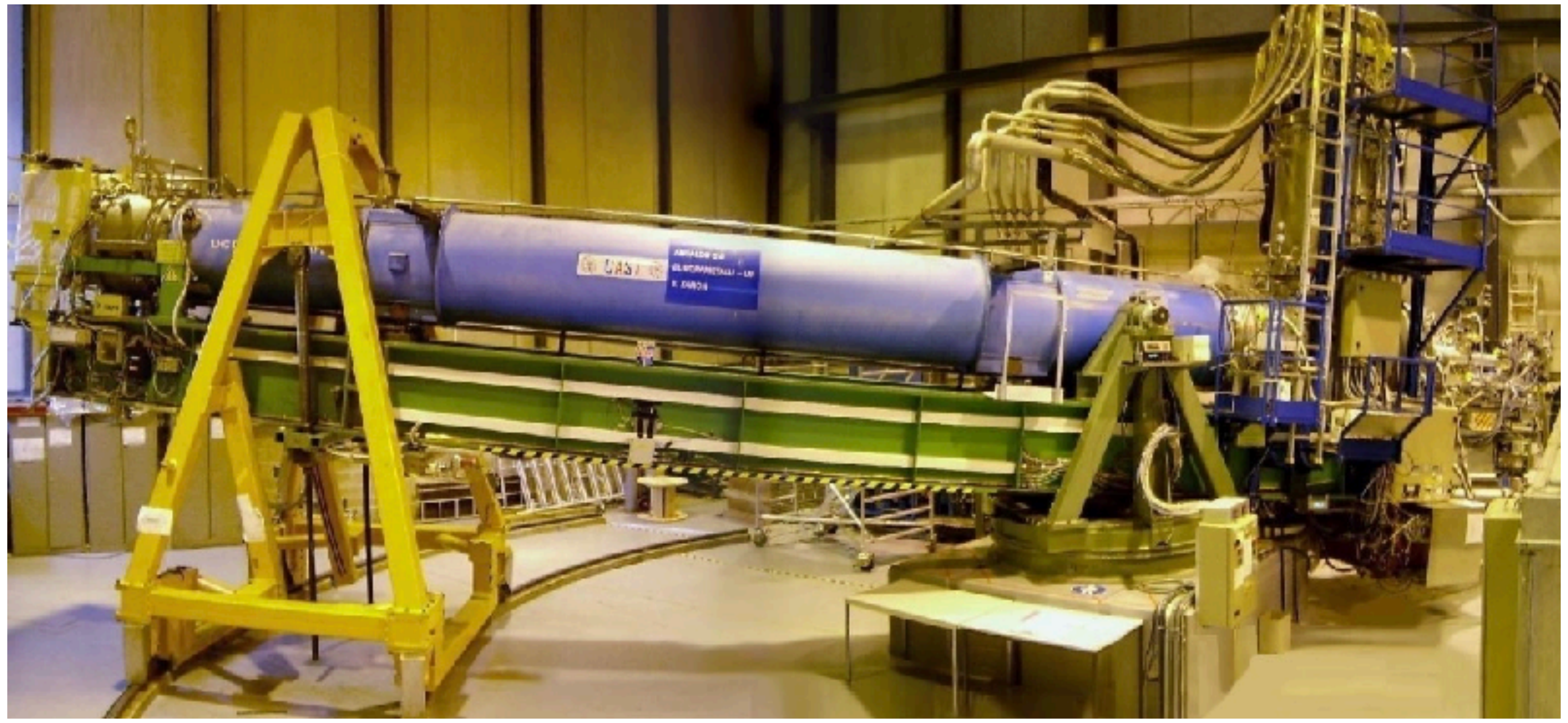
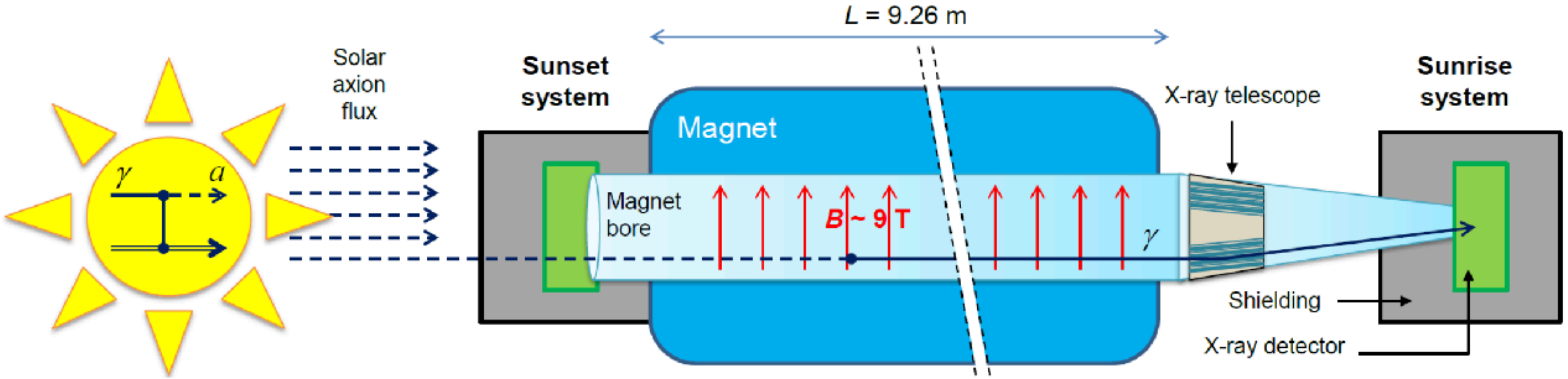
Searches for QCD Axions with BabyIAXO

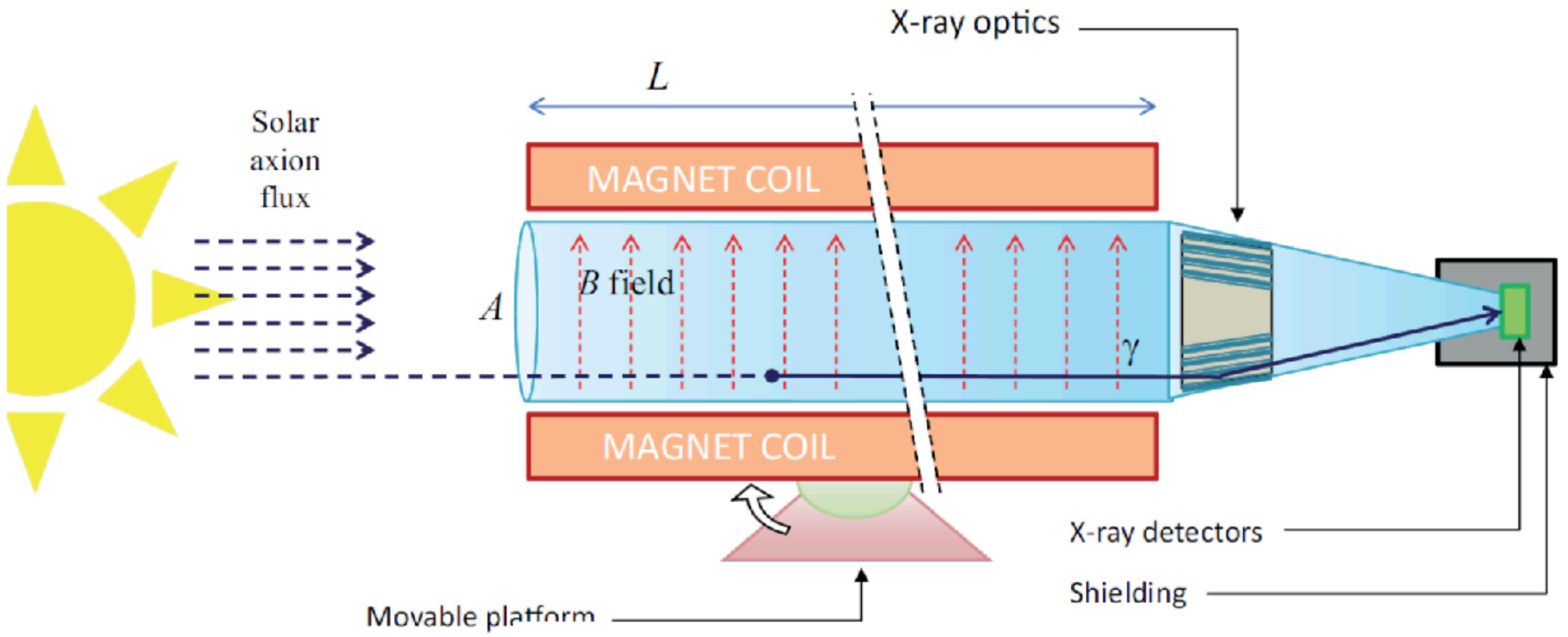
CAST

- First helioscope using low background techniques and x-ray focusing
- Superconducting LHC dipole magnet
- X-ray detectors
- Use of buffer gas to extend sensitivity to higher masses (QCD axion band)
- Most sensitive measurements until now





Enhanced Axion Helioscope IAXO



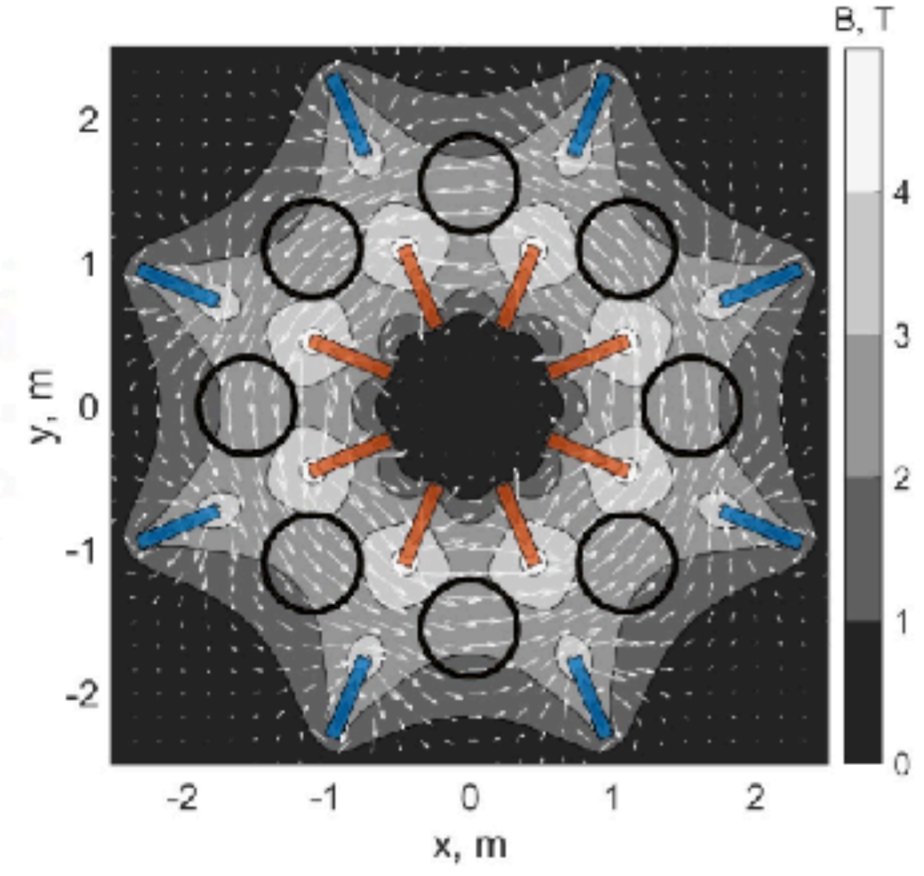
$$g_{a\gamma}^4 \propto \underbrace{b^{1/2}\epsilon^{-1}}_{\text{detectors}} \times \underbrace{a^{1/2}\epsilon_o^{-1}}_{\text{optics}} \times \underbrace{(BL)^{-2}A^{-1}}_{\text{magnet}} \times \underbrace{t^{-1/2}}_{\text{exposure}}$$

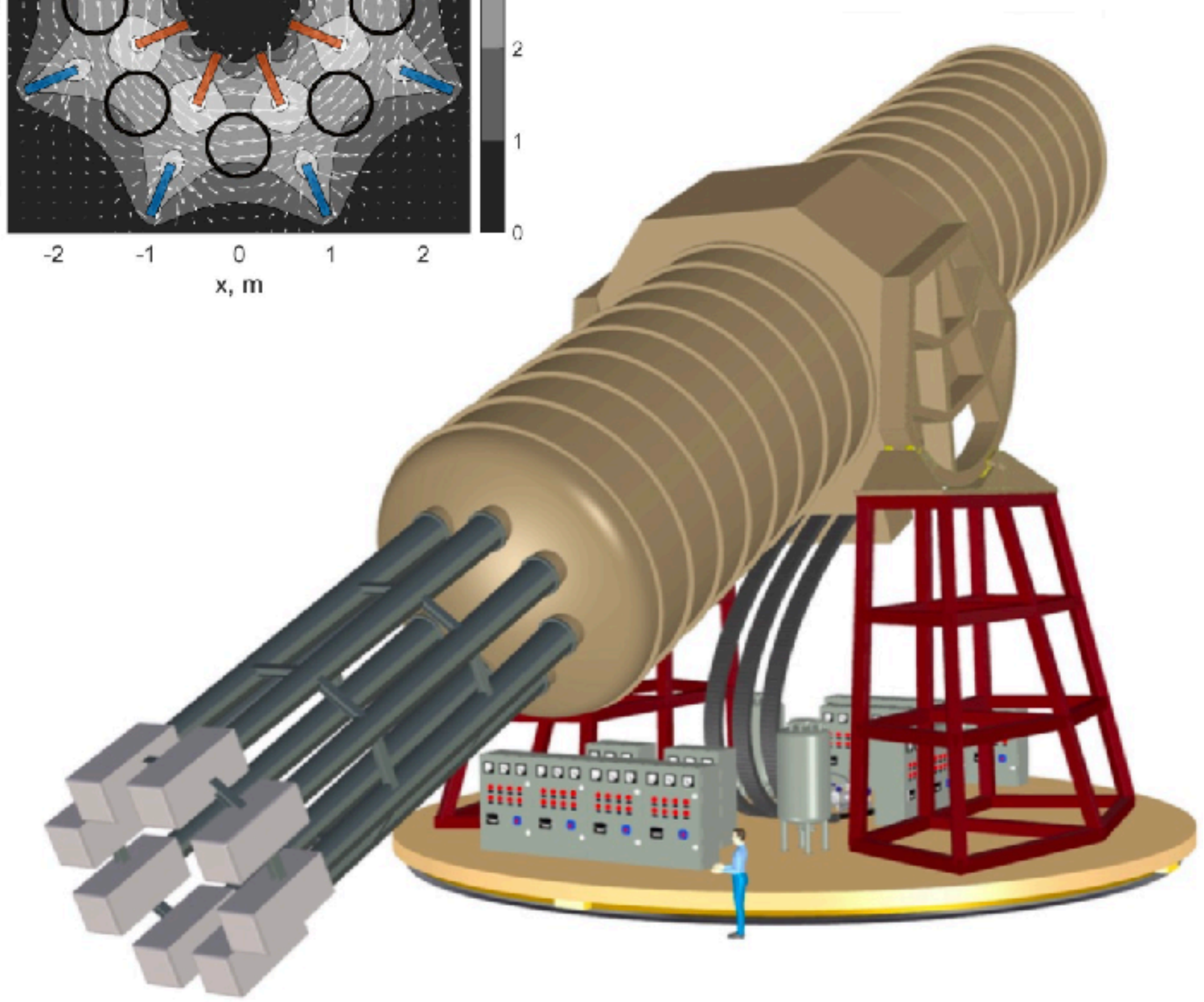
Enhanced axion helioscope:
Irastorza et al.,JCAP1106:013,2011

- IAXO conceived as large-scale, realistic enhanced axion helioscope
- $>10^4$ better SNR than CAST
- Sensitive to g_{ag}~x20
- lower than CAST

International Axion Observatory

- Next generation "axion helioscope" after CAST
  - Purpose-built large-scale magnet:
    >300 times larger B^2L^2A than CAST magnet
- Toroid geometry, very similar to ATLAS μ toroid
- 8 conversion bores of 600mm Ø, ~20 m long
- Detection systems (x-ray telescopes + detectors)
- We need
  - Low-background techniques for detectors
  - X-Ray Optics
  - ~50% Sun-tracking time
  - Large magnetic volume available for additional "axion"physics (e.g. dark matter setups)

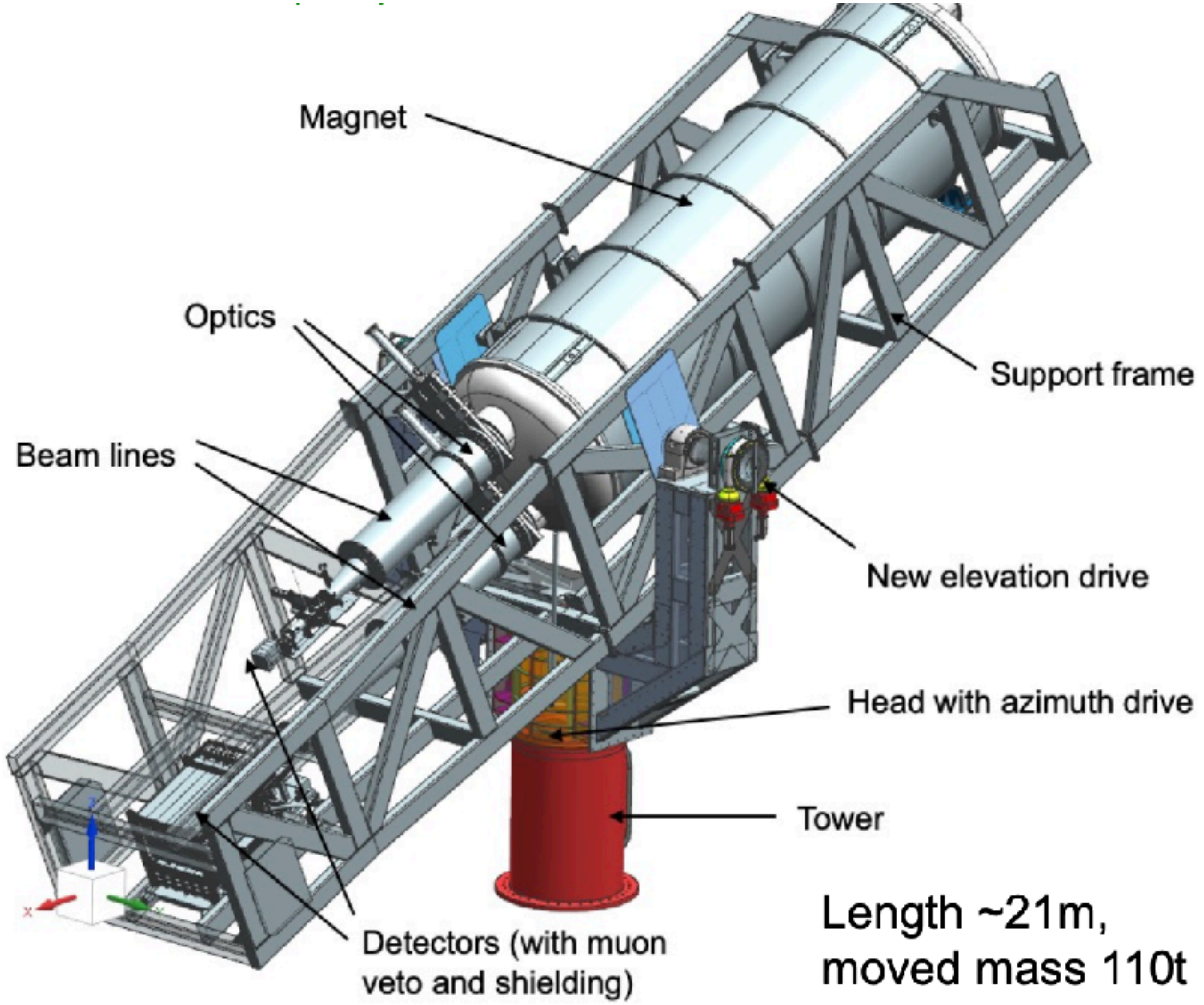




BabyIAXO

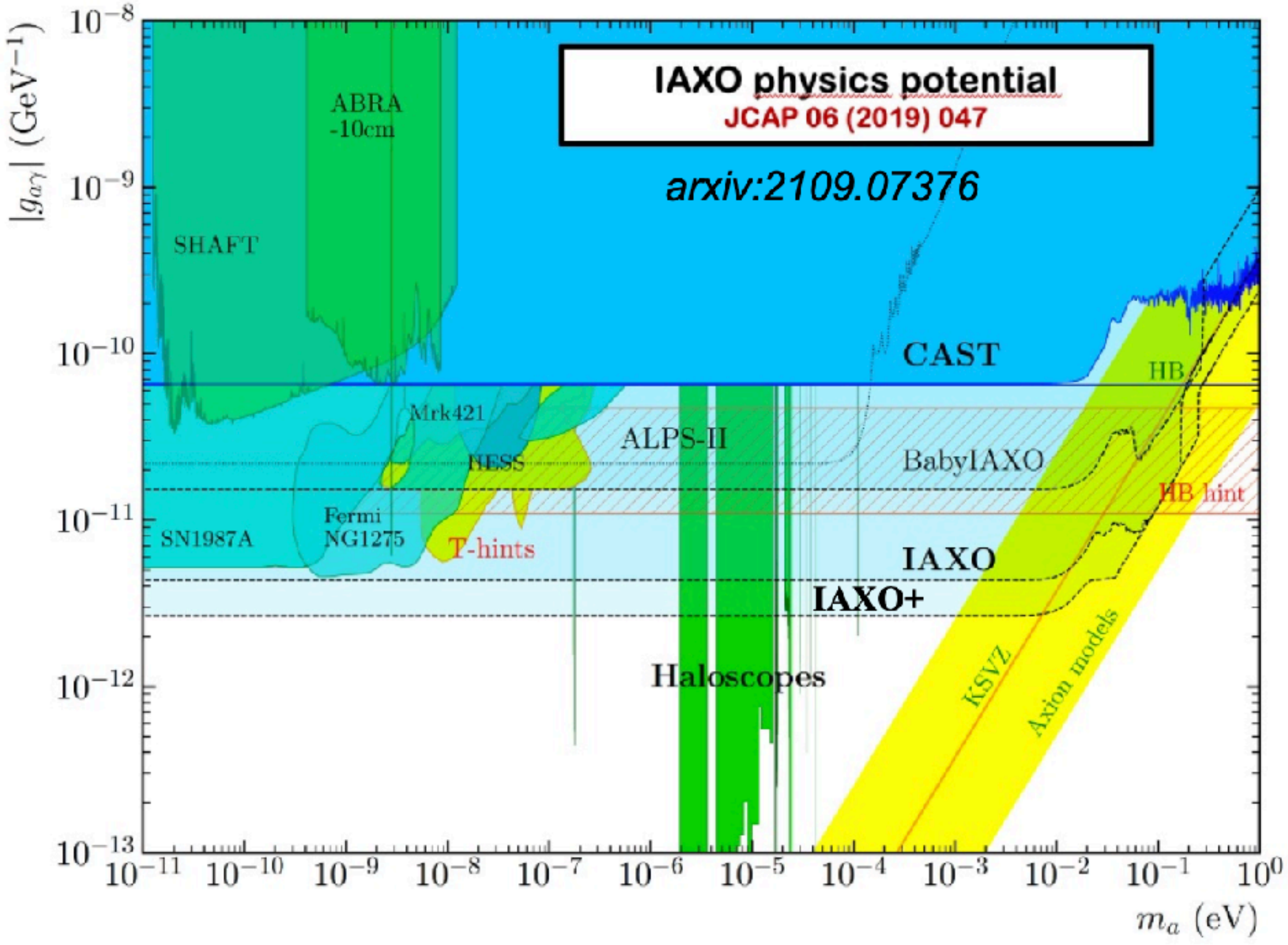
- Intermediate experimental stage before IAXO
  - Two bores of dimensions similar to final IAXO bores à detection lines representative of final ones
  - Magnet will test design options of final IAXO magnet
  - Test & improve all systems. Risk mitigation for full IAXO

- Physics: will also produce relevant physics outcome
  - FOM (SNR) ~100 times larger than CAST

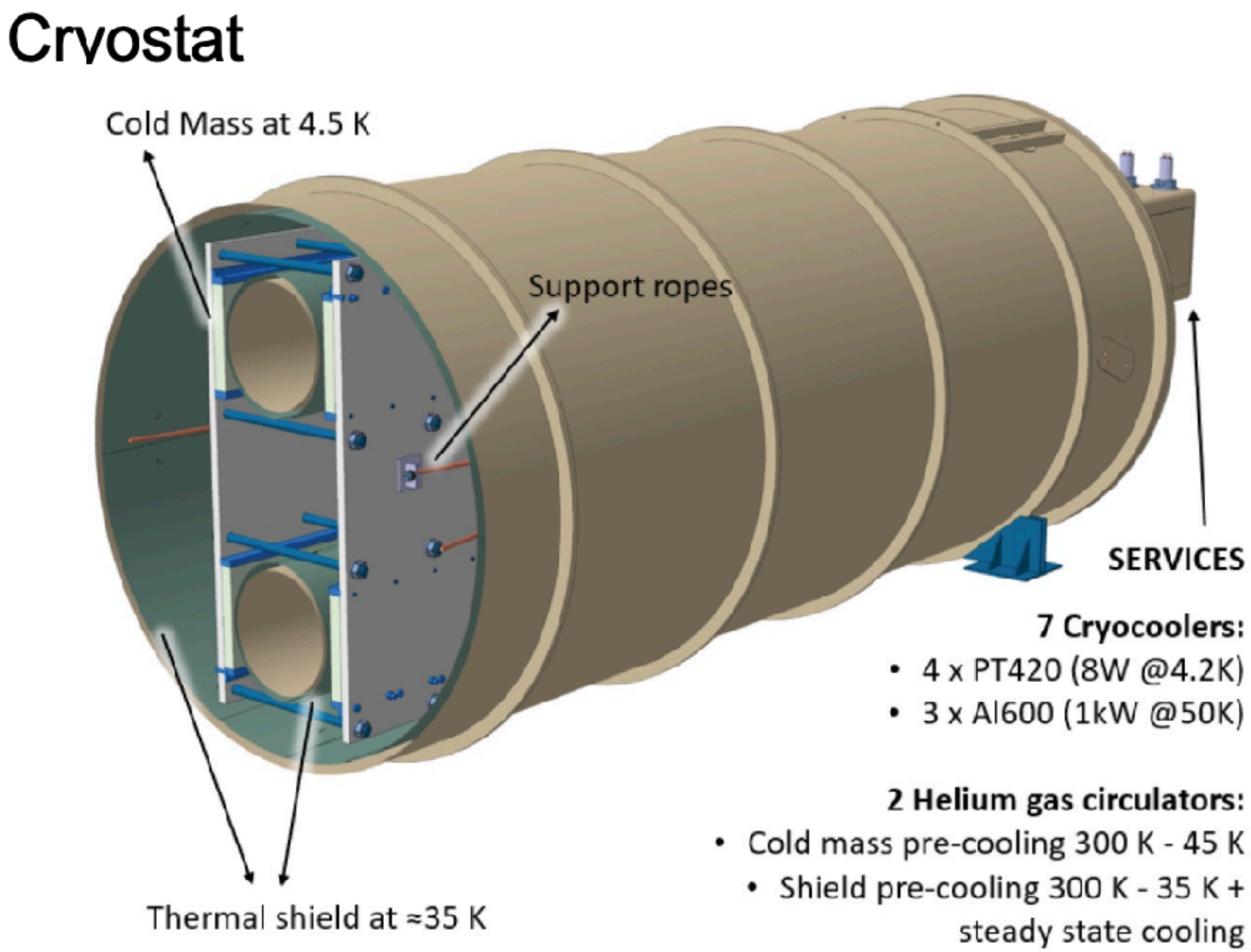


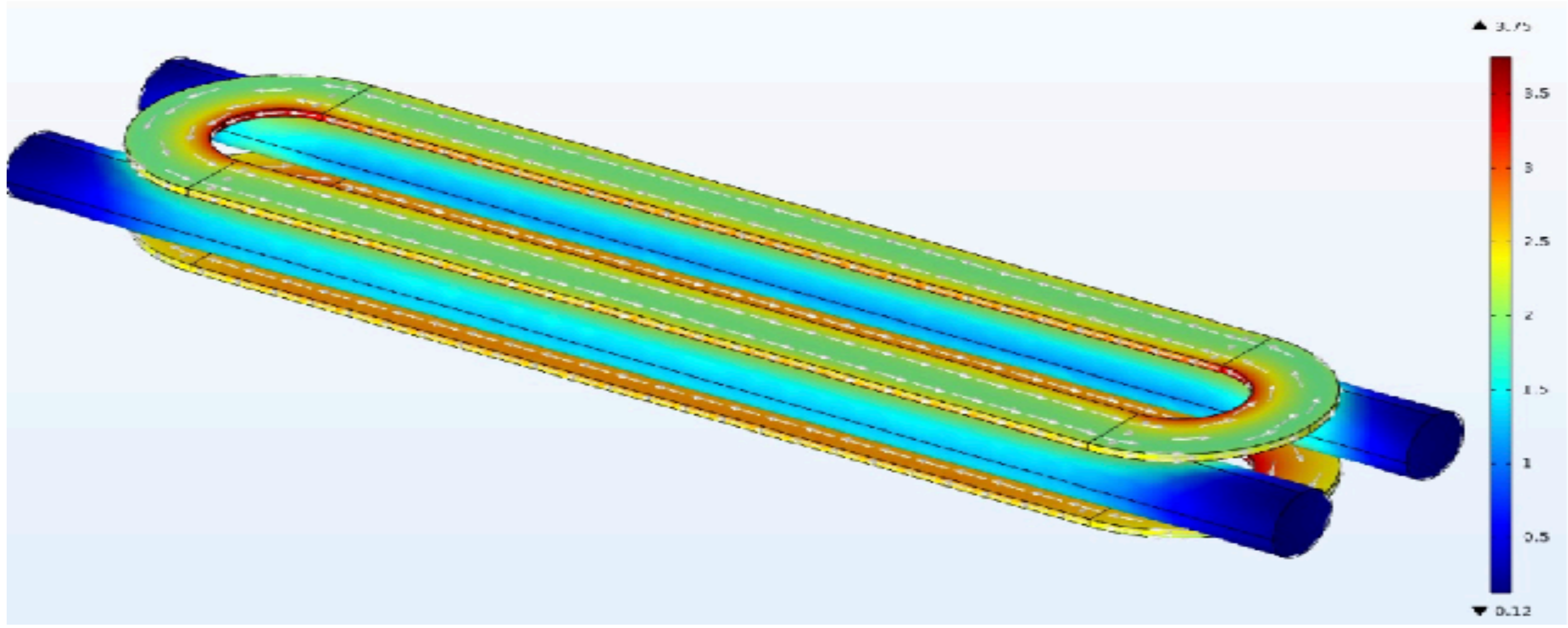
BabyIAXO

- Large generic unexplored ALP space
  - QCD axion models in the meV to eV mass band.
- Astrophysically hinted regions
  - ALP region invoked to solve the transparency anomaly
  - axion region invoked to solve the stellar cooling anomaly
- Cosmologically interesting regions
  - viable QCD axion DM models,
  - ALP Dark Matter + inflation models
- All this, independent of the axion-as-DM hypothesis.



Magnet System

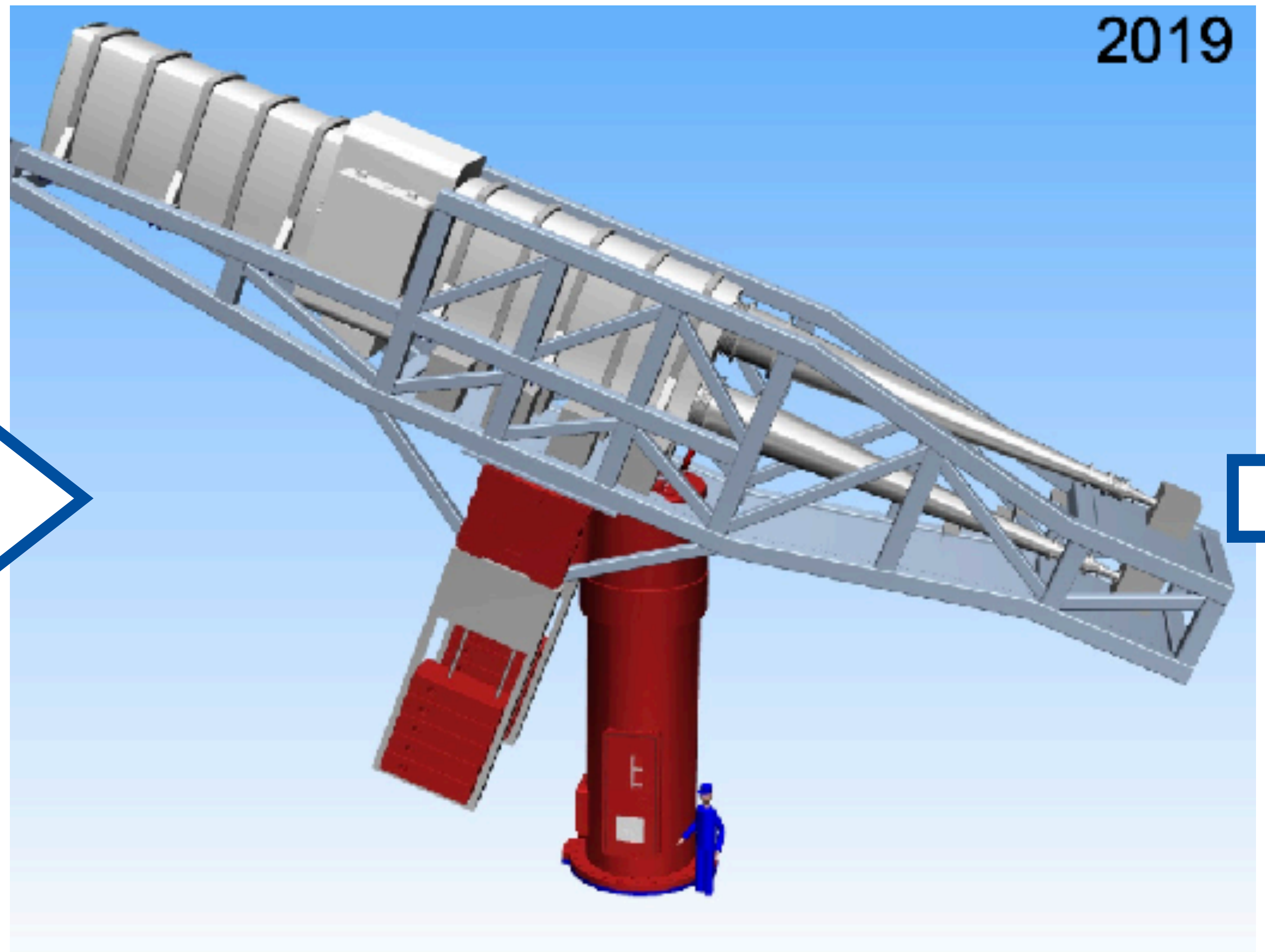


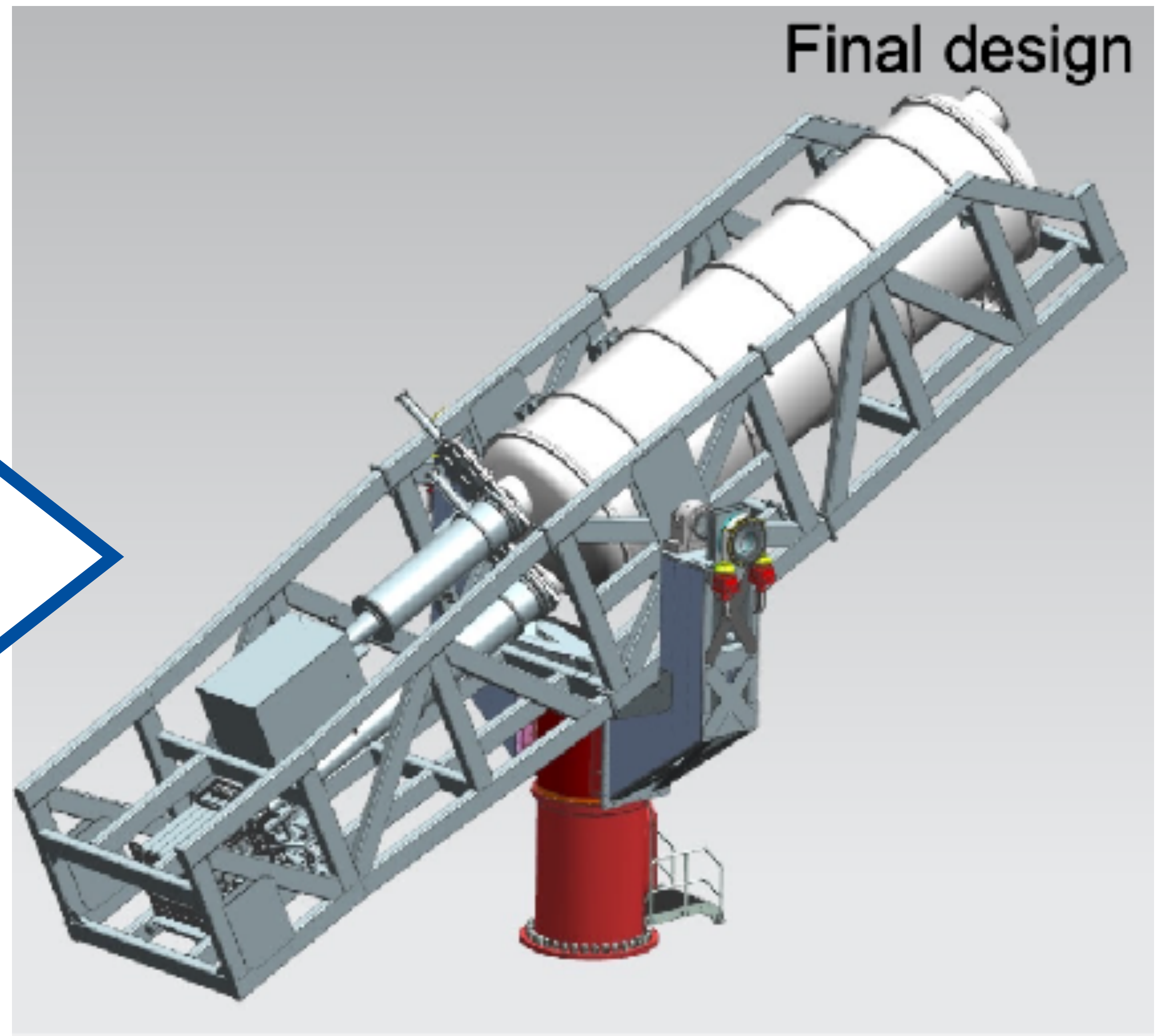


- Common coil" configuration
  - Minimal risk: conservative design choices
  - Cost-effective: Best use of existing infrastructure and experience at CERN
  - Prototyping character: winding layout very close to that of IAXO toroidal design.

Structure and Drive System

- Reusing CTA MST prototype from Berlin (DESY Zeuthen). Dissembled, moved to HERA South Hall in May 2020
- Designed large support frame holding magnet, optics, vacuum system and detectors
- Redesigned elevation drive due do large torque





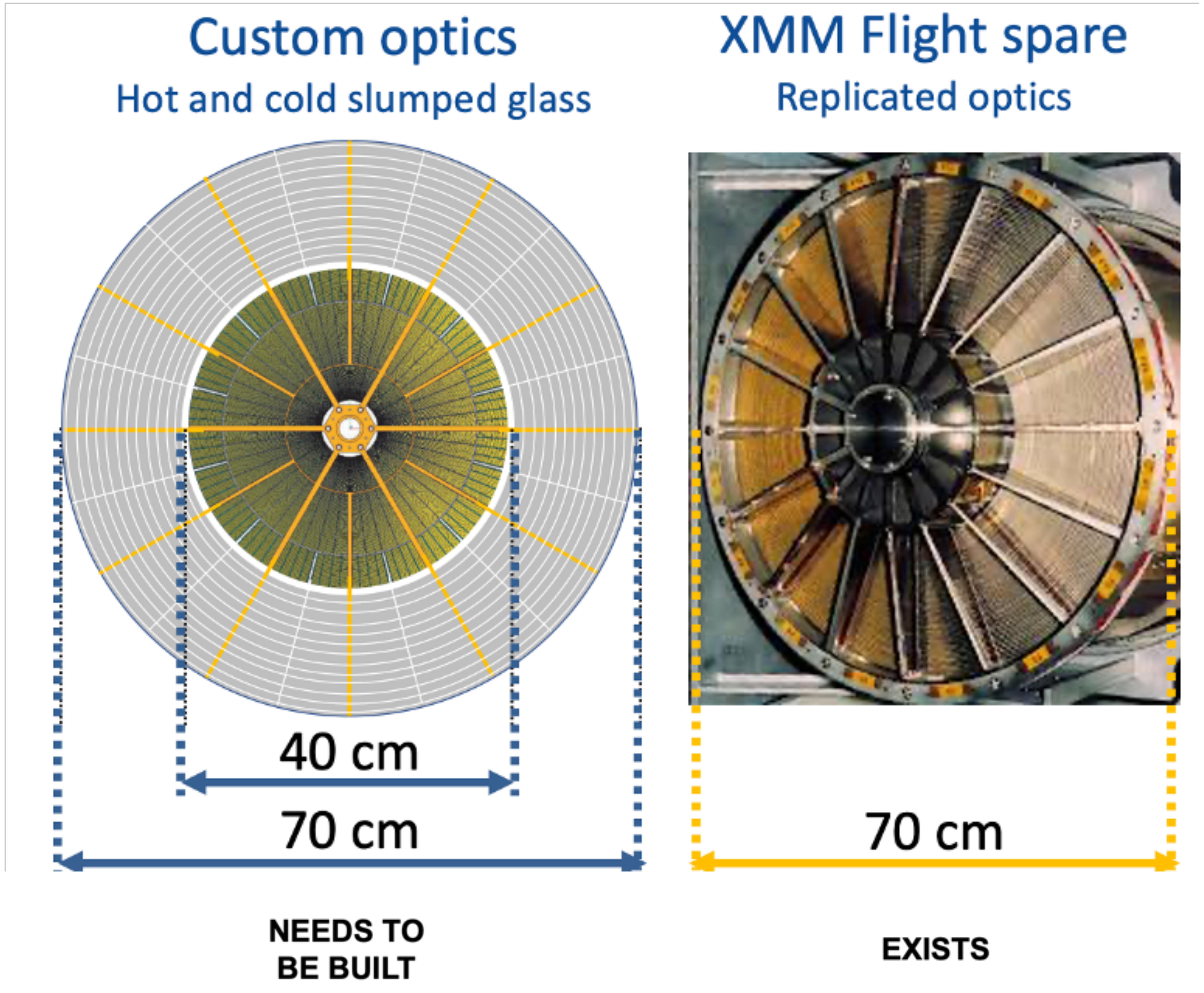
BabyIAXO Optics

- What (Baby)IAXO needs in terms of x-ray optics?

- Maximized throughput efficiency
  - Tuned to axion spectrum and detector response
  - Can be enhanced with multilayer coatings for region of interest and low energy response

- Minimized focal spot area (0.2 cm2/ r < 2.5 mm)
  - Modest spatial resolution (arcmin level)
  - Moderate focal length

- Cost effective way to build 1 to 8 highly nested, high-efficiency optics



BabyIAXO Detectors

- Low background Micromegas detectors
  - “Discovery detectors” (priority to low background)
  - Experience in CAST
  - Low background capability, radiopurity, shielding.
  - Implementation of 4 pi muon veto.
  - Enough to obtain 10-7 cts/keV/cm2/s

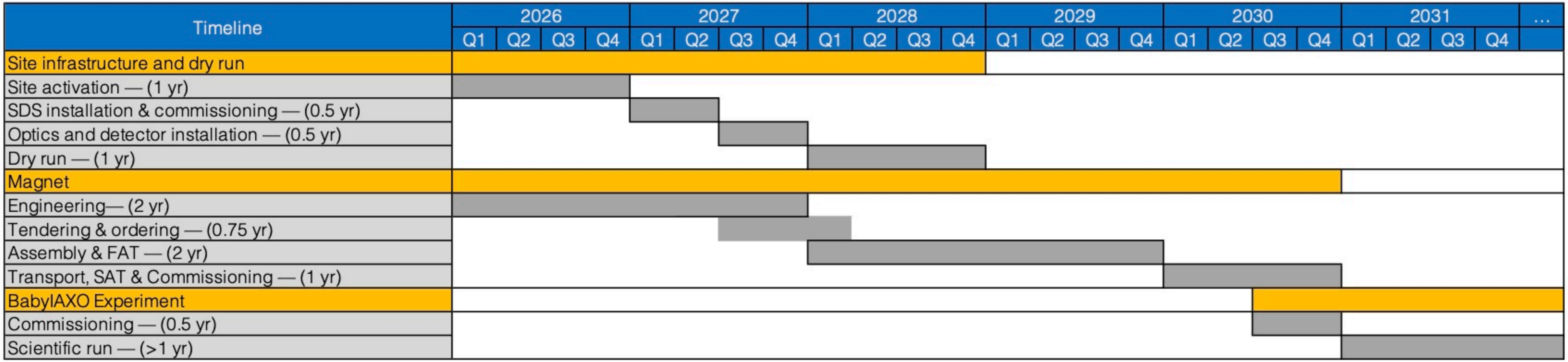
Gridpix

color meets flavor

BabyIAXO in Color Meets Flavor

What is missing? Timeline?

- Nearly all components are financed
- Missing: Funding of 6 Million Euros for the BabyIAXO Magnet System



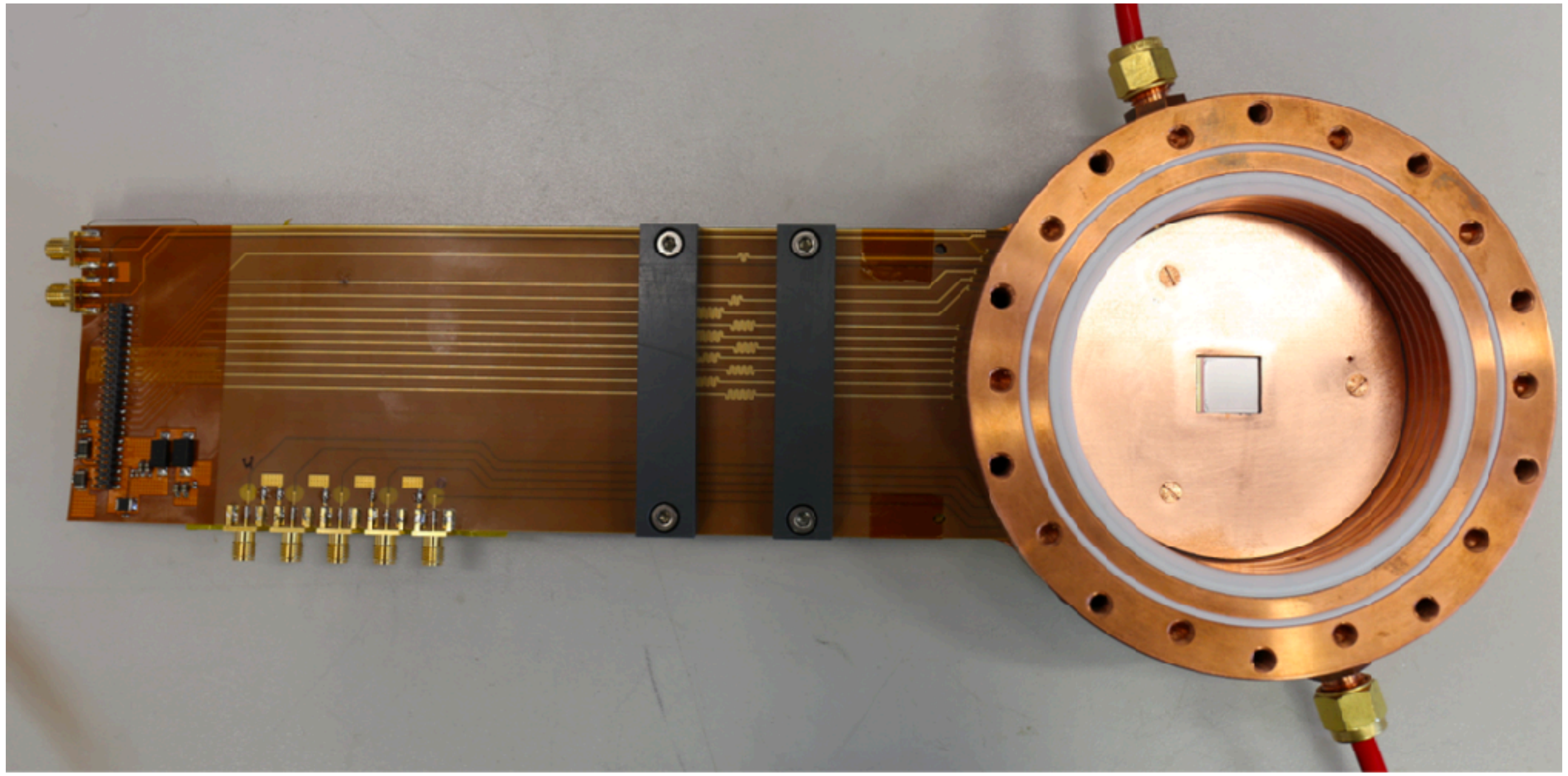
Magnet Purchasing

- The BabyIAXO Magnet System is a R&D Prototype
  - Extensive Studies and Cost-Estimates by the private Sector which cost a 6-figure number
- Agreement with Cluster-Universities and NRW: 50% of the funding will be provided in case of a successful CmF application and a successful DFG Major Equipment application
  - Application was submitted in October (60 pages). Result expected in second half of 2026

Parameter	Value
Number of turns per layer	120
Number of layers per coil	4
Number of coils	2
Conductor length (excluding extra for leads, connections, QC, etc.)	20 km
Magnetic field	2–3 T
Magnetic area	0.77 m^2
Maximum magnetic field on conductor	3.9 T
Maximum current	6 kA
Nominal operating current	6 kA
Stored energy	38 MJ
Voltage at power supply	Up to 10 V
Ramp rate	0.5 A/s
Inductance	3.1 H
Voltage drop across leads	Not yet defined
Operating temperature	~4.3 K
Cold mass dimensions (L × W × H)	10.2 m × 2.63 m × 1.1 m
Diameter of the two room temperature bores	700 mm
Magnet dimensions	11 m × 3.35 m (without turret)
Weight	50 t
Maximum tilt angle during nominal operation	±25°

Future Work of AG Desch / Fleck

- Ultra-low background GridPix detector for BabyIAXO
  - Single-chip, Timepix3-based, GridPix detector which uses radiopure materials has been recently assembled
  - Full Geant4-based simulation of the detector
  - Improved ultra-thin Silicon Nitride X-Ray entrance windows



Future Work of AG Vogel

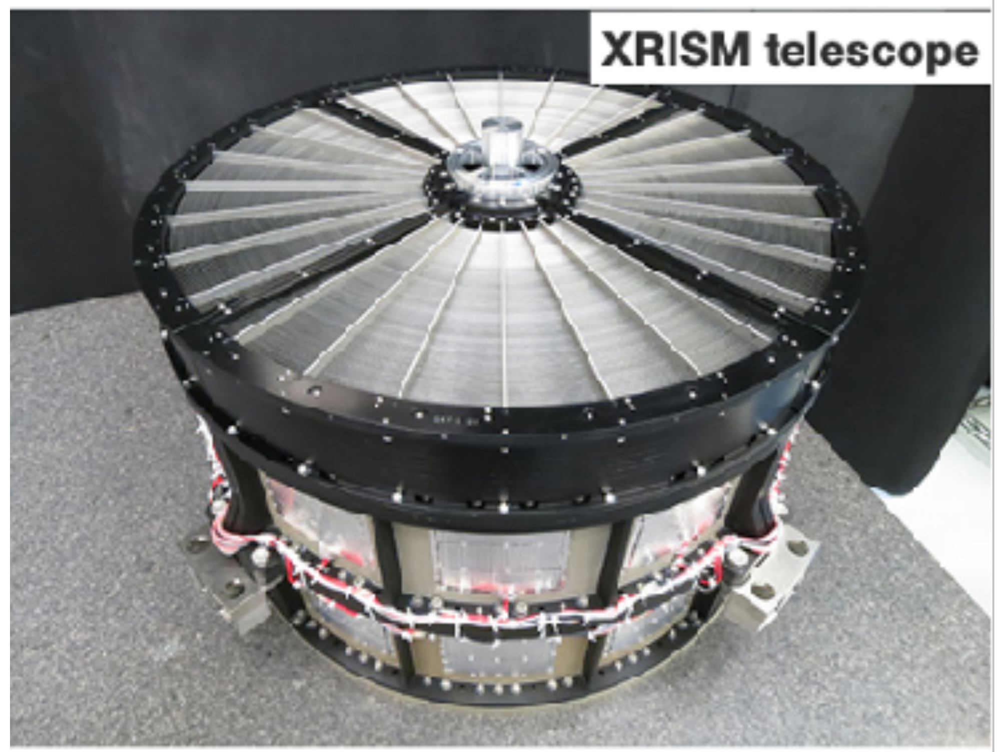
- Current and Future plans for TUDO

- XMM XRT for BIAXO (PANTER/INAF/TUDO/UNIZAR)
  - Vacuum vessel for XMM XRT (Design at TUDO)
  - Recalibration of XMM at Panter (TUDO expertise)
  - Implementation at DESY (Beamline and optics coordination at TUDO)

- NUSTAR XRT for BIAXO (CU/DTU/LLNL/UNIZAR/TUDO)
  - NuSTAR glass characterization (Future X-ray reflectometer @TUDO)
  - Simulations and multilayer coatings (Close collaboration with CU/DTU/TUDO)

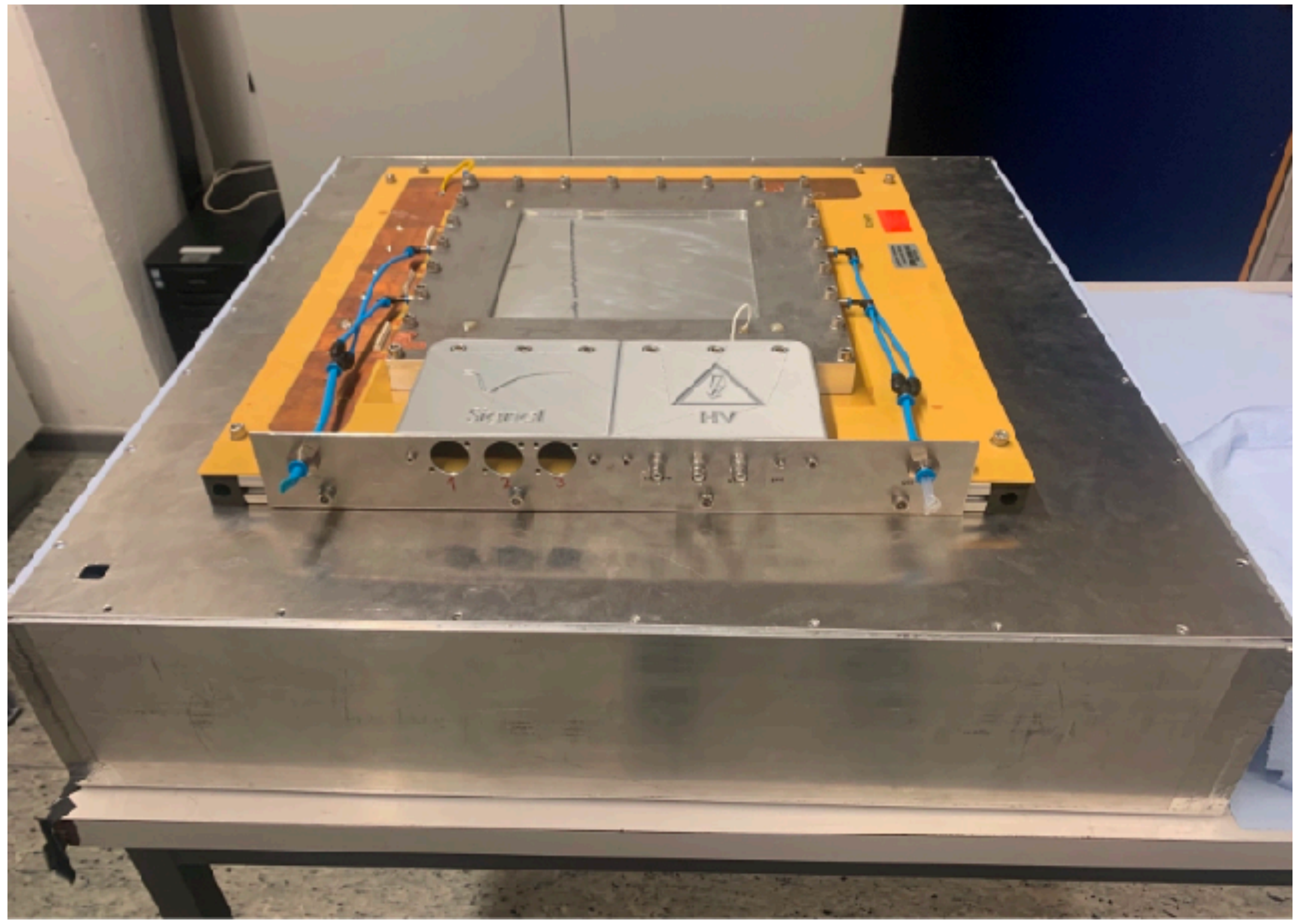
- BRAVO XRT for BIAXO (INAF/BCV/DTU/TUDO)
  - Outer part of custom-built optic: TUDO involvement in Multilayer coating (Close collaboration with DTU)

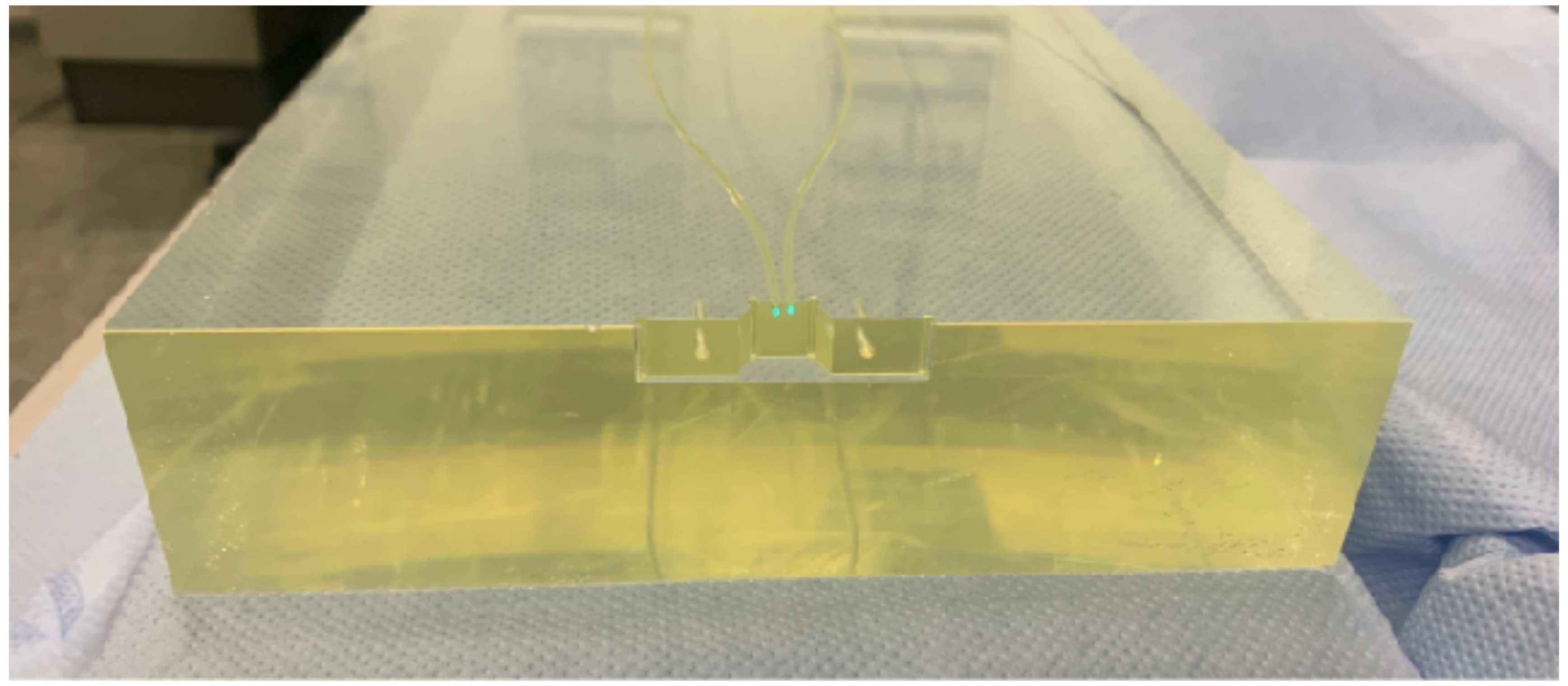
- Other developments
  - Radiopurity measurements @LSC (Unizar/TUDO a.o.)
  - NASA/JAXA XRISM optic as Plan B for NuSTAR-like optic

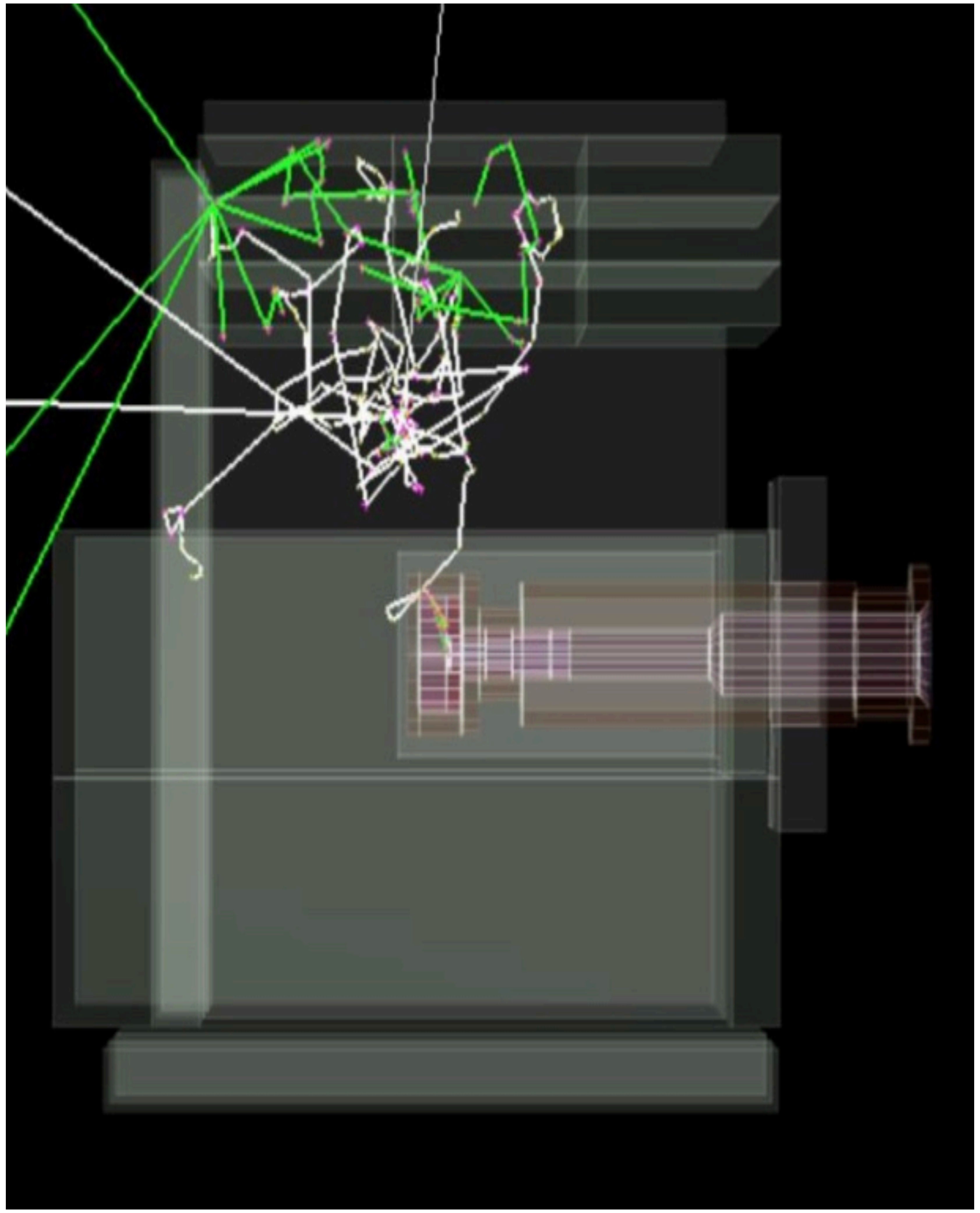


Future Work of AG Schott

- Prototype-Myon Veto-System already developed with an efficiency >99.999%
  - Based on SiPMs
  - 4 Layers of old scintillators from Mainz
  - Modular Design
- Think of Neutrons
- Construction of the full system during the first half of CmF







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Zur Diskussion

- CmF will enable the BabyIAXO Experiment
- Key Objective: Find QCD Axion
- Main Investment via DFG Major Equipment Funding
- Need to take over responsibilities in the magnet design/procurement