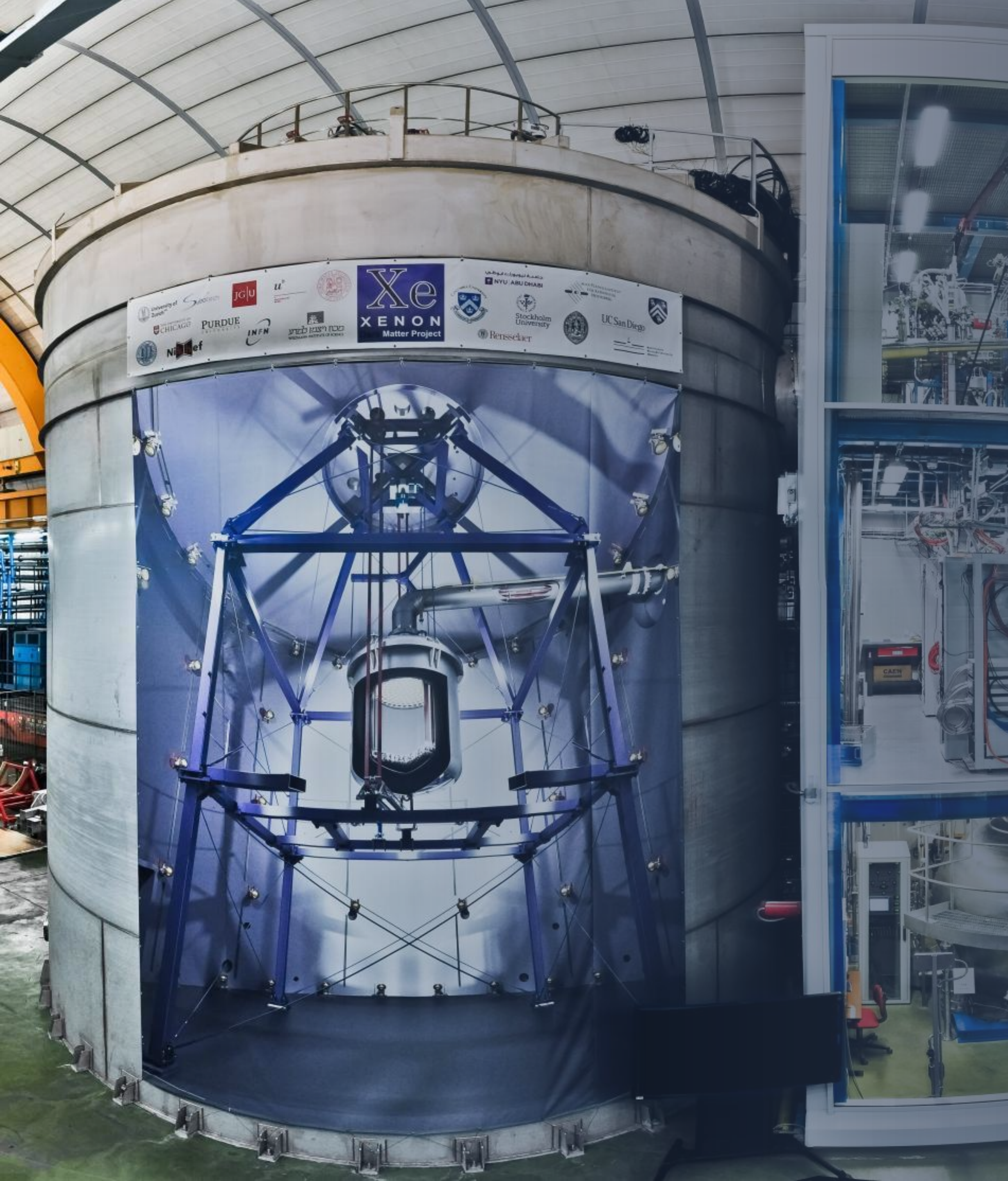


Latest XENON1T results & a glimpse into the future with XENONnT

Alexey Elykov
University of Freiburg

On behalf of the XENON Collaboration + X. Mougeot

The XENON Collaboration

~ 170 scientists ◆ 26 institutions ◆ 11 countries

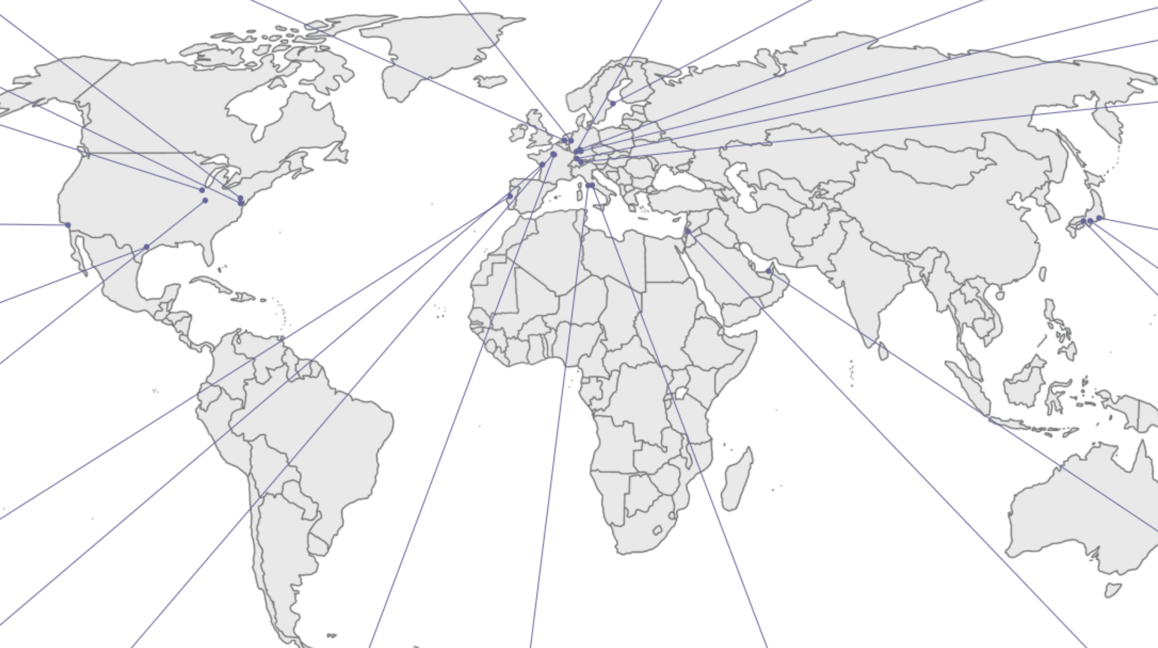
Columbia | RPI | Nikhef | Muenster | KIT | Stockholm | Mainz | MPIK, Heidelberg | Freiburg

Chicago

UCSD

Rice

Purdue



Zurich

Tokyo

Nagoya

Coimbra | Subatech | LPNHE | IJCLab | L'Aquila | Bologna | LNGS | Torino | Napoli | Weizmann | NYUAD | Kobe


Marc Schumann
Manfred Lindner
arianna rocchetti
ChristianWittweg
Andrii Terliuk (MPIK/Uni He...
Alexey Elykov
Ethan Brown
Christopher Hils (JGU-Mai...
Michele Iacovacci
Xe
XENON
Dark Matter Project
XENON Technical Meeting, May 12-14, 2020

The XENON1T Detector

Located at Laboratori Nazionali del Gran Sasso, Italy
1500 m rock overburden (3600 m.w.e.) • Operated 2016 - 2018

Water Tank
700 t ultra-pure water

Muon Veto
84 PMTs

Calibration
AmBe, Cs-137, Th-228, D-D neutron generator

TPC

Cryogenics & Purification
Internal Calibration Kr83m, Rn220

DAQ & Slow Control

Xenon Storage & Recovery
Distillation Column, Kr, Rn removal

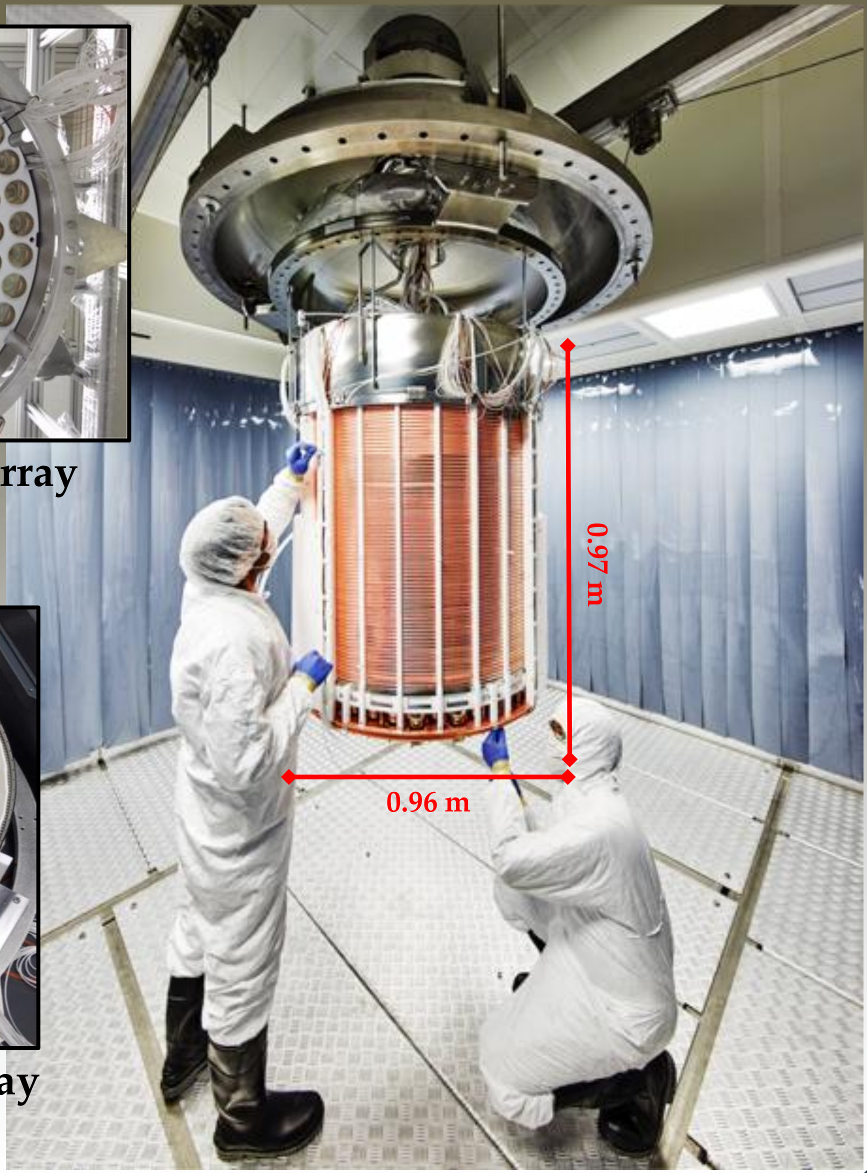
The XENON1T Time Projection Chamber (TPC)

- 3.2t LXe total (2.0t in target)
- 248 3″ PMTs
- Radiopure and screened materials

Eur. Phys. J. C (2017) 77: 881

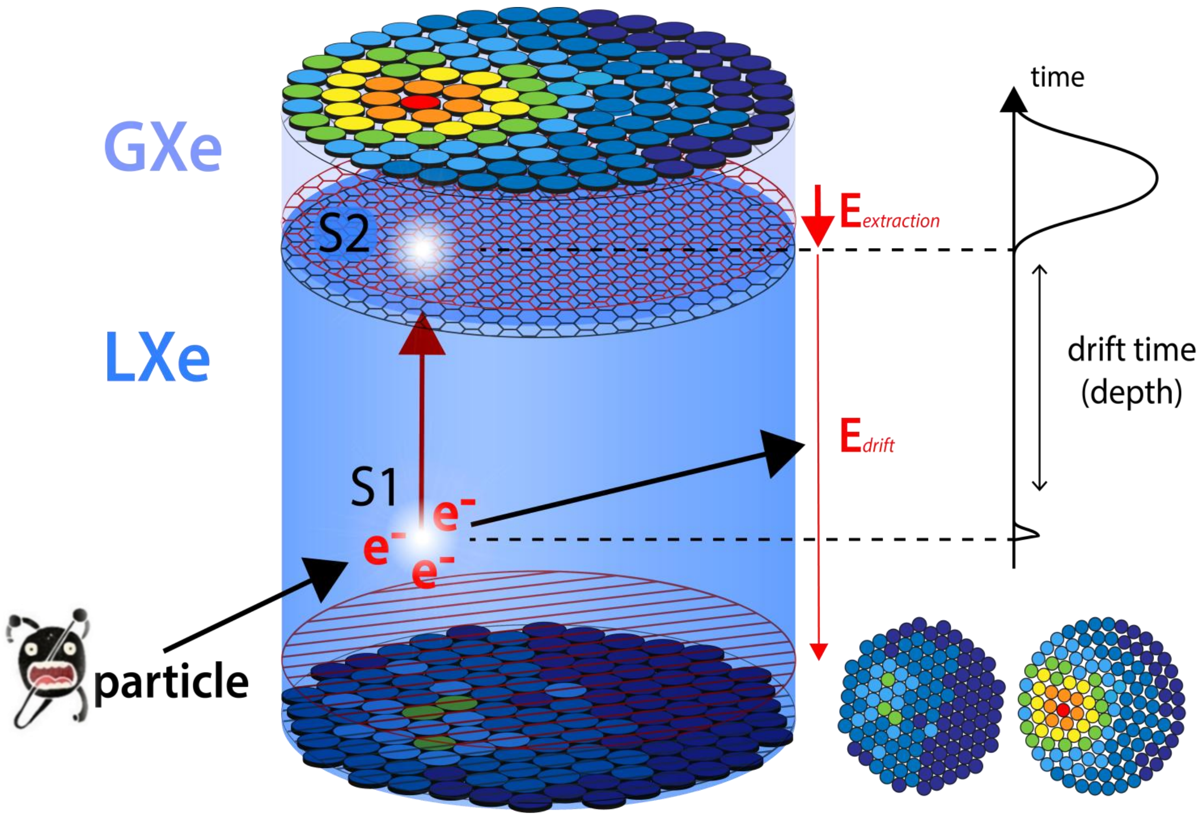
127 3″ PMTs - Top Array

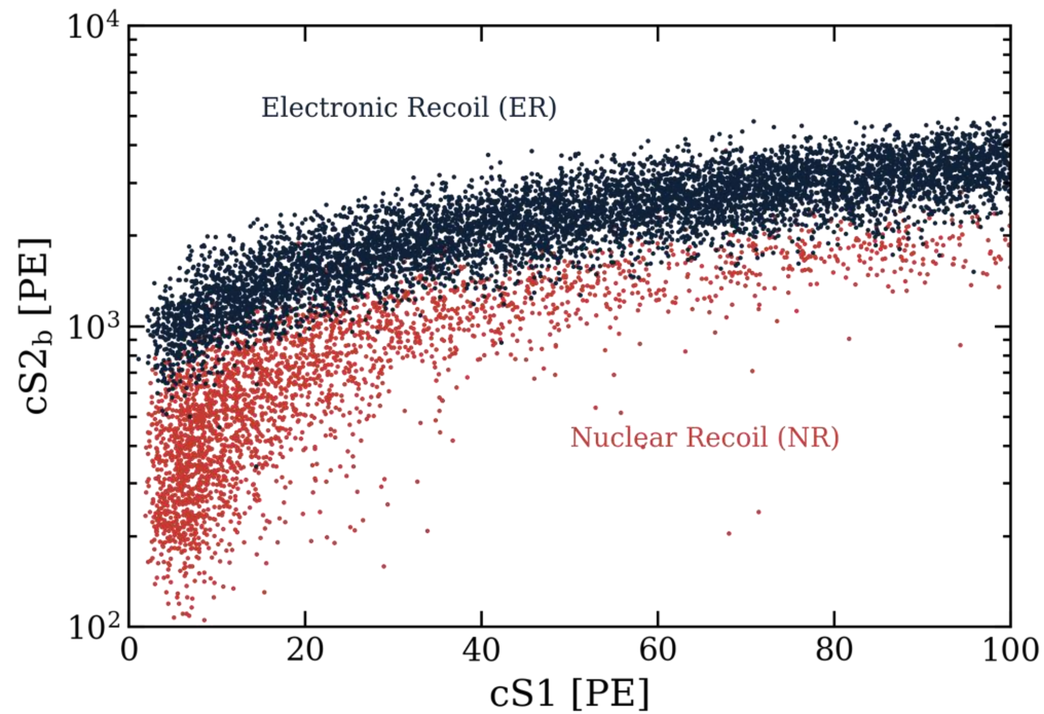
121 3″ PMTs - Bottom Array



Dual-phase Time Projection Chamber (TPC)

- Initial scintillation light: **S1**
- Proportional scintillation signal: **S2**
- **Energy:** **S1** area, S2 area
- **Position:** X-Y (S2 signal), Z (drift time)
- **Interaction type:** S2/S1 ratio (ER/NR)



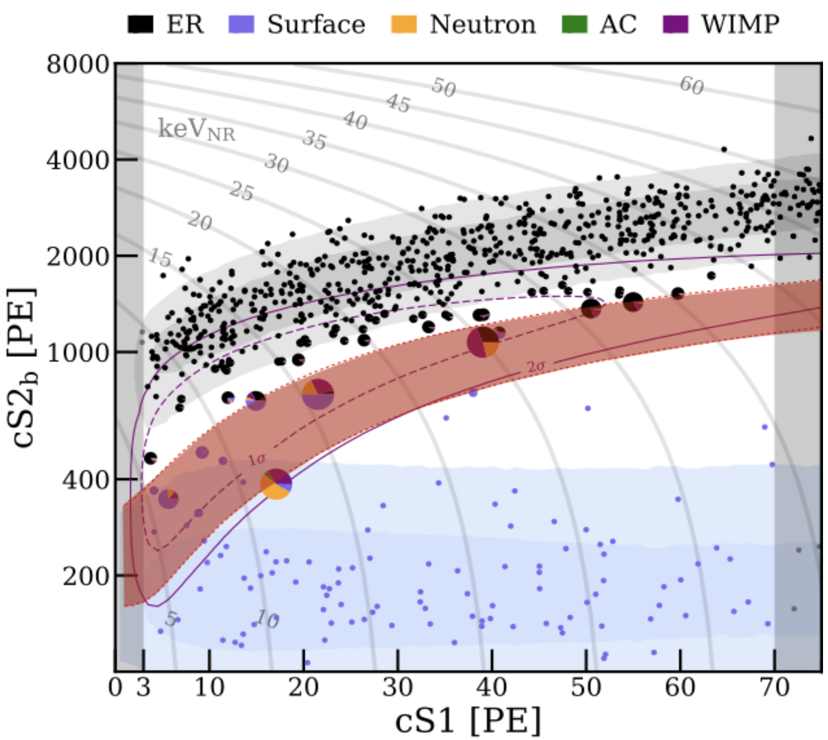


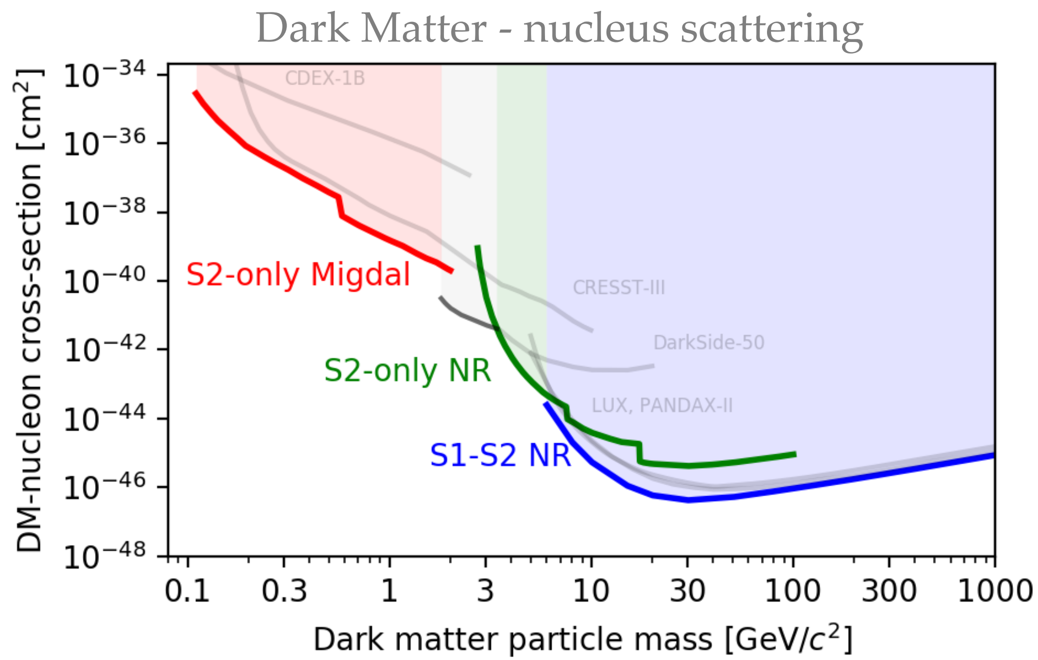
Signal & Background Discrimination

Low threshold:
~1 keV_{ee} (4.9 keV_{nr})

Large exposure:
1 tonne x year

ER/NR discrimination





PRL 123, 241803 - Migdal effect

PRL 123, 251801 - Light dark matter

PRL 122, 141301 - Spin-dependent WIMPs

PRL 122, 071301 - WIMP-pion interaction

PRL 121, 111302 - Main WIMP search

PRL 119, 181301 - First results

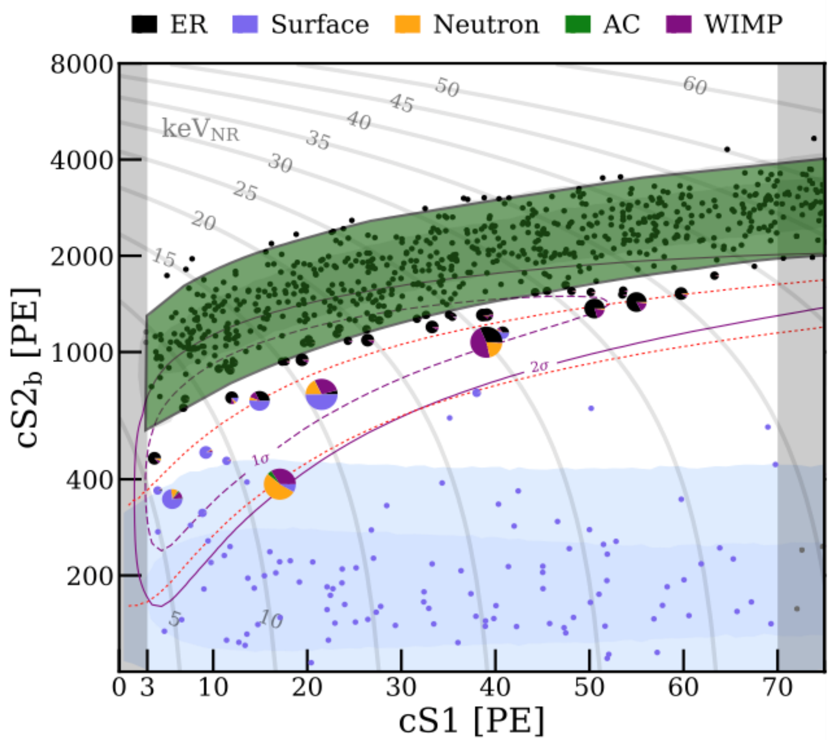
Most stringent constraint on WIMP Dark Matter down to 3 GeV/c^2 masses

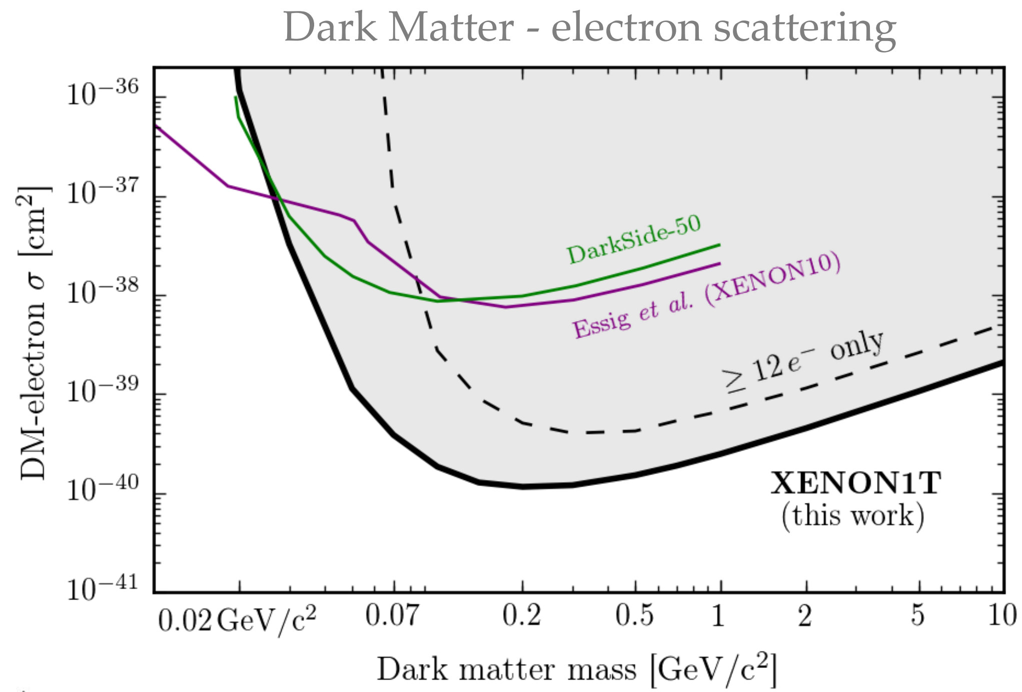
Signal & Background Discrimination

Low threshold:
~1 keV_{ee} (4.9 keV_{nr})

Large exposure:
1 tonne x year

ER/NR discrimination

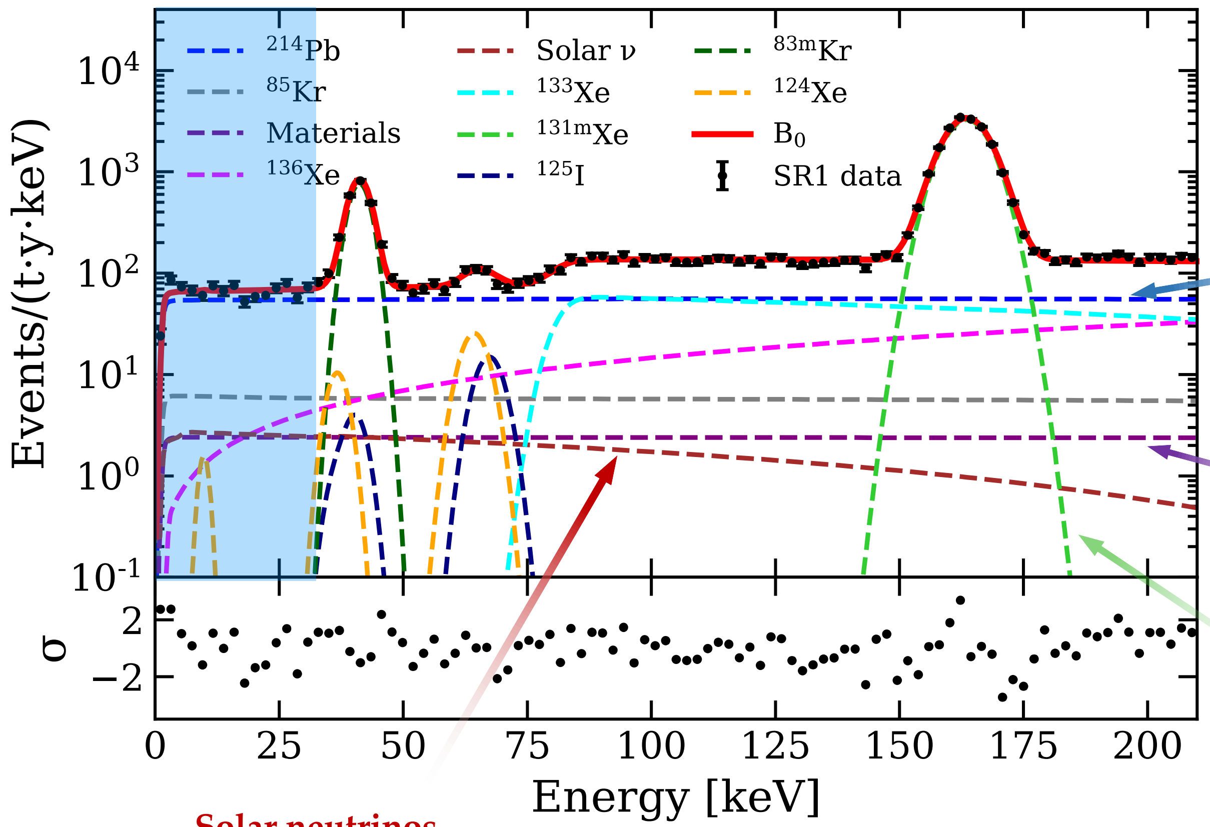




PRL 123, 251801 - Light dark matter

Nature 568, 532–535 ^{124}Xe 2νECEC

ER Background in XENON1T



Solar neutrinos

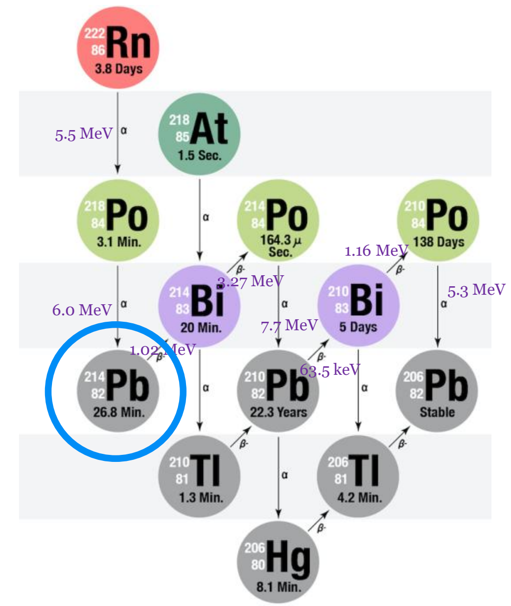
Intrinsic backgrounds

^{214}Pb, ^{136}Xe, ^{124}Xe, ^{83m}Kr, ^{85}Kr

Detector materials γ

Neutron activation

^{131m}Xe, ^{133}Xe, ^{125}I

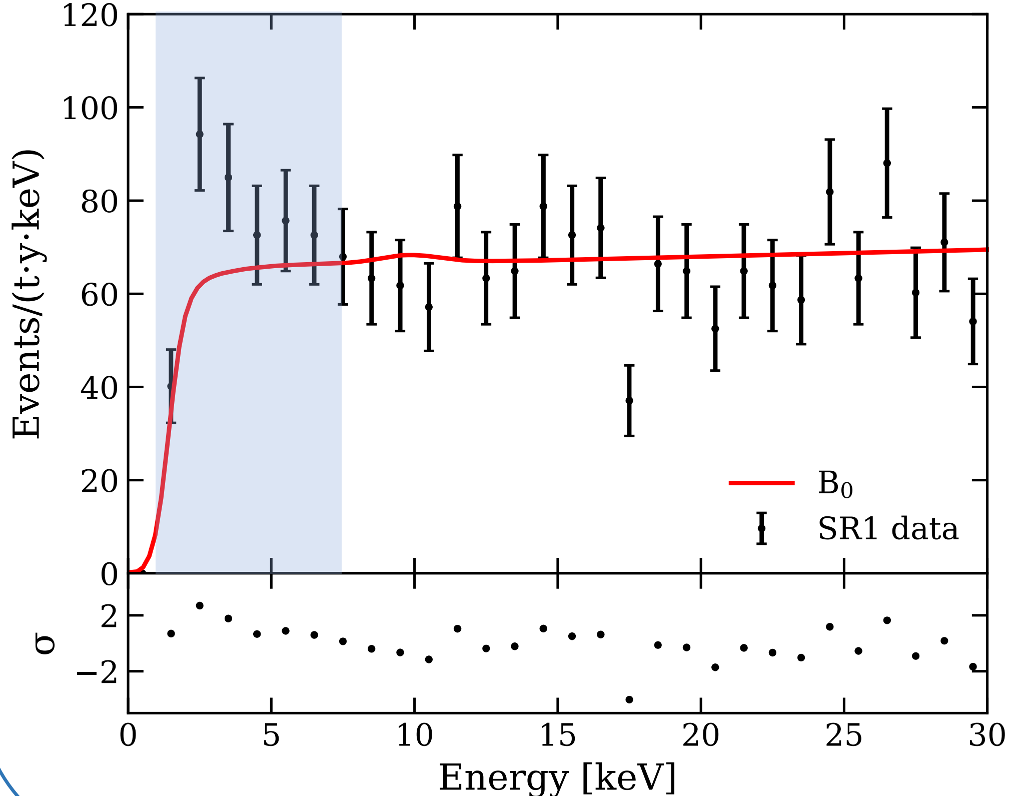


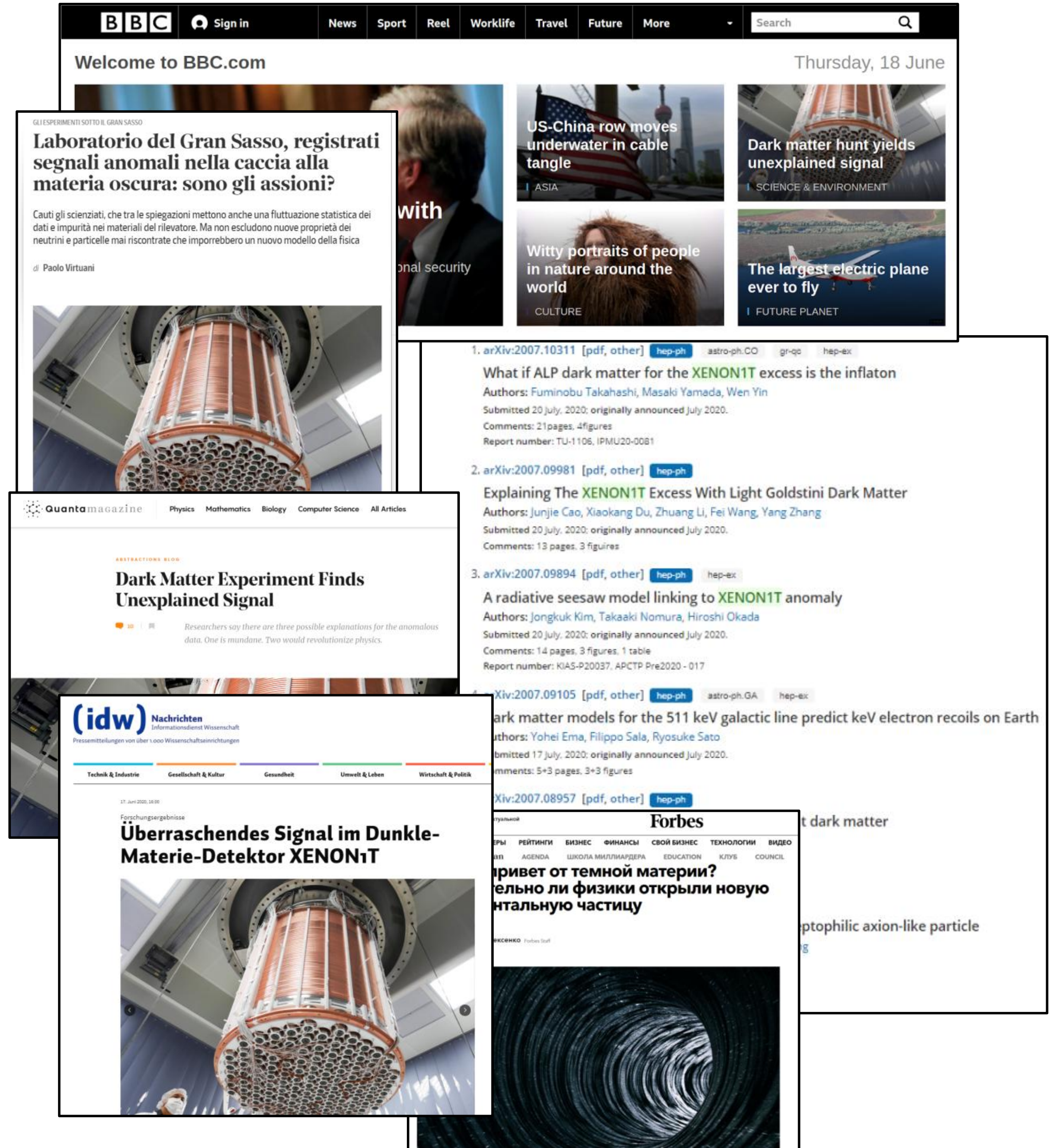
- Good match between MC and data
- Predicted background spectra based on Geant4 simulations smeared with detector effects

Use lowest background rate ever achieved (76 +/- 2) events/(t·y·keV) in [1, 30] keV to search for excesses in the ER band!

Low-ER Excess in XENON1T

arXiv: 2006.09721v2





Excess between 1 - 7 keV!

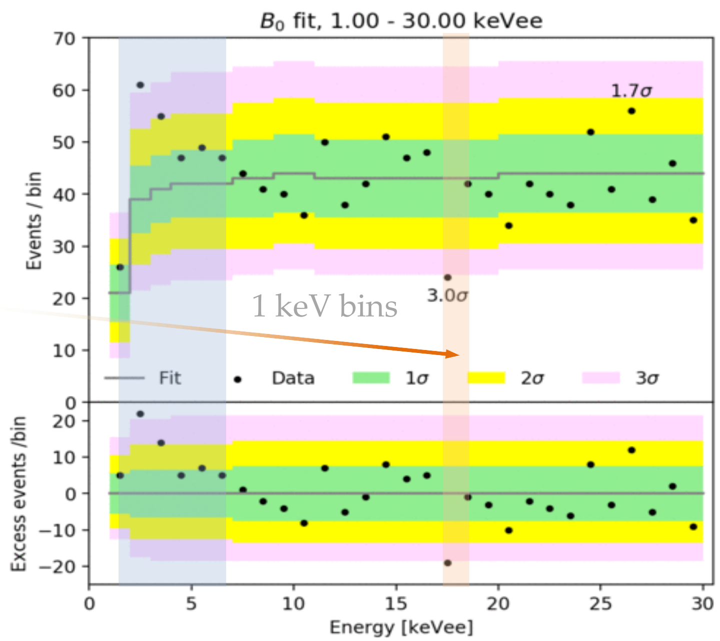
Expectation: 232 ± 15
Observation: 285

Binning Effects

What could it be?

We use an unbinned profile likelihood analysis!

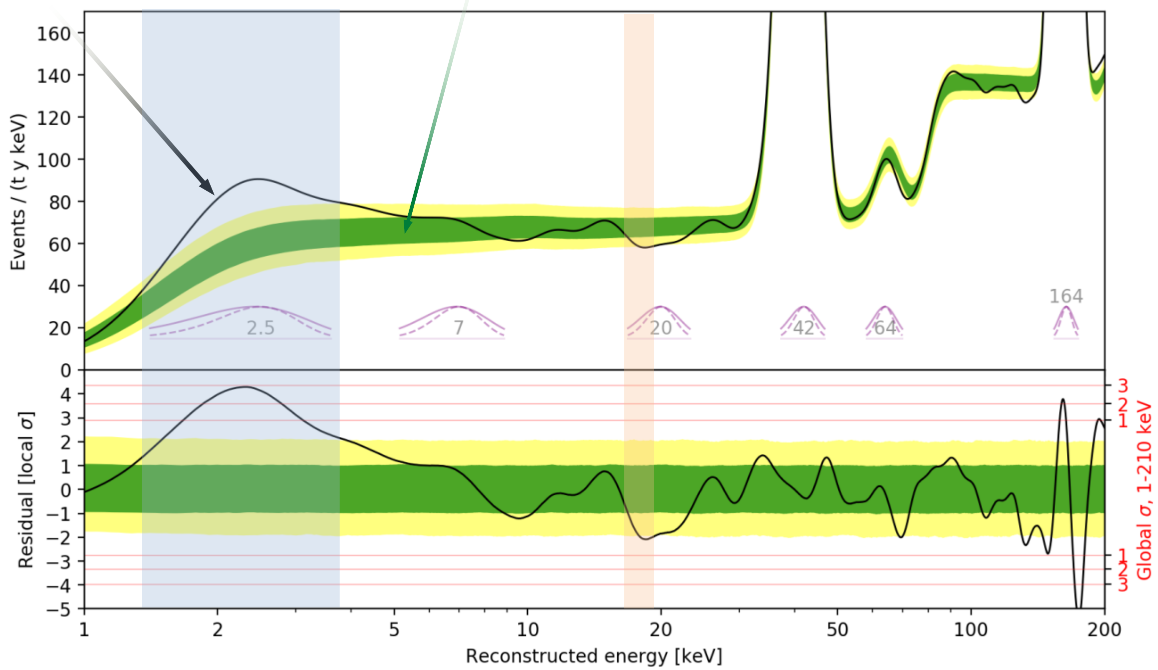
18 keV "deficit":
Local significance 1.5 - 3.4 σ
Max global significance 2.3 σ



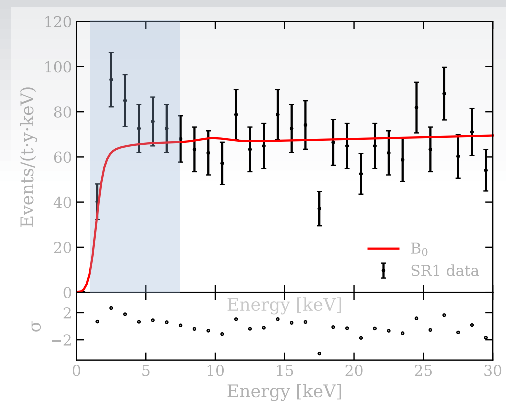
1. **Statistical flukes?**
2. **Background mismodeling?**
3. **Background shape?**
4. **Instrumental backgrounds?**
5. **Missed background?**
6. **New background?**
7. **New Physics?**

KDE with kernel ~ E resolution

MCs from
background best fit



Low-ER excess
local significance ~4 σ
global significance ~3 σ



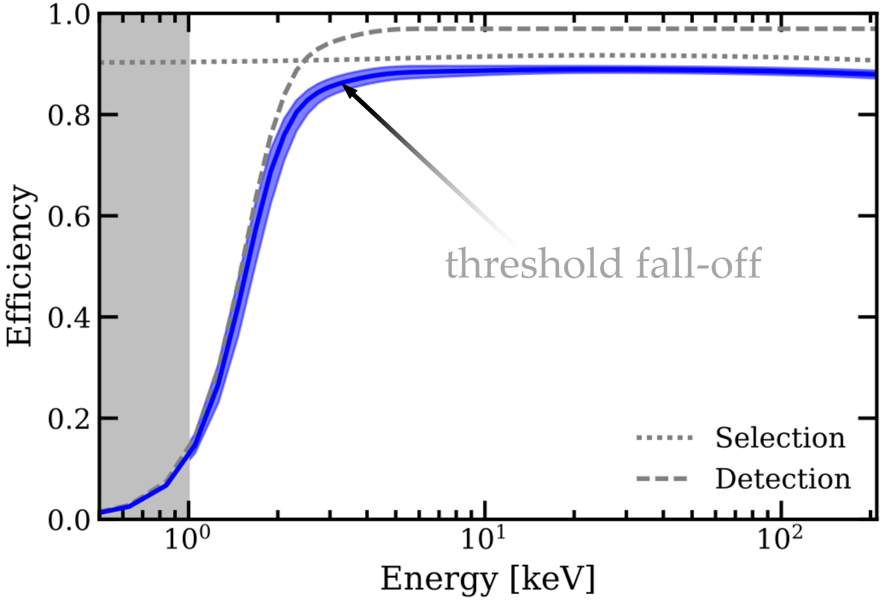
Background in XENON1T

What could it be?

1. ~~Statistical flukes?~~
2. Background mismodeling?
3. Background shape?
4. Instrumental backgrounds?
5. Missed background?
6. New background?
7. New Physics?

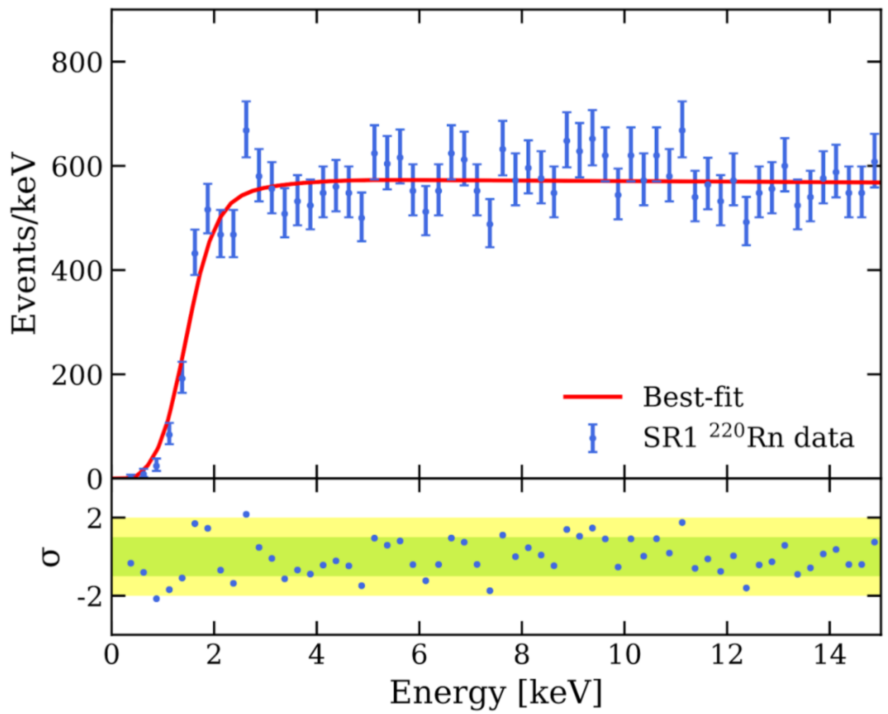
Excess is not a low threshold effect

Persists when:
Doubling analysis threshold
Doing a (cS1, cS2 profile likelihood)

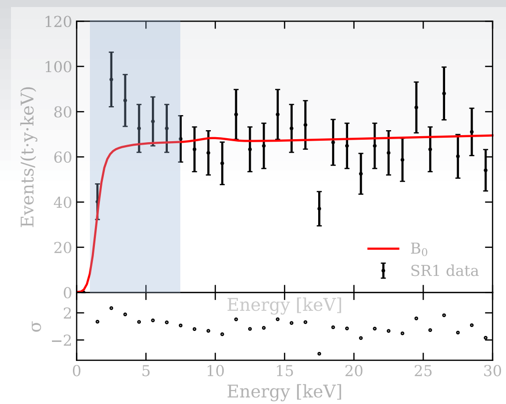


^{220}Rn calibration data

^{212}Pb β decay used to calibrate detector's response to ER background



Good match between data and MC down to the energy threshold < ~2keV

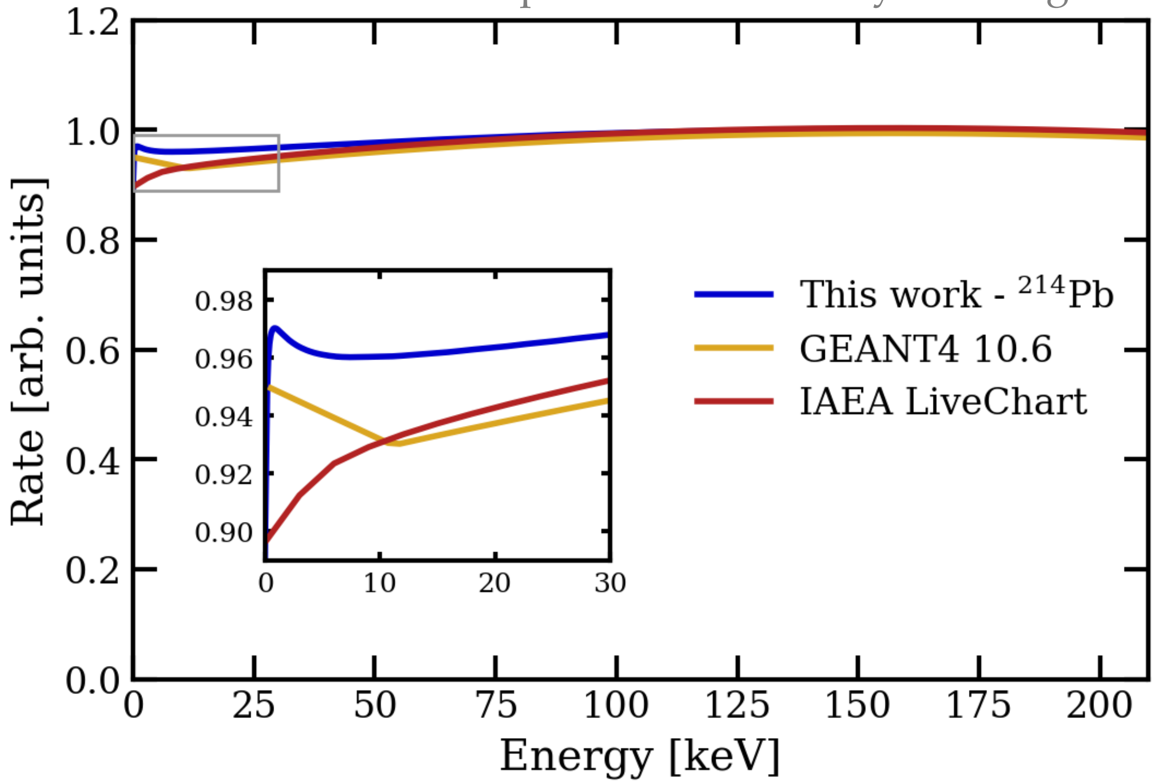


β Decay Spectrum Shape in XENON1T

Atomic screening and exchange effects can slightly increase the rate at low energies

~ 6% uncertainty on the shape, while **~ 50%** needed to account for the excess

Spectra calculated by X. Mougeot



What could it be?

1. ~~Statistical flukes?~~
2. ~~Background mismodeling?~~
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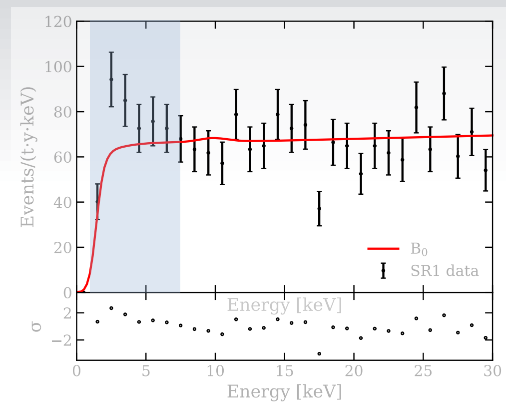
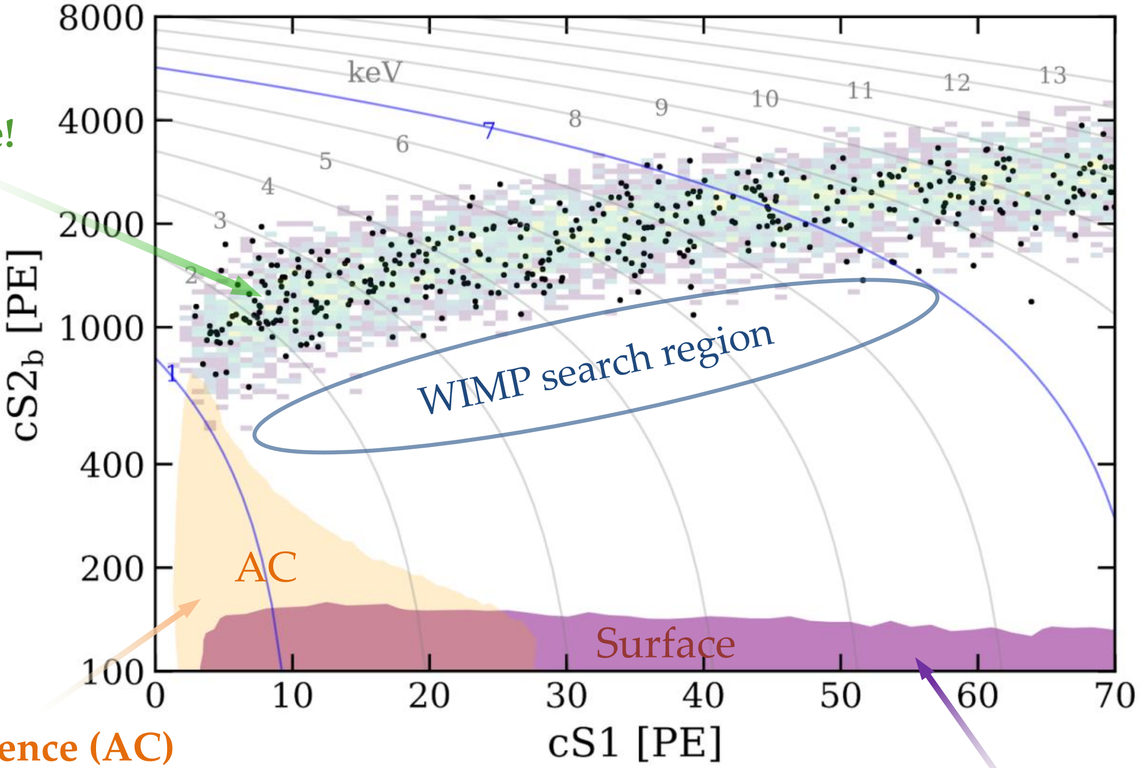


AC & Wall Events

Background events appear at a different S2/S1 ratio compared to true ER events.
All observed excess events are within the ER band.

Low-ER excess is here!

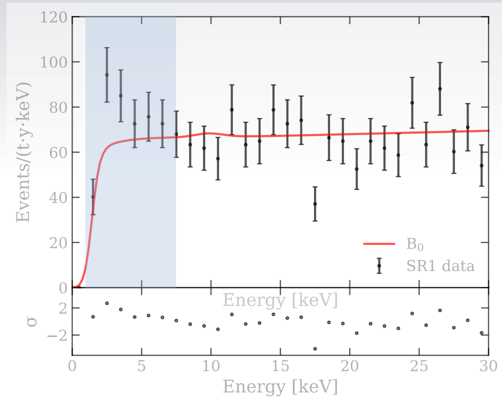


Accidental coincidence (AC) background events

Mis-reconstructed events from detector surfaces

What could it be?

1. ~~Statistical flukes?~~
2. ~~Background mismodeling?~~
3. ~~Background shape?~~
4. Instrumental backgrounds?
5. Missed background?
6. New background?
7. New Physics?



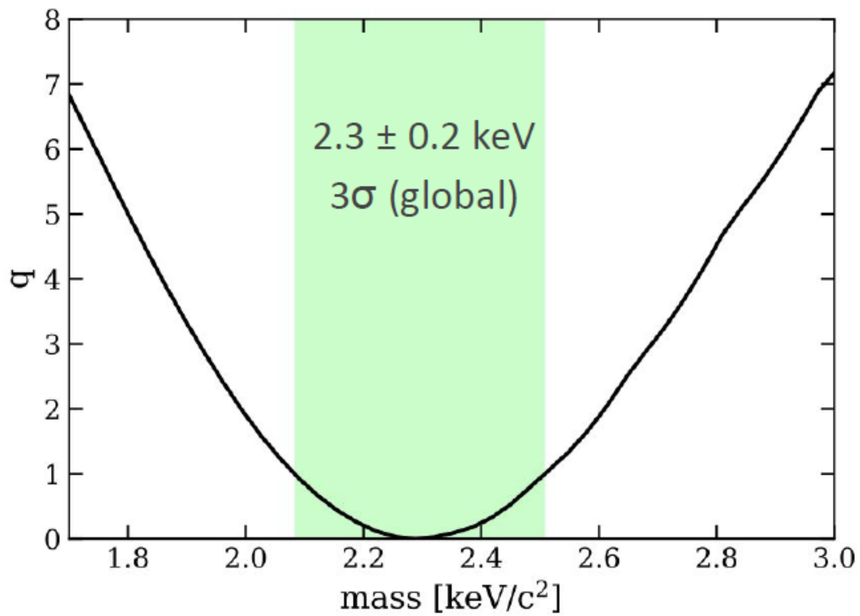
^{37}Ar contamination?

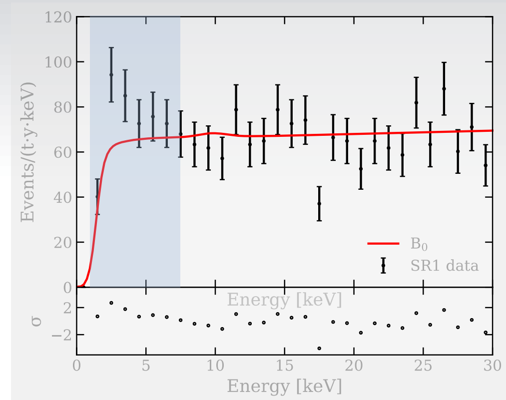
What could it be?

1. ~~Statistical flukes?~~
2. ~~Background mismodeling?~~
3. ~~Background shape?~~
4. ~~Instrumental backgrounds?~~
5. Missed background?
6. New background?
7. New Physics?

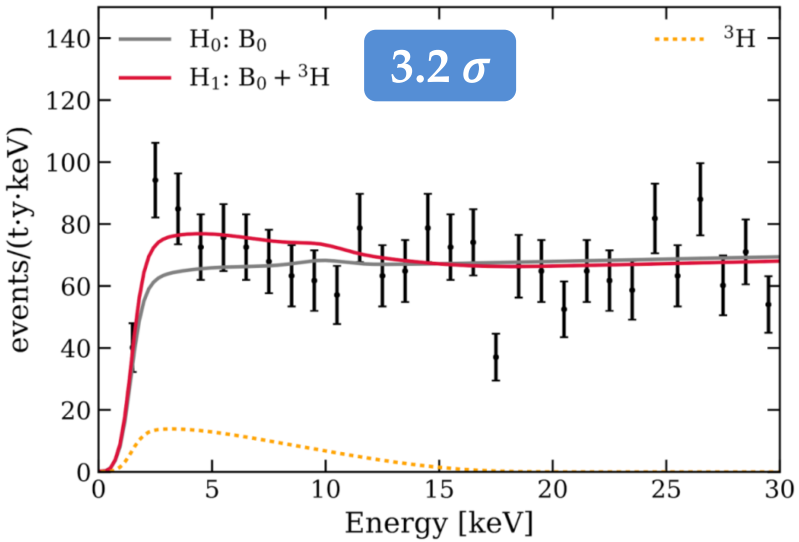
Air leak needed to account for the excess by ^{37}Ar contamination!
Air leak in XENON1T < 1 liter/year (rare gas mass spectrometry constraints)

^{37}Ar produces a mono-energetic peak at 2.82 keV$_{ee}$
Best mono-energetic peak fit at 2.3±0.2 keV$_{ee}$



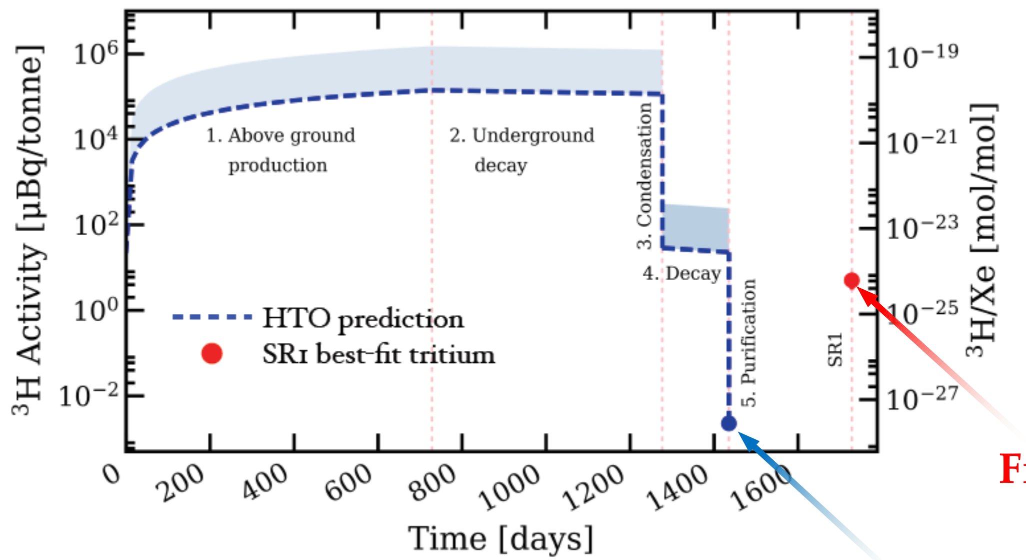


Tritium



- Long half life (12.3 years)
- Abundant in atmosphere & cosmogenically produced in xenon
- Removed continuously by gas purification

A. <u>Cosmogenic activation in Xe</u>



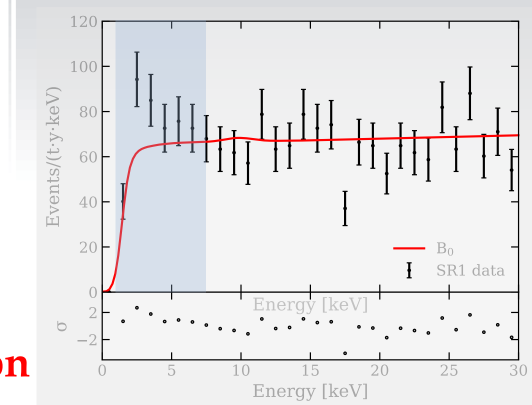
Fitted concentration

Expected concentration

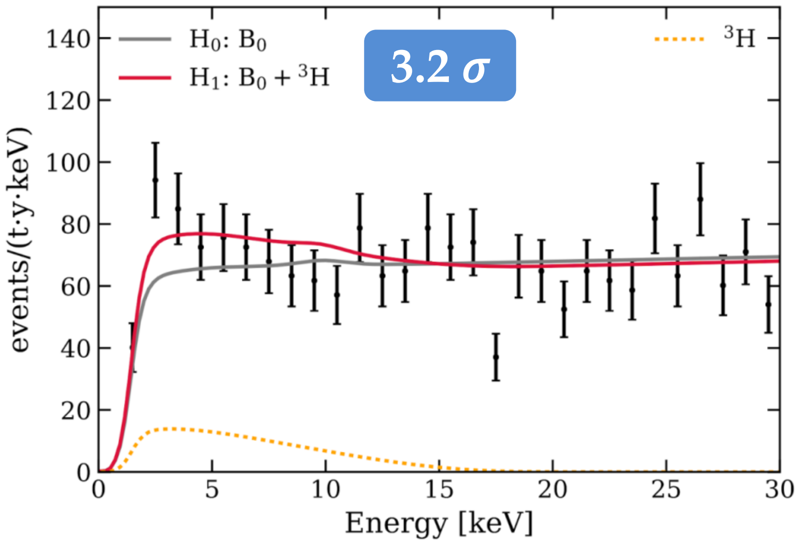
What could it be?

1. ~~Statistical flukes?~~
2. ~~Background mismodeling?~~
3. ~~Background shape?~~
4. ~~Instrumental backgrounds?~~
5. ~~Missed background?~~
6. New background?
7. New Physics?

Maybe



Tritium



- Long half life (12.3 years)
- Abundant in atmosphere & cosmogenically produced in xenon
- Removed continuously by gas purification

B. <u>Emanation from materials</u>

Materials could release tritiated water (HTO) or gaseous tritium (HT):

Needed amount of $^3H : Xe \sim 10^{-24}$ mol/mol

HTO : $H_2O \sim 10^{-17}$ mol/mol

To explain excess $H_2O : Xe \sim 100$ ppb

HT : $H_2 \sim 10^{-17}$ mol/mol

To explain excess $H_2 : Xe \sim 100$ ppb

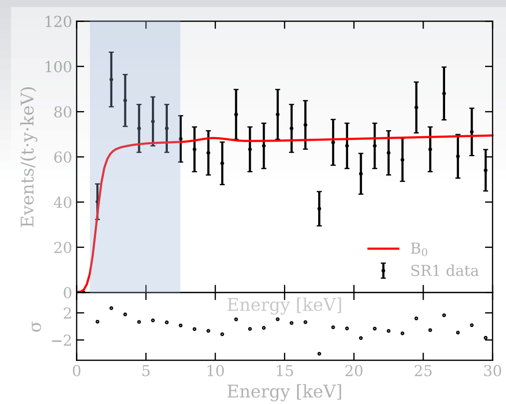
O_2 from Xe purity < 1 ppb

Constraint from light yield measurements $H_2O : Xe \sim 1$ ppb

No constraints on H_2

What could it be?

1. ~~Statistical flukes?~~
2. ~~Background mismodeling?~~
3. ~~Background shape?~~
4. ~~Instrumental backgrounds?~~
5. ~~Missed backgrour~~ Maybe
6. New background?
7. New Physics?

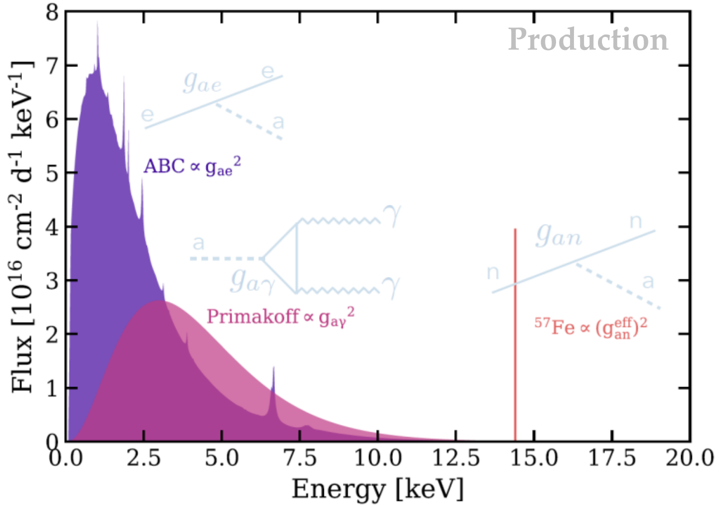


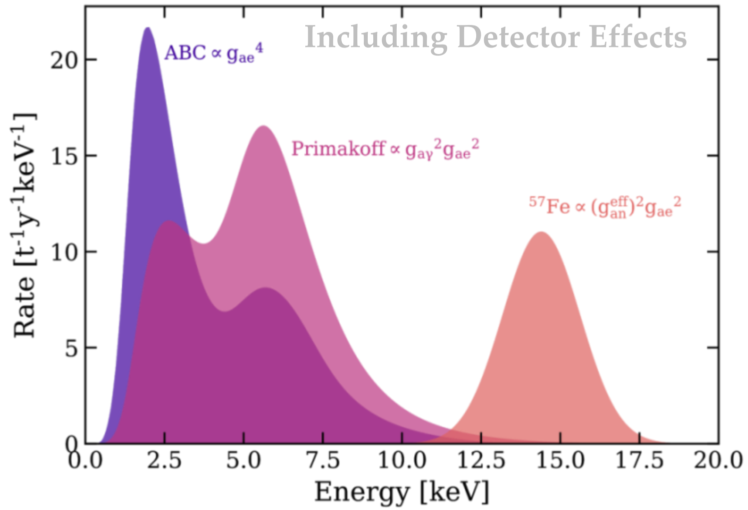
Solar Axions

What could it be?

1. ~~Statistical flukes?~~
2. ~~Background mismodeling?~~
3. ~~Background shape?~~
4. ~~Instrumental backgrounds?~~
5. ~~Missed backgrour~~
6. New background? Maybe
7. New Physics? Maybe

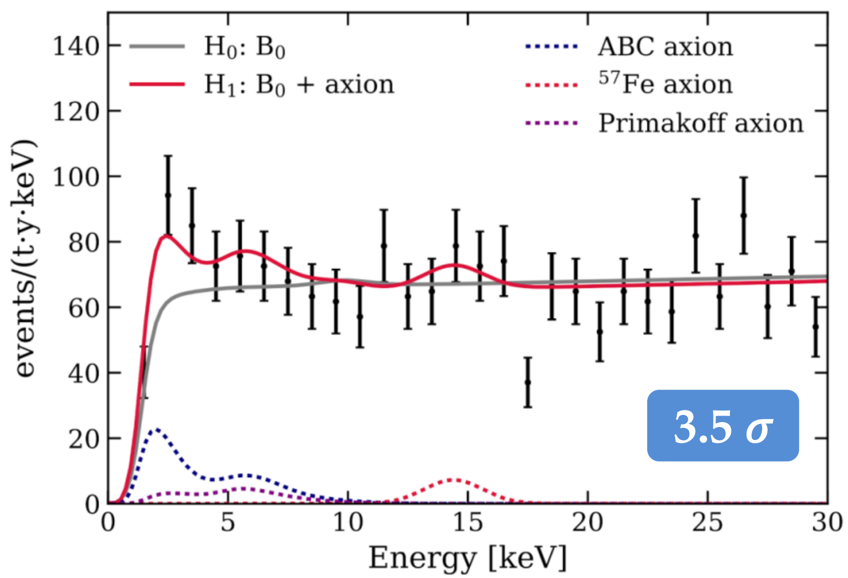
Can detect axions via the axio-electric effect

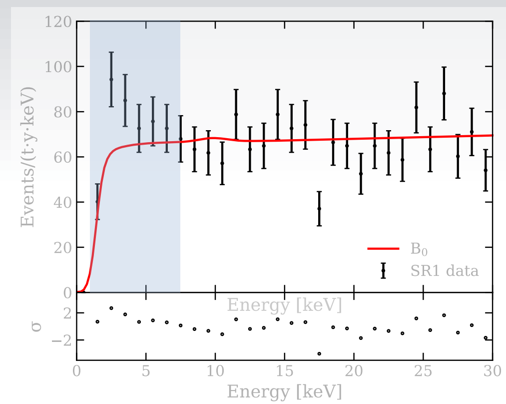




- Looking for axions produced in the sun
- Model-dependent couplings
- Three production mechanisms as independent free parameters

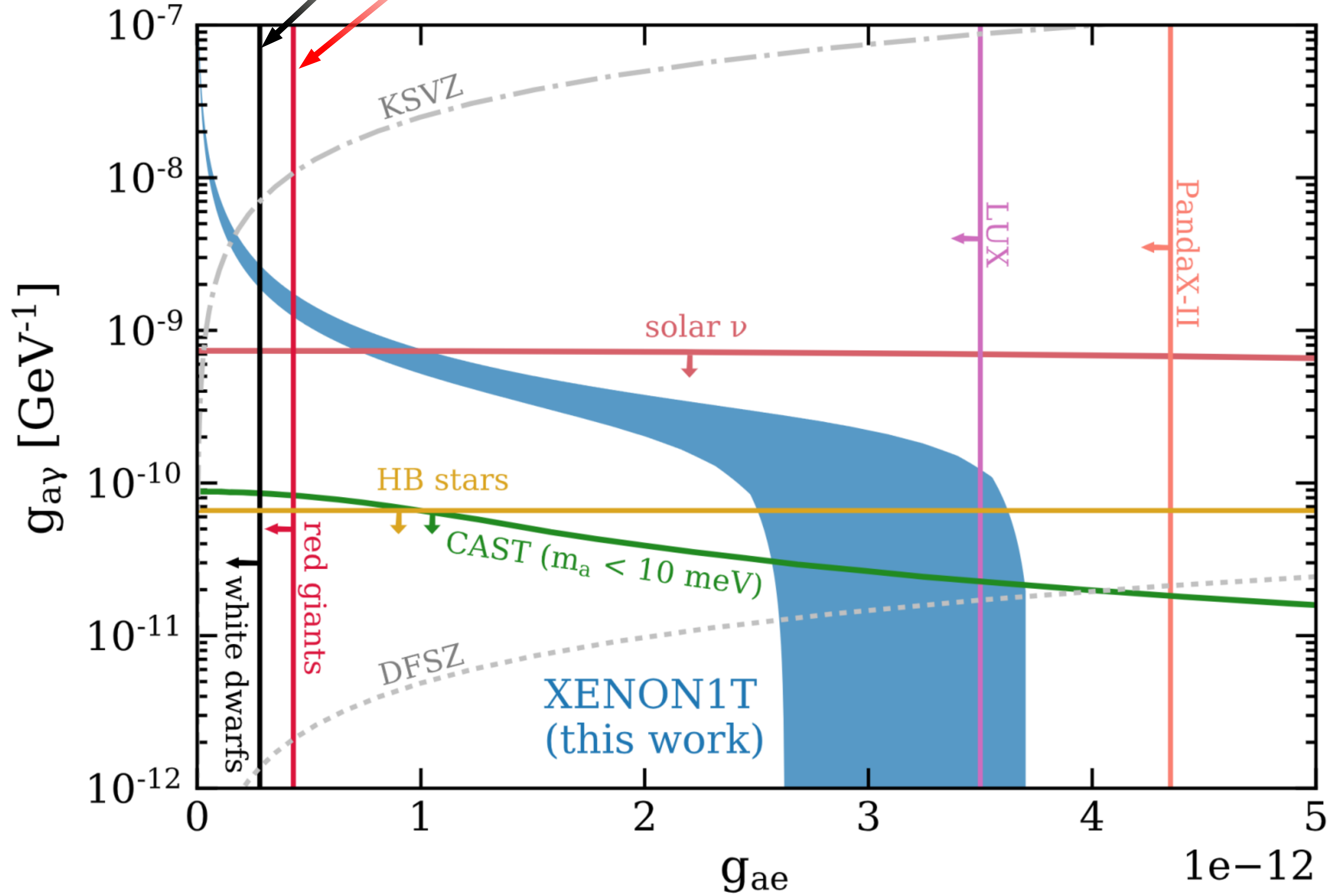
Axion favored over background at 3.5σ
Axion hypothesis favored (2.1σ) over B_0 + ^{3}H





Solar Axions

Axion interpretation is in tension with astrophysical constraints from stellar cooling (arXiv: 2003.01100)



What could it be?

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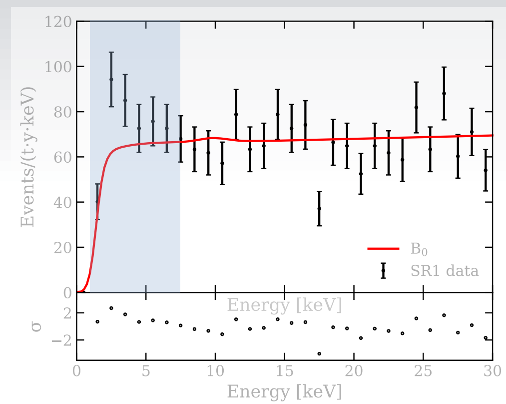
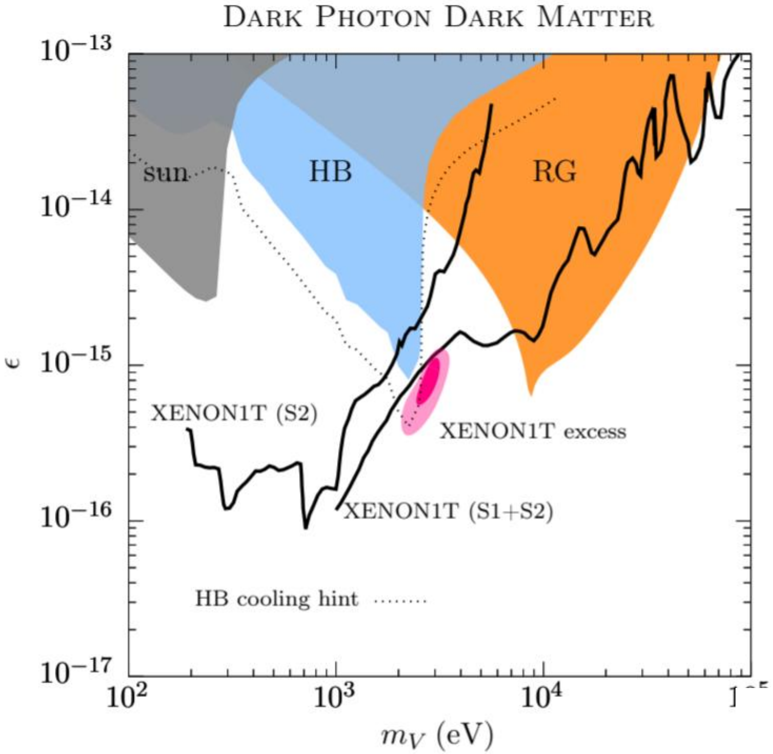


Other interpretations of the Excess

arXiv: 2006.09721v2, arXiv: 2006.13929



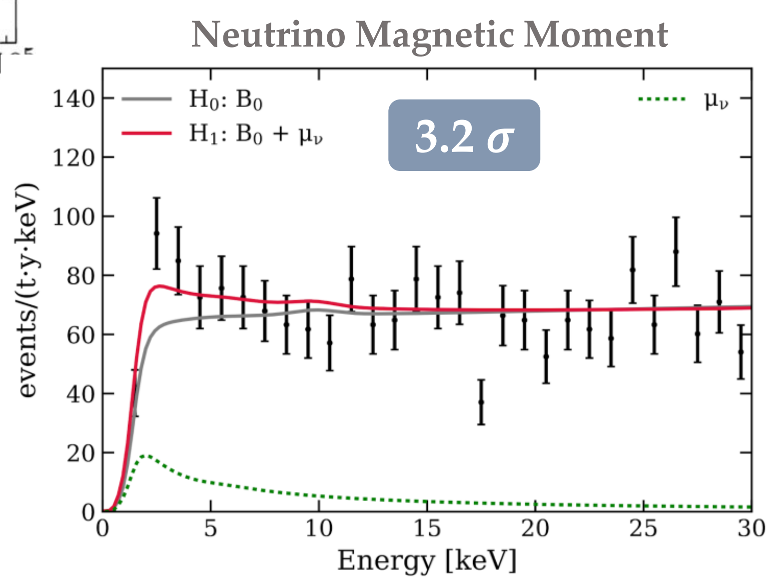
Axion-like particles (ALPs) and dark photons appear as mono-energetic peaks

Favored mass value (2.3 ± 0.2) keV

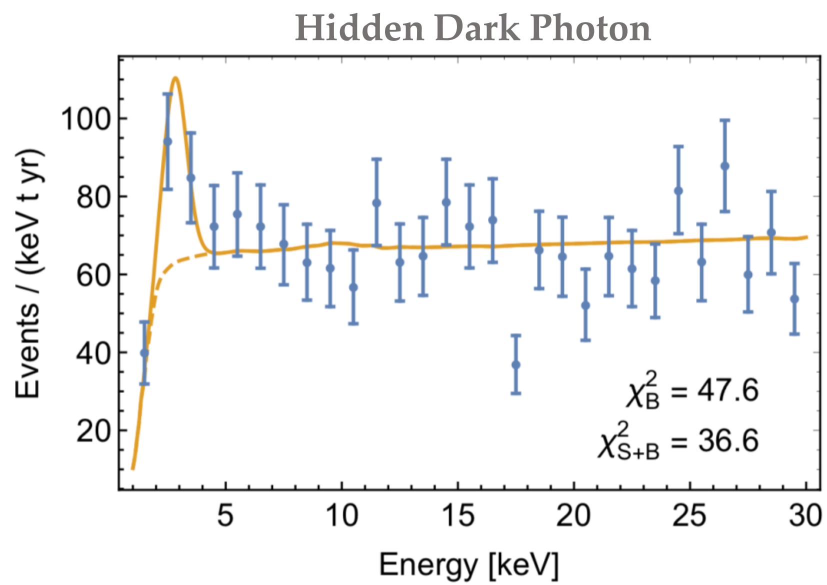
No global significance above 3σ

Other interpretations …

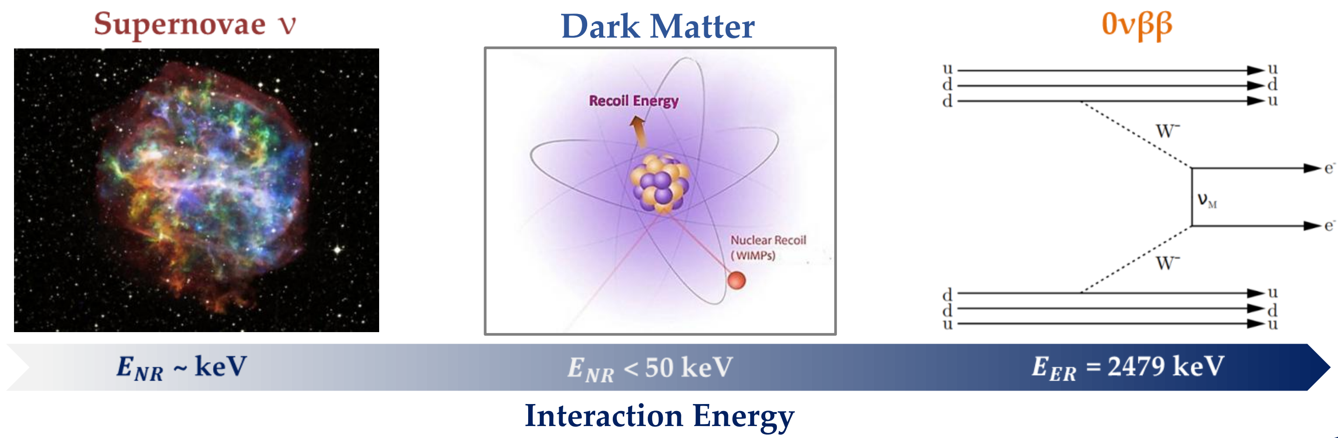
arXiv: 2006.09721v2



arXiv: 2006.11243



The Future - XENONnT Detector



3x LARGER ACTIVE VOLUME

1/6 BACKGROUND LEVEL

COMMISSIONING ONGOING!

First science results in 2021!

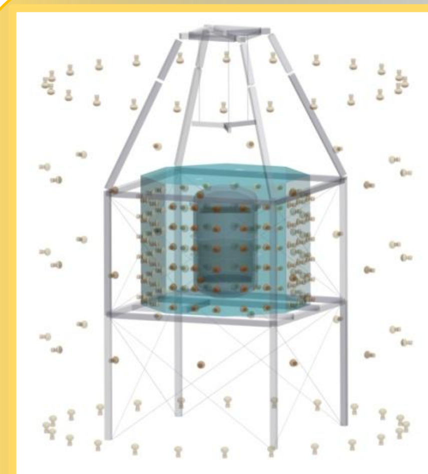
XENONnT Detector

LXe Purification

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

^{222}Rn Distillation

- Reduce Rn (^{214}Pb) from pipes, cables & cryogenic system

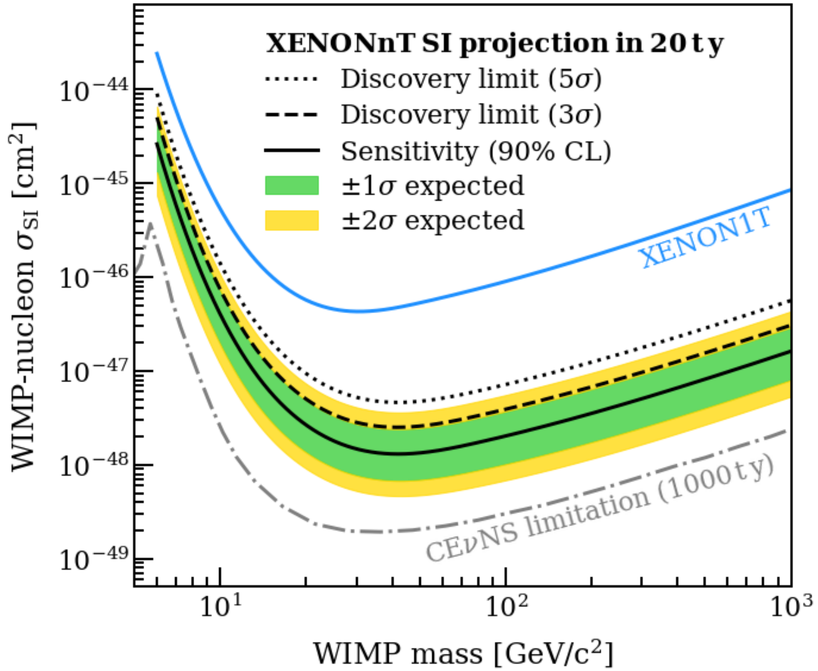


Neutron Veto

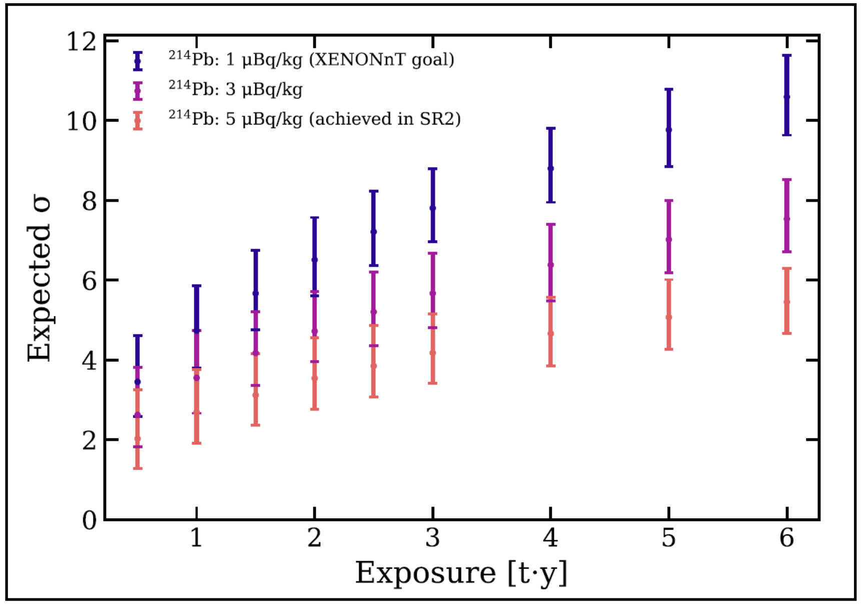
- Optical separator
- 120 PMTs around cryostat
- Gd in the water tank

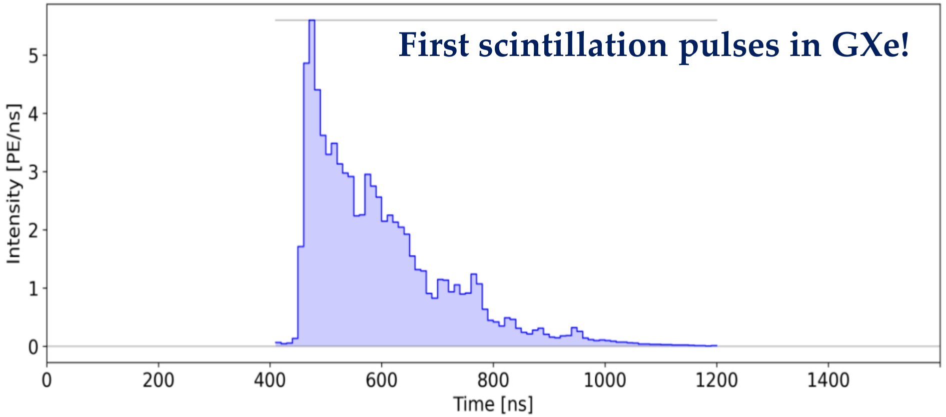
The Future - XENONnT Detector

arXiv: 2007.08796



Discriminate axions vs. tritium with few months of data





xe-pr@lngs.infn.it

www.xenonexperiment.org

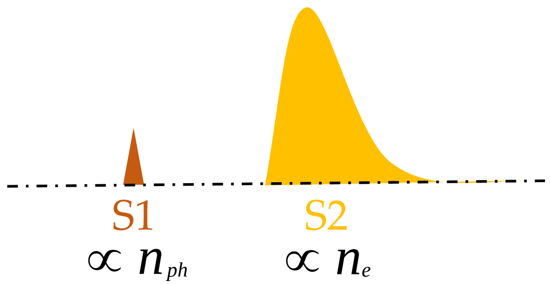
Twitter: https://twitter.com/XENONexperiment

Facebook: https://www.facebook.com/XENONexperiment

Instagram: https://www.instagram.com/xenon_experiment

Backup Slides

Energy Reconstruction & Resolution



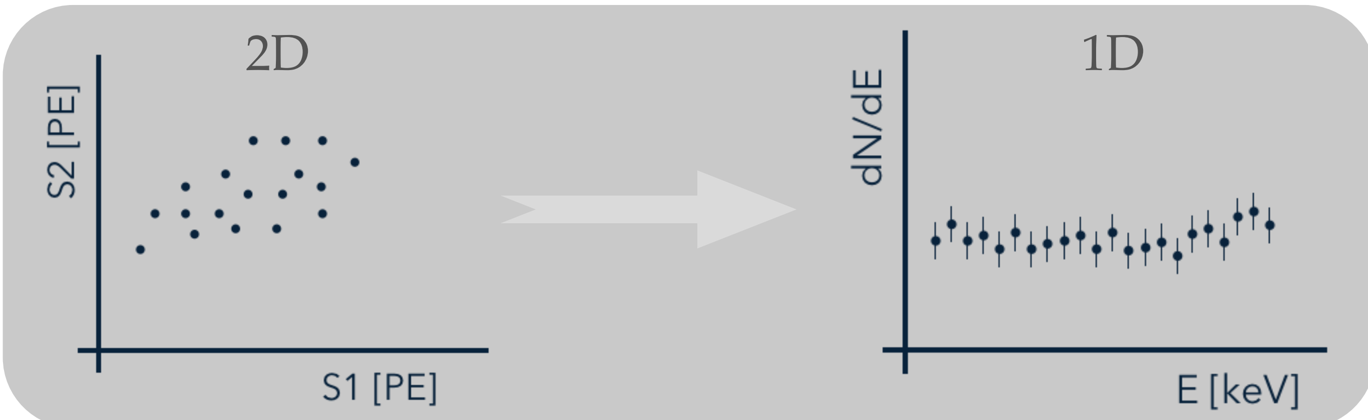
$$E = (n_{ph} + n_e) \cdot W = (\frac{S1}{g1} + \frac{S2}{g2}) \cdot W$$

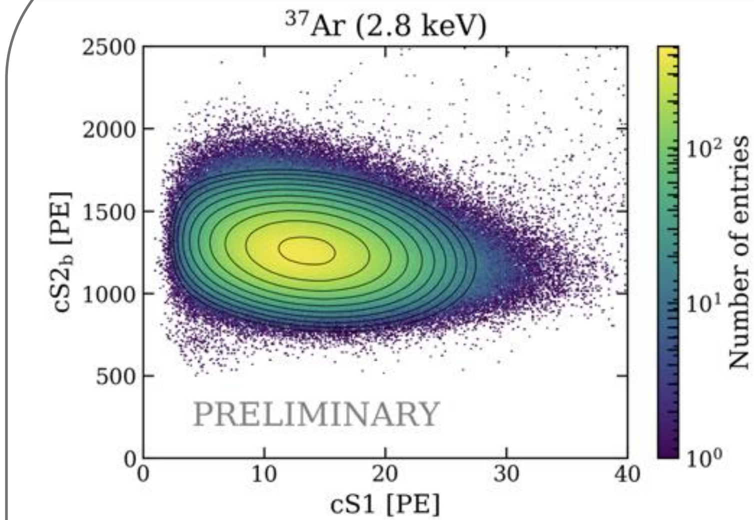
$$\frac{S2}{E} = -\frac{g_2}{g_1}\frac{S1}{E} + \frac{g_2}{W}$$

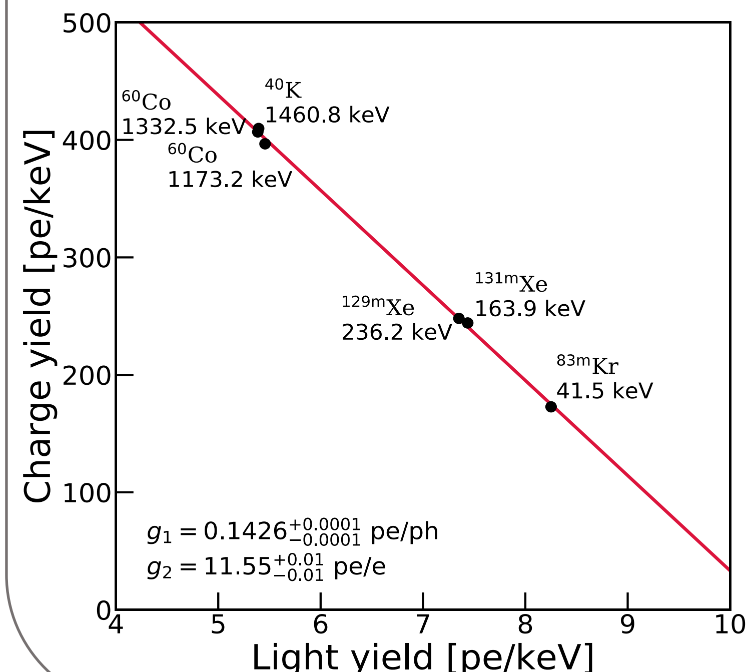
$$y = b + mx$$

$W = 13.7\ eV/quanta$

g1 and g2: detector-specific gain constants

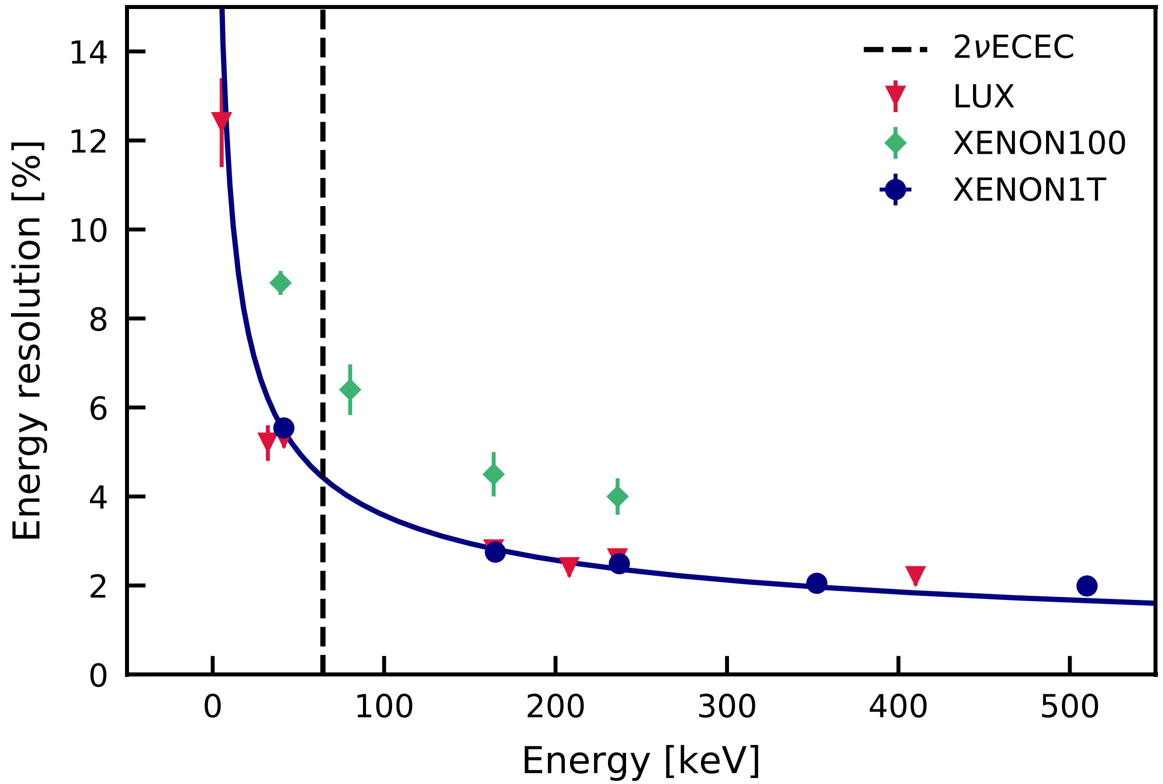






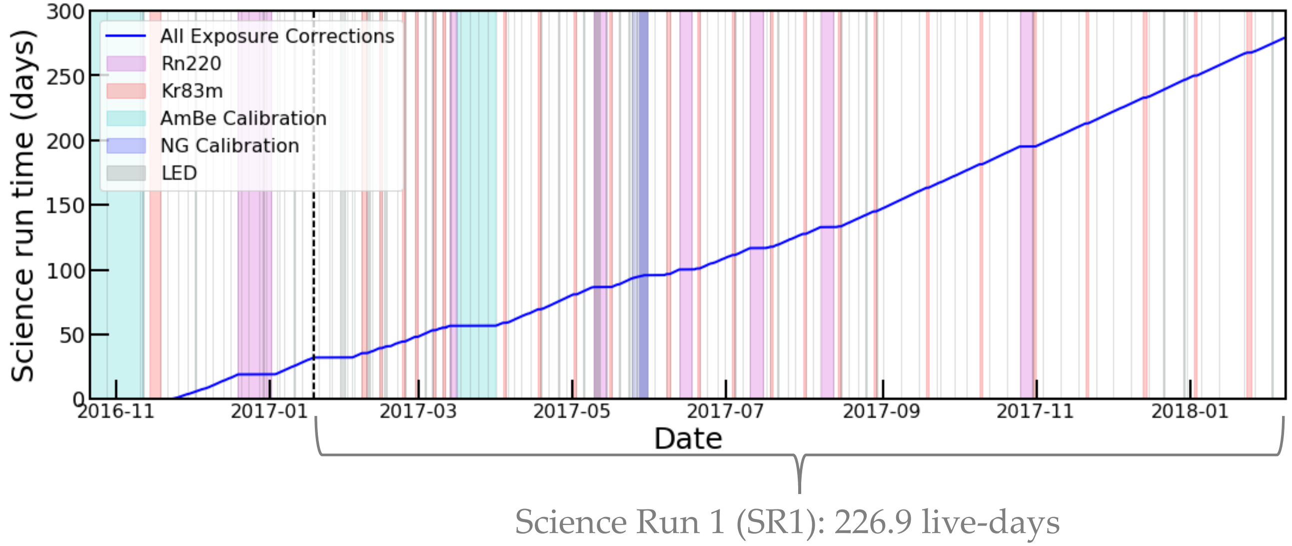
Energy Resolution XENON1T

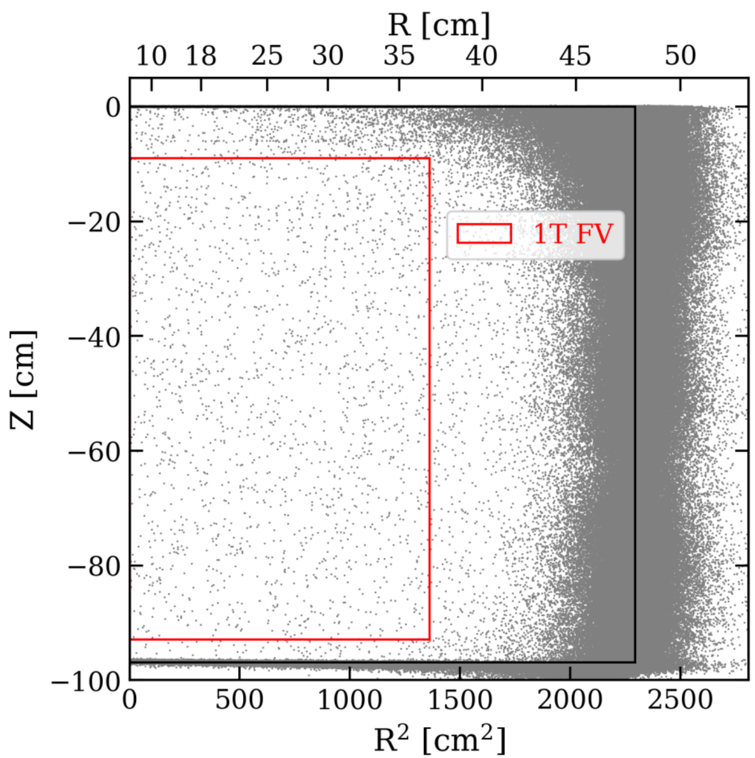
Verified to low energies with XENON1T's microphysics model

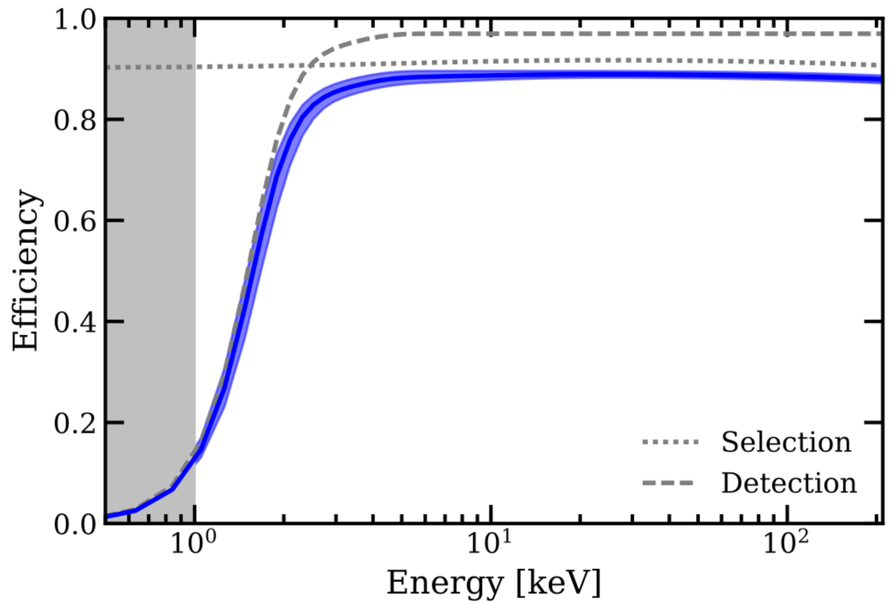


Low-ER Data Selection & Detection Efficiency

- Exposure: 0.65 t · y
- Single-scatter events within [1, 210] keV_{ee}
- 3-fold PMT coincidence for S1 detection
- Standard quality cuts with higher S2 threshold



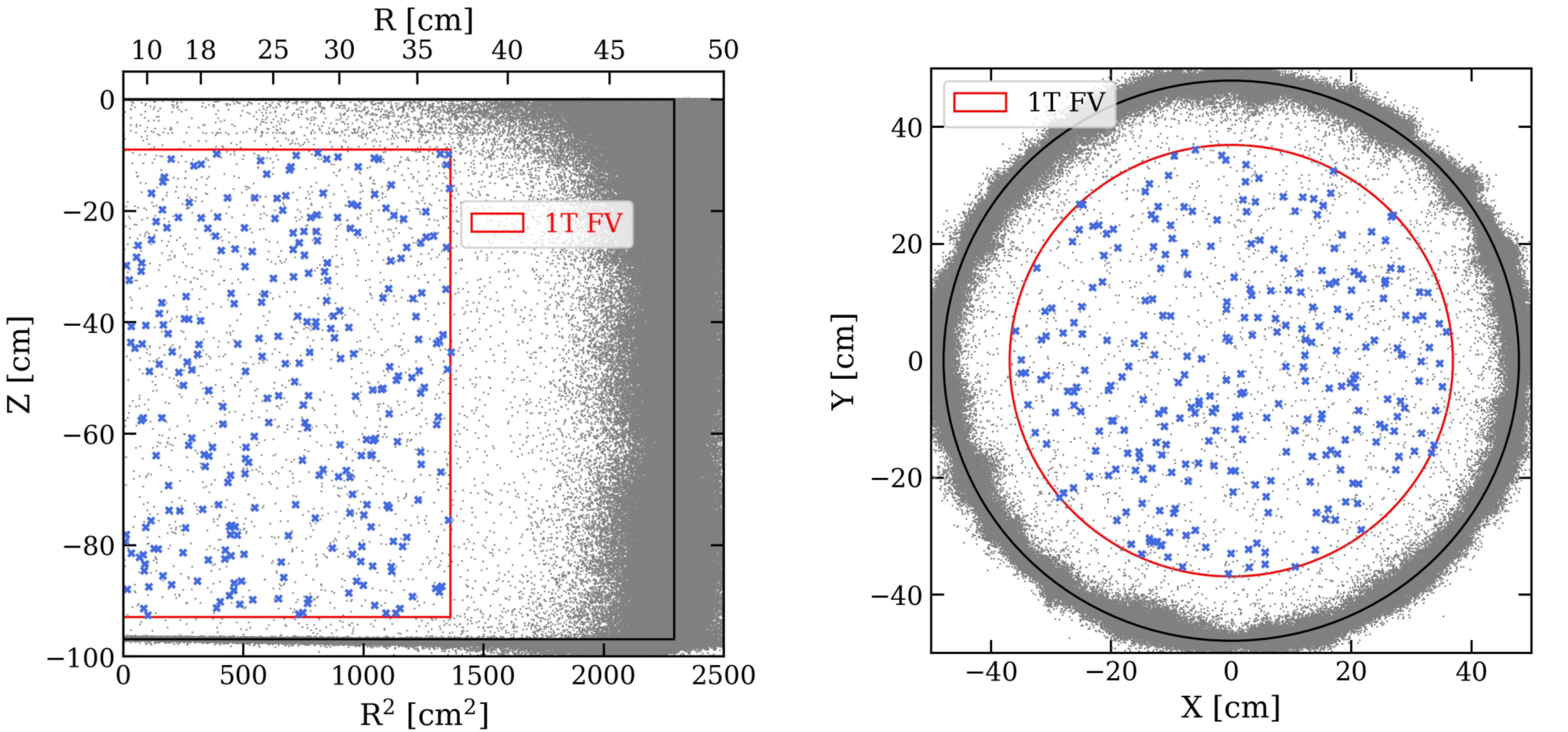




Low-ER Excess Events are Uniform in the Detector

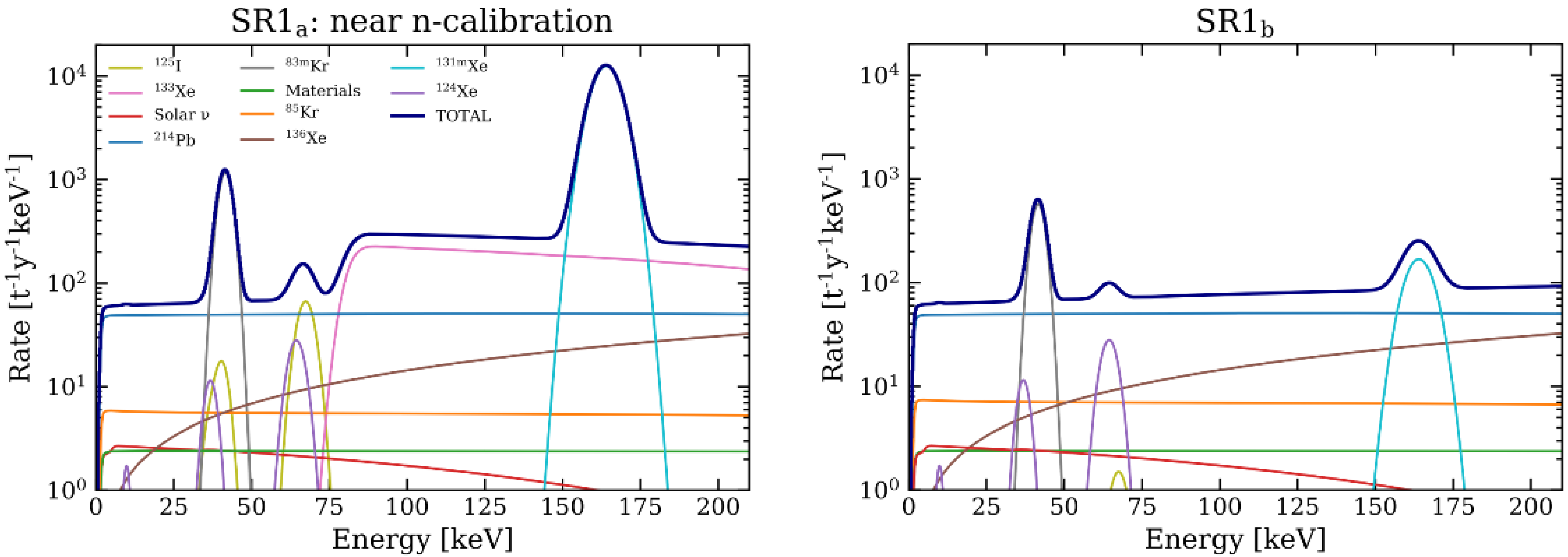
Events energy range:

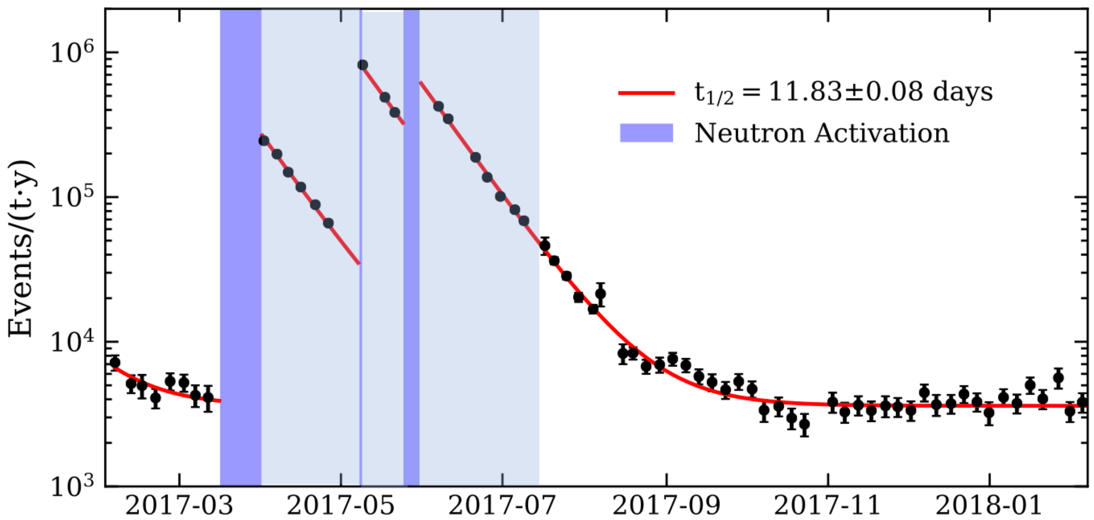
• [1, 210] keV **x** [1, 7] keV



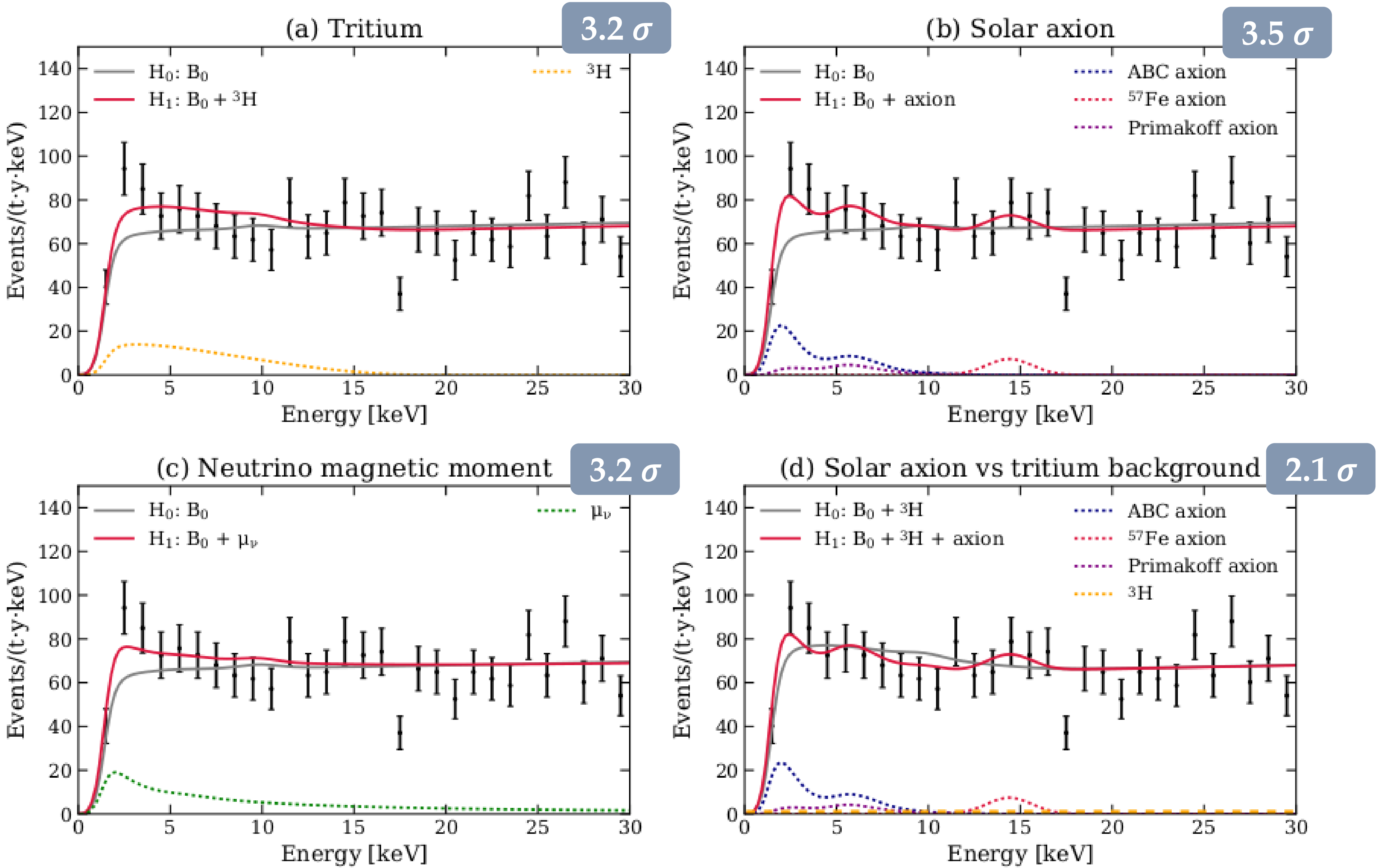
Background Model (SR1a + SR1b)

- Two data partitions to account for activation of Xe during neutron calibration
  - Simultaneous fit of the two datasets

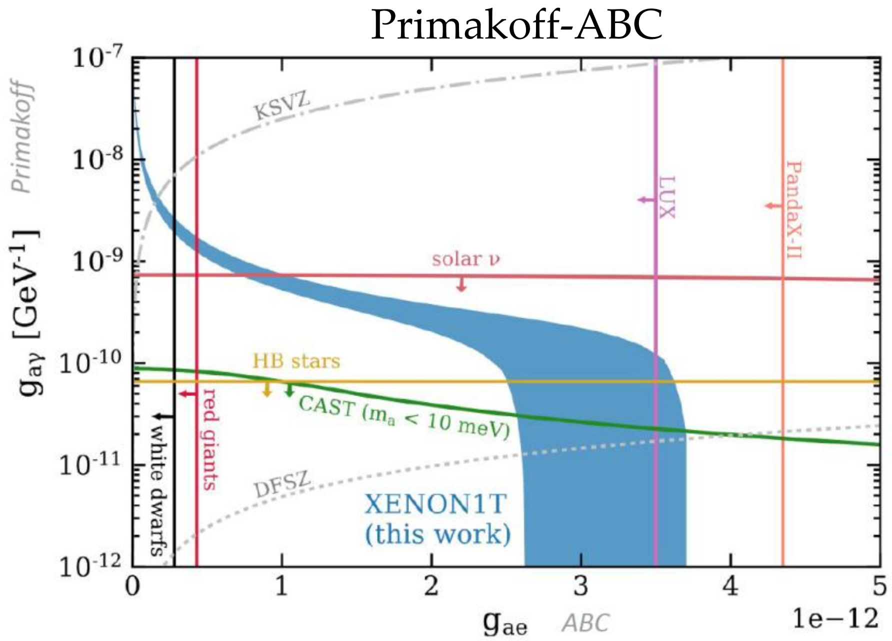


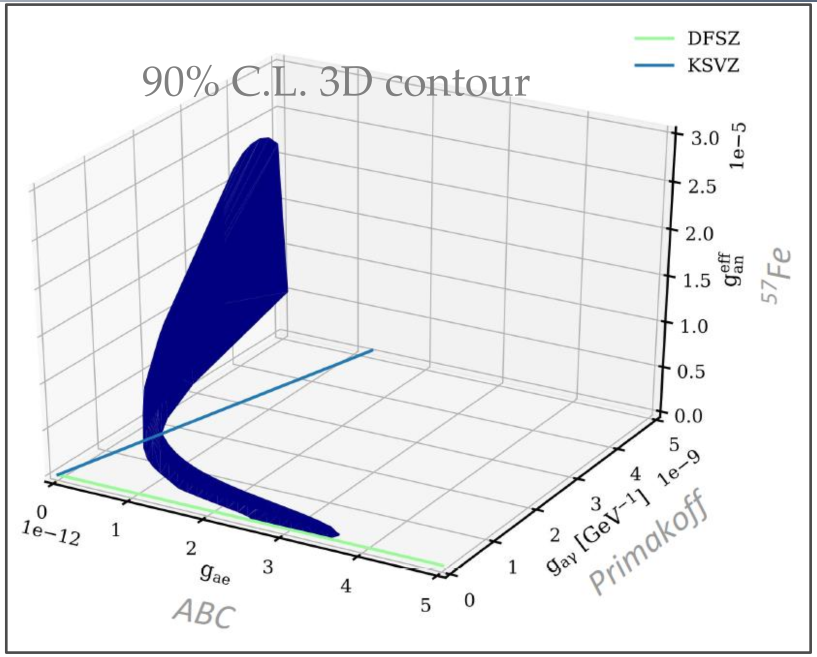


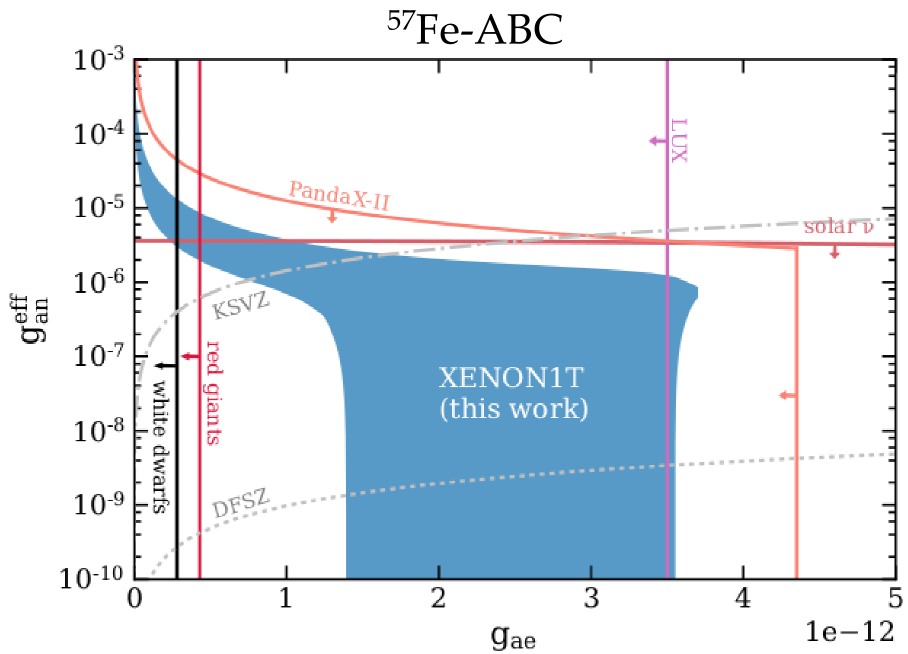
Various Hypotheses

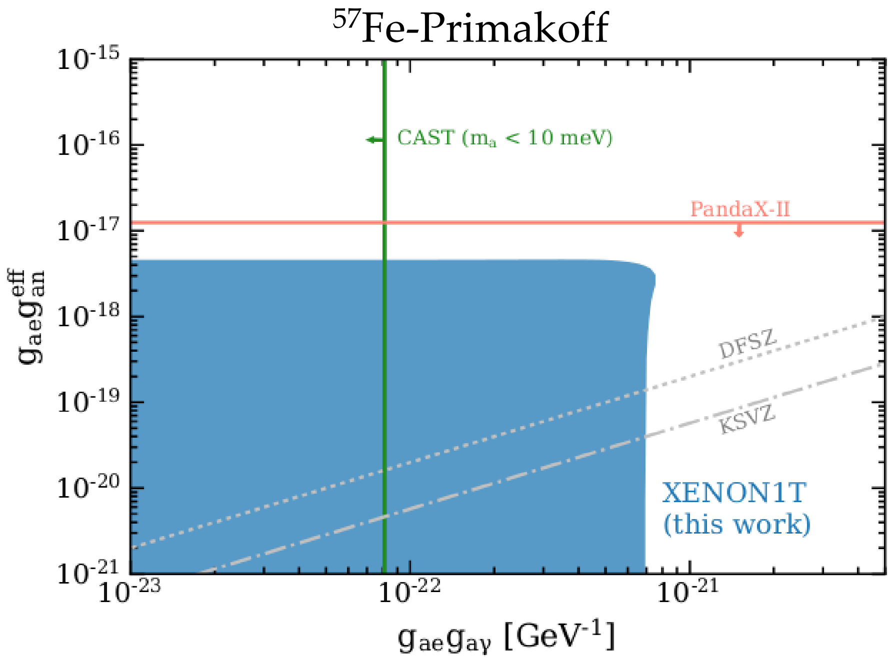


Axion Models Parameter Space Projection

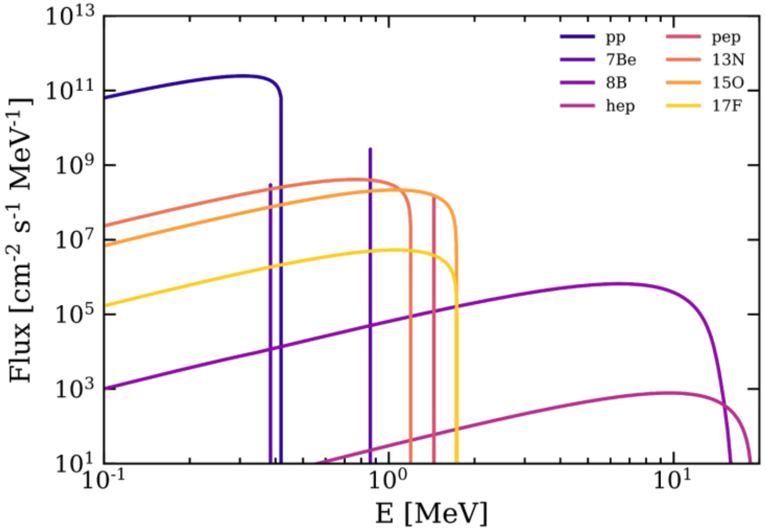


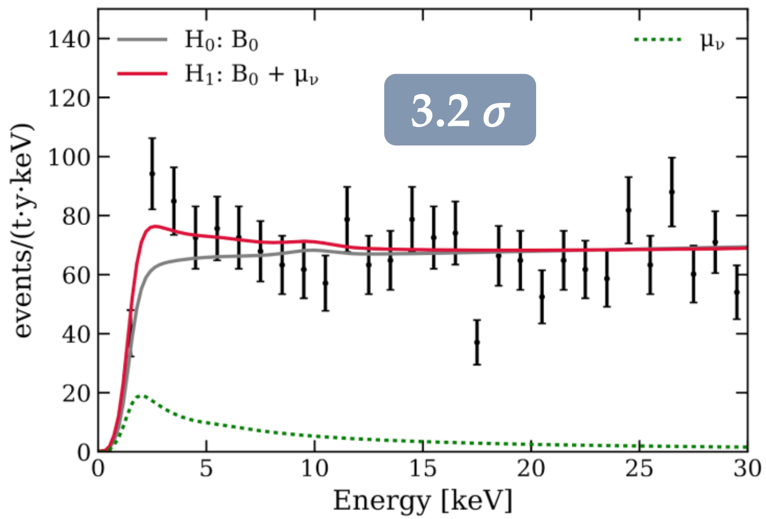






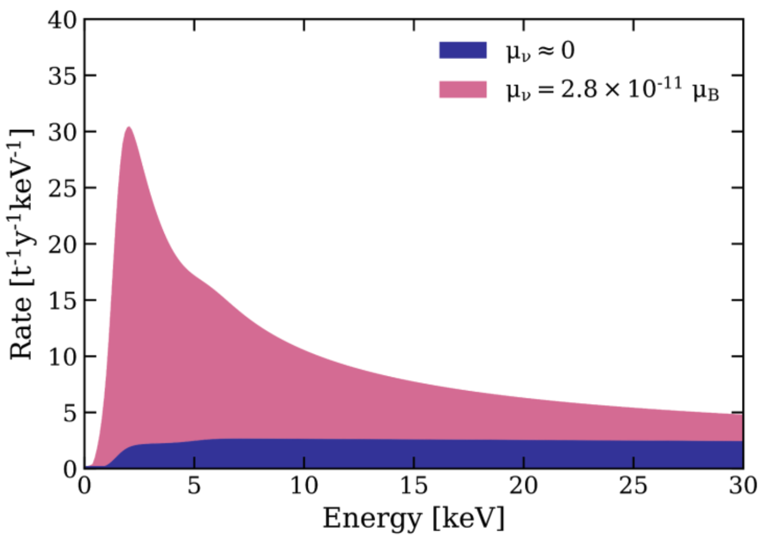
Neutrino Magnetic Moment

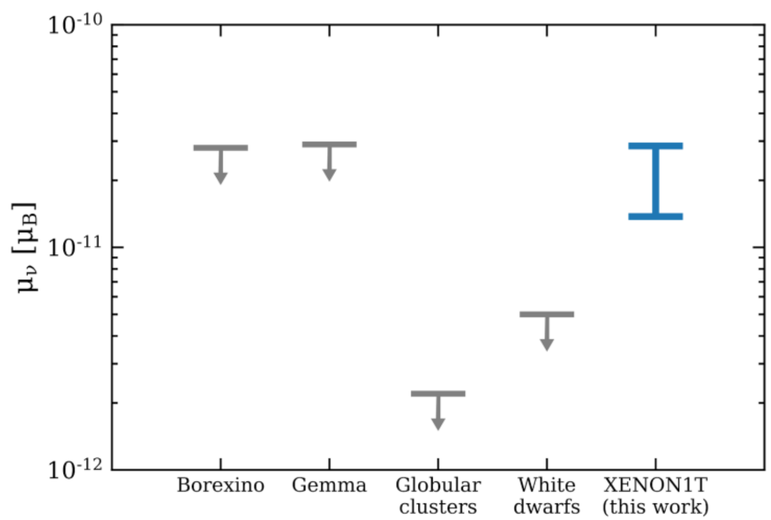




μ_ν in [1.4, 2.9] * 10^{-11} μ_B at 90% C.L.

In strong tension with astrophysical constraints
0.9σ when tritium is included in the background model

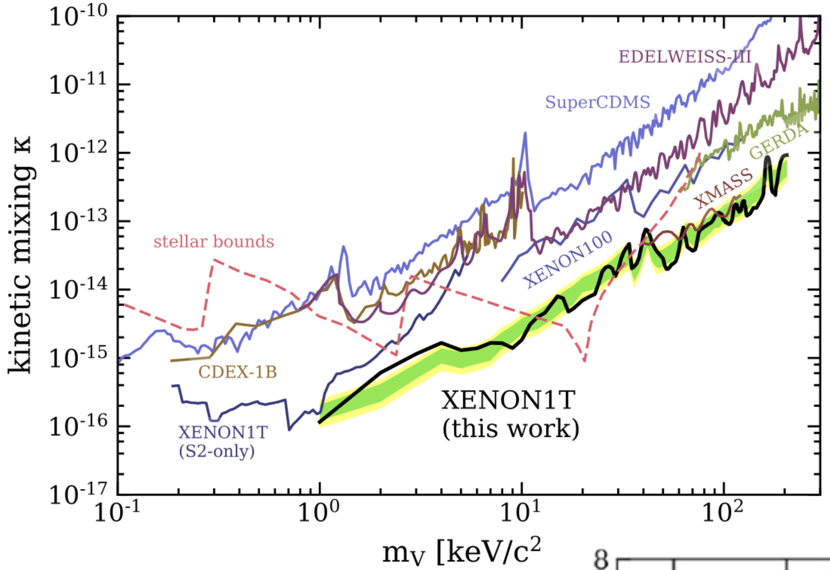


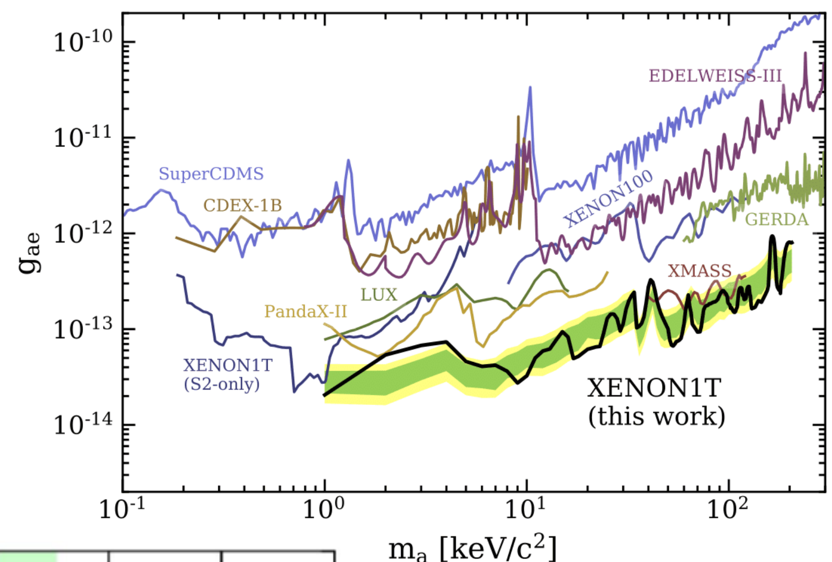


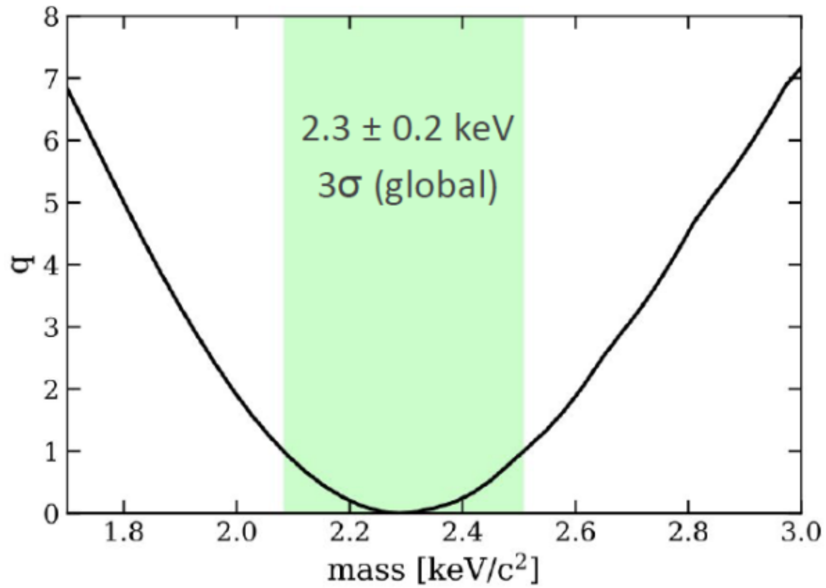
Bosonic Dark Matter

Axion-like particles (ALPs) and dark photons can produce mono-energetic peaks

No global significance above 3σ for this search under background model B_0







Low-ER Excess Time Dependence