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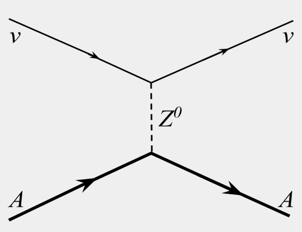
# RED-100 results&prospects

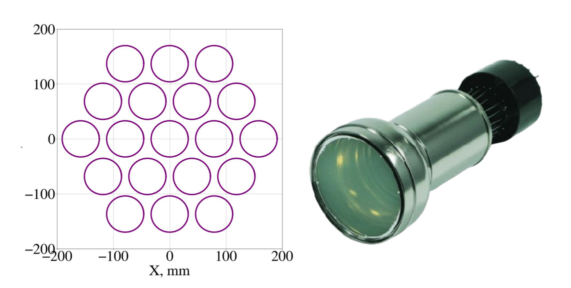
## Coherent elastic neutrino-nucleus scattering



- predicted by Standard Model
- very low energy (in keV range) of recoil nucleus
- first observed in 2017 by COHERENT

## RED-100 detector

- designed in order to study coherent elastic scattering of reactor electron antineutrinos off xenon atomic nuclei
- two-phase emission detector
- contains ~200 kg of LXe (~ 100 kg in FV) or ~100 kg of LAr (~50 kg in FV)

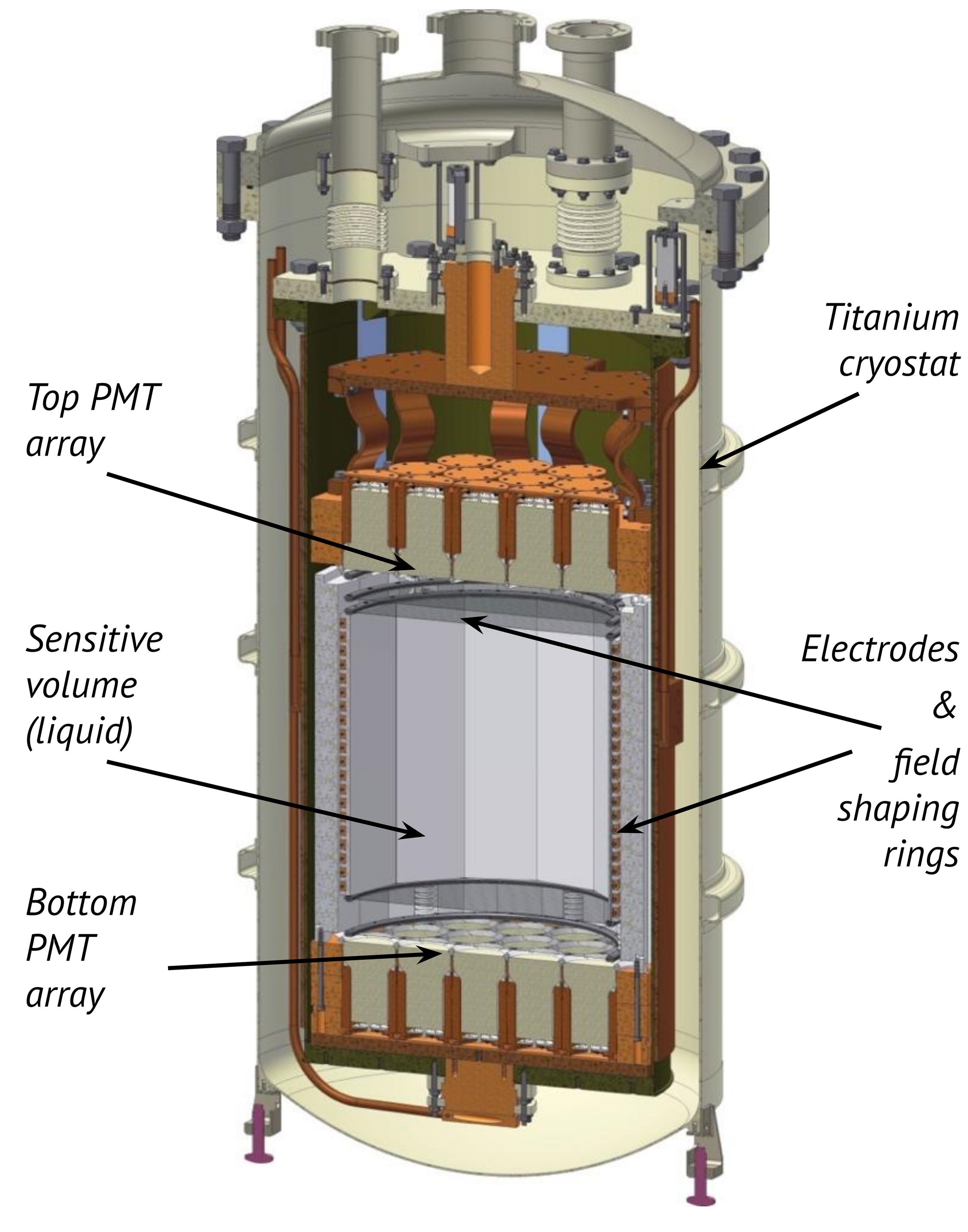


*geometry of the top PMT array*

- 26 Hamamatsu R11410-20 PMTs (19 in the top array, 7 in the bottom array)
- Thermosyphon-based cooling system ($LN_2$)

- Sensitive to the single ionization electron (SE) signal. CEvNS response is expected to be of several electrons.

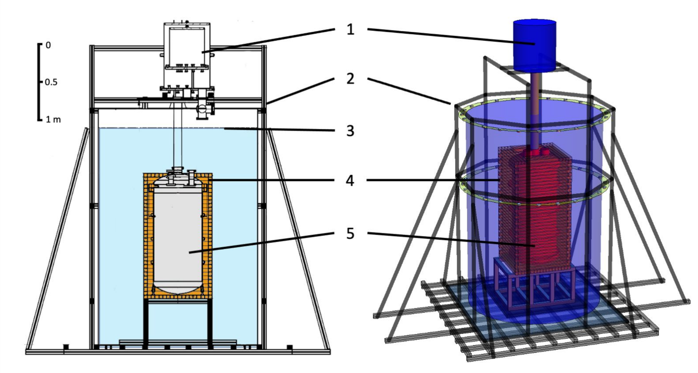

D.Z. Freedman, Phys. Rev. D 9 (1974) 1389
Kopeliovich V B, Frankfurt L L JETP Lett. 19 145 (1974); Pis'ma Zh. Eksp. Teor. Fiz. 19 236 (1974)
D.Akimov, J. Albert, P. An et.al., Science. – 2017.
First ground-level laboratory test of the two-phase xenon emission detector RED-100, Akimov D. et.al., JINST 2020


**Scheme of the RED-100 detector**

## RED-100 at Kalinin NPP


- 19 meters from the reactor core
- reactor and reactor building&infrastructure as a passive shielding from muons
- water tank as a passive shielding from neutrons
- 5 cm of copper passive shielding from gamma sources
- Antineutrino flux at place ~ $1.35 \cdot 10^{13}$ $cm^{-2}s^{-1}$
- 65 m.w.e. in vertical direction

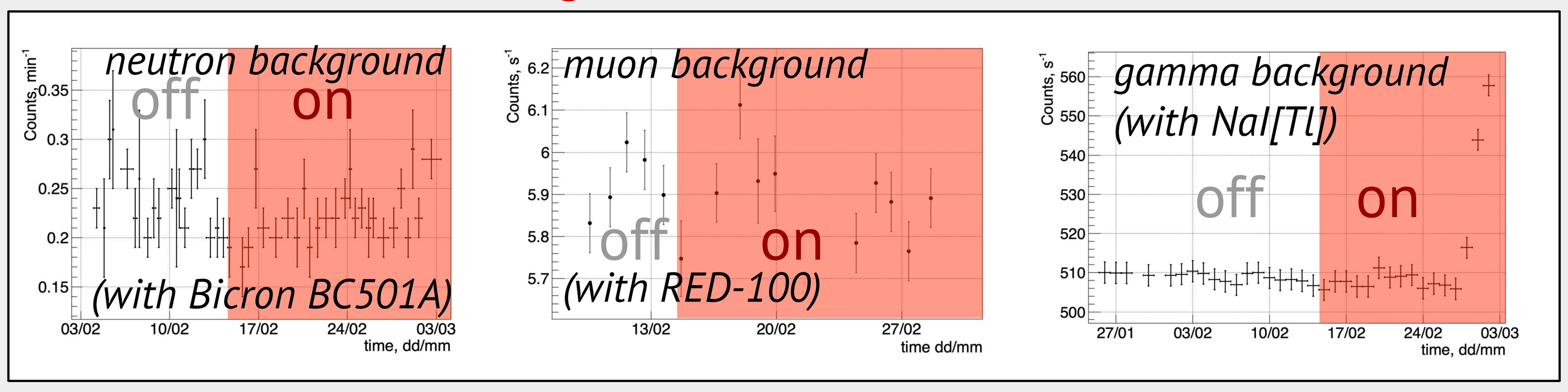


*1: LN2 tank, 2: support frame, 3: water tank, 4: Cu shielding, 5: RED-100*

- 2020: RED-100 was shipped to KNPP
- 2021: Deployed and tested
- 2022: (Jan-Feb) Physical run
- reactor OFF and reactor ON periods


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

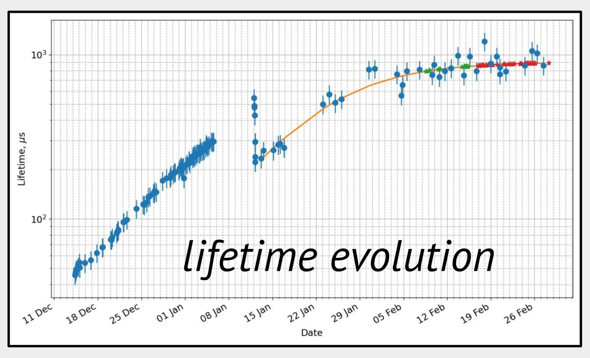

## Background conditions at KNPP

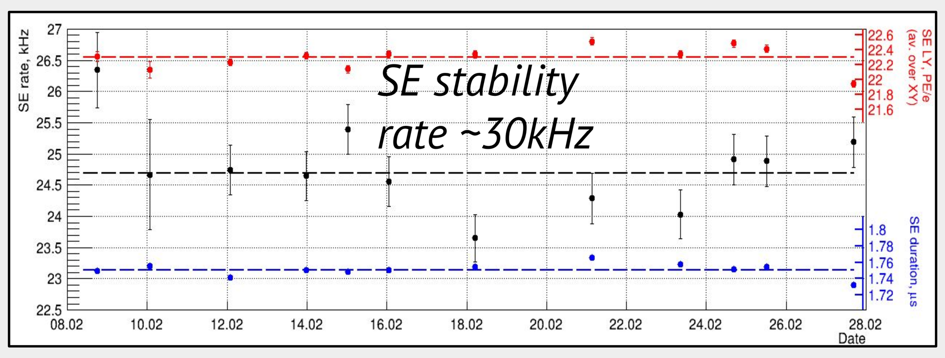


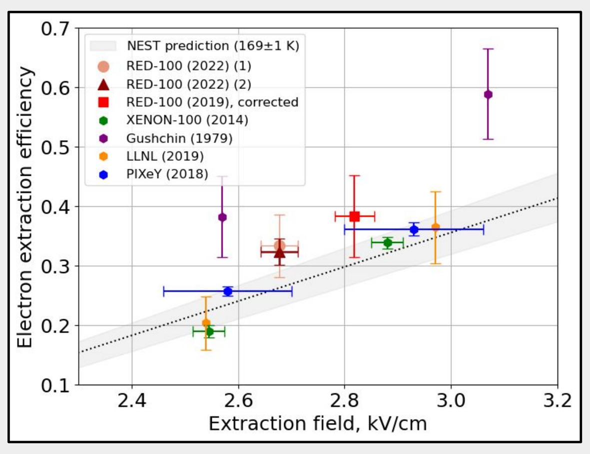

- background was measured with RED-100 itself and with different additional detectors
- no significant correlation in external background count rate with reactor operation

## Calibration and characterization of the detector

- LED calibration (for the SPE parametrization)
- SE calibration (with zero hardware threshold)
- calibration with the cosmic muons (for the electron lifetime measurement)
- calibration with gamma-sources ($^{137}$Cs and $^{60}$Co) (for the light response functions (LRFs) reconstruction and electron extraction efficiency calculation)



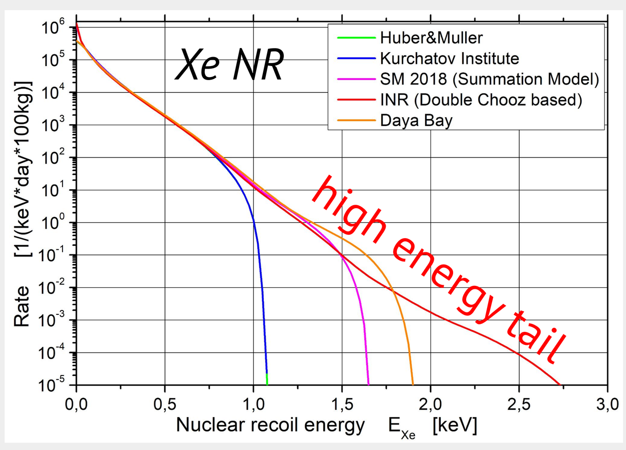





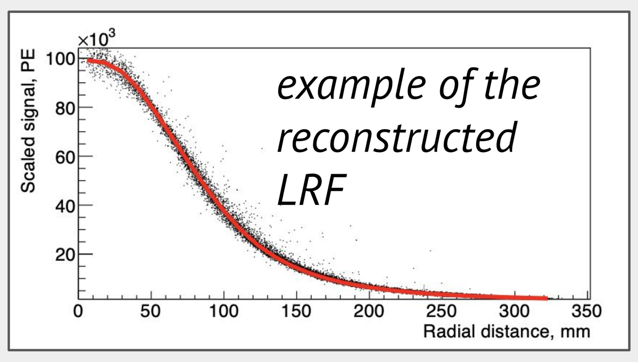
D.Y. Akimov et al 2023 JINST 18 P12002
https://arxiv.org/abs/2403.12645


## Reactor antineutrino spectrum

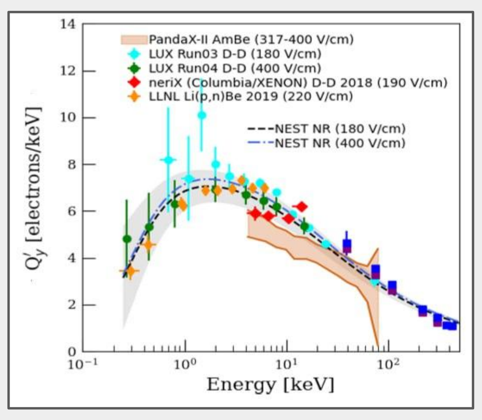



- contribution of the high energy tail is significant in our ROI (>4 extracted ionization electrons)
- the partial shares of the main fissile isotopes of nuclear fuel were considered unchanged throughout the data taken period
- the average energy per fission is ~205.3 MeV

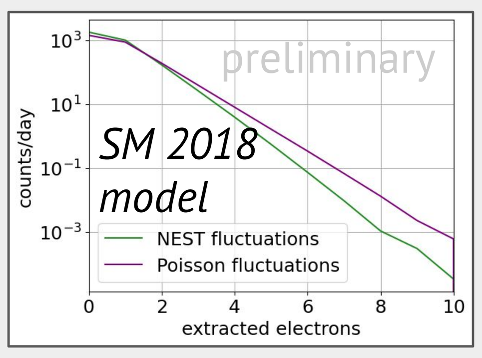
## Signal simulation




- every signal consists of several SE signals
- SE signals were simulated using measured SE parameters and reconstructed LRFs



- charge yield was calculated using NEST 2.1.4
- there is a significant dependence on charge yield dispersion model
- The Poisson dispersion is based on assumption that SE are results of counting experiment
- The NEST dispersion is based on first principles (mechanism of total quanta distribution to scintillation and ionization channels with correction to non-binomal component)



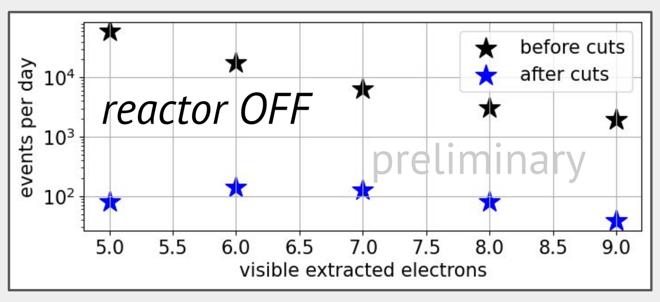


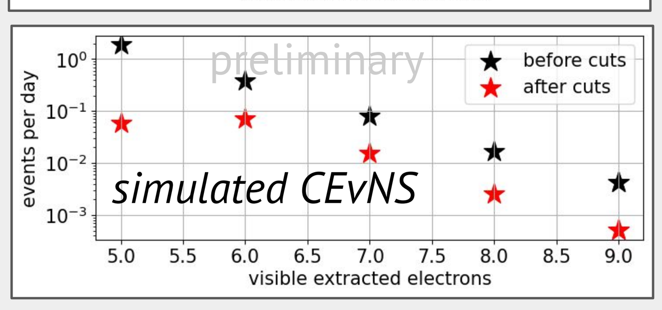
V.I. Kopeikin, L.A. Mikaelyan, and V.V. Sinev,Reactor as a Source of Antineutrinos: Thermal Fission Energy, Physics of Atomic Nuclei, 1892 (2004)
Szydagis et al., Noble Element Simulation Technique (v2.3.6) // Zenodo. – 2022.


## Data in ROI (ON and OFF)

- **Trigger:**
  – counts SPEs in individual channels in 2μs time window with vetos after muons and gammas
  – veto high SPE rate
  – has livetime ~60%
- **Cuts:**
  – on the number of random SPE on the wf
  – on the energy (>4.5 visible ionization electrons)
  – on the reconstructed radius (140 mm)
  – on the duration (cut depends on energy)
  – pointlike cut by two neural networks

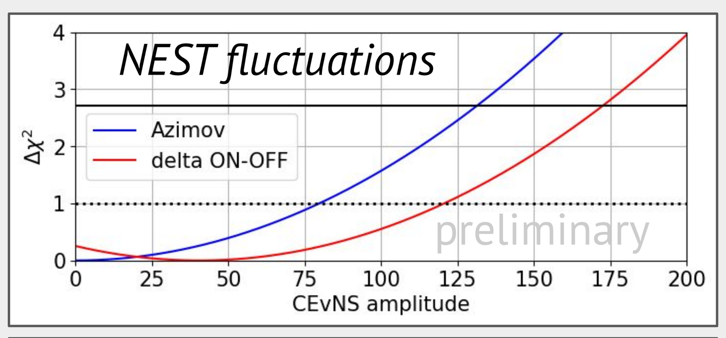
**Unexpectable pointlike high energy background!**

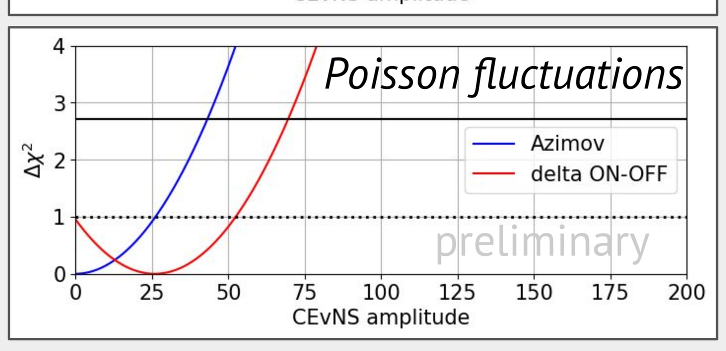



*T off = 65 kg ·day, T on = 172 kg ·day*

## Sensitivity&CEvNS upper limit




- combined histogram (reconstructed energy+radius+duration)
- Azimov dataset for sensitivity calculation
- ON-OFF residual for CEvNS limit calculation

**90% C.L.**

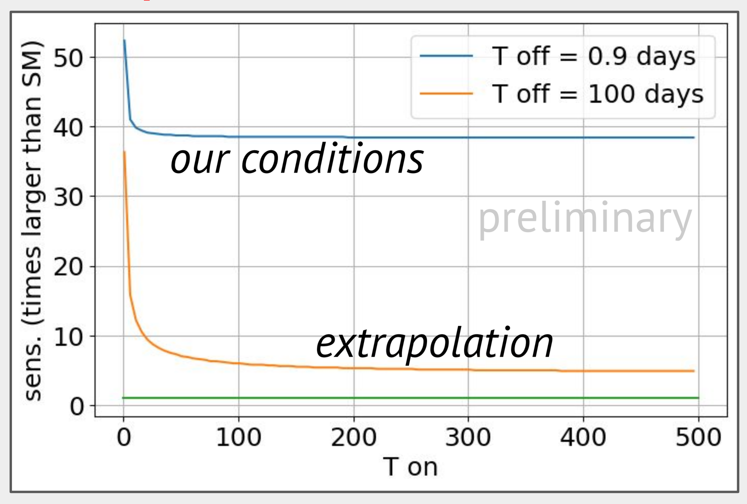
*NEST fluctuations*: sensitivity ~131 and upper limit ~172
*Poisson fluctuations*: sensitivity ~43 and upper limit ~70
*(times larger than SM prediction)*

**Significant dependence on the fluctuations model!**

## LXe summary

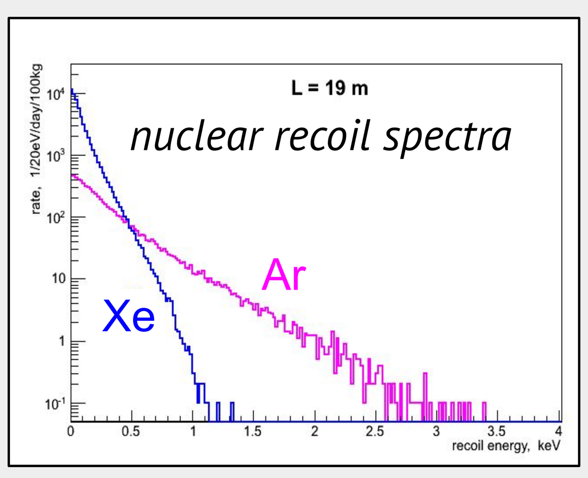
- the possibility of the detector operation with stable parameters at NPP was demonstrated **for the first time for this detector type**
- threshold 4.5 SE
- the sensitivity to single ionization electrons was shown (SEG = 27.4±0.03 SPE/SE)
- advanced data analysis methods were applied
- ~190 times background suppression in ROI (~16 times signal suppression) (NEST fluctuations)
- **unexpectable pointlike background in ROI**
- **significant result dependence on the fluctuation model**

with **optimistic** Poisson fluctuations:




*100 days reactor OFF livetime requires at least 10 years detector exposition at the KNPP*

## RED-100/LAr




- higher nuclear recoils energies → more electrons per CEvNS event
- ~100% electron extraction

Engineering tests are ongoing
– PMTs were coated with TPB
– the cooling system was upgraded
– the extraction field was raised up to 5kV/cm
- LY and SE study is ongoing