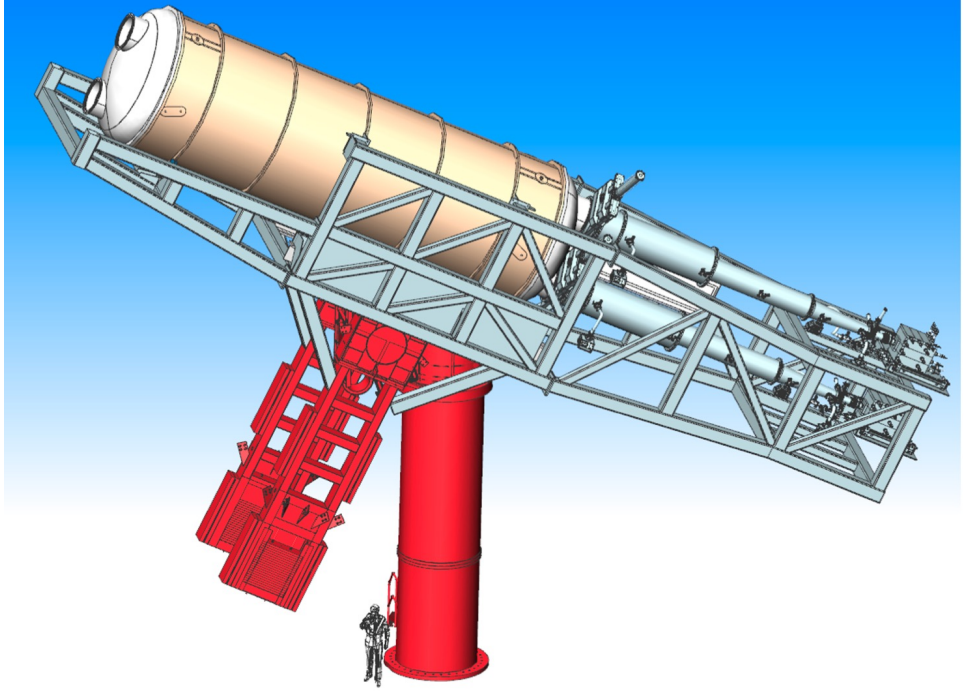
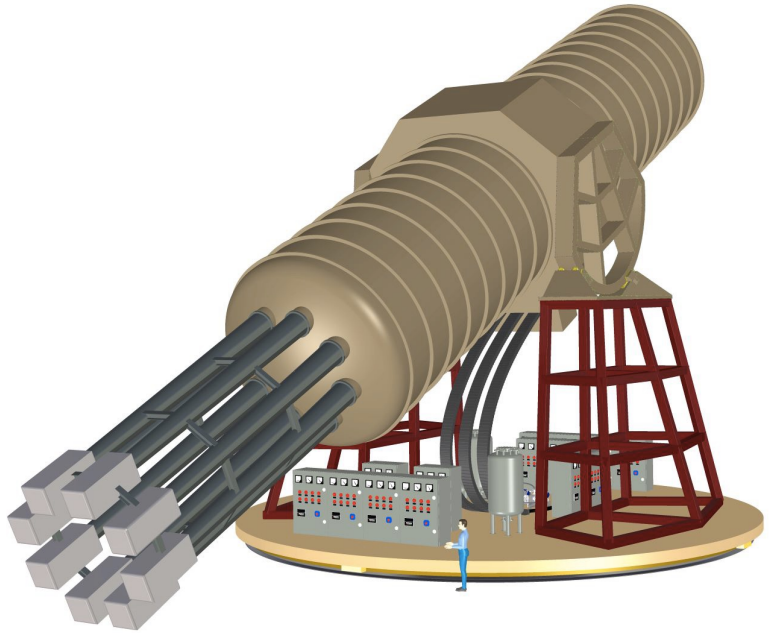
The International Axion Observatory (**IAXO**), **BabyIAXO**, and the next generation of solar axion searches





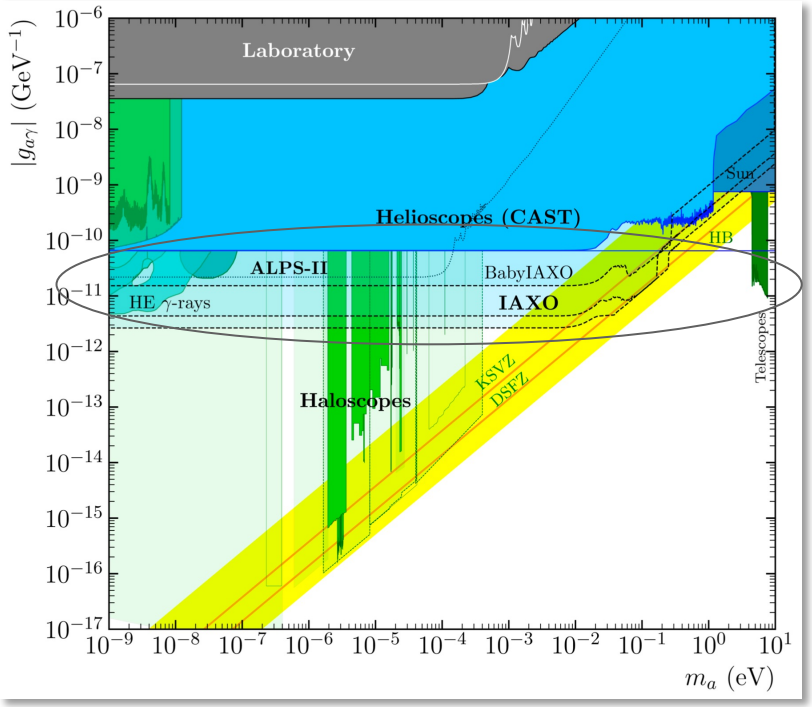
Kerstin Perez

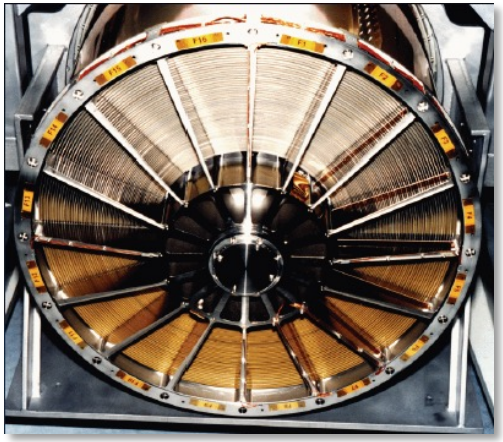
Julia Vogel

CF02 Snowmass 2021

Summary

- The International Axion Observatory (IAXO) is the successor to the CAST axion helioscope experiment
- IAXO will provide the **best sensitivity to axions and ALPs across a wide mass range**, in particular the high-mass (>10^{-3} eV) region
- **BabyIAXO**, a preliminary experiment **scheduled for operation in 2025**, will already deliver **a factor of ~5 improvement in sensitivity to the axion-photon coupling.** IAXO will offer a factor of ~20 improvement.
- *MIT and Livermore have already begun work to establish the US as a leader of the BabyIAXO X-ray optics system*
- *Key opportunity for US in the coming decade*

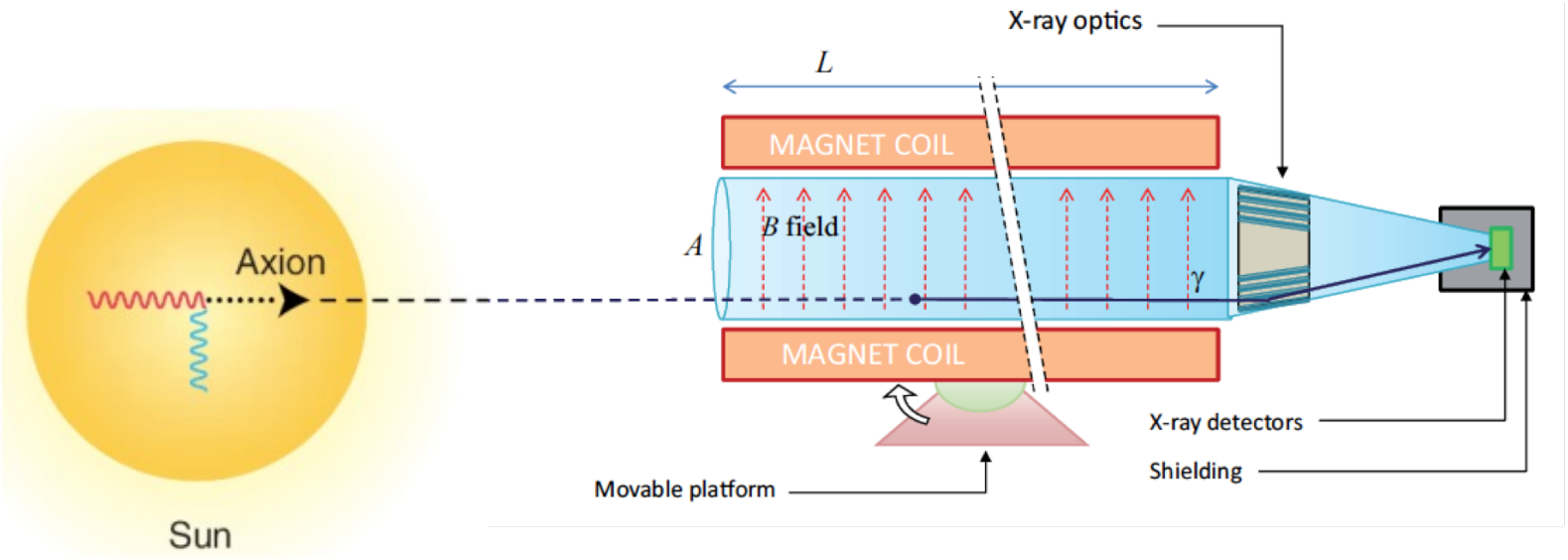




IAXO Collaboration, JHEP 05 (2021) 137

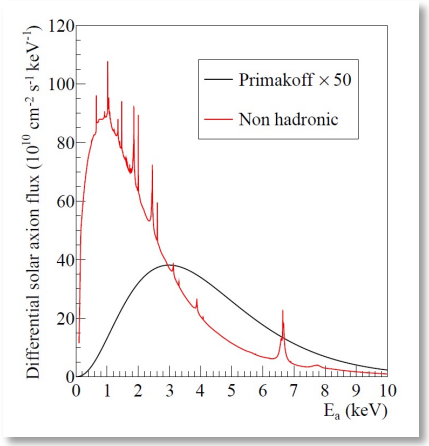
IAXO builds on successful helioscope design

IAXO will use a strong magnetic field to convert solar axions into X-ray photons that are focused onto low-background detectors



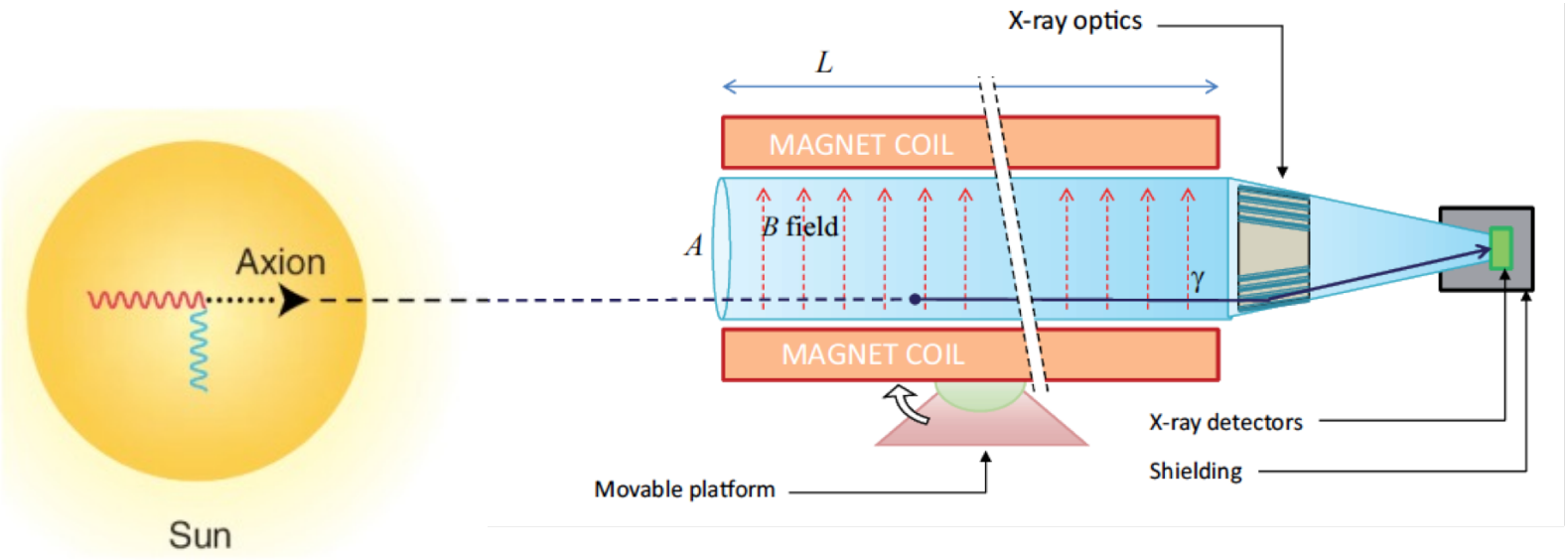
Primakoff conversion of photons in solar core
Sikivie PRL 51:1415 (1983)

Reconversion to *X-ray photons* in strong laboratory magnetic field
Redondo JCAP 1312 008 (2013)



IAXO builds on successful helioscope design

Expected IAXO improvement over CAST:
1−1.5 orders of magnitude in sensitivity to $g_{a\gamma}$ (factor of 1-2x10^4 in S/N)



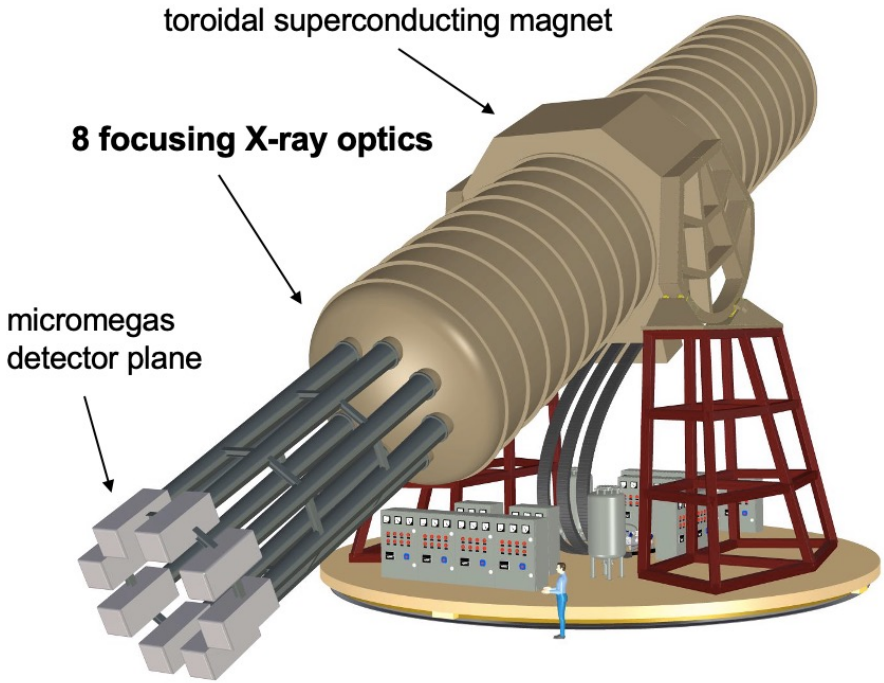
$$g_{a\gamma}^4 \propto \underbrace{(BL)^{-2}A^{-1}}_{\textbf{magnet}} \times \underbrace{t^{-1/2}}_{\textbf{exposure}} \times \underbrace{s^{1/2}\varepsilon_0^{-1}}_{\textbf{optics}} \times \underbrace{b^{1/2}\varepsilon^{-1}}_{\textbf{detectors}}$$

IAXO optimizes design parameters:

- **magnet**: B = magnetic field; L = magnet length; A = cross-sectional area
- **exposure**: t = time
- **optics**: s = spot size; ε_0 = efficiency
- **detectors**: b = background; ε = efficiency

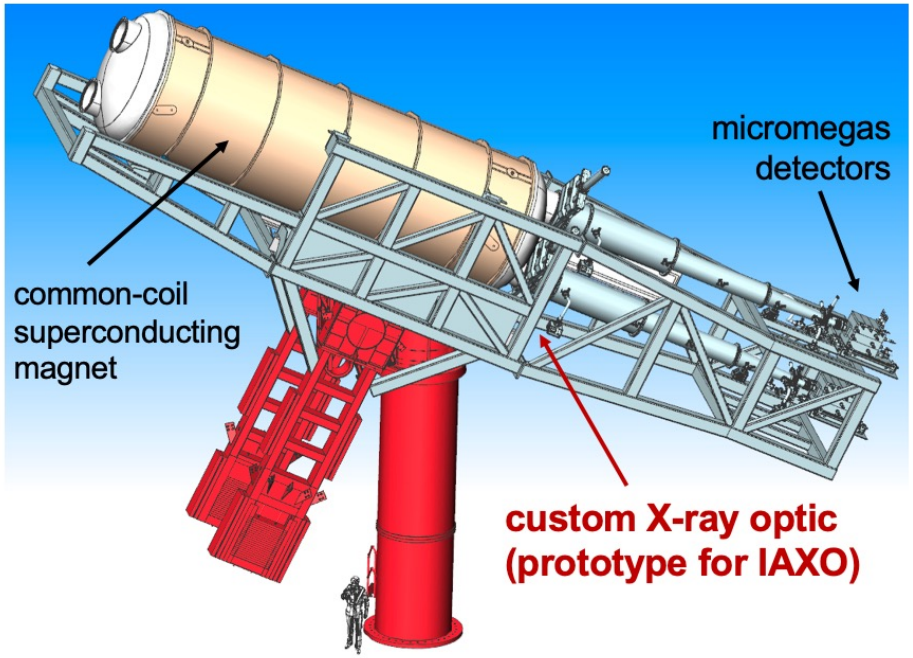
BabyIAXO: design validation + novel sensitivity

IAXO



IAXO Collaboration,
JCAP 1906 (2019) 047

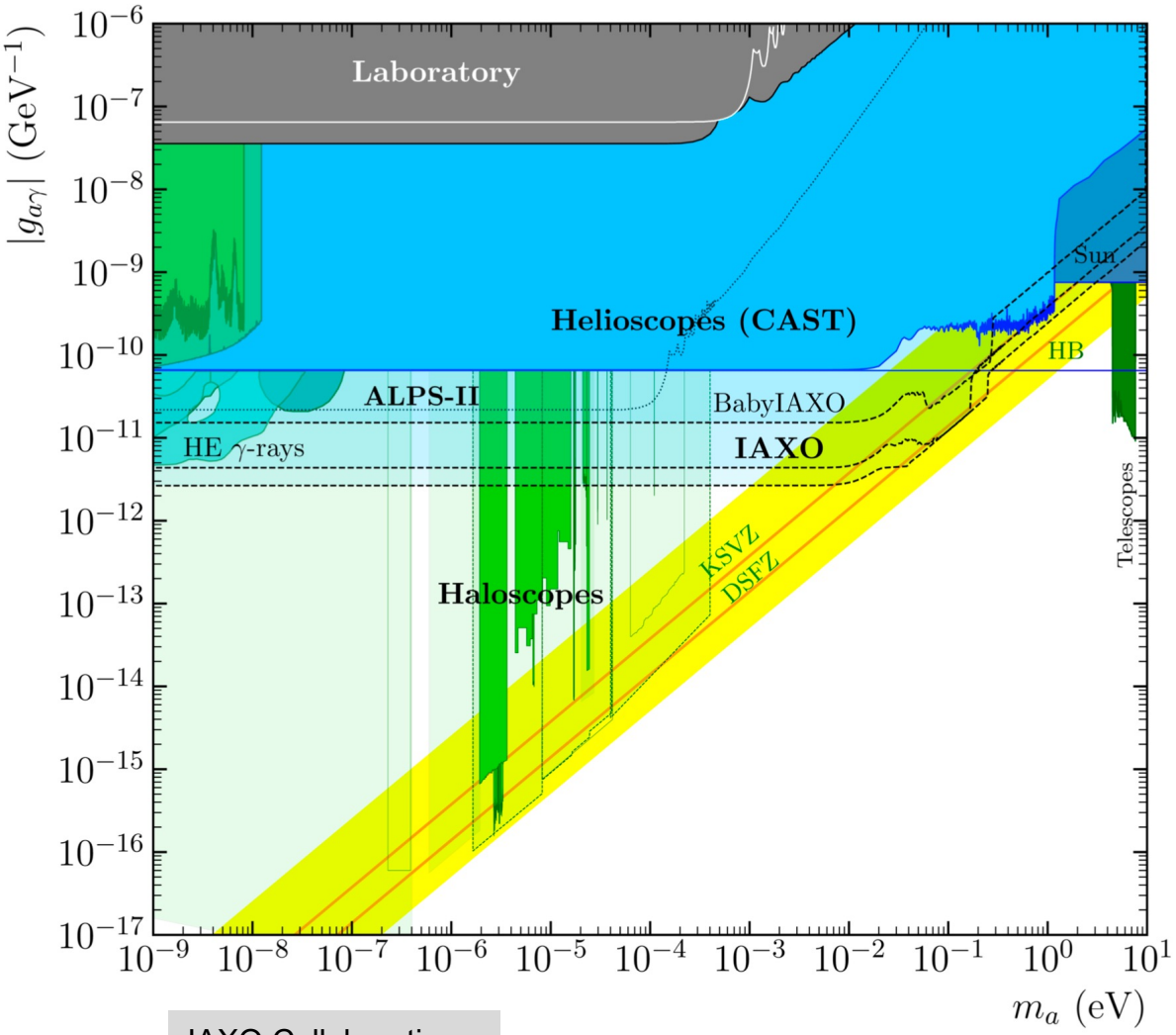
BabyIAXO



- Bore dimensions and detection lines representative of IAXO
- Magnet will validate coil design
- Risk mitigation/improvement for all systems
- *Novel axion sensitivity!*

IAXO Collaboration,
JHEP 05 (2021) 137

Improved sensitivity across broad mass range



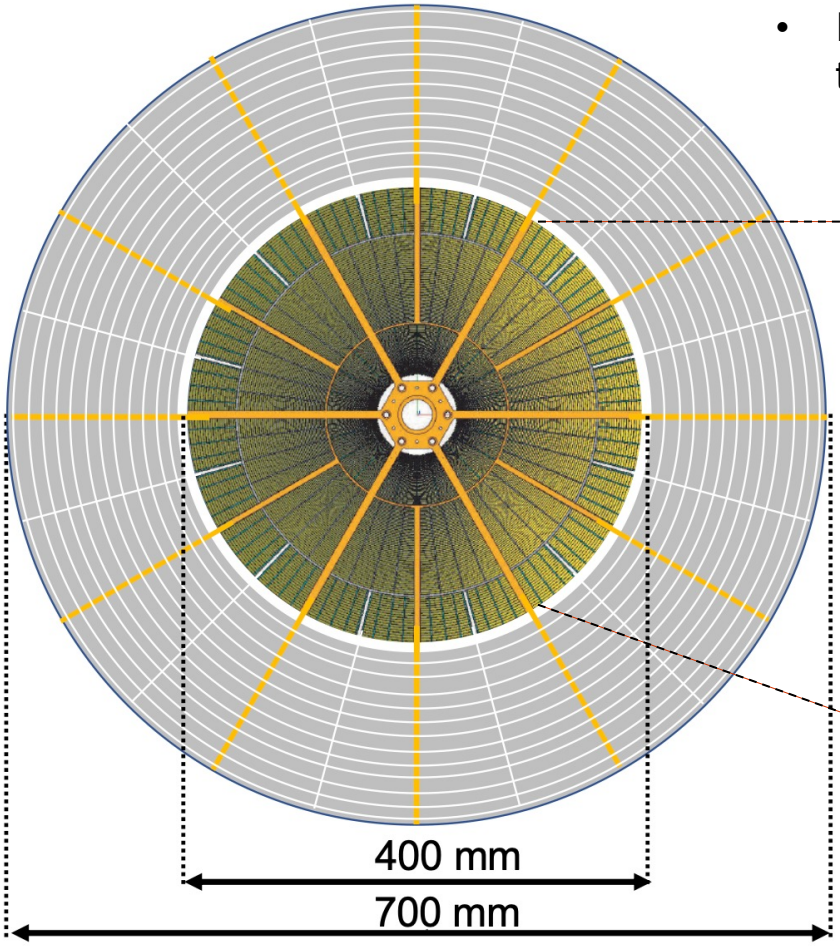
IAXO Collaboration, JHEP 05 (2021) 137

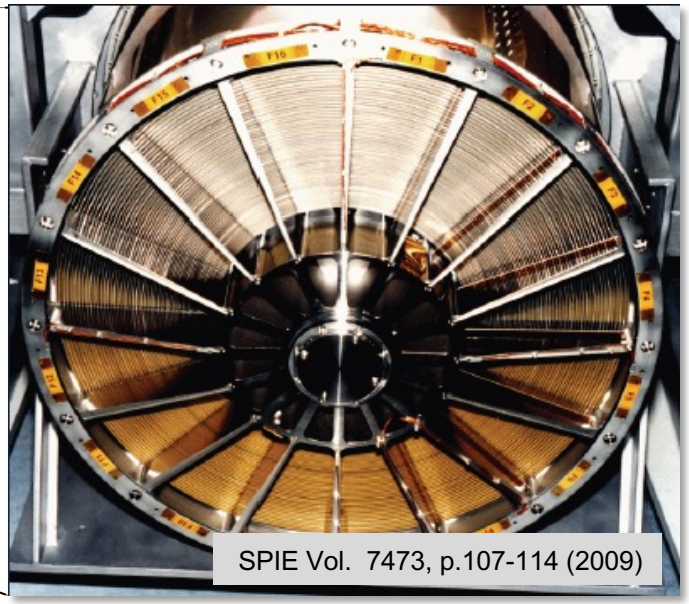
- Improve sensitivity over one order of magnitude across broad mass range
- **Unique sensitivity to QCD axions with m > 10^{-3} eV**
- *Sensitivity is independent of assumption that axion is dark matter*
- Axions in the mass range could be cold dark matter candidates, depending on tuning of vacuum realignment mechanism, axion string or domain walls decay to axion post-inflation

X-ray optics for axion research

Henriksen, et al. Applied Optics 60, 22 (2021)

- Each magnet bore will be instrumented with a large-diameter X-ray focusing optic
- Inner optics utilize the same segmented glass technology as the NuSTAR satellite telescope



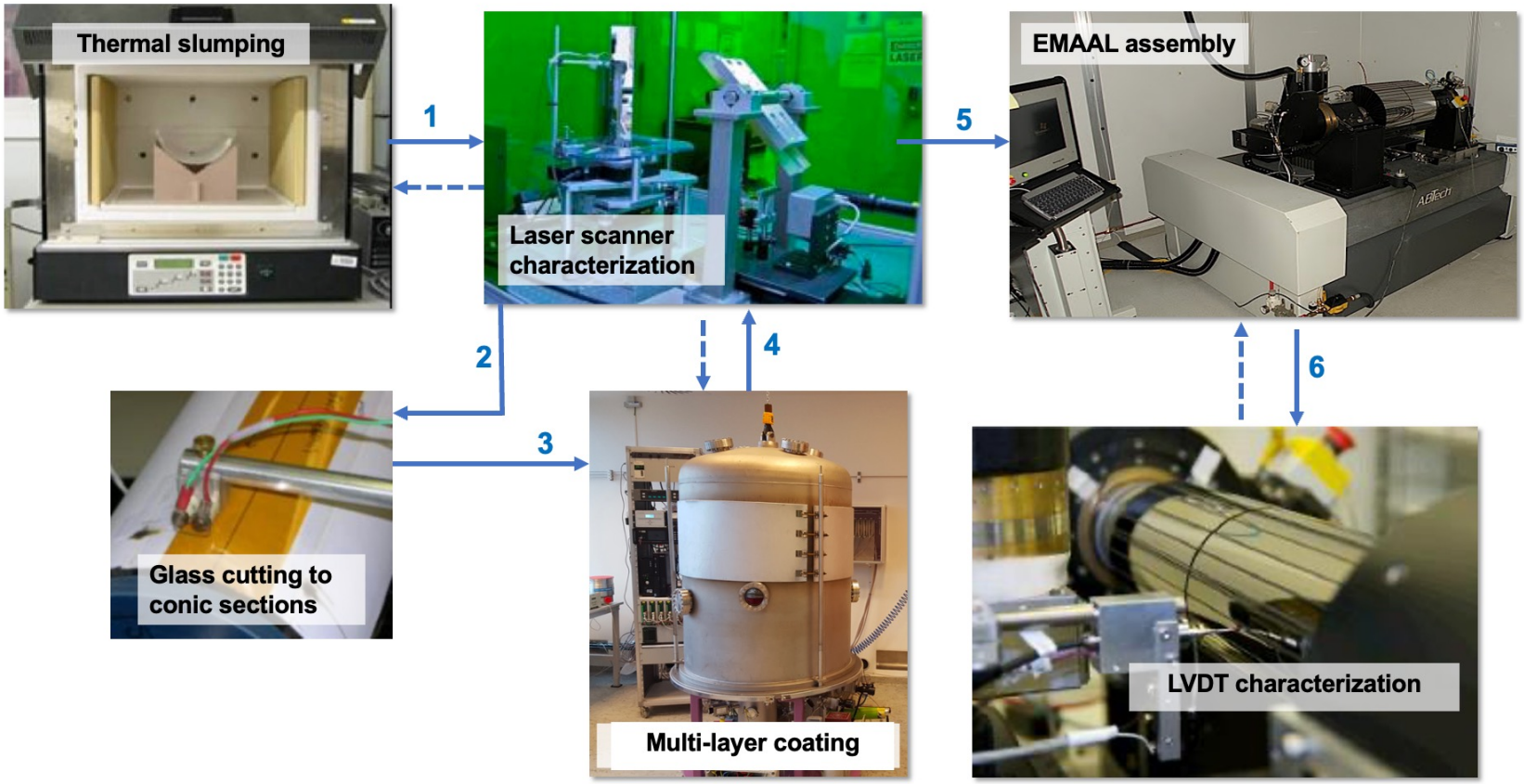


Outer corona optic: Cold-slumped glass

Civitani, et al. SPIE, 9905 (2016)

U.S. preparing for BabyIAXO optic construction

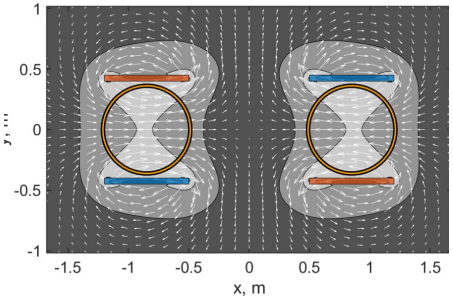
- Leverage facilities, materials, and team expertise from NuSTAR
- *Unique opportunity for U.S. leadership in IAXO instrument and science*

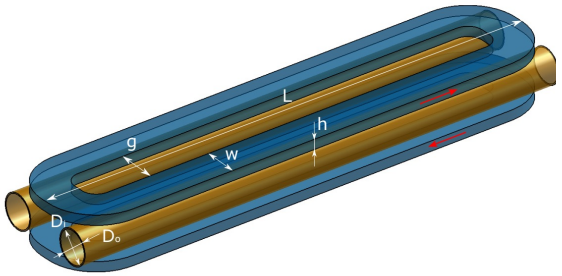


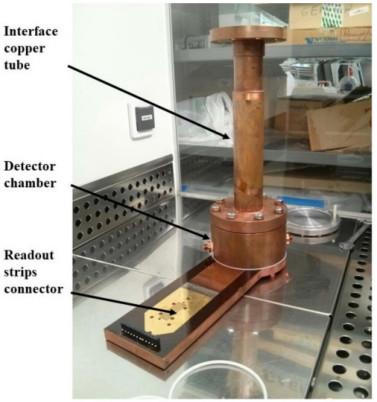
Progress on all BabyIAXO systems

Site at DESY:
HERA South Hall, former ZEUS detector hall

Common-coil "racetrack" magnet:
Uses existing infrastructure and expertise at CERN, winding layout very close to that of IAXO toroidal design







Support and drive:
Re-use CTA MST prototype

Micromegas detectors:
Surface tests improved shielding, 4pi muon veto
Underground tests underway

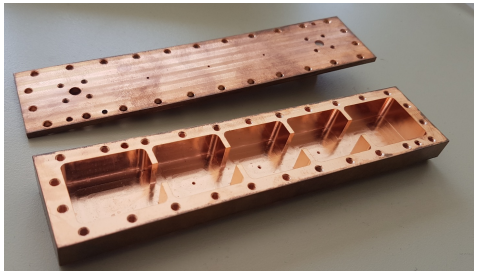
Haloscopes within (Baby)IAXO

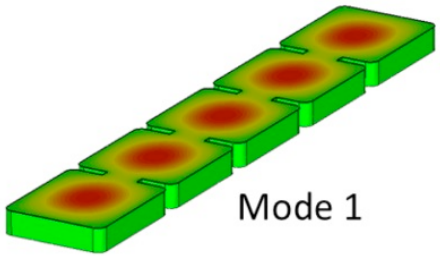
- Use of (Baby)IAXO large magnetic volume for axion haloscope designs

- **RADES** R&D exploring new concept in which sub-cavities coupled by inductive irises used to instrument large volumes
  - Proof-of-concept at small scale successfully tested in CAST
  - Technological connection with CERN

- Aim: to become the seed of a program to implement haloscope DM search in BabyIAXO

Part of ERC-StG (2018)
B. Döbrich/CERN





CAST Collaboration, *First results of the CAST-RADES haloscope search for axions at 34.67 μeV* (2021)

Vibrant and Growing Collaboration!

~125 scientists from 20 full member institutions + 5 associate institutions

Full members: Kirchhoff Institute for Physics, Heidelberg U. (Germany) | IRFU-CEA (France) | CAPA-UNIZAR (Spain) | INAF-Brera (Italy) | CERN (Switzerland) | ICCUB-Barcelona (Spain) | Petersburg Nuclear Physics Institute (Russia) | Siegen University (Germany) | Barry University (USA) | Institute of Nuclear Research, Moscow (Russia) | University of Bonn (Germany) | DESY (Germany) | University of Mainz (Germany) | MIT (USA) | LLNL (USA) | University of Cape Town (S. Africa) | Moscow Institute of Physics and Technology (Russia) | Max Planck Institute for Physics, Munich (Germany) | CEFCA-Teruel (Spain) | U. Politecnia de Cartena (Spain), U. Hamburg (Germany)

Associate members: DTU (Denmark) | U. Columbia (USA) | SOLEIL (France) | IJCLab (France) | LIST-CEA (France)

Summary

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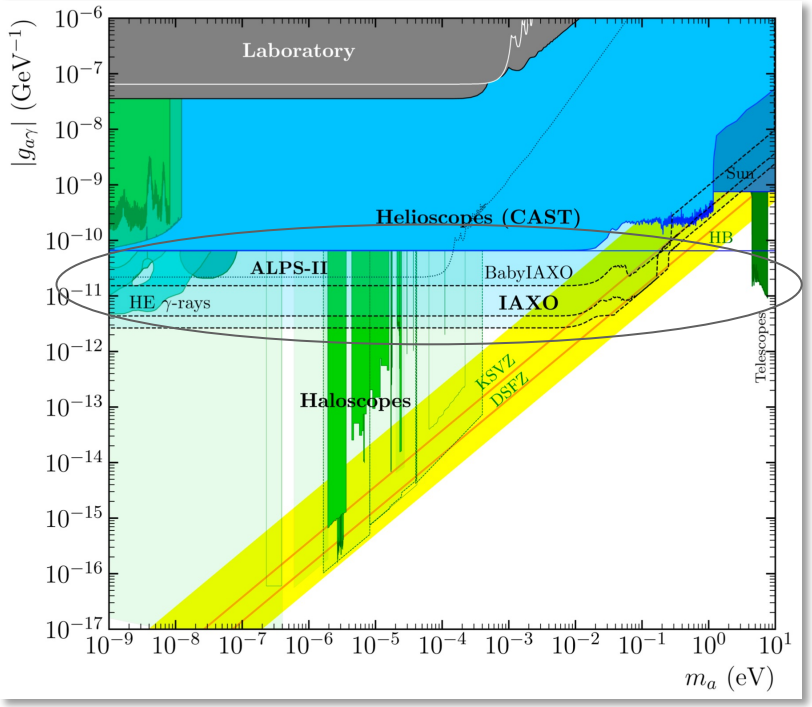
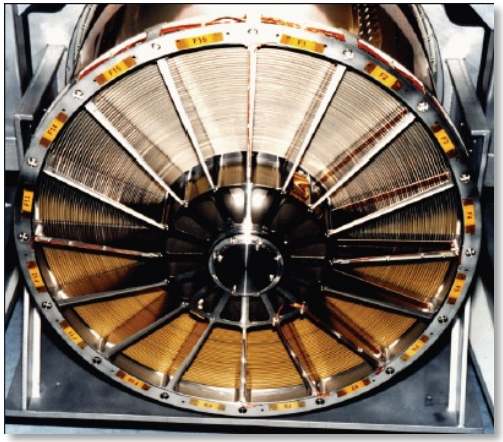
- **BabyIAXO**, a preliminary experiment **scheduled for operation in 2025**, will already deliver **a factor of ~5 improvement in sensitivity to the axion-photon coupling.** IAXO is designed to offer a factor of ~20 improvement.

- *U.S. assuming natural role in leadership of X-ray optics subsystem*





IAXO Collaboration, JHEP 05 (2021) 137

Backup

Parameter	Units	CAST	BabyIAXO	IAXO	IAXO+
B	T	9	~2	~2.5	~3.5
L	m	9.26	10	20	22
A	m^2	0.003 (*)	0.77	2.3	3.9
f_M	T^2m^4	21	~230	~6000	~24000
b	$keV^{-1}\,cm^{-2}\,s^{-1}$	1×10^{-6} (**)	1×10^{-7}	10^{-8}	10^{-9}
ϵ_d		~ 0.6	0.7	0.8	0.8
ϵ_o		0.3	0.35	0.7	0.7
a	cm^2	0.15	2×0.3	8×0.15	8×0.15
ϵ_t		0.12	0.5	0.5	0.5
t	year	~ 1	1.5	3	5