Novel, Hybrid RF Injector as a High-average-current Electron Source

Dinh Nguyen
Los Alamos National Laboratory

Lloyd Young
TechSource

Energy Recovery Linac Workshop
Thomas Jefferson National Accelerator Facility
March 19-23, 2005

Outline

- Normal-Conducting RF Gun Problems
- Superconducting RF Gun Problems
- Hybrid RF Photoinjector
  - Normal-conducting 1½-cell + SRF cells
  - How might it solve the above problems?
- Preliminary Cavity Design
- Preliminary PARMELA Simulation Results
- Summary

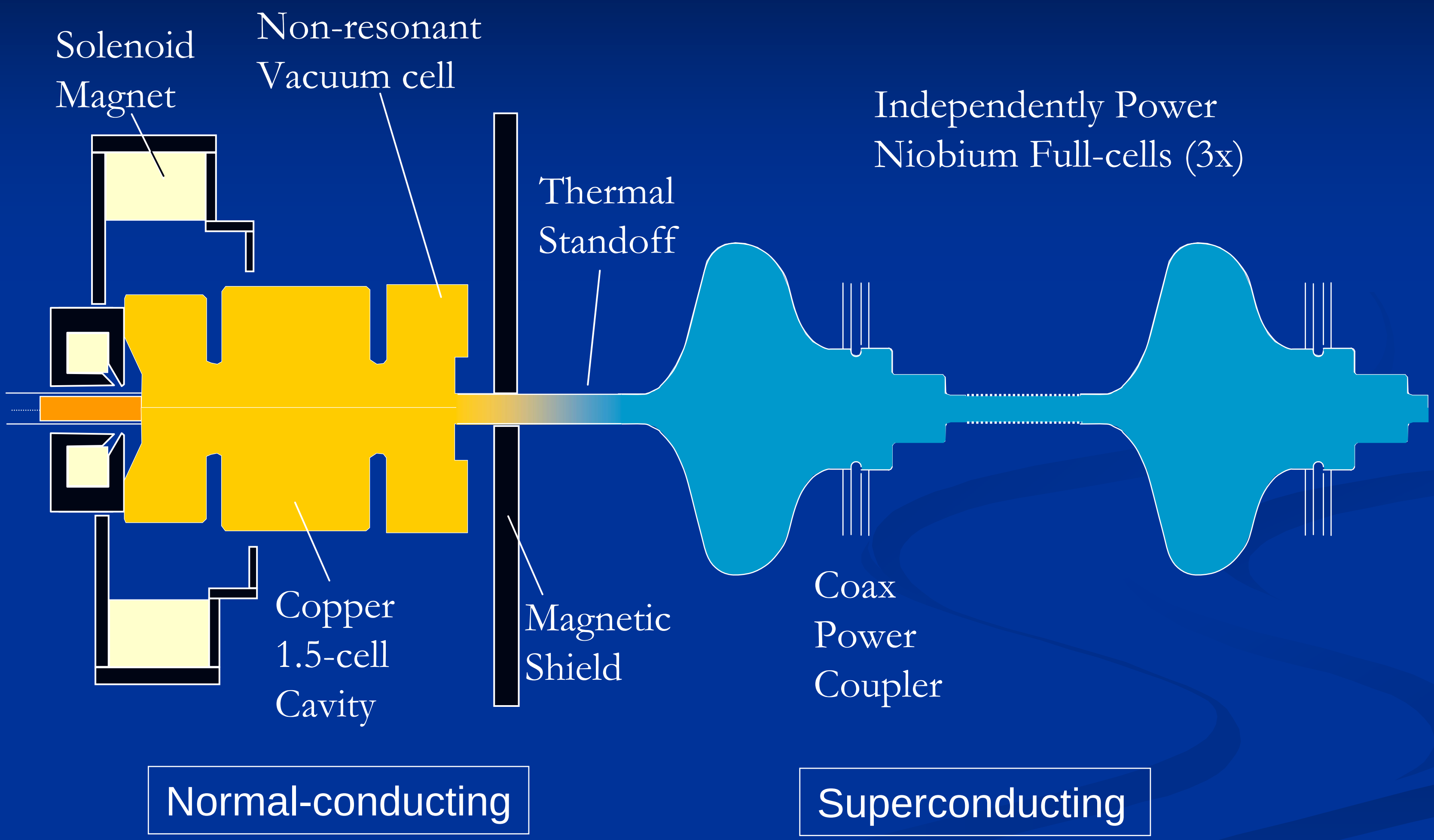
Normal-Conducting RF Gun Problems

- Ohmic loss scales with $(\text{gradient})^2$. Using a high gradient multi-cell cavity leads to large ohmic losses and requires careful thermal management.
- Thermal distortion in a multi-cell cavity leads to cavity detuning and loss of RF field flatness.
- High Q.E. photocathodes are poisoned by contaminations desorbed from the heated cavity walls.

Superconducting RF Gun Problems

- Magnetic field for emittance compensation near the cathode is incompatible with SRF cavities.
- Operating a semiconductor cathode at low temperature in an SRF cavity leads to low Q.E.
- Debris released from semiconductor cathodes could quench the SRF cavities.

Hybrid, NC-SRF Gun Concept



How the hybrid gun may solve the NC or SRF gun problems

- Solutions to NC gun problems
  - Cryo-pumping reduces cathode contamination
  - Ohmic loss is reduced with only 1.5-cell NC injector
- Solutions to SRF gun problems
  - NC gun can admit solenoid field for emittance compensation at high bunch charge
  - NC cathode is isolated from SRF cavities
    - Allows semiconductor cathode to operate at RT
    - Protect SRF cavities

Basic Injector Design Physics

- Gradients
  - Image charge field

$$E_z\left(0,\phi_{inj}\right) \geq 2E_{IC}$$

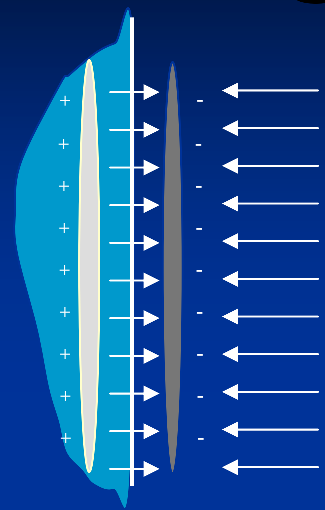
  - Invariant Envelope

$$\sigma_i = \left(\frac{2}{\gamma'}\right)\sqrt{\frac{I}{3I_0\gamma}}$$

- Space-charge emittance growth in drift

$$\varepsilon_{SC} = \left(\frac{I}{I_0}\right)\frac{G\left(L/A\right)}{\left(\beta\gamma\right)^2}D$$

- Keep the thermal standoff relatively short to reduce emittance growth in drift



$$E_{IC} = \frac{q}{\varepsilon_0 A}$$

$$E_z(z,t) = E_0\cos(kz)\sin(\omega t)$$

q = Bunch charge
A = Emission area
E_z = Cathode cell gradient
E_{IC} = Image charge field
σ_i = input rms radius
γ = beam's gamma
γ' = gradient ($d\gamma/dz$)
I = peak current
I_0 = Alvén current
$G(L/a)$ = geometric factor
0.05 (parabolic)
D = drift distance

LA-UR-05-1133

Example Parameter Set

Frequency	f	700 MHz
Bunch charge	q	1 nC
Beam energy	E_k	5 MeV
Emission area	A	1.13 cm^2
Image charge field	E_{IC}	1 MV/m
Injection phase	ϕ_{inj}	15^o
Cathode cell gradient	E_C	5 MV/m
Drift distance	D	0.7 m
SRF cell gradient	E_{SRF}	10 MV/m
Invariant rms radius	σ_i	2.6 mm

Minimizing Emittance

- Thermal emittance $\varepsilon_{n,T}$ scales with radius
- Space charge emittance $\varepsilon_{n,SC}$ scales with radius^{-1}
- RF-induced emittance $\varepsilon_{n,RF}$ scales with radius^{2}
- Total emittance ε_{n}

Thermal emittance

$$\varepsilon_{n,T} = \sigma_r \sqrt{\frac{kT}{mc^2}}$$

Space-charge emittance

$$\varepsilon_{n,SC} = \frac{I}{\gamma' I_A \left(\frac{3\sigma_r}{\sigma_z} + 5 \right)}$$

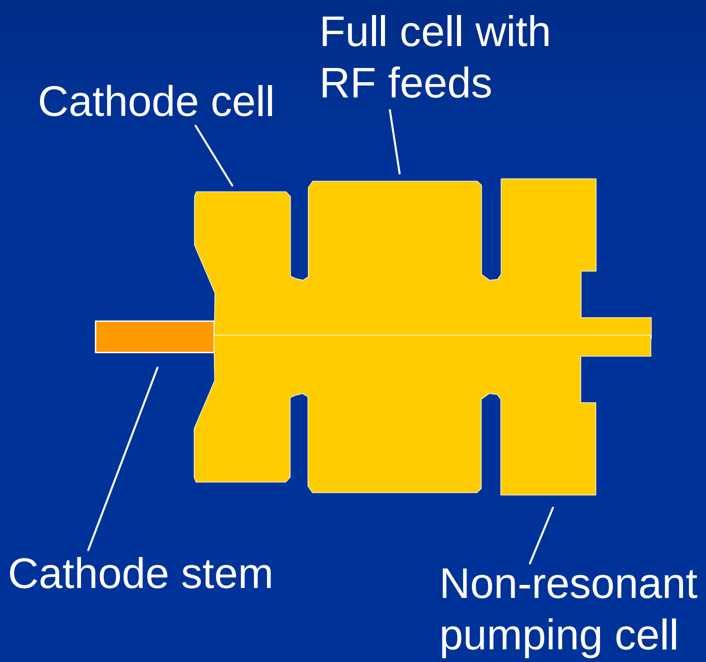
RF induced emittance

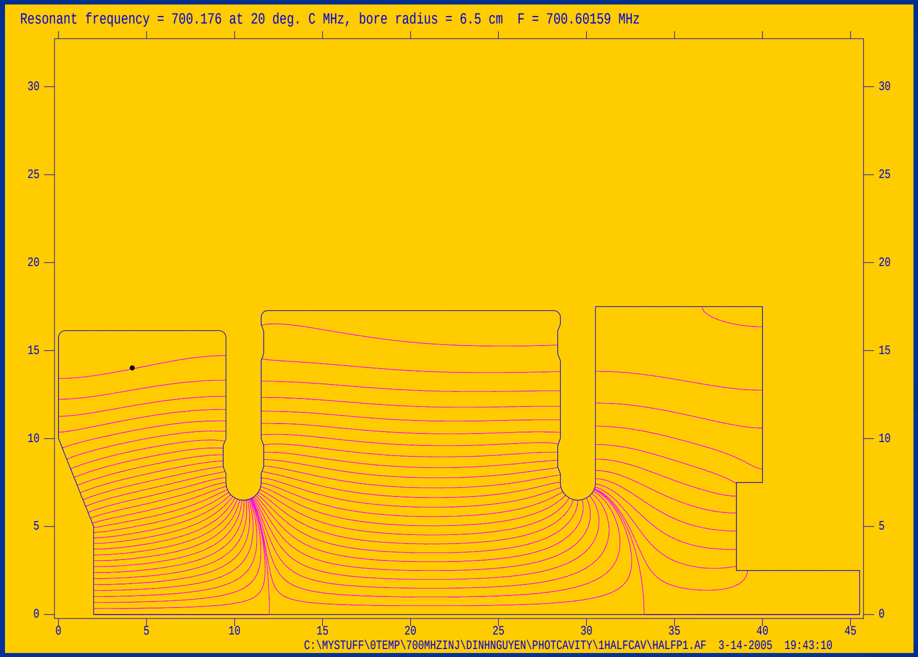
$$\varepsilon_{n,RF} = \gamma' k_{RF}^2 \sigma_r^2 \sigma_z^2$$

Total emittance

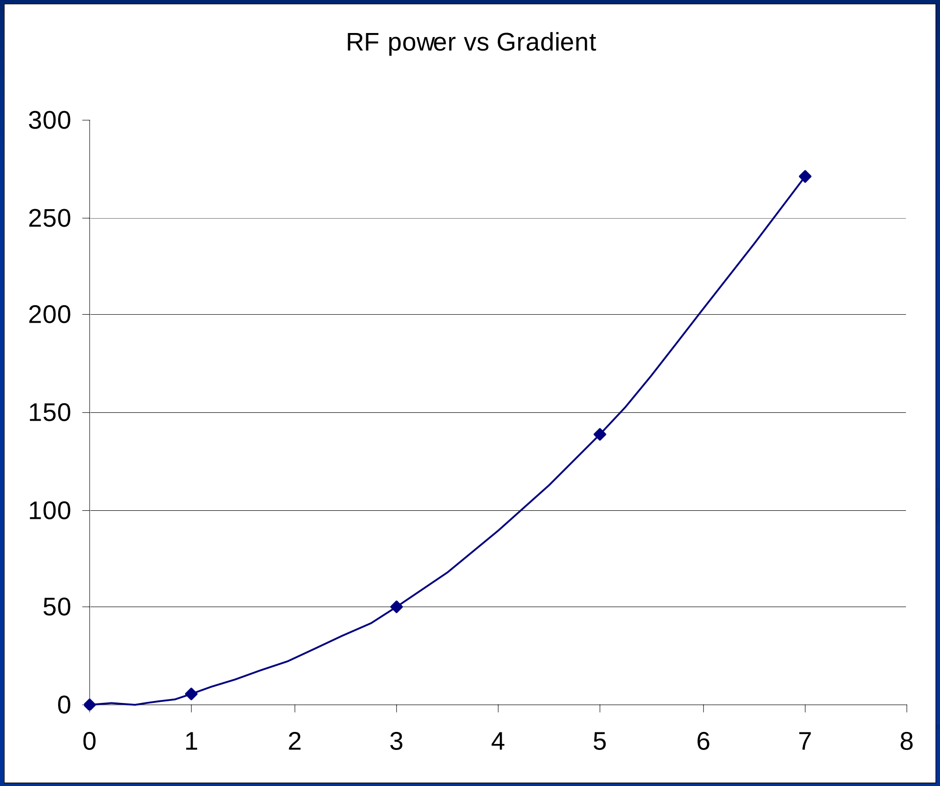
$$\varepsilon_n = \sqrt{\varepsilon_{n,SC}^2 + \varepsilon_{n,RF}^2 + \varepsilon_{n,T}^2}$$

Preliminary Design of 1.5-cell Normal-conducting Injector





RF Loss in RT Cu 1.5-cell Gun

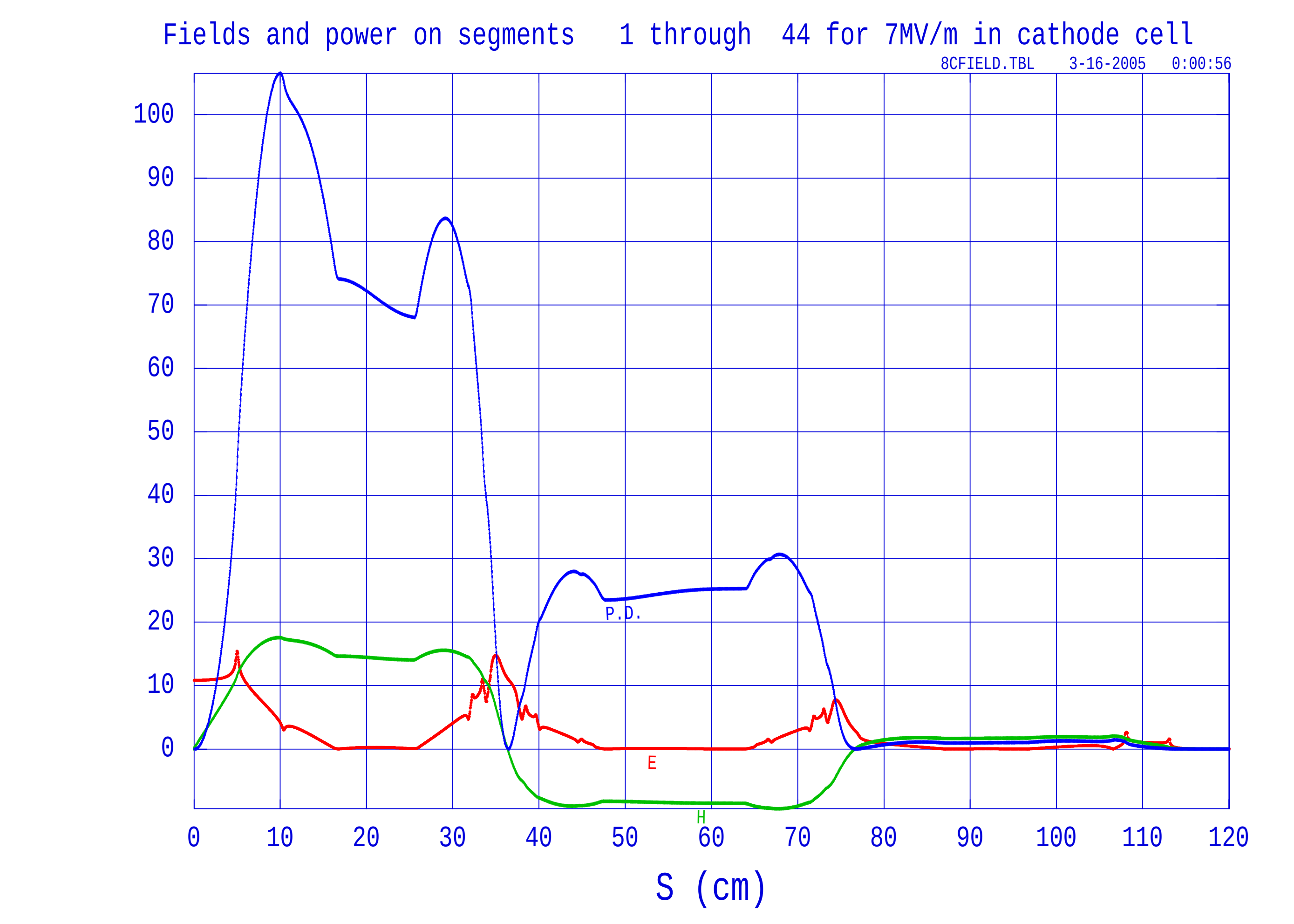


Ohmic loss (kW)

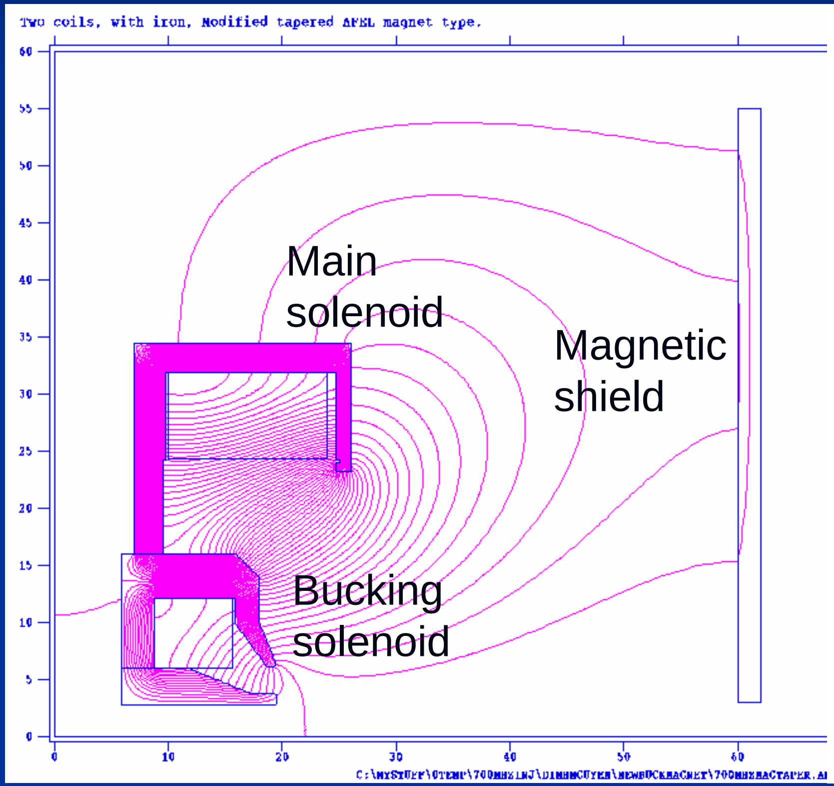
Gradient (MV/m)

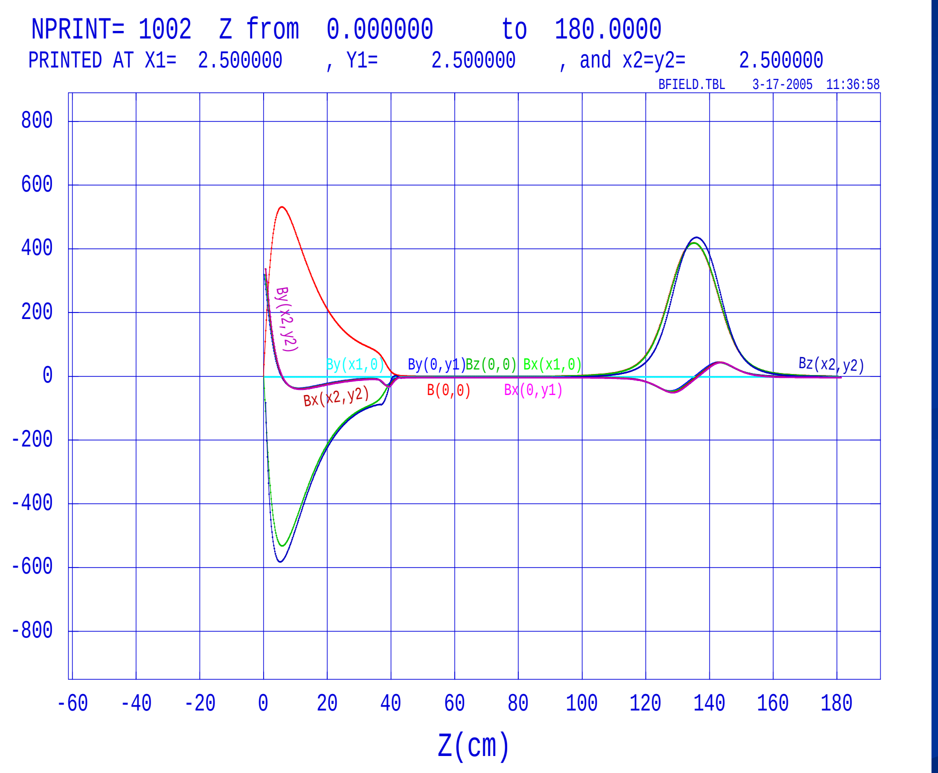
Total RF consumption =	**Ohmic loss +**	**Beam power**
At 5 MV/m and 100 mA	**139 kW**	**100 kW**
At 5 MV/m and 1 A	**139 kW**	**1 MW**

The calculated power density at 7 MV/m is ~100 W/cm^2



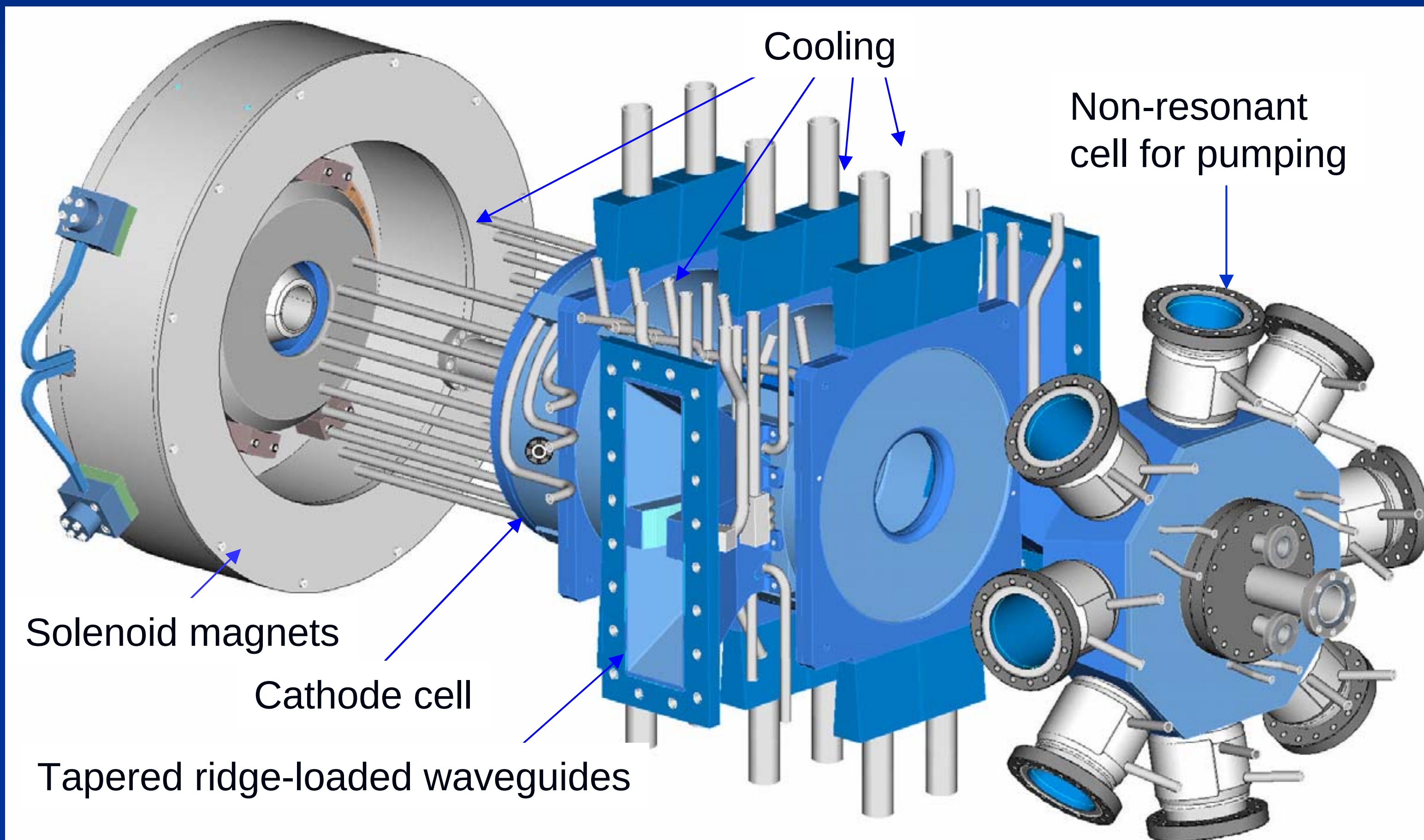
On-axis Magnetic Fields for Emittance Compensation





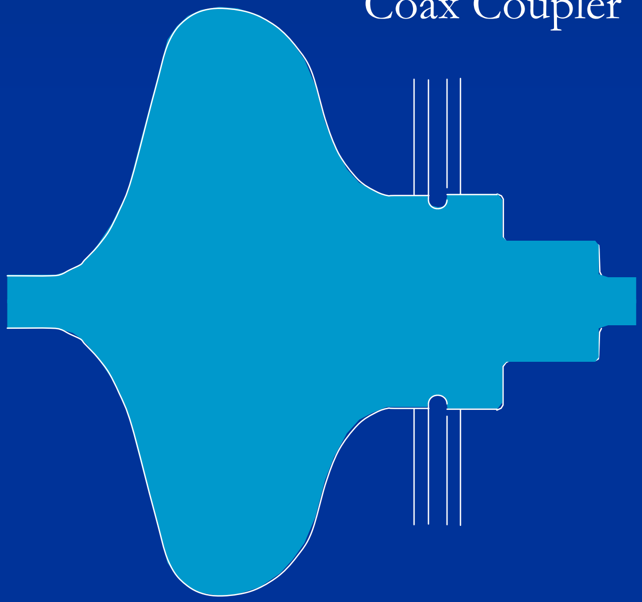
A magnetic shield is used to reduce stray magnetic field in SRF region
All solenoids have to be off when SRF cavities are being cooled down

A similar 2.5-cell NC injector is in fabrication at AES with 9/05 delivery

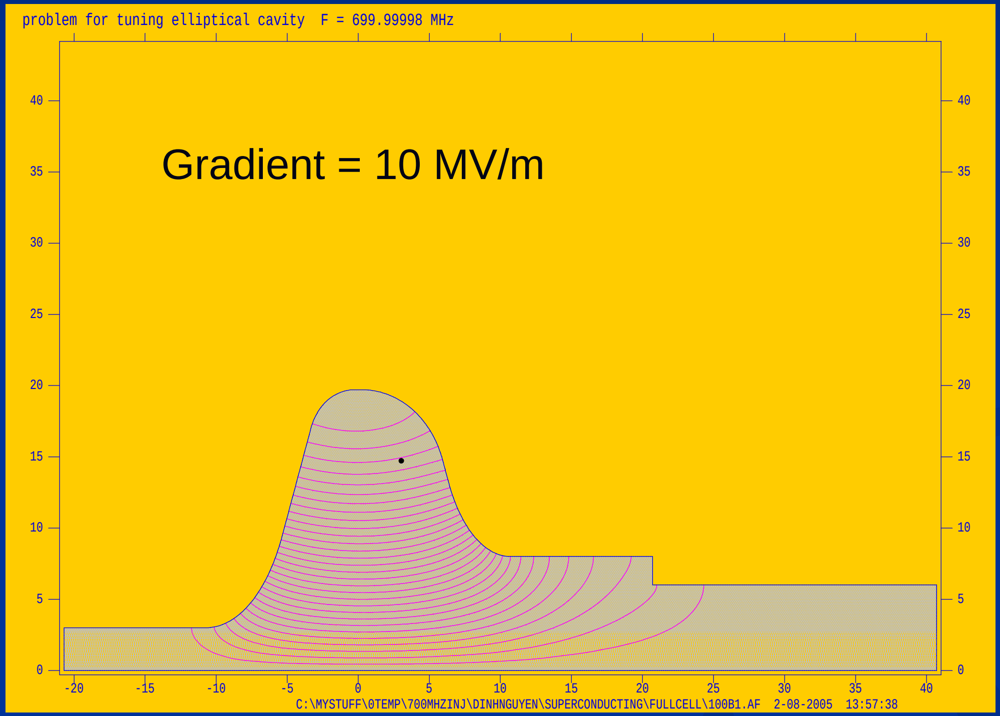


Preliminary Design of SRF Cavity

High-Power
Coax Coupler

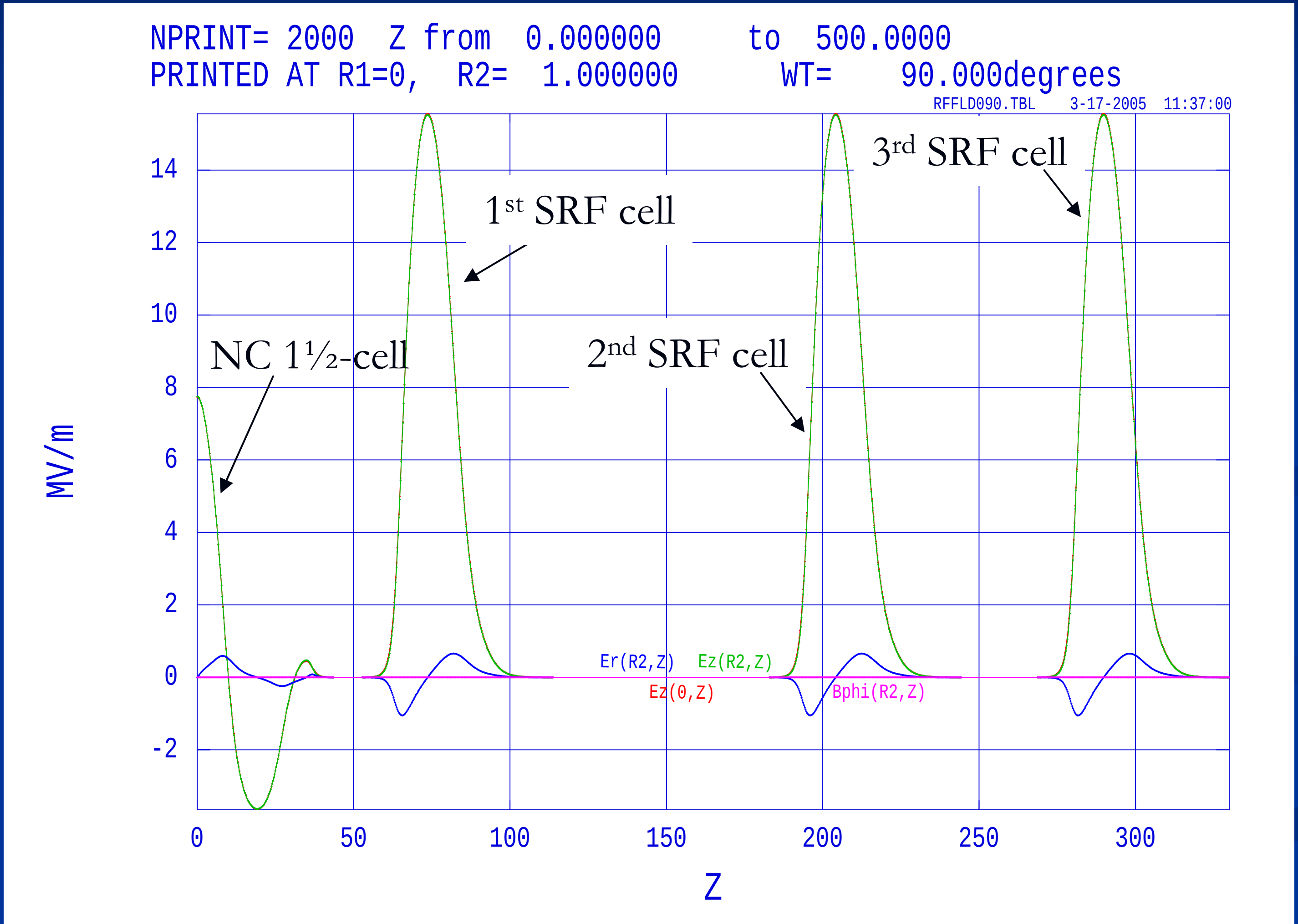


Asymmetric SRF Cavity

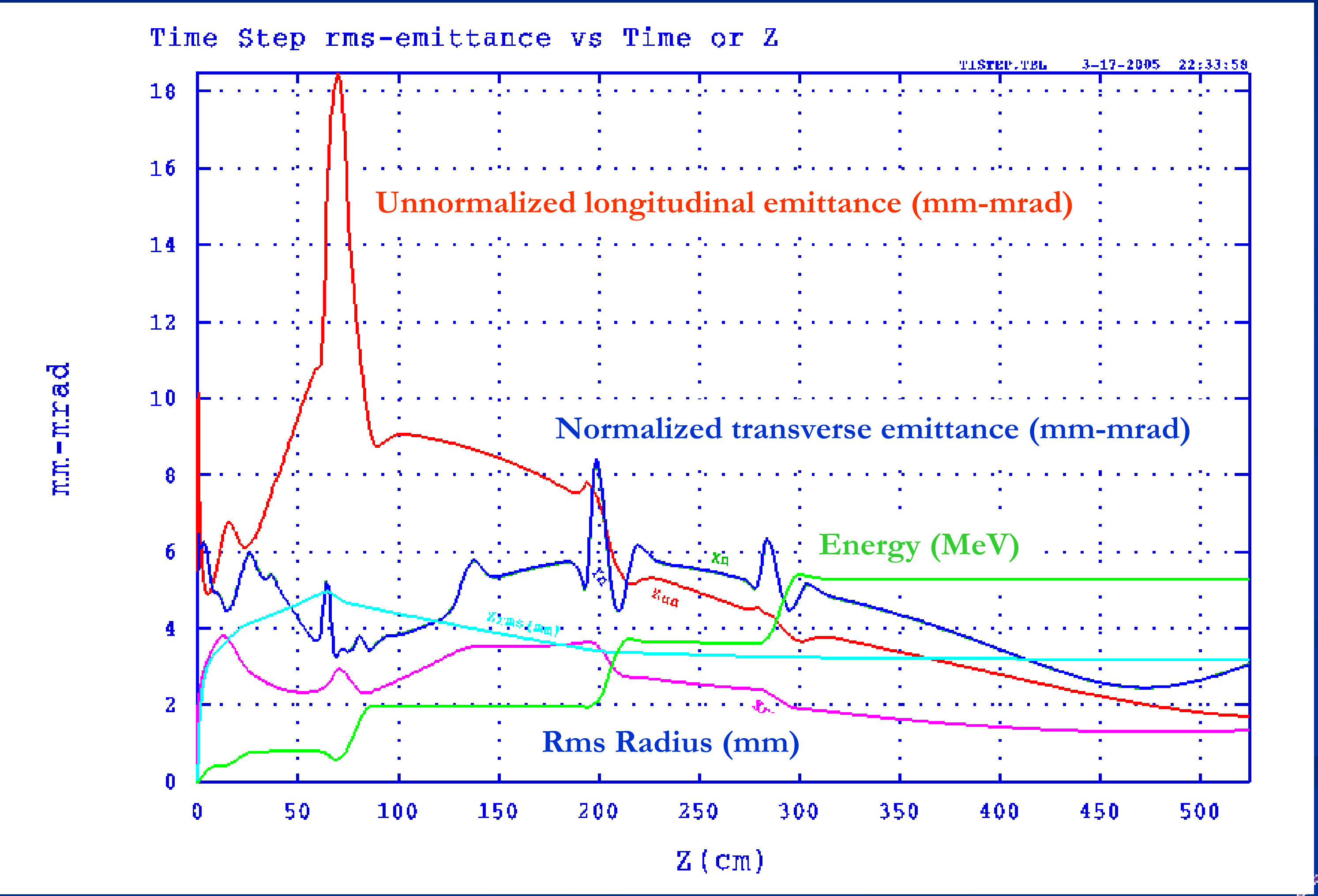


LA-UR-05-1133

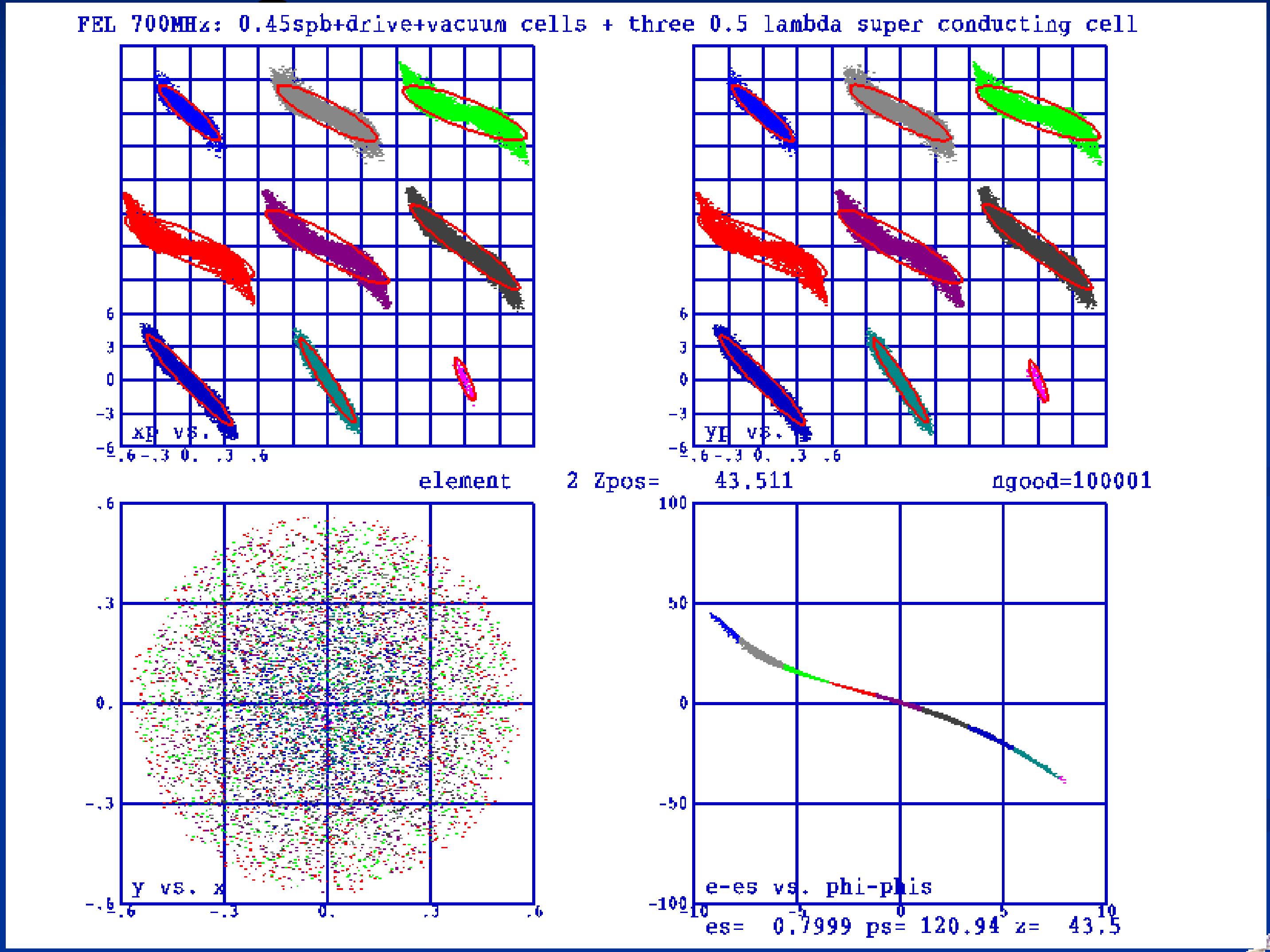
RF Field Plots



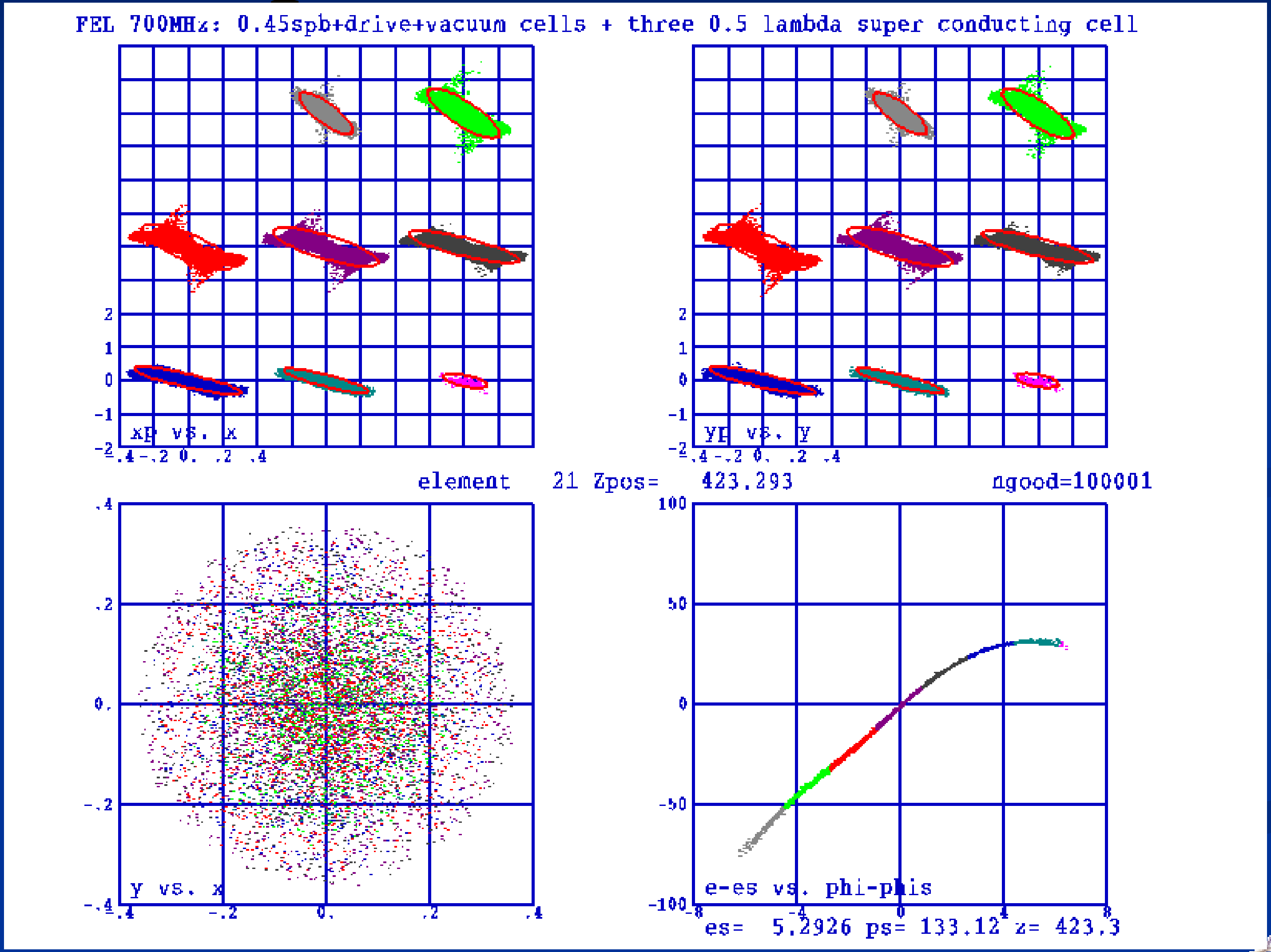
Hybrid injector at 5 MV/m NC and 10 MV/m SRF yields >5 MeV



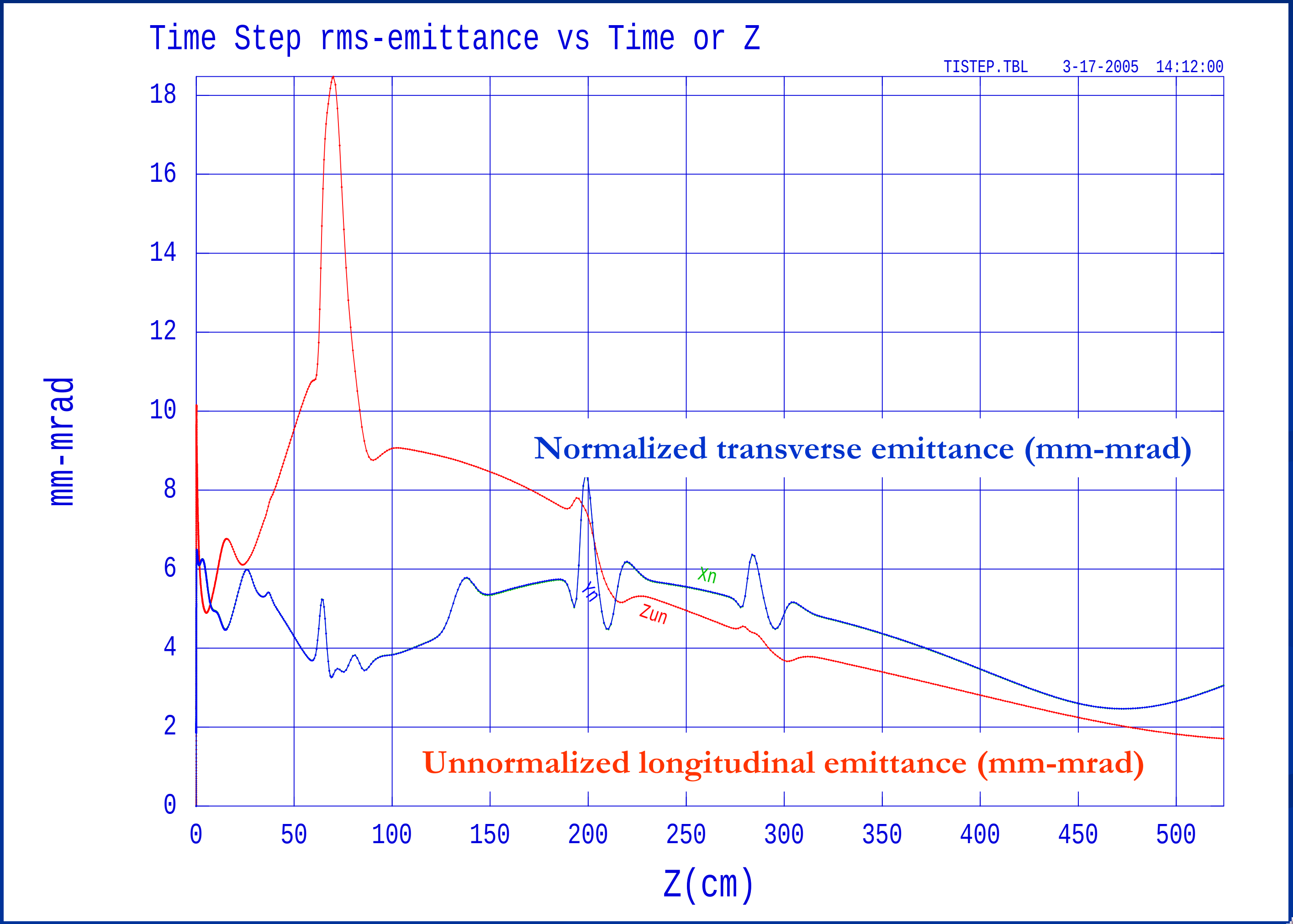
PARMELA Simulations
Phase-space Plots at z = 43.5 cm



PARMELA Simulations
Phase-space Plots at z = 423 cm



PARMELA simulation for 1 nC shows rms emittance <3 microns



Summary

- A novel hybrid injector with 1½-cell normal-conducting gun and 3 independently powered superconducting RF cells is presented.
- The hybrid injector admits an external magnetic field near the cathode for emittance compensation.
- PARMELA simulations show the feasibility of achieving 5 MeV energy from 1½-cell NC at 5 MV/m and 3 SRF cells at 10 MV/m.
- Preliminary simulations show emittance from the hybrid injector is less than 3 microns for 1 nC.