New results from XENON1T and status of XENONnT

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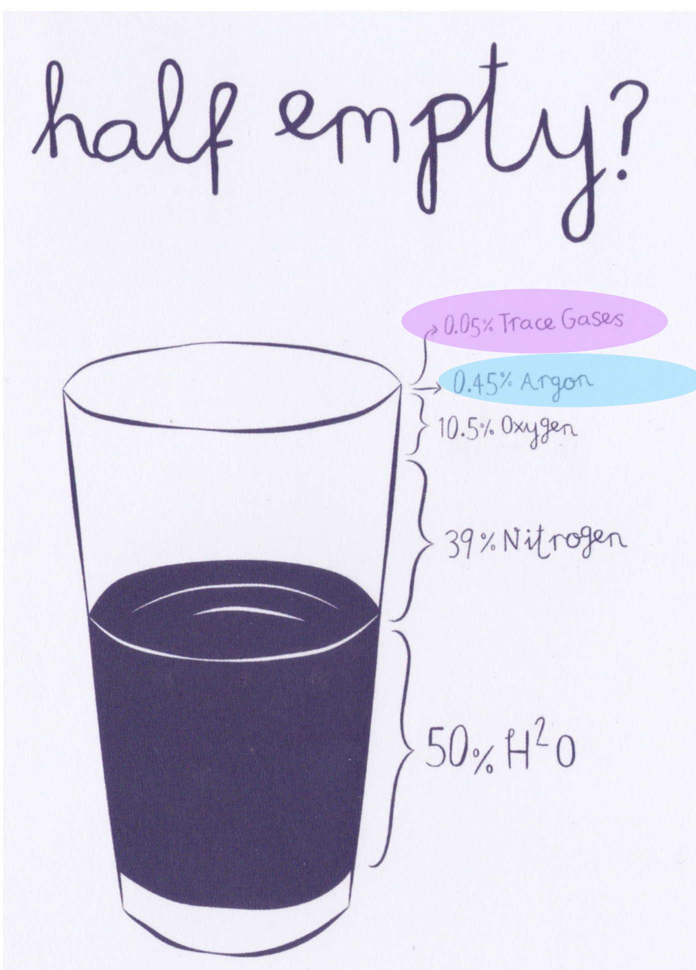
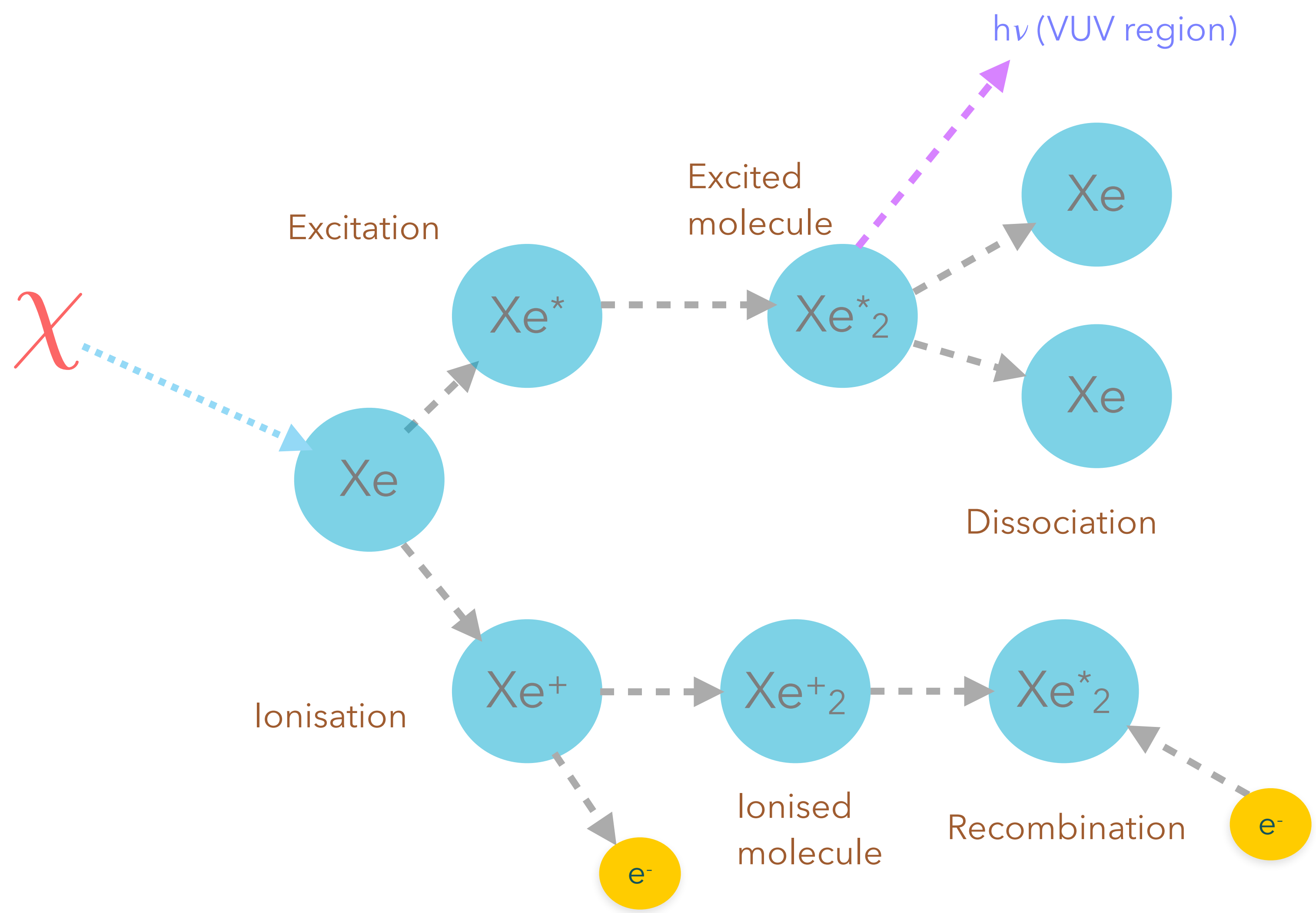
on behalf of XENON

PSI colloquium, October 22, 2020

THE XENON PROGRAMME

- Use a large amount of clean liquid xenon target & detect ionisation and excitation from particle interactions
- Xenon: "the strange one", concentration in the atmosphere: 87 ppb* (by volume)

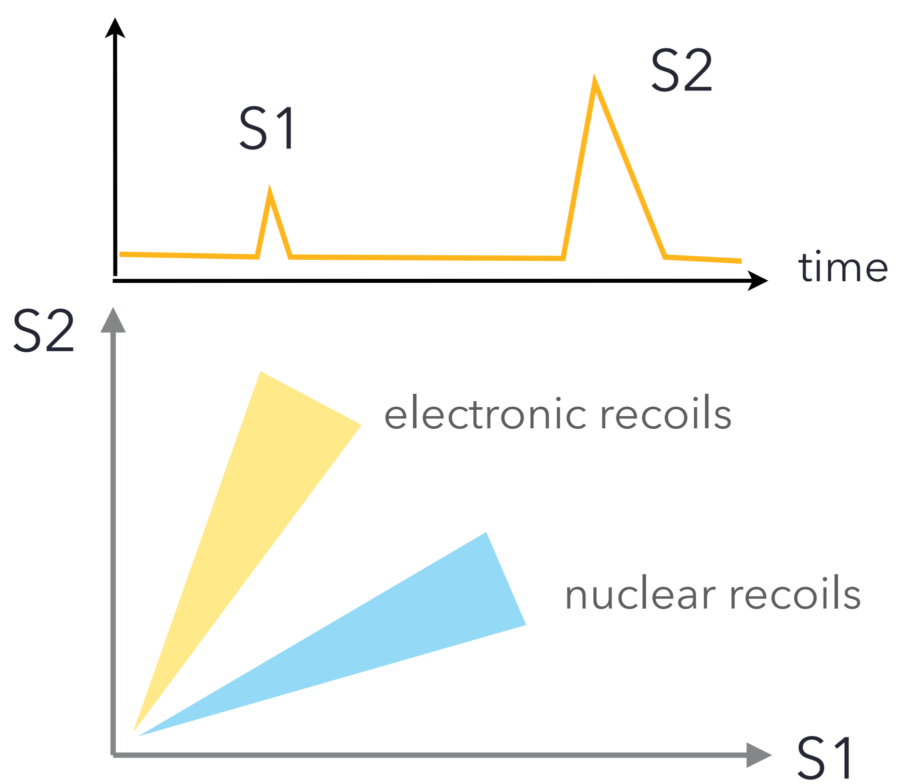


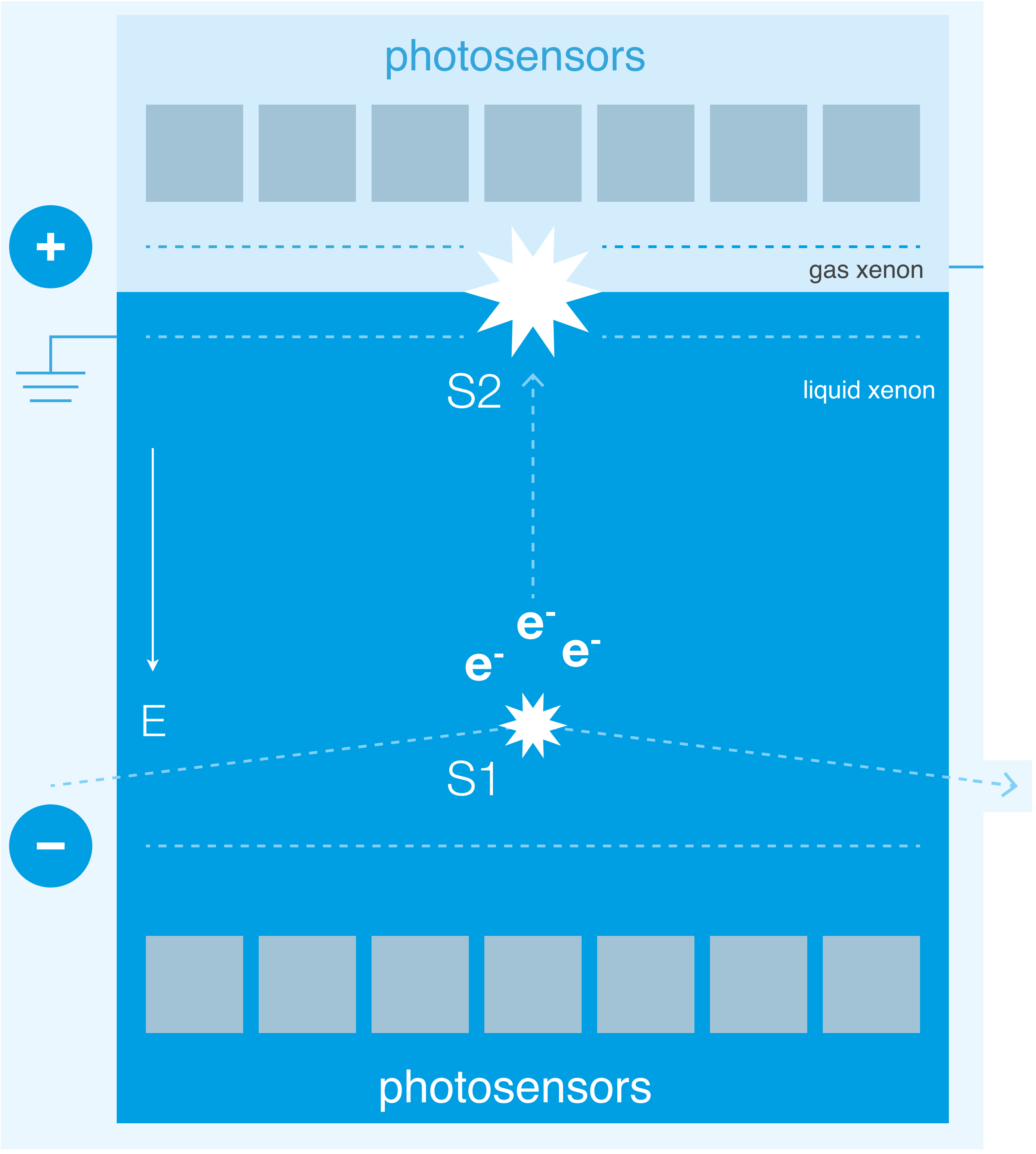


*https://doi.org/10.1007/978-3-319-39312-4_202

DETECTION PRINCIPLE: A TWO-PHASE TPC

- 3D position resolution via light (S1) and charge (S2) signals
  - S2/S1 depends on particle ID
  - Fiducialisation
  - Single versus multiple interactions





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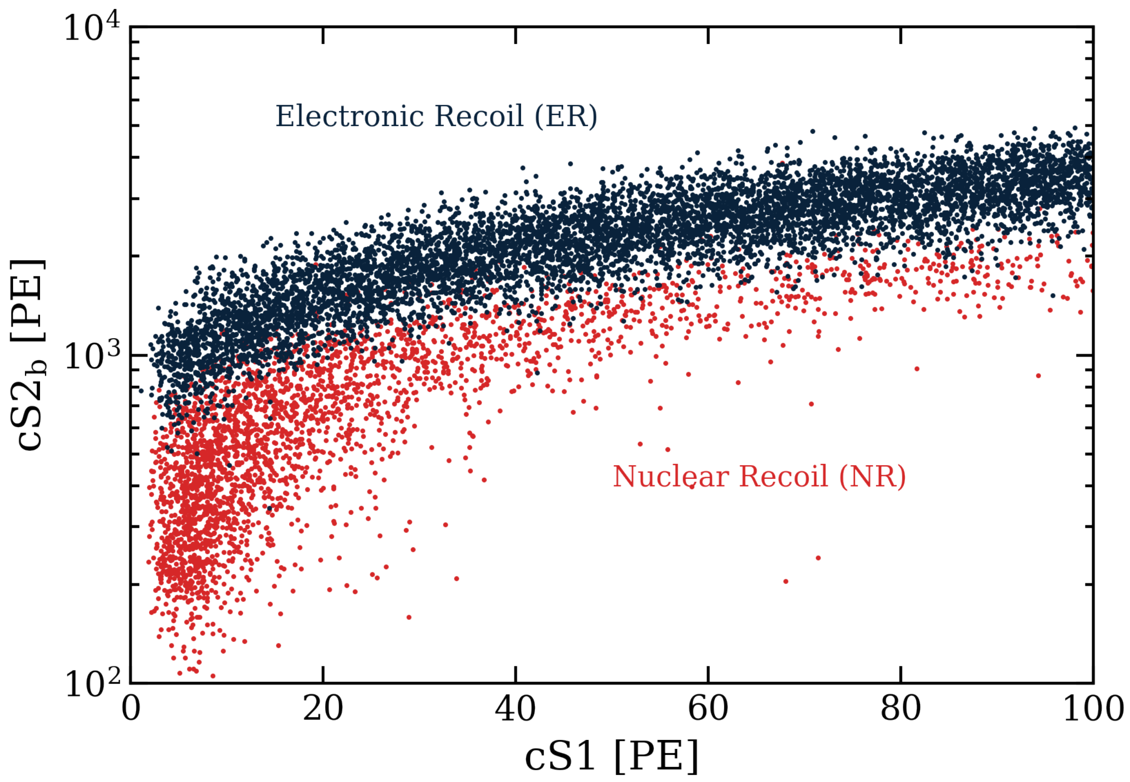
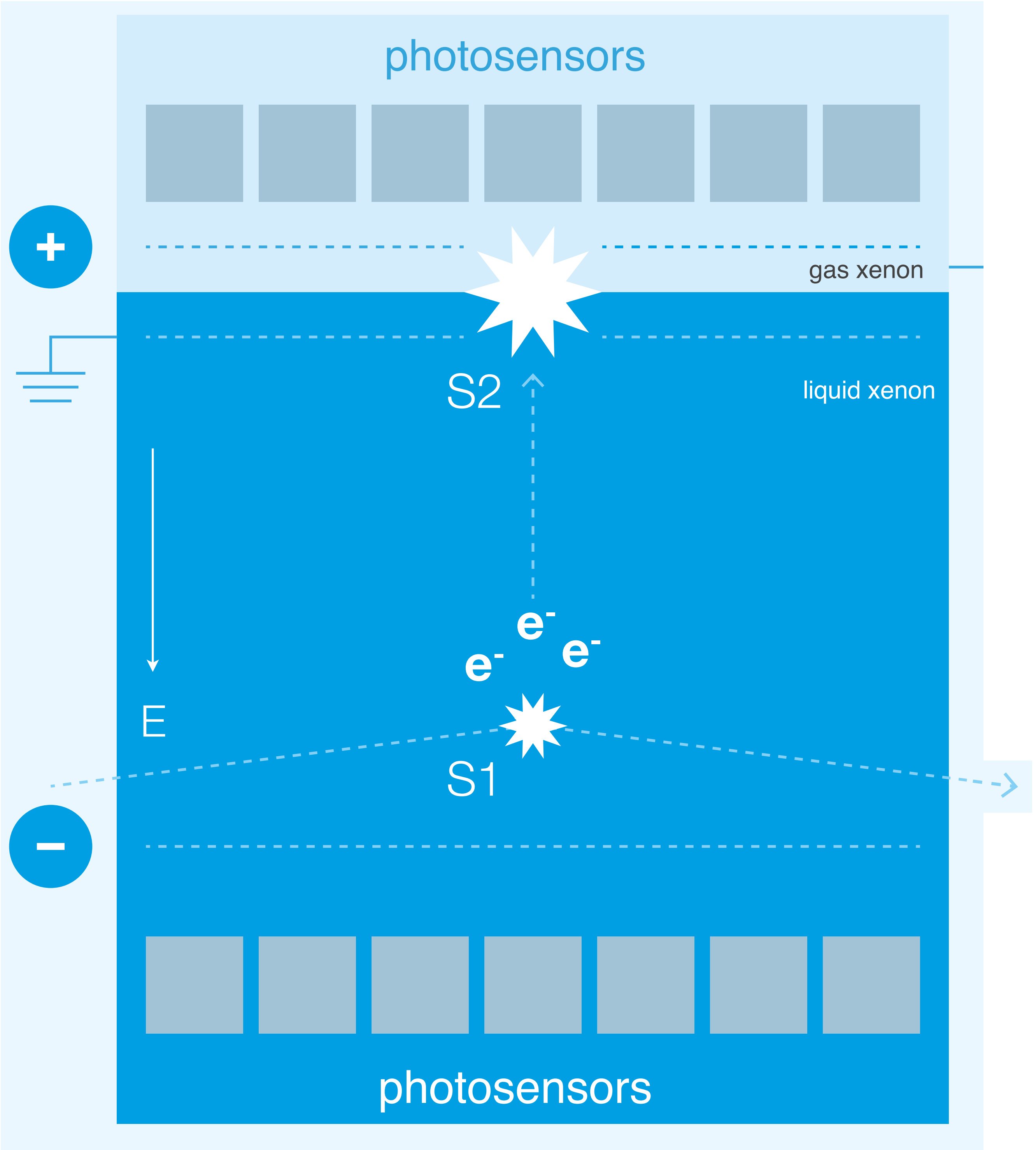
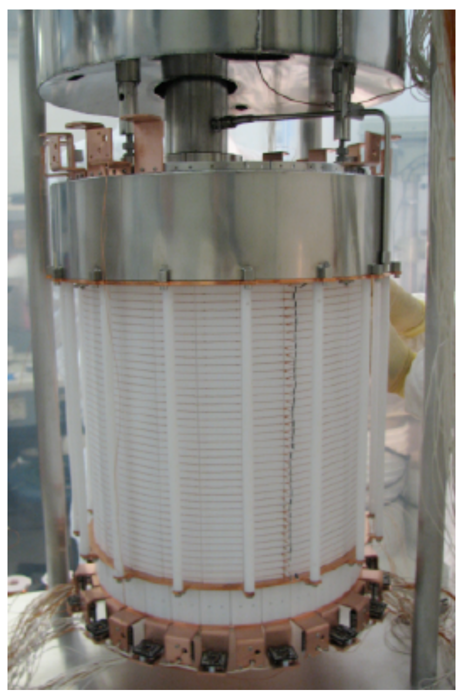




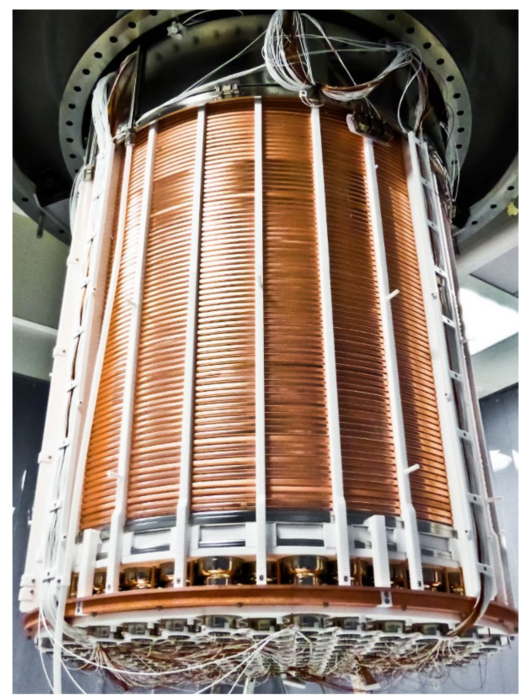
THE XENON (AND DARWIN) TIMELINE

XENON10

XENON100

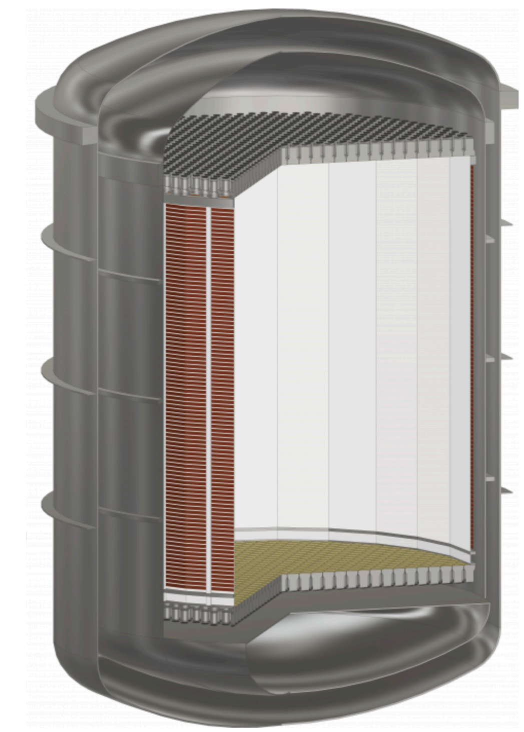


XENON1T



XENONnT

DARWIN

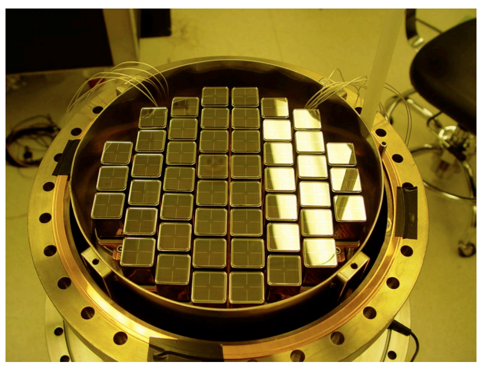


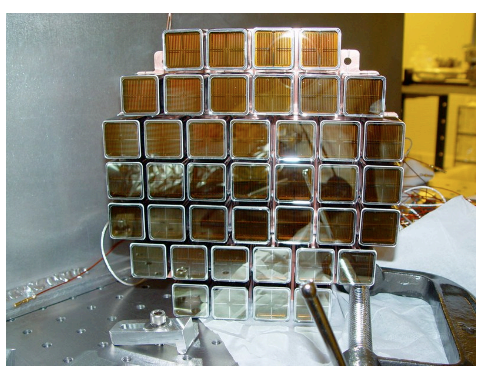
2005-2007	2008-2016	2012-2018	2020-2025	2027–
15 kg	161 kg	3200 kg	8400 kg	50 tonnes
15 cm	30 cm	96 cm	150 cm	260 cm
$\sim 10^{-43}$ cm^2	$\sim 10^{-45}$ cm^2	$\sim 10^{-47}$ cm^2	$\sim 10^{-48}$ cm^2	$\sim 10^{-49}$ cm^2

THE XENON (AND DARWIN) TIMELINE

XENON10

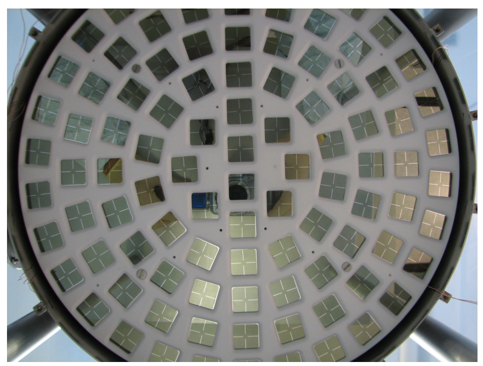
89 PMTs

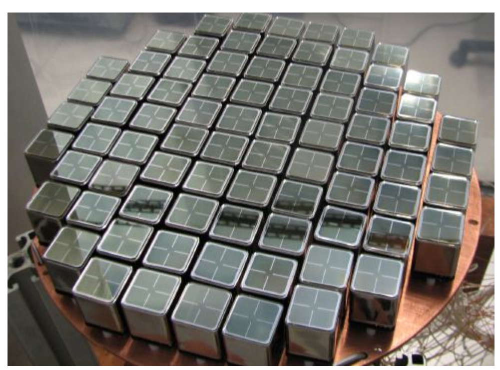




XENON100

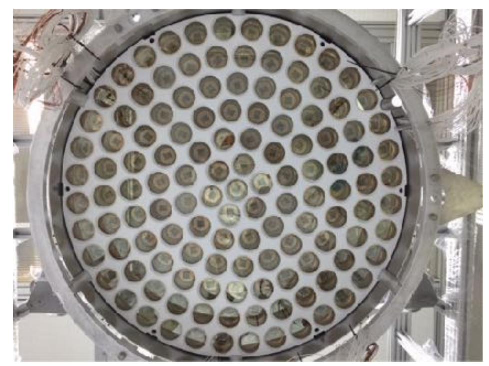
178 PMTs





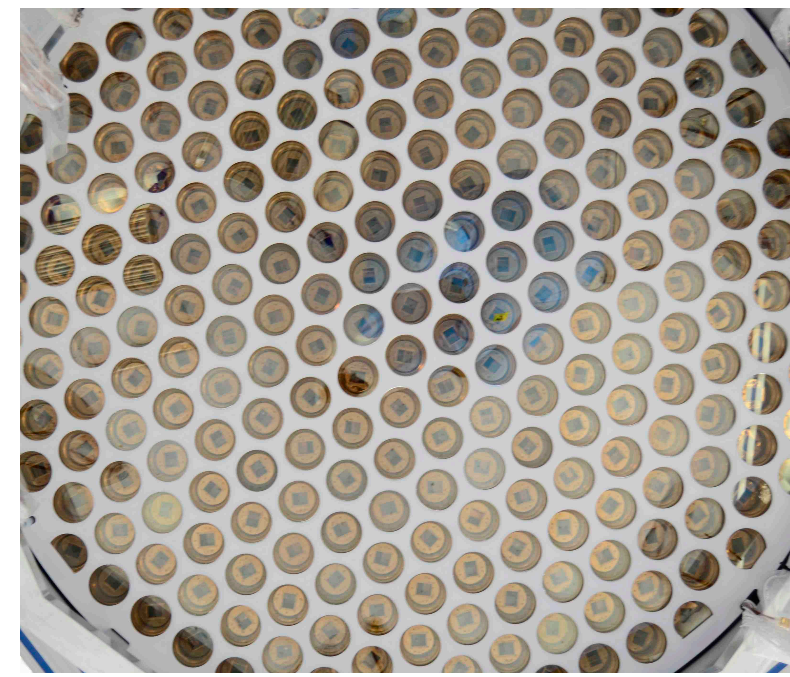
XENON1T

248 PMTs



XENONnT

494 PMTs



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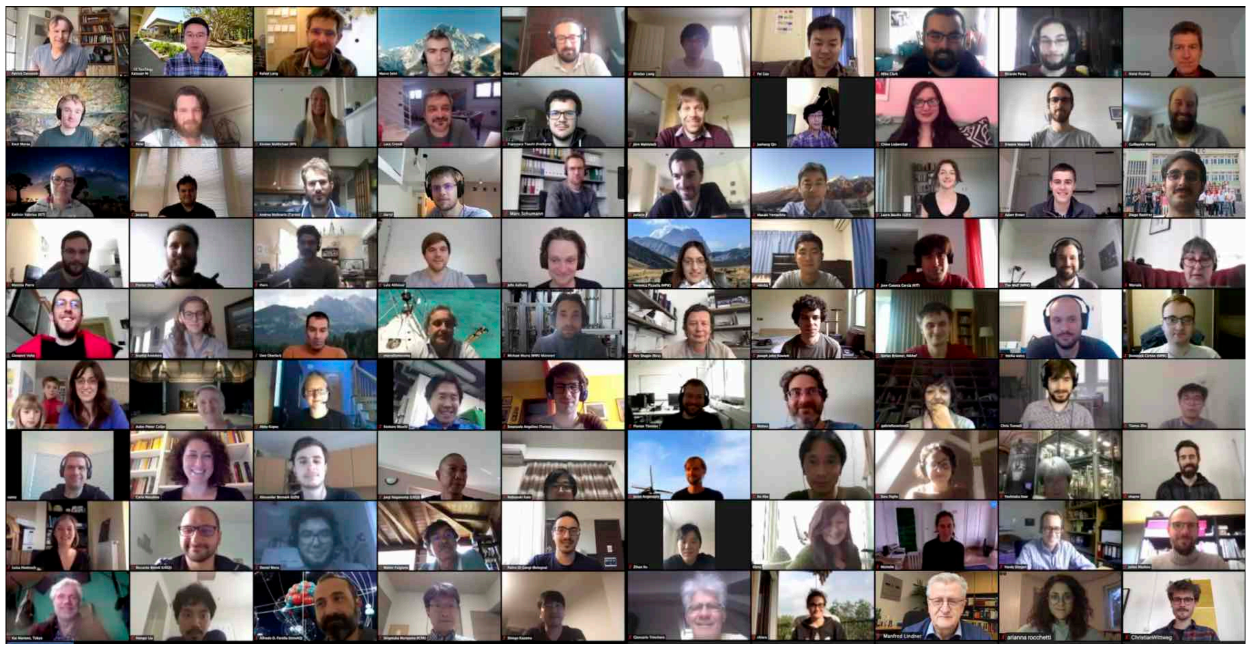
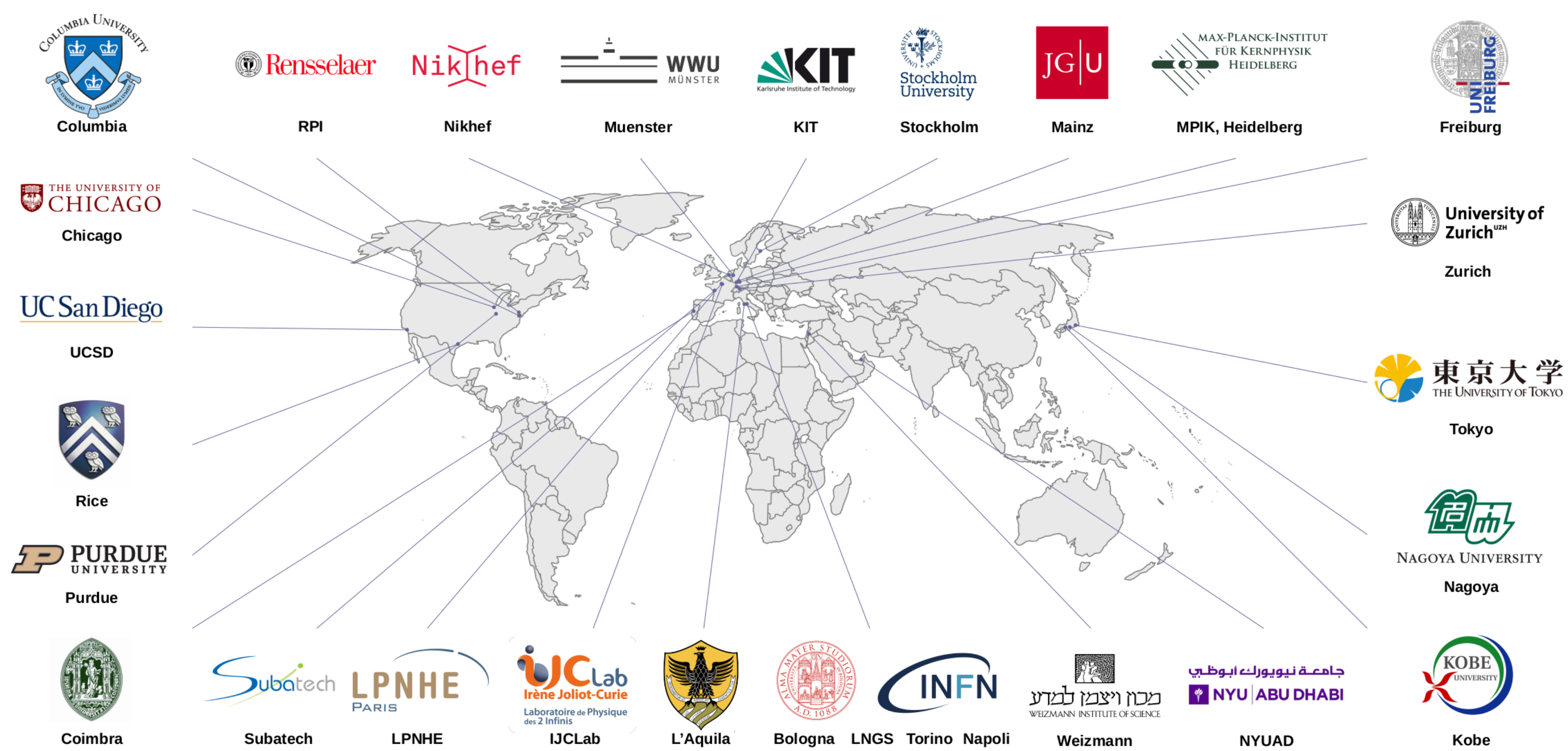
THE XENON COLLABORATION



170 scientists,
26 institutions,
11 countries



XENON1T AT THE GRAN SASSO LABORATORY

Water tank and Cherenkov muon veto

Cryostat and support structure for TPC

Time projection chamber

Cryogenics pipe (cables, xenon)

Cryogenics and purification

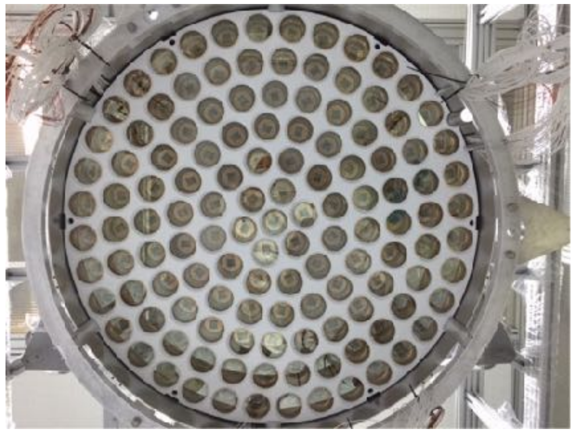
Data acquisition and slow control

Xenon storage, handling and Kr removal via cryogenic distillation

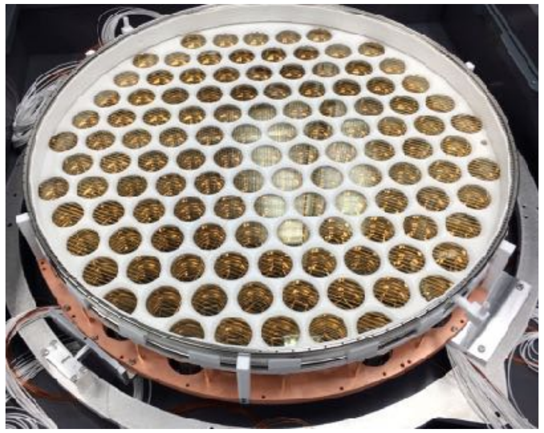
THE TIME PROJECTION CHAMBER

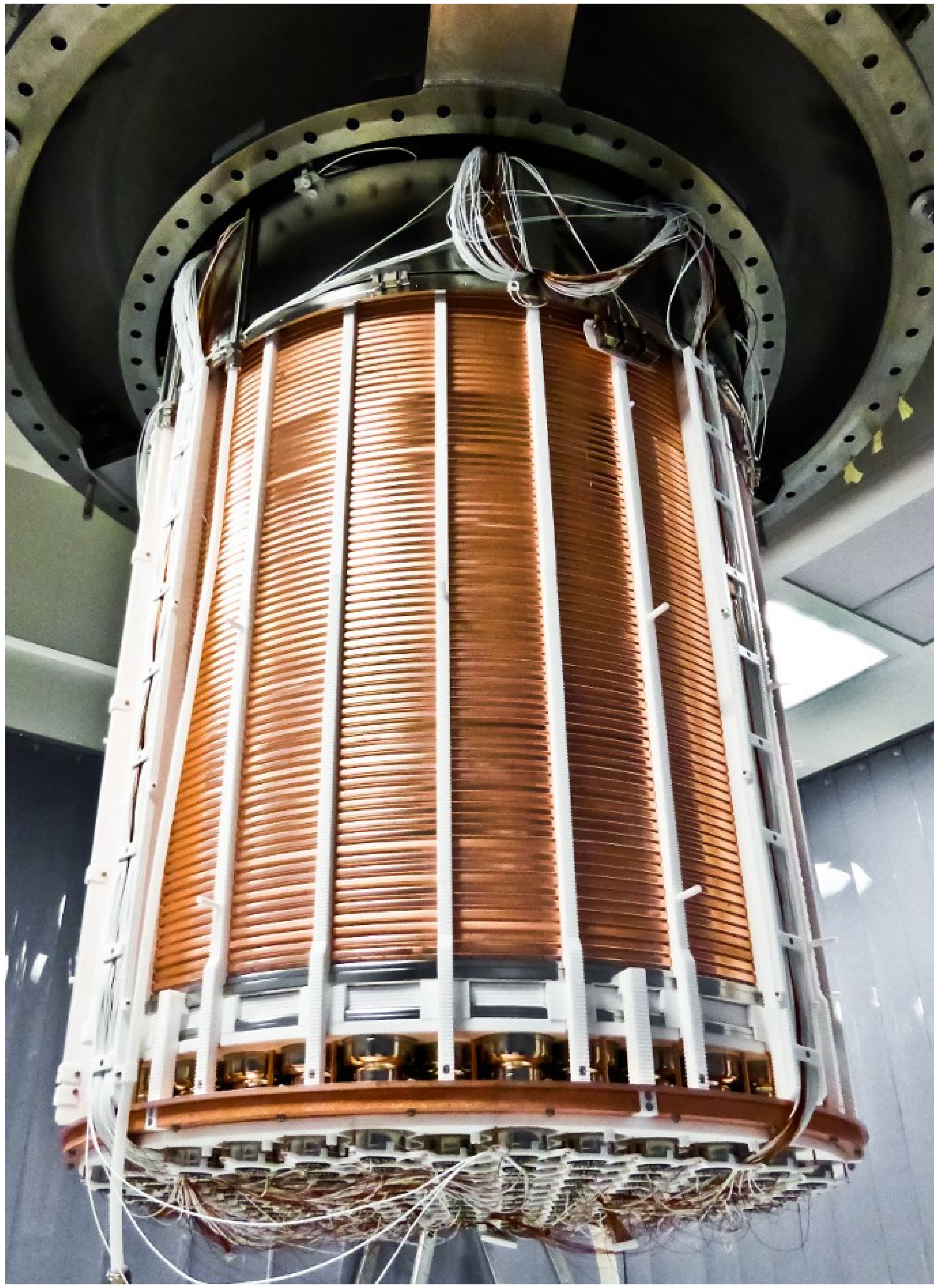
- 3.2 t LXe in total, 2 t in the TPC
- 97 cm drift, 96 cm diameter
- 248 3-inch PMTs
- 74 Cu field shaping rings, 5 electrodes, 4 level meters

127 PMTs top array

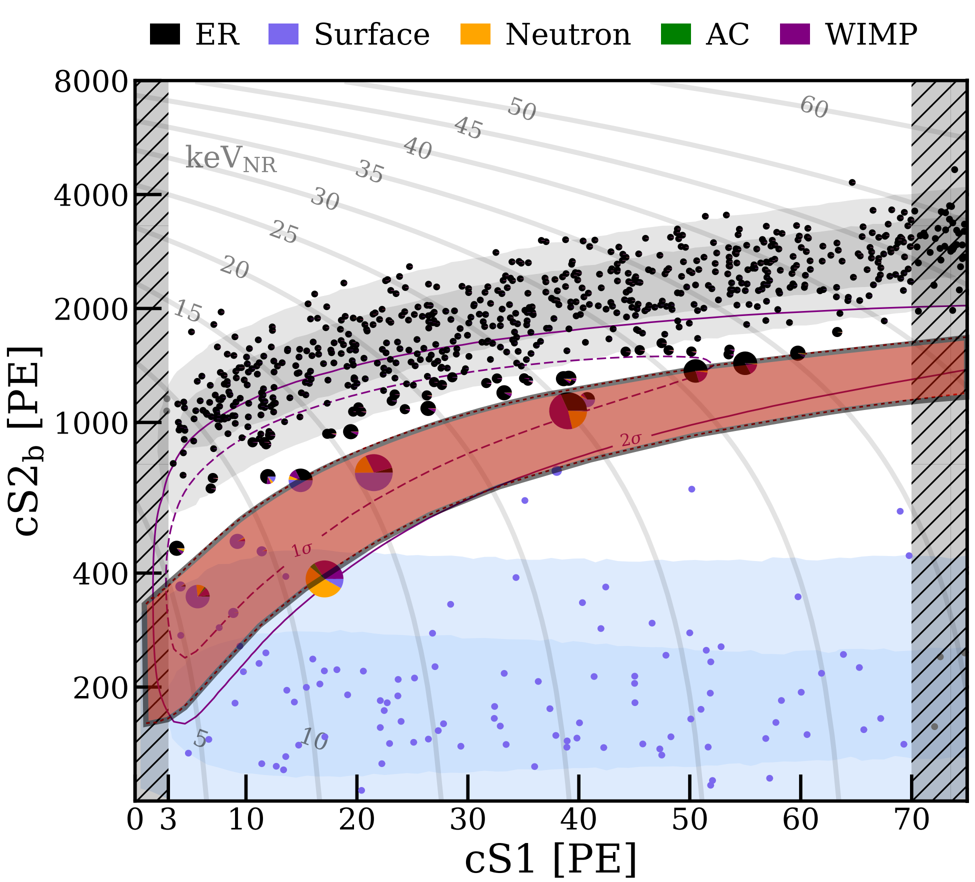


121 PMTs bottom array

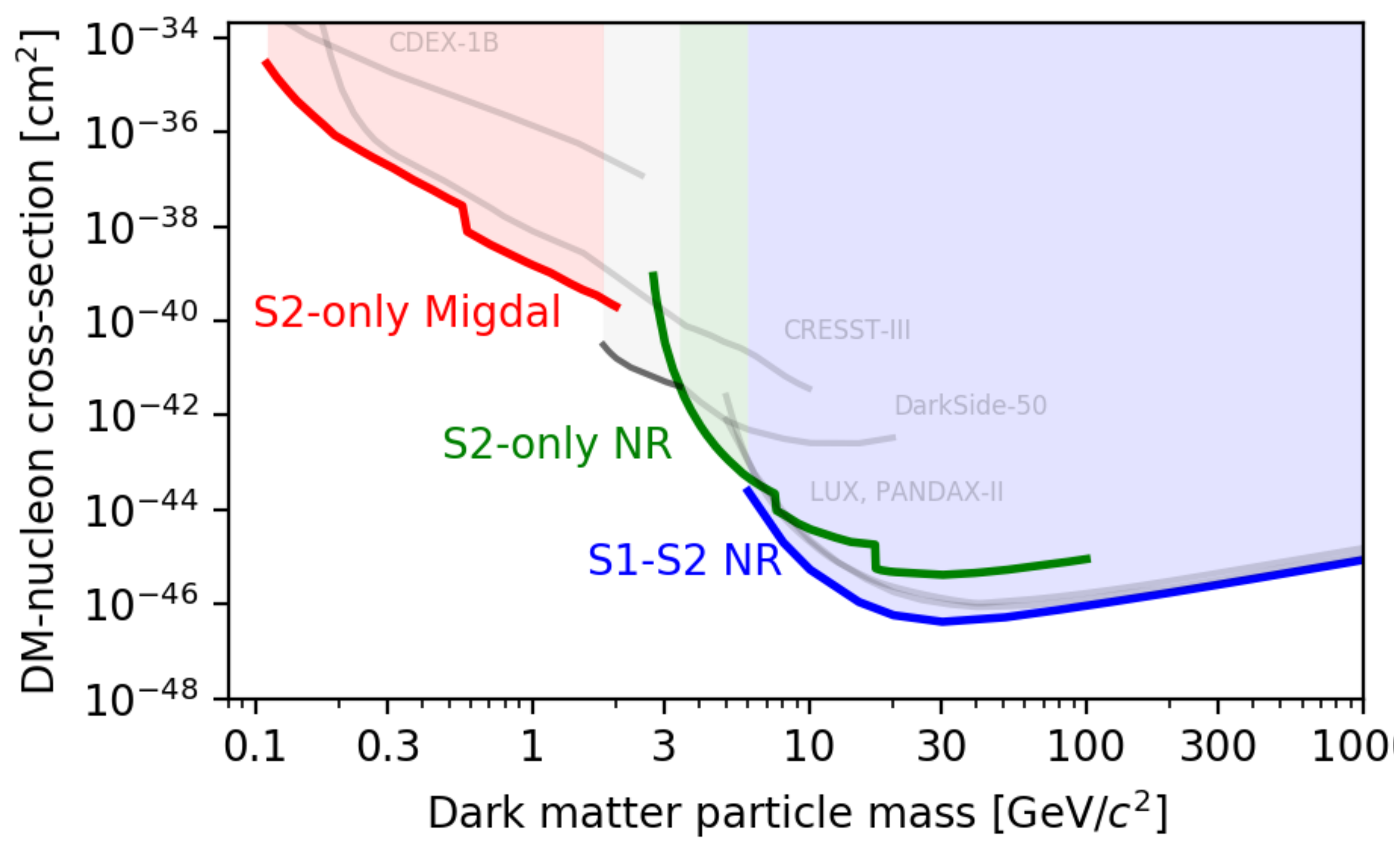




NUCLEAR RECOIL SEARCHES



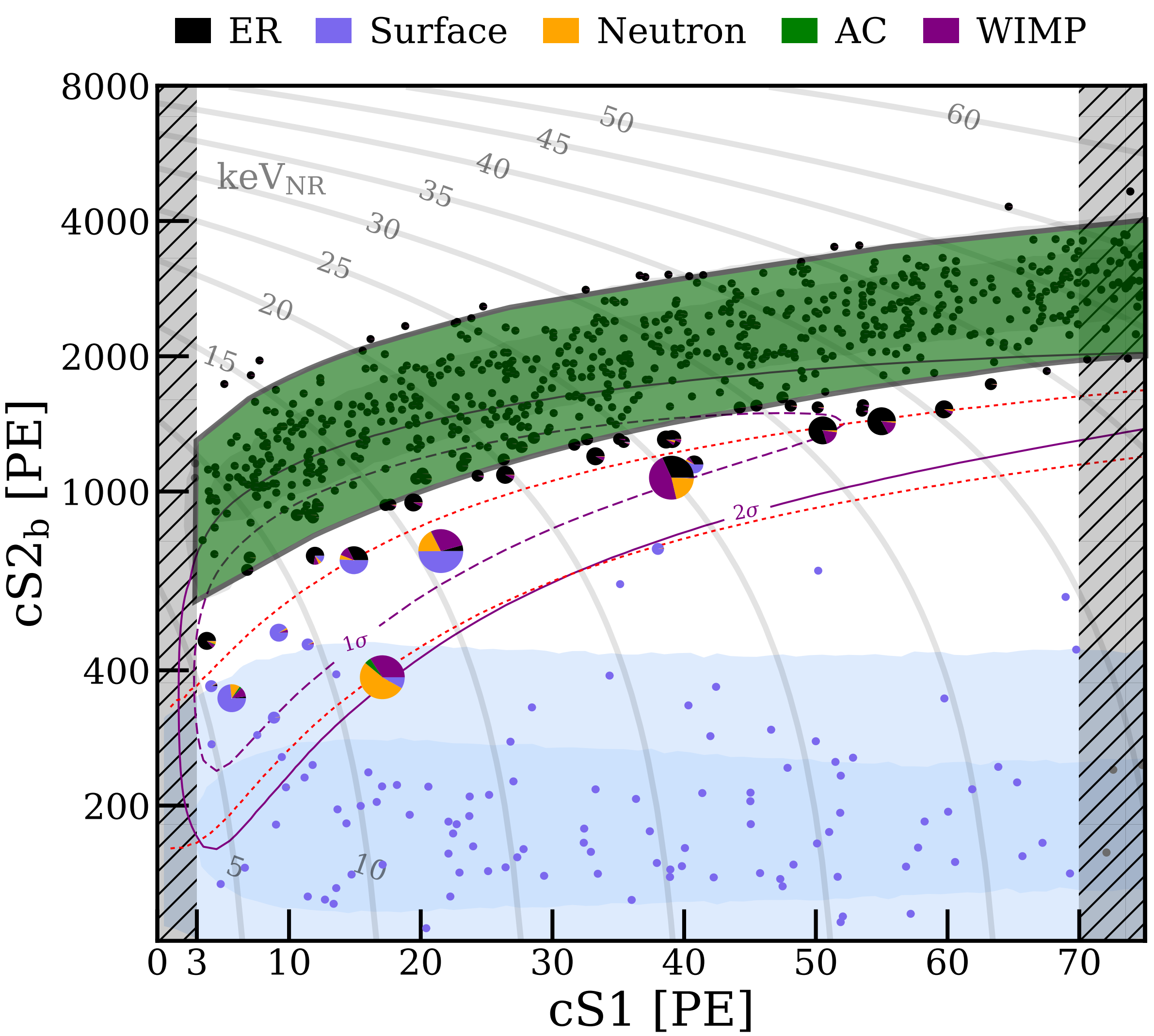
$\sigma_{SI} < 4.1 \times 10^{-47} \mathrm{cm}^2$ at $30\,\mathrm{GeV/c}^2$



Energy threshold: 4.9 keV NR
Exposure: 1 tonne x year

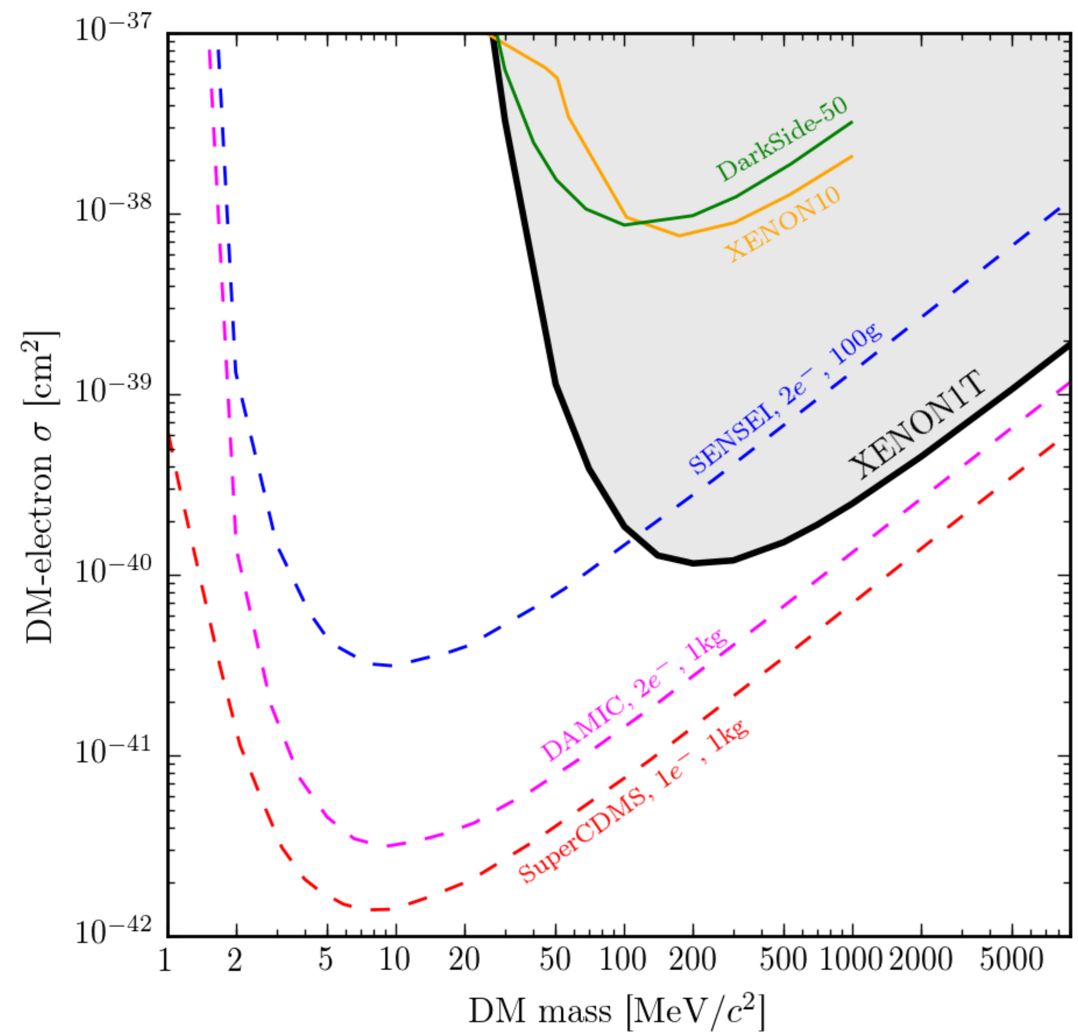
Most stringent constraints on WIMP-nucleon cross section down to ~3 GeV masses

ELECTRONIC RECOIL SEARCHES



Energy threshold: 1 keV ER
Exposure: 1 tonne x year
Low background: 76 ± 2 events/(t y keV)

S2-only analysis, DM-e$^-$ scattering

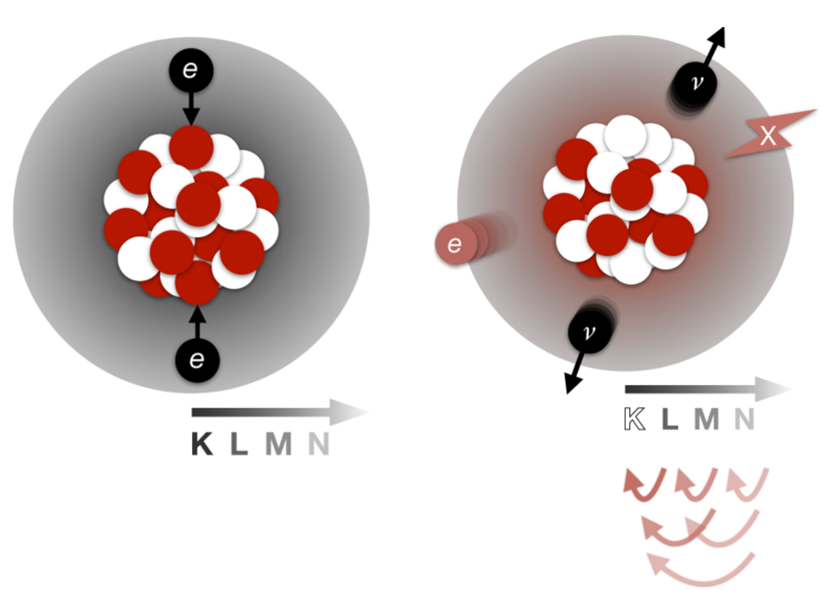


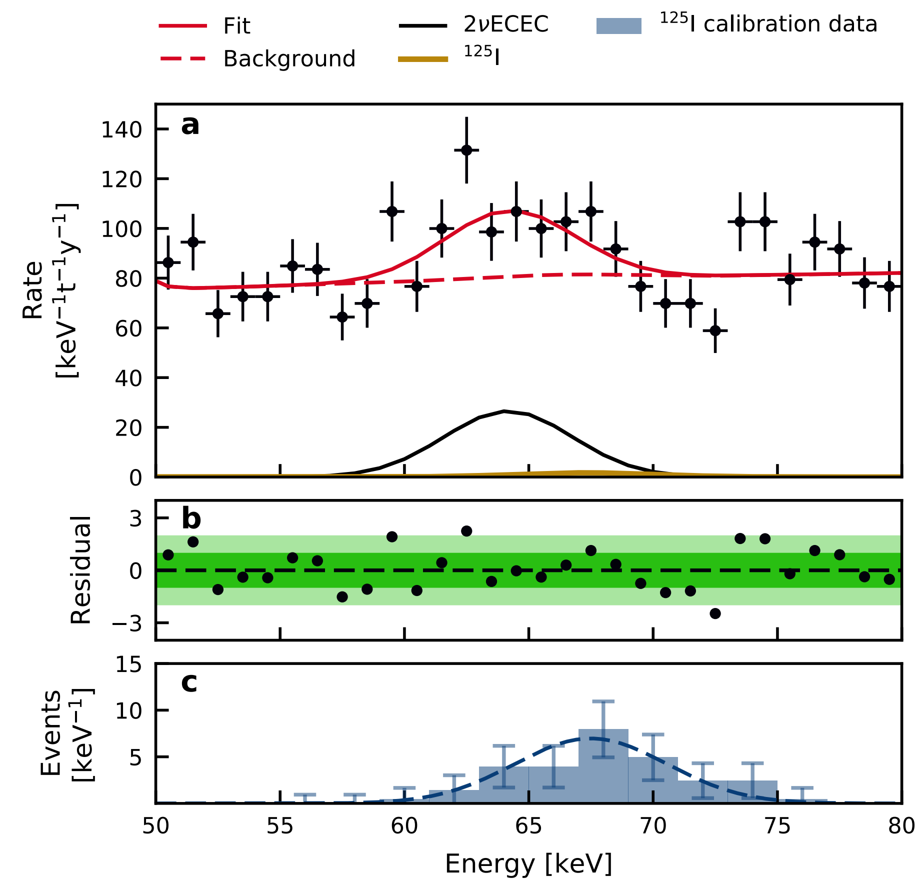
Energy threshold: ~0.18 keV
New parameter space excluded for DM masses > 30 MeV

DOUBLE ELECTRON CAPTURE

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

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





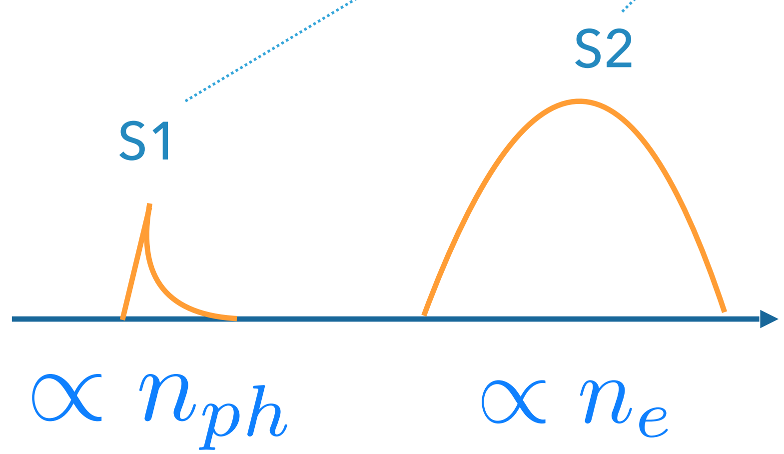
σ/E = (4.1 ± 0.4)% at 64 keV

- ^{124}Xe in $^{\mathrm{nat}}$Xe: 0.095% => 1 t $^{\mathrm{nat}}$Xe ≈ 1 kg ^{124}Xe
- Total obs energy: 64.33 keV (2 x K-shell binding energy, Q-value: 2.96 MeV)
- Blind analysis: (56-72) keV region masked
- Signal events: (126±29), expected bg from ^{125}I: (9±7) events (at 67.5 keV)

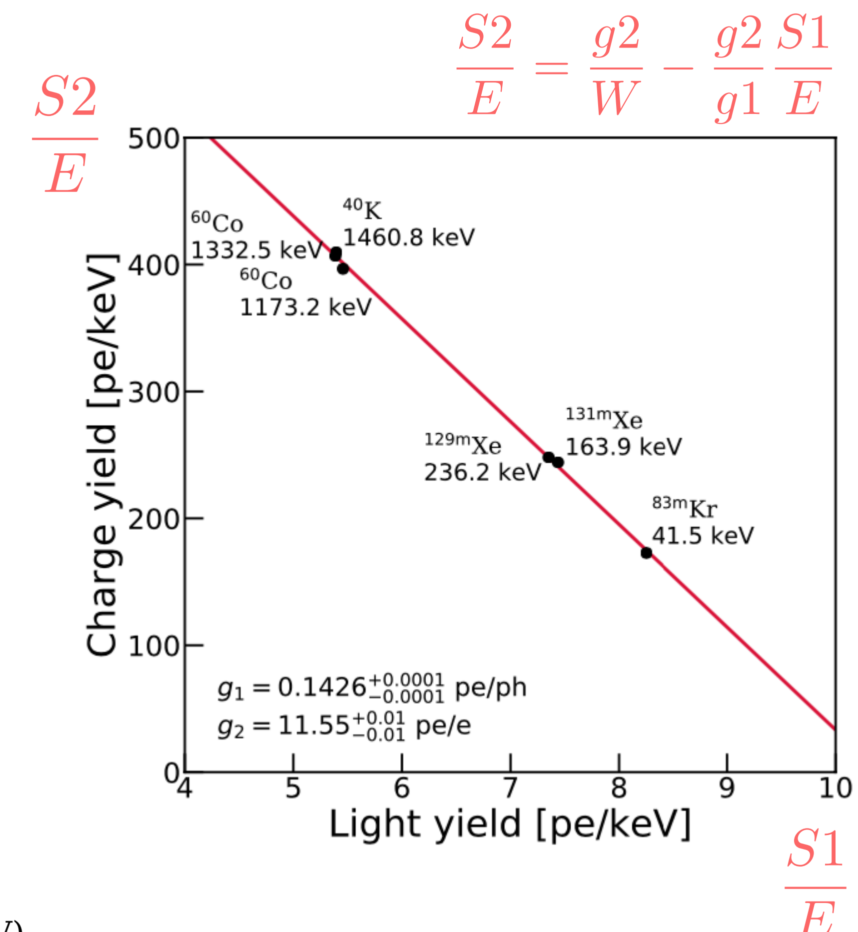
ENERGY RECONSTRUCTION

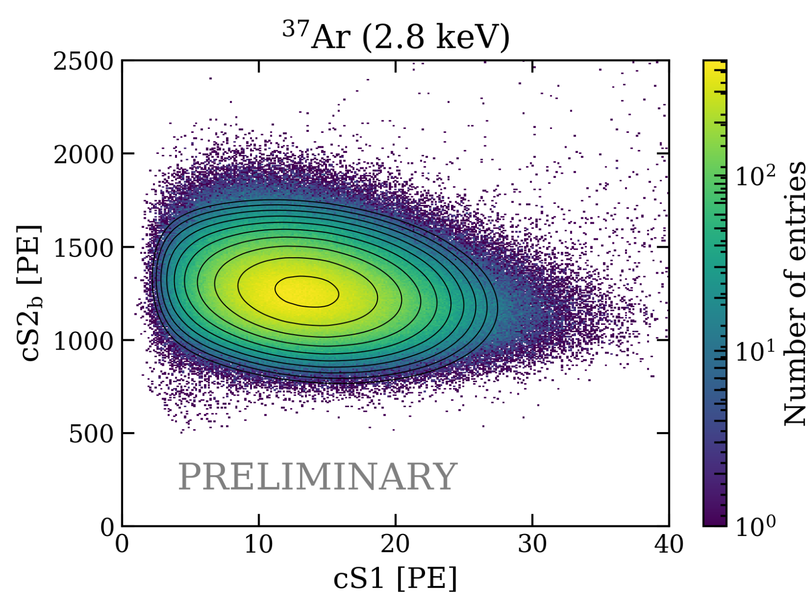
- Anti-correlation between light (S1) and charge (S2)
- Energy scale uses *linear combination of S1 and S2*
    - hv gain: g_1 (pe/photon), e^- gain: g_2 (pe/electron)

$$E = (n_{ph} + n_e) \cdot W = \left(\frac{S_1}{g_1} + \frac{S_2}{g_2}\right) \cdot W$$



Once g1 and g2 are known => reconstruct the energy of the event





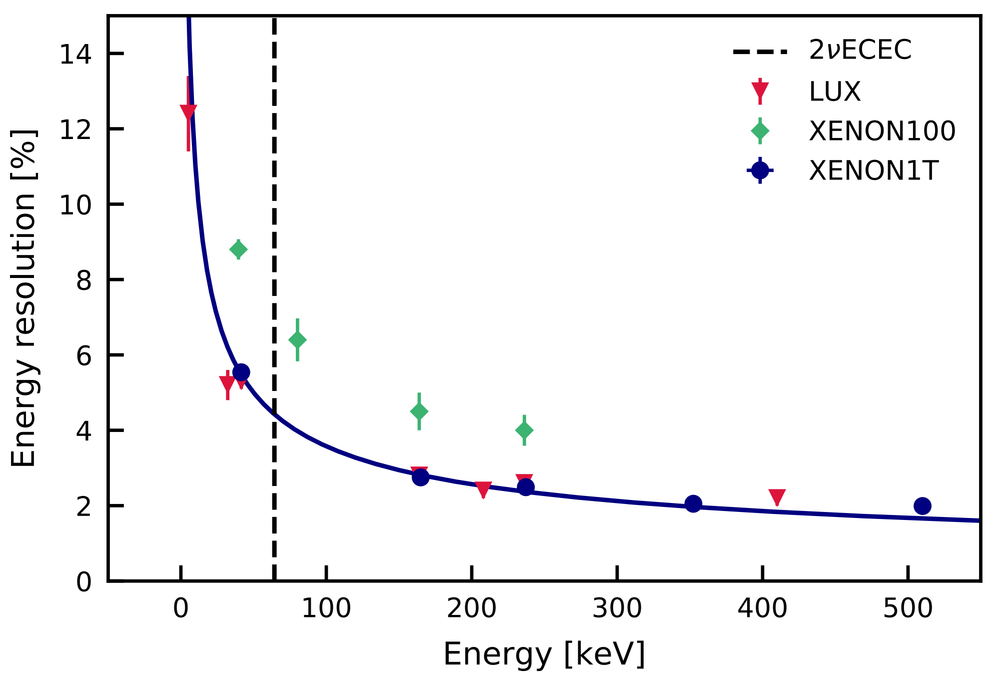
^{37}Ar calibration (2.8 keV X-ray)

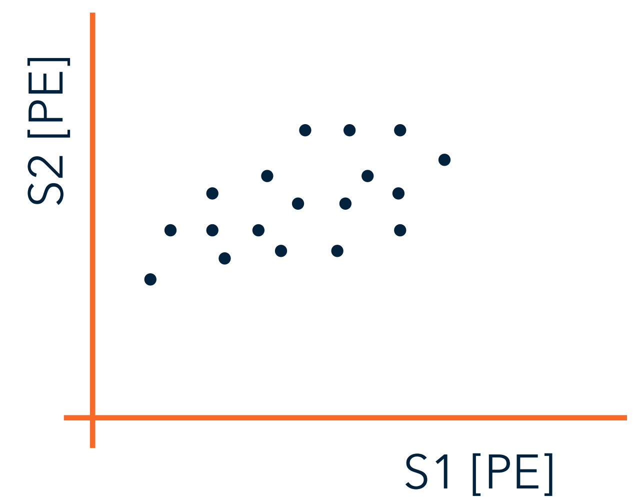
ENERGY RESOLUTION

- Energy scale: linear combination of S1 and S2
- WIMP search: 2 D analysis; here: 1D analysis

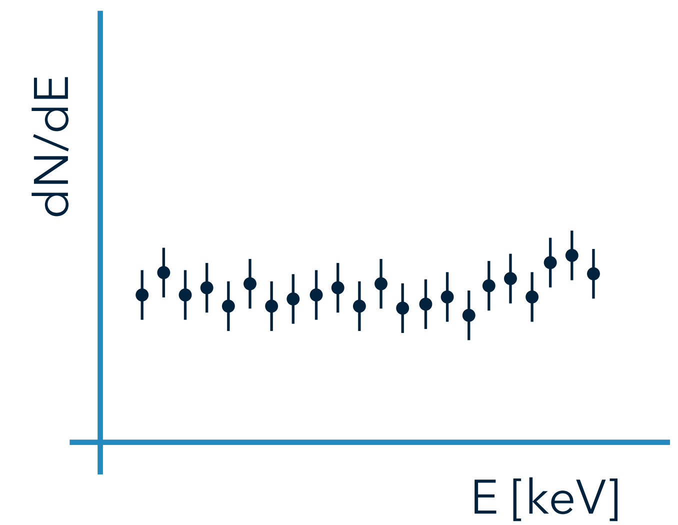
$$\sigma(E) = a \cdot \sqrt{E} + b \cdot E$$

$$a = (0.310 \pm 0.004)\sqrt{E}$$
$$b = 0.0037 \pm 0.0003$$





$$E = \left(\frac{S1}{g1} + \frac{S2}{g2}\right) \cdot W$$



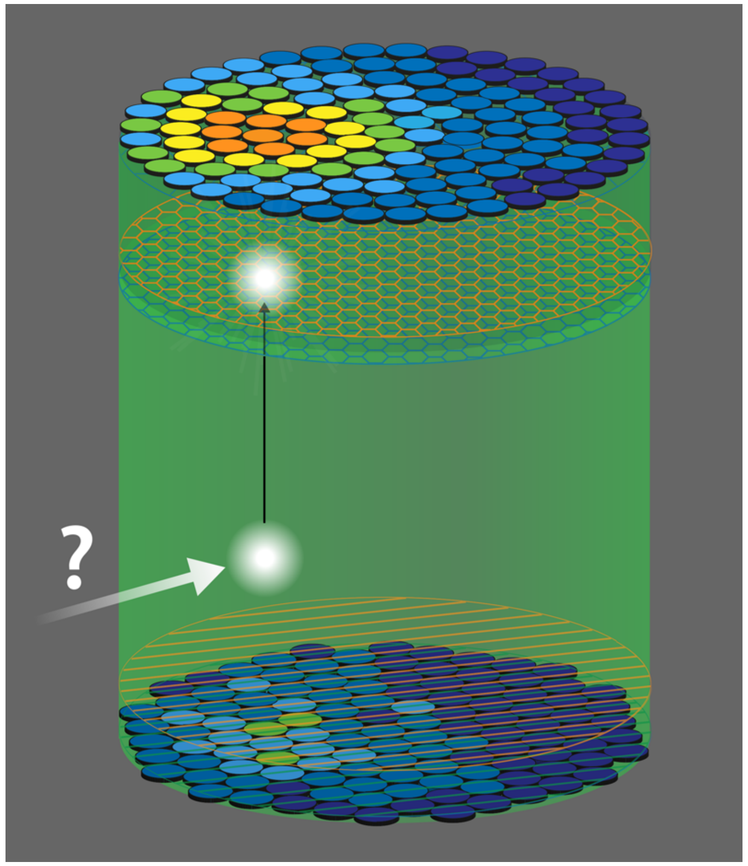
THE LOW ENERGY EXCESS

Dark Matter Detector Delivers Enigmatic Signal

Tongyan Lin
Department of Physics, University of California, San Diego, La Jolla, CA, USA

October 12, 2020 • *Physics* 13, 135

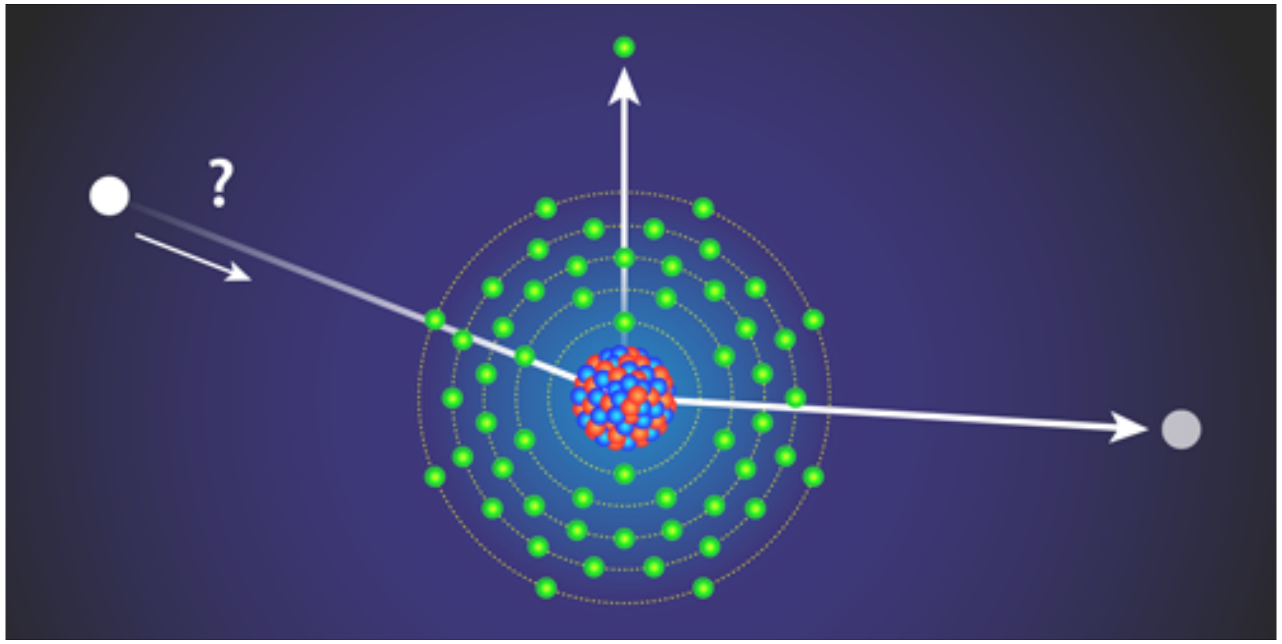
Are the excess events detected by the XENON1T experiment a harbinger of new physics or a mundane background?



Theorists React to Potential Signal in Dark Matter Detector

October 12, 2020 • *Physics* 13, s132

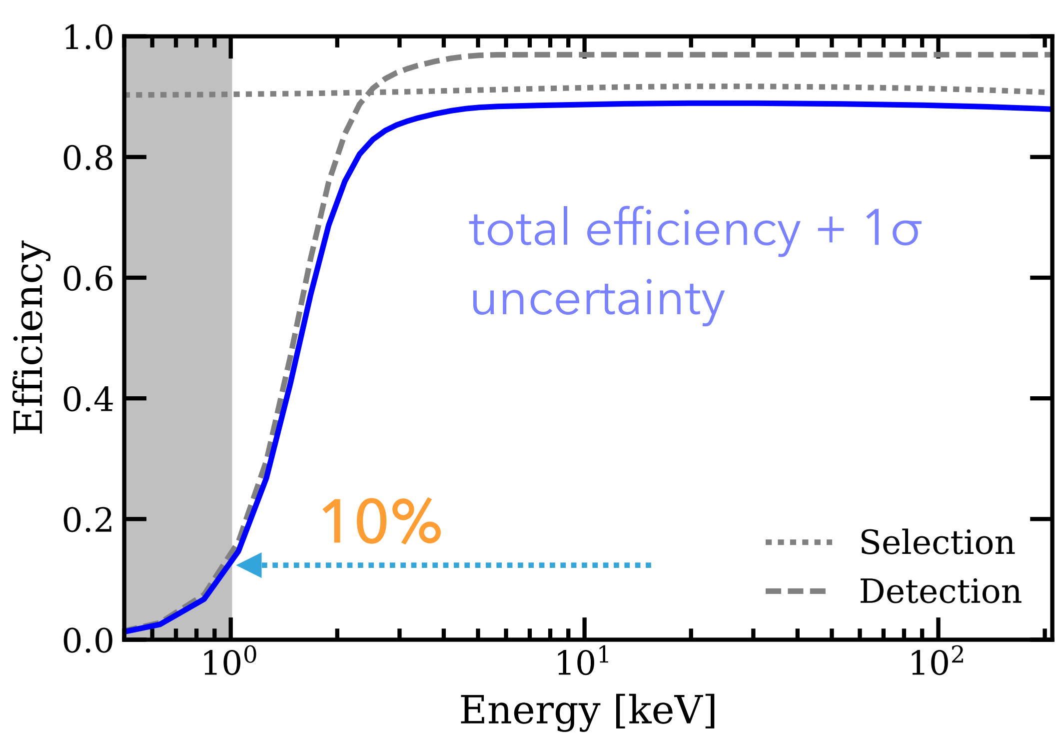
A tantalizing signal reported by the XENON1T dark matter experiment has sparked theorists to investigate explanations involving new physics.

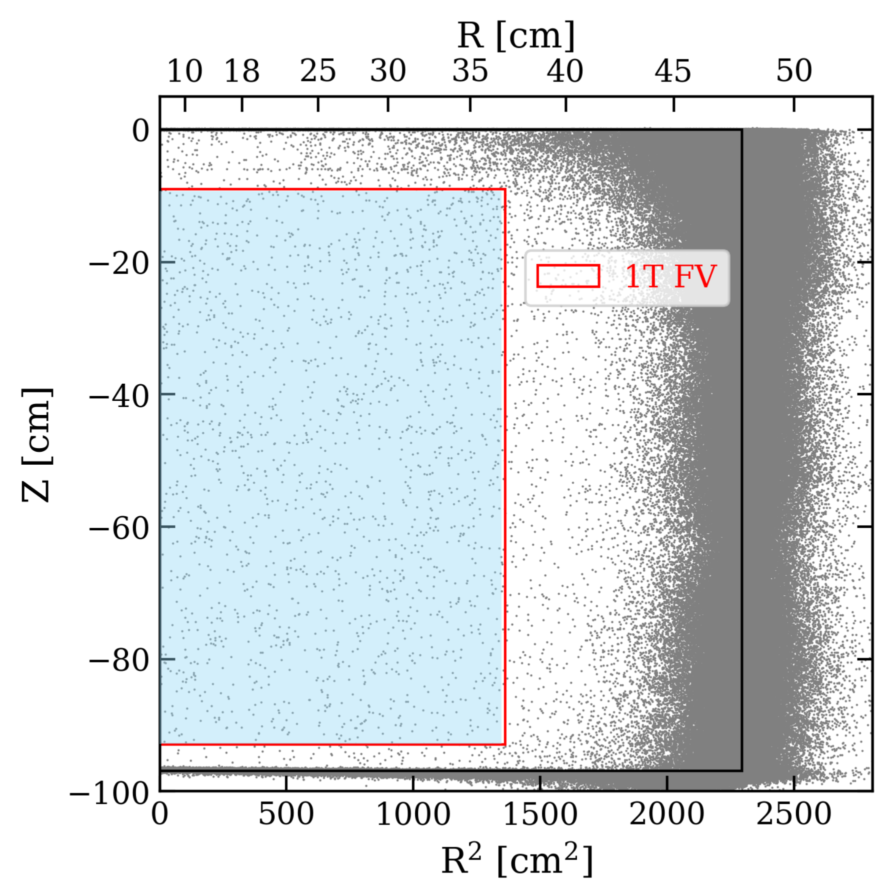


DATA SELECTION AND EFFICIENCIES

Science Run 1(SR1)

- 226.9 live days, 1 tonne LXe in fiducial volume
- Analysis energy range: [1,210] keV
- Efficiencies of reconstruction and data quality cuts taken into account
    - Energy threshold: at 10% detection efficiency
    - [S1: signal in at least 3 PMTs; S2: 500 pe threshold]





BACKGROUND COMPONENTS

- Modelled with Geant4-based MC simulations or theoretical predictions
- Most rates constrained by other measurements or time dependance
    - Search for excess over *known backgrounds* between 1 and 210 keV

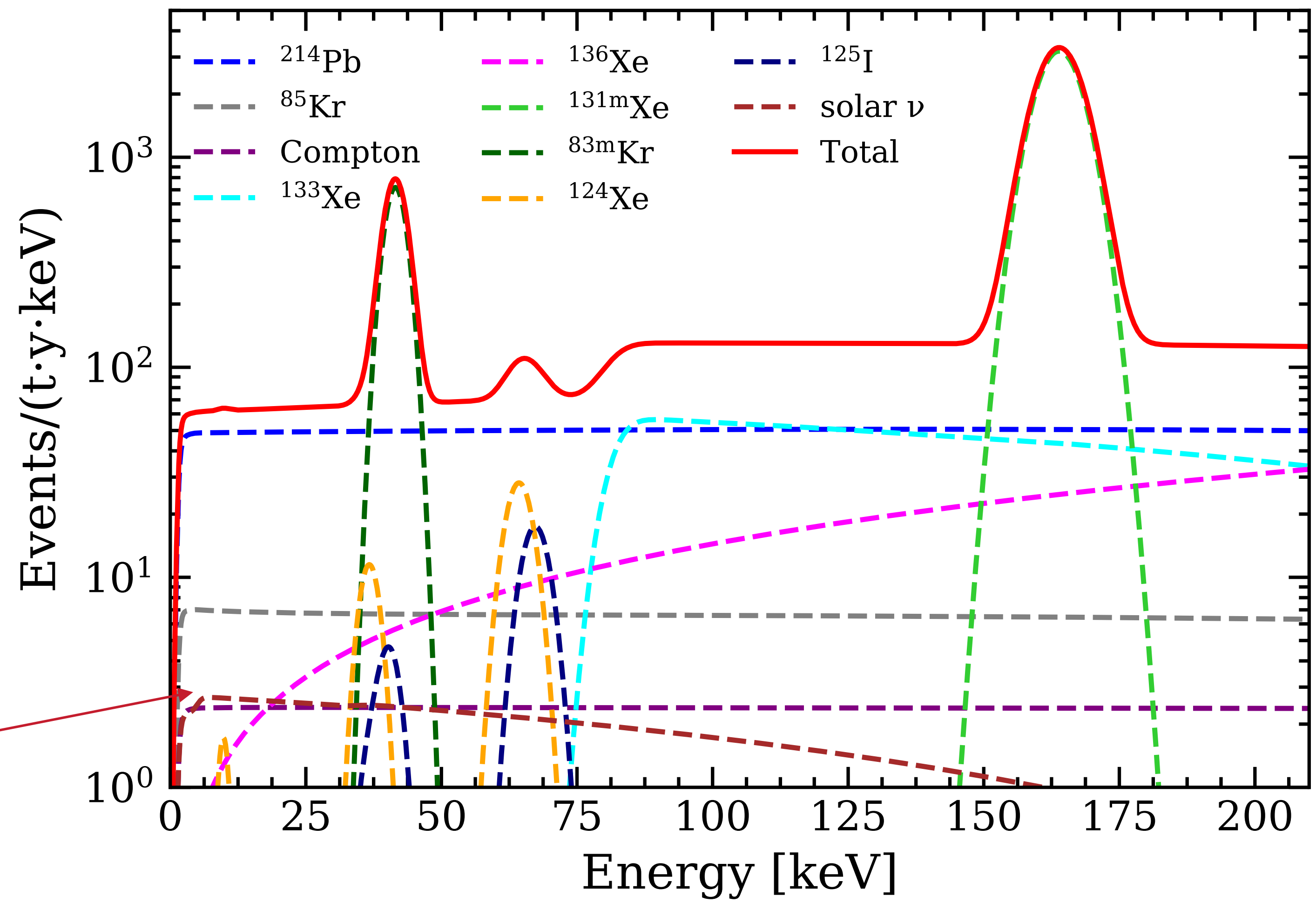
Neutron-activation:

^{131m}Xe ($T_{1/2}$ = 11.9 d)

^{133}Xe ($T_{1/2}$ = 5.3 d)

^{125}I ($T_{1/2}$ = 60 d)

Solar neutrinos



Intrinsic backgrounds:

^{214}Pb (from ^{222}Rn in LXe)

^{136}Xe ($T_{1/2}$ = 2.16 x 10^{21} y)

^{124}Xe ($T_{1/2}$ = 1.8 x 10^{22} y)

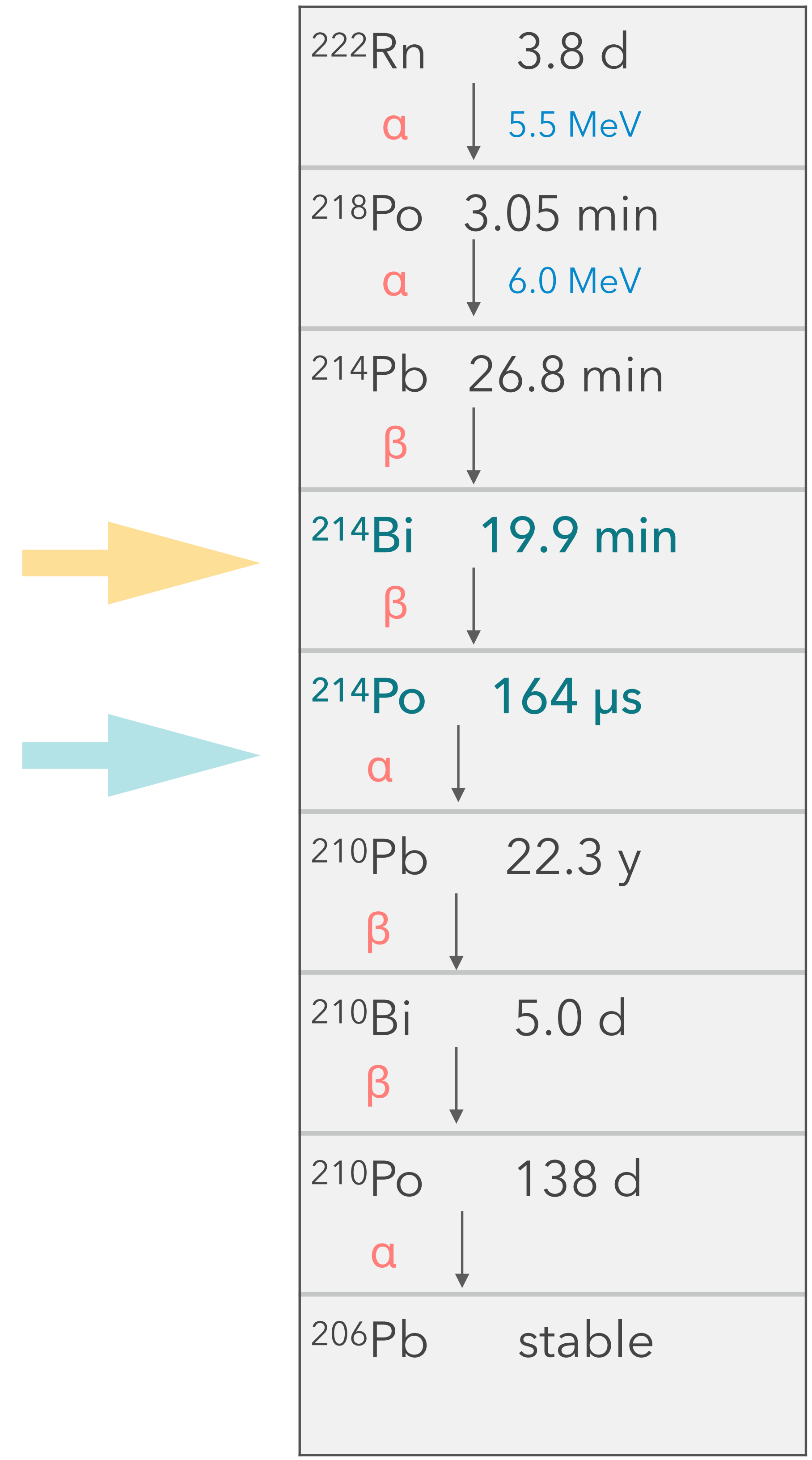
^{85}Kr ($T_{1/2}$ = 10.76 y)

^{83m}Kr ($T_{1/2}$ = 1.83 h)

Detector materials: γ

BACKGROUND COMPONENTS

- Main background in ROI: ^{214}Pb β-decays (from ^{222}Rn emanation from materials)
    - Lower bound: (5.1 ± 0.5) μBq/kg from ^{214}Bi^{214}Po coincidences
    - Upper bound: (12.6± 0.8) μBq/kg from ^{218}Pb α-decays
- Left unconstrained in the fit
- Evaluated activity $(11.1 \pm 0.2_{stat} \pm 1.1_{sys})$ μBq/kg
    - well within upper/lower bounds

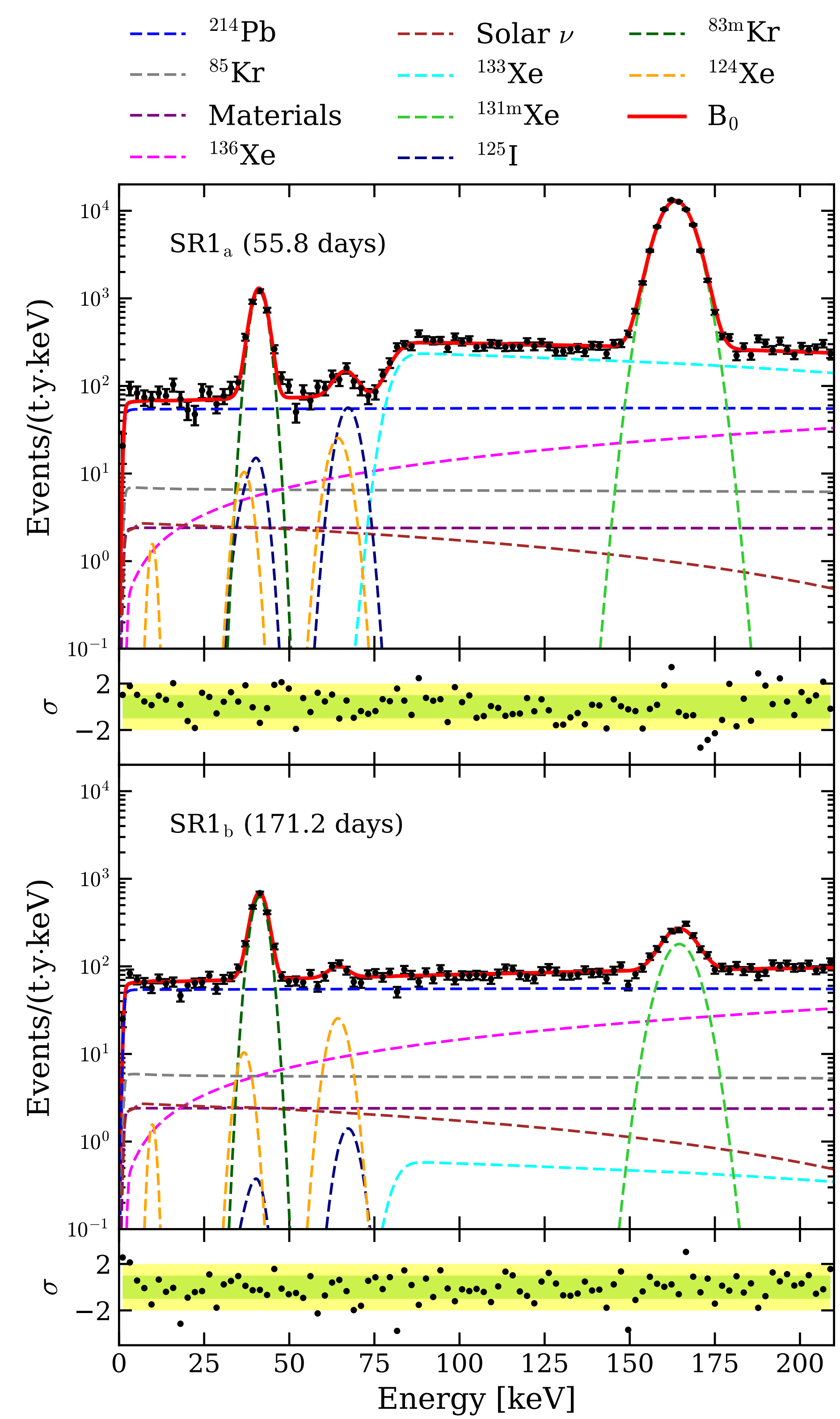


BACKGROUND MODEL AND DATA

- Unbinned ML fit profiling over nuisance parameters
- Two partitions of data (due to n-activation) $\mathcal{L} = \mathcal{L}_a \times \mathcal{L}_b$
- 76±2 events/(t y keV) in [1,30] keV interval
- Good fit over most of the energy region
- Excess between (1,7) keV: number of observed events: 285, expected from background: (232±15) events

$$\mathcal{L}(\mu_s, \boldsymbol{\mu_b}, \boldsymbol{\theta}) = \mathrm{Poiss}(N|\mu_{tot}) \times \prod_i^N \left(\sum_j \frac{\mu_{b_j}}{\mu_{\mathrm{tot}}} f_{b_j}(E_i, \boldsymbol{\theta}) + \frac{\mu_s}{\mu_{\mathrm{tot}}} f_s(E_i, \boldsymbol{\theta}) \right) \times \prod_m C_{\mu_m}(\mu_{b_m}) \times \prod_n C_{\theta_n}(\theta_n),$$

$$\mu_{\mathrm{tot}} \equiv \sum_j \mu_{b_j} + \mu_s$$



STATISTICAL METHOD

- Likelihood construction:

expected total signal events

expected total background events

i - over all observed events, N = 42251

background PDF

signal PDF

$$\mathcal{L}(\mu_s, \boldsymbol{\mu_b}, \boldsymbol{\theta}) = \mathrm{Poiss}(N|\mu_{tot}) \times \prod_i^N \left(\sum_j \frac{\mu_{b_j}}{\mu_{\mathrm{tot}}} f_{b_j}(E_i, \boldsymbol{\theta}) + \frac{\mu_s}{\mu_{\mathrm{tot}}} f_s(E_i, \boldsymbol{\theta}) \right) \times \prod_m C_{\mu_m}(\mu_{b_m}) \times \prod_n C_{\theta_n}(\theta_n),$$

$$\mu_{\mathrm{tot}} \equiv \sum_j \mu_{b_j} + \mu_s$$

μ_b, θ : nuisance parameters

θ = includes shape parameters for the eff. spectral uncertainty & peak location uncertainty

constraints on the expected nr of background (m) events and shape parameters (n=6)

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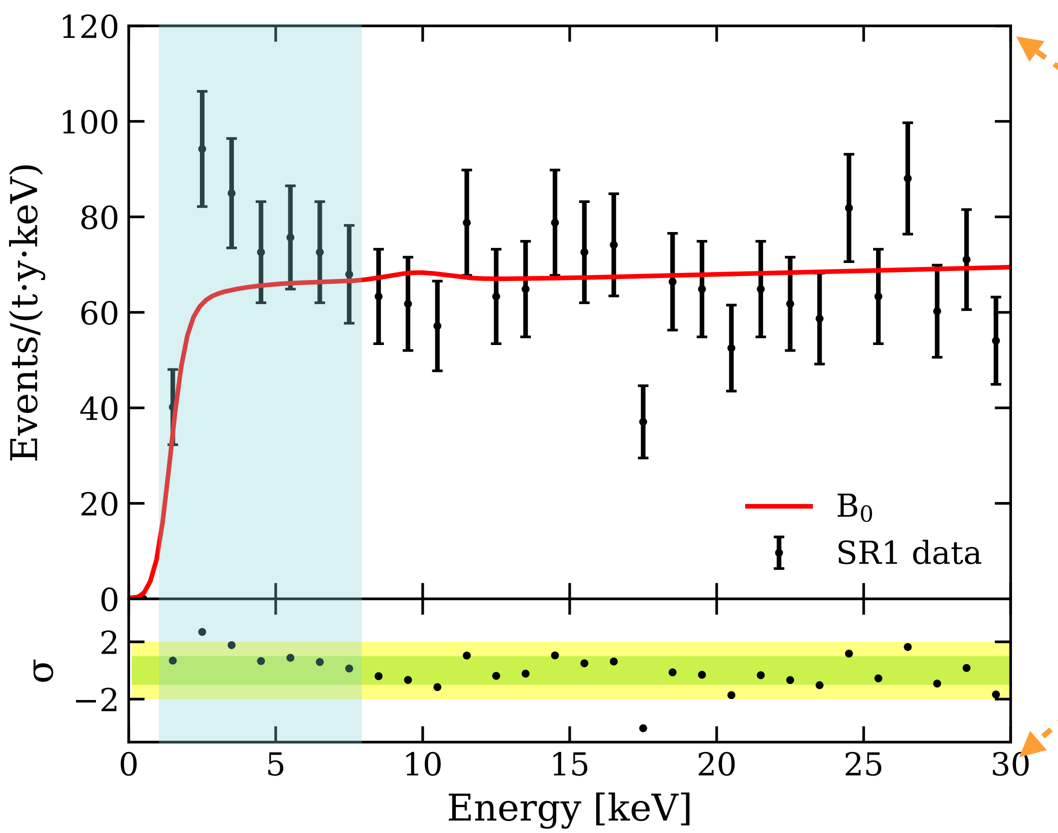
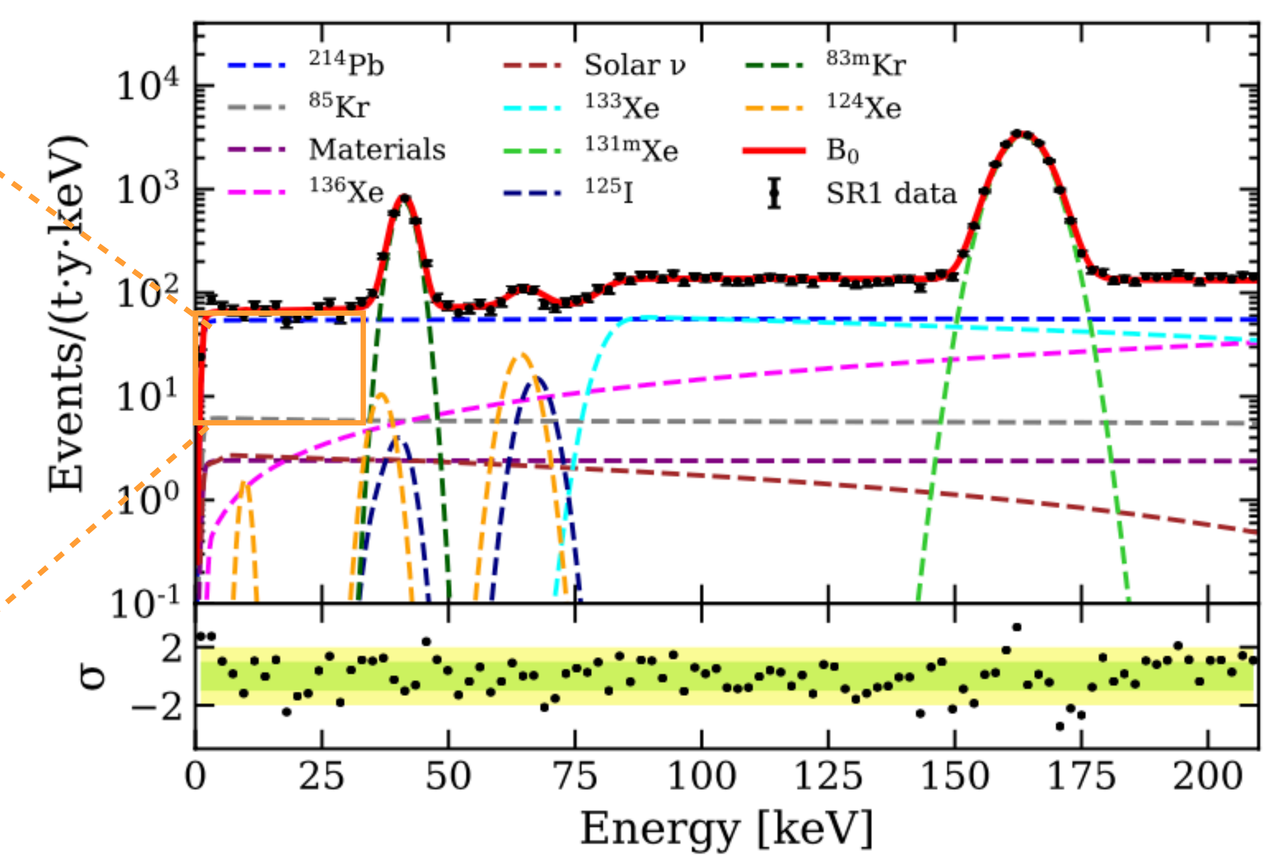
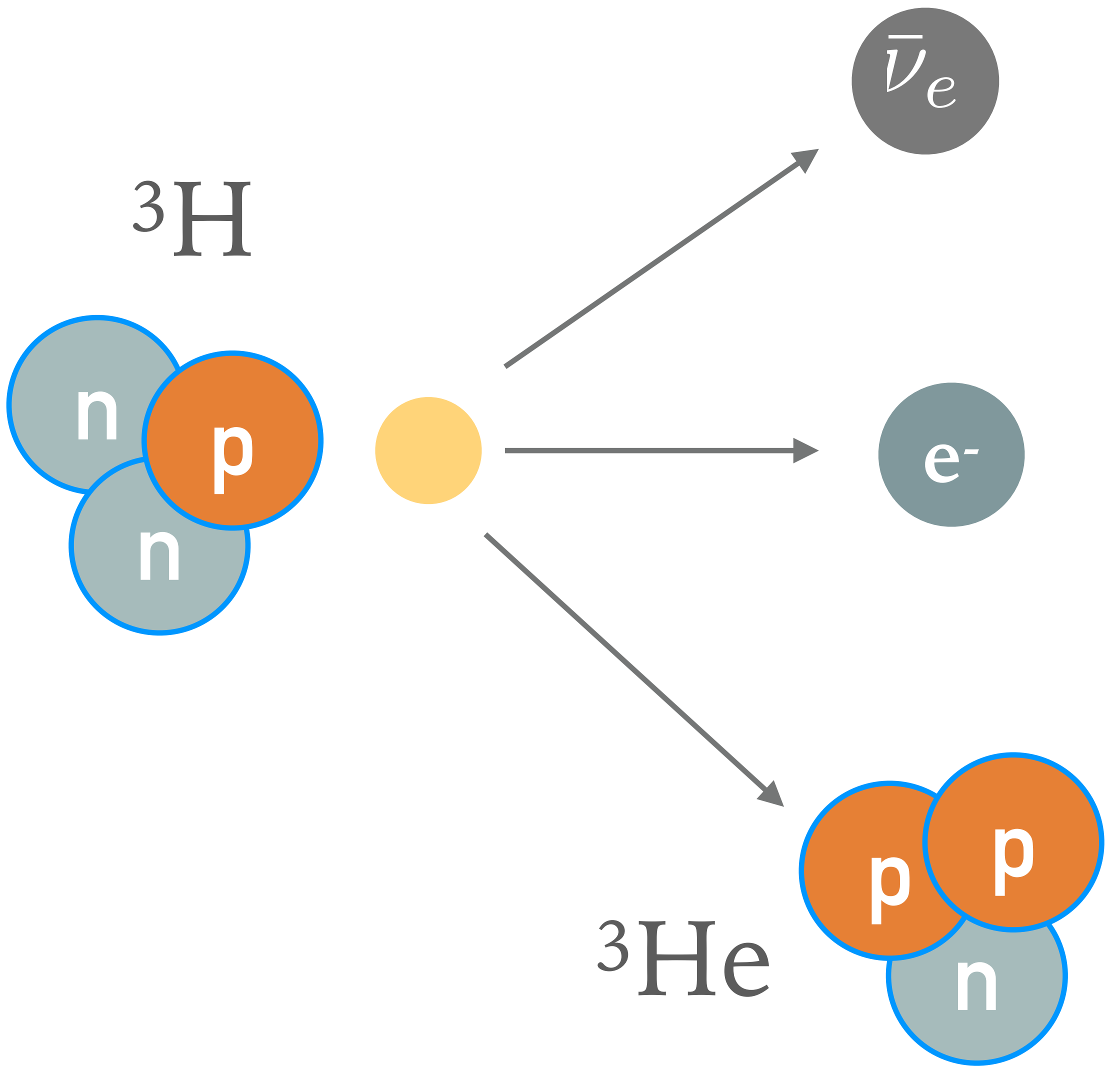


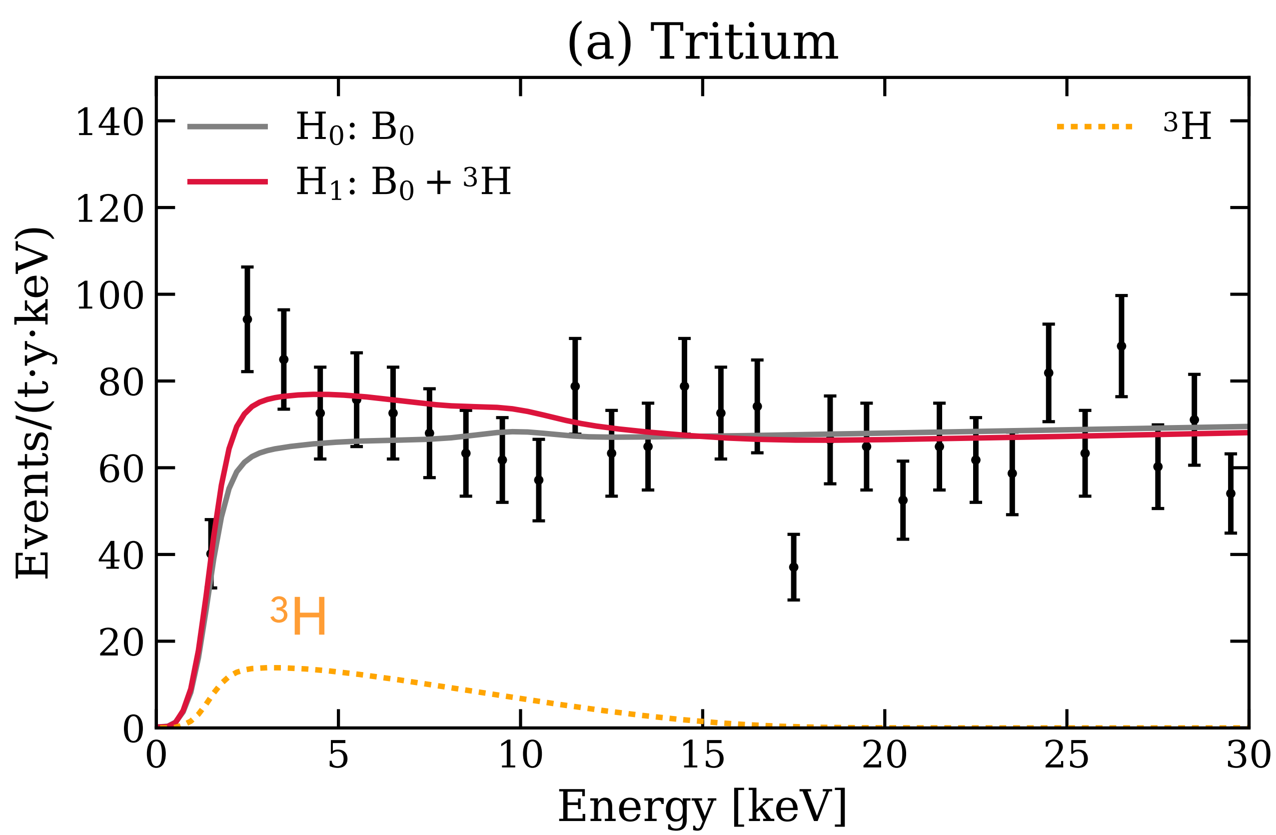


NEW BACKGROUND, NEVER OBSERVED BEFORE?

TRITIUM DECAYS

- Low energy β-decay with 18.6 keV endpoint, $T_{1/2}$ = 12.3 y
- Cosmogenic production in xenon & emanation of HTO and HT from detector materials
  - Removed by continuous gas purification





Best fit: (159 ± 51) events/(t y)

(6.2 ± 2.0) x 10^{-25} mol/mol

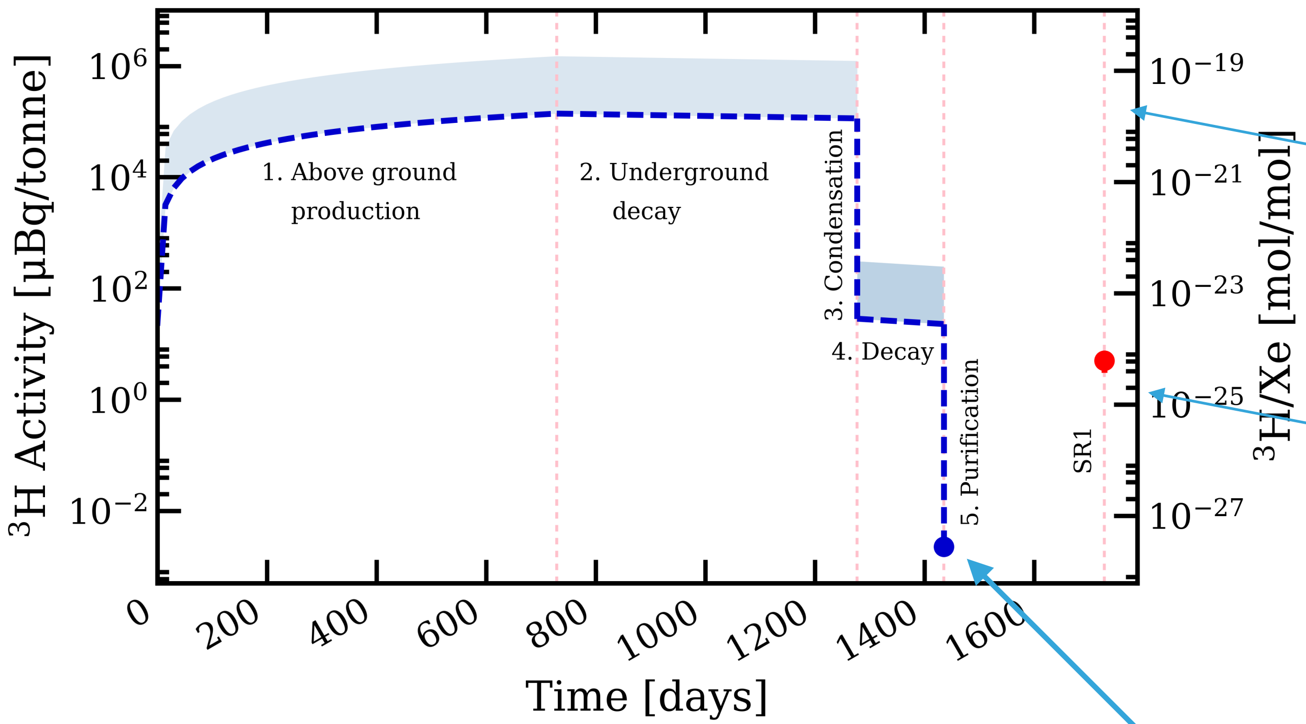
~ 3 ^{3}H atoms per kg of xenon

Tritium favoured over background at 3.2 σ

TRITIUM FROM COSMOGENIC ACTIVATION

- Spallation of Xe produces ^3H: activation at sea level = 31.6/(kg day)*
- Measured H_2O abundance in Xe bottles suggest HTO dominant species
  - Estimate concentration from activation and its evolution through Xe gas handling

*Zhang et al., Astropart. Phys 84, 62 (2016)



Initial concentration <4 x 10^{-20} mol/mol

Fitted concentration: 6.2 x 10^{-25} mol/mol

Expected concentration: < 10^{-27} mol/mol

Estimated tritium activity (not measurements)

TRITIUM FROM NATURAL ABUNDANCE IN MATERIALS

- Could tritium be emanated from materials and be in equilibrium with online removal?
  - Atmospheric abundance: (5-10) x 10^{-18} HTO/H_2O
  - ^3H could be in detector materials as HT (H_2) and HTO (H_2O)
- Best fit: 30 - 60 ppb for H_2O + H_2 concentration in Xe

H_2O/Xe

- O(1) ppb from light yield measurements

H_2/Xe

- Not constrained by measurement
- O_2 equiv concentration < ppb from Xe purity
- 100 x higher emanation rate than from electronegative impurities needed

^3H: CAN BE NEITHER CONFIRMED, NOR RULED OUT PRESENTLY

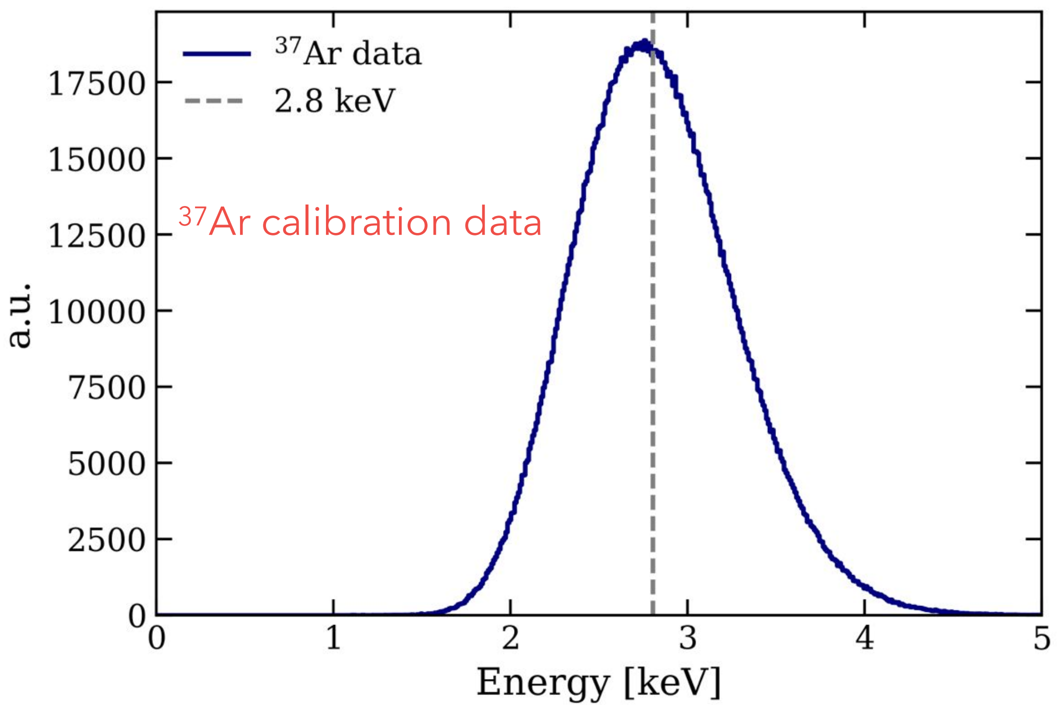
SIGNIFICANCE OF SIGNALS: WITH AND WITHOUT ^3H IN THE BACKGROUND MODEL

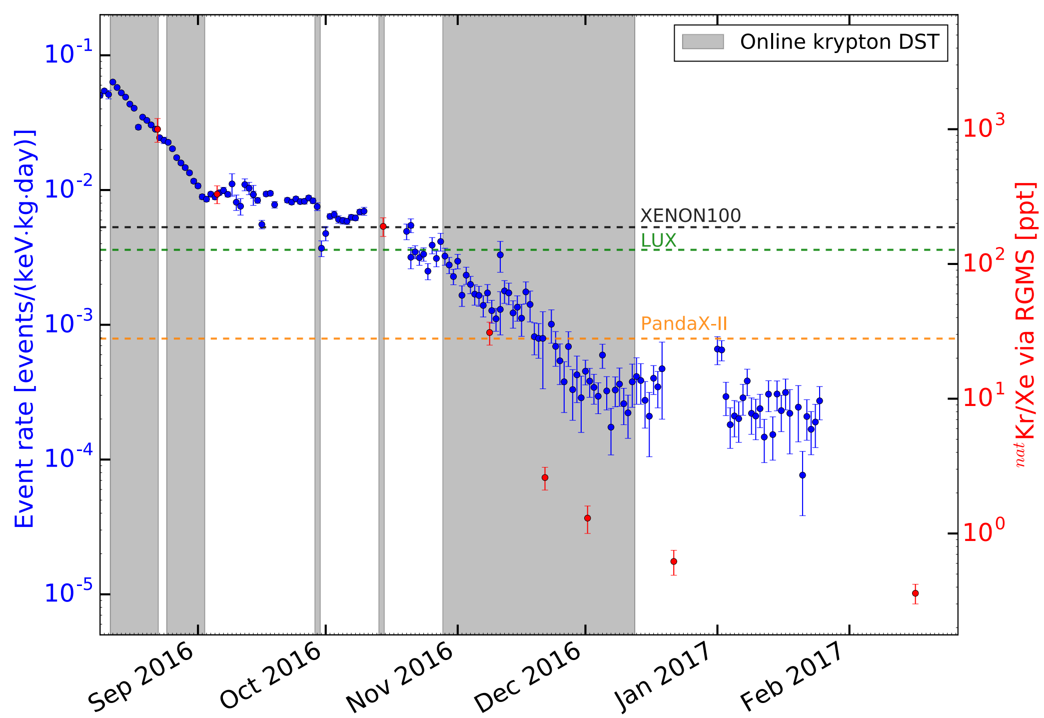
37-AR DECAYS

- ^{37}Ar K-electrons capture ($T_{1/2}$ = 35 d) with 2.82 keV energy released as X-rays & Auger electrons
- ^{37}Ar used as calibration source (after Science Run I)
- Best fit for monoenergetic peak in the science data: at (2.3±0.2) keV

^{37}Ar during filling $\Longrightarrow$ ^{85}Kr distillation also removes Ar

^{37}Ar from air leak $\Longrightarrow$ ^{85}Kr concentration & activity would increase

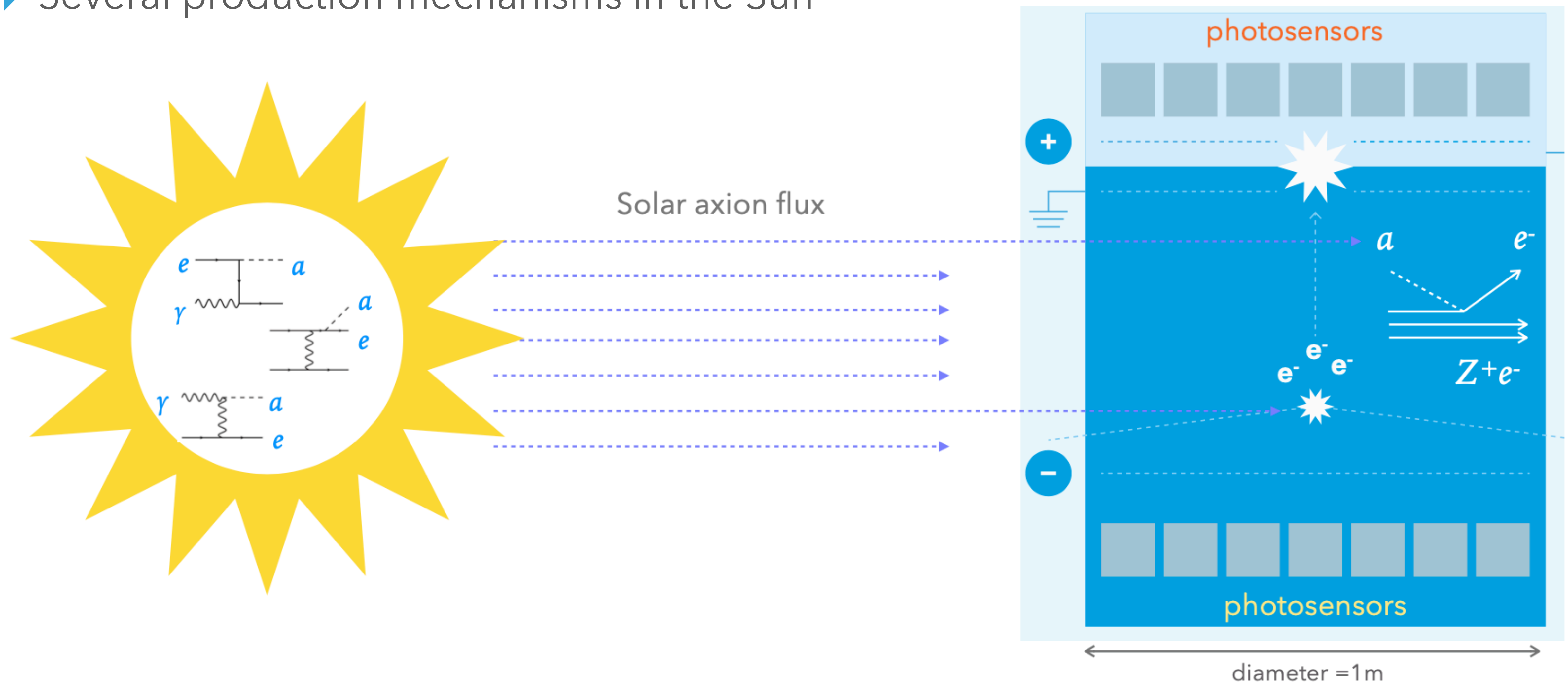




OR A SIGNAL (ALSO NEVER OBSERVED BEFORE ;-)?

SOLAR AXIONS

- Axion could be produced in the Sun with ~keV kinetic energies
- They can travel to Earth and be detected in the XENON1T TPC
- Several production mechanisms in the Sun



SOLAR AXIONS

- Axion could be produced in the Sun with ~keV kinetic energies
- They can travel to Earth and be detected in the XENON1T TPC
- Several production mechanisms in the Sun

ABC: atomic recombination & de-excitation, bremsstrahlung & Compton interactions

g_{ae}

axion-electron

Primakoff effect

$g_{a\gamma}$

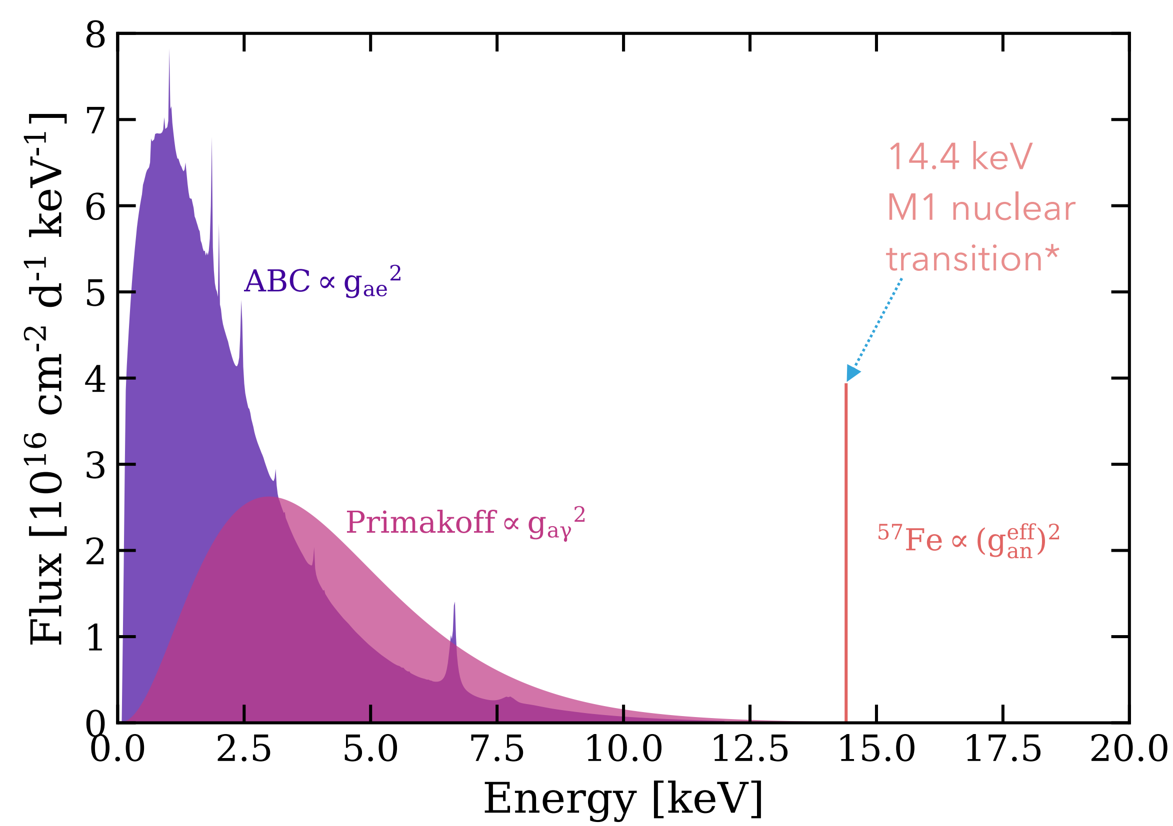
axion-photon

Nuclear de-excitation

g_{an}

axion-nucleon

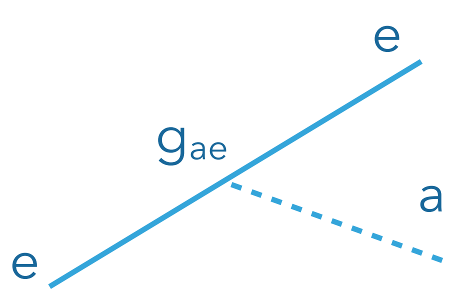
Solar axion fluxes: ~ $(g)^2$

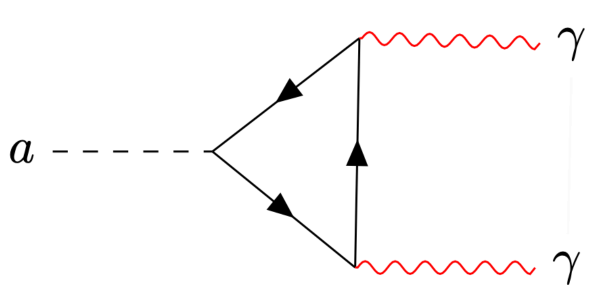


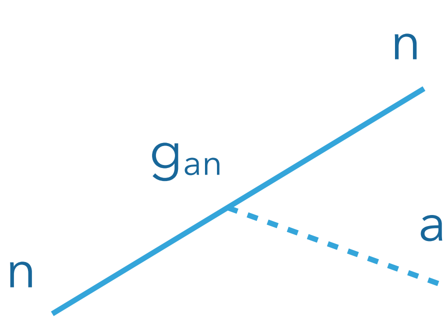
* W. Haxton & K. Lee, PRL66, 1991, S. Moriyama, PRL 75, 1995

SOLAR AXIONS

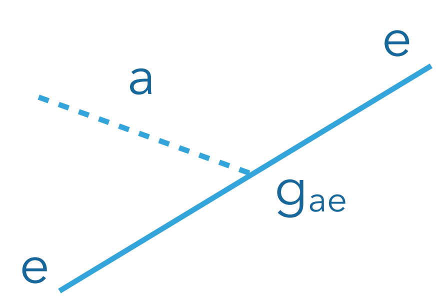
Production
Solar physics







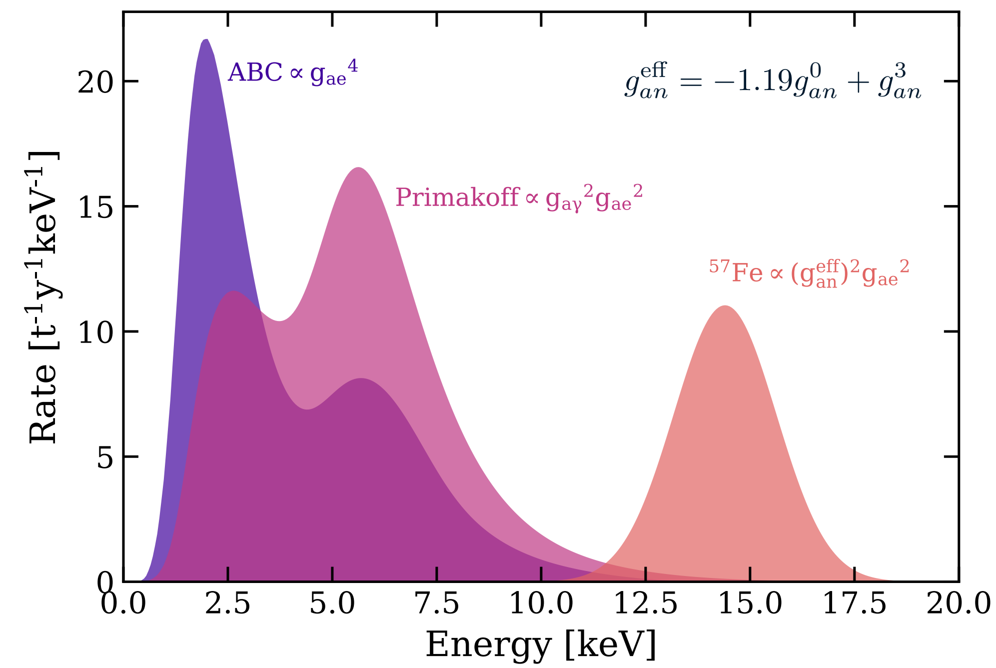
Detection:
Axioelectric effect



σ for detection, analogous to photoelectric effect

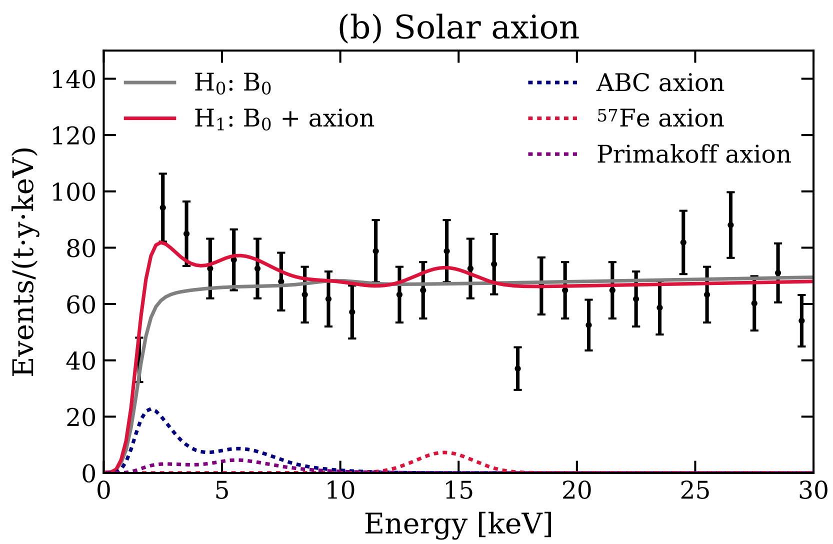
$$\sigma_{ae} = \sigma_{pe} \frac{g_{ae}^2}{\beta} \frac{3E_a^2}{16\pi\alpha m_e^2} \left(1 - \frac{\beta^{2/3}}{3}\right)$$

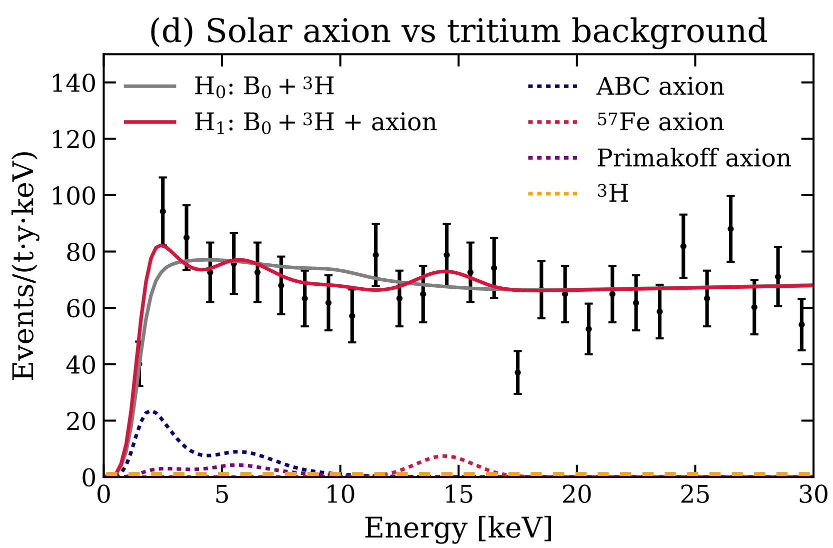
Reconstruction
XENON1T resolution, efficiency



- Production & detection: constrain $|g_{ae}|$, $|g_{ae}g_{an}|$, $|g_{ae}g_{a\gamma}|$
- No axion model assumed in the analysis, the 3 fluxes considered independent of one another

SOLAR AXION RESULTS





Solar axion:

favoured at 3.4 σ over background only

Solar axion +^3H:

favoured at 2.0 σ over ^3H hypothesis

- Null hypothesis: the background model B_0
- Alternative hypothesis: B_0 plus the signal

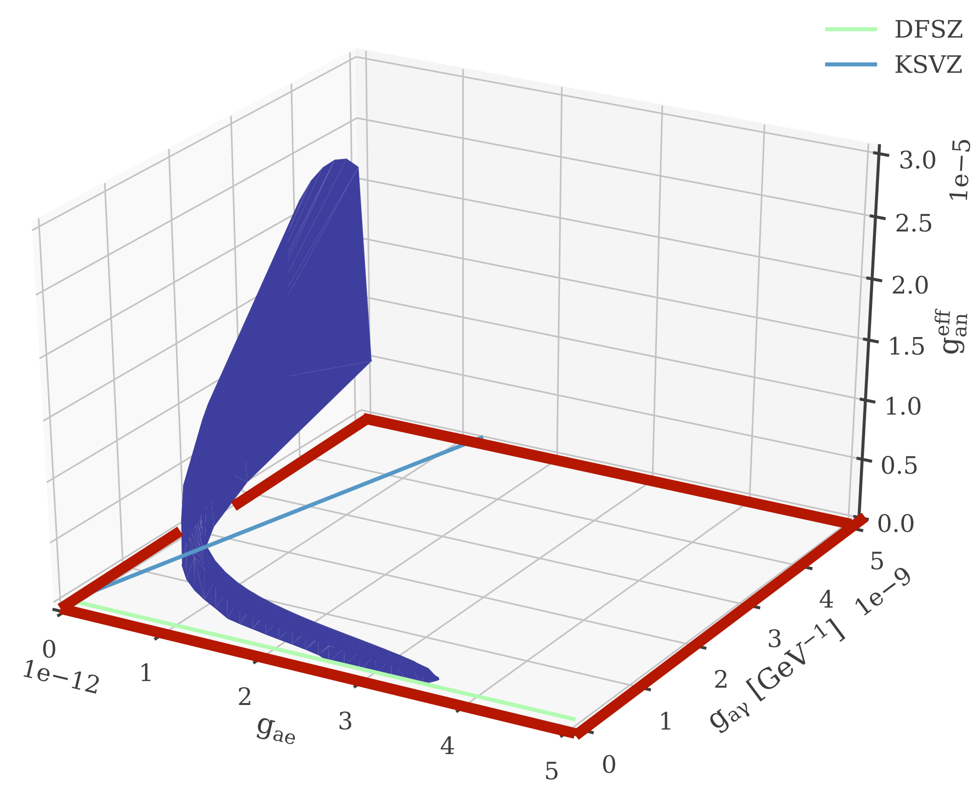
SOLAR AXION RESULTS

- Calculate 3D confidence volume (90% CL) in space of g_{ae} vs $g_{ae}g_{an}$ vs $g_{ae}g_{a\gamma}$
- Inscribed in a cuboid given by:

$$g_{\rm ae} < 3.8 \times 10^{-12}$$

$$g_{\rm ae}g_{\rm an} < 4.8 \times 10^{-18}$$

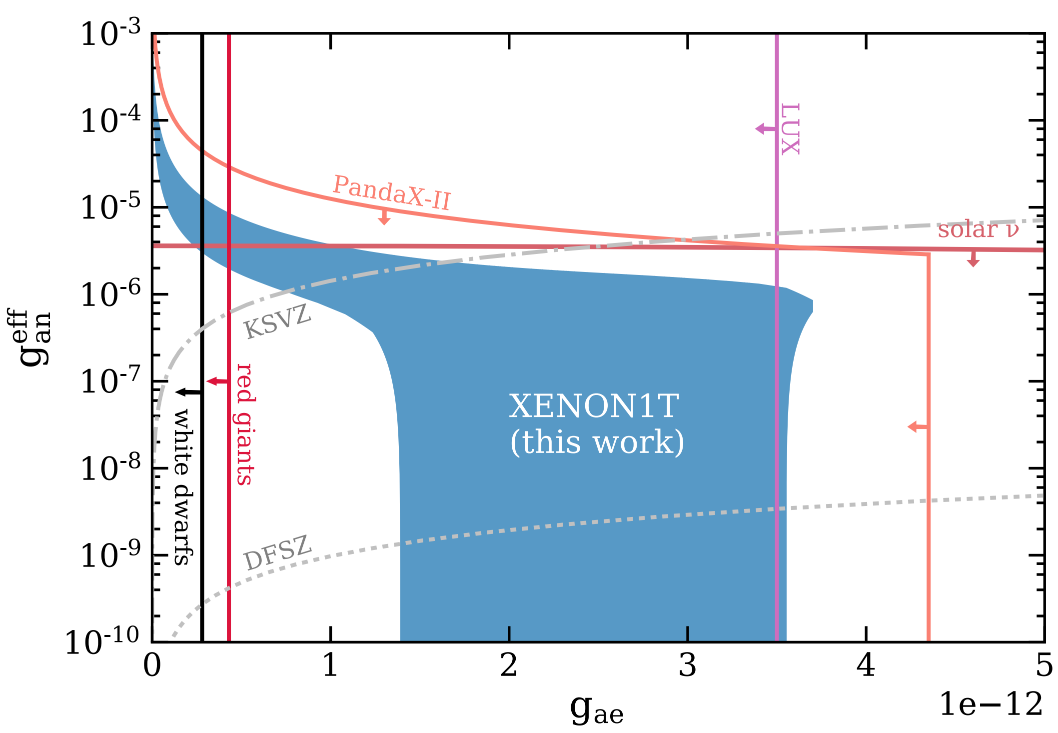
$$g_{\rm ae}g_{\rm a\gamma} < 7.7 \times 10^{-22}\ \mathrm{GeV}^{-1}$$



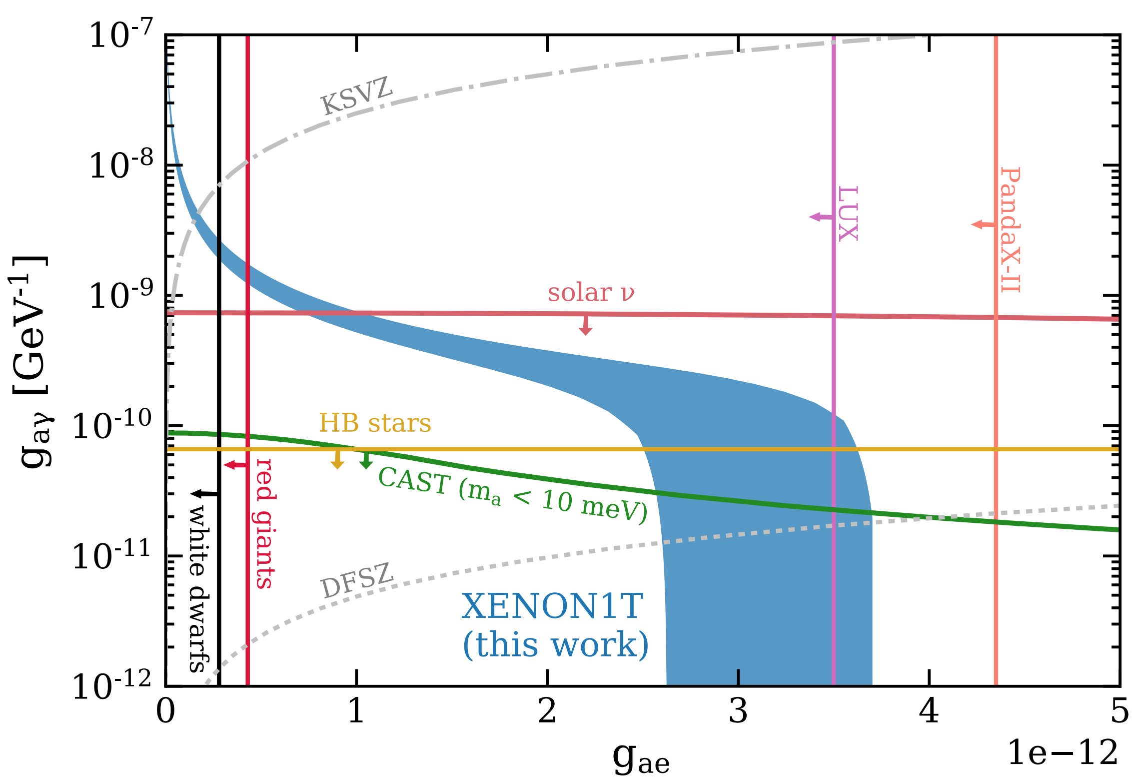
SOLAR AXION RESULTS

- Project 90% confidence volume onto 2D plane
- Profile over $g_{a\gamma}$ or over g_{an}, as examples

Arrows show allowed regions



At least one of ABC and Primakoff non-zero



In tension with astrophysical constraints, e.g. from stellar cooling

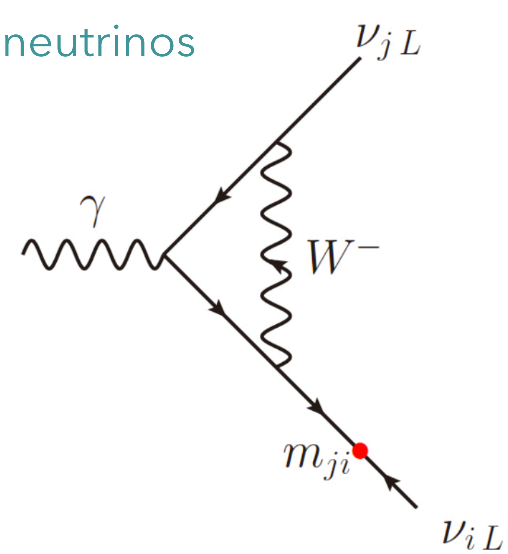
NEUTRINO MAGNETIC MOMENT

- Massive neutrinos have a magnetic moment

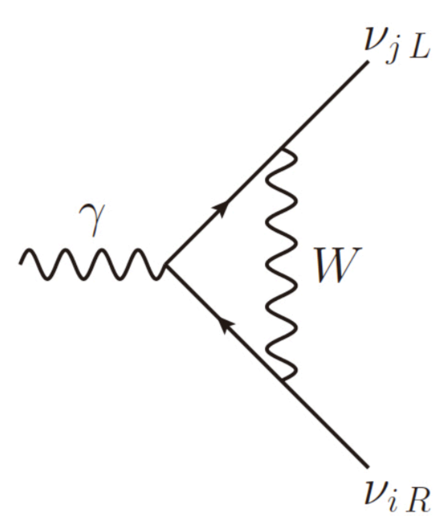
$$\mu_\nu = \frac{3eG_F m_\nu}{8\pi^2\sqrt{2}} = 3 \times 10^{-19}\mu_B \times \left(\frac{m_\nu}{1\,\mathrm{eV}}\right)$$

- A larger value $\left(\gtrsim 10^{-15}\mu_\mathrm{B}\right) \Longrightarrow$ Majorana neutrinos*
- Leads to enhanced neutrino-electron scattering cross section

Majorana neutrinos



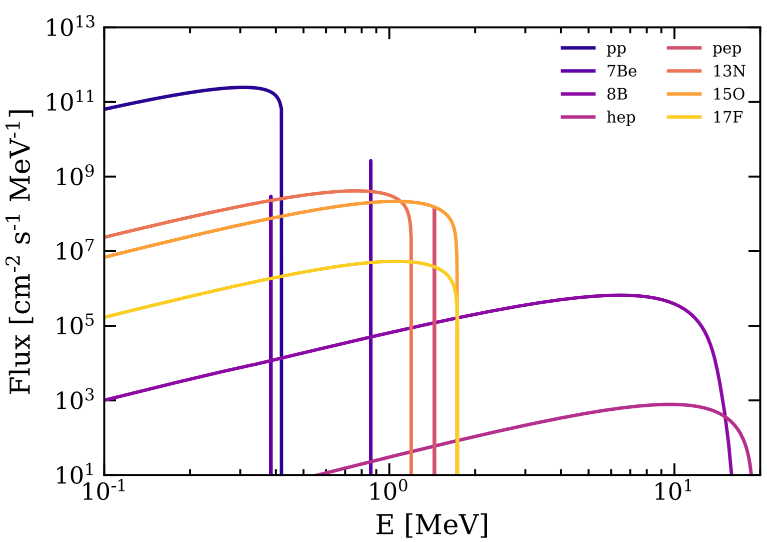
Dirac neutrinos



*Jihn E. Kim, 1911.06883, 2019, N. Bell et al., PLB 642, 2006

NEUTRINO MAGNETIC MOMENT

Production
Solar neutrinos



Detection
Elastic scattering off e-

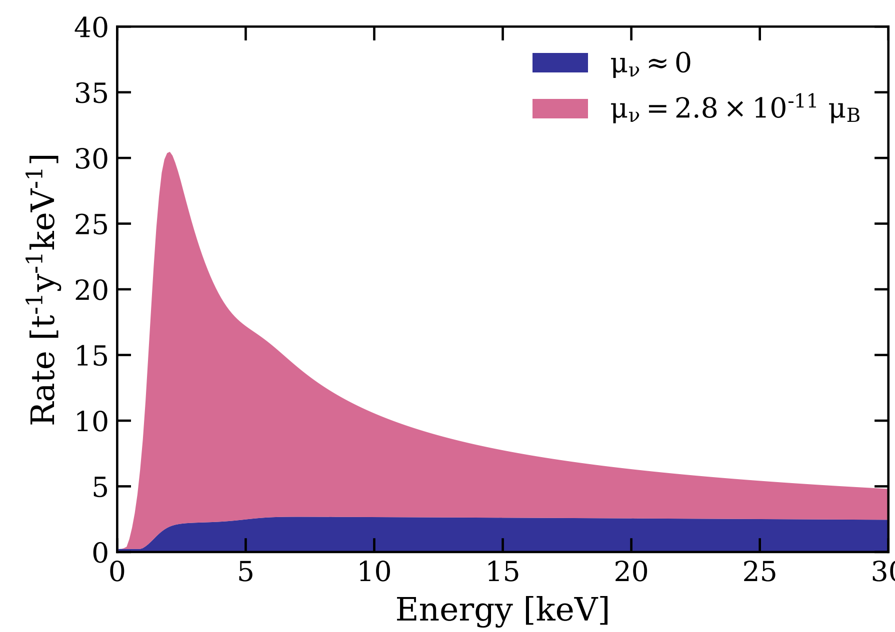
$$\frac{d\sigma_\mu}{dE_r} = \mu_\nu^2 \alpha \left(\frac{1}{E_r} - \frac{1}{E_\nu} \right)$$

Cross section (here for free electrons) is enhanced

E_r = electronic recoil energy

E_ν = neutrino energy

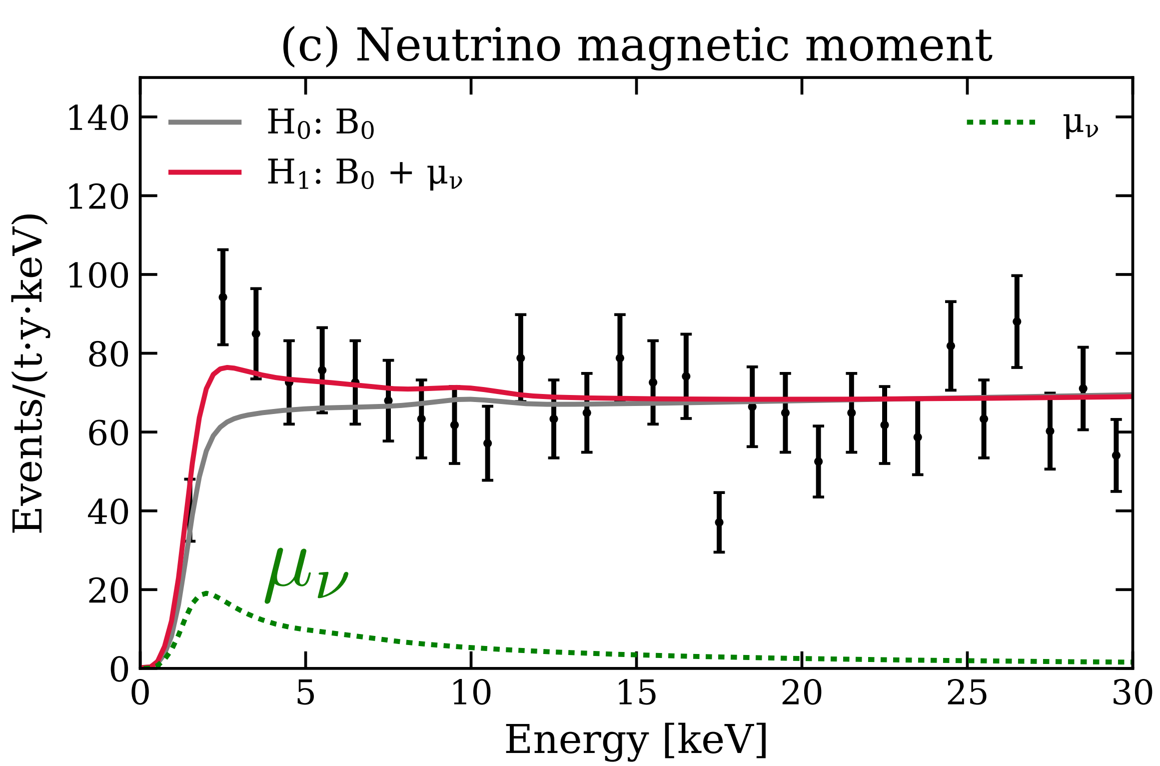
Reconstruction
XENON1T resolution, efficiency



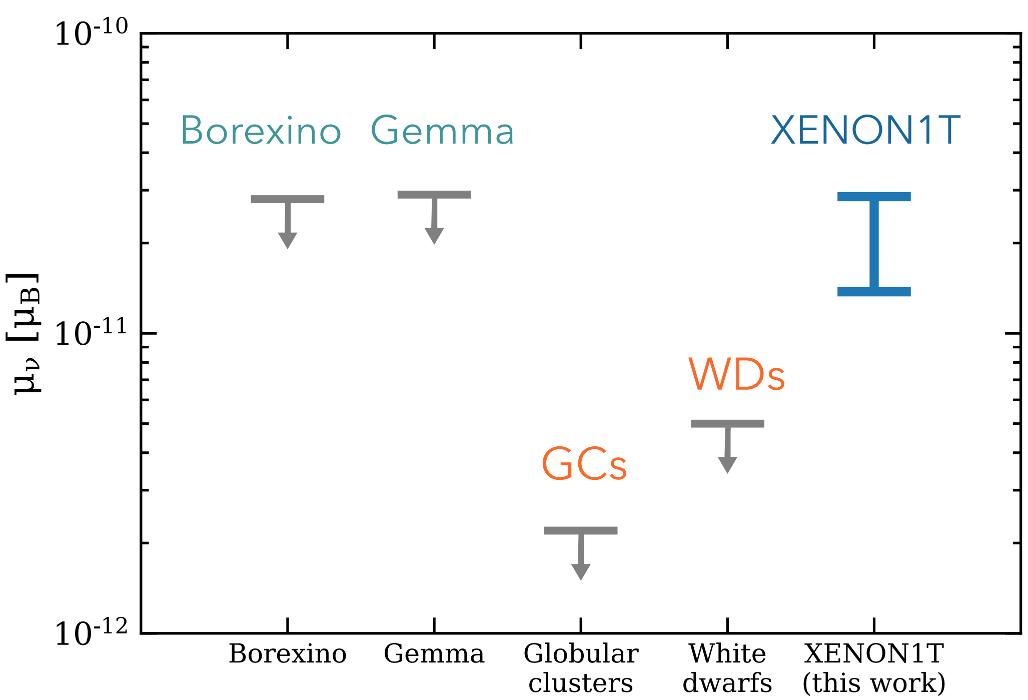
Search with mainly pp solar neutrinos
Account for electron binding energies

NEUTRINO MAGNETIC MOMENT

- Single fit parameter μ_ν
- Neutrino magnetic moment favoured over background only at 3.2 σ
- Significance decreases to 0.9 σ when ^3H is included in the background model



$\mu_\nu = [1.4, 2.9] \times 10^{-11}\ \mu_B$ (90% C.L.)



Compatible with other experiments

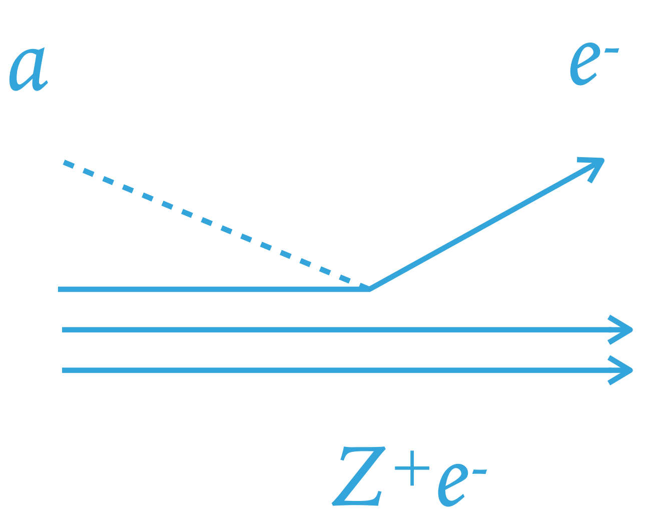
In tension with astrophysical constraints

BOSONIC DARK MATTER

- ALPs and dark photons: absorption results in peak at boson mass
- Rates ~ φ x σ ~ ρ x v/m x σ (here below for ρ = 0.3 GeV/cm³)

$$R \simeq \frac{1.5\times10^{19}}{A} g_{ae}^2 \left(\frac{m_a}{\mathrm{keV}}\right)\left(\frac{\sigma_{pe}}{\mathrm{b}}\right) \mathrm{kg}^{-1}\mathrm{d}^{-1}$$

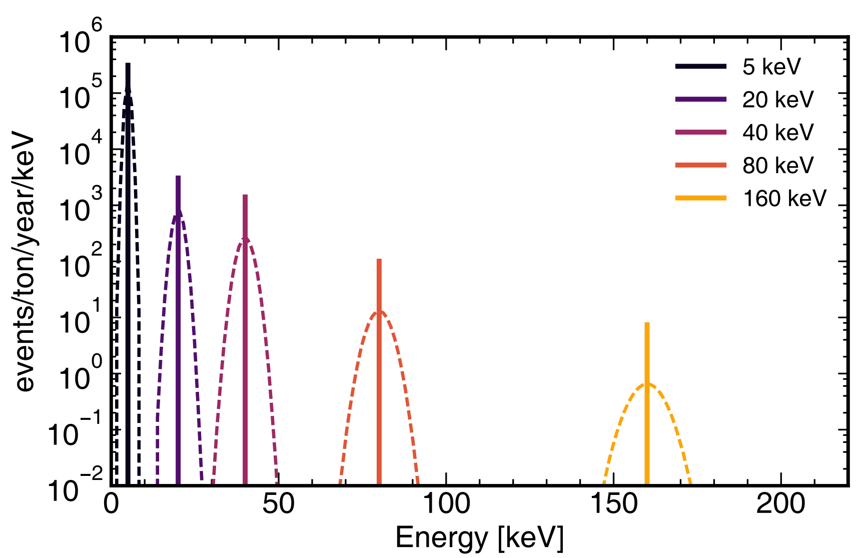
$$\sigma_{ae} = \sigma_{pe}\frac{g_{ae}^2}{\beta}\frac{3E_a^2}{16\pi\alpha m_e^2}\left(1-\frac{\beta^{2/3}}{3}\right)$$



$$R \simeq \frac{4.7\times10^{23}}{A}\kappa^2\left(\frac{\mathrm{keV}}{m_V}\right)\left(\frac{\sigma_{pe}}{\mathrm{b}}\right)\mathrm{kg}^{-1}\mathrm{d}^{-1}$$

$$\sigma_v \simeq \frac{\sigma_{pe}}{\beta}\kappa^2$$

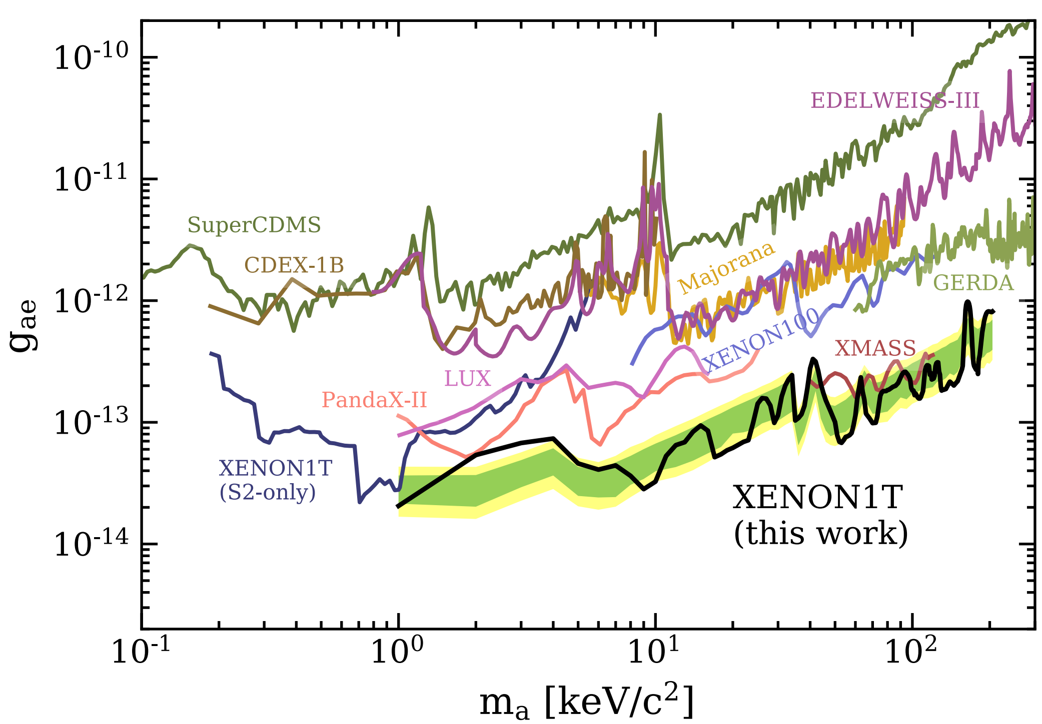
strength of kinetic mixing between photon and dark photon



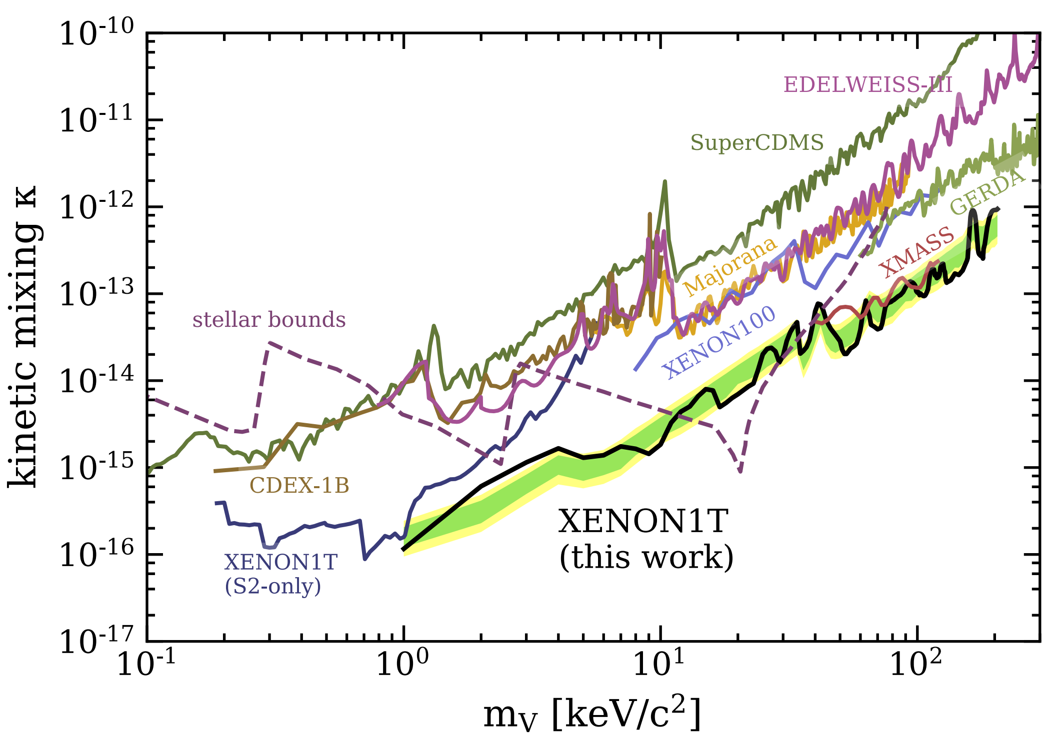
ALPS AND DARK PHOTONS

- Constraints on couplings for bosonic pseudoscalar DM with (fixed) masses [1, 210] keV
- No global significance above 3-σ under the background model
- ALPs and dark photons: 90% CL upper limits and sensitivities

Upper limits on g_{ae} versus ALP mass



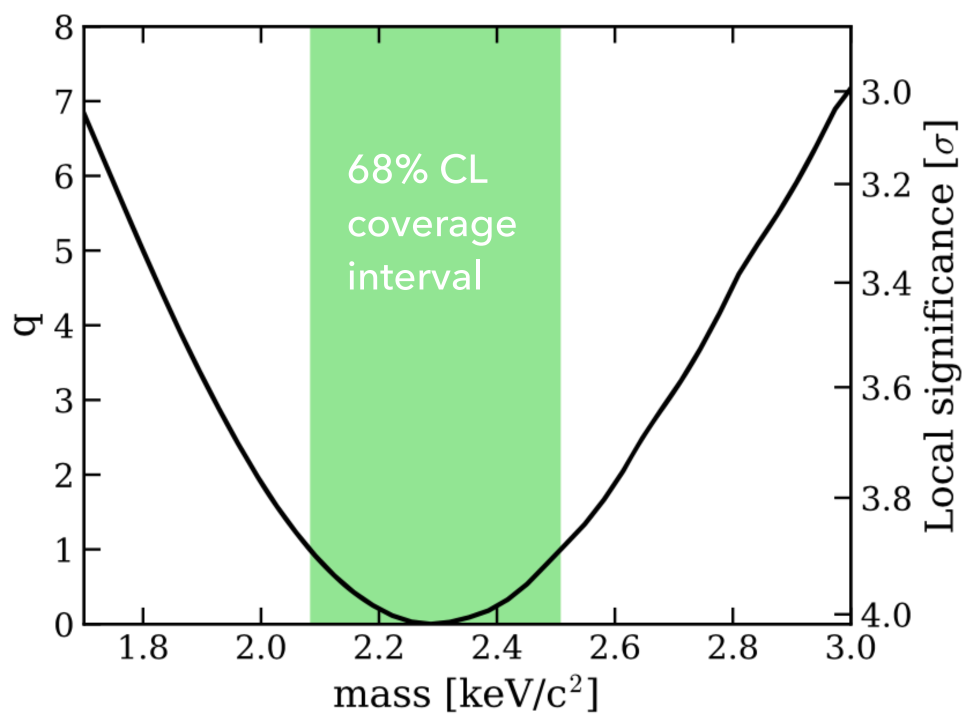
Upper limits on κ versus dark photon mass



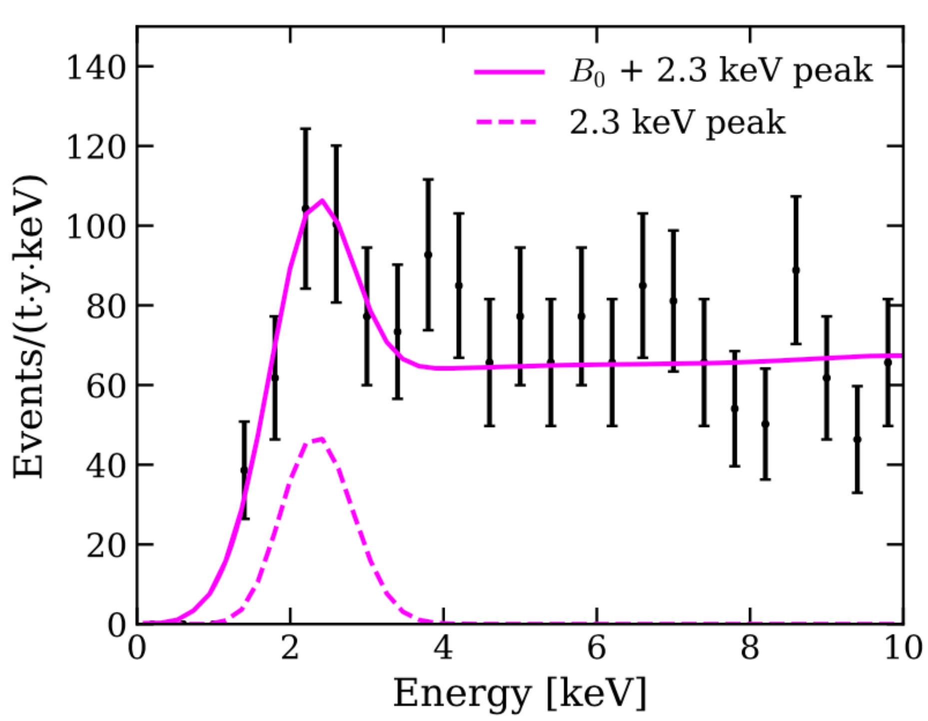
ALPS AND DARK PHOTONS

- Constraints on couplings for bosonic pseudoscalar DM with (fixed) masses [1, 210] keV
- No global significance above 3-σ under the background model
- A 3-σ global (4-σ local) significance for a peak at (2.3±0.3) keV (68% CL)

Log-likelihood ration versus ALP mass



Best fit for a 2.3 keV peak and the background

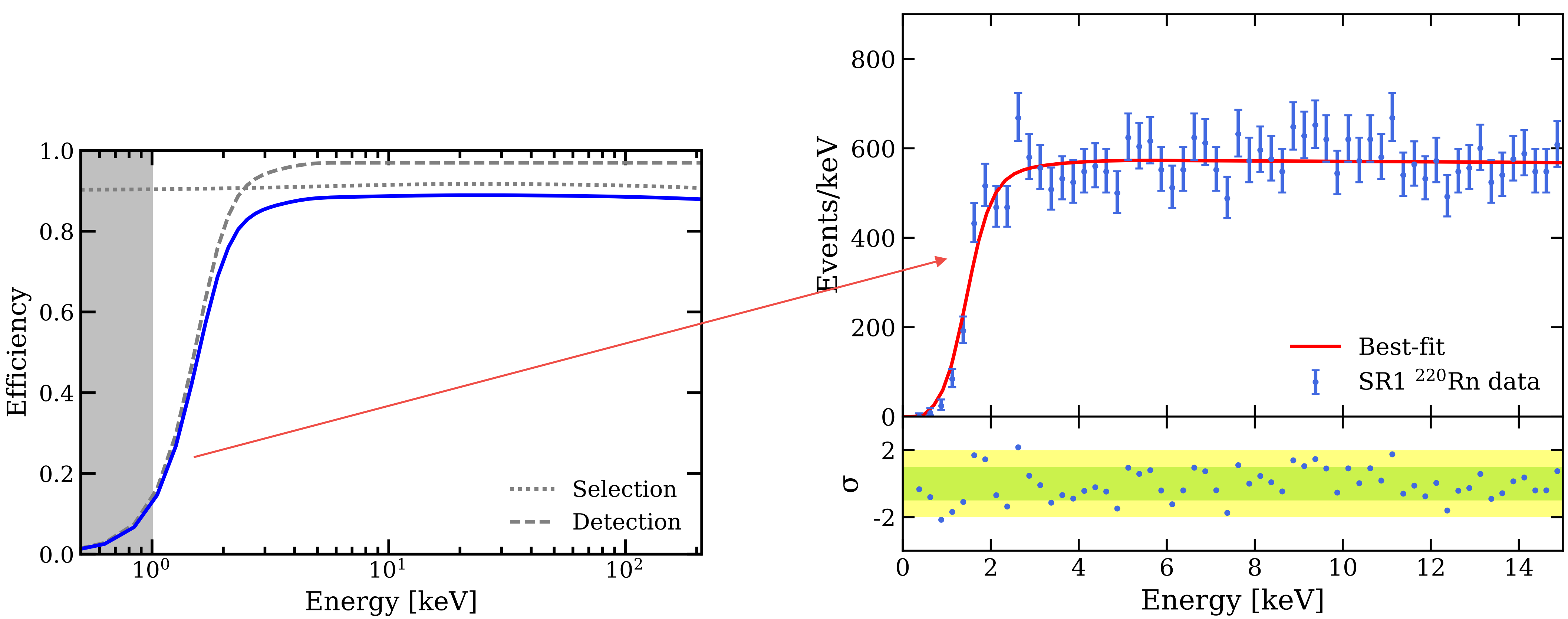


WHERE ELSE COULD THE EXCESS COME FROM?

MISMODELING OF EFFICIENCY OR ENERGY RECONSTRUCTION?

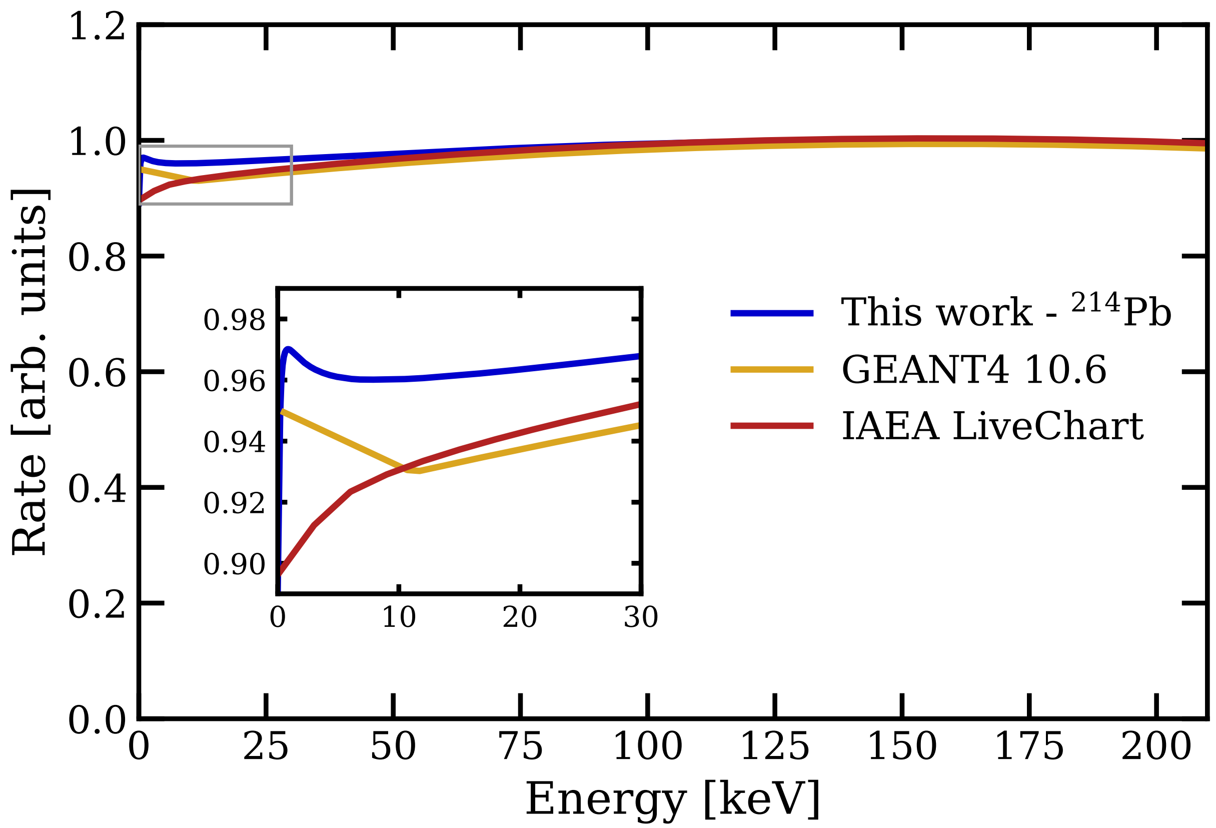
- To validate efficiency and energy reconstruction
  - fit simulated ^{220}Rn events to calibration data
  - ^{212}Pb β-decays (Q-value = 574 keV): proxy for background from ^{214}Pb β-decays (Q-value = 1024 keV)
- Good fit ⟹ unlikely the cause of the excess

Calibration data from ^{220}Rn



SHAPE OF THE 214-BI SPECTRUM?

- Atomic effects (e.g. static Coulomb effect of nucleus on e^-) can enhance the rate at low energies
- Not properly considered in Geant4 nuclear decay module or spectra from nuclear data sheets for the first-forbidden, non-unique transition of ^{214}Pb to the ^{214}Bi ground state
  - Teamed with X. Mougeot (CEA) to calculate the correct shape of the spectrum at low energy

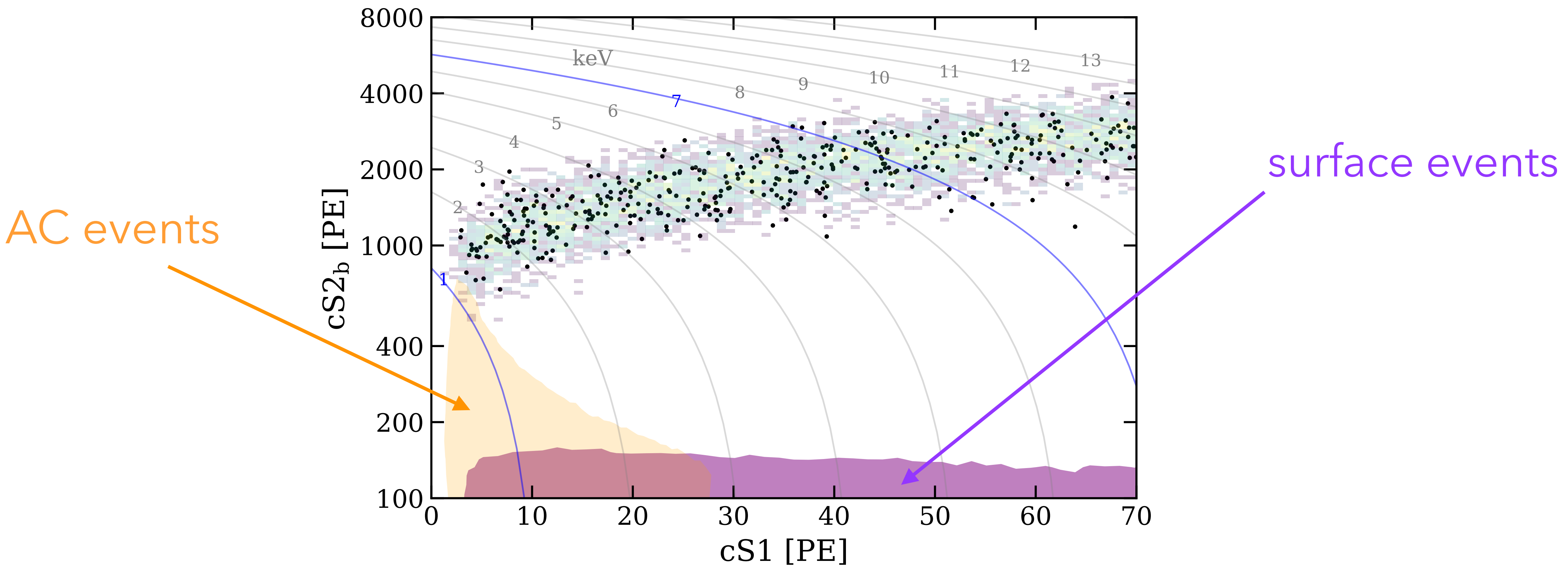


$\Longrightarrow$ the rate uncertainty of 6% can not account for the excess

(50% enhancement required)

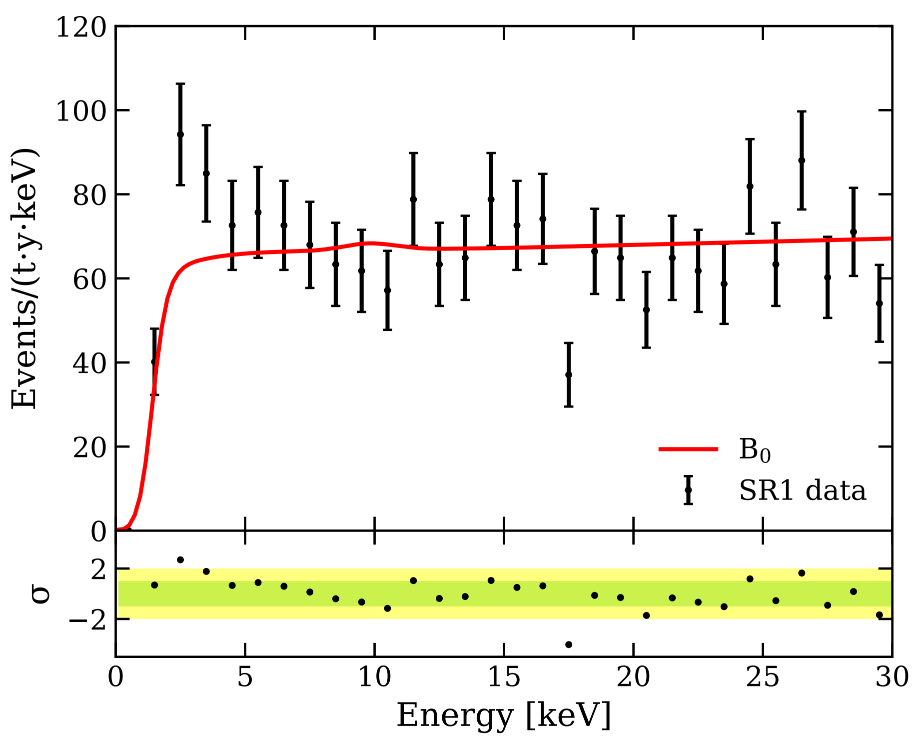
INSTRUMENTAL BACKGROUND?

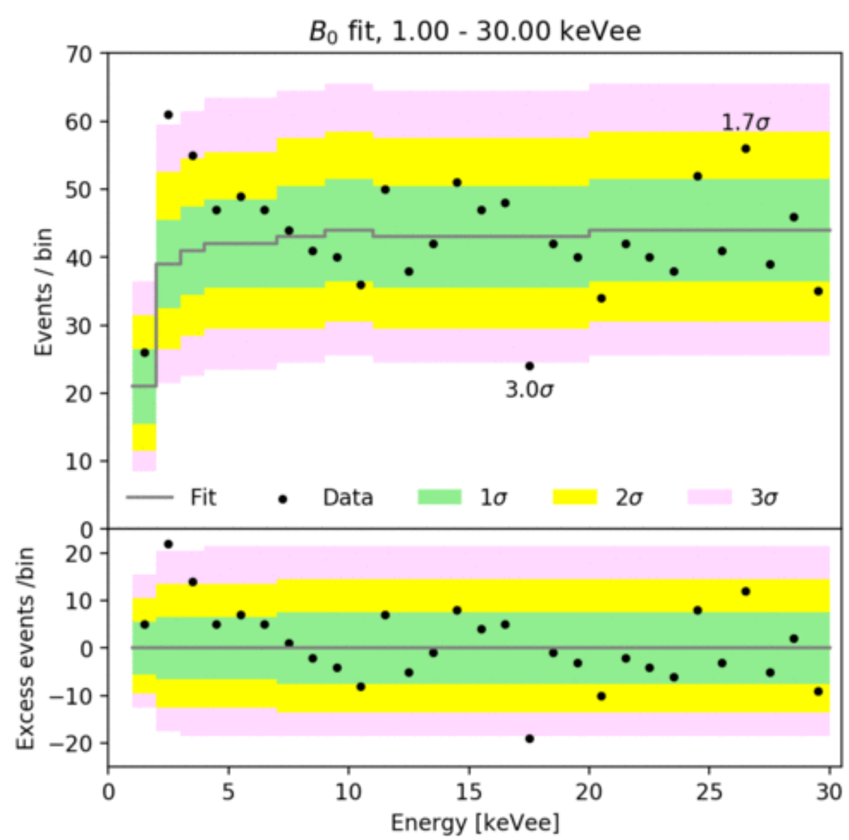
- No accidental coincidences and mis-reconstructed events from the detector surfaces
  - at different S2/S1-ratio than true ER events
  - all observed events fall in the ER band



STATISTICAL FLUCTUATION OR BINNING ARTEFACTS?

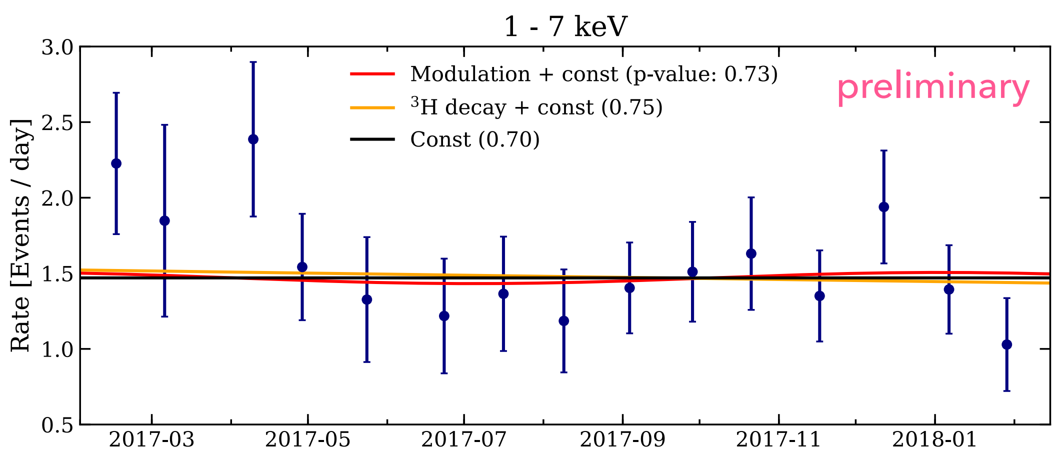
- Unbinned profile likelihood analysis
- "Dip around 17 keV" - not statistically significant (even in a binning that maximises the "deficit", global p-value is 2.3 sigma)
    - dip goes away when rebinning



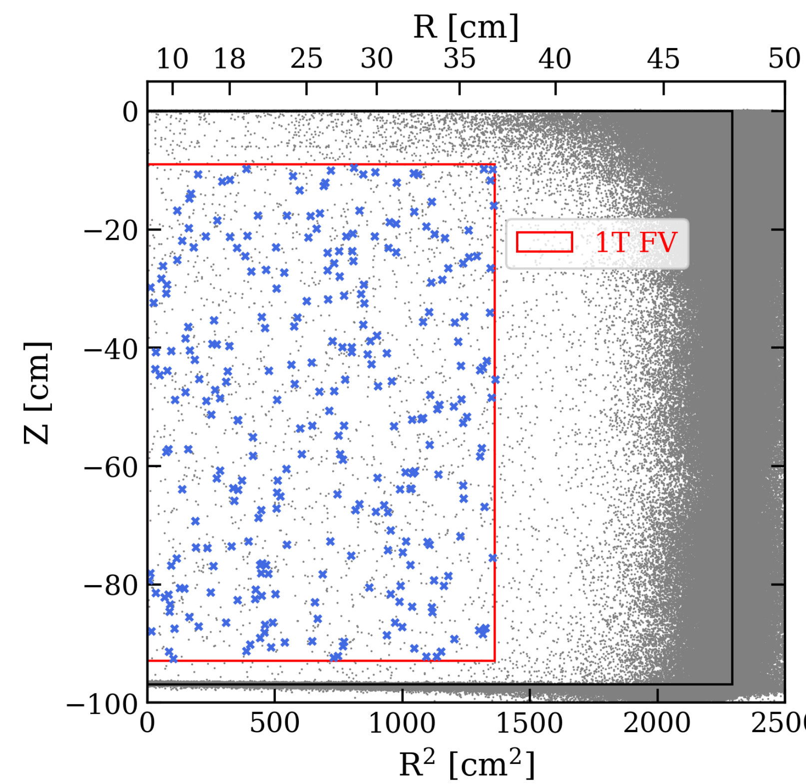


OTHER CHECKS

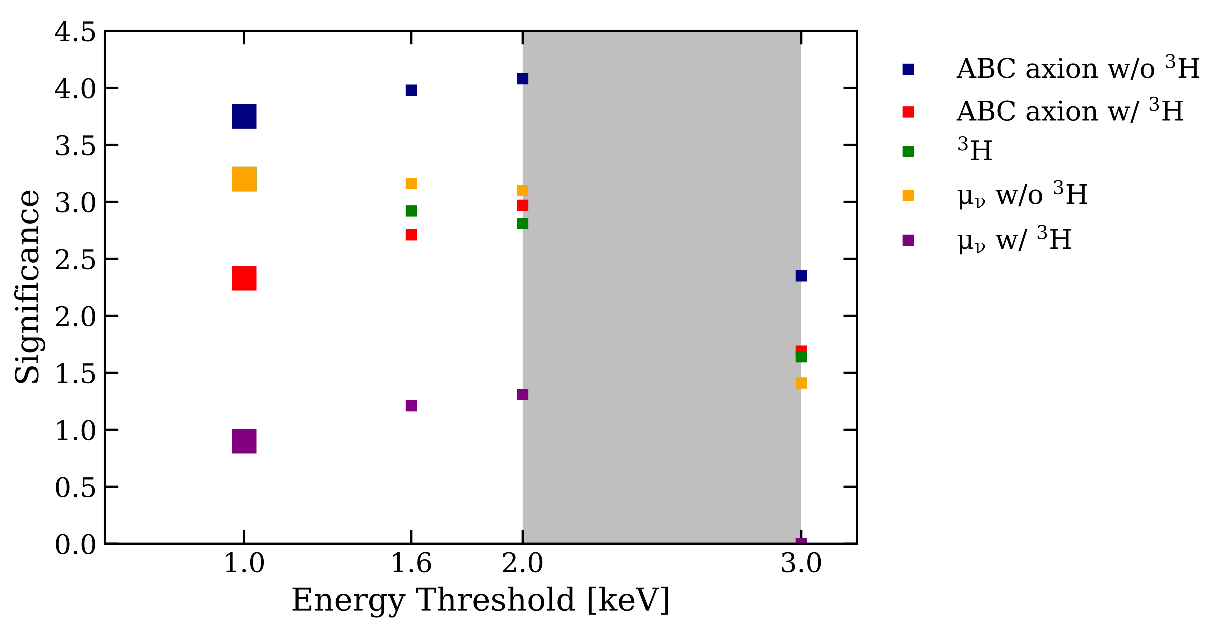
Time dependance



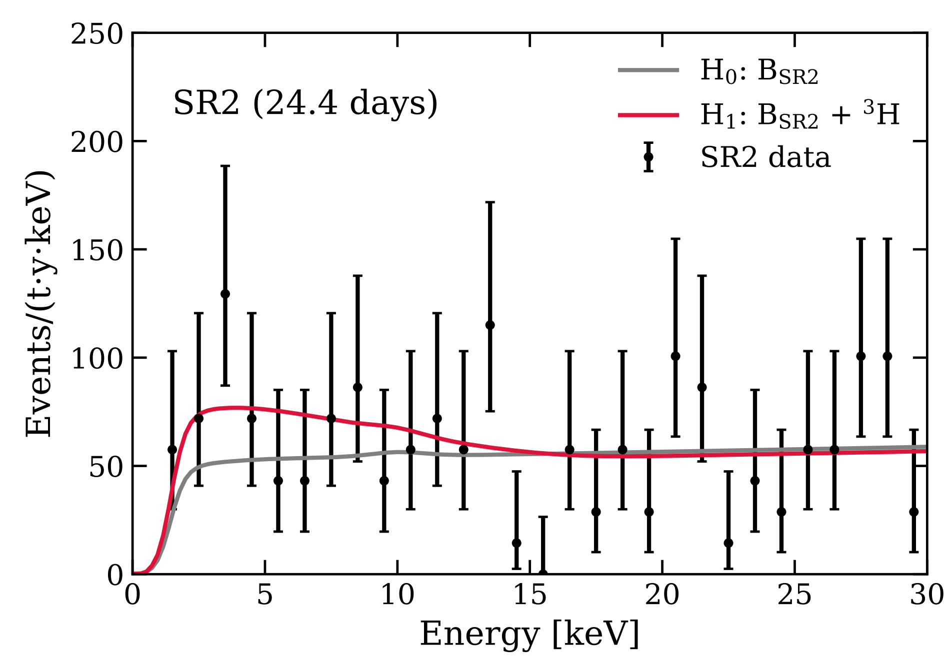
Spatial distribution



Energy threshold

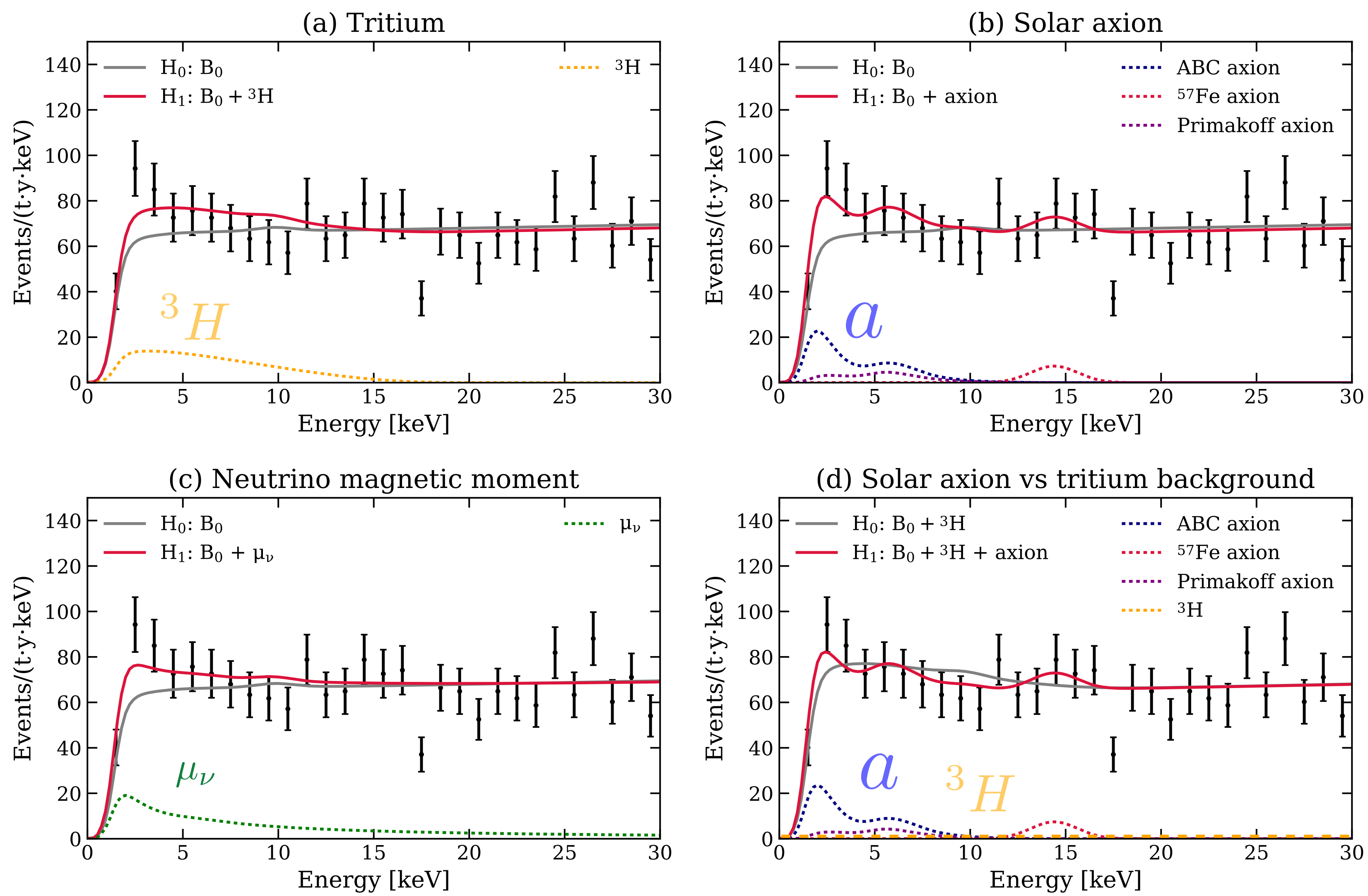


Additional data (24.4 days in SR2)



SUMMARY SO FAR

^{3}H over background-only: 3.2σ

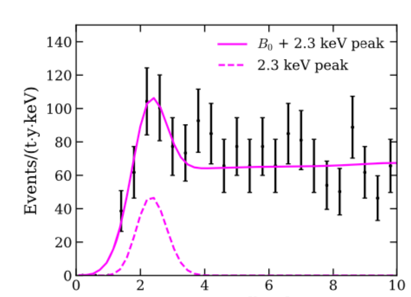


Solar axion over background-only: 3.4 σ

Neutrino magn. moment over background-only: 3.2σ

Solar axion + ^{3}H over ^{3}H hypothesis: 2.0σ

+ Monoenergetic peak at (2.3 ±0.2) keV over background-only at 3.0σ (global)



NEXT STEPS

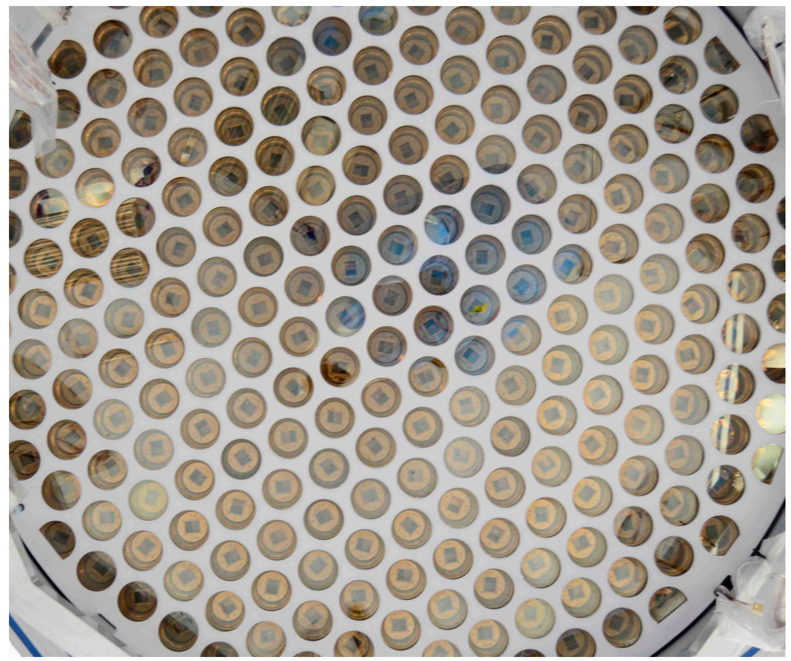
XENON-NT

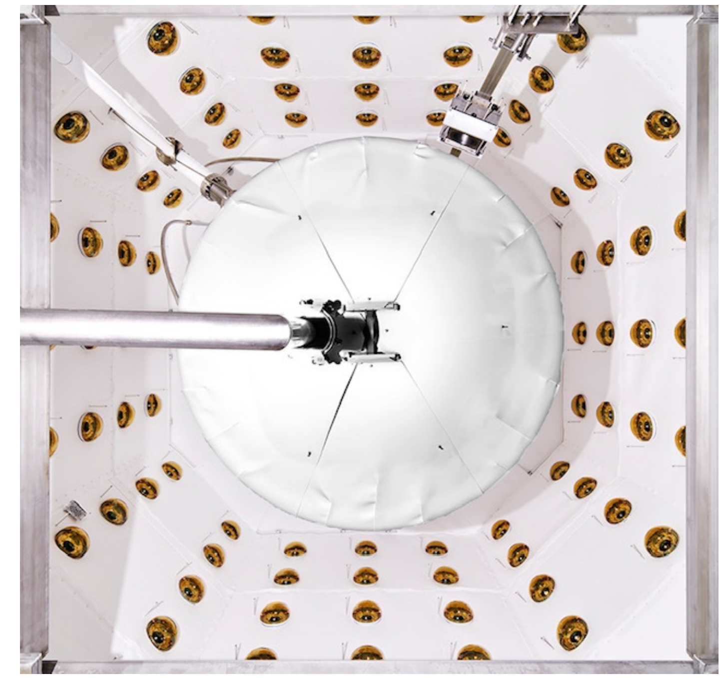
- Upgrade to 8.4 t of LXe, 5.9 t in the TPC
- Many sub-systems in place from XENON1T, but:
  - New inner cryostat, new TPC, 494 PMTs
  - Neutron veto: Gd doped (0.5% $Gd_2(SO_4)_3$) water Cherenkov detector
  - ^{222}Rn distillation tower, additional xenon storage system, faster LXe purification
- Commissioning at LNGS in progress
- Start data taking by the end of 2020

XENON-NT

TPC (5.9 t LXe, 4 t fiducial), 1.3 m diameter, 1.5 m tall

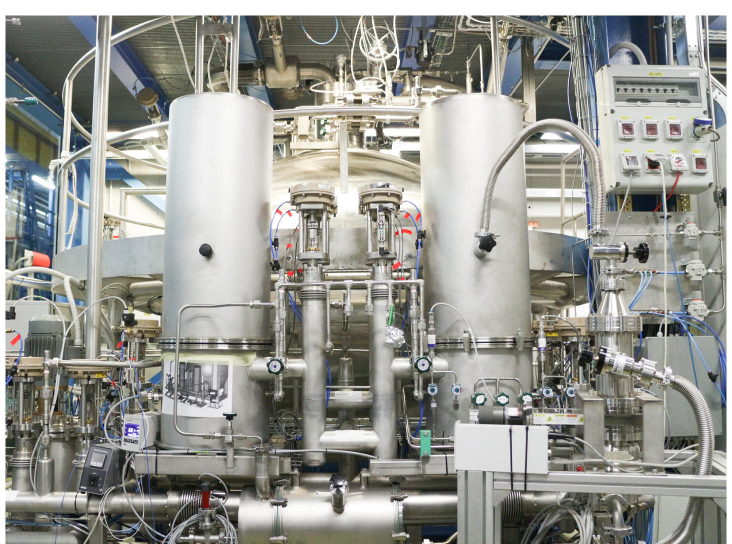
Neutron veto (120 additional PMTs, Gd doped (0.5% $Gd_2(SO_4)_3$))





PMT array (494 PMTs in total, in 2 arrays)

LXe purification system (5 L/min LXe, faster cleaning; 2500 slpm)

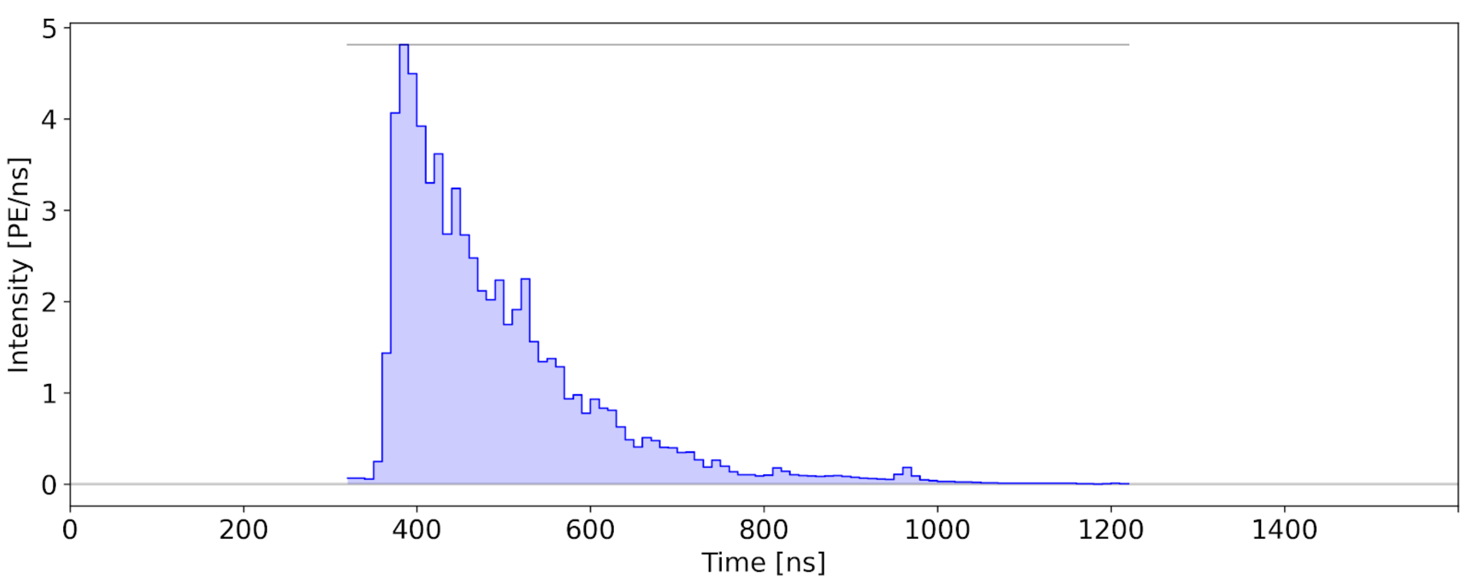


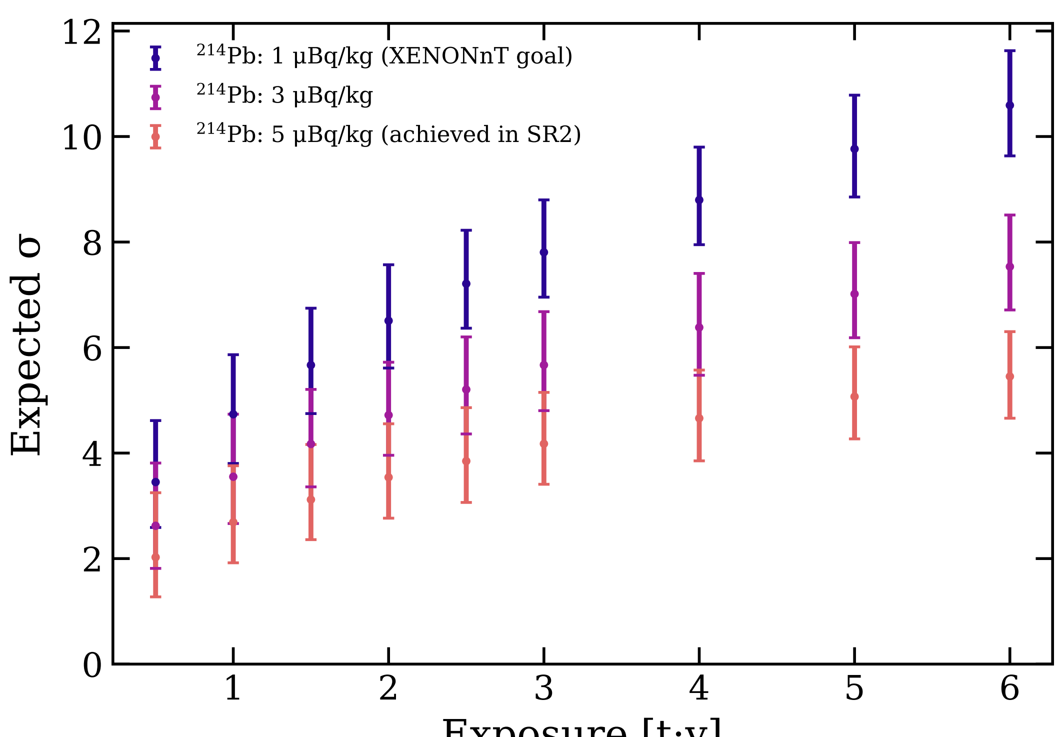
Rn distillation column (reduce ^{222}Rn - hence also ^{214}Bi - from pipes, cables, cryogenic system)

CONCLUSIONS AND OUTLOOK

- Excess of ER events observed in XENON1T in (1,7) keV region
  - Could be due to ^{3}H or new physics
- XENONnT in advanced commissioning at LNGS
  - with backgrounds reduced to ~ 1/6 of XENON1T: discriminate axion versus tritium hypothesis within a few months of data

First scintillation light (in gas Xe)





THE END

ADDITIONAL MATERIAL

BACKGROUND MODEL

Component		Expected nr. of events	Constraint	Fitted nr. of events
^{214}Pb		(3450, 8530)	BiPo and α-decays (^{222}Rn)	7480±160
^{85}Kr		890 ±150	RGMS measurement	773±80
^{136}Xe		2120 ± 210	Abundance, half-life	2150±120
^{133}Xe		3900 ± 410	Activation and decay	4009±85
^{131m}Xe		23760 ± 640	Activation and decay	24270±150
^{83m}Kr		2500 ± 250	Injection and decay	2671±53
Materials		323 (fixed)	Screening	323 (fixed)
Solar neutrinos		220.7 ± 6.6	Flux and cross-section	220.8±4.7
^{124}Xe	KK	125 ± 50	-	113±24
	KL	38 ± 15	-	34.0±7.3
	LL	2.8 ± 1.1	-	2.56±0.55
^{125}I	K	79 ± 33	Activation and decay	67±12
	L	15.3 ± 6.5	Activation and decay	13.1±2.3
	M	3.4 ± 1.5	Activation and decay	2.94±0.50

37-AR DECAYS

- ^{37}Ar abundance in ^{nat}Ar: ~10^{-20} mol/mol; initial ^{nat}Ar concentration < 5 ppm

  $\Longrightarrow$ decayed to negligible level by the start of commissioning phase

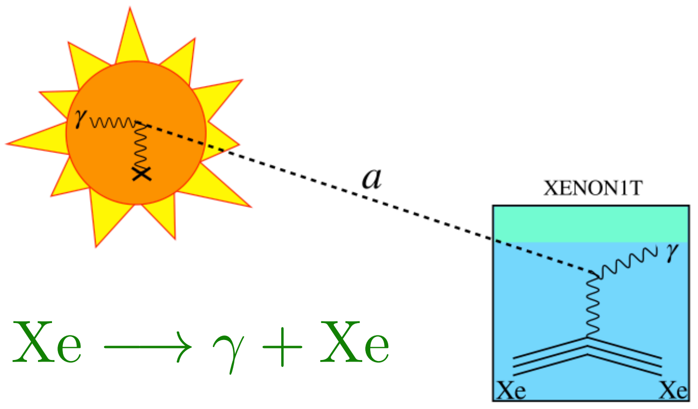
  $\Longrightarrow$ < 1 event/(t y) after > 400 d

- ^{37}Ar not removed by online purification, but removed by ^{85}Kr distillation
- Constant air leak hypothesis:
  - observed increased ^{nat}Kr concentration (via RGMS) < 1 ppt/y
  - air inside the hall at LNGS < 3.2 mBq/m^3 ^{37}Ar concentration
- We use 5 mBq/m^3 as conservative upper limit

  $\Longrightarrow$ < 5.2 events/(t y) expected

  - however, a rate of 65 events/(t y) required to explain the excess

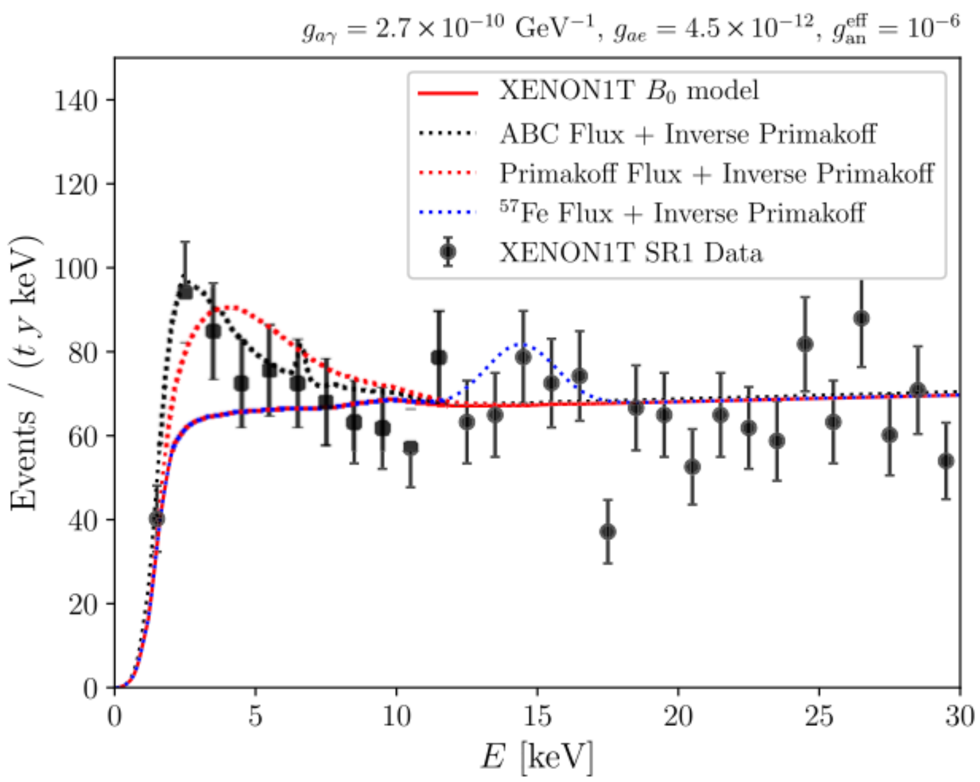
INVERSE PRIMAKOFF EFFECT



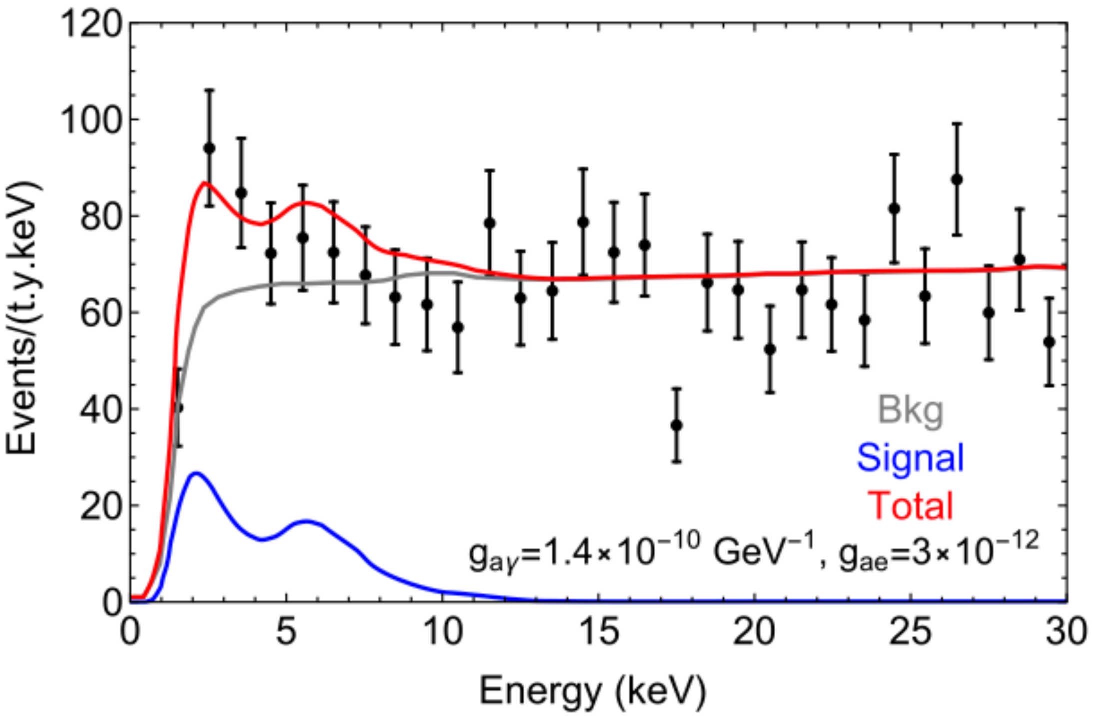
$$a + \mathrm{Xe} \longrightarrow \gamma + \mathrm{Xe}$$

- Solar axion can also scatter via axion-photon coupling; emitted photon yields an ER signal
  - Tension with astrophysical constraints is reduced

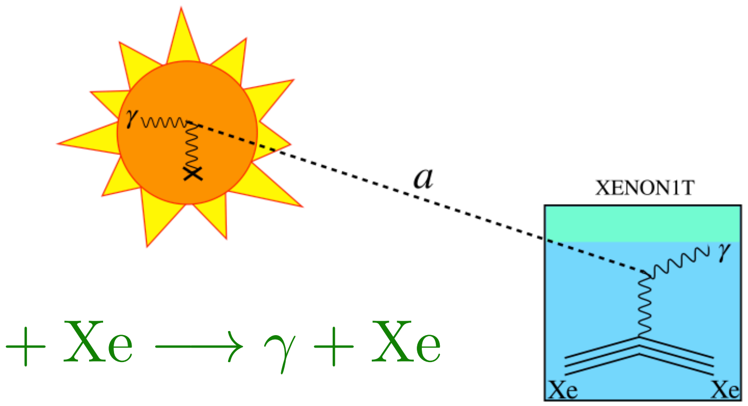
Dent, Dutta, Newstead, Thomson, PRL 125, 2020



Gao, Liu, Wang, Wang, Xue, Zhong PRL 125, 2020



INVERSE PRIMAKOFF EFFECT



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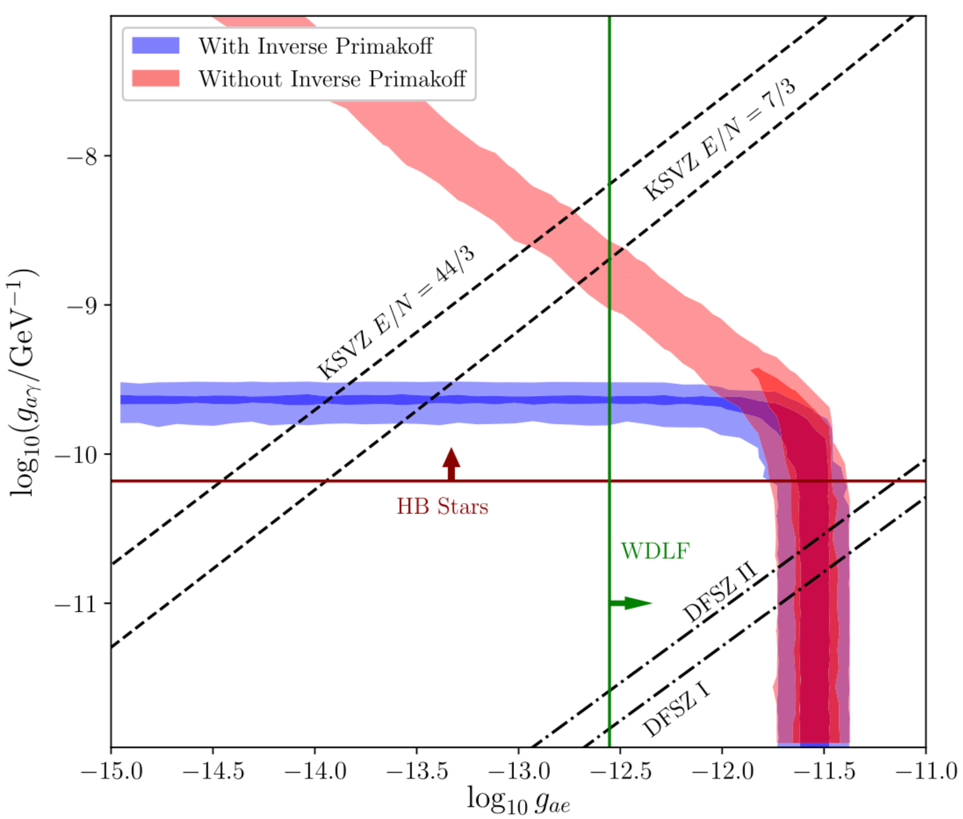
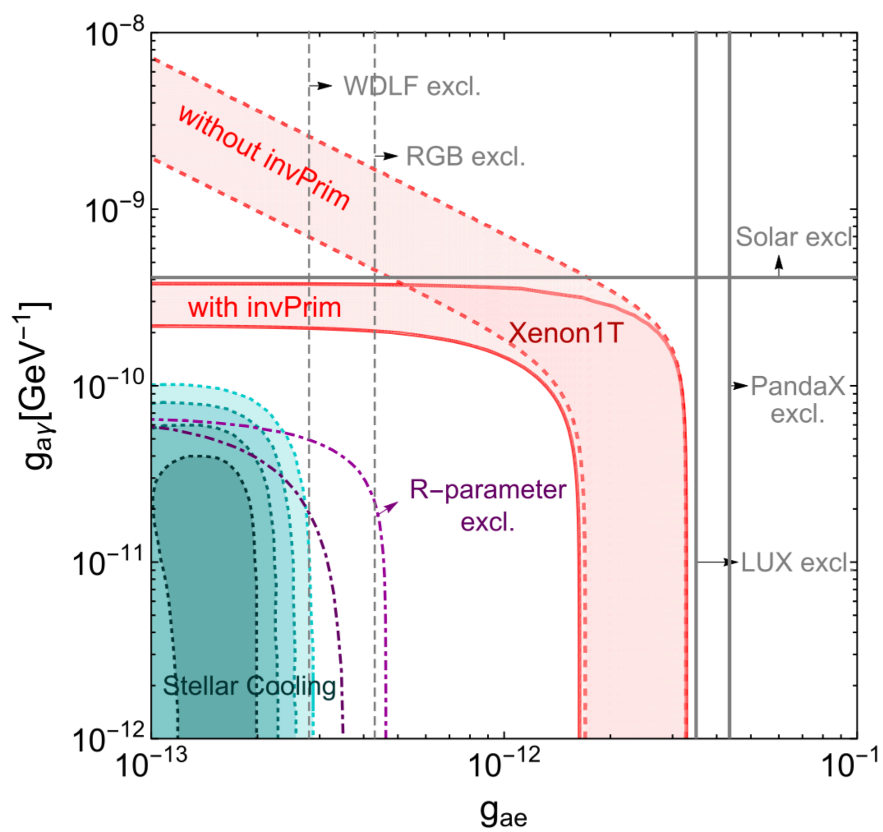
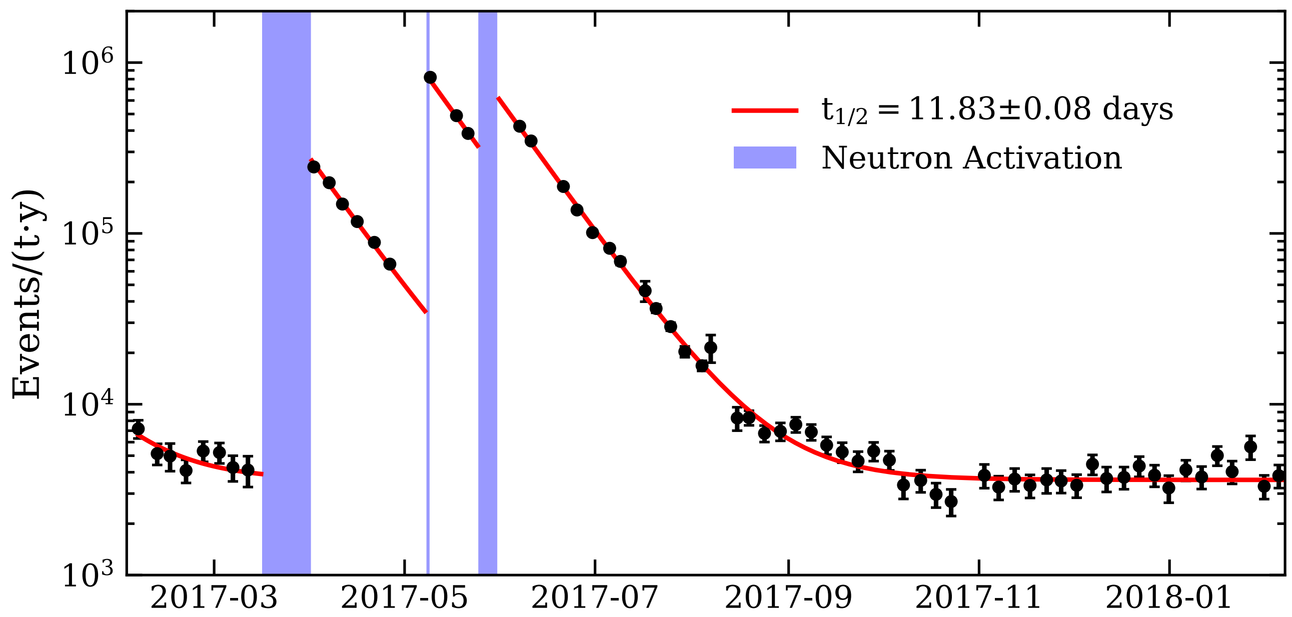
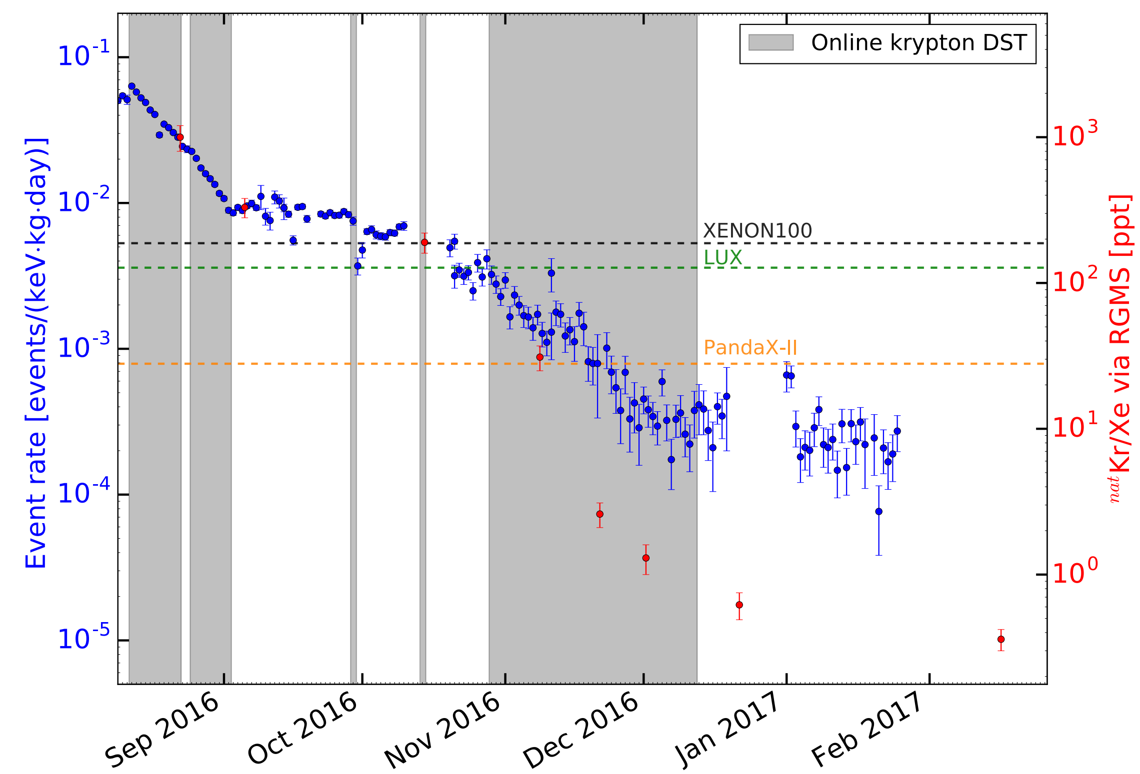


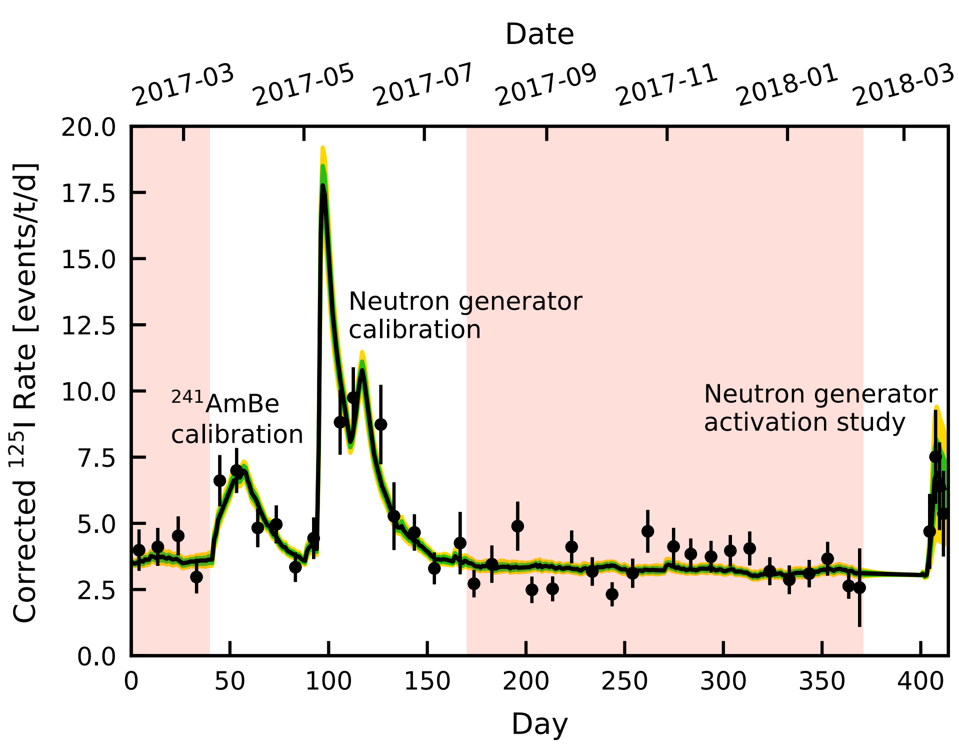
Gao, Liu, Wang, Wang, Xue, Zhong PRL 125, 2020

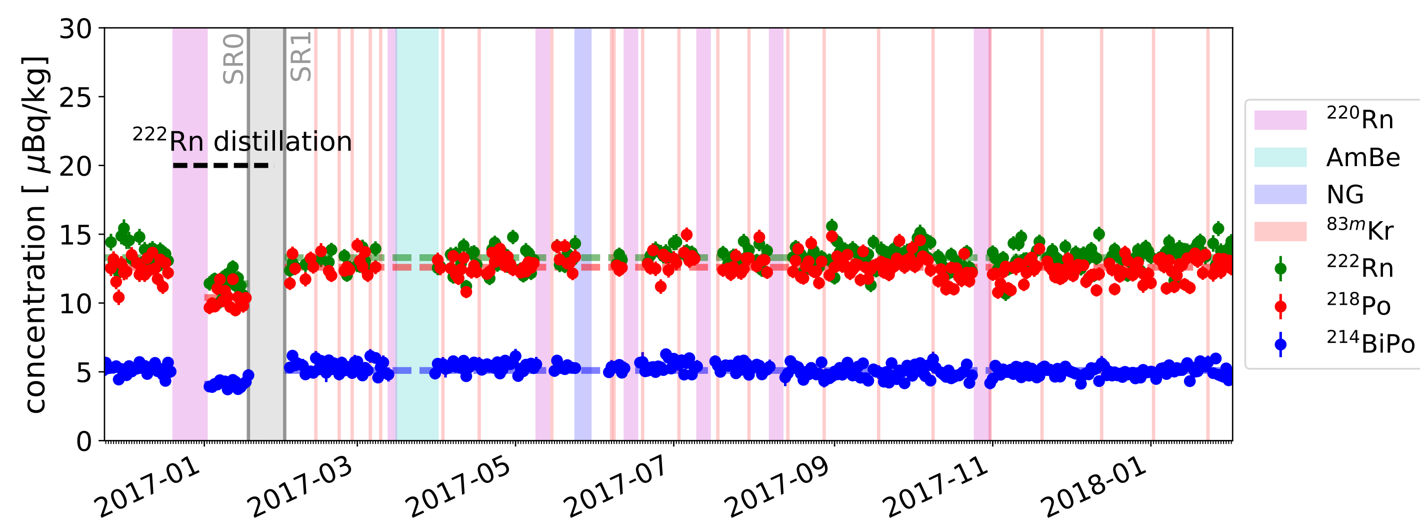


BACKGROUND COMPONENTS IN TIME



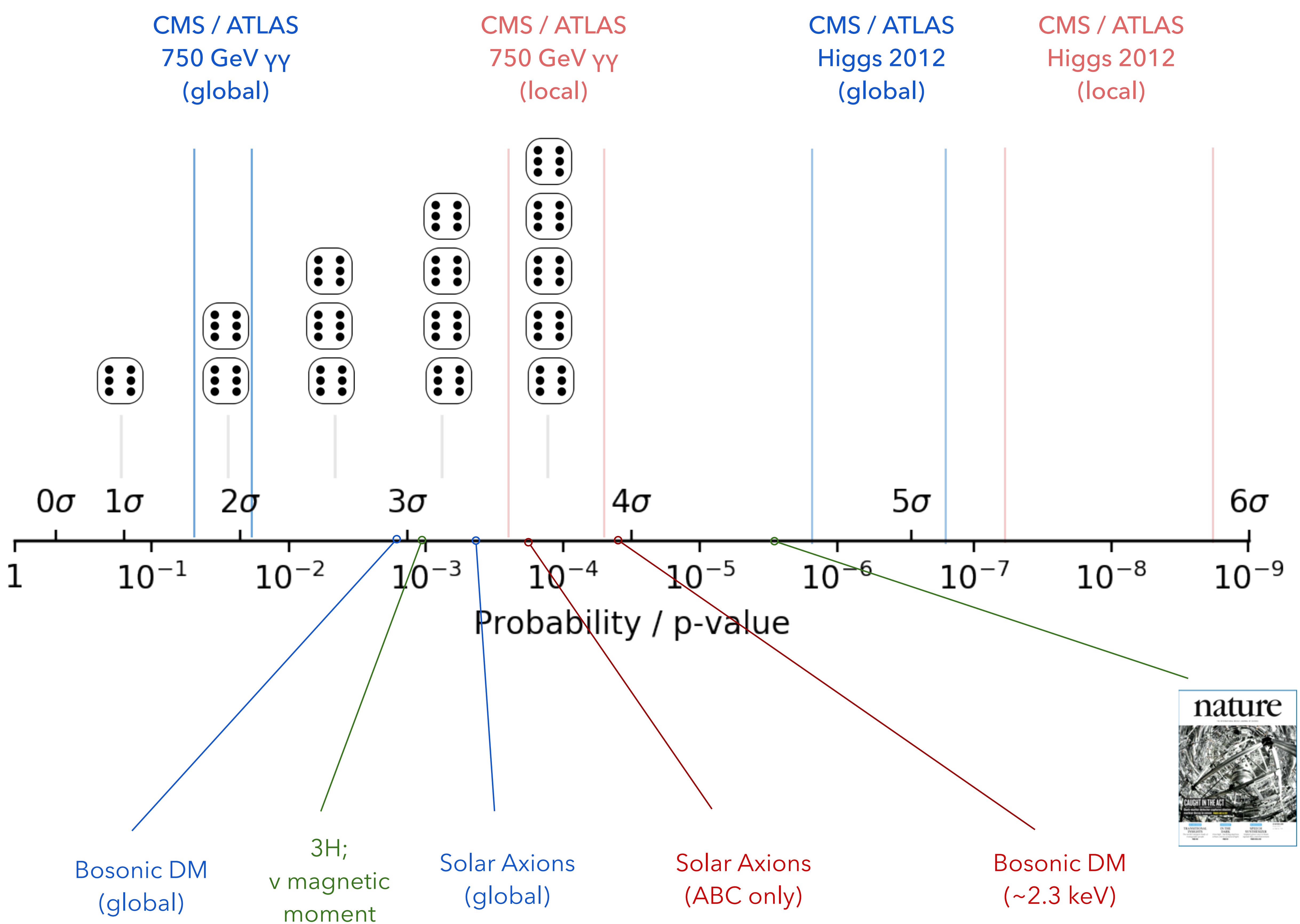




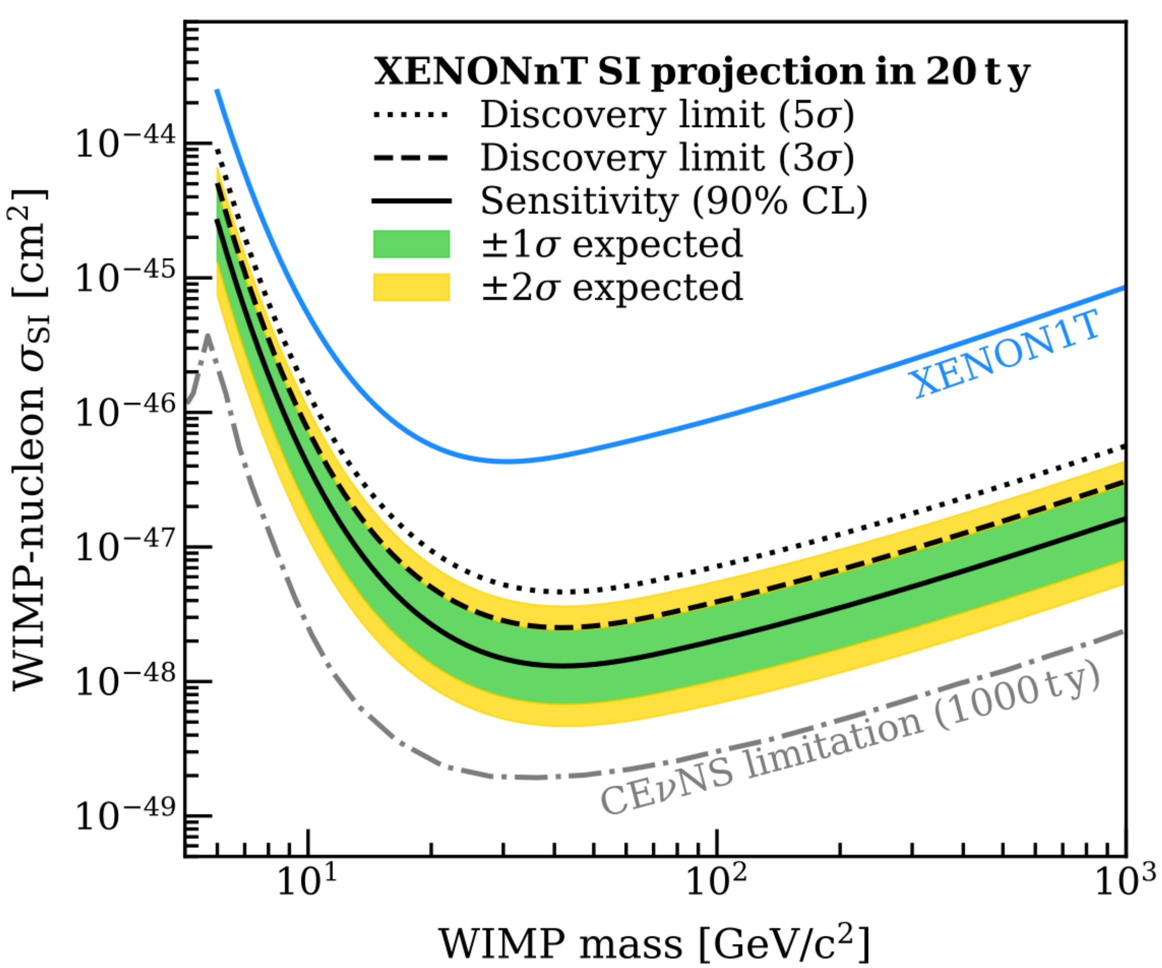


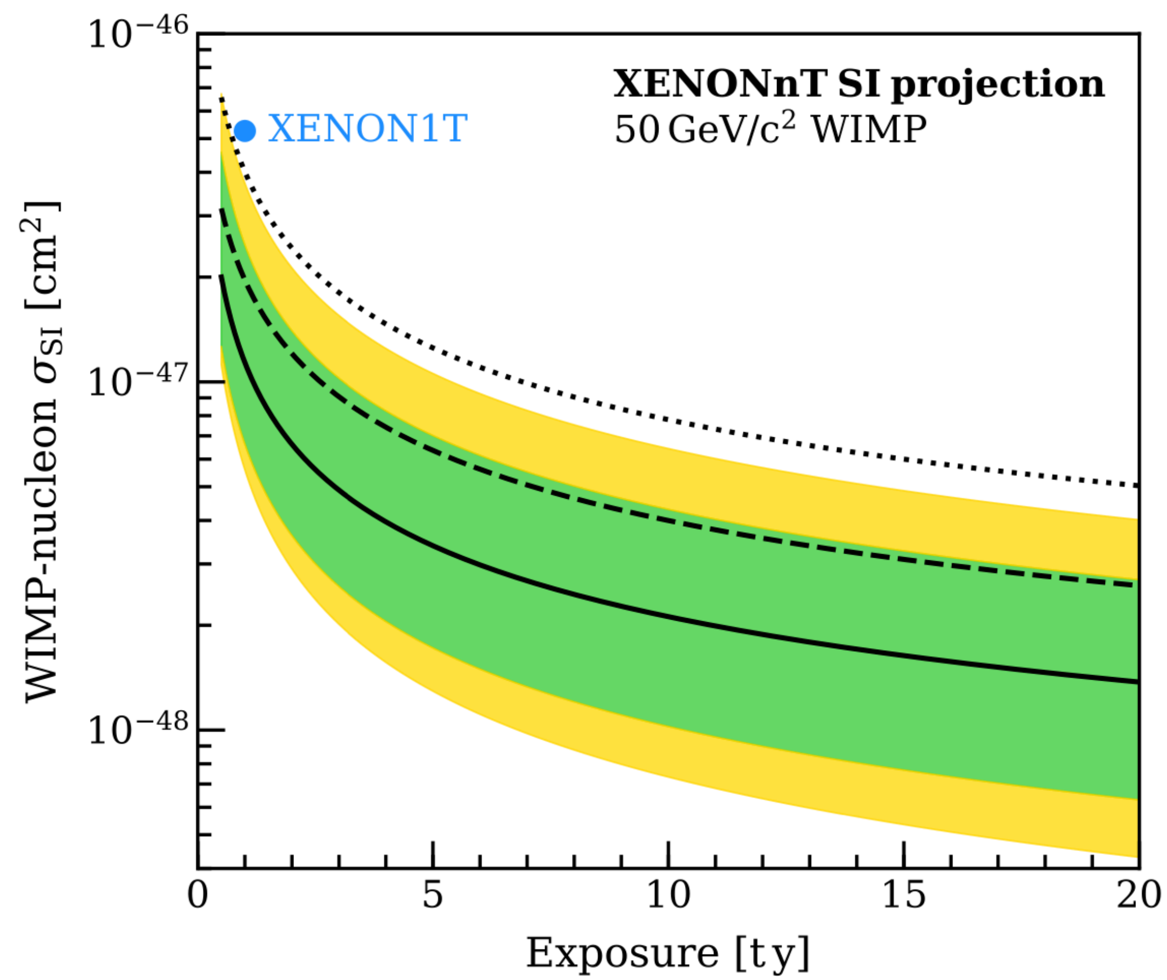
PROBABILITIES

Plot by Jelle Albers

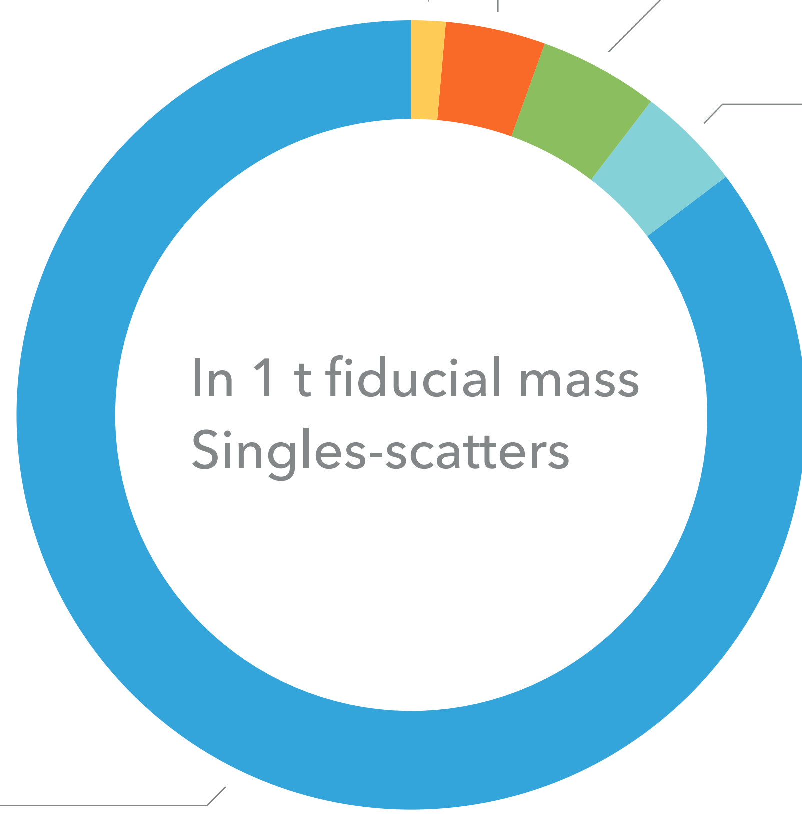


XENON-NT: SCIENCE REACH

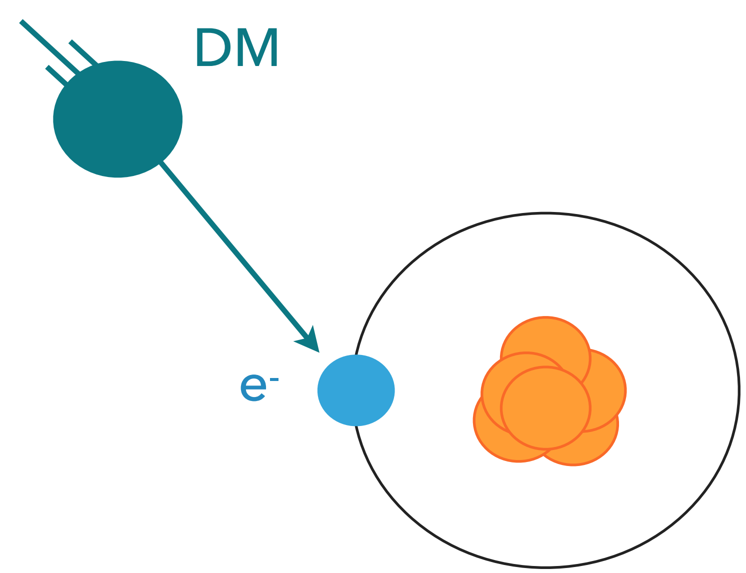


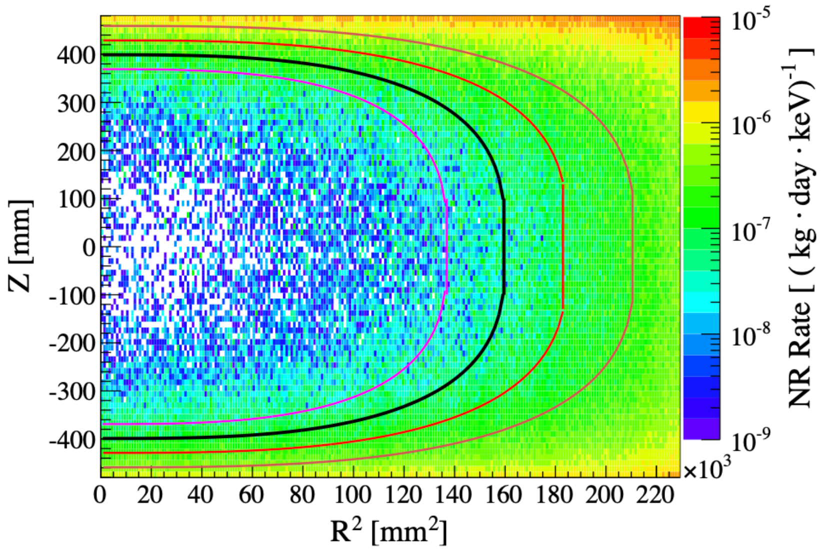


- ER rate: (82±5) events/(keV t y), in 1.3 t and below 25 keV_{ee}
- Lowest background in a dark matter detector



Control surface emanation
Reduce by online distillation



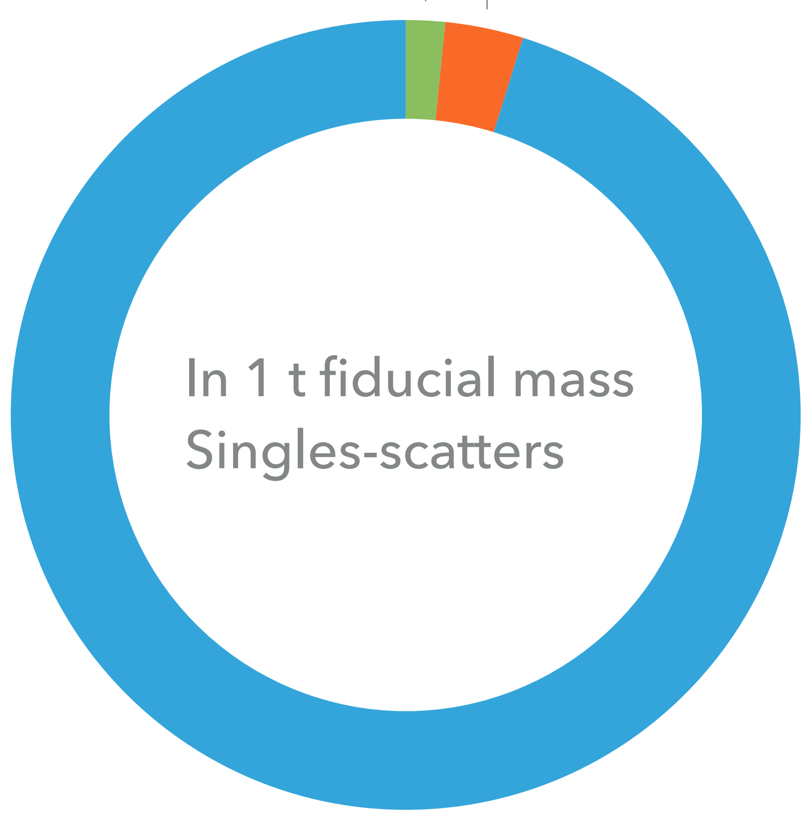


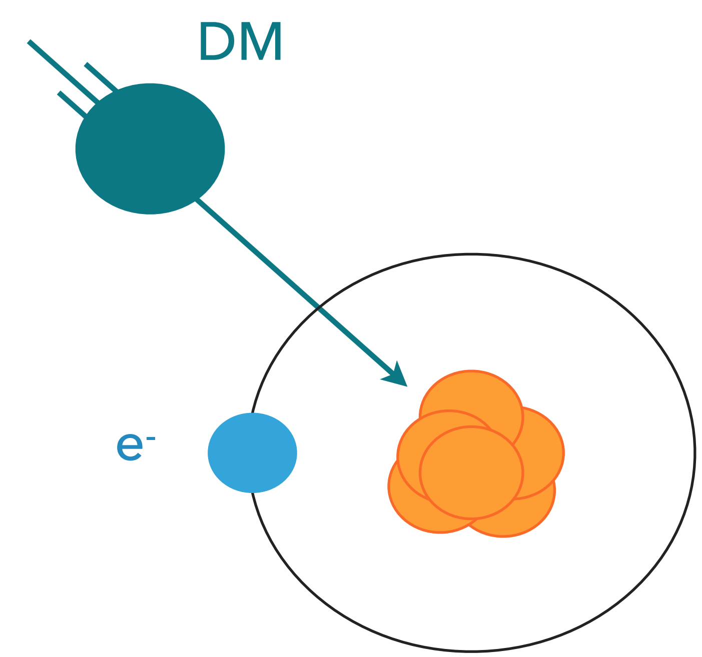
Cosmogenic neutrons (muon induced neutrons); rock overburden, water Cherenkov shield (here upper limit)

1.6%

3.2%

Coherent neutrino-nucleus scattering from ^{8}B neutrinos; irreducible, but relevant at low (<1 keV) energies





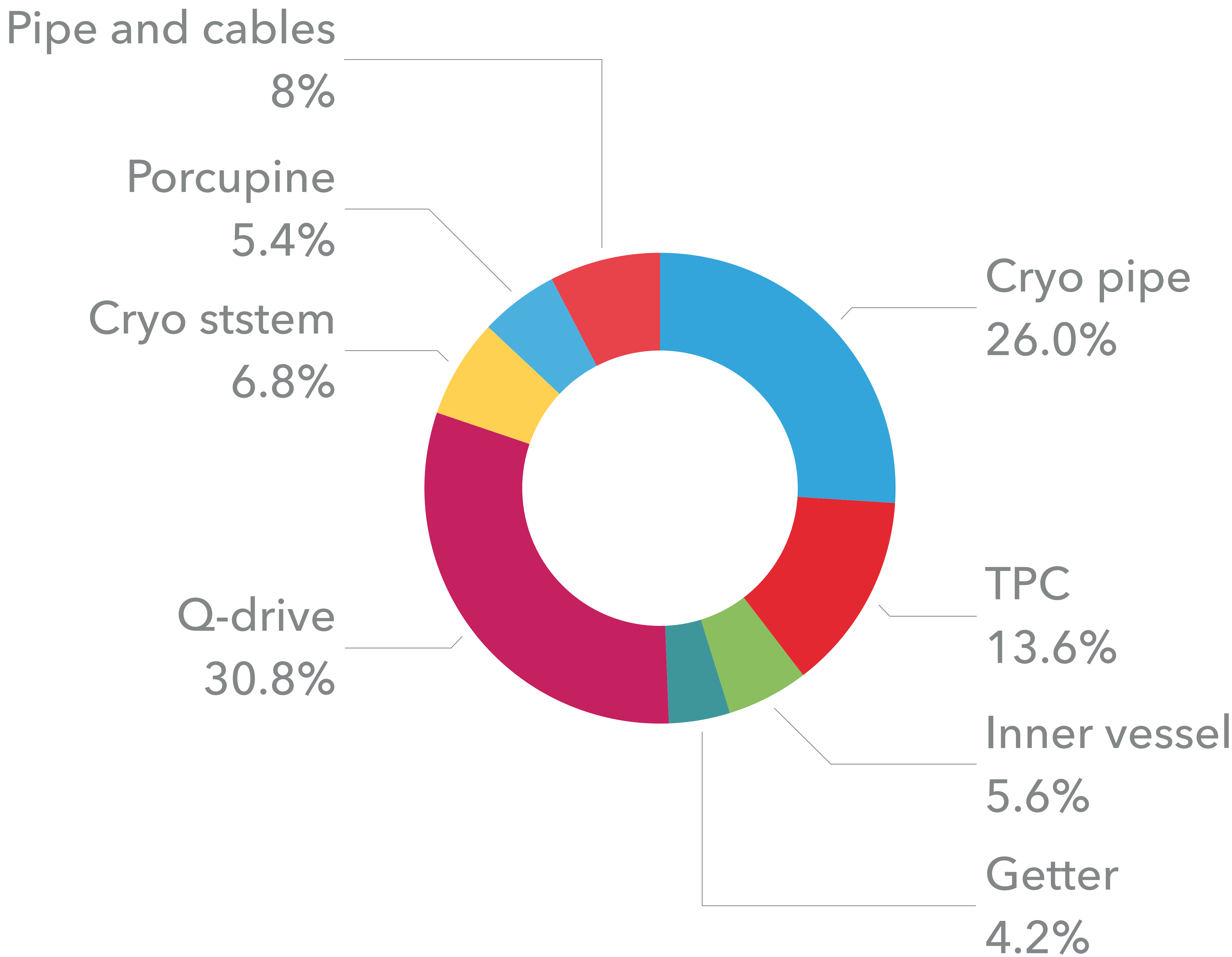
95.2%

Radiogenic neutrons

From (α,n) and SF reactions; material selection; single versus multiple-scatters

RADON BUDGET IN XENON1T

10 μBq/kg (before replacement of Q-drive pumps)



RADON BACKGROUND

- Assumption:
  - 0.1 μBq/kg ^{222}Rn (cryogenic distillation + material selection)
- Problematic:
  - ^{214}Bi decay, Q-value = 3.27 MeV, "naked" β-decay without γ emission: 19.1% BR
- ^{214}Po:
  - α-decay with short half-life, $T_{1/2}$ =164.3 μs => active veto for ^{214}Bi-decays
- Assumption:
  - 99.8% BiPo tagging efficiency

^{222}Rn	3.8 d	α	5.5 MeV
^{218}Po	3.05 min	α	6.0 MeV
^{214}Pb	26.8 min	β	
^{214}Bi	19.9 min	β	
^{214}Po	164 μs	α	
^{210}Pb	22.3 y	β	
^{210}Bi	5.0 d	β	
^{210}Po	138 d	α	
^{206}Pb	stable		