Reactor antineutrino measurements with DANSS experiment

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THE 4TH INTERNATIONAL CONFERENCE ON PARTICLE PHYSICS AND ASTROPHYSICS (ICPPA-2018)

OCTOBER 22-26, 2018, MOSCOW, RUSSIA

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

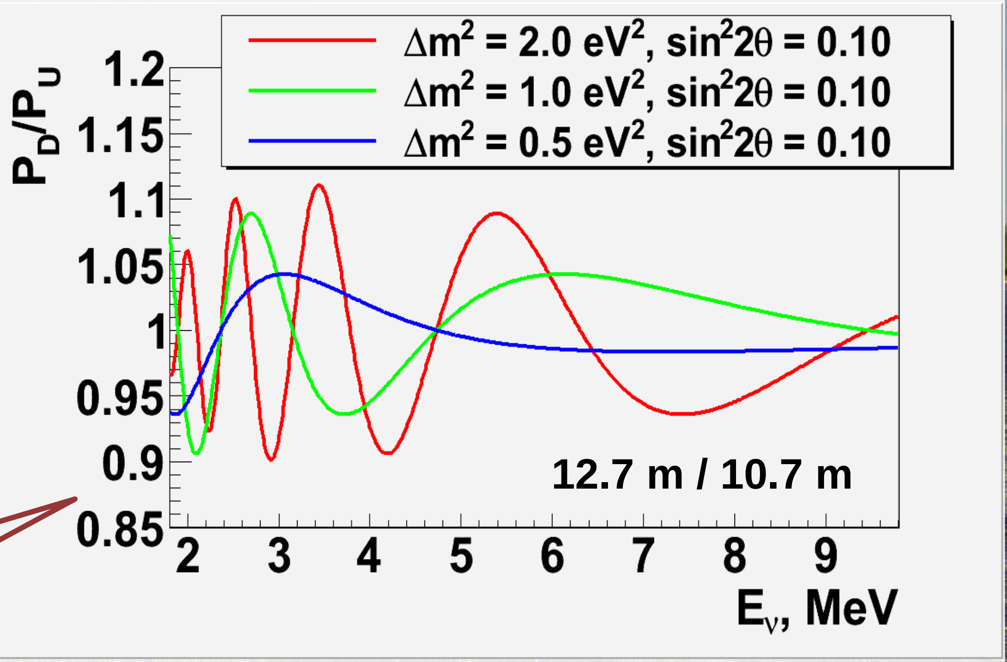
$$P_{ee}^{2\nu}(L) = 1 - \sin^2(2\theta_i)\sin^2\left(1.27\frac{\Delta m_i^2[\mathrm{eV}^2]L[\mathrm{m}]}{E_{\bar{\nu}_e}[\mathrm{MeV}]}\right)$$

Expected parameters (G. Mention et al. Phys. Rev D83 073006 (2011):

$$|\Delta m^2_{\mathrm{new}}| > 1.5\ \mathrm{eV}^2\ \ (95\%)\ \text{and}\ \sin^2(2\theta_{\mathrm{new}}) = 0.14 \pm 0.08\ \ (95\%)$$

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.

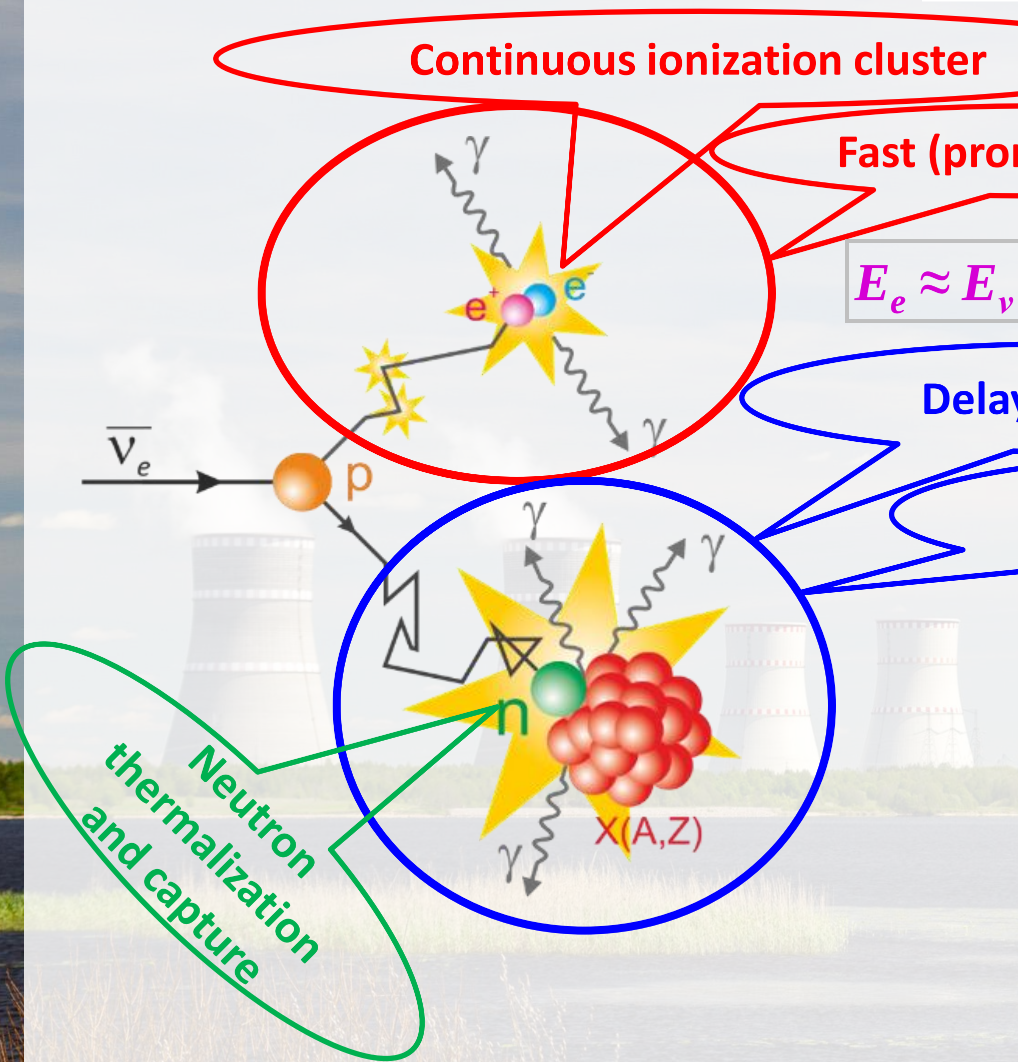
Naïve ratio without smearing by reactor and detector sizes and the resolution

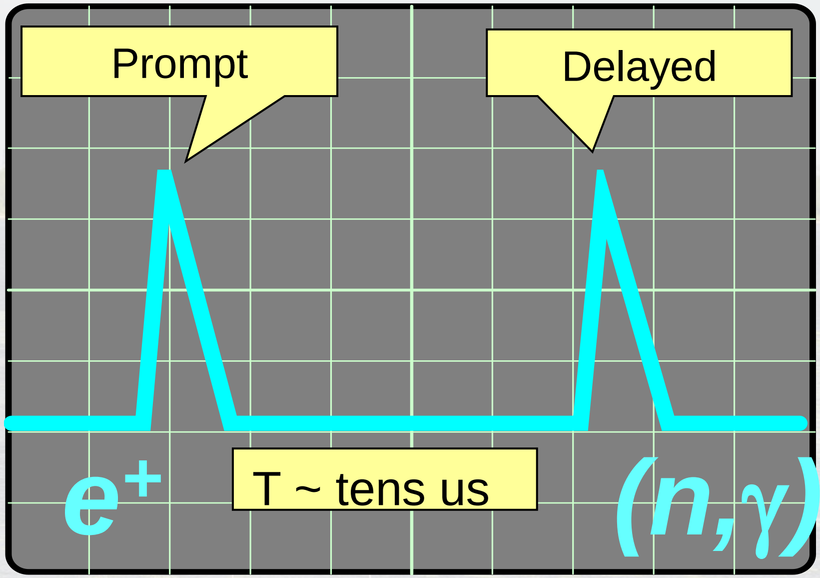


Inverse Beta-Decay (IBD)

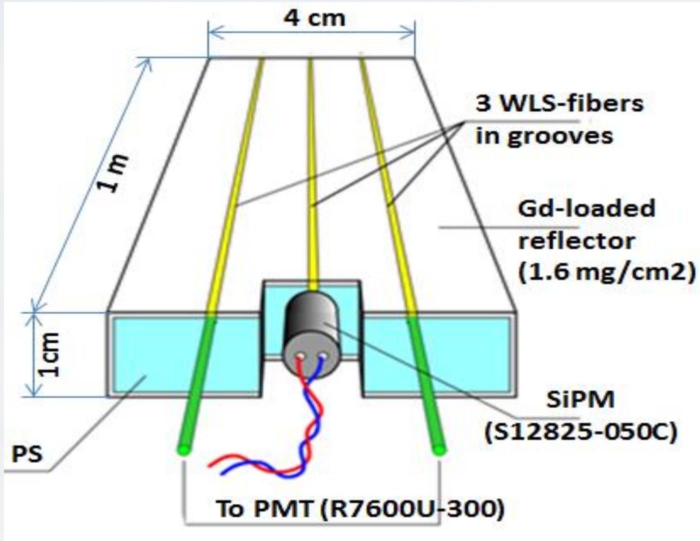
$$\bar{\nu}_e + p \rightarrow e^+ + n$$

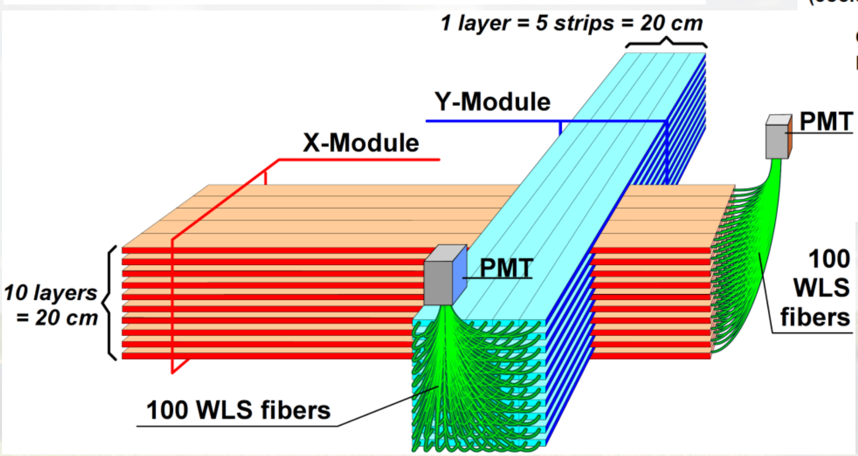
H. Bethe and R. Peierls 1934.
F. Reines and C. L. Cowan 1953-56

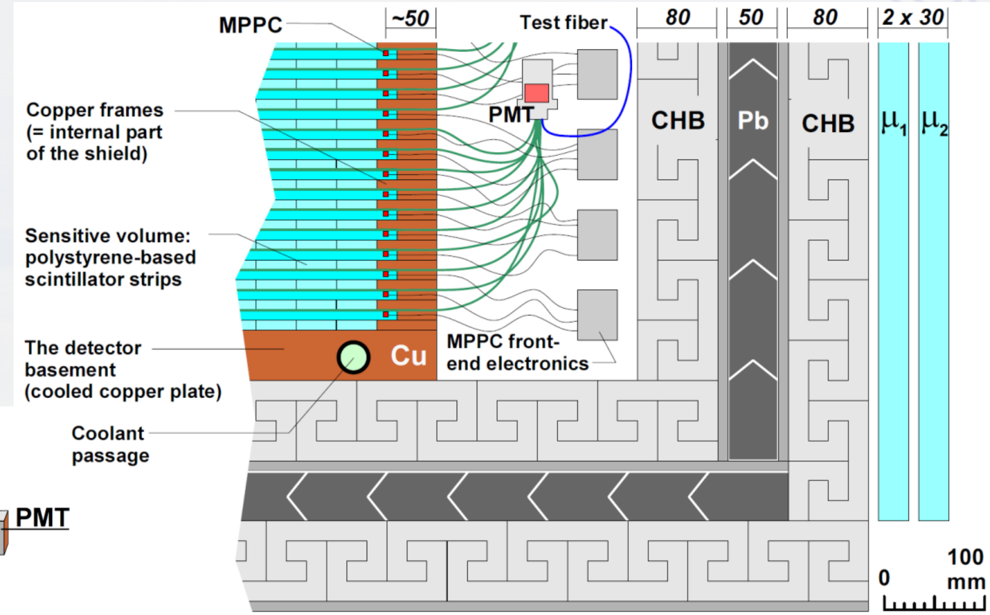




Detector of the reactor AntiNeutrino based on Solid-state Scintillator



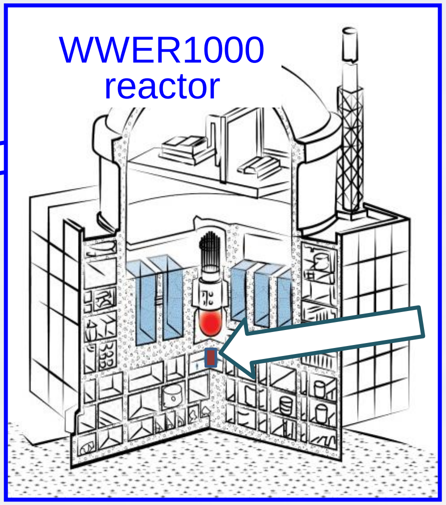




- Scintillation strips 10x40x100 mm^3 with Gd-dopped coating
- Double PMT (groups of 50) and SiPM (individual) readout
- Strips along X and Y – 3D-picture
- 2500 strips = 1 m^3 of sensitive volume

- 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)

JINST 11 (2016) no.11, P11011

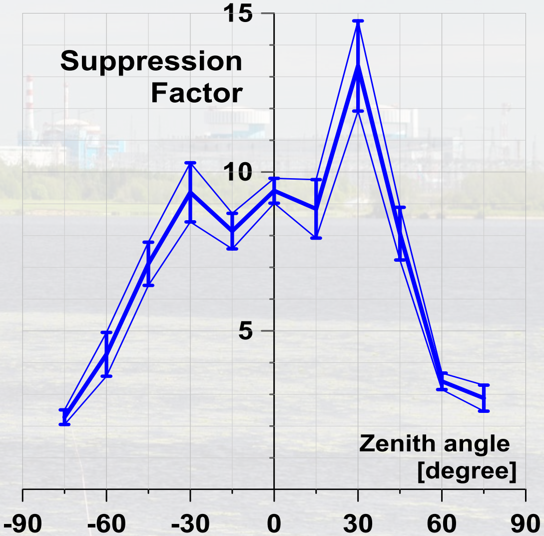


KNPP - Kalinin Nuclear Power Plant, Russia, ~350 km NW from Moscow

Below 3.1 GW commercial reactor ~ $5 \cdot 10^{13}\ \nu \cdot cm^{-2} c^{-1}$

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

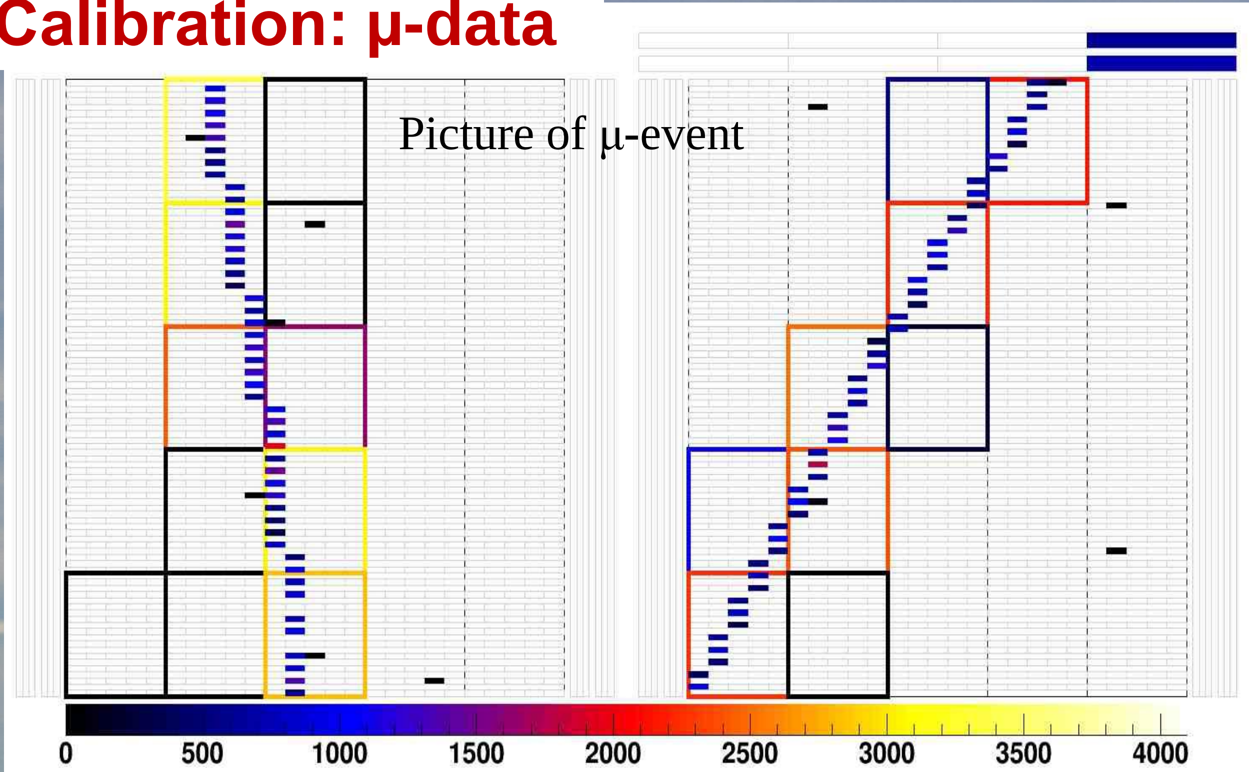
- **No flammable or dangerous materials – can be put just after reactor shielding**
- **Reactor fuel and body with cooling pond and other reservoirs provide overburden ~50 m w.e. for cosmic background suppression**
- **Lifting system allows to change the distance between the centers of the detector and of the reactor core from 10.7 to 12.7 m on-line**
- **The top position corresponds to ~15000 IBD events per day for 100% efficiency**



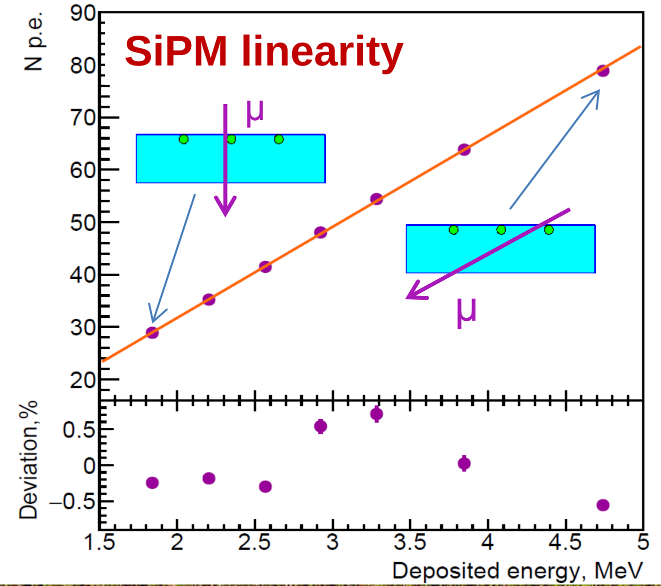
Cosmic muon suppression measured

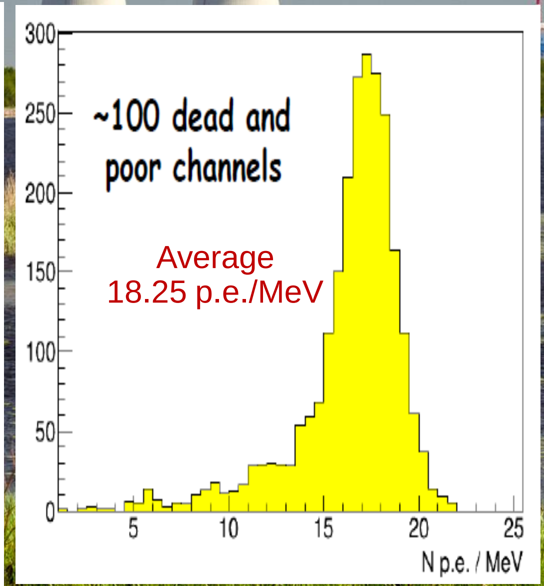
Calibration: μ-data

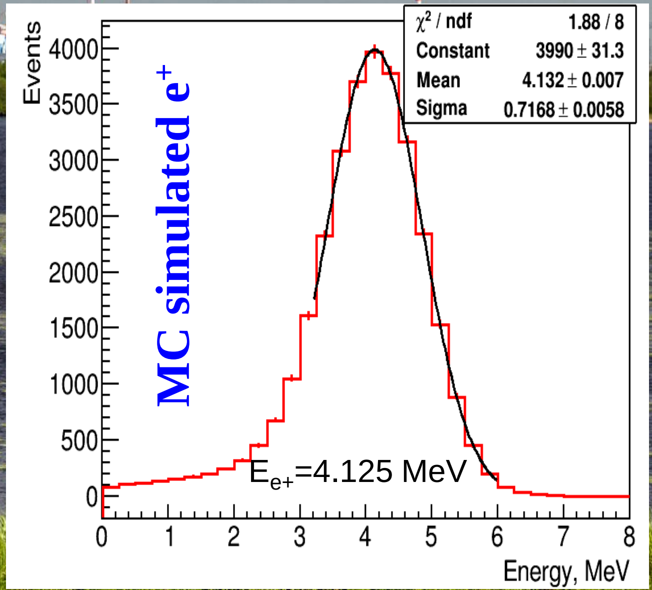
Phys.Part.Nucl.Lett.
15 (2018) no.3, 272-283



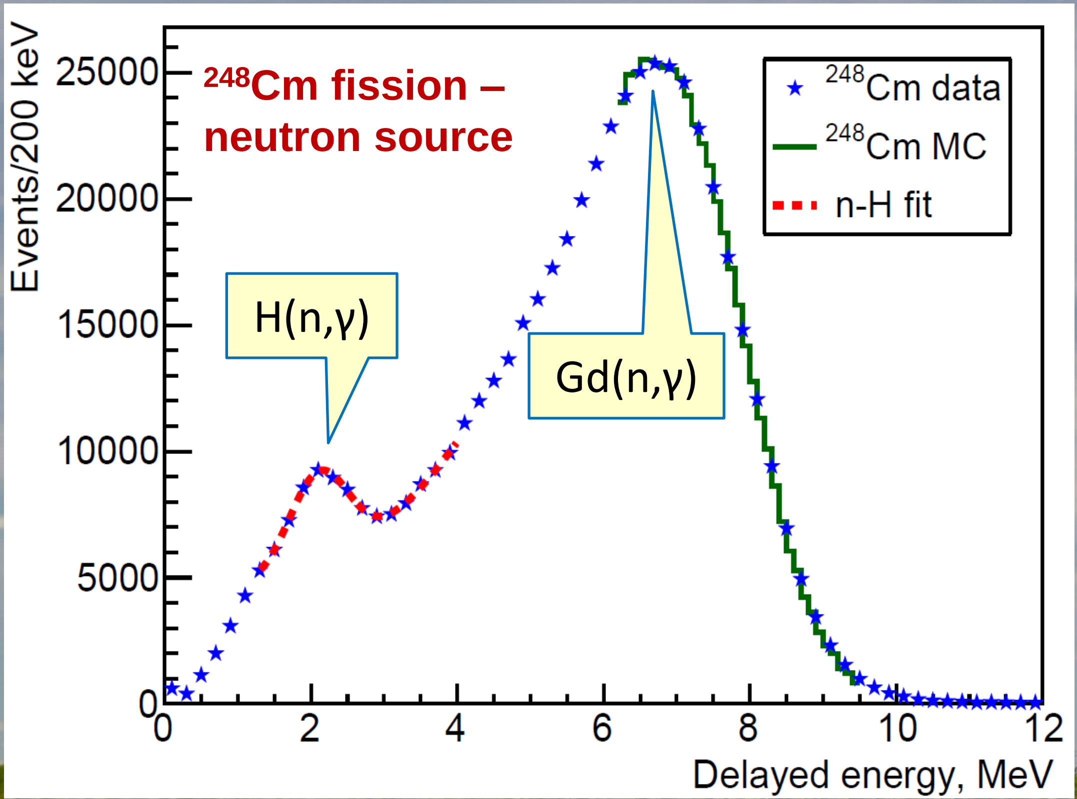
- Calibration is done using cosmic muons
- We have average ≈ 18(20) p.e./MeV SiPM (PMT)
- Additional 15% resolution smearing is added to MC to describe muon energy loss
- SiPM response linearity better 0.7 %
- Basing on MC simulation positron energy is corrected for missed energy and γ's overlapping the cluster

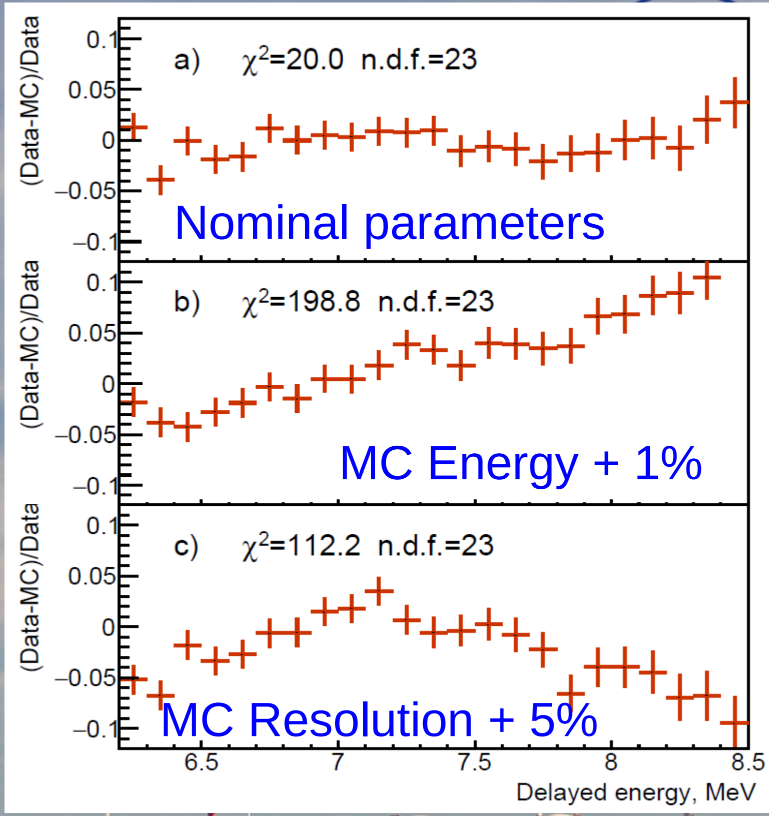






Neutron source check of the calibration



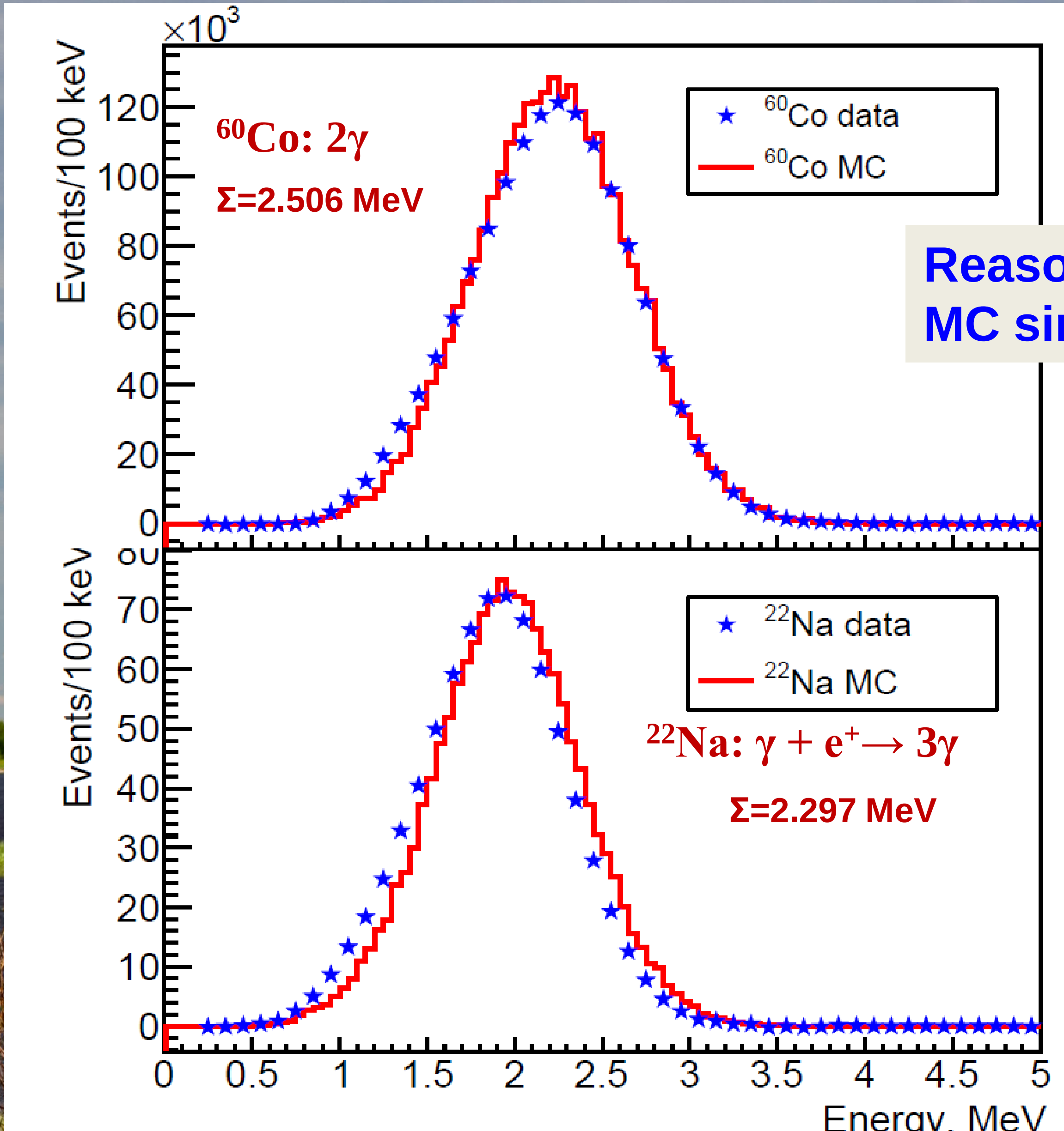


Variation of energy scale and resolution

✓Gaussian fit position and width of neutron capture by protons are in reasonable agreement with MC

✓Comparison of the right edge of the energy spectrum between ^{248}Cm data and MC simulation is very sensitive to calibration and resolution

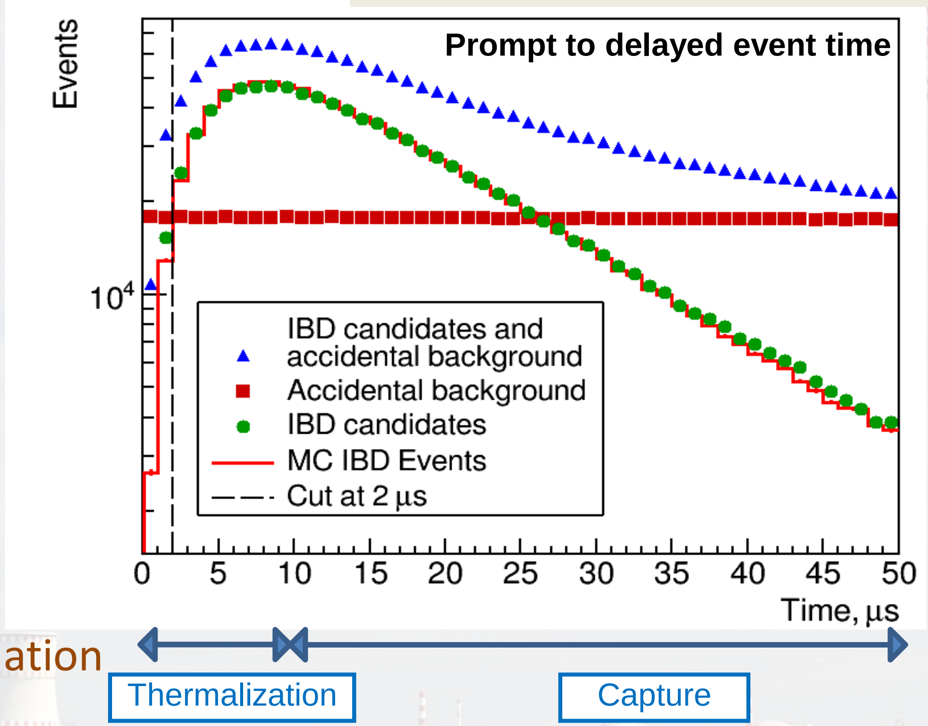
Check with ^{22}Na and ^{60}Co radioactive sources



Reasonable agreement between MC simulations and experiment

Trigger and events

- **Trigger = digital sum of PMT > 0.7 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 ± 15 ns
  - Single pixel 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

Muon Cuts

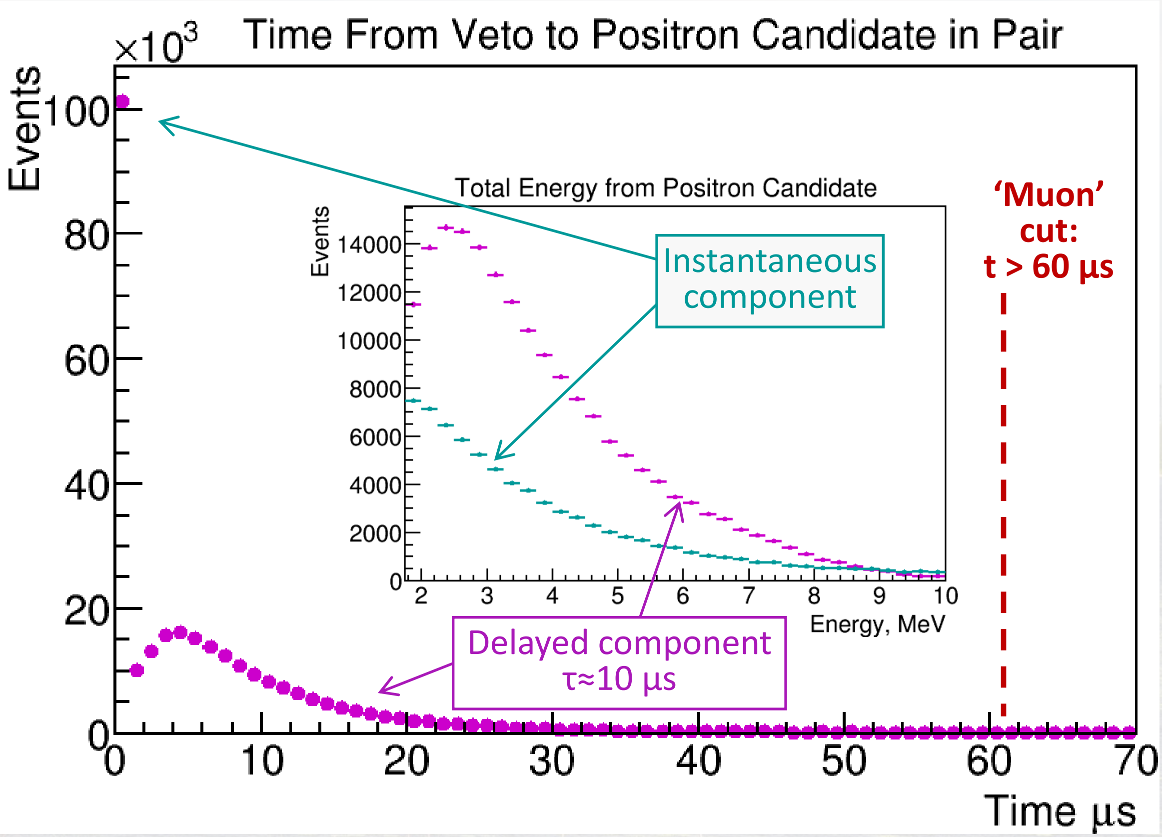
VETO 'OR':
- 2 hits in veto counters
- veto energy >4MeV
- energy in strips >20 MeV

Two distinct components of muon induced paired events with different spectra:
- 'Instantaneous' – fast neutron
- 'Delayed' – two neutrons from excited nucleus

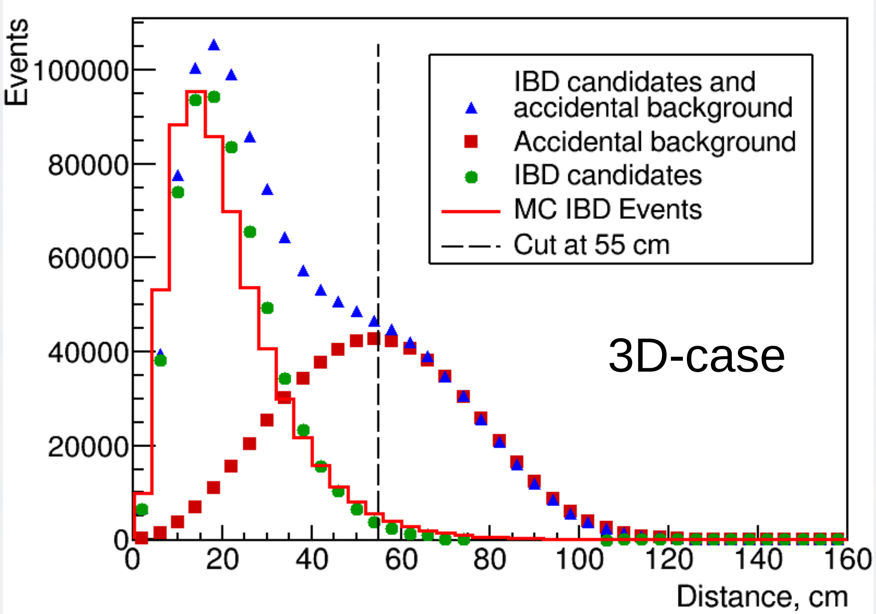
'Muon' cut : NO VETO 60 µs before positron

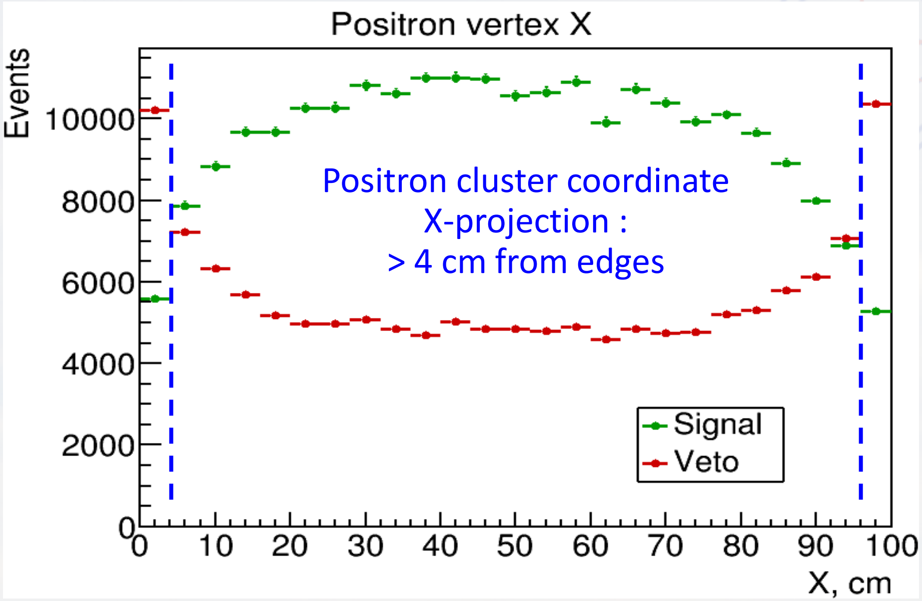
'Isolation' cut : NO any triggers 45 µs before and 80 µs after positron (except neutron)

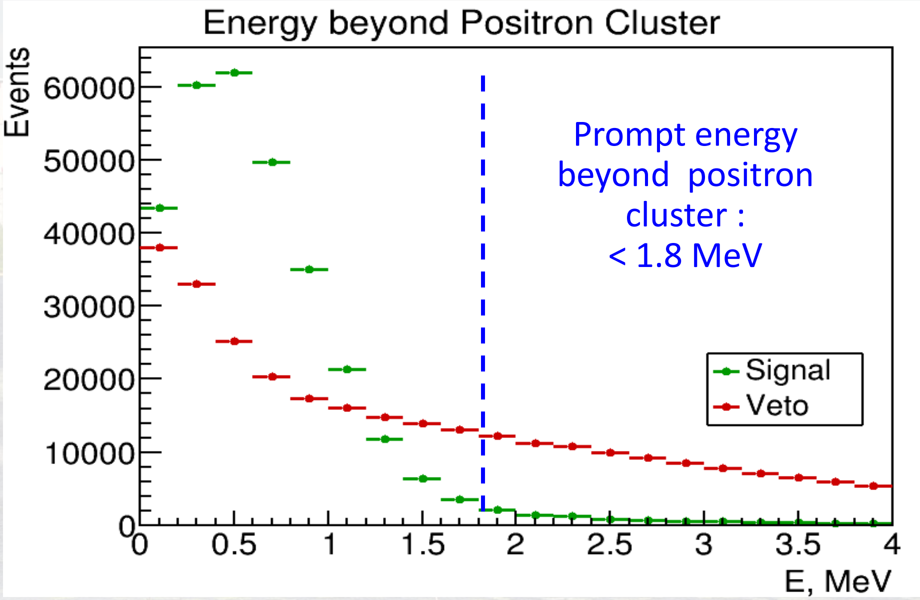
'Showering' cut : NO VETO with energy in strips > 300 MeV for 200 µs before positron



Analysis cuts







Cuts – suppress accidental and muon induced backgrounds:

Positron to neutron distance is less than 55(45) cm for 3D(2D) case.

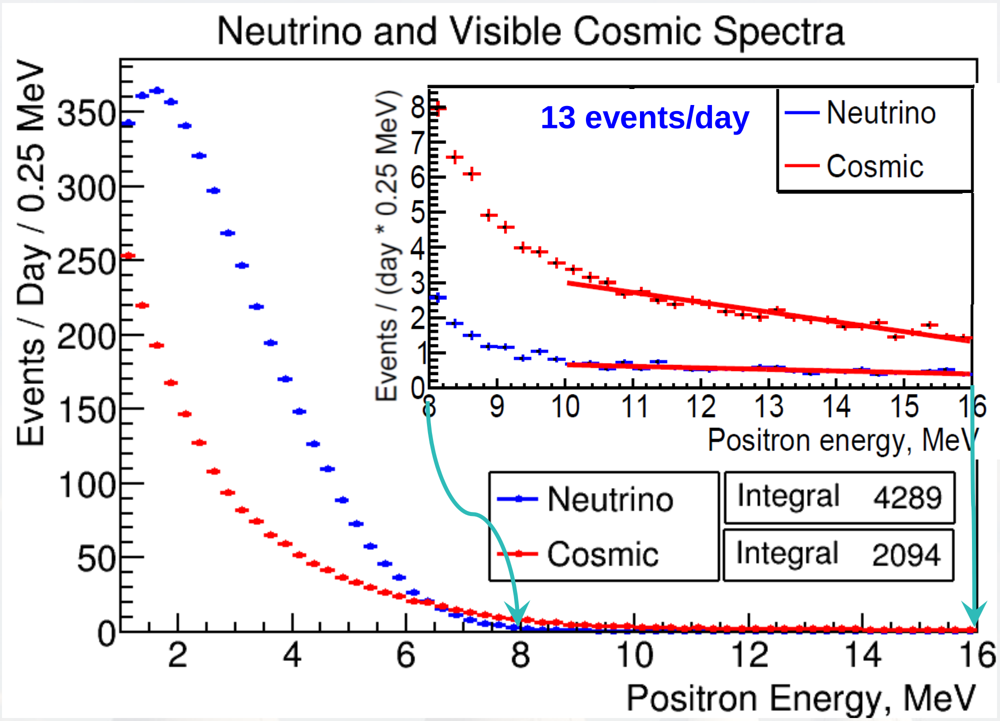
Fiducial volume - positron cluster position: 4 cm from all edges

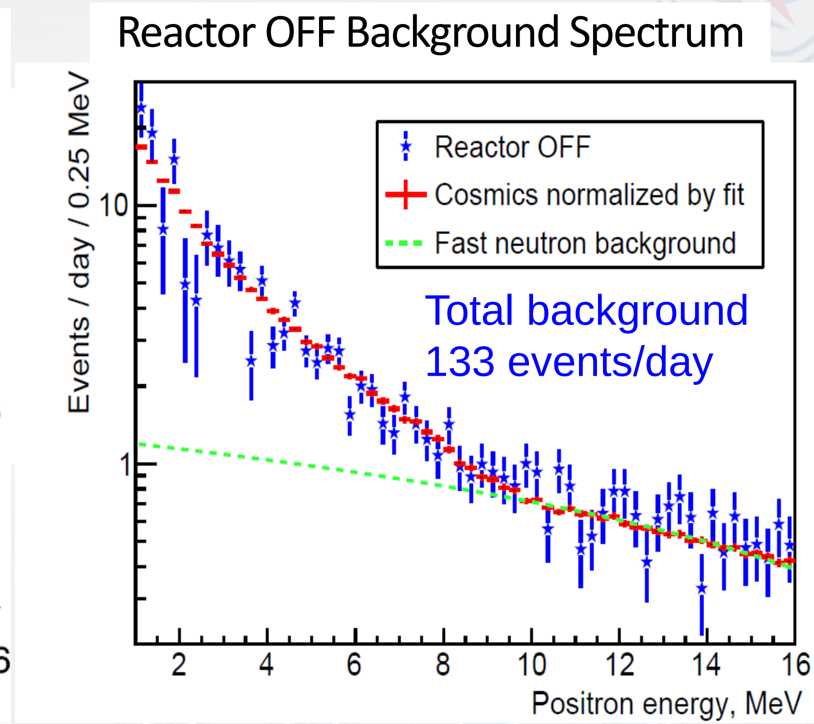
Energy in the prompt event beyond the cluster < 1.8 MeV

The most energetic hit beyond the cluster < 0.8 MeV

Multiplicity beyond positron cluster: <11

Cosmic muon induced background





Fast neutron tails: linearly extrapolate from high energy region and subtract separately from positron and visible cosmic spectra ~ 13 events/day

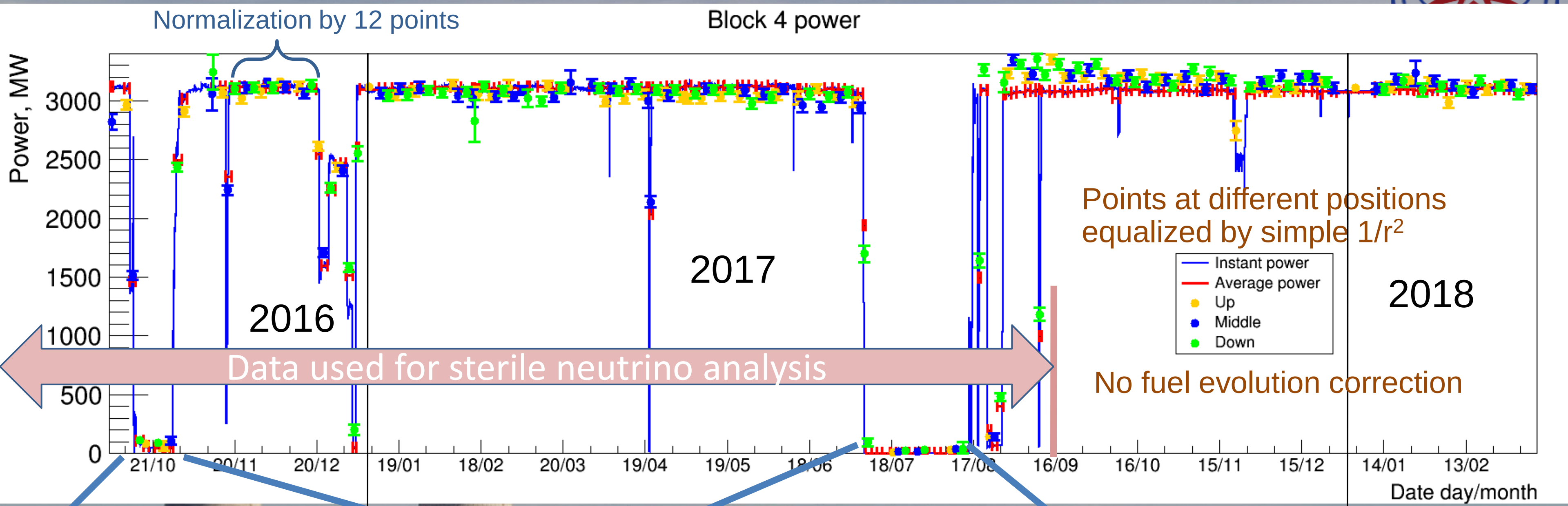
Amount of rejected by the VETO cosmics ~50% of neutrino signal

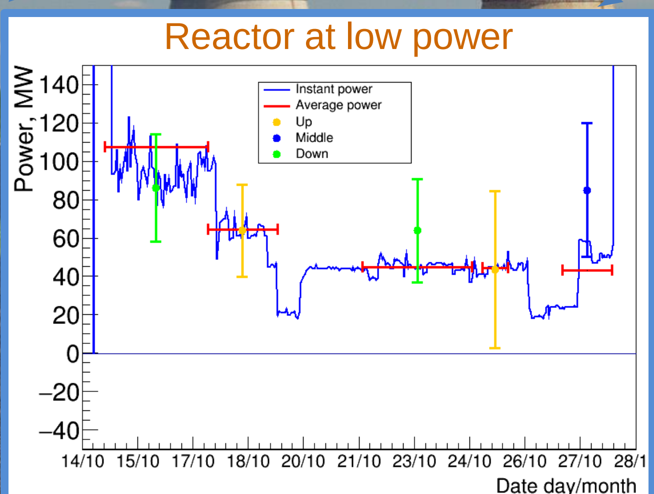
Cosmic background fraction 2.7% of neutrino signal (up position), subtracted

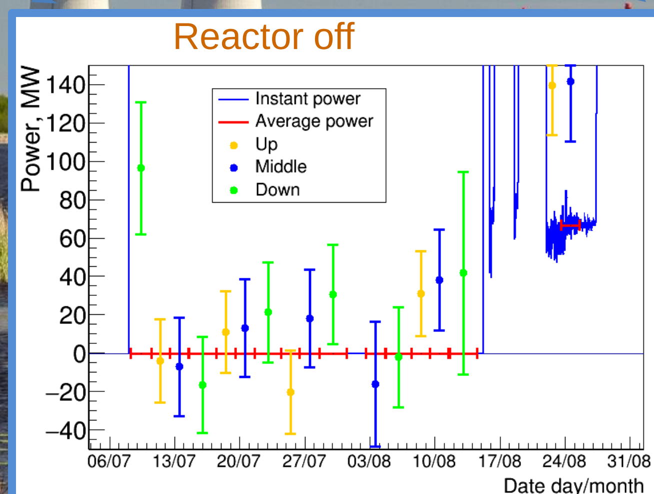
Neighbor reactors at 160 m, 334 m, and 478 m, 0.6% of neutrino signal at up position, subtracted

^{9}Li and ^{8}He background estimates: 4.4±1.0 events/day

Reactor power seen by neutrino flux







Data accumulation:

April-June 2016 – start of data taking

July-September 2016 – shutdown for cooling system repair

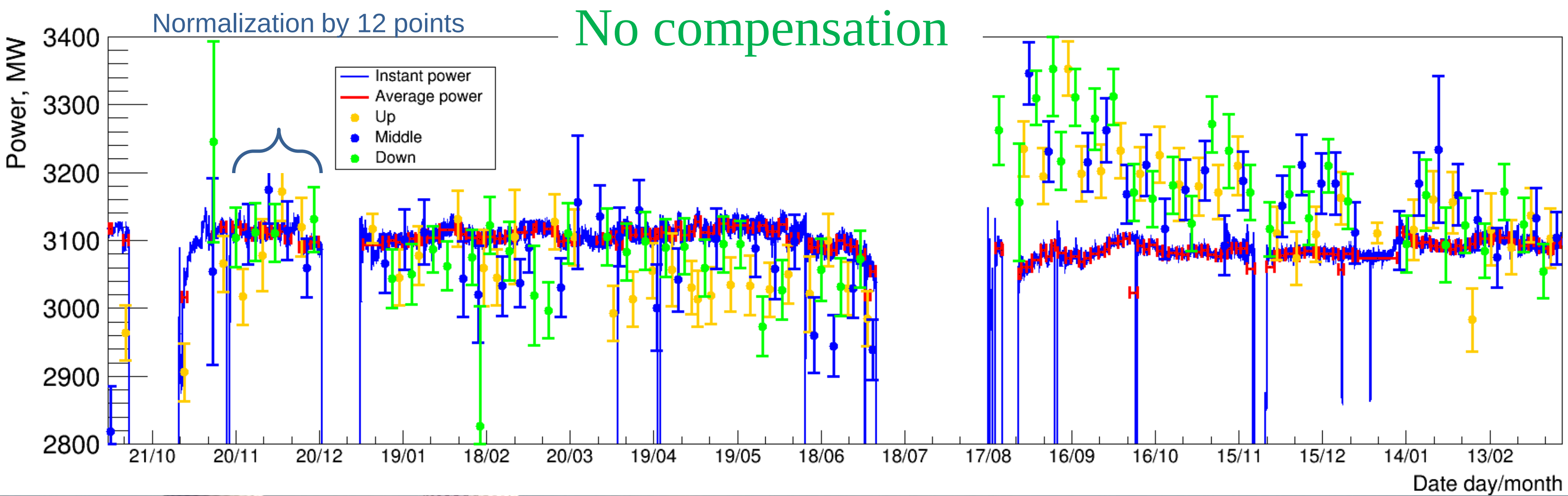
October 2016 – March 2018 – the first run ~ 1.63·10^6 IBD events

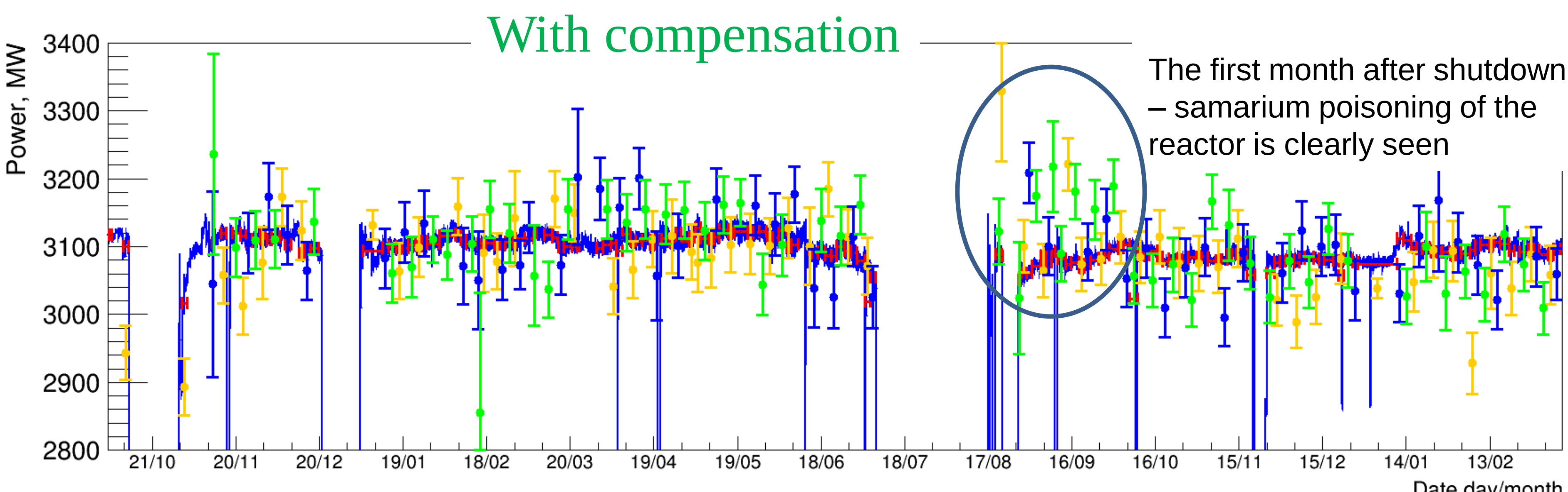
April 2018 – shutdown to improve grounding and recover ~50 SiPM channels. Trigger threshold was lowered to 0.5 MeV.

May 2018 – the second run started

We are running now.

Compensation of the fuel evolution





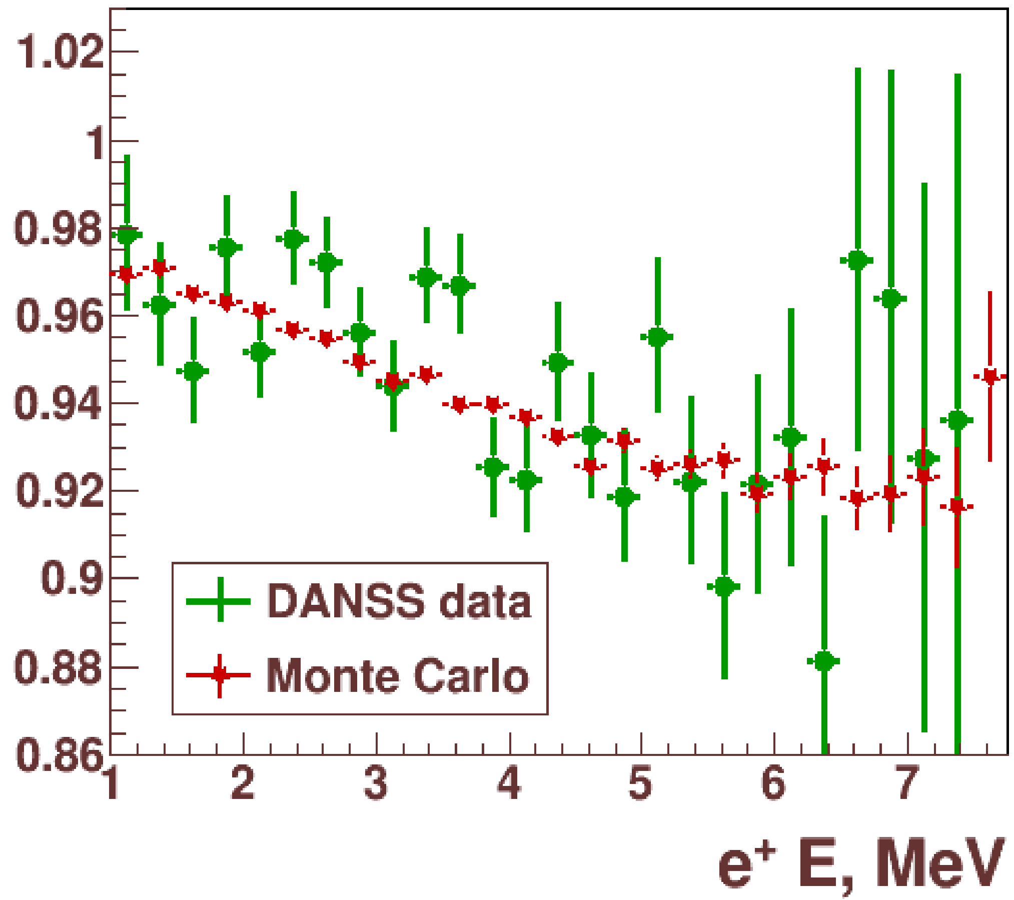
Fuel evolution

	Begin 4	End 4	Begin 5
^{235}U	63.7%	44.7%	66.1%
^{238}U	6.8%	6.5%	6.7%
^{239}Pu	26.6%	38.9%	24.9%
^{241}Pu	2.8%	8.5%	2.3%

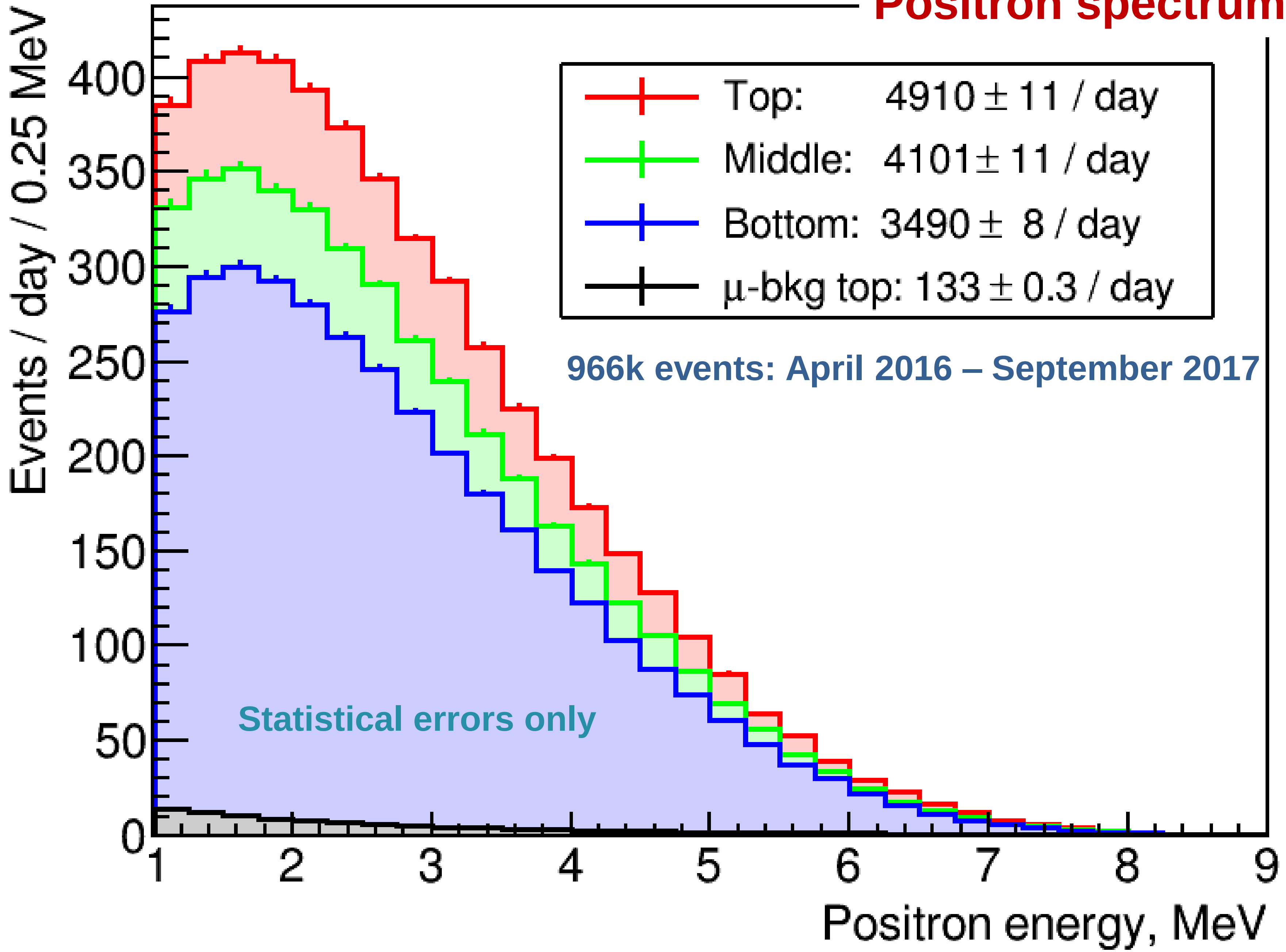
Spectra ratio: 3 months at the very end of campaign 4 to 3 months a month after campaign 5 start.

The first month at the start of campaign skipped because of samarium poisoning of the reactor.

No contradiction to Monte Carlo simulations using Huber and Mueller spectra seen.



Positron spectrum



❑ DANSS recorded the first data in April 2016 and now takes statistics at full speed of about **5000** antineutrino events per day in the closest position after subtraction of the muon induced background about **130** events per day.

❑ The experiment is running. About **$2.2 \cdot 10^6$** IBD events are already collected

See next presentation by Natalia Skrobova for sterile neutrinos analysis

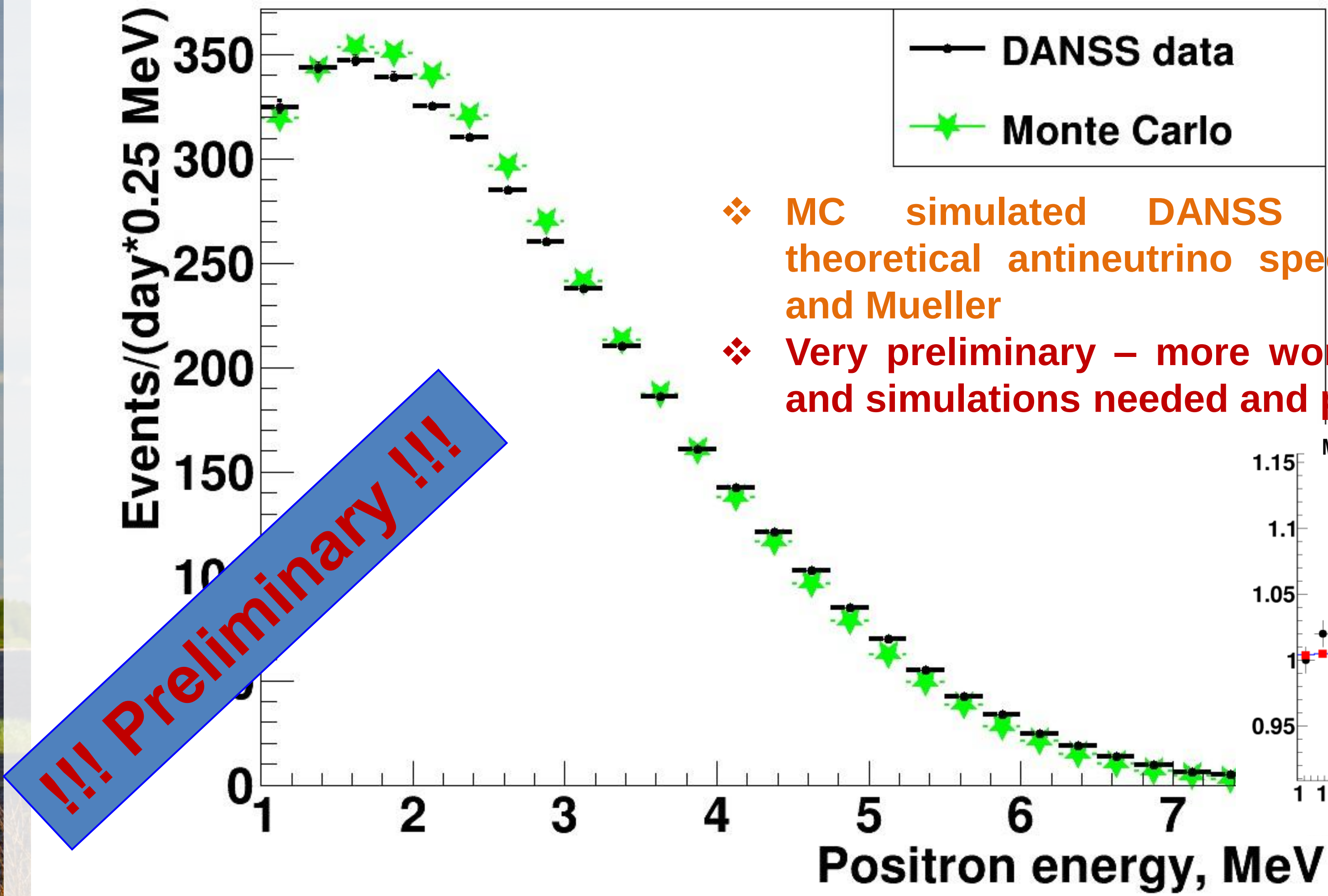
- ❑ Data analysis is in progress. We plan:
  - ❑ Analyze all the data collected
  - ❑ Do more detector calibrations and tests
  - ❑ Continue systematic studies
  - ❑ Elaborate more analysis methods for better sensitivity

More results are coming !

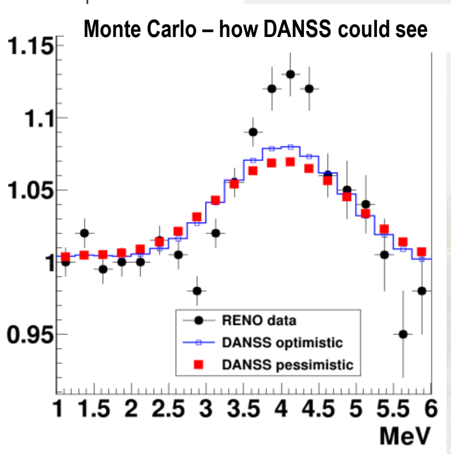
The detector construction was supported by the Russian State Corporation ROSATOM (state contracts H.4x.44.90.13.1119 and H.4x.44.9B.16.1006). The operation and data analysis became possible due to the valuable support from the Russian Science Foundation grant 17-12-01145. The collaboration appreciate the permanent assistance of the KNPP administration and Radiation and Nuclear Safety Departments.

Thank you !

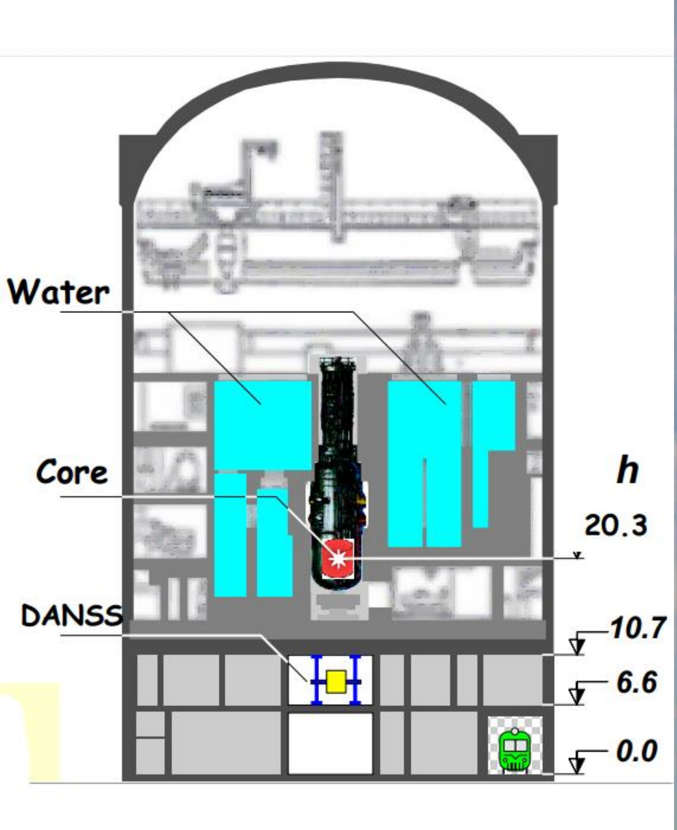
Positron spectrum - compare to the theory



- MC simulated DANSS response use theoretical antineutrino spectrum by Huber and Mueller
- Very preliminary – more work on calibration and simulations needed and planned



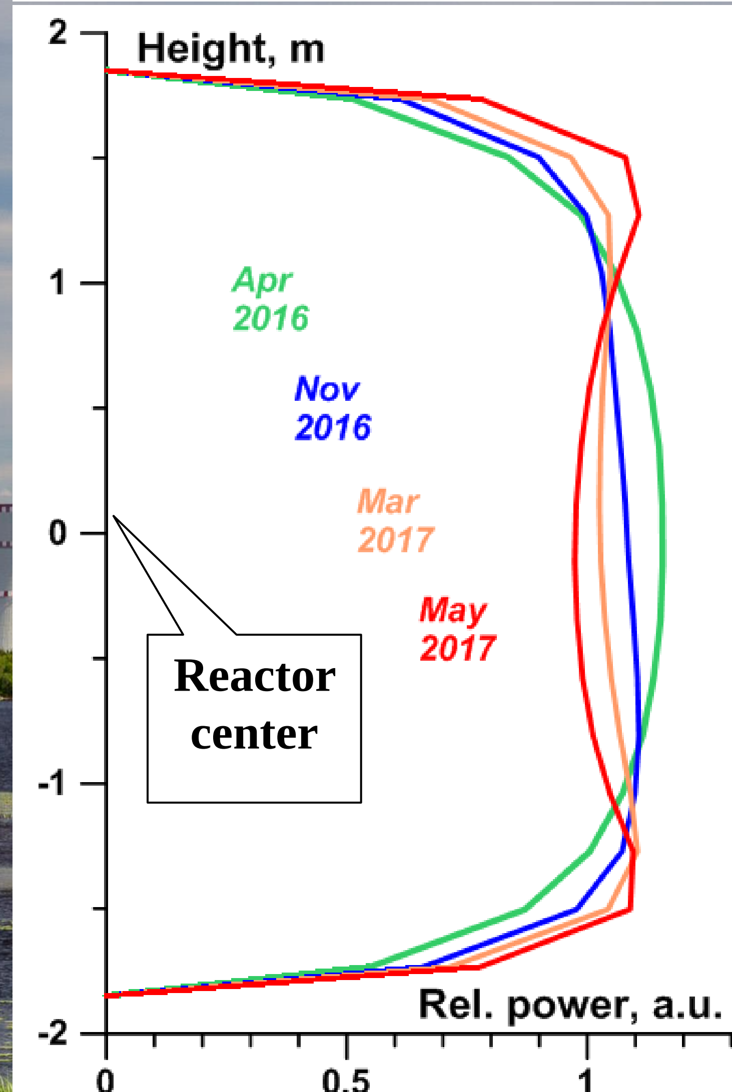
Reactor



Fuel contribution during the campaign

	Begin 4	End 4	Begin 5
^{235}U	63.7%	44.7%	66.1%
^{238}U	6.8%	6.5%	6.7%
^{239}Pu	26.6%	38.9%	24.9%
^{241}Pu	2.8%	8.5%	2.3%

Reactor vertical burning profile for 100% power during the campaign



^{9}Li and ^{8}He background ~ 4 events per day