Axion search with Dark Matter detector

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Durham IPPP, 14th March 2016

Direct DM search

Dark matter (**DM**) Milky Way's halo

=> flux on Earth ~ 10^5 cm^{-2}s^{-1}

ρ_χ ~ 0.3 GeV/cm^3 and 100 GeV/c^2

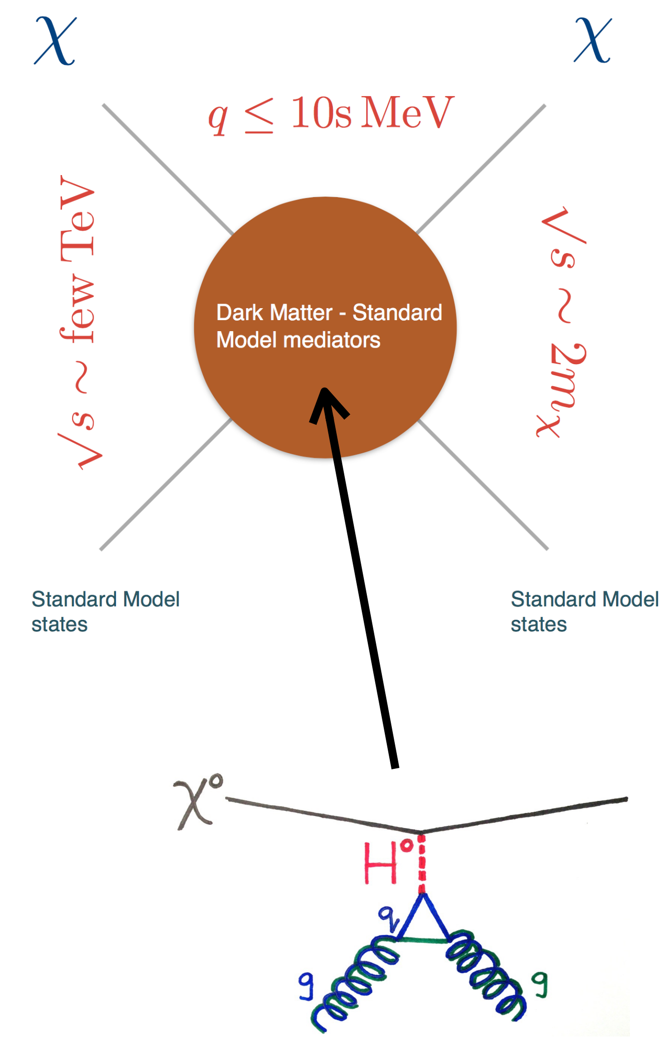
Basic goal: search for nuclear recoil from DM elastic scattering.

Simple dynamics: *cross section ∝ (form-factor)^2*

Spin-independent: nucleon form-factor gives rise to A^2 enhancement due to coherence.

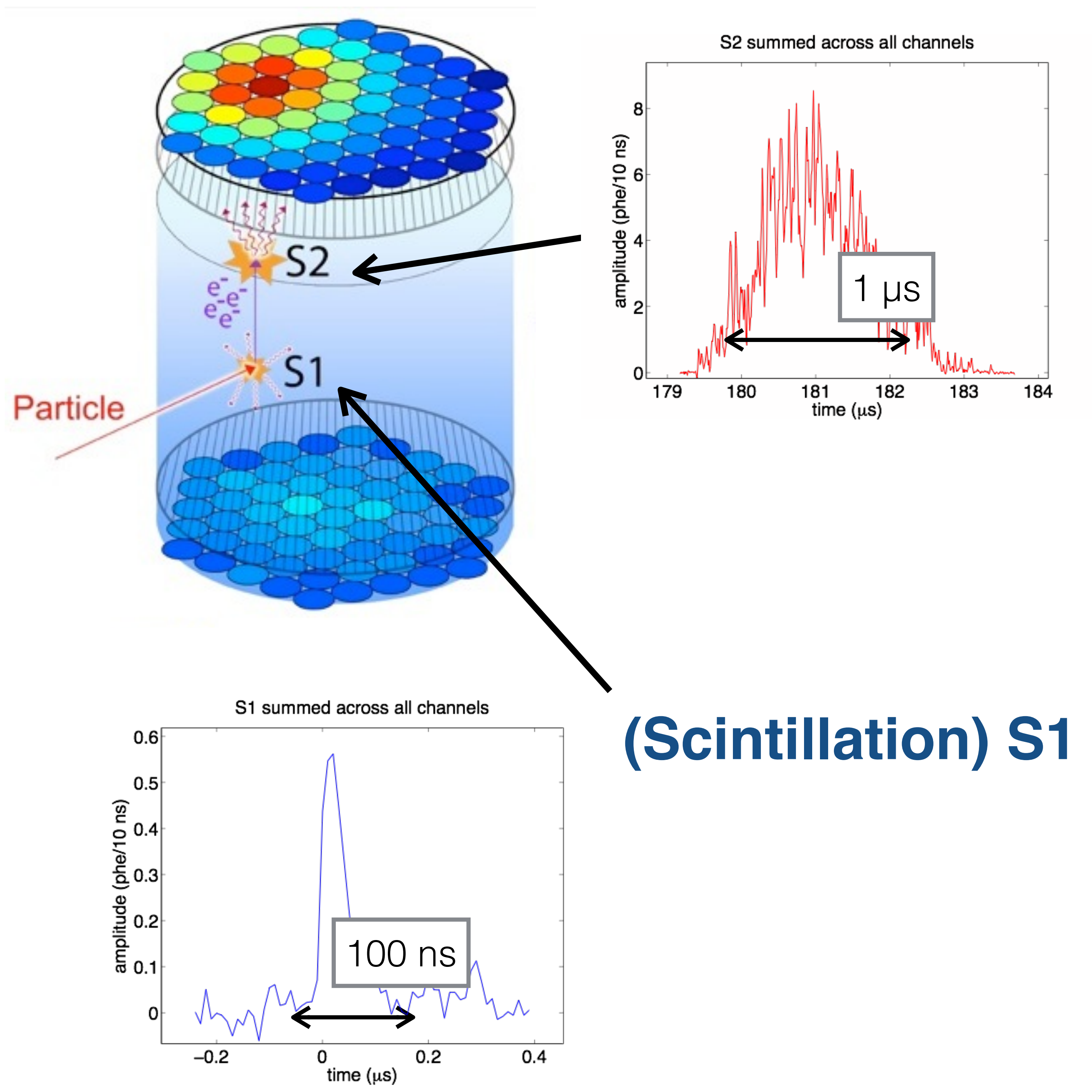
The dependence on q^2 is also contained in the form-factors.

Spin-dependent: form-factor depends on nuclear spin. No coherence enhancement.



S1, S2 and CES

Liquid xenon / dual-phase time projection chamber (TPC)



(Ionisation) S2

(Scintillation) S1

S1, S2 and CES

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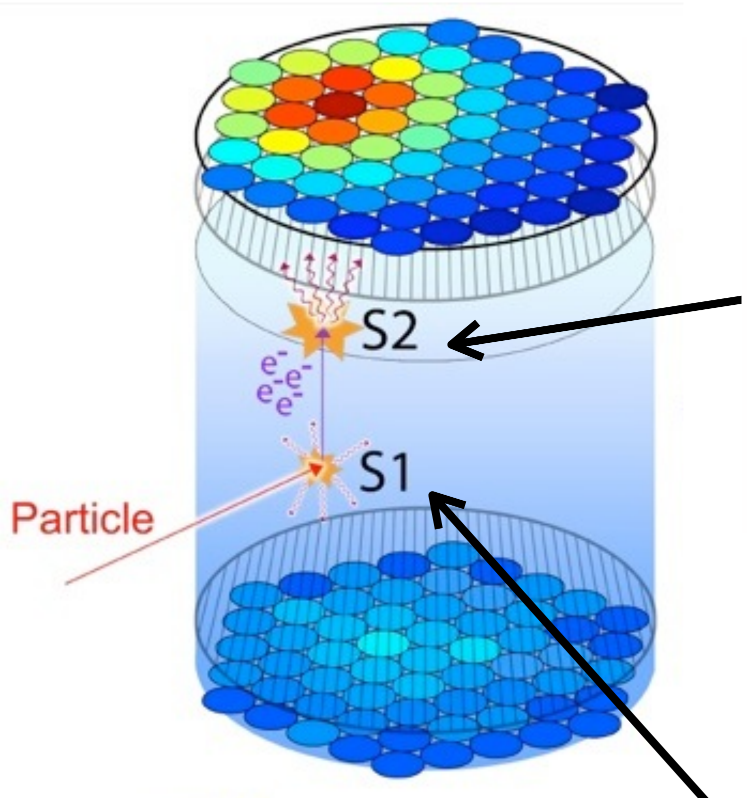
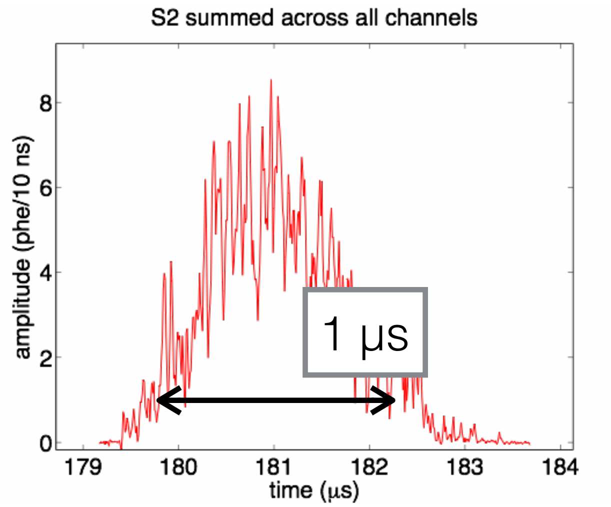
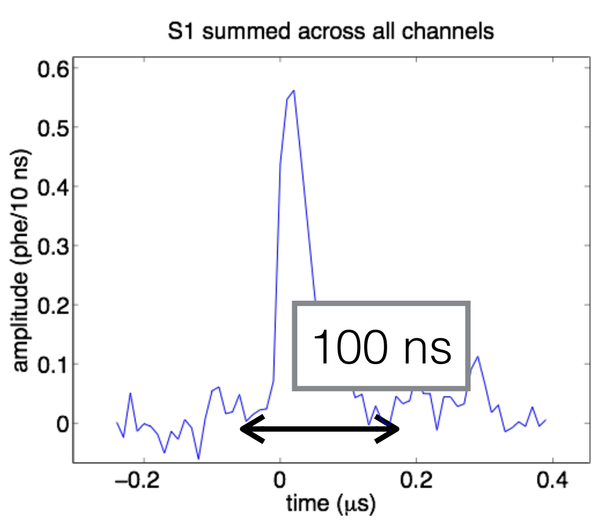




(Ionisation) S2



(Scintillation) S1

'Combined Energy scale'

$$E = \frac{1}{L(E)} \cdot \left(\frac{S1}{g_1} + \frac{S2}{g_2} \right) \cdot W$$

- W = 13.7 eV
- g_1 = Light Collection
- g_2 = Extraction + Light Eff.
- $L(E)$ = Lindhard Factor

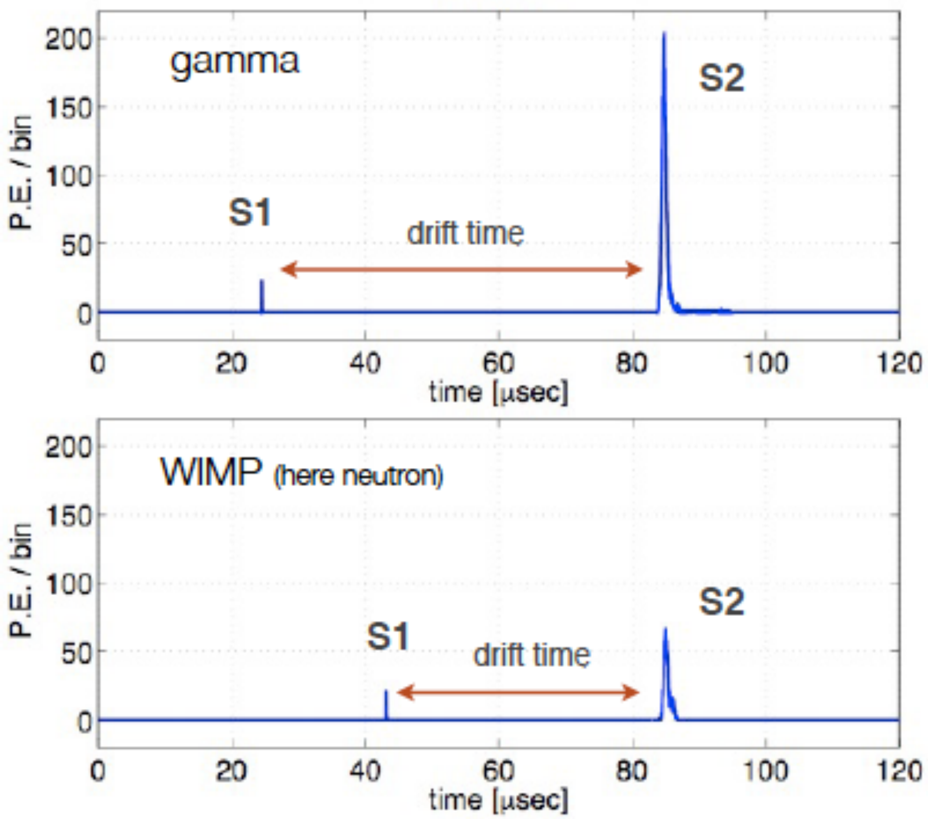
  Nuclear recoil enhancement of heat relative to electron recoils

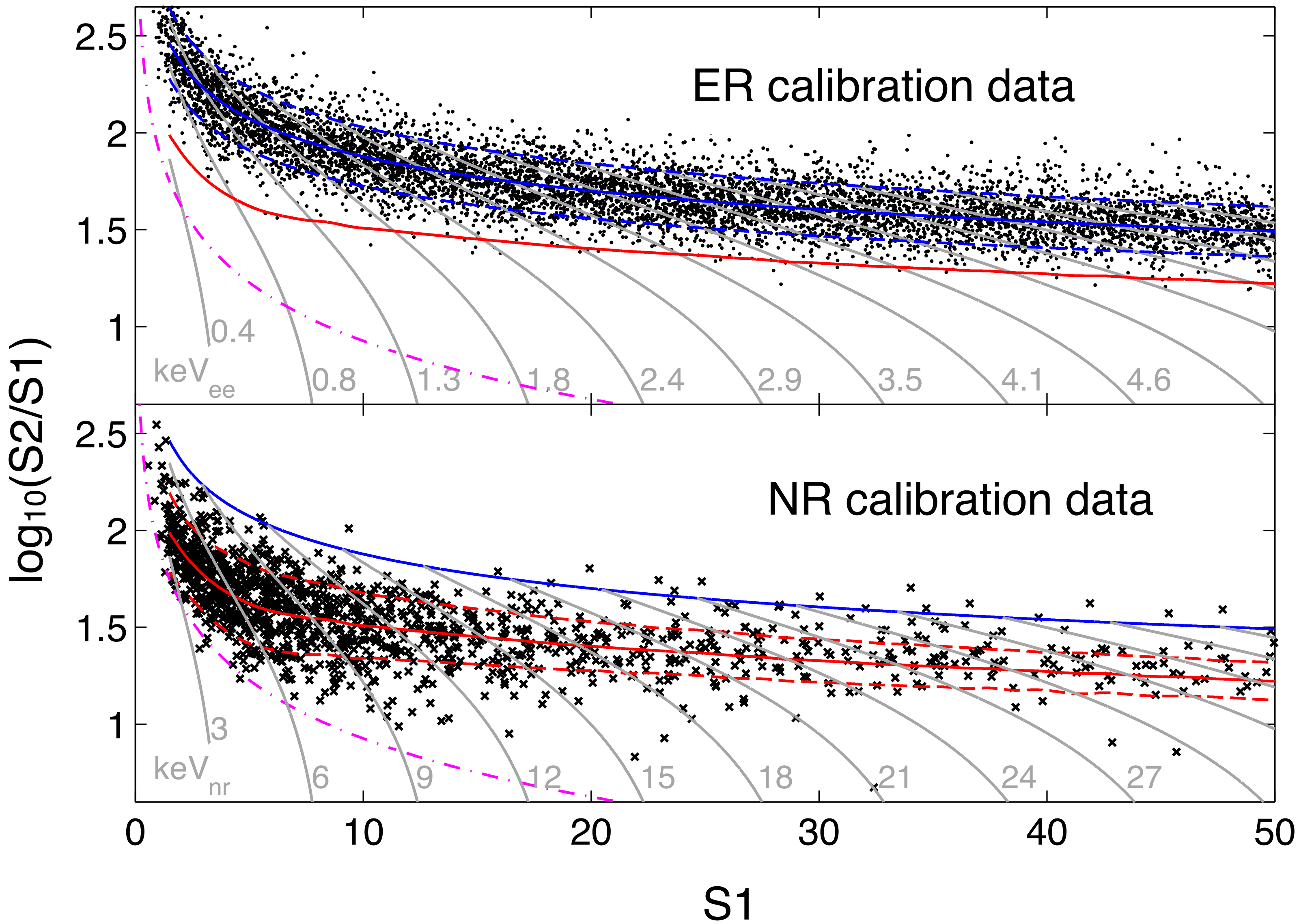
Nuclear vs. Electron recoil

Combination of Scintillation (S1) and Ionisation (S2) event-by-event particle identification

Electron Recoil (ER) events

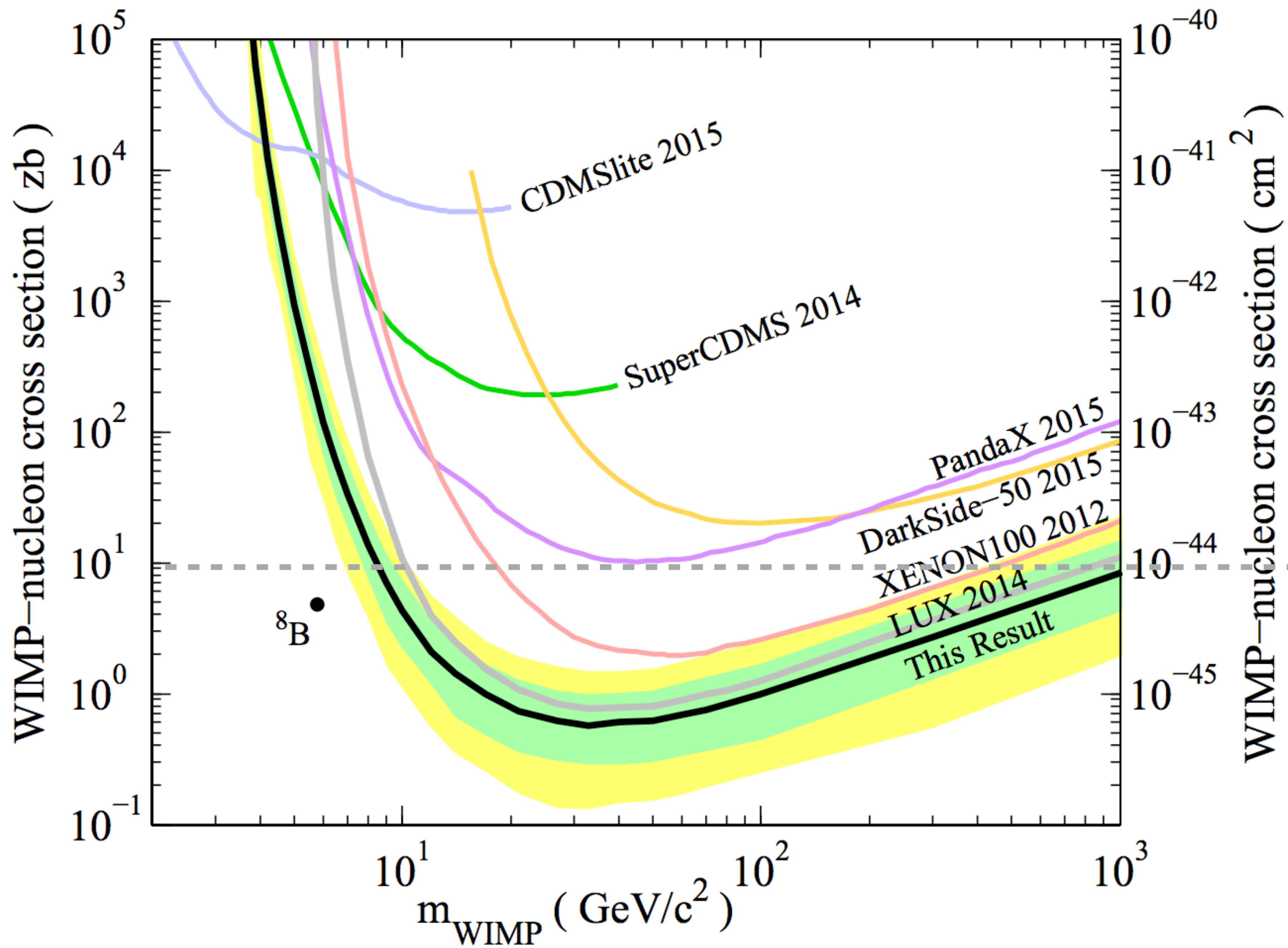
Nuclear Recoil (NR) events





Spin-independent

arXiv:1512.03506



10^{-38} cm^2

Z exchange

$\sigma \sim 10^{-2}\lambda^2_{Z\chi}$ pb

Higgs exchange

$\sigma \sim 10^{-8}\lambda^2_{h\chi}$ pb

Limit on Spin-Independent WIMP-nuclei at 6×10^{-46} cm^2 at 33 GeV/c^2

LZ = LUX + ZEPLIN

Counts: 31 Institutions
≈ 200 Headcount

Center for Underground Physics (Korea)
LIP Coimbra (Portugal)
MEPhI (Russia)
Edinburgh University (UK)
University of Liverpool (UK)
Imperial College London (UK)
University College London (UK)
University of Oxford (UK)
STFC Rutherford Appleton, and Daresbury, Laboratories (UK)
University of Sheffield (UK)

University of Alabama
University at Albany SUNY
Berkeley Lab (LBNL)
Brookhaven National Laboratory
University of California Berkeley
Brown University
University of California, Davis
Fermi National Accelerator Laboratory
Lawrence Livermore National Laboratory
University of Maryland
Northwestern University
University of Rochester
University of California, Santa Barbara
University of South Dakota
South Dakota School of Mines & Technology
South Dakota Science and Technology Authority
SLAC National Accelerator Laboratory
Texas A&M
Washington University
University of Wisconsin
Yale University

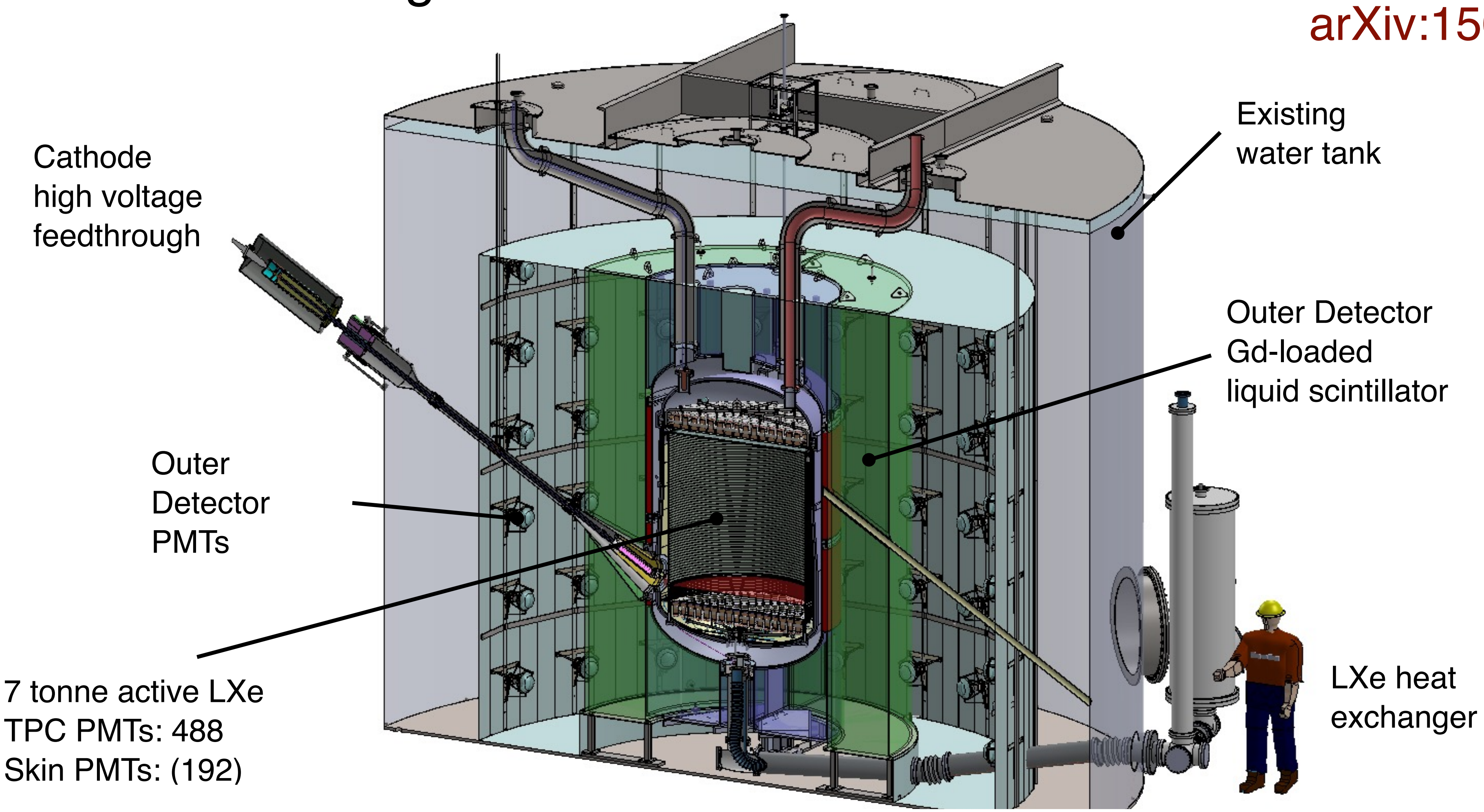
The detector

(LUX):
world leading Generation-1 experiment, Sanford Underground Research Facility (SURF),
250 kg of active LXe target

→

LUX-ZEPLIN (LZ):
Generation-2 flagship experiment for Direct Detection in US and UK,
7 tonnes of active LXe target

arXiv:1509.02910



LZ timeline

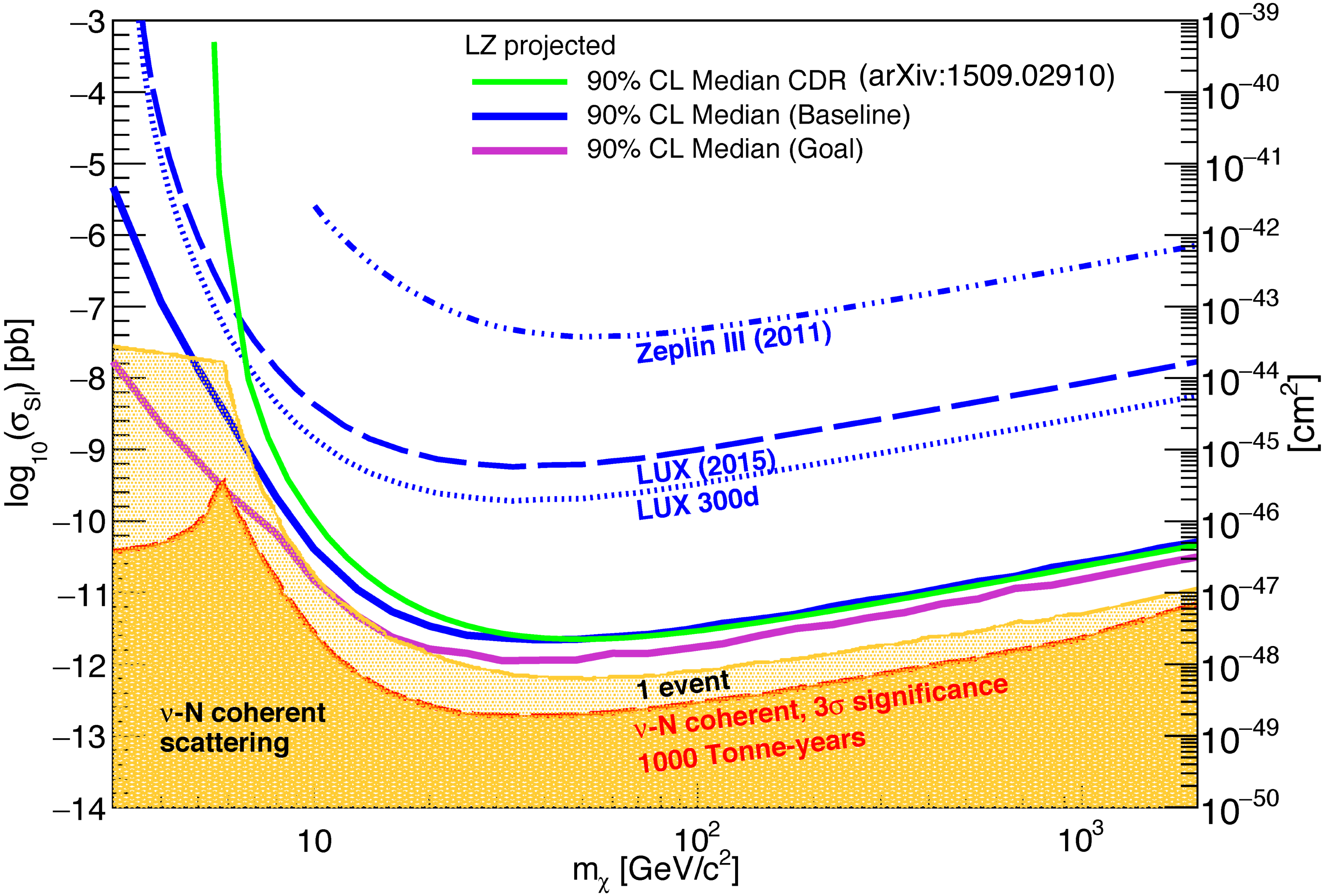
Year	Month	Activity
2012	March	LZ (LUX-ZEPLIN) collaboration formed
	September	DOE CD-0 for G2 dark matter experiments
2013	November	LZ R&D report submitted
2014	July	LZ Project selected in US and UK
2015	April	DOE CD-1/3a approval, similar in UK Begin long-lead procurements (Xe, PMT, cryostat)
2016	April	DOE CD-2/3b review
2017	February	LUX removed from underground
2017	July	Begin surface assembly prep @ SURF
2018	May	Begin underground installation
2019	April	Begin commissioning
2021	Q3FY21	CD-4 milestone (early finish July 2019)
2025		Planning on ~5 year of operations

Projected sensitivity

Simulated LZ experiment (1000 days, 5.6 tonnes fiducial)

Baseline
σ_{SI} = 2.2 x 10^{-48} cm²
B-8 = 7
ATM ν = 0.4

Goal
σ_{SI} = 1.2 x 10^{-48} cm²
B-8 = 220
ATM ν = 3



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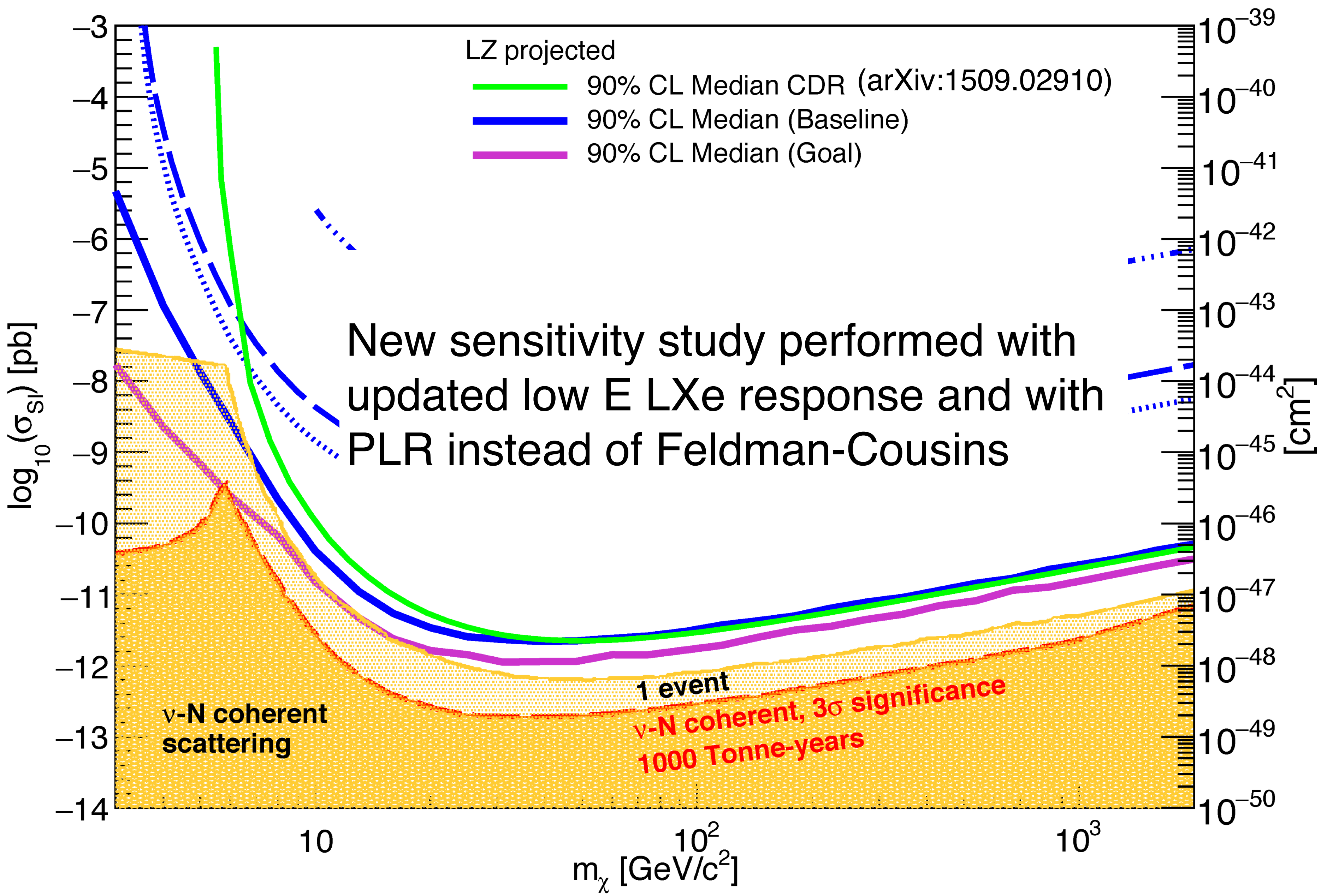
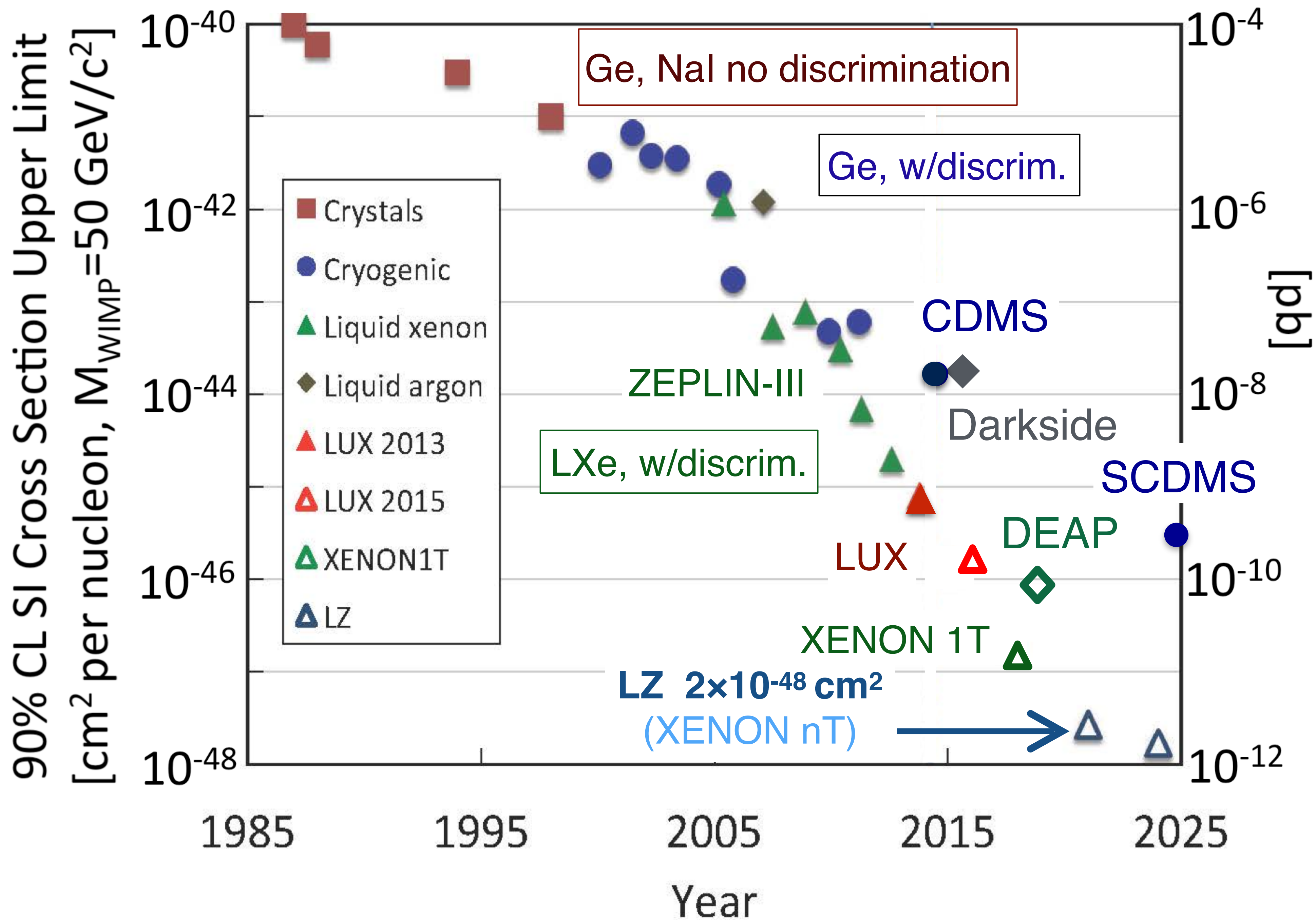


Direct detection timeline



Axion with DM direct search experiment

Publications

K. Arisaka, P. Beltrame et al., Astroparticle Physics 44 (2013) 59–67

M. Pospelov et al., Phys. Rev. D 78 (2008), 115012

$$R[/\mathrm{kg/day}] = \left(\frac{1.29 \times 10^{19}}{A}\right) g_{Ae}^2 m_A[\mathrm{keV}/c^2]\sigma_{pe}[\mathrm{barns}]$$

E. Aprile et al. (XENON100), Phys. Rev. D90 (2014), 062009

Theory

Invisible axion could be the QCD axion solving the CP violation problem

Axion-Like Particle, introduced by several extension of the SM, are good Dark Matter candidates

Experimental detection with xenon

Axions and axion-like particles can couple with electron (g_{Ae})

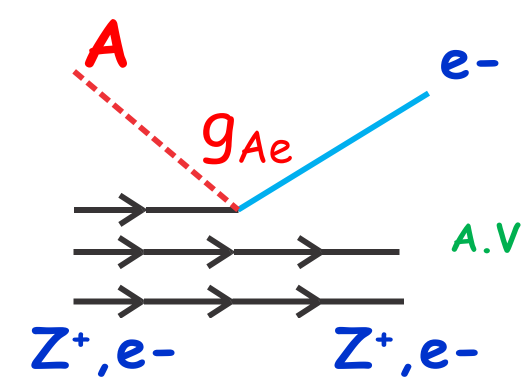
Sources:

- Solar Axion from Sun
- Axion-Like particle slowly moving within our galaxy

Axio-electric effect

- Axion-Like particles
- Experimentally detectable in the Xe exploiting the axion-electric effect (proportional to the photo-electric effect)

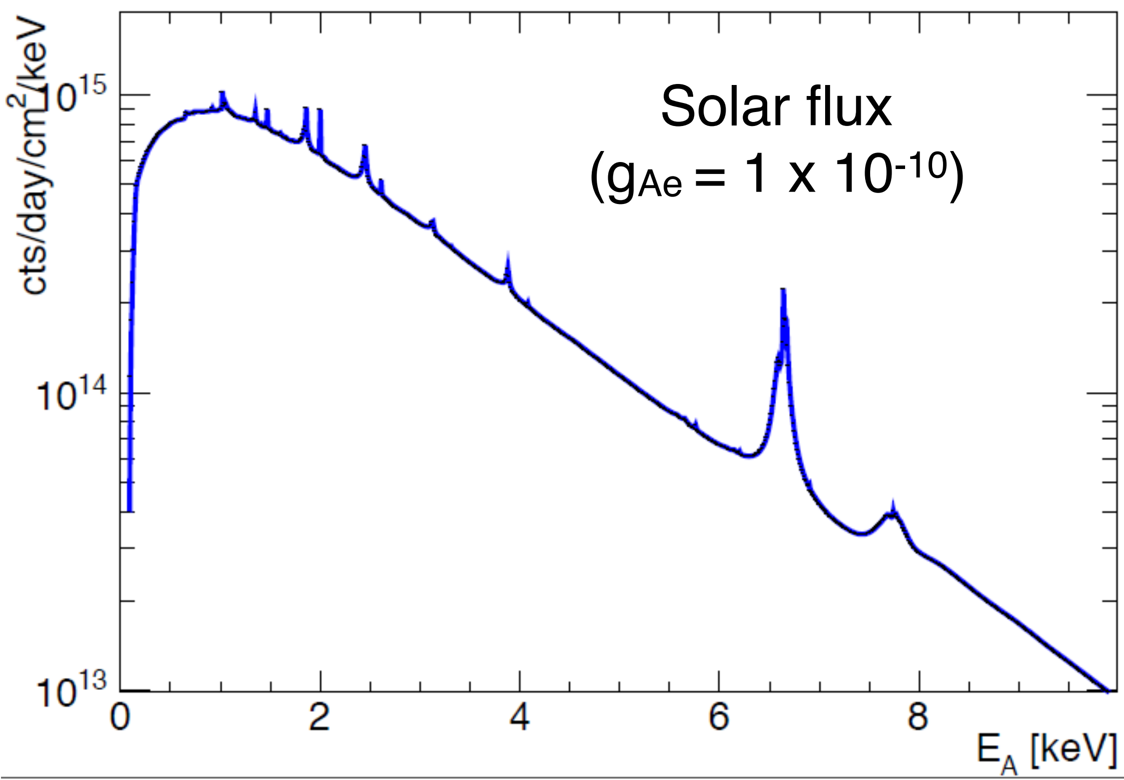
$$\sigma_{Ae} = \sigma_{pe}(E_A)\frac{{g_{Ae}}^2}{\beta_A}\frac{3{E_A}^2}{16\pi\,\alpha_{em}\,{m_e}^2}\left(1-\frac{\beta_A^{2/3}}{3}\right)$$



Axio-electric effect (solar)

Production from Sun

J. Redondo, JCAP12 (2013) 008

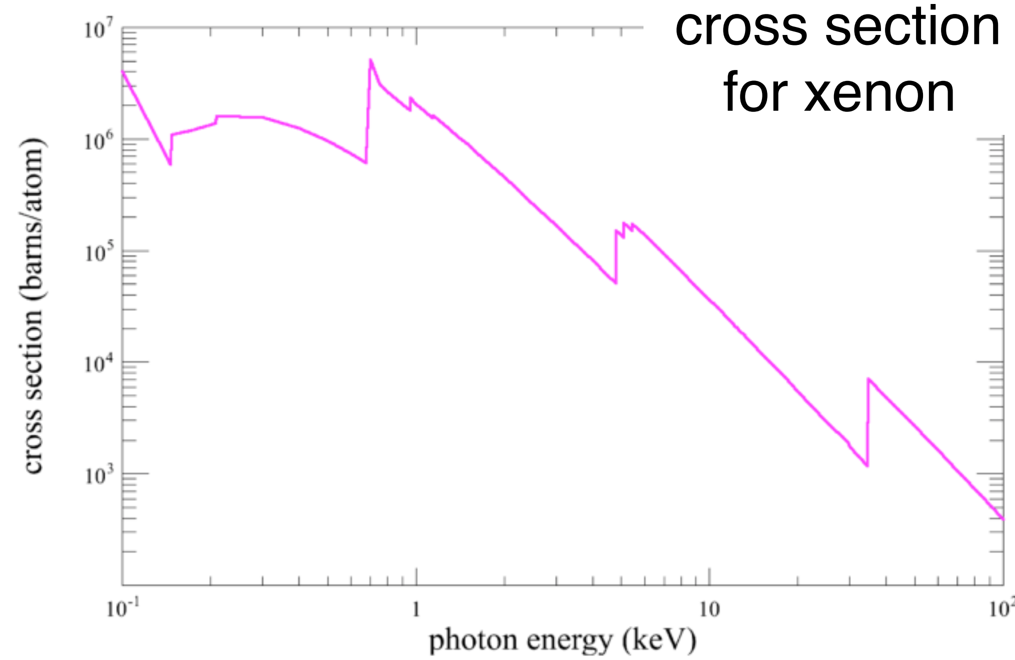


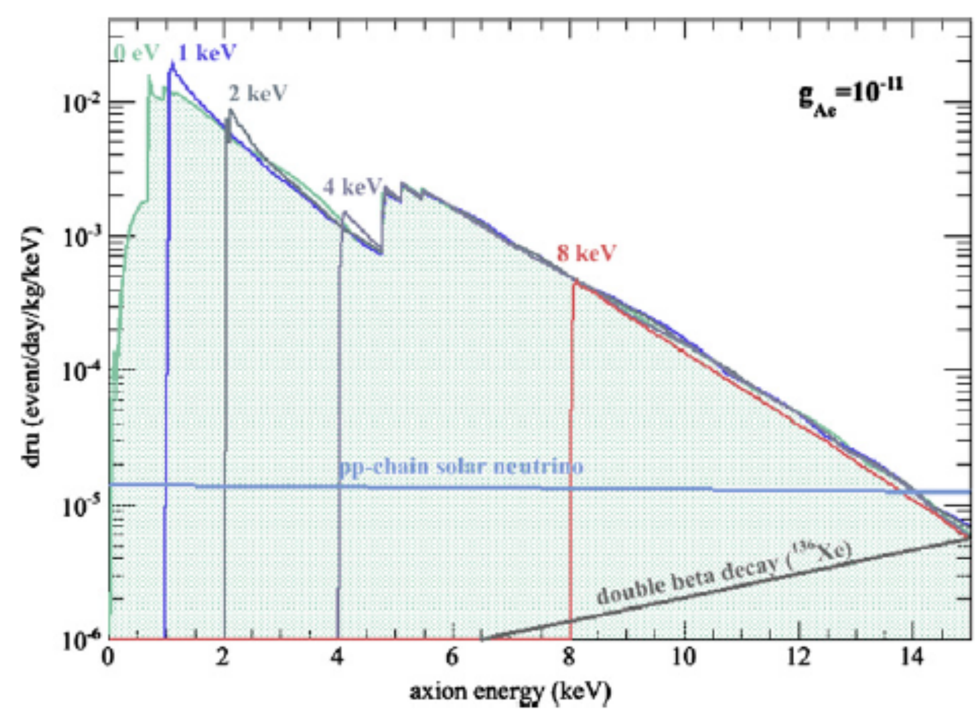
Valid up to 1 keV

$$\sigma_{Ae} = \sigma_{pe}(E_A)\frac{{g_{Ae}}^2}{\beta_A}\frac{3{E_A}^2}{16\pi\,\alpha_{em}\,{m_e}^2}\left(1-\frac{\beta_A^{2/3}}{3}\right)$$

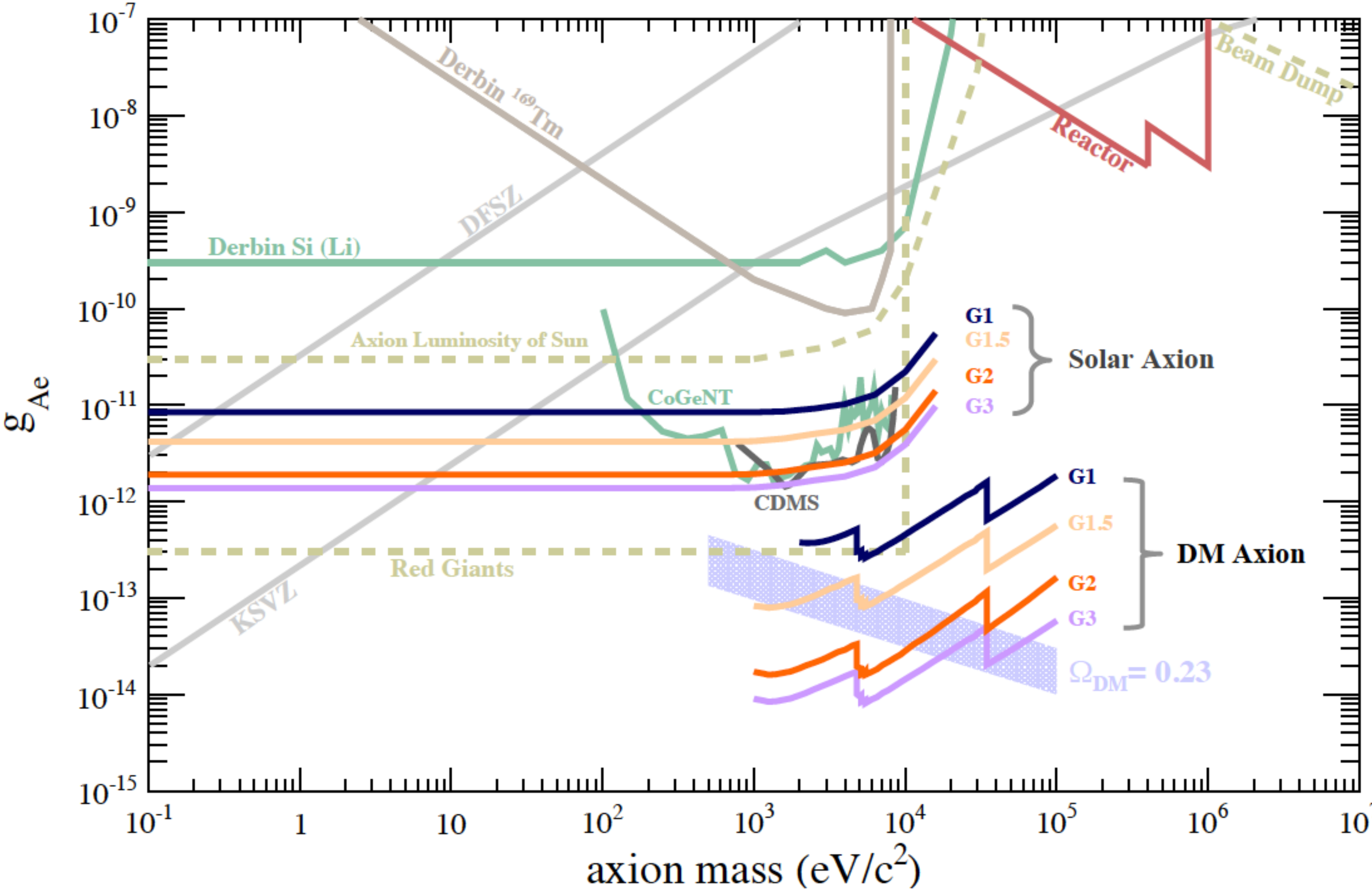
Detection within the detector

photo-electric cross section for xenon

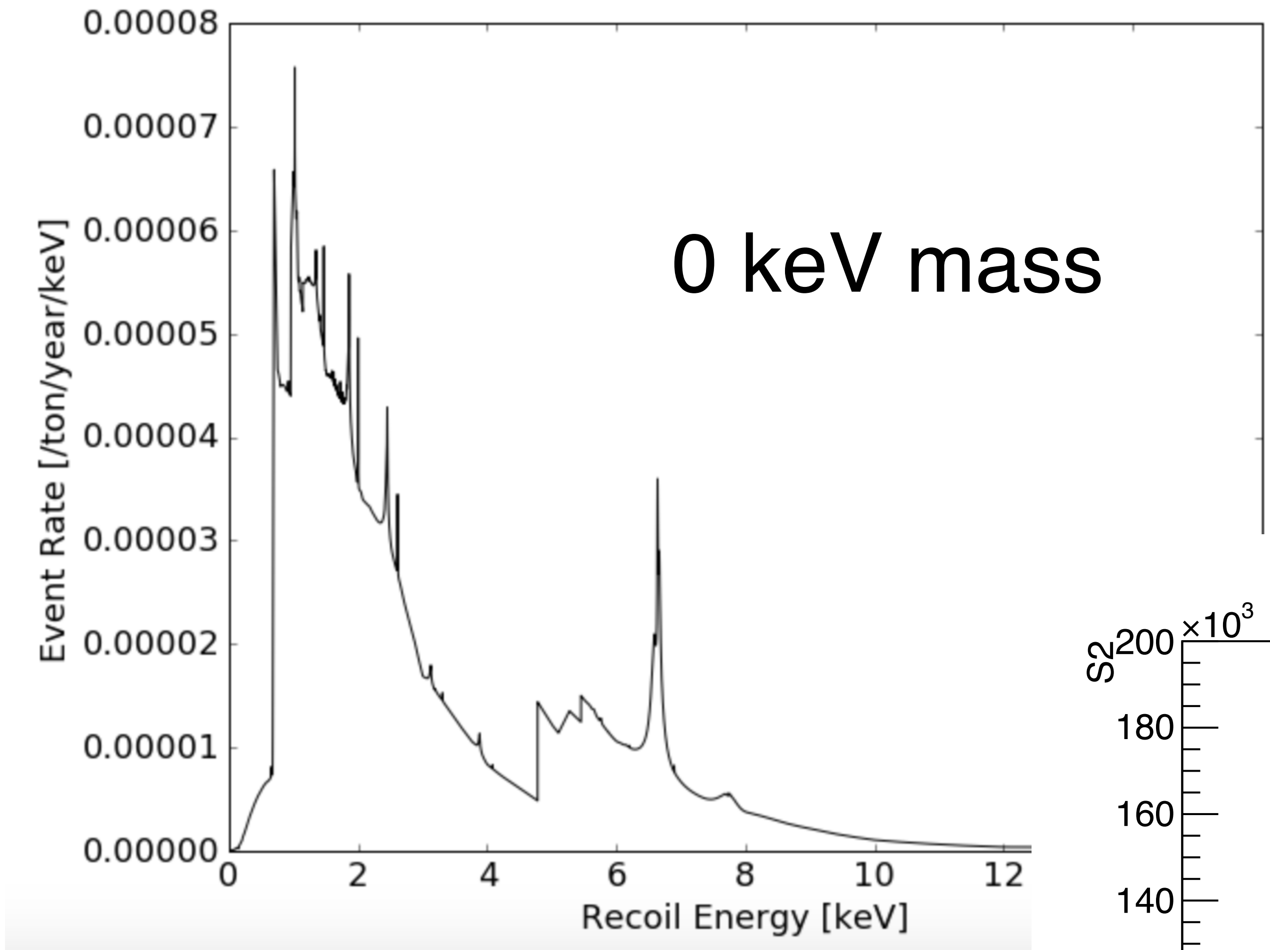


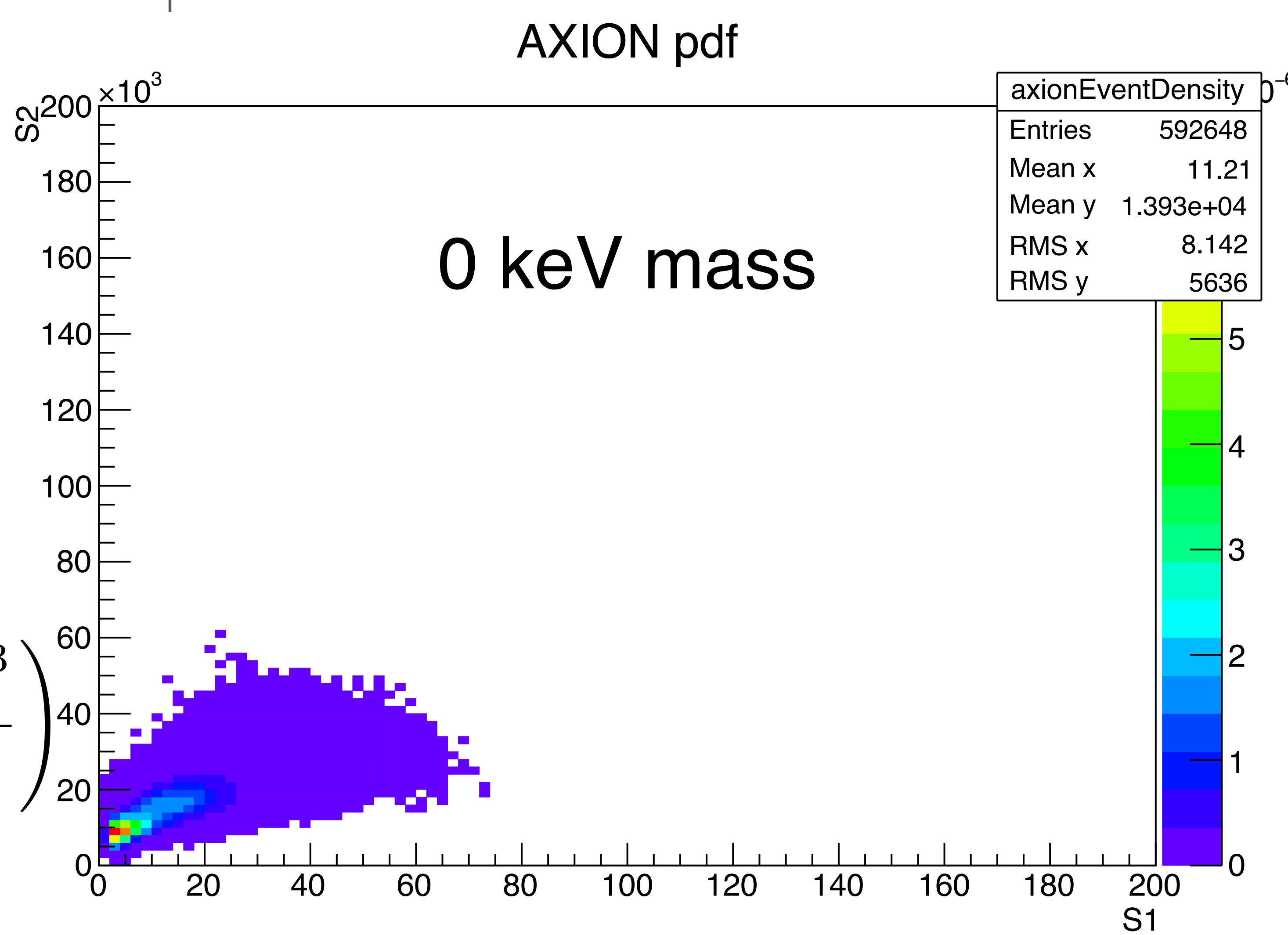


Astroparticle Physics 44 (2013) 59–67



Solar Axion





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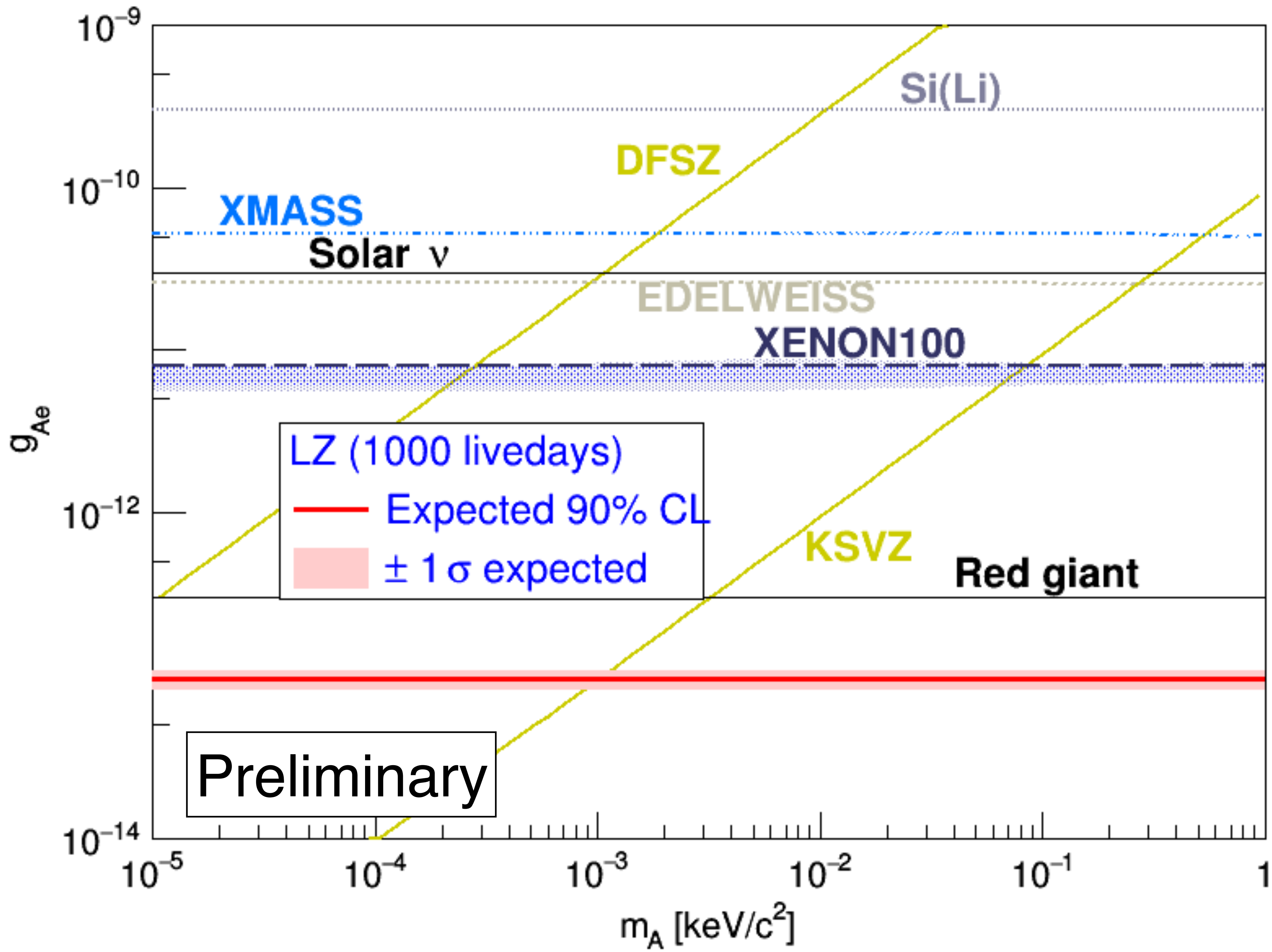
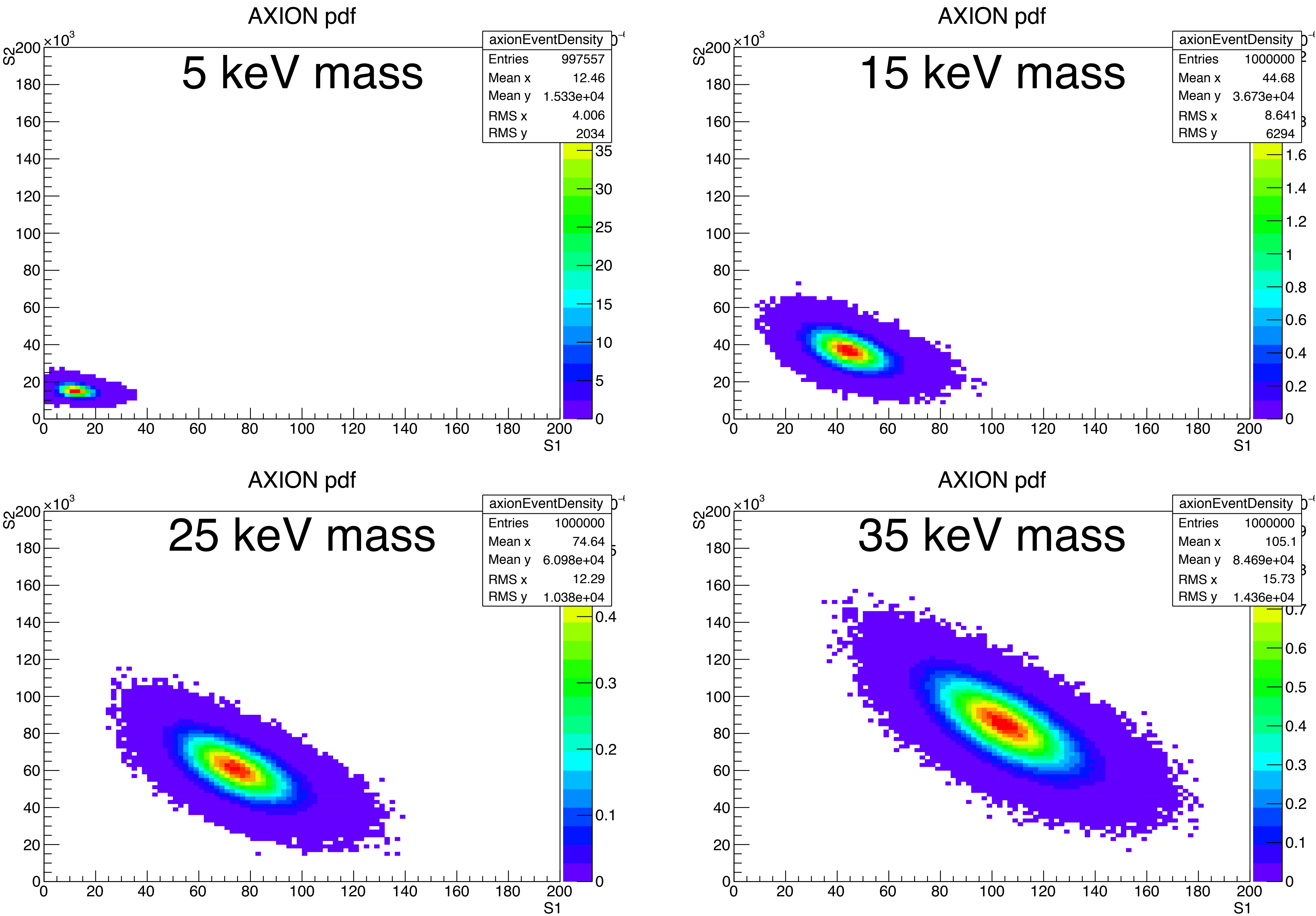


XMASS
Solar ν
Si(Li)
DFSZ
EDELWEISS
XENON100
LZ (1000 livedays)
Expected 90% CL
± 1 σ expected
KSVZ
Red giant
Preliminary
g_{Ae}
10^{-9}
10^{-10}
10^{-12}
10^{-14}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
m_A [keV/c^2]

Galactic ALPs



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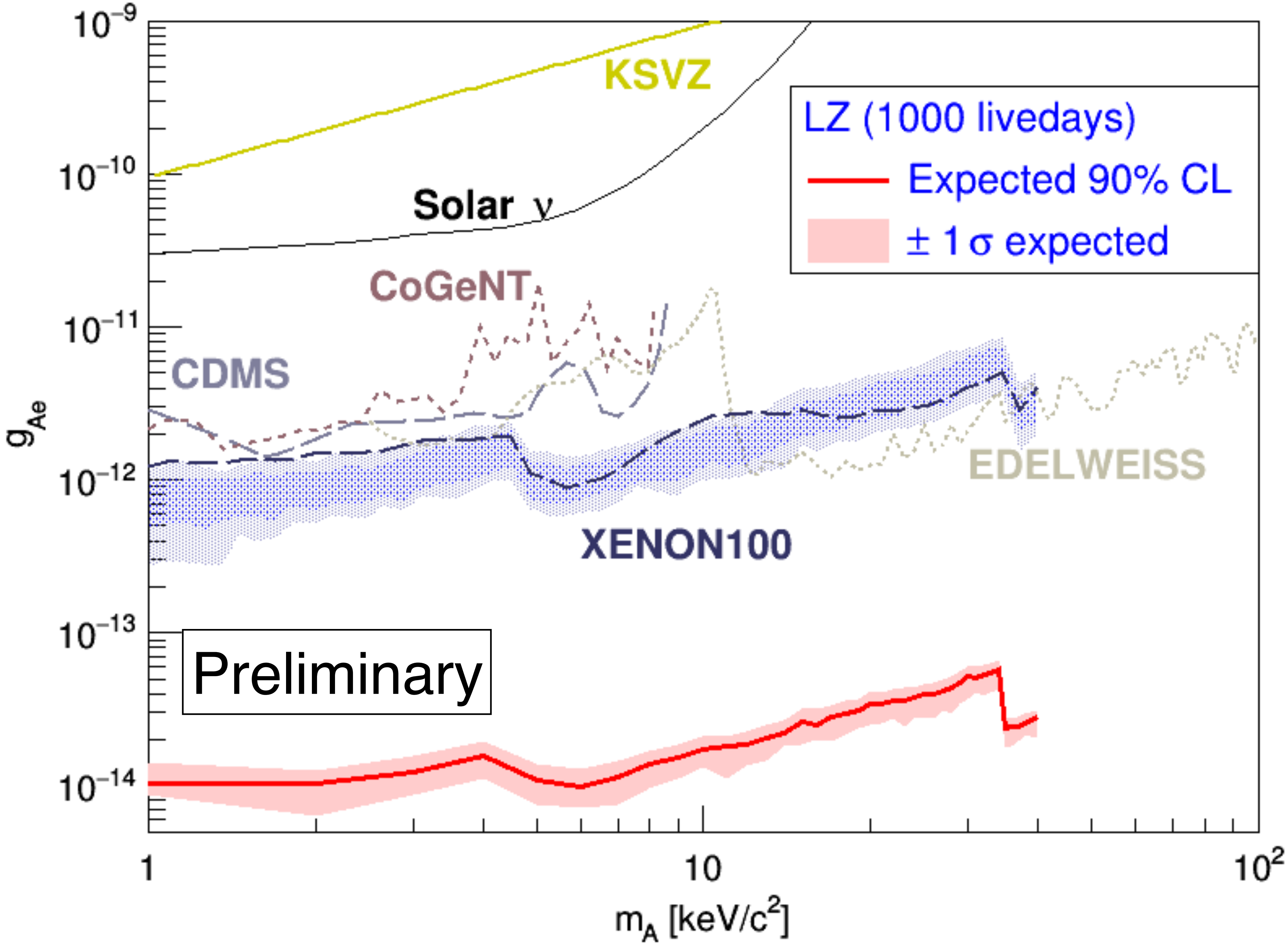

Summary

- Dual-phase Xe DM direct detector are suitable for axion searches
  - Proven by XENON100 (E. Aprile et al. (XENON100), Phys. Rev. D90 (2014), 062009)
- Sensitivity to g_{Ae}
- Issue: signal sitting exactly where the dominant background is (ER events)