# HIGH GRADIENT NORMAL CONDUCTING RADIO-FREQUENCY (NCRF) PHOTOINJECTOR SYSTEM FOR SINCROTRONE TRIESTE

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# INTRODUCTION

The Radio-Frequency (RF) design of an NCRF Gun for the Sincrotrone Trieste facility, which is termed “FERMI RF Gun 2” was originally based on the UCLA-University of Rome-INFN-LNF high repetition rate photoinjector*, which was improved upon the LCLS[#] version by use of large radius of curvature of the input coupler irises, and by inclusion of enhanced cooling channels in the most highly dissipative regions in the structure.

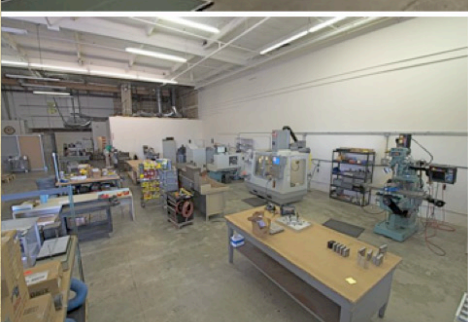
*L. Faillace *et al.,* “ An Ultra-high repetition rate S- band RF Gun”, FEL Conference 2008
[#]C.Limborg *et al.,* “RF Design of the LCLS Gun”, LCLS Technical Note LCLS-TN-05-3 (Stanford,2005).

# OUTLINE

- Company Overview
- Radio-Frequency design of the photoinjector system
- Beam dynamics simulations
- Thermal/Stress Analysis
- Conclusions

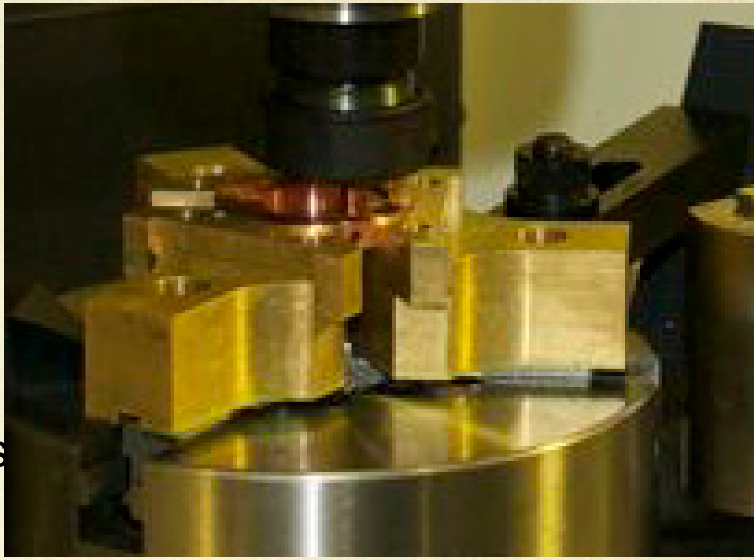
# RESOURCES AND CAPABILITIES

- Enhanced engineering/manufacturing capabilities
  - New Facility + recent expansion
  - New Equipment
- Studied and Developed RF manufacturing process workflows
- Increased RF testing/validation capabilities
- Developed custom UHV/RF component cleaning and assembly facilities
  - Following SLAC developed guidelines
  - Presents us with full control over *almost* all critical processes (no oven)
- Collaborations with Universities and National Laboratories

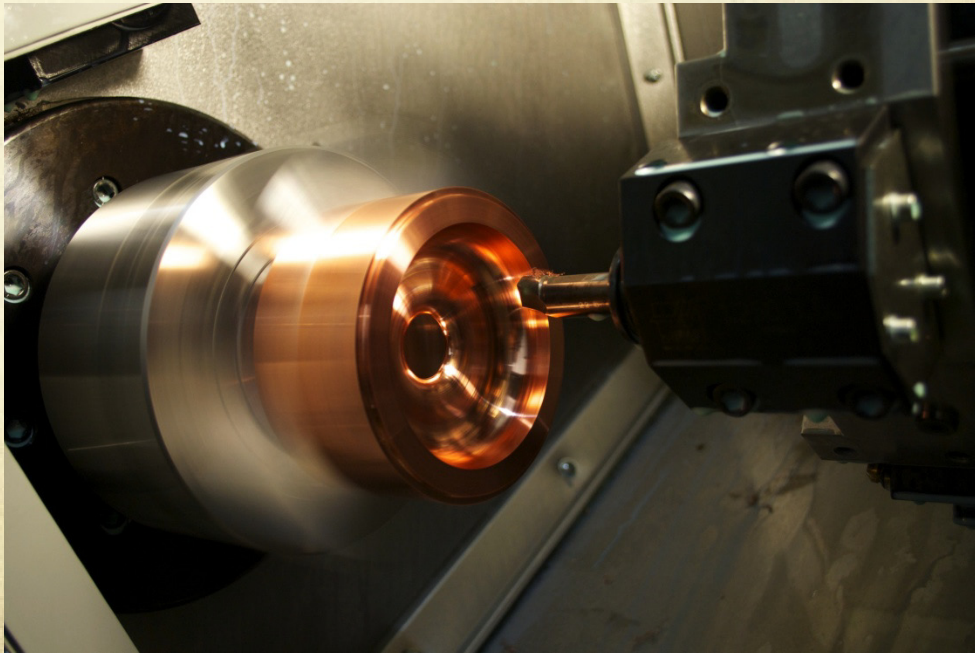


# CELL MACHINING AND CLEANING

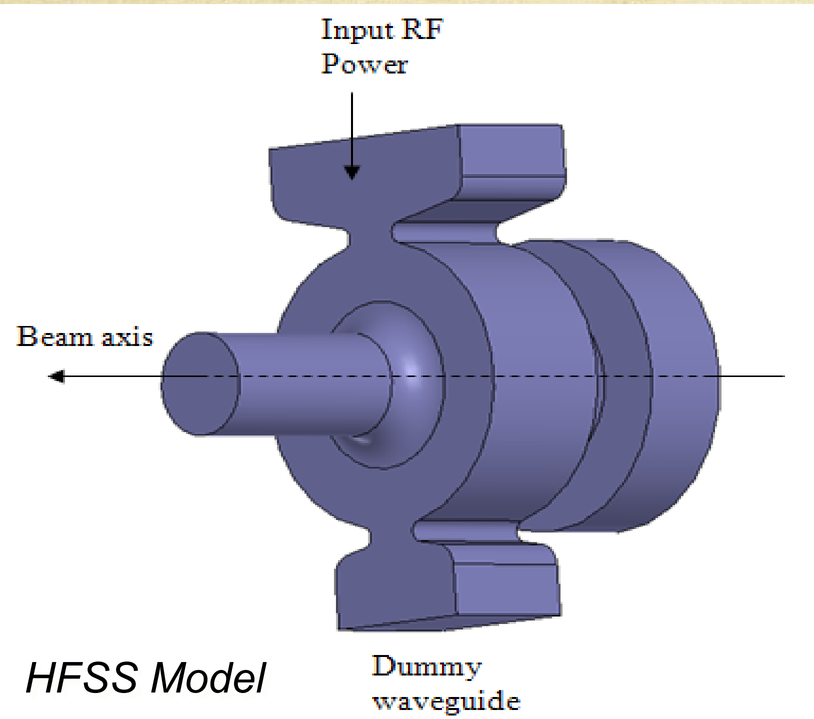
- CNC mills and lathes
  - Capable of 0.0002” precision and repeatability (lathe)
  - 2-4 micron flatness
  - 4-6 micro-inch surface finishes (100-150nm)
  - Developed specialized workholding tooling
  - Optimized cutting tooling (PCD)
  - Refurbished or manufactured storage and travel containers
  - Considerable man-hours invested into process and handling systematics



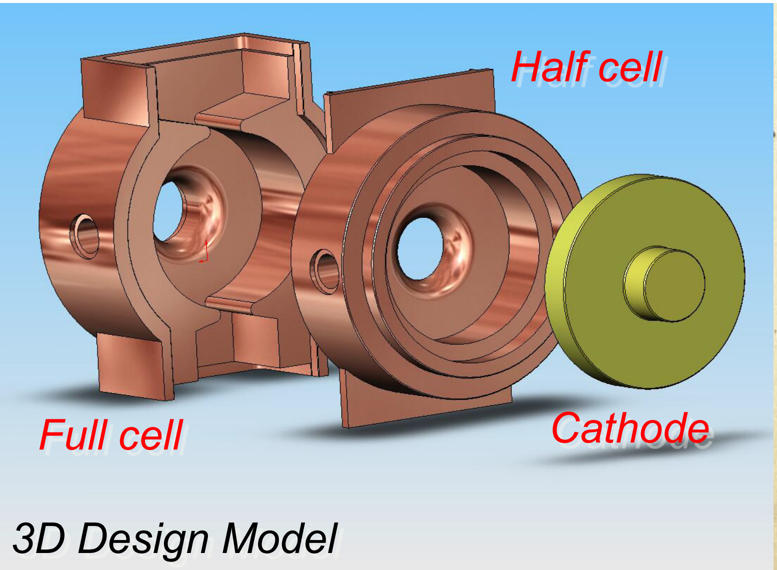
- Chemical cleaning room
  - With guidance from SLAC MFD
  - Utilize a modified version of SLAC cleaning processes
- Clean Assembly / Testing Room
  - Class 100 / Class 1000



# RF GUN DESIGN



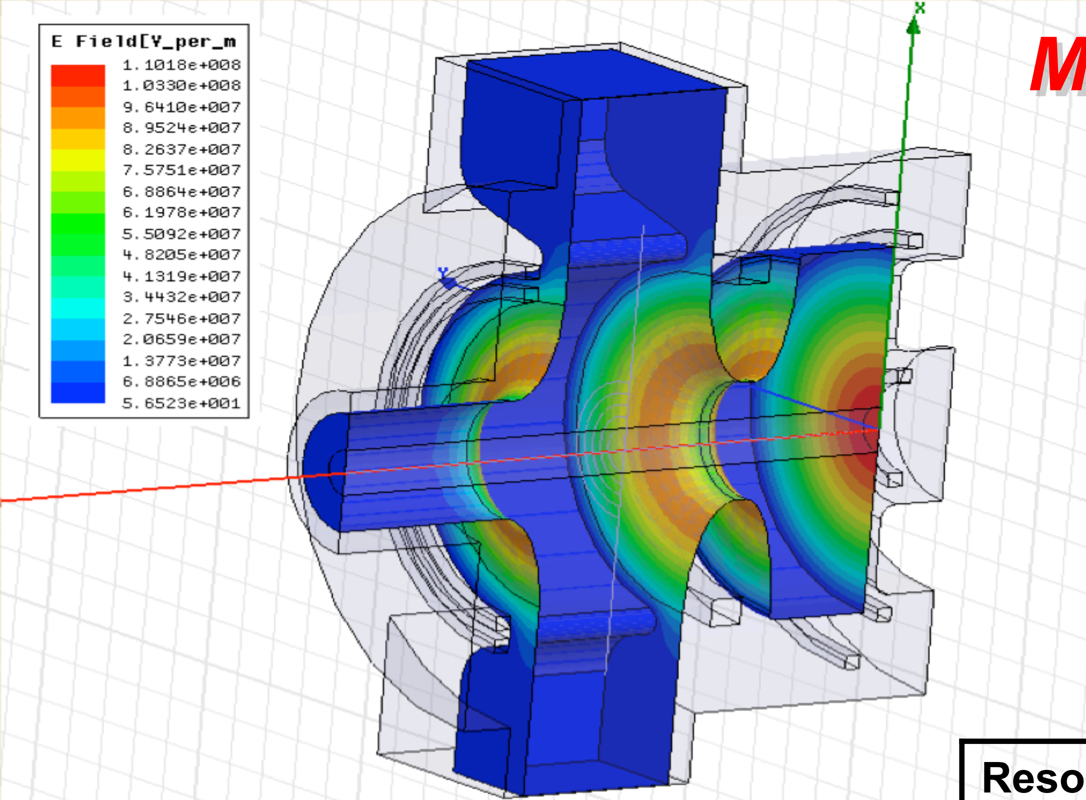

*HFSS Model*



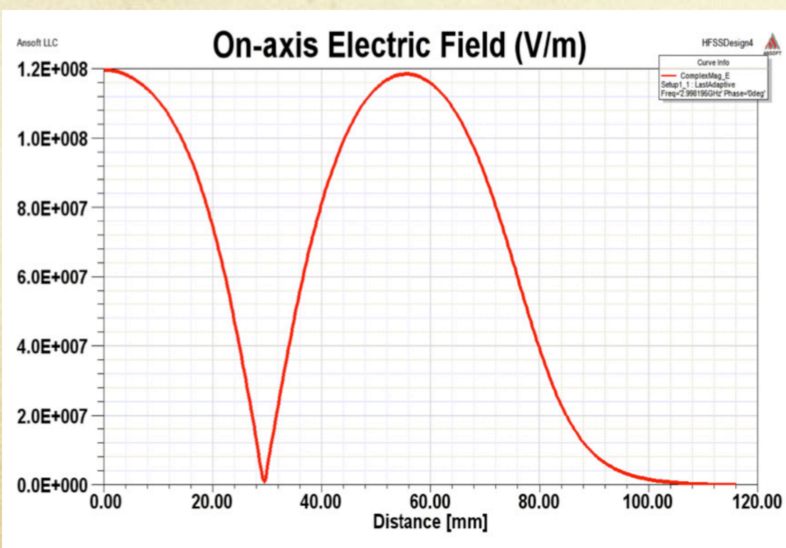

*3D Design Model*

- Operation frequency 2.998 GHz, π-mode
- 1.6 cell gun
- Single feed
  - ✓simpler RF power system than the case of dual feed
  - ✓Avoid phase shift between the two input waves in the case of dual feed
  - ✓dummy waveguide to diminish dipole field
- Race track geometry
  - ✓To minimize quadrupole field
- "z-coupling"
  - ✓To reduce H field, i.e. temperature rise, at the coupling slots
- Elliptical coupling irises
  - ✓To decrease surface electric field (cause of RF breakdowns)
- 50 Hz repetition rate
- Numeric codes for simulations: HFSS, Superfish.

# MAIN RF PARAMETERS

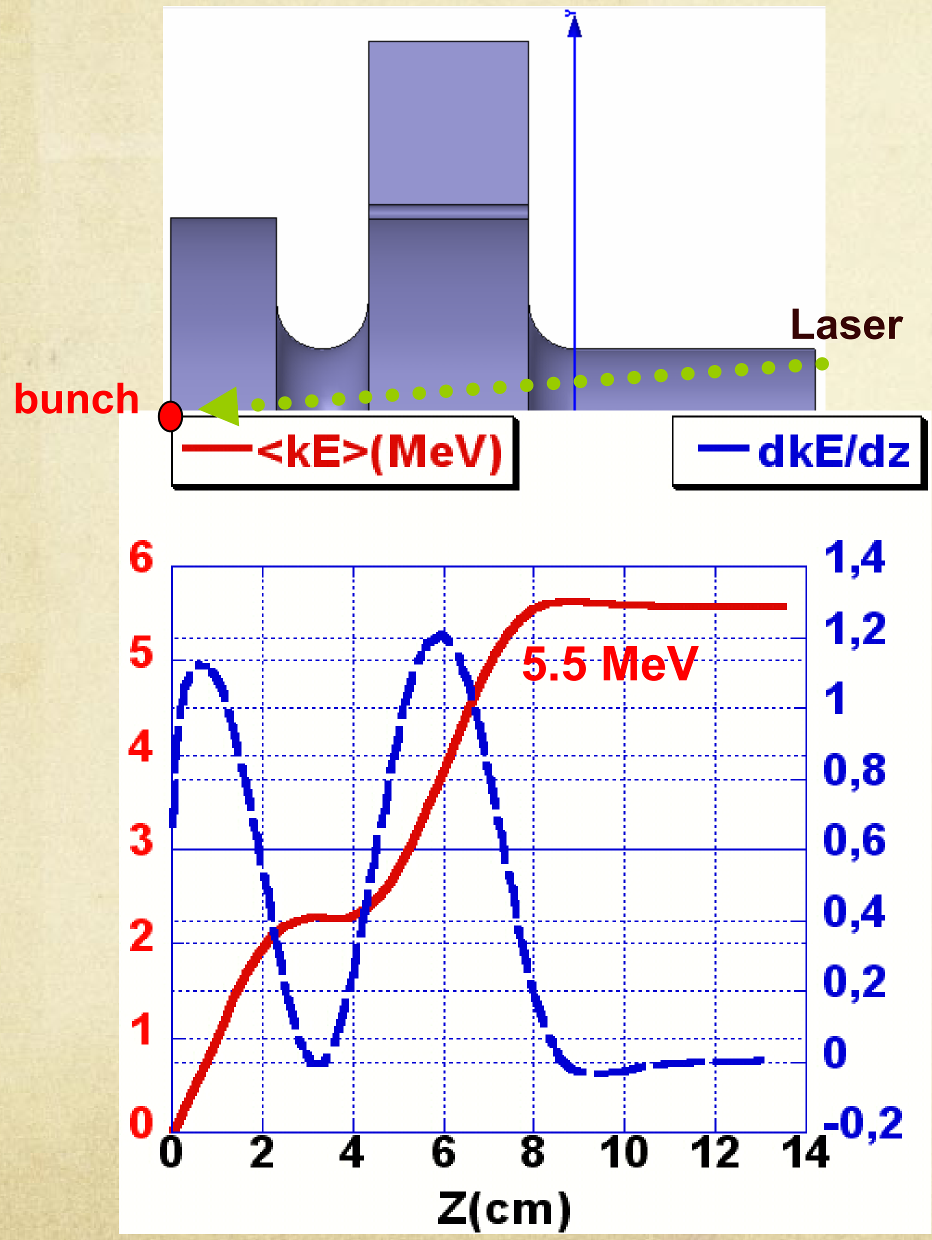



HFSS surface model, Electric field




| | |
|---|---|
| **Resonant frequency $f_\pi$** | **2.998 GHz** |
| **Mode separation $\Delta f=f_\pi-f_0$** | **14.5 MHz** |
| **Shunt Impedance $R_{shunt}$** | **60.8 MΩ/m** |
| **Unloaded Quality Factor $Q_0$** | **13500** |
| **Cupling coefficient β** | **1.22** |
| **accelerating $E_{peak}$** | **120MV/m @ $P_{RF}$=8.8 MW** |
| **surface $E_{peak}$** | **102MV/m** |

# DYNAMICS SIMULATIONS




Numeric code for simulations:
PARMELA

Beam charge Q = 1 nC
Beam current <I> = 0.3 A
Flat-top bunch

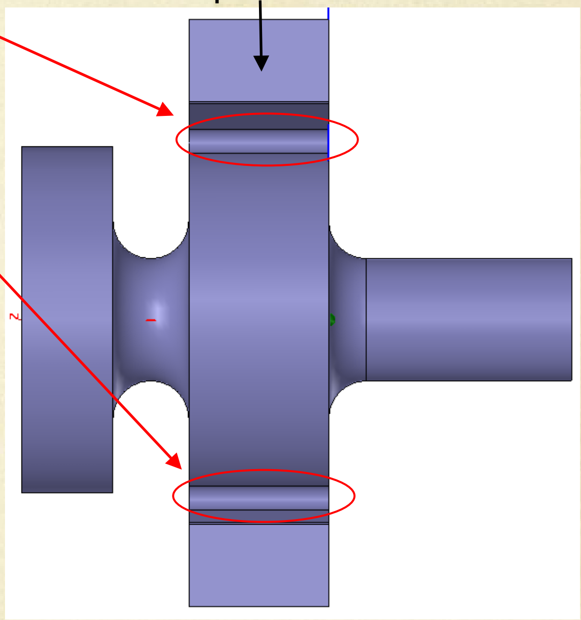
# RF PULSED HEATING

RF pulsed heating, due to surface magnetic field, causes a temperature gradient *ΔT* on the metal.

- ΔT is independent of the surface thickness and the cooling system. “Safe limit” in case of copper is about 110° C.
- Crucial areas are the waveguide-to-coupling-cell irises
- “rounded irises” are used (6mm diameter).
- The peak surface magnetic field is nearly

$H_{||}$= 3.9*10$^5$ A/m @ input RF power = 8.8 MW

Input RF power



Dummy waveguide

$$\Delta T = \frac{|H_{||}|^2 \sqrt{t_{RF}}}{\sigma\delta\sqrt{\pi\rho' c_{\varepsilon} k}}$$

→ **$\Delta T$ = 56° C**

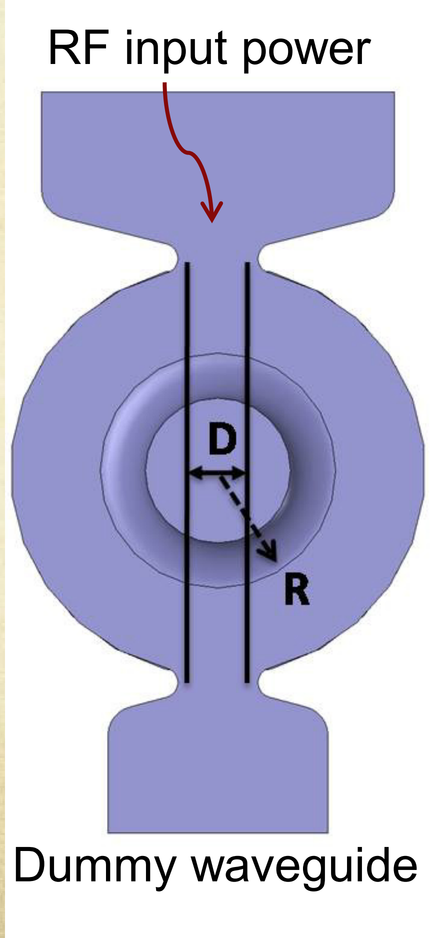
below the upper limit!

$t_{RF}$ : pulse length
$\sigma$: electrical conductivity
$\delta$: skin depth
$\rho'$ : density
$c\varepsilon$ :specific heat
$k$ : thermal conductivity

*D.P. Pritzkau, “RF Pulsed Heating”, SLAC-Report-577, Ph.D. Dissertation, Stanford University, 2001

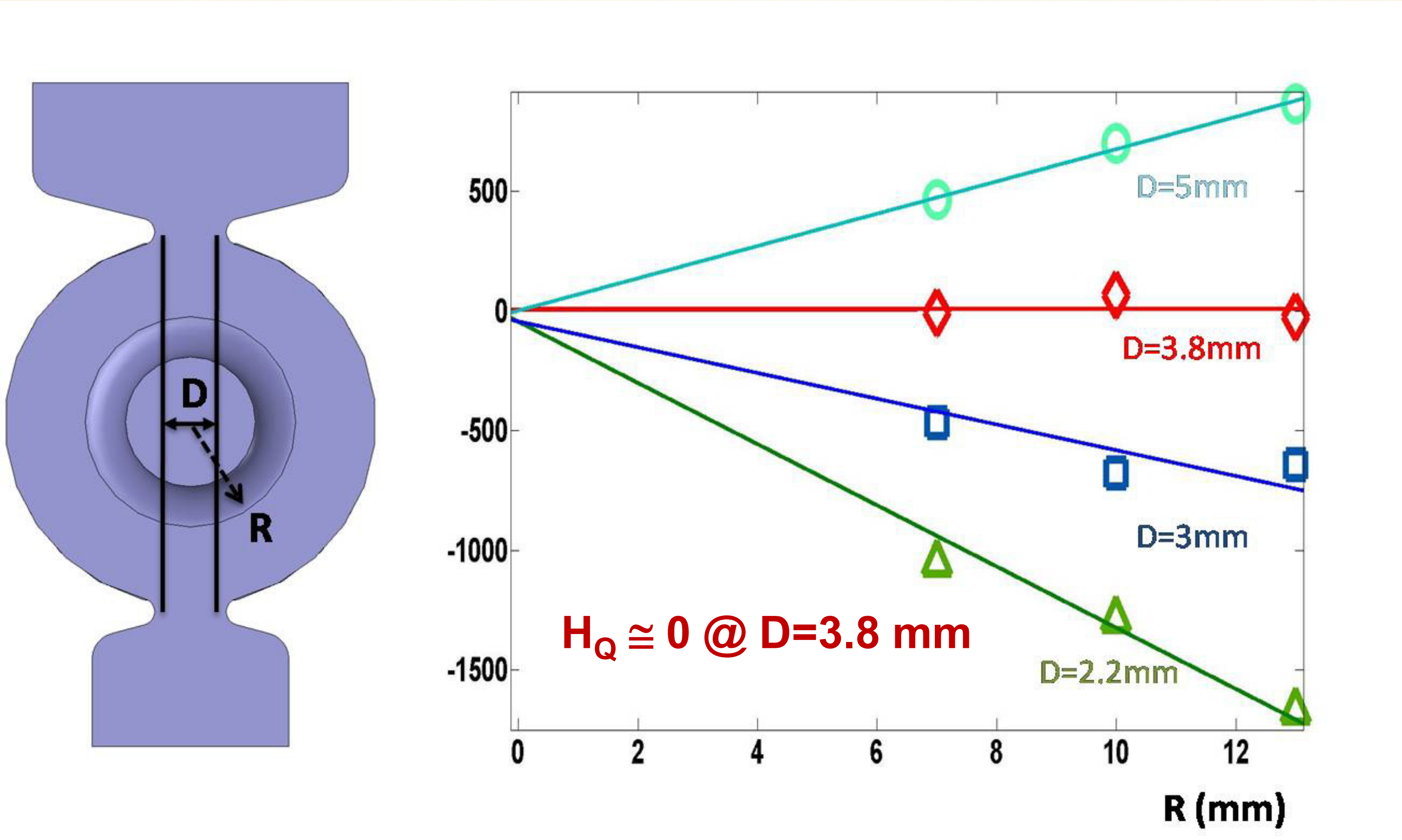
# DIPOLE AND QUADRUPOLE MAGNETIC FIELD COMPONENTS

- A dummy waveguide (higher cut-off frequency), symmetric to the RF input waveguide, allows to erase the field dipole component.
- The quadrupole component is eliminated by using a "race track" geometry.
- Higher order modes are considered negligible.

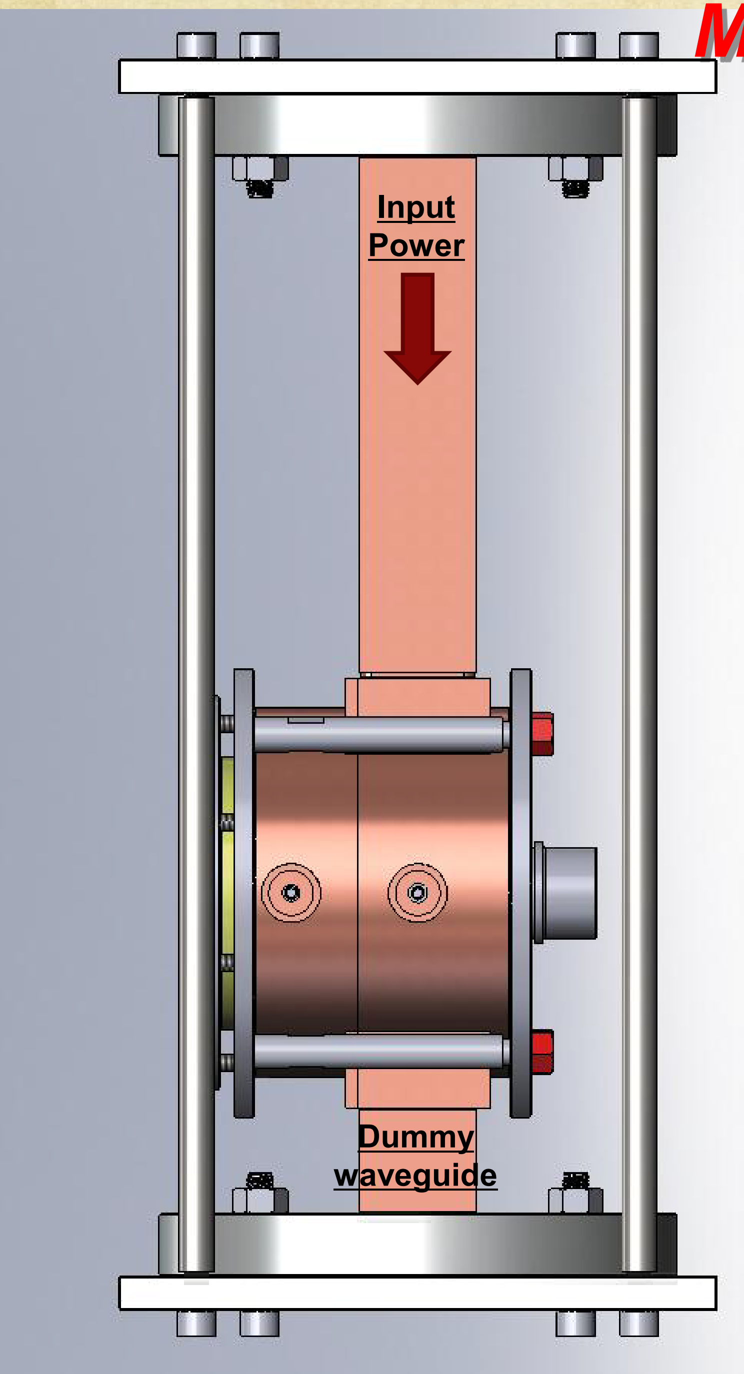



Cross section of the full cell. The field is calculated along circumferences with different radii R and for different values of the offset D, by which the two cell arcs are drifted apart.

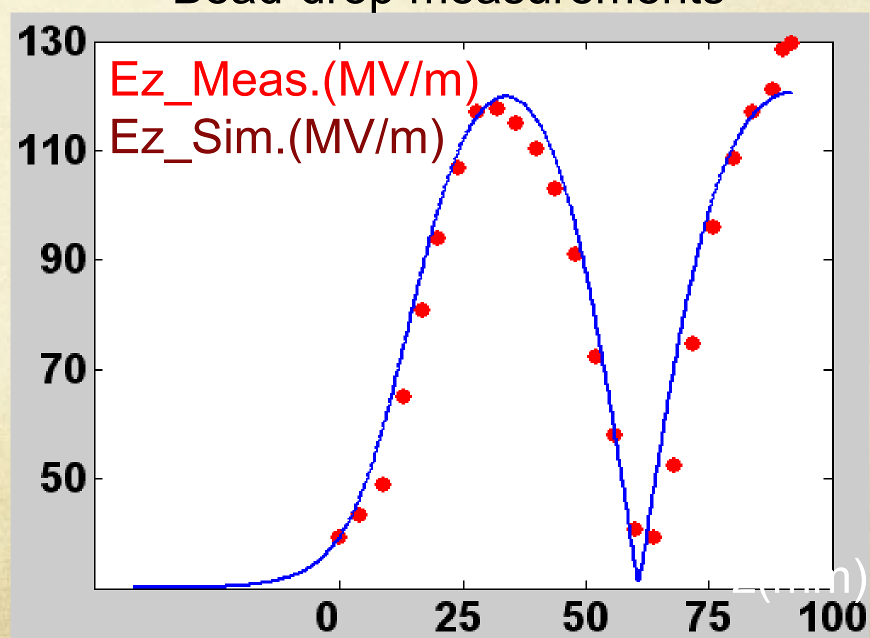
# QUADRUPOLE MAGNETIC FIELD COMPONENT $H_Q$



# MEASUREMENTS OF PREVIOUS RF GUN PROTOTYPE



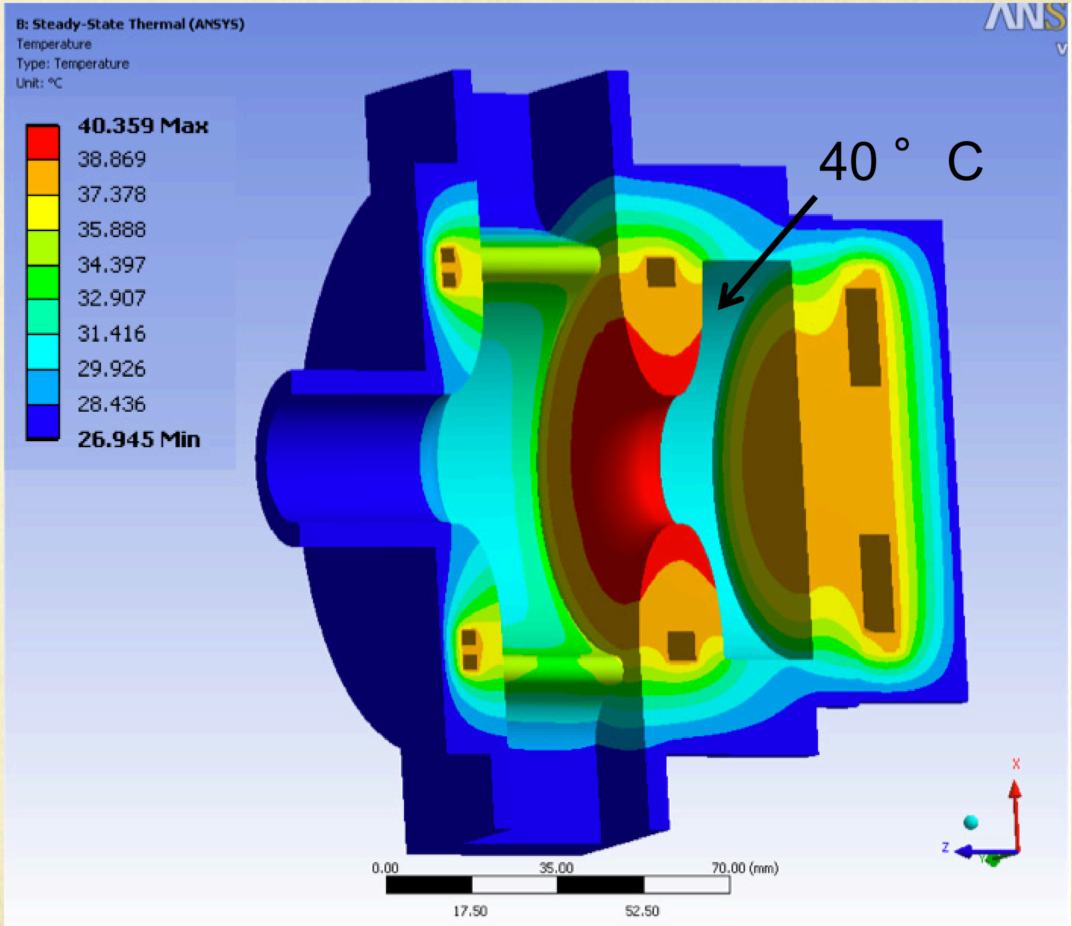

Bead-drop measurements



# THERMAL ANALYSIS

Thermal analysis of the RF Gun has been carried out by using Ansys13 (Coupling with HFSS)

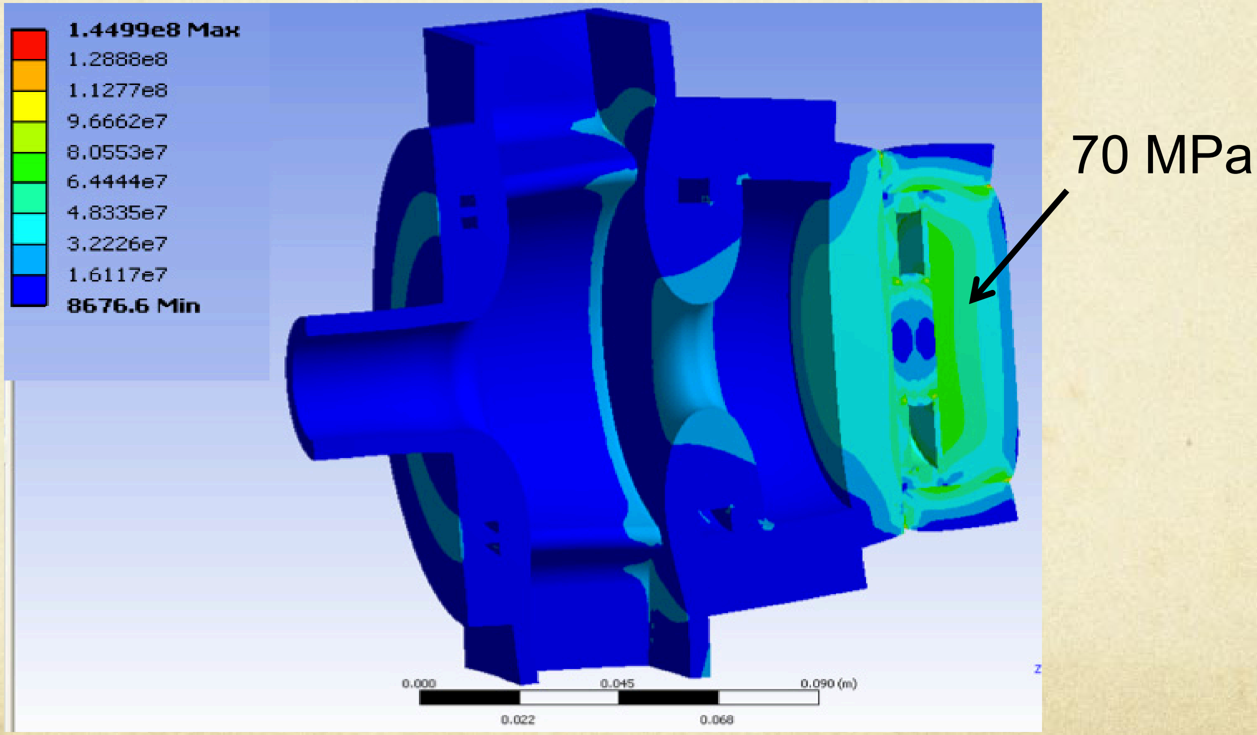
| | |
|---|---|
| RF Pulse length | 3 μs |
| Duty factor | 1.5 E-4 |
| $P_{peak}$ | 8.8 MW |
| $P_{avg}$ | 1.32 kW |
| Water velocity | 4 m/s |
| Water temperature | 38 ° C |
| Ambient Lab temperature | 27 ° C |




Temperature distribution (° C)

# STRESS ANALYSIS

The deformation produces a frequency shift, adjustable by moving the tuners. The von Mises stress is a measure of the yield strength (in terms of pressure Pa) of the metal, above which the material starts to deform plastically, i.e. non-reversible change of the shape.




Equivalent Stress distribution (Pa)

# CONCLUSIONS

- Presentation of the RF design of a high gradient normal conducting radio frequency (NCRF) 1.6 cell photoinjector system for the Sincrotrone Trieste (ST) facility.

  - RF field optimization and symmetrization
  - RF pulsed heating
  - Beam dynamics
  - Thermal/Stress analysis

- The engineering for the final Gun system is in progress.