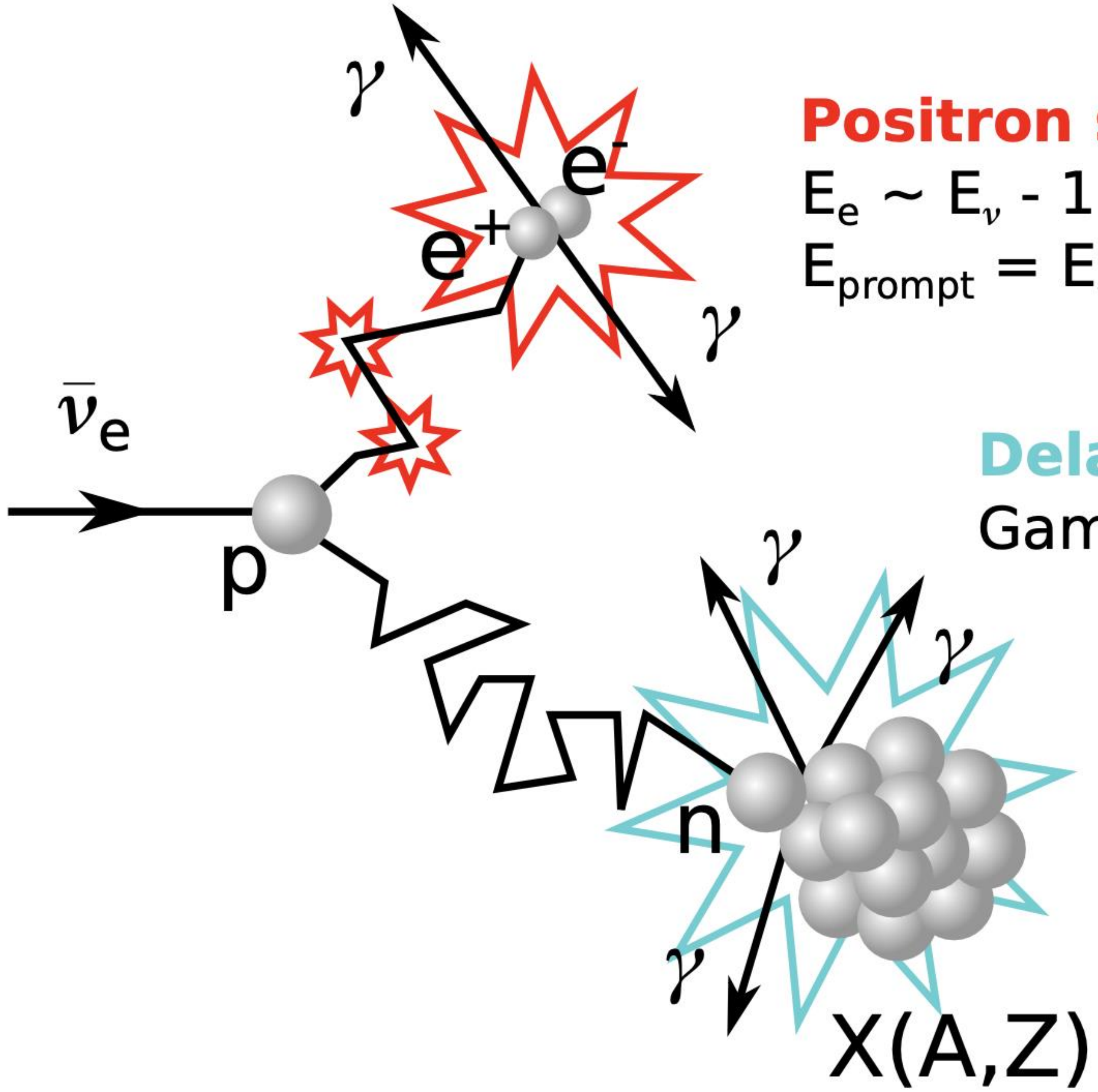
T – time from the campaign start,
F(t) – number of fissions per second
e_i – average fission energy of the *i* isotope
a – detector efficiency
I_i – Integral positron spectra

- Independent reactor power monitoring
- Determination of fuel burnout
- Reactor tomography

The detection idea

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





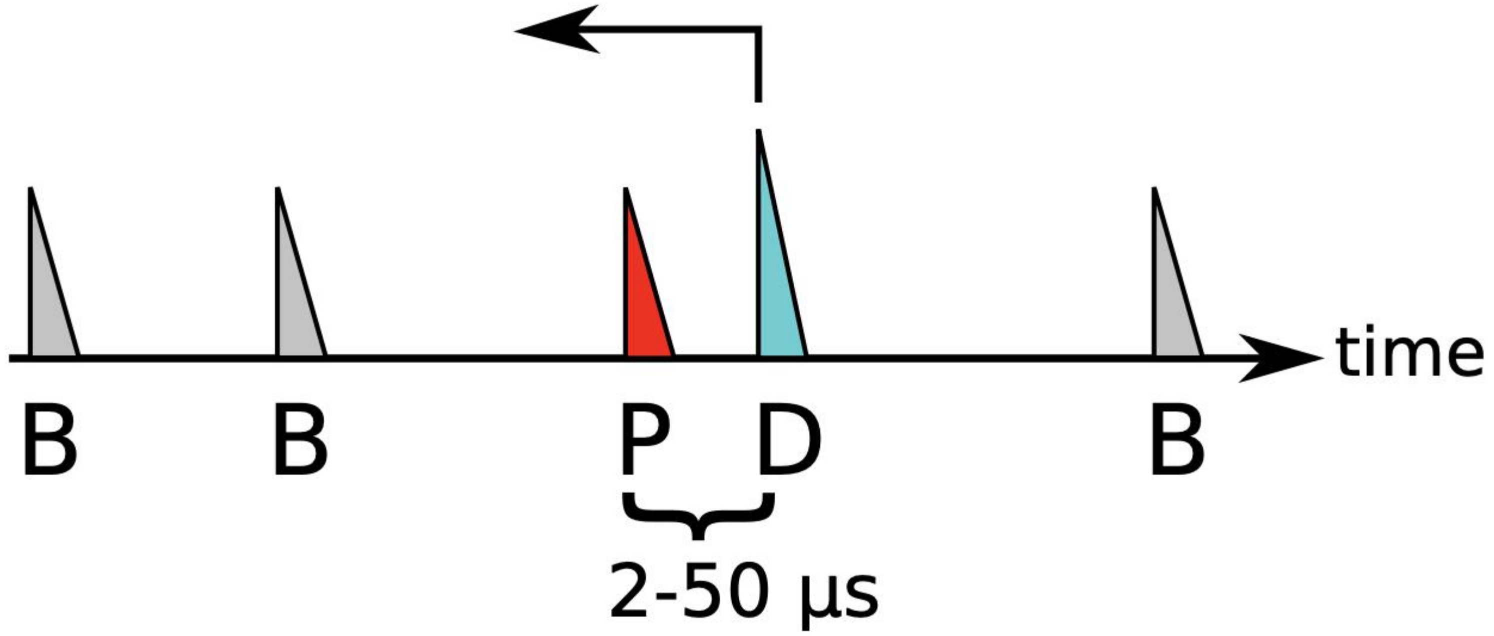
Positron signal

$E_e \sim E_\nu$ - 1.806 MeV

$E_{prompt} = E_e + E_{2\gamma}$

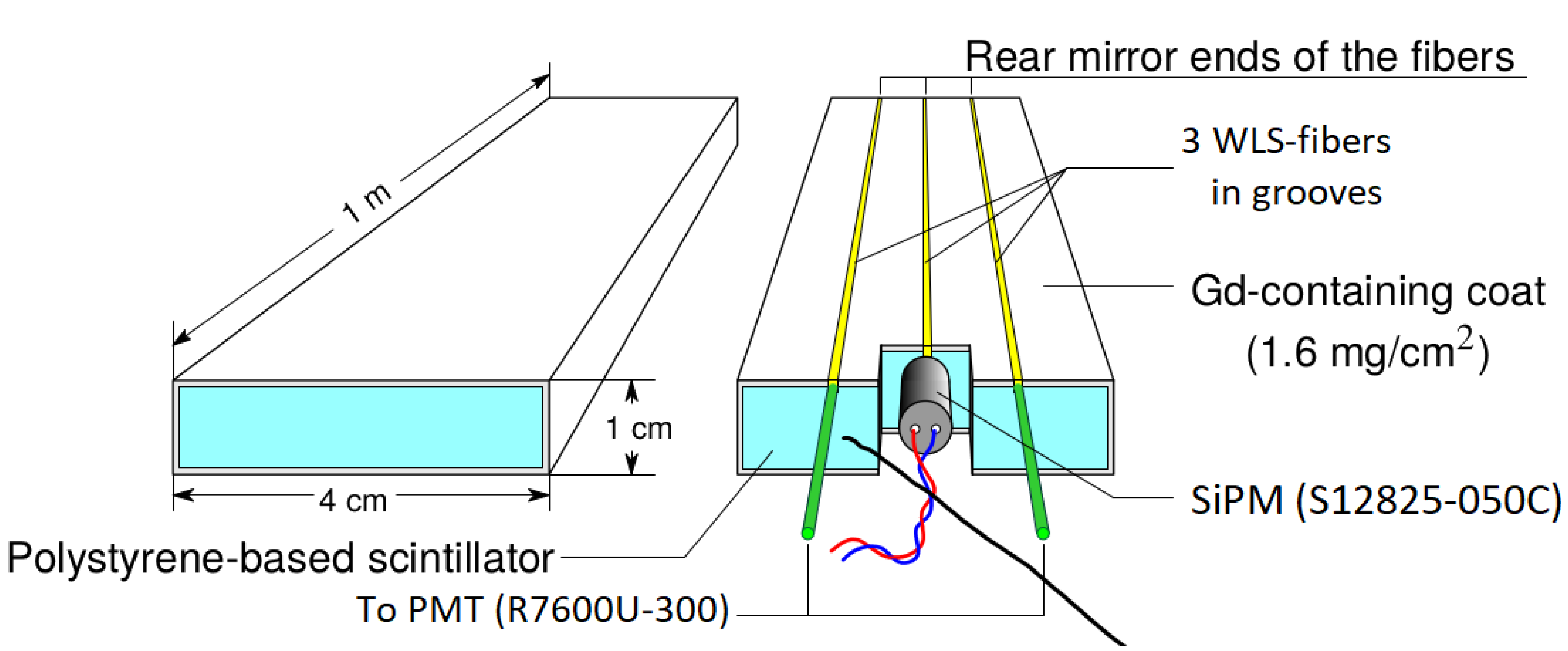
Delayed signal

Gamma flush in the whole detector

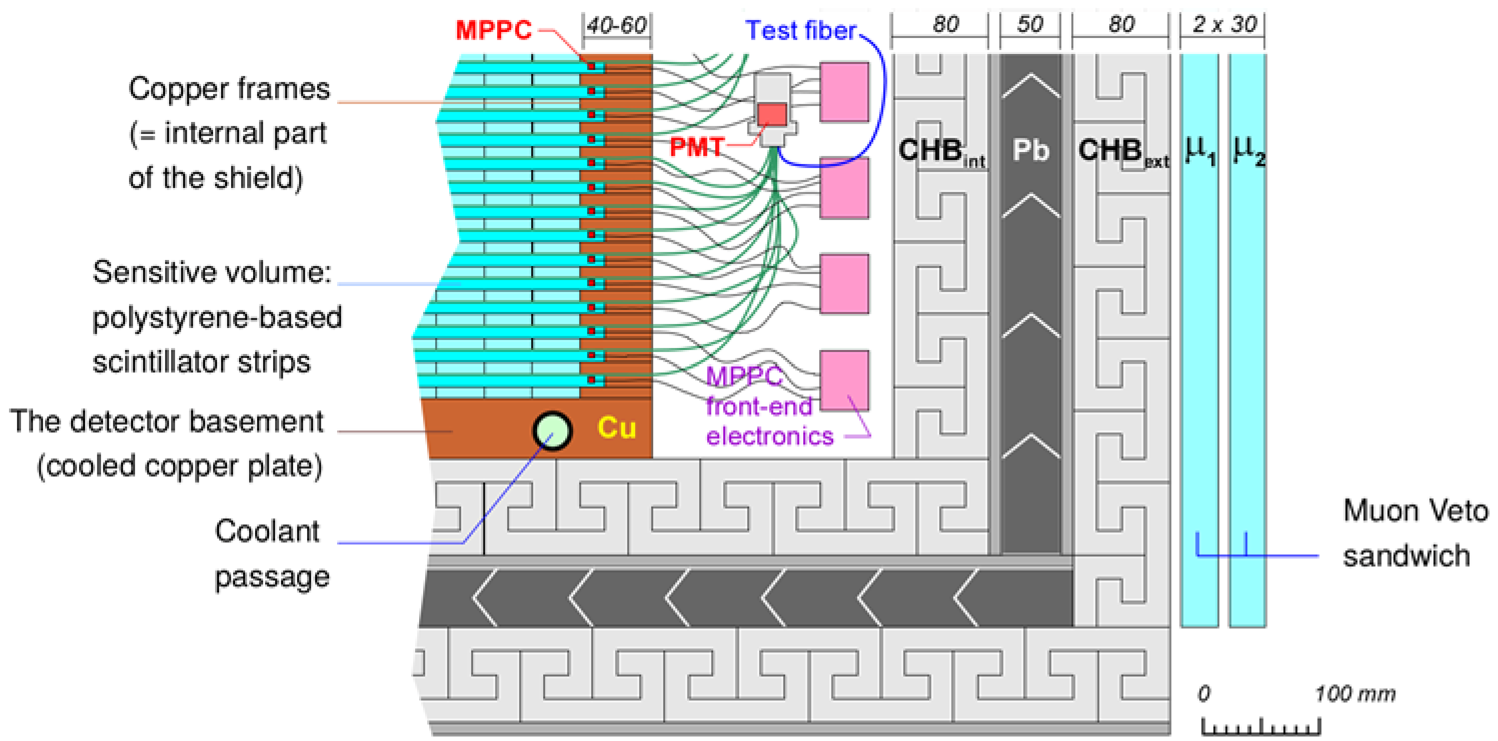


Scintillator for positron and gammas
Gadolinium for neutrons capture

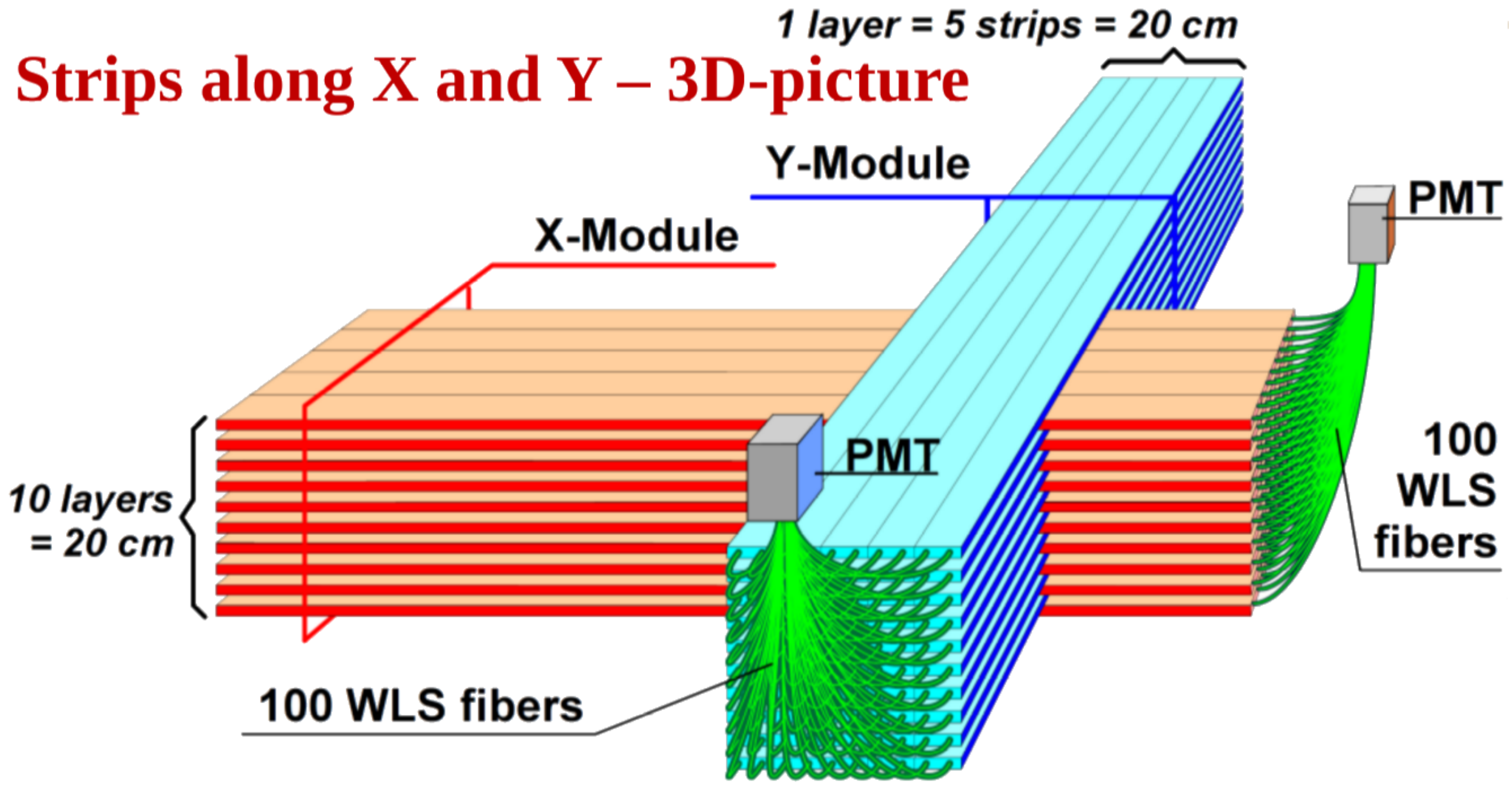
Detector



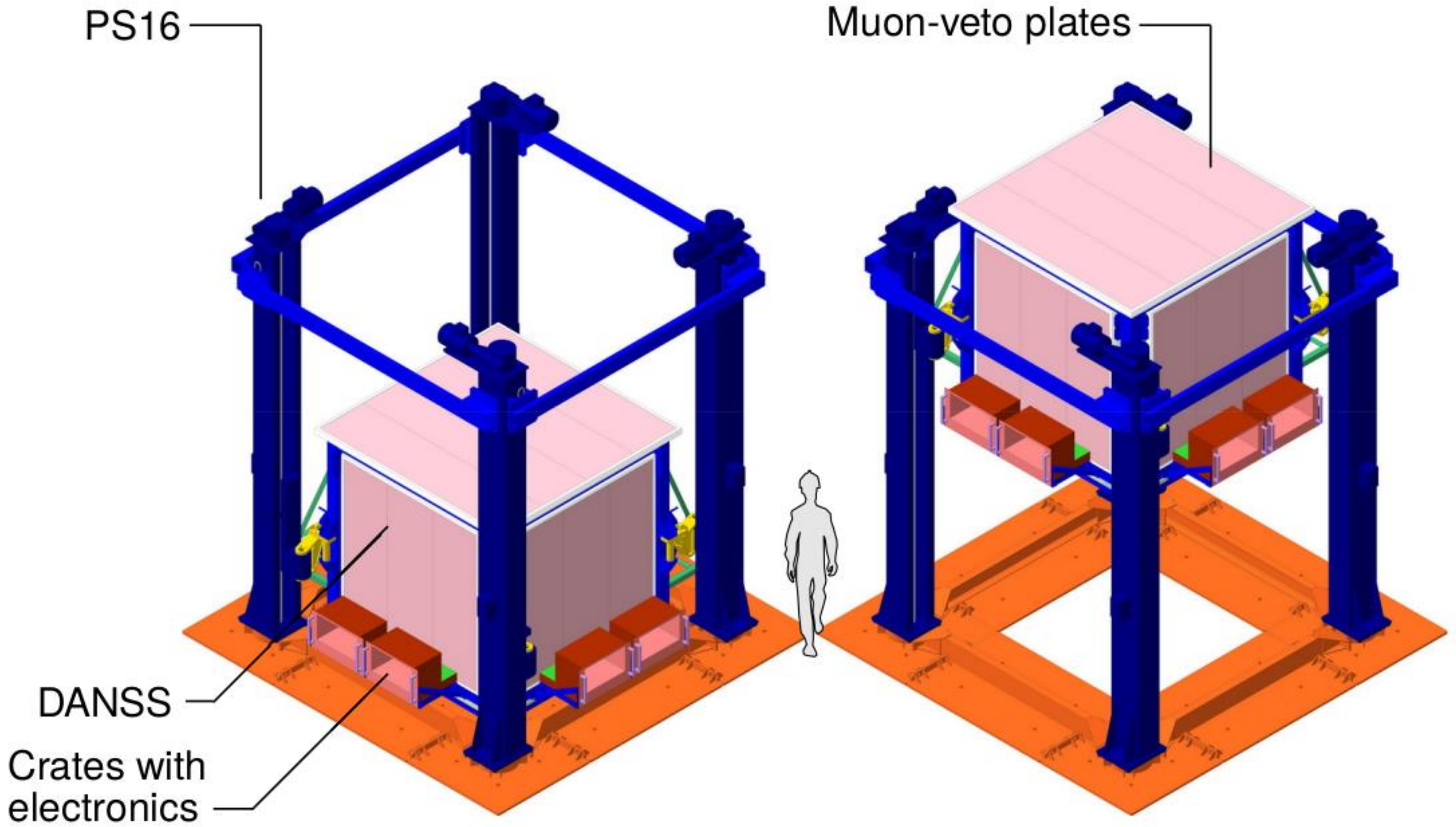
Rear mirror ends of the fibers
1 m
3 WLS-fibers
in grooves
Gd-containing coat
(1.6 mg/cm^2)
1 cm
4 cm
SiPM (S12825-050C)
Polystyrene-based scintillator
To PMT (R7600U-300)



MPPC
40-60
Test fiber
80
50
80
2 x 30
Copper frames
(= internal part
of the shield)
PMT
CHB$_{int}$
Pb
CHB$_{ext}$
μ_1
μ_2
Sensitive volume:
polystyrene-based
scintillator strips
MPPC
front-end
electronics
The detector basement
(cooled copper plate)
Cu
Coolant
passage
Muon Veto
sandwich
0
100 mm

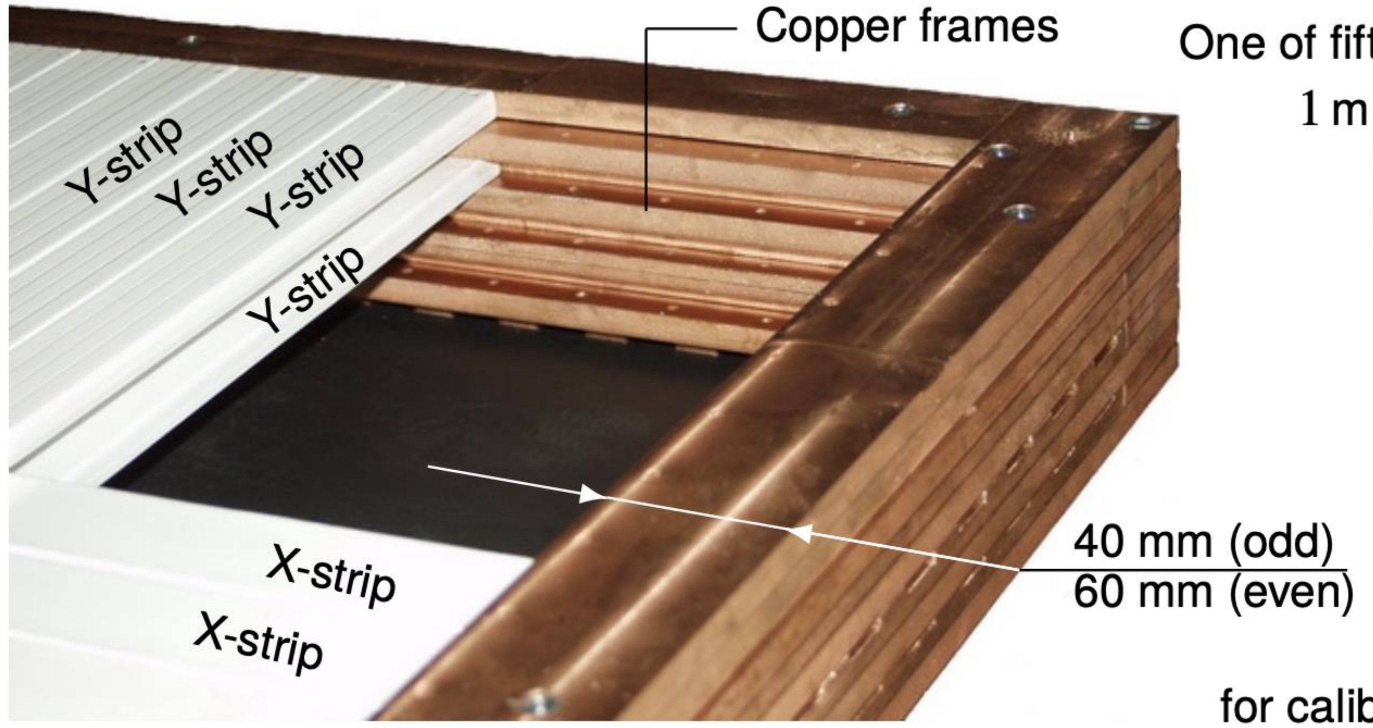


1 layer = 5 strips = 20 cm
Strips along X and Y – 3D-picture
Y-Module
X-Module
PMT
PMT
100
WLS
fibers
10 layers
= 20 cm
100 WLS fibers

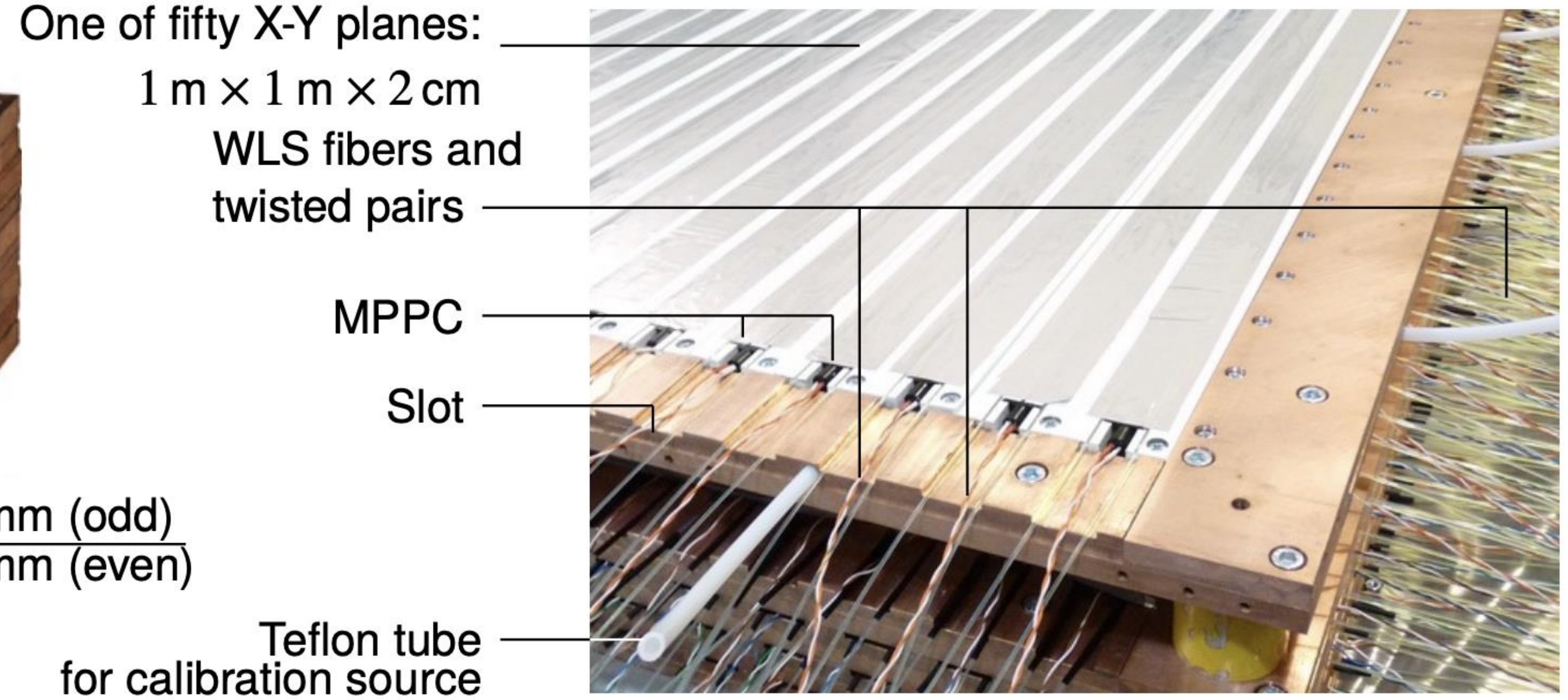


PS16
Muon-veto plates
DANSS
Crates with
electronics

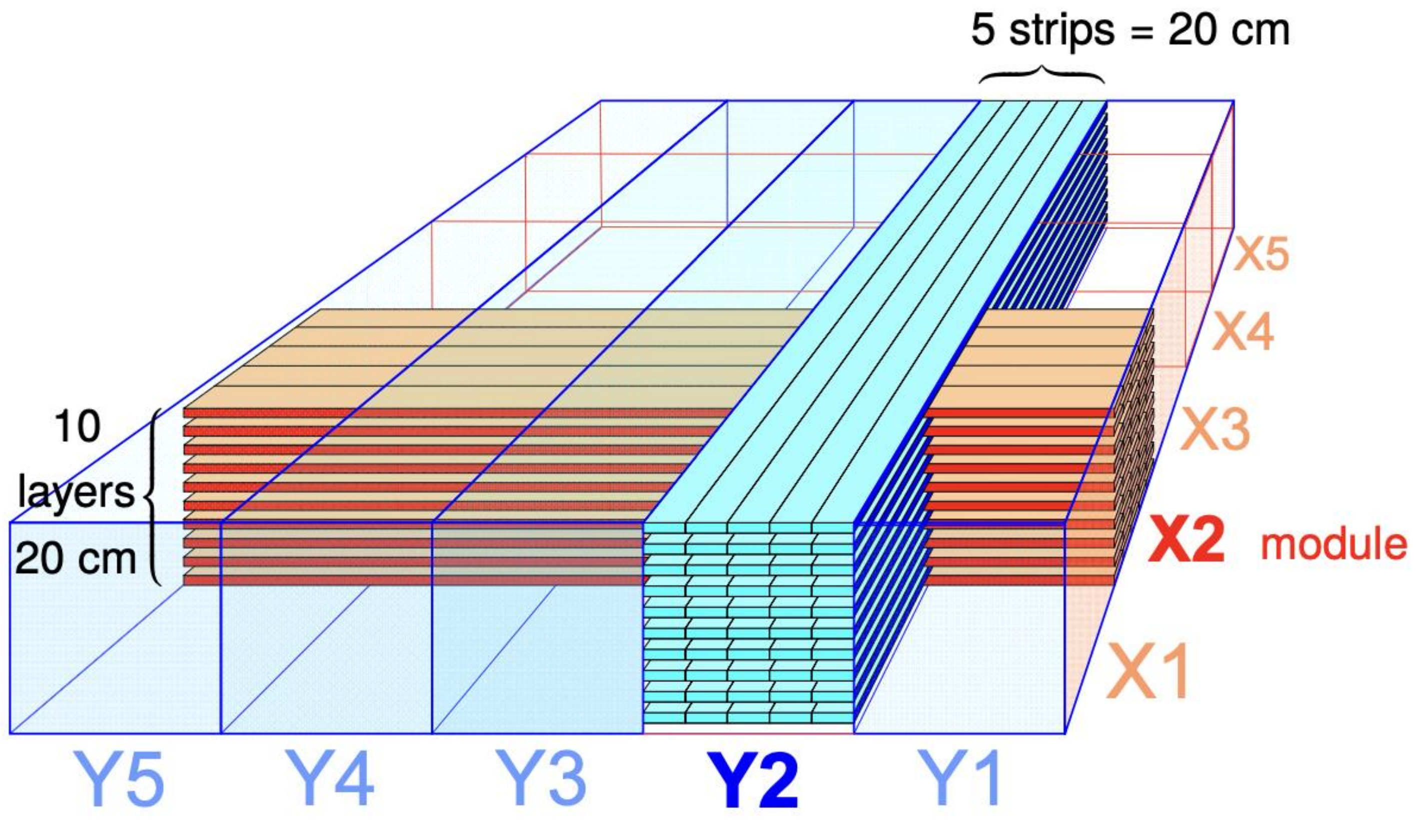
Detector



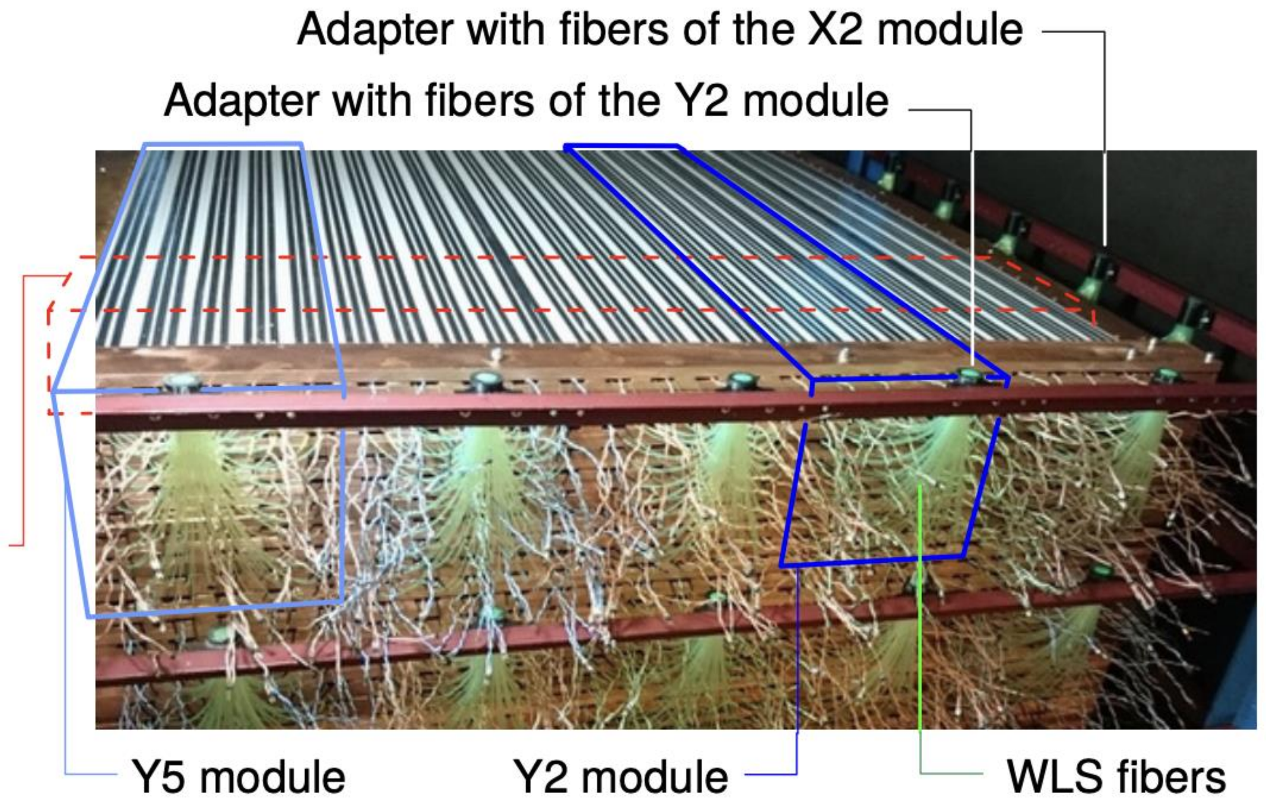
Copper frames
Y-strip
Y-strip
Y-strip
Y-strip
X-strip
X-strip
40 mm (odd)
60 mm (even)



One of fifty X-Y planes:
$1\,\mathrm{m} \times 1\,\mathrm{m} \times 2\,\mathrm{cm}$
WLS fibers and
twisted pairs
MPPC
Slot
Teflon tube
for calibration source

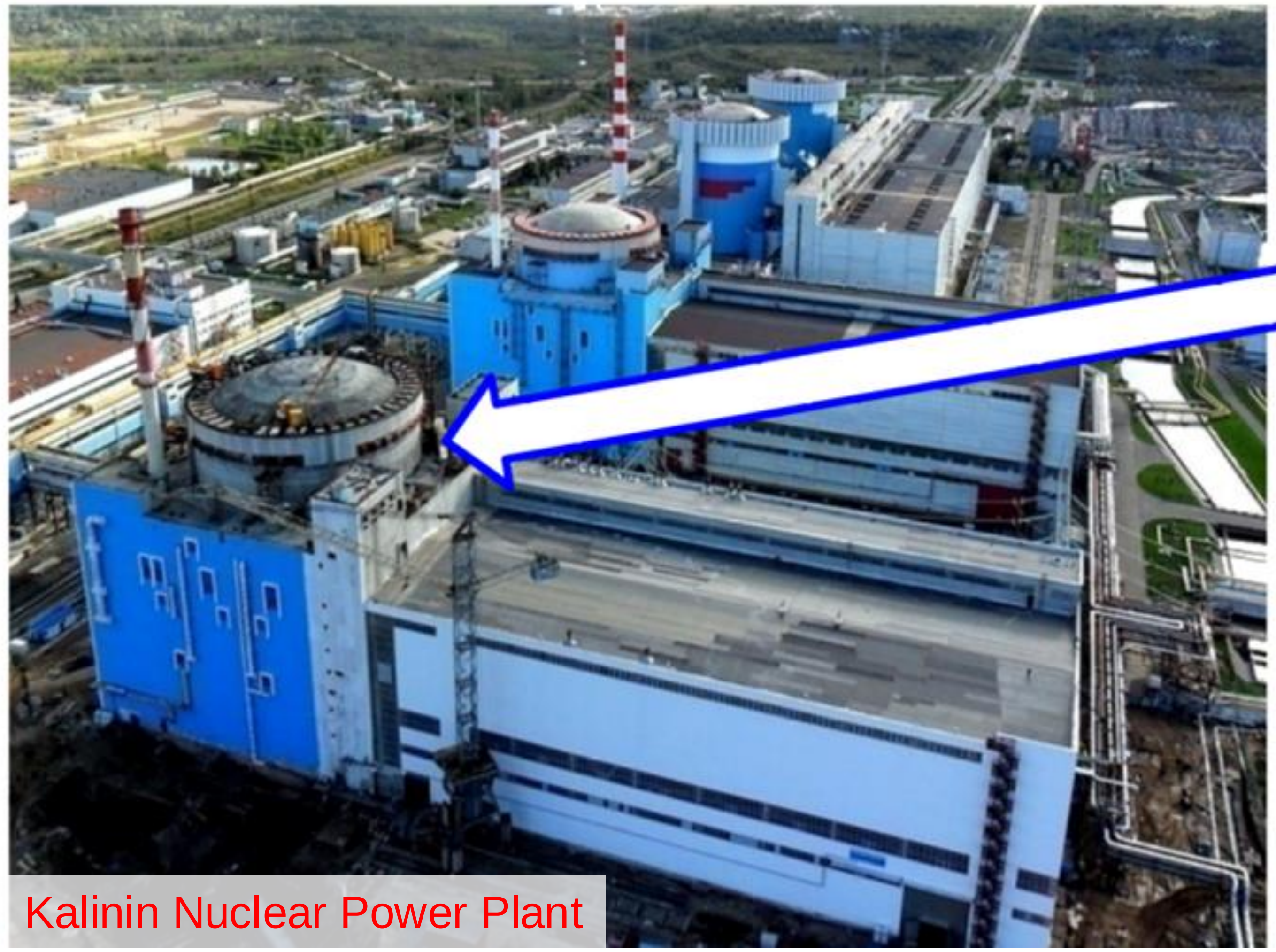


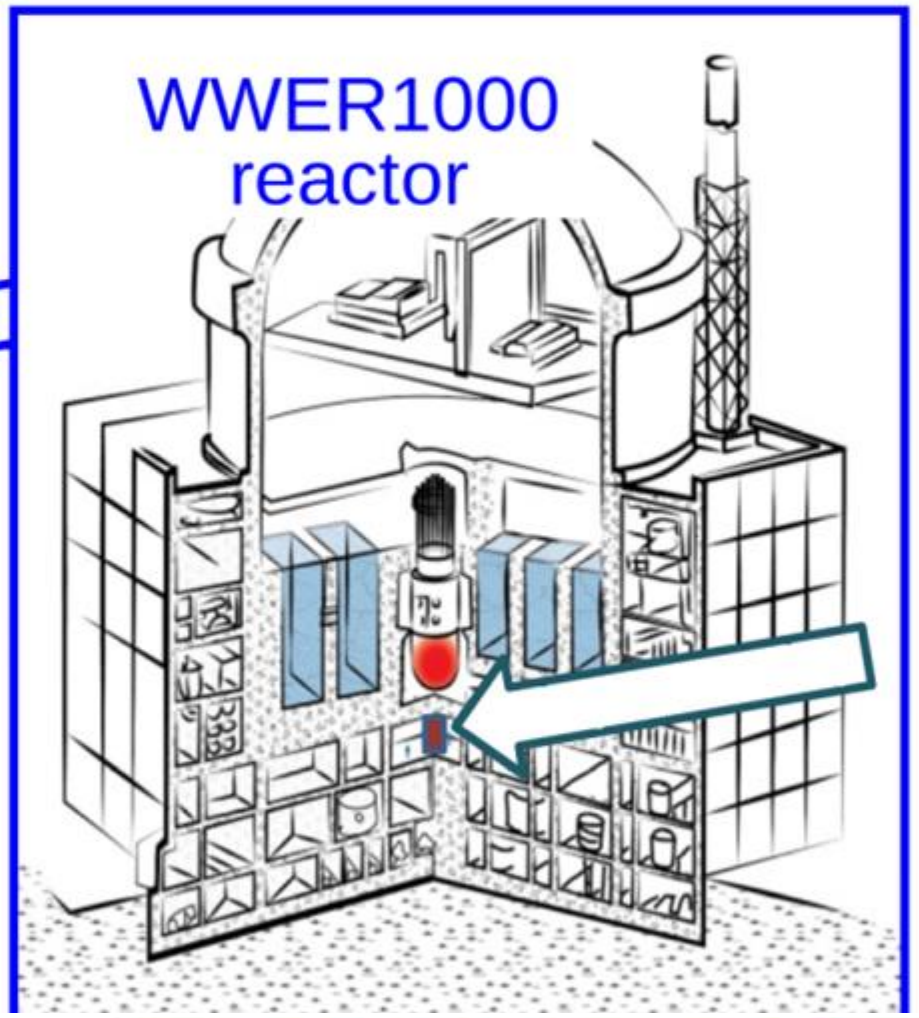
5 strips = 20 cm
10
layers
20 cm
X5
X4
X3
X2 module
X1
Y5
Y4
Y3
Y2
Y1



Adapter with fibers of the X2 module
Adapter with fibers of the Y2 module
Y5 module
Y2 module
WLS fibers

DANSS (Detector of the reactor AntiNeutrino based on Solid-state Scintillator)

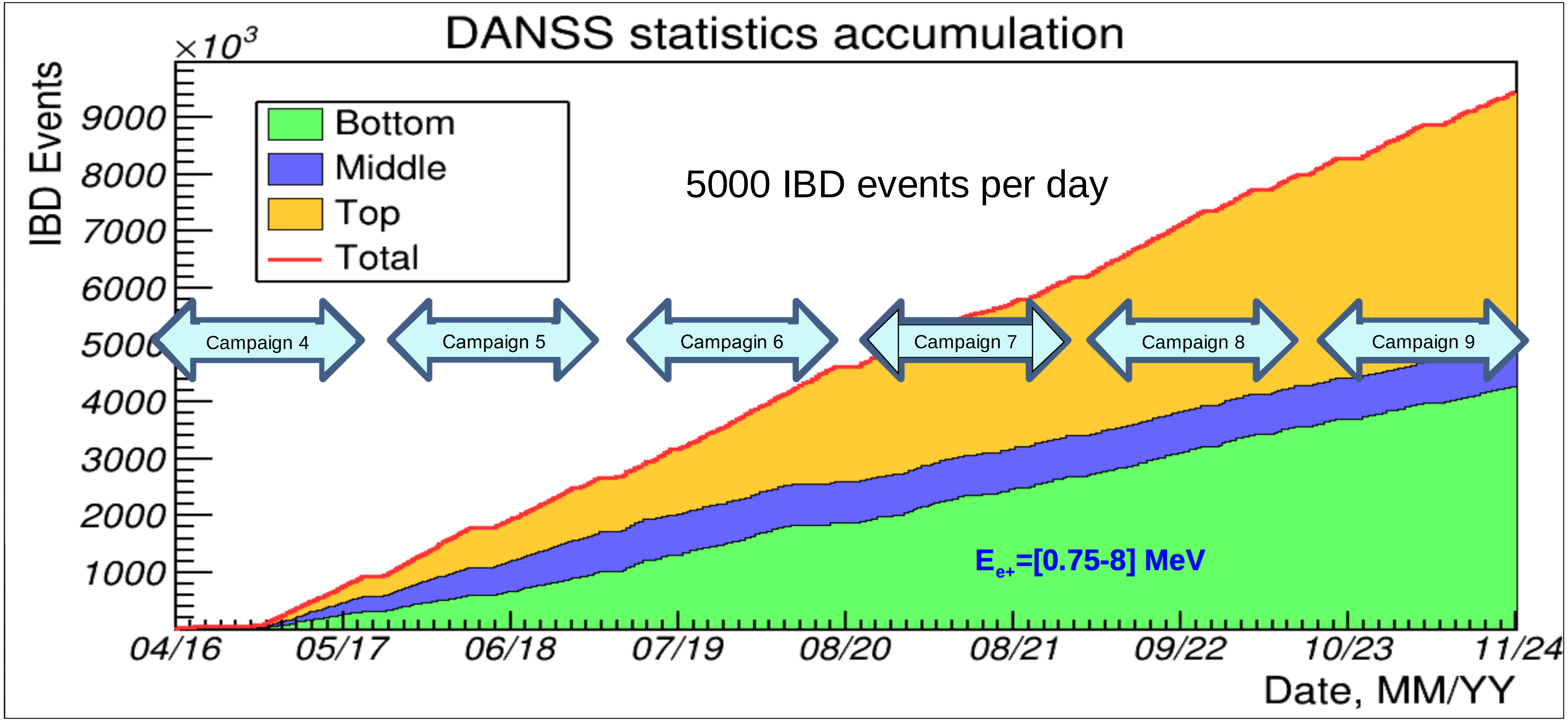




- Located below 3.1 GW_{th} commercial reactor **~5·10^{13} ν·cm^{-2}c^{-1}@11m**
- Reactor provide overburden **~50 m w.e.** for cosmic background suppression
- Lifting system allows to change the distance between the centers of the detector and of the reactor core **from 10.9 to 12.9** m on-line
- 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 m^3** of sensitive volume
- IBD ($\bar{\nu}_e + p \to e^+ + n$) reaction is used

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

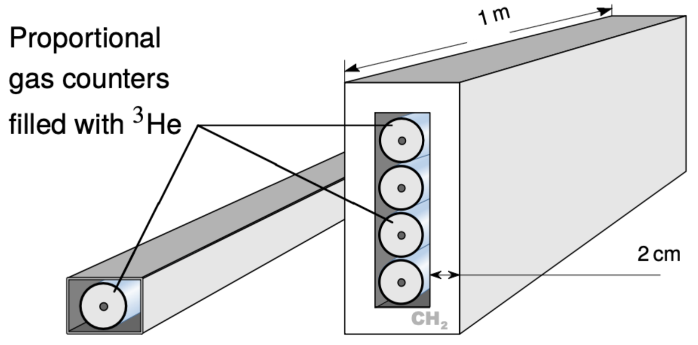
Accumulated data

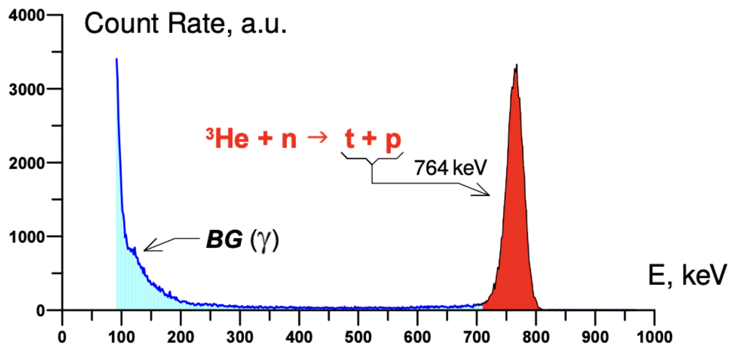


Background

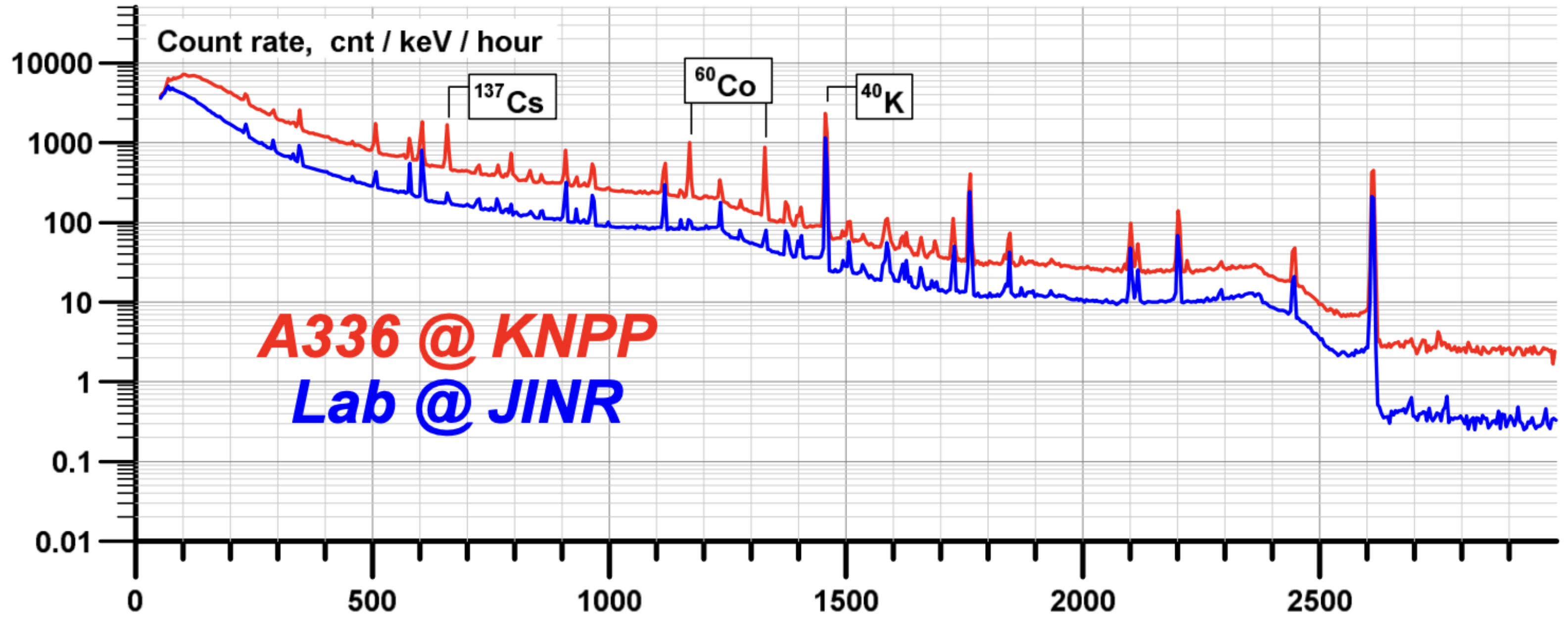
Neutron background

Site	Outdoor	4-A336		
P_r [GW$_{th}$]	—	0	3.1	3.1
CHB [cm]	0	0	0	0
Φ_n [n/m^2/s]	11_2	1.2_1	1240_5	590_3

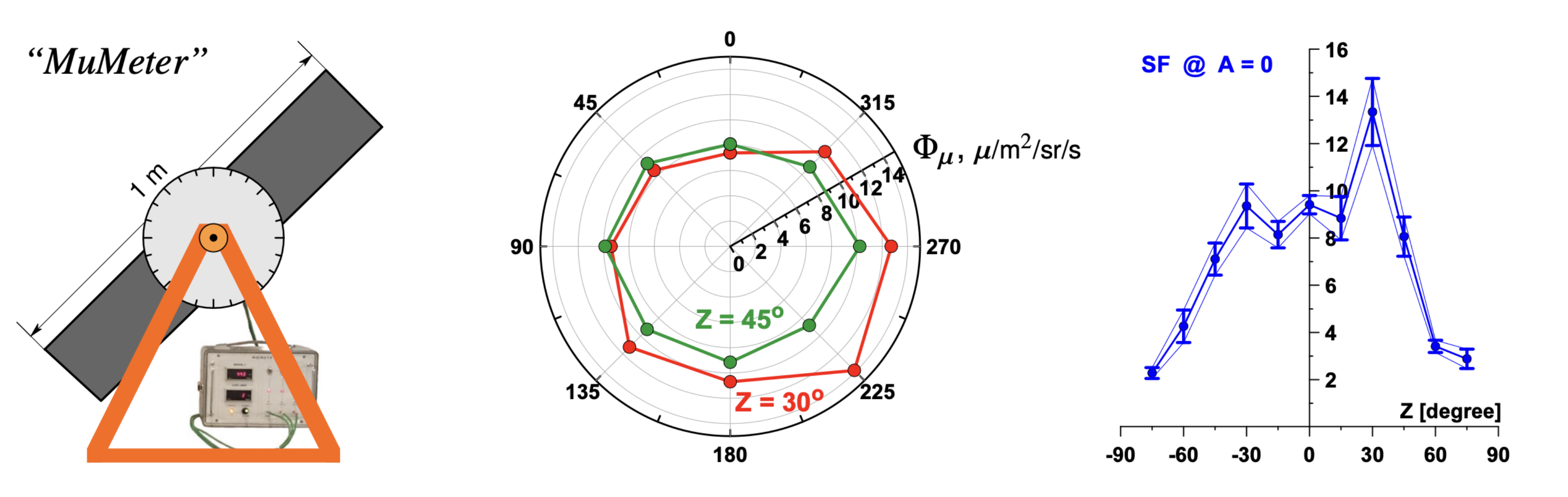




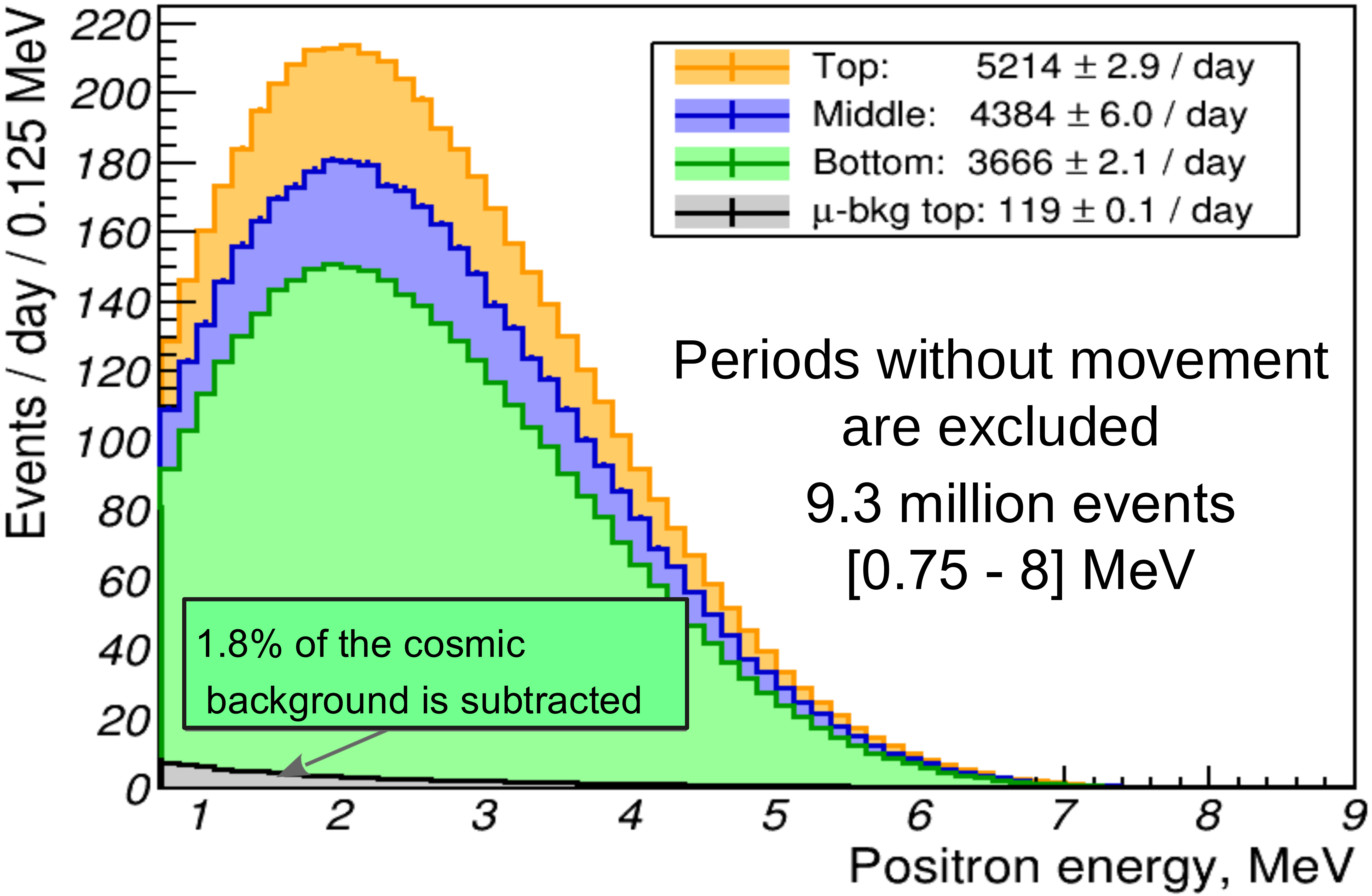
Gamma background



Cosmic background

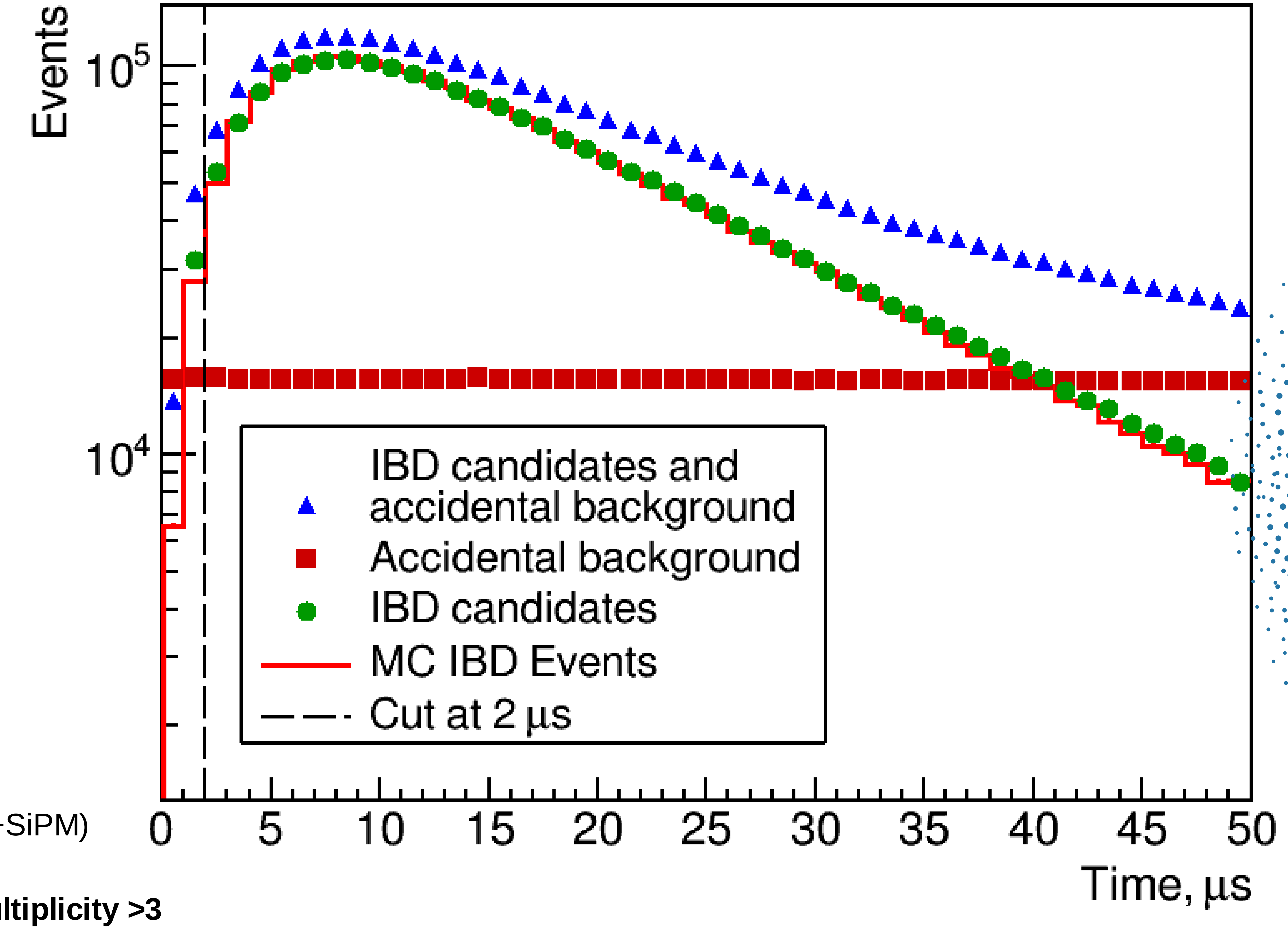


Background



- 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**.

Trigger and events



- **Trigger** = digital sum of **PMT > 0.5 MeV** or VETO
  - Total trigger rate ≈ **1 kHz**
  - Veto rate ≈ **400 Hz**
  - True muon rate ≈ **180 Hz**
  - Positron candidate rate ≈ **170 Hz**
  - Neutron candidate rate ≈ **30 Hz**
  - IBD rate ~ **0.1 Hz**
- **IBD event** = two time separated triggers:
  - Positron track and annihilation
  - Neutron capture by gadolinium
- **SiPM noise cut:**
  - Time window **± 10 ns**
  - SiPM hits require PMT confirmation
- Building **Pairs**
  - **Positron candidate**:
    > 1 MeV in continuous ionization cluster (PMT+SiPM)
  - **Neutron candidate**:
    > 3.5 MeV total energy (PMT+SiPM), **SiPM multiplicity >3**
  - Search **positron 50 µs backwards** from **neutron**

Significant background by uncorrelated triggers. Subtract accidental background events: search for a positron candidate where it can not be present **– 50 µs intervals 5, 10, 15 ms** etc. away from neutron candidate. Use **16 non-overlapping intervals** to reduce statistical error. All physics distributions = events - accidental events/16

Selection criteria

Cuts – suppress accidental and muon induced backgrounds:

- Fiducial volume - positron cluster position: 4 cm from all edges
- Positron cluster has < 8 strips
- Energy in the prompt event beyond the cluster < 1.2 MeV and there are < 12 hits out of the cluster
- Delayed event energy is < 9.5 MeV and number of hits is < 20
- Positron (cluster) energy E_e dependent cuts on prompt to delayed cluster distance and delayed event energy:

$$L_{2D}[cm] < 40 - 17 \cdot e^{-0.13 \cdot E_e^2}$$

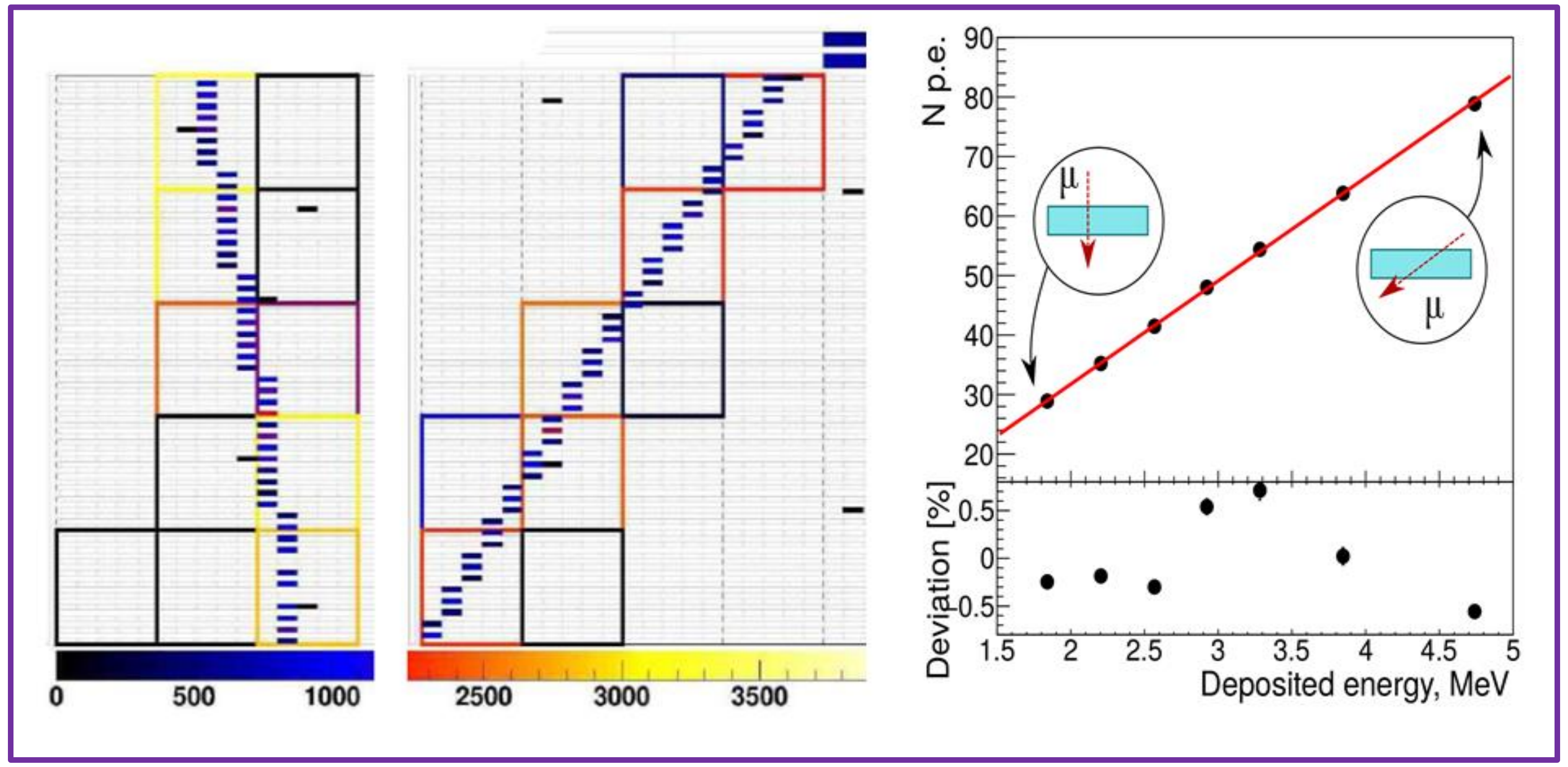
$$L_{3D}[cm] < 48 - 17 \cdot e^{-0.13 \cdot E_e^2}$$

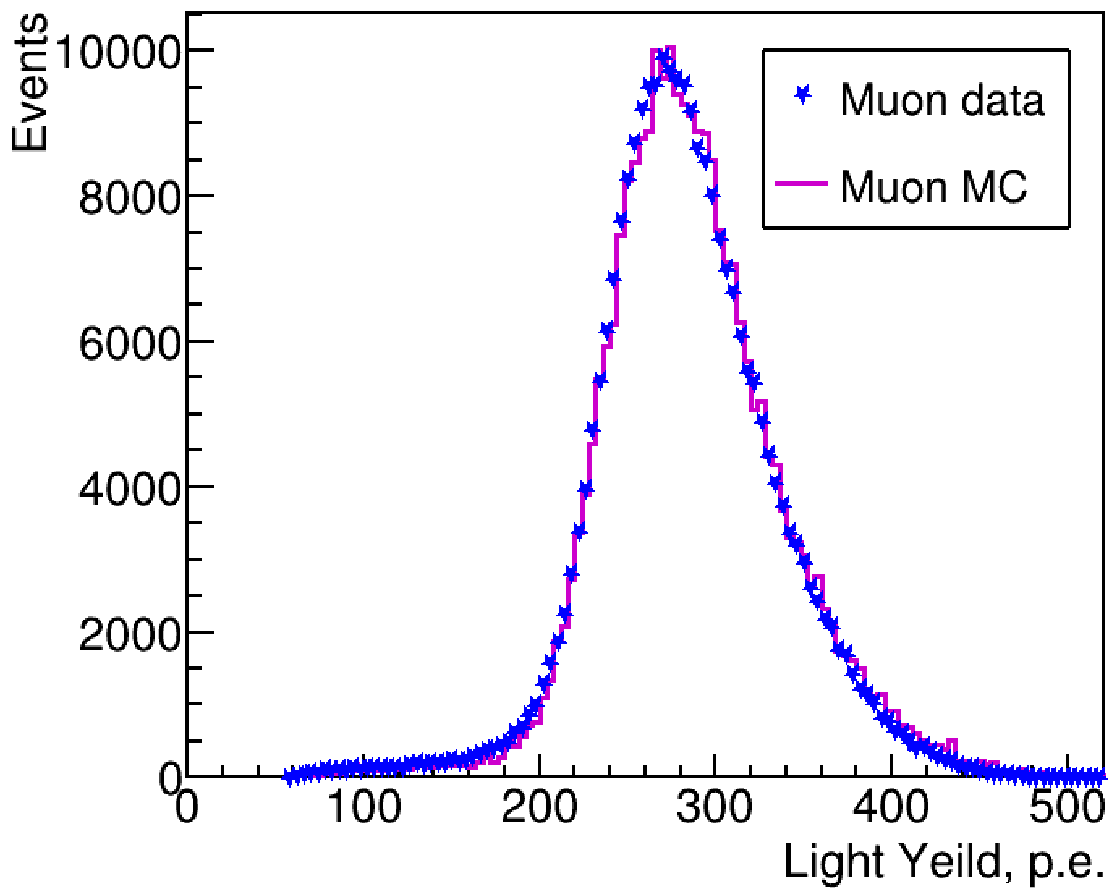
$$E_N[MeV] > 1.5 + 2.6 \cdot e^{-0.15 \cdot E_e^2}$$

For events with single hit positron cluster additional requirement of at least a hit out of the cluster and the energy beyond the cluster > 0.1 Me

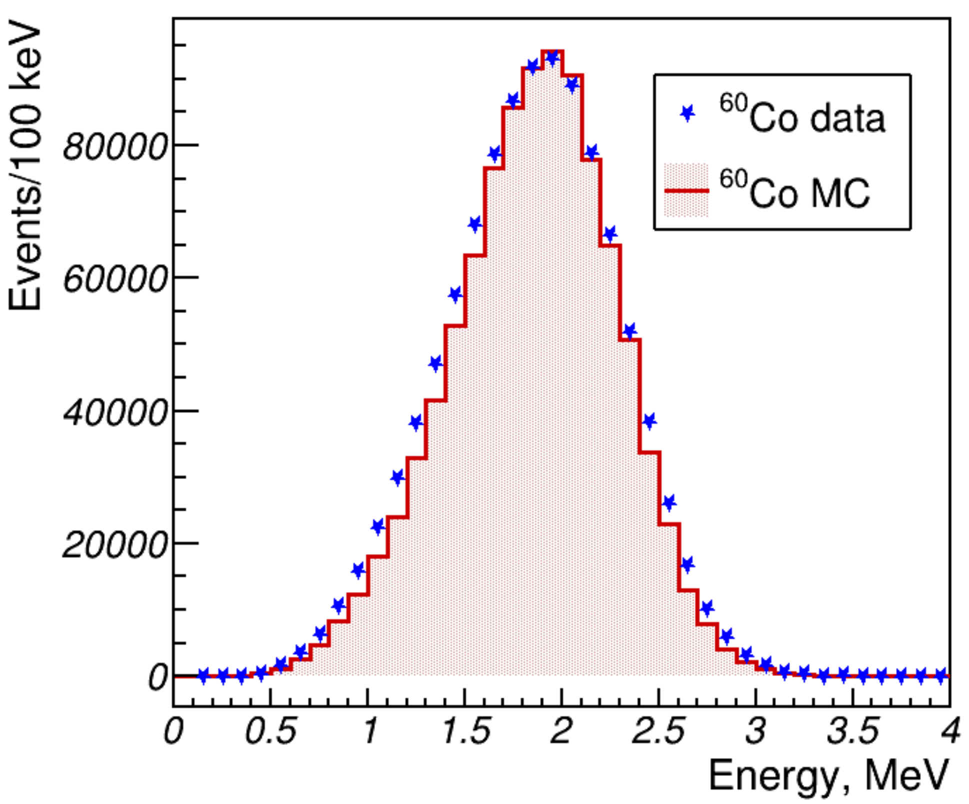
Calibration

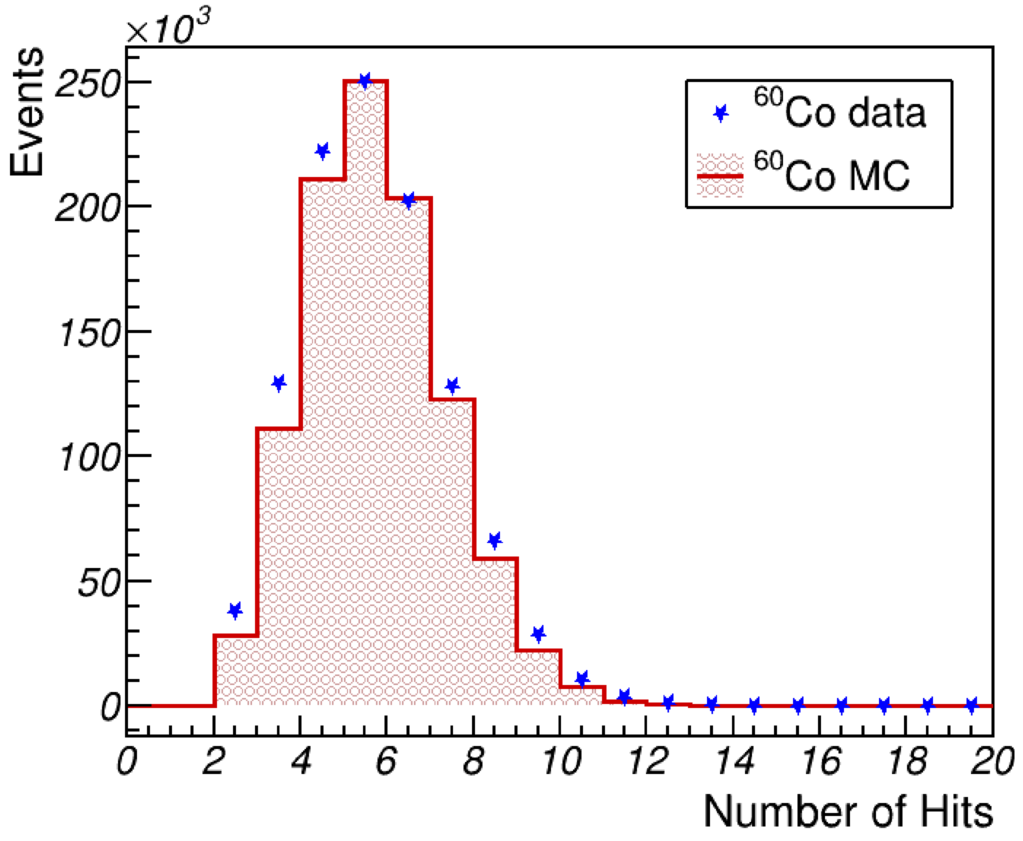
2500 SiPM gains and X-talks are calibrated **every 30-40 min**.
All **2550 channel**s are calibrated **every 1-2 days** using cosmic muons

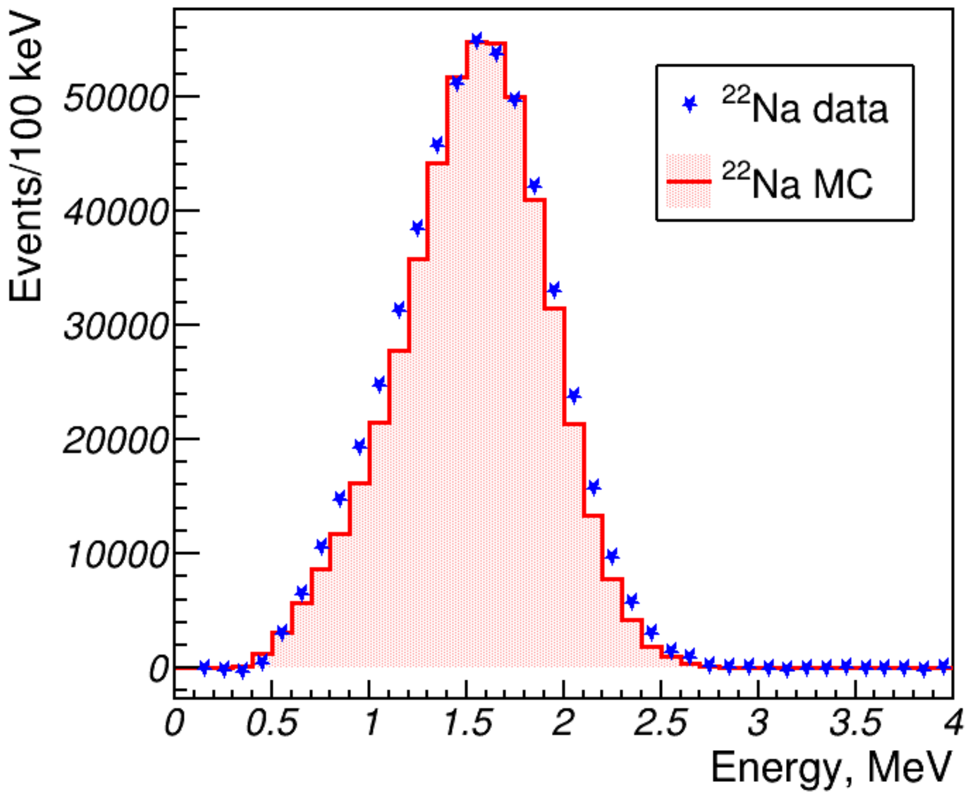




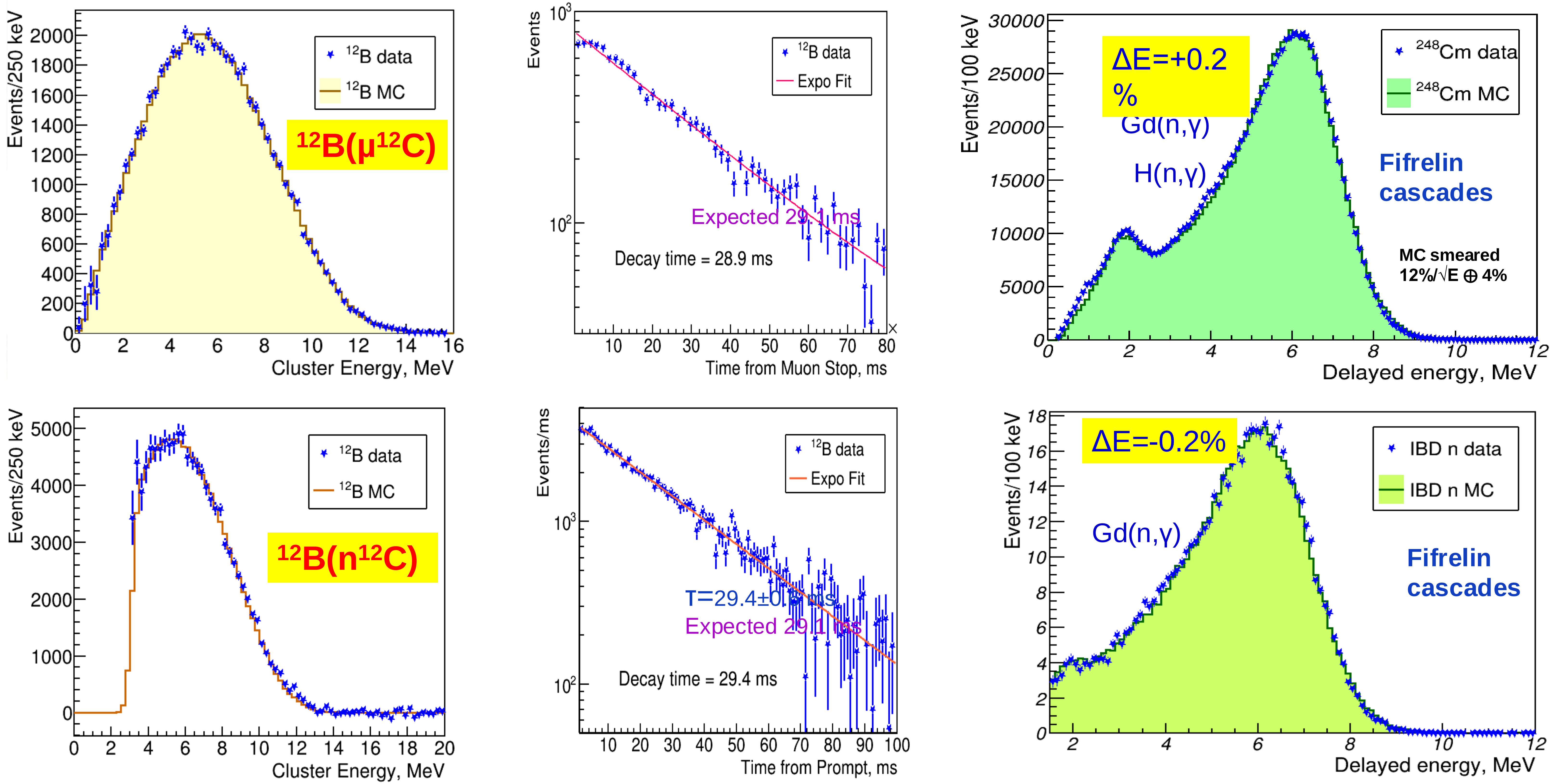
Several calibration sources are used to check the detector response





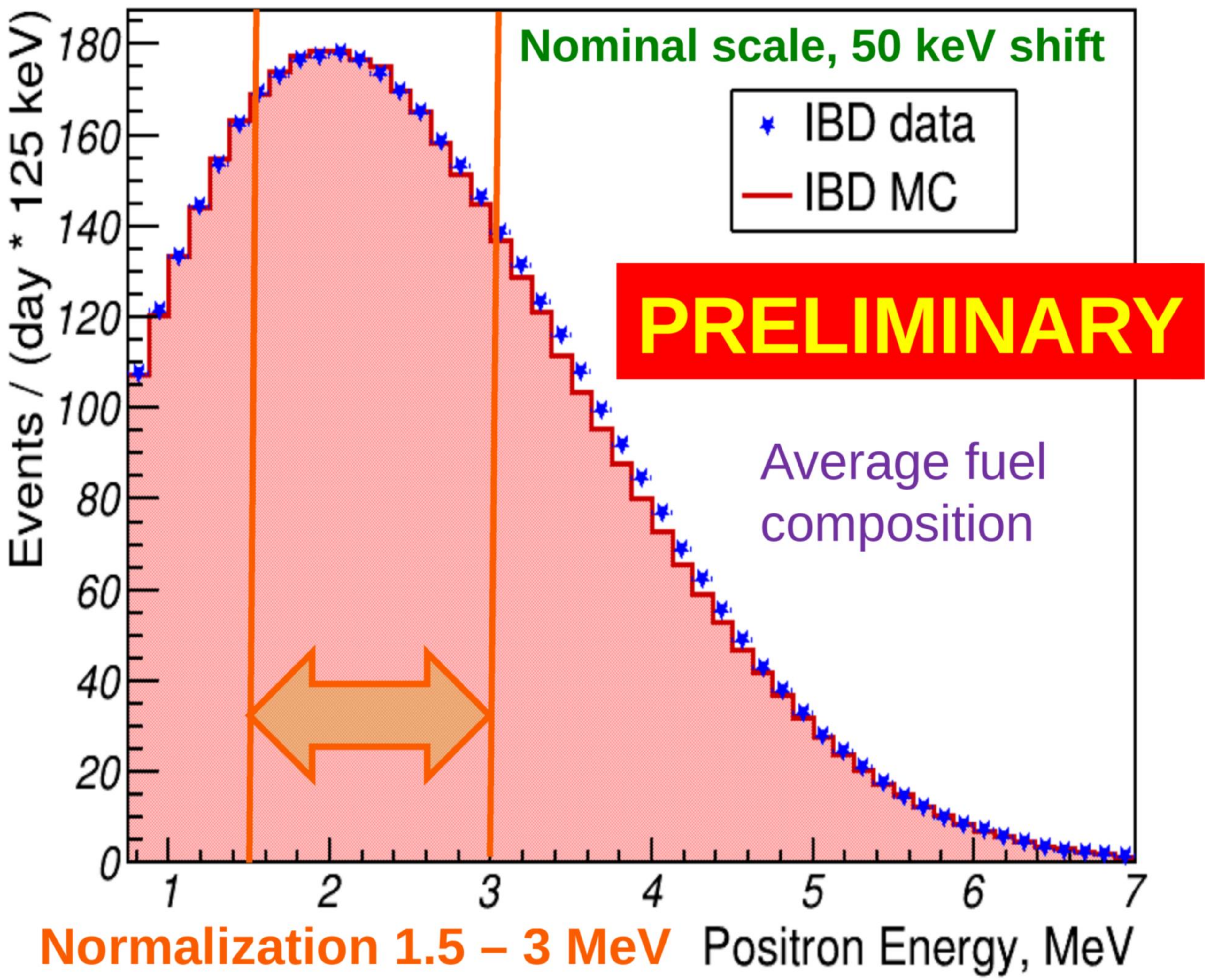


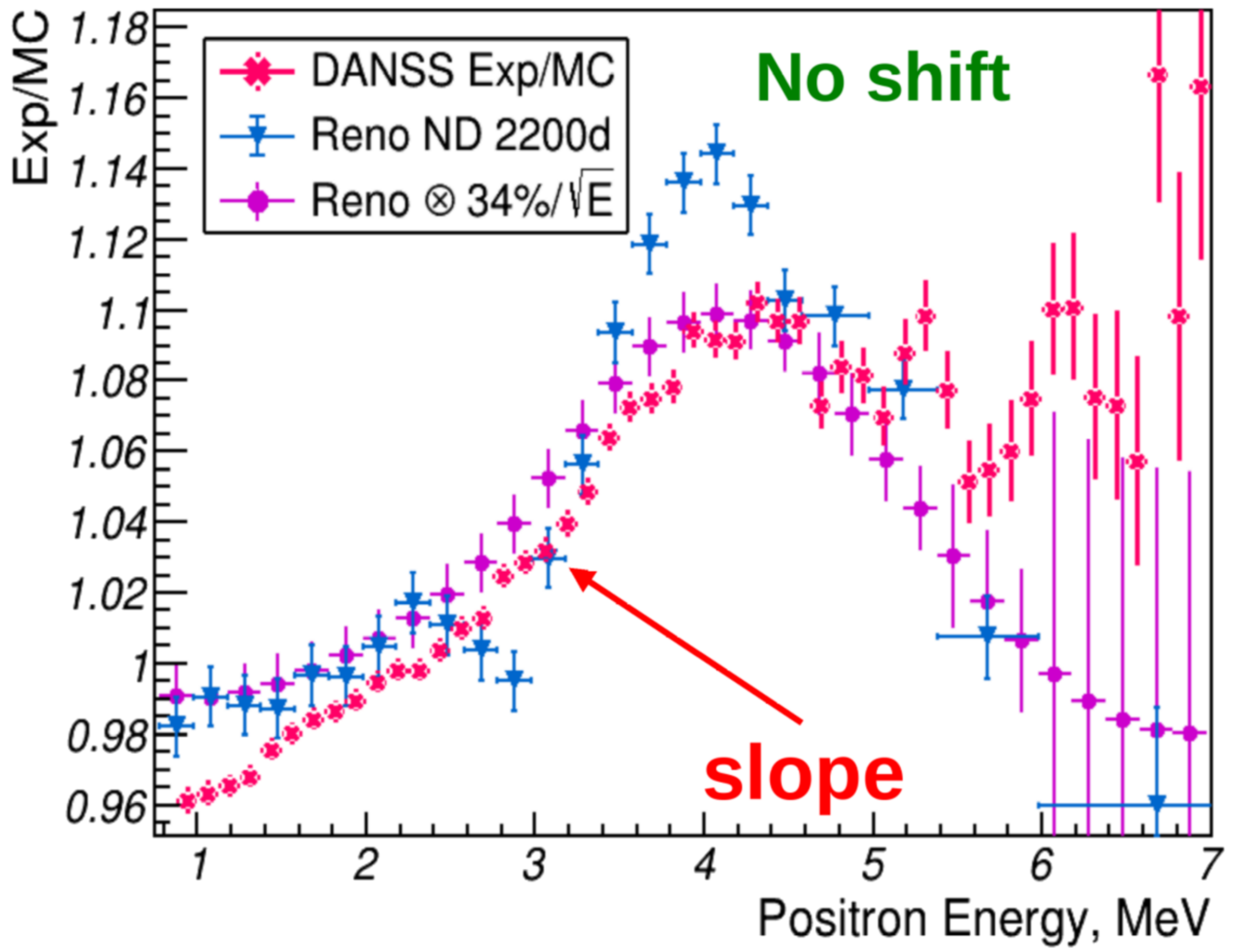
Calibration

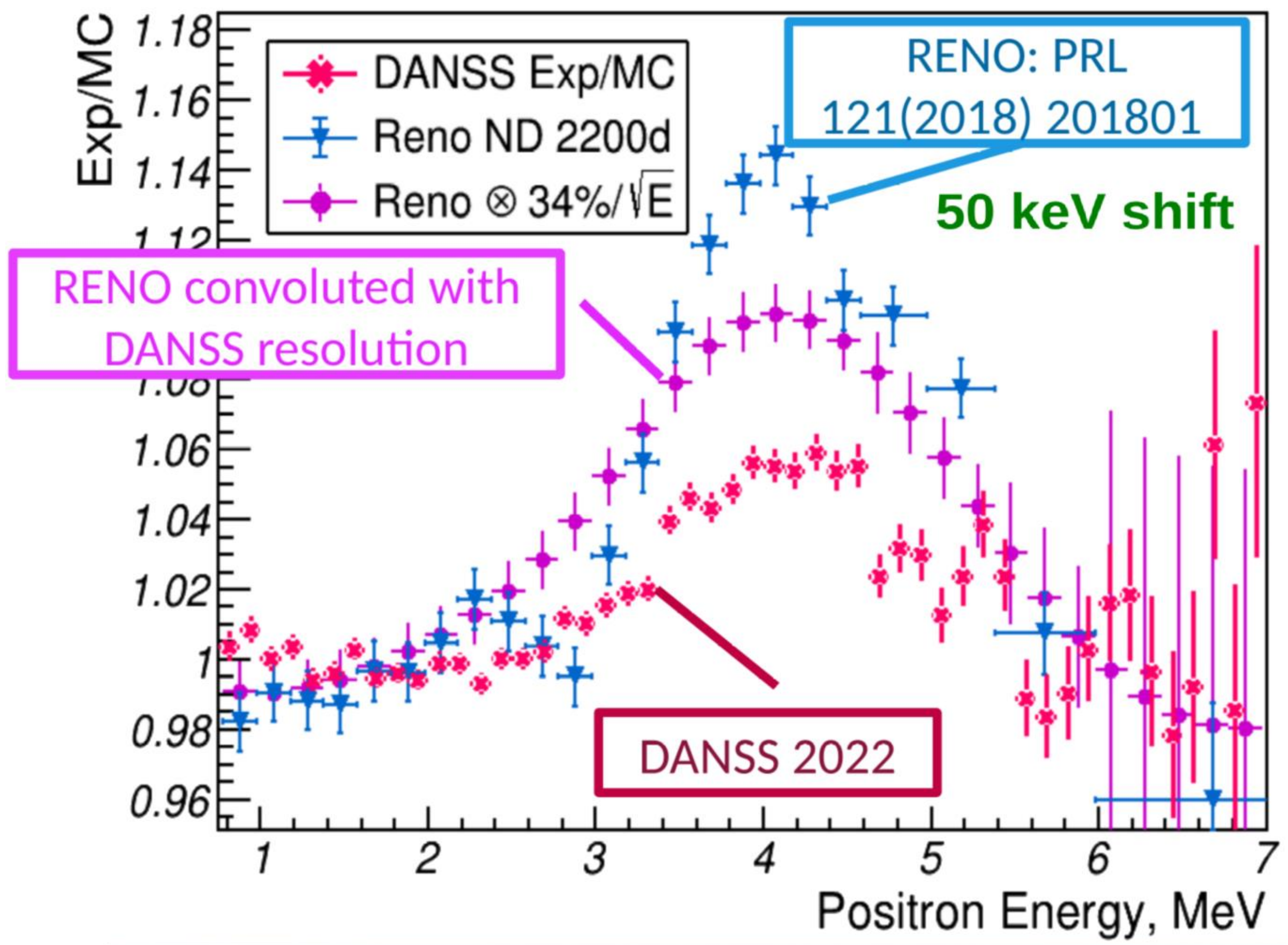


- Energy scale has been fixed using β-spectrum of ^{12}B, which is similar to positron signal
- Other sources agree within +/- 0.2% with exception of ^{22}Na which is 1.8% below.
- Systematic error on E scale of +/-2% was added due to ^{22}Na disagreement
  Hope to reduce this error soon

Positron spectrum vs model







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

Sterile neutrino analysis

For diferent points in parameter space Θ predicted e^+ spectra are calculated for each (*Top, Middle, Bottom*) detector position.

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

Observed (R^{obs}) and predicted (R^{pre}) e^+ **spectra ratios** (per day normalization) are compared using test statistics:

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

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

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

Data taking in two positions

R_{bt}=Bottom/Top,

Data taking in three positions

R_{mbt}=Middle/$\sqrt{\text{Bottom}\times\text{Top}}$,

W – covariance matrix

Penalty terms

$\eta(\eta^0)$ nuisance parameters

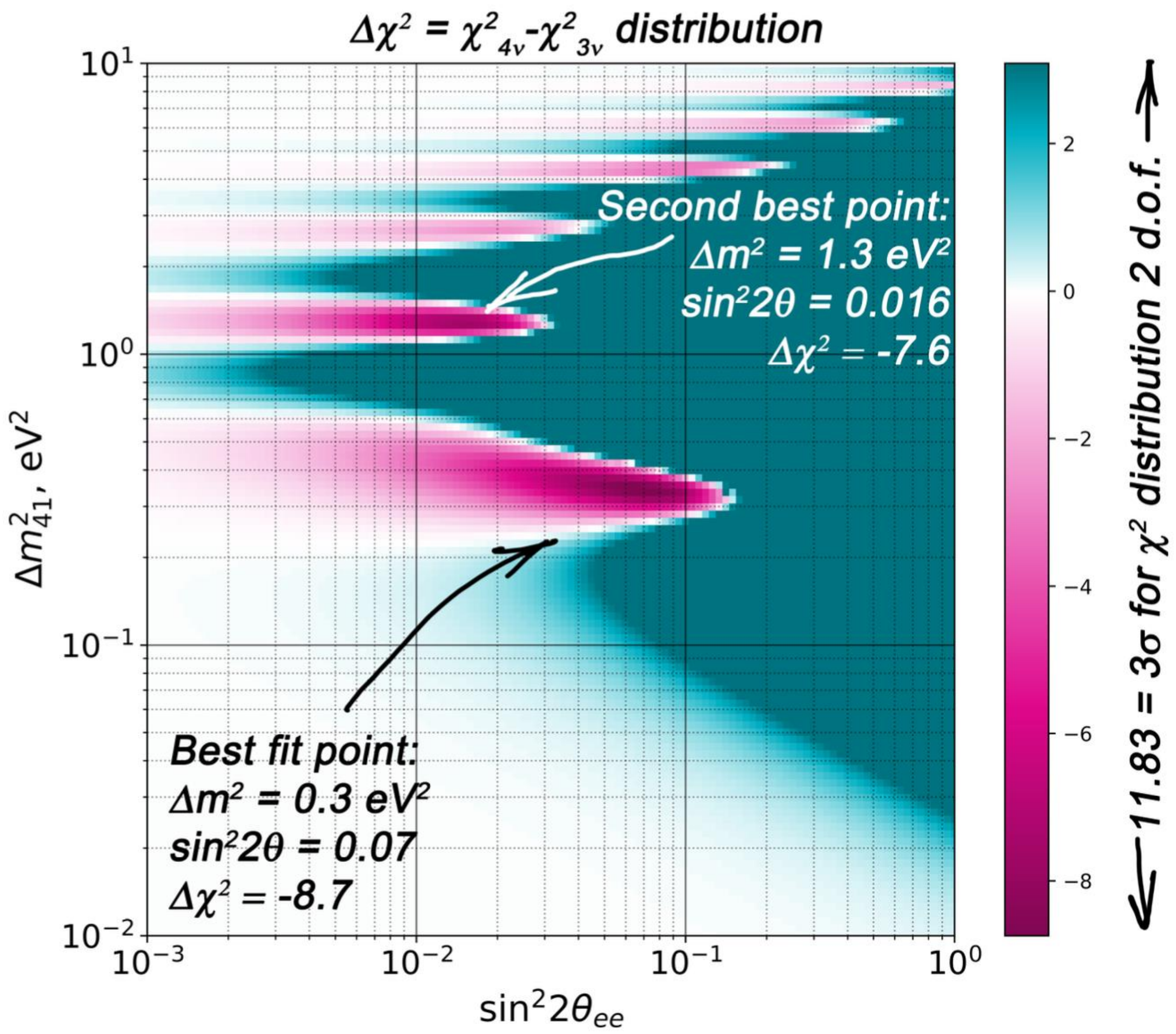
Systematic uncertainties are treated as nuisance parameters

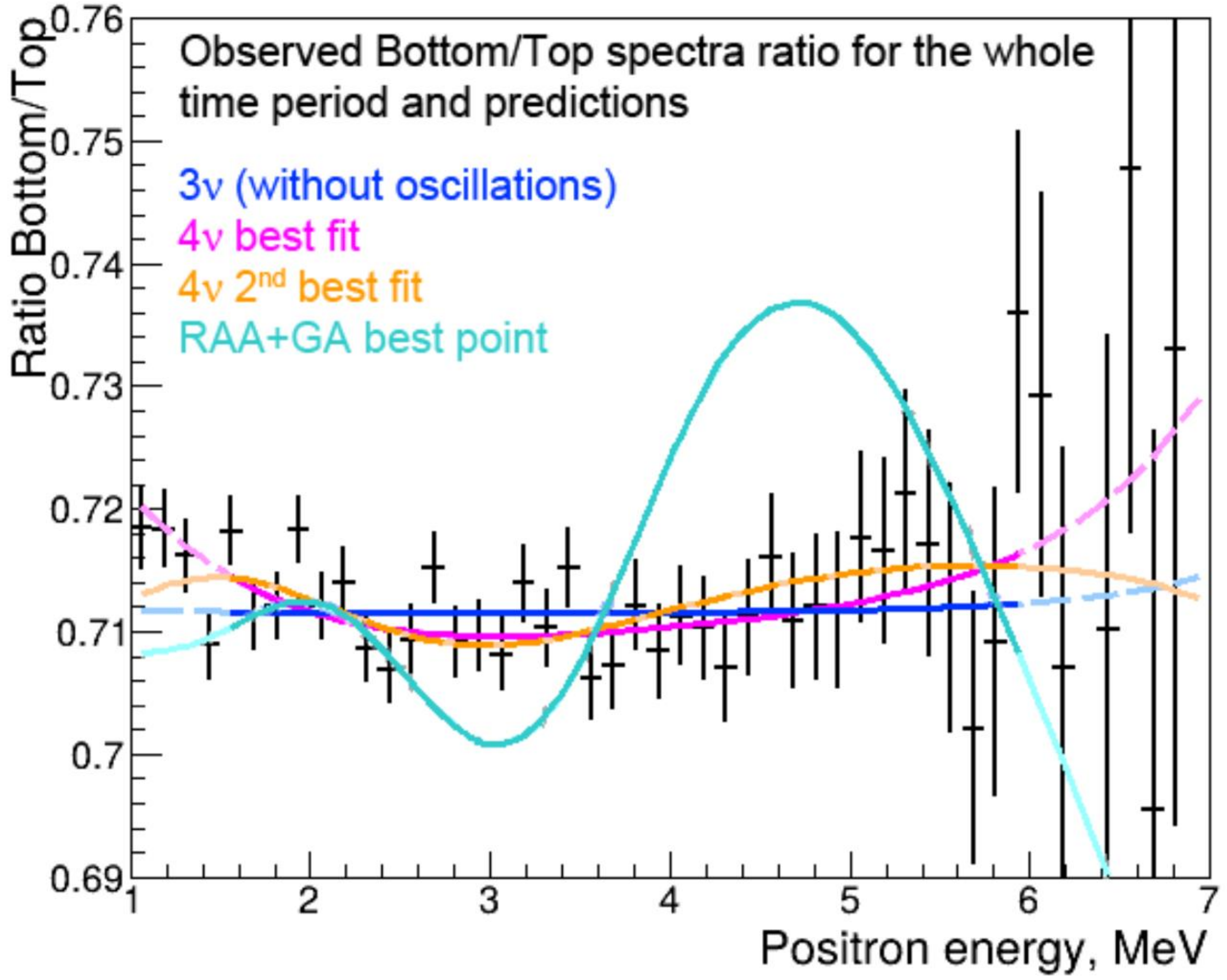
During the fit each absolute (*Top,Middle,Bottom*) spectrum $S(E,\eta)$ was approximated using first-order Taylor expansion:

$$S(E,\eta) = S(E,\eta^0) + \textstyle\sum_i {}^{\delta S}/_{\delta \eta_i} \cdot \delta\eta_i$$

Sterile neutrino analysis

Diference in χ^2 between 4ν and 3ν hypotheses. Magenta: $\chi^2_{4\nu} < \chi^2_{3\nu}$, cyan: $\chi^2_{4\nu} > \chi^2_{3\nu}$





Using current statistics 2016-2024 we see no statistically signicant evidence of 4ν signal.

Best points:

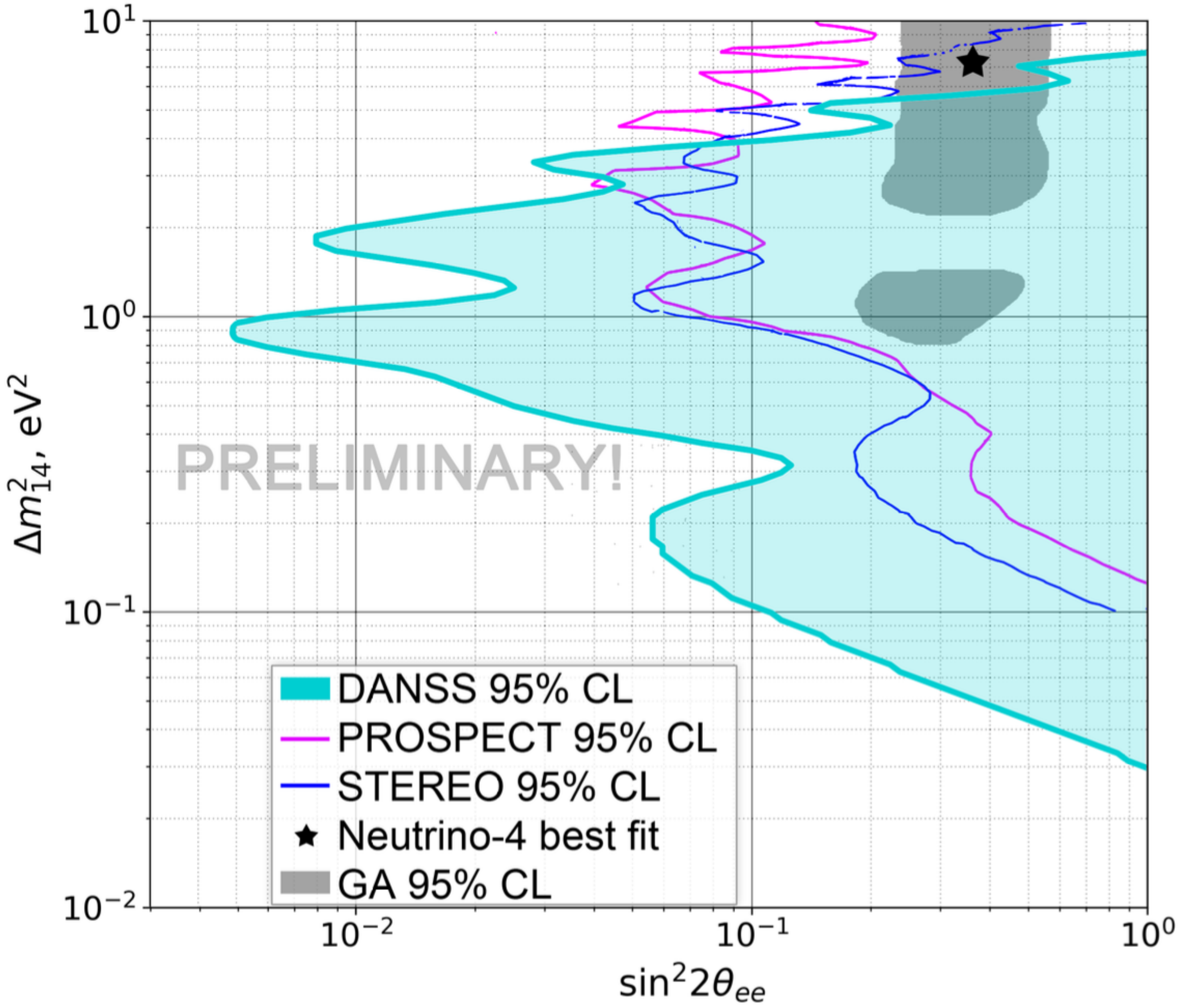
$\Delta m^2_{41} = 0.33eV^2, sin^2 2\theta_{ee} = 0.07, \chi^2_{4\nu}$- $\chi^2_{3\nu} = -8.7$ (~2.5 σ)

$\Delta m^2_{41} = 1.3eV^2, sin^2 2\theta_{ee} = 0.016, \chi^2_{4\nu}$- $\chi^2_{3\nu} = -7.6$

RAA and GA best point has been excluded with much more than 5σ

Sterile neutrino search

95% C.L. exclusion calculated using Gaussian CL_s method.



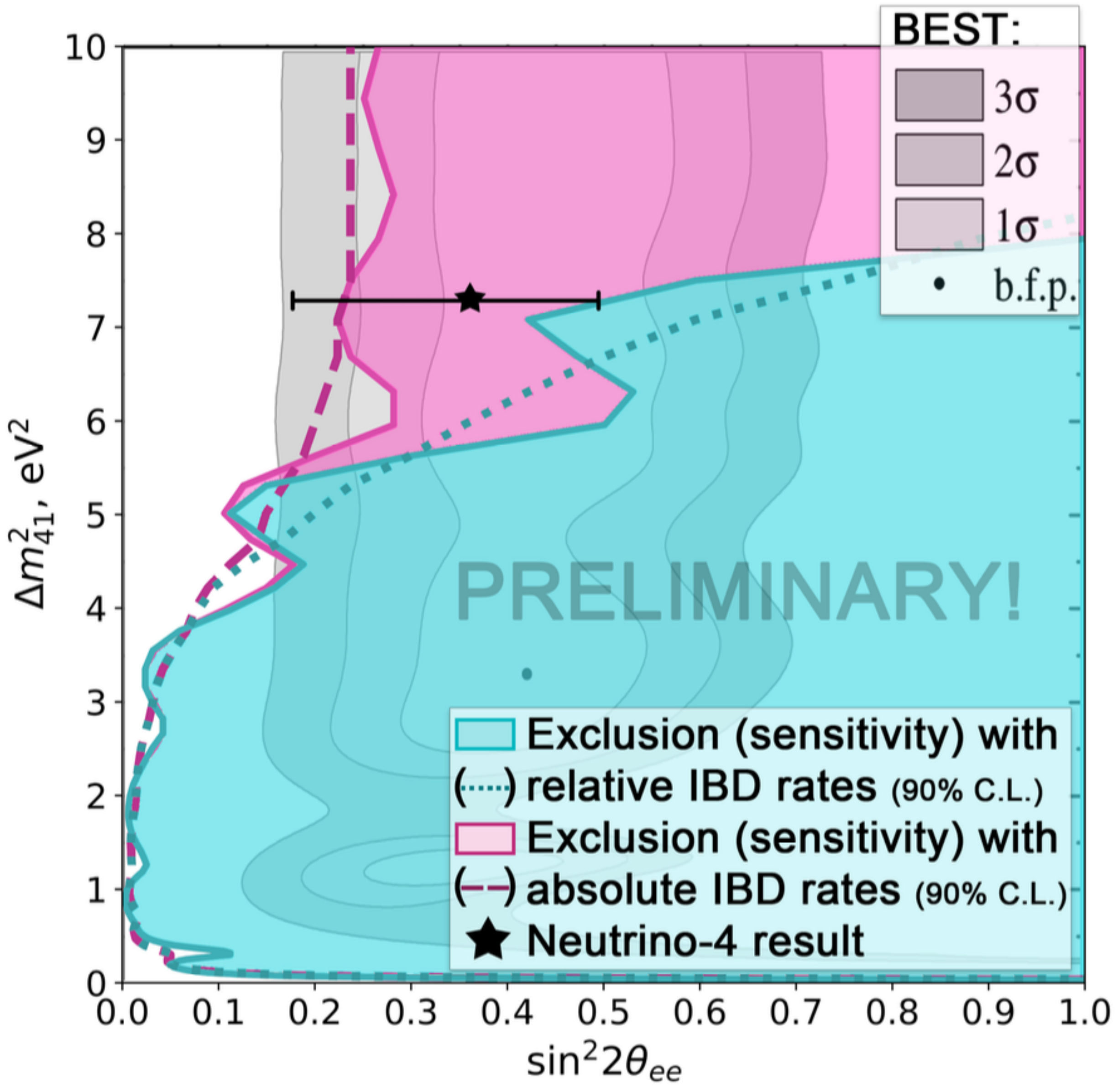
1σ values used in the penalty terms (changes with respect to nominal values):

- 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)

DANSS analysis without absolute counting rates excludes a large and the most interesting fraction of sterile neutrino parameter space using only ratio of e^+ spectra at 3 distances (6.8 mln IBD events).

Sterile neutrino search using absolute counting rates

Test statistics with absolute counting rates: $\chi^2_{abs} = \chi^2_{rel} + ((N_{top} + N_{mid} + N_{bottom})^{\rm obs} - (N_{top} + k_2 \cdot \sqrt{k_1} \cdot N_{mid} + k_1 \cdot N_{bottom})^{\rm pre})^2/\sigma^2_{abs}$
σ_{abs} – total systematic uncertainty (7% in absolute rates). HM model used for predictions.



A large and the most interesting fraction of available parameter space for sterile neutrino was excluded with model-independent analysis.

Exclusions based on absolute counting rates for large Δm^2_{41} support previous results (Daya Bay, Bugey-3, ...)

Our preliminary results exclude the dominant fraction of BEST expectations as well as best fit point of Neutrino-4 experiment. In KI model exclusions are even more more strict.

These results depend on the predictions of the $\tilde{\nu}_e$ flux from reactors, for which we assumed a conservative unsertainty of 5%.

6.2 mln IBD events, will be updated soon

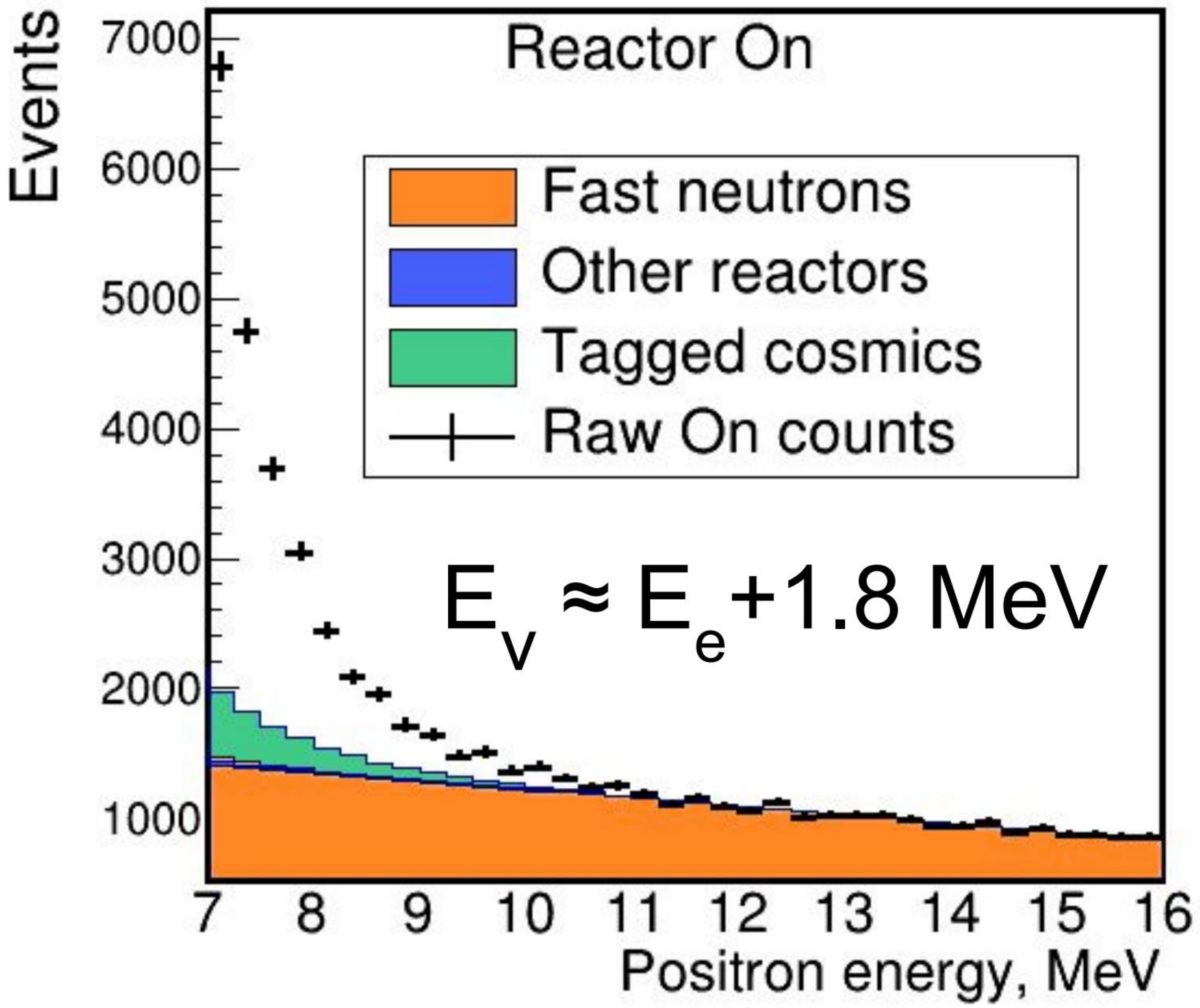
Sterile neutrino search using absolute counting rates

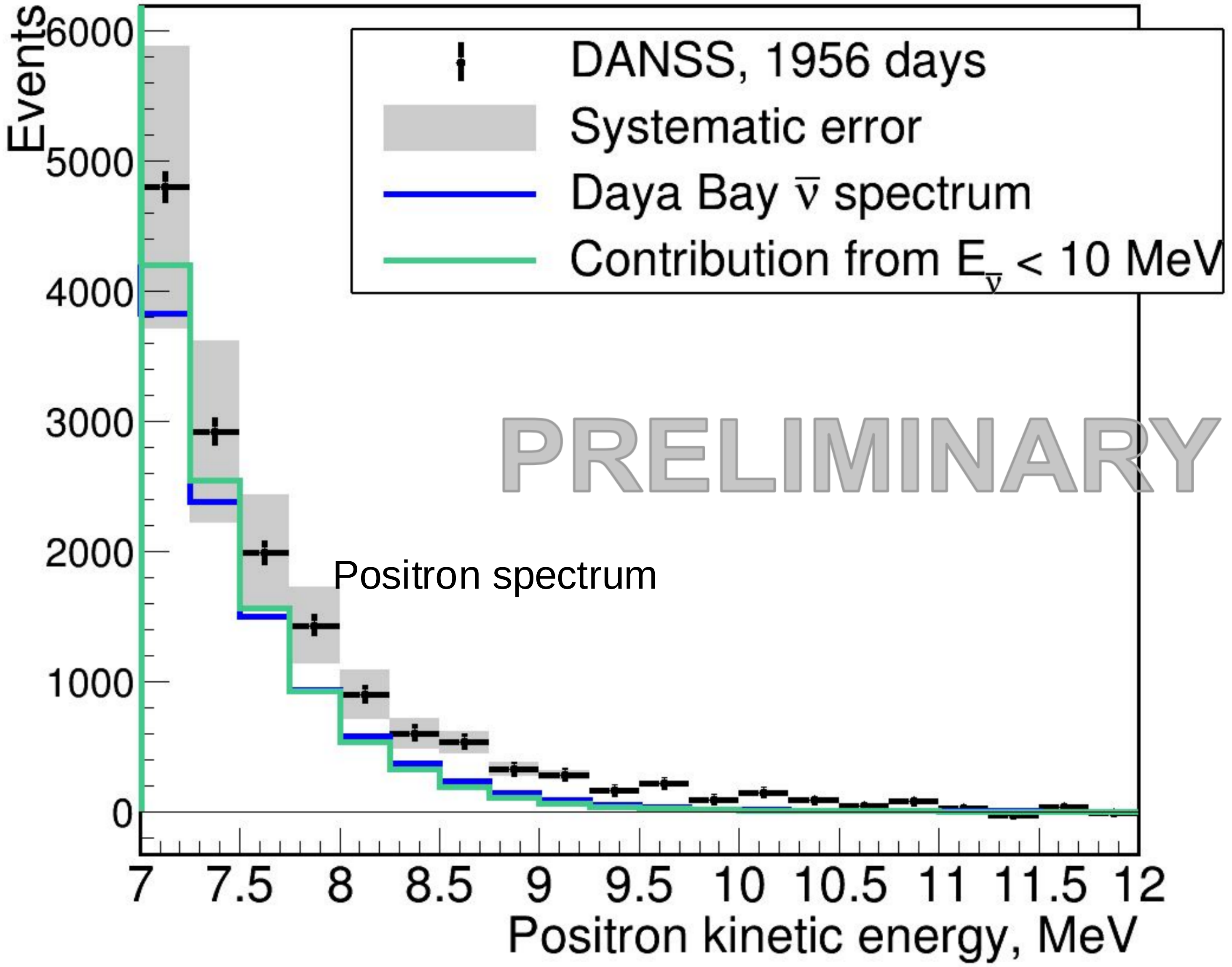
Source	Rate uncertainty
Number of protons	2%
Selection criteria	2%
Geometry (distance + fission points distribution)	1%
Fission fractions (from KNPP)	2%
Average energy per fission (Phys. Rev. C 88, 014605)	0.3%
Reactor power (from KNPP)	1.5%
Backgrounds	0.5%
Total	4%
Flux predictions	2-5%
Total with fluxes	5-7%

The values of uncertainties are our estimates of the 1σ deviations and are given in percent according to their contributions to the absolute $\tilde{\nu_e}$ counting rate. We hope to reduce experimental uncertainties in future. However, flux prediction uncertainty dominates.

High energy spectrum

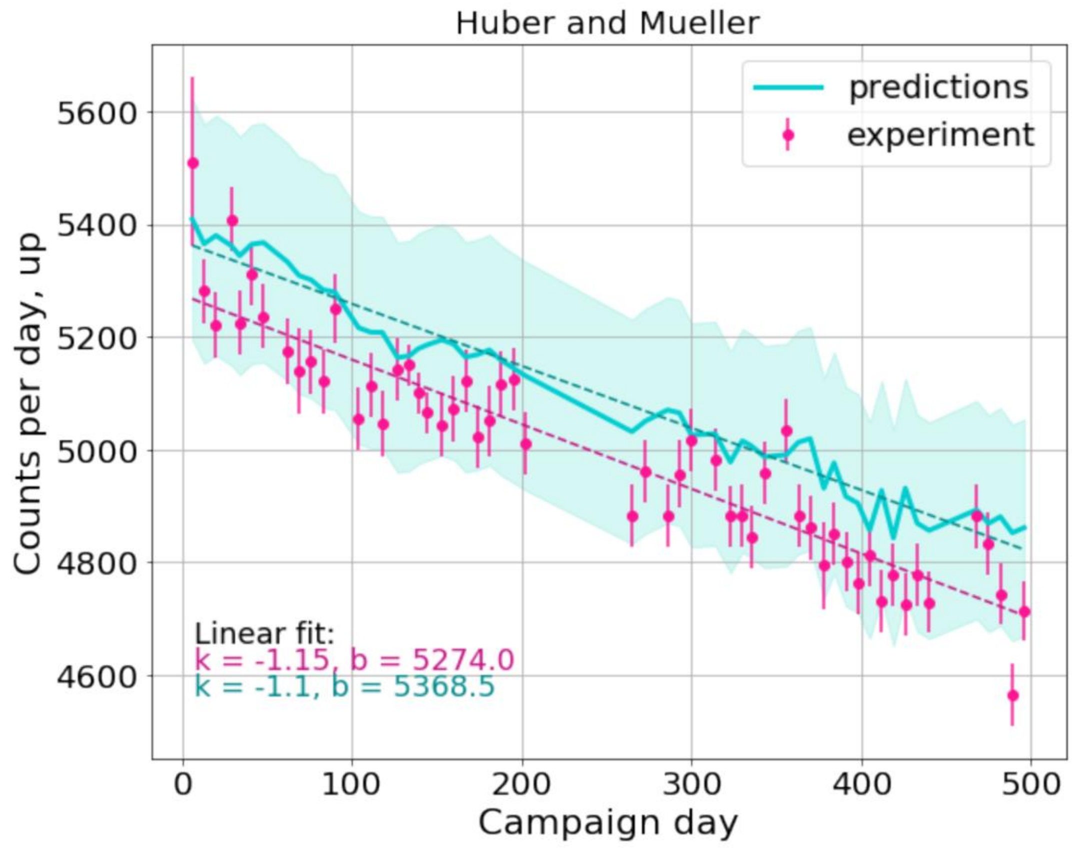
Motivation: CEvNS experiments needs a information about high-energy part of antineutrino spectra.



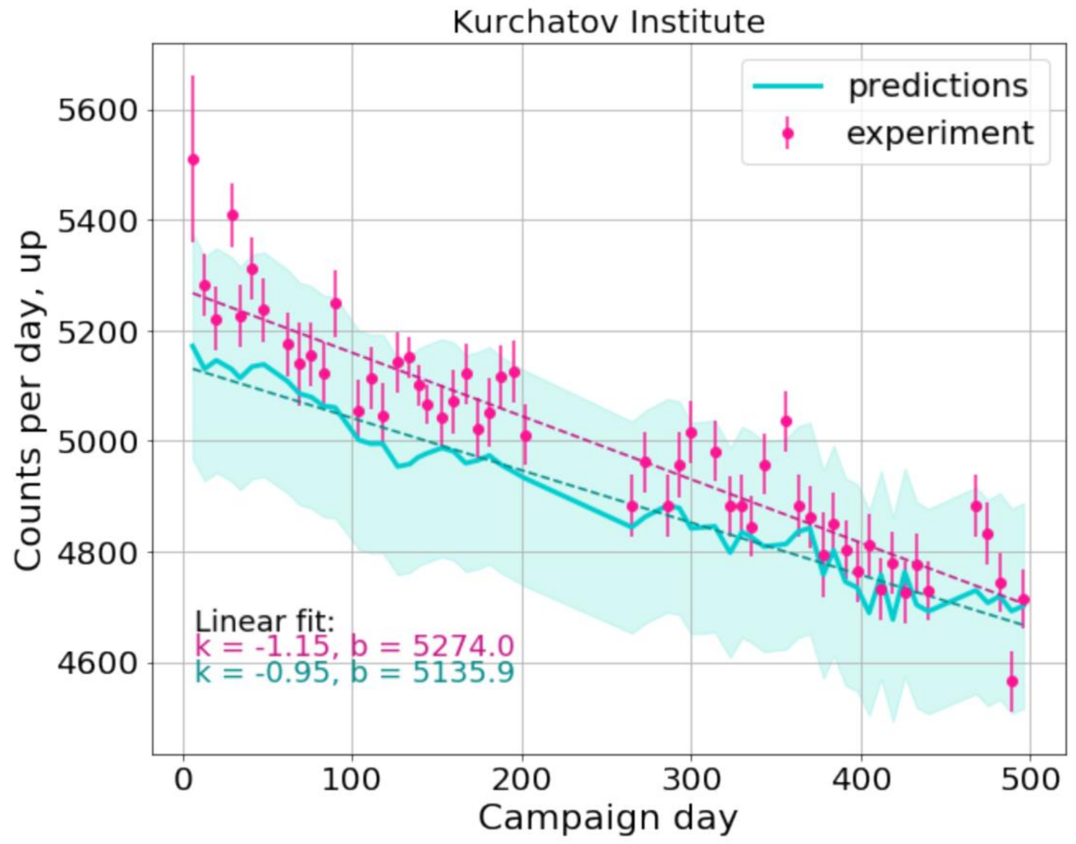


- Background subtraction is based on 5 "reactor off" periods
- DANSS observes $\bar{\nu}_e$ events with energy > 10 MeV: **1561 ± 157_{stat} ± 168_{sys} ev. (6.8σ)**
- Fraction of high energy $\bar{\nu}_e$ events is somewhat larger than at Daya Bay **[PhysRevLett.129.04180]**

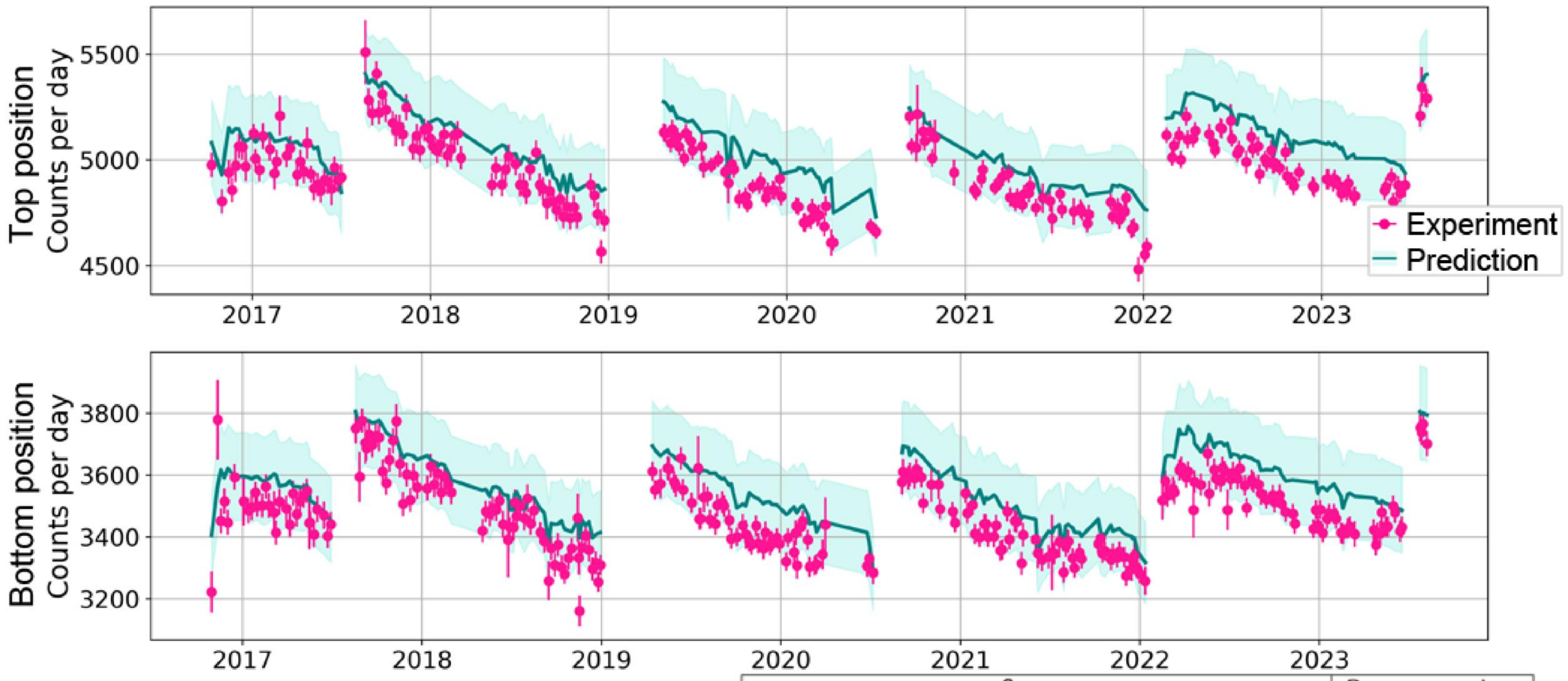
Absolute counting IBD rates

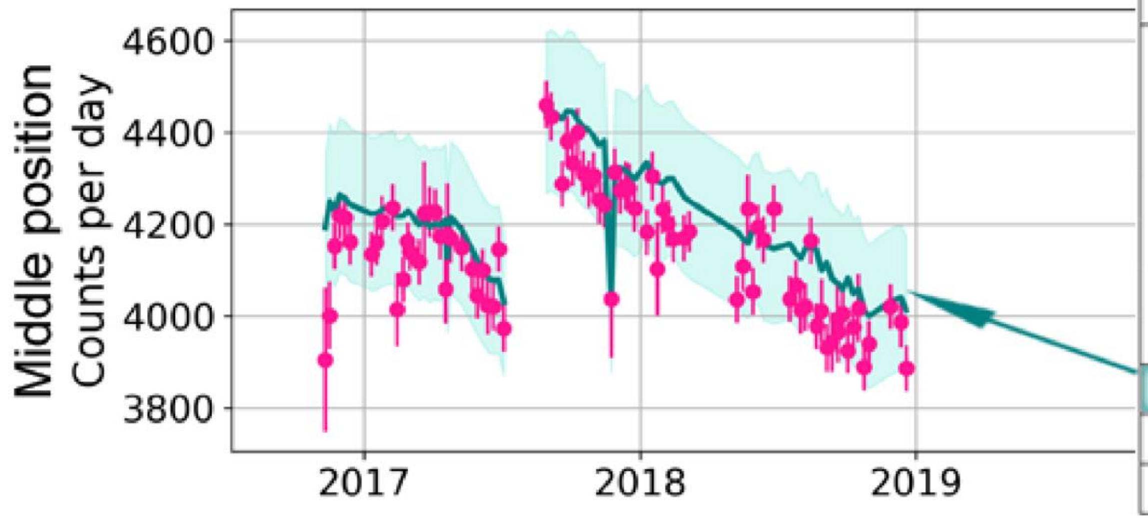


Observed to predicted ratio:
0.98±0.04 (HM model)
1.02±0.04 (KI model)



DANSS data

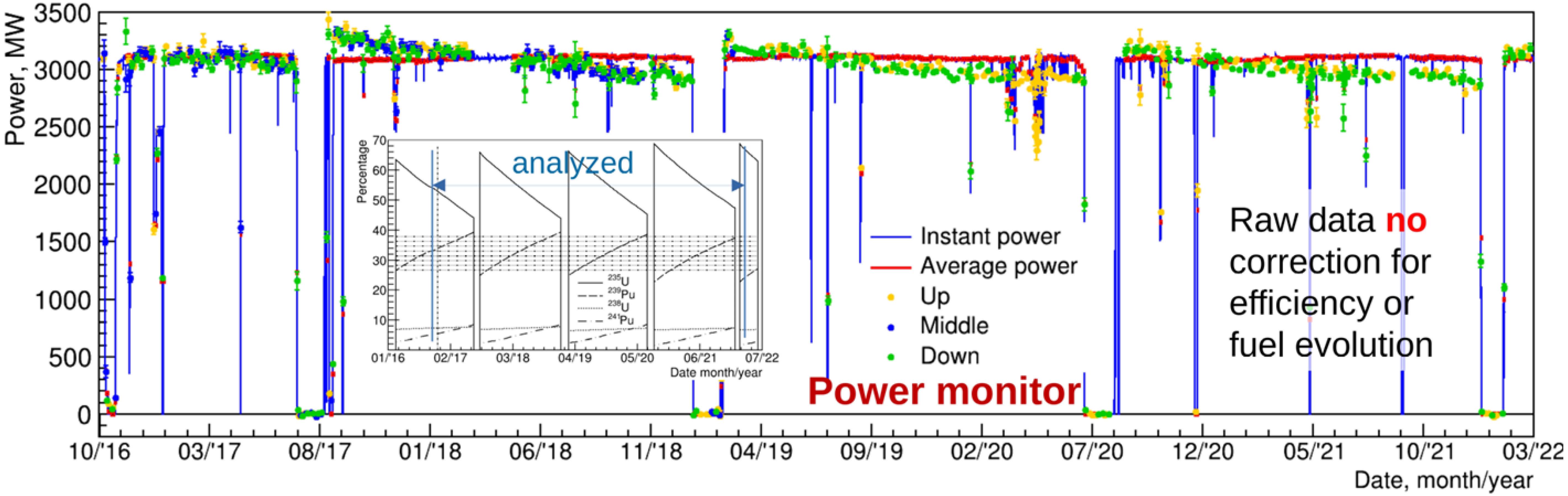


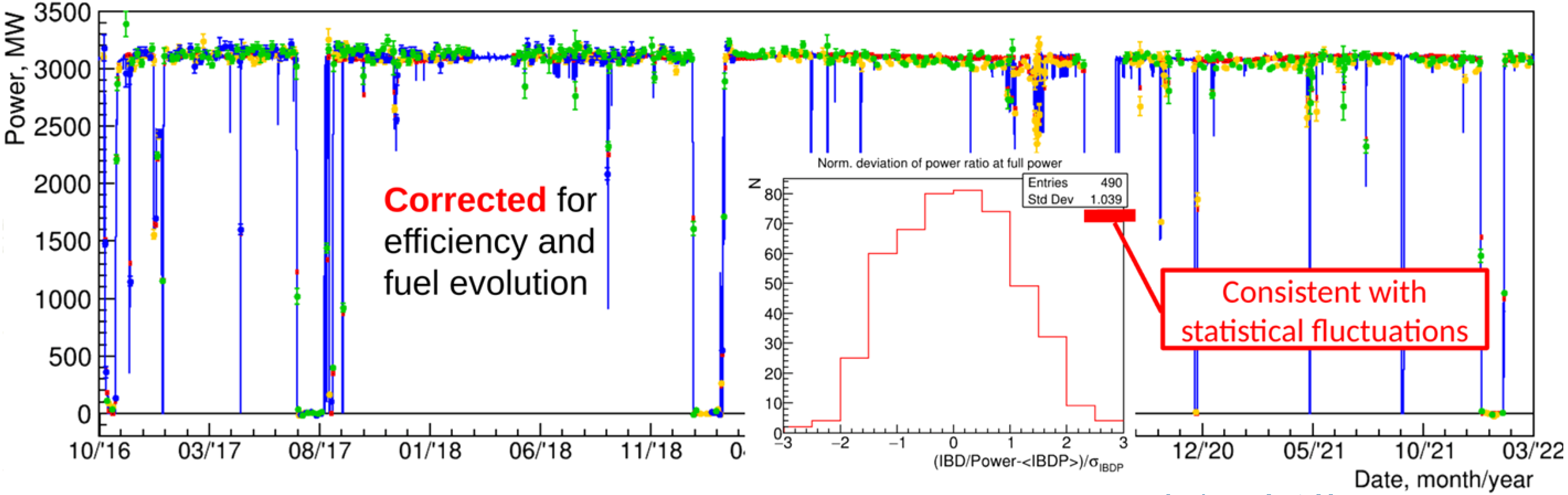


Source	Rate uncertainty
Number of protons	2%
Selection criteria	2%
Geometry (distance + fission points distribution)	1%
Fission fractions (from KNPP)	2%
Average energy per fission (Phys. Rev. C 88, 014605)	0.3%
Reactor power (from KNPP)	1.5%
Backgrounds	0.5%
Total	4%
Flux predictions	2-5%
Total with fluxes	5-7%

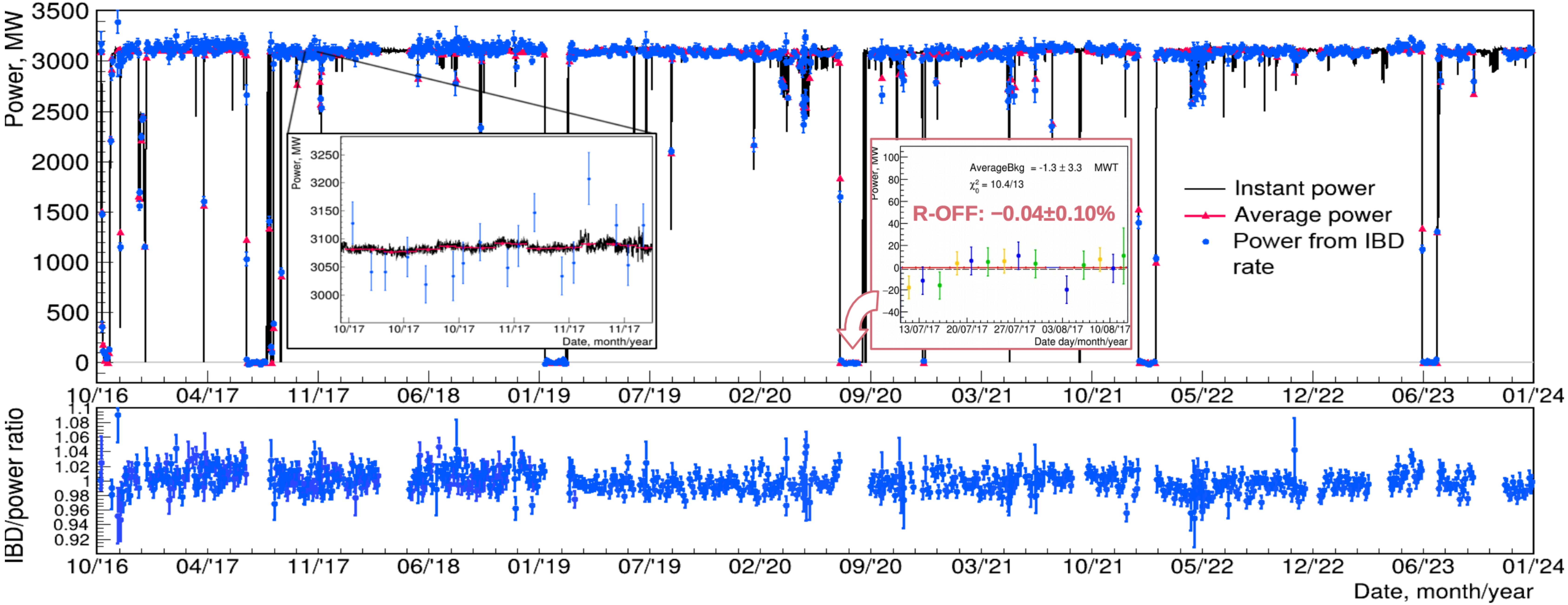
Huber and Mueller (HM) model was used

Reactor power monitoring





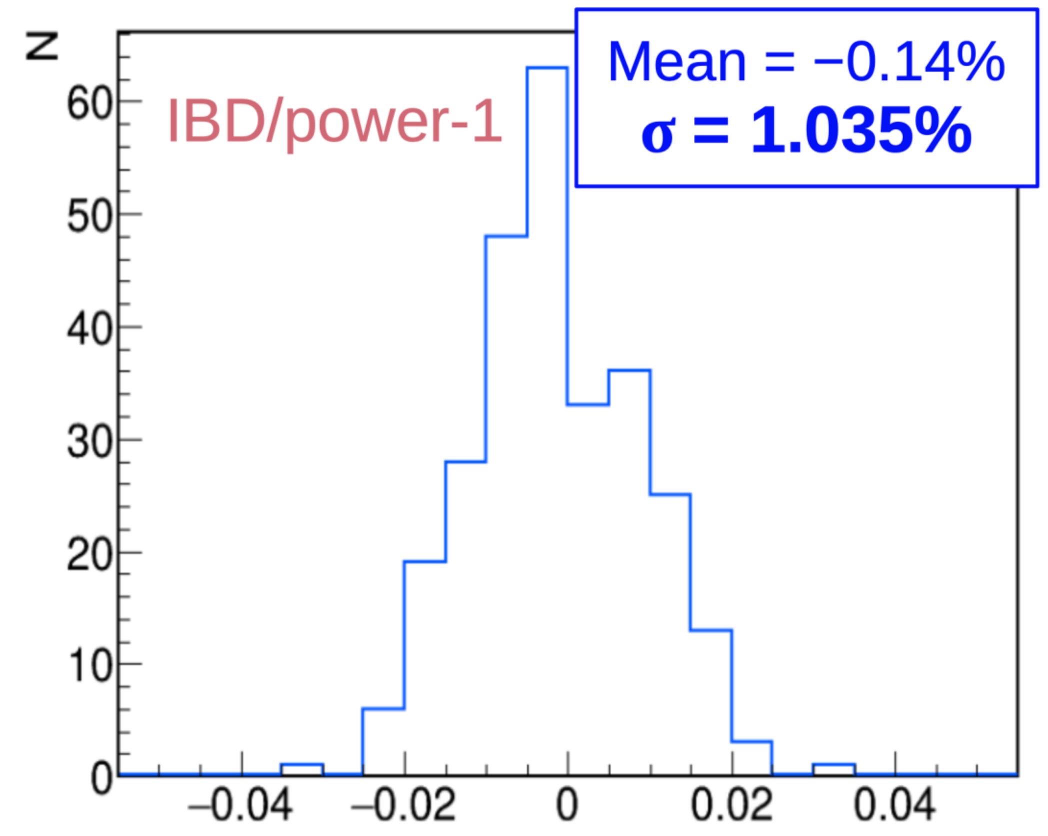
Reactor power monitoring



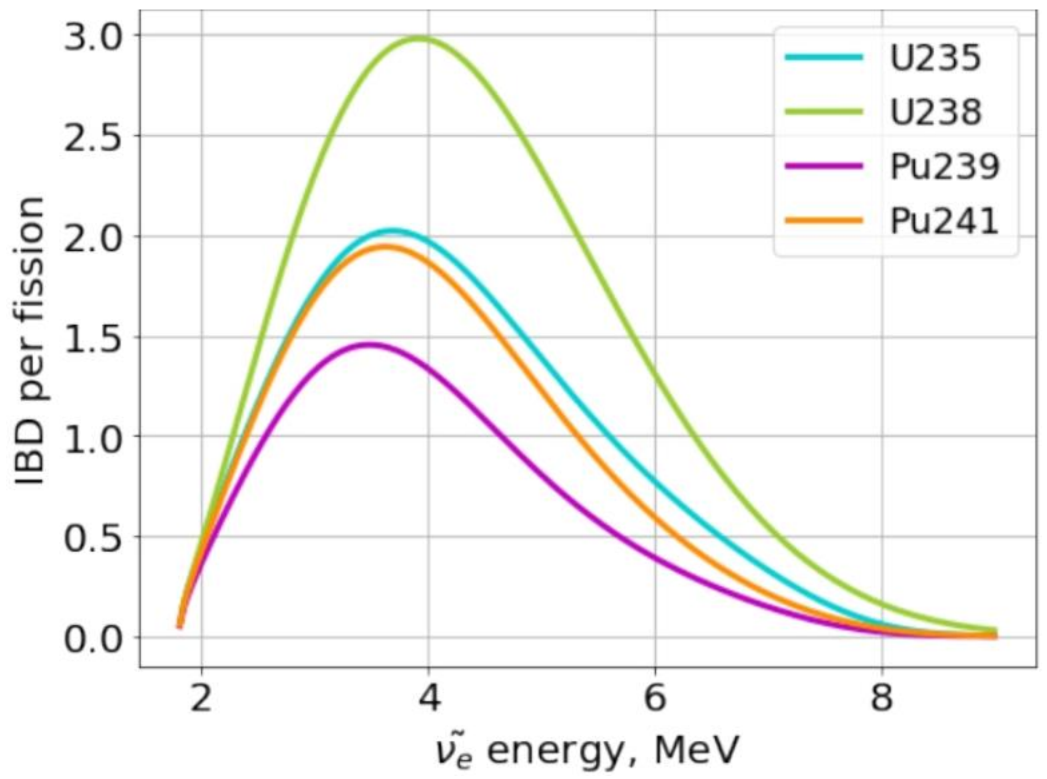
IBD count corrections:

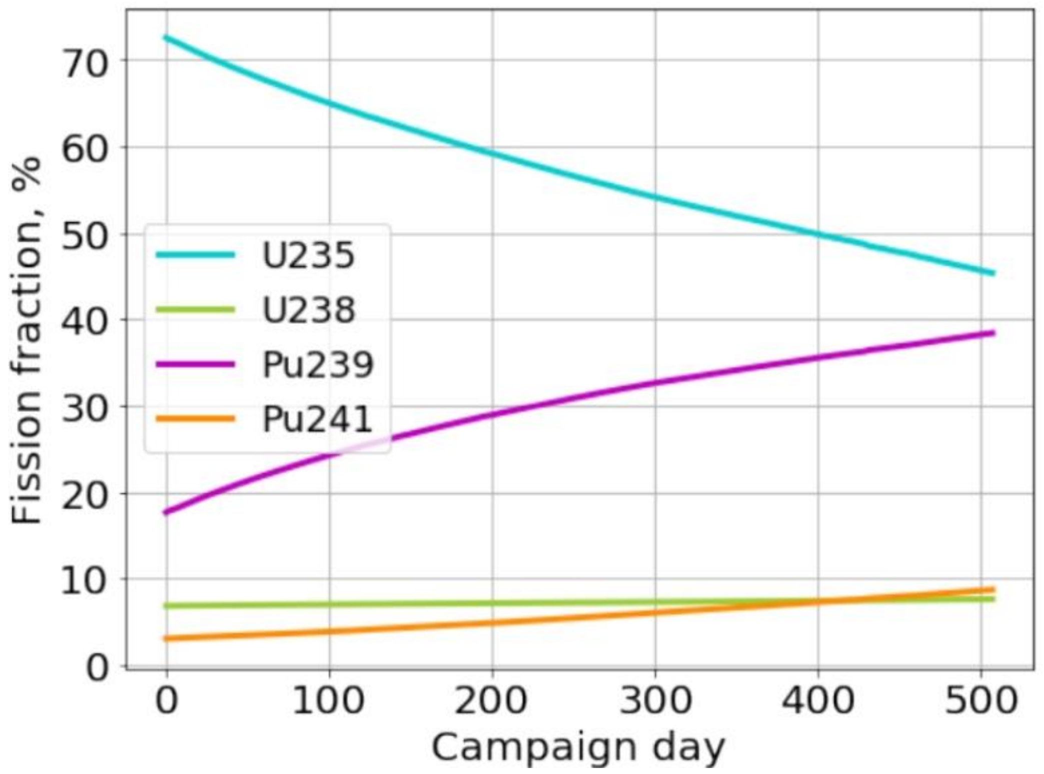
- H-M fuel composition change
- Registration efficiency (channel map)
- Dead time (isolation cuts)
- Neighbouring reactors ~0.6%

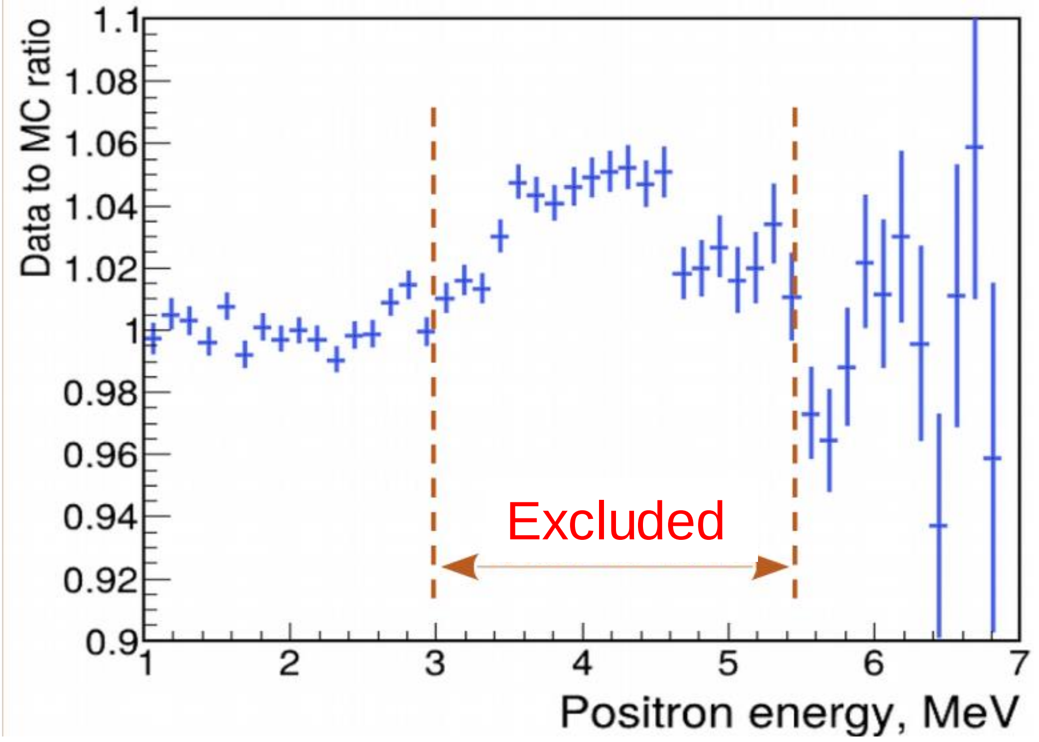
Uniform normalisation by 1 month (10.2016)
Non-significant drift of 0.14% over 8 years
Stat. weekly measurement accuracy 0.66%
Actual spread 1.04%
DANSS systematics+reactor measurements 0.8%
KNPP estimates: no better than 1%



Fission fractions determination

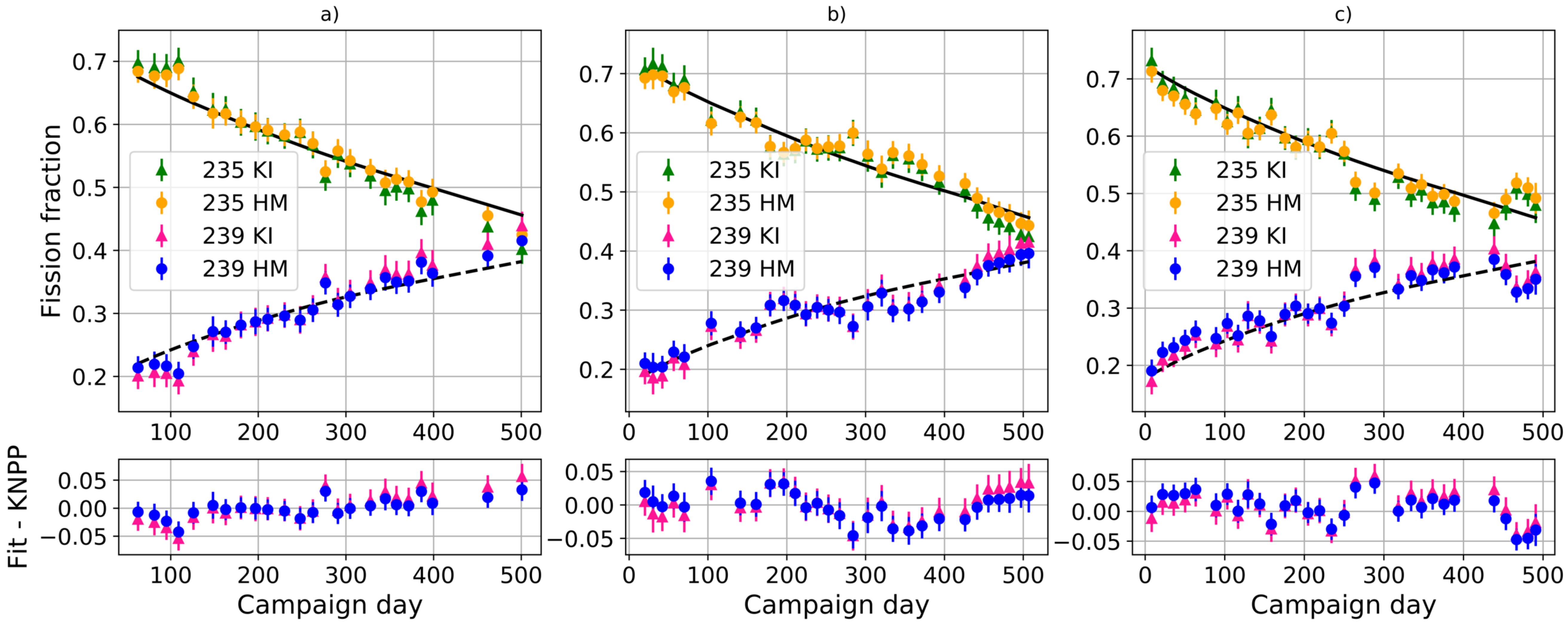


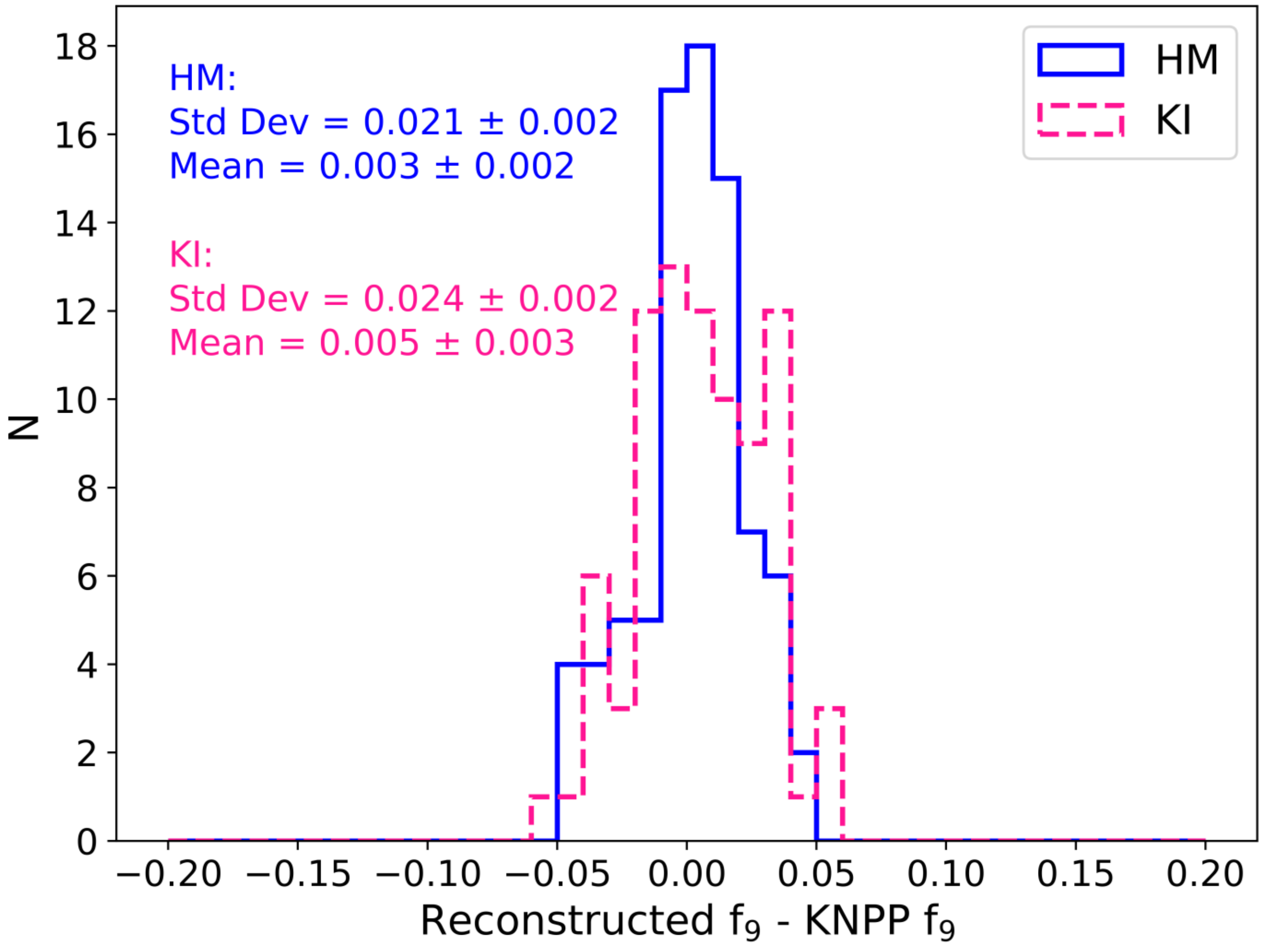




The antineutrino spectra from different isotopes are different
The total spectrum and count rate change with the fuel composition
One measurement - 12-15 days
We fit the observed positron spectra with the sum of the 4 main isotopes using the H-M model.
4 main isotopes according to H-M model in each measurement
Parts of spectra in the ‘bump’ region (3-5.5 MeV e+)
excluded from the fit.
Small contributions of ^{238}U and ^{241}Pu are by typical campaign (campaign 5), total sum is one
Virtually one fit parameter. Normalisation - by campaign average
Counts in different positions are matched by ‘toy MC’ points in reactor and detector
Corrections for dead time, efficiency, neighbouring reactors
Exact value of reactor power and the position of the combustion centre are not taken into account

Fission fractions determination

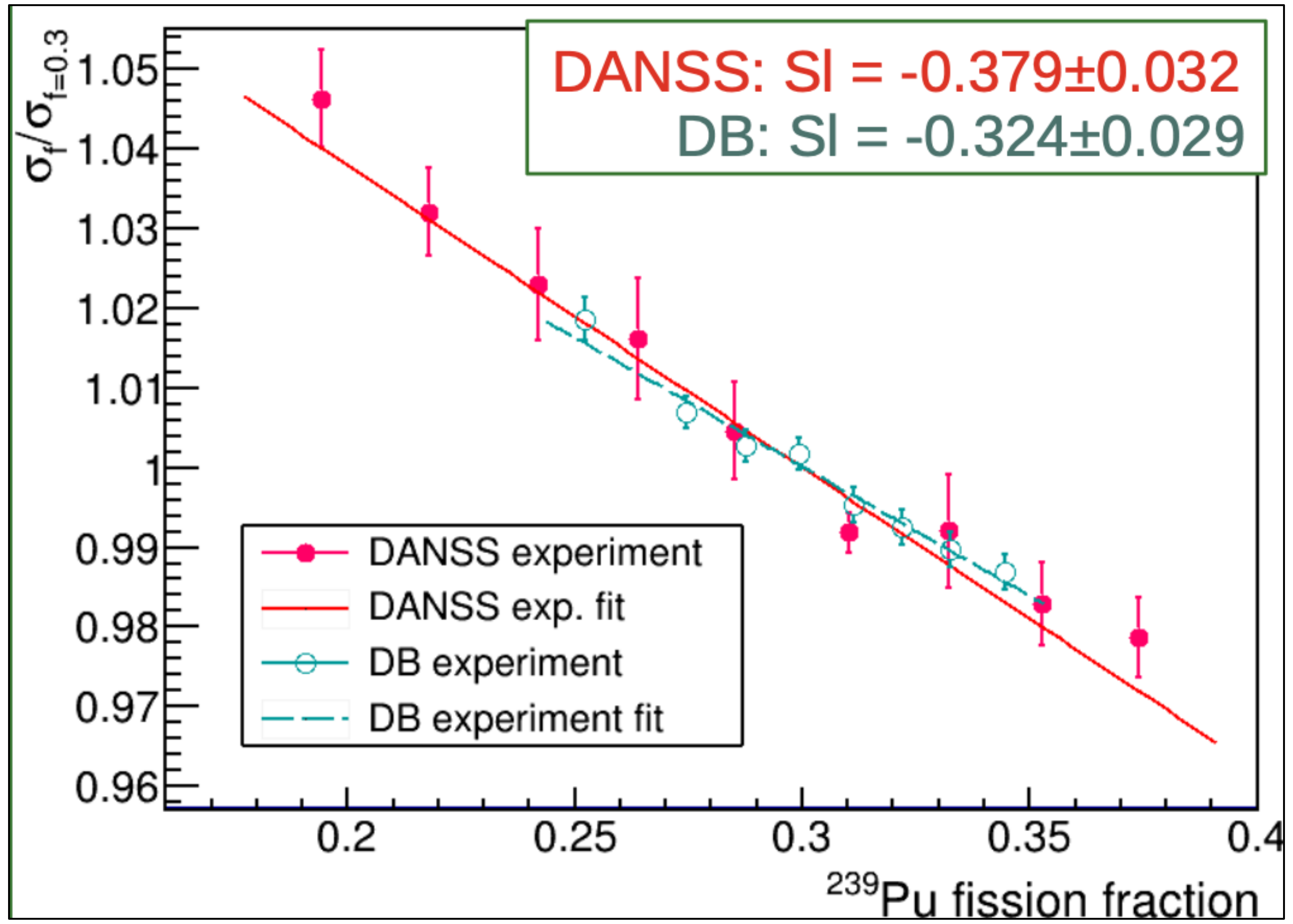




- The results are consistent with KNPP data
- Mean difference is almost zero
- Scatter of differences 2.1% - NPP estimate 5%
- The good agreement between the two very different methods adds confidence in both results
- It is demonstrated that it is possible to determine the isotopic composition without interfering with the reactor operation and information on its parameters.

The ratio of σ_5/σ_9

Inversed problem: knowing everything about the reactor: power, fission fractions, position of the burning centre, let's study the count rate (and spectra)
Normalised slope Sl is the relative rate of change of the IBD count rate when the fraction of ^{239}Pu changes DANSS measurements: 1.3σ higher slope than DB



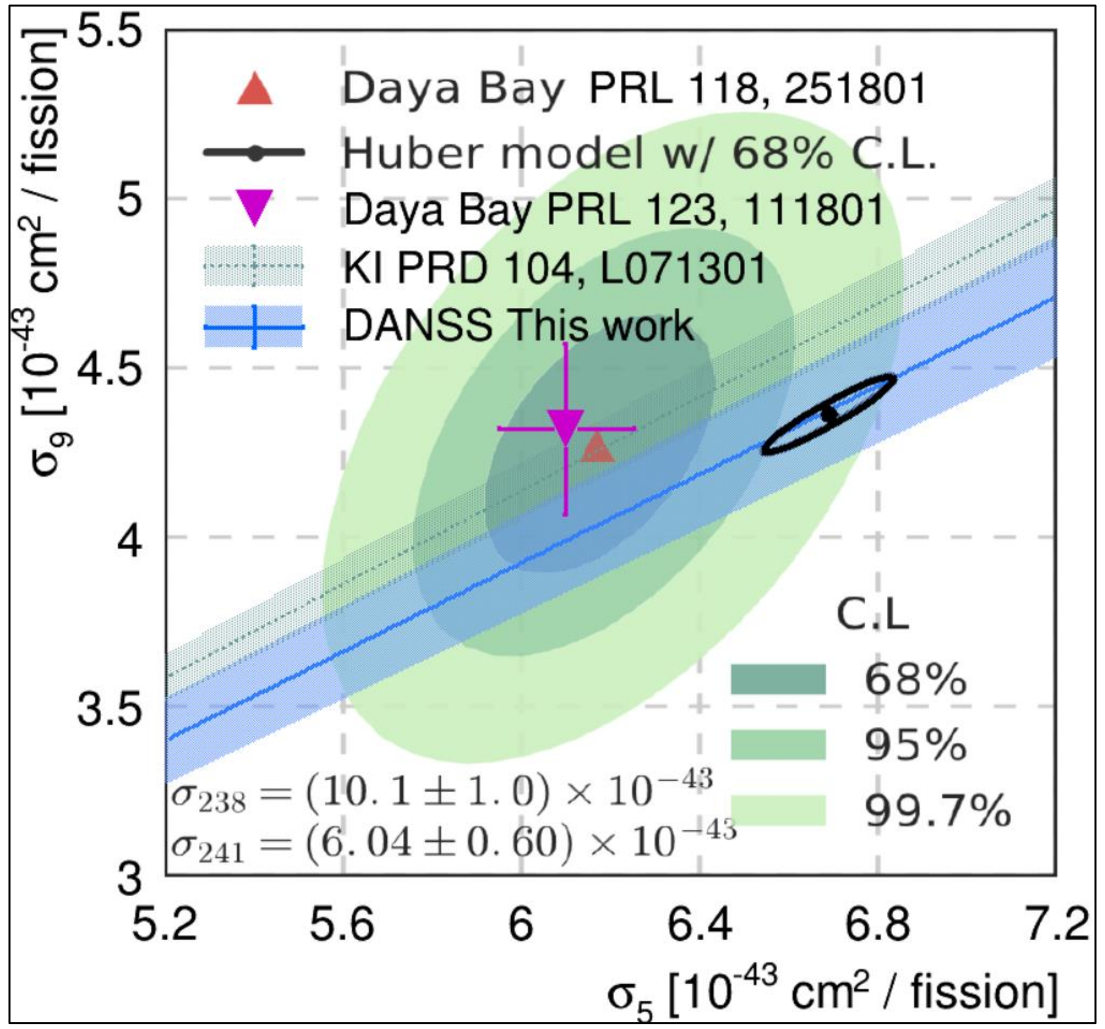
$$N = \alpha \cdot (\sigma_8 f_8 + \sigma_1 f_1 + \sigma_5 f_5 + \sigma_9 f_9)$$

$$\frac{dN}{df_9} = \alpha \cdot \left(\sigma_8 \frac{df_8}{df_9} + \sigma_1 \frac{df_1}{df_9} + \sigma_5 \frac{df_5}{df_9} + \sigma_9\right)$$

N – счет ОБР на деление
σ_i – выходы ОБР
f_i – доли делений

$$Sl = \left(\frac{dN}{df_9}\right) / N = \frac{\frac{\sigma_8}{\sigma_9}\frac{df_8}{df_9} + \frac{\sigma_1}{\sigma_9}\frac{df_1}{df_9} + \frac{\sigma_5}{\sigma_9}\frac{df_5}{df_9} + 1}{\frac{\sigma_8}{\sigma_9} f_8 + \frac{\sigma_1}{\sigma_9} f_1 + \frac{\sigma_5}{\sigma_9} f_5 + f_9}$$

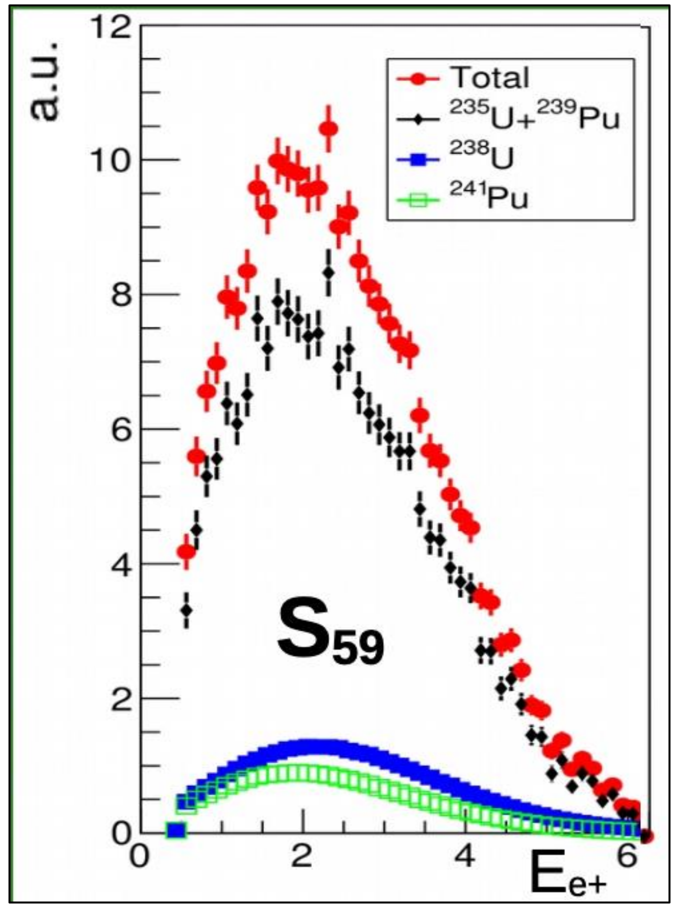
$$\frac{\sigma_5}{\sigma_9} = -\frac{\frac{\sigma_8}{\sigma_9}\left(Sl \cdot f_8 - \frac{df_8}{df_9}\right) + \frac{\sigma_1}{\sigma_9}\left(Sl \cdot f_1 - \frac{df_1}{df_9}\right) + (Sl \cdot f_9 - 1)}{Sl \cdot f_5 - \frac{df_5}{df_9}}$$

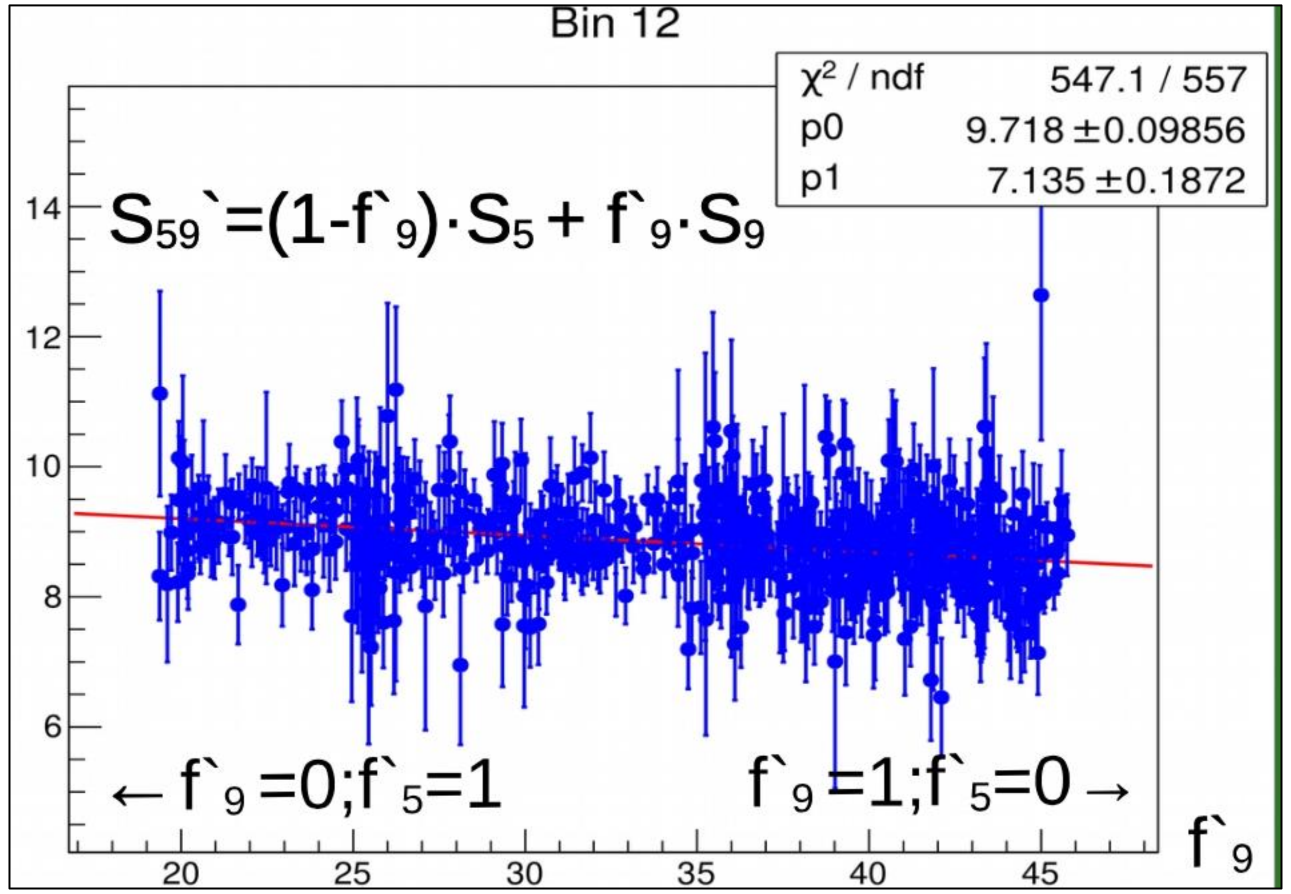


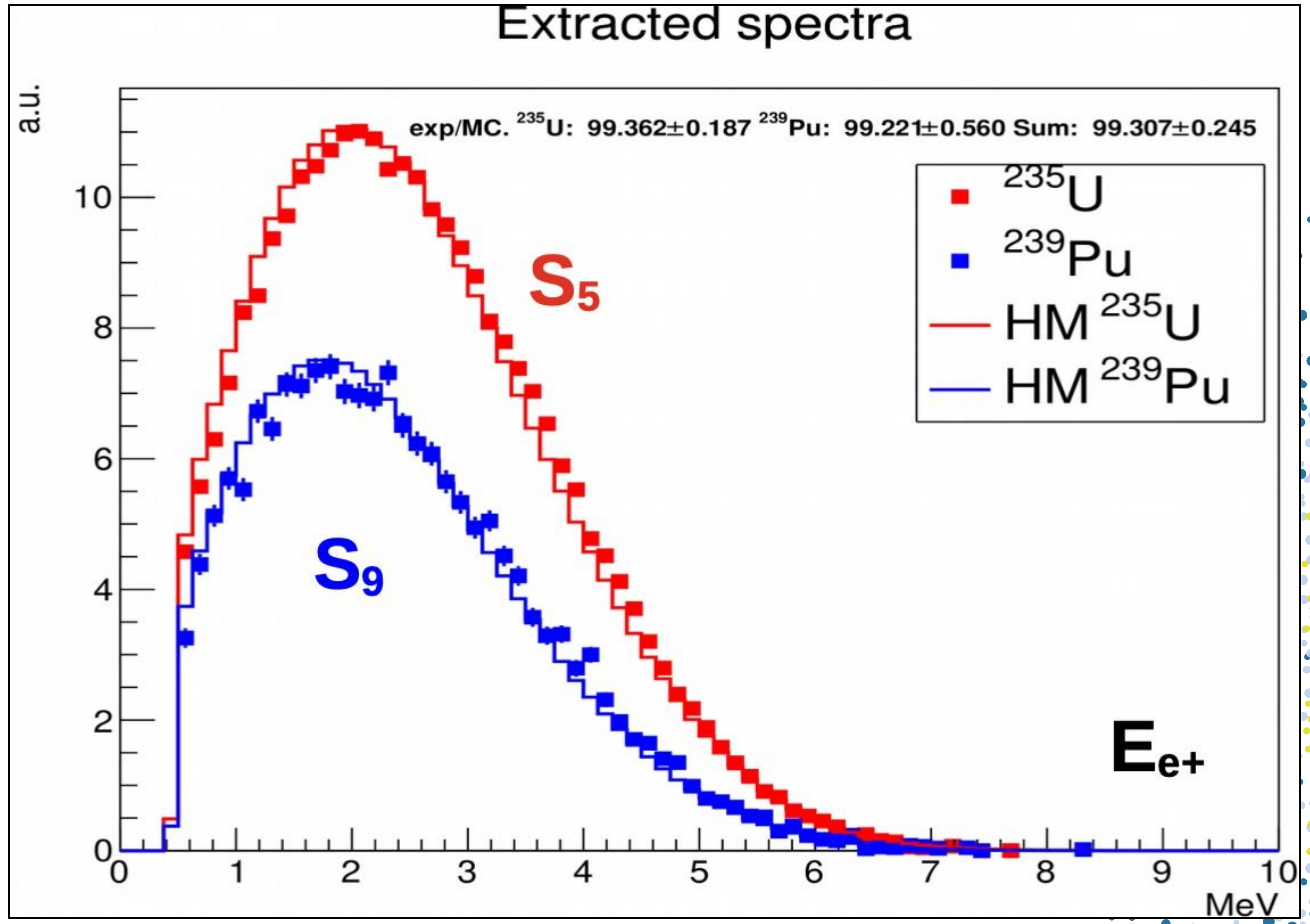
- A simple but very stable formula for σ_5/σ_9
- DANSS result σ_5/σ_9 = 1.528±0.058 almost matches H-M (1.53±0.05) but differs from DB (1.412±0.089, 1.1σ) and KI (1.45±0.03, 1.2σ)

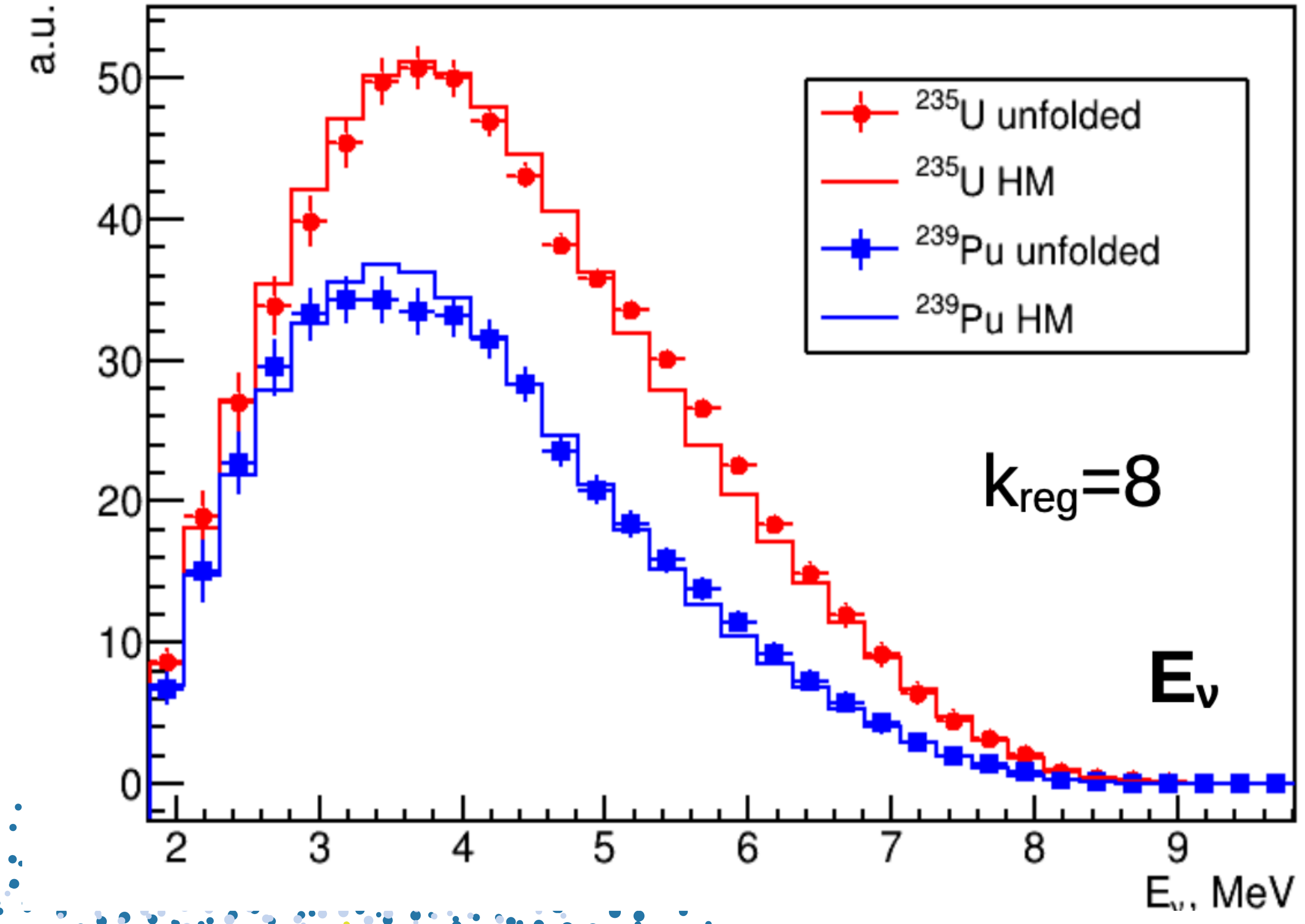
✓ Interestingly, the slope of DB in our formula gives 1.459±0.052 => differences due to slope.

Separation of ^{235}U and ^{239}Pu Spectra









- Individual 'weekly' points at full power. Total 559 points, range E_{e+}(0.5 –10 MeV)
- At each point we renormalise the positron spectrum (on fission) on MC by H-M with known FF
- We subtract the MC spectra of ^{238}U and ^{241}Pu from their FF
- We make the substitution: $f`_5=f_5/(f_5+f_9)$, $f`_9=f_9/(f_5+f_9)$, $S`_{59}=S_{59}/(f_5+f_9)$ so $f`_5+f`_9=1$
- For each energy bin, $S_{59}`=(1-f`_9)\text{-}S_5 + f`_9\text{-}S_9$
- In each energy bin, perform a linear fit with free parameters S_5 and S_9
- Relative normalisation, but the correct ratio
- Using the SVD method we convert the spectrum of positrons to the antineutrino spectrum (regularisation 8)
- Not bad for the first try!

DANSS detector upgrade

Limitations of the DANSS detector

- A significant limitation for SN searches is the resolution of the detector

34 % @ 1 MeV

(At the moment, increasing the statistics does not significantly improve the results).

- Outdated PMT+SiPM light collection system leads to a decrease in effectively collected light.

34.2 f.e./MeV -> 15.3 f.e./MeV

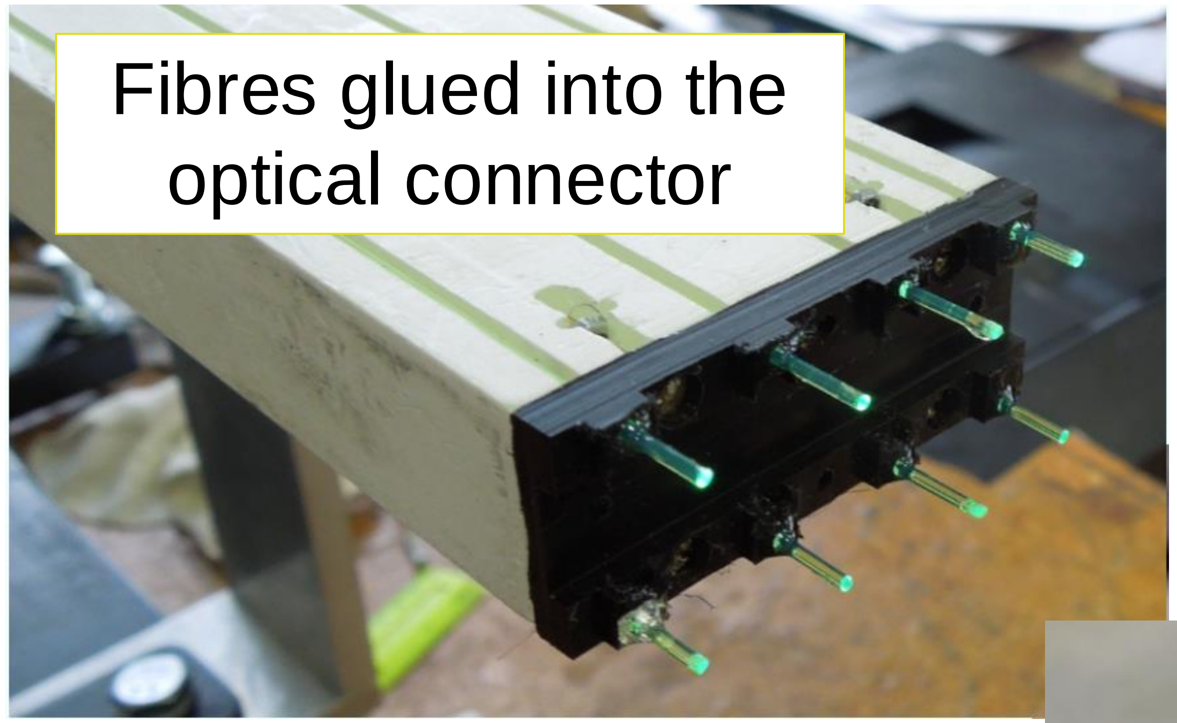
- There is a small problem with inhomogeneity of light collection (~ 8%)
- Non-uniformity of gadolinium layer (difficult for modelling)
- It would be nice to have information about event location by time of signal arrival

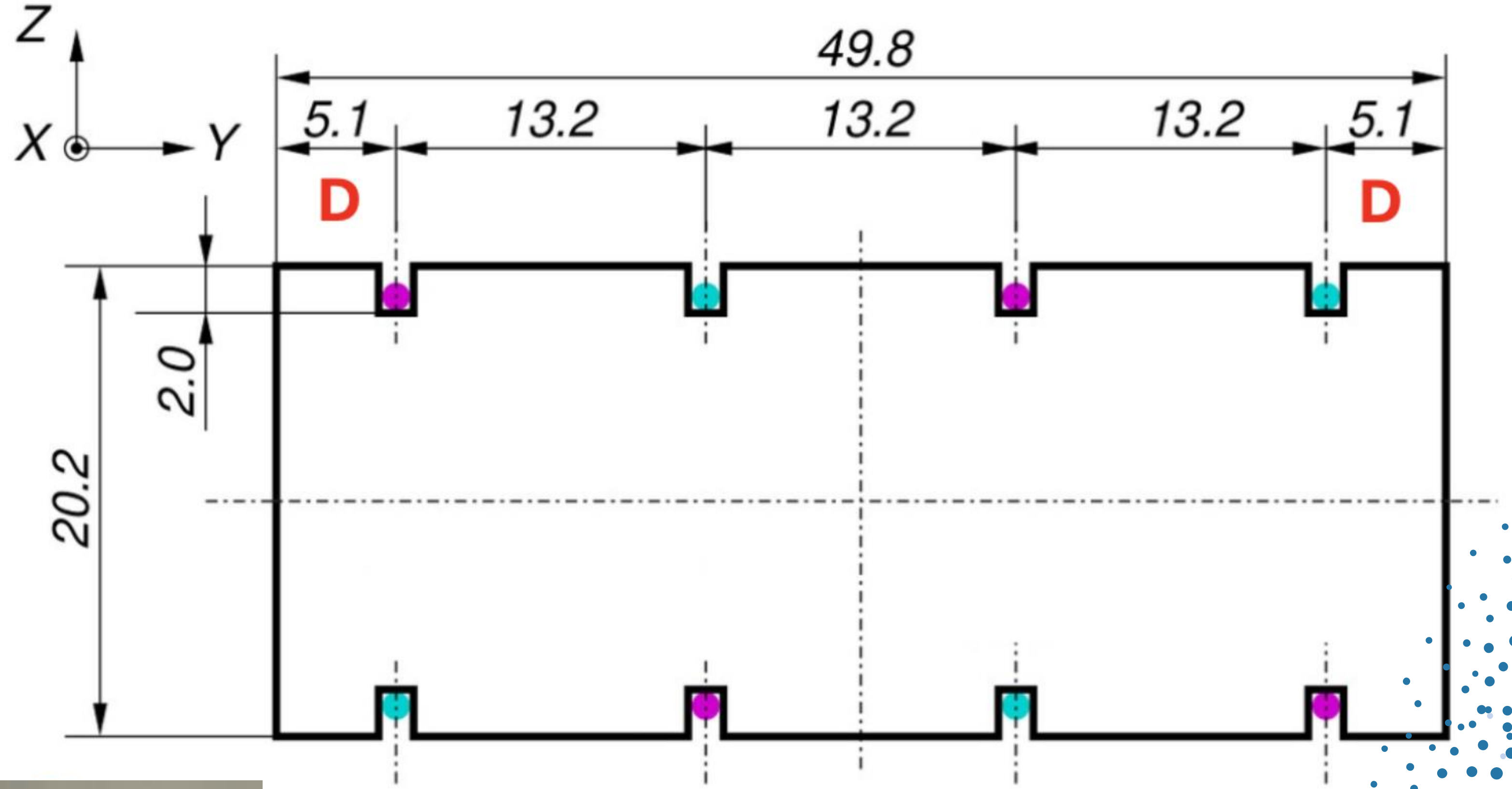
DANSS detector upgrade

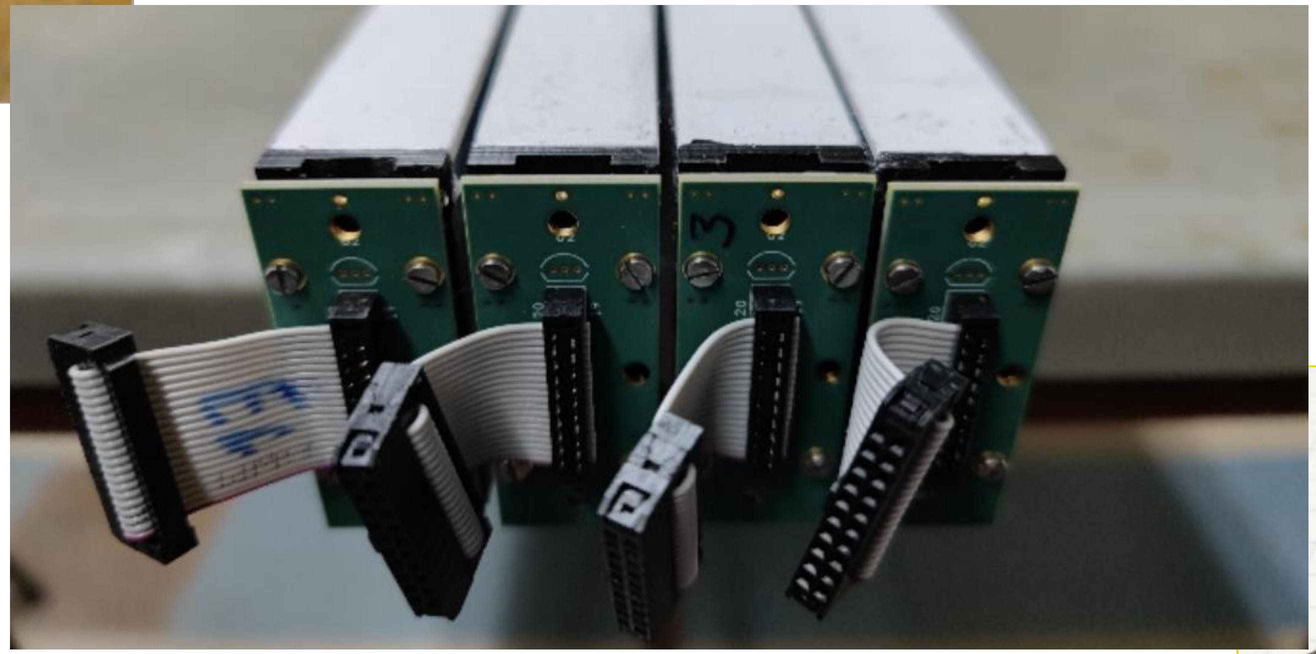
Upgrade goals

- Improve energy resolution
- Increase active volume without significantly changing the geometric dimensions of the setup
- Obtain the information about the location of an event based on the time of signal arrival
- Get rid of PMT. No trigger events.
- Use of gadolinium film instead of paint

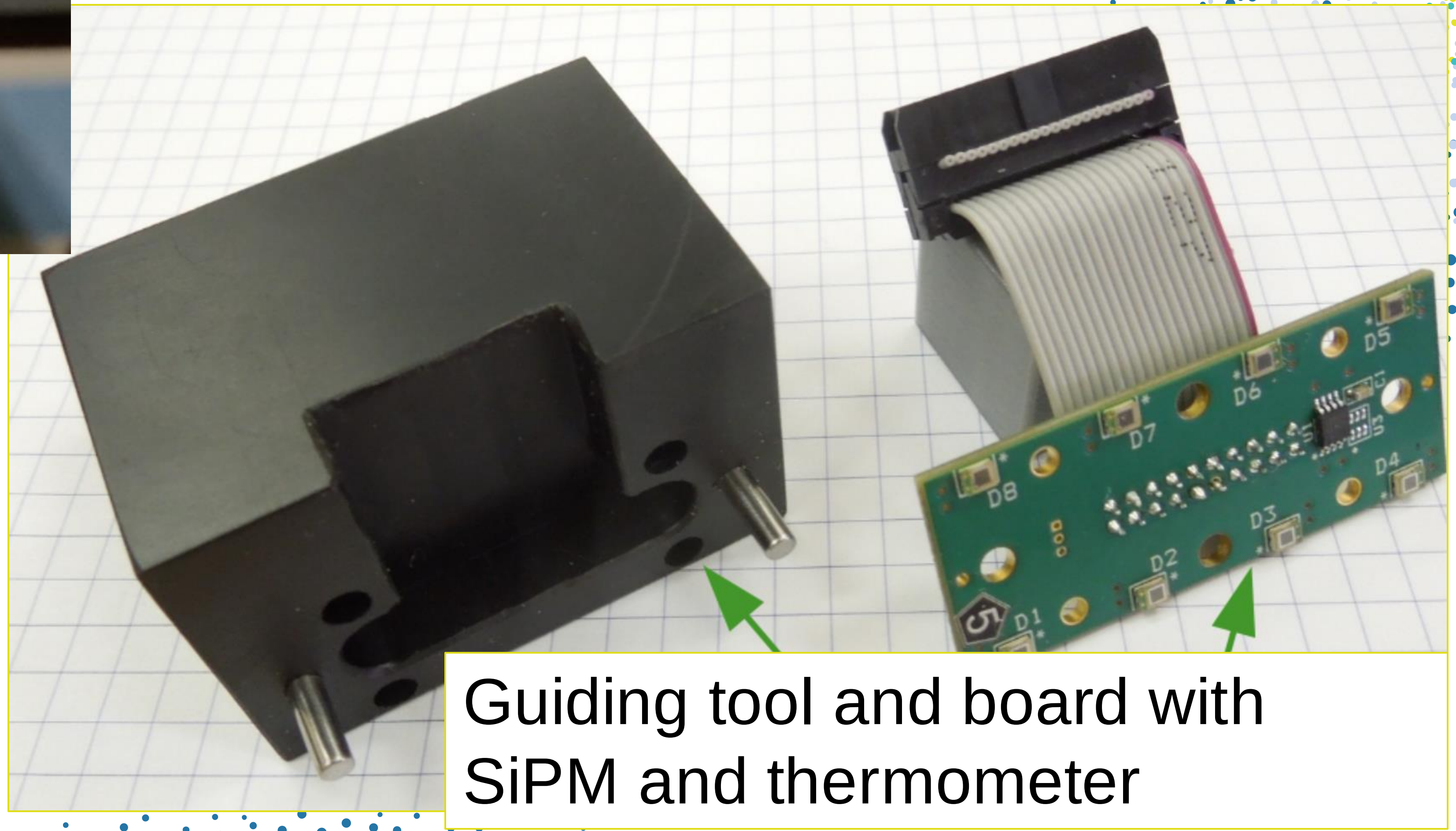
New detector design



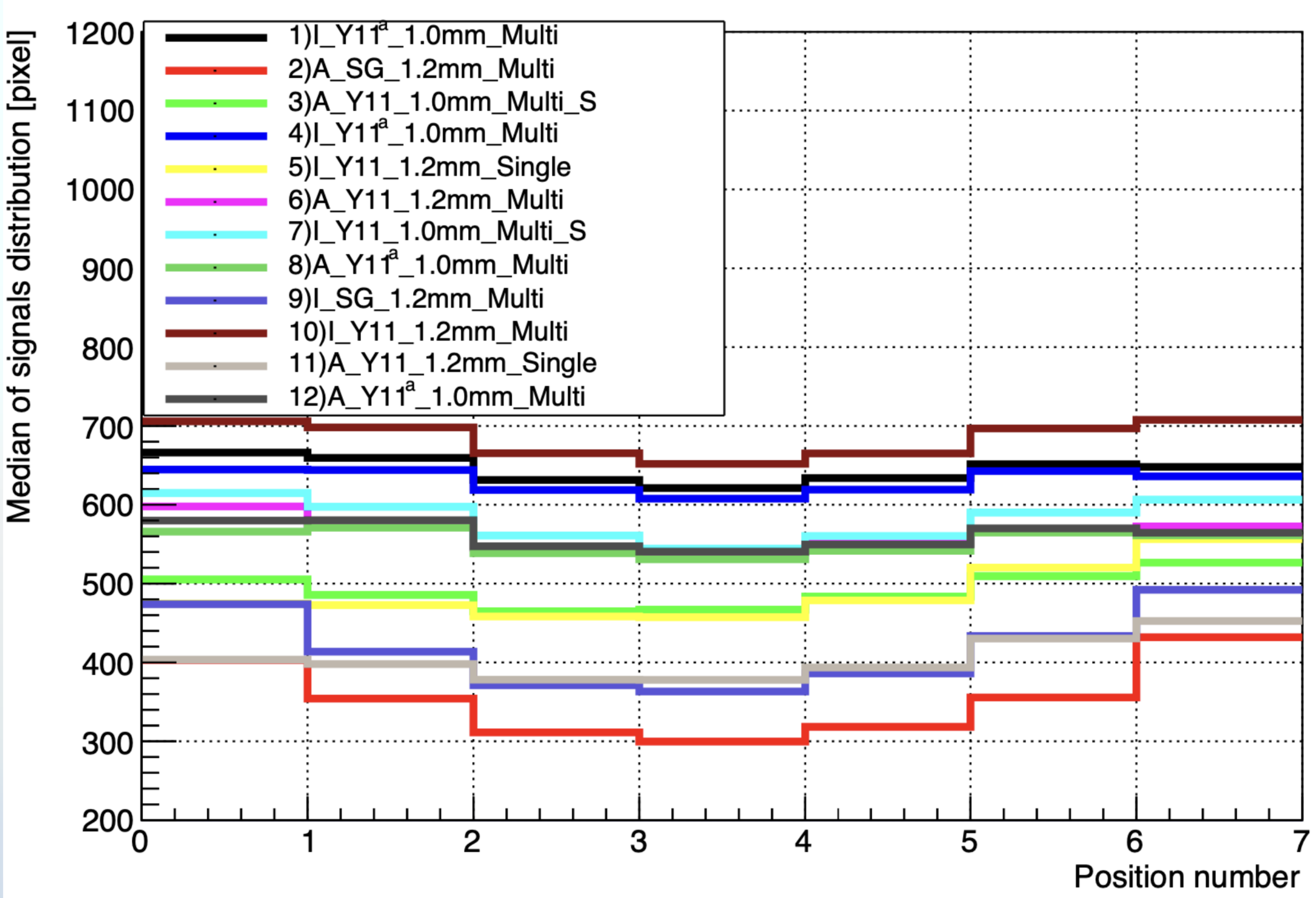


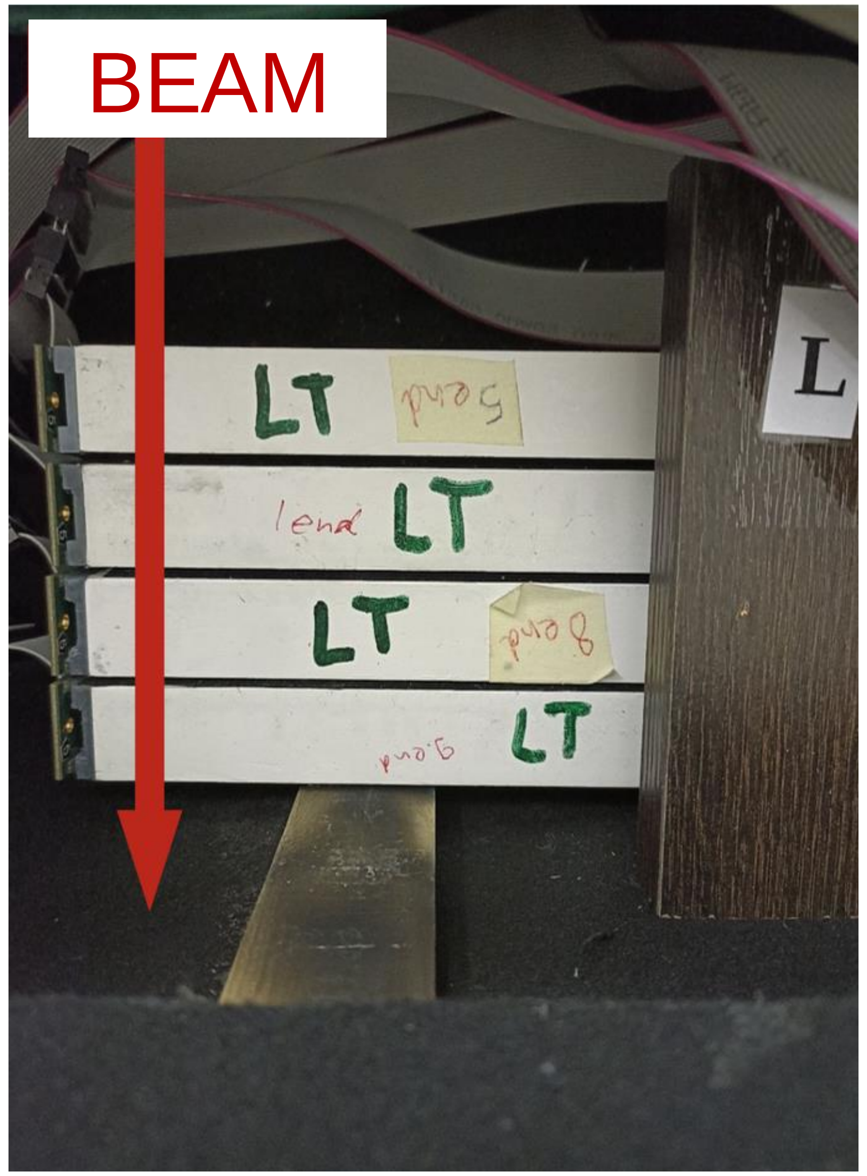


- Reading of 8 optical fibres from both sides
- SiPM read only
- New electronics - better temperature conditions for SiPM
- Optical connector proximity

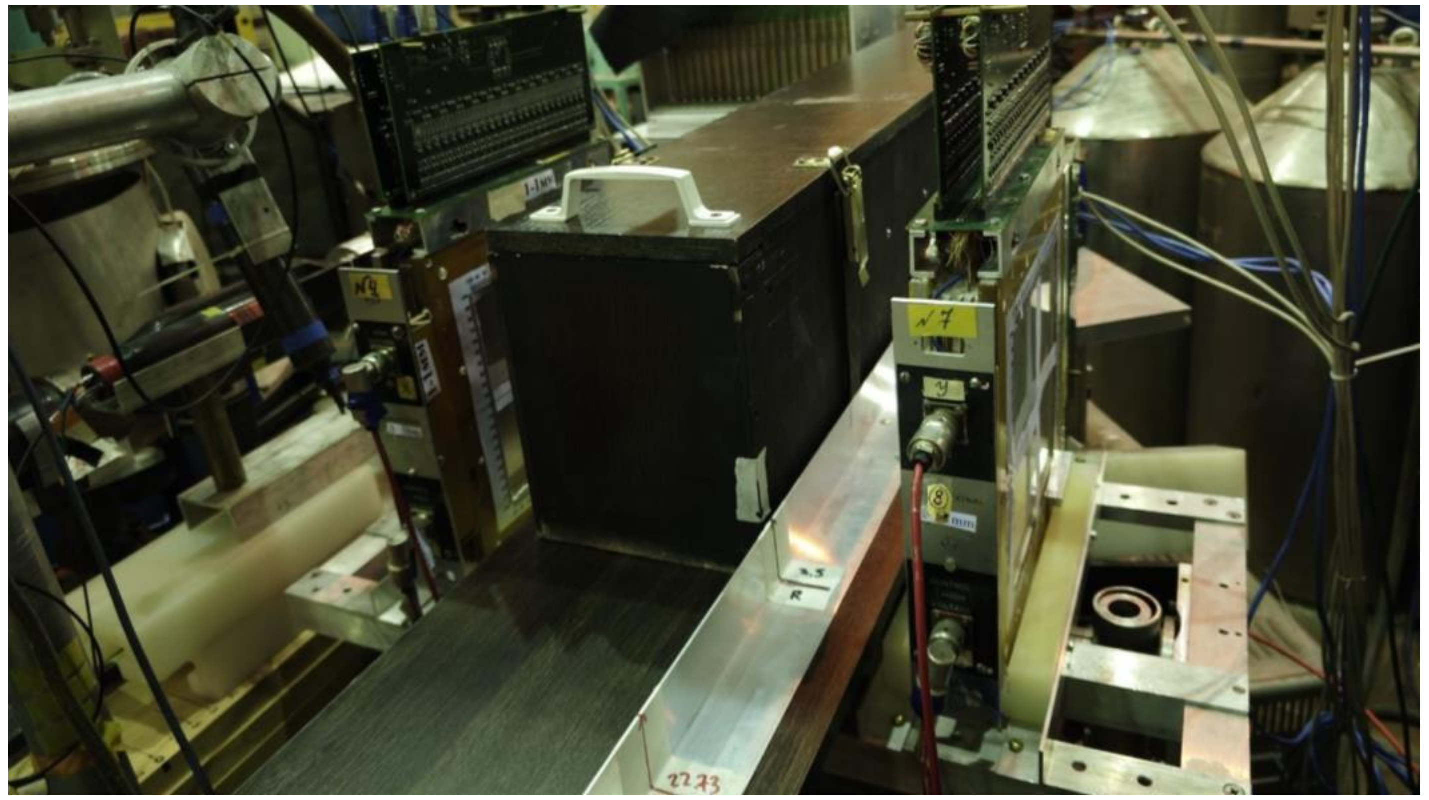


Detectors tests





7 beam positions
Step ~ 19 cm
Statistics for each position ~ 1 million events.

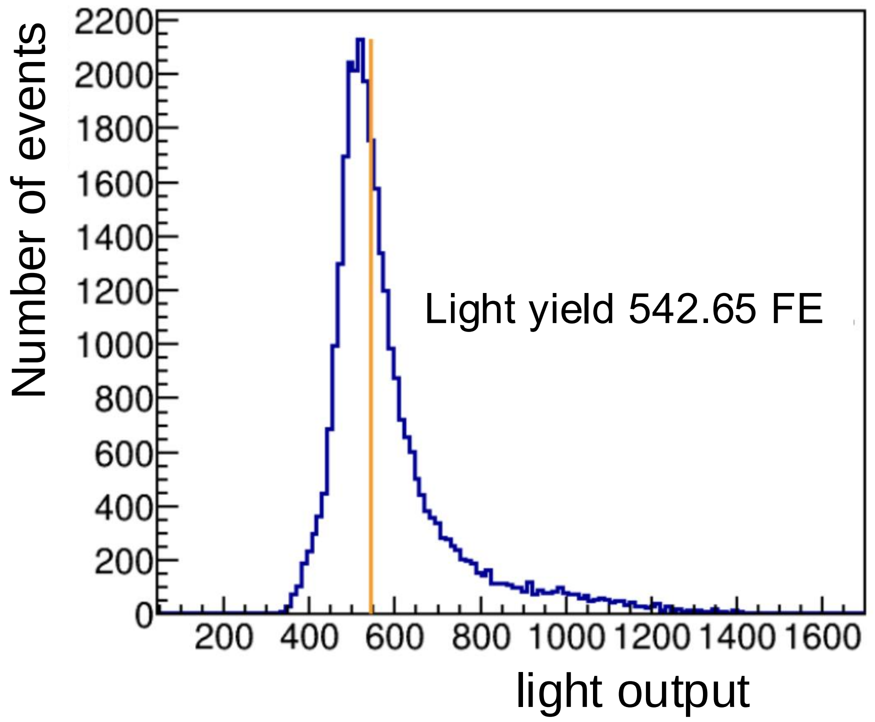


Detectors tests

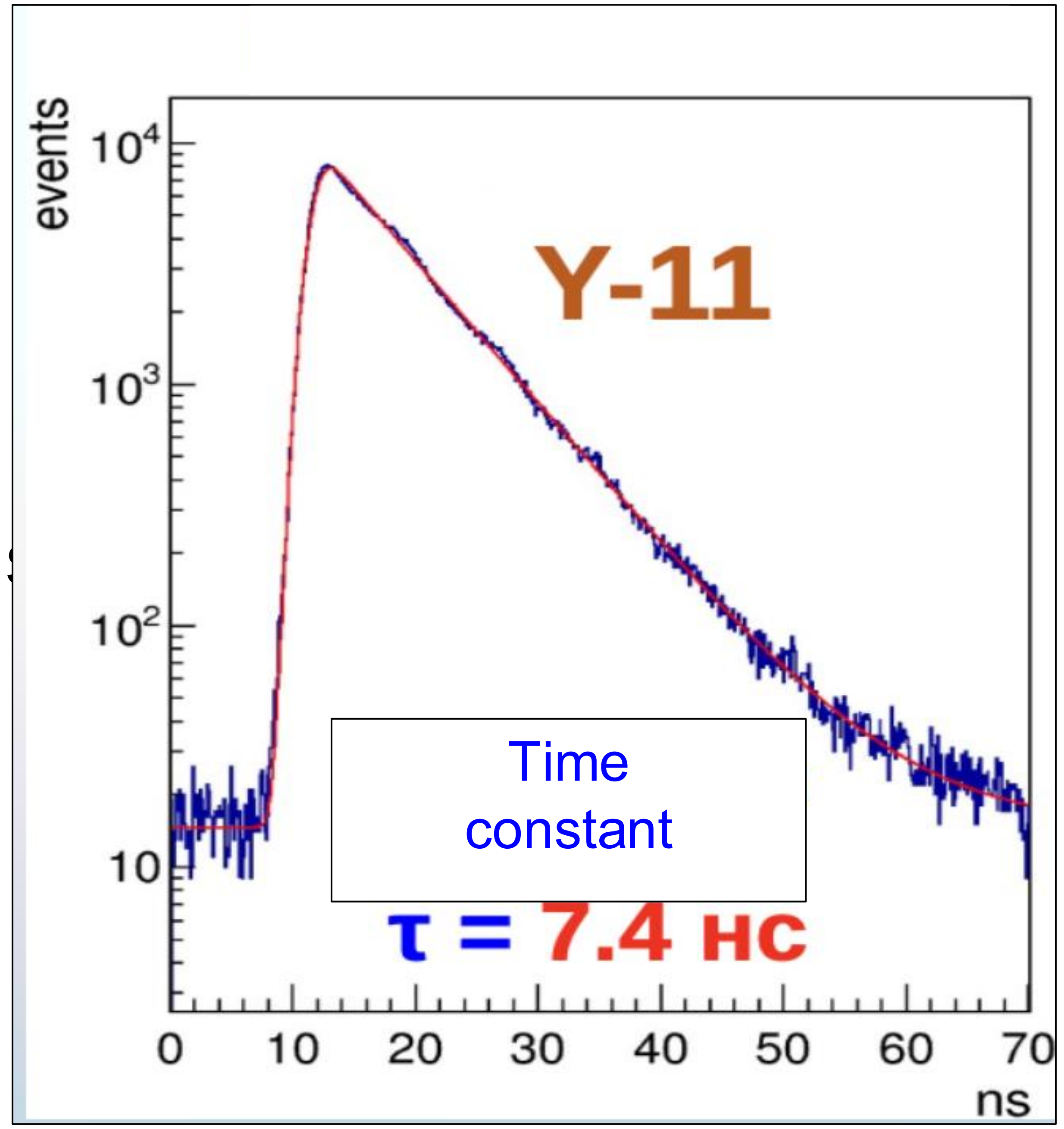
Number	Type of Plastic	Type of fiber	Median average [pixels]	Time resolution [ns]	Time slope [ns/m]
12	ИФТП	1.0 Y11 m	645	0.73	-16.14
3	Аспект	1.2 Bicron m	353	1.03	-17.29
4*	Аспект	1.0 Y11 m (K)	492* (510)	0.96	-16.57
11	ИФТП	1.0 Y11 m (K)	630	0.72	-16.07
7	ИФТП	1.2 Y11 s	488	0.88	-16.17
2	Аспект	1.2 Y11 m	564	0.81	-16.19
10	ИФТП	1.0 Y11 m (K)	582	0.74	-16.33
6	Аспект	1.0 Y11 m	553	0.79	-16.44
9	ИФТП	1.2 Bicron m	419	0.95	-16.69
8	ИФТП	1.2 Y11 m	684	0.71	-16.09
1	Аспект	1.2 Y11 s	405	0.95	-16.58
5	Аспект	1.0 Y11 m (K)	562	0.77	-16.32

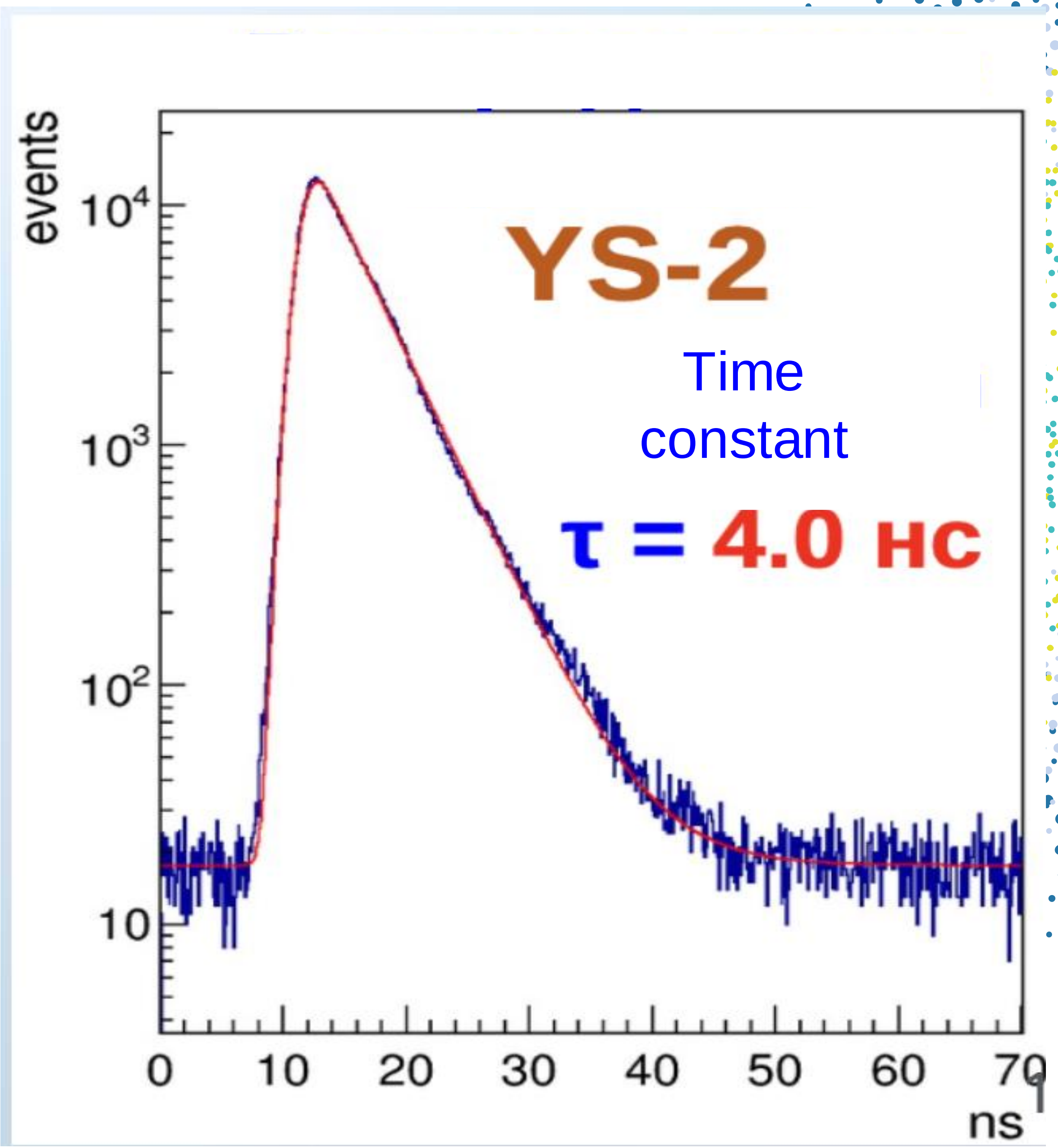
* – one channel with poor optical link

New optical fibers



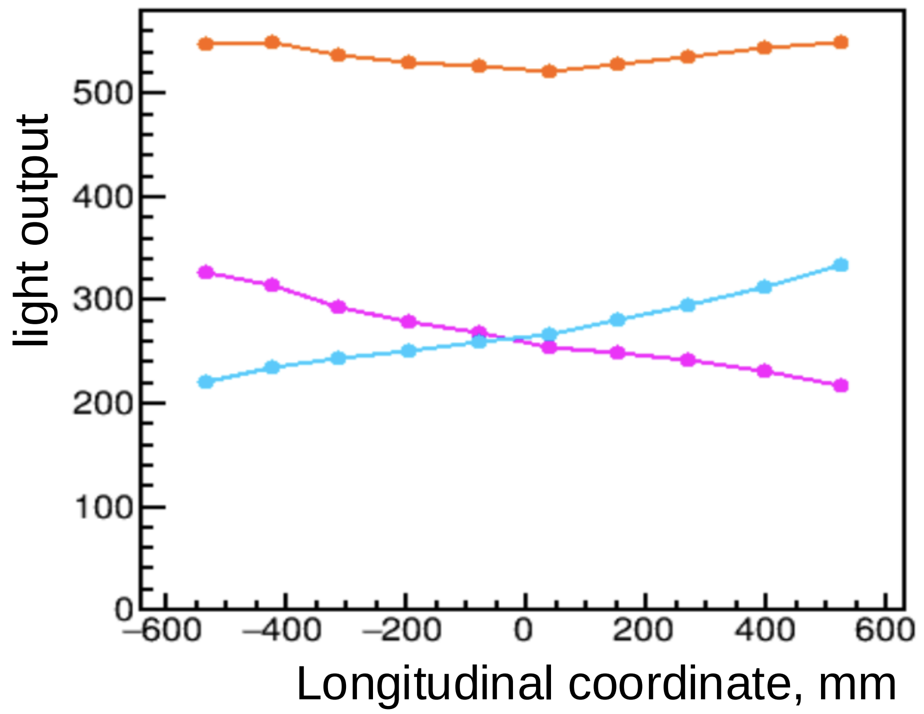
Time distribution of single-pixel events





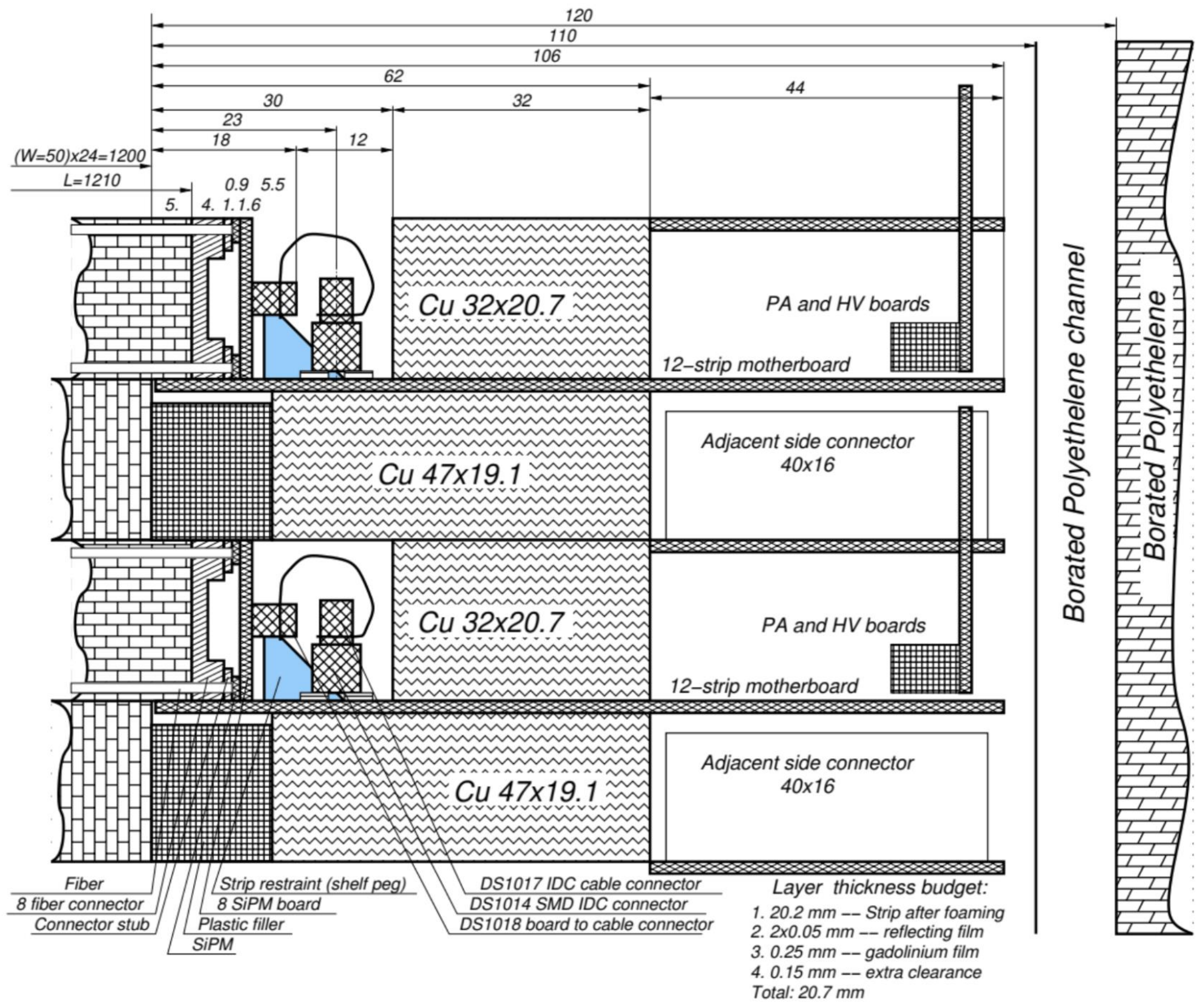
The light output is 542.7 f.e. (from one

or 147 f.e./1 MeV.



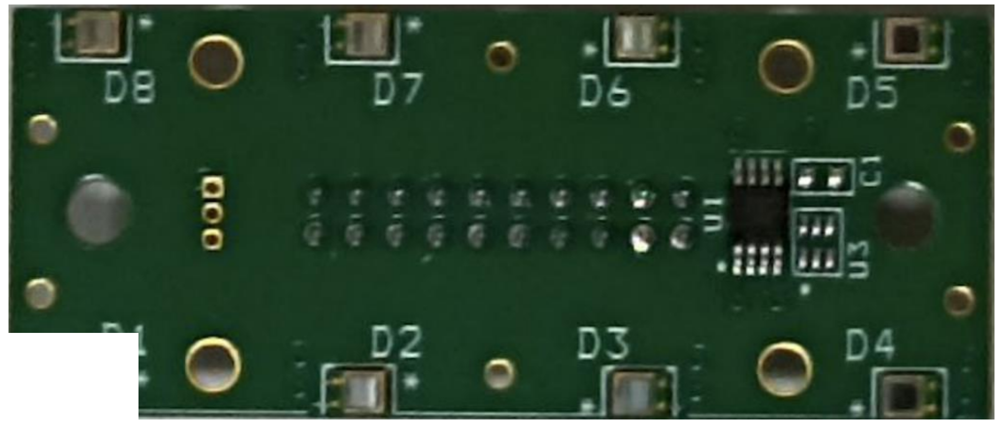
Increasing the active volume

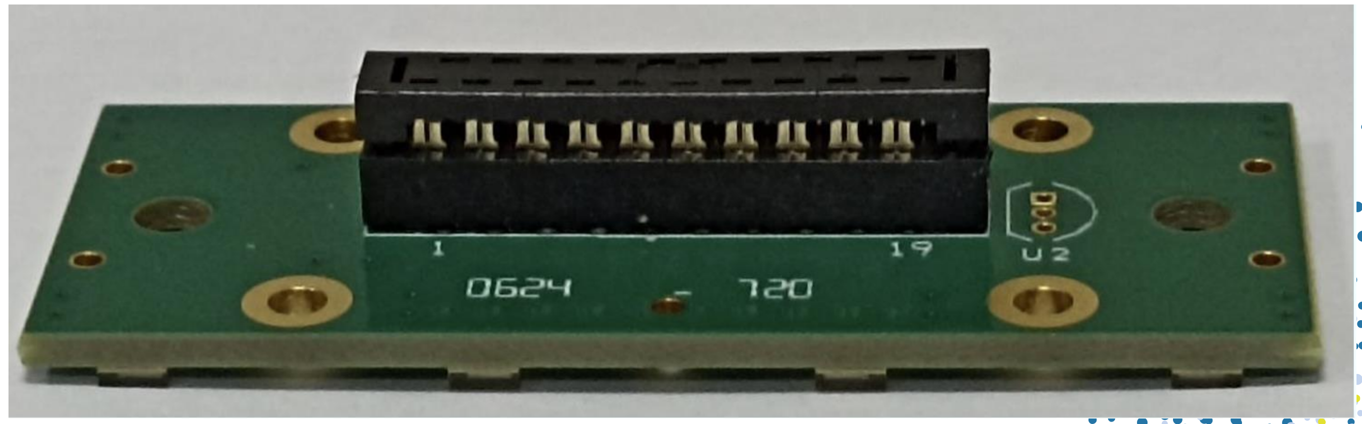
- cable lines for output the scintillation counter signals outside the internal protection circuit are excluded.
- Instead, multi-layer interconnecting PCBs between the copper plates are used.
- The thickness of the copper shielding is reduced
  (no effect on background conditions)

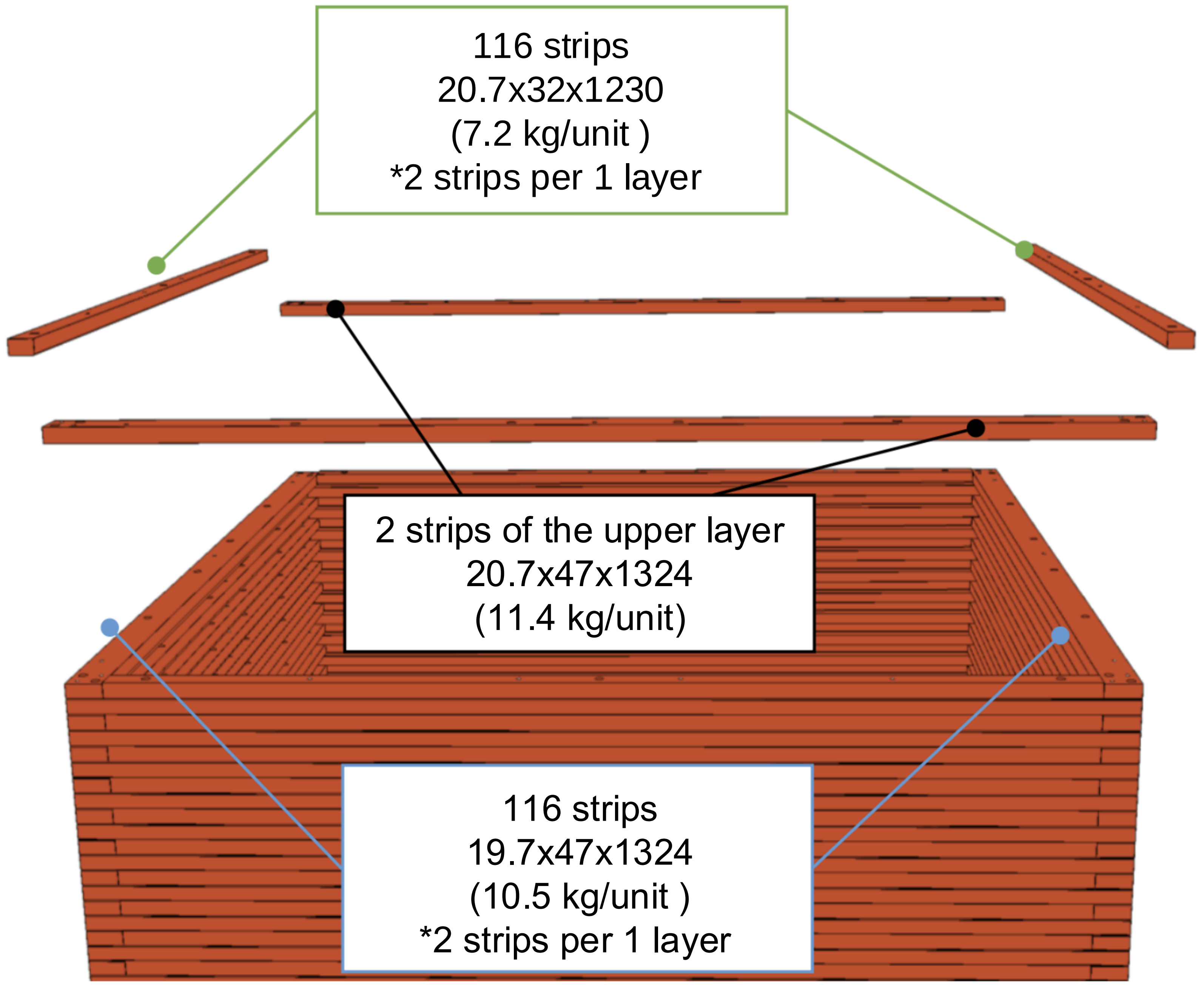


Result:
60 layers of 24 detectors (20x50x1200 mm)+ 70% to sensitive volume

Ongoing work







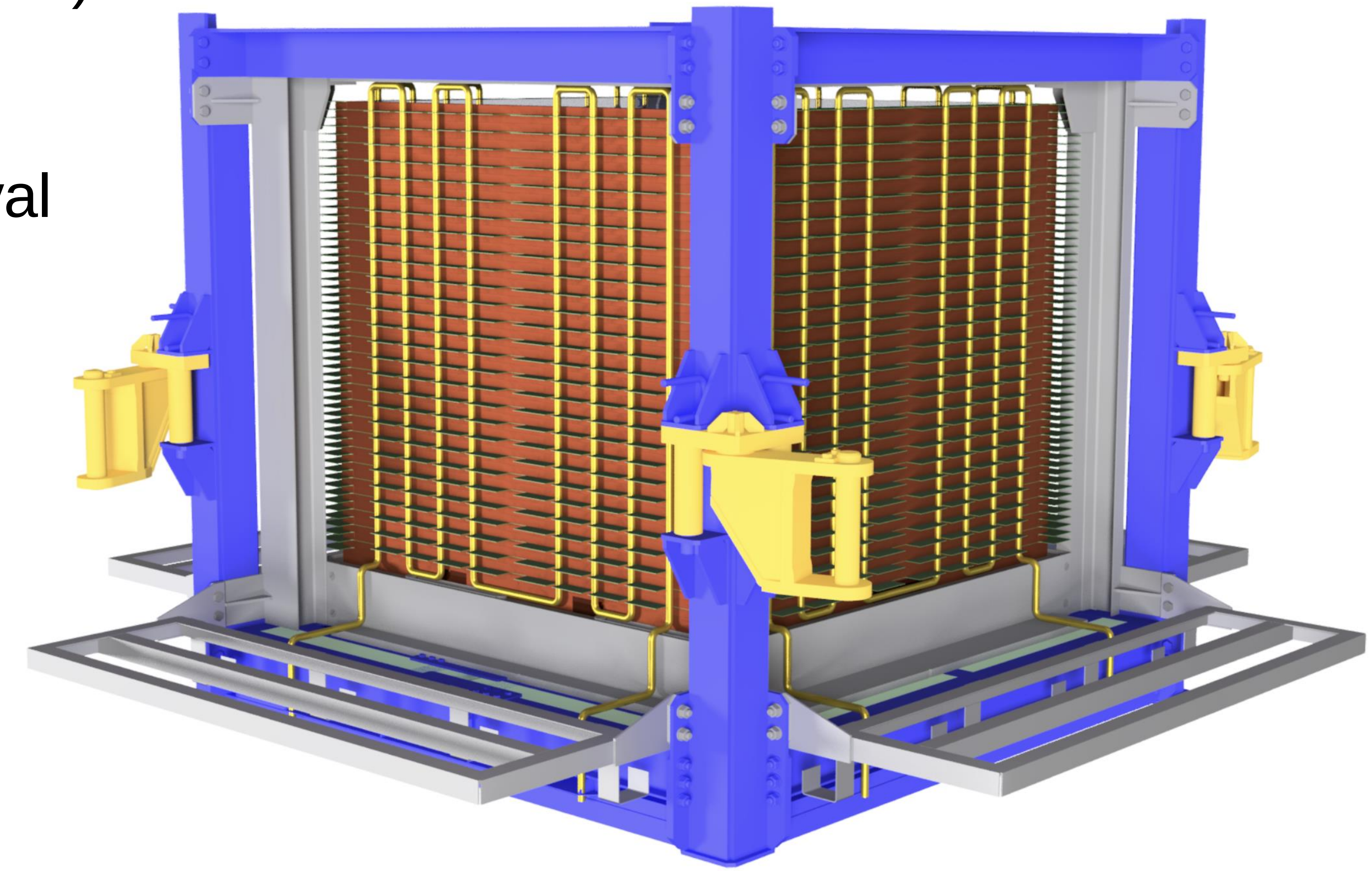
- Start of detector mass production of strips (March 2025)
- Purchases of components and materials
- Manufacturing of electronic boards
- Modelling of the future detector

DANSS – 2

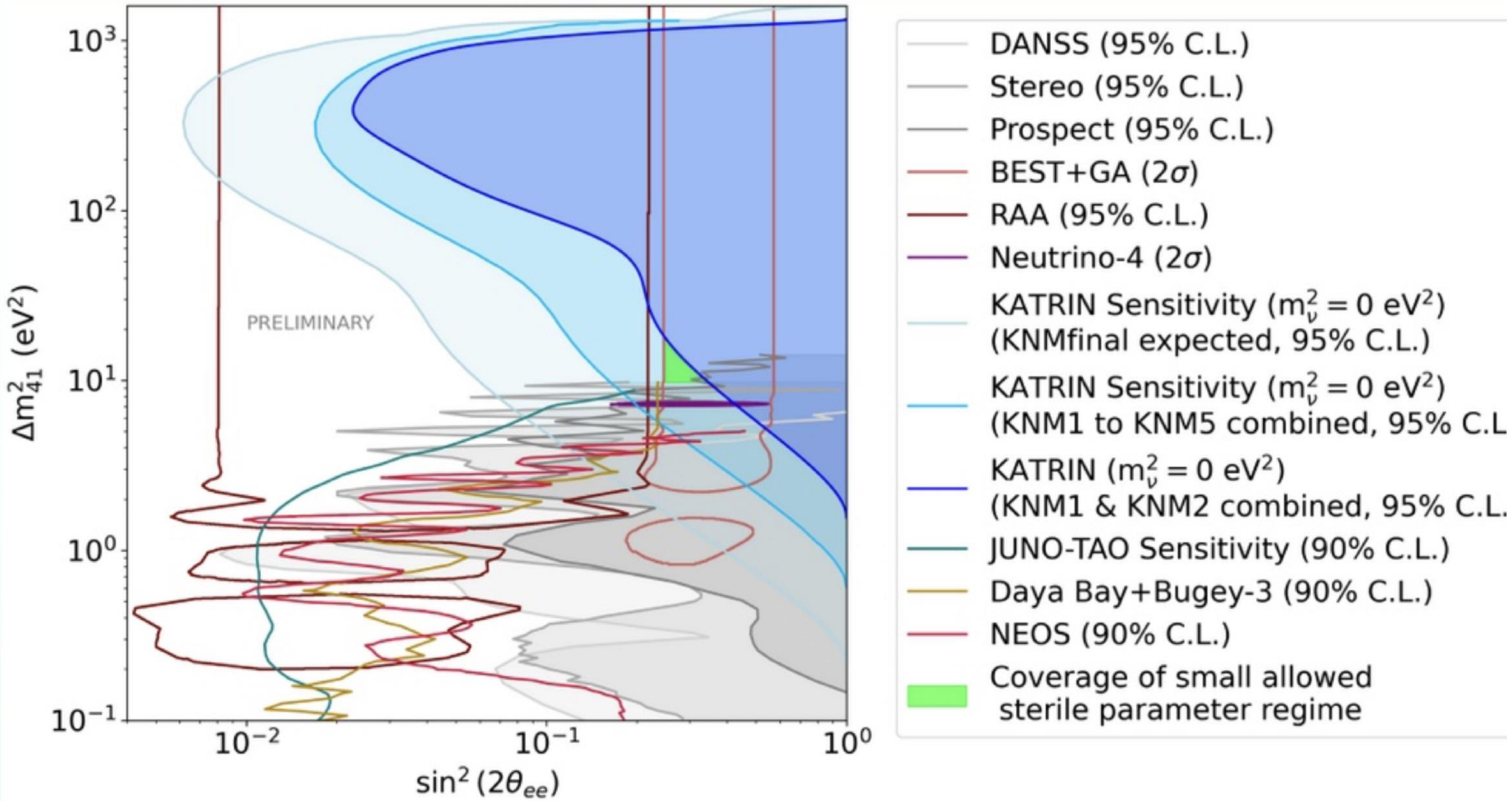
1440 detection cells

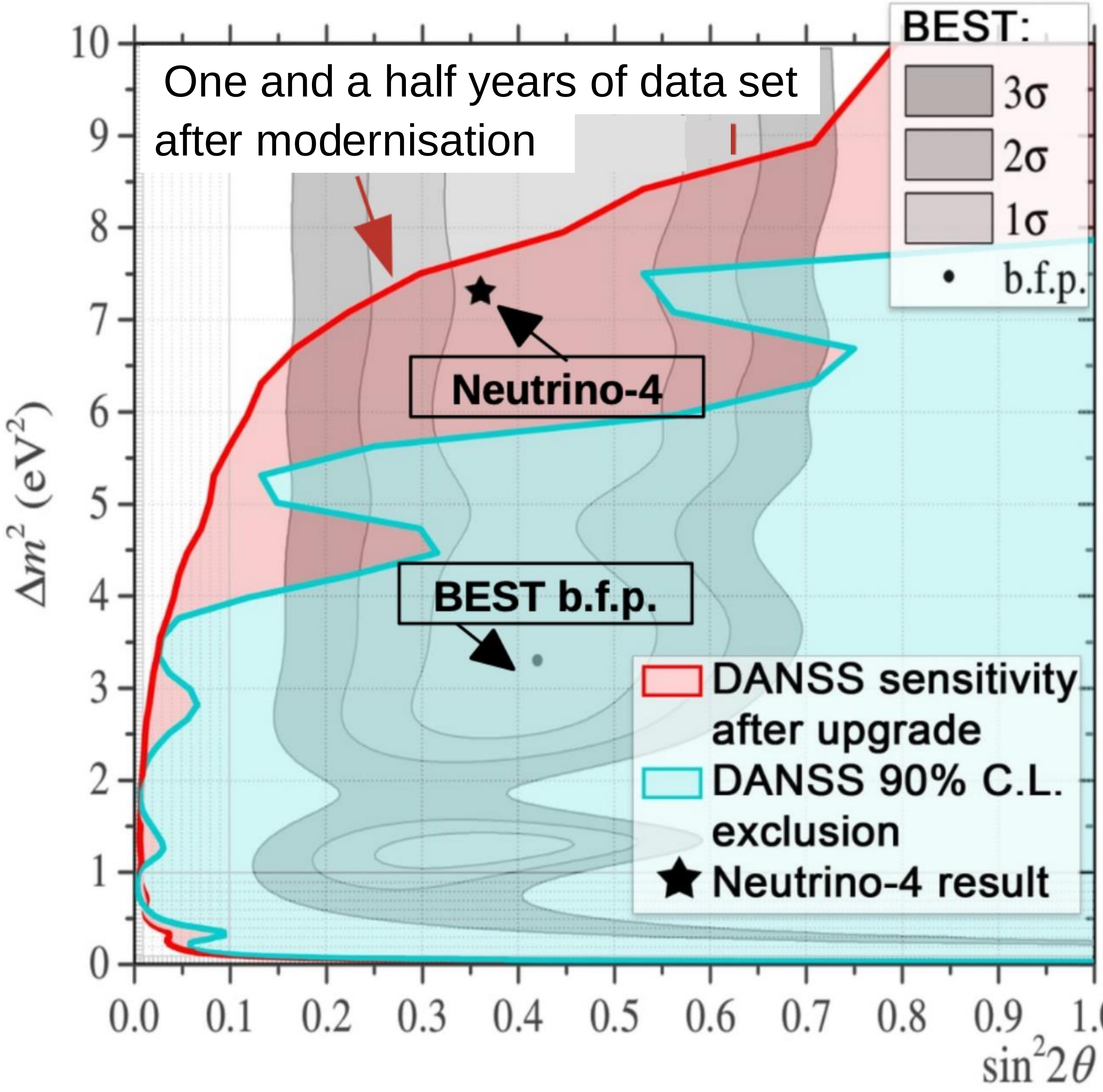
- New detectors with improved light output (IFTP, Dubna)
- Energy resolution = 12 % @ 1 MeV
- Longitudinal coordinate measurement by signal arrival time
- Sensitive volume is Increased by 70%
- Better temperature conditions for SiPM (PMTs are not used)
- Gadolinium as a constant thickness film
- Reduction in cost by using the old platform,

lift, passive protection



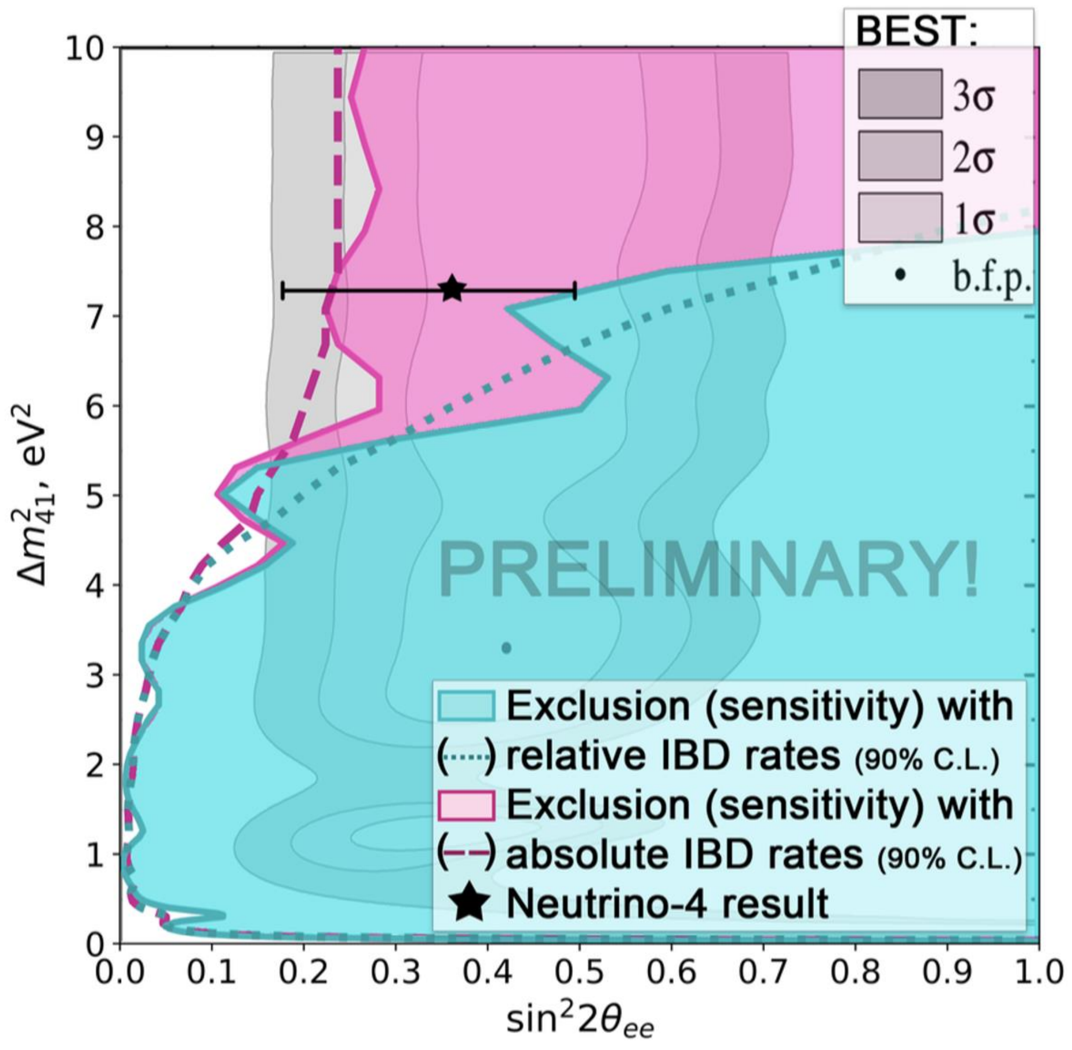
Expected sensitivity

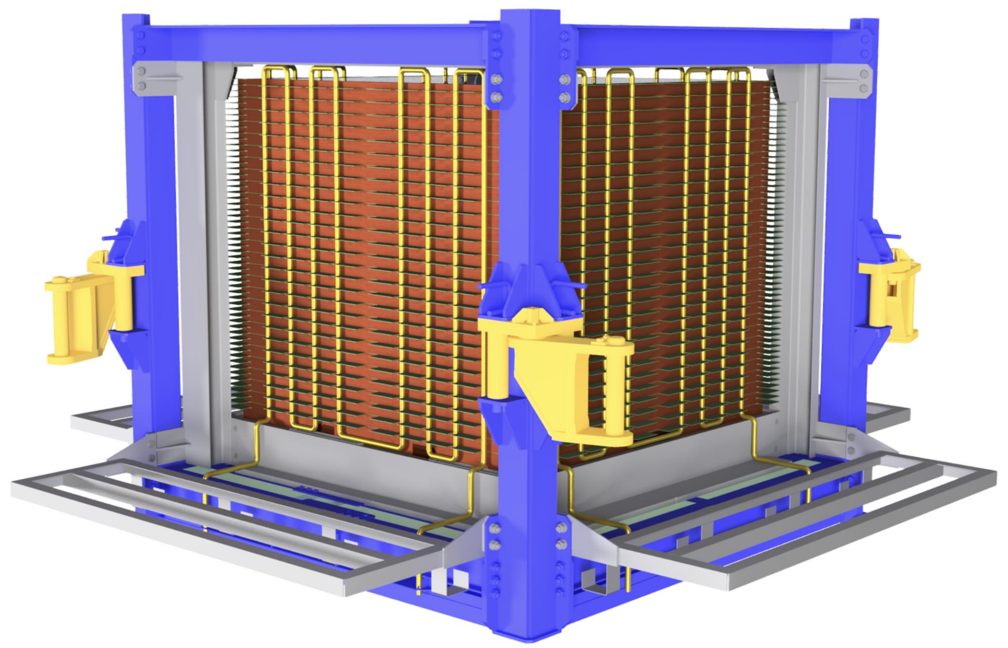




Conclusion

- The DANSS detector has been taking up data since 2016 at a rate of ~ 5000 events per day, which is a world record. Currently, over 9 million IBD events have been accumulated
- We still do not see any sagnificant hint for the sterile neutrino hypothesis
- The reactor power is measured to an accuracy of 1% per week, including 0.8% of the total systematic uncertainties of DANSS and KNPP operational measurements
- For the first time in the world, a reconstruction of fission fractions from measured spectra has been performed, the agreement with the data of KNPP calculations is within 2.1%; this adds confidence in both approaches
- The relative change in the count rate in the fuel campaign is consistent with the H-M model and slightly larger than the DB result
- The output ratio σ_5/σ_9 = 1.528±0.058 is almost the same as H-M (1.53±0.05) but a bit different from DB (1.412±0.089, 1.1σ) and KI (1.45±0.03, 1.2σ) data
- With the future upgrade to DANSS-2 the sensitivity for the sterile neutrino as well as for the reactor processes will be significantly improved





Test statistics
(absolute IBD rates analysis)

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

3-position movement Oct.2016-Dec.2018

2-position movement Mar.2019-Jan.2024

Penalty terms for nuisance parameters: relative efficiencies and systematics

$$+\left(\left(\mathrm{N}_{top} + \mathrm{N}_{mid} + \mathrm{N}_{bottom}\right)^{obs} - \left(\mathrm{N}_{top} + k_2 \cdot \sqrt{k_1} \cdot \mathrm{N}_{mid} + k_1 \cdot \mathrm{N}_{bottom}\right)^{pre}\right)^2 / \sigma_{abs}^2$$

Term for absolute rates

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

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

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

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

k – relative efficiency,

η(η⁰) – nuisance parameters (and their nominal values)

W – covariance matrix to take into account correlations in spectra ratios at different postions (Z_1 and Z_2)

N – total absolute rates

$\boldsymbol{\sigma_{abs}}$ **–** systematic uncertainty (7% in absolute rates)

Nuisance parameters and their errors ($\sigma_{k,\eta}$):

- Relative detector efficiencies – **0.4%**
- Energy scale – **2%**
- Energy shift **50 keV**
- Distance to fuel burning profile center – **5 cm**
- Cosmic background – **25%**
- Fast neutron background – **30%**
- Additional smearing energy resolution: **$(6\%/\sqrt{E} \oplus 2\%)$**

Gaussian CLs

[X. Qian et al. Nucl.Inst. Meth. A 827 (2016) 63]

Aging of DANSS scintillator

T2K (several detectors) — **0.9-2.2 %/year**; **MINOS — 2 %/year**; **MINERvA — 7-10 %/year @ 80F(**27.6^{o}C)

DANSS – 7 years of continuous operation.

The experimental hall is air conditioned and very dry.

A chilled water cooling system is used for electronics inside the passive shielding, providing a stable temperature for the central part of the detector.

Scintillator strips extruded from polystyrene by Institute of Scintillating Materials, Kharkiv, Ukraine.

The surface is covered by ~0.2 mm co-extruded layer with admixture of TiO_2 and Gd_2O_3 which serves as a diffuse reflector. Gadolinium is used to capture neutrons from the inverse beta-decay after their moderation.

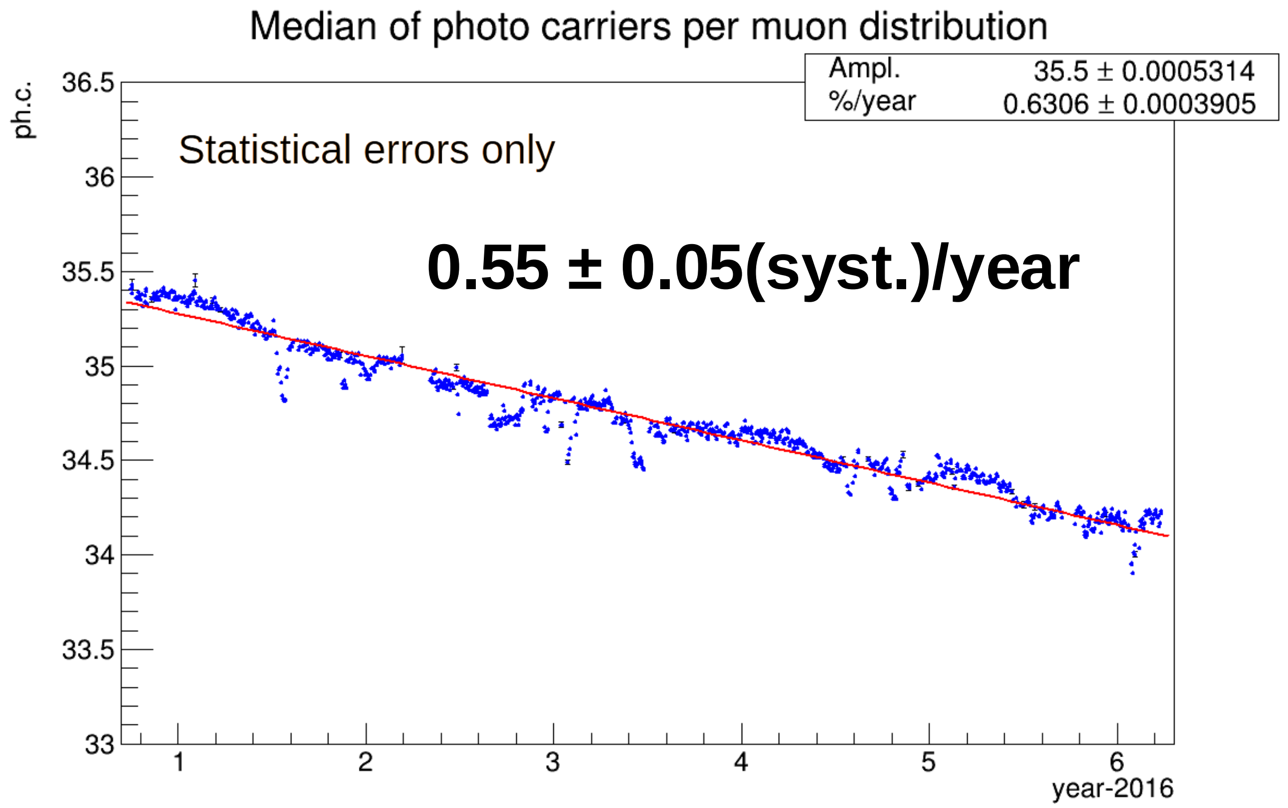
Light collection by 3 wave length shifting fibers **KURARAY Y-11(200)M**

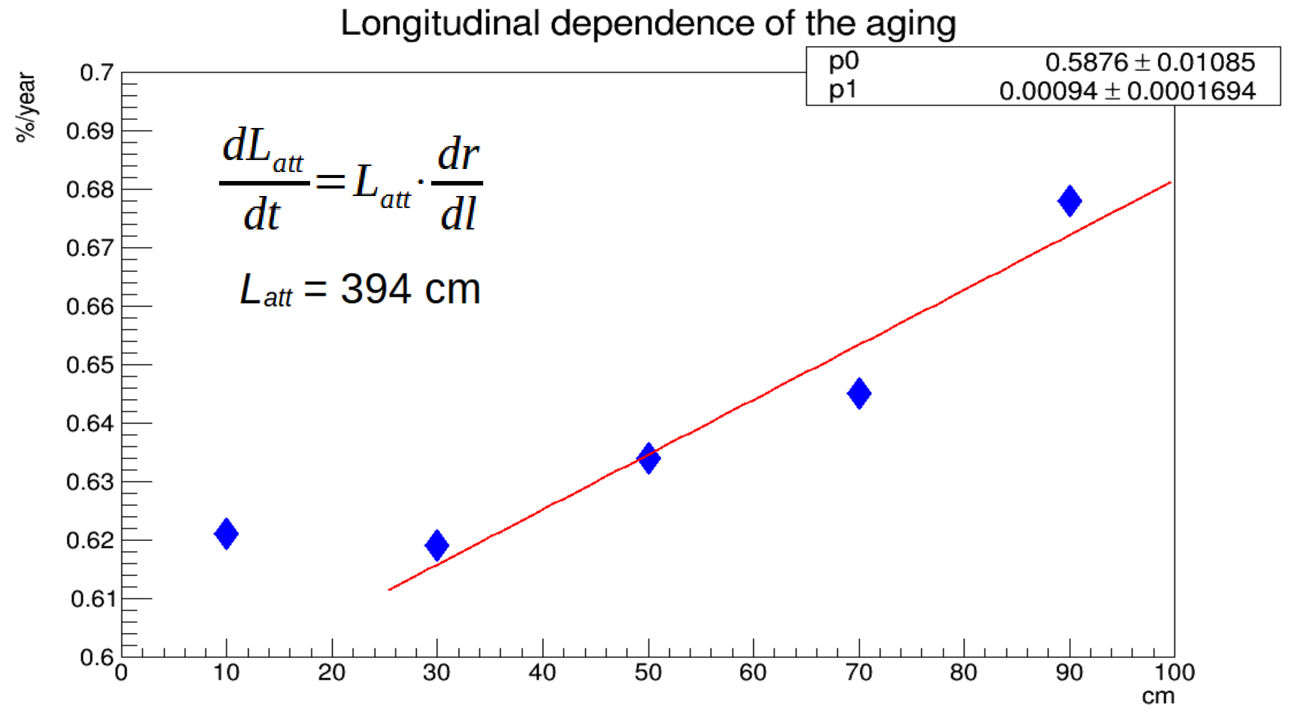
Central fiber is read by **SiPM HAMAMATSU S12825-050C**. Two side fibers are read by PMT. The other ends of the fibers are polished and covered by reflective paint.

Only SiPM data is used in the analysis. SiPM bias voltages were set once at the very beginning and never changed.

Close to vertical muon tracks with tgθ < 0.2 selected.

Median value of Landau distribution.

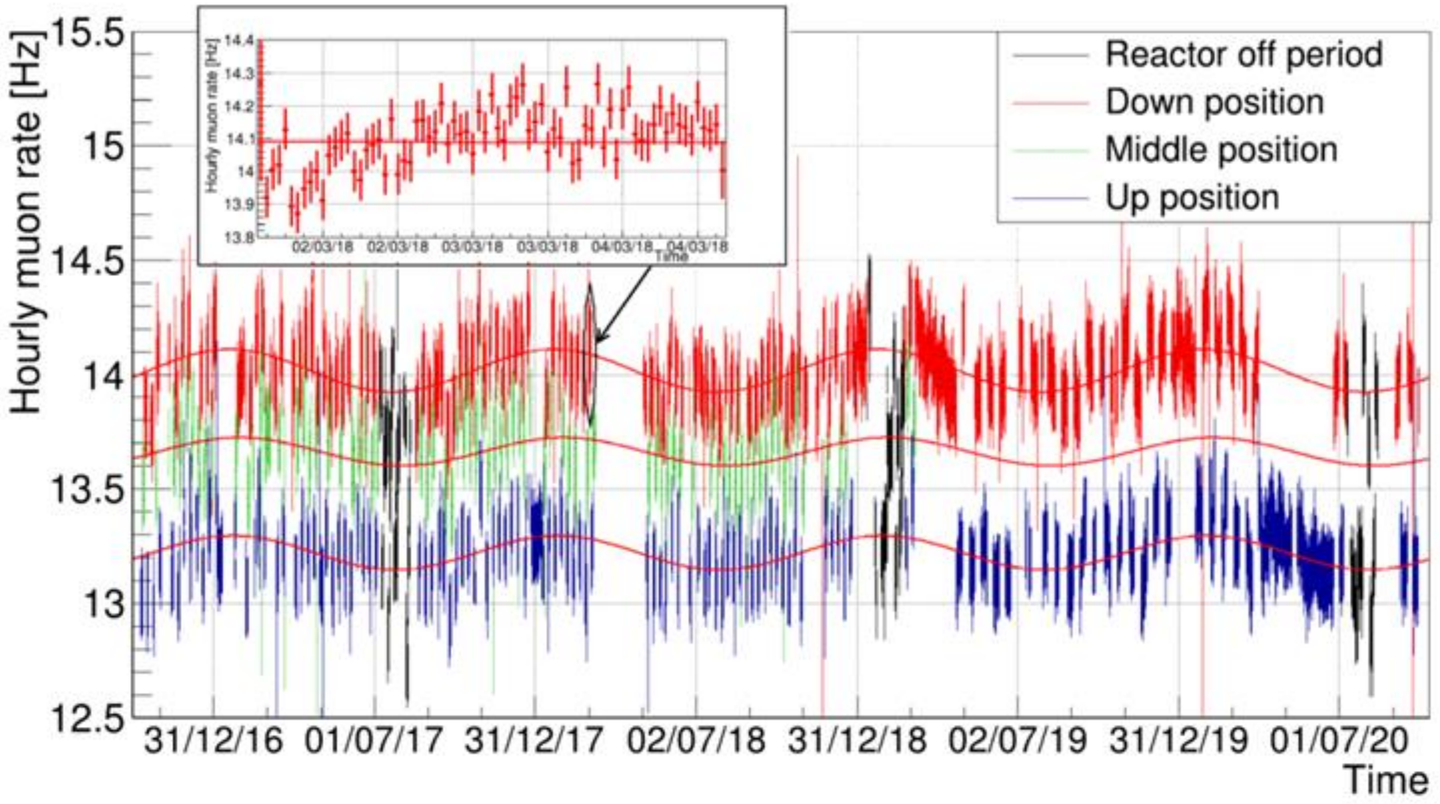


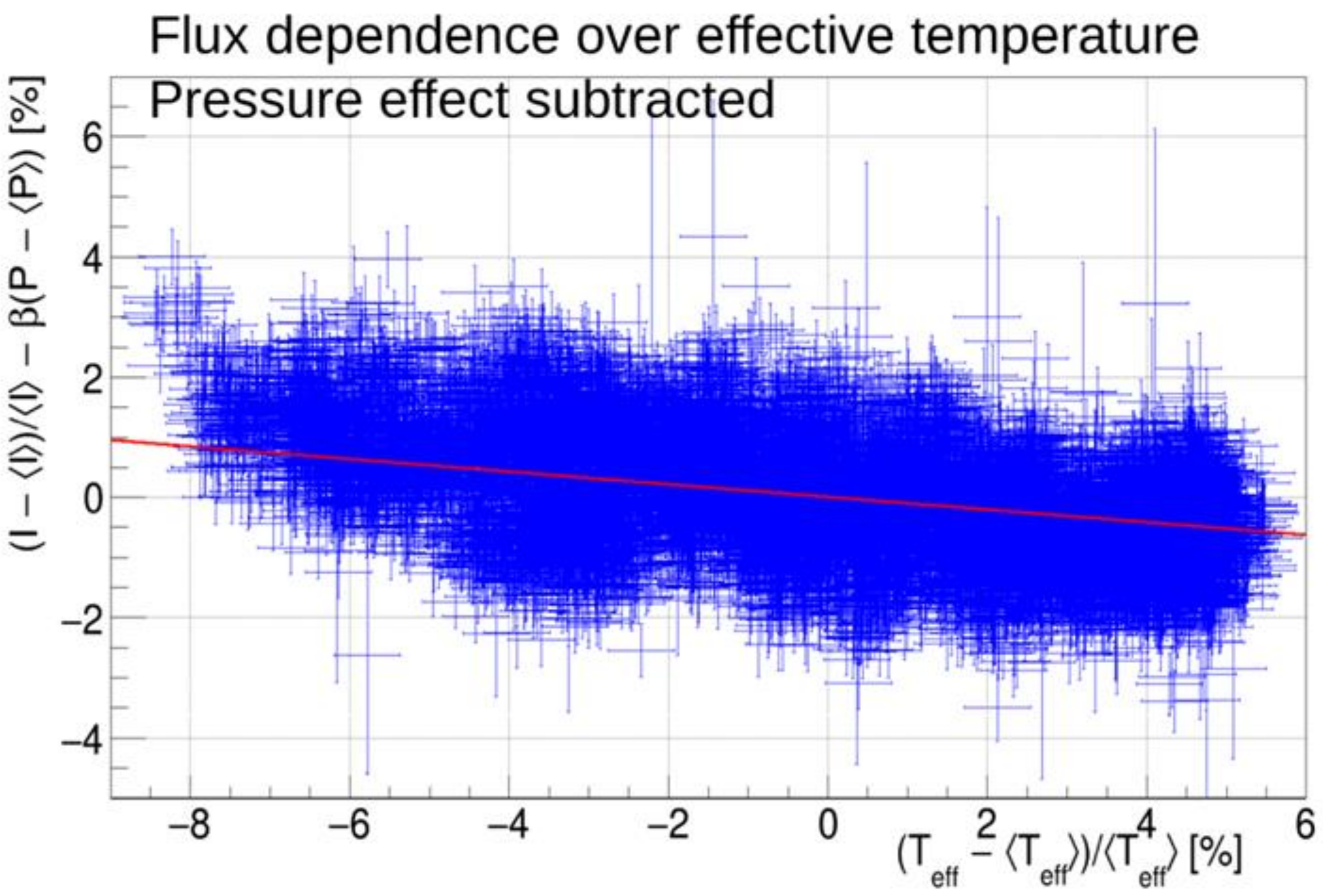


We can not separate aging of the scintillator and of the conversion efficiency of the WLS fiber. But we observe a hint of some decrease in its attenuation length. The increase of aging effect with the distance from SiPM gives an estimation of WLS attenuation length shortening $-dL_{att}/dt$ = **0.26 ± 0.04**(stat.) %/year

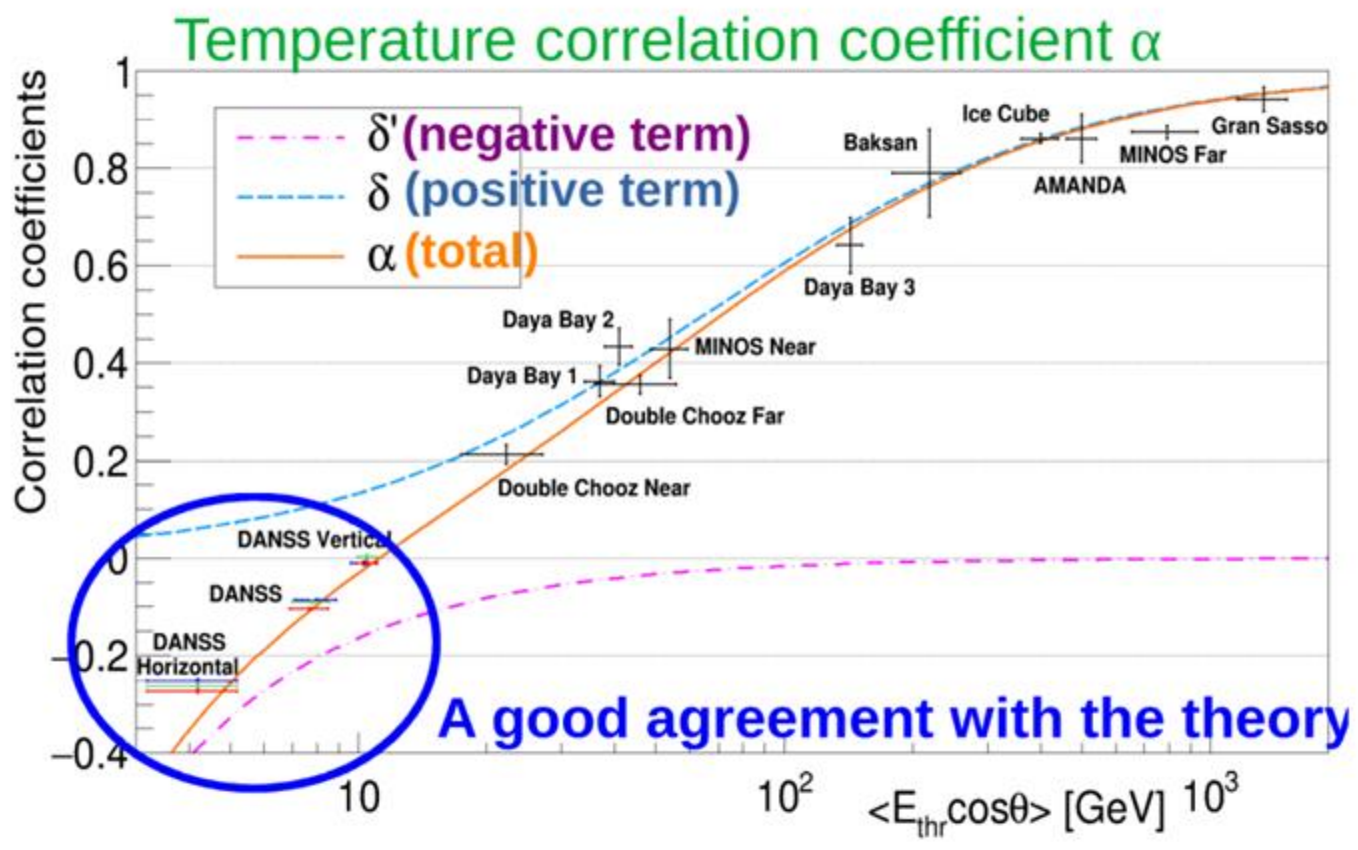
Meteorological effects on cosmic muon flux

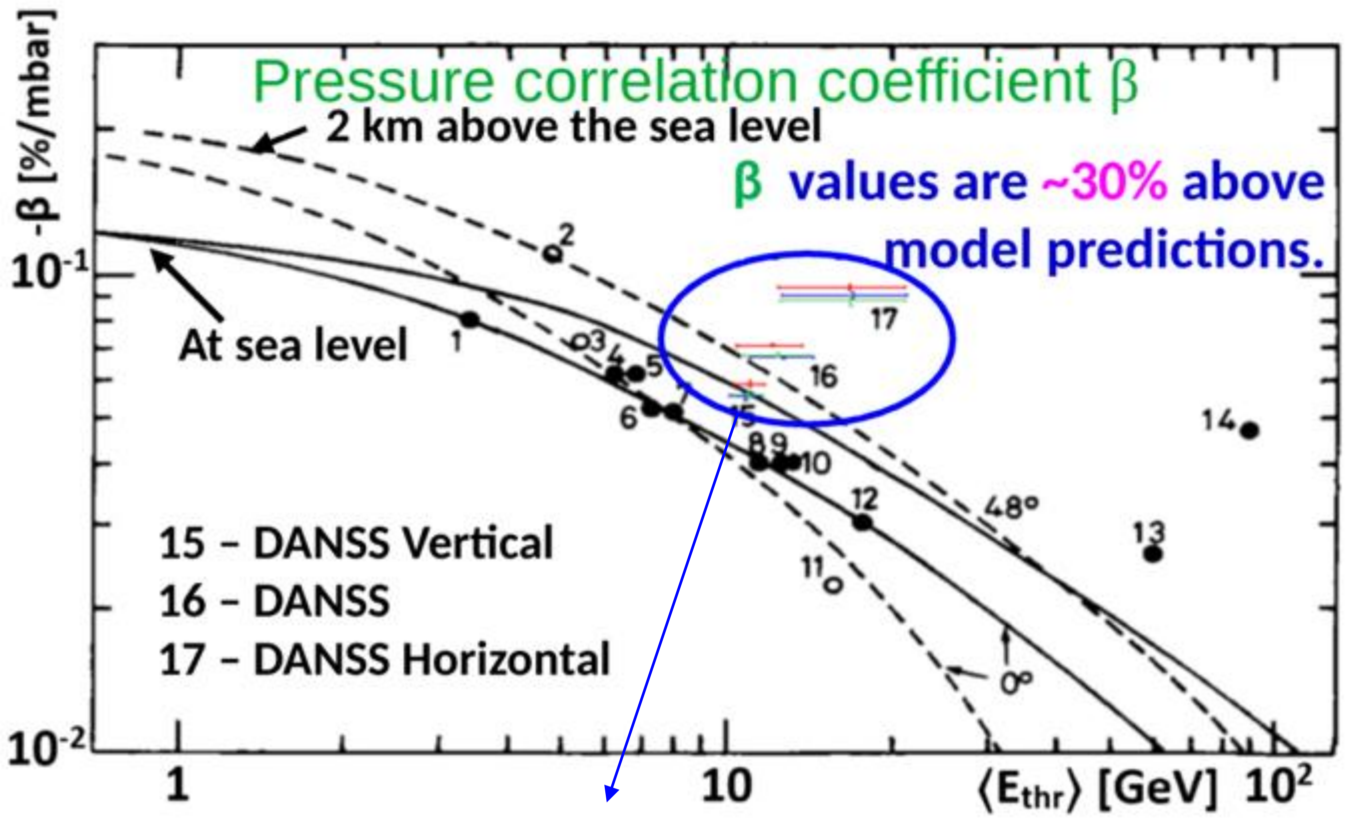
[European Physical Journal C, 2022, 82(6), 515]





Weather data obtained from ERA5 database of European Center for Medium-Range Weather Forecasts (ECMWF).

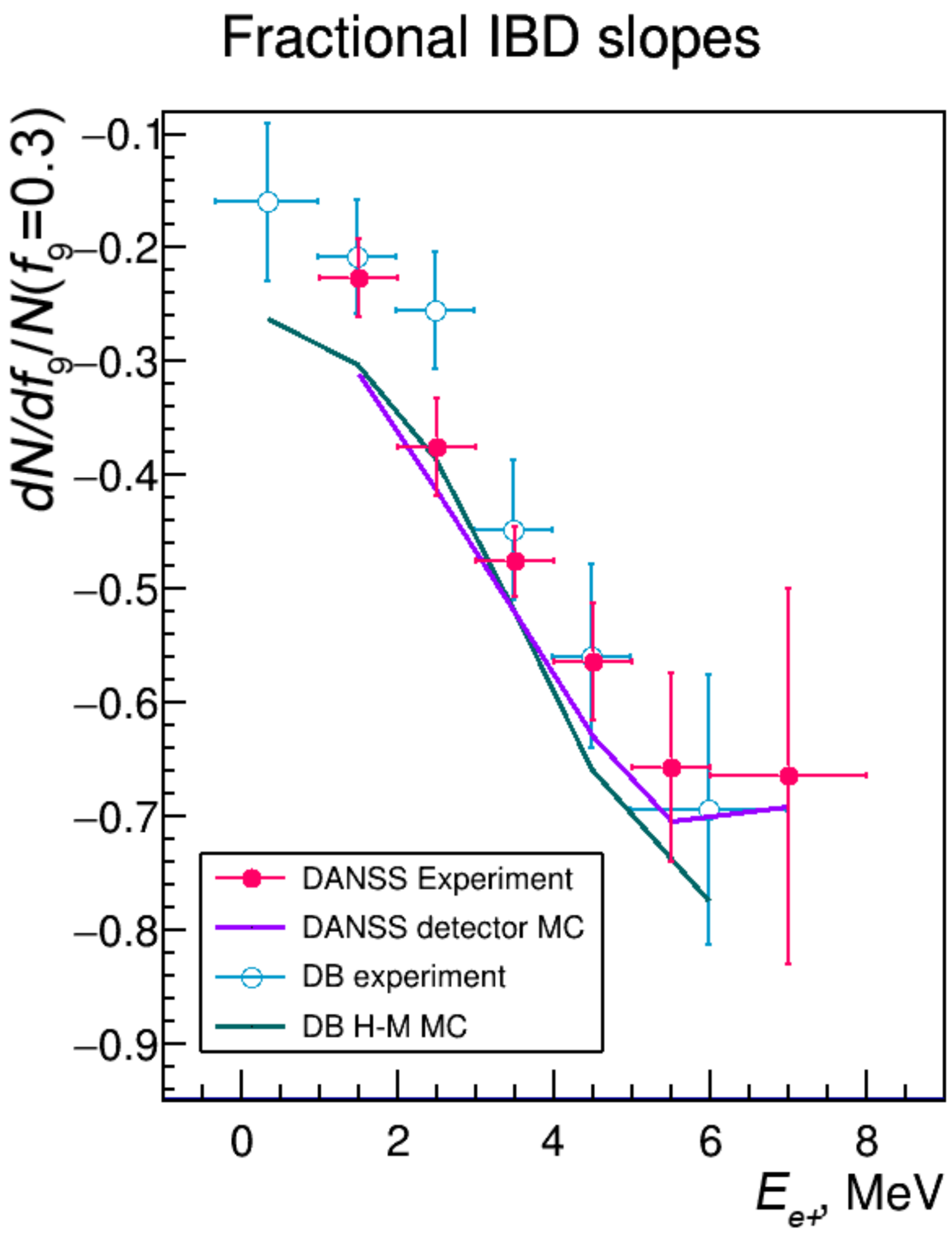


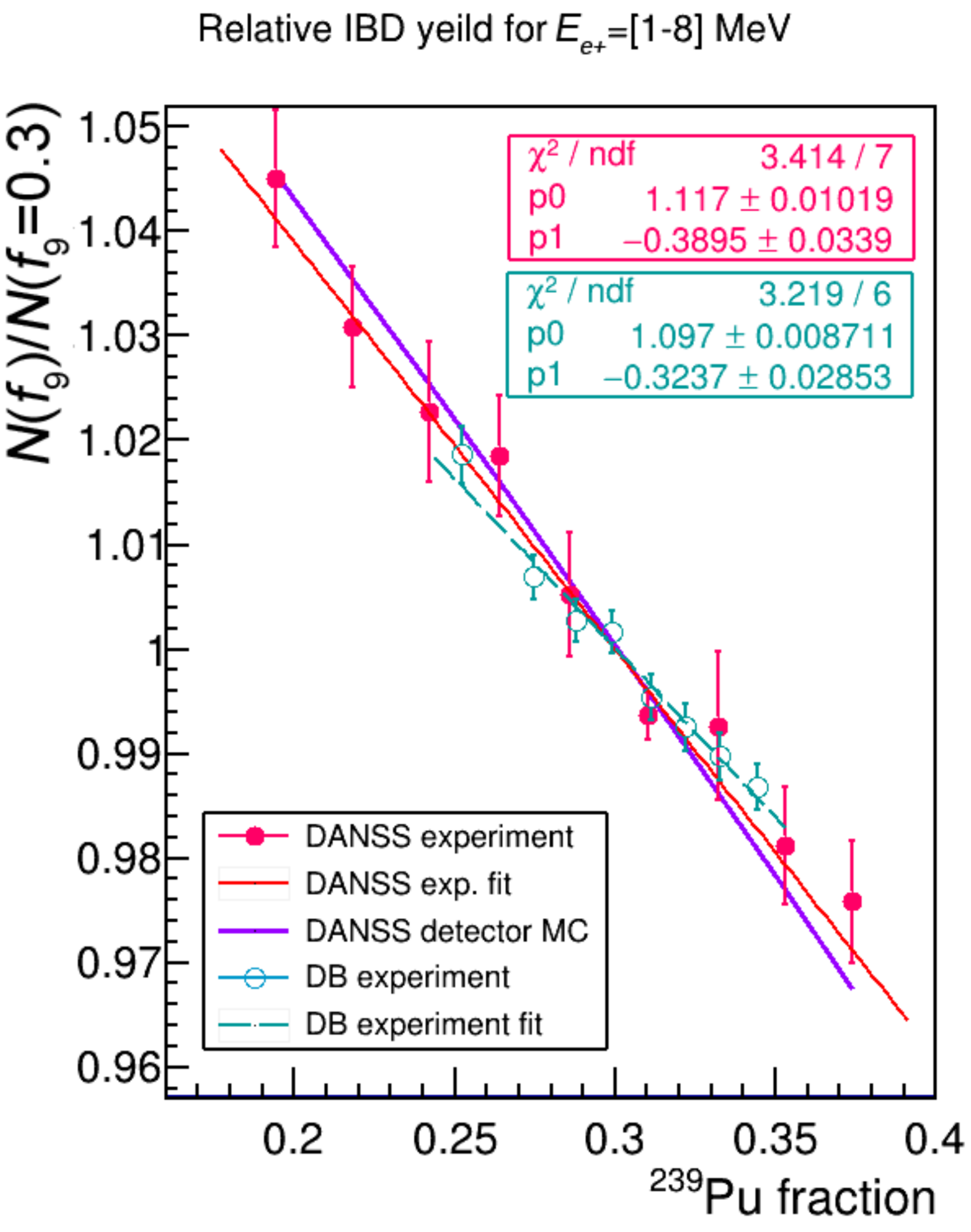


Possible explanation:

J. Dutt and T. Thambyahpillai [Journal of Atmospheric and Terrestrial Physics, vol. 27, no. 3, pp. 349–358 (1965)]

Spectrum dependence on fuel composition





IBD rate dependence on ^{239}Pu fission fraction $(dN/df_9)/N(f_9=0.3)$ for various E_{e+} agrees with HM model and a bit more steep than at Daya Bay

DANSS result $\sigma_5/\sigma_9 = 1.54 \pm 0.06$ is larger than Day Bay (1.445 ± 0.097) and agrees with HM (1.53 ± 0.05).

Use of DB-Slope in our formula gives: $\sigma_5/\sigma_9 = 1.459 \pm 0.052$

Difference between DANSS and DB is due to slope

Заключение

- Исключительная стабильность ДАНССа позволяет выполнять прецизионные измерения на протяжении 8 лет
- Мощность реактора по счету антинейтрино измеряется с точностью 1% за неделю, включая 0.8% суммарных систематических неопределенностей ДАНСС и эксплуатационных измерений КАЭС
- Впервые в мире выполнено восстановление долей делений по измеренным спектрам, согласие с данными расчетов КАЭС в пределах 2.1%; это прибавляет уверенности в обоих подходах
- Относительное изменение скорости счета в топливной кампании согласуется с моделью H-M и несколько больше, чем результат DB
- Отношение выходов σ_5/σ_9 = 1.528±0.058 почти совпадает с H-M (1.53±0.05), но отличается от DB (1.412±0.089, 1.1σ) и КИ (1.45±0.03, 1.2σ)
- Первые результаты по разделению спектров ^{235}U и ^{239}Pu хорошо описывают соотношение позитронных спектров по H-M и позволяют восстановить спектры нейтрино методом SVD

Спасибо за внимание !

Грант РНФ https://rscf.ru/project/23-12-00085/