New results from the DANSS experiment

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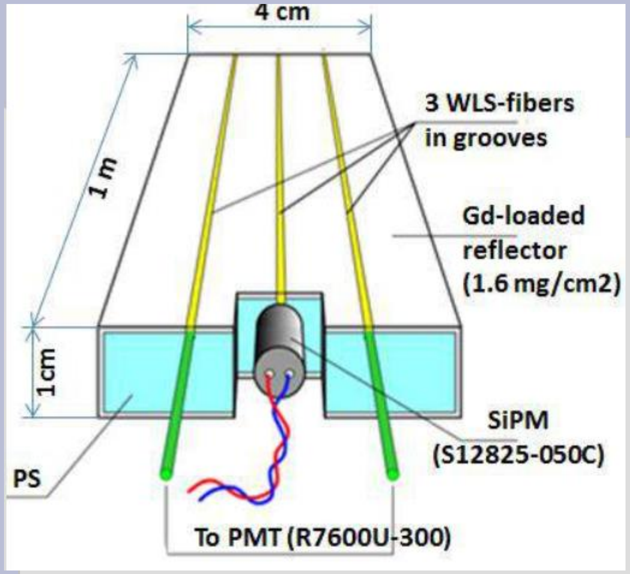
for the DANSS collaboration

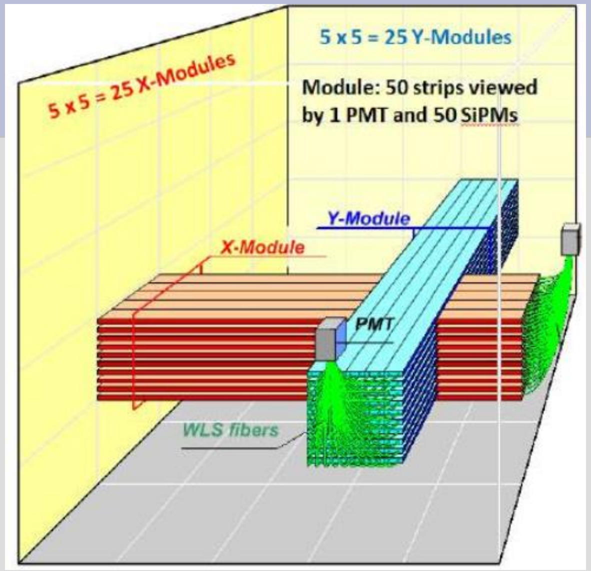
LP 2019 @ Toronto

The DANSS design

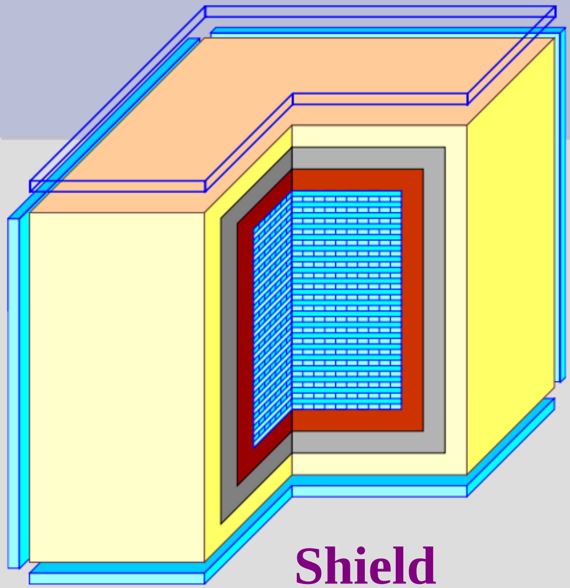
Strip



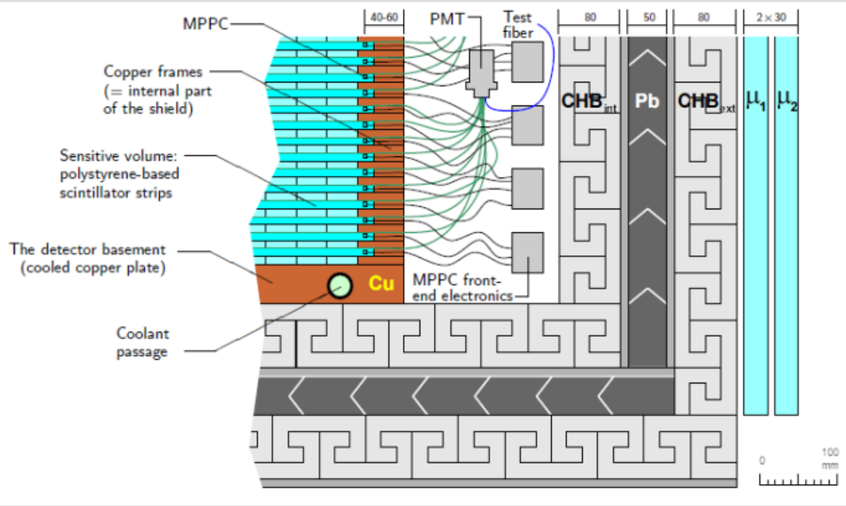
Module



Detector

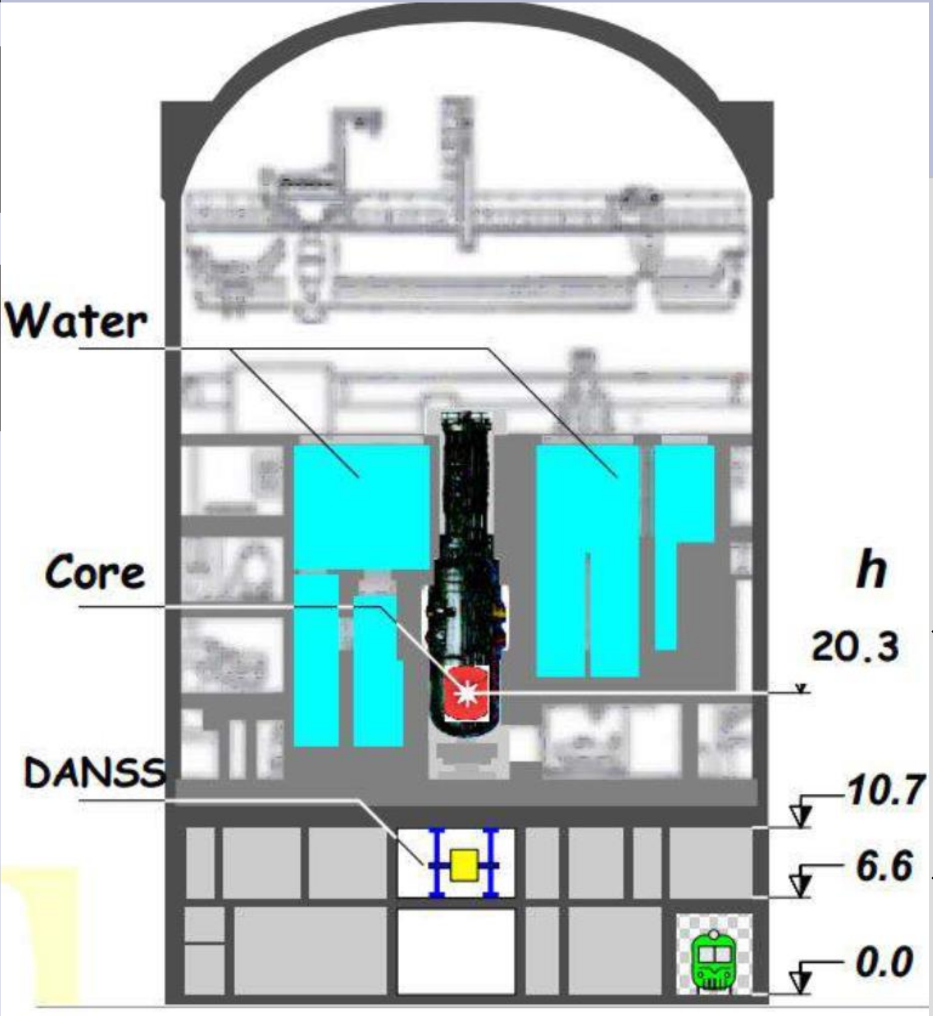


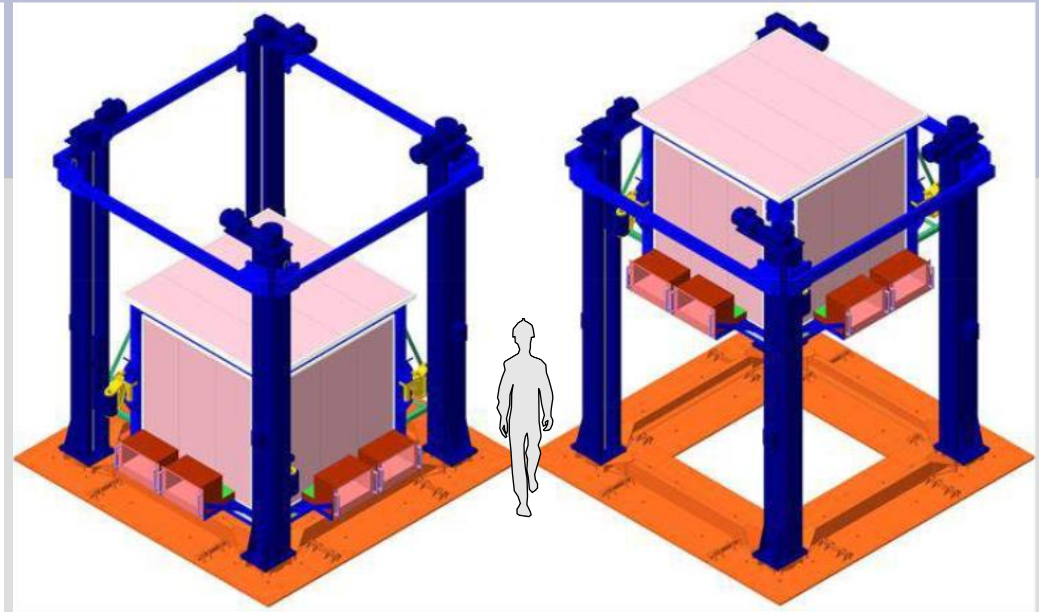
Shield



- Cubic meter highly segmented neutrino spectrometer made of 2500 PS strips viewed by 2500 SiPMs & 50 PMTs.
- Multilayer passive shielding: Cu/CHB/Pb/CHB=5/8/5/8 cm
- Active muon veto made of 2 x 3 cm PS plates from all sides except bottom.

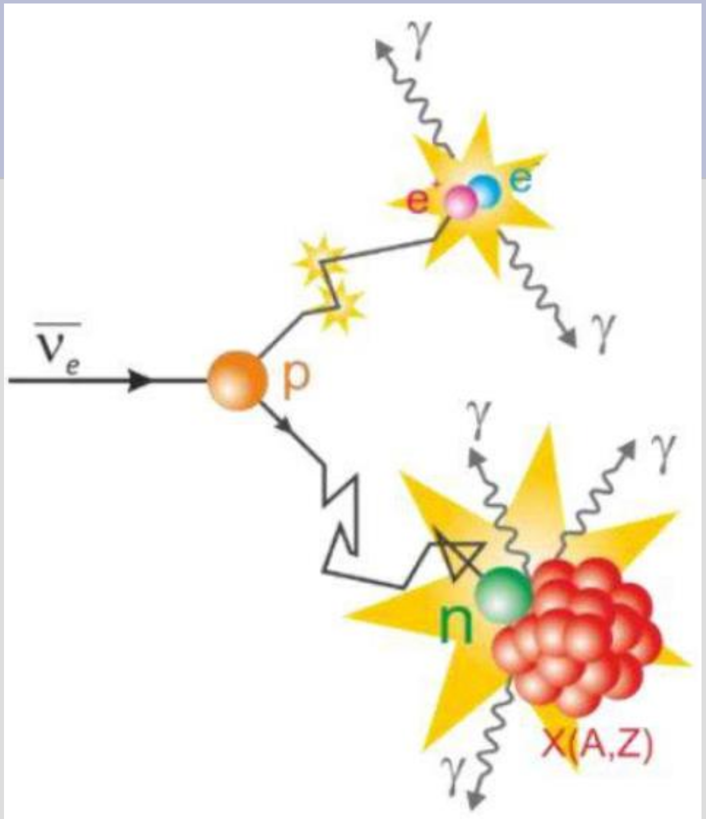
The location and movable platform

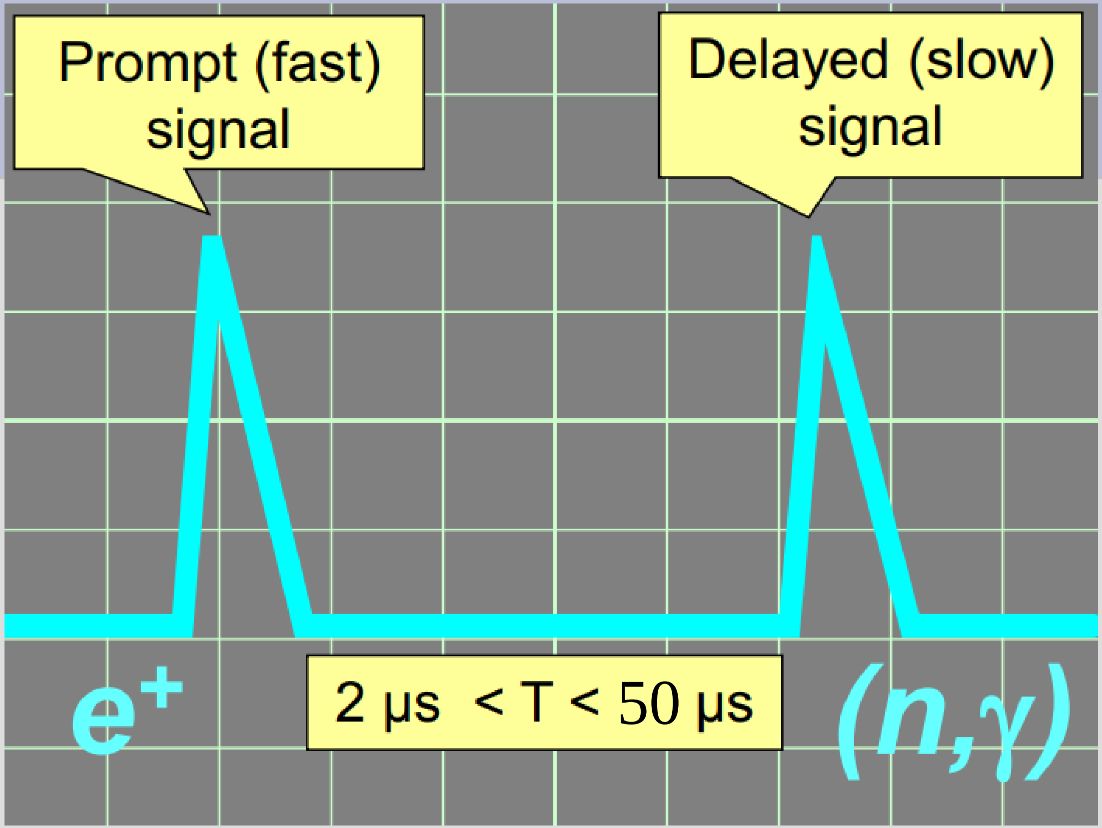




- The DANSS is located at Kalininskaya NPP (KNPP) under 3 GW WWER-1000 reactor (H=3.6 m, ∅ =3.1 m), which provides ~ 50 m.w.e. (6-fold μ reduction and no cosmic n).
- The detector is built on a movable platform. Data are taken at 3 distances 10.7 m (Up), 11.7 m (Middle), and 12.7 m (Down) from the reactor (center to center), changed sequentially 3 times per week.

IBD signal pattern & basic cuts





Main cuts (maximally relaxed):
- Prompt signal (E > 0.7 MeV)
- Delayed signal (E>3 MeV)
- Time between signals is in [2, 50] μs
- No muons before prompt signal in 60 μs

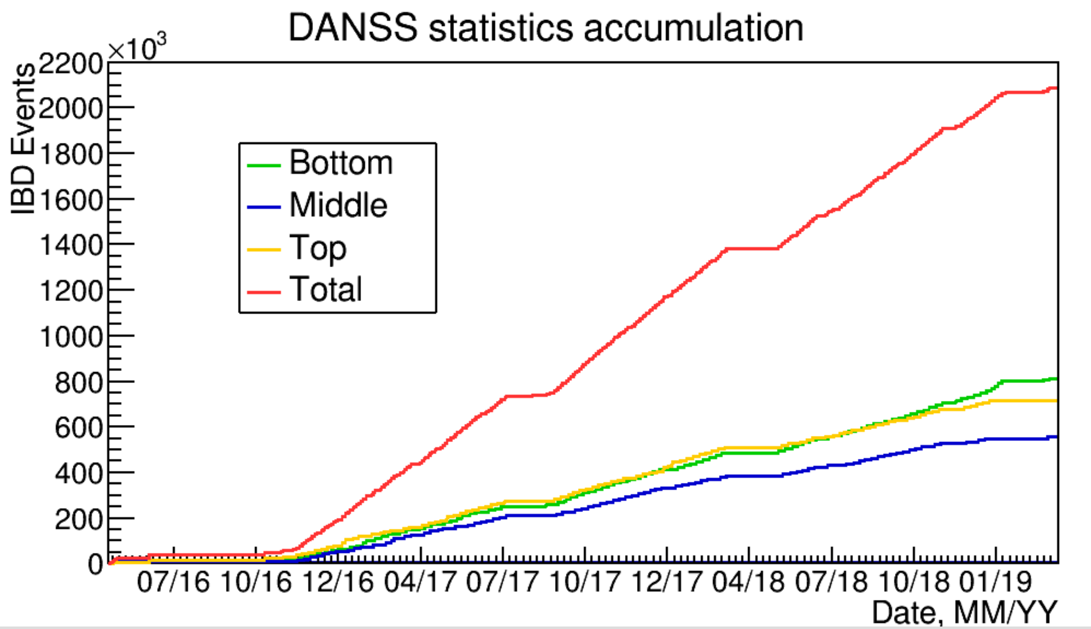
Additional cuts:
- Hit multiplicities for both signals
- Positron clustering pattern cuts
- Spatial cut on distance between fast and slow signal vertexes

Improvements in analysis*

- Improvement in signal processing (use of SiPM and PMT signal shapes for T_0 and charge determination) and MC simulations (signal WF simulations, taking into account Birks effect & Cherenkov radiation).
- Cut modification (requirement for PMT-SiPM coincidences to suppress noise, requirement of annihilation photons for 1strip positron clusters to reduce accidental/neutron background for low energy positrons).
- More frequent energy calibrations (gain – each 15min, MIP – each 2 days).
- Usage of ^{12}B spectrum for energy scale calibration.
- Two lowest detector layers added to the VETO system
- Four times finer grid of points on the (Δm^2, $\sin^2(2\theta)$) phase space

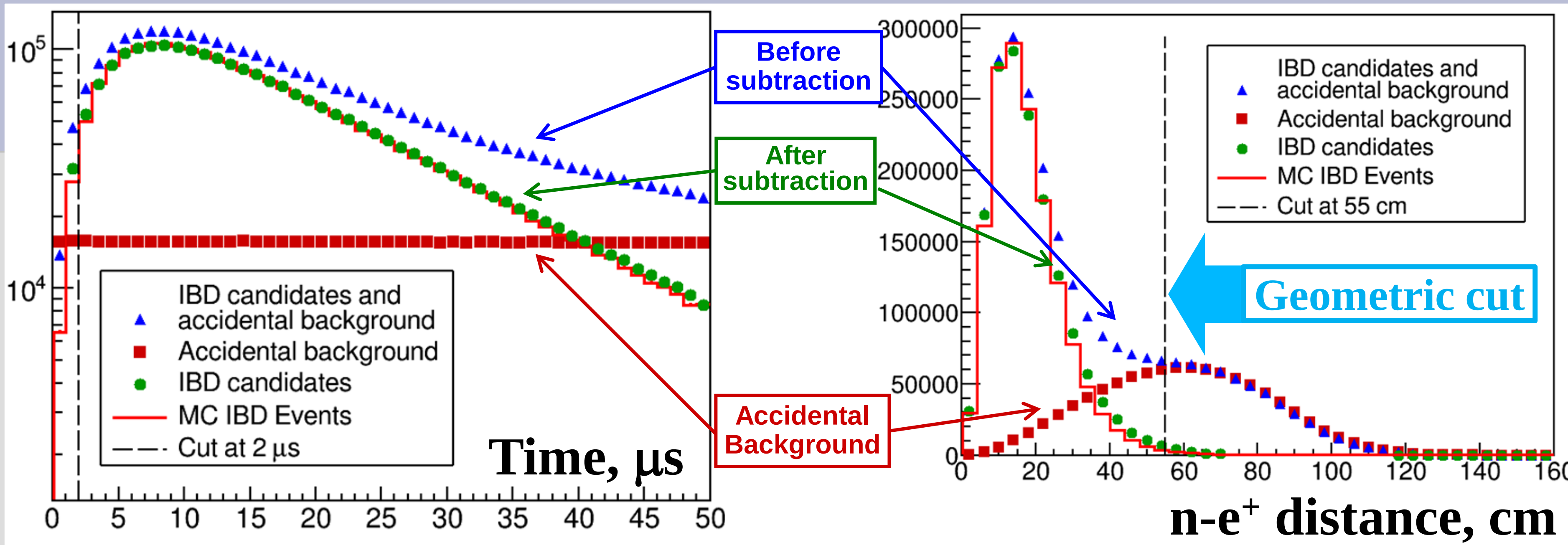
*) in comparison with our last published result Phys.Lett. B787 (2018) 56

Results of improvements



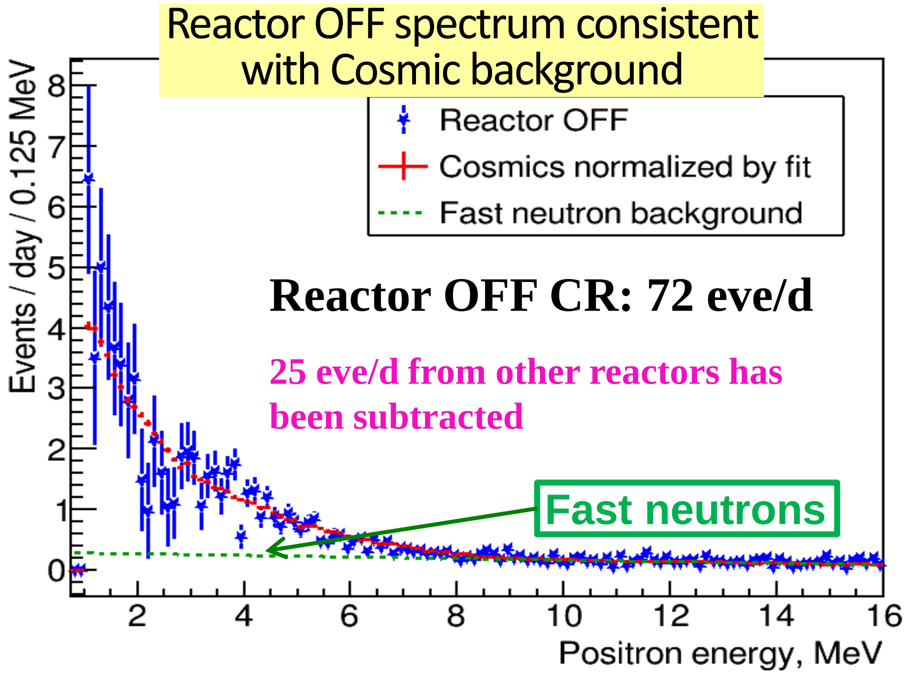
- ❖ **Accidental energy in event has been reduced from 100 keV to 5 keV**
- ❖ **Accidental background was suppressed from 71% to 29% (up position)**
- ❖ **Cosmic background is reduced from 2.8% to 1.9%**
- ❖ **Statistics has been increased from 0.97 to 2.1 million IBD events: old data (10/2016-07/2017) + new data (09/2017-01/2019)**
- ❖ **Sensitivity of experiment has been improved by a factor of ~1.4**
- ❖ **Energy resolution for calibration sources is still worse than in MC and additional smearing of 17%/√E has been added to MC (as in published results)**

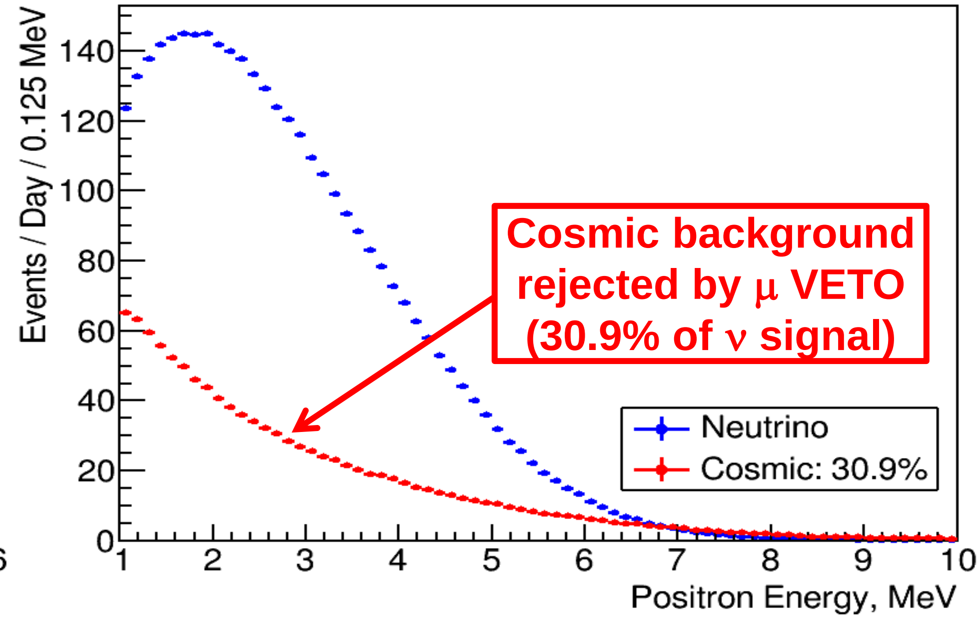
Accidental coincidence background



- Accidental coincidence of 2 uncorrelated signals (e+-like and neutron-like) in a IBD window [2-50] μs → accidental coincidence background (ACB)
- ACB spectrum is constructed directly from data applying the same physics cuts as for IBD signal except coincidence time taken outside IBD time window [2-50] μs in numerous non-overlapping intervals (large statistics is essential to decrease statistical errors of subtraction).
- ACB rate is ~29% of IBD rate (up detector position)
- Selection of cuts (e.g. geometric) to reduce ACB ⇒ smaller statistical errors

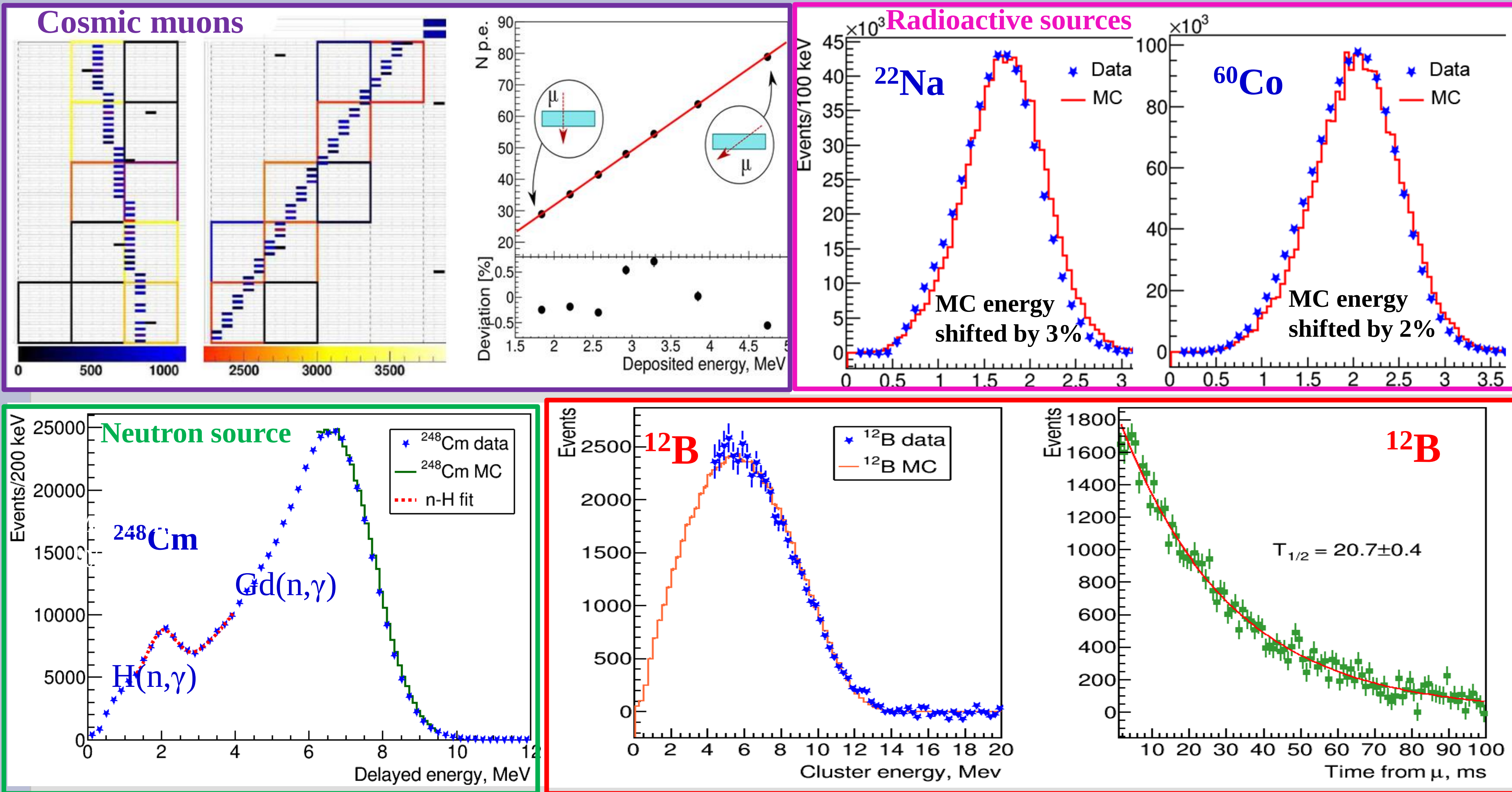
Subtraction of residual backgrounds





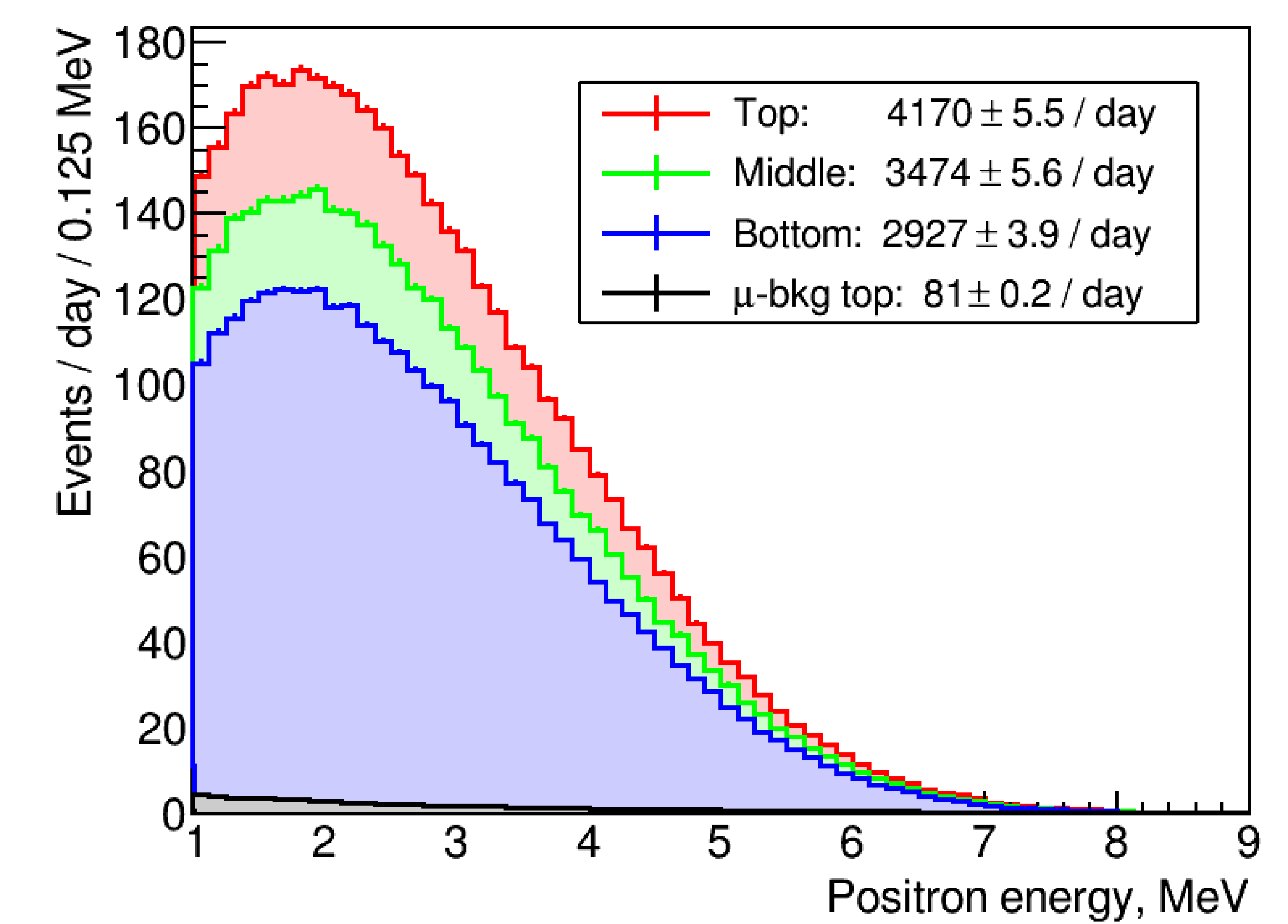
- **Fast neutrons**: linearly extrapolate from high energy region and subtract separately from positron and visible cosmic spectra
- **Visible cosmic background (CB)** has been directly rejected by VETO, it is 30.9% of neutrino signal (for up position)
- Additional CB presents in the IBD-signal due to VETO inefficiency, which was found to be 6.2% from reactor OFF spectra.
- **Not vetoed CB fraction** (due to VETO inefficiency) at level of ~1.9% (=6.2%*30.9%) of IBD-signal has been subtracted from IBD signal (positron spectrum).
- **Final anti-neutrino spectrum (Ee^+ + 1.8 MeV) has no background!**

Calibrations



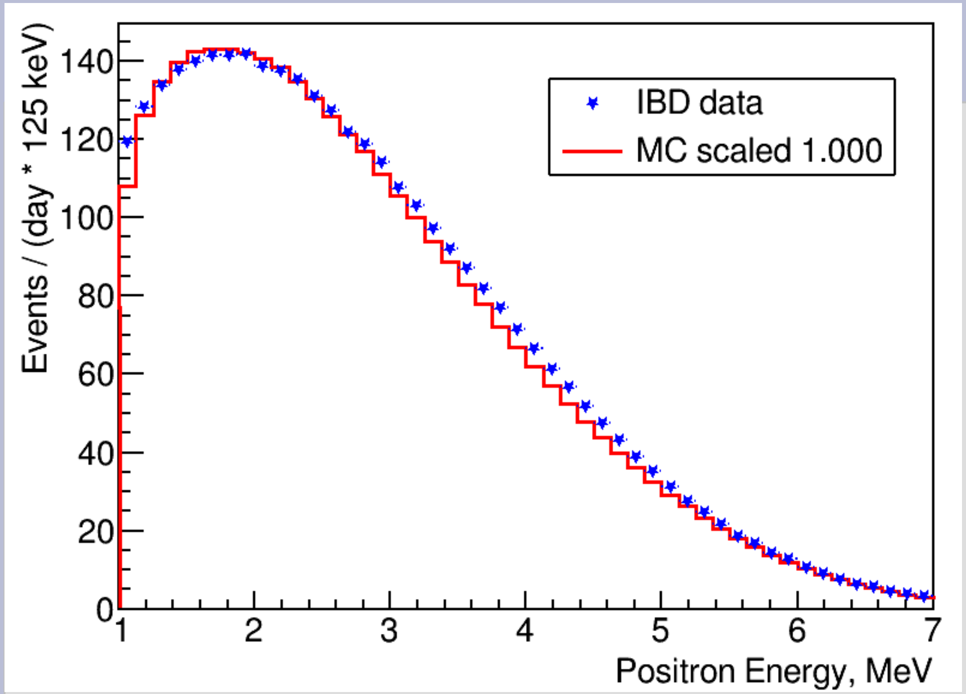
- Energy scale has been fixed using β-spectrum of ^{12}B, which is similar to positron signal
- Systematic error on E scale of +/-2% has added due to source response uncertainties

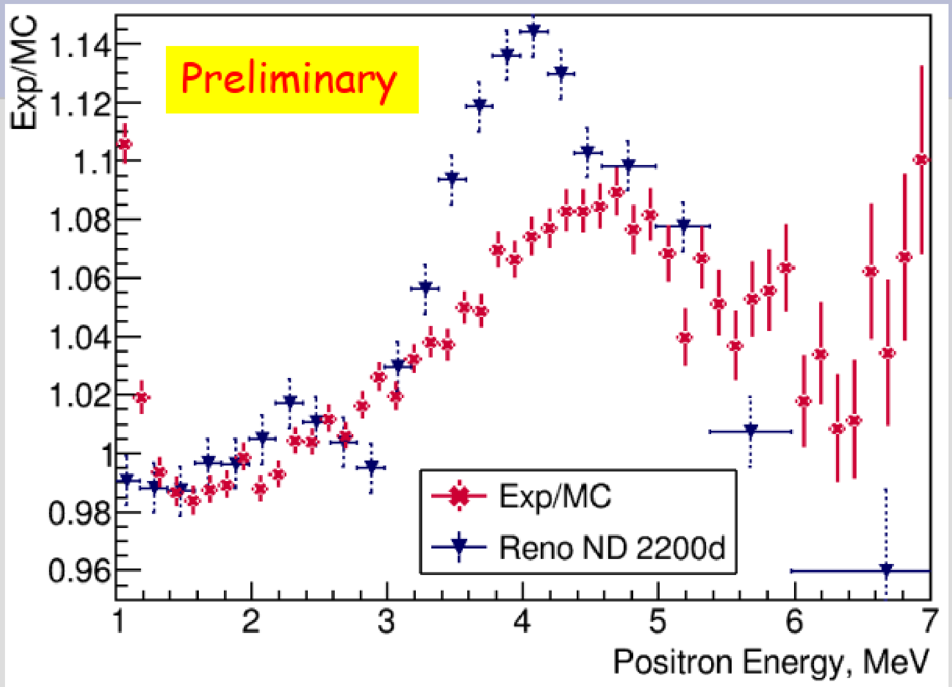
Positron spectrum of IBD-signal



- **Pure positron spectra @ 3 positions (no annihilation photons)**
- **> 4000 eve/d in detector fiducial volume (78% of full volume) @ 'Up' position (closest to the reactor).**

Positron spectrum: experiment vs. theory

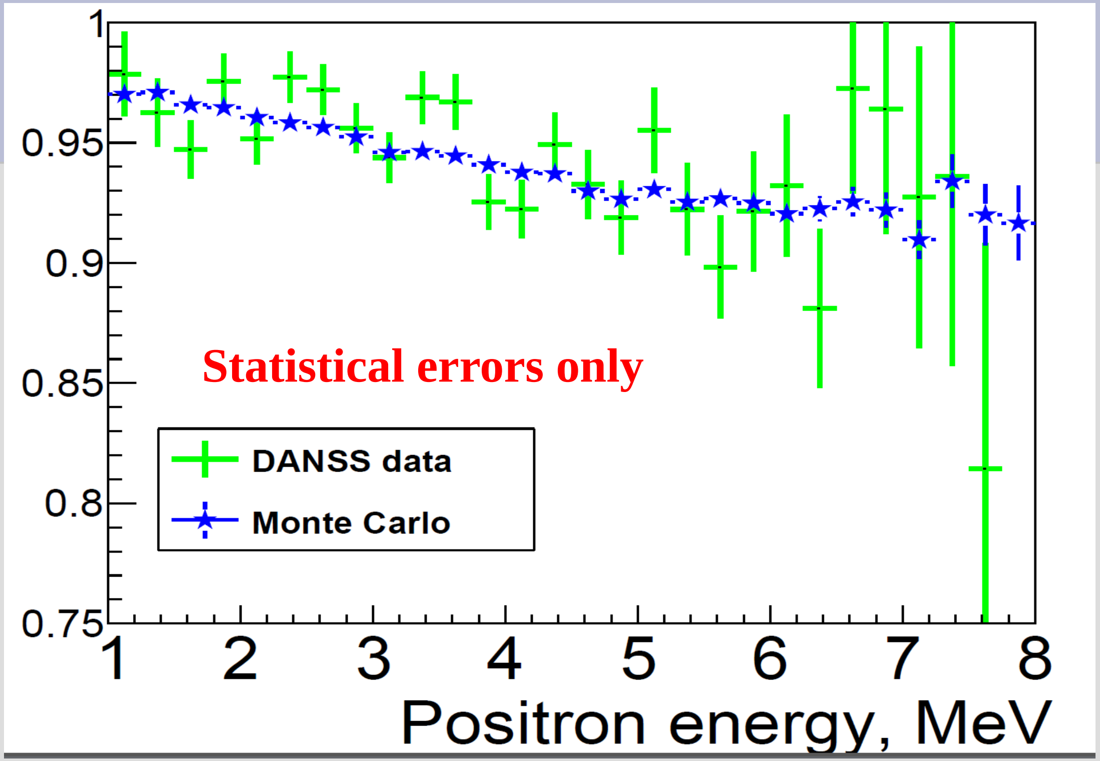




- Experimental spectrum is in rough agreement with MC using Huber-Muller theoretical neutrino spectrum.
- Indication of a bump (normalization in 1.5-3 MeV), but no conclusion on the bump existence now due to strong sensitivity to energy scale.
- More work on calibration is required before precision comparison.

Sensitivity to fuel composition

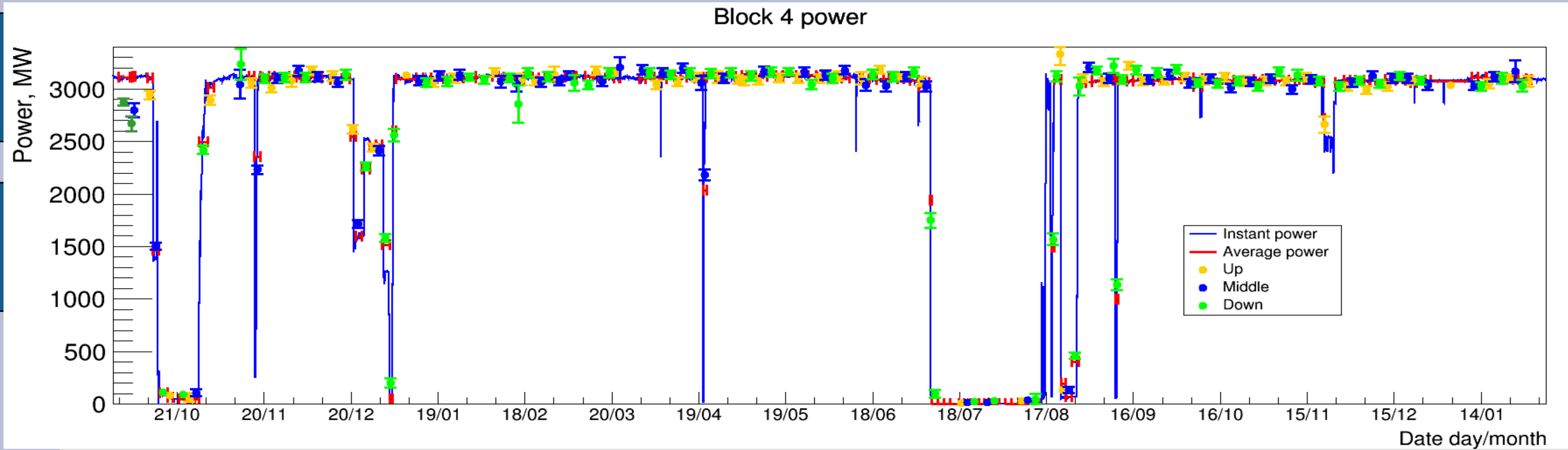
- The figure shows the ratio (bin per bin) of the e^+ energy spectrum collected in the last 4 months of the campaign to the one collected in the 2-5 months of the next campaign.
- Clear evidence for spectrum evolution, which is consistent with MC.
- Result is for old + fraction of new data. For full data set more work is needed for absolute efficiency calibration of the new data (not important in oscillation analysis).



Fission fractions [%]

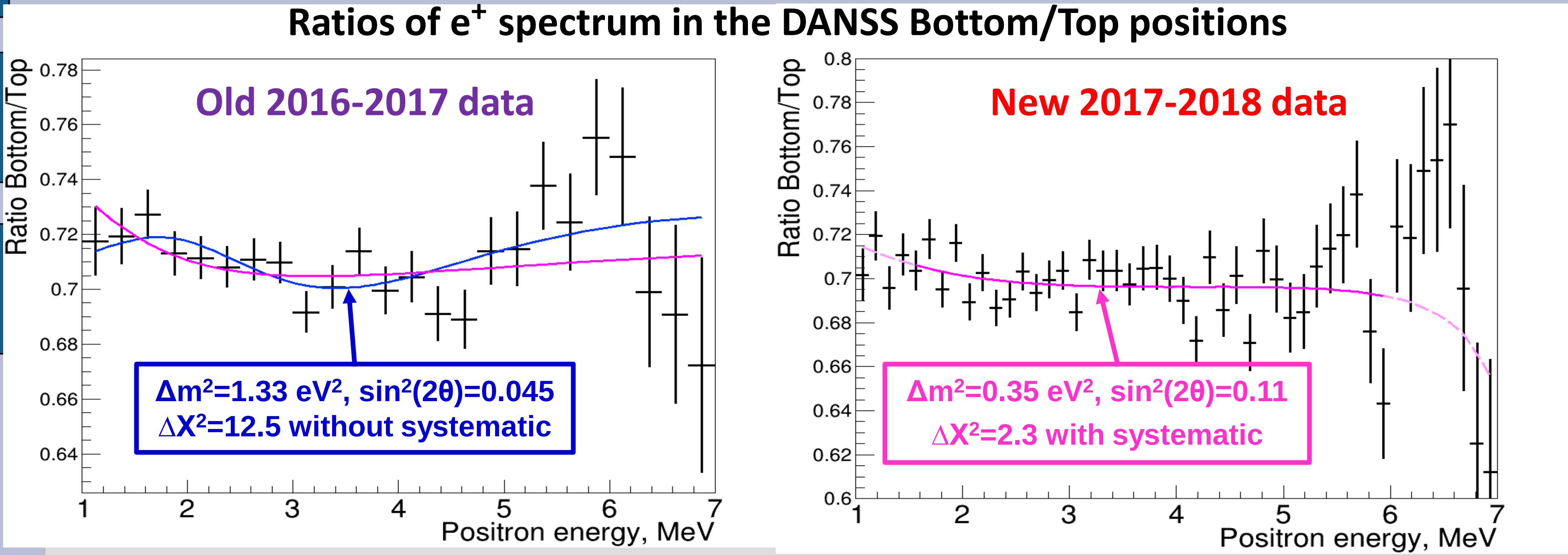
	^{235}U	^{238}U	^{239}Pu	^{241}Pu
End	45.8	7.7	38.3	7.9
Start	61.7	7.1	28.0	3.1

Reactor power monitoring



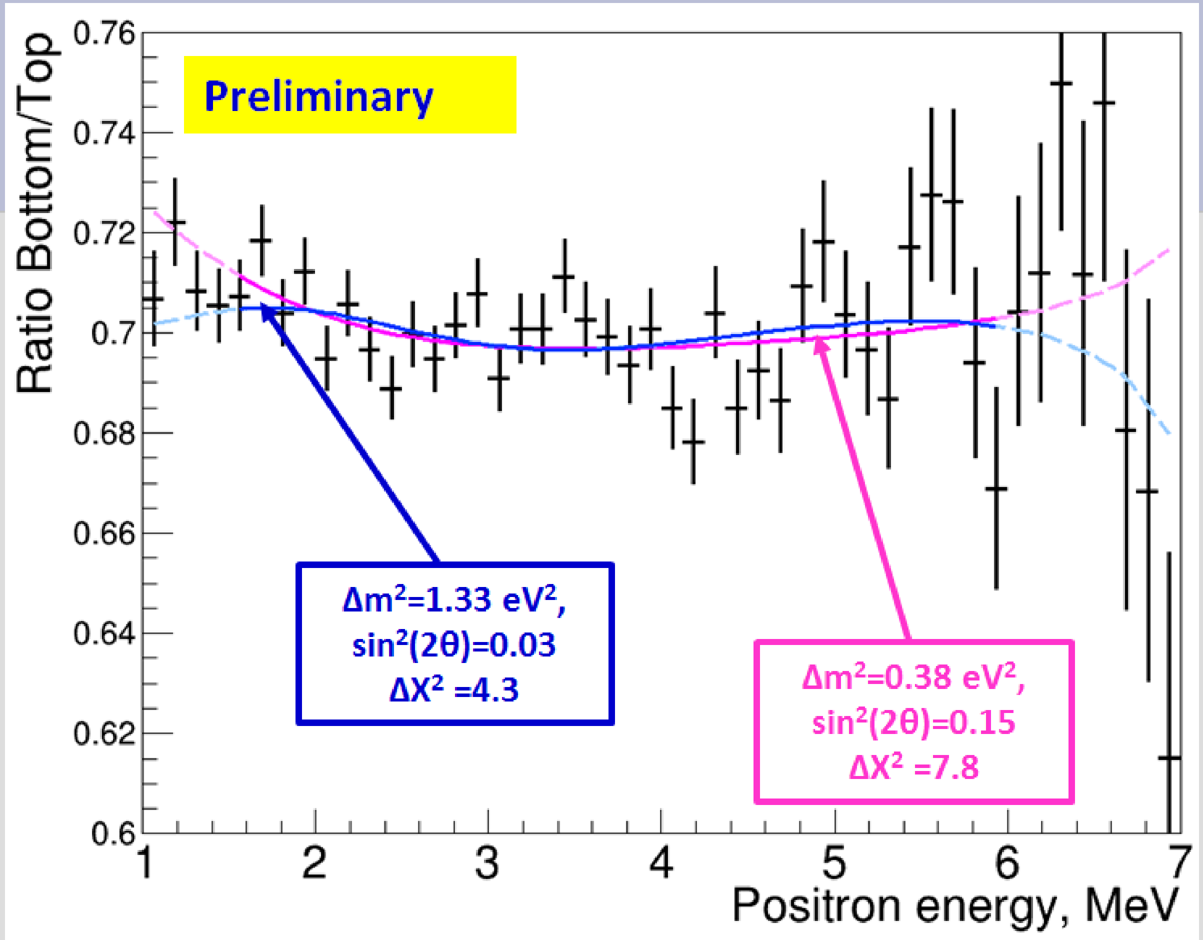
- Points at different positions equalized by $1/r^2$; normalization by 12 points in November-December 2016
- Cosmics and adjacent reactor fluxes (0.6%) has been subtracted; spectrum dependence on fuel composition has been included
- Reactor power is measured by the DANSS with neutrino flux with 1.5% accuracy in 2 days
- Result is for old + fraction of new data. For full data set more work is needed for absolute efficiency calibration of the new data (not important in oscillation analysis).

The DANSS: new vs. old results



- **In the first data (2016-2017) 4ν hypothesis had smaller X^2 than 3ν one ($\Delta X^2=12.5$).**
- **This triggered a lot of excitement in the field although we clearly stated that significance of this difference would be studied taking into account systematics after collection of more data.**
- **On the new statistics 2017-2018 (1 million events) we see no indication of 4ν signal ($\Delta X^2=2.3$ for 4ν hypothesis).**

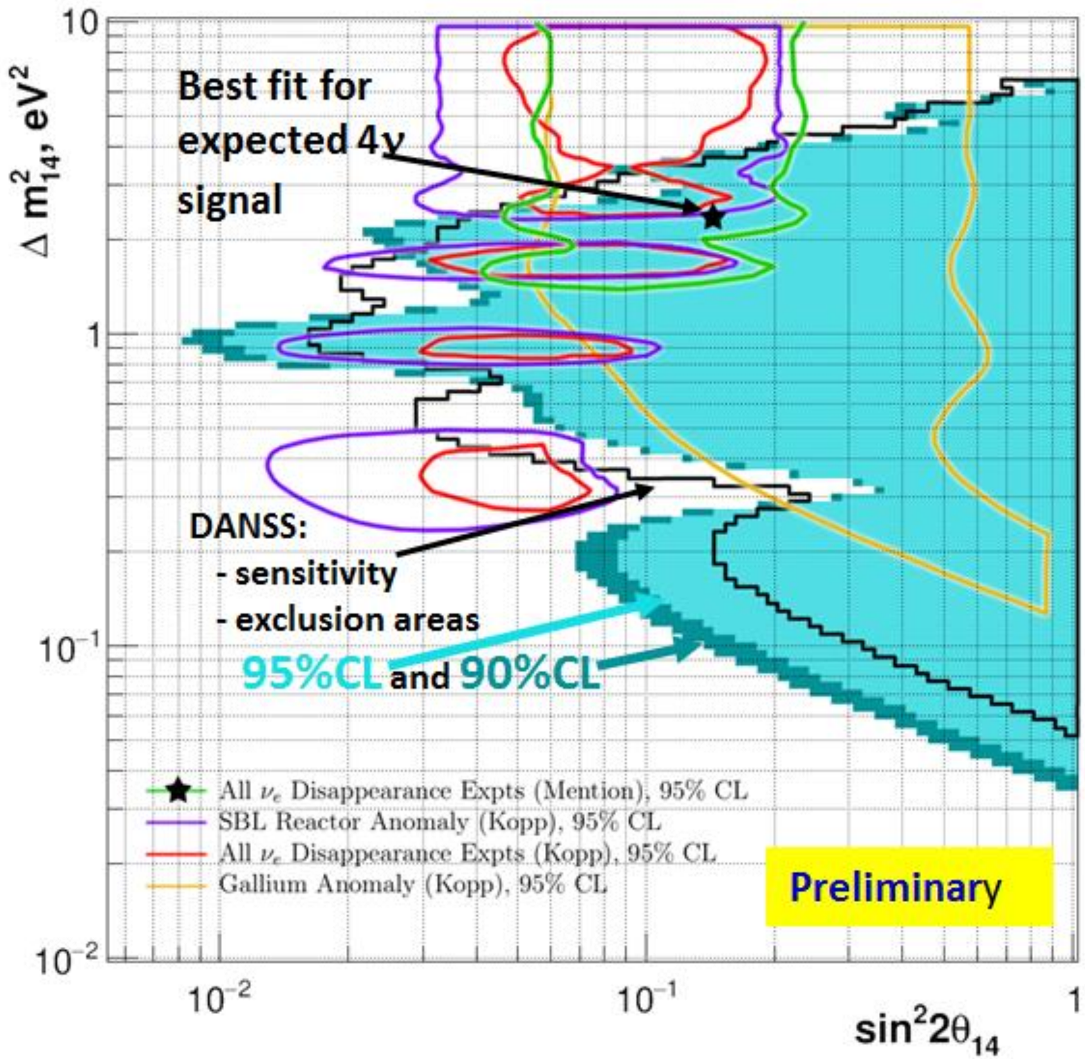
The DANSS: result with full dataset



- The best 4ν point (Δm^2=0.38 eV^2, $\sin^2(2\theta)$=0.15, ΔX^2 =7.8) has CL of 1.8σ: **no statistically significant sign of the sterile neutrino effect.**
- Best point in old data (Δm^2=1.33 eV^2) is also shown.

The DANSS: sensitivity plot

- Exclusion region was calculated using Gaussian CLs method (for e^+ in 1.5-6 MeV to be conservative), which is also more conservative than usual CI method.
- Systematics included:
  - Energy resolution +/-10%
  - Energy scale +/-2%
  - Cosmic background +/-25%
  - Flat background +/-30%
- Systematics influence is small, results of our method are independent from shape of ν-spectrum and detector efficiency.
- New data allowed to extend excluded area of 4ν phase space in comparison with old results published in 2018.

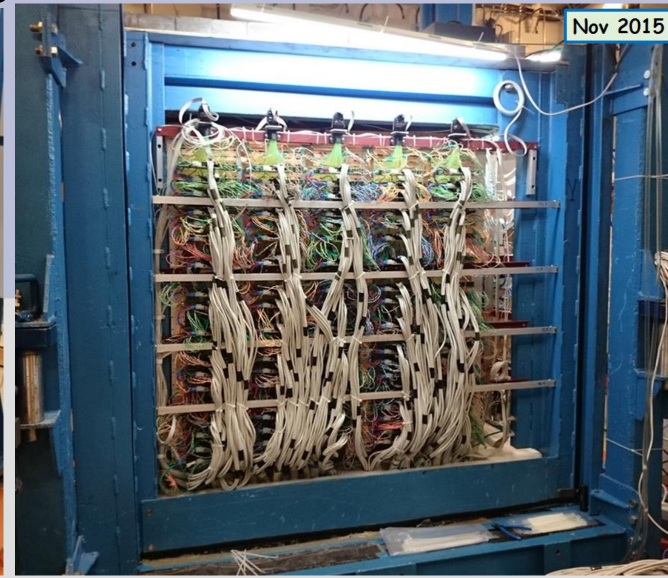


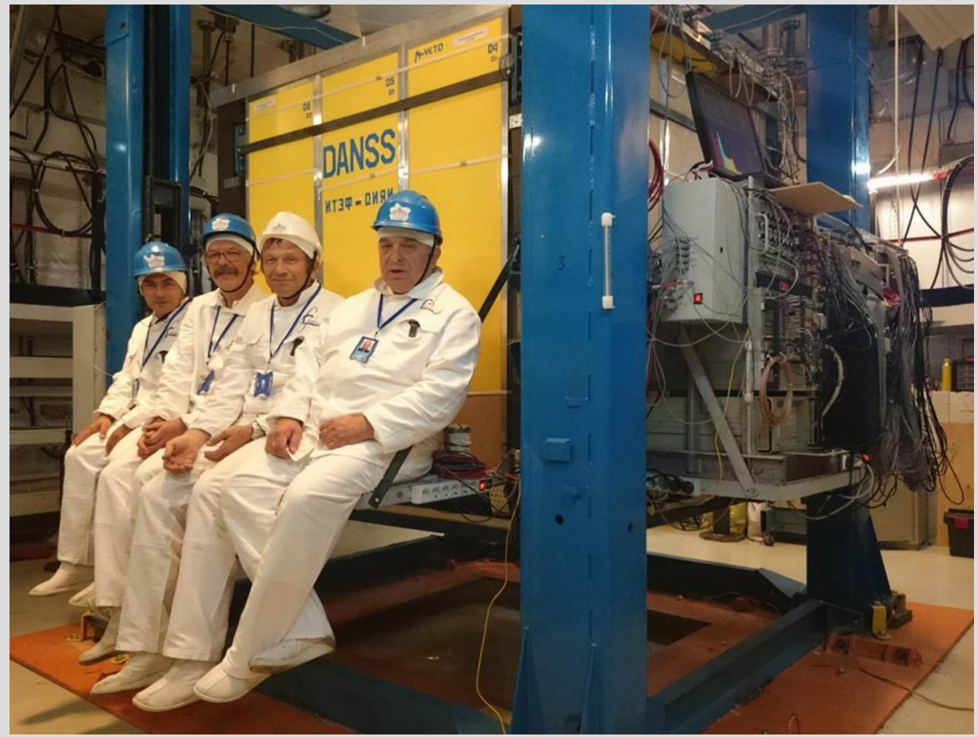
Summary

- DANSS is in operation since April 2016 with regular (physics) data taking since October 2016 at a rate of ~4000 events per day with cosmic background ~ 1.7%.
- Antineutrino spectrum and counting rate dependence on fuel composition is clearly demonstrated.
- Reactor power was measured using anti-ν rate with statistical error of ~1.5% in two days during > 1 year of operation.
- With doubled data set we have no sign of sterile ν oscillations.
- Preliminary DANSS analysis (based on 2 million statistics) excludes a large fraction of available parameter space for sterile neutrino using only ratio of e^+ spectra at two distances. This method is independent from shape of ν-spectrum and detector efficiency (+ small systematics influence).
- Future plans: further improvements of MC & calibrations; detector upgrade; precision comparison of ν spectra with theory (bump problem).

Backup slides

Detector Assembly



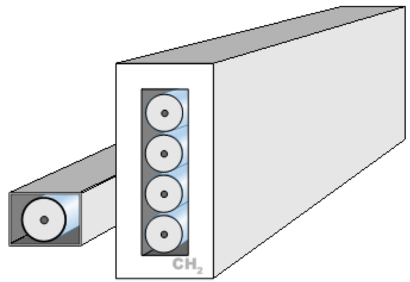


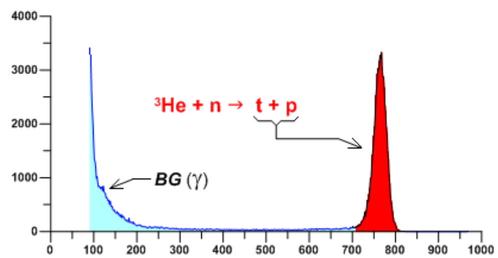
Background monitoring

- **Permanent monitoring of gamma-BG with four NaI (3’x3’): 1 inside + 3 outside the DANSS shield**

  no (ON – OFF) visible difference

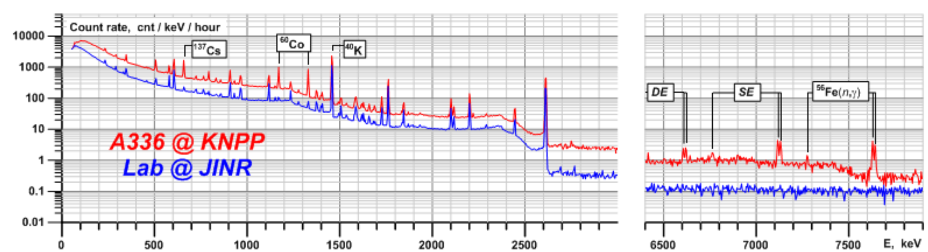
- **Permanent monitoring of neutron flux with three ^{3}He neutron counters: 1 inside + 2 outside the shield**

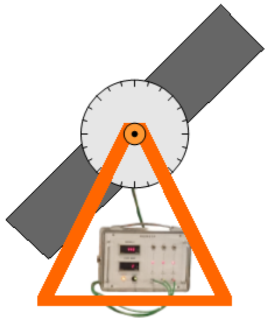


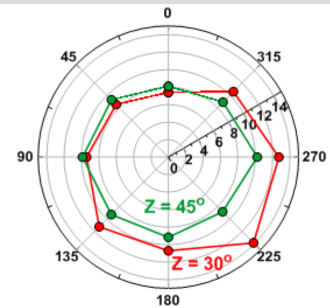


Φn =	0.57	outside (OFF)
Φn =	300.4	outside (ON)
Φn =	0.03	inside (OFF)
Φn =	0.04	inside (ON)
Φn =	6.0	en plein air

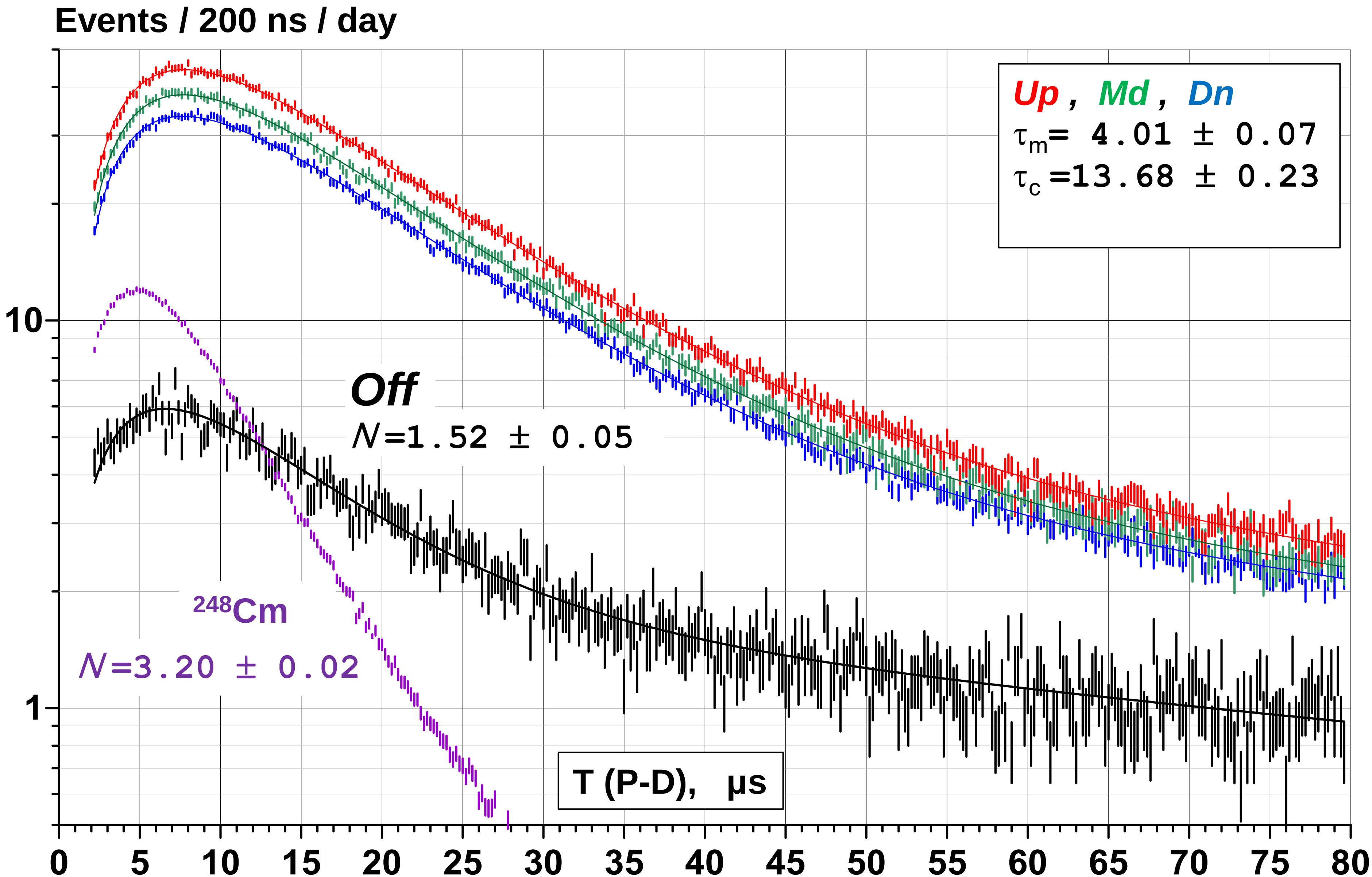
- **Episodic measurements with HPGe and “MuMeter”**



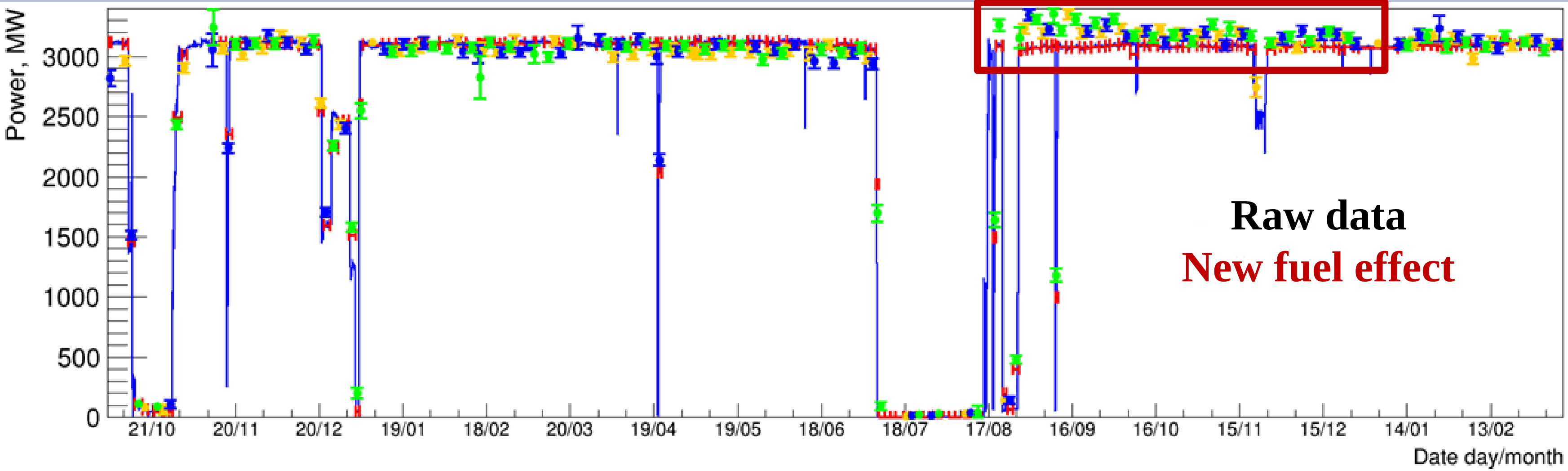


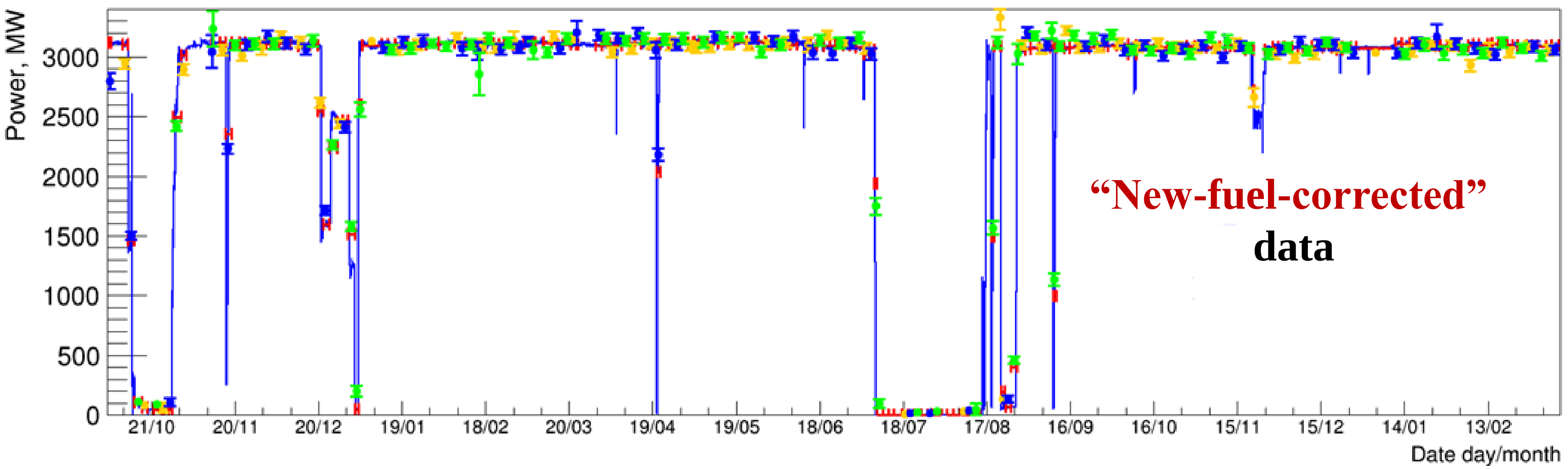


Time distribution spectra (PMT only)



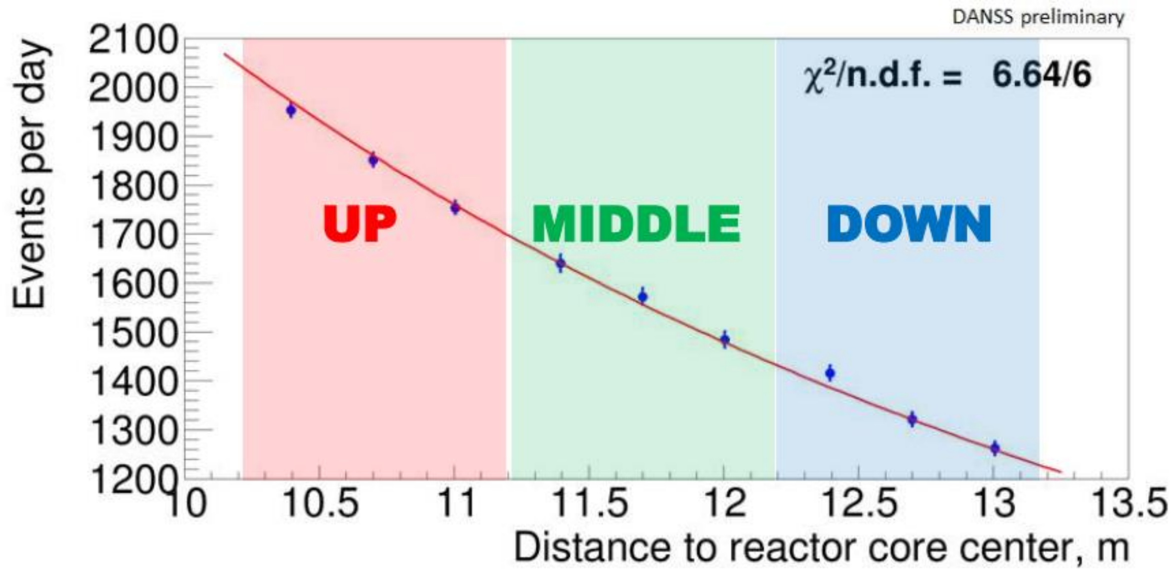
Reactor monitoring: Up – Middle – Down data

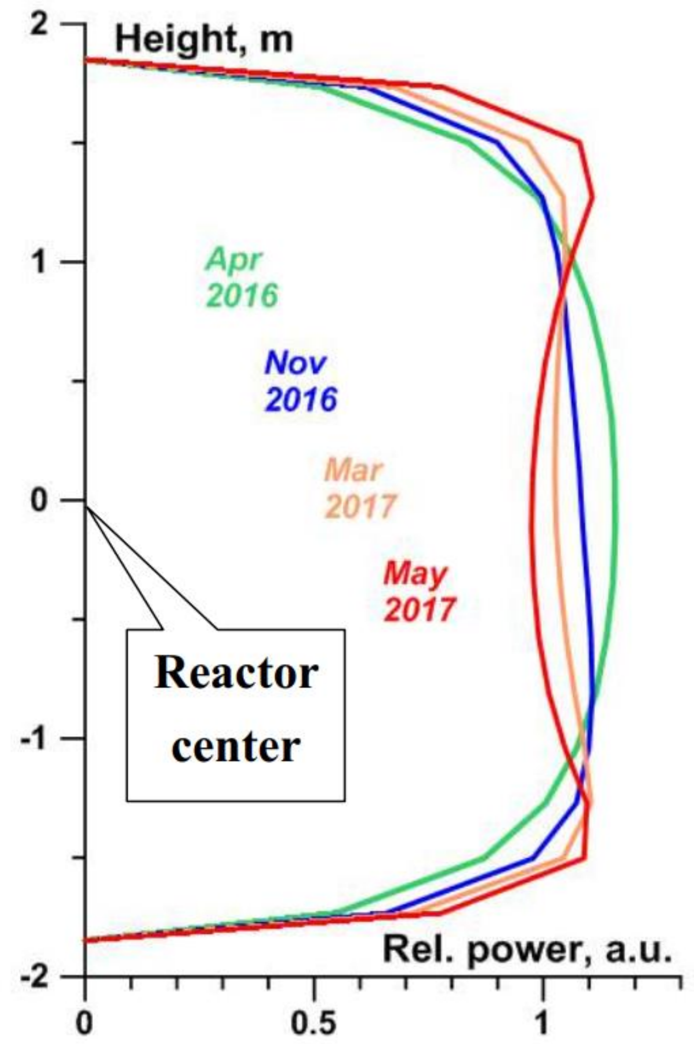




- **The DANSS is constantly monitoring reactor since October 2016.**
- **We are sensitive to the fuel composition (U-Pu content in fuel)**

IBD total rate vs. effective distance





Time evolution of the core burning profile

- **IBD intensity follows reasonably the 1 / L^2 dependence.**
- **Effective distance L takes into account real spatial distribution of the detection efficiency and the reactor core burning profile (monitored permanently by the KNPP staff) .**
- **The time variation of reactor core burning profile is available with a precision of 30 min and ~10 cm.**
- **Average core burning profile has been used in analysis, and it has negligible effect for the results.**