ELECTRON BEAM ION SOURCE

Physics Design

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Acknowledgements

ELECTRON BEAM ION SOURCE

Contributors:

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Outline

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- Introduction
- LEBT
- Physics design of the RFQ
- MEBT
- Physics design of the LINAC
- Error Studies
- End-to-End Simulations
- Summary

Requirements

- EBIS based linac should provide all the ions species which Tandem presently provides, at 2 MeV/u

	Z	A	Q	Q/m	Vext(kV)	I
						(all ch states
He3*	2	3	2	0.67	25.5	10
D	1	2	1	0.50	34.0	6
C	6	12	6	0.50	34.0	10
O	8	16	8	0.50	34.0	10
Si	14	28	12	0.43	39.7	10
Fe	26	56	16	0.29	59.5	10
Au	79	197	32	0.16	104.7	10

*** Out of EBIS Linac scope**

Simulations were carried out for two extreme Q/m namely Au^{+32} and $_4He^{+2}$.

Proposed Linac–Based RHIC Preinjector

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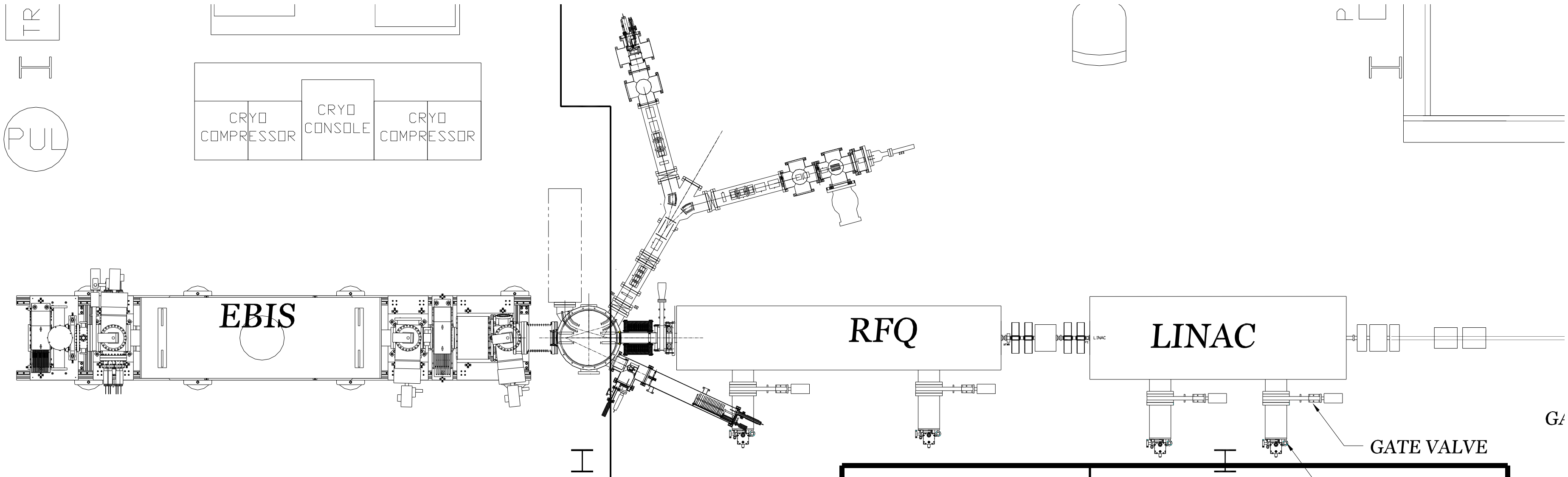

RFQ: 17 - 300 keV/u; 100.625 MHz

IH Linac: 0.3 - 2.0 MeV/u; 100.625 MHz

Ion	U - D
Charge	38 – 1 (q/m =.16-0.5)
Current	1.5 emA (for 1 turn inj)
Pulse Length Rep. Rate Duty Factor	10 μs 5 Hz 0.0005 %
Emittance	0.14 π mm rad (nor, rms)
Energy Spread	2.0 keV/u

LEBT TEST

Pikin, Beebe, Raparia, Alessi, Ritter

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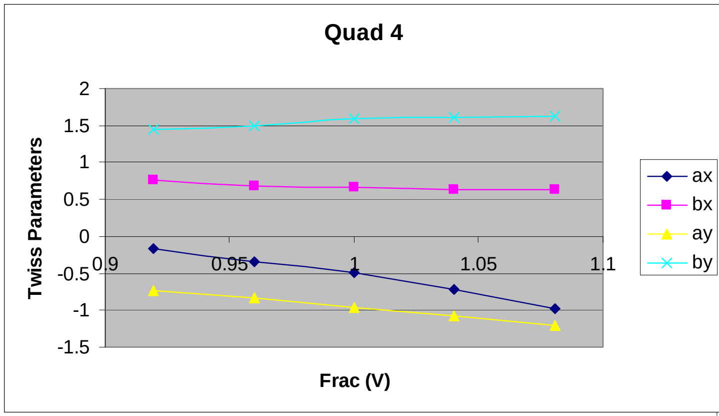
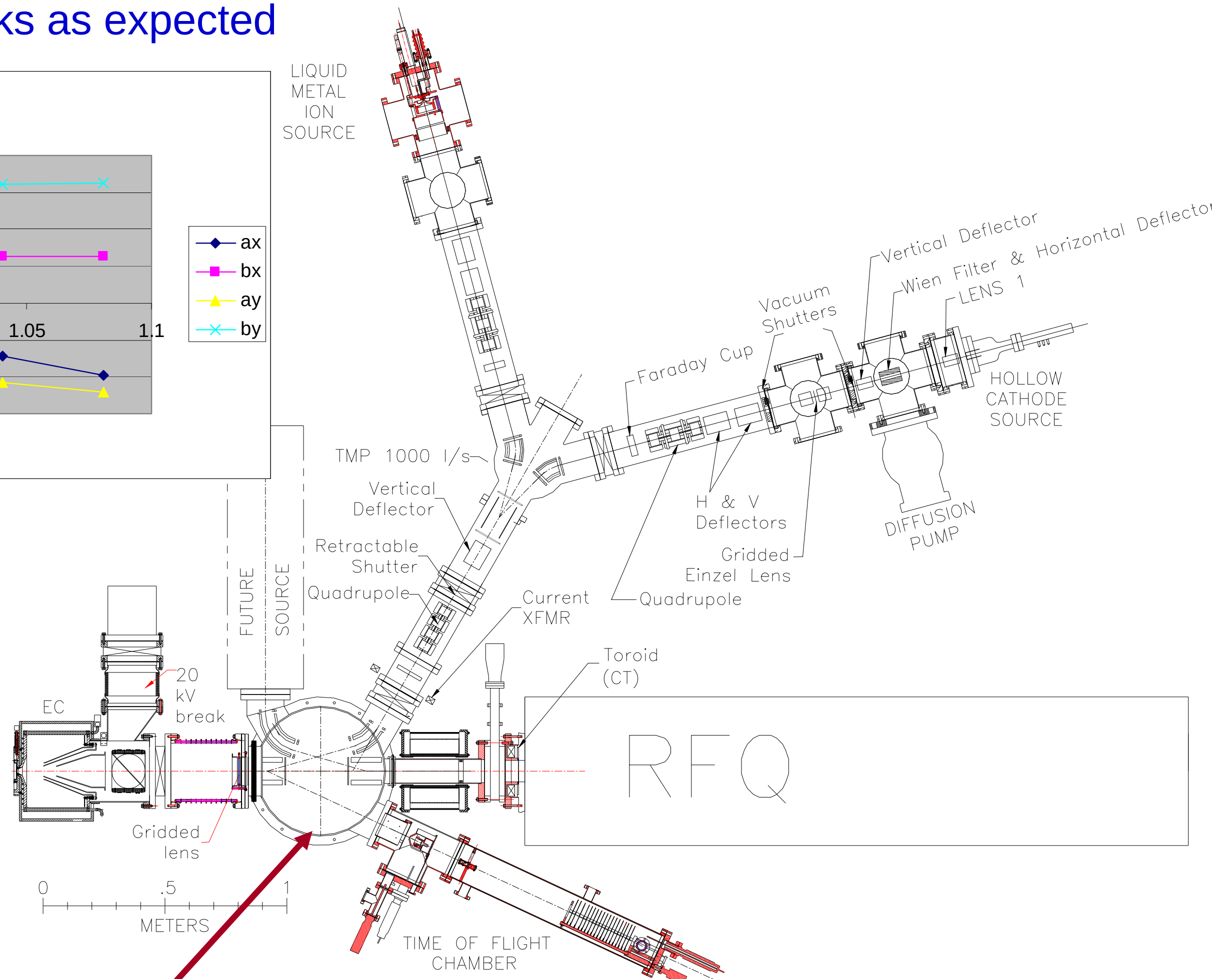
LEBT switch yard works as expected





LEBT Switch yard

Final Physics Design of the RFQ

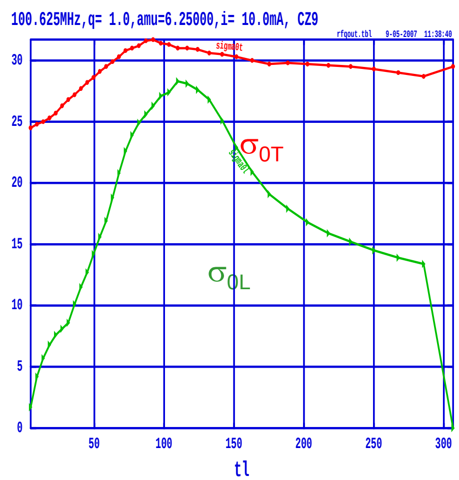
- The Physics design of the RFQ is frozen

Basic RFQ Parameters

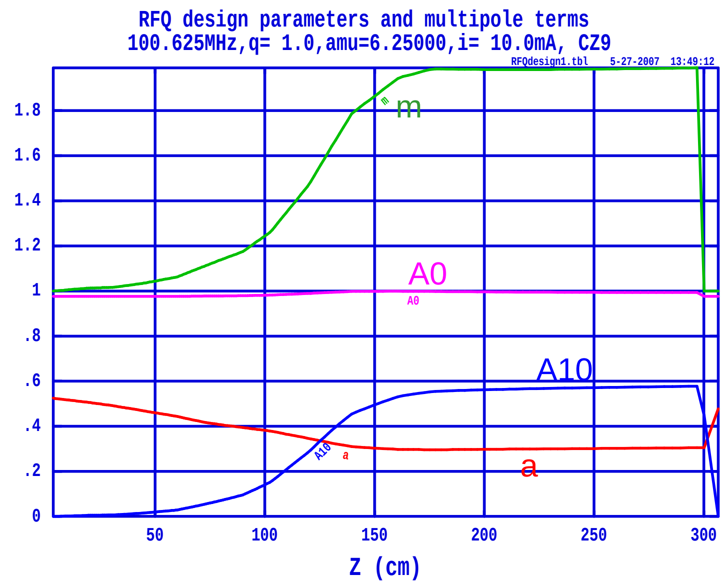
Frequency	100.624 MHz
Input energy	17 keV/u
Output energy	0.3 MeV/u
Mass to charge ratio	6.25
Beam current	10 mA
Output rad. emittance rms norm. 90%	< 0.38 π mm mrad
Output long. emittance 90%	< 220 deg keV
Transmission	98%
Electrode voltage	70 kV
RFQ length	3.08 m
Cell number	191
Aperture min - max	2.96-5.25 mm

- Transport > 30mA with > 90% efficiency
- Provides symmetric beam in transverse
- Only 3.08 meters long

Transverse and long. phase advance



Basic RFQ Parameters



Final Physics Design of the RFQ (cont…)

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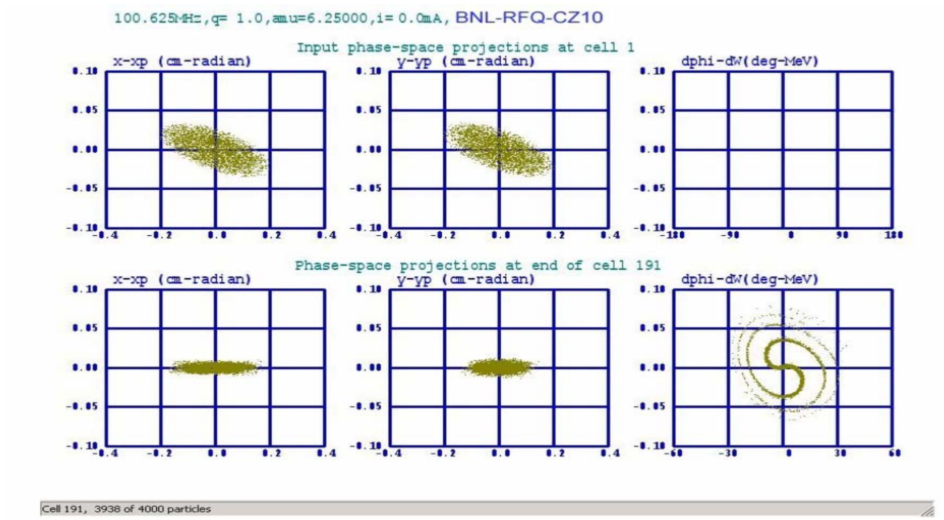
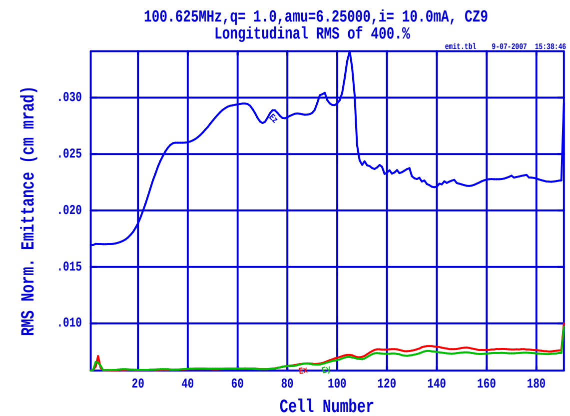
Input and output phase spaces for 0.0 mA

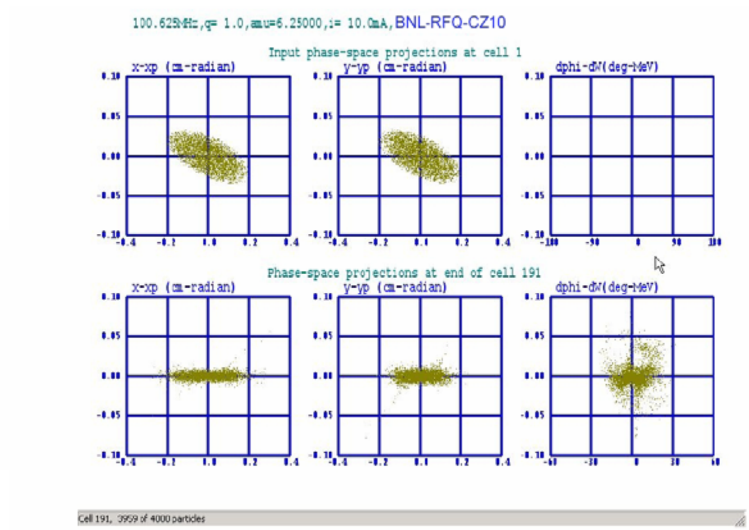


Input and output particle distribution with I=0mA

Emittance along the cell



Input and output phase spaces for 10 mA



Input and output particle distribution with I=10mA

PARMTEQM simulations for different input beam current and emittance

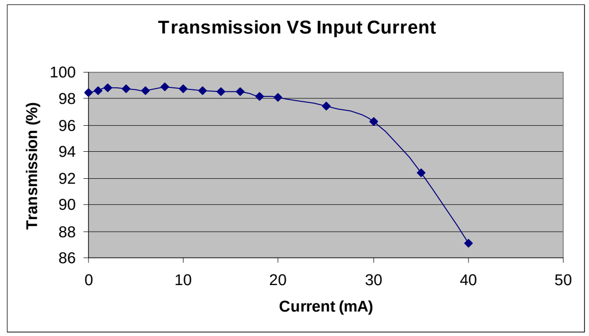
$\varepsilon_{in}^{trans.,un., real}$ [π mm-rad]	Transmission [%] 4000	$\varepsilon_{out}^{z,\ rms}$ [MeV-deg] 100%	$\varepsilon_{out}^{xy,\ rms}$ [π mm mrad] 100/90%
0.05790 I=0	99.0	0.284	0.064/0.0271
0.08685 I=10	98.7	0.243	0.09/0.038
0.11580 I=0	98.4	0.27	0.126/0.053
0.11580 I=10	98.7	0.33	0.15/0.060

Final Physics Design of the RFQ (cont…)

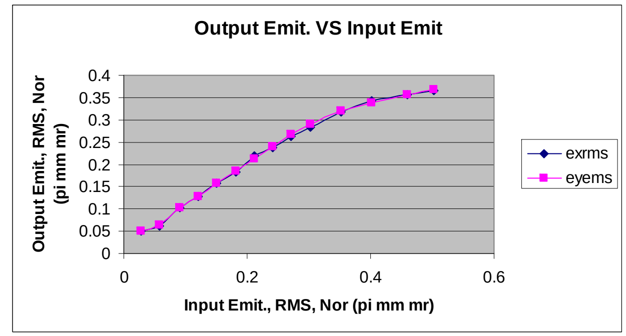
- Beam dynamics design is very flexible

  - Transmission vs. input current
  - Trans. Emit vs. input current
  - Long. Emit vs. input current
  - Transmission vs. input emit
  - Output emit vs. input emit
  - Transmission vs. Au Charge state
  - Transmission vs. Vane Voltage
  - Transmission vs. input energy error
  - Trans. Emit. Vs. input energy error
  - Long. Emit vs. input energy error
  - Transmission vs. input energy spread
  - Trans. Emit vs. input energy spread
  - Long. Emit vs. input energy spread
  - Transmission vs. aiming error (x,x',y,y',r,r')
  - Transmission vs. mismatch factor
  - and more

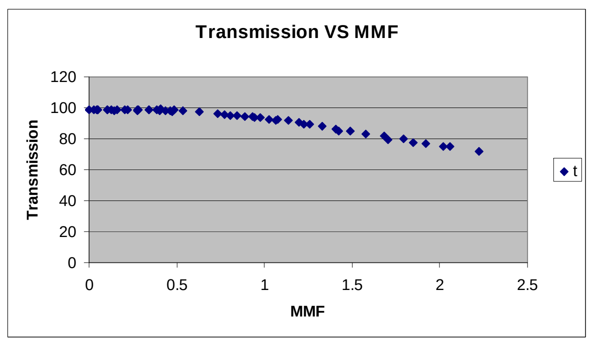
Transmission vs Current



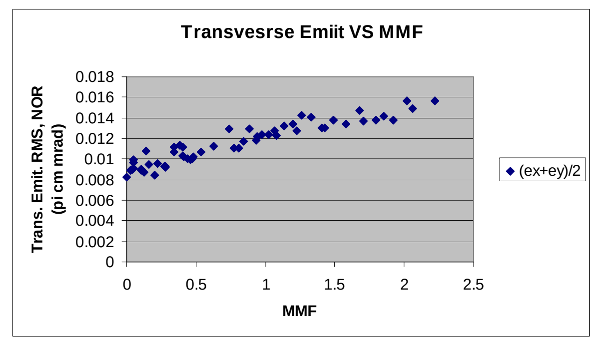
Output Emit vs Input Emit



Transmission vs MMF



Trans. Emit. vs MMF

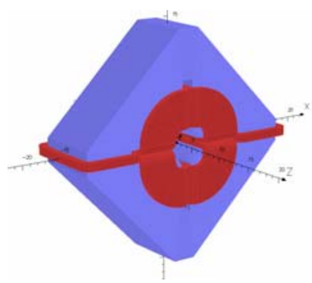


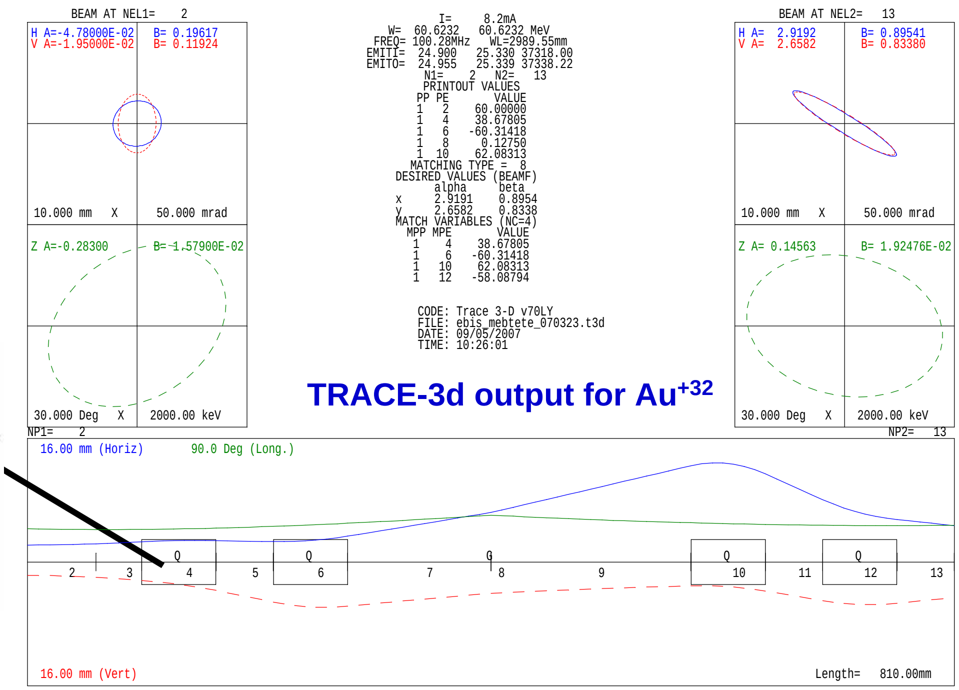
MEBT design is finalized

Raparia, Ritter, Brodowski, Alessi

- MEBT length with new quads is 810 mm.10 cm space after the RFQ to accommodate a current transformer. 5 cm space before the IH Linac for Faraday cup. 30 cm space for 20 cm long buncher
- New quad length=65 mm, G=70T/m, air cooled (Okamura)
- End-to-end simulations show transmission to booster and emittance are acceptable

New Quad Cross Section

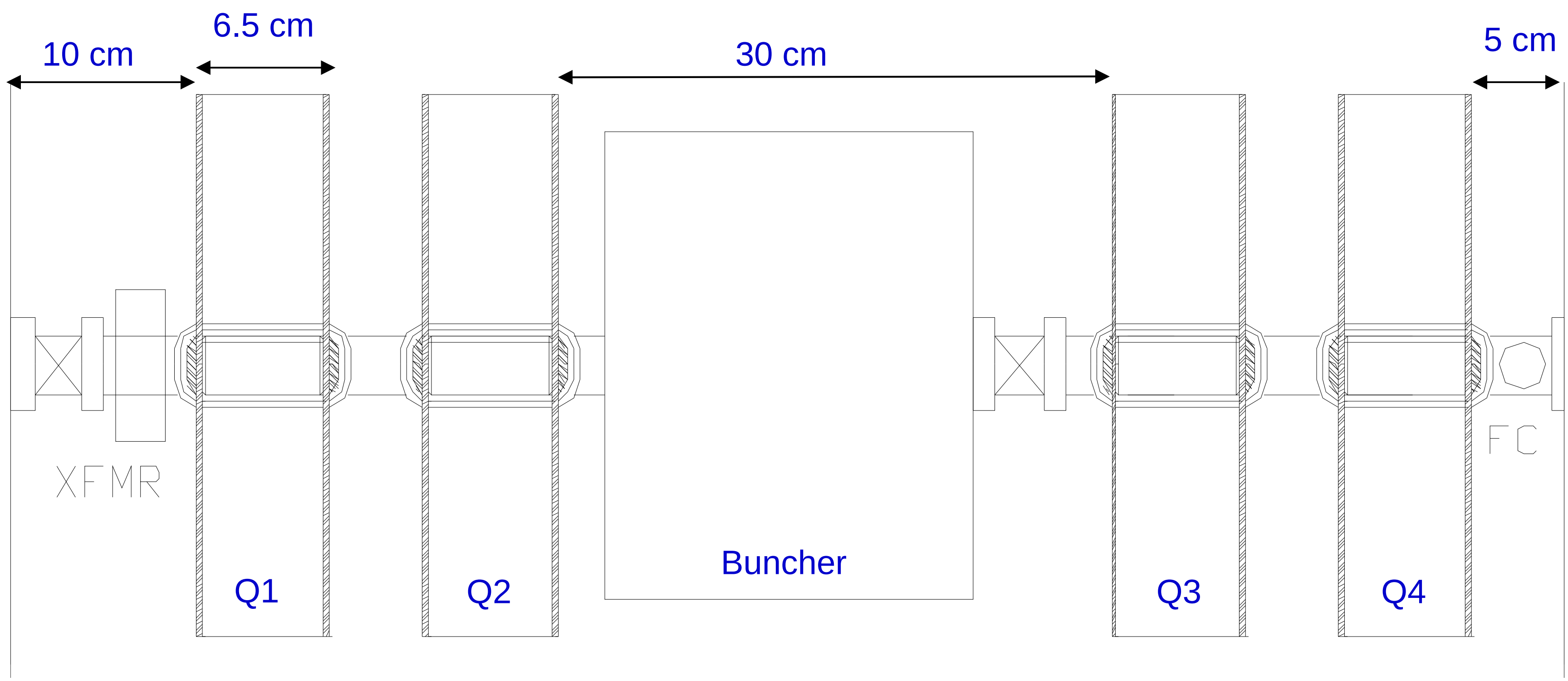




TRACE-3d output for Au^{+32}

MEBT Layout

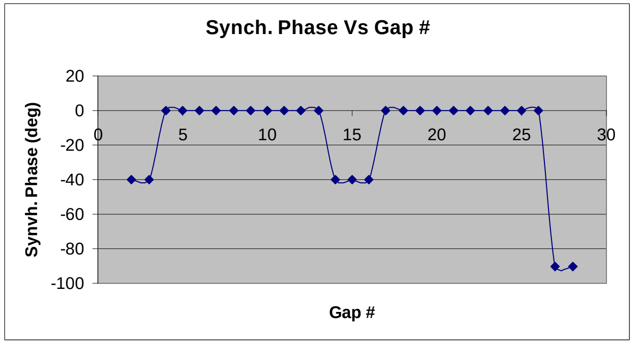
Ritter, Raparia, Brodowski, Alessi



Final Physics Design of the Linac

- First two cells -40 degrees to provide longitudinal focusing
- Last two cells at -90°, to reduce energy spread at Booster
- 2.16 meters long
- Includes only one triplet

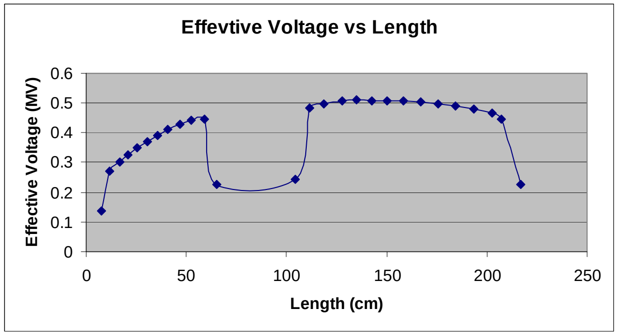
Synchronous Phase



Basic Parameters of IH-DTL Linac

Charge-to-mass ratio		0.16 - 0.5
Operating frequency	MHz	100.625
Input / output energy	MeV/u	0.3 / 2.0
Beam current	mA	0 - 10
Length of the whole linac array	m	3.5
Length of the IH tank	m	2.5
Number of the IH tank gaps		27
Number of the internal triplets		1
Aperture diameter of IH drift tubes	mm	18, 20
Maximum effective gap voltage	kV	509
Effective voltages at the first buncher (0 mA / 10 mA)	kV	70 / 80
Effective voltages at the final buncher (0 mA / 10 mA)	kV	117 / 155
Maximum on-axis electric field	MV/m	15
Aperture diameter of quadrupole lenses	mm	30
Maximum magnetic gradient	T/m	72
Transverse rms emittance growth (0 mA / 10 mA)	%	32 / 40
Longitudinal rms emittance growth (0 mA / 10 mA)	%	3 / 12
Transv. outp. emittance (norm, 90% effective, 0 mA/10 mA)	mm*mrad	0.36 π / 0.6 π
Long. outp. emittance (norm, 90% effective, 0 mA/10 mA)	keV/u*ns	6.2 π / 3.0 π
Output energy spread after final buncher (0 mA / 10 mA)	keV/u	± 7 / ± 5
Transmission	%	100

Effective voltages across the gaps



Final Physics Design of the Linac (cont…)

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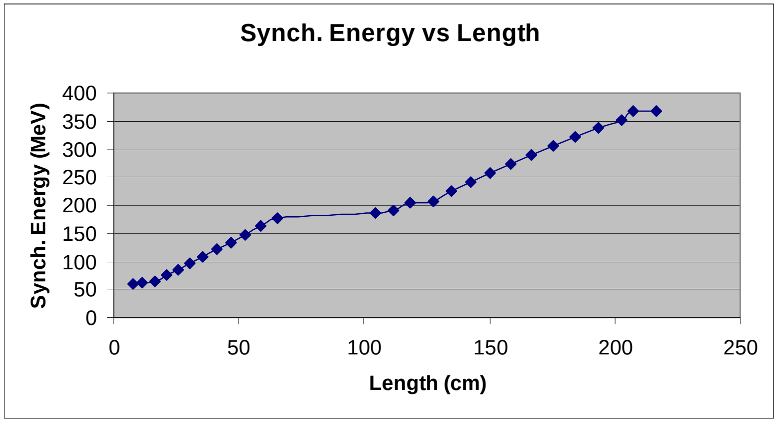
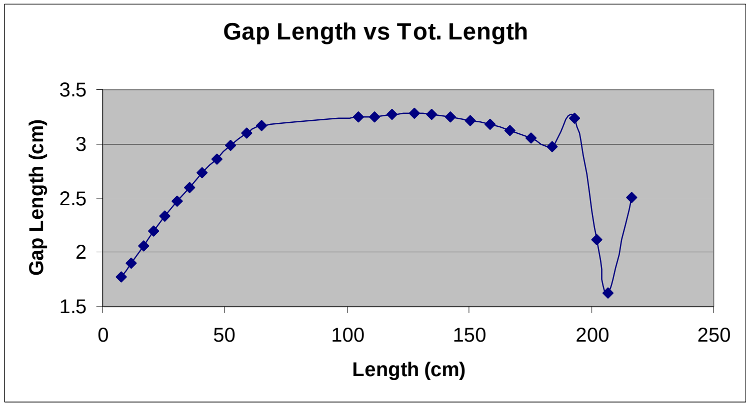
Synchronous Energy vs. Length



Accelerating gap lengths vs. length



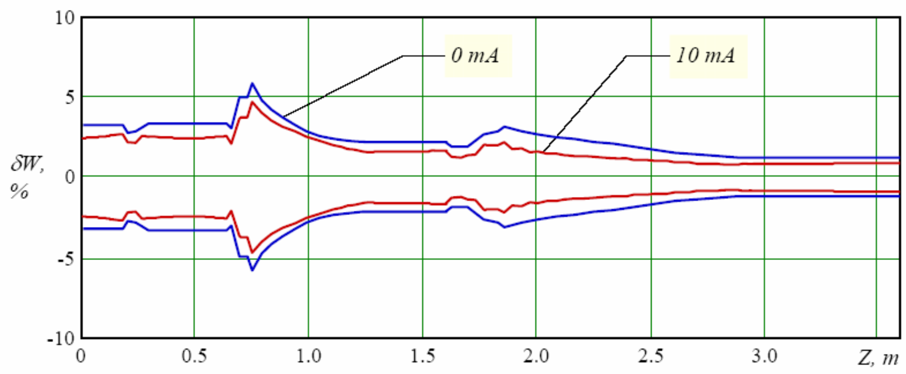


Fig.6. Energy spread along the structure for 98% of the particle

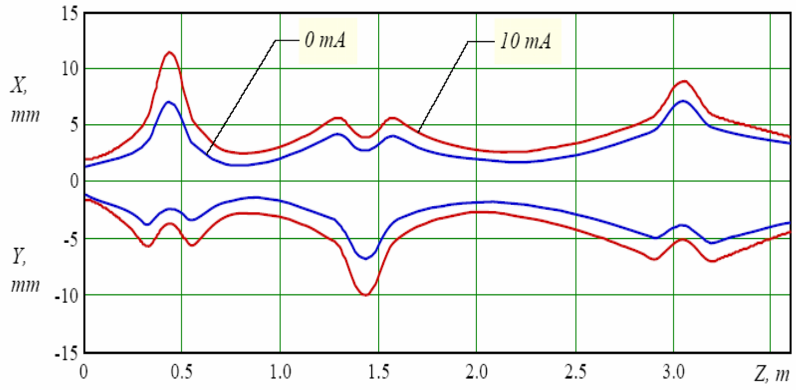


Fig.4. Transverse envelopes of the bunch for 98% of the particle

Final Physics Design of the Linac (cont…)

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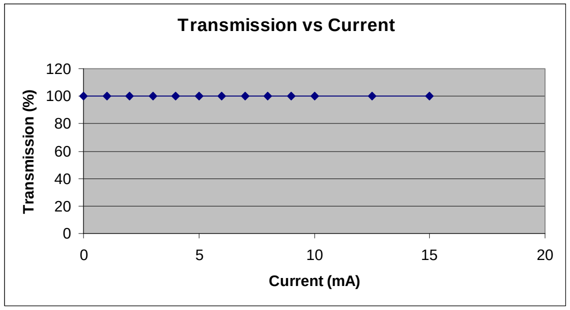
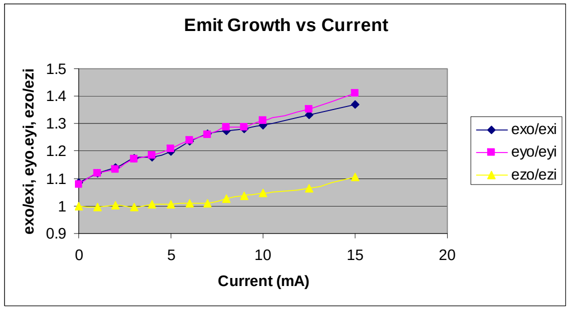
- Robust Beam dynamics design
  - Transmission vs input current (Au^{+32})
  - Emittance growth vs input current (Au^{+32})
  - Transmission vs input emittance (Au^{+32})
  - Emittance growth vs input emittance (Au^{+32})
  - Transmission vs input energy (Au^{+32})
  - Emittance growth vs input energy (Au^{+32})
  - Transmission vs input energy (Au^{+32})
  - Transmission vs input phase (Au^{+32})
  - Emittance growth vs input phase (Au^{+32})
  - Transmission vs Au charge states (Au)
  - Transmission vs input current (He^{+2})
  - Emittance growth vs input current (He^{+2})
  - Transmission vs input emittance (He^{+2})
  - Emittance growth vs input emittance (He^{+2})
  - Transmission vs input energy (He^{+2})
  - Emittance growth vs input energy (He^{+2})
  - Transmission vs input energy (He^{+2})
  - Transmission vs input phase (He^{+2})
  - Emittance growth vs. input phase (He^{+2})

Au^{+32}

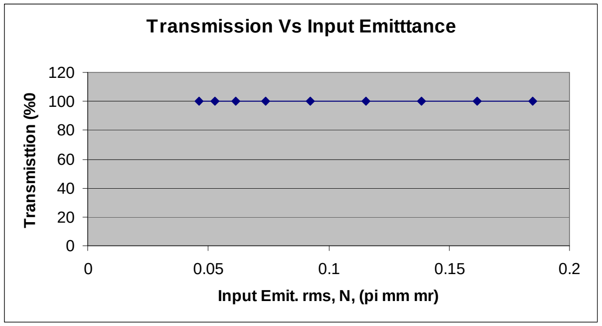
Transmission vs. Current



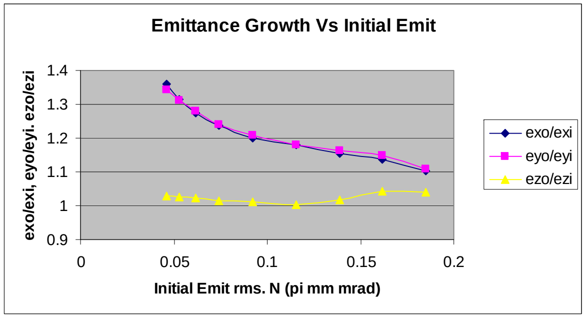
Emittance Growth vs. Current



Transmission vs. Input Emittance



Emittance Growth vs. Input Emittance



Error Studies

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- LEBT
  - Ion Extraction (x), Ion lens (x), Adapter (x), Gridded Lens(x), Platform (x), Solenoid (x)
- RFQ
  - Amplitude (x), Injection trajectory (x), Matching (x)
- MEBT
  - Buncher Amp & Phase (x), Quad Strength, Quad alignment (x)
- IH Linac
  - Phase and Amp (x), Quad Strength (x), Quad Alignment (X), Matching (x), Manufacturing errors()
- HEBT
  - Buncher Phase and Amplitude (x), Quad Alignment (x), Quad Strength (x), Matching (x)

LEBT, Au^{+32}

Pikin

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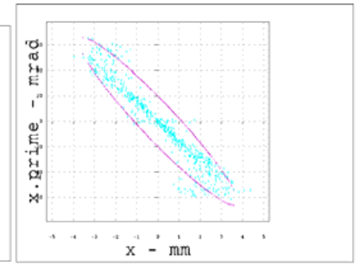
2-D simulation with TRAK

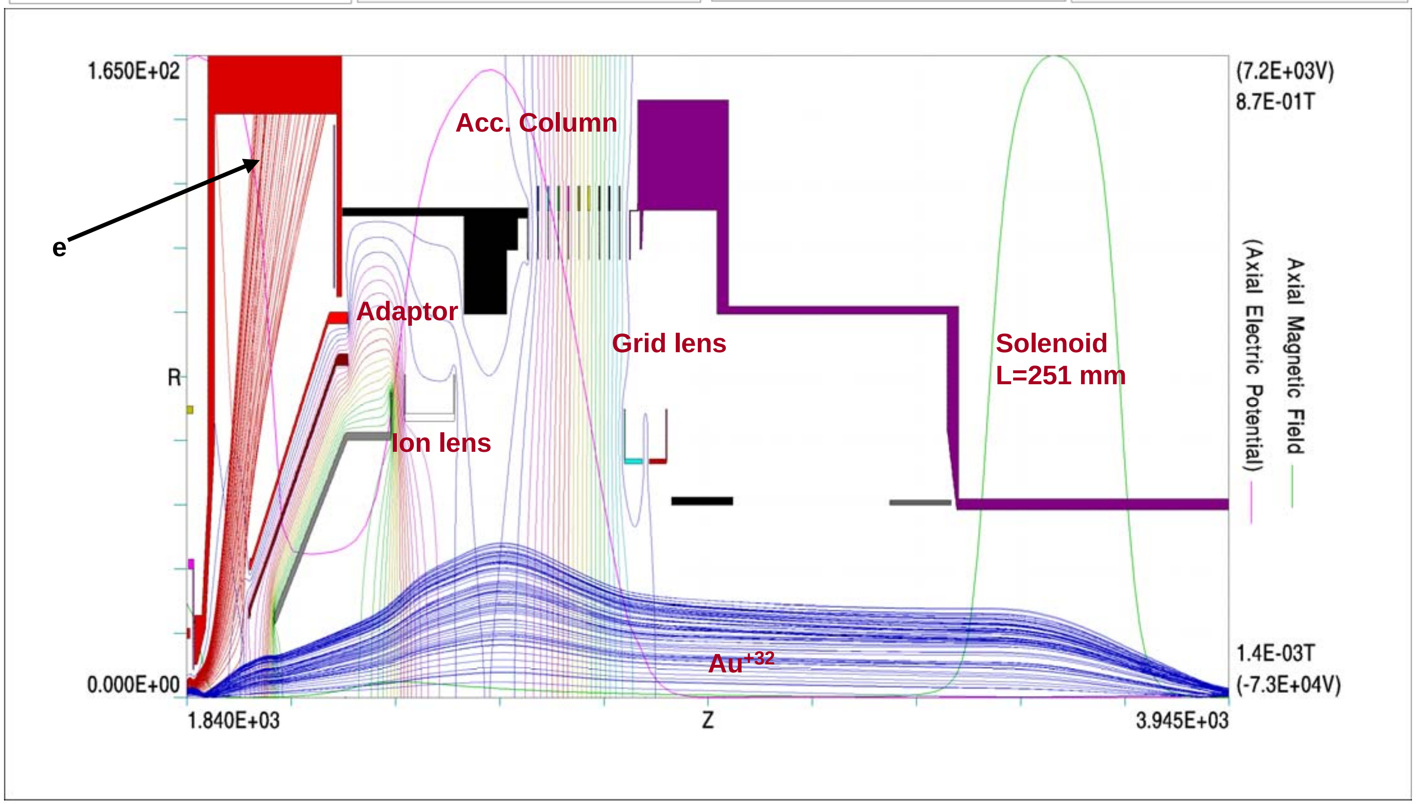
This Plot Created On: March 24, 2006

EOU File: FE55_0_67_500.EOU
BOU File: FBLEBT_6.BOU
TOU File: 55_0_67_1_78E5_2A.TOU

Optics parameters:
U_ion lens = -65 kV
U_adaptor = -10 kV
U_grid = +5.5 kV
IN_magnet lens = 1.78E+5 AmpxTurns

Beam parameters:
I_el = 10.0 A
I_ion =8.0 mA
E_RMS_norm_init = 0.068 pi.mm.mrad
E_RMS_norm_final = 0.0803 pi.mm.mrad
Alfa_final = 1.01
Beta_final = 0.068
X_final = 2 mm
X'_final = 40 mrad





Error Studies (LEBT)
MMF(RFQ) vs. % Error

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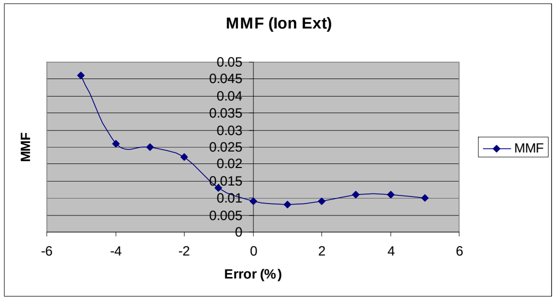
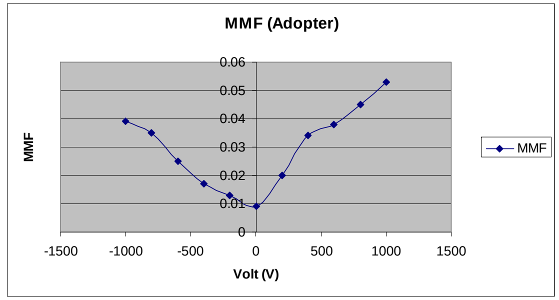
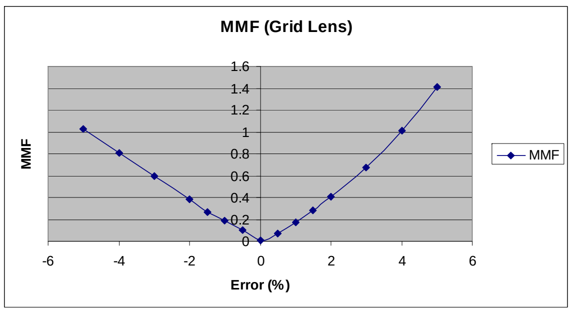
MMF vs. Ion Ext. Voltage Error



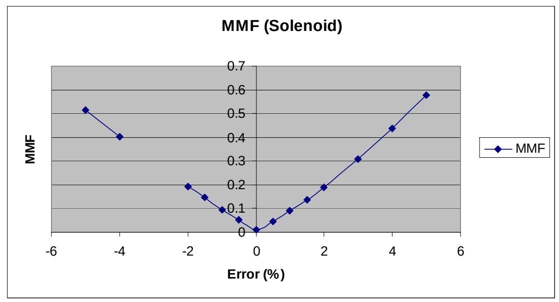
MMF vs. Adapter Voltage Error



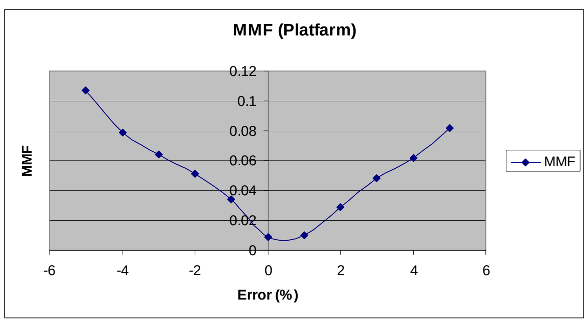
MMF vs. Grid Lens voltage Error



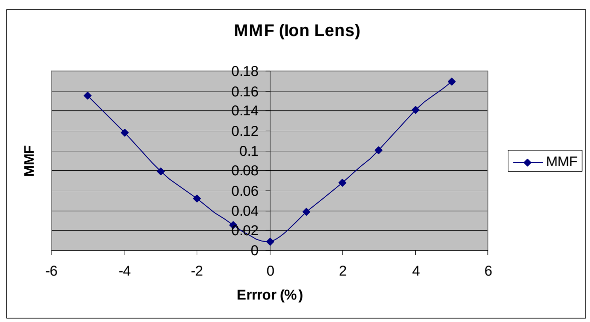
MMF vs. Solenoid Field Error



MMF vs. Platform Voltage Error



MMF vs. Ion Lens Voltage Error



Mismatch factor defined as

$$\gamma x^2 + 2\alpha x x' + \beta (x')^2 = \varepsilon \quad (\text{mateched condition})$$

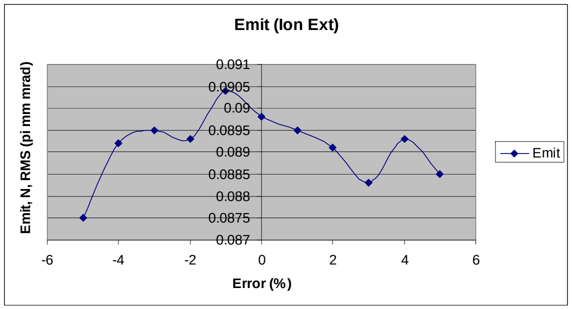
$$G x^2 + 2 A x x' + B (x')^2 = \varepsilon \quad (\text{to be matched})$$

$$M = \left[\frac{1}{2}\left(R + \sqrt{(R^2 - 4)}\right)\right]^{\frac{1}{2}} - 1$$

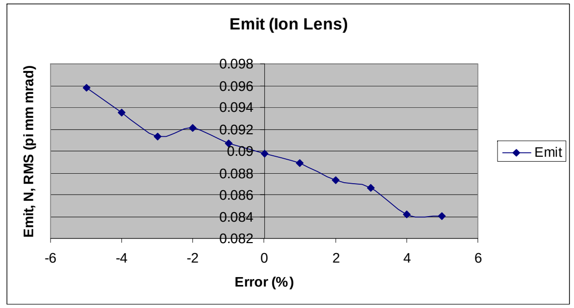
$$\text{Where} \quad R = \beta G + B\gamma - 2\alpha A$$

Error Studies (LEBT)
Emittance vs. % Error

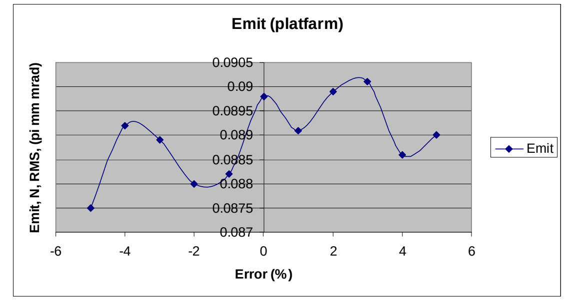
Emittance vs. Ion Ext. Voltage Error



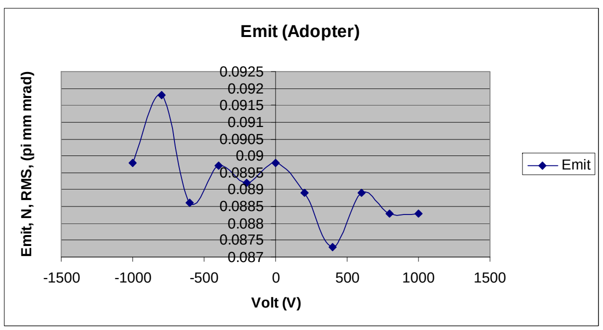
Emittance vs. Ion Lens Voltage Error



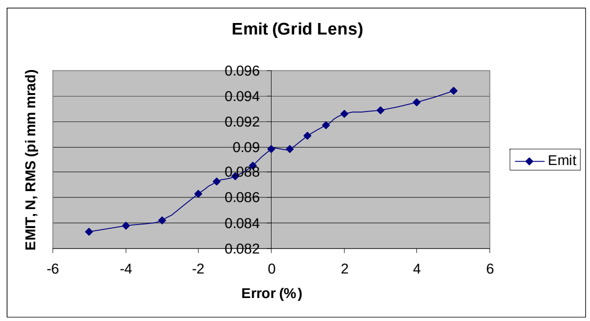
Emittance vs. Platform Voltage Error



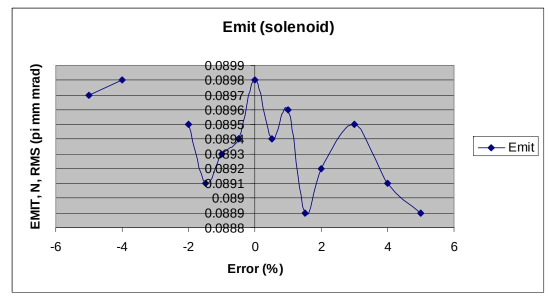
Emittance vs. Adapter Voltage Error



Emittance vs. Grid Lens Voltage Error



Emittance vs. Solenoid Field Error



Error Studies (RFQ)

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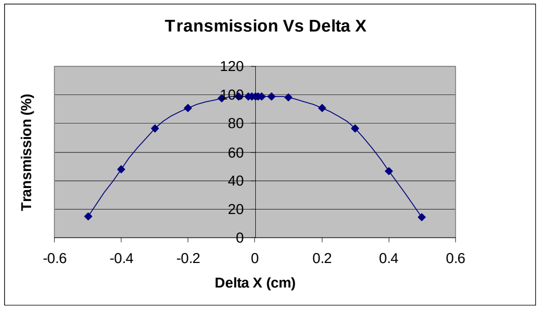
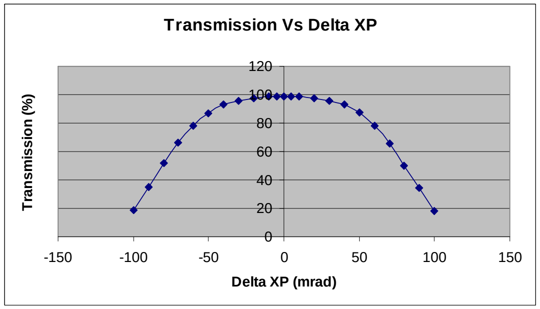
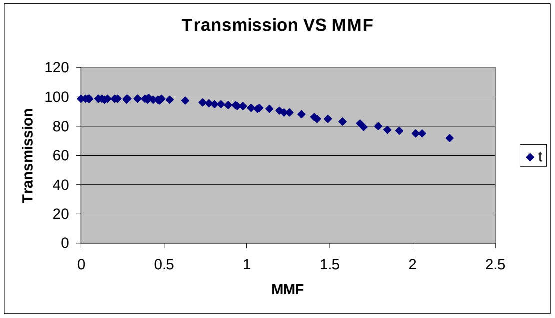
Transmission vs. Δx



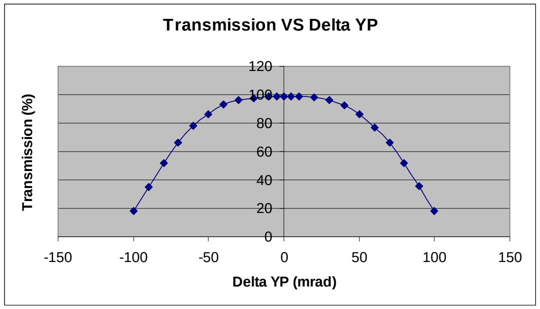
Transmission vs. Δx'



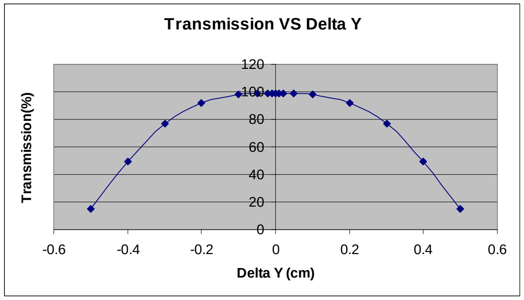
Transmission vs. MMF



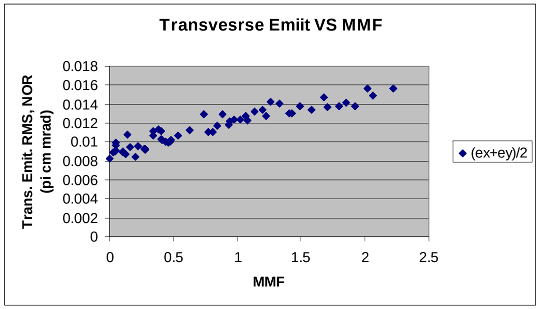
Transmission vs. Δy'



Transmission vs. Δy

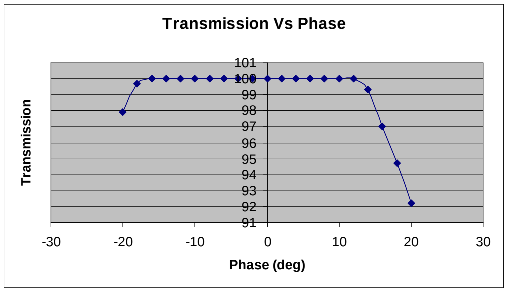


Transmission Emittance vs. MMF

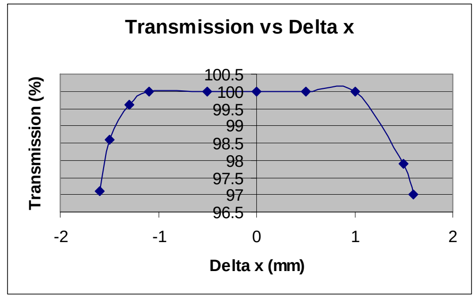


Error Studies (Linac)

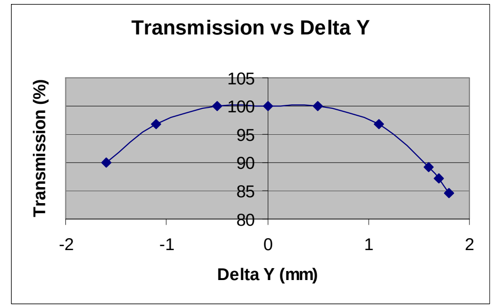
Transmission vs. Input φ



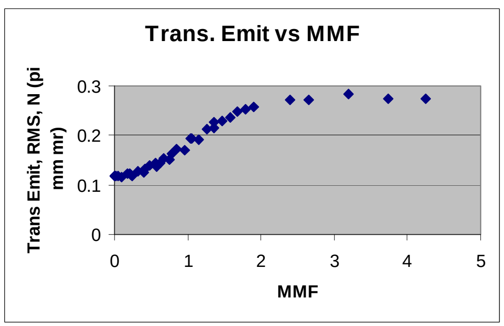
Transmission vs. Δx



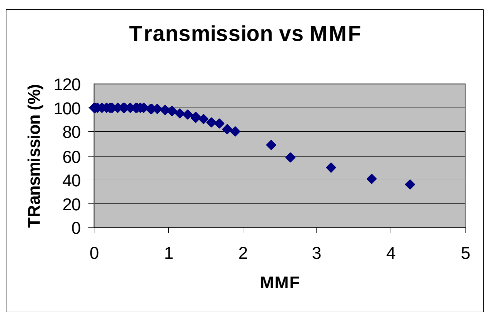
Transmission vs. ΔY



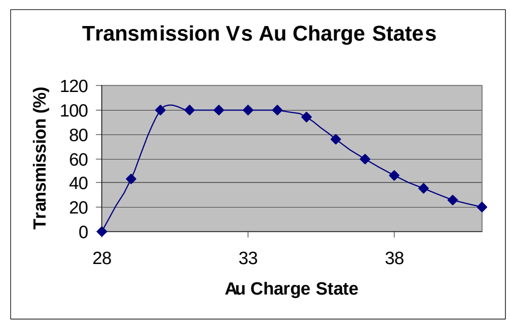
Transmission Emittance vs. MMF



Transmission vs. MMF



Transmission vs. Au Charge States



End-to-End Simulations

ELECTRON BEAM ION SOURCE

- Computer Codes used

  LEBT -TRAK

  RFQ -PARMTEQ

  MEBT -PARMILA

  IH -LORAS

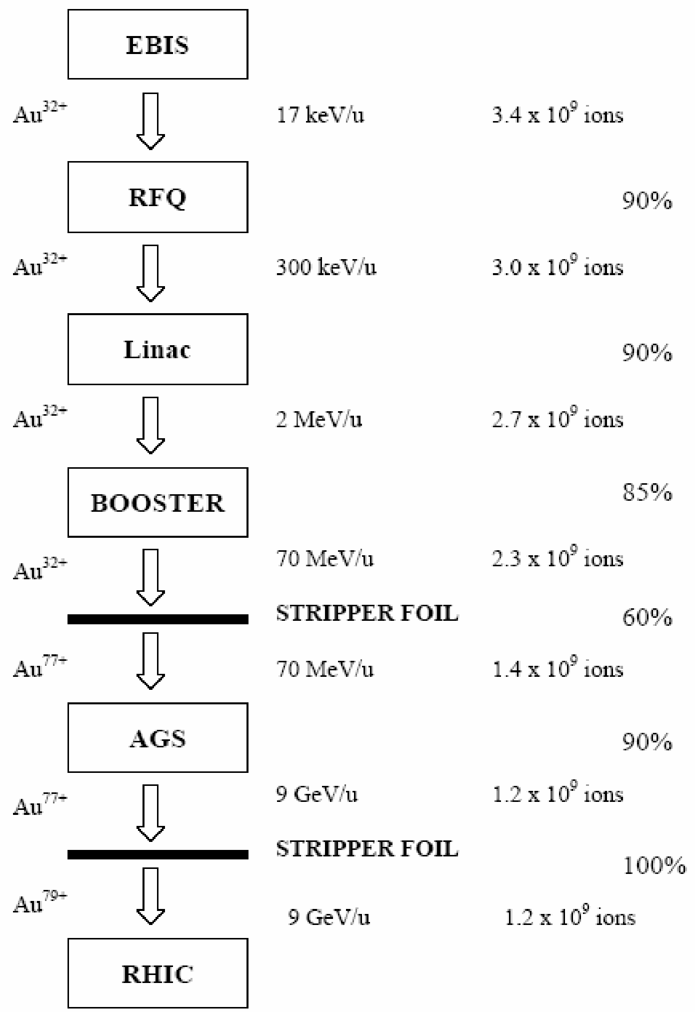
  HEBT -PARMILA

- Following ion species were simulated

  Au^{+32}, 8 mA

  $He^{+2,}$ 3 mA

Ion/Pulse and Efficiencies for Au^{+32}



End-to-End Simulations (LEBT, Au^{+32})

Pikin

ELECTRON BEAM ION SOURCE

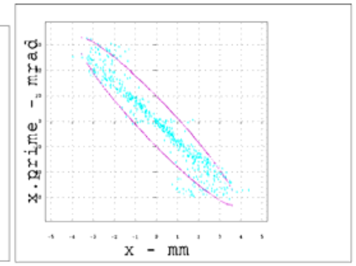
2-D simulation with TRAK

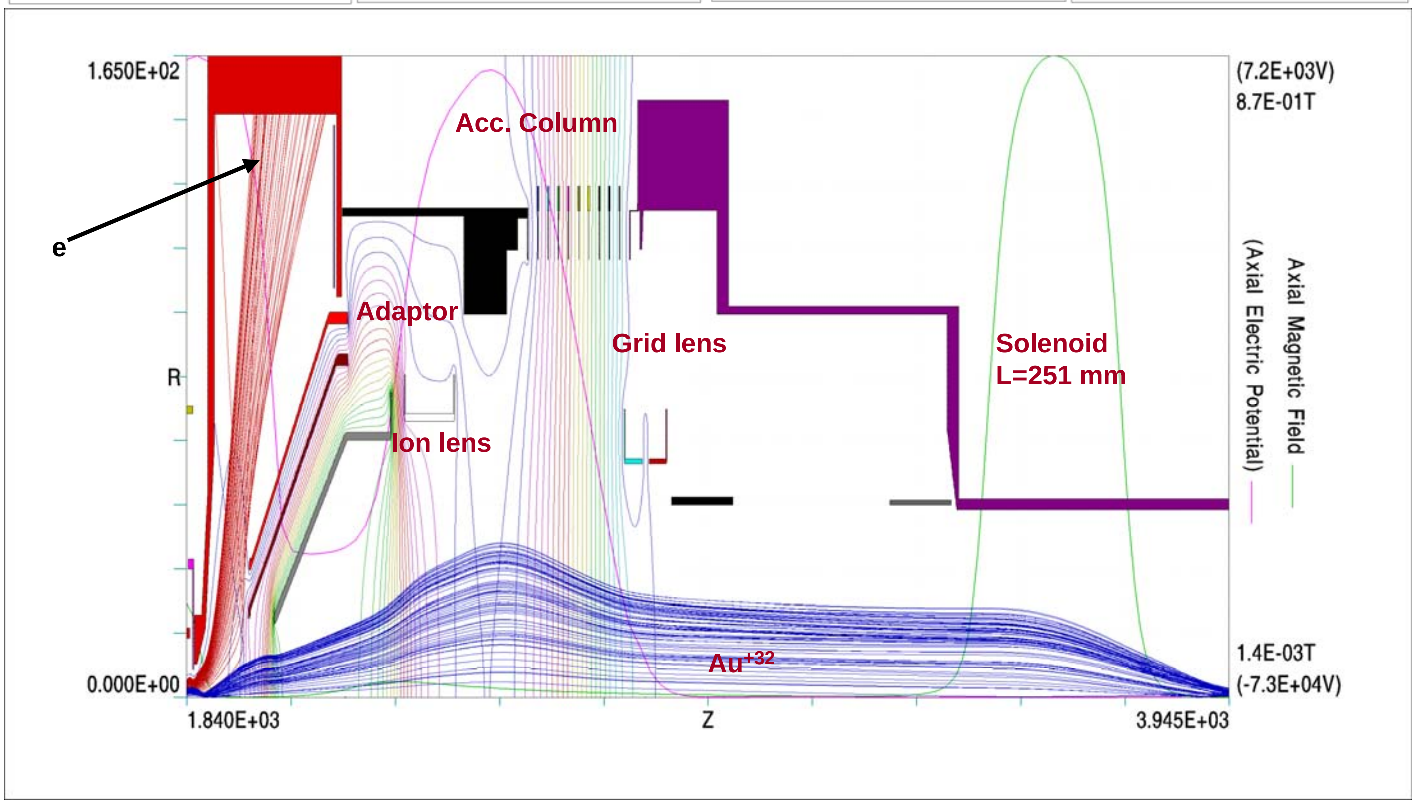
This Plot Created On: March 24, 2006

EOU File: FE55_0_67_500.EOU
BOU File: FBLEBT_6.BOU
TOU File: 55_0_67_1_78E5_2A.TOU

Optics parameters:
U_ion lens = -65 kV
U_adaptor = -10 kV
U_grid = +5.5 kV
IN_magnet lens = 1.78E+5 AmpxTurns

Beam parameters:
I_el = 10.0 A
I_ion =8.0 mA
E_RMS_norm_init = 0.068 pi.mm.mrad
E_RMS_norm_final = 0.0803 pi.mm.mrad
Alfa_final = 1.01
Beta_final = 0.068
X_final = 2 mm
X'_final = 40 mrad





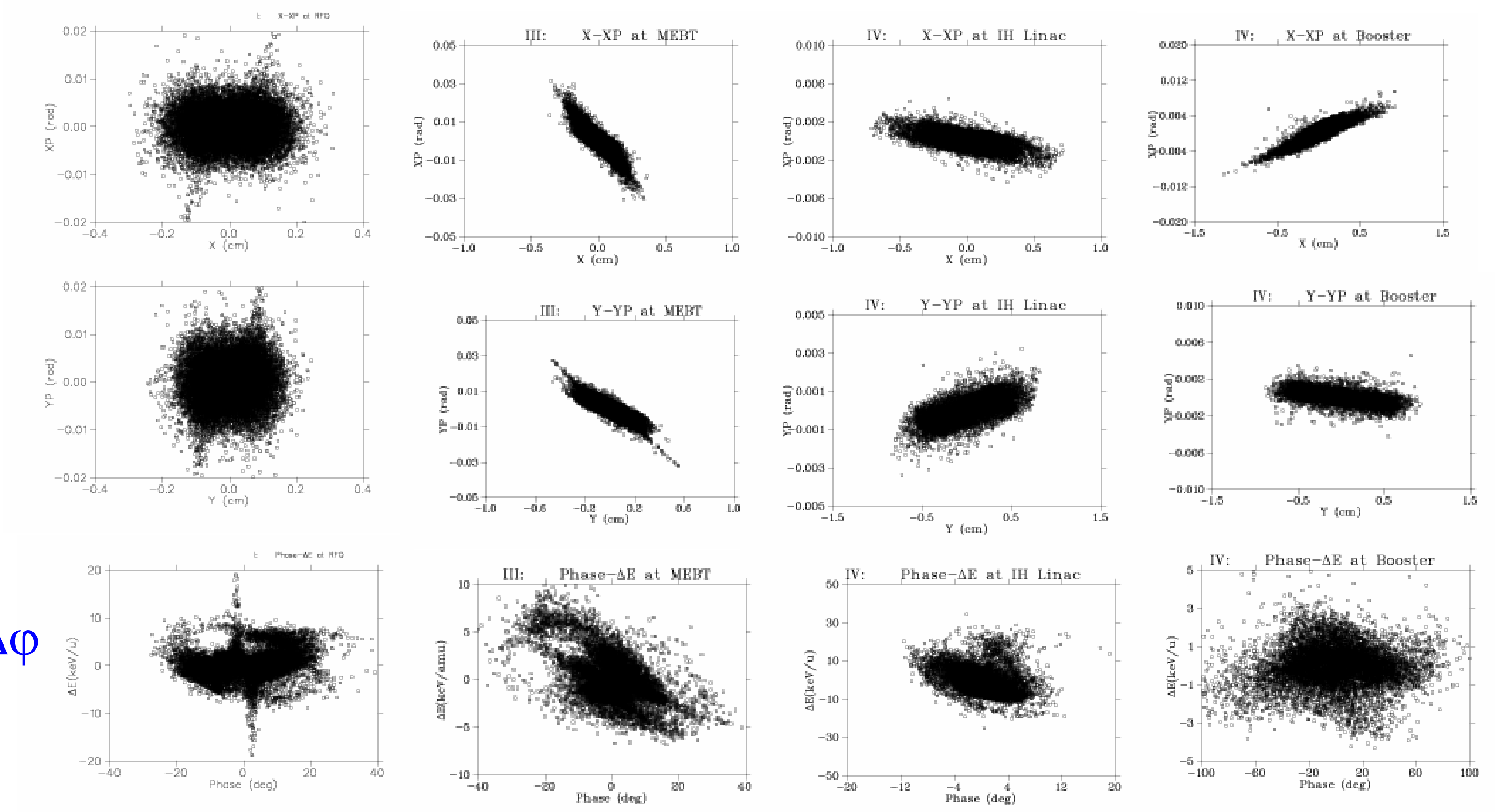
End-to-end Simulations

RFQ MEBT IH HEBT

X-XP

Y-YP

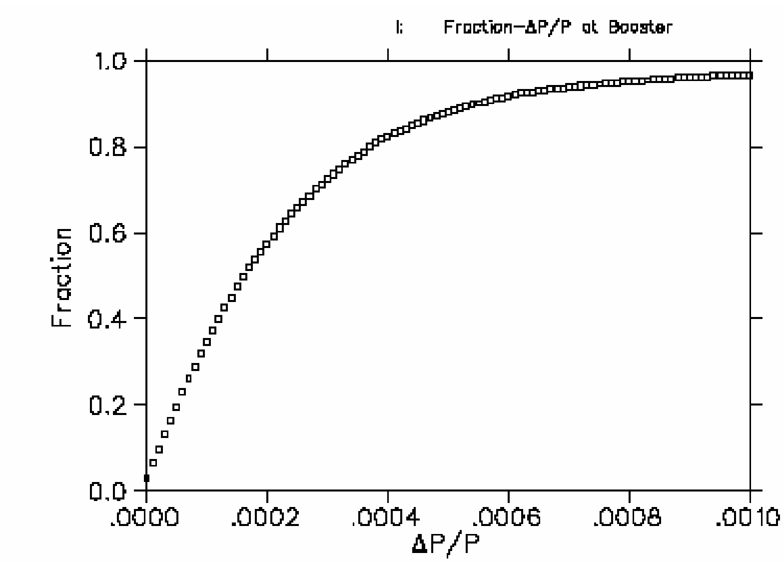
ΔW-Δφ



End-to-End Simulations

Transmission is defined with respect to the EBIS source

Fraction of the beam vs./P on the x-axis



Location	ε (N, RMS)	
LEBT	E_T(π mm mr)	0.085
RFQ	E_x (π mm mr)	0.086
	E_y (π mm mr)	0.092
	E_z(π ns-keV/u)	0.0658
	Transmission	0.987
MEBT	E_x(π mm mr)	0.096
	E_y (π mm mr)	0.090
	E_z (π ns-keV/u)	1.425
	Transmission	0.982
IH-DTL	E_x (π mm mr)	0.097
	E_Y (π mm mr)	0.096
	E_Z (π ns-keV/u)	0.779
	Transmission	0.966
HEBT	E_x (π mm mr)	0.146
	E_y (π mm mr)	0.122
	T.(Δp/P=0.1%)	0.960
	T.(Δp/P=0.05%)	0.896

End-to-End Simulations with error tolerances

ELECTRON BEAM ION SOURCE

- Ion extractor ± 1%, Ion lens ± 0.5%, Adapter ± 1%, Gridded lens ± 0.2%, Platform ± 0.5%, Solenoid ± 0.2%
- Quad Alignment ± 0.1 mm (MEBT, IH-DTL, HEBT)
- Quad Strength ±0.1% (MEBT, IH-DTL, HEBT)
- Phase and Amplitude ±0.5 deg, ±0.5% (RFQ, IH-DTL, Bunchers)
- Dipole Field Uniformity ±0.1 % (x-y plane)
- Dipole Alignment ±0.1mm
- Harp 0.2 mm

End-to-End Simulations with Errors

- 20 random seeds were used
- All the errors were uniformly distributed
- Simulation started at EBIS with 1000 micro-particles (TRAK 2D)
- At RFQ r-r' converted to x-x' and y-y' with >10000 micro-particles
- Alignment errors were corrected with automated steering scheme

End-to-End Simulations with Errors

- Transmission with respect to the EBIS Source
- Transmission for HEBT defines as particles with $\Delta p/p < \pm 0.05\%$

Location	Transmission (%)	ε (RMS, N) π mm mrad	ε (RMS, N) π mm mrad	ε (RMS) π ns-keV/u	MMF (x/y)
LEBT Average (STD)	100 (0.00)	0.0927 (0.001)	0.0897 (0.003)	0.1390 (0.002)	0.05/0.25 (0.04/0.02)
RFQ Average (STD)	97.6 (0.75)	0.1223 (0.020)	0.1160 (0.009)	0.8500 (0.010)	0.04/0.06 (0.03/0.03)
MEBT Average (STD)	96.7 (0.79)	0.1159 (0.004)	0.1102 (0.006)	0.8043 (0.079)	0.55/0.46 (0.12/0.12)
IH-DTL Average (STD)	92.6 (1.19)	0.1286 (0.008)	0.1380 (0.012)	1.4513 (0.328)	0.38/0.57 (0.09/0.12)
HEBT Average (STD)	86.4 (1.22)	0.1670 (0.008)	0.1480 (0.011)	0.8078 (0.054)	0.03/0.08 (0.04/0.18)

Ion/Pulse and Efficiencies for Au^{+32}

ELECTRON BEAM ION SOURCE

Stage / Ion	Energy	Ions	Efficiency	Simulations (Au^{+32})
EBIS				
Au^{32+}	17 keV/u	3.4×10^9 ions		
RFQ			90%	97.6%
Au^{32+}	300 keV/u	3.0×10^9 ions		
Linac			90%	94.9%
Au^{32+}	2 MeV/u	2.7×10^9 ions		
BOOSTER			85%	93.3%¥, §
Au^{32+}	70 MeV/u	2.3×10^9 ions		
STRIPPER FOIL			60%	
Au^{77+}	70 MeV/u	1.4×10^9 ions		
AGS			90%	
Au^{77+}	9 GeV/u	1.2×10^9 ions		
STRIPPER FOIL			100%	
Au^{79+}	9 GeV/u	1.2×10^9 ions		
RHIC				

§ $\Delta P/P$ =0.05% **¥ Longitudinal only**

Summary

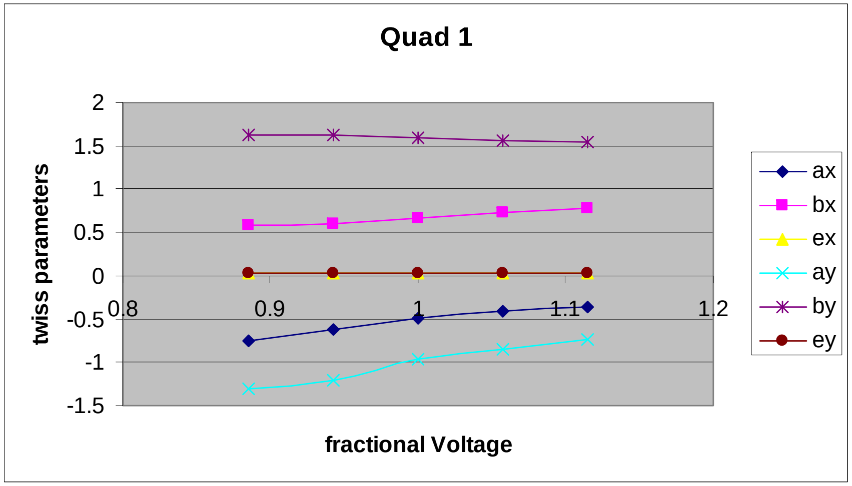
- External ion injection through LEBT works as expected.
- Physics design for RFQ is completed. The final design is improved over that presented last year.
- MEBT Physics design completed.
- Physics design for IH-DTL Linac is completed. The final design is improved over that presented last year.
- Error Simulations are essentially completed. Results show that the design is very forgiving.
- End-to-end simulations are essentially completed. Results show that we can meet all the requirements for Booster injection, with a good safety margin.
- Next step end-to-end simulations with multiple charge states

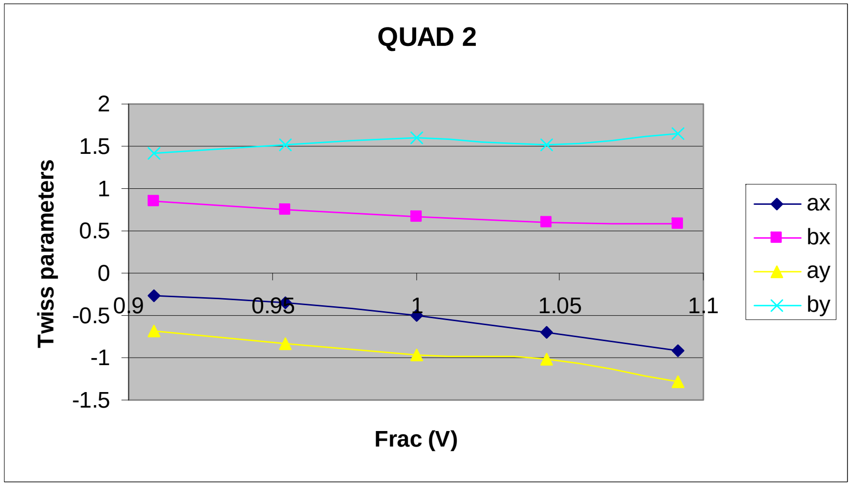
Backup Slides

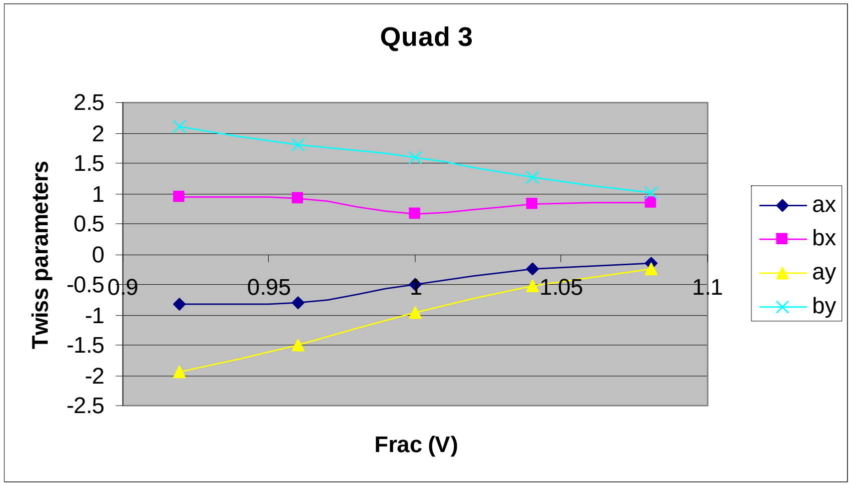
LEBT Experimental Studies

ELECTRON BEAM ION SOURCE

Experimental results for external LEBT
Voltage vs. Twiss parameters for different quads



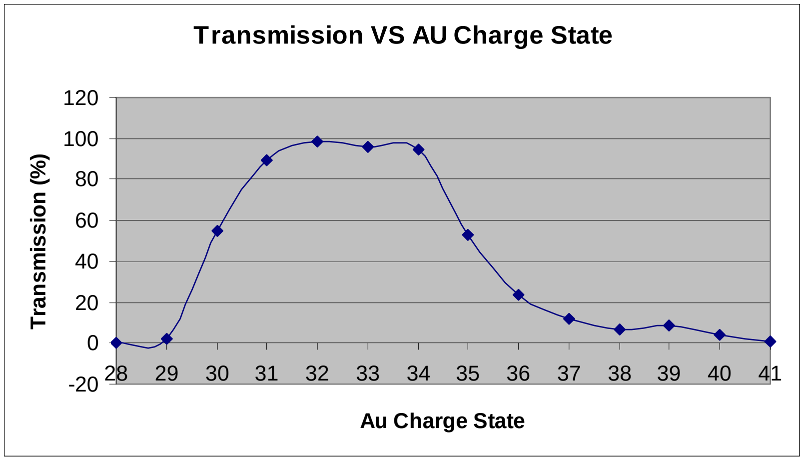




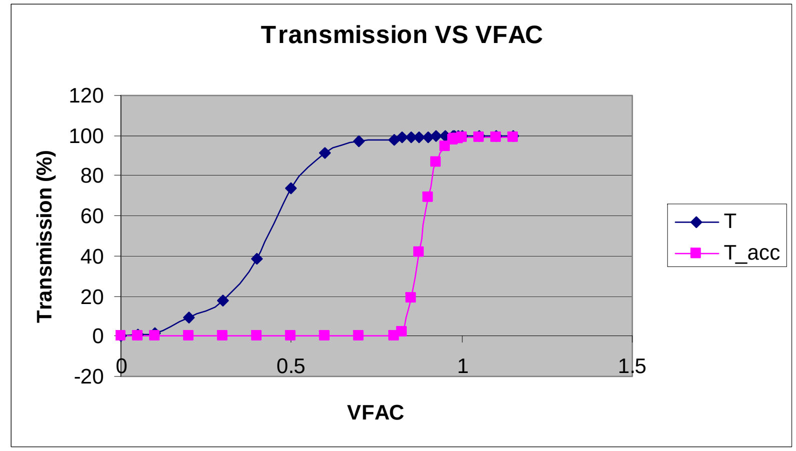
RFQ: Physics Design

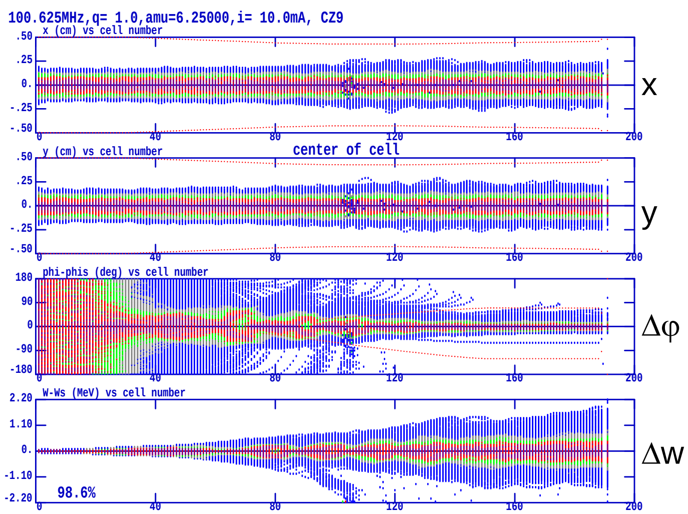
ELECTRON BEAM ION SOURCE

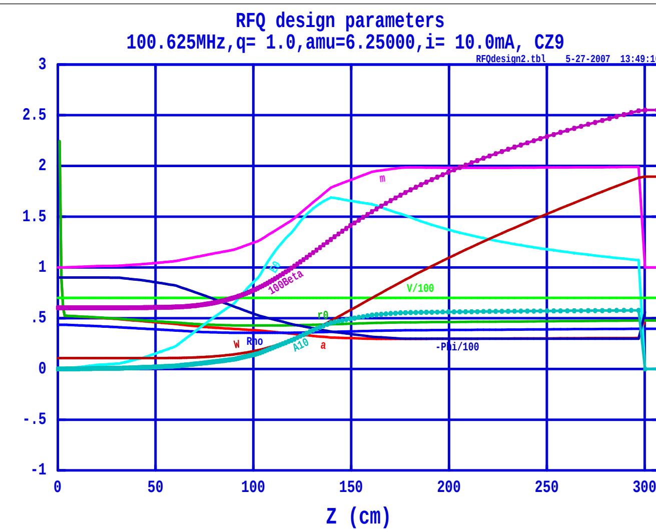
Transmission vs. Au Charge States



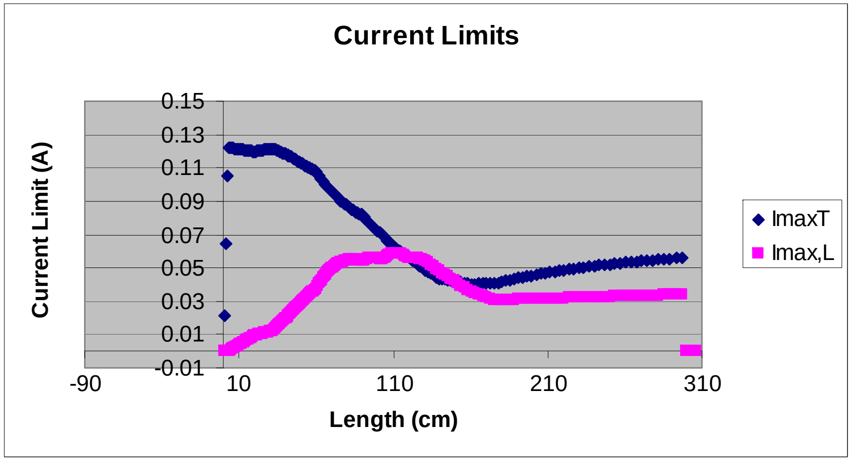
Transmission vs. Voltage

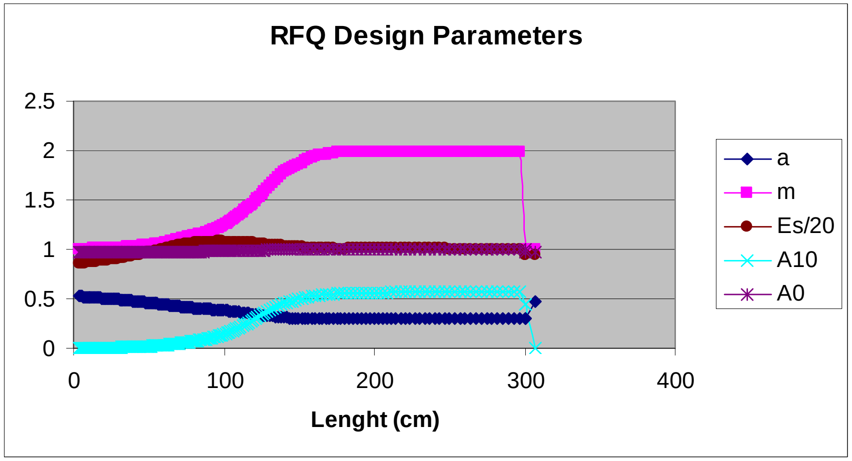


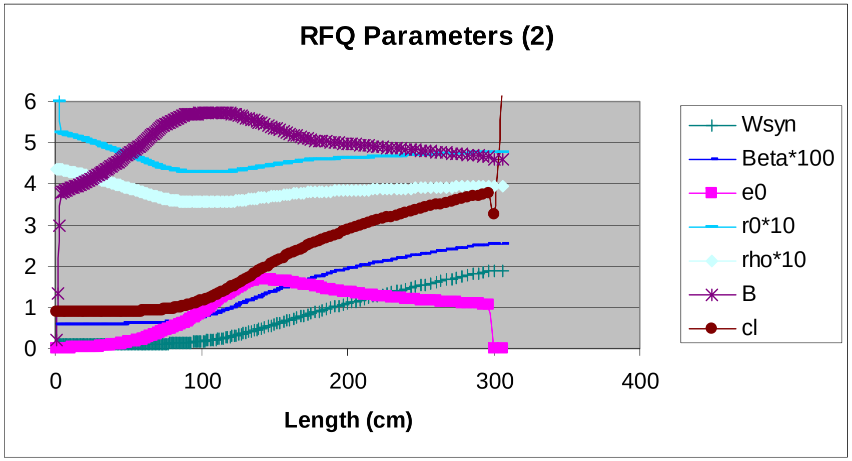




RFQ: Physics Design

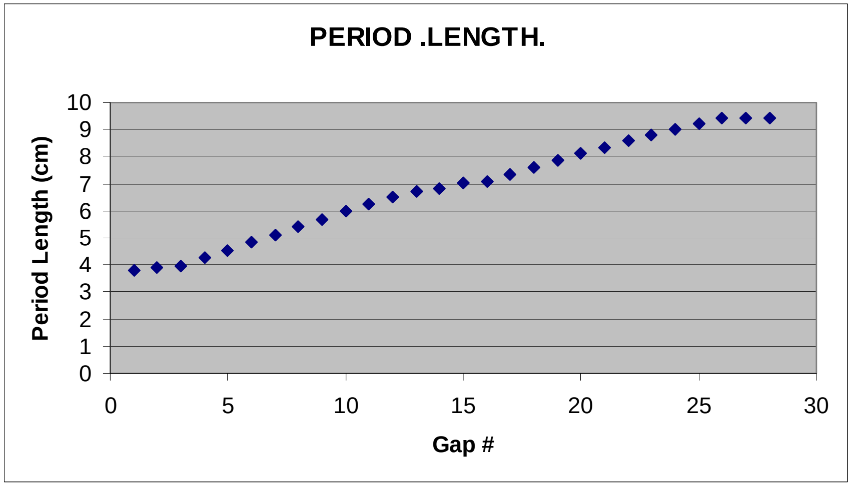


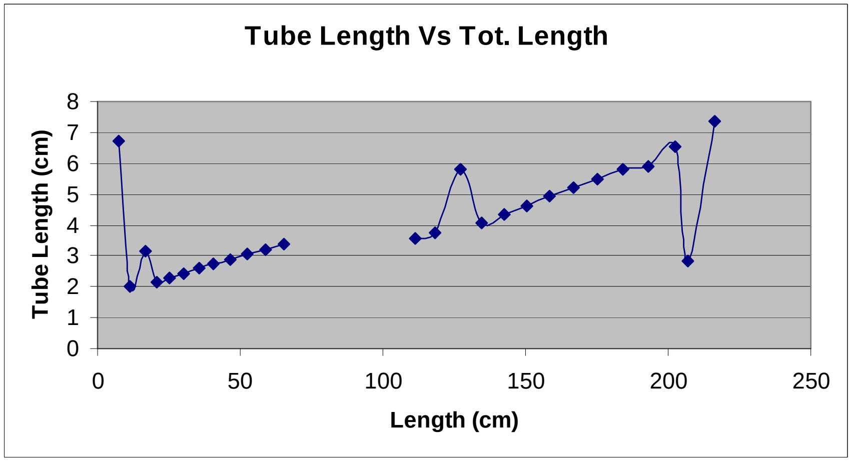


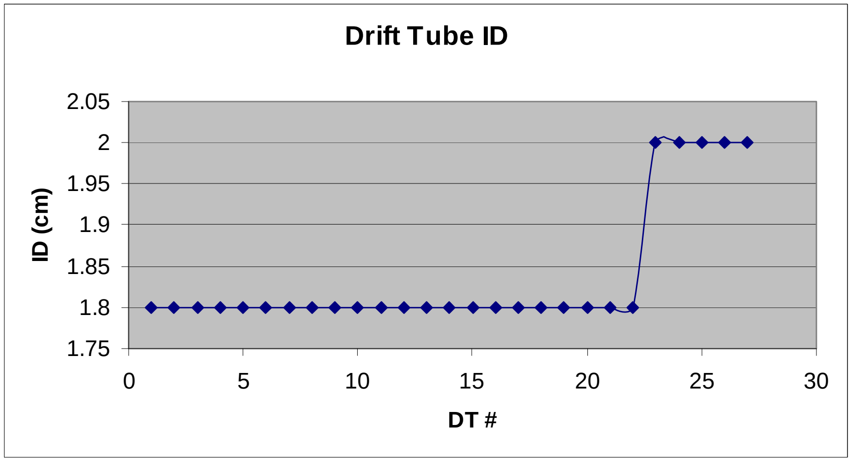


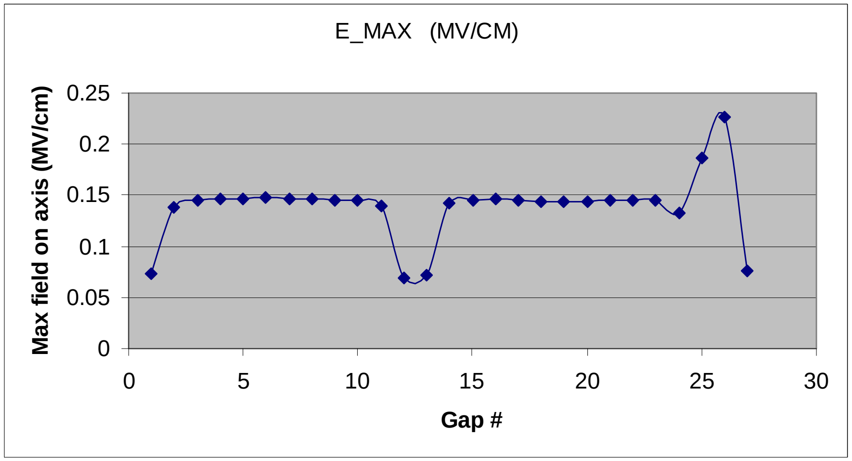
Linac: Physics Design

ELECTRON BEAM ION SOURCE





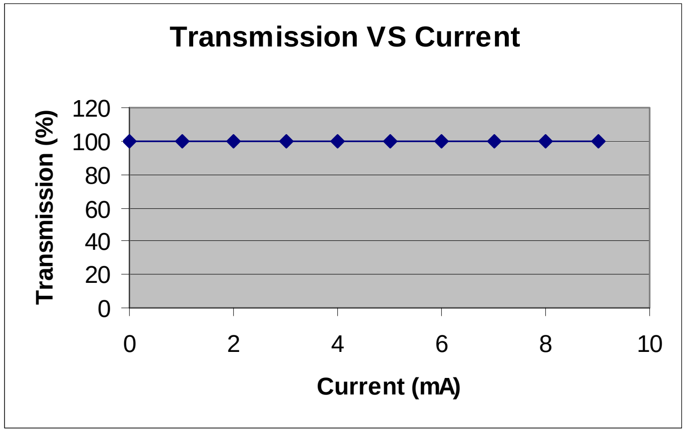




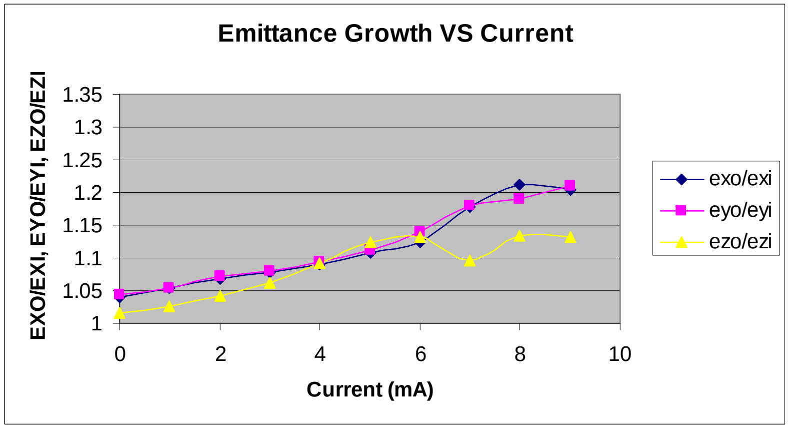
Linac Physics Design
He^{+2}

ELECTRON BEAM ION SOURCE

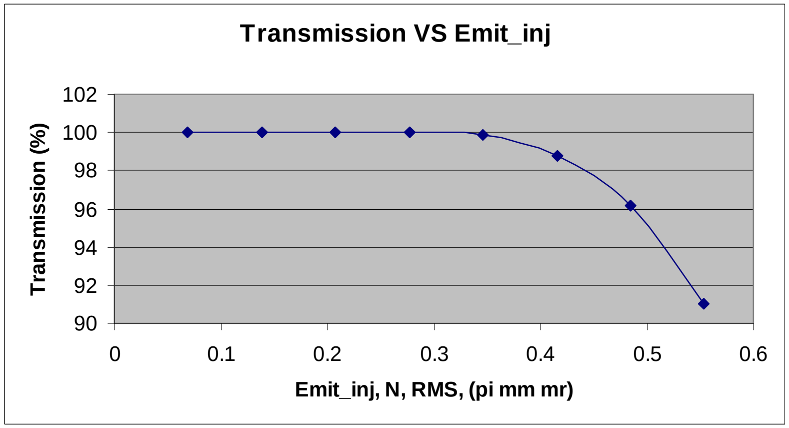
Transmission vs. Current



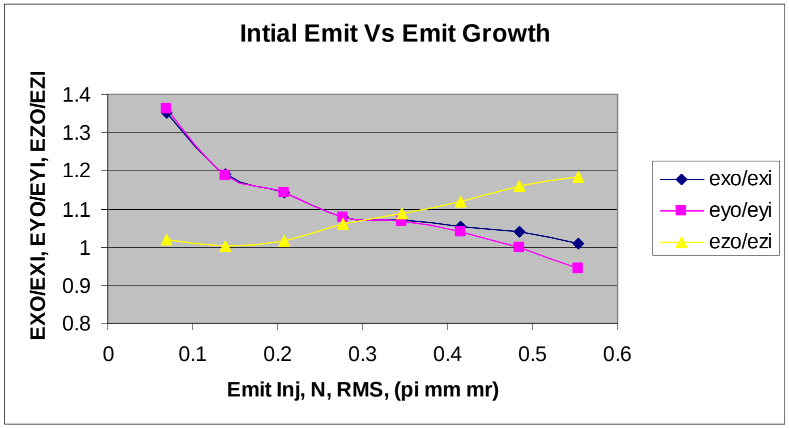
Emittance Growth vs. Current



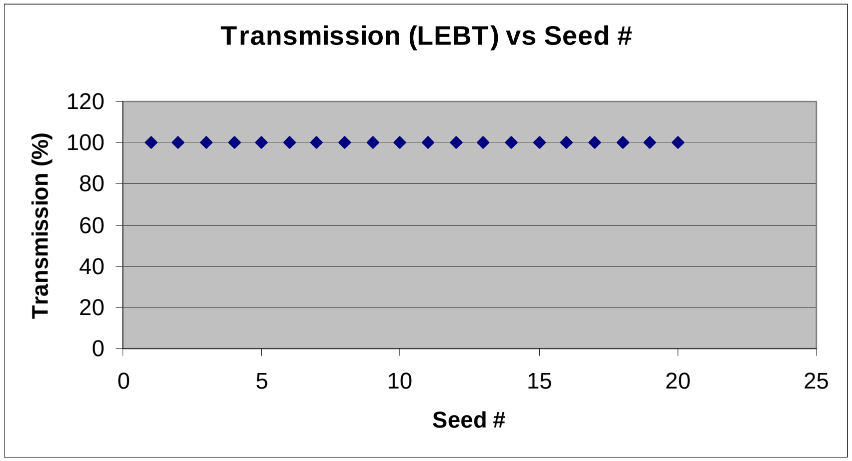
Transmission vs. Input Emittance

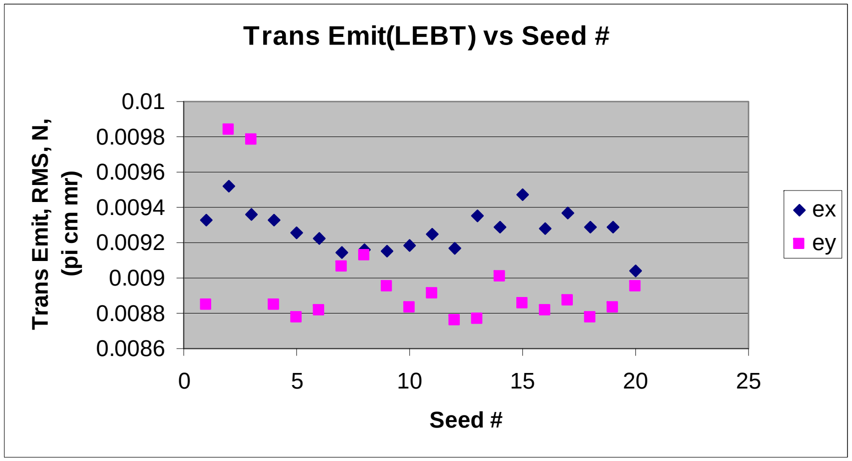


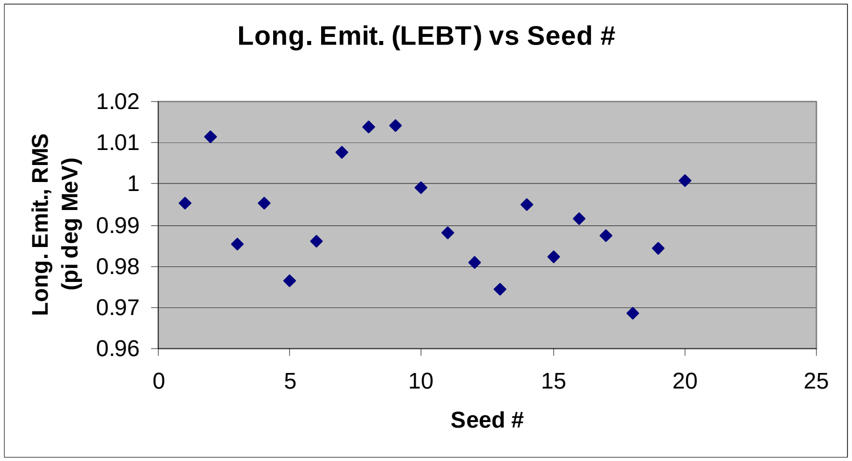
Growth vs. input Emittance



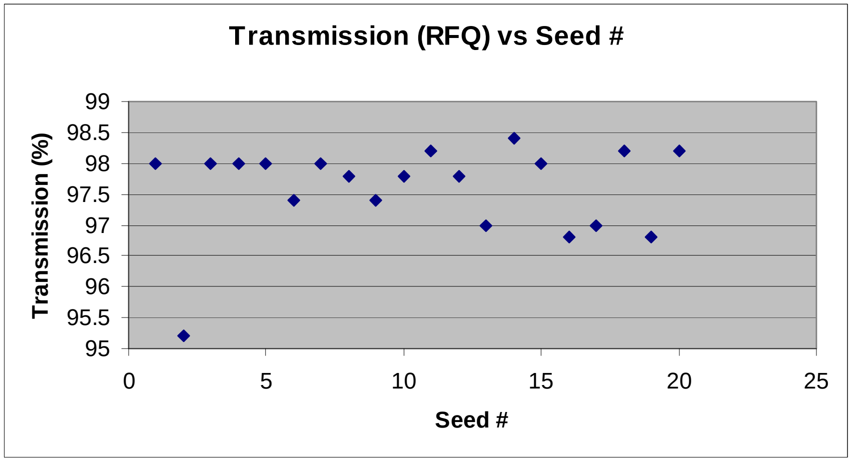
End-to-End Simulations (LEBT)

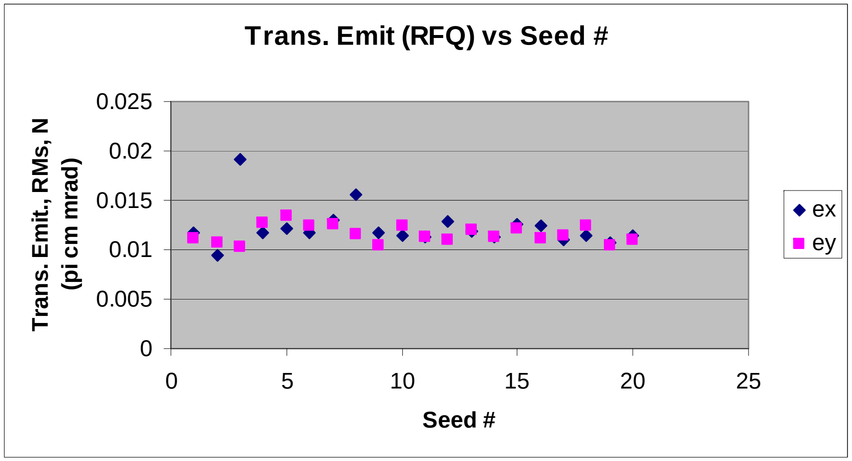


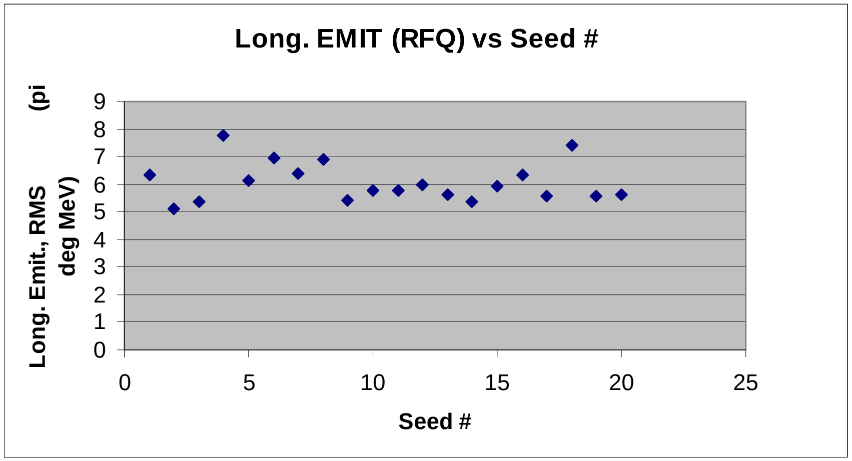




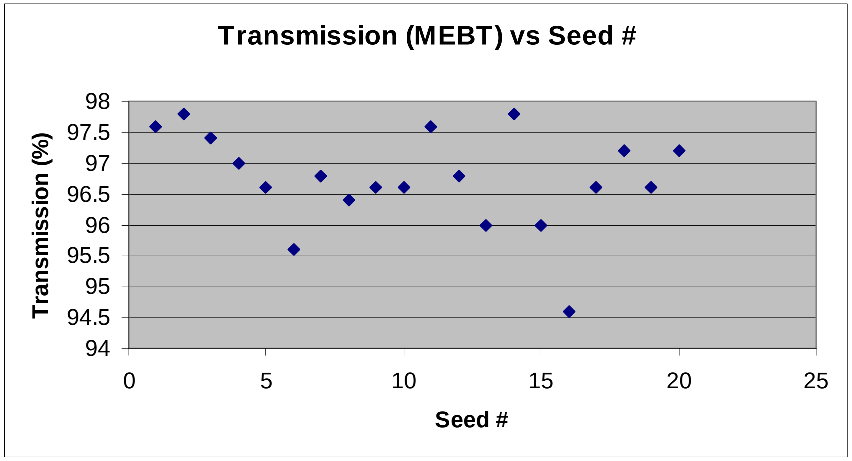
End-to-End Simulations (RFQ)

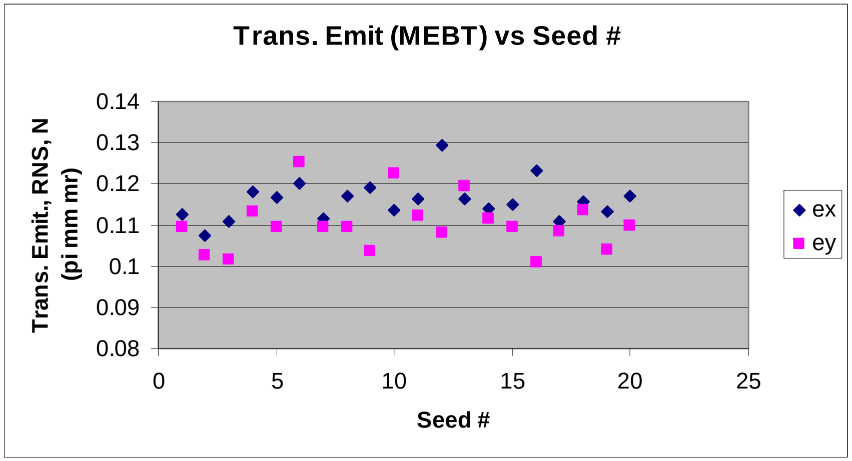


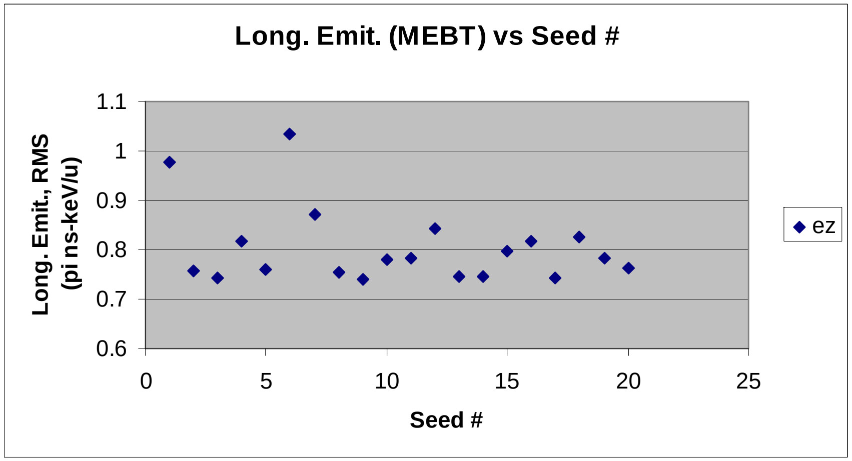




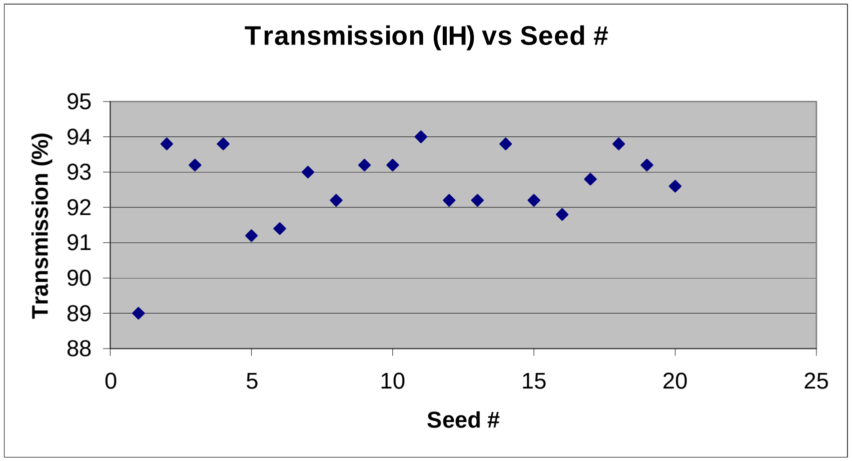
End-to-End Simulations (MEBT)

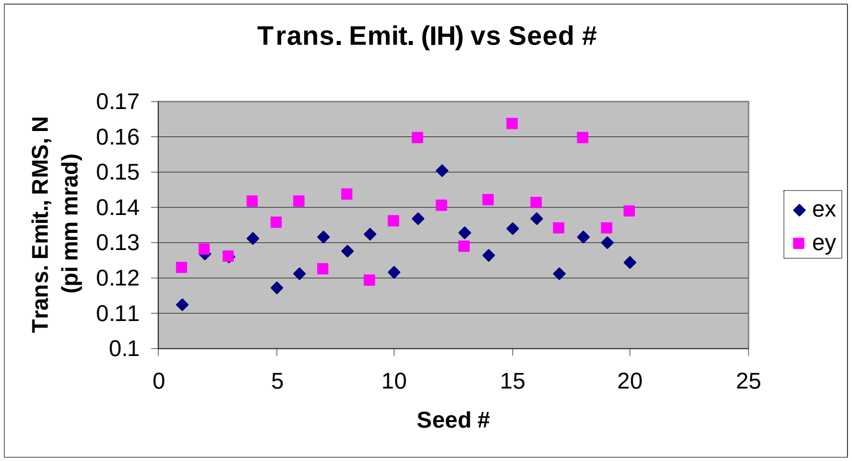


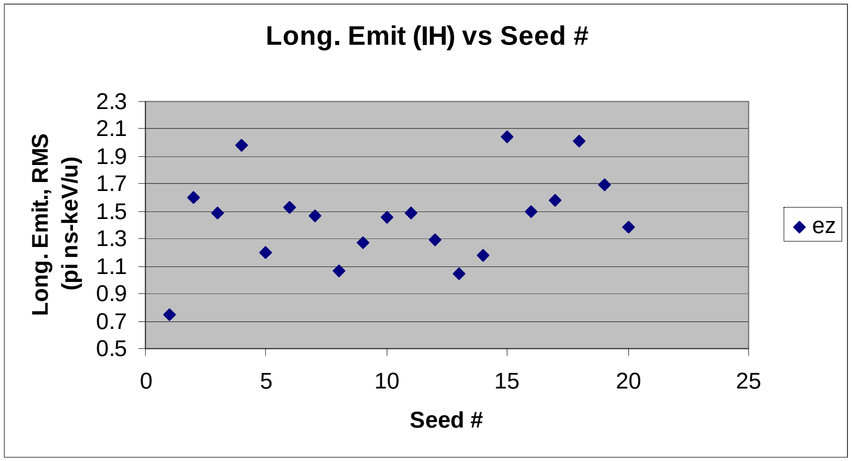




End-to-End Simulations (IH-DTL)







End-to-End Simulations (HEBT)