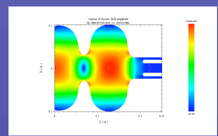
Beam Dynamics in RF photocathode Gun

M. Ferrario, J. B. Rosenzweig, J. Sekutowicz, L. Serafini

INFN, UCLA, DESY



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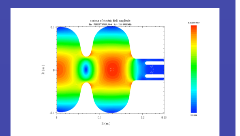
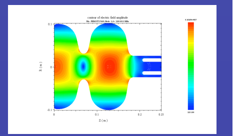
* ANL Theory Institute on Production of Bright Electron Beam - September 22-26 2003 *

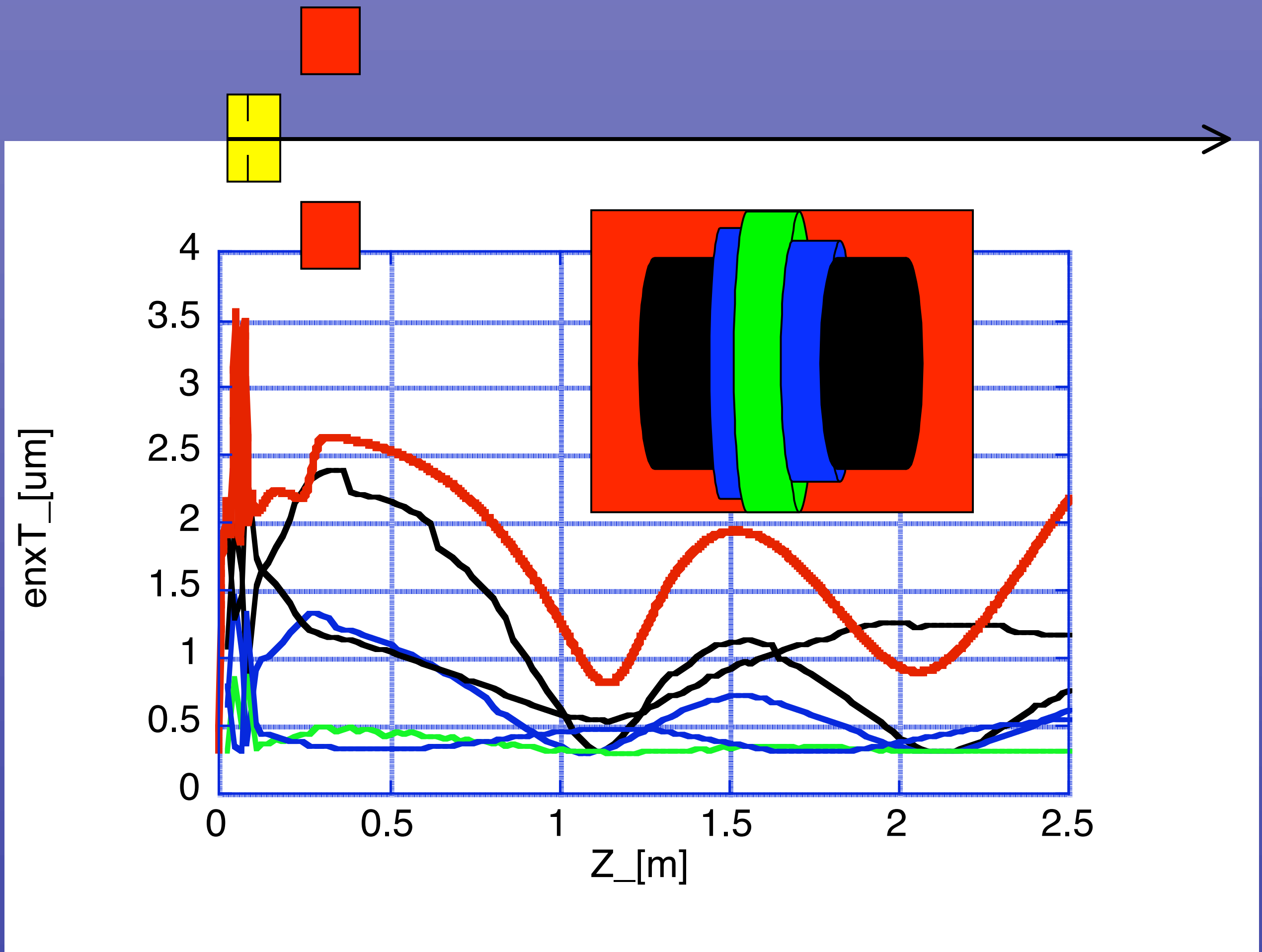


- Chromatic Effect in the Gun Solenoid

- Towards a Superconducting High Brightness Photoinjector

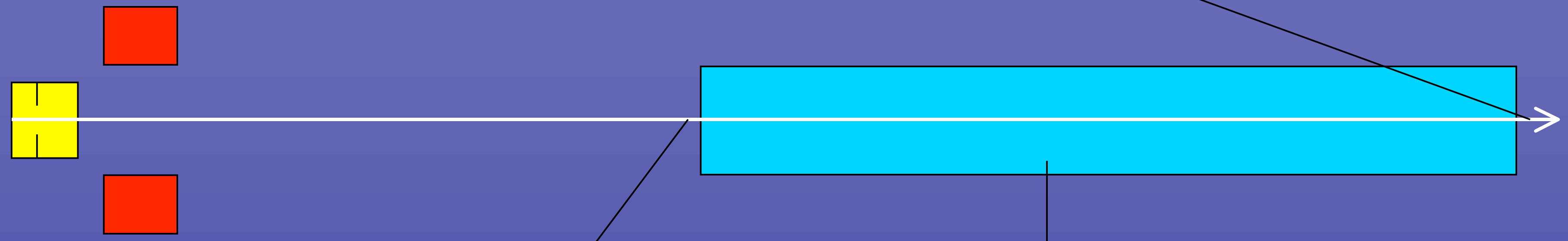


Gun Working Point



Matching Conditions with the Linac

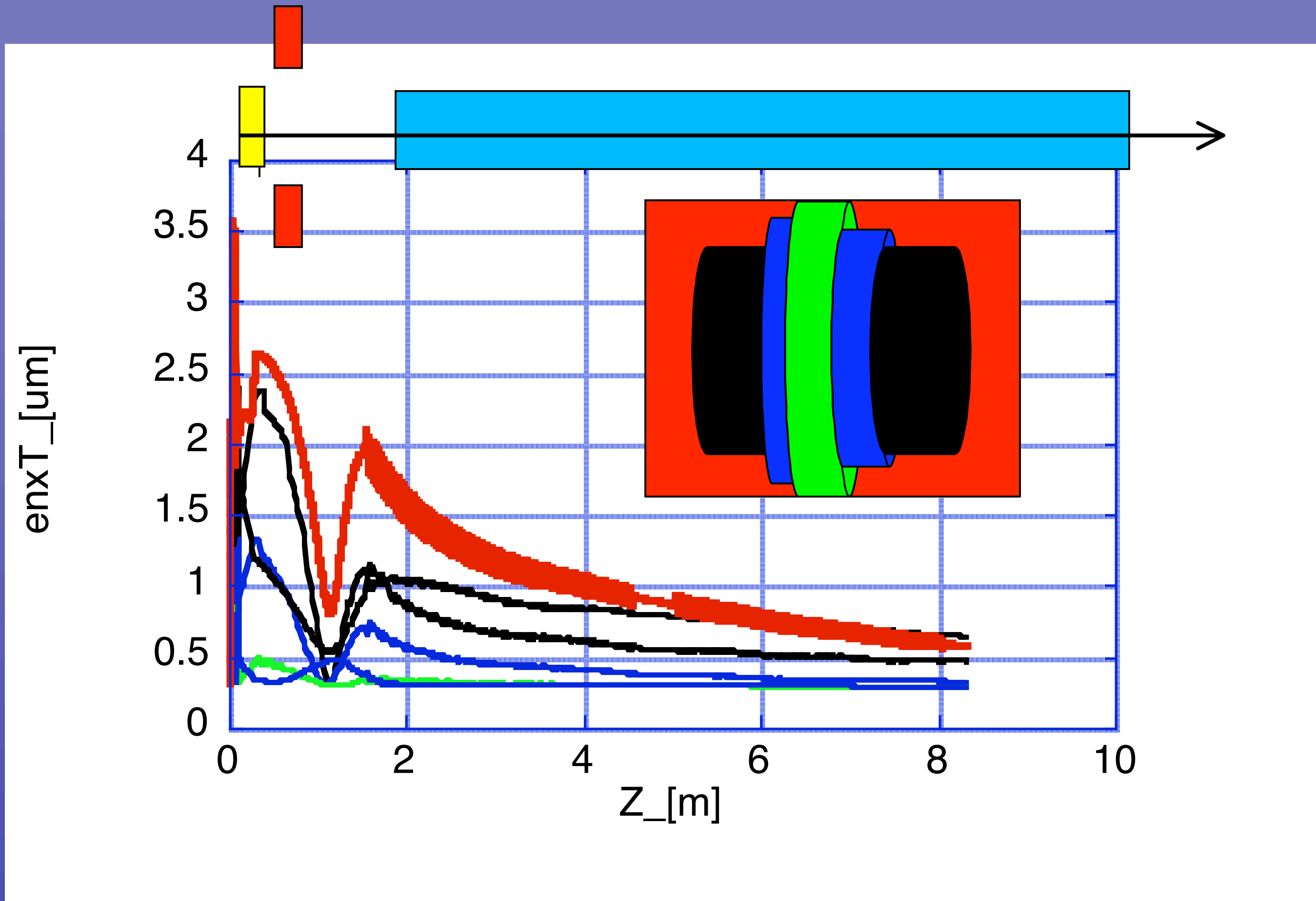
$$\sigma_w = \sqrt{\frac{8}{3}}\,\frac{\hat{I}}{2 I_o \epsilon_{th} \gamma'}$$



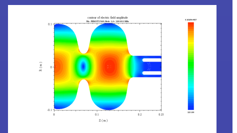
$$\sigma' = 0$$

$$\gamma' = \frac{2}{\sigma_w}\sqrt{\frac{\hat{I}}{3 I_0 \gamma}}$$

Linac Working Point



The emittance compensation occuring in the booster when the invariant envelope matching conditions are satisfied is actually limited by the head and tail slice behavior



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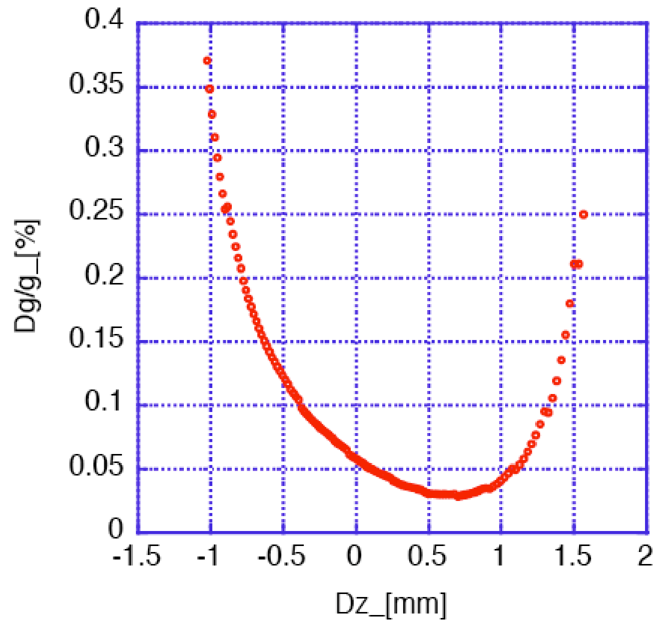
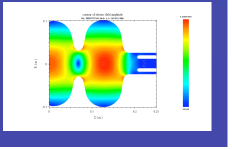
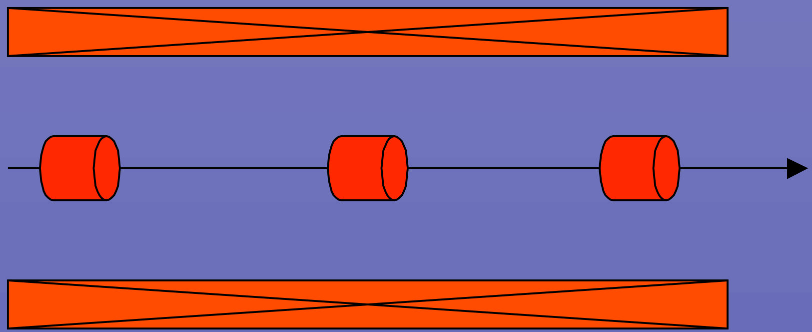
these slices also carry the most pronounced energy spread



Energy deviation along the bunch at z=0.2 (solenoid centre) computed for a 400 μm long slice centered at Dz.



Simple Case: Transport in a Long Solenoid

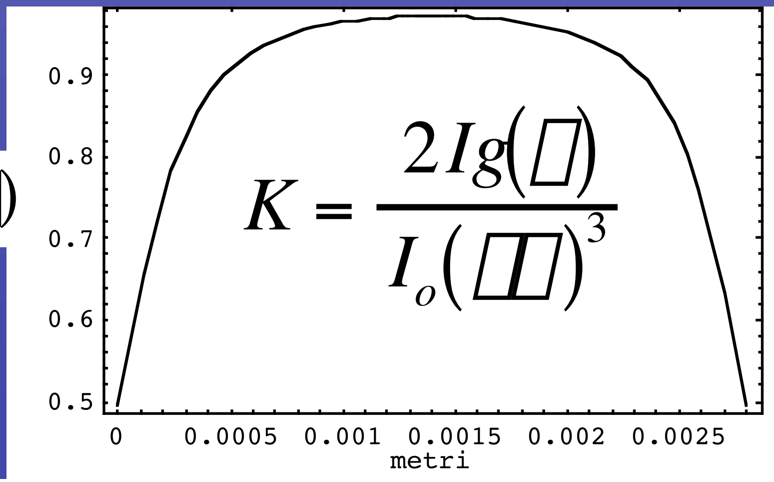


$$\square'' + k_s^2 \square = \frac{K}{\square}$$

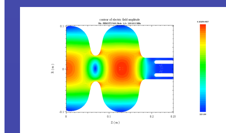
$$\square'' = 0$$ ==> Equilibrium solution ? ==> $$\square_{eq}(\square) = \frac{\sqrt{K(\square)}}{k_s}$$

$$k_s = \frac{qB}{2mc\square\square}$$

g(□)



$$K = \frac{2Ig(\square)}{I_o(\square\square)^3}$$



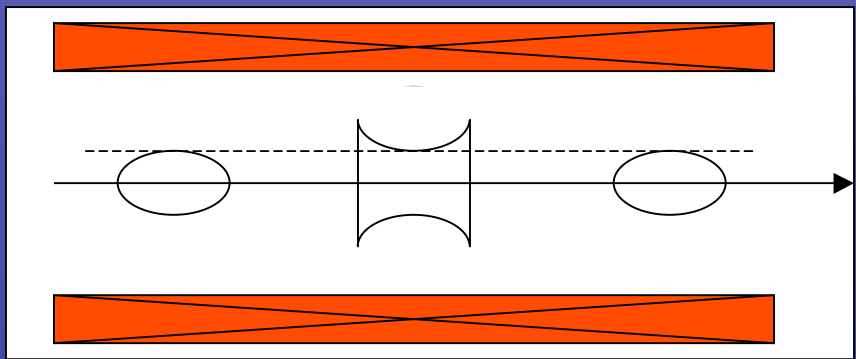
Small perturbations around the equilibrium solution

$$\square = \square_{eq} + \square\square$$

$$\square\square'' + 2k_s^2 \square\square = 0$$

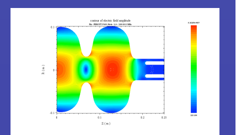
$$\square(\square) = \square_{eq}(\square) + \left(\square(\square)\ \square\square_{eq}(\square)\right)\cos\left(\sqrt{2}k_s z\right)$$

$$\square'(\square) = \square\sqrt{2}k_s\left(\square(\square)\ \square\square_{eq}(\square)\right)\sin\left(\sqrt{2}k_s z\right)$$

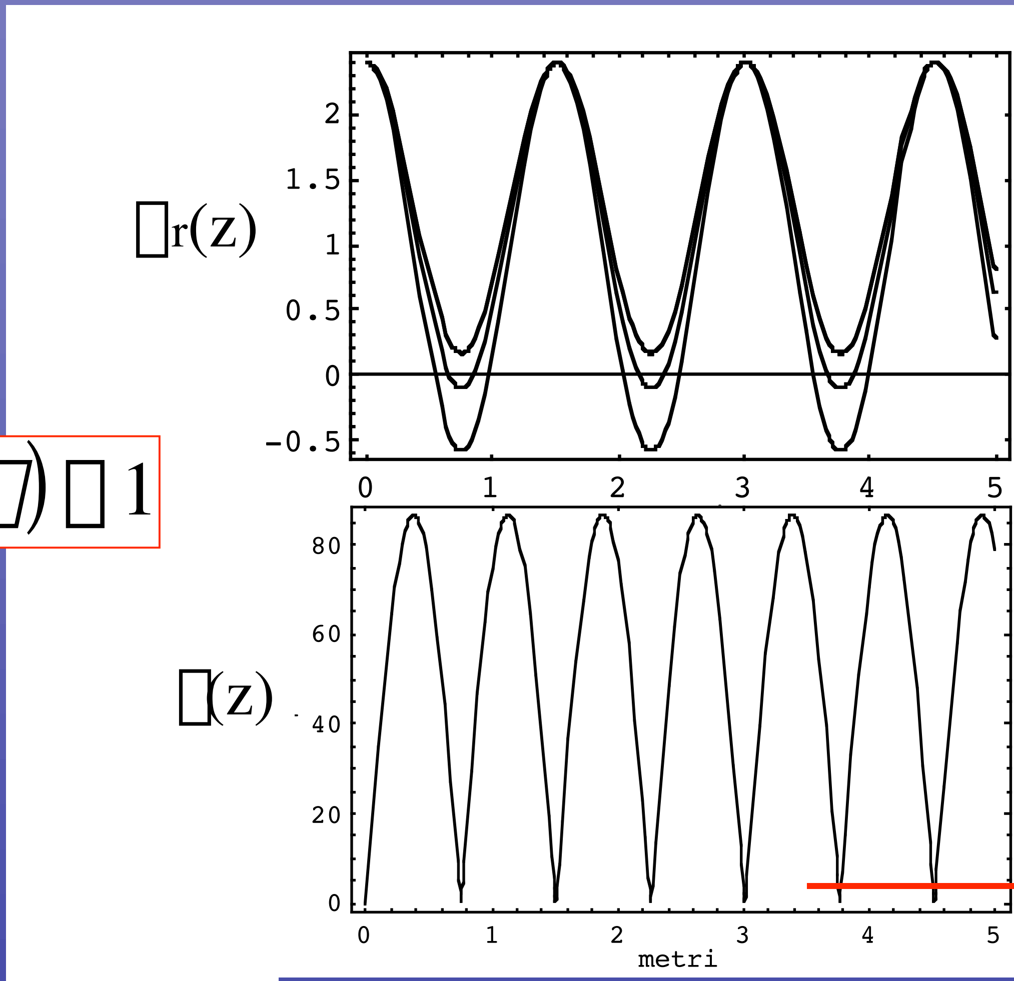


Same Plasma Frequencies

Different Amplitudes



Envelope oscillations drive Emittance oscillations

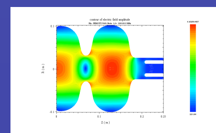


$$0.5 \,\square\, g(\square) \,\square\, 1$$

$$\frac{\square\square}{\square} = 0$$

$$\square\square = 0$$

$$\square(z) = \sqrt{\langle \square_r^2 \rangle \langle \square_r'^2 \rangle \,\square\, \langle \square_r \square_r' \rangle^2} \div \left| \sin\left(\sqrt{2} k_s z\right) \right|$$



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Bunch with a Linear Energy Spread Correlation

$$\gamma_+ = \gamma_o(1+\delta_\gamma)$$

$$\gamma_- = \gamma_o(1-\delta_\gamma)$$

$$\delta_\gamma = \frac{\Delta\gamma}{\gamma_o}$$

$$\sigma_+ = \sigma_{eq+} + \delta\sigma_+ \cos\left(\sqrt{2}k_+ z\right)$$
$$\sigma'_+ = -\sqrt{2}k_+\delta\sigma_+ \sin\left(\sqrt{2}k_+ z\right)$$

$$\sigma_- = \sigma_{eq-} + \delta\sigma_- \cos\left(\sqrt{2}k_- z\right)$$
$$\sigma'_- = -\sqrt{2}k_-\delta\sigma_- \sin\left(\sqrt{2}k_- z\right)$$

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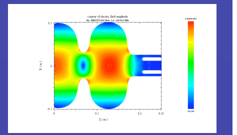
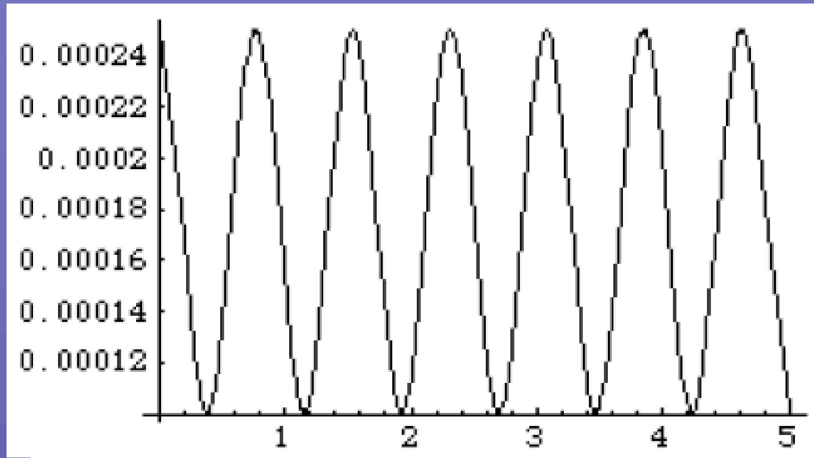
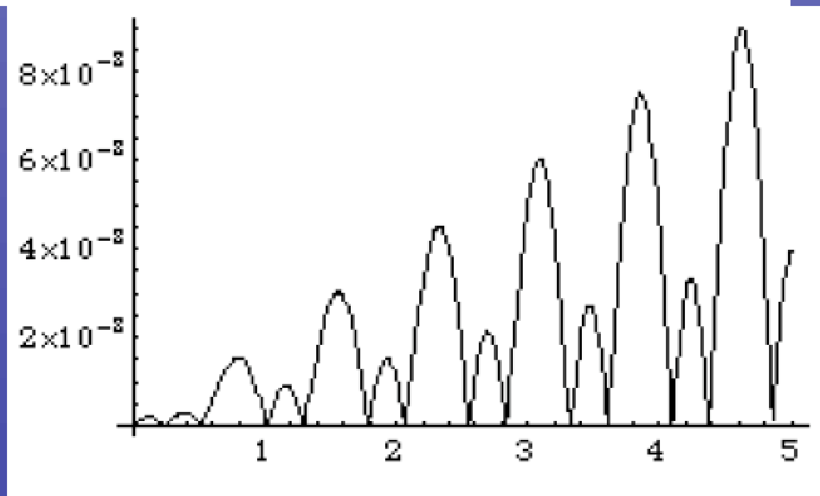


A Spread in Plasma Frequencies drives a Beating in Emittance Oscillations



$$\square\square_o = \square_c \square \square_{eqo}$$

$$\langle k \rangle = \frac{1}{\sqrt{2}}\left(k_+ + k_\square\right) = \sqrt{2}k_o$$



$$\square k = \sqrt{2}\left(k_\square \square k_+\right) = 2\sqrt{2}k_d\square$$

$$\square_n = \frac{\square}{\sqrt{2}} k_o \left| \square_{eqo}\left(2\square\square_o + \square_\square\right) \sin\left(\frac{\square k}{2} z\right) \cos\left(\langle k \rangle z\right) + \square\square_o^2 \sin\left(\square k z\right) \right|$$

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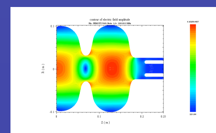
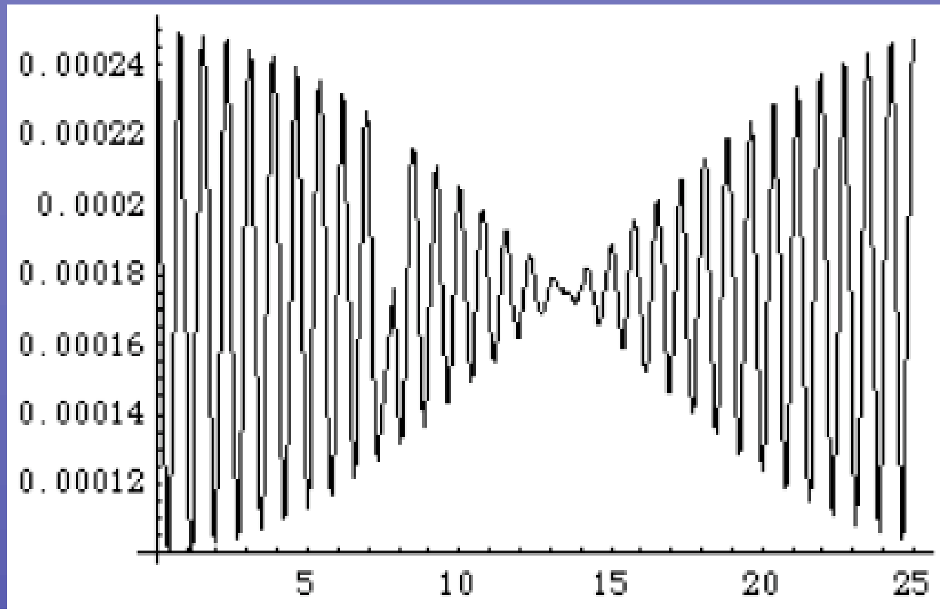
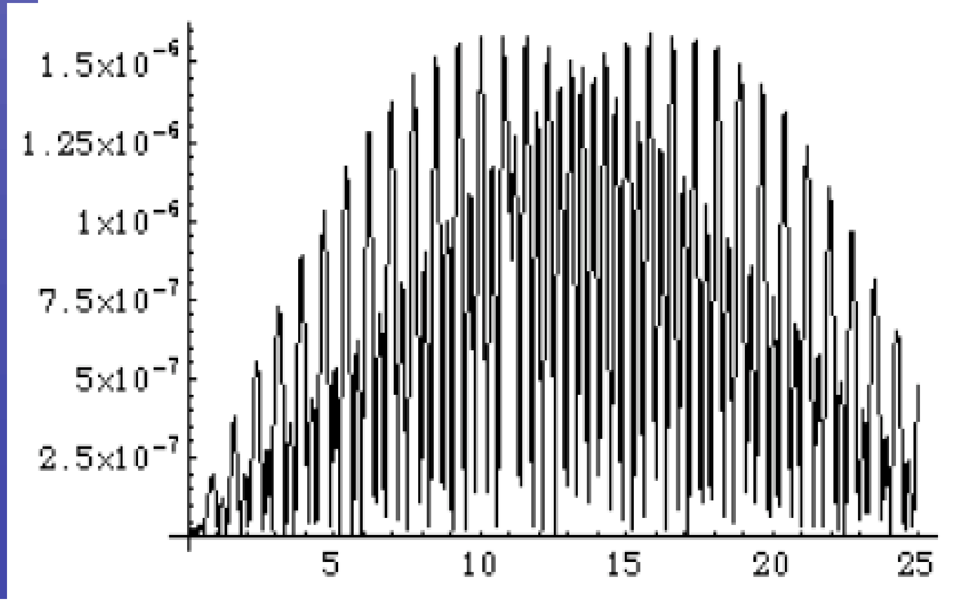
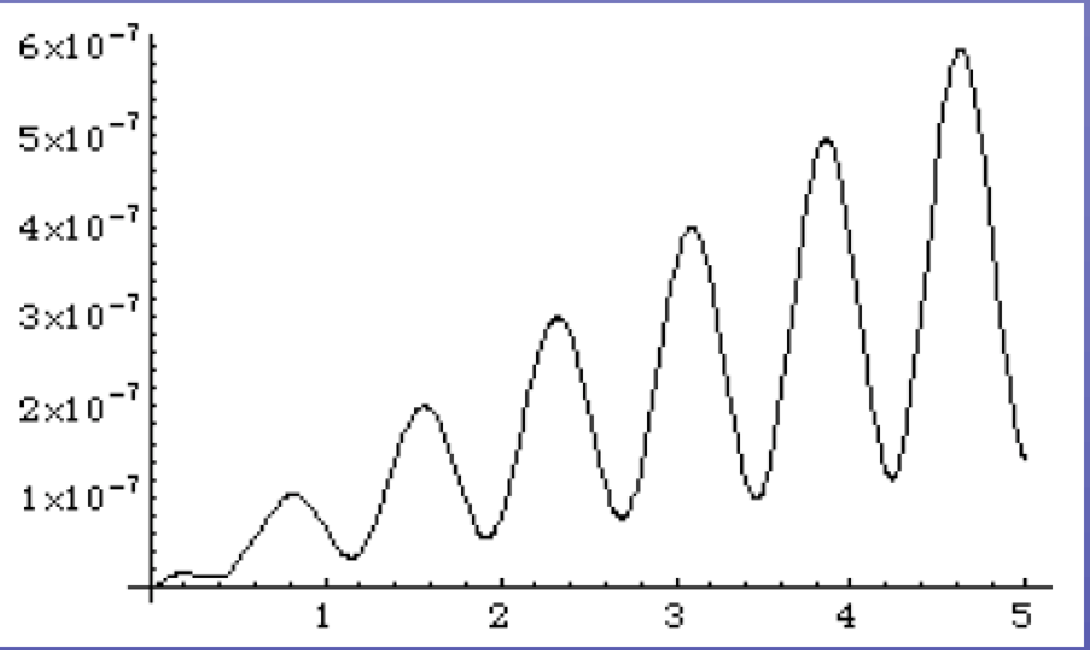


On a longer time scale







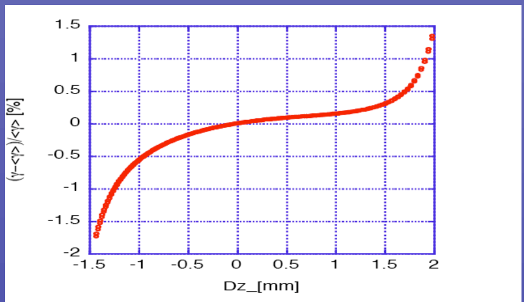
increasing the initial envelope offset the emittance evolution is dominated by the beating term and the original minimum is recovered only after a longer period

Scaling with □

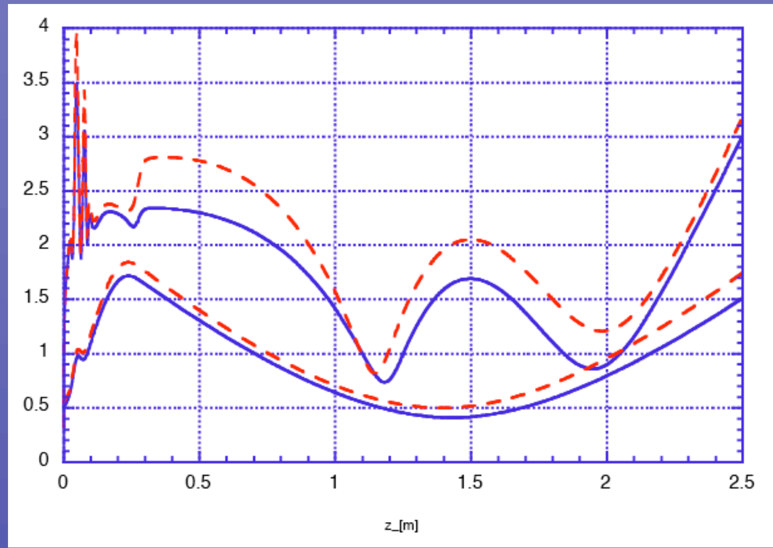
$B \quad \langle \square \rangle$

$\dfrac{\square_r}{\square_l} \quad \langle \square \rangle$

$J \quad \langle \square \rangle^{3}$

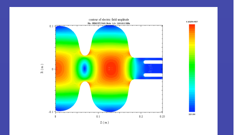


: Longitudinal phase space in the center of the solenoid (z=0.2 m).



$\square_l \quad \langle \square \rangle^{\square 5/3}$

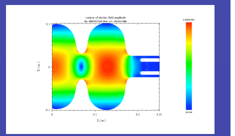
$\square_r \quad \langle \square \rangle^{\square 2/3}$



Towards a Superconducting High Brightness RF Photoinjector

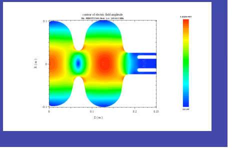
M. Ferrario, J. B. Rosenzweig, J. Sekutowicz, L. Serafini

INFN, UCLA, DESY



Main Questions/Concerns

- RF Focusing vs Magnetic focusing ?
- High Peak Field on Cathode ?
- Cathode Materials and QE ?
- Q degradation due to Magnetic Field ?



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Section A

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RF focussing – an instrument for beam quality improvement in superconducting RF guns

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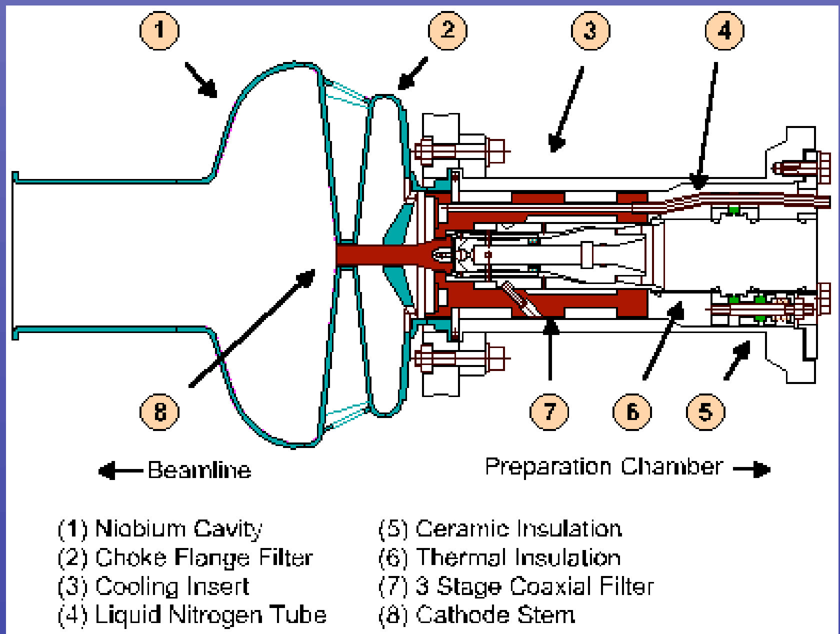
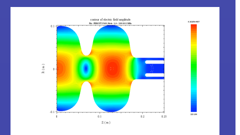
[b]Budker INP, 630090, Lavrentev Avenue, 11, Novosibirsk, Russia





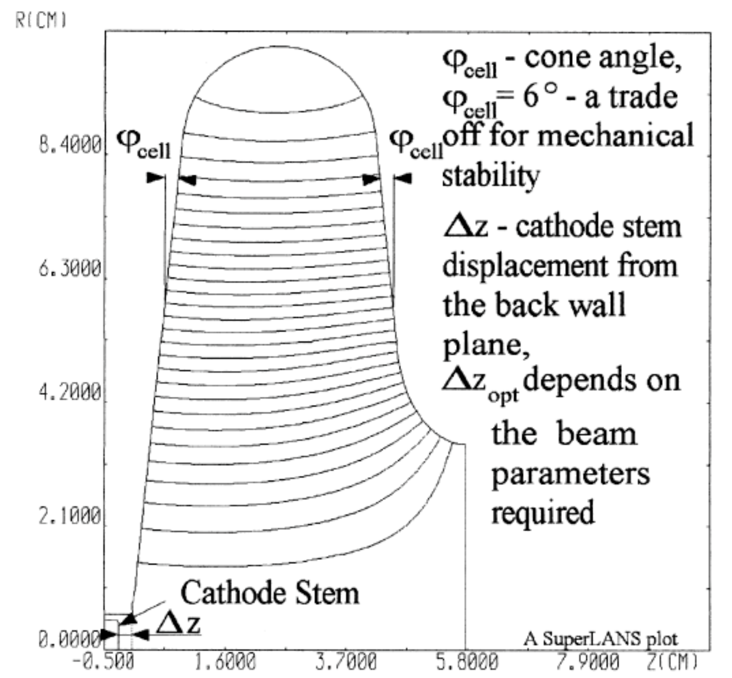


Fig. 2. Geometry and the field pattern of the first cell.

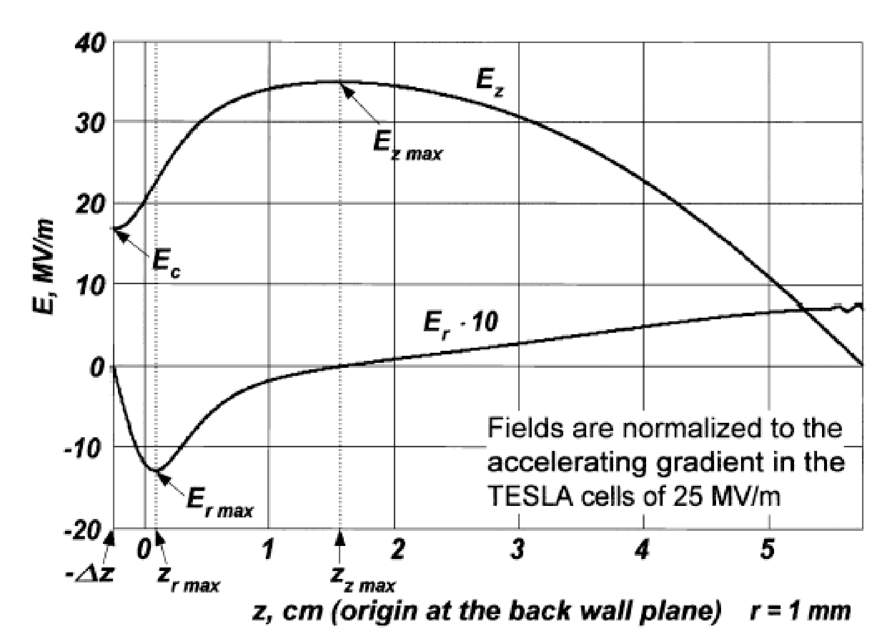
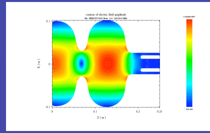


Fig. 4. Electric field components in the first cell of the 1.3 GHz RF gun cavity.

No independent tuning of accelerating field and RF focusing effects

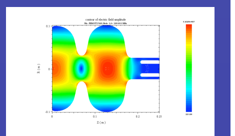
$$E_r \cong -\frac{r}{2}\frac{\partial}{\partial z}E_z(z,0)+\frac{r^3}{16}\frac{\partial^3}{\partial z^3}E_z(z,0)+.......$$

Transverse non linearities



Recent results allow us to look for a simpler design

(PAC 2003)



DEVELOPMENT OF ELECTROPOLSHING TECHNOLOGY FOR SUPERCONDUCTING CAVITIES

K.Saito#, KEK, 1-1 Oho, Tsukuba-shi, Ibaraki-ken, Japan

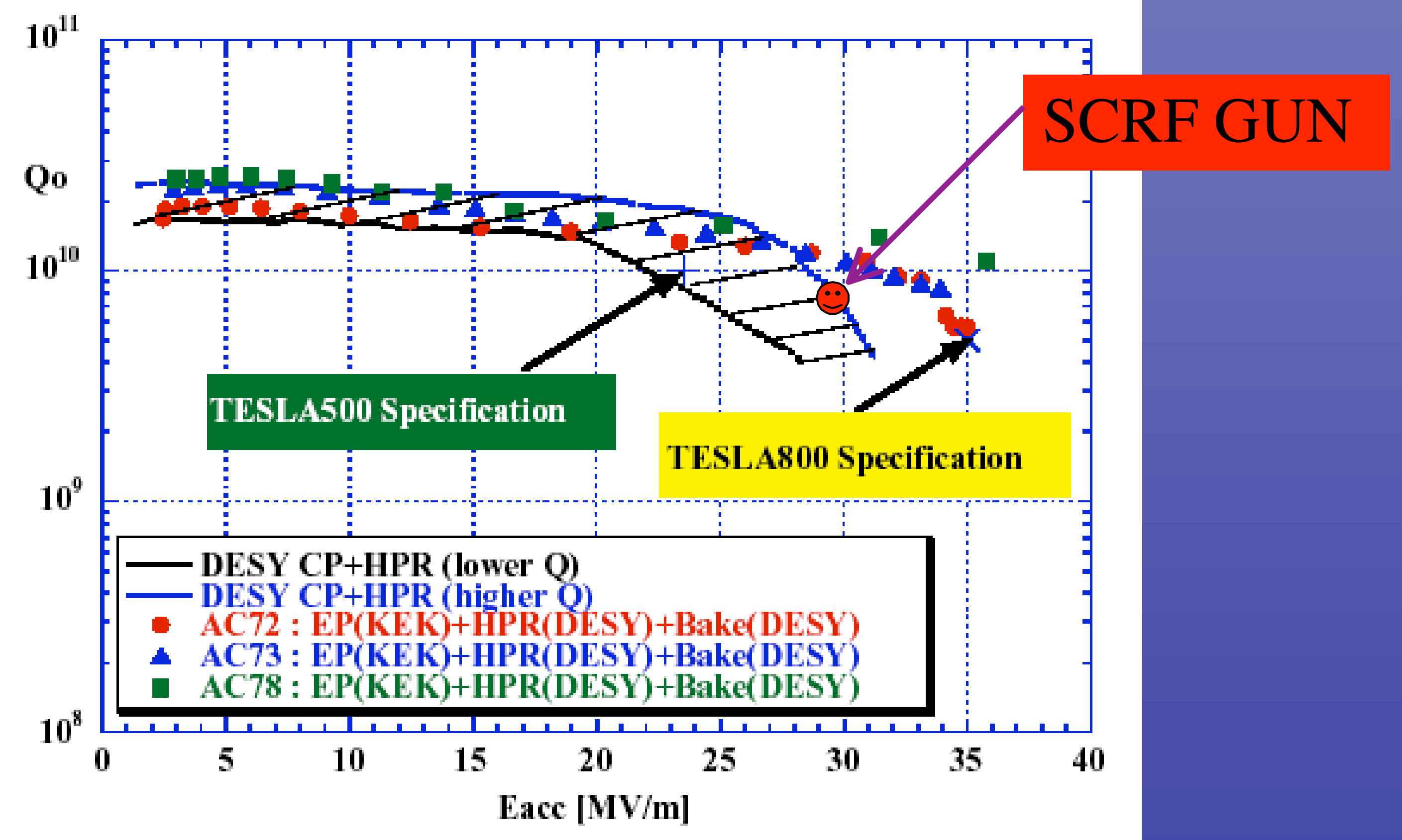


Figure 8: Results of electropolished TTF cavities.

TESTS OF NIOBIUM CATHODE FOR THE SUPERCONDUCTING RADIO FREQUENCY GUN

Qiang Zhao, Triveni Srinivasan-Rao, BNL, Upton, NY 11973, USA
Mike Cole, Advanced Energy Systems, Medford, NY 11763, USA

Laser Cleaning

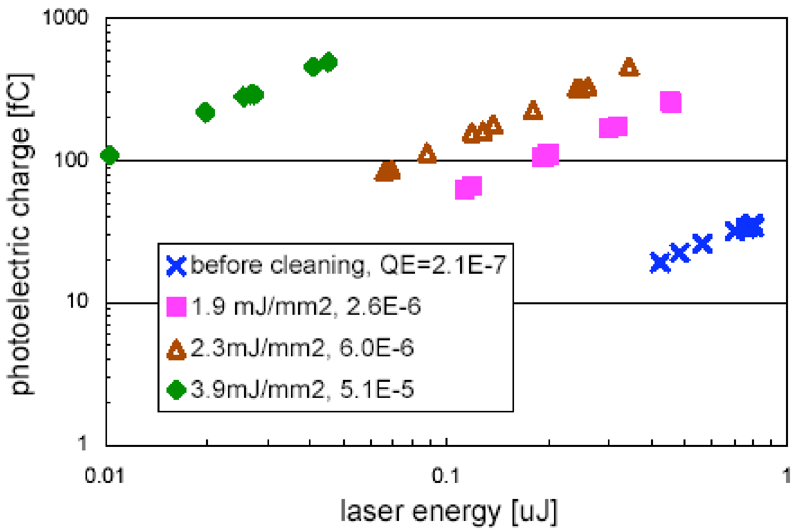


Figure 3: QE of BCP Niobium sample cleaned by 248nm, measured by 266nm

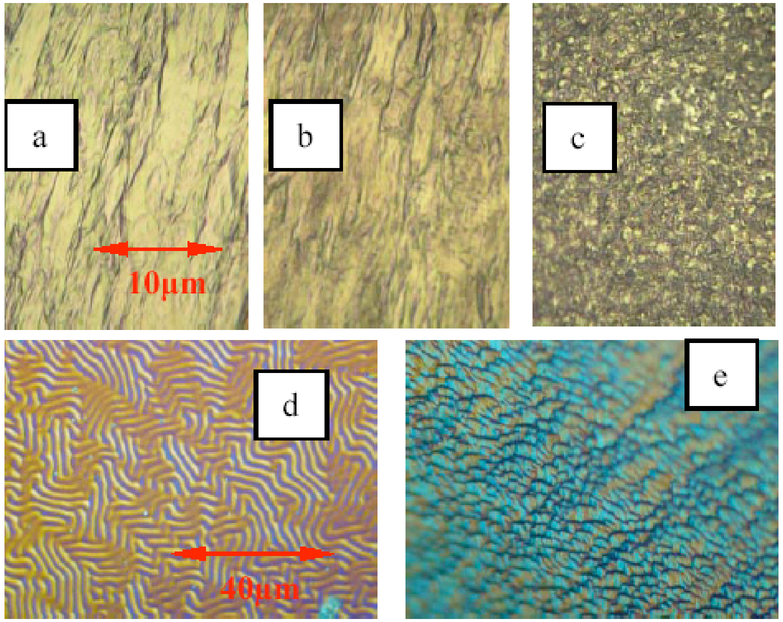


Figure 2: Niobium surfaces cleaned with different ps-YAG laser energy densities, observed under optical microscope. BCP sample: a) before laser cleaning, b) laser energy density 0.25mJ/mm^2, c) laser energy density 0.67mJ/mm^2 EP sample: d) before cleaning; e) laser energy density 0.45mJ/mm^2

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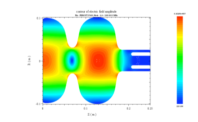
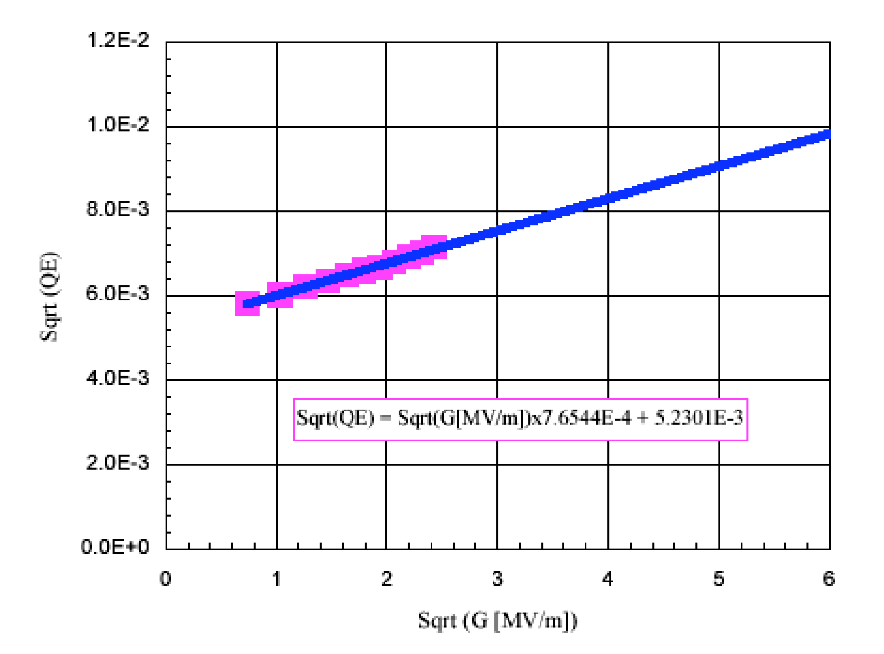
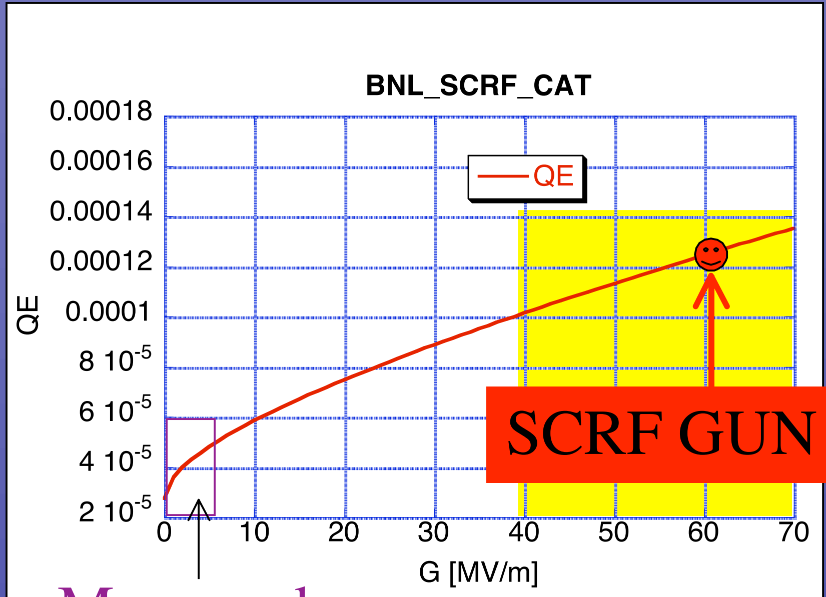
QE limited by surface morphology degradation



Measurements at room T on a dedicated DC system

Extrapolation to Higher Field





Measured

$$\eta = K(h\nu - \phi_o + \sqrt{e/4\pi\varepsilon_o}\sqrt{E_s})^2$$

$\eta = QuantumEfficiency$

$h\nu = PhotonEnergy$

$\phi_o = ElectronWorkFunction$

$K = Const.$

$E_s = AppliedElectricField$

Limited by the available voltage

DESIGN, CONSTRUCTION AND STATUS OF ALL NIOBIUM SUPERCONDUCTING PHOTOINJECTOR AT BNL

T. Srinivasan-Rao, I. Ben-Zvi, A. Burrill, G. Citver, A. Hershcovitz, D. Pate, A. Reuter, J. Scaduto, Q. Zhao, Y. Zhao, BNL, Upton, NY, USA

J. Delayen, P. Kneisel, TJNAF, Newport News, VA, USA

H. Bluem, M. Cole, A. Favale, J. Rathke, T. Schultheiss, Advanced Energy Systems, Medford, USA

Figure 4: Photograph of ½ cell Nb cavity

Ready for cold test: QE? Thermal Effects?

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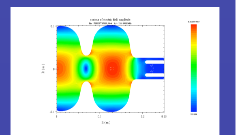
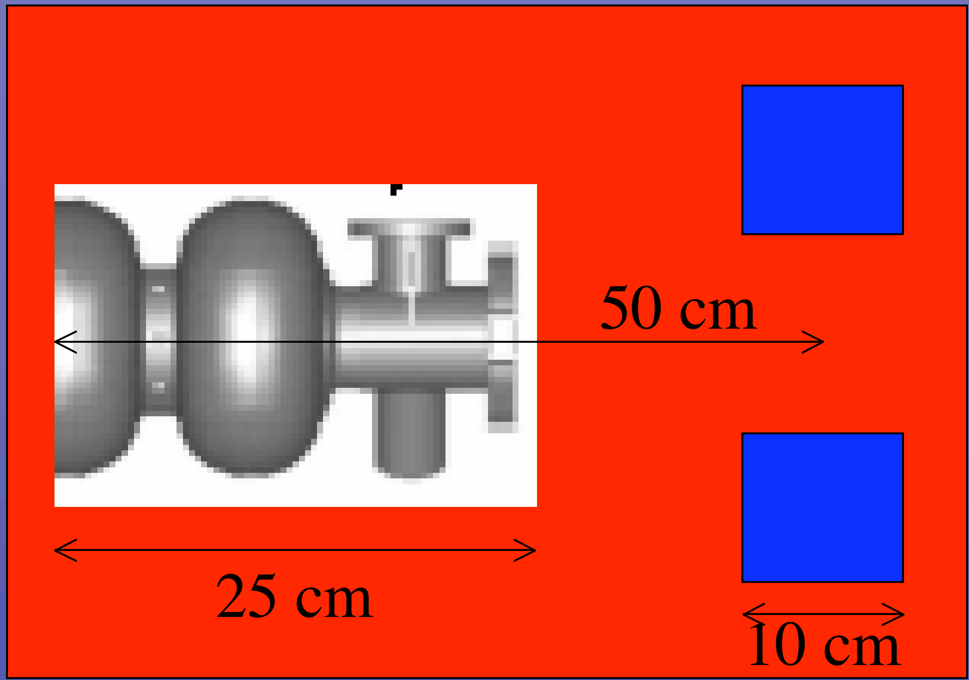
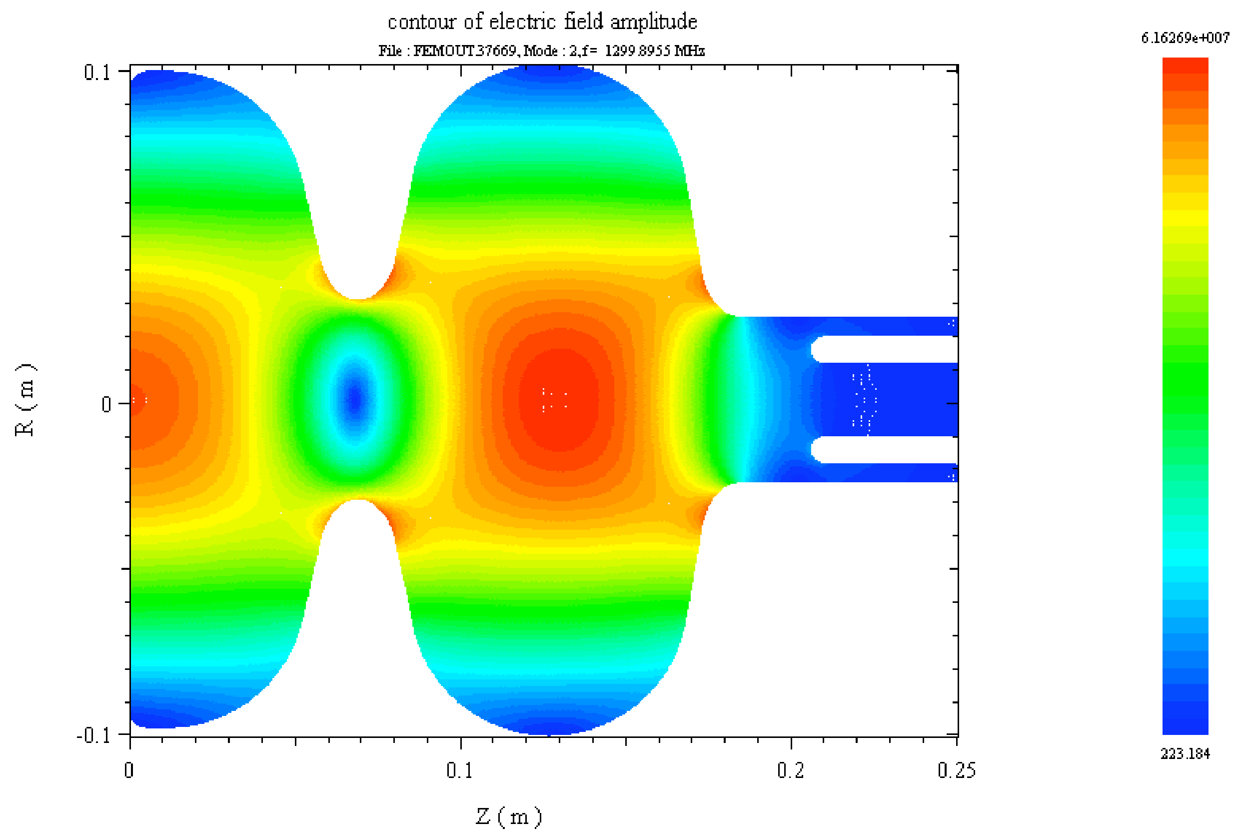


Splitting Acceleration and Focusing

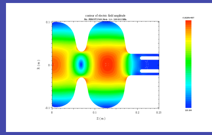


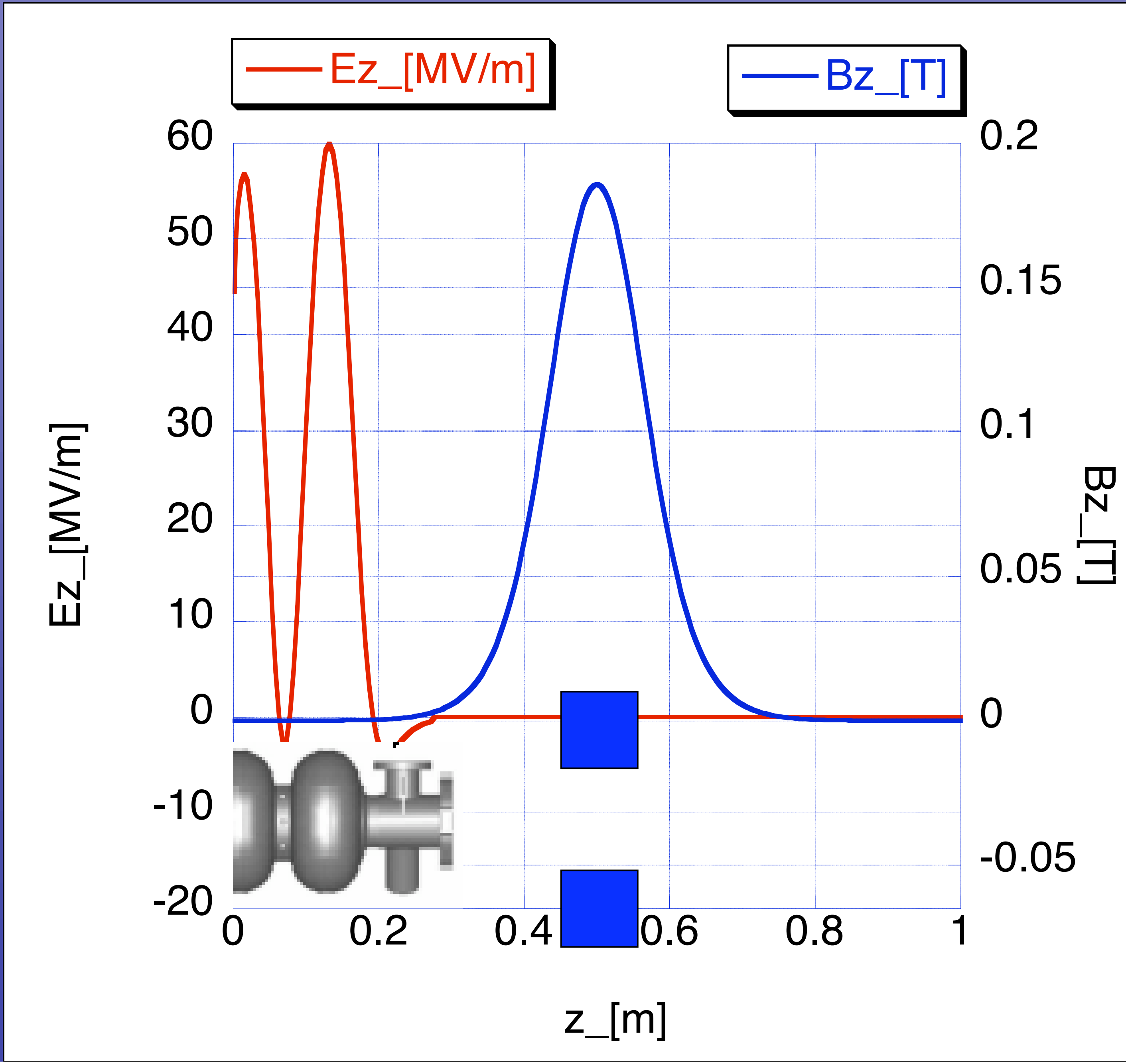
- The Solenoid can be placed downstream the cavity
- Switching on the solenoid when the cavity is cold prevent any trapped magnetic field

L-band SC gun design with coaxial coupler



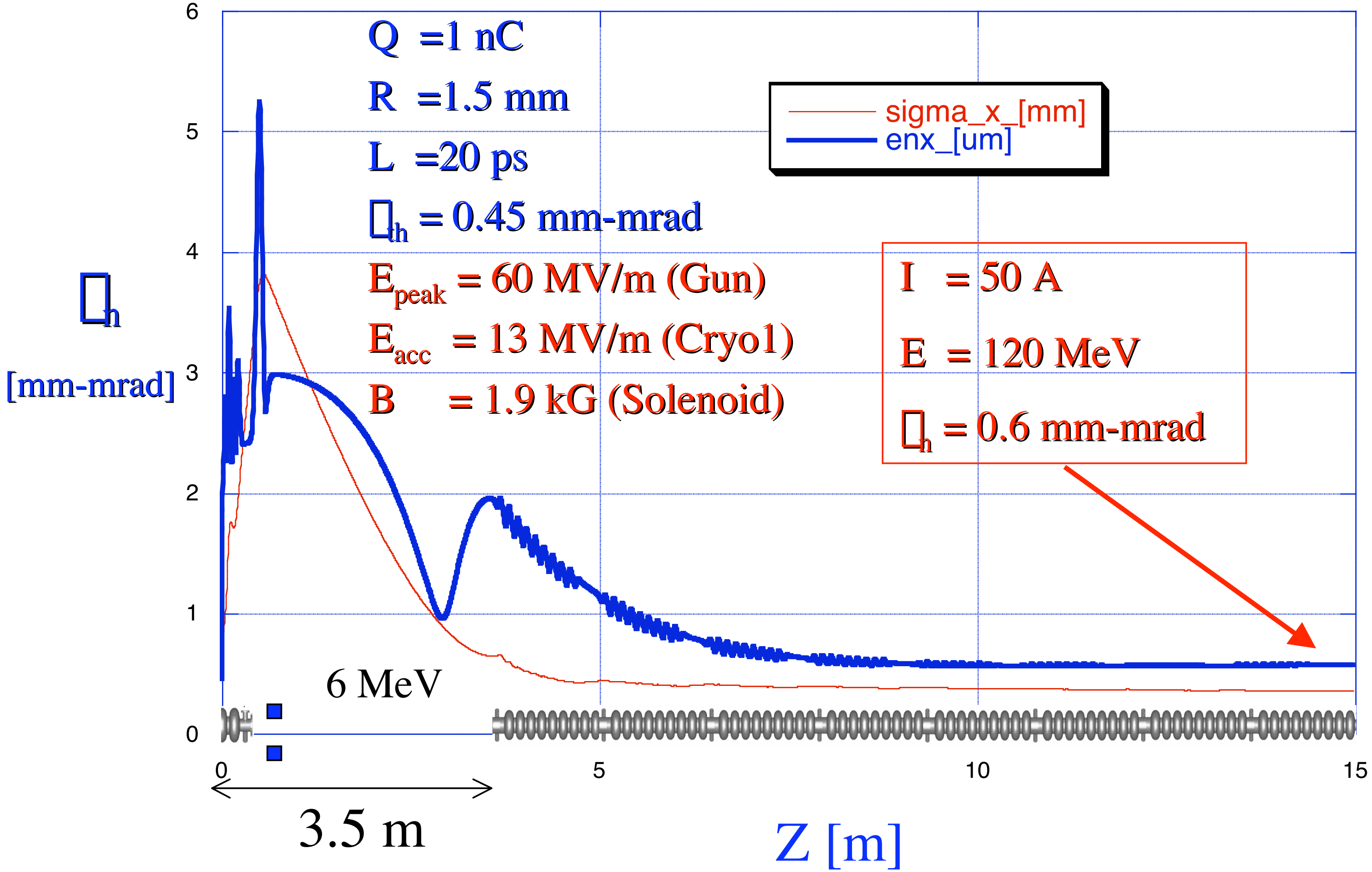
J. Sekutowicz





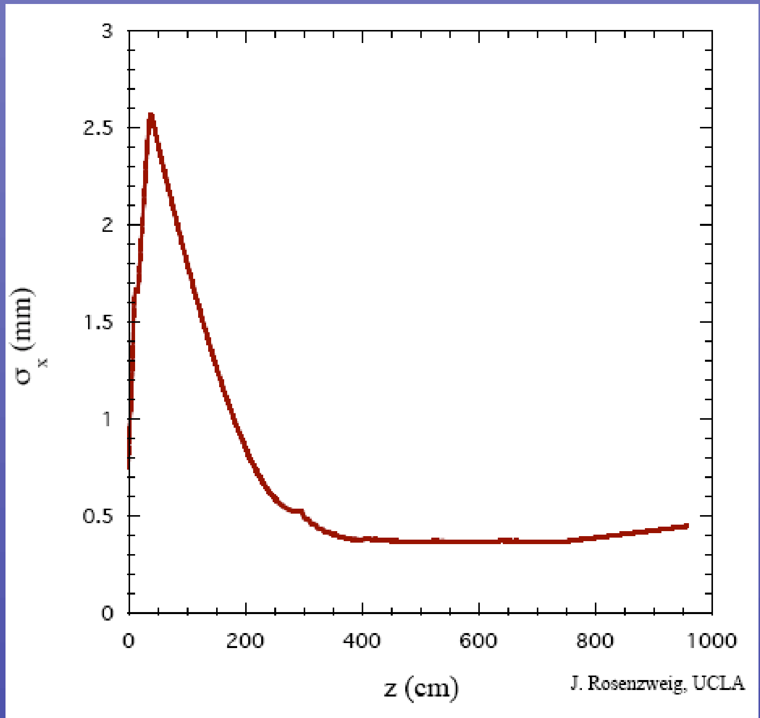
Ez_[MV/m]
Bz_[T]
60
50
40
30
20
10
0
-10
-20
0.2
0.15
0.1
0.05
0
-0.05
0
0.2
0.4
0.6
0.8
1
Ez_[MV/m]
Bz_[T]
z_[m]

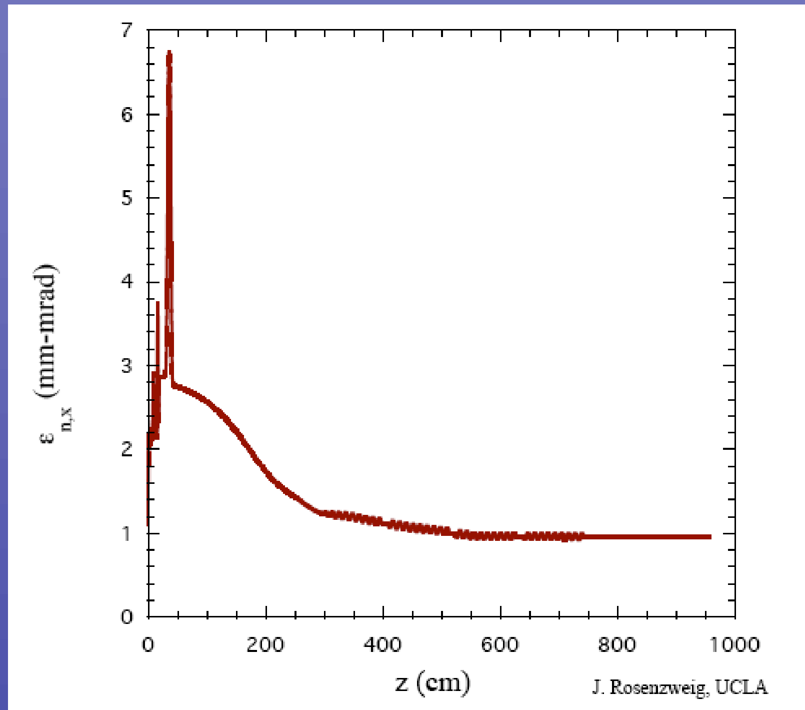
HOMDYN Simulation



scaling laws for Q and E_{peak} available

PARMELA simulations





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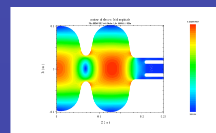

CONCLUSIONS

- RF focusing is not necessary
- 60 MV/m peak field in SC cavity have been already demonstrated
- Work in progress @ BNL to demonstrate Nb QE ~ 10^{-4} @ 60 MV/m
- Multibunch effects
- The new working point for a Split Photoinjector can be easily adopted by a SCRF gun

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