Mechanical design and Analysis of the Baby-IAXO magnet's cold mass, cryostat and support system

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Baby-IAXO

Baby-IAXO is a (down-scaled IAXO) helioscope for seeking solar axions, a hypothetical particle that may help to explain dark matter and more. In presence of a strong magnetic field an axion may convert into two X-ray photons and then detected.

This requires a magnet 24/7 tracking the sun, thus 360° rotation and a ± 25° tilting system.

Magnet Figure of Merit proportional to:

$$f_M = \int \left(\int B_\perp(x,y,z)dz \right)^2 dx\, dy$$

$$\sim (\boldsymbol{B_\perp\ x\ Length\ \ x\ Diameter\ bore})^2$$

Magnet is 10 m long and has two ϕ 0.7 m detection bore tubes.

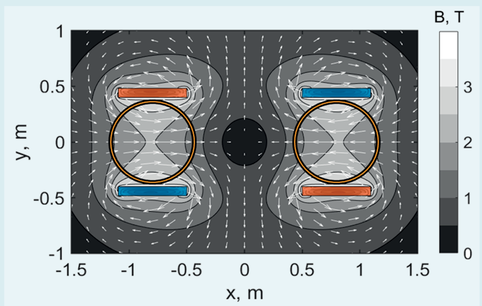
Magnet design

Aiming at most cost effective design & maximum Figure Of Merit.

Magnet is one of a kind. Risk of training minimized by coils with simple geometry & by using well-known winding techniques.

Dual racetrack coils in a quadrupole configuration provide two regions of high transverse field.

Can be used to test two distinct optics and detector technologies.

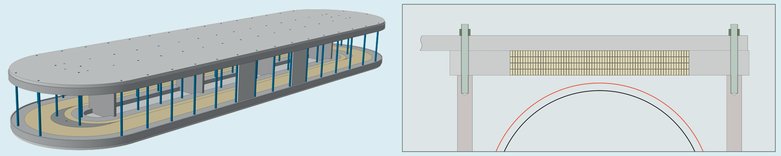


Winding width [mm]	595
Winding height [mm]	82
Coil length [m]	10
Pole gap [mm]	1000
Coil gap [mm]	800
Stored energy [MJ]	50
Inductance [H]	1.0
Peak field [T]	3.2
Current density [A/ mm²]	56
Operating current [kA]	9.8
MFOM 3D [T²m⁴]	232

Cold mass analysis

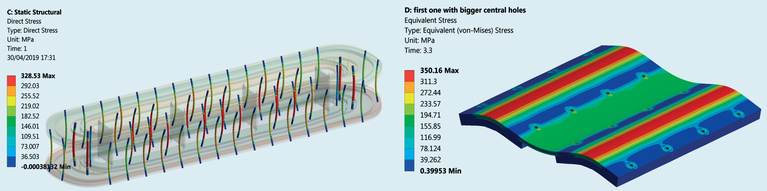
Maximum coil repelling load of 3.4 MN/m in the straight section.

All structural components are of Aluminum alloy to match the thermal contraction of the coil pack and avoid thermal stress.



The top plate is a 50 mm thick, weld free Al 6061-T651 plate, with a yield stress of 360 MPa at 4 K. The high-strength alloy helps minimizing the magnet's cold mass, an important issue for a fully cryocooler based system.

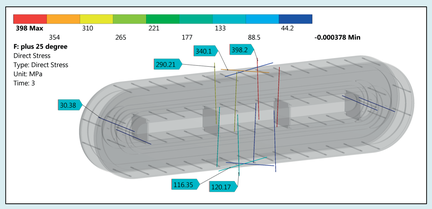
The Al 7075-T6 rods are loaded with the repelling load, while the small plates are taking the misalignment loads. The plates act as spacers and enable connections of the suspension system.



Magnet support system

- Self-centering structure
- No pre-stressing of rods during installation
- Rods used only in tension
- Pre-stress occurs during cool down

	Fx [kN]	Fy [kN]	Fz [kN]	My [kN.m]
Tilted -25 °	-71	0	-200	73
Horizontal	-7	0	-220	87
Tilted 25 °	-91	0	-220	151
Transport[1]	±144	0	-180	0
Lowering (60°)	160	0	-90	0



	XX	YY	ZZ	Total
Length [m]	1.6	2	1.8	
Diameter [mm]	16	16	16	
Number of rods	4	4	8	
Heat load @50K [W]	1.1	1.3	1.9	4.3
Heat load @4.5 K [mW]	50	40	90	180
Material	Ti6Al4V			

Cryostat design

Connection of cryostat to support frame is in the center post where all services are connected too.

Side cylinders and torispherical heads only resist vacuum.

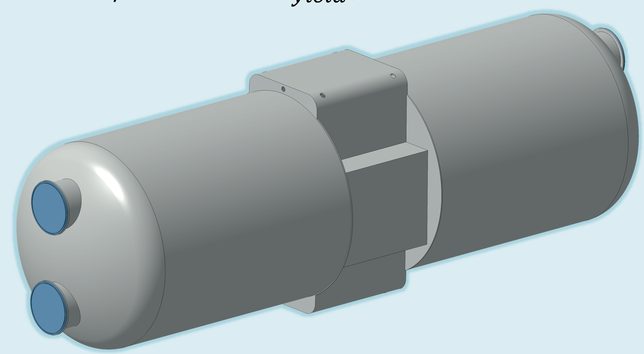
Stainless steel is the chosen material for highest reliability of vacuum welds and seals.

Outer cylinder and bore tube wall thickness according to EN13445

Bore tubes need to resist a ΔP of ±1 atm.

Central part thickness is limited by its stress state:

- Primary bending stress < σ_{yield} (210 MPa)
- Secondary stress < $2 \times \sigma_{yield}$ (420 MPa)



	Central part	Cylinders	Torispherical heads	Bore tubes	Total
Thickness [mm]	15	12	8	6	-
Mass [t]	3.6	2 x 3.5	2 x 0.95	2 x 1.1	~15

Conclusion and Outlook

Conceptual design of this new & unique magnet system finalized.

Design mostly driven by the system's need of installation on a rotating tower and that it is cooled by cryocoolers only.

Currently the technical design is progressing and manufacturing is expected to start in 2020.