The 7th international conference on particle physics and astrophysics

Antineutrino measurements with the iDREAM detector at Kalinin NPP

Oralbaev Aldiyar

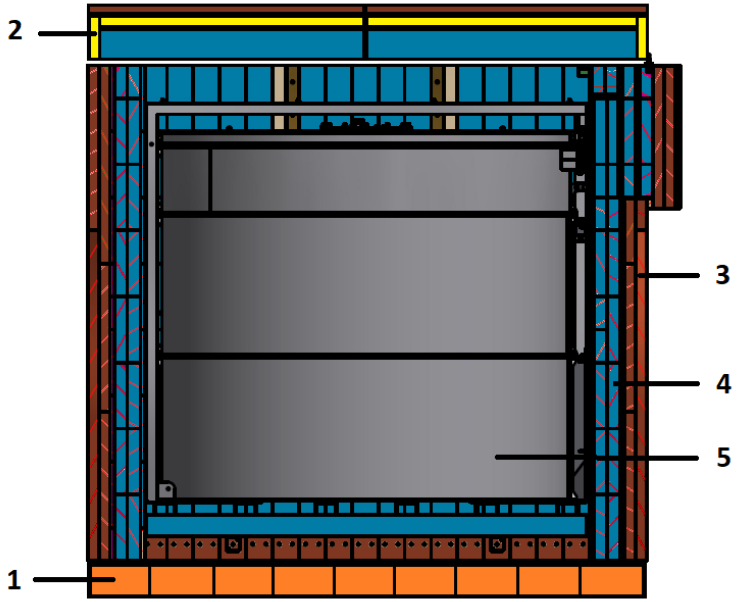
NRC Kurchatov institute

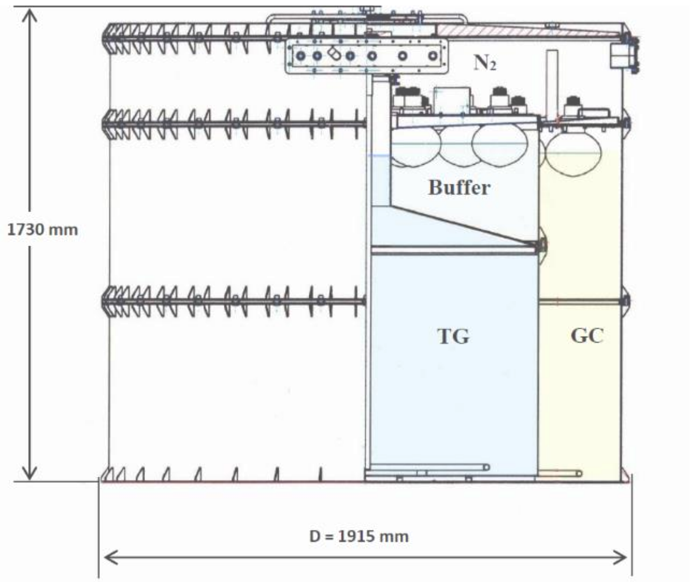
2024

The iDream project aim

- The successor of the more than 40 years experience in neutrino counting.
- Develop a detector which is applicable for a remote control of the active zone;
- It should be based on proved domestic technologies in order to be easily scaled-up;
- To collect an experience in testing materials and methods for a future industrial instruments which could service as a part of the Russian NPP complexes, including a floating NPPs;
- To investigate different scenarios of the monitoring and select corresponding methods in order to give a solid information.

Detector design and site

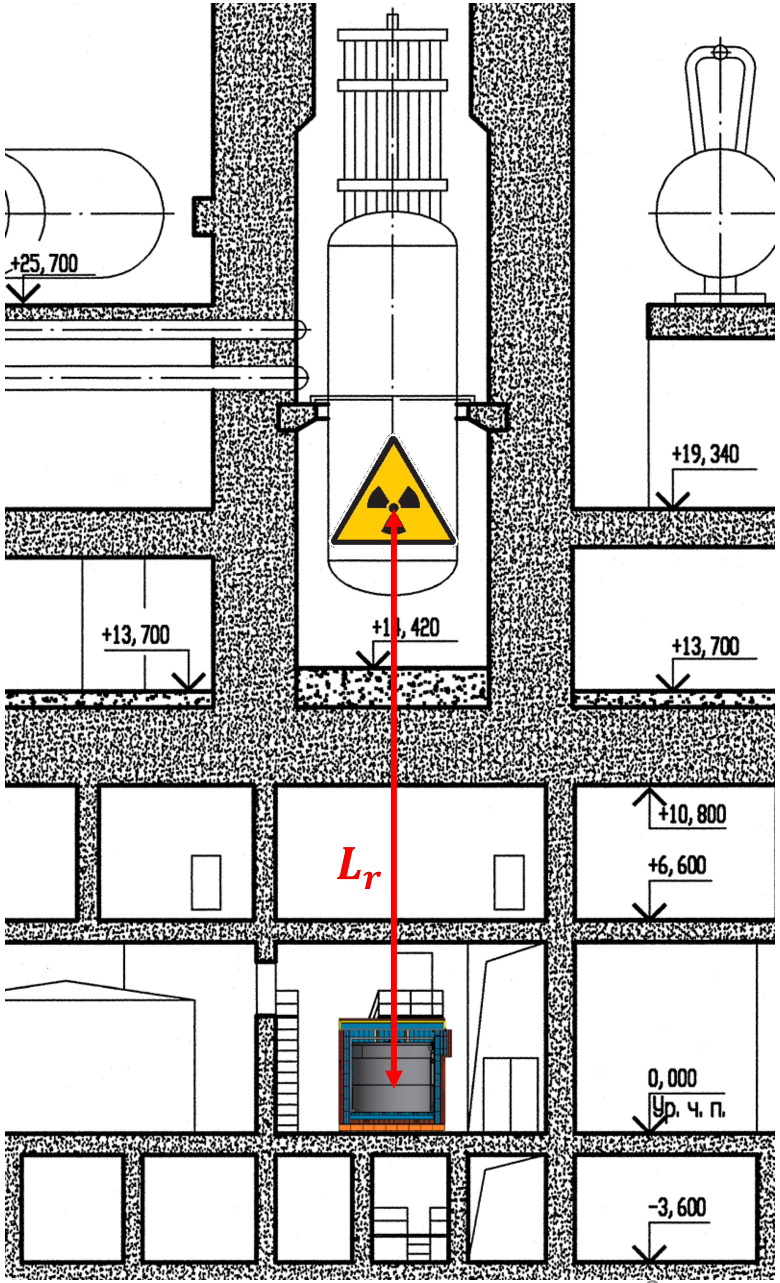




1 (orange) – cast iron (14 см)
2 (yellow) – lead (5 см)
3 (brown) – pure polyethylene (10 cm)
4 (blue) – borated polyethylene (16 см)
5 – detector body

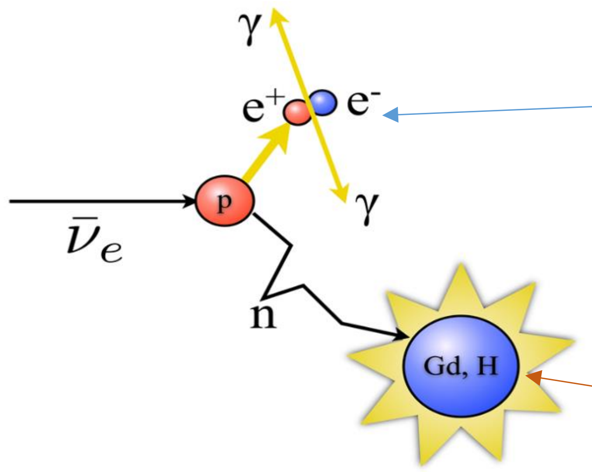
3 GWt PWR-1000
Active zone
(KNPP 3-rd energy unit, Russia)
$L_r = 19.5 \pm 0.1\ m$
The specialized Geodetic measurements
The uncertainty $\leq$ 0.5%

- Buffer – pure LAB, 0.5 m^3
- γ-catcher (GC) – LOS w/o Gd, 1.8 m^3
- Target (TG) – Gd-LOS (1 g/l) , 1 m^3
- 16 R5912 PMT in TG, 12 in GC
- Two μ –plates above detector



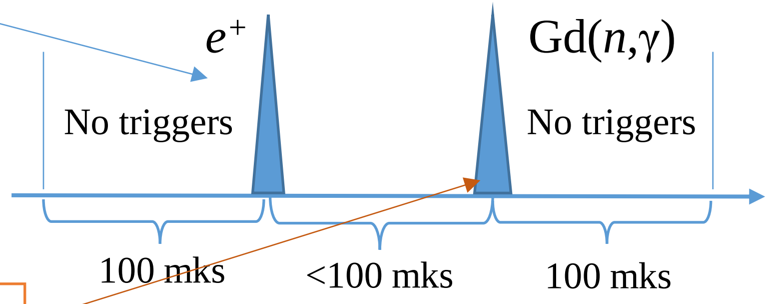
Detection principle and selection criteria

Delayed coincidence technique:



Prompt event- positron

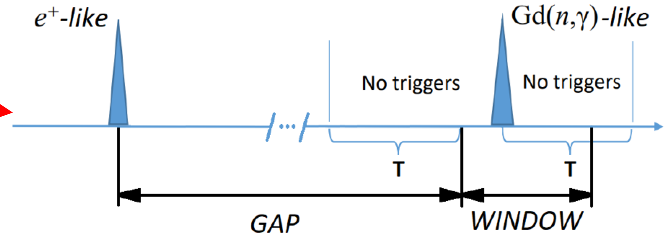
Delayed event - neutron



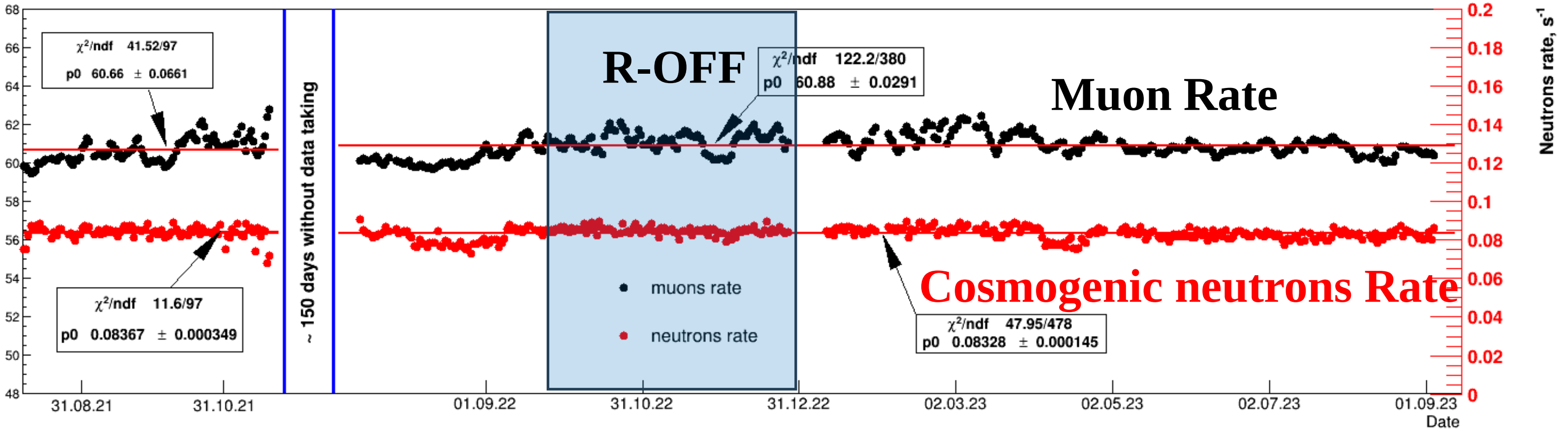
$\bar{\nu}_e + p \rightarrow e^+ + n$ – the inverse beta-decay reaction
E_{th} = 1,8 MeV – energy threshold
$E_{prompt} = E_\nu - 0{,}78$ MeV – the E_{e^+} and the $E_{\bar{\nu}_e}$ connection

Selection criteria:
- $E_{prompt} \in [4; 8]$ MeV
- $E_{delayed} \in [5;10]$ MeV
- $\Delta T < 100\ \mu s$
- Isolation cut: absence of any trigger within 100 μs before prompt and after the delayed event;

Accidentals apprximation(“off-time window” method)
- GAP = 500 μs;
- WINDOW = 100 μs;
- 100 consecutive windows.

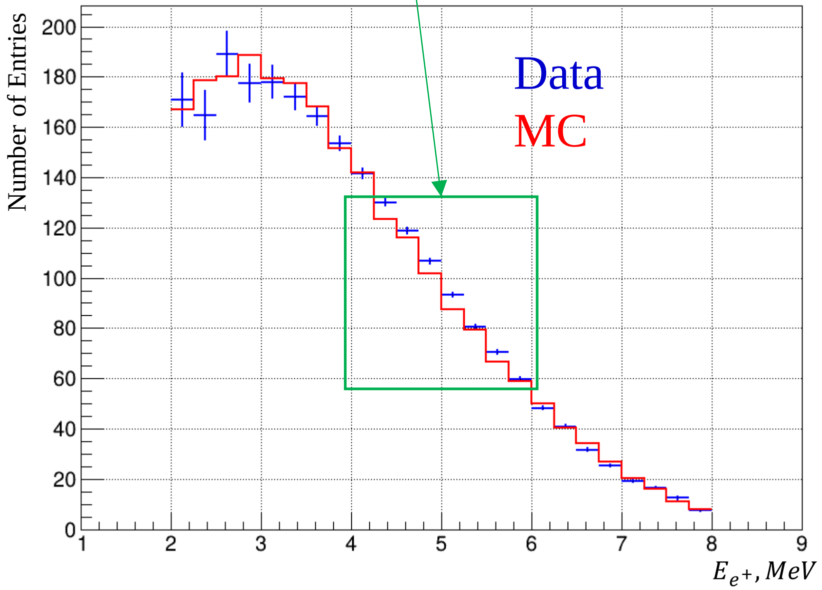


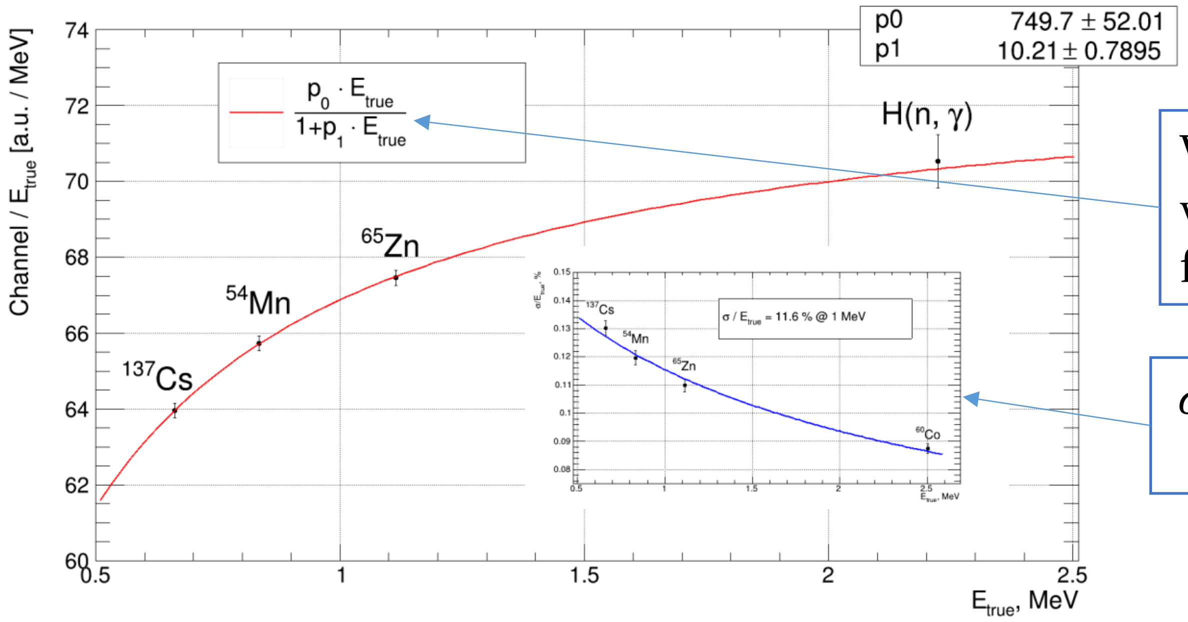
Signal and Background



Dedicated study

There is a trace of the 5MeV spectral distortion ("Bump")



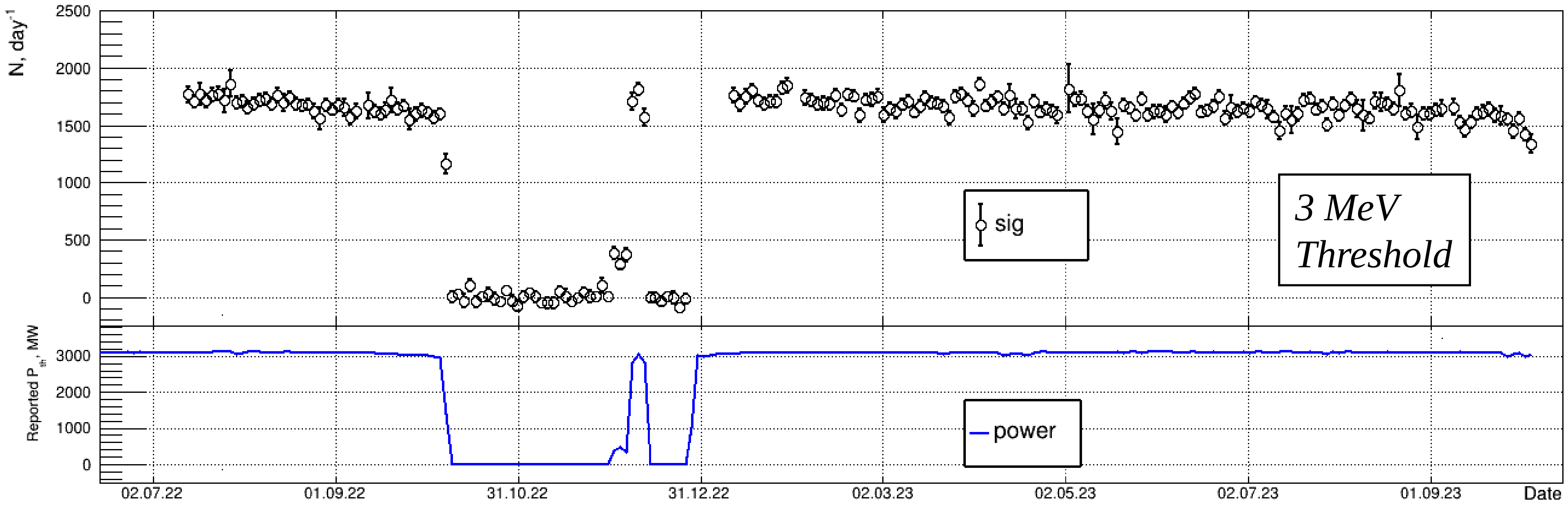


Well-described with "Birks" function

$\sigma/E_{true} = 12\%$ at $1\ MeV$

The Gd-doped scintillator is stable during three years. A successful experience.

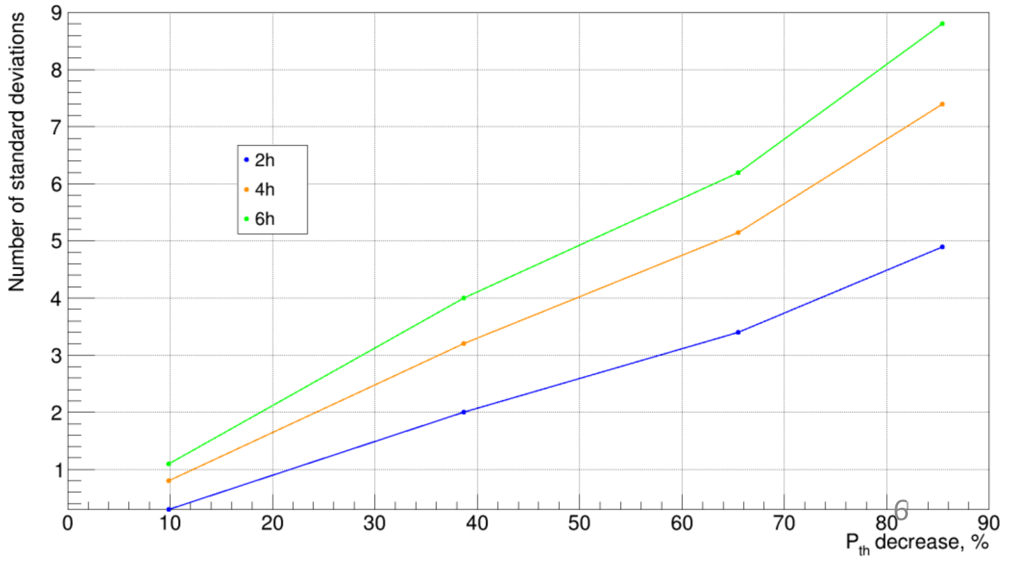
The power change measurements



The iDream sensitivity for the operational power decrease

$$\sigma = 20 \frac{\overline{\nu}_e}{4h.}$$

- The 50% power decrease can be registered within 2 (4) hours with 2.6 (4)σ stat. significance;
- The 10% power decrease can be registered within 6 hours with 1.1 σ stat. significance.



The power output measurements

The number of events is equal:

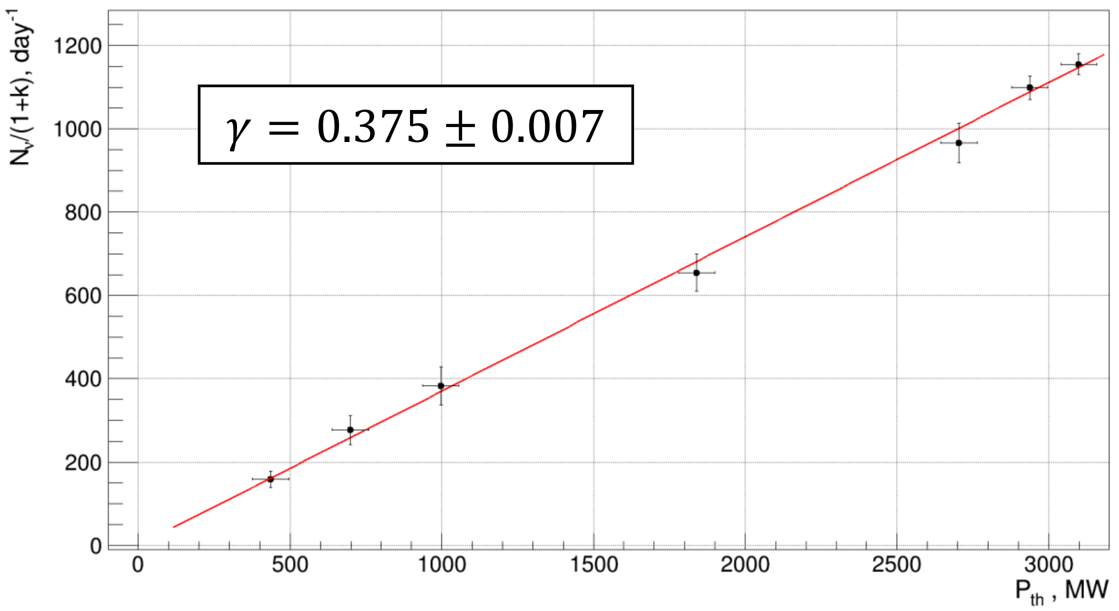
$$N_\nu = \gamma(1+k)P_{тепл}$$

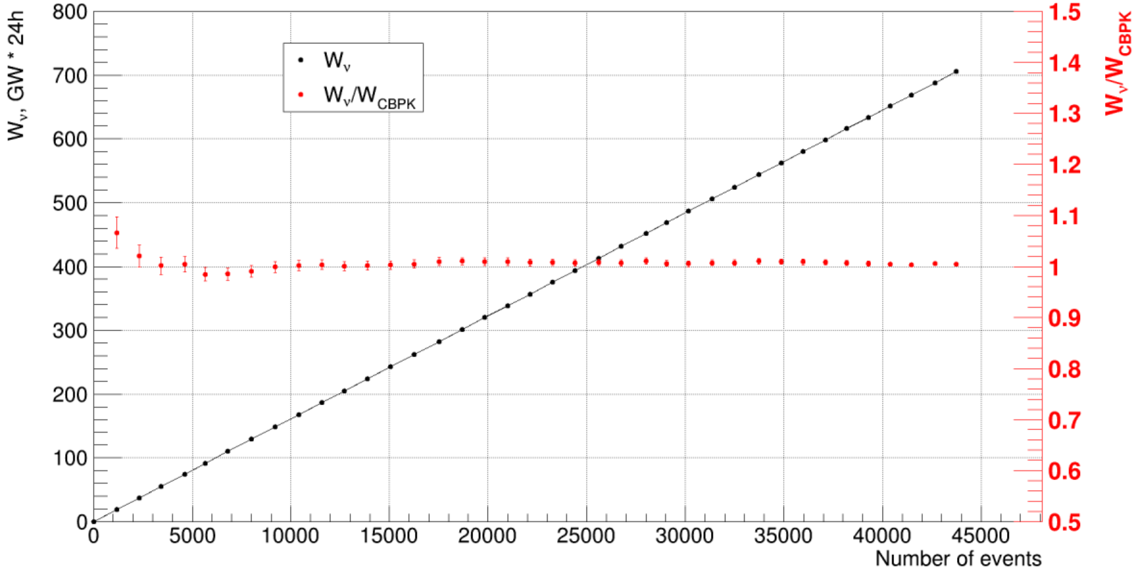
$\gamma = \frac{\epsilon N_p}{4\pi R^2}\frac{\sigma_5}{\overline{E}_5}$ - Detector dependent parameter

$1 + k = \frac{1+\sum_i \alpha_i(\sigma_i/\sigma_5 - 1)}{1+\sum_i \alpha_i(E_i/E_5 - 1)}$ - Reactor dependent parameter

$N_\nu = 224 \pm 20\,\frac{\overline{\nu}_e}{4h.}$ for 103% of nominal power

$$\frac{N_\nu}{1+k} = \gamma P_{th}$$





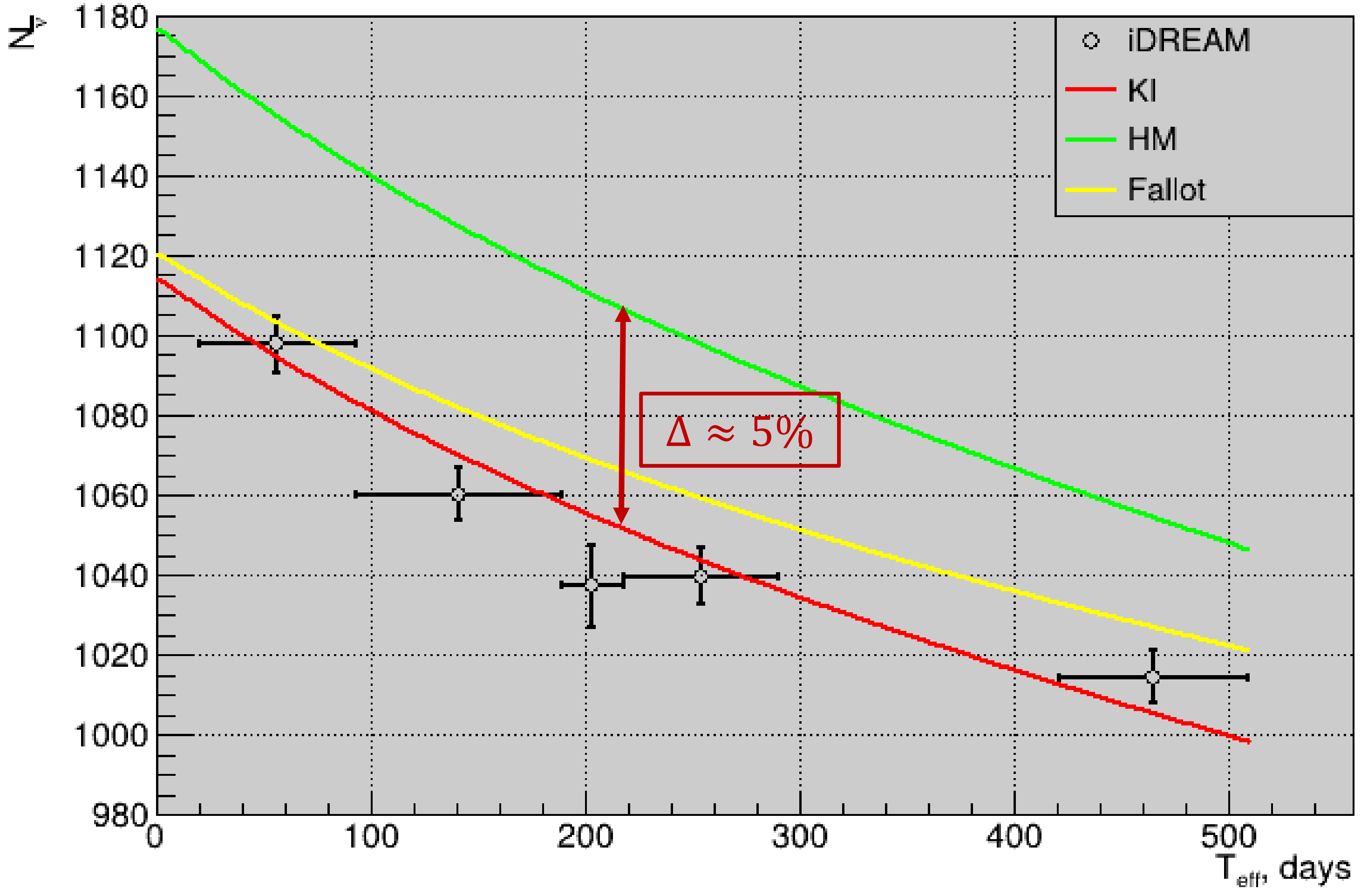
Relative method:

- Operational power data and fission fractions estimates have been provided by the NPP;
- The detector properties parameter γ determined by the calibrations with known operational power.

Power output: $W_{th} = \int P_{th}(t)dt$;

If $\boldsymbol{N_\nu}$ **~ 10000,** $\boldsymbol{W}_{\text{СВРК}}$ **agrees with** $\boldsymbol{W_\nu}$ **within less than 1%.**

The $\overline{\nu}_e$ rate evolution during the campaign.



- The $\overline{\nu}_e$ rate decrease over the full cycle is ~10%. Energy range [4; 8] MeV
- Δ is due to the normalization of ^{235}U spectrum;
- Seems like that KI model represents the data better.

KI – Kurchatov institute model[1]
HM – Huber-Muller model[2]
Fallot – Estienne-Fallot model[3]

References:

[1] V. Kopeikin, M. Skorokhvatov, and O. Titov, Phys. Rev. D 104, L071301 (2021).

[2]T. A. Mueller, D. Lhuillier, M. Fallot, A. Letourneau, S. Cormon, M. Fechner, L. Giot, T. Lasserre, J. Martino, G. Mention, et al., Phys. Rev. C 83, 054615 (2011). P. Huber, Phys. Rev. C 84, 024617 (2011)

[3] M. Estienne, M. Fallot, A. Algora, J. Briz-Monago, V. M. Bui, S. Cormon, W. Gelletly, L. Giot, V. Guadilla, D. Jordan, et al., Phys. Rev. Lett. 123, 022502 (2019).

Conclusion:

- Technology development is on-going:
  - Stable Gd-doped LOS;
  - Materials compatibility measurements;
- The power output measurements: If $\boldsymbol{N_{\nu}}$ **~ 10000,** $\boldsymbol{W}_{\text{СВРК}}$ **agrees with** $\boldsymbol{W_{\nu}}$**, within less than 1%.**
- The unauthorized reactor shutdowns registering:
  - The 50% power decrease can be registered within 2 (4) hours with 2.6 (4)σ stat. significance;
  - The 10% power decrease can be registered within 6 hours with 1.1 σ stat. significance.

Thank you for your attention!