Status of the DANSS project: in pursuit of a light sterile neutrino

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Motivations for the DANSS experiment

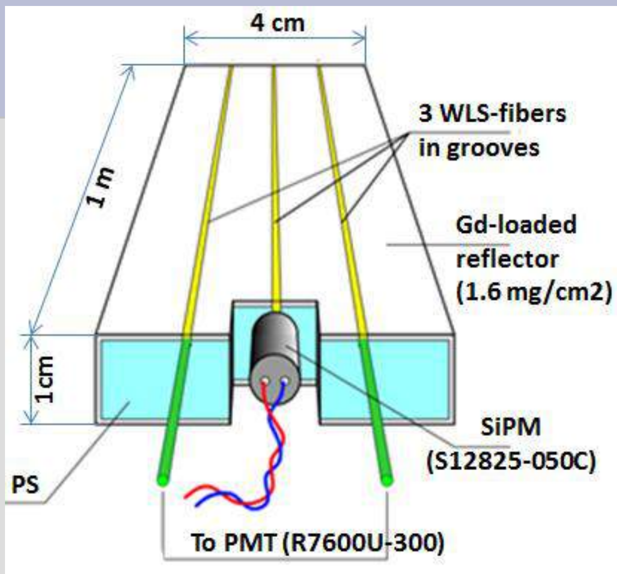
Detector of the reactor AntiNeutrinos on Solid Scintillators

- **Fundamental physics**
  - Probe of SBL reactor antineutrino oscillations to the sterile state.

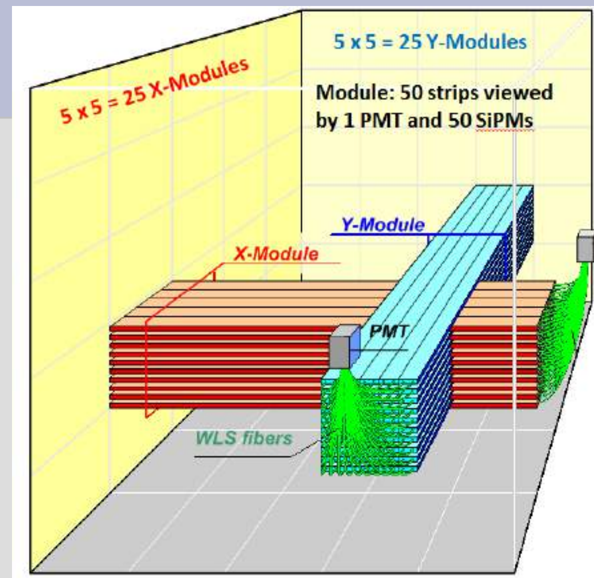
- **Applied physics**
  - On-line reactor monitoring by measuring the reactor power.
  - Nonproliferation of nuclear materials by monitoring Pu/U ratio from precise measurement of antineutrino energy spectrum.

The DANSS design

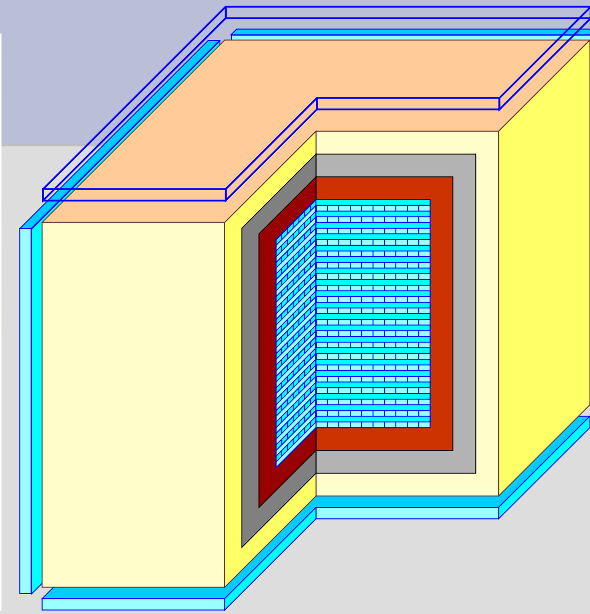
Single detection strip



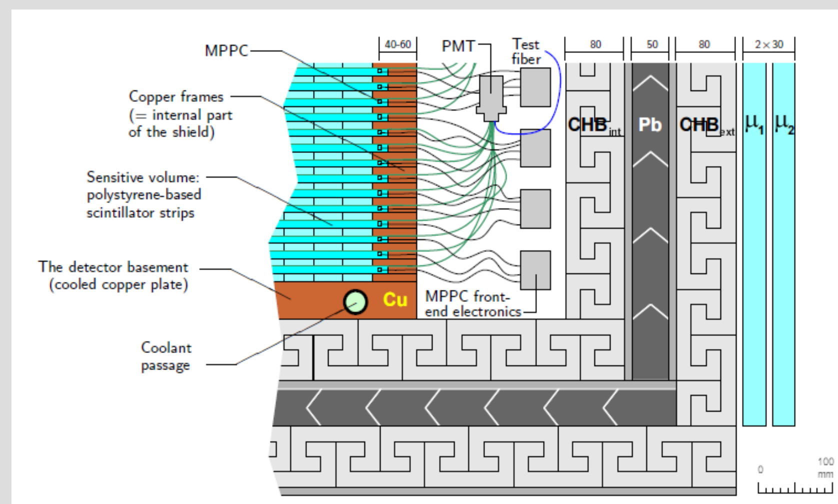
Modules



Detector in shield

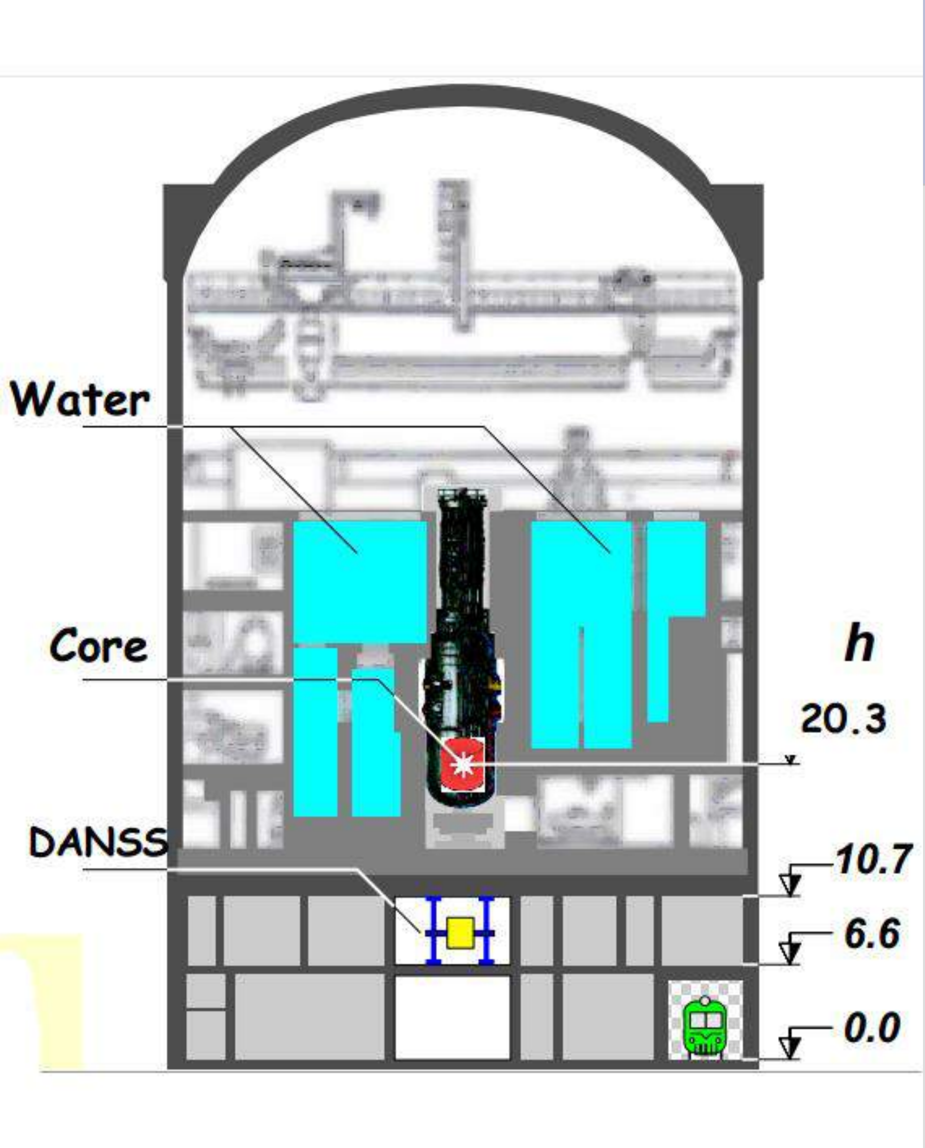


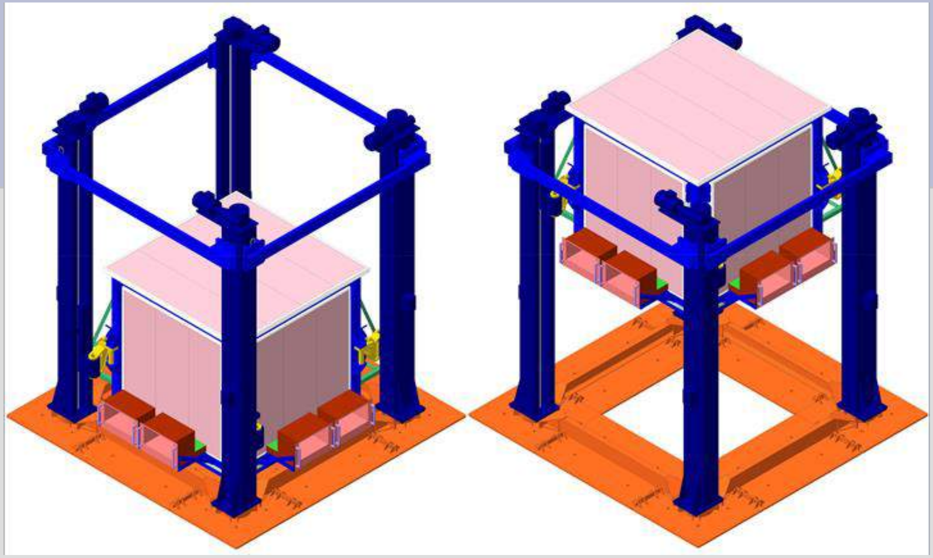
- Cubic meter highly segmented neutrino spectrometer made of 2500 PS strips viewed by 2500 SiPMs & 50 PMTs.
- Multilayer passive shielding: Cu/CHB/Pb/CHB=5/8/5/8 cm
- Active muon veto made of 2 x 3 cm PS plates from 5 sides.



Shield

Location of the detector

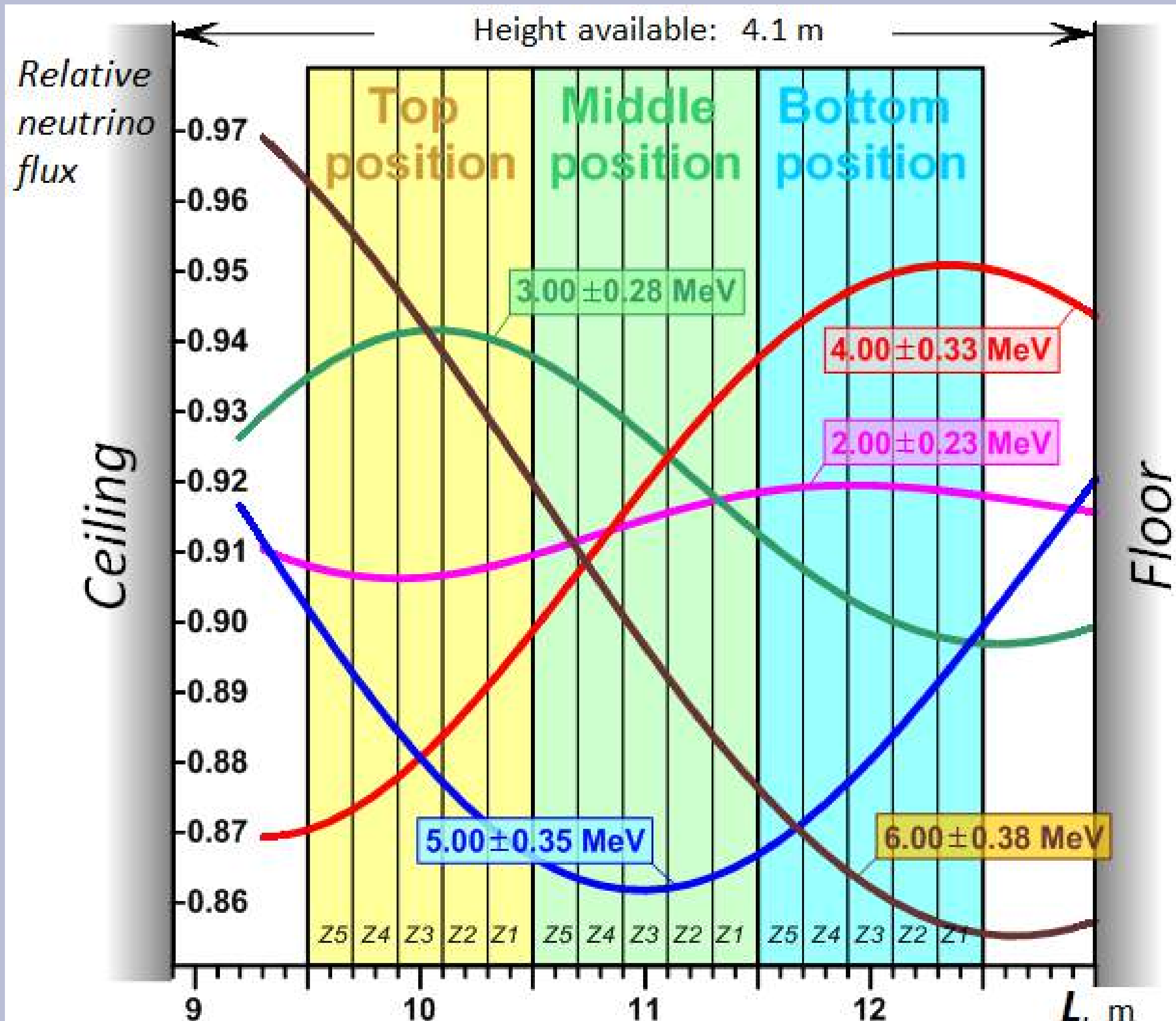




The DANSS is located at Kalininskaya NPP (KNPP) under 3GW WWER-1000 reactor (H=3.6 m, ∅=3.1 m), which provides ~ 50 m.w.e. shield against cosmic muons (6-fold muon reduction and no cosmic neutrons).

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.

Expected oscillation patterns



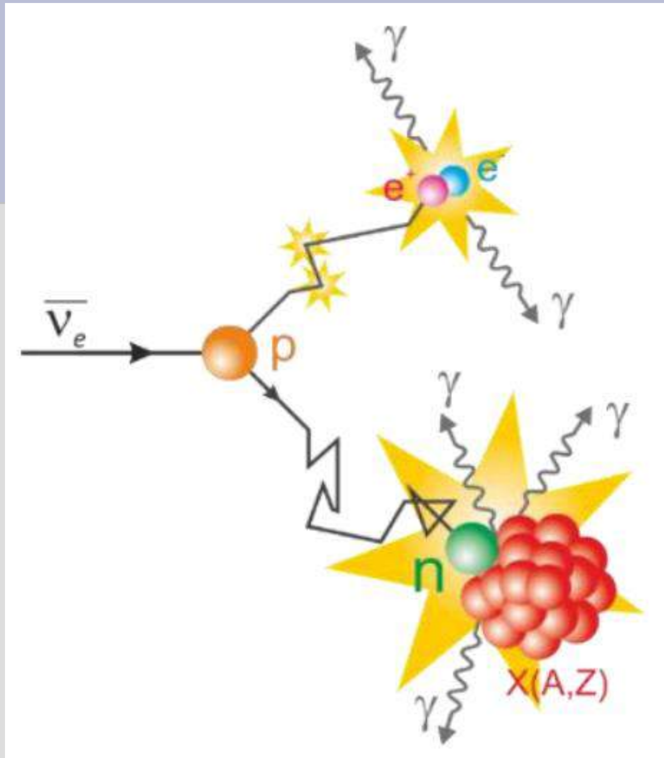
Antineutrino fluxes for different energies on DANSS in the case of oscillations to the sterile state (3+1 model)

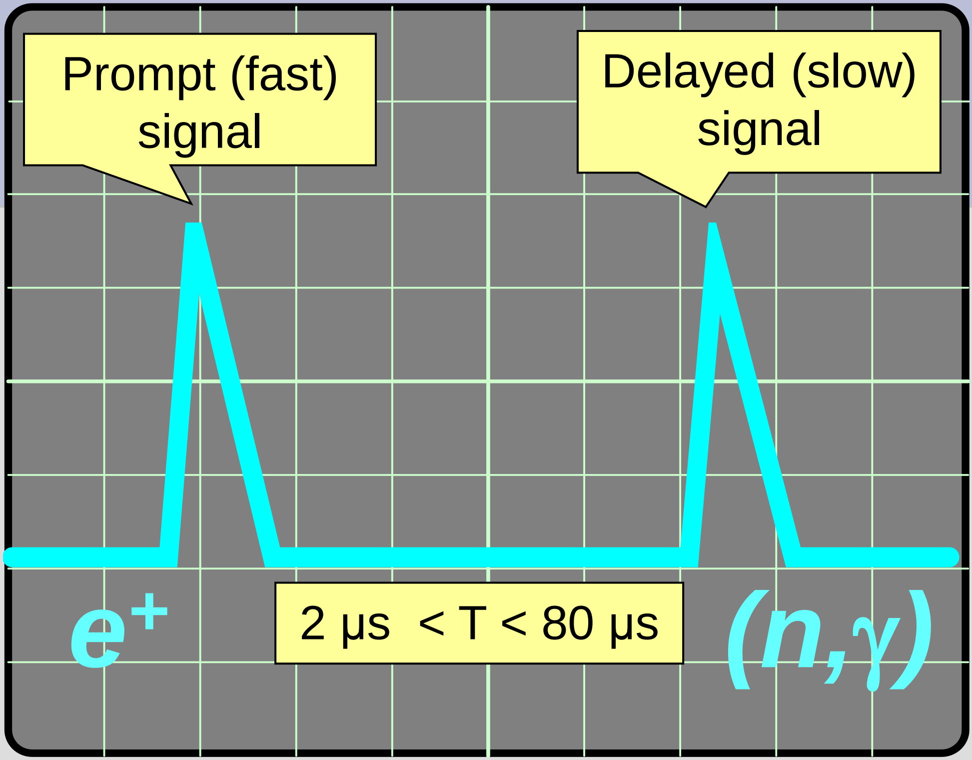
We are looking for the ratios of spectra measured at different detector positions, which should oscillate in the case of coupling to the sterile neutrino.

This method is insensitive to crucial systematics:

1) **Shape of antineutrino spectrum**
2) **Detector efficiency**
3) **Long term time variations (instability) of experimental conditions**

IBD signal pattern and cuts





Main cuts (maximally relaxed):

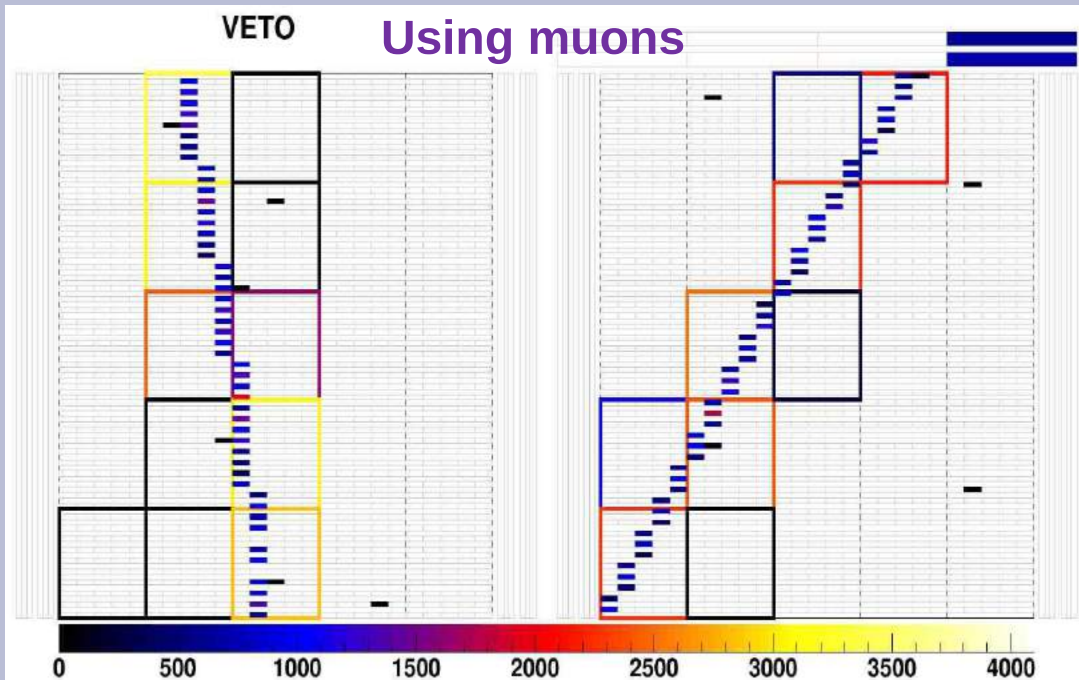
- **Prompt signal E > 0.7 MeV**
- **Delayed signal**
- **Time between signals is in [2, 80] μs**
- **No muons before prompt signal in ≥ 60 μs**

Additional cuts:

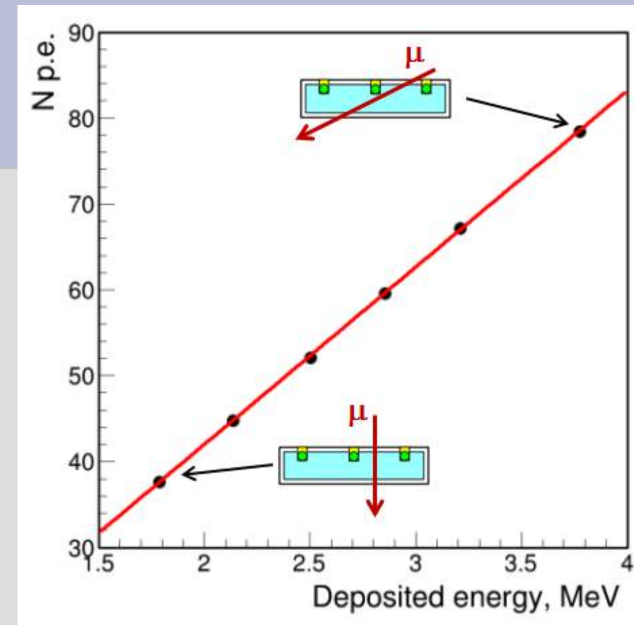
- **Hit multiplicities for both signals**
- **Positron clustering pattern cuts**
- **Spatial cut on distance between fast and slow signal vertexes**

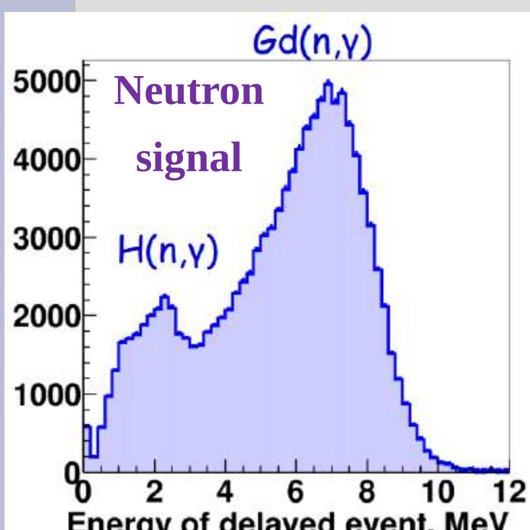
Work is in progress to find optimal combination of IBD cuts

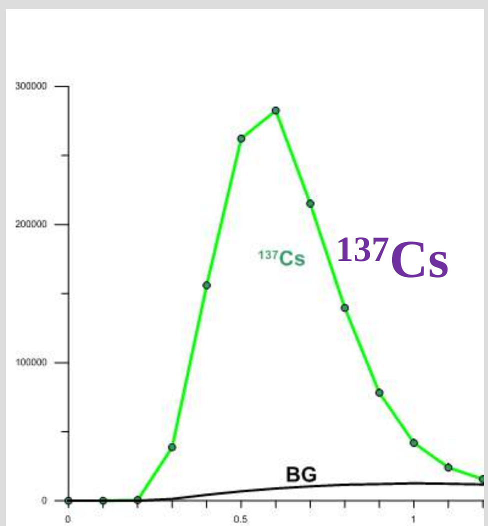
Energy calibrations

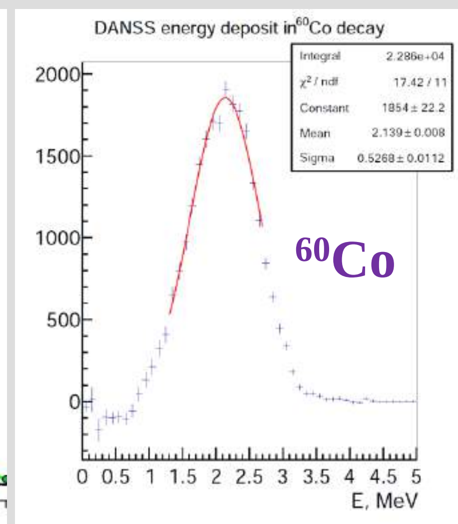


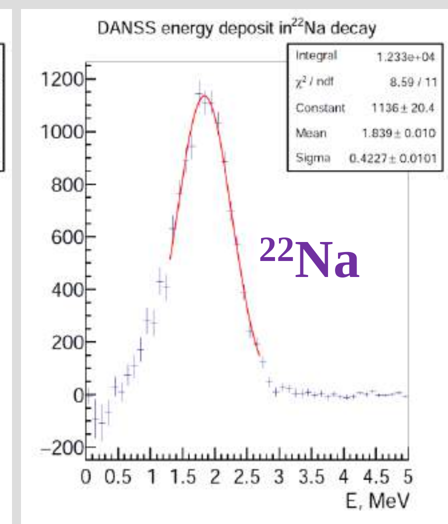
Linearity from μ data



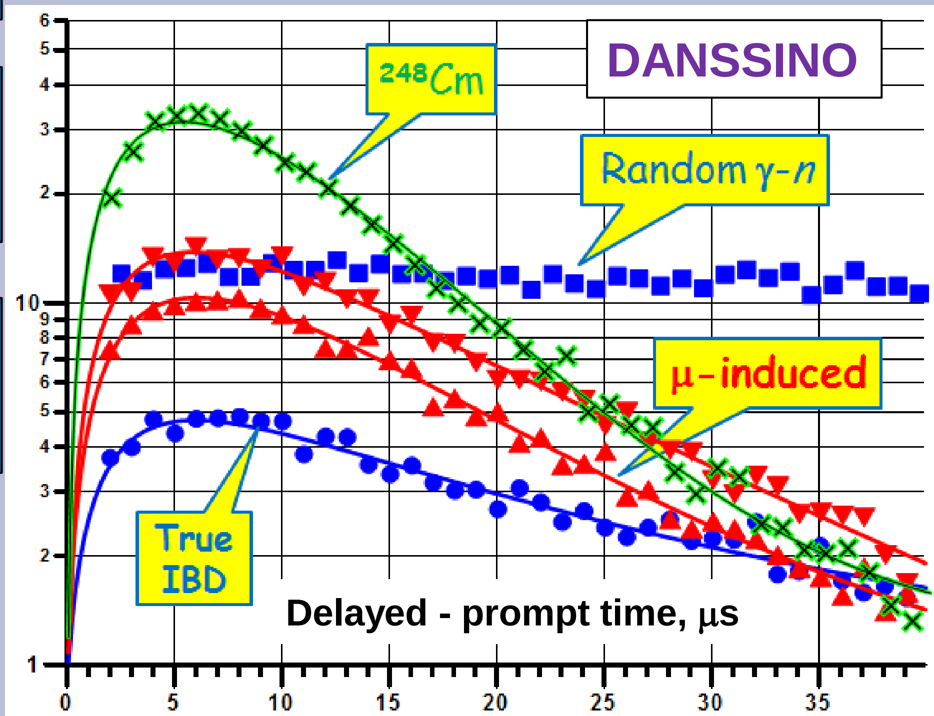


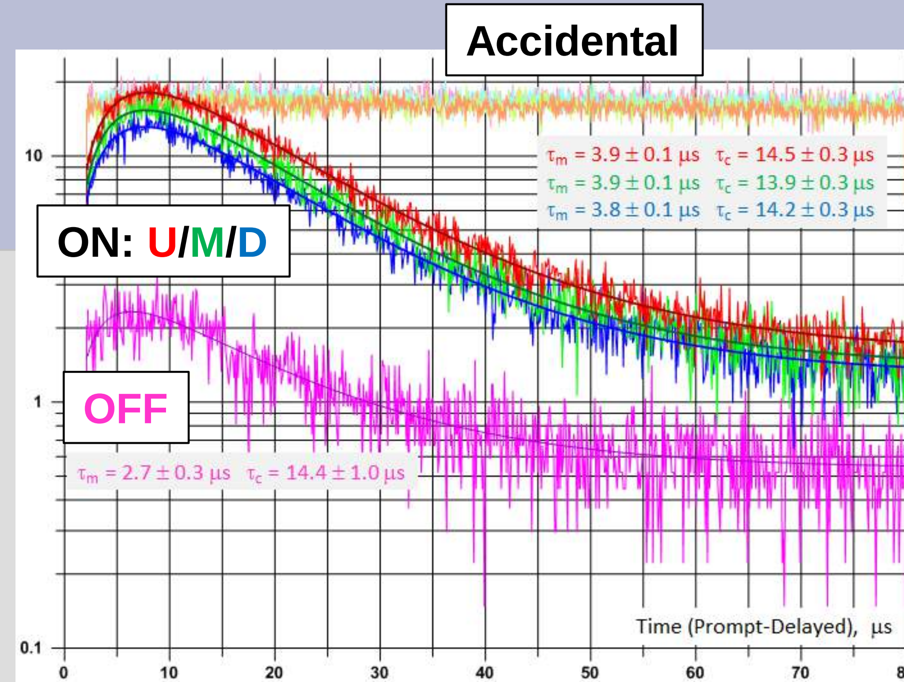






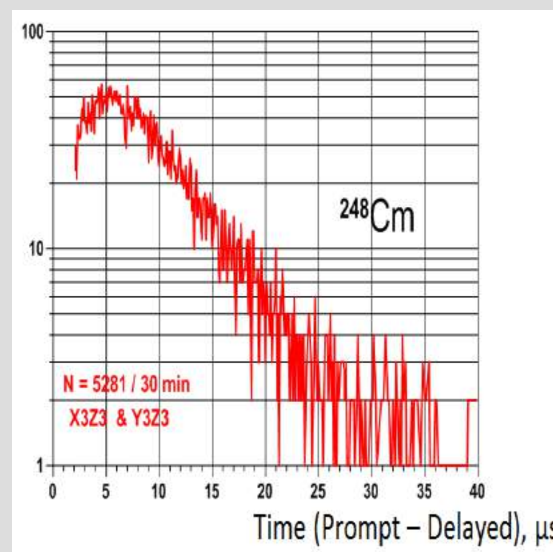
Time calibrations



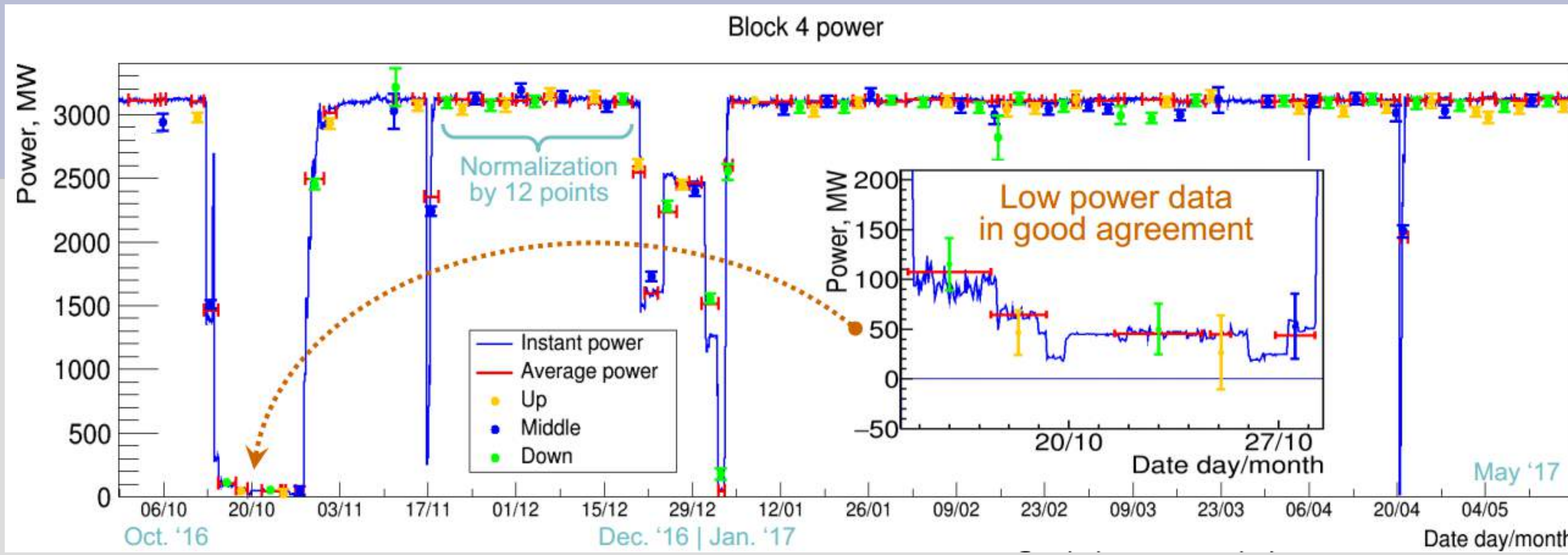


Different processes have different time curves, tagged by the detector (left up fig. - DANSSINO data).

Reactor ON IBD time curves don’t depend on detector position, but differ from reactor OFF IBD-like background as well as from neutron source measurements (right figures - DANSS data).

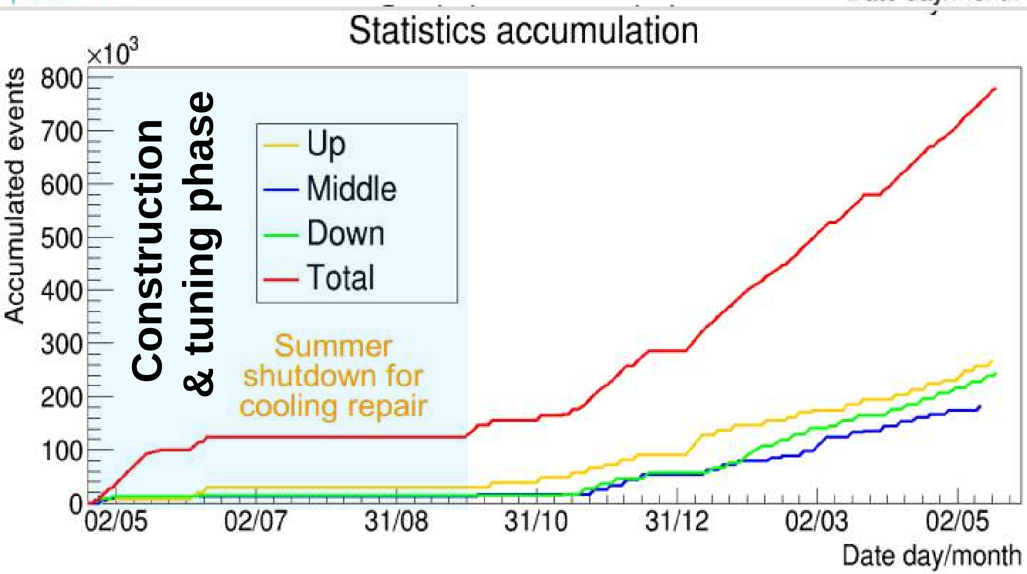


Detector performance & reactor monitoring

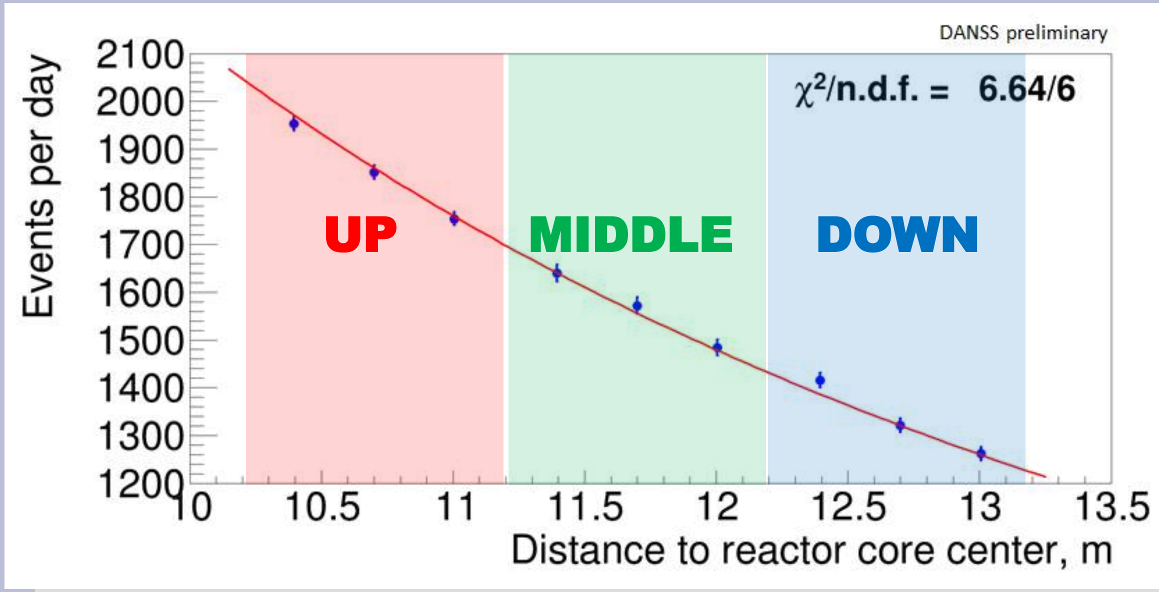


IBD flux measured by the DANSS perfectly matches the actual reactor power timetable, reported by the KNPP. So, the DANSS is really monitoring the reactor power since October 2016.

Statistics accumulated:
Reactor ON @ 100%: ~170 days
Reactor OFF: 13 days (problem)



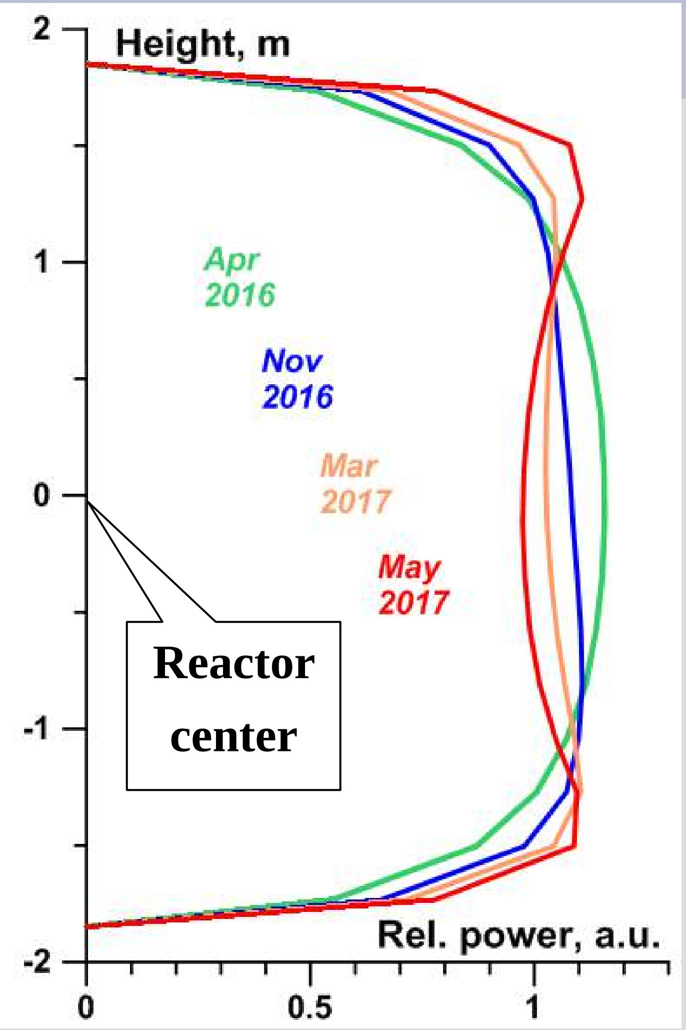
IBD total rate vs. effective distance



IBD flux follows perfectly the $1/R_{EFF}^2$ dependence.

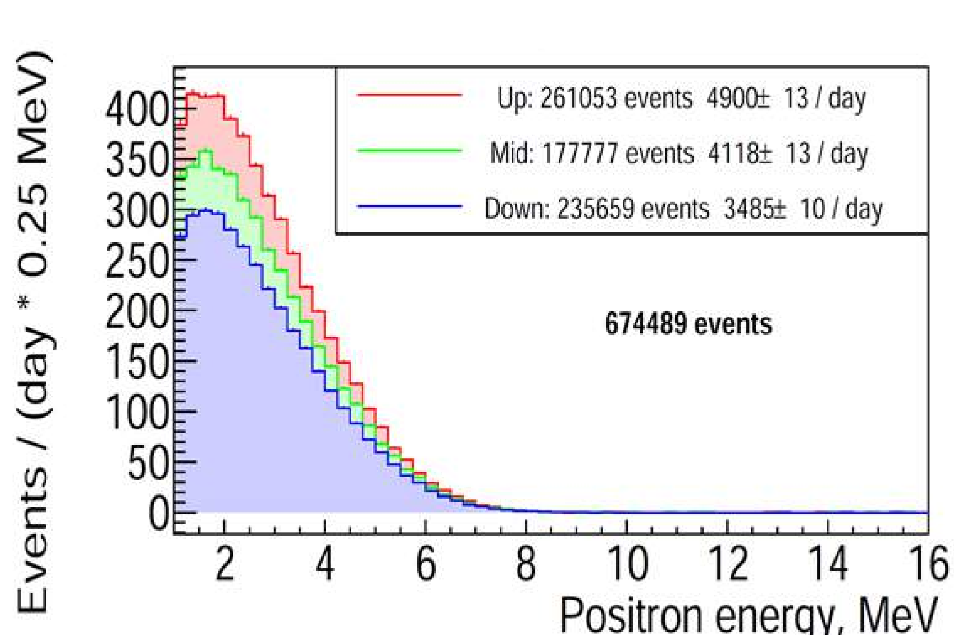
Effective distance R_{EFF} takes into account real spatial distribution of detection efficiency and the reactor core burning profile, which is monitored permanently by the KNPP (see the right figure).

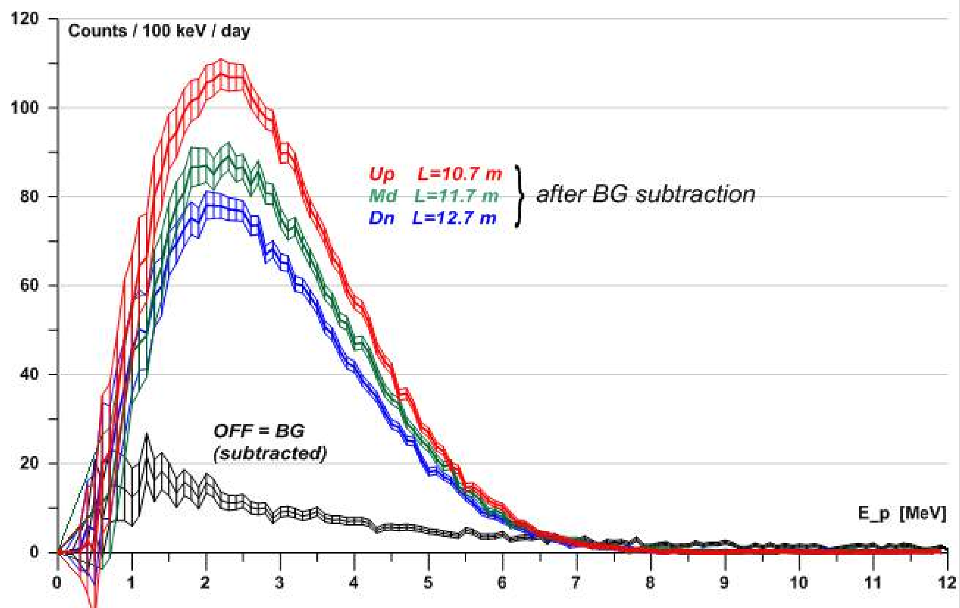
The time variation of reactor core burning profile has been also taken into account in sensitivity estimations.



Reactor core burning profile vs. time

Positron spectra





Prompt energy spectra of IBD-events produced in two independent analysis made by ITEP and JINR. Different analysis – close results, which is additional result consistency check.

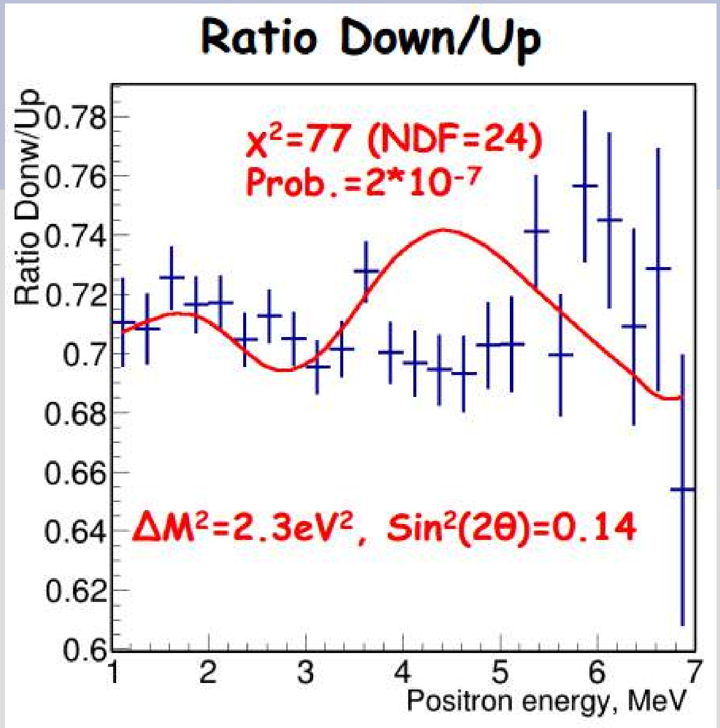
About 5000 IBD events/day.

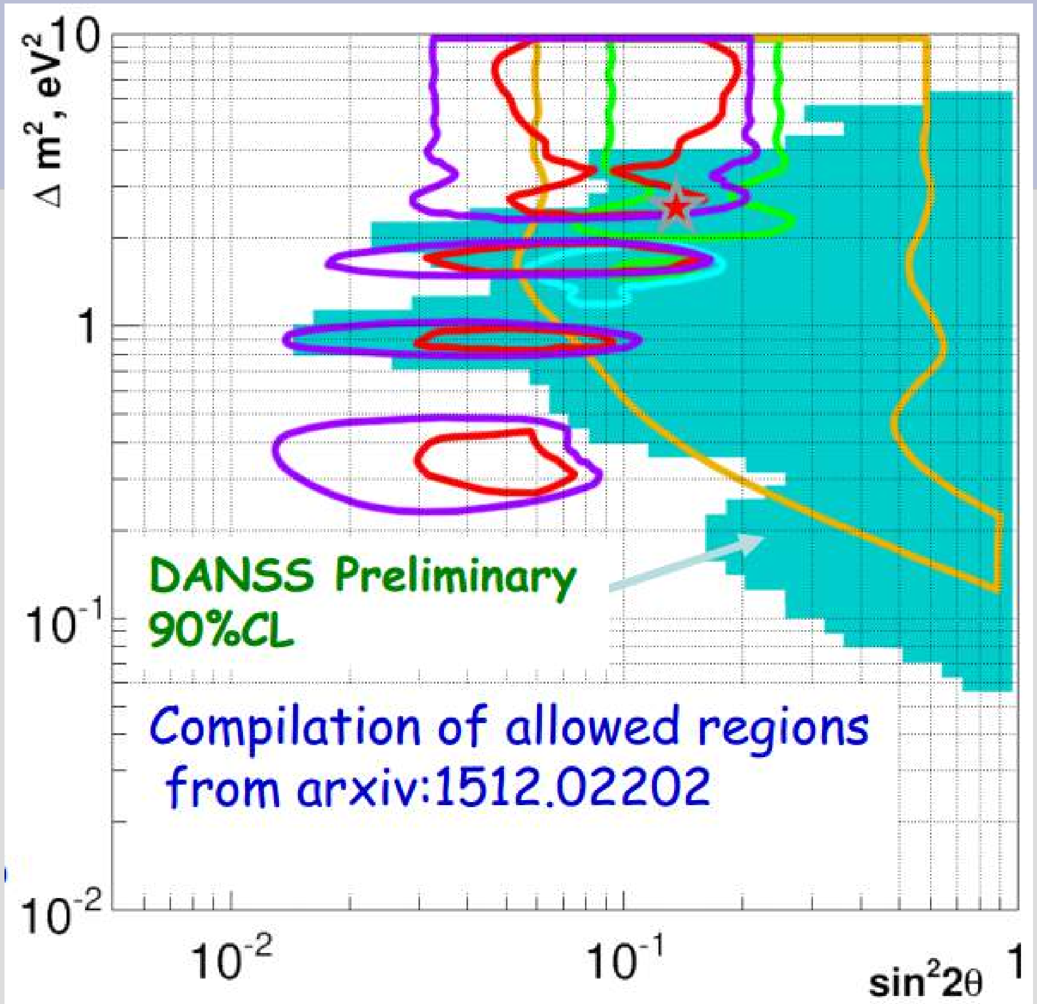
Reactor OFF data are independent on detector position. Most probably it originates from fast neutrons produced by cosmic muons in surrounding materials.

Lack of Reactor OFF data is largest systematics at the moment.

Since 8/07/2017 the reactor is OFF for 50 days due to scheduled fuel re-loading happened once per 1.5 years. Crucial period for us, as we are taking reactor OFF data, which will allow us to decrease uncertainties dramatically. So far, so good, fingers crossed…

Oscillation sensitivity: preliminary results from portion of data

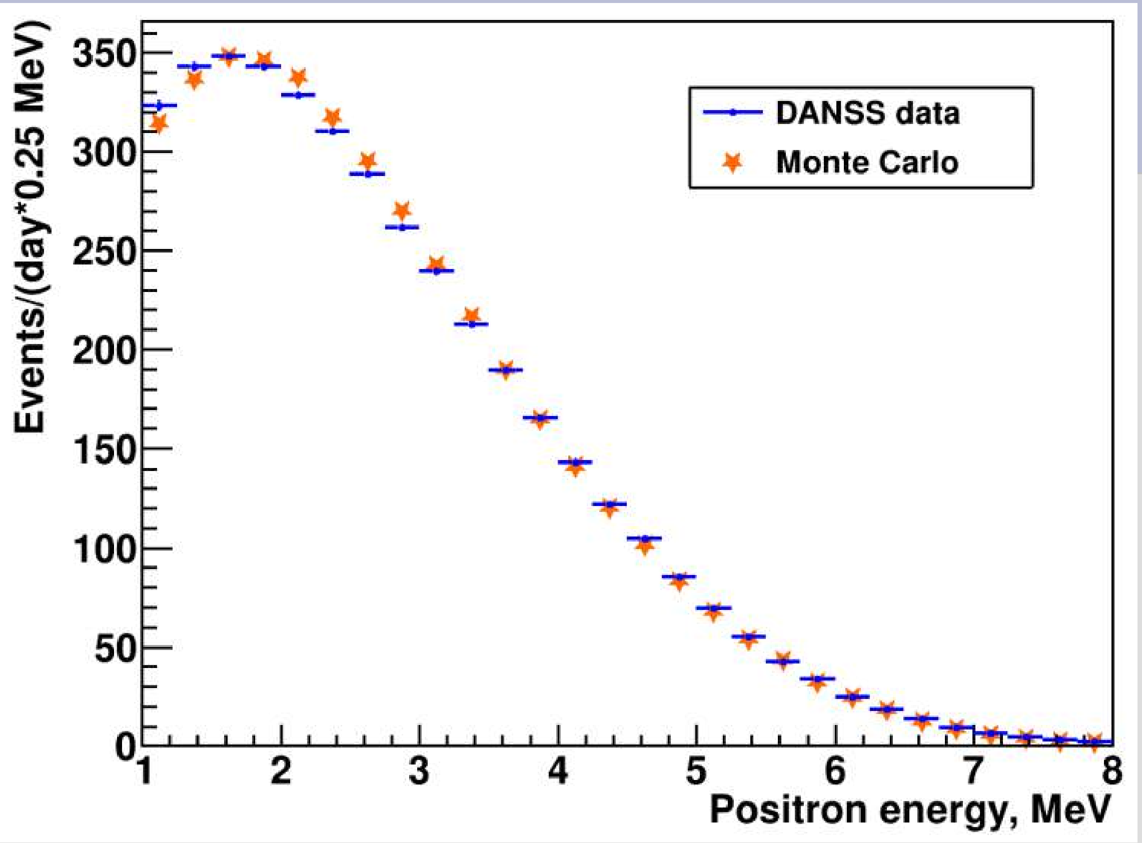




Down/Up spectrum ratio is consistent with straight line. Most probable oscillation phase space point is excluded (left fig.) as well as essential range of phase space (right fig.), but it is very preliminary results based on portion of data.

Work in progress to improve results: more data, calibration, systematic studies, etc.

Positron spectra: data vs. theory



Real measured spectrum is in agreement with theoretical estimation calculated on Huber-Mueller model. This is very preliminary qualitative conclusion, the precise quantitative result will be released after more detailed study.

Let us emphasize again, that the DANSS sterile neutrino oscillation probe is not sensitive to the shape of the antineutrino spectrum.

Summary

•DANSS is in trial operation since April 2016 with regular (physics) data taking since 2017 at a rate of 5000 events per day.

• Basic energy and time calibrations have been done, detector performance match the expectations.

•The monitoring of the reactor power by measurement of antineutrino events has been successively demonstrated since October of 2016.

•Preliminary analysis of portion of data accumulated shows no evidence of the antineutrino oscillation into the sterile state at essential range of the phase space.

• We don’t see essential discrepancies between measured and simulated antineutrino spectra calculated on Huber-Mueller model.

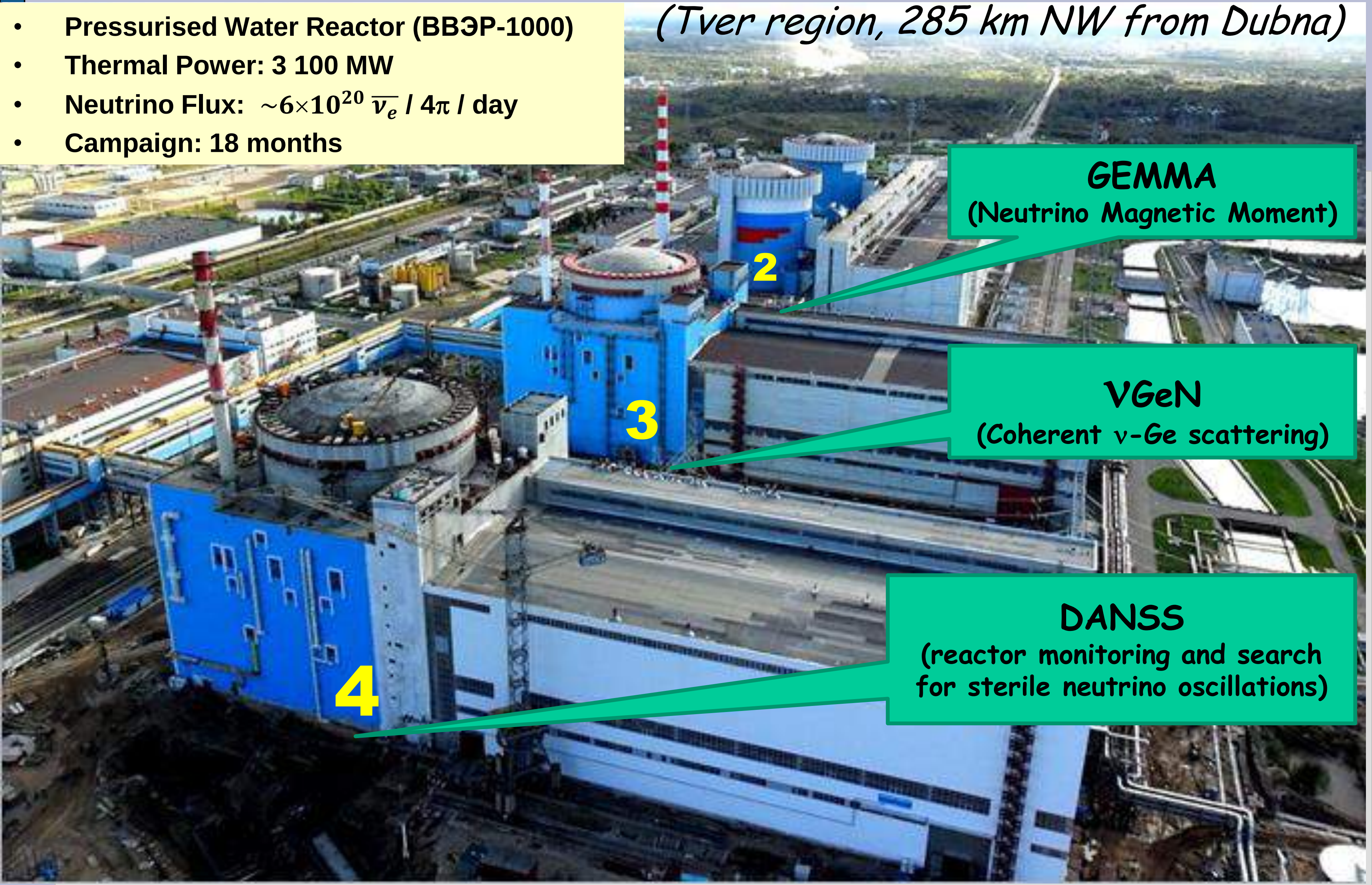
• Work is in progress to improve preliminary results: more data (especially reactor OFF data taken now during 50-day scheduled reactor stop for fuel reloading), more calibrations, systematic studies, etc.

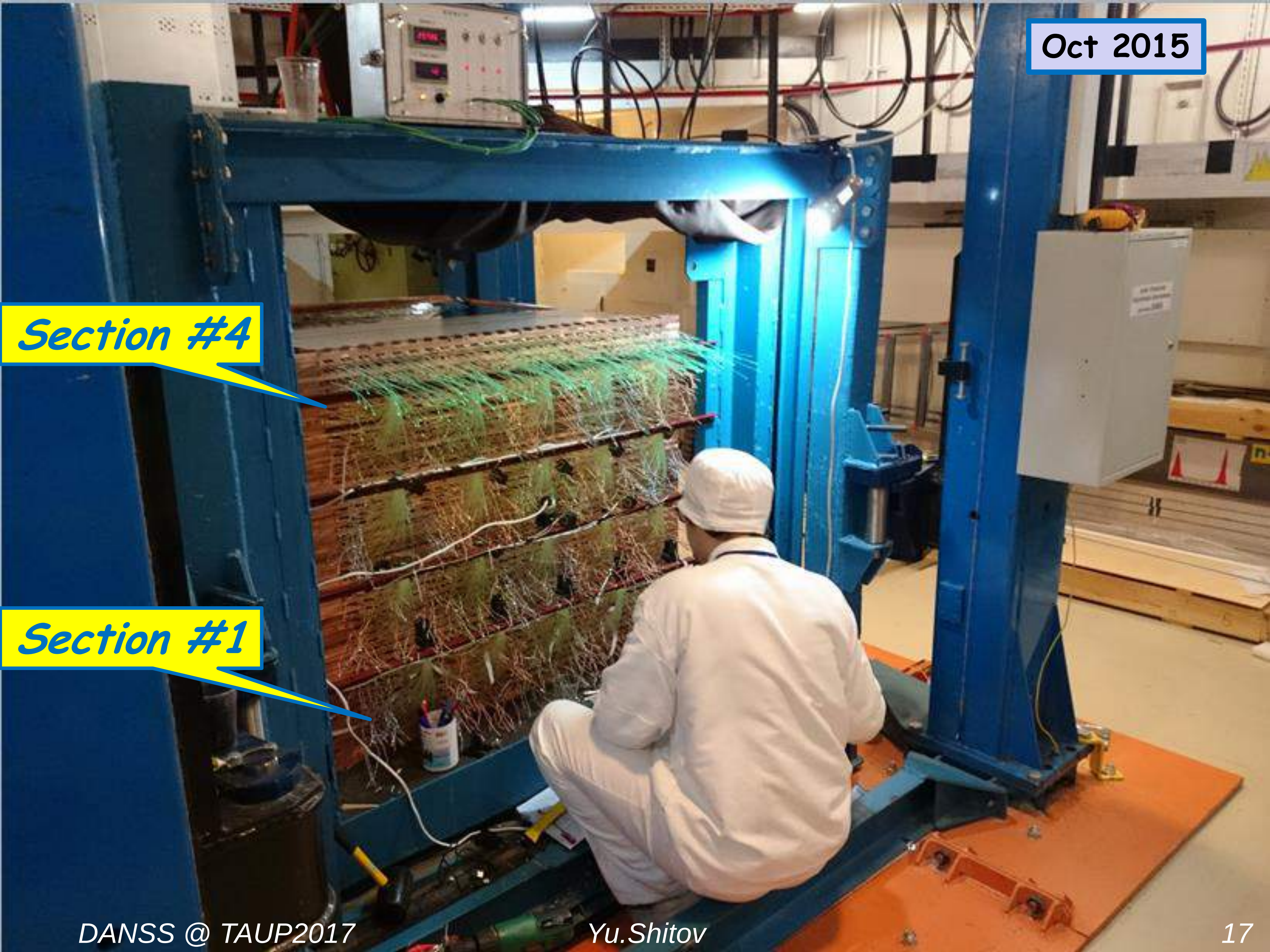
BONUS SLIDES

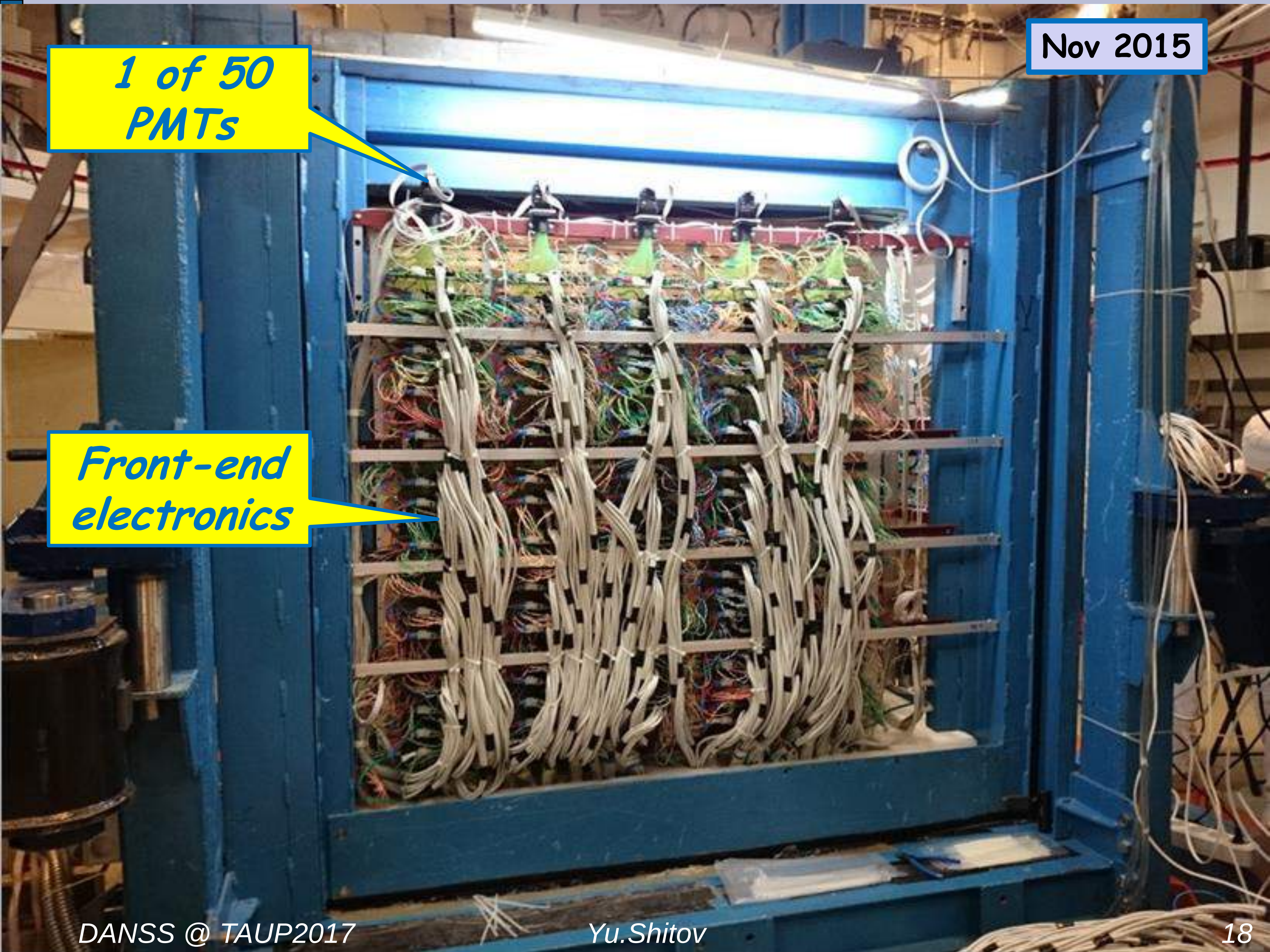
Neutrino laboratory at the Kalinin NPP

(Tver region, 285 km NW from Dubna)

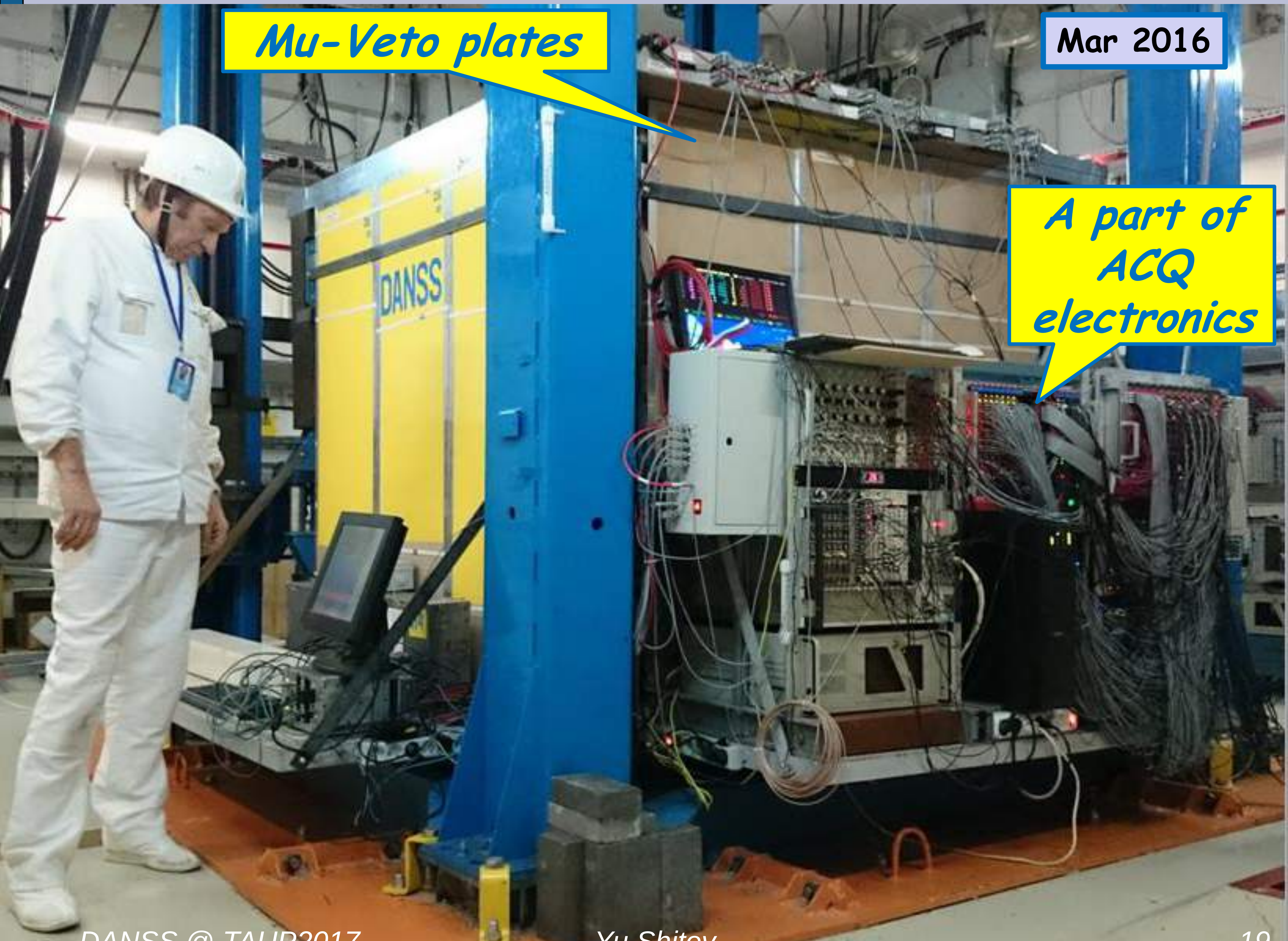
- **Pressurised Water Reactor (ВВЭР-1000)**
- **Thermal Power: 3 100 MW**
- **Neutrino Flux: $\sim 6\times 10^{20}\ \overline{\nu_e}$ / 4π / day**
- **Campaign: 18 months**



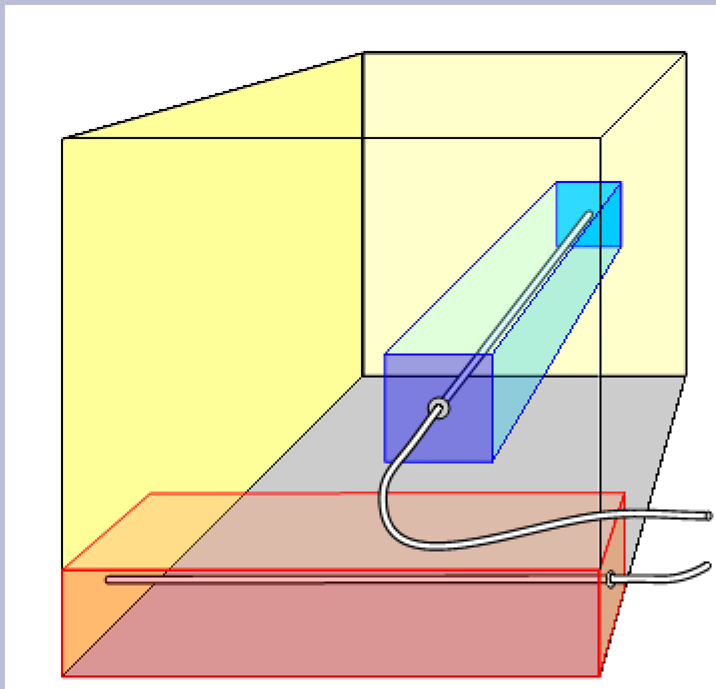

Oct 2015
Section #4
Section #1

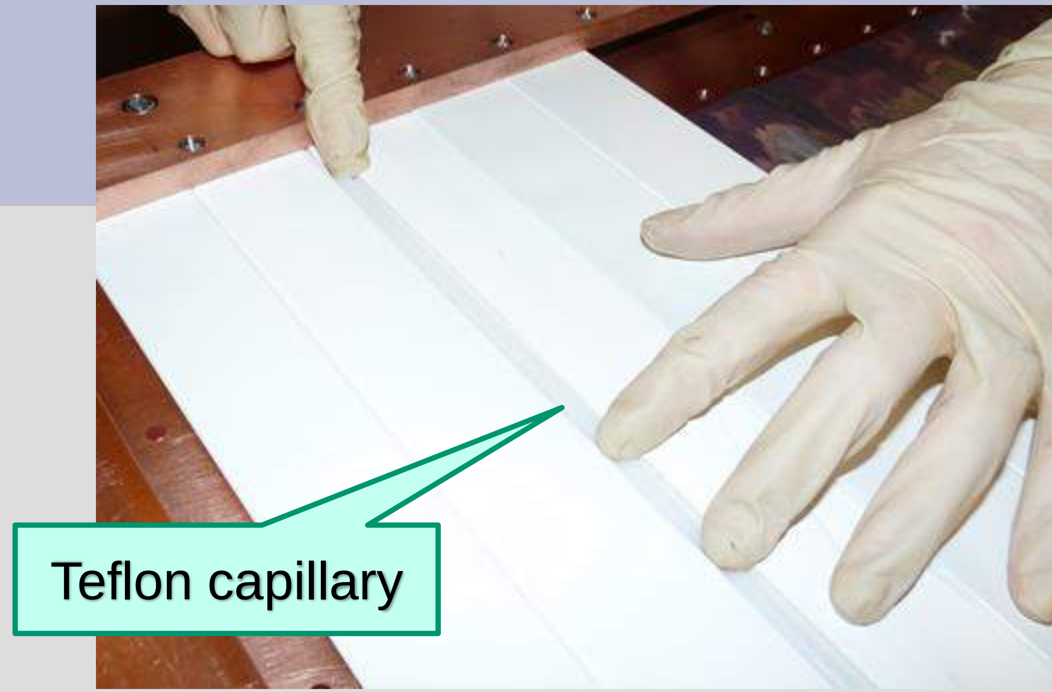


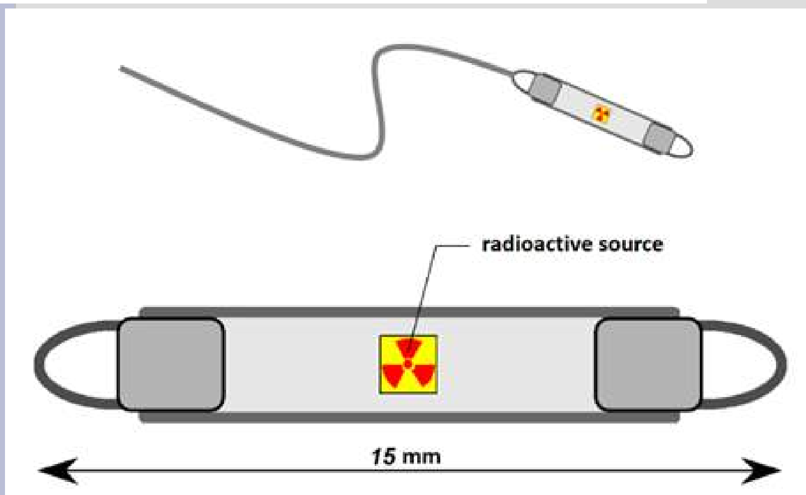
Nov 2015
1 of 50 PMTs
Front-end electronics

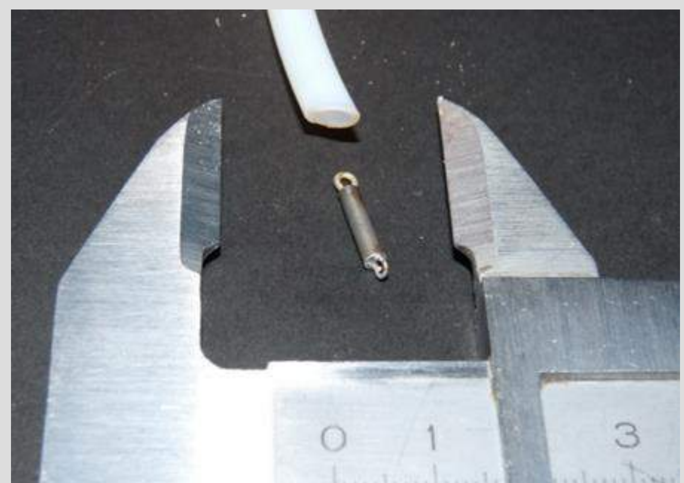

Mu-Veto plates
Mar 2016
A part of ACQ electronics
DANSS

Calibration techniques

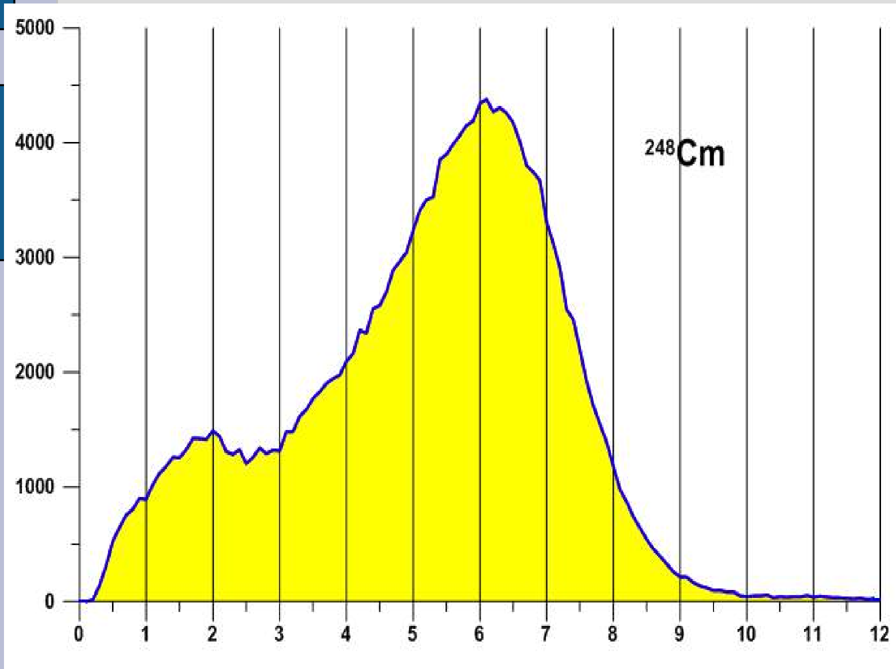




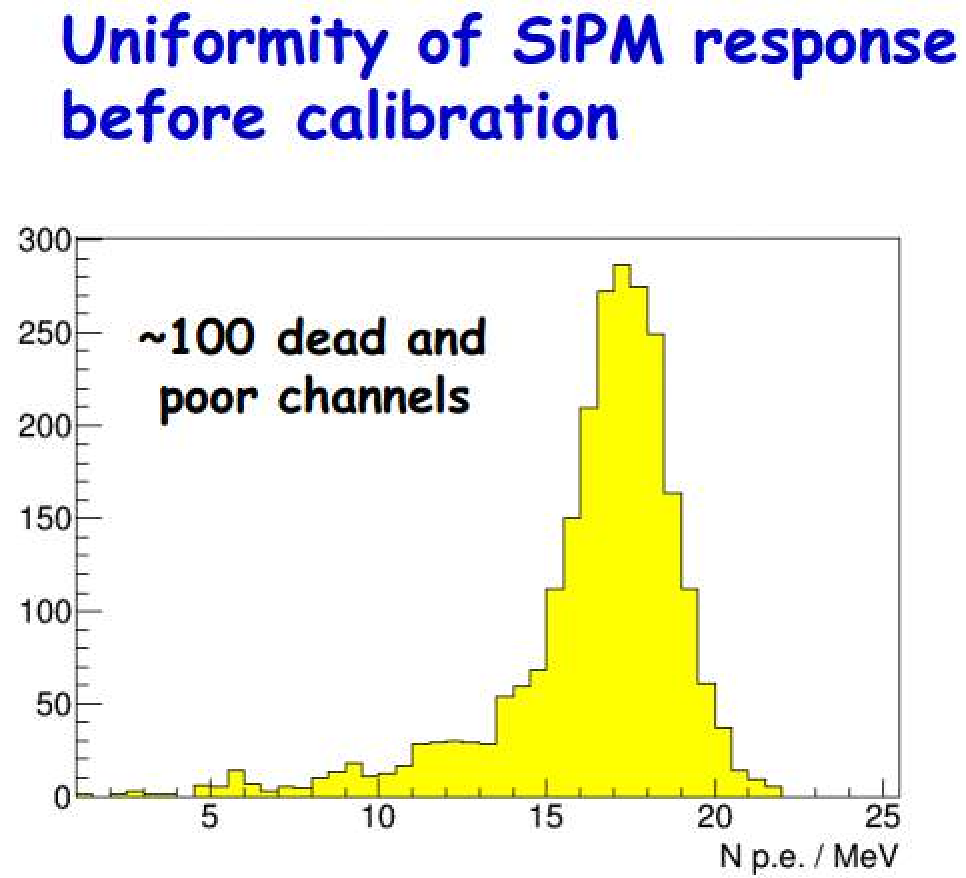




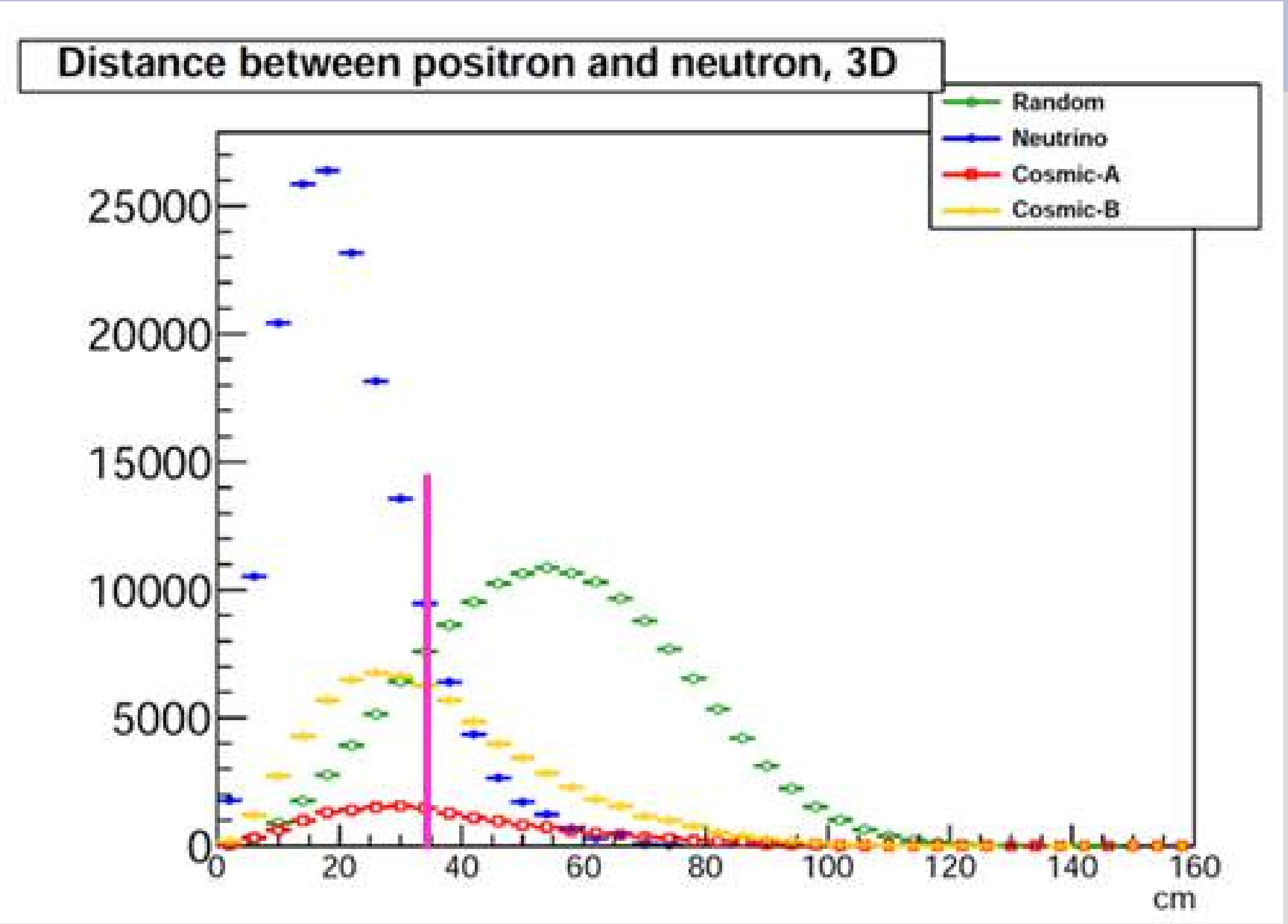
Calibration features



Prompt energy spectra of ^{248}Cm neutron source

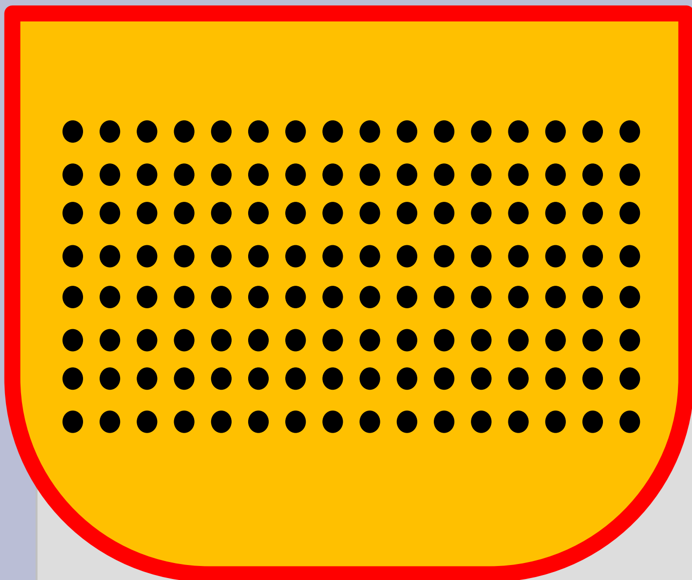


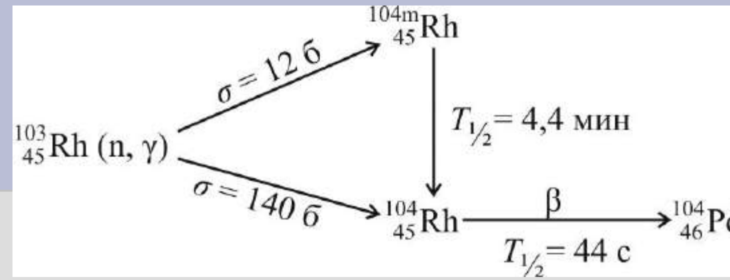
Distance between vertexes of fast and slow signals

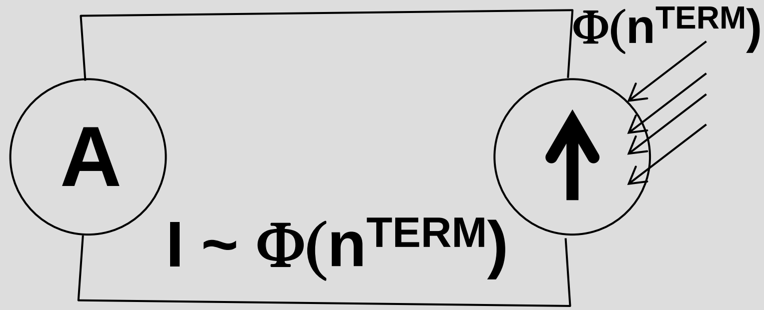


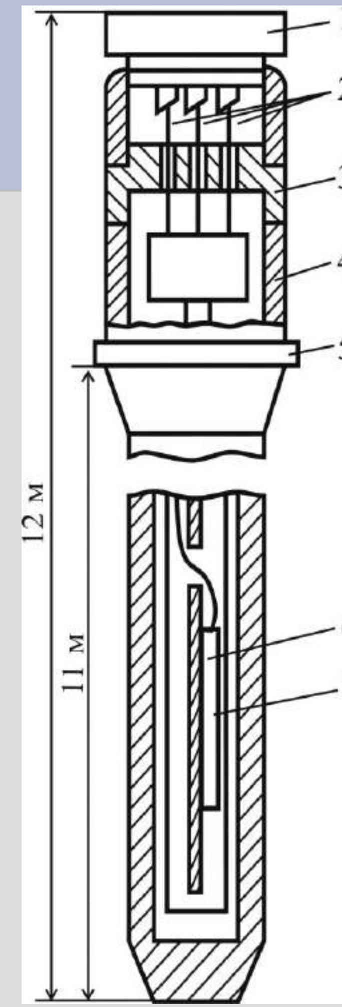
Spatial cut could help to reduce contribution of accidental background

Monitoring of reactor burning core profile







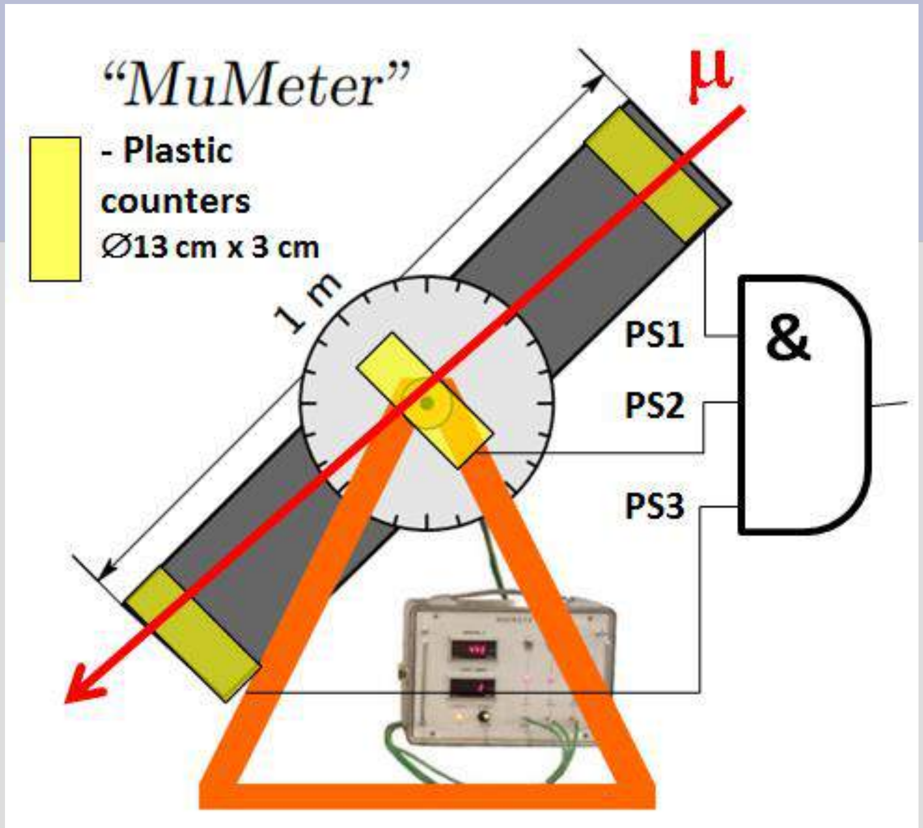


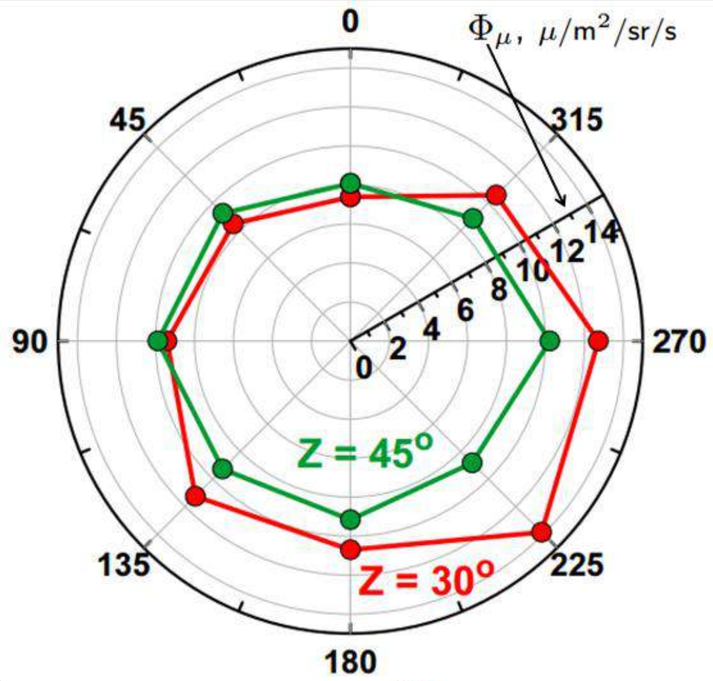
1) Homogeneous grid of 256 point-like direct-charge detectors measured flux of thermal neutrons. Emitter (Rhodium here) captures neutrons and generates measured current of electrons produced in following β- decay.
2) 3D profile of active zone is reconstructed by software.

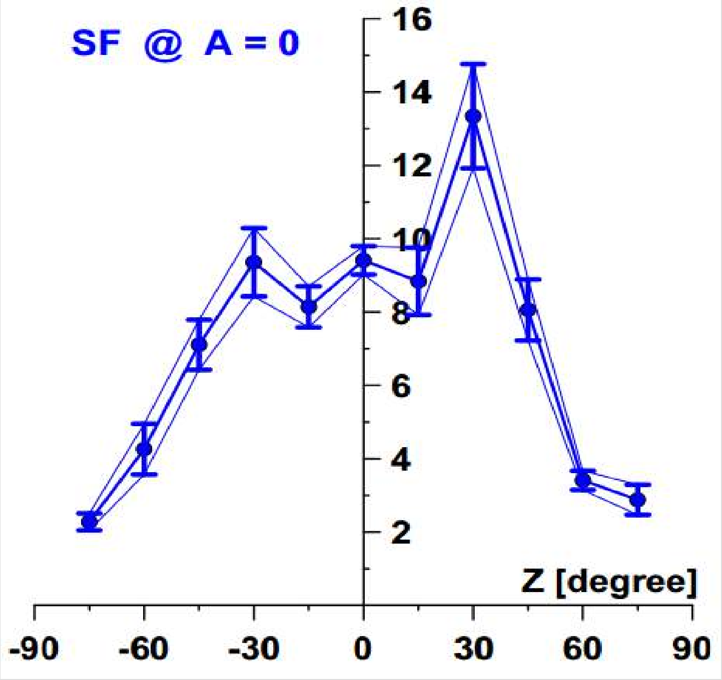
Advantages: simple, technological, compact, cheap, no external power, lifetime >=1 fuel cycle (1.5 years), stable and reproducible.
Disadvantages: weak (~ μA) and slow (1 min) signal, sensitive to varying conditions of active zone (burning out of fuel, boric acid concentration, enrichment of nearest fuel cells, coolant temperature, etc.) and burning out of detector's emitter.

ДПЗ-1М detector used on WWER

On-site muon measurements

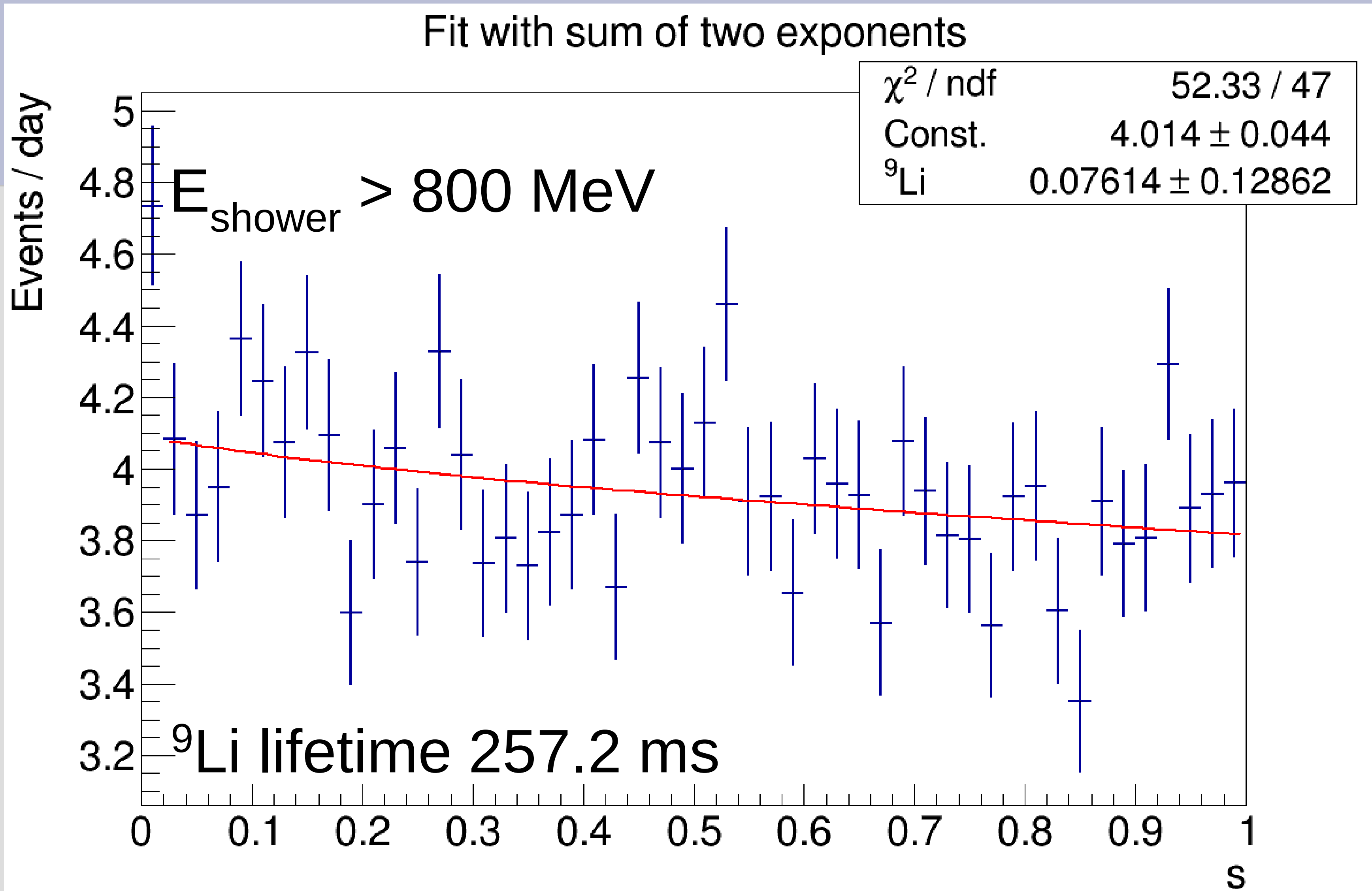






- Telescope to measure cosmic muons at different angles (left up fig.)
- Results of measurements at the DANSS location (under 4-th reactor of the KNPP):
  - azimuthal flux for zenith angles Z=30°/45° (right up fig.)
  - Zenith suppression factor (SF) w.r.t. plain air for azimuthal angle A=0° (right bottom fig.)

Background contribution from ^{9}Li and ^{8}He



1.64 * 0.129 * 257.2 / 20 = 2.7 events/day (@ 90% CL)