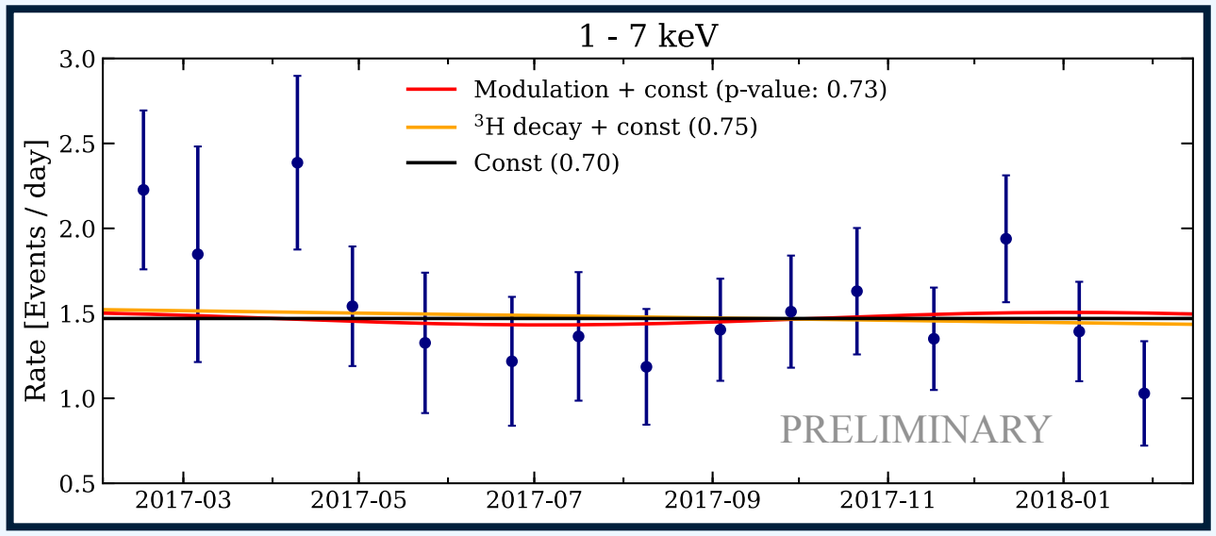
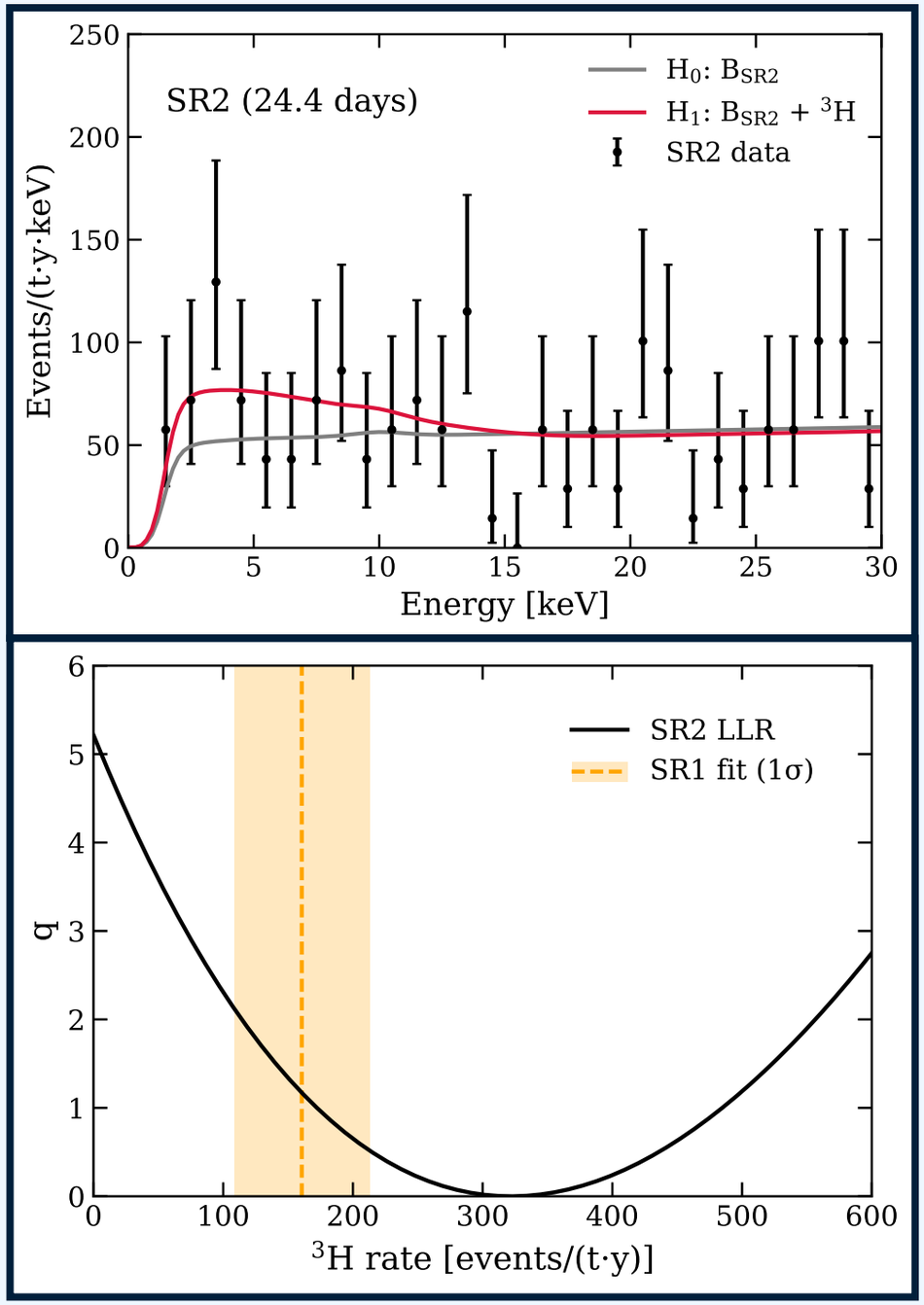
# Additional checks

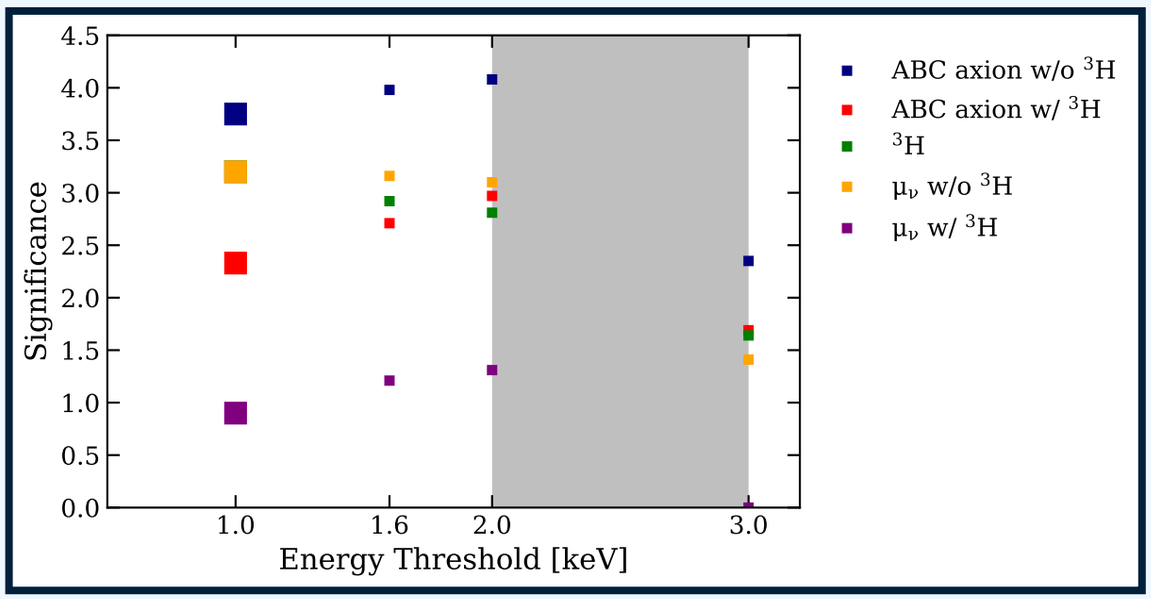
## Time dependence



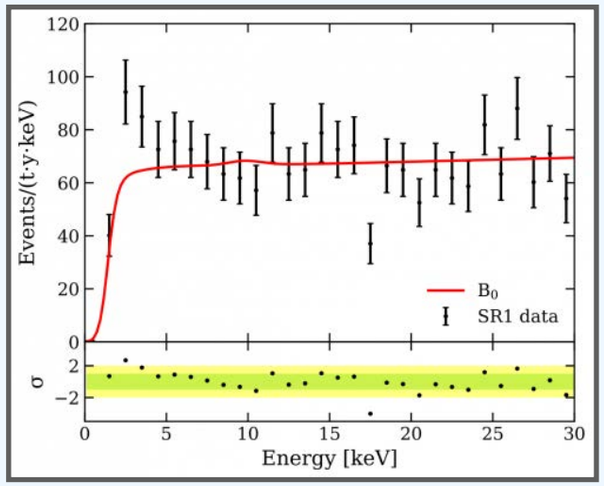

## Additional data




## Threshold effects



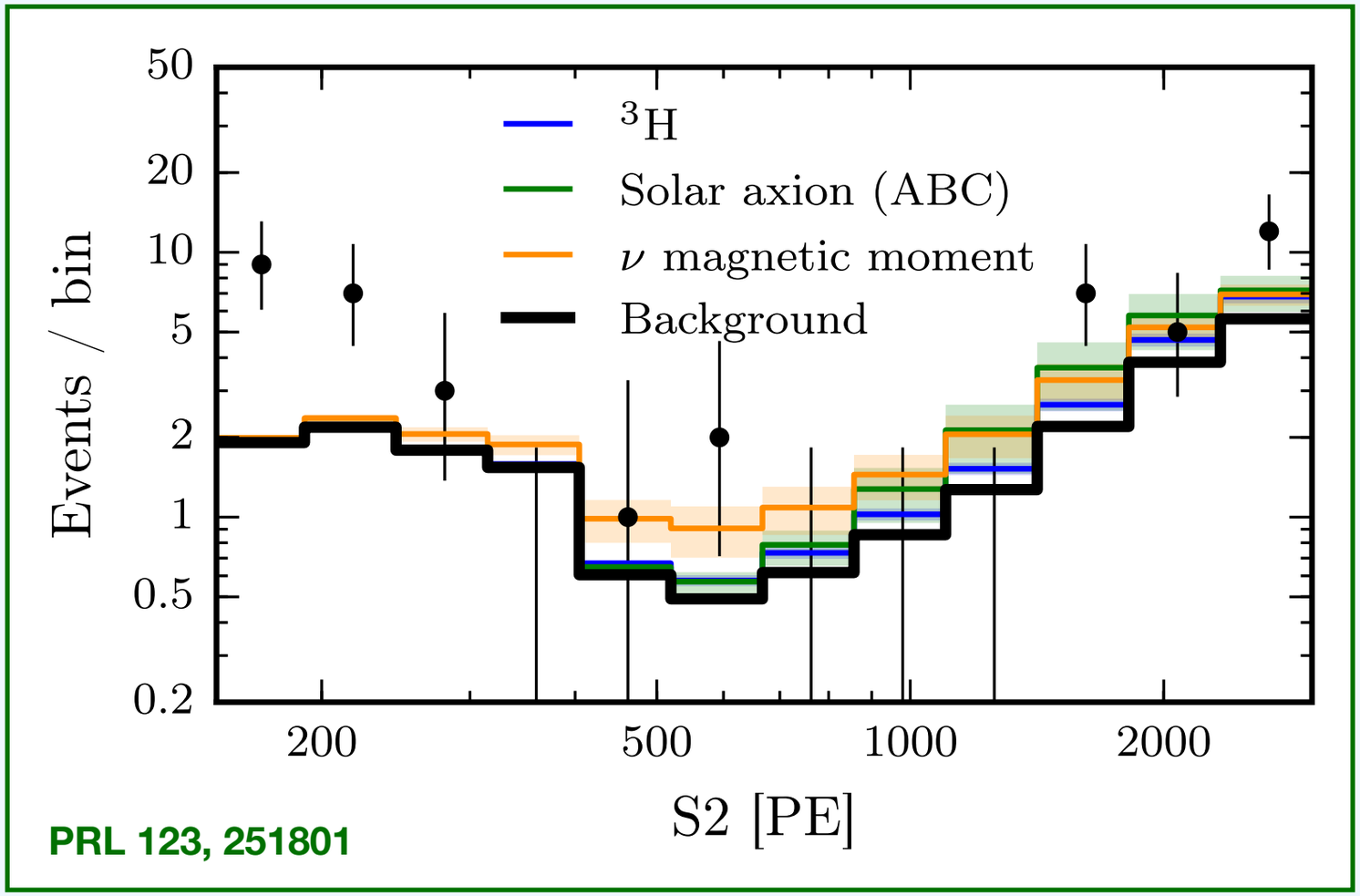
# S2-only analysis




S2-only analysis

limit-setting only

allows for a lower energy threshold




$\mu_\nu < 3.1 \times 10^{-11}\ \mu_B$

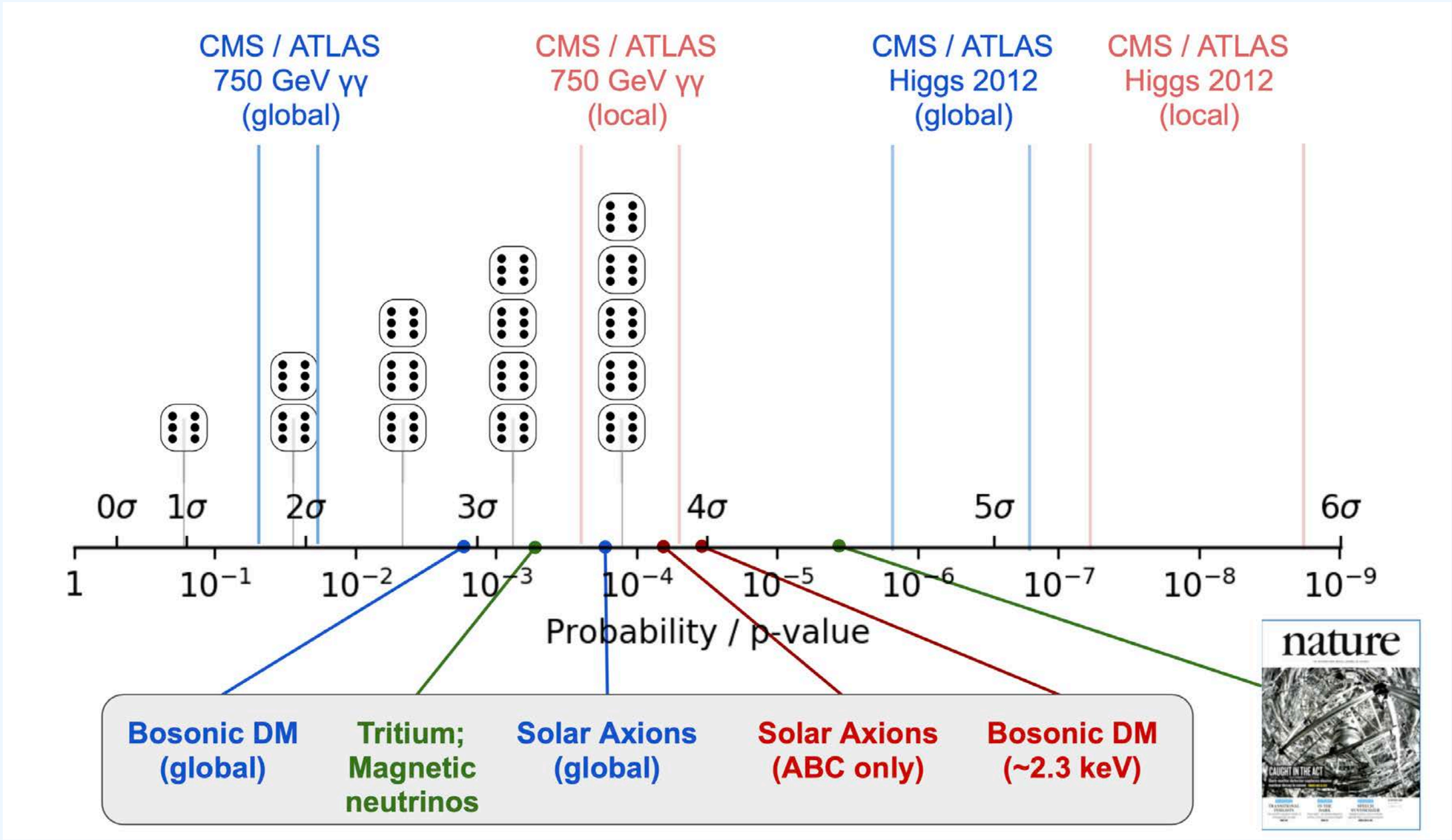
$g_{ae} < 4.8 \times 10^{-12}$

$R_{\mathrm{H3}} < 2256$ events/t/y

**consistent with this work for all 3 hypotheses**

# Putting it all together.

# Multiple hypotheses



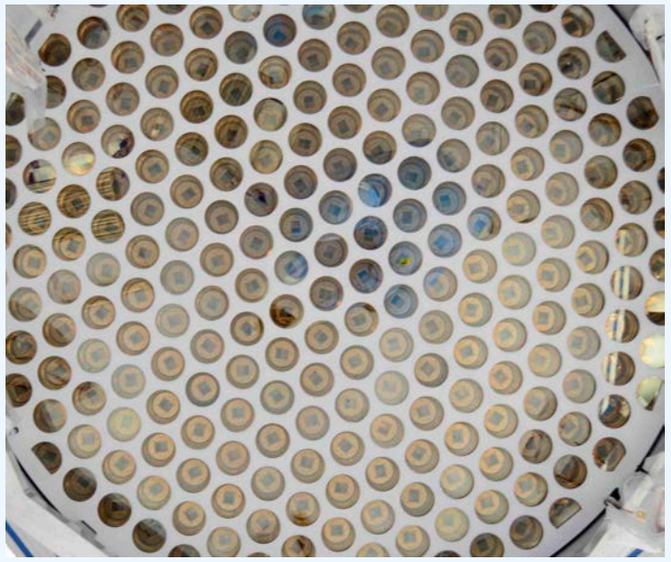
# Our results are... inconclusive.

**(what's next?)**

# XENONnT

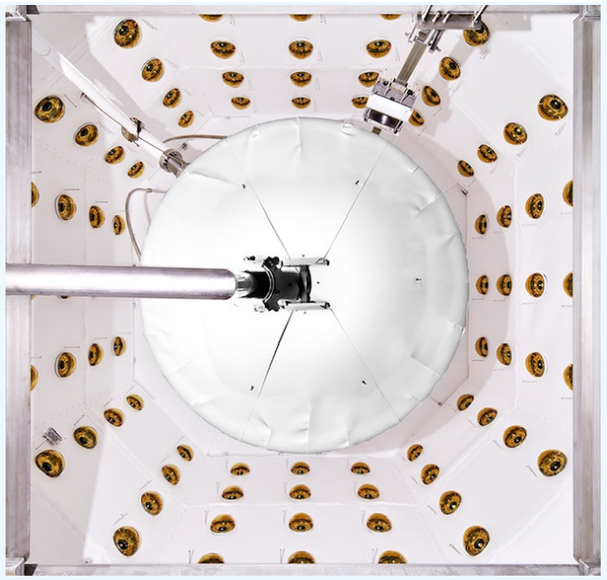
LXe purification system
(faster purification)

Rn distillation column
reduce $^{222}$Rn ($^{214}$Pb)



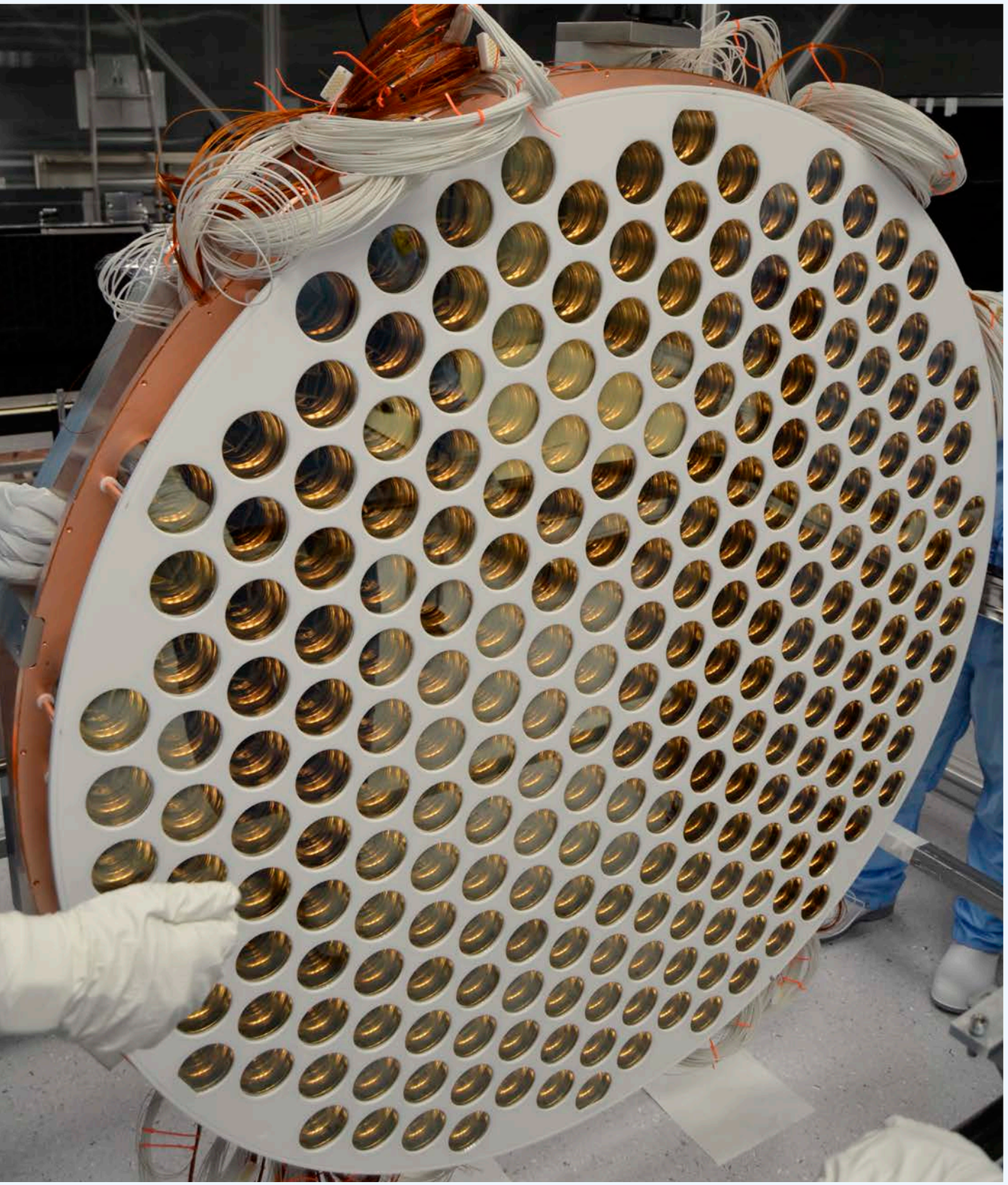
PMT array (494 PMTs in total,
in 2 arrays)

TPC (5.9 t LXe,
4 t fiducial)



Neutron veto (120 PMTs,
Gd-doped water)

# XENONnT

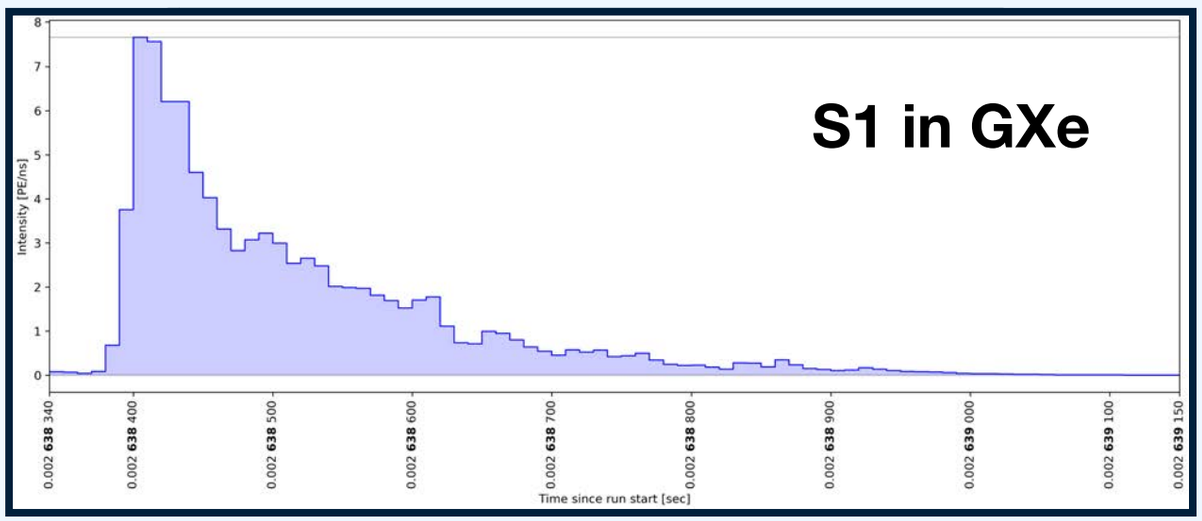


**3x**

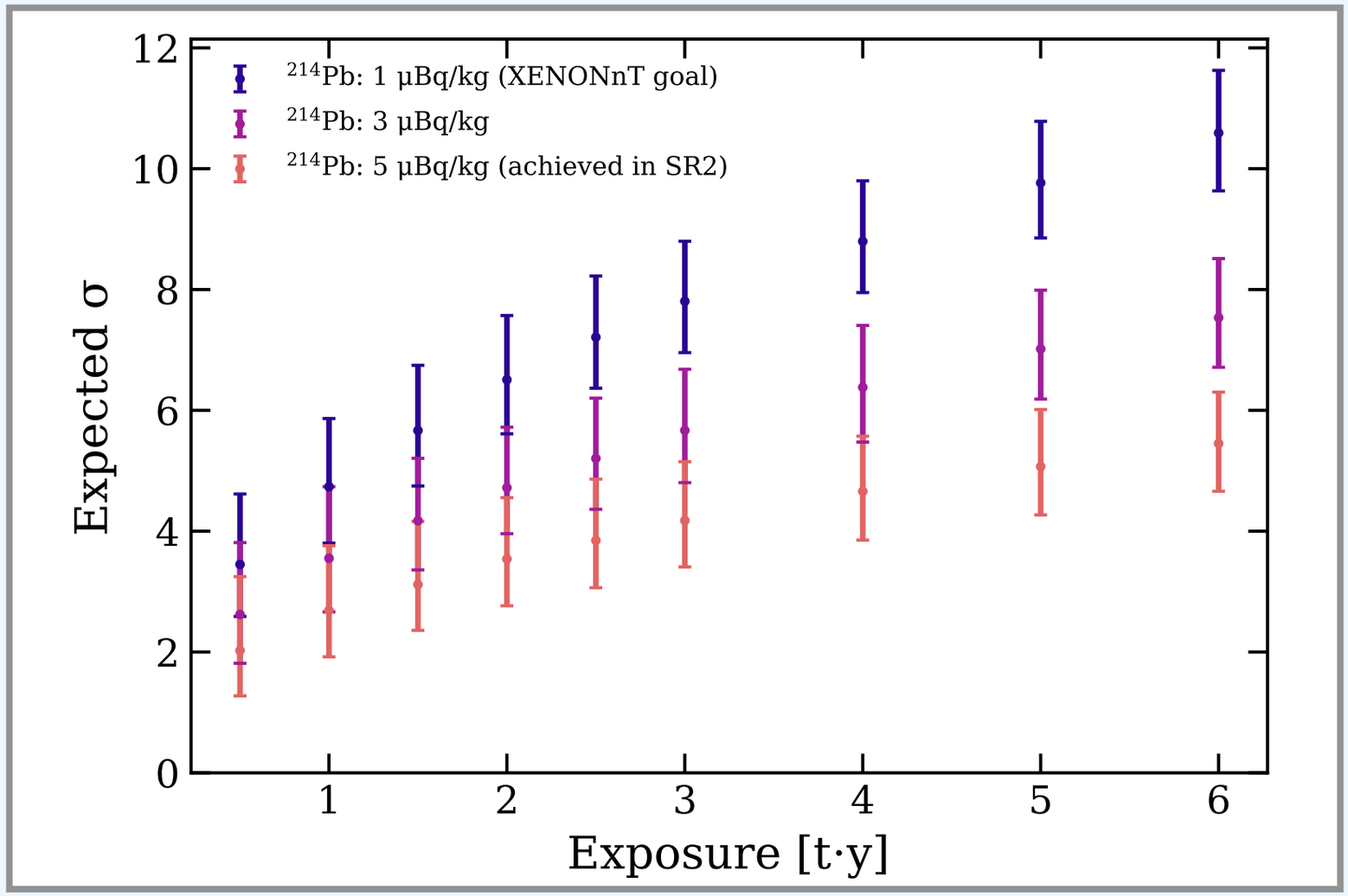
Larger active volume

**~1/6**

Reduced background level



# XENONnT




Based on energy spectrum alone.

Uses best-fit from 1T search.

**XENONnT will discriminate axions from tritium with ~ few months of data**

# Conclusions

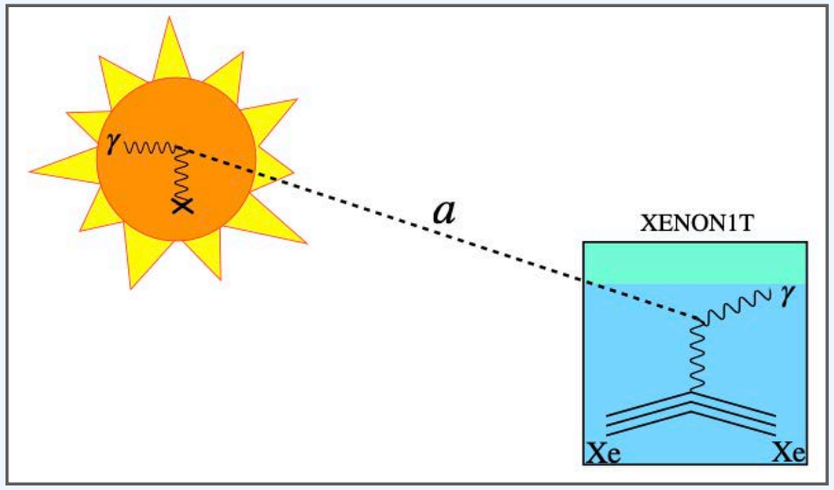
- Solar axions favoured over background at 3.4σ, *but*
- it is in strong tension with stellar constraints, *and*
- a tritium background at 3.2σ can neither be confirmed nor excluded.
- an $^{37}$Ar-37 background is strongly constrained and not likely to explain the excess
- An enhanced neutrino magnetic moment favoured over background at 3.2σ (0.9σ w/ $^{3}$H)
- Bosonic dark matter peak at 2.3 +/- 0.2 keV has 4.0σ local significance, but note 3.0σ global.

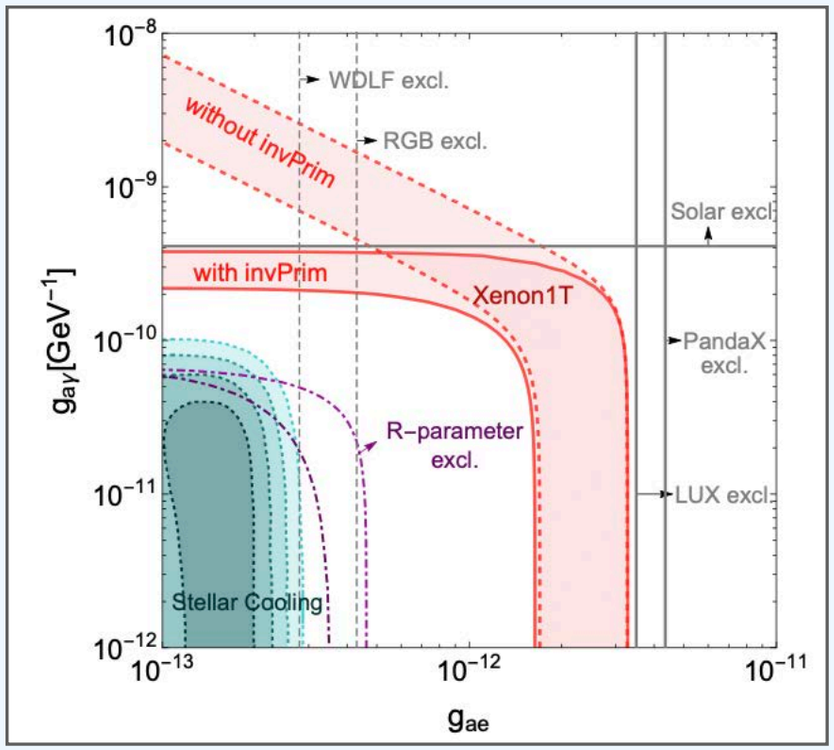
**It is too soon to draw any conclusions; however**

**XENONnT is coming soon!**

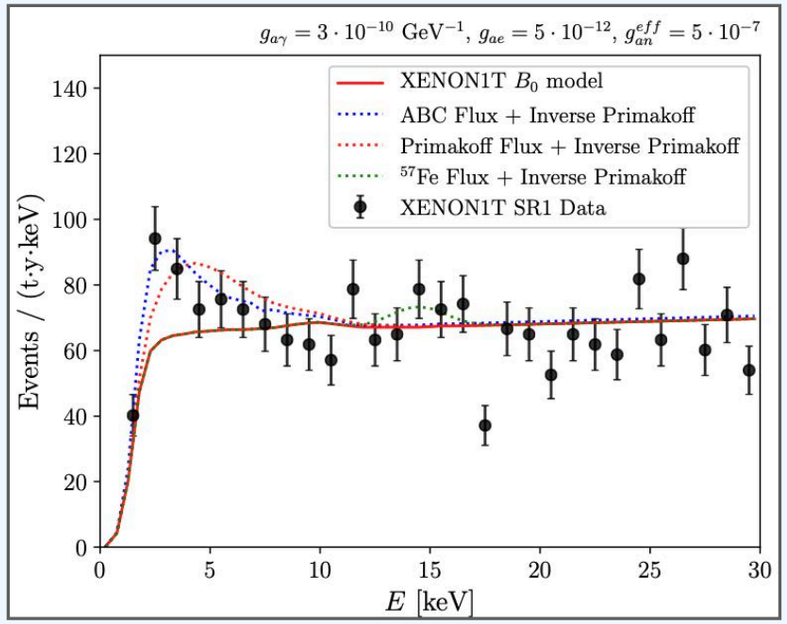
XENON collaboration, Phys. Rev. D 102, 072004, October 12, 2020

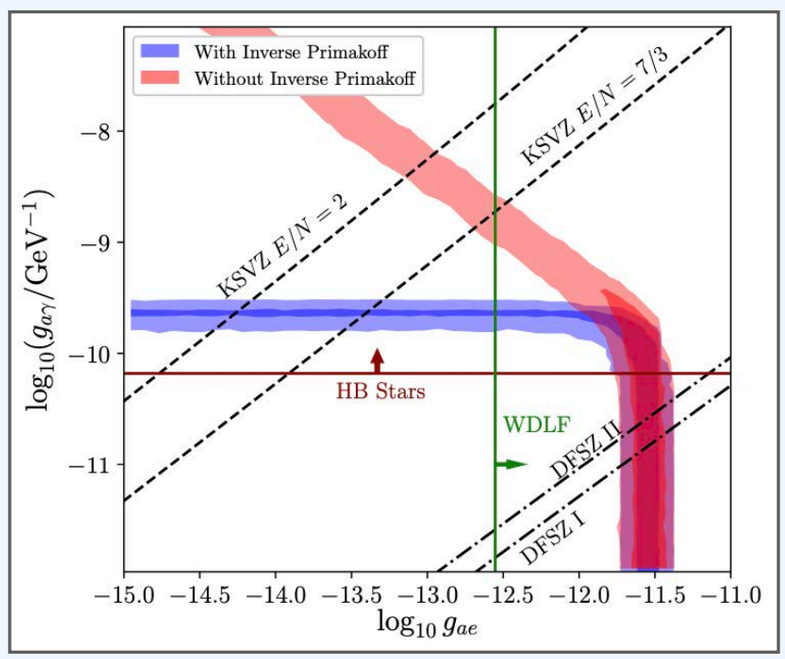
# Inverse Primakoff Effect




C. Gao, et al.
arXiv:2006.14598




J.B. Dent, et al.
arXiv:2006.15118

Minimising the tension with stellar constraints

# QCD axion models

$$m_a \simeq \frac{6 \times 10^6 \text{ GeV}}{f_a} \text{ eV/c}^2$$

DFSZ: two Higgs doublets model
couplings to leptons at tree level

Dine-Fischler-Srednicki-Zhitnitsky (DFSZ)

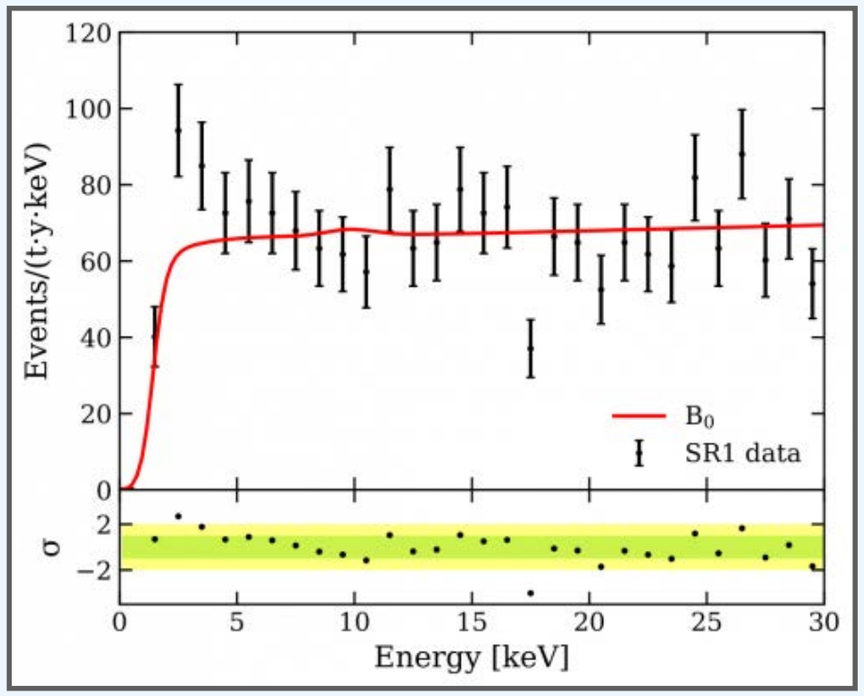
KSVZ: heavy quark model
couplings to leptons only at loop level

Kim-Shifman-Vainshtein- Zhakharov (KSVZ)

**axion-photon coupling**
**same for both models**

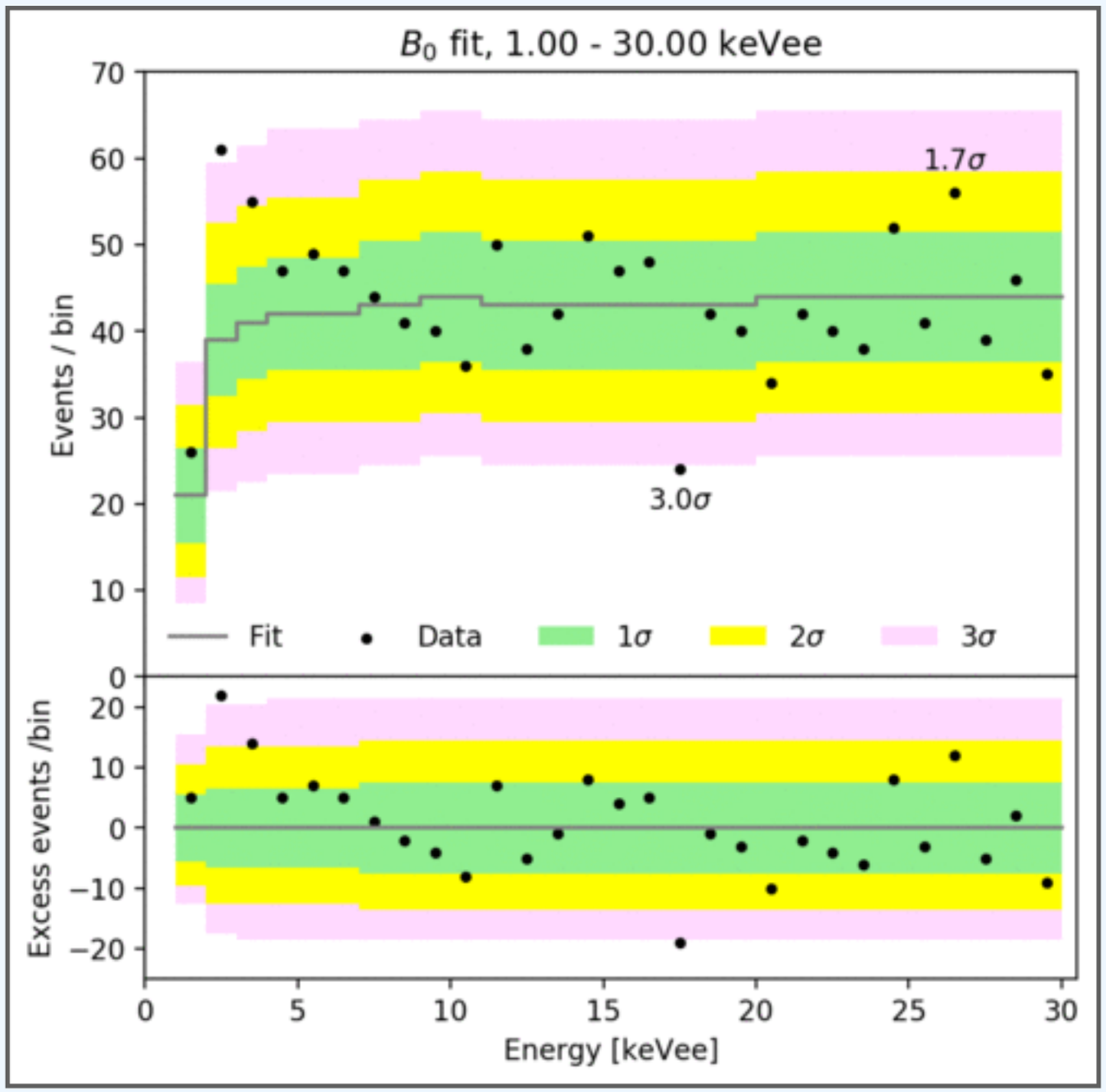
- relative contributions from each component can allow to distinguish between models (Primakoff dominates in KSVZ models); can also constrain $\beta_{DFSZ}$
- nuclear transition contribution always relatively small

# Fluctuations and correlations



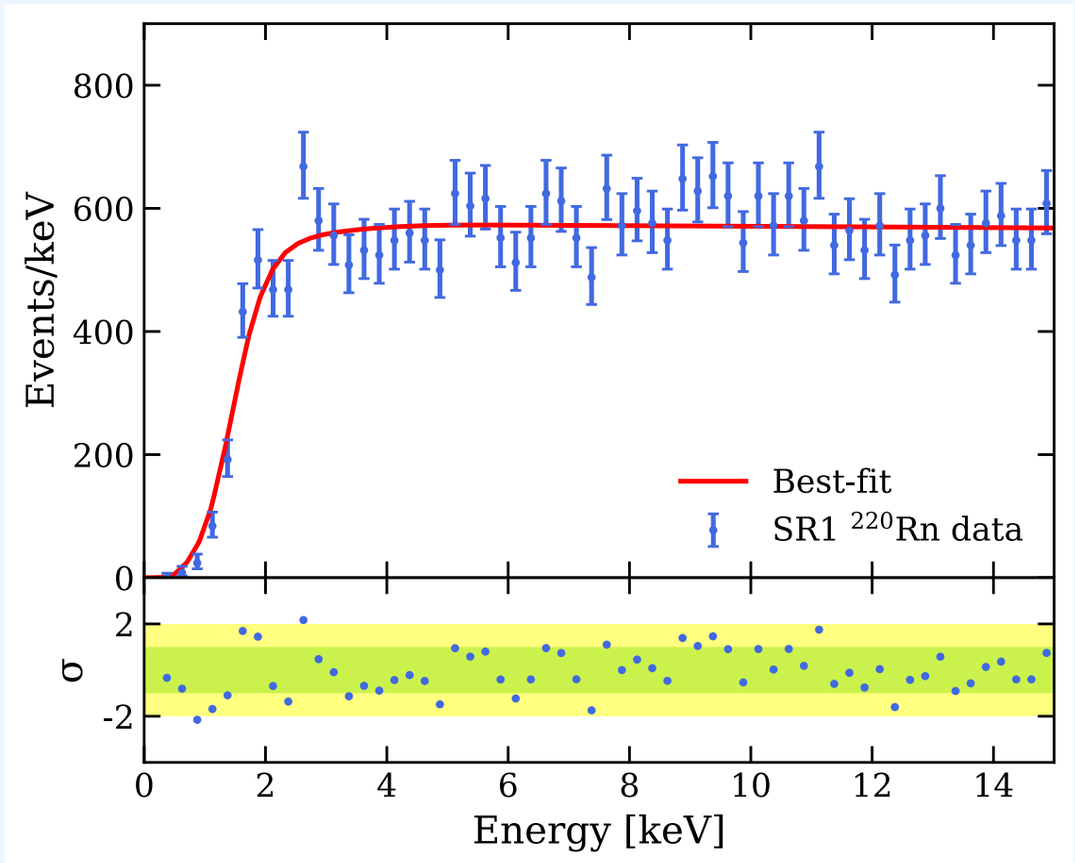

statistical fluke? (see 17 keV dip)

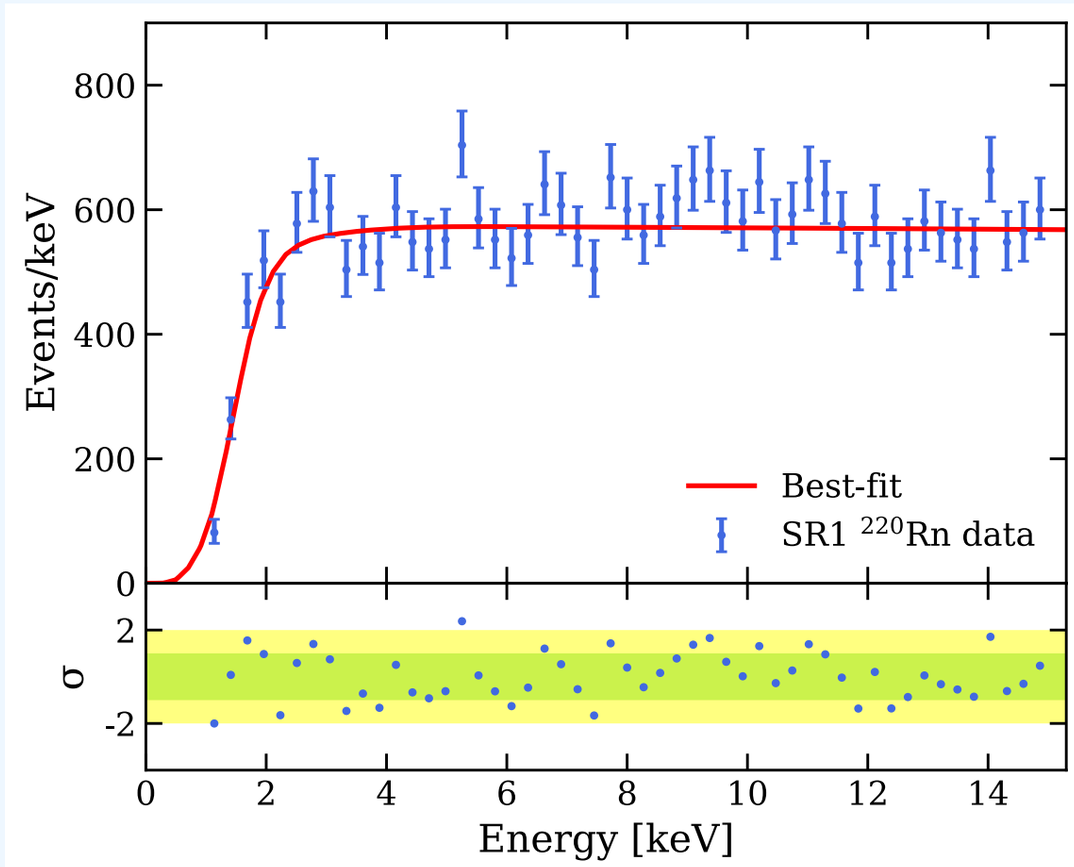
funny correlation? (1-10 keV rising steadily)




**Note: we use an unbinned profile likelihood analysis**

# Calibration data




$^{220}$Rn rebinned

# SR2

Data taken after SR1 through end of 2018

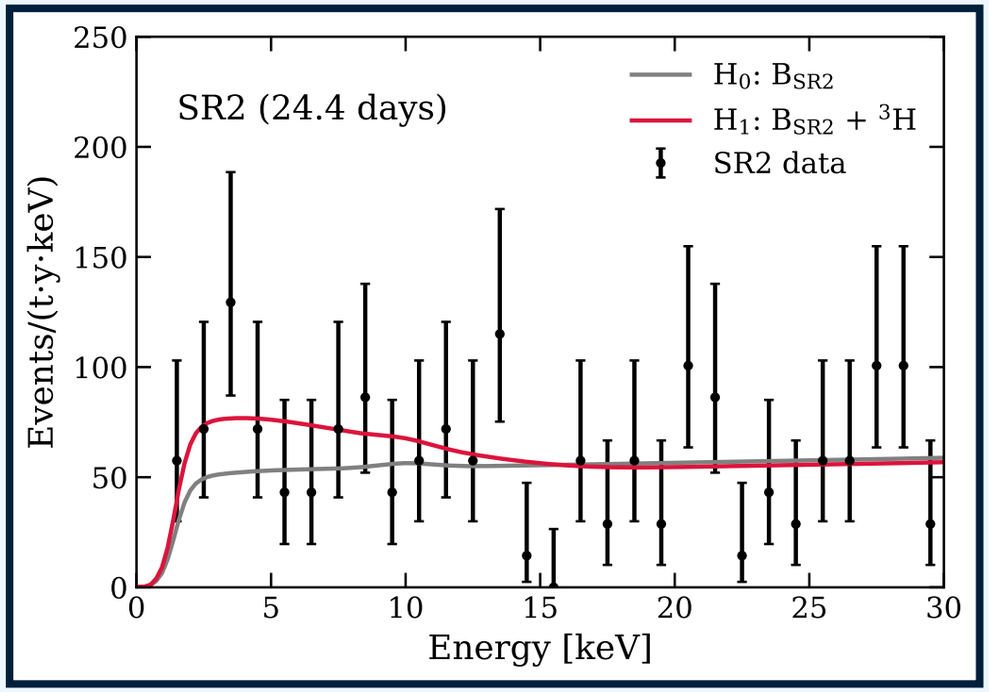
Require strict data selection due to changing detector conditions

24.4 live-days in total used for cross-check

20% reduced background level

Improved purification

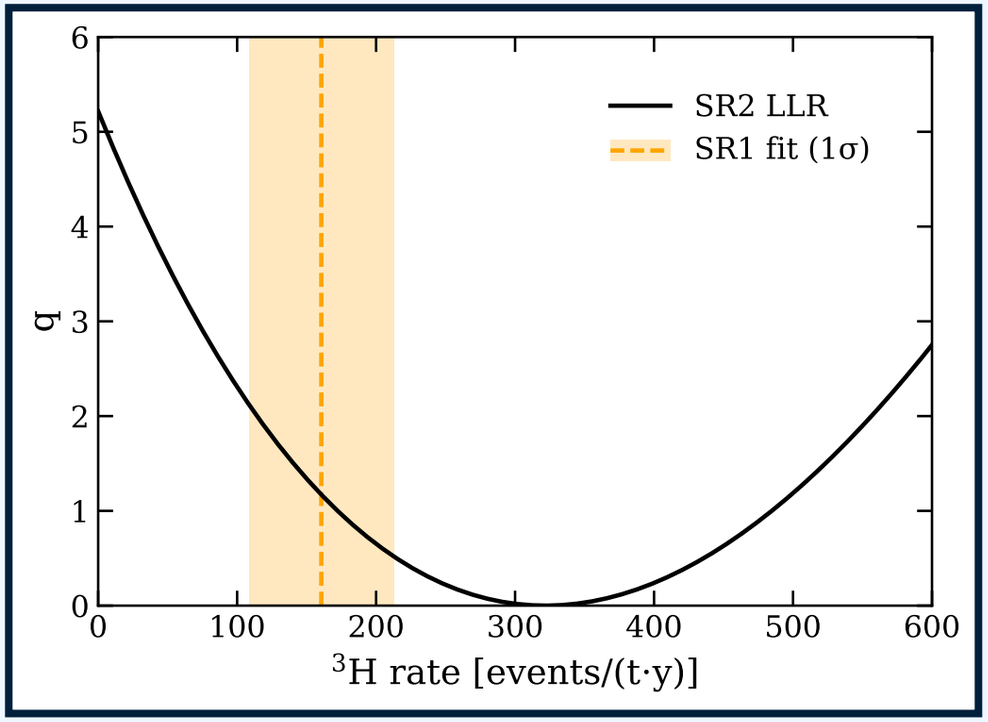
**Goal: test the tritium hypothesis**




**Tritium favored over background-only at 2.3σ.**

Rate consistent with SR1

Similar results for solar axion and magnetic moment (~2σ)

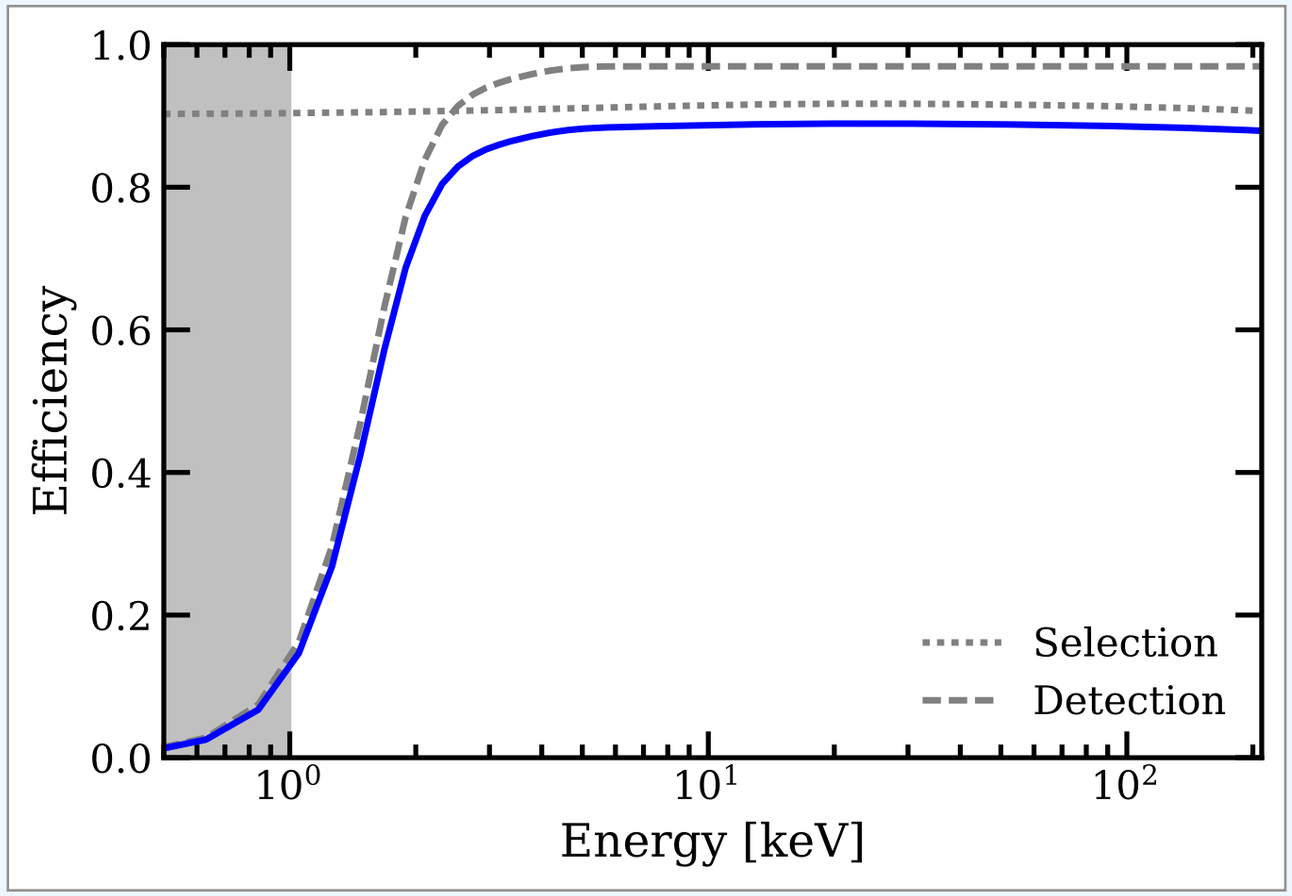


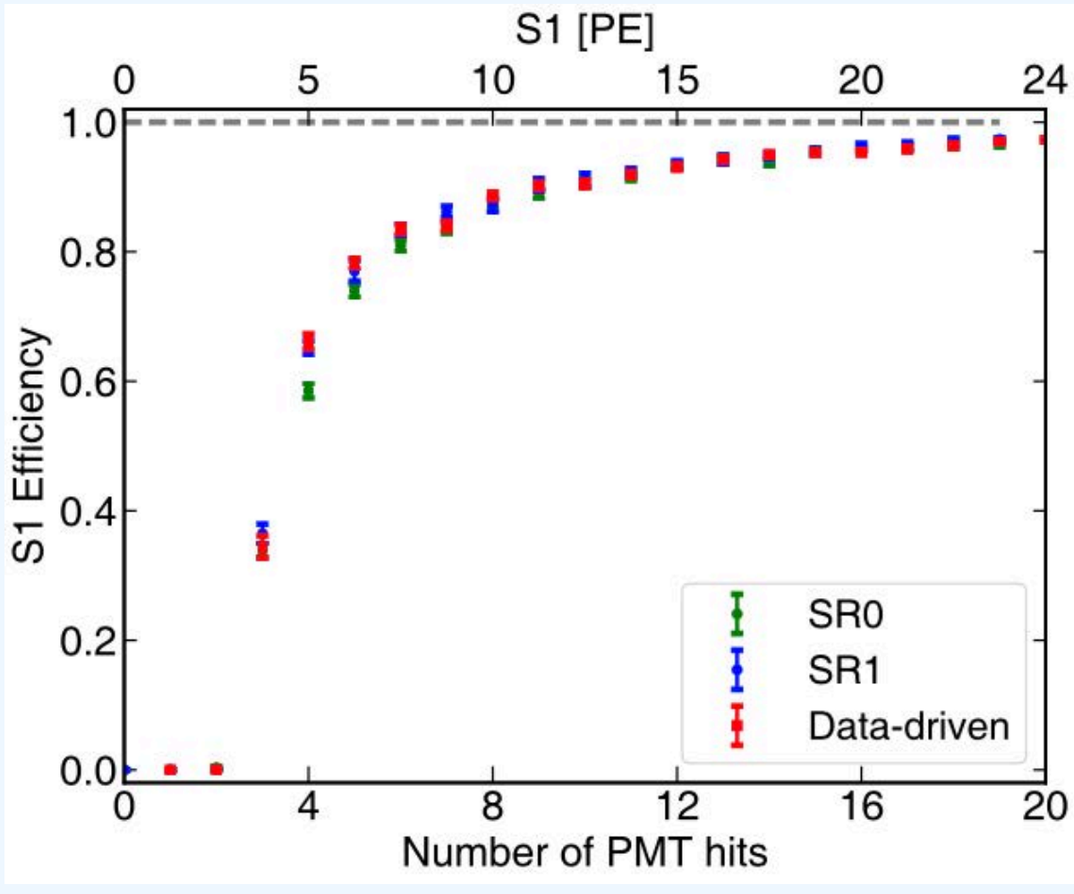
# Background Fit

| Component | | Expected Events | Fitted Events | Constant in time? (shared across partitions) |
|---|---|---|---|---|
| $^{214}Pb$ | | (3450, 8530) | 7480 +/- 160 | YES |
| $^{85}Kr$ | | 890 +/- 50 | 773 +/- 80 | NO |
| $^{136}Xe$ | | 2120 +/- 210 | 2150 +/- 120 | YES |
| $^{133}Xe$ | | 3900 +/- 410 | 4009 +/- 85 | NO |
| $^{131}Xe$ | | 23760 +/- 640 | 24270 +/- 150 | NO |
| $^{83m}Kr$ | | 2500 +/- 250 | 2671 +/- 53 | NO |
| *Materials* | | 323 (fixed) | 323 (fixed) | YES |
| *Solar neutrino* | | 220.7 +/- 6.6 | 220.8 +/- 4.7 | YES |
| $^{124}Xe$ | *KK* | 125 +/- 50 | 113 +/- 24 | YES |
| | *KL* | 38 +/- 15 | 34.0 +/- 7.3 | YES |
| | *LL* | 2.8 +/- 1.1 | 2.56 +/- 0.55 | YES |
| $^{125}I$ | *K* | 79 +/- 33 | 67 +/- 12 | NO |
| | *L* | 15.3 +/- 6.5 | 13.1 +/- 2.3 | NO |
| | *M* | 3.4 +/- 1.5 | 2.94 +/- 0.50 | NO |

*unconstrained in the fit*

# Efficiency



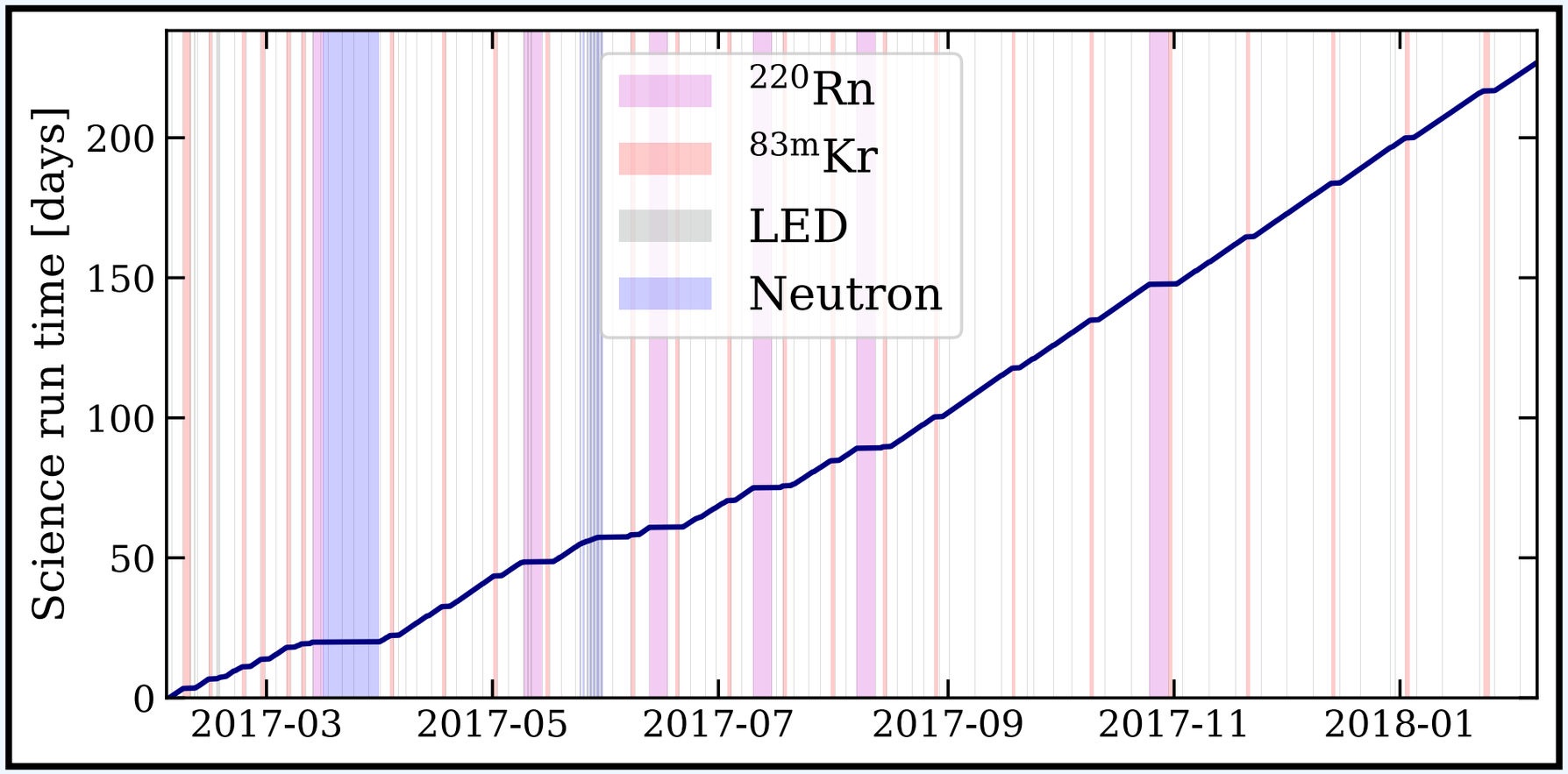




arXiv:1906.04717

3-fold PMT coincidence

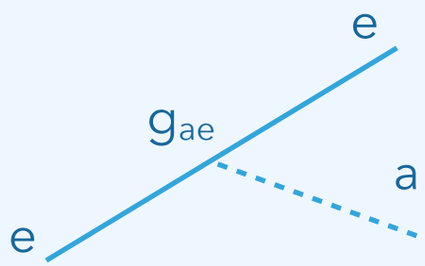
Efficiency validated with both waveform simulations and data-driven method using Rn220

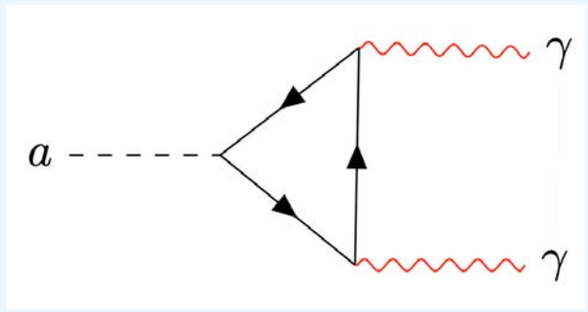
# Calibration

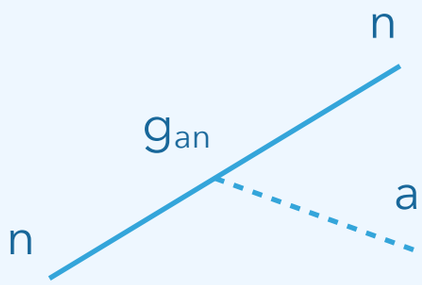


# Solar axions

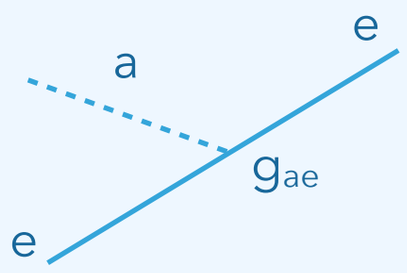
Production
Solar physics



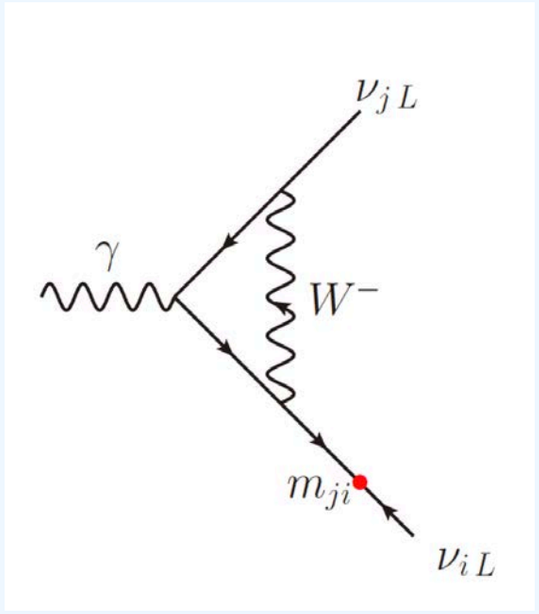

Detection:
Axioelectric effect



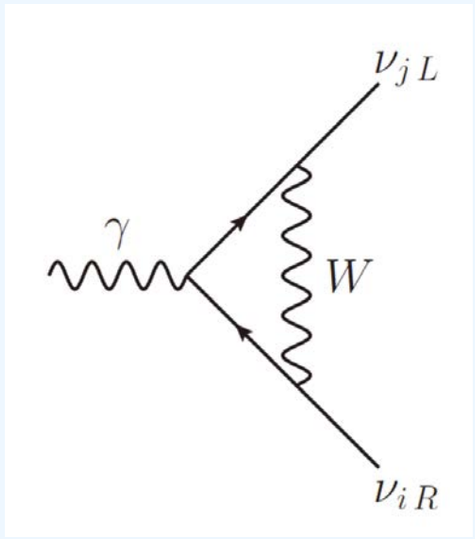

σ for detection, analogous to photoelectric effect

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

# Neutrino magnetic moment




Majorana neutrinos




Dirac neutrinos

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

# The XENON Collaboration