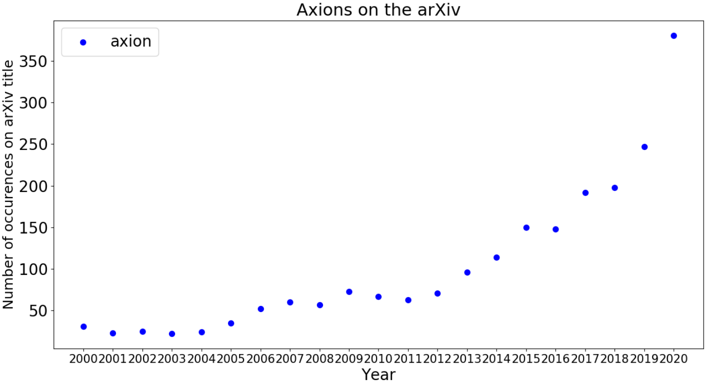
CERN

(Opportunistic) direct search for axion Dark Matter with the Relic Axion Detector Eexploratory Setup

Babette Döbrich

European Research Council
Established by the European Commission

Community interest explodes in something called 'the axion'



The Axion was not invented to be the Dark Matter!

More details already given in talks e.g. by J. Jäckel (Tuesday) and B.M. Schäfer (Monday)

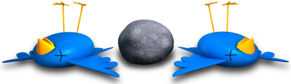
CP Conservation in the Presence of Pseudoparticles*

R. D. Peccei and Helen R. Quinn†
Institute of Theoretical Physics, Department of Physics, Stanford University, Stanford, California 94305
(Received 31 March 1977)

We give an explanation of the CP conservation of strong interactions which includes the effects of pseudoparticles. We find it is a natural result for any theory where at least one flavor of fermion acquires its mass through a Yukawa coupling to a scalar field which has nonvanishing vacuum expectation value.

It is experimentally obvious that we live in a

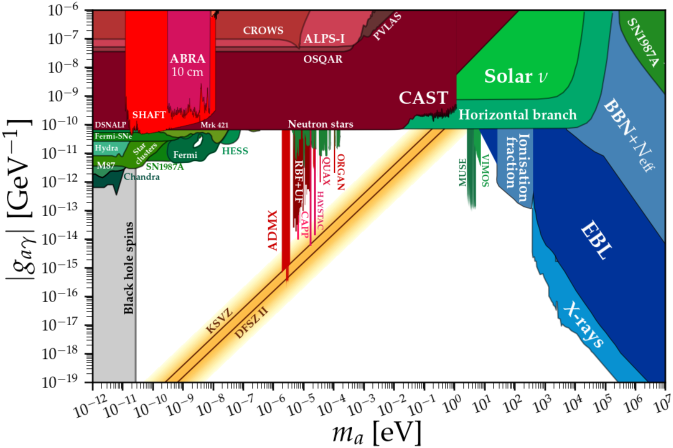
grangian.
If all fermions which couple to the non-Abelian



but Axions (or more generally axion-like particles (ALPs)) which must be extremely weakly interacting can be the Dark Matter or a portal to it!

Present and future hide-outs of (low-mass) axions

limit compilation (and disclaimer) by C O'Hare `https://github.com/cajohare/AxionLimits`



QCD axion lives on yellow line

an ALP almost anywhere.

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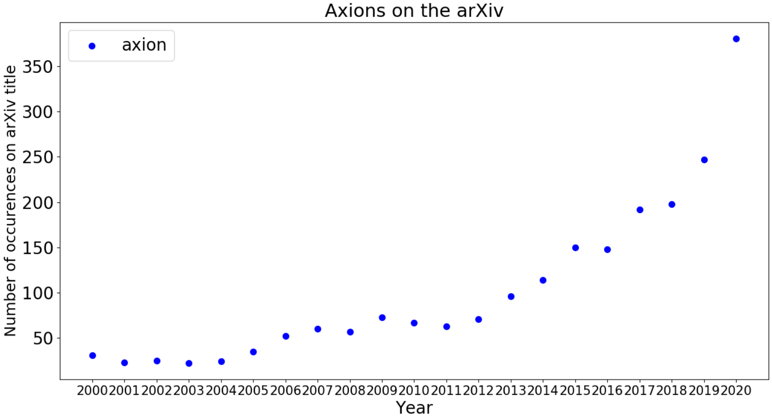

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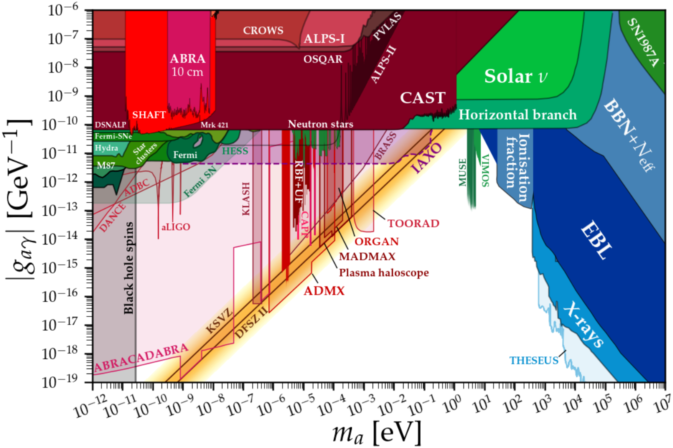

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Projections!!! with

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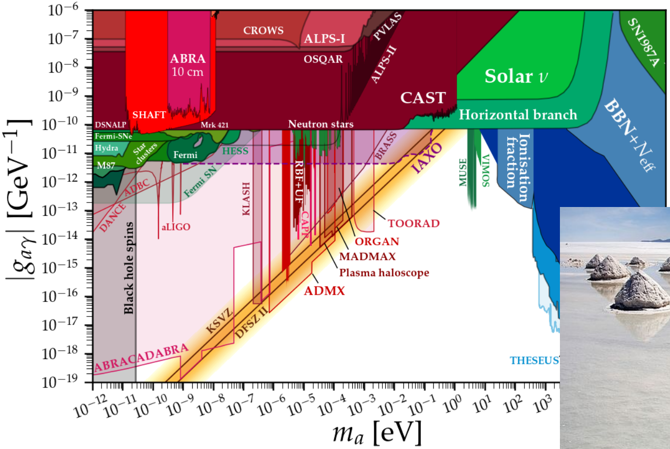

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an ALP almost anywhere.

Projections!!! with

more than a grain of salt

Luca Galuzzi via Wikimedia Commons

Main search types

1. **Produce** an axion, then detect it: light shining through walls also beam dump, LHC (at higher masses)
2. look for axions from a **natural source**, most prominently solar axion searches: CAST, (baby-)IAXO
3. **assume that axions are THE Dark matter** (normally assume they are all of Dark Matter), infer their presence

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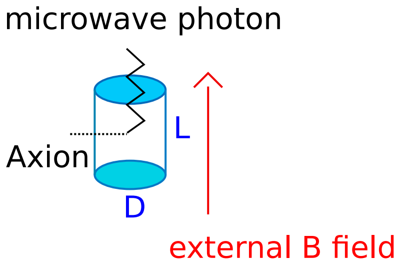
... I exploit my talk

to elaborate more on point 3 and what we do about that at CERN

A poor (wo-)man's axion haloscope



- figure of merit: $F \sim g^4 m^2 B^4 V^2 T_{\text{sys}}^{-2} \mathcal{G}^4 Q$
- typically high-field solenoids, several Tesla
- typically few-/sub- Kelvin
- scanning: tune in steps $\sim$ size of axion width
- resonance quality Q worth to push up to $\sim 10^6$
- design requirement $\mathcal{G}$: cavity modes: right direction/ well spaced/ correctly coupled

The pioneers & ‘old hands’ - ADMX

Bartram et al: Axion Dark Matter eXperiment: Run 1B Analysis

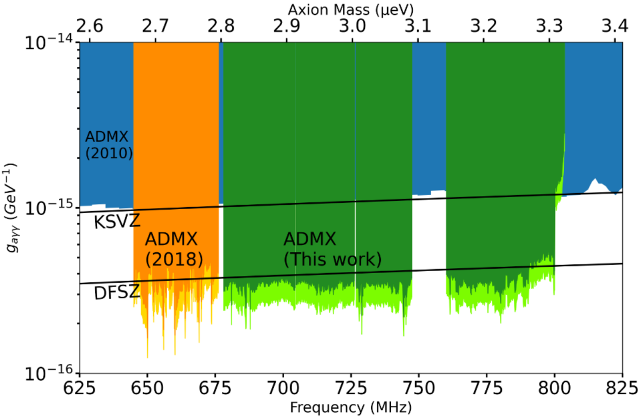
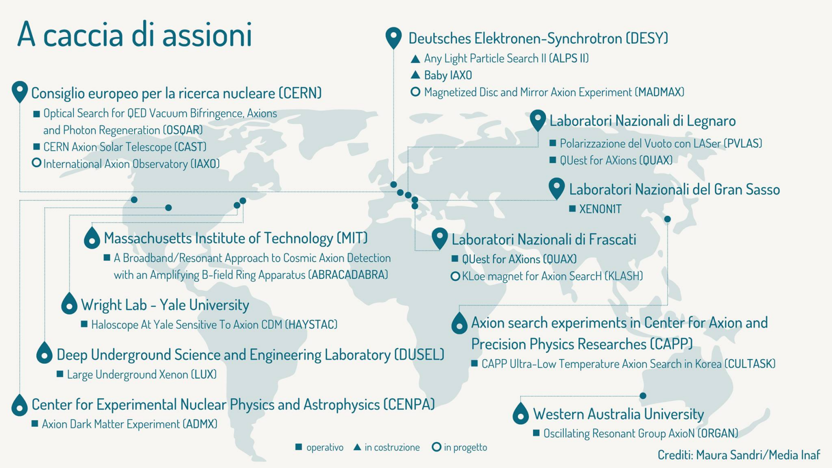
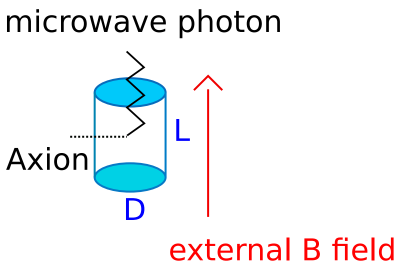


FIG. 17. Exclusion plot for Run 1B, shown in green. Dark green represents the region excluded using a standard Maxwell-Boltzmann filter, whereas light green represents the region excluded by an N-body filter [42].

That's not all... (incomplete, but nicely prepared)

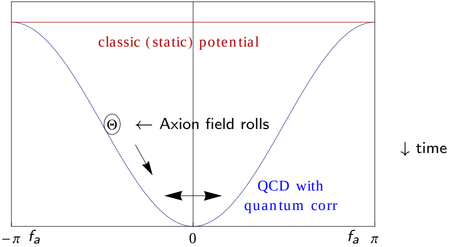


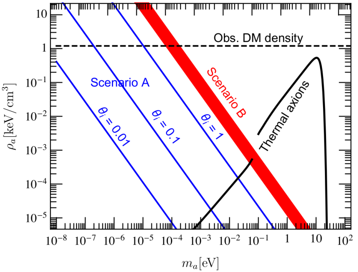
Interlude: Why large masses are harder to test



- figure of merit: $F \sim g^4 m^2 B^4 V^2 T_{\rm sys}^{-2} \mathcal{G}^4 Q$
- naively: large $m \to$ higher resonance $f \to$ lower dimension
- $Q \sim \frac{V}{\delta S}$ Volume to surface ratio: gets bad at low Volumes

Interlude: Why large masses are interesting to test

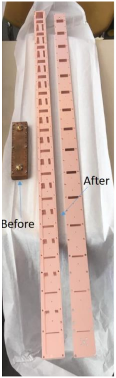


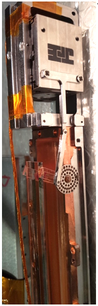


- axion mass depends on initial misalignment angle & inversely proportional to symmetry breaking scale
- large axion masses test the 'post-inflationary' axion, in which the axion mass can be more "easily" predicted

  (average of possible initial conditions, whereas otherwise one unknown initial condition stretched by inflation)
- scenario B: *m* prediction somewhat possible

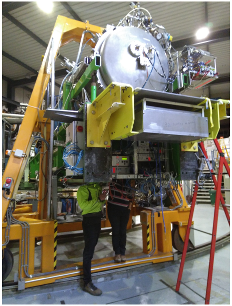
The opportunists - RADES & CAPP-CAST





2018-2021 ⟶

in CAST LHC dipole



⟵ true dedication:
hands-on and heads-in
(80% of us: this is 'hobby'!)

cavity R&D to search DM axions in **dipole magnets**

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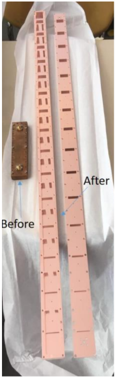
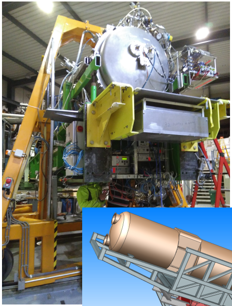


2018-2021 → in CAST LHC dipole

RADES: long term → babyIAXO (lower frequ)



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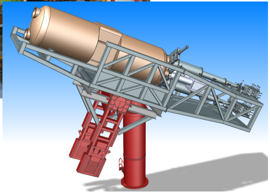
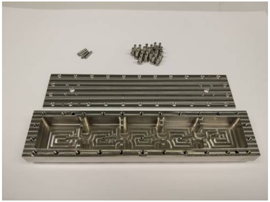


cavity R&D to search DM axions in **dipole magnets**

see e.g. Alvarez-Melcon et al, JHEP 07 (2020) 084

Basic idea of RADES: E pluribus unum JCAP 05 (2018) 040



- retain large volume at high resonance frequencies using a division into subcavities
- sub-cavity scale sets resonance scale

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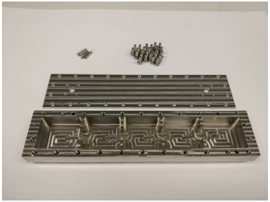

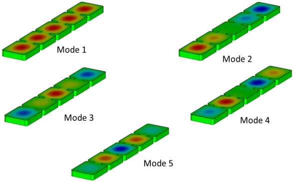

↑

ext. B-field

- retain large volume at high resonance frequencies using a division into subcavities
- sub-cavity scale sets resonance scale
- N of subcavities = N of modes: not all cavity modes couple to the axion, but we can find one, here 'mode 1'!

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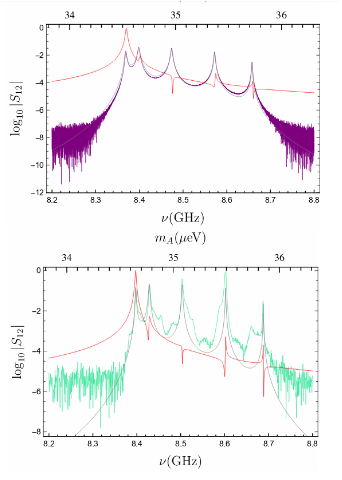
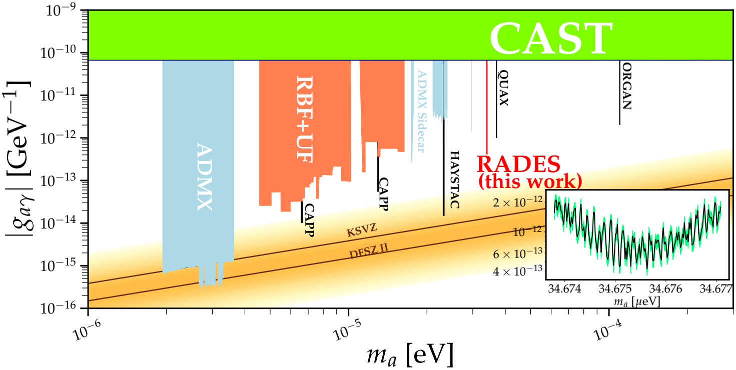


- retain large volume at high resonance frequencies using a division into subcavities
- sub-cavity scale sets resonance scale
- N of subcavities $=$ N of modes: not all cavity modes couple to the axion, but we can find one, here 'mode 1'!
- (mode mixing at big N & tuning solved)

modest but brand-new: RADES **preliminary** **not through CAST procedure**

CAST collaboration, forthcoming (main analyst: S. Arguedas Cuendis from Costa Rica)

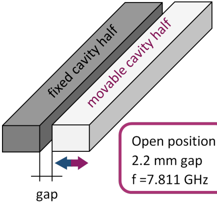
$\rightarrow$ one of the strongest results to date above 25μeV



RADES tuning

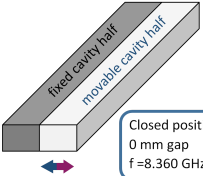
courtesy of Jessica Golm (CERN & University of Jena)

Mechanical tuning by changing the distance of cavity halves

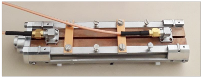


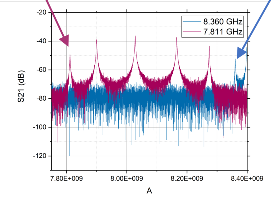
Open position
2.2 mm gap
f =7.811 GHz

Tuning range:
550 MHz



Closed position
0 mm gap
f =8.360 GHz





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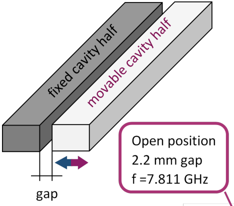
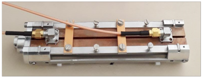
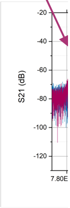
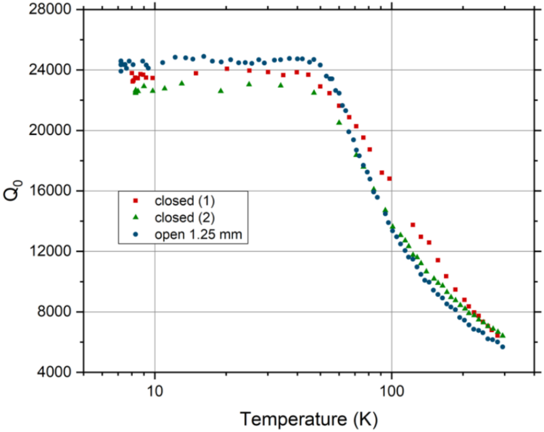
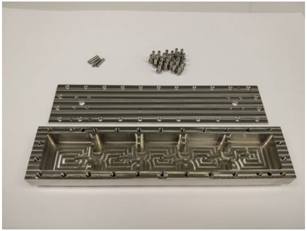








Solving the mode-mixing issue Alvarez-Melcon et al, JHEP 07 (2020) 084



- reminder: sub-cavities coupled by irises, parameterized by k_i

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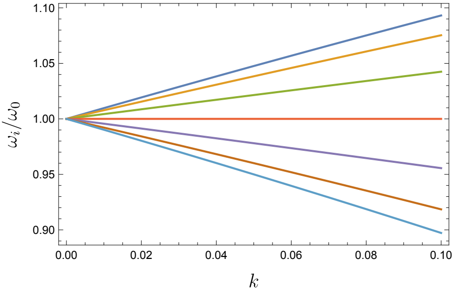
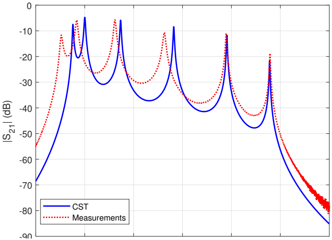
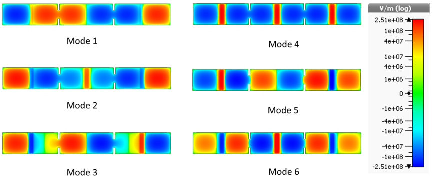
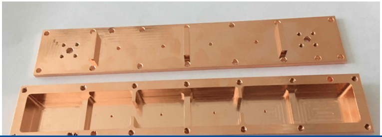


- reminder: sub-cavities coupled by irises, parameterized by k_i
- observation: central modes more seperated from their neighbours, especially at high N $\Rightarrow$ should couple that one to axions







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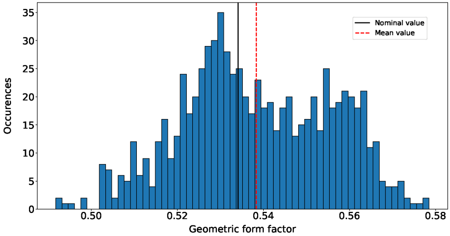
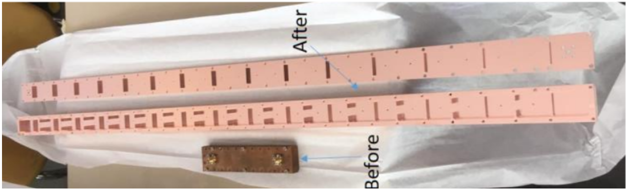
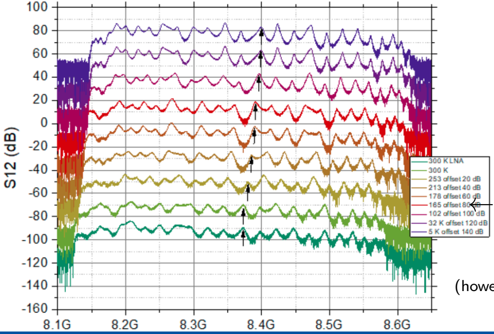


varying randomly all geometrical in the range of $\pm 30\,\mu$m.

- reminder: sub-cavities coupled by irises, parameterized by k_i
- observation: central modes more seperated from their neighbours, especially at high N $\Rightarrow$ should couple that one to axions
- solution: alternate between inductive and capacitive irises
- Better resistance to fabrication errors

30-cavities structure (1m) took data in 2020!





← peak structure during cool-down alternating is indeed scalable!

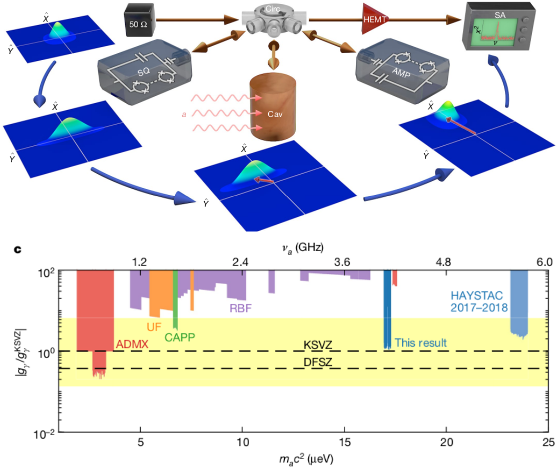
(however issue with Q factor due to manner of fabrication)

Conclusions

- the axion warrants to build some **strategic** (Dark Matter) experiments that cover large chunks of parameter space (like MADMAX, babyIAXO, DMRadio ....)
- there is also space for **opportunistic** searches that might just be 'lucky' to 'hit' the right axion mass (or target it in case of prediction). RADES is an example for that, long-term plans of these studies aimed at exploiting the babyIAXO magnet (that is then strategic)
- remain optimistic that within (few) decades, a final word on axions is spoken
- happy to take questions now or later: babette@cern.ch
- **thanks to the RADES/CAST teams + CERN technical support + ERC 802836 AxScale**

RADES team 2019

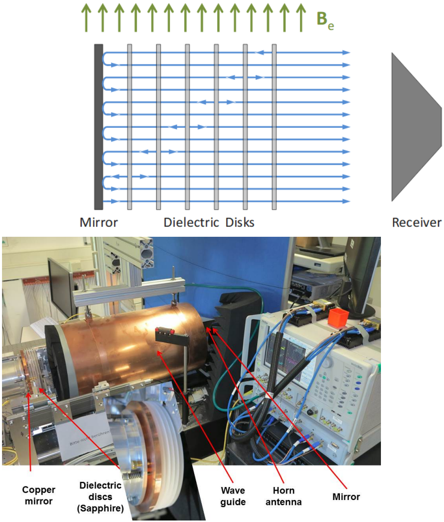
Notable progress at large m: going 'beyond' quantum uncertainty



Bakes et al. Nature volume 590, pages 238–242(2021)

Backup: biggest european contender at large mass - MADMAX

- constructively combine axion emission at dielectric surface by choice of plate separation → allows to probe 'large' axion DM mass
- amongst challenges: 9T dipole with 1.35m bore



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