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# A HYBRID REBACUO-CU COATING FOR THE FCC-HH BEAM SCREEN

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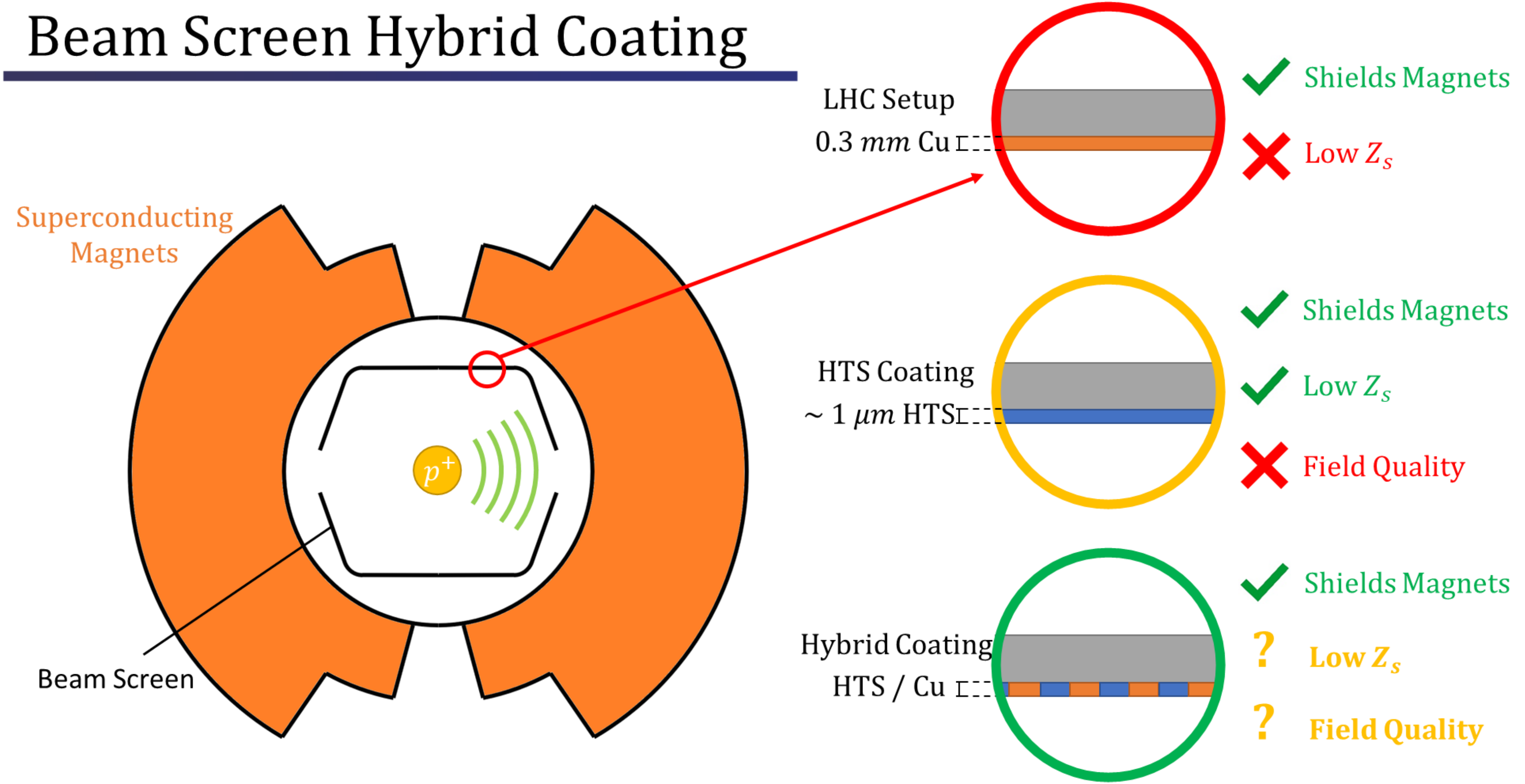
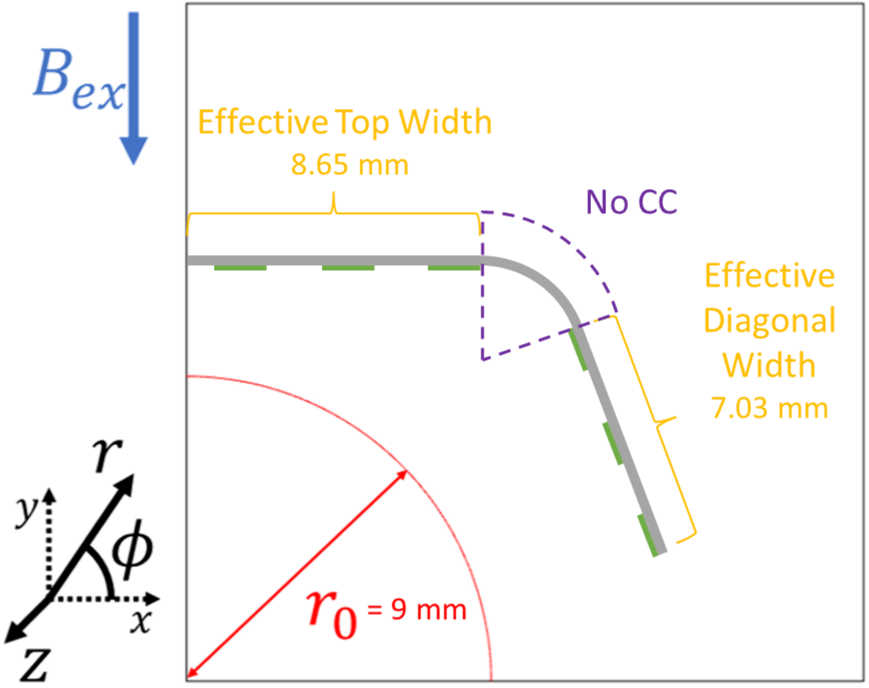
# Beam Screen Hybrid Coating



# Objective: high field quality




Number of CC segments (n)

Area ratio with CC (p)

↓

Relative Field Distubance

Multipole Coefficients

$\sim 10^{-4}$ within reference radius

# Outline

- Numerical Model of the Hybrid Coating
    - Dipole Simulation Results
    - Field quality considering external correction of the dipole field
    - Quadrupole Simulation Results
- Experimental Results
- Tilting and Displacing the Beam Screen
- Conclusions and Final Remarks

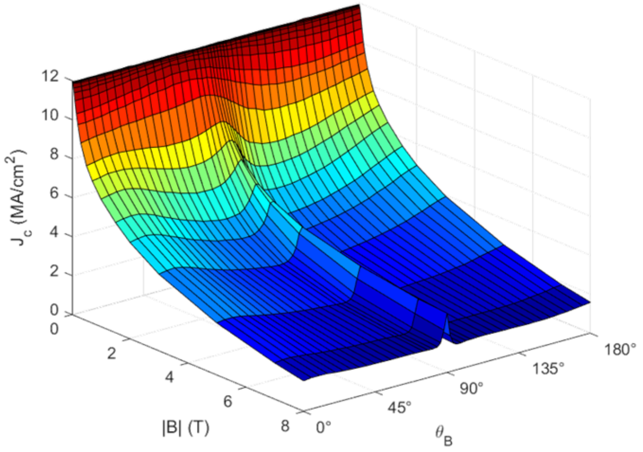
# Numerical Model of the Hybrid Coating

# Simulation Model

- Domain Constraint: $I_{sc} = \int J dS_i = 0$

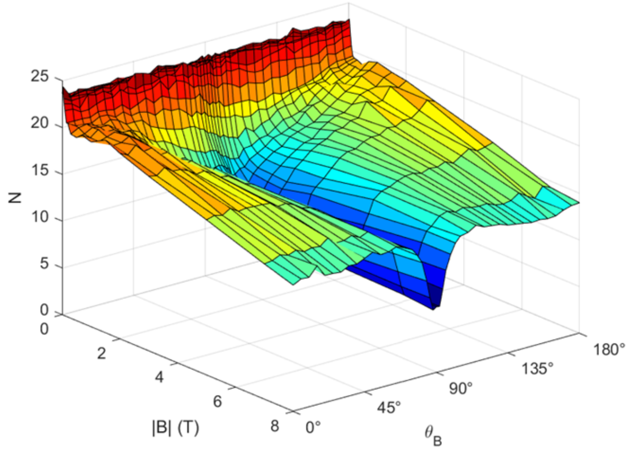
$$\begin{cases} \vec{J} = \dfrac{1}{\mu_0} \nabla \times \vec{B} \\ \dfrac{\partial \vec{B}}{\partial t} = -\nabla \times \vec{E} \end{cases}$$

$$E(J,H,h) = \underbrace{E_c \left| \frac{J}{J_c(\vec{B})} \right|^{N(\vec{B})}}_{\text{Thermal energy Contribution [1]}} \underbrace{+ \mu_0 f d^2 J \left[ \frac{2h}{d J_c(\vec{B})} - \left( 1 - \left| \frac{J}{J_c(\vec{B})} \right| \right) \right]}_{\text{Proton beam demagnetizing effect [2]}}$$




$J_c$ and $N$ data of *SuperPower Inc.* coated conductors at 50 K from

VICTORIA UNIVERSITY OF WELLINGTON TE HERENGA WAKA [3]

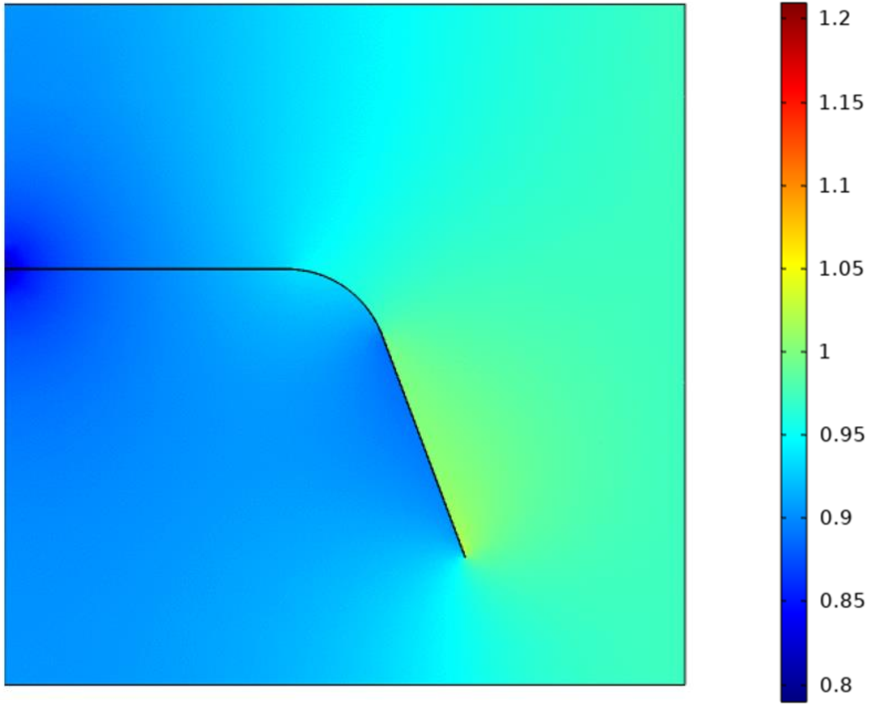


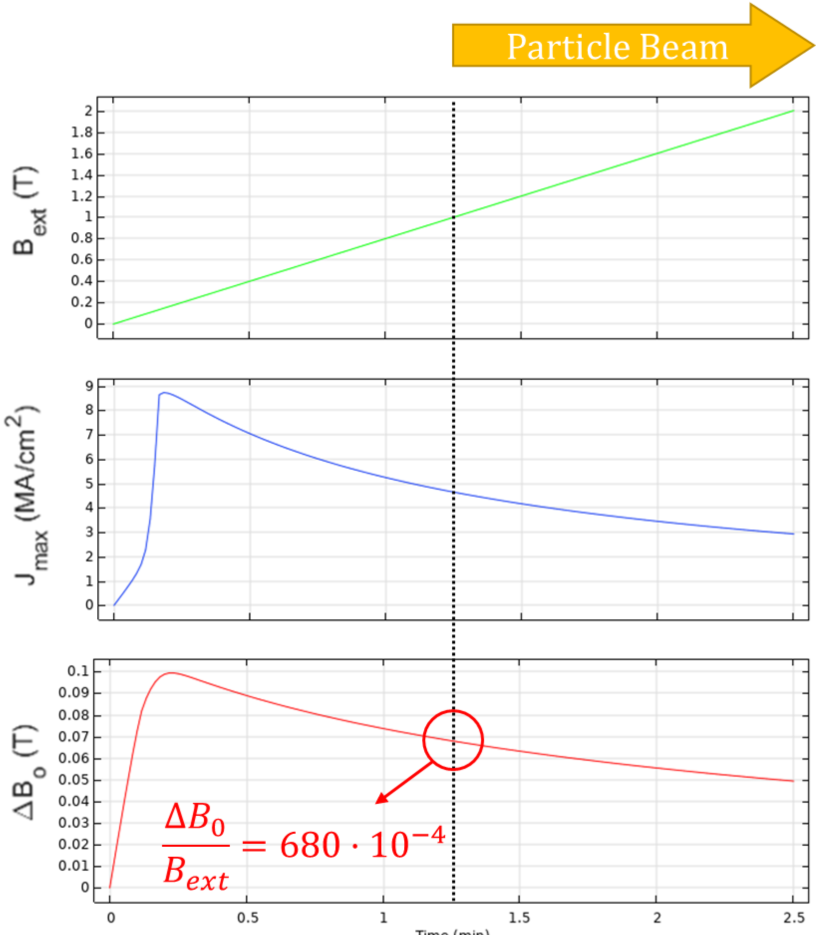

[1] Anderson P W and Kim Y B 1964 Rev. Mod. Phys. 36(1) 39–43

[2] Brandt E and Mikitik G 2002 Physical review letters 89 027002

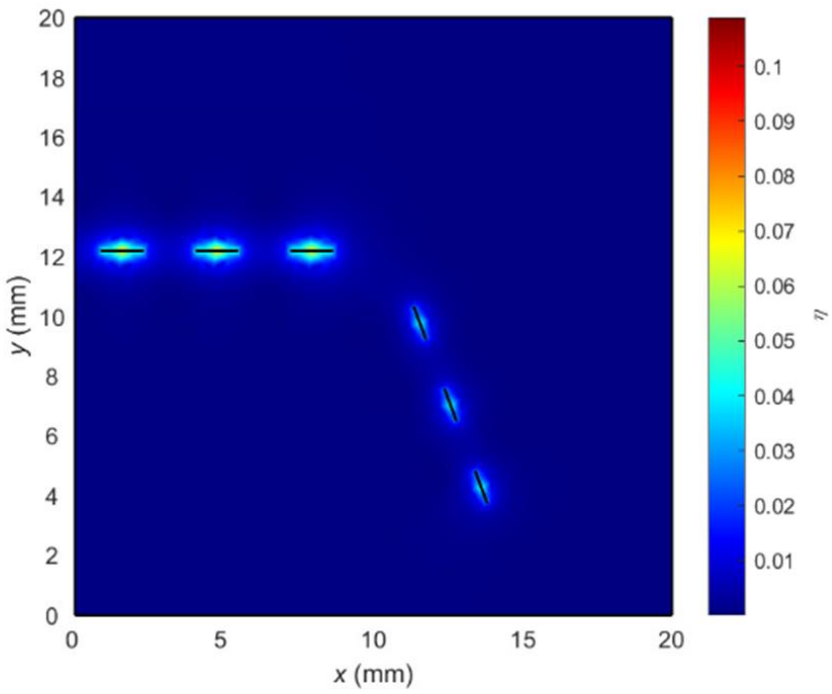
[3] Wimbush S, Strickland N and Pantoja A 2017 Figshare. Dataset. https://doi.org/10.6084/m9.figshare.4256624

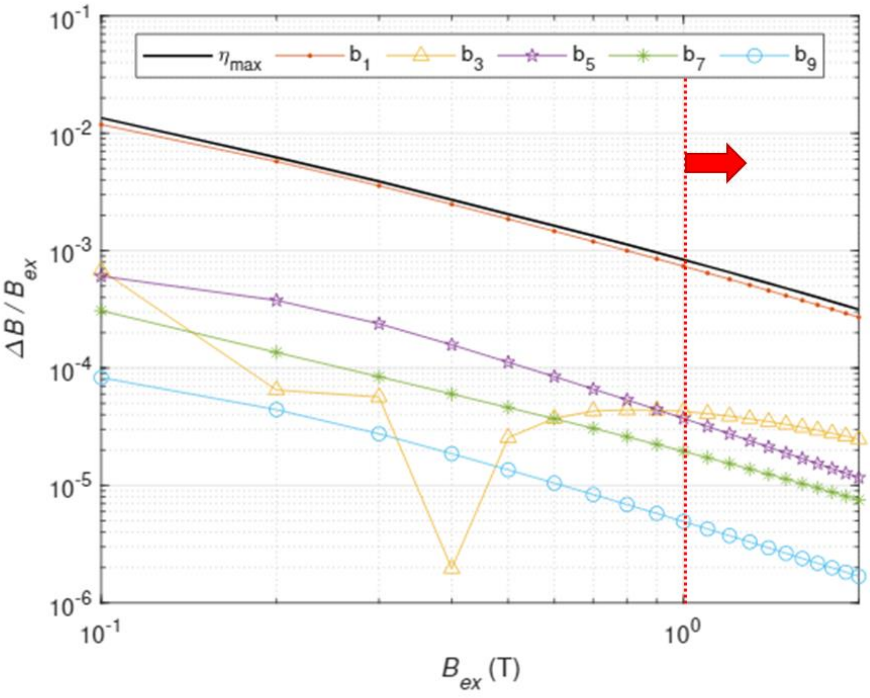
# Reference Case: Full coating



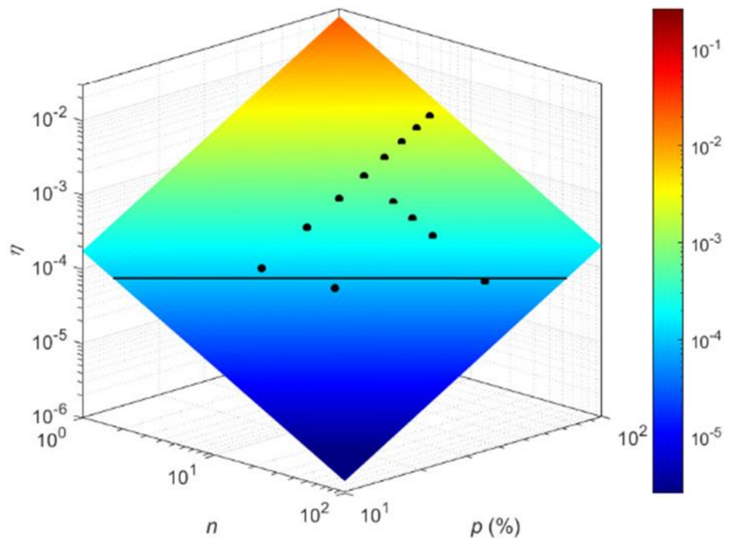



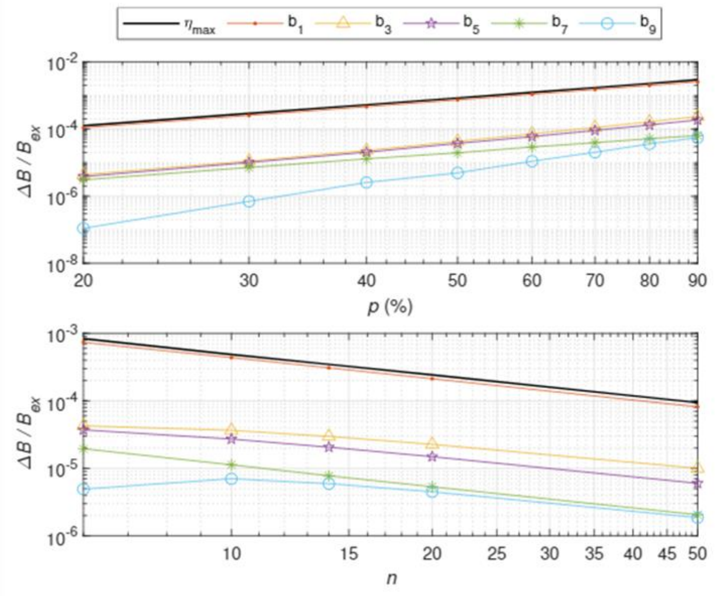
# One simulation: $n = 6$; $p = 50\%$



# A broad range of complying geometries



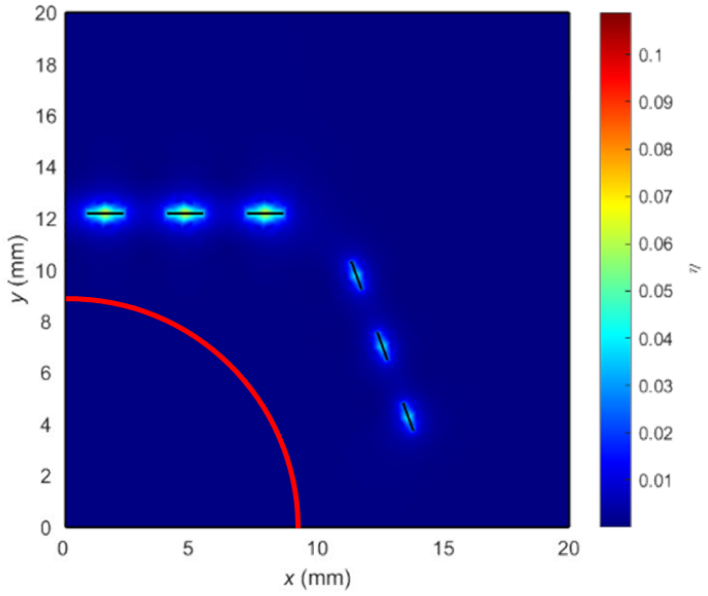

$$\eta_{max} = \frac{p^{2.1}}{n} \cdot 24 \cdot 10^{-4}$$

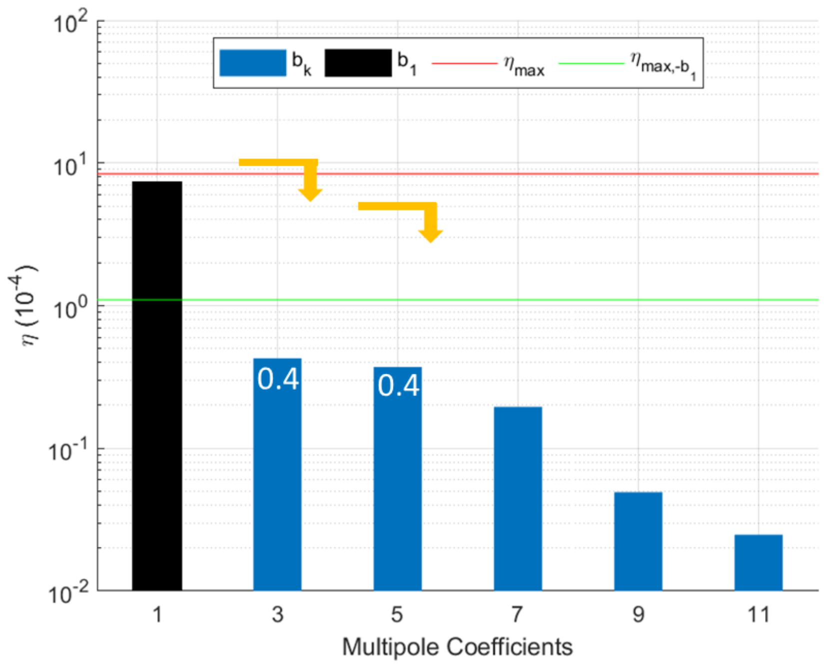
$$\eta_{max} \leq 10^{-4} \quad \leftrightarrow \quad \frac{p^{2.1}}{n} \leq 42 \cdot 10^{-4}$$

| $p$ | $n$ | $w_{top}$ ($\mu$m) | $w_{diag}$ ($\mu$m) | $g_{top}$ ($\mu$m) | $g_{diag}$ ($\mu$m) | $\eta_{max}$ ($\times 10^{-4}$) |
|---|---|---|---|---|---|---|
| 0.25 | 12 | 361 | 293 | 1180 | $1055^a$ | 0.928 |
| 0.50 | 48 | 180 | 147 | 184 | $153^b$ | 0.959 |
| 0.75 | 106 | 123 | 99 | 41 | $34^c$ | 0.997 |
| 0.95 | 172 | 96 | 78 | 5 | $4^d$ | 0.996 |

Technology:
[a]Mechanical scribing
[b]Ink-jet printing
[c]2LUPS
[d]Laser scribing

# Assuming Dipole Field Correction



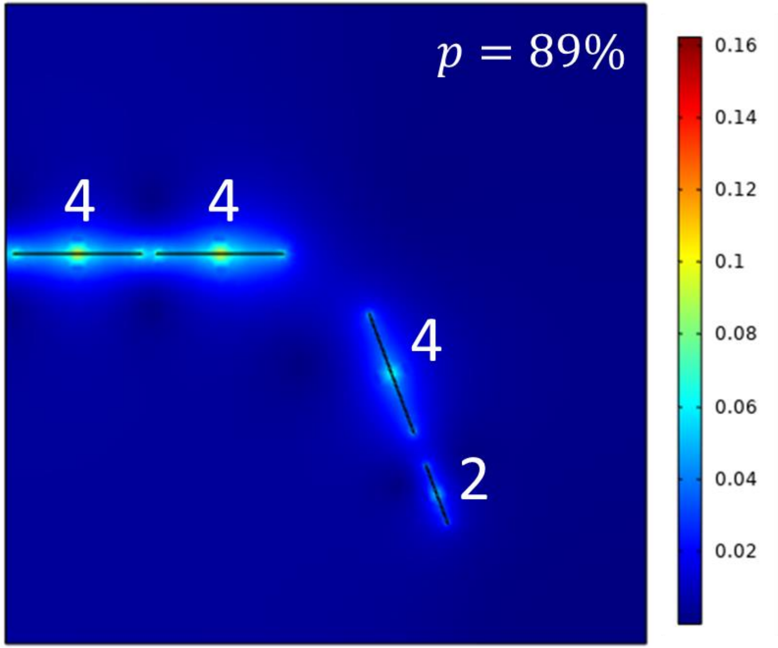

Assumption: The dipole component will be corrected by the orbit feedback or even by adjusting the main dipole.

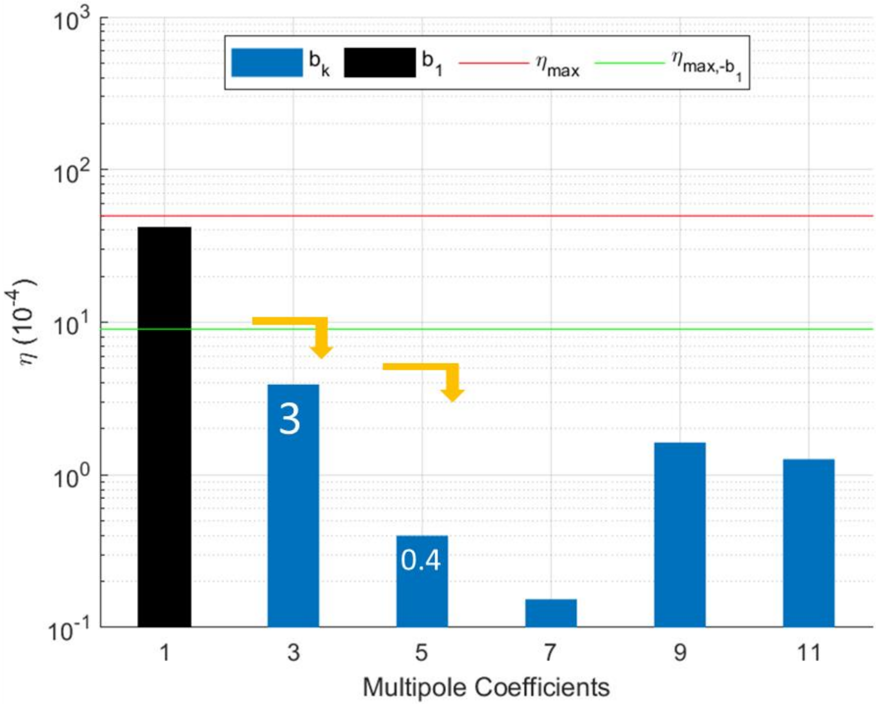
$b_3 \leq 10$
and
$b_5 \leq 5$

✔ **Field Quality**

# Proposed geometry with no striation

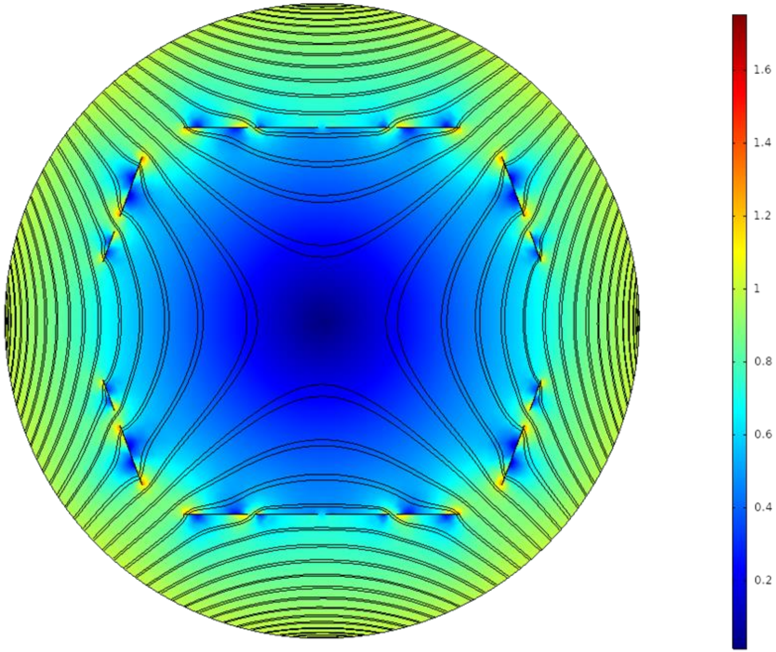
Commercially available CC widths:
2 and 4 mm

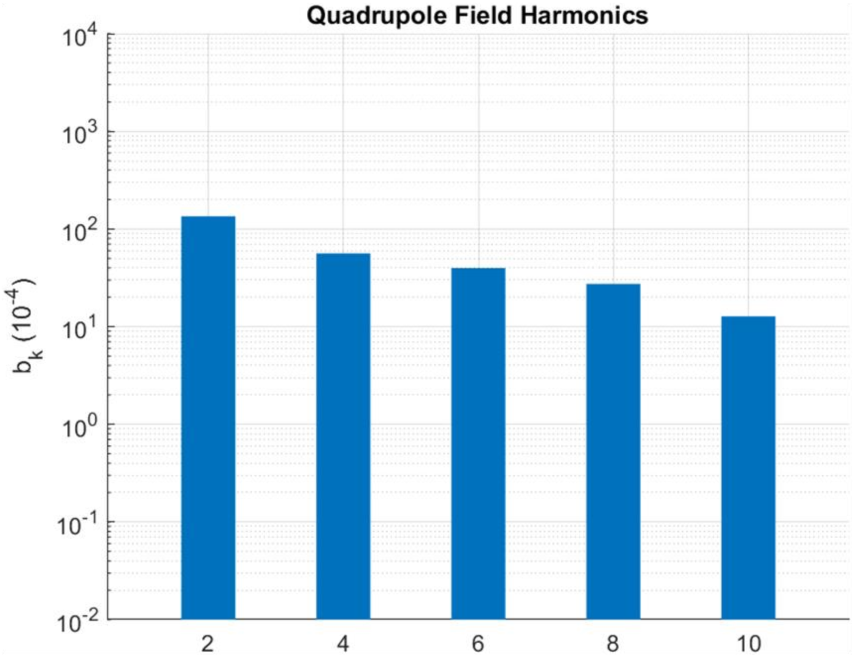


# Quadrupole Field Harmonics

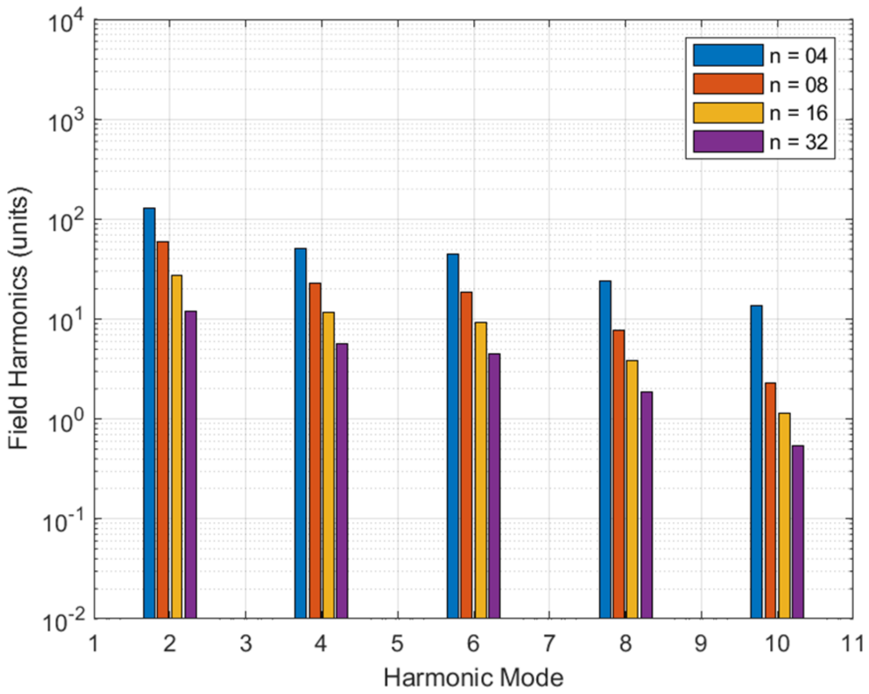
Field Harmonics are too high…

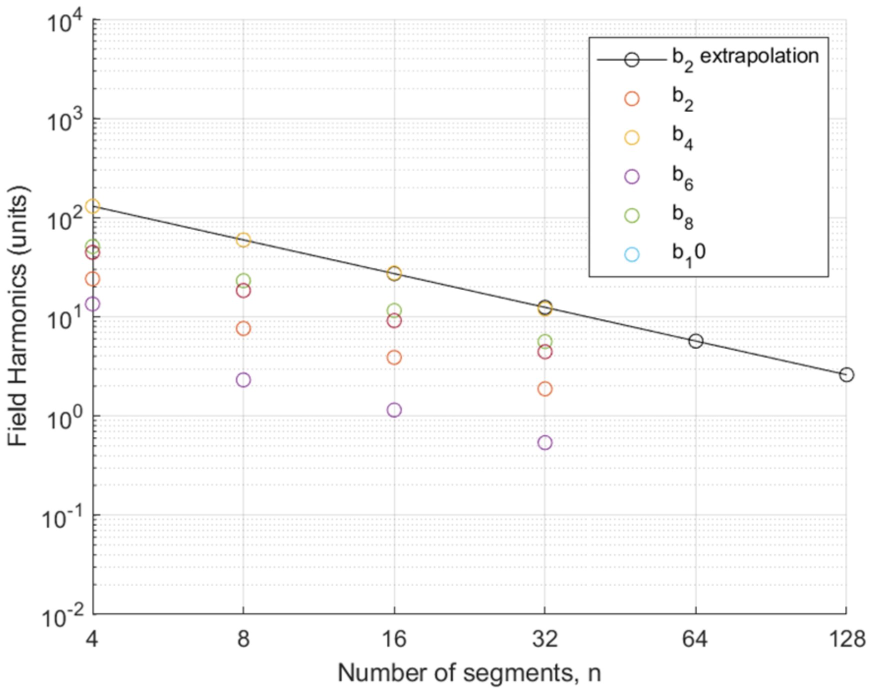


# Quadrupole: back to striation

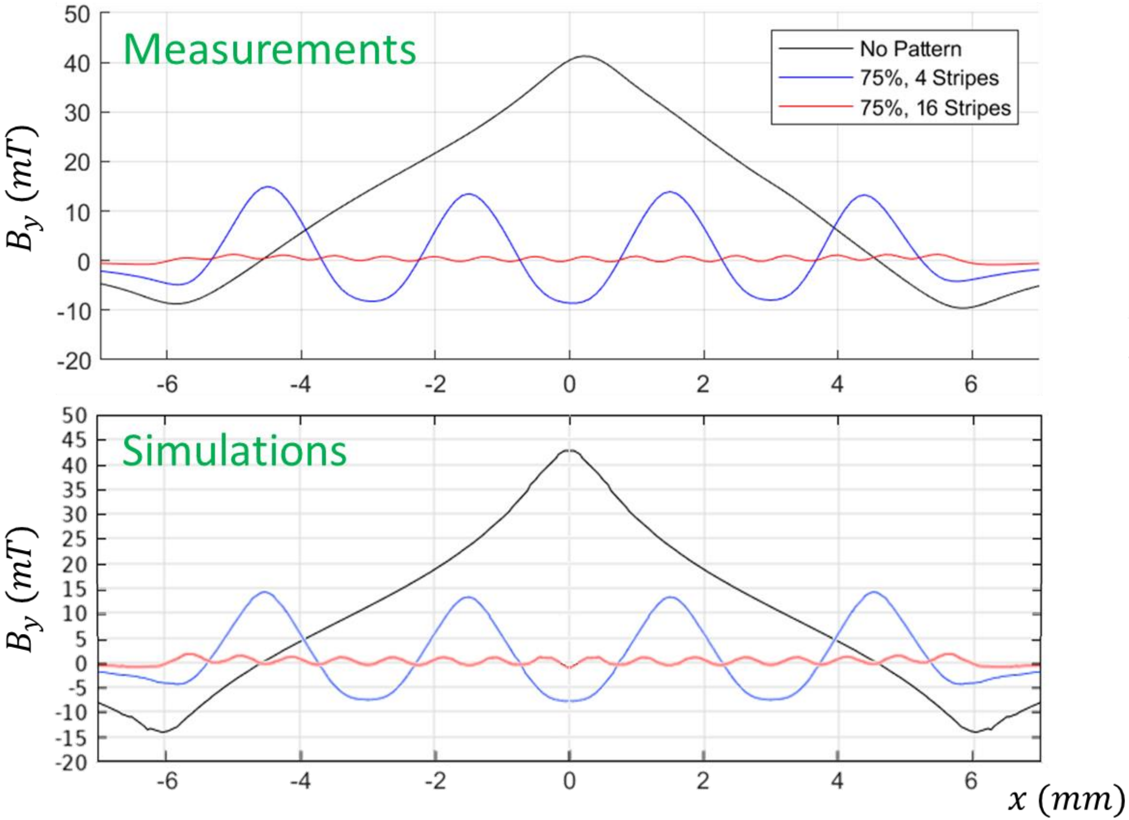
Field Harmonics are too high...
... but can be reduced

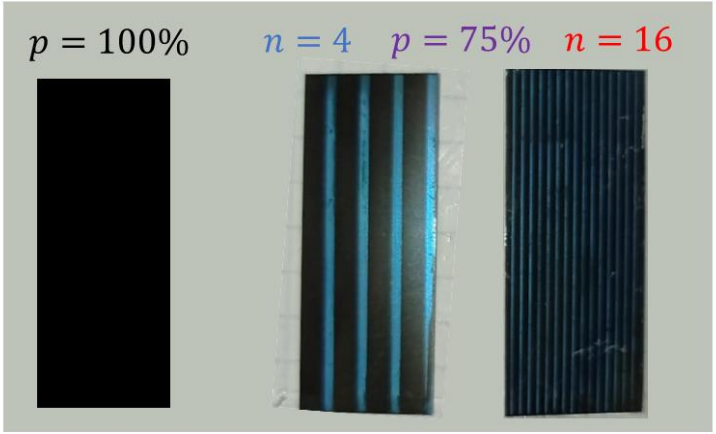


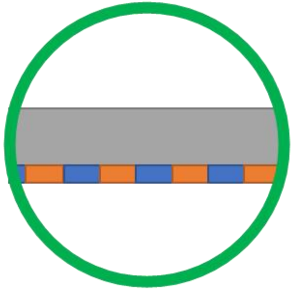
# Experimental Results

# Hall Microscopy: low trapped field




$T = 77\ K, \quad h = 400 \pm 100\ \mu m$



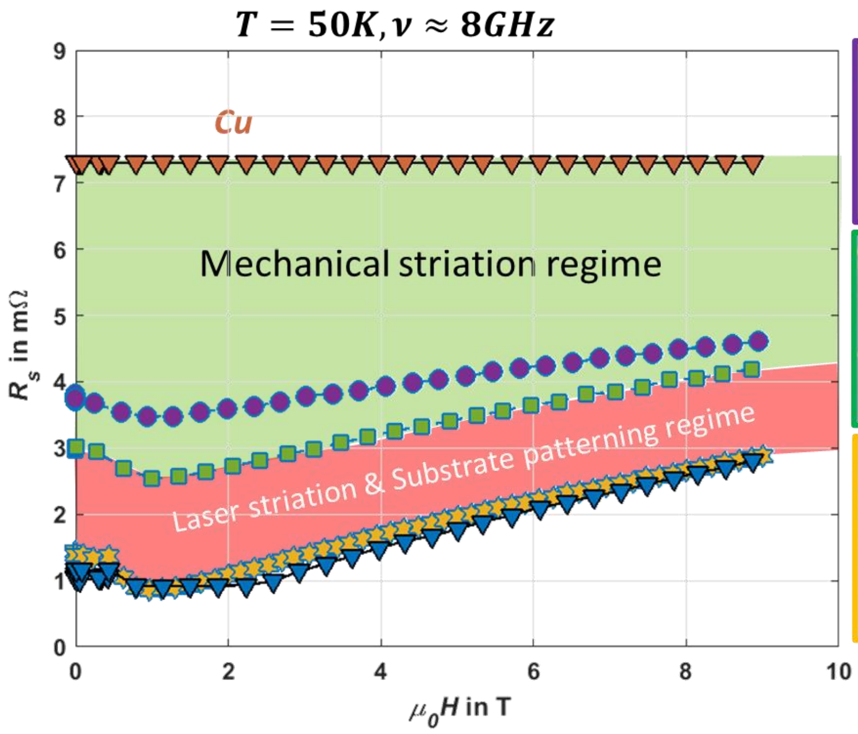
✓ Shields Magnets

**Low $Z_s$**

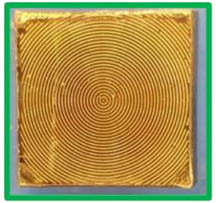
✓ **Field Quality**

# Surface Resistance: almost no change

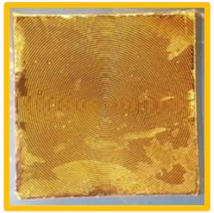
✔ Surface resistance very close to full REBCO



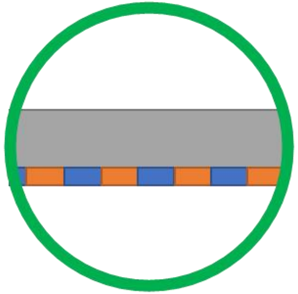

240 μm stripes
250 μm trenches
**49% HTS**



165 μm stripes
55 μm trenches
**67% HTS**



130 μm stripes
6 μm trenches
**92% HTS**



✔ Shields Magnets

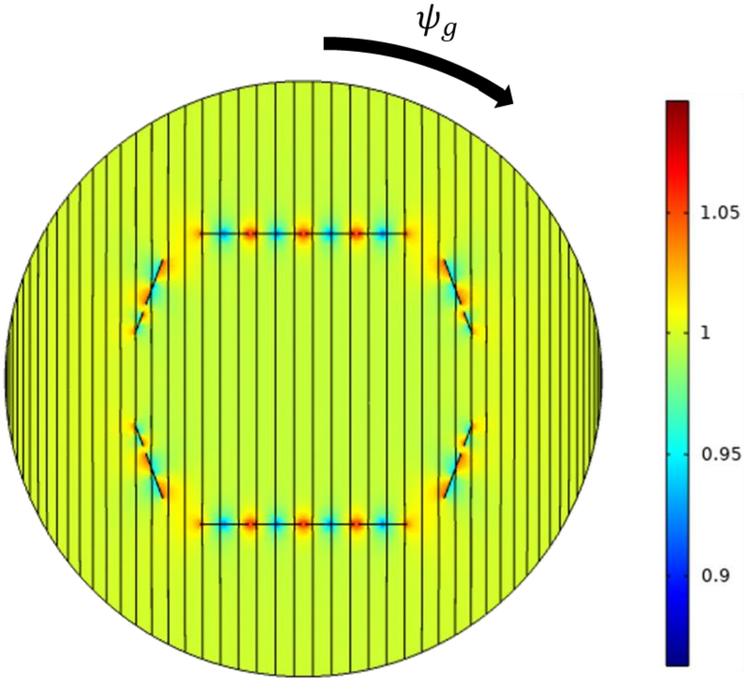
✔ **Low $Z_s$**

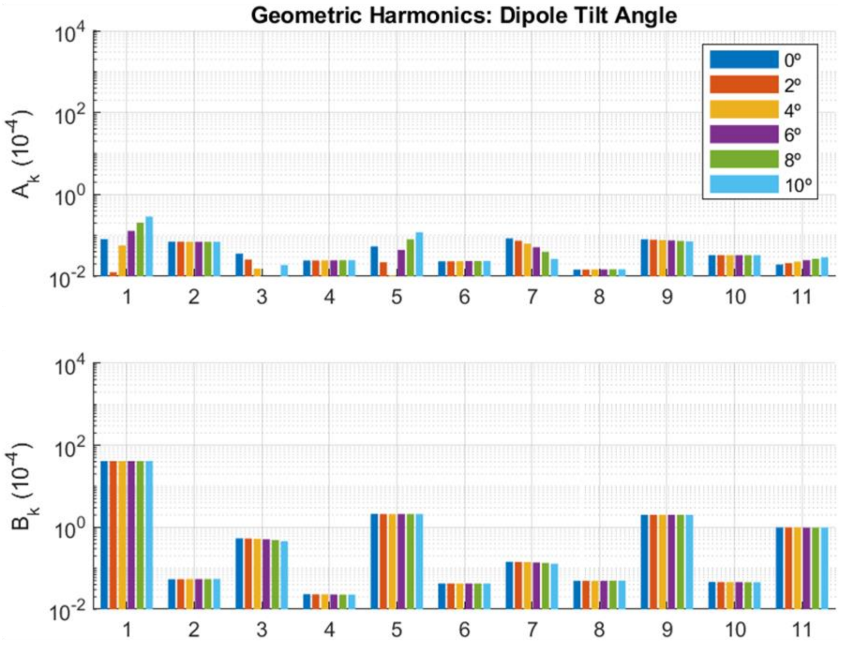
✔ **Field Quality**

# Tilting and Displacing the Beam Screen

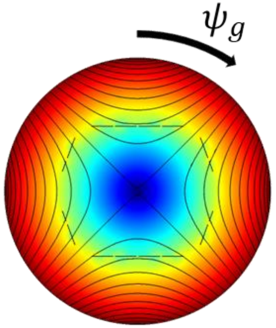
# Dipole Angle Sweep

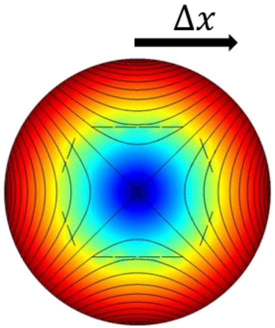
**No significant changes** in harmonics due to tilting of the dipole field.

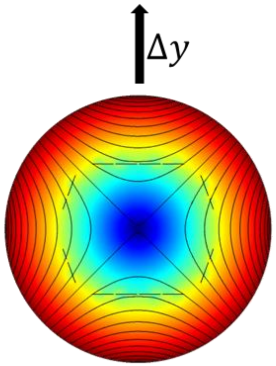


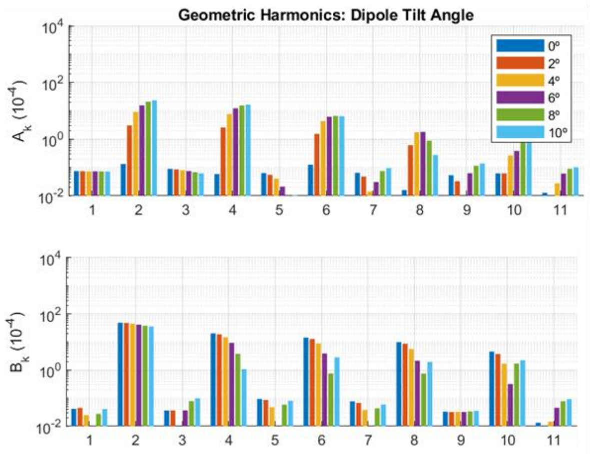



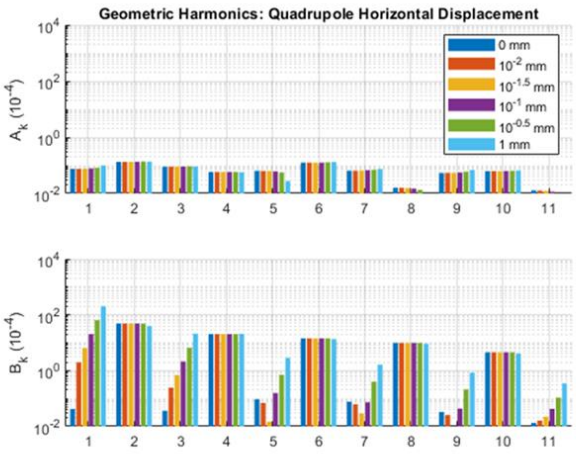
# Quadrupole: Tilting and Displacing

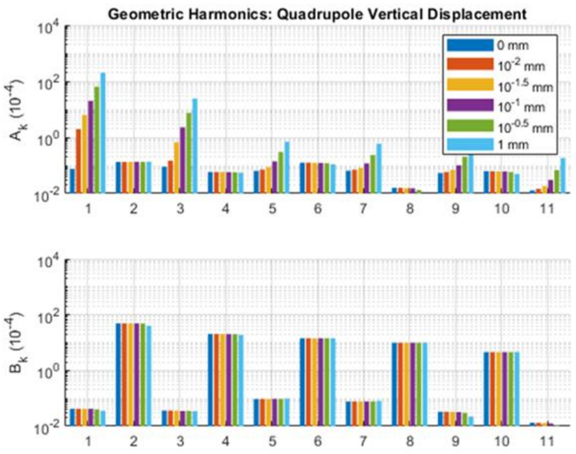


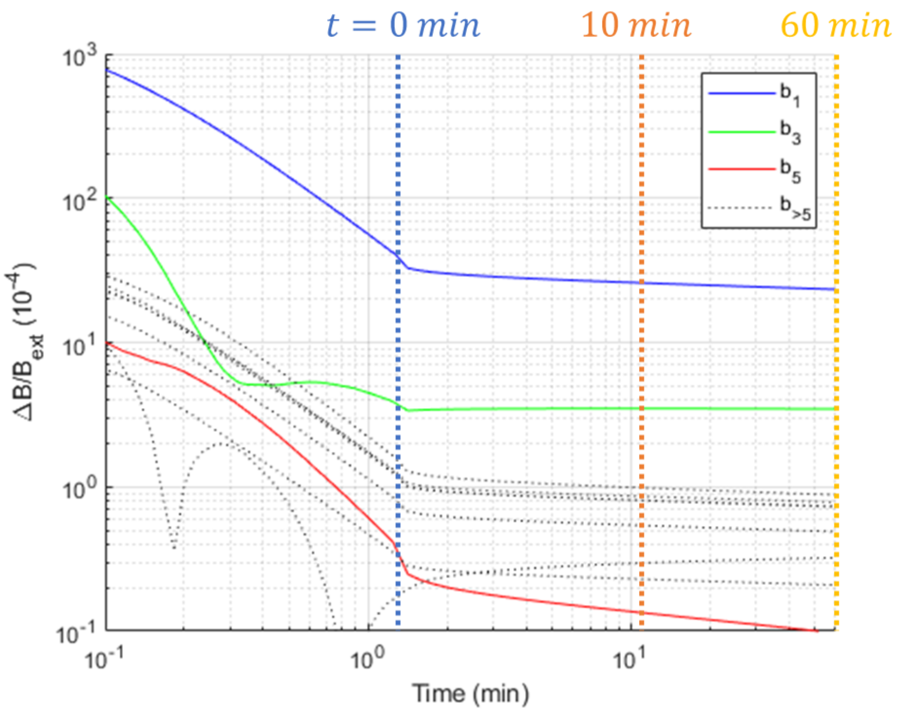



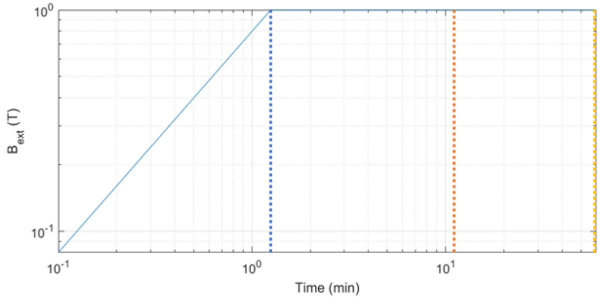
# Conclusions

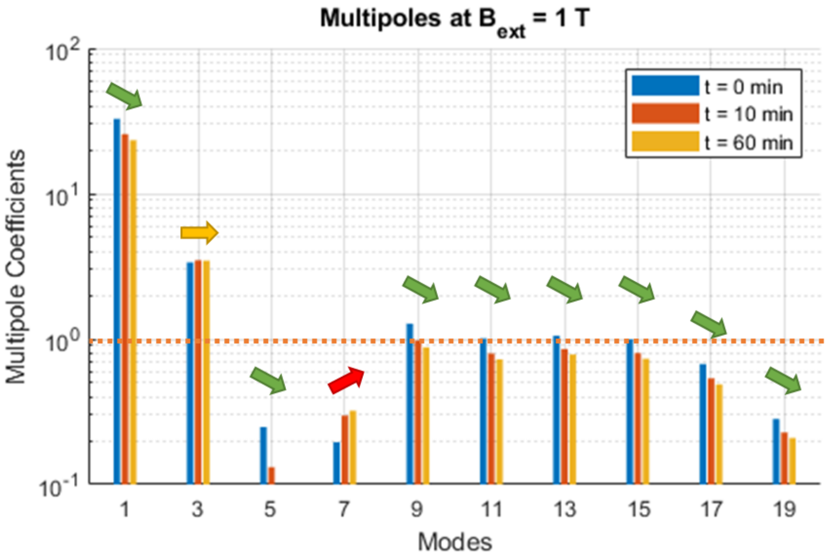
- Simulations show that **creep**, **AC field demagnetization**, $J_c(\vec{B})$ and $N(\vec{B})$ dependencies, and **SC anisotropy** are relevant factors for the field quality behaviour of the hybrid coating, with the **most critical point being at particle injection**.
- Results show a **broad range of geometries** that comply with both the **Relative Field Disturbance** and **Field Harmonics** criteria;
- Considering external correction of the dipole component, **we propose a geometry** that requires a decreased number of segments, making **striation unnecessary** through the usage of **commercally available widths** of coated conductors.
- Quadrupole simulations show **high field harmonics without striation**, which can be corrected by increasing the number of segments.
- Experimental results show that the hybrid coating can increase **field quality** while maintaining **very low surface resistance**, and that the simulations can be used as a **prediction tool** for different geometries and providers;
- **Tilting and displacing** the beam screen have **significant effects for the quadrupole** but **dipole is unaffected** for $\psi_g \leq 10°$.

# Thank you for your attention.

# Creep effect at $B_{ext} = 1\,T$ for one hour




After 10 min: all higher modes are below 1 unit but $b_7$ increases with time.