Recent results from the DANSS experiment

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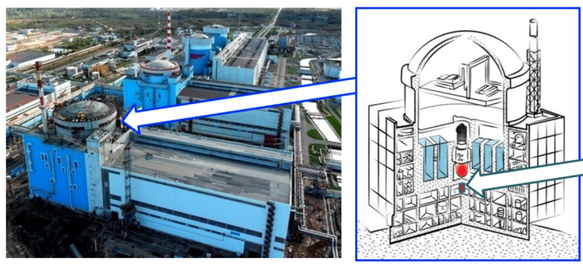
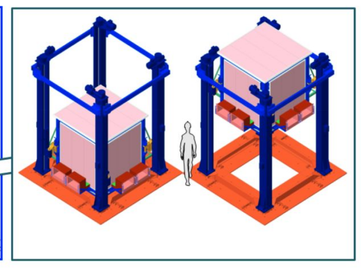
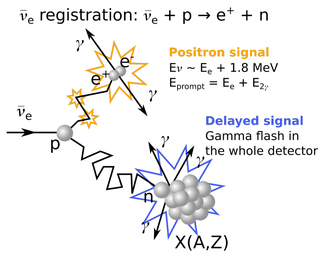
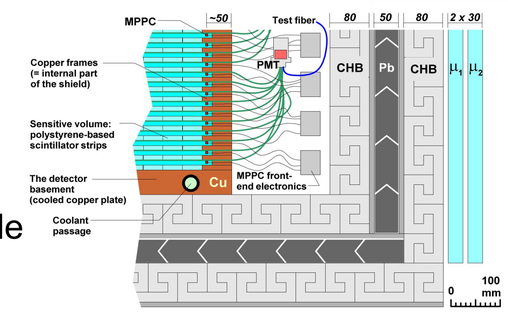
DANSS design [JINST 11 (2016) no.11, P11011]

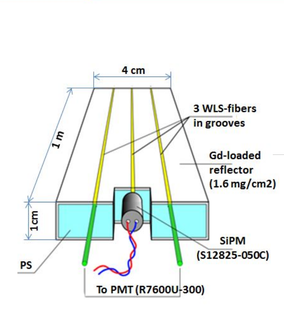
- DANSS – Detector of reactor AntiNeutrino based on Solid-state Scintillator
- Location: Kalinin Nuclear Power Plant (KNPP), 3.1 GW commercial reactor $5 \cdot 10^{13}$ ν cm^{-2} s^{-1}, 50 m w.e. overburden
- 10.9 -12.9 m from the reactor core center, movement online
- Multilayer Cu + CHB + Pb + CHB passive shielding
- Two-layer muon veto on 5 sides
- 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
- Dedicated WFD-based DAQ system

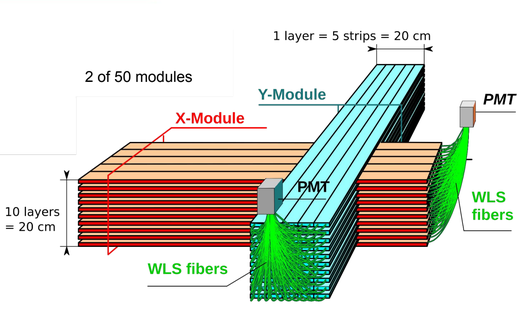




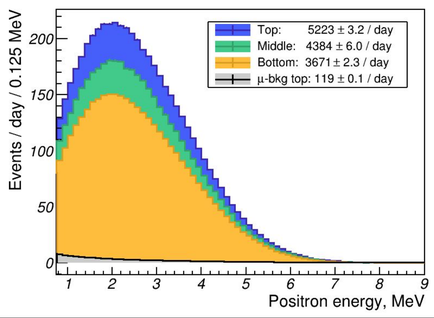




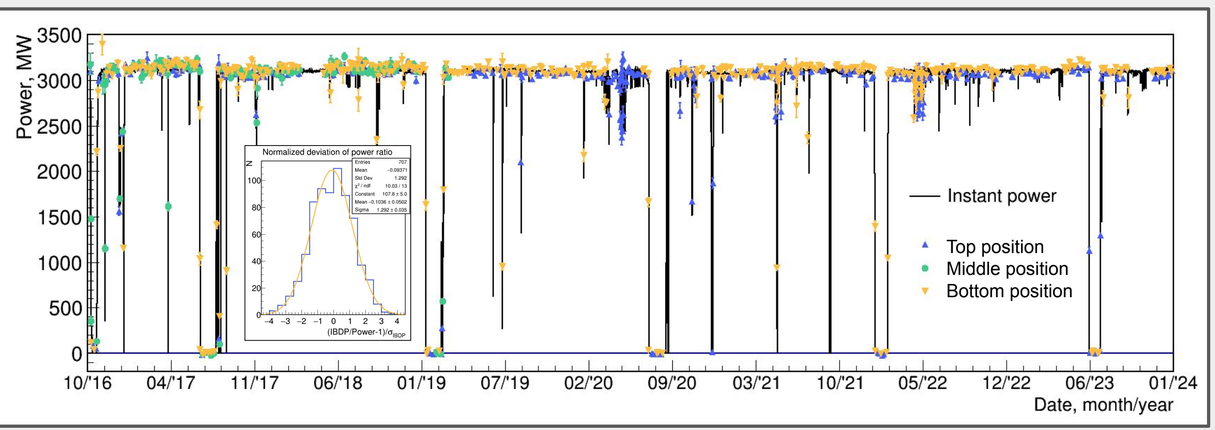




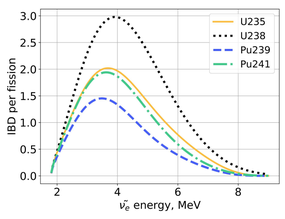
7 years of running



- 3 detector positions, pure positron kinetic energy (annihilation photons not included)
- > 8 mln IBD events, ~ 5000 events per day in the closest position
- Signal/Background > 50
- Reactor power is measured by the DANSS with neutrino flux with 1.3% accuracy in 3 days during more than 7 years!

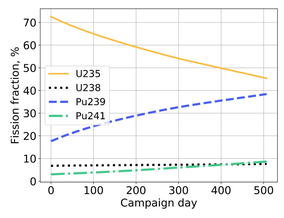


Measurements of σ_5/σ_9



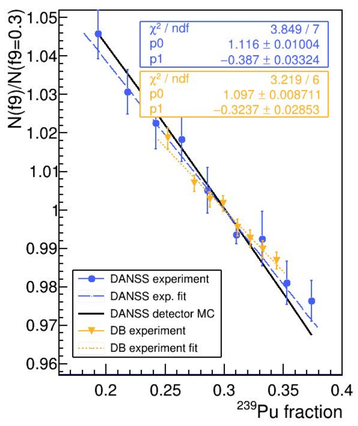
$$N = \alpha \cdot (\sigma_8 f_8 + \sigma_1 f_1 + \sigma_5 f_5 + \sigma_9 f_9)$$

$$\frac{dN}{df_9} = \alpha \cdot \left(\sigma_8 \frac{df_8}{df_9} + \sigma_1 \frac{df_1}{df_9} + \sigma_5 \frac{df_5}{df_9} + \sigma_9\right)$$



$$SI = \left(\frac{dN}{df_9}\right) / N = \frac{\frac{\sigma_8}{\sigma_9}\frac{df_8}{df_9} + \frac{\sigma_1}{\sigma_9}\frac{df_1}{df_9} + \frac{\sigma_5}{\sigma_9}\frac{df_5}{df_9} + 1}{\frac{\sigma_8}{\sigma_9} f_8 + \frac{\sigma_1}{\sigma_9} f_1 + \frac{\sigma_5}{\sigma_9} f_5 + f_9}$$

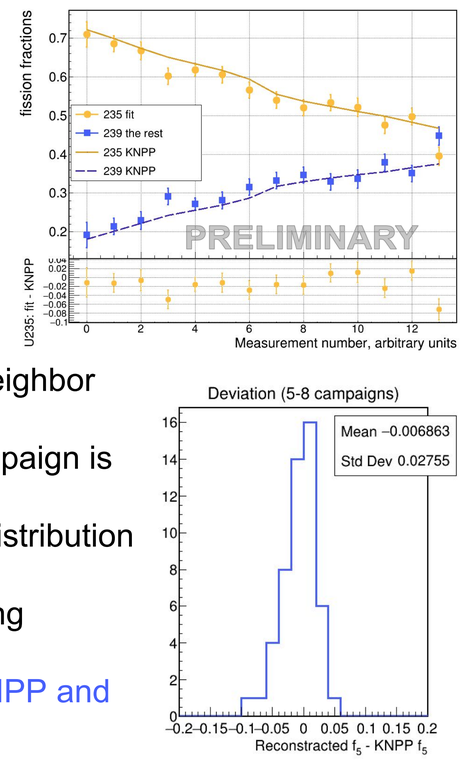
$$\frac{\sigma_5}{\sigma_9} = -\frac{\frac{\sigma_8}{\sigma_9}\left(SI \cdot f_8 - \frac{df_8}{df_9}\right) + \frac{\sigma_1}{\sigma_9}\left(SI \cdot f_1 - \frac{df_1}{df_9}\right) + (SI \cdot f_9 - 1)}{SI \cdot f_5 - \frac{df_5}{df_9}}$$



(σ_8/σ_9 and σ_1/σ_9 are taken from Huber [Phys.Rev.C,84,024617] and Mueller [Phys.Rev.C,83,054615])
DANSS result $\sigma_5/\sigma_9 = 1.54 \pm 0.06$ is larger than Day Bay [Phys.Rev.Lett.120,022503] (1.445 ± 0.097) and agrees with Huber + Mueller (1.53 ± 0.05).
Use of DB-Slope in our formula gives: $\sigma_5/\sigma_9 = 1.459 \pm 0.052$ ⇒ difference between DANSS and Daya Bay is due to slope

Fission fraction reconstruction

- We fit the observed positron spectra using the sum of 4 isotopes (HM model)
- ^{238}U and ^{241}Pu fission fractions are fixed (corresponding to KNPP data),
- ^{235}U fission fraction is free parameter
- Each measurement corresponds to ~ 6-10 days of data taking (~1% stat. accuracy)
- Correction for dead time, efficiency, neighbor reactors power (individually)
- Mean normalization for the whole campaign is used
- Reactor #4 power and fission points distribution profile are not taken into account
- Fit range: 1-3 and 5.5-7 MeV (excluding so-called “bump”)
- Difference in ^{235}U fraction between KNPP and DANSS is ~3%



Measurements of absolute ν_e flux

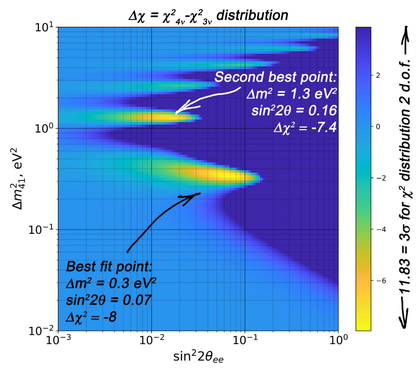
$$\frac{dN(t)}{dt} = N_p \cdot \int_{E_{min}}^{E_{max}} \varepsilon \frac{1}{4\pi L^2} \sigma(E_\nu) \frac{d^2\phi(E_\nu, t)}{dEdt} dE$$

$$\frac{d^2\phi(E,t)}{dEdt} = \frac{W_{th}}{< E_{fis} >} \sum f_i \cdot s_i(E), \text{ where } < E_{fis} >= \sum E_i \cdot f_i$$

N_p – the number of target protons,
ε – detector efficiency,
L – the distance between the centers of the detector and the reactor core (distribution of fission points, reactor and detector sizes are taken into account)
$\sigma(E_\nu)$ – the IBD reaction cross section,
W_{th} – reactor thermal power (data provided by KNPP),
E_{fis} – energy released per fission [Phys.Rev.C,88,014605],
f_i – fission fraction (data provided by KNPP),
s_i – $\tilde{\nu_e}$ energy spectrum per fission (Huber + Mueller and Kurchatov Institute [Phys.At.Nucl.,84,1;Phys.Rev.D,104,L071301] models are considered)

Experimental uncertainty without ν_e flux – 4%
Observed to predicted ratio: 0.98±0.04 (HM model), 1.02±0.04 (KI model)
DANSS results are consistent with both models within errors
Total uncertainty in IBD rates (including ν_e flux) – 7%

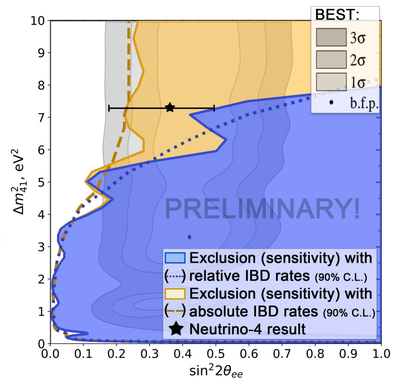
Searches for sterile neutrinos



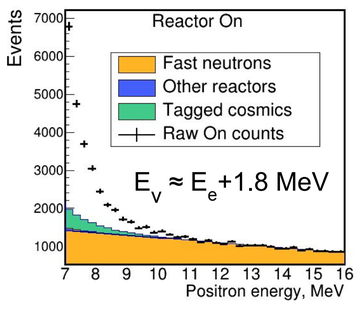
Systematic uncertainties (1σ):
- Energy scale (2%) and shift (50 keV)
- Energy resolution (additional smearing 6%/√E ⊕ 2%)
- Correlated backgrounds (35%)
- Distance to the fuel burning profile center (5 cm)
- Relative efficiencies (0.4%)

Using current statistics we see no statistically significant evidence of 4ν signal (best point significance: ~2.0σ)

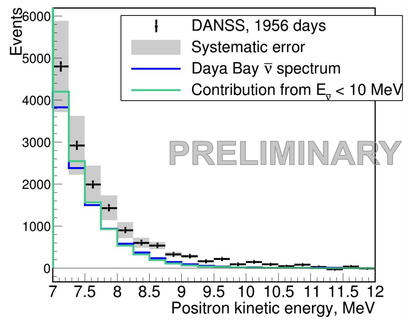
Exclusions are calculated using Gaussian CL_s method
- DANSS analysis without absolute counting rates excludes a large and the most interesting fraction of sterile neutrino parameter space using only ratio of e+ spectra at 3 distances.
- Oscillation analysis with absolute counting rates (HM model) excludes practically all sterile parameter space preferred by BEST [Phys.Rev.Lett.128,232501] and the best fit point of Neutrino-4 [Phys. Rev. D 104, 032003] experiment. A conservative uncertainty of 7% was assumed for absolute counting rates.
- In KI model exclusion is even more strict.
- Exclusions based on absolute IBD rates for large Δm^2 support previous results (Daya Bay, Bugey-3, ...)



High energy neutrinos



- Background subtraction is based on 5 “reactor off” periods
- DANSS observes ν_e events with ν_e energy > 10 MeV: $1561 \pm 157^{stat} \pm 168^{sys}$ ev. (6.8σ)
- Fraction of high energy ν_e events is somewhat larger than at Daya Bay [PhysRevLett.129.041801]



Conclusions

- The estimated ratio of $\sigma_5/\sigma_9 = 1.54 \pm 0.06$ is consistent with the HM model and it is slightly larger than the KI and Daya Bay results
- Obtained accuracy in ^{235}U fission fraction reconstruction is ~3%
- Observed to predicted ratio with absolute ν_e counting rates is 0.98±0.04 for HM model, and is 1.02±0.04 for KI model
- DANSS excludes a large and the most interesting fraction of sterile neutrino parameter space using only ratio of e^+ spectra and practically all parameter space preferred by BEST and the best point of Neutrino-4 using absolute ν_e rates
- DANSS observes ν_e events with ν_e energy > 10 MeV (6.8σ)