



Sergio Calatroni

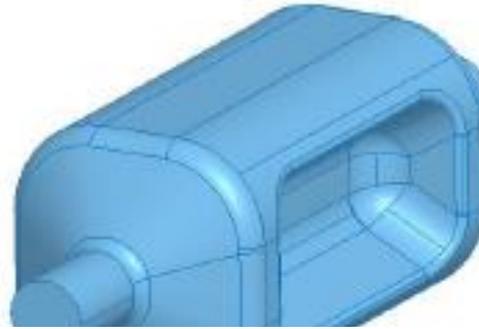
# **Nb/Cu crab cavities: evaluation and proposal**

# Crab cavity designs

4 rods



RF dipole



$\frac{1}{4}$  wave



# Can they be coated?

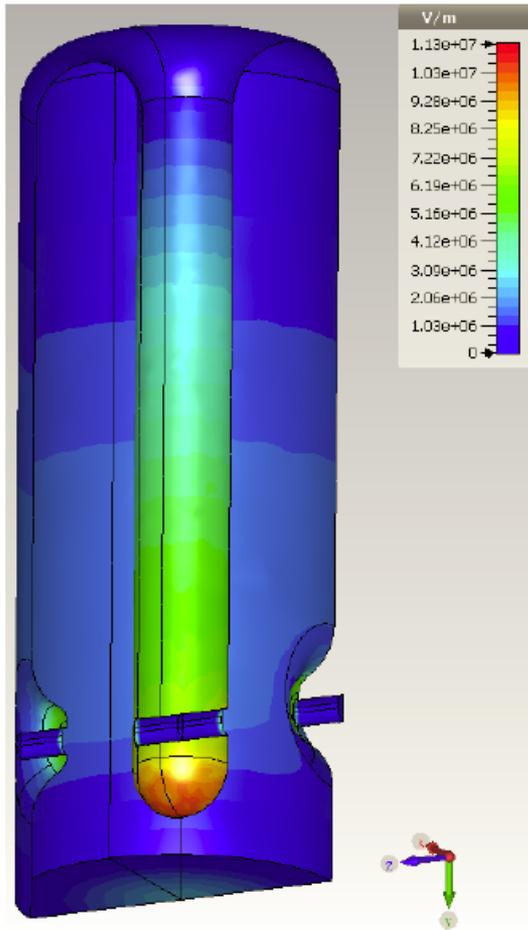


These geometries are extremely challenging for a typical sputter coating process

- **Motivation**
  - To avoid fast quenches for machine protection
  - Backup solution of baseline programme
  
- **Topics**
  - An example of a possible coating configuration
  - Necessary compromises
  - Expected performance
  - Future plans

# HIE-ISOLDE cavity characteristics

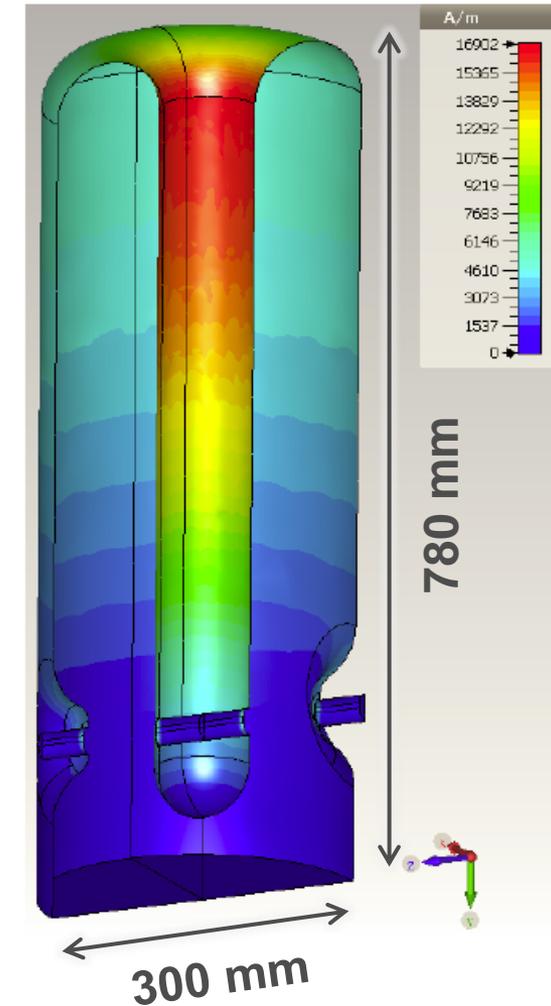
**|E| field**



Niobium coated on copper

Frequency	101.28 MHz
$E_{\text{acc}}$	6 MV/m
$\beta_{\text{optimum}}$	10.9%
R/Q	553 $\Omega$
$E_{\text{peak}}/E_{\text{acc}}$	5.0
$H_{\text{peak}}/E_{\text{acc}}$	95.6 G/(MV/m)
$G=R_s Q$	30.7 $\Omega$
$P_c$	7.7 W

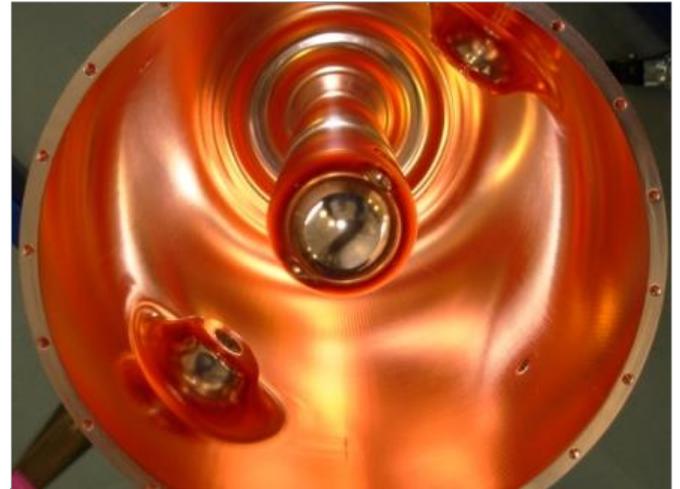
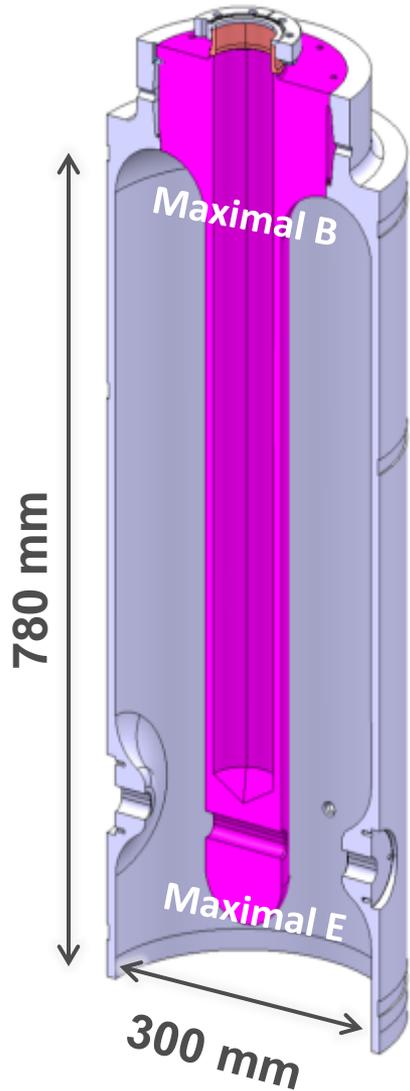
**|H| field**



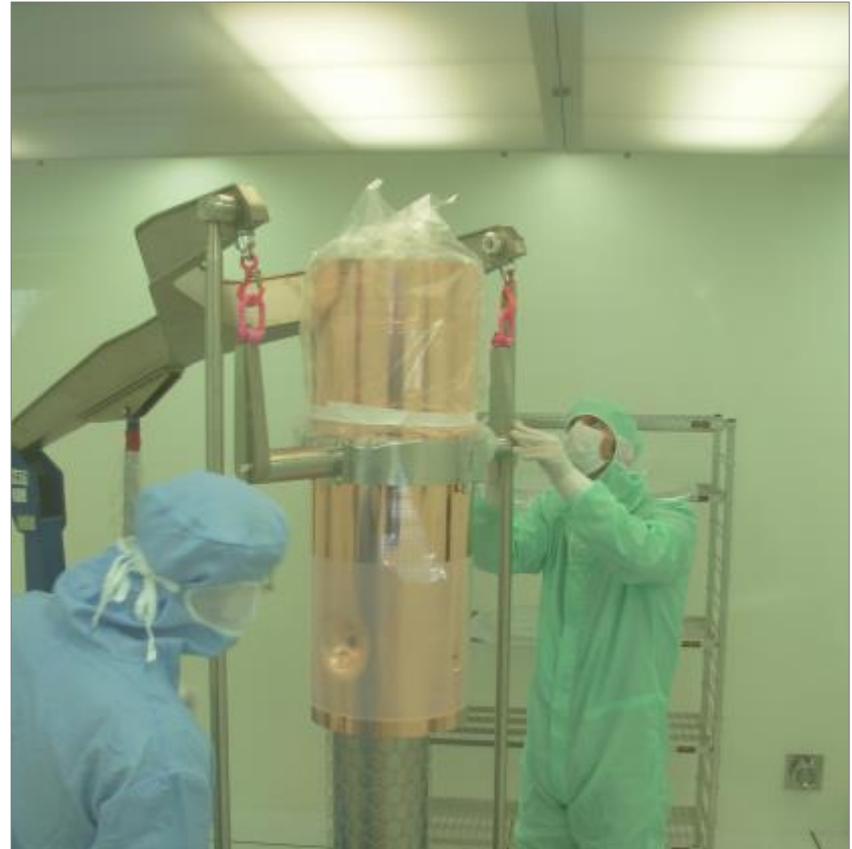
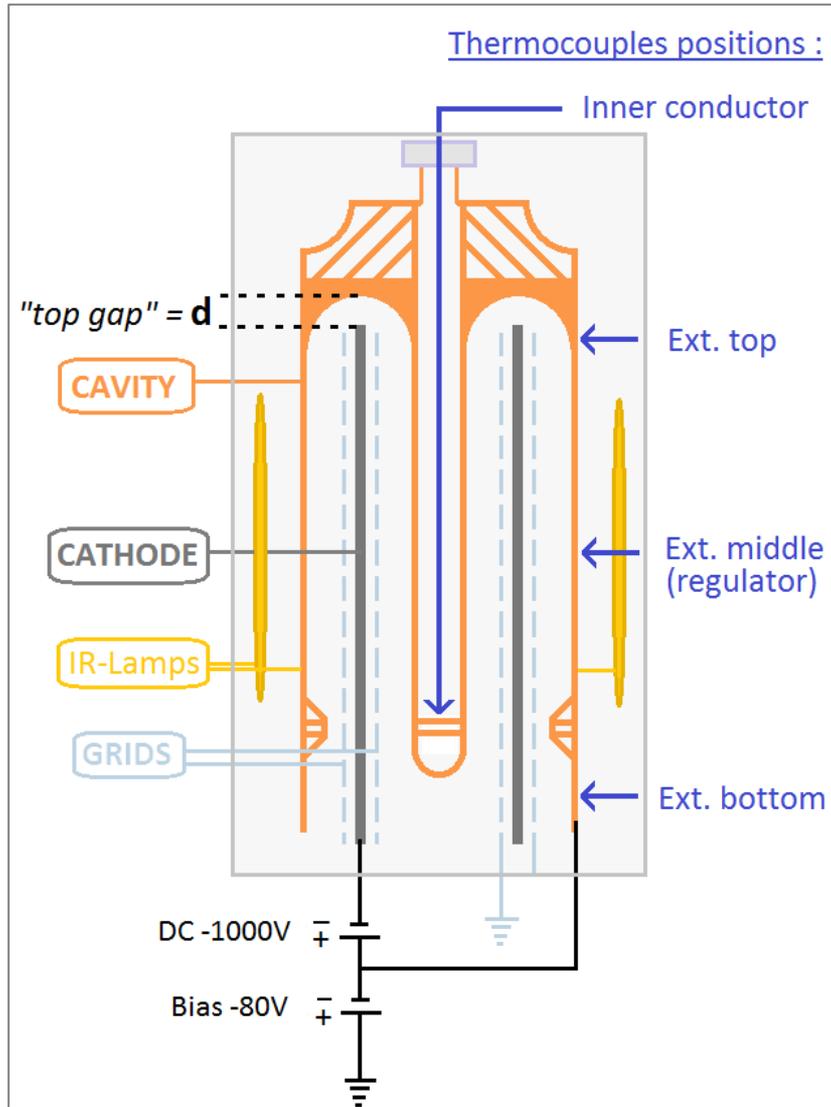
Courtesy: Pei Zhang

All plots are normalized to 1J of stored energy

# HIE-ISOLDE QWR coatings

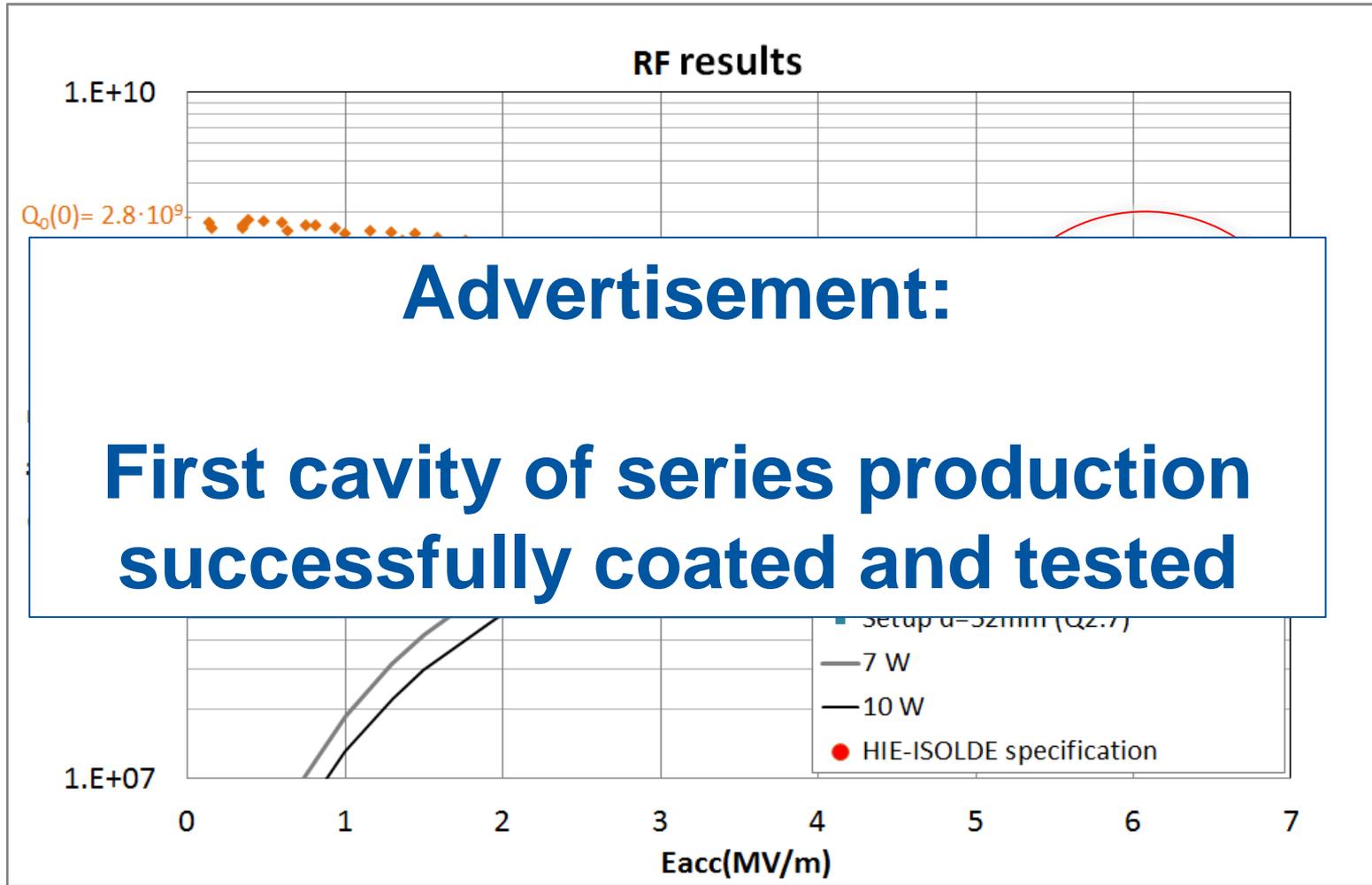


# HIE-ISOLDE coating process



Please refer to Noémie Jecklin's presentation at the recent HIE-ISOLDE workshop for details  
[Link here](#)

# HIE-ISOLDE performance

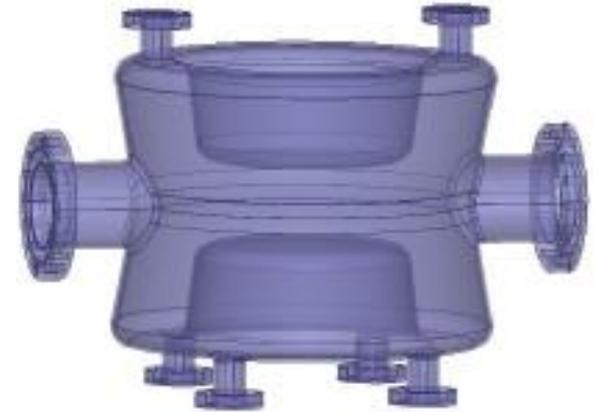
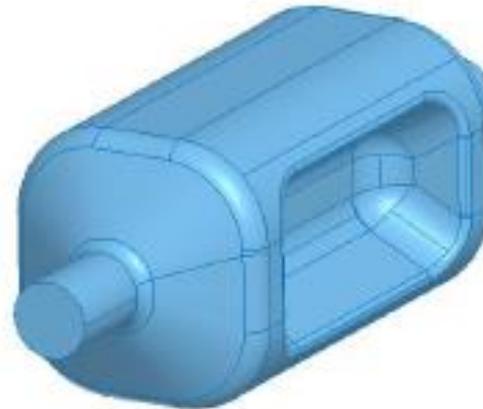
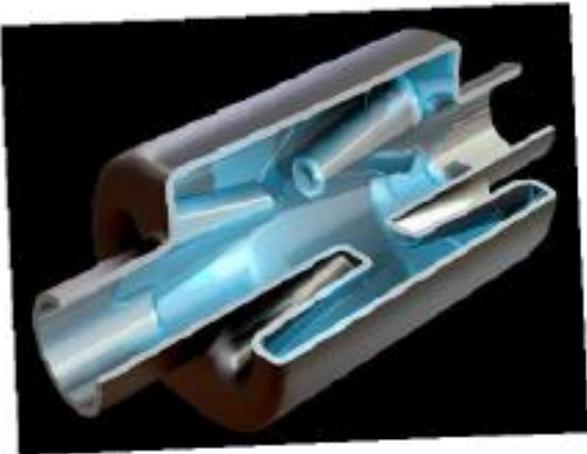


Courtesy: W. Venturini Delsolaro, I. Mondino

# Coated crabs

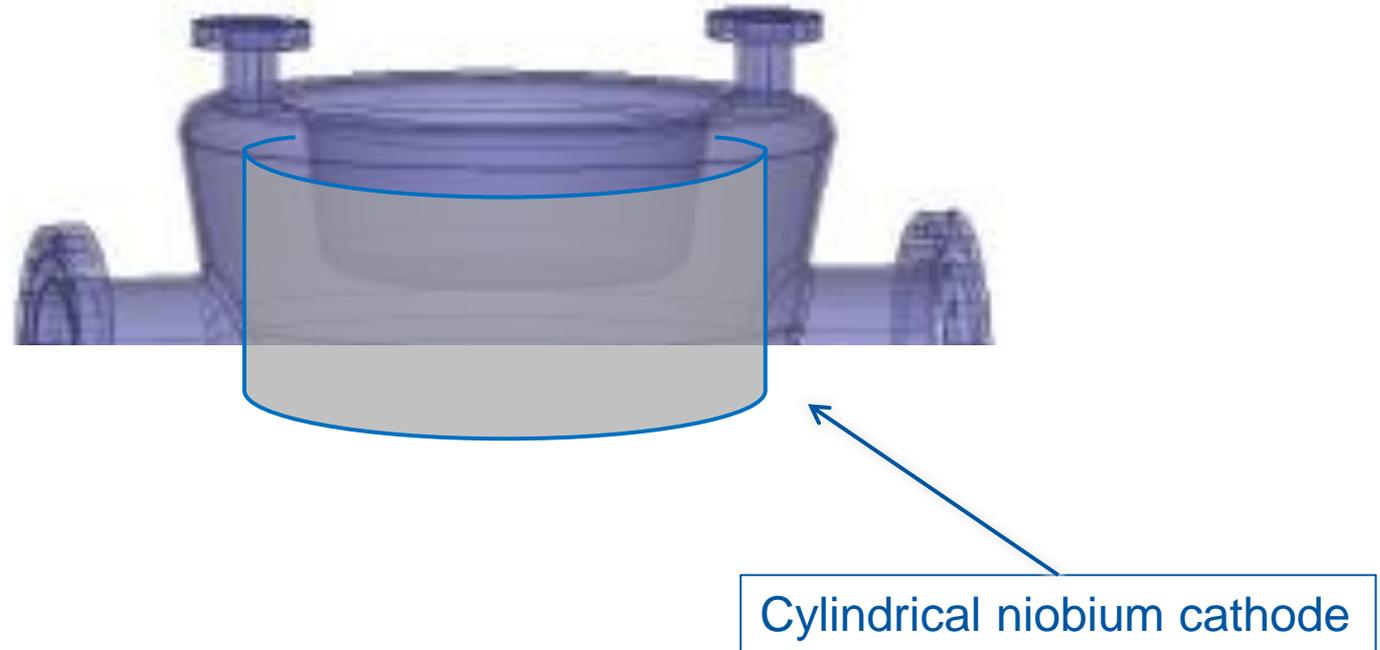
- It is proposed to **rely upon the technology available for the coating of QWR cavities**
- It is possible to identify suitable symmetry planes in order to obtain **a similar coating topology**

# Topologies



# Quarter wave

A topological configuration similar to HIE-Isolde QWR is possible

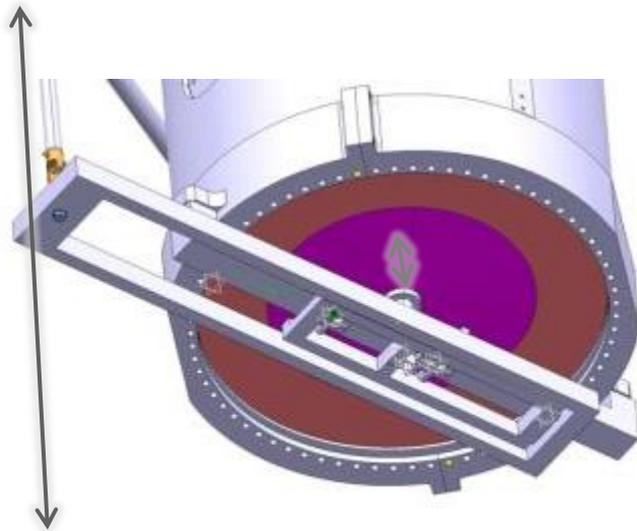
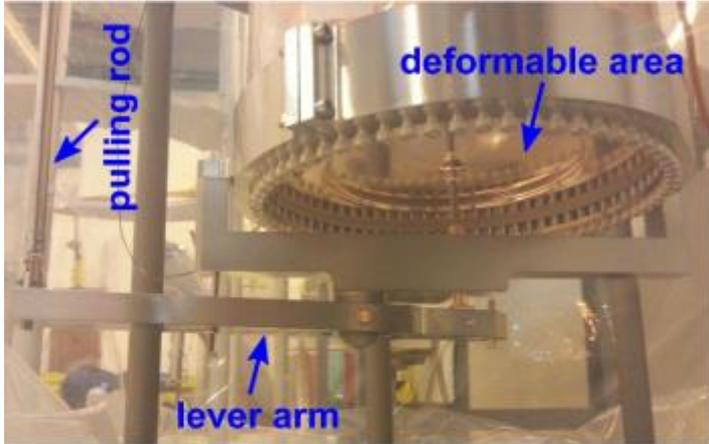


Coat, then clamp onto the other symmetric half

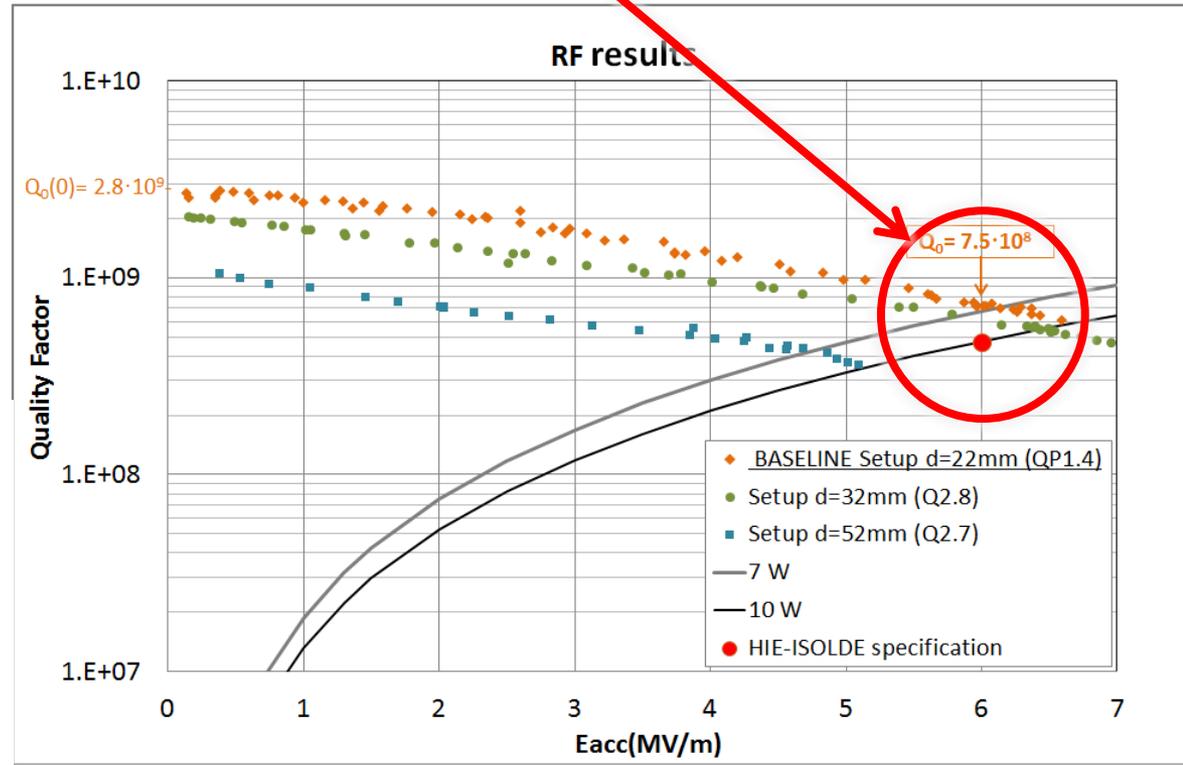
# Major questions

- Impact of the cut
  - Effect on performance
  - Joining techniques
  - Common vacuum or separate vacuum cryostat
- Expected performance
  - $R_{\text{BCS}}$  and  $R_{\text{res}}$
  - Frequency scaling

# HIE-ISOLDE tuning plate

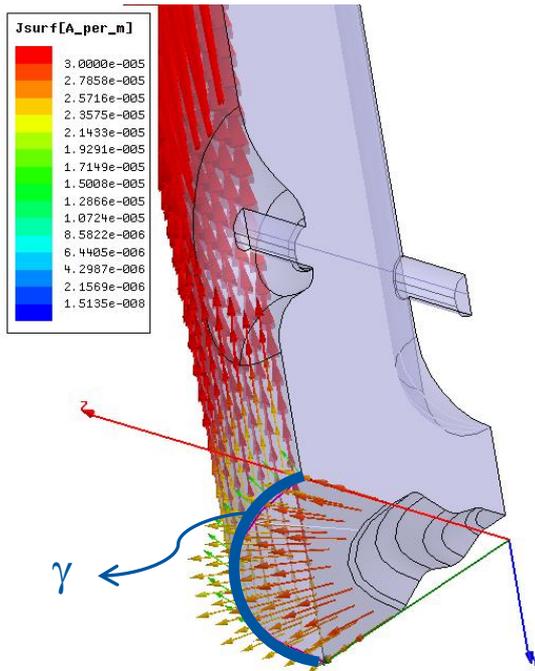


Losses due to clamped tuning plate certainly lower than 7 W at 6 MV/m



Courtesy: L. Alberty, O. Capatina

# HIE-ISOLDE tuning plate



$$I_{junction} @ 6MV/m = 4\alpha \oint \vec{H} \cdot d\vec{\ell} = -1.1553kA$$

$$\langle I_{junction}^2 \rangle \left( \equiv \frac{I_j^2}{\dots} \right)$$

Depending on contact force, we have measured lower contact resistances at room temperature, as indirectly confirmed by RF measurement

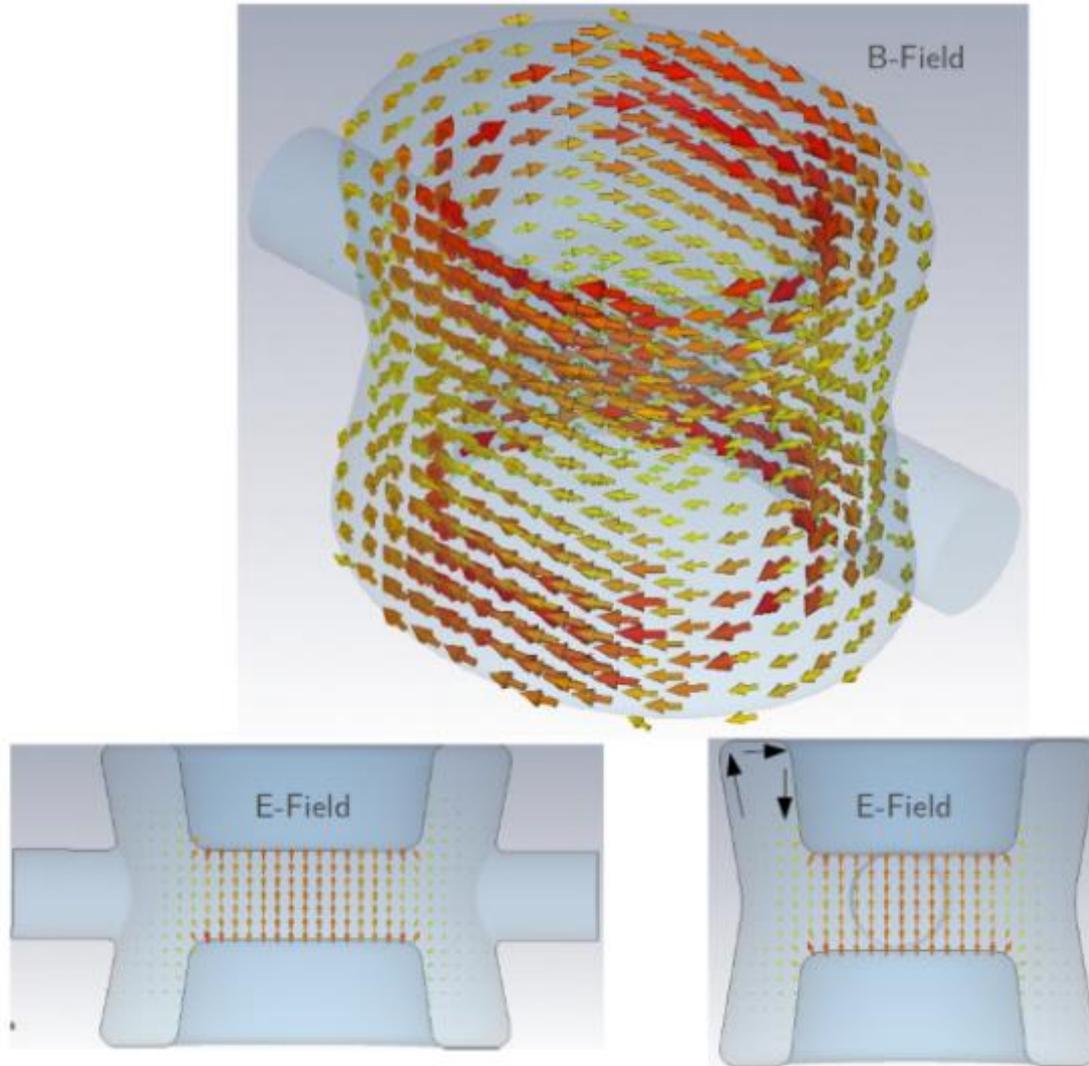
$$P_{junction} [W] = R_C \langle I^2 \rangle$$

Thermal stability studies of the tuning plate indicate losses are much lower

	$R_C = 4.5\mu\Omega$	$R_C = 5\mu\Omega$	$R_C = 14\mu\Omega$
$P_{junction} (W) @ 6MV/m$	3	3.34	9.34

Courtesy: A. D'Elia

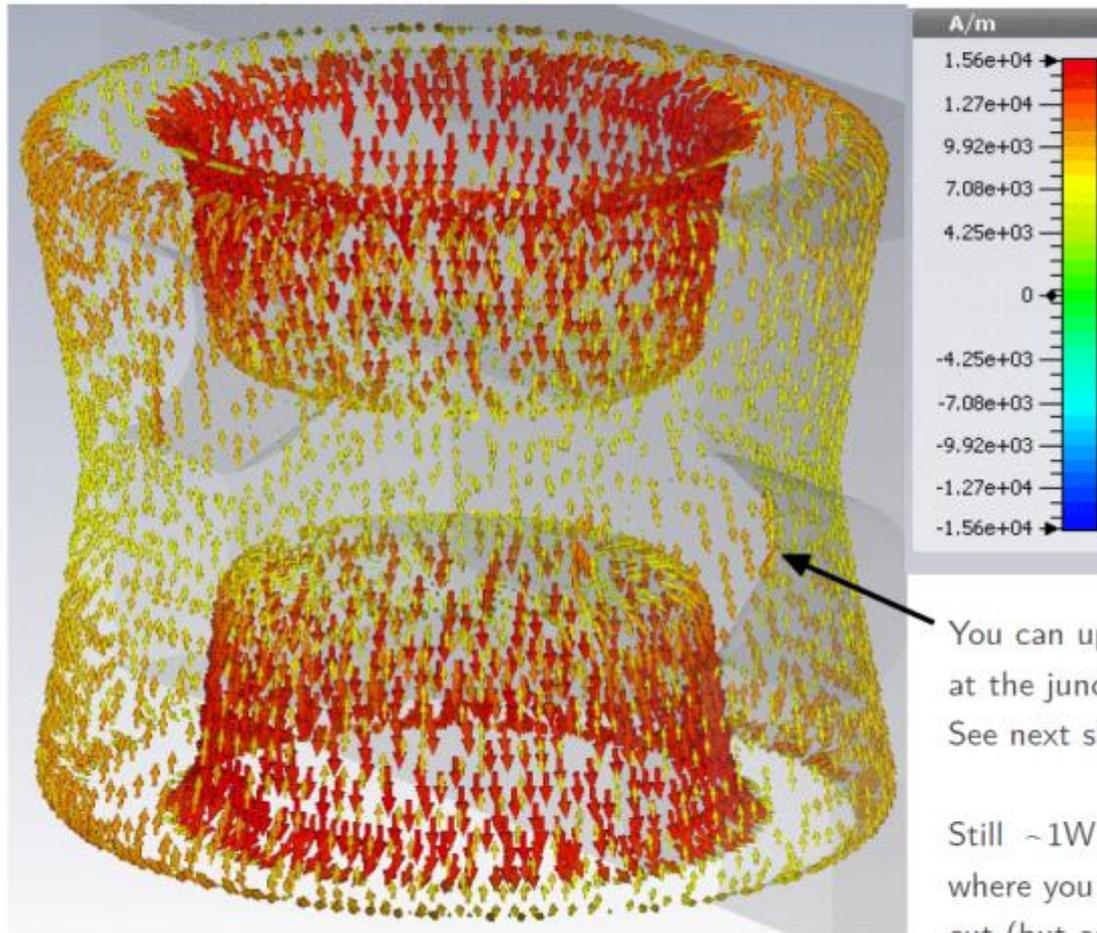
# QWR-crab field configuration



Courtesy: R. Calaga

# QWR-crab surface currents at mid-plane I

Surface Currents



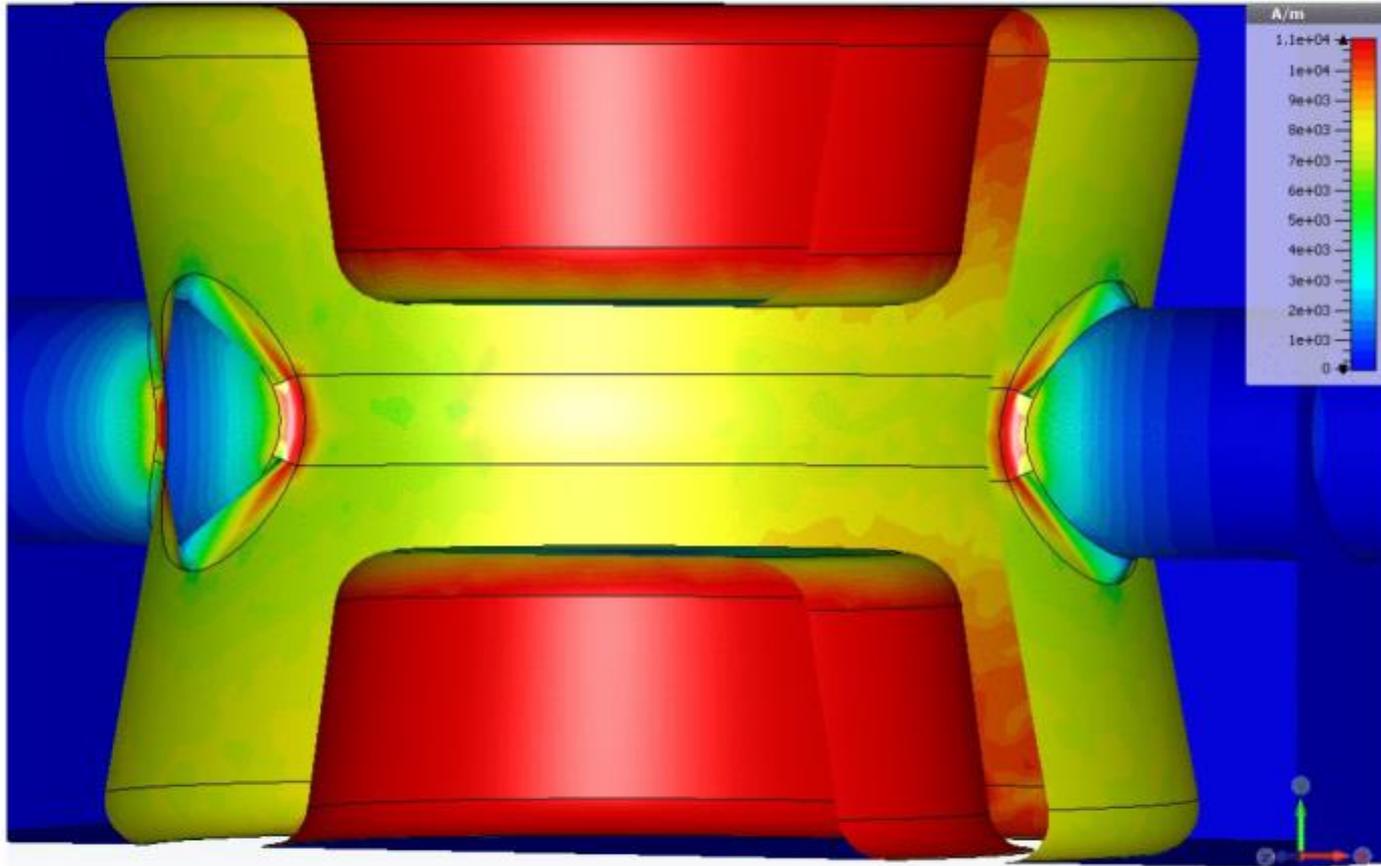
You can up to 40 kA/m  
at the junction  
See next slide for contour plot

Still  $\sim 1\text{W}$  in the critical region  
where you want to implement a  
cut (but assuming  $\sim 150\text{ nOhms}$ )

Courtesy: R. Calaga

# QWR-crab surface currents at mid-plane II

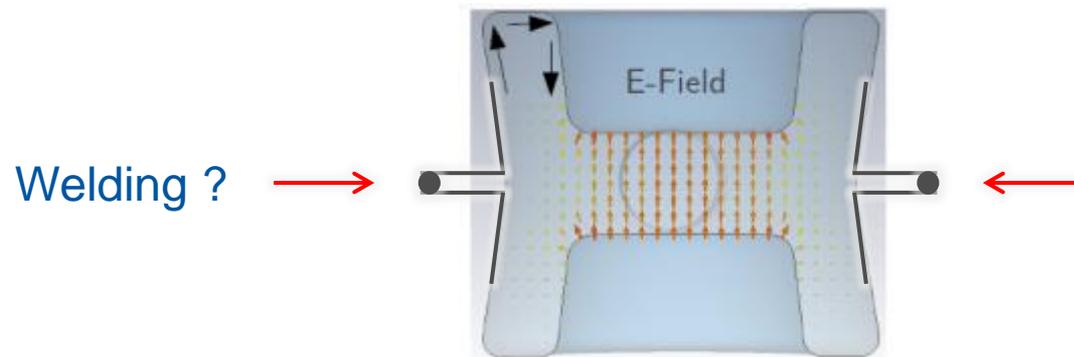
Surface Currents



Courtesy: R. Calaga

# Summary current across cut

- Current of the order of a few kA/m, total current a few kA
  - RF design of beam port region can be optimized
- Maximum losses of a **few watts** in case of clamped connection
  - Other connection possibilities can be studied which might allow also leak tightness (HIE-ISOLDE has common vacuum cryostat)



# Expected global performance

	Frequency	Rs at nominal field	Peak surface magnetic field	Peak surface electric field	Dissipated power	Operating temperature
HIE-ISOLDE QWR	101 MHz	65 nOhm	60 mT	34 MV/m	10 W	4.5 K
Crab Nb-bulk	400 MHz	~ 10 nOhm	65 mT	35 MV/m	A few watts	1.7 K
LHC RF Nb/Cu	400 MHz	300 nOhm	45 mT	20 MV/m	Few tens W	4.5 K

- (Reference to data sources missing, apologies)
- **Substantial equivalence of peak fields between QWR and crab**
- **Losses (surface resistance) analysed in next slide**

# Performance scaling

101 MHz HIE-ISOLDE Nb/Cu	Surface resistance at 4.5K	Dissipated power at 4.5K	BCS component	Residual component
	65 nOhm	10 W	5 nOhm	60 nOhm

400 MHz LHC-Crab Nb/Cu	Calculated BCS component	Extrapolated residual component	Total surface resistance	Power dissipation range at 4.5 K
	80 nOhm	240 nOhm	320 nOhm	50 W <b>[**]</b>

$\omega^2$  scaling

$\omega$  scaling **[\*]**

[\*] Using recent data from Tobias Junginger's thesis with Quadrupole Resonator, 400/800/1200 MHz, instead of Tadashi Jogi's

[\*\*] Assuming similar geometry factor as for HIE-ISOLDE QWR's. Operation at 1.7 K would reduce this to 40 W (BCS->0). Data from Binping Xiao this morning match the above estimates

# Summary of performance

- Required surface fields can be achieved
- Losses estimated at 50 W at 4.2 K
- (Estimated at 40 W at 1.7 K)
- Expected losses from the cut are small

# Summary...

- A backup solution is needed in parallel of baseline, if machine protection is a showstopper for crab cavities
- Safety (from quenches) has a cost: power dissipation
- Surfaces fields can be attained with Nb/Cu
- Having a split cavity is common in SC technology (ALPI, HIE-ISOLDE, FRIB...)
- A common vacuum individual cryostat is also common, lots of experience in cold-warm transitions
  
- Cooling by conduction is an option with copper cavities, may suppress bath cryostat in favour of free flow circulation
- Massive copper allows excellent stability, even at 4.5 K
- Joining technology is presently a hot subject (probably a future TTC topical workshop on this)
- A sealed cavity would allow of course a separated vacuum cryostat
  
- Work is under way on improvements in coating technology for HIE-ISOLDE; experience will be reused

## ... and outlook

### Short term proposal (2-3 years)

- RF design to be optimized for a split cavity
- Engineering design to be implemented
- Simple prototypes can then be manufactured for a proof of principle
- Coating à la HIE-ISOLDE (2<sup>nd</sup> coating system soon available)
- Development and test can be done on one half cavity with a simple shorting plate
- Validation of principle

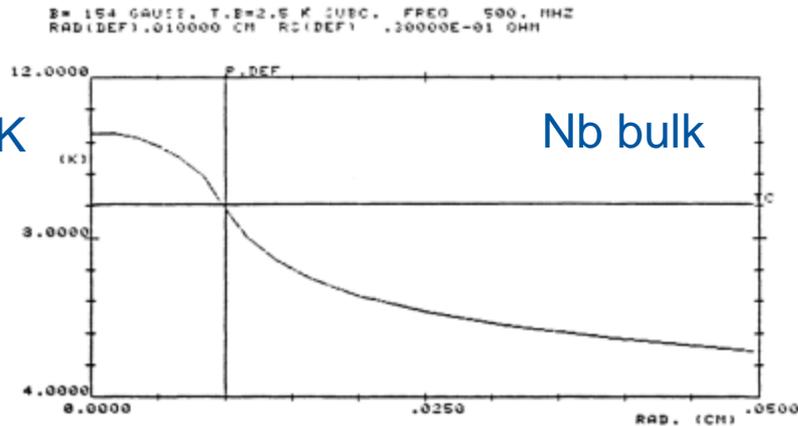
### Longer term, or in parallel

- Joining technology
- Cryostat design + ancillaries



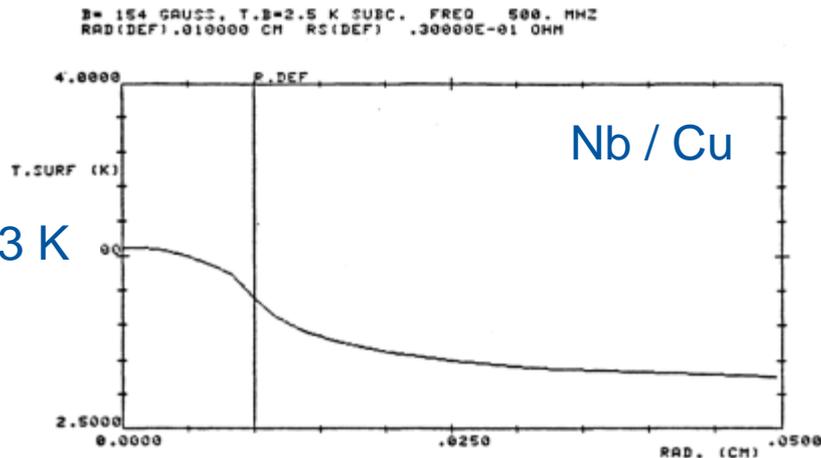
# Basic historic motivation

Nb: 10.2 K



Temperature distribution calculation for a 100 micron radius steel defect embedded either in niobium or in copper

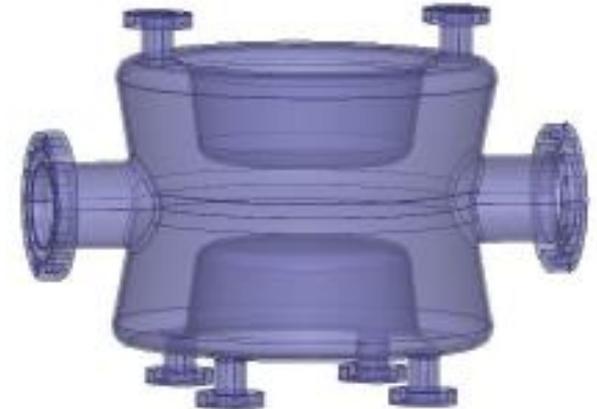
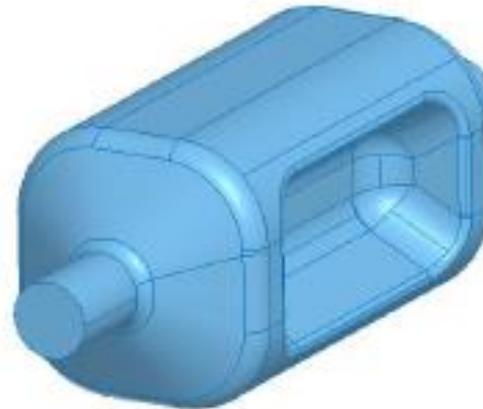
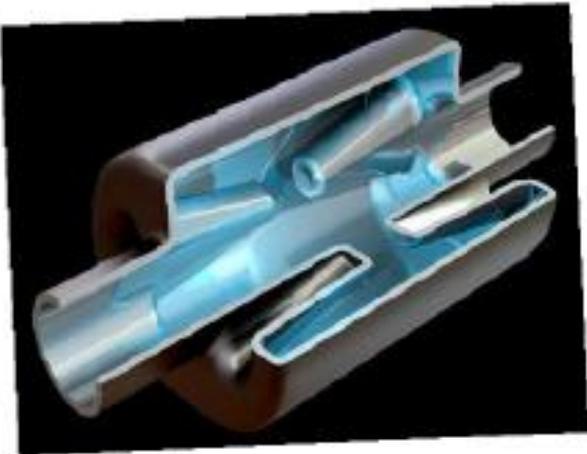
Nb/Cu: 3.3 K

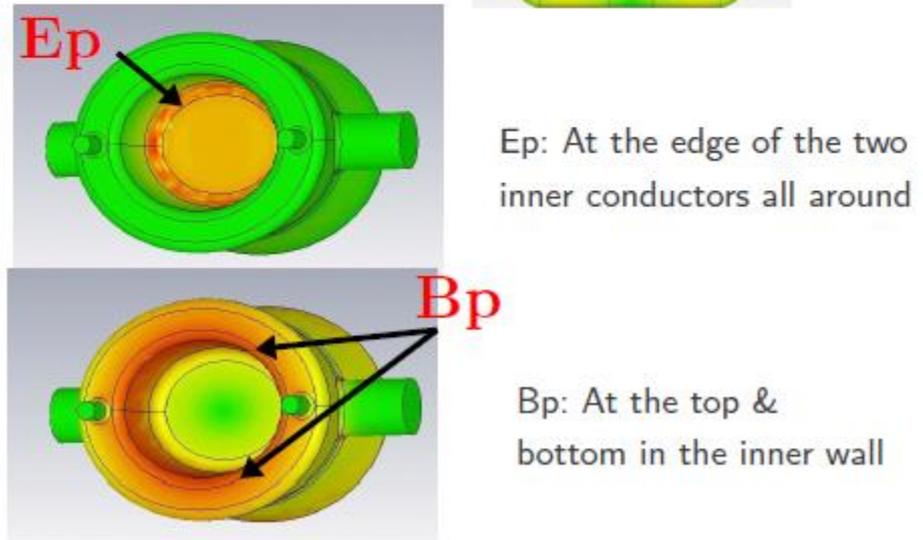
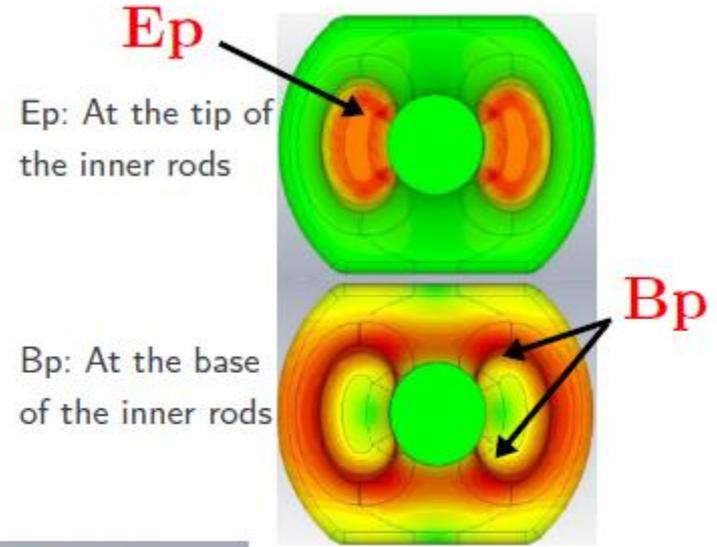
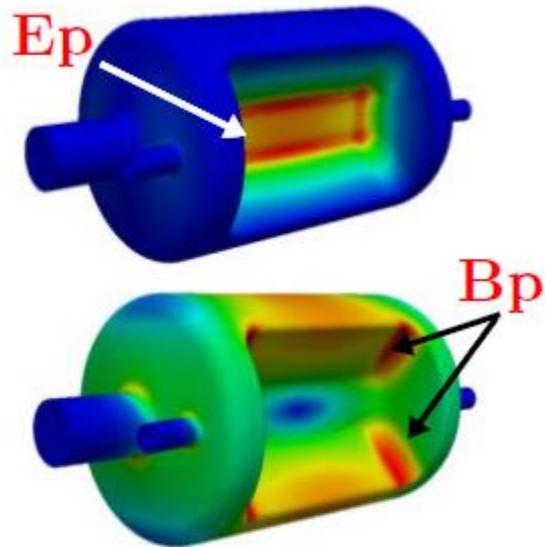


Joachim Tuckmantel - Thermal effects in superconducting RF cavities: some new results from an improved program  
CERN-EF-RF-84-6. - 1984.

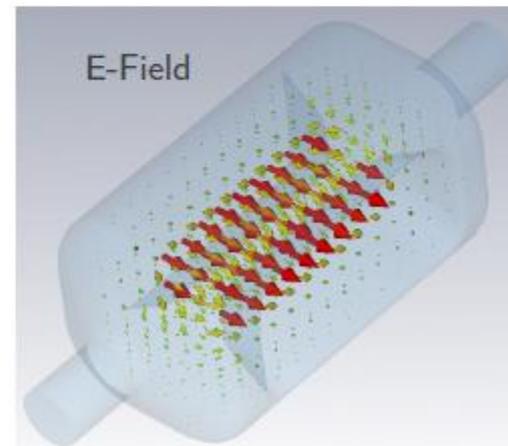
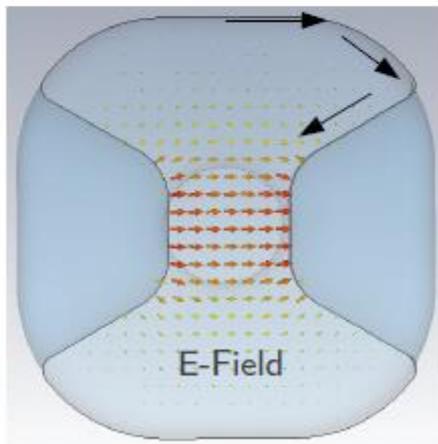
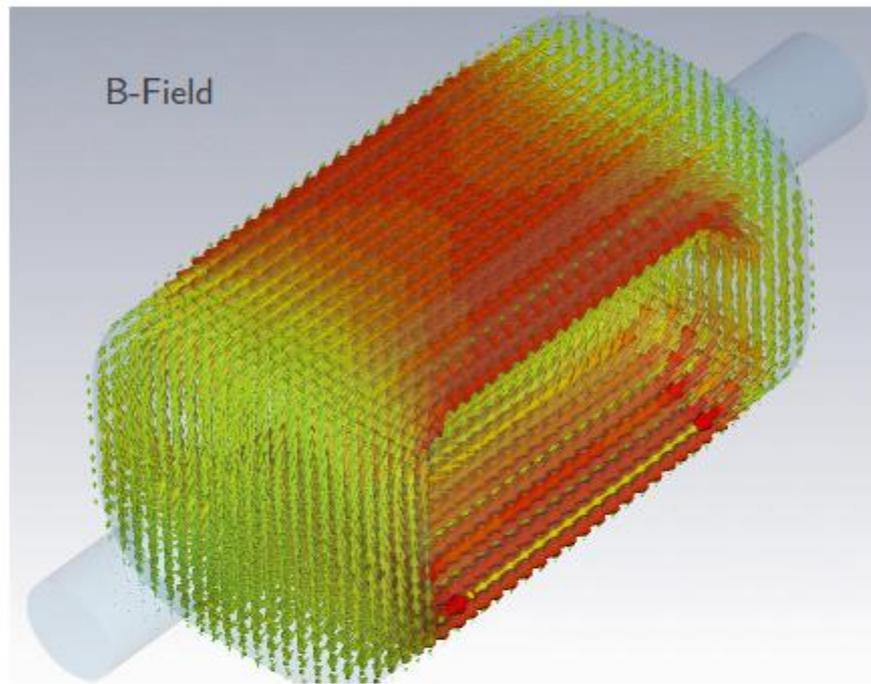
**Quenches cannot happen** because of the stabilising effect of the copper with respect to thermo-magnetic breakdown

# Topologies

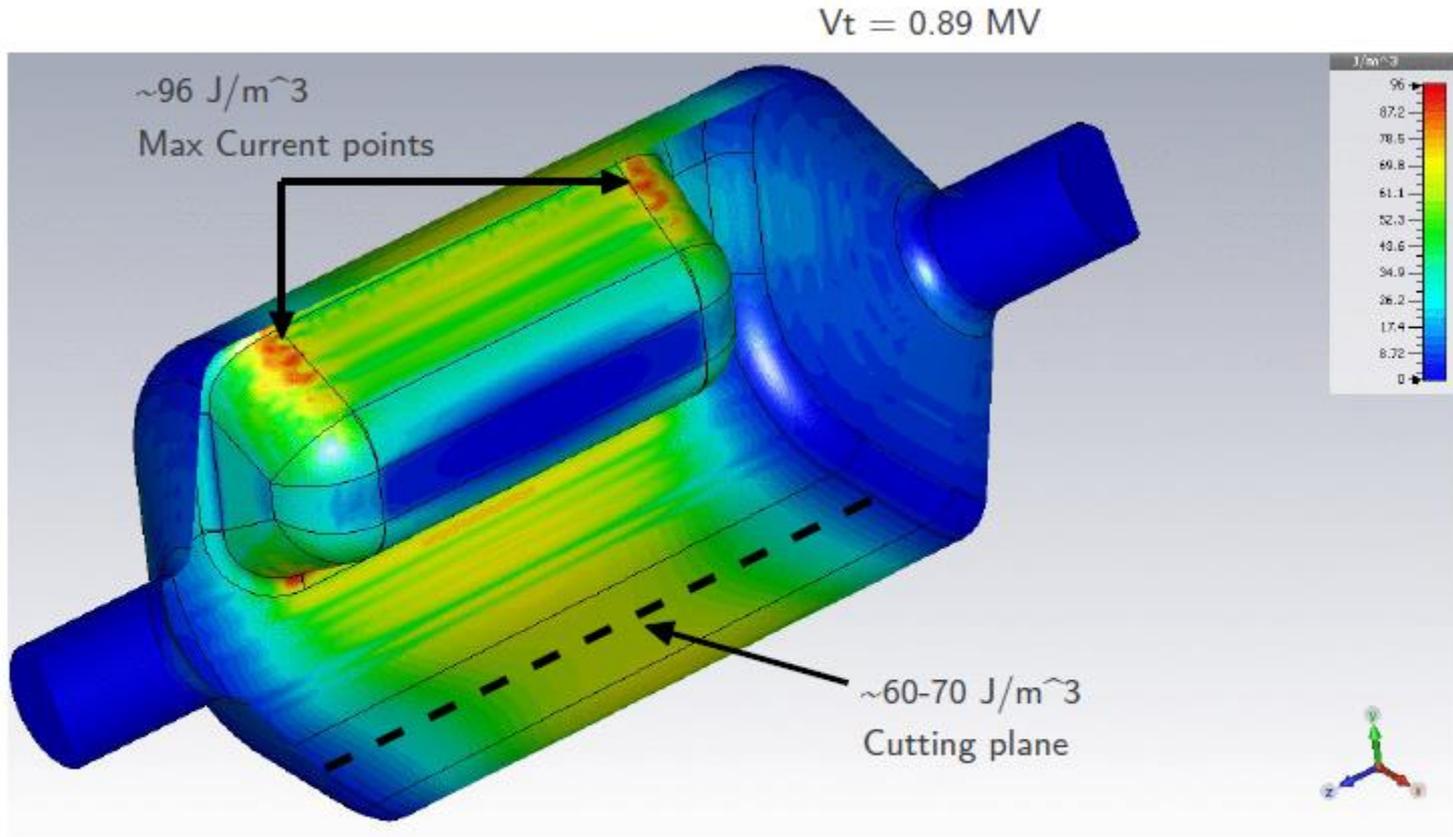




Courtesy: R. Calaga



Courtesy: R. Calaga



Most of the cutting plane has small currents  
except for beam pipe transition point (perhaps  
can be readjusted for coating purposes)

Courtesy: R. Calaga