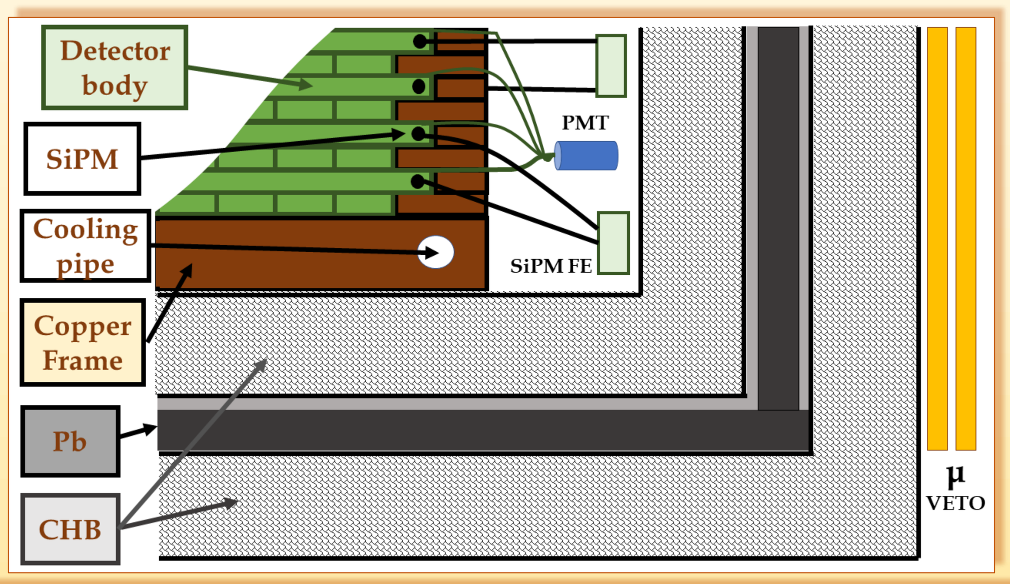
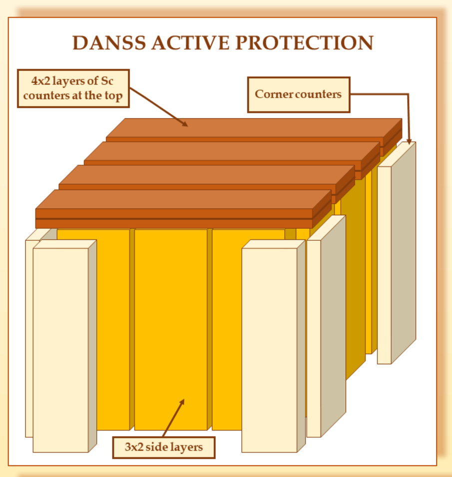
RECONSTRUCTION OF THE INVERSE β-DECAY IN THE DANSS EXPERIMENT

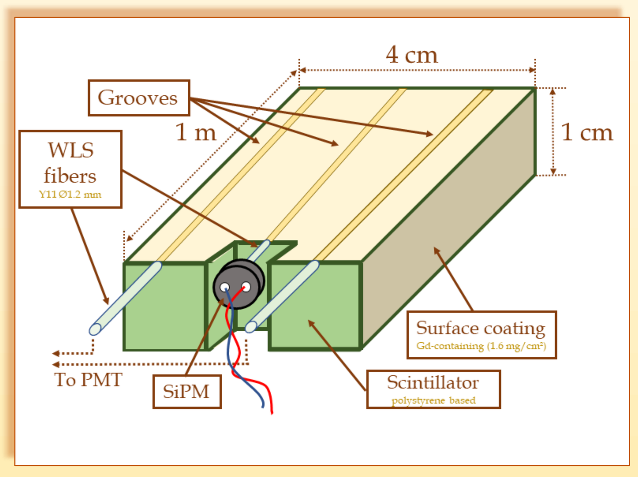
Irina Machikhiliyan for the DANSS collaboration (ITEP(Moscow) / JINR(Dubna))





Scintillator Strip

- polystyrene + 1% PPO + 0.03% POPOP
- Gd-containing surface coating (0.35% by weight): light reflector / (n, γ)-converter
- Sc light is readout by three WLS fibers
- central fiber: silicon photomultiplier (SiPM), individual strip readout
- two peripheral fibers: conventional phototube (PMT) which readouts one module (50 detector cells)
- light yield: 18 p.e./MeV (SiPM) and 20 p.e./MeV(PMT)



Basic Information

Location: under the reactor of the Kalinin Nuclear Power Plant

Detector platform is movable in vertical direction

Three detector positions from the reactor core: 10.7 m (**top**), 11.7 m (**middle**) and 12.7 m (**bottom**), changed every 2÷3 days

Size of the sensitive detector volume: ~1 m³ (1 tonne)

Material: plastic scintillator (Sc) - no flammable or otherwise dangerous materials

Structure: 100 horizontal layers of Sc strips, laid at 90° to the strips of the adjacent layers

Granularity: 2500 cells (strips) / 50 modules

Photodetectors: PMTs / SiPMs. Light readout is performed from 2 neighboring detector sides

DANSS Shielding

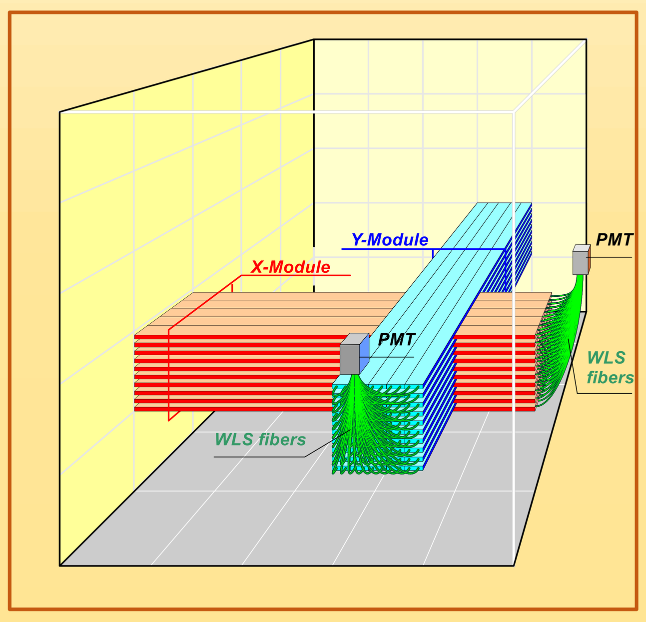
Multi-layer passive shielding: suppression of γ-background and thermal / epithermal neutrons

- copper frame (5 cm)
- borated polyethylene (2x8 cm)
- lead (5 cm)

Active protection: muon VETO system

- 40 scintillator plates, covering top, sides and corners of the detector
- PMT readout
- 2.5% inefficiency: small fraction of untagged cosmic muons

Also: ~50 meters of water equivalent from the bulk of the reactor building eliminate the hadronic component of cosmic rays and ensure further suppression of the muon component by a factor of 6



Dual Detector Readout

SiPMs:

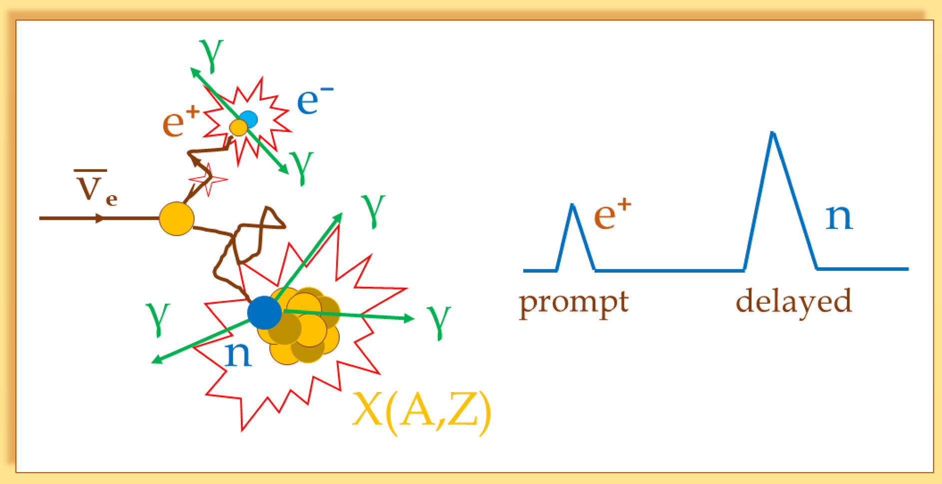
- ✓ detailed reconstruction of event structure
- − intrinsic low-amplitude pulses of dark current (~100 kHz)
- − temperature dependence of parameters
- − cross-talk between pixels

PMTs:

- ✓ robust to environmental changes
- ✓ more precise estimate of energy deposition
- − much worse spatial resolution

DANSS Data

- **stored signals:** digitized current profiles in 512 ns window with time step 8 ns
- **extracted data:** (1) integral signal I and (2) signal arrival time t_0
- location of the signal pulse is done with the suppression of SiPM noise or accidental overlapping pulses (few percent of events)



Detection of Antineutrino

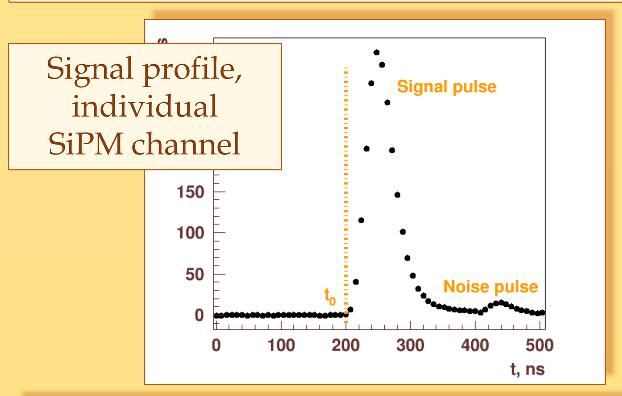
- done by the reconstruction of the inverse beta decay reaction (IBD)
- IBD event is seen in the DANSS as the time correlated pair of the prompt positron and delayed neutron events

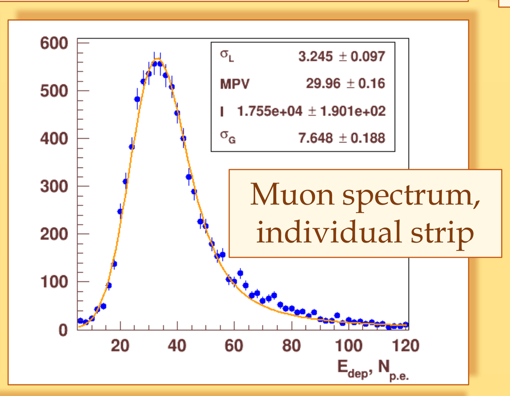
Trigger Signal

- net PMT energy deposition > 0.7 MeV

OR

- net VETO energy deposition > 4 MeV





Calibration

- for all three subsystems of SiPMs, PMTs and VETO the energy scale is defined by the signal of minimum ionizing particles (muons)

Possible Background Sources for the Spectra of Reactor Antineutrino

- uncorrelated background: accidental combinations of two positron-like and neutron-like events
- correlated background due to cosmic muons:
  - fast neutrons
  - two or more neutrons from excited nuclei
  - unstable ⁹Li / ⁸He nuclei emitting beta-particles and low energy neutron
- IBD events from the other three reactors of the Kalinin Nuclear Power Plant

Selection of IBD-candidates

Step 1: SiPM noise suppression

The requirements for SiPM hits:

- $(t_0 - T) < \pm 15$ ns, where T is the average t_0 for physics hits
- 1-pixel signal must be confirmed by the PMT hit

Step 2: Selection of e+ and n-candidates as well as μ-candidates for background estimates

μ-candidate

- more than one hit in VETO counters **OR**
- more than 4 MeV in one VETO counter **OR**
- more than 20 MeV in detector body

e+ candidate

- no μ-candidates in the event
- 1÷20 MeV in ionization cluster (visible energy is corrected to compensate energy losses e. g. in the inactive detector material as well as the contribution of photons from positron annihilation. Typical size of the correction is ~2%)
- the most energetic hit in cluster must be at least 4 cm from the detector borders (leaves 78% of detector fiducial volume)
- number of SiPM hits beyond the cluster < 11
- energy beyond the cluster < 1.8 MeV
- the most energetic hit beyond the cluster < 0.8 MeV

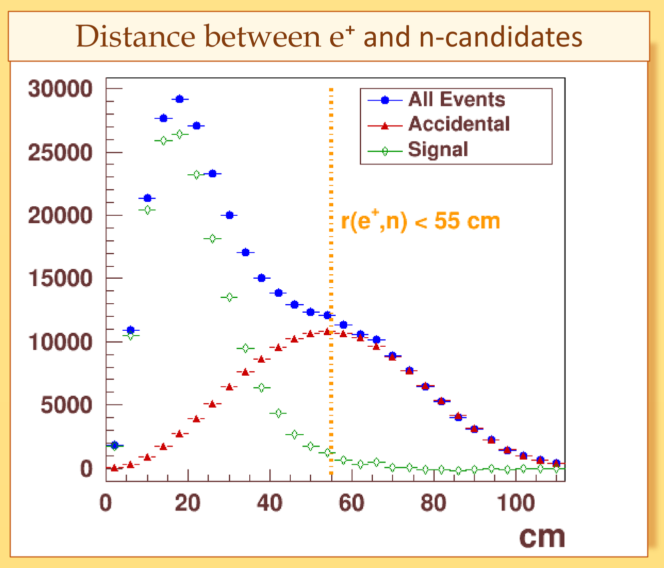
n-candidate

- no μ-candidates in the event
- 3.5÷15 MeV of total energy
- more than 3 SiPM hits

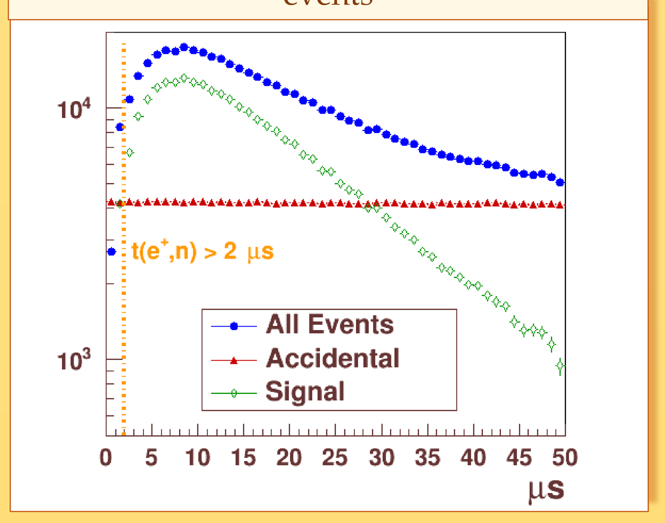
Step 3: Construction of IBD pairs

- distance between e+ and n-candidates:
  - < 55 cm, if all three coordinates of e+ are known
  - < 45 cm, if only two coordinates of e+ are known
- time between prompt and delayed events: 2÷50 μs
- cuts to suppress the background due to cosmic muons:
  - no event with μ-candidate within at least 60 μs prior to the prompt event
  - no other triggers except for the delayed event within 45 μs before and within 80 μs after the prompt event
  - no trigger with total energy deposition in the detector > 300 MeV within at least 200 μs before the prompt event

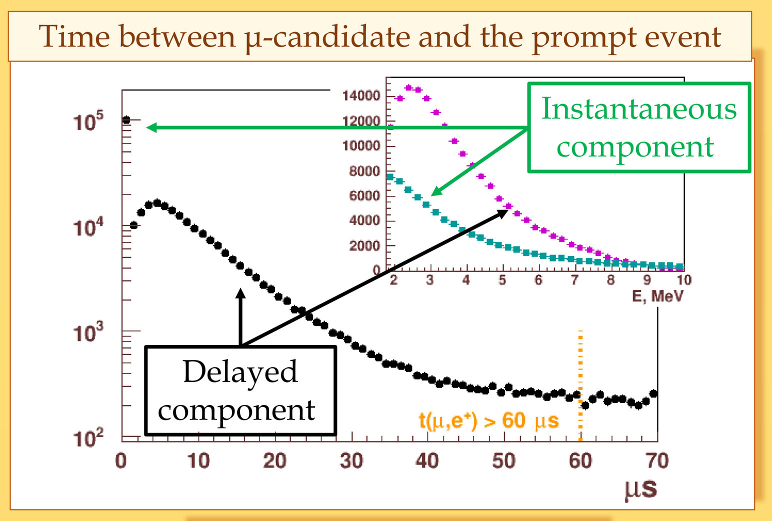
Distance between e⁺ and n-candidates

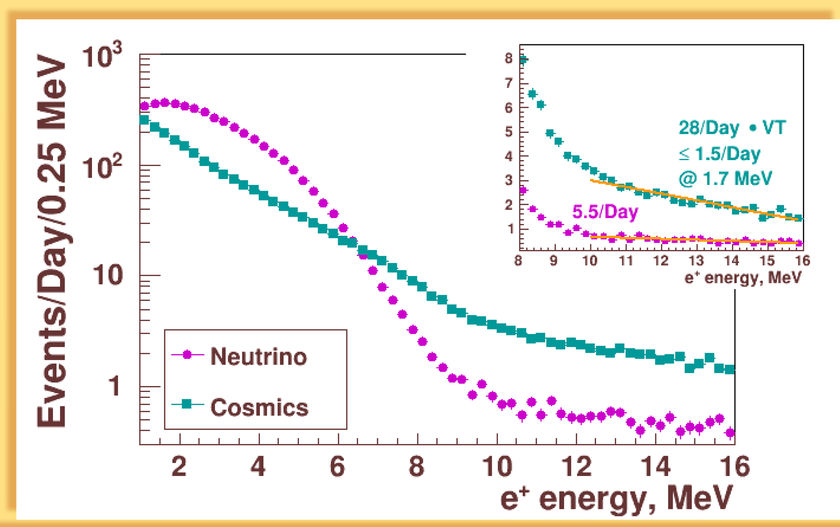


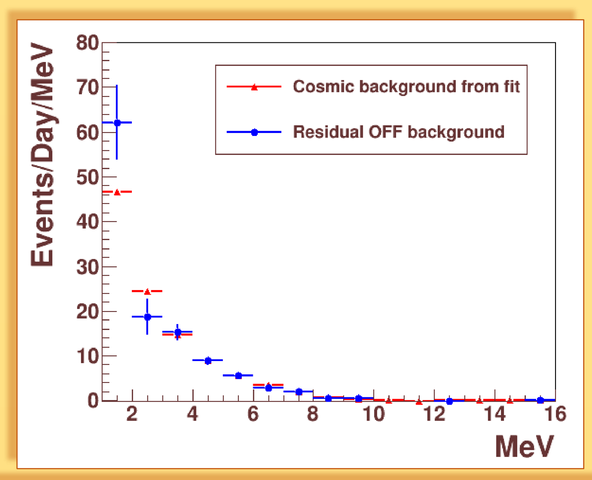
Time between the prompt and delayed events



Time between μ-candidate and the prompt event







Fast Neutrons Background

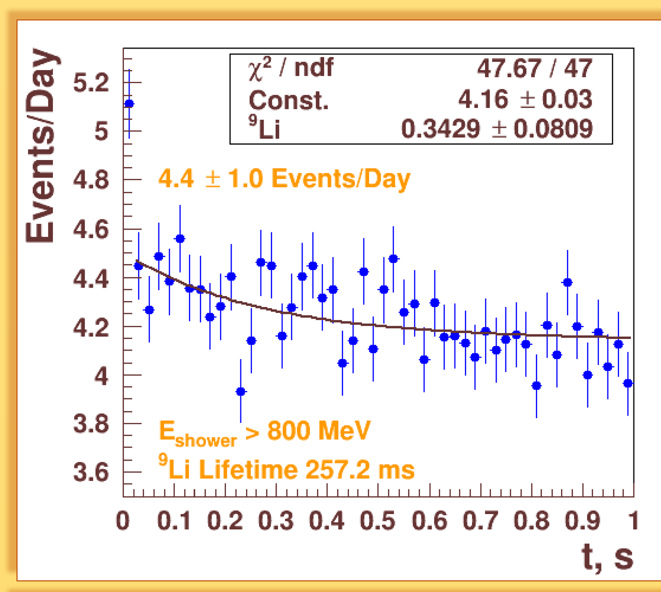
- ~0.1% of the IBD signal in 1÷8 MeV region
- obtained by a linear extrapolation from the high energies region 10÷16 MeV
- visible cosmic spectrum is constructed the same way as the IBD positron spectrum, but with prompt events accompanied by μ-candidate. Fast neutrons background is estimated and subtracted separately for both types of spectra

Residual Contribution of Untagged Cosmic Muon Events due to the VETO Inefficiency

- estimated during reactor shutdown periods
- the spectrum is assumed to have the same shape as the visible cosmic spectrum
- obtained by the fit of the energy spectrum of identified e+ candidates
- 2.7% of IBD rate

Accidental Background

- estimated by combining the delayed event with identified e+ candidates in sixteen 50 μs intervals: 5, 10, … 80 ms prior to the neutron candidate, where positron could not be present. Such fake IBD pairs go through the same selection procedure as normal IBD-candidates
- the accidental rate is comparable with the IBD rate



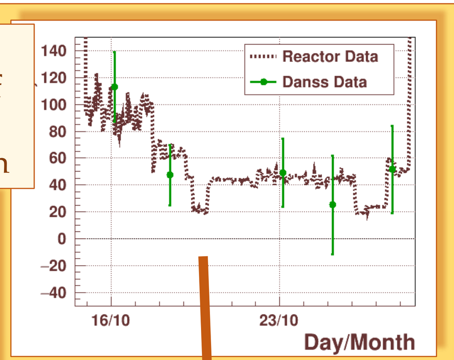
Contribution from the Other Three Reactors

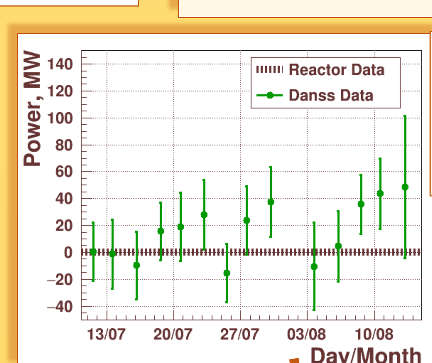
0.6% of the IBD counting rate from the nearest reactor

⁹Li / ⁸He Background

- obtained from the time distribution between a cosmic event with net energy deposition in the detector > 800 MeV and an IBD-candidate

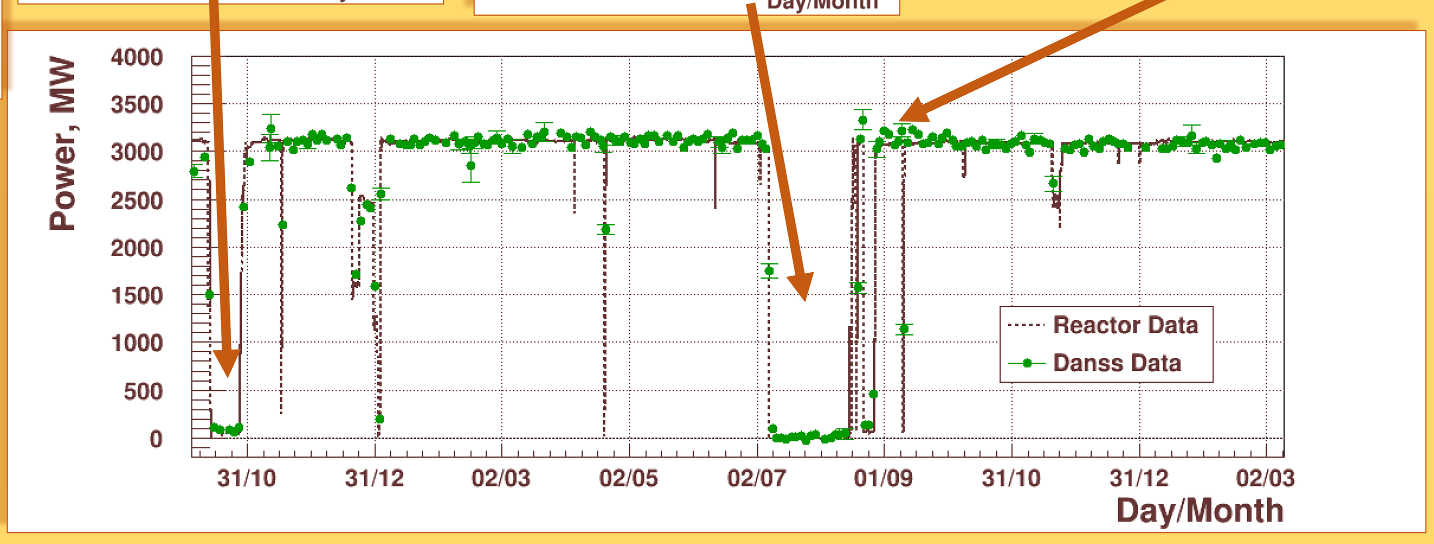
The first period of reactor shutdown

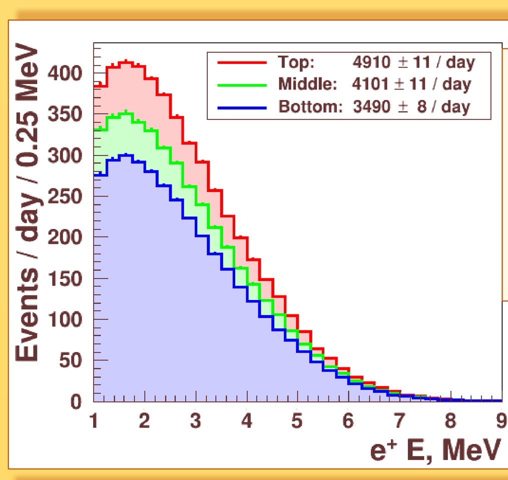




The second period of reactor shutdown, the start of the reactor 5th campaign

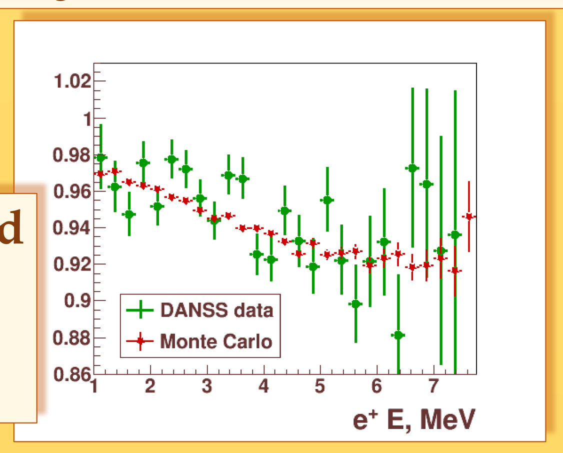
~7% discrepancy at the beginning of the new campaign: samarium burnup





Reconstructed e+ Spectra

- annihilations photons are not included
- ~ 5000 antineutrino / day in fiducial volume
- all background is subtracted



Ratio of e+ Spectra at the End and the Beginning of Two Reactor Campaigns

Consistent with MC-simulations

Measurement of Reactor Power by the DANSS Counting Rate

- time span: years 2016÷2018
- normalization period: 12 points of Nov-Dec 2016
- points of different positions are equalized according to the 1/r² rule
- all background is subtracted
- two reactor OFF periods
  - the first period: used to measure the VETO inefficiency
  - the second period: the DANSS rate is consistent with zero

The collaboration is grateful to the directorates of ITEP and JINR for constant support of its work. The collaboration appreciate the permanent assistance of the KNPP administration and Radiation and Nuclear Safety Departments. 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

Poster design: irina.machikhiliyan@mail.itep.ru