iDREAM detector at Kalinin NPP: antineutrino signal, backgrounds

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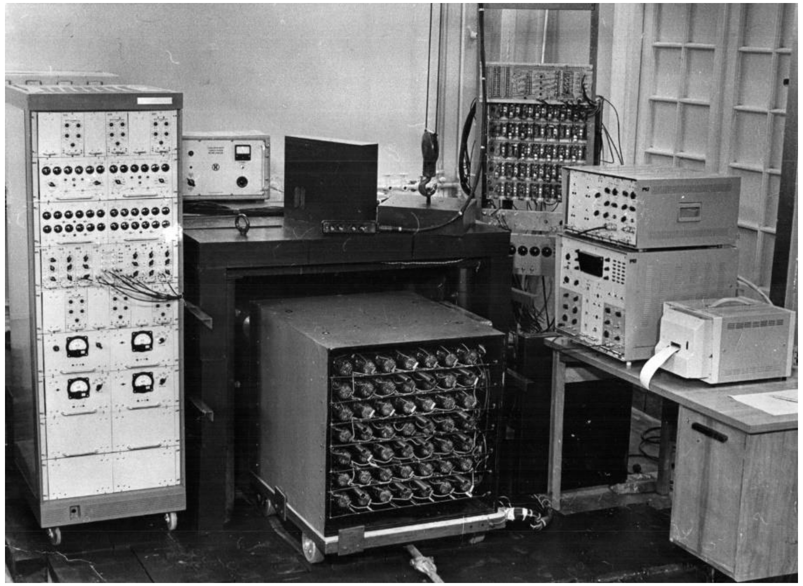
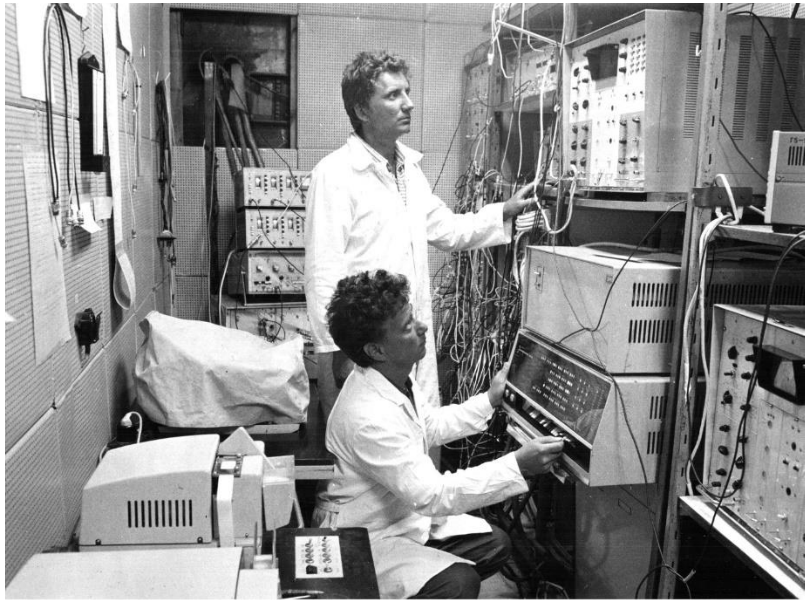
Motivation

- Antineutrinos first detected 60+ years ago
- Idea to utilize neutrinos as a tool for nuclear reactor monitoring expressed 40+ years ago. Isotopic evolution of a nuclear reactor leads to:
  - changes in antineutrino flux
  - changes in antineutrino spectrum
- Many proof-of-principle studies performed since then, starting with ROVNO neutrino detectors 30+ years ago
- NOW time for quantitative study of neutrino reactor monitoring method, including the context of nuclear safeguards



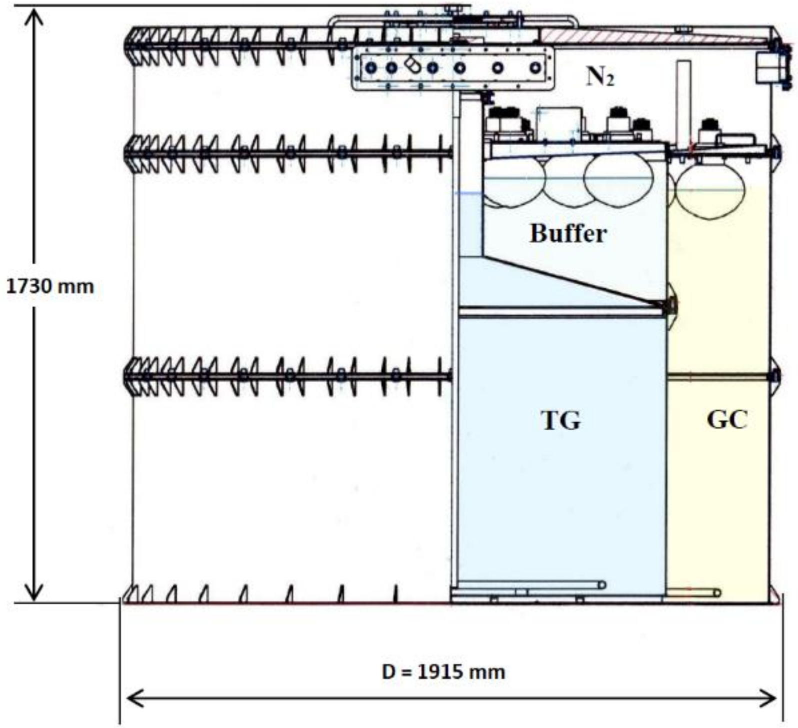
ROVNO antineutrino detector



ROVNO counting room

iDREAM basics

- Initial idea:
  - Build neutrino detector for applied physics based on proven technologies, in order to provide easy manufacturing and maintenance
  - Implement the <u>complementary</u>, non-intrusive, neutrino-based tool for the monitoring of the reactor state and the estimation of the accumulated fissile elements for non-proliferation treaties
- Gain experience studying new materials and solutions for future industrial neutrino detectors, and provide them to Russian power units, including floating power plants
- Move towards precision measurement of the nuclear fuel burnup



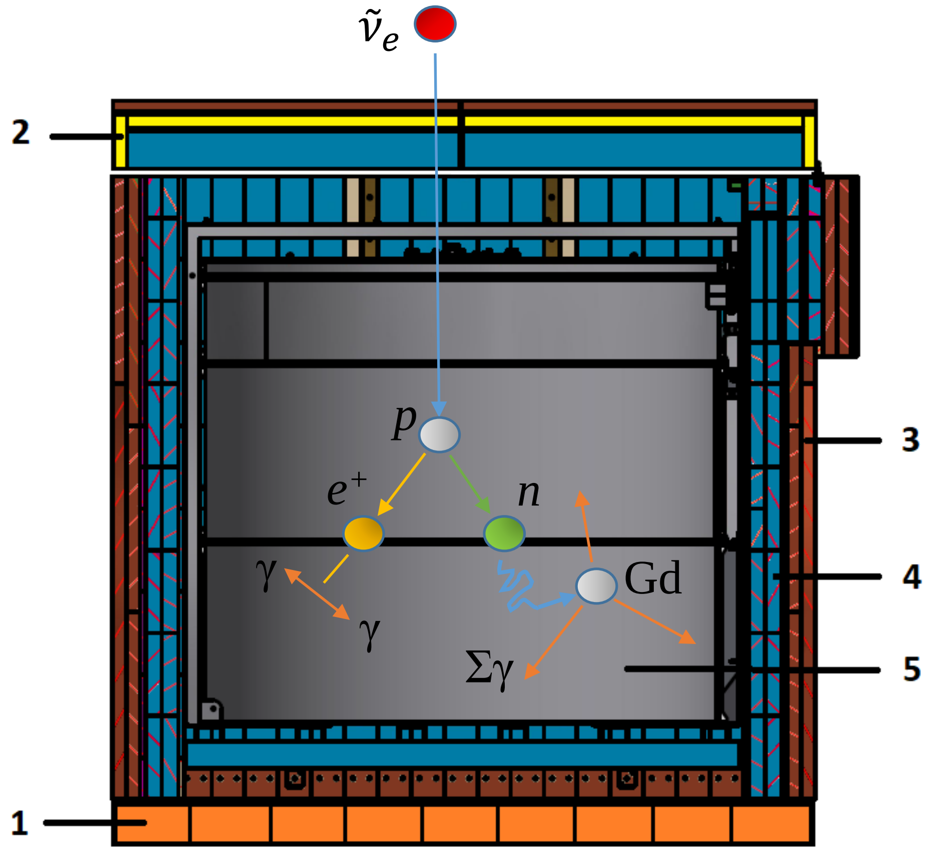
- Target (TG) – Gd-LS (1 g/l) in an inner SS tank, 1 m^3
- G-catcher (GC) – LS w/o Gd in an external SS tank, 1.8 m^3
- Buffer – pure LAB, 0.5 m^3
- 16 R5912 PMTs in the TG, 12 in the GC
- Two muon veto plates on top

For detailed description: A. Abramov *et al* JINST **17** (2022) P09001

iDREAM basics

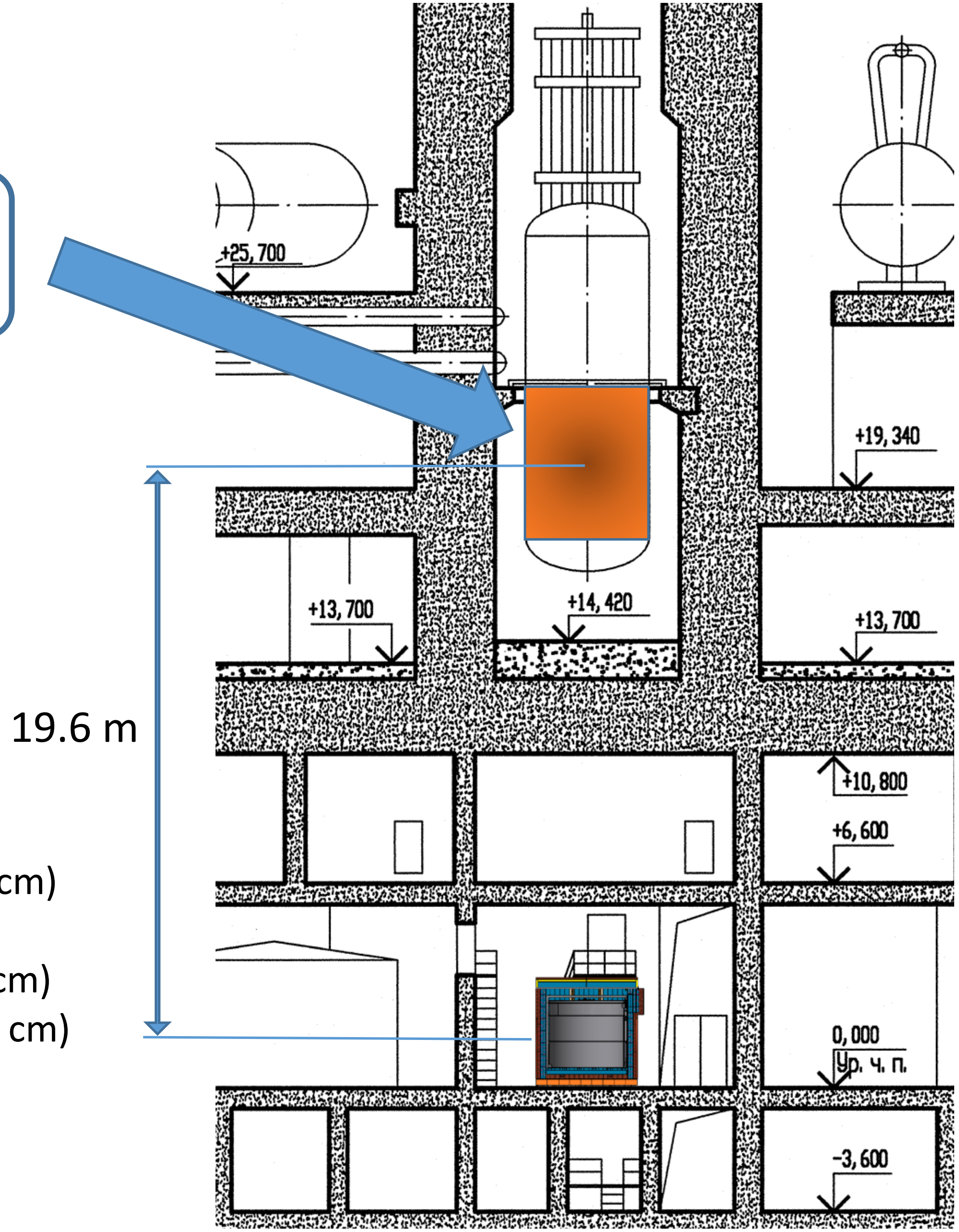
$$\tilde{\nu}_e + p \rightarrow e^+ + n$$

E_{th} = 1,8 MeV $\quad$ $E_{prompt} = E_\nu - 0{,}78$ MeV

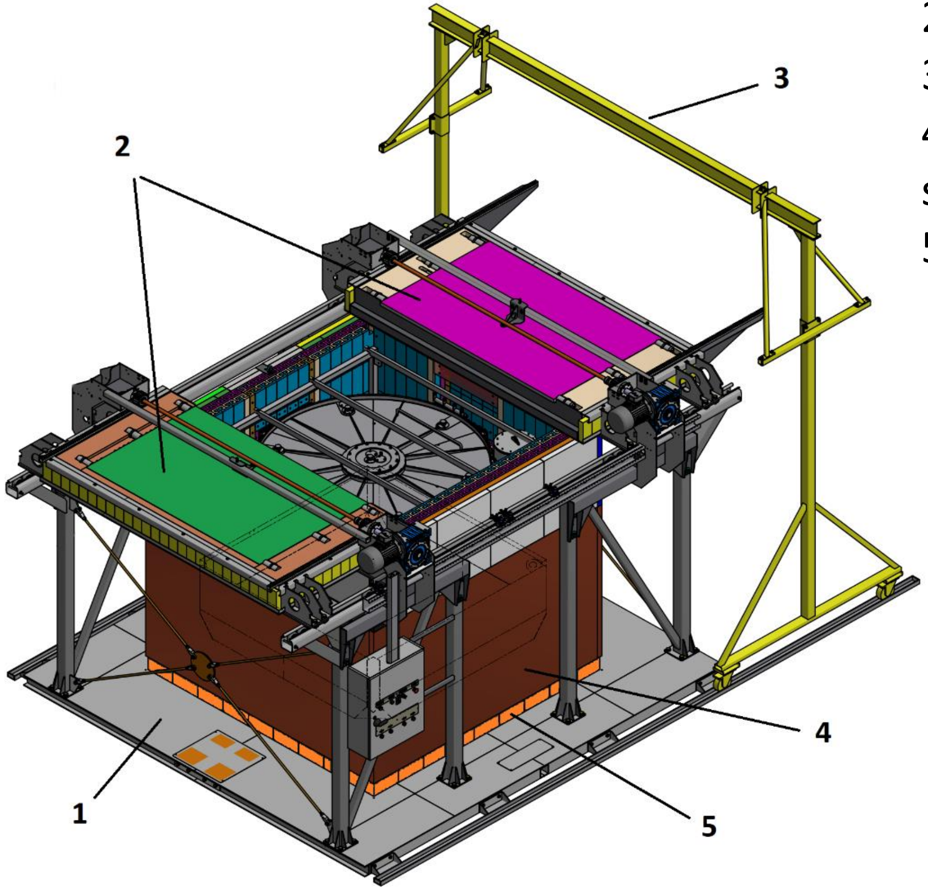


1 (orange) – cast iron (14 cm)
2 (yellow) – lead (5 cm)
3 (brown) – pure p/e (10 cm)
4 (blue) – borated p/e (16 cm)
5 – detector

3 GW_{th} VVER type power reactor core (KNPP 3rd unit, Russia)



iDREAM basics



1 – skid platform
2 – muon plates
3 – gantry mobile crane
4 – pure p/e (outermost shielding layer)
5 – cast iron shielding layer

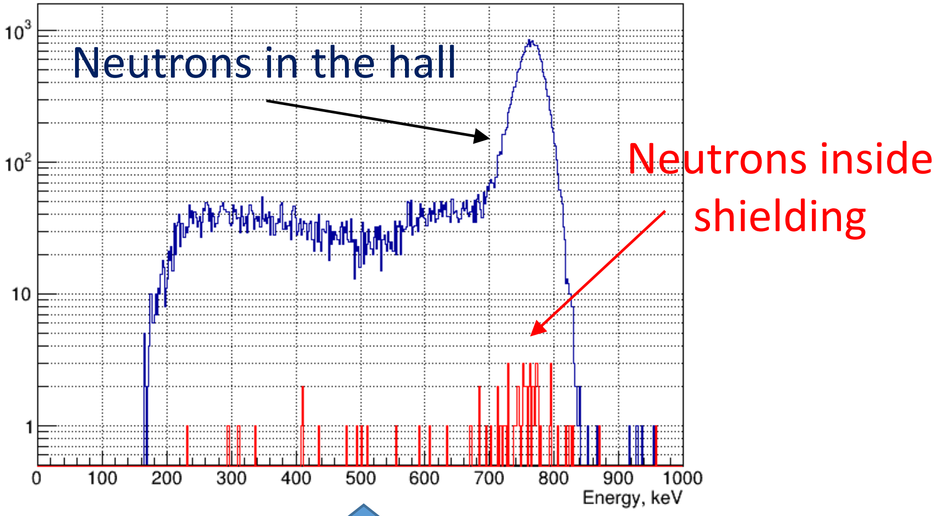
	2021										2022										
	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11
Installation, commissioning																					
Debugging, test running																					
Antineutrino data-taking										No DAQ											
Reactor ON/OFF	R-OFF		R-ON																	R-OFF	

Detector installed in Mar-May 2021.
DAQ paused in Dec-2021 – Apr-2022 due to reasons not related to the detector state.

Current state: data-taking during R-OFF

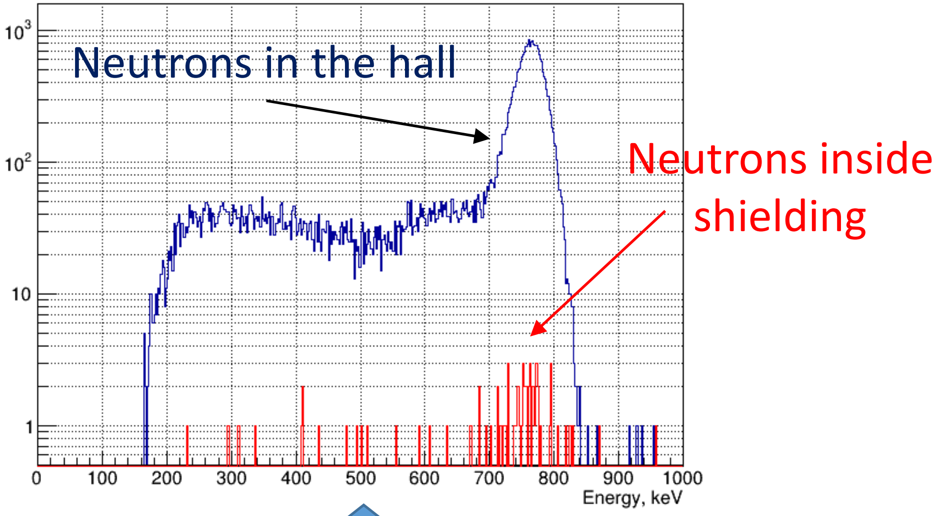
Backgrounds

Backgrounds



Factor of 100 suppression of neutron flux achieved (measured by ^{3}He counters)

Backgrounds



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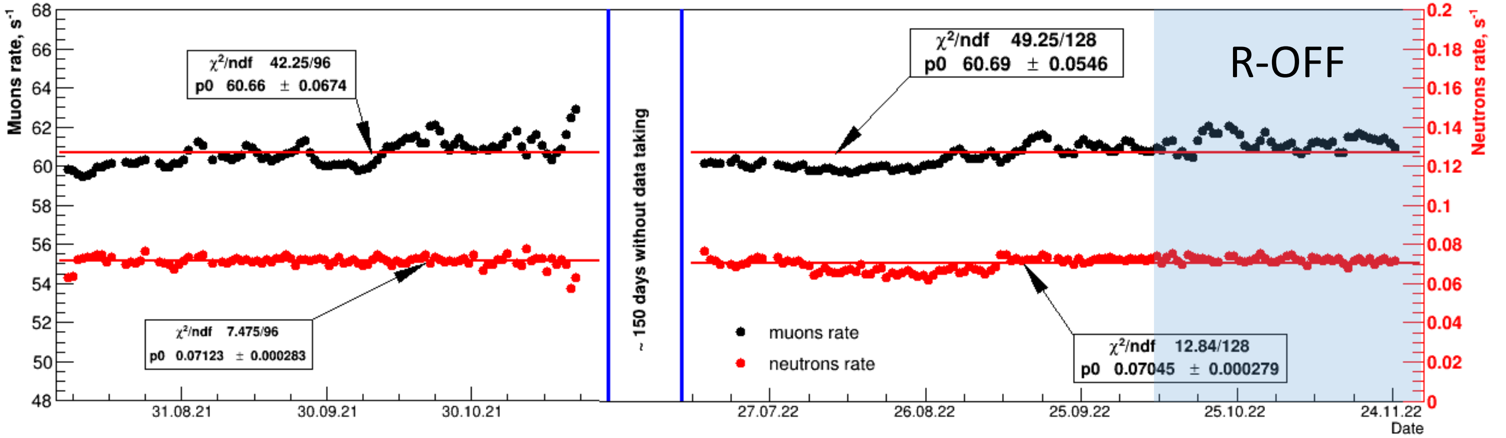
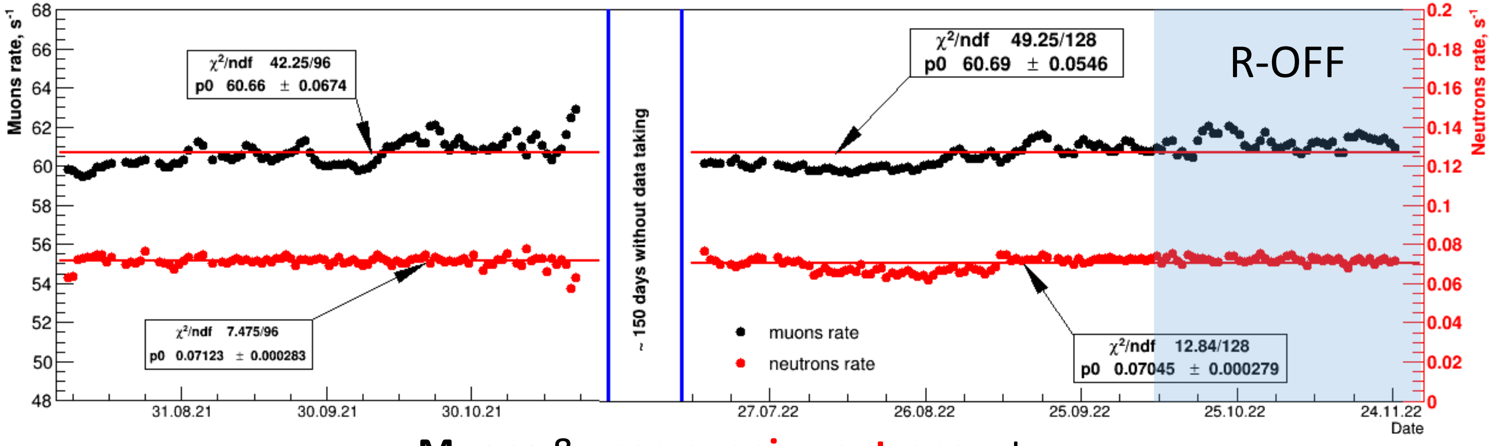
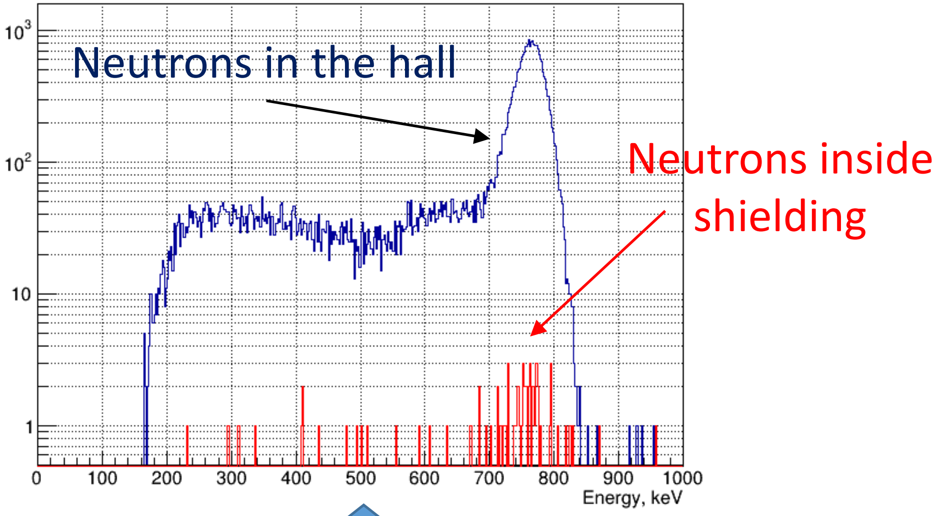


Muons & **cosmogenic neutrons** rate

Backgrounds



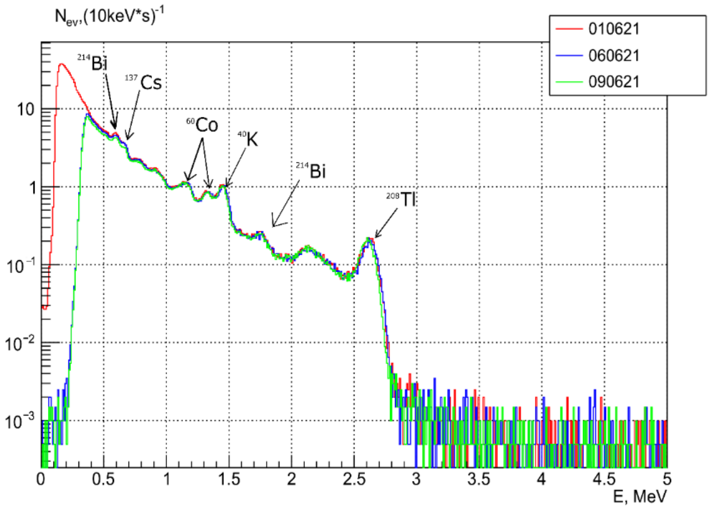
Muons & **cosmogenic neutrons** rate

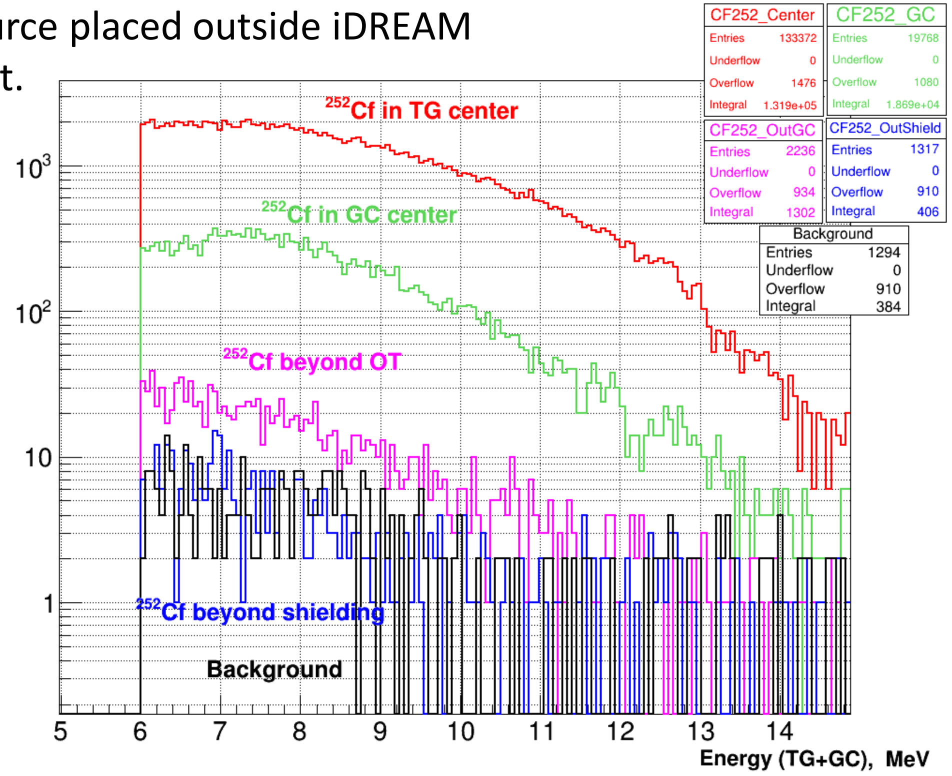


Factor of 100 suppression of neutron flux achieved (measured by ^{3}He counters)

Spontaneous γ's of the ^{252}Cf source placed outside iDREAM shielding <u>do not reach</u> the target.

External γ bkgd is equal or lower than internal



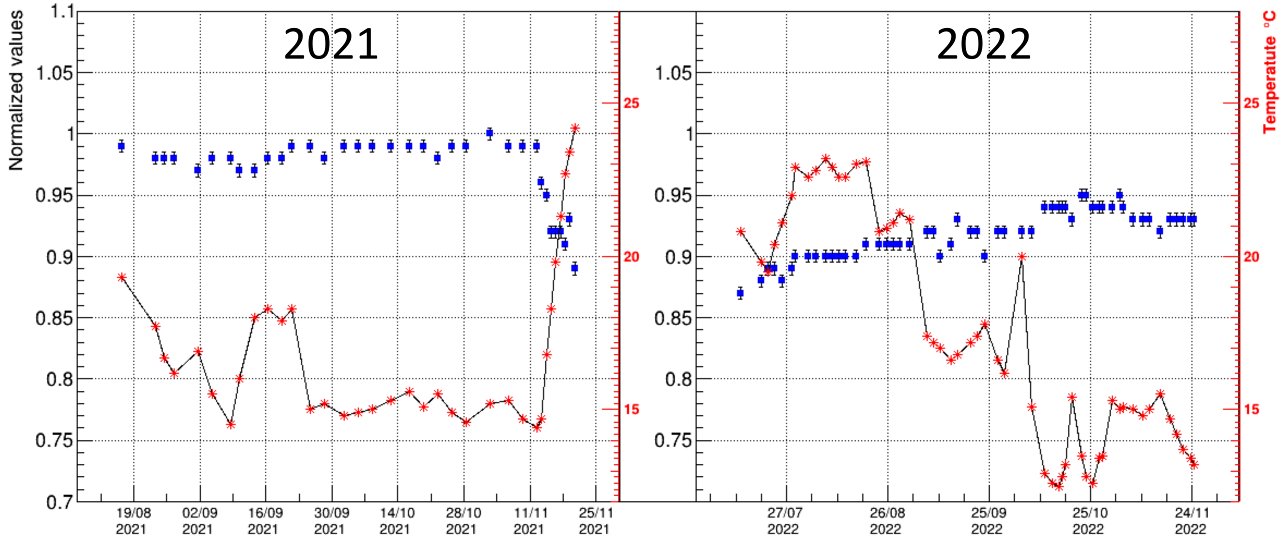


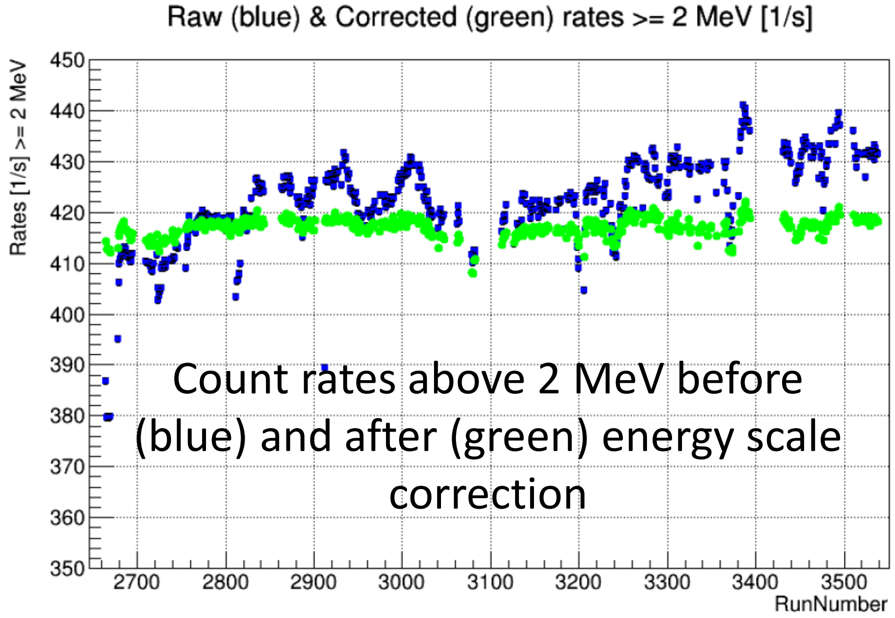
Structure of γ background in the experimental hall <u>understood</u> (measured by NaI)

iDREAM data treatment

- Detector response monitored every 2-3 days via ^{60}Co and ^{252}Cf sources
- Because counting rate fluctuates, the event selection cuts evolve in time
- To account for this effect, iDREAM spectrum in every run is corrected with respect to the one chosen as a reference. Correction coefficients are obtained via the minimization of the difference between two spectra

Relative iDREAM response & Gd-LS temperature





Count rates above 2 MeV before (blue) and after (green) energy scale correction

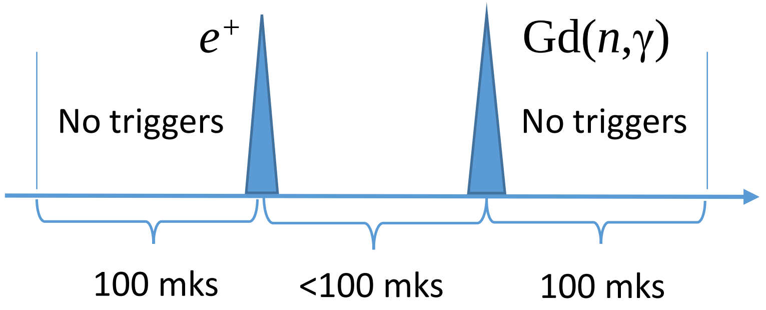
For iDREAM calibration see poster #168 (A. Oralbaev)

Antineutrino signal

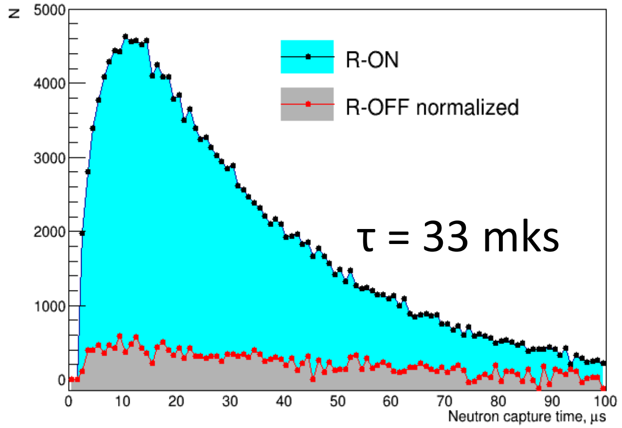
$$N_{det} = \frac{\epsilon}{4\pi L^2} \cdot N_p \cdot \frac{P_{th}}{E_f} \cdot \langle\sigma\rangle$$ - predicted rate

E_f from V. Kopeikin *et al*, Phys. Atom. Nucl. **67** (2004) 1963
$\langle\sigma\rangle$ from V. Kopeikin *et al*, Phys. Rev. D **104** (2021) L071301

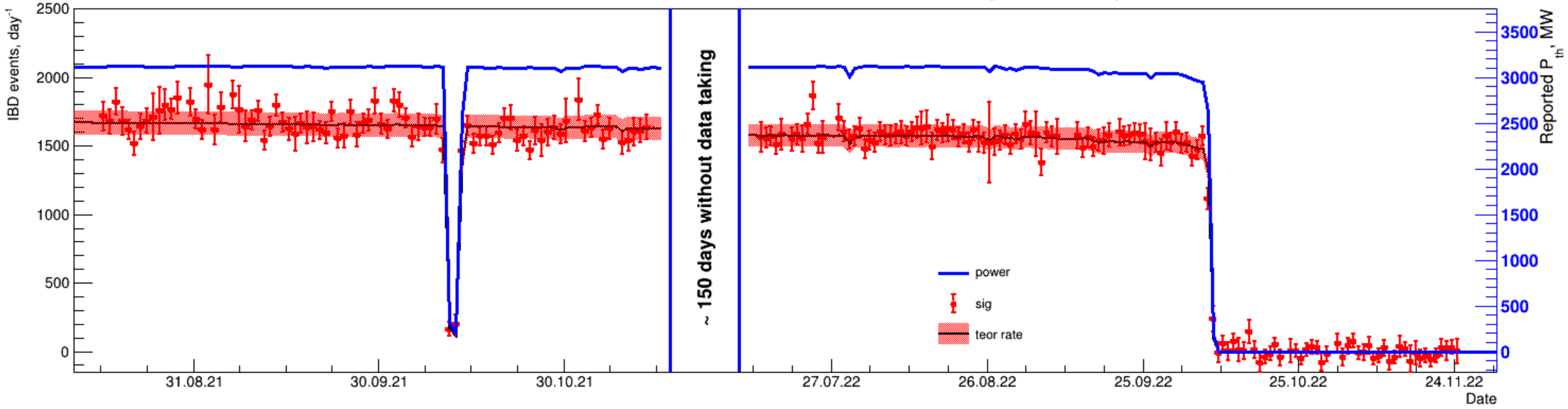
Detection efficiency ϵ = 0.22 ± 0.01 (not finalized yet)

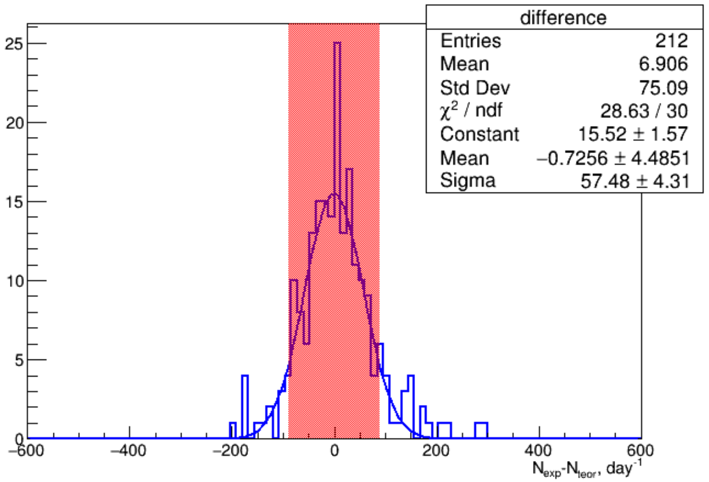


101.7 live days in R-ON
27.5 live days in R-OFF



IBD rate (accidentals subtracted) & reported power





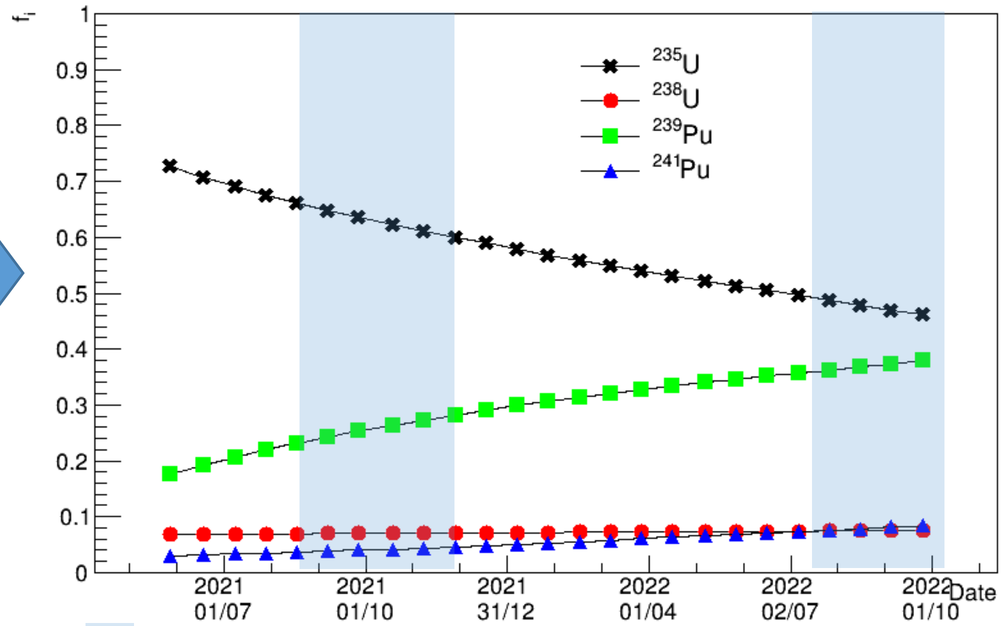
1σ region for predicted rate, calculated according to Z Djurcic *et al* 2009 J. Phys. G: Nucl. Part. Phys. **36** 045002 (includes 5% error for efficiency)

Candidates	Correlated bkgd	Effect
1788.6 ± 5.6$_{stat.}$ day^{-1}	204.7 ± 7.8$_{stat.}$ day^{-1}	1583.9 ± 9.6$_{stat.}$ day^{-1}

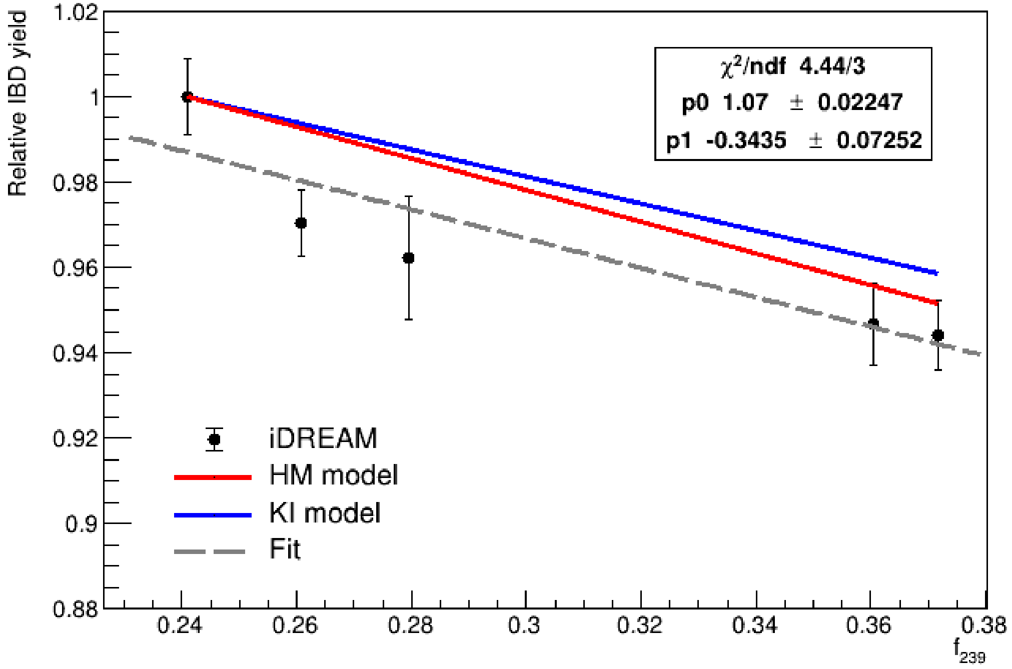
Relative IBD yield

Evolution of the fission fractions during campaign, according to the KNPP 3rd unit power curve

Time evolution of fission fractions



Periods in campaign covered by iDREAM data



No absolute IBD yield, until the detector efficiency is known. Nonetheless, even with such a fragmentary statistics the fuel burn-up is clearly visible

HM model – P. Huber, Phys. Rev. C **84** (2011) 024617; Th. A. Mueller *et al*, Phys. Rev. C **83** (2011) 054615

KI model – V. Kopeikin *et al*, Phys. Rev. D **104** (2021) L071301

Conclusion

- As of today, 101.7 live days in R-ON and 27.5 live days in R-OFF mode are available. Accumulation of the statistics is ongoing
- Antineutrinos and fuel burn-up are clearly visible, no doubts in proper work of the detector as a counting device
- Understanding of the detector as a spectrometer in progress

iDREAM team

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