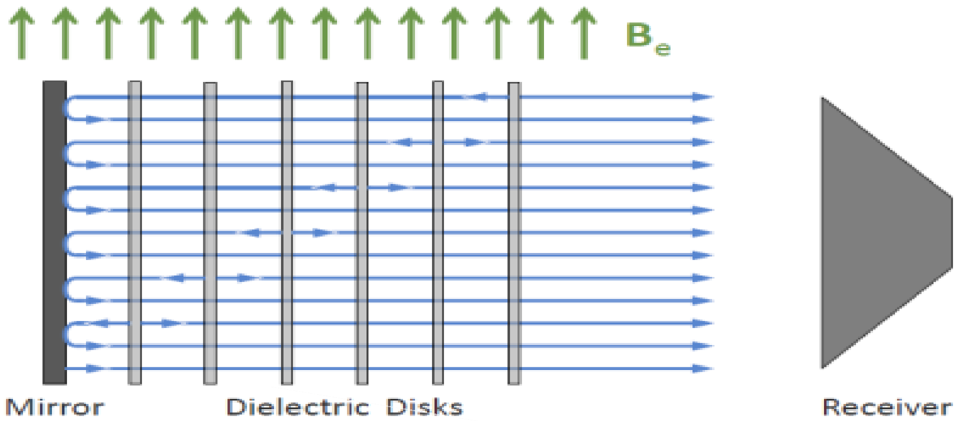
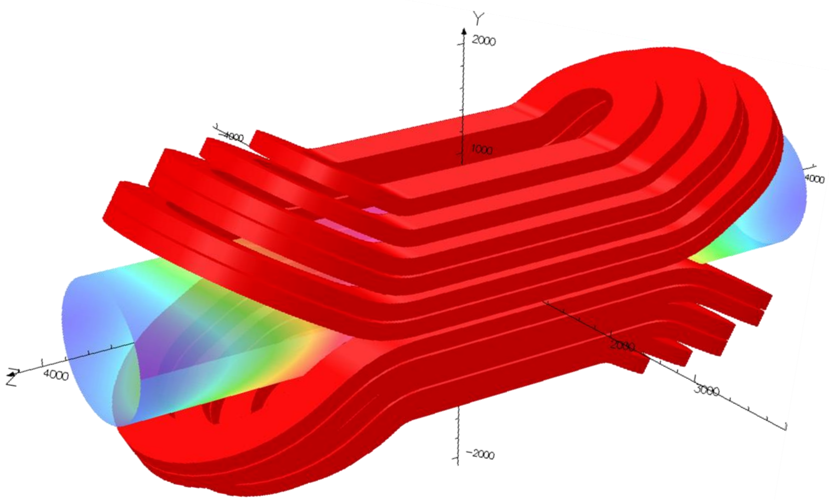
A new Road to Axion Dark Matter Detection

MADMAX





- Axions in a nutshell
- Dielectric haloscope concept
- Simulations
- Proof of Principle Setup
- The magnet
- The booster
- Outlook

MADMAX @ MPP

Director:	Allen Caldwell	
	Gia Dvali	
Projec leader:	Béla Majorovits	Spokesperson
	Olaf Reimann	Exp
Scientists:	Georg Raffelt	Theory
	Frank Steffen	Theory
Postdocs:	Kenichi Saikawa	Theory
	Chang Lee	Exp
	Xiaoyue Lie	Exp
PhD Students:	Stefan Knirck	Exp
Master students:	Jacob Egge (until Nov 18)	Exp
	Alexander Partsch (until Jun 18)	Exp
Engineering:	Armen Hambardzumjan	
	Christopher Gooch	
	David Kittlinger	
	Alexander Sedlak	

Many thanks for the continuous support from the **mechanical workshop!**

The strong CP problem

CP violating term in QCD

$$\bar{\Theta}\frac{\alpha_s}{8\pi}G_{\mu\nu a}\tilde{G}_a^{\mu\nu} \in \mathcal{L}_{QCD}$$

Induces neutron EDM:

$$d_n \sim \bar{\Theta} \cdot 10^{-16} \text{ e cm}$$

Experimental limits on EDM of neutron:

$$d_n < 3 \cdot 10^{-26}$$

Pendlebury et al.,
Phys. Rev. D 92, 092003 (2015)

$$\bar{\Theta} = \Theta - \arg\det M_q < 10^{-10}$$

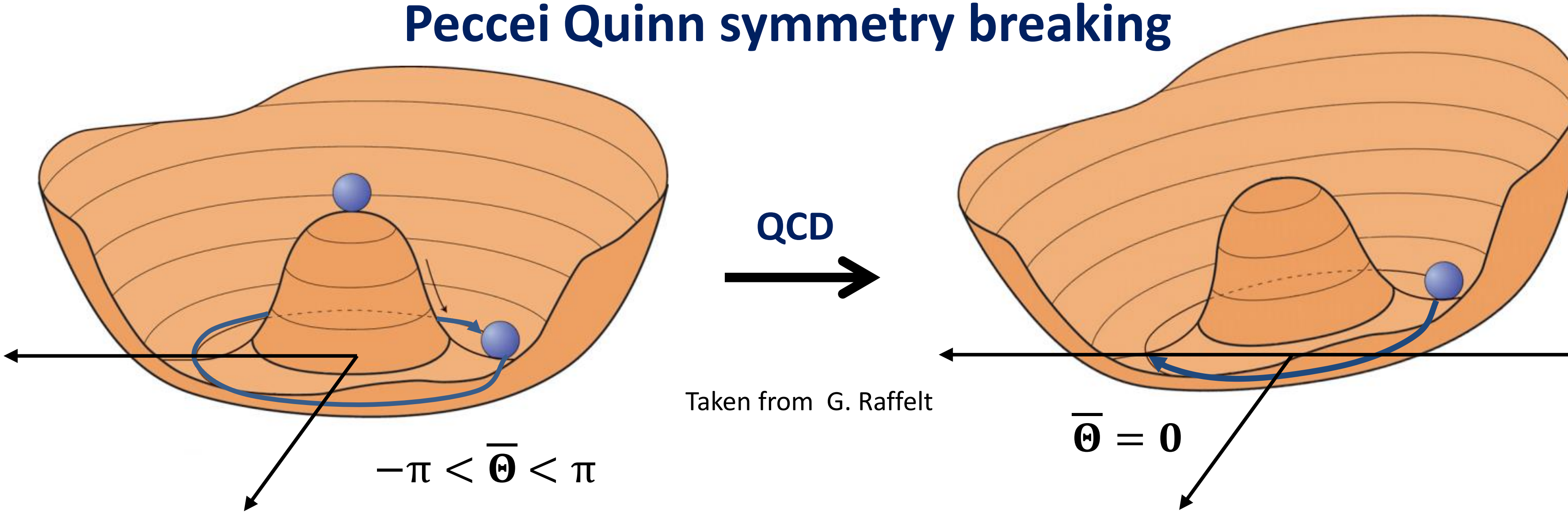
Random phase from Θ-vacuum

phases from Yukawa coupling: CKM matrix

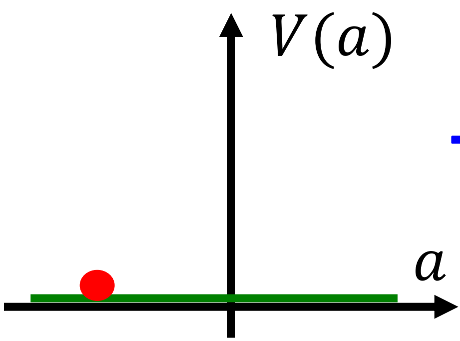
Why does random vacuum Θ term compensate phases from CKM matrix to 1 in 10^{10} ???

Solution to the strong CP problem?

Peccei Quinn symmetry breaking



Potenital after PC symmetry breaking **Potenital after QCD phase transition**

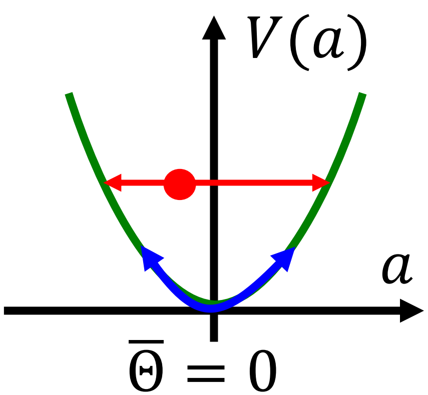


If axion exists:

→ contribution to Dark Matter!

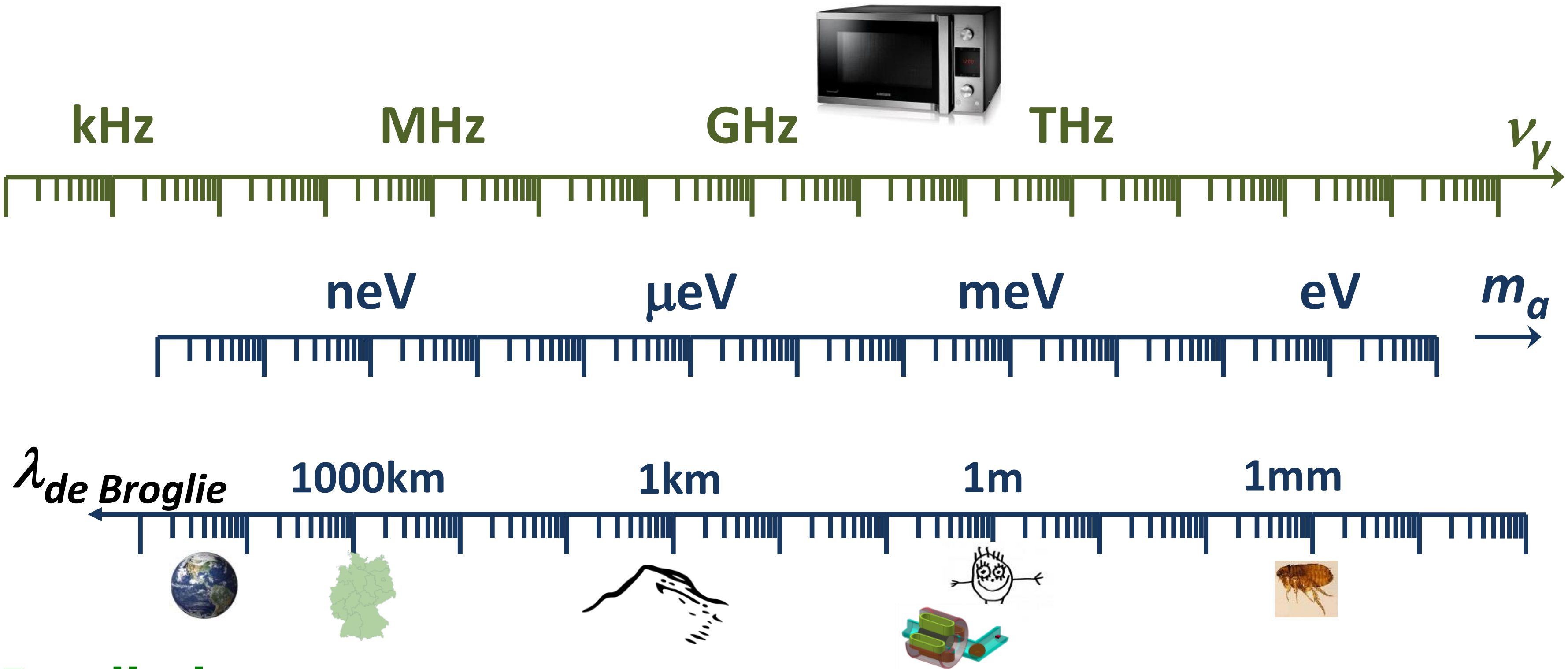
As relic oscillations of

$\bar{\Theta}$ around minimum



QCD CP invariant at minimum, i.e. for $\bar{\Theta} = 0$

The „Grandeur“ of axions?



Predictions:

Pre-inflationary

$|\Theta_i|$ arbitrary–π – π

scenario

Post-inflationary

$|\Theta_i|$ Ø of all possible values

Experiment fits into wave (particle)!

arXiv.org > hep-th > arXiv:1811.03079

Search or Ar

(Help | Advanced

High Energy Physics - Theory

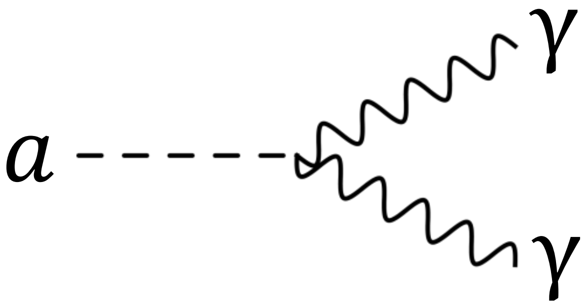
A Proof of the Axion?

Gia Dvali, Cesar Gomez, Sebastian Zell

(Submitted on 7 Nov 2018)

We show that the de Sitter quantum breaking bound when applied to QCD exposes the necessity of the axion solution to the strong CP problem. The Peccei-Quinn mechanism emerges as a consistency requirement independent of the naturalness questions. The θ-angle must be unphysical rather than simply small. All other approaches including a fine-tuning of θ lead to the existence of de Sitter vacua and are excluded by consistency.

Axion couples to photon



$$\mathcal{L}_{a\gamma} = -\frac{g_{a\gamma}}{4} F\tilde{F}a = g_{a\gamma}\,\mathbf{E}\cdot\mathbf{B}\,a$$

$$= \frac{\alpha}{2\pi}\left(\frac{E}{N} - 1.92\right)\frac{a}{f_a}\mathbf{E}\cdot\mathbf{B}$$

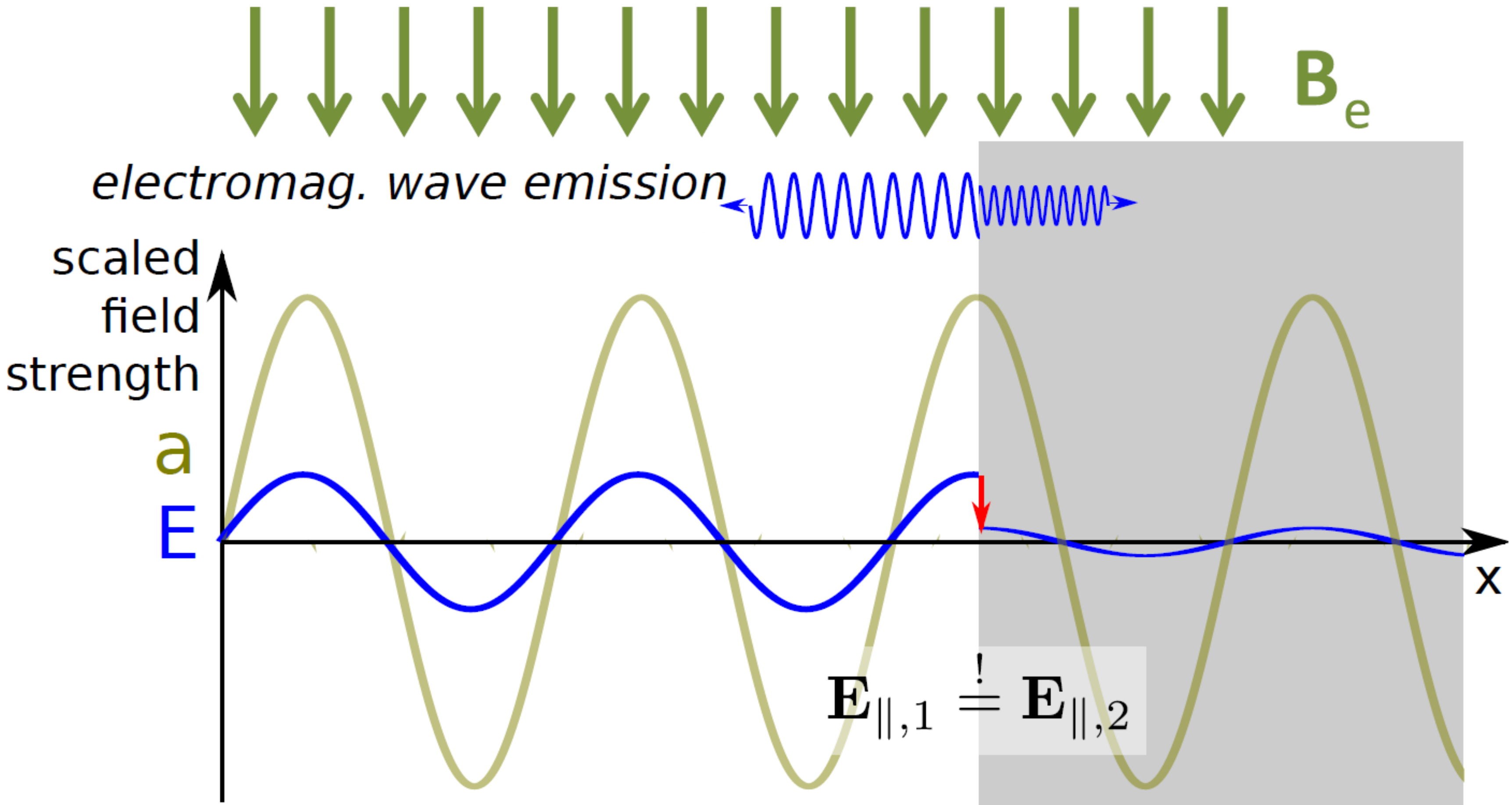
Modifies Maxwell equations → Additional source term

$$\nabla \times \boldsymbol{B} - \dot{\boldsymbol{E}} = \boldsymbol{J} + g_{a\gamma}\,\boldsymbol{B}\dot{a}$$

External B-field
→ Axion-field sources an E-field
→E-field oscillations!

Effect of dielectrics

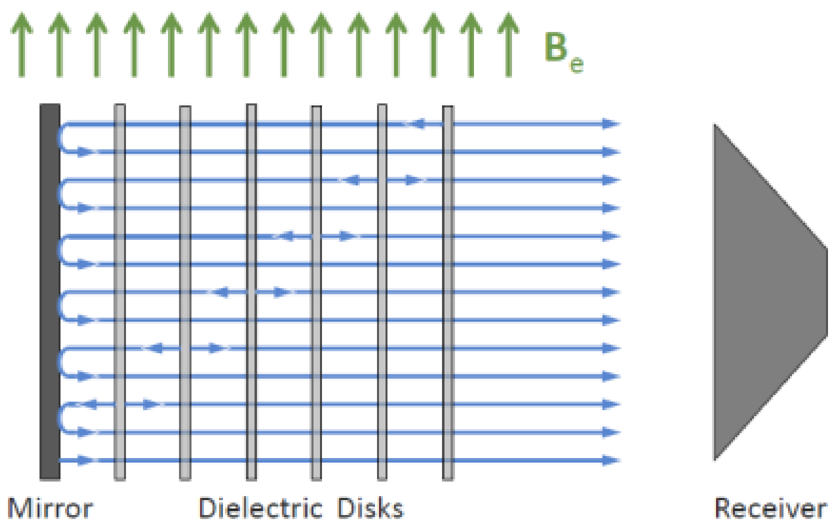
in oscillating E-field:



$$\left(\frac{P}{A}\right)_{mirror} \sim 2 \cdot 10^{-27} \frac{W}{m^2} \left(\frac{B_{\|}}{10\ T}\right)^2 (g_{a\gamma\gamma} m_a)^2$$

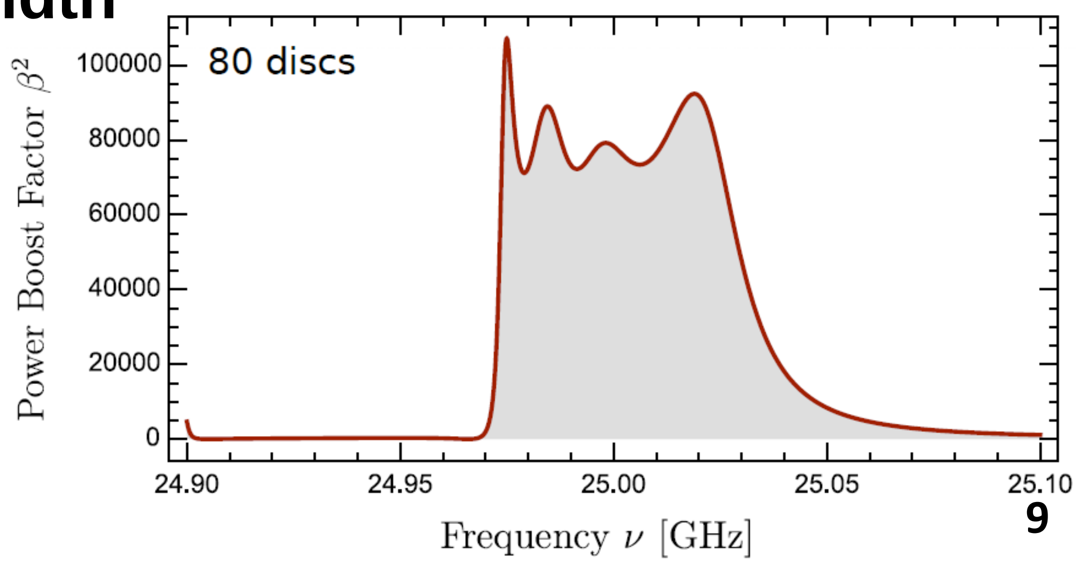
$\epsilon = 1$ $\epsilon = 4$

Dielectric haloscope



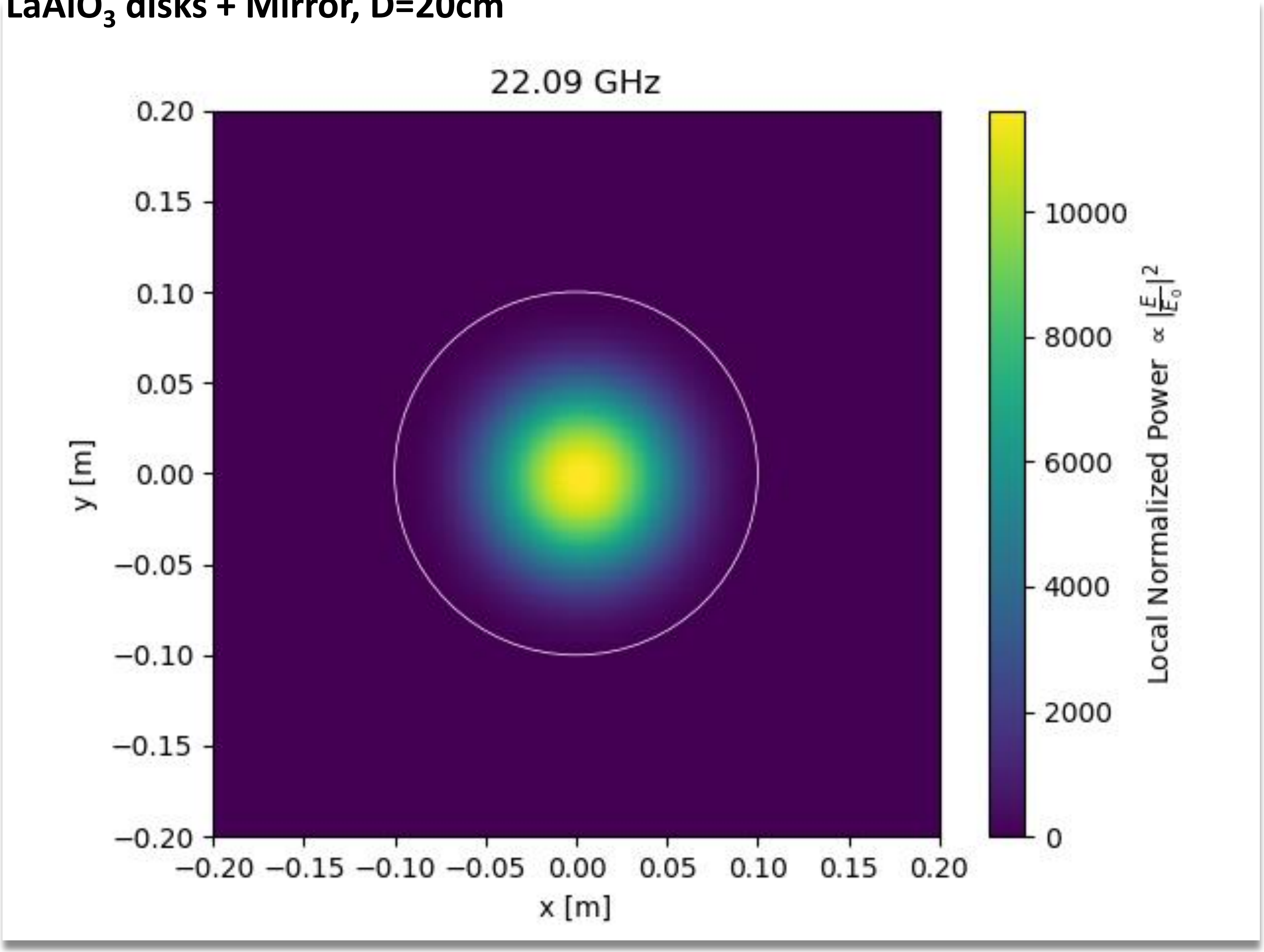
- **Add up coherent emission from all surfaces**
- **Set disk distances to use resonant effects**
- **Changing distances changes sensitive frequency range**

- **„Power boost“ X bandwidth ~ proportional $\varepsilon \cdot N_{disk}$**
- **Power boost few·10^4**
  → ~ 80 disc of $LAlO_3$
  → P ~ 10^{-23}W
  → Detectable!



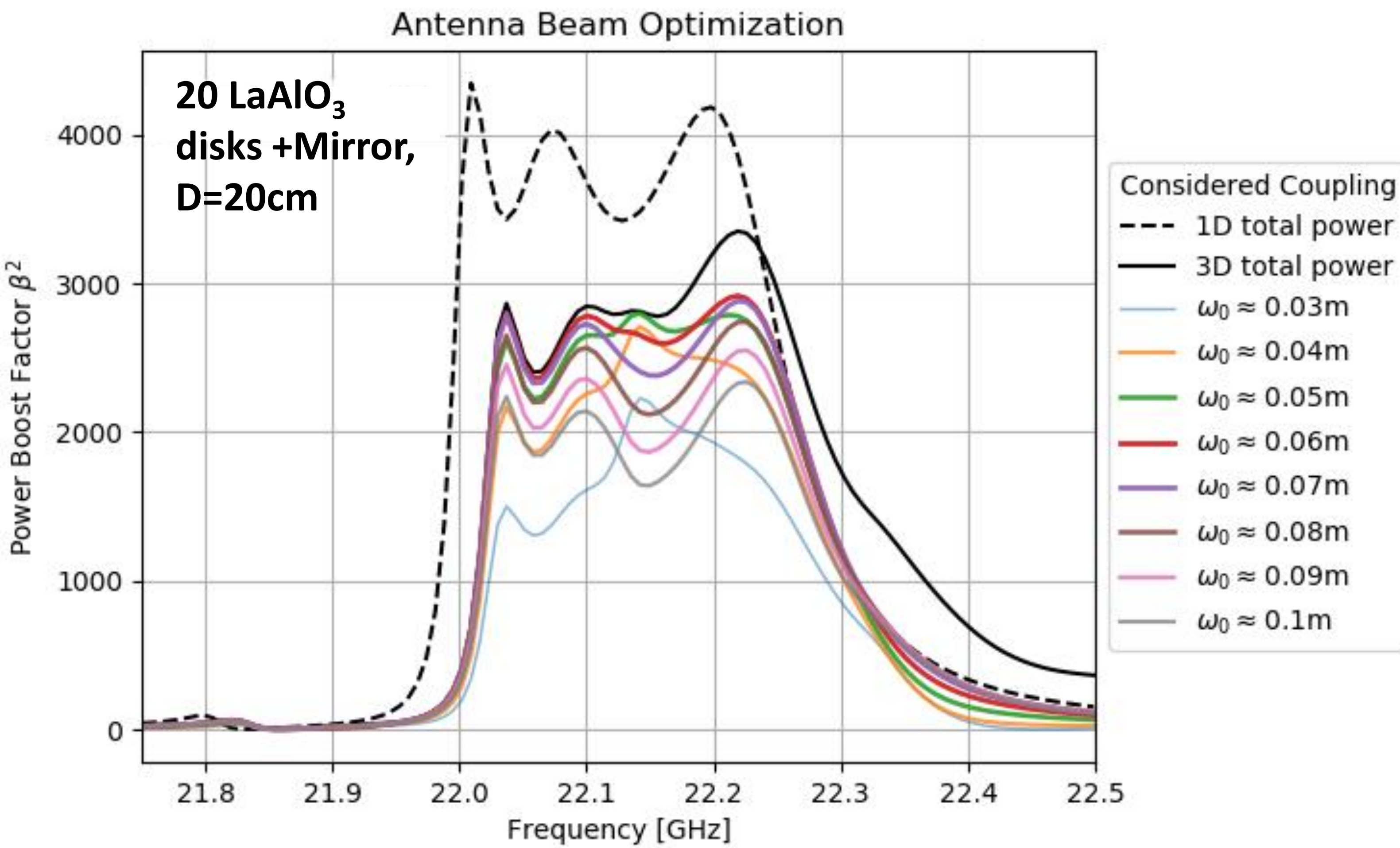
Simulation of beam shape:

20 $LaAlO_3$ disks + Mirror, D=20cm



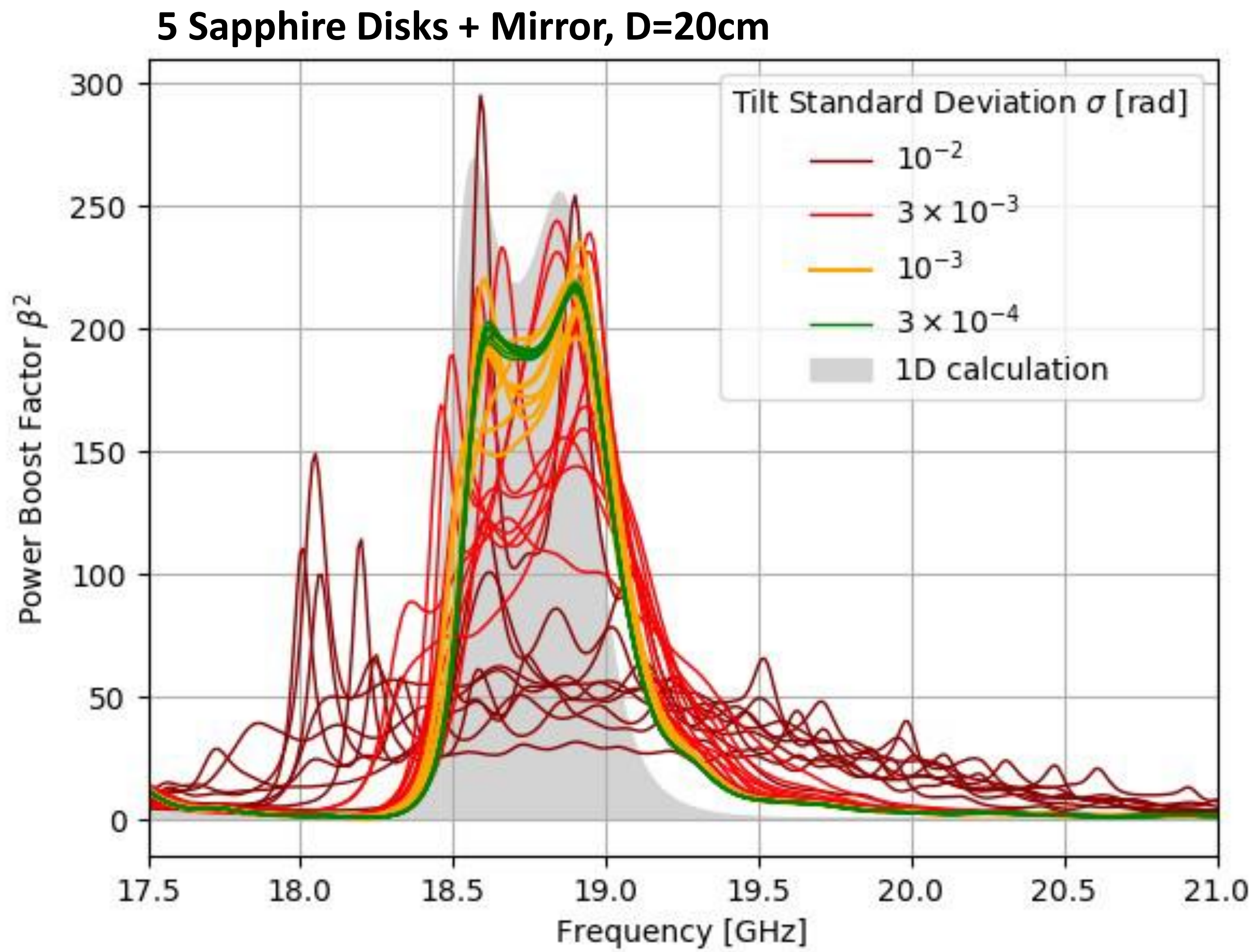
Work in progress, Stefan Knirck, Chang Lee

Simulation of antenna coupling:



Work in progress, Stefan Knirck

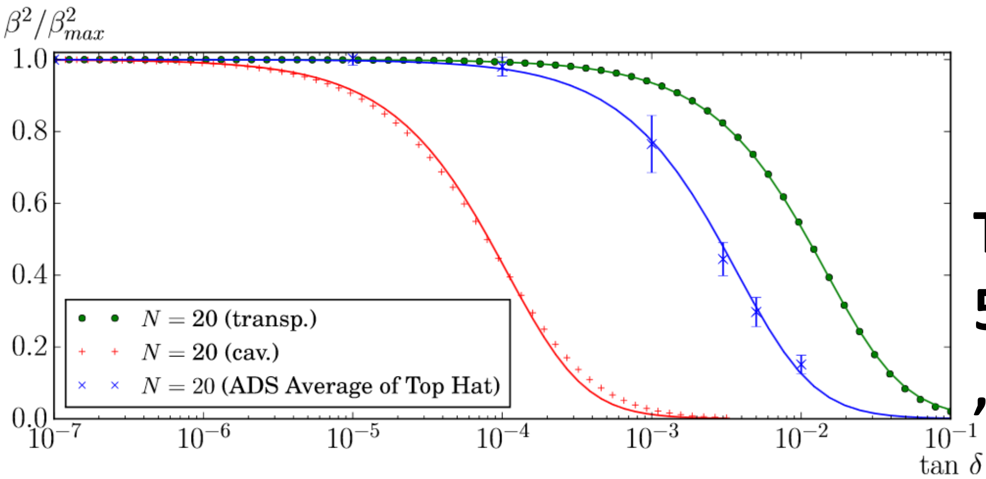
Sensitivity to disk tilts:



Work in progress, Stefan Knirck

Effect of dielectric loss:

Master thesis Alexander Partsch, 2018

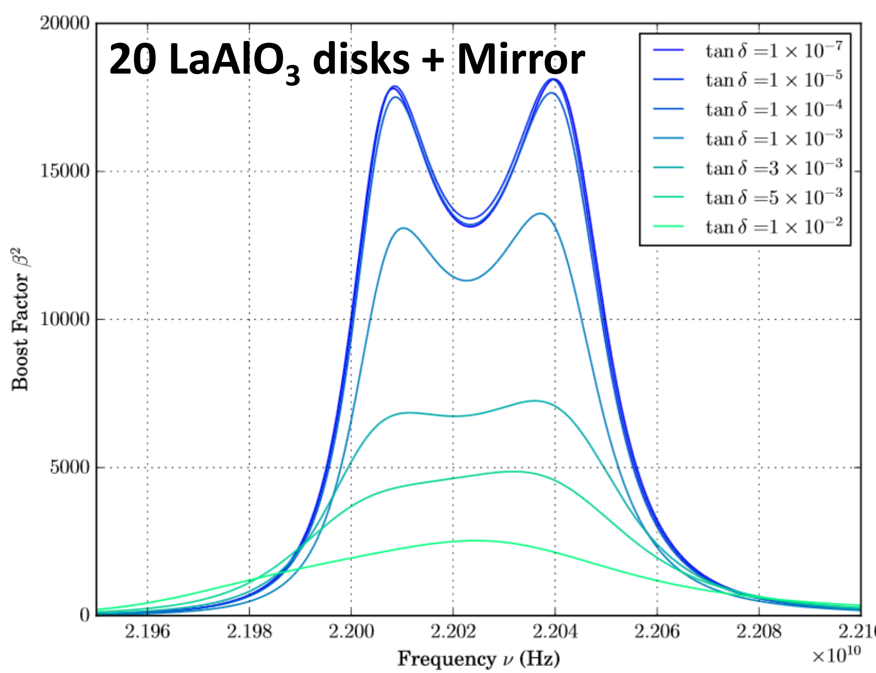


Realistic tanδ~10^{-4}

Transparent case:	**<1%loss**
50MHz booster config:	**~2% loss**
„Resonant" case:	**~50% loss**

→Dielectric loss of material not a problem for 20 disks

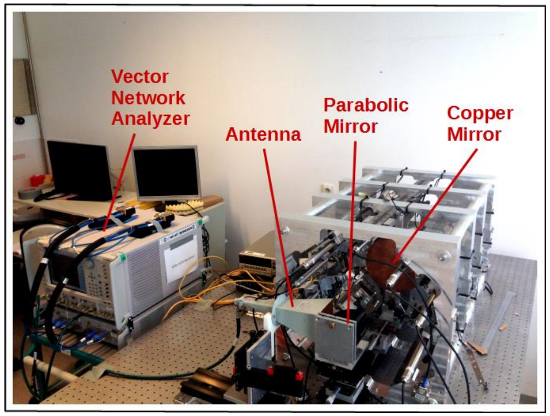
→To be confirmed for 80 disks



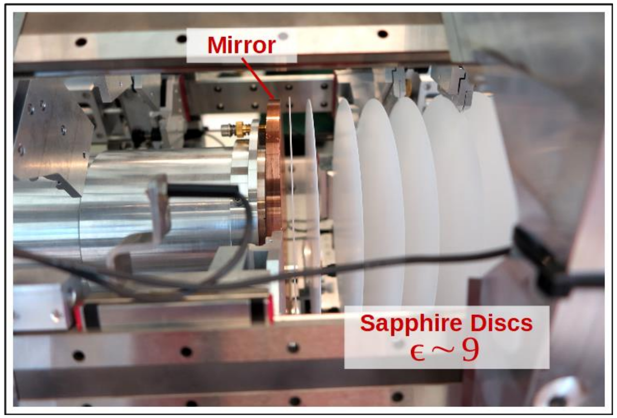
Proof of principle:

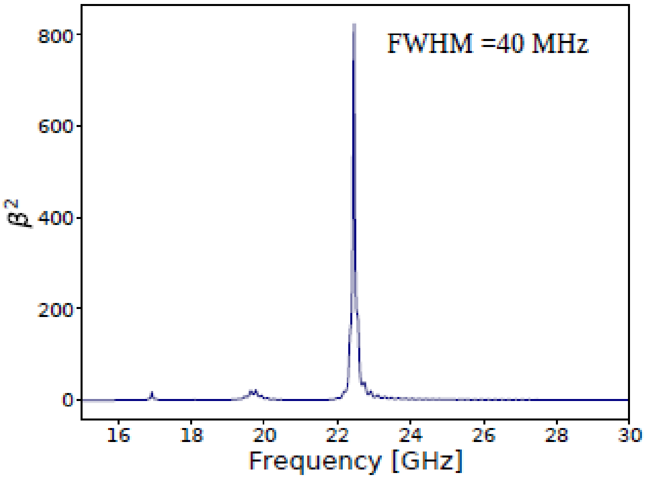
Reproducibility of boost factor

Master thesis Jacob Egge, 2018



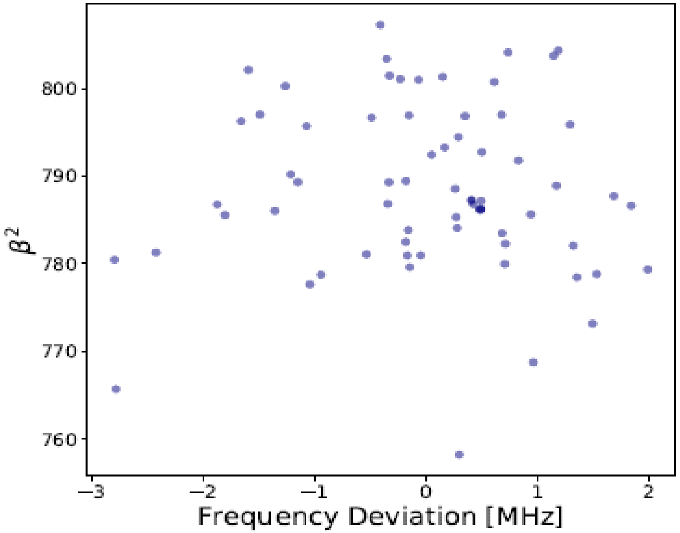
Precision of disk positioning: under control for up to 5 disks.





More disks : Reflections need supression

→ Work in progress
(Mirror – Antenna design)



MADMAX COLLABROATION

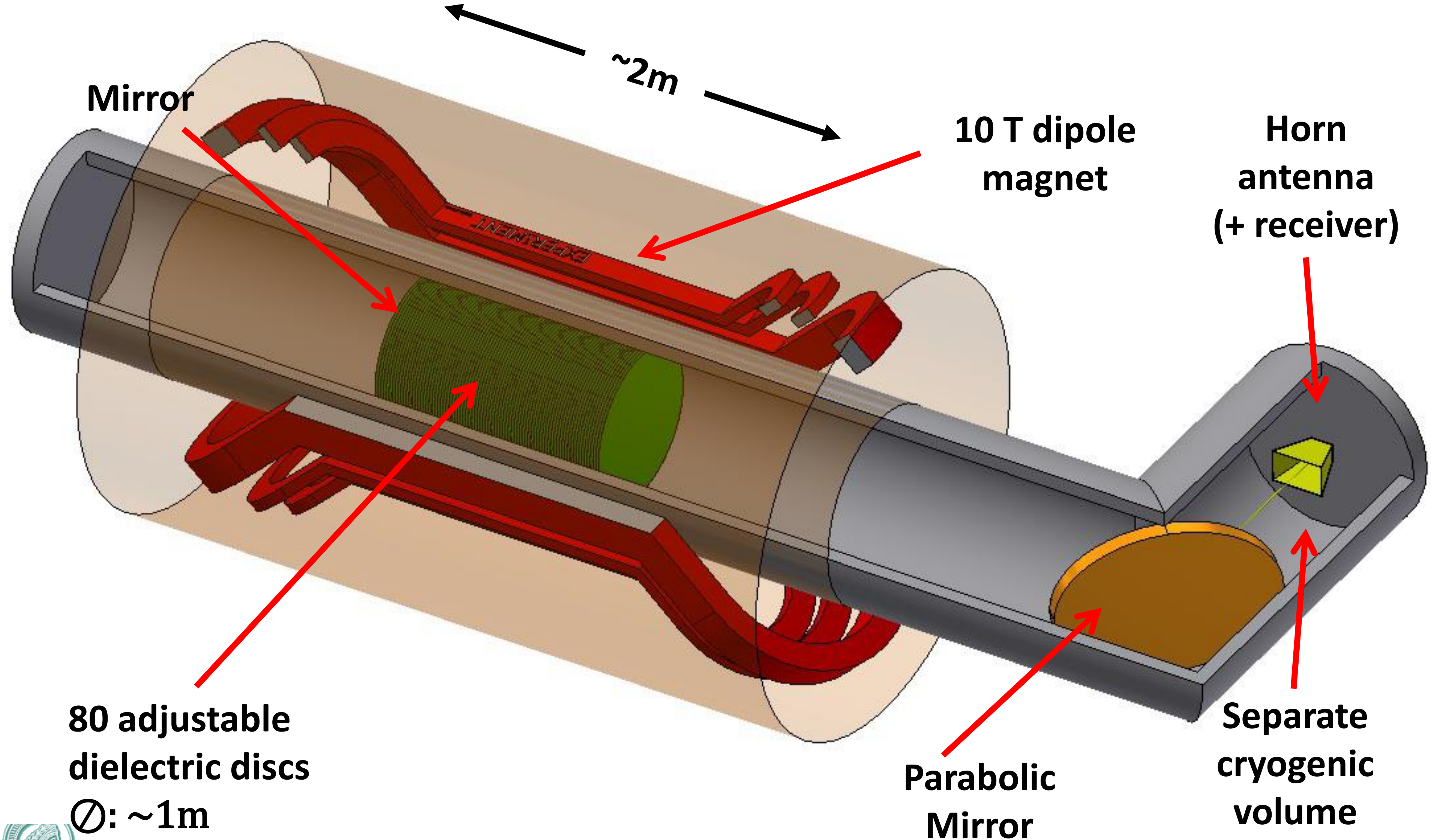
MAgnetized Disc and Mirror Axion eXperiment

RWTH Aachen
MPIfR Bonn
DESY Hamburg
Universität Hamburg
MPI für Physik München
CEA Irfu Saclay
Universität Tübingen
Universidad Zaragoza

Associate member:
CPPM, Marseille

Discussions with:
IKZ, Berlin

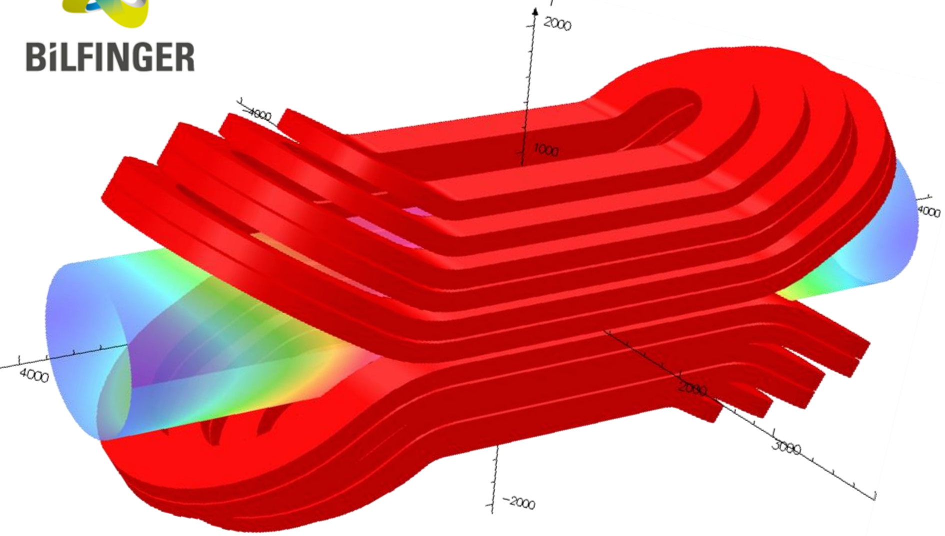
MAgnetized Disc and Mirror Axion eXperiment

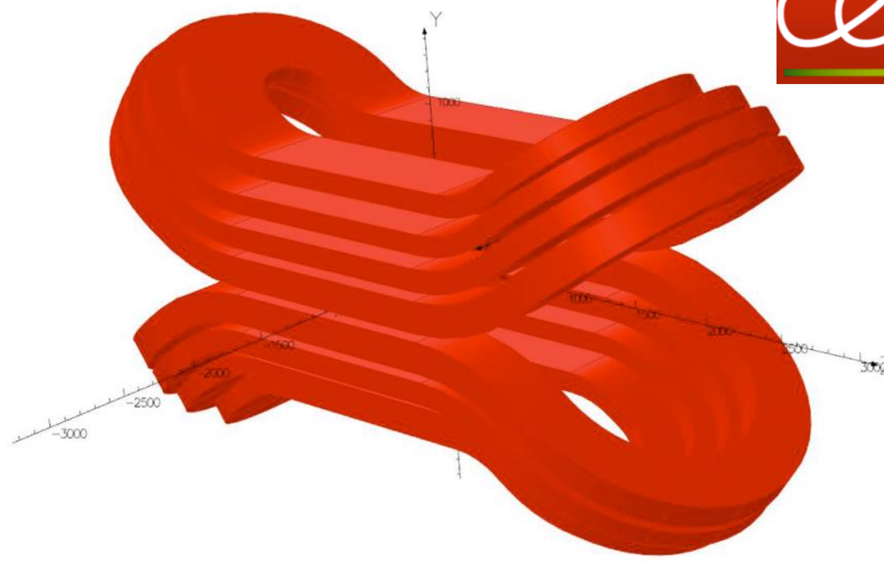


The MADMAX magnet

Design studies by innovation partners:
Both built on NbTi coils

BILFINGER



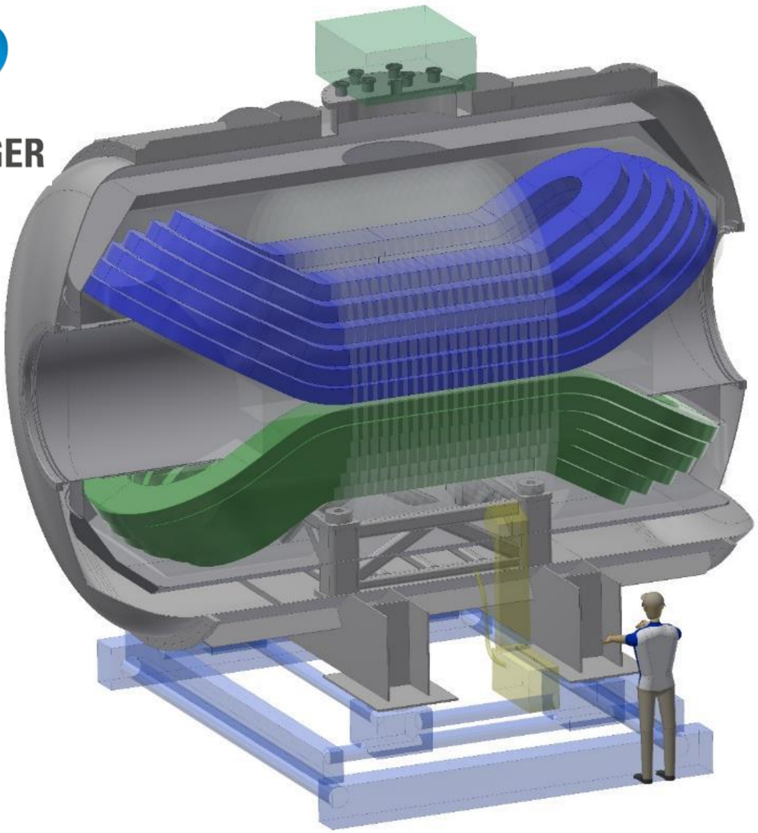


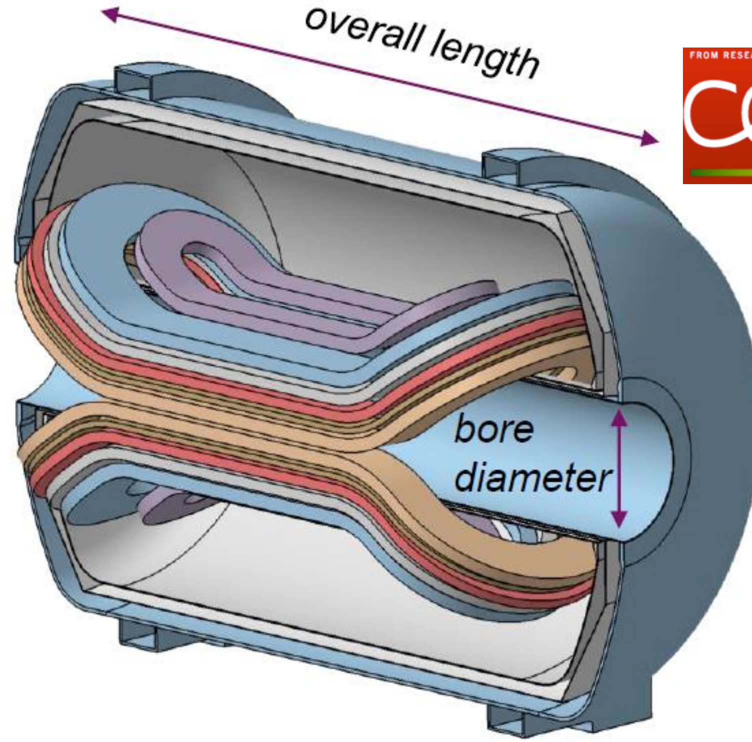
cea
FROM RESEARCH TO INDUSTRY

FoM > 100 T²m² can be reached using NbTi:
9T 1.25 m² aperture:

- **Homogeneity acceptable**
- **Forces under control**
- **Quenching behavior ok**

The MADMAX magnet





Design status evaluated by expert team:

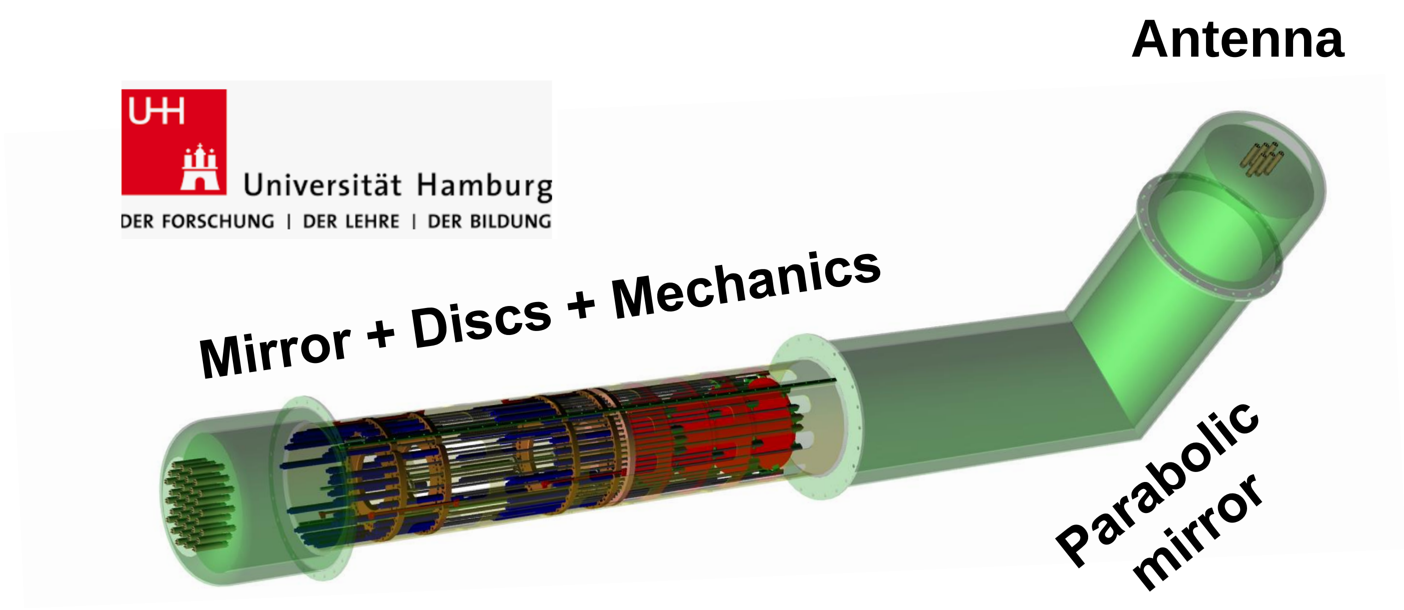
No show stoppers! We have the right „innovation partners“

The show must go on!

The MADMAX (prototype) Booster

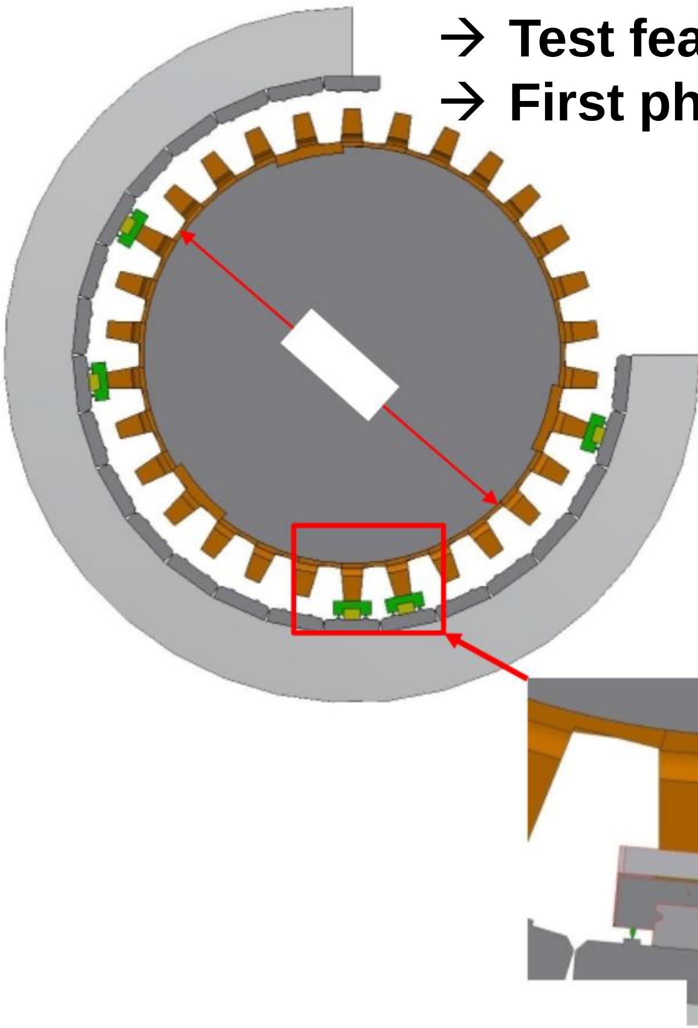
Build prototype with 20 discs, 30cm diameter
Potentially use inside prototype (few T) magnet:
→ Test feasibility of 1m² booster
→ First physics results (without magnet: hidden photons)

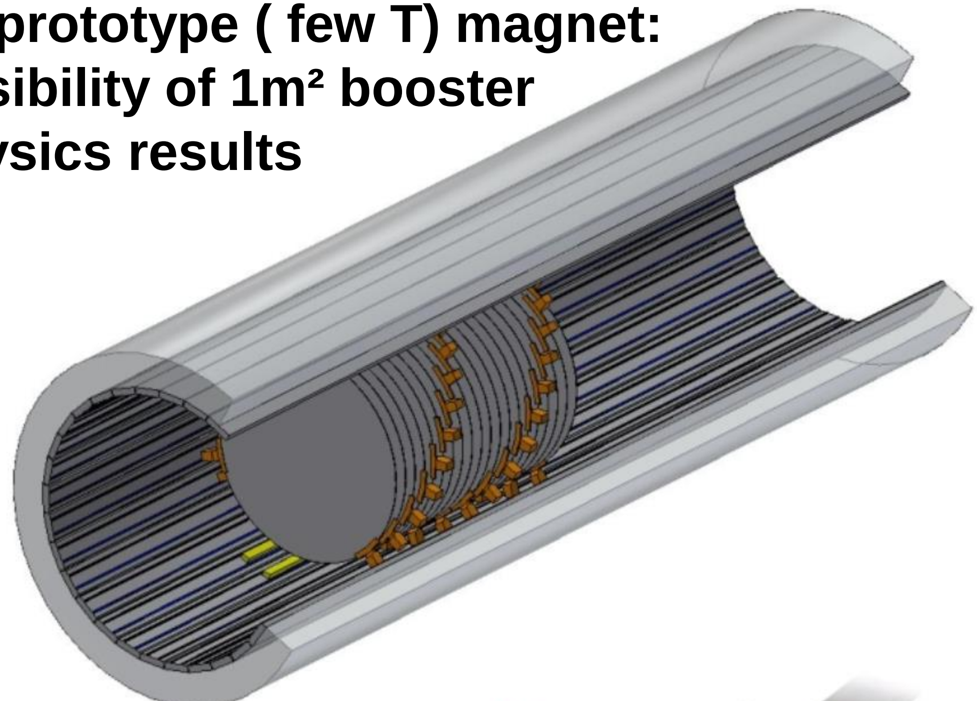
Design tasks shared between UHH and MPP



The MADMAX (prototype) Booster

Build prototype with 20 discs, 30cm diameter
Use inside prototype (few T) magnet:
- → **Test feasibility of 1m² booster**
- → **First physics results**



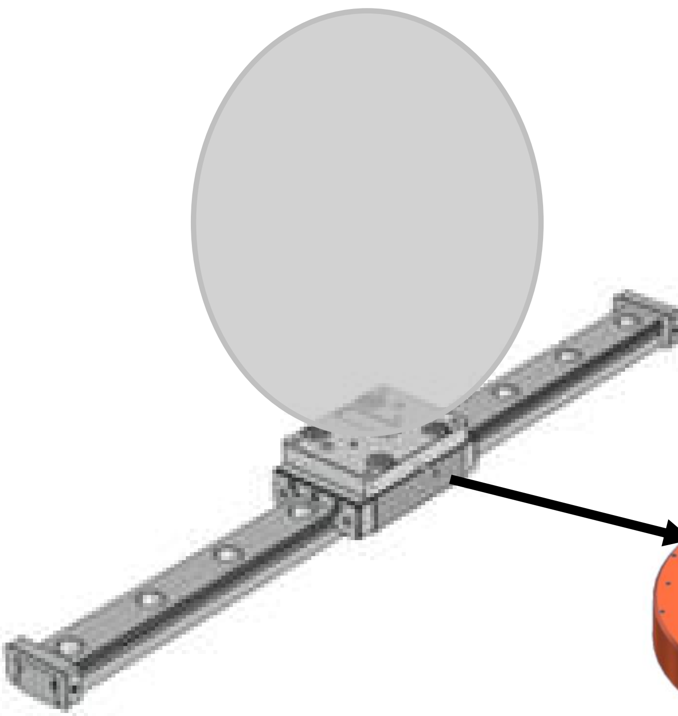


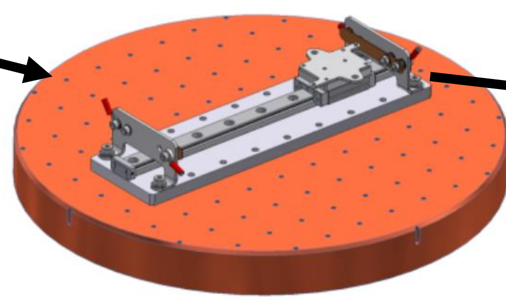
Work in progress, D. Kittlinger, A. Sedlak

The MADMAX (prototype) Booster

Development and test of Piezo motors for operation at 4 K in 10T B-field: In cooperation with company

→ **Tests at 4K coming soon**

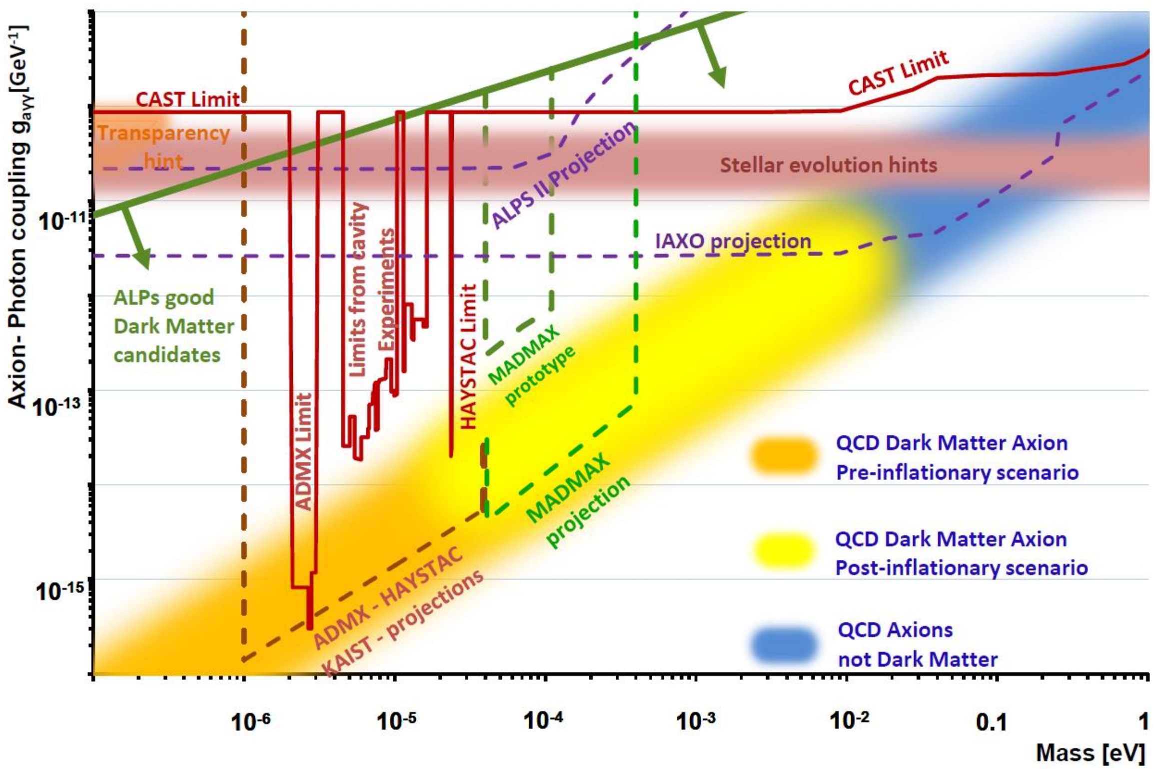




Work in progress, Chang Lee, David Kittlinger, Chris Gooch

Tentative MADMAX time scale

2019	**Magnet decision**
2021	**Demonstrator coil**
	Prototype Booster
2022	**First Physics results (Prototype magnet?)**
2025	**Final magnet availability**



Statement by the German Astroparticle Physics Community as input to the European Strategy for Particle Physics

draft version 1.2, 30.11.18

Dark Matter searches

Experiments searching for WIMPs and axion-like particles, and projects searching for light very weakly interacting particles are strongly recommended.

Experiments using natural particle sources or performed at accelerators in fixed-target or beam-dump setups are able to address fundamental questions that are complementary to collider experiments. Various Standard Model problems are addressed by Beyond the Standard Model theories predicting very weakly interacting particles (neutral leptons, dark photons/scalars, ALPs, WIMPs, but also light dark matter). The German astroparticle physics community is particularly interested in the WIMP search experiment DARWIN, in the solar axion experiment IAXO and in the dark matter axion experiment MADMAX, both at DESY.

A European Strategy Towards Finding Axions and Other WISPs

K. Desch[1], *B. Döbrich*[2], *I. Irastorza*[3], *J. Jaeckel*[4], *A. Lindner*[5], *B. Majorovits*[6], *A. Ringwald*[5],
[1]Physikalisches Institut, Uni. Bonn, Nußallee 12, D-53115 Bonn, Germany
[2]CERN, 1 Esplanade des Particules, CH-1211 Geneva 23, Switzerland
[3]Departamento de Fisica Teorica, Uni. de Zaragoza, Pedro Cerbuna 12, E-50009, Zaragoza, Spain
[4]Institut für Theoretische Physik, Uni. Heidelberg, Philosophenweg 16, D-69120 Heidelberg, Germany
[5]DESY, Notkestraße 85, D-22607 Hamburg, Germany
[6]Max-Planck-Institut für Physik, Föhringer Ring 6, D-80805 Munich, Germany

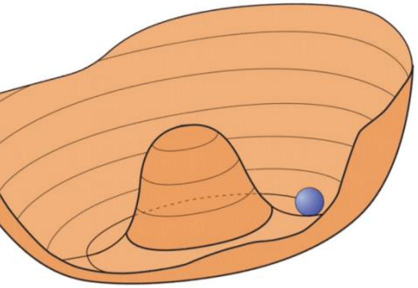
Abstract
Since the last update of the European strategy on particle physics (ESPP) the interest in hypothetical very weakly interacting slim particles, dubbed WISPs, has gained significant momentum. Searches for WISPs with masses below about 1 eV require new approaches beyond accelerator experiments. This document summarizes the physics case, the experimental status and its prospects for the coming 10-20 years. Its focus is on larger scale experiments with European leadership requiring a more strategic approach for their potential realization. This document will be submitted in December 2018 as an input to the update process of the European Strategy on Particle Physics (ESPP).

Sign up to support axion research in Europe:

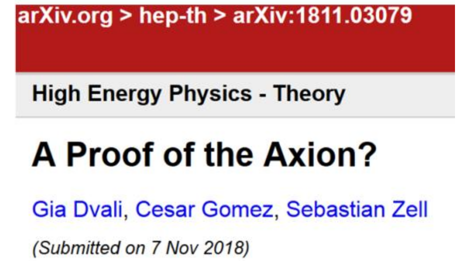
https://indico.desy.de/indico/event/22018/

Your support would be very welcome!

MADMAX Conclusions



- Axions solve strong CP problem



A Proof of the Axion?

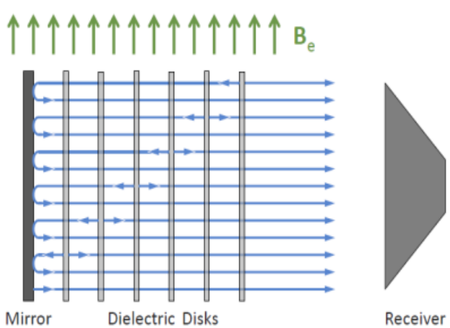
arXiv.org > hep-th > arXiv:1811.03079

High Energy Physics - Theory

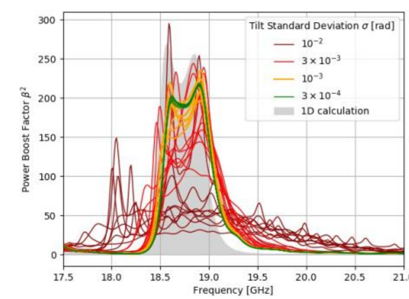
Gia Dvali, Cesar Gomez, Sebastian Zell

(Submitted on 7 Nov 2018)

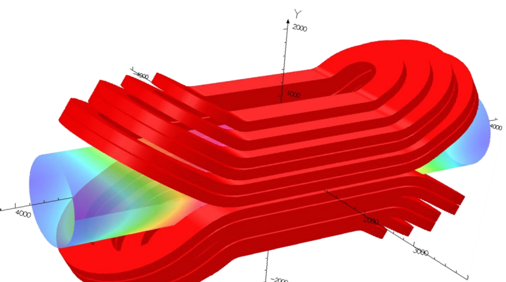
- Axions are very good DM candidate



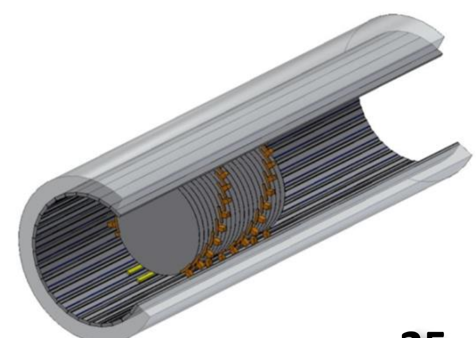
- Dielectric haloscope could be route to their discovery



- Simulations give confidence in concept



- Magnet is big but feasible



- Booster R&D ongoing