Prospects of detecting CEvNS using XENON100

a joint study by:

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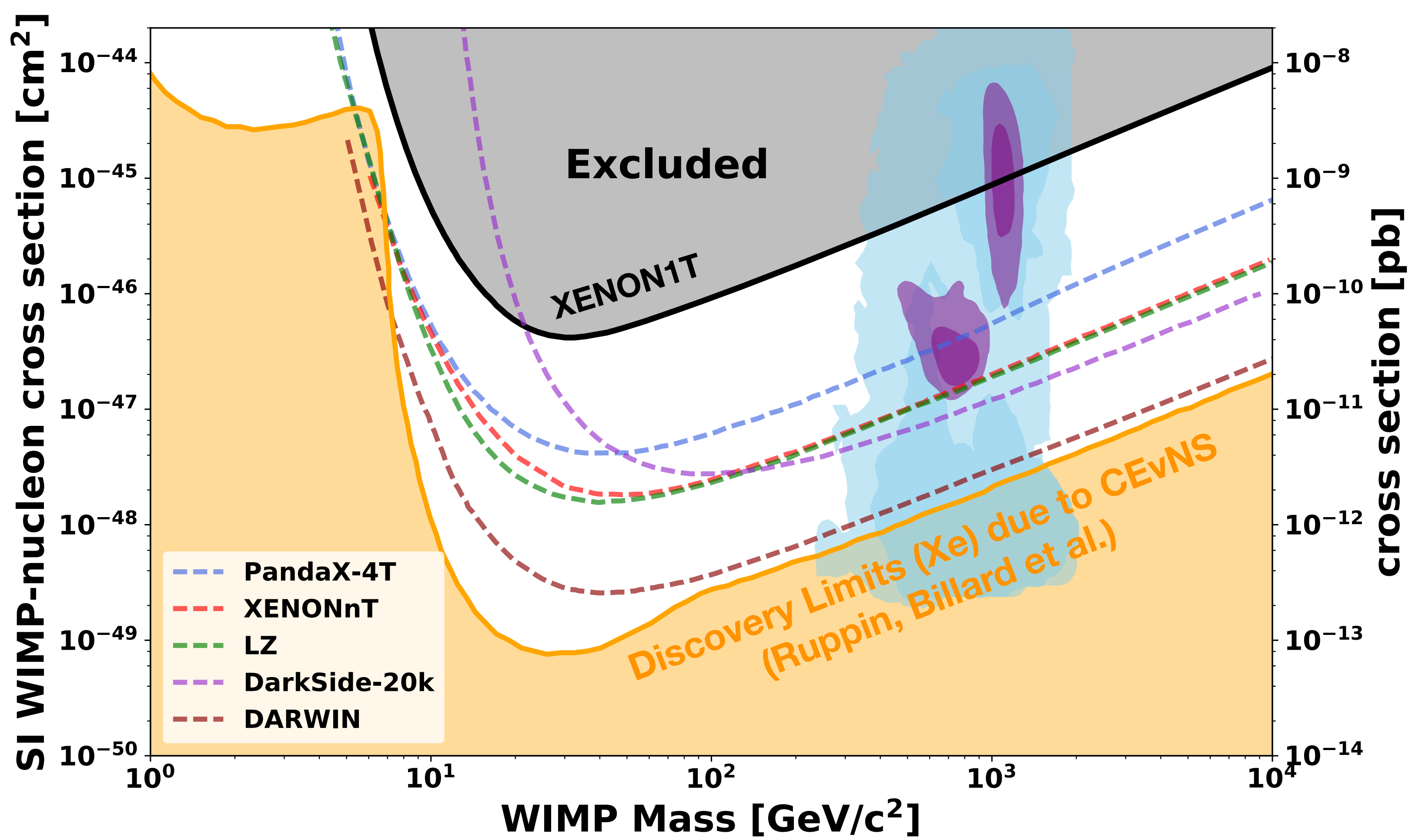
Magnificent CEvNS Workshop, Nov. 9-11, 2019

Sources of CEvNS for detection in liquid xenon detectors

- **Spallation Neutron Source**: XENON100 (proposed)
- **Reactor Neutrinos**: RED-100 (+one in the US?)
- **Solar/atmospheric neutrinos**
  - an avoidable background for future DM experiments
  - expected background from ^8B neutrinos in XENONnT, LZ



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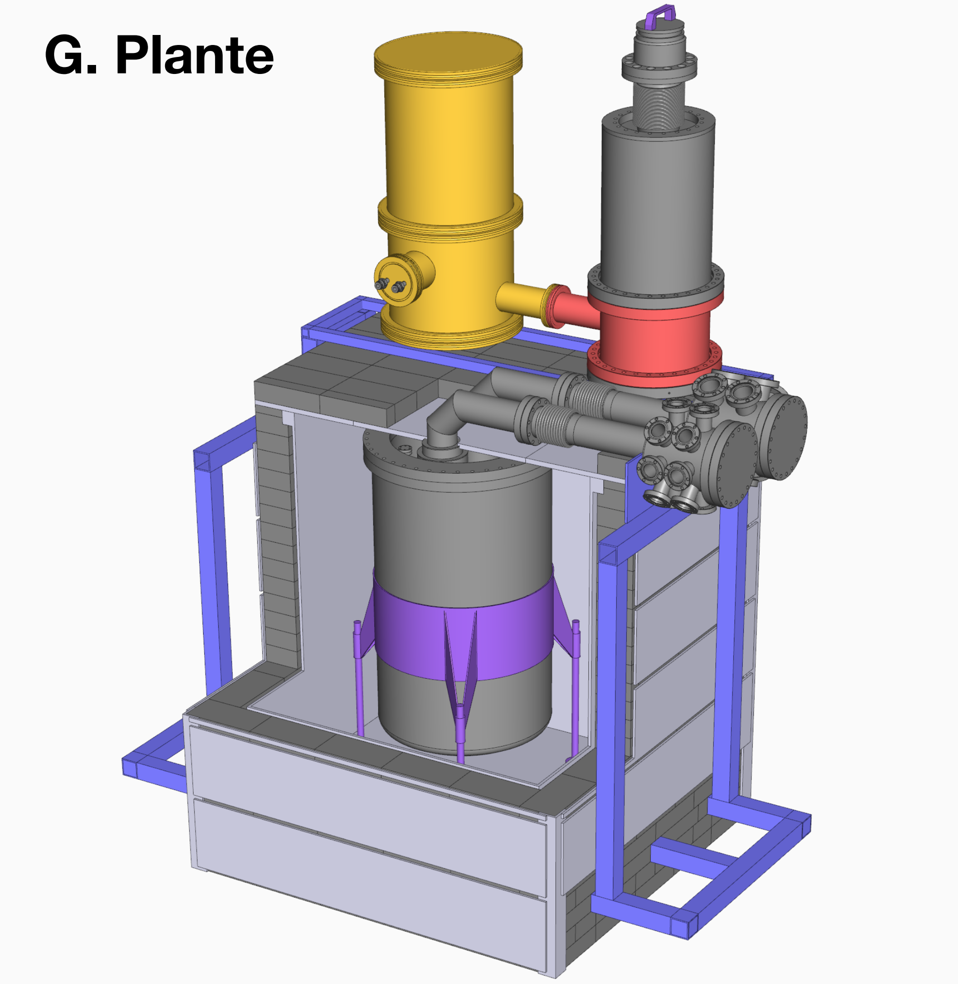
The XENON100 Detector

- Made big contributions to DM direct detection (2010-2016)
- Now enjoying retirement (doing nothing!) at Gran Sasso underground lab
- Compact enough: a foot-print of ~2 m x 4 m at LNGS (with shield)
- Detector itself < 1 m^2
- Cryohead/Shield can be modified to require < 2m x 2m foot print for SNS

XENON100 @ LNGS



Possible XENON100 @ SNS

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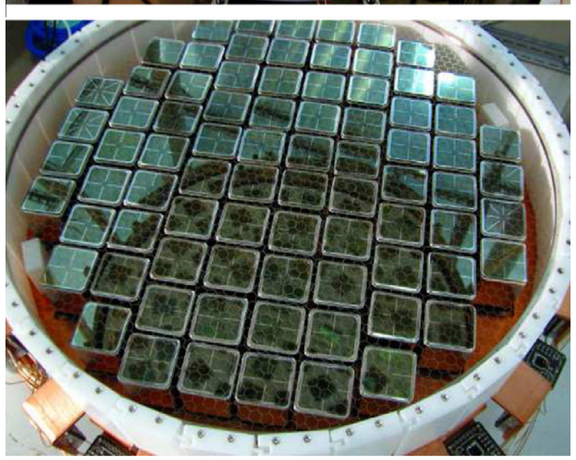
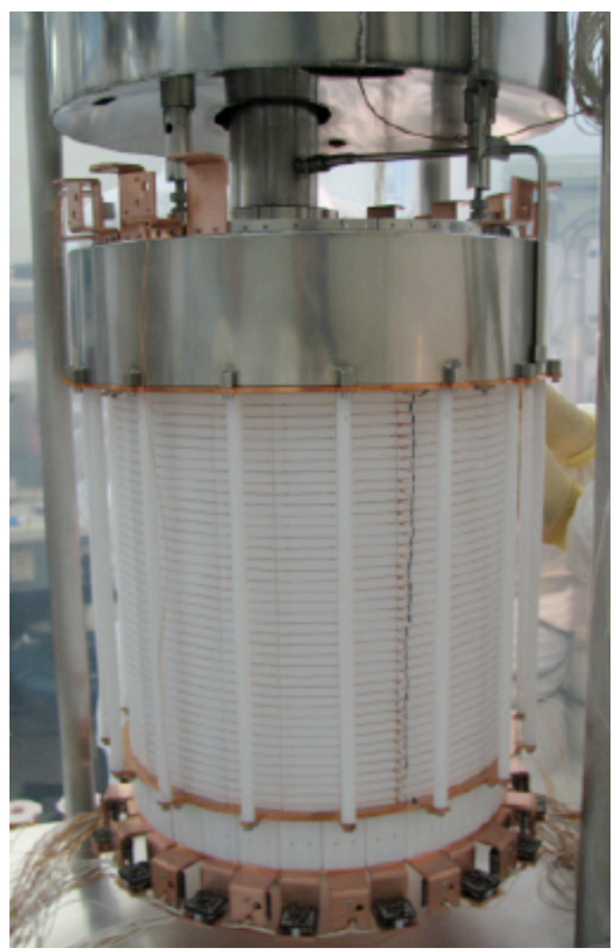
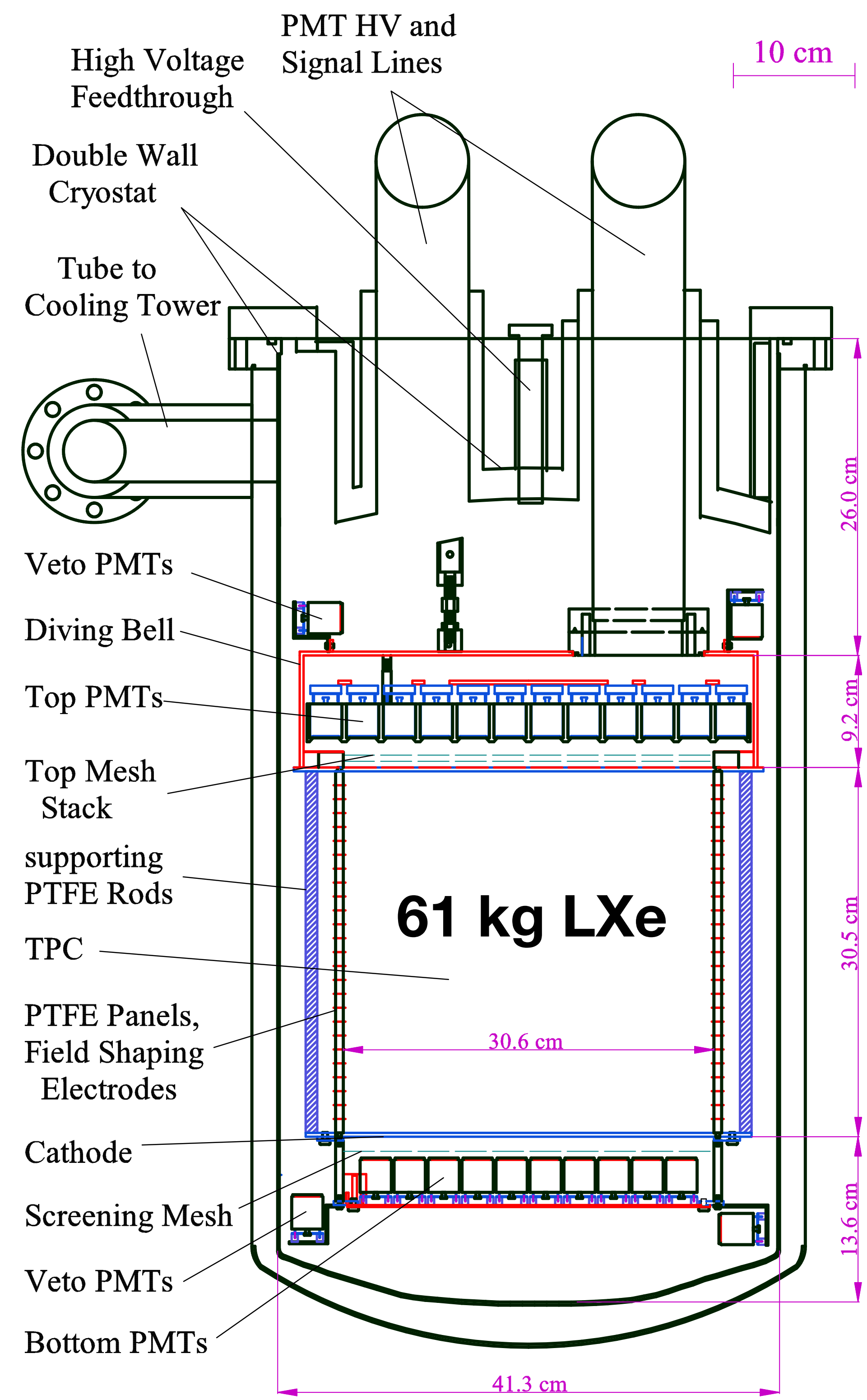
The XENON100 Detector

- TPC with 178 R8520 (1"square) PMTs
- active liquid xenon: ~61 kg (defined by the 30 cm x 30 cm drift volume)
- total liquid xenon filled ~160 kg







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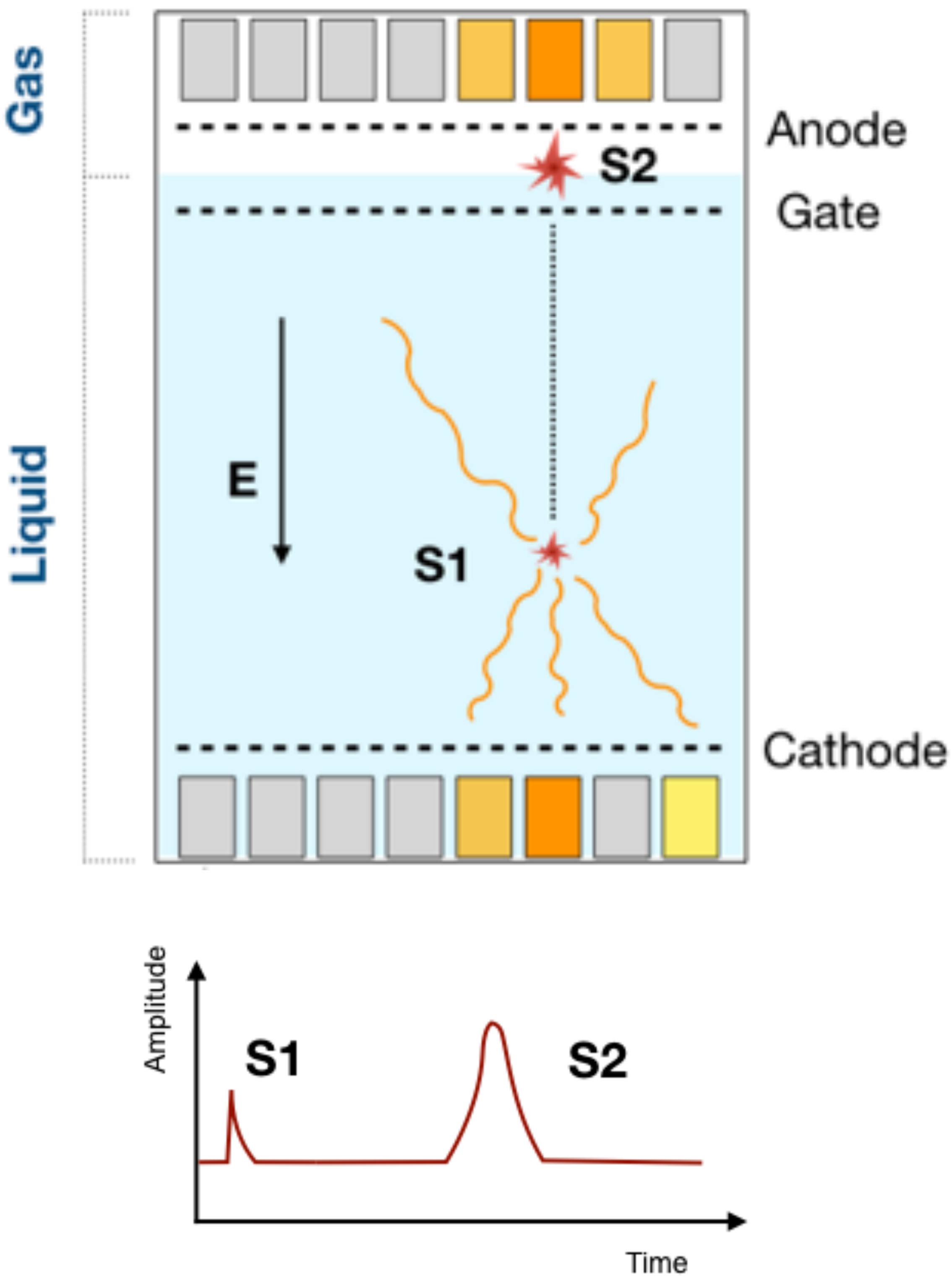
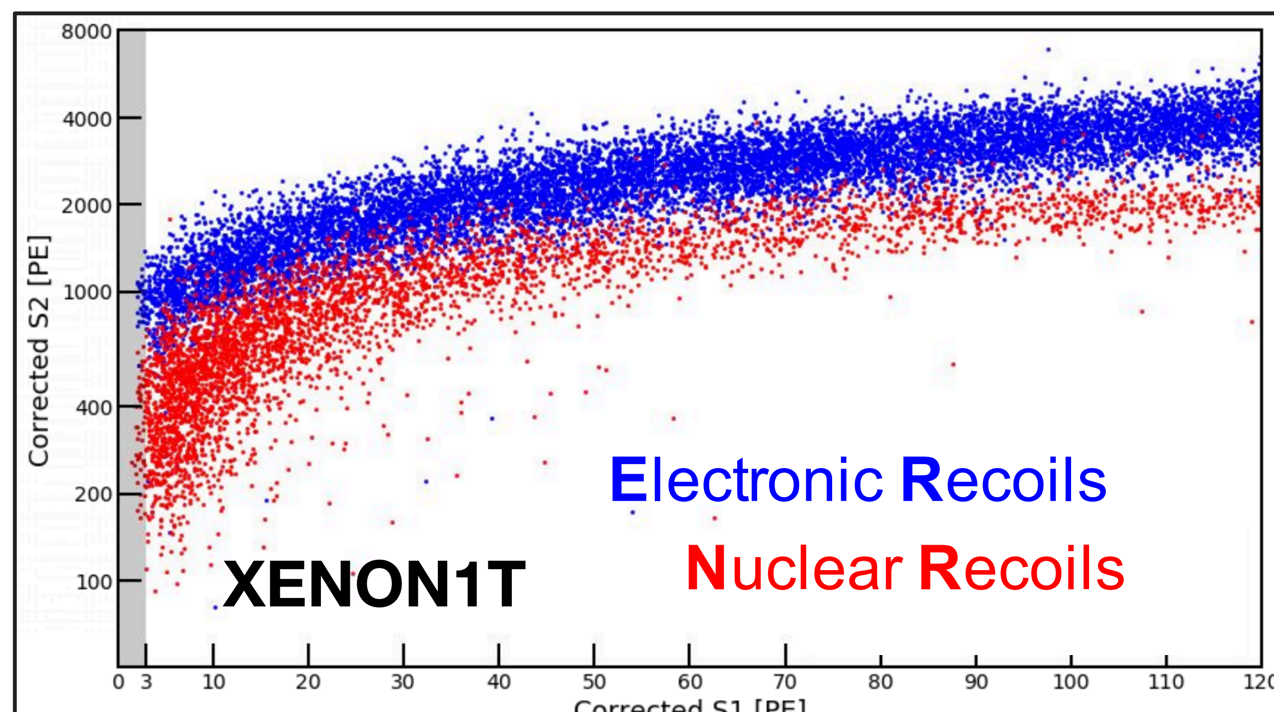
Signals from the Two-phase xenon TPC



With both S1 and S2 signals (TPC mode):

- **Low threshold: keV (set by S1: 2-3 PE)**
  - **Corresponding S2: > 200 PE**
- **Ultra-low background**
  - **3D fiducialization**
  - **ER/NR discrimination with S2/S1**



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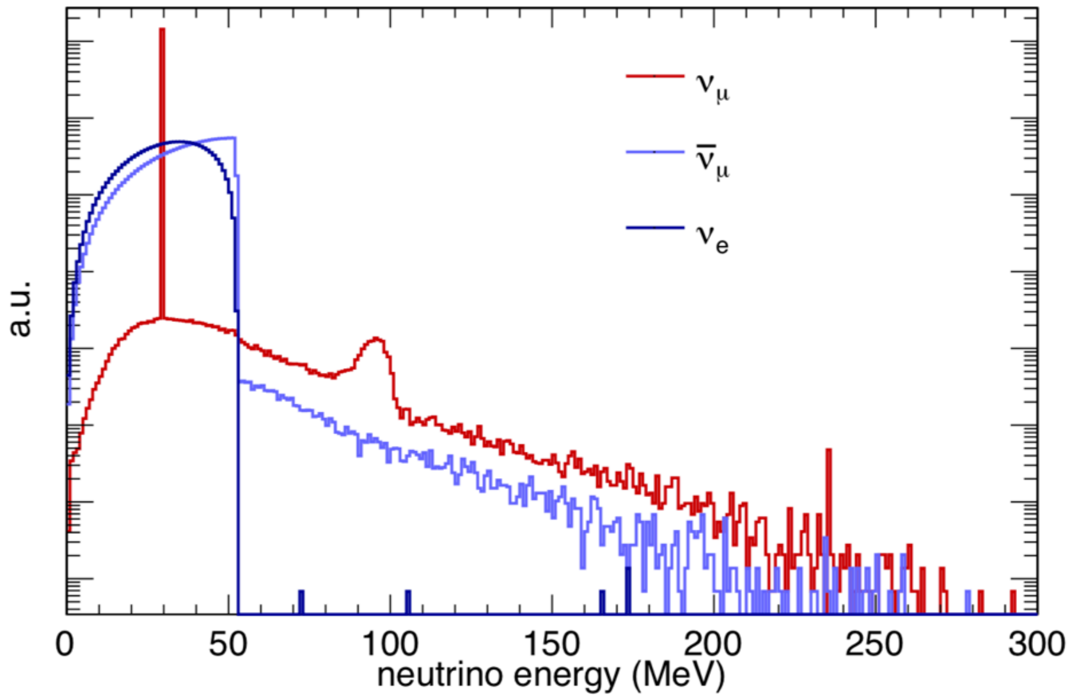
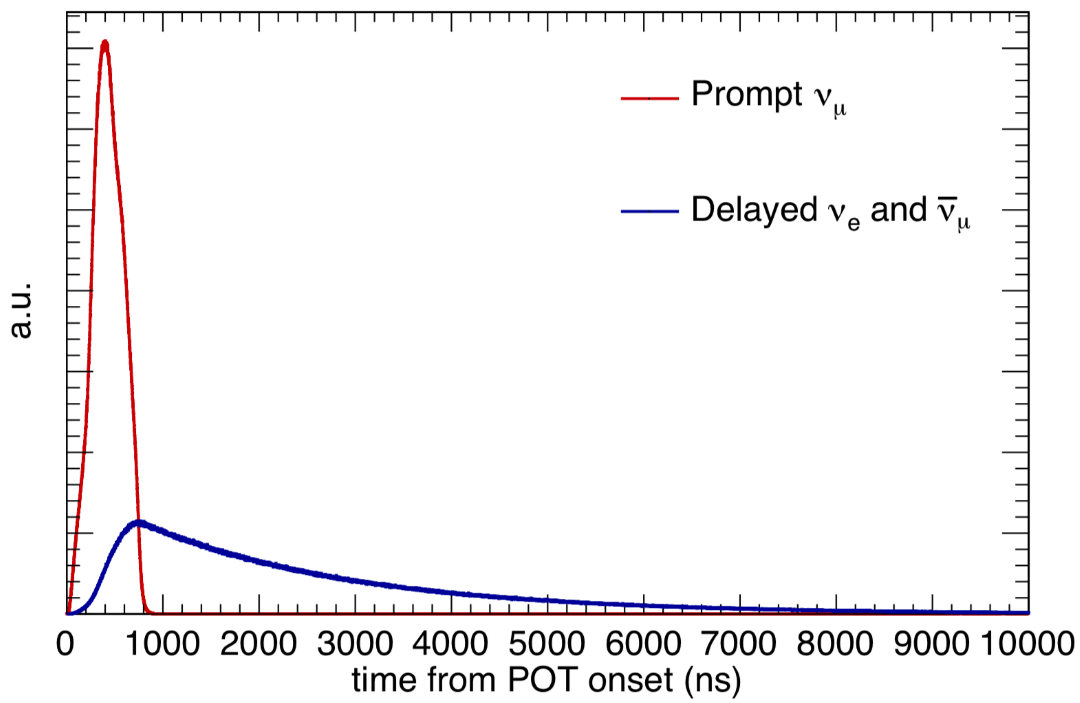
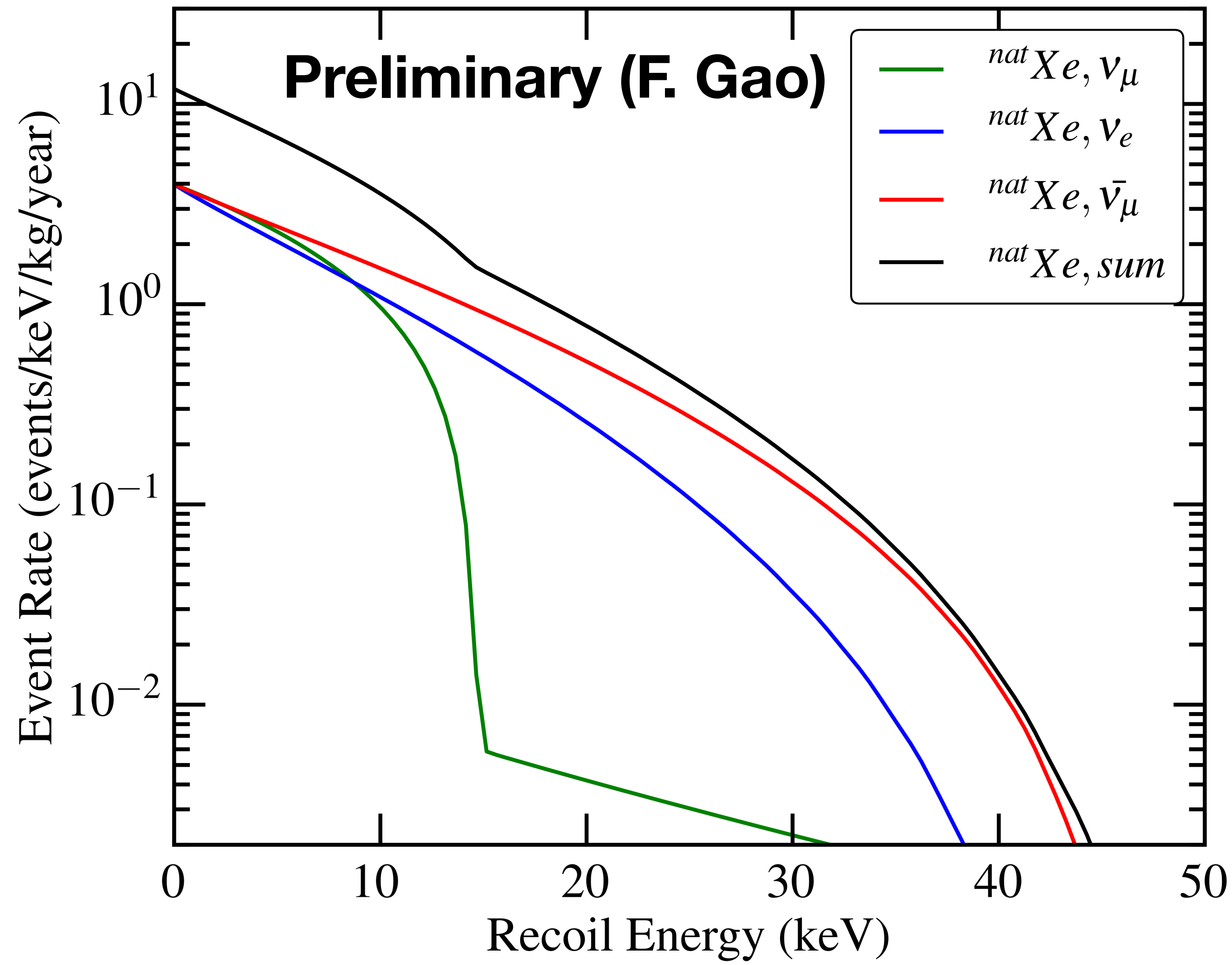
Expected CEvNS rate in XENON100 from SNS

Neutrinos from SNS





- three flavors of neutrinos produced
  - 4 x 10^{19}/flavor/day
  - different energy and timing characteristics
- detector placed ~20 m from the target



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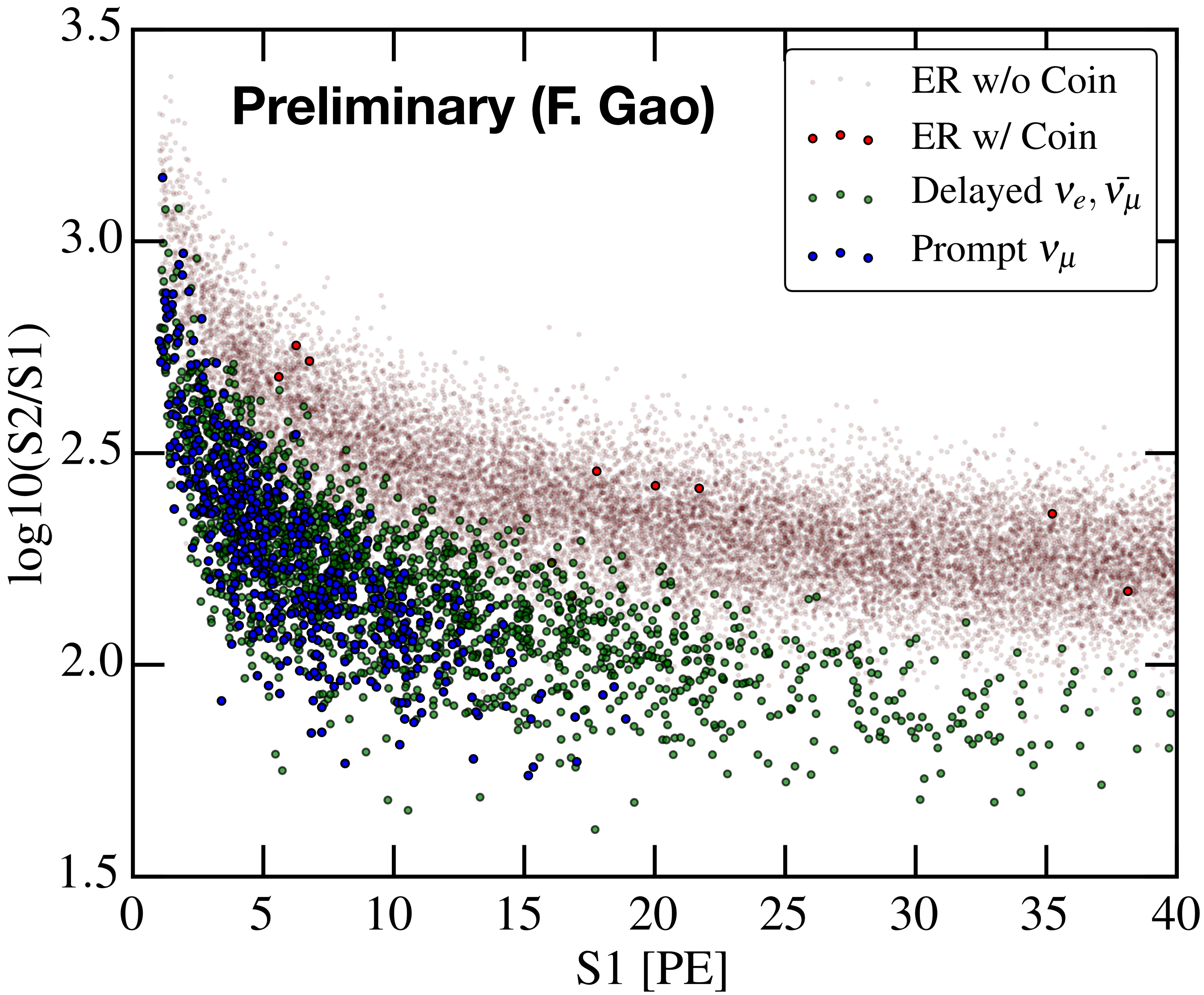
Response of Prompt and Delayed Neutrinos in XENON100



Simulated S2 vs S1 response with NEST for XE100 at SNS

- **g1 = 10%, g2 = 20 PE/e-**
- **50 kg x year exposure**
- **Total assumed ER bkg: 20000 events/year: 20 times higher due to reduced/ compact shielding**

- Expected CEvNS events: ~2280 events/year (490 produced by the prompt ν_μ)
- Coincidence cut with the pulsed neutrino beam: reject ER down to 12 event/ year (before ER/NR discrimination)

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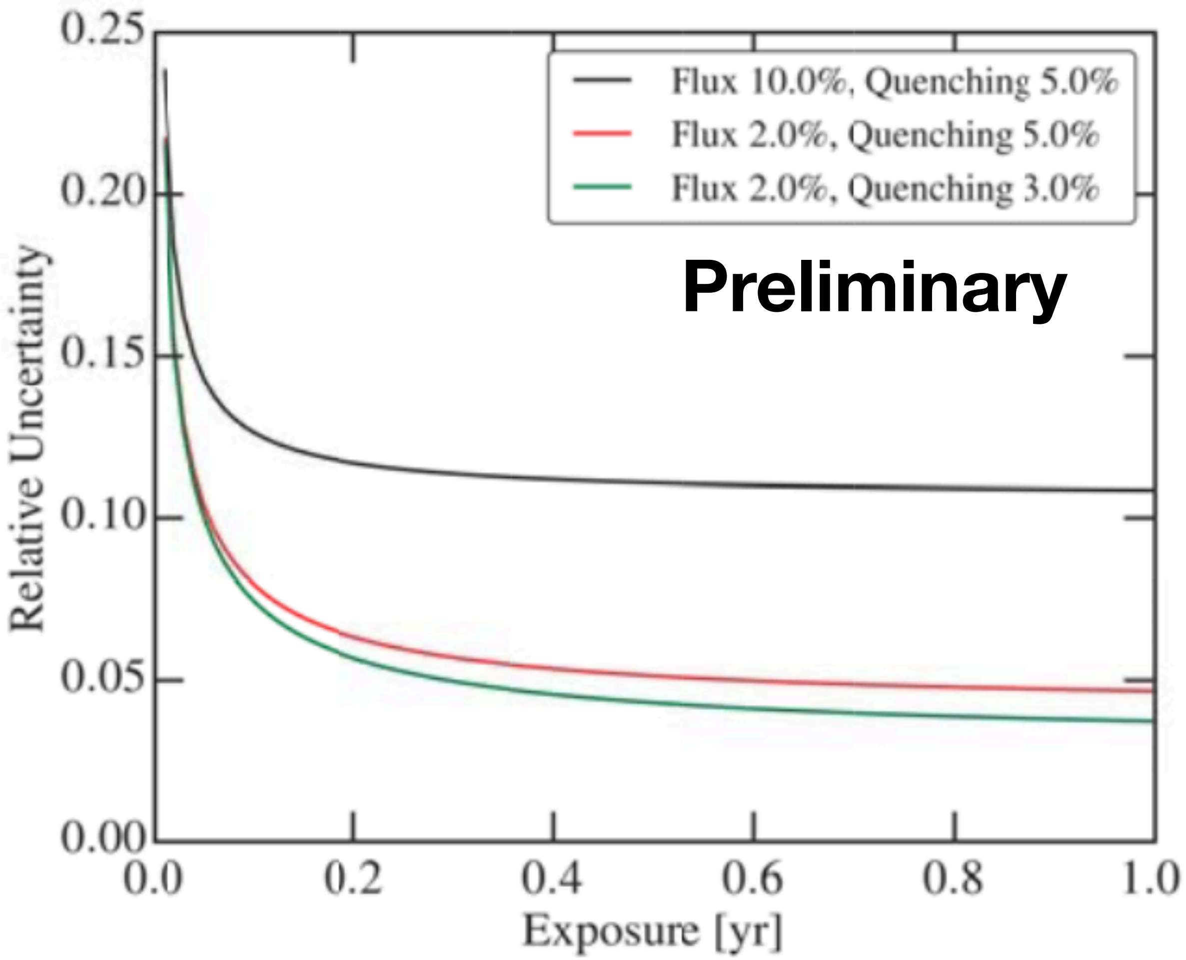
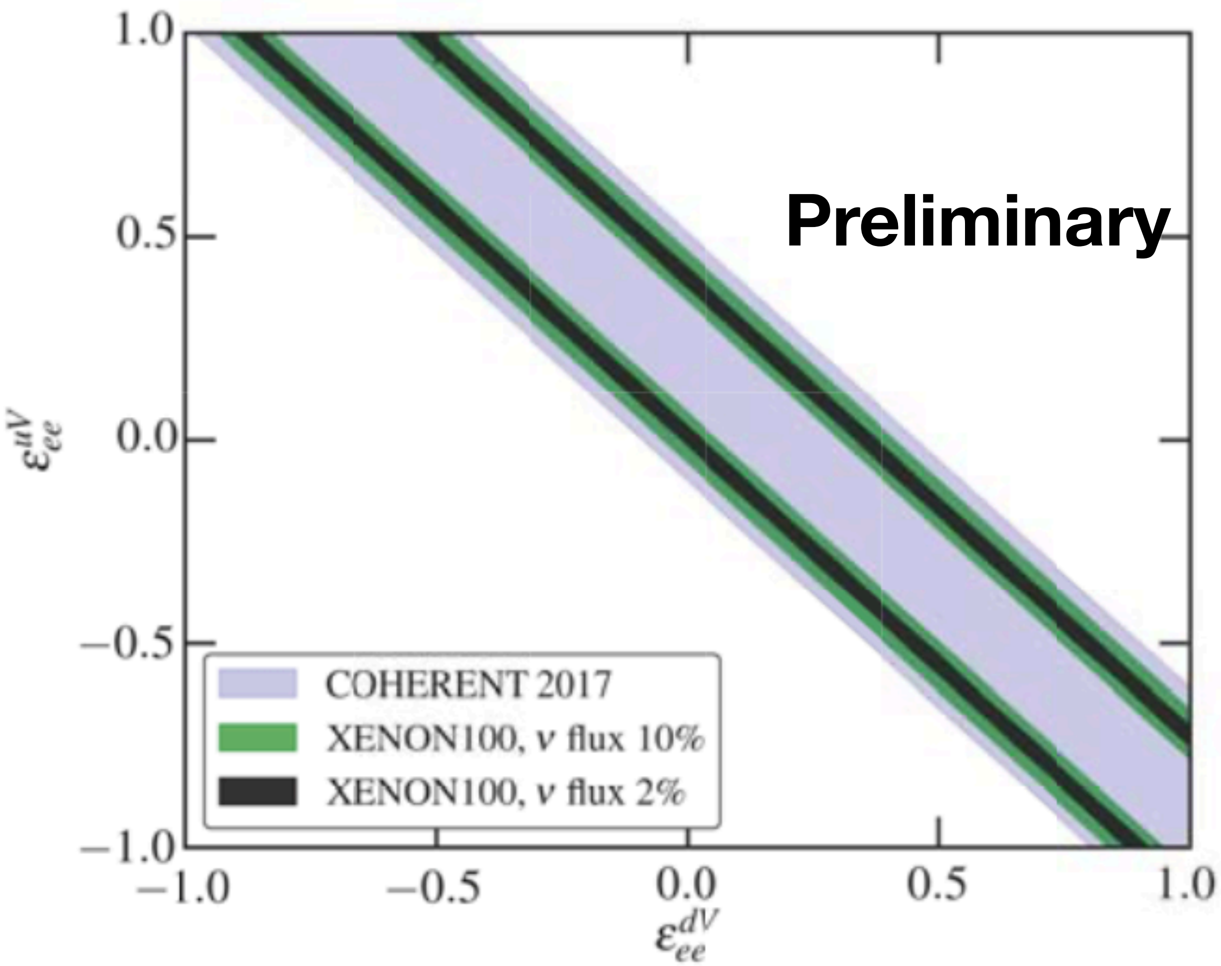
Prospect of detecting CEvNS using XENON100 at SNS





- Measure CEvNS cross section with Xe with ~5% uncertainty within one year
- Constraining parameters of the new effective couplings between ν_e-quarks and many other new physics (learned at this workshop!)

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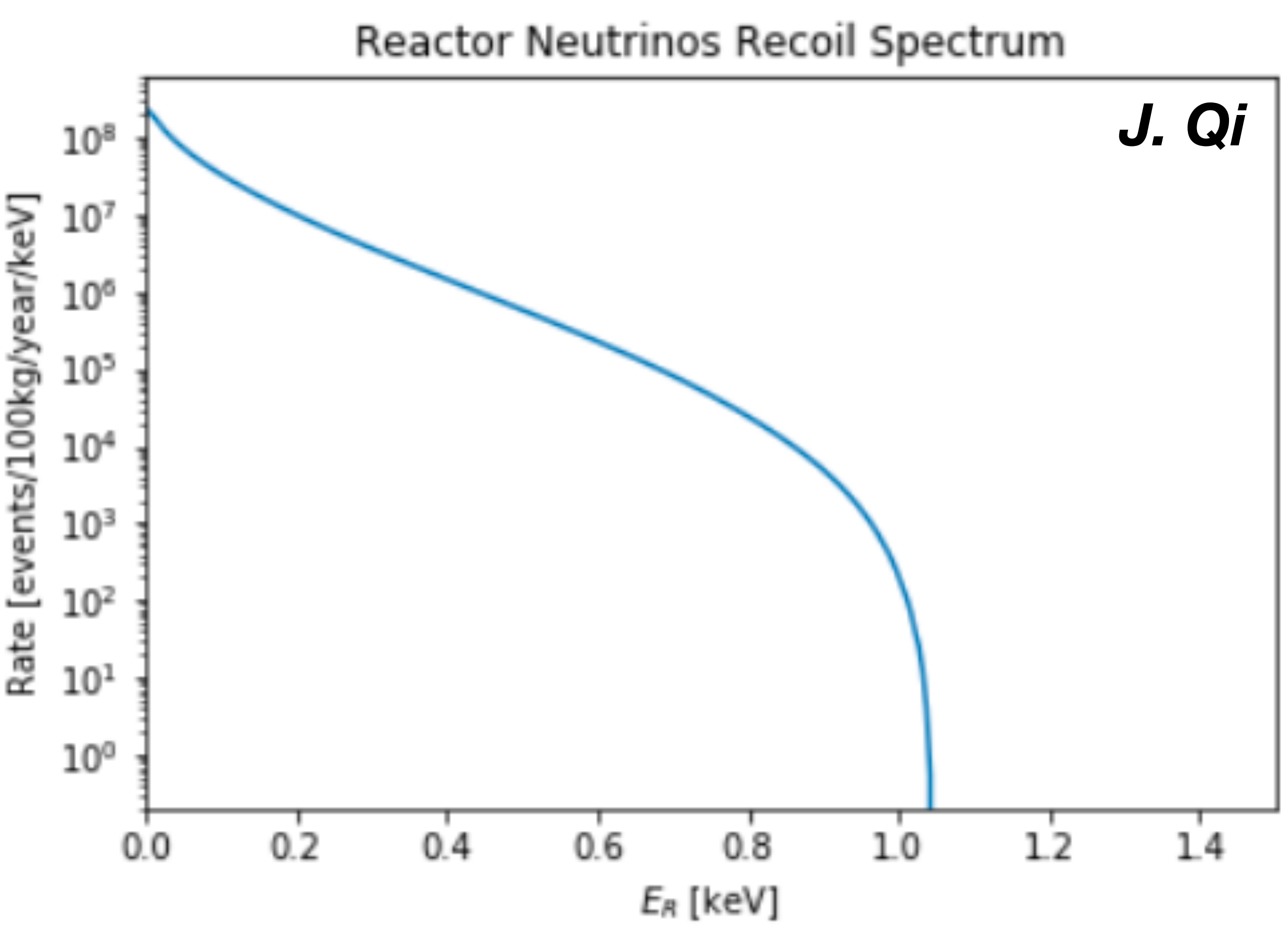
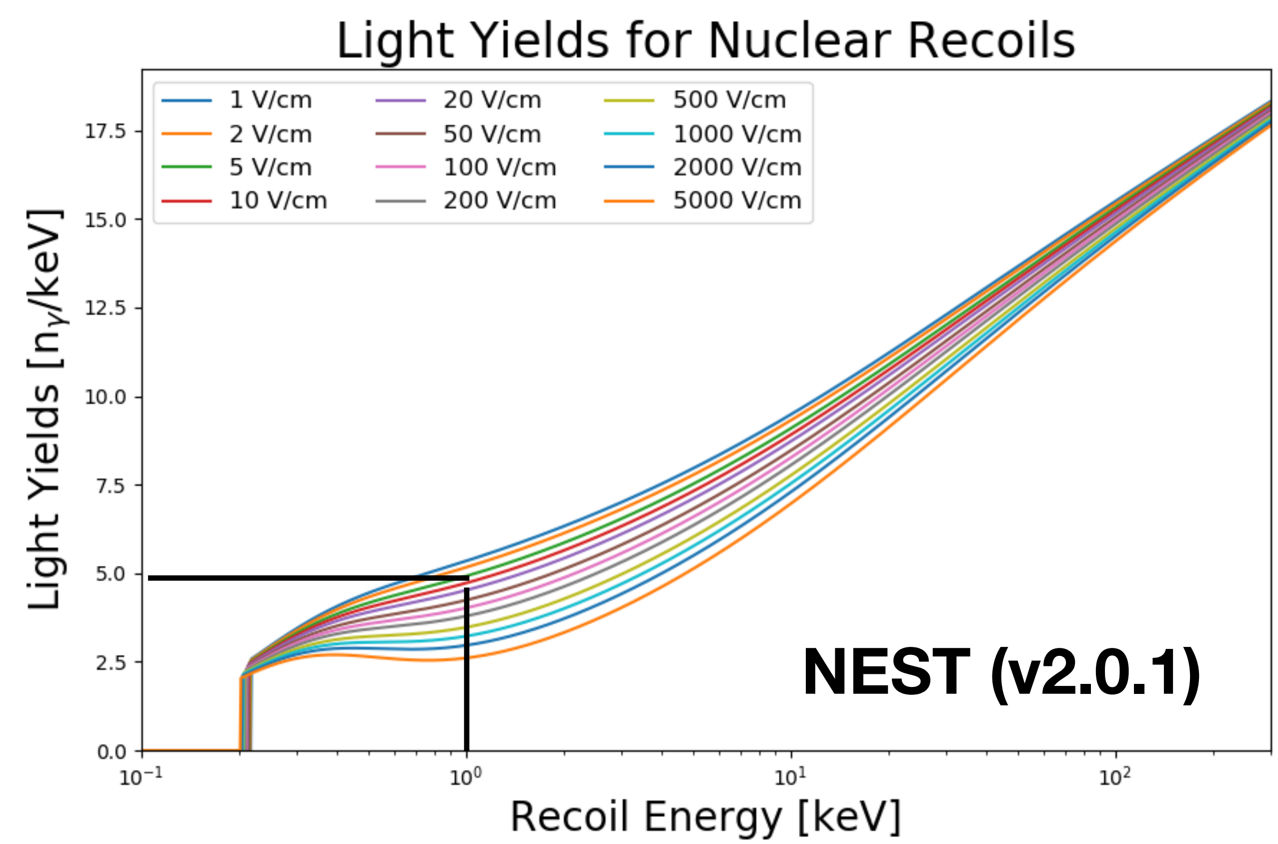
How about using a XENON100-like detector for reactor neutrinos?

- Reactor antineutrino spectrum taken from Hayes, Vogel (1605.02047), and used a mixture of ^{235}U (61.9%), ^{238}U (6.7%),^{239}Pu (27.2%) and ^{241}Pu (4.2%)

- Flux normalized to 6 x 10^{12} cm^{-2}s^{-1} (25 m from a 3 GWth reactor, same as used in Hagmann, Bernstein nucl-ex/0411004)





It's NOT possible to detect S1 below 1 keVnr.

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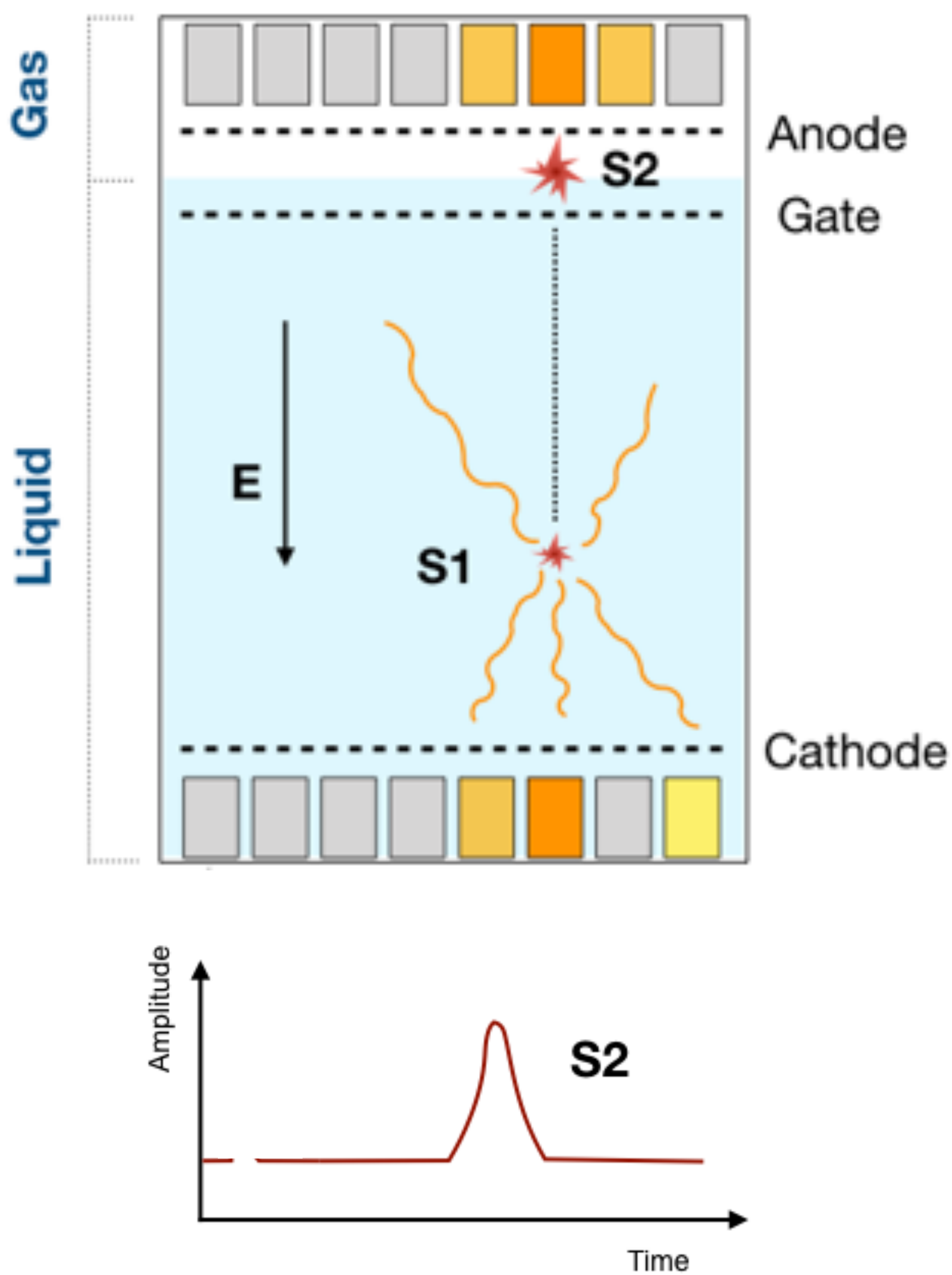
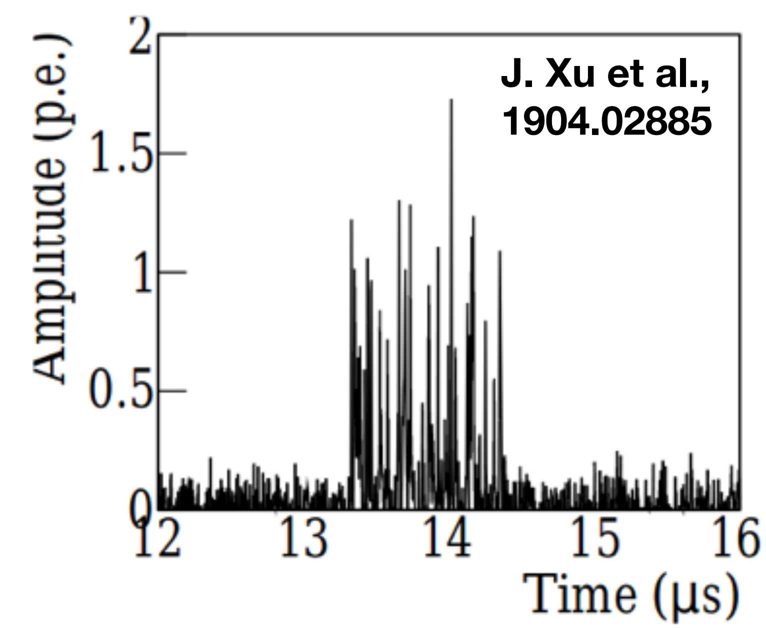
Two-phase Xenon Detector in Electron Counting mode





a single e- signal in S2

With S2-only signal
(EC - Electron Counting mode):

- **Ultra-low threshold: 10-100 eV** (set by S2)
  - single e- signal: 10~100 PE
- Background control a challenge:
  - No ER/NR discrimination
  - Only XY position determined, no Z
  - single/few electrons background high

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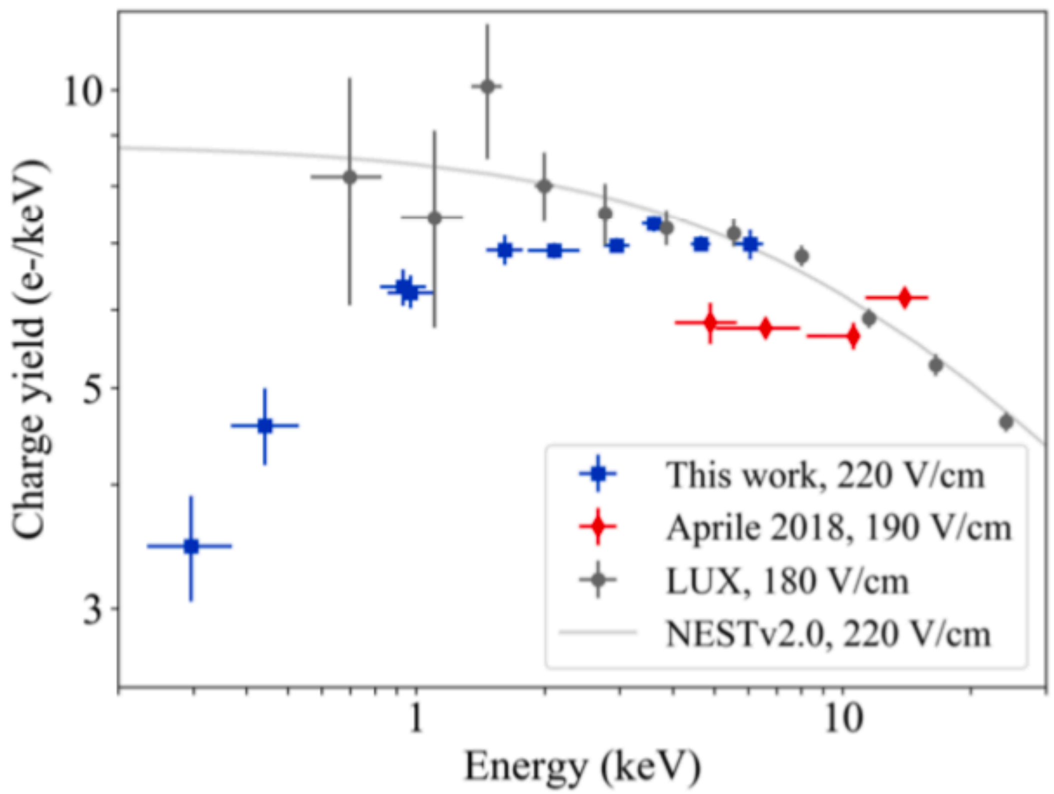
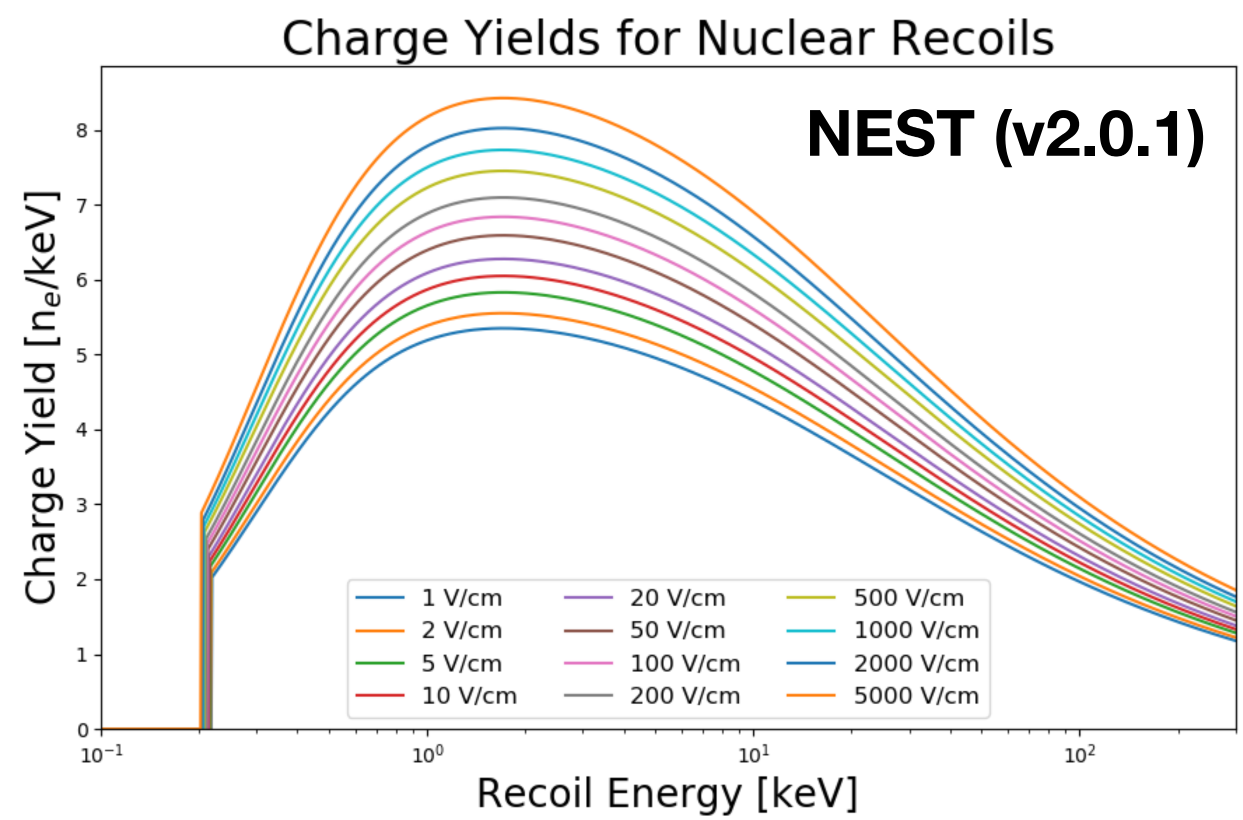
Ionization Yield for sub-keV Nuclear Recoils in LXe

Latest measurement
Lenardo, Xu et al., 1908.00518



Latest model from NEST
http://nest.physics.ucdavis.edu



1 keVnr gives 5~8 ionization electrons: large S2 signal!

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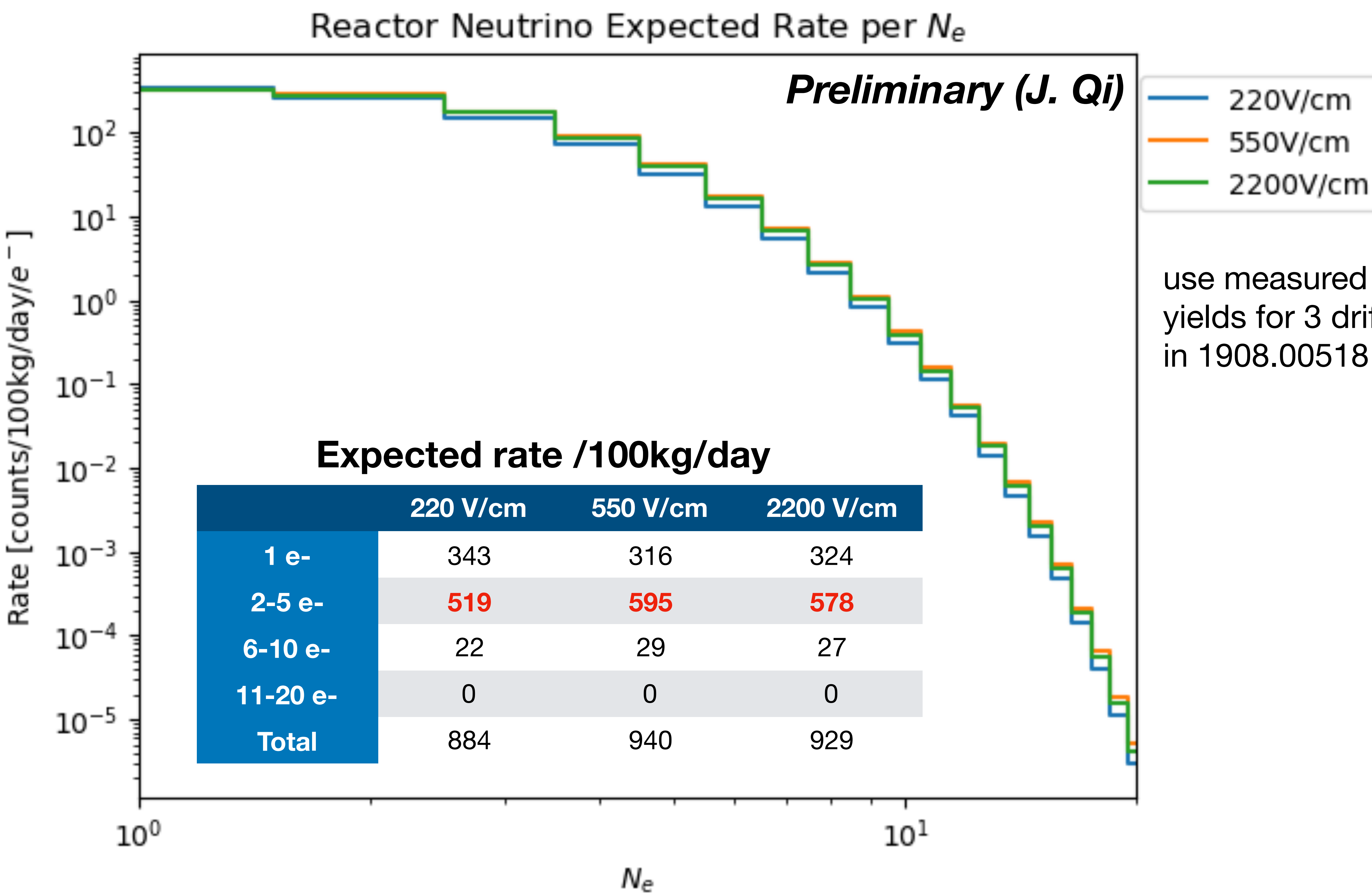
Expected Ionization Electrons to be Detected in S2



Expected rate /100kg/day

	220 V/cm	550 V/cm	2200 V/cm
1 e-	343	316	324
2-5 e-	519	595	578
6-10 e-	22	29	27
11-20 e-	0	0	0
Total	884	940	929

use measured charge yields for 3 drift fields in 1908.00518

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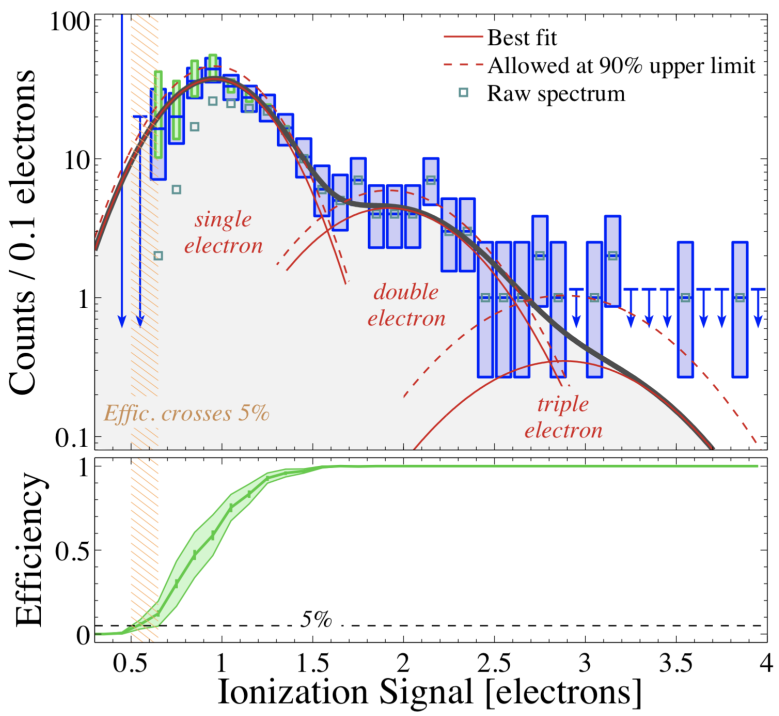
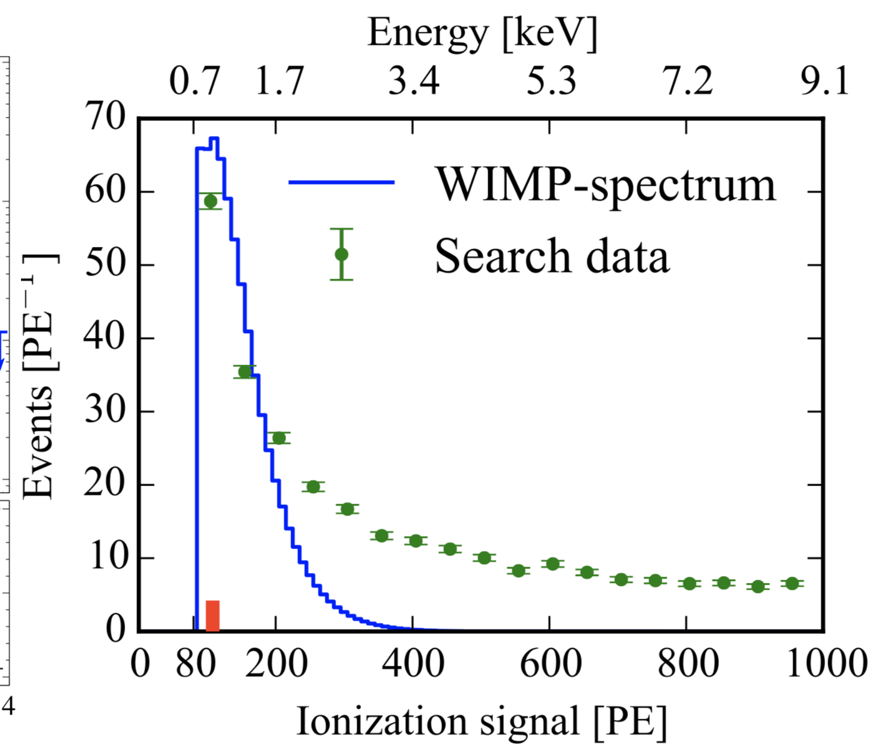
The single-and-few electrons background in XENON detectors

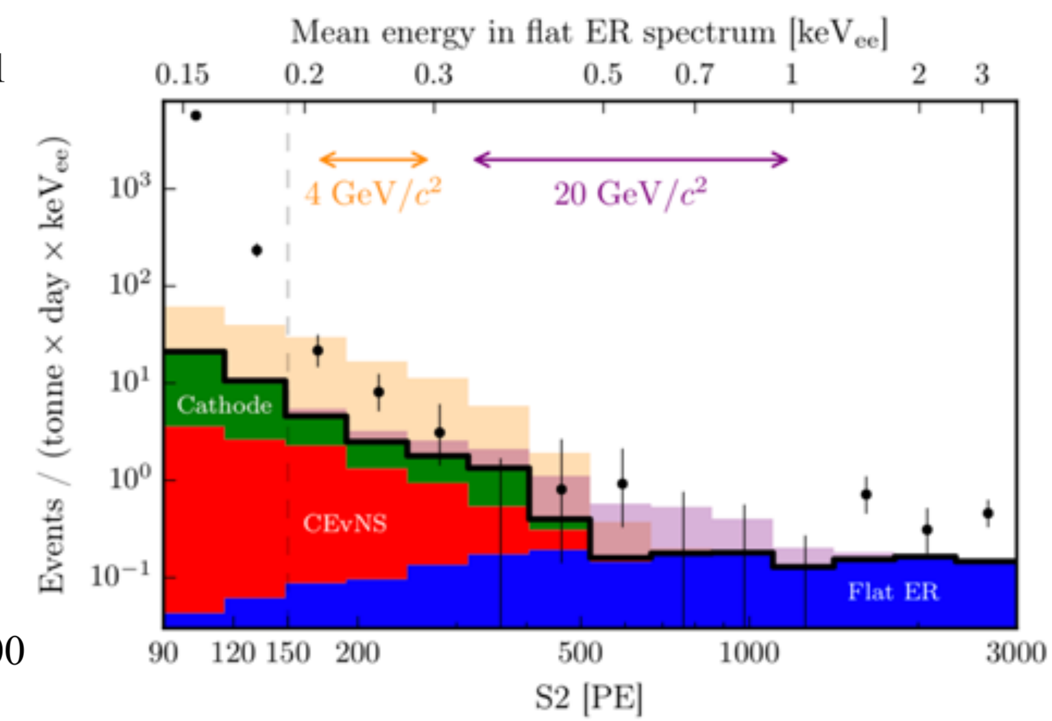
XENON10, 1206.2644



XENON100, 1605.06262



XENON1T, 1907.11485



15 kg-day

Rate: 0.1~10/kg/day at 2~3 e-

10~100/kg/day at single e-

11,000 kg-day

Rate: 0.1/kg/day at ~4 e-

22,000 kg-day

0.01~1/kg/day at 3~4 e-

- **Background at a few electron level is not always going down with increasing target mass.**
- **We now understood much better the sources of these background electrons.**

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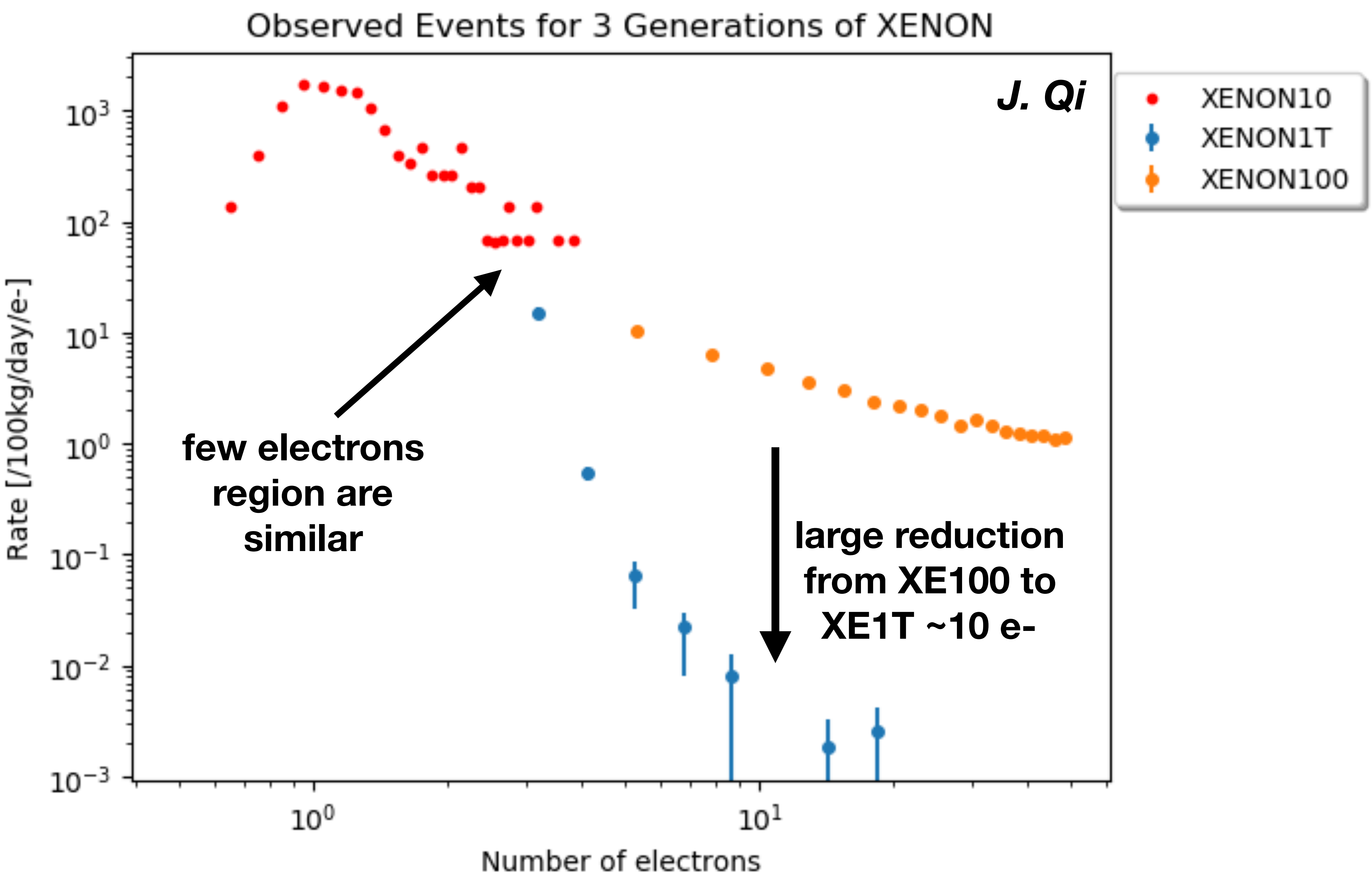
The single-and-few electron background in XENON detectors



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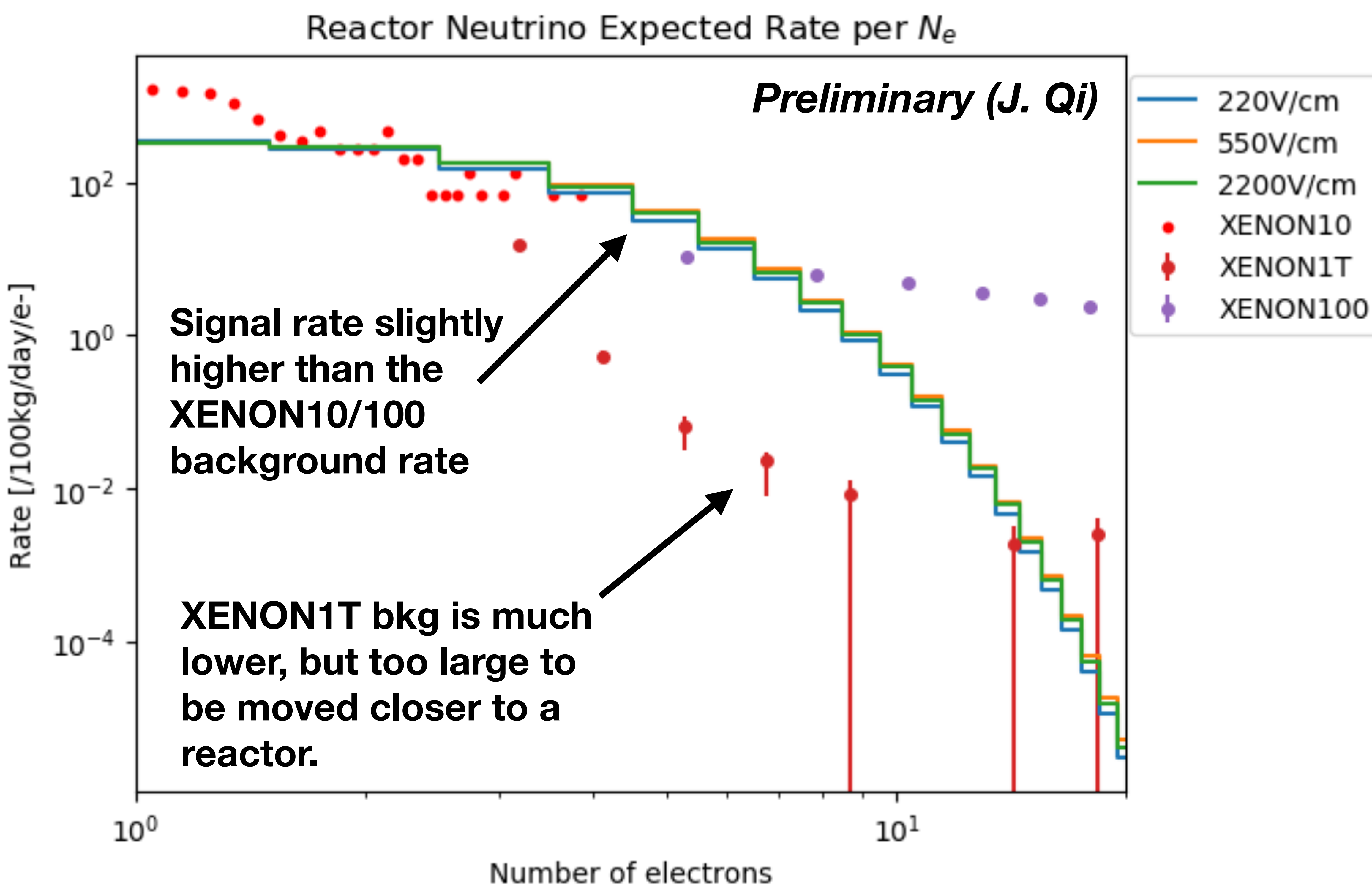
The background vs reactor neutrino CEvNS signal



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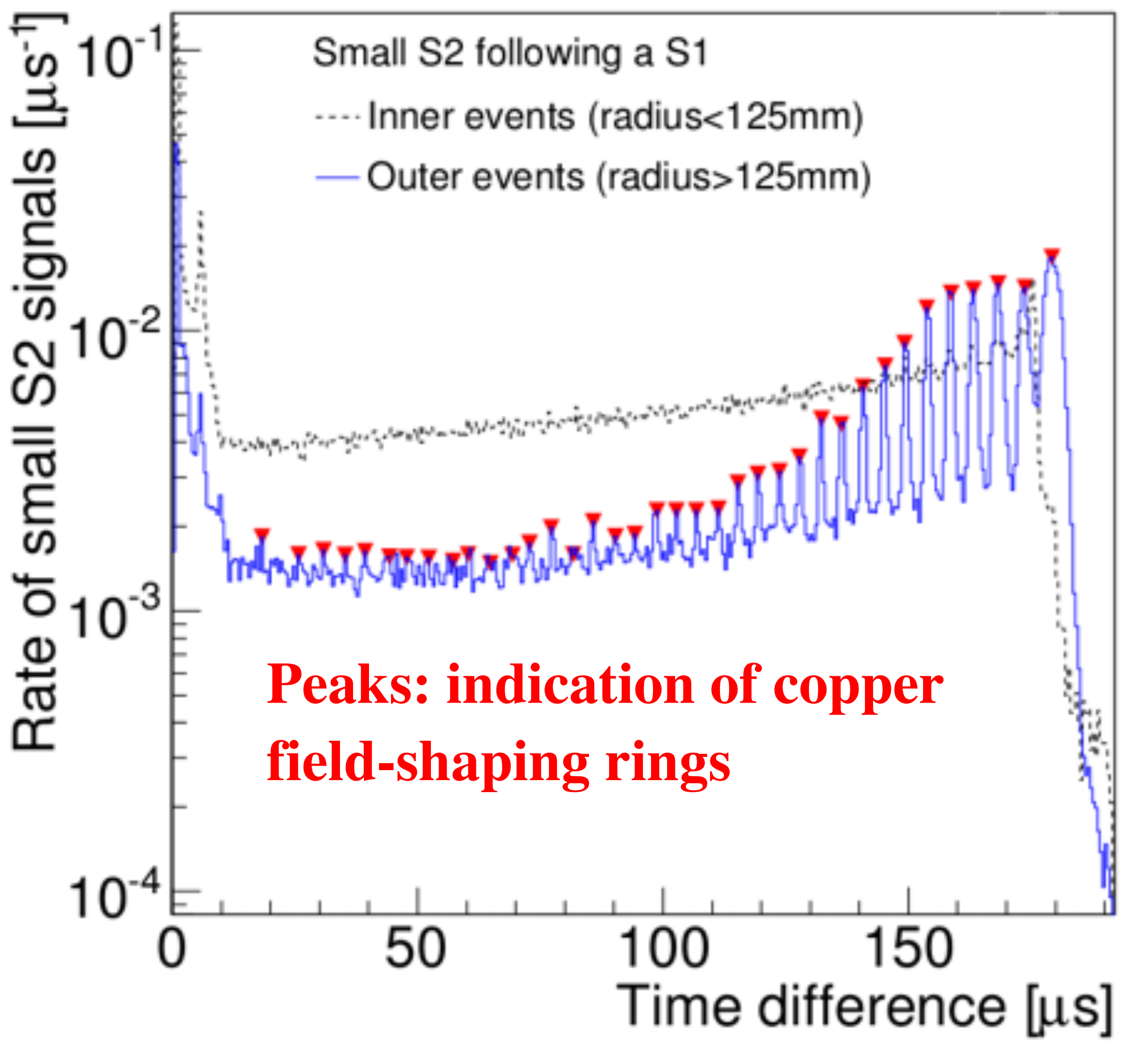
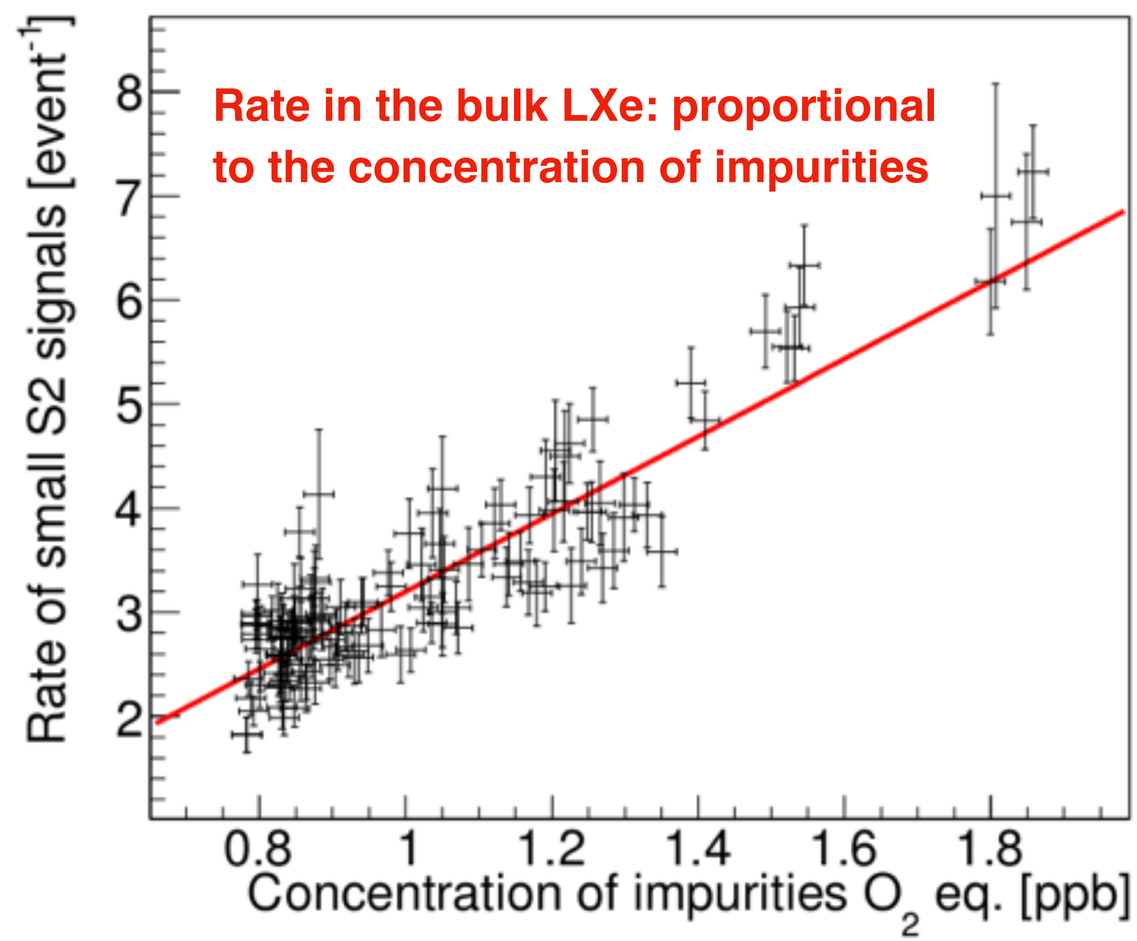
Understand and Suppress the Single-and-few Electron Background

Observation and applications of single-electron charge signals in the XENON100 experiment

arXiv:1311.1088





Mitigation solutions:

- **reduce metal components directly contacting the LXe target in the TPC**
- **significantly improve the purity of LXe target**

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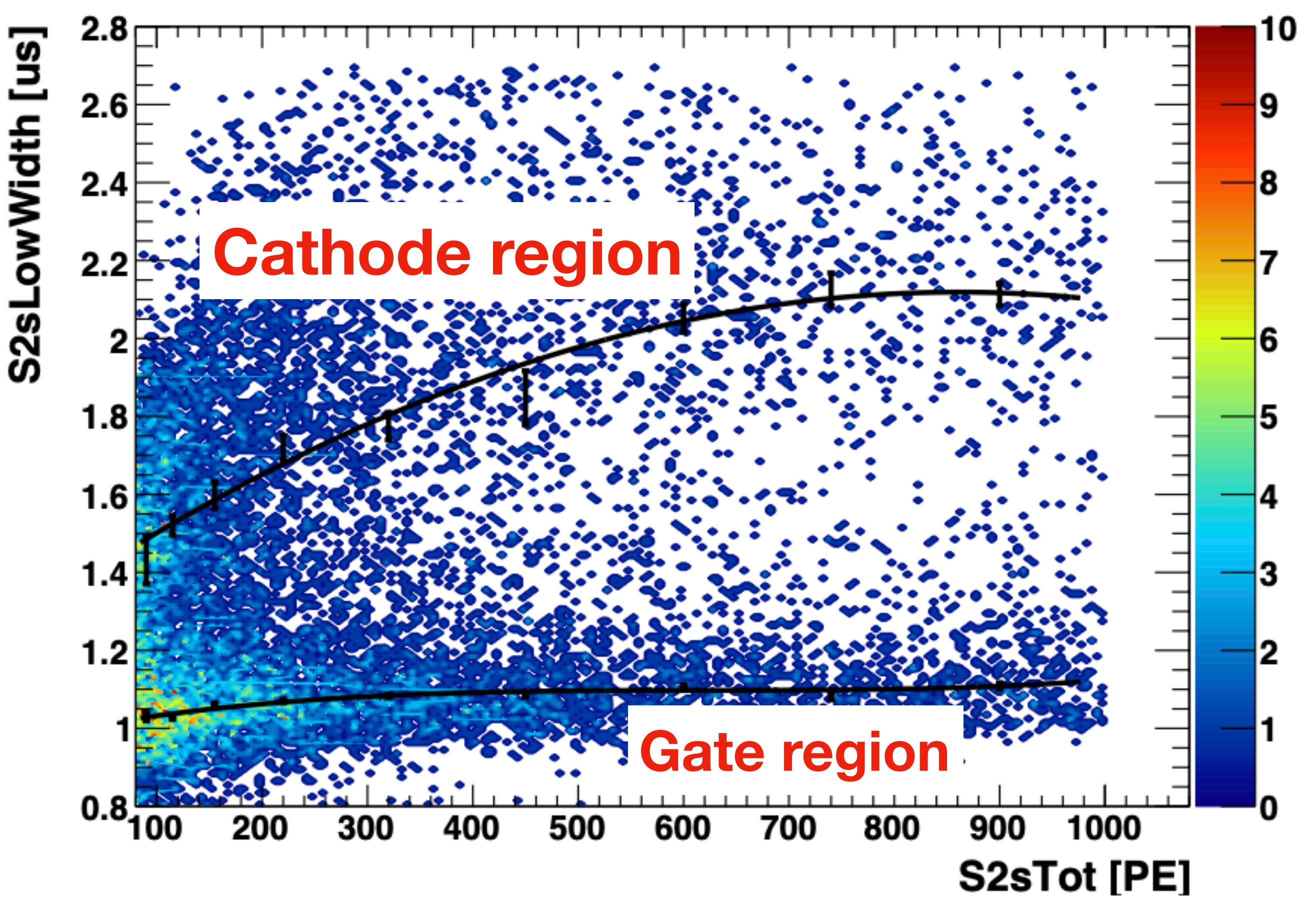
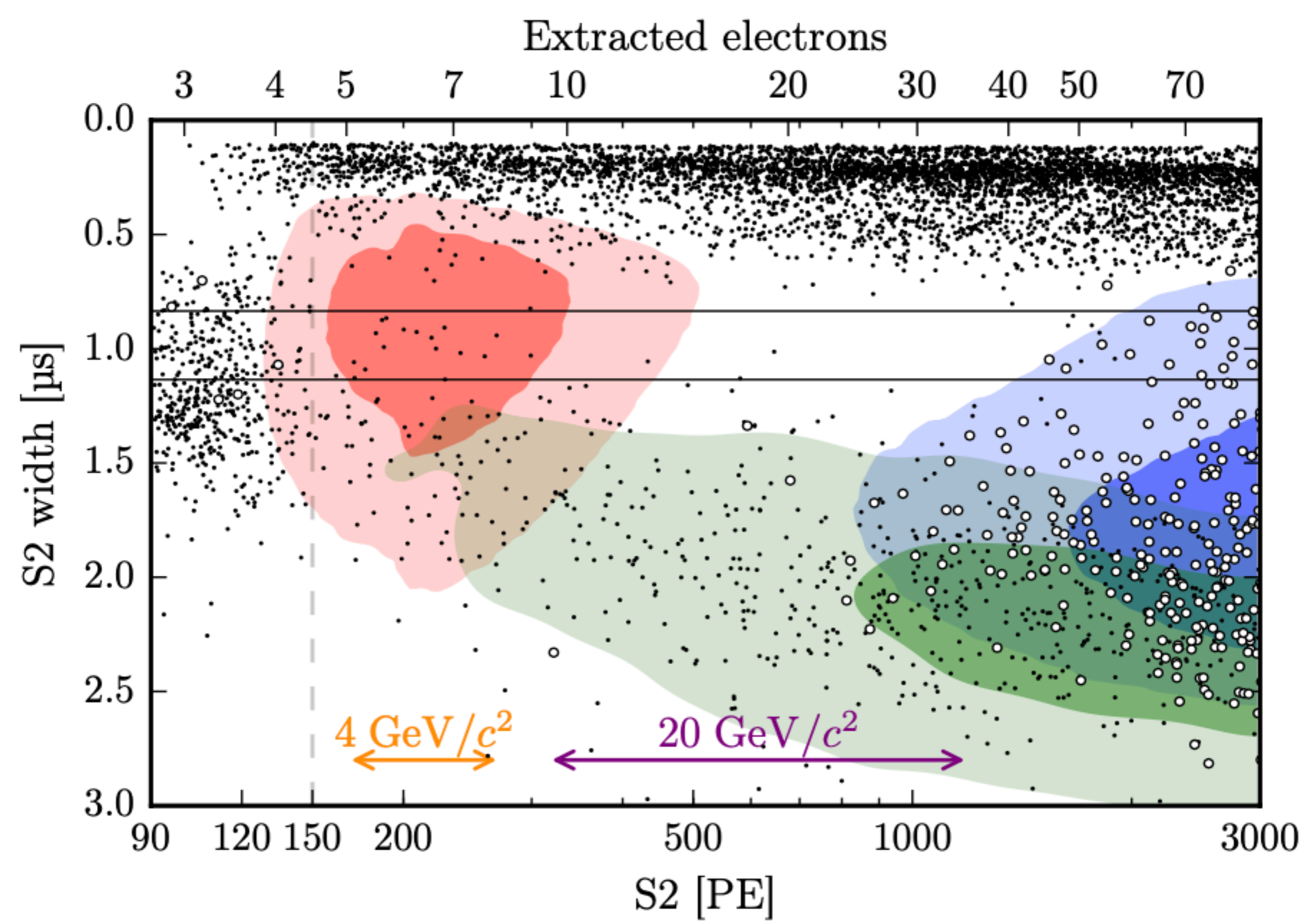
Reduce few-electron background with S2-width selection

XENON100



XENON1T, 1907.11485



S2-width cut applied in XENON100 would further reduce the few-electron background rate

S2-width cut applied for XENON1T data

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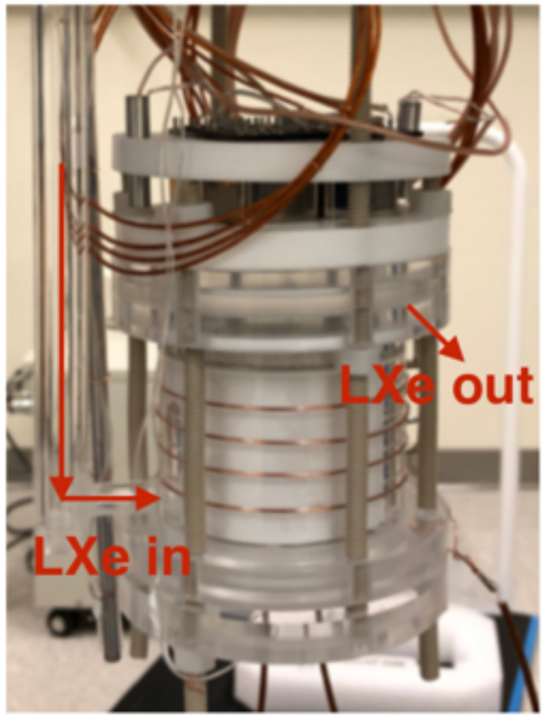
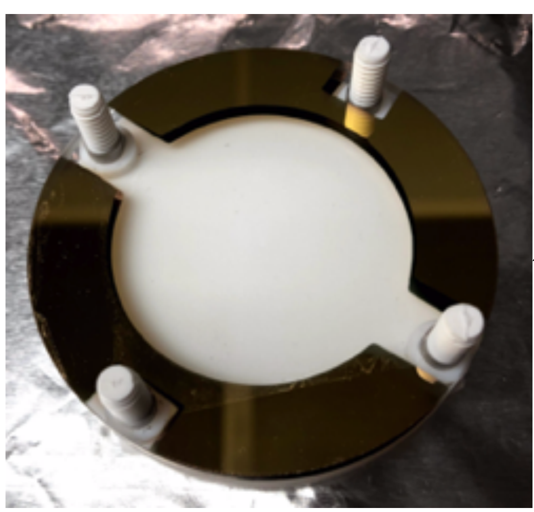
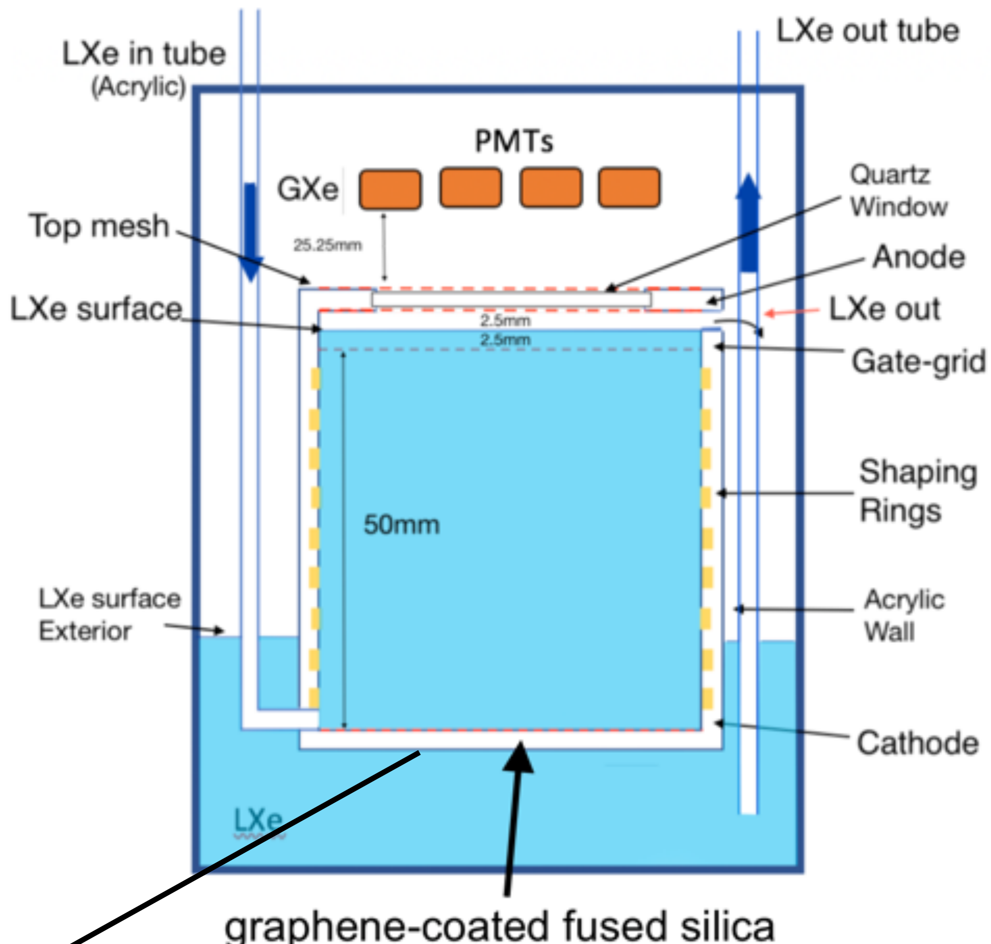
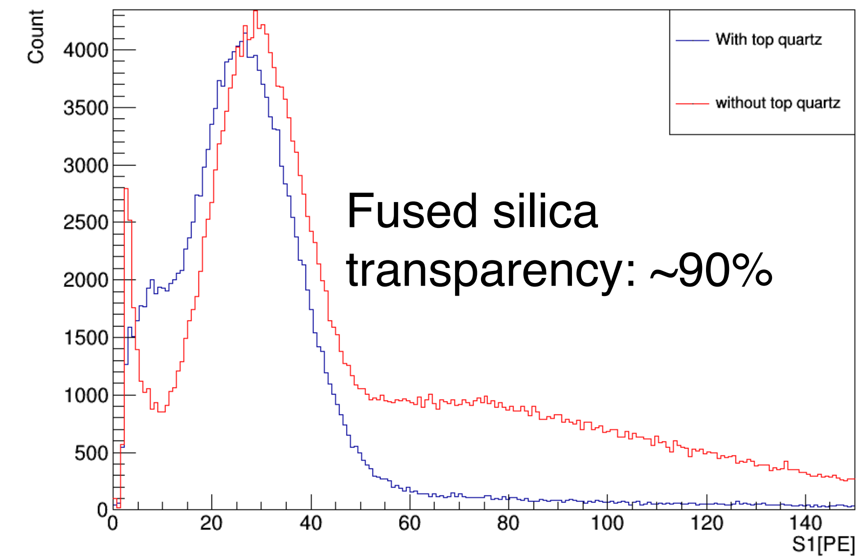
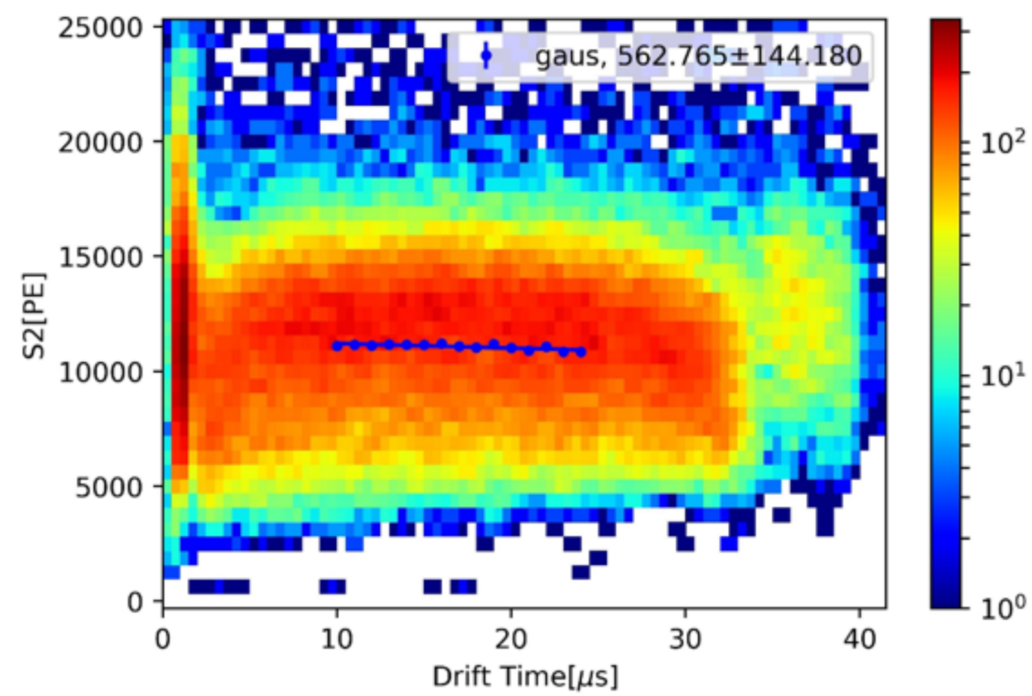
R&D at UCSD: *Sealed Chamber* to improve purification efficiency





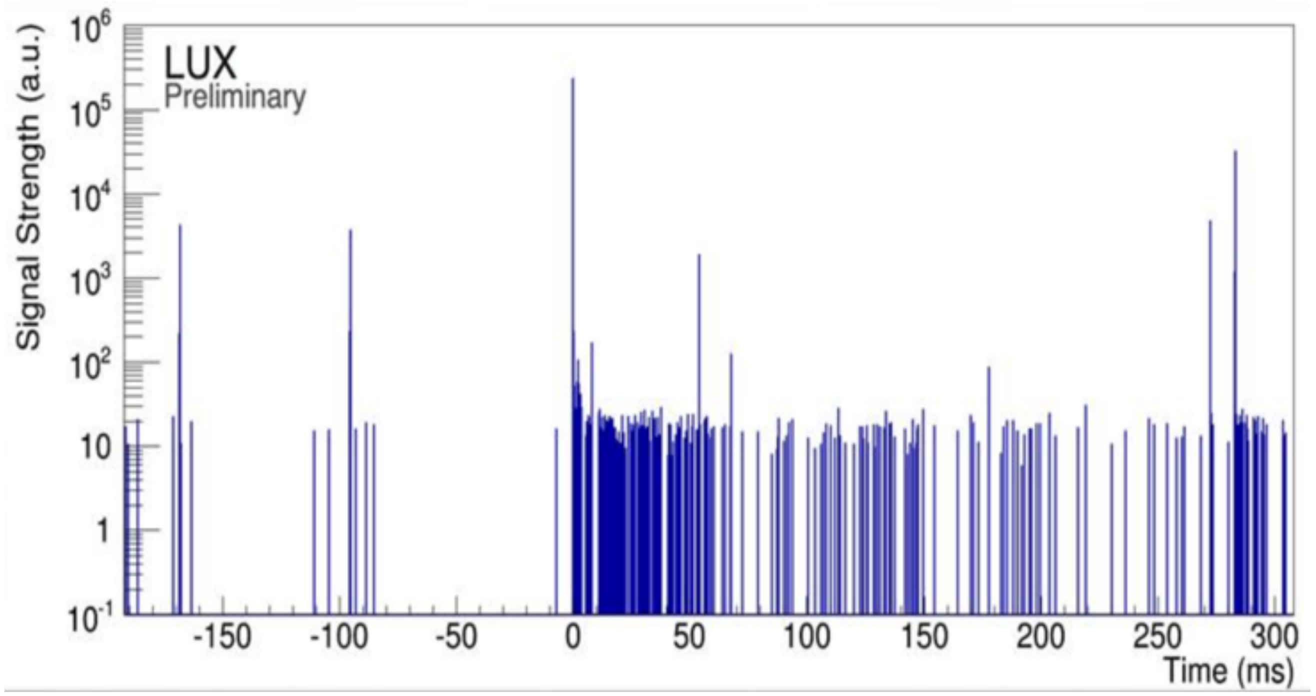


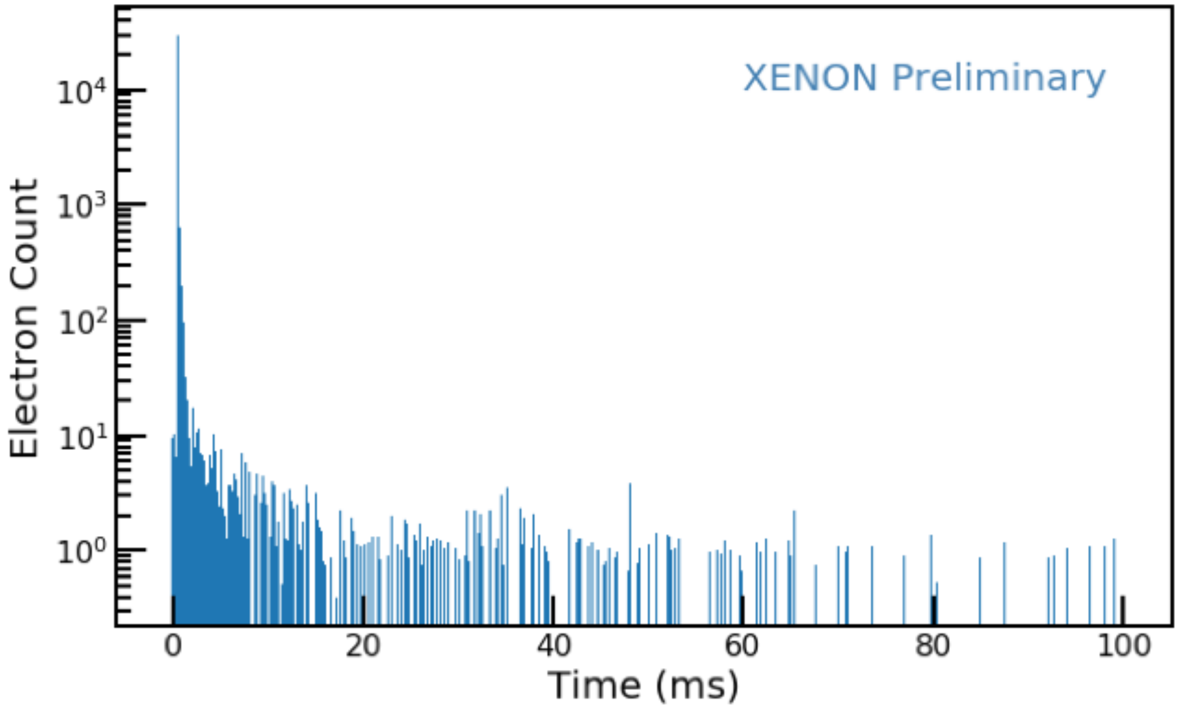




~0.5 ms electron lifetime achieved with <1 day of circulation at 5 SLPM

Delayed single and a few electrons background

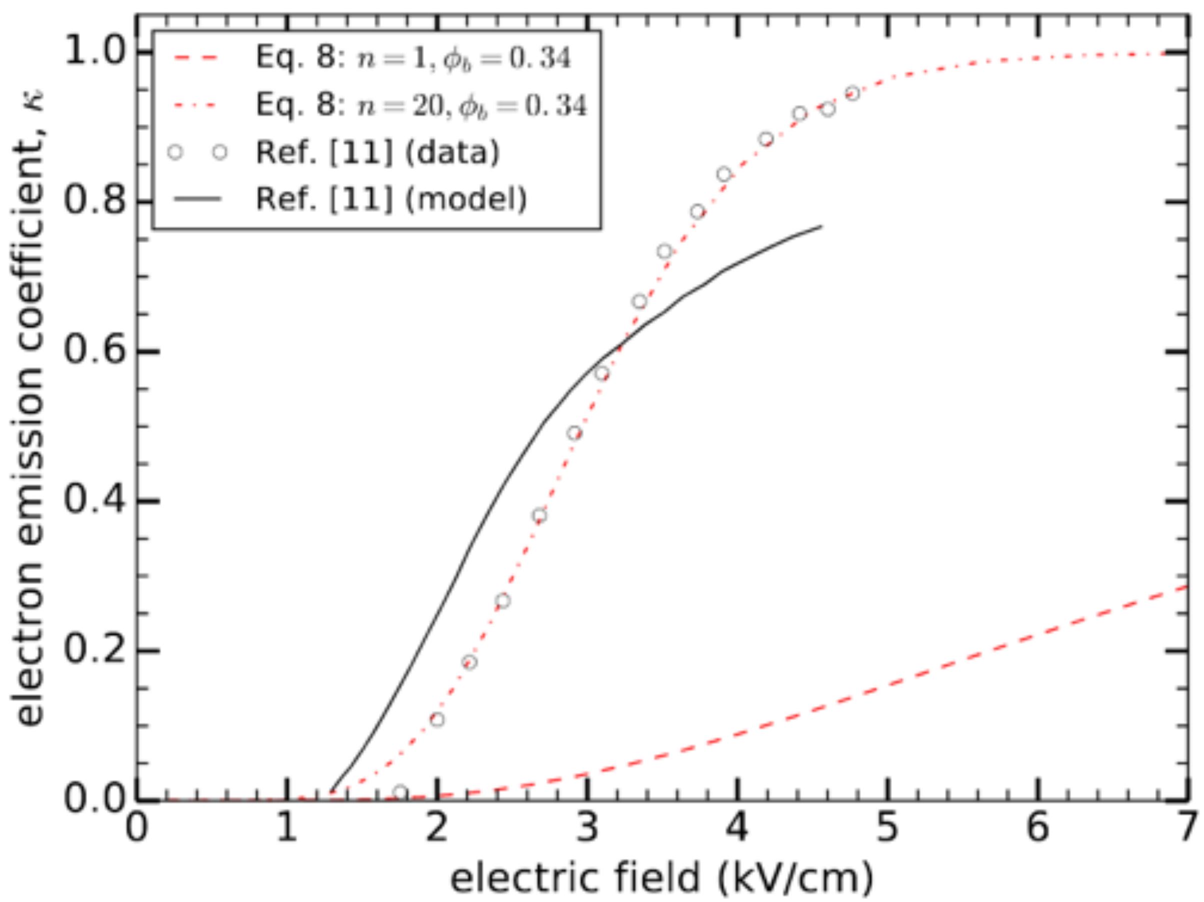




- Show up after several hundreds of milliseconds after an S2
- Drifting electrons trapped at the liquid-gas interface and extracted from time to time
- from RED-100 yesterday: see rate reduction with improved liquid purity!

Delayed extraction of electrons trapped at the liquid-gas interface

P. Sorensen, arXiv:1702.04805



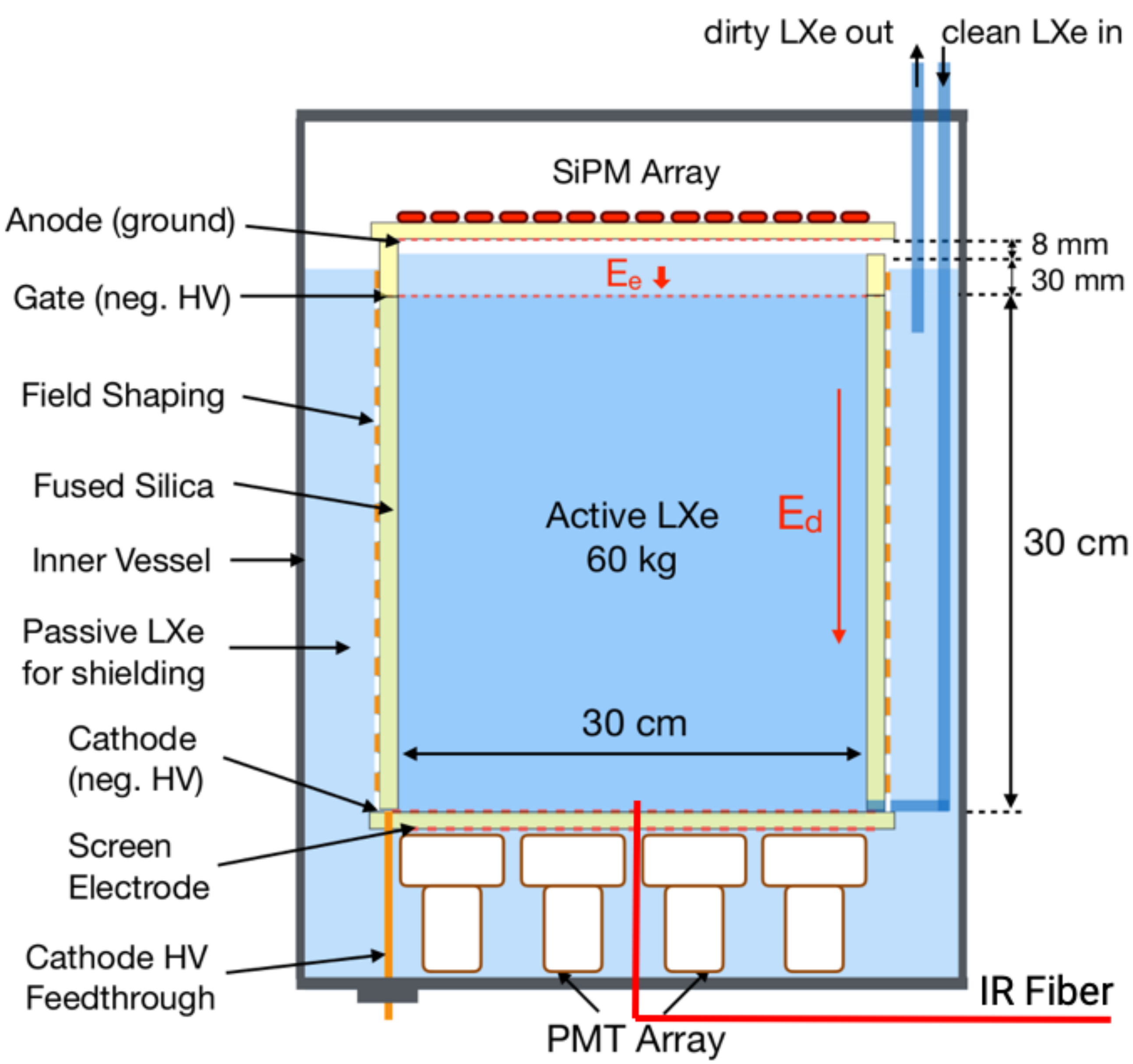
theoretical investigation

- the *Shottky barrier* model: an electron approaches a dielectric boundary held at a constant potential feels a force due to it's image charge (energy barrier)
- the *n-th chance* model: electron fails to escape the barrier at the initial attempt will continue to scatter
- The electron emission coefficient depends on the liquid emission field (approaching 100% at 7 kV/cm)

Techniques being developed at LLNL/Purdue to enhance electron extraction.

- **Apply strong emission field: at least 7 kV/cm in the liquid**
- **Implement a fast (~μs) high voltage switching: push the electrons back to the gate electrode**
- **Stimulate the electron emission using IR photons**

Development for the Low Background Electron Counting Apparatus (LBECA) for Light Dark Matter Search



- **100-kg LXe detector** with ~60 kg active target
- Two-phase operation with **S2 only** signals
- ***Sealed Chamber***:
  - Less outgassing (fused silica vs. Teflon)
  - External outgassing prevented entering easily into the target
  - Improve purification speed (clean LXe fed directly into the target)
- **Strong extraction field**:
  - 7~10 kV/cm (liquid)
  - Extra: HV switching
- IR light to **stimulate electron emission**
- SiPM Array on top: high XY position resolution
- Extra: alternative electrode material (graphene, gold or platinum coating, etc.)

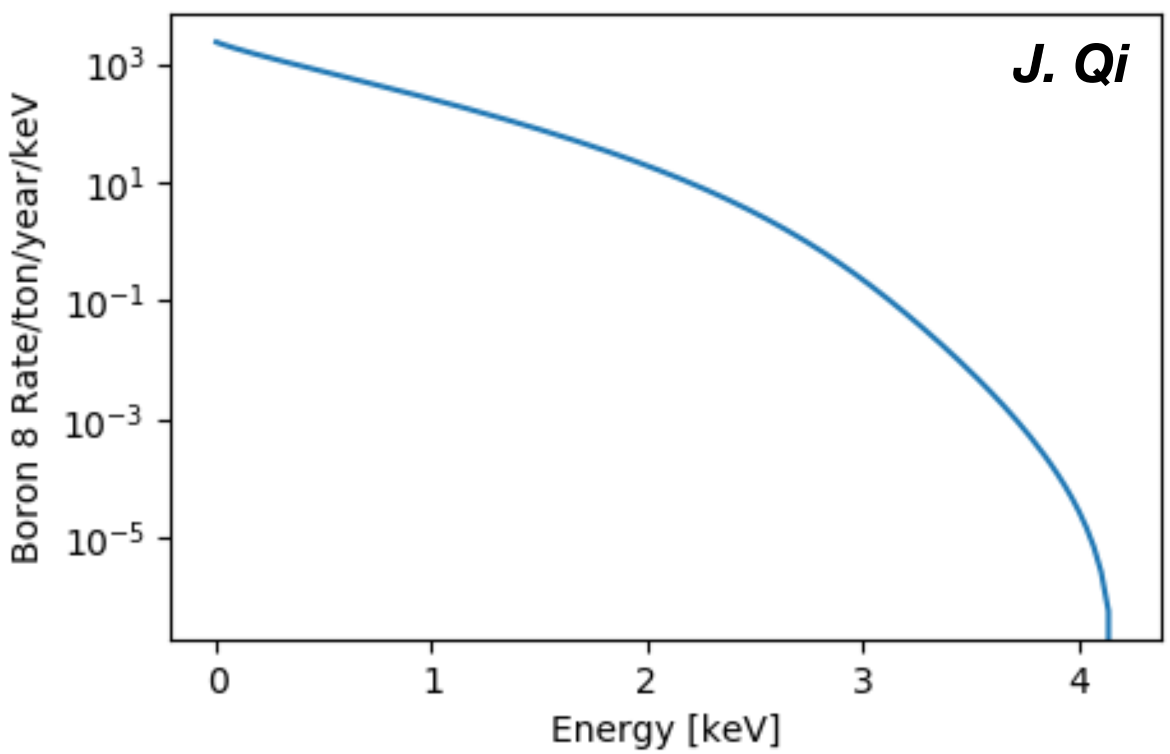
The same kind of *Sealed Chamber* design can be installed in XENON100 cryostat

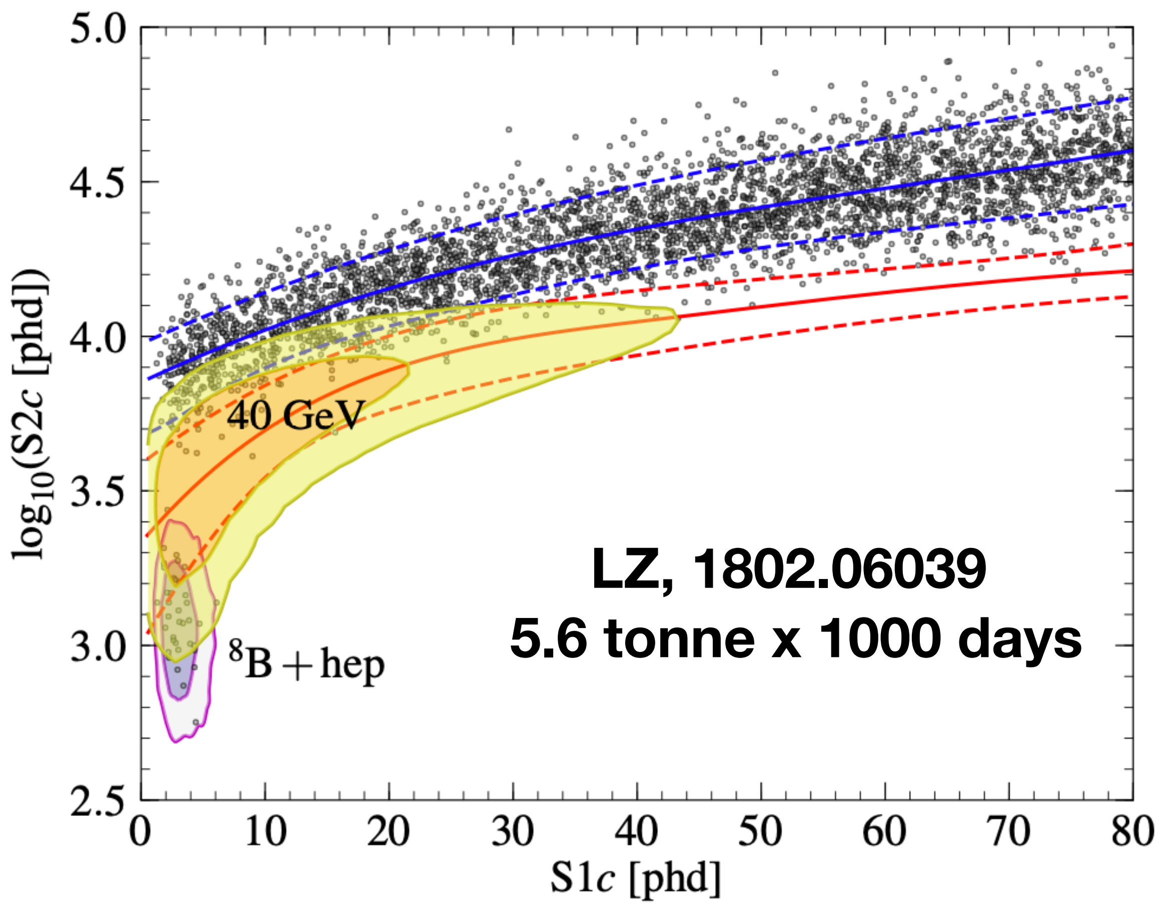
➡ reduce single/few electron background by 2 orders of magnitude

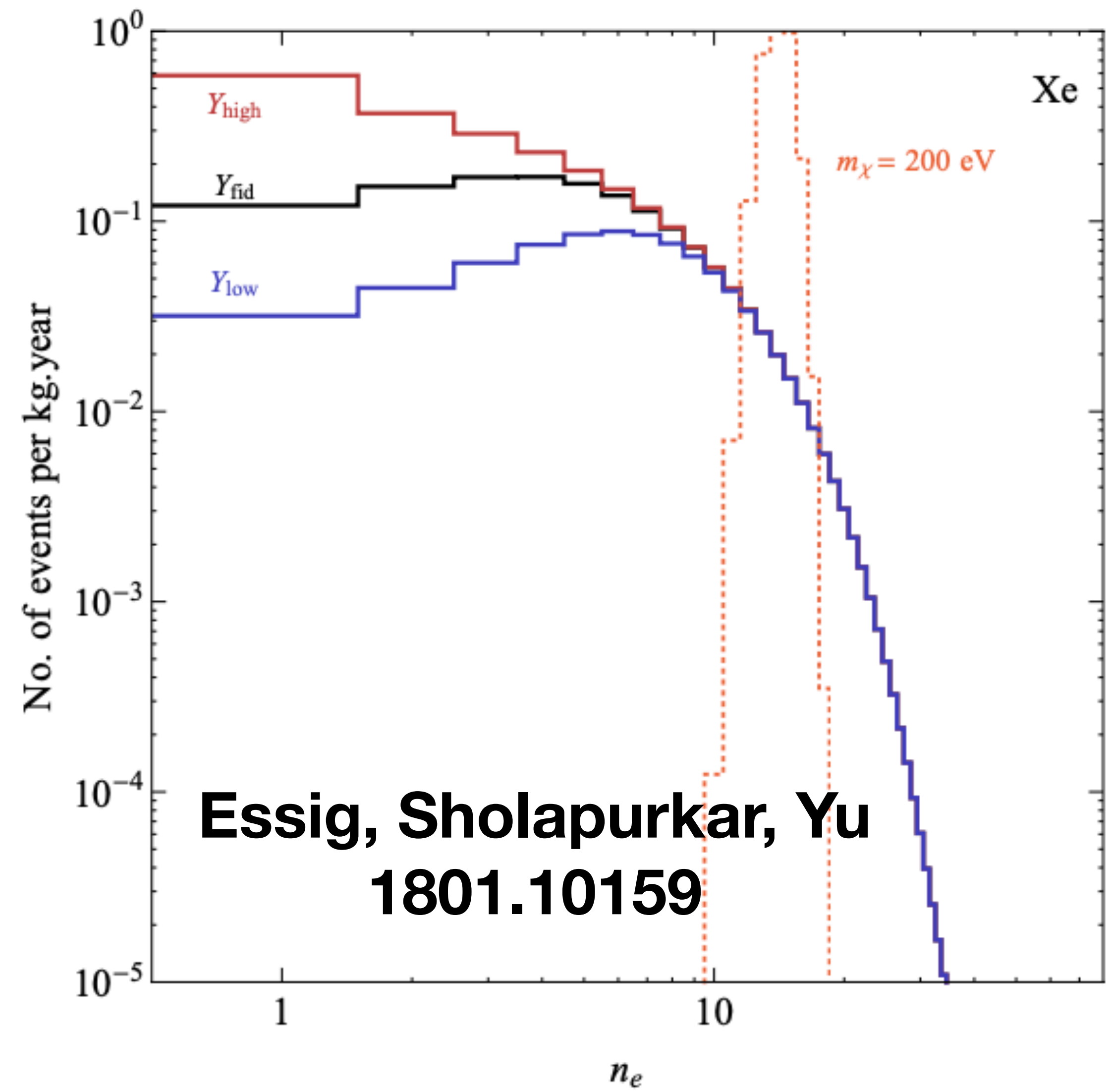
➡ sufficient for real-time monitoring reactor neutrinos through CEvNS

*How about detecting **Solar Neutrinos** CEvNS with **S2-only** in XENON100?*

CEvNS spectrum from ^{8}B solar neutrinos







It will be valuable to the DM experiments with the "known background" from solar neutrinos measured beforehand!

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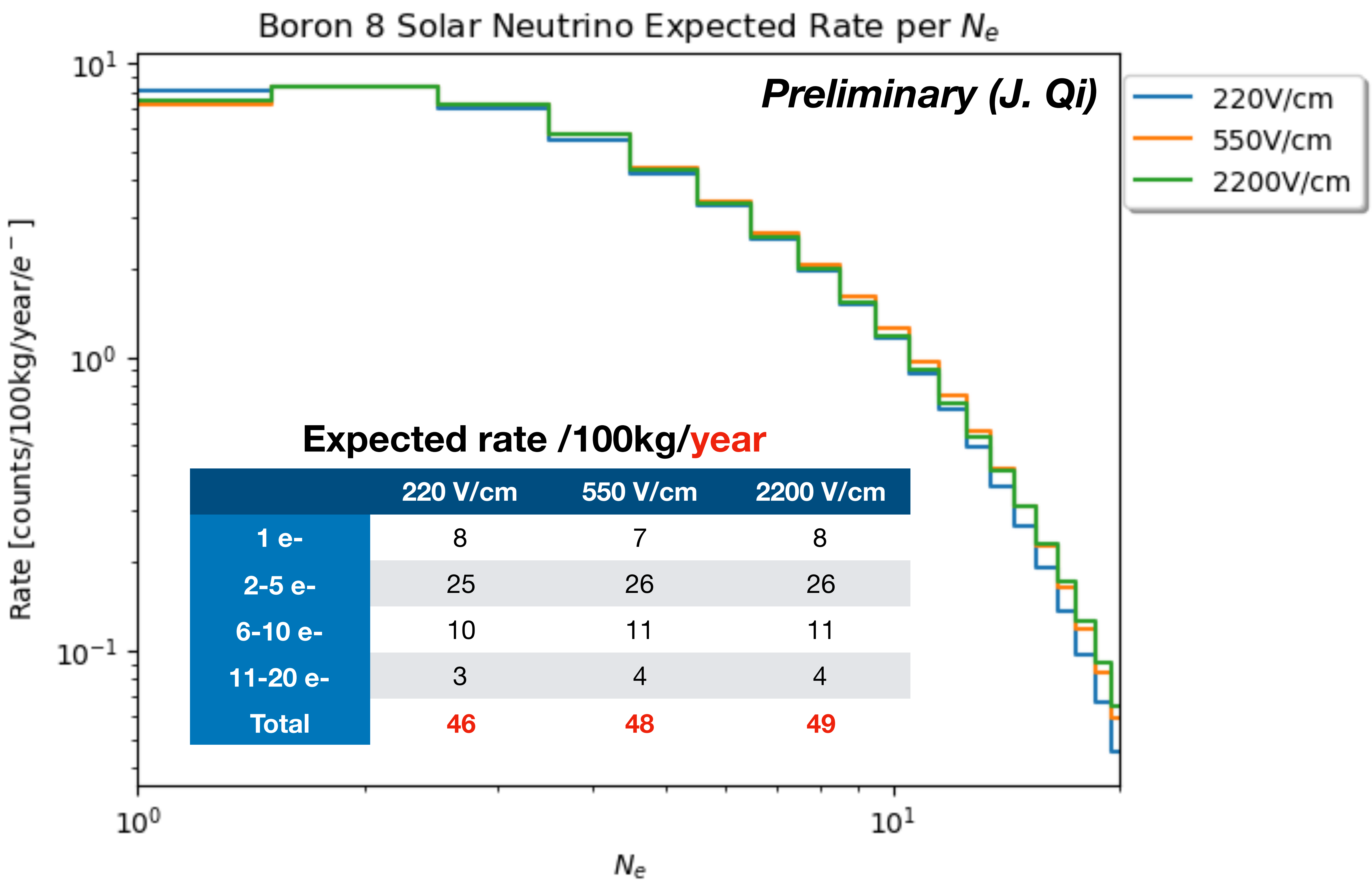
How about detecting Solar Neutrinos CEvNS with S2-only in XENON100?

using the latest charge yield measurement from Lenardo, Xu et al. (1908.00518)



Expected rate /100kg/year

	220 V/cm	550 V/cm	2200 V/cm
1 e-	8	7	8
2-5 e-	25	26	26
6-10 e-	10	11	11
11-20 e-	3	4	4
Total	46	48	49

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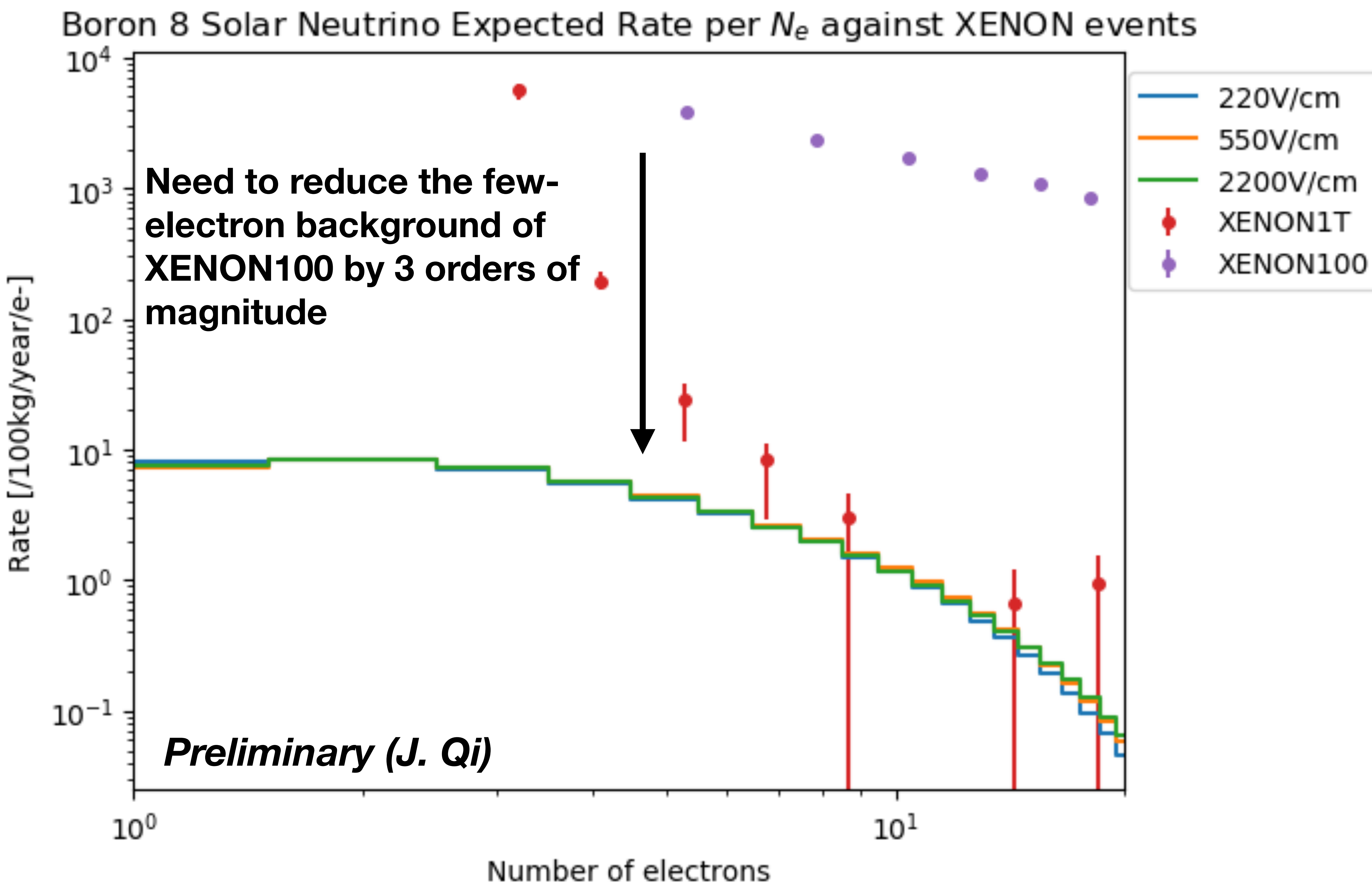
How about detecting Solar Neutrinos CEvNS with S2-only in XENON100?



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Summary

- XENON100, with a minimal modification of shield and cooling tower, can be relocated to SNS for a precise measurement of CEvNS with Xe
- Using S2-only signal and reduced few-electron background, a XENON100-like detector can do real-time monitoring of reactor antineutrinos through CEvNS
- Detecting CEvNS from solar neutrinos in the 100-kg liquid xenon detector is difficult, unless with further reduction of the few-electron background