Sub-keV dark photon search with S2-only data in PandaX4T

Shuaijie Li
Yalong Hydro (CJPL) / SJTU
On behalf of the low energy group

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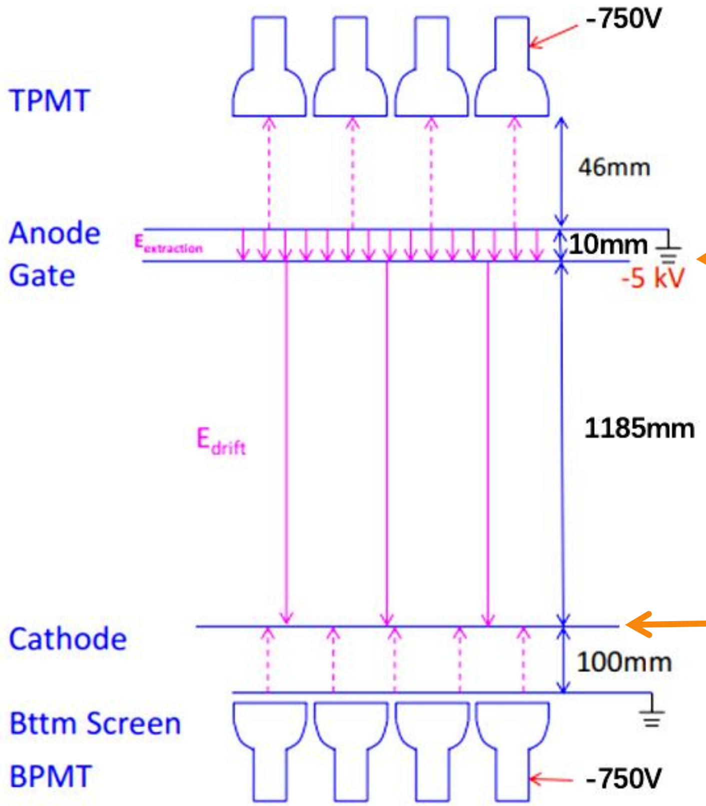
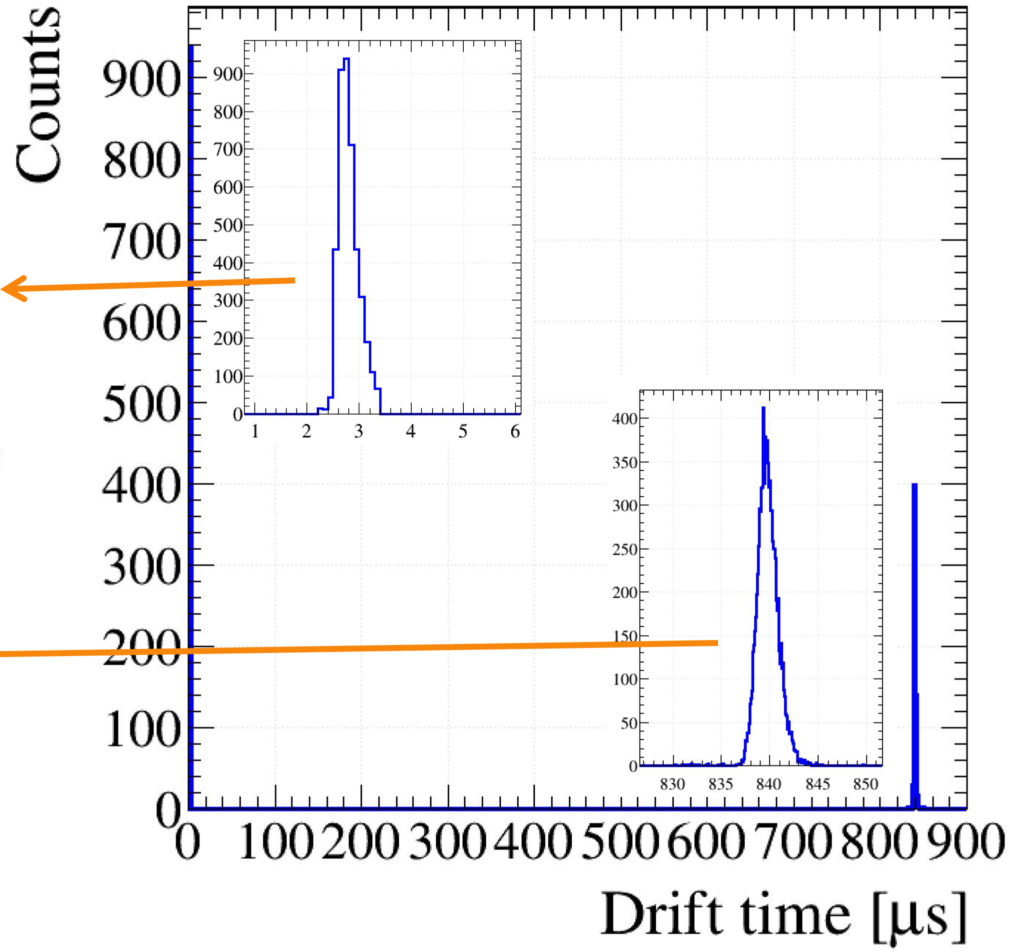
PandaX-4T experiment

➢Dual-phase Time Projection Chamber





Dark photons as DM candidate

- DPs are the gauge bosons of dark U(1), which kinetically mix (κ) with the SM photons. Since κ is a free parameter, DPs < 1 MeV are possible.
- Dark photons produce a monochromatic energy signal by kinetically mixing with the SM photons. (or ALP, B−L Gauge Boson...)

$$R_{\mathrm{DPs}} = \frac{4.7 \times 10^{23}}{A} \kappa^2 \left(\frac{\mathrm{keV/c^2}}{m_V} \right) \left(\frac{\sigma_{pe}}{\mathrm{b}} \right) \mathrm{d}^{-1}\mathrm{kg}^{-1}$$

κ: kinetic mixing parameter

σ_{pe}: photo-electric cross section

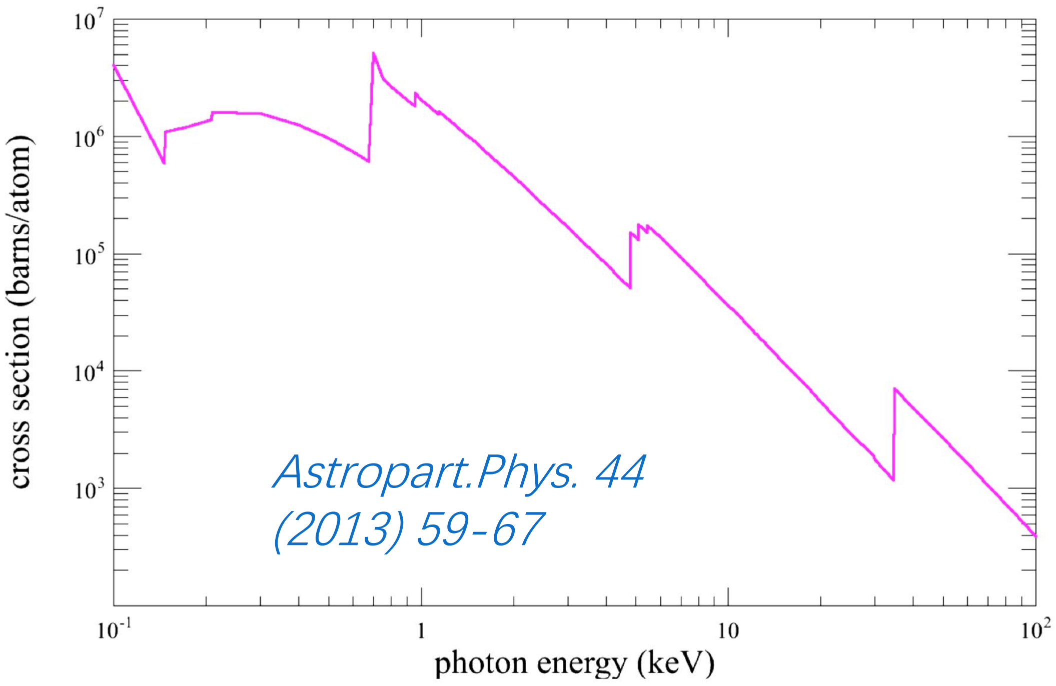
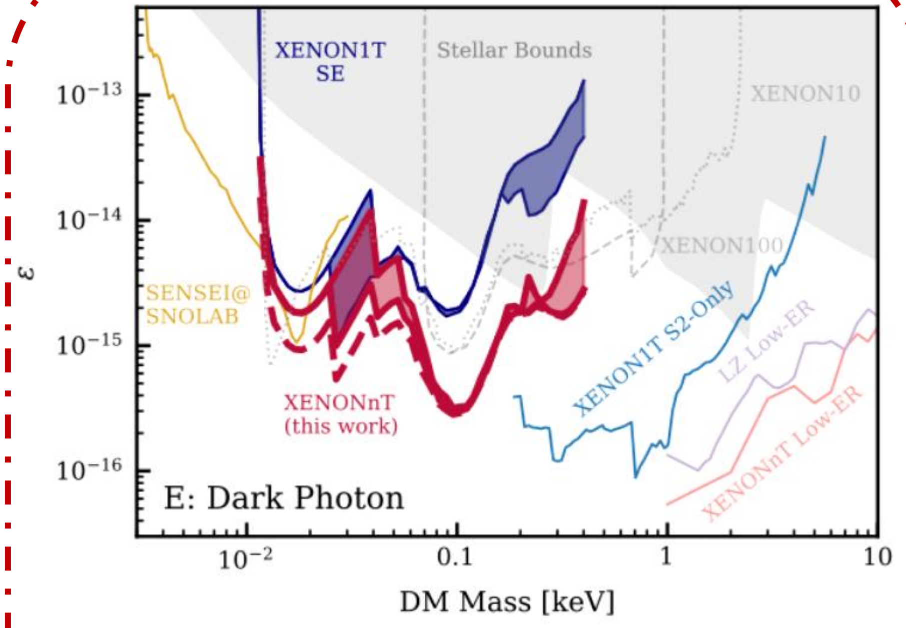


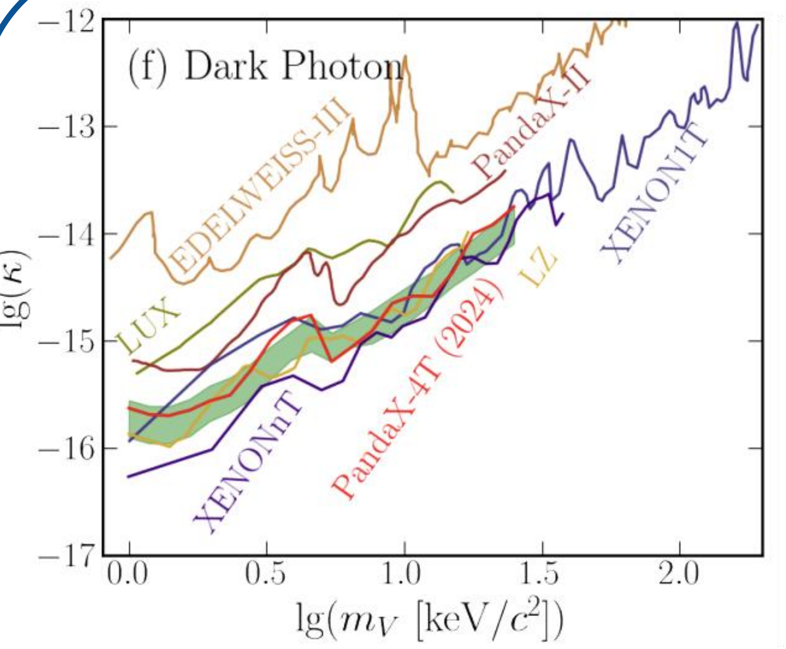
Figure 1: Photo-electric cross section on Xenon atom [27].

Dark photons results

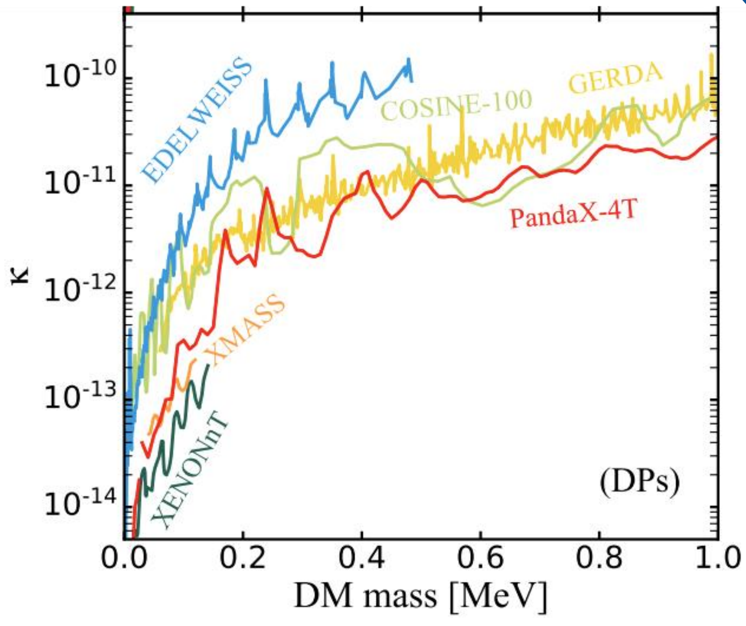
➢ S2-only channel analysis in LDM and boron-8 neutrino decreased the low energy threshold to < 0.1 keV



PHYSICAL REVIEW LETTERS 134, 161004 (2025)



PHYSICAL REVIEW LETTERS 134, 041001 (2025)



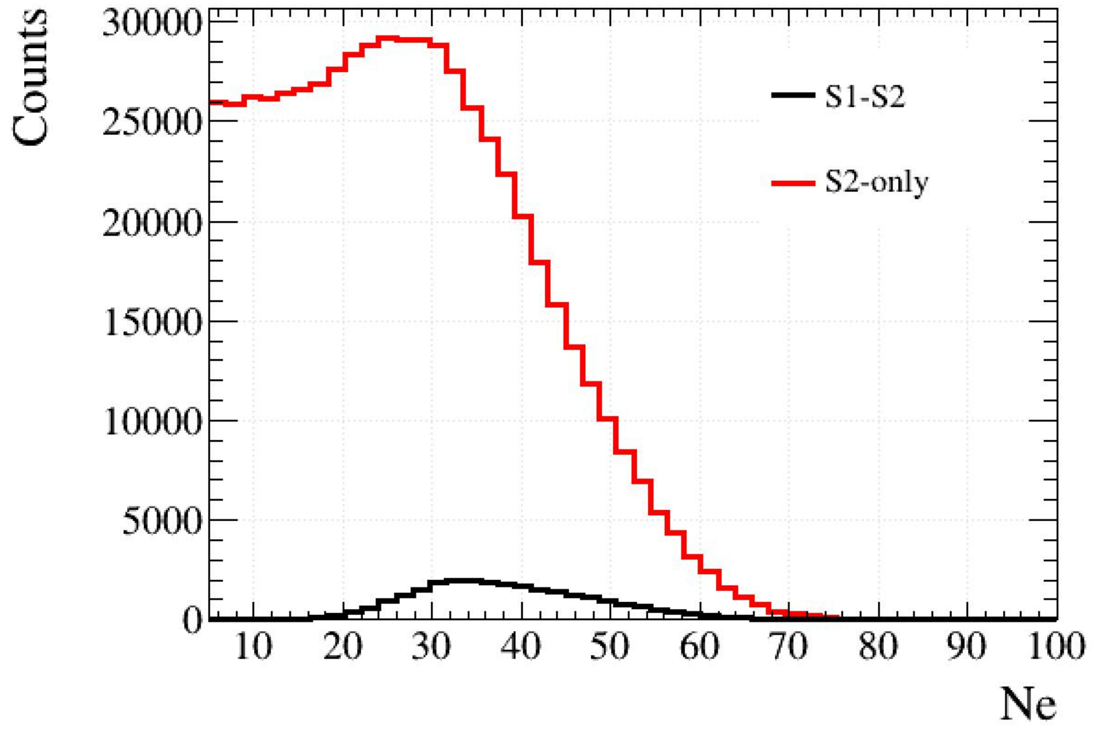
PHYSICAL REVIEW LETTERS 134, 071004 (2025)

Sub-keV DPs searching in PandaX-4T

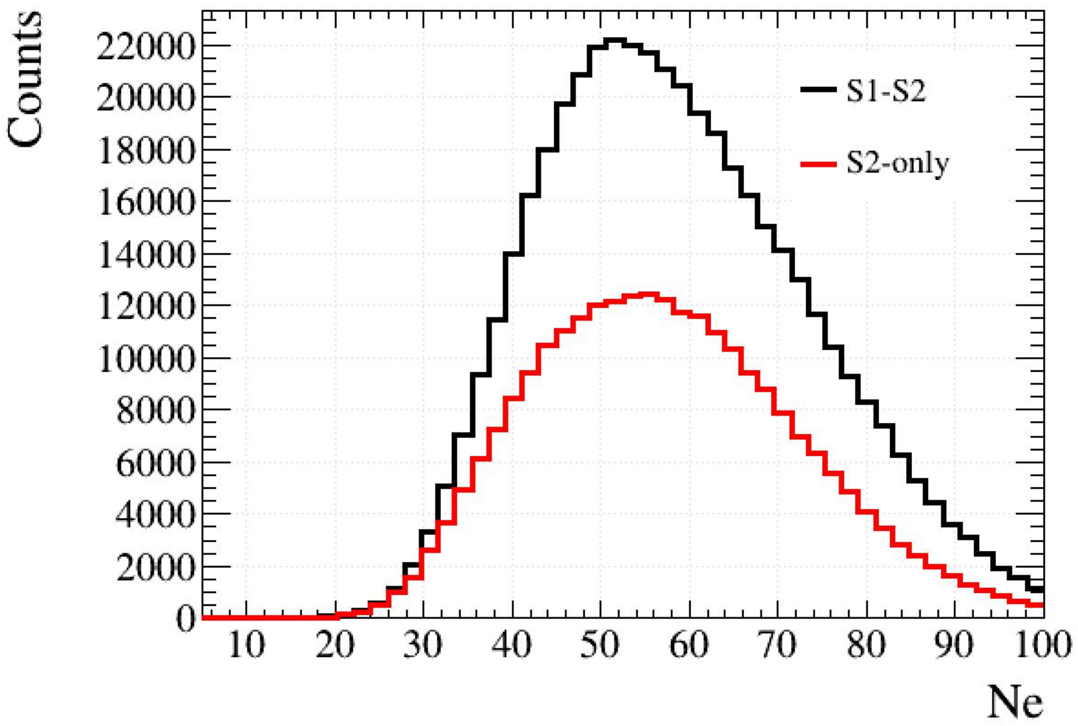
ROI for Sub-keV Dark Photons

- ➢low efficiency of S1 makes the energy threshold to 1 keV for S1-S2 evts
- ➢S2-only data are dominant below 1 keV

flat ER nest simulation (**0-1 keV**)



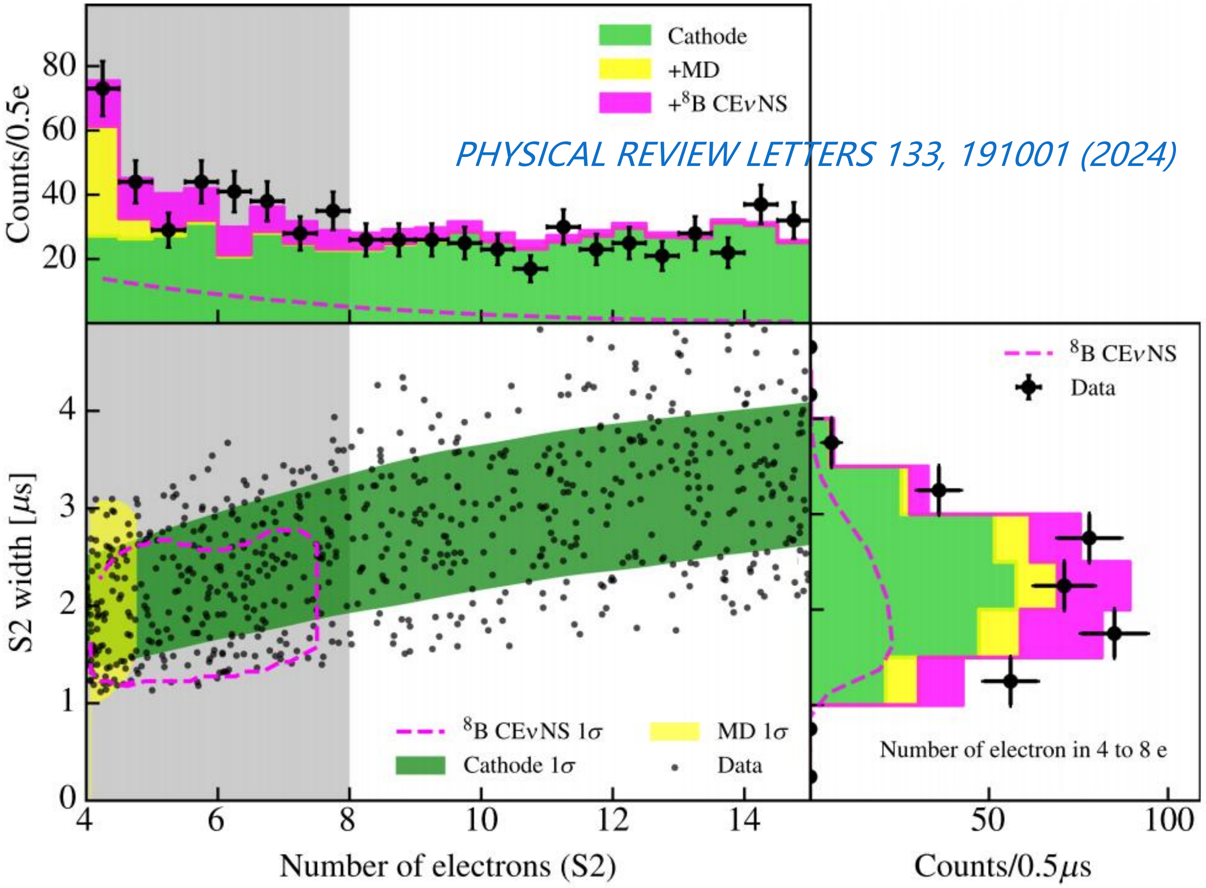
flat ER nest simulation (**1-2 keV**)



Use 65e as the upper edge of ROI to search Sub-keV DPs

ROI for Sub-keV Dark Photons

- <5 e S2-only data are dominant by MD background

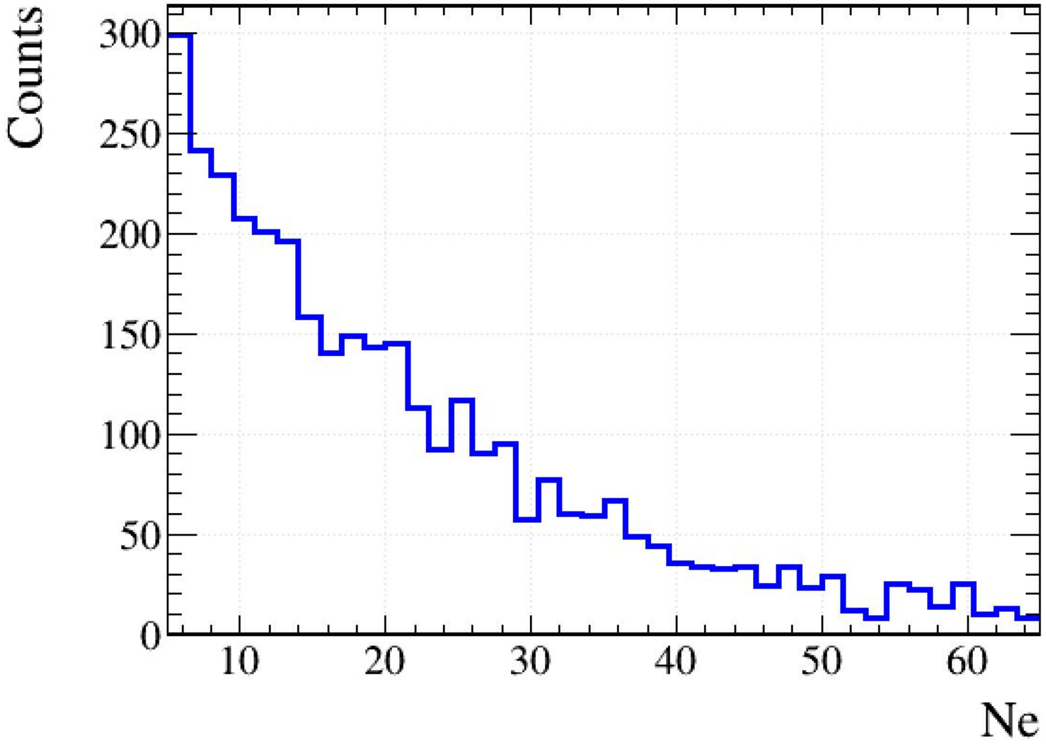


PHYSICAL REVIEW LETTERS 133, 191001 (2024)

Use 5e as the lower edge of ROI to search Sub-keV DPs

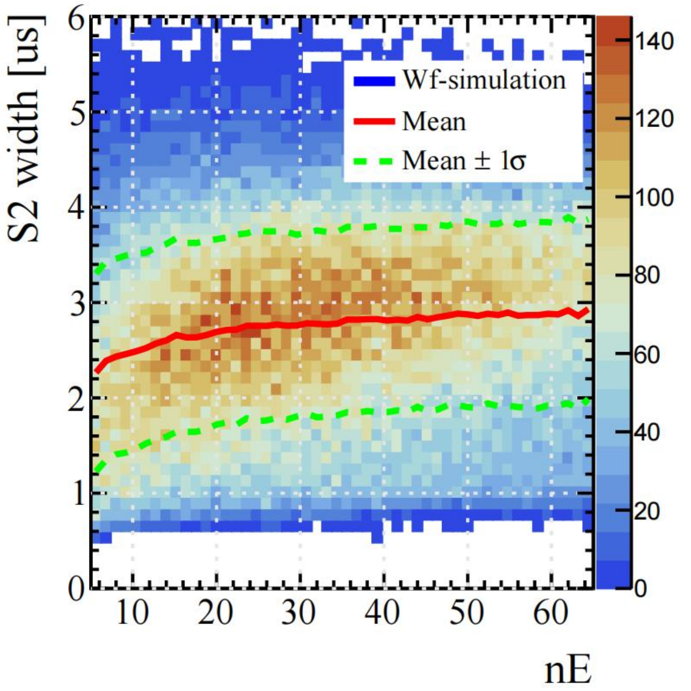
Data

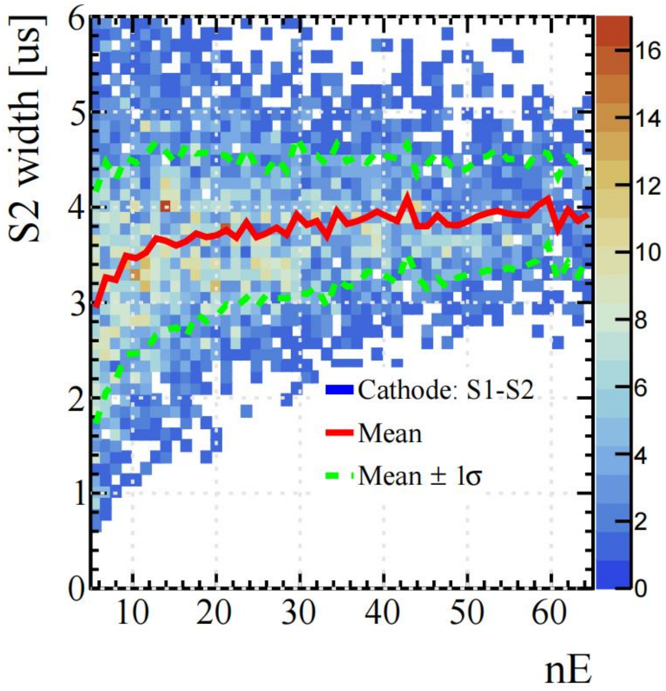
- ➢Randomly opened data in run0 (7.3 d) and run1 (6.4 d)
- ➢all data: run0+run1 1.04 tonne*year: S2-only in ROI, blind
- ➢Waveform simulation: 1-100 e flat S2 simulation
- ➢Neutron calibration data: (including secondary scattered neutron evts)

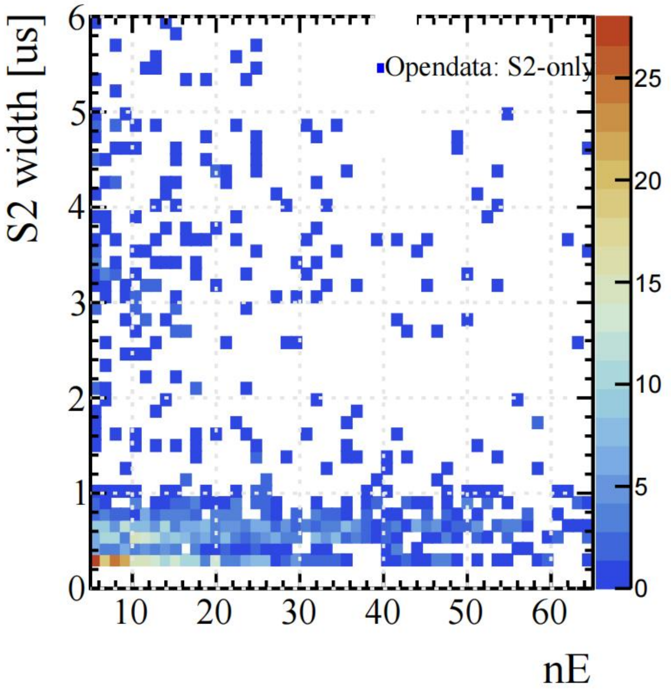


Selections

- ➢Inherited the selections from boron-8 analysis
- ➢By using basic cuts , the opendata shows dominance by cathode and gate events in ROI. (run0 as eg.).



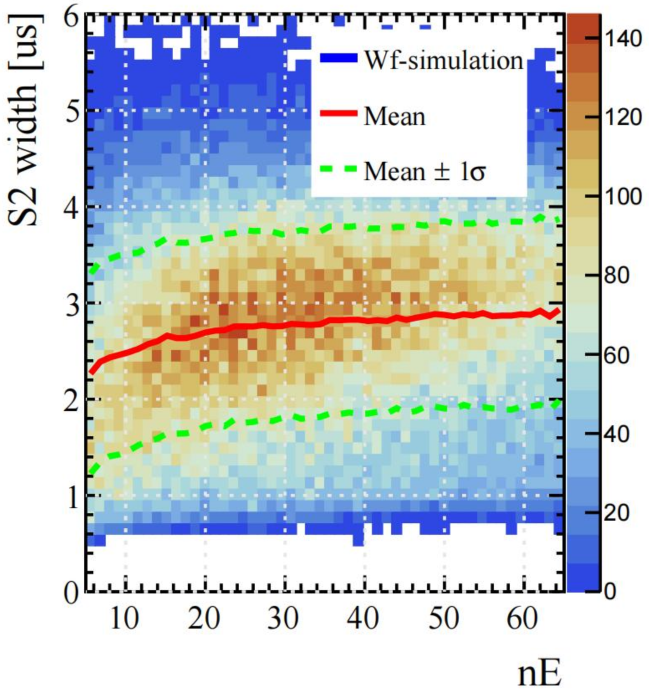


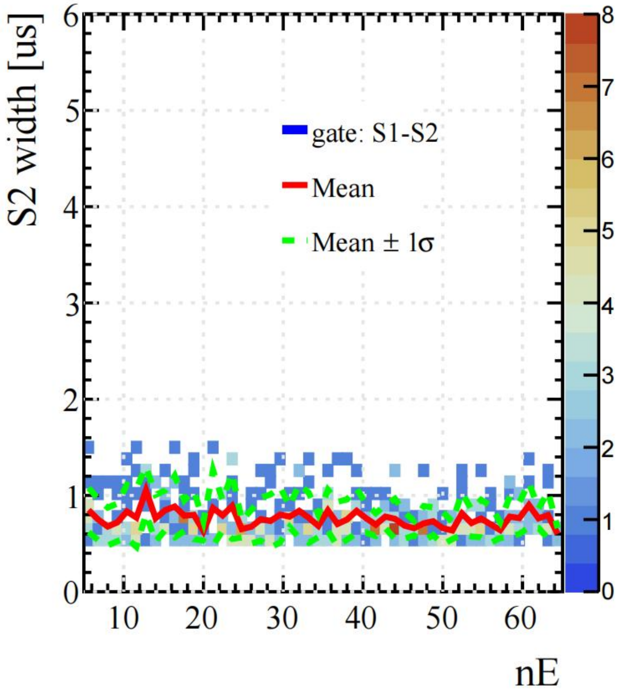


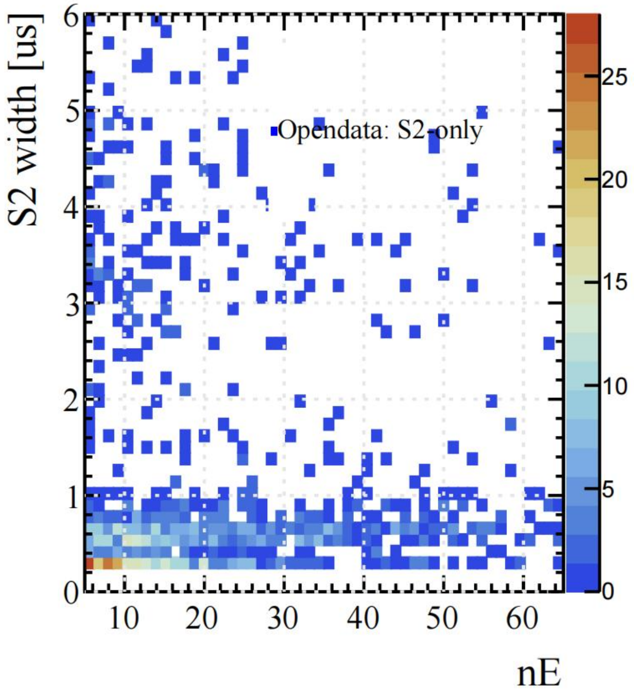
Adjust suitable selections for S2-only data above 8 e

Selections

- Inherited the selections from boron-8 analysis
- By using basic cuts , the opendata shows dominance by cathode and gate events in ROI. (run0 as eg.).



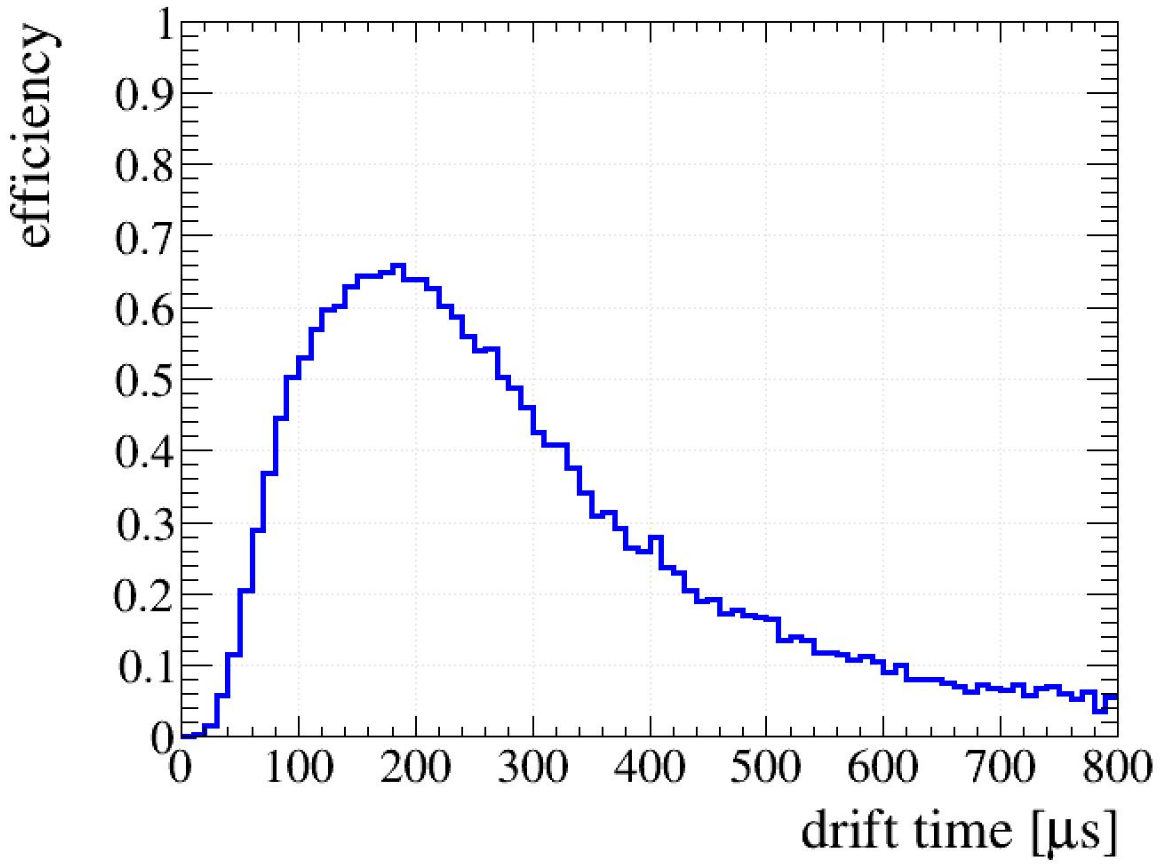




Adjust suitable selections to suppress electrode evts

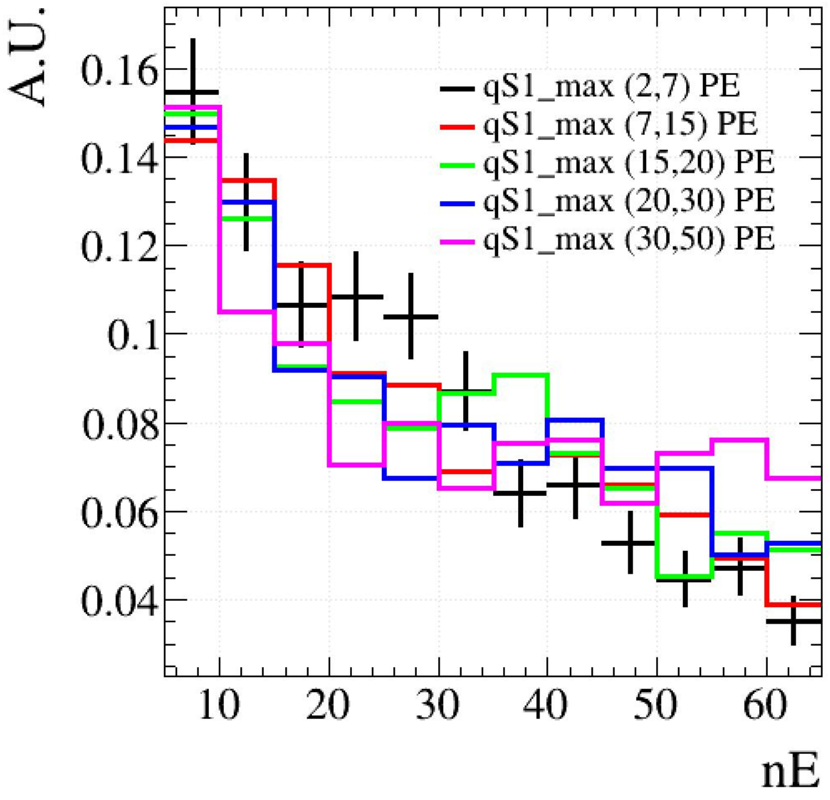
Electrode backgrounds efficiency

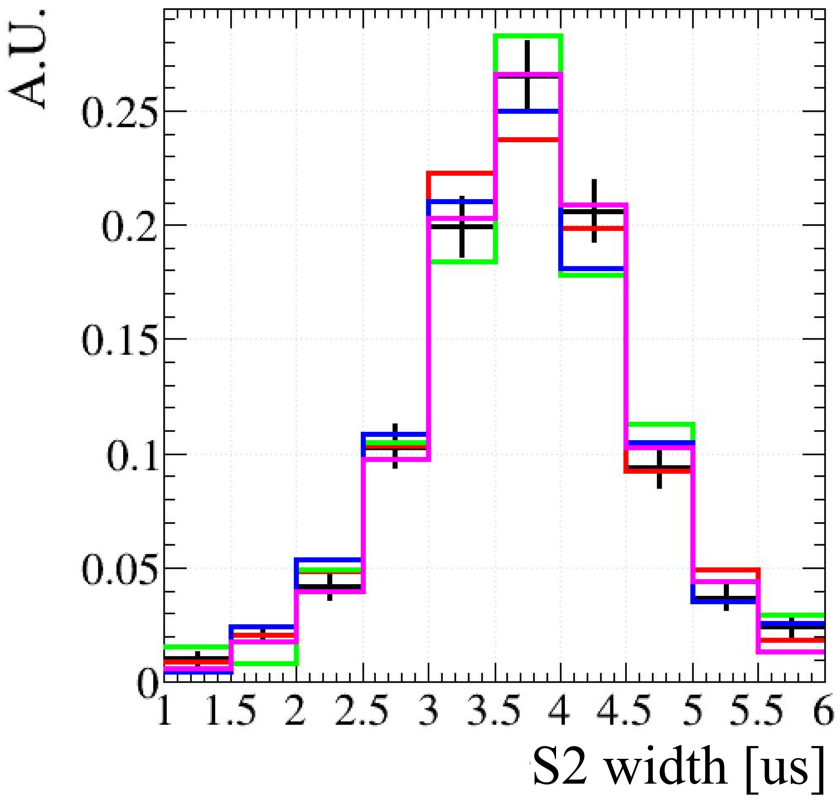
- use wf-simulation data to check the drift time efficiency
- The efficiency curve shows strong ability to reduce electrode backgrounds



Background - cathode

➢Paired cathode S2 spectrum is independent with S1

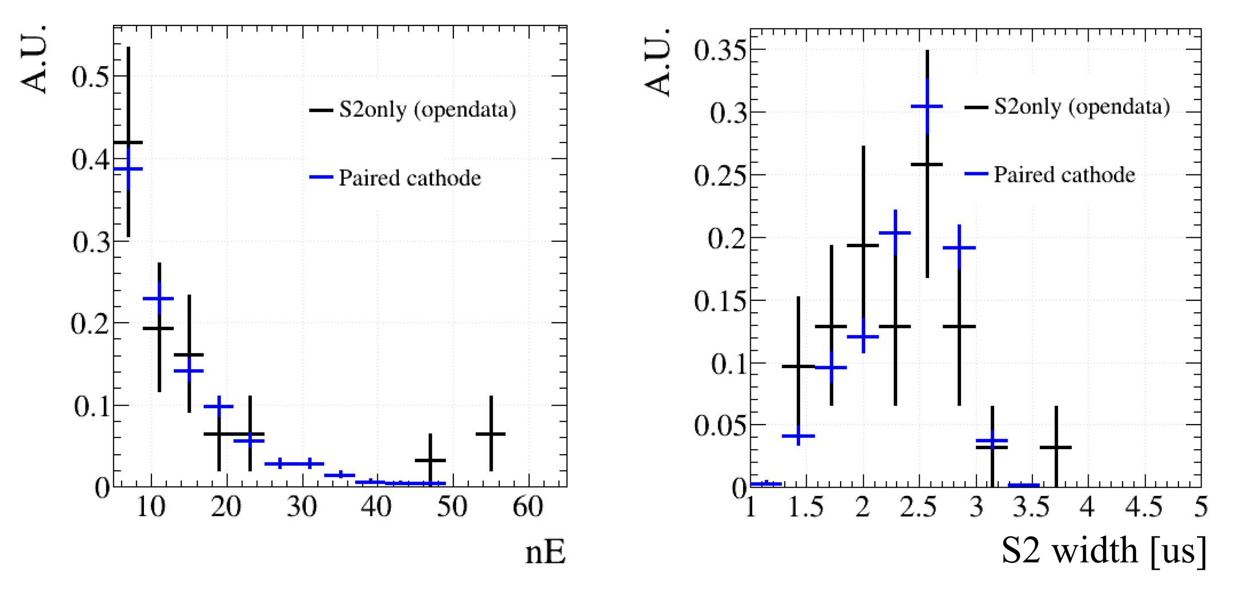




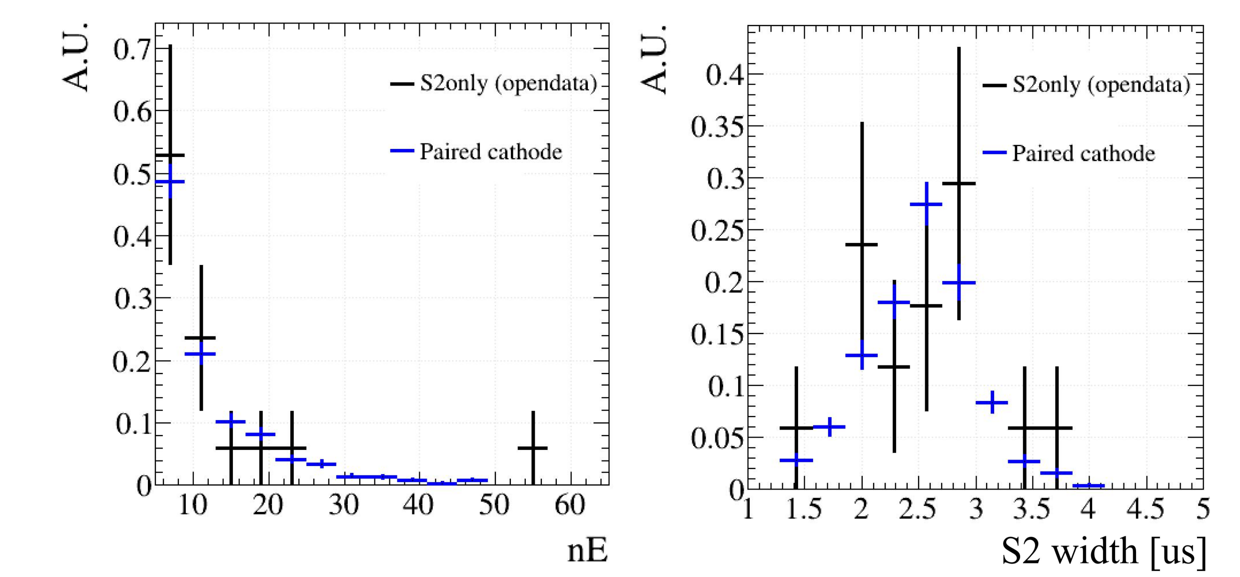
S2-only cathode has the similar features with paried cathode

compare paired cathode evts and open data (all cuts)

- Paired cathode events and S2-only events (opendata) have similar features



run0

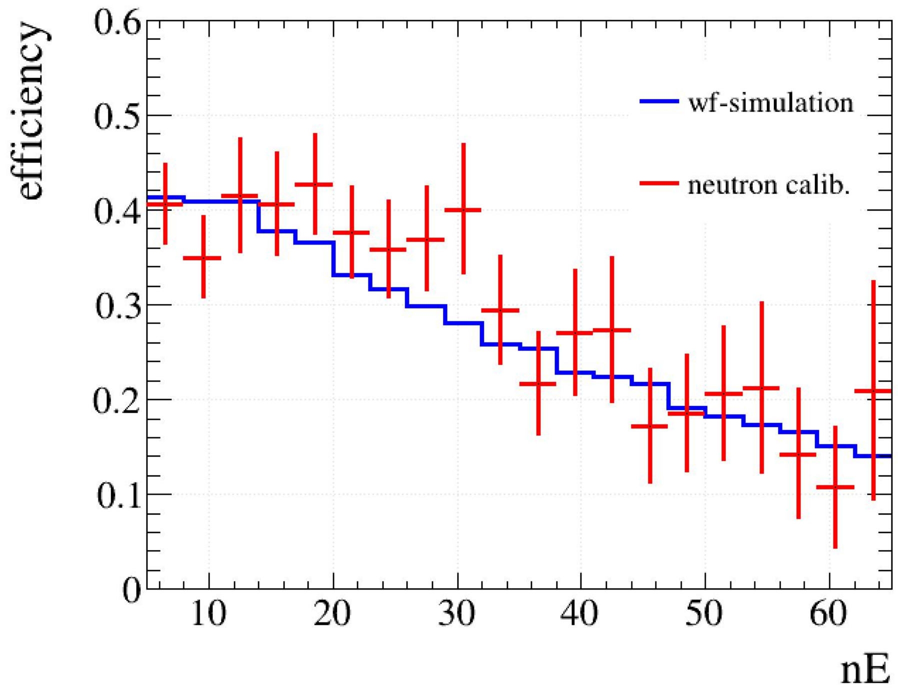


run1

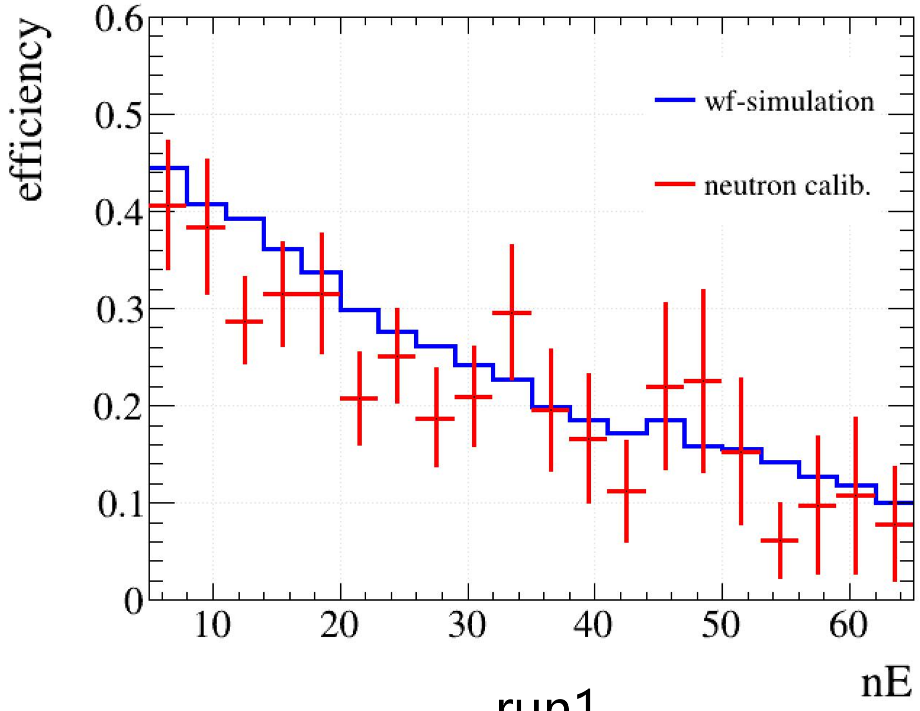
Cathode contribution is non-negligible

Signal efficiency

- compare the efficiency performance between wf-simulation and neutron calibration



run0

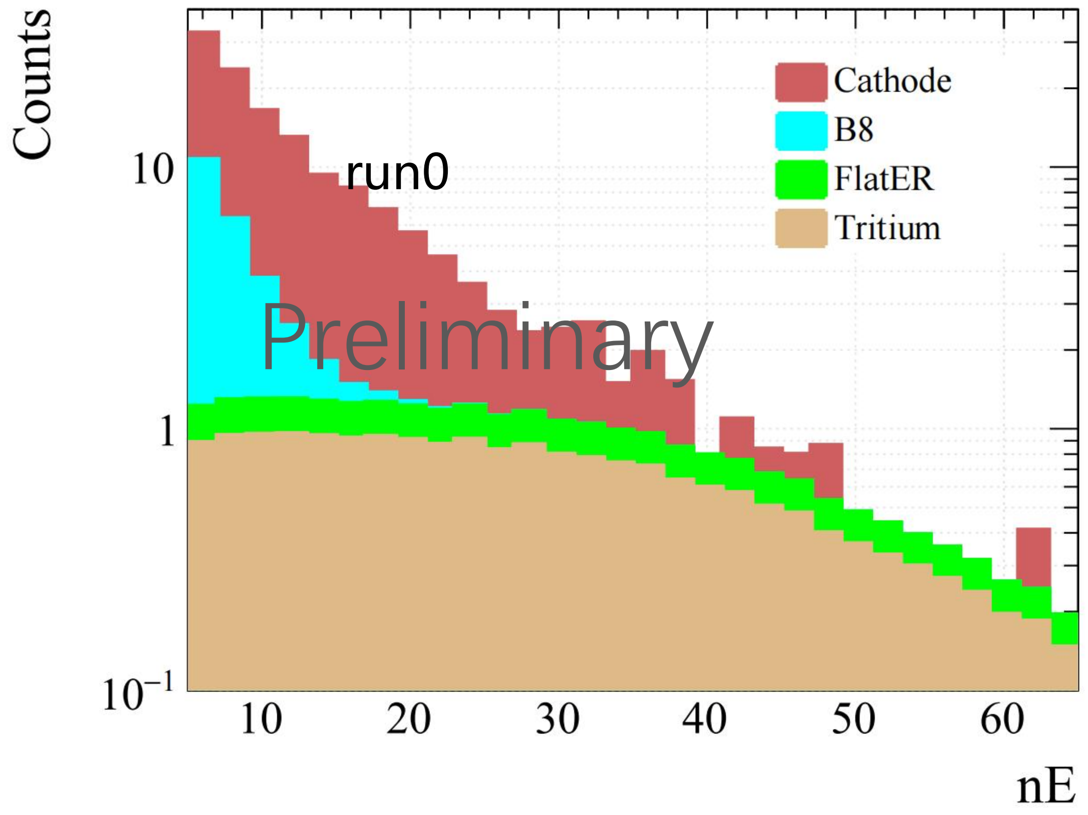


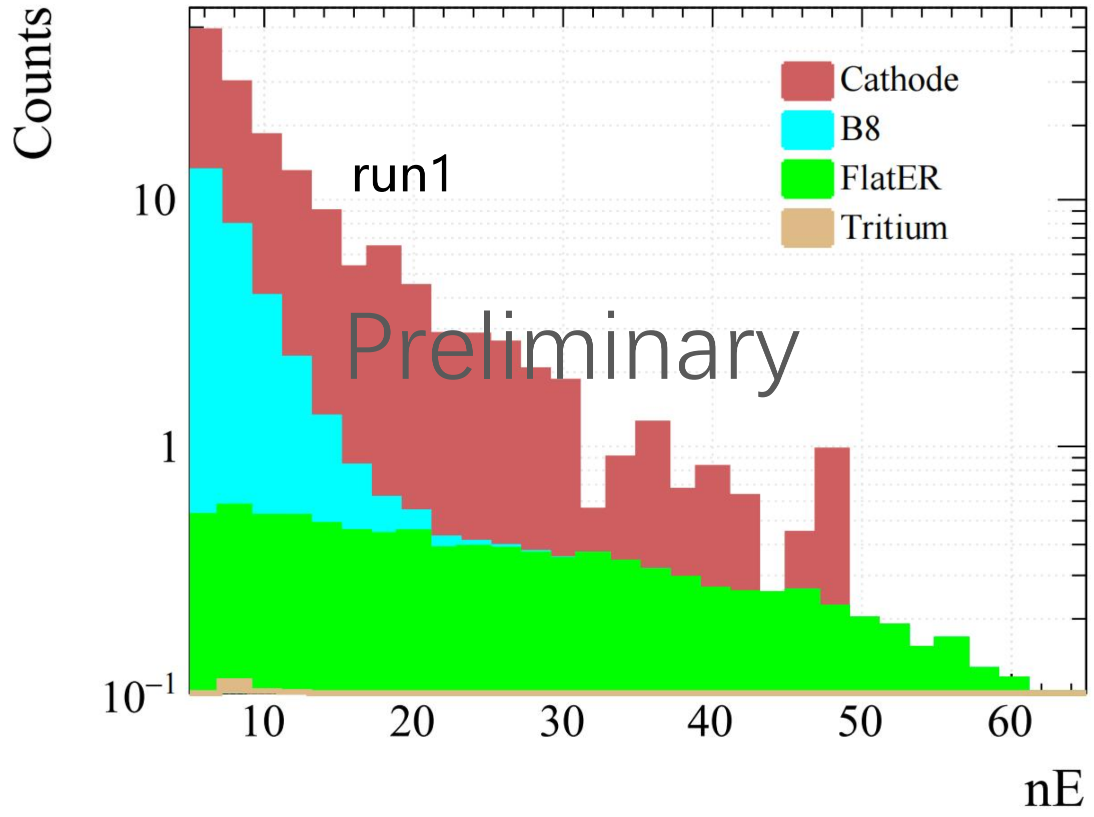
run1

Consistent with wf-simulation and calibration

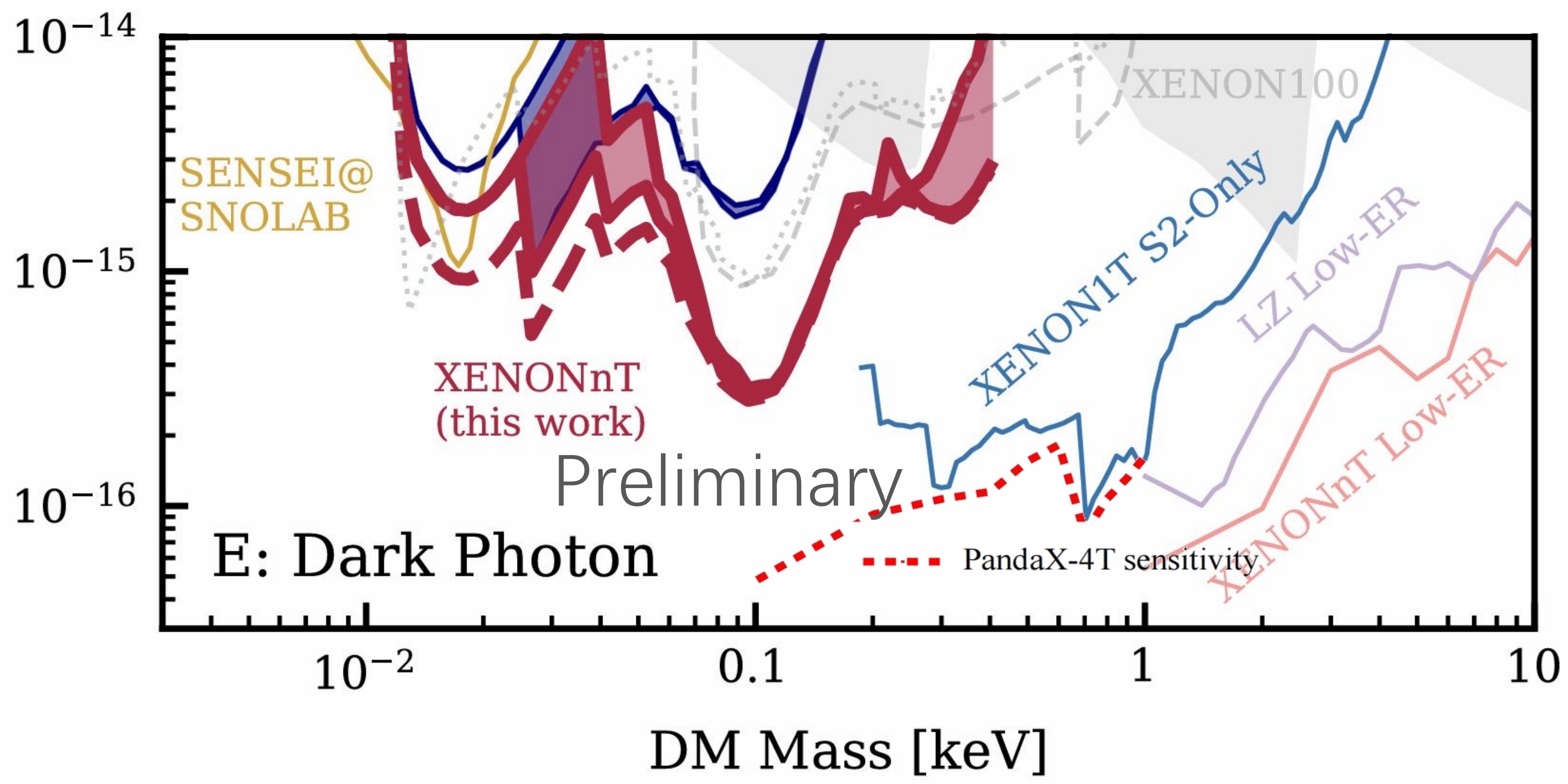
Expect backgrounds

- Consider the S2-only data consists of cathode, b8, ER events.
- Cathode contributions are scale from large width region in which the cathode S2-only events are dominant.
  - Open all S2-only data in 40-50 e, width in 3-5 us for sensitivity test





Sensitivity



Summary and Plans

- To search Sub-keV dark photons, we expanded the S2-only energy region from 4-8 e to 5-65e.
- The selections have a high ability to veto electrode backgrounds.
- The sensitivity is competitive with existing constraints for Sub-keV dark photons.
- Unblind data…

Thanks!

Back Up

Xenon1T exposure

- s2only use 258.2 days run1 data of Xenon1T, fiducial mass ~1 ton, efficiency ~ 10%, exposure: 22 ton*day

Data selection.— We use the main science run (SR1) of XENON1T [5, 6] with a livetime of 258.2 days, after excluding time when the data acquisition was insensitive, the muon veto fired, or a PMT showed excessive pulse rates [7]. Ref. [5] derived a ∼4% shorter livetime because it excluded time just after high-energy events. Backgrounds from these periods are mitigated by other methods here.

We report the first dark matter search results from XENON1T, a ∼2000-kg-target-mass dual-phase (liquid-gas) xenon time projection chamber in operation at the Laboratori Nazionali del Gran Sasso in Italy and the first ton-scale detector of this kind. The blinded search used 34.2 live days of data acquired between November 2016 and January 2017. Inside the (1042±12) kg fiducial mass and in the [5, 40] keV_{nr} energy range of interest for WIMP dark matter searches, the electronic recoil background was $(1.93 \pm 0.25) \times 10^{-4}$ events/(kg × day × keV_{ee}), the lowest ever achieved in such a dark matter detector. A profile likelihood analysis shows that the data is consistent with the background-only hypothesis. We derive the most stringent exclusion limits on the spin-independent WIMP-nucleon interaction cross section for WIMP masses above 10 GeV/c^2, with a minimum of 7.7×10^{-47} cm^2 for 35-GeV/c^2 WIMPs at 90% confidence level.

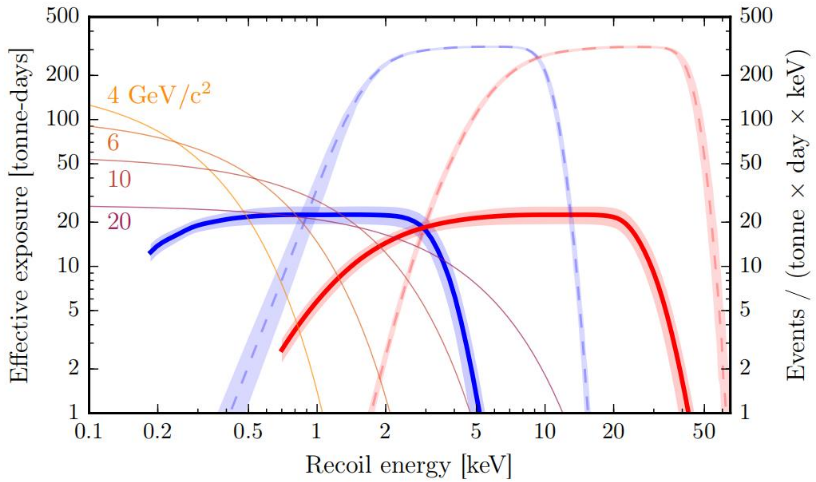


FIG. 1. Effective remaining exposure after event selections for NR (red) and ER (blue) signals of different energies, for S2 ∈ [150, 3000] PE, on the left y-axis. Dashed lines show the same for XENON1T's main analysis [5], and shaded bands show $\pm 1\sigma$ systematic uncertainties. Thin lines show the expected differential event rate for 4, 6, 10, and 20 GeV/c^2 spin-independent (SI) DM-nucleus scattering with $\sigma = 10^{-43}$ cm^2, under the nominal signal model, on the right y-axis.

PandaX4t: 1.04 ton*year * 0.2 ~ 76 ton*day effective exposure

data

- ➢all data are after s2-only recluster algorithm
- ➢waveform simulation and neutron calibration
- ➢all paired events, and s2-only events in open run

Dataset summary

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- Combine adaptive deadtime, bad files

Run0	duration	livetime
Set1	1.955	0
Set2	13.540	10.300
Set3	5.534	0
Set4	37.224	26.514
Set5	36.607	27.787
Total	94.858	64.6

Run1	duration	livetime
Set1	9.406	0
Set2	10.501	4.095
Set3	6.182	3.566
Set4	14.003	2.613
Set5	38.441	25.312
Set6	85.076	57.871
Total	163.615	93.46

- Combine fiducial volume, eburst, off pmt

	run0	run1	Total
FV mass(ton)	2.78	2.16	/
Exposure(ton·year)	0.49	0.55	1.04

Published s2only: 0.55ton·year

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run0	livetime	totaltime
3026	~~9.26652~~	~~11.9689~~
3031	~~17.2275~~	~~22.287~~
3180	4.51674	5.75401
3181	3.13397	3.97455
~~3424~~	~~12.3921~~	~~20.3345~~
~~3439~~	~~10.5874~~	~~20.3059~~
3506	16.7903	22.3684
3509	12.96	17.4442
3550	3.07622	23.9055
3552	17.8586	23.4861
3600	3.91894	5.12163
3601	7.19873	15.3361
3730	14.3723	18.8436
3731	17.8457	23.5222
3777	18.2868	23.9892
3778	0.555916	0.71985
3805	13.2594	17.3507
3806	4.3591	5.71446
3839	18.2629	24.0268
3840	12.3248	16.3861
	7.3 day	

run1	livetime	totaltime
~~4679~~	~~9.40012~~	~~15.0668~~
~~4680~~	~~15.3629~~	~~24.5382~~
~~4735~~	~~14.3074~~	~~25.9843~~
~~4737~~	~~3.44349~~	~~6.23841~~
~~4858~~	~~10.9969~~	~~16.3836~~
4883	2.90539	4.33747
4907	15.6828	23.3187
4909	1.27248	1.88857
~~4930~~	~~11.6747~~	~~27.1523~~
~~4931~~	~~13.6777~~	~~23.3445~~
~~4950~~	~~14.2889~~	~~23.7954~~
4951	13.7678	22.9999
5015	16.2411	23.9126
5016	23.3837	34.3499
5141	0.772023	1.12422
5142	15.813	23.0934
5216	16.0451	23.6257
5217	16.2356	23.9009
5245	16.0138	23.5223
5246	16.4769	24.1366
	6.4 day	

How the interaction happens

The dark-photon dark matter is non-relativistic and interacts with ordinary matter mostly through the photo-electric process in which a photon (with energy $m_{A'}$) is captured by an atom, with atomic number Z, with a cross section given, for ordinary photons, by

$$\sigma_{p.e.} = 4\alpha^4 \sqrt{2} Z^5 \frac{8\pi r_e^2}{3} \left(\frac{m_e}{\omega}\right)^{7/2} , \tag{1.33}$$

where ω is the photon energy and r_e the classical radius of the electron $r_e = \alpha/m_e$. The cross section for the dark photons is that of ordinary photons rescaled by the mixing parameter ε:

$$\sigma_{A'} = \varepsilon^2 \sigma_{p.e.} \, . \tag{1.34}$$

This scenario is made accessible to the experiments by considering the rate of absorption of the dark photon by the detector [93, 94]:

$$\Gamma_{A'} = \frac{\rho_{A'}}{m_{A'}} \sigma_{A'} v_{A'} \, , \tag{1.35}$$

where the density $\rho_{A'}$ is estimated from the relic density (or the flux from the Sun).