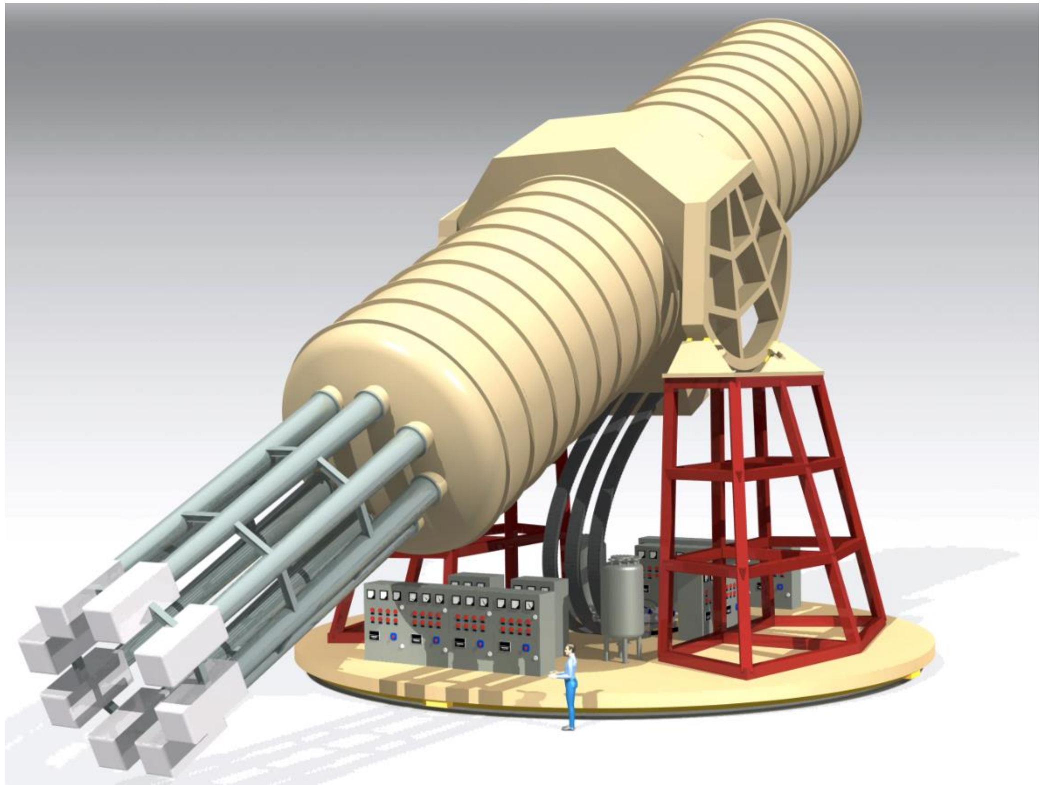
Status and Progress of the International Axion Observatory



Esther Ferrer Ribas

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MADMAX meeting, Jussieu, Paris, 10 May 2017

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Institut de recherche
sur les lois fondamentales
de l'Univers

IAXO: International AXion Observatory

- Baseline search: **solar axions**

- Why are we looking for axions?

  - Most elegant solution to explain the apparent symmetry between matter and anti-matter in the strong interactions (CP violation);

  - Predicted by SM extensions, neutral, very light, low interacting cross-section;

  - Dark matter candidates;

  - Astrophysical hints for axion/ALPs?
    - Transparency of the Universe to UHE gammas;
    - Anomalous cooling of different types of stars;

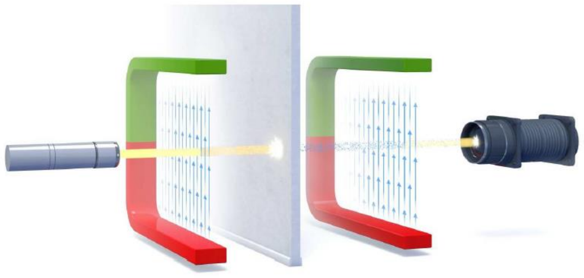
  - Relevant axion/ALP parameter space at reach of current and near-future experiments;

  - Still too little experimental effort devoted to axions when compared to WIMP;

Search strategies

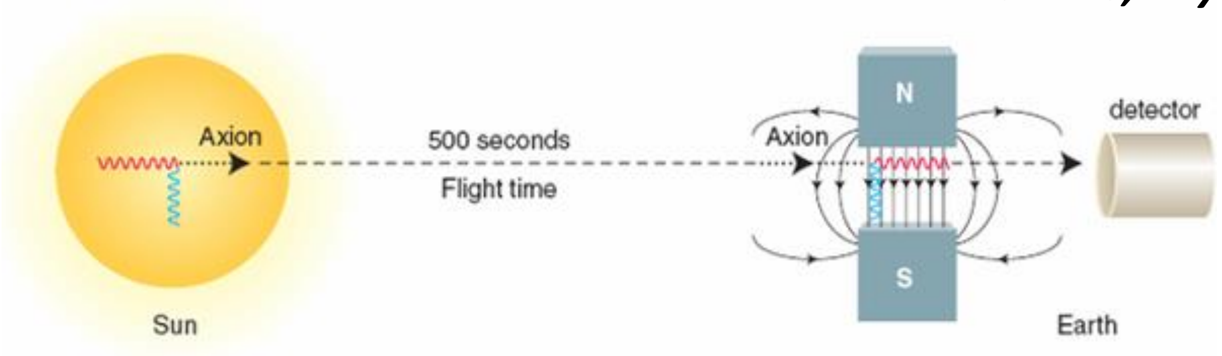
Axions couple to photons in the presence of a magnetic field in all models.

- Relic Axions
  - Axions that are part of galactic dark matter halo:
    - Axion Haloscopes (ADMX)
- Solar Axions
  - Emitted by the solar core.
    - Axion Helioscopes **(CAST → IAXO)**
    - Crystals
- Axions in the laboratory
    - "Light shinning through wall" experiments



Helioscope Physics

Sikivie, Phys. Rev. Lett 51 (1983)

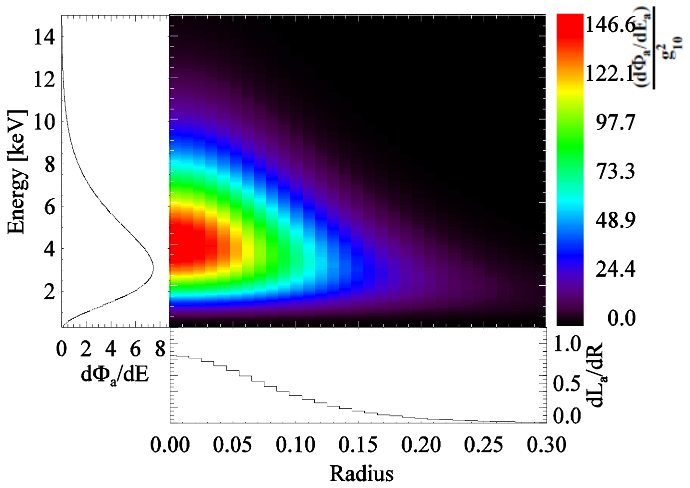


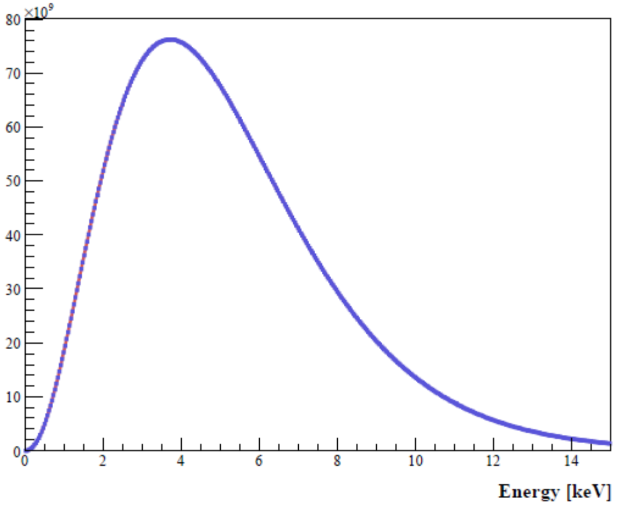
Production in the Sun

Conversion of thermal photons into axions via Primakoff effect in the solar core

Detection in the helioscope

Conversion of axions into photons via the inverse Primakoff effect in a strong magnetic field





Expected number of photons:

$$N_\gamma = \Phi_a \cdot A \cdot P_{a\to\gamma}$$

$$P_{a\to\gamma} = 1.7\times 10^{-17}\left(\frac{B\cdot L}{9.0\mathrm{T}\cdot 9.3\mathrm{m}}\right)^2\left(\frac{g_{a\gamma}}{10^{-10}\mathrm{GeV}^{-1}}\right)^2$$

$\approx$ 0.3 evts/hour

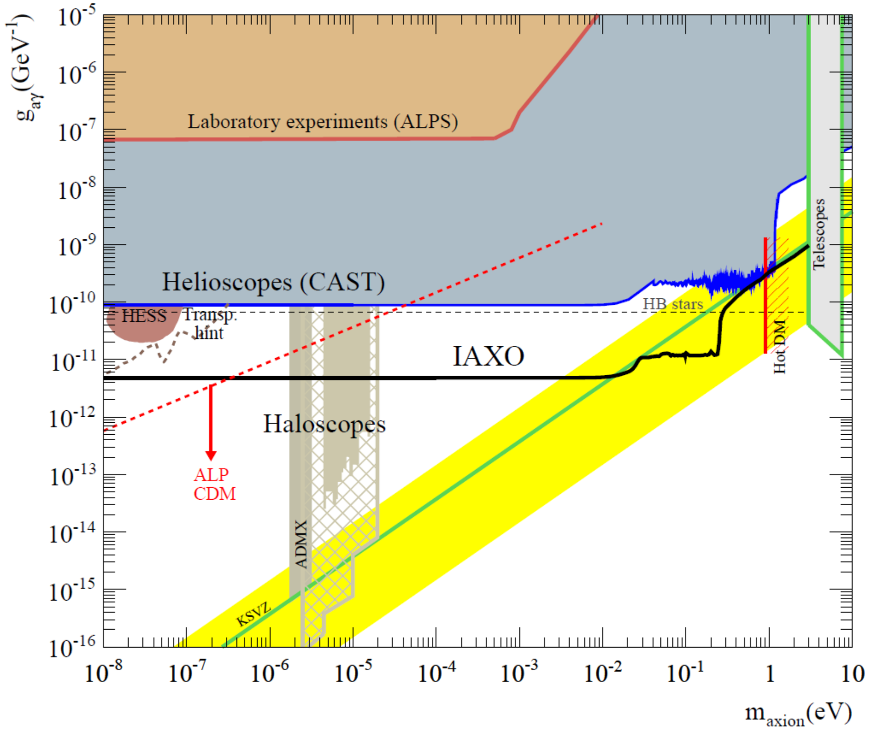
with $g_{a\gamma} = 10^{-10}$ GeV^{-1} and A = 14 cm^2

CAST: CERN Axion Solar Telescope

LHC dipôle : L = 9 m, B = 9 T

Rotating platform to follow the sun

2003 – 2004	CAST phase I: vacuum in the magnet bores
2006	CAST phase II - ^{4}He Run: axion masses explored up to 0.39 eV (160 P-steps)
2007	^{3}He Gas system implementation
2008 - 2011	CAST phase II - ^{3}He Run • axion masses explored up to 1.17 eV • bridging the hot dark matter limit
2012	•Revisit 4He Run with improved detectors
2013-2015	•Revisit vacuum phase with improved detectors •**Final QCD axion results**



The axion has not been observed ➔ limit on the coupling constant

Best world-wide limit for a wide range of masses

CAST Coll., JCAP 0704(2007) 010

CAST Coll., PRL (2005) 94, 121301

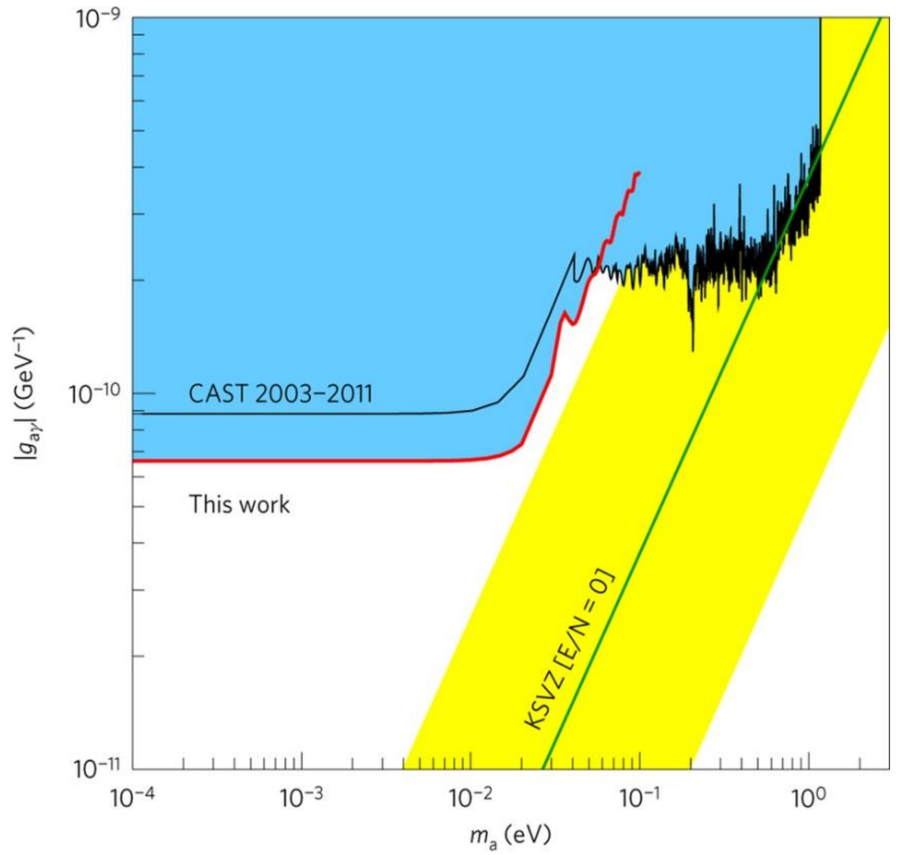
CAST Coll., JCAP 0902 (2009) 008

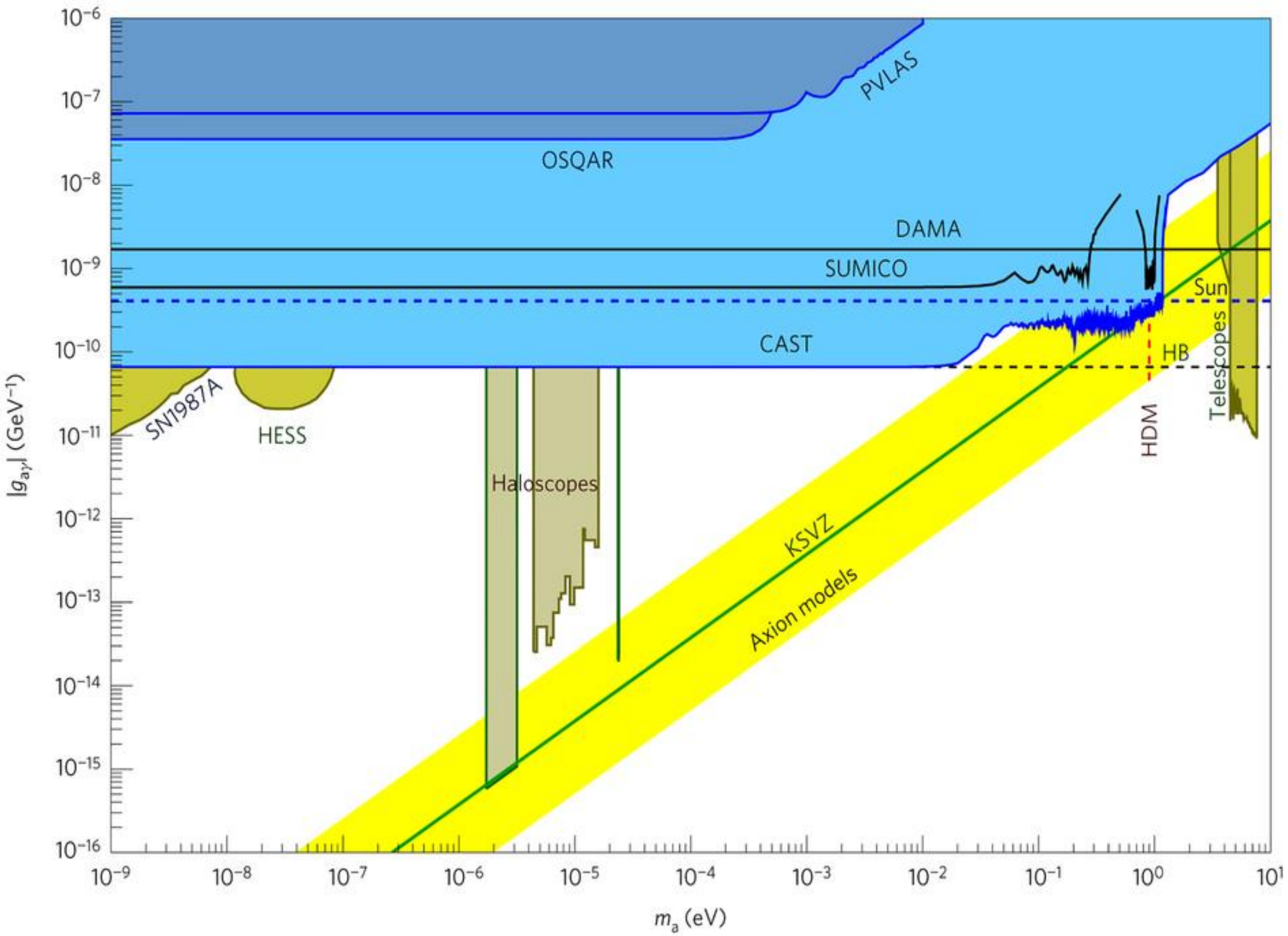
CAST Coll, PRL (2011) 107 261302

CAST Coll., Phys. Rev. D92 (2015) no2, 021101

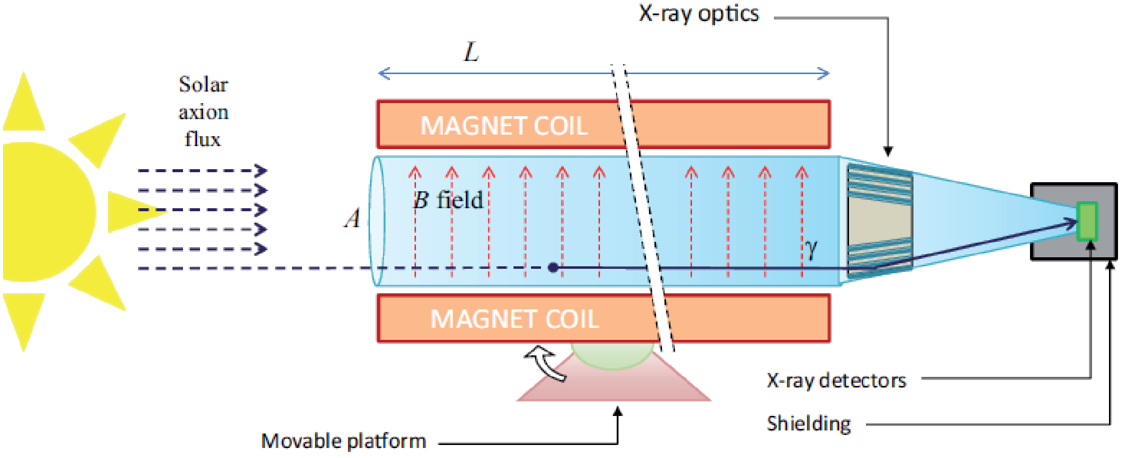
CAST Coll, Nature Physics (2017) doi:10.1038/nphys4109

CAST Coll, Nature Physics (2017)





IAXO concept

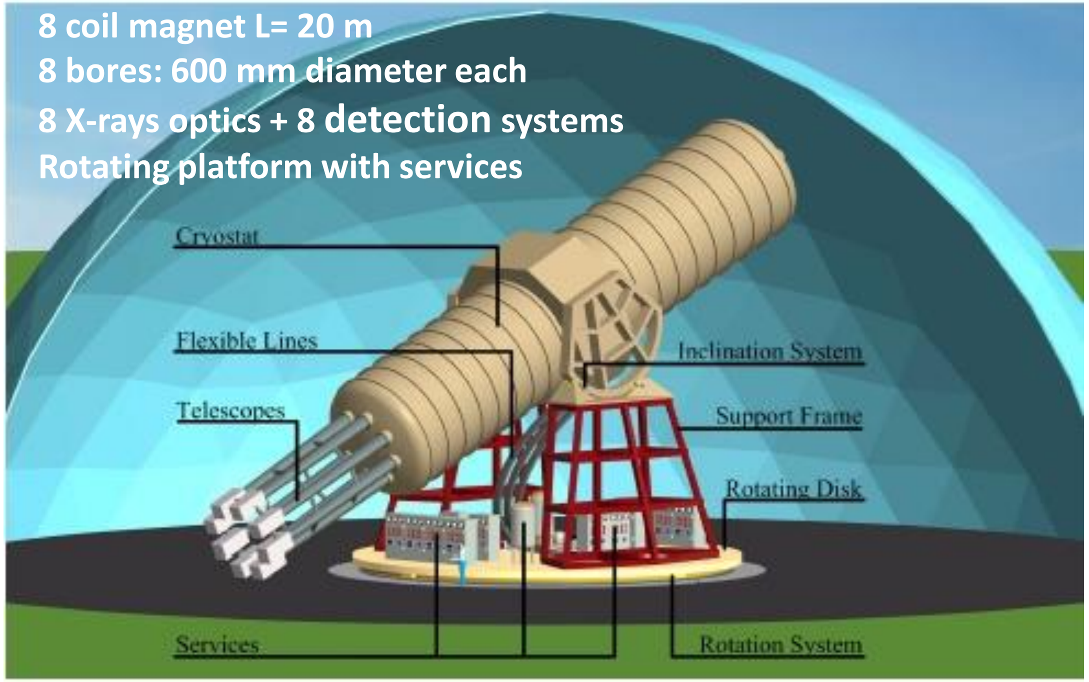


Goal: in terms of signal to background ratio 4-5 orders of magnitude more sensitive than CAST, which means sensitivity to axion-photon couplings down to a few $\times 10^{-12}$ GeV^{-1}

$$g_{a\gamma}^4 \propto \underbrace{b^{1/2}\epsilon^{-1}}_{\text{detectors}} \times \underbrace{a^{1/2}\epsilon_o^{-1}}_{\text{optics}} \times \underbrace{(BL)^{-2}A^{-1}}_{\text{magnet}} \times \underbrace{t^{-1/2}}_{\text{exposure}}$$

No technology challenge (built on CAST experience)

- ✓New dedicated superconducting magnet
- ✓Use of X-ray focalisation over ~m^2 area
- ✓Low background detectors (improve bck by 1-2 orders of magnitude)

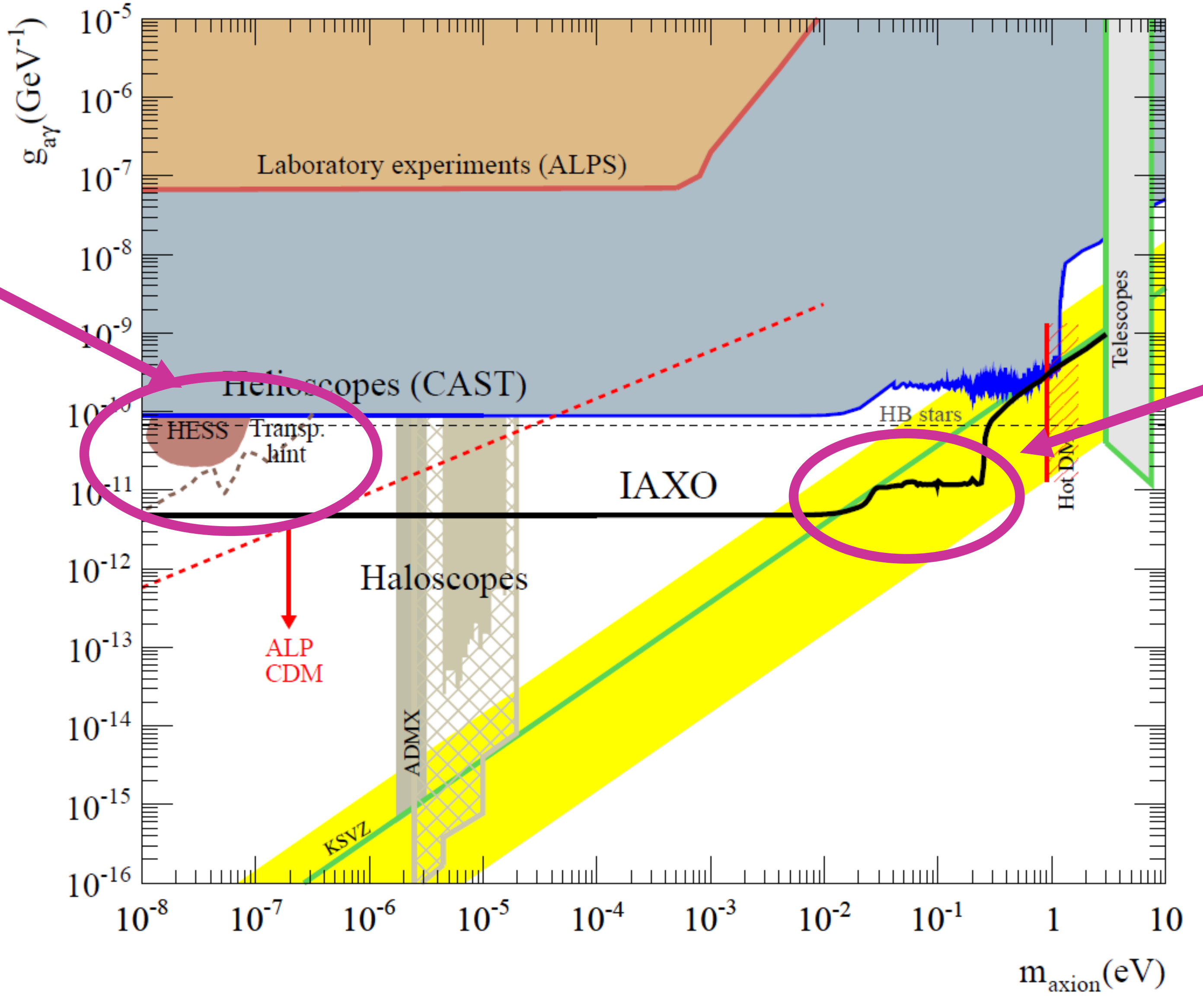


I. Irastorza et al., JCAP 06 (2011) 013

E. Armengaud et al., JINST 9 (2014) T05002

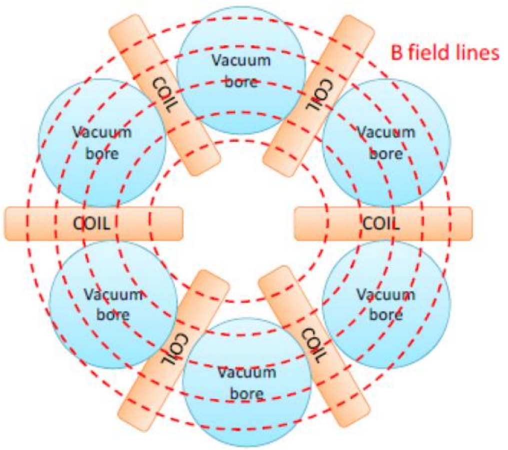
IAXO Sensitivity

Transparency ALP hints Accesible to IAXO & ALPS-II

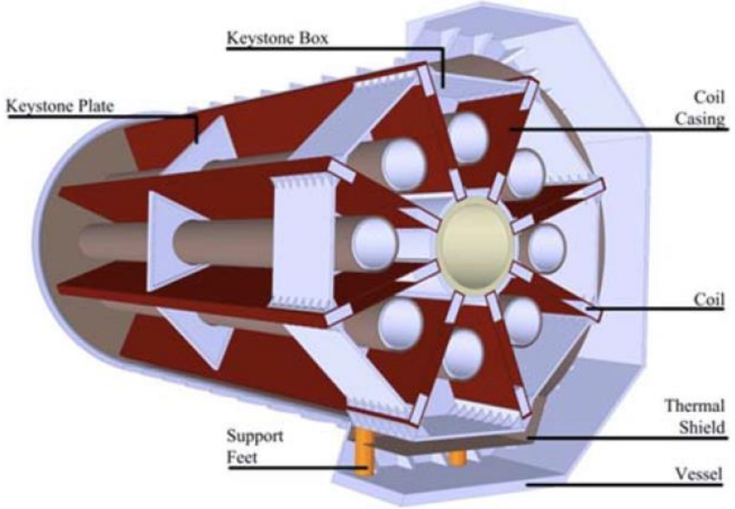


Few meV scale QCD axion & anomaly cooling hints accessible to IAXO

IAXO magnet



Shilon et al. IEEE T. Ap. SupCond 23:4500604 (2013)
Shilon et al. AIP Conf. Proc. 1573:1574 (2014)
Shilon et al. IEEE T. Ap. SupCond 24:4500104 (2014)



Optimised configuration: TOROIDAL with 8 bores
25 m long, 5 m diameter and a peak field of 5.4 T

Property		*Value*
Cryostat dimensions:	Overall length (m)	25
	Outer diameter (m)	5.2
	Cryostat volume (m^3)	~ 530
Toroid size:	Inner radius, R_{in} (m)	1.0
	Outer radius, R_{out} (m)	2.0
	Inner axial length (m)	21.0
	Outer axial length (m)	21.8
Mass:	Conductor (tons)	65
	Cold Mass (tons)	130
	Cryostat (tons)	35
	Total assembly (tons)	~ 250
Coils:	Number of racetrack coils	8
	Winding pack width (mm)	384
	Winding pack height (mm)	144
	Turns/coil	180
	Nominal current, I_{op} (kA)	12.0
	Stored energy, E (MJ)	500
	Inductance (H)	6.9
	Peak magnetic field, B_p (T)	5.4
	Average field in the bores (T)	2.5
Conductor:	Overall size (mm^2)	35 × 8
	Number of strands	40
	Strand diameter (mm)	1.3
	Critical current @ 5 T, I_c (kA)	58
	Operating temperature, T_{op} (K)	4.5
	Operational margin	40%
	Temperature margin @ 5.4 T (K)	1.9
Heat Load:	at 4.5 K (W)	~150
	at 60-80 K (kW)	~1.6

(ATLAS toroid 26 m long, 20 m diameter, peak field 3.9 T)

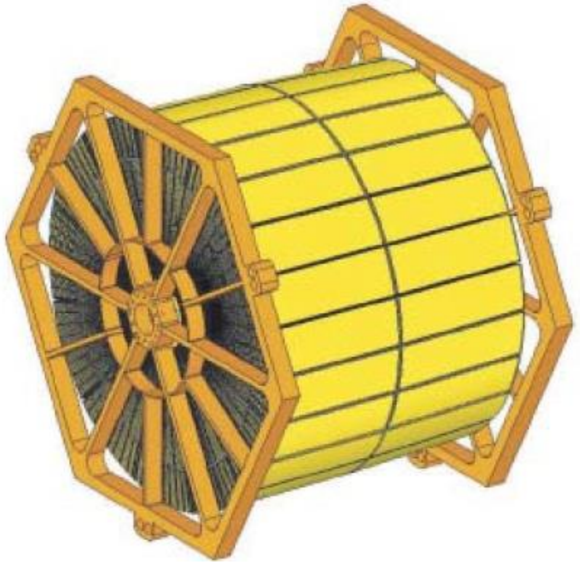
IAXO x-ray optics

Baseline : Use approach NASA's NUSTAR satellite

Each bore equipped with an X-ray optics
8 systems of 600 mm diameter each

Specifications:

- Refined imaging not needed
- Need to cover large area (cost-effective)
- Good throughput (0.3-0.5)
- Small focal point (~1 cm^2)



Telescopes	8
N, Layers (or shells) per telescope	123
Segments per telescope	2172
Geometric area of glass per telescope	0.38 m^2
Focal length	5.0 m
Inner radius	50 mm
Outer Radius	300 mm
Minimum graze angle	2.63 mrad
Maximum graze angle	15.0 mrad
Coatings	W/B_4C multilayers
Pass band	1 – 10 keV
IAXO Nominal, 50% EEF (HPD)	0.29 mrad
IAXO Enhanced, 50% EEF (HPD)	0.23 mrad
IAXO Nominal, 80% EEF	0.58 mrad
IAXO Enhanced, 90% EEF	0.58 mrad
FOV	2.9 mrad

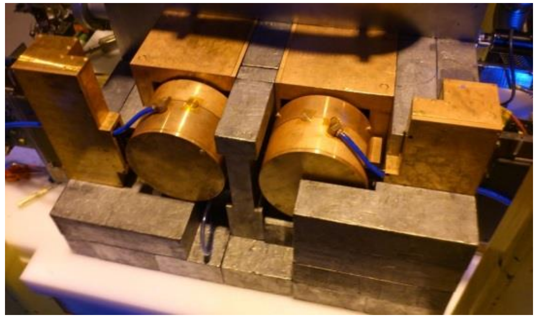
Jakobsen et al. Proc SPIE 8861:886113 (2013)

IAXO low background detectors

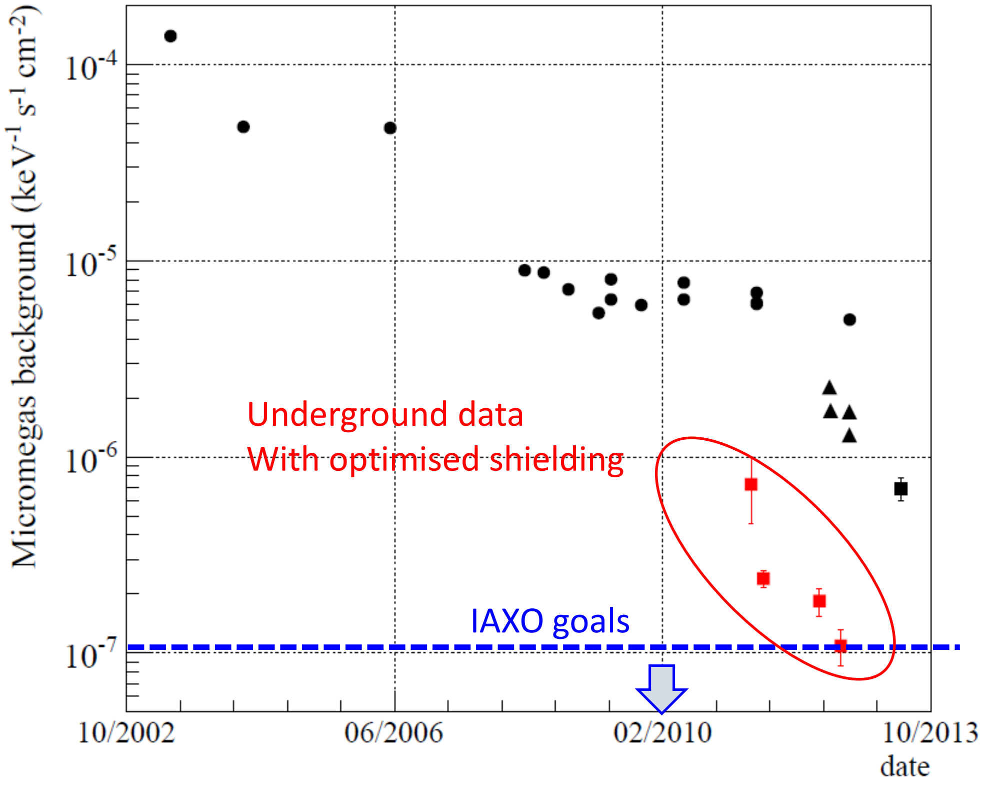
Baseline: Micromegas detectors

Goal: below 10^{-7} c/keV/s/cm^2

Key elements:
•Radiopure components
•Shielding
•Offline discrimination

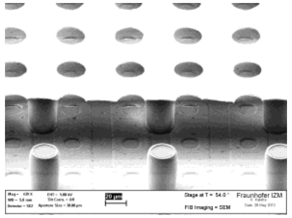


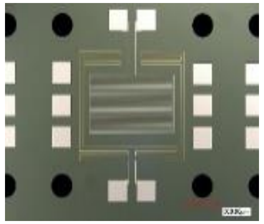
IAXO Pathfinder system at CAST 2014-2015:
last generation of Microbulk detectors + optimised shielding + Xray telescope IAXO pathfinder ➔ CASTMM 2014 : 0.85 x 10^{-6} c/keV/s/cm^2

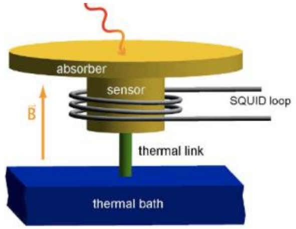


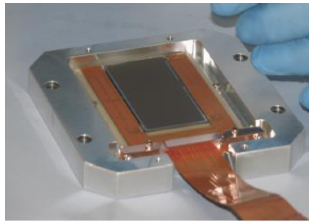
S. Aune et al., JINST 9 (2014) 9 P01001
F. Aznar et al., JCAP 12 (2015) 9 008

Micromegas are the base-line for IAXO but additional technologies, **Ingrid Micromegas, TES, MMC, CCD** will also show their potential in the coming years





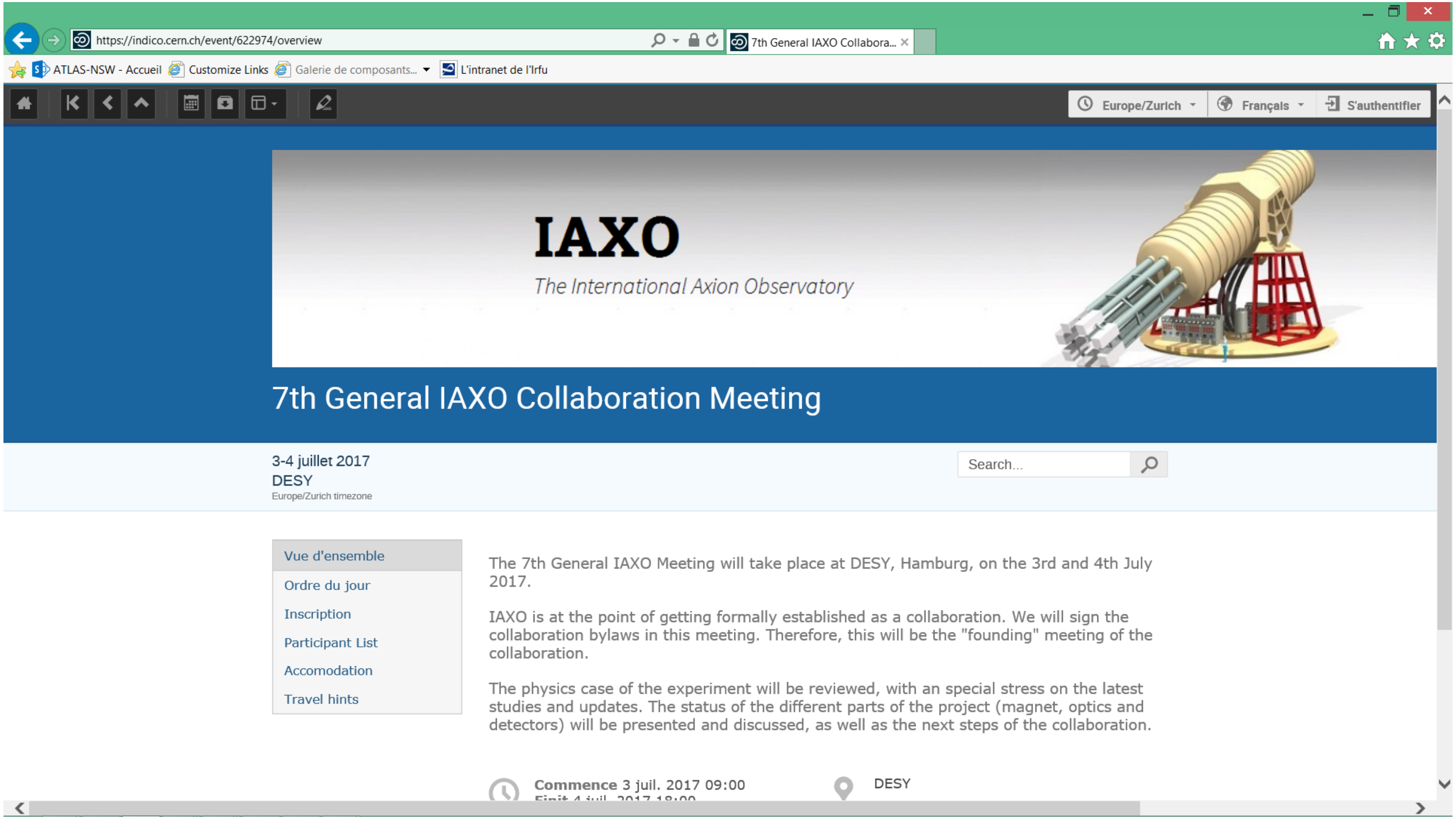




IAXO status of project

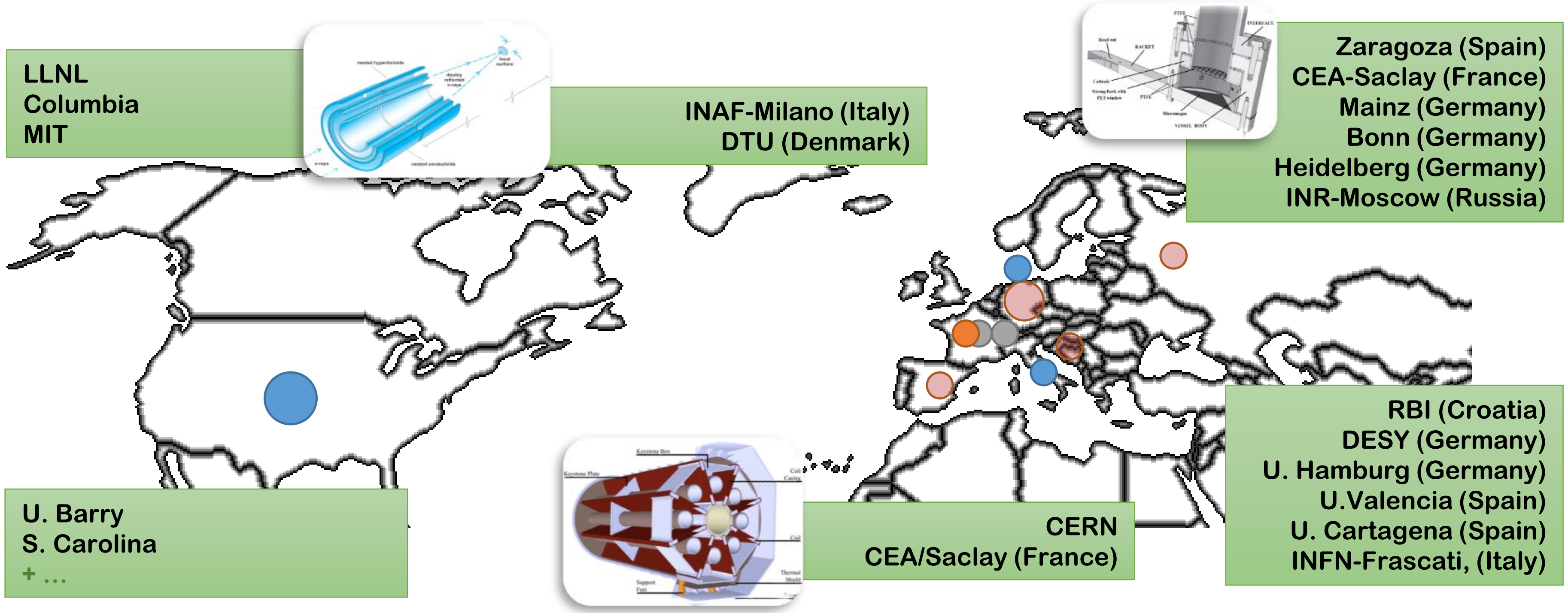
- 2011: First studies ***Irastorza et al. JCAP (2011) 1106:013***
- ASPERA/APPEC Roadmap acknowledges axion physics, CAST and recommends progress towards IAXO (C. Spiering Krakow 2012)
- IAXO is also present in US roadmapping (Snowmass and P5 process) (december 2013)
- 2013: Conceptual Design: ***Armengaud et al. JINST 9 (2014) T05002***
- August 2013: Letter of Intent submitted to the **CERN SPSC [CERN-SPSC-2013-022]**
- January 2014: Recommendations of CERN SPSC
- 2014-15: Transition phase towards TDR (technical design)
    - Some IAXO preparatory activity already going on as part of CAST near term program: IAXO pathfinder system in CAST in 2014-15
    - Preparation of a MoU to carry out TDR work.
    - Strengthen collaboration, awareness actions, meetings, coordinated funding applications
    - First discussion on long-term plan to construction
- 2017: Formal constitution of collaboration
  "Founding" IAXO collaboration meeting to happen 3-4th July 2017, DESY

“Founding” IAXO collaboration 3-4th July: You are all welcome!!



IAXO proto-collaboration

- Big effort to strengthen collaboration → large consortium involved in a number of funding applications, covering all TDR needs

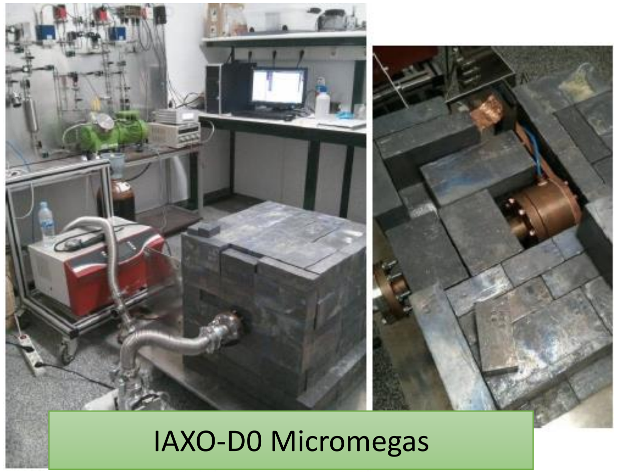


New partners welcome…

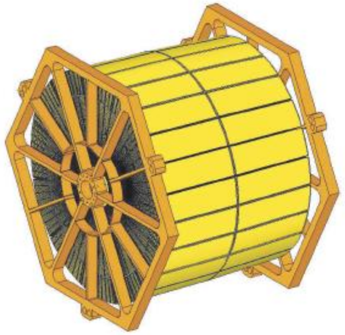
(*) Only shown groups for which formal activity is ongoing or under discussion/preparation.
Potentiaal interest in more groups than shown

IAXO TDR baseline plans

- **IAXO-T0:** demonstration coil magnet
- **IAXO-X0:** prototype x-ray optics
- **IAXO-D0**: prototype low background detector setup testing different technologies for detector
- Studies to refine IAXO physics case
- Additional physics potential (DM options)
- Site studies
- Consolidate and structure collaboration

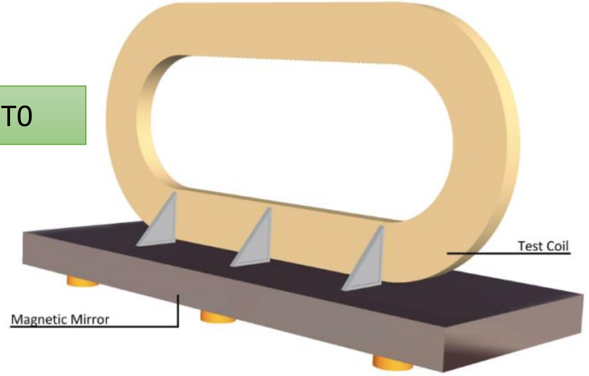


IAXO-D0 Micromegas

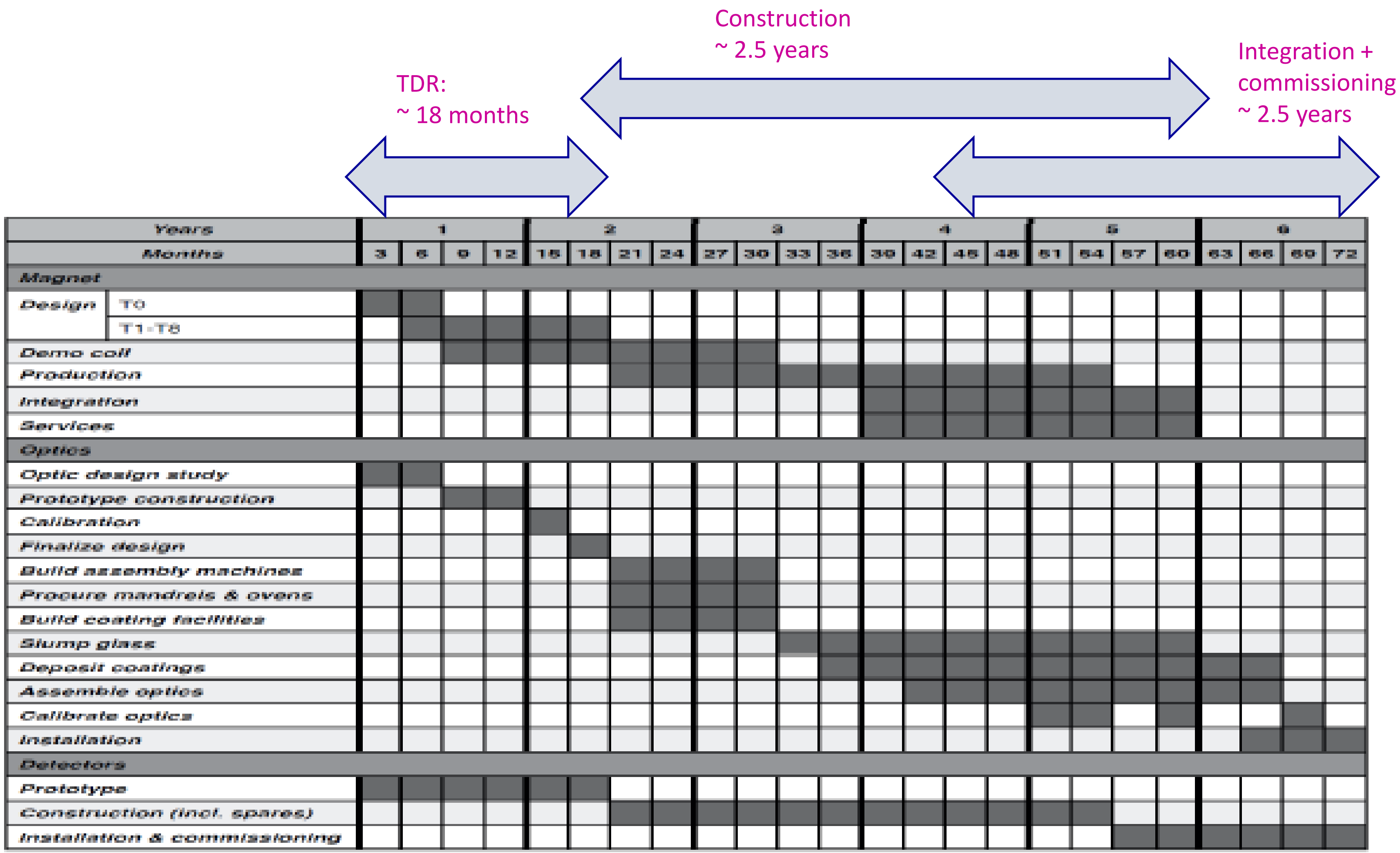


IAXO-X0

IAXO-T0



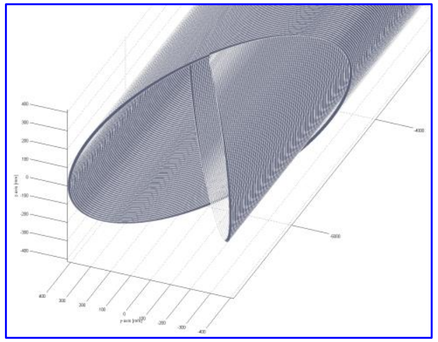
IAXO timeline

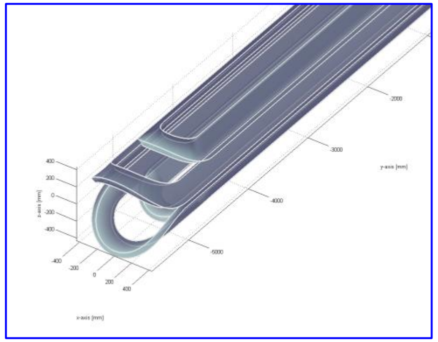


Extended TDR (→Mini-IAXO / BabyIAXO concept)

- Alternative magnet designs
  - **Pros**: higher FOM with less conductor, modularity
  - **Cons**: higher risk → need intermediate demonstrating magnet prototype
- **BabyIAXO concept:**
  - Test magnet design at relevant scale (only 1 bore full diameter)
  - Test bench for optics + detector
  - Will deliver relevant physics (at intermediate level)
- Will better mobilize community & increase interest
- Better (and more staged) access to funding
- Effect on near-term planning under study

Single 60-cm bore
Several conductor configurations under consideration





Conclusions and next steps

Axion searches→ strong physics case

Increasing experimental effort in the different axion searches strategies: solar axions, relic axions, laboratory axions…

CAST has been a very important milestone in axion research during the last decade

IAXO can probe deep into unexplored axion-ALP parameter space

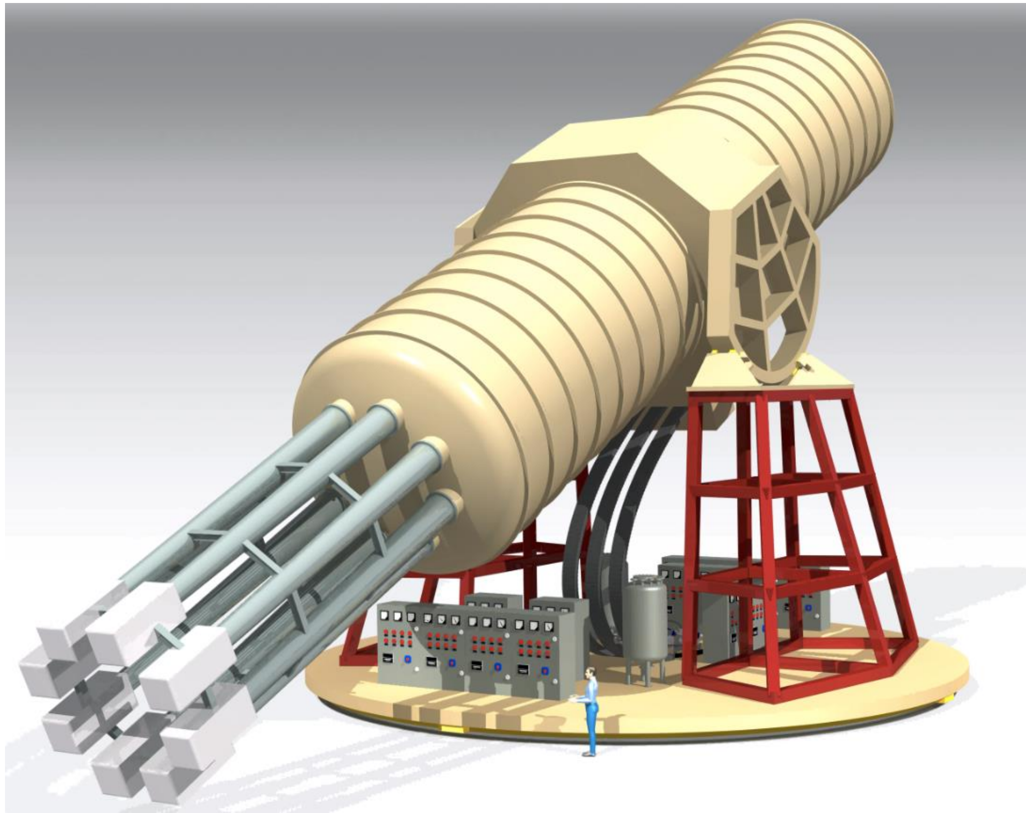
IAXO could become next large project & a **generic axion facility with discovery potential in the next decade**

Need to continue with TDR & preparatory activities, formal endorsement & resources finding

MiniIAXO / BabyIAXO → new concept that can

- Enhance final FOM of experiment
- Catalize near-term activities in the collaboration towards an intermediate experiment with relevant physics outcome

Exciting work in front us: join us!



http://iaxo.web.cern.ch/iaxo/

IAXO Collaboration

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TECHNICAL REPORT

Conceptual design of the International Axion Observatory (IAXO)

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2014 JINST 9 T05002

~80 authors

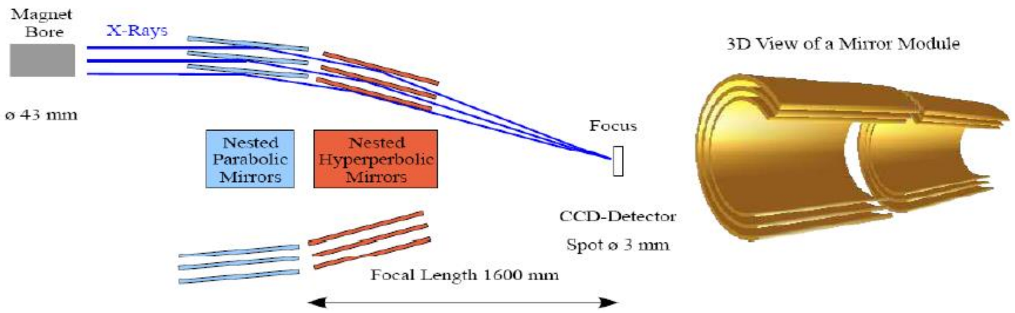
IAXO costs

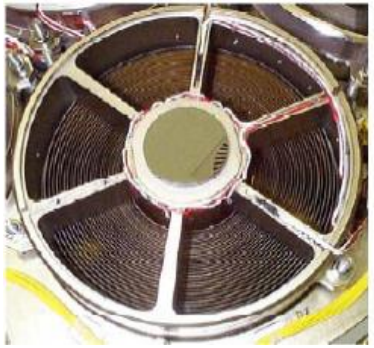
Item	Cost (MCHF)	Subtotals (MCHF)
Magnet		31.3
Eight coils based assembled toroid	28	
Magnet services	3.3	
Optics		16.0
Prototype Optic: Design, Fabrication, Calibration, Analysis	1.0	
IAXO telescopes (8 + 1 spare)	8.0	
Calibration	2.0	
Integration and alignment	5.0	
Detectors		5.8
Shielding & mechanics	2.1	
Readouts, DAQ electronics & computing	0.8	
Calibration systems	1.5	
Gas & vacuum	1.4	
Dome, base, services building and integration		3.7
Sum		**56.8**

Table 5: Estimated costs of the IAXO setup: magnet, optics and detectors. It does not include laboratory engineering, as well as maintenance & operation and physics exploitation of the experiment.

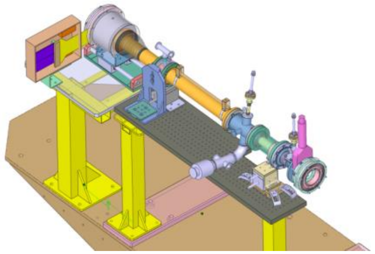
Originalities of CAST

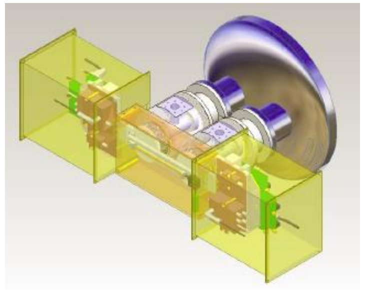
- Use of X-ray telescope ➔ increase S/B noise➔ sensitivity improved by a factor 150 by focusing a ø43 mm x-ray beam to ø3mm

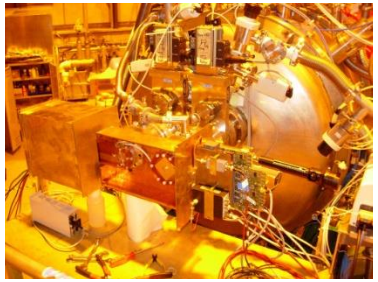




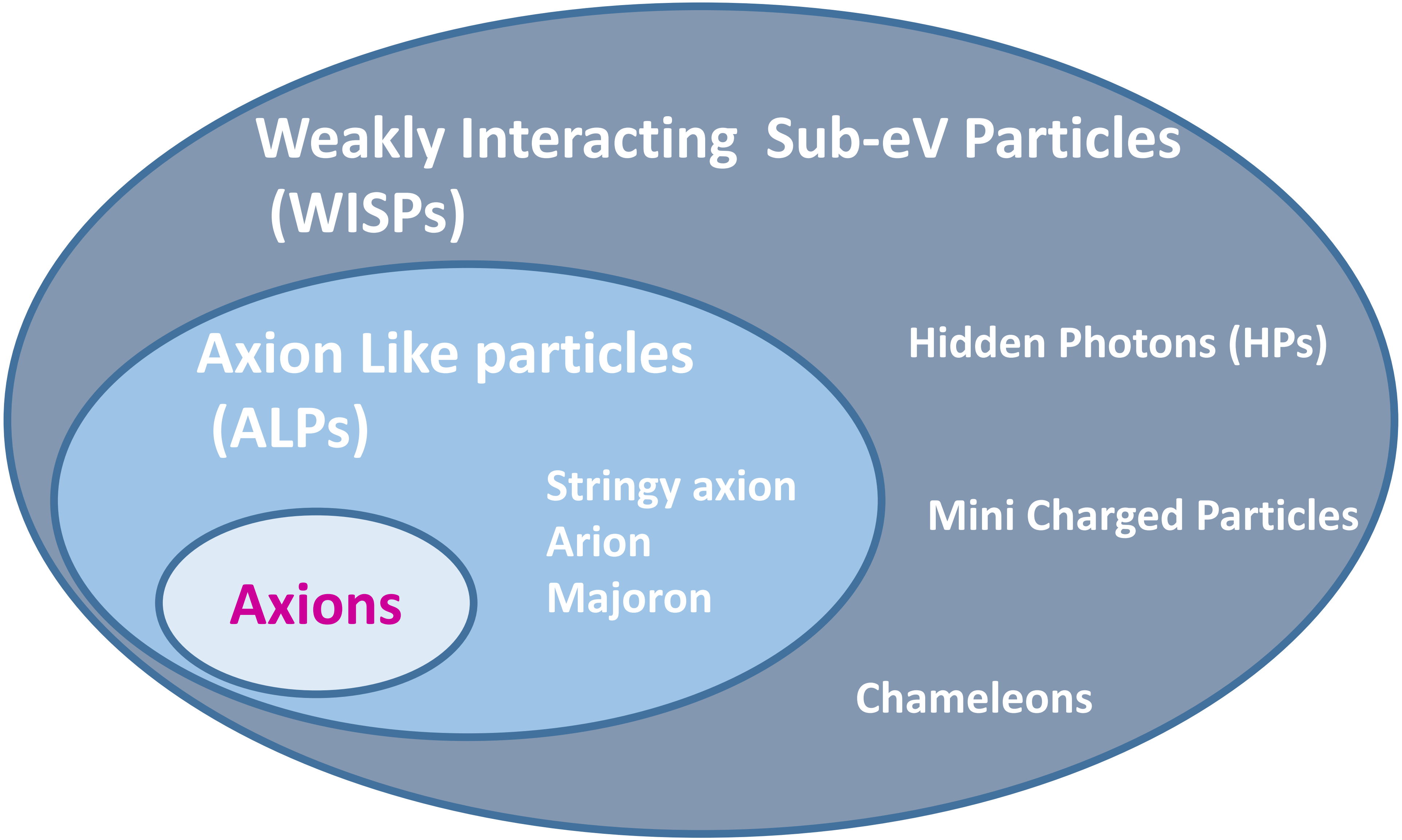
- Low background techniques➔ shieldings, low radioactive materials, simulation and modeling of backgrounds….







The WISPs zoo



$g_{a\gamma}$ and m_a are two independent "phenomenological" parameters