RED-100: Results and status

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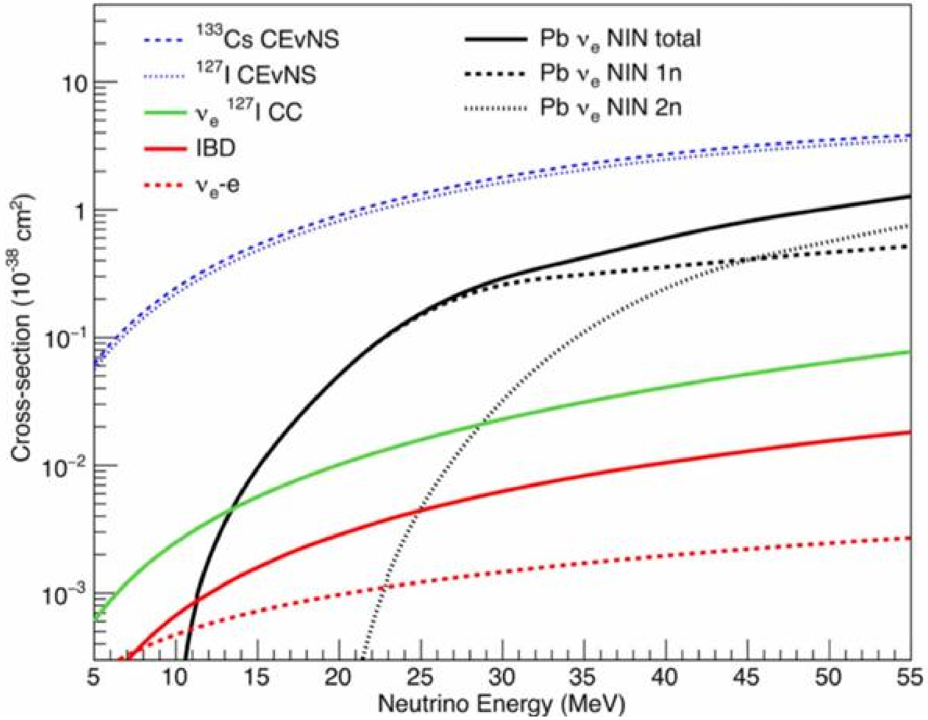
on behalf of the RED-100 collaboration

TAUP 2025

Coherent Elastic Neutrino-Nucleus Scattering (CEvNS)

- Process predicted by Standard Model
- High cross-section
- First observation by COHERENT collaboration (2017)
- Low (keVnr or even sub-keVnr) energy signal
- Important for:
    - Astrophysics (supernovae physics)
    - Non-standard neutrino interactions
    - Reactor monitoring
    - Much more!

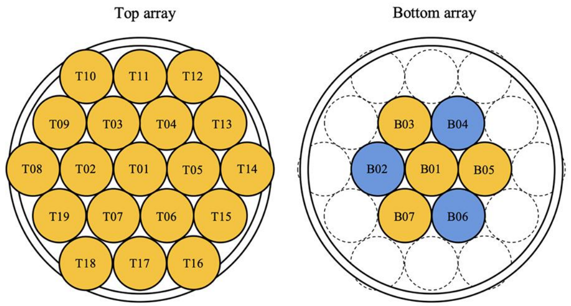
$$\sigma \approx \frac{G_F^2}{4\pi}(N-(1-4\sin^2\theta_W)Z)^2E_\nu^2 \propto N^2$$

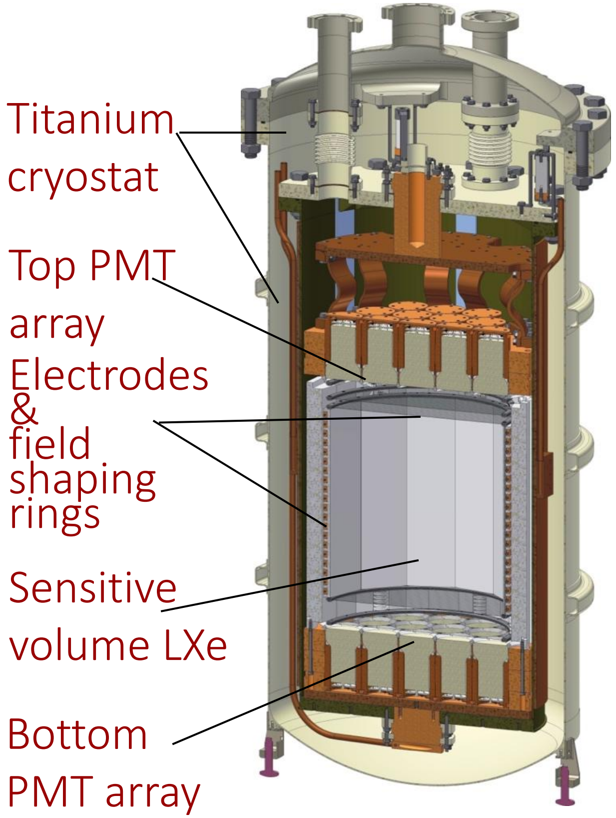


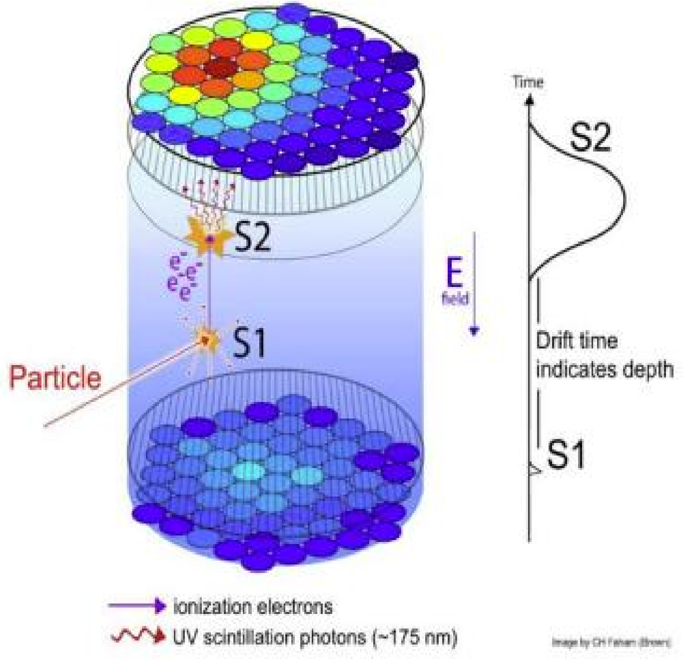
[D.Yu. Akimov et al.,Science Vol 357, Issue 6356]()
[Kopeliovich, V. B. and Frankfurt, L. L., PismaZhETF.19.236]()
[D.Z. Freedman, Physical Review D 9 (1974) 1389]()

RED-100 detector

- ~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







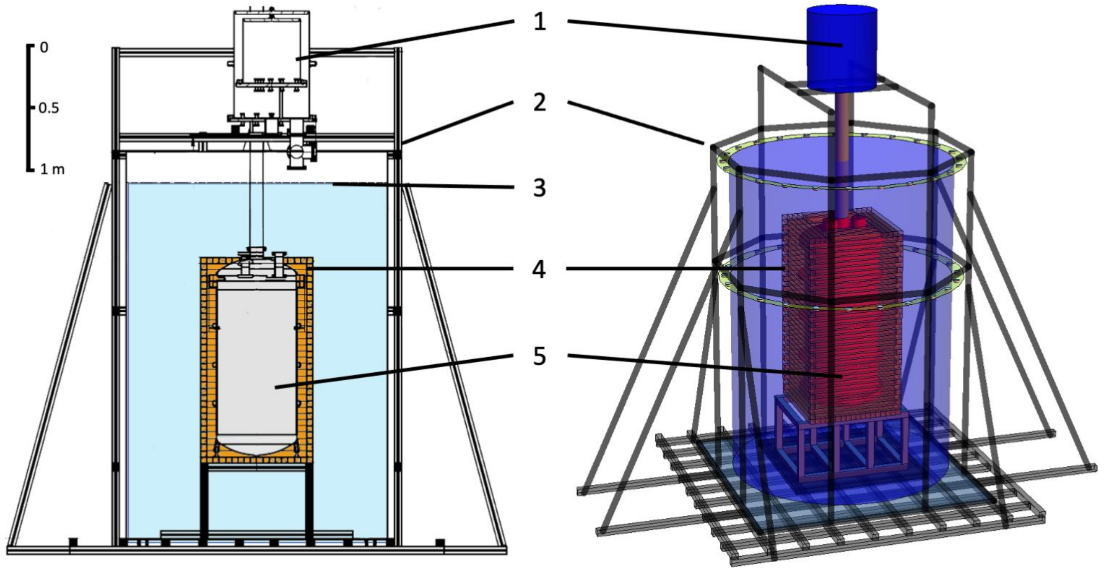
[B. A. Dolgoshein et al, JETP Lett. 11, 513 (1970)]

[D.Y. Akimov et al 2020 JINST **15** P02020]

Two-phase emission detectors are widely used for rare events searching:

- Unlimited (kind of) size of working medium
- Possible to obtain coordinates and time of event
- Sensitive to very low energy events
- Well-known methods of working medium purification
- All of that in the same time!

RED-100 @ KNPP



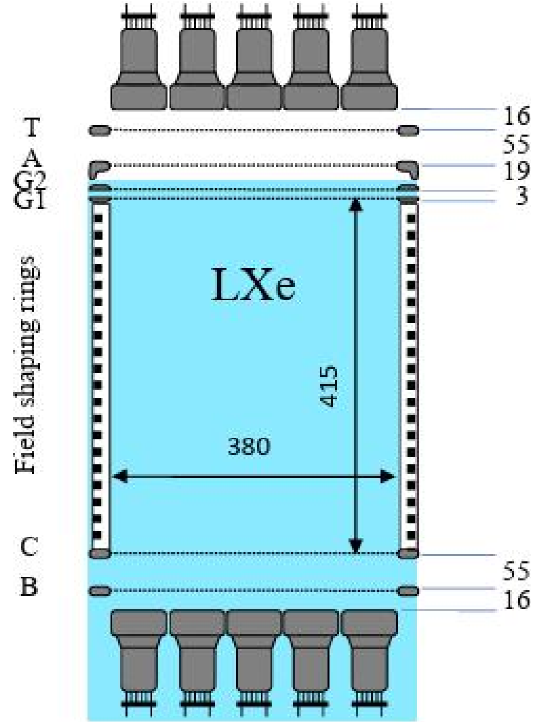
Design of the RED 100 passive shielding
1 — LN2 tank, 2 — support frame, 3 — water tank, 4 — Cu shielding, 5 — Ti cryostat of the RED-100

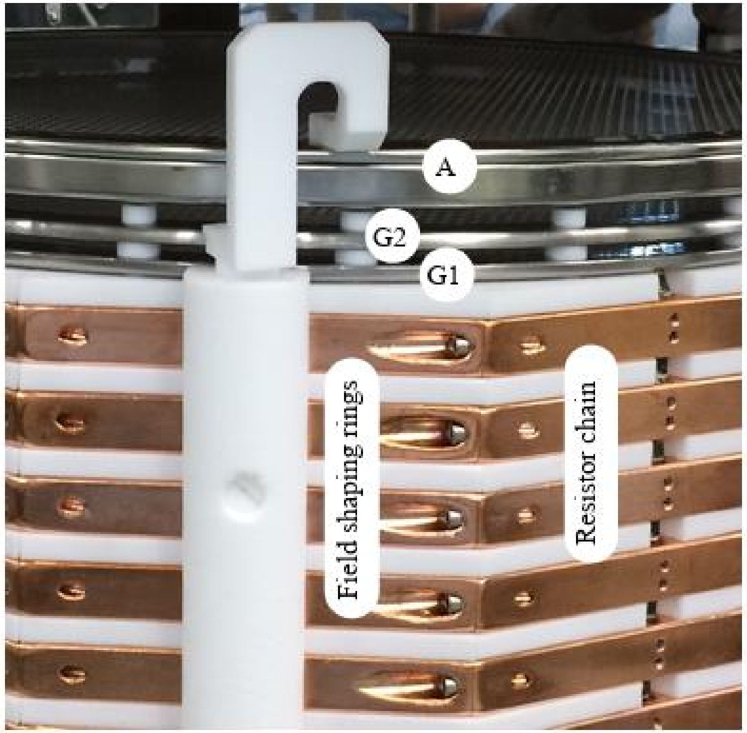
- 70 cm of passive water shielding from neutrons
- 5 cm of copper passive shielding from gamma

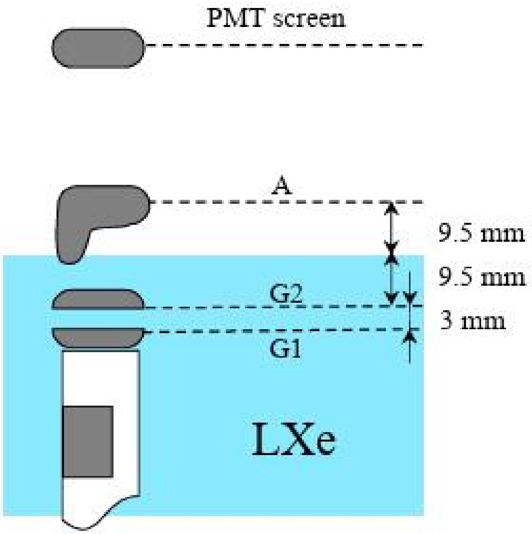
- 19 meters from the reactor core
- reactor core, building&infrastructure work as a passive shielding from cosmic muons
- Antineutrino flux at place ~ $1.35*10^{13}$ $cm^{-2}s^{-1}$
- >50 m.w.e. in vertical direction

D.Yu. Akimov et al 2022 JINST 17 T11011

Muons et al.: electron shutter







T – top grounded grid (PMT screen)

B –bottom grounded grid

A – anode grid

G1 – electron shutter grid

G2 – extraction grid

C – cathode grid

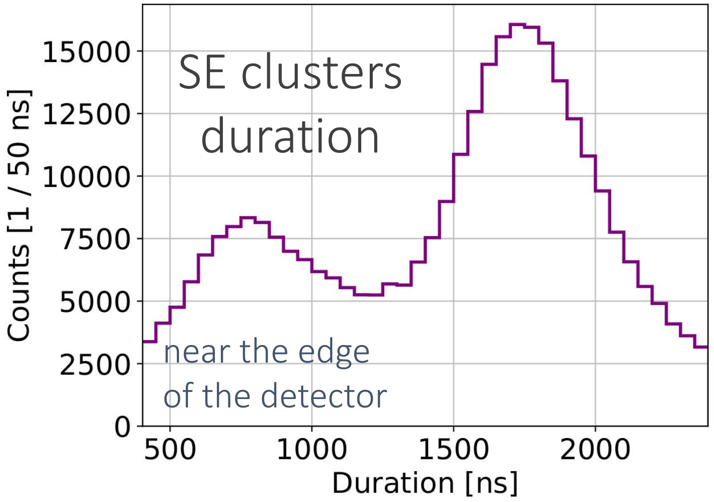
Gas Xe: 4.96 ± 0.07 kV/cm

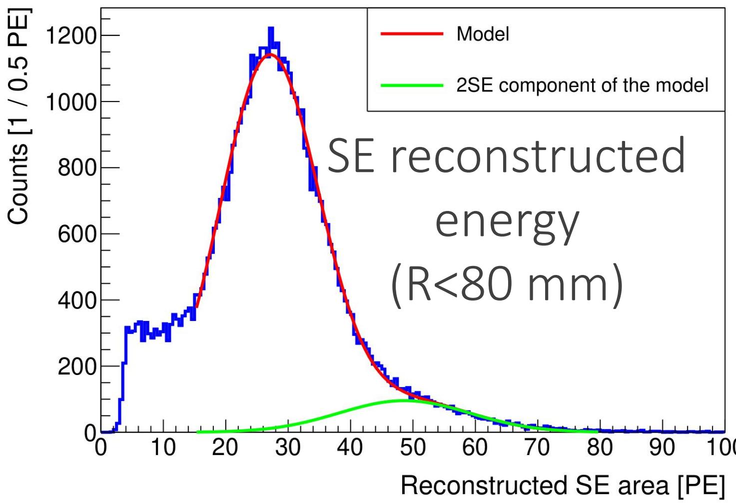
LXe (above G2): 2.68 ± 0.04 kV/cm

LXe (sens. volume): 0.22 kV/cm

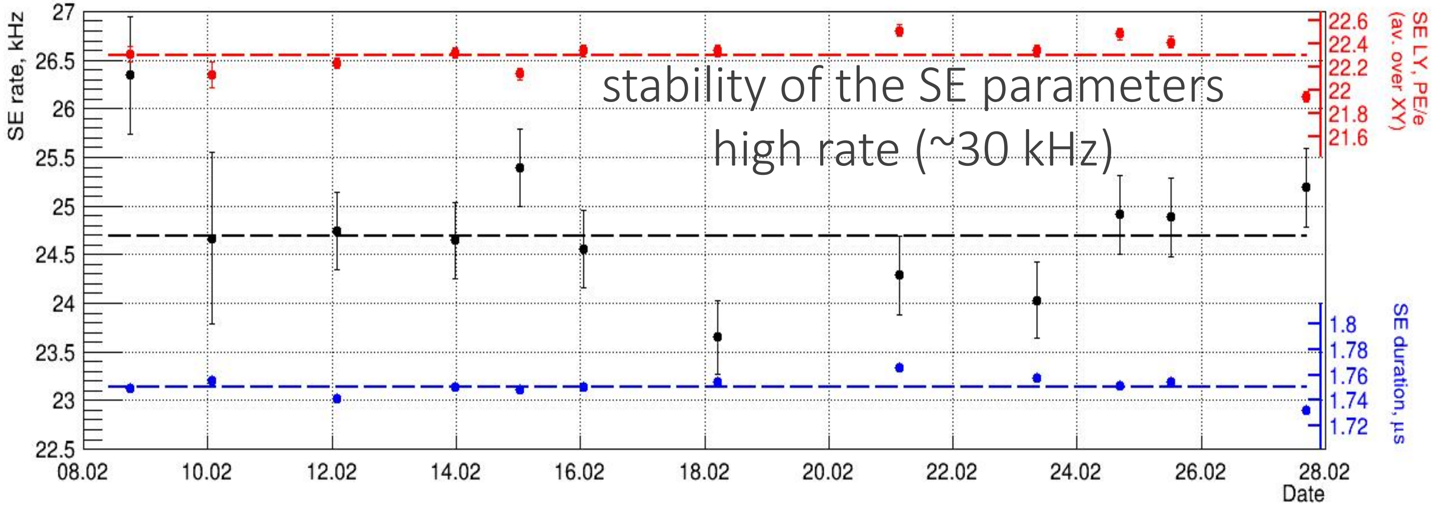
more interesting info on slide 14 :)

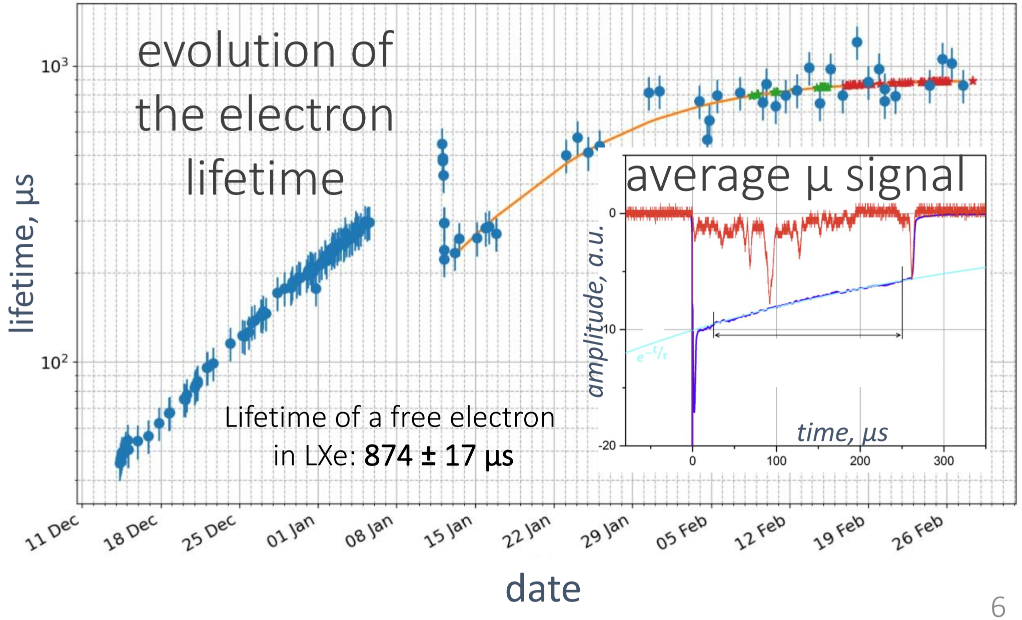
Calibration and characterization of the detector





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

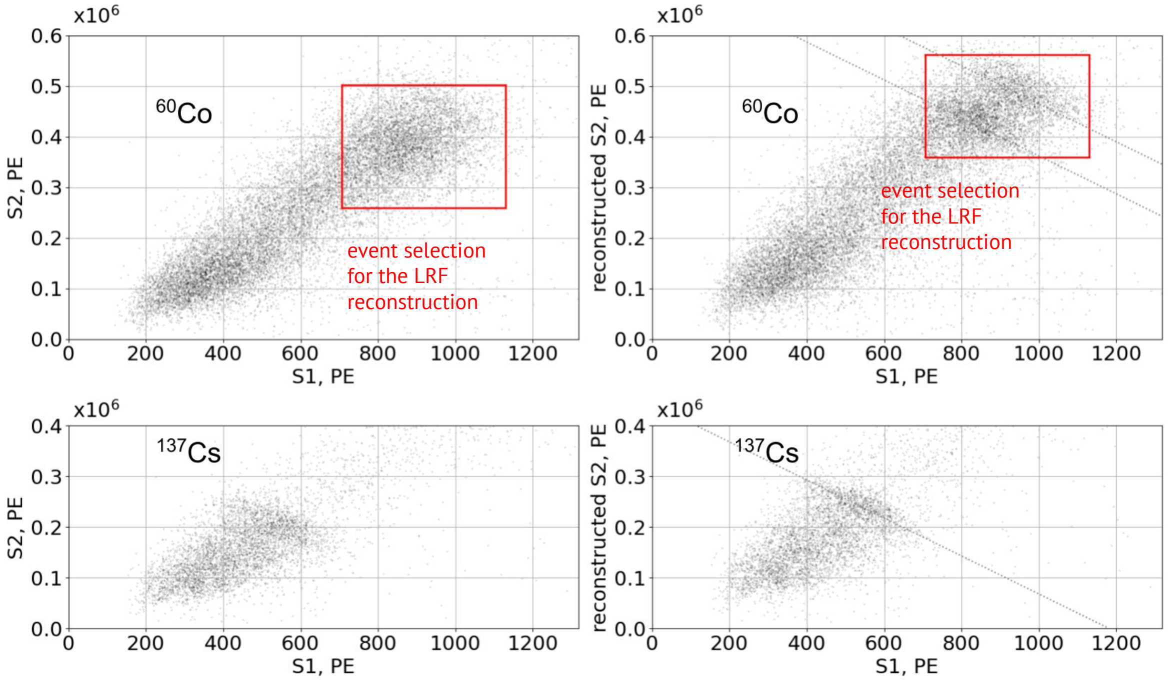


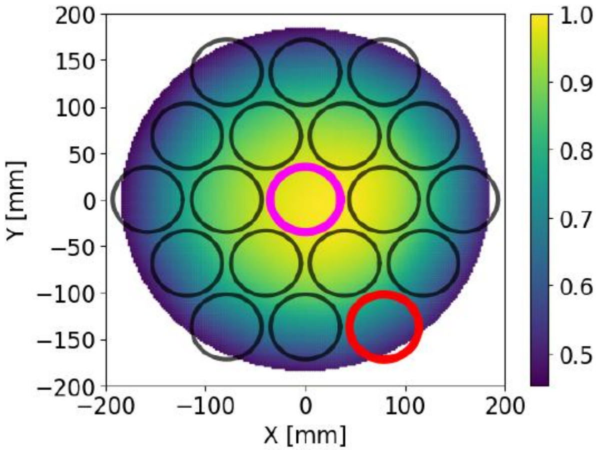


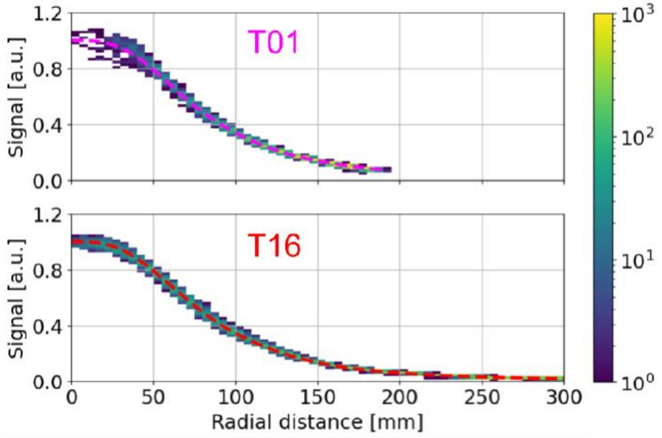
D.Yu. Akimov et al 2024 JINST 19 T11004

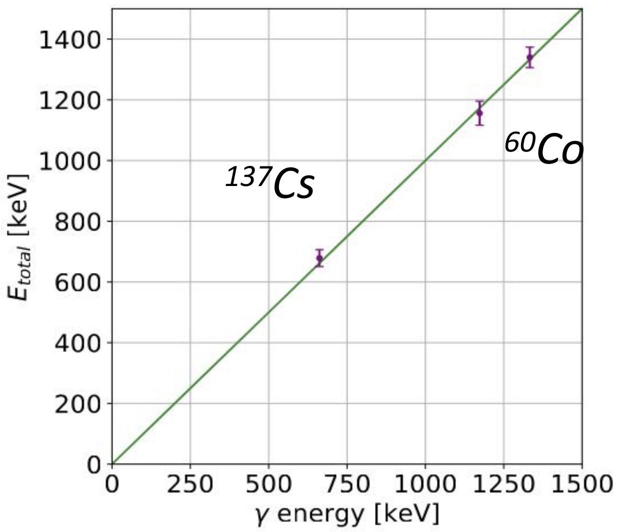
Calibration and characterization of the detector

Before and after reconstruction

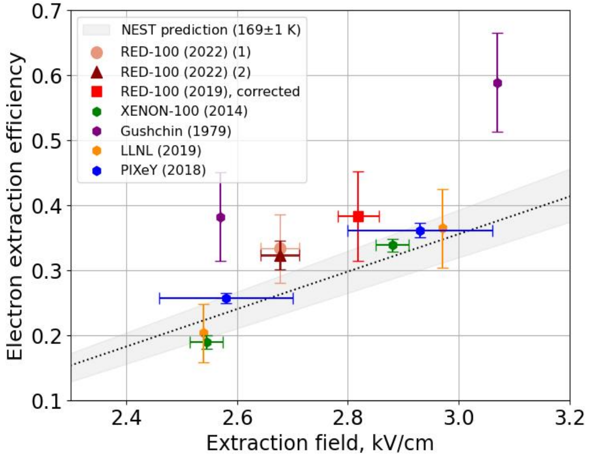








- calibration with gamma-sources (^{137}Cs and ^{60}Co) for the light response functions (LRFs) reconstruction with ANTS2
- LRFs were used for the position and energy reconstruction of all data types



- electron extraction efficiency (EEE) was calculated with two approaches
  - using comparison visible QY with NEST QY prediction (**33.4±5.4%**)
  - using S1-S2 anticorrelation coefficient (**32.8±2.8%**)

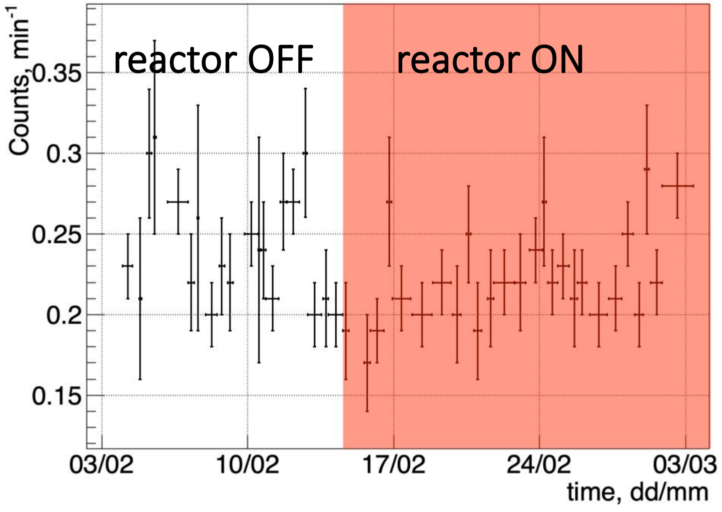
D.Yu. Akimov et al 2024 JINST 19 T11004

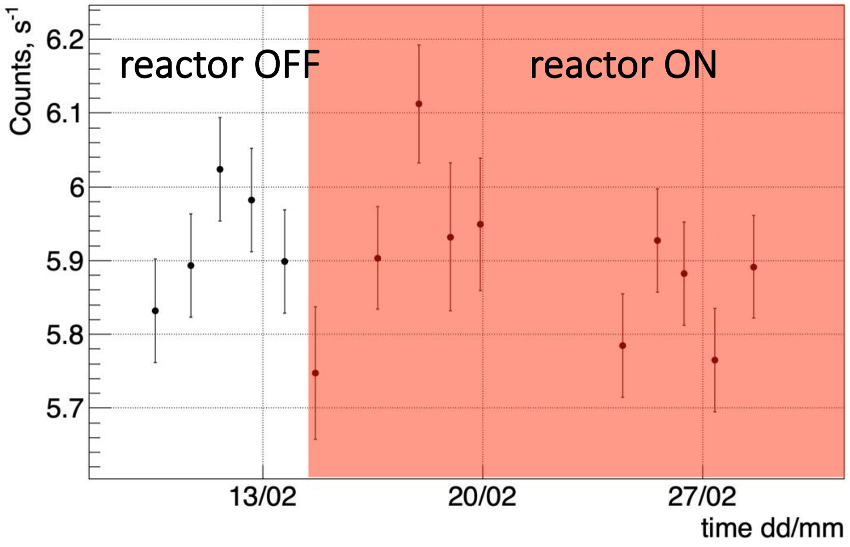
External background conditions

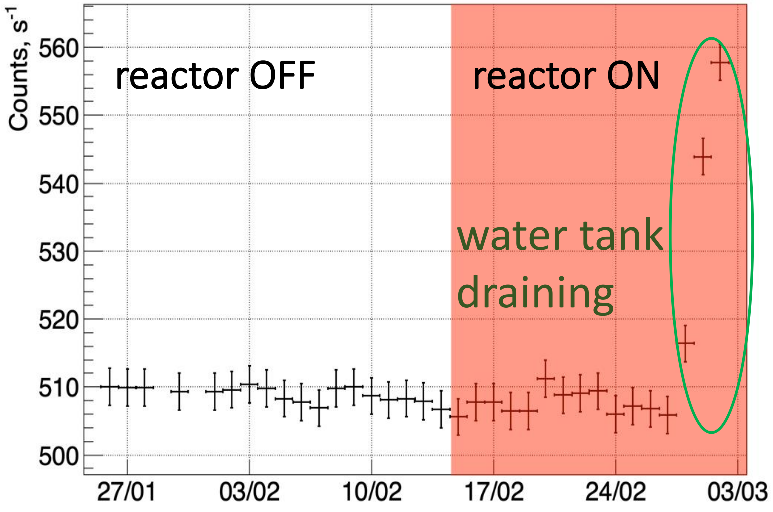
Neutron

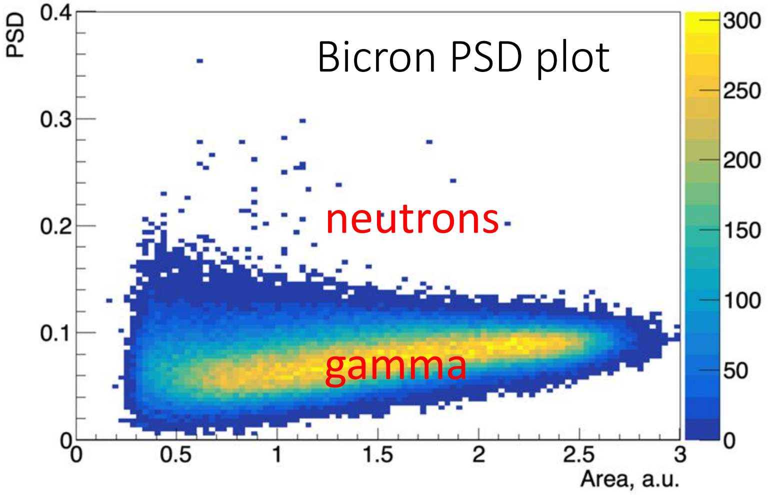
Muon

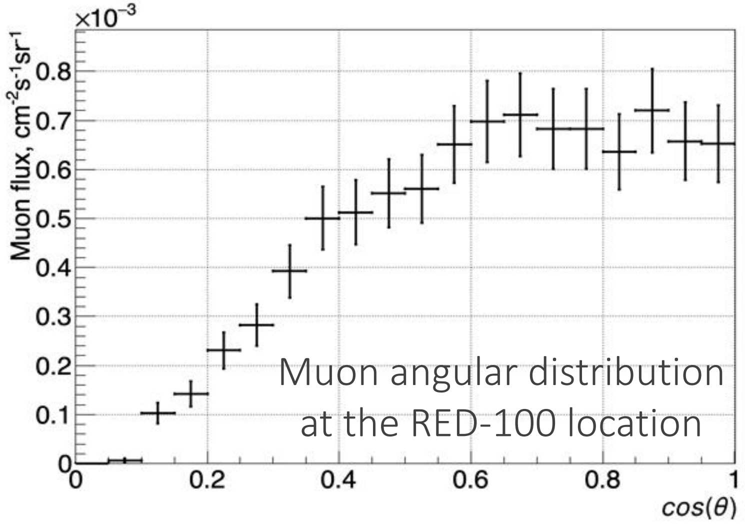
Gamma

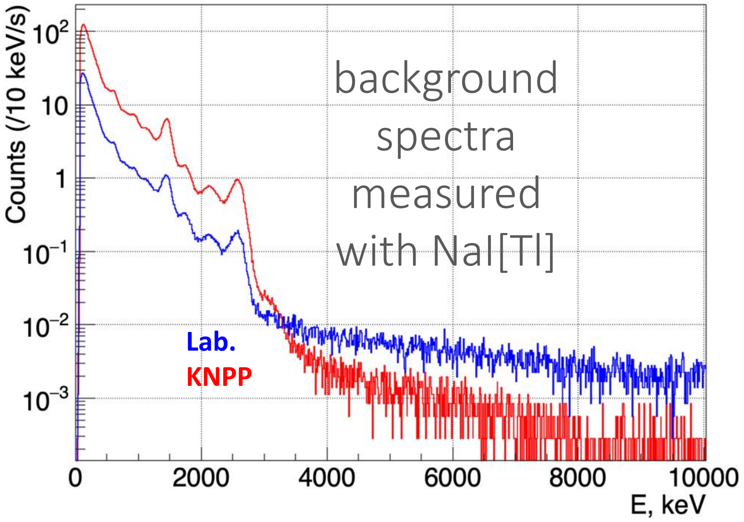












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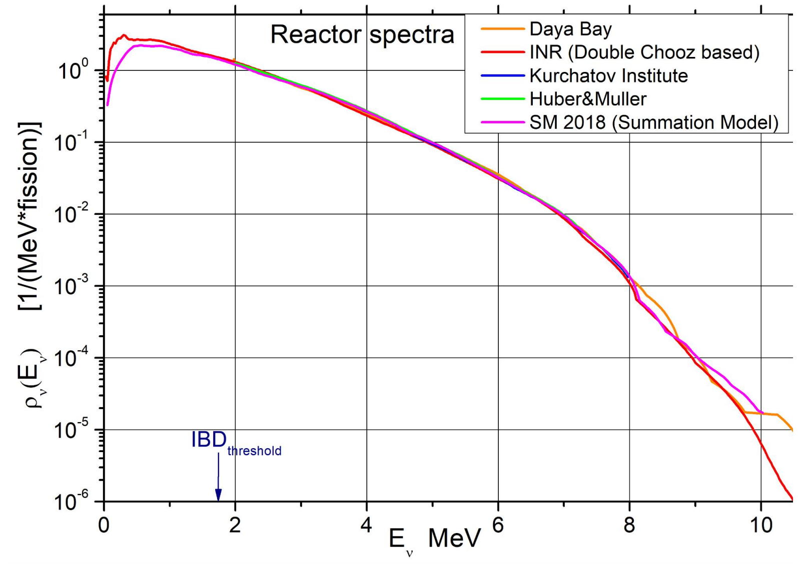
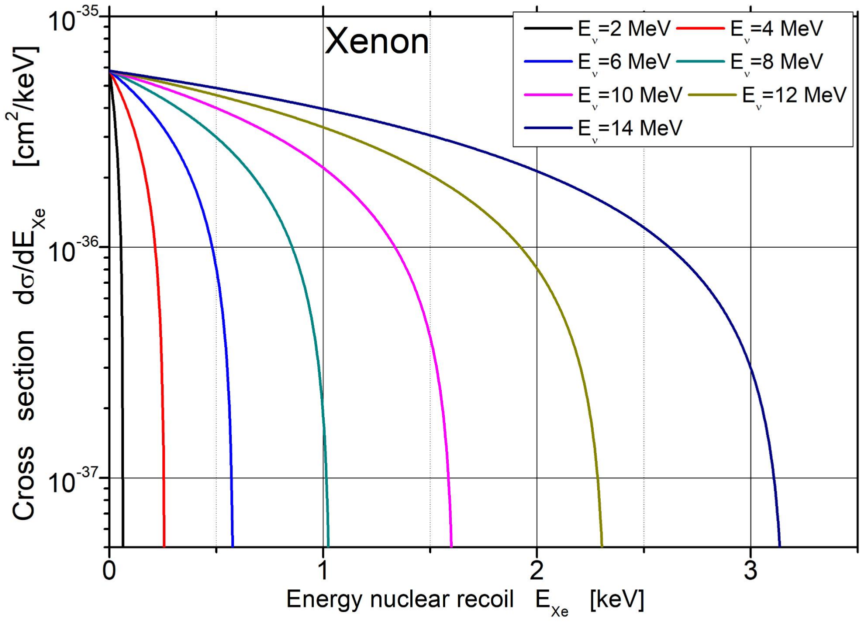
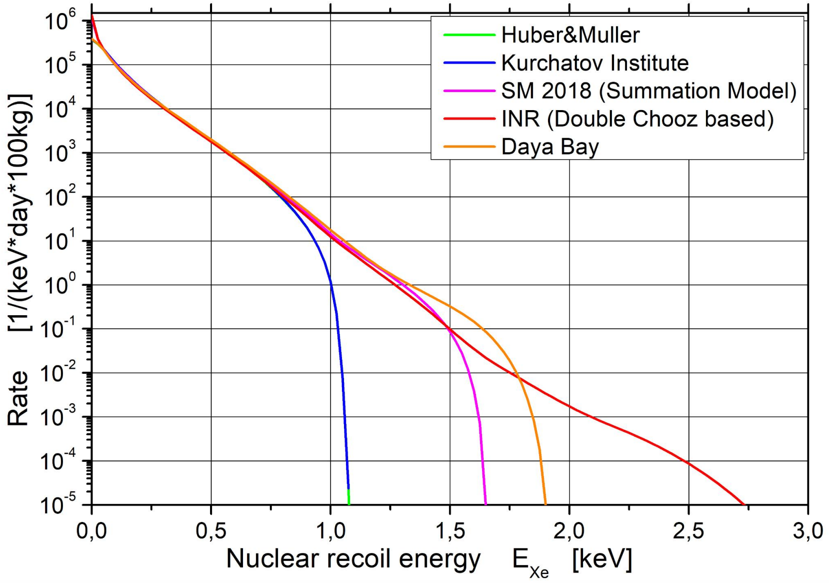
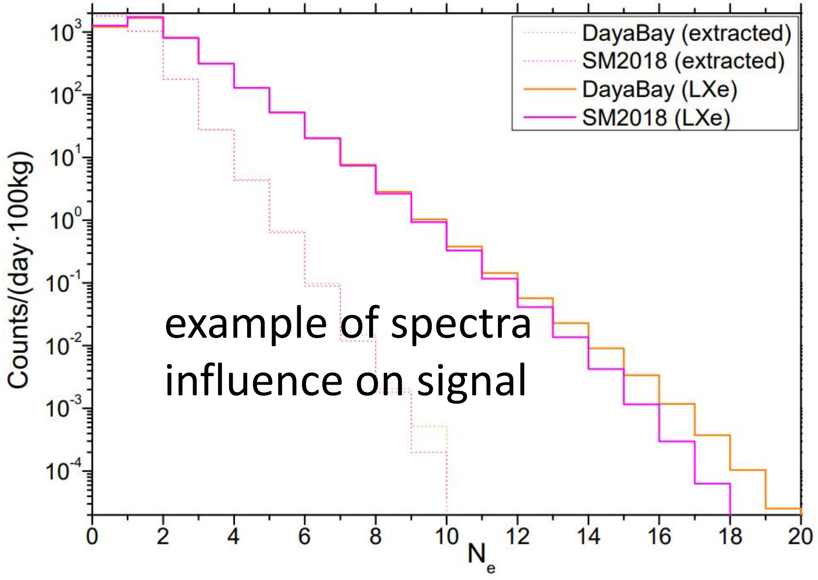
Reactor antineutrino spectra





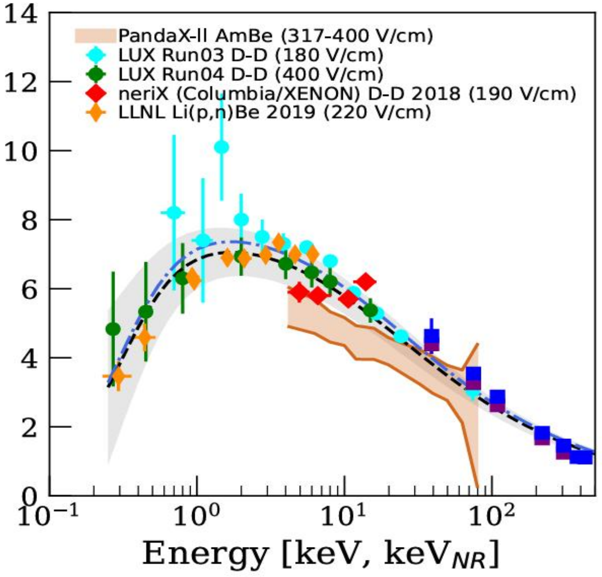




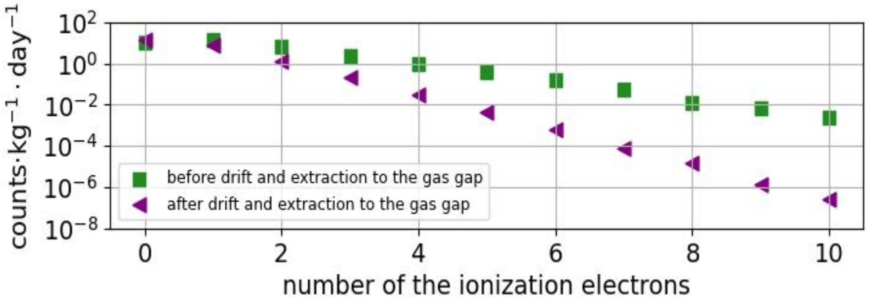
- contribution of the high energy tail is significant in our ROI (>4 extracted ionization electrons)
  - the partial shares of the isotopes of nuclear fuel were considered unchanged throughout the data taken period
    - the average energy per fission is ~205.3 MeV

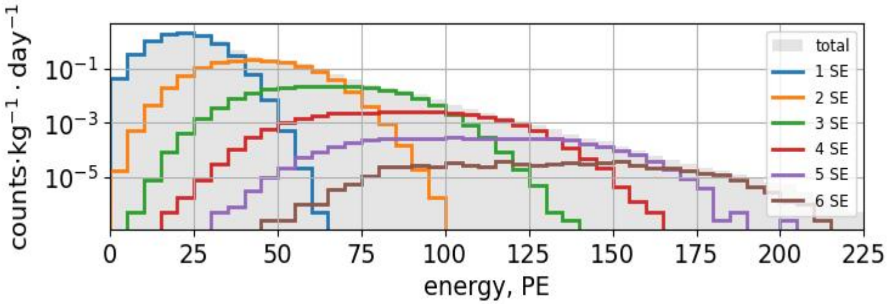
T. A. Mueller et al, Phys. Rev. C 83, 054615 (2011)
P. Huber, Phys. Rev. C 84, 024617 (2012)
V. I. Kopeikin et al, Phys. Rev. D 104, L071301 (2021)
M. Estienne et al, Phys. Rev. Lett. 123, 022502 (2019)
F. P. An et al, Chinese Physics C 45, 073001 (2021)

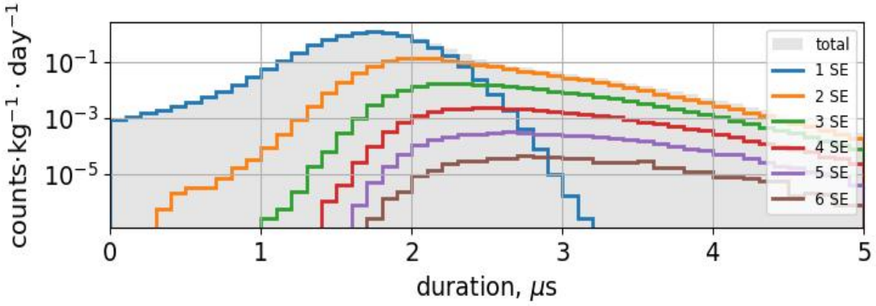
CEvNS simulation

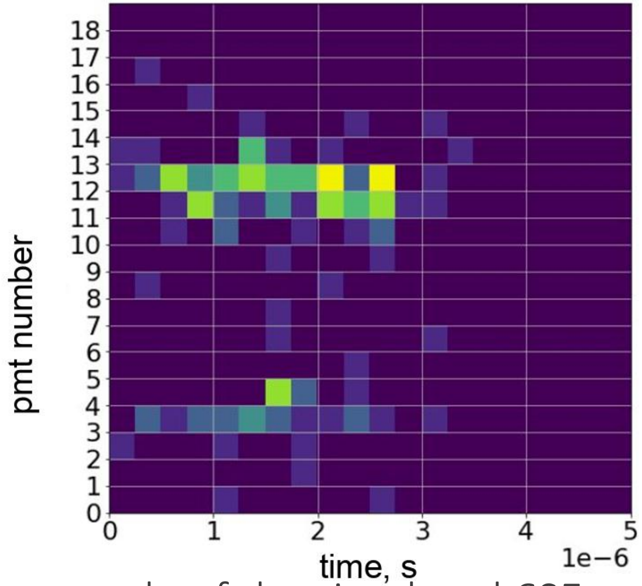


- NEST v2.4 for initital electrons
- every signal consists of several SE signals
- SE signals were simulated using measured SE parameters and reconstructed LRFs

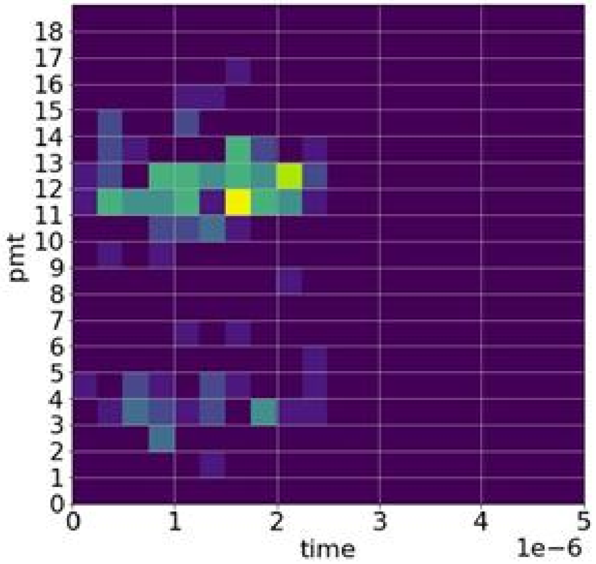








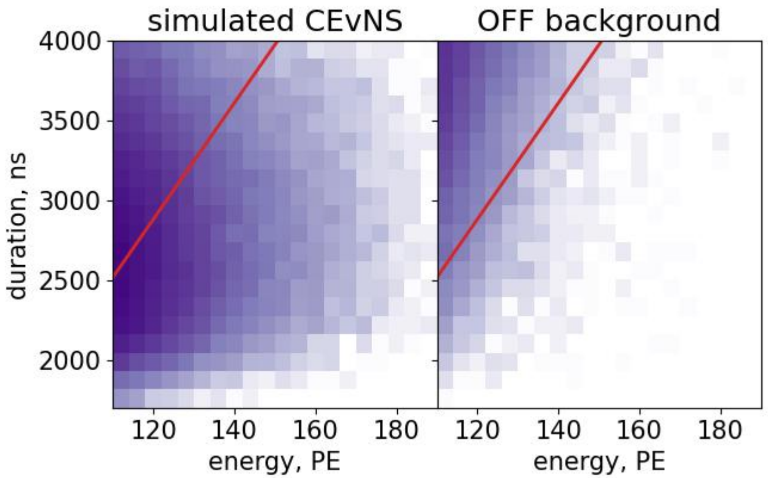
example of the simulated 6SE event

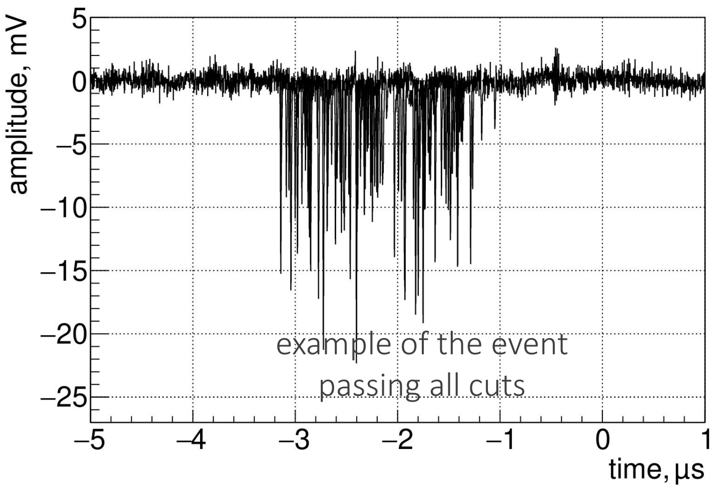


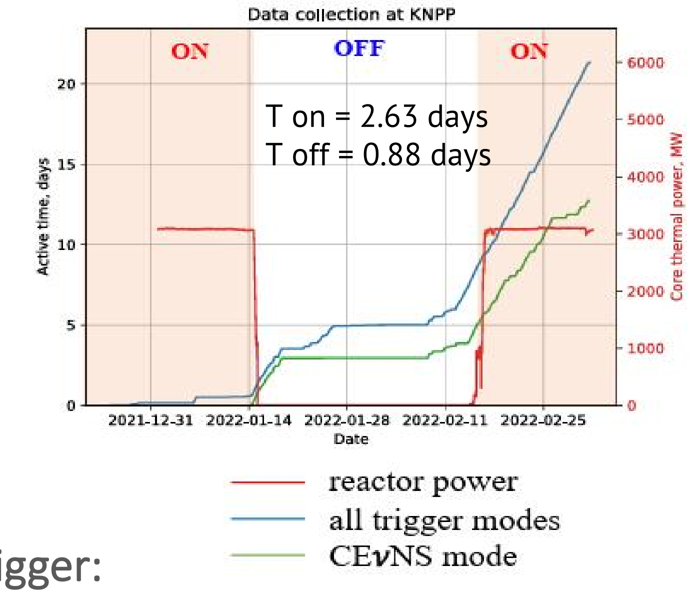
example of the actual point-like bkg event

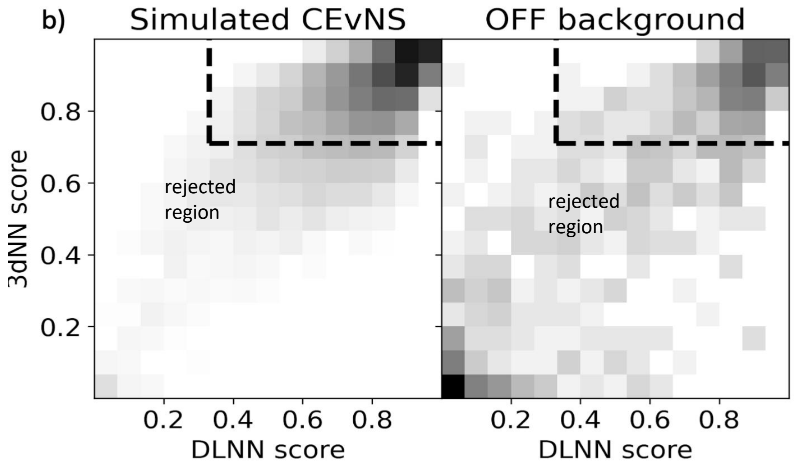
[M.Szydagis et al, Front. Detect. Sci. Technol., Vol. 2, 2025]

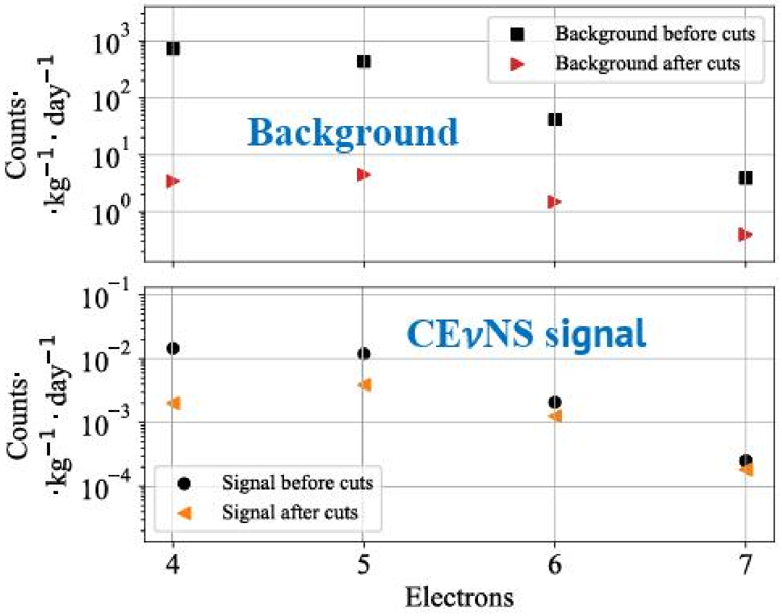
Data in ROI











Trigger:

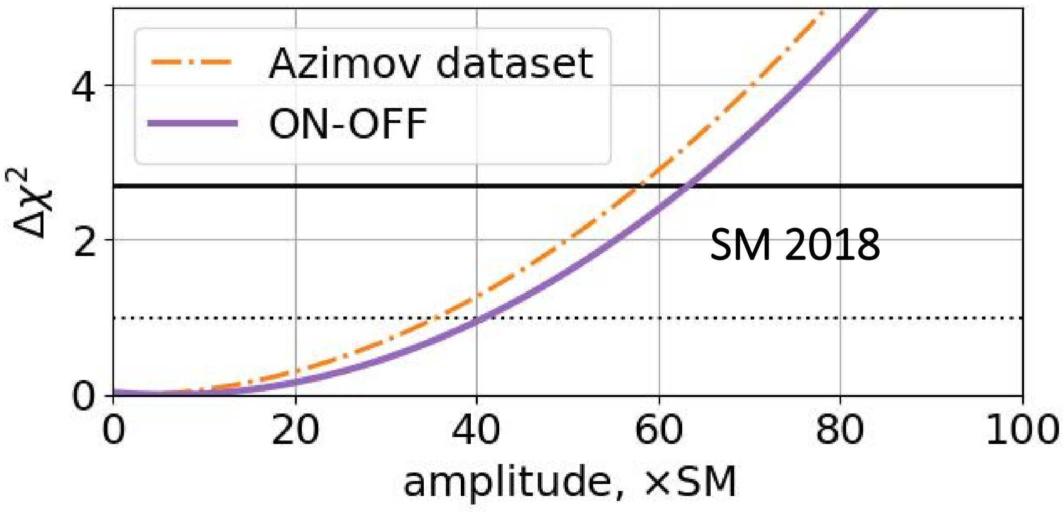
- counts SPEs in individual channels in 2μs time
- vetoed on the high SPE rate
- vetoed after muons and gammas
- has livetime ~60%

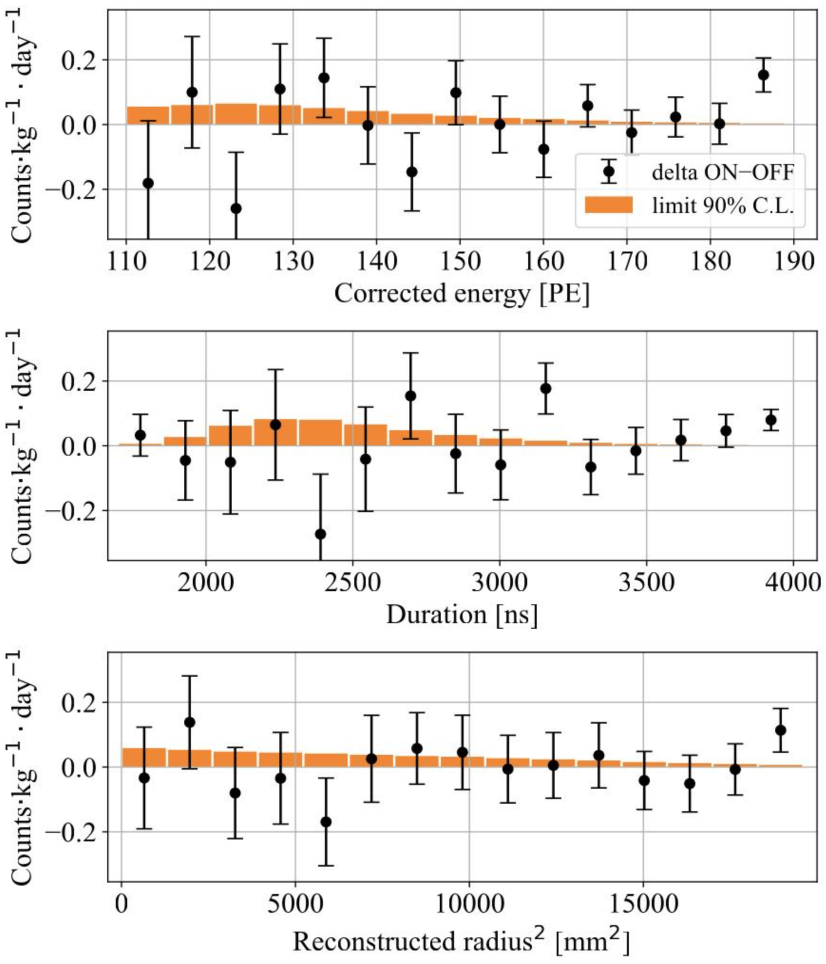
Cuts:

- on the number of random pulses on the wf
- on the energy ($4 < \text{visible } e^- \leq 7$)
- on the reconstructed radius (<140 mm)
- on the duration (cut depends on energy)
- pointlike cut by two neural networks

Results: reactor ON-OFF analysis

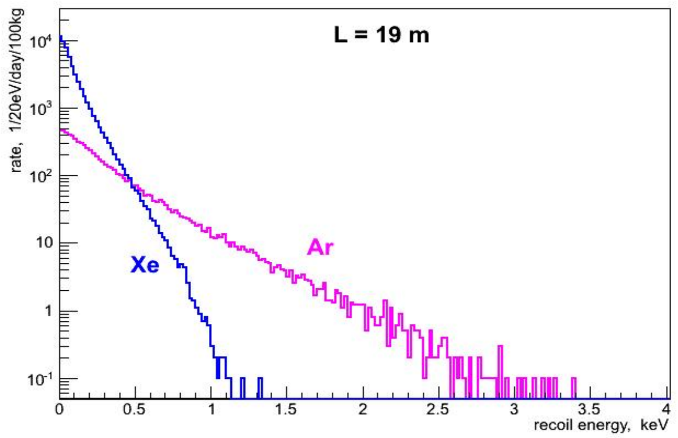
- Combined histogram (reconstructed energy+radius+duration)
- Azimov dataset for sensitivity calculation
- delta ON-OFF for CEvNS limit calculation
- significant dependence of the result on neutrino spectra model
- Final limit (sensitivity) values: $\mathbf{63^{+26}_{-16}(58^{+24}_{-15})}$

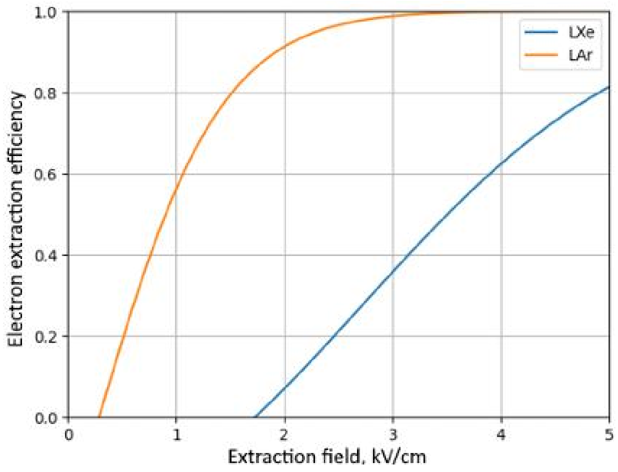


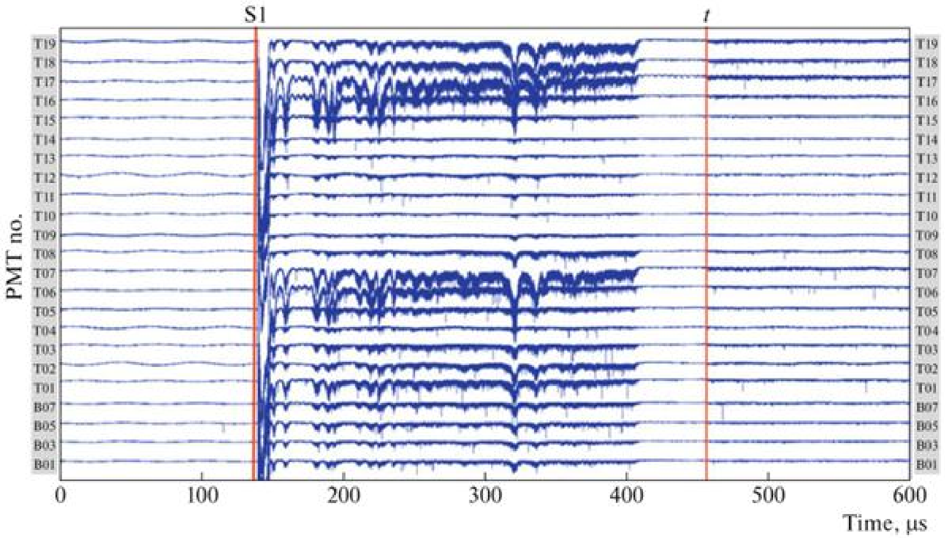


Future plans: RED-100/Ar

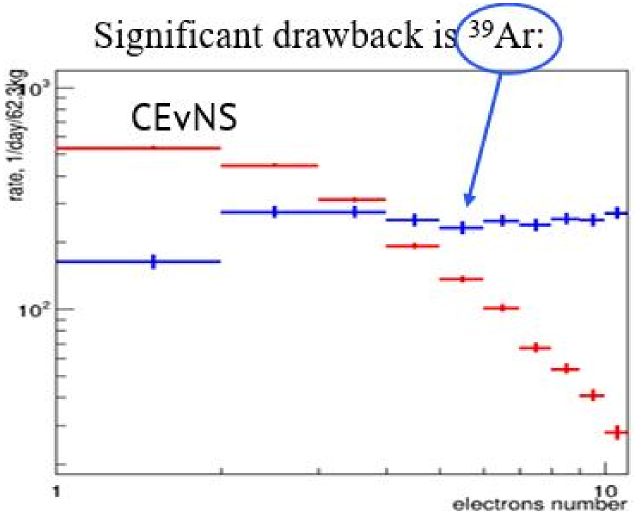
- Main LXe issue: SE noise
- Possible reasons:
  - Impurities
  - Subsurface electrons captured by potential barrier
  - Bounded states inside LXe
- Possible solution: LAr







Pros	Cons
Lower amount of delayed electrons (10^{-5} vs 10^{-3})	Ar-39 (~1Bq/kg for AAr)
Higher recoil energy for CEvNS	Short wavelength
~100% extraction efficiency	Lower temperature
Price	Longer SE duration (possibly)



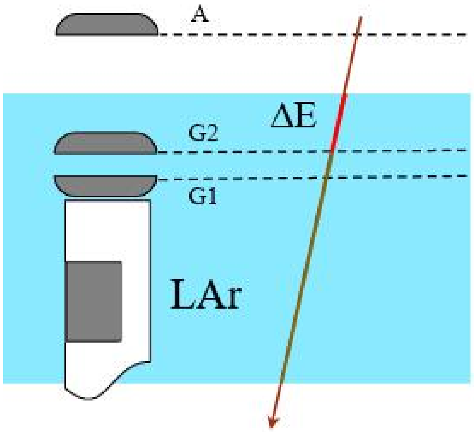
Future plans: RED-100/Ar

Old design:

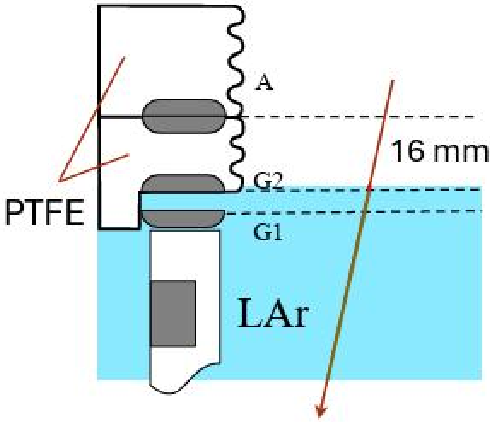
- Muon’s ΔE in LAr above G2 ~ 2 MeV produces afterglow in TPB with τ ~ 1 ms
- TPB afterglow => SPE noise ~ 2 MHz which didn’t allow us to set low threshold
- EL amplification is quite low: several SPE/SE ($U_{A\text{-}G2}$ ~ 11 kV)

New design:

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

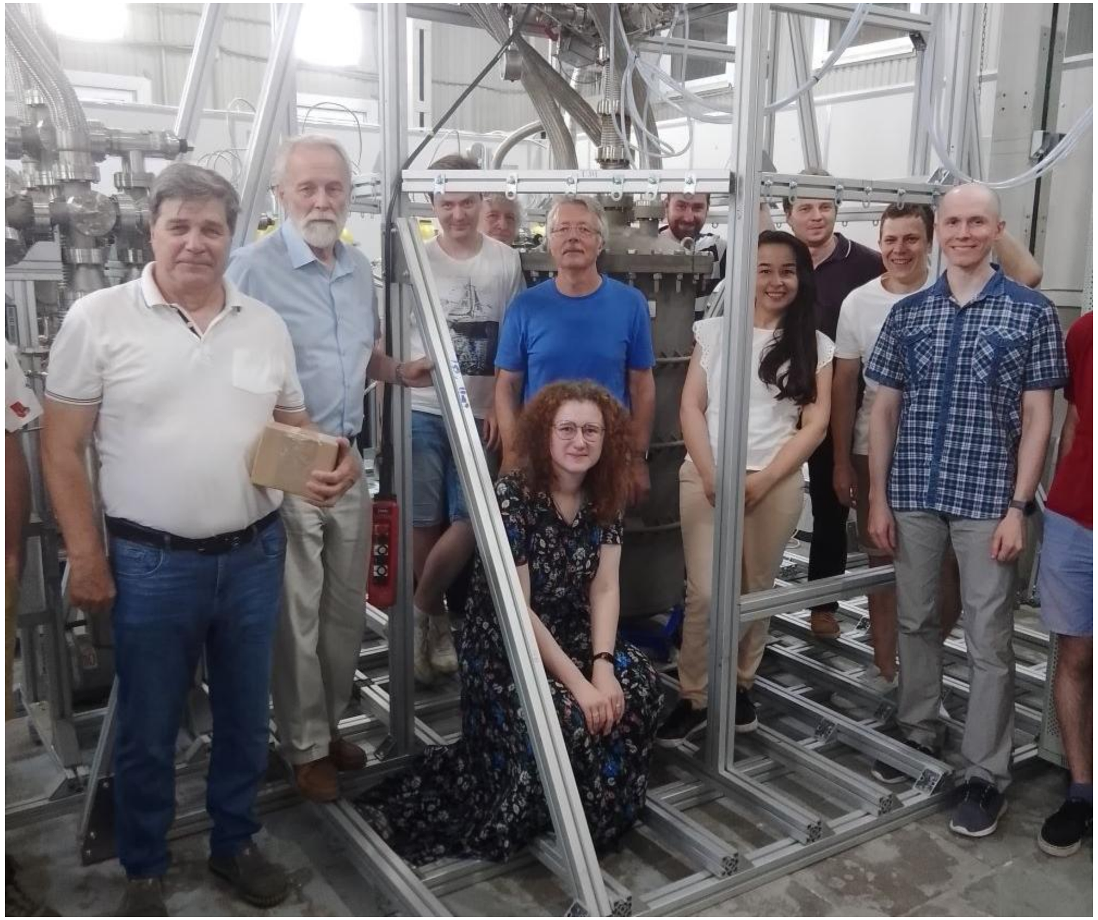


old design



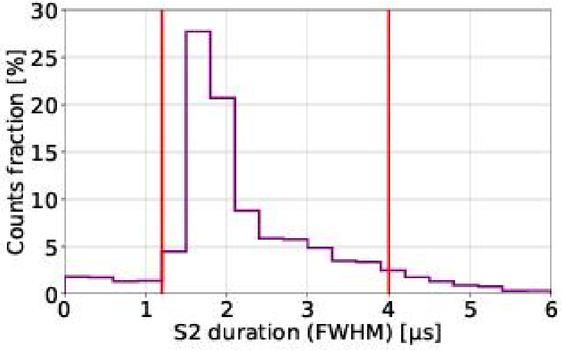
new design

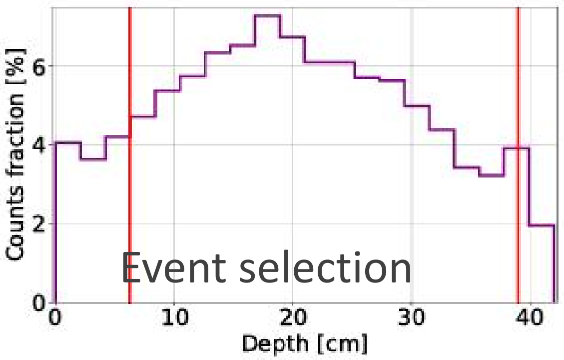
Thank you for your attention!

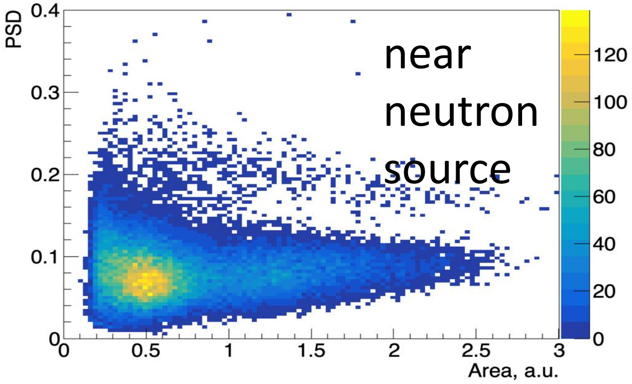


Backup slides

Calibration cuts and conditions







TPB