SEARCHES OF AXIONS/ALPS WITH (Baby)IAXO

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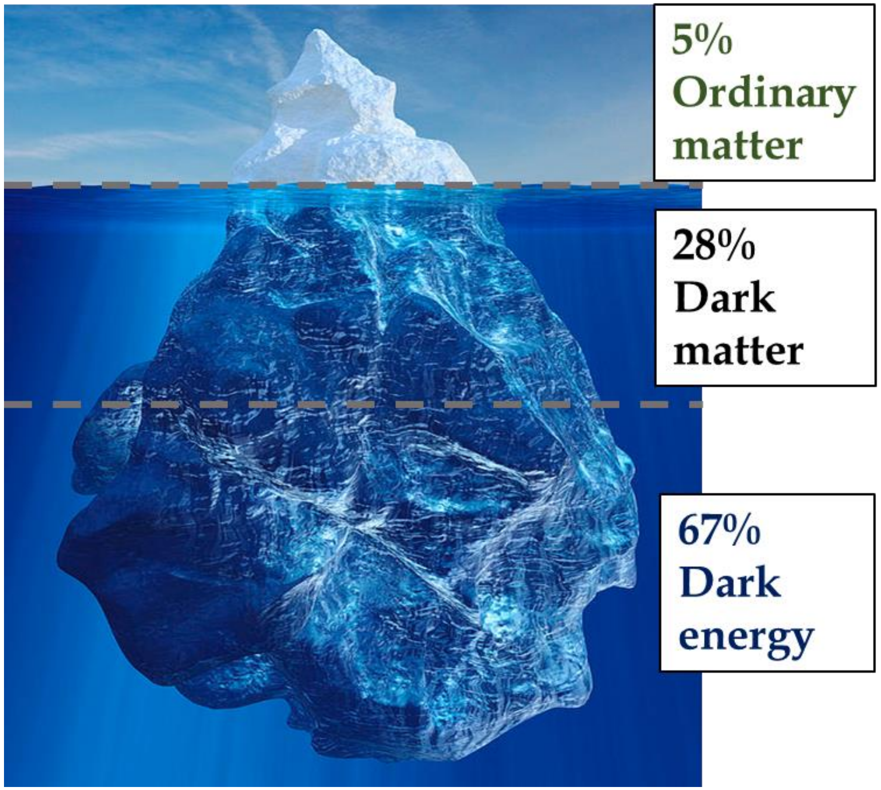
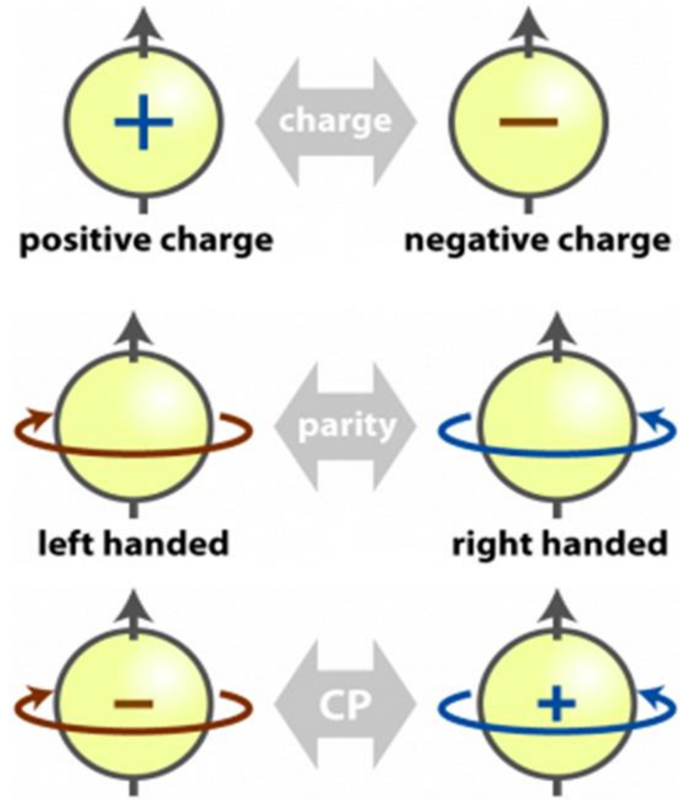
Centro de Astropartículas y Física de Altas Energías
Universidad Zaragoza

AXIONS AND ALPS

The Dark Matter problem

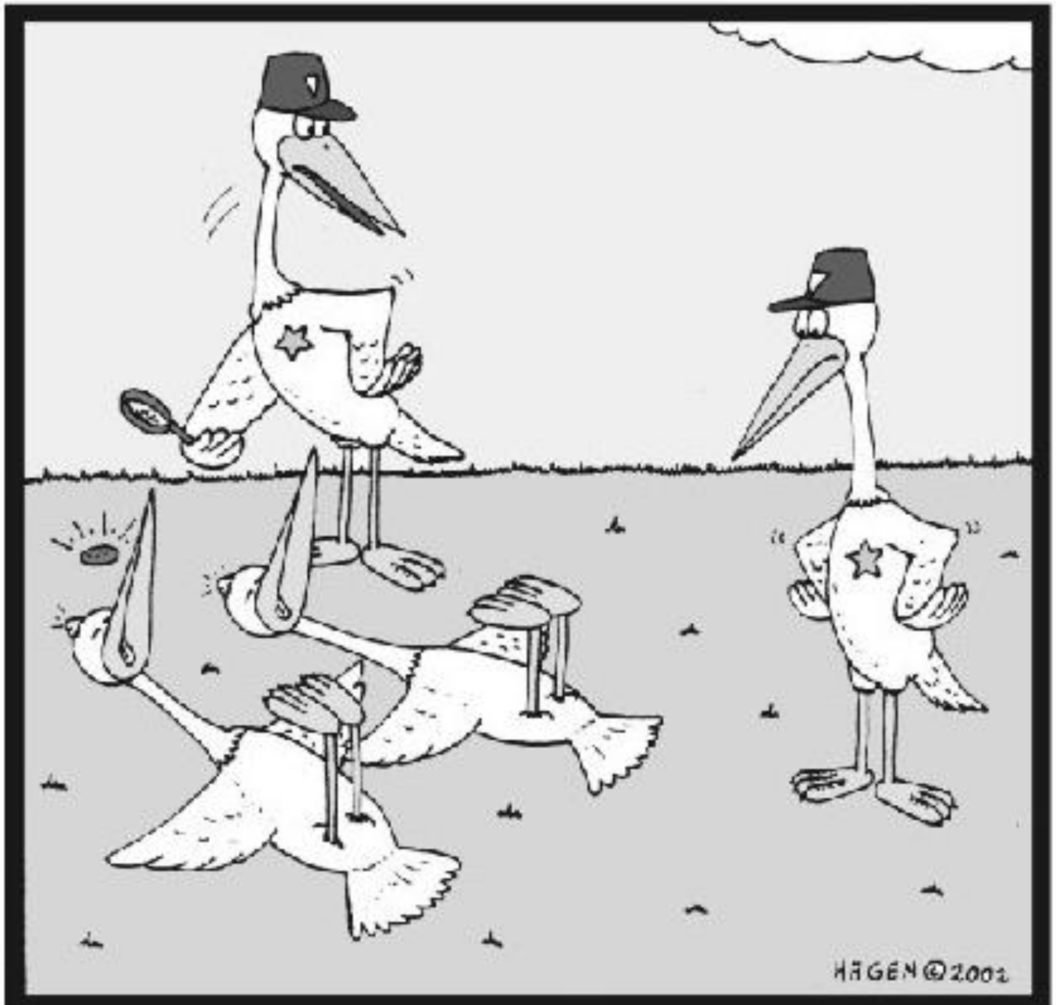


The strong-CP problem



AXIONS AND ALPS

The Peccei-Quinn solution



Unbelievable! It looks like they've both been killed by the same stone...

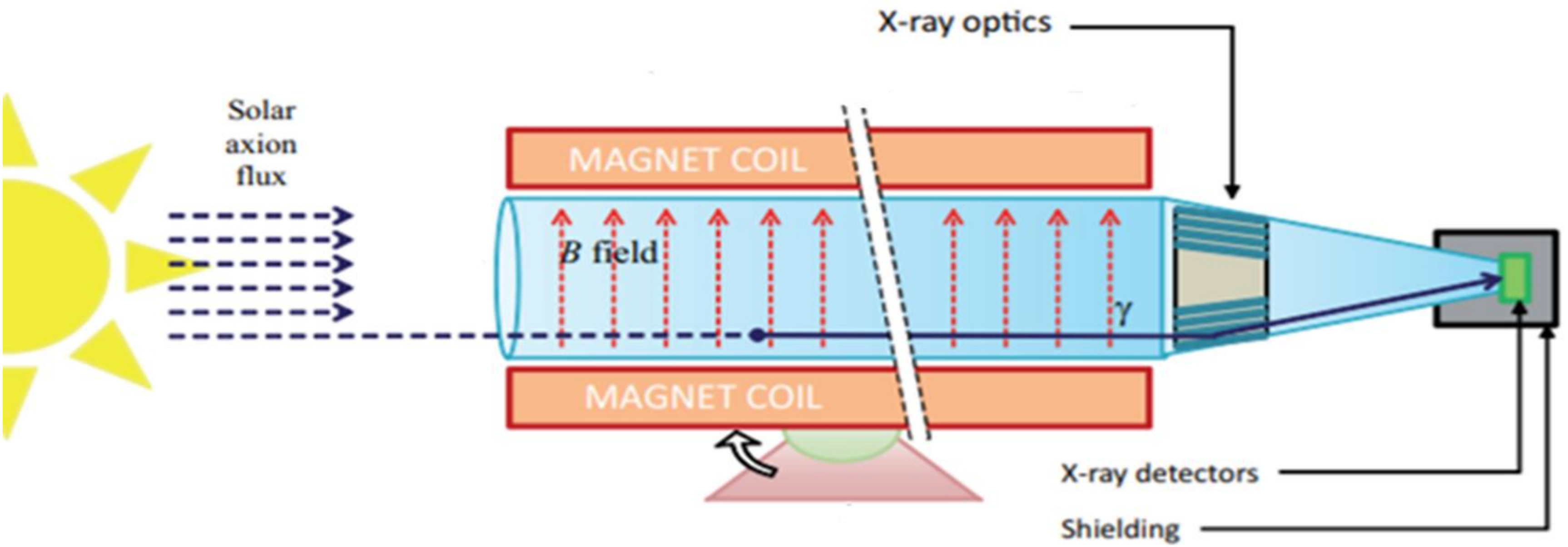
The axion

Killing two birds with one ~~stone~~ particle:

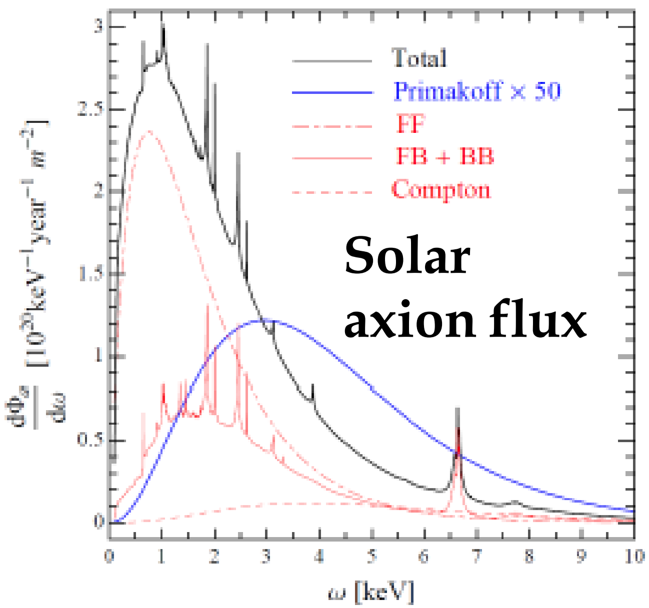
1. Solves the strong-CP problem
2. Can solve the Dark Matter problem

Axion Like Particles (ALPs) arises from other symmetries in extensions of the Standard Model. Although, with different properties they share the same phenomenology of axions.

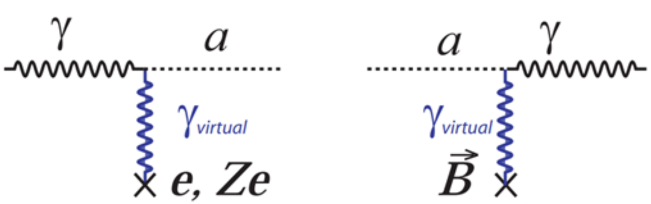
THE HELIOSCOPE TECHNIQUE



Solar axion emission spectra

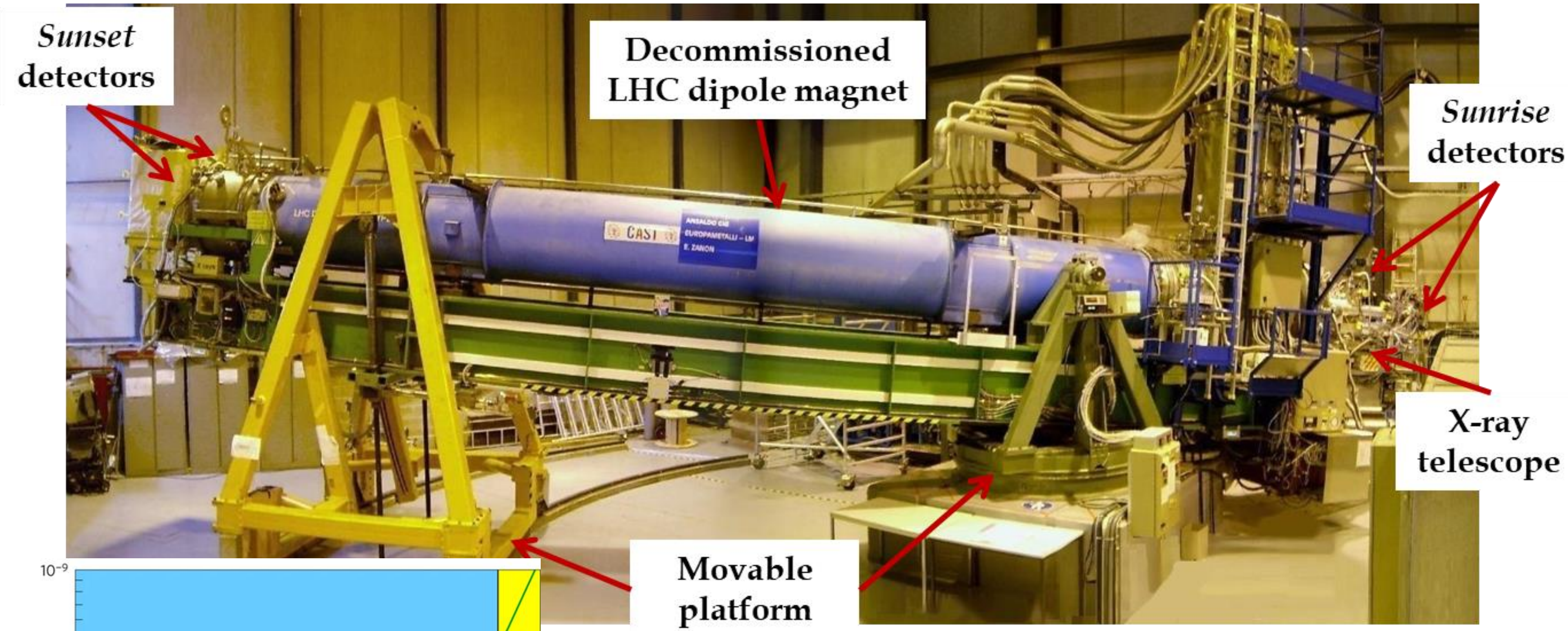


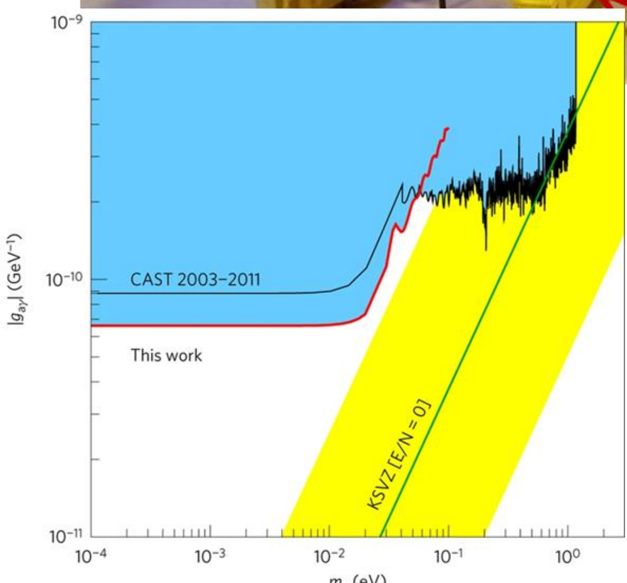
The Primakoff effect



THE HELIOSCOPE TECHNIQUE

CAST is the most sensitive helioscope so far…

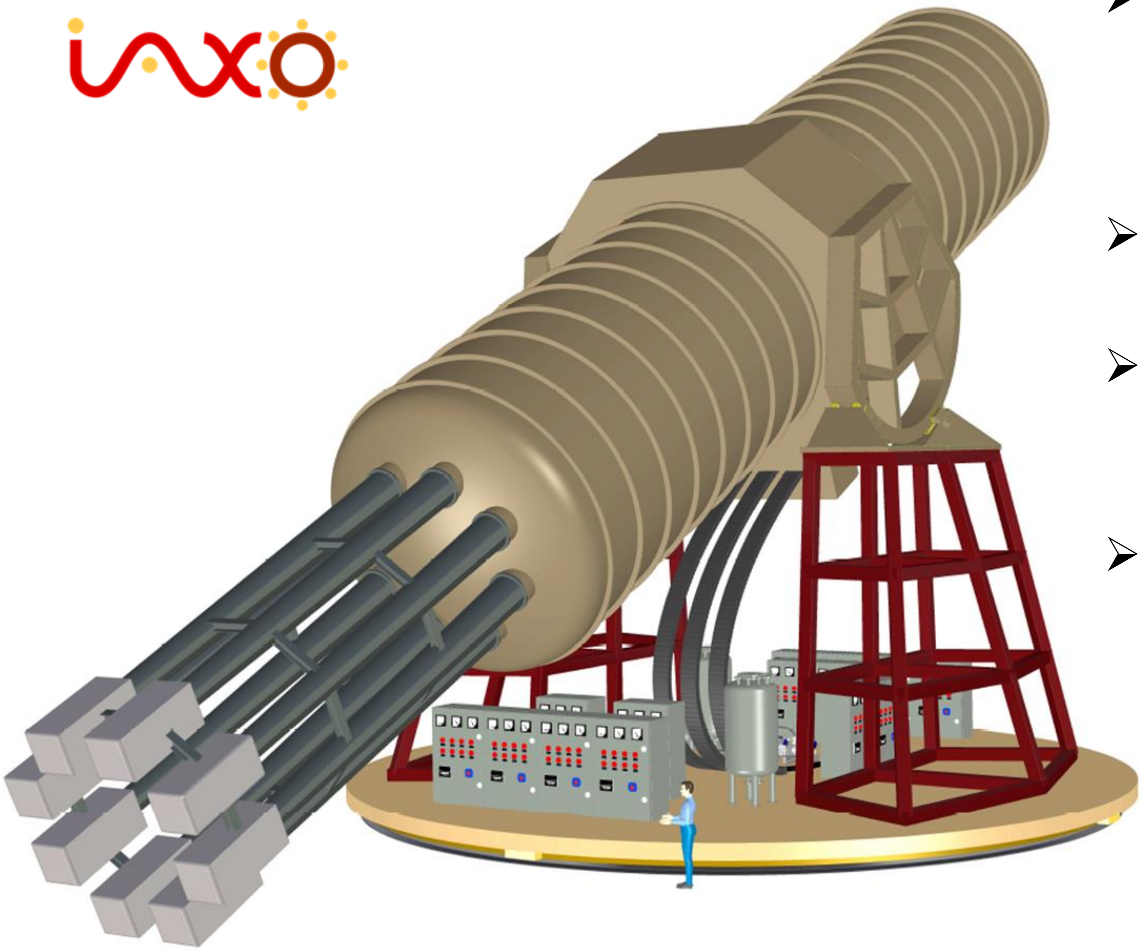




Coupling limit m_a < 0.01 eV
$|g_{a\gamma}|$ < 0.66×10^{-10} [GeV^{-1}] (95% C.L.)

[10.1038/nphys4109](https://doi.org/10.1038/nphys4109)

IAXO-The International Axion Observatory



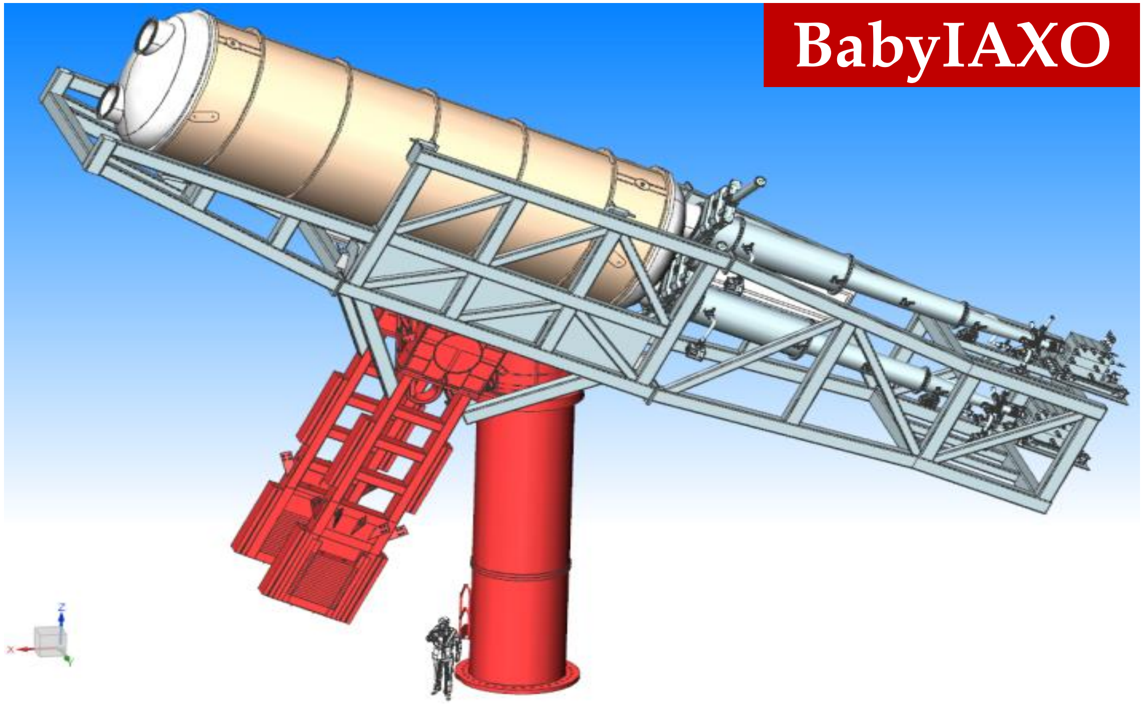
- Super toroidal magnet
  - 20 meters long
  - Magnetic field up to 5.4 T
  - 8 bores of 60 cm Ø
- Dedicated X-ray optics
  - 0.2 cm^2 focal spot
- Tracking system
  - Based on gamma ray telescopes
  - 50% of Sun-tracking time
- X-ray detector technologies
  - Micromegas
  - GridPix
  - Metallic Magnetic Calorimeters (MMC)
  - Transition Edge Sensors (TES)
  - Silicon Drift Detectors (SDD)

CERN-SPSC-2013-022

IAXO aims to improve CAST sensitivity to solar axions in 1 order of magnitude!

BabyIAXO

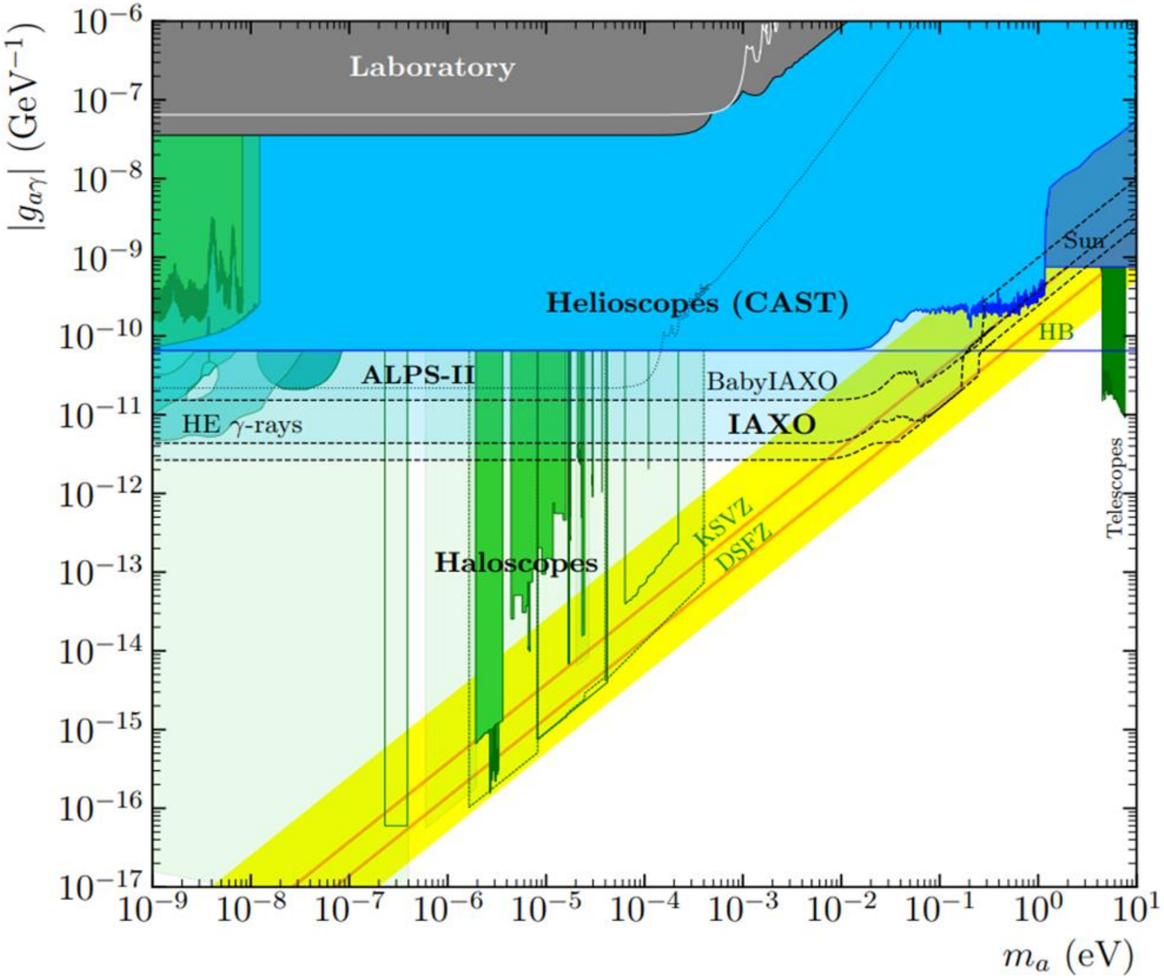
BabyIAXO is currently under construction and DESY!



- Dipole magnet
  - 10 meters long
  - Magnetic field ~2 T
  - 2 bores of 70 cm Ø
- Dedicated X-ray optics
  - 0.2 cm² focal spot
- Tracking system
  - Based on gamma ray telescopes
- X-ray detector technologies
  - Micromegas (baseline)

[10.1007/JHEP05(2021)137](https://doi.org/10.1007/JHEP05(2021)137)

IAXO and BabyIAXO sensitivity prospects



BabyIAXO will be sensitive to realistic QCD axion models!

IAXO will improve CAST sensitivity in more than a factor 10

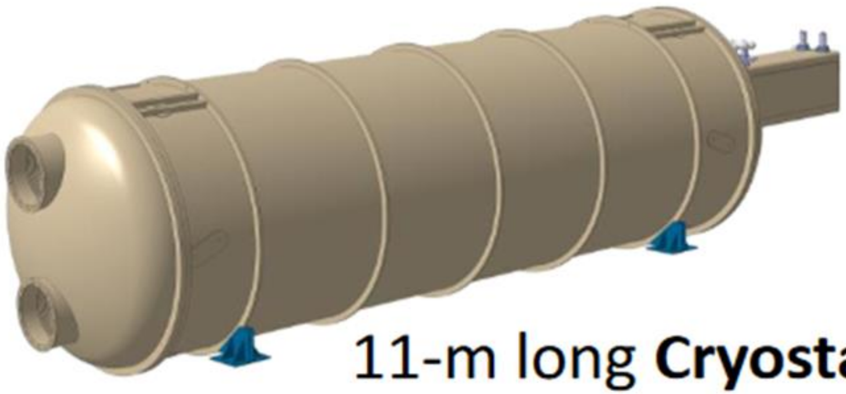
Further physics potential of (Baby)IAXO:

- Axion-electron coupling
- Cold Dark Matter axions using the haloscope technique
- Most favoured ALPs parameter space

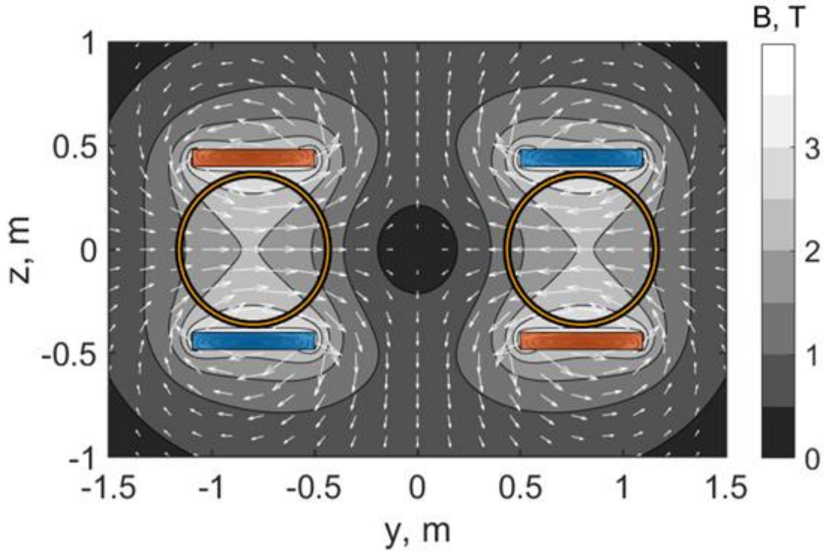
RECIPE FOR BabyIAXO

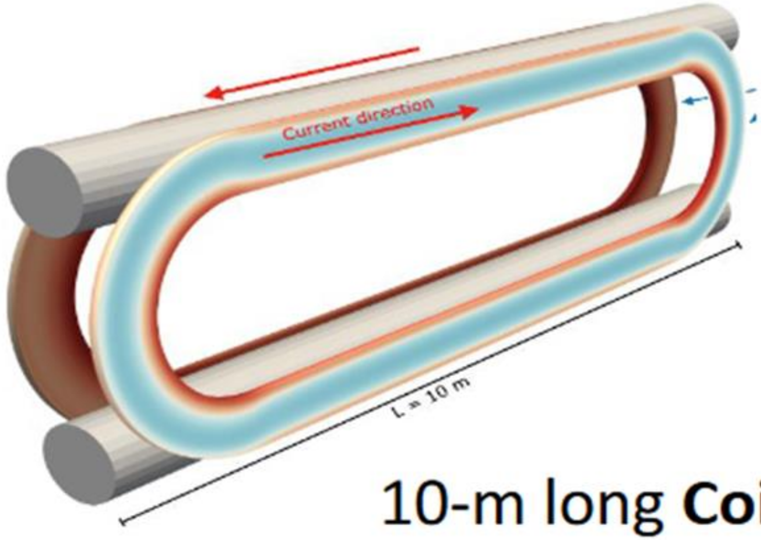
Long superconducting dipole magnet:

- 2 parallel coils 10m long
- 2 bores: 70 cm diameter; vacuum & buffer gas
- Cold mass at 4.5 K
- Minimal risk: straightforward and robust design choices



11-m long **Cryostat**





10-m long **Coils**

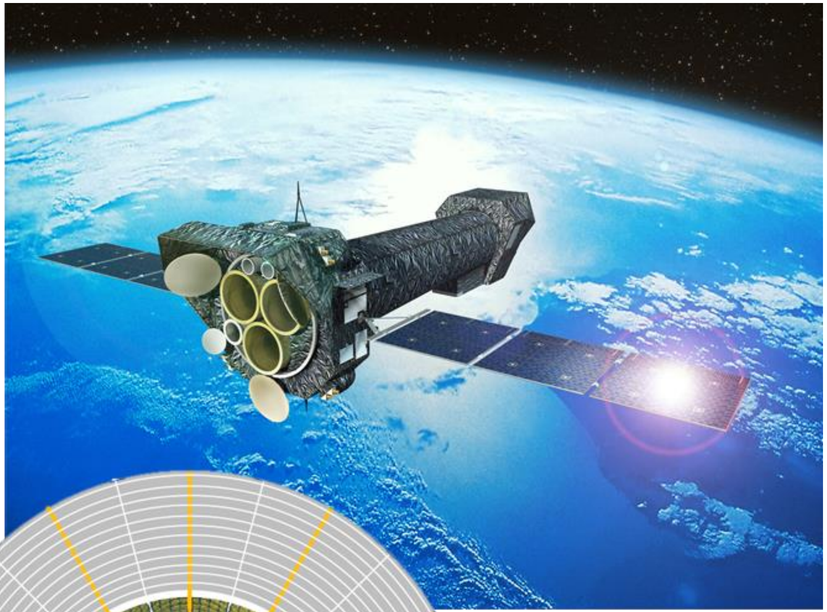
RECIPE FOR BabyIAXO

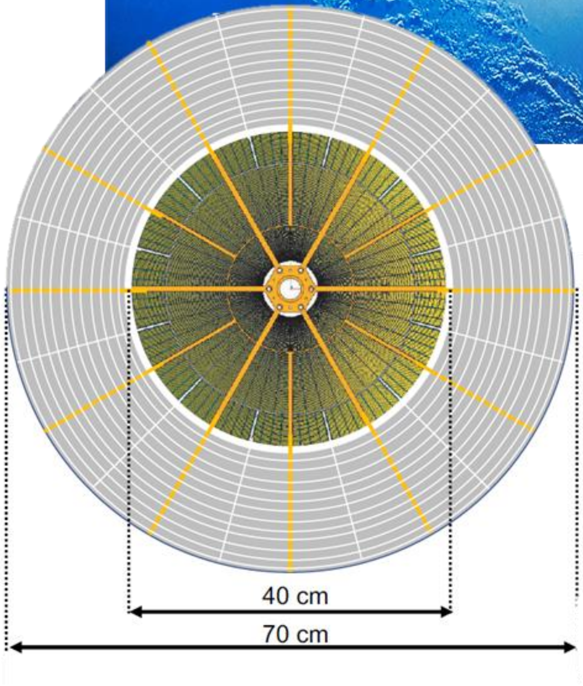
Dedicated X-ray optics

- Multilayer-coated segmented-glass Wolter-I optics
- Signal from the 0.7 m diameter bore focused to 0.2 cm^2 area
- Mature technology based on NASA's NuSTAR telescopes

Two different telescopes:

- Custom made telescope
  - 5 m focal length
  - Hybrid approach with different inner and outer optics to increase the diameter and cover the bore
- XMM flight spare
  - 7.5 m focal length
  - Already available and compatible with BabyIAXO

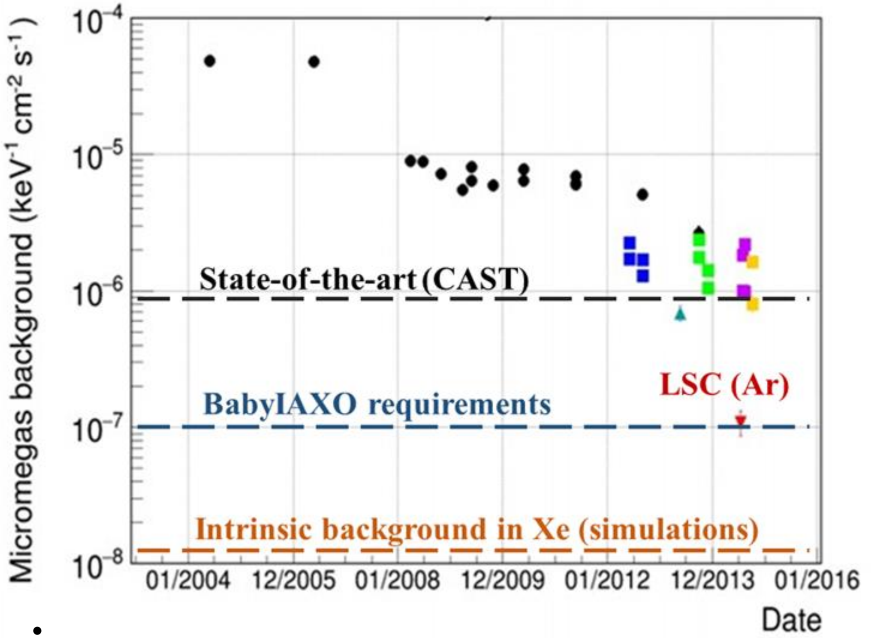




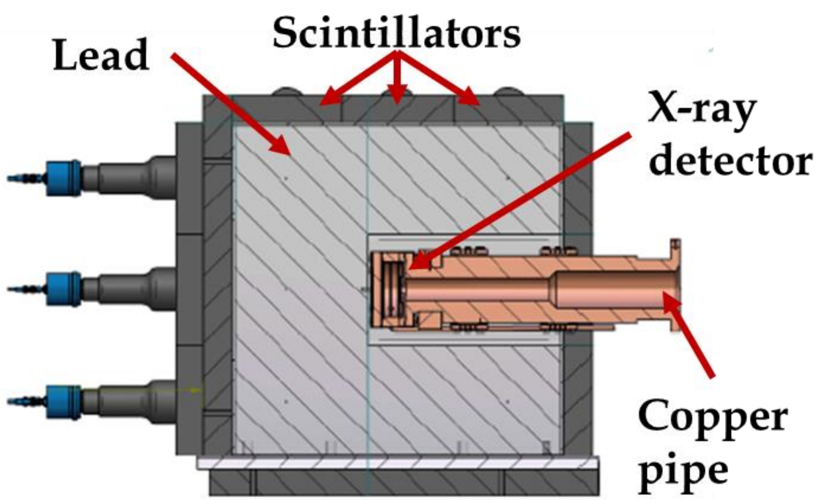
RECIPE FOR BabyIAXO

Ultra-low background X-ray detectors:

- Required to distinguish axion signal above the nominal background of the detector.
- Required background level 10^{-7} c keV^{-1} cm^{-2} s^{-1} in the RoI [0-7] keV
- Current baseline Micromegas, but other technologies (GridPix, MMC, TES and SDD) are under study.



State of the art on low-background techniques:

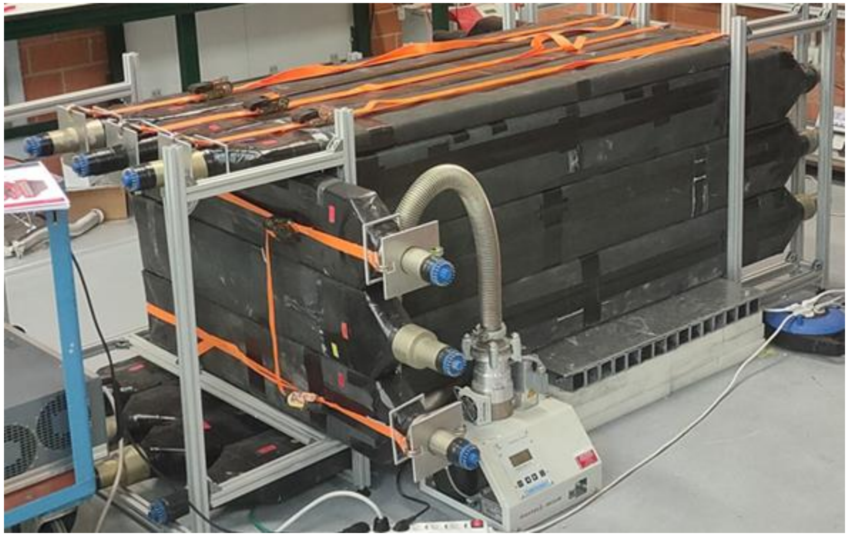


- Intrinsic radiopurity of the X-ray detector (measured at the LSC)
- Event discrimination (X-ray like events)
- Shielding strategies:
  - Radiopure copper
  - Lead shielding (20 cm)
  - Active muon veto (cosmic rays and secondaries)

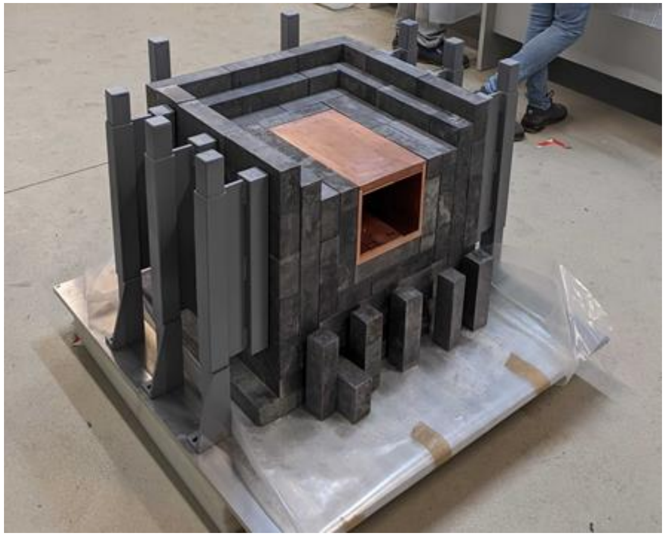
RECIPE FOR BabyIAXO

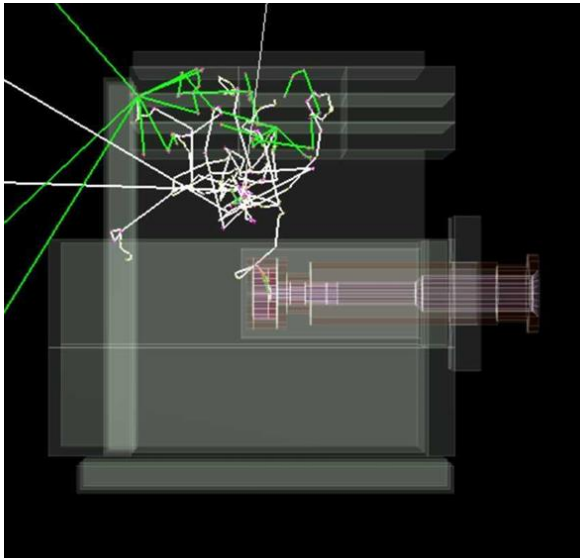
Latest developments on low-background techniques:

Optimized veto system at surface level



Intrinsic background underground (LSC)





Simulations

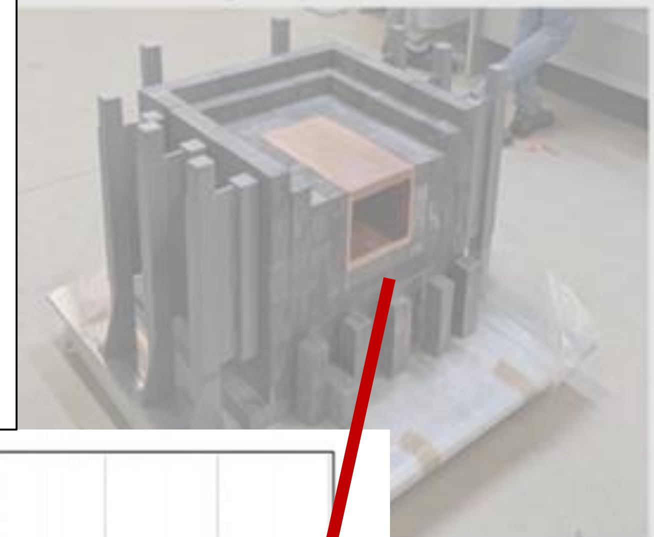
- Background at LSC limited by ^{39}Ar
- Intrinsic background from simulations in Xe 10^{-8} c keV^{-1} cm^{-2} s^{-1}
- Background at surface level might be limited by cosmogenic induced neutrons

RECIPE FOR BabyIAXO

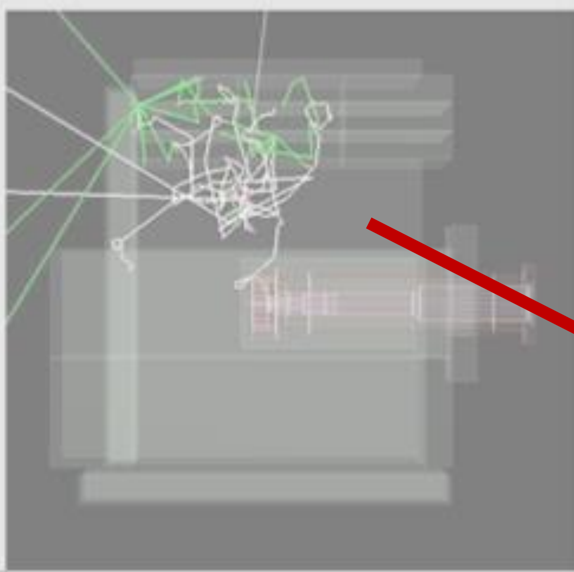
Latest developments on low-background techniques:

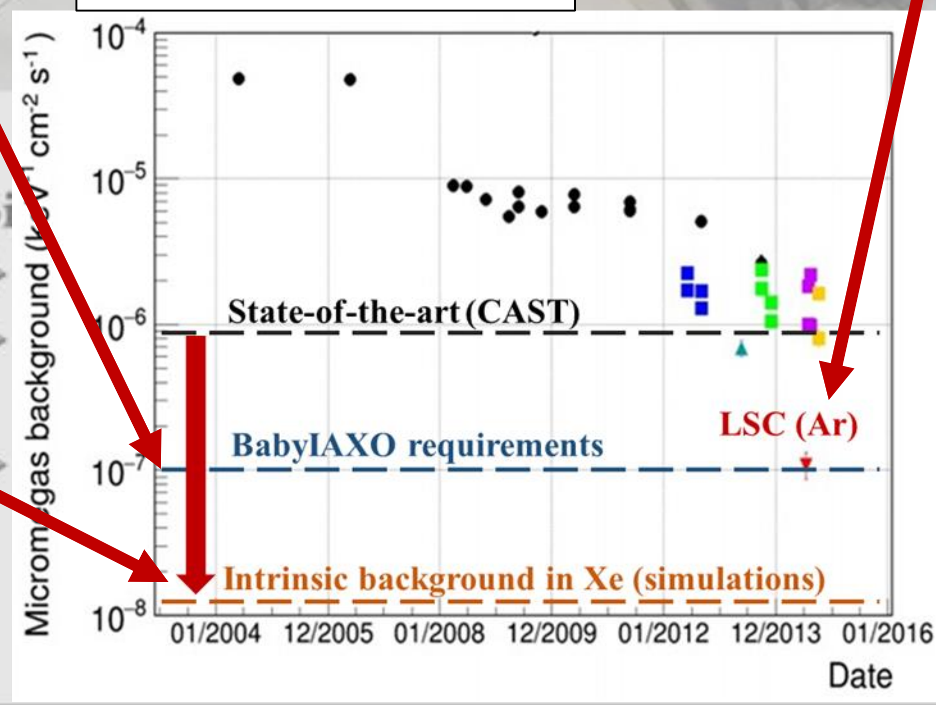
Optimized veto system at surface level

Intrinsic background underground (LSC)



An efficient active shielding neutron tagger would reduce the background levels to BabyIAXO requirements!





SUMMARY AND CONCLUSIONS

- Axions and ALPs are well motivated particles beyond the Standard Model that can solve the Dark Matter problem
- IAXO, a new generation helioscope aims to improve current sensitivities by more than one order of magnitude
- An intermediate version of IAXO, BabyIAXO is under construction at DESY
  - Long superconducting magnet → Late design stage
  - Dedicated X-ray optics → 1 available, another under design
  - Ultra-low background detectors → On-going R&D on low background techniques
- BabyIAXO is expected to start the commissioning in 2026
- Further physics potential of IAXO and BabyIAXO
  - Axion-electron coupling
  - Cold Dark Matter axions (haloscope)
  - ALPs parameter space from astrophysical hints

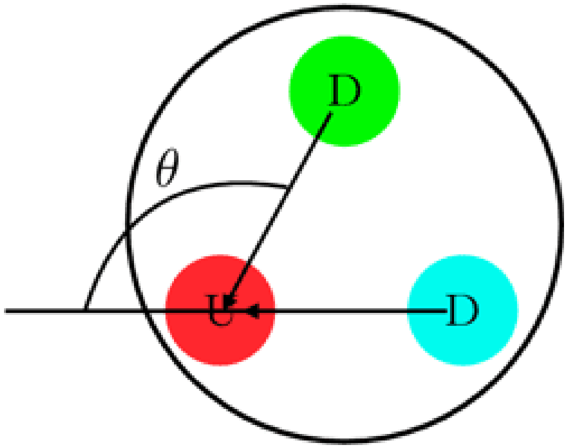
BACK UP

BACK UP

The strong-CP problem

QCD Lagrangian

$$\mathcal{L}_{QCD} = \mathcal{L}_{pert} + \bar{\theta}\frac{g^2}{8\pi^2}G^a_{\mu\nu}\tilde{G}^{\mu\nu}_a \qquad \bar{\theta} = \theta + \theta_{weak}$$



Neutron dipole moment

$$|d_n| < 2.9 \times 10^{-26}\ \text{e cm} \quad \Longrightarrow \quad \bar{\theta} \leq 10^{-10}$$

The Peccei-Quinn solution

Introduction of new global, axial symmetry that is spontaneously broken at the energy scale of the symmetry f_a

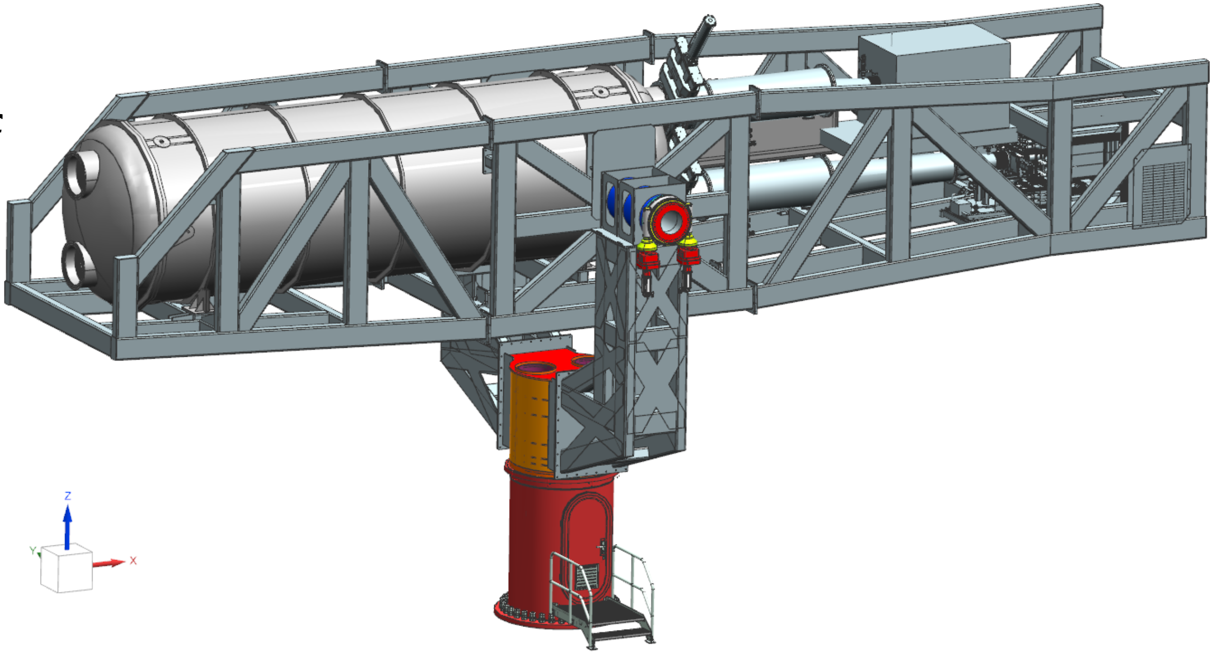
$$\mathcal{L}_a = -\frac{1}{2}\partial_\mu a \partial^\mu a + \mathcal{L}_{int} + C_a \frac{a}{f_a}\frac{g^2}{32\pi^2}G^a_{\mu\nu}\tilde{G}^{\mu\nu}_a$$

It implies the existence of a new field *a* which appears as the pseudo Nambu-Goldstone boson of the new symmetry → **The axion**

BACK UP

BabyIAXO tracking system

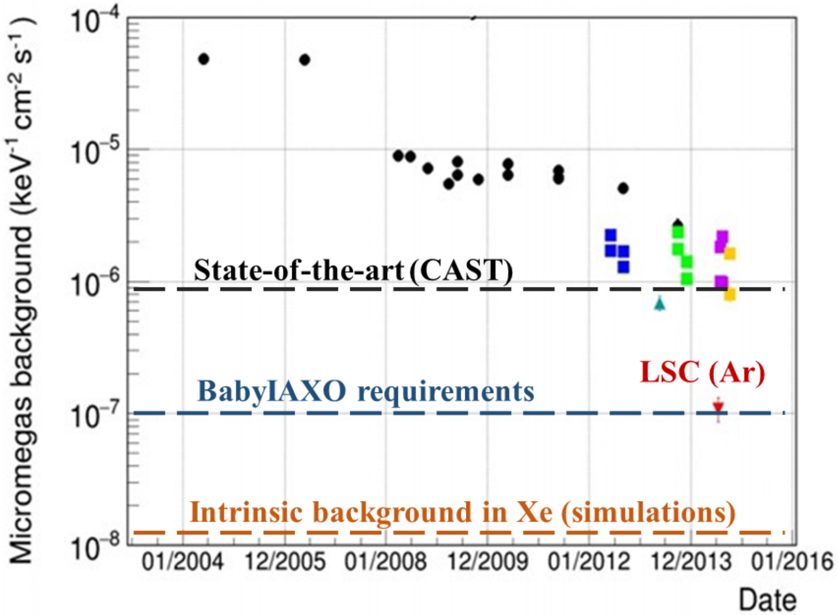
- Tracking ± 21.1° → 50% of average exposure
- Load on drive system: up to 90 T
- Solar tracking precision < 0.01°



- Design almost completed and manufacturing in preparation
- Some parts reused from CTA telescope (MST)

BACK UP

State-of-the-art on low background techniques



- CAST
  - 10^{-6} counts keV^{-1}cm^{-2}s^{-1}
- Underground (LSC)
  - 10^{-7} counts keV^{-1}cm^{-2}s^{-1}
  - Limited by ^{39}Ar
- Intrinsic (simulations) in Xe
  - 10^{-8} counts keV^{-1}cm^{-2}s^{-1}
- IAXO-D0 (Xe)
  - 10^{-6} counts keV^{-1}cm^{-2}s^{-1}
  - Limited by cosmogenic neutrons