Enlightening the dark with XENON1T and looking forward to XENONnT

CNNP 2020, 24th February 2020, Cape Town

Christian Wittweg on behalf of the XENON collaboration
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The XENON collaboration

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~ 160 scientists

27 institutes

11 countries

Columbia, RPI, Nikhef, Muenster, KIT, Stockholm, Mainz, MPIK, Heidelberg, Freiburg

Chicago, UCSD, Rice, Purdue, Coimbra

Zurich, Tokyo, Nagoya, Kobe

Subatech, LPNHE, LAL, Bologna, LNGS, Torino, Napoli, Weizmann, NYUAD

Follow the XENONnT commissioning

@XENONexperiment

The XENON Dark Matter Project

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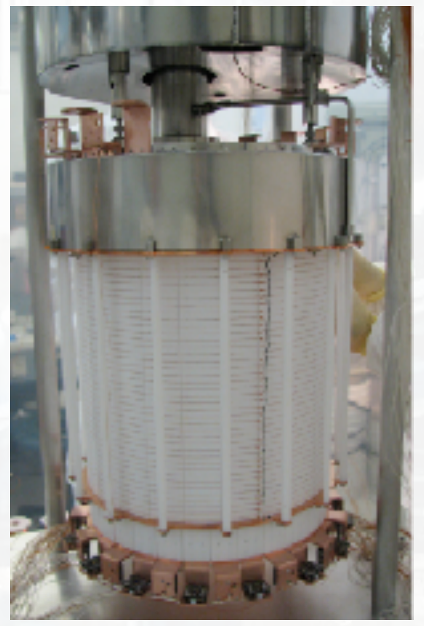
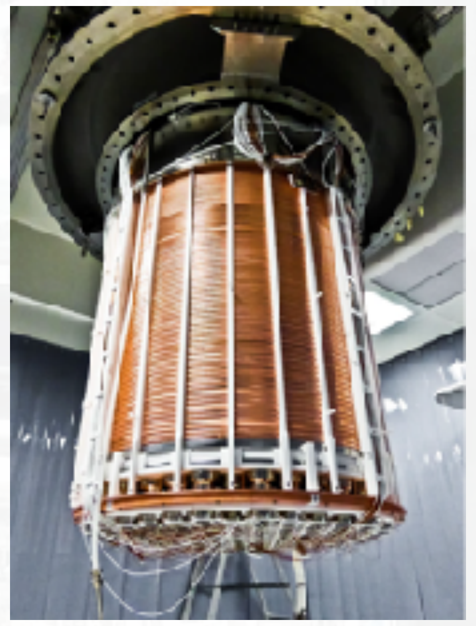
15 kg	161 kg	3.2 t	8.4 t	50 t
XENON10	XENON100	XENON1T	XENONnT	DARWIN

2005 2007 2009 2016 2019 2023 2025





2 pixels

20 t · yr

200 t · yr

	XENON10	XENON100	XENON1T
Exposure	0.87 kg · yr	48 kg · yr	1 t · yr
BG index	~ 1	~ 5 · 10^{-3}	~ 2 · 10^{-4}

XENON1T

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1500 m overburden
(3600 m.w.e.)

TPC

Water Cherenkov
muon veto

LNGS hall B

700 t
pure water

84
8“ PMTs

Cryostat

Google street view: tinyurl.com/lngstour

The XENON1T time projection chamber

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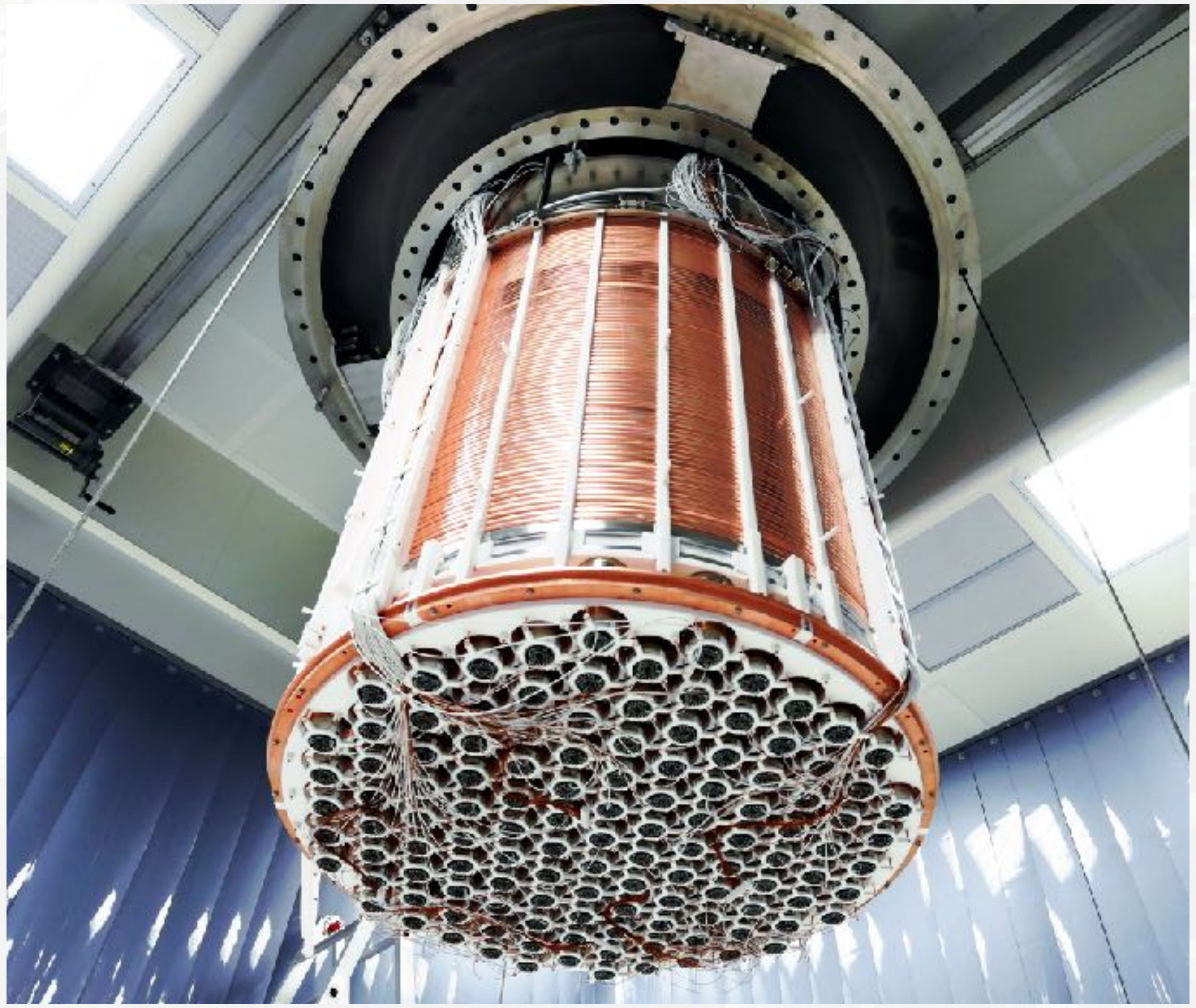
2 t LXe in active volume

~ 1 m diameter
~ 1 m length

Highly reflective
PTFE walls

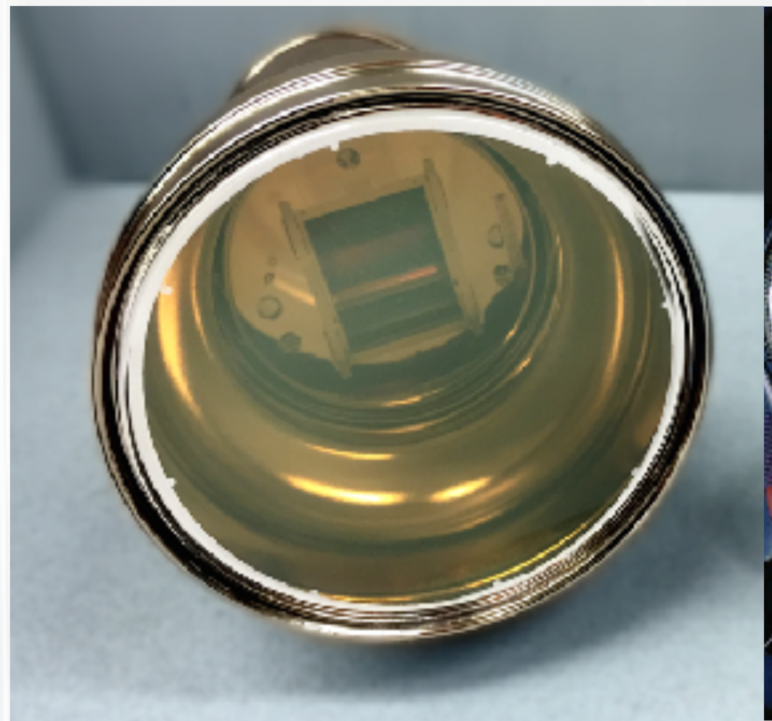
74 copper field shaping
rings

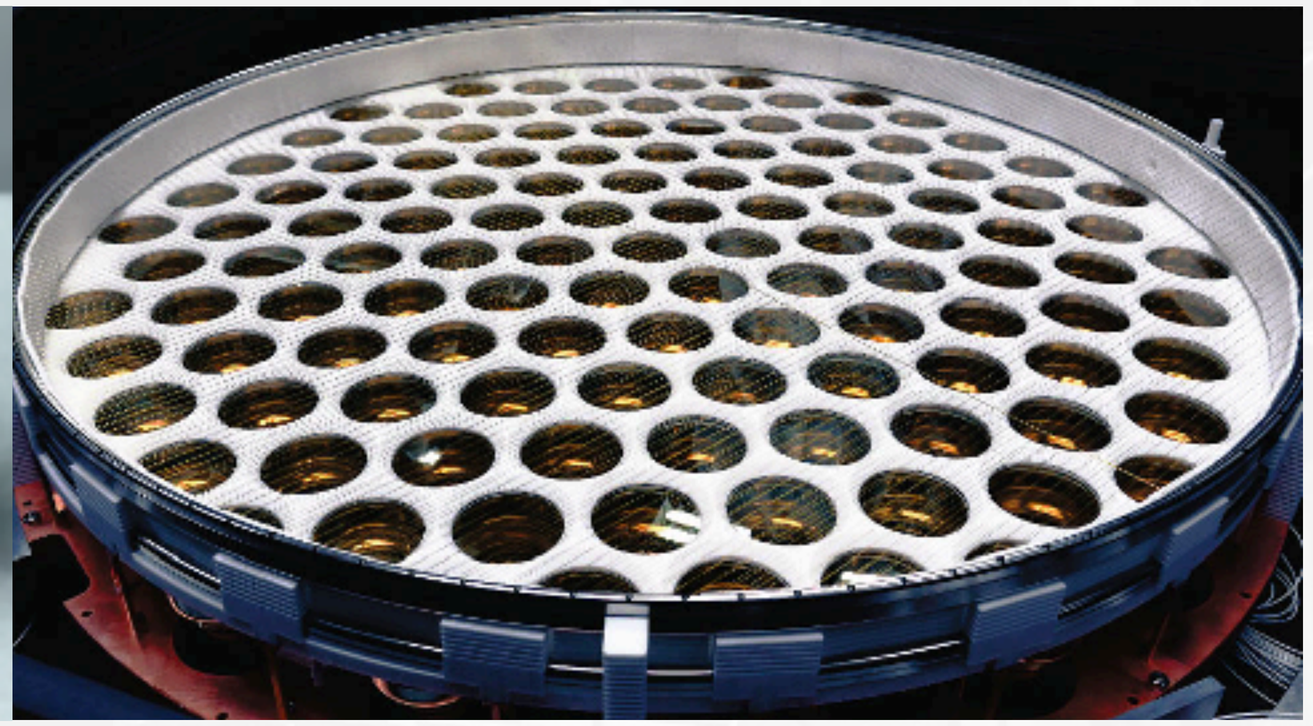
Five high-transparency
electrodes



238 Hamamatsu R11410-21 PMTs

3“ PMTs, low radioactivity, QE ~ 35 % at 175 nm





EPJ C 11:546 (2015)

Dual-phase TPC measuring principle

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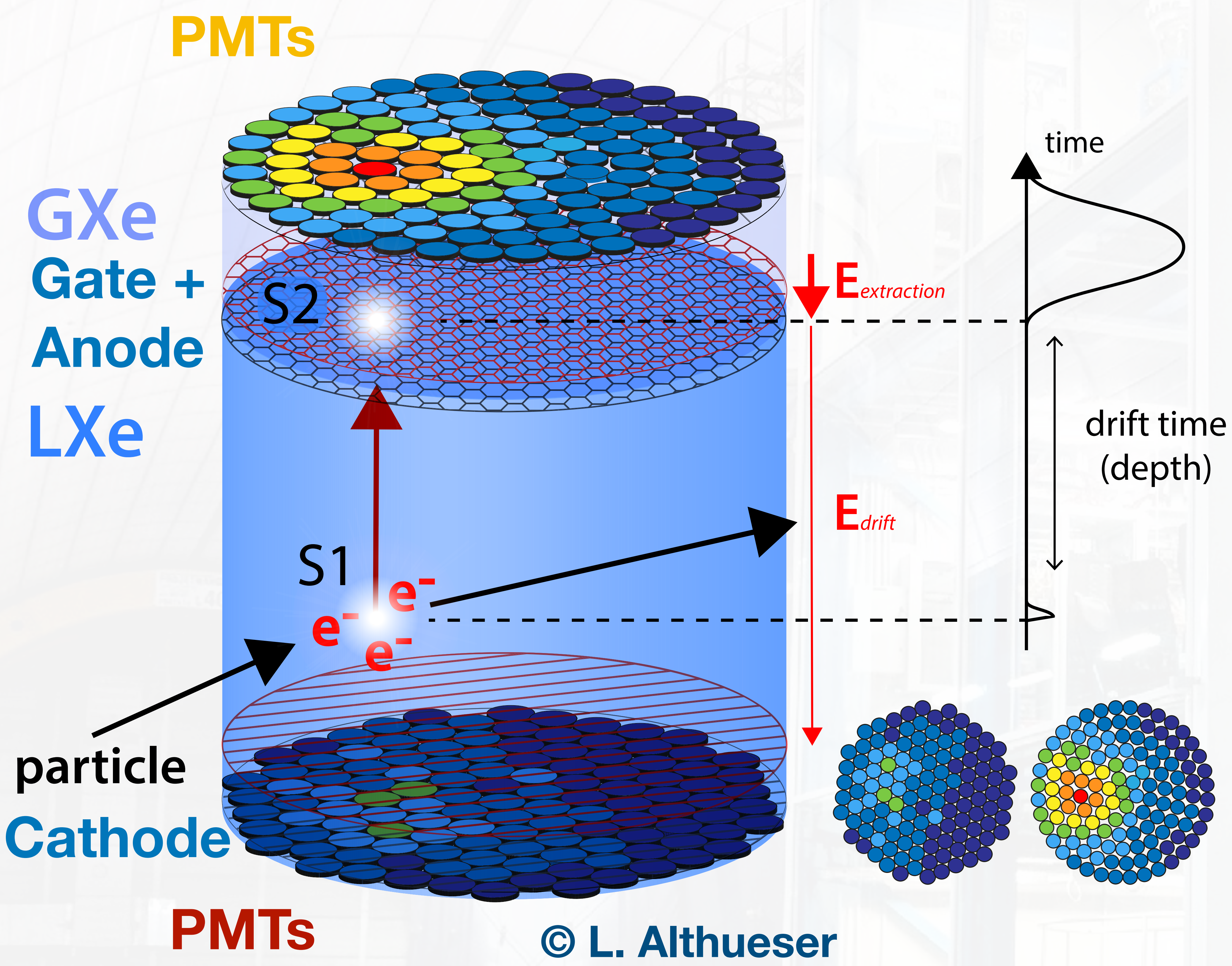
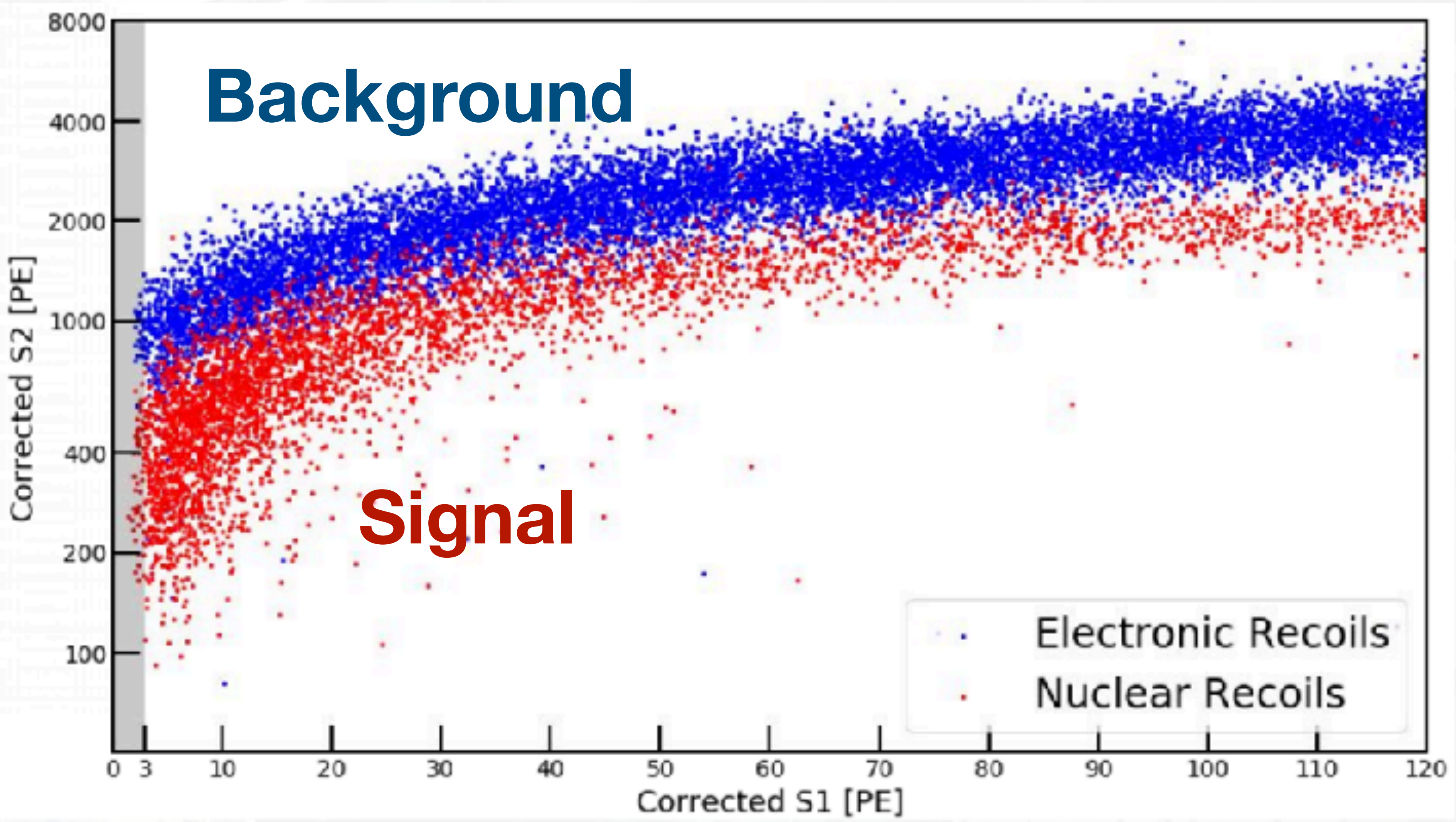
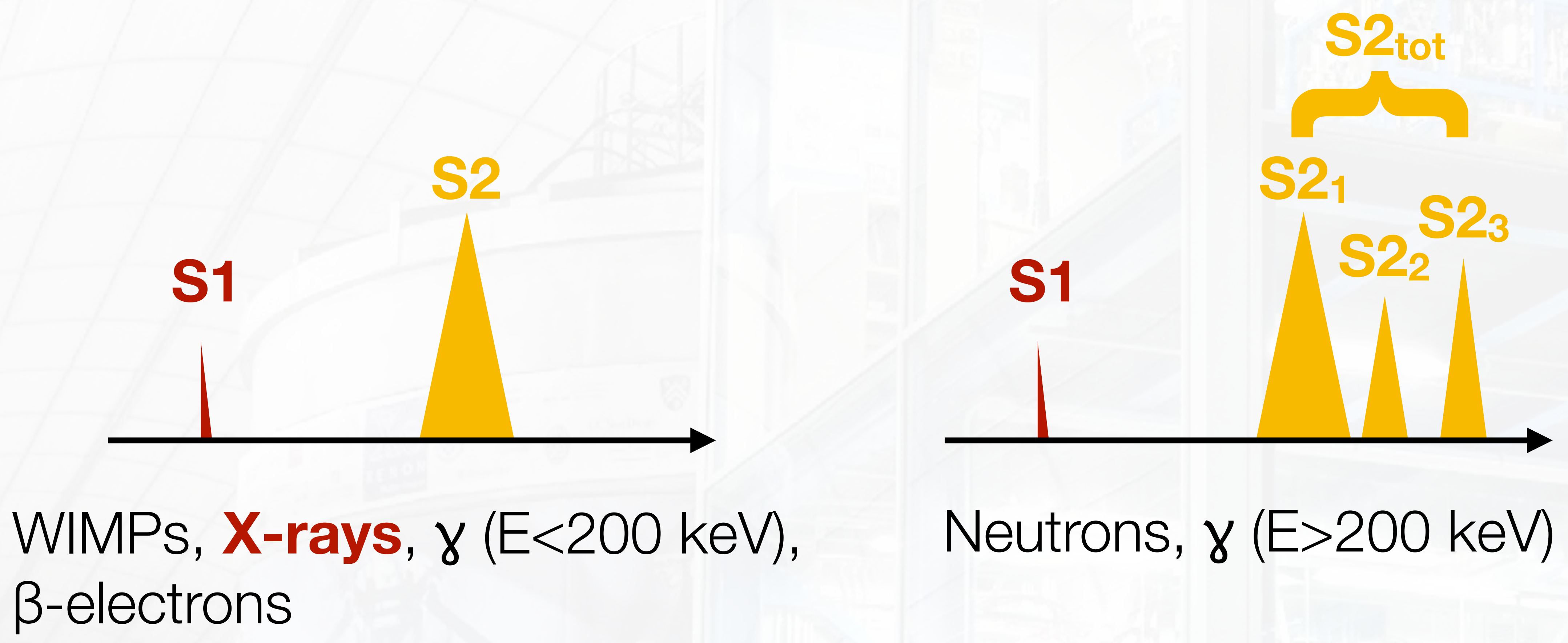


Scintillation and ionization

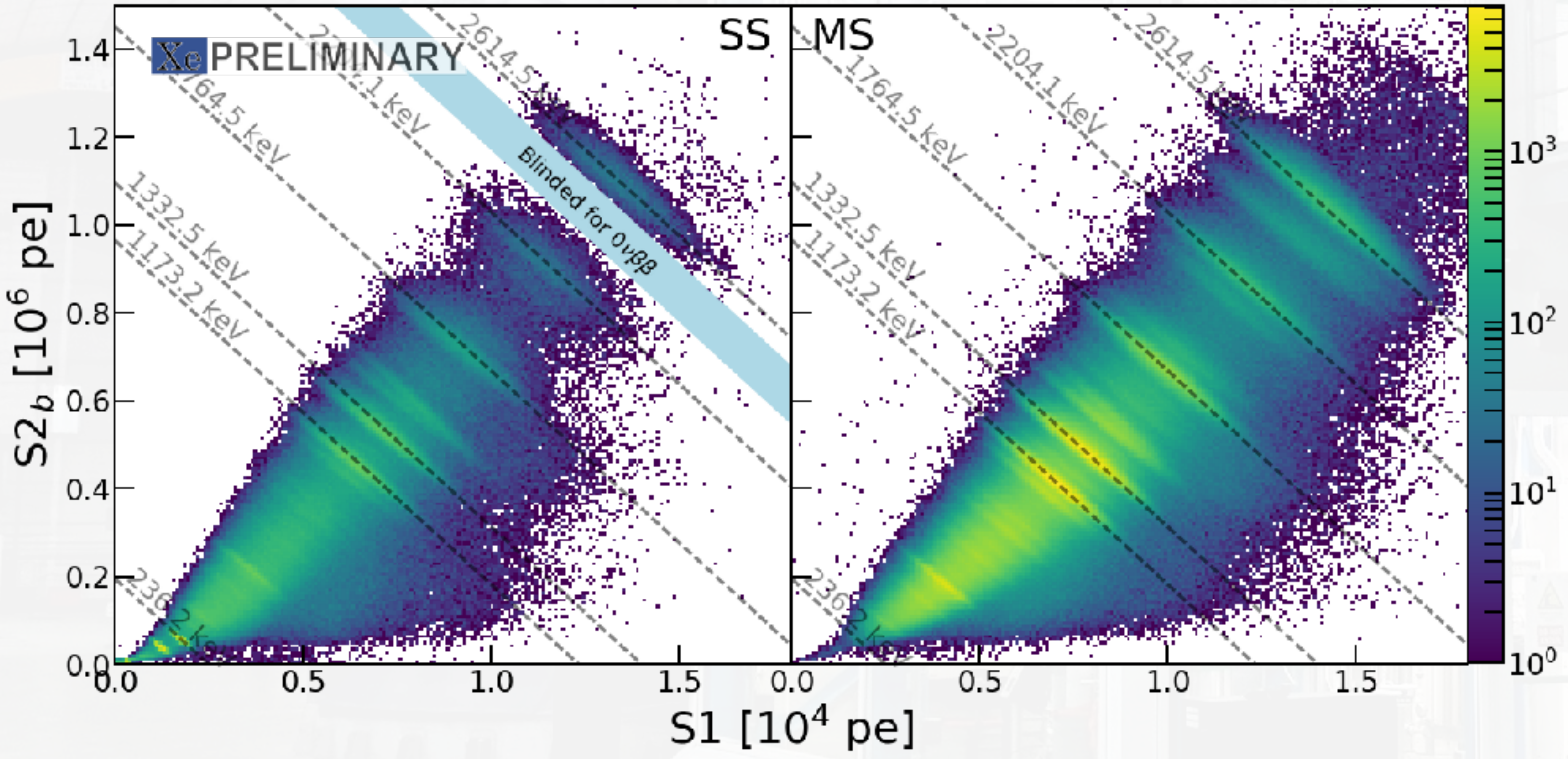
- Prompt light signal (**S1**)
- Secondary light in GXe from drifted charges (**S2**)
  - **Energy** from **S1**-**S2**-magnitude
  - **x-y** from **S2** hit pattern
  - **z** from **S1**-**S2**-delay
  - **ER/NR discrimination** from **S1**-**S2** ratio



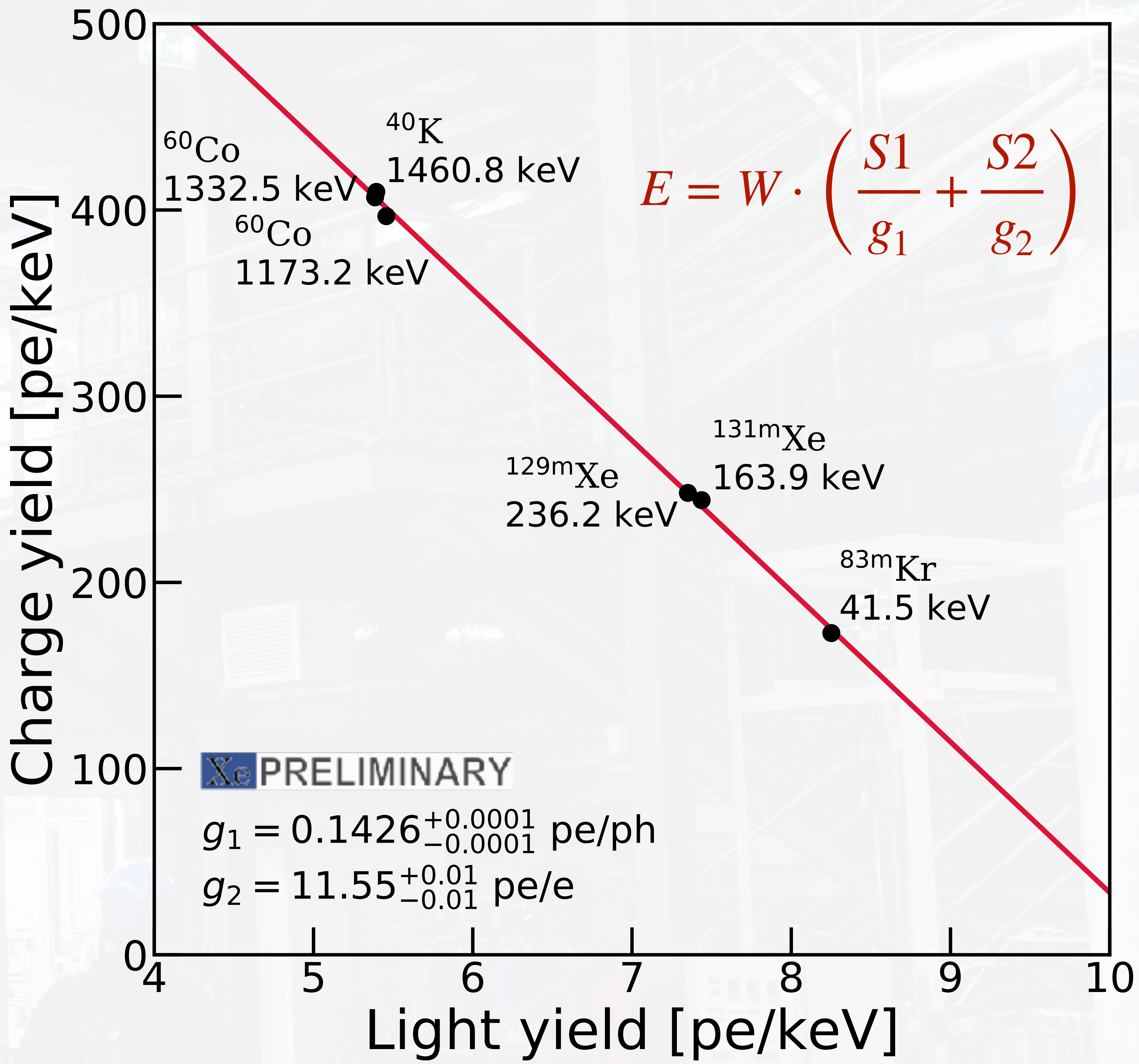
See Elena Aprile's talk on Tuesday 11:30 for a xenon TPC overview!



S1
S2
WIMPs, **X-rays**, ɣ (E<200 keV), β-electrons
S1
S2tot
S2₁
S2₂
S2₃
Neutrons, ɣ (E>200 keV)



PRELIMINARY
SS
MS
Blinded for 0νββ
1764.5 keV
2204.1 keV
2614.5 keV
1332.5 keV
1173.2 keV
236.2 keV
S2_b [10^6 pe]
S1 [10^4 pe]



Charge yield [pe/keV]
Light yield [pe/keV]
60Co 1332.5 keV
40K 1460.8 keV
60Co 1173.2 keV
131mXe 163.9 keV
129mXe 236.2 keV
83mKr 41.5 keV
$E = W \cdot \left(\frac{S1}{g_1} + \frac{S2}{g_2}\right)$
PRELIMINARY
$g_1 = 0.1426^{+0.0001}_{-0.0001}$ pe/ph
$g_2 = 11.55^{+0.01}_{-0.01}$ pe/e

Spin-independent WIMP search results

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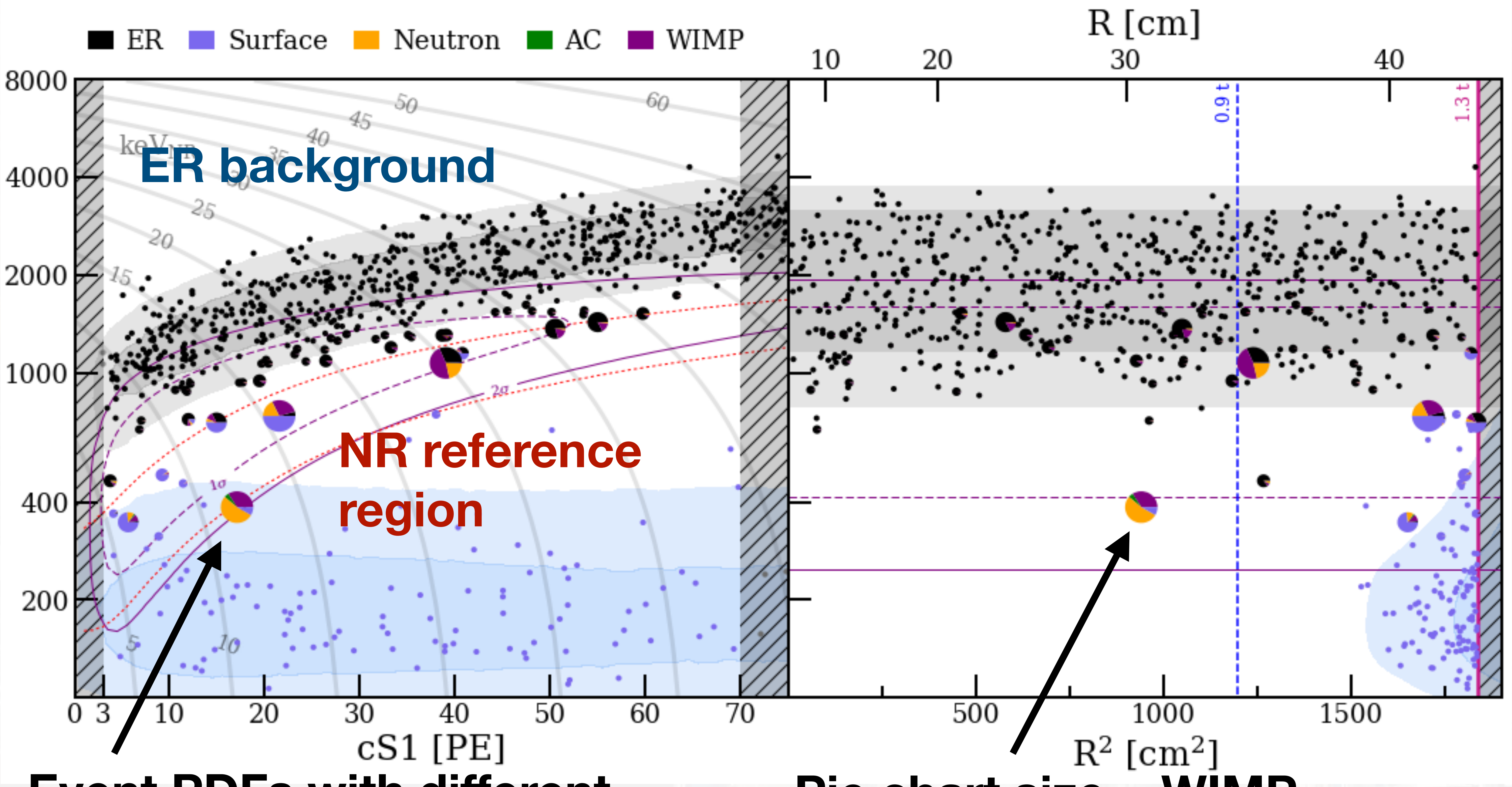
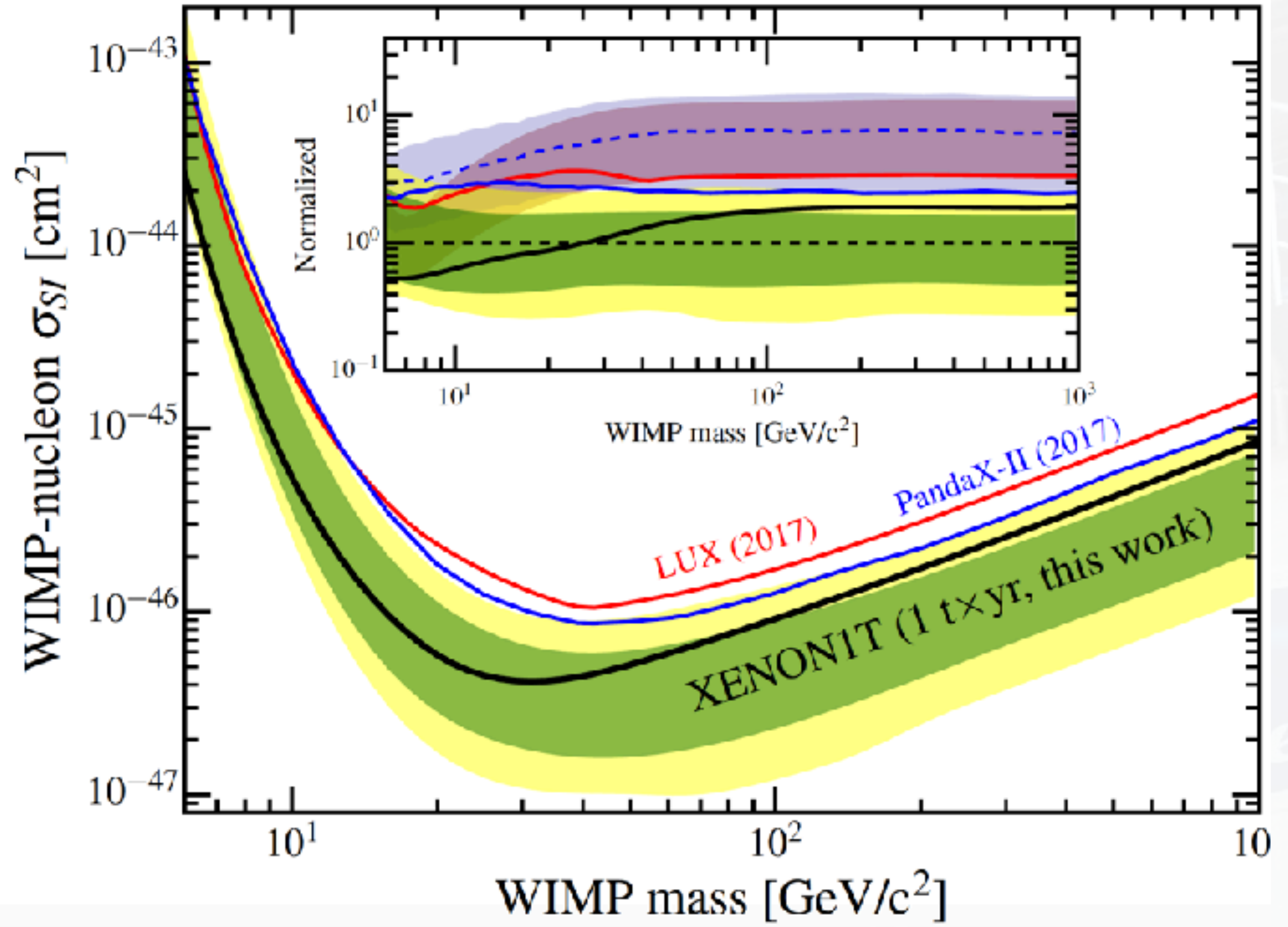
Analysis

- 4-dimensional profile likelihood
- 3 continuous (cS1, cS2bottom, R) and one discreet (inner, outer)



Event PDFs with different relative signal contributions

Pie chart size ~ WIMP probability



Sensitivity and Limit

- Strongest exclusion limits for WIMPs above 6 GeV
- Factor 7 sensitivity improvement w.r.t. previous generation owed to lowest ever BG rate
- $\sigma_{SI} < 4.1 \times 10^{-47}$ cm^2 at 30 GeV

Phys. Rev. Lett. 121, 111302 (2018)

Going beyond standard WIMP analysis

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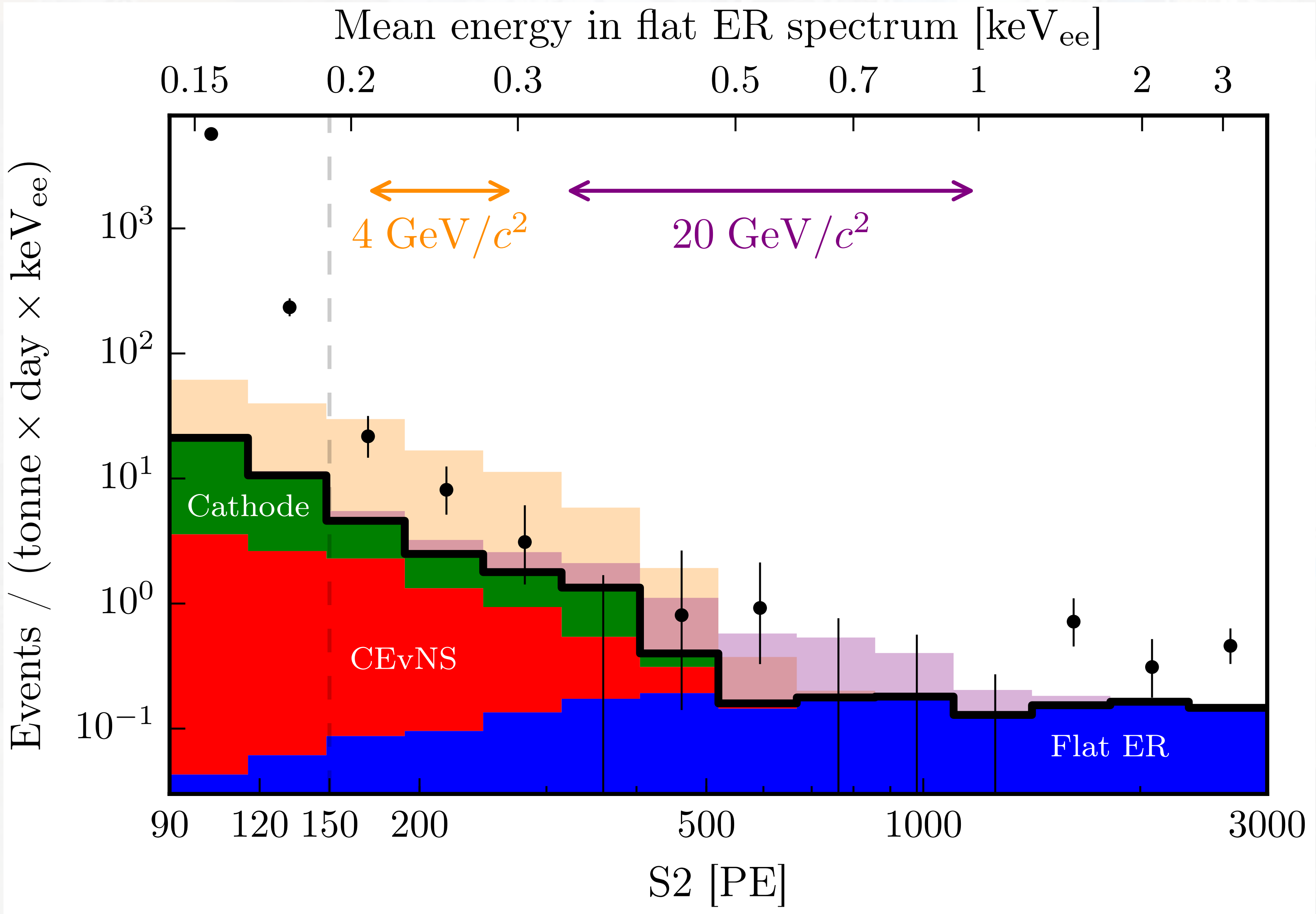
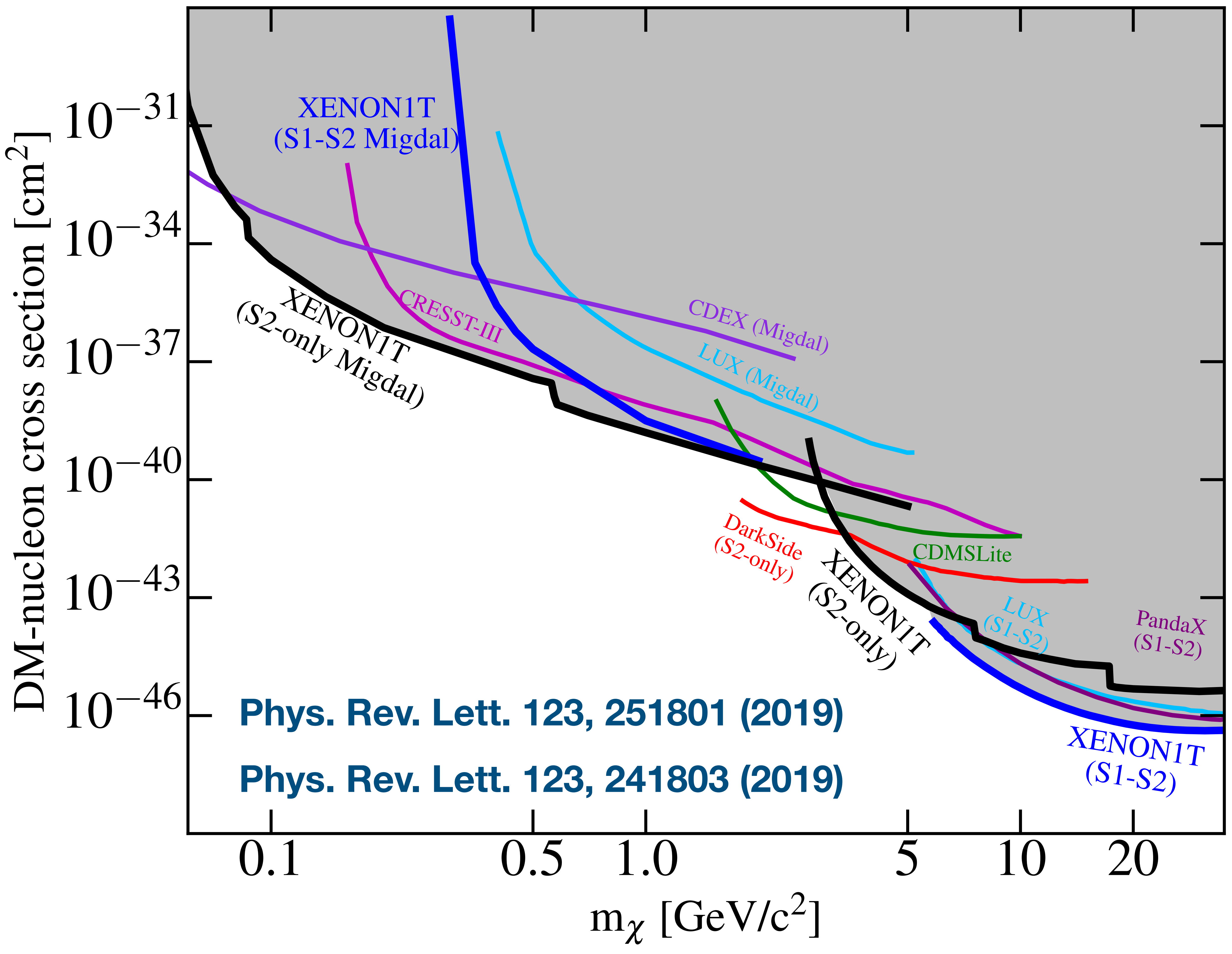
Different interactions

- Spin-dependent WIMP scattering
- WIMP-Pion scattering
- Migdal effect

Lower threshold

- Ionization-only (S2) analysis (limit)





Phys. Rev. Lett. 123, 251801 (2019)

Phys. Rev. Lett. 123, 241803 (2019)

There is more one can do with a dual-phase xenon TPC:

- Axions, ALPs, bosonic Dark Matter
- Neutrinoless double-β decay of ^{136}Xe
- Inelastic WIMP nucleus scattering
- Annual signal modulation
- Double-electron capture of ^{124}Xe

More to come in the future…

Two-neutrino double electron capture in ^{124}Xe

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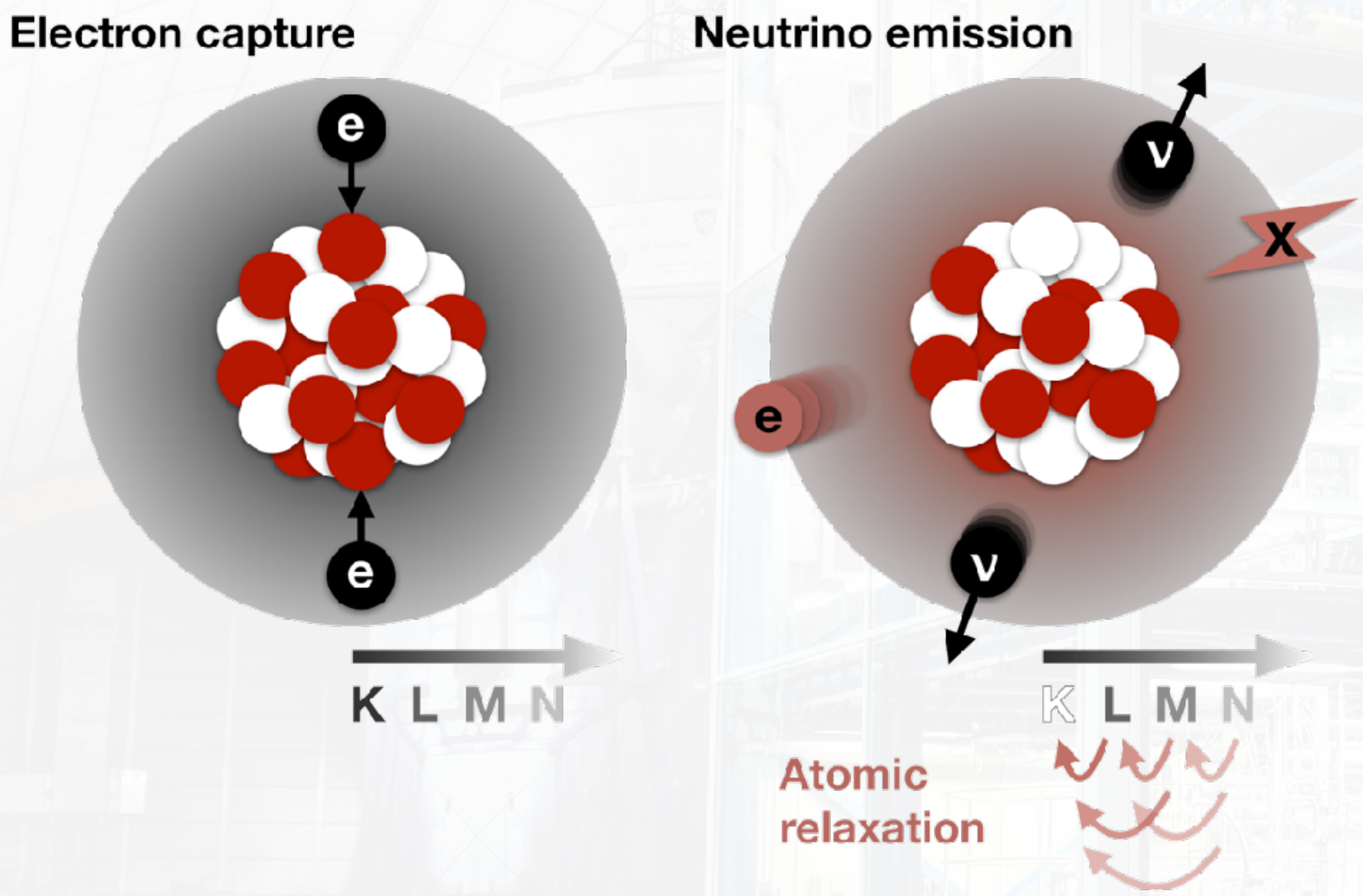

$$^{124}\mathrm{Xe} + 2e^- \rightarrow {}^{124}\mathrm{Te} + 2\nu_e$$

- Nucleus captures two electrons, most likely K-shell
- Recoil of nucleus O(10 eV) negligible
- Neutrinos leave detector
- Observe X-rays and Auger electrons

$Q_{2\nu ECEC}$ = 2857 keV

$E_{2\nu KK}$ = 64.3 keV

Fit results after unblinding

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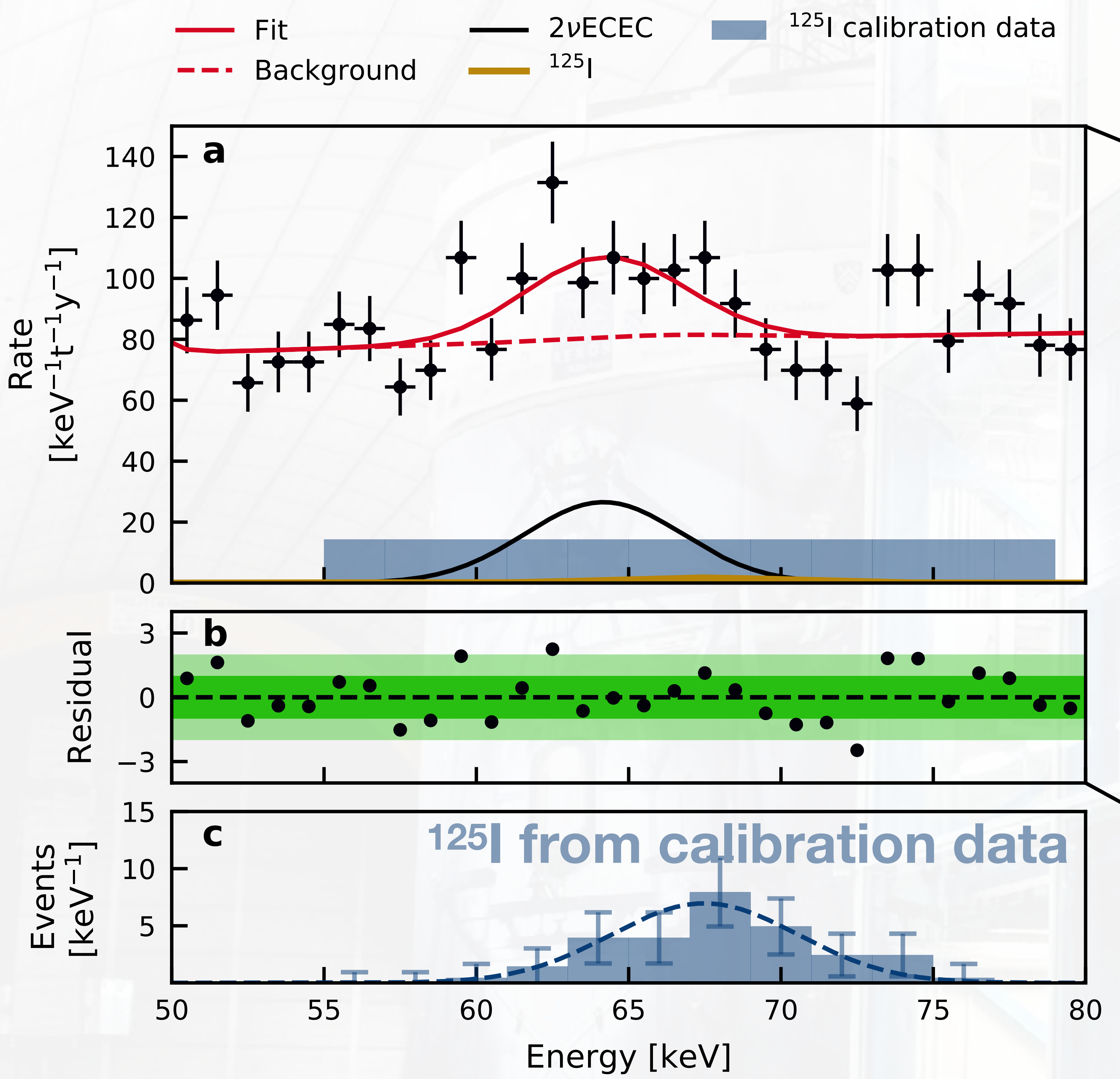
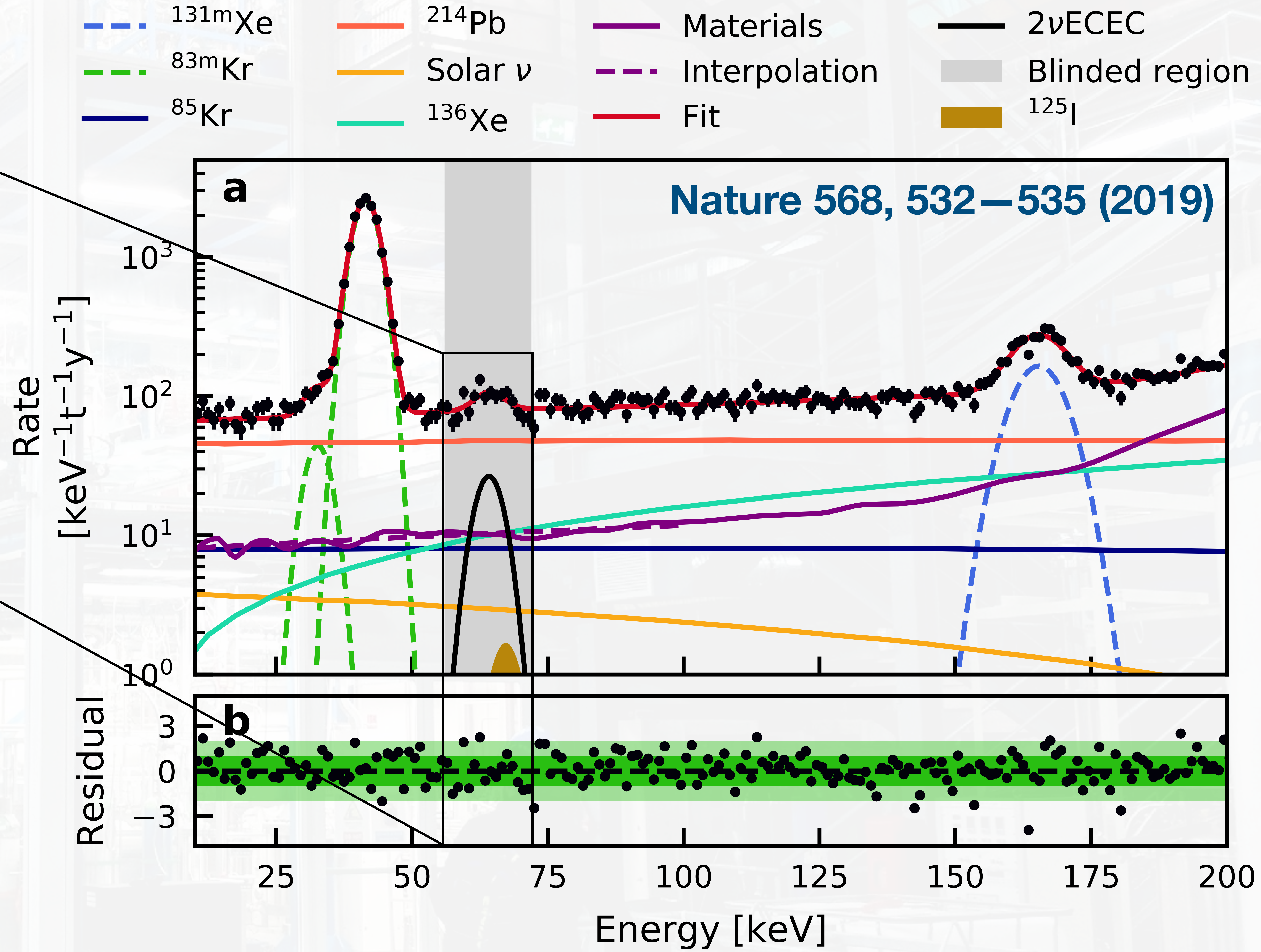


$N_{2\nu ECEC}$ = 126 events

$N_{I\text{-}125}$ = 9 events



Half-life and signal significance

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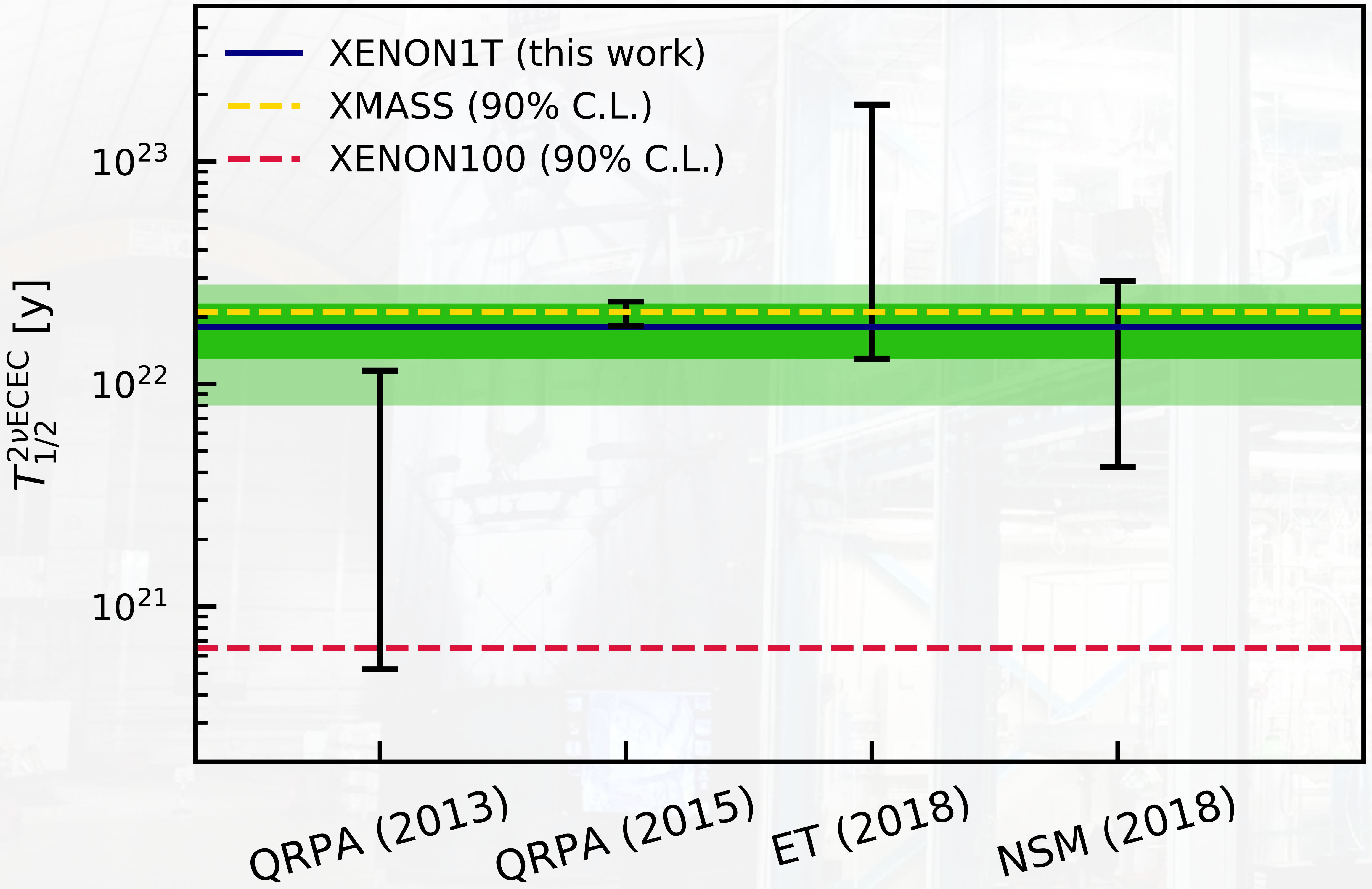
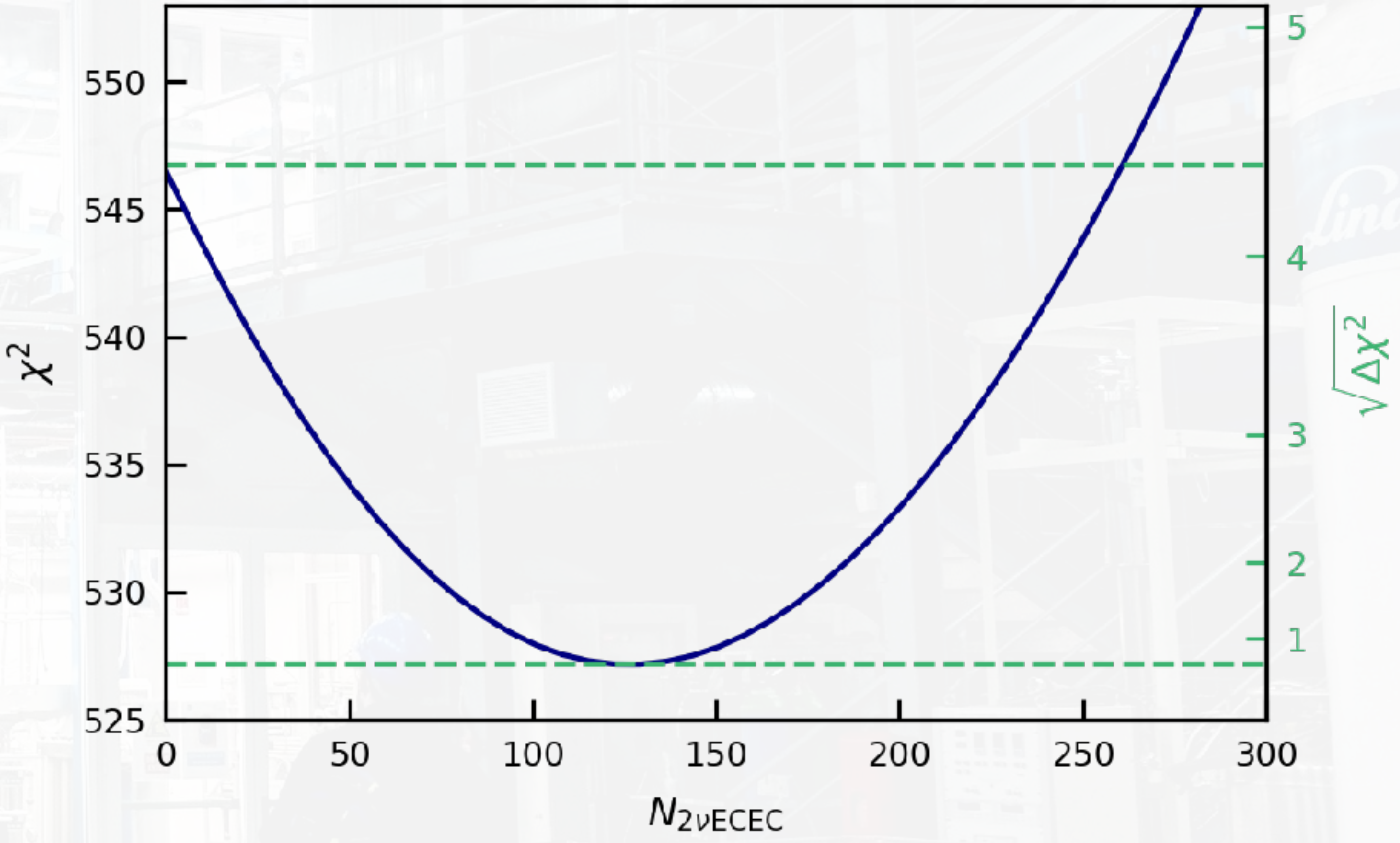
- Exclude null-hypothesis at **4.4σ**
- Benchmark for NMEs and compatible with XMASS

$$T_{1/2}^{2\nu\mathrm{ECEC}} = (1.8 \pm 0.5_{\mathrm{stat}} \pm 0.1_{\mathrm{sys}}) \times 10^{22}\ \mathrm{yr}$$





Nature 568, 532—535 (2019)

Up next: More second order decays of ^{124}Xe

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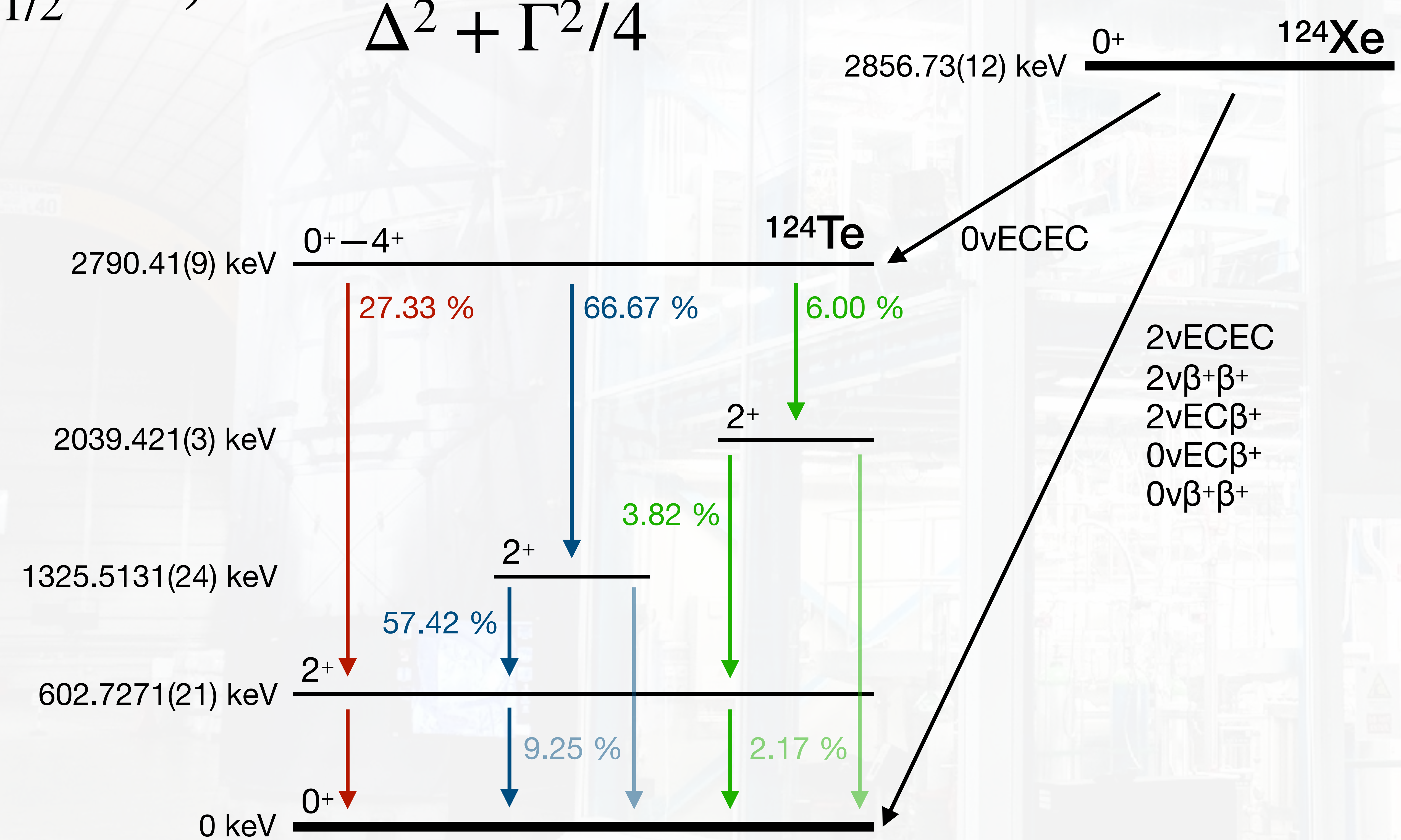
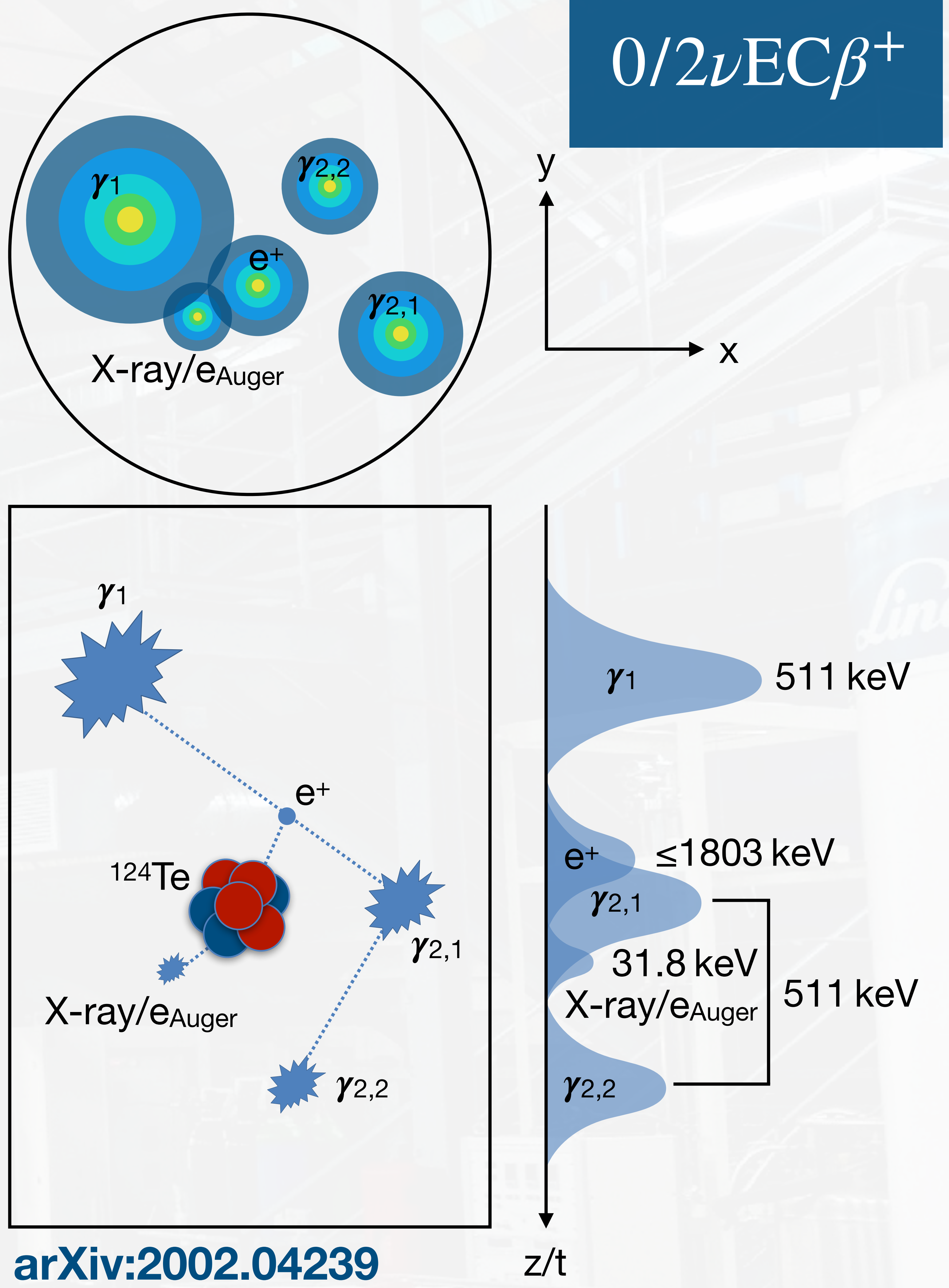
- Q-value **2758 keV** allows $EC\beta^+$, $\beta^+\beta^+$
- Resonant (?) 0vECEC

$$(T_{1/2}^{0\nu ECEC})^{-1} \propto \frac{m_e c^2 \Gamma}{\Delta^2 + \Gamma^2/4}$$



$0/2\nu EC\beta^+$



arXiv:2002.04239

Going to higher energy for ^{136}Xe 0νββ

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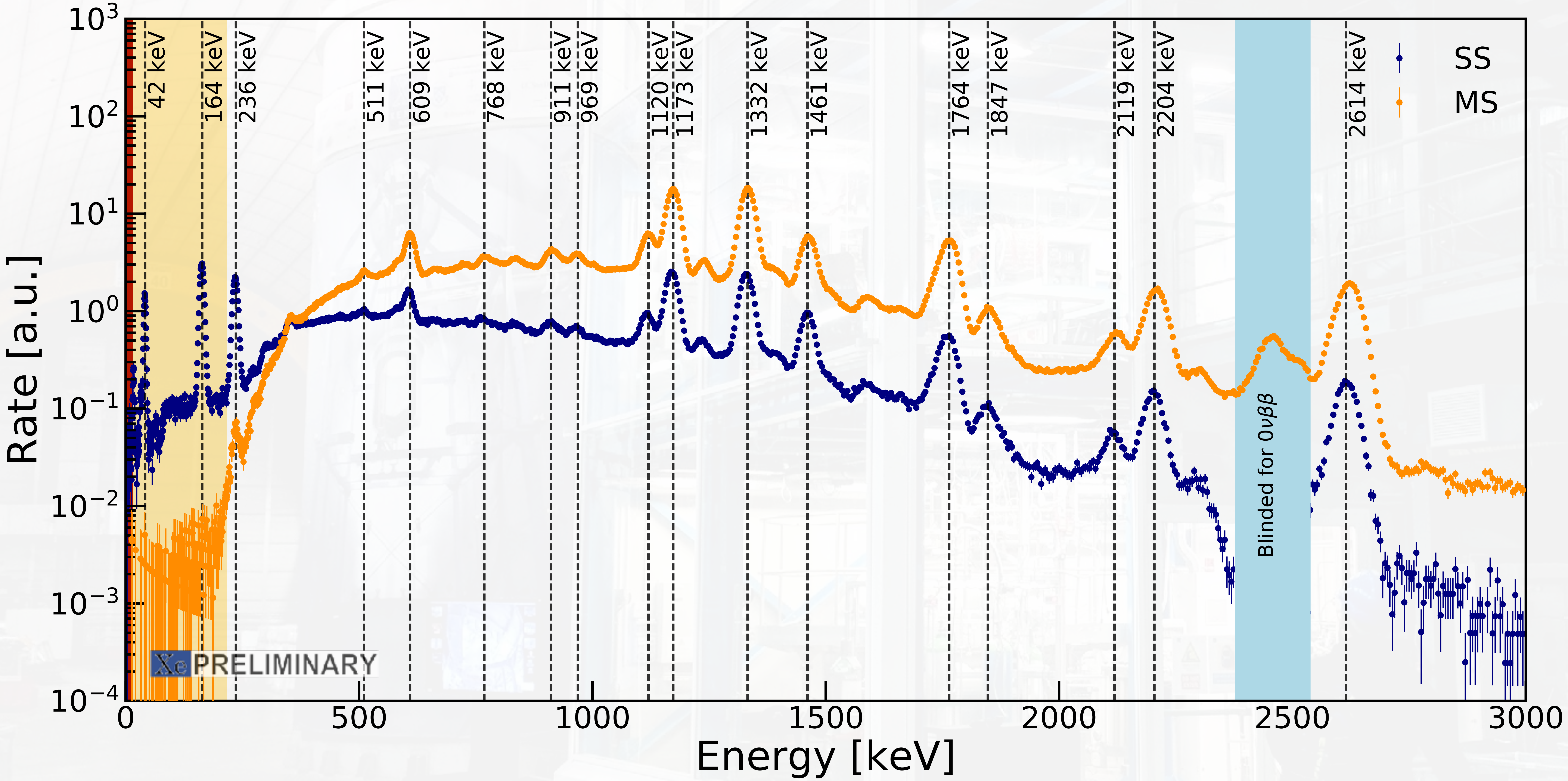
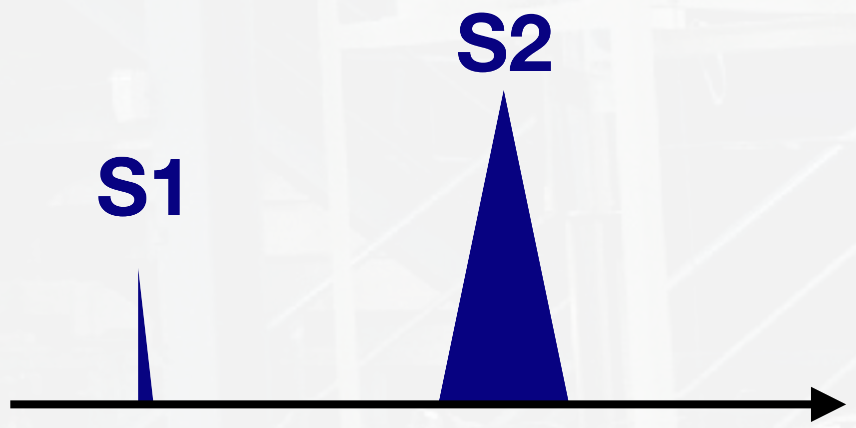
Dark Matter ~ keV
S2 ~ 10^2 - 10^3 pe
S1 ~ 1 - 10 pe

^{136}Xe 0νββ ~ MeV
S2 ~ 10^6 pe



Neutrons, γ (E>200 keV)



WIMPs, X-rays, γ (E<200 keV), β-electrons

Correcting saturated S2 signals

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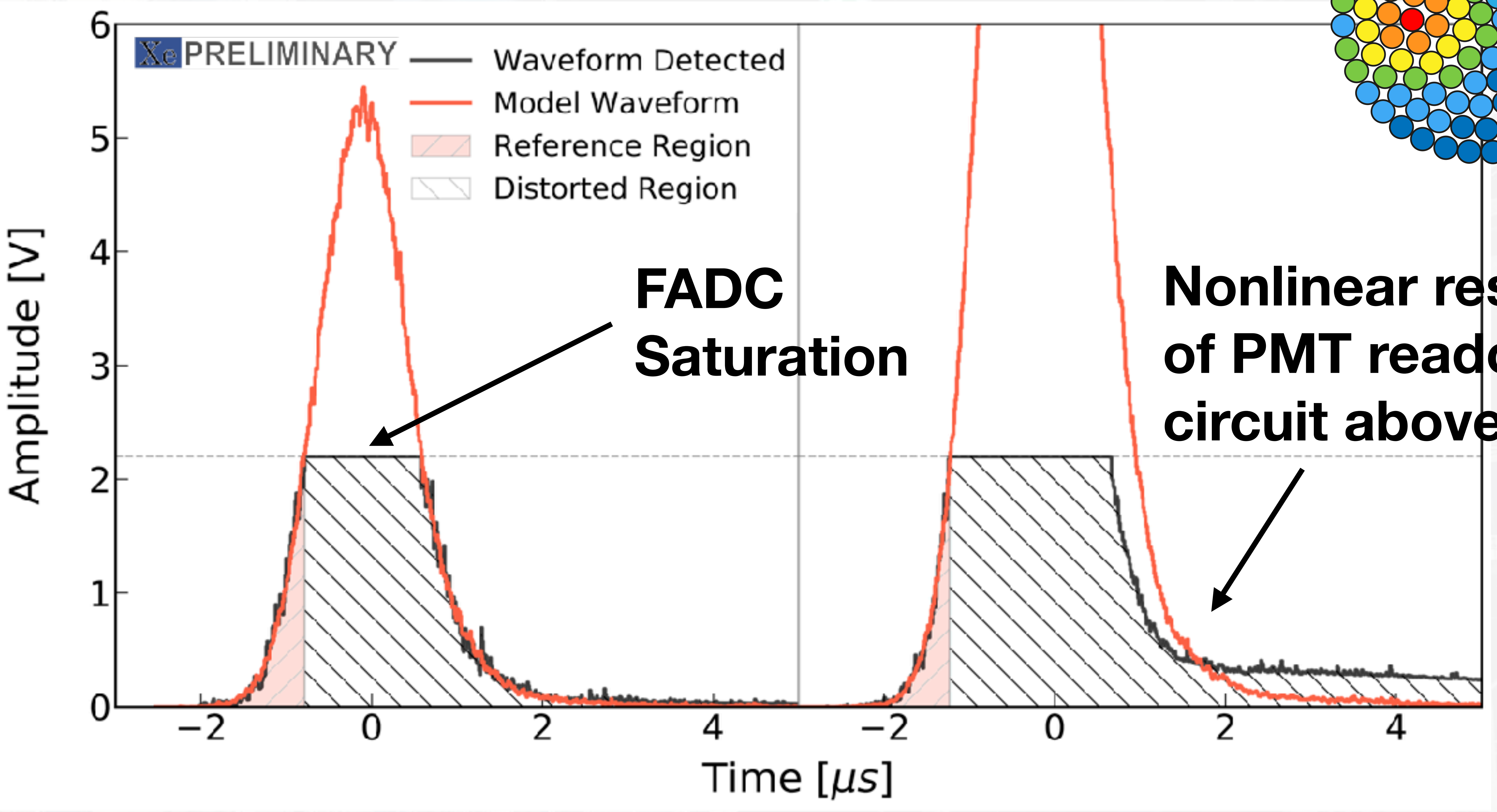
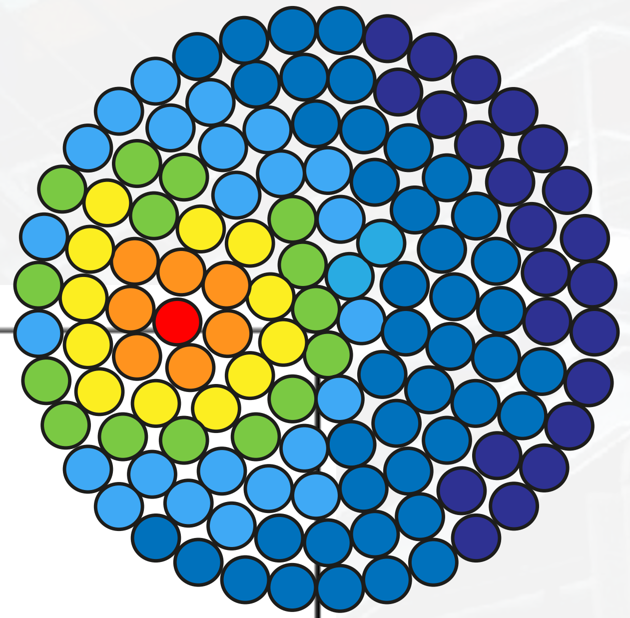
10x amplification

2.25 V FADC dynamic range

Use unsaturated channels as signal template

Scale using peak onset reference region





Separating multiple interactions

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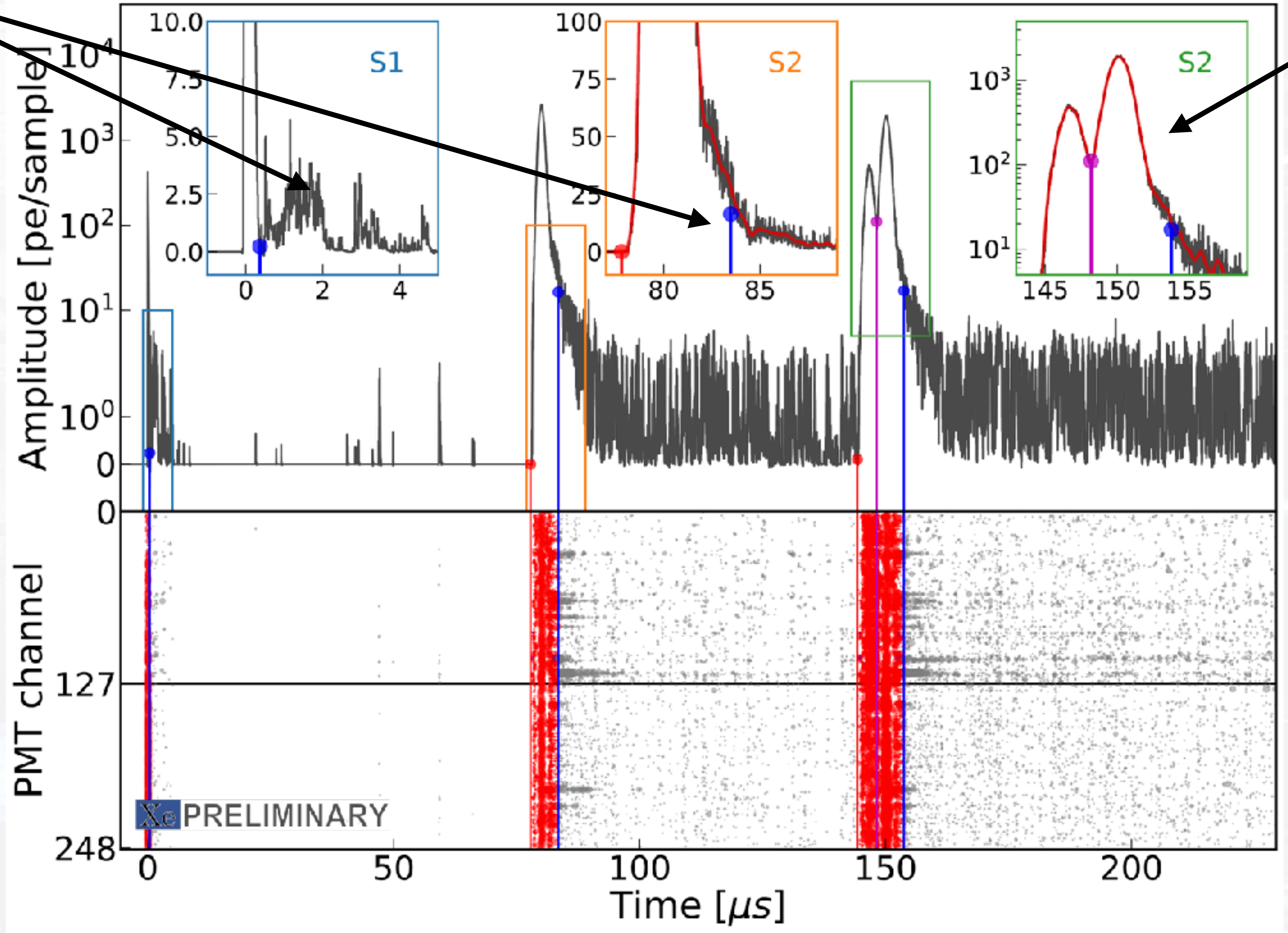
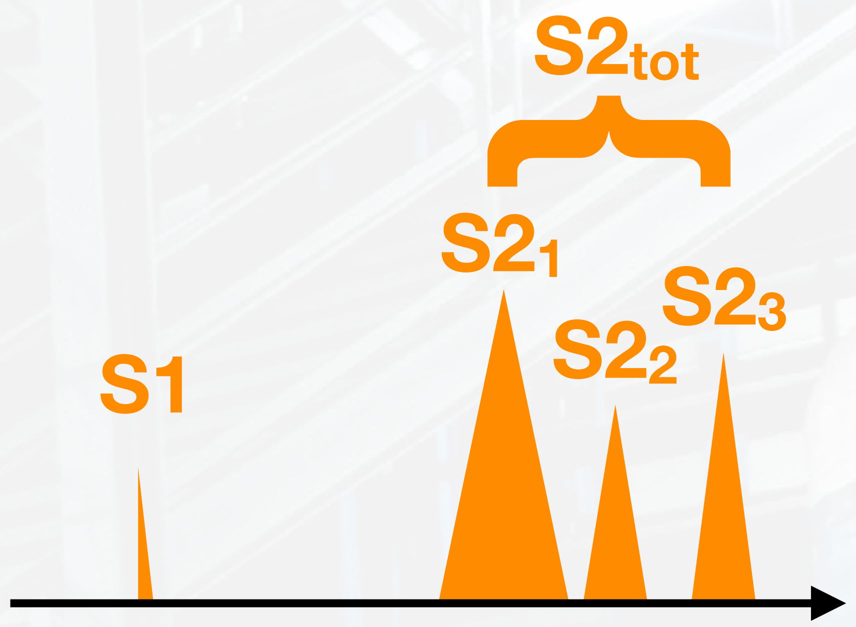
Separate tails from physical peaks

Separate multiple scatters in S2





Energy resolution after corrections

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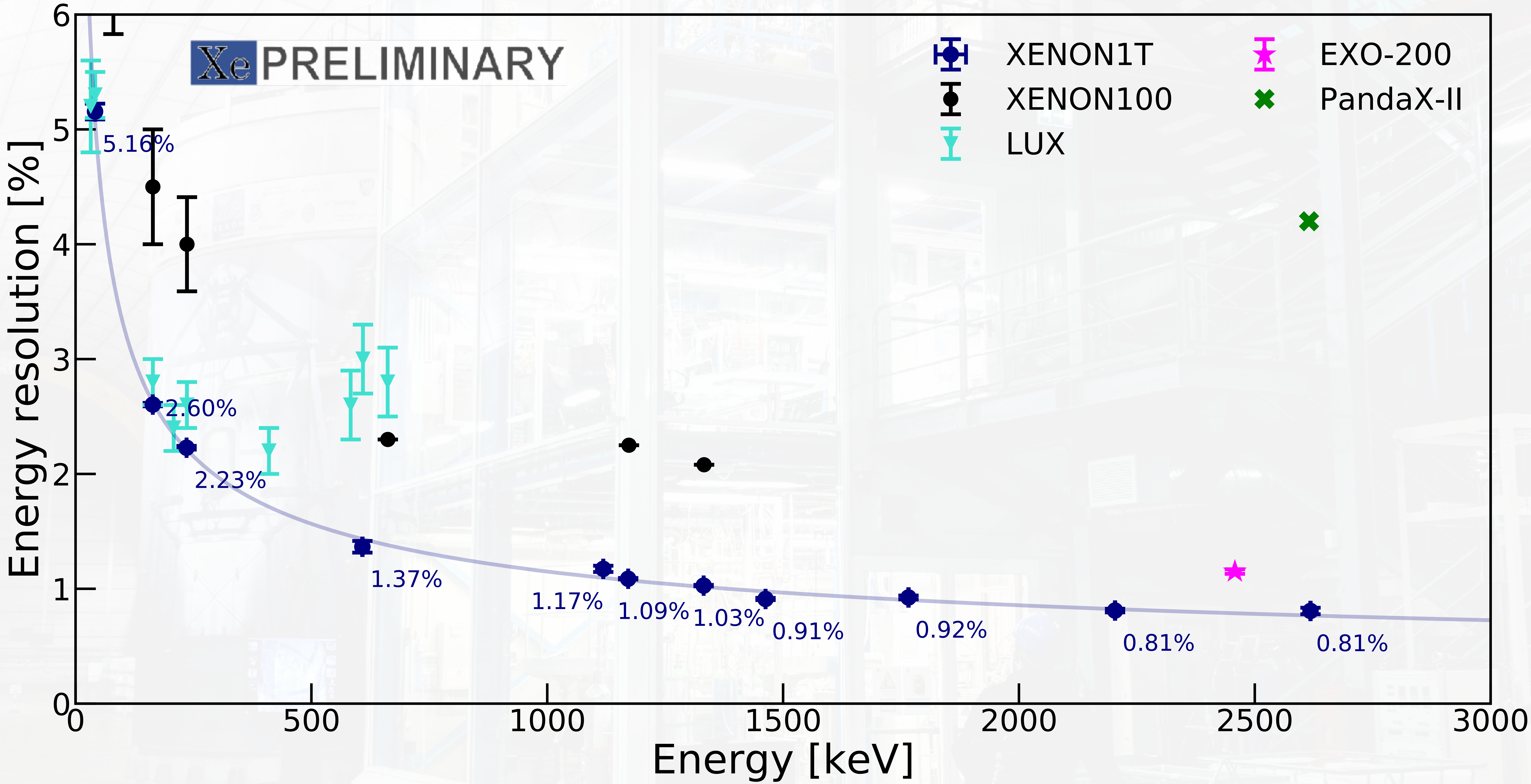

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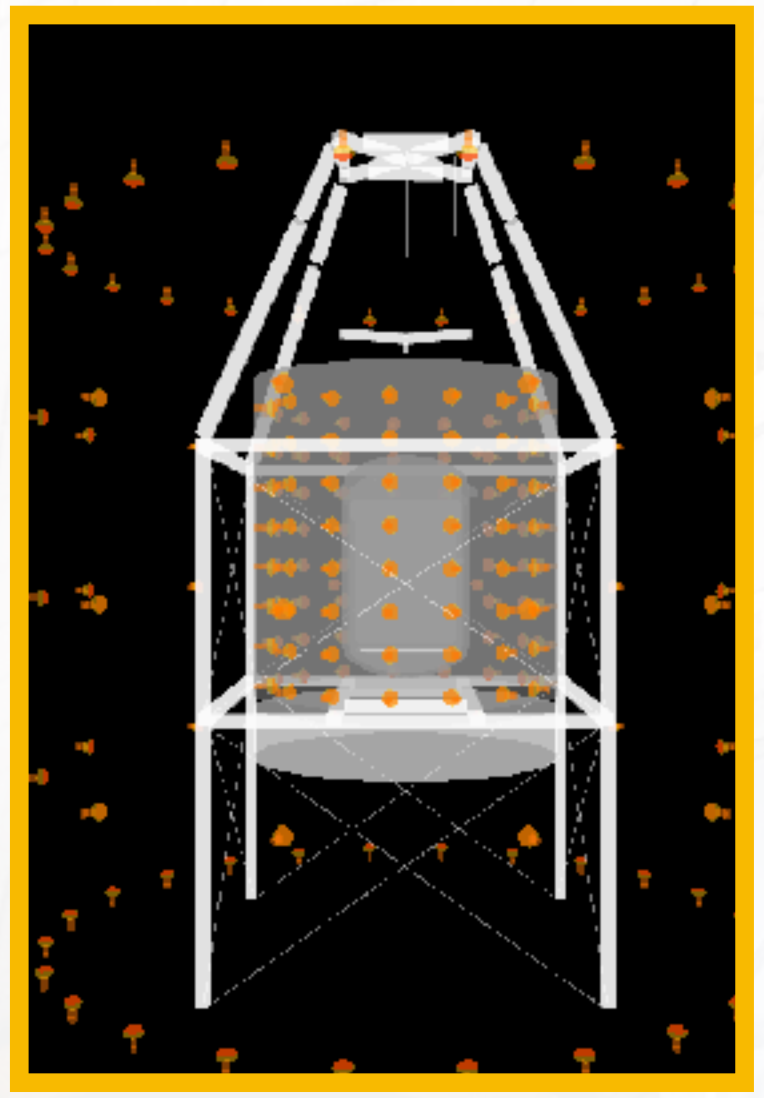
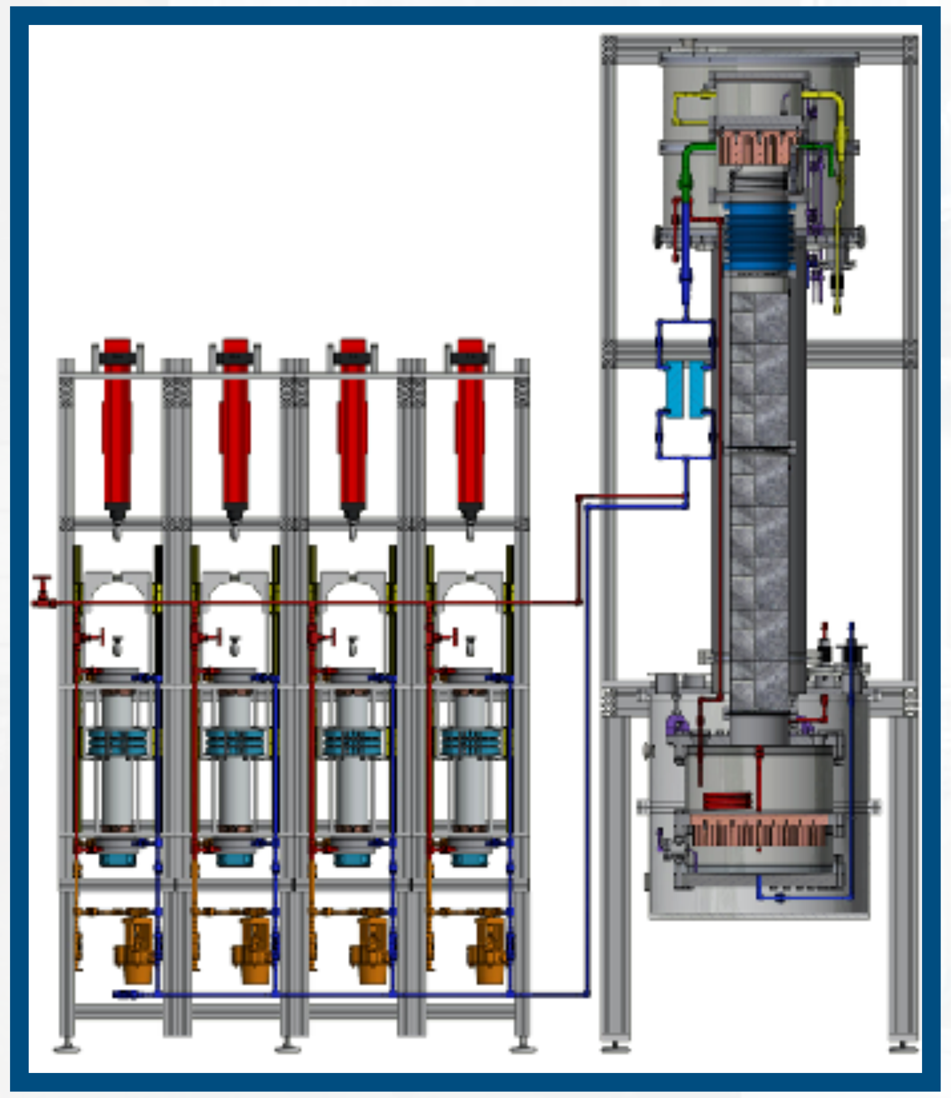


Neutron veto

- Inner region of existing muon veto
- optically separate
- 120 additional PMTs
- Gd in the water tank
- 0.5 % $Gd_2(SO_4)_3$

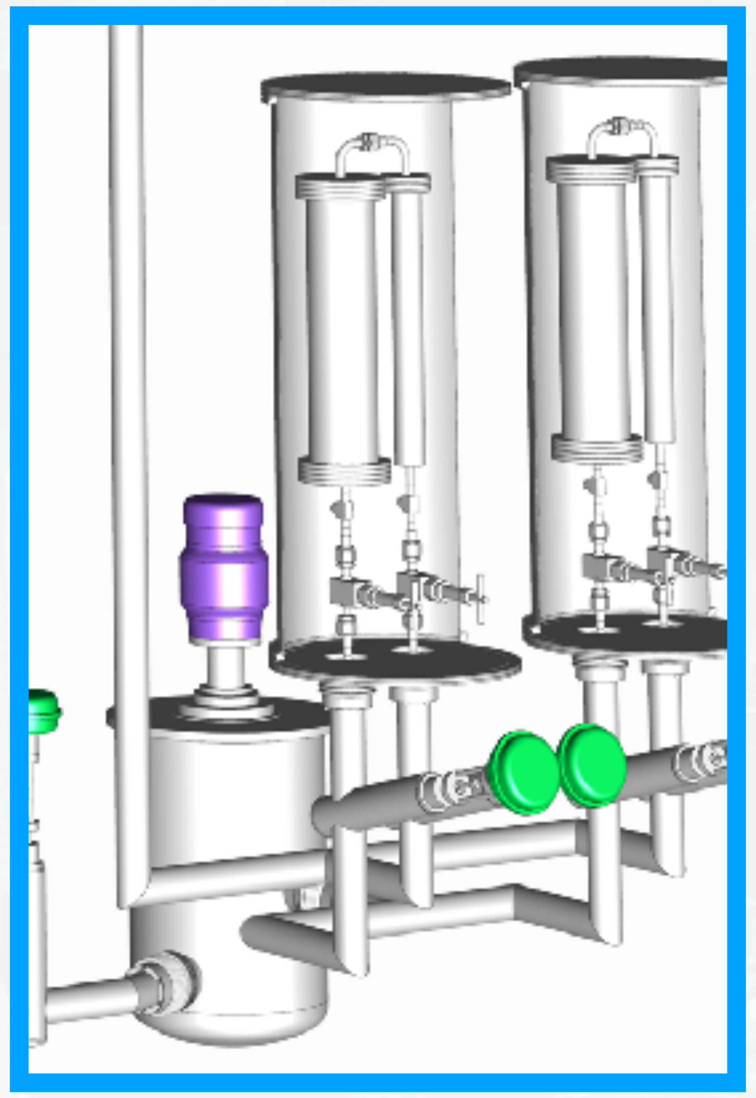
Larger TPC

- Total 8.4 t LXe
- 5.9 t in TPC
- ~ 4 t fiducial
- 248 → 494 PMTs



^{222}Rn distillation

- Reduce radon from pipes, cables, cryogenic system
- New system, PoP in XENON1T



LXe purification

- Faster xenon cleaning
- 5 L/min LXe (2500 slpm)
- XENON1T ~ 100 slpm

Summary

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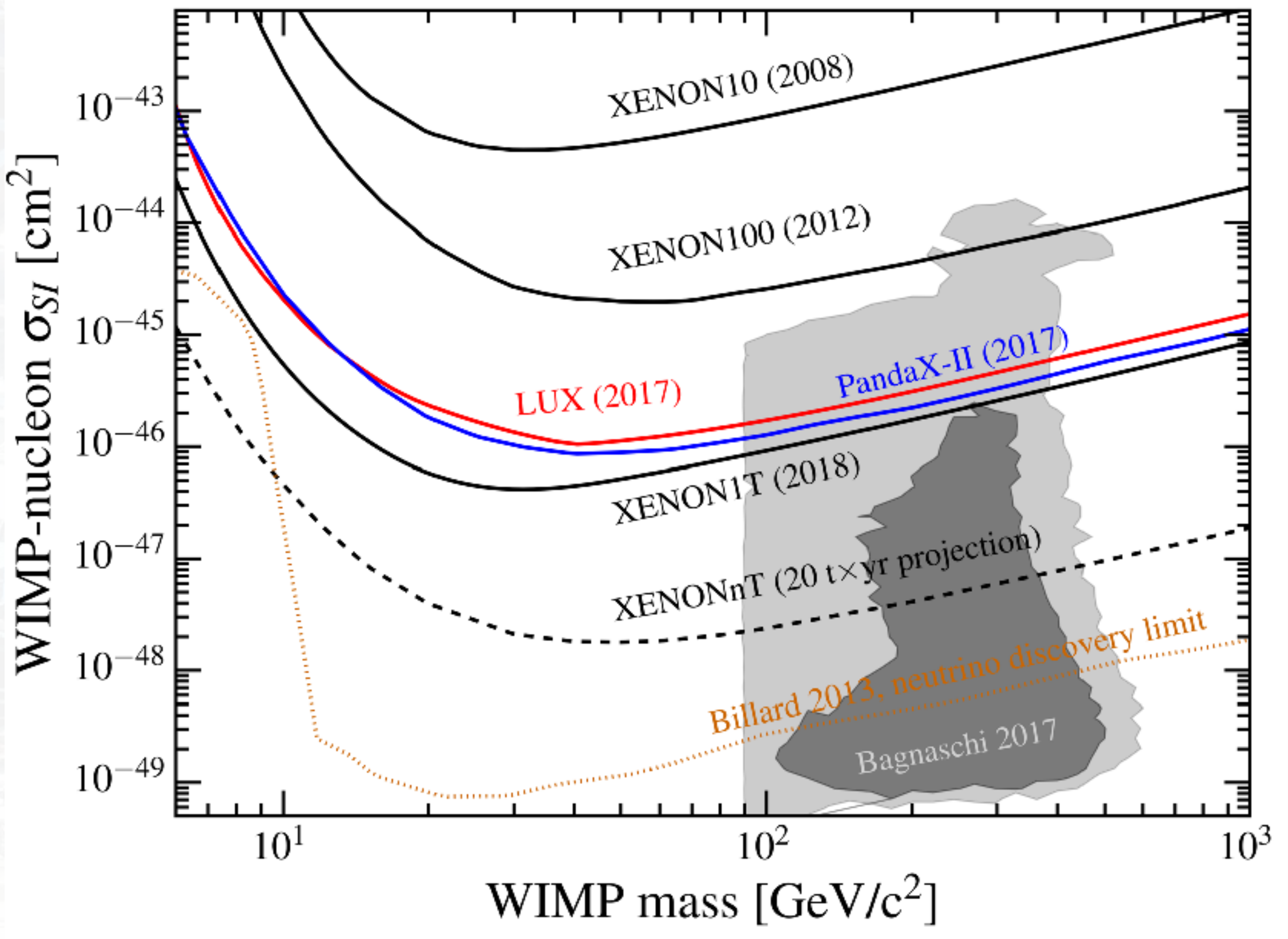
- XENON1T set most stringent limits for several WIMP masses and interactions types
- Physics potential beyond WIMPs at higher energies (0νββ, axions)
- First observation of ^{124}Xe 2νECEC
- High energy reconstruction demonstrated with < 1 % energy resolution at $Q_{\beta\beta}$
- XENONnT on track and will take data in 2020



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