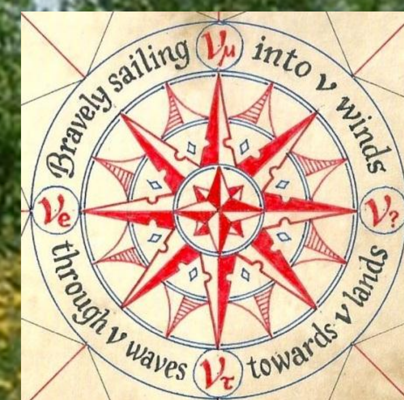
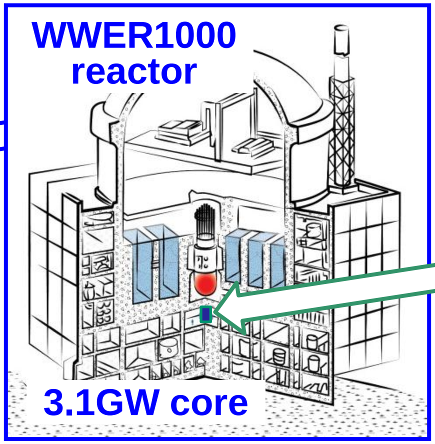
Searches for sterile neutrinos at the DANSS experiment

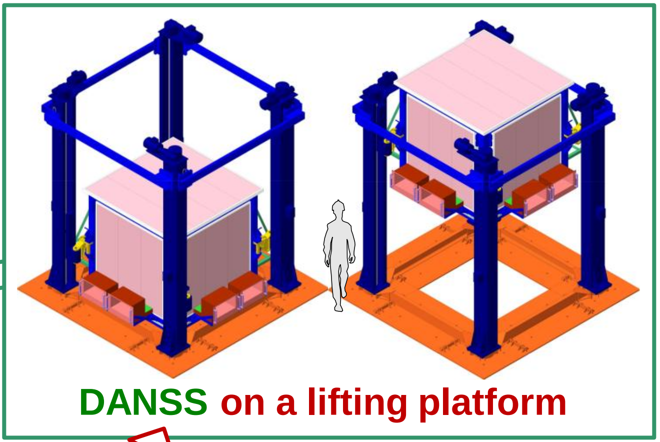


Dmitry Svirida for the DANSS Collaboration ITEP-JINR

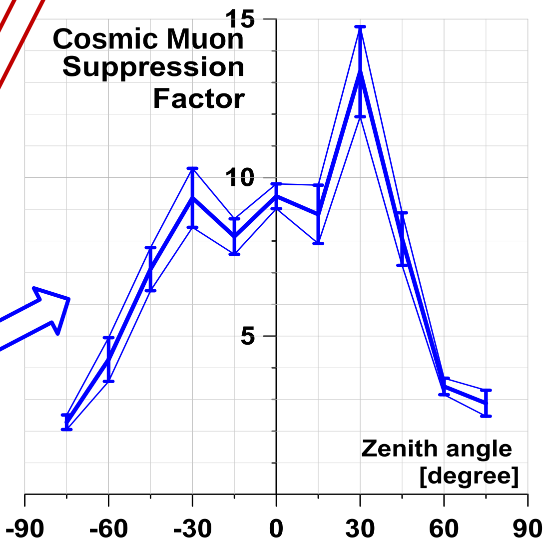
DANSS project

Detector of reactor AntiNeutrino based on Solid Scintillator



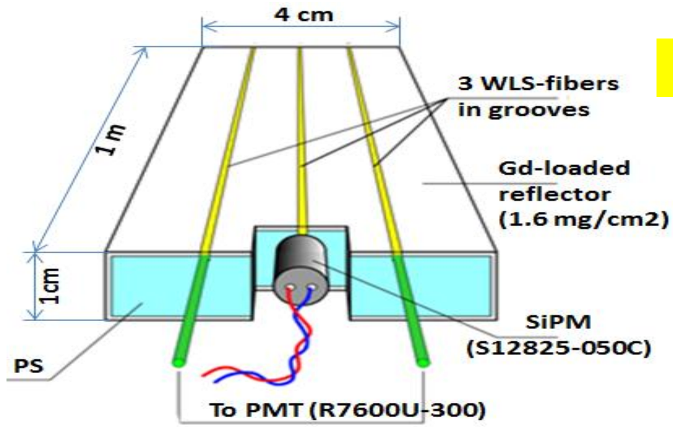


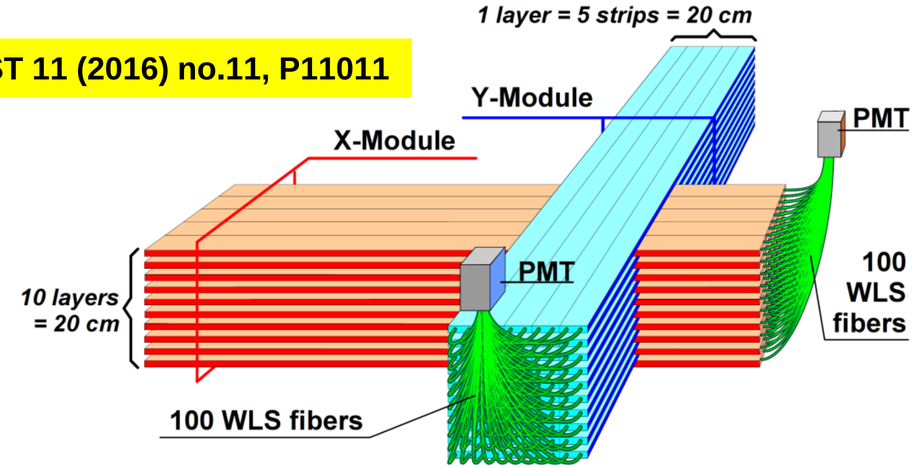
- Detection of the reactor antineutrino spectrum through the reaction of inverse β-decay: $\tilde{\nu}_e + p \rightarrow e^+ + n$
- Designed to contain no flammable or other dangerous liquids or materials
- Lifting system: 10.7 to 12.7 m between the centers of the detector and of the reactor core
- Sensitive volume: 1 m^3 plastic
- Uses reactor body and shielding for cosmic background suppression ~50 m.w.e.
- Physics goal: sterile neutrino search in the very short range region: different distances – one detector



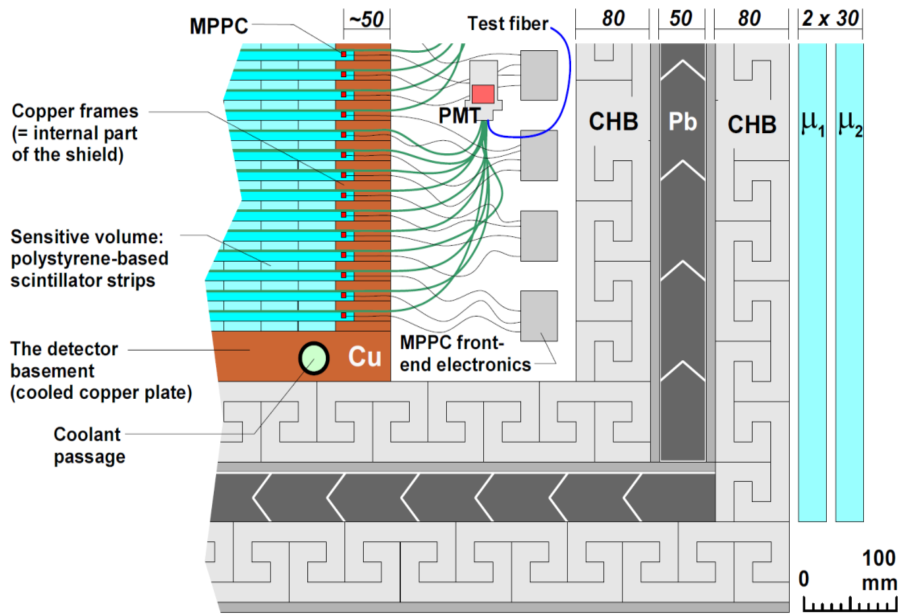
DANSS detector design

JINST 11 (2016) no.11, P11011

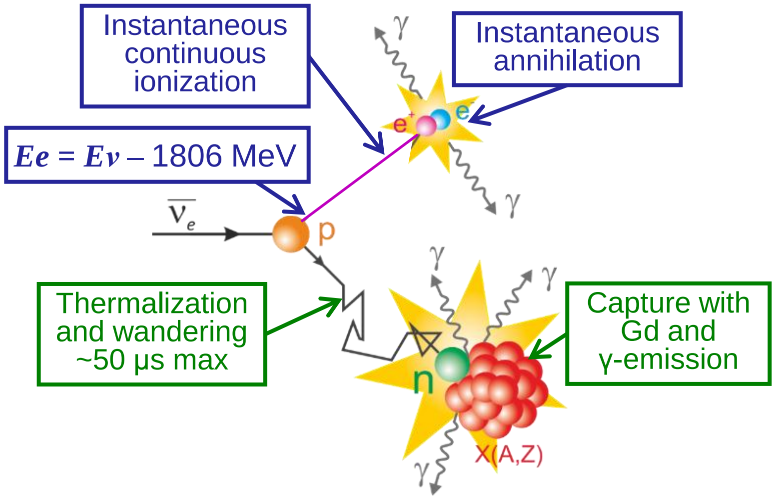


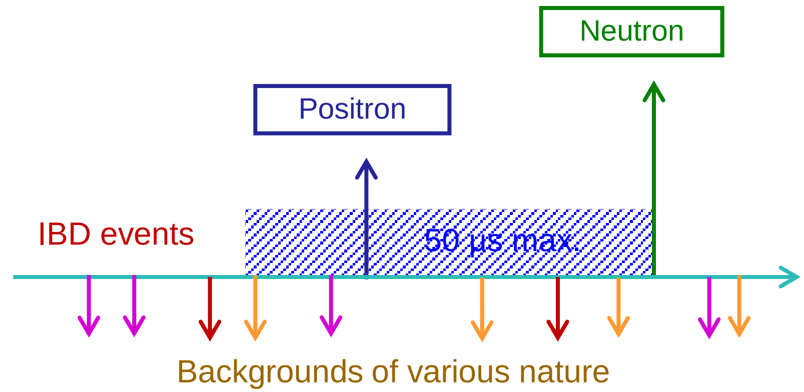


- 2500 scintillator strips with Gd containing coating for neutron capture
- Light collection with 3 WLS fibers
- Central fiber read out with individual SiPM
- Side fibers from 50 strips make a bunch of 100 on a PMT cathode = Module
- Two-coordinate detector with fine segmentation – spatial information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



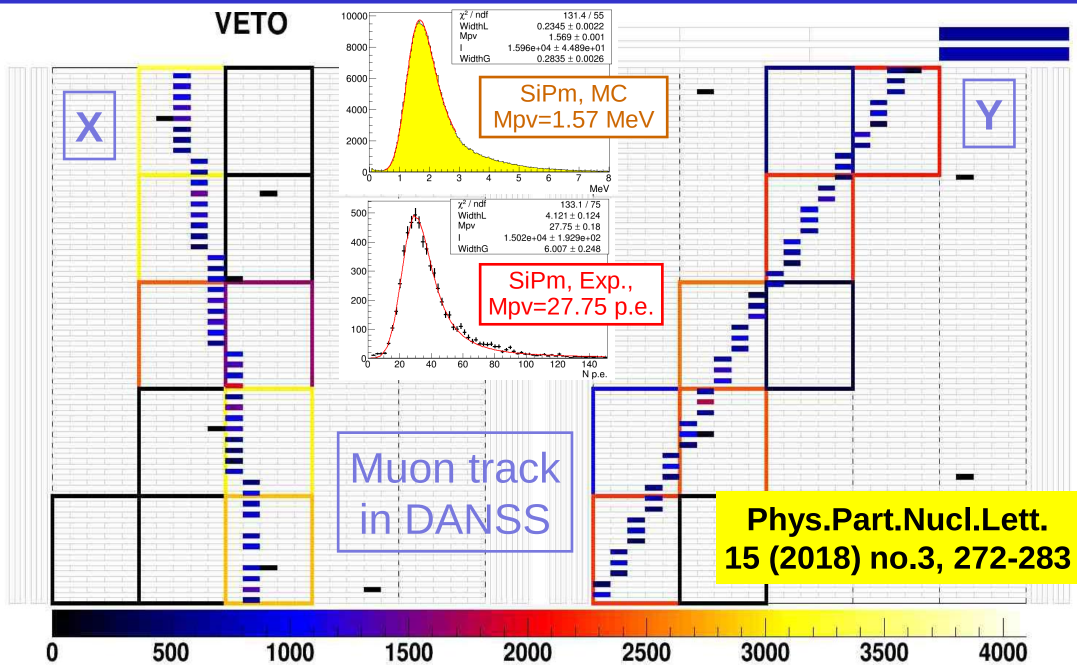
Inverse Beta Decay and triggering



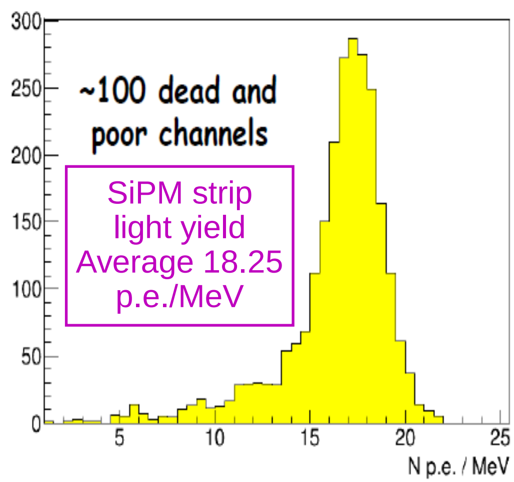


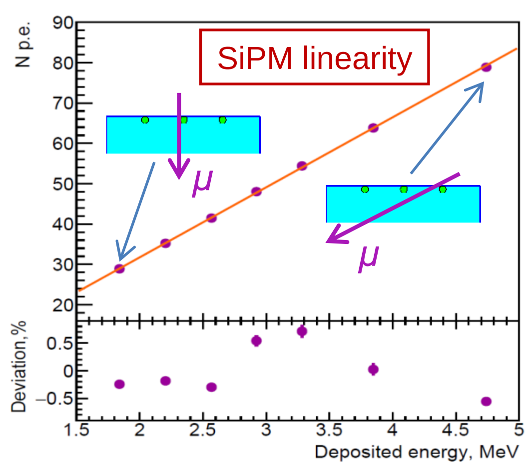
- Positron: instantaneous response from ionization and annihilation
- Neutron: thermalization (~5 μs) and up to ~50 μs travel before Gd capture with γ-emission
- Separate recording of positron and neutron candidates, **time correlation OFF-Line**
- Not practical to store 50 μs records
- System trigger: <Energy deposit in the sensitive volume >0.7 MeV> OR <VETO>
- Trigger rate ~1 kHz, dead time 600 ns, negligible data loss, soft trigger condition
- All PMTs and SiPMs are recorded with zero suppression threshold ~0.5 p.e.
- Good opportunity for accidental background estimates and muon-correlated analysis

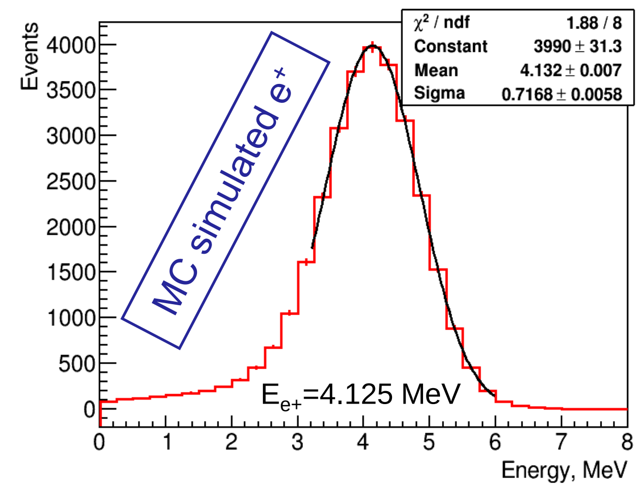
Energy calibration by cosmic muons



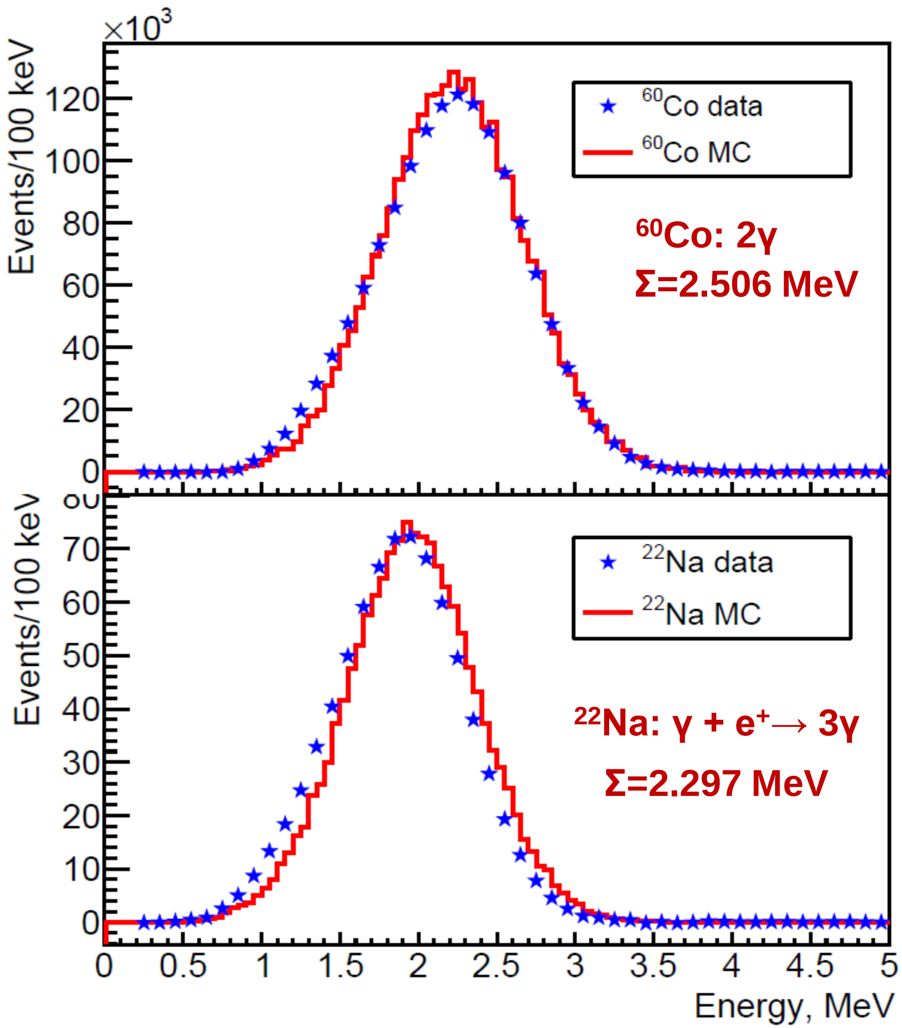
- SiPM noise spectrum: account for cross-talk and saturation
- Compare MC-simulated energy to the experimental by Mpv
- SiPMs: ~18 p.e./MeV, PMTs: ~20 p.e./MeV
- SiPM response linearity <0.7 %
- Attenuation ~20%/m, corrected by second coordinate
- Based on MC simulation positron energy is corrected for missed energy and γ's overlapping the cluster

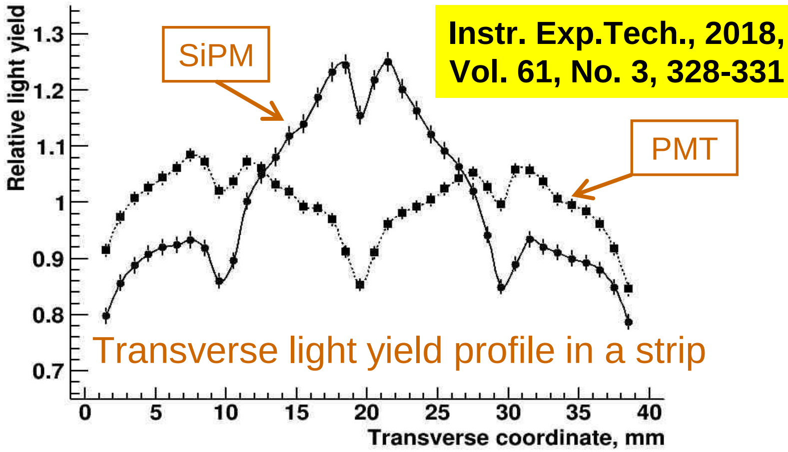






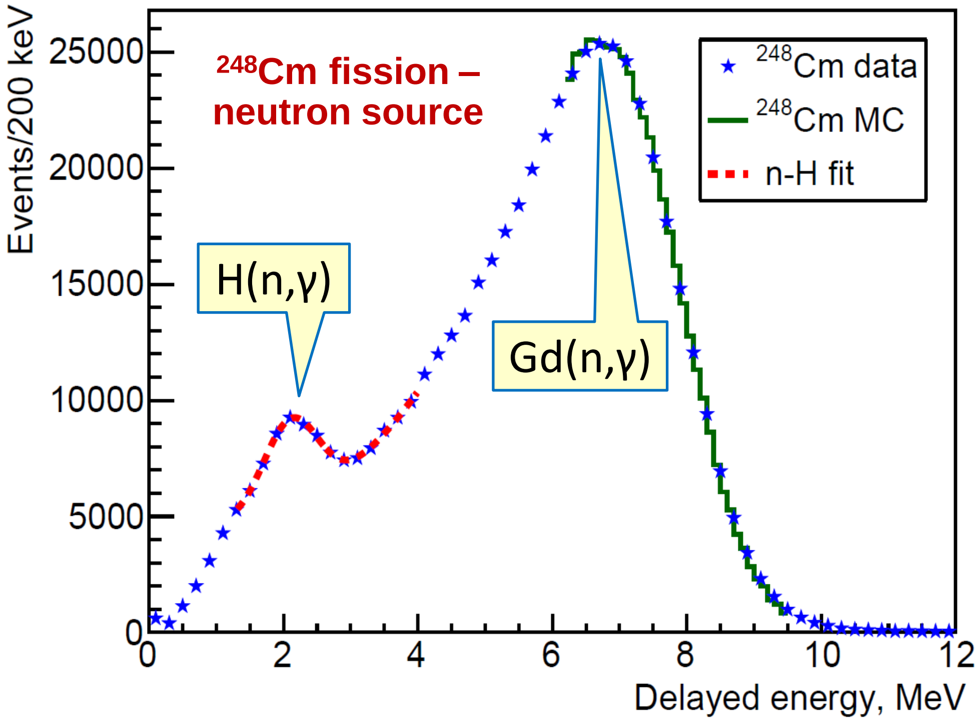
Check with ^{22}Na and ^{60}Co sources

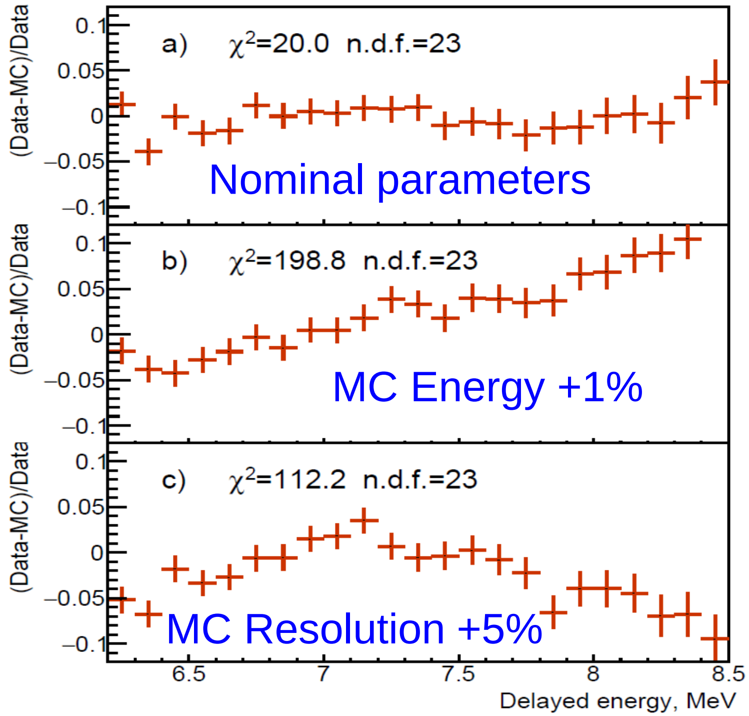




- Energy resolution is dominated by p.e. statistics – sum SiPM and PMT
- MC includes:
  - Crosstalk (SiPM) and first dynodes (PMT)
  - Individual strip light yields and dead channels
  - Transverse light collection inhomogeneity and longitudinal profile
- Add 17%/√E smearing to MC to describe experimental energy resolution (muons, sources)
- Source data shows reasonable agreement between MC and experiment

Check with ^{248}Cm neutron source



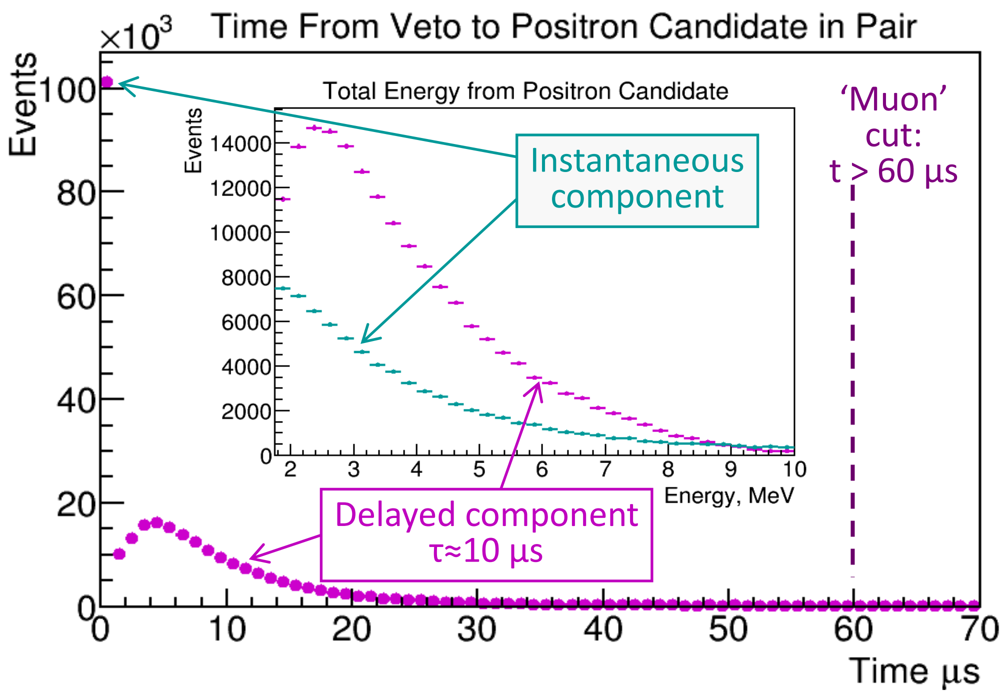


- Neutron capture by protons: Gaussian fit position and width are in reasonable agreement with MC
- Right edge of gadolinium peak is very sensitive to energy scale and resolution
- Good agreement between MC and experiment with nominal parameters

Event building and muon cuts

Building Pairs

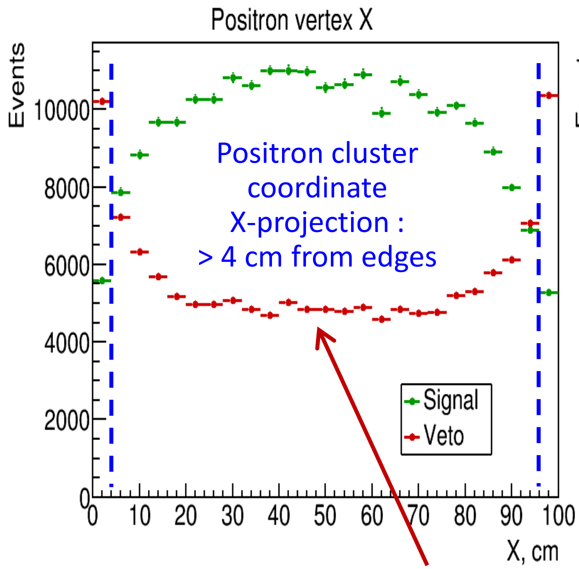
- Positron candidate: 1-20 MeV in continuous ionization cluster
- Neutron candidate: 3.5-20 MeV total energy, SiPM multiplicity >3
- Search positron 50 μs backwards from neutron

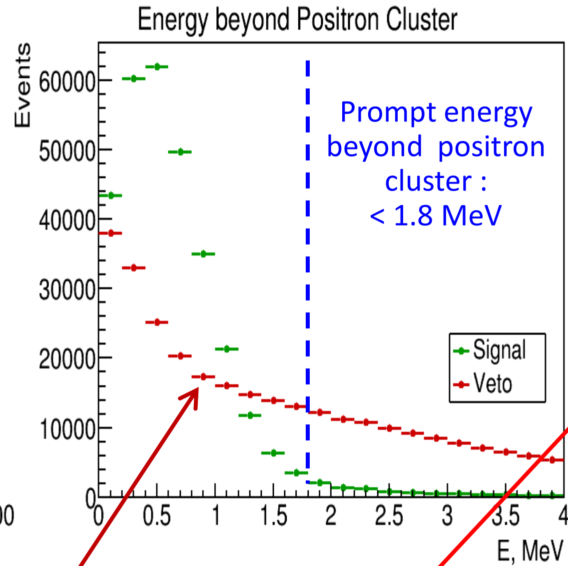


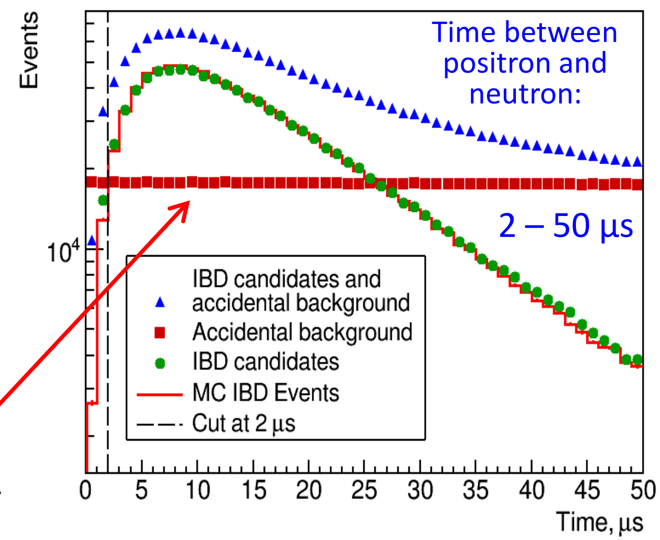
Muon Cuts

- 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 200 μs before positron

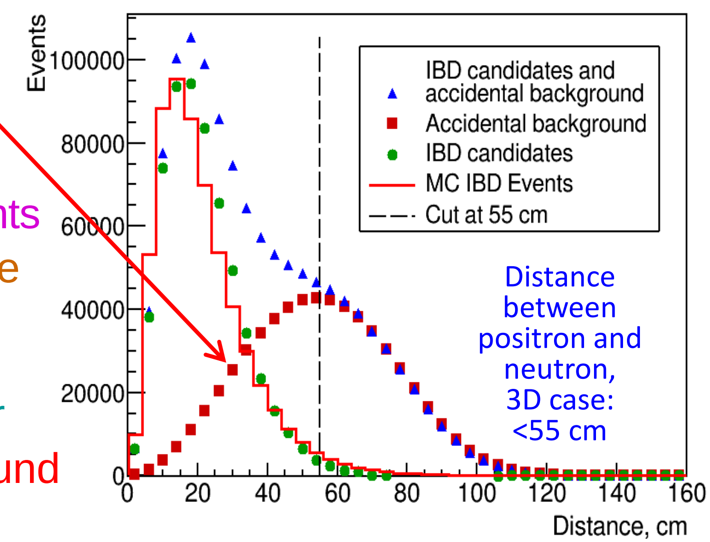
More cuts and accidental background



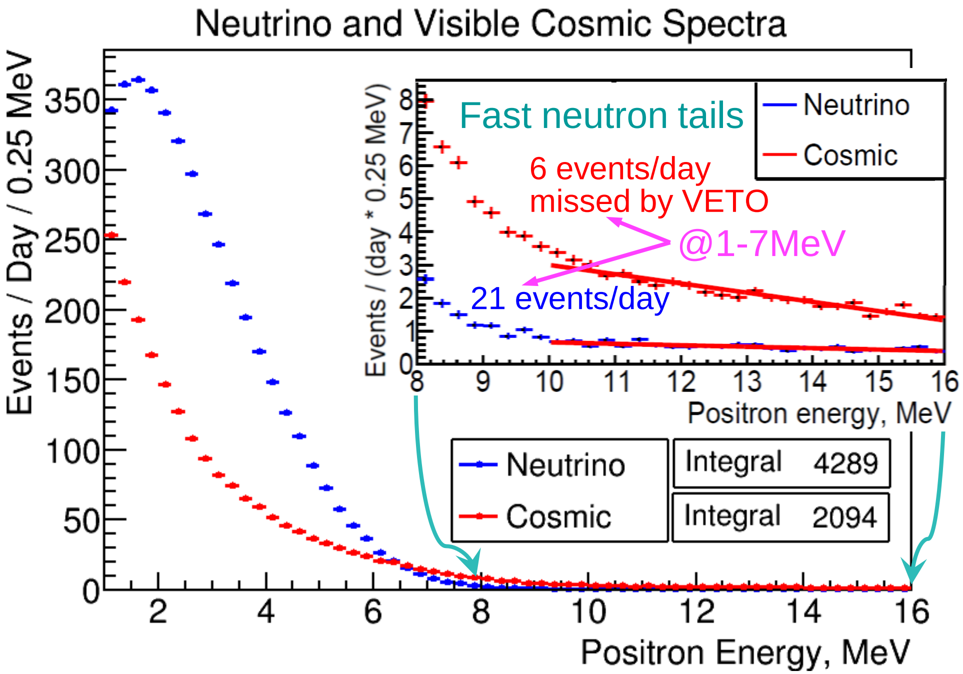


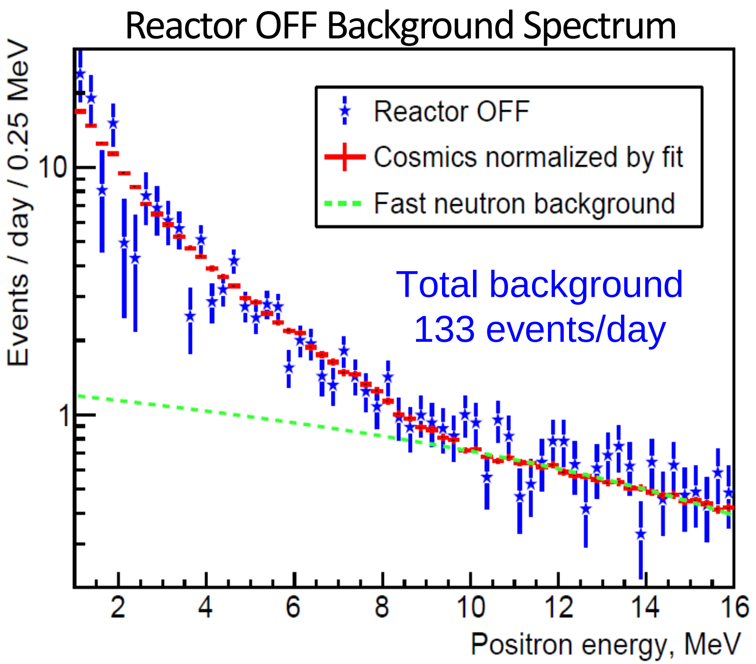


- Cuts to suppress muon-induced and accidental backgrounds compared to good events
- Totally about 10 cuts based on fine segmentation: timing, geometry, multiplicity and partial energy
- Reduce backgrounds several times, but only 15% events
- Accidental sample from data: look for a positron where it can not be present – same 50 µs intervals but far away from neutron (5, 10, 15 etc millisec)
- 16 non-overlapping intervals to reduce statistical error
- Any distribution – physics events, accidental background events (same cuts) and their difference



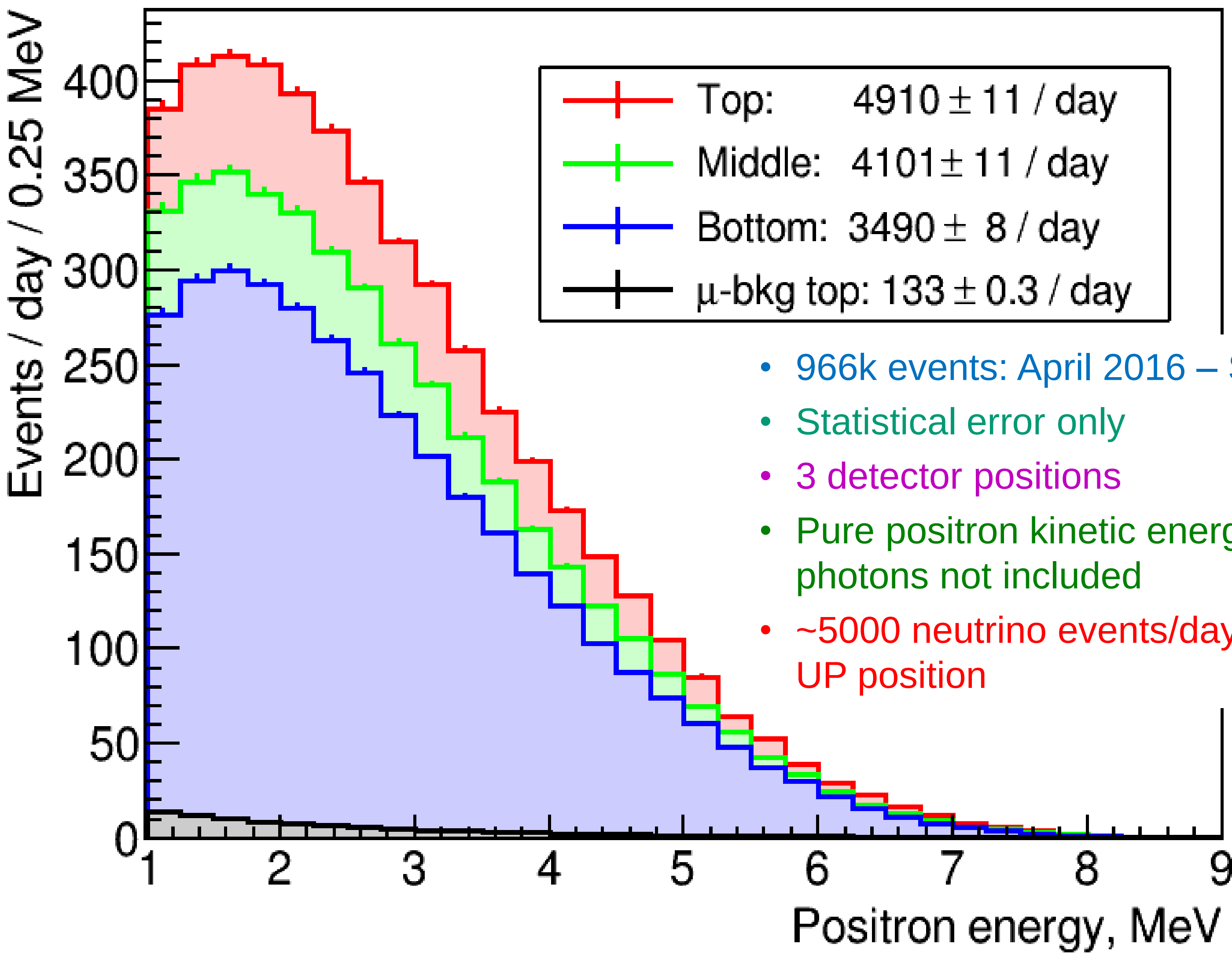
Residual background subtraction





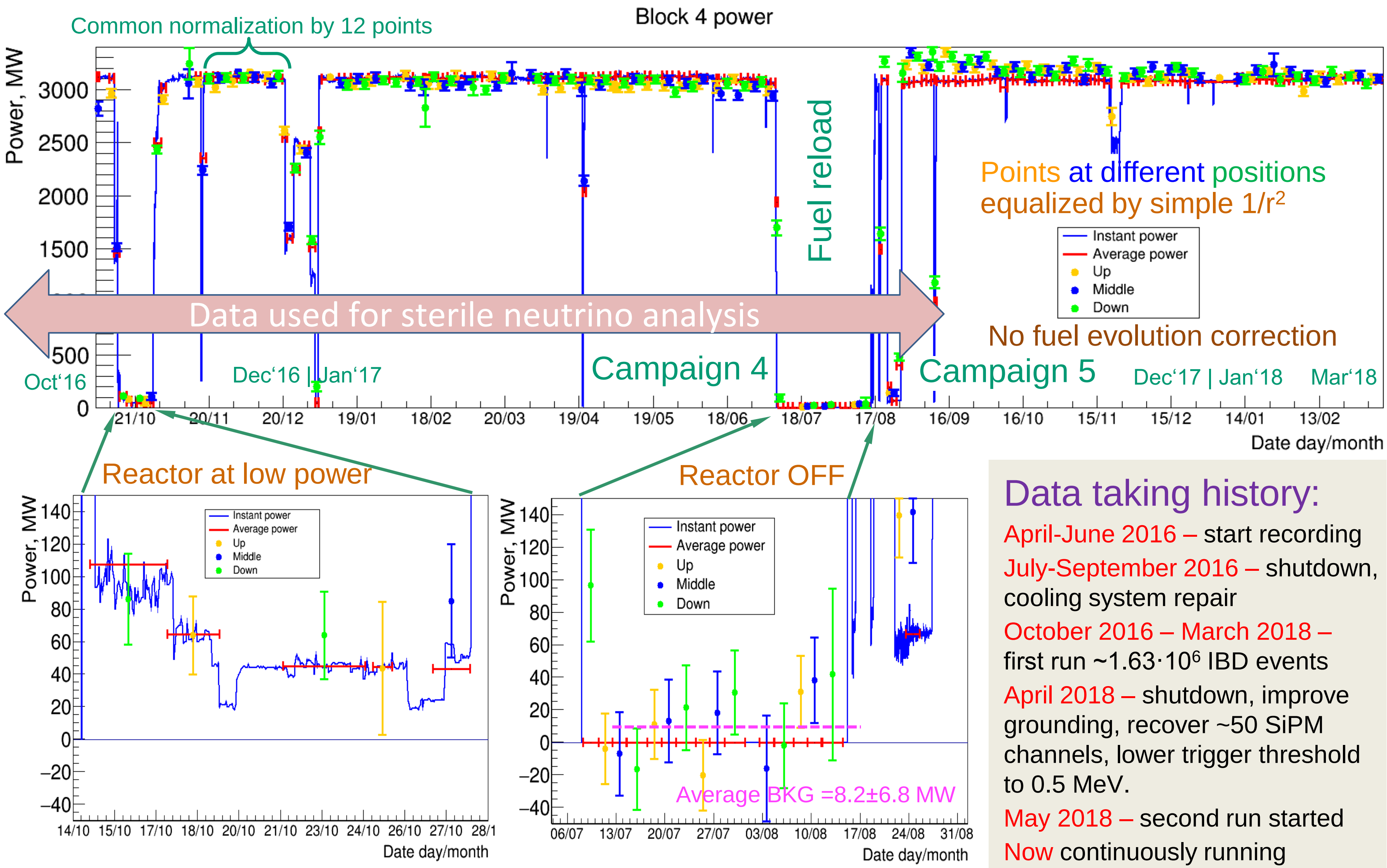
- Amount of visible cosmics (≡ tagged by VETO) ~50% of neutrino signal
- Reactor OFF spectrum: same shape as visible cosmic
- Subtract fraction of visible cosmics based on VETO transparency (from fit of OFF data)
- Cosmic background fraction 2.7% of neutrino signal (up position), **subtracted**
- Fast neutron tails: linearly extrapolate from high energy region 10-16 MeV and **subtract** separately from neutrino and visible cosmic spectra
- Neighbor reactors at 160 m, 334 m, and 478 m, 0.6% at up position, **subtracted**
- ^{9}Li and ^{8}He background estimates: 4.4±1.0 events/day

Positron spectrum



- 966k events: April 2016 – September 2017
- Statistical error only
- 3 detector positions
- Pure positron kinetic energy, annihilation photons not included
- ~5000 neutrino events/day @1-7 MeV, UP position

Reactor power and neutrino flux

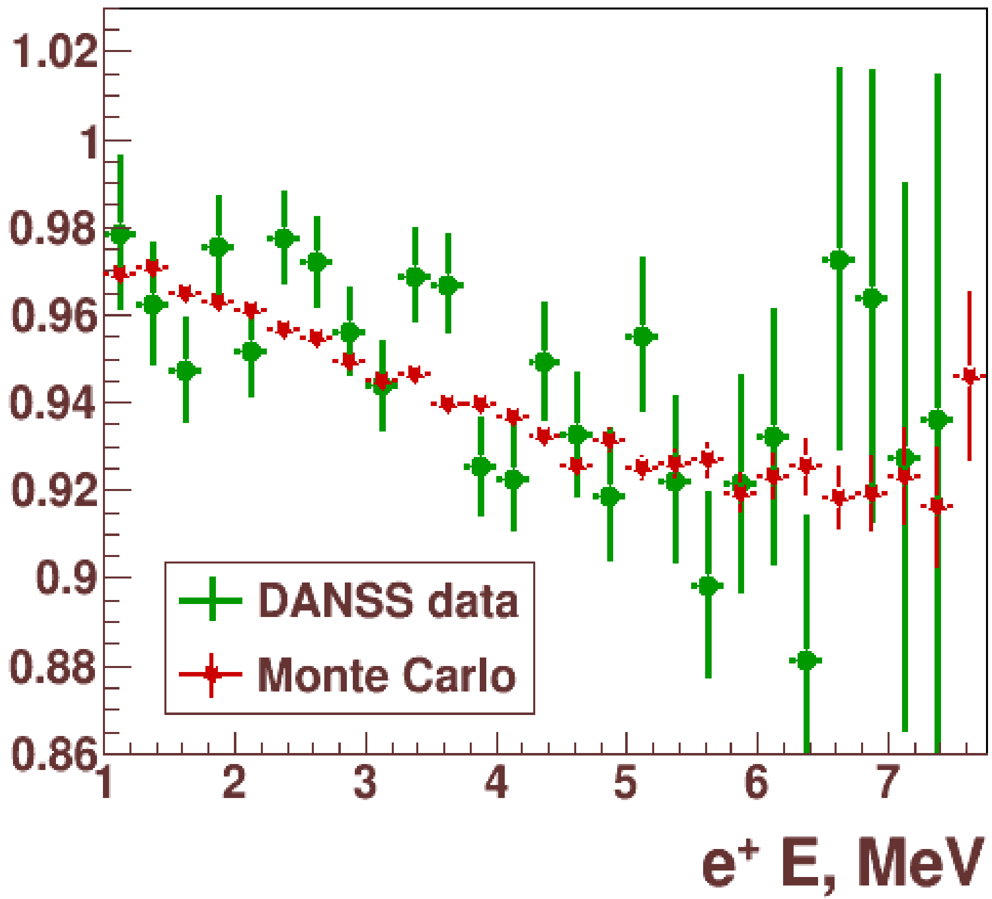


Data taking history:

- April-June 2016 – start recording
- July-September 2016 – shutdown, cooling system repair
- October 2016 – March 2018 – first run ~$1.63 \cdot 10^6$ IBD events
- April 2018 – shutdown, improve grounding, recover ~50 SiPM channels, lower trigger threshold to 0.5 MeV.
- May 2018 – second run started
- Now continuously running

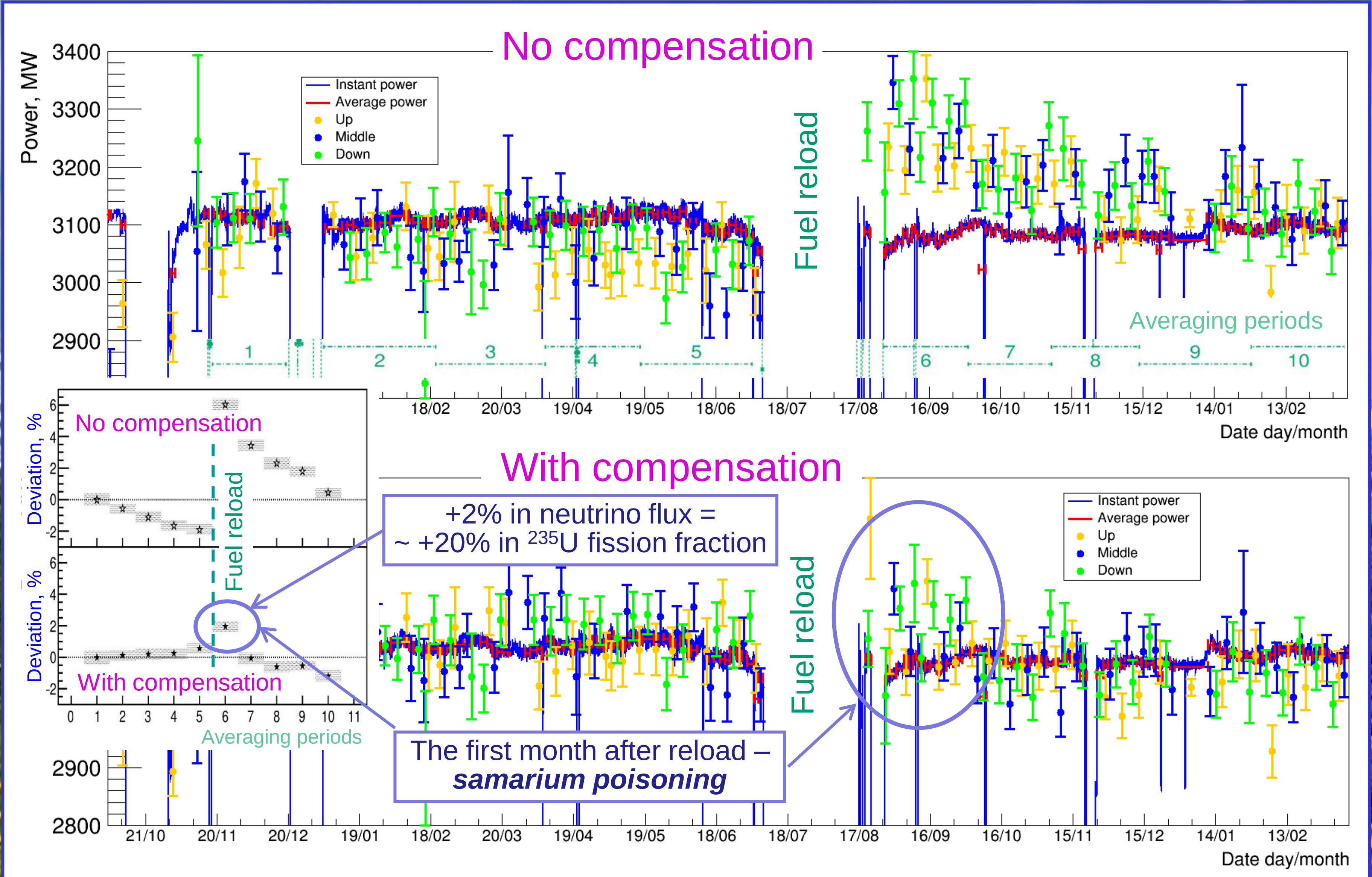
Fuel evolution

Fission fractions			
	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%



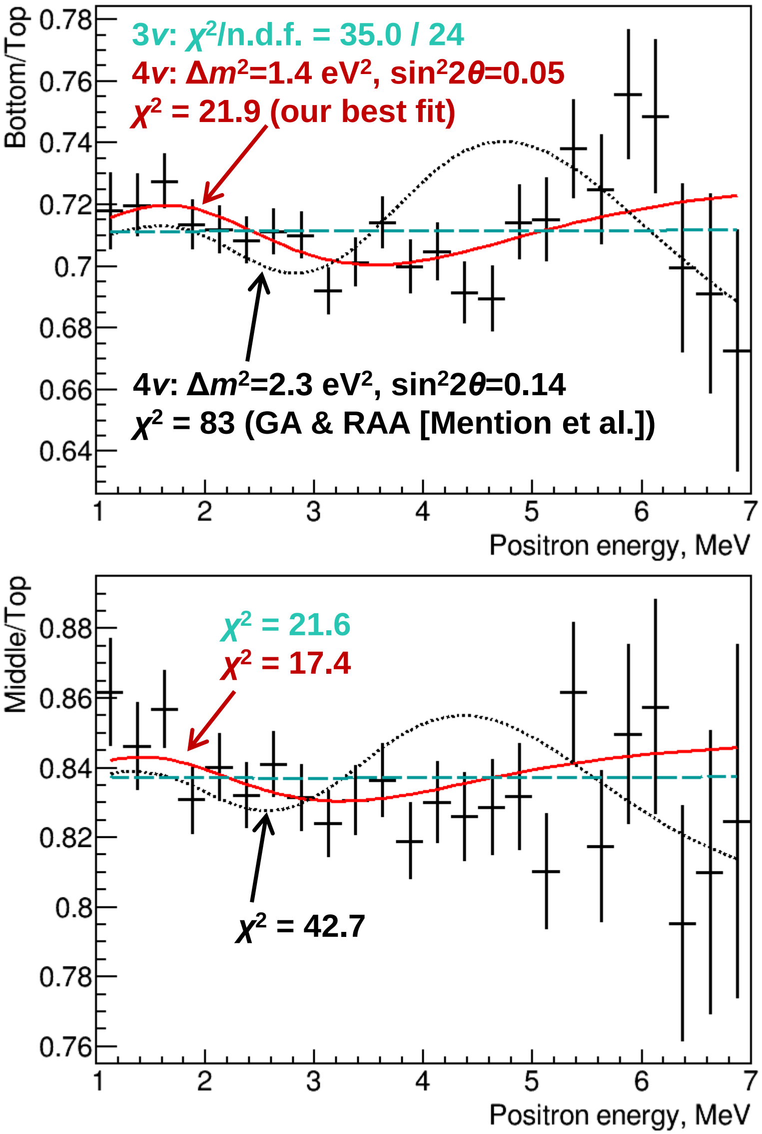
- Spectra ratio: 3 months at the very end of campaign 4 to 3 months a month after campaign 5 start
- The first month at the start of campaign 5 skipped because of samarium poisoning of the reactor
- No contradiction to Monte Carlo simulations using Huber and Mueller spectra seen.

Compensation of the fuel evolution



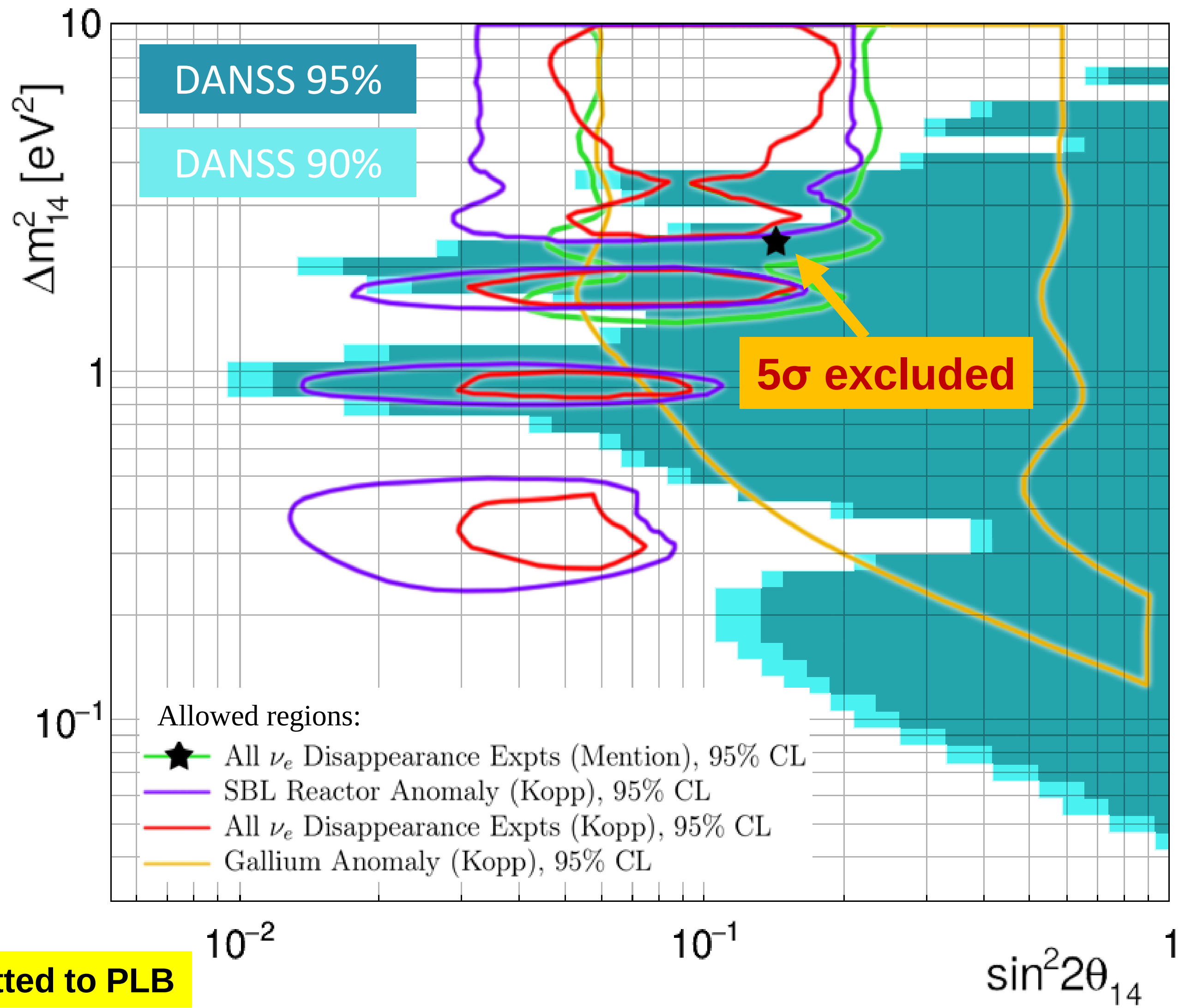
Probing for sterile neutrino

- Based only on spectra ratio at different distances – independent on model neutrino spectrum, detector efficiency etc.
- Theoretical curves for each Δm^2 and $\sin^2(2\theta)$ calculated based on:
  - Model neutrino spectrum from Huber and Mueller
  - Fuel burning profile from NPP
  - Detector size
  - Detector energy response including tails
- Systematics studies include variations in:
  - Detector energy resolution ±10% of the resolution
  - Levels of cosmic backgrounds (veto and fast neutrons) ±15% of the background
  - All combinations of the above
  - Reduced energy interval used in fit



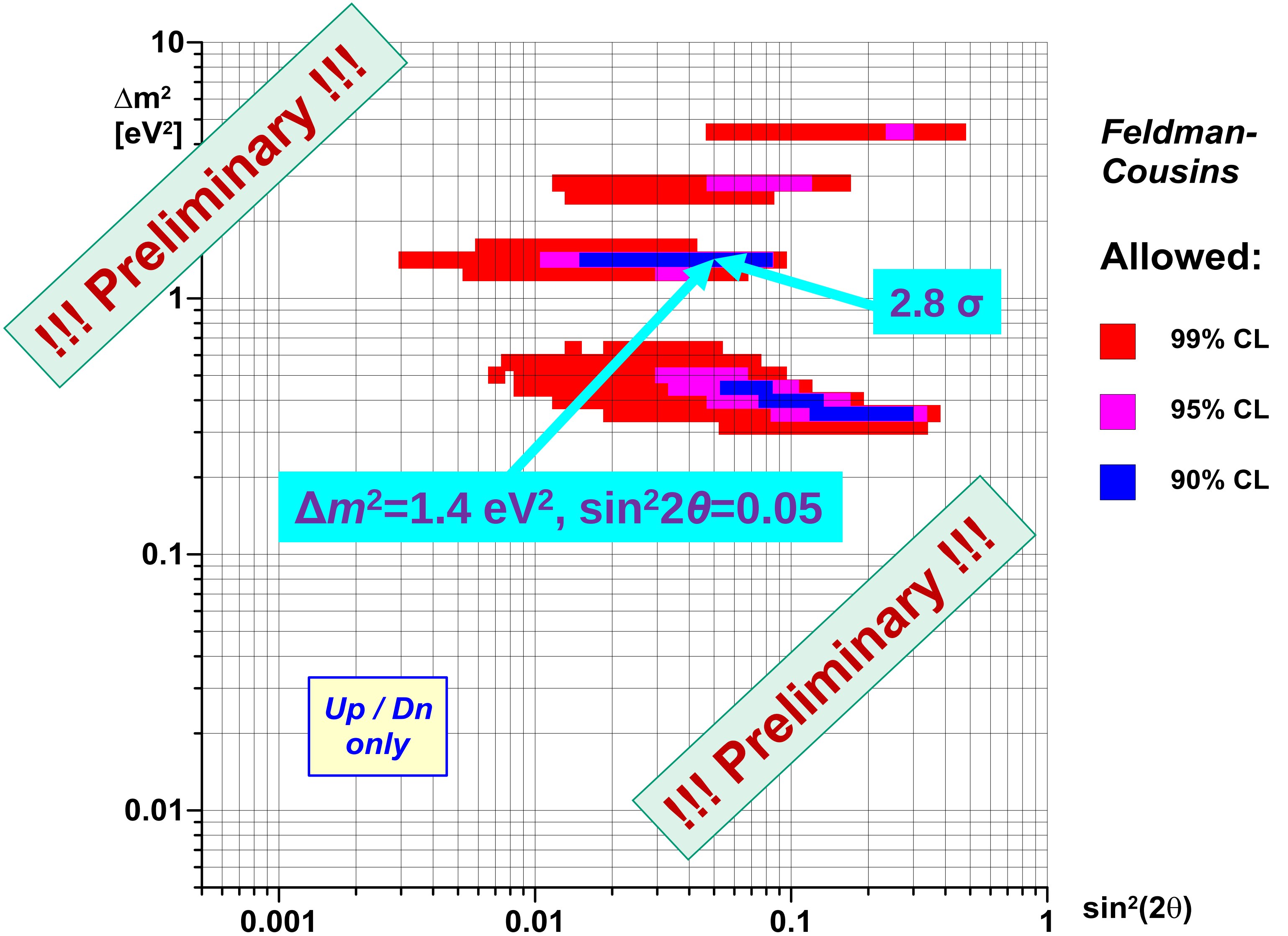
Exclusion region

- Only Bottom/Top ratio used so far – no clear procedure for dependent ratios
- Gaussian CLs method (X. Qian et al. Nucl.Inst. Meth. A 827 (2016) 63) – conservative estimate
- Most conservative intersection of systematics variations
- A large fraction of allowed parameter space is reliably excluded by current DANSS results



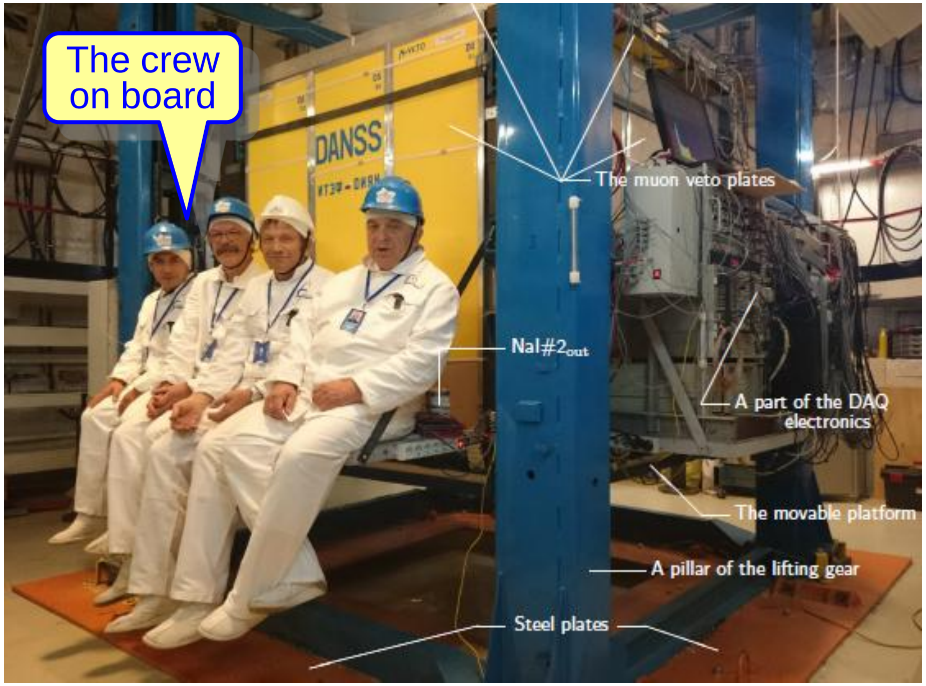
arXiv:1804.04046, submitted to PLB

Feldman-Cousins analysis



Summary

- DANSS recorded 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.
- Analysis of the data collected till September 2017 already excludes a large fraction of the sterile neutrino parameter space, using only the ratio of positron spectrum at two distances
- The very preliminary analysis gives 2.8 σ significance to the best point (Δm^2=1.4 eV^2, $\sin^2 2\theta$=0.05)
- The experiment is running, more than $2 \cdot 10^6$ IBD events are recorded by now
- Data analysis is in progress. We plan:
  - Analyze all the data collected
  - Refine detector calibration
  - Continue systematic studies
  - Elaborate more analysis methods for better sensitivity



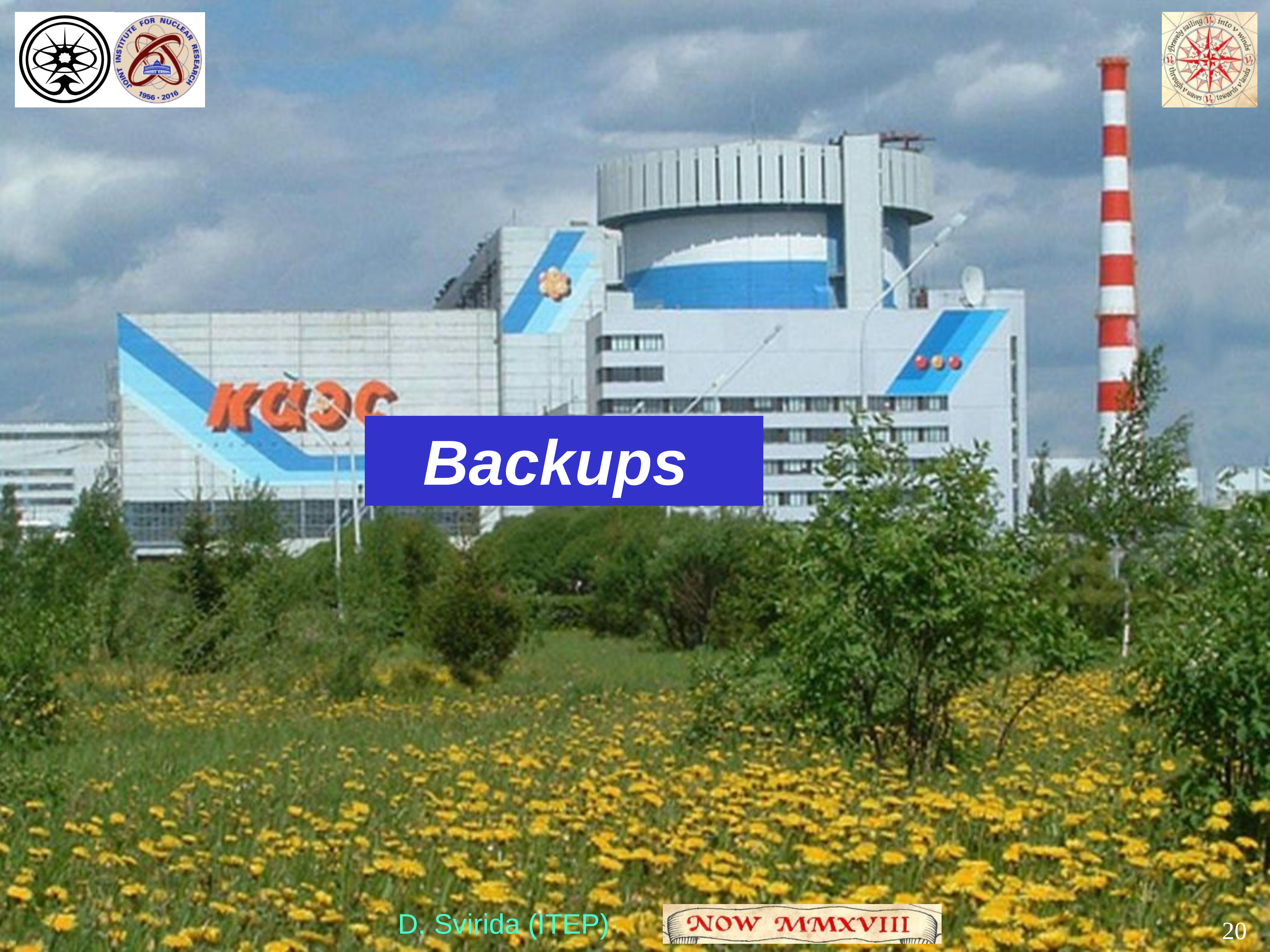
The detector construction was supported by the Russian State Corporation ROSATOM, state contracts H.4x.44.90.13.1119 and H.4x.44.9B.16.1006. The operation and data analysis became possible due to the valuable support from the Russian Science Foundation grant 17-12-01145. The collaboration appreciate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

КАЭС

Thank you !

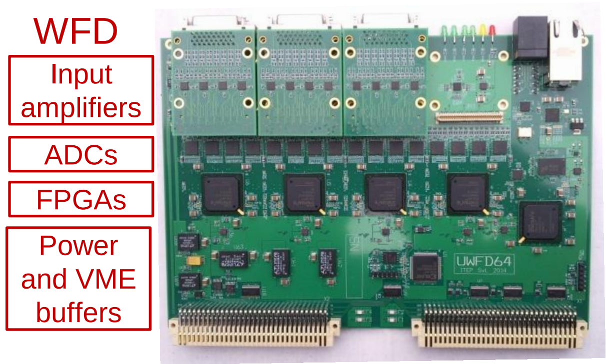
Bravely sailing ν_μ into ν winds
ν_e
$\nu_?$
through ν waves ν_τ towards ν lands

NOW MMXVIII

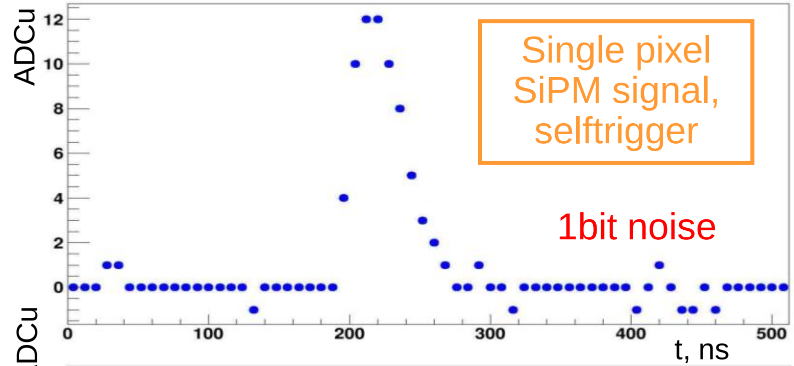


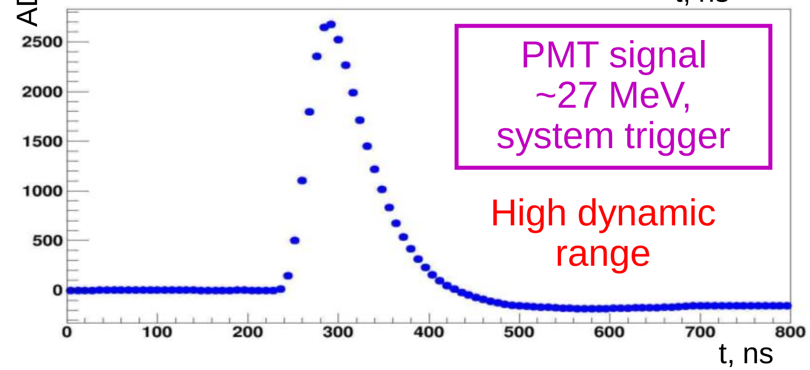
Backups

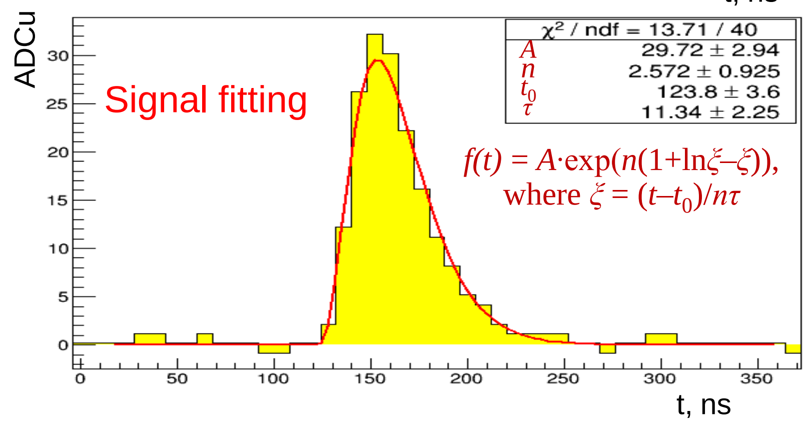
Data acquisition system



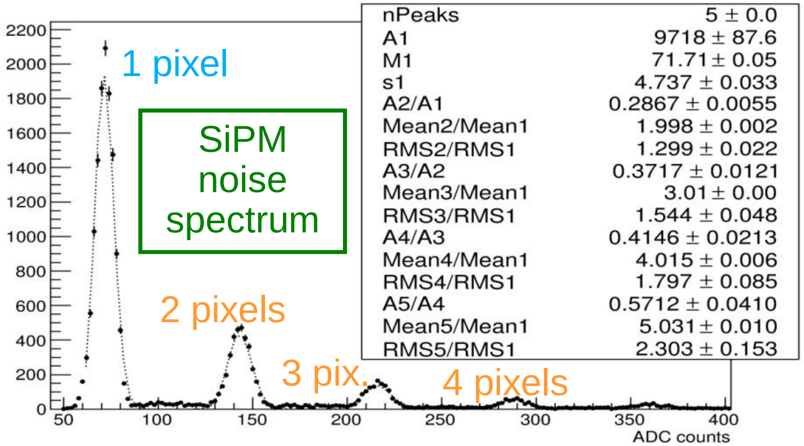
- Preamplifiers PA in groups of 15 and SiPM power supplies HVDAC for each group inside shielding, current and temperature sensing
- STP cables to get through the shielding
- Total 46 Waveform Digitisers WFD in 4 VME crates on the platform
- WFD: 64 channels, 125 MHz, 12 bit dynamic range, signal sum and trigger generation and distribution (no additional hardware)
- 2 dedicated WFDs for PMTs and μ-veto for trigger production
- Each channel low threshold selftrigger on SiPM noise with decimation
- Exceptionally low analog noise ~1/12 p.e.

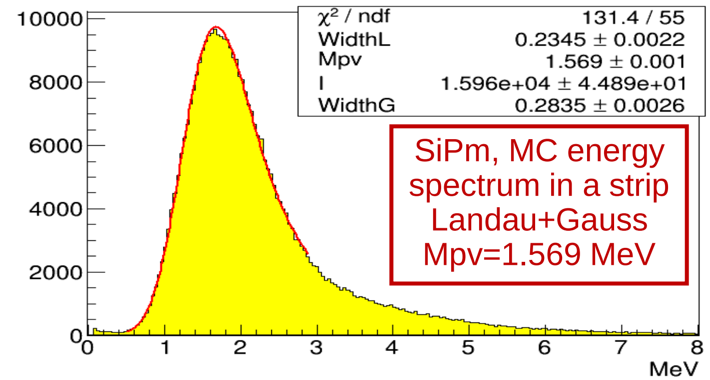


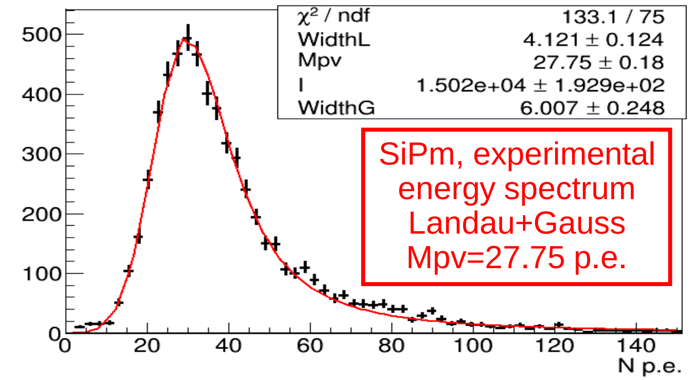


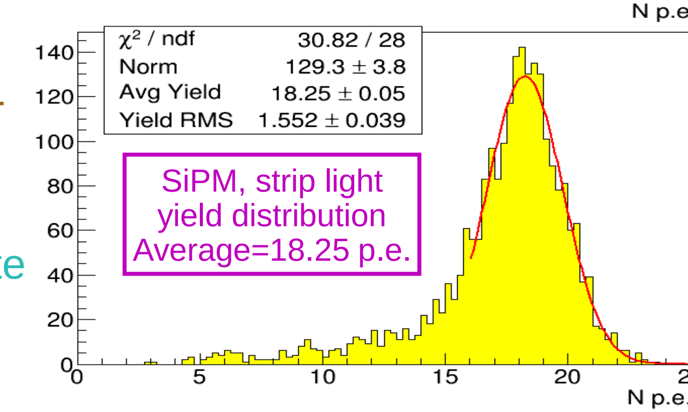


Energy calibration



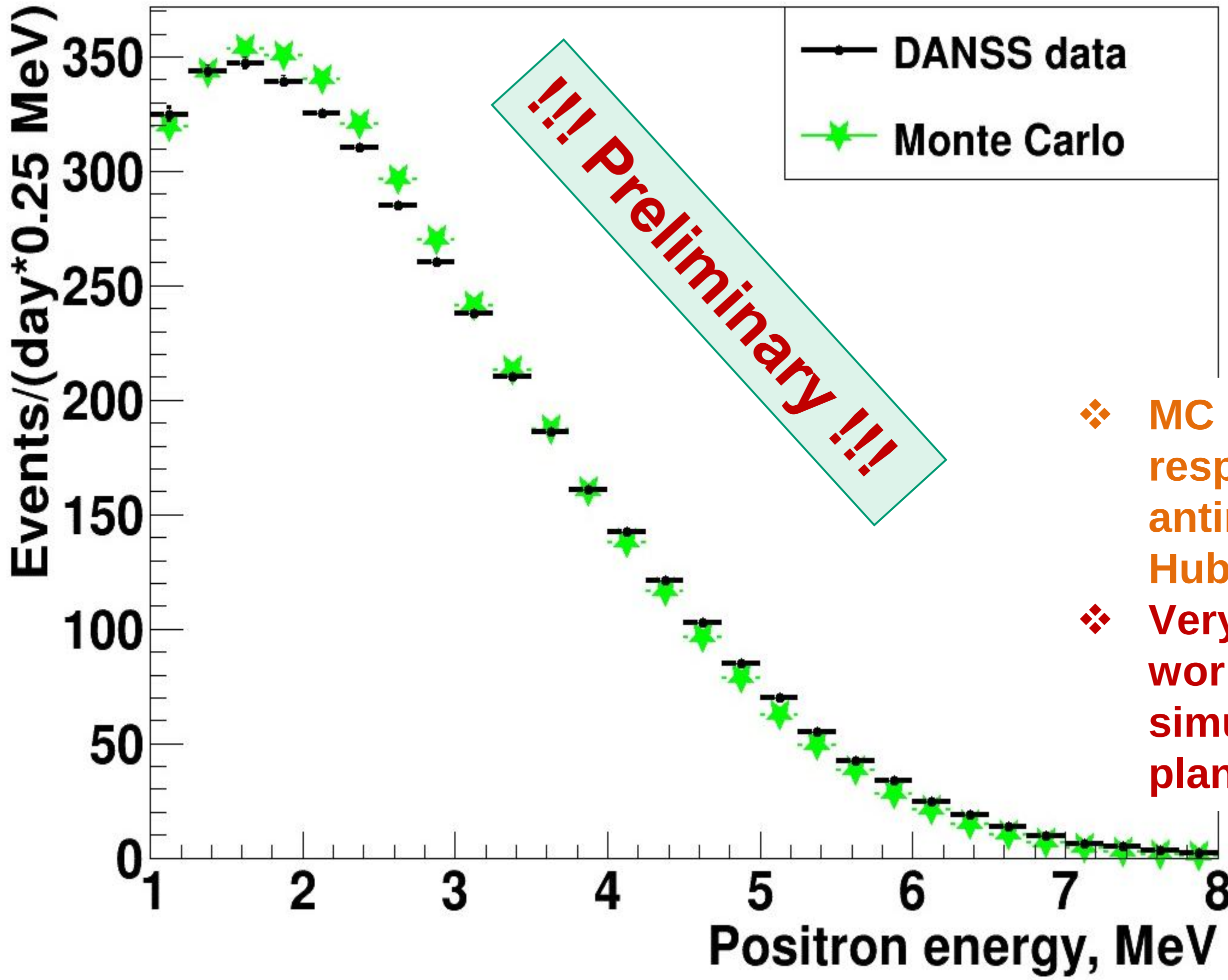


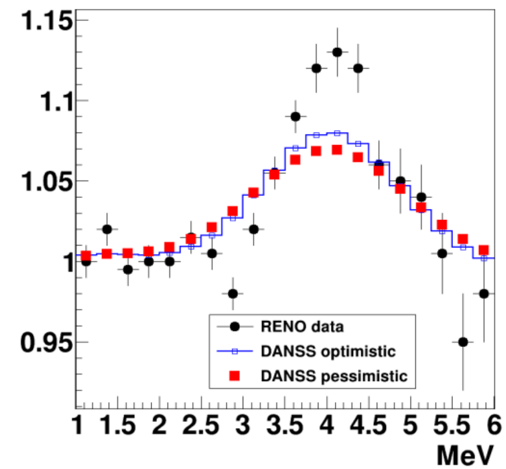




- Noise spectrum: SiPM calibration in terms of ADCu/p.e., including cross-talk accounting
- Temperature dependent – after every instability
- Strip light yield, p.e./MeV – stable, ~twice per month
- Using vertical muons: PMT tower 100x20x20 cm
- Compare MC-simulated energy deposit to the experimental by Mpv
- Direct muon calibration for PMTs: ADCu/MeV, similar Mpv technique
- SiPMs: ~18 p.e./MeV, PMTs ~20 p.e./MeV
- Attenuation ~20%/m, corrected by second coordinate
- Energy resolution is dominated by p.e. statistics – add SiPM and PMT signals to improve

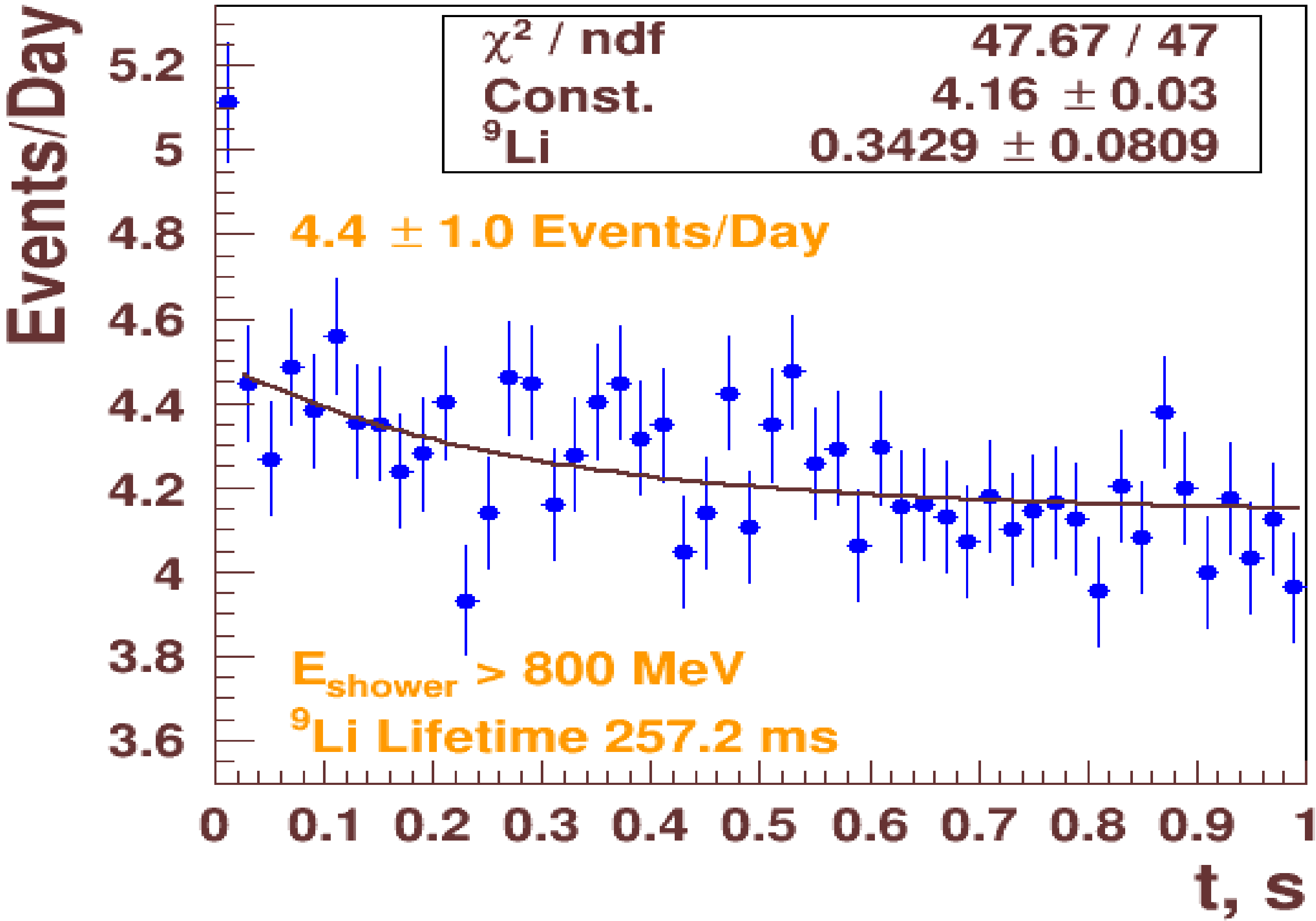
Positron spectrum - compare to model



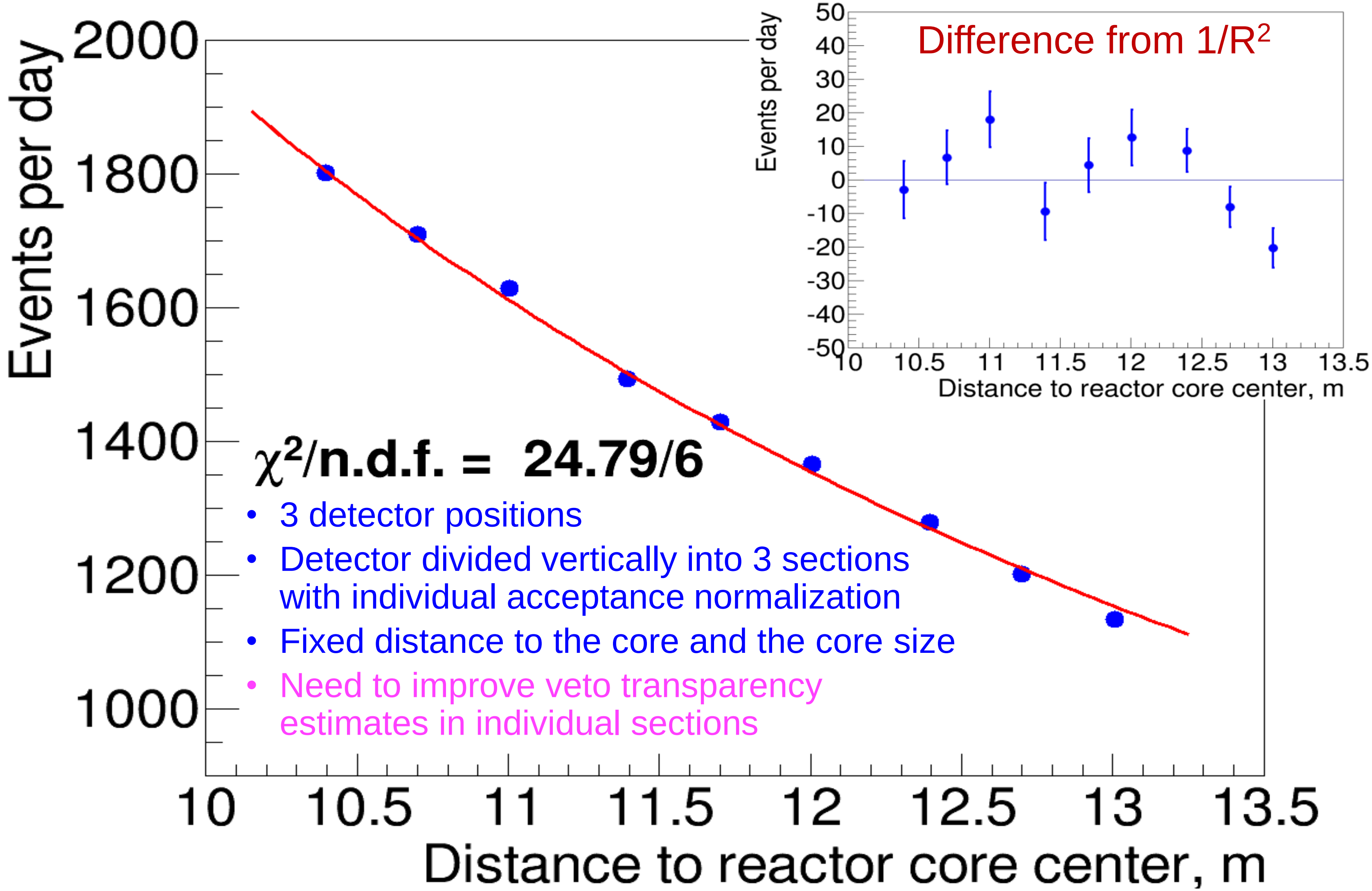


- MC simulated DANSS response use theoretical antineutrino spectrum by Huber and Mueller
- Very preliminary – more work on calibration and simulations needed and planned

^{9}Li and ^{8}He background



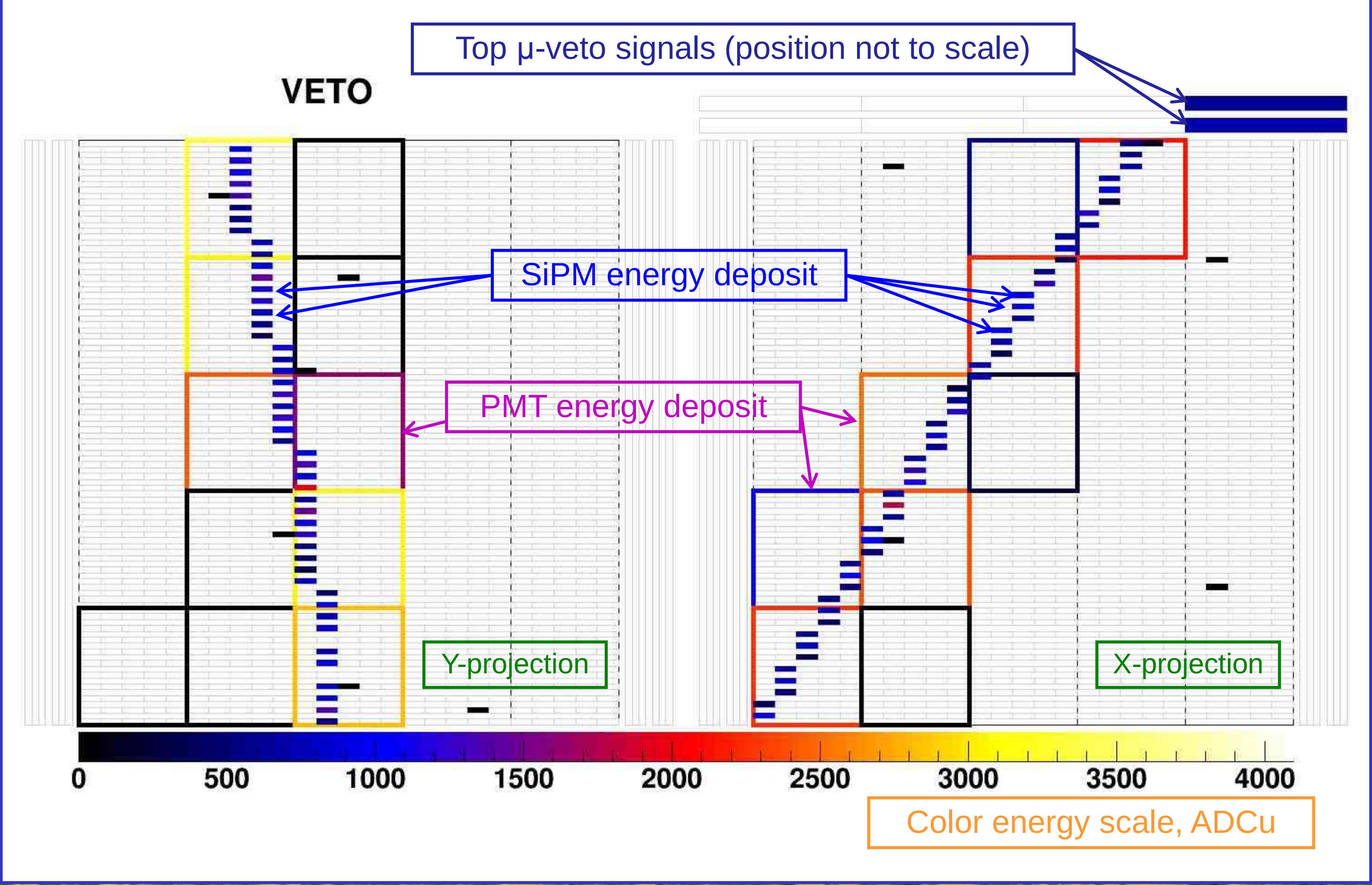
$1/R^2$ – still needs elaboration



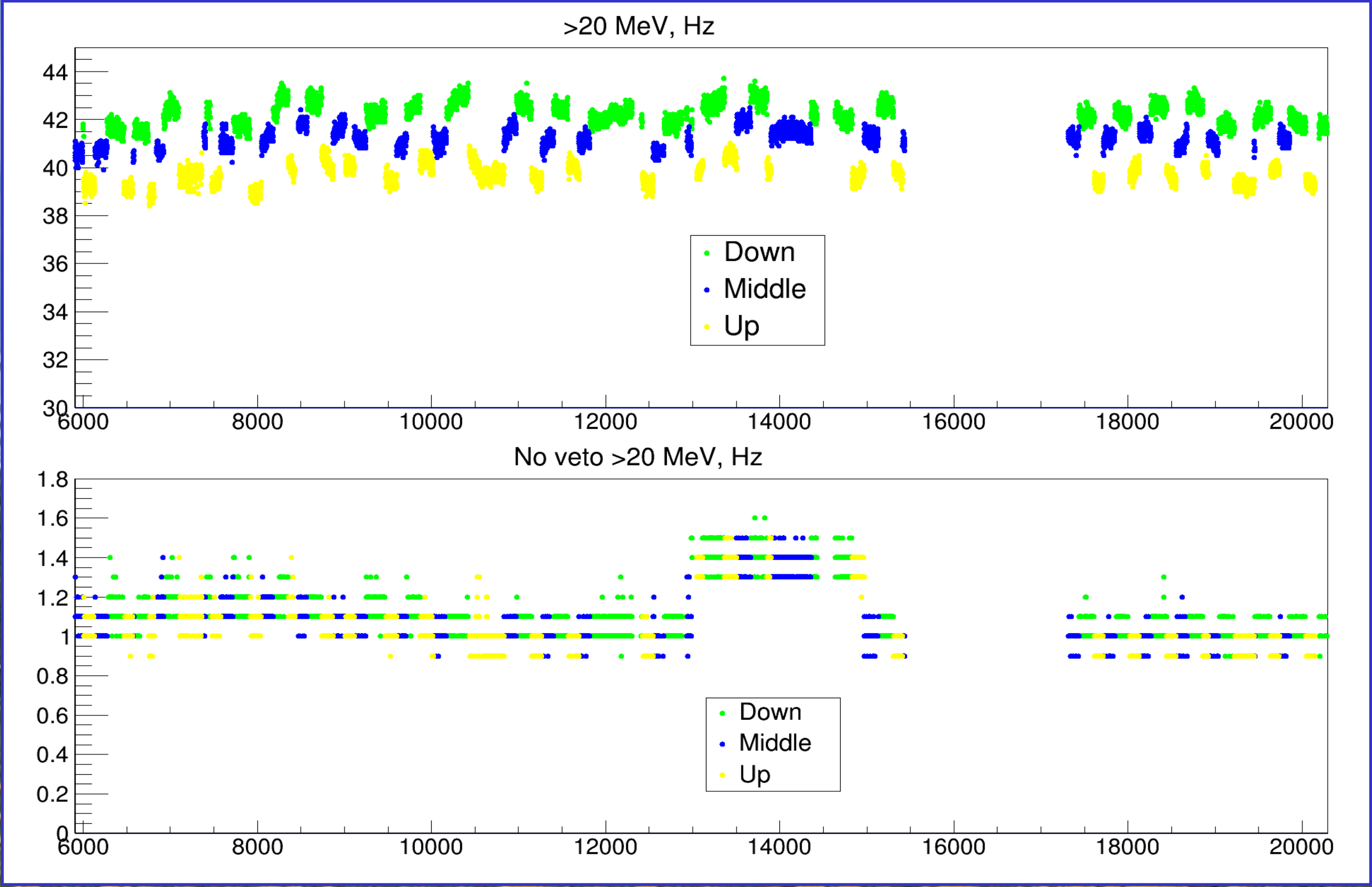
χ^2/n.d.f. = 24.79/6

- 3 detector positions
- Detector divided vertically into 3 sections with individual acceptance normalization
- Fixed distance to the core and the core size
- Need to improve veto transparency estimates in individual sections

Cosmic muon event in the setup



Veto transparency estimates



Single counts