Axion search prospects with the LZ experiment

Maria Francesca Marzioni

The University of Edinburgh

DM-UK Meeting, Oxford, 08-12-2014

Outline

- **Axions: why and how?**
- **LUX/ZEPLIN**
- **Profile Likelihood analysis**
- **Signal expected and projected sensitivity for both solar and galactic axions in the LZ expertiment**

Why have axions been introduced?

- CP violation is predicted by the Standard Model QCD
- But, CP violation in QCD has not been observed

Why have axions been introduced?

- CP violation is predicted by the Standard Model QCD
- But, CP violation in QCD has not been observed

- **Strong CPV problem**, solved by Peccei and Quinn: a new U(1) symmetry has been introduced
- This symmetry is spontaneously broken: the axion is the Nambu-Goldstone boson obtained as a result of that process

R. D. Peccei and H. R. Quinn, Phys. Rev. D 16, 17911797 (1977)

Axions: the current scenario

- The axion, as introduced by Peccei and Quinn, has been ruled out by observation
- BUT **«invisible» axions** are still allowed and could be **QCD axions**

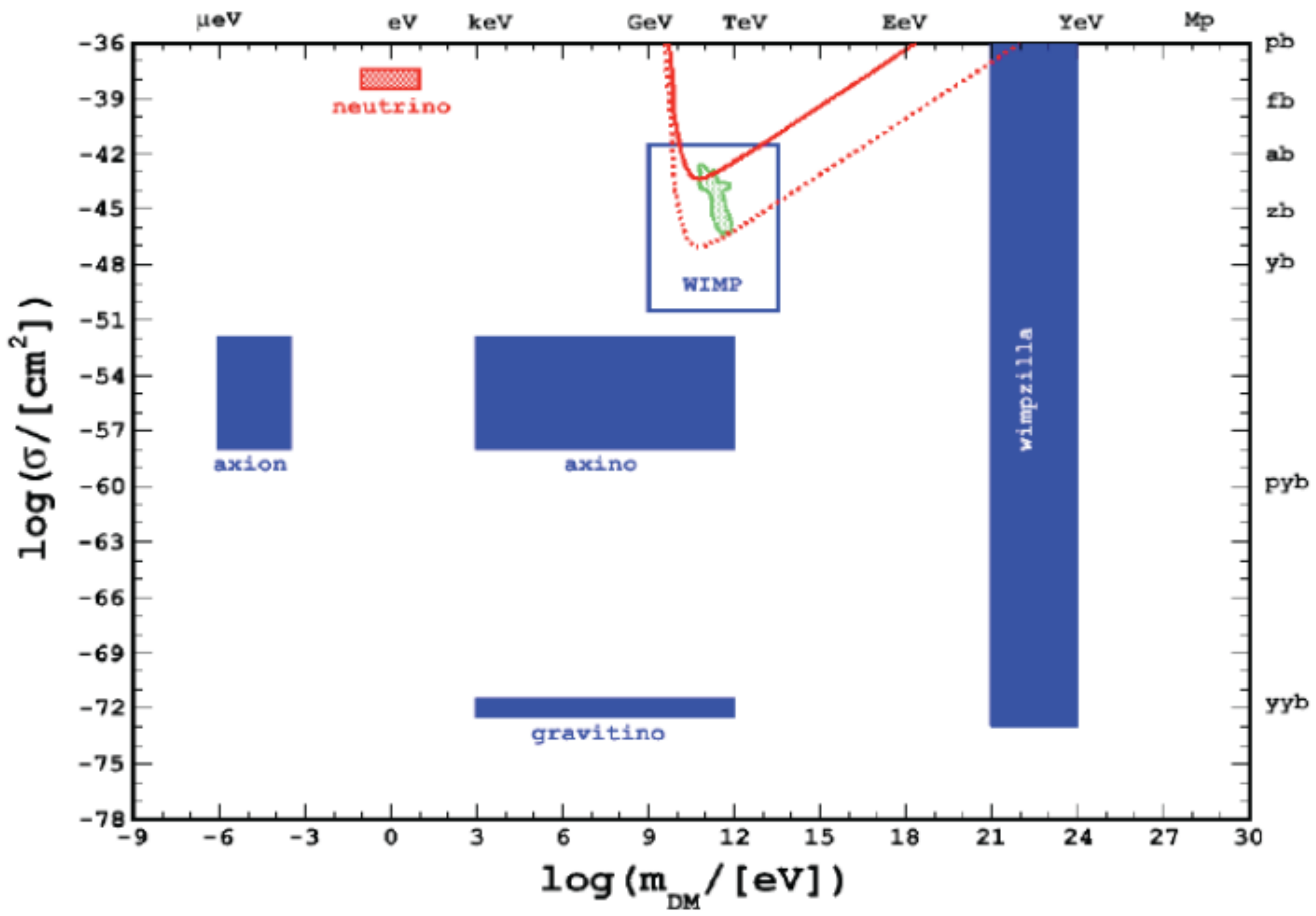
$m_A = 6\ eV (10^6\ GeV / f_A)$

Due to their extremely weak couplings and lower masses than postulated by PQ

The simmetry is spontaneously broken at the energy scale f_A

- AND **extensions of the Standard Model** also introduce the axion-like particles (**ALPs**)

Why are we interested in axions?



From theory to experimental detection with Xenon

Theory

QCD axions could solve the CPV problem within some theoretical model

ALPs could be dark matter particles

From theory to experimental detection with Xenon

Theory

QCD axions could solve the CPV problem within some theoretical model

ALPs could be dark matter particles

Solar axions (produced via Bremsstrahlung, Compton scattering, axio-recombination and axio-deexcitation): **interaction rate scales with g_{Ae}^{4}**

Galactic ALPs (produced within the early universe, via a non-thermal mechanism): **interaction rate scales with g_{Ae}^{2}**

Experimental Detection

From theory to experimental detection with Xenon

Theory

QCD axions could solve the CPV problem within some theoretical model

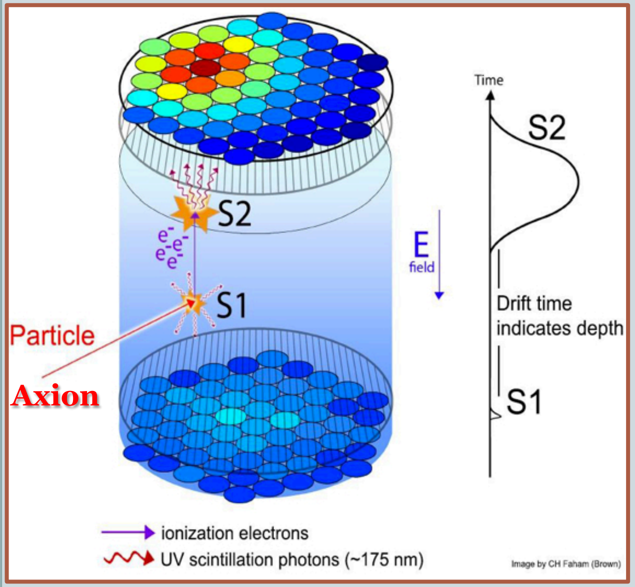
ALPs could be dark matter particles

Solar axions (produced via Bremsstrahlung, Compton scattering, axio-recombination and axio-deexcitation): **interaction rate scales with** g_{Ae}^4

Galactic ALPs (produced within the early universe, via a non-thermal mechanism): **interaction rate scales with** g_{Ae}^2

Experimental Detection

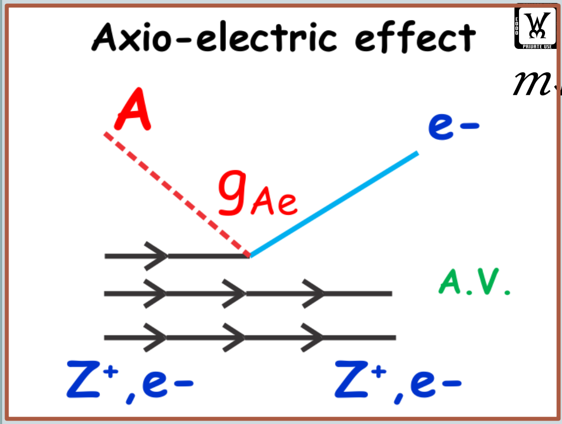
Axions detection: axio-electric effect



- Measurement of **coupling** between axions or ALPs and electrons (***g_{Ae}***)
- Axion signal: **electronic recoil (ER)** scattering

Axio-electric effect:

just like the photo-electric effect, but with an axion absorbed instead of a photon

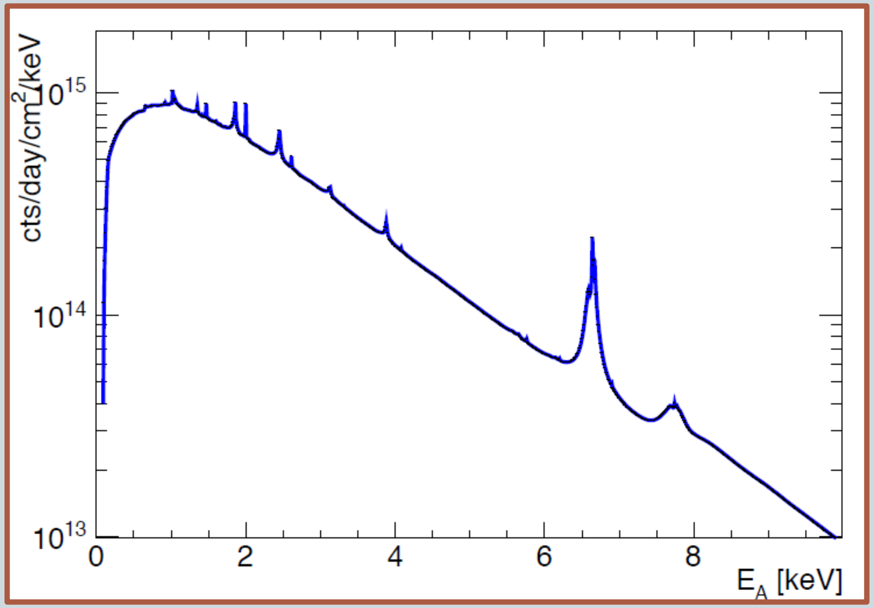


$$\sigma_{Ae} = \sigma_{pe}(E_A) \frac{g_{Ae}^2}{\beta_A} \frac{3E_A^2}{16\pi\alpha_{em} m_e^2} \left(1 - \frac{\beta_A^{2/3}}{3}\right)$$

F. T. Avignone and al., Phys. Rev. D 35, 2752 (1987);
M. Pospelov and al., Nucl. Rev. D 78, 115012 (2008);
A. Derevianko and al., Phys. Rev. D 82, 065006 (2010)

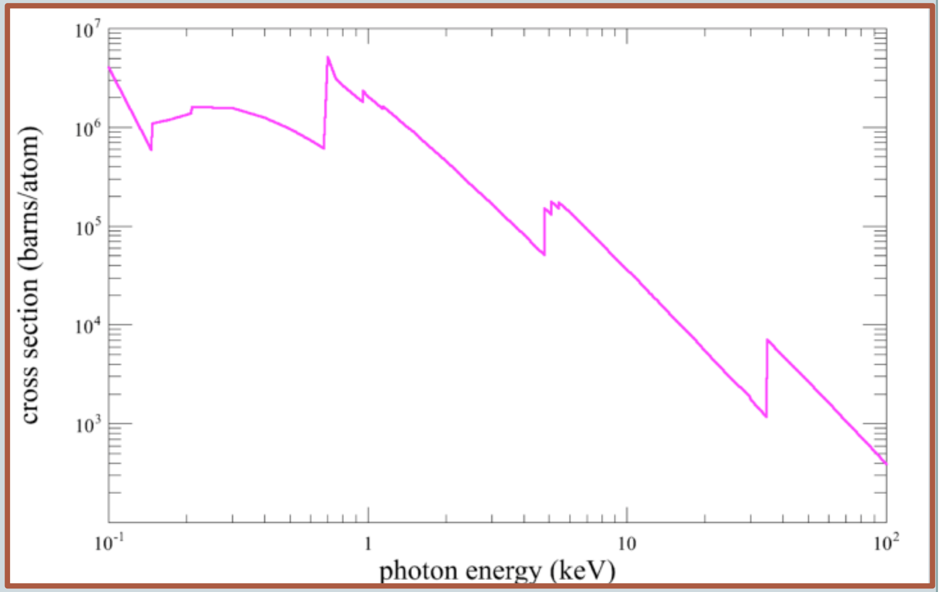
Solar axions

Solar axions flux



J. Redondo, JCAP12 (2013) 008

Photo-electric cross section on Xenon



The expected rate is obtained as a **convolution** of the solar axions flux and the axio-electrict cross section (proportional to the photo-electric one)

LUX/ZEPLIN (LZ)

- WIMP signal: nuclear recoil (NR) scattering
- Axion signal: **electronic recoil (ER) scattering**

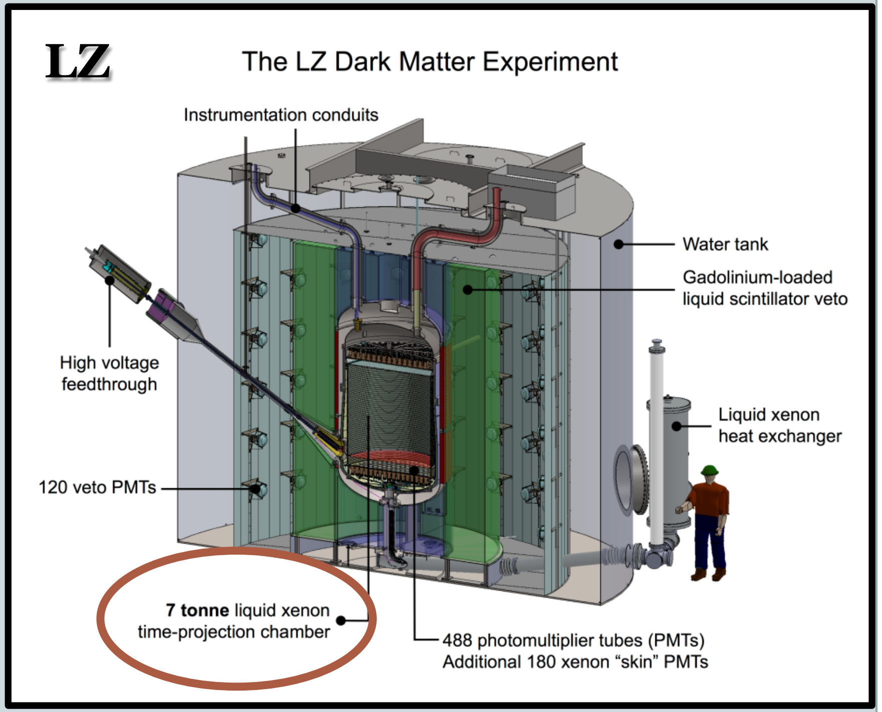
Assumptions:

✓ Exposure: 5600 kg x 1000 live days

✓ Background: astrophysical neutrinos + subdominant component from detector (total ~ 10 μdru flat)

✓ Analysis method: Profile Likelihood Ratio

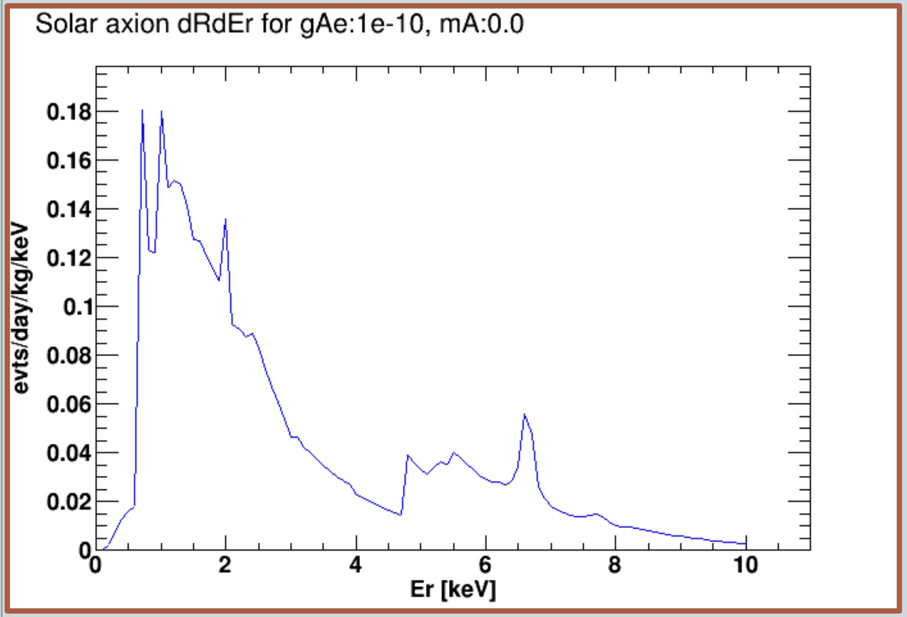
[By definition: dru = counts/keV/kg/day]



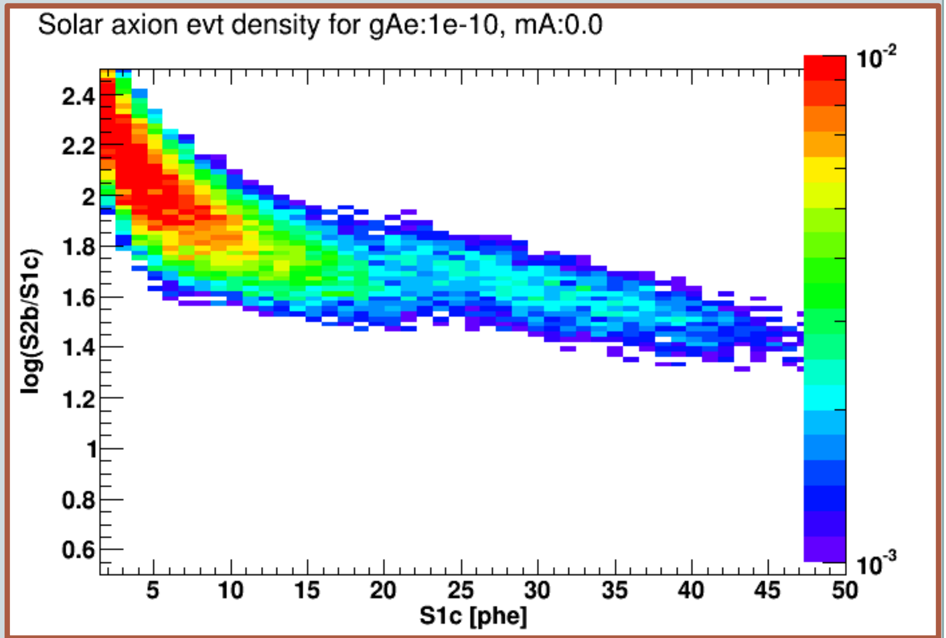
Solar Axions

Spectrum

dR/dEr



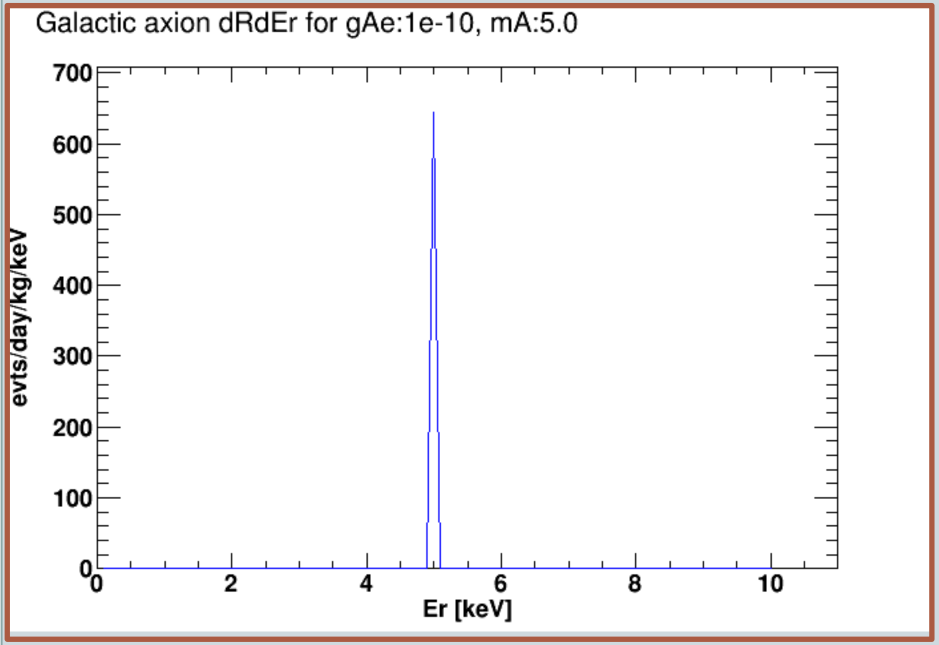
Expected signal in the observable phase space (log(S2/S1) vs S1)



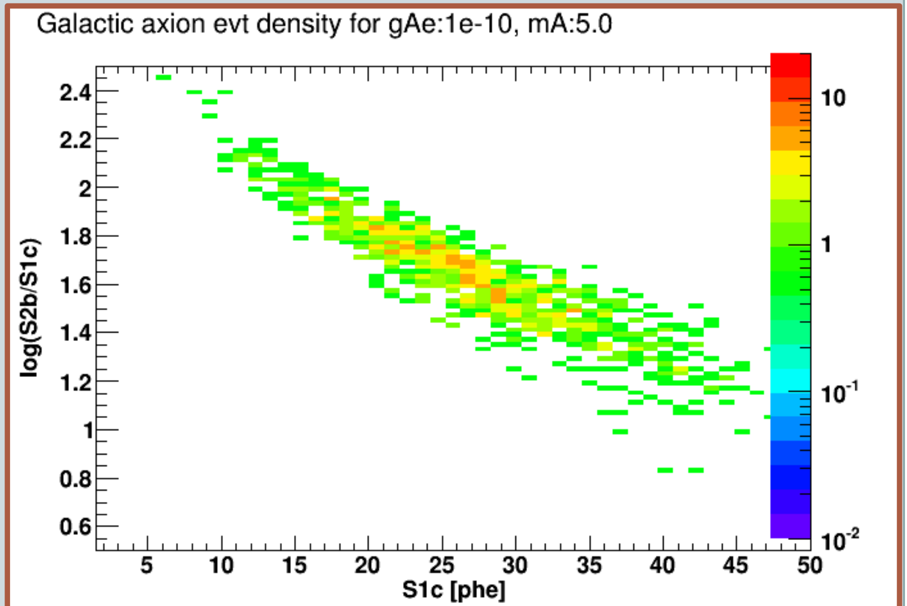
Galactic axions

Spectrum

dR/dEr $@m_A = 5\ keV$



Expected signal in the observable phase space (log(S2/S1) vs S1)



Profile Likelihood

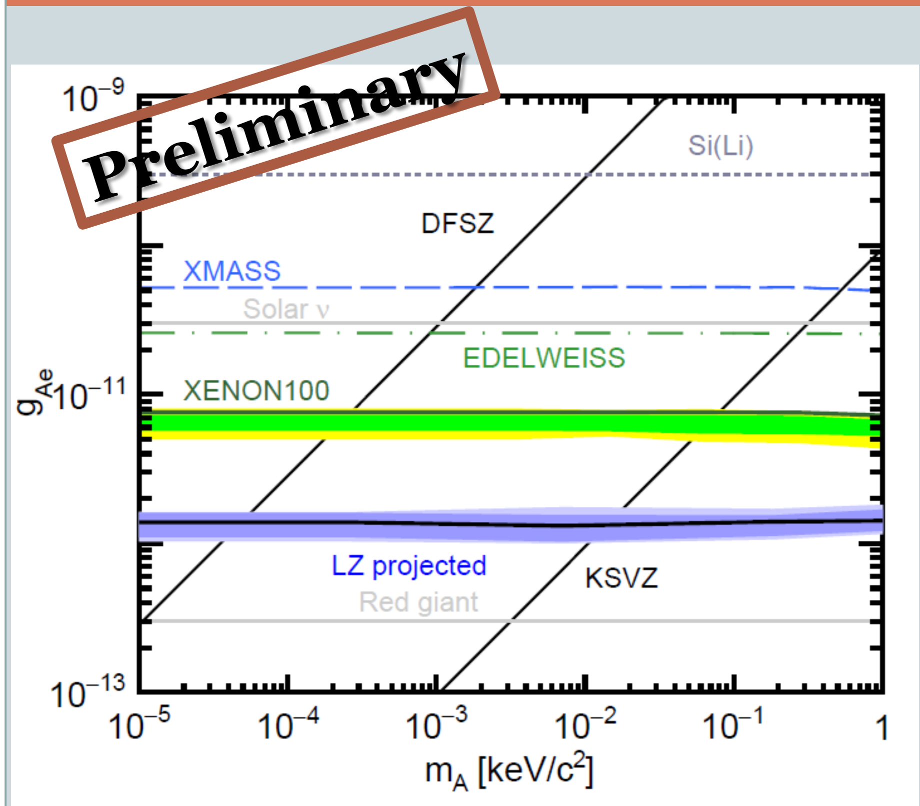
- Goal: using a **version of LUX PLR** (2013), optimized for axions search
  - Observables: x = [r, z, S1, log_{10} (S2/S1)]

- What follows comes from a simplified PLR, based on a reduced number of parameters, since **work is still in progress…**
- Test statistics:

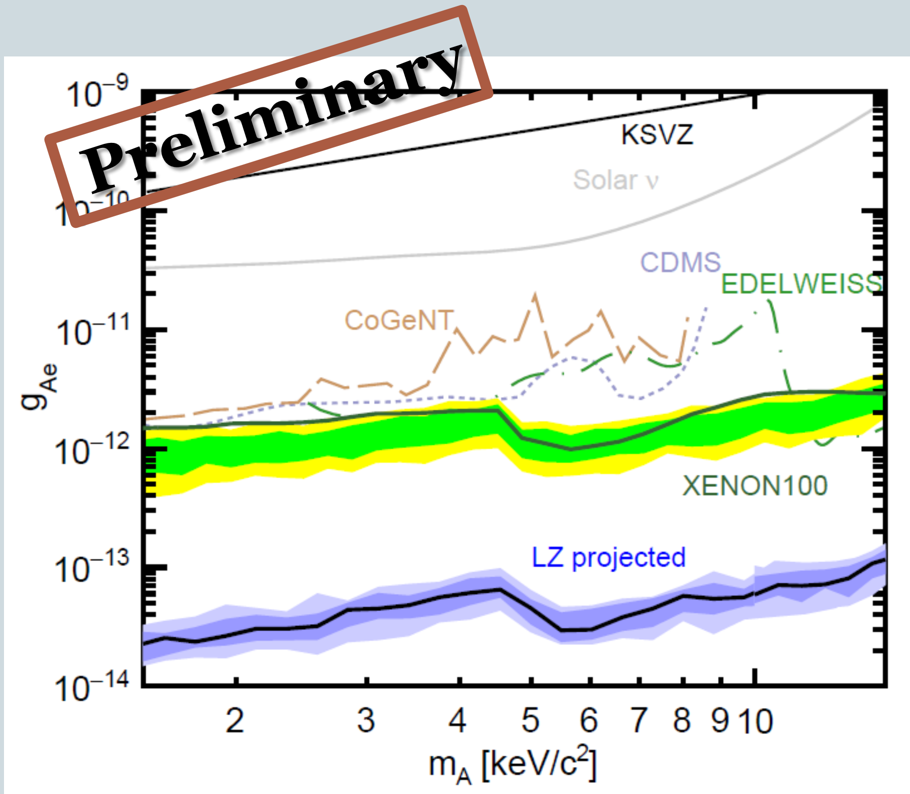
$$q(g_{Ae}) = -2\log\lambda(g_{Ae}) = -2\log L(g_{Ae}, \hat{\hat{\theta}}) / L(\hat{g}_{Ae}, \hat{\theta})$$

Projected sensitivity

Solar Axions



Galactic Axions



Summary

- ALPs are suitable dark matter candidates
- Xenon detectors (such as LUX and LZ) present suitable characteristics to test phase-spaces still unexplored, by measuring the coupling g_{Ae}
- **We are working on axions analysis framework** (detector response, simulation, PLR,…) for both LUX (real data) and LZ (case study)

Thanks for your attention!

Backup

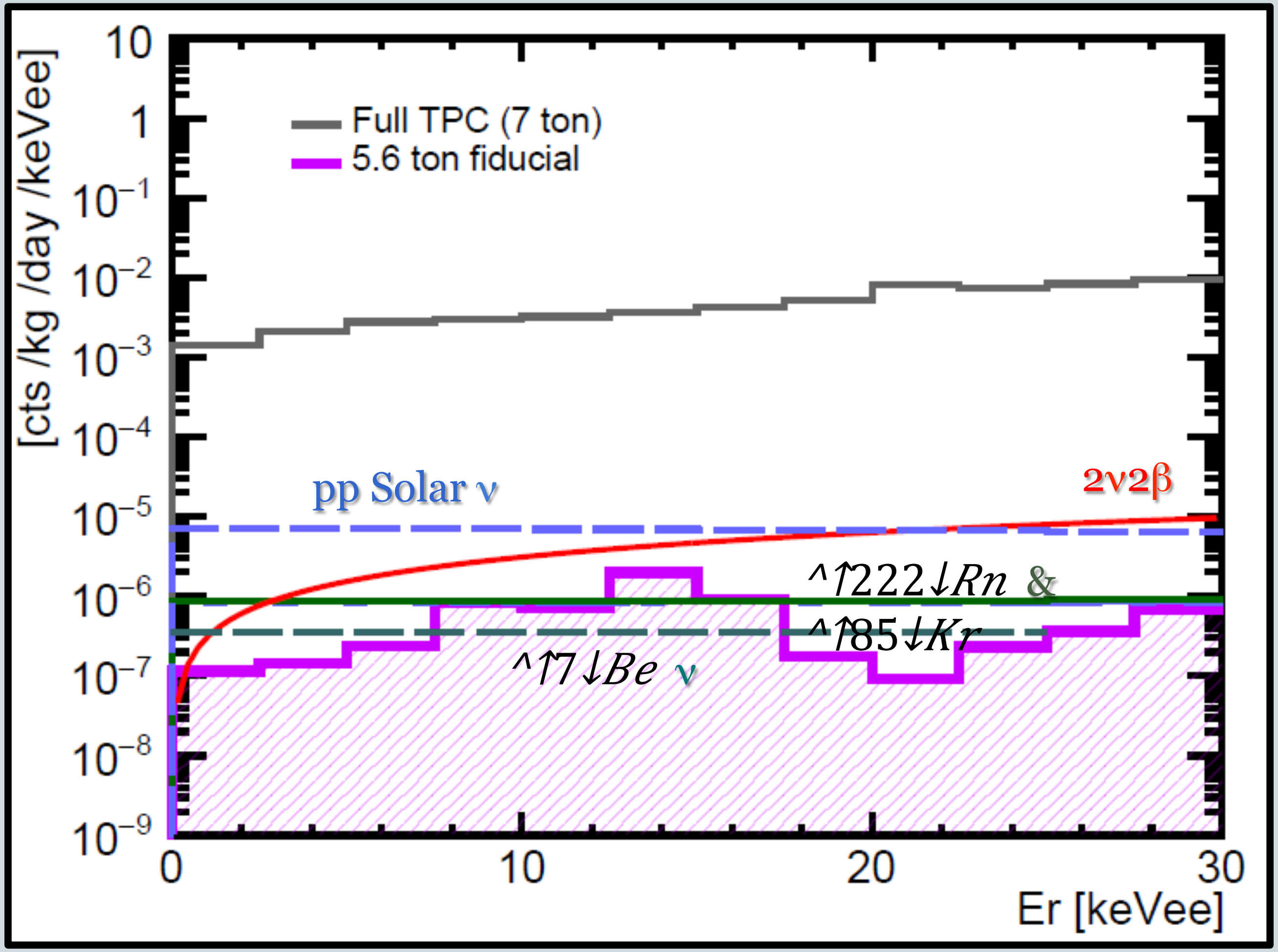
Theoretical QCD Axion Models

- **«Invisible» axions** are allowed if PQ symmetry is spontaneously broken at a much higher energy scale f_A:

❖ KSVZ model → Axion as the phase of a new electroweak singlet scalar field. Axions coupled to a new heavy quark, not to SM ones.

❖ DFSZ model → Axion does not couple directly to quarks and leptons, but via its interaction with two Higgs doublets.

Background

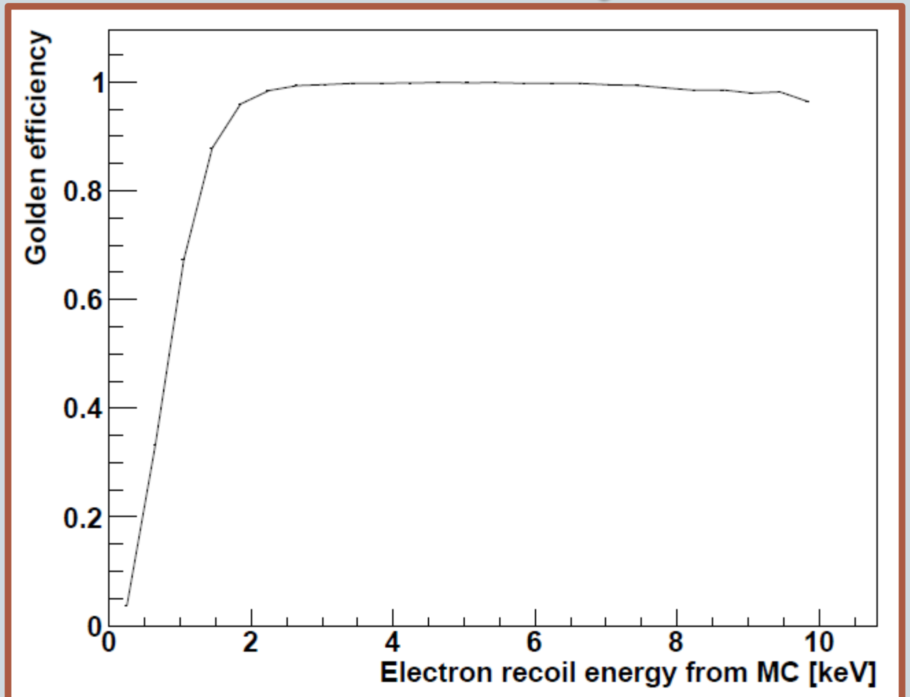


Full TPC (7 ton)
5.6 ton fiducial
[cts /kg /day /keVee]
Er [keVee]
pp Solar ν
2ν2β
^↑222↓Rn &
^↑85↓Kr
^↑7↓Be ν

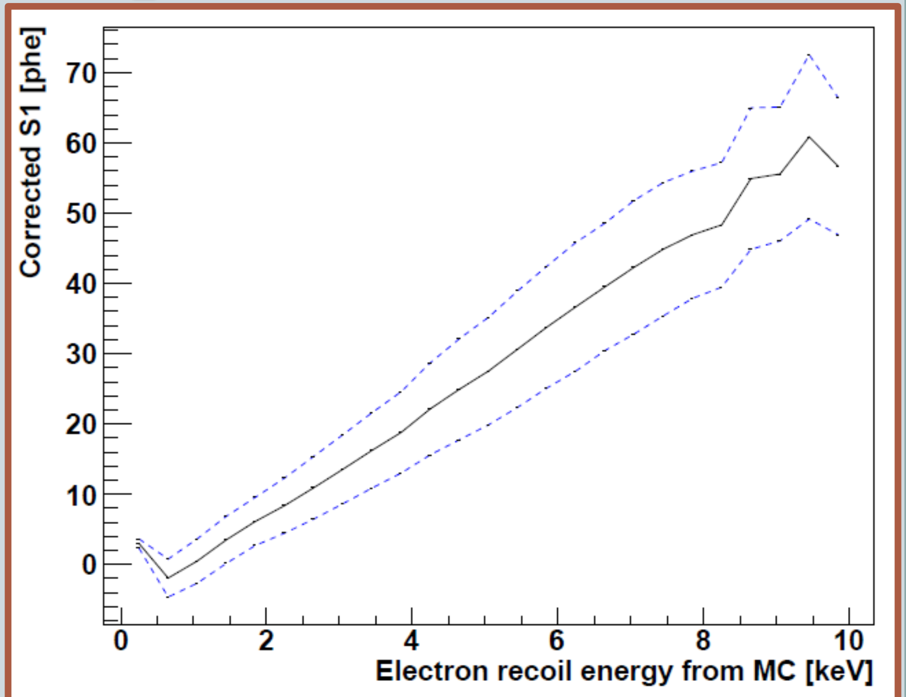
Assumptions for the sensitivity estimation

- We assume a flat background of 10 μdru

- **Efficiency**

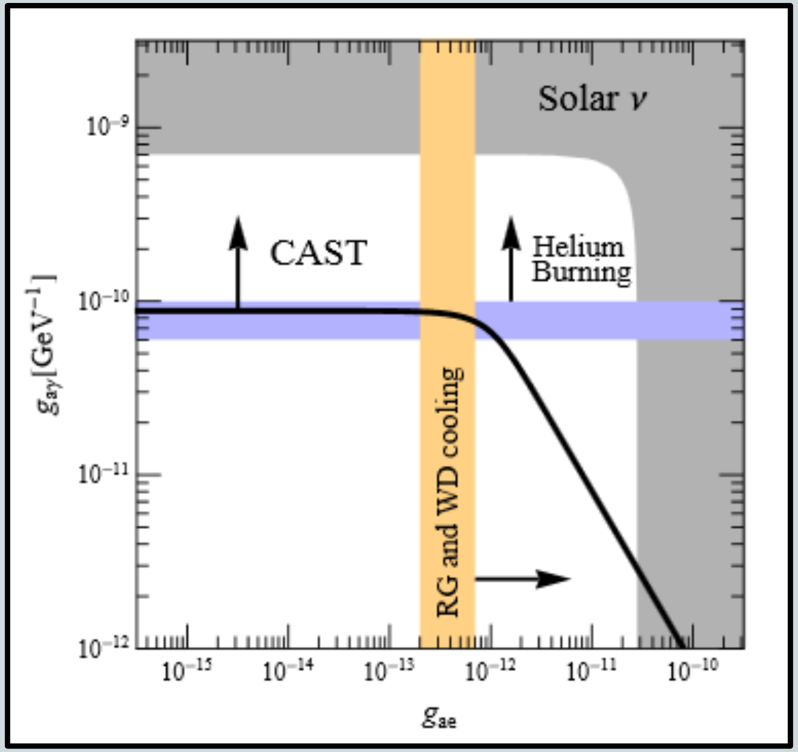


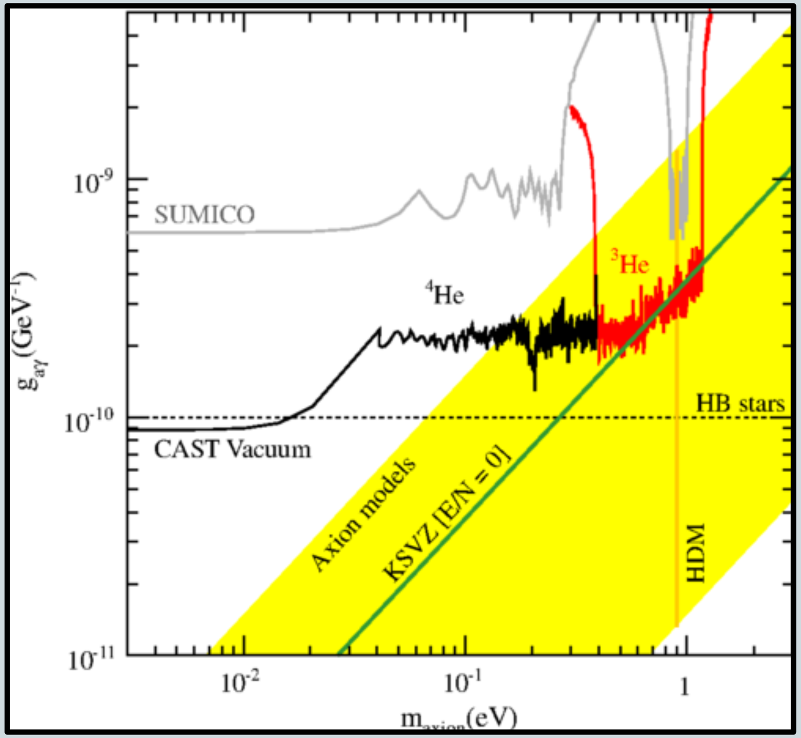
- **Conversion from photoelectrons to keV**



The CERN Axion Solar Telescope (CAST) results

- CAST tests the coupling to photons ($g_{A\gamma}$)
- Conversion of limit on coupling into limit on axion mass



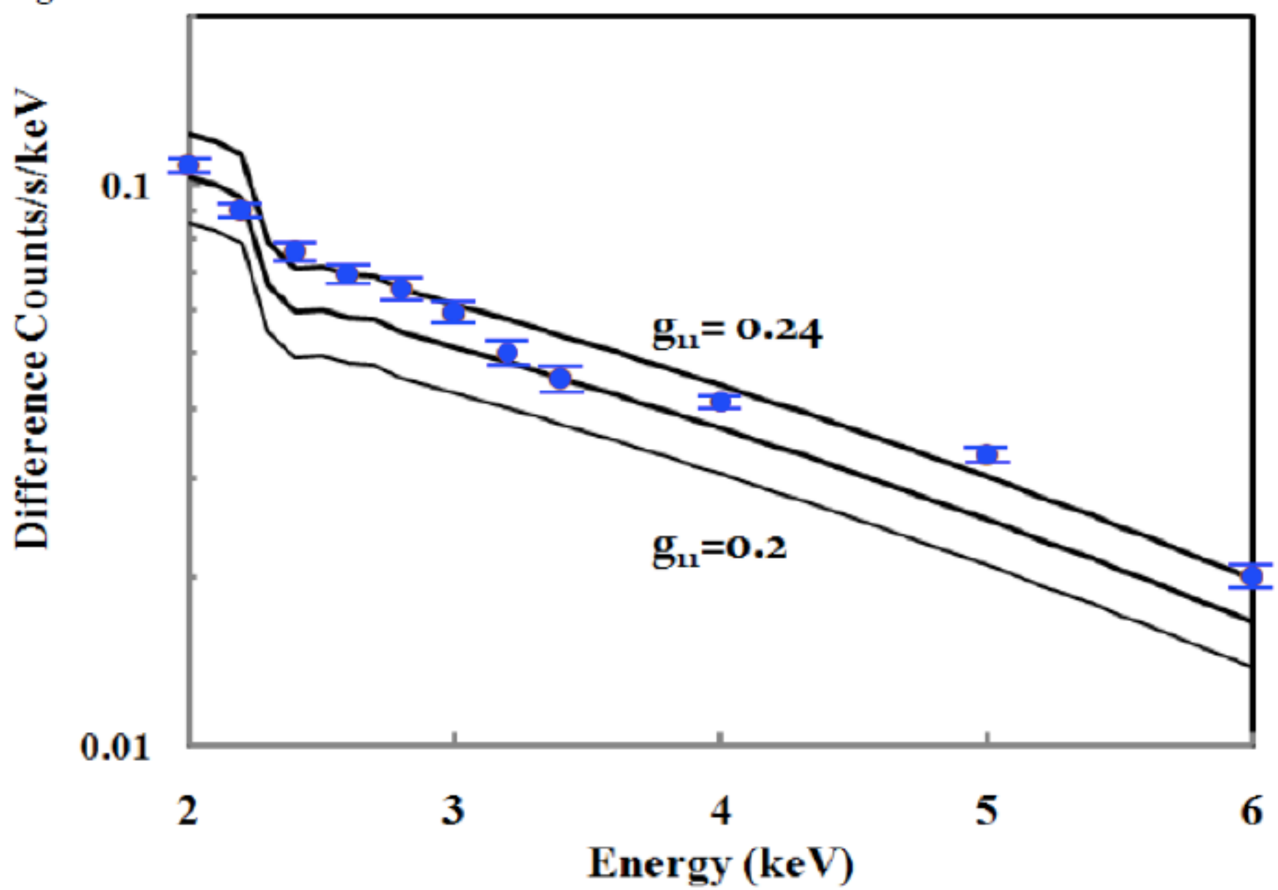


K. Barth et al., JCAP05 (2013) 010

M. Arik et al., Phys. Rev. Lett. 112, 091302 (2014)

Potential solar axion signatures with the XMM-Newton observatory

Fig. 20.



G.W. Fraser et al. (2014), arXiv:1403.2436