RED
RUSSIAN EMISSION DETECTOR

МИФИ
Национальный исследовательский ядерный университет

The RED-100 Experiment: Recent Results and Future Prospects

Aleksei Shakirov on behalf of the RED collaboration

22nd Lomonosov Conference on Elementary Particle Physics

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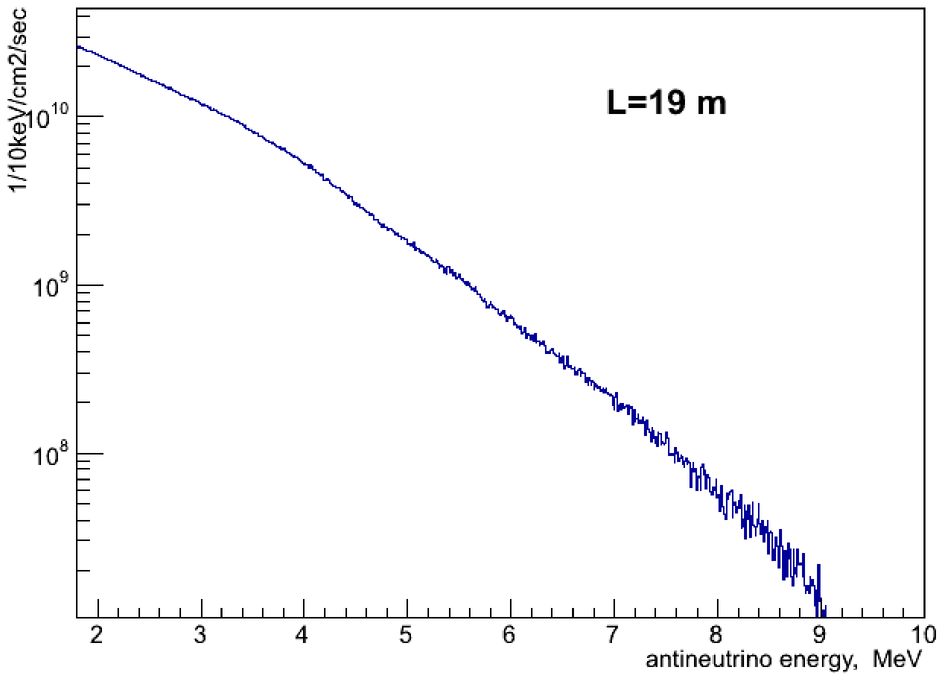
Coherent Elastic Neutrino-Nucleus Scattering (CEvNS)

$$\sigma \approx \frac{G_F^2}{4\pi}(N - (1 - 4\sin^2\theta_W)Z)^2 E_\nu^2 \propto N^2$$

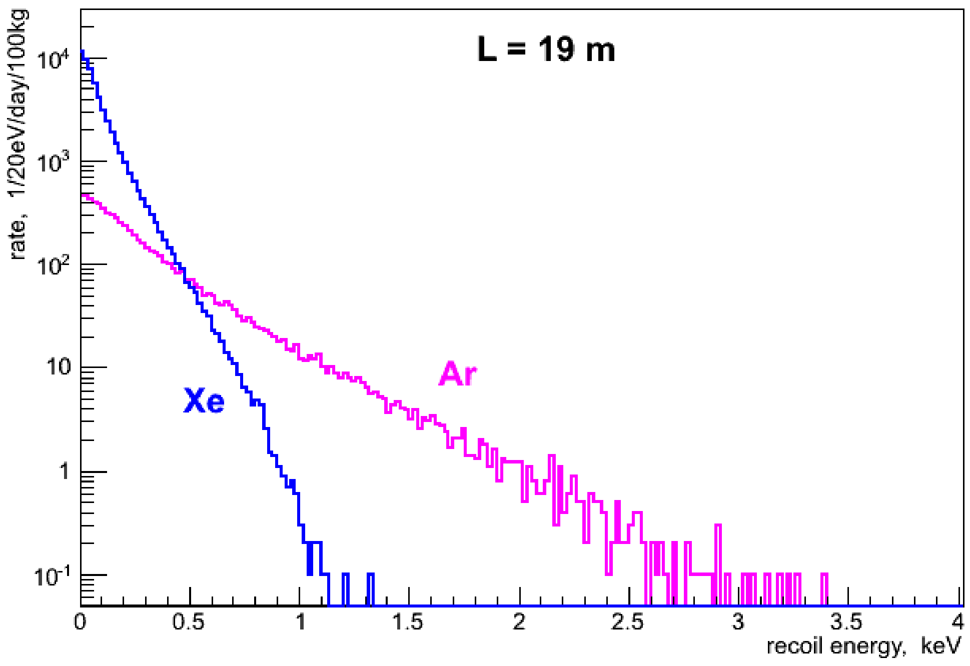
$$T_{max} = \frac{2E_\nu^2}{M + 2E_\nu}$$

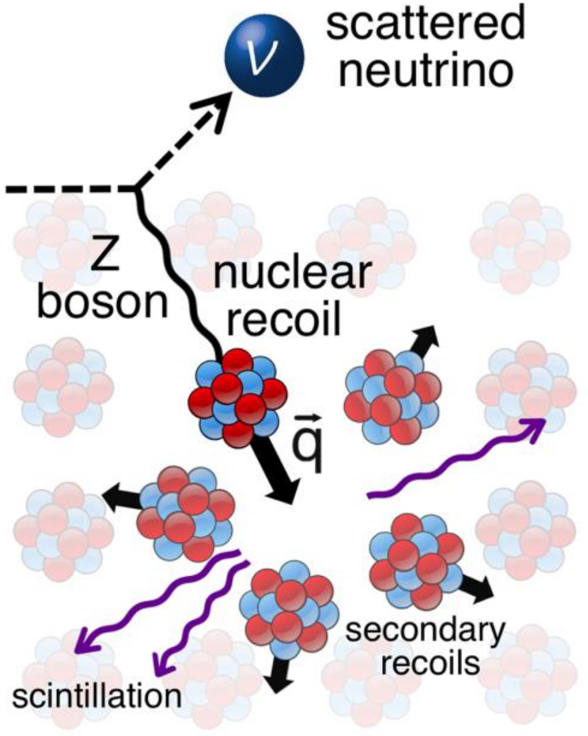
- Largest neutrino cross-section
- Very low nuclear recoil energy, difficult to detect
- Predicted in 1974, detected in 2017 by COHERENT collaboration
- Valuable both for fundamental physics and nuclear reactors monitoring

reactor $\bar{\nu}_e$ spectrum



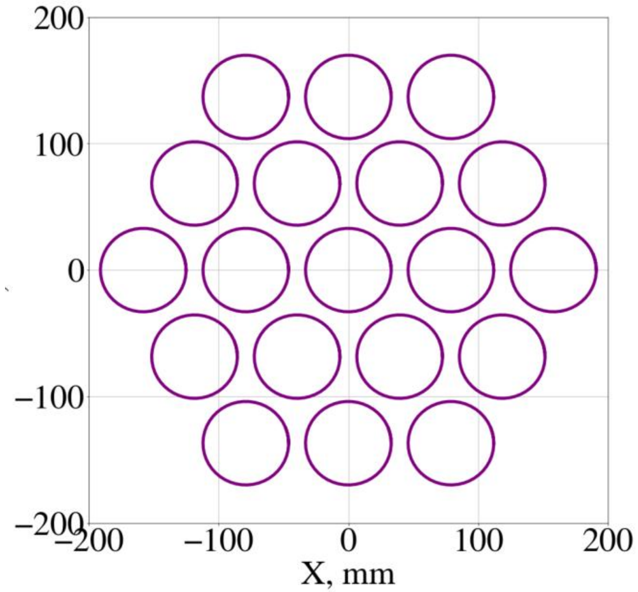
nuclear recoil spectra



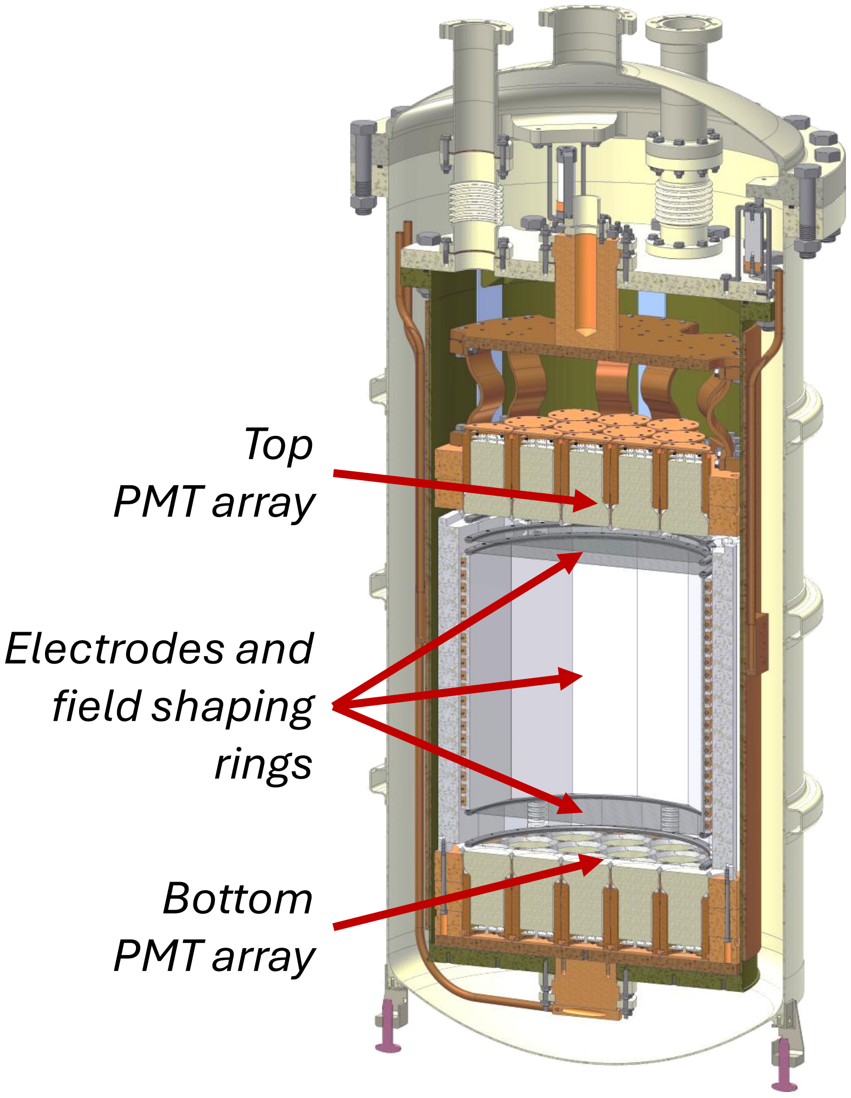


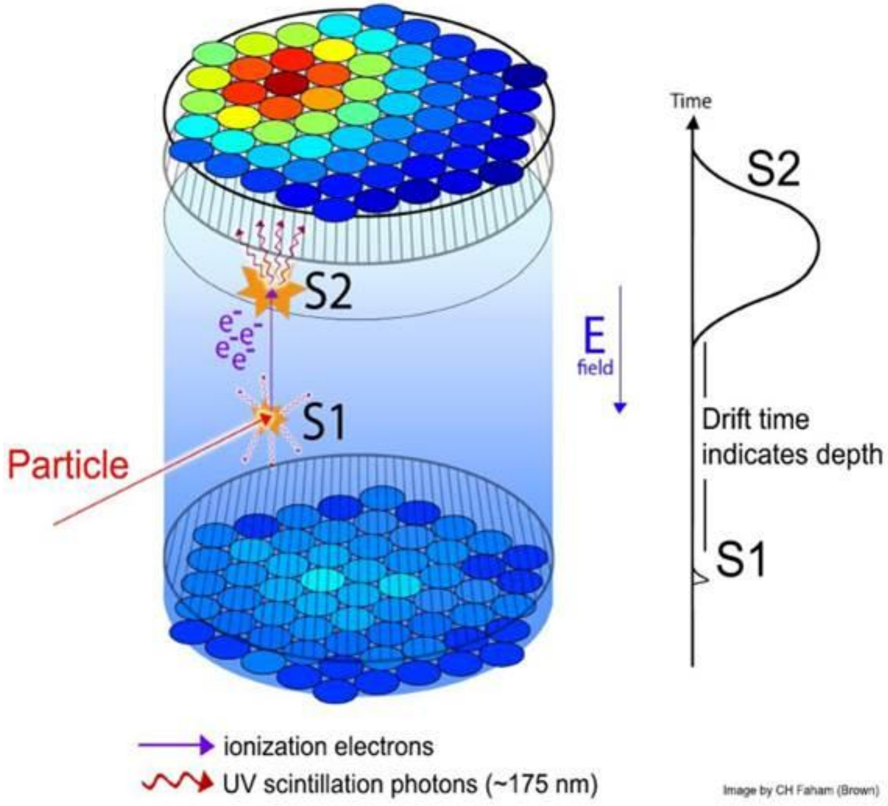
RED-100 Detector

- Contains
  - ~200 kg LXe (~75 kg in the active volume)
  - ~100 kg LAr (~35 kg in the active volume)
- PMT Hamamatsu R11410-20
  - 19 in the top array
  - 7 in the bottom array



Geometry of the PMT array



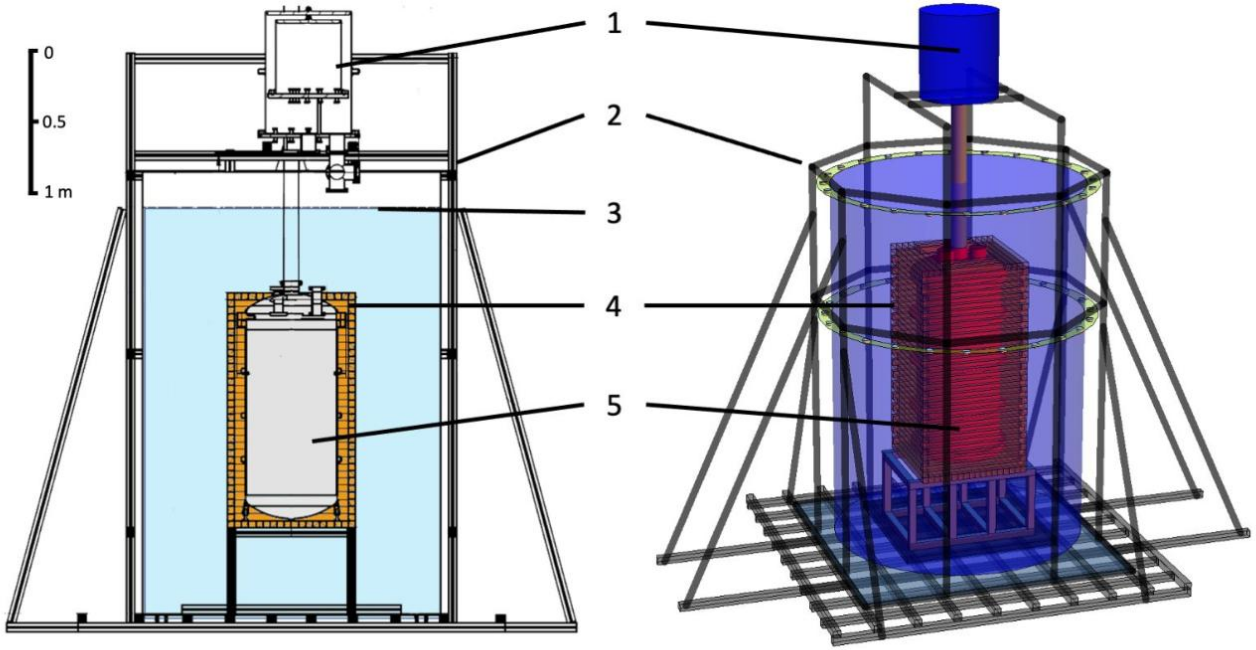


- Two-phase emission method
- Widely used in dark matter experiments
- Sensitive to single ionization electrons. Several SE are expected from CEvNS

[B. A. Dolgoshein et al, JETP Lett. 11, 513 (1970)](#)
[D.Y. Akimov et al 2020 JINST 15 P02020](#)

RED-100 at Kalinin NPP

- 19 m from the reactor core
- Antineutrino flux is ~ 1.35 x 10^{13} cm^{-2} s^{-1} (thermal power of reactor is ~ 3.1 GW)
- Reactor core, building and infrastructure work as passive shielding from cosmic muons
- ~50 m.w.e. in vertical direction
- Passive shielding contains:
  - 5 cm of copper (gamma shielding)
  - 70 cm of water (neutrons shielding)
- Timeline:
  - 2020: RED-100 was shipped to KNPP
  - 2021: Deployment and test
  - 2022: Science run (reactor OFF & ON periods)

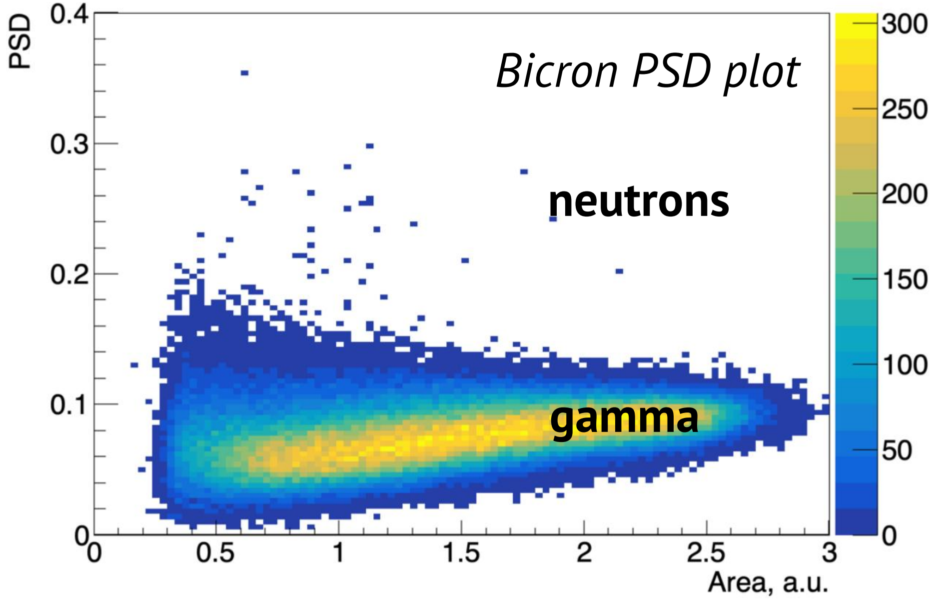


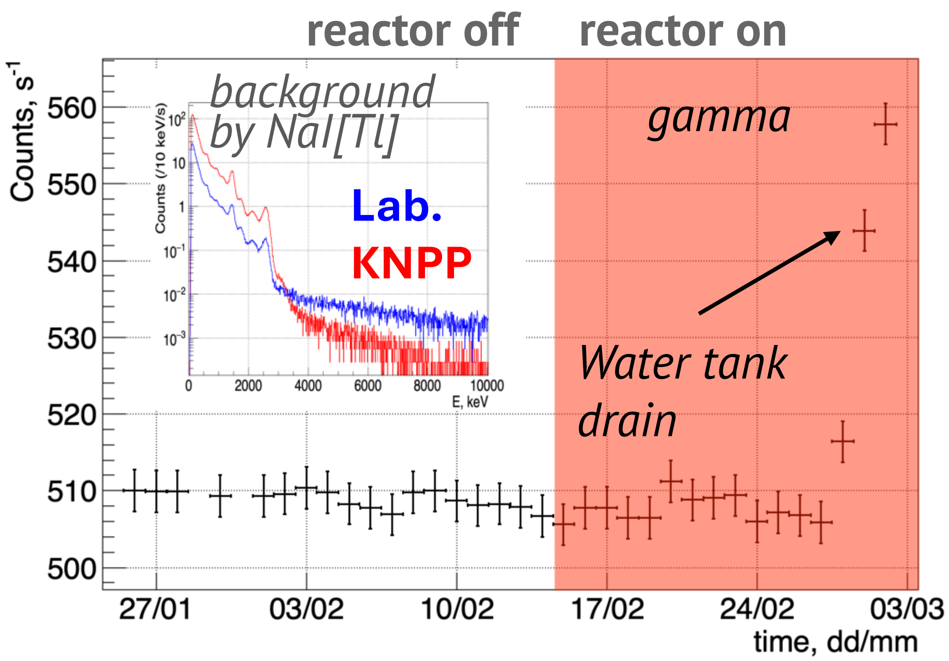
RED 100 passive shielding: 1 — LN_2 tank, 2 — support frame, 3 — water tank, 4 — Cu shielding, 5 — Ti cryostat

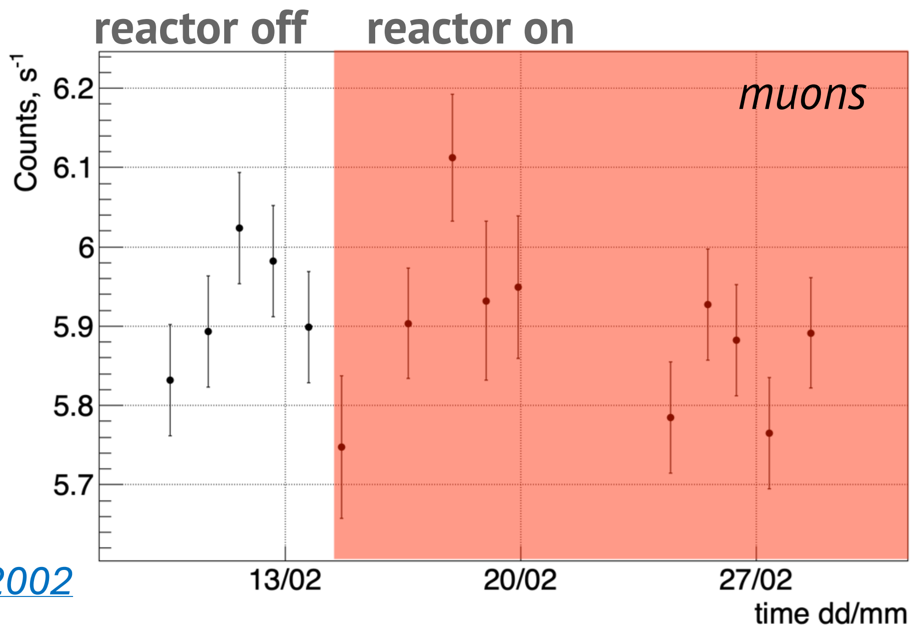
Akimov D. Y., et al. JINST 17.11 (2022), T11011

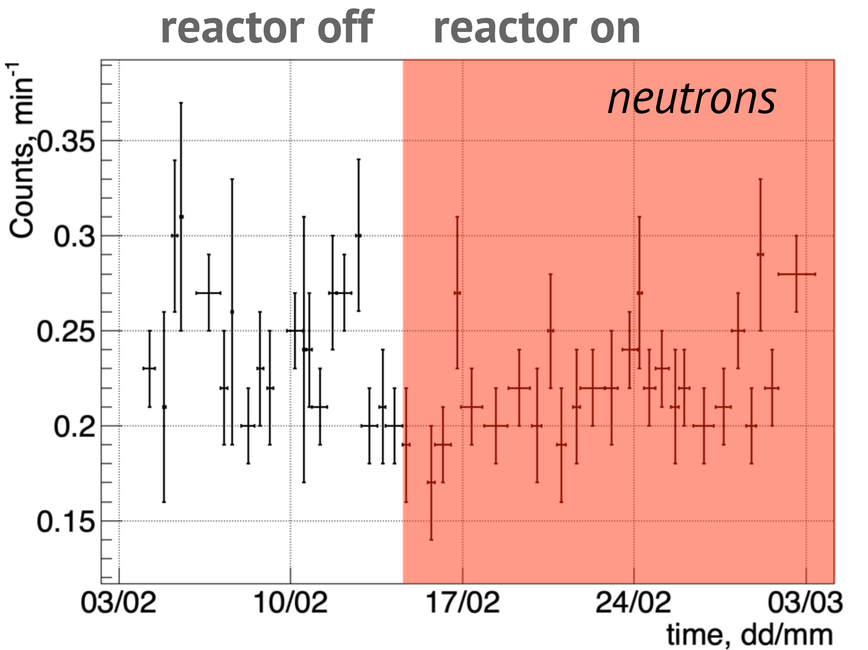
External background

- Background was measured with:
  - RED-100 – muon background
  - NaI[Tl] — gamma background
  - Bicron (BC501A liquid scintillator) — neutron background
- No significant correlation in external background count rate with reactor operation
- Muon background appears to be a source of the random SE







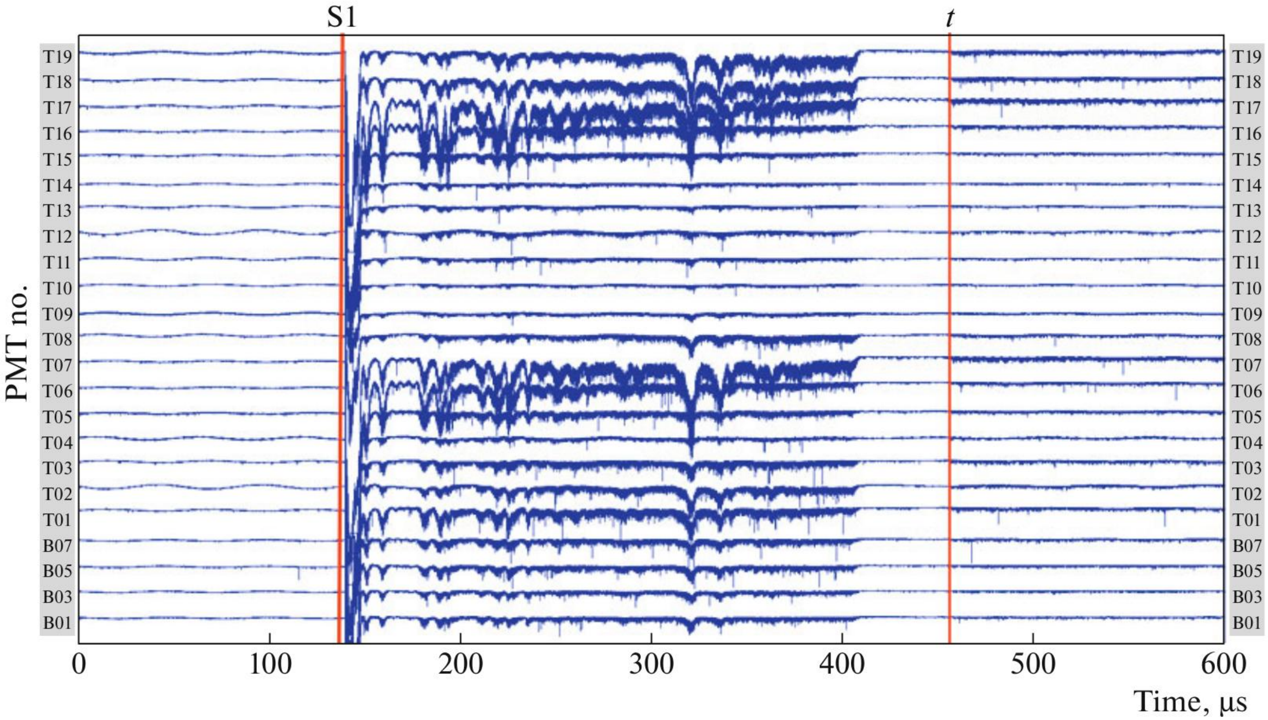


D.Y. Akimov et al 2023 JINST 18 P12002

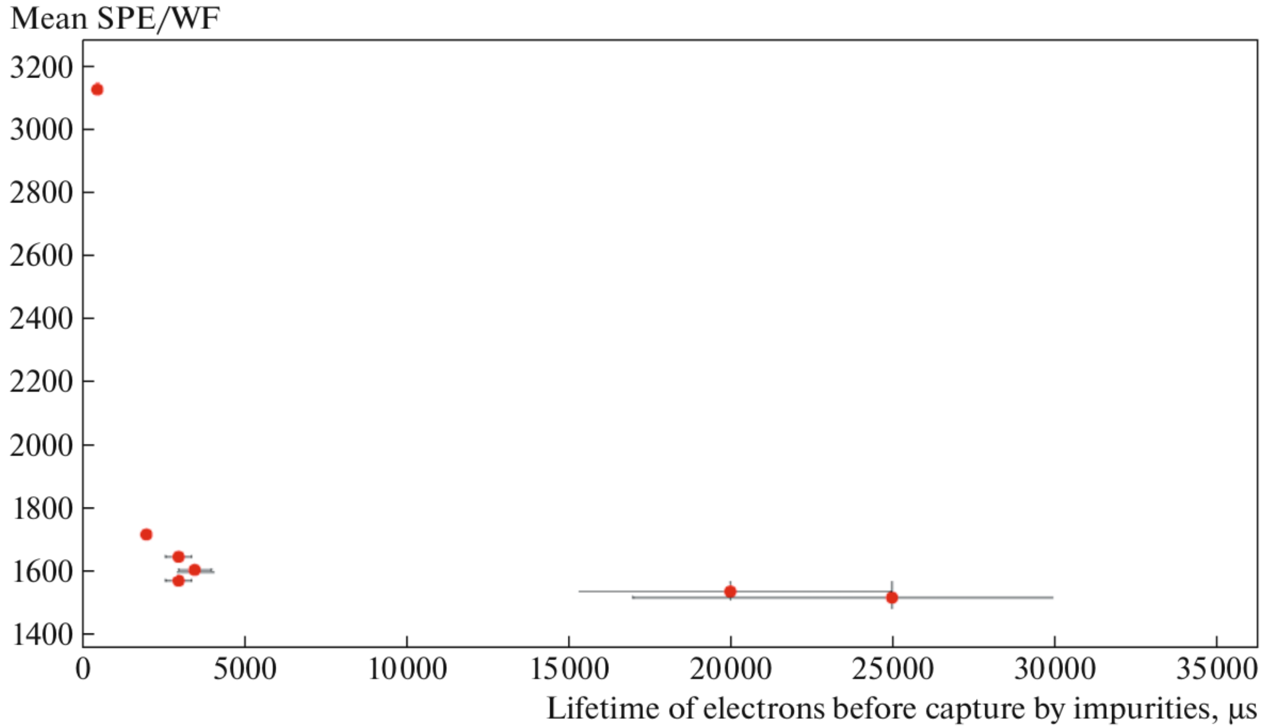
SE noise

- Muon background appears to be a source of the random SE
- Random SE frequency at KNPP was ~30 kHz (rate of muons was ~6 Hz)
- High background is typical for weak protection from cosmic rays

An example of SE noise after muon in LXe

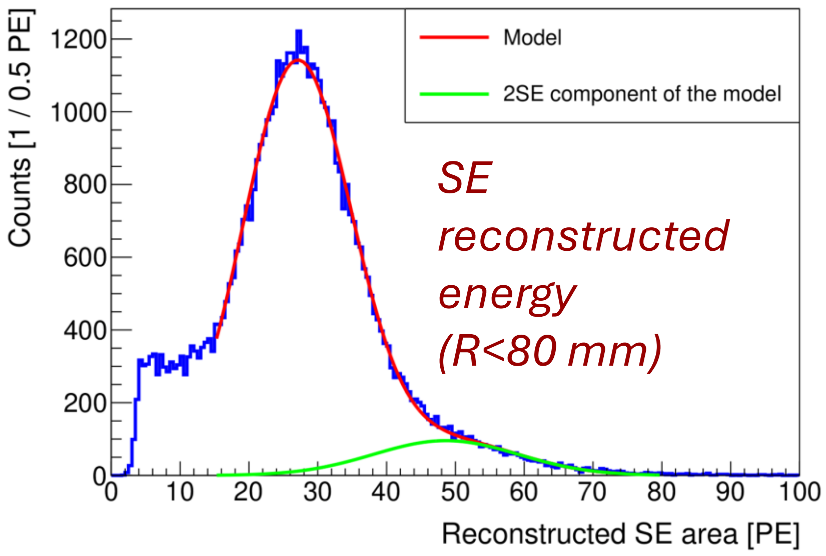


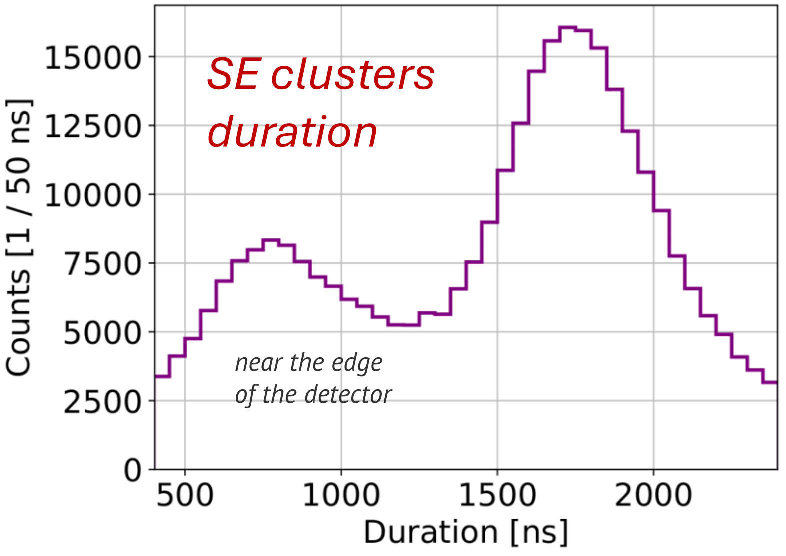
Number of SPE/waveform vs electrons lifetime in LXe

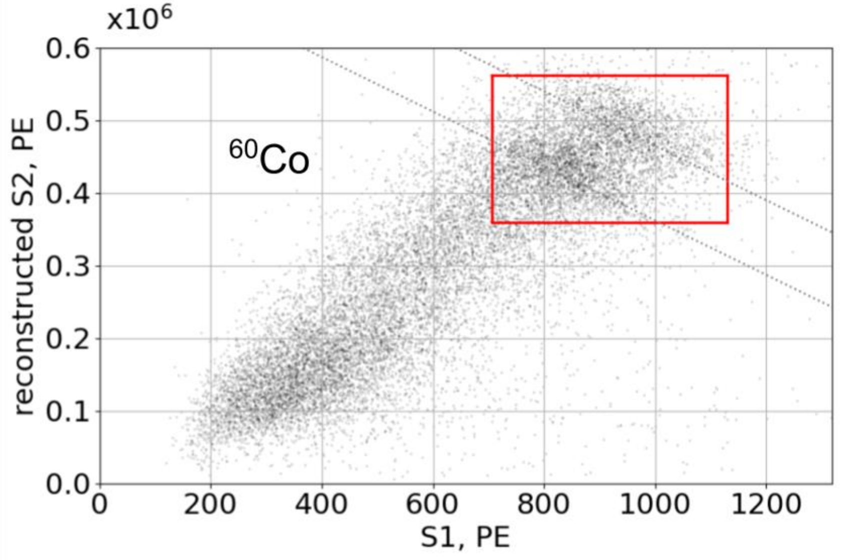


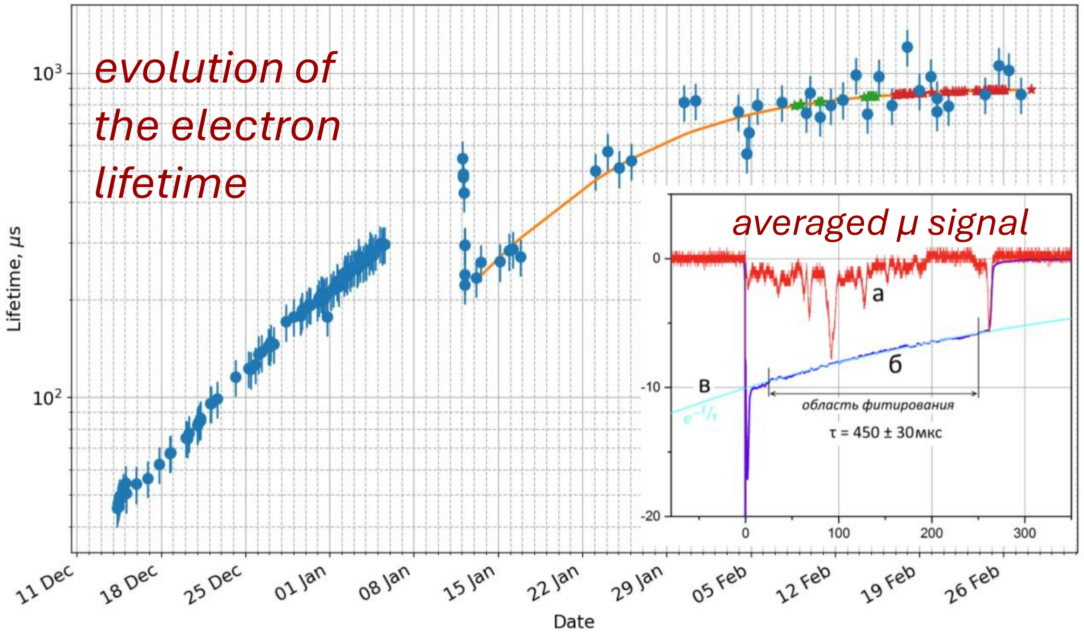
D.Y. Akimov et al 2023 IET 66, 199–206

Calibration and characterization of the detector

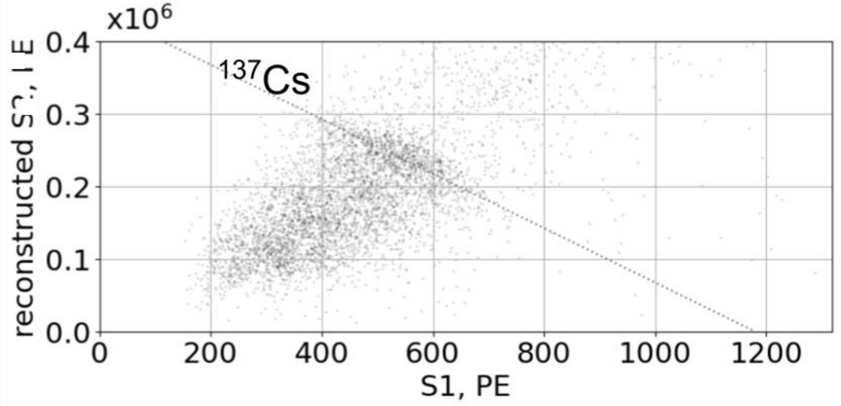








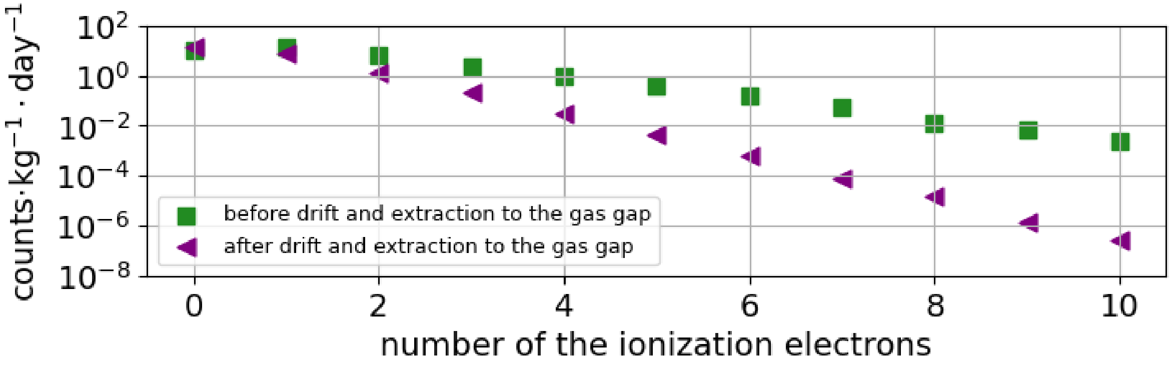
- LED calibration (for the SPE parametrization)
  SE (single electron) calibration (with zero hardware threshold)
- Calibration with the cosmic muons (for the electron lifetime measurement)

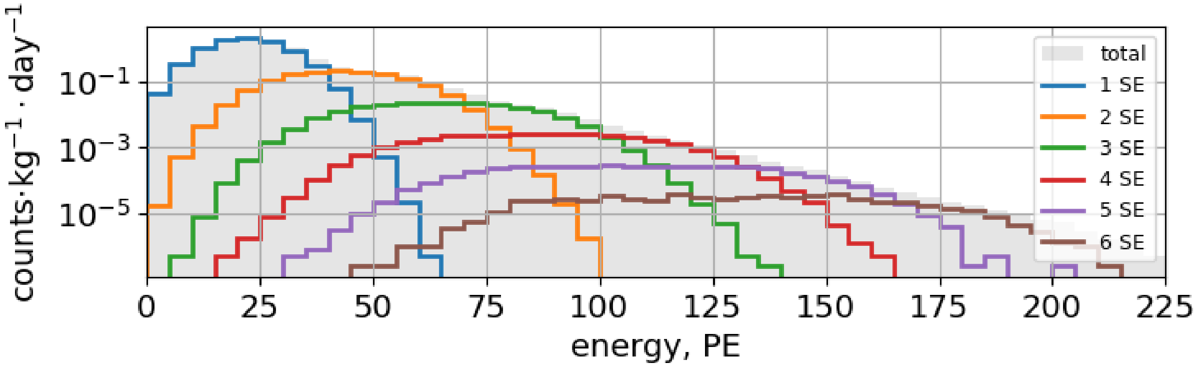


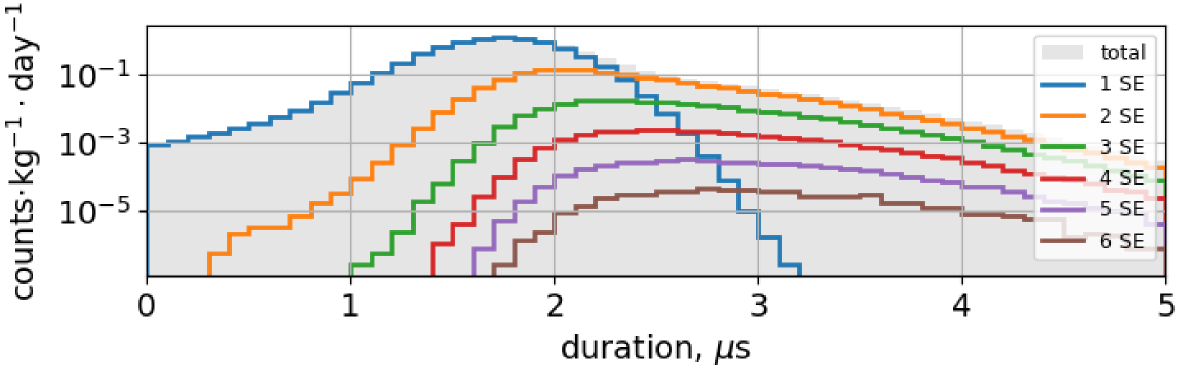
- Light response functions calculated from gamma signals (^{137}Cs and ^{60}Co) with ANTS2
- Electron extraction efficiency (EEE) was calculated to be ~ 33%

D.Yu. Akimov et al 2024 JINST 19 T11004

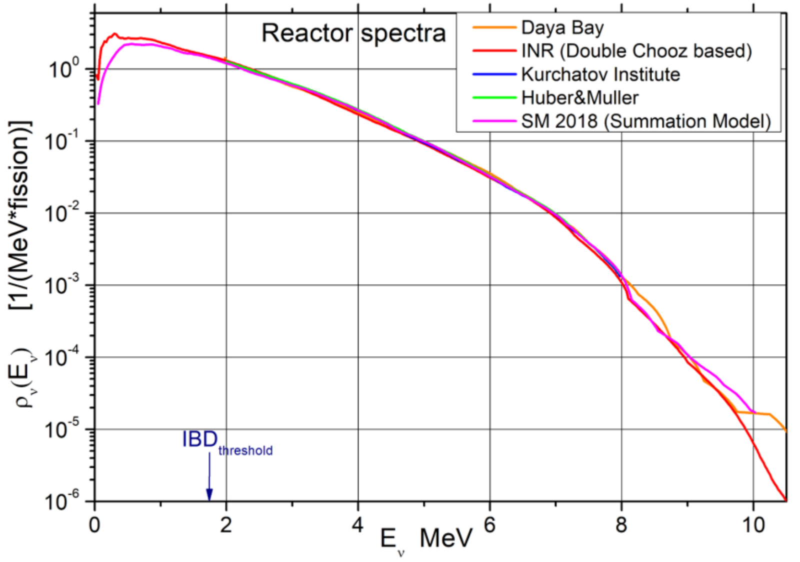
CEvNS simulation

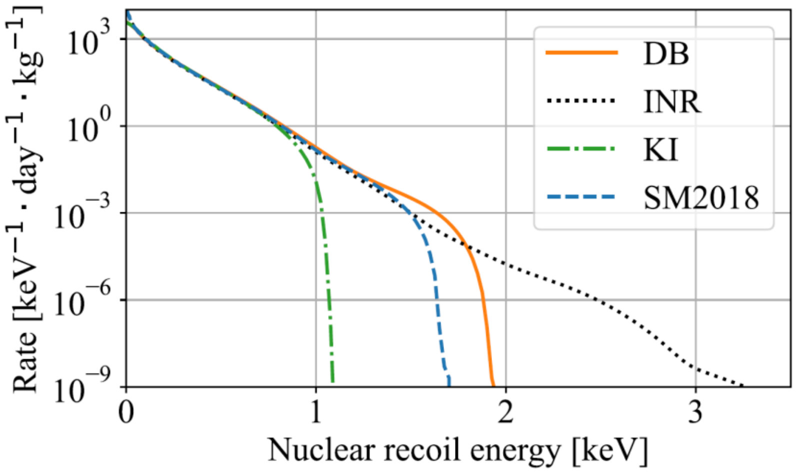






- Charge yield was calculated using NEST v 2.4
- Every event consists of several SEs
- SE signals were simulated using measured SE parameters and reconstructed LRFs
- SM2018 reactor spectrum was chosen for simulations



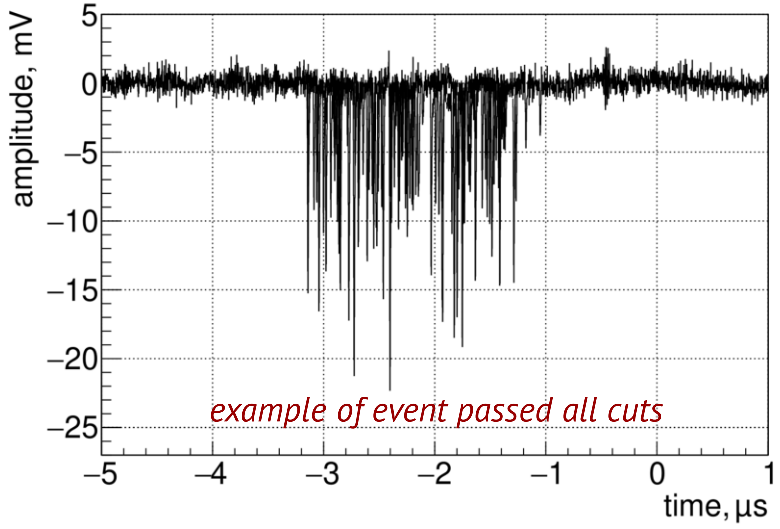


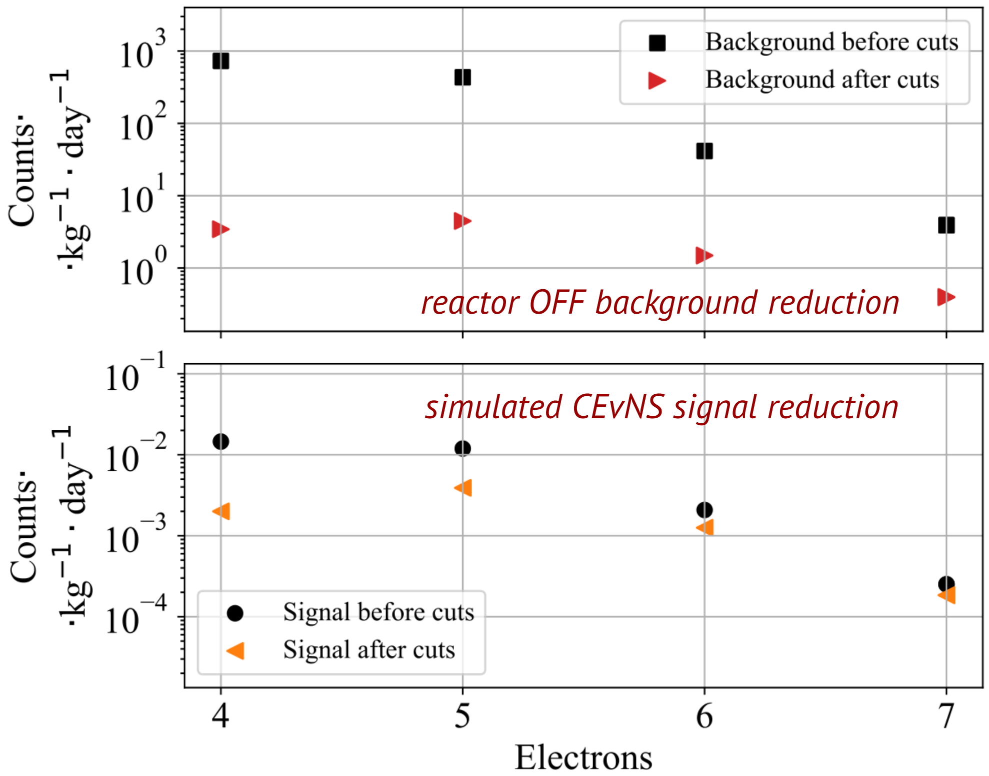
https://nest.physics.ucdavis.edu/

Phys. Rev. D 111, 072012

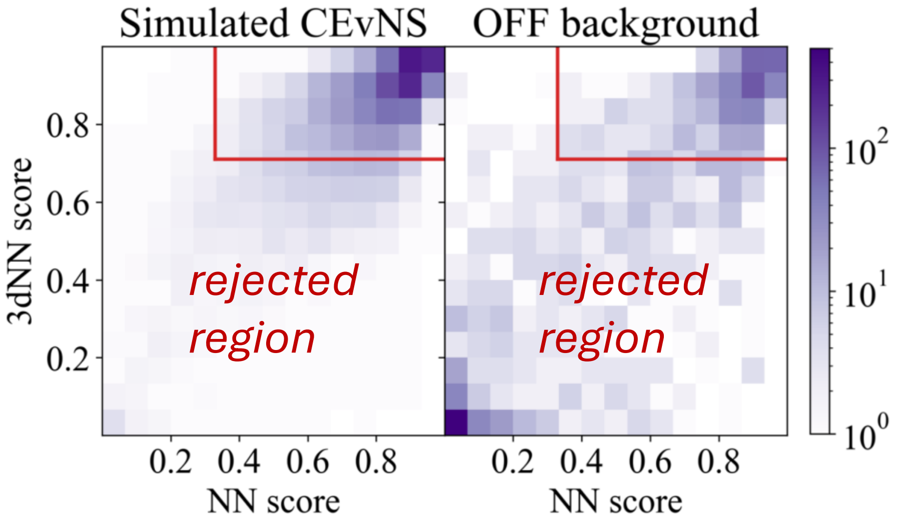
Events selection

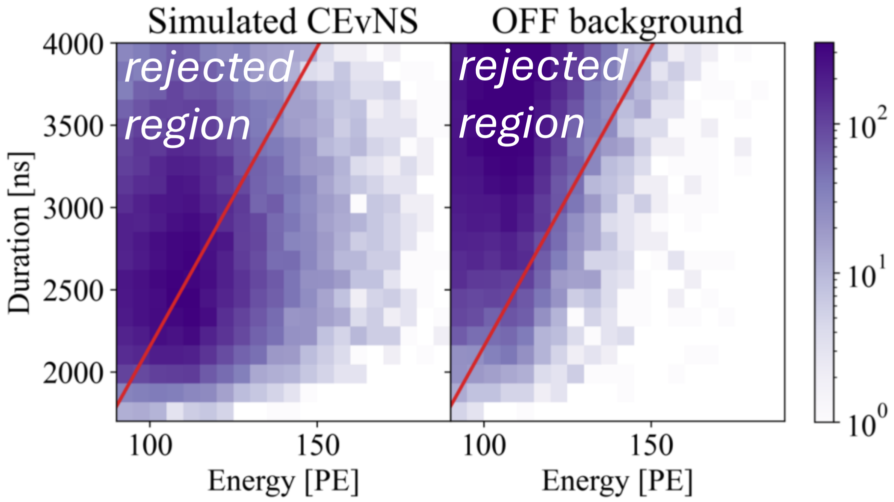
Trigger:
- counts SPEs in individual channels in 2μs time
- vetoed on the high SPE rate
- vetoed after muons and gammas
- has livetime ~60%





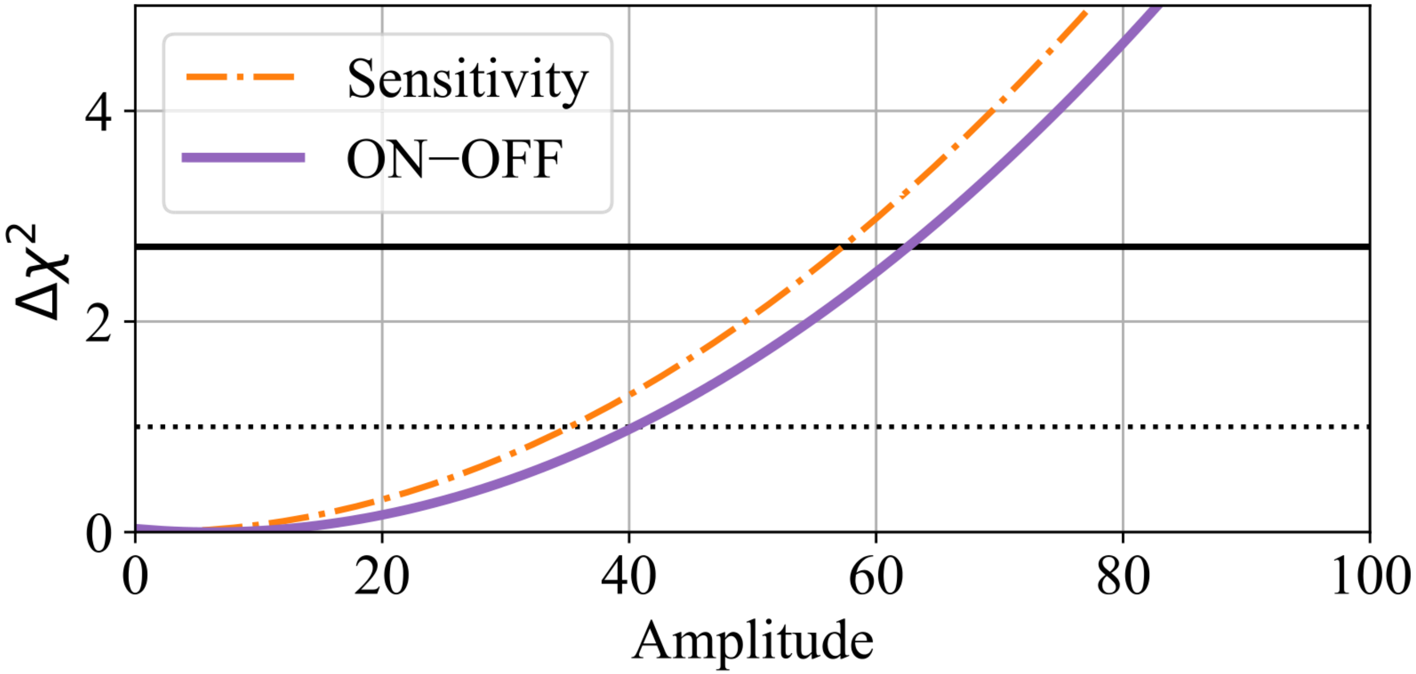
Cuts on:
- number of pulses on the wf
- energy (>4 visible ionization electrons)
- reconstructed radius (<140 mm)
- duration (cut depends on energy)
- pointlike cut by two neural networks

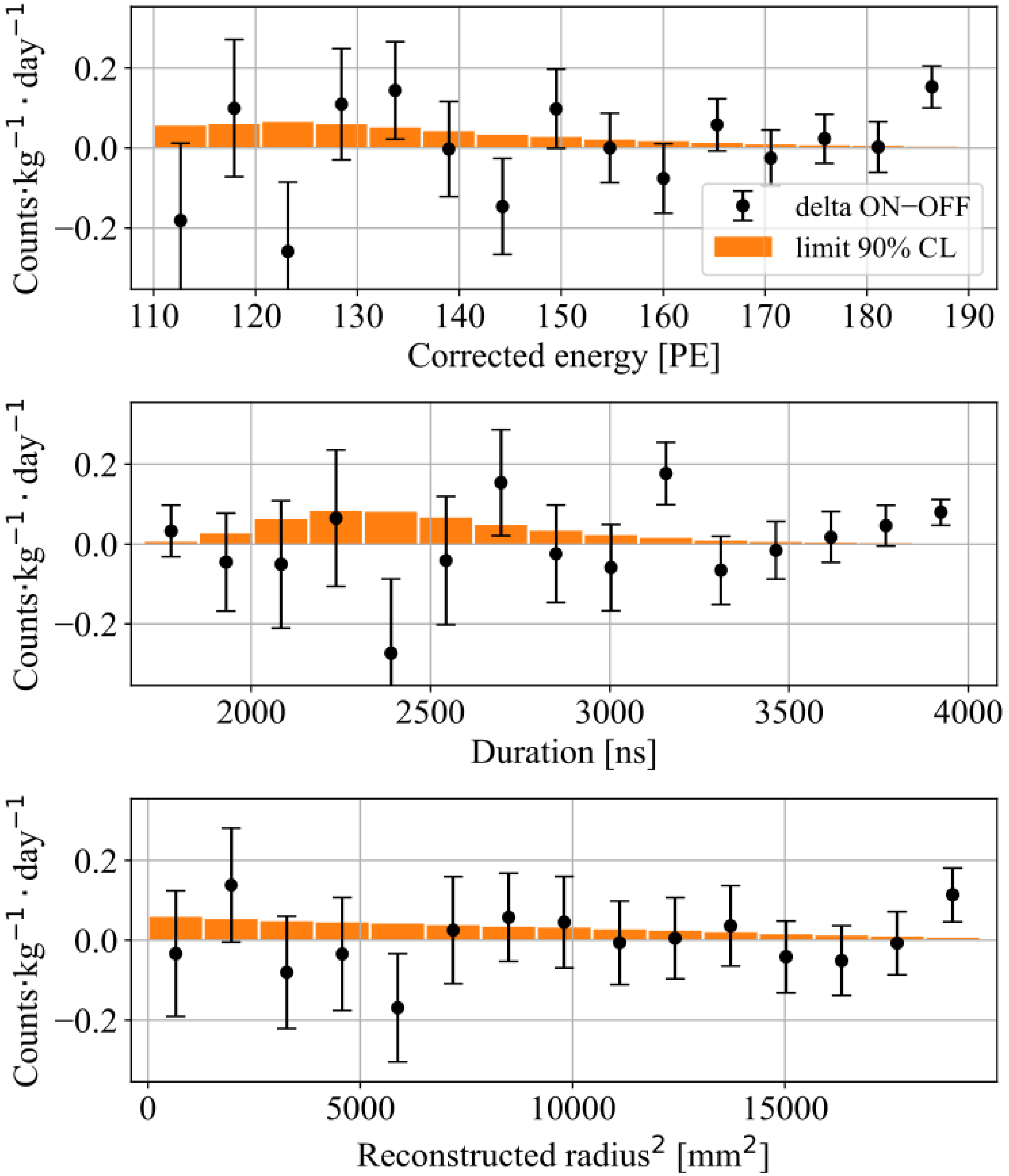




Results

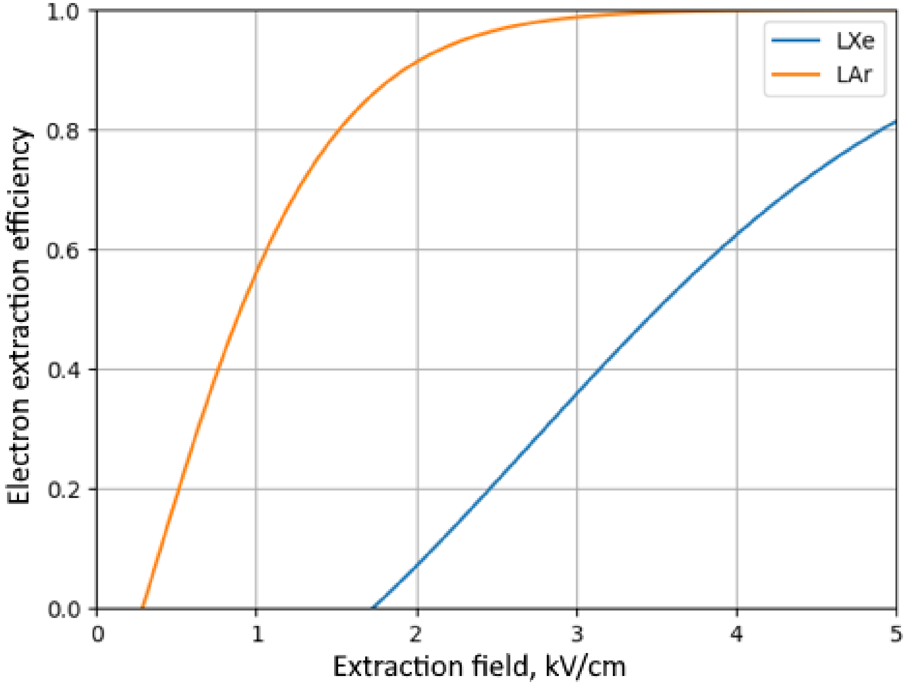
- Constrains on the CEvNS cross-section
- Delta ON-OFF for CEvNS limit calculation
- Significant dependence of the result on neutrino spectra model
- Final limit (sensitivity) values: 63^{+26}_{-16} (58^{+24}_{-15})





RED-100 with LAr

- Using LXe suffers from SE noise. It is caused by:
  - Subsurface electrons captured by potential barrier
  - Bounded states inside LXe
- LAr looks like a good substitute
  - ~10^{-5} of created e^- are delayed in LAr vs 10^{-3} in LXe (*P. Agnes et al 2018 PRL 121 081307, E. Aprile et al 2022 PRD 106 022001*)
  - Ar has higher recoil energy and more electrons per CEvNS event
  - Ar has ~100% electron extraction efficiency at the same field as used in LXe



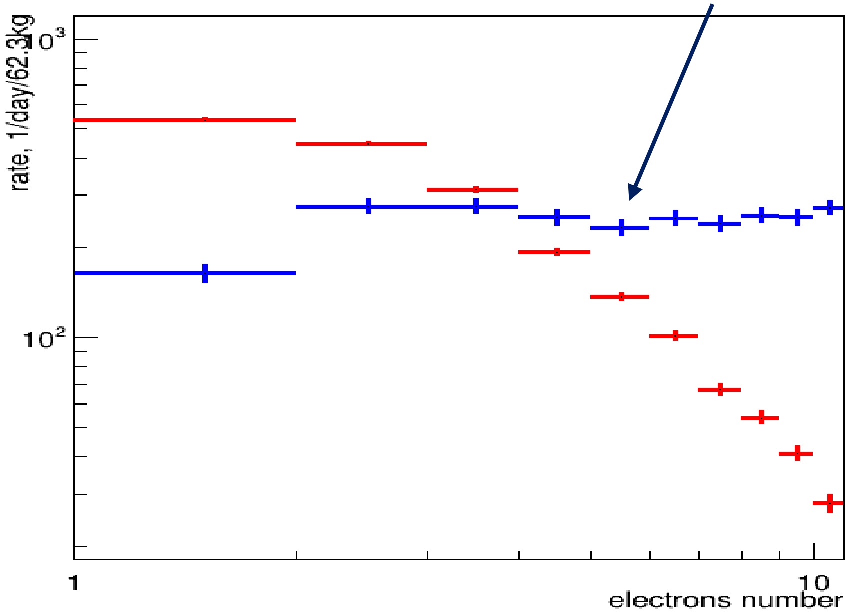
Electron extraction efficiency vs field for LAr and LXe

- Disadvantages:
  - ^{39}Ar isotope (~1 Bq/kg)
  - 128 nm wavelength (WLS required)
  - Longer SE duration
  - Lower temperature (-183°C)

Plans:

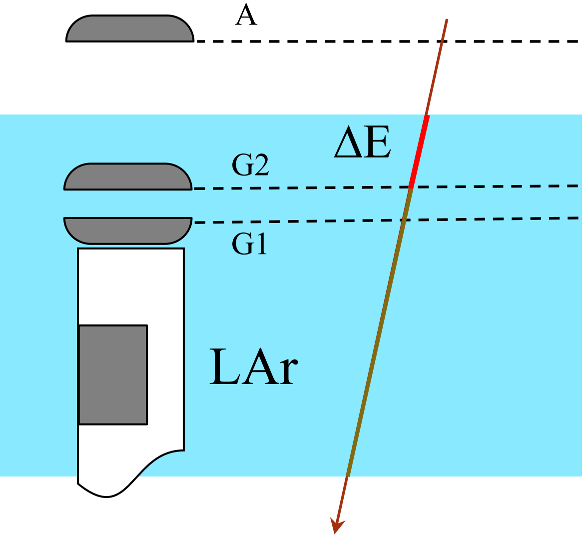
- test in the lab. with full shielding
- ^{39}Ar and ^{85}Kr level measurements
- calibration with ^{37}Ar

Significant drawback is ^{39}Ar

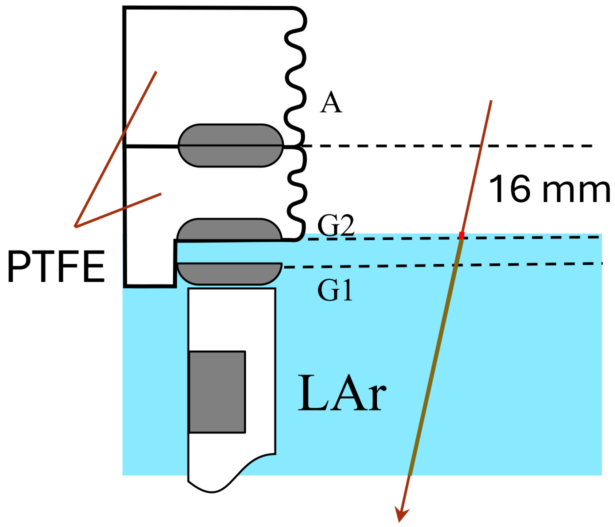


RED-100 with LAr

New design of electrode system (to be tested soon)



old design



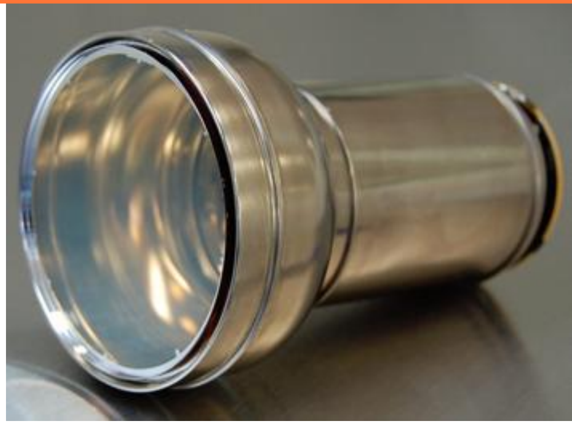
new design

Old design

- Muon's ΔE in LAr above G2 ~ 2 MeV produces afterglow in TPB with τ ~ 1 ms
- TPB afterglow => SPE noise ~ 2 MHz which didn't allow us to set low threshold
- EL amplification is quite low: several SPE/SE ($U_{A\text{-}G2}$ ~ 11 kV)

New design

- ΔE from muons reduced (~1 mm against ~10 mm LAr above G2)
- $U_{A\text{-}G2}$ increased up to ~15 kV



PMT R11410-20

The same PMT coated with TPB

Summary

- The RED-100 experiment was successfully carried out at the industrial nuclear power plant
- It was shown that the threshold of the detector was ~4 SE
- The sensitivity to single ionization electrons was shown as 27.0 ± 0.05 SPE/SE
- Data analysis is already finished (see *Phys. Rev. D 111, 072012*)
- Sensitivity and CEvNS upper limits (90% C.L.):
  - *sensitivity:* 58^{+24}_{-15} *xSM prediction*
  - *limit:* 63^{+26}_{-16} *xSM prediction*
- The result is comparable to the first physical runs of other experiments (e.g. CONNIE *Phys. Rev. D 100, 092005*)
- Very high rate of pointlike background in ROI was observed
- Upgrade with LAr is ongoing

Thank you for your attention!

BACKUP

Calibration

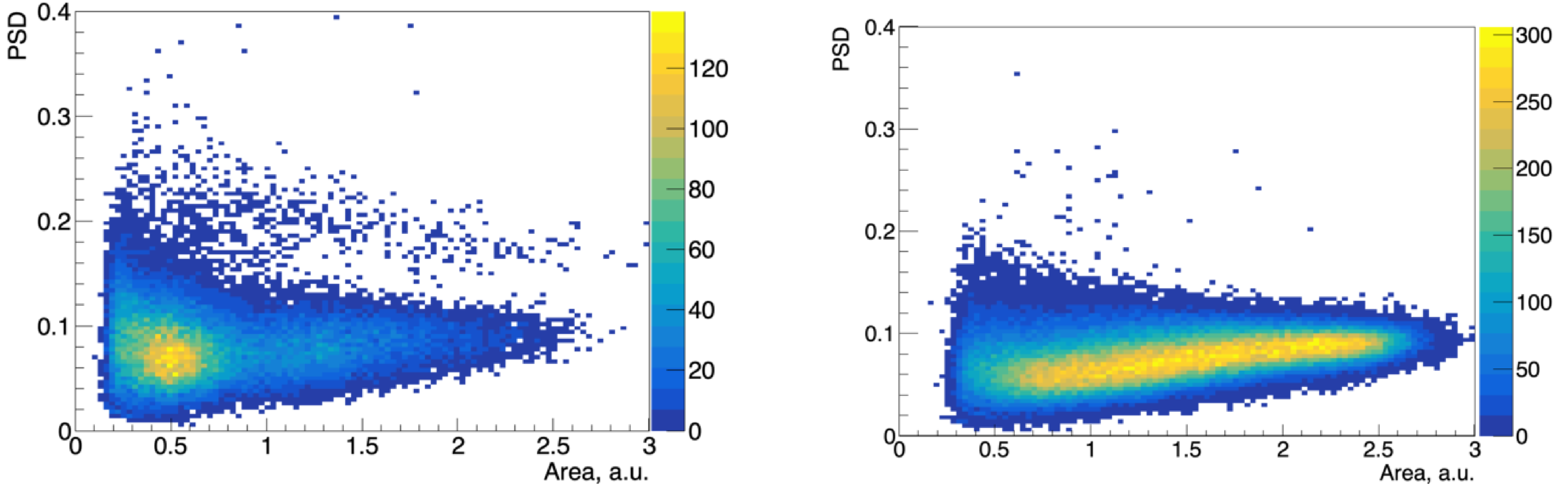


Figure 5. Dependence of PSD parameter on the area of the scintillation signal for the PuBe source (left) and the background at the RED-100 location (right).