Dark matter Axion Wide-band Approach

Laurent Chevalier
CEA-IRFU/DPHP

DAWA

H.Deschamps
M.Gautier
N.Jonqueres
JM.Reymond

} **DEDIP** *Electronics, Detectors and Computing Division*

P.Brun ← ERC
E.Savalle
R.Signoret

} **DPHP** *Particle Physics Division*

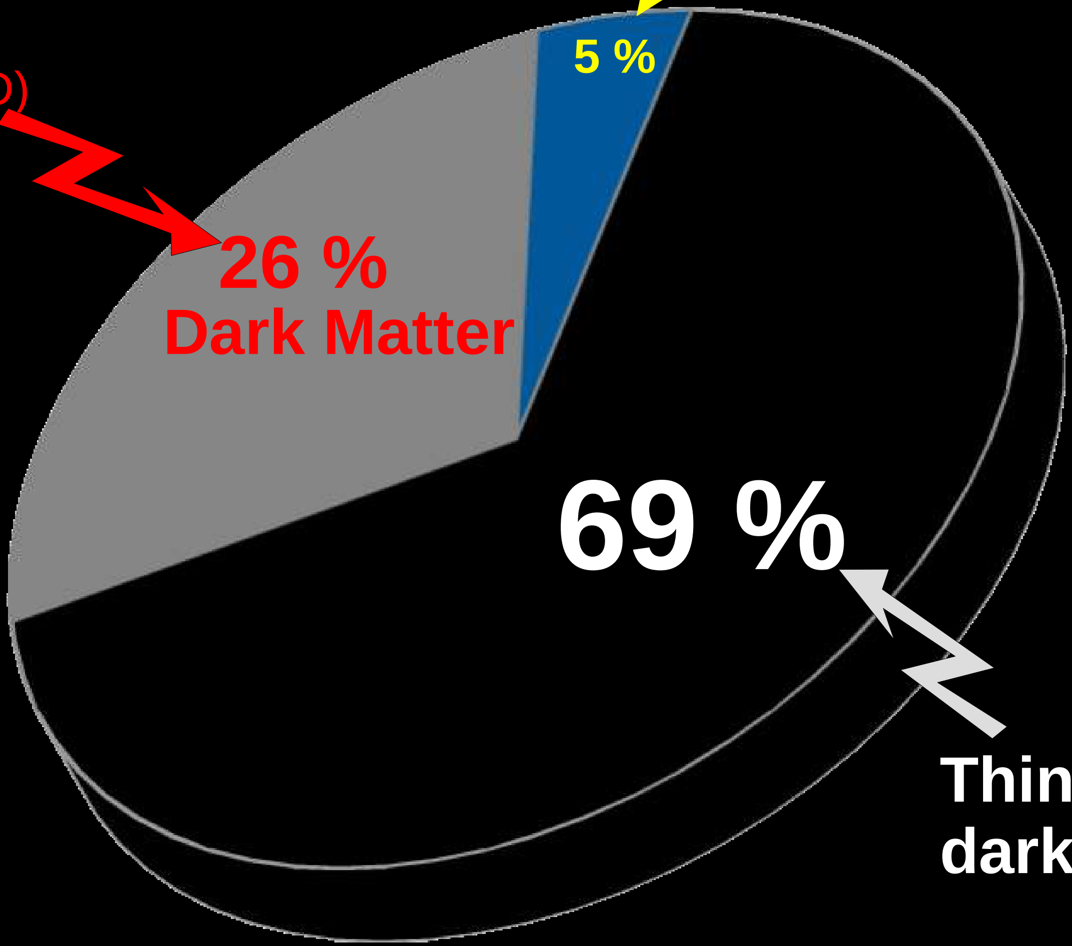
T.Benoit
C.Berriaud
T.Donga
C.Genot
R.Godon
P.Hamel
T.Pontarollo

} **DACM** *Accelerators, Cryogenics and Magnetism Division*

DM candidates

- Wimps
- Axions
  - Axions (QCD)
  - ALP's
- ...

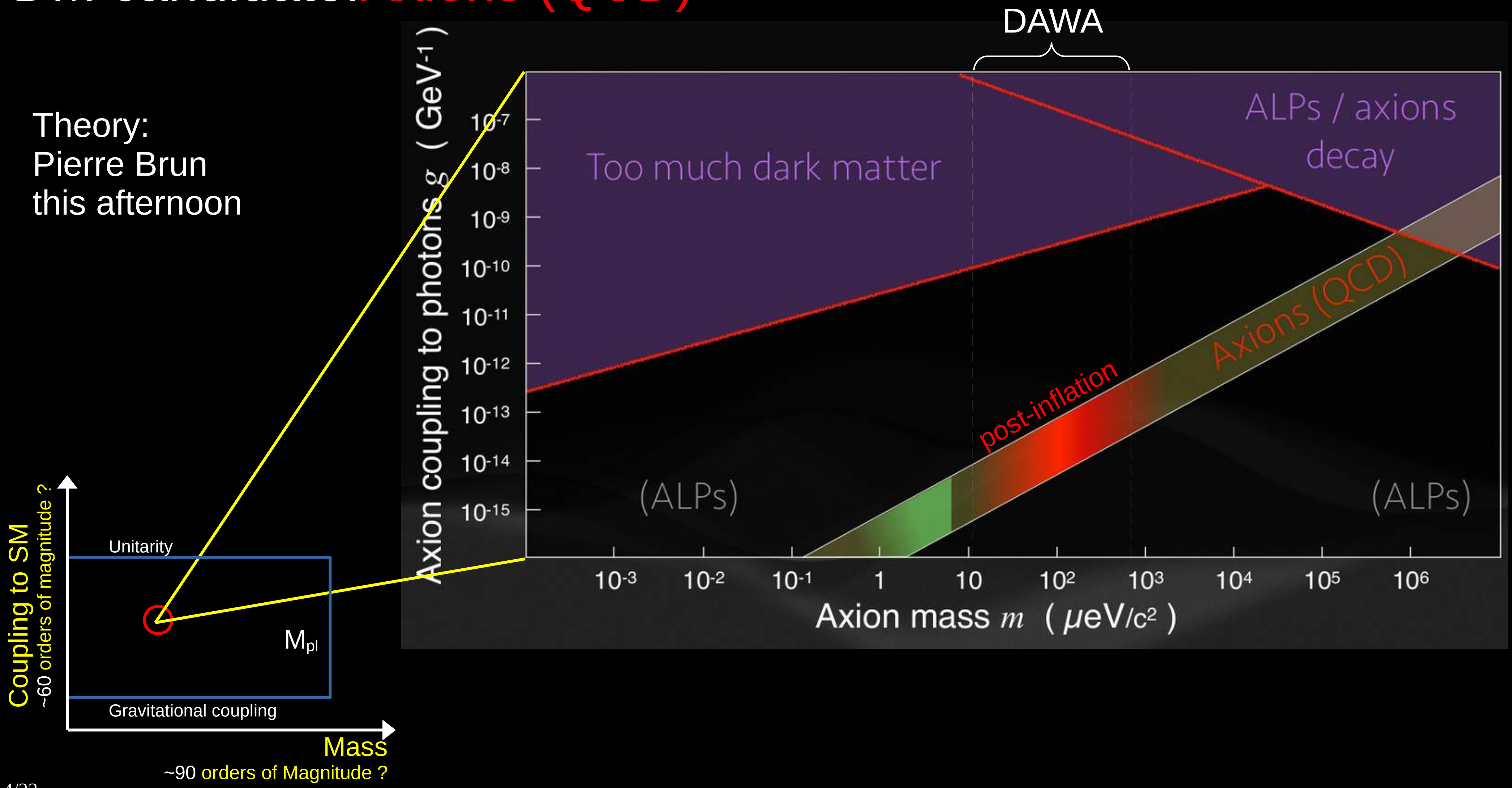
You, me, stars...



Thing is unclear dark, too dark

DM candidate: Axions (QCD)

Theory:
Pierre Brun
this afternoon



DM candidate: Axions (QCD)

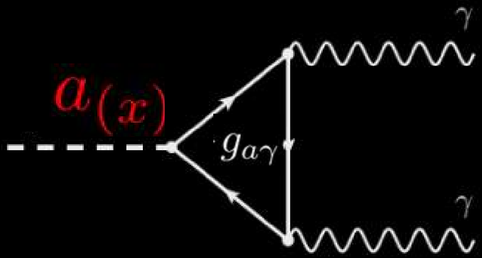
$$\mathcal{L}_{QCD\ vacuum} = \theta_{total} \frac{\alpha_s}{8\pi} G^{(b)}_{\mu\nu} \tilde{G}^{\mu\nu(b)}$$

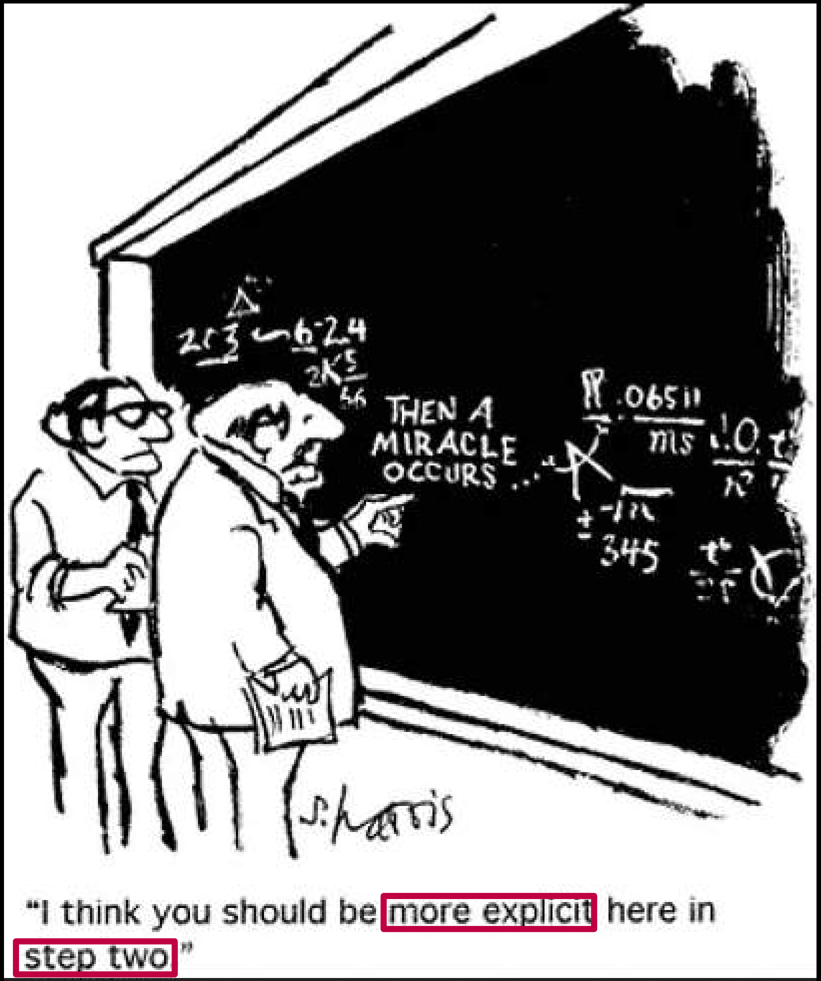
Step 1

$$\mathcal{L}_{axion} = \frac{a(x)}{f_a} \frac{\alpha_s}{8\pi} G^{(b)}_{\mu\nu} \tilde{G}^{\mu\nu(b)}$$

Step 2

$$\mathcal{L}_{a\gamma} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} - \frac{1}{4} g_{a\gamma} \phi F_{\mu\nu} \tilde{F}^{\mu\nu}$$





DM candidate: Axions (QCD)

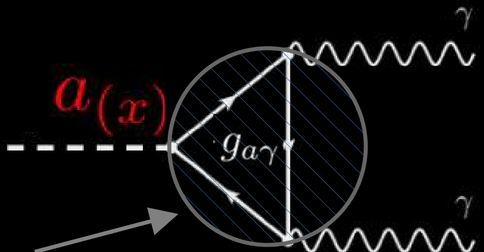
$$\mathcal{L}_{QCD\ vacuum} = \theta_{total} \frac{\alpha_s}{8\pi} G^{(b)}_{\mu\nu} \tilde{G}^{\mu\nu(b)}$$

Step 1

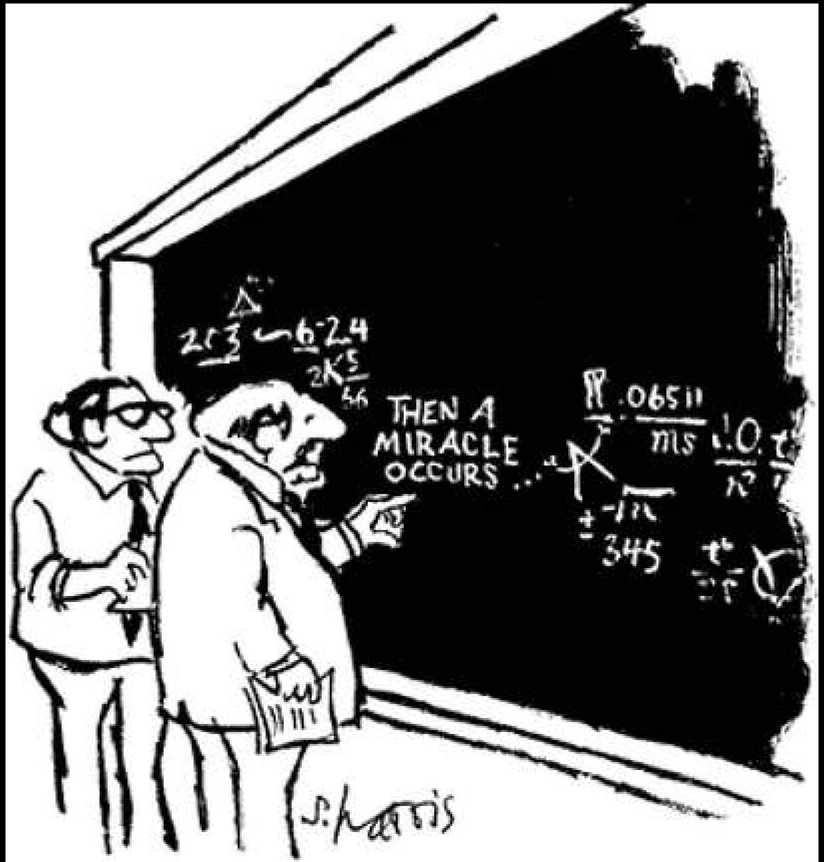
$$\mathcal{L}_{axion} = \frac{a(x)}{f_a} \frac{\alpha_s}{8\pi} G^{(b)}_{\mu\nu} \tilde{G}^{\mu\nu(b)}$$

Step 2

$$\mathcal{L}_{a\gamma} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} - \frac{1}{4} g_{a\gamma} \phi F_{\mu\nu} \tilde{F}^{\mu\nu}$$



$g_{a\gamma}$ effective coupling



"I think you should be more explicit here in step two"

DM candidate: Axions (QCD)

Effective Lagrangian

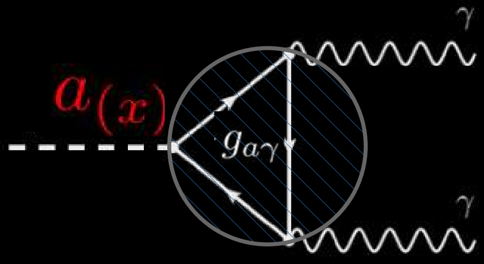
step 2

$$\mathcal{L}_{a\gamma} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}g_{a\gamma}\,\phi F_{\mu\nu}\tilde{F}^{\mu\nu} = -\frac{1}{2}\left(\vec{E}^2 - \vec{B}^2\right) - g_{a\gamma}\,\phi\vec{E}\cdot\vec{B}$$

Modified Maxwell's equations

$$\vec{\nabla}\cdot\vec{B} = 0 \qquad \vec{\nabla}\cdot\vec{E} = \rho - g_{a\gamma}\vec{\nabla}\phi\cdot\vec{B}$$

$$\partial_t\vec{B} + \vec{\nabla}\wedge\vec{E} = \vec{0} \qquad \vec{\nabla}\wedge\vec{B} = \vec{j} + g_{a\gamma}\dot{\phi}\vec{B} + g_{a\gamma}\vec{\nabla}\phi\wedge\vec{E}$$

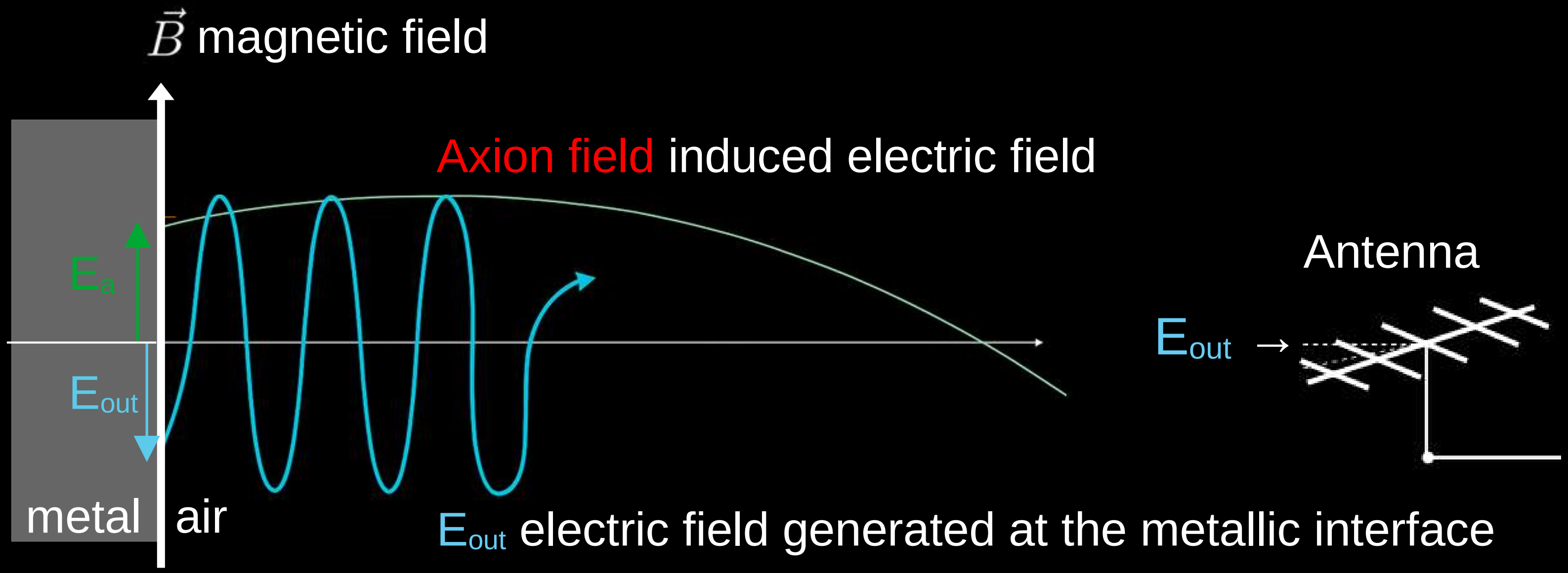


$\vec{E}$ electric field induced at the metal interface

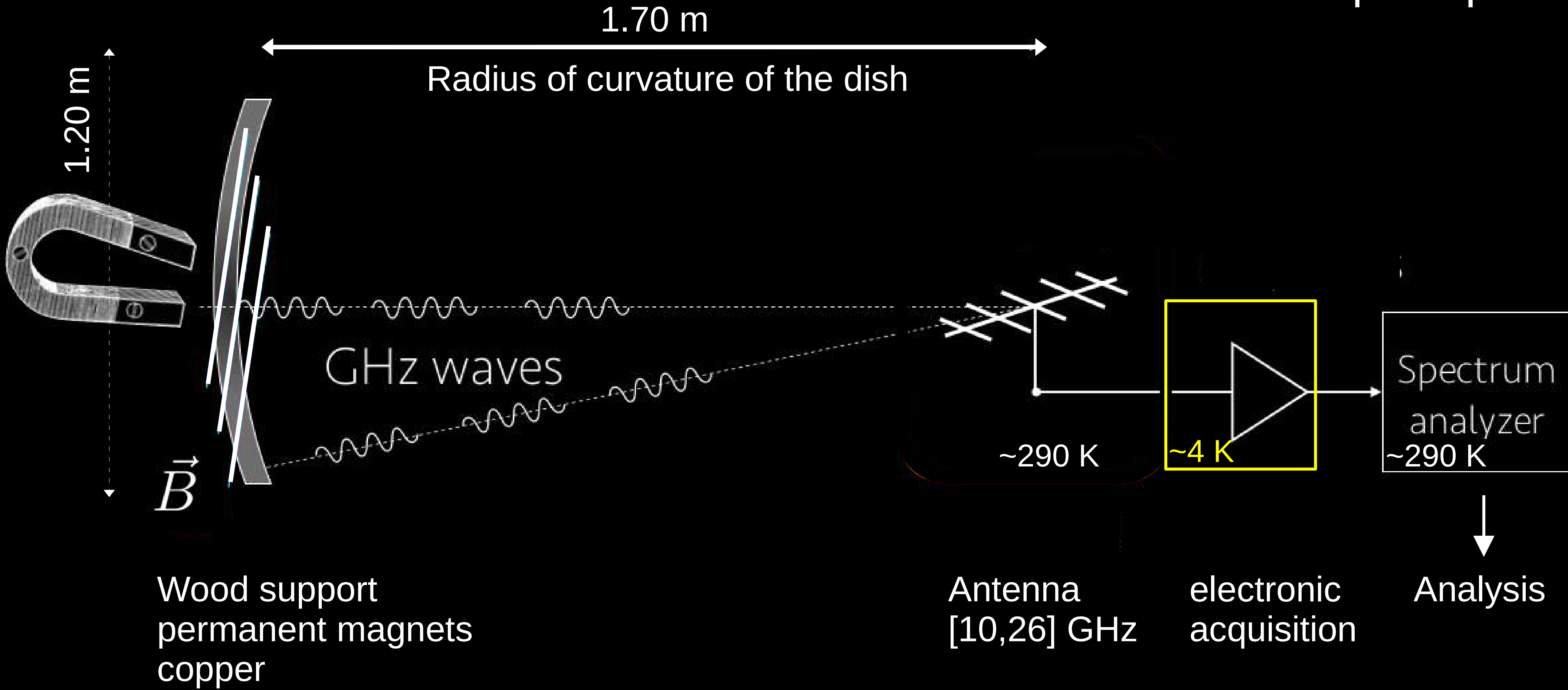
$\vec{B}$ magnetic field coupling

Detection principle

Maxwell's equations → $E_{\parallel}^{(metal)} - E_{\parallel}^{(air)} = 0$



Detection principle



Detection hypothesis

Power generated at the metallic interface:

$$P_{DM}[W] = 5.5 \times 10^{-26} \left(\frac{\rho_{DM}}{0.3\ \mathrm{GeV/cm^3}}\right) \left(\frac{m_a}{100\mu eV}\right)^{-2} \left(\frac{g_{a\gamma}}{10^{-12}\mathrm{GeV}}\right)^2 \left(\frac{B}{1\mathrm{T}}\right)^2 \left(\frac{S}{1\ \mathrm{m}^2}\right)$$

→ 0.25 T^2m^2

Sensitivity estimation of our experiment:

$$P_{\mathrm{det}} = k_B T_{\mathrm{sys}} \sqrt{\frac{\Delta\nu}{\tau}}$$

→ $< 10^{-21}$ W

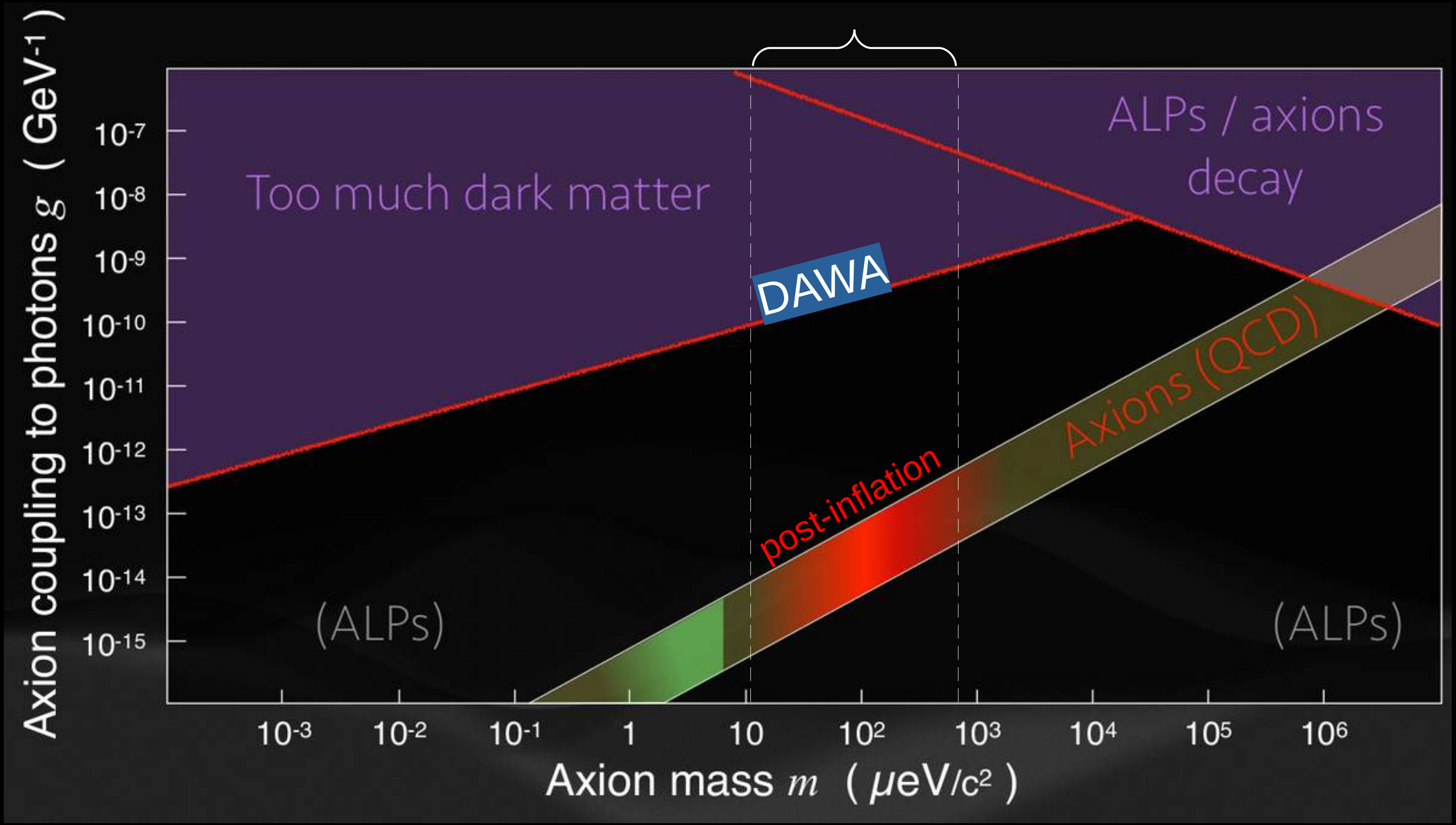
With

$$T_{sys} = (T_{ampli} + T_{cryo} + T_{other}) * \epsilon$$

→ < 100 K

Detection

expected range



Detector magnets support

Mallet

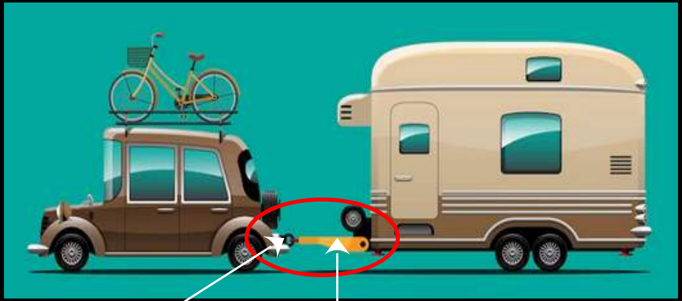
Plywood support

Iron frame to ensure the spherical shape of the permanent magnet support

Detector

magnets support

How to get a spherical support ?



tow ball

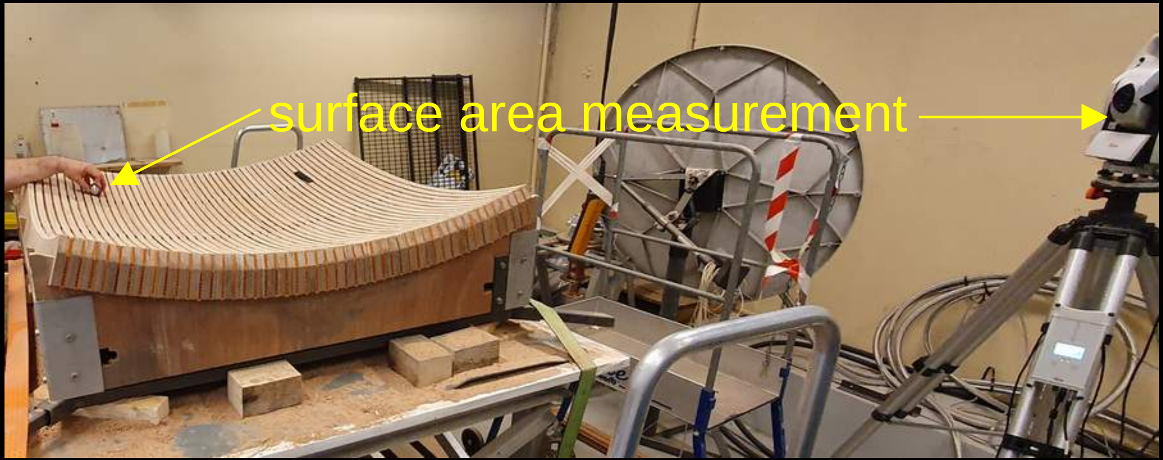
trailer hitch

tow ball

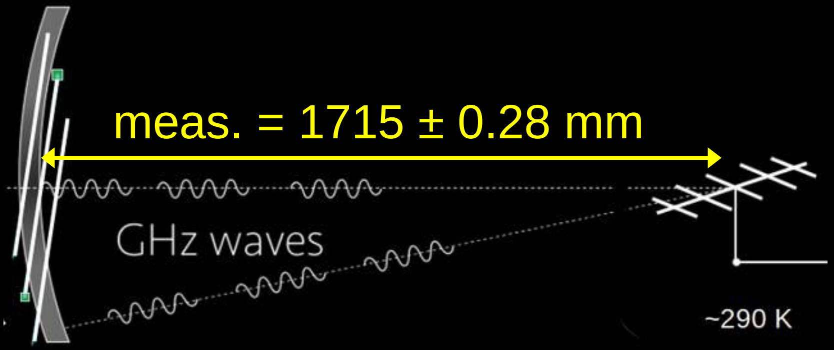
trailer hitch

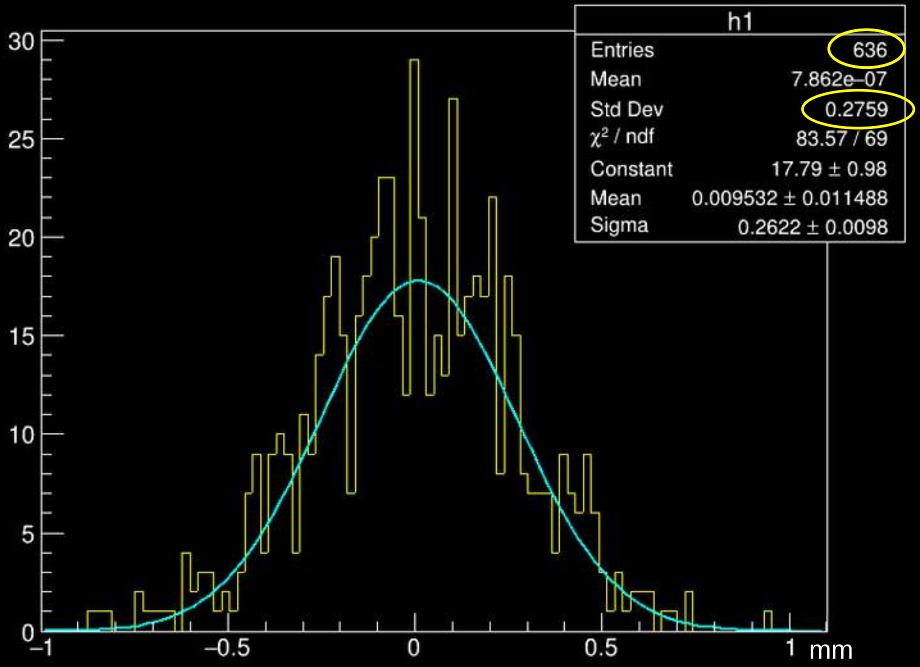
Défonceuse → Plunge router
(french translation)

Detector



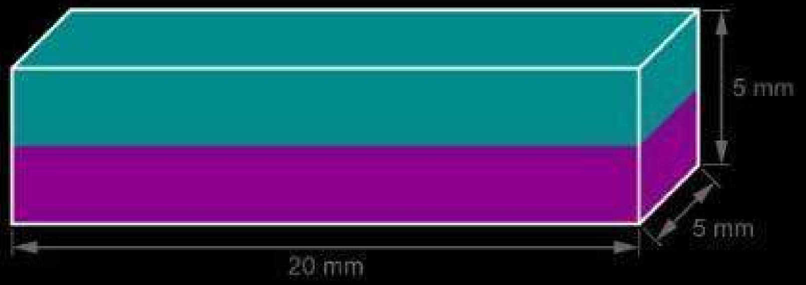
636 measurements →





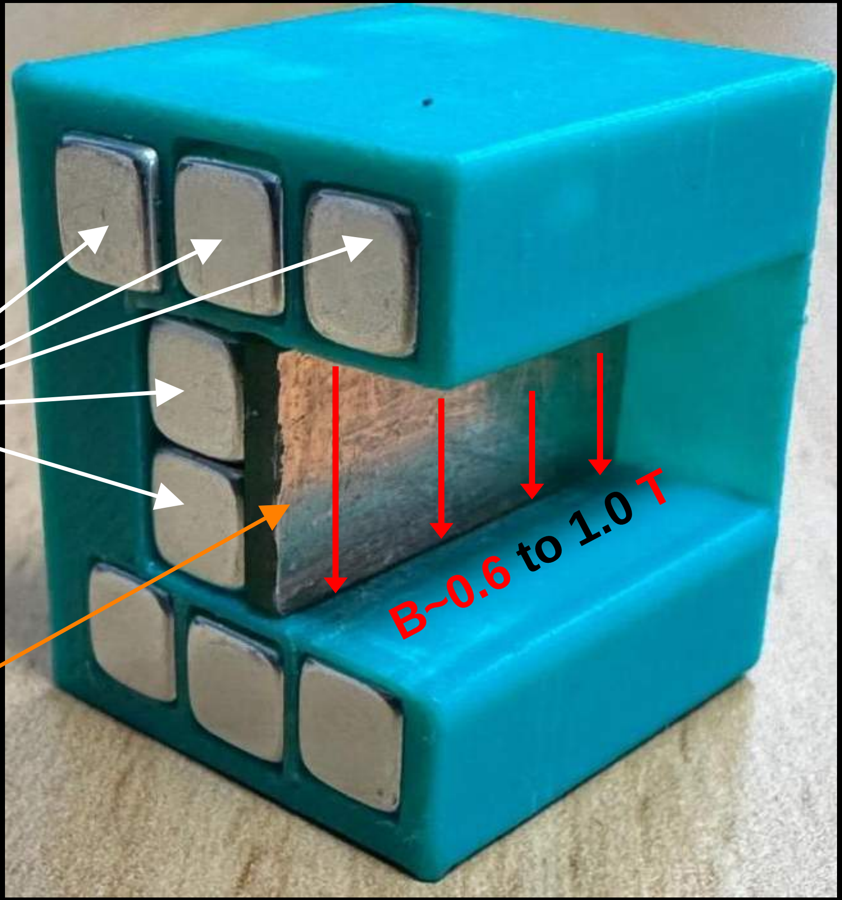
Magnetic field

permanent magnets



ID article	Q-20-05-05-Z
EAN	7640155439824
Matériau	NdFeB
Forme	Parallélépipède
Dimensions	20 x 5 x 5 mm
Côté 1	20 mm
Côté 2	5 mm
Côté 3	5 mm
Pôles	20 x 5 mm
Tolérance	+/- 0,1 mm
Sens de magnétisation	Axe 5 mm
Revêtement	zingué (Zn)
Méthode de fabrication	par frittage
Magnétisation	N42
Force d'adhérence	env. 2,5 kg (env. 24,5 N)
Force de cisaillement	env. 500 g (env. 4,9 N)
Température max. d'utilisation	80°C
Poids	3,8000 g
Température de Curie	310 °C
Rémanence Br	12900-13200 G 1.29-1.32 T
Champ coercitif bHc	10.8-12.0 kOe, 860-955 kA/m
Champ coercitif iHc	≥12 kOe, ≥955 kA/m
Produit énergétique (BxH)max	40-42 MGOe, 318-334 kJ/m³

8 magnets



PCB + copper

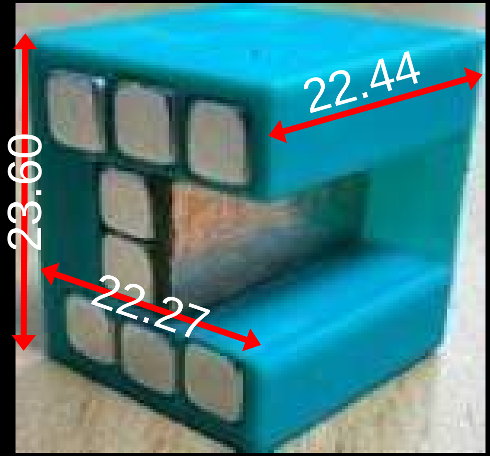
0.2 mm 0.05 mm

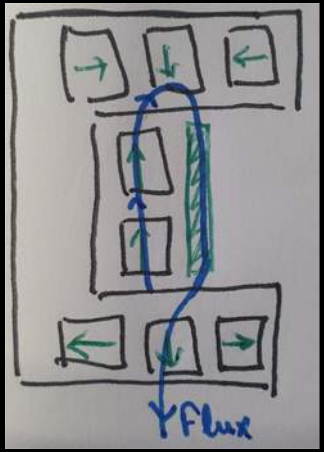
Magnetic field

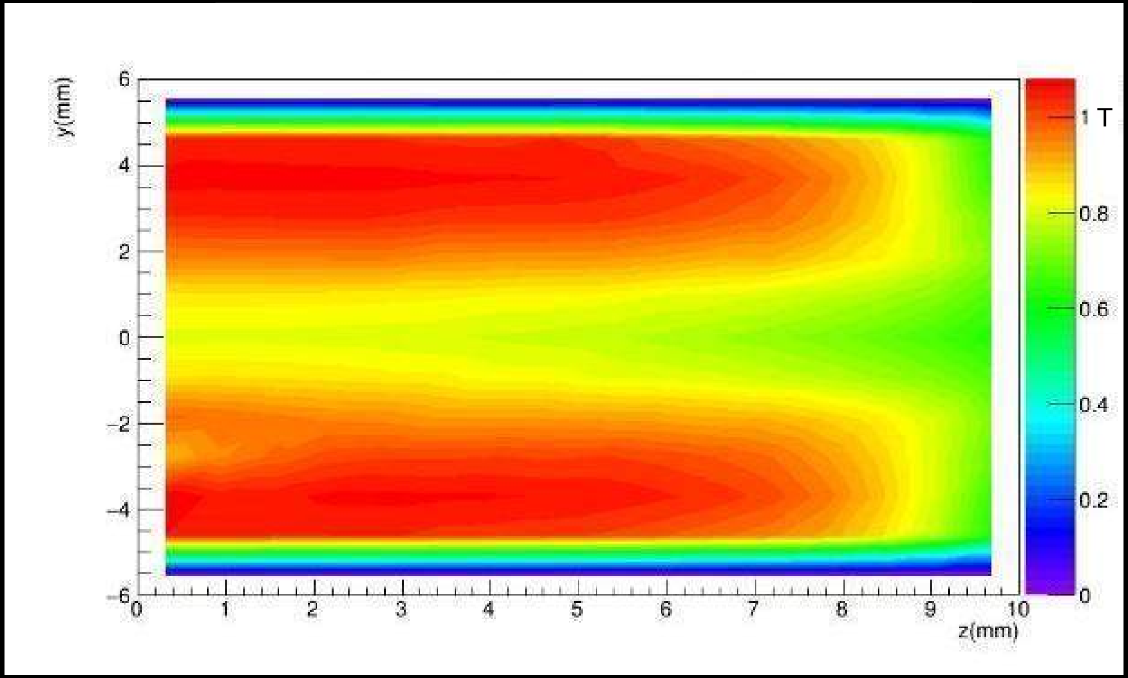
permanent magnets

COMSOL
calculation at 200 µm from central magnet → ~0.6 T < B < ~1.1 T

All in mm







S~2. cm² ← 2 magnets 0.5 cm x 2 cm
<B²S> ~0.88 T² cm²

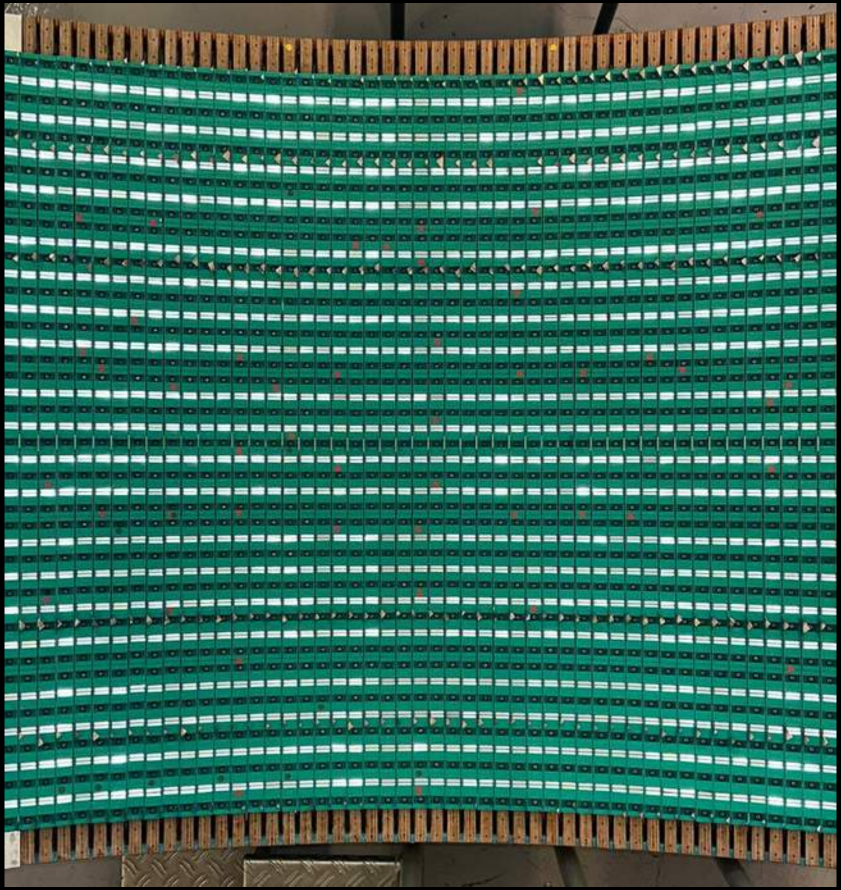
Half module calculation

Magnetized metallic dish

emitter

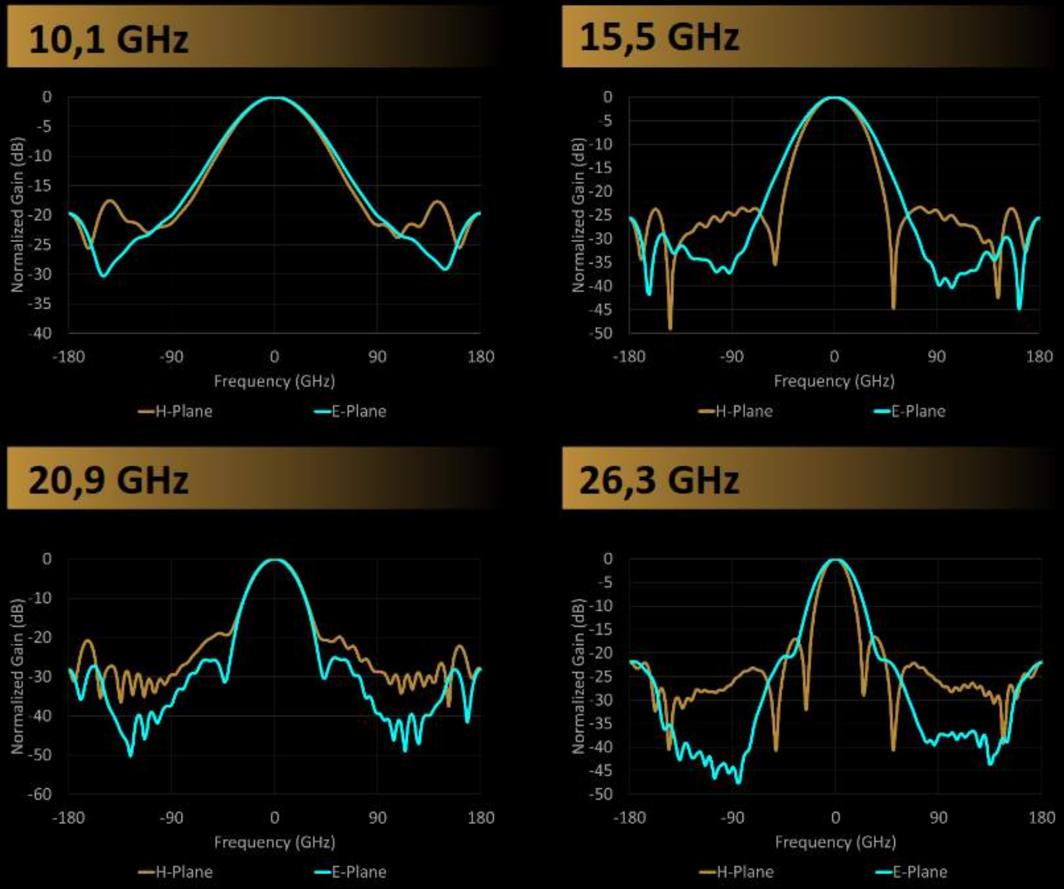
X 2205 (phase 2 $\rightarrow$ 3087)
screwed into the wood support

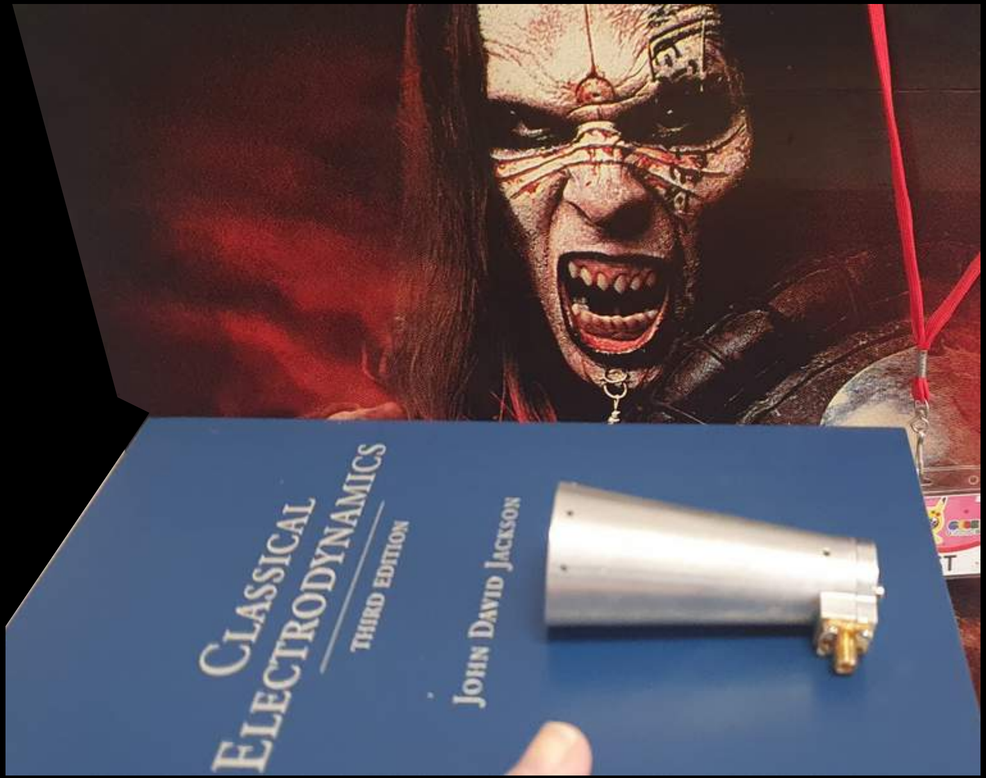
$\langle B^2 S \rangle \sim 0.25\ T^2\ m^2$



Antenna

[10,26] GHz

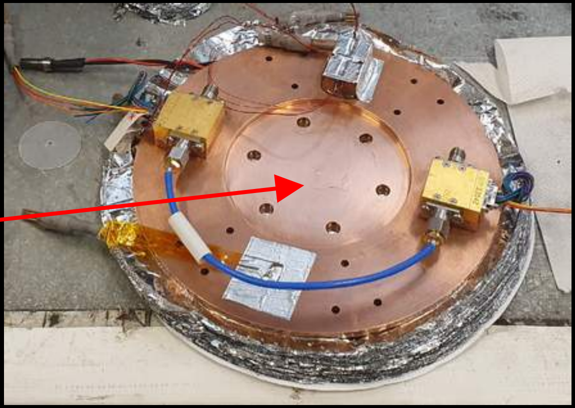




Electronics

Cryostat

Cryocooler 1.5 W

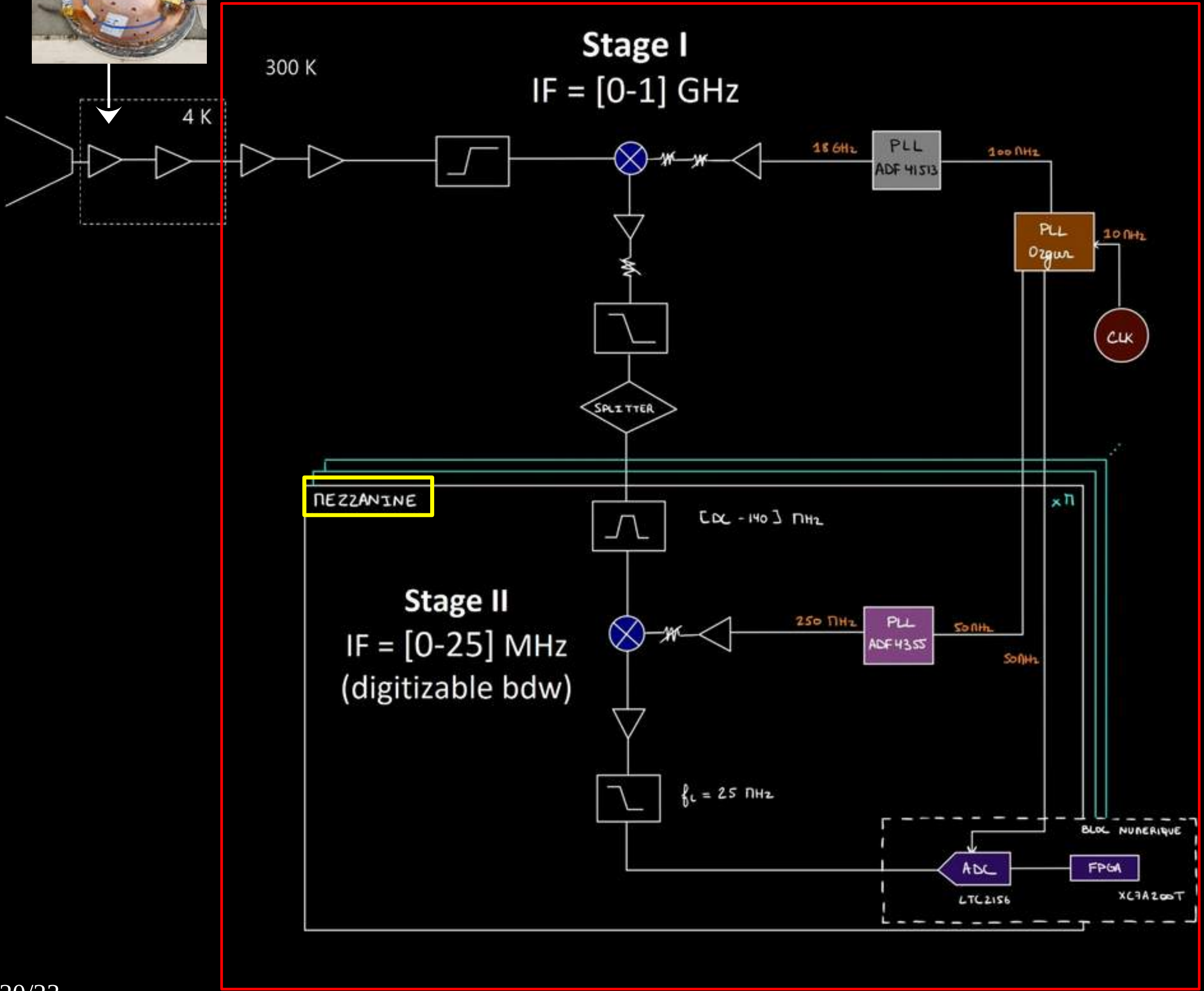


2 LNA’s

Electronics

hot

[10,40] GHz



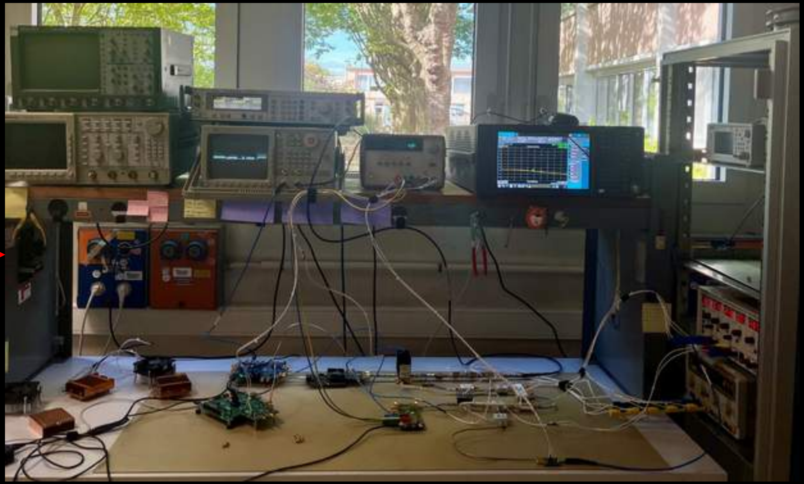
[10,11] GHz (30 x 1 meas.)

Stage 1

[0,1] GHz

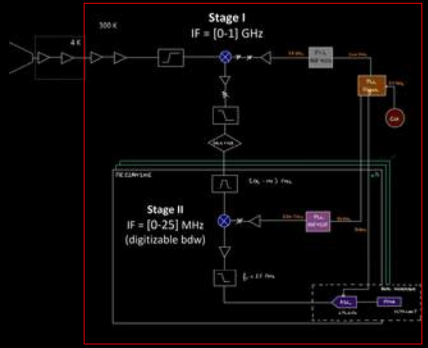
Stage 2

[0,100] MHz (10 x 1 mezzanine)

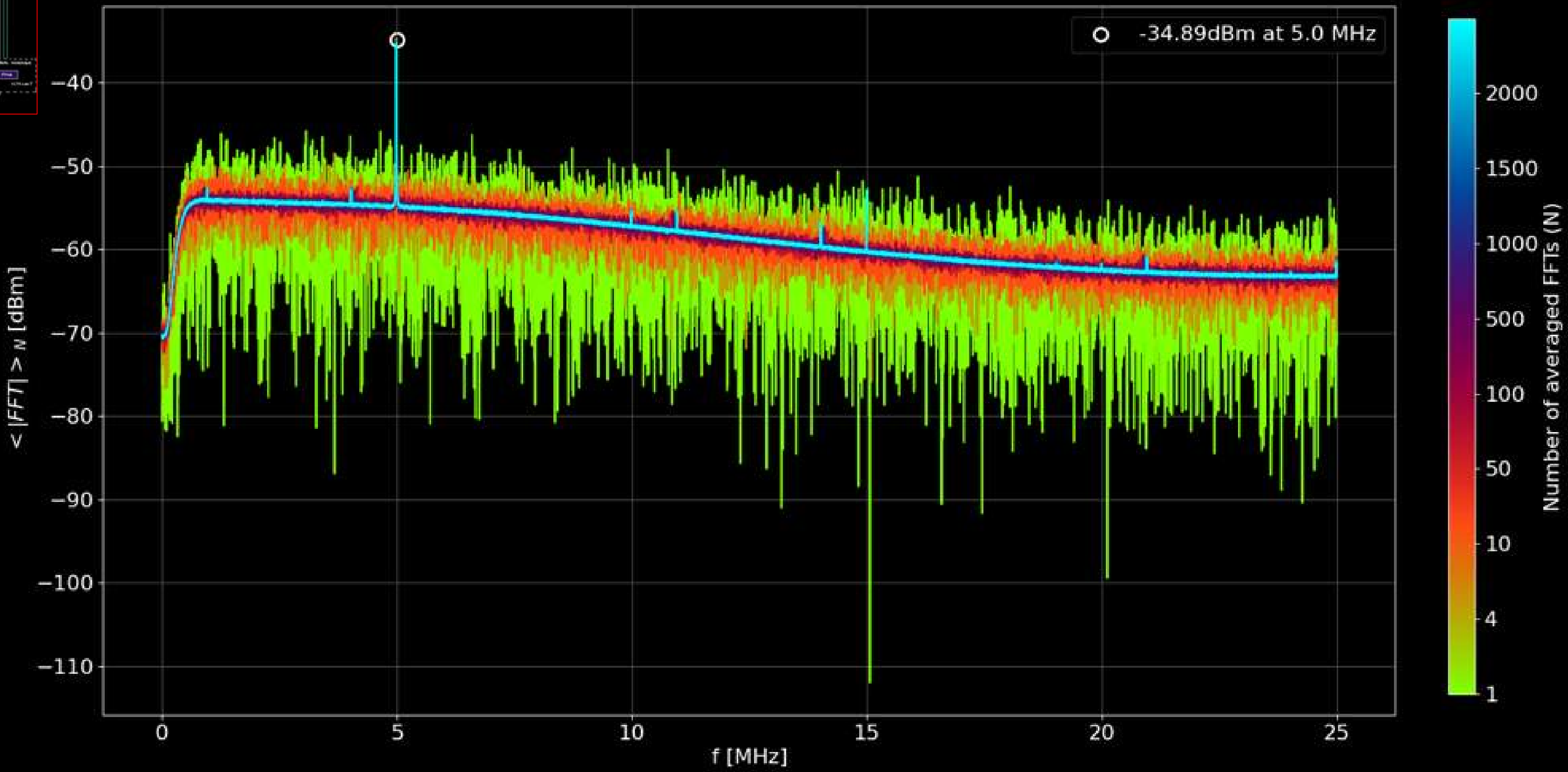


Electronics

prototype



Stage 2
18 GHz → 1 mezzanine [0,25] MHz



Conclusion (1)

2026 DAWA

emitter
- ✓ support
- ✓ permanent magnets

electronics
- ✓ radiometer prototype (1 mezzanine)
- ✓ spectrum Analyzer

tests

end of this year

first physics run

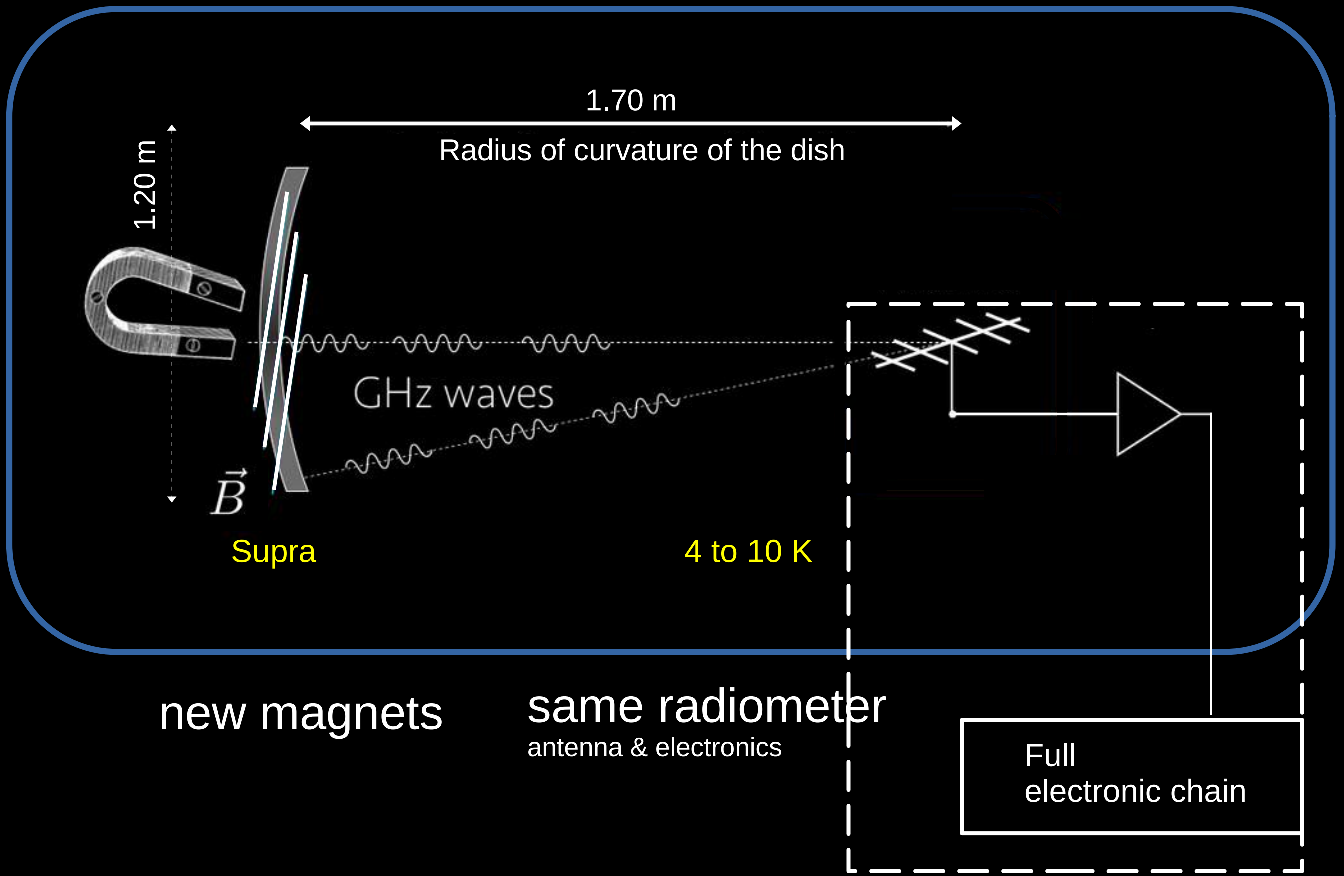
beginning of 2026

Conclusion (2)

2026 DAWA
- first results

2027 Super DAWA
- cryostat
- emitter supra
- antenna ~10 K
- full electronics chain

Cryostat under construction: 4 m x Ø 2 m



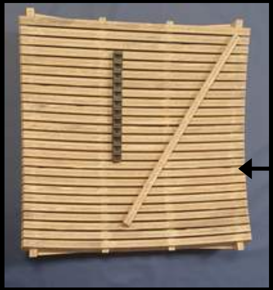
new magnets

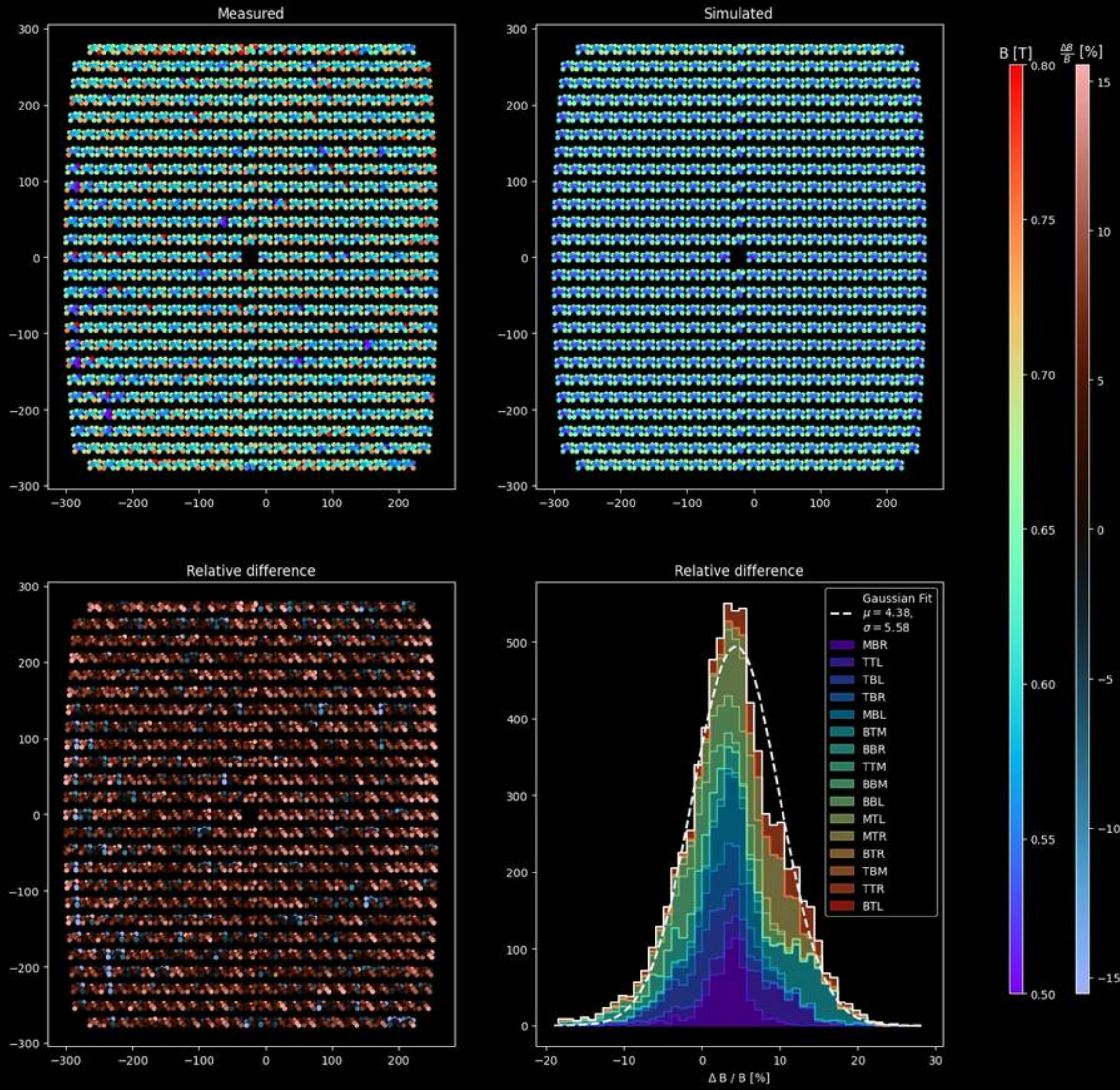
same radiometer
antenna & electronics

backup

(mini) DAWA magnets tests

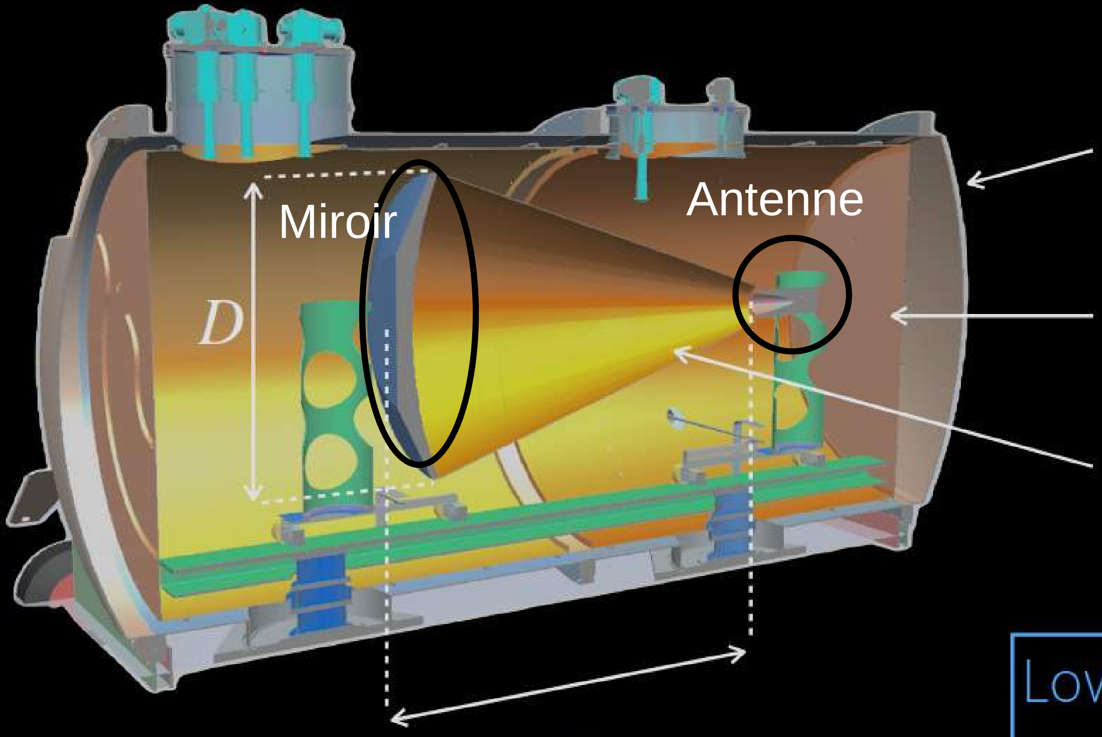
Prototype 1/4 50x50 cm²





SuperDAWA

→ Outer dimensions: $L = 3.7$ m $H = 1.8$ m $m \simeq 5$ t



Low temperature required:
- superconducting phase
- reduce detection noise

Emitter :

→ Radius of curvature $R = 1.7$ m

→ Diameter $D = 1.2$ m