Fermilab

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# PIP-II cavities RF design plan

Timergali Khabiboulline

PIP-II meeting

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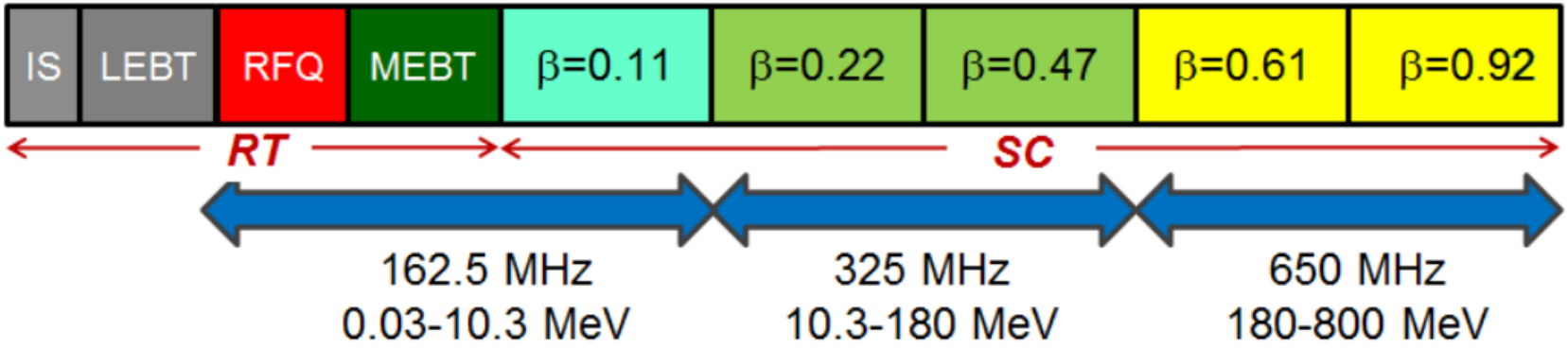
# Scope

- Current design status of PIP-II cavities
- PIP-II accelerator is a unique hadron machine
  - Superconducting from low energies
  - Should be able to operate in CW regime
  - Should be able to operate in pulsed regime
  - At FNAL we have experience of developing SRF cavities
- Electrical and mechanical properties are self-consistent
  - Design of the cavity starts with RF optimization
  - Then Electro-Mechanical optimization in order to reduce LFD and keep tune-ability
  - Next come design of helium jacket optimized for low df/dP
  - Mechanical optimization could require change Electrical design and vice versa
- What questions we should still address
  - Need to optimize for low LFD and df/dP and acceptable tune-ability
  - Multipacting lower than for SSR1 (which requires multipactor conditioning time of many hours compared to minutes for 1.3 GHz elliptical cavity)

# PIP-II Linac Reference Design




| Section | Freq | Energy (MeV) | Cav/mag/CM | Type |
|---|---|---|---|---|
| RFQ | 162.5 | 0.03-2.1 | | |
| HWR ($\beta_{opt}$=0.11) | 162.5 | 2.1-10.3 | 8/8/1 | HWR, solenoid |
| SSR1 ($\beta_{opt}$=0.22) | 325 | 10.3-35 | 16/8/ 2 | SSR, solenoid |
| SSR2 ($\beta_{opt}$=0.47) | 325 | 35-185 | 35/21/7 | SSR, solenoid |
| LB 650 ($\beta_g$=0.61) | 650 | 185-500 | 33/22/11 | 5-cell elliptical, doublet* |
| HB 650 ($\beta_g$=0.92) | 650 | 500-800 | 24/8/4 | 5-cell elliptical, doublet* |

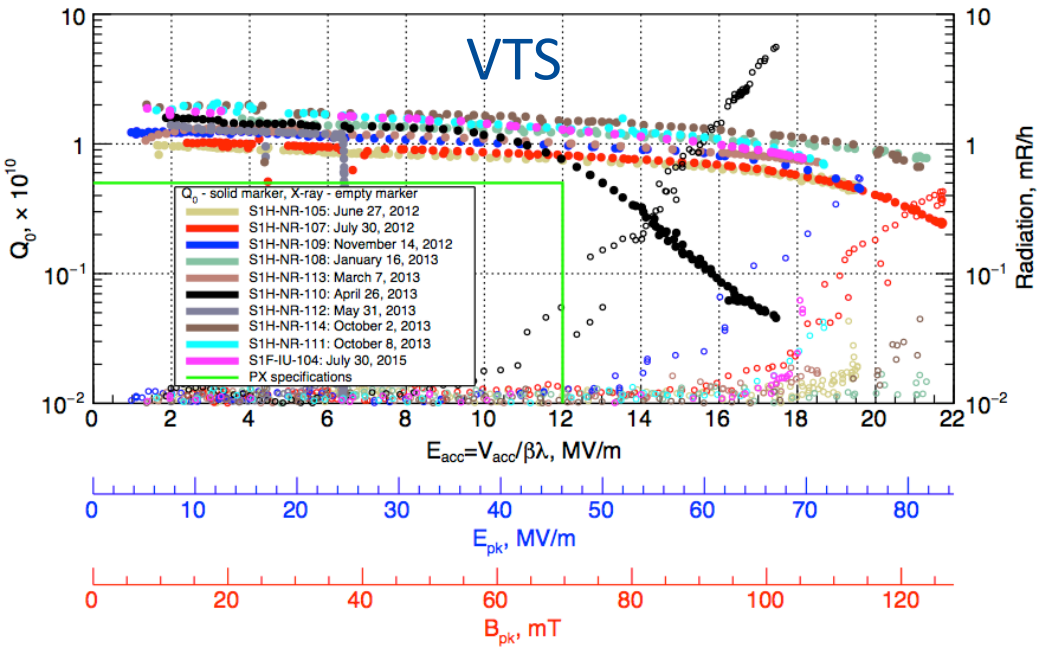
*Warm doublets external to cryomodules

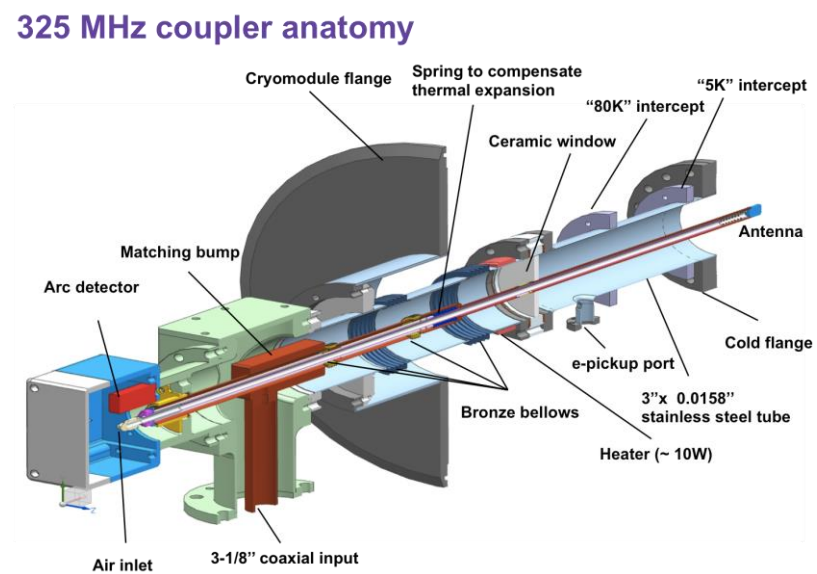
***All components CW-capable***

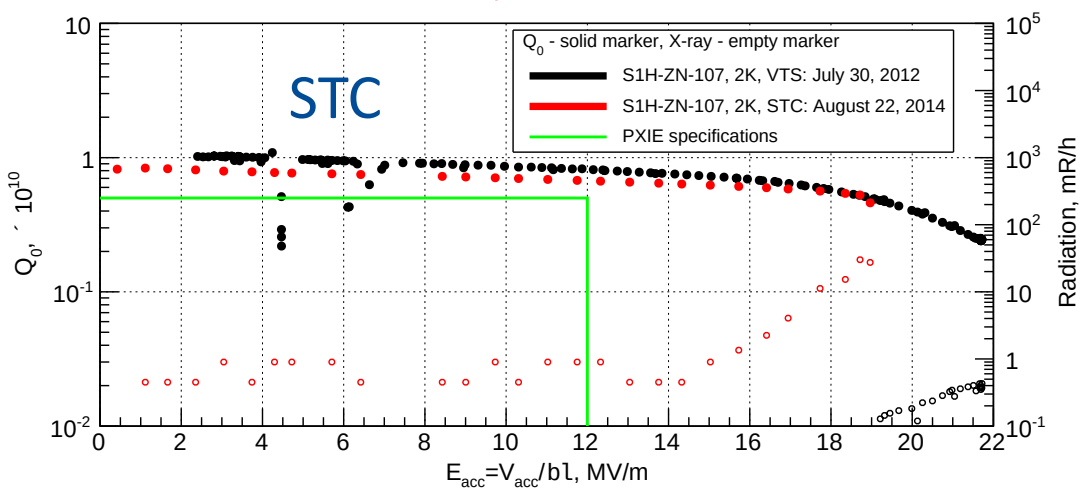
# SSR1 cavity RF design completed

- RF Design of the bare cavity started ~ 10 years ago
- Two prototype bare cavities were tested in VTS and one of them dressed and successfully tested in STC
- Ten bare production cavities were qualified in VTS
- 2nd generation low df/dP helium vessel designed
- Ten SSR1 cavities dressed with the helium vessel
- High power coupler was developed
- Frequency tuner was developed
- One dressed production cavity qualified in STC

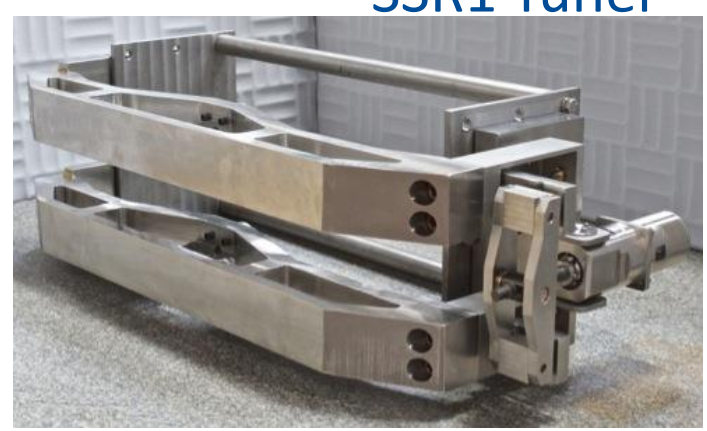
# SSR1 cavity tested in VTS and STC




SSR1 Tuner



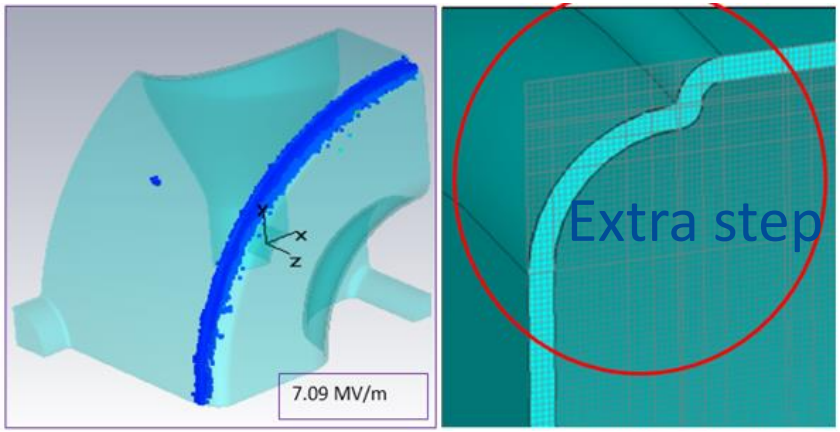
# SSR2 design requirements

| | |
|---|---|
| • Operating frequency | 325 MHz |
| • Number of spokes | 1 |
| • Aperture diameter | > 35 mm |
| • Shunt impedance R/Q | > 200 Ω |
| • Geometrical factor G | > 100 Ω |
| • Accelerating range | 30-185 MeV |
| • Energy gain per cavity | > 5 MeV |
| • Maximum surface magnetic field* | < 70 mT |
| • Maximum surface electric field * | < 40 MV/m |
| • Sensitivity to He pressure fluctuations df/dP | < 25 Hz/mbar |
| • Lorentz Force Detuning coefficient | < 4 Hz/ (MV/m)^2 |
| • Multipactor growth rate for $SEY_{max}$=1.3 | < 0.2 per period |

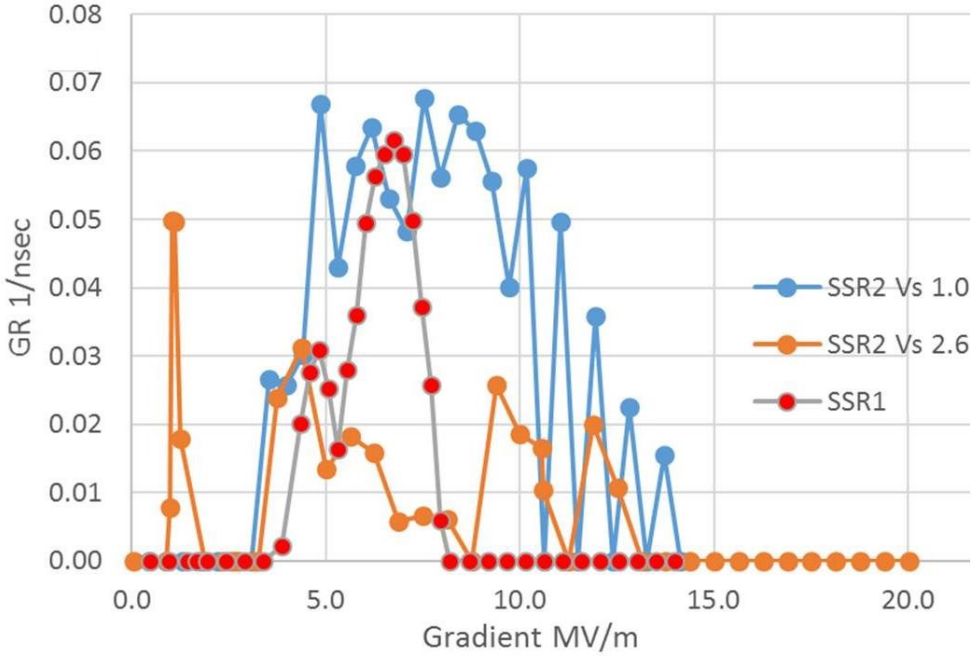
*At operating energy gain 5 MeV

# SSR2 cavity RF design status

- Reference RF design of the cavity is complete
  - Modifications for reducing multipactor proposed
  - Multipactor reduced to levels compatible to SSR1
  - Initial RF optimization complete




| Parameters | SSR2 |
|---|---|
| Optimal beta | 0.475 |
| Aperture [mm] | 40 |
| Frequency [MHz] | 325 |
| Effective length 2βλ/2 [m] | 0.438 |
| $E_{peak}/E_{acc}$ | 3.69 |
| $B_{peak}/E_{acc}$ [mT/(MV/m)] | 5.95 |
| G [Ohm] | 114.9 |
| R/Q [Ohm] | 295.6 |



# SSR2 cavity design plan

- Next steps of SSR2 design
  - Electromechanical design of dressed cavity with
    - Reduced LFD
    - “Zero” df/dP
    - Acceptable tune-ability
    - Mitigate low MP
  - HOM simulations
- Design Verification
  - Build “prototype” cavity
    - Release drawing
    - Purchase material
    - Put order for 1-2 cavity
  - Test cavity in VTS and STC
    - Multipactor study
    - Quench limit
    - X-ray limit
    - Coupler and Tuner study

Preliminary design of dressed SSR2 cavity version #1K

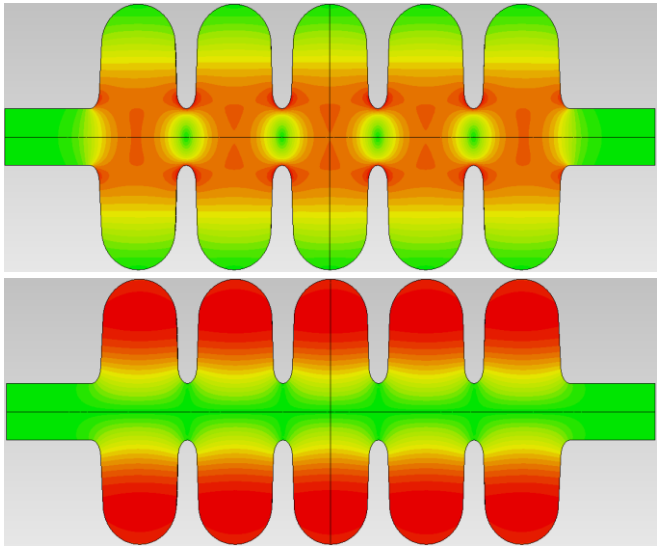
# LB650 cavity design requirements

| | |
|---|---|
| • Operating frequency | 650 MHz |
| • Number of cells | 5 |
| • Aperture diameter | > 80 mm |
| • Shunt impedance R/Q | > 300 Ω |
| • Geometrical factor G | > 150 Ω |
| • Accelerating range | 185-500 MeV |
| • Energy gain per cavity | > 12 MeV |
| • Maximum surface magnetic field* | < 70 mT |
| • Maximum surface electric field * | < 40 MV/m |
| • Sensitivity to He pressure fluctuations df/dP | < 25 Hz/mbar |
| • Lorentz Force Detuning coefficient | < 1 Hz/ (MV/m)^2 |
| • Multipactor growth rate for $SEY_{max}$=1.3 | < 0.2 per period |

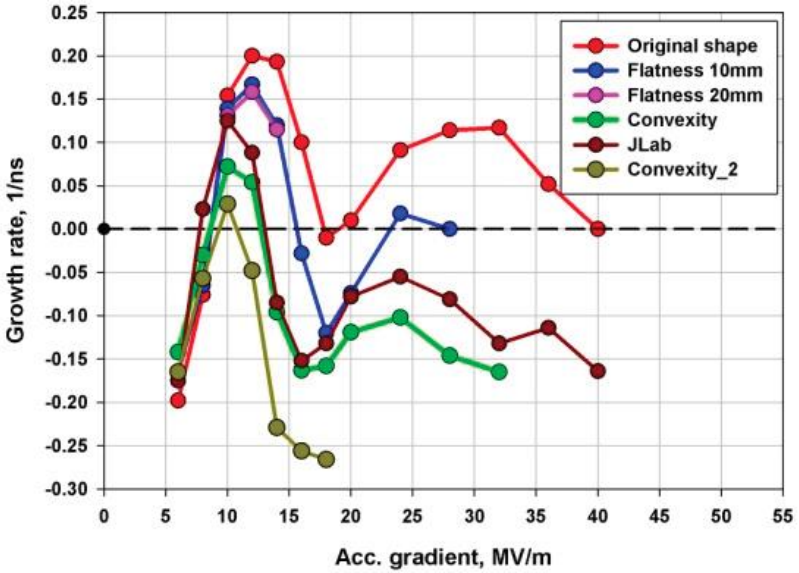
*At operating energy gain 11.9 MeV

# LB650 cavity design status

- RF design of 5 cell cavity
  - RF optimization complete
  - Preliminary multipactor simulations done
  - Preliminary LFD and df/dP simulations done for helium vessel scaled from HB650

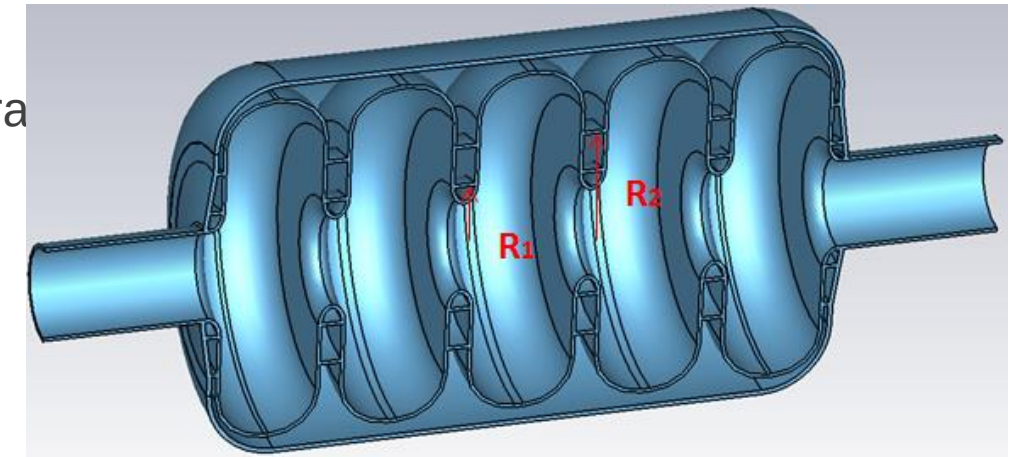


| | |
|---|---|
| Iris Diameter, mm | 83 |
| Angle, degree | 2.0 |
| $\beta_{opt}$ | 0.647 |
| $R/Q(\beta_{opt})$, Ohms | 377.0 |
| $E_{surf}/E(\beta_{opt})$ | 2.26 |
| $B_{surf}/E(\beta_{opt})$, mT/MeV/m | 4.21 |
| G, Ohms | 191 |



# LB650 cavity design problems next to be solved

- Next steps of LB650 design
  - Reduce LFD to allow stable opera pulsed mode
  - df/dP < 20 Hz/mBar
- Cavity properties study
  - Multipactor
  - HOMs
  - Mechanical resonances
  - Pressure tests study
  - Stress and gravity analysis
  - Tune ability study
- Design verification
  - Build “prototype” cavity
  - Test cavity in VTS and HTS
  - Coupler Tuner study




- Minimize a sensitivity to microphonics due to He pressure fluctuations (df/dP) and mechanical vibrations
- Minimize a Lorentz Force Detuning (LFD) coefficient
- To keep the stiffness and tuning sensitivity at suitable level to allow for tuning.
- Keep provision for slow and fast tuner integration.

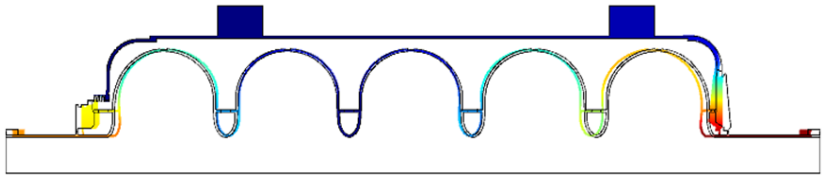
# HB650 cavity design requirements

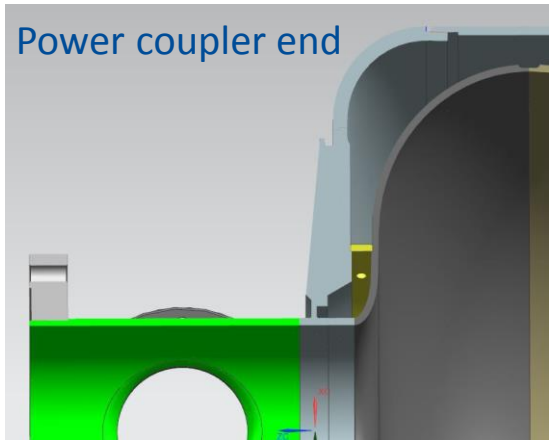
| | |
|---|---|
| • Operating frequency | 650 MHz |
| • Number of cells | 5 |
| • Aperture diameter | > 100 mm |
| • Shunt impedance R/Q | > 500 Ω |
| • Geometrical factor G | > 200 Ω |
| • Accelerating range | 500-800 MeV |
| • Energy gain per cavity | > 20 MeV |
| • Maximum surface magnetic field* | < 70 mT |
| • Maximum surface electric field * | < 40 MV/m |
| • Sensitivity to He pressure fluctuations df/dP | < 25 Hz/mbar |
| • Lorentz Force Detuning coefficient | < 1 Hz/ (MV/m)^2 |
| • Multipactor growth rate for $SEY_{max}$=1.3 | < 0.2 per period |

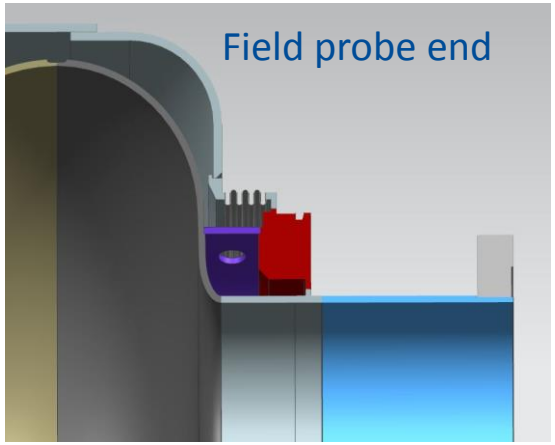
*At operating energy gain 19.9 MeV

# HB650 cavity design status

- RF design of 5 cell cavity
  - RF optimization complete
  - Helium vessel design proposed
  - LFD and df/dP optimization complete for current design of dressed cavity
  - Dressed cavity stress analysis complete for current design





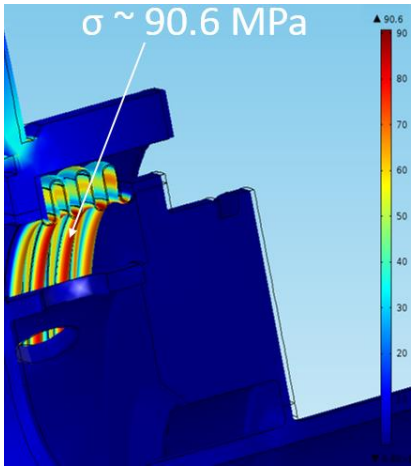

| | |
|---|---|
| Iris diameter | 118 |
| $\beta_{opt}$ | 0.97 |
| $R/Q(\beta_{opt})$, Ohms | 610 |
| $E_{surf}/E(\beta_{opt})$ | 2.07 |
| $B_{surf}/G(\beta_{opt})$, mT/MeV/m | 3.89 |
| G, Ohms | 260 |

# HB650 remaining cavity design work

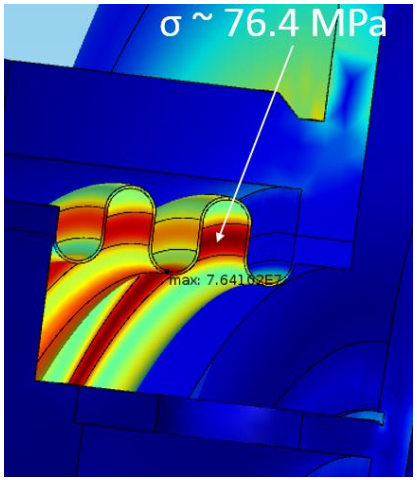
- Next steps of HB650 design
  - Modify bellow design
  - Simulate properties of final design
    - Multipactor
    - Mechanical resonances
    - LFD and df/dP
    - Pressure tests study
    - Stress and gravity analysis
  - Tuner simulations
  - RF Coupler, Field Probe study

- Design verification
  - Build “prototype” cavity
  - Test cavity in VTS, HTS

2 bar + gravity, RT,
Tuner = 80 kN/mm




Maximum allowable
Stress is 88.7MPa



# Summary

| Proposed RF design time, hours | | **2392** | | Comments |
|---|---|---|---|---|
| SSR2 RF design work | | **680** | | |
| 1 | Develop helium vessel for SSR2 | 300 | MechEng | |
| 2 | LFD and df/dP optimization | 300 | RF design Eng | |
| 3 | HOM simulations | 80 | RF design Eng | |
| LB650 RF design work | | **1336** | | |
| 1 | Electromechanical design | 300 | RF design Eng | |
| 2 | Mechanical design | 300 | Mech Eng | |
| 3 | Multipactor simulations | 60 | RF design Eng | |
| 4 | Mechanical resonances | 60 | RF design Eng | |
| 5 | LFD | 48 | RF design Eng | |
| 6 | df/dP | 48 | RF design Eng | |
| 7 | Stress, gravity analysis | 40 | RF design Eng | |
| 8 | Pressure case analysis | 80 | RF design Eng | |
| 9 | Tune-ability simulations | 100 | RF design Eng | |
| 10 | Tuner simulations | 120 | RF design Eng | |
| 11 | HOMs | 180 | RF design Eng | |
| HB650 RF design work | | **376** | | |
| 1 | Multipactor simulations | 40 | RF design Eng | Review request. |
| 2 | Update Model | 24 | Mech Eng | |
| 3 | Mechanical resonances | 40 | RF design Eng | |
| 4 | LFD | 24 | RF design Eng | |
| 5 | df/dP | 16 | RF design Eng | |
| 6 | Stress, gravity analysis | 32 | RF design Eng | |
| 7 | Pressure case analysis | 40 | RF design Eng | |
| 8 | Tunerability simulations | 48 | RF design Eng | |
| 9 | Tuner simulations | 64 | RF design Eng | |
| 10 | Power coupler, field probe | 48 | RF design Eng | |