# RF in strong magnetic fields: Test stand plans in UK

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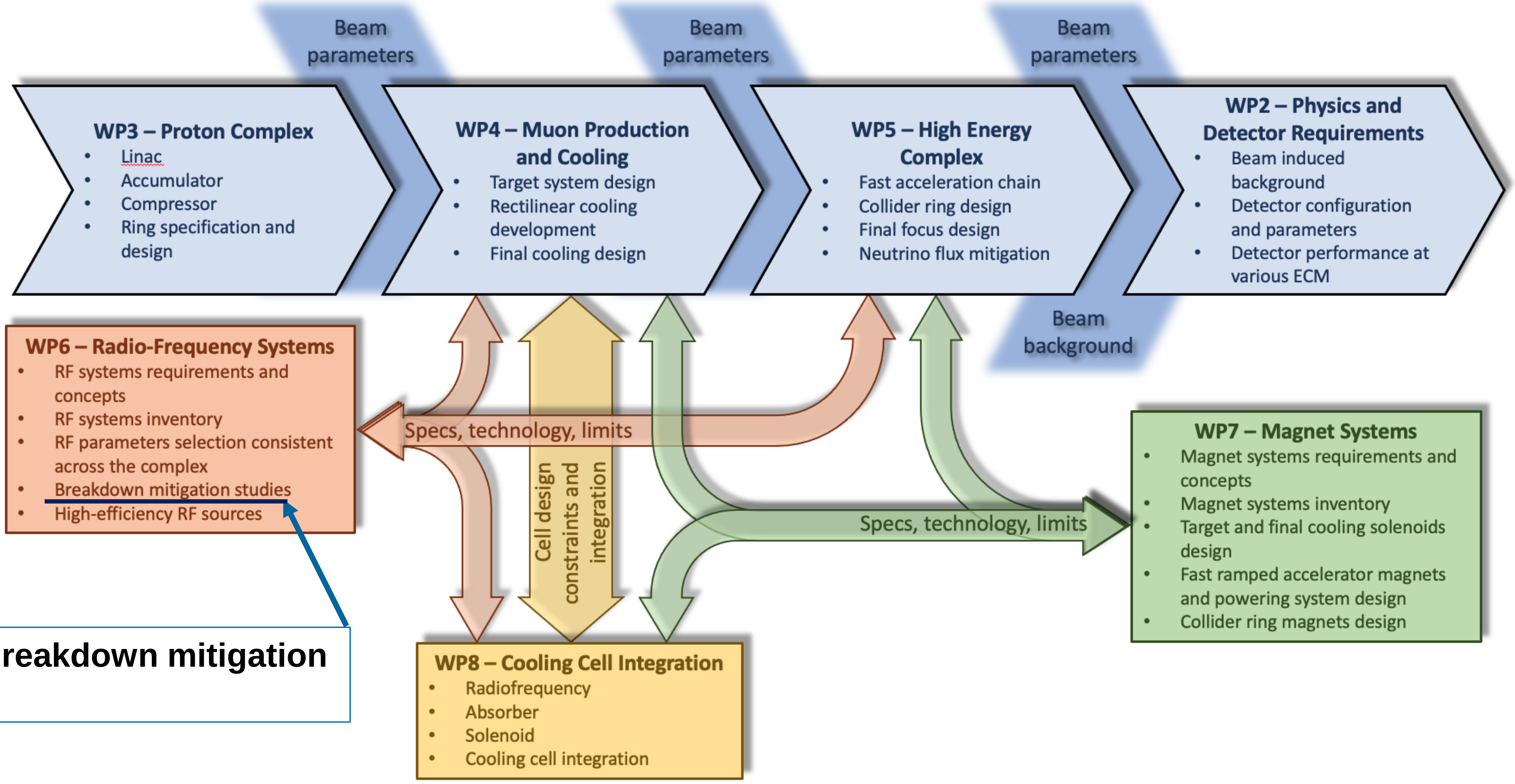
# Interfaces between MUCOL WP's




**WP6.3 Breakdown mitigation studies**

# Task 6.3: Break-down mitigation studies for muon cooling cell cavities (CEA, INFN, Strathclyde)

**Task objectives**:
- Define cavity parameters & RF properties to minimize BD due to HG in a high magnetic field

**Methodology (proposed by CEA):**
- Enhance theory and models of breakdown in B field (build on prior US work – beamlet approach)
- Define (and conduct) suitable experimental tests (DC and RF) to study the influence of as many as possible of the expected control parameters on BD rates:
  - RF frequency, E field, RF pulse length, B field, material (Cu, Be, Al), temperature, surface preparation, conditioning algorithms, …
- Provide design and cost of a few RF test stands for the above tests to be included in the LDG roadmap (CEA, INFN, Strathclyde, CERN)

**Deliverable:**
- Consolidated report on baseline concepts of the RF systems for the MCC and HEC complexes, including breakdown mitigation studies for MCC cavities at month 45
- A PhD thesis at Strathclyde at Month 42

**Manpower:**
- 1 PhD student funded by RAL-PPD and Strathclyde University

# Proposed research

- **Theory and simulations**
  - Study surface/breakdown physics as a function of
    - Frequency, duty pattern/pulse duration, and magnetic field
    - Surface preparation
    - Material selection
- **Design and optimization**
  - Cavity design for RF breakdown test and muon collider
- **Experiments and data analysis**
  - Undertaking and interpreting experimental measurements in test stands
  - RF breakdown test stands: Daresbury/Saclay?
  - DC breakdown test stands: CERN/Strathclyde?

# Research plan

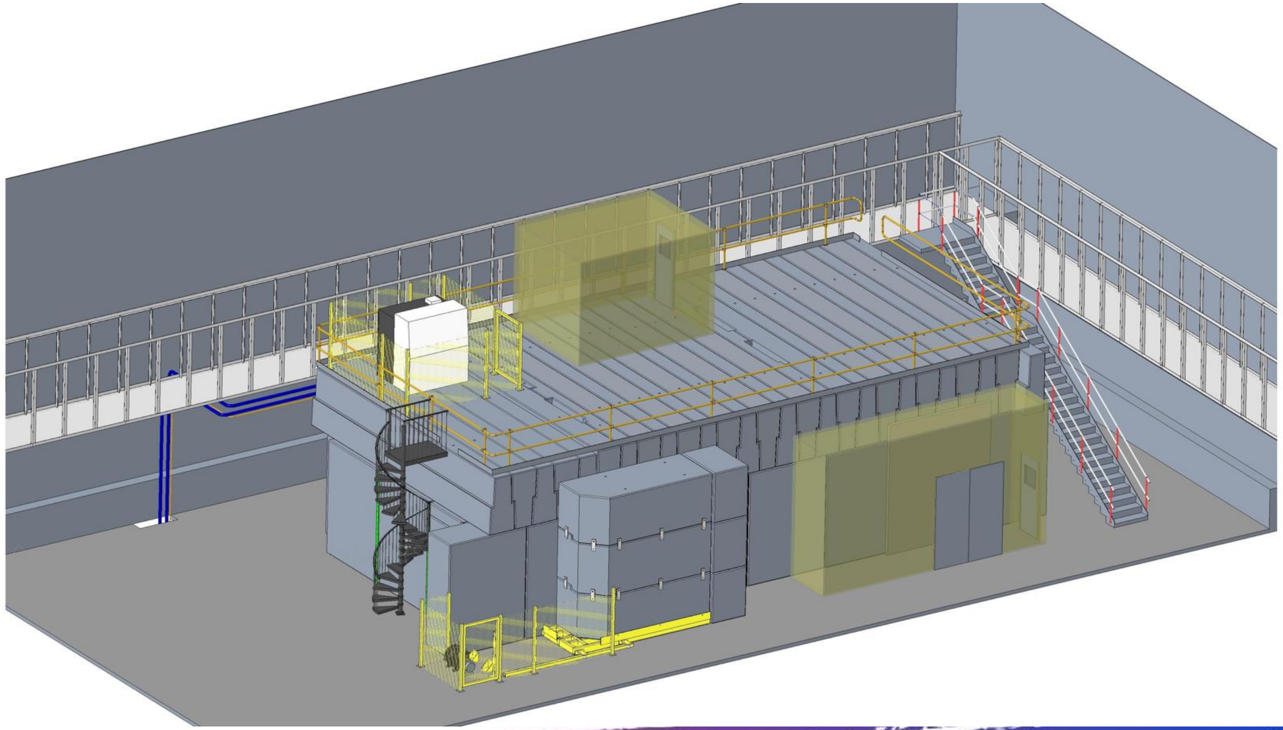
**PhD student will start in July 2023.**

- **T1:** Summarise analytical description of the breakdown limit as a function of the control parameters
- **T2:** Breakdown simulations cross check with different packages; Identify the weak points of the cavity, optimise design for breakdown testing
  - Astra + SuperFish (fast particle tracking)
  - CST Particle Studio and RFtrack (field emission, multipactor) -
  - XOOPIC/Vsim (field emission + plasma ionization process)
- **T3:** Re-optimize the shape of the acceleration cavity based on T2 to reduce the BRD. Other novel concepts will also be evaluated.
- **T4:** Breakdown experiments and AI-enhanced data analysis to benchmark T1-T3

This research plan is made to meet the criteria and completeness of a PhD thesis. It may have some overlapping with CEA. Further adjustments will be made accordingly.
T1-T3 can be carried out stand-alone. T4 will be dependent on the progress of the test stands.

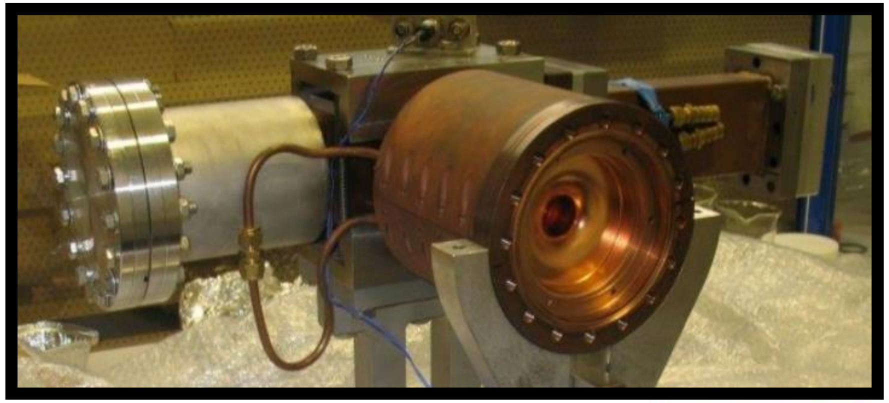
# UK Test Opportunities: Daresbury CI RF bunker

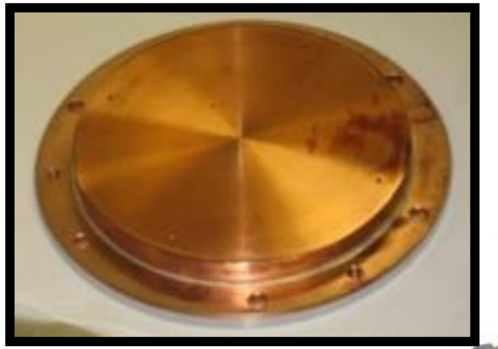
- Lancaster: RF testing & cavity design, Klystron design
- Strathclyde: Physics of breakdown & cavity design
- Southampton: Solenoid Design and construction
- STFC: Mechanical design, controls, lower B field testing on CLARA gun

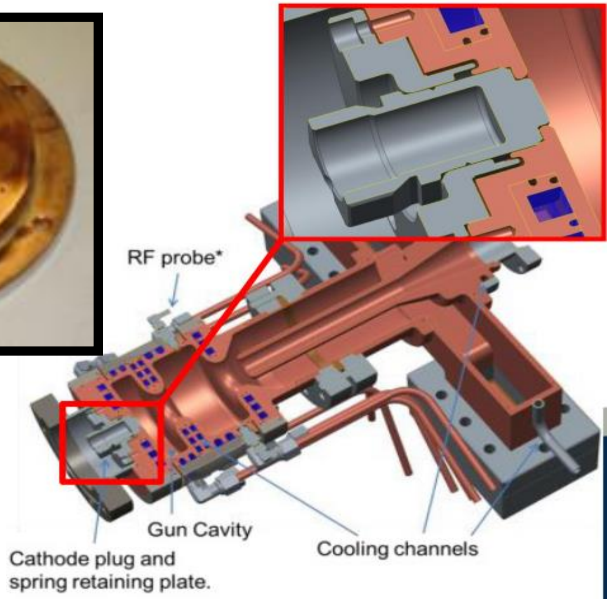


# RF breakdown testing

- S-band 7 MW klystron is available
- Southampton will design a magnet
- Can test different materials
- Can test the same sample with DC
- Still need
  - Design the RF cavity and magnet
  - Funds to construct both
  - Upgraded electrical, cryo and control for magnet
  - Effort to run the experiment
  - Effort for running low field tests on CLARA

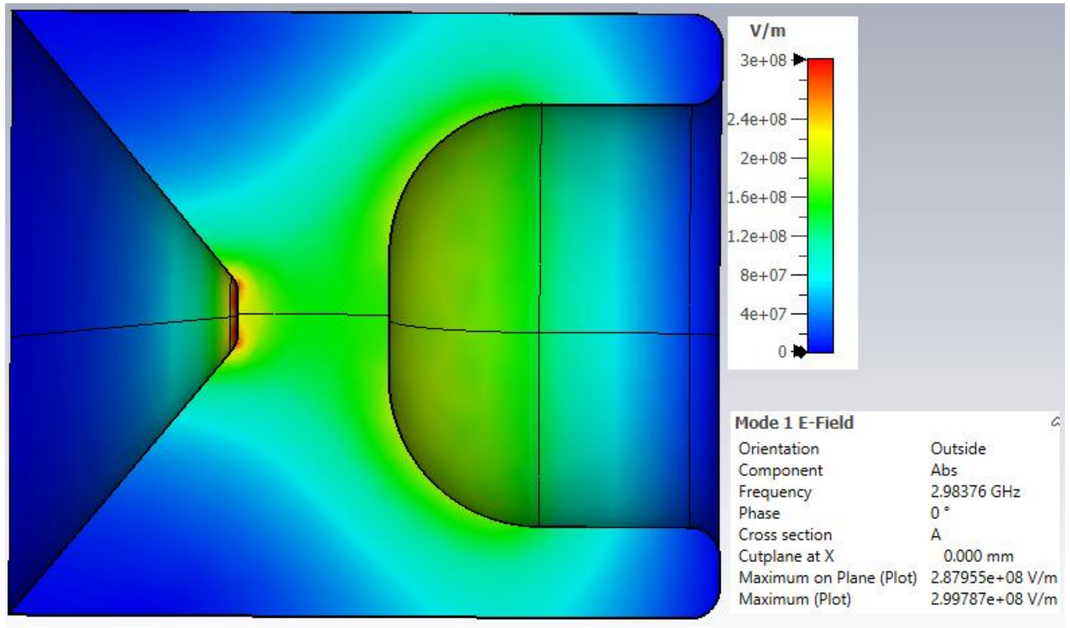


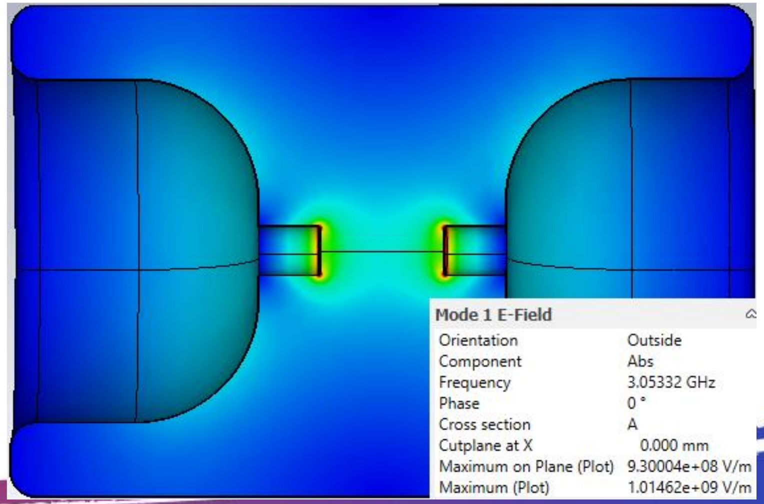




# Possible S band cavity schemes

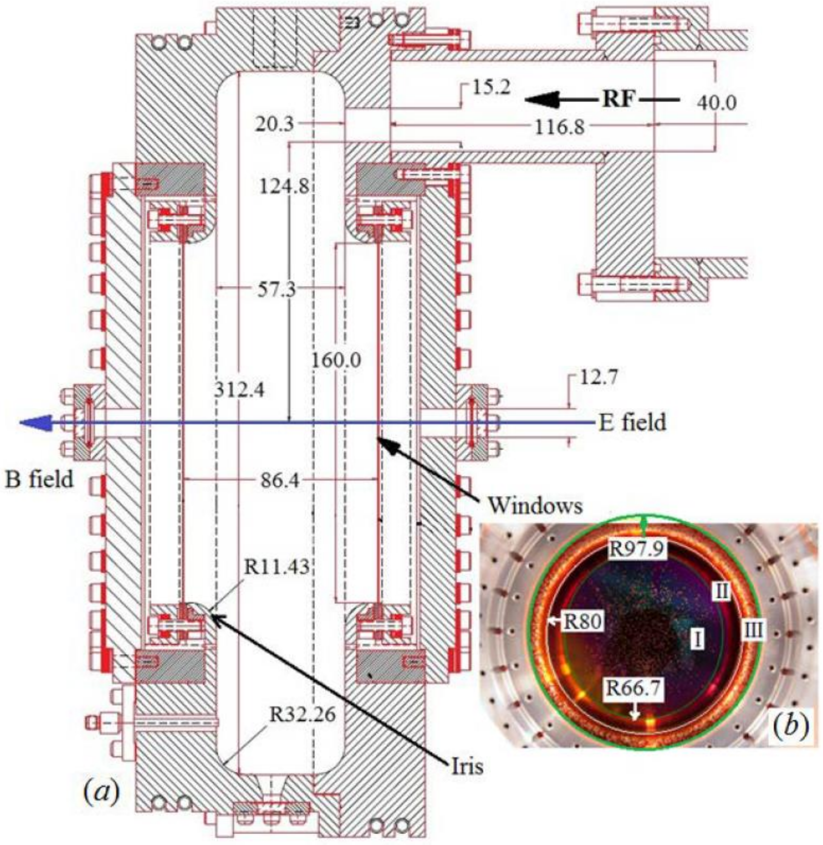
- Intend to have flexible scheme
  - Compatible with confines of likely magnet
- Diagram shows 40mm diameter system
- Cone/tips concentrates field strength
- Readily changeable endcap
  - Vary material easily
  - Asymmetric material test
  - Asymmetric fields
- Exploring options for compact nominally symmetric system
  - To compare with asymmetric scheme

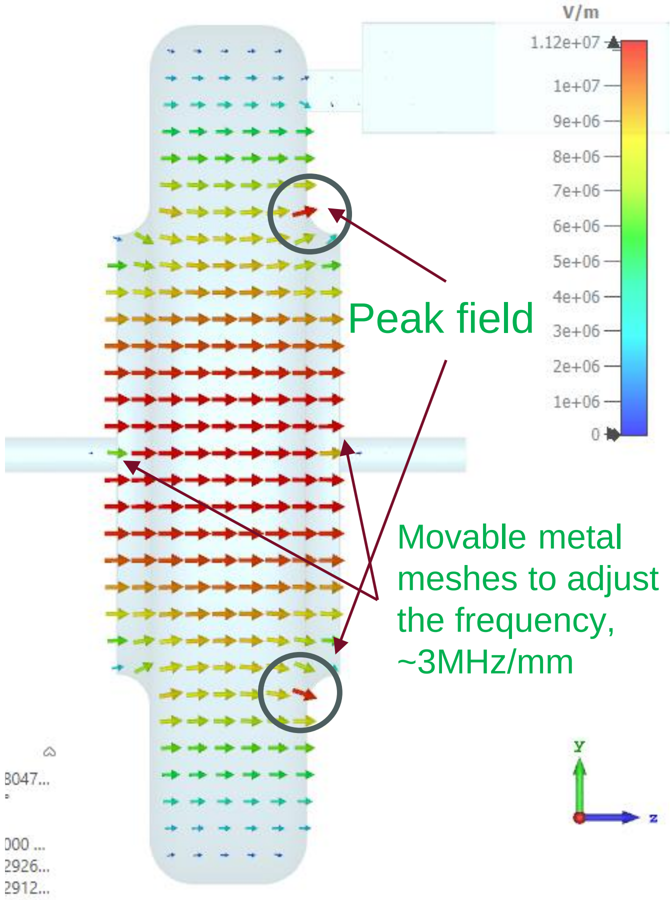


# Preliminary simulations - CST

## Validation of an 805MHz accelerator cavity




Next steps:

1. Postprocess the field distribution: find the maximum field points.
2. Apply the field emission model and B field to the model. Explore integration with RFtrack
3. Multipactor simulation of with secondary electron emission with/without B field.
4. Cavity shape re-optimizing

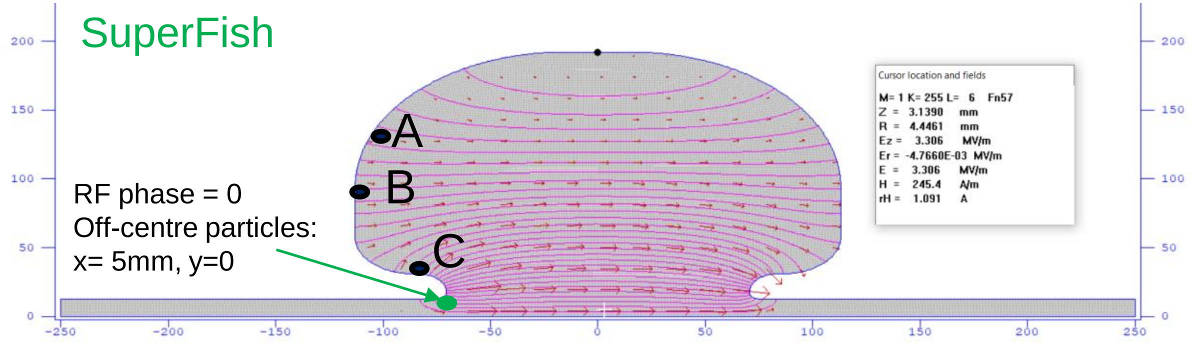
Potential challenges:

1. Accurate field emission model
2. Multi-physics simulation may be needed to include thermal
3. How to quantify better shapes (current? Peak field strength? Trajectories?)

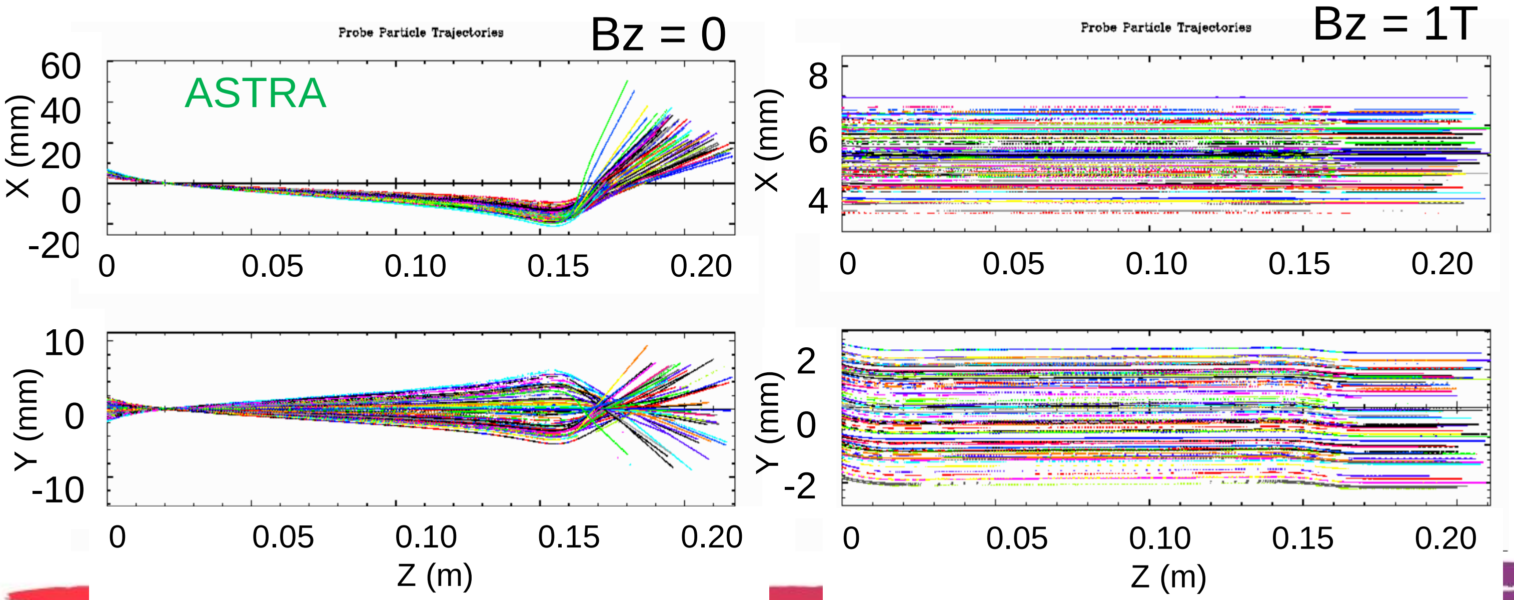
[1] M.R. Jana, et. al, Investigation Of Breakdown Induced Surface Damage On 805 MHz Pillbox Cavity Interior Surfaces, NAPAC2013, 2013

# Preliminary simulations – ASTRA

Example of a 600MHz cavity, not for Muon acceleration




Particle trajectories calculated with ASTRA look reasonable.
The B field has a big impact on the particle trajectories.




Questions to be solved:

1. ASTRA takes the on-axis field distribution. It is suspected that the off-axis field, e.g. points A-C, can be calculated correctly. Further investigation is required.
2. 3D field mapping may be used.
3. ASTRA does not have the field emission model, needed to generate the particles separately. [opportunity to add optimised, self-consistent emission model.]
4. Integrate SuperFish + ASTRA into automatic cavity shape optimisation

# Conclusion

- Our goal is to support the Muon collider working with other partners to address the physics questions on RF breakdown
  - Make optimal use of experimental capacity
- The research plan can be adjusted to align with broader program
  - Accommodate resource availability i.e. funding.
- Any suggestions are appreciated