Beam Dynamic Simulations of ASTA Photoinjector using PARMELA

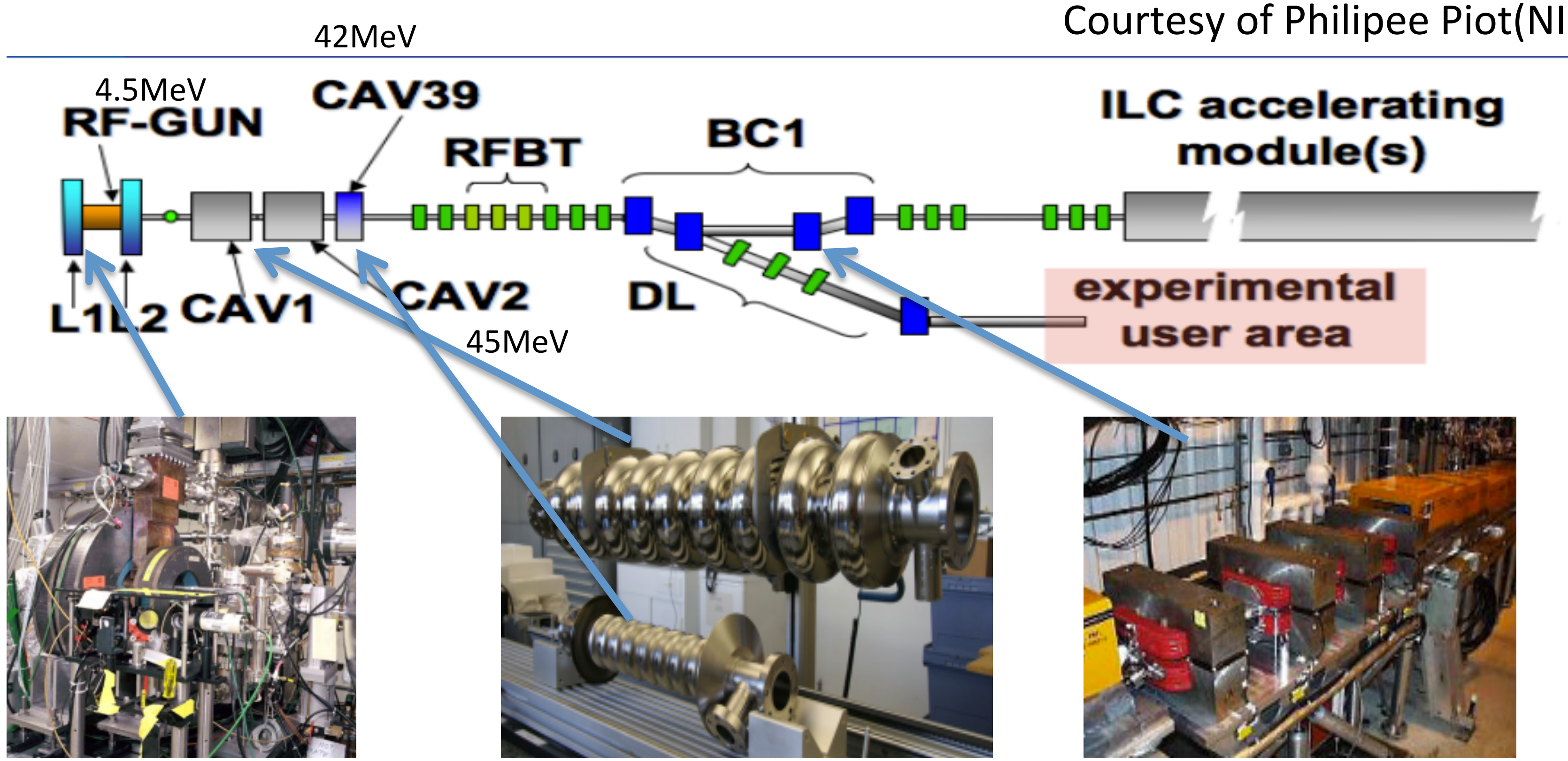
Yuan Hui Wu
UMass Amherst

August 10th, 2012

Motivations

1. Beam dynamic studies of the Advanced Superconducting Test Accelerator (ASTA) Facility at Fermilab
2. Optimize gun, cavities, solenoid and chicane parameters to minimize space charge related emittance growth and maximize bunch compression.
3. Compare no space charge with space charge effects.
4. Simulations are done with PARMELA code.

Courtesy of Philipee Piot(NIU)



Solenoid Magnet: Focus the beam

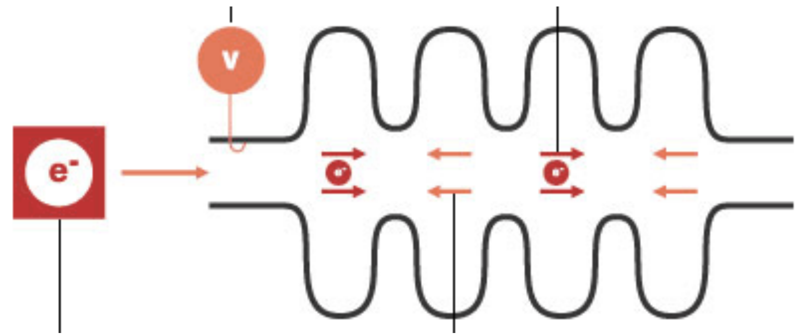
1.3 GHz 9 Cell cavity and 3.9 GHz cavity

4 dipoles bunch compressor

Background

RF Cavity Acceleration

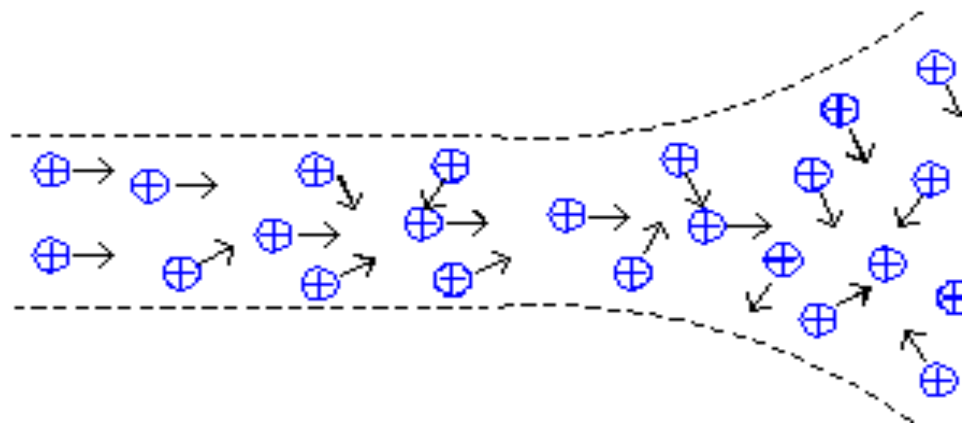
$$E = eV_0 \cos(\omega_{rf} t + \phi)$$



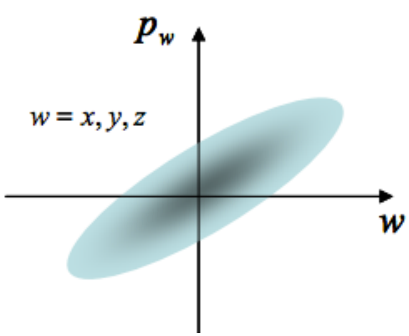
When t=0, ϕ Is said to the phase of crest, and when ϕ =0, the phase is on crest and gain maximum energy.

Space charge effect

$$F = \frac{1}{4\pi\varepsilon_0}\frac{|q_1 q_2|}{r^2}$$



Phase space



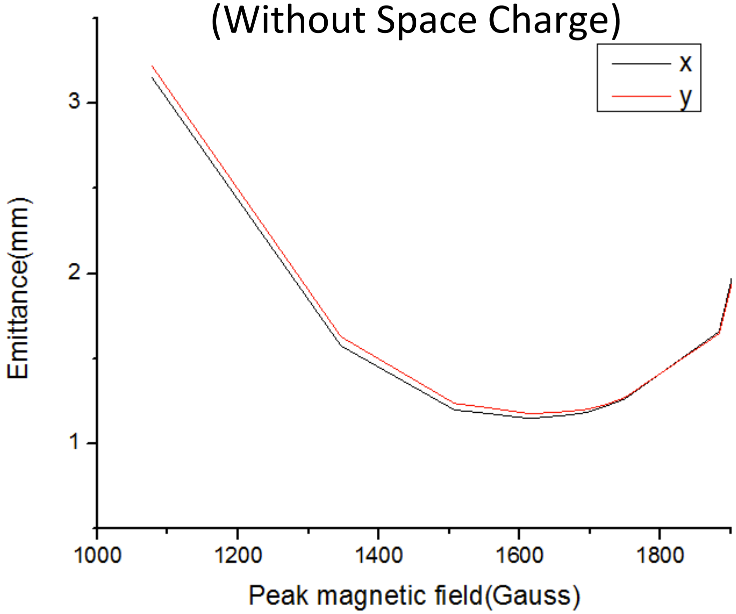
Phase space use for represent particles,
Phase space is conserved.

Optimization Procedure

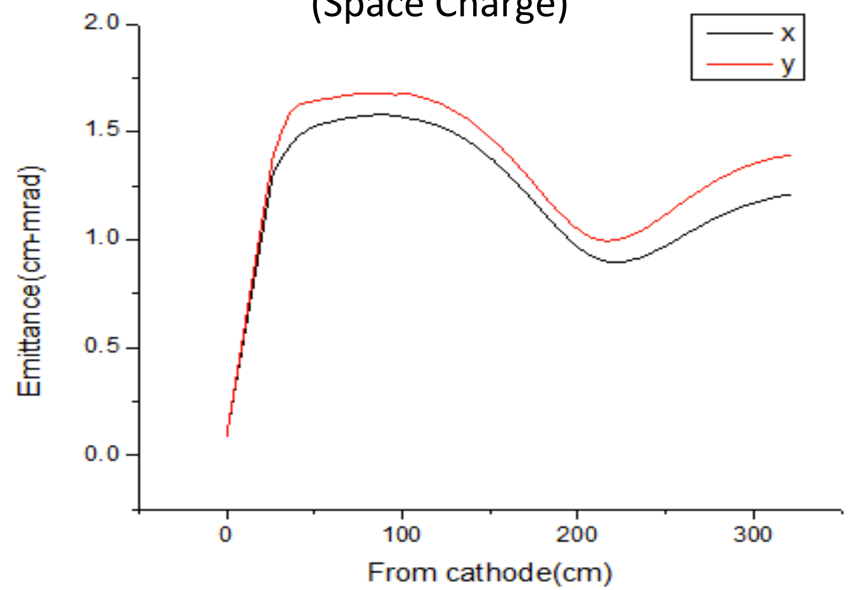
- 1. Begin with no space charge case and then space charge case.
- 2. Adjust the solenoid currents to have B=0 at photocathode surface and minimize the transverse emittance.
- 3. Bunch is on crest in cavity 1 for maximum energy gain and off crest in cavity 2 to introduce a rotation in longitudinal phase space (LPS).
- 4. use cavity 39 to linearize the phase space.

Step 1: Minimize the transverse emittance

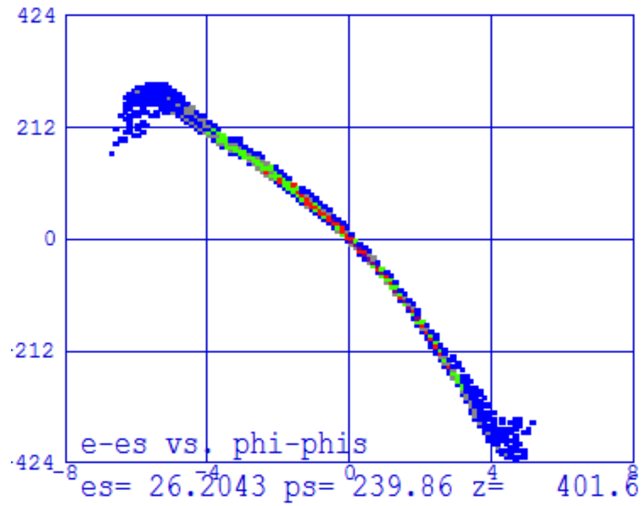
Peak Magnetic Field versus Emittance (Without Space Charge)



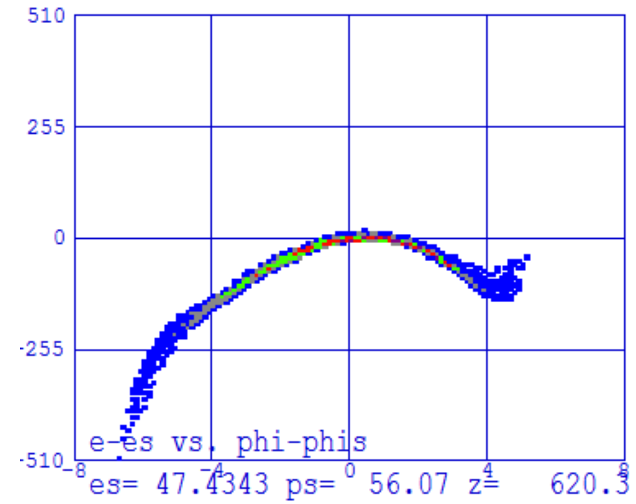
Emittance Oscillation in Drift Space (Space Charge)



Step 2: CAV1 and CAV2

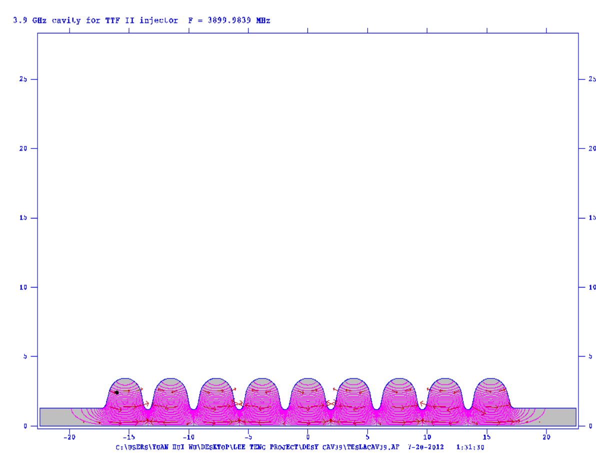


LPS after cavity 1 (bunch length=4.8ps)

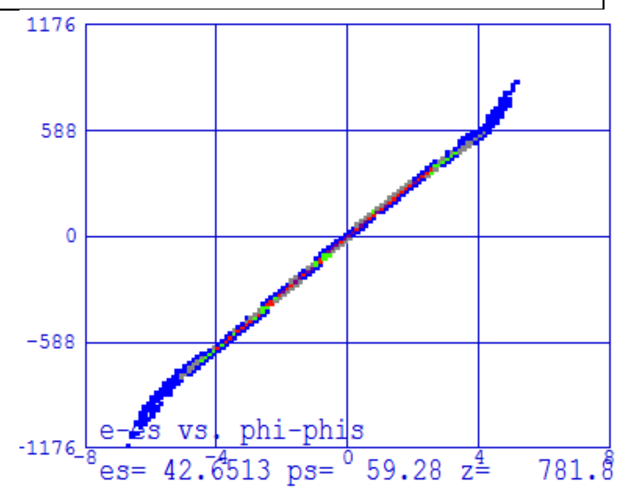


LPS after cavity 2 (bunch length =5.78ps)

Step 3: CAV 39 to linearize the longitudinal phase space



Superfish model of 3.9GHz cavity



LPS after cavity 39 (bunch length=5.79ps)

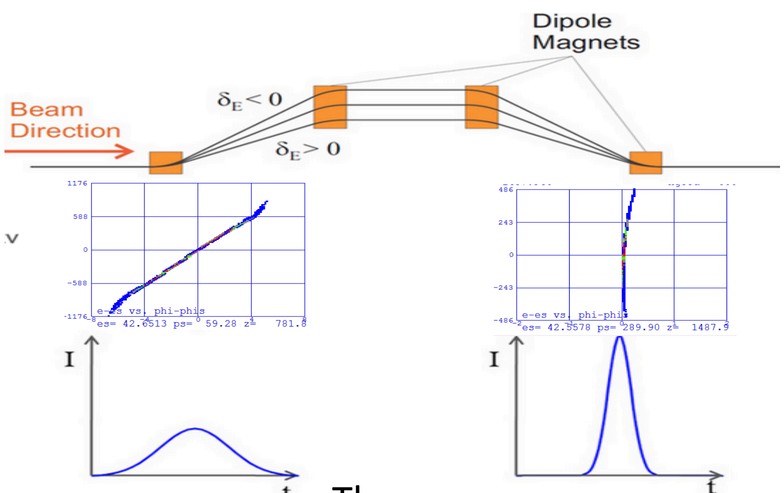
Step 4: Quadrupole Channel

Consists of 8 quadrupoles, 3 of them are skew quadrupoles and individual magnetic Gradient is determined by another program.

Quadruple #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Without Space charge (gauss/cm)	42.58	38.45	0	0	0	10.08	-98.00	50.70
With Space charge (gauss/cm)	-94.5	98.19	0	0	0	105.8	-155.4	48.31

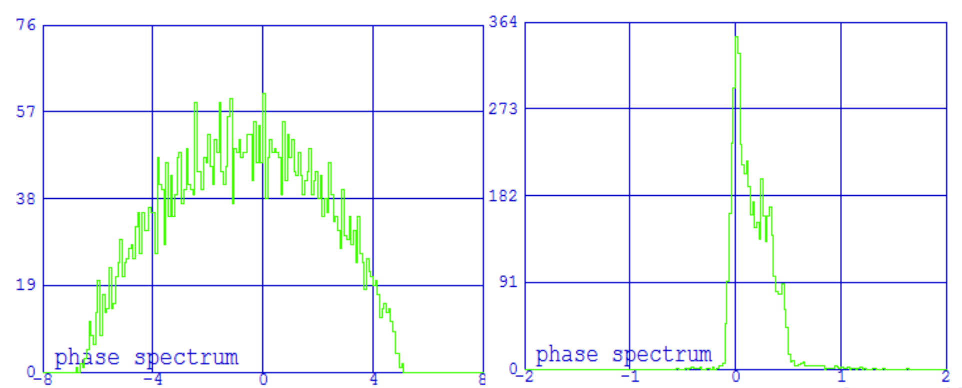
Courtesy of Chris Prokop (NIU)

Step 5: Bunch Compressor (BC1)



Theory

PARMELA does not have CSR effect



Bunch length=5.82ps　　Bunch length=0.39ps

Longitudinal bunch profile before and after BC1

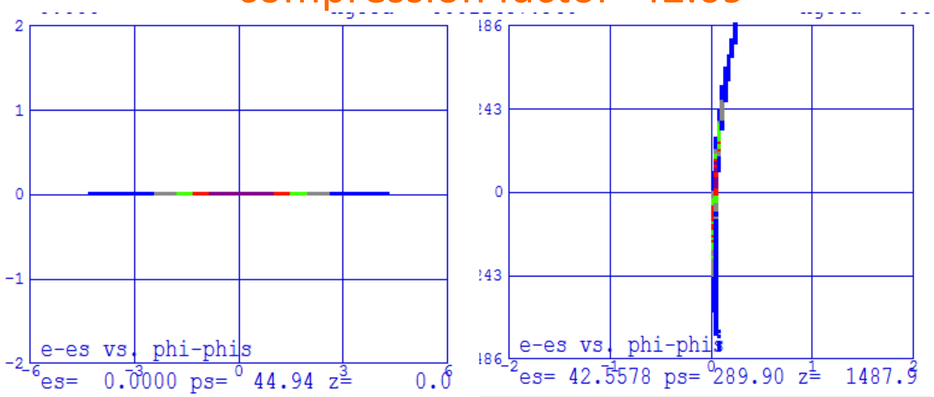
Simulation Parameters Comparison

Without space charge

Element	Gradient (MV/m)
RF GUN	23.67 MV/m
CAV1	22 MV/m
CAV2	22 MV/m
CAV39	14 MV/m

Element	Gauss
Focusing Solenoid	1668.723

compression factor=42.09



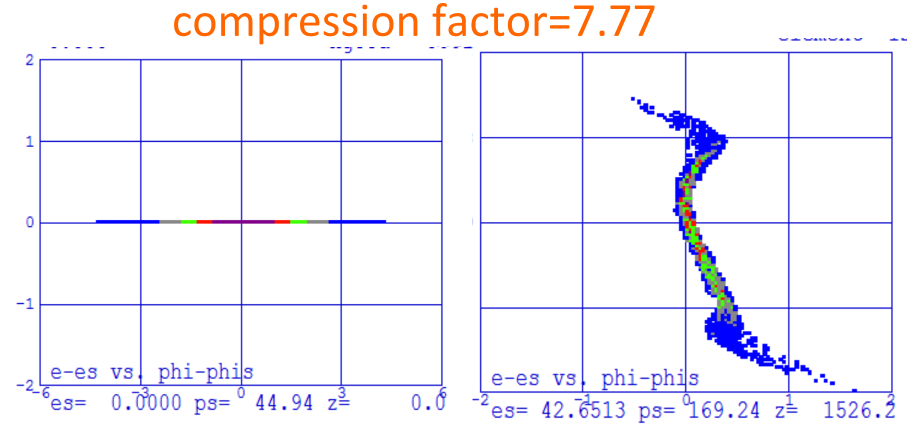
Bunch length from 3ps to 0.07ps

With Space charge

Element	Gradient (MV/m)
RF GUN	23.67
CAV1	22
CAV2	22
CAV39	16

Element	Gauss
Focusing Solenoid	1776.094

compression factor=7.77

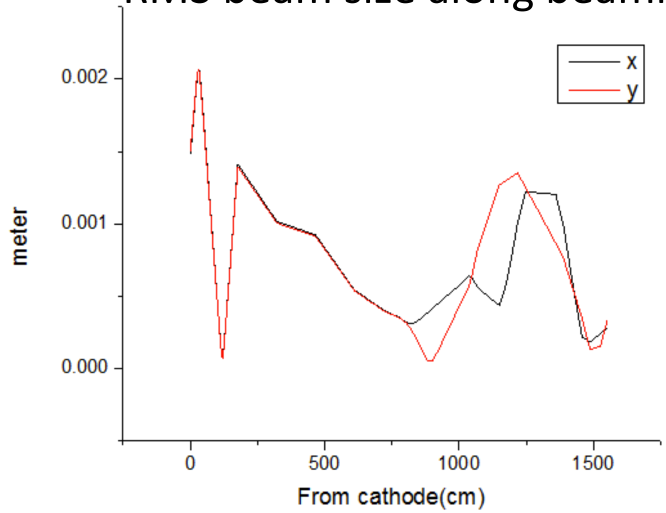


Bunch length from 3ps to 0.39 ps

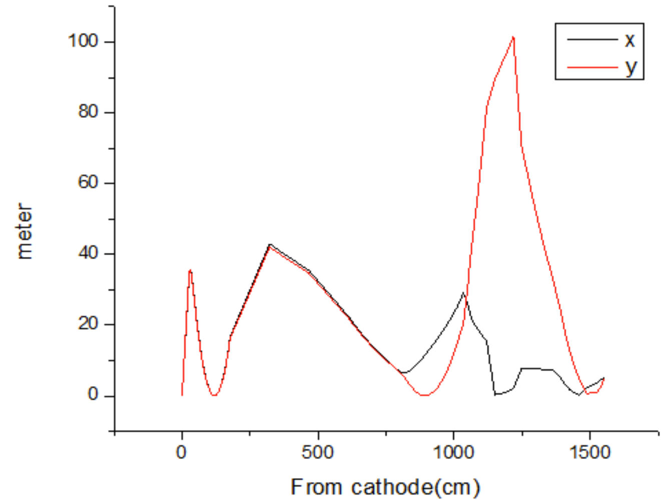
RMS beam size and Beta function

Without space charge

RMS beam size along beamline

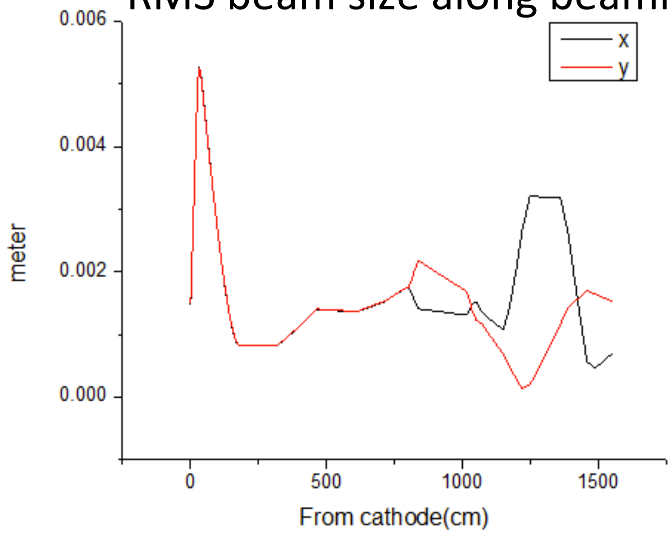


Beta function along the beamline

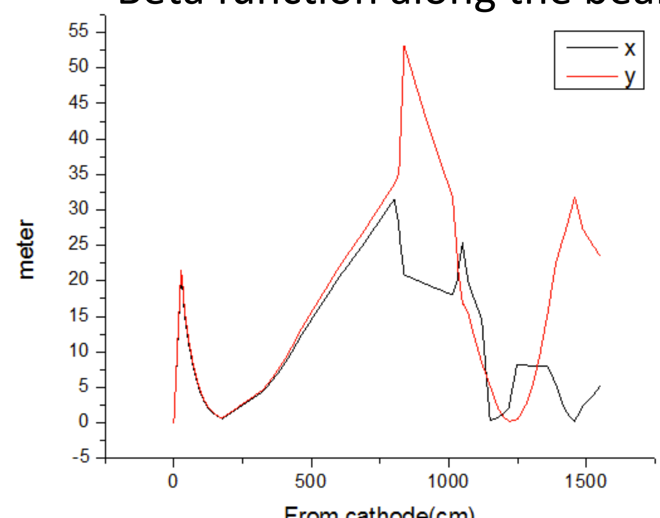


with space charge

RMS beam size along beamline



Beta function along the beamline



Conclusions

1. We have optimized gun, cavities, solenoid and chicane parameters to minimize space charge related emittance growth and maximize bunch compression.

2. Without space charge case, the bunch length compressed from 3ps to 0.07ps . With space charge case, bunch length from 3ps to 0.39 ps.

3. The final normalized emittance for space charge case is ~7.8 mm using PARMELA and ~4.6 mm using ASTRA.

Future work

1. We should try to implement the CSR effect into PARMELA, CSR effect is still one of the concerns which affect the beam quality.

2. Compare the different simulation results and parameters for low charge and high charge electron.

Acknowledgement

I would like to express my sincere thanks to my advisors, Tanaji Sen and Philip Piot whose advice, support and direction made this project possible, and Daniel Mihalcea and Chirs Prokop from NIU who teach me how to use PARMELA and provide me research resources. Also, I would like to thank Eric Prebys for organizing this programs and making this internship very memorable.