Ultrafast High-Brightness Tabletop Electron Source

Advanced Energy Systems

10/1/2015

UED Approach

- The production and preservation of ultrafast, high-brightness electron beams is a major R&D challenge for ultrafast electron diffraction (UED) < 100 fs bunch
  - Transverse and longitudinal space charge forces drive emittance dilution and bunch lengthening in such beams
  - Several approaches, such as velocity bunching and magnetic compression, have been considered to solve this problem but each has drawbacks.
- We present a concept that uses radial bunch compression in an X-band photocathode radio frequency electron gun.
  - By compensating for the path length differential with a curved cathode in an extremely high acceleration gradient cavity
  - We have demonstrated numerically the possibility of achieving more than a factor of four increase in beam brightness over existing electron guns.
- The thermo-structural analysis and mechanical design and progress of this electron source are presented.

Bunch Lengthening

- For a high-aspect-ratio (short bunch length) electron bunch, the asymptotic bunch length due to the space charge forces of a uniformly accelerated bunch, ignoring the drive laser duration and assuming prompt response from a copper cathode where the laser spot radius is kept constant, is expressed by:

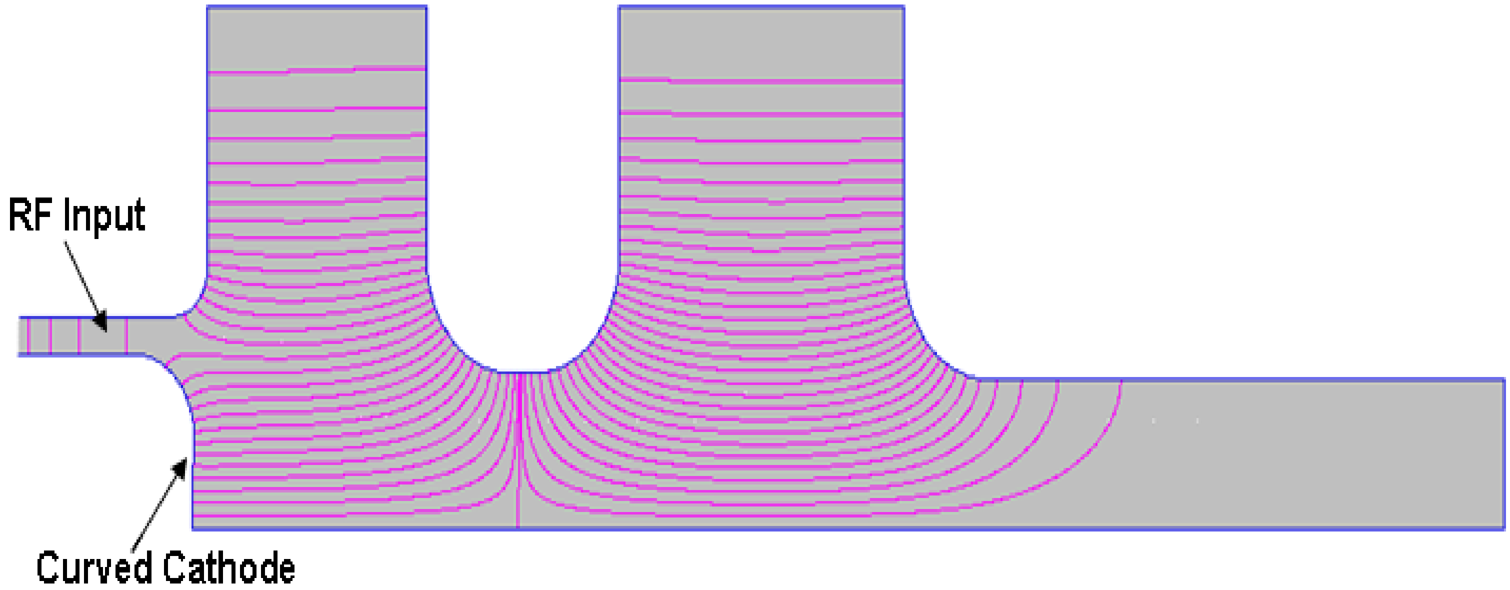
$$\Delta t_{sc}(\infty) = \frac{mc^2}{e} \frac{Q}{\pi R^2 \varepsilon_0 c E^2}$$

- Bunch lengthening due to space charge is inversely proportion to the square of the bunch radius and the square of the accelerating field.
- Bunch length stretches due to the longer path lengths of the outer particles compared to electrons emitted closer to the axis.
- Bunch lengthening due to geometrical effects is proportional to the square of the beam radius.

Key Features of UED RF Geometry

High acceleration field with X-band RF gun

- Curved copper cathode
- Axisymmetry coupling
- Backward RF Feeding



Cavity Field Profile

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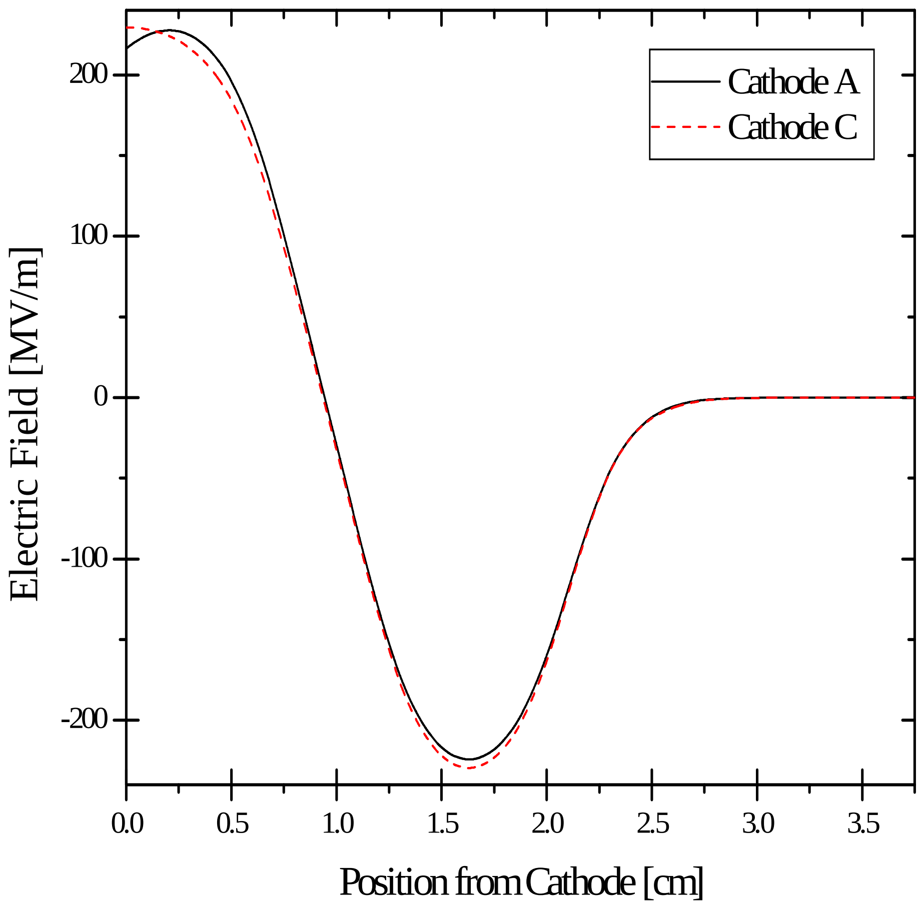
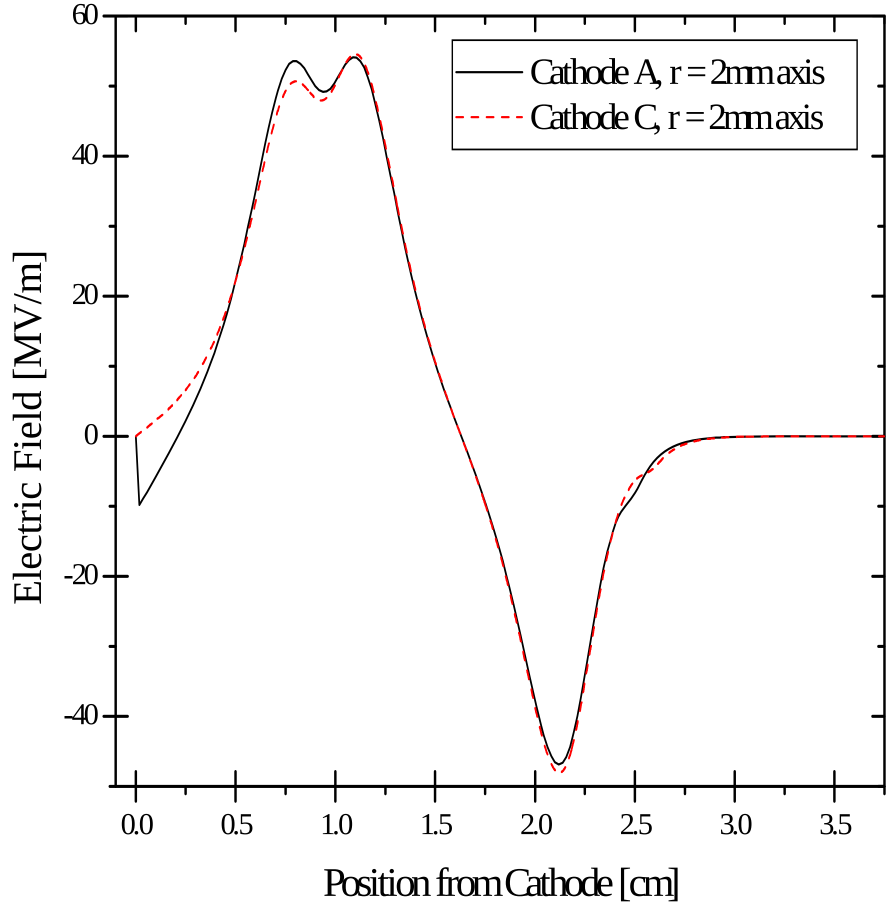
Axial Field



Radial Field



Cathode A curved cathode

Cathode C straight cathode

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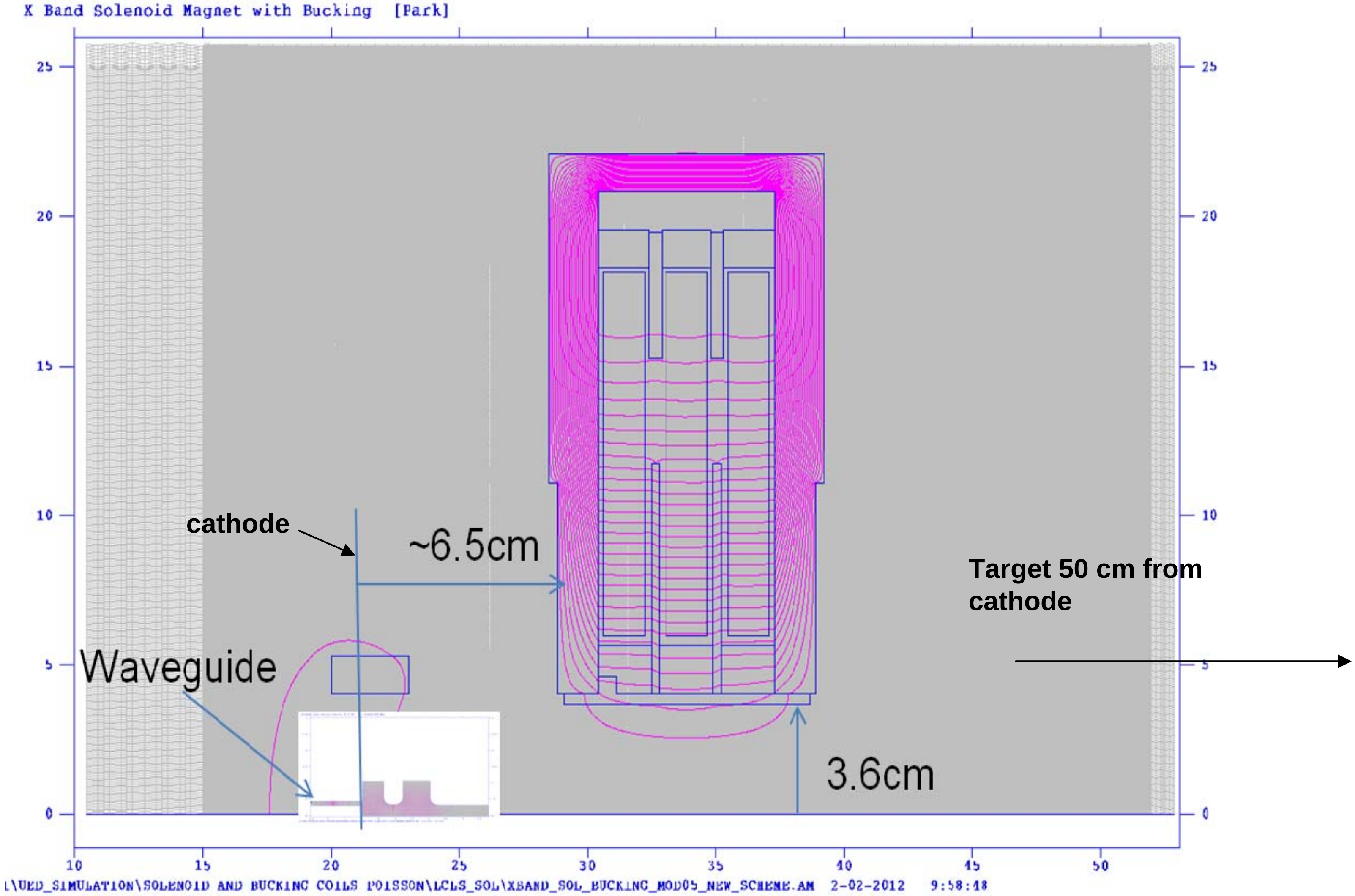
T-Step Configuration



Bunch Length

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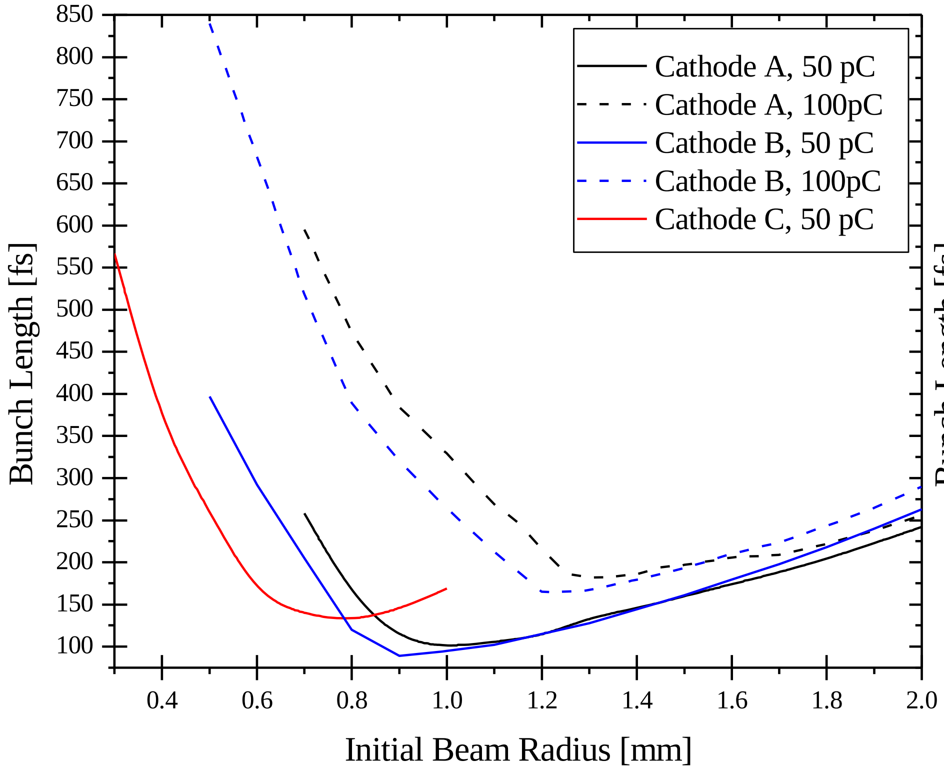

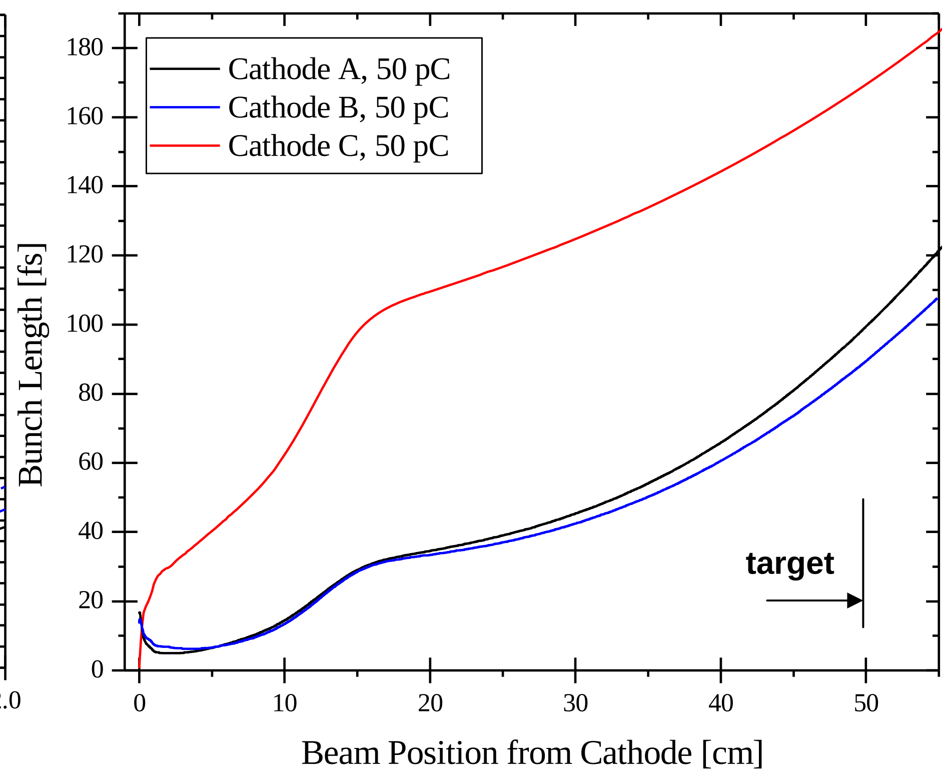

- **Cathode A curved cathode**
- **Cathode B curved cathode with shaped laser pulse – outer region of pulse is ahead of inner region**
- **Cathode C straight cathode**

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RMS-Emittance

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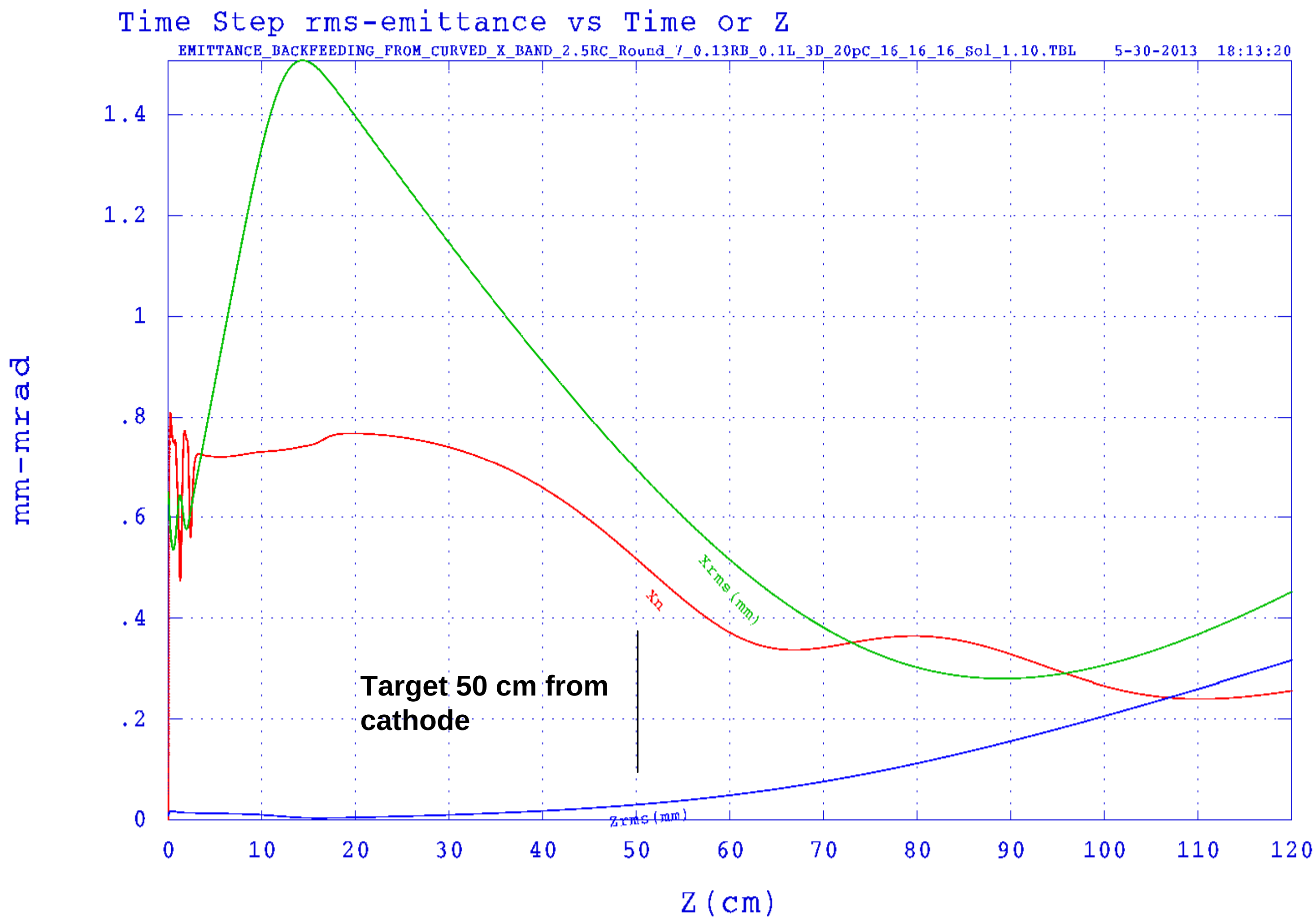
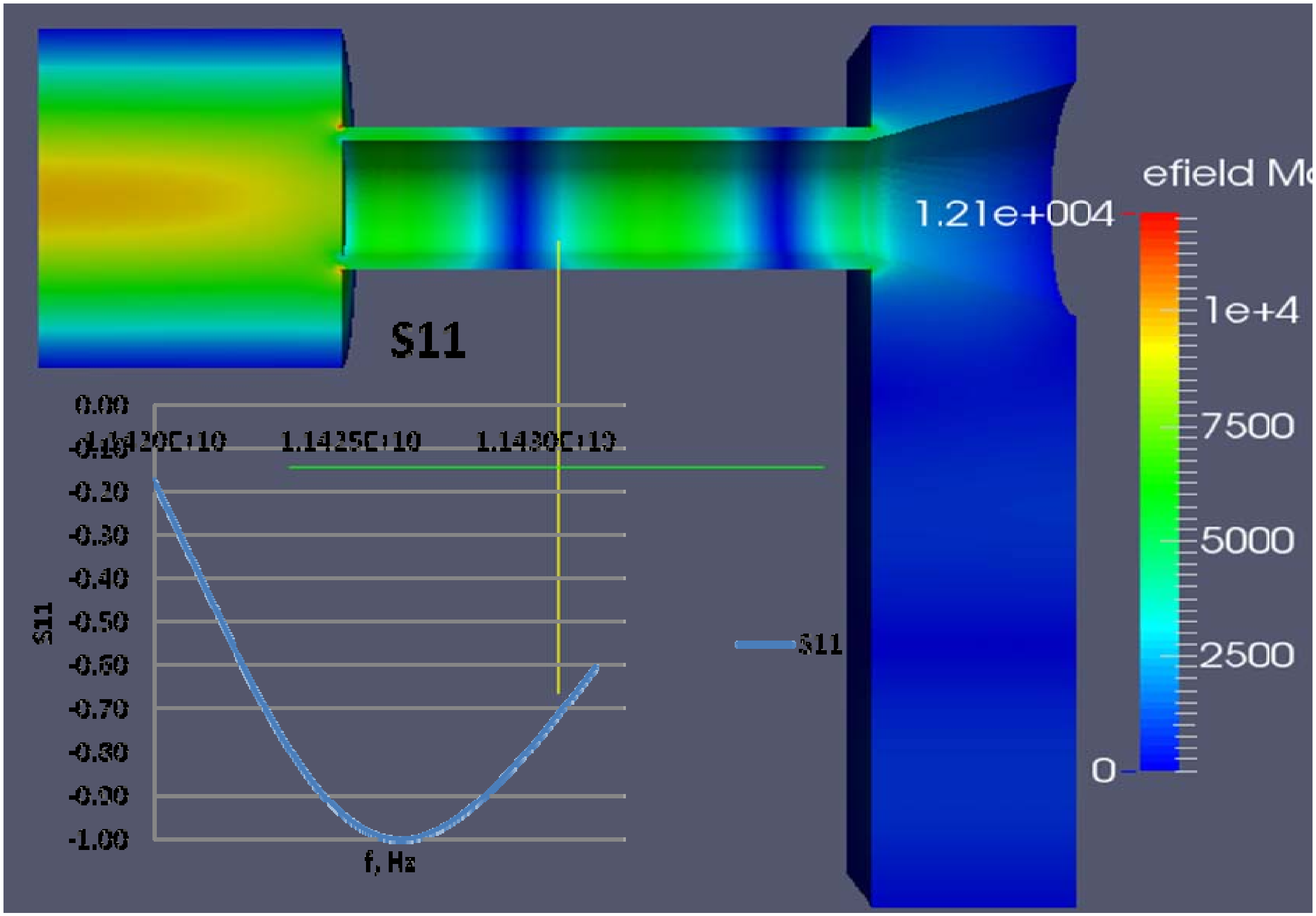


Waveguide to Coax RF Coupling



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SUPERFISH Field Scaling – Duty Factor

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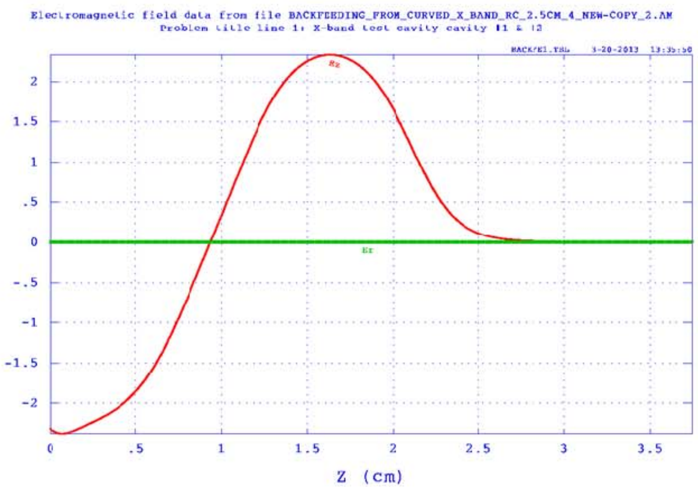
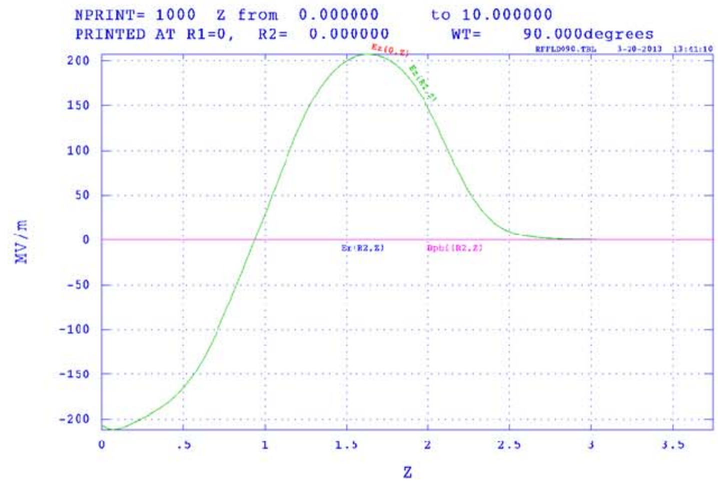


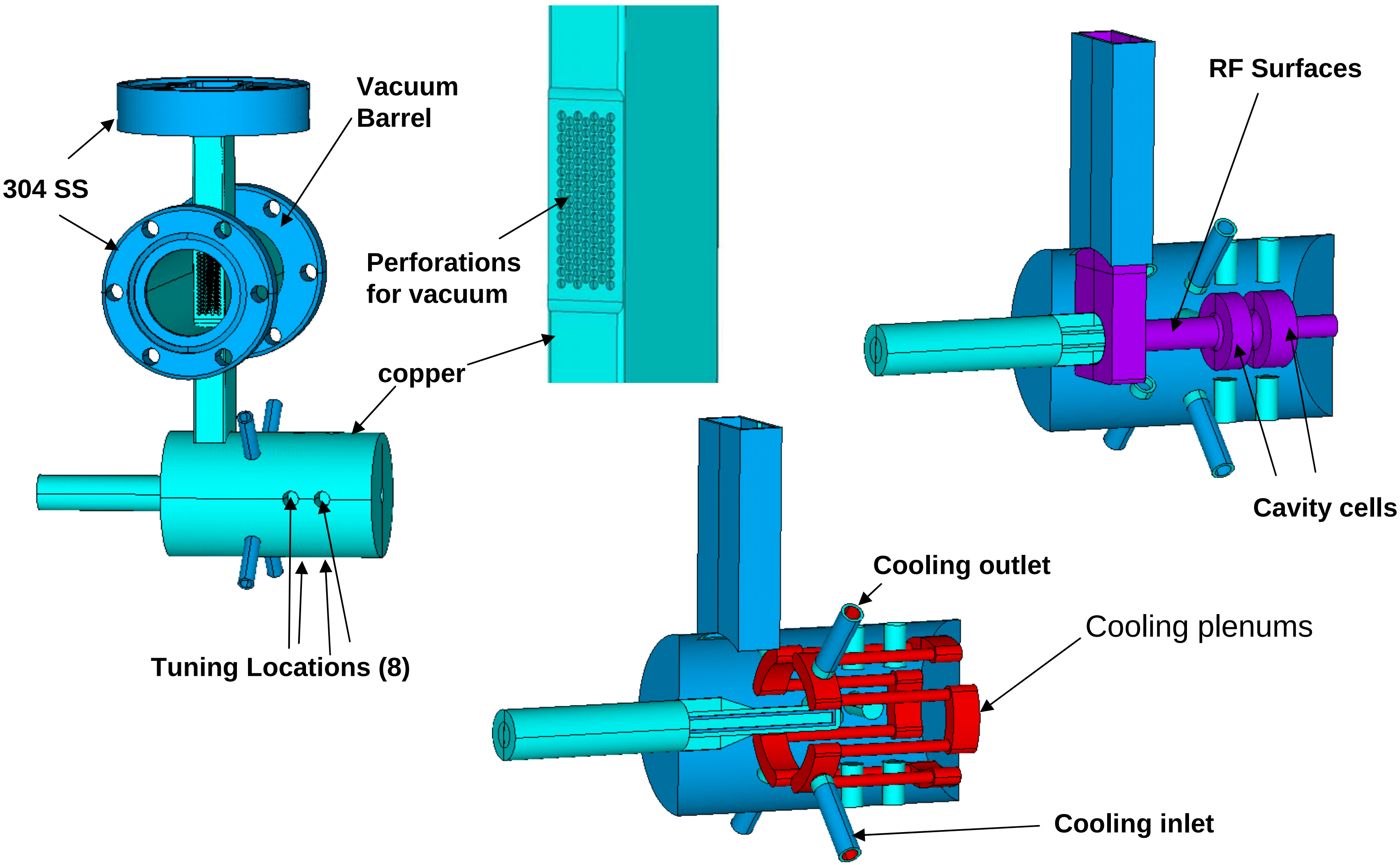


2.63 MV/m   scale to   250 MV/m

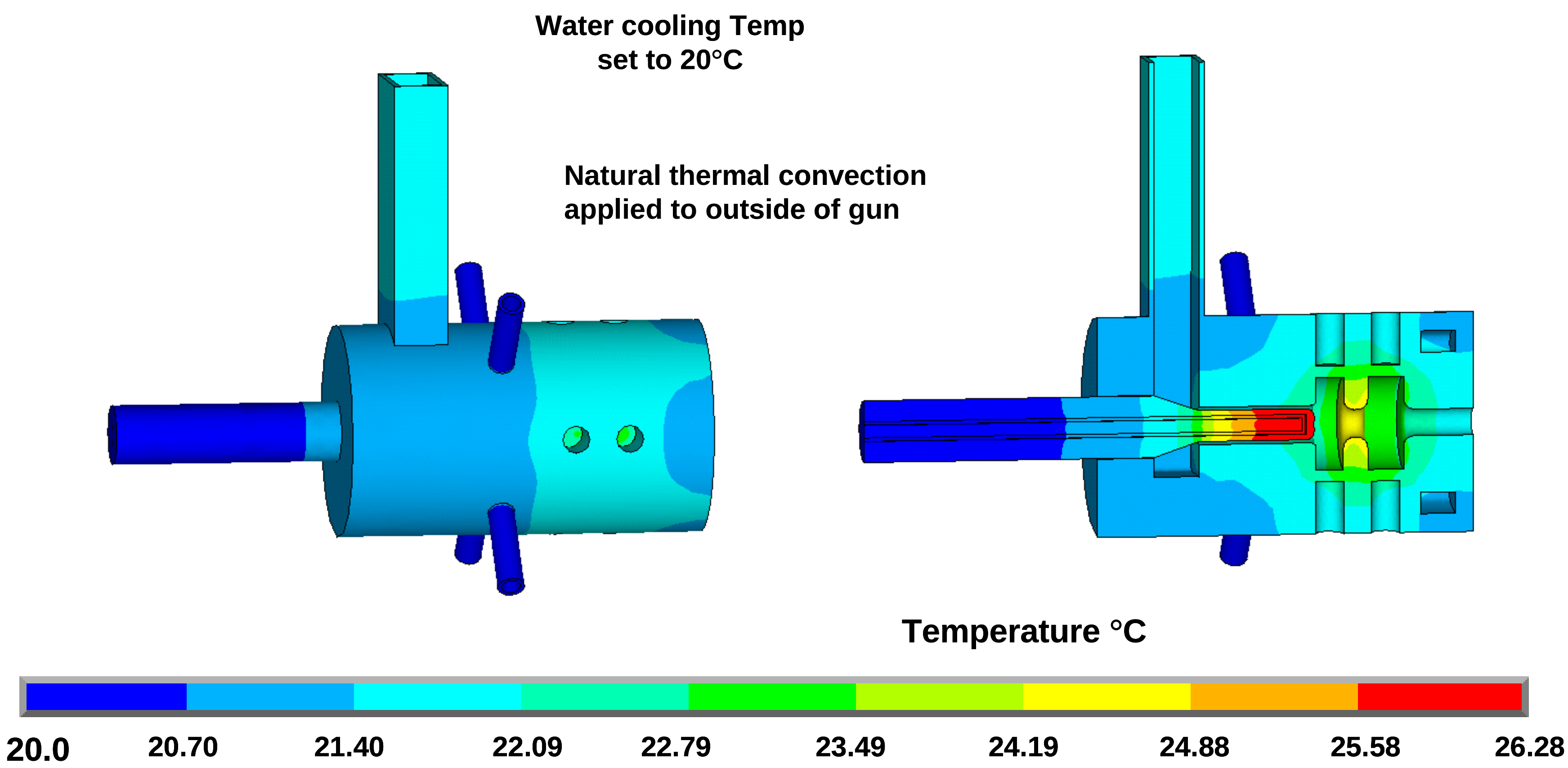
- Wall losses scale from
- 467 watts to 4.22 MW CW

- For a duty factor of 4.e-5 the wall losses are 169 watts in cavity

Geometry and Materials



Temperatures



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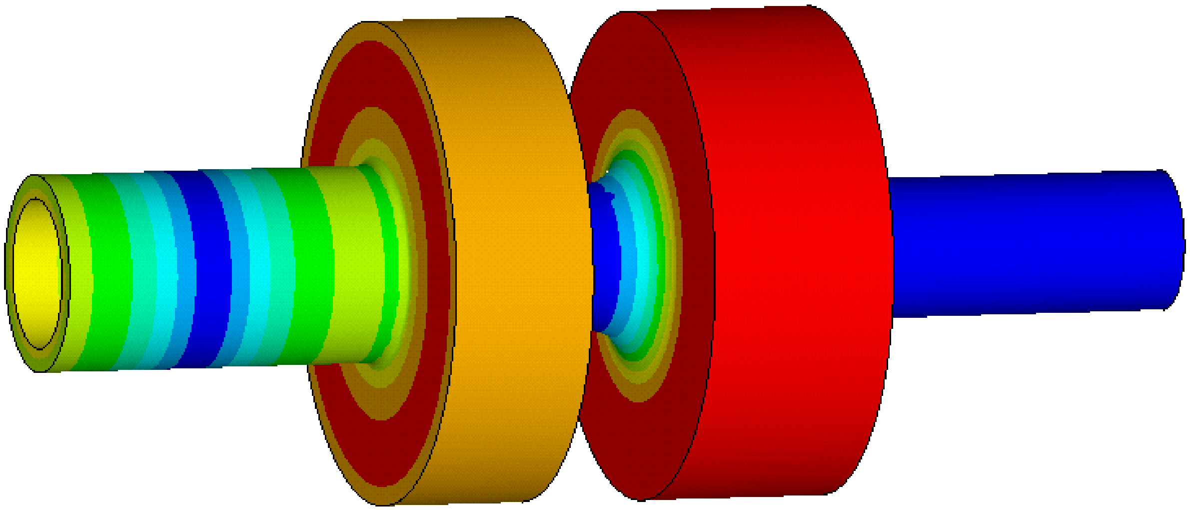
Frequency Shift

- Frequency Shift determined on model shown below
- Waveguide not included
- Geometry as per SUPERFISH
- Frequency shift -644. kHz - Requires coolant temperature decrease of 3.4°C
- The geometry is designed for an initial coolant inlet temperature of 25°C to 30°C



General Experiment Layout

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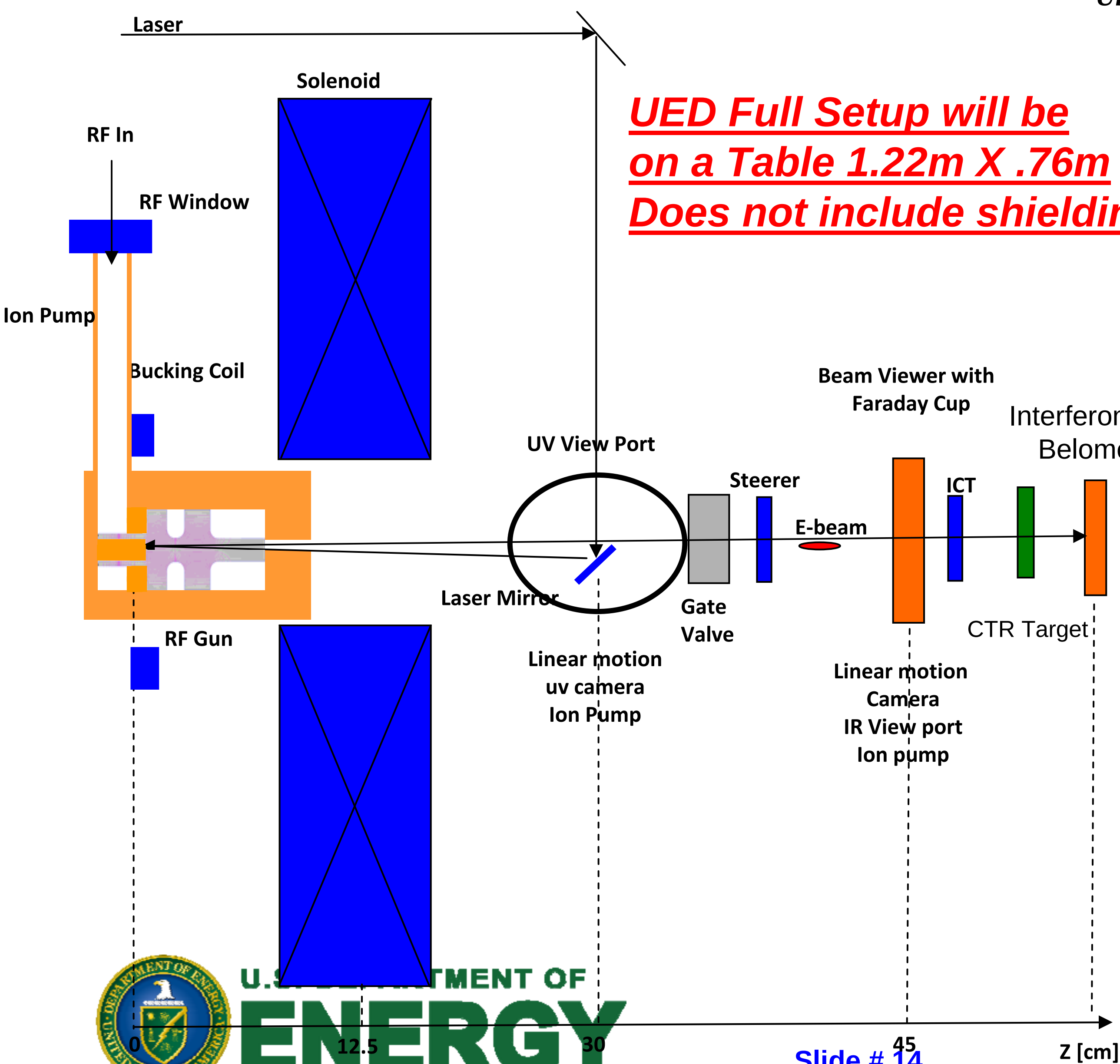
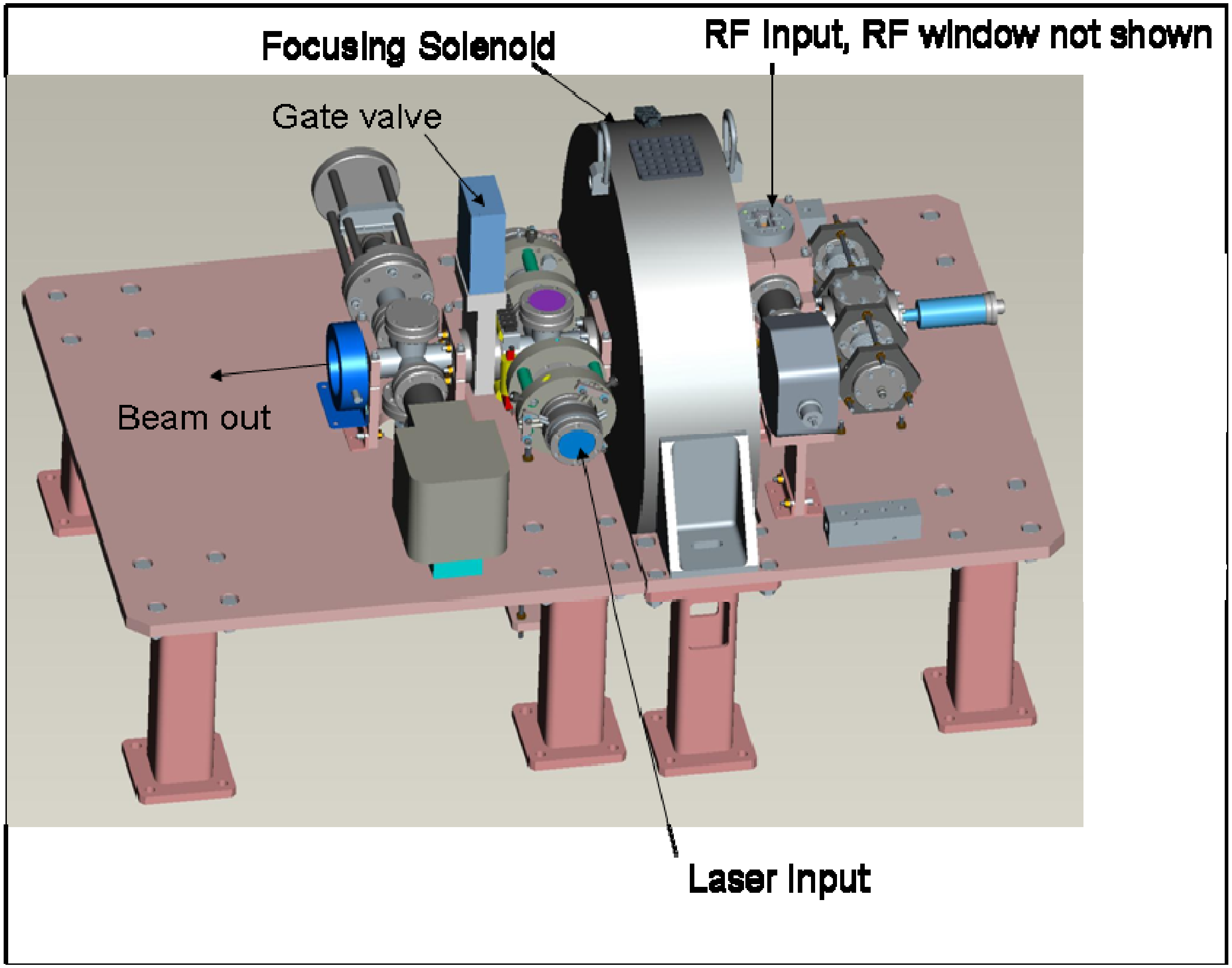


UED Full Setup will be on a Table 1.22m X .76m
Does not include shielding

- Beam
  - 50pC max
  - <2.7MeV
  - <100fs
- RF
  - ~15MW
  - Duration: 200 ns
- Laser
  - <10 uJ on cathode
  - ~50fs
- Shielding
  - 250MV/m max E-Field
  - Duration: 200 ns
  - Rep: <3Hz
  - Duty factor: 6X10E-7
  - Suggestion: 4” lead full setup cover + 4” lead gun itself cover
- Wall power for solenoid: 1kW max (51A X 9V)
- Water Chiller for gun: 0.1 deg. Accuracy

Gun on Table with Solenoid



Schedule

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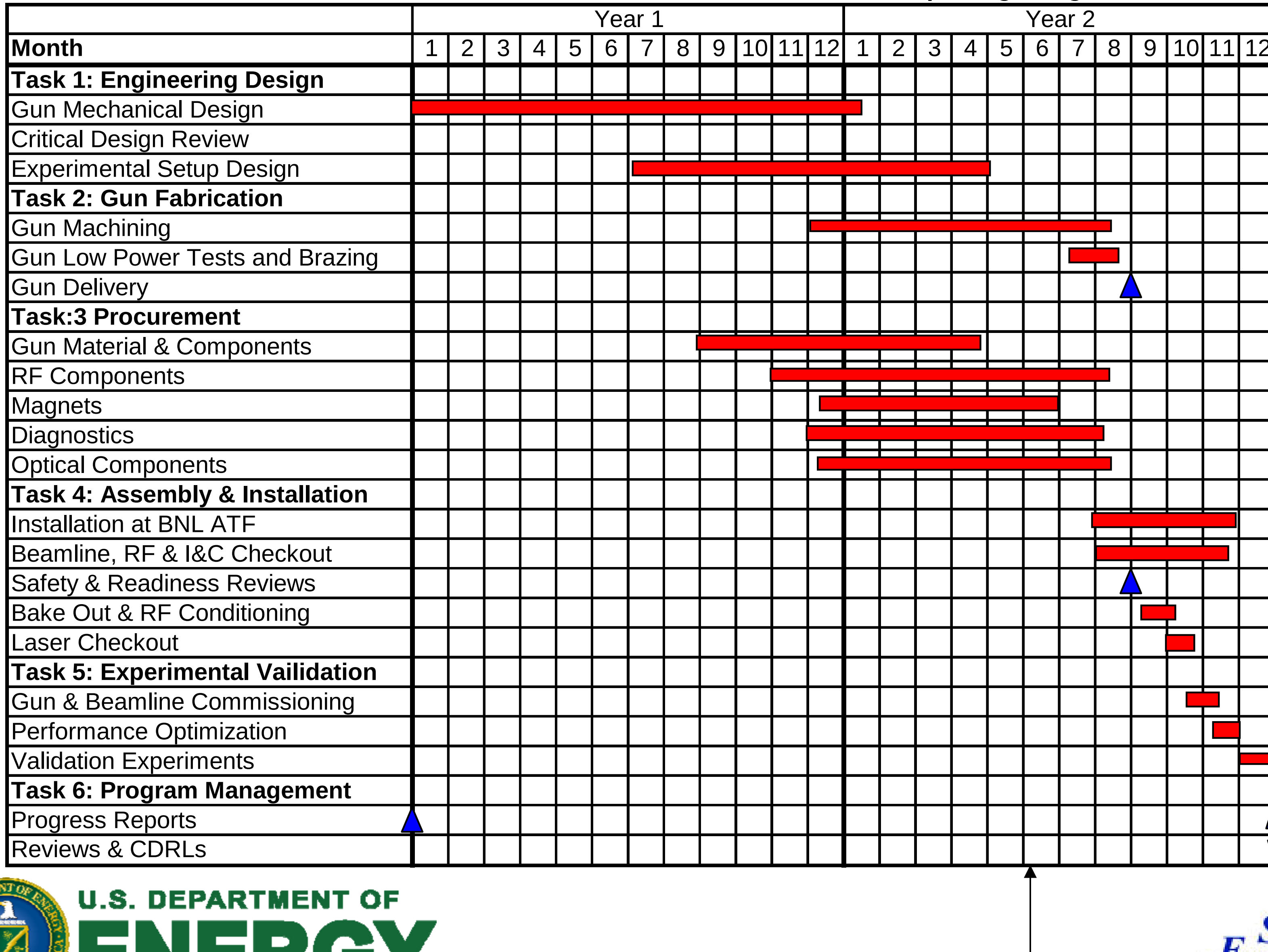

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