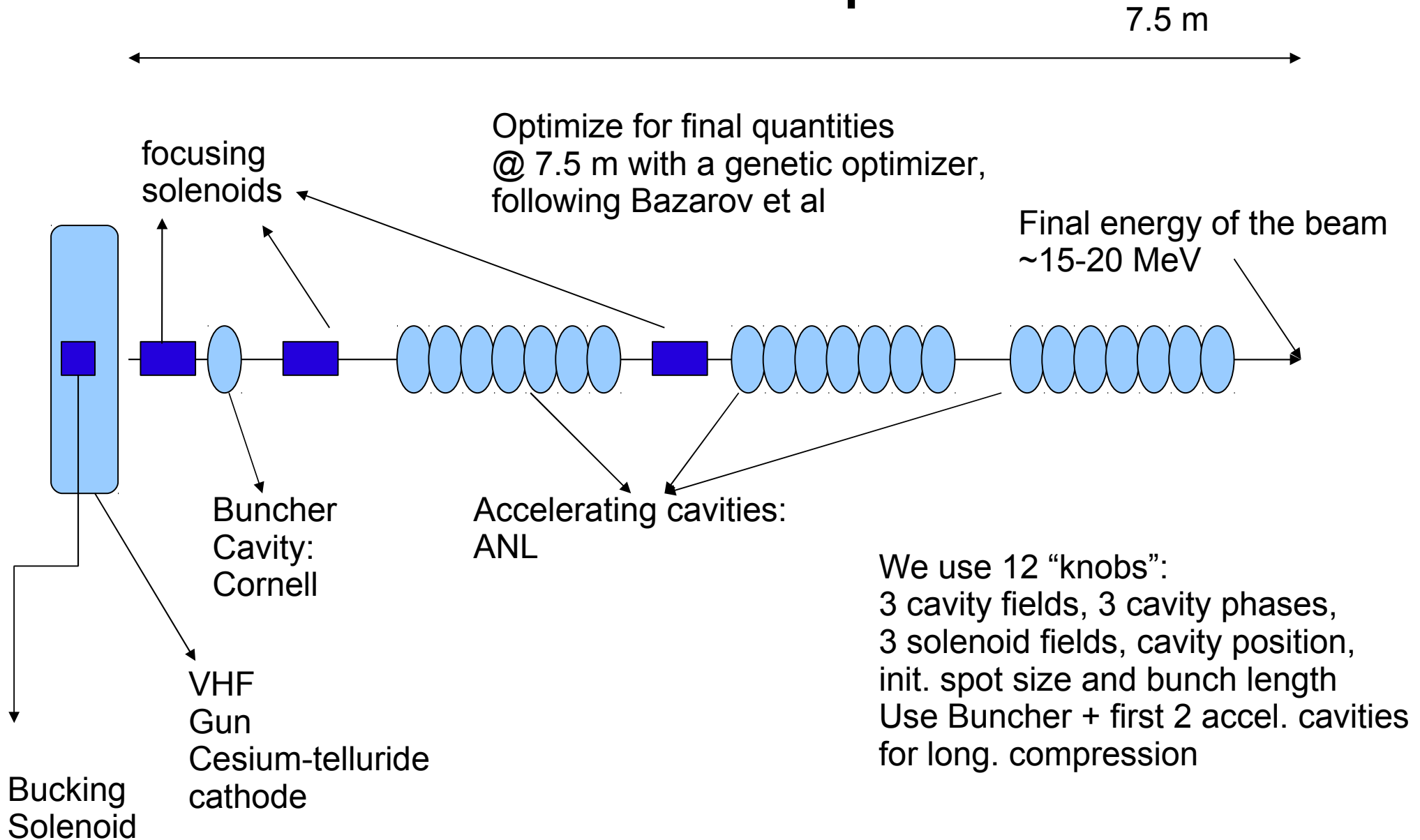


# LBNL Injector Beam Dynamics

C. Papadopoulos, F. Sannibale

Compact X-Ray FELs Using High Brightness Beams Mini-Workshop  
LBNL, August 5, 2010

# BTF setup



# Scaling of size and emittance at the exit of the injector with charge

$$\left. \begin{array}{l} \sigma_x \sim Q^{1/3} \\ \sigma_z \sim Q^{1/3} \\ \sigma_x \sim \epsilon_{nx}^{1/2} \\ \sigma_z \sim \epsilon_{nl}^{1/2} \end{array} \right\} \rightarrow \begin{array}{l} \epsilon_{nx} \sim Q^{2/3} \\ \epsilon_{nl} \sim Q^{2/3} \end{array} \rightarrow B = \frac{Q}{\epsilon_{nx}^2 \epsilon_{nl}} \sim Q^{-1}$$

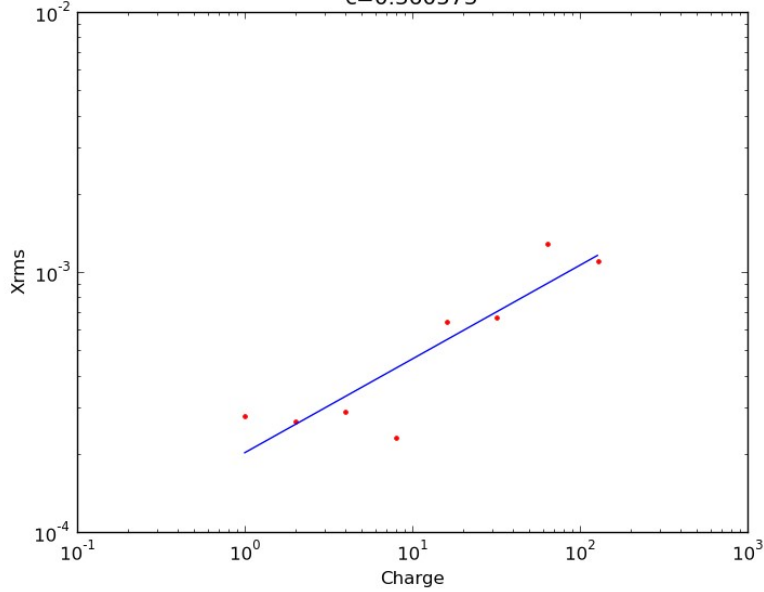
Following Kim 1988 and Rosenzweig, Colby 1994

The simple scalings hold for low pulse charges  $\rightarrow$  short bunch lengths compared to RF wavelength

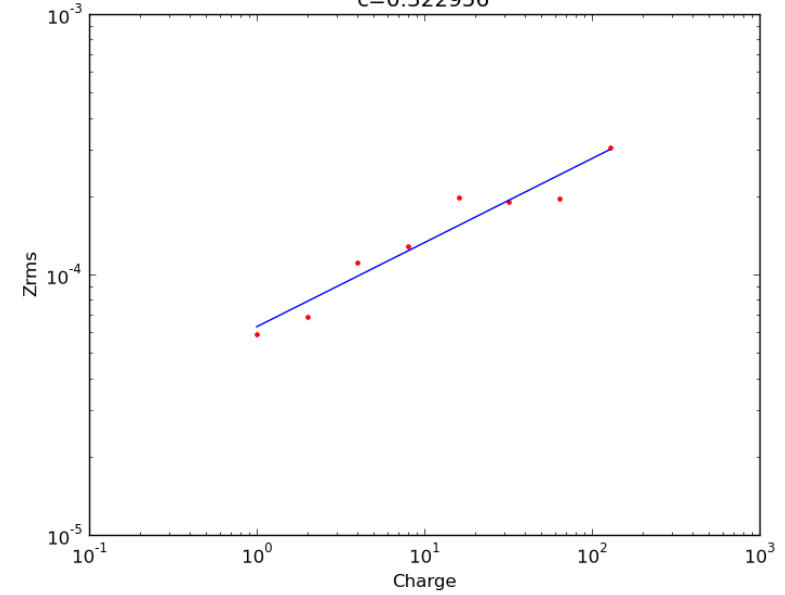
(For longer pulses, the RF curvature is also contributing to emittance growth)

# Size and emittance scalings with charge: Optimize for 6D brightness

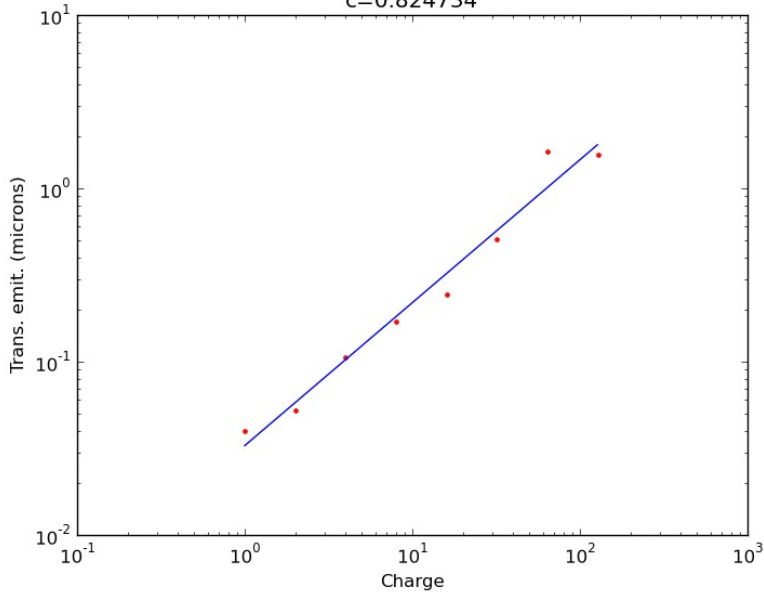
Scaling of Xrms with charge:  $x_{rms} \sim Q^c$ ,  
 $c=0.360573$



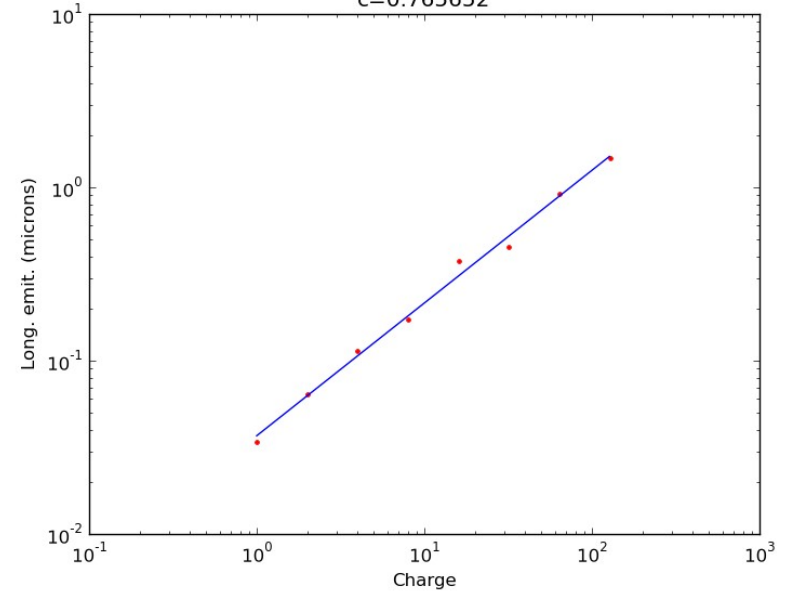
Scaling of Zrms with charge:  $z_{rms} \sim Q^c$ ,  
 $c=0.322956$



Scaling of trans. emittance with charge:  $e_x \sim Q^c$ ,  
 $c=0.824734$



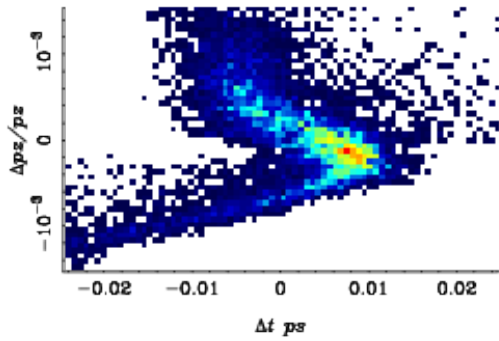
Scaling of long. emittance with charge:  $e_l \sim Q^c$ ,  
 $c=0.765652$



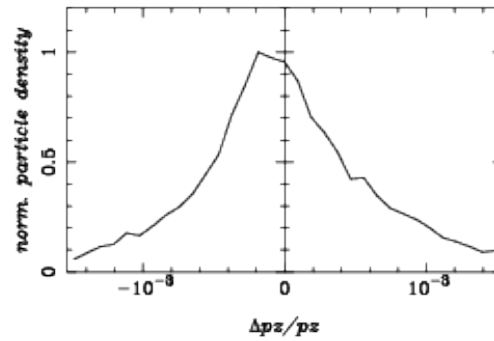
# 1 pC: High compression

$z = 7.500 \text{ m}$

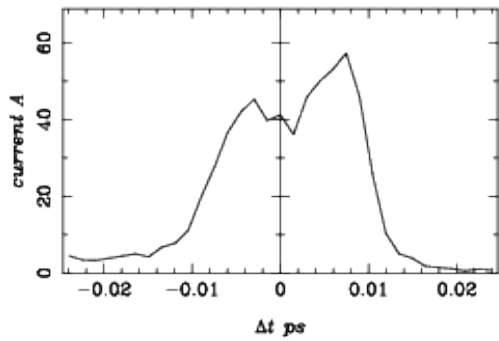
Longitudinal Phase-Space



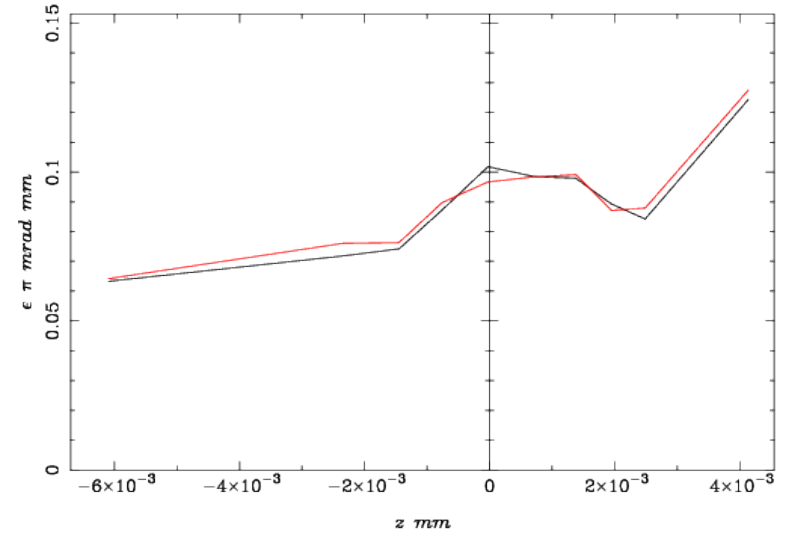
Momentum Spread



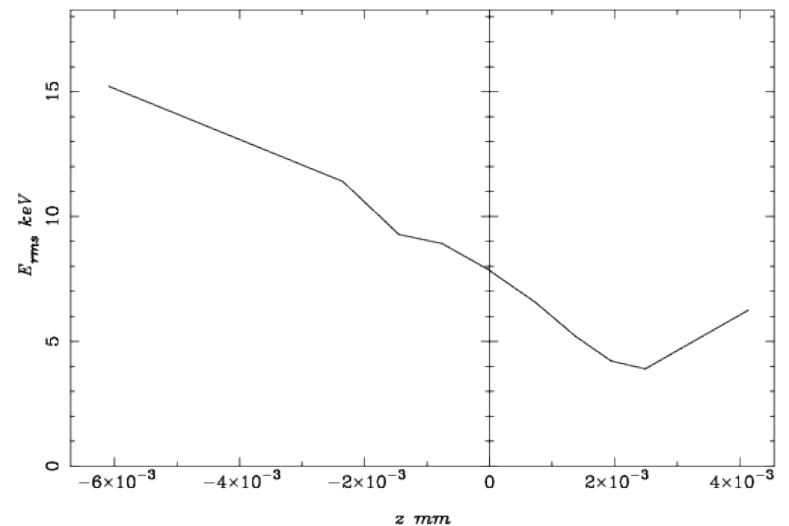
Longitudinal Distribution



Slice Emittance

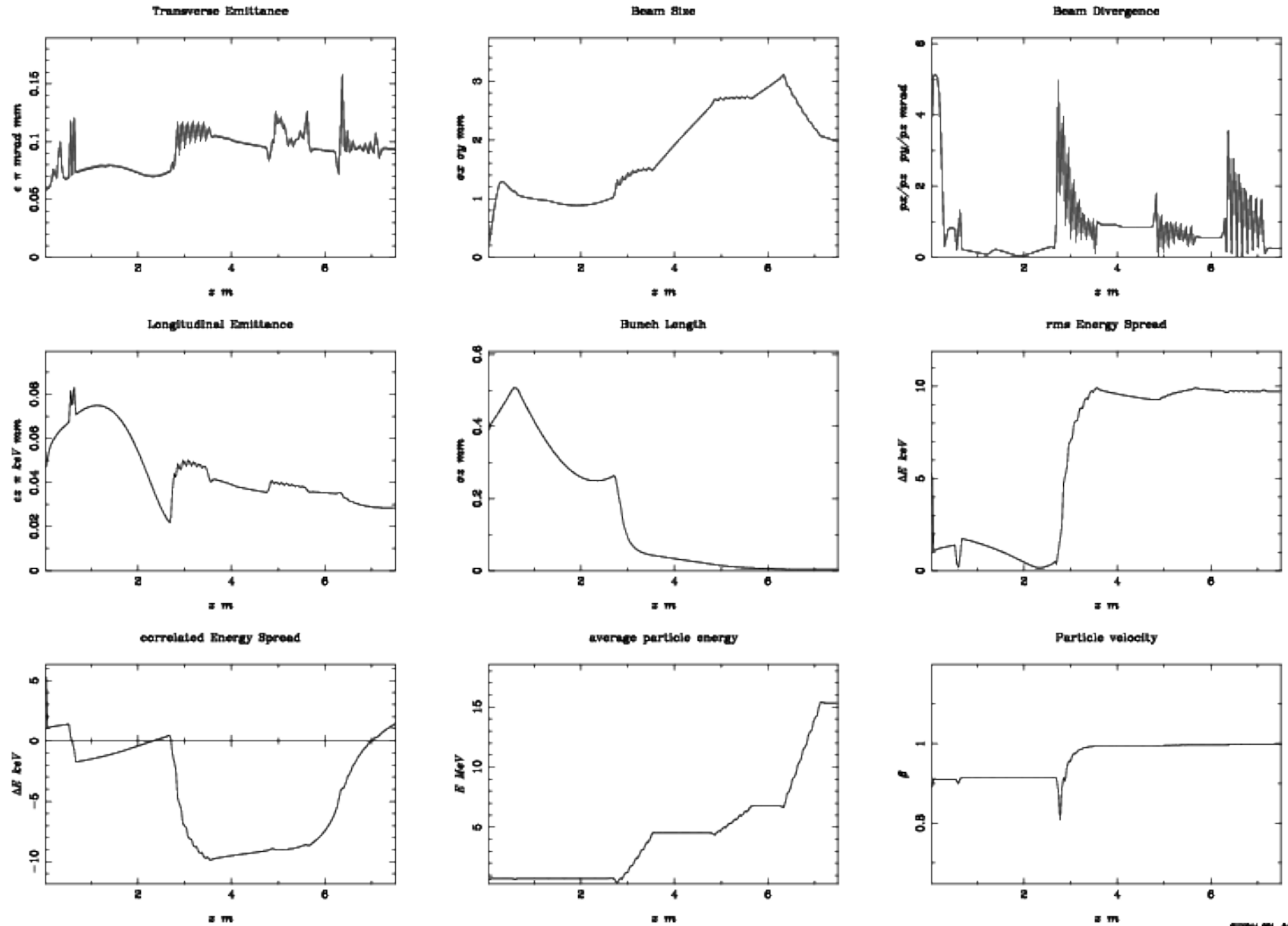


Slice Energy Spread



$I_{\text{peak}} \sim 40 \text{ A}$   
 $\epsilon_x \sim 0.1 \text{ mm-mrad}$   
 $\Delta E/E \sim 0.25 \times 10^{-3}$

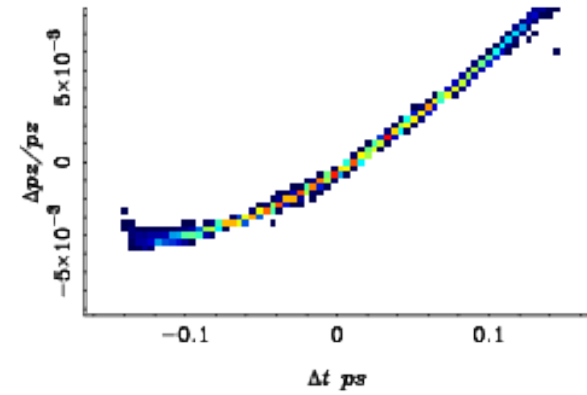
# 1 pC: High compression



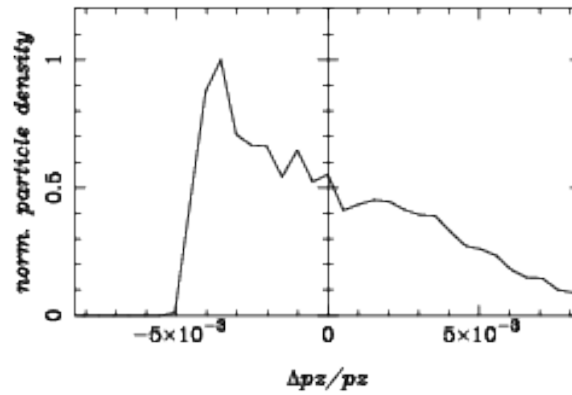
# 1 pC: Low compression

$z = 7.500 \text{ m}$

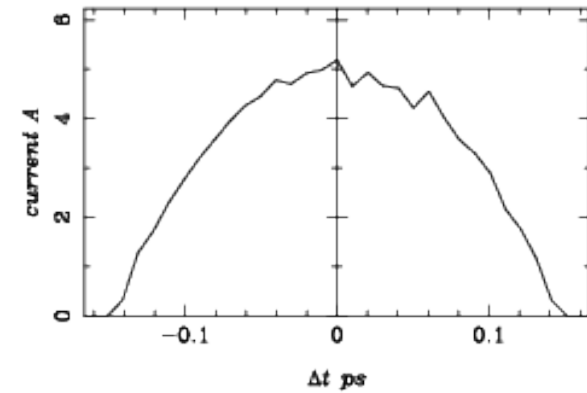
Longitudinal Phase-Space



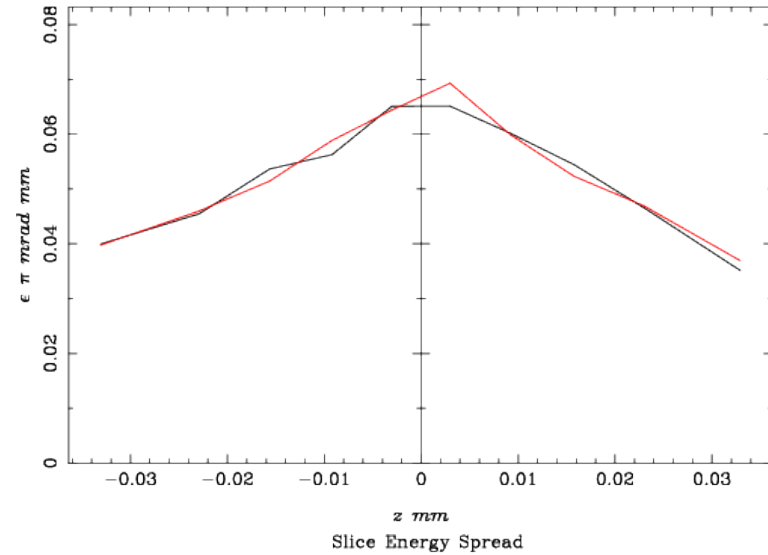
Momentum Spread



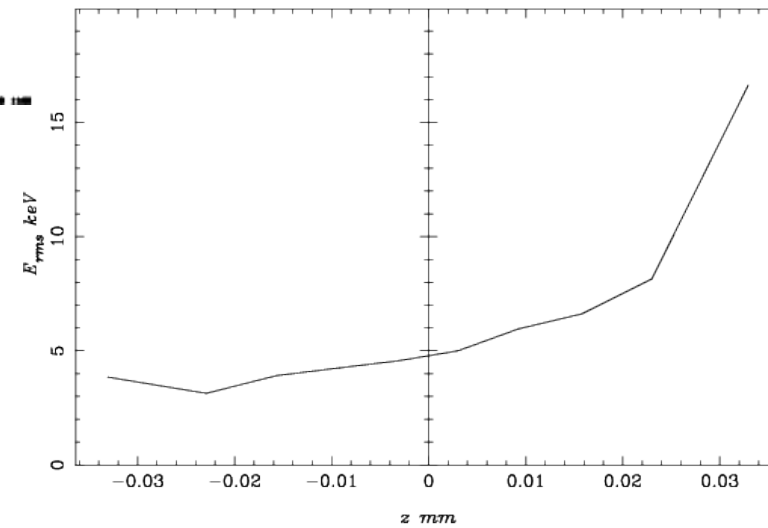
Longitudinal Distribution



Slice Emittance

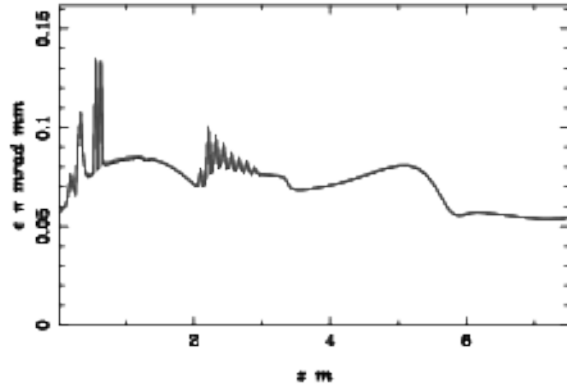


$I_{\text{peak}} \sim 5 \text{ A}$   
 $\epsilon_x \sim 0.06 \text{ mm-mrad}$   
 $\Delta E/E \sim 0.3 \times 10^{-3}$

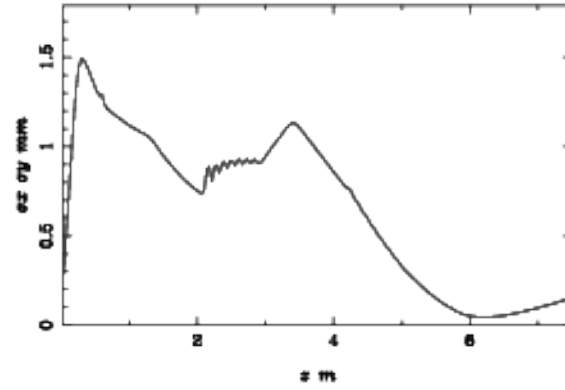


# 1 pC: Low compression

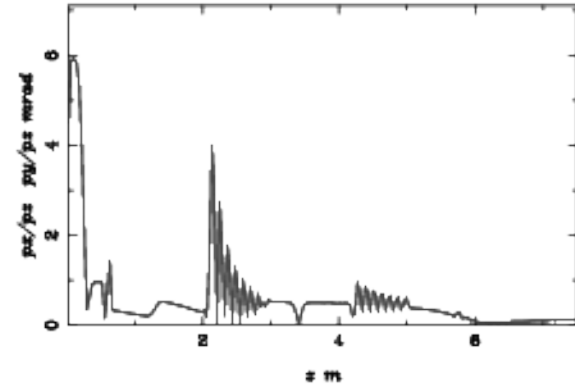
Transverse Emittance



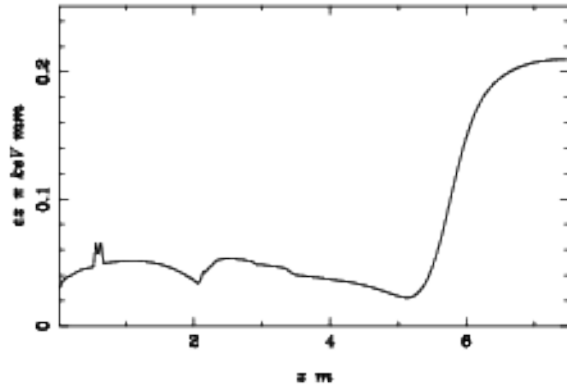
Beam Size



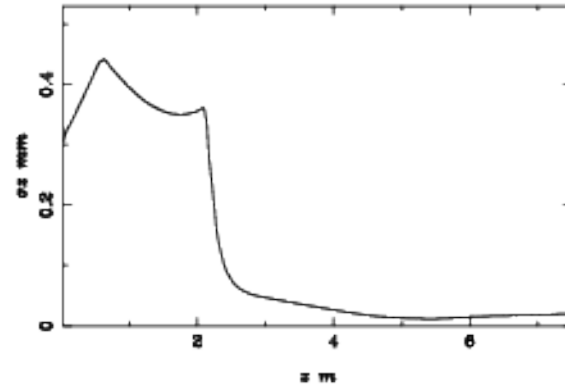
Beam Divergence



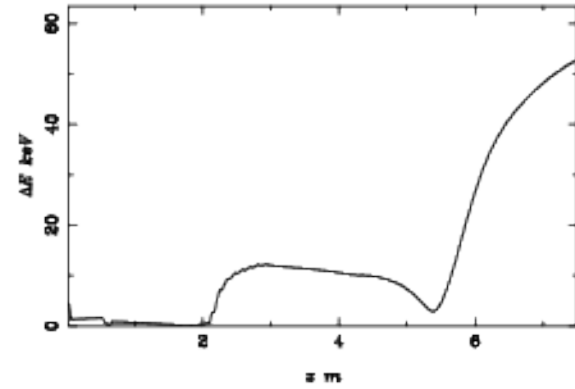
Longitudinal Emittance



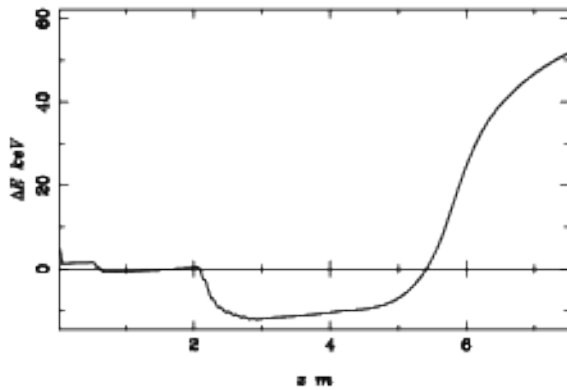
Bunch Length



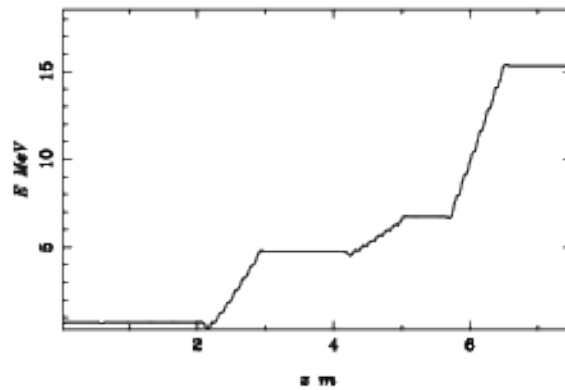
rms Energy Spread



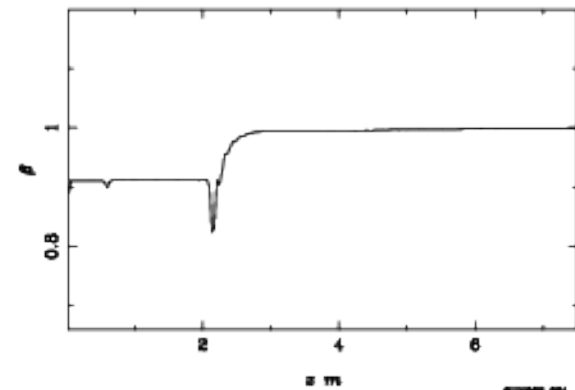
correlated Energy Spread



average particle energy

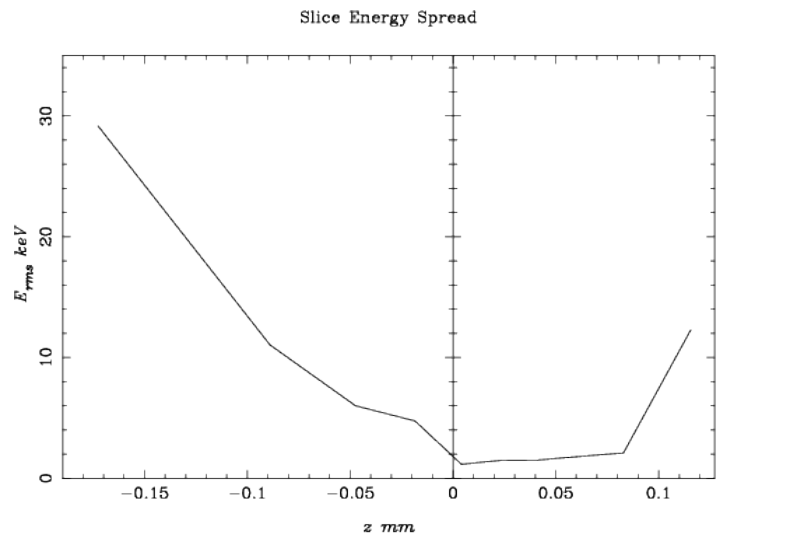
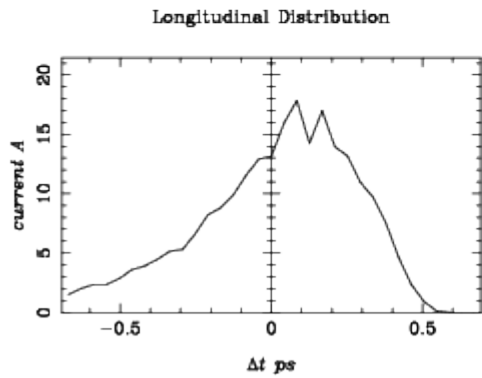
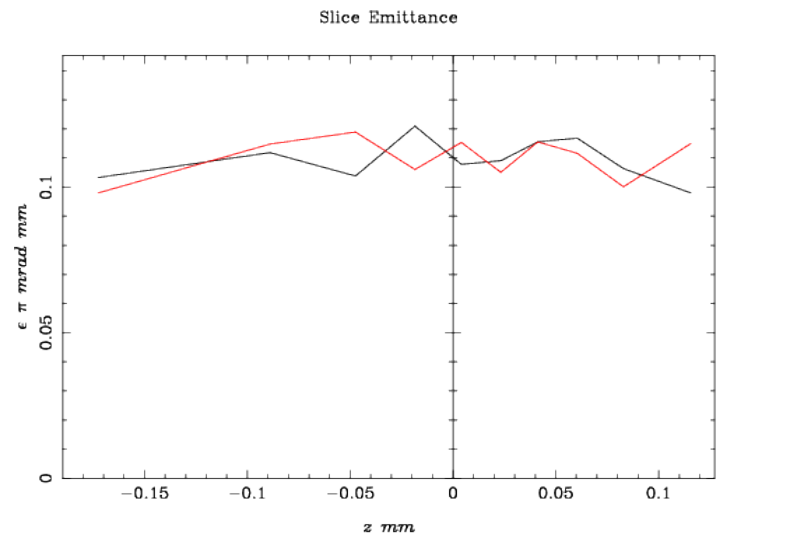
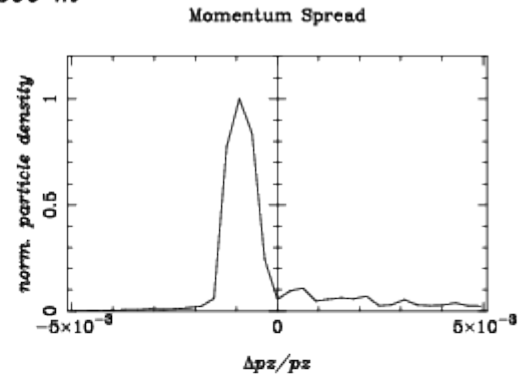
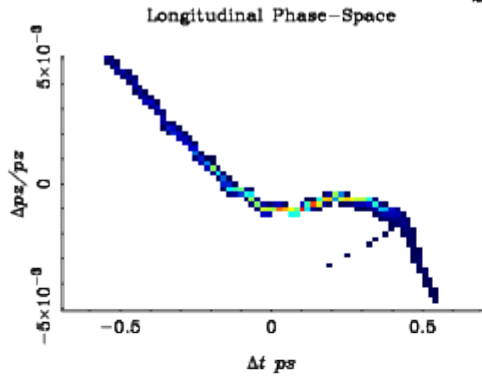


Particle velocity



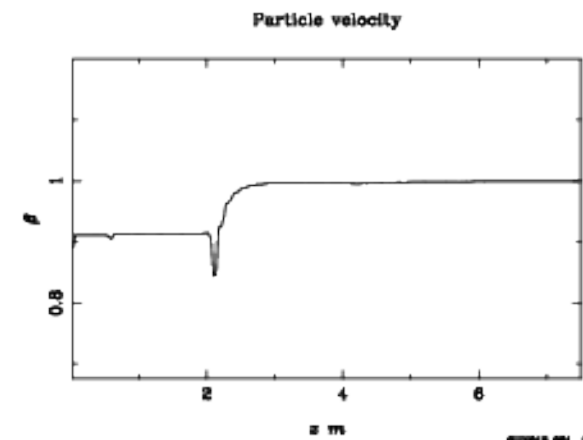
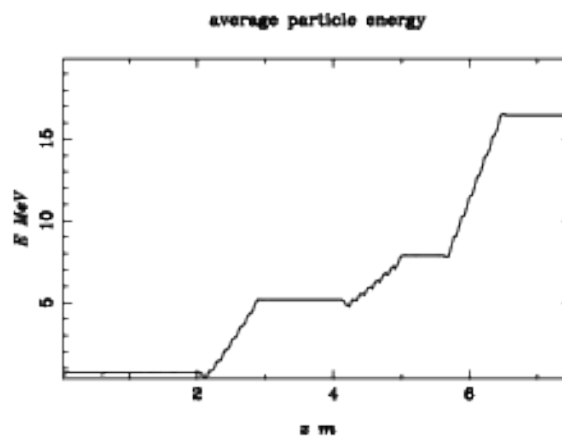
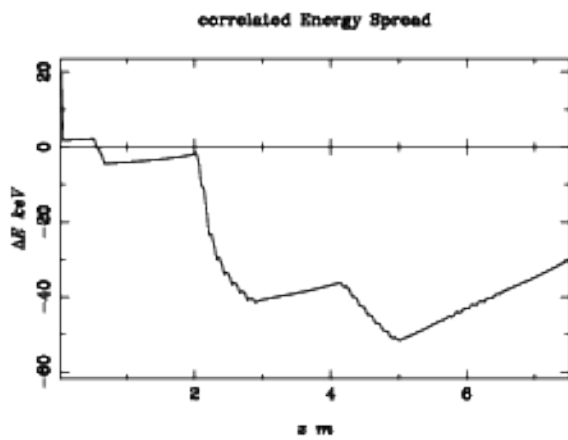
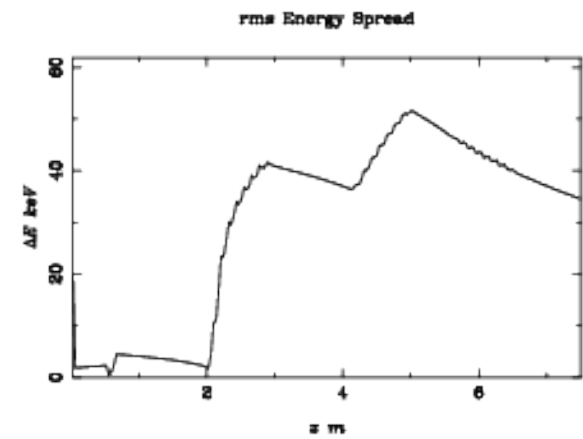
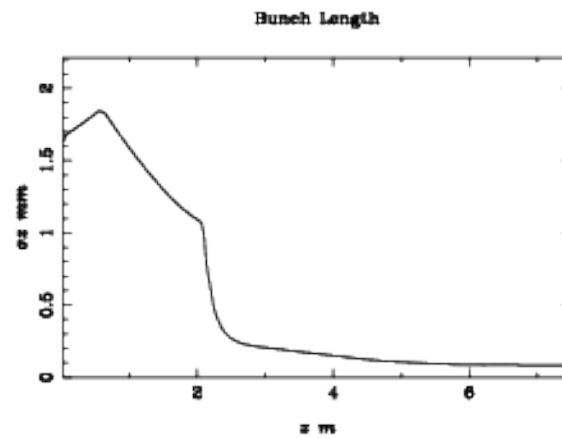
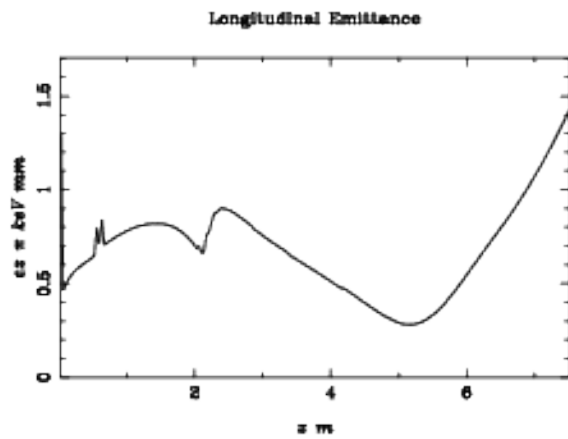
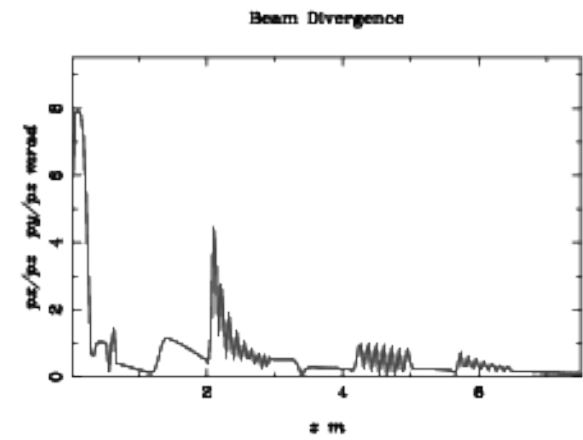
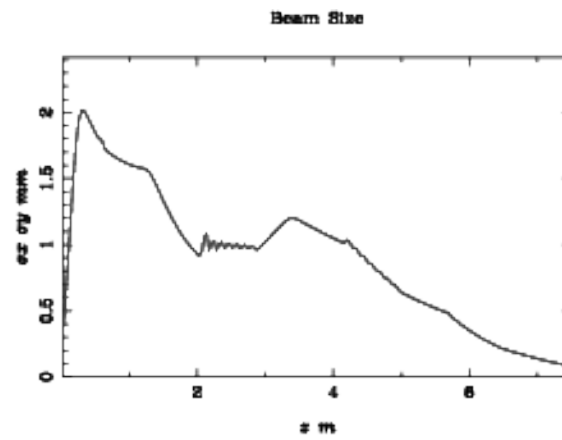
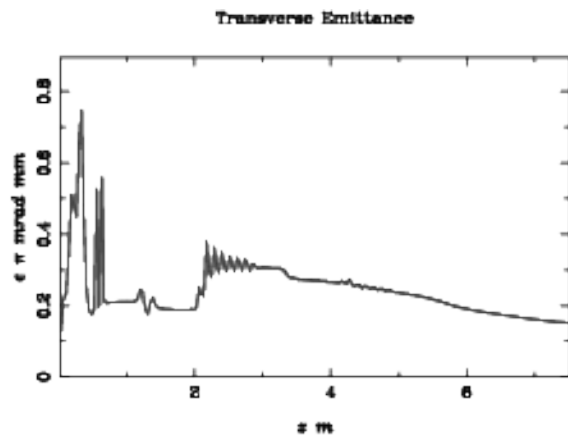
# 10 pC: Low compression

$z = 7.500 \text{ m}$



$I_{peak} \sim 15 \text{ A}$   
 $\epsilon_x \sim 0.11 \text{ mm-mrad}$   
 $\Delta E/E \sim 0.15e-3$

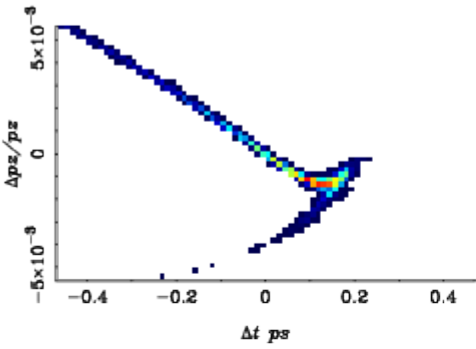
# 10 pC: Low compression



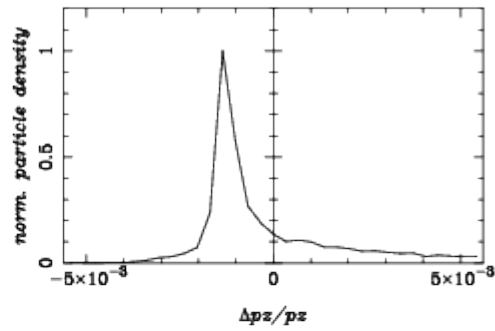
# 10 pC: High Compression

$z = 7.500 \text{ m}$

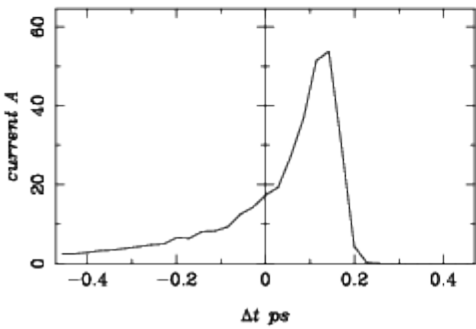
Longitudinal Phase-Space



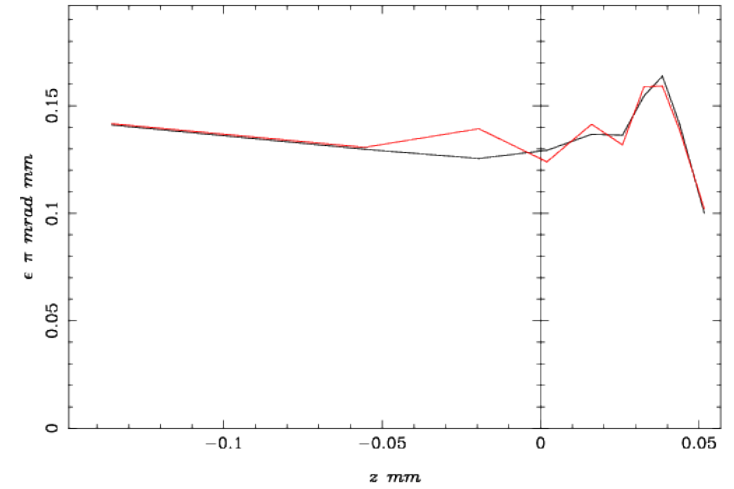
Momentum Spread



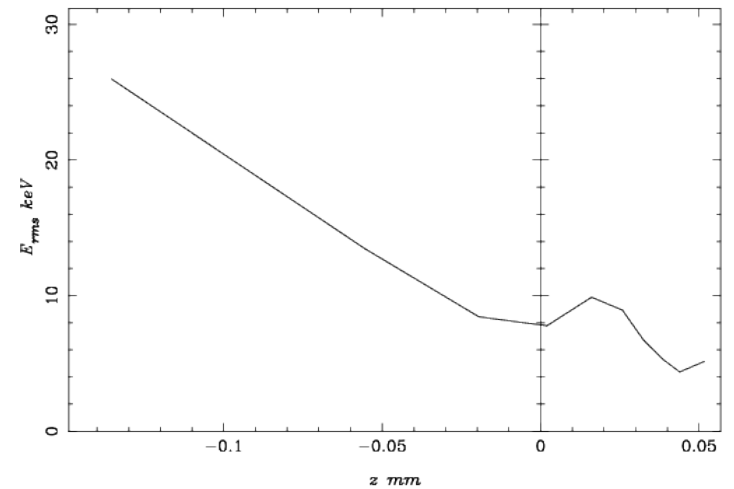
Longitudinal Distribution



Slice Emittance

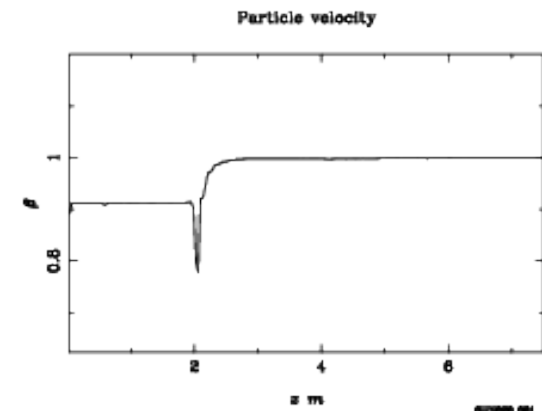
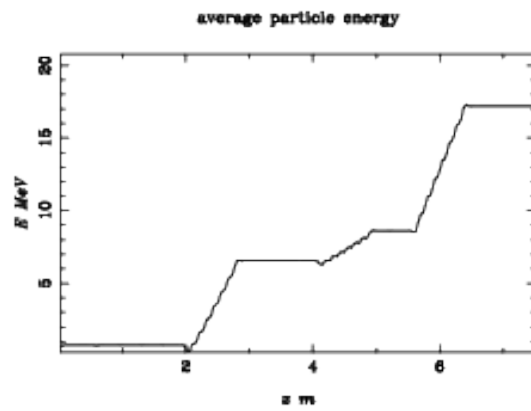
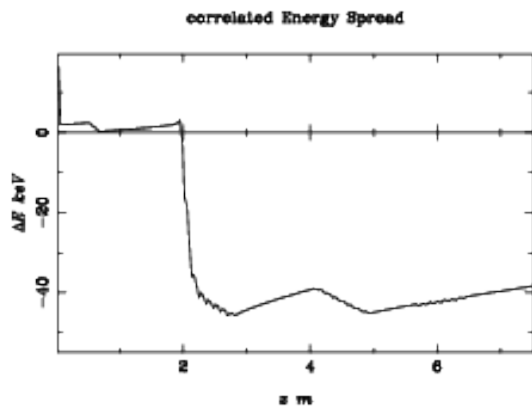
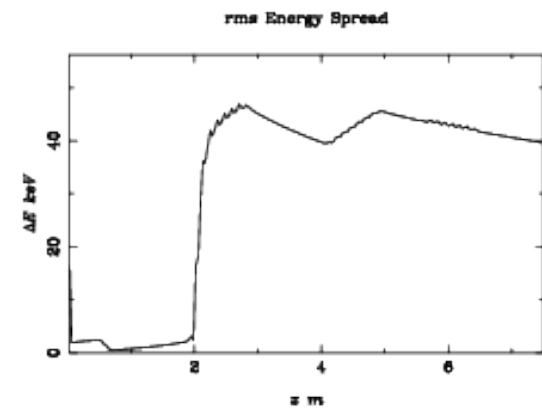
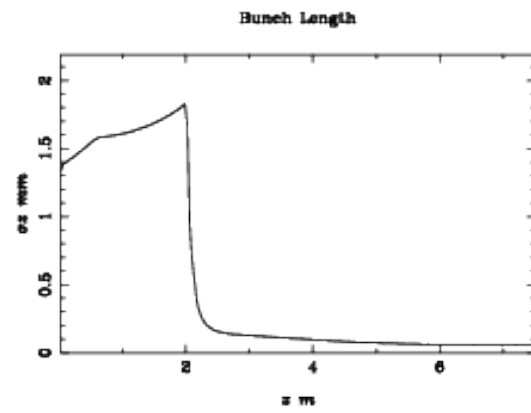
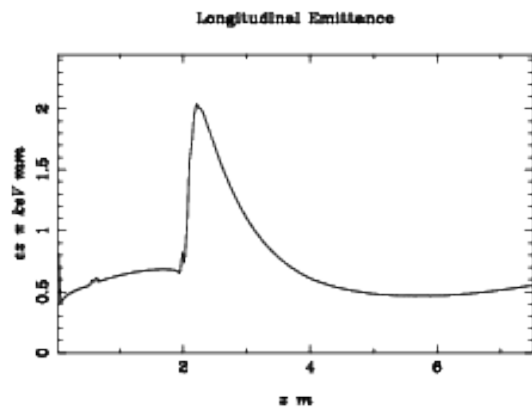
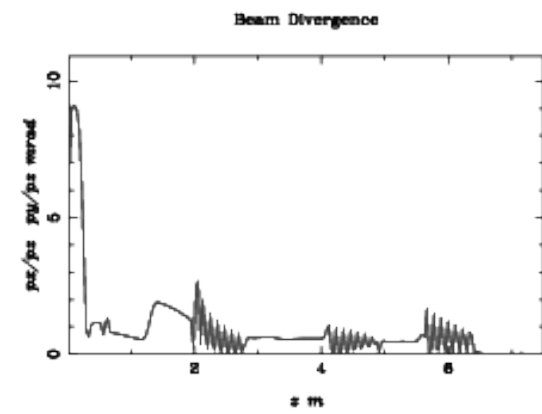
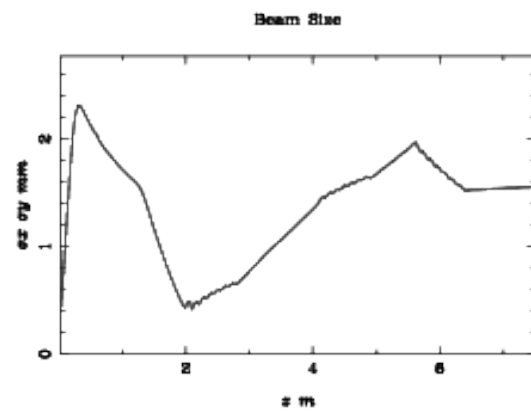
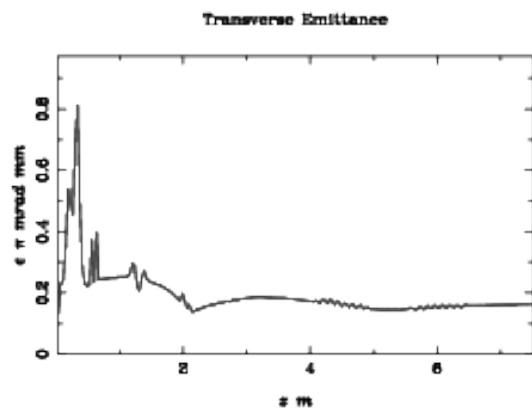


Slice Energy Spread



$I_{\text{peak}} \sim 50 \text{ A}$   
 $\epsilon_x \sim 0.15 \text{ mm-mrad}$   
 $\Delta E/E \sim 0.5 \times 10^{-3}$

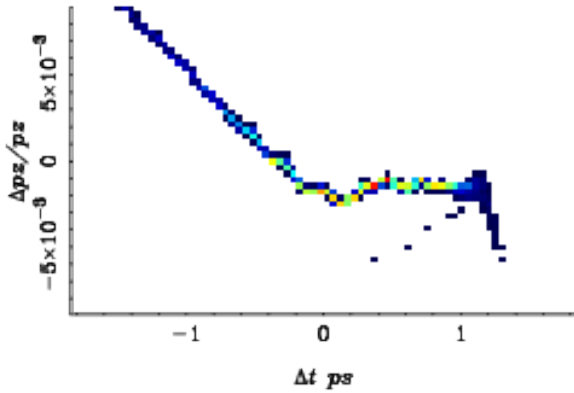
# 10 pC: High Compression



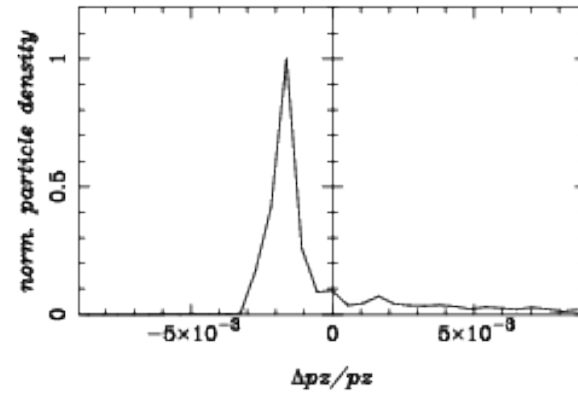
# 50 pC: High Compression

$z = 7.500 \text{ m}$

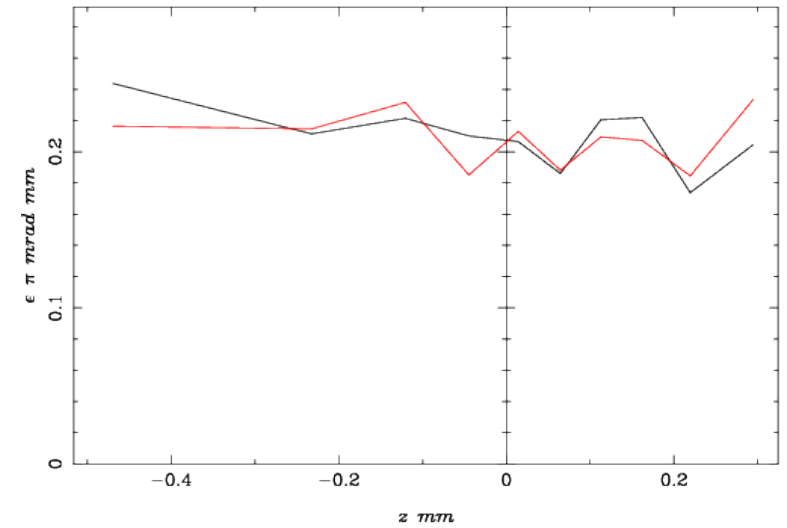
Longitudinal Phase-Space



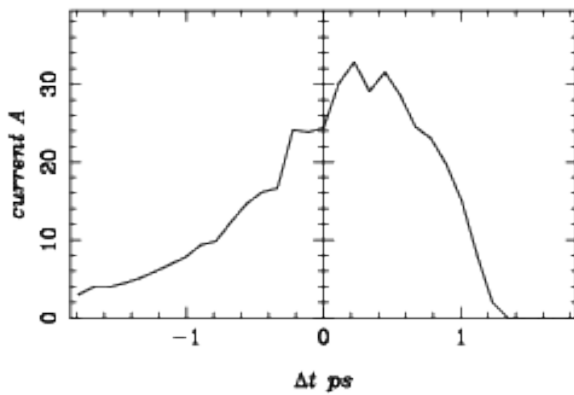
Momentum Spread



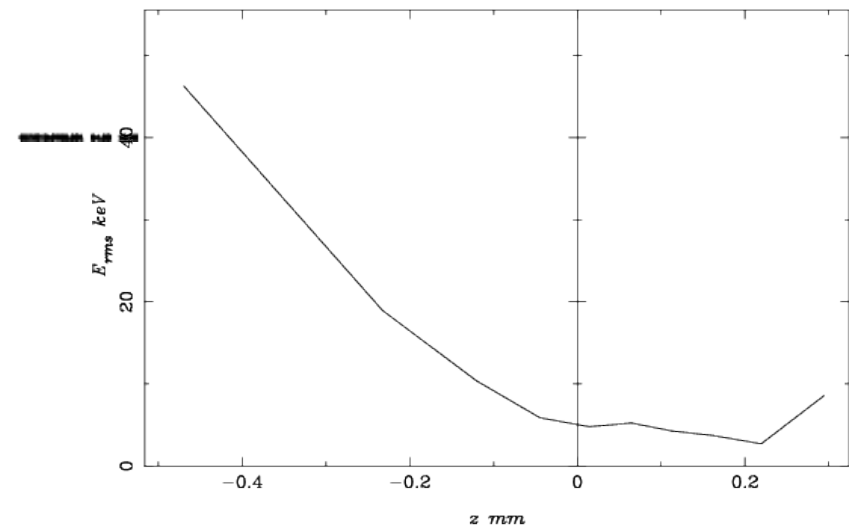
Slice Emittance



Longitudinal Distribution



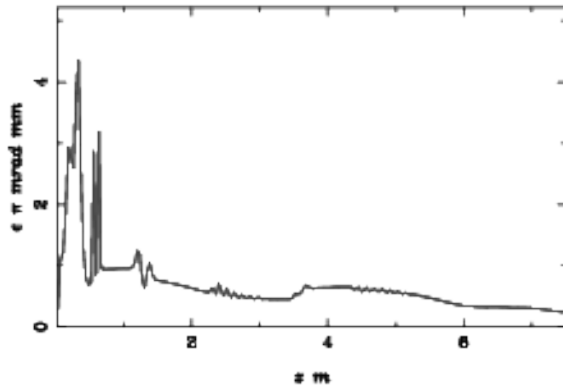
Slice Energy Spread



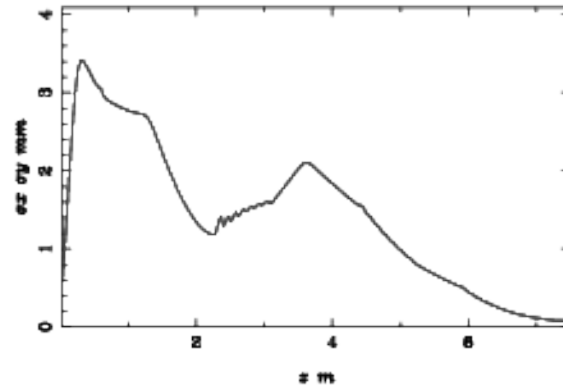
$I_{peak} \sim 30 \text{ A}$   
 $\epsilon_x \sim 0.2 \text{ mm-mrad}$   
 $\Delta E/E \sim 0.3e-3$

# 50 pC: High Compression

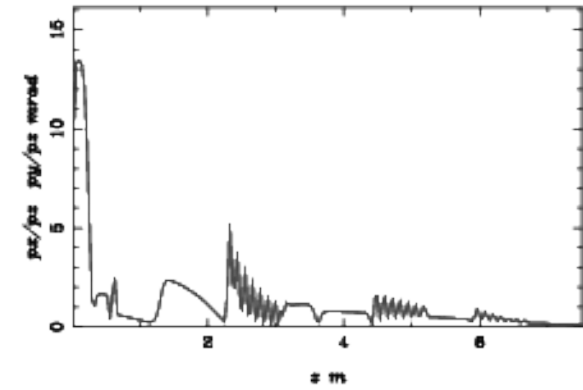
Transverse Emittance



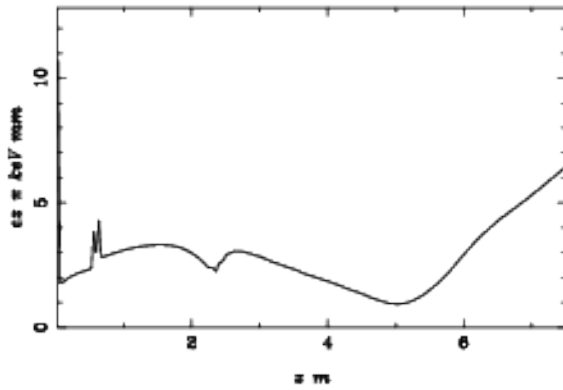
Beam Size



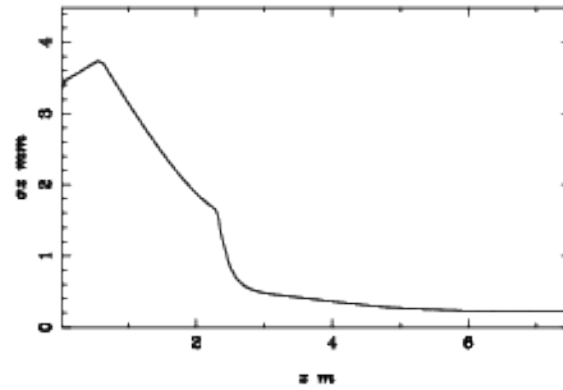
Beam Divergence



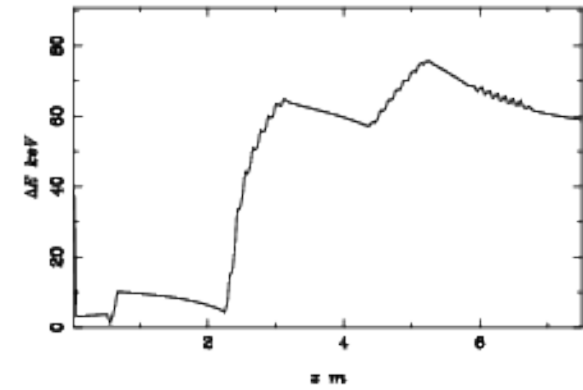
Longitudinal Emittance



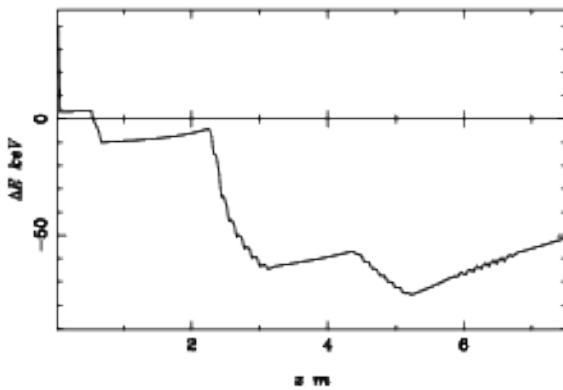
Bunch Length



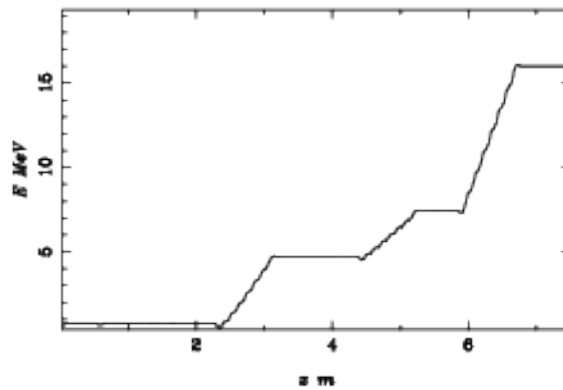
rms Energy Spread



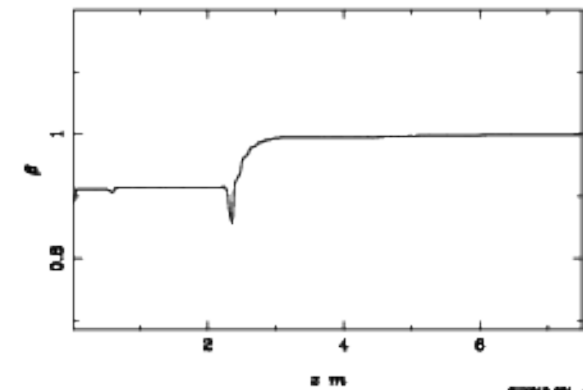
correlated Energy Spread



average particle energy



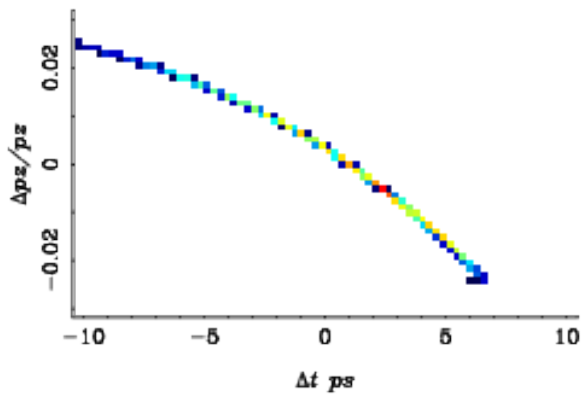
Particle velocity



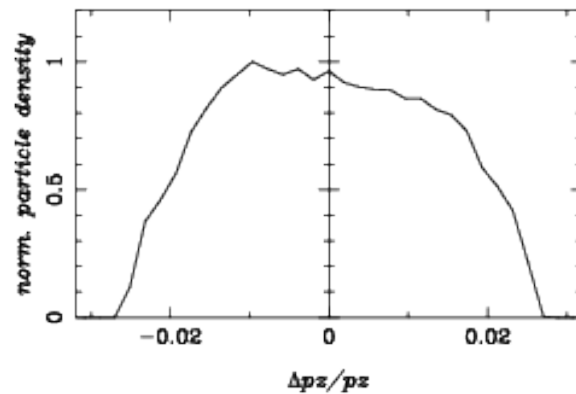
# 50 pC: Low Compression

$z = 7.500 \text{ m}$

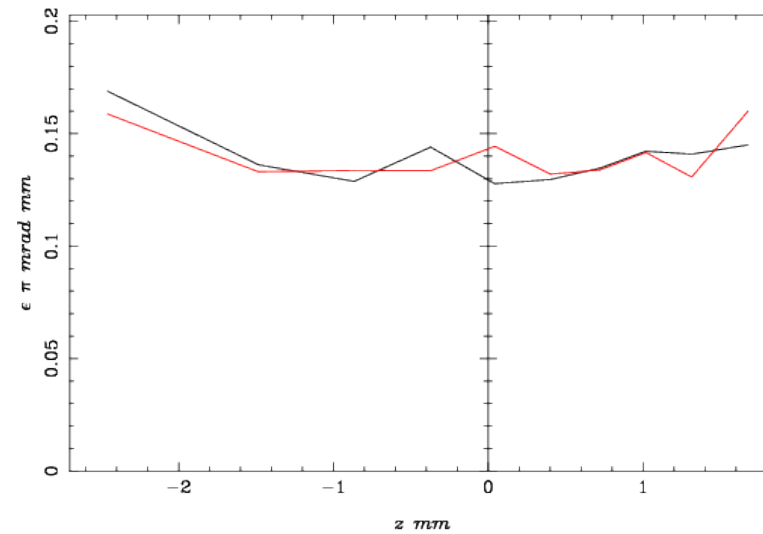
Longitudinal Phase-Space



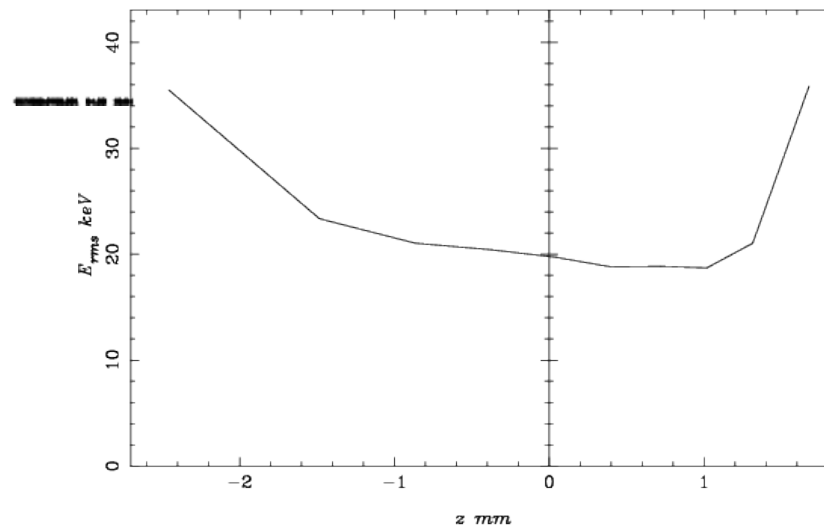
Momentum Spread



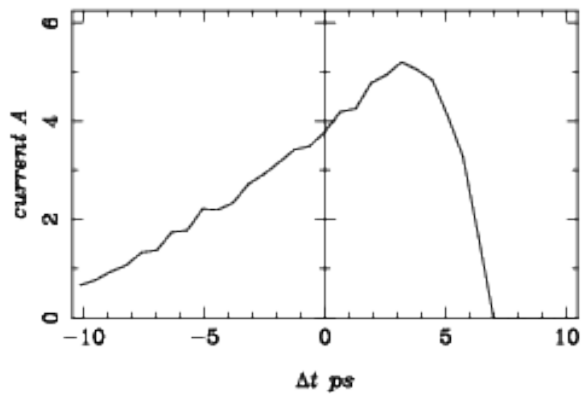
Slice Emittance



Slice Energy Spread



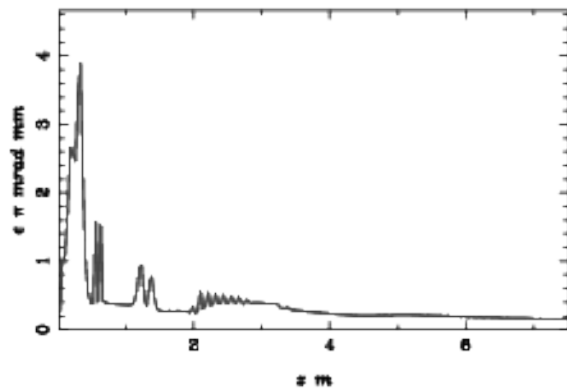
Longitudinal Distribution



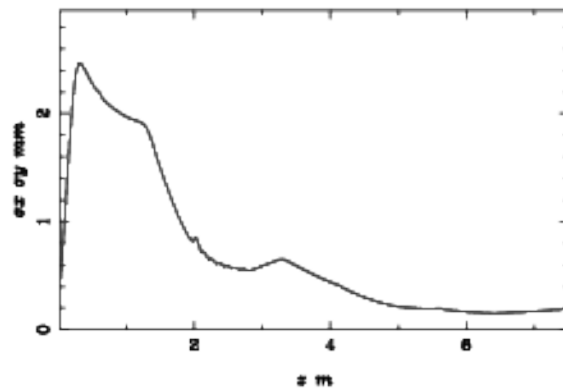
$I_{\text{peak}} \sim 5 \text{ A}$   
 $\epsilon_x \sim 0.15 \text{ mm-mrad}$   
 $\Delta E/E \sim 1.3 \times 10^{-3}$

# 50 pC: Low Compression

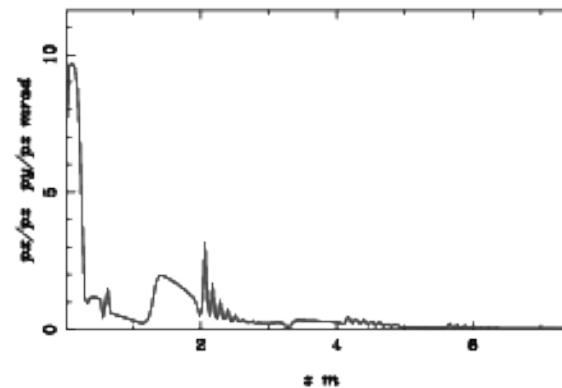
Transverse Emittance



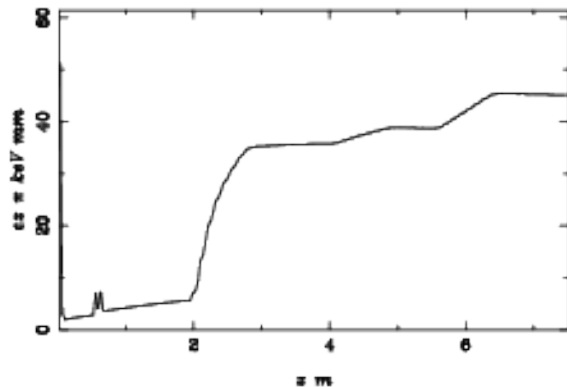
Beam Size



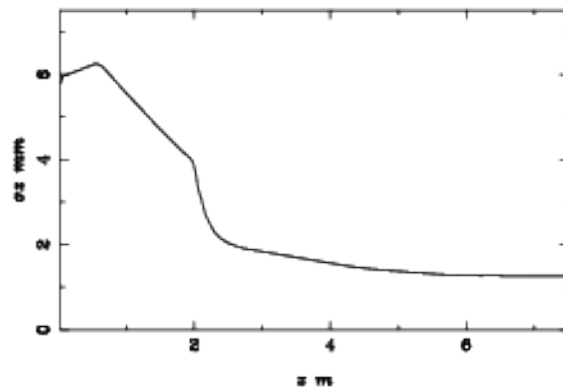
Beam Divergence



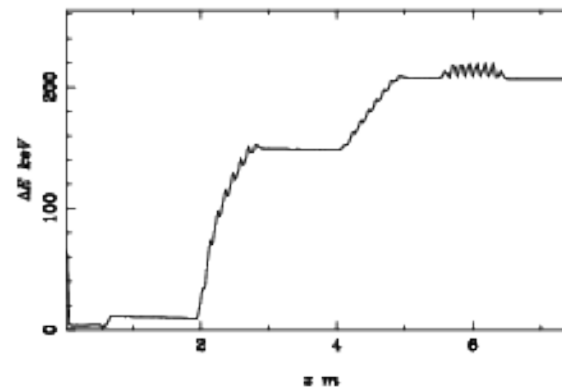
Longitudinal Emittance



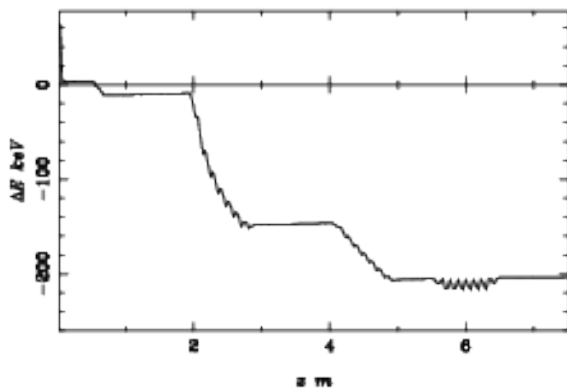
Bunch Length



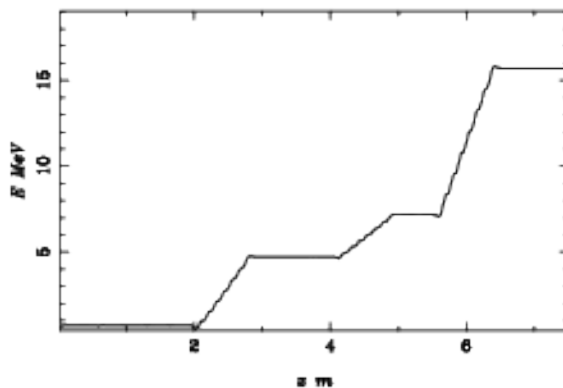
rms Energy Spread



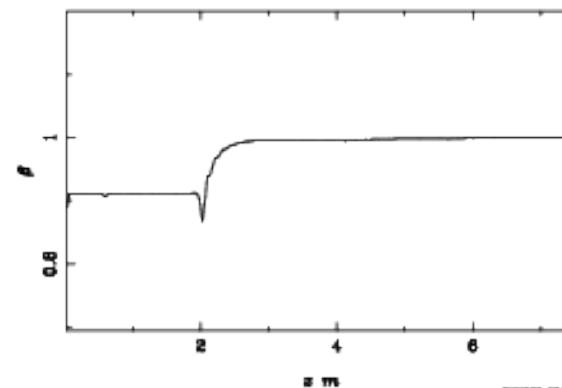
correlated Energy Spread



average particle energy



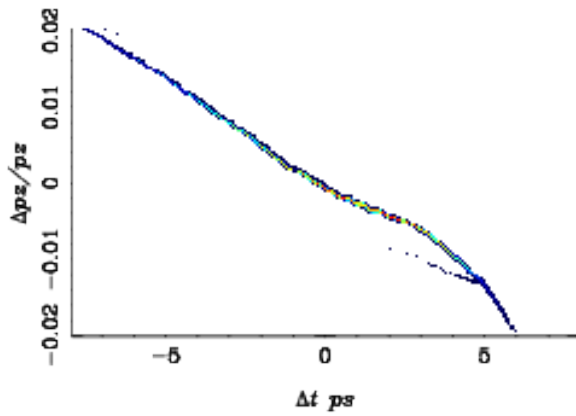
Particle velocity



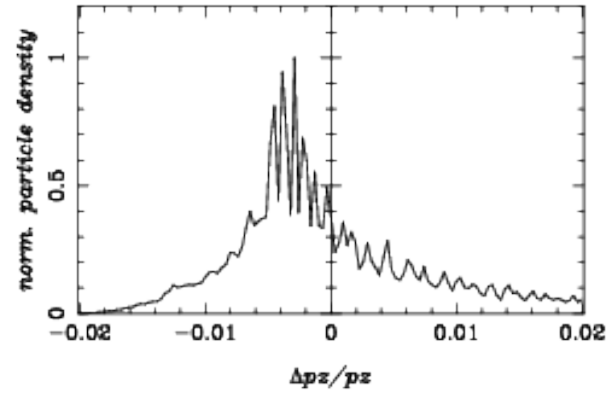
# 300 pC: Low Compression

$z = 7.500 \text{ m}$

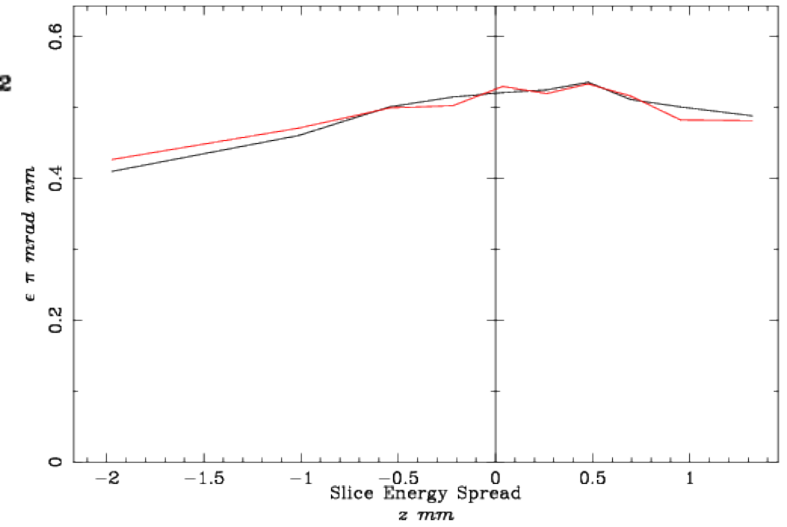
Longitudinal Phase-Space



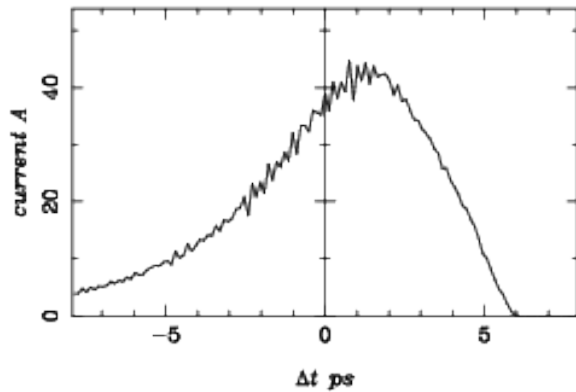
Momentum Spread



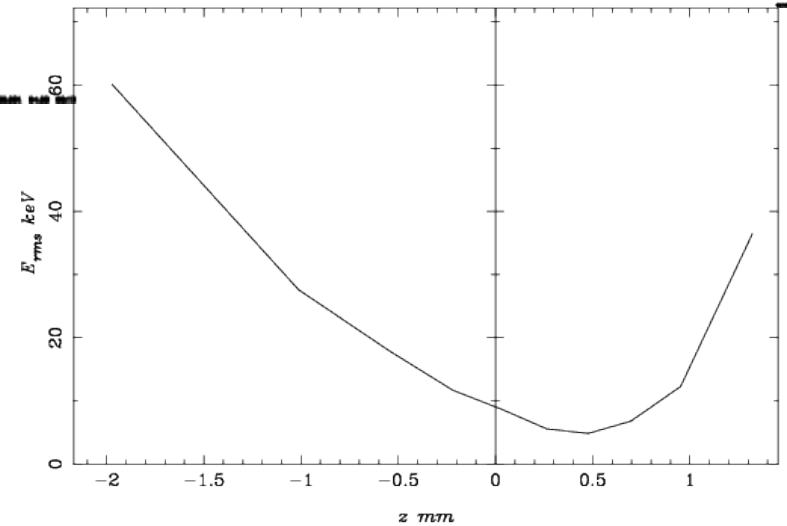
Slice Emittance



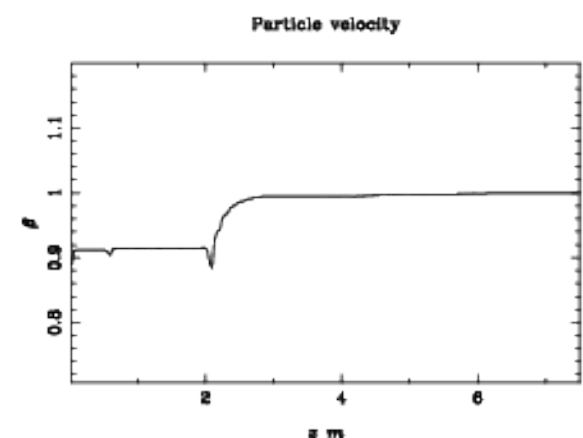
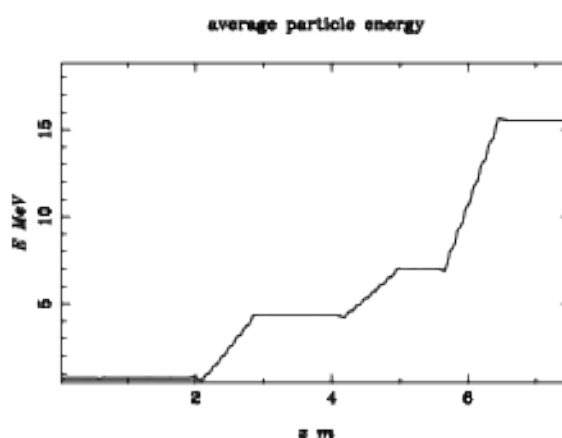
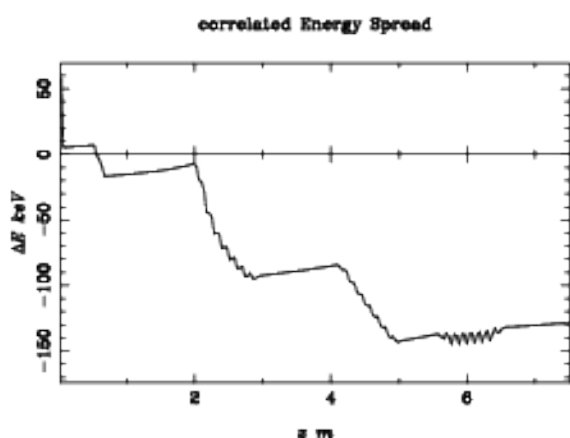
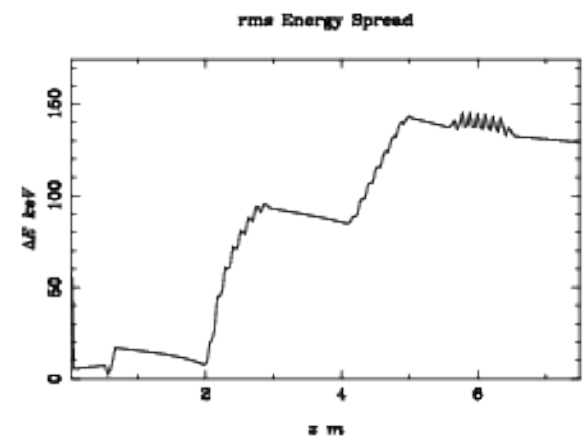
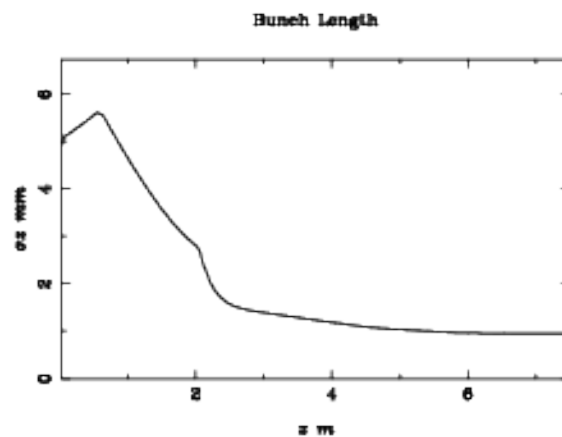
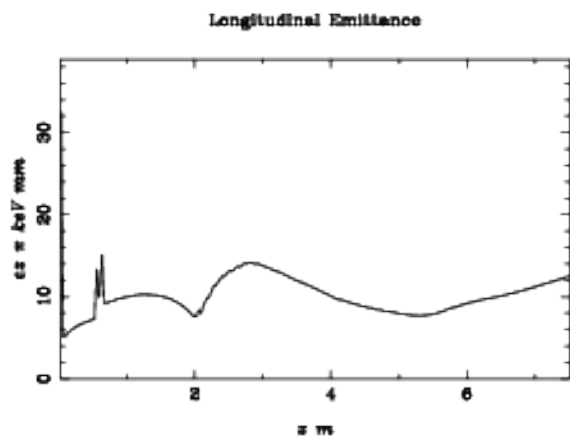
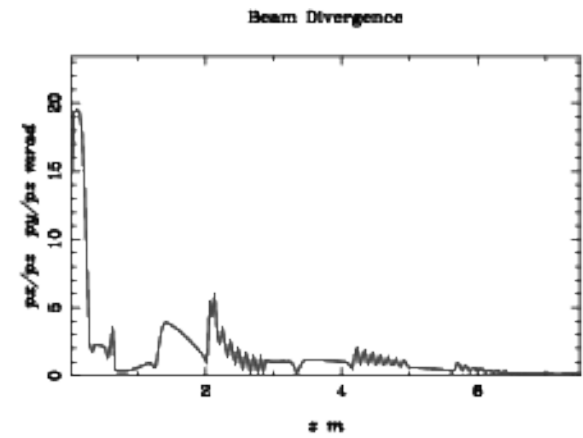
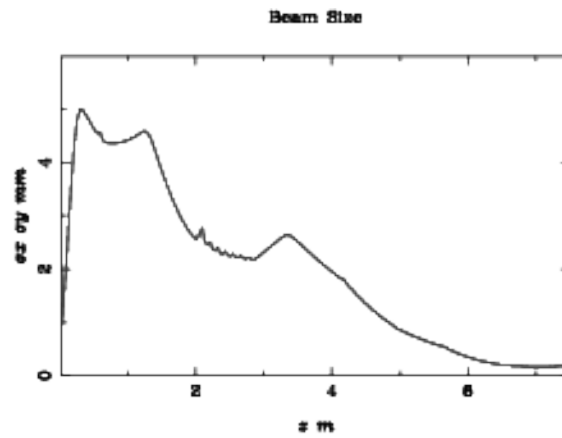
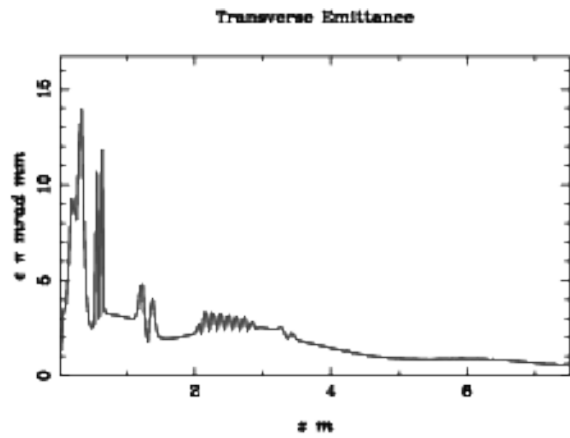
Longitudinal Distribution



$I_{\text{peak}} \sim 40 \text{ A}$   
 $\epsilon_x \sim 0.5 \text{ mm-mrad}$   
 $\Delta E/E \sim 0.3 \times 10^{-3}$



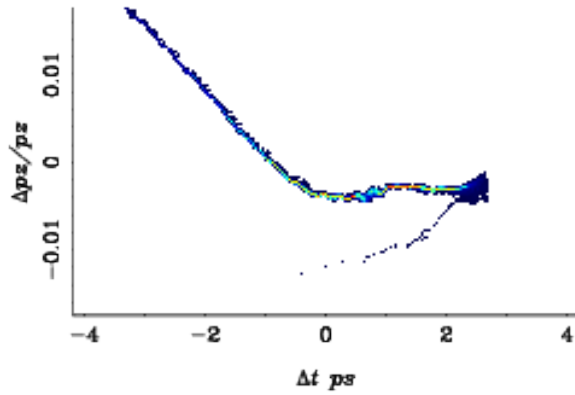
# 300 pC: Low Compression



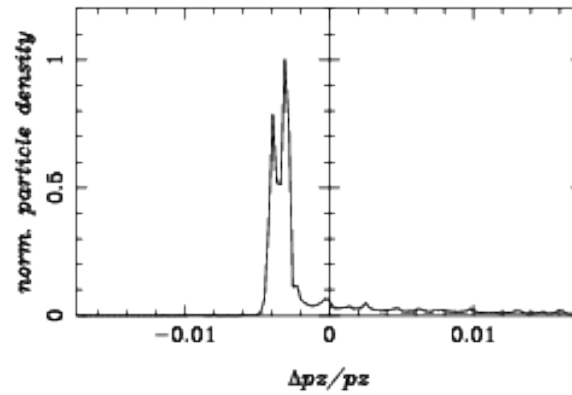
# 300 pC: High Compression

$z = 7.500 \text{ m}$

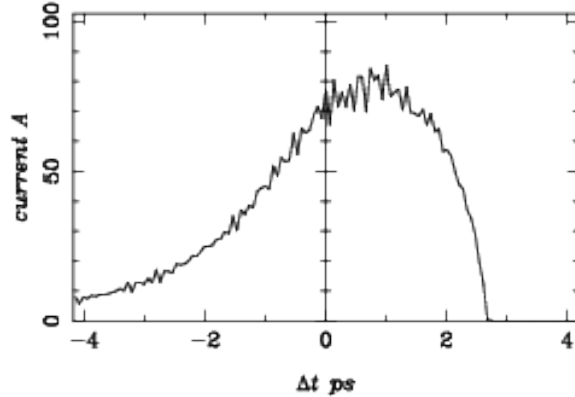
Longitudinal Phase-Space



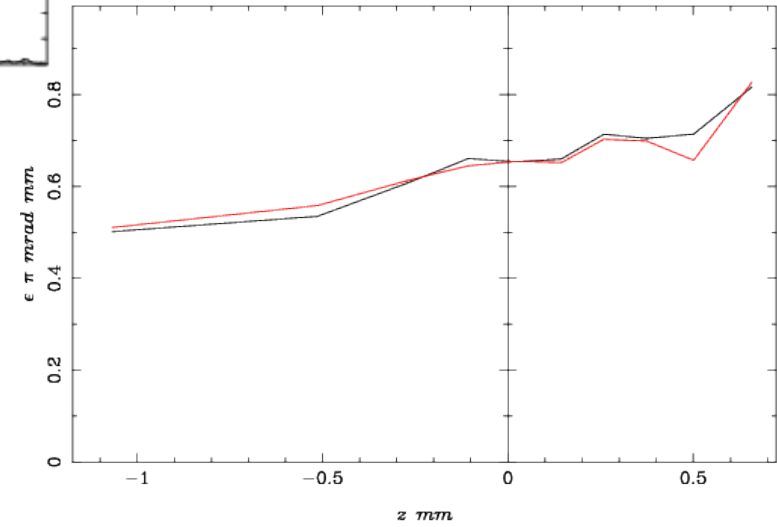
Momentum Spread



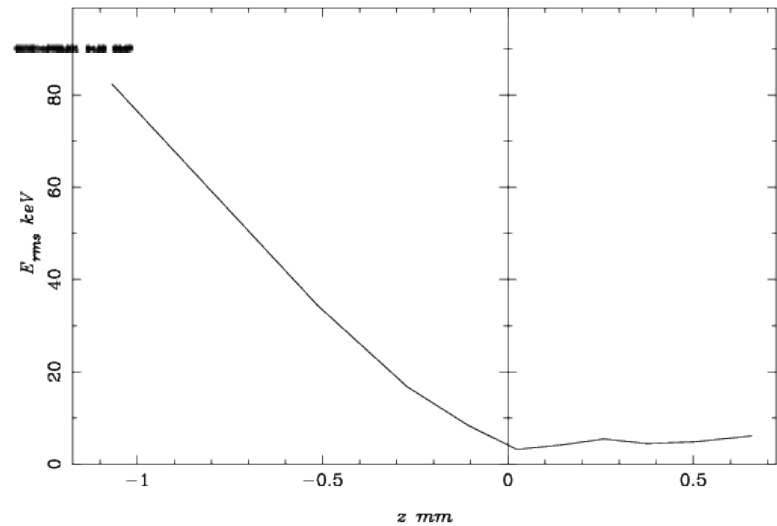
Longitudinal Distribution



Slice Emittance



Slice Energy Spread



$I_{peak} \sim 75 \text{ A}$   
 $\epsilon_x \sim 0.7 \text{ mm-mrad}$   
 $\Delta E/E \sim 0.3e-3$

# 300 pC: High Compression

