MADMAX

MAgnetized Disc and Mirror Axion EXperiment

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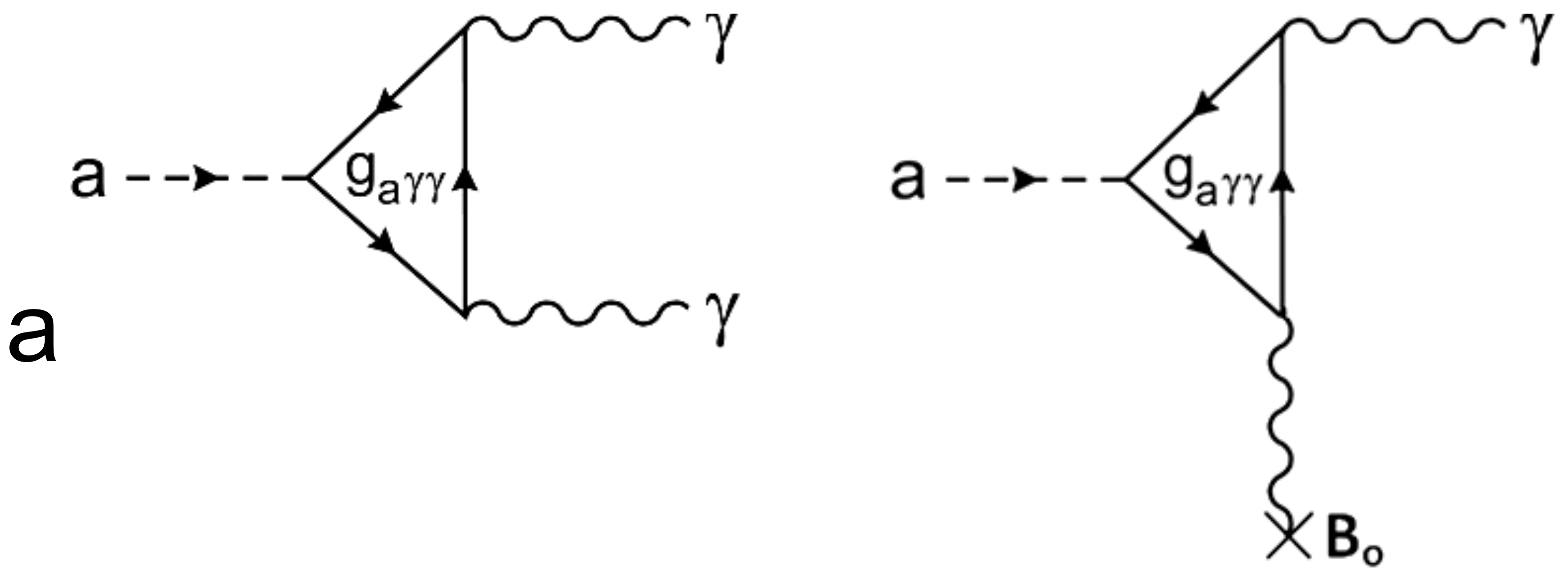
HELMHOLTZ
GEMEINSCHAFT

DESY

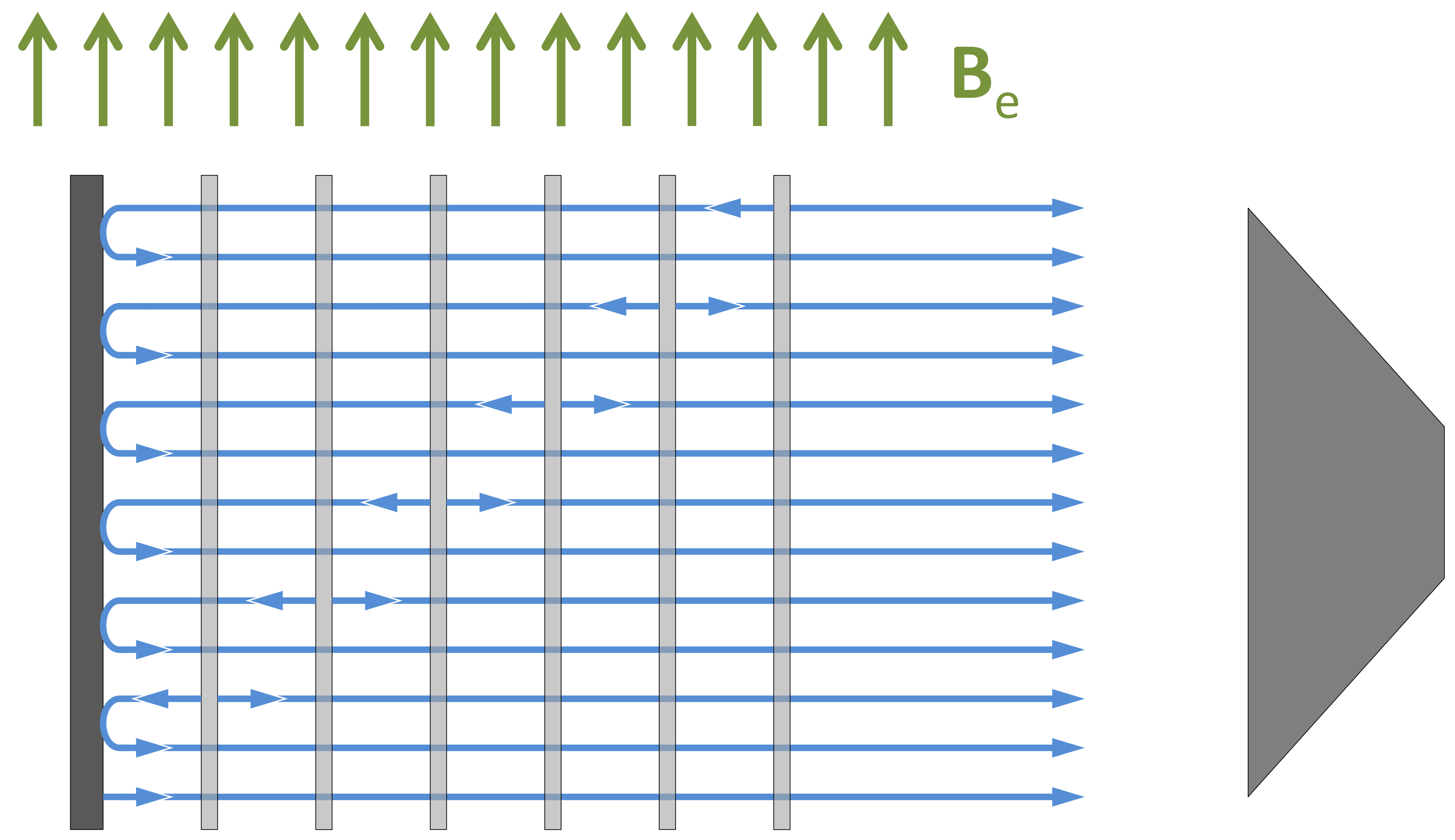
Axions

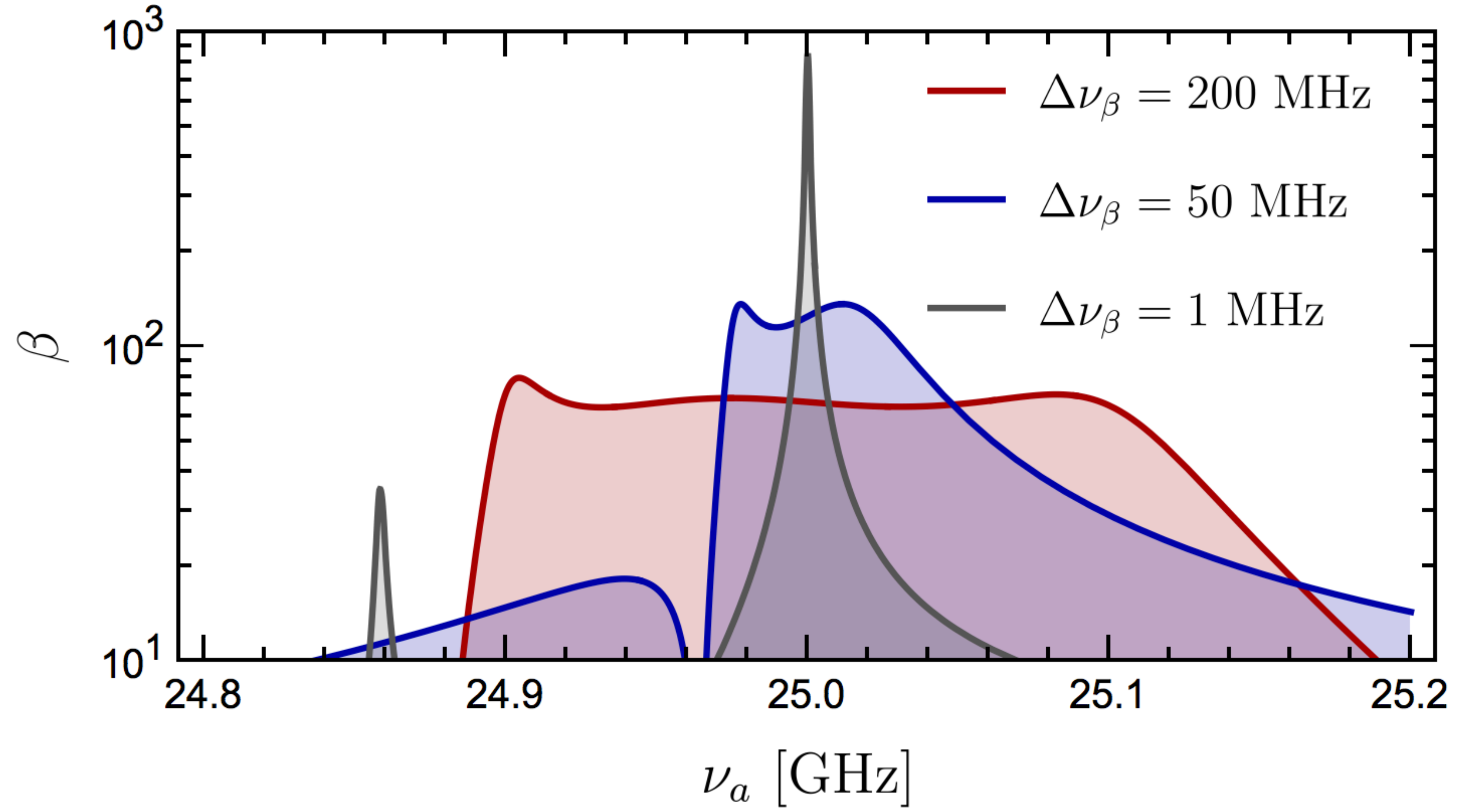
- Proposed to solve the strong CP-violation problem
  - Why is there no CP violation in strong interactions?
- Peccei-Quinn solution: CP violating phase is replaced by Axion field Θ
- Field has a minimum at Θ =0
  - i.e. it relaxes towards zero CP-violation, independent of the initial conditions
    - fulfilling Neutron EDM constraints
- Relics of these excitations from the early universe could be a component of Dark Matter
  - Frequency given by the Axion mass m_a oscillating around Θ=0
- In principle, m_a can cover a broad range
- In certain cosmic models, however, m_a is predicted to be ~100 µeV
  - when cosmic inflation took place before correlation between Θ within patches of event horizon got lost
- Axions couple to photons
  - e.g. an Axion can be converted to a photon in the presence of a strong magnetic field
- ALPS-II: „Light shining through wall“, search for Photon-Axion-Photon conversions
- MADMAX: „Haloscope“, search for Axions in galactic halo via Axion-Photon conversions



Dielectric Haloscope - Principle

- An Axion of ~100µeV can convert into a microwave photon in the presence of a ~10T magnetic field:
  - shine an Axion on a mirror and get a photon back
- Clever idea to amplify the tiny signals:
  - add dielectric disks that also convert Axions into photons
- Disks are semi-transparent; waves are reflected by and transmitted through the other disks
- With suitable arrangement: get coherent amplification by up to factors of O(1000)
- Arrangement of disks allows for broad frequency amplification into microwave receiver

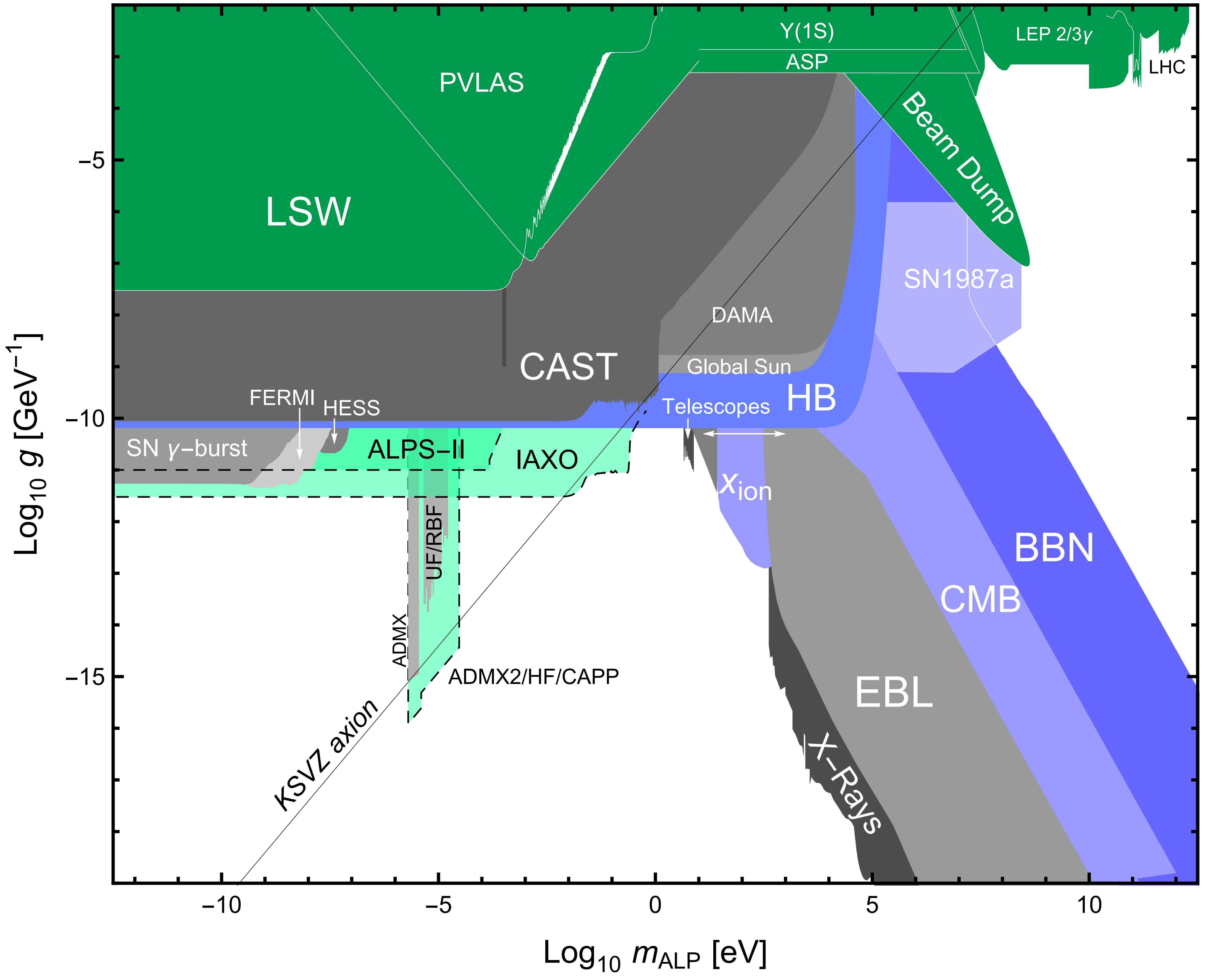


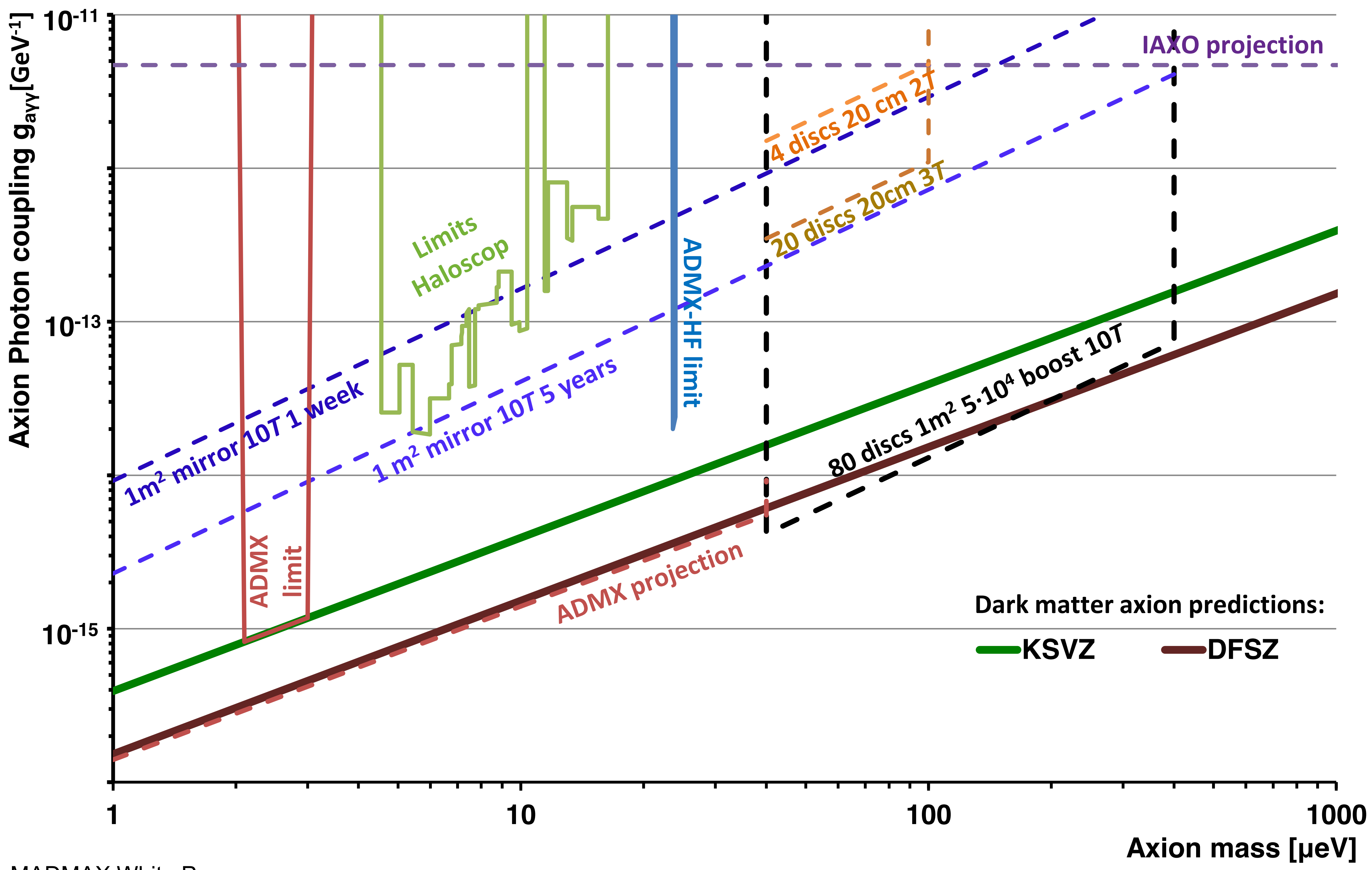


arXiv: 1611.05865

Axion Limits

- World data (left), dielectric Haloscope (right)
  - A prototype (4 disks, 2T) would already exceed IAXO in this mass regime





MADMAX White Paper

MADMAX Setup

- Dipole magnet:
  - ~1m² aperture and ~10T field
- Booster:
  - Mirror
  - ~80 dielectric disks
    - positioned to a few µm precision by motor
- Parabolic mirror:
  - focus microwaves on receiver
- Receiver:
  - Horn antenna
  - Cryogenic pre-amplifier

MADMAX White Paper

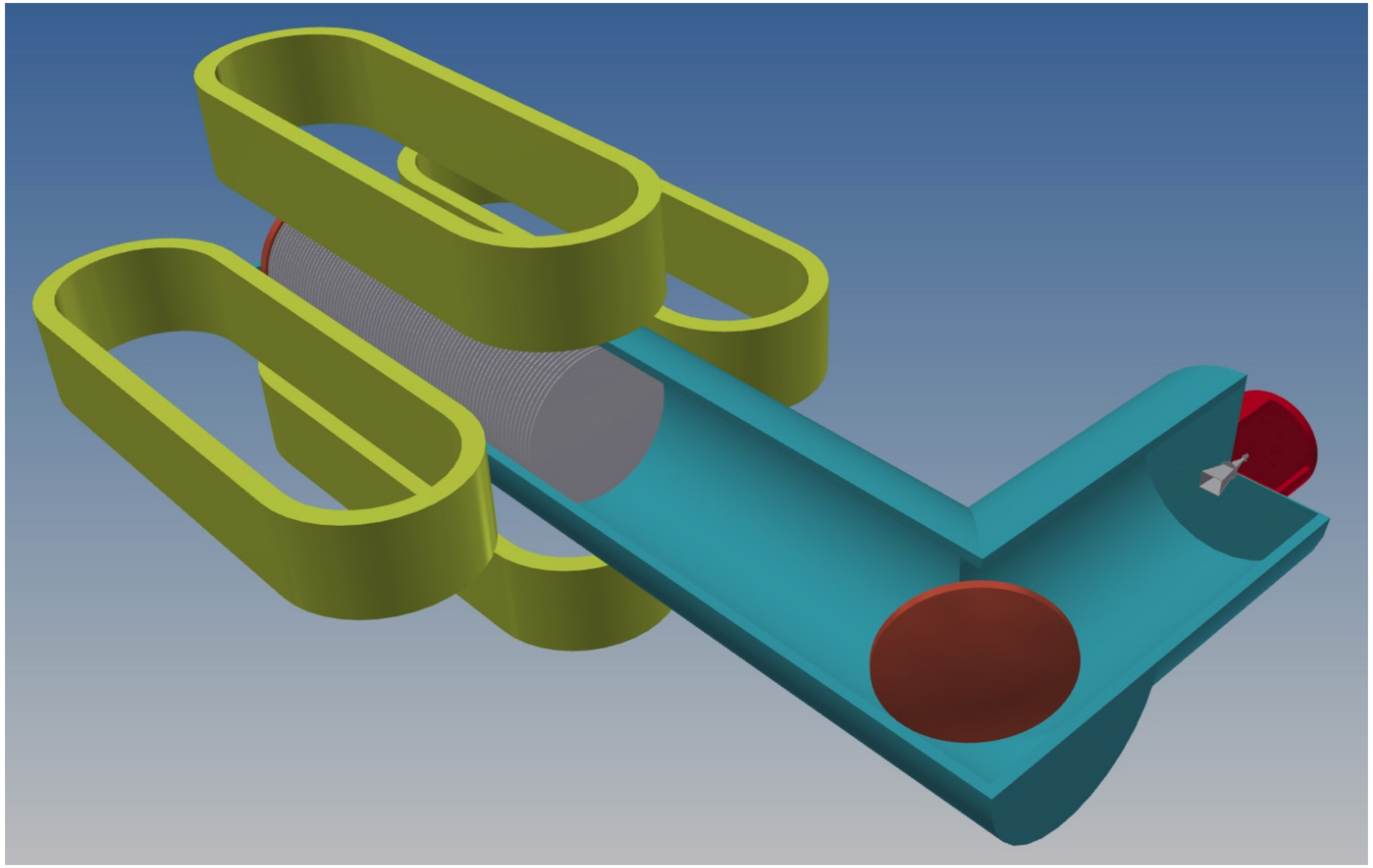


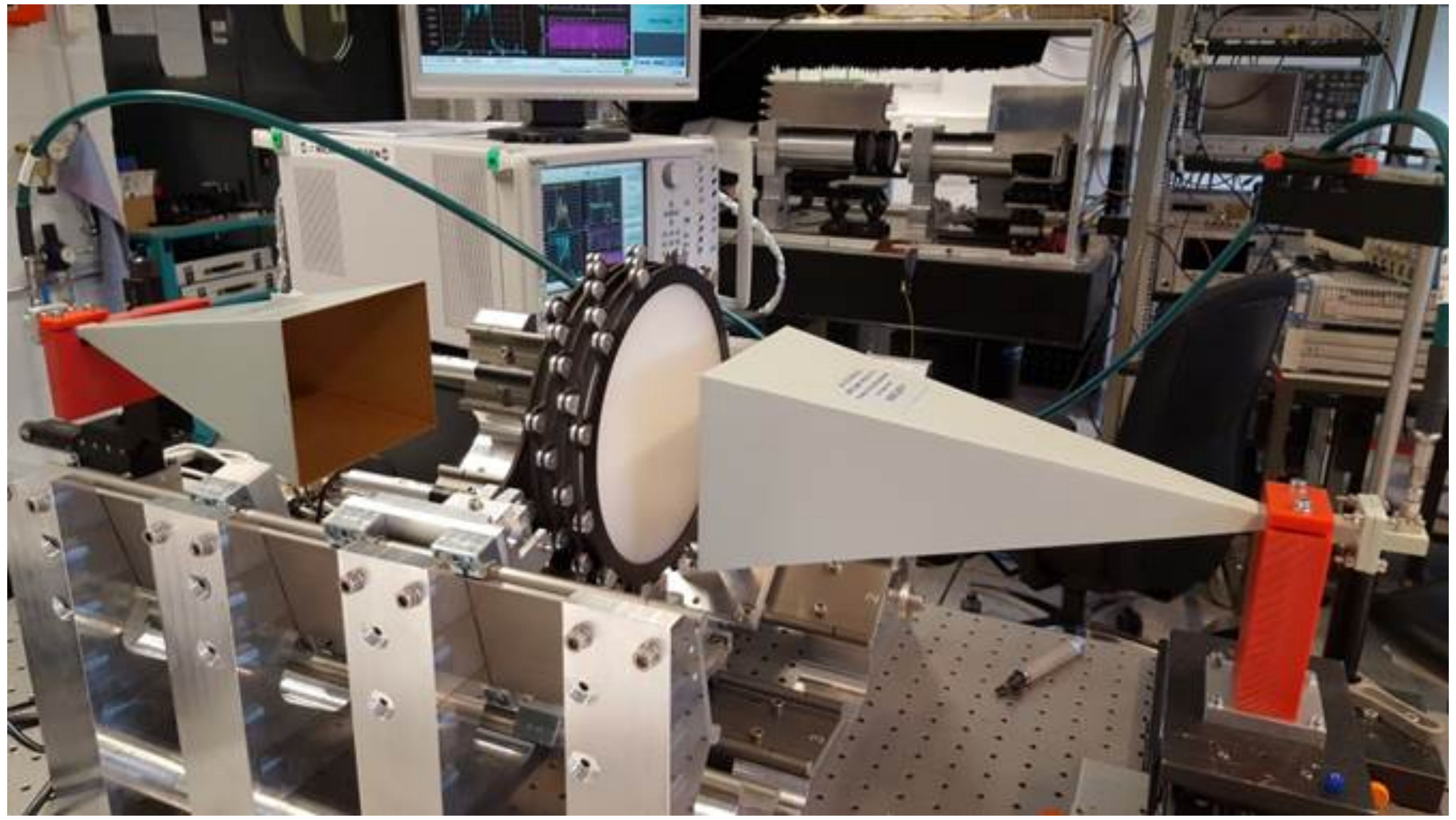
Figure 7. *Baseline design of the MADMAX approach. The experiment can be divided into three parts: 1) magnet (yellow racetracks), 2) booster – consisting of the mirror (copper disc at the far left), the 80 dielectric discs (gray) plus parabolic mirror (copper disc at the right) and the system to adjust disc spacing (not shown) – 3) the receiver – consisting of the horn antenna (gray) and the cold preamplifier inside a separated cryostat (red).*

MADMAX White Paper

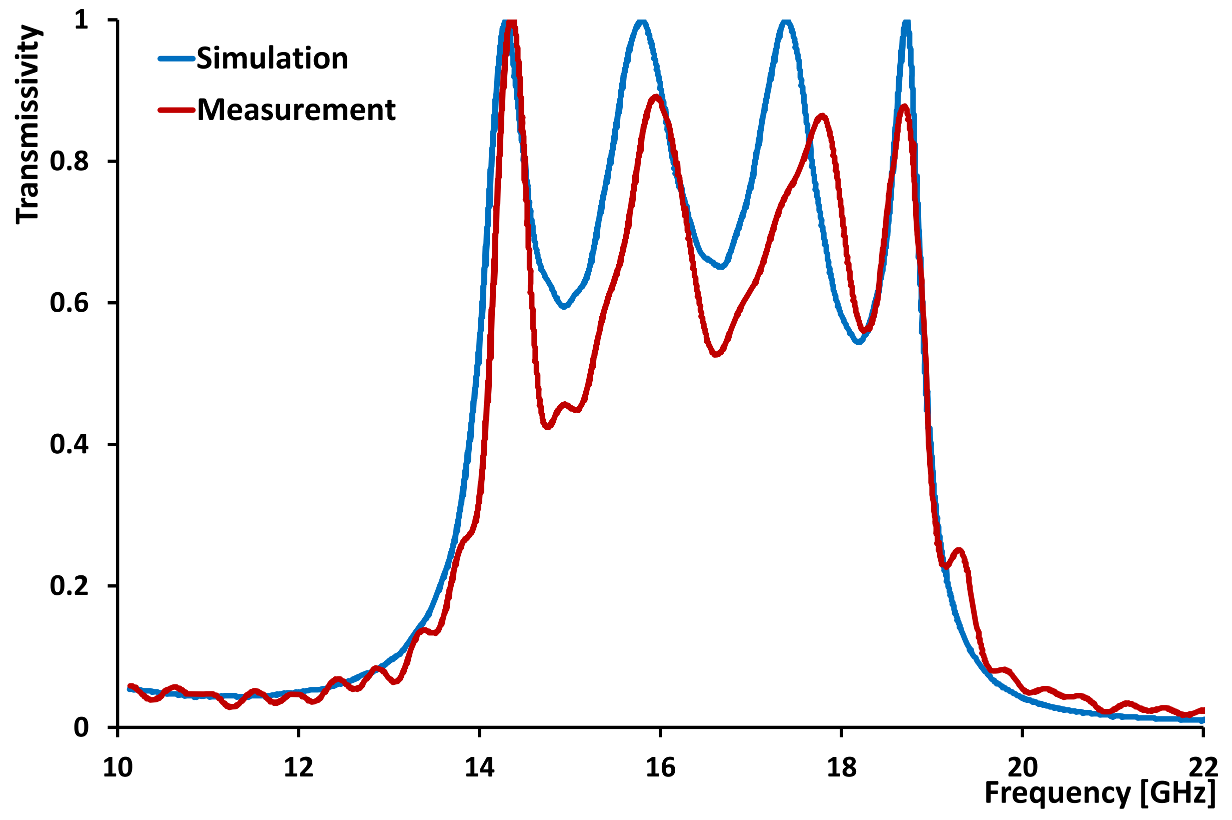
Proof-of-principle Experiment (MPI)

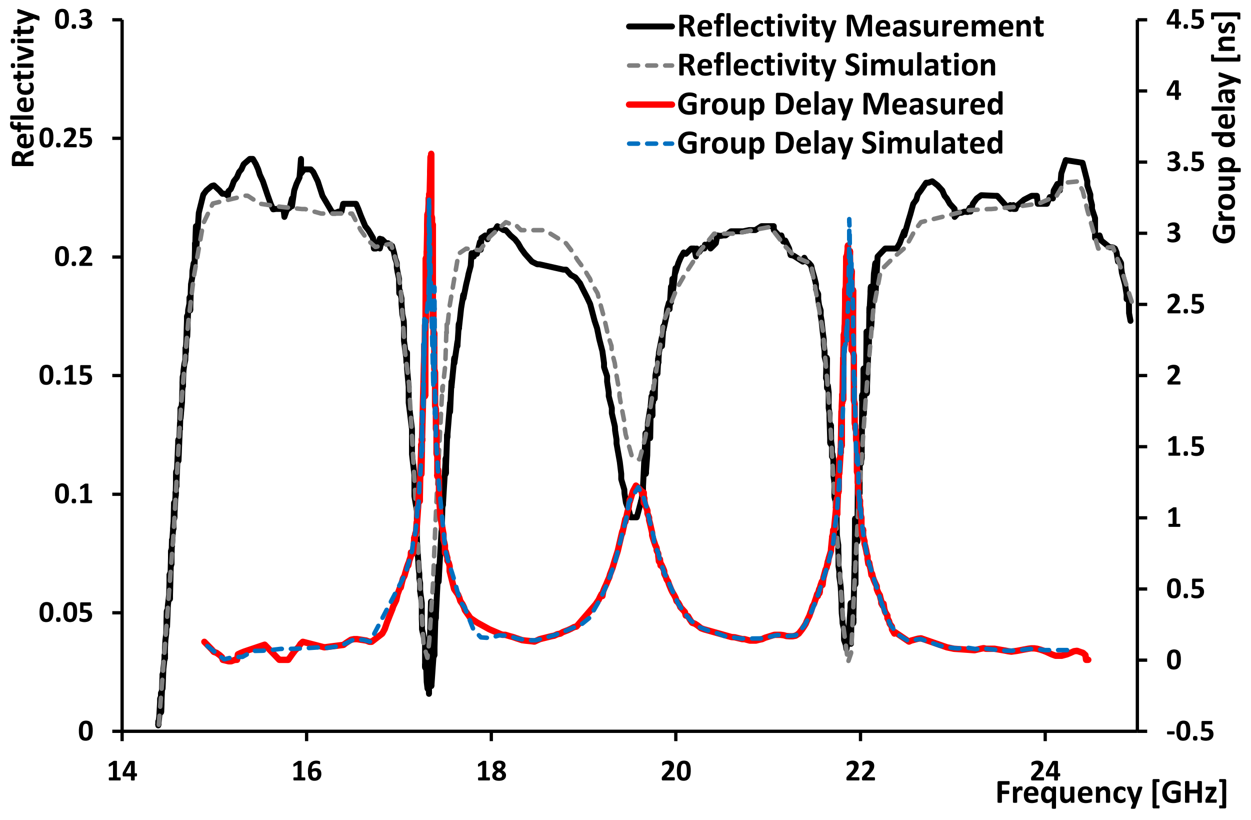
- Five sapphire disks (200mm diameter)
- Positioning to better than 15 µm
- Cold pre-amplifier

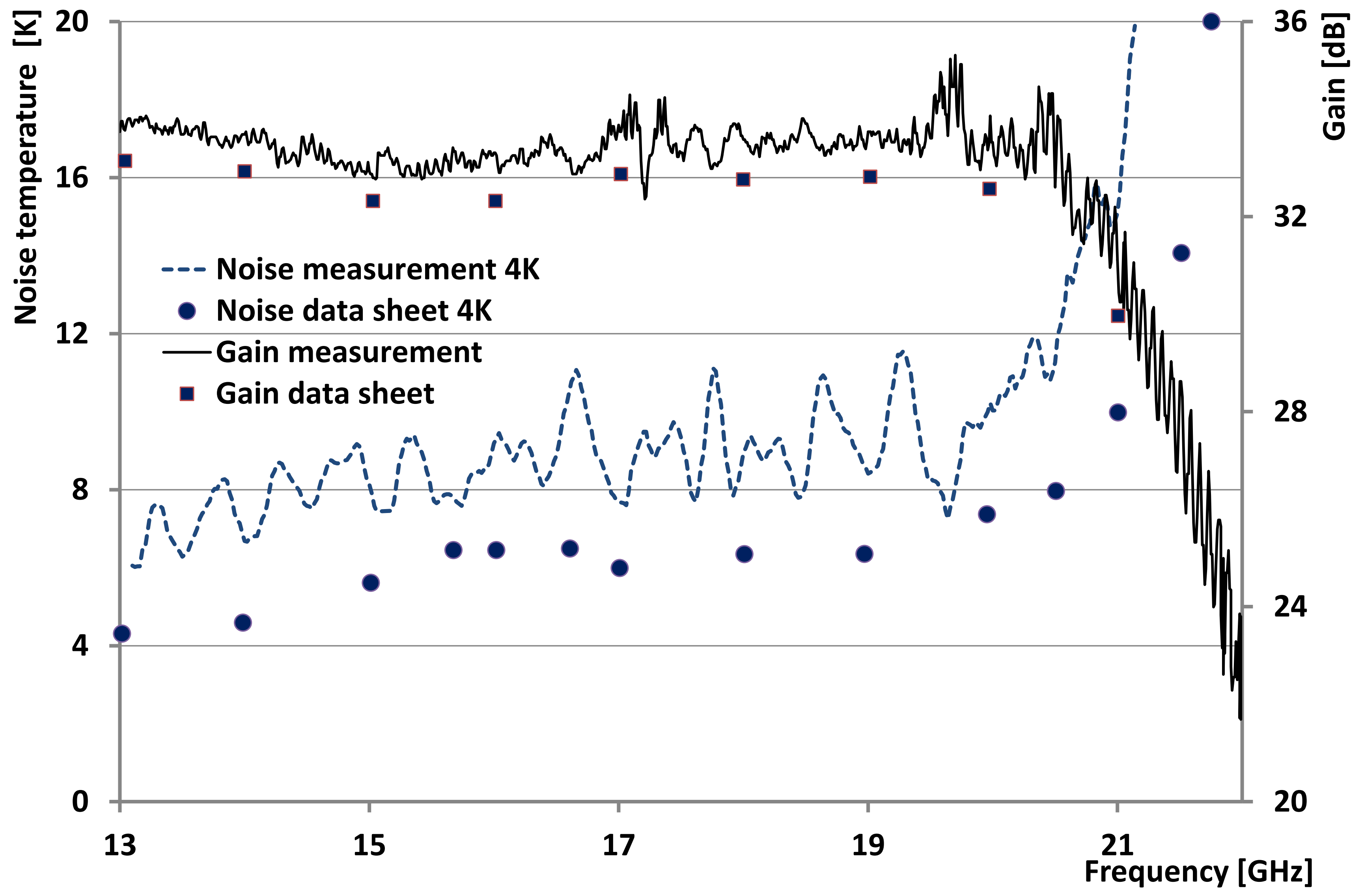
- Measured
  - amplifier properties
  - transmissivity and reflexivity of disks



MADMAX White Paper







MADMAX at H1

- MADMAX Magnet Infrastructure

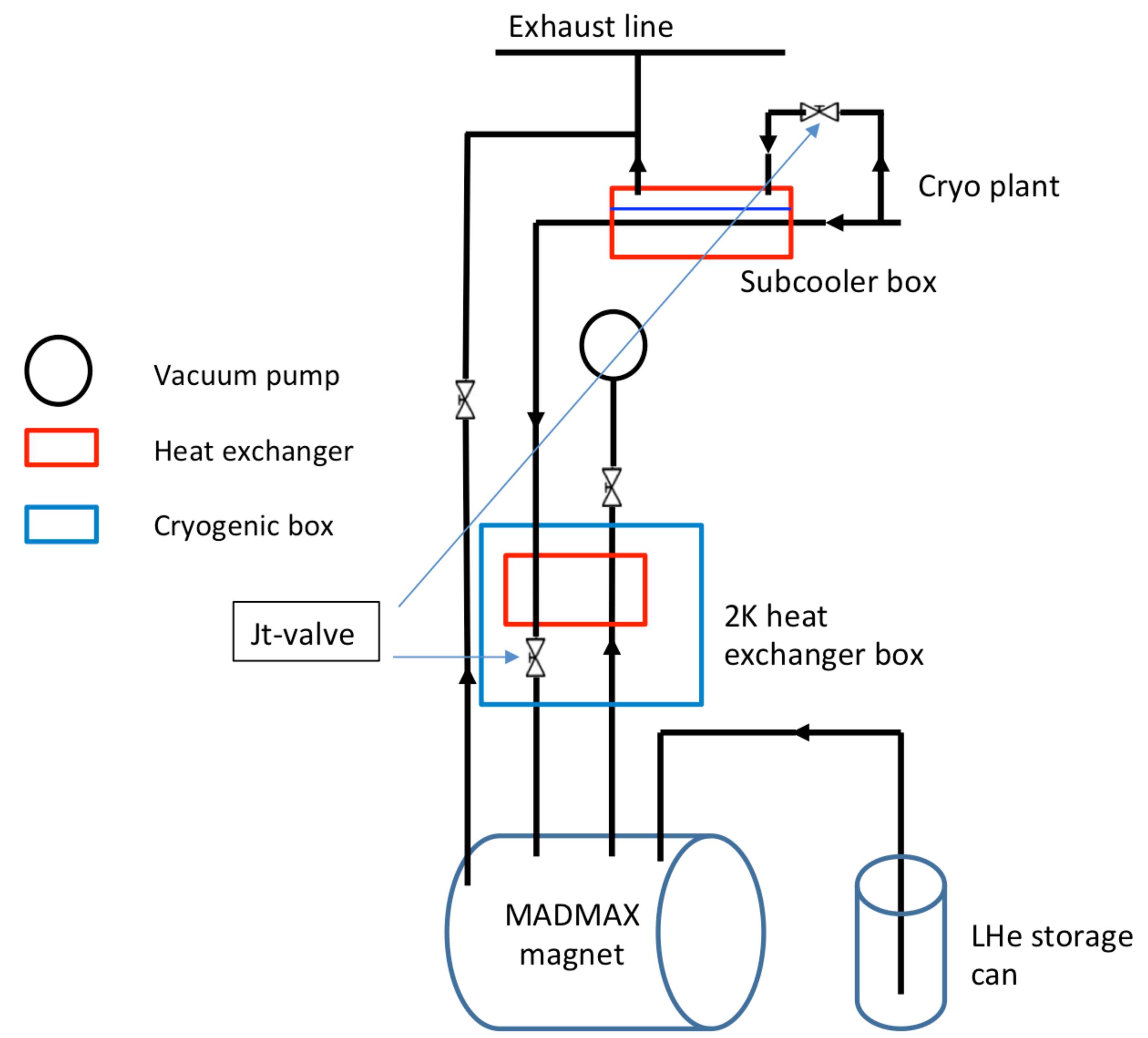
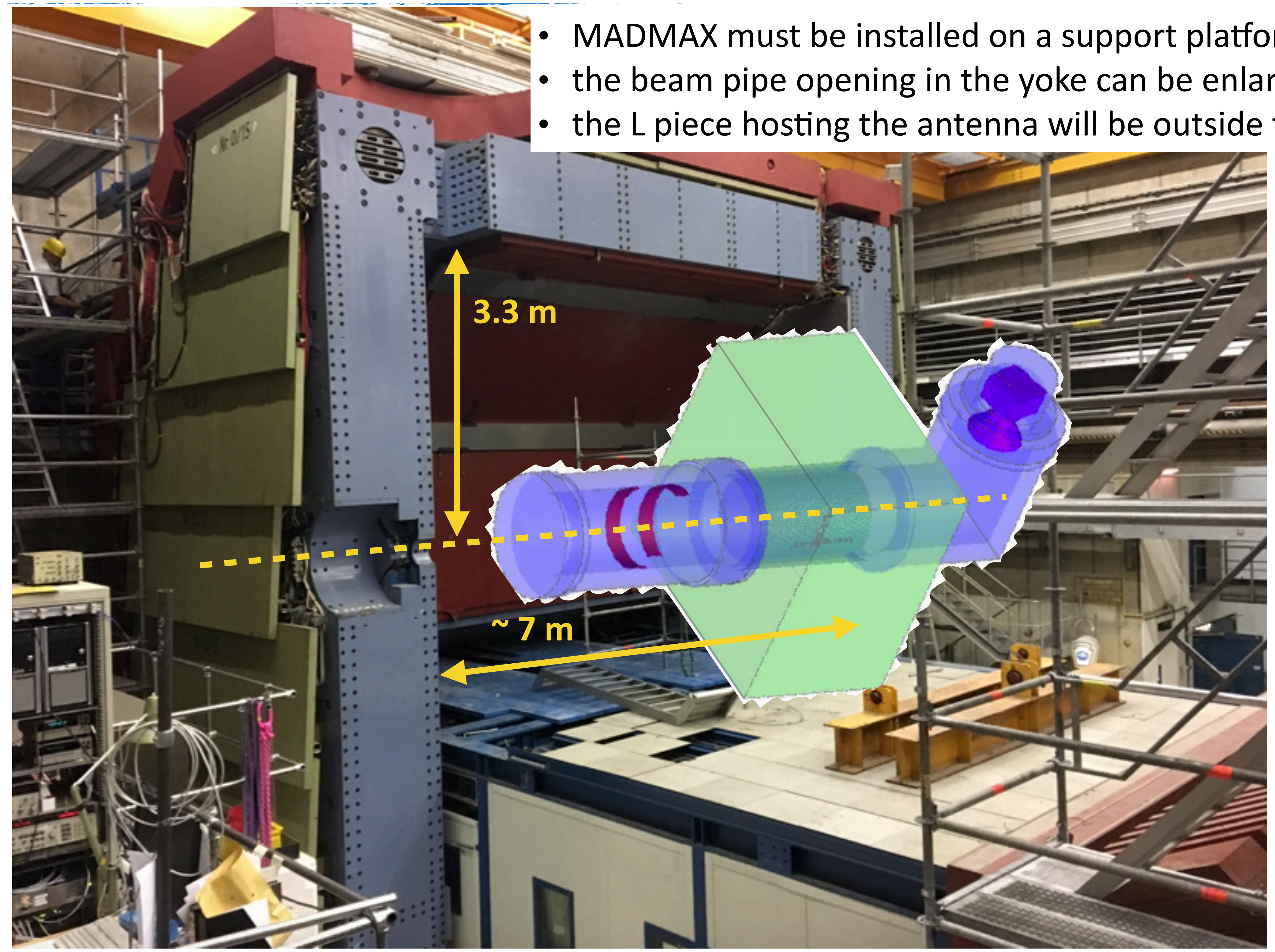
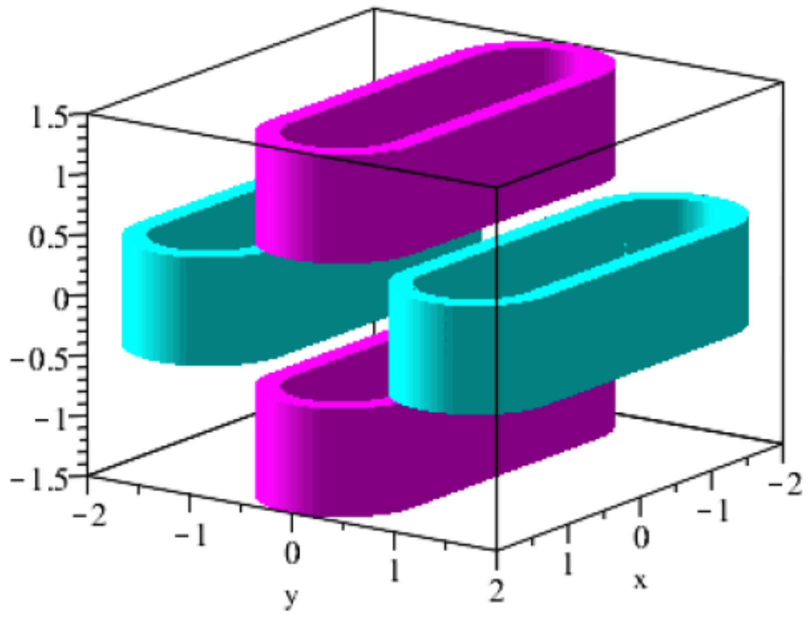


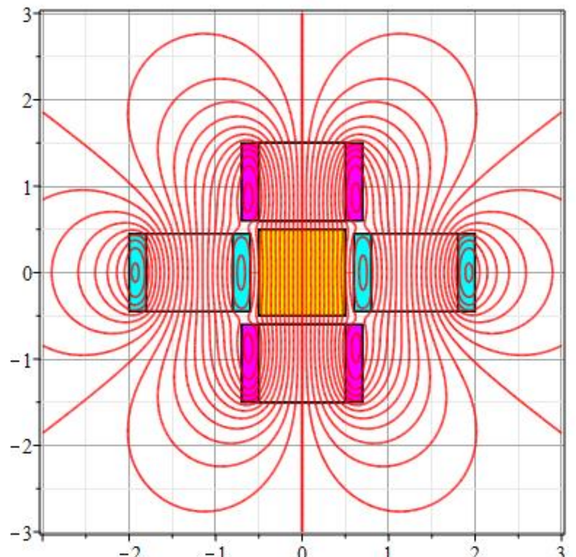
Figure 1: Schematics of cryogenics connections and installations for an example experiment ("MADMAX").

E. Garutti

- MADMAX must be installed on a support platform
- the beam pipe opening in the yoke can be enlarged
- the L piece hosting the antenna will be outside the yoke



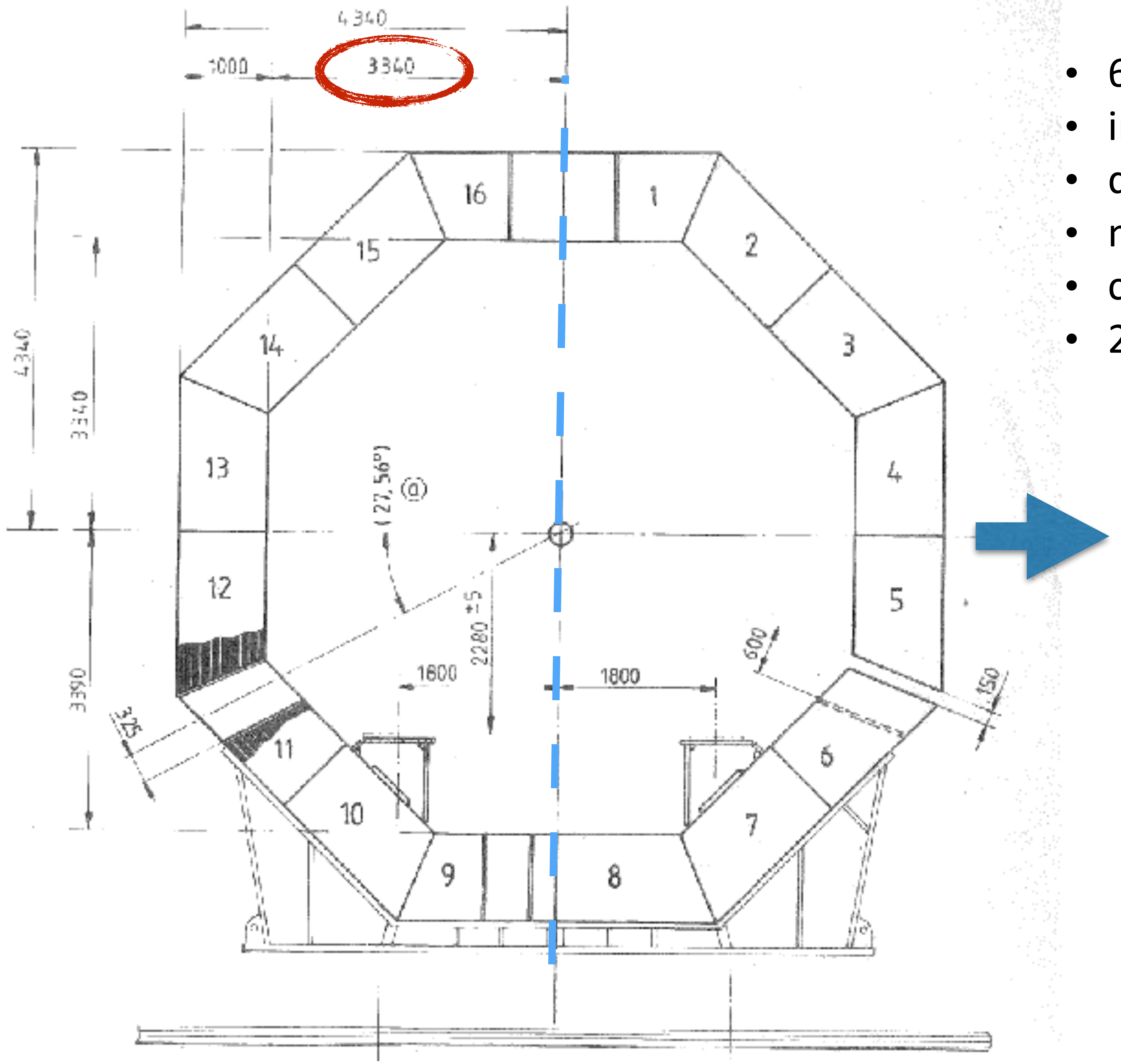




Field lines

W. Abdel Maksoud

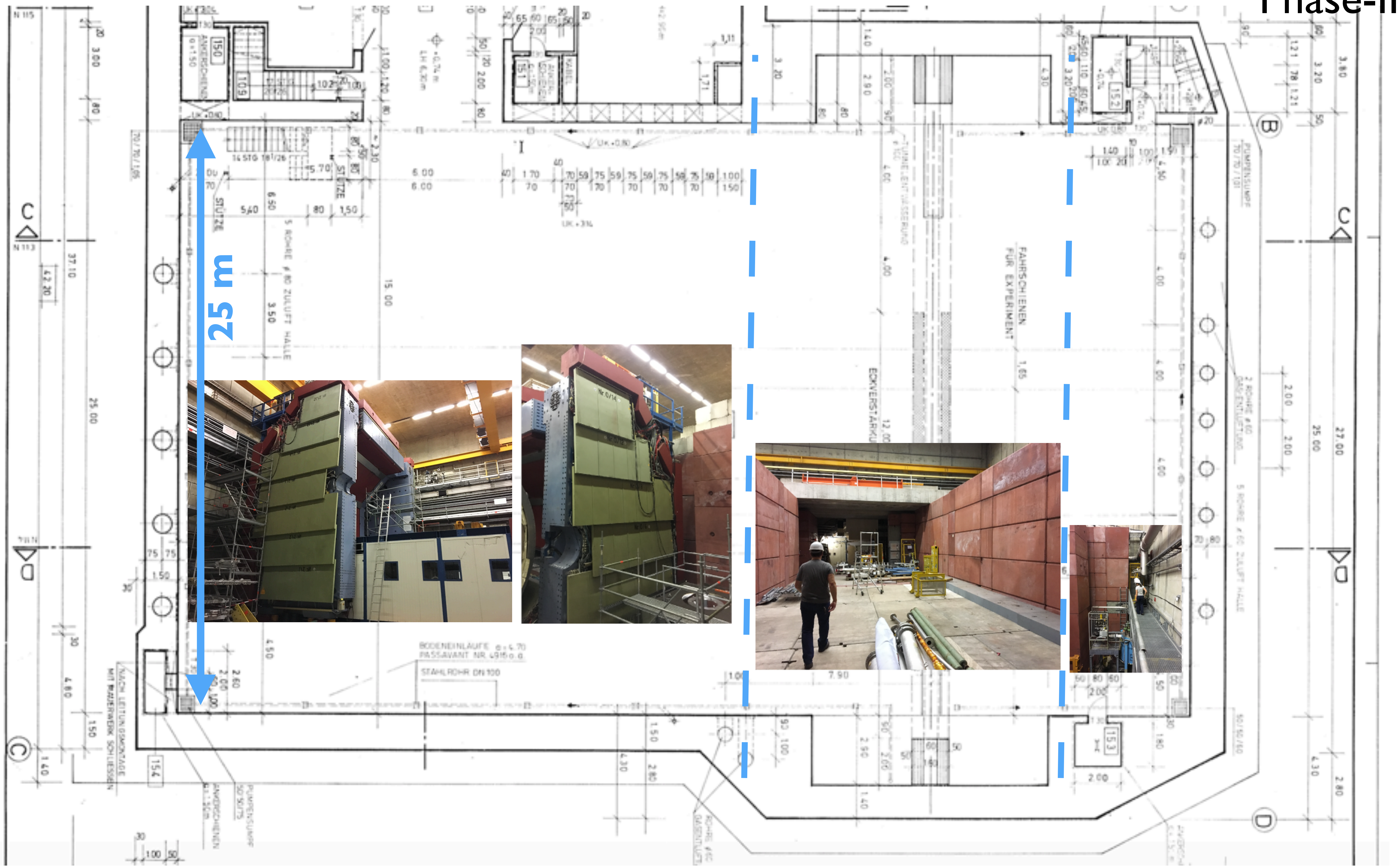
The H1 magnet yoke



- 60 cm thick stainless steel
- inner radius 3.3 m
- divided in two vertical halves
- mounted on movable rails
- can be opened to access inner volume
- 2 m movement in ~ 20 min.

MADMAX in the DESY North Hall

Phase-II

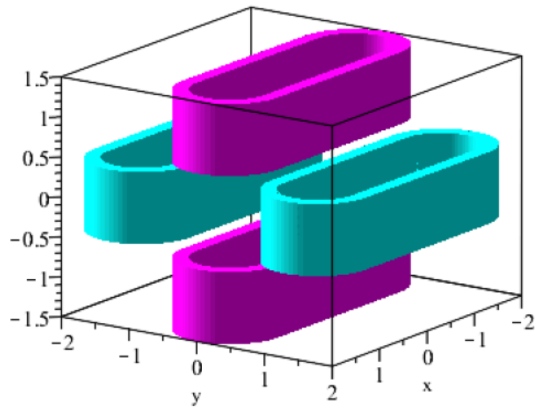
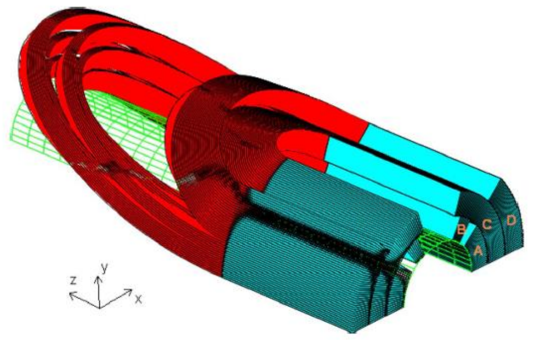
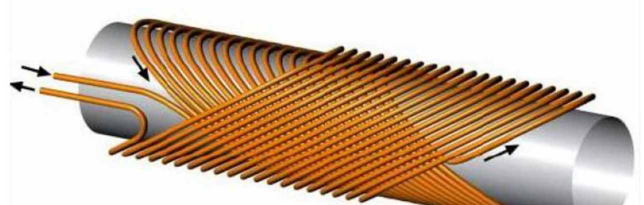
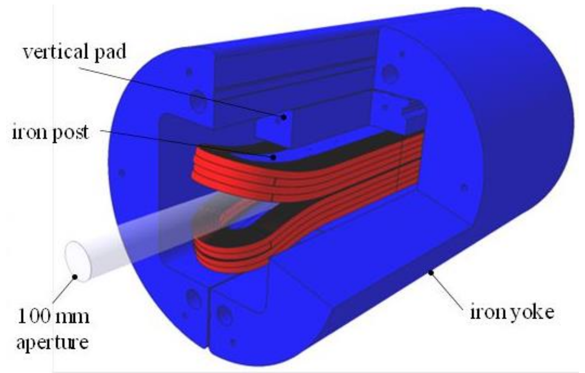


MADMAX Magnet Design

- Design studies in MADMAX collaboration:
  - Babcock Noell
  - CEA Saclay
- Challenging magnet design
  - large field (>10T)
  - large bore (>1m)
- Stray fields should be low enough to allow co-use of the experimental area

- Use of H1 yoke would have an impact

First evaluations summary

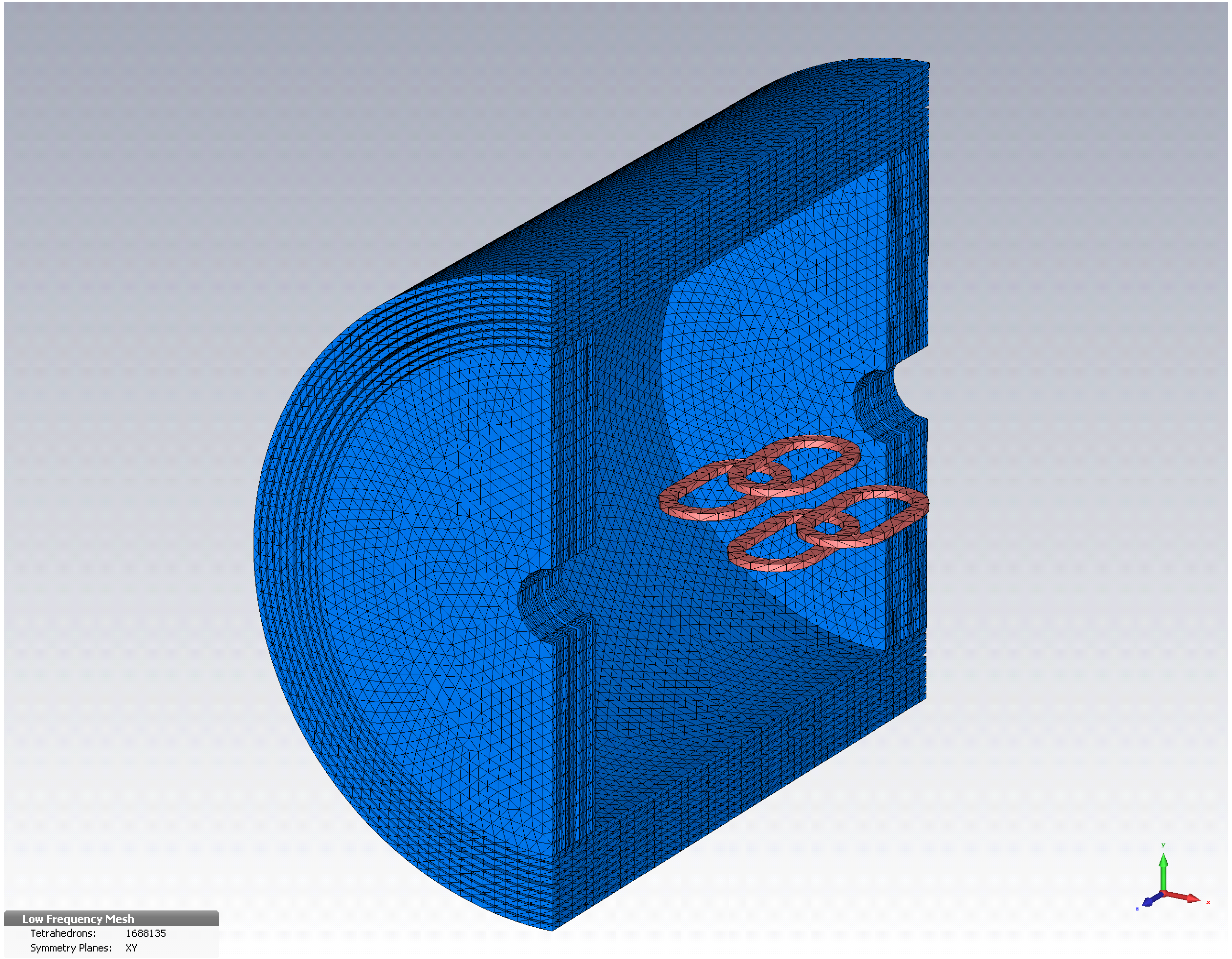





Field specification	+ +	+ +	- -	+ +
Peak field	-	++	+	++
Stress analysis	+	- -	- -	+
Conductor design	+	- -	- -	+
Mechanical layout	+ +	- -	+ +	- -
Superconductor	-	+ +	+	+ +
Stray field	+ +	- -	- -	- -
Compatibility H1 yoke	- -	+ +	-	+ +
Magnet volume	+	+ +	- -	+ +
First order conclusions that will be confirmed by further detailed studies	**Encouraging solution that has to be optimized if shielding is required**	**Seems not feasible due to technological limits (conductor , layers, …)**	**Seems not feasible due to design, techno and cost limits (field, cond, vol)**	**Encouraging solution if the H1 yoke fits with the stray field requirements**

W. Abdel Maksoud

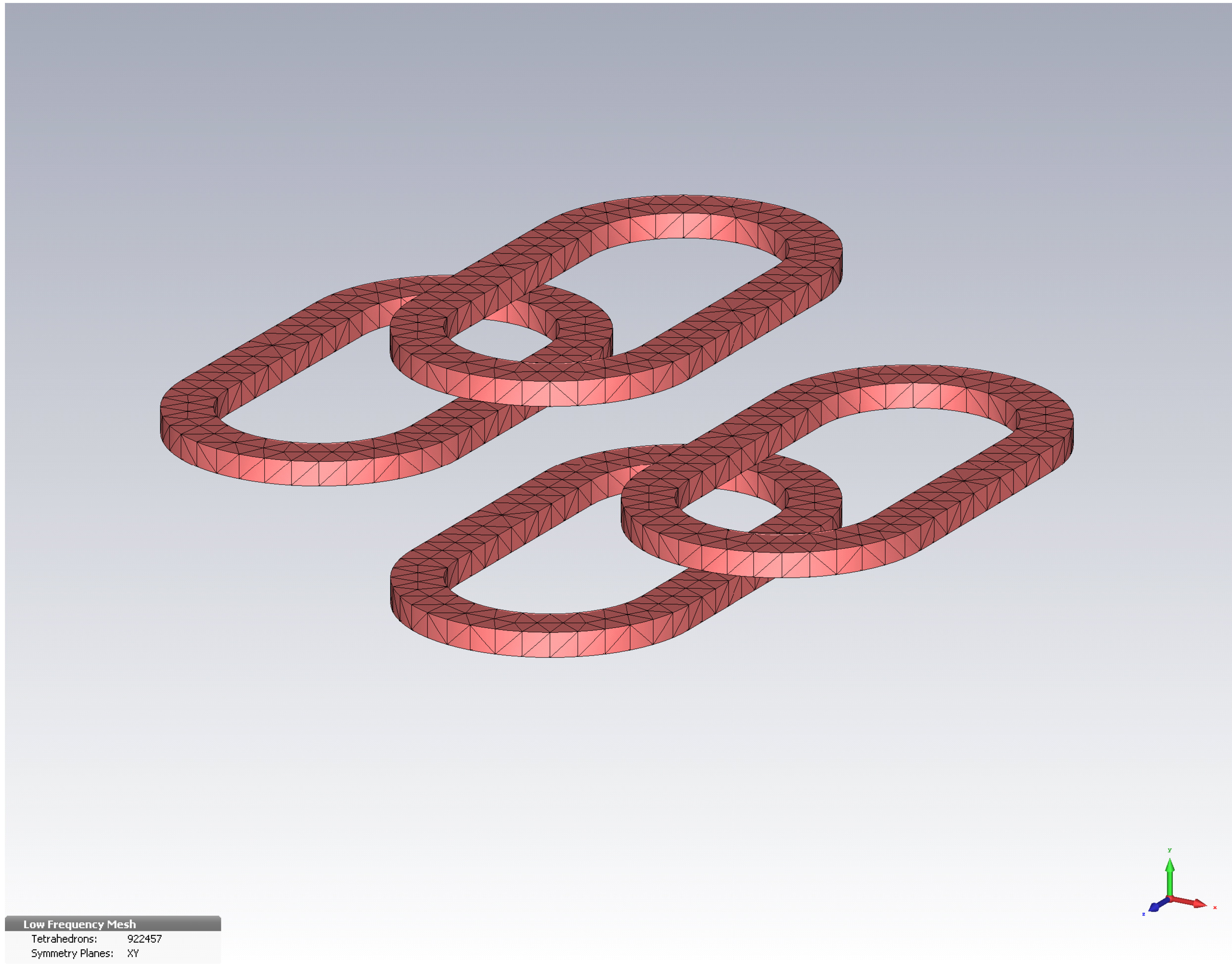
H1 Yoke Simulation

- CST EM Studio
  - specialised tool for low-frequency and static EM calculations
- Full 3D tetrahedral mesh, magnetostatic solver
- Simplified model of the H1 yoke
  - Cylindrical model instead of octagonal
  - Plate structure
  - Steel ST1010



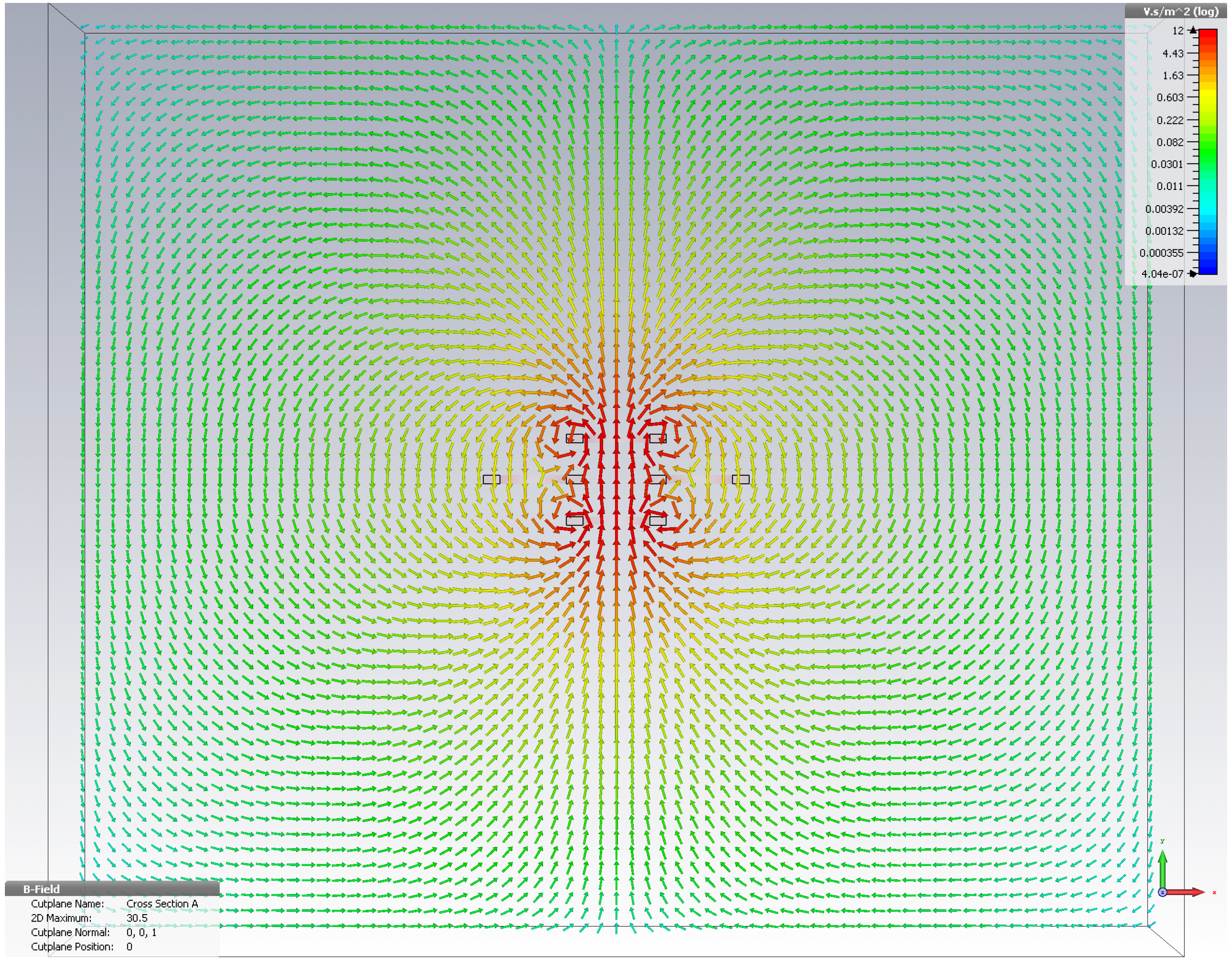
Coil Modelling

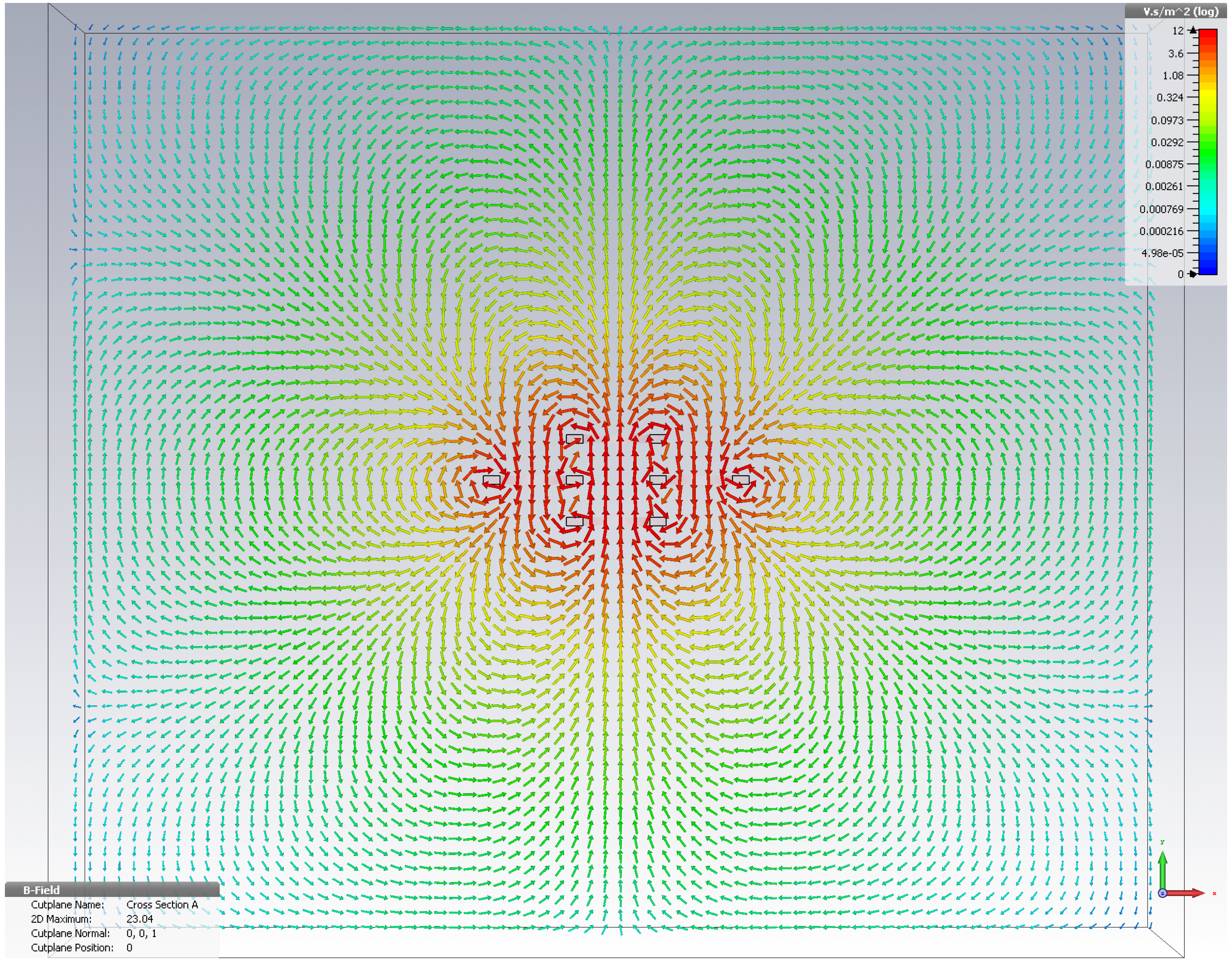
- Magnet is a simple arrangement of four „Helmholtz-like" coils
  - 2m long, 1x1m space in the centre
  - no mechanics, no check of forces, nothing…
- Number of windings and current tuned to reach 10T central field
- Correction („anti-Helmholtz") coils with switched polarity
- When correction coils are off, set central coils to have 1/3 higher current to recover central field at ~10T



Magnetic Fields without Yoke

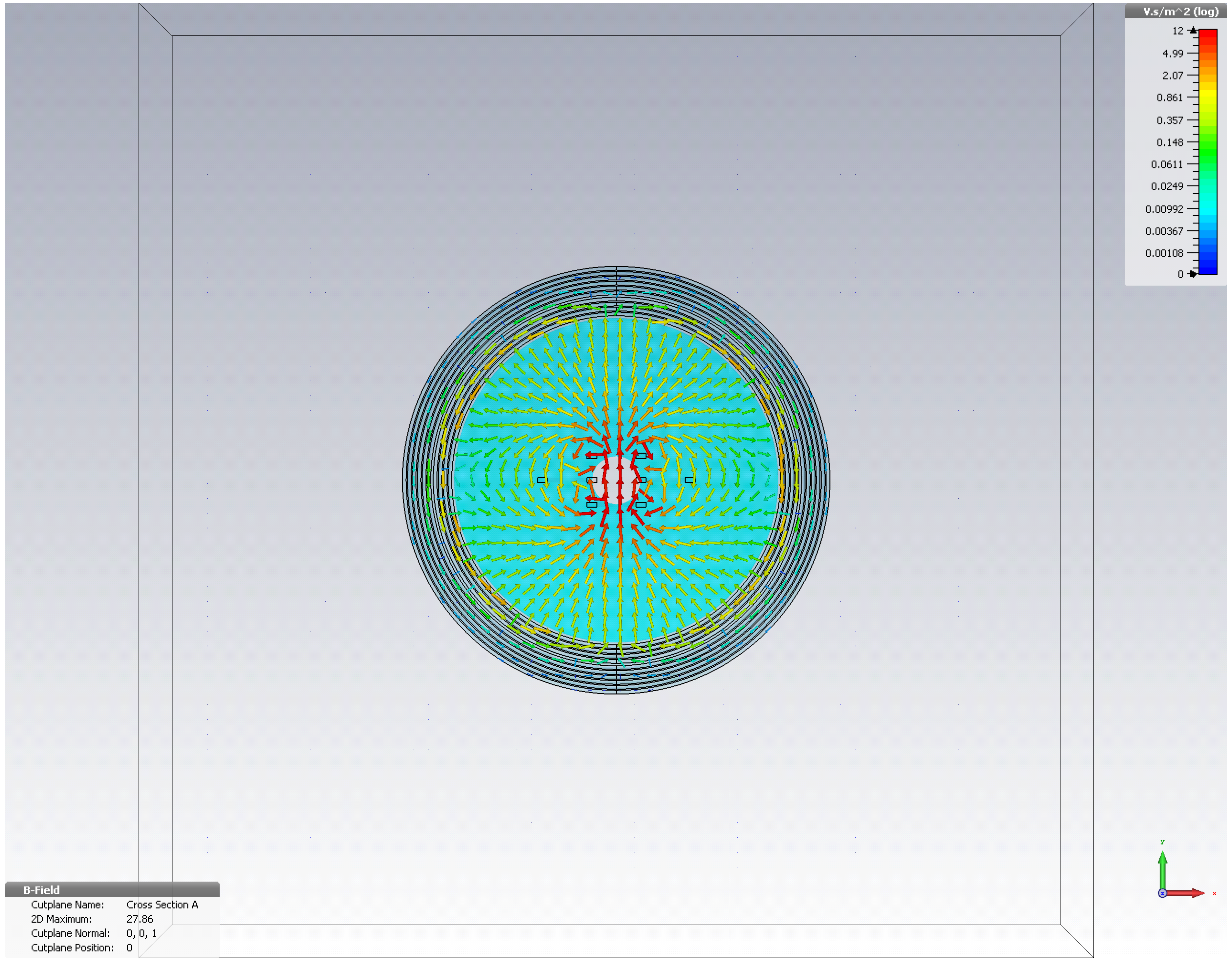
- Front view, cutting plane at z=0
  - left: correction coils off
  - right: correction coils on

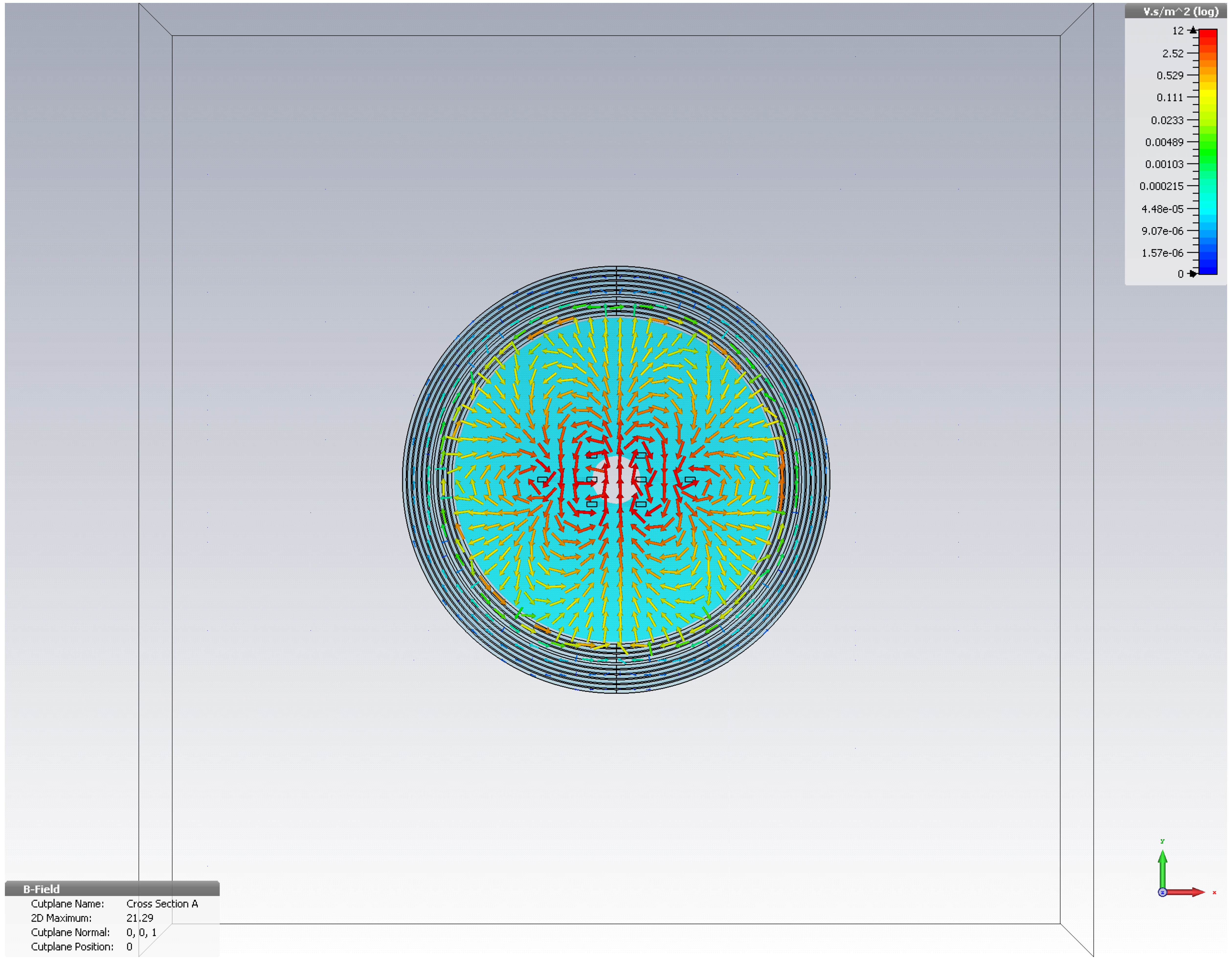




Magnetic Fields with H1 Yoke Closed

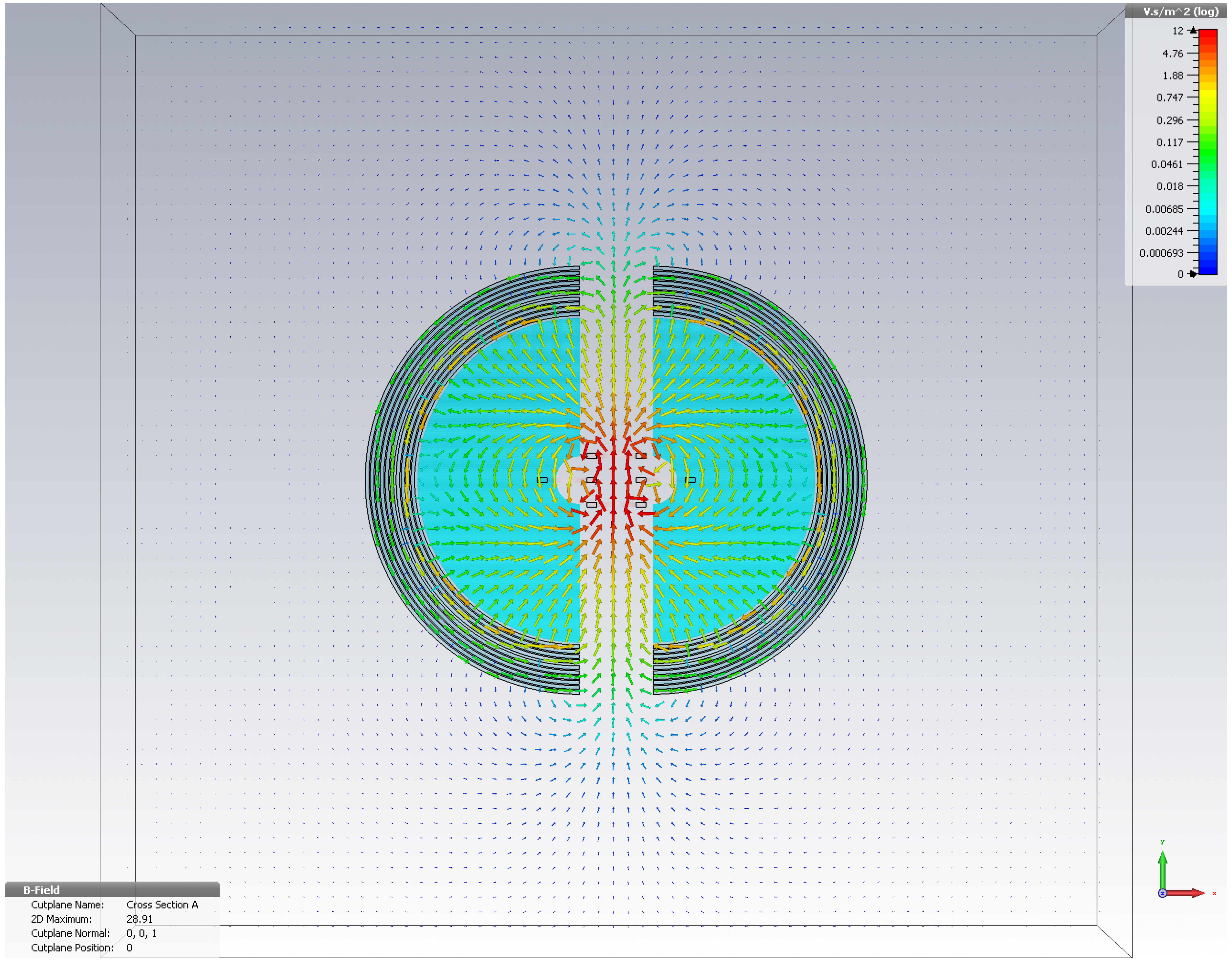
- Front view, cutting plane at z=0
  - left: correction coils off
  - right: correction coils on

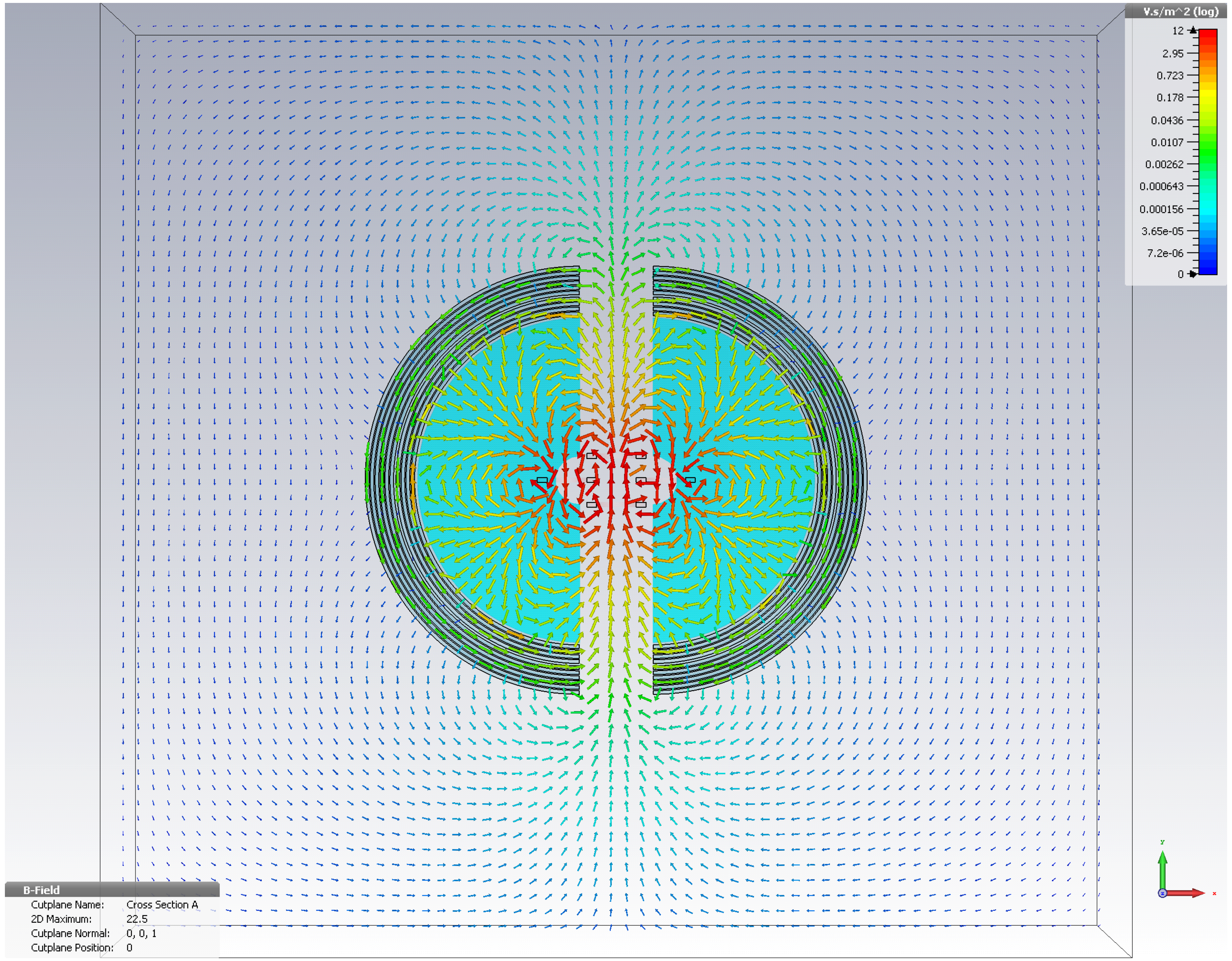




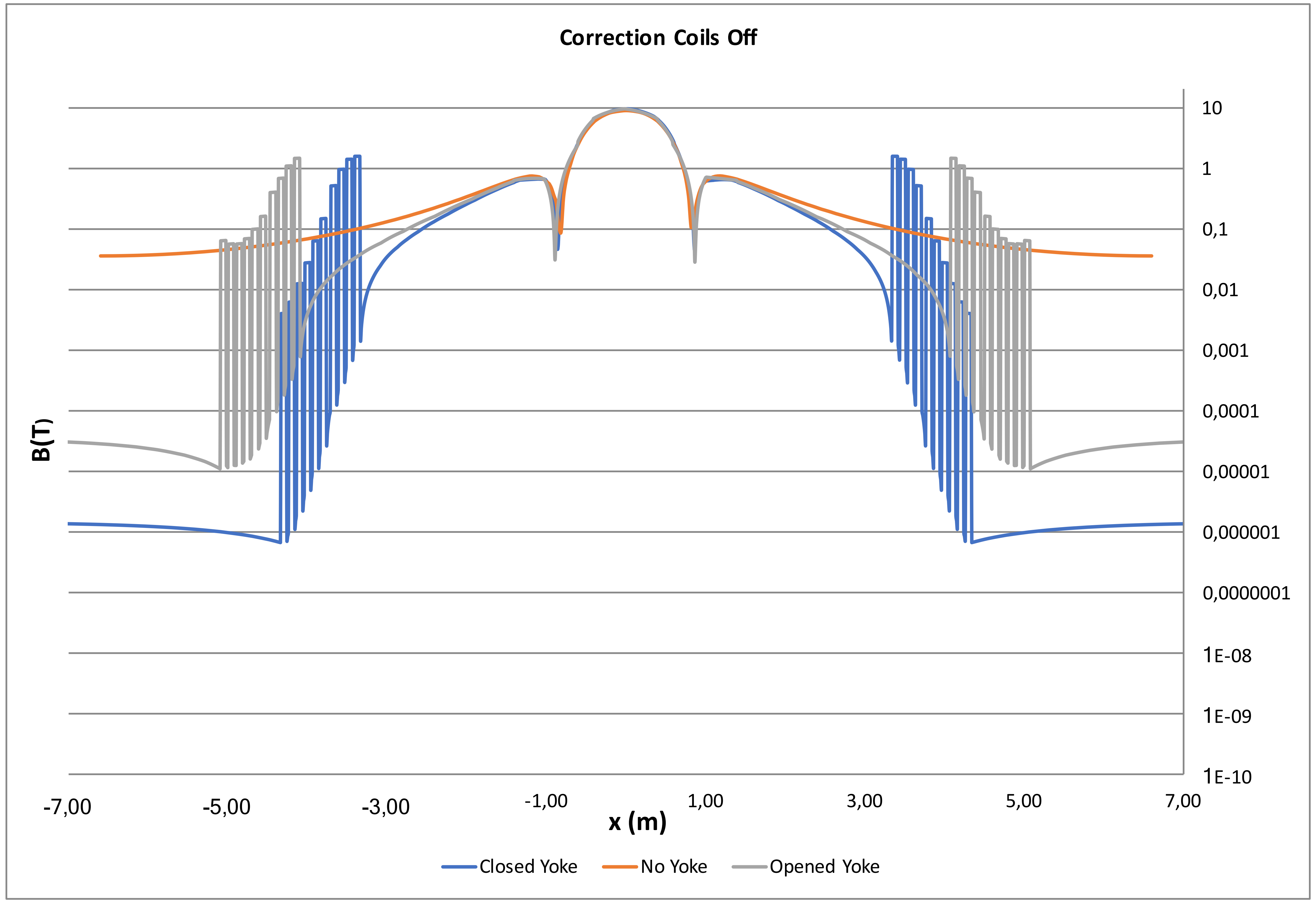
Magnetic Fields with H1 Yoke Opened by 1.5m

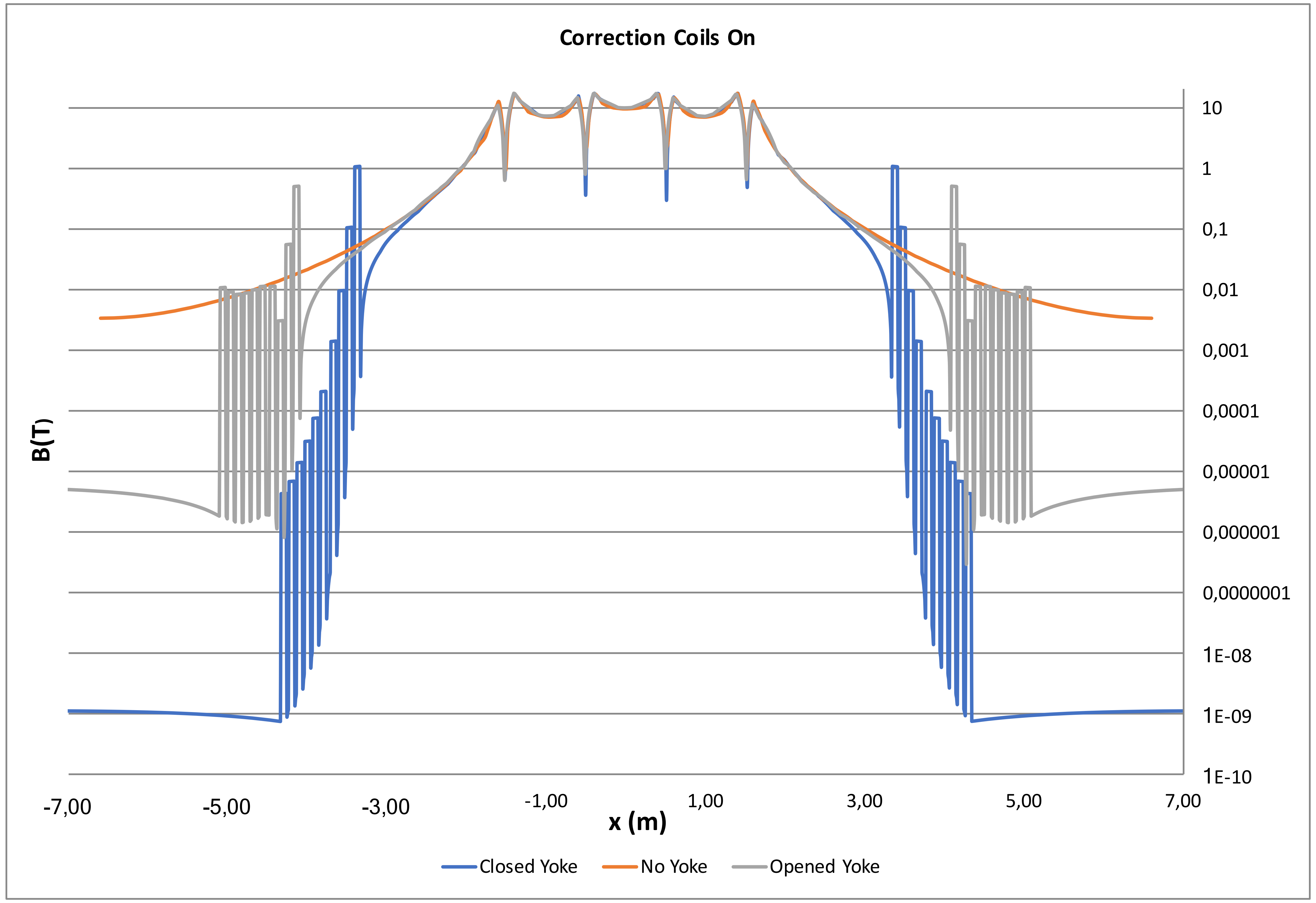
- Front view
  - left: correction coils off
  - right: correction coils on





MADMAX in H1 Yoke





MADMAX Collaboration

- Formally founded on 18 October 2017
- Groups:
  - U Aachen (D)
  - U Hamburg (D)
  - U Tübingen (D)
  - U Zaragoza (E)
  - MPI für Radioastronomie, Bonn (D)
  - MPI für Physik, Munich (D)
  - CEA-IRFU Saclay (F)
  - DESY
- Timeline
  - Finding Phase
    - verify concept, review of theoretic background
  - Design studies for magnet concept and mechanics
  - Smaller prototype by 2021
    - some physics reach
  - Real experiment after 2021

What is in it for FLC?

- So far FLC is/was involved in:
  - Support in simulation of magnetic stray fields
    - „Spin-off“ from the cryo platform work
    - Expertise in FLC: Uwe, KB
  - Technical support:
    - H1-Hall preparation (K. Gadow)

- Physics is interesting, but of course closer to ALPS-II (Ringwald, Lindner, et al.)
- Expertise for MADMAX technologies is not so strong in FLC
  - Magnet design, cryogenics
  - Mirrors
  - Microwave receiver
  - Positioning

- But, it could be fun
- It is in-house and it will (most probably) happen
- Timelines are commensurate with ILC:
  - most technical work done before, e.g. ILD construction would start