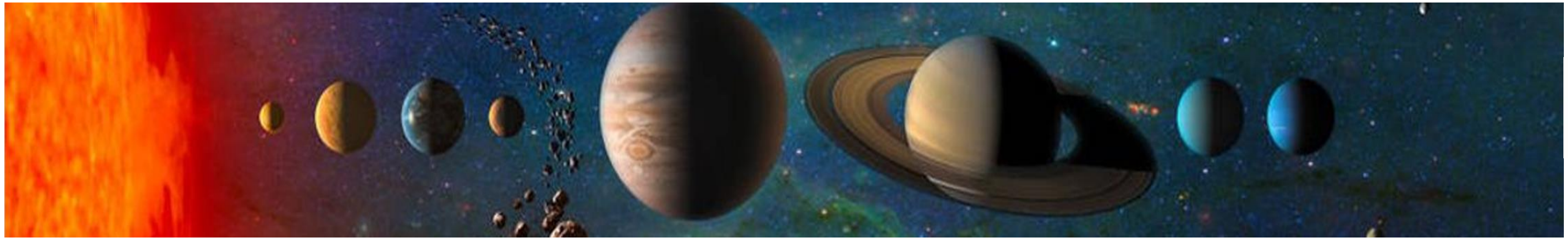


Search for solar neutrino and light dark matter in the PandaX-4T experiment

Qing Lin

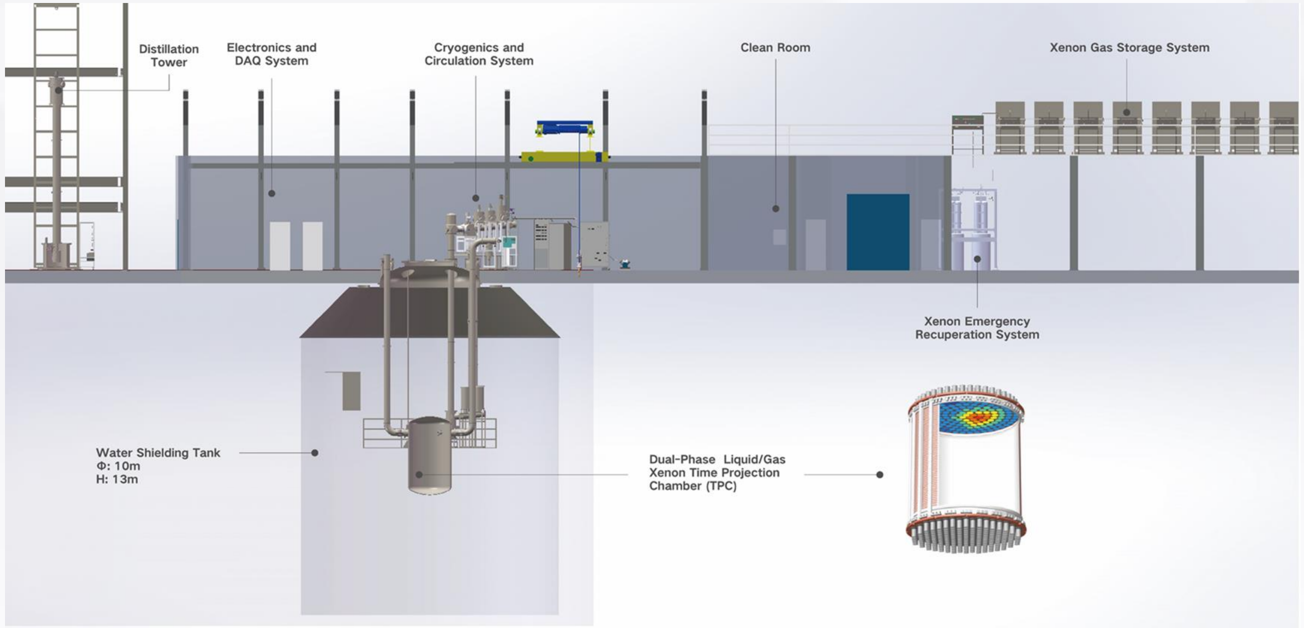
(on behalf of PandaX collaboration)

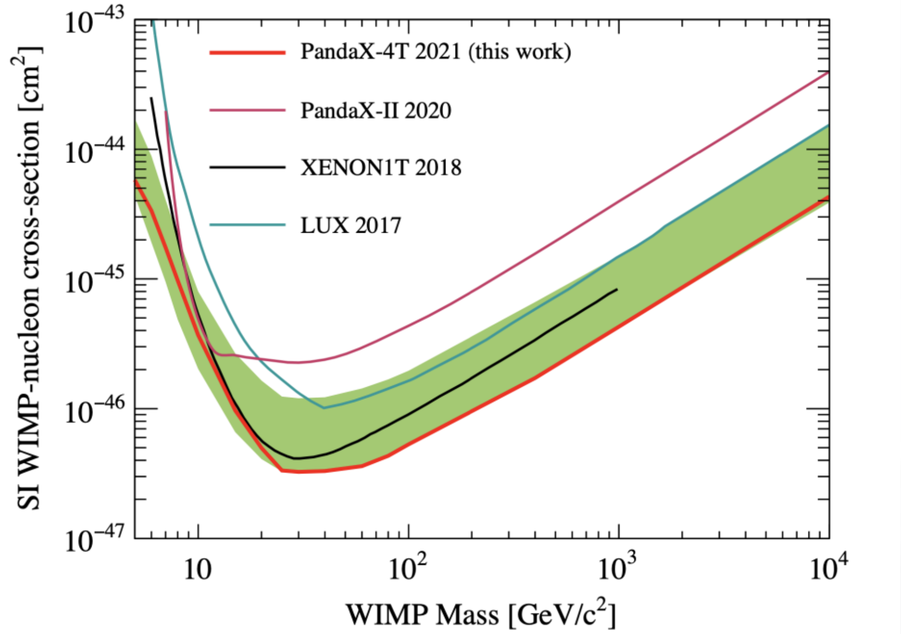
University of Science and Technology of China

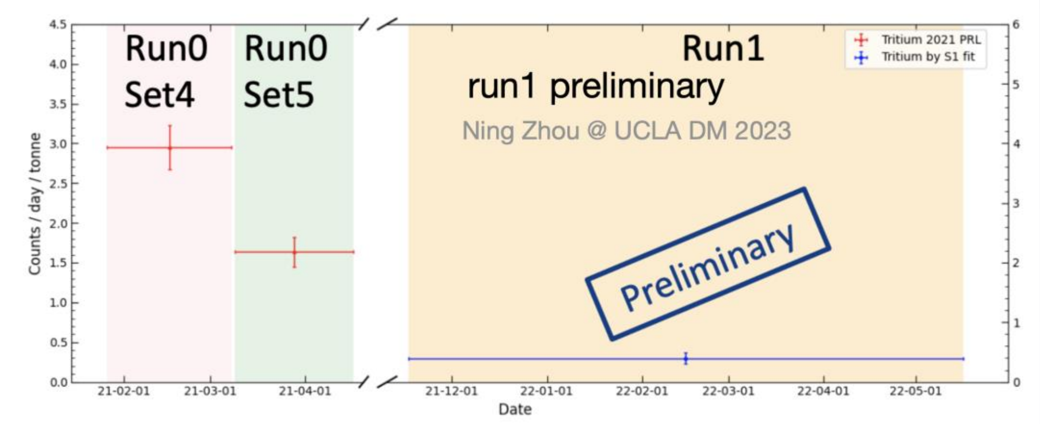
TAUP, 2023.08.28

PandaX-4T Experiment & Its first data

- 5.6-tonne liquid xenon detector at CJPL-II;
- 2020-2021: Commissioning run (run0), 95 days;
- 2021-2022: Tritiated methane removal and run1, ~160 days

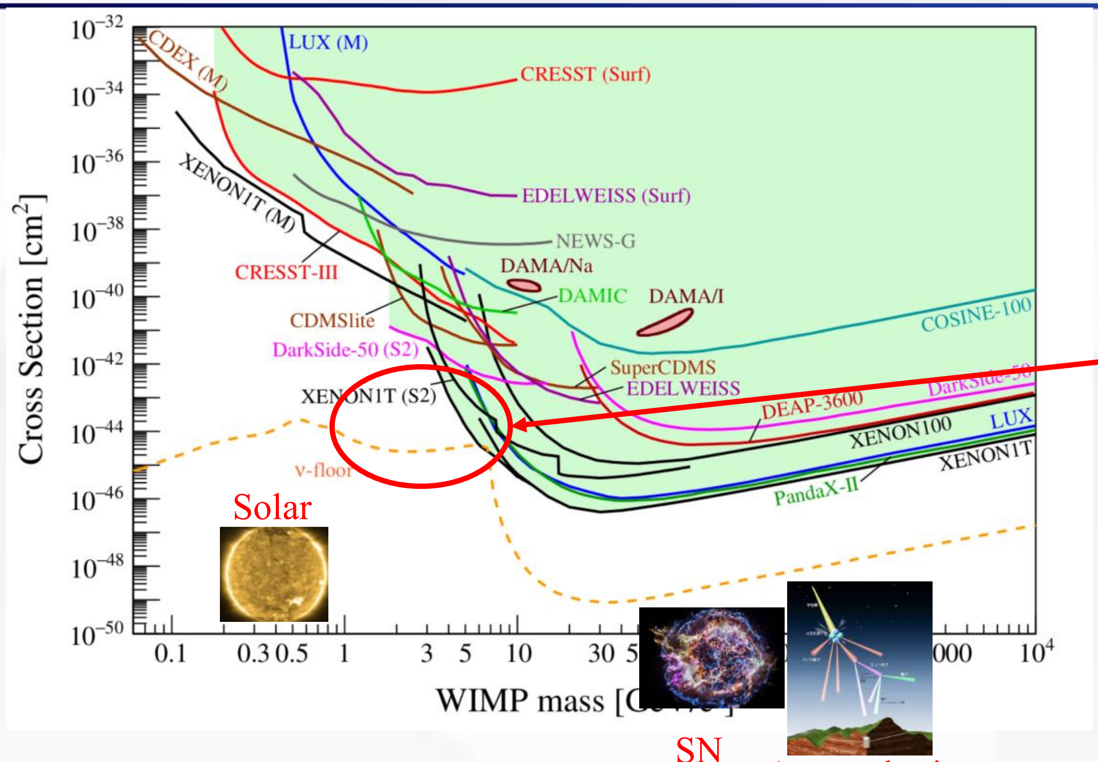


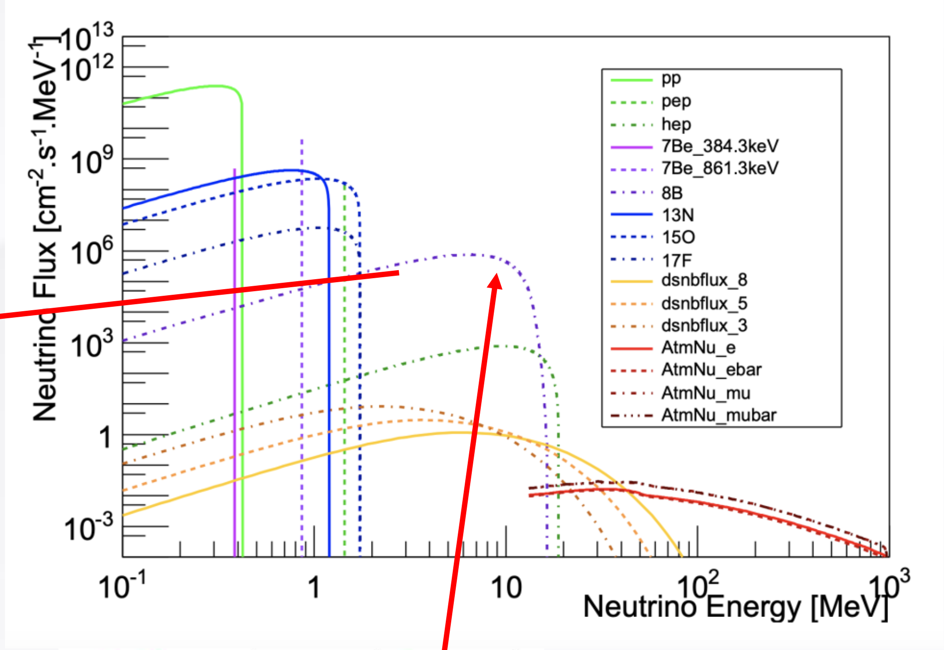




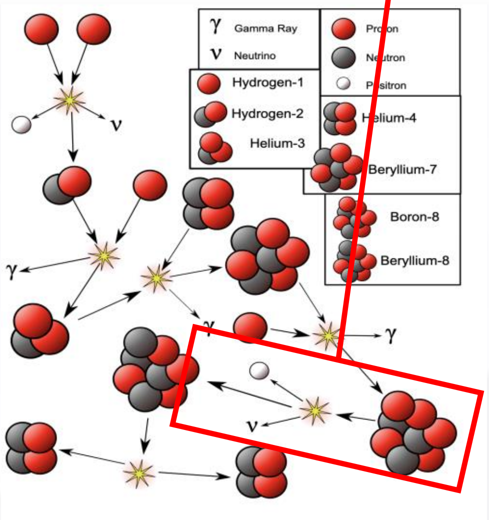
- ❑ Ultrapure water shield: 13 m (H) x 10 m (D) ~ 900 m^3
- ❑ TPC: 1.2 m (H) x 1.2 m (D)
- ❑ 3-in PMTs: 169 top/199 bottom
- ❑ Sensitive volume: 3.7-tonne

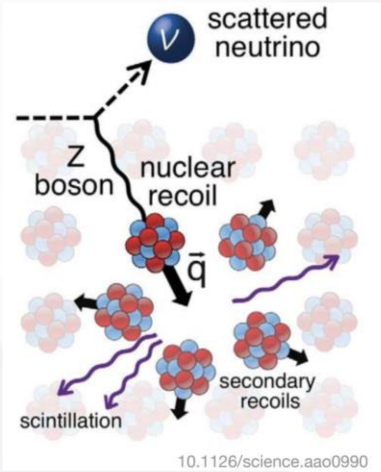
Solar neutrino CEvNS detection in DM experiment





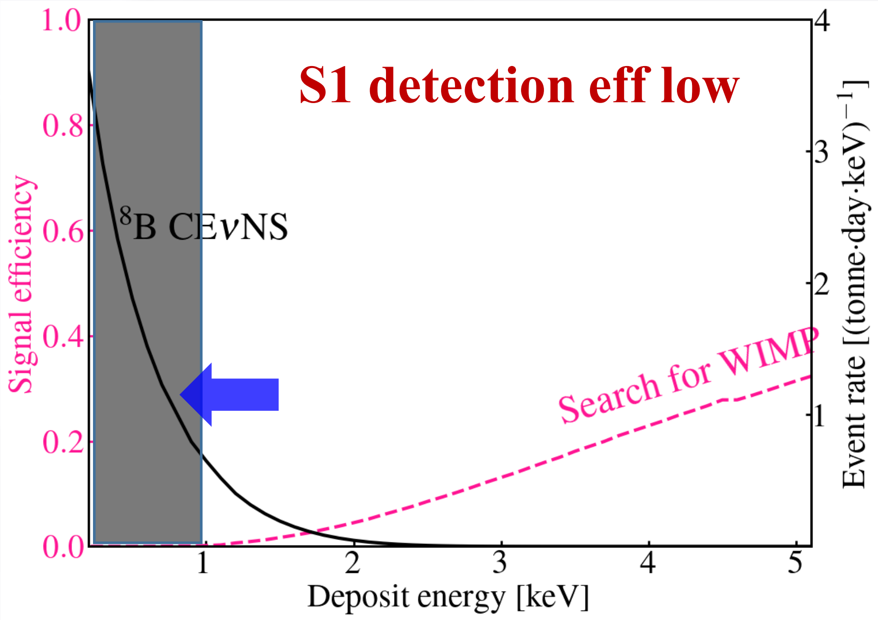
➢ Large underground experiment is going to be able to see Coherent Elastic ν_e-Nuclear Scatting (CEvNS)





Difficulties of B8 CEvNS search

PANDA X



10% detection

>90% detection

S1>2hit

S1>2PE

1.6 per year in 2.7 ton FV.

S1

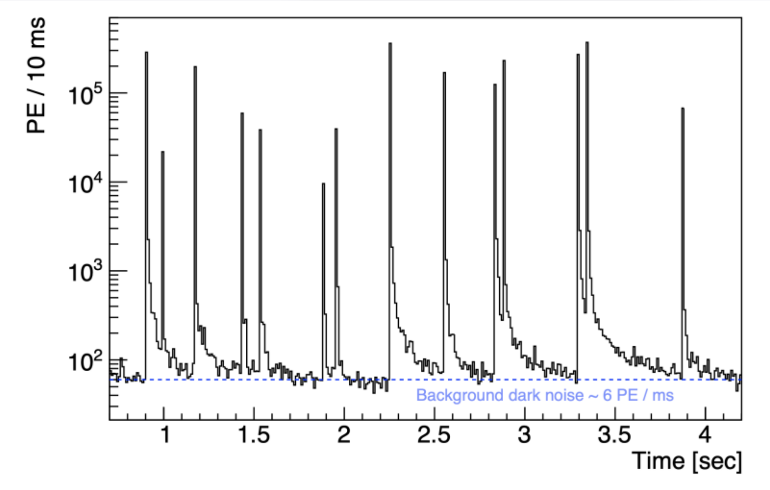
S2

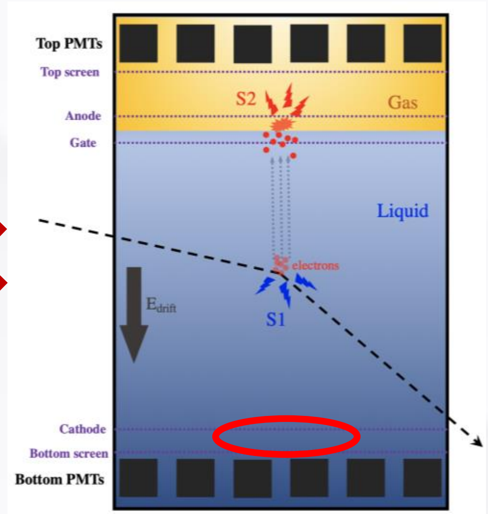
S1=2，3hit

S2~[65,200]PE

High rate of accidental pileups

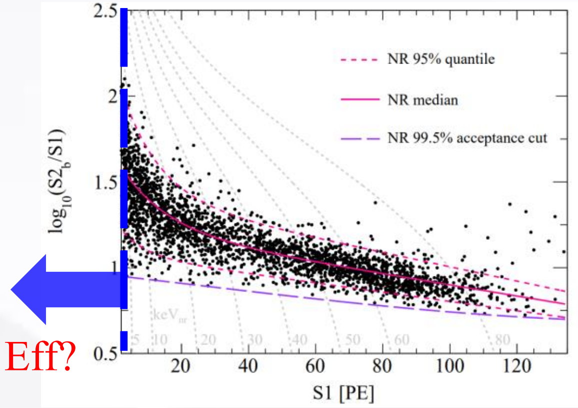
1 -> ~ 100



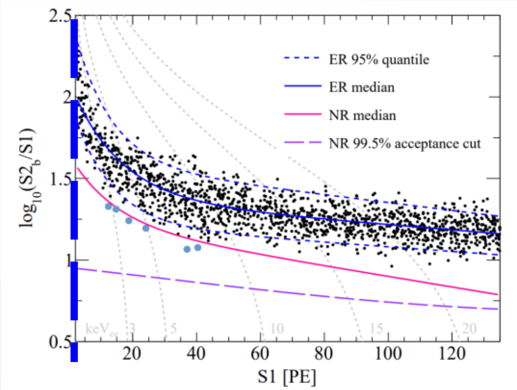


Low stats of calibration

NR calibration



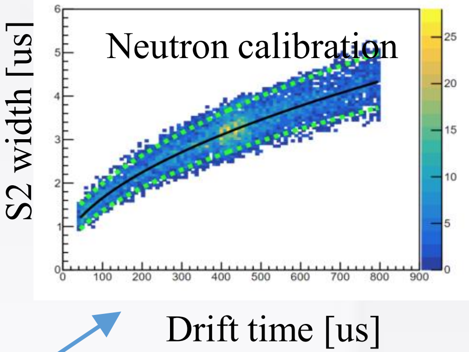
ER calibration

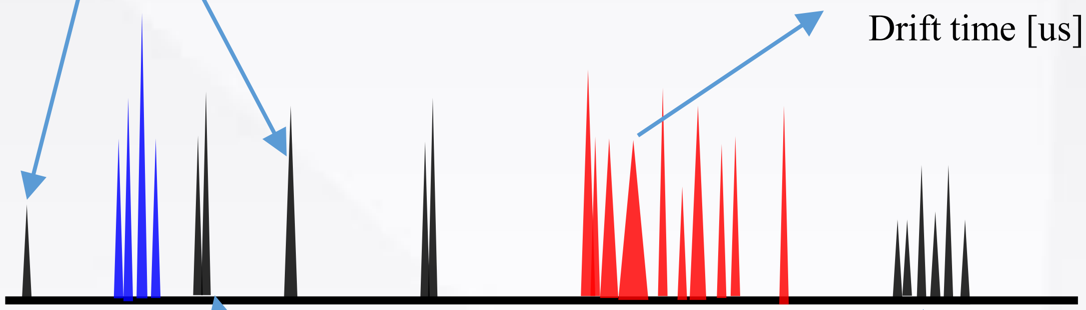


Waveform simulation

Reassembling data waveform segments

PMT dark count





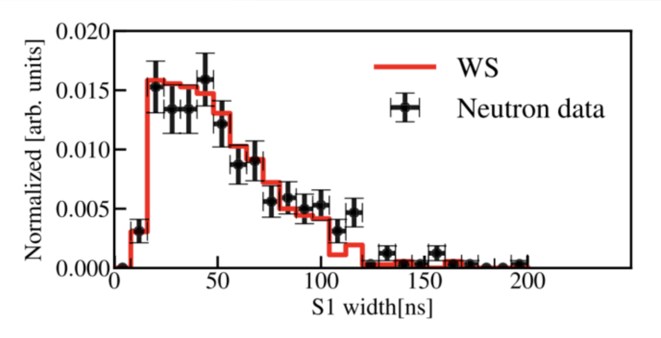
Main S1

Main S2

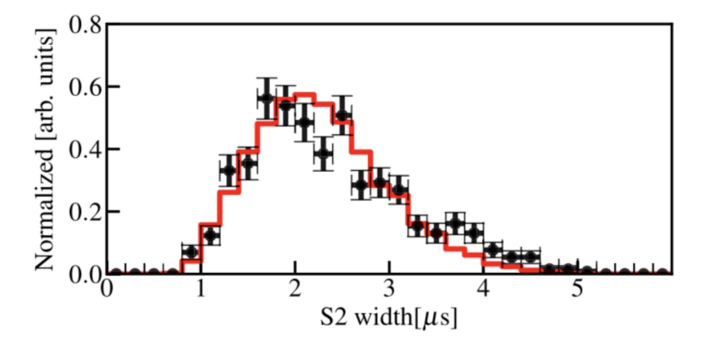
PMT afterpulsing

Impurity photoionization;
Electron trapping at surface;
Delayed electrons

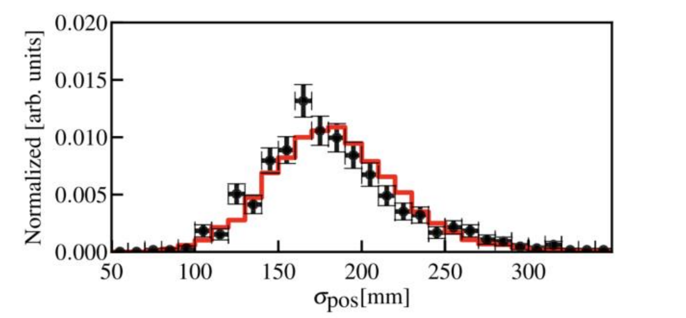
S1 width



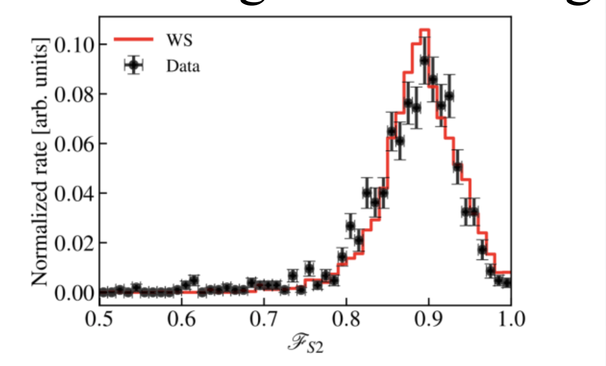
S2 width



S2 pattern parameter



Else charge / Total charge

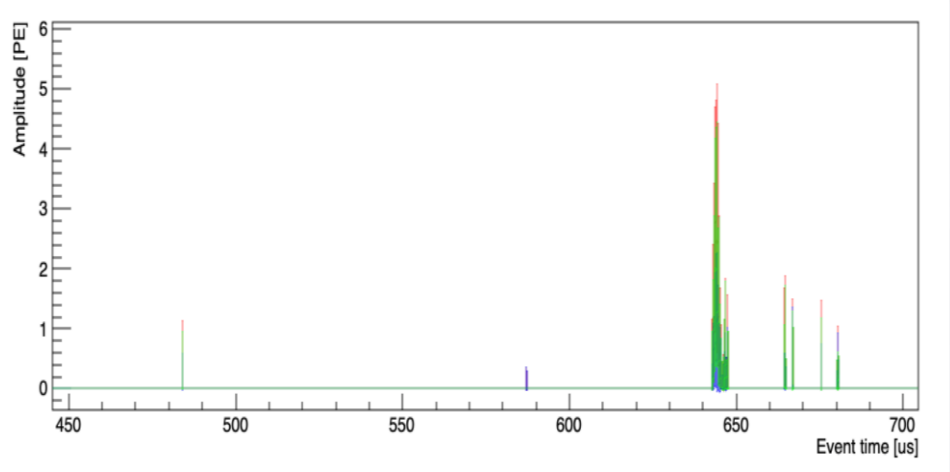


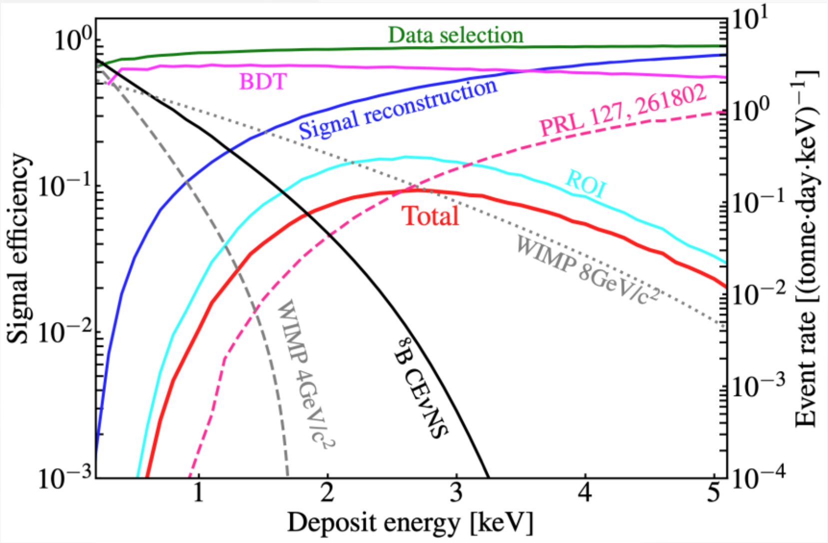
Good match between data and wf-sim in terms of S1/S2 shape, pattern, and waveform "dirtiness".

Machine-Learning based selection

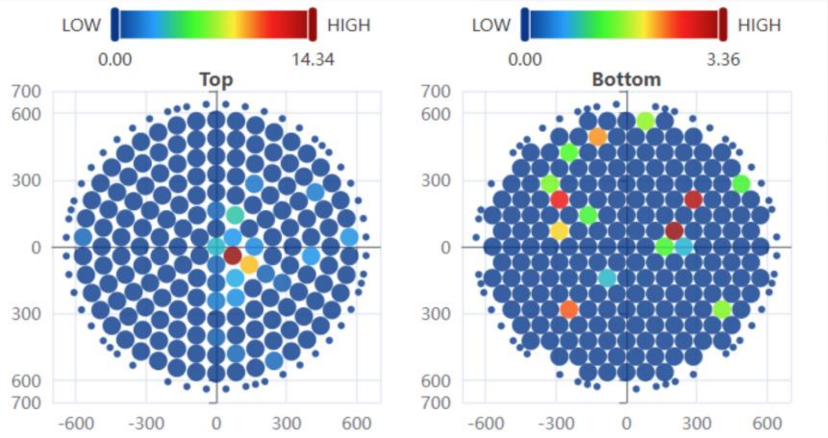
Boosted Decision Tree (BDT)

- S1 & S2 width
- Spurious charges beside S1&S2
- S2 pulse shape
- Width/height ….





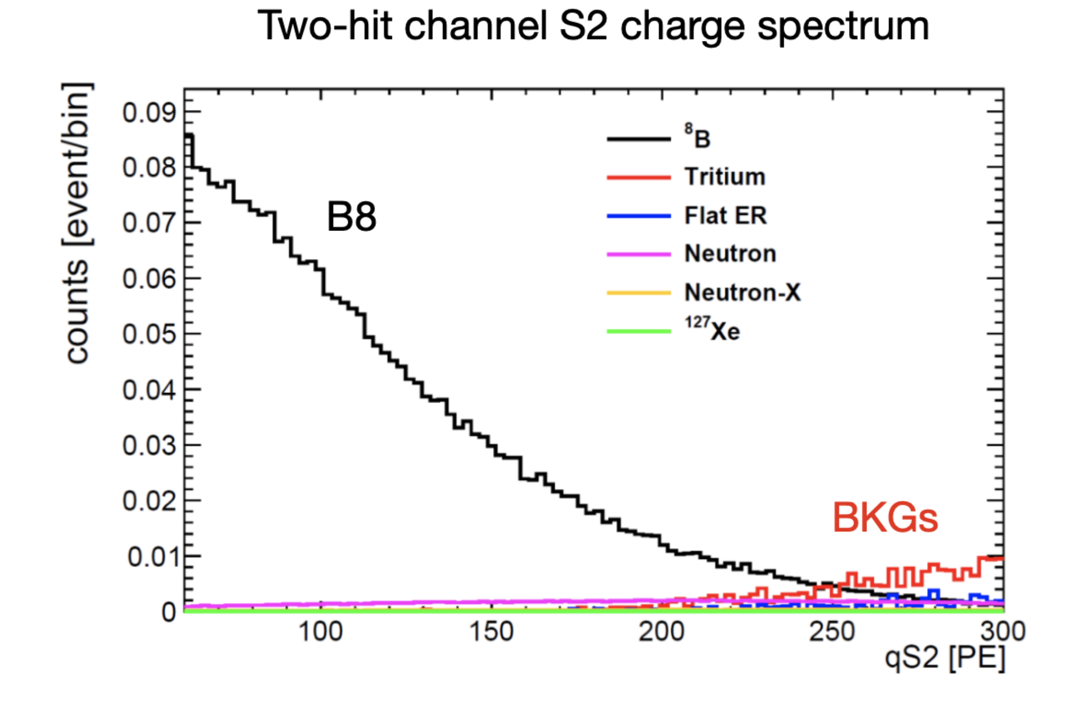
- Difference of reconstructed positions;
- Goodness-of-fit between data and sim;
- Top-bottom asymmetry



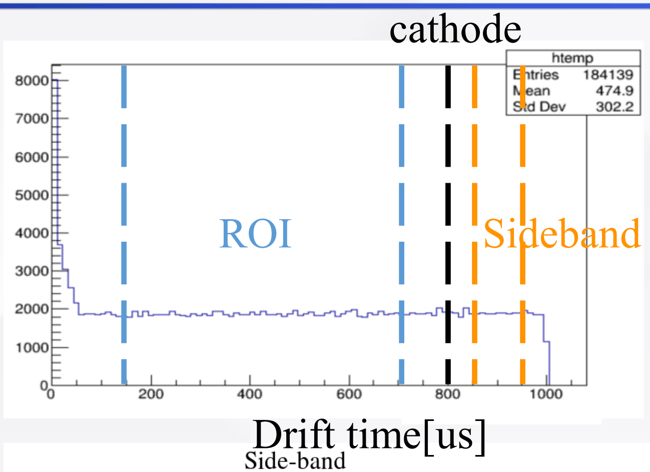
- WF-sim as signal sample;
- Randomly paired S1-S2 as bkg sample;
- 18 variables as BDT input;

Background budget

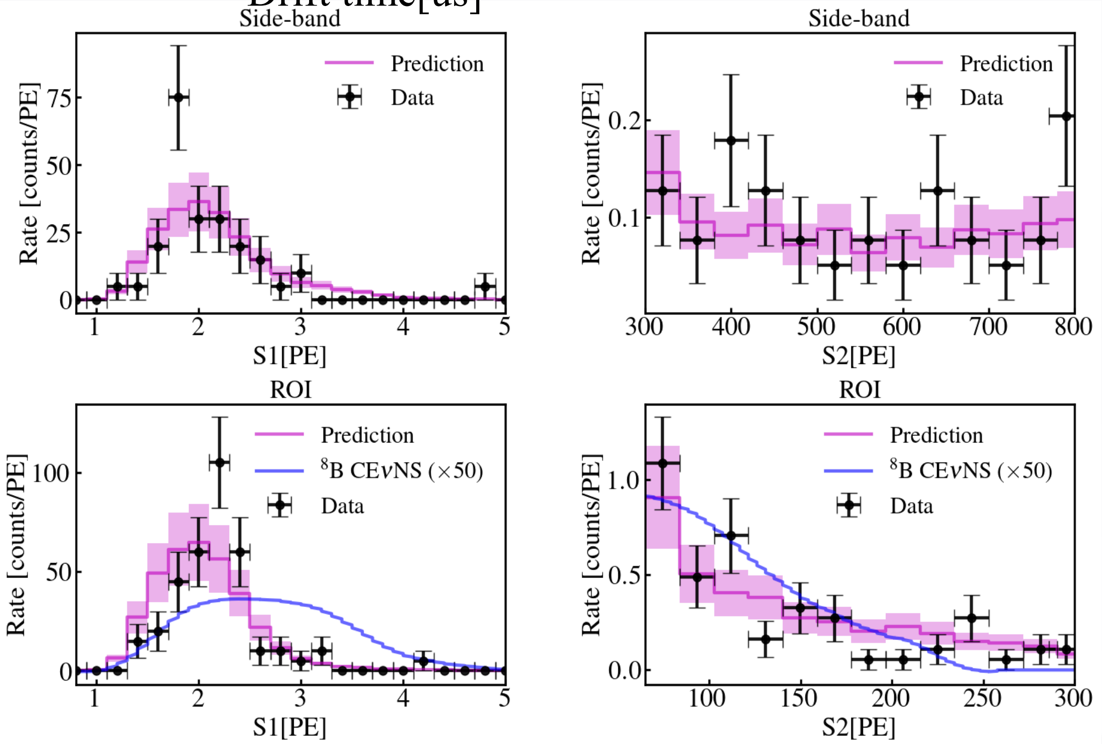
Physical bkg negligible!



N_{hit}	$S2$ range [PE]	BDT	ER	NR	Surf	AC	Total BKG	^{8}B	**Obs**
2	65-230	pre	0.04	0.10	0.14	62.43	62.71	2.32	**59**
		post	0.02	0.04	0.03	1.41	1.50	1.42	**1**
3	65-190	pre	0.01	0.05	0.08	0.79	0.93	0.42	**2**
		post	0.00	0.02	0.03	0.02	0.07	0.29	**0**



- AC is the dominant bkg;
- Use data with drift length > max drift length as sideband check;
- Good match between data and model;

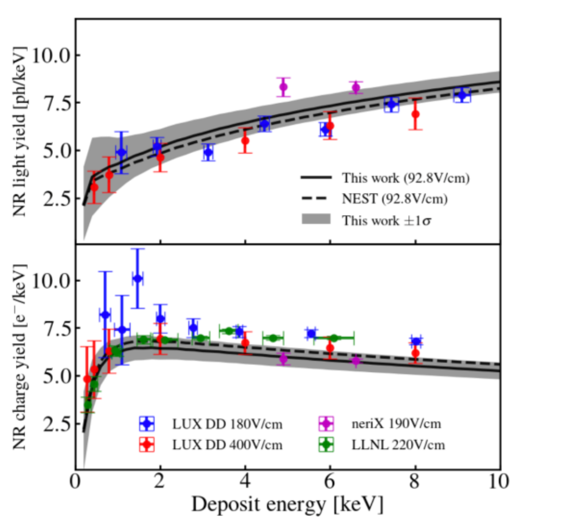


Uncertainty analysis

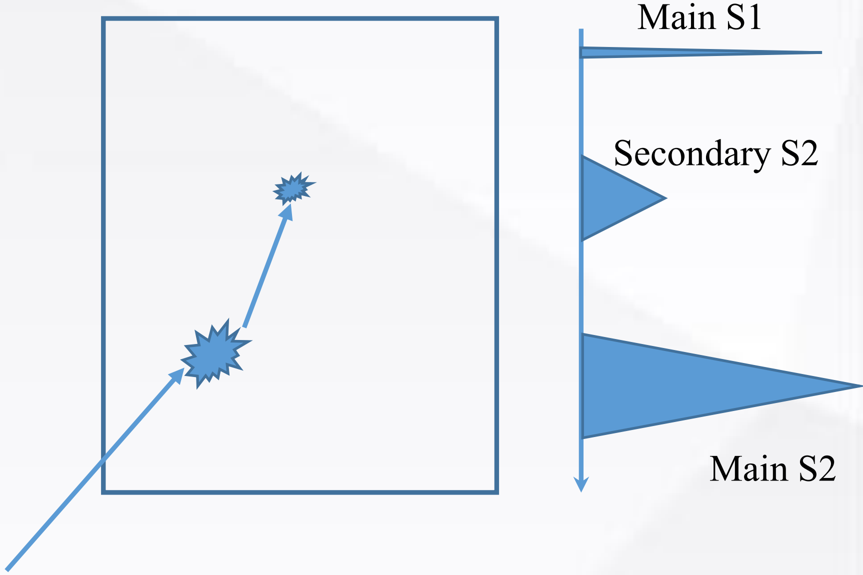
Systematic uncertainties

Uncertainties	2-hit bin	3-hit bin
quality cuts	0.14	0.14
light and charge yield	**0.29**	**0.39**
accidental bkg	**0.30**	**0.30**
BDT cut for signal	**0.14**	**0.13**
BDT cut for bkg	**0.19**	**0.18**
solar B8-v flux	0.04	0.04

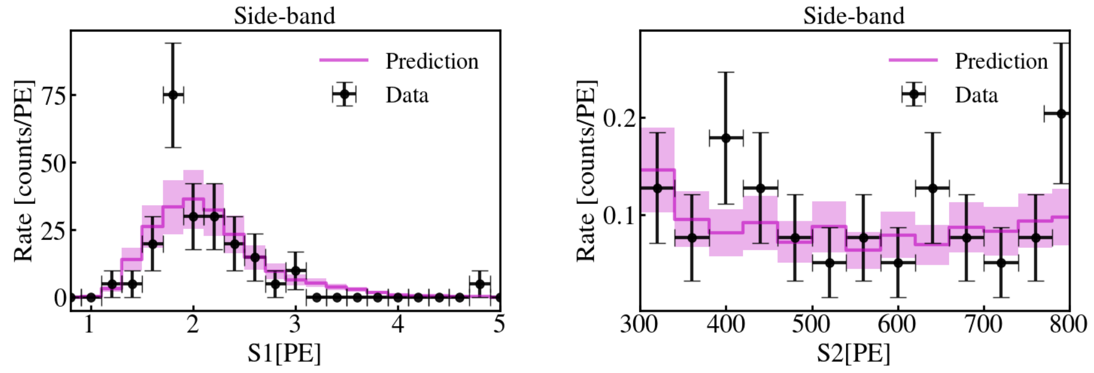
Light and charge yield band



Use secondary S2s or events without S1 for checking sys.



Diff between data and sideband

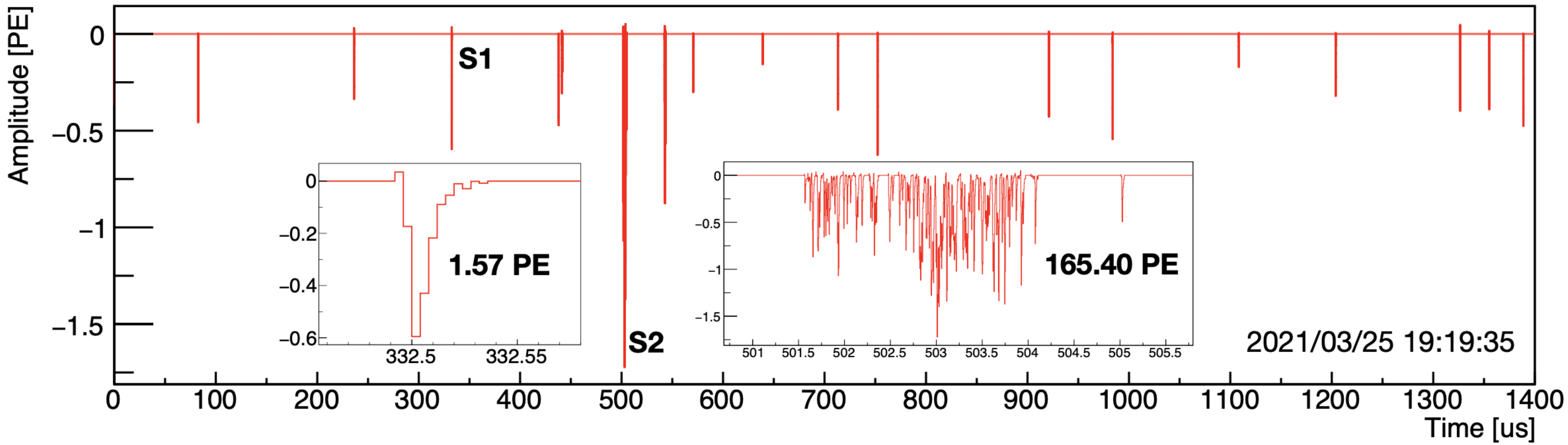


Unblinding

- One event found after unblinding;
- Statistically consistent with our expectation.

Apply-BDT result

N-hit	Total bkg	B8	Data
2	1.50	1.42	1
3	0.07	0.29	0



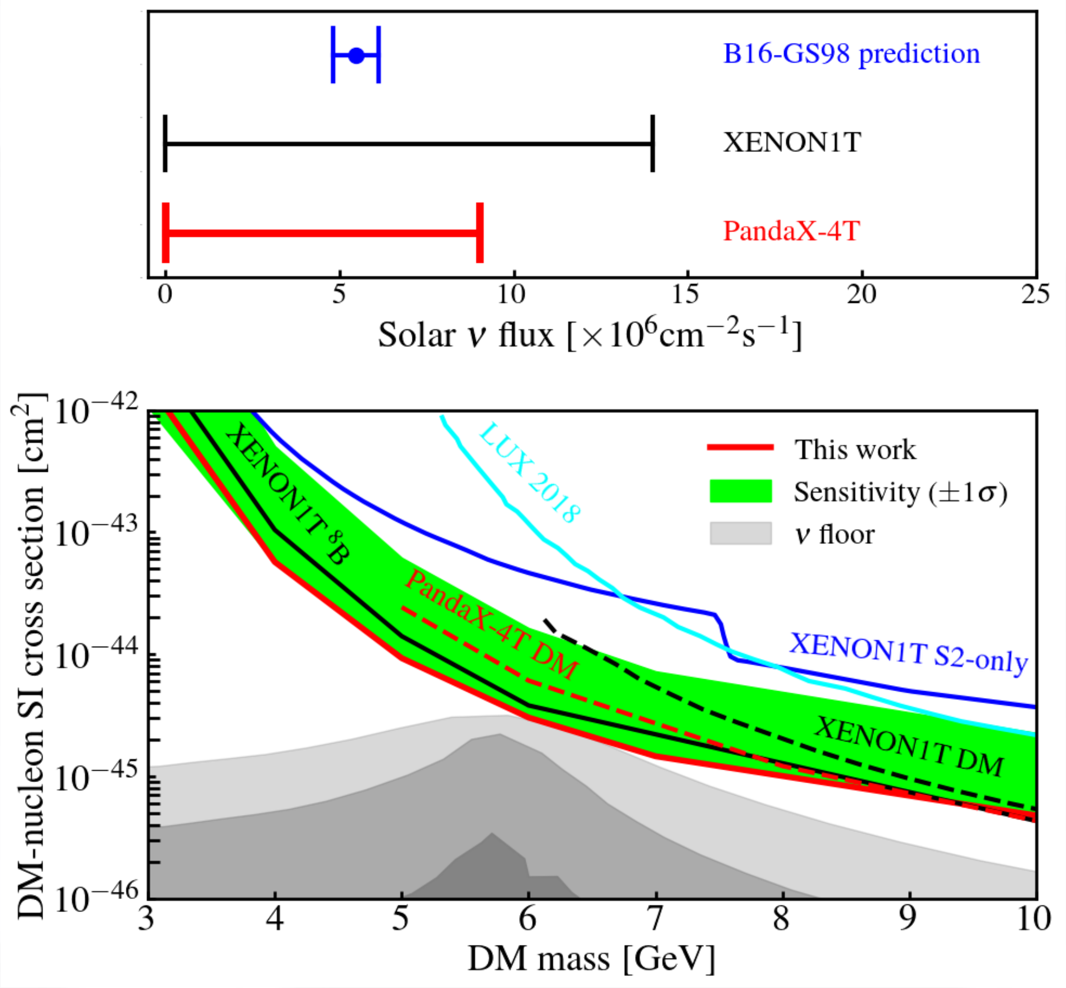
First B8 CEvNS search in PandaX-4T

$$\mathcal{L} = G(\delta_\epsilon)G(\delta_s)G(\delta_b)G(\delta_\Phi) \times \left[\prod_i G(\delta^i_{\mathrm{BDT},s})G(\delta^i_{\mathrm{BDT},b})\frac{\lambda_i^{N_i}}{N_i!}e^{-\lambda_i}\right]$$

$$\begin{aligned}
\lambda_i^\nu &= N_\nu(1+\delta_s f_i^\nu)(1+\delta_\epsilon)(1+\delta^i_{\mathrm{BDT},s}) \\
&\quad + N_{\mathrm{AC}}(1+\delta_b)(1+\delta_\epsilon)(1+\delta^i_{\mathrm{BDT},b}) + N_{\mathrm{other}}, \\
\lambda_i^\chi &= N_\chi(1+\delta_s f_i^\chi)(1+\delta_\epsilon)(1+\delta^i_{\mathrm{BDT},s}) \\
&\quad + N_\nu(1+\delta_s f_i^\nu)(1+\delta_\epsilon)(1+\delta^i_{\mathrm{BDT},s})(1+\delta_\Phi) \\
&\quad + N_{\mathrm{AC}}(1+\delta_b)(1+\delta_\epsilon)(1+\delta^i_{\mathrm{BDT},b}) + N_{\mathrm{other}},
\end{aligned}$$

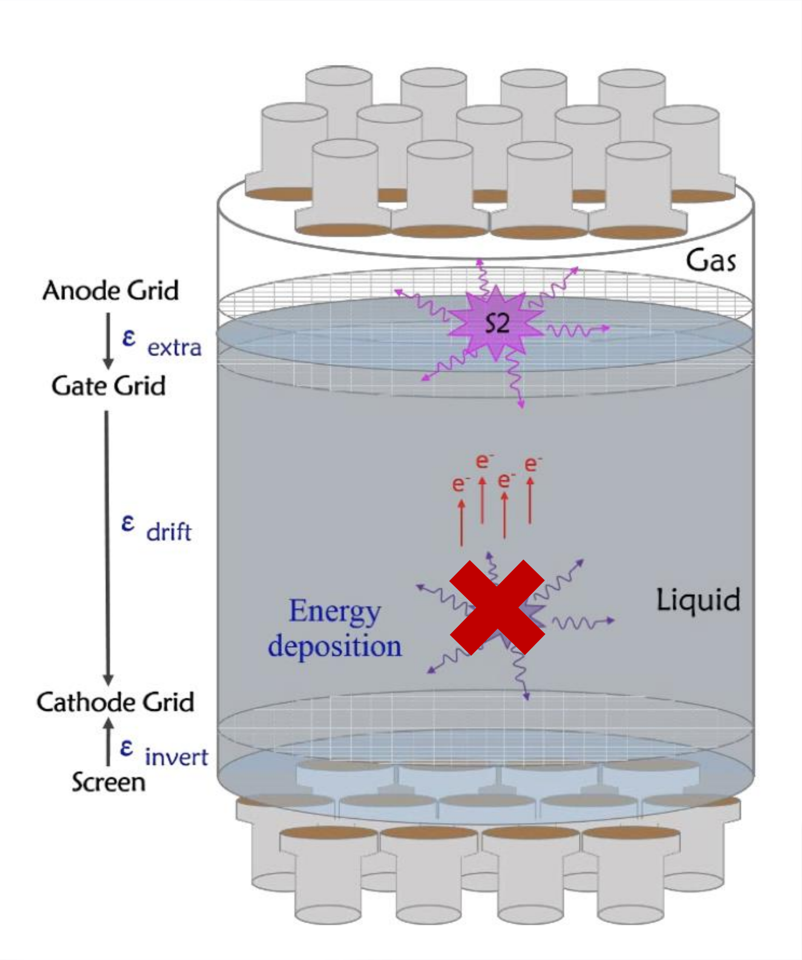
- Profile Likelihood Ratio method, combining 2-hit and 3-hit data;
- Most stringent limit to solar neutrino flux using CEvNS channel;
- Also updated the GeV DM upperlimit.

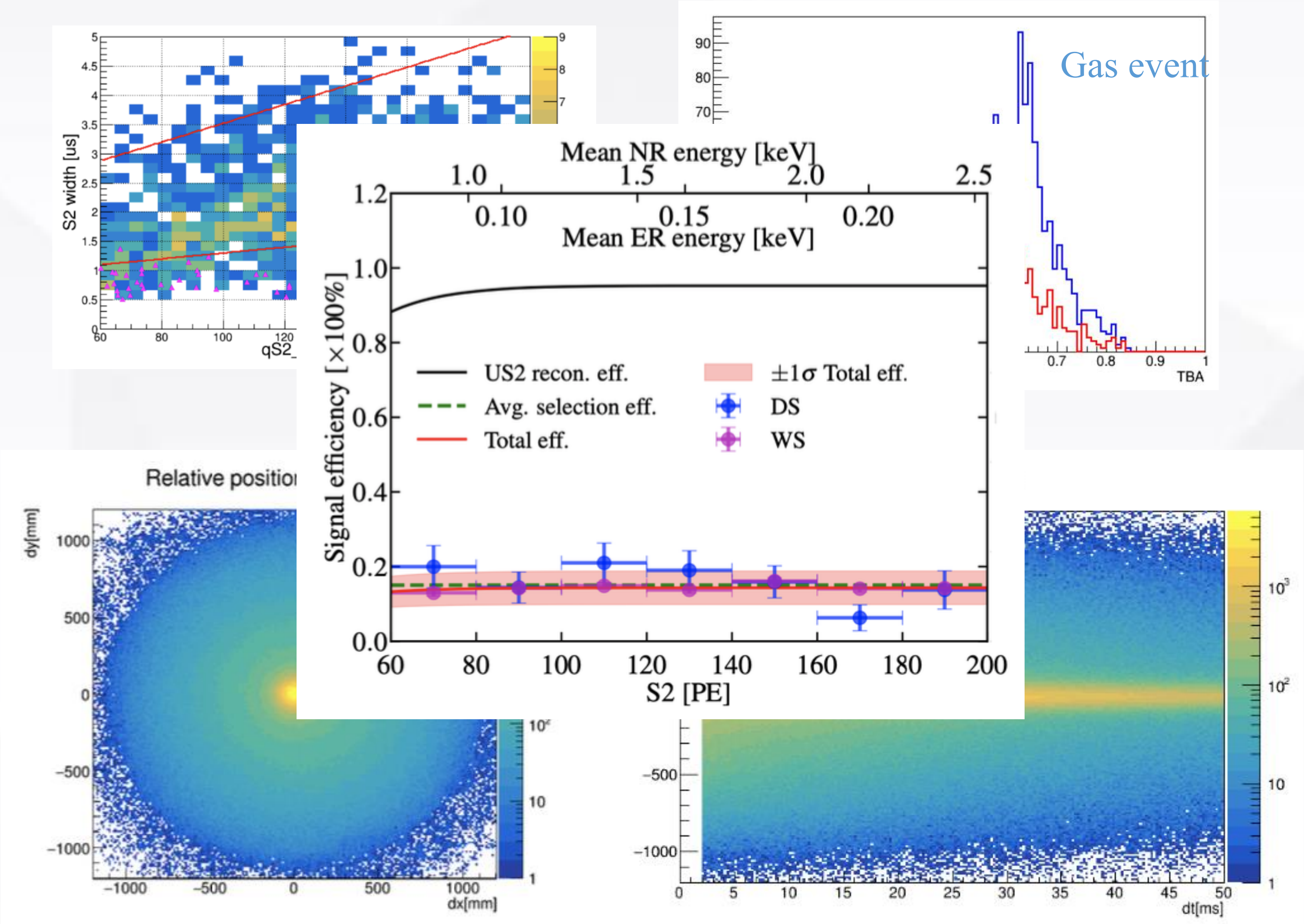
Phys. Rev. Lett. 130, 021802



S2-only approach

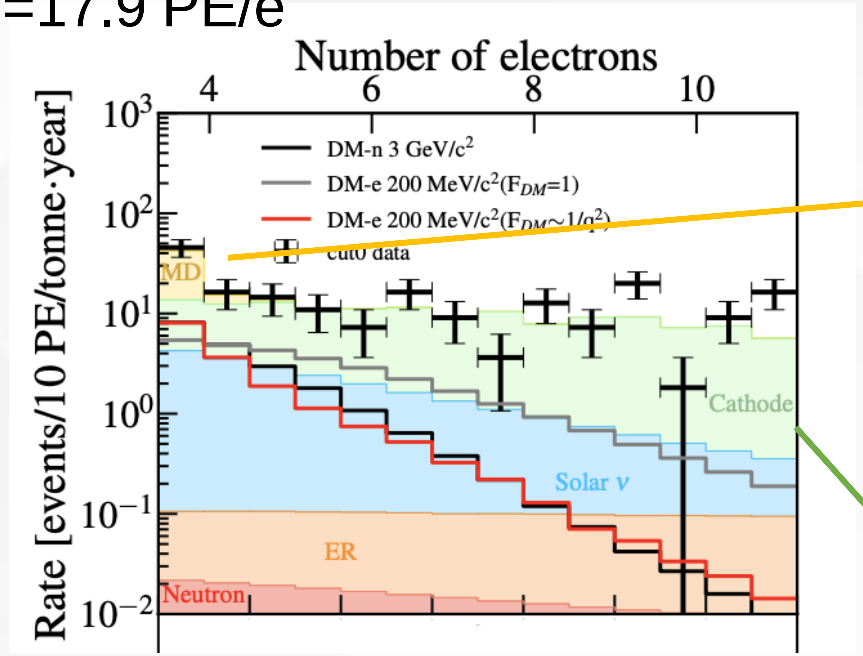
Cathode event and gas event



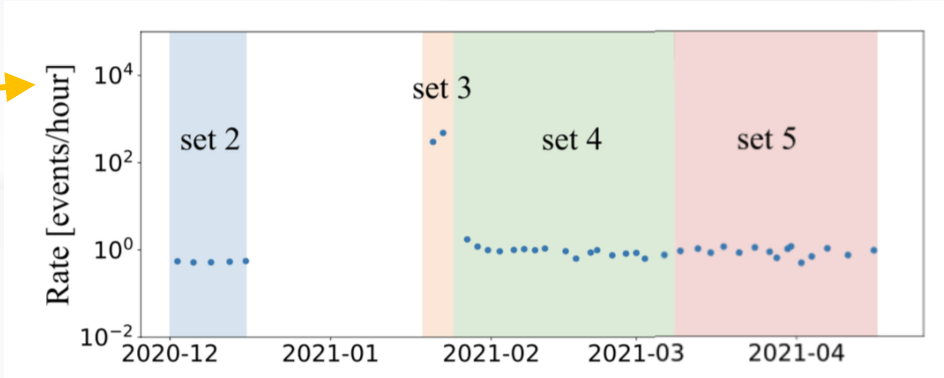


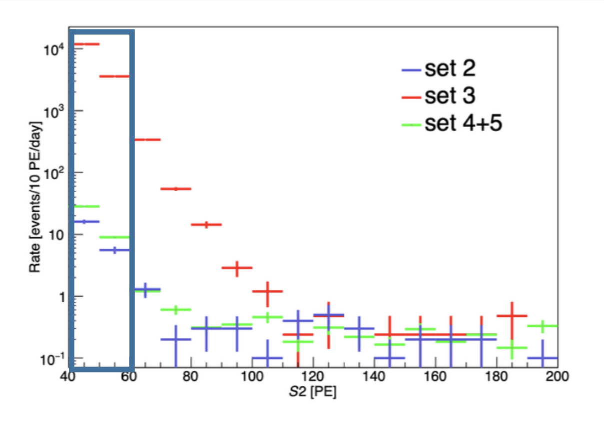
Background for S2-only data

g2=17.9 PE/e



Set 3 with very high rate as template for MD





Use fixed-dt data as estimate for cathode!

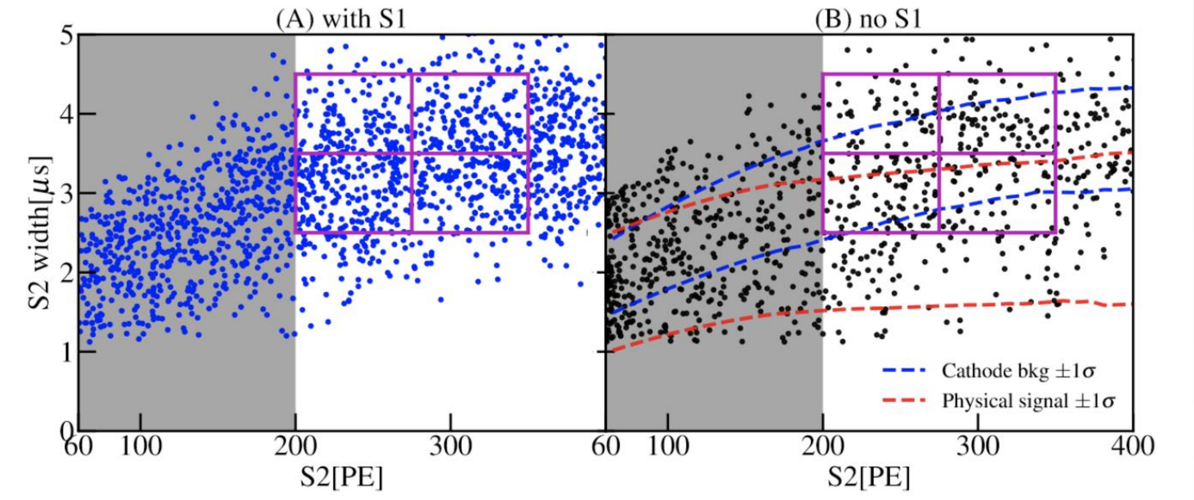
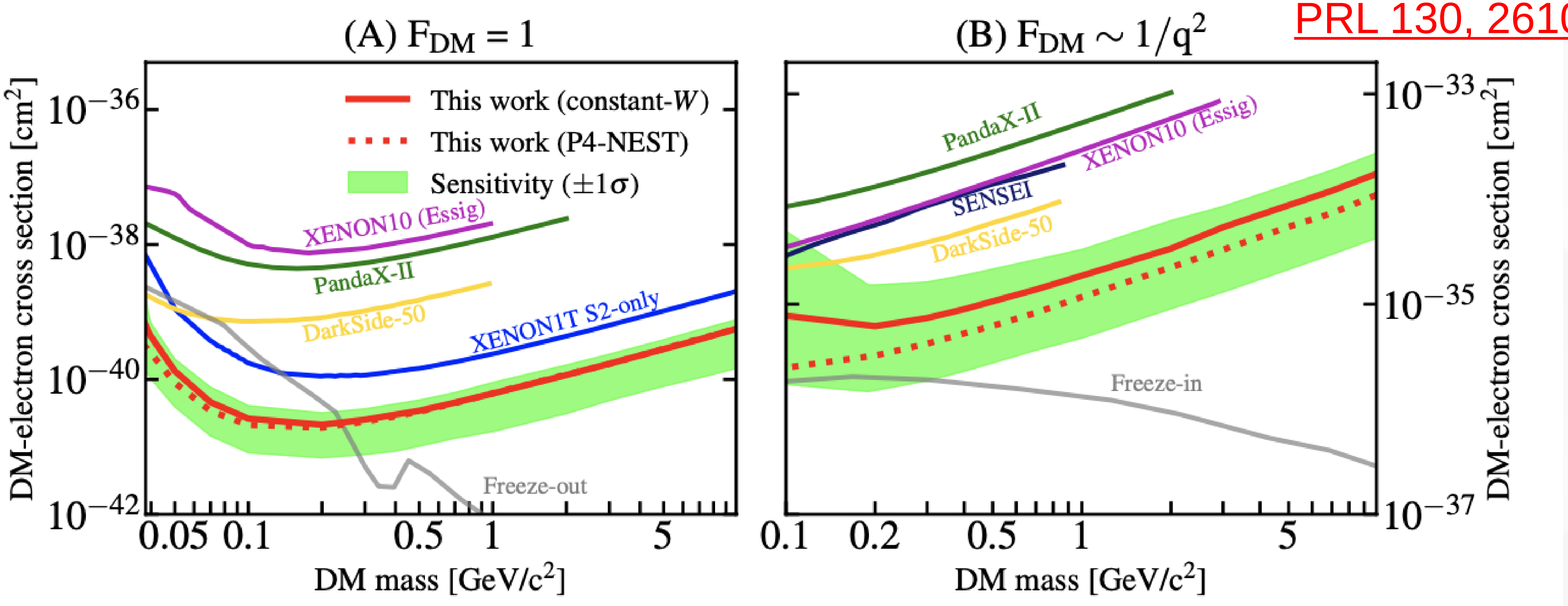


TABLE I. Nominals and background-only best-fits of the background components in the US2 candidates.

	Nominal	Best-fit
Cathode	41.6 ± 10.6	63.9 ± 9.1
MD	$6.9^{+9.0}$	17.7 ± 5.3
Solar ν	10.8 ± 3.7	11.7 ± 3.6
ER	2.3 ± 0.6	2.5 ± 0.5
Neutron	0.1 ± 0.1	0.1 ± 0.1
Total	$61.7^{+14.4}_{-11.2}$	95.8 ± 11.3

Low-mass DM-e search

PRL 130, 261001 (2023)



- The most stringent constraints for the DM- electron interactions with mass in range of 40 MeV/c^2 to 10 GeV/c^2 with F_{DM} =1, and 100 MeV/c^2 to 10 GeV/c^2 with $F_{DM} \sim 1/q^2$
- Our results challenge the freeze-out mechanism for DM mass range from 0.04 to 0.25 GeV/c^2 with F_{DM}=1, and are closing in on the freeze-in prediction with $F_{DM} \sim 1/q^2$, assuming such light DM provides the entire DM abundance.

Summary & Prospect

- Most stringent constraint on solar neutrino flux using CEvNS channel was obtained, using S1-S2 paired data.
- We understand the bkg component of S2-only channel, mostly surface bkg from cathode and S2 pileup from micro-discharging;
- Using S2-only data, the most stringent constraint on low-mass DM through DM-e scattering is given;
- Analysis combining Run0 and newly taken Run1 is ongoing;
- Dedicated calibration on ultra-low energy region is planned.

Thanks for listening!

Backups

Coherent Elastic Neutrino-Nucleus Scattering (CEvNS)

EVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

Coherent effects of a weak neutral current

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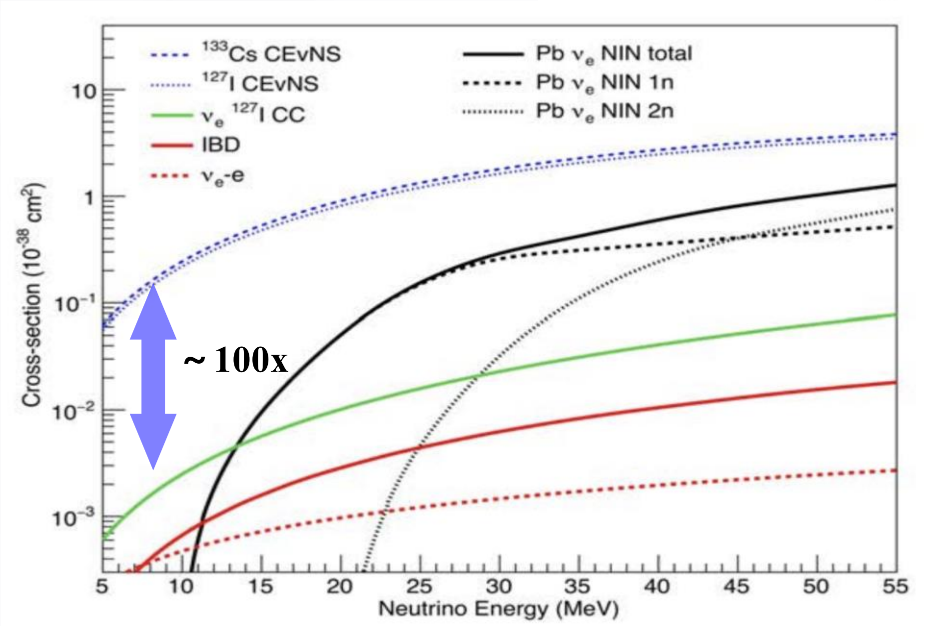
stitute for Theoretical Physics, State University of New York, Stony Brook, New York 11790

(Received 15 October 1973; revised manuscript received 19 November 1973)

Our suggestion may be an act of hubris, because the inevitable constraints of interaction rate, resolution, and background pose grave experimental difficulties for elastic neutrino-nucleus scattering. We will discuss these problems at the end of this note, but first we wish to present the theoretical ideas relevant to the experiments.



Scientific goals of detection:

- New channel for cosmic neutrino detection;
- Weak mixing angle under low momentum transfer;
- Non-standard neutrino interaction;
- Technique for remove nuclear safeguard;

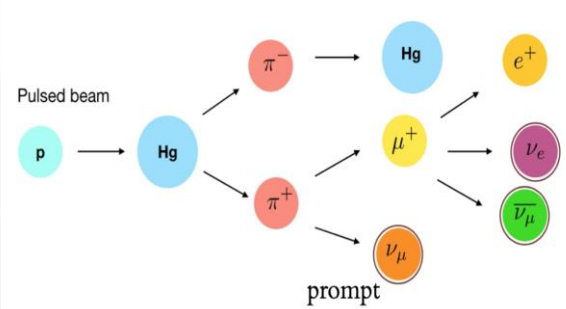
$$\frac{d\sigma}{dT} = \frac{G_F^2}{4\pi} Q_W^2 M\left(1 - \frac{MT}{2E_\nu^2}\right) F(Q^2)^2.$$

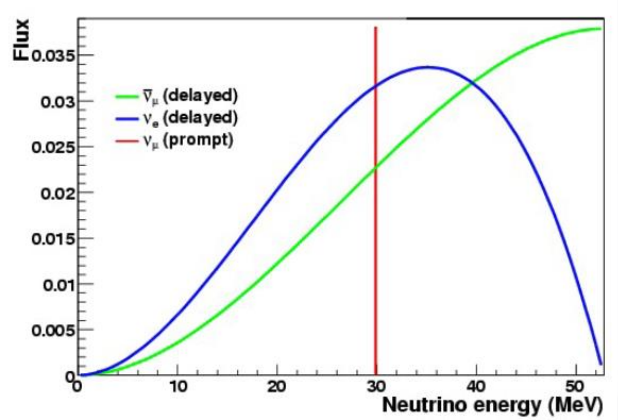
$$Q_W = N - (1 - 4\sin^2\theta_W)Z$$

$$Q_W \propto N \Longrightarrow \boxed{\frac{d\sigma}{dT} \propto N^2}$$

Neutrino sources

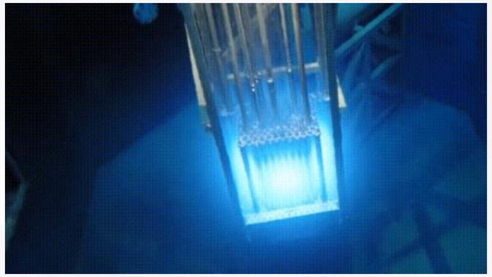
Spallation neutron source

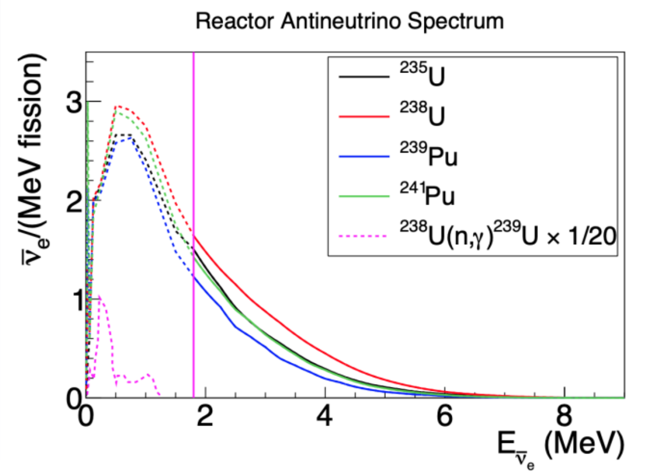




- e&μ flavors;
- **1e6/s/cm2 @ 20m**;
- E<50MeV;
- Observed in 2017;

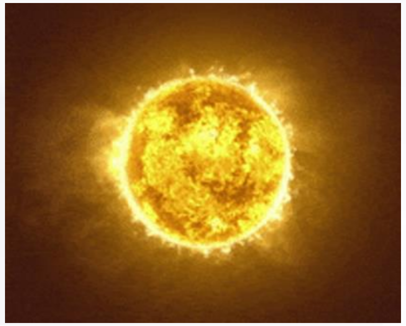
Nuclear reactor

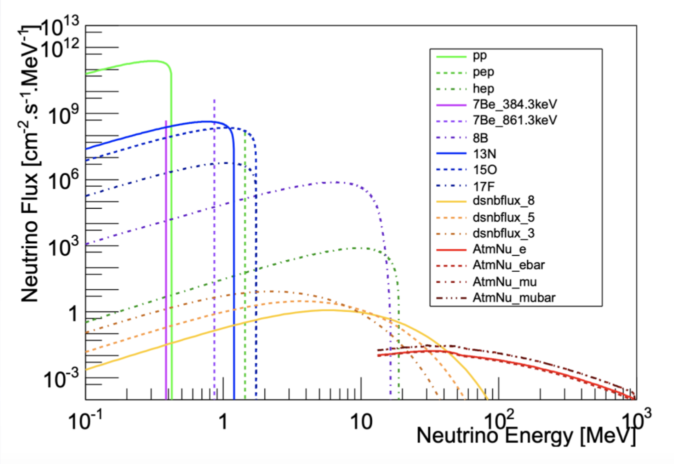




- **1e13/s/cm2 @ 25 m with 3GW power**;
- E<2MeV;
- Not observed yet;

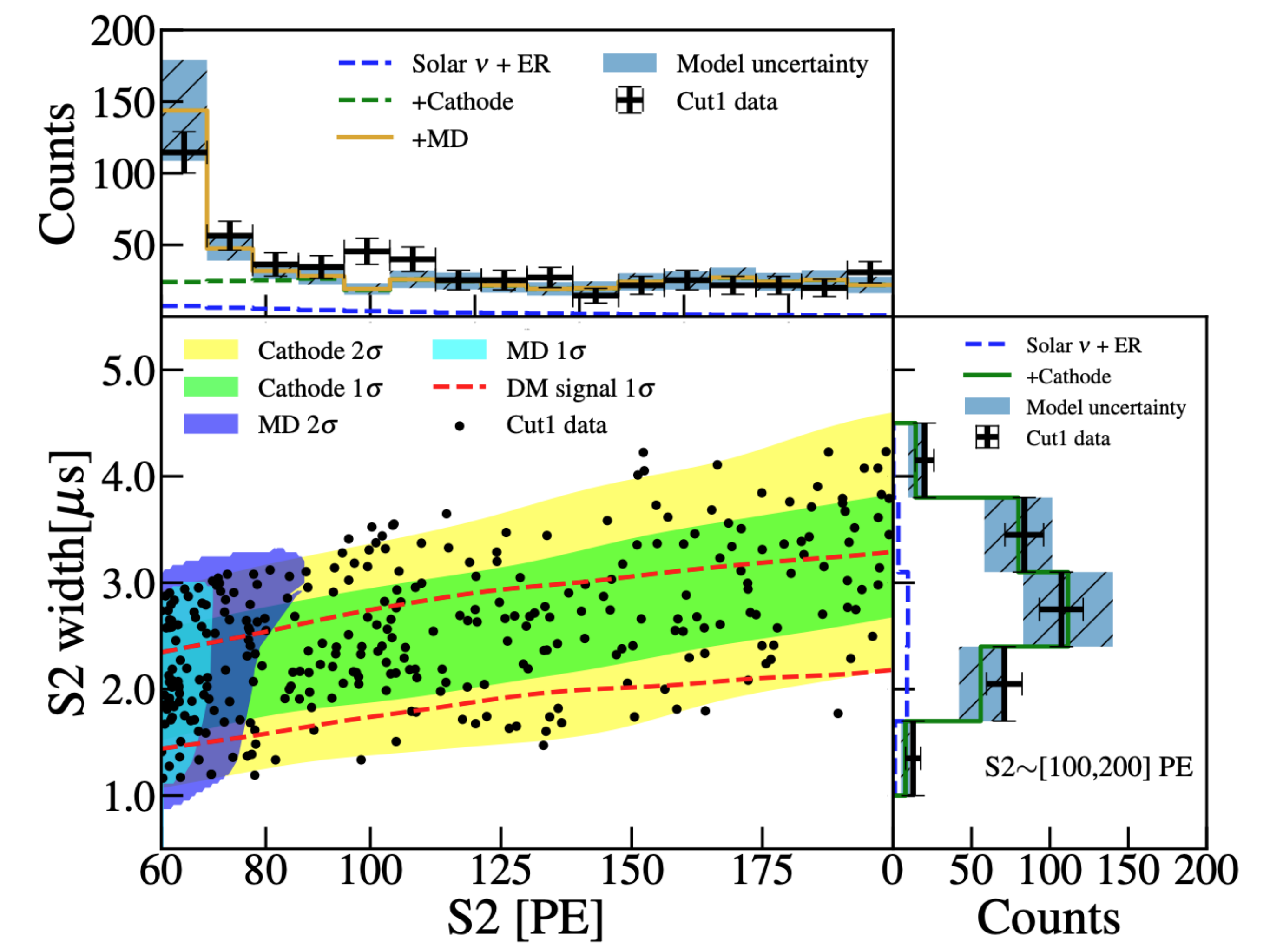
Solar





- **～5e6/s/cm2** for B8 **ν**;
- Mostly E<0.4MeV;
- Not observed yet.

Validation of bkg model



- Use a (loose cut – final cut) sample as control for bkg validation;
- Good match between data / control data both in width and S2 spectral shape