

# The LZ Dark Matter Experiment: Update for the 2022 SURF User Association General Meeting



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LZ Physics Coordinator

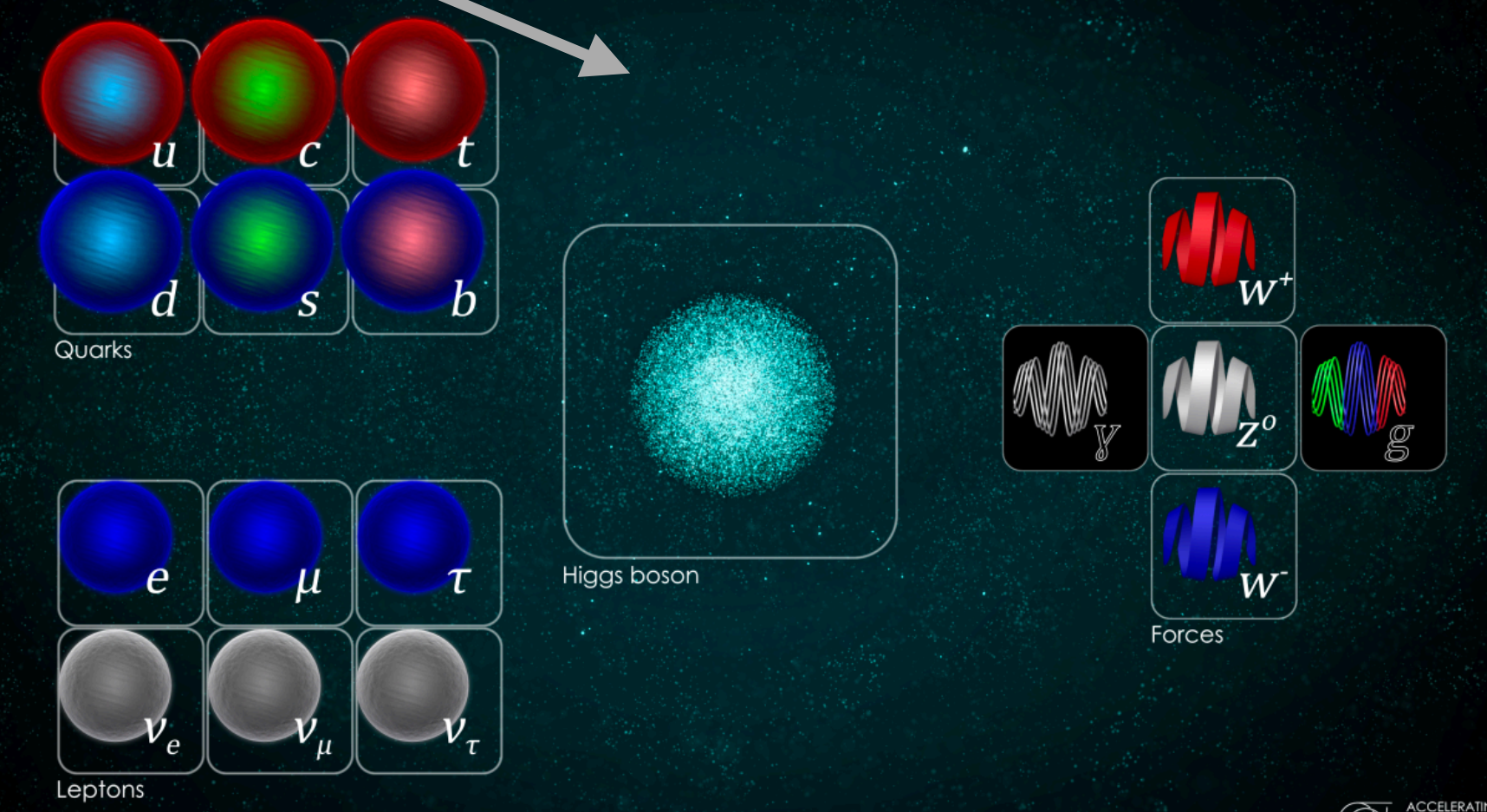
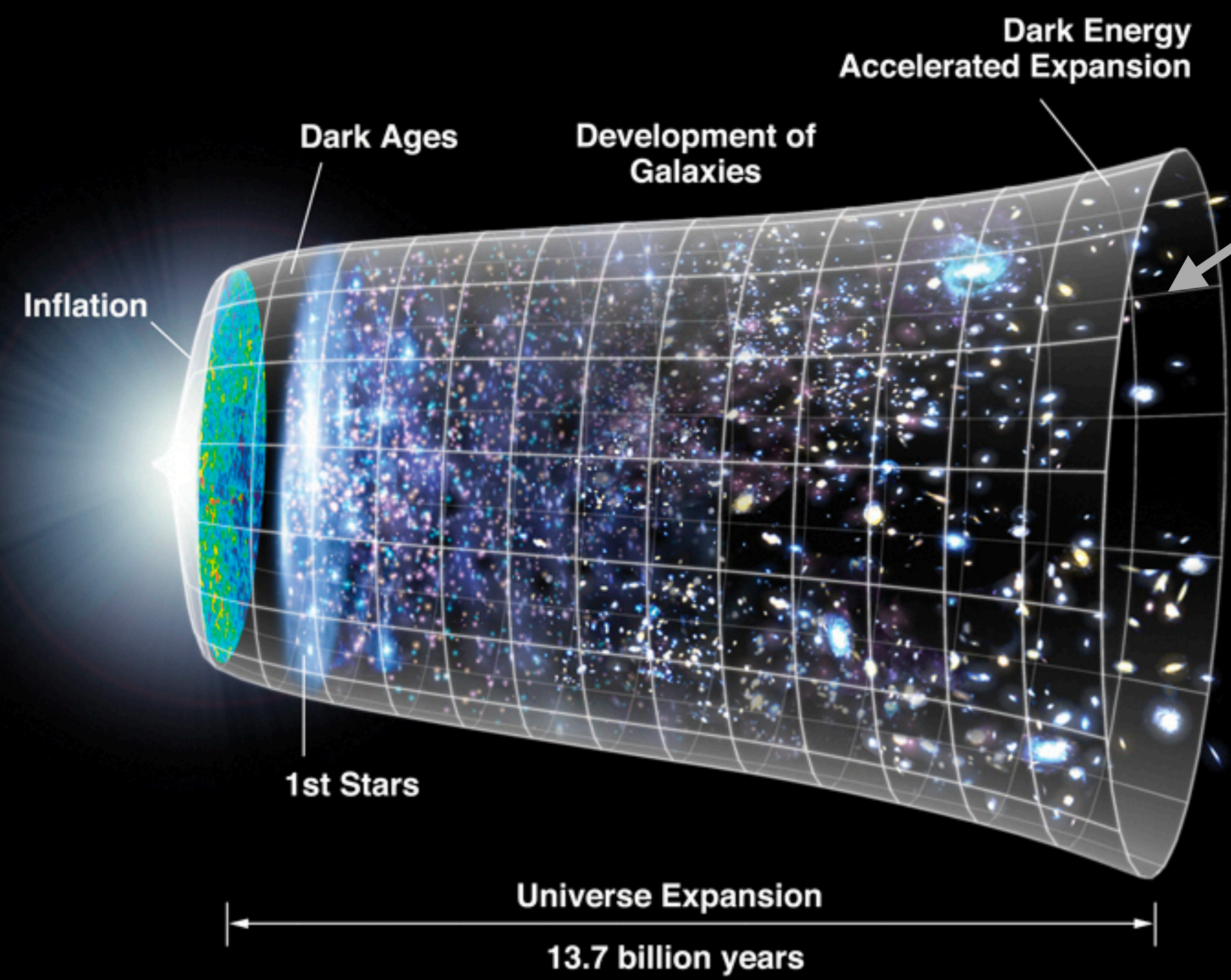
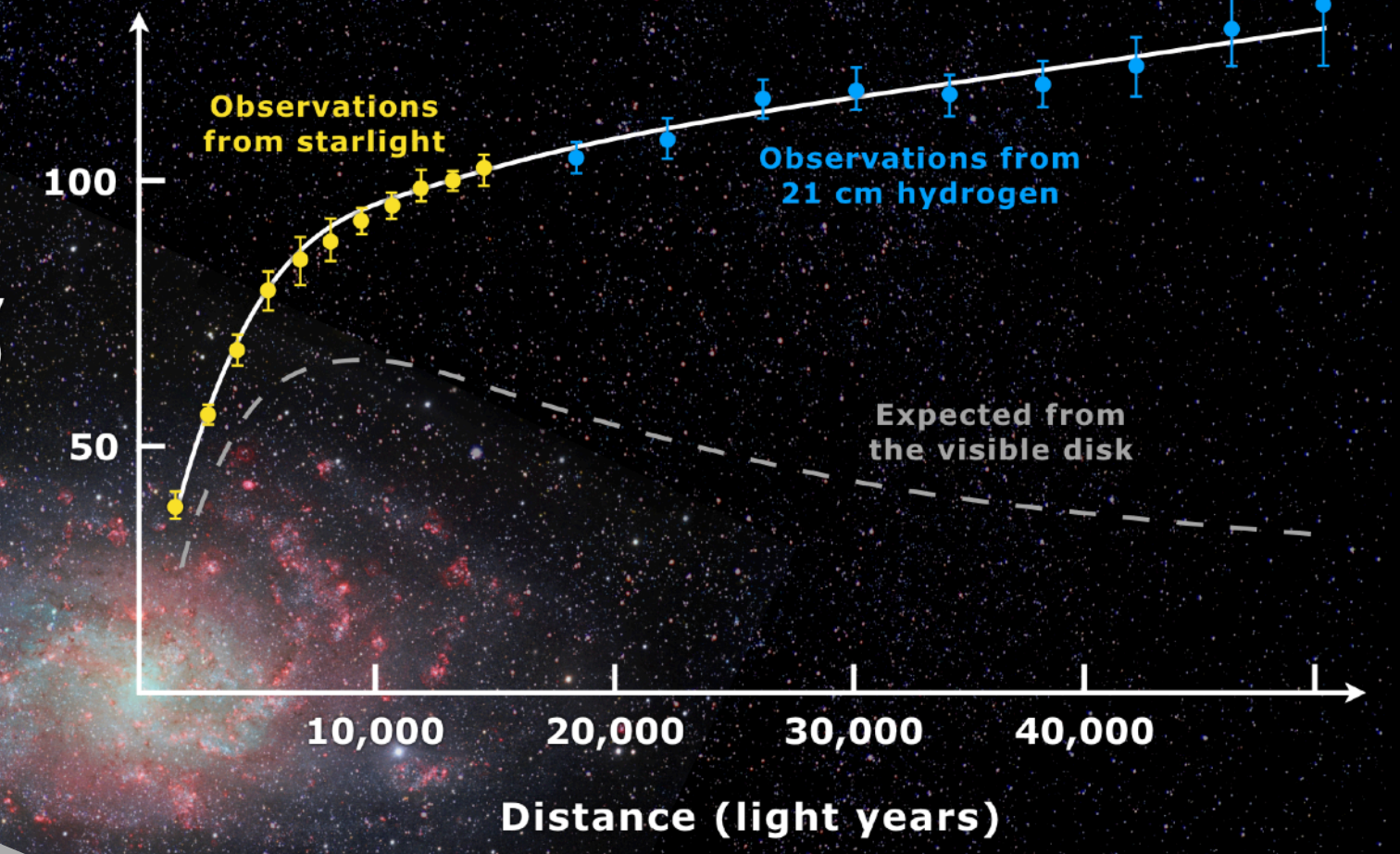
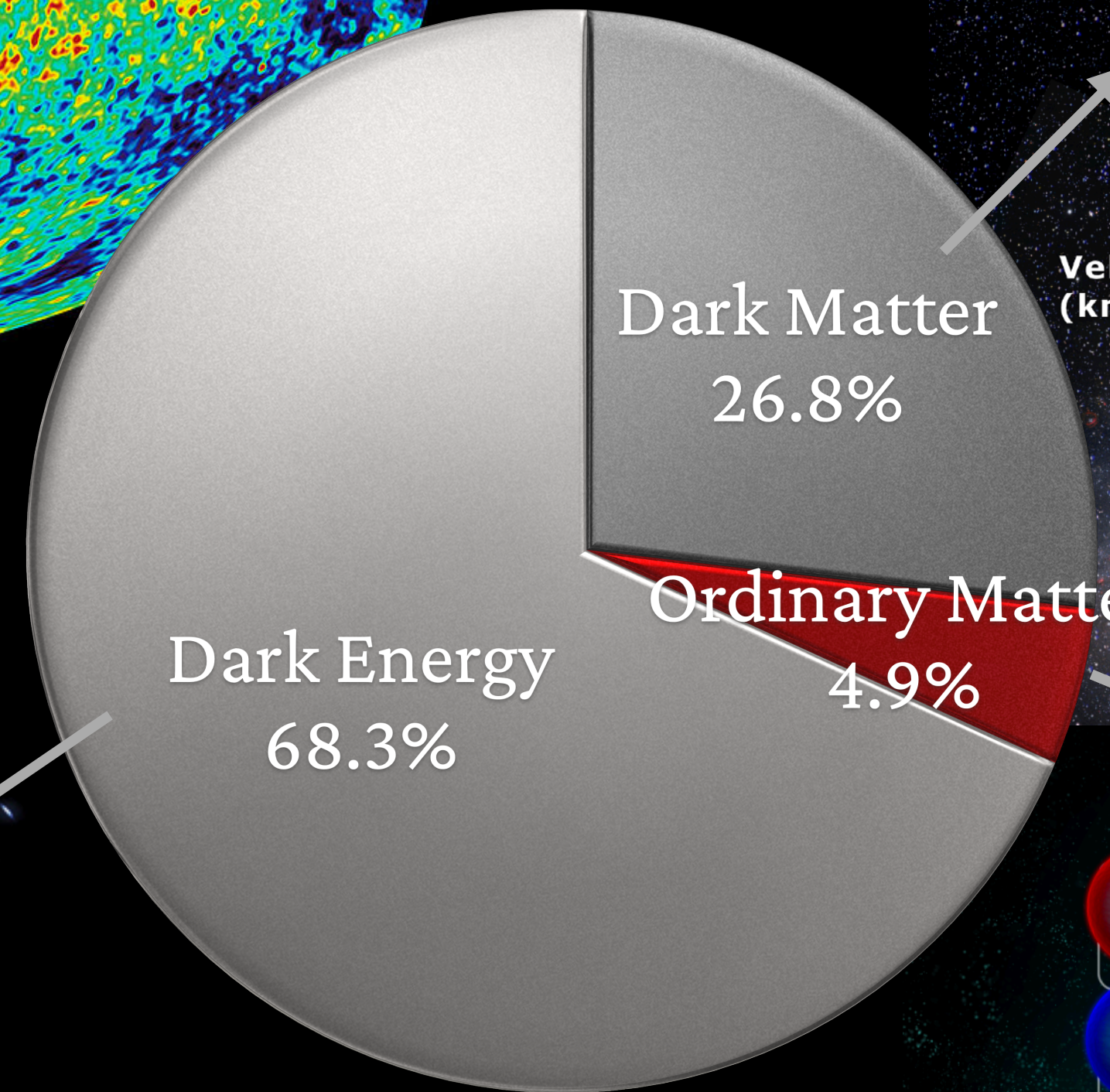
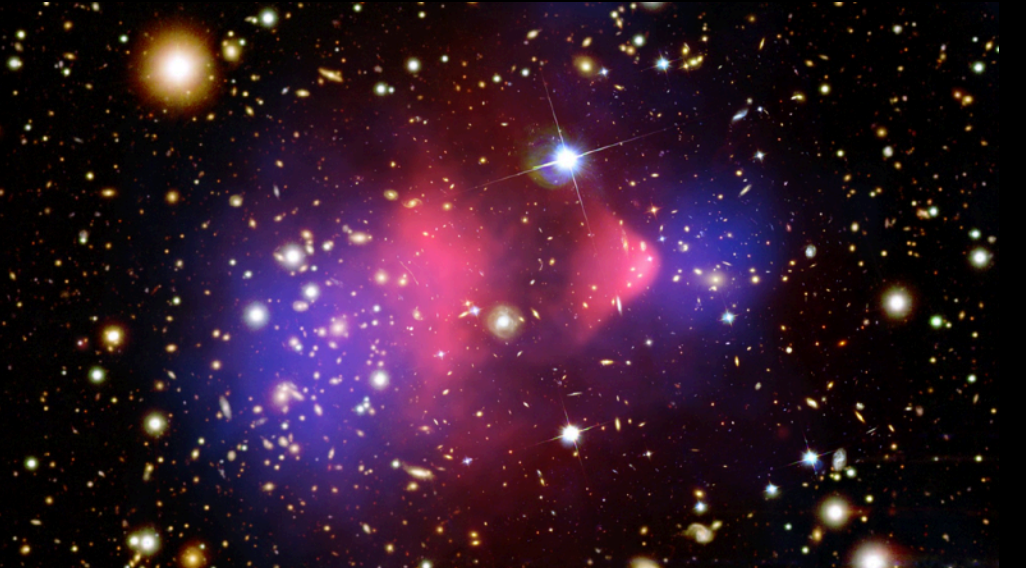
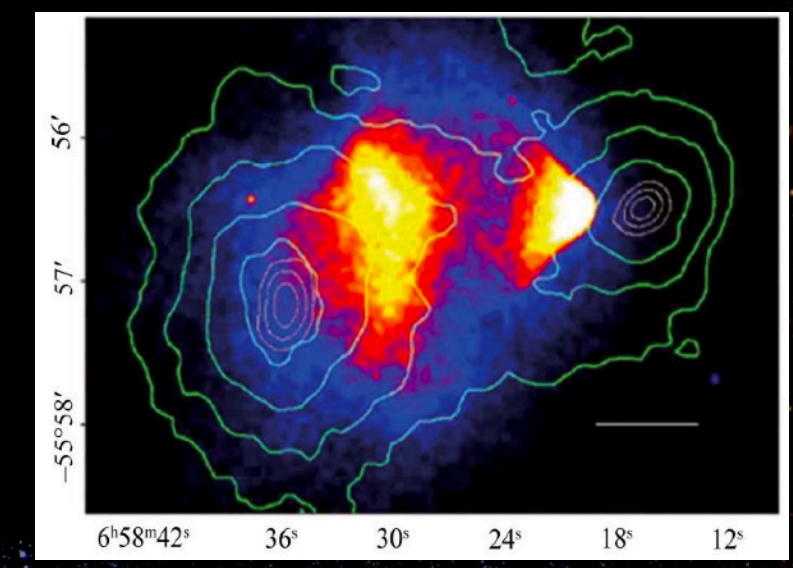
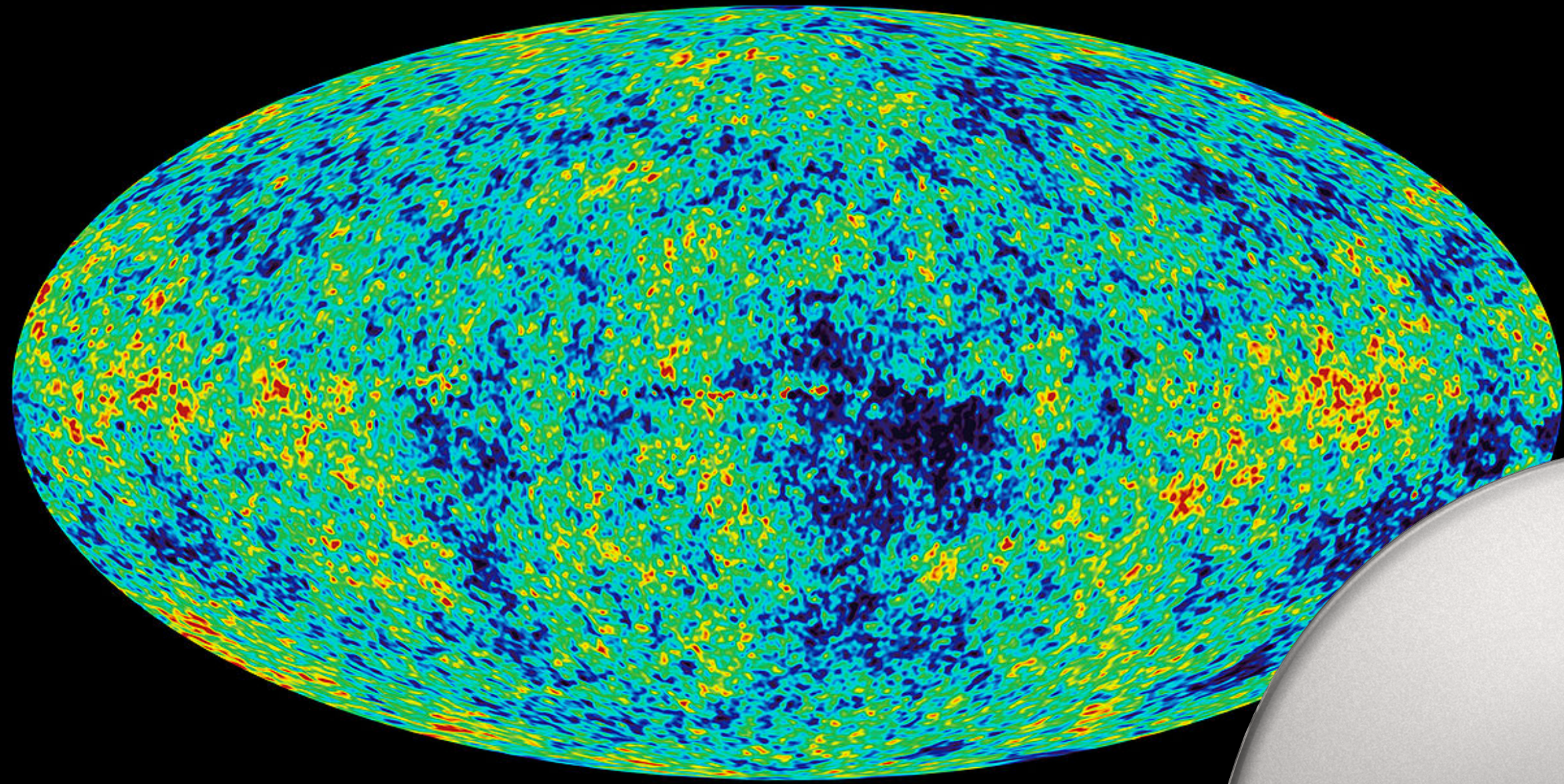


# The LZ Collaboration

- Black Hills State University
- Brandeis University
- Brookhaven National Laboratory
- Brown University
- Center for Underground Physics
- Edinburgh University
- Fermi National Accelerator Lab.
- Imperial College London
- Lawrence Berkeley National Lab.
- Lawrence Livermore National Lab.
- LIP Coimbra
- Northwestern University
- Pennsylvania State University
- Royal Holloway University of London
- SLAC National Accelerator Lab.
- South Dakota School of Mines & Tech
- South Dakota Science & Technology Authority
- STFC Rutherford Appleton Lab.
- Texas A&M University
- University of Albany, SUNY
- University of Alabama
- University of Bristol
- University College London
- University of California Berkeley
- University of California Davis
- University of California Santa Barbara
- University of Liverpool
- University of Maryland
- University of Massachusetts, Amherst
- University of Michigan
- University of Oxford
- University of Rochester
- University of Sheffield
- University of Wisconsin, Madison





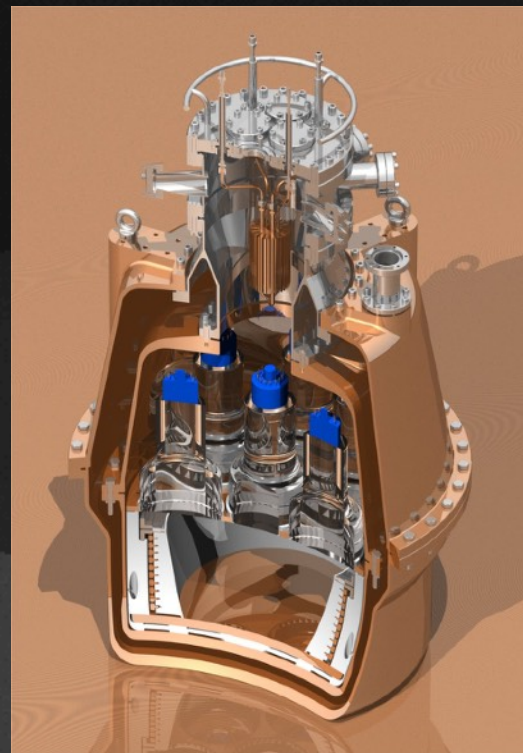


# The Universe



# History of Direct Detection with Liquid Xenon

**ZEPLIN-II**

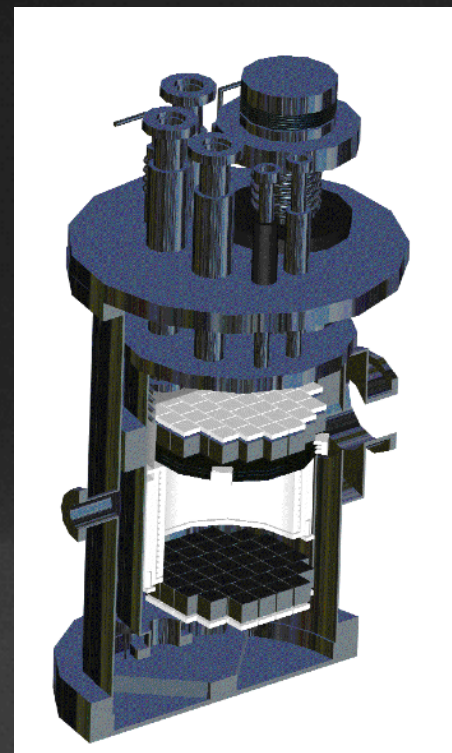


**31 kg  
(7.2 kg)**

$6.6 \times 10^{-43} \text{ cm}^2$

2007

**XENON10**

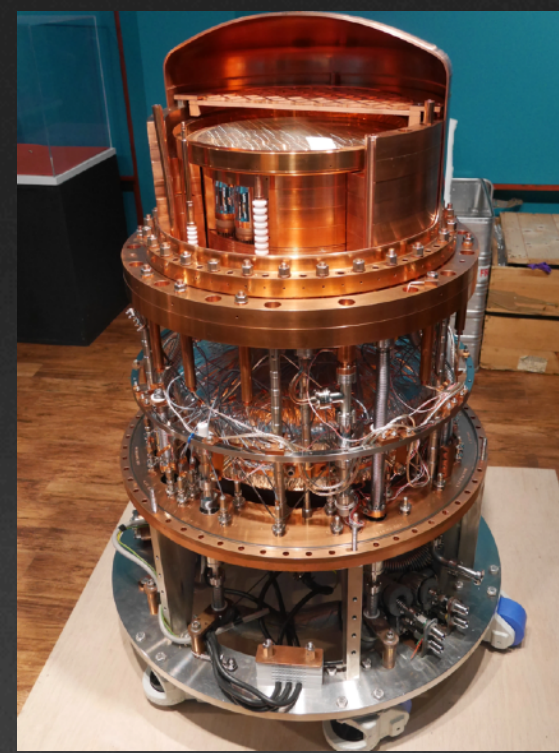


**15 kg  
(5 kg)**

$8.8 \times 10^{-44} \text{ cm}^2$

2007

**ZEPLIN-III**

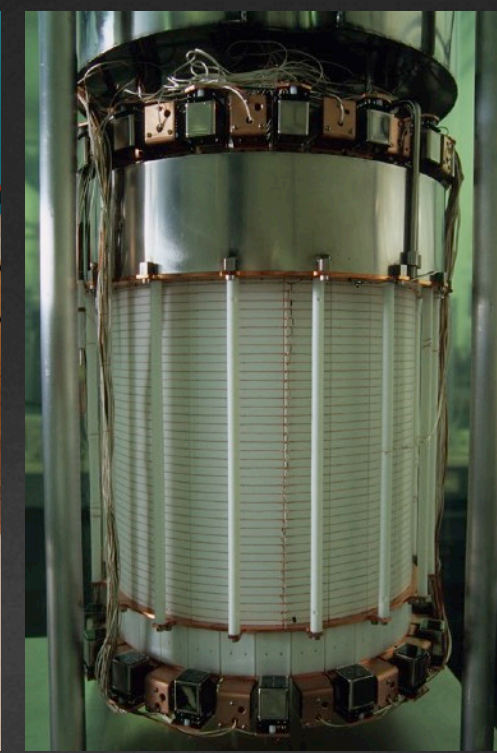


**12 kg  
(7 kg)**

$8.1 \times 10^{-44} \text{ cm}^2$

2008

**XENON100**



**62kg  
(34 kg)**

$3.4 \times 10^{-44} \text{ cm}^2$

2010

**LUX**



**250 kg  
(100 kg)**

$2.2 \times 10^{-46} \text{ cm}^2$

2016

**PANDAX-II**



**580 kg  
(362 kg)**

$2.5 \times 10^{-46} \text{ cm}^2$

2016

**XENON1T**

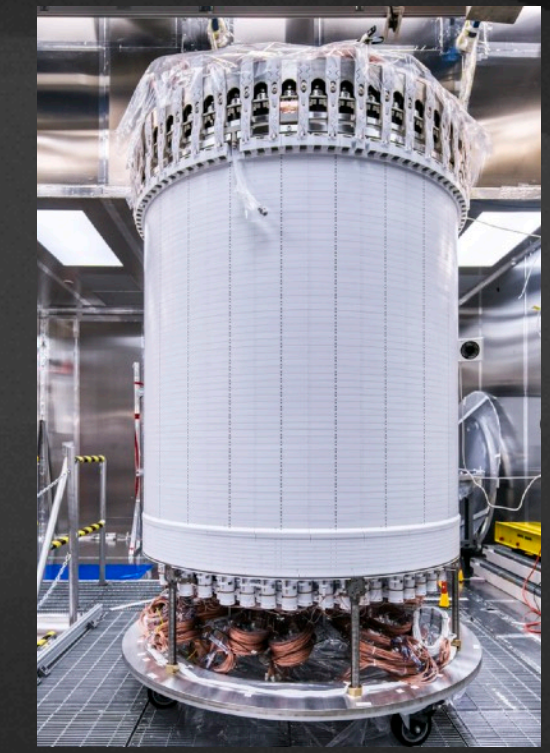


**2,000 kg  
(1,042 kg)**

$4.1 \times 10^{-47} \text{ cm}^2$

2019

**LZ**



**7,000 kg  
(5,500 kg)**

$5.9 \times 10^{-48} \text{ cm}^2$

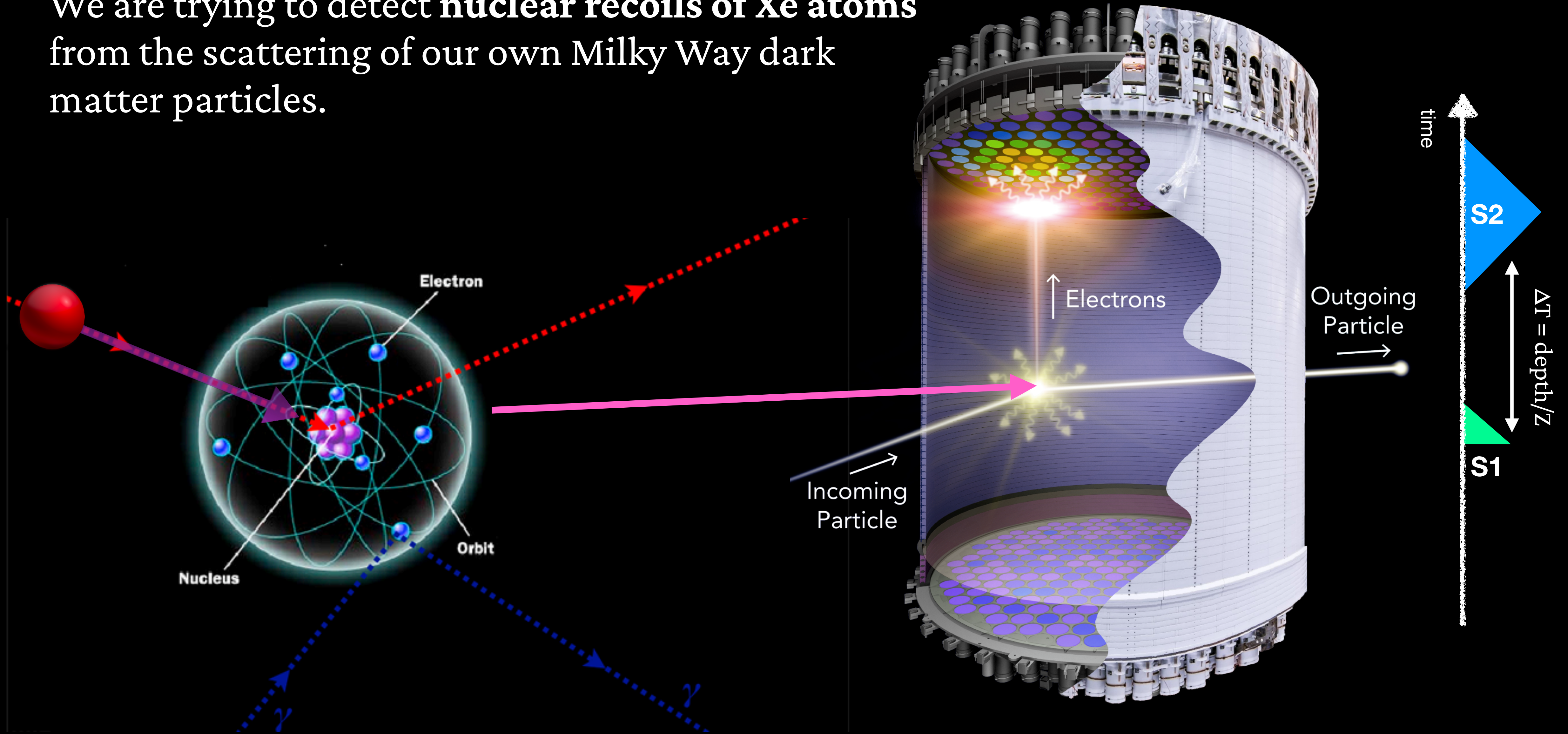
2022





# LZ: a Dual Phase Liquid Xenon TPC

We are trying to detect **nuclear recoils of Xe atoms** from the scattering of our own Milky Way dark matter particles.





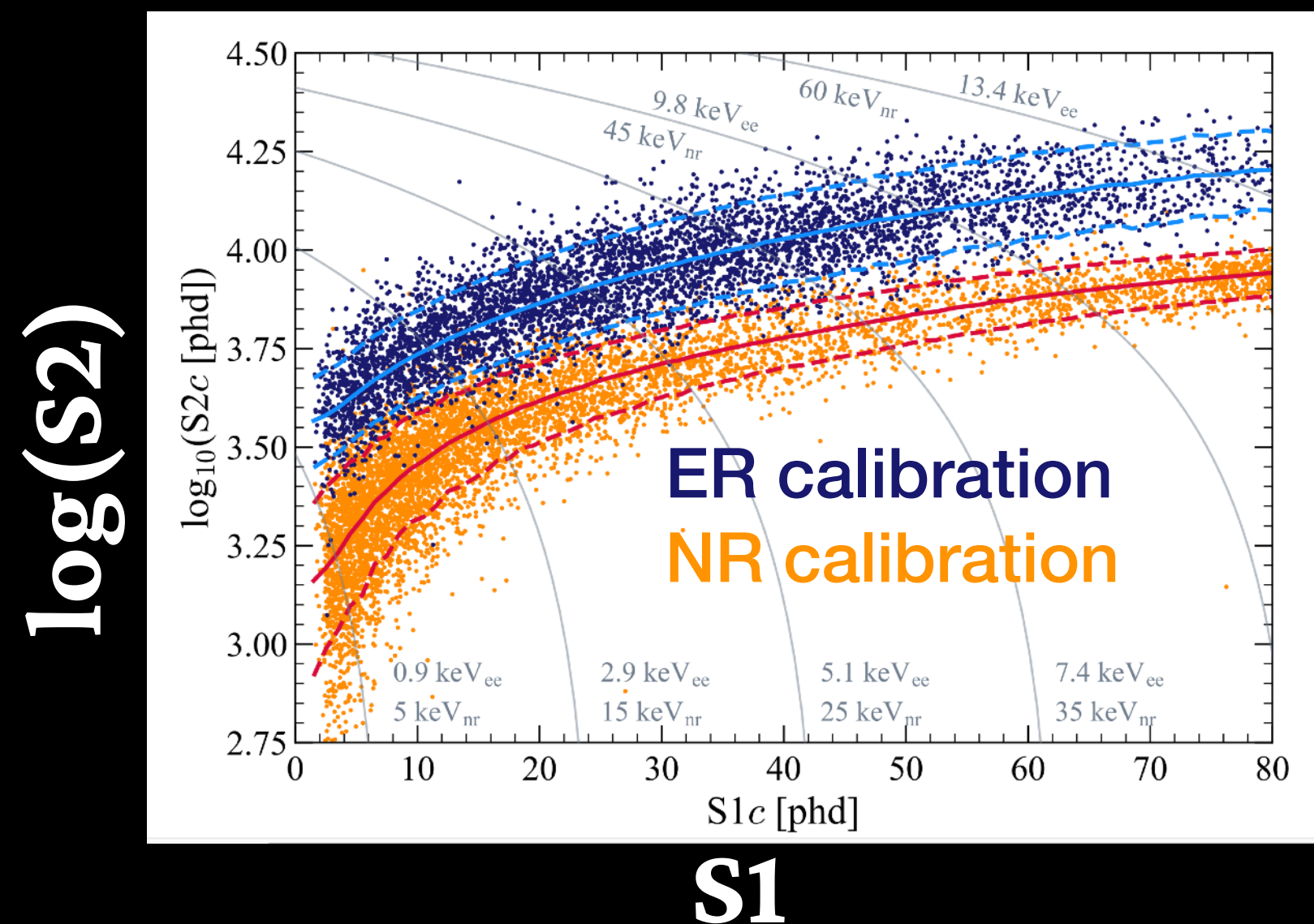
# LZ: a Dual Phase Liquid Xenon TPC

We are trying to detect **nuclear recoils of Xe atoms** from the scattering of our own Milky Way dark matter particles.

Most backgrounds are electron recoils.

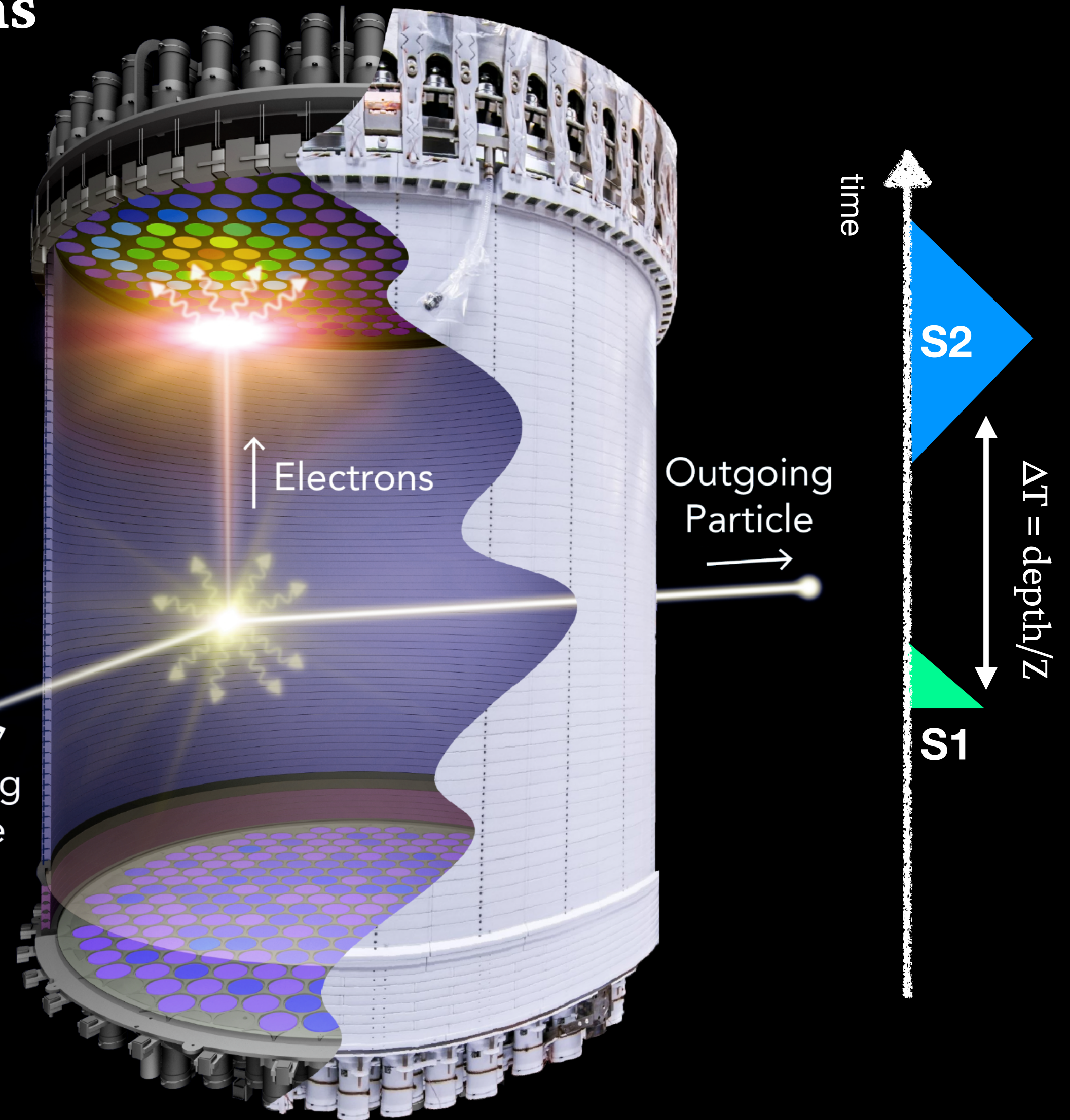
**Two signals:**

- scintillation (**S1**) in liquid
- ionisation (**S2**) in gas



**ER/NR discrimination:**  
from ratio of S1 and S2 signals

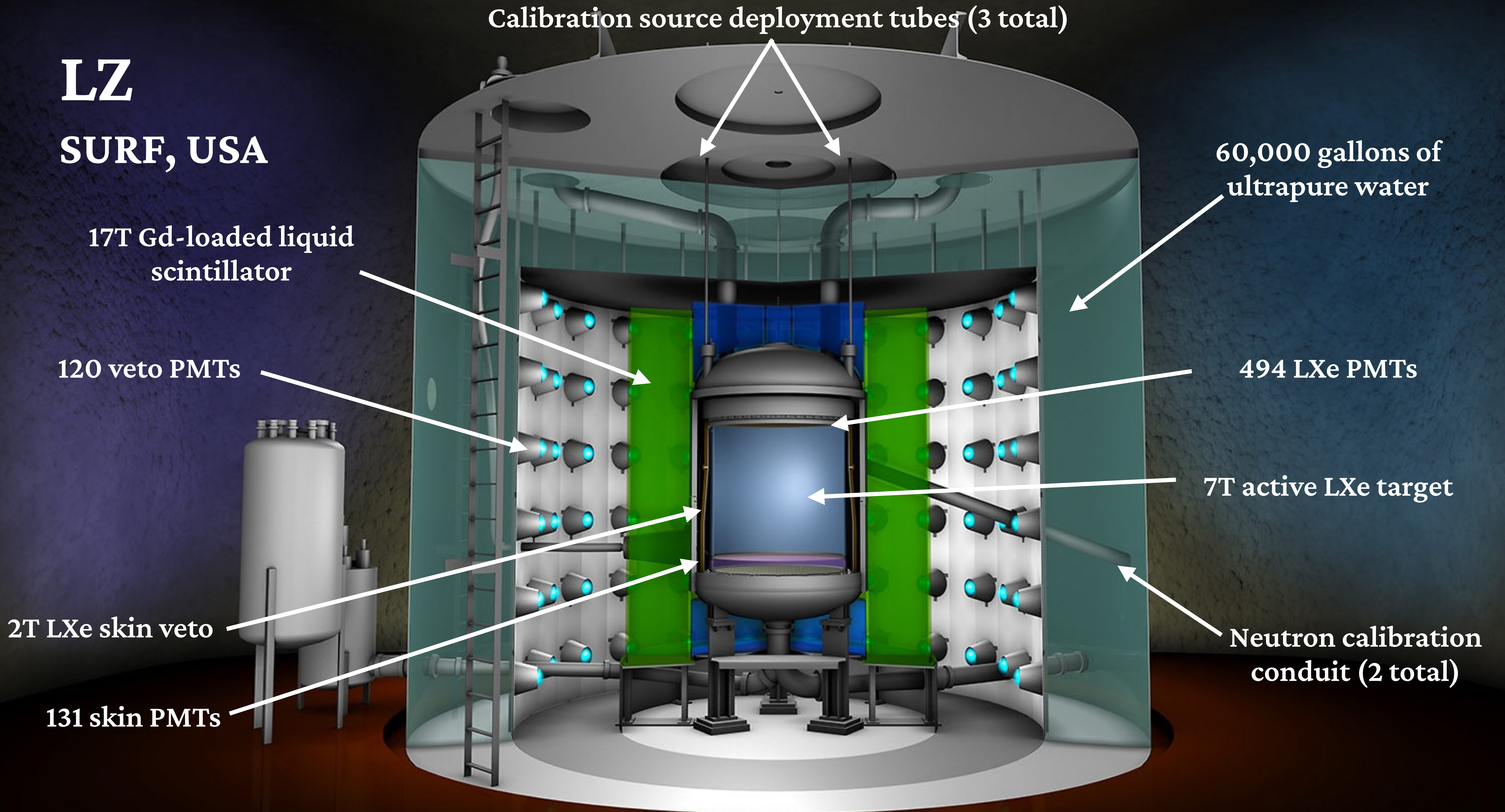
**3D position reconstruction:**  
XY → PMT array  
Z →  $\Delta t$  of S1 & S2





# LZ

## SURF, USA

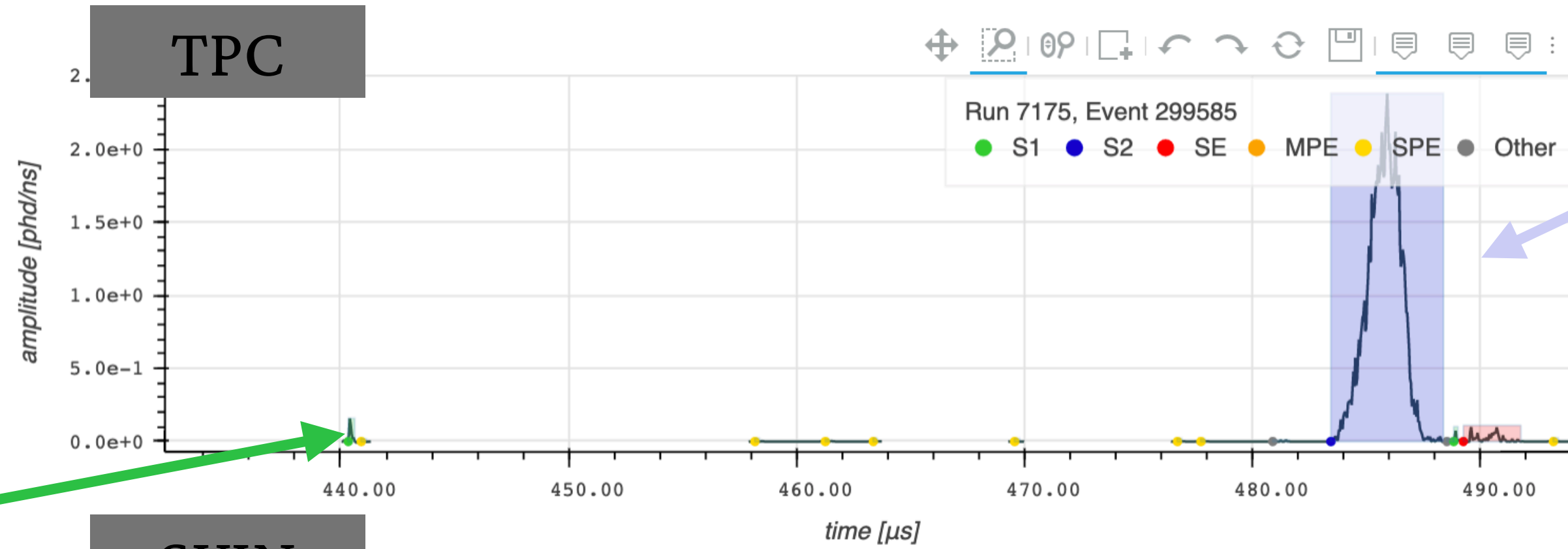




# LZ: a Triple Threat Detector

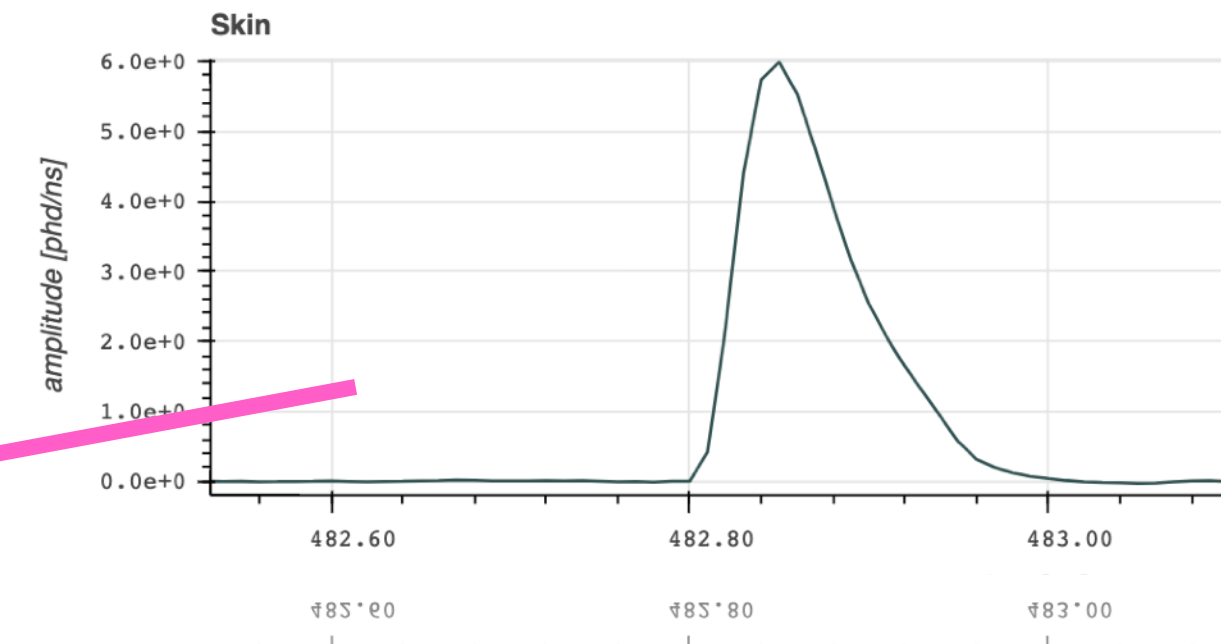
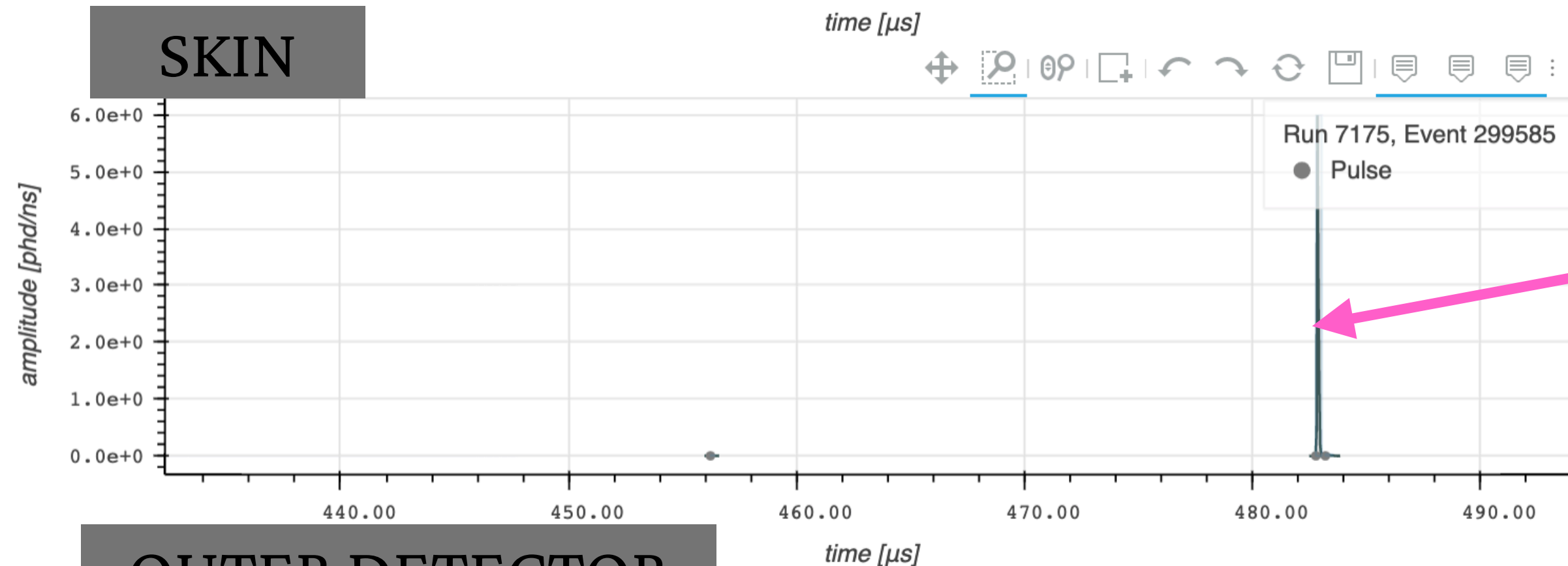
Nuclear recoil  
Single scatter in TPC  
Tagged by the OD

S1

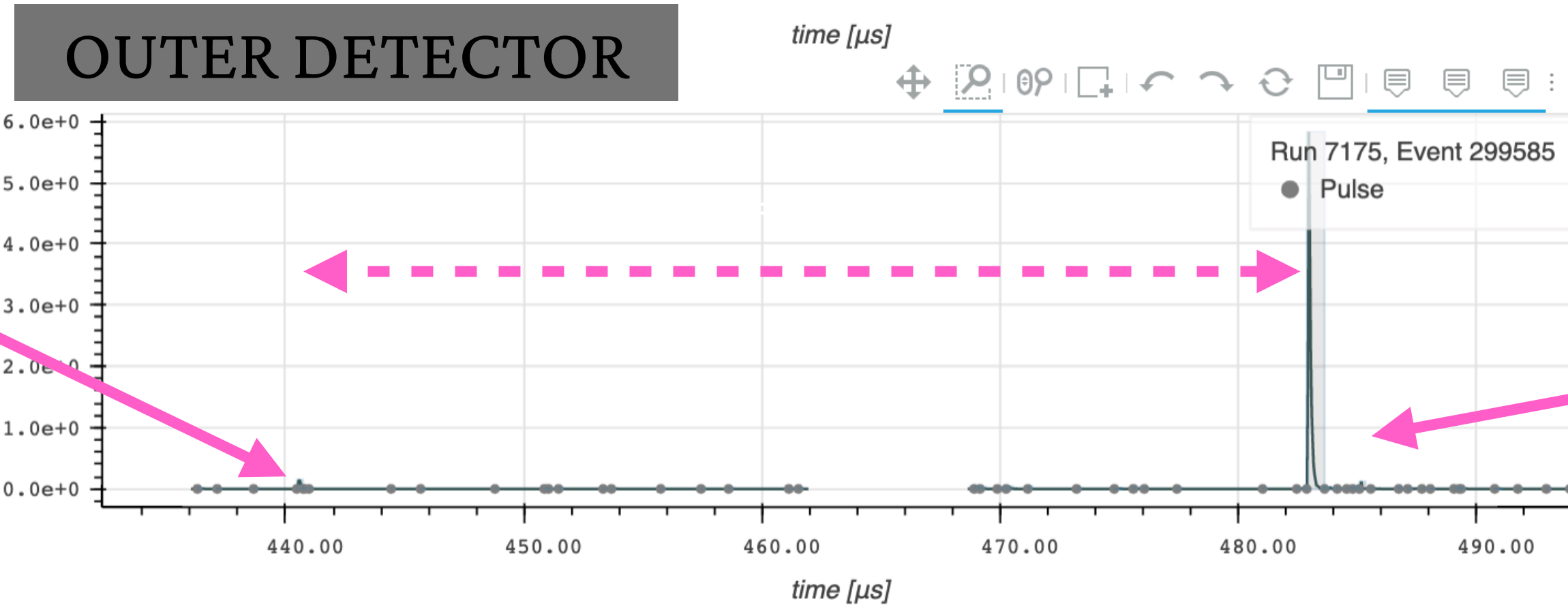
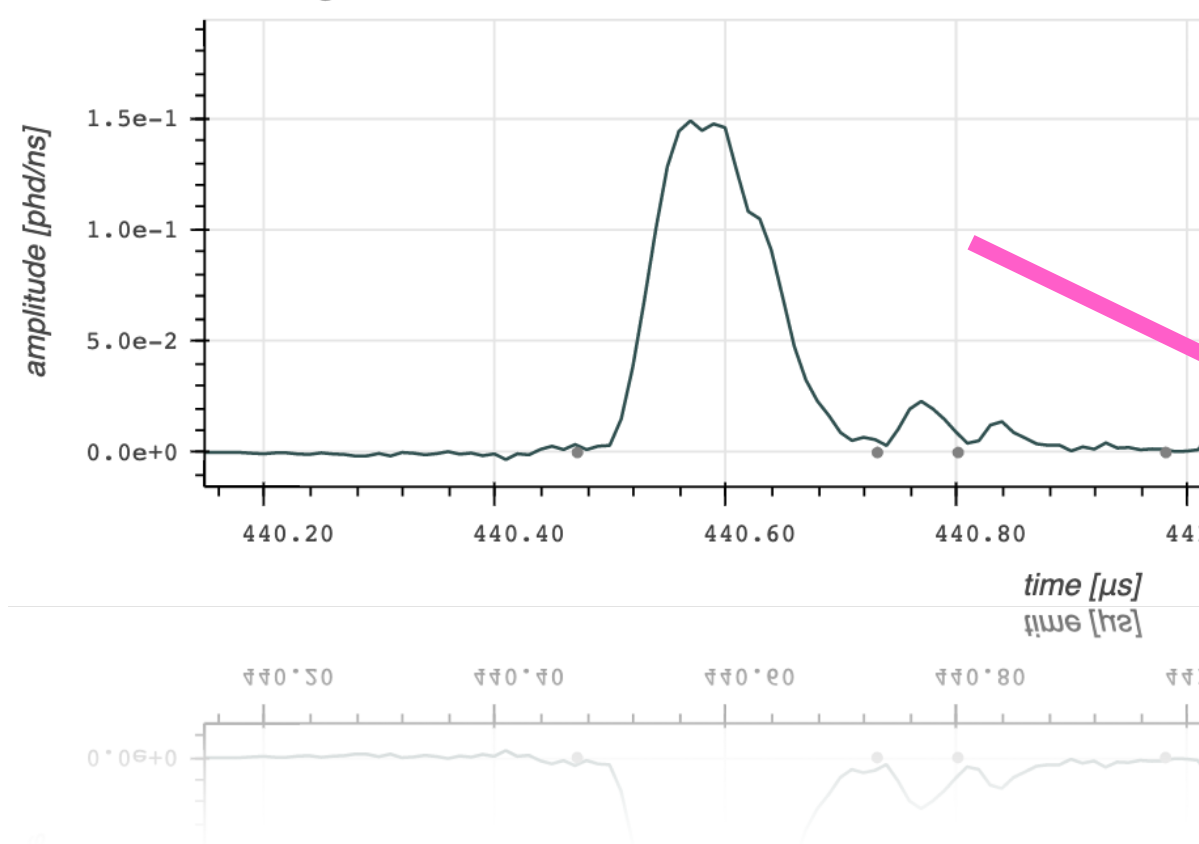


S2

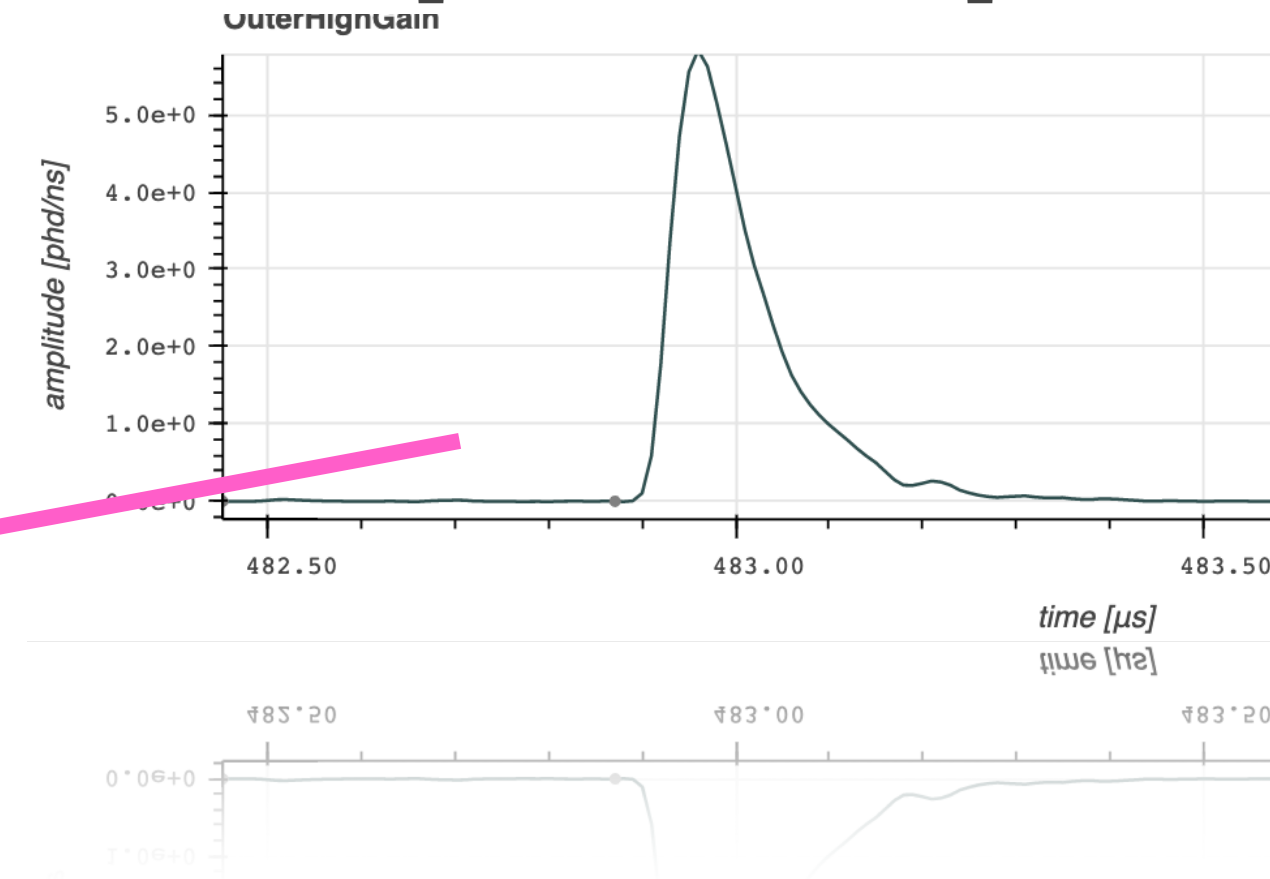
Skin catches one of the Gd post-capture  $\gamma$ -rays



Prompt proton recoil  
 $\sim 17$  phe



Gd capture:  $\sim 680$  phe





# LZ Timeline

CD3 & TDR  
March 2017

PMT arrays arrive  
Dec 2018

TPC Complete  
Aug 2019

Cryostat & TPC move  
underground  
Oct 2019

Electronics installation  
Autumn 2020

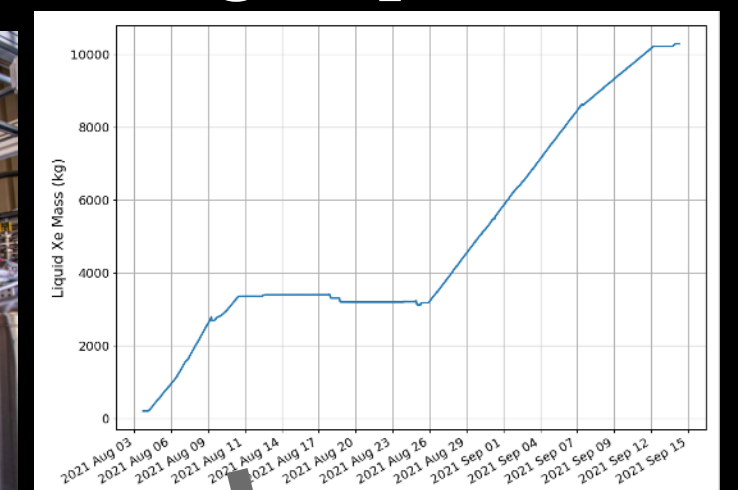
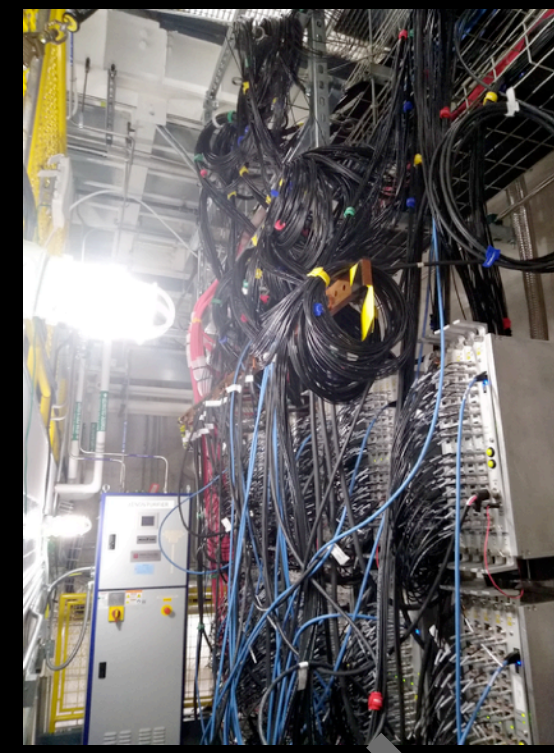
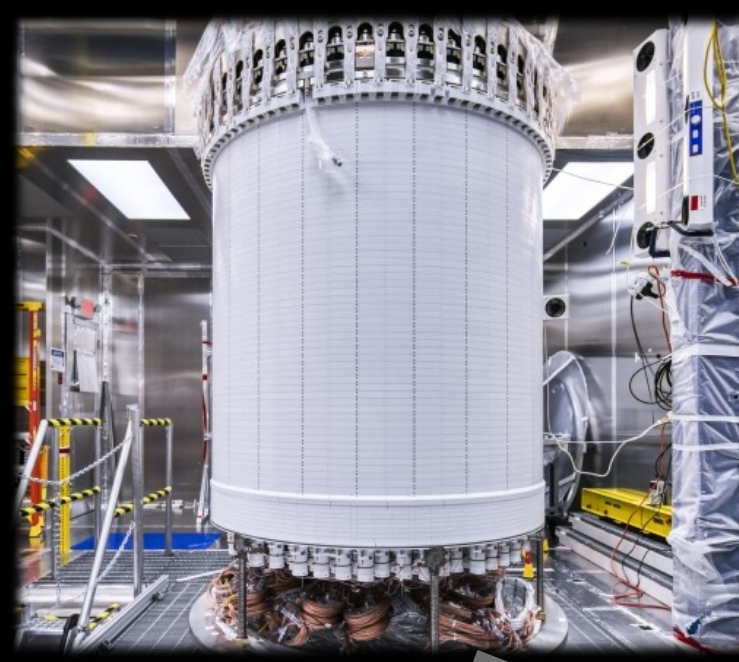
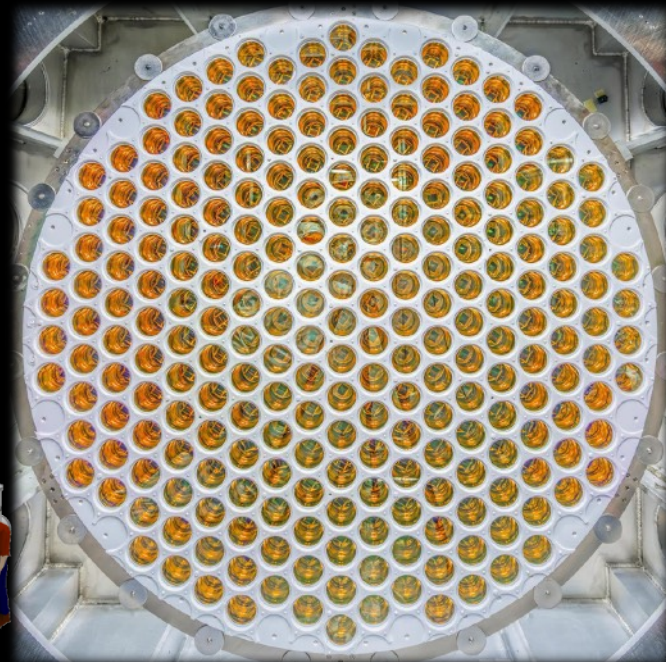
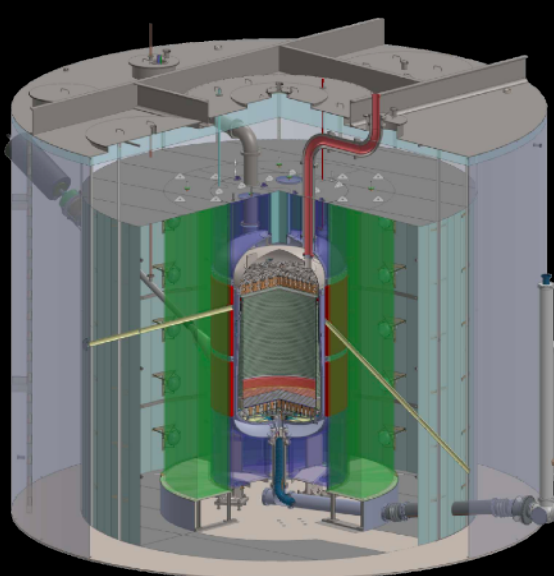
Kr operation  
Jan - Aug 2021

Xe fill  
Aug-Sept 2021

Commissioning  
Autumn 2021

Science running!

Dec 2021  
OD Fill  
June 2021



2017

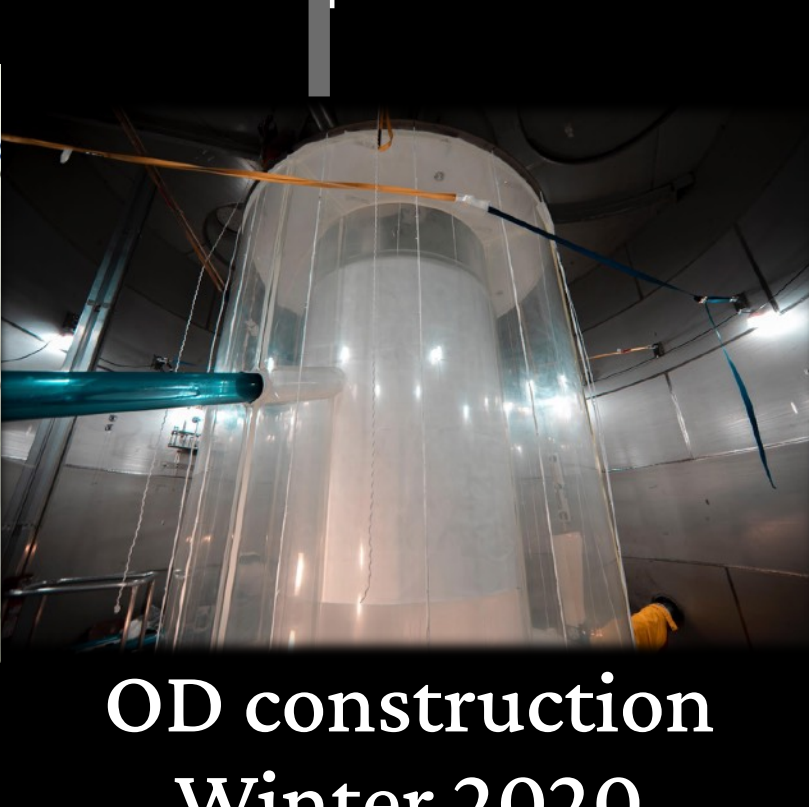
2018

2019

2020

2021

2022



Cryostat arrives  
May 2018

OD tanks go  
underground  
Oct-Nov 2018

FFR assembly  
Dec 2018

Grid manufacture  
Spring 2018

HV install & sealed  
March 2020

OD construction  
Winter 2020



# Science Run 1



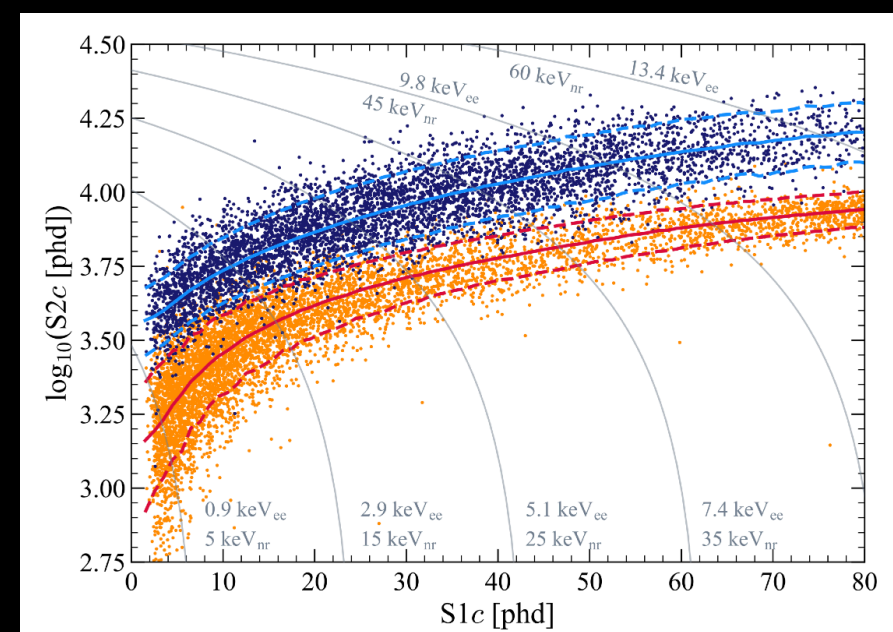


# SR1 Timeline

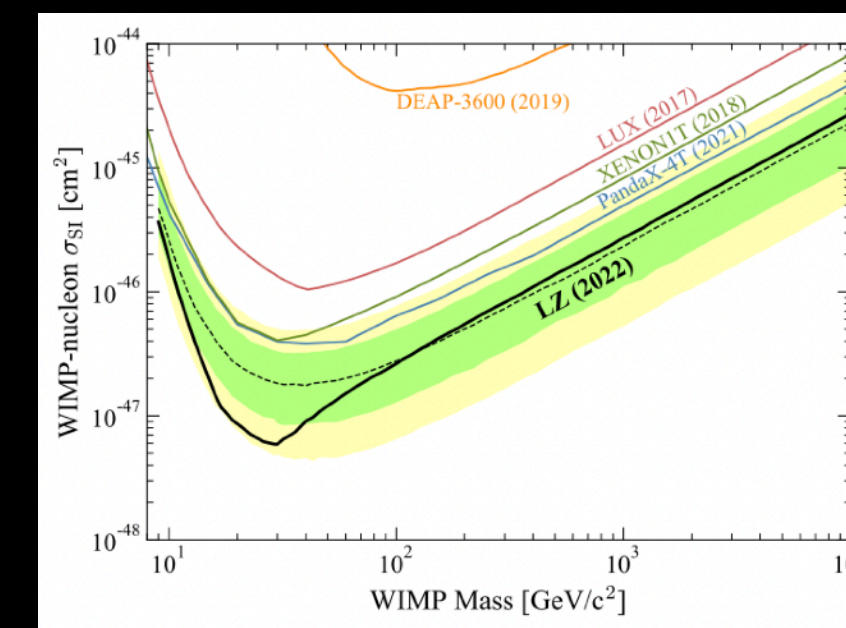
Goal: collect 60 livedays

→ Prove successful detector operation and expectation for competitive sensitivity to existing results

Pause for calibrations  
17th - 26th Jan



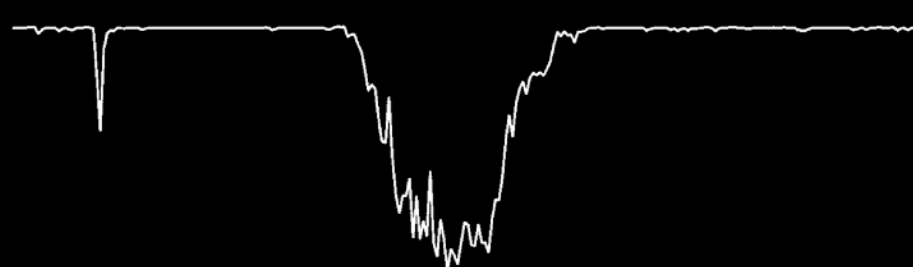
SR1 ends  
17th April



Results!  
7th July 22

SR1 begins  
22nd Dec

LET'S LOOK AT  
SOME WAVEFORMS



Post-SR1 Calibrations  
18th April - 11th May





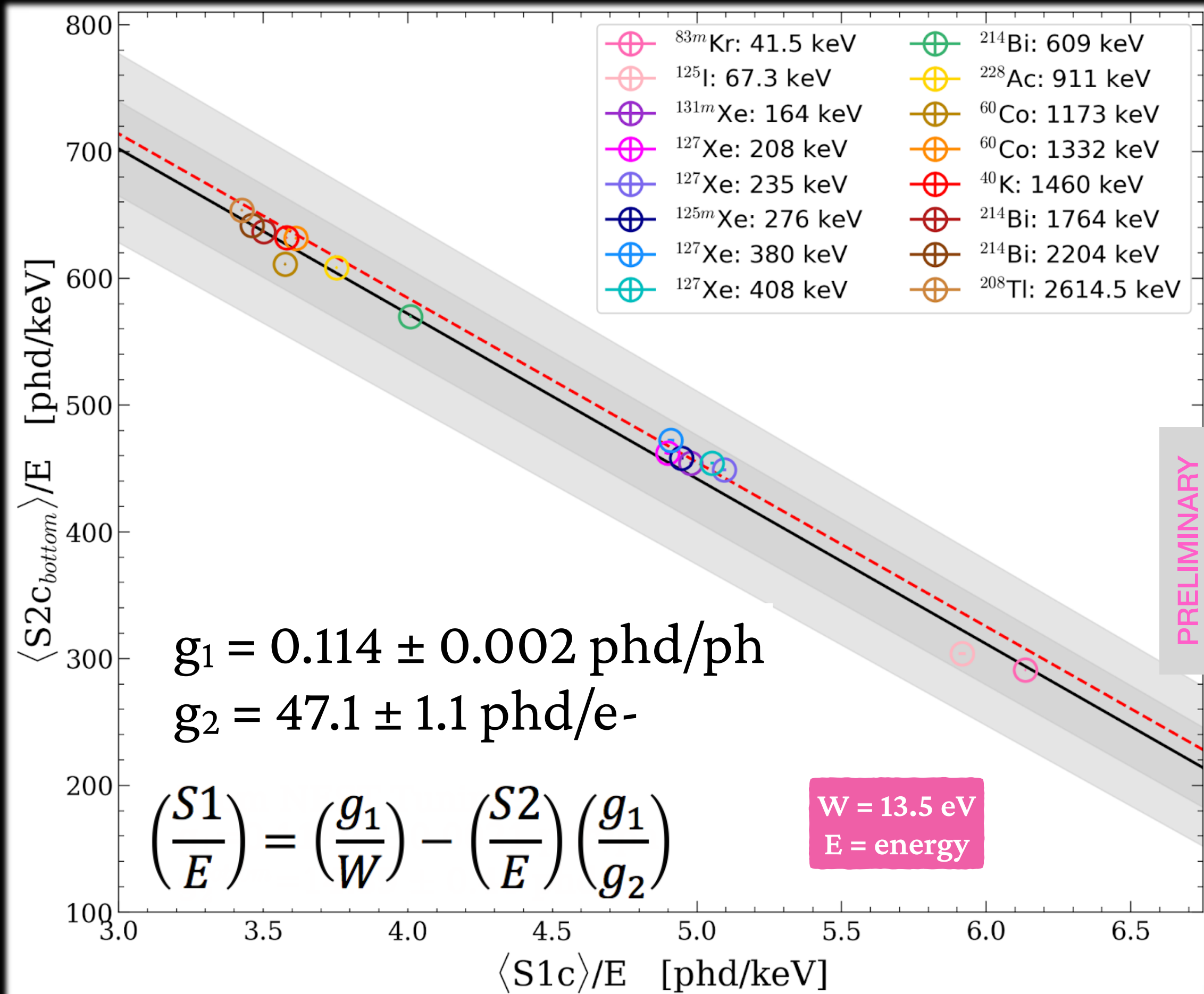
# Results Day



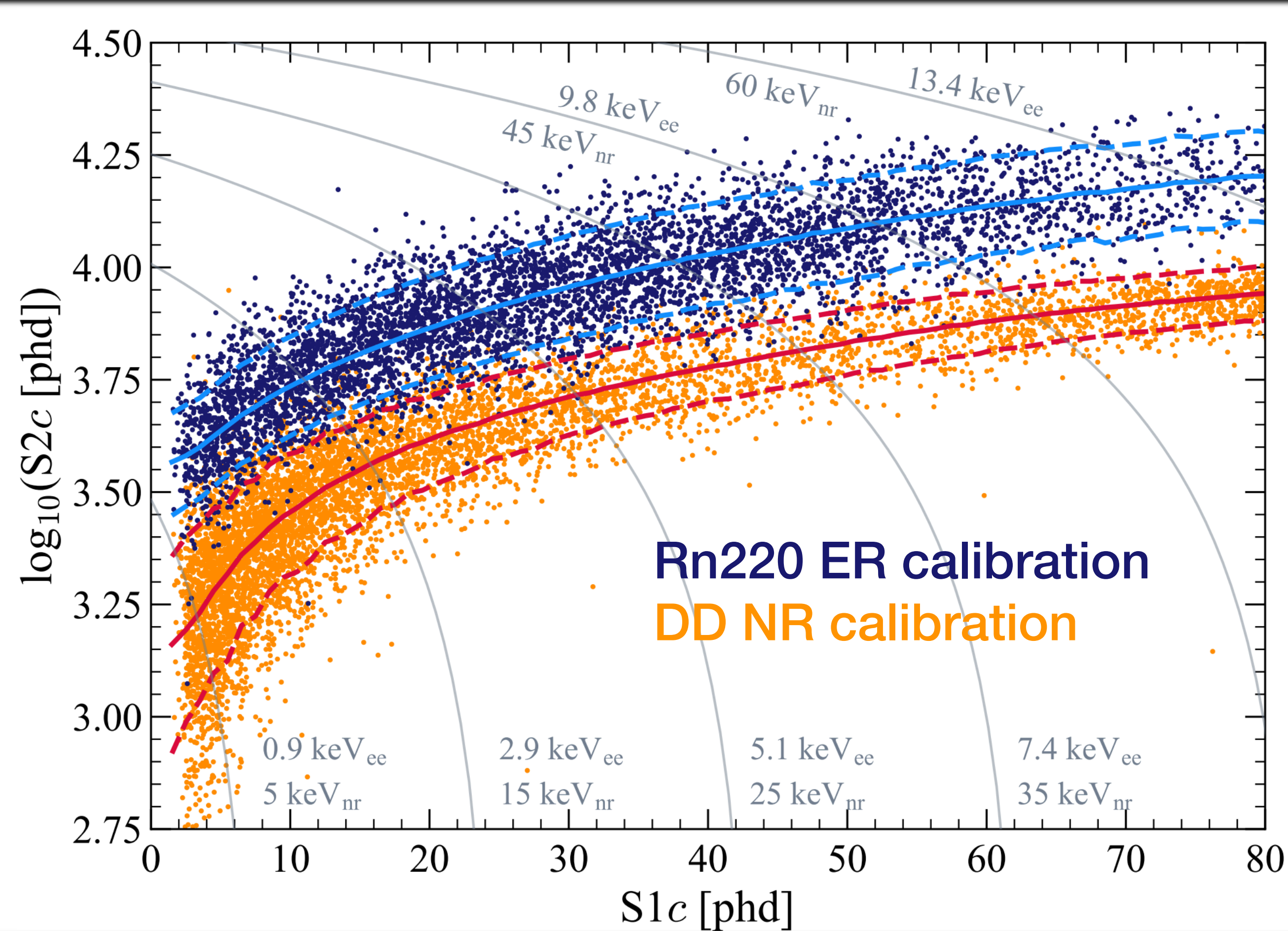


# Detector Response

Mono-energetic ER peaks used to determine initial detector gains through a **Doke plot analysis**

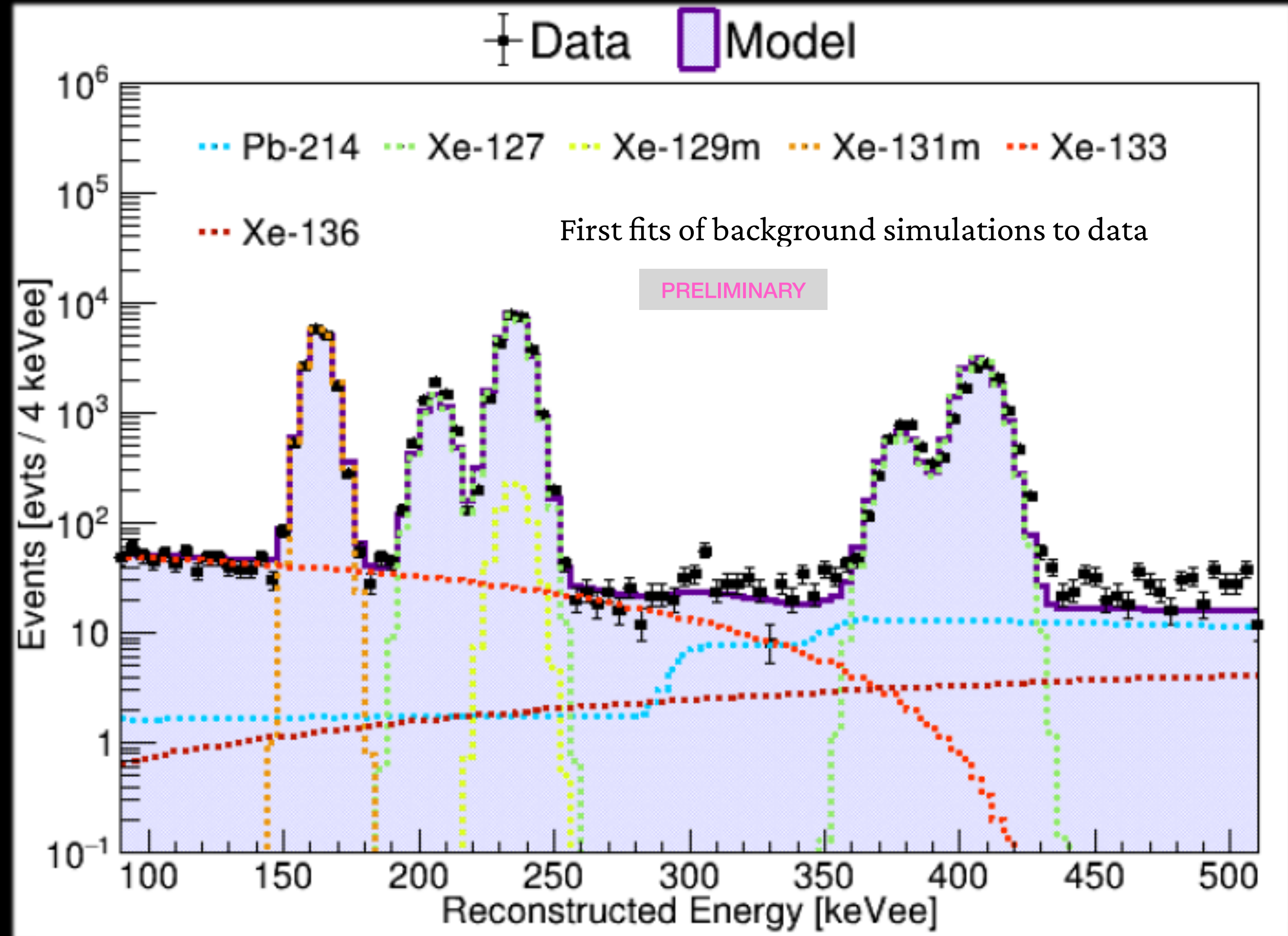
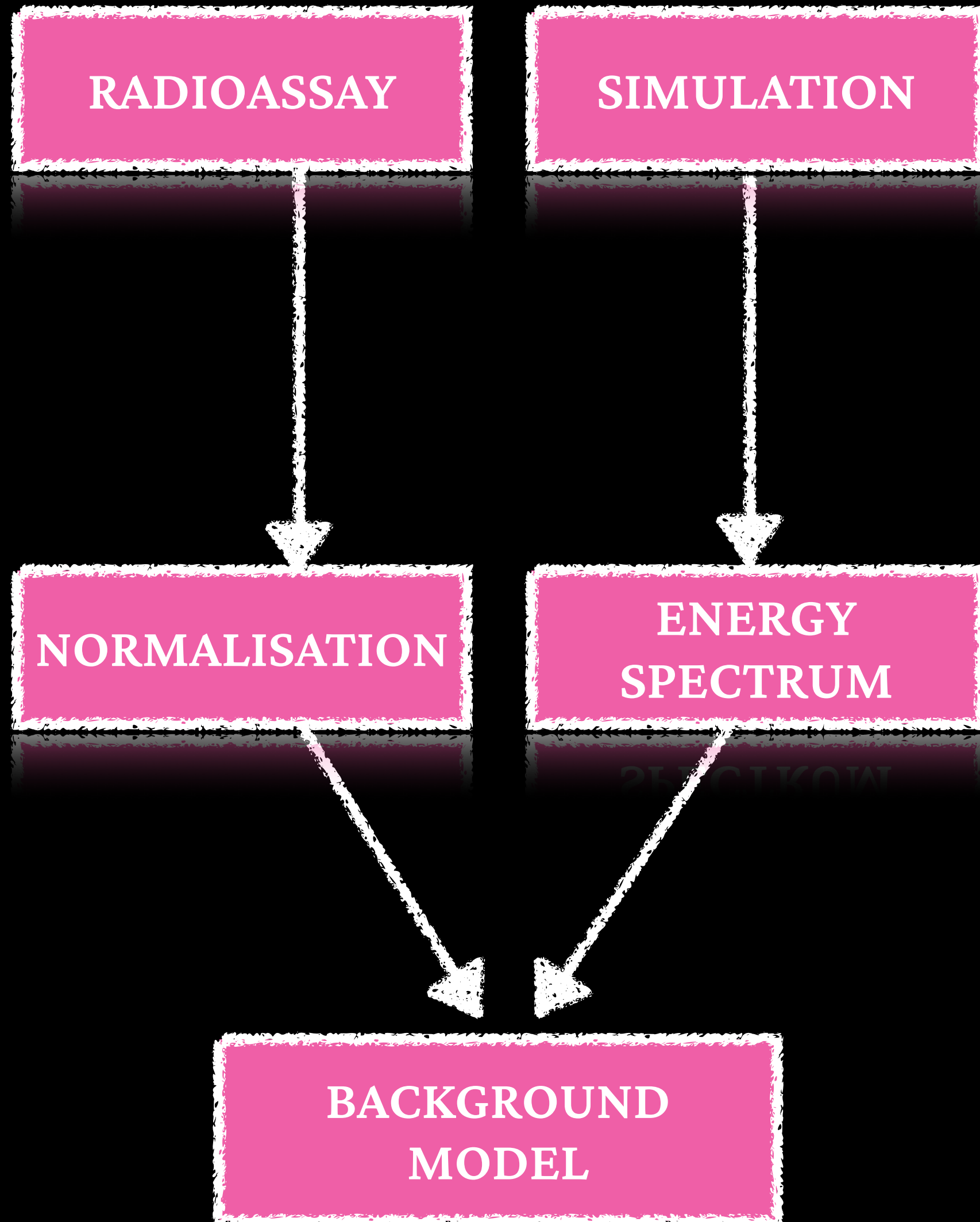


ER & NR bands characterised through  $^{220}\text{Rn}$  injection and DD, NEST tuned to provide final  $g_1$  &  $g_2$





# Background Modeling





# Science Run 1

WIMP Search

60 live days

5.5 t LXe

335 events

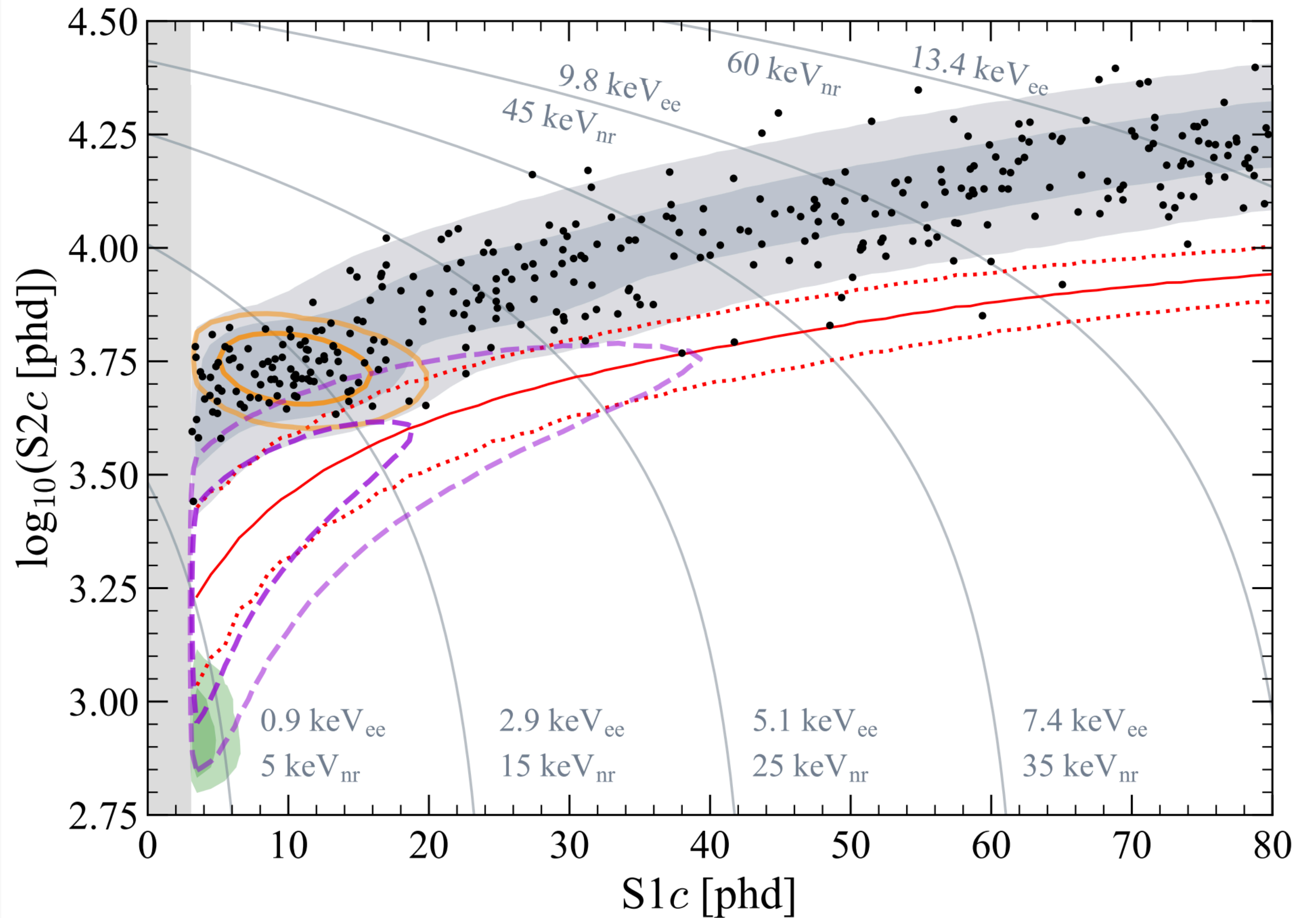
Background model

NR Band

Ar37

B8 solar  $\nu$

30 GeV WIMP



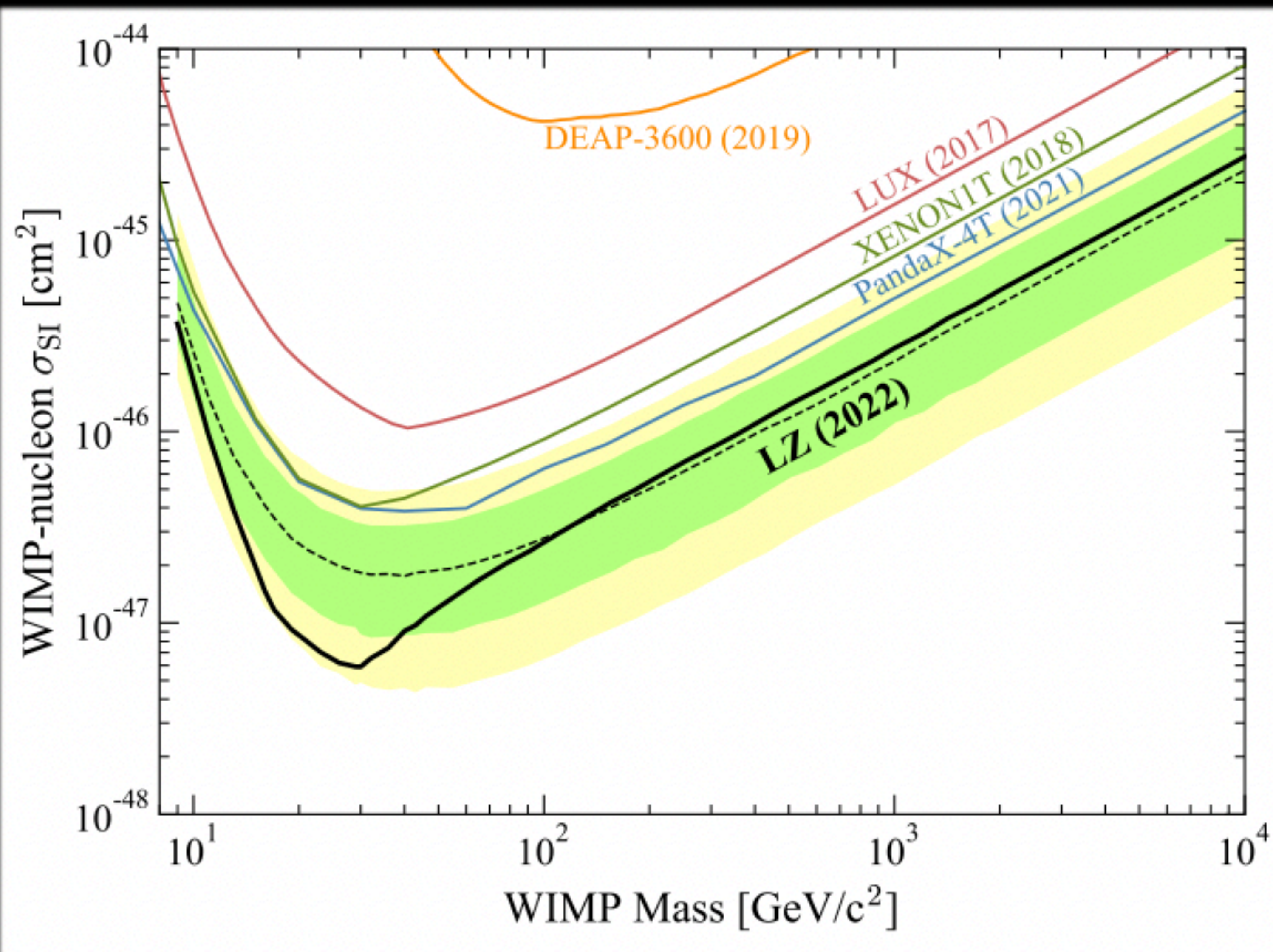


# Spin-Independent WIMP Limits

Spin-independent WIMP-nucleon-scattering

World leading sensitivity to WIMPs established with just 60-livedays of data

Minimum cross section:  
 $5.9 \times 10^{-48}$  at 30 GeV

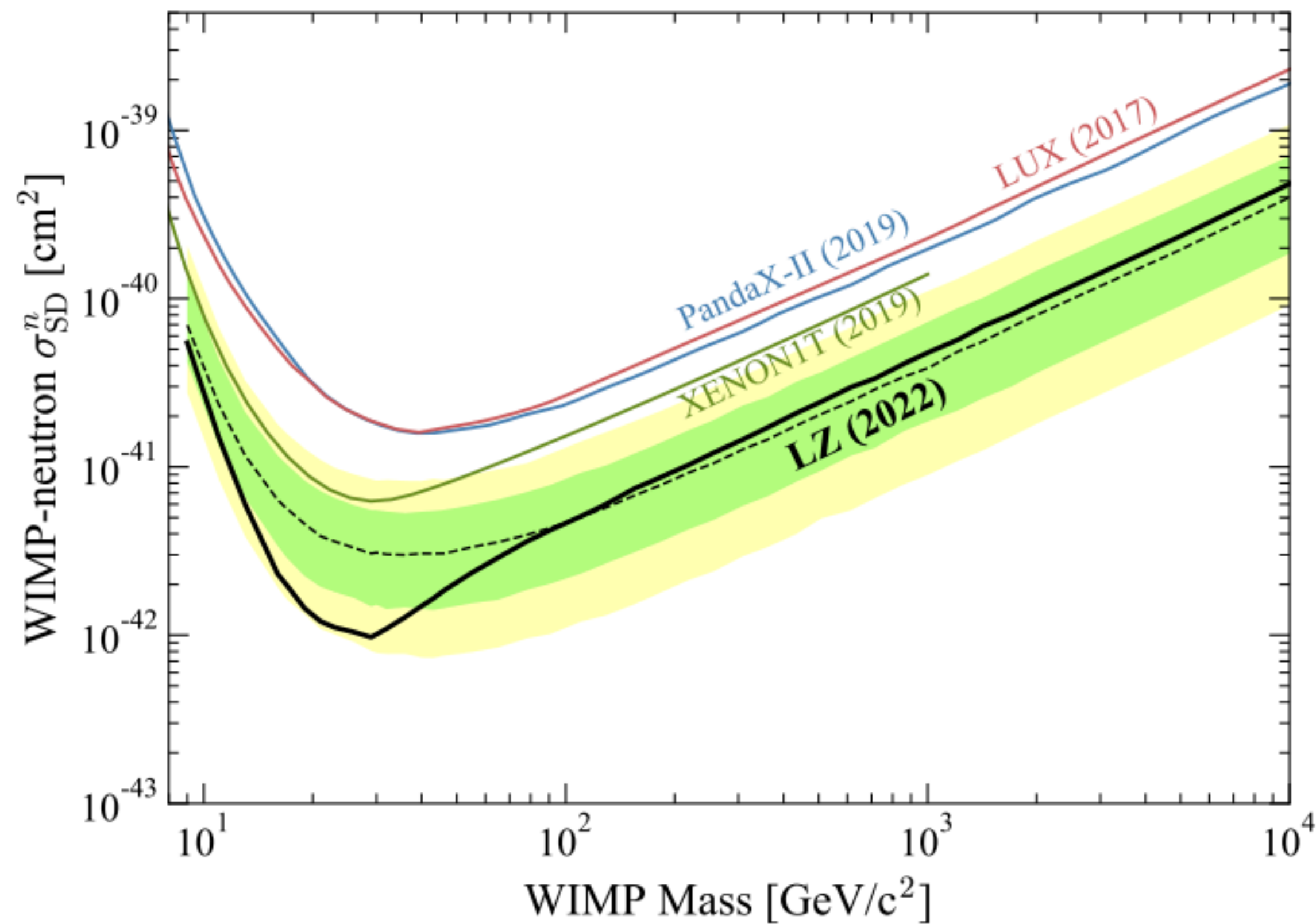




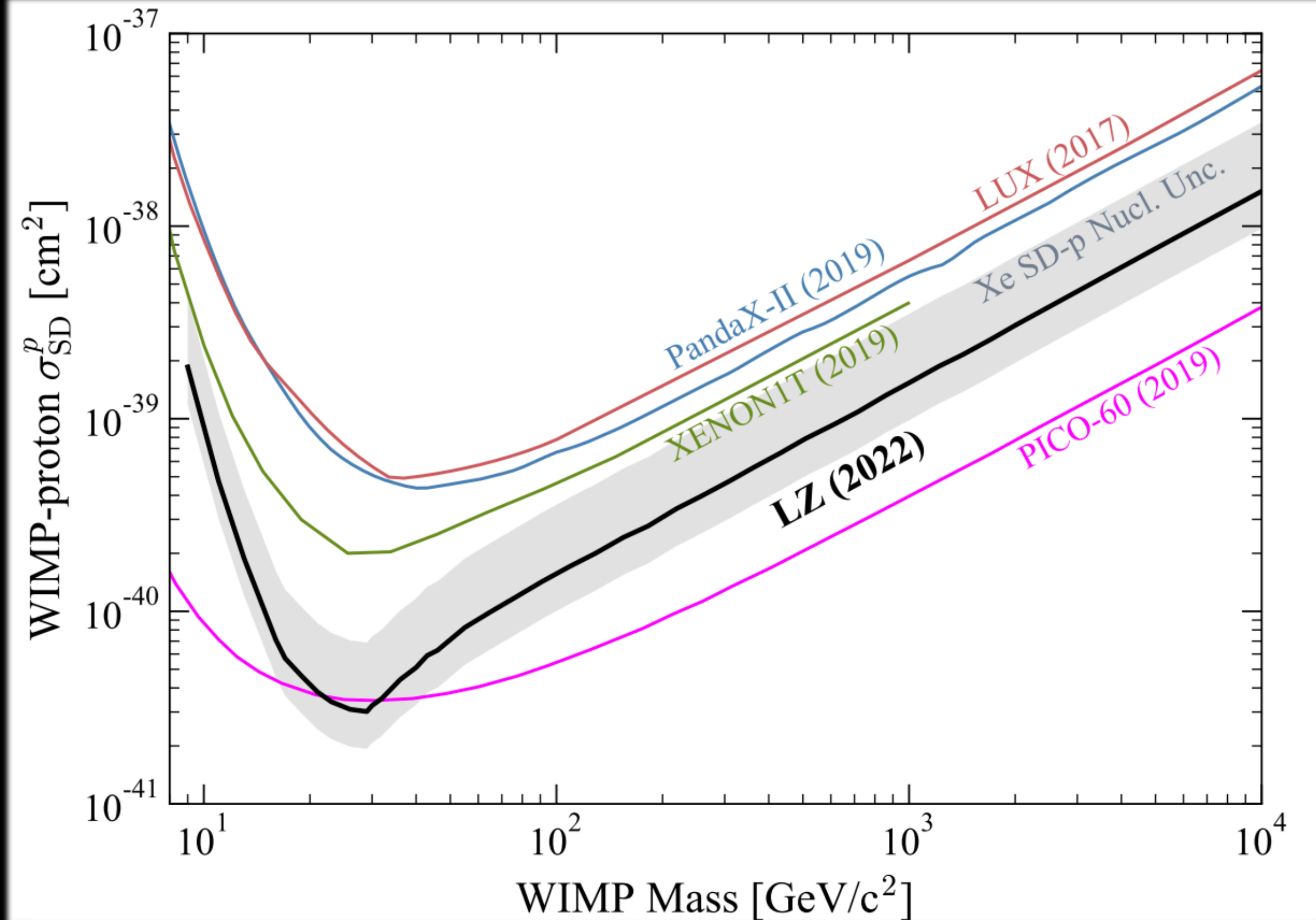
# Spin-Dependent WIMP Limits

World leading for SD WIMP-neutron scattering

SD: WIMP-neutron



SD: WIMP-proton





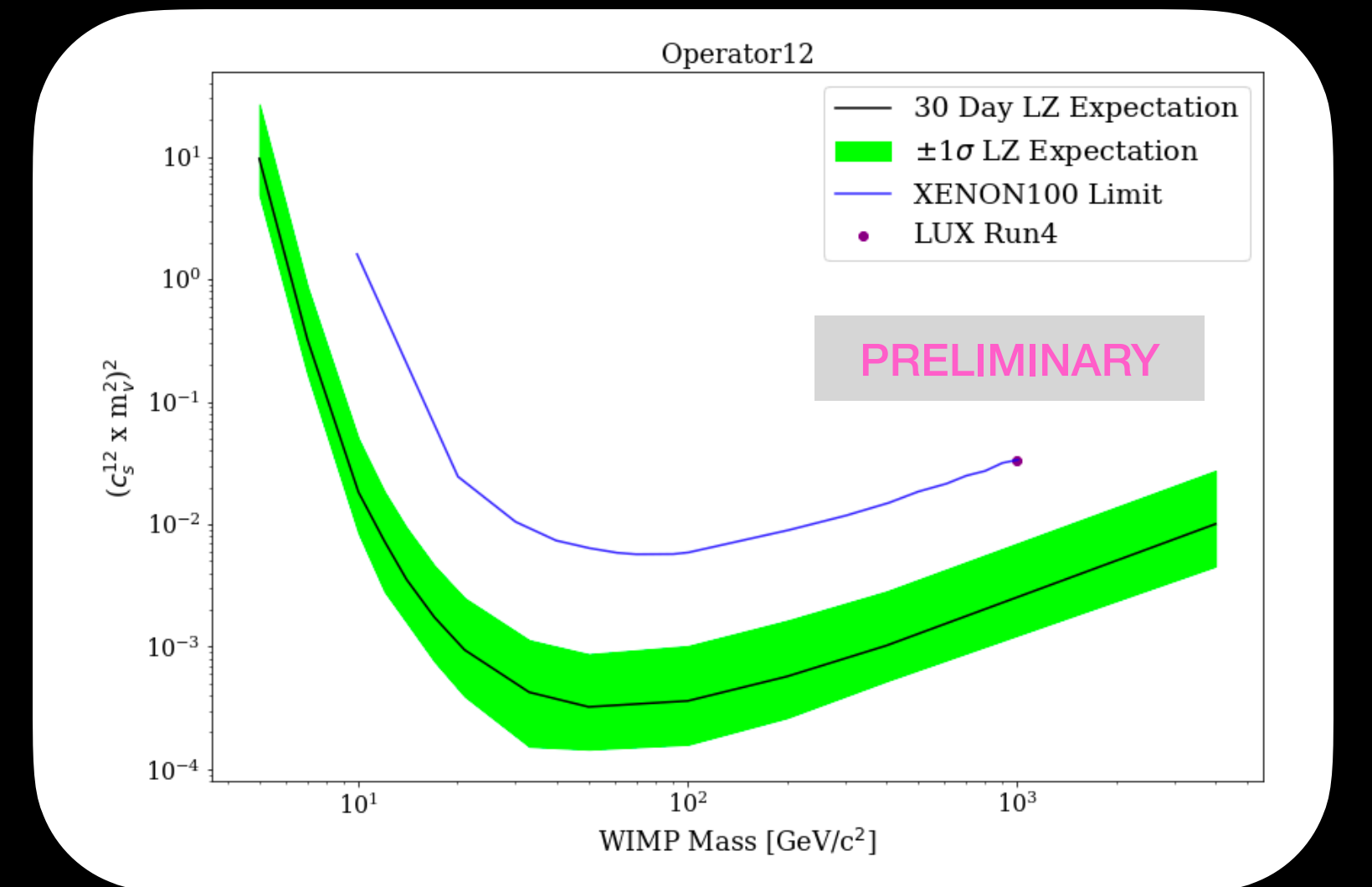
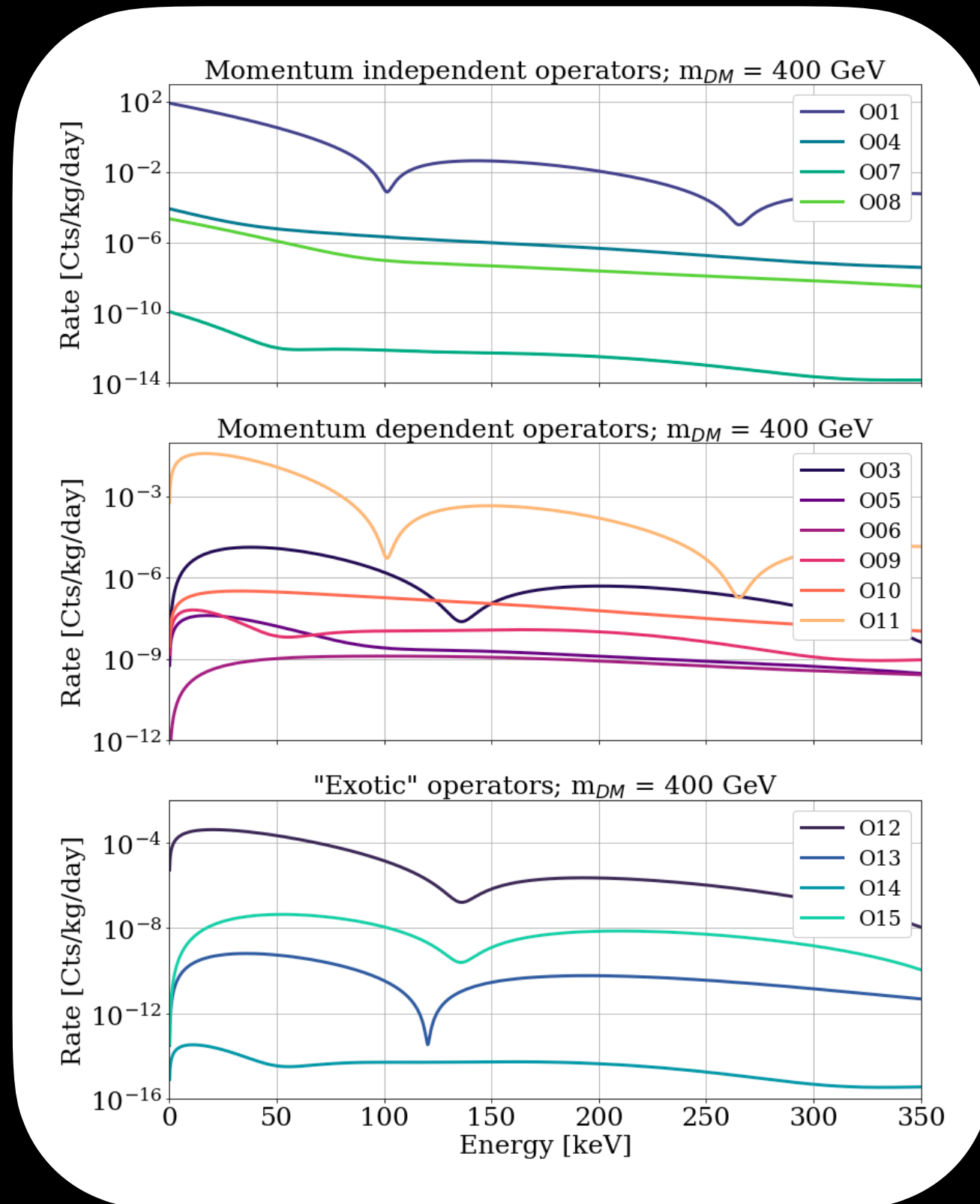
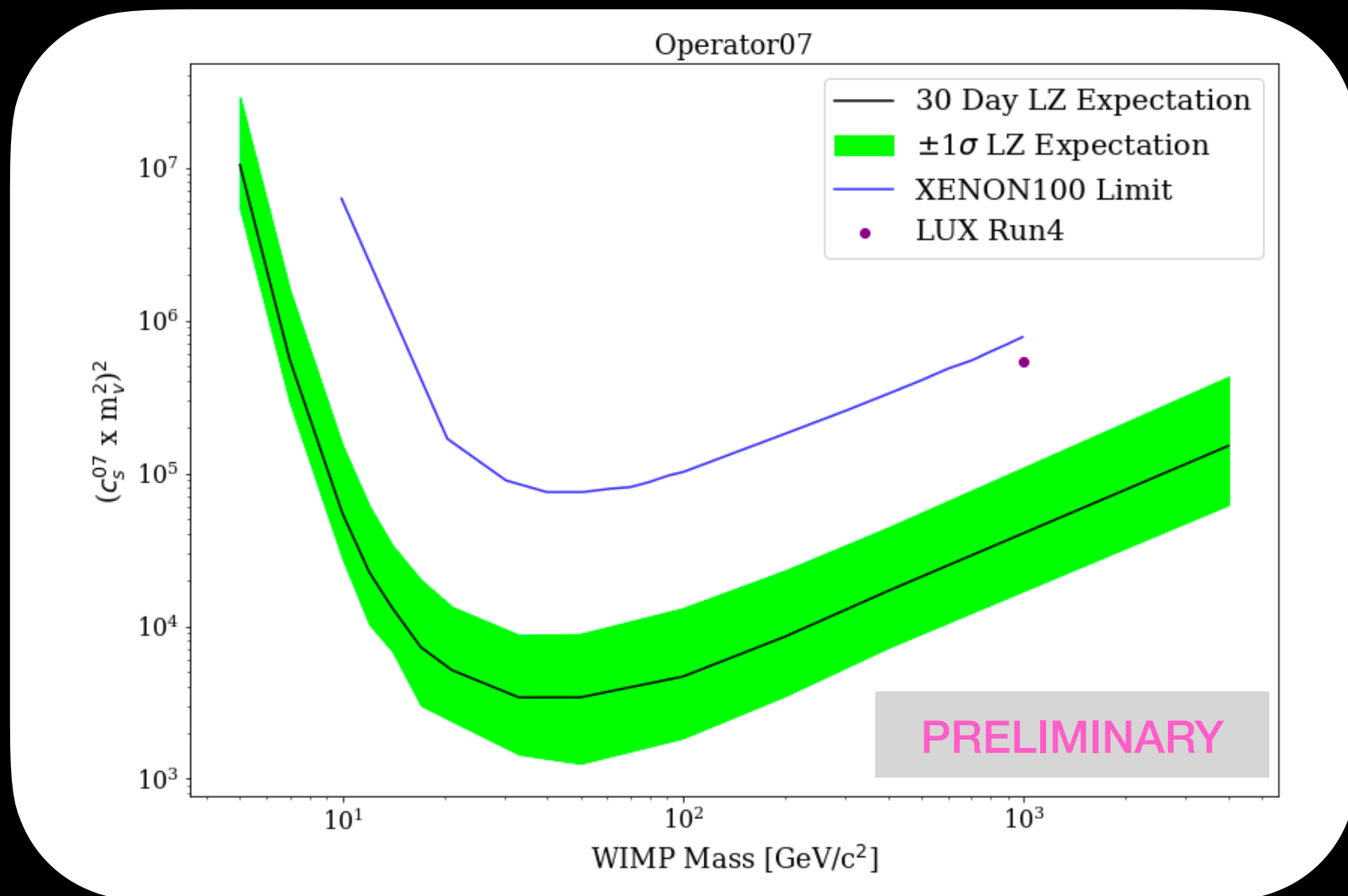
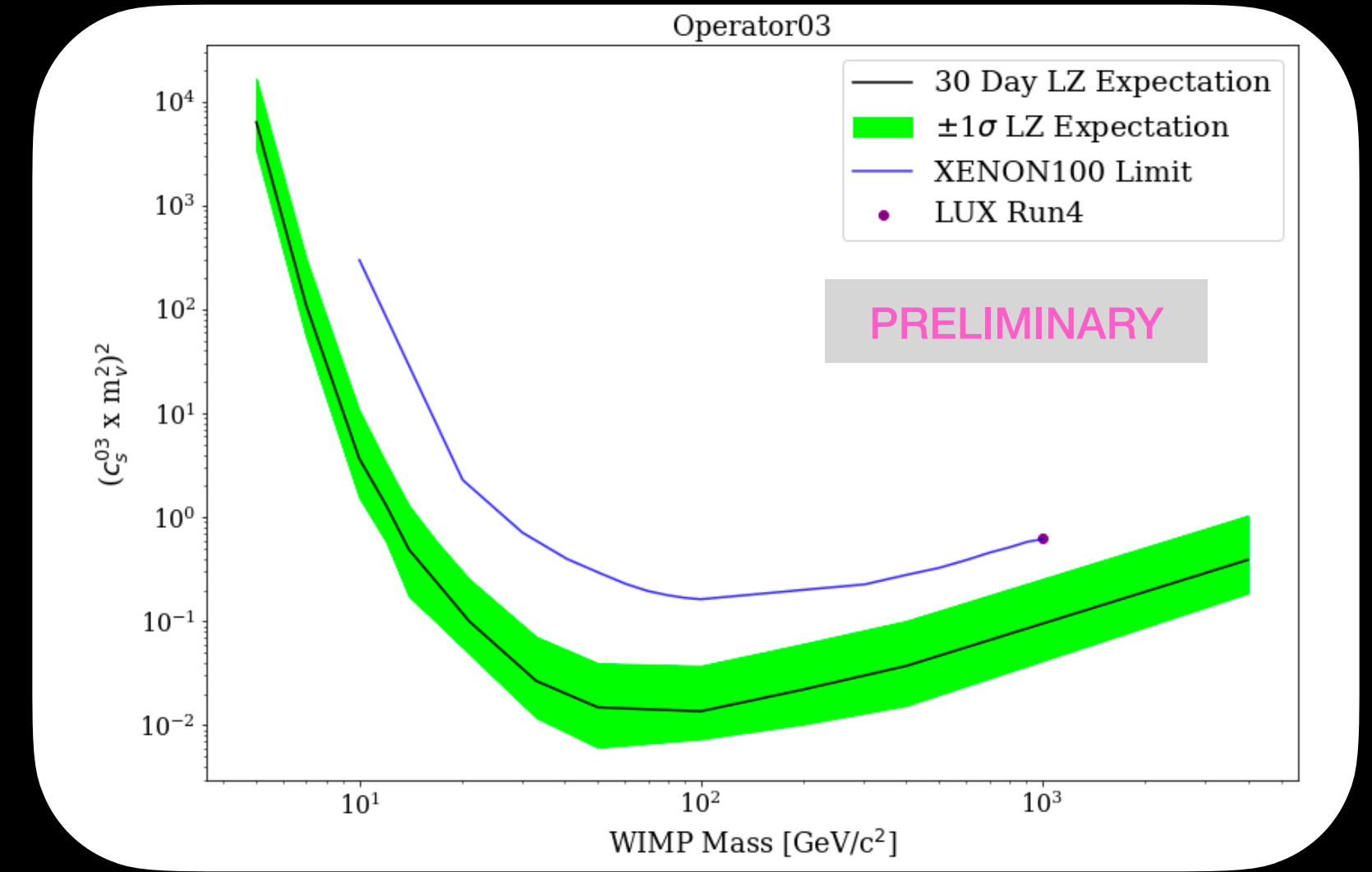
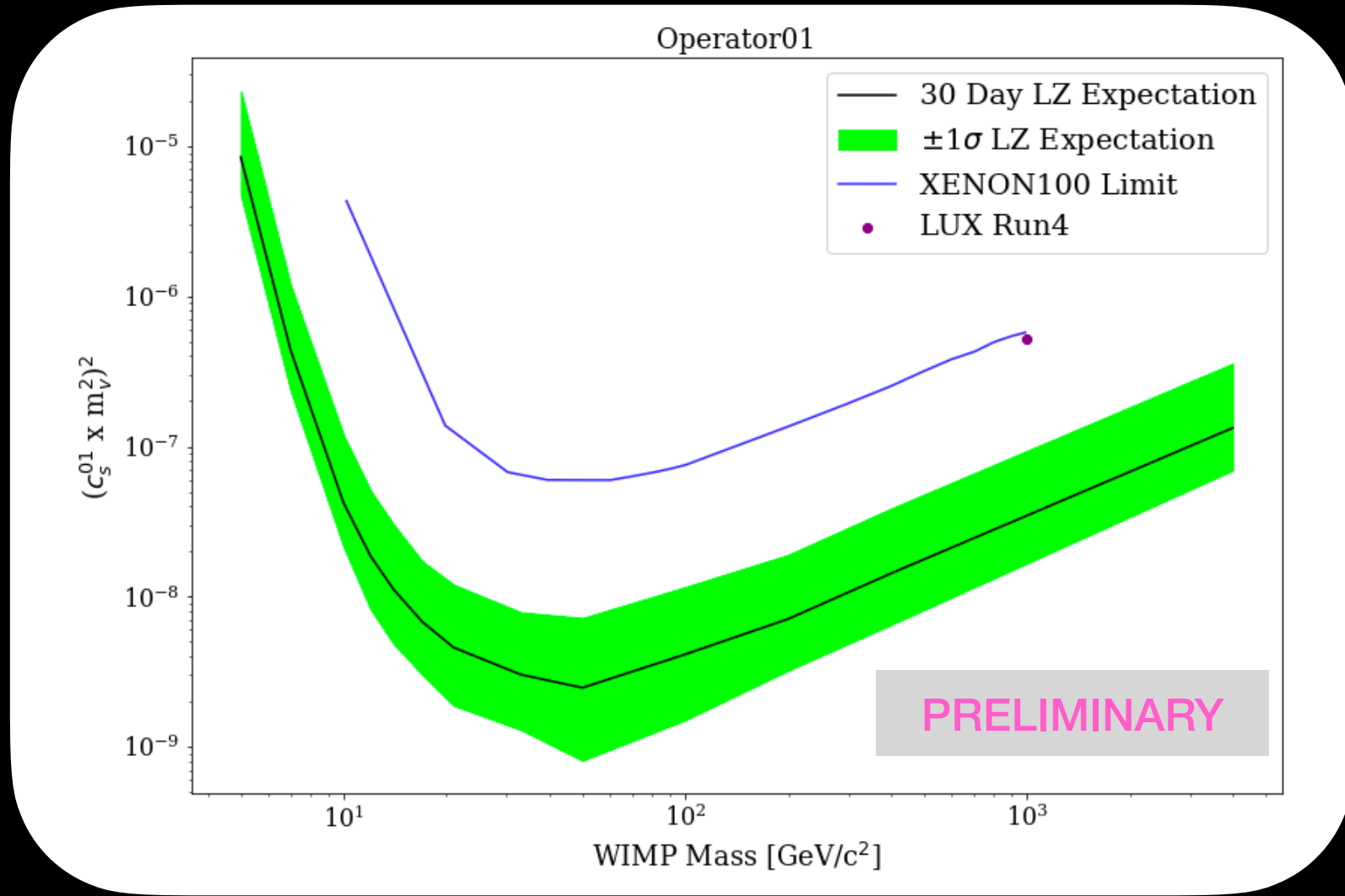
# Physics Reach & Future Sensitivity





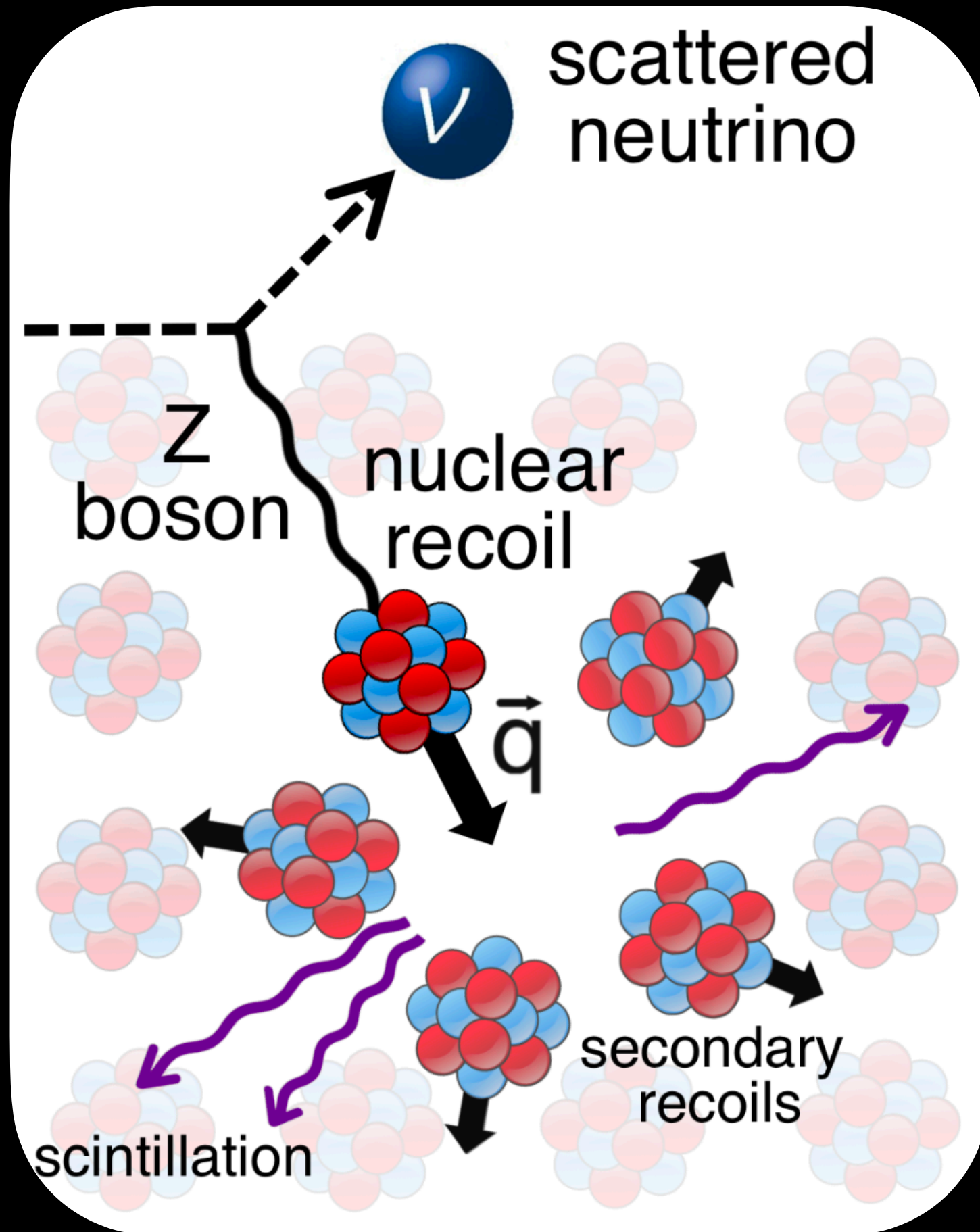
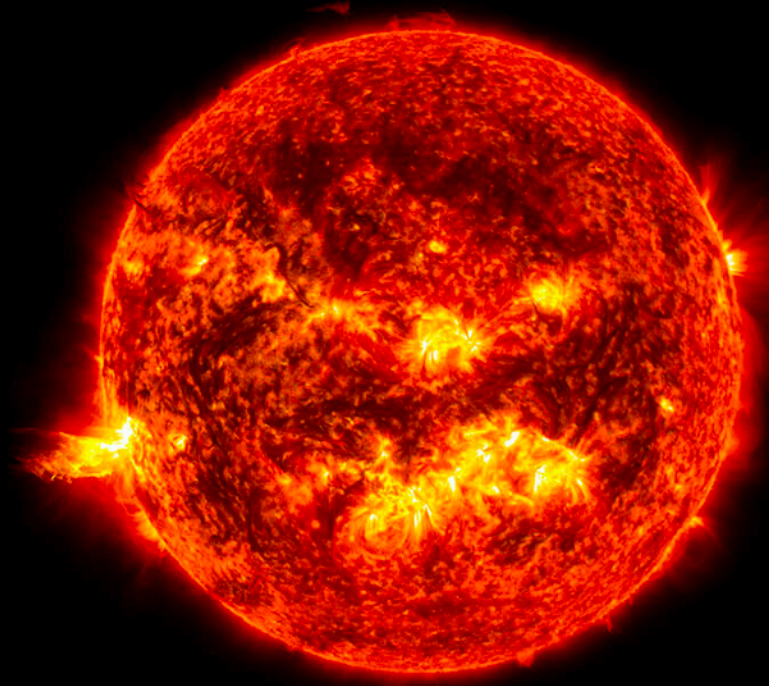
# Effective Field Theory Couplings

Investigating other WIMP-nucleon couplings through Effective Field Theory

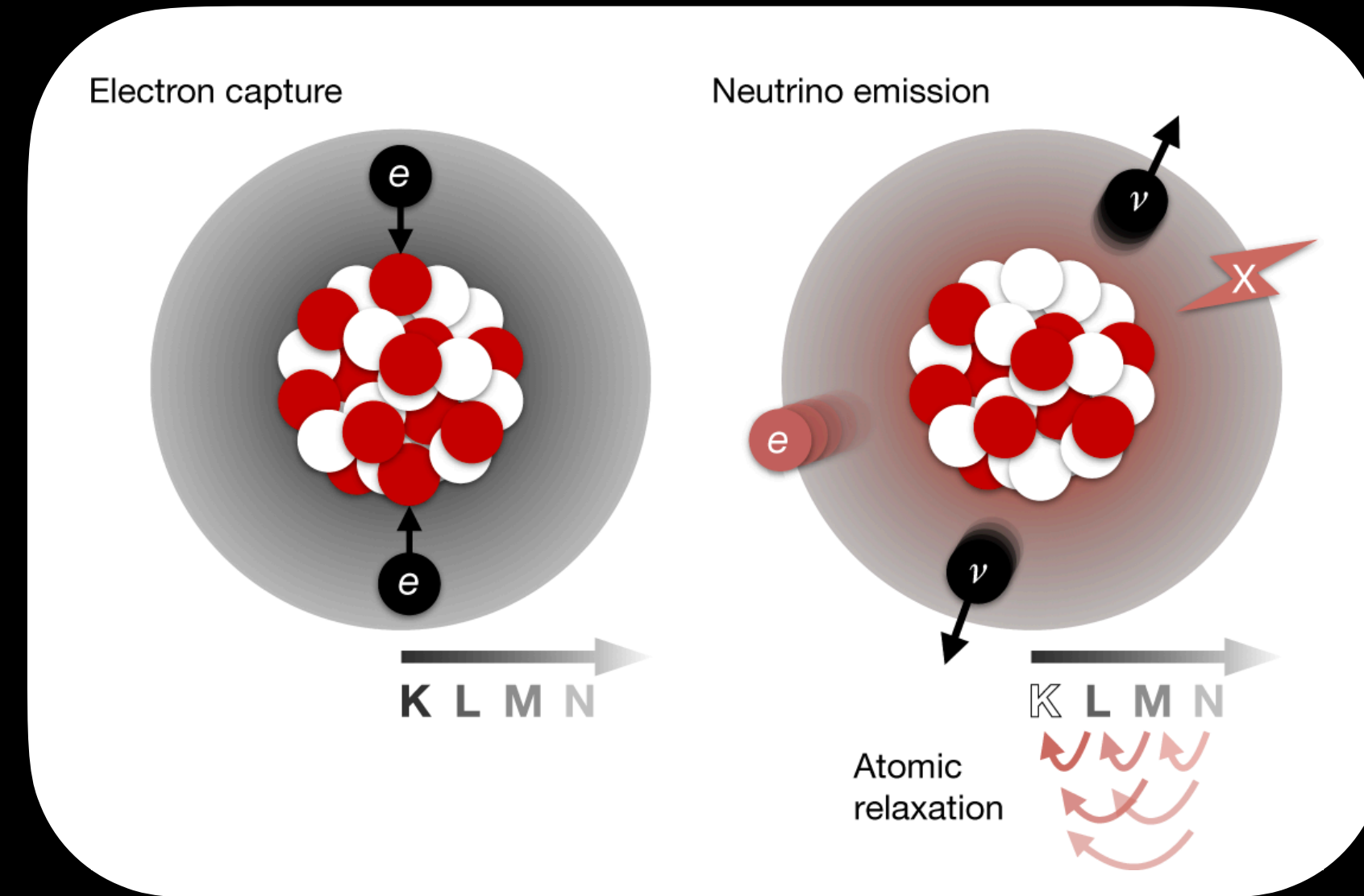




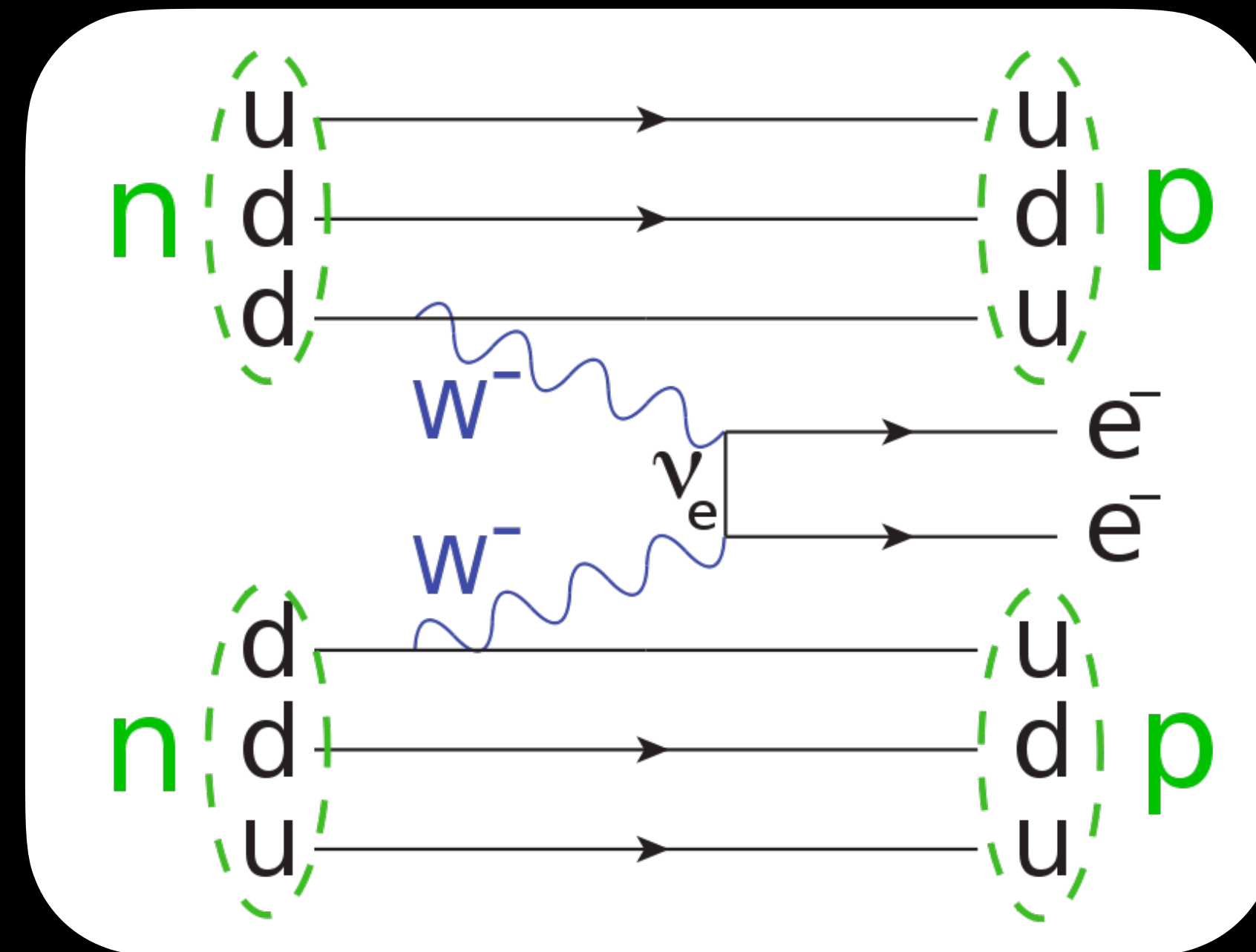
# Neutrino & Nuclear Physics



Coherent elastic neutrino-nuclear scattering (CEvNS) of Boron-8 solar neutrinos



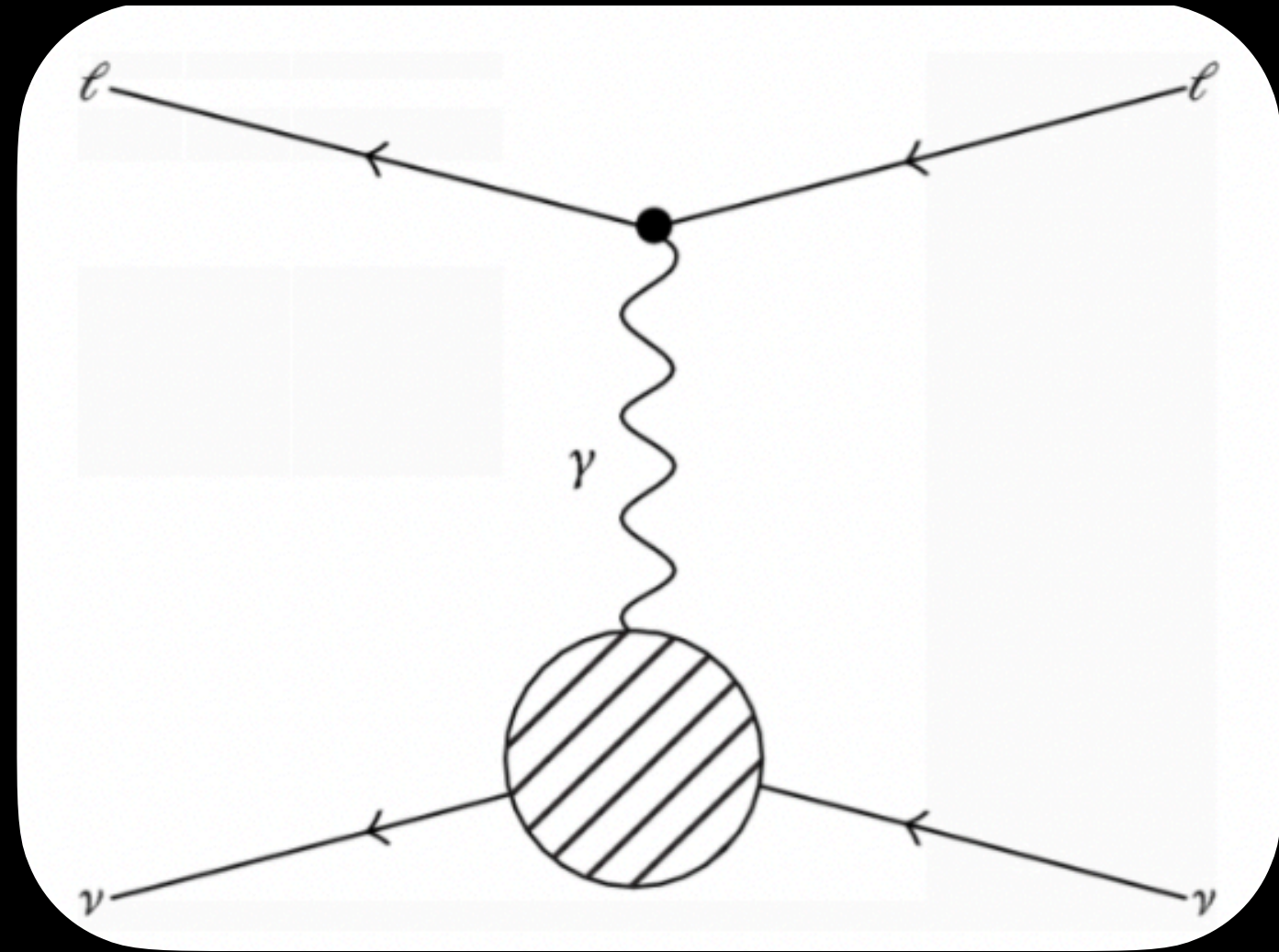
2-neutrino double electron capture ( $2\nu\text{DEC}$ ) of Xe124



Neutrinoless double beta-decay ( $0\nu\beta\beta$ ) of Xe134 and Xe136

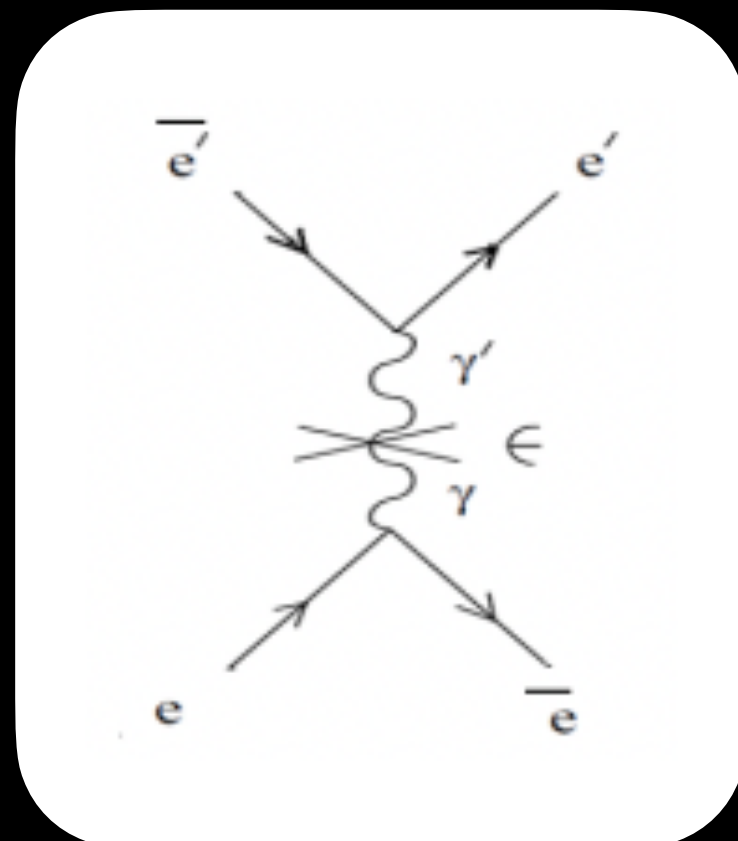


# Exotic Low Energy ER Physics

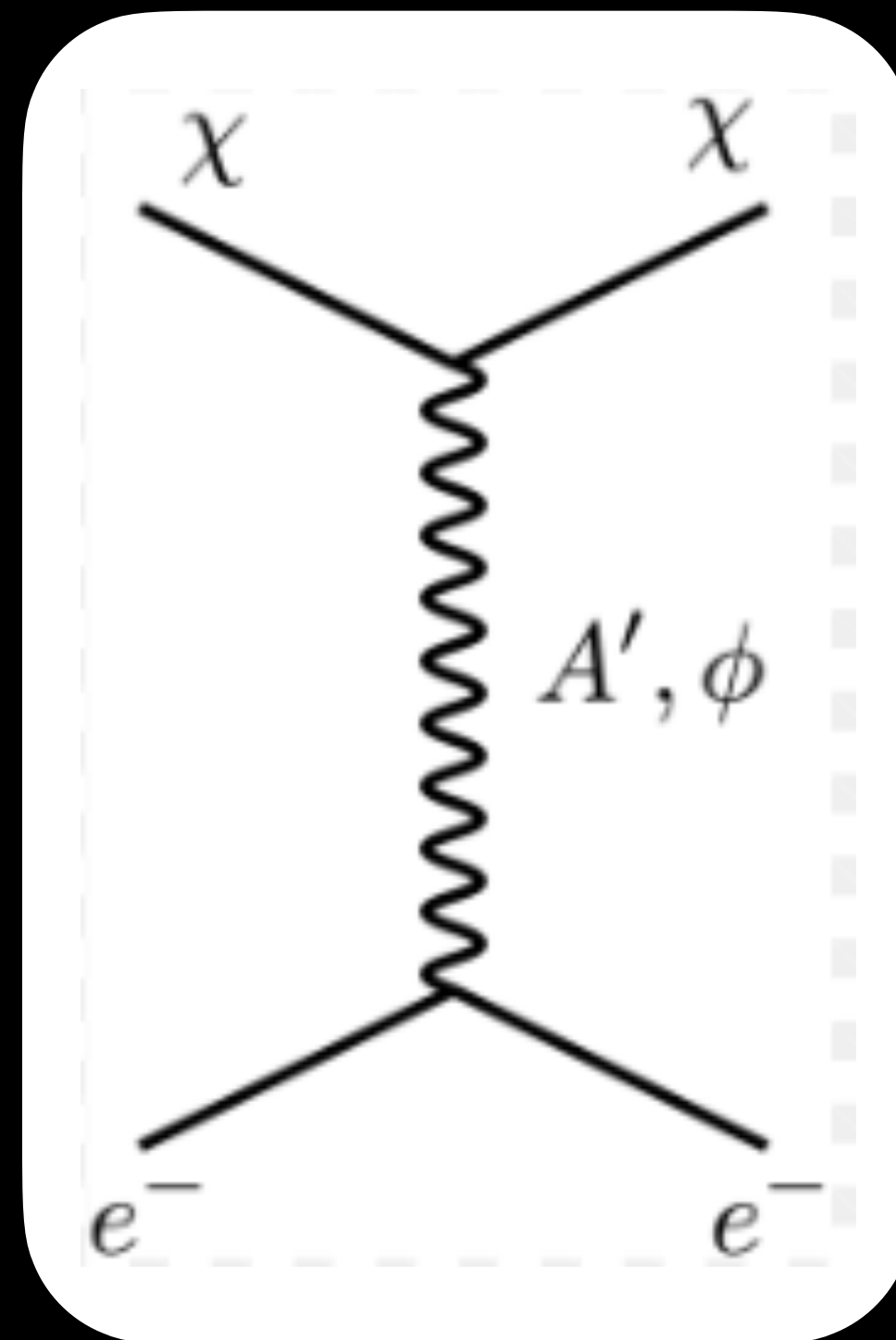


Leptophilic Dark Matter

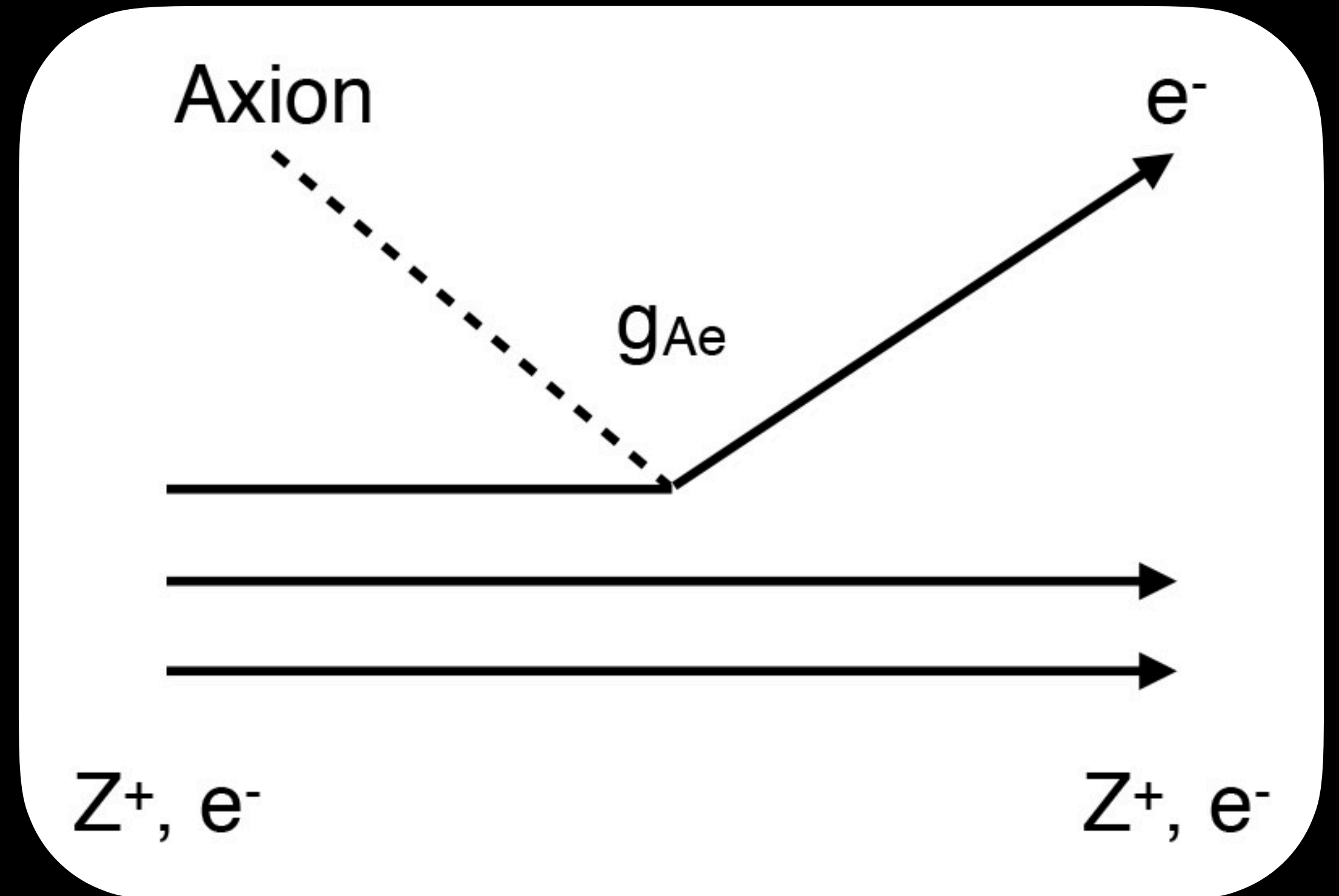
ν Millicharge & Magnetic Moment



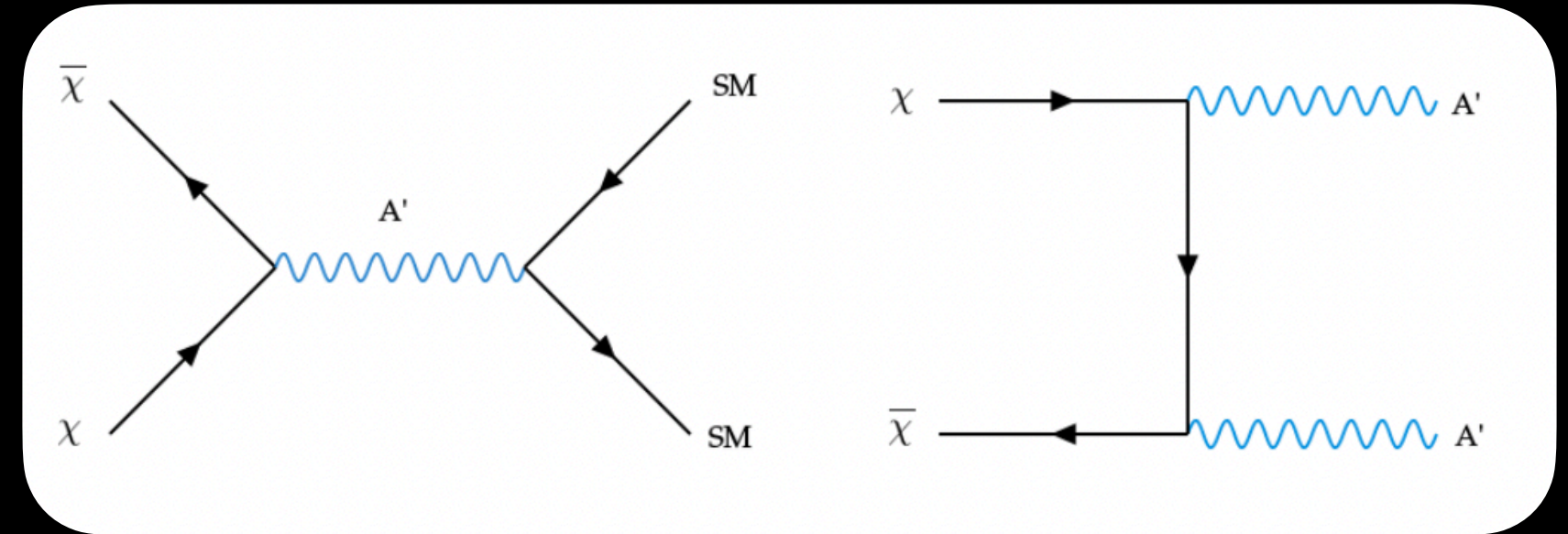
Mirror Dark Matter



Axions and Axion-Like Particles (ALPs)

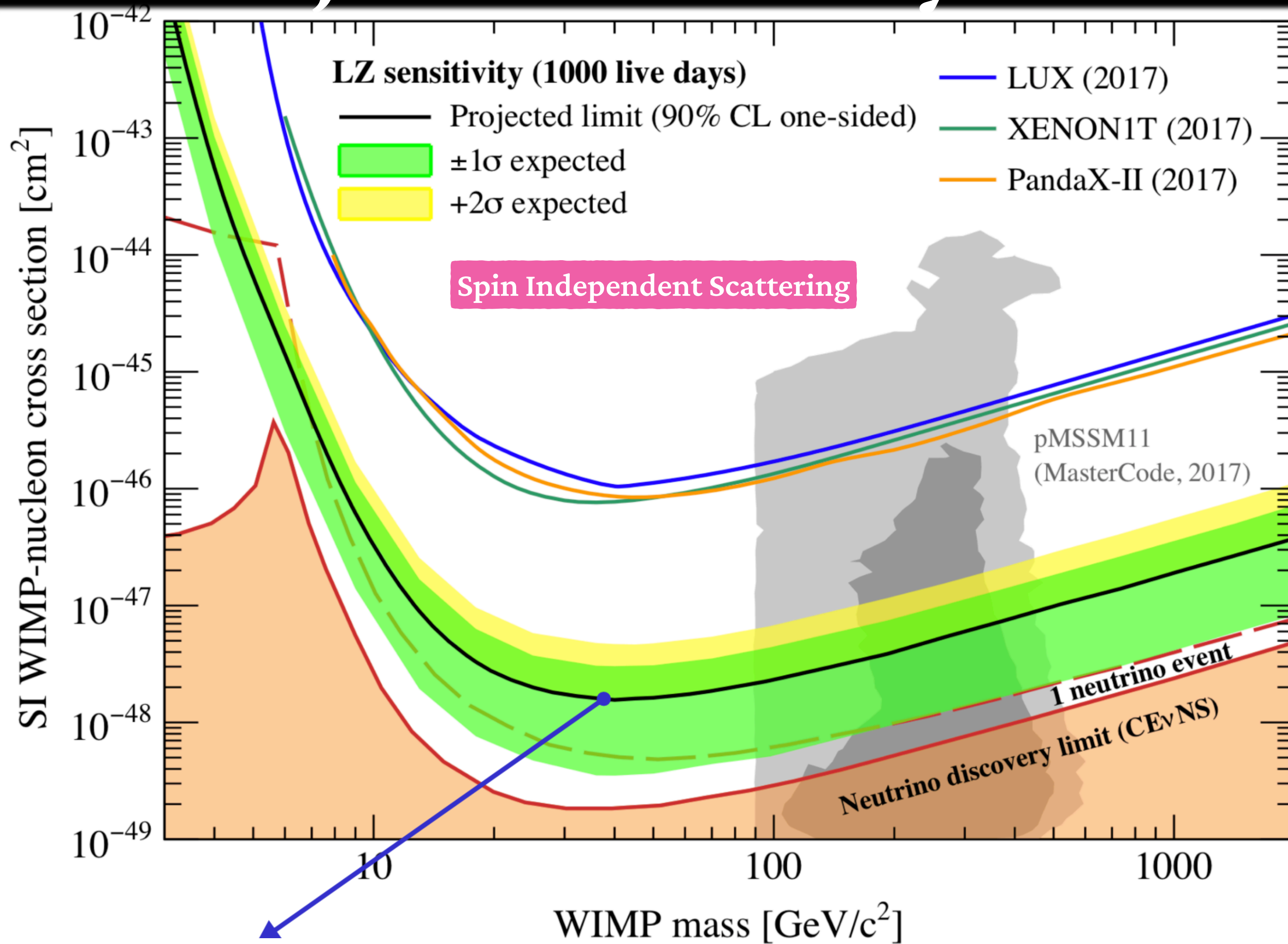


Hidden Photons

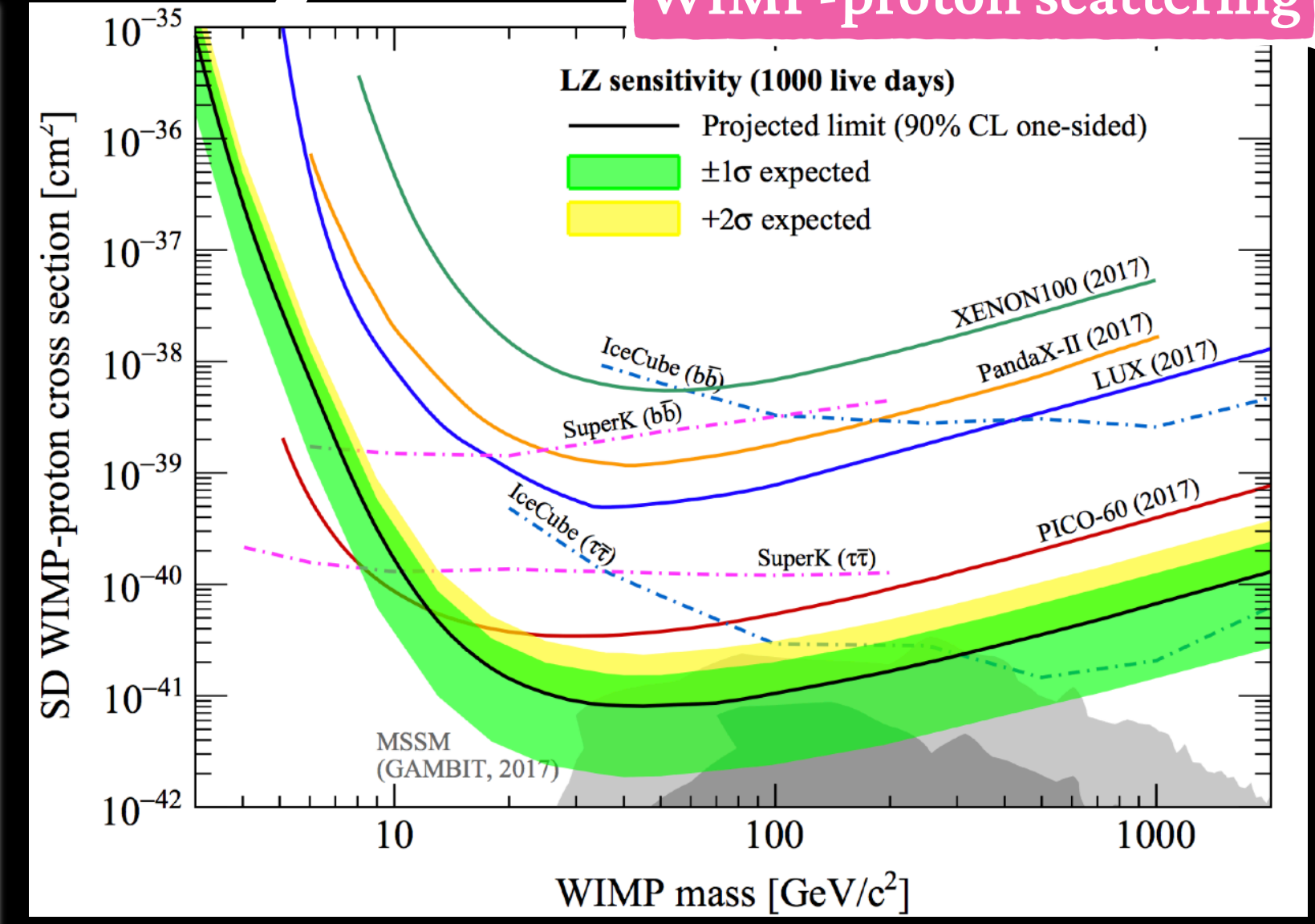




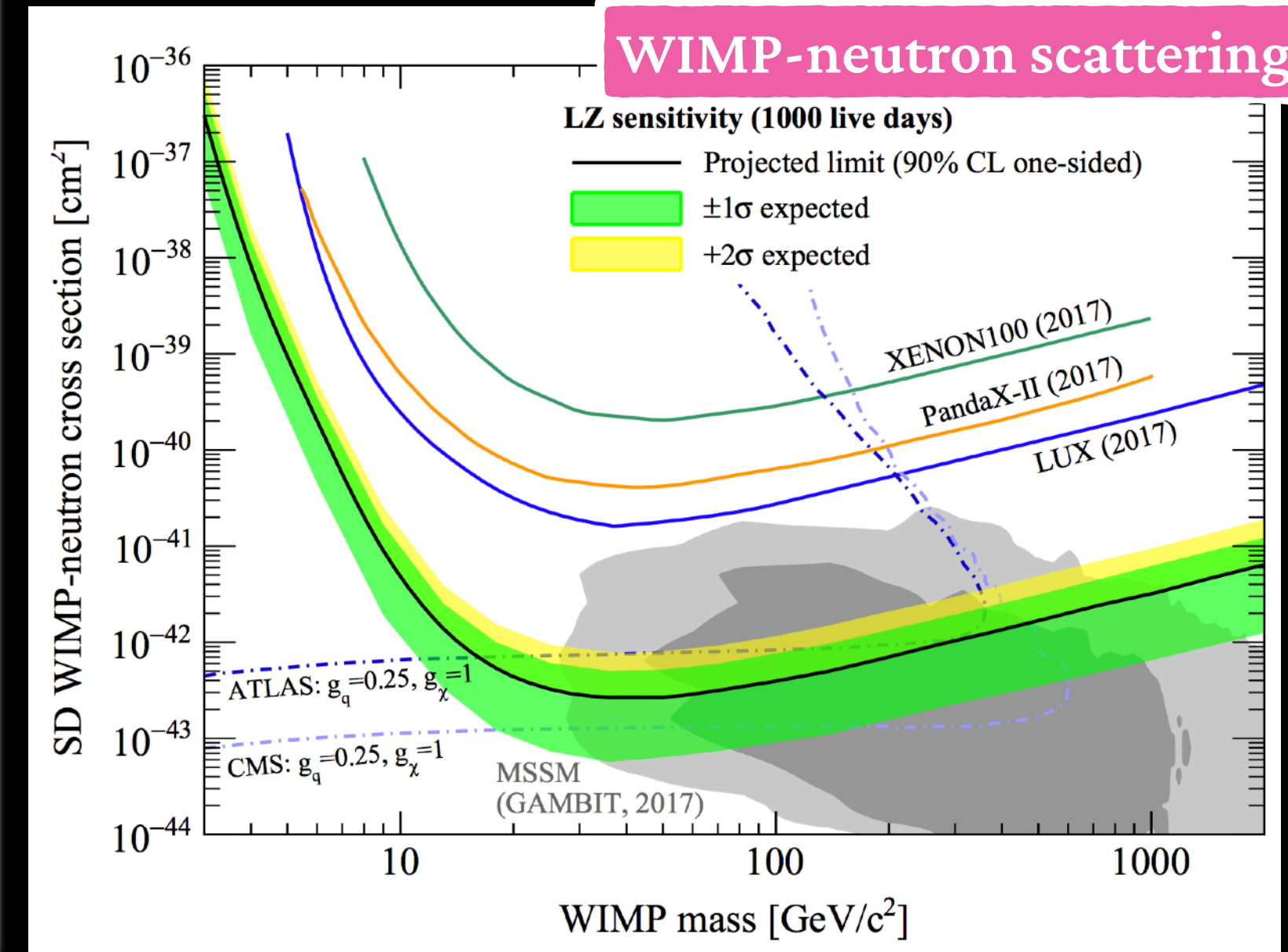
# LZ Projected Sensitivity- 1000 live days



## WIMP-proton scattering



## WIMP-neutron scattering

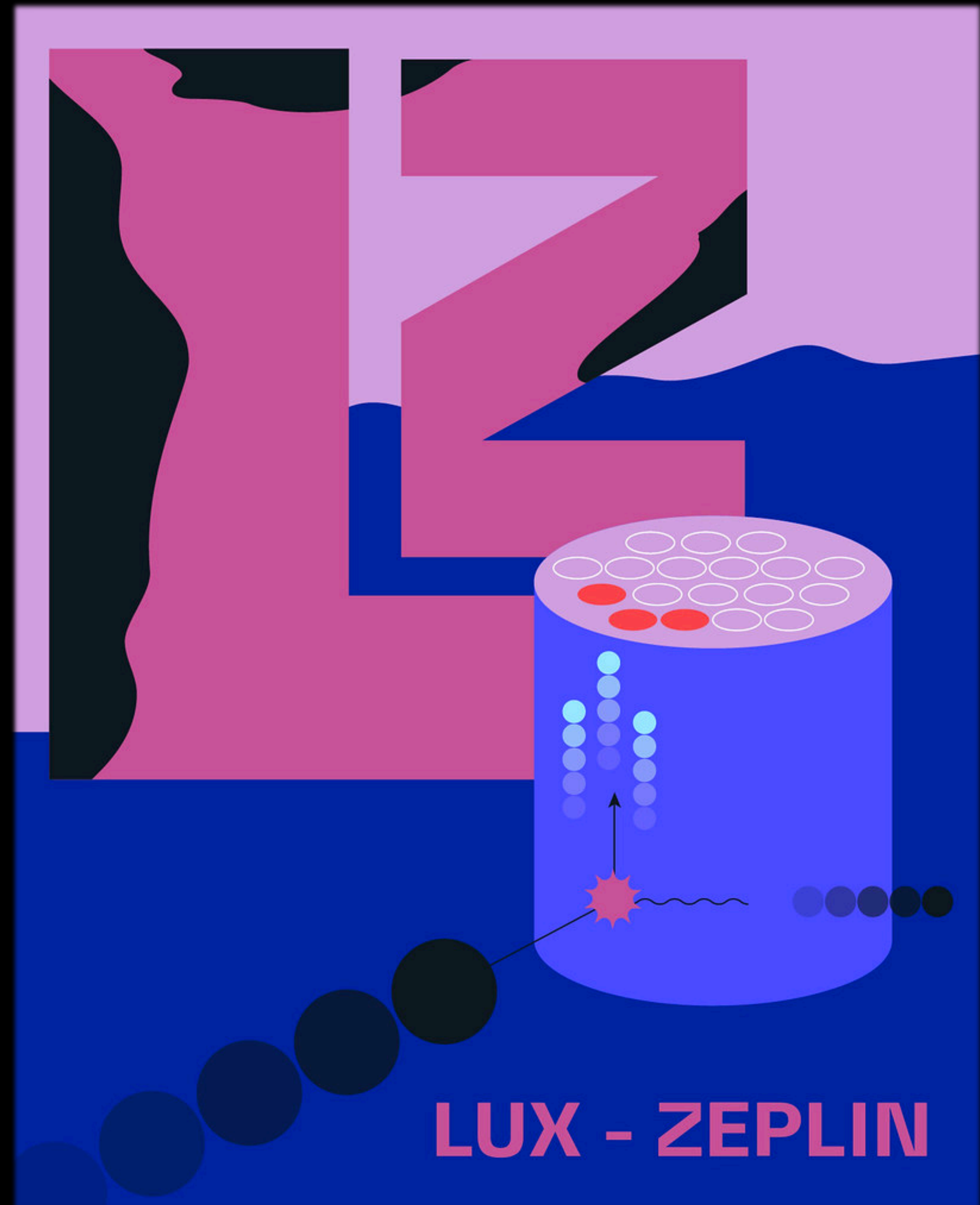


$1.4 \times 10^{-48} \text{ cm}^2 @ 40 \text{ GeV}/c^2$



# Summary

- LZ is currently **world leading!** Results were released July 2022
- Summer 2022 was spent making improvements & optimizing detector conditions
- Science Run 1 was just 60 livedays but proved LZ's capability to do excellent science
- We are taking science data again, expect ~1 year of exposure
- **Exciting physics on the horizon!**
  - WIMP searches, EFT models, axions, ALPs, hidden photons, MIMPs,  $0\nu\beta\beta$ ,  $2\nu\text{DEC}$ ,  $\text{CE}\nu\text{NS}$  and more...







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