XENON1T and its excess of electronic recoil events

HEPHY, Vienna, September 8, 2020

On behalf of the XENON collaboration

Sebastian Lindemann
University of Freiburg

sebastian.lindemann@physik.uni-freiburg.de

Welcome to BBC.com

Thursday, 18 June

Trump sought China's help with election - Bolton

Details from the new book by the president's ex-national security adviser include damning accusations.

US & CANADA

US-China row moves underwater in cable tangle

ASIA

Dark matter hunt yields unexplained signal

SCIENCE & ENVIRONMENT

Witty portraits of people in nature around the world

CULTURE

The largest electric plane ever to fly

FUTURE PLANET

News

The XENON collaboration

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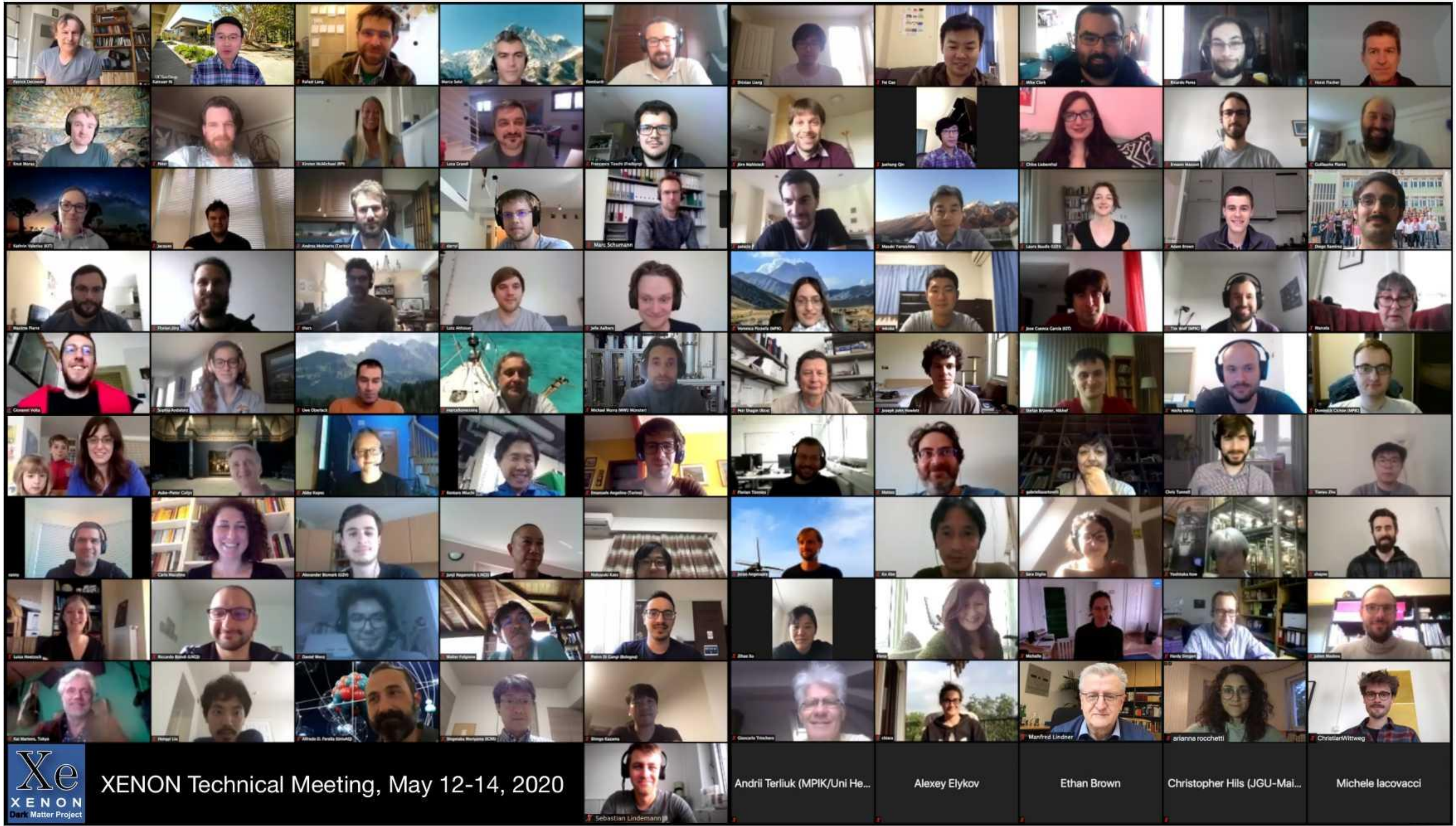
Marc Schumann
Manfred Lindner
arianna rocchetti
ChristianWittweg
Xe
XENON
Dark Matter Project
XENON Technical Meeting, May 12-14, 2020
Sebastian Lindemann
Andrii Terliuk (MPIK/Uni He...
Alexey Elykov
Ethan Brown
Christopher Hils (JGU-Mai...
Michele Iacovacci


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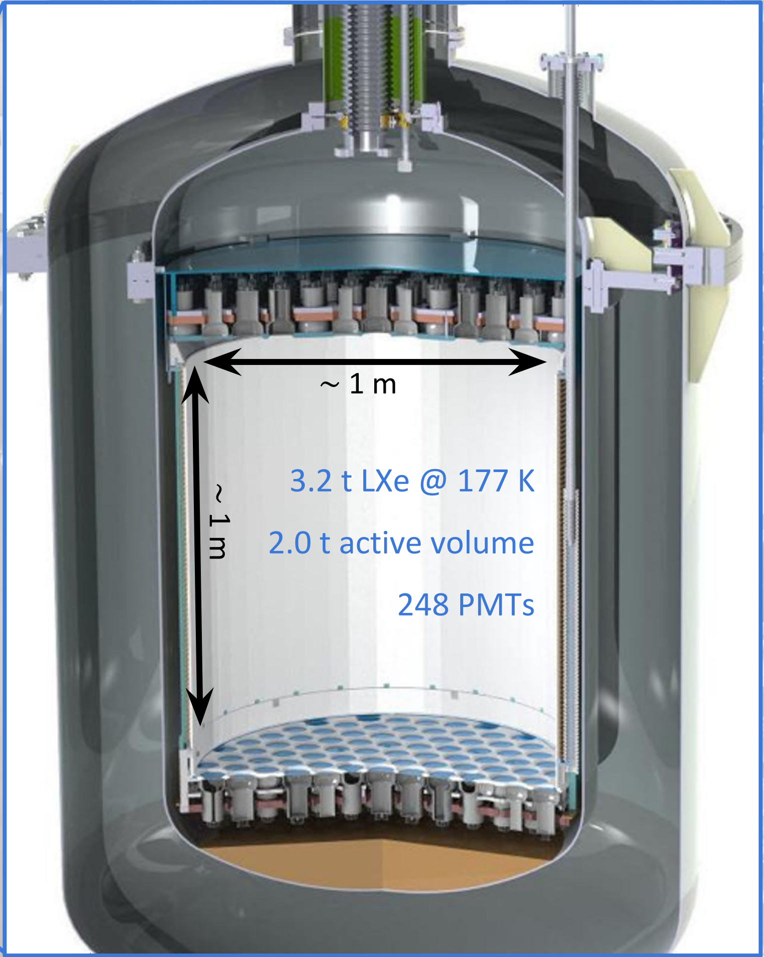
@ Laboratori Nazionali del Gran Sasso



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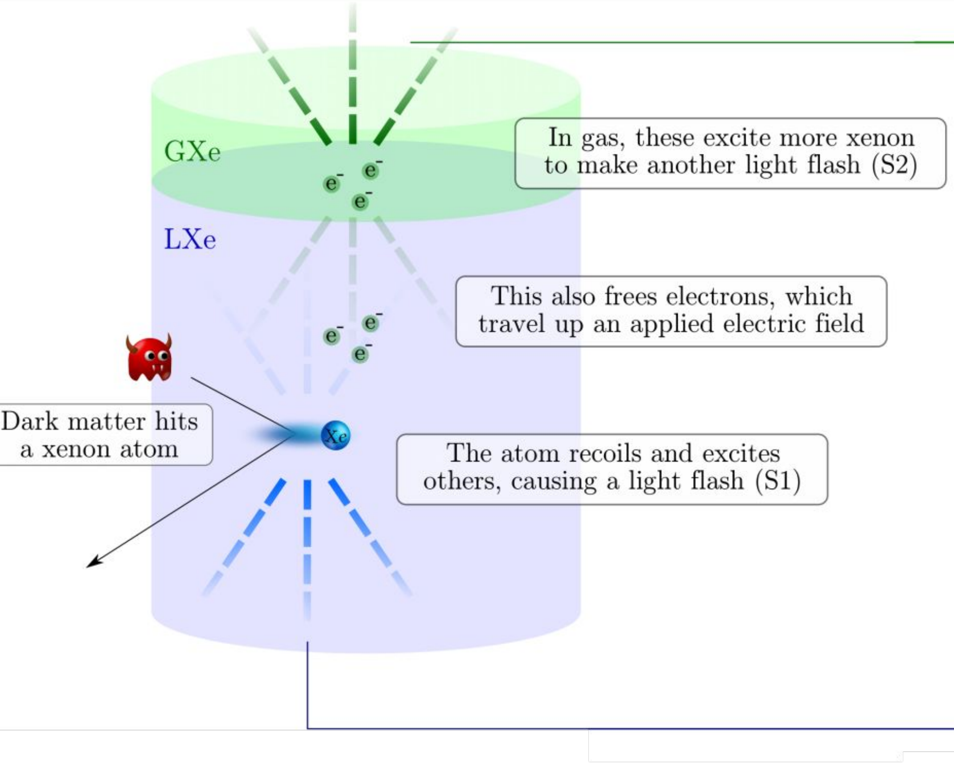
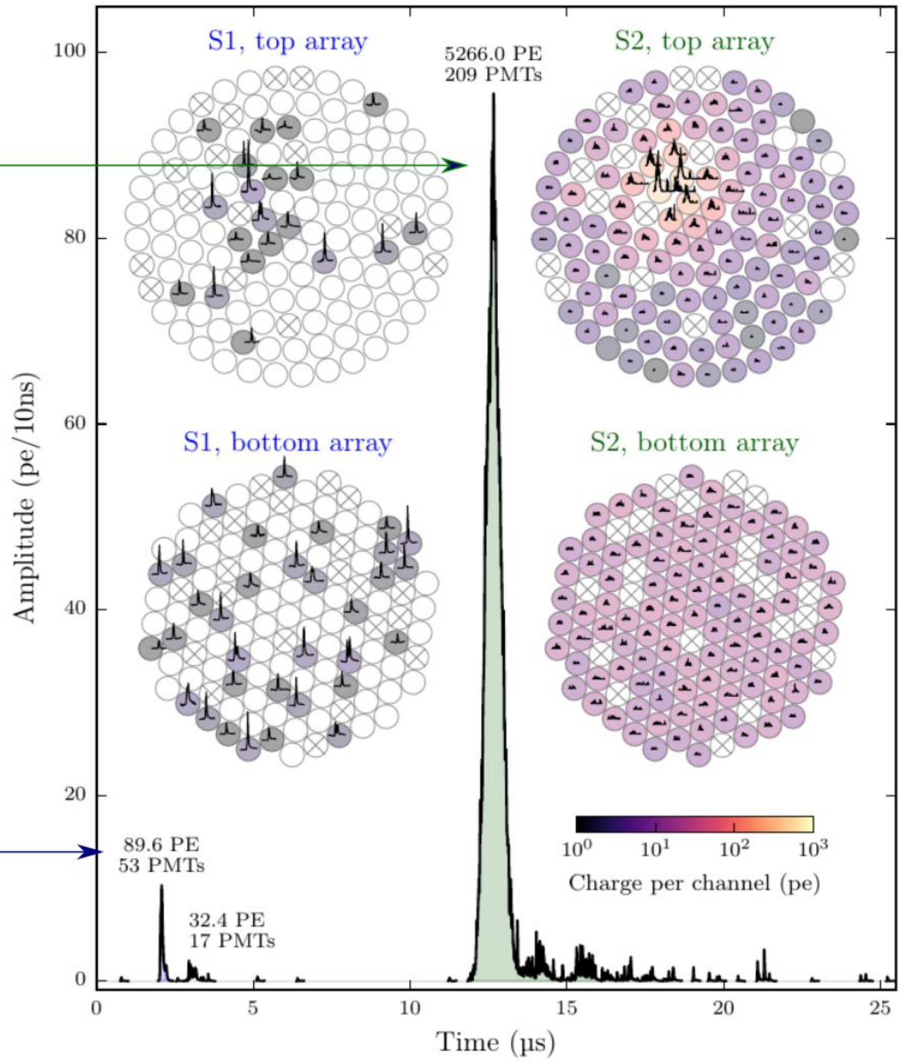
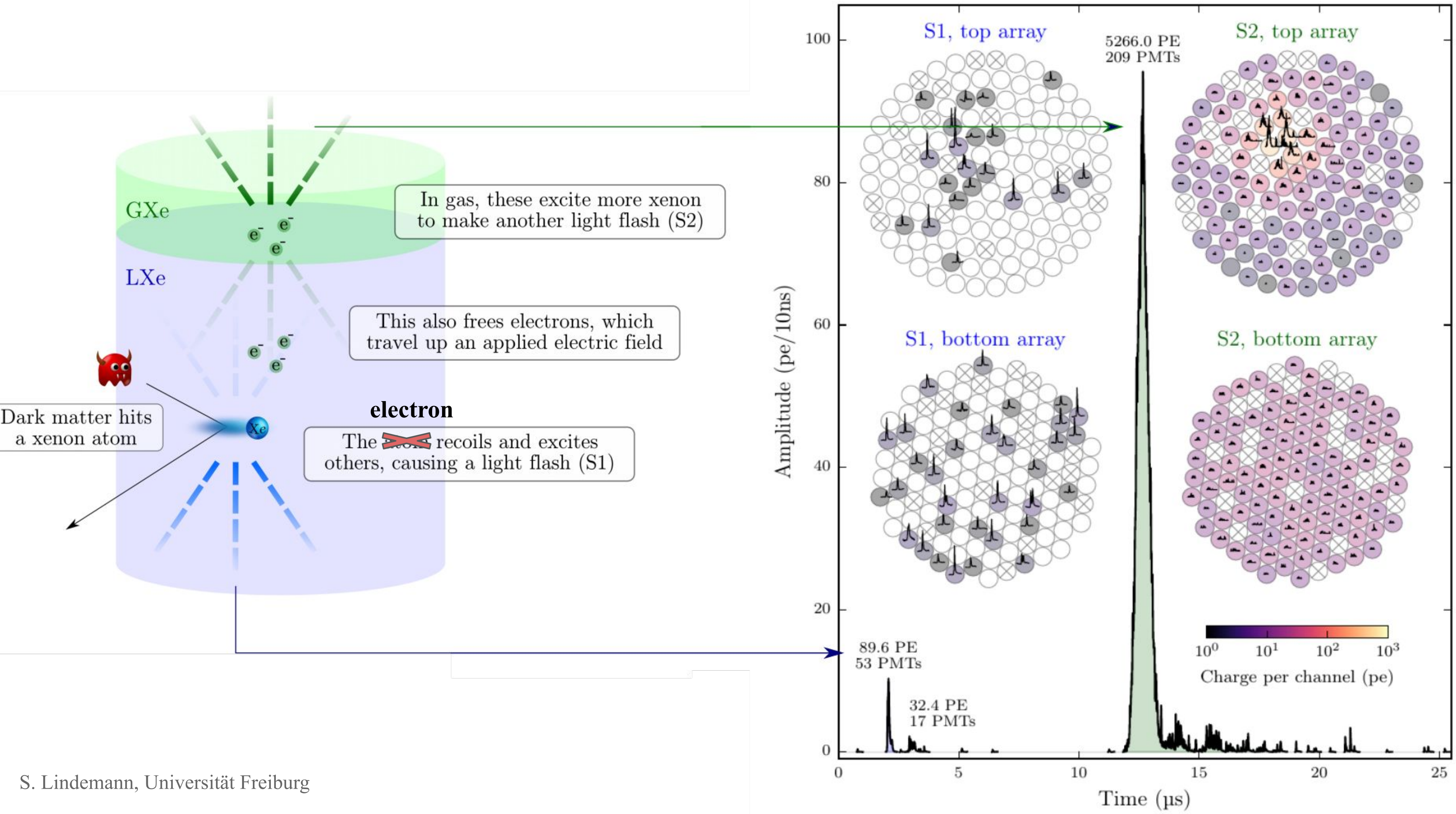


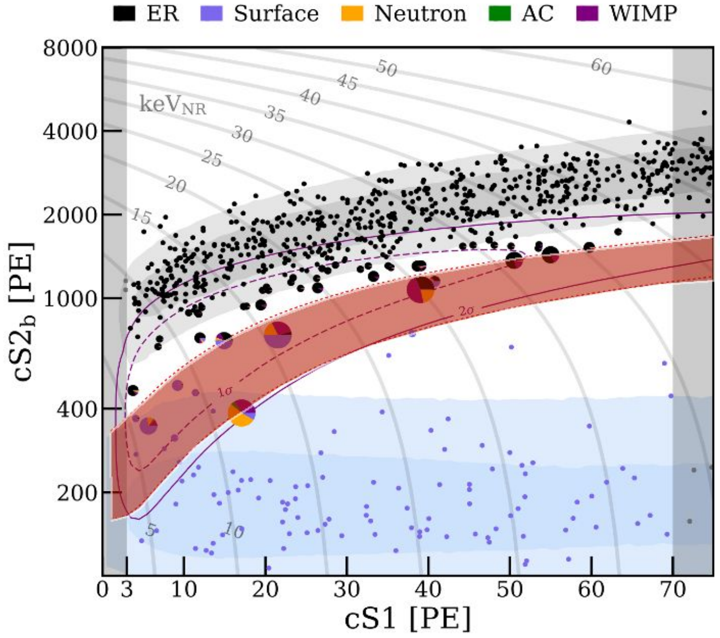


S. Lindemann, Universität Freiburg



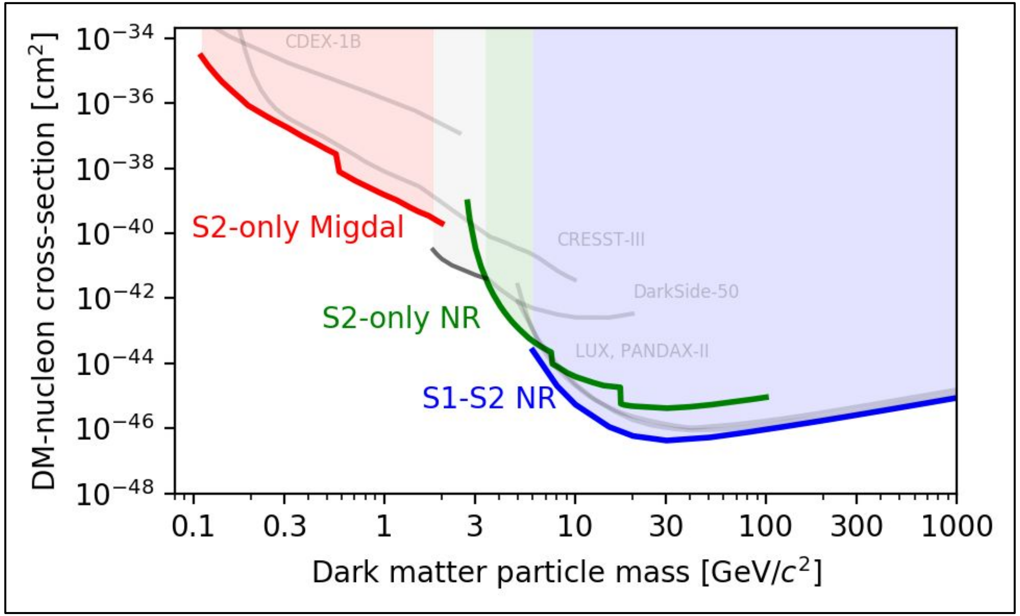
S. Lindemann, Universität Freiburg

Nuclear Recoil Search



ER “leakage” in the NR band < 0.3 %

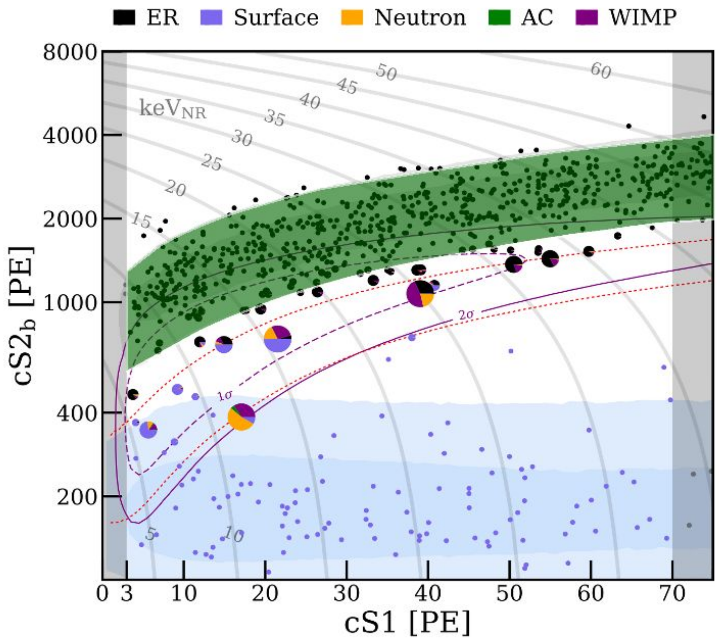
Best constraints on WIMP dark matter with masses > 3 GeV/c^2



PRL 123, 241803 - Migdal effect

PRL 123, 251801 - Light dark matter

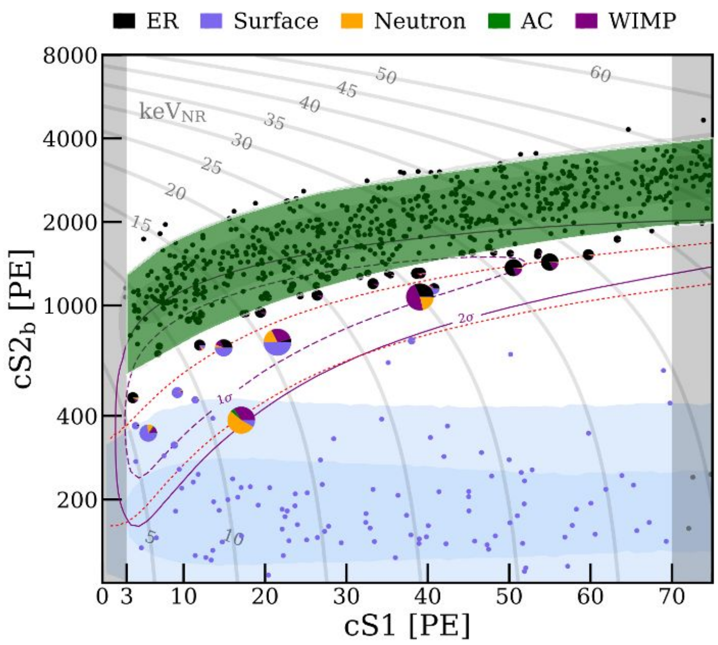
PRL 121, 111302 - Main WIMP search

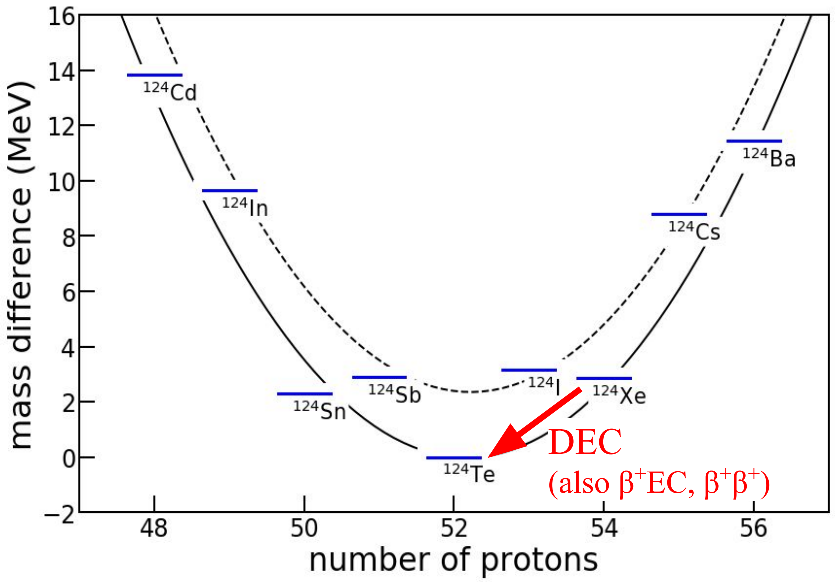


Electronic Recoil Search (this talk)

ER band search for excess above known backgrounds

^{124}Xe DEC





nature
International journal of science

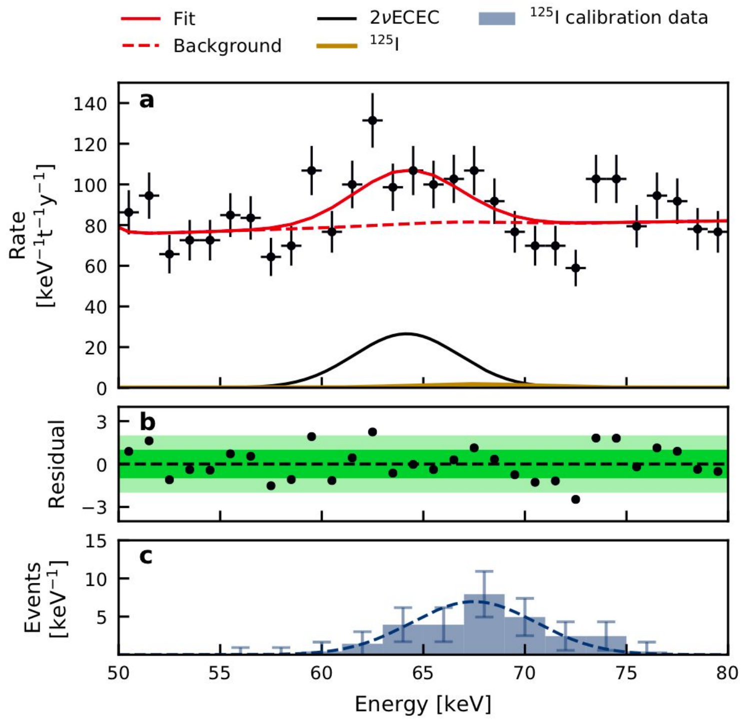
Letter | Published: 24 April 2019

Observation of two-neutrino double electron capture in ^{124}Xe with XENON1T

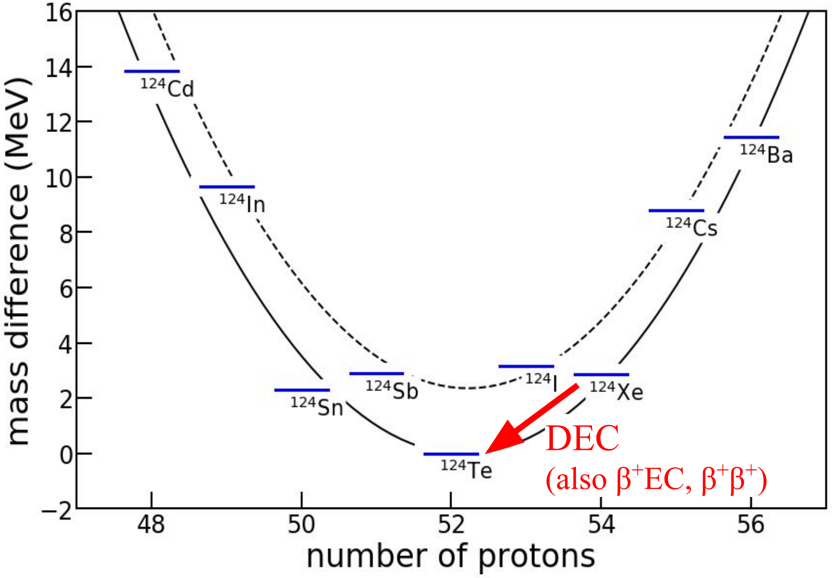
XENON Collaboration*

Nature **568**, 532–535 (2019) | Download Citation

^{124}Xe DEC

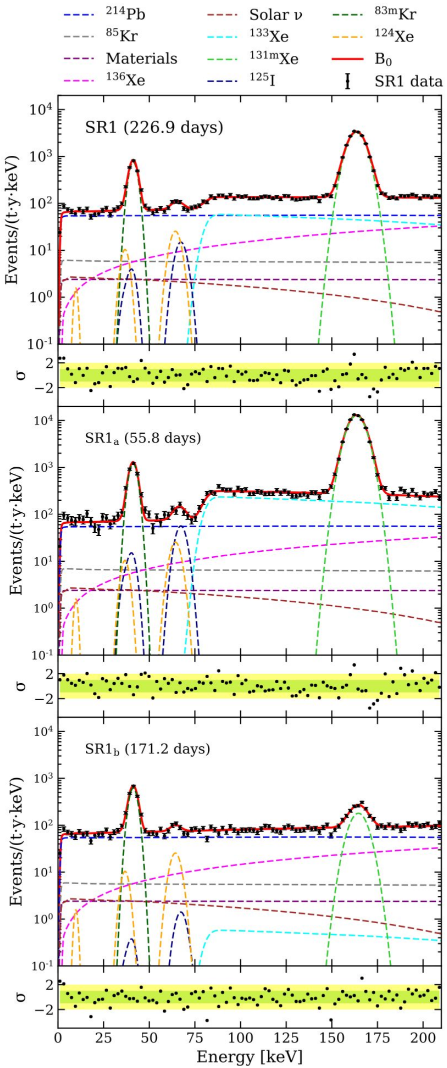


double K-shell capture: **E_{DEC}= 64.3 keV**

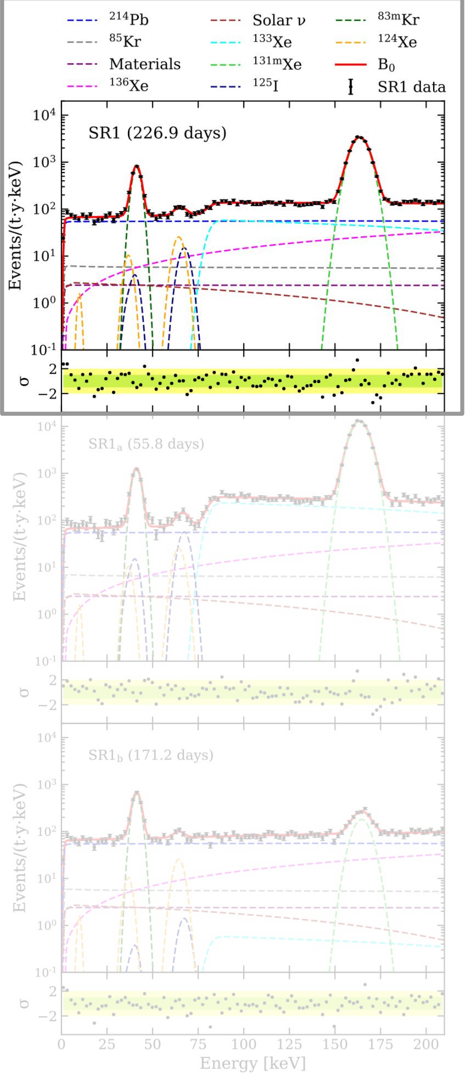


$T_{1/2} = (1.8 \pm 0.5_{stat} \pm 0.1_{sys}) \times 10^{22}$ yr

Longest direct measured half-life

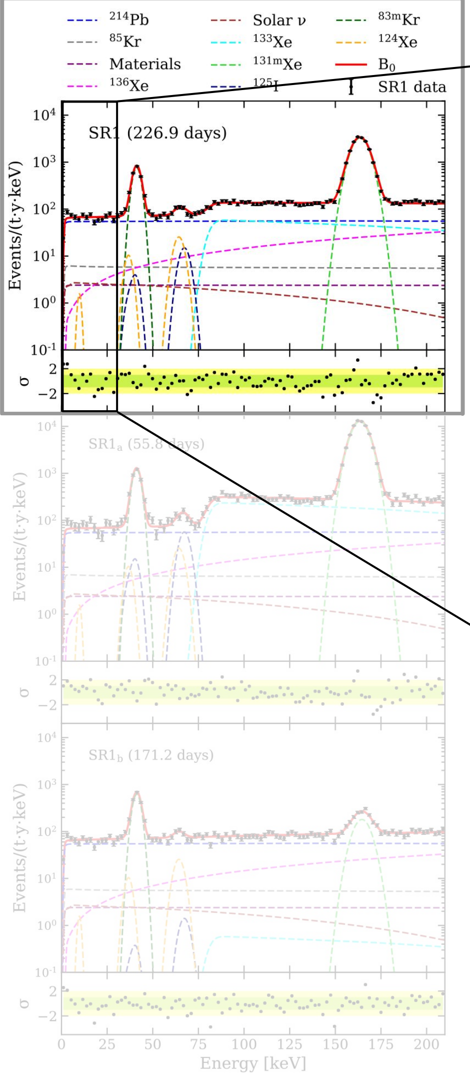


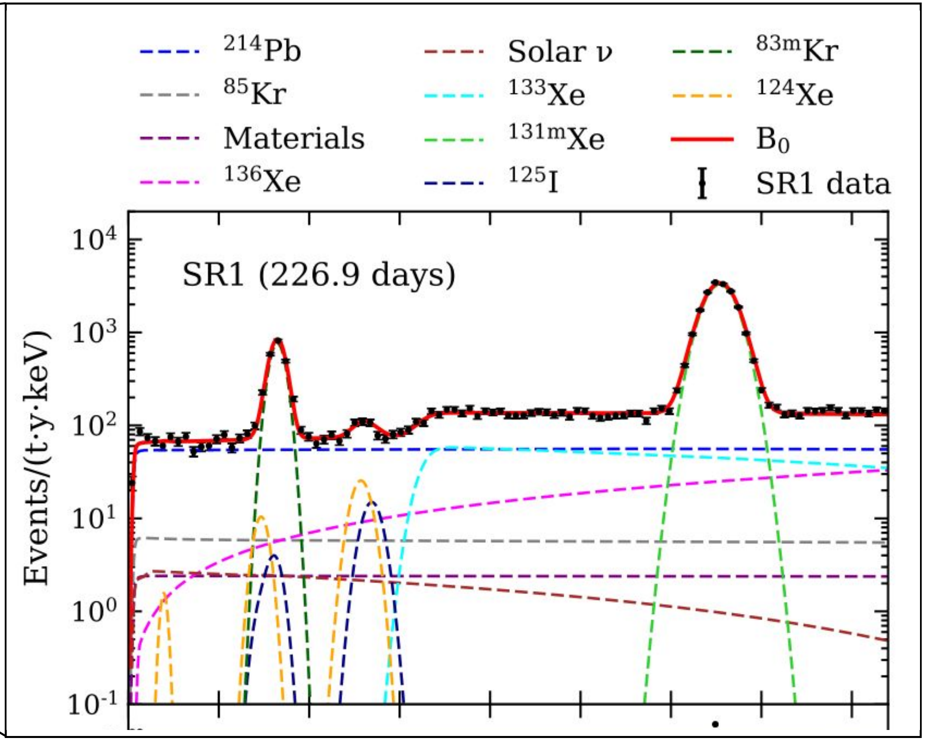
^{214}Pb
^{85}Kr
Materials
^{136}Xe
Solar ν
^{133}Xe
^{131m}Xe
^{125}I
^{83m}Kr
^{124}Xe
B_0
SR1 data
SR1 (226.9 days)
SR1$_a$ (55.8 days)
SR1$_b$ (171.2 days)
Events/(t·y·keV)
σ
Energy [keV]



(76 ± 2) events/(t·y·keV) in [1, 30] keV

Lowest background rate ever achieved in this energy range!

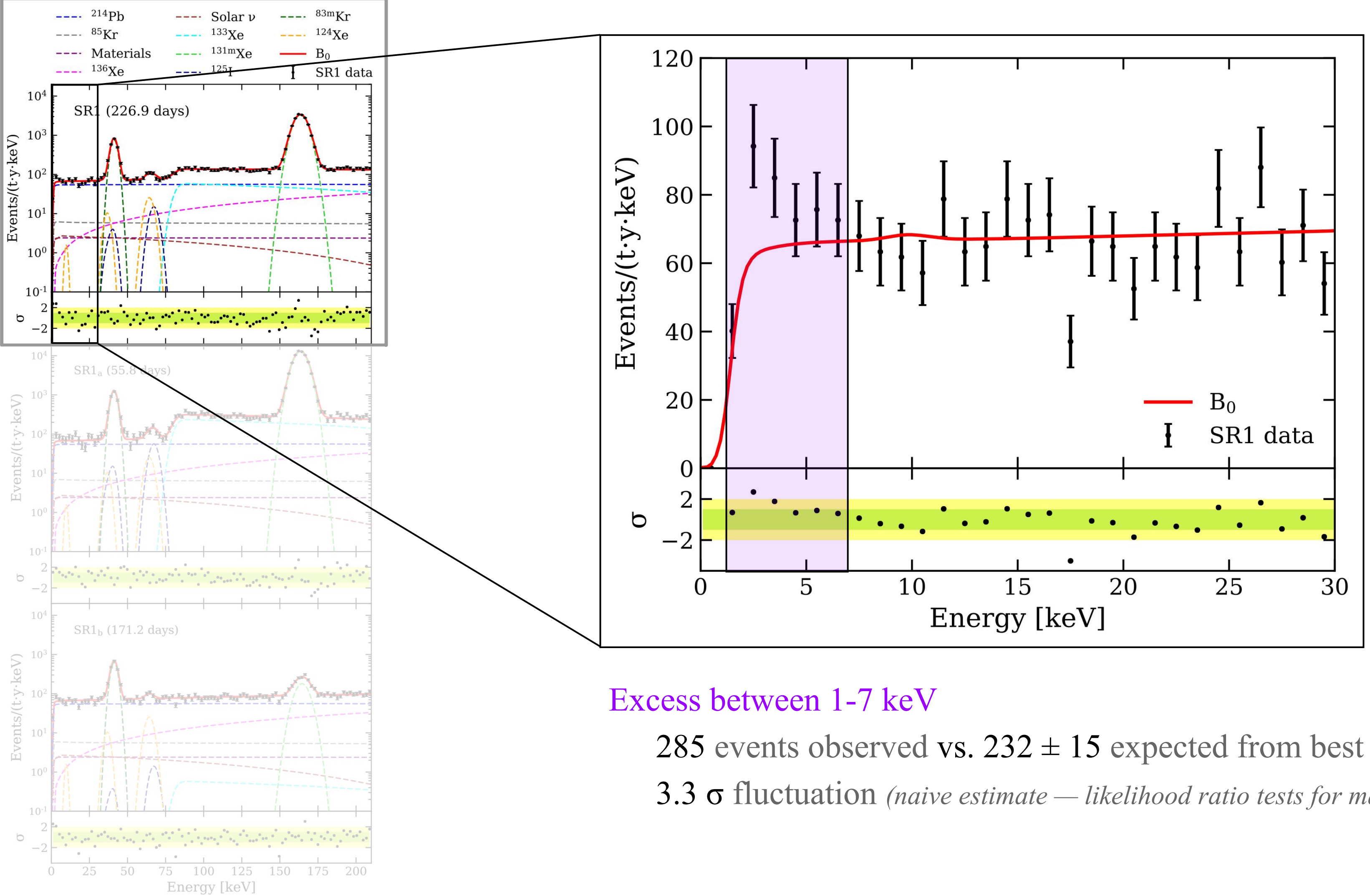




Excess between 1-7 keV

285 events observed vs. 232 ± 15 expected from best fit

3.3 σ fluctuation *(naive estimate — likelihood ratio tests for main analysis)*

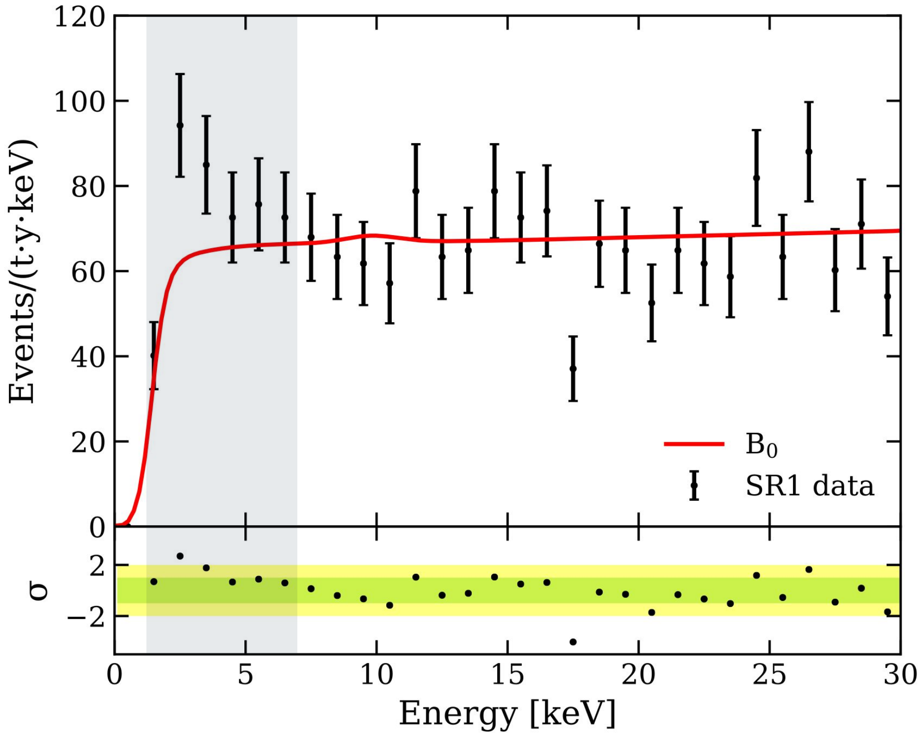


Excess between 1-7 keV

285 events observed vs. 232 ± 15 expected from best fit

3.3 σ fluctuation *(naive estimate — likelihood ratio tests for main analysis)*

ArXiv:2006.09721 : 3 - 3.4 σ excess in electronic recoils



Statistical fluke?

Systematic error?

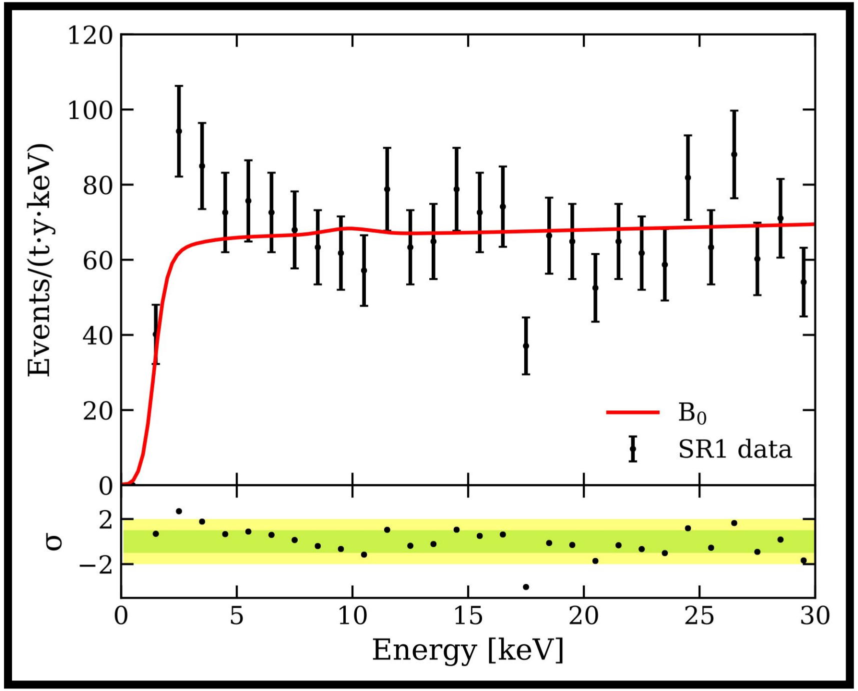
New background?

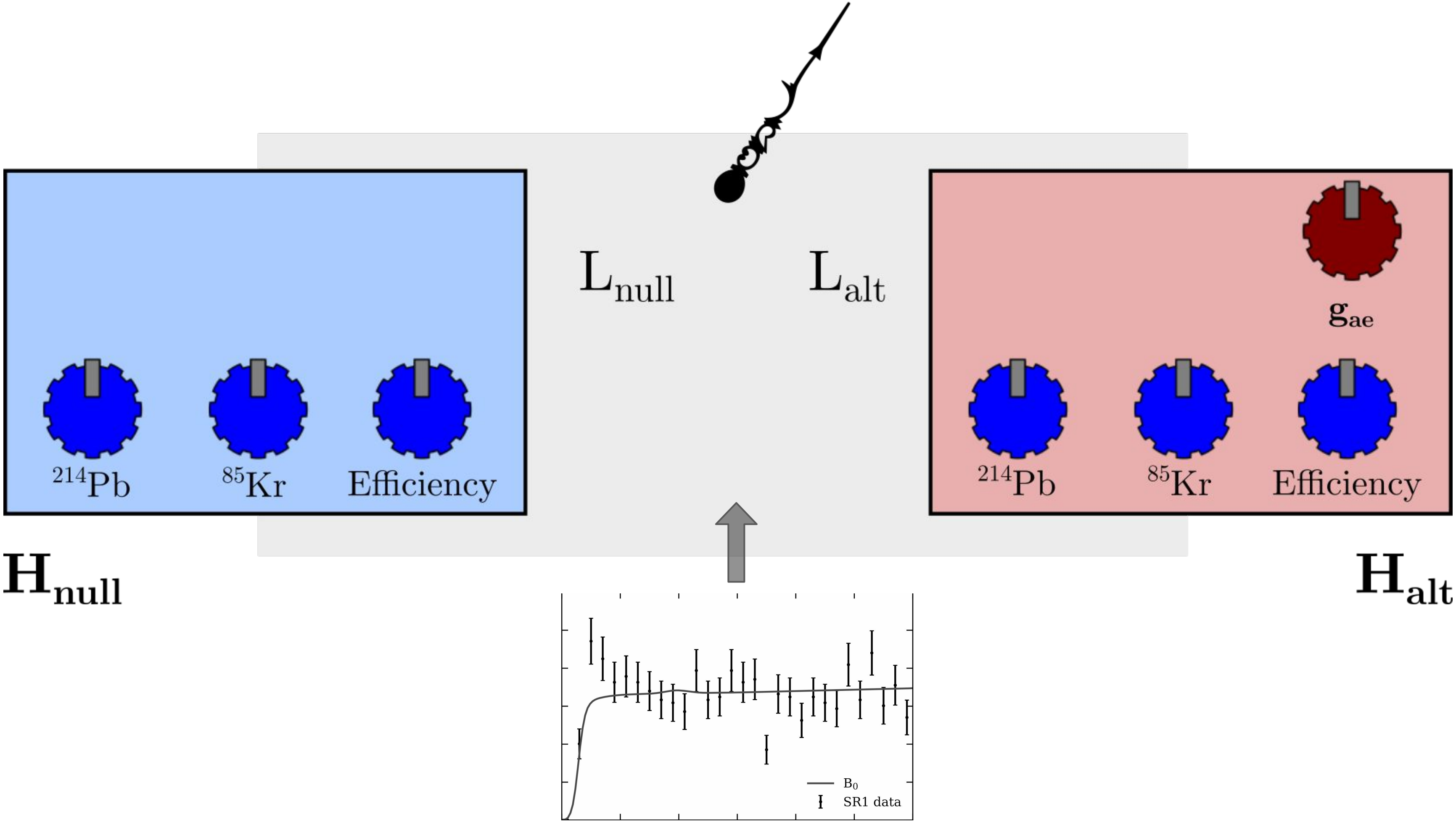
New physics?

Statistical fluke!!

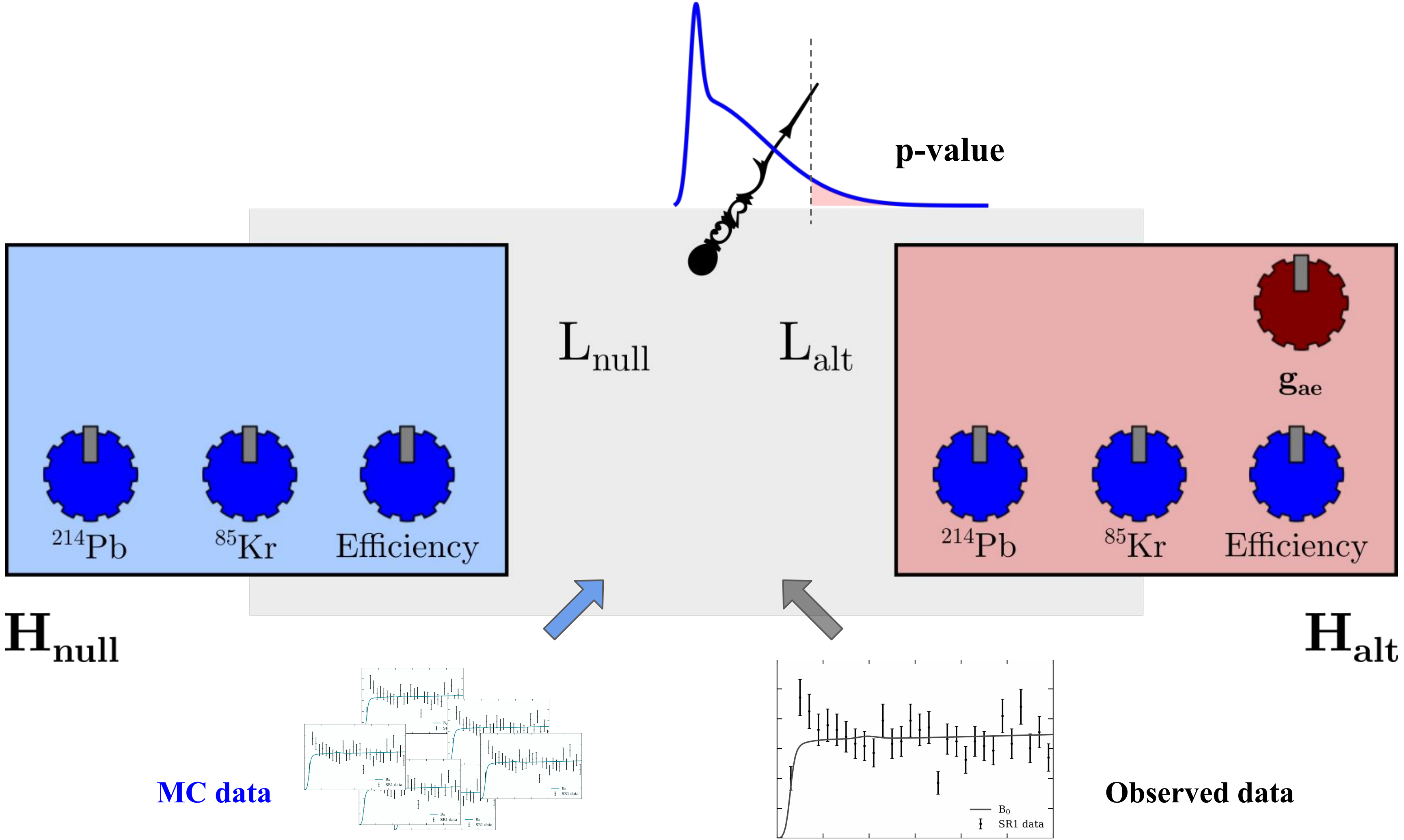
I don't see anything significant in your plot…

and there is a 3 sigma deficit at 17 keV….

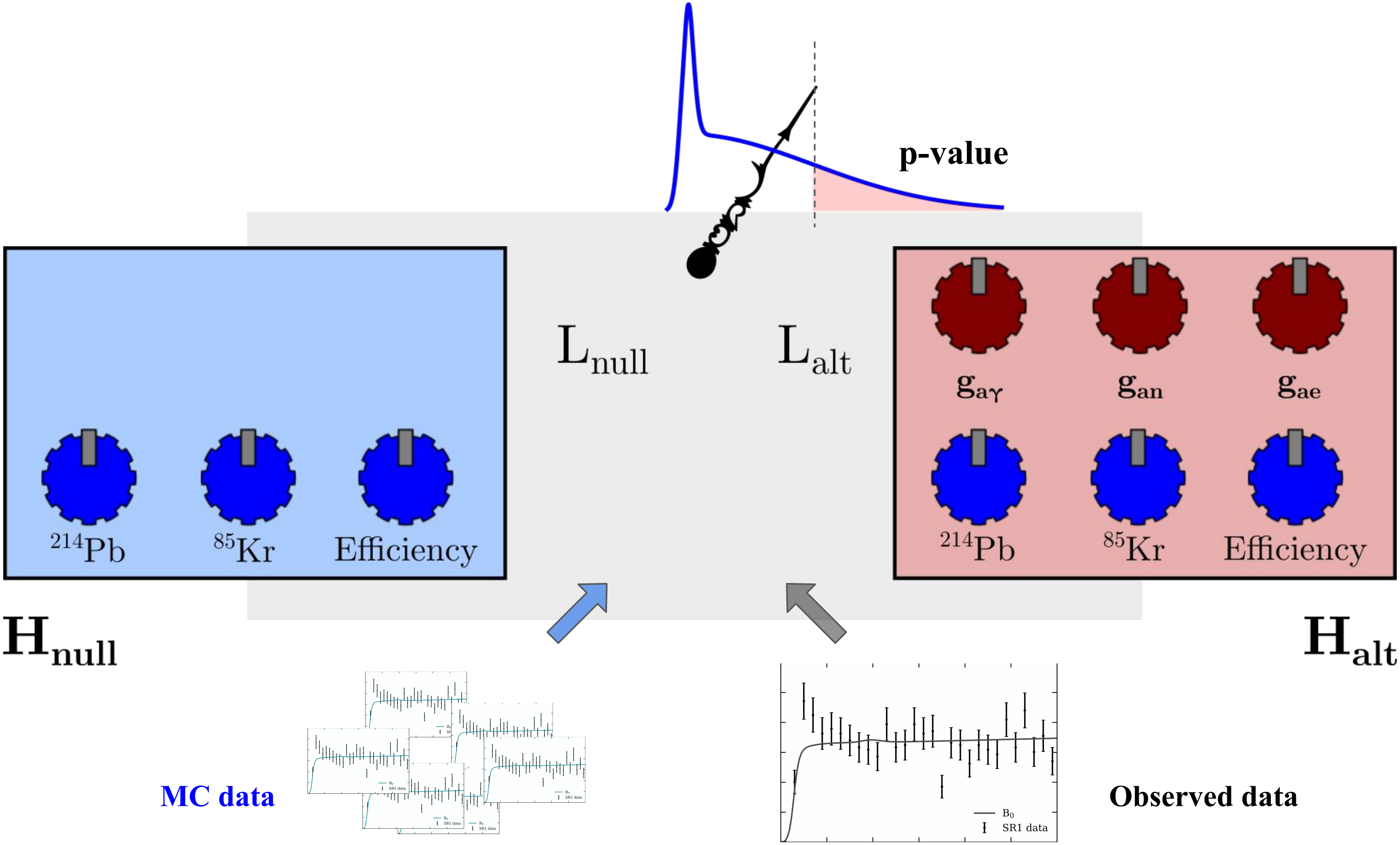




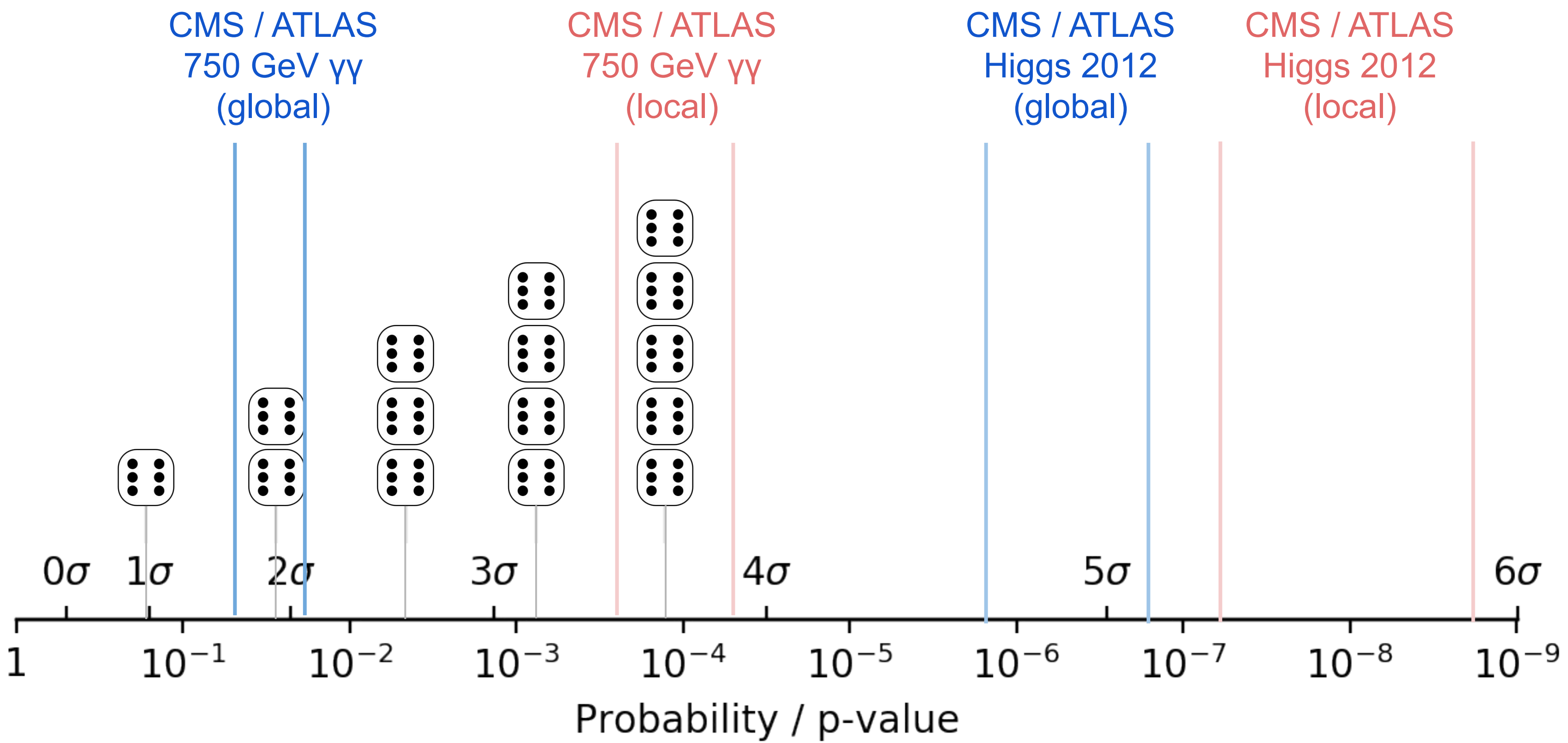
L_{null}
L_{alt}
g_{ae}
^{214}Pb
^{85}Kr
Efficiency
^{214}Pb
^{85}Kr
Efficiency
H_{null}
H_{alt}
B_0
SR1 data

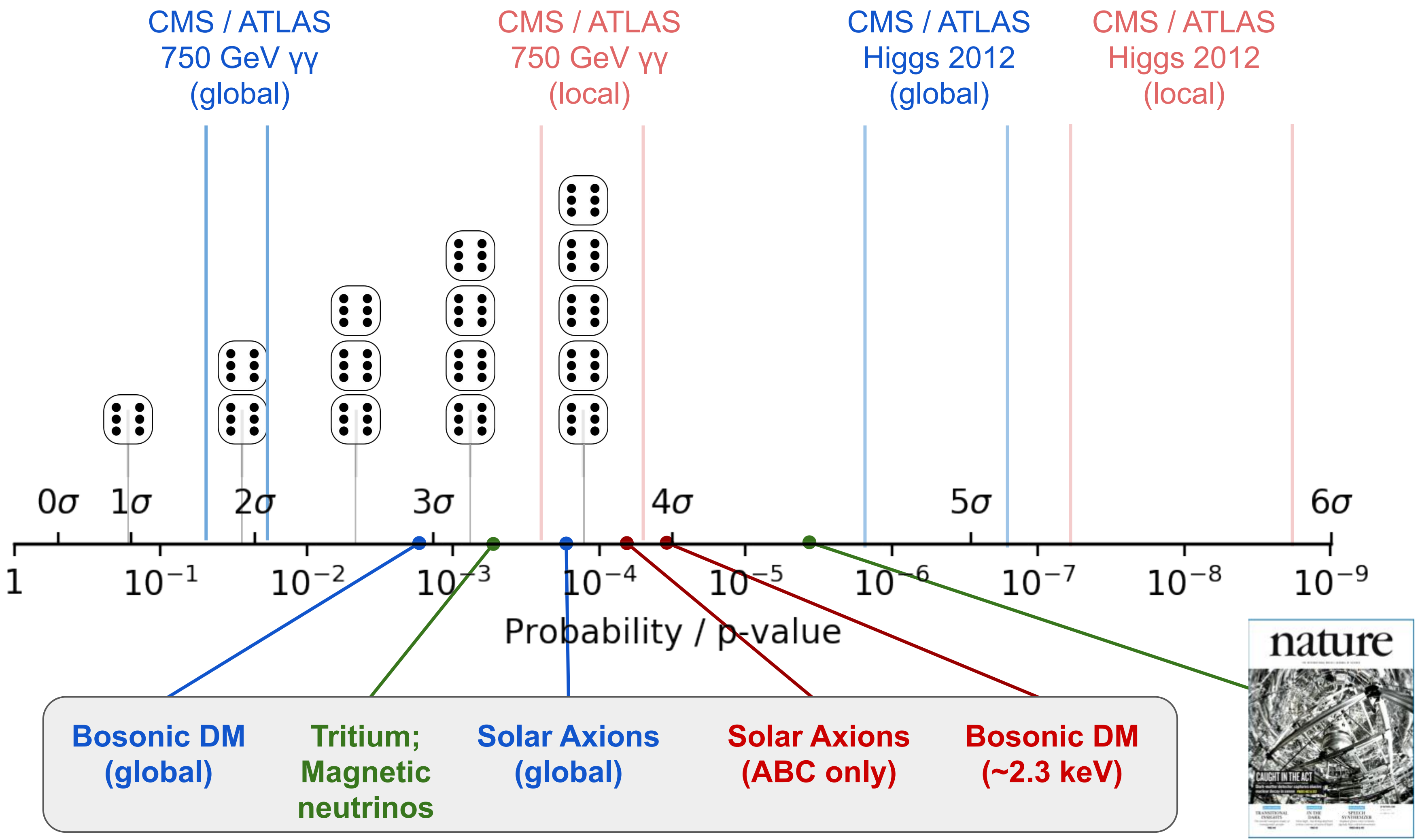


p-value
L_{null}
L_{alt}
^{214}Pb
^{85}Kr
Efficiency
g_{ae}
^{214}Pb
^{85}Kr
Efficiency
H_{null}
H_{alt}
MC data
Observed data
B_0
SR1 data

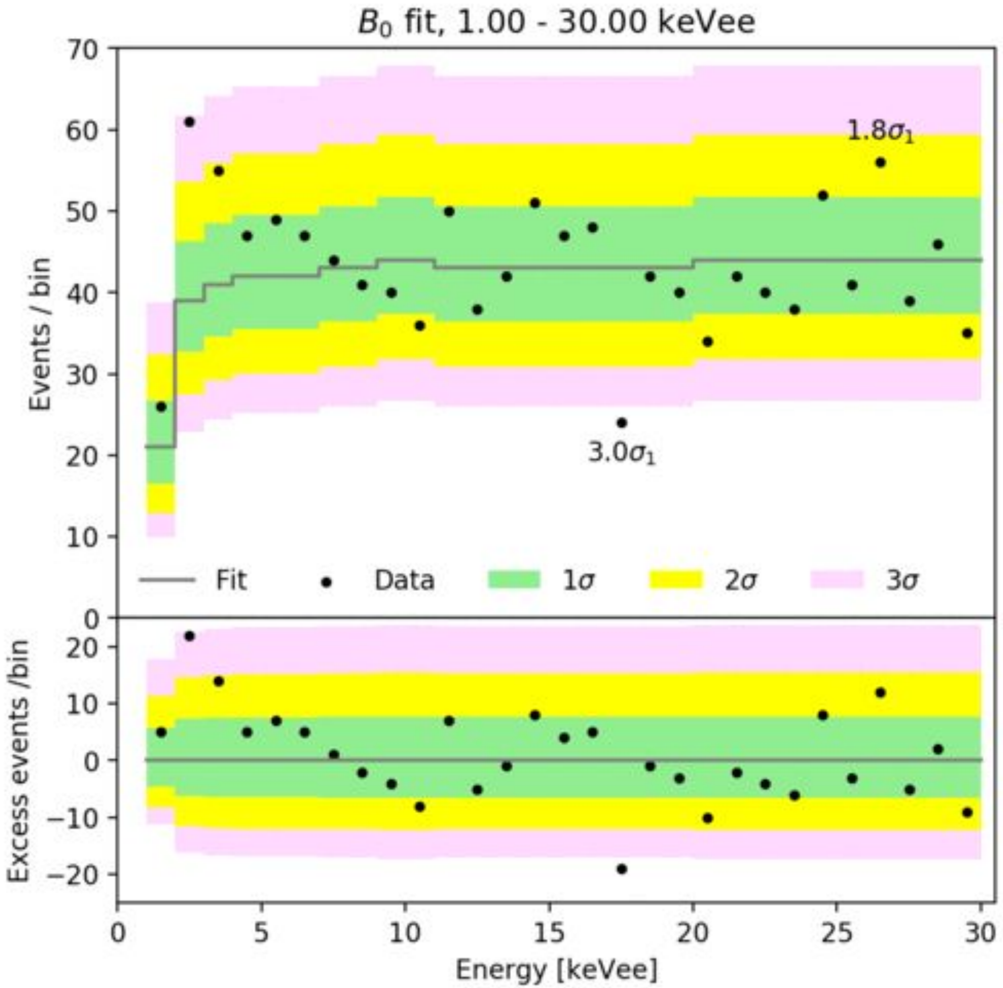


p-value
L_{null}
L_{alt}
^{214}Pb
^{85}Kr
Efficiency
$g_{a\gamma}$
g_{an}
g_{ae}
^{214}Pb
^{85}Kr
Efficiency
H_{null}
H_{alt}
MC data
B_0
SR1 data
Observed data


CMS / ATLAS
750 GeV γγ
(global)
CMS / ATLAS
750 GeV γγ
(local)
CMS / ATLAS
Higgs 2012
(global)
CMS / ATLAS
Higgs 2012
(local)
0σ
1σ
2σ
3σ
4σ
5σ
6σ
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
Probability / p-value

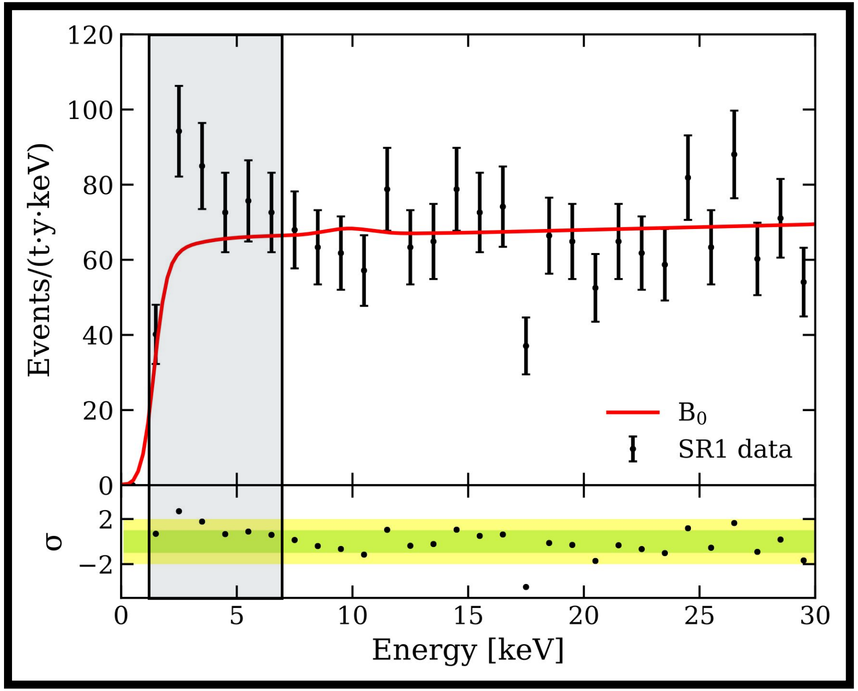


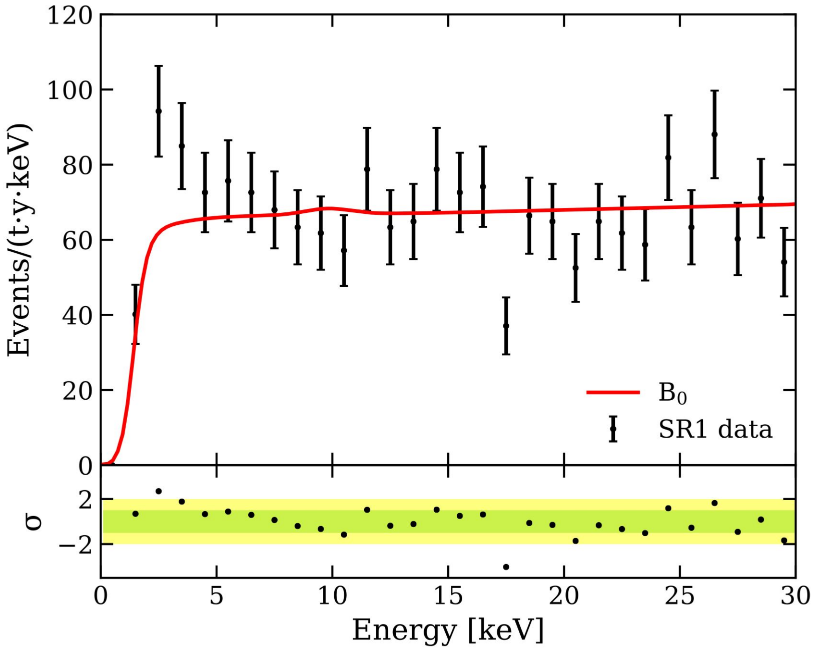
CMS / ATLAS
750 GeV γγ
(global)
CMS / ATLAS
750 GeV γγ
(local)
CMS / ATLAS
Higgs 2012
(global)
CMS / ATLAS
Higgs 2012
(local)
0σ 1σ 2σ 3σ 4σ 5σ 6σ
1 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9}
Probability / p-value
Bosonic DM (global)
Tritium; Magnetic neutrinos
Solar Axions (global)
Solar Axions (ABC only)
Bosonic DM (~2.3 keV)
nature
CAUGHT IN THE ACT



B_0 fit, 1.00 - 30.00 keVee
Events / bin
Excess events /bin
Energy [keVee]
$1.8\sigma_1$
$3.0\sigma_1$
Fit
Data
1σ
2σ
3σ

Yet another **thresholdino...**
A slight mis-modelling would explain this…





Excess **is not <u>at</u> our threshold fall-off**

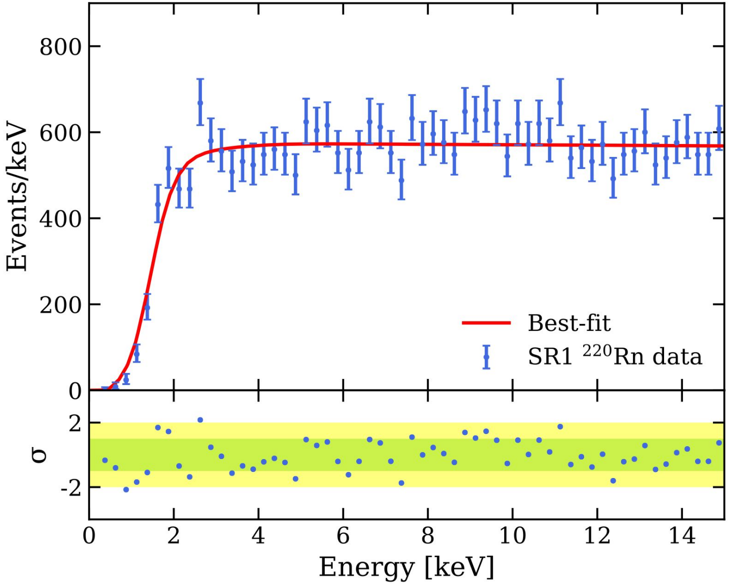
Persists if we would:

… double the analysis threshold post-hoc

… fix efficiency at +-1 sigma

… use different software versions

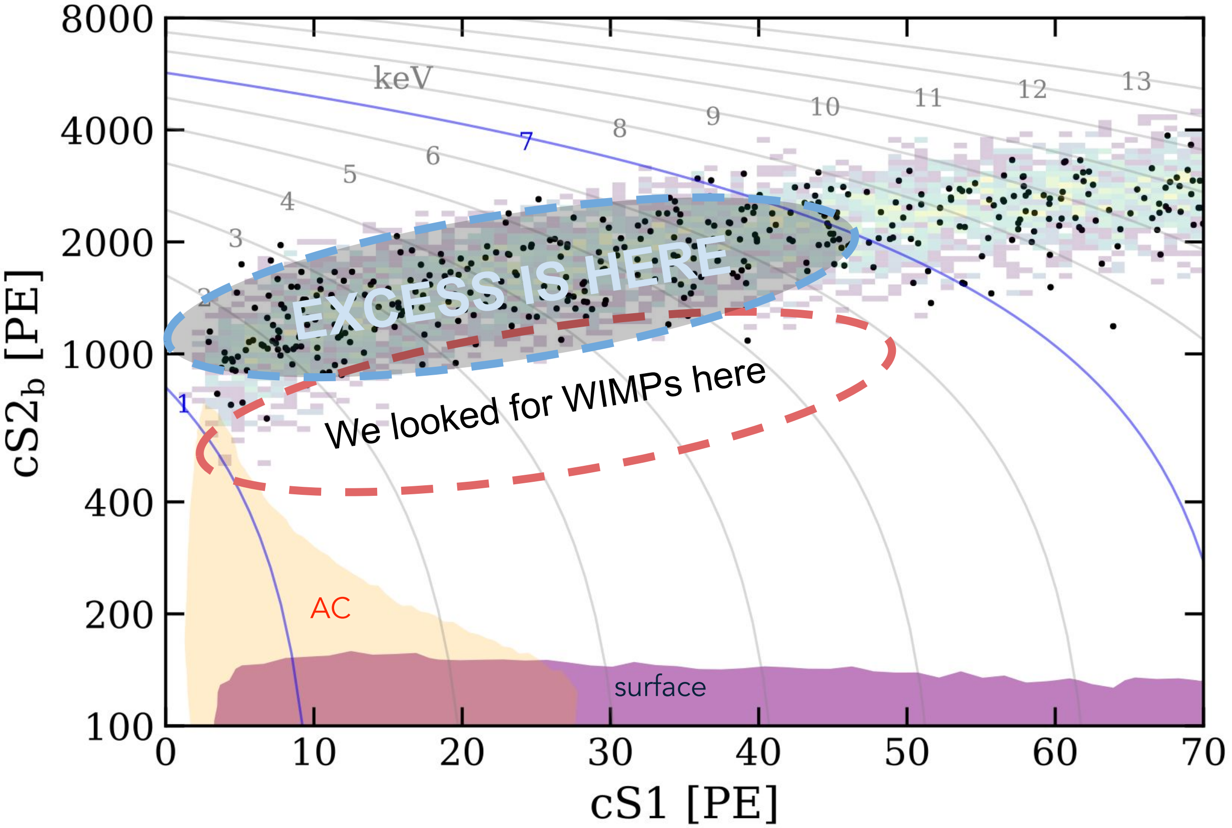
… do a (cS1, cS2) profile likelihood



^{220}Rn calibration data validates our model

To explain the excess, you need:

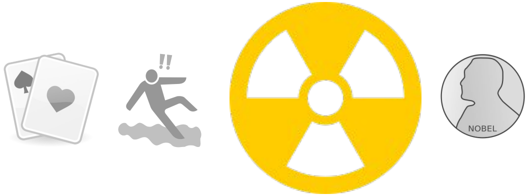
- a large systematic
- that is absent when we calibrate

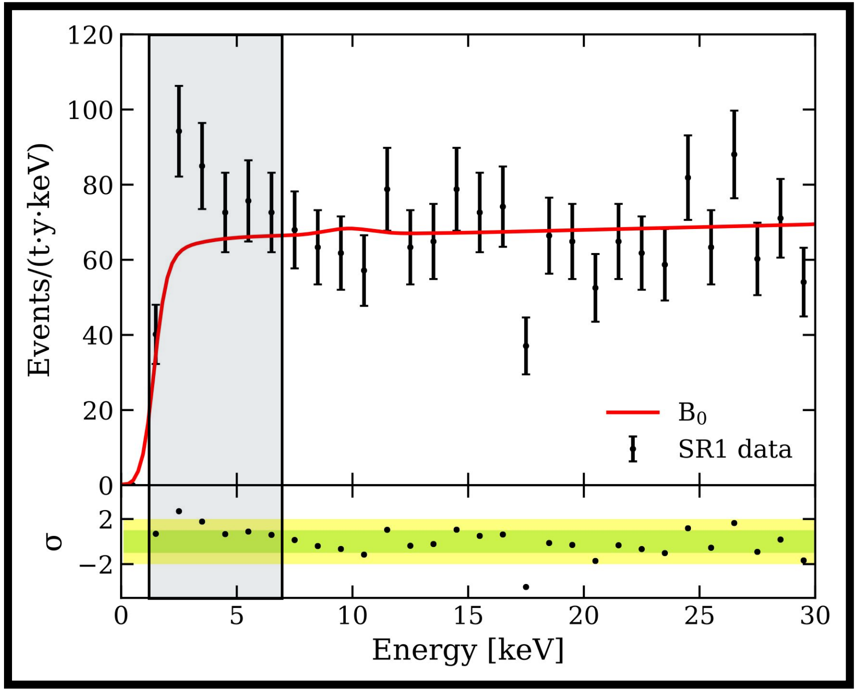


The excess is **right next to our prime WIMP search region**

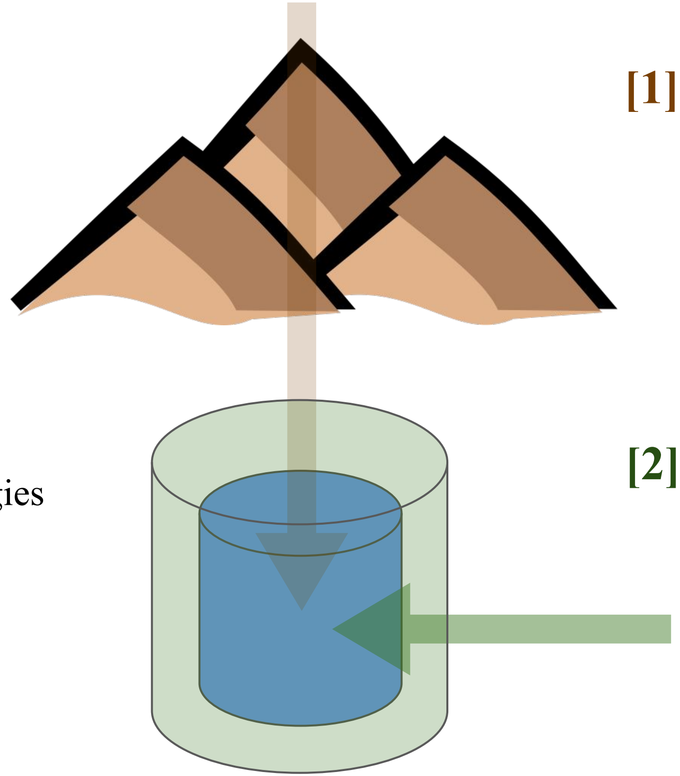
No other event source relevant besides electronic recoils

Surely you just forgot some **background**...





How to make a XENON1T event



[1] Go through > km of rock

Muons: too high energy

Neutrinos, dark particles

[2] Go through cm^s of metal and xenon

Neutrons: different S1/S2

Beta, gamma: too high energy

[3] Infiltrate the LXe

^{214}Pb, ^{85}Kr, ^{136}Xe, ^{133}Xe, ^{124}Xe (!)

Accounted for, different energies

^{127}Xe, ^{37}Ar

$t_{1/2}$ ~ month, too short

> 6 L/day air leak not seen

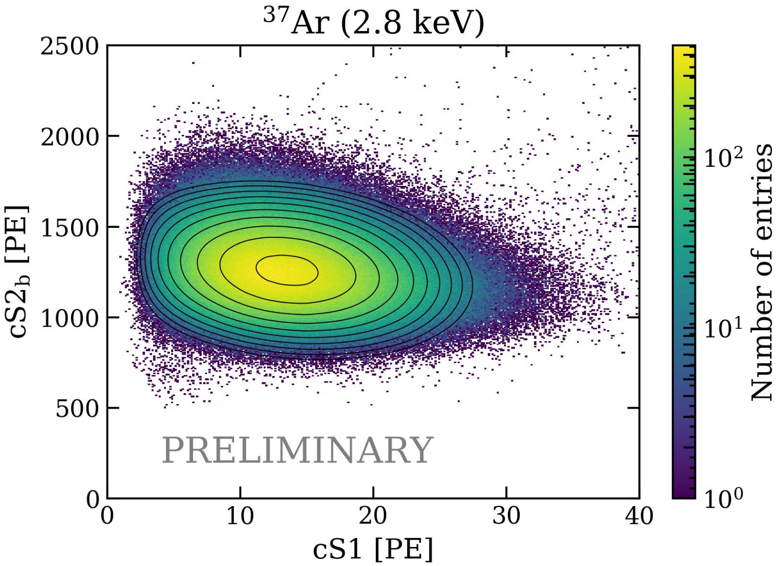
Tritium

...

Argon-37?

^{37}Ar K-electron capture to the ground state of ^{37}Cl

- Half-live of 35 days & 2.8 keV energy in X-rays & Auger e^- s
- Calibration with ^{37}Ar performed in XENON1T at the end of SR2
  → good understanding of the detector at those energies
- Publication under preparation



Argon-37?

- Xenon cryogenically distilled before the science run to reduce krypton XENON1T, Eur. Phys. J. C 77 (2017) 275
  → Argon is strongly reduced by distillation & decay

- Leak hypothesis: ruled out by ^{nat}Kr measurement ^{36}Ar

- In-situ production: neutron reactions with ^{36}Ar or ^{40}Ca
  → negligible contribution

- A fit to the excess gives (2.3 ± 0.2) keV as best fit value (see later)

Tritium?

$t_{1/2}$ ~ 12 years

Fits data at 3.2 σ

Inside xenon initially?

H_2O impurities could have HTO, but...

Removed by condensation & purification

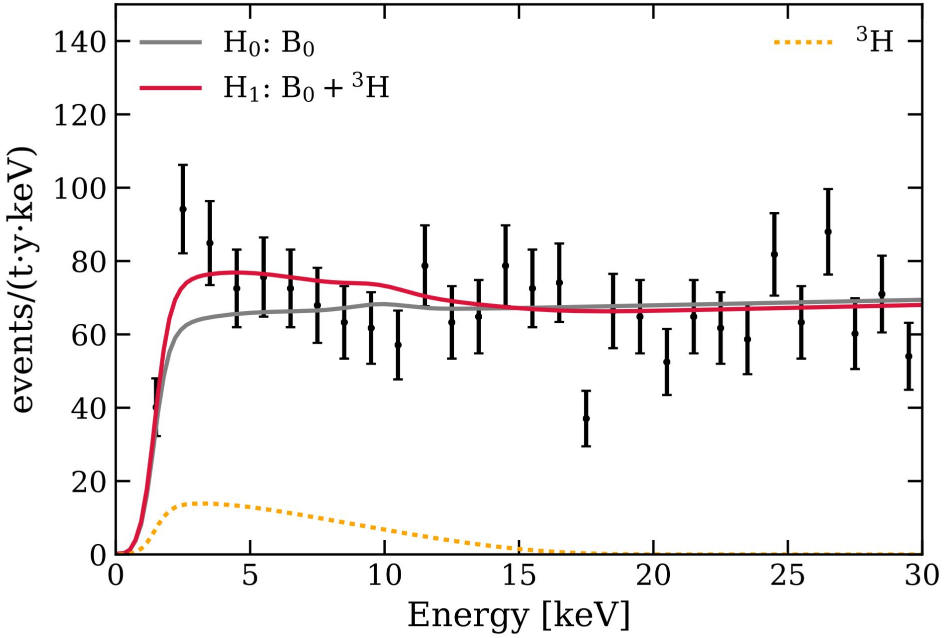
Emanating from materials?

Need ~60 ppb of H_2O or H_2 for excess

H_2O ~ 1 ppb from light yield, electron lifetime

H_2 = ??

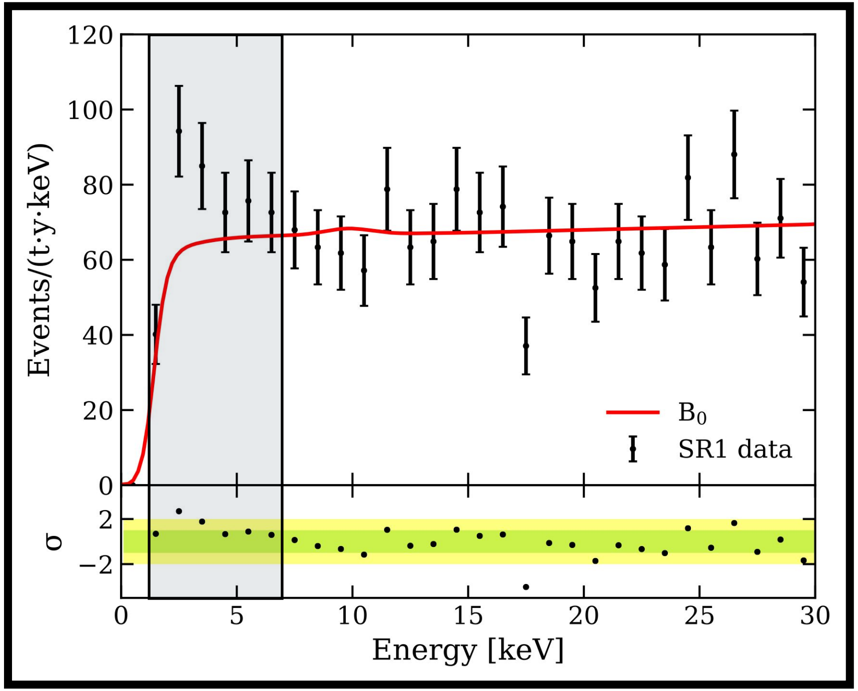
C_xH_xT = ???



Tritium explanation of the excess requires much more H_2 or C_xH_x in XENON1T than H_2O

… but no way to measure that!

So… what are the **new physics** options?



Explaining the XENON1T excess with Luminous Dark Matter #9

Nicole F. Bell (Melbourne U.), James B. Dent (Sam Houston State U.), Bhaskar Dutta (Texas A-M), Sumit Ghosh (Texas A-M), Jason Kumar (Hawaii U.) et al. (Jun 22, 2020)

e-Print: 2006.12461 [hep-ph]

pdf cite 45 citations

Exploring New Physics with O(keV) Electron Recoils in Direct Detection Experiments #10

Itay M. Bloch (Tel Aviv U.), Andrea Caputo (Valencia U., IFIC), Rouven Essig (YITP, Stony Brook), Diego Redigolo (CERN and INFN, Florence and Florence U.), Mukul Sholapurkar (YITP, Stony Brook) et al. (Jun 25, 2020)

e-Print: 2006.14521 [hep-ph]

pdf cite 44 citations

Neutrino self-interactions and XENON1T electron recoil excess #11

Andreas Bally (Heidelberg, Max Planck Inst.), Sudip Jana (Heidelberg, Max Planck Inst.), Andreas Trautner (Heidelberg, Max Planck Inst.) (Jun 21, 2020)

e-Print: 2006.11919 [hep-ph]

pdf cite 43 citations

Sun Heated MeV-scale Dark Matter and the XENON1T Electron Recoil Excess #12

Yifan Chen (Beijing, Inst. Theor. Phys.), Jing Shu (Beijing, Inst. Theor. Phys. and Beijing, GUCAS and CAS, CEPP, Beijing and HIAS, UCAS, Hangzhou and Peking U., CHEP and ICTP-AP, Beijing), Xiao Xue (Beijing, Inst. Theor. Phys. and Beijing, GUCAS), Guanwen Yuan (Purple Mountain Observ. and USTC, Hefei), Qiang Yuan (Purple Mountain Observ. and USTC, Hefei and Peking U., CHEP) (Jun 22, 2020)

e-Print: 2006.12447 [hep-ph]

pdf cite 42 citations

Boosted Dark Matter Interpretation of the XENON1T Excess #5

Bartosz Fornal (Utah U.), Pearl Sandick (Utah U.), Jing Shu (Beijing, Inst. Theor. Phys. and Beijing, GUCAS and CAS, CEPP, Beijing and Peking U., CHEP and HIAS, UCAS, Hangzhou and ICTP-AP, Beijing), Meng Su (Hong Kong U.), Yue Zhao (Utah U.) (Jun 19, 2020)

e-Print: 2006.11264 [hep-ph]

pdf cite 56 citations

Solar axions cannot explain the XENON1T excess #6

Luca Di Luzio (DESY), Marco Fedele (ICC, Barcelona U.), Maurizio Giannotti (Barry U.), Federico Mescia (ICC, Barcelona U.), Enrico Nardi (Frascati) (Jun 22, 2020)

e-Print: 2006.12487 [hep-ph]

pdf cite 53 citations

Light vector mediators facing XENON1T data #7

D. Aristizabal Sierra (Santa Maria U., Valparaiso and Liege U.), V. De Romeri (Valencia U., IFIC), L.J. Flores (Mexico U.), D.K. Papoulias (Ioannina U.) (Jun 22, 2020)

Published in: *Phys.Lett.B* 809 (2020) 135681 • e-Print: 2006.12457 [hep-ph]

pdf DOI cite 49 citations

XENON1T Anomaly and its Implication for Decaying Warm Dark Matter #8

Gongjun Choi (Tsung-Dao Lee Inst., Shanghai), Motoo Suzuki (Tsung-Dao Lee Inst., Shanghai), Tsutomu T. Yanagida (Tsung-Dao Lee Inst., Shanghai and Tokyo U., IPMU) (Jun 22, 2020)

e-Print: 2006.12348 [hep-ph]

pdf cite 46 citations

Dark Matter and the XENON1T electron recoil excess #1

Kristjan Kannike (NICPB, Tallinn), Martti Raidal (NICPB, Tallinn), Hardi Veermäe (NICPB, Tallinn), Alessandro Strumia (Pisa U.), Daniele Teresi (Pisa U. and INFN, Italy) (Jun 18, 2020)

e-Print: 2006.10735 [hep-ph]

pdf cite 66 citations

XENON1T anomaly from anomaly-free ALP dark matter and its implications for stellar cooling anomaly #2

Fuminobu Takahashi (Tohoku U. and Tokyo U., IPMU), Masaki Yamada (Tohoku U. (main)), Wen Yin (Tokyo U.) (Jun 17, 2020)

e-Print: 2006.10035 [hep-ph]

pdf cite 61 citations

Hidden Photon Dark Matter in the Light of XENON1T and Stellar Cooling #3

Gonzalo Alonso-Álvarez (Heidelberg U.), Fatih Ertas (RWTH Aachen U.), Joerg Jaeckel (Heidelberg U. and U. Heidelberg, ITP), Felix Kahlhoefer (RWTH Aachen U. and u), Lennert J. Thormaehlen (Heidelberg U.) (Jun 19, 2020)

e-Print: 2006.11243 [hep-ph]

pdf cite 61 citations

Light new physics in XENON1T #4

Celine Boehm (Sydney U.), David G. Cerdeno (Madrid, IFT), Malcolm Fairbairn (King's Coll. London), Pedro A.N. Machado (Fermilab), Aaron C. Vincent (Queen's U., Kingston and CPARC and Perimeter Inst. Theor. Phys.) (Jun 19, 2020)

e-Print: 2006.11250 [hep-ph]

pdf links cite 58 citations

Inelastic Dark Matter Electron Scattering and the XENON1T Excess #13

Keisuke Harigaya (Princeton, Inst. Advanced Study), Yuichiro Nakai (Tsung-Dao Lee Inst., Shanghai and Shanghai Jiao Tong U.), Motoo Suzuki (Tsung-Dao Lee Inst., Shanghai and Shanghai Jiao Tong U.) (Jun 21, 2020)

e-Print: 2006.11938 [hep-ph]

pdf DOI cite 41 citations

Atmospheric Dark Matter from Inelastic Cosmic Ray Collision in Xenon1T #14

Liangliang Su (Nanjing Normal U. and Yantai U.), Wenyu Wang (Beijing U. of Tech.), Lei Wu (Nanjing Normal U.), Jin Min Yang (Beijing, Inst. Theor. Phys. and Beijing, KITPC and Beijing, GUCAS), Bin Zhu (Yantai U. and Chung-Ang U.) (Jun 21, 2020)

e-Print: 2006.11837 [hep-ph]

pdf cite 40 citations

Shining dark matter in Xenon1T #15

Gil Paz (Wayne State U.), Alexey A. Petrov (Wayne State U.), Michele Tammaro (Cincinnati U.), Jure Zupan (Cincinnati U.) (Jun 22, 2020)

e-Print: 2006.12462 [hep-ph]

pdf cite 39 citations

Galactic Origin of Relativistic Bosons and XENON1T Excess #16

Jatan Buch (Brown U.), Manuel A. Buen-Abad (Brown U.), JiJi Fan (Brown U.), John Shing Chau Leung (Brown U.) (Jun 22, 2020)

e-Print: 2006.12488 [hep-ph]

pdf cite 39 citations

Well,
the list is long...

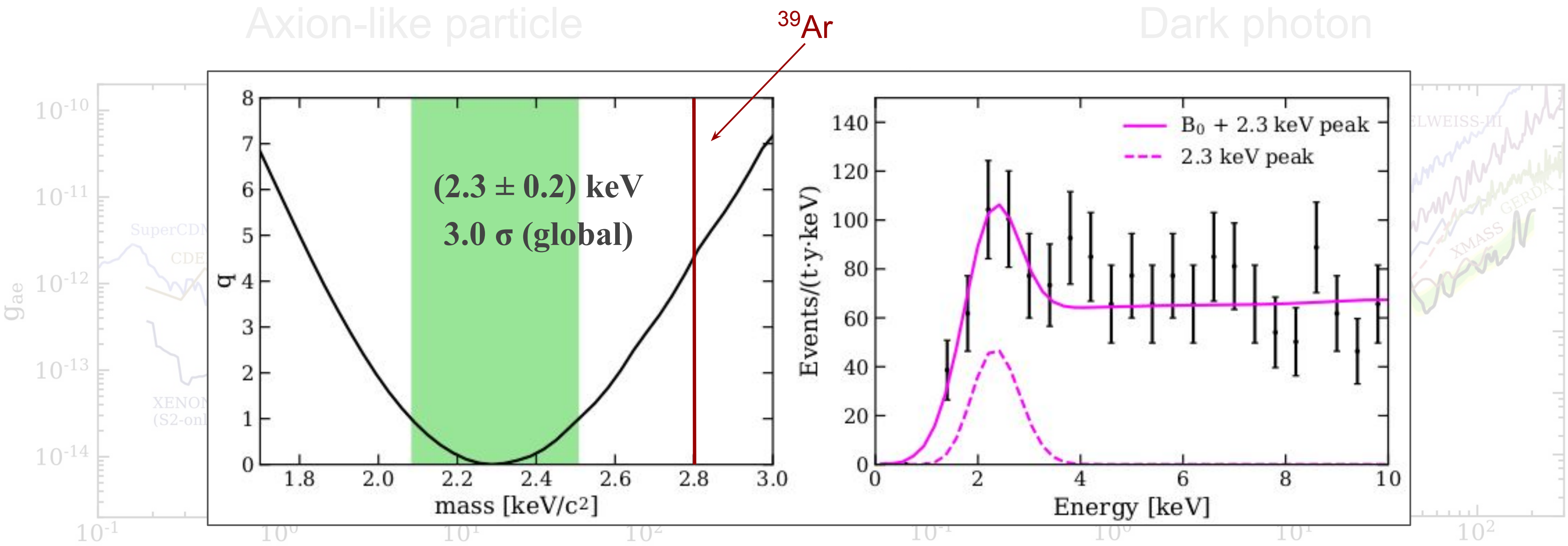
*“**Bosonics** for a peak.*

***Neutrino magnetic moment** for an ~ exponential* [power law] *spectrum.*

*And **axions** for something fun in between.“*

Rafael Lang

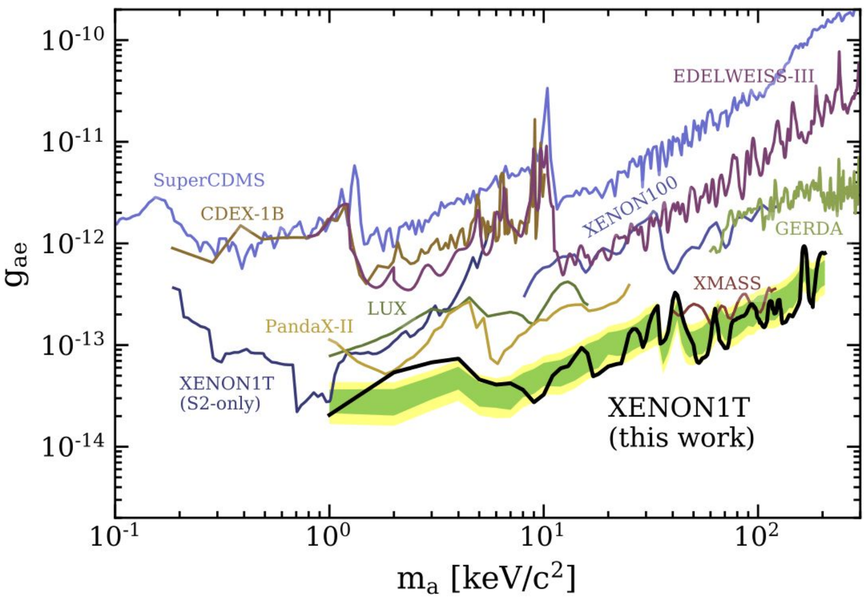
Bosonic Dark Matter



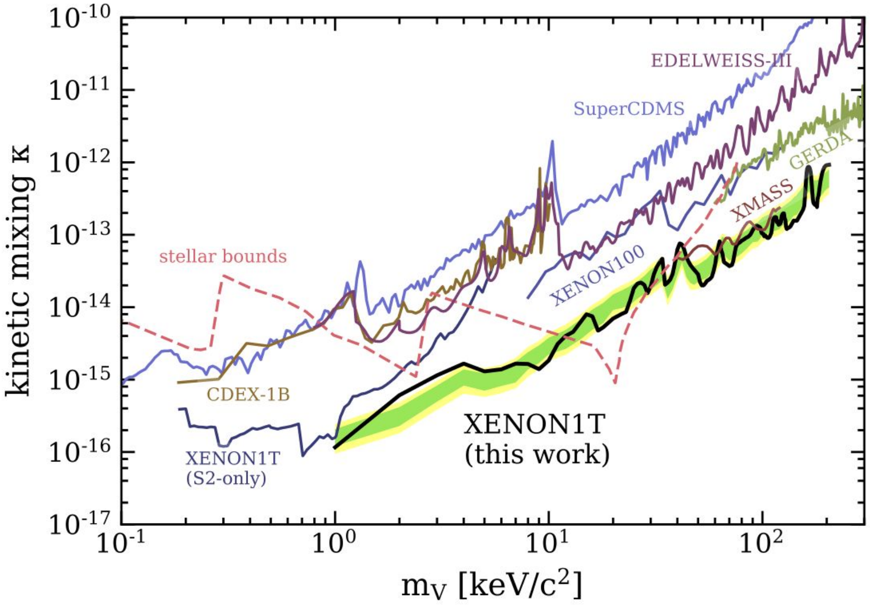
Fitting a monoenergetic peak to the excess

Bosonic Dark Matter

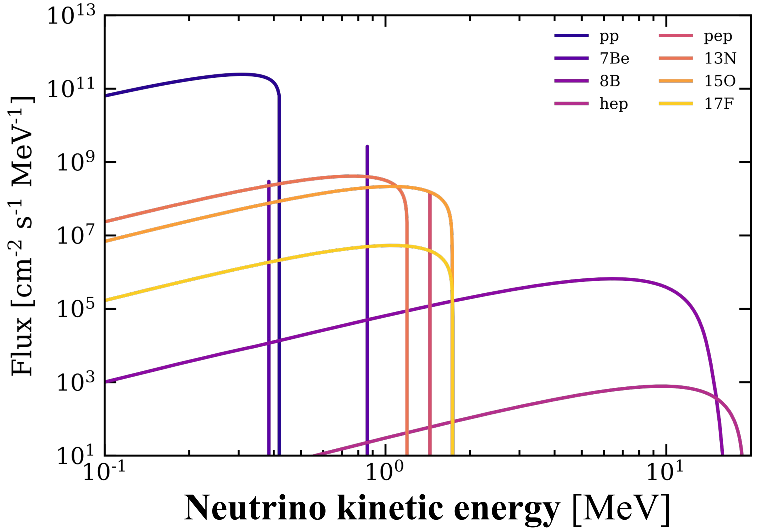
Axion-like particle

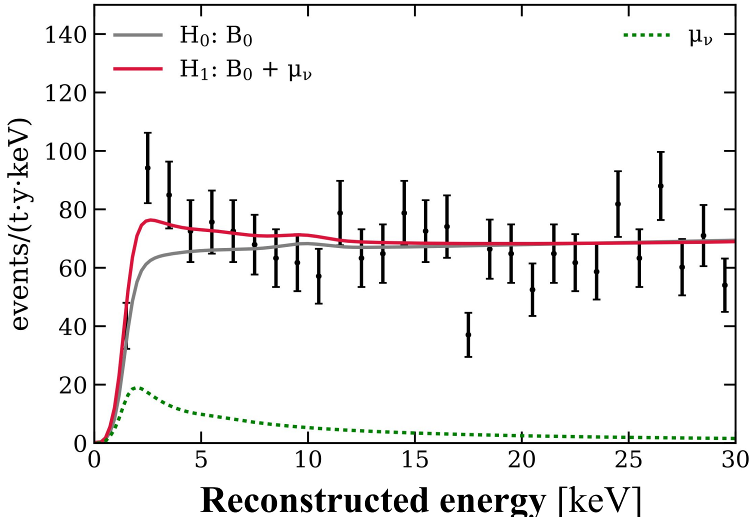


Dark photon

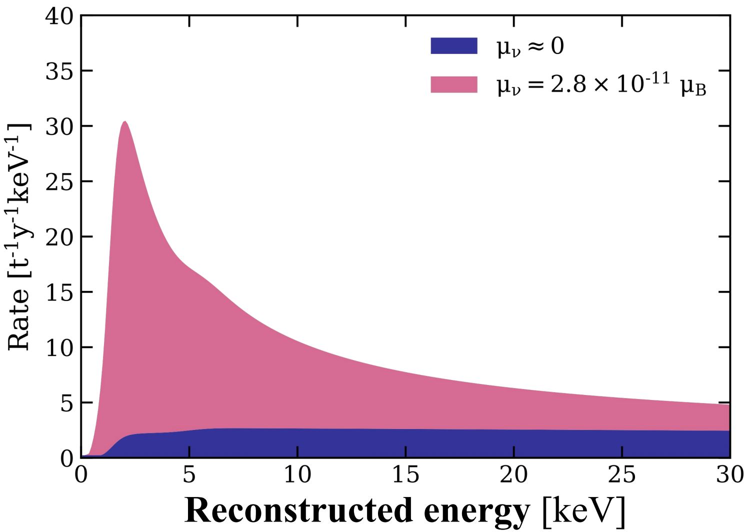


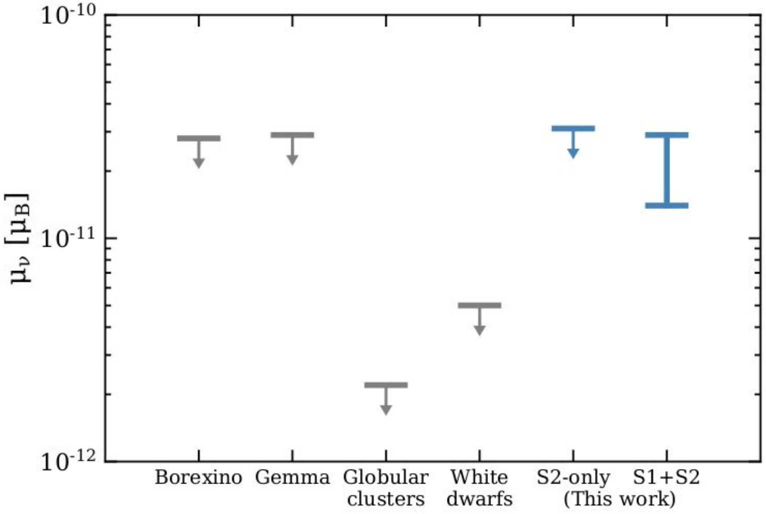
Neutrino magnetic moment





Hypothesis favoured at 3.2 σ



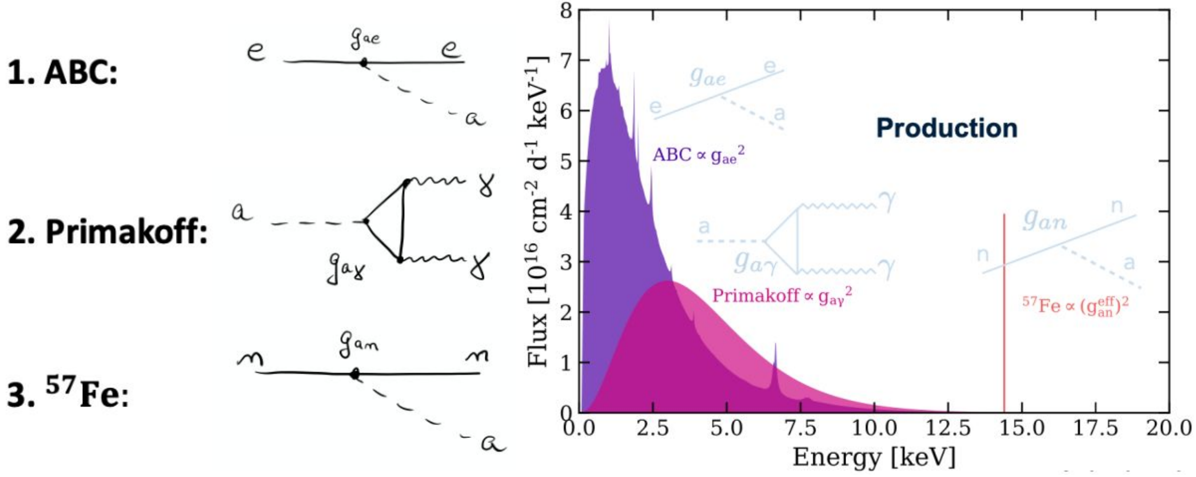


Solar Axions

Hypothetical **axions** proposed as a solution to the '*strong CP-problem*'

→ Solar axions would be produced in the Sun with ~ keV energies:

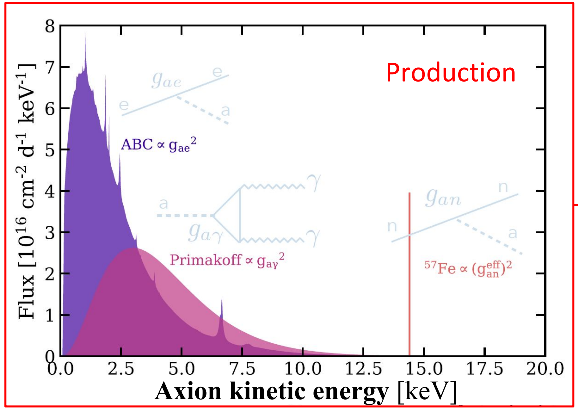
- Atomic recombination and de-excitation, Bremsstrahlung and Compton: ABC
- Primakoff conversion of photons to axions
- A mono-energetic 14.4 keV nuclear transition of ^{57}Fe

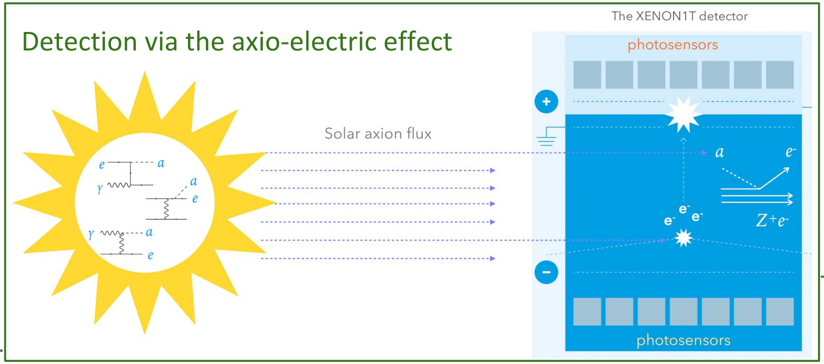


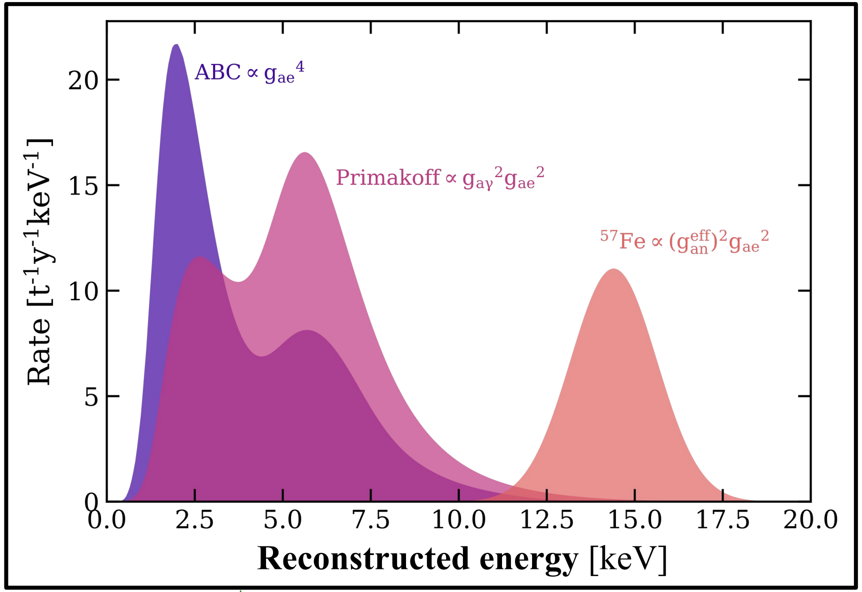
Solar Axions

No dark matter axions (mass range μeV-meV) with XENON1T

Model-dependent couplings to matter



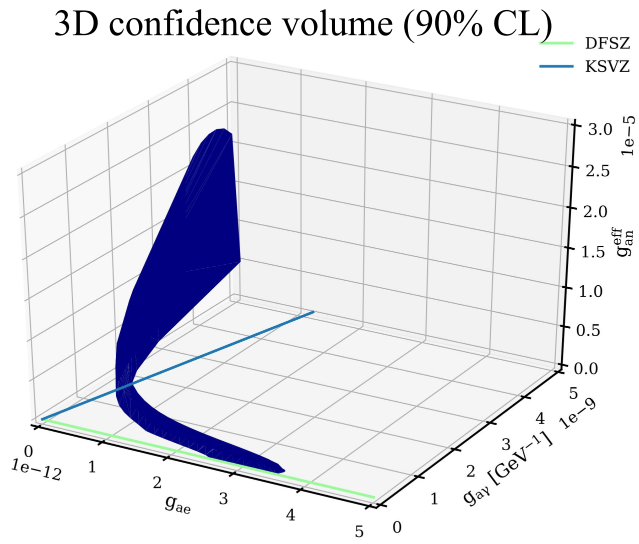


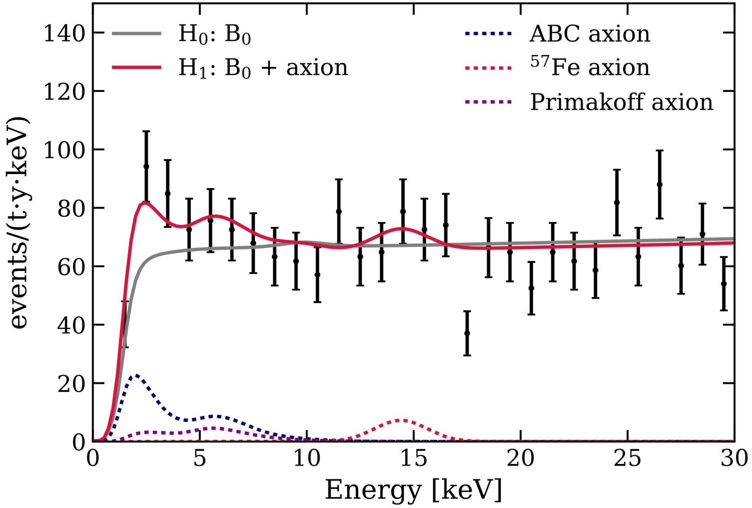


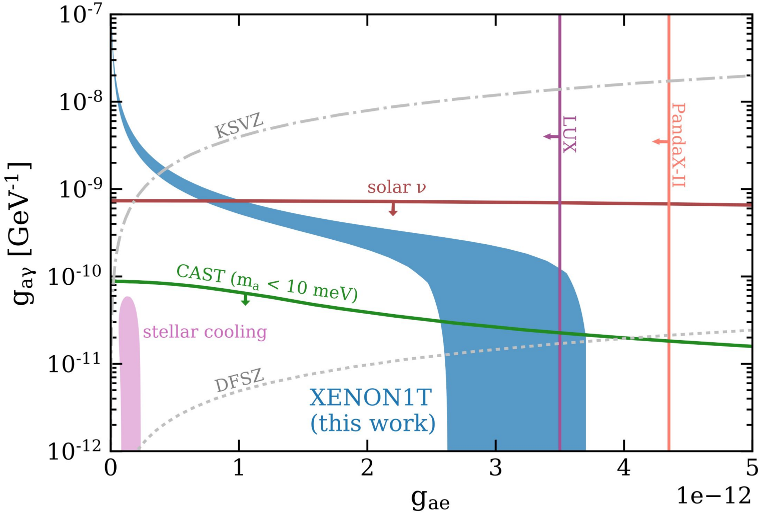
XENON1T resolution and efficiency

S.

Solar Axions





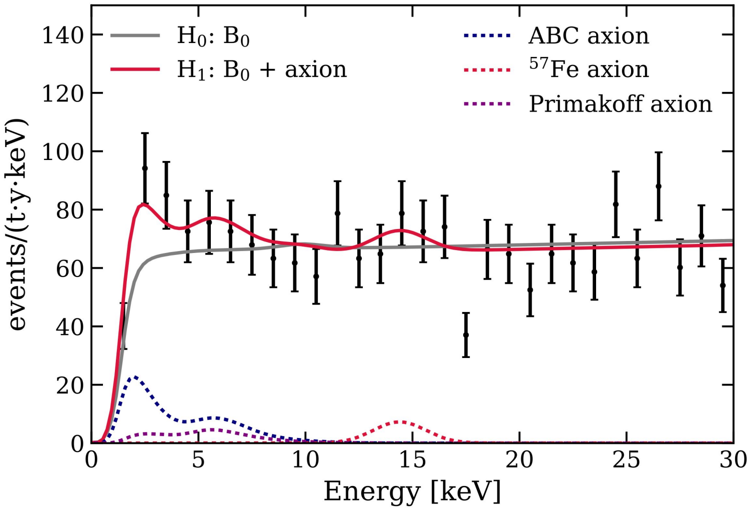


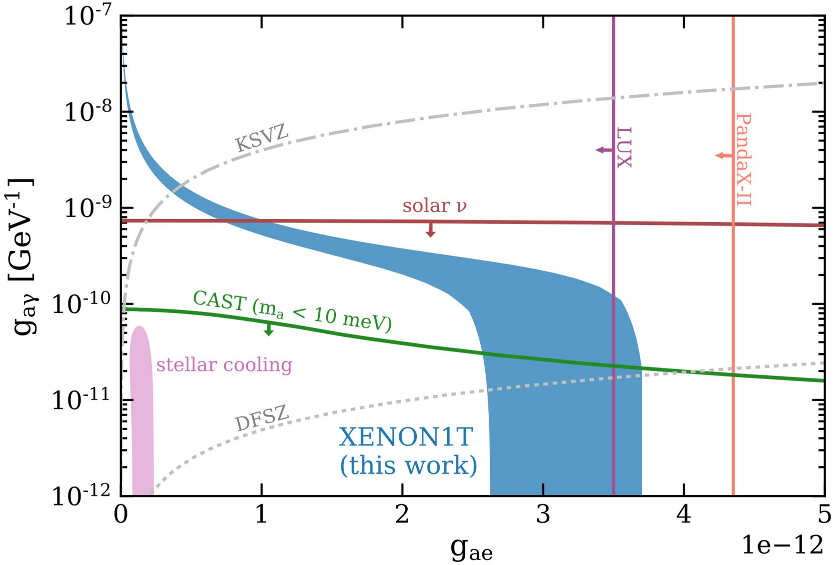
Search for ABC, Primakoff and ^{57}Fe axions simultaneously

Axion hypothesis favoured at 3.4 σ

But: strong tension with astrophysical constraints from stellar cooling (see for instance arXiv:2003.01100)

Solar Axions





Search for ABC, Primakoff and ^{57}Fe axions simultaneously

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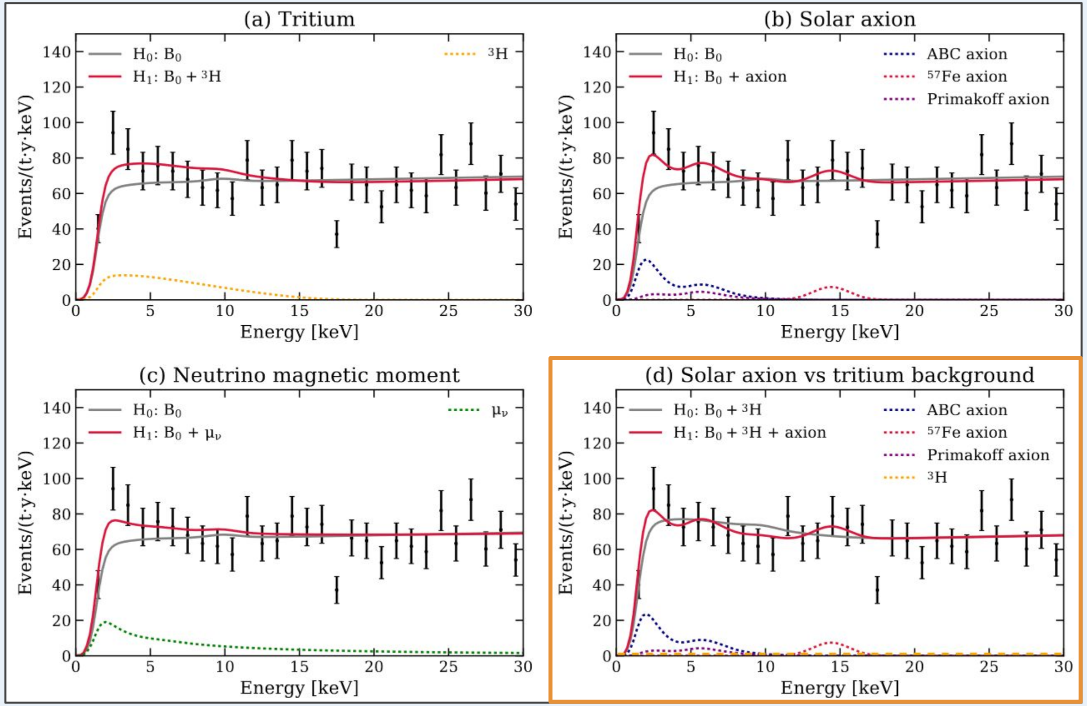
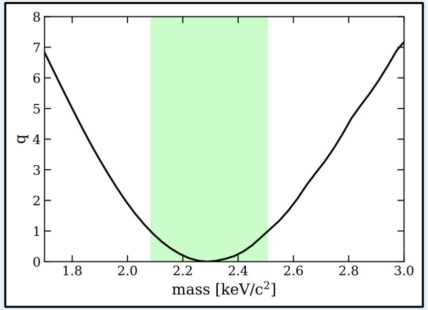
^{3}H
fits data at 3.2 σ

Solar axion
fits data at 3.4 σ



μ_ν
fits data at 3.2 σ

Solar axion + ^{3}H
favored over ^{3}H at 2.0 σ



Monoenergetic peak
at (2.3 ± 0.2) keV
fits data at 3.0 σ (global)

XENONnT

XENONnT


S. Lindemann, Universität Freiburg

x3

Active volume

1/6

Background

Under commissioning

Discriminate axions from tritium with ~ few months of data