The International Axion Observatory (IAXO)

8th Patras Workshop on Axions, WIMPs and WISPs

22 July 2012, Chicago, IL, USA

Julia K. Vogel
Lawrence Livermore National Laboratory
On behalf of the IAXO collaboration

Lawrence Livermore National Laboratory

LLNL-PRES-566177

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Overview

- Solar Axion Searches
- The International Axion Observatory (IAXO)
  - Magnet
  - X-ray optics for IAXO
  - Low-background detectors for IAXO
  - Prototype Testing
- IAXO Prospects
  - Sensitivity Prospects
  - Collaboration and Schedule
- Conclusions

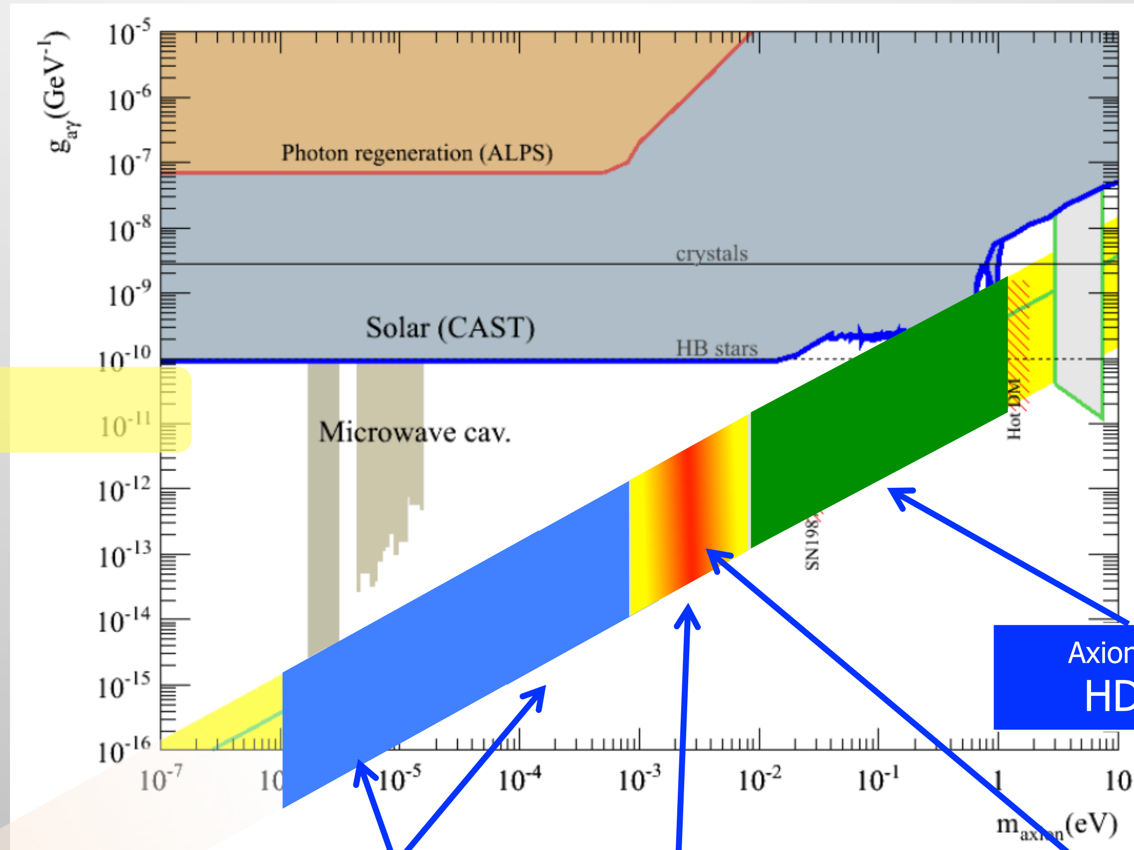
Irastorza et al. JCAP 06 (2011) 013

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

Towards a new generation axion helioscope

I.G. Irastorza,[a] F.T. Avignone,[b] S. Caspi,[c] J.M. Carmona,[a] T. Dafni,[a] M. Davenport,[d] A. Dudarev,[d] G. Fanourakis,[e] E. Ferrer-Ribas,[f] J. Galán,[a,f] J.A. García,[a] T. Geralis,[e] I. Giomataris,[f] H. Gómez,[a] D.H.H. Hoffmann,[g] F.J. Iguaz,[f] K. Jakovčić,[h] M. Krčmar,[h] B. Lakić,[h] G. Luzón,[a] M. Pivovaroff,[j] T. Papaevangelou,[f] G. Raffelt,[k] J. Redondo,[k] A. Rodríguez,[a] S. Russenschuck,[d] J. Ruz,[d] I. Shilon,[d,i] H. Ten Kate,[d] A. Tomás,[a] S. Troitsky,[l] K. van Bibber,[m] J.A. Villar,[a] J. Vogel,[j] L. Walckiers[d] and K. Zioutas[n]

Solar Axion Searches



Astrophysical hints for ALPs

CDM
"anthropic window"

CDM
"classical window"
Vacuum mis. + defects

CDM
Defects dominate
hep-ph/1202-5851

White Dwarfs

Axions as HDM

IAXO – The new generation helioscope

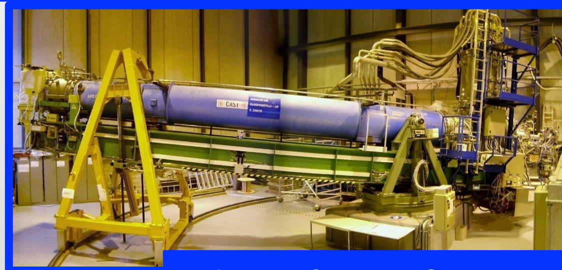
→ 1st generation: Brookhaven Experiment

→ 2nd generation: Tokyo Helioscope

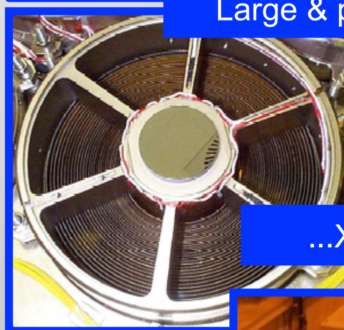
→ 3rd generation: CAST

- **IAXO = 4th generation axion helioscope**
- Based on the more than a decade CAST experience!!
- CAST is established as a reference result in experimental axion physics
- No other technique can realistically improve CAST in such a wide mass range.
- No miracle needed!
  IAXO builds on CAST innovations to improve the helioscope technique…

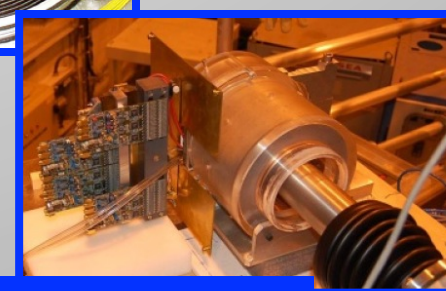
Ingredients of a successful helioscope



Large & powerful magnet...

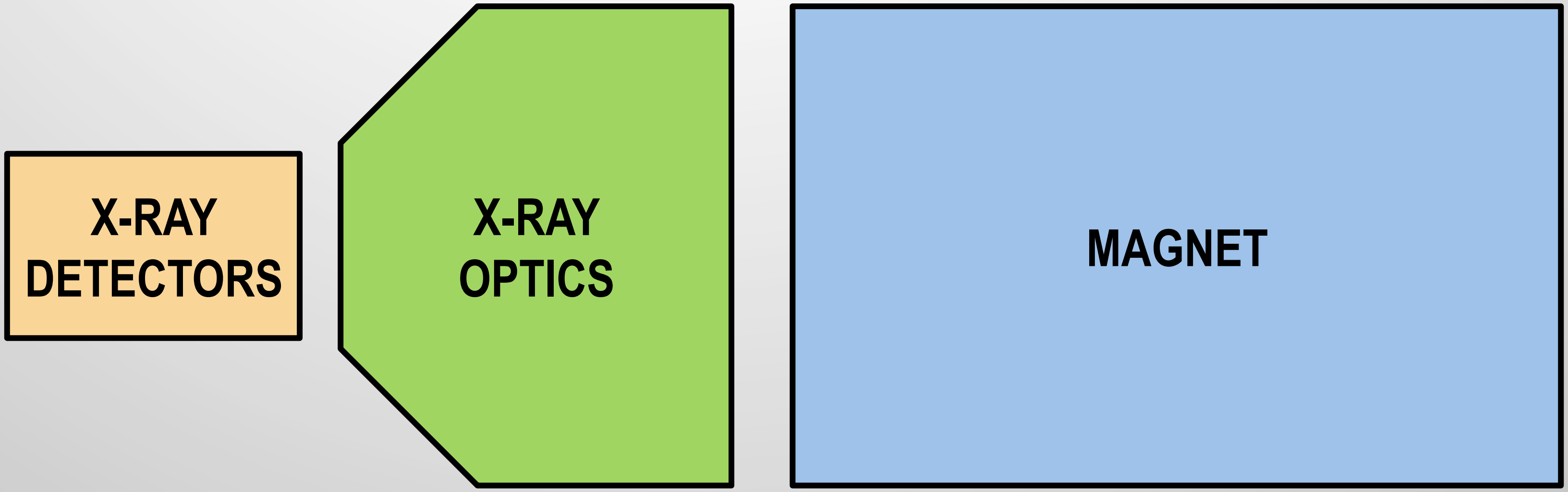


...X-ray optics,...



...and low background detectors

IAXO – How to improve sensitivity



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

detectors

b = background
ε = efficiency

optics

s = spot size
ε_0 = efficiency

magnet

B = magnetic field
L = magnet length
A = cross-sectional area

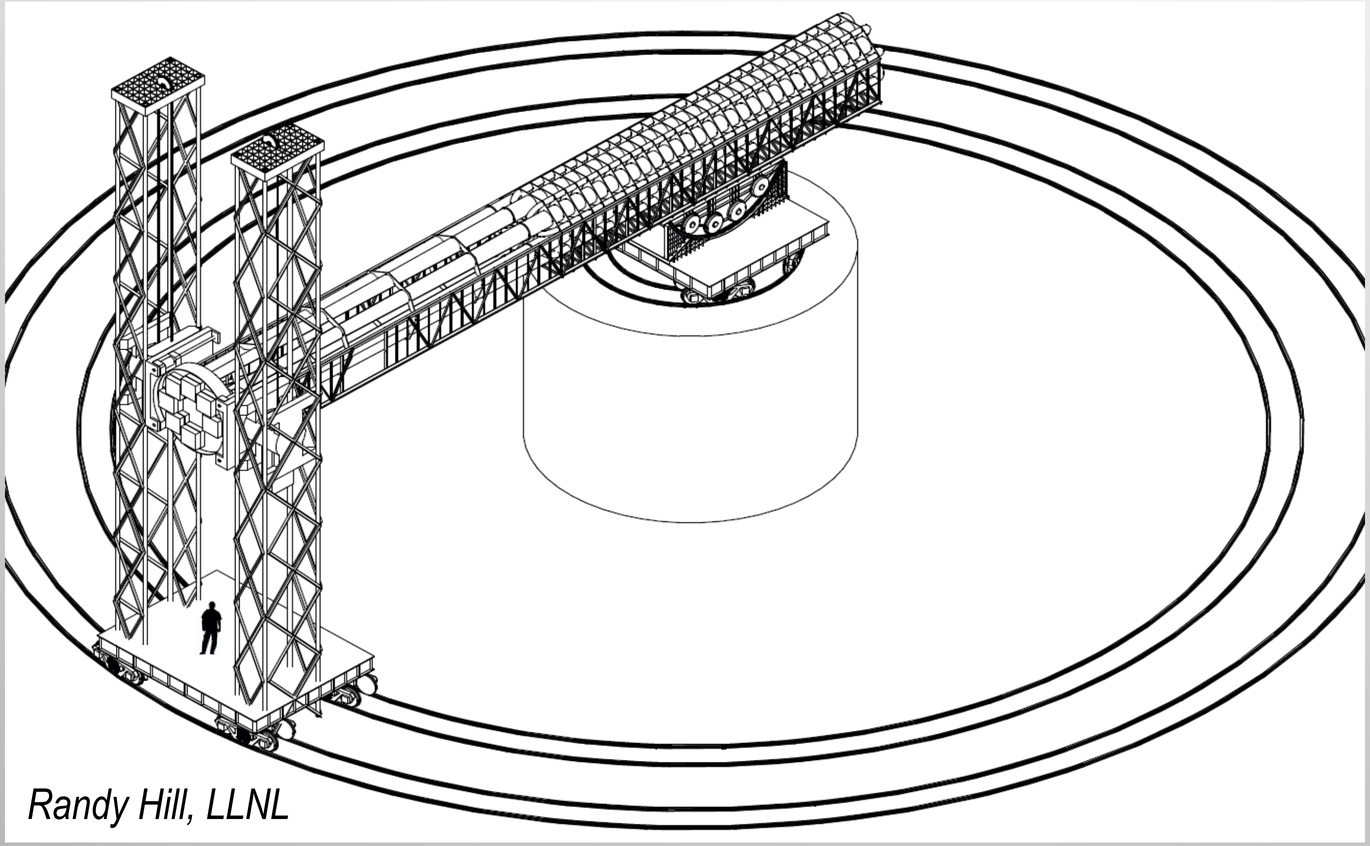
exposure

t = time

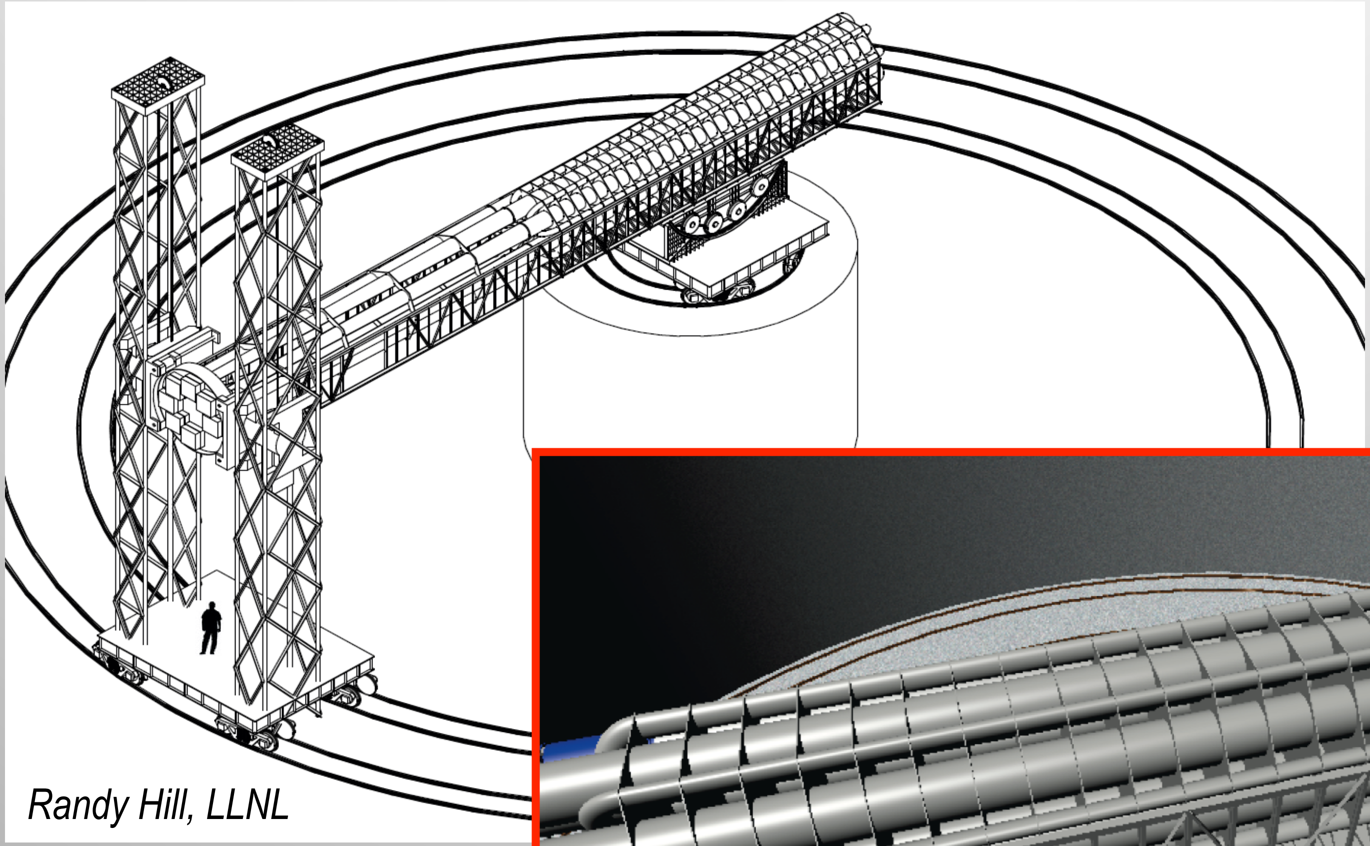
IAXO – How to improve sensitivity

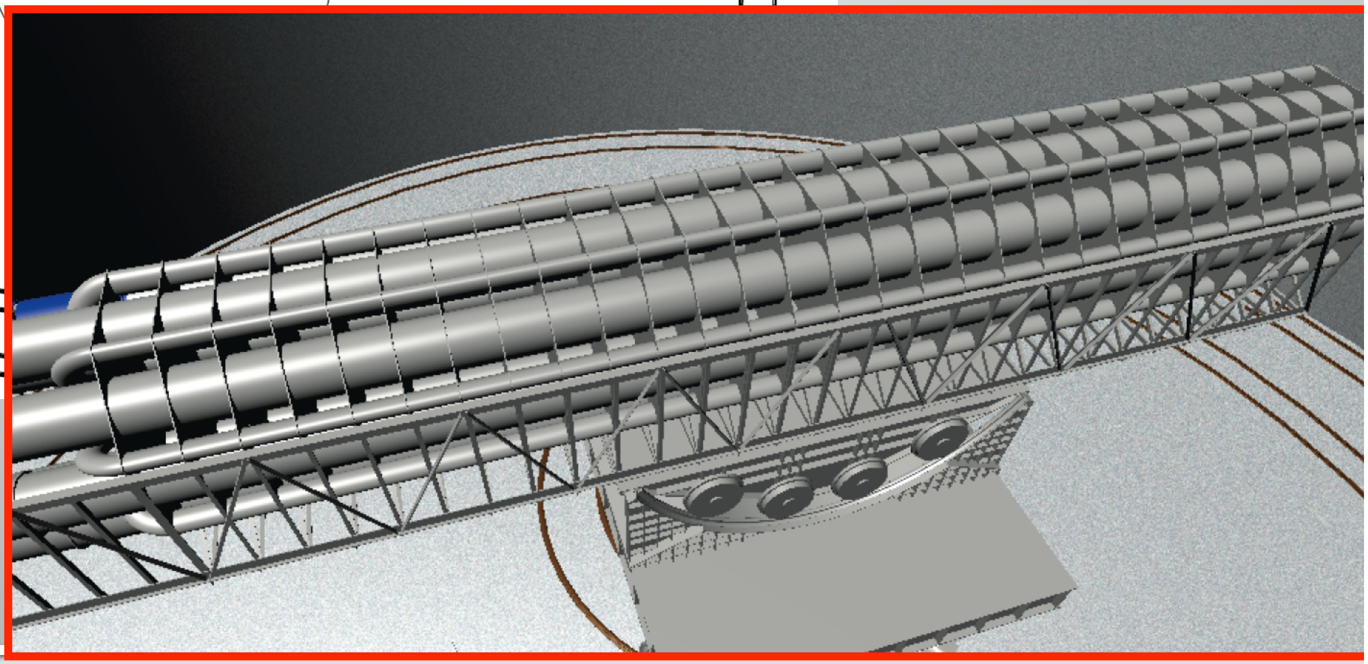
Parameter	Unit	CAST-I	Scenario 1	Scenario 2	Scenario 3	Scenario 4
B	T	9	3	3	4	5
L	m	9.26	12	15	15	20
A	m^2	2×0.0015	1.7	2.6	2.6	4.0
f^*_M		1	100	260	450	1900
b	$\frac{10^{-5}\,\mathrm{c}}{\mathrm{keV\,cm^2\,s}}$	~ 4	3×10^{-2}	10^{-2}	3×10^{-3}	10^{-3}
ϵ_d		0.5–0.9	0.7	0.7	0.7	0.7
ϵ_o		0.3	0.3	0.3	0.6	0.6
a	cm^2	0.15	3	2	1	1
f^*_{DO}		1	6	14	40	40
ϵ_t		0.12	0.3	0.3	0.5	0.5
t	year	~ 1	3	3	3	3
f^*_T		1	2.7	2.7	3.5	3.5
f^*		1	1.6×10^3	9.8×10^3	6.3×10^4	2.7×10^5

IAXO – The new generation helioscope

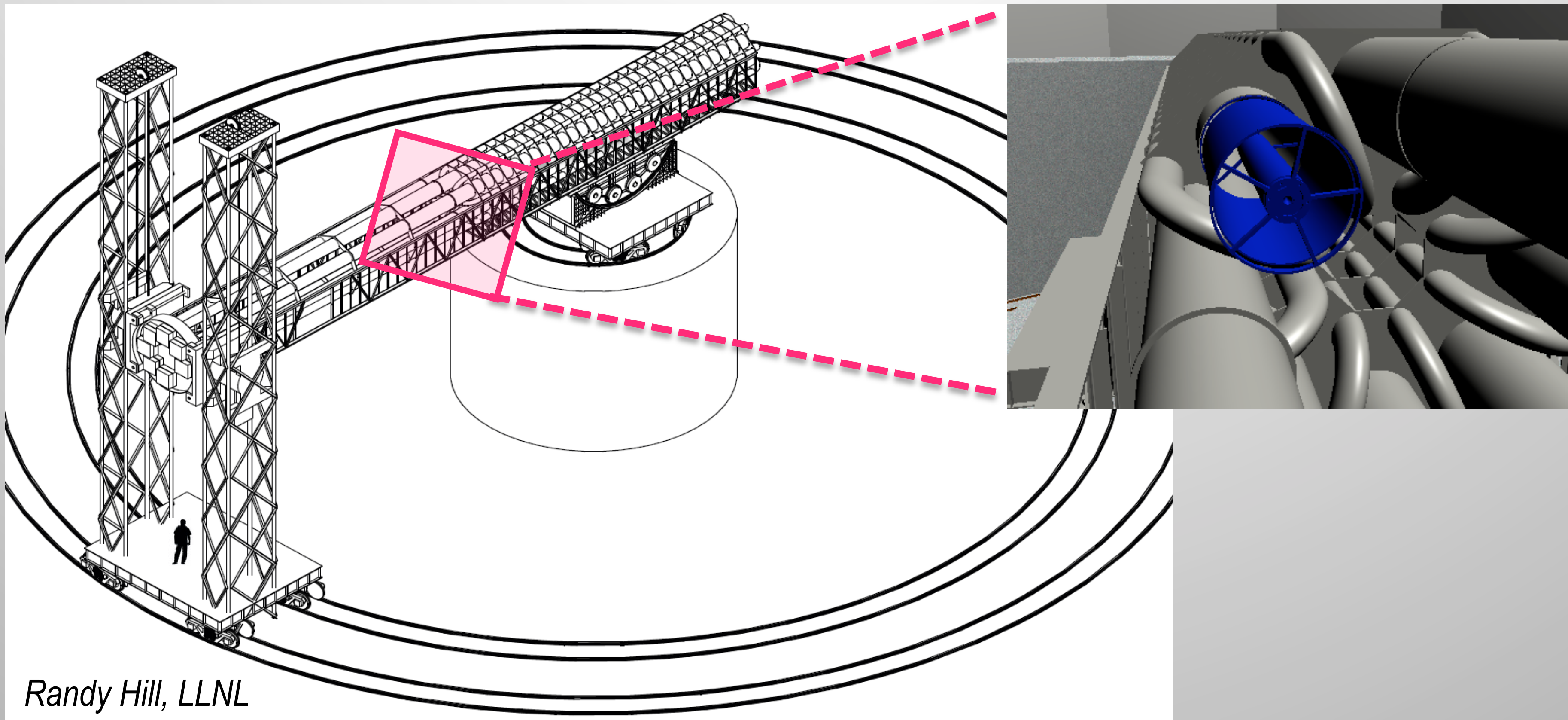


IAXO – The new generation helioscope

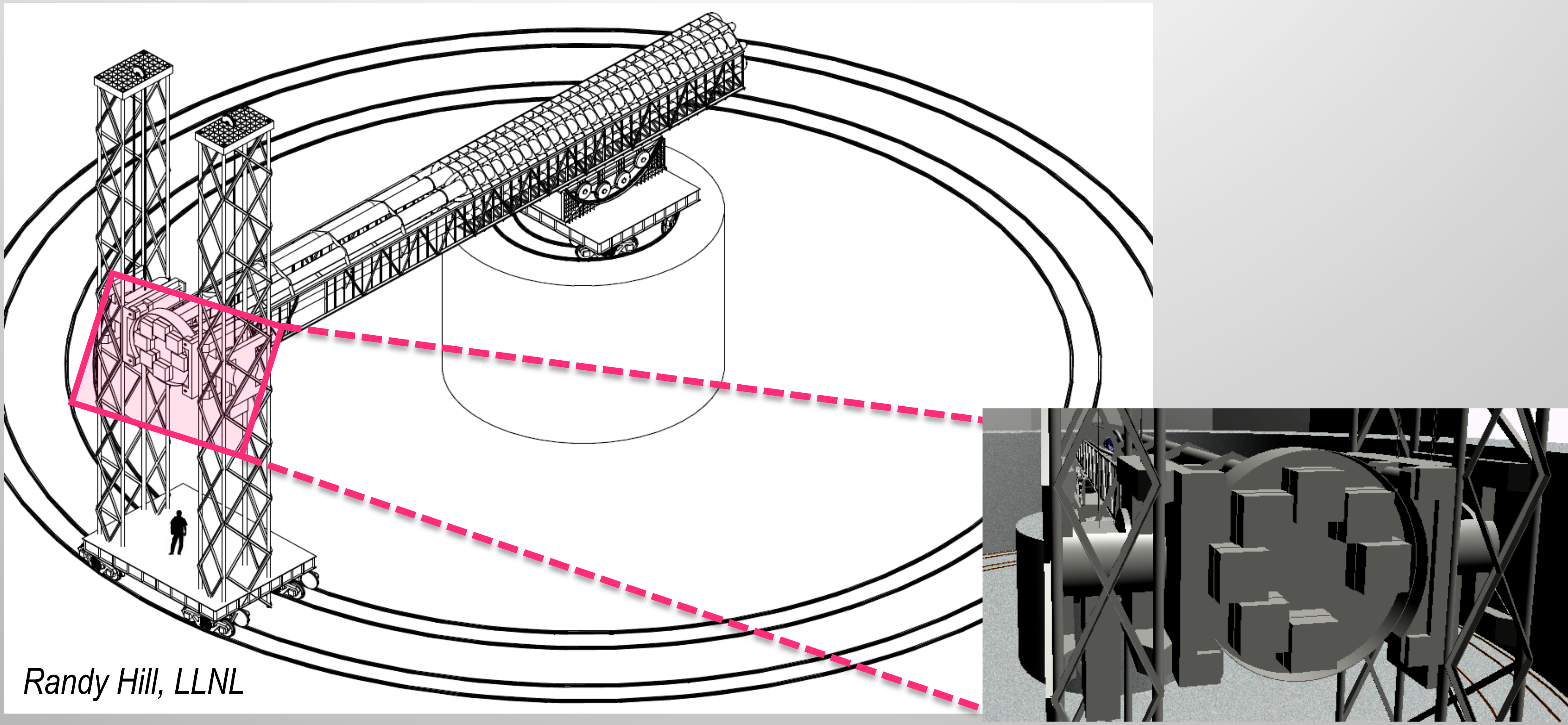




IAXO – The new generation helioscope



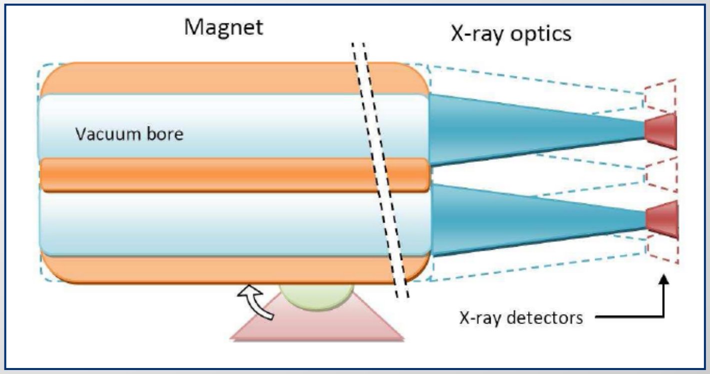
IAXO – The new generation helioscope

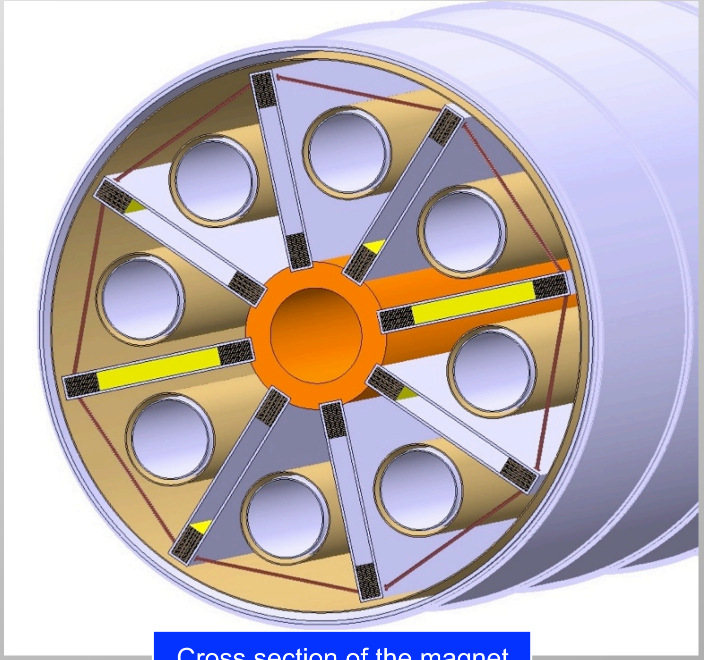


Magnet for IAXO

- CAST has one of the best existing magnets than one can “recycle” for axion physics (LHC test magnet)
- Only way to make a step further is to build a new magnet, specifically for axions
- Work ongoing, but best option up to now seems to be a **toroidal configuration** (similar to ATLAS):
  - Much bigger aperture than CAST: ~0.5-1 m per bore
  - Relatively light (no iron yoke)
  - Bores possibly at room temperature

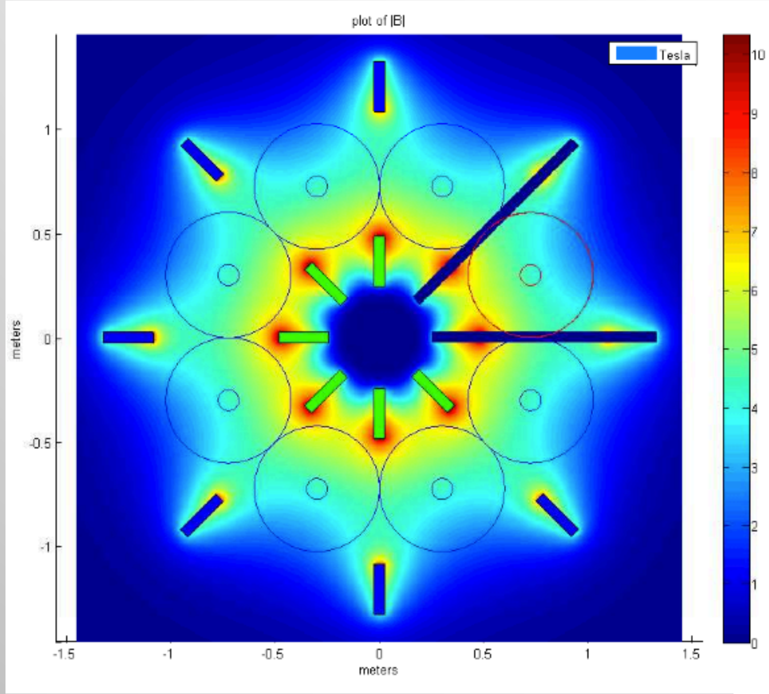
→ A magnet that looks like a detector magnet with the behavior of an accelerator magnet (little stress, strong field,…)

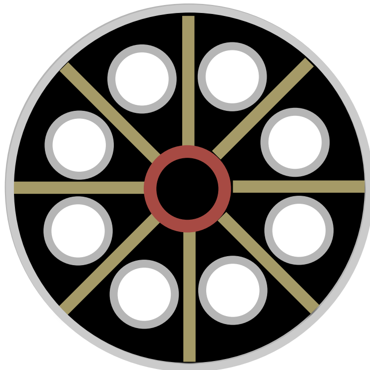




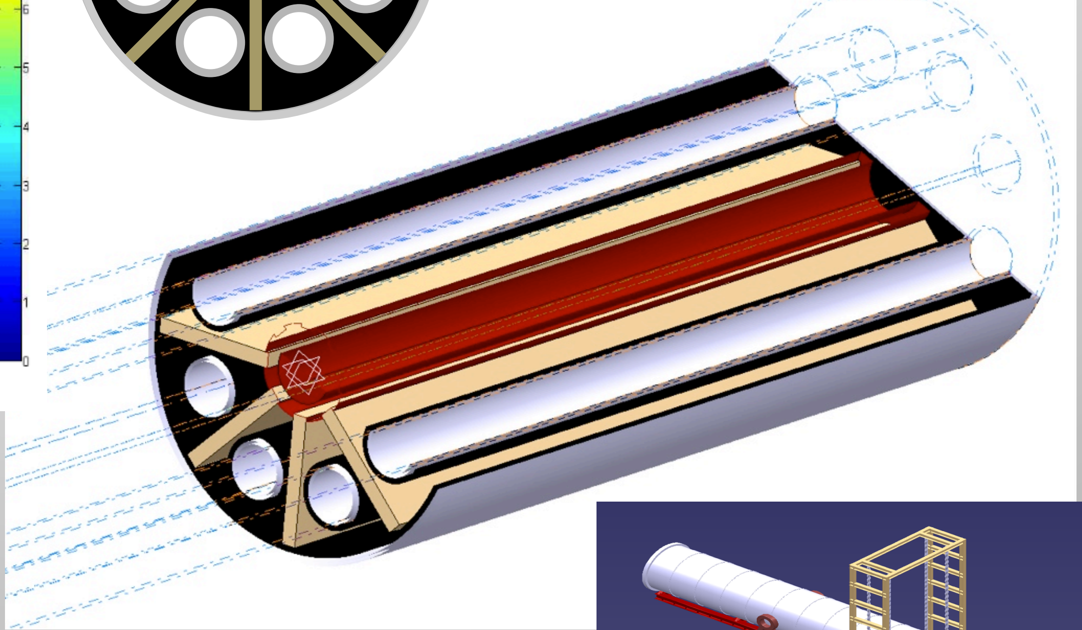
Cross section of the magnet

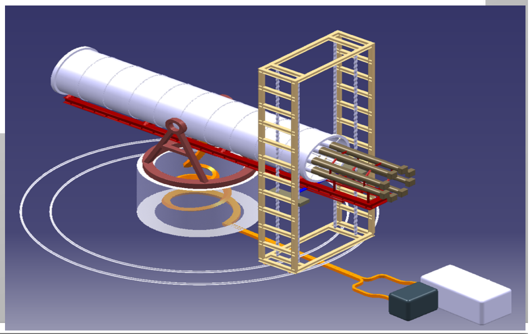
Magnet for IAXO





Total Radius	**= 2 m**
Bore diameter	**= 600 mm**
Number of bores	**= 8**
Peak field	**= 6 T**
Stored Energy	**= 500 MJ**
MFOM	**= 300**



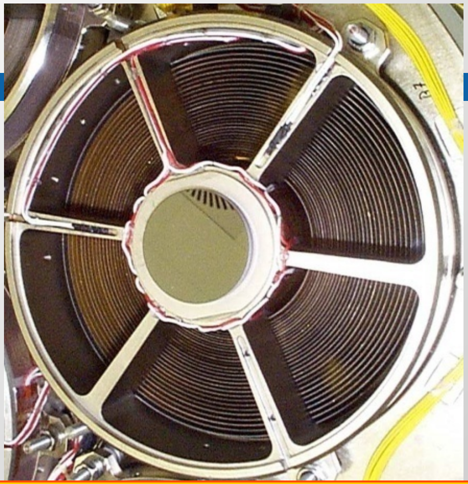


- Current IAXO design favors bores between coils
  - FOM
  - More flexibility
- Scenario 2 conservative, better than scenario 3 is possible

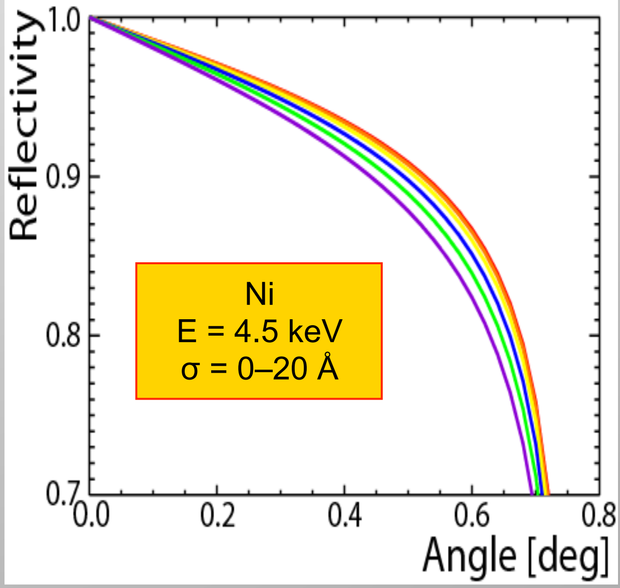
  →Work on further optimization ongoing

X-ray Optics

- X-ray community put lots of money and effort into development of reflective x-ray optics:
  - HighTech, expensive, unique
  - Excellent imaging capabilities
- Innovations include:
  - Nested designs (i.e. Wolter telescopes)
  - Low-cost substrates
  - Highly reflective coatings
- IAXO optics requirements:
  - Exquisite imaging not needed
  - Need to cover large area:
    → IAXO requires dedicated but cost-effective optics
  - Good throughput (0.3 – 0.5)
  - Small focal point (~1 cm^2)



ABRIXAS flight-spare telescope

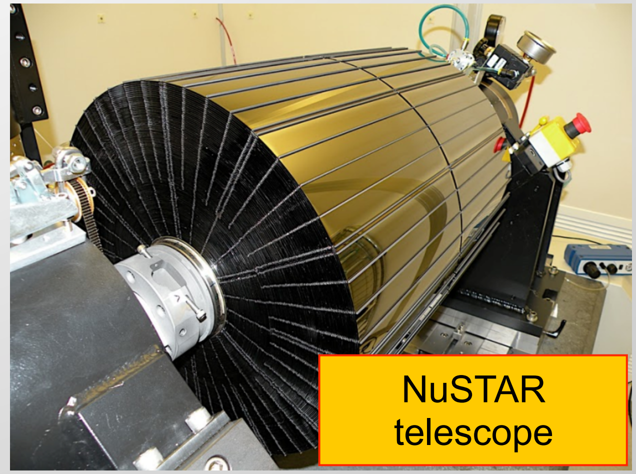


X-ray Optics

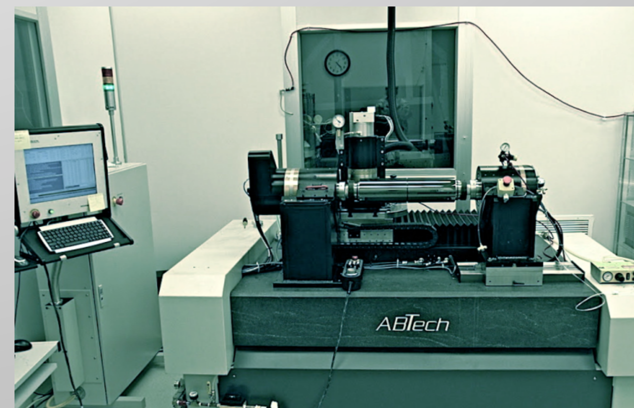
- **Most favored IAXO solution:**
  thermally-formed glass substrates optics
  - Successfully used for NuSTAR
  - Leverage of existing infrastructure
    → Minimize costs & risks
  - Allows for optimization of the reflective coating (multilayers or thin metal films) of each layer

- **NuSTAR launched 13 June 2012**
  - Specialized tooling to mirror production and telescope assembly now available
  - Hardware can be easily configured to make optics with a variety of designs and sizes

- Key institutes of NuSTAR optics team
  Columbia, DTU Space, LLNL → **All in IAXO!**



NuSTAR telescope



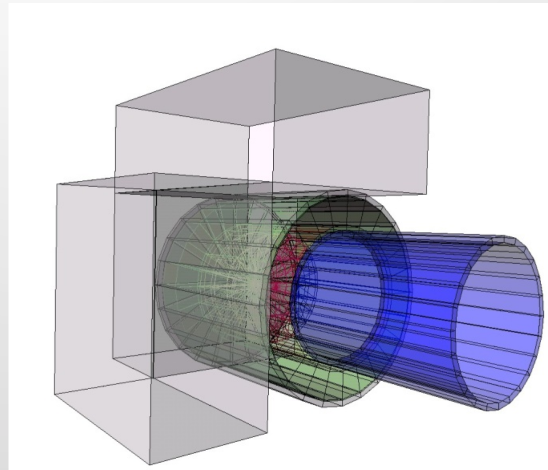
NuSTAR optics assembly machine

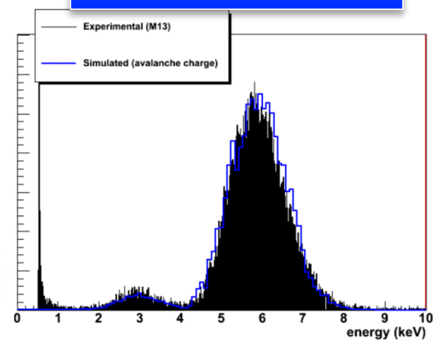
J Koglin *et al.*, *Proc SPIE*, **8147,** (2011)
W Craig *et al.*, *Proc SPIE*, **8147,** (2011)

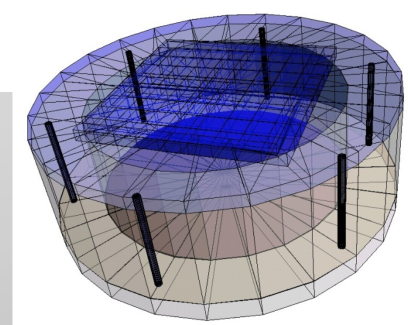
Low-background detectors

- **Goal**
  - Micromegas detectors with at least 10^{-7} cts/(keV×cm^2×s)
  - If possible go down to 10^{-8} cts/(keV×cm^2×s)
- **Work ongoing**
  - Experimental tests with current micromegas detectors at CERN, Saclay & Zaragoza
  - Underground setup at Canfranc
  - Simulation works to build up a background model
  - Design a new detector with improvements implemented

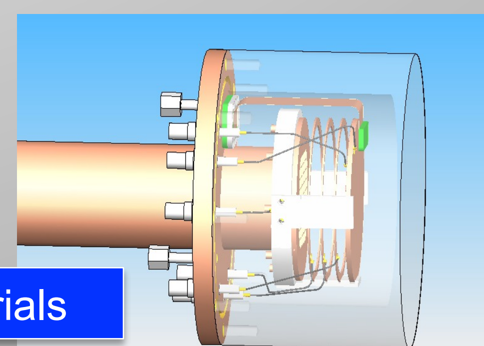
Simulations







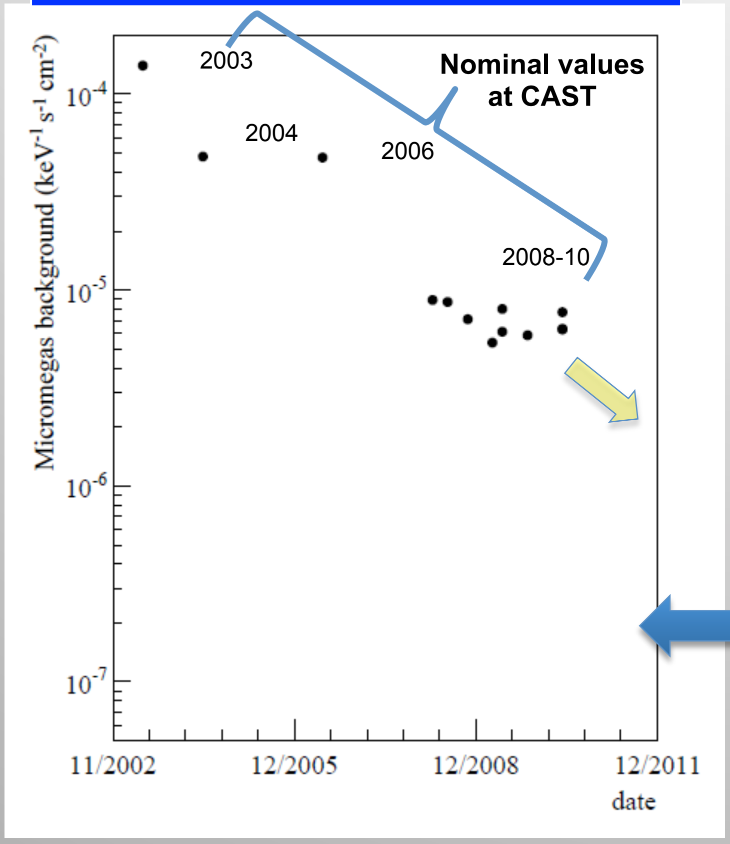
Shielding



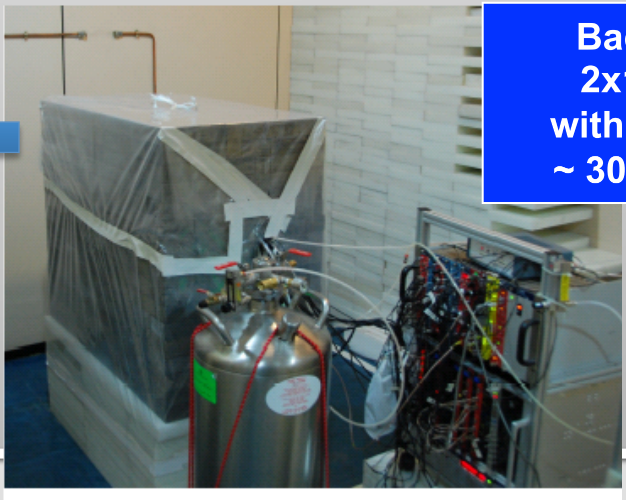
Radiopure materials

Low-background detectors

History of background improvement of Micromegas detectors at CAST



- Latest Micromegas:
  Background improved by factor 20
  - Shielding
  - Radiopurity & new manufacturing technique (microbulk readouts)
  - More powerful offline cuts
- Tests in controlled conditions underground at Canfranc:
  - Better shielding coverage
  - Thicker shielding



Backgrounds around 2x10-7 cts/keV/s/cm^2 with improved shielding ~ 30 × better than CAST

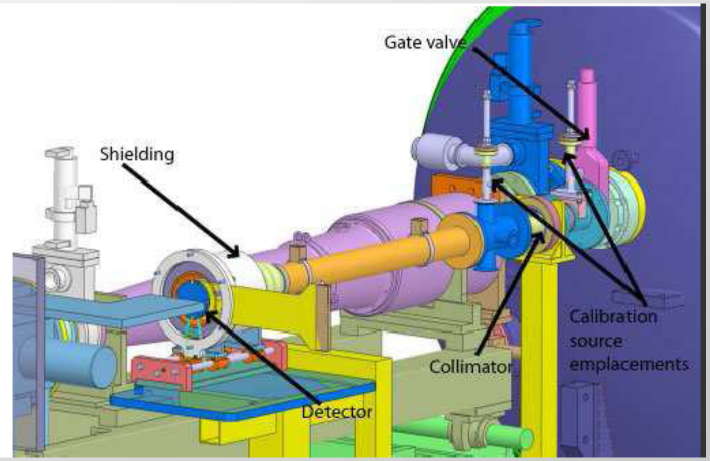
Recent upgrade of shielding at CAST improves background further towards IAXO!

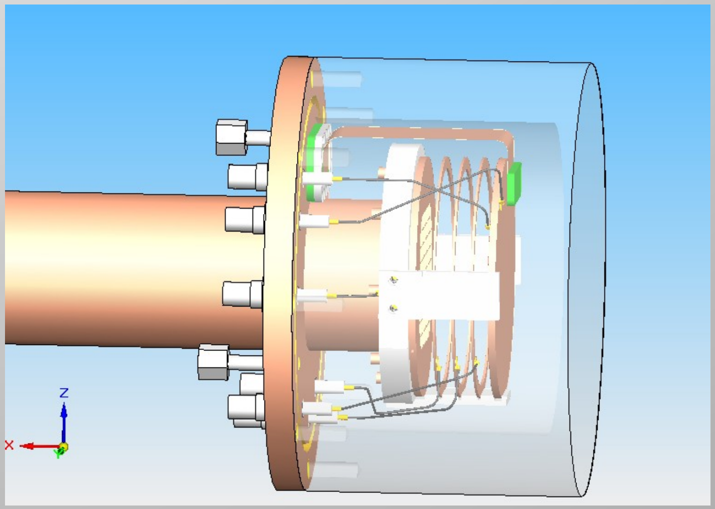
Pathfinder detector+optics for IAXO

- Small x-ray optics
  - Fabricated purposely using thermally-formed glass substrates (NuSTAR-like)
- Micromegas low background detector:
  - Apply lessons learned from R&D: compactness, better shielding, radiopurity,…
  - Aim for background of 10^{-7} cts/(keV×cm^2×s) or lower
- Collaboration of key groups:
  Saclay, Zaragoza, LLNL, DTU, Columbia

➡ Operation at CAST in 2013

➡ Tests of techniques and acquisition of know-how for IAXO





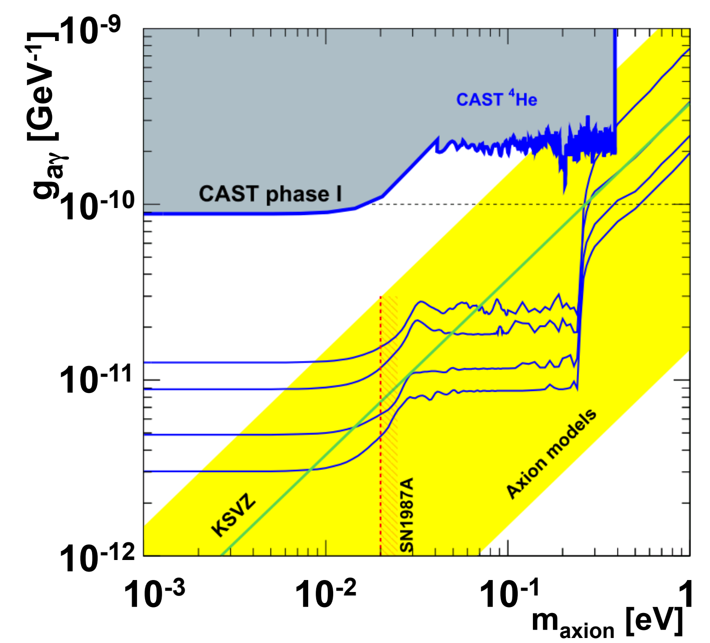
IAXO sensitivity prospects

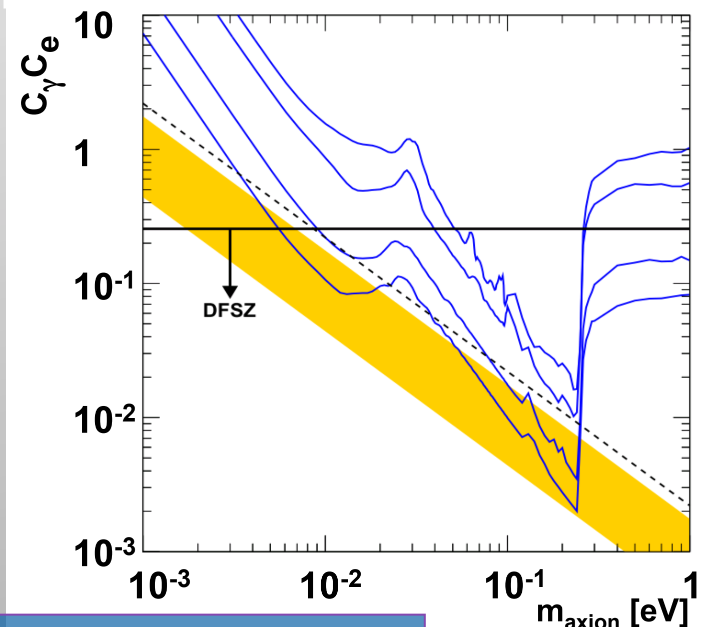
- **Hadronic axion models**
  - Improvements of **factor 8-30** in $g_{a\gamma}$ (4×10^3-1×10^6 in signal strength!!)
  - QCD axions at masses of ~meV seem out of reach even for an improved axion helioscope...

But…

- **Non-hadronic axion models** provide extra axion emission from the Sun through axion-electron compton and bremsstrahlung processes

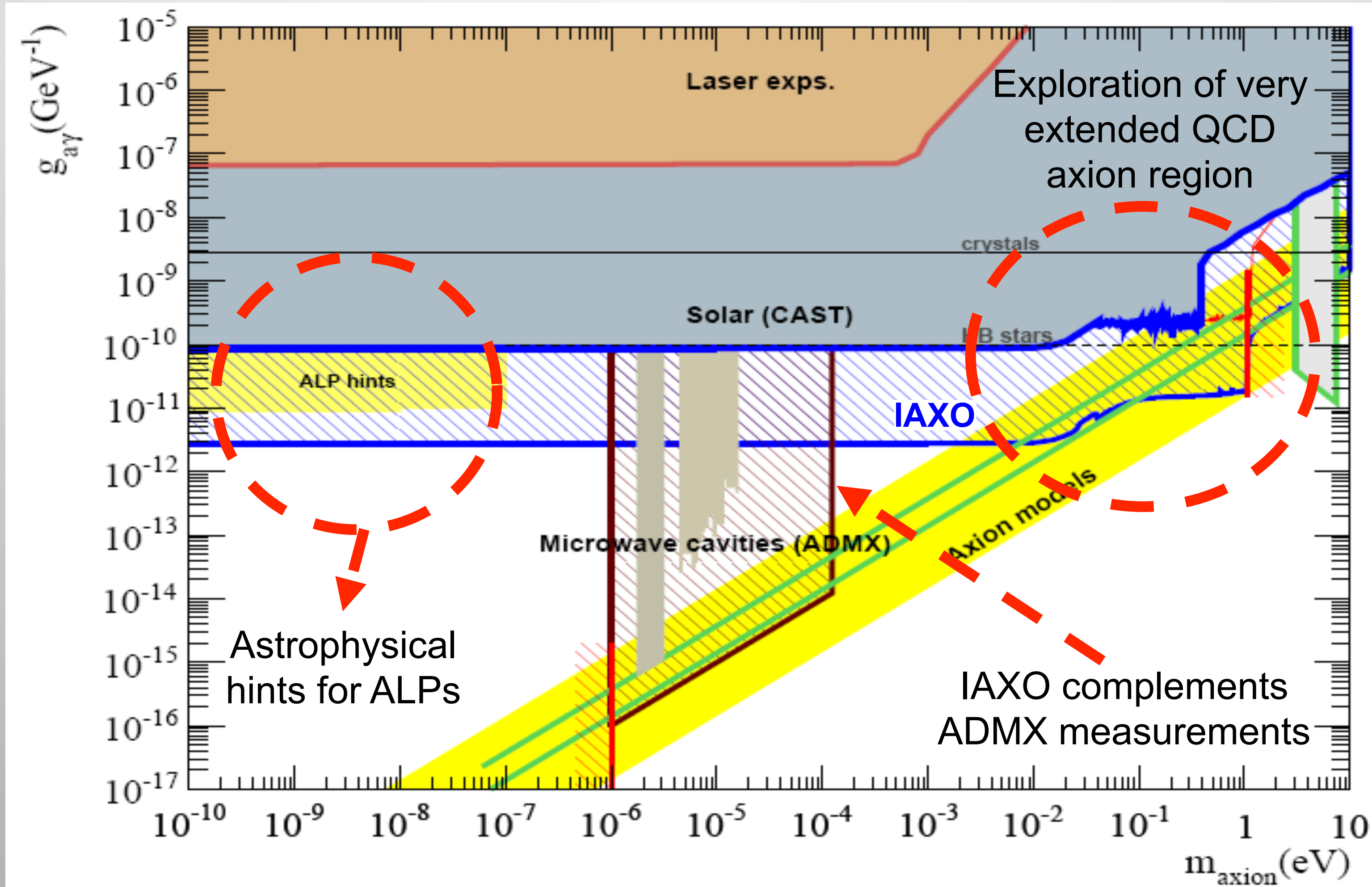
IAXO could improve current CAST sensitivity to non-hadronic axions by about 3 orders of magnitude





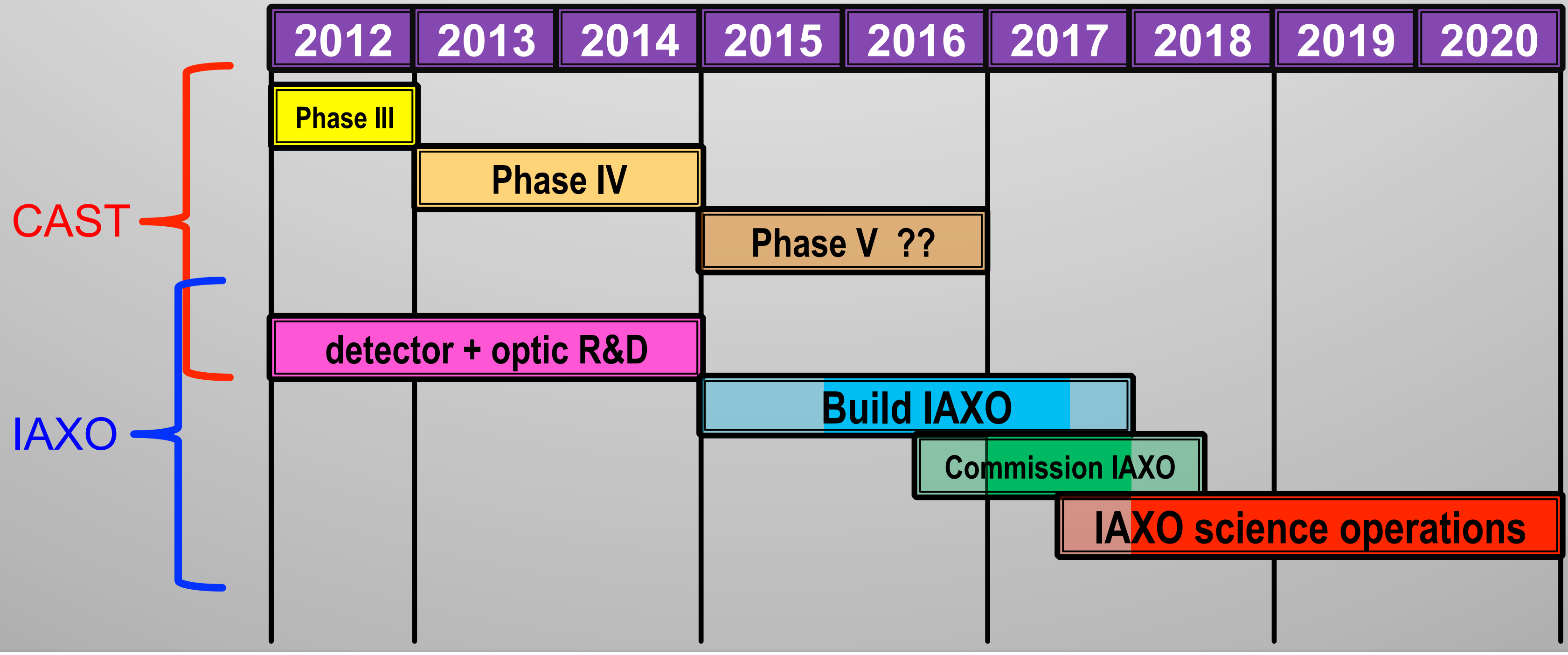
Irastorza et al. *JCAP* 06 (2011) 013

IAXO sensitivity prospects



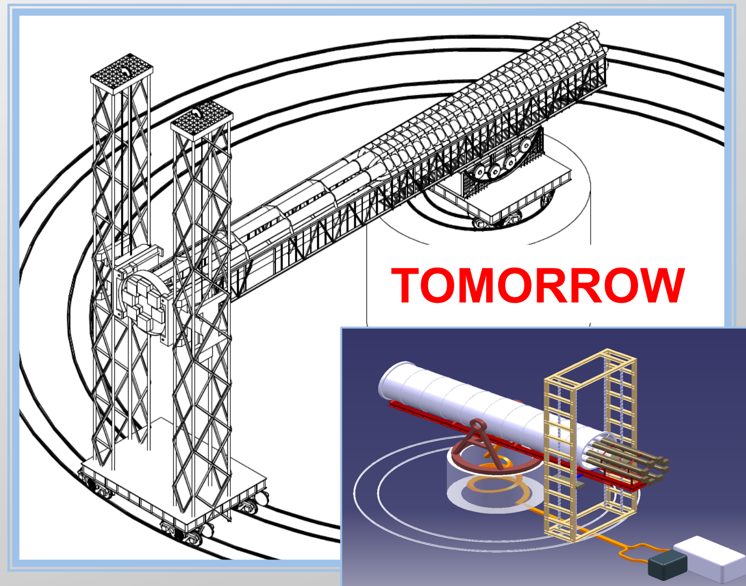
Notional plan

- Proto-collaboration formed
  - Most CAST groups
  - New groups + extended expertise (magnet, optics,…)
  - Open for interested groups
- Conceptual design report in preparation, LoI to be submitted to CERN soon
- 4th generation helioscope supported in latest draft of ASPERA roadmap 2011



Conclusions

- **CAST is established as a reference result in experimental axion physics**
  - CAST PRL2004 most cited experimental paper in axion physics
  - Expertise gathered in magnet, optics, low background detectors, gas systems
  - No other technique can realistically improve CAST in such wide mass range.



- **IAXO is the new generation helioscope (4th generation) to search for axions**
  - Good prospects to improve CAST by 1-1.5 orders of magnitude in sensitivity
  - First solid steps towards conceptual design
  - Together IAXO and haloscopes (ADMX) could explore a big part of the QCD axion model region in the next decade
  - Potential for other physics (White Dwarfs, ALPs,…)

Thank you!

Lawrence Livermore National Laboratory