Acceleration and Transportation of Multiple Ion Species at EBIS-Based Preinjector

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Acknowledgements

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Outline of Talk

- Brookhaven Accelerator Complex
- Overview of the EBIS Pre-injector
- Electron Beam Ion Source (EBIS)
- Why Multiple Ion Species
- Acceleration and Transportation of multiple ion species
- Conclusions

Many (or all) of these can be running simultaneously!

avy ions for the Single-Event Upset Facil

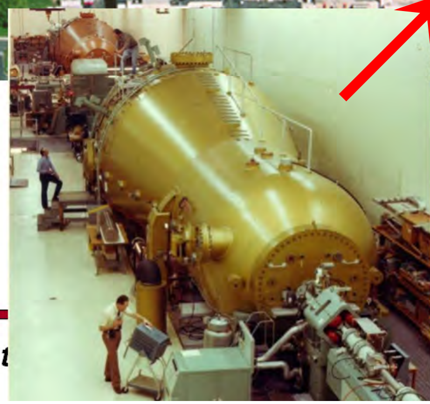
NSRL – biological effects of space radiation

EBIS

200 MeV Linac

BLIP – medical isotopes

SEU – Radiation effects on electronics



Two 14 MV Tandem Van de Graaffs

Motivation

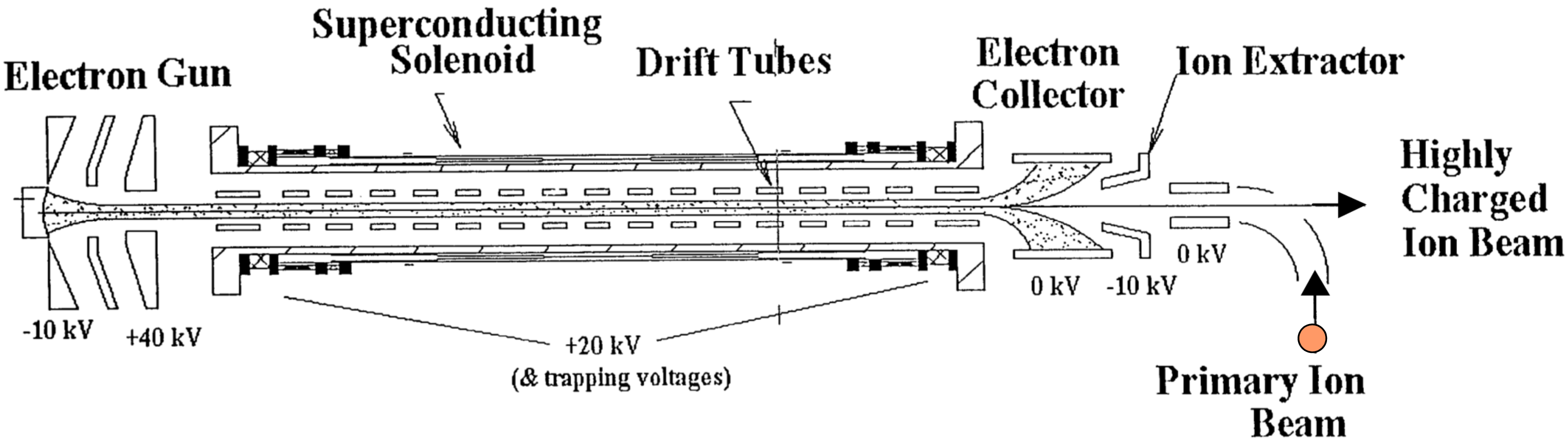
- Increased flexibility to handle the simultaneous needs of RHIC and NASA (fast switching between species ~ 1s)

- Capability to provide ions not presently available, such as noble gas ions (for NASA), uranium (RHIC).

- Simpler technology, robust, more modern

- Elimination of two stripping stages and an 860 m long transport line, leading to improved performance

Principle of EBIS

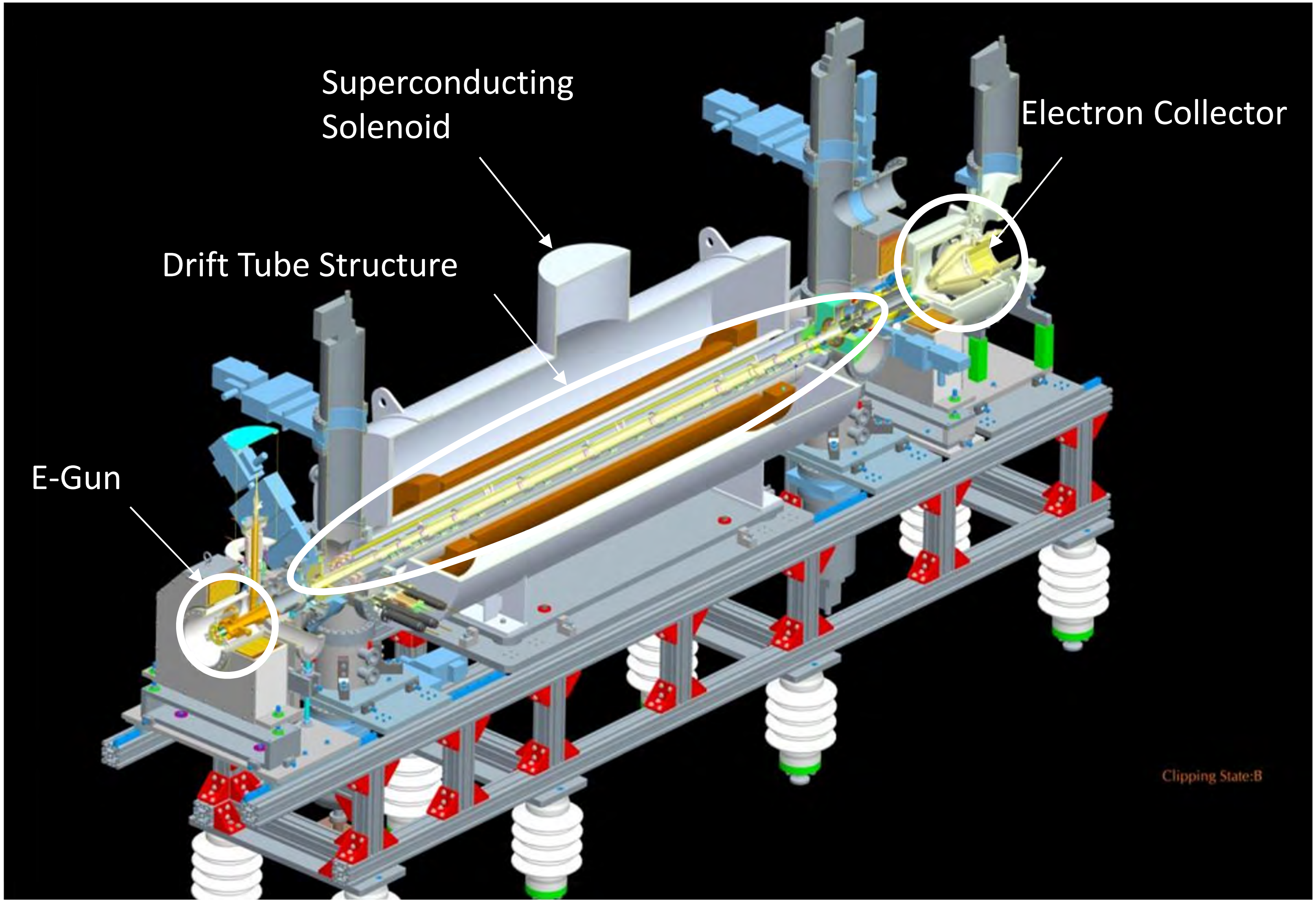


Radial trapping of ions by the space charge of the electron beam.
Axial trapping by applied electrostatic potentials at ends of trap.

- **The total charge of ions extracted per pulse is ~ (0.5 – 0.8) x (# electrons in the trap)**
- **Ion output per pulse is proportional to the trap length and electron current.**
- **Ion charge state increases with increasing confinement time.**
- **Output current pulse is ~ independent of species or charge state!**

Electron Beam Ion Source (EBIS)

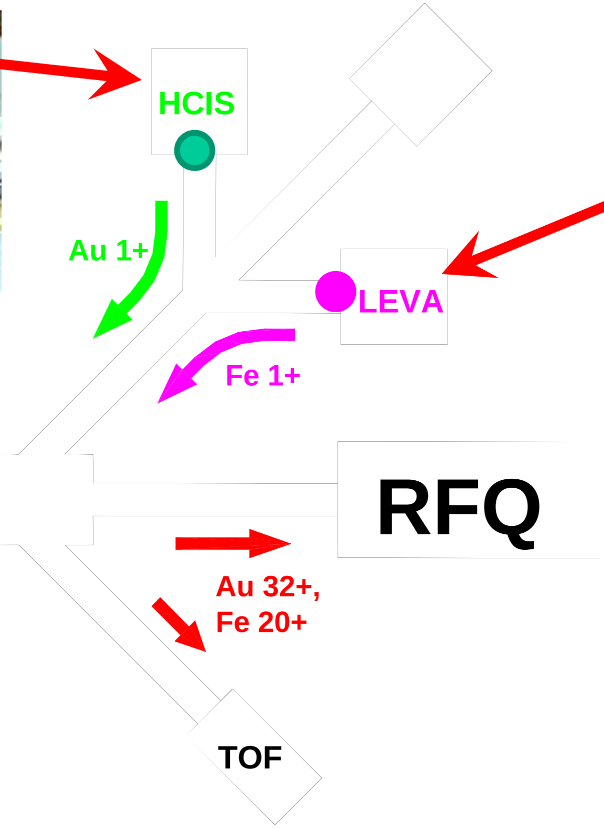
High charge state heavy ions produced by trapping and stepwise ionizing in an electron beam

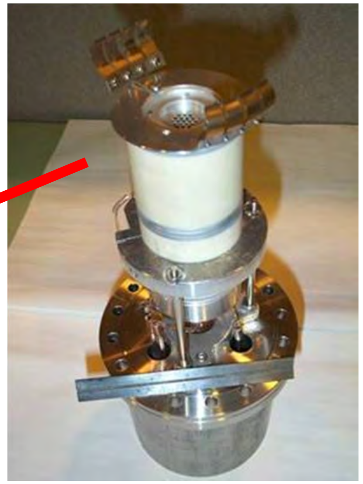


BNL: 10 A electron beam; 5T magnet; 1.5 m long trap region

Ion Injection and Extraction from the EBIS

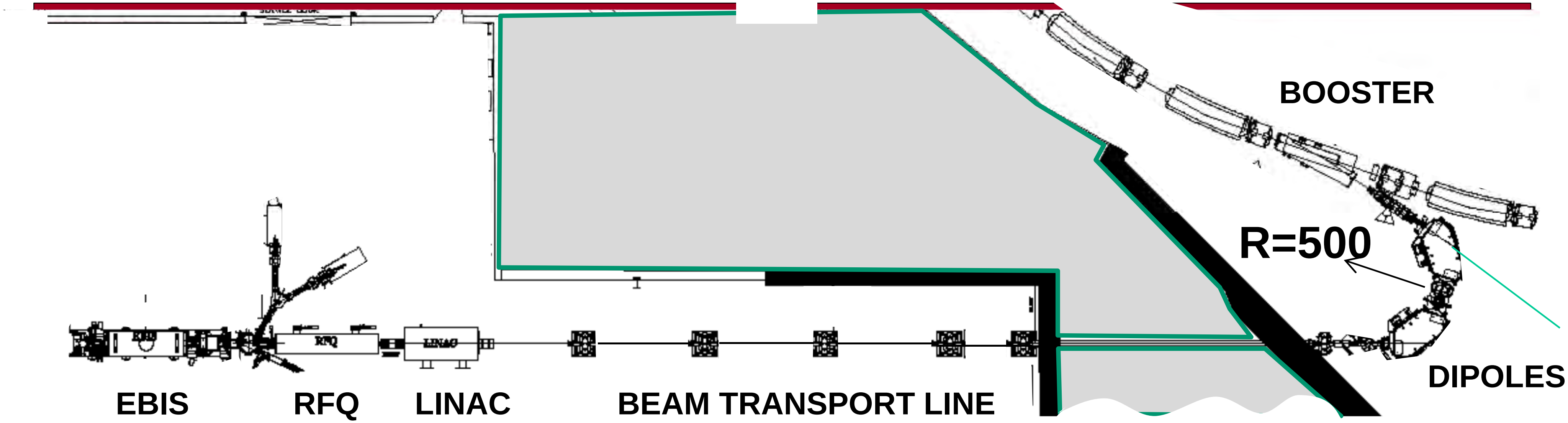
External ion injection provides most ion species.

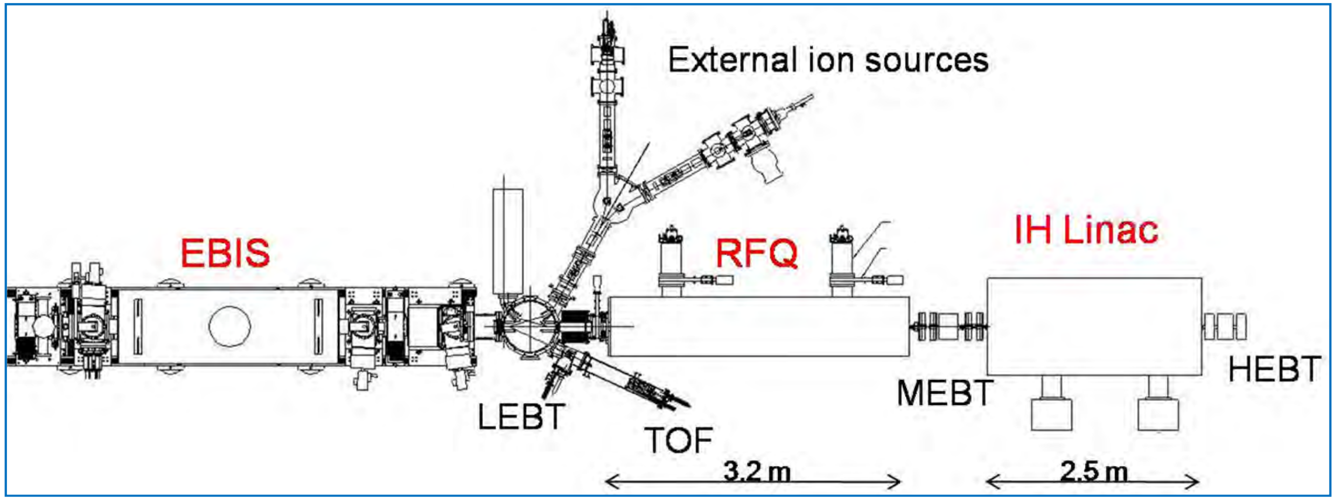




One can change species and charge state **<u>on a pulse to pulse basis</u>**

EBIS Preinjector in lower equipment bay of the 200 MeV Linac

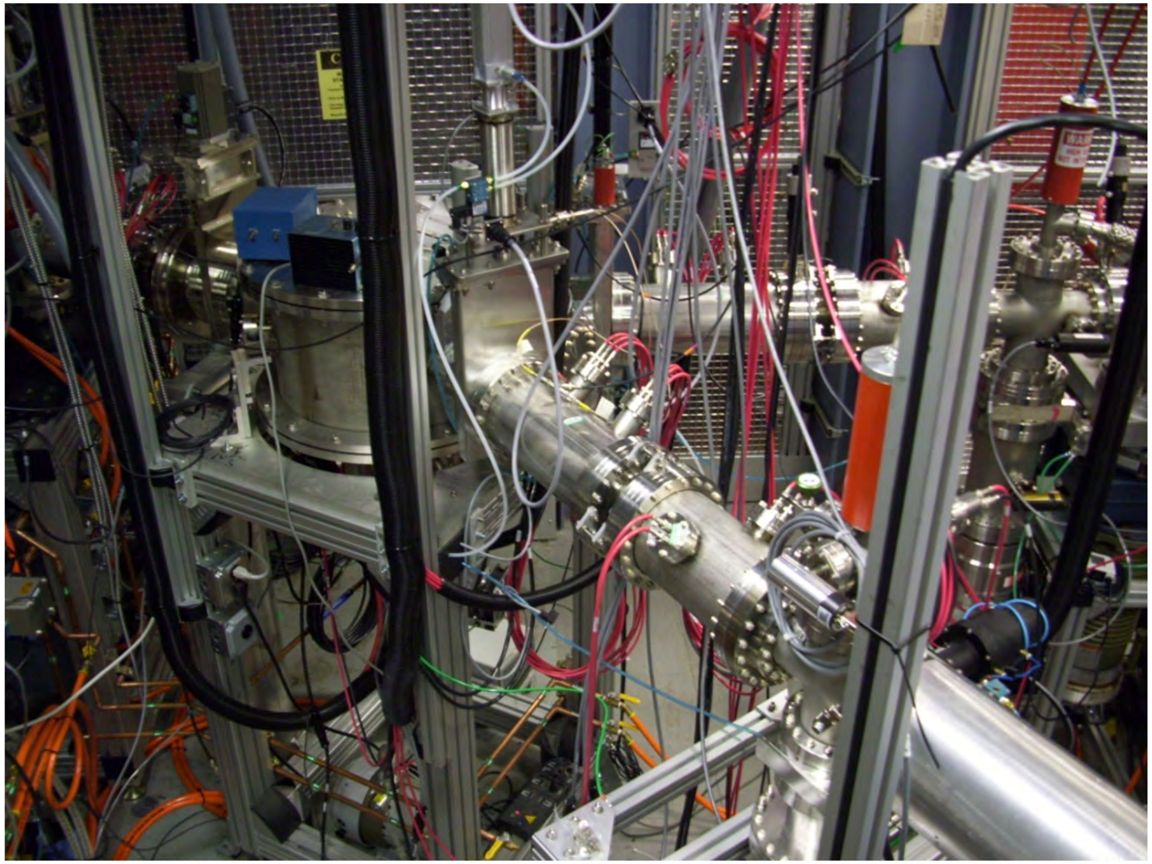




Ions	He - U
Q / m	≥1/6
Current	> 1.5 emA (10 μS)
Pulse length	10-40 μs
Rep rate	5 Hz
Output energy	2 MeV / u
ΔP/P	<0.05%
Time to switch species	1 second

1+ ion injection lines

ELECTRON BEAM ION SOURCE



Hollow Cathode Ion Source based on design used on Saclay EBIS.

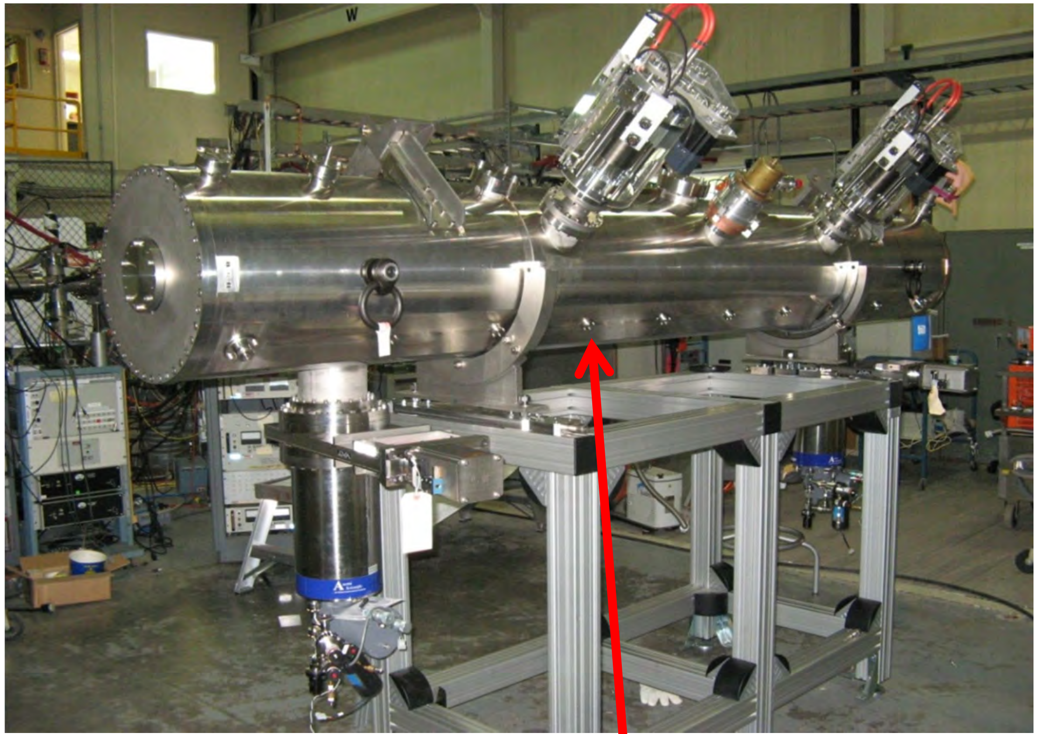
Low Energy Vacuum Arc Source (I. Brown);

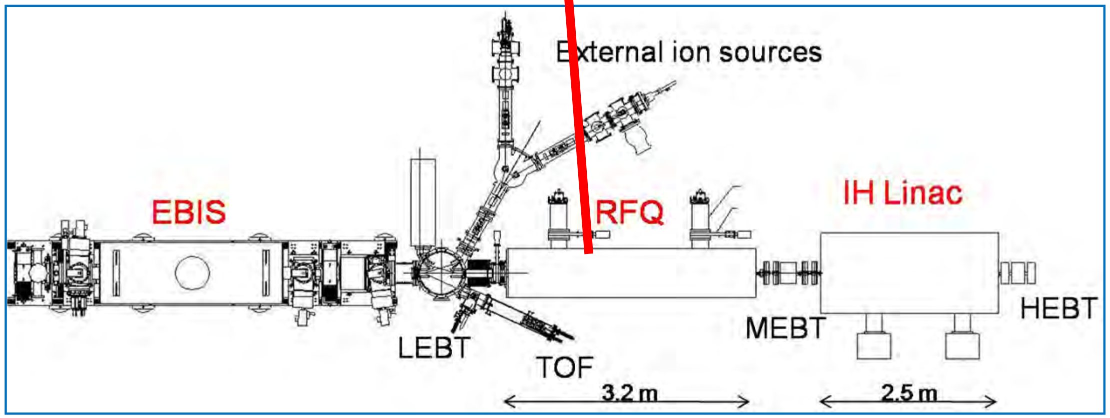
RFQ from IAP, Frankfurt (A. Schempp)

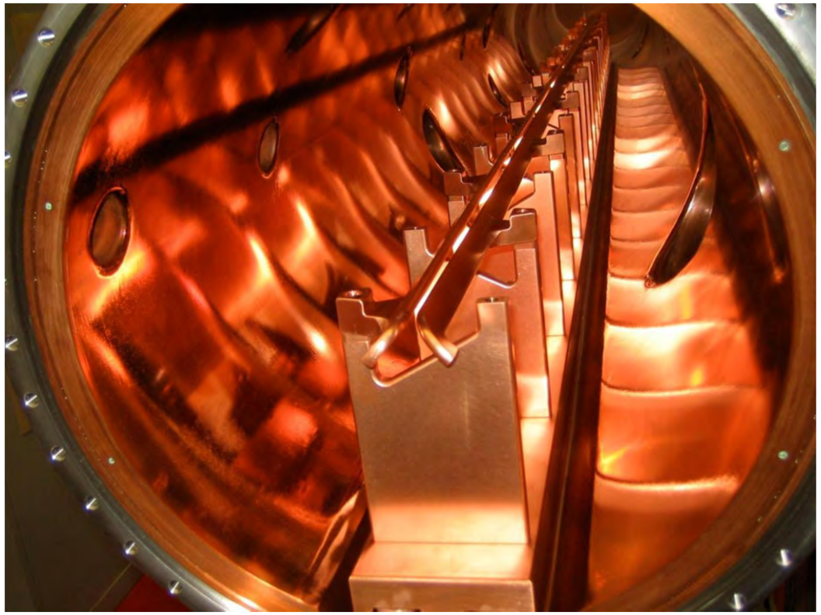
100 MHz

Accelerates the beam from 17 keV/u to 300 keV/u

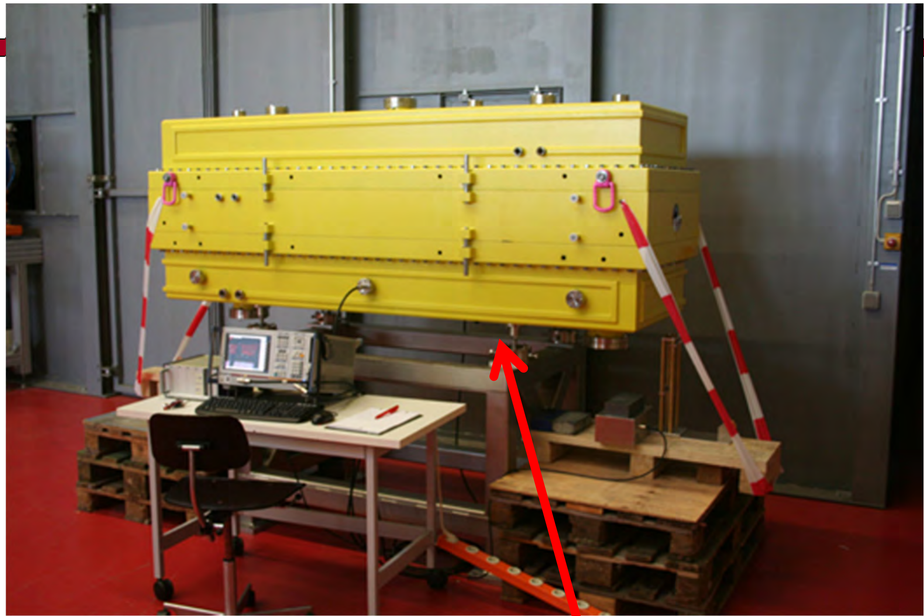
Fabricated by NTG



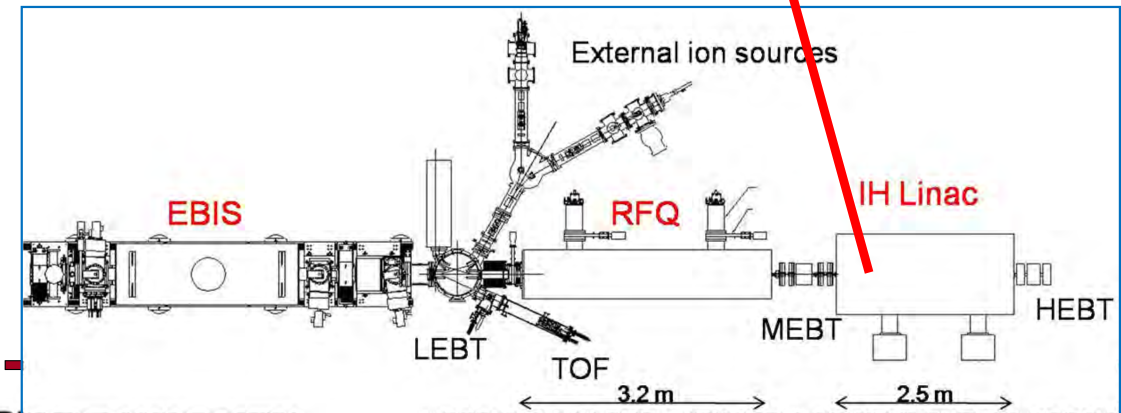




Linac from IAP, Frankfurt (U. Ratzinger)

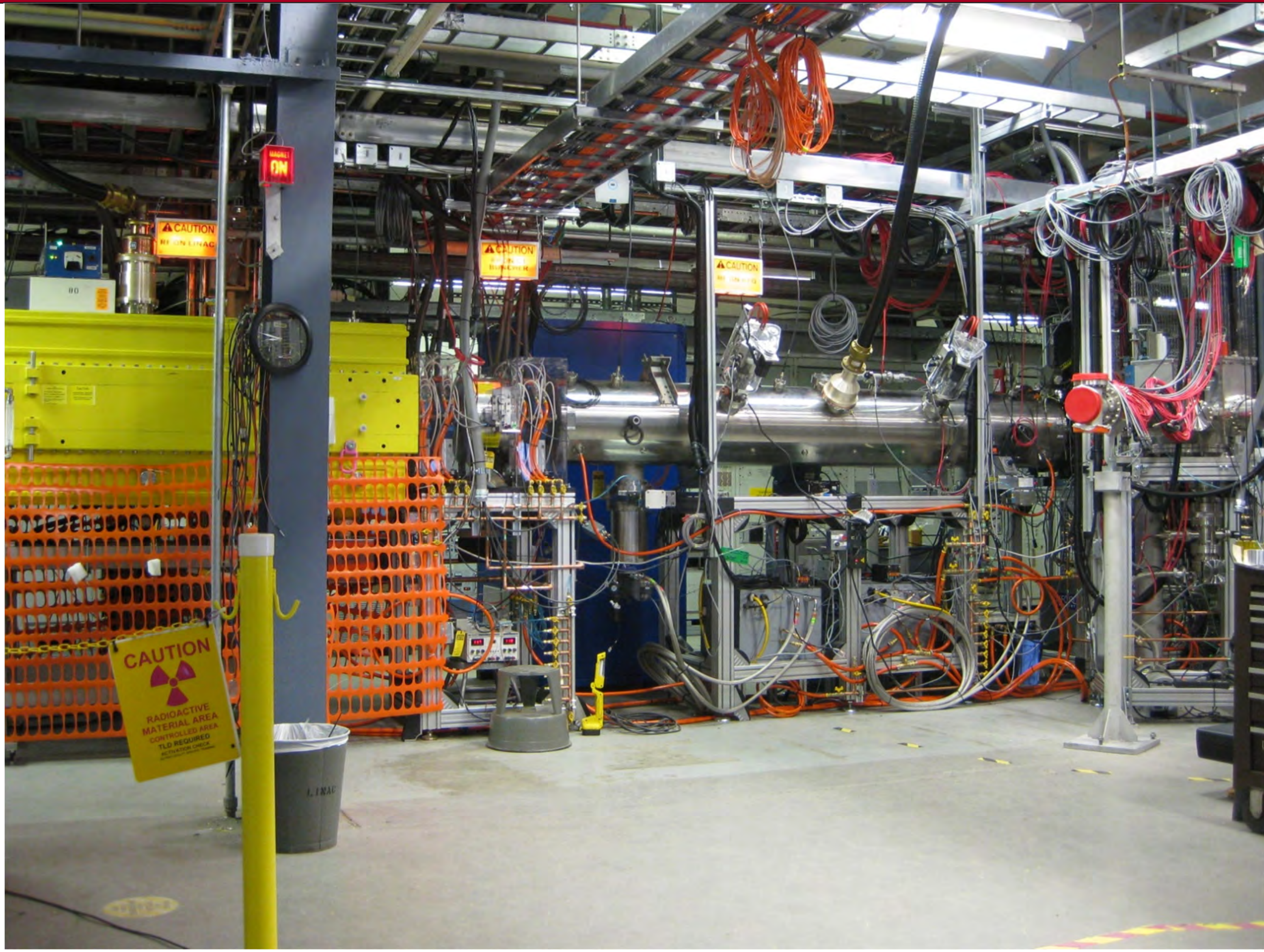


100 MHz
Accelerates the beam from 300 keV/u
to 2 MeV/u
Cavity Fabricated by PINK; Quad by Bruker



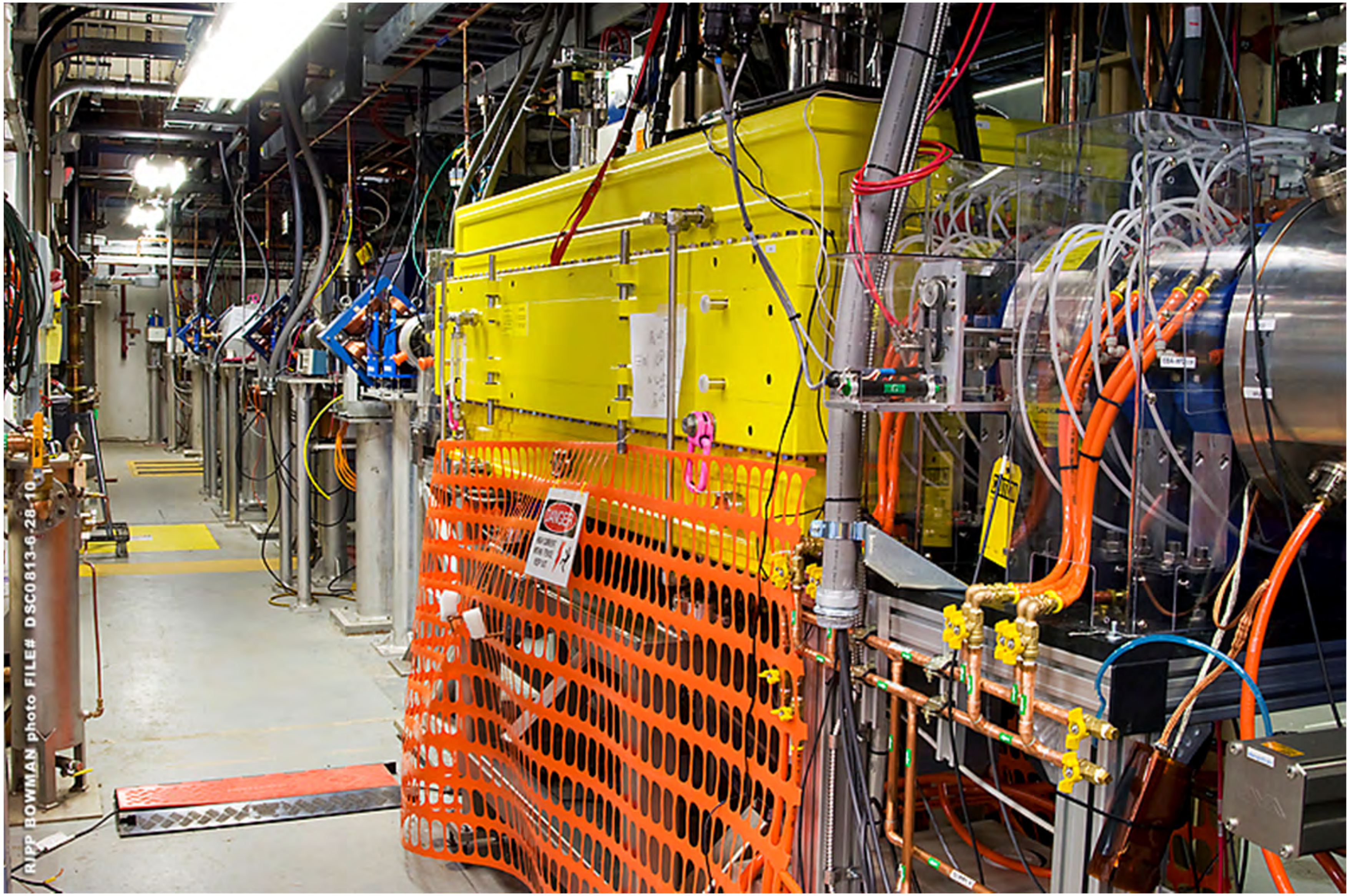
RFQ. MEBT, and Linac

ELECTRON BEAM ION SOURCE



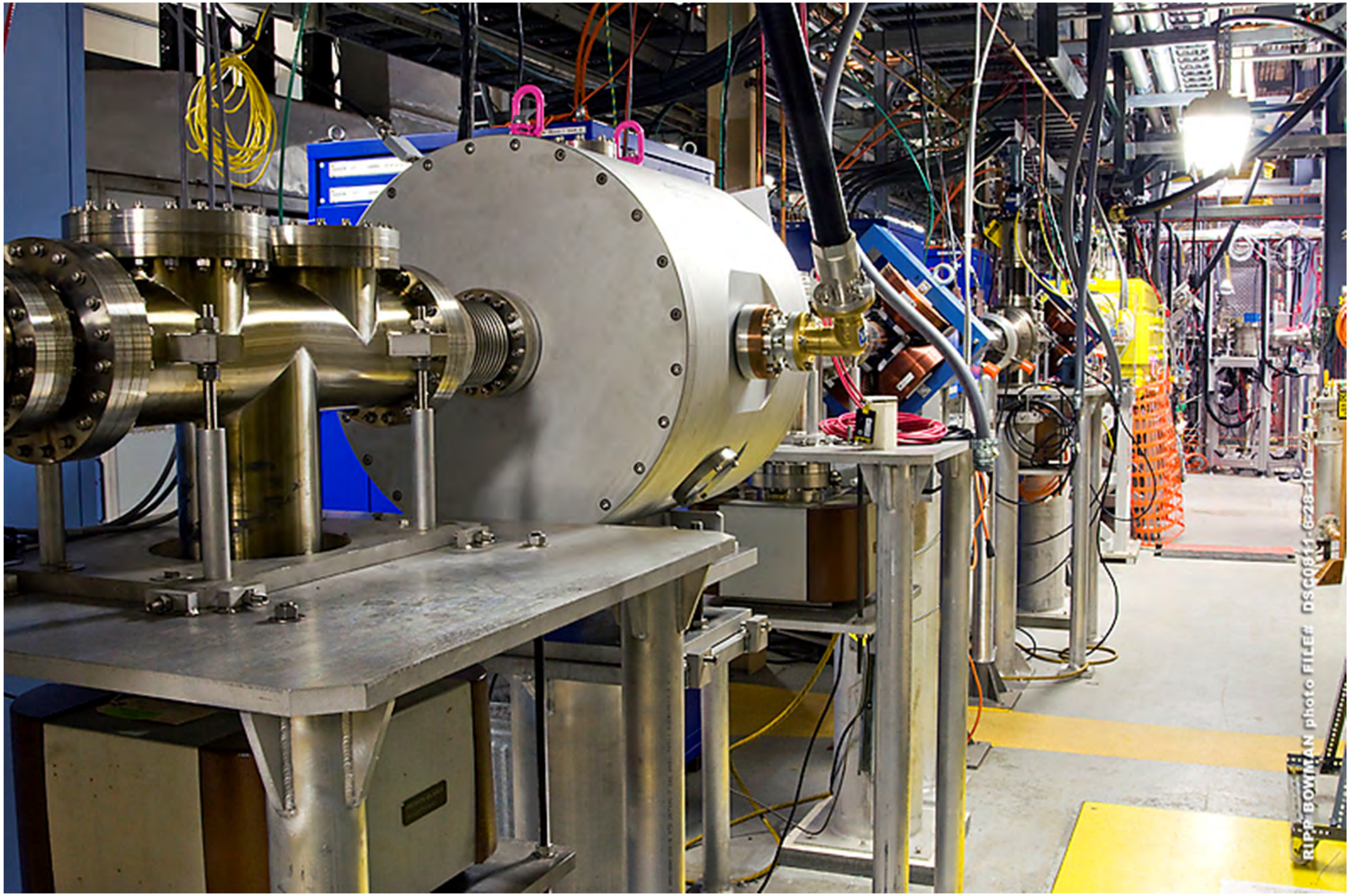
Linac and EBIS-to-Booster transport

ELECTRON BEAM ION SOURCE

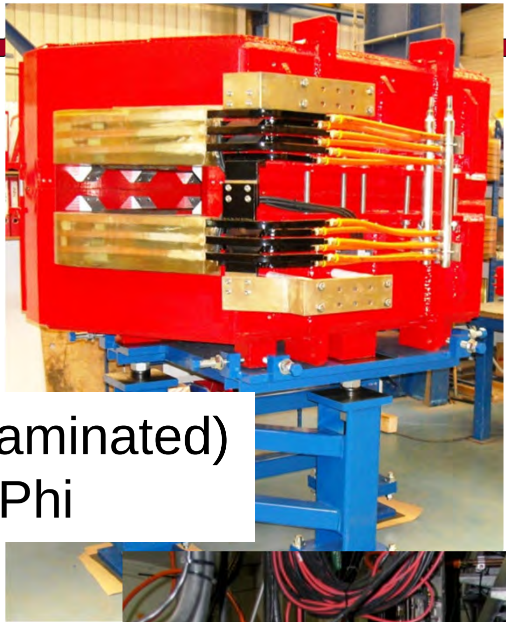


Buncher C-2 in transport line

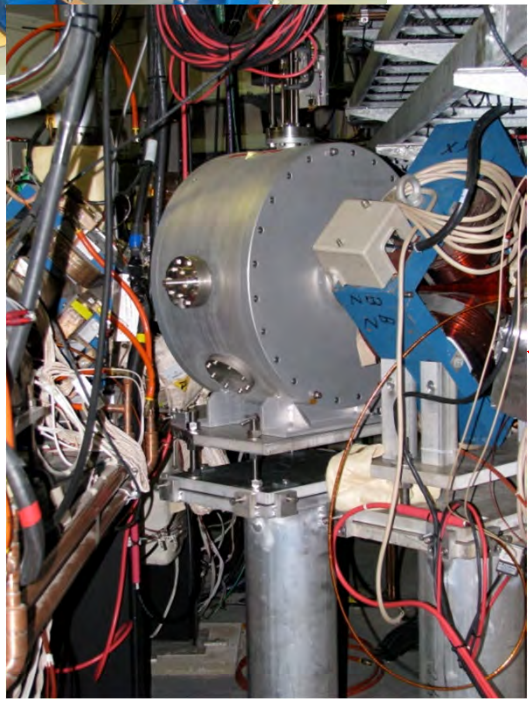
ELECTRON BEAM ION SOURCE



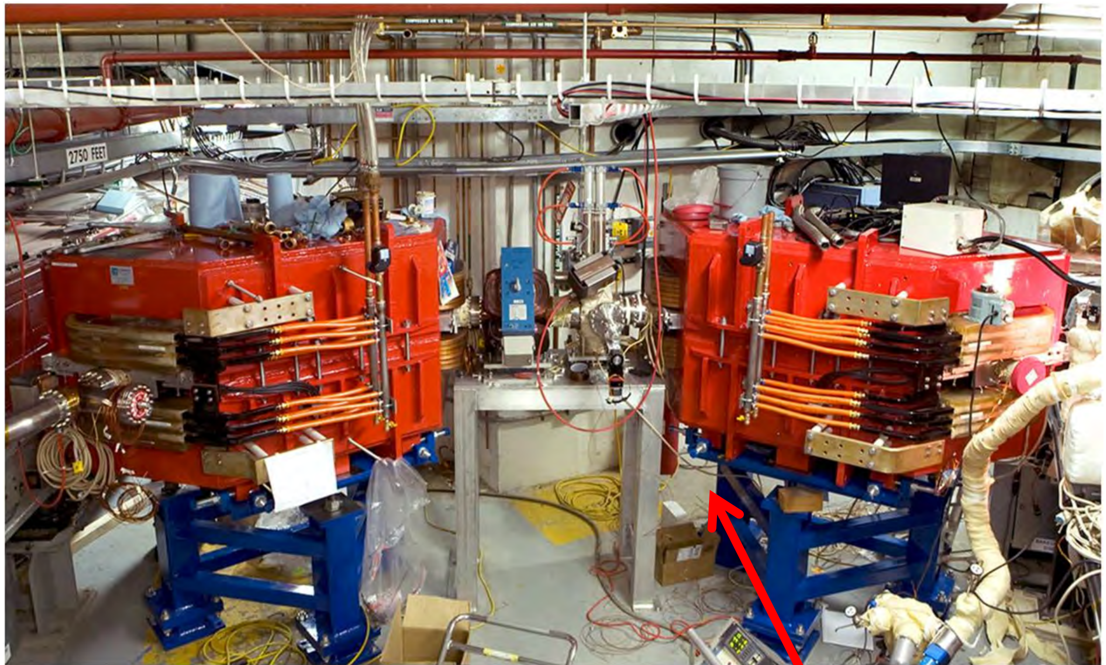
Beamline in Booster

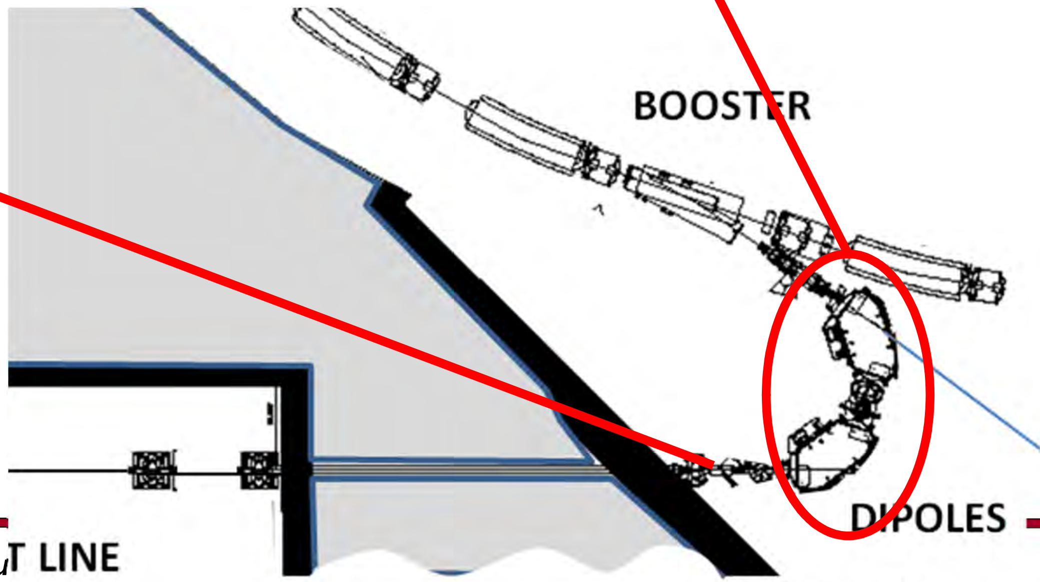


Dipole (laminated)
 - SigmaPhi



Buncher



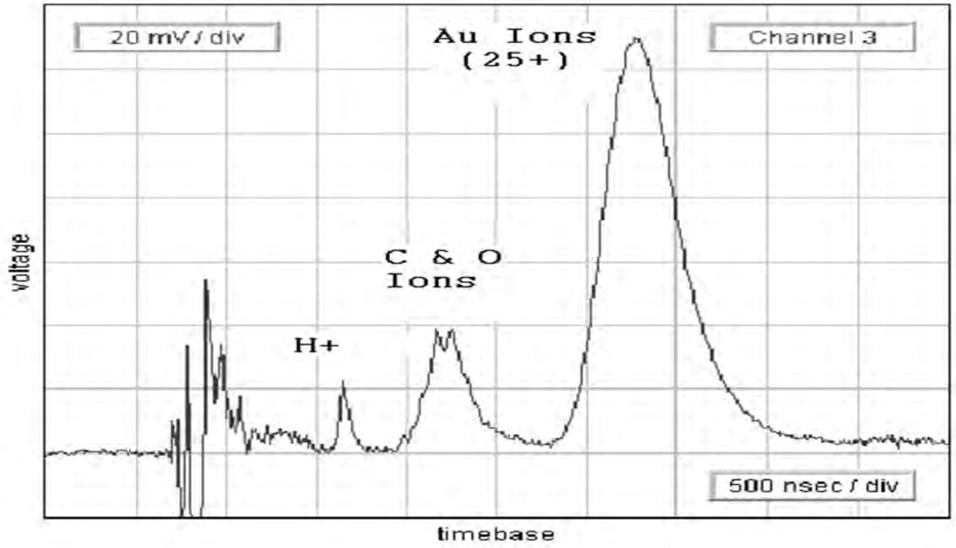


Ion Beam Delivered to NSRL and RHIC

ELECTRON BEAM ION SOURCE

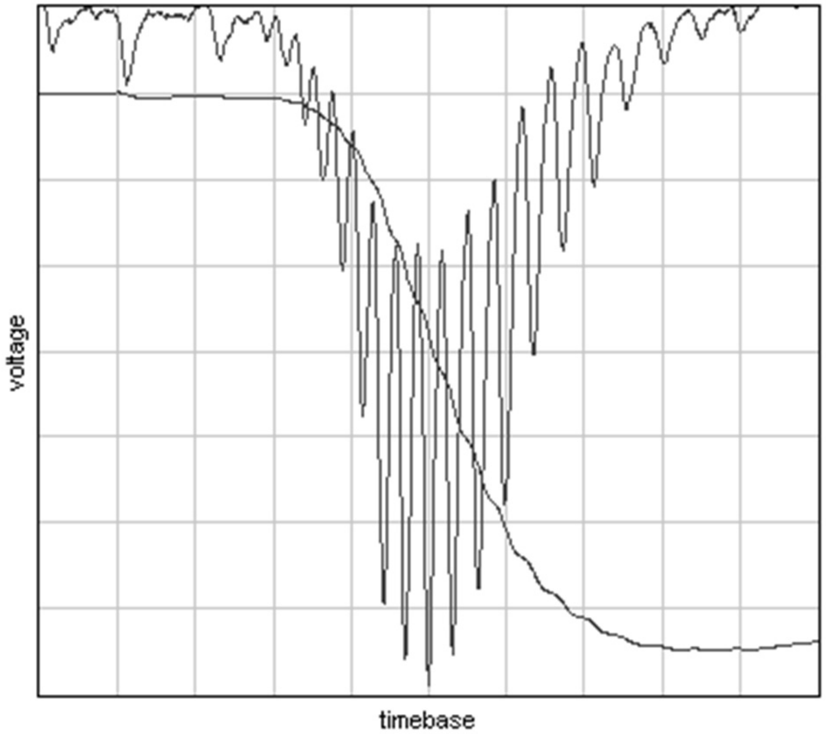
IONS	Q/m	delivered to	
${}_{3}He^{2}$	0.6667	AGS	
${}_{4}He^{2}$	0.5000	NSRL	
${}_{12}C^{6}$	0.5000	NSRL	
${}_{16}O^{8}$	0.5000	NSRL	
${}_{4}He^{1}$	0.2500	NSRL	
${}_{20}Ne^{+5}$	0.2500	NSRL	
${}_{40}AR^{+10}$	0.2500	NSRL	
${}_{63}Cu^{11}$	0.1746	RHIC	4.8e9
${}_{40}AR^{+7}$	0.1750	AGS	
${}_{48}TI^{+9}$	0.1875	NSRL	
${}_{56}Fe^{+10}$	0.1786	NSRL	
${}_{84}Kr^{+20}$	0.2439	NSRL	
${}_{131}Xe^{+30}$	0.2290	NSRL	
${}_{181}Ta^{+40}$	0.2210	NSRL	
${}_{197}Au^{+32}$	0.1624	RHIC, NSRL	1.6e9
${}_{238}U^{+39}$	0.1638	RHIC	1.3e9

Why Multiple Ion Species



- Full ion beam sampled and collected on Faraday Cup

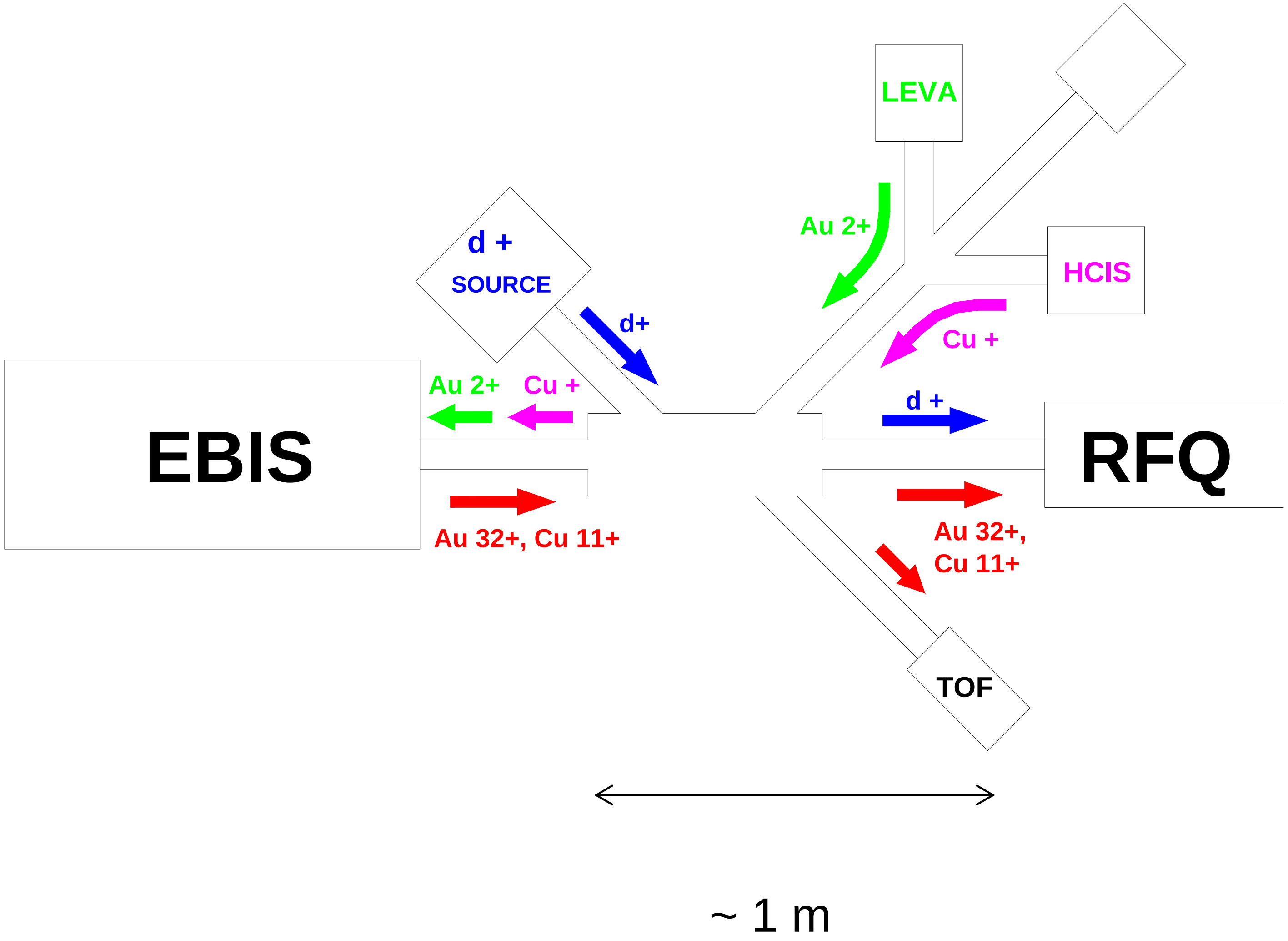
- I_e= 7A;
- 10 ms confinement
- Au = 83%; C&O = 15%; H = 2%



Au time-of-flight charge state distribution; Peak at Au 31+

I(e)=7.6 A; 65ms confinement

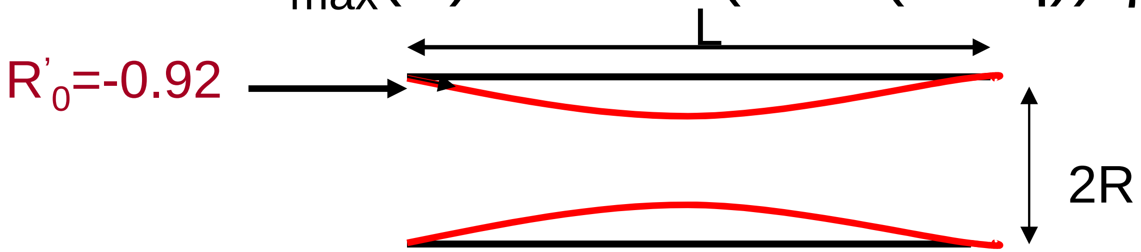
Drift space needed for injection in LEBT



LEBT Length

- Distance needed between two lenses for external ion injection (L) ~ 1 m.
- Beam radius (R) ~ 2.0 cm, Lenses (solenoid) aperture radius 5.0 cm
- Maximum beam current for SC dominated drift (L), maximum beam radius (R) and initial slop $R'_0=-0.92$ given by

$$I_{max}(A)=1.166*(mc^2/(30*q))*\beta^3\,\gamma^3\,(R/L)^2$$



$=20$ mA for Au^{+32}

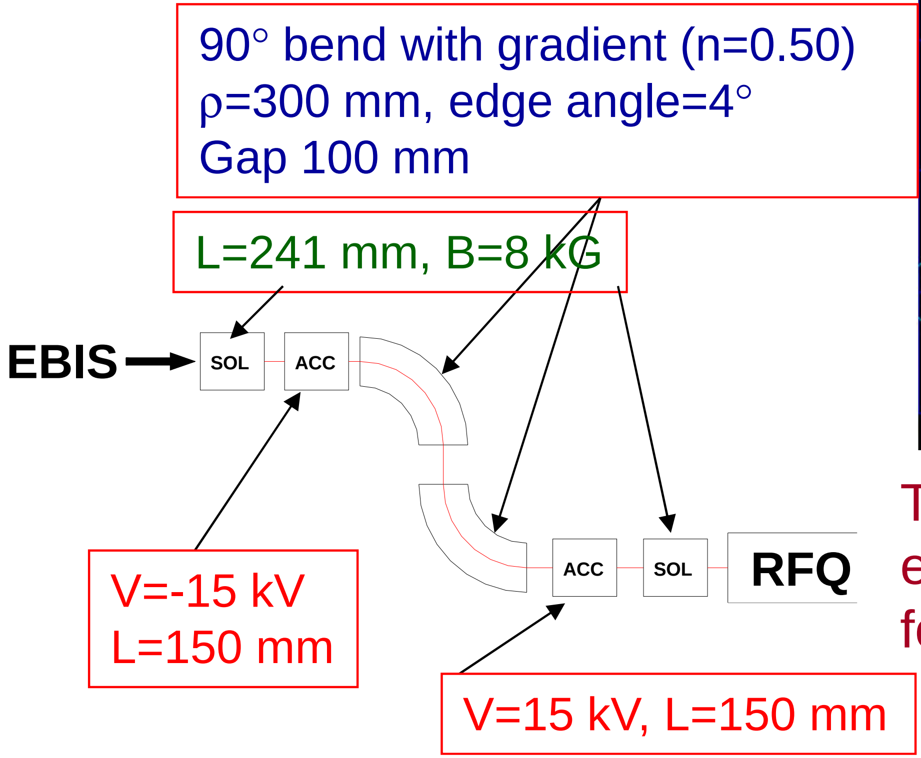
$= 6$ mA for D

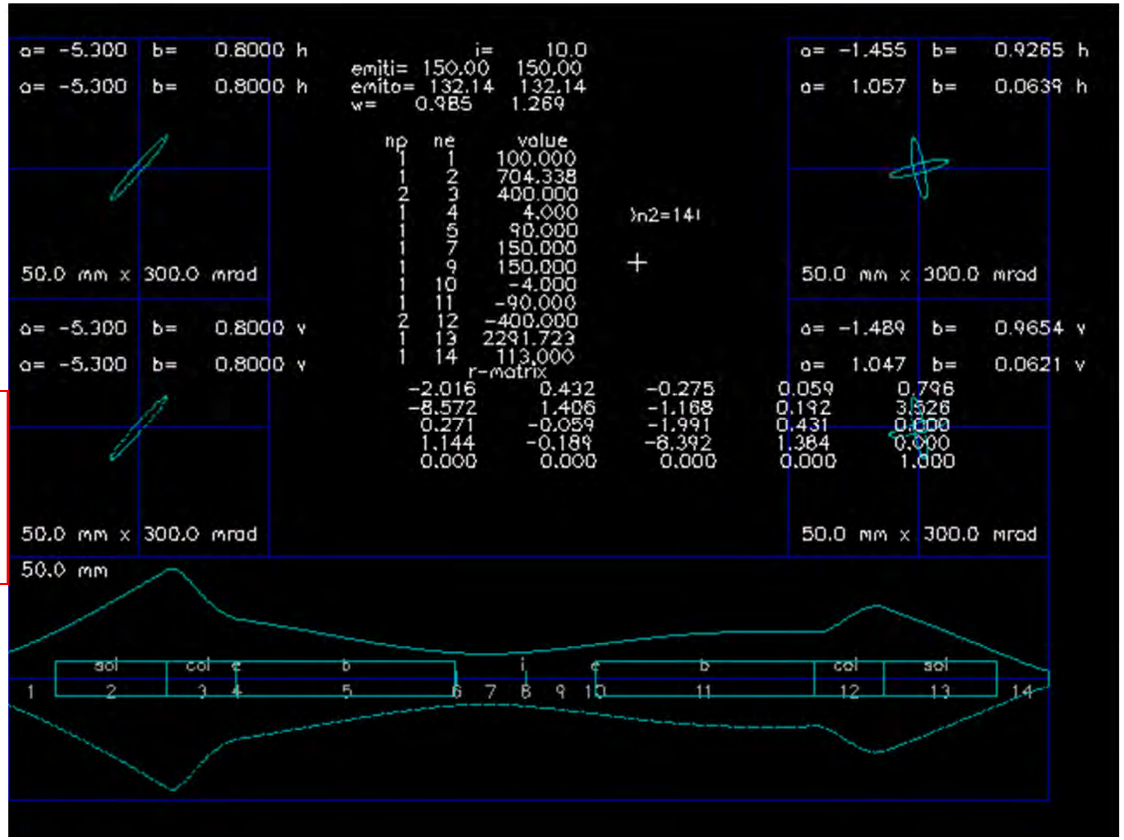
$= 5$ mA for $_3He^{+2}$

Alternative LEBT: Charge Separation before RFQ

ELECTRON BEAM ION SOURCE

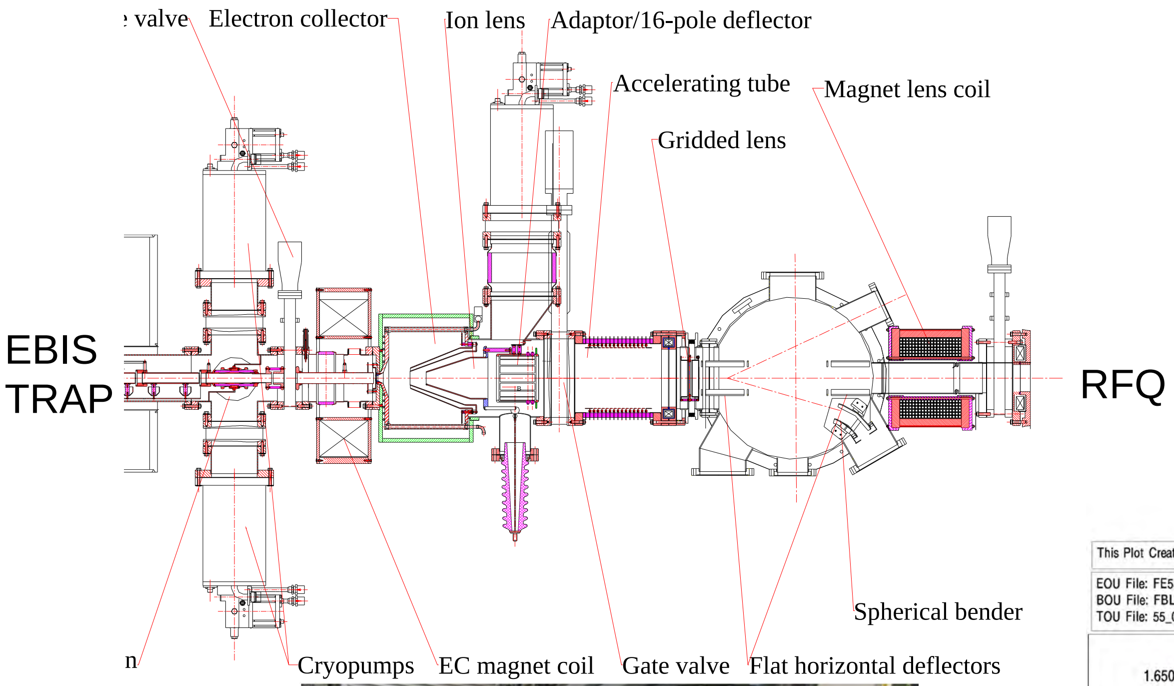
- -Dispersion 0.8 meter
- -Sufficient for charge separation
- -Magnets has to float to 40 kV
- -Unnecessary complication
- -Cost

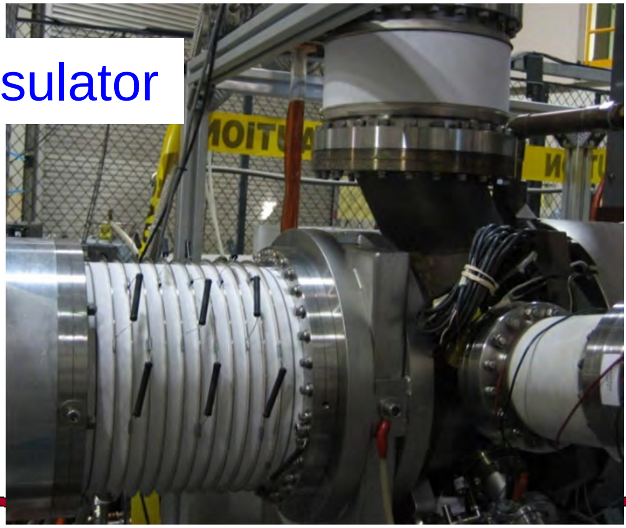




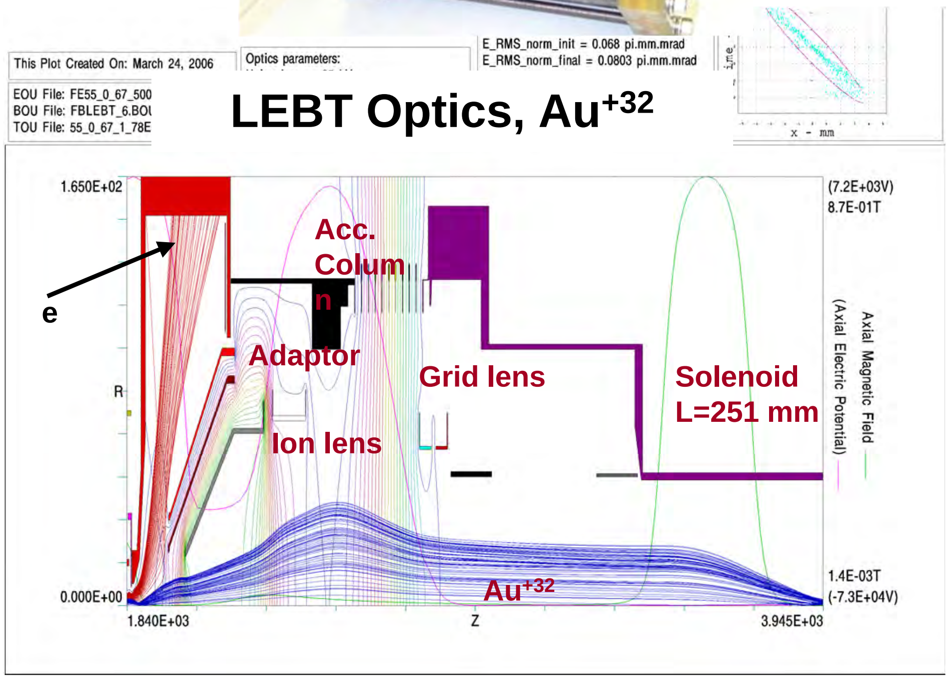
Two 90 degree gradient magnet with 4° edge angle, 10 cm gap, Float at 40 kV for $_3He^{+2}$

Matching to the RFQ

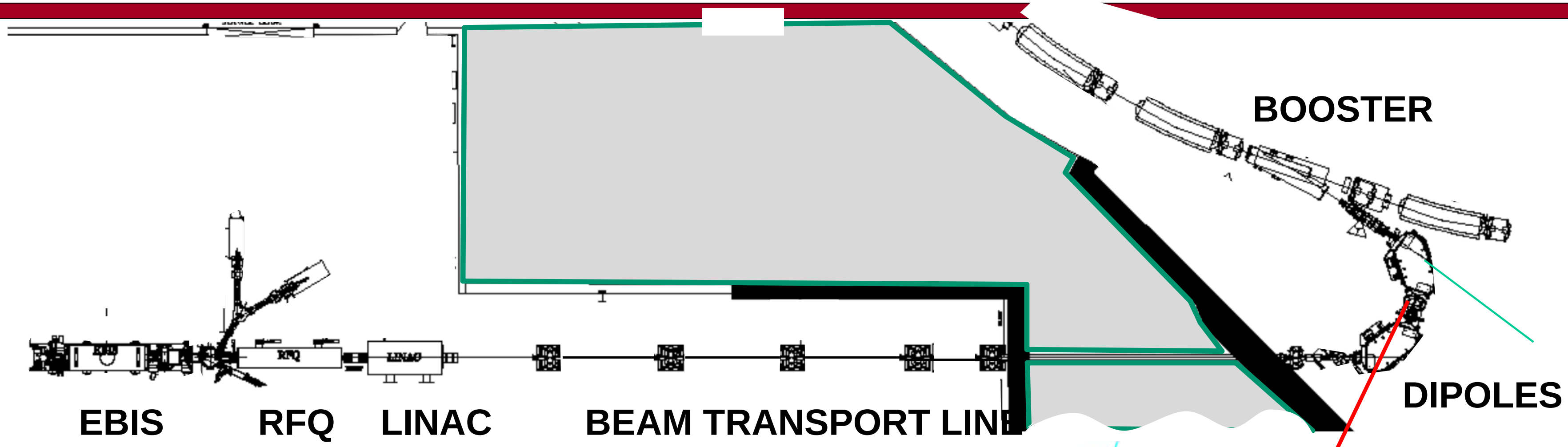


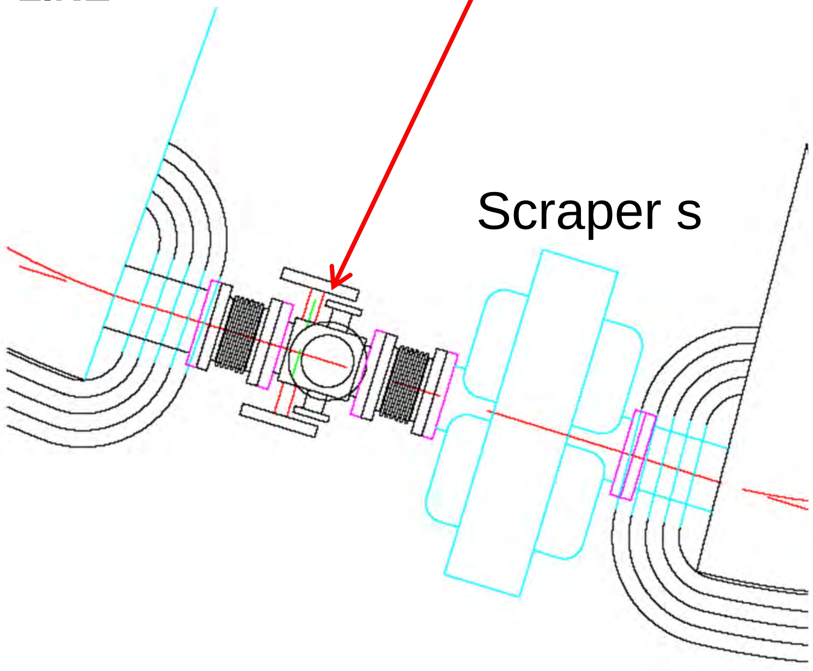


100 kV insulator



Charge Discrimination



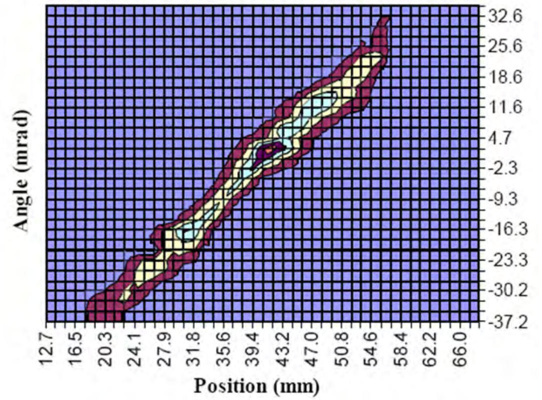


At this location
-R_{16}=1.1 m
-$2r_0$=2.2 mm
-Resolution = 500 @2MeV/u 310@0.3 MeV/u
-Efficiency =100%

Emittance

ELECTRON BEAM ION SOURCE

Measured emittance of a 1.7 ma Au beam



ε (n, rms)= 0.1 π mm mrad.

We have assumed emittance scales as Q/m for different ion Species

$\varepsilon(n) = 0.16 * r^2 * Bz * (Q/M)$ m-rad (100% of beam)

=> He^{+2} emittance will ~3 times of Au^{+32}

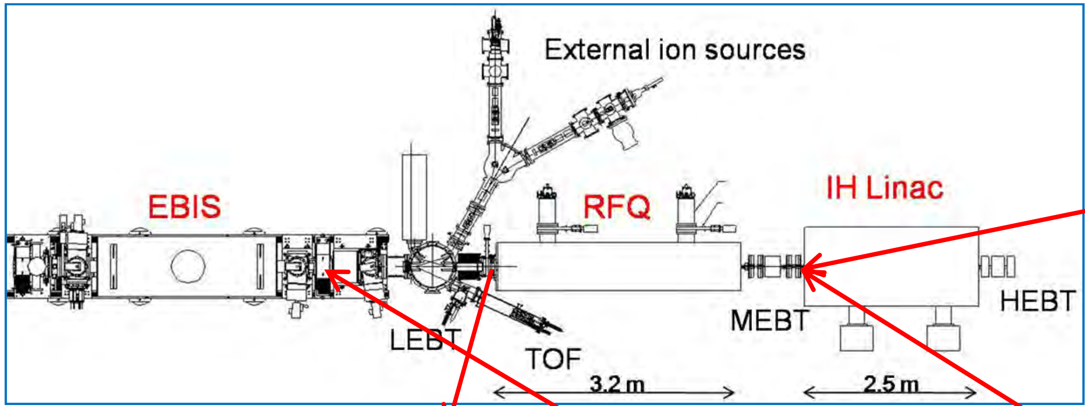
Emittance Budget for the EBIS-Injector

	Vertical π mm mrad (N, 95%)	Horizontal π mm mrad (N, 95%)
Booster*	4.5	10.0
Linac	1.4	1.4
Source	0.7	0.7

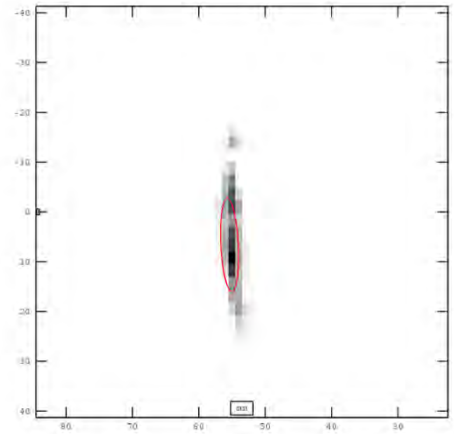
*mismatch injection

Note: Booster acceptance (VXH) 4.5 X 15 π mm mrad (N,95%)

The LEBT and MEBT beam lines were each first commissioned with temporary diagnostics, before moving the RFQ, and then the linac, into place.

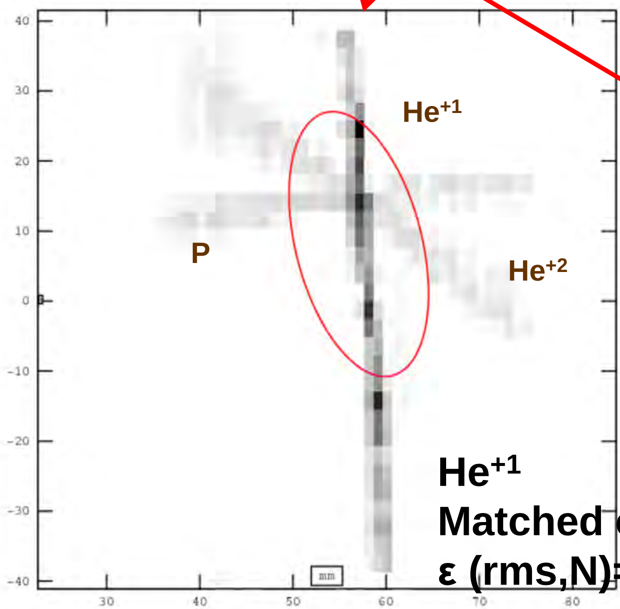


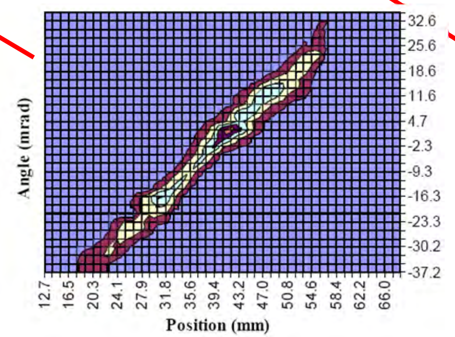
MEBT

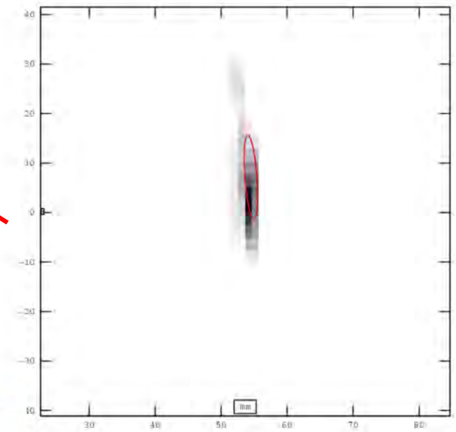


Helium: matched condition into LINAC
ε(n,rms) 0.13 π mm mrad

LEBT







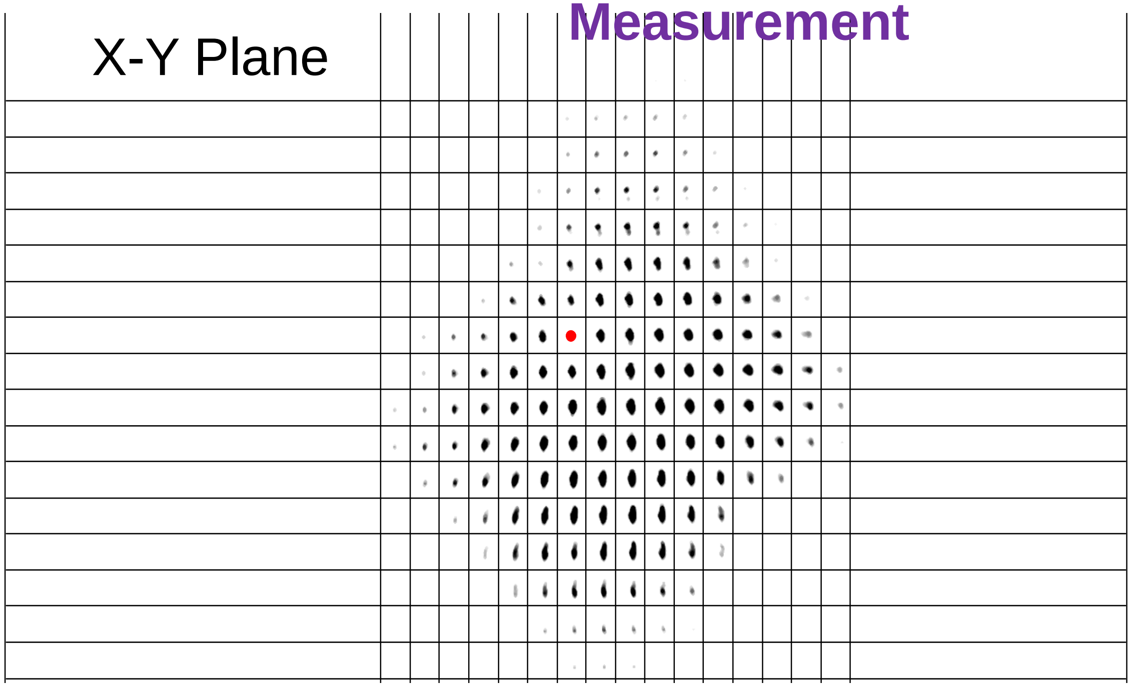
He+1
Matched condition into the RFQ
ε (rms,N)= 0.09 πmm mrad

Gold: ε (n, rms)= 0.1 π mm mrad.

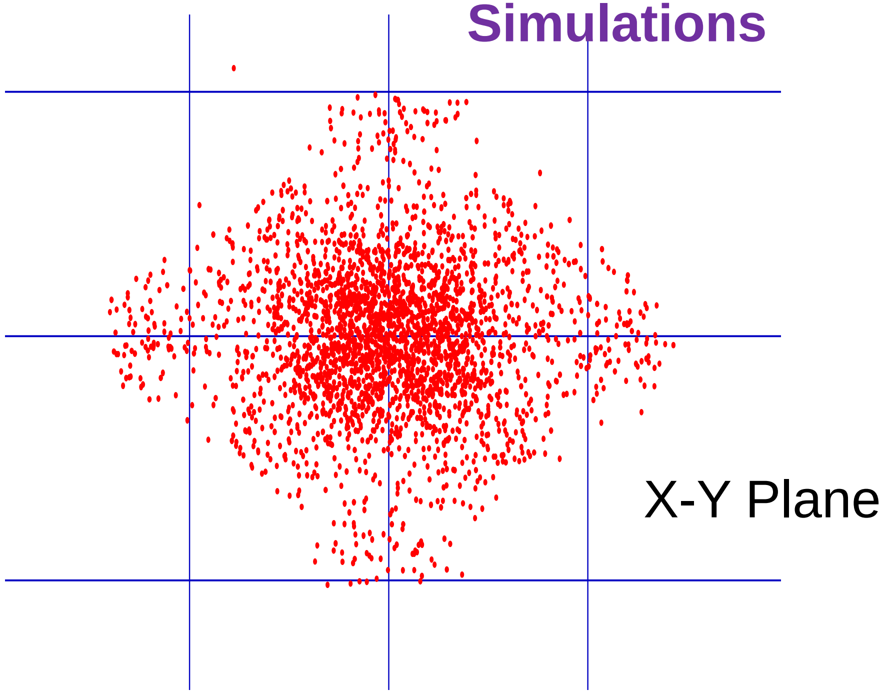
Gold: Matched conditions into linac
ε(n,rms) 0.19 π mm mrad

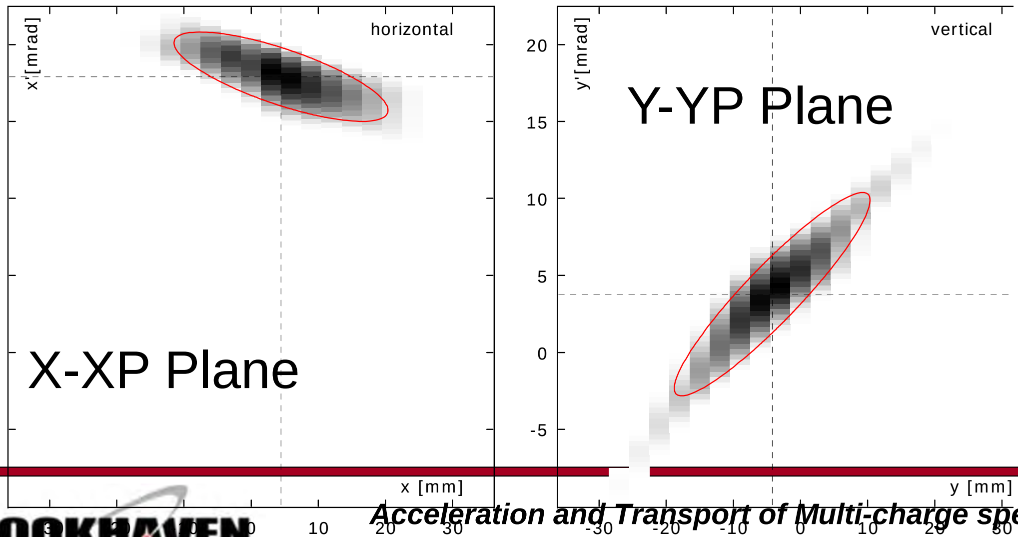
Image of the Beam (U) after linac

Measurement

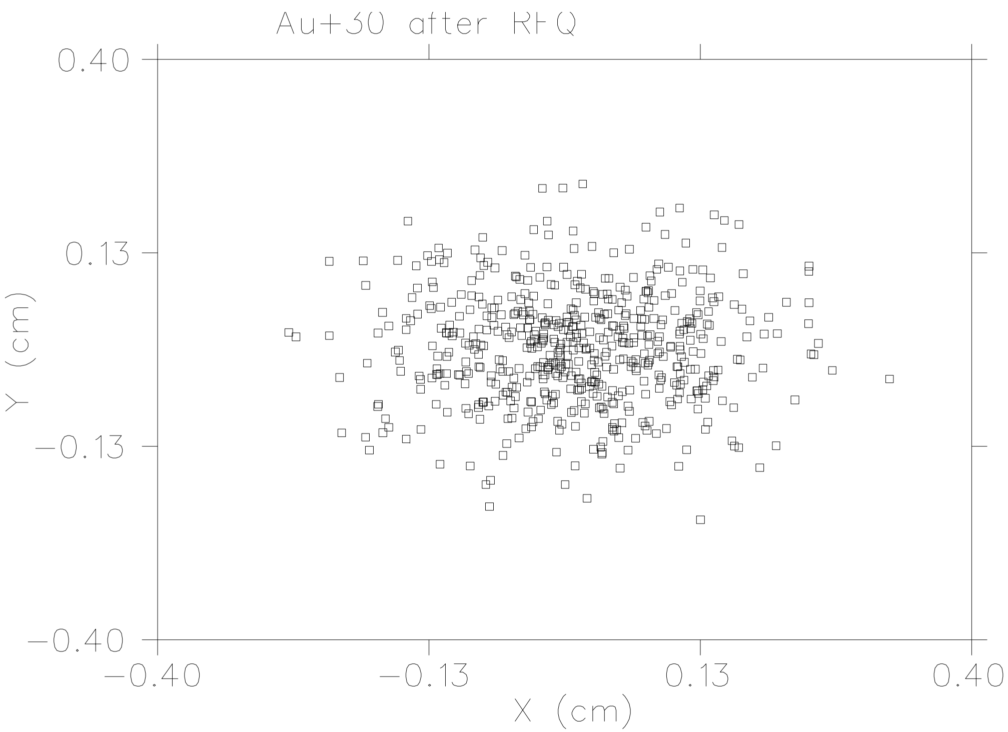


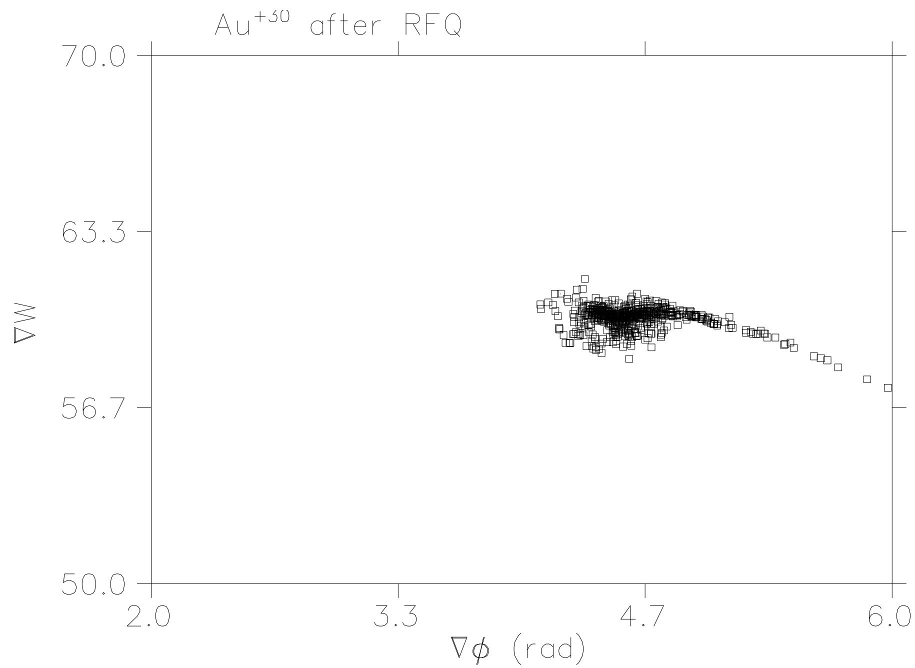
Simulations





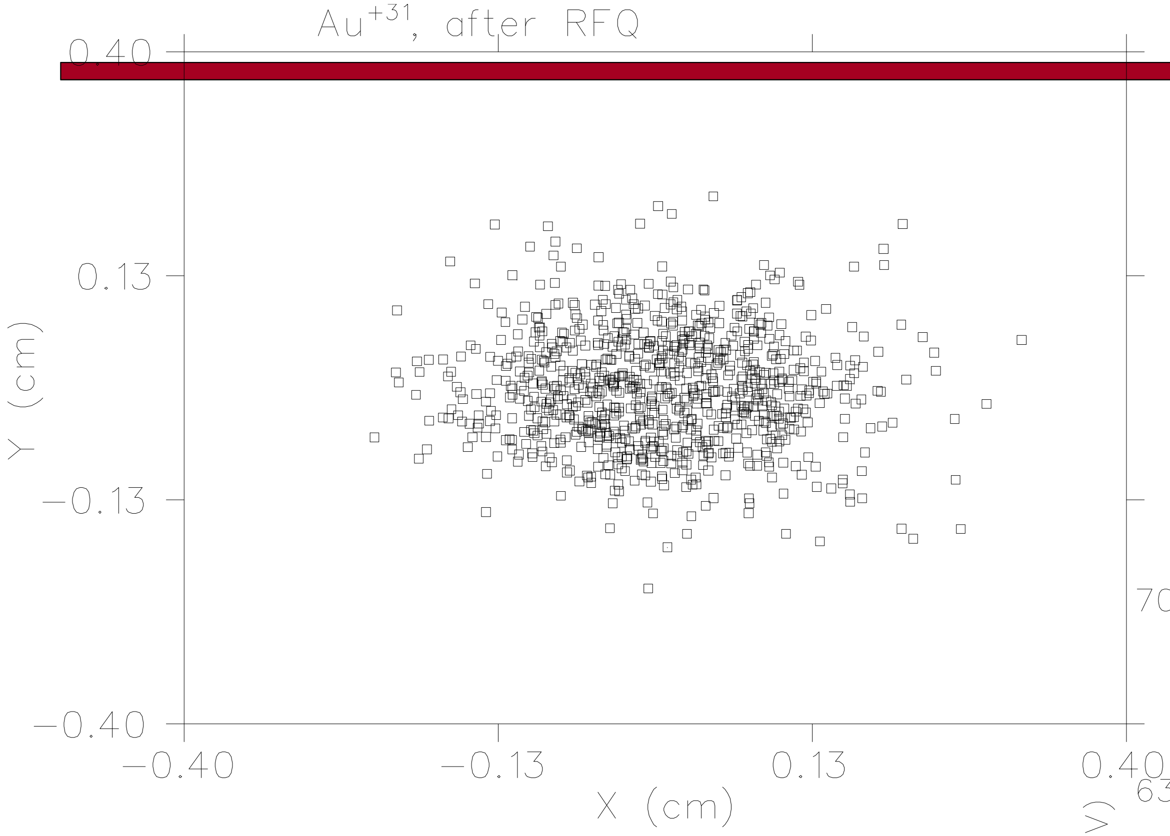
Au +30

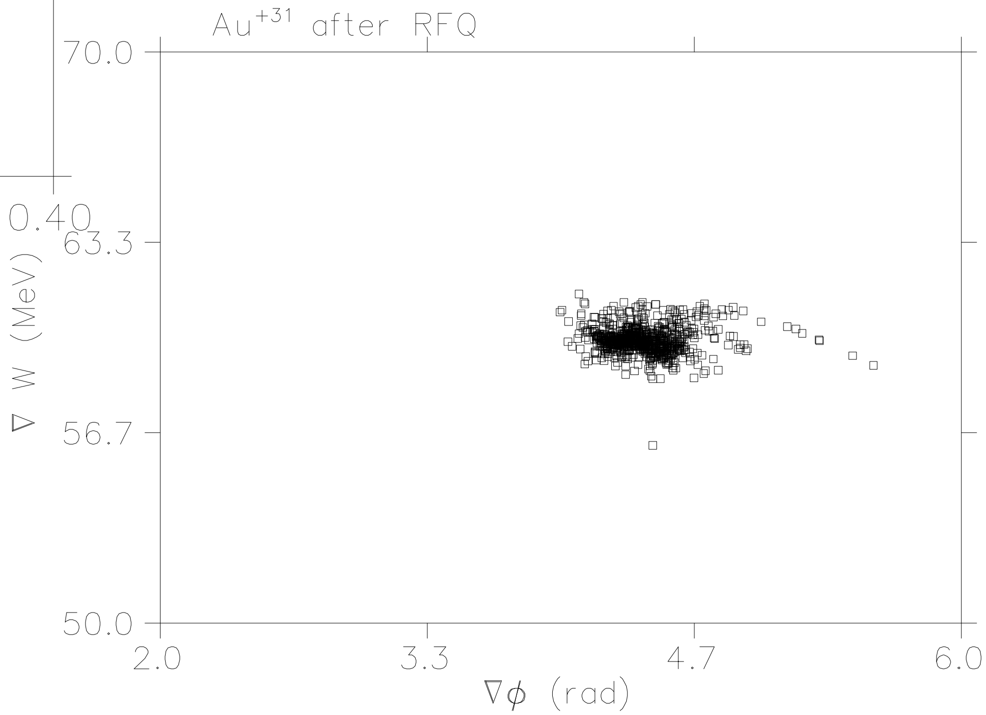

Au+30 after RFQ
0.40
0.13
−0.13
−0.40
Y (cm)
−0.40
−0.13
0.13
0.40
X (cm)


Au+30 after RFQ
70.0
63.3
56.7
50.0
∇W
2.0
3.3
4.7
6.0
∇φ (rad)

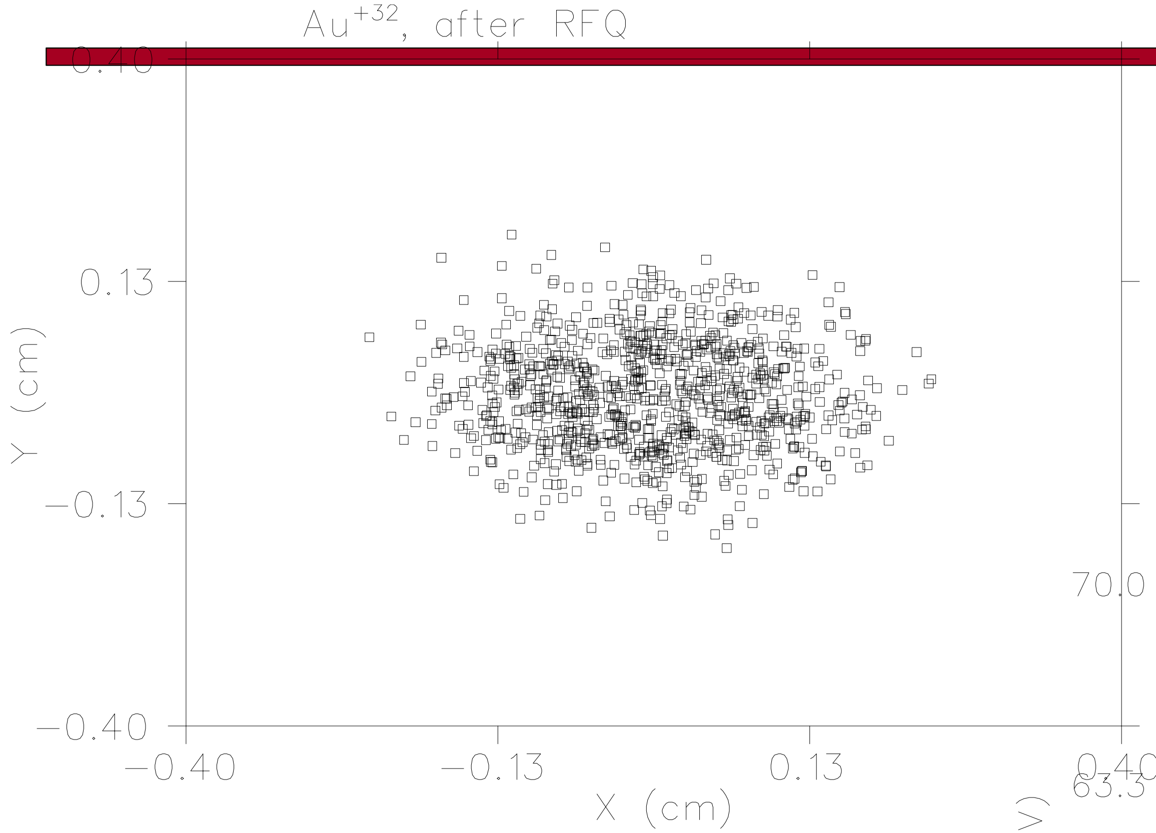
Au 31

ELECTRON BEAM ION SOURCE

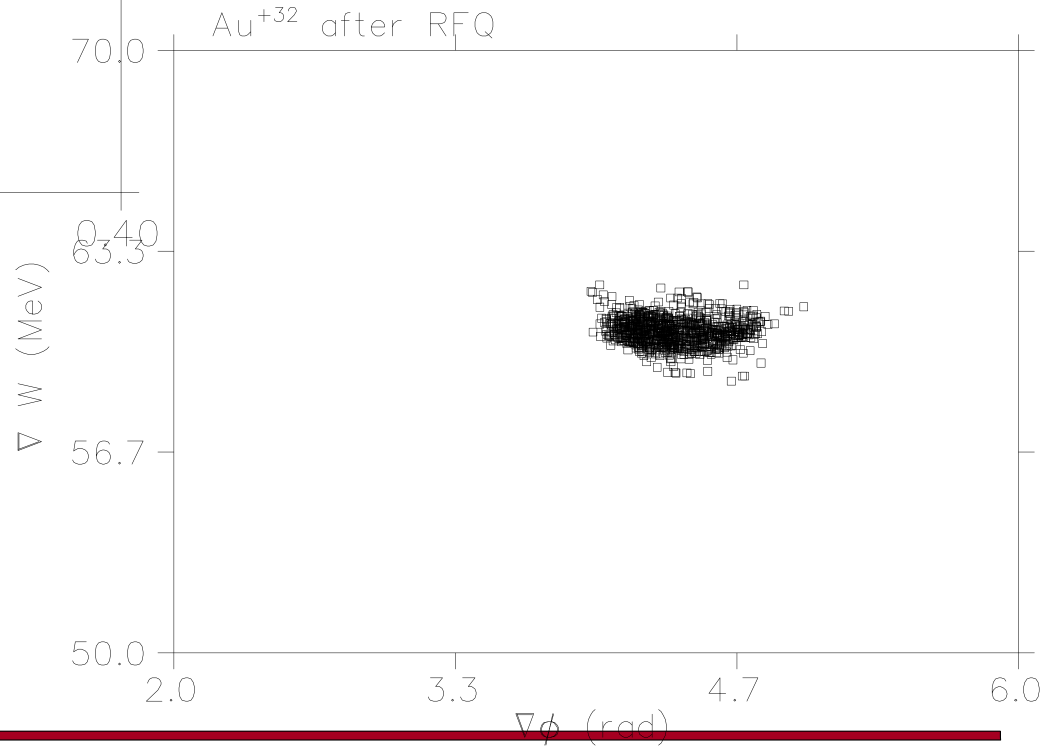




Au+32

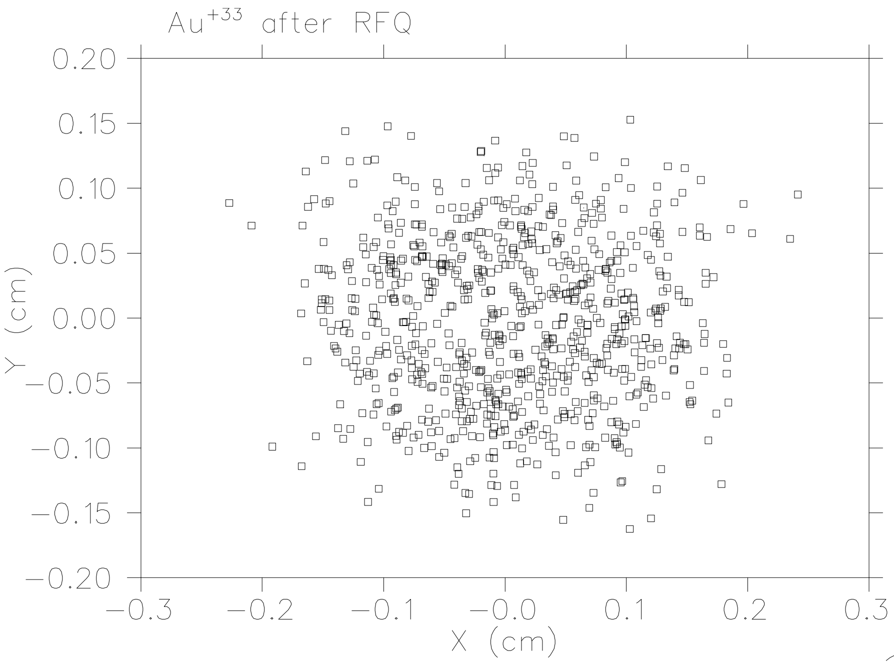


Au+32, after RFQ
0.40
0.13
−0.13
−0.40
Y (cm)
−0.40
−0.13
0.13
0.40
X (cm)

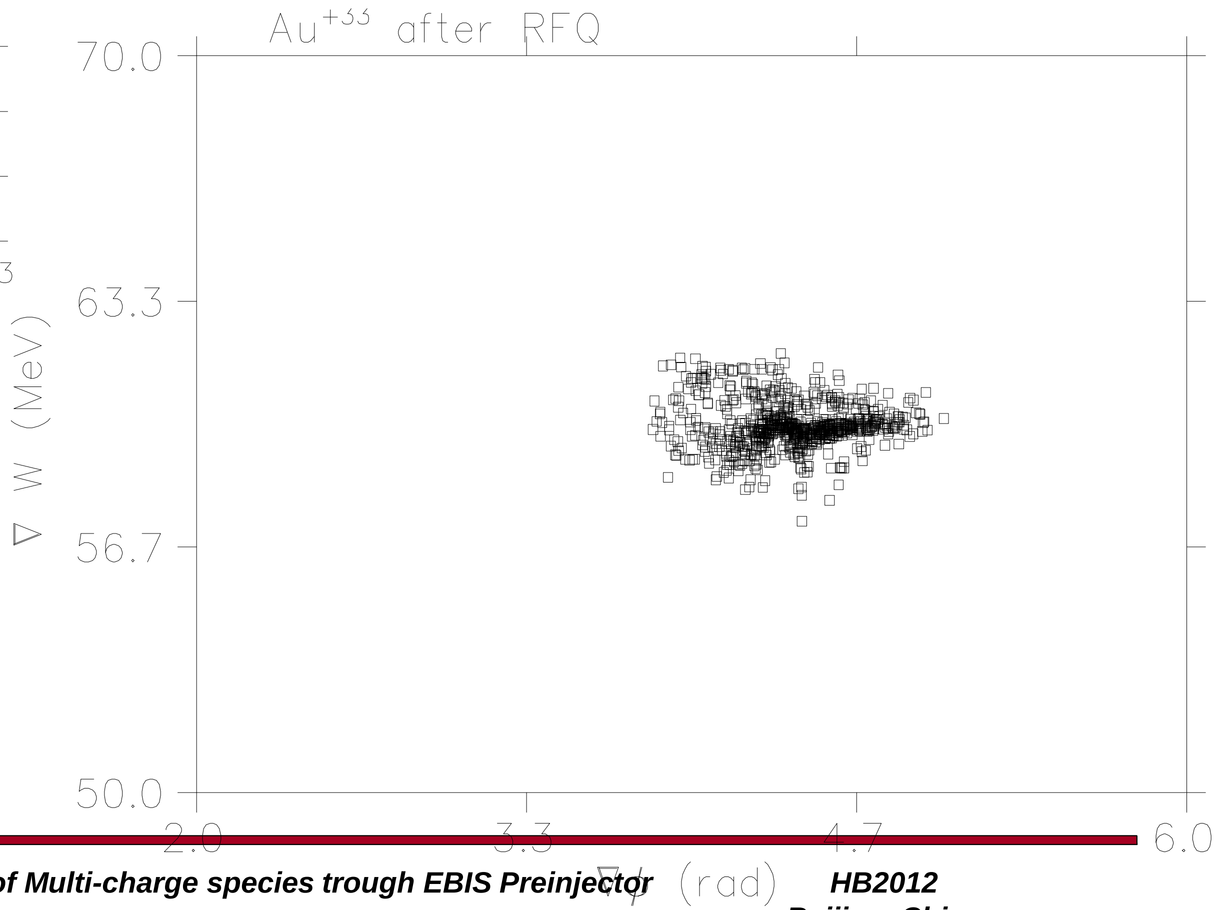


Au+32 after RFQ
70.0
63.3
56.7
50.0
∇ W (MeV)
2.0
3.3
4.7
6.0
∇ϕ (rad)

Au +33

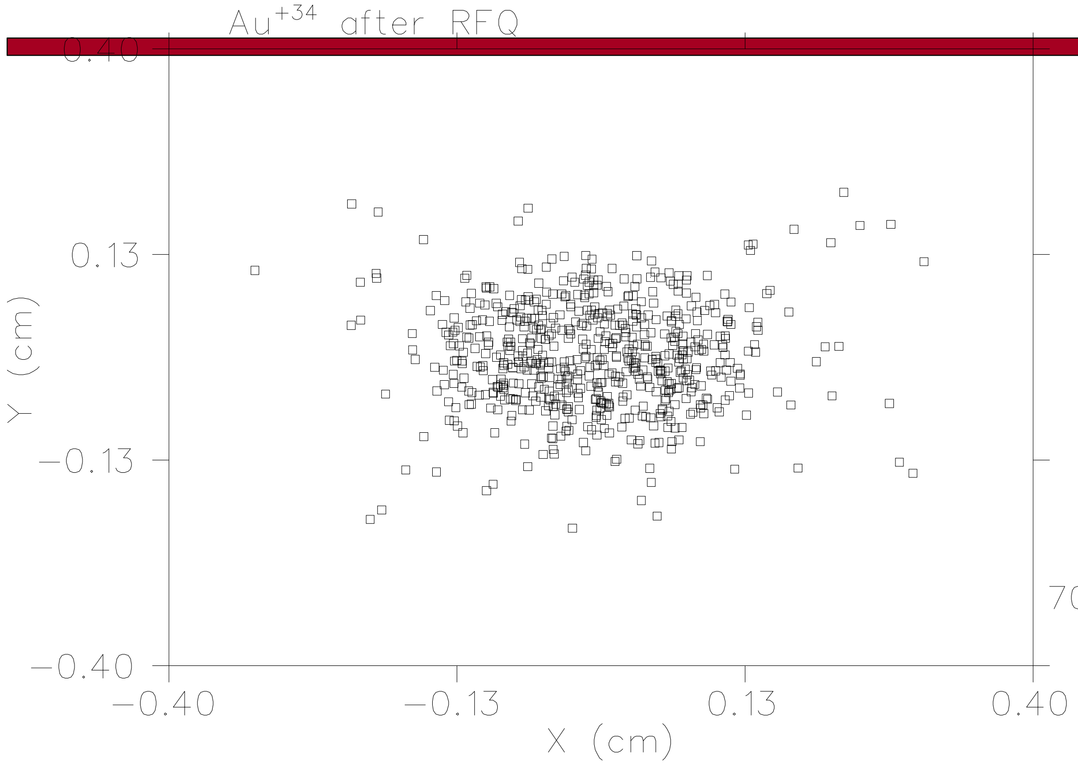


Au+33 after RFQ
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20
Y (cm)
−0.3
−0.2
−0.1
−0.0
0.1
0.2
0.3
X (cm)

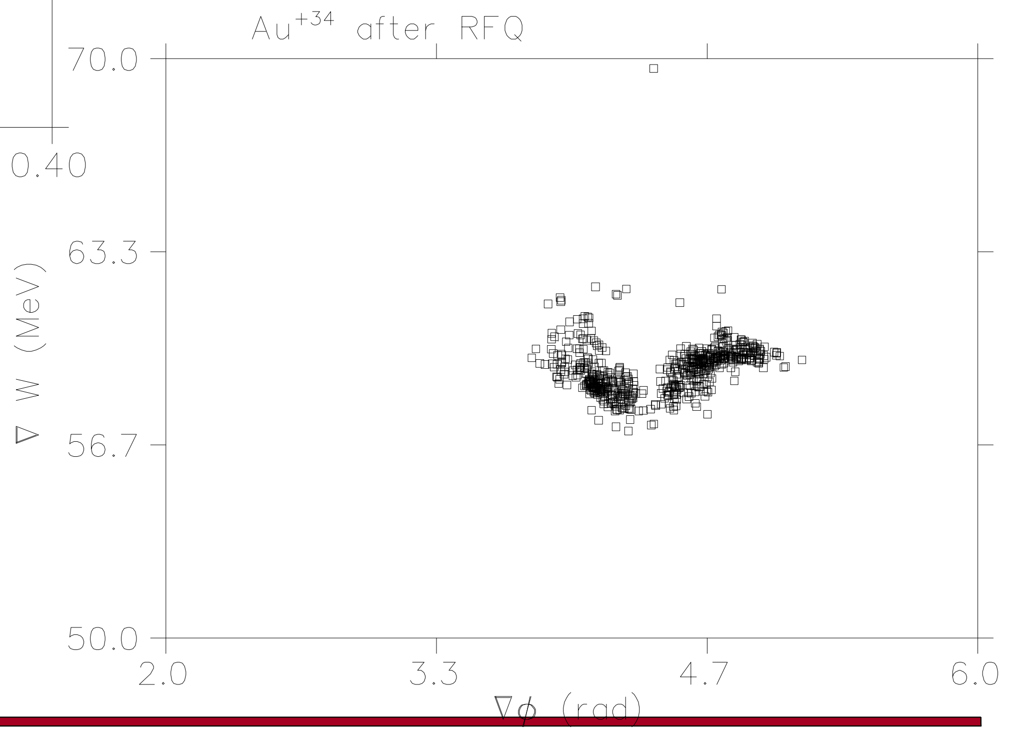


Au+33 after RFQ
70.0
63.3
56.7
50.0
Δ W (MeV)
2.0
3.3
4.7
6.0
Δφ (rad)

Au +34

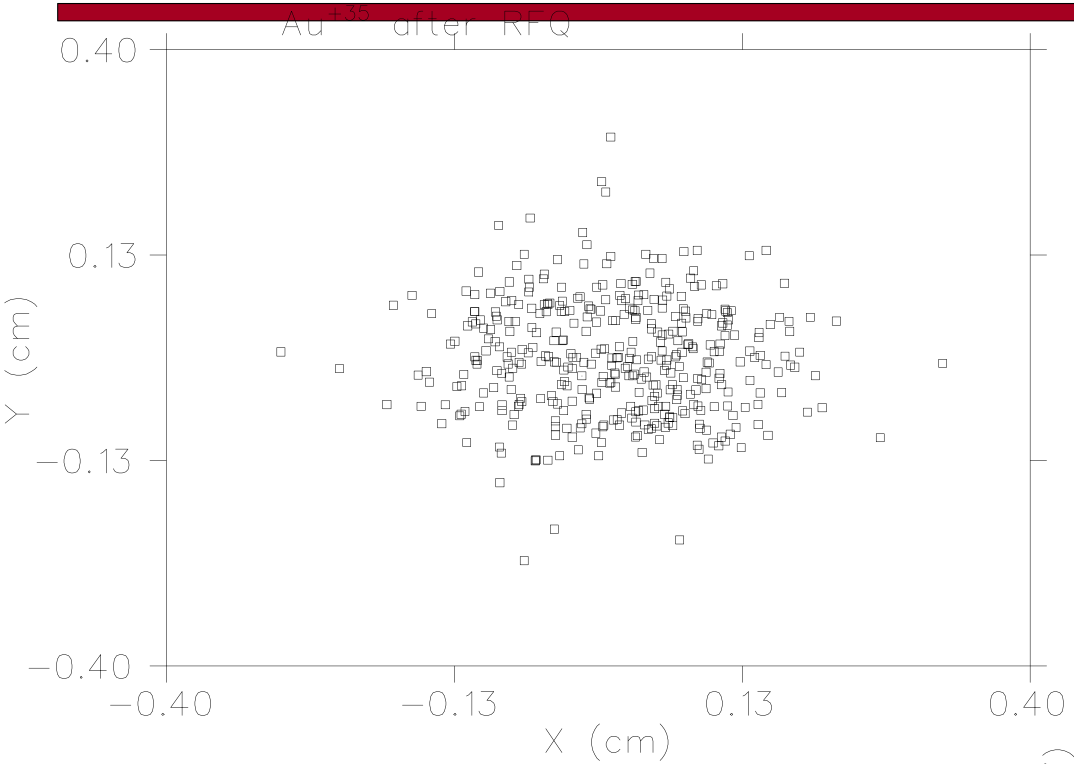


Au^{+34} after RFQ
0.40
0.13
−0.13
−0.40
Y (cm)
−0.40
−0.13
0.13
0.40
X (cm)

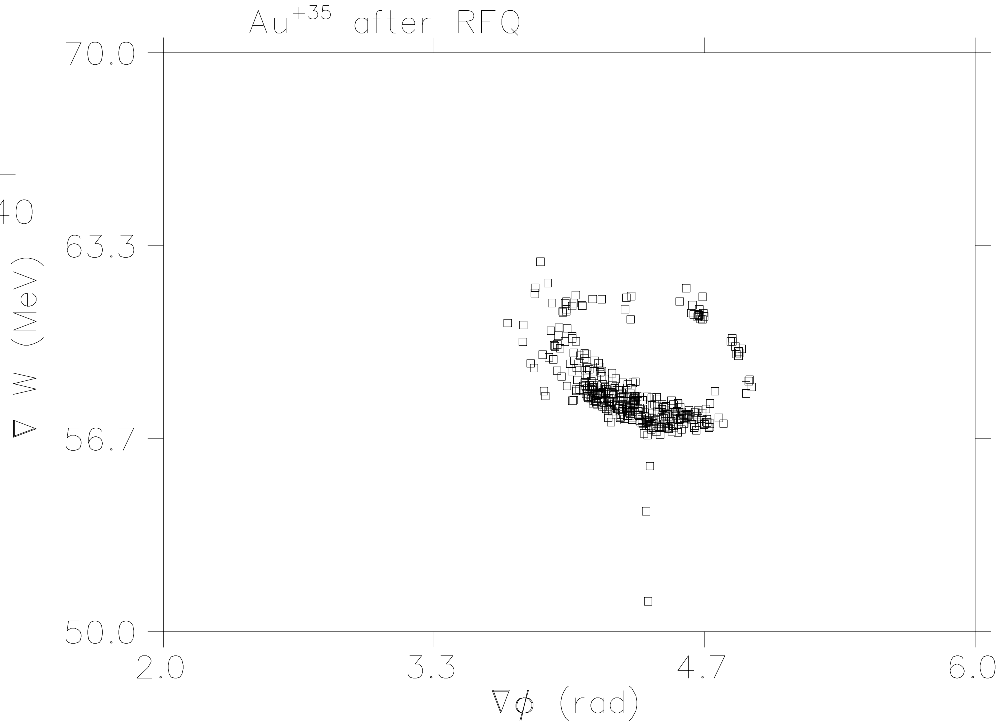


Au^{+34} after RFQ
70.0
63.3
56.7
50.0
∇ W (MeV)
2.0
3.3
4.7
6.0
∇ϕ (rad)

Au +35

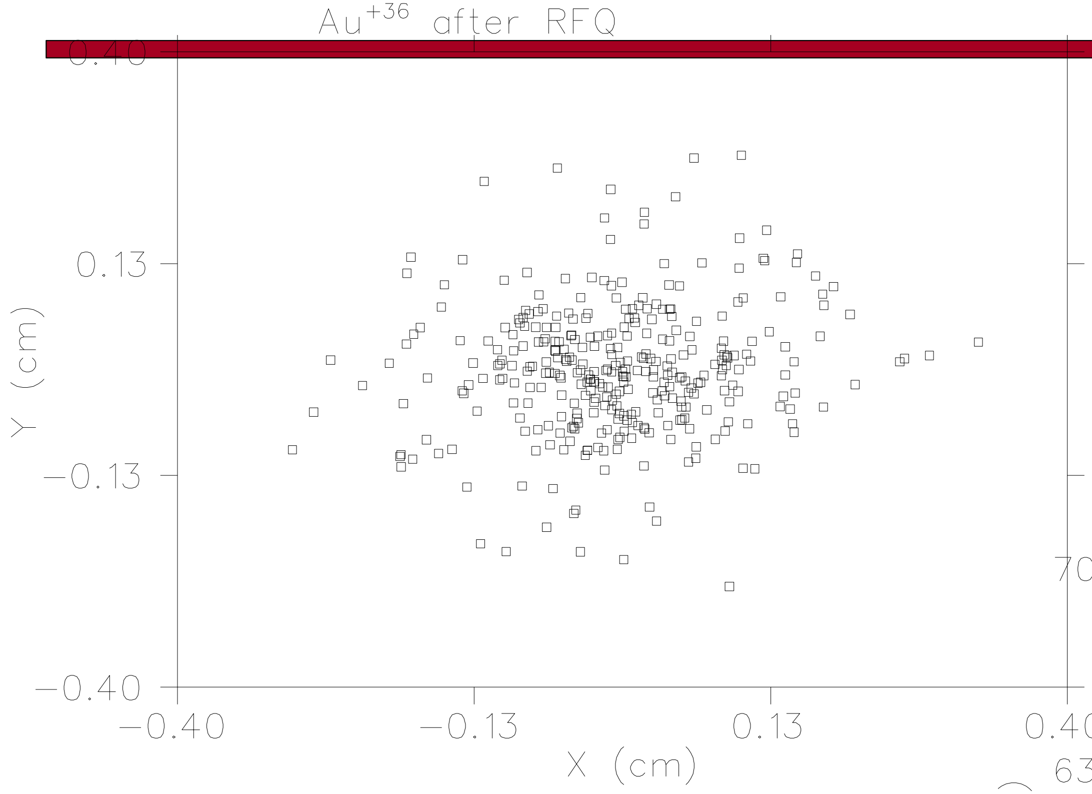


Au^{+35} after RFQ
0.40
0.13
−0.13
−0.40
Y (cm)
−0.40
−0.13
0.13
0.40
X (cm)

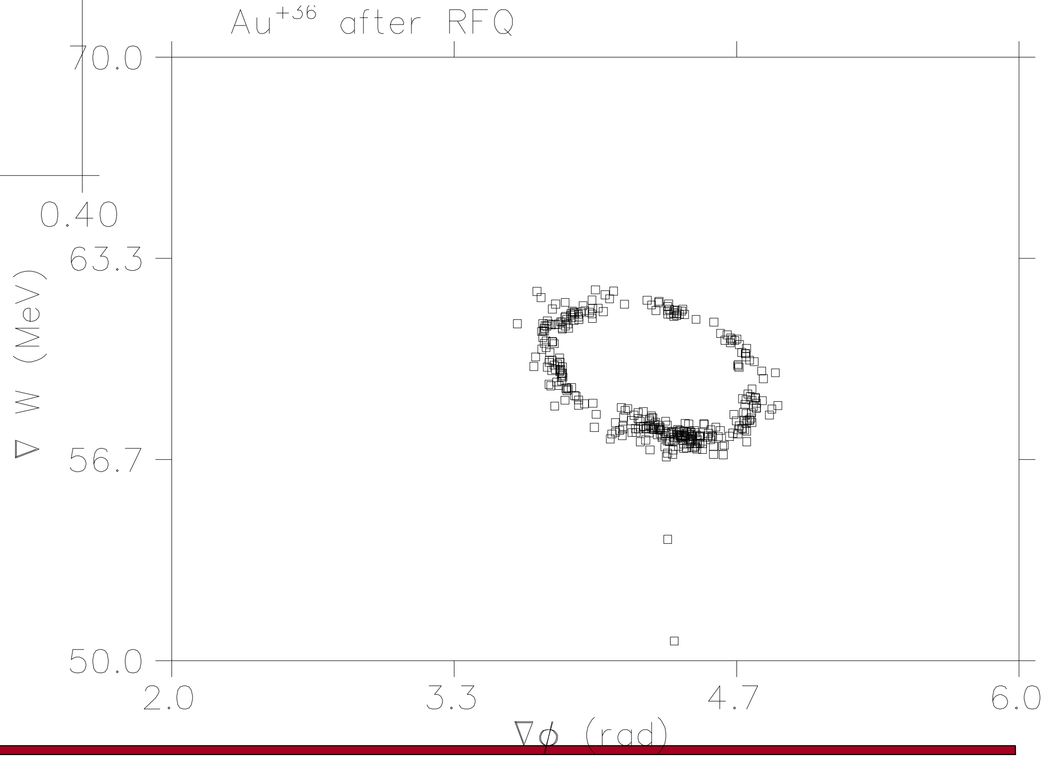


Au^{+35} after RFQ
70.0
63.3
56.7
50.0
∇ W (MeV)
2.0
3.3
4.7
6.0
∇φ (rad)

Au +36

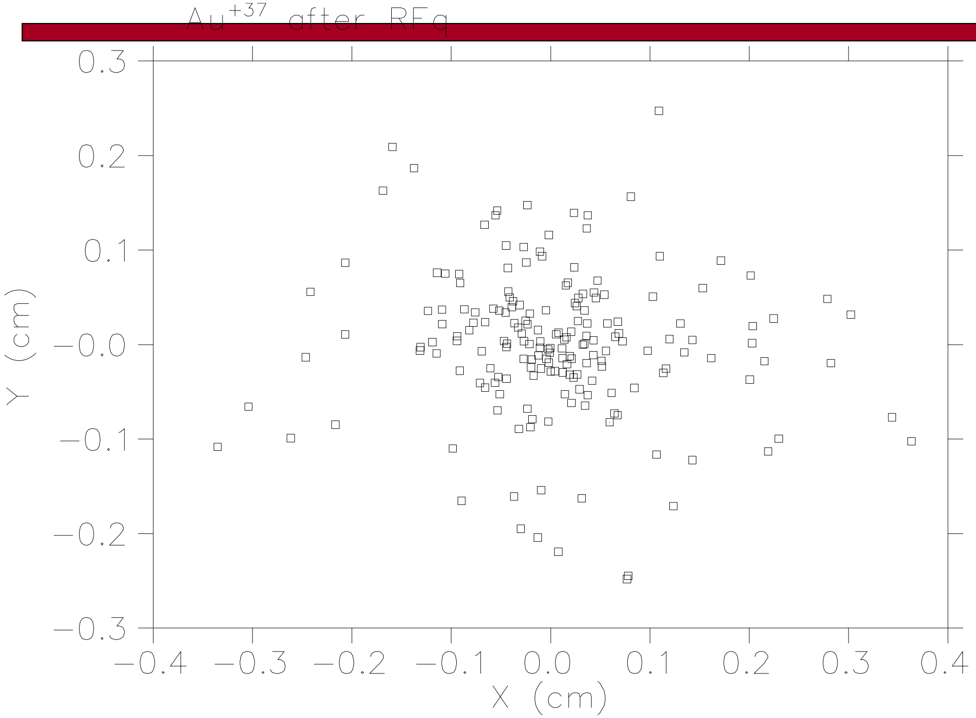


Au^{+36} after RFQ
0.40
0.13
−0.13
−0.40
Y (cm)
−0.40
−0.13
0.13
0.40
X (cm)

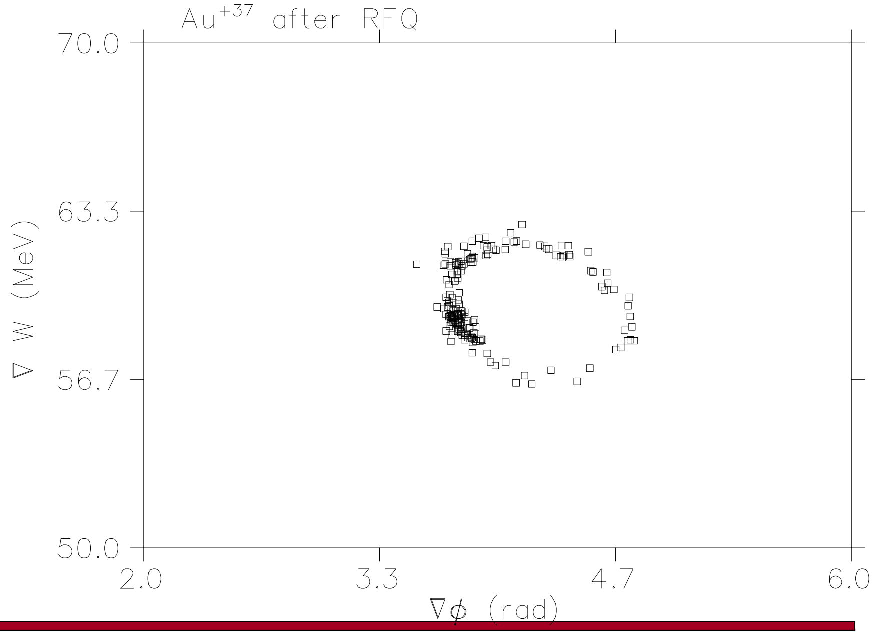


Au^{+36} after RFQ
70.0
63.3
56.7
50.0
∇ W (MeV)
2.0
3.3
4.7
6.0
∇φ (rad)

Au +37

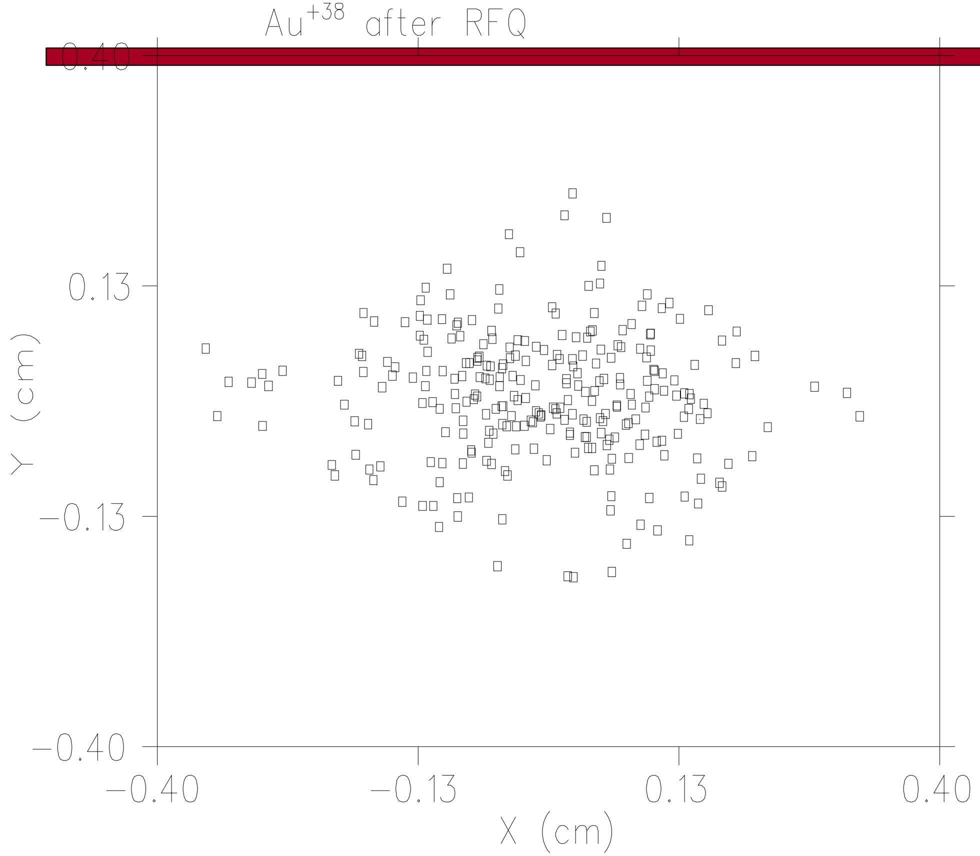


Au+37 after RFq
0.3
0.2
0.1
−0.0
−0.1
−0.2
−0.3
Y (cm)
−0.4 −0.3 −0.2 −0.1 0.0 0.1 0.2 0.3 0.4
X (cm)

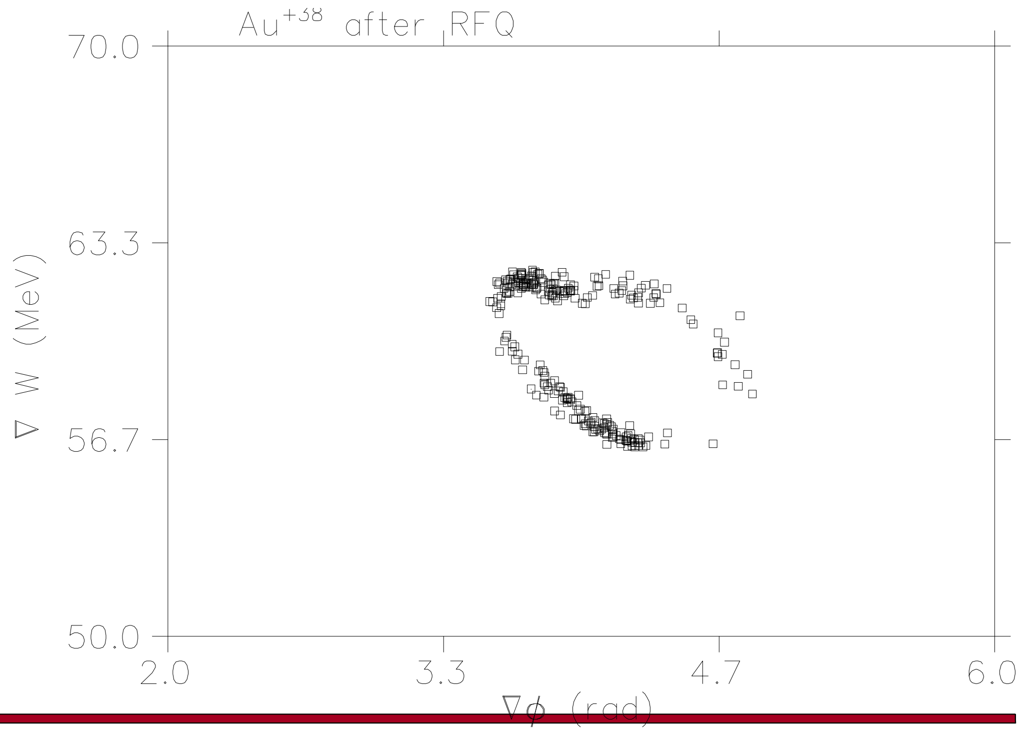


Au+37 after RFQ
70.0
63.3
56.7
50.0
∇ W (MeV)
2.0 3.3 4.7 6.0
∇ϕ (rad)

Au +38

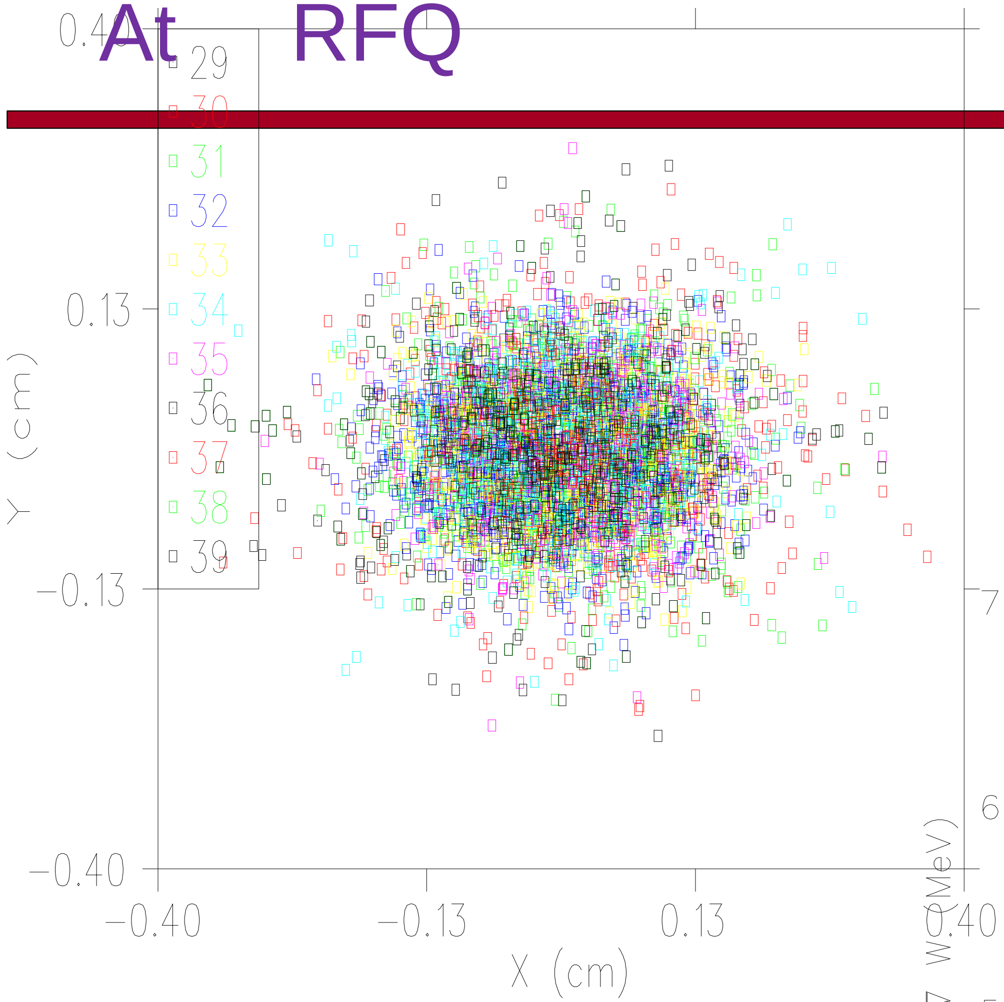


Au+38 after RFQ
0.40
0.13
-0.13
-0.40
Y (cm)
-0.40
-0.13
0.13
0.40
X (cm)

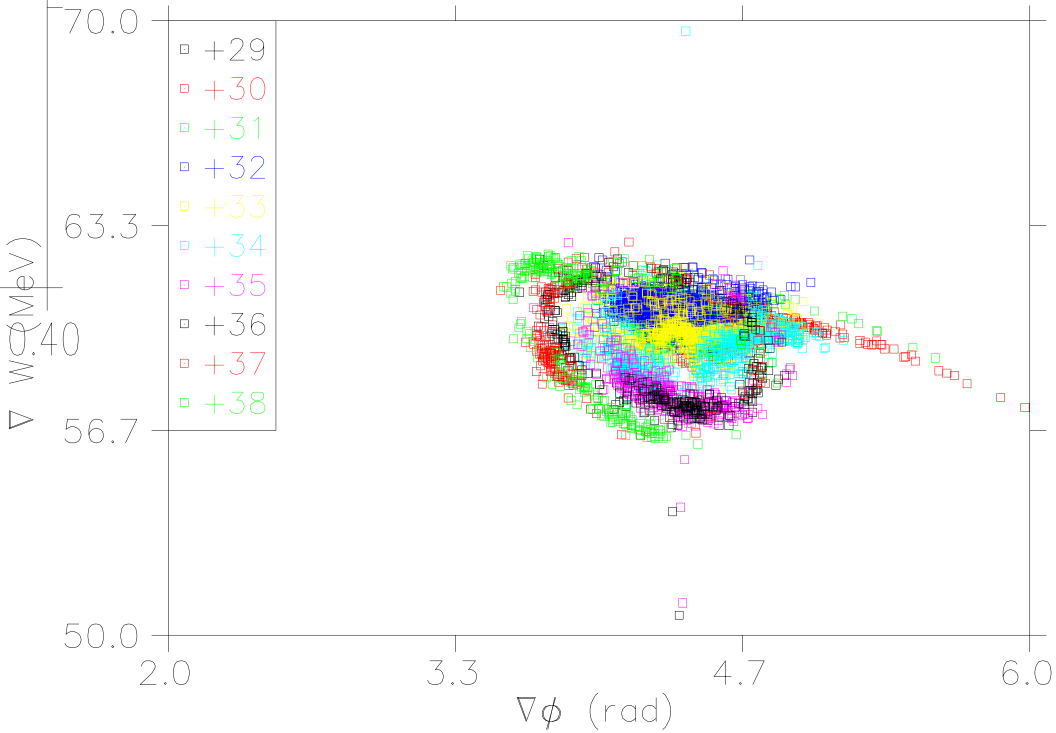


Au+38 after RFQ
70.0
63.3
56.7
50.0
∇ W (MeV)
2.0
3.3
4.7
6.0
∇φ (rad)

At RFQ

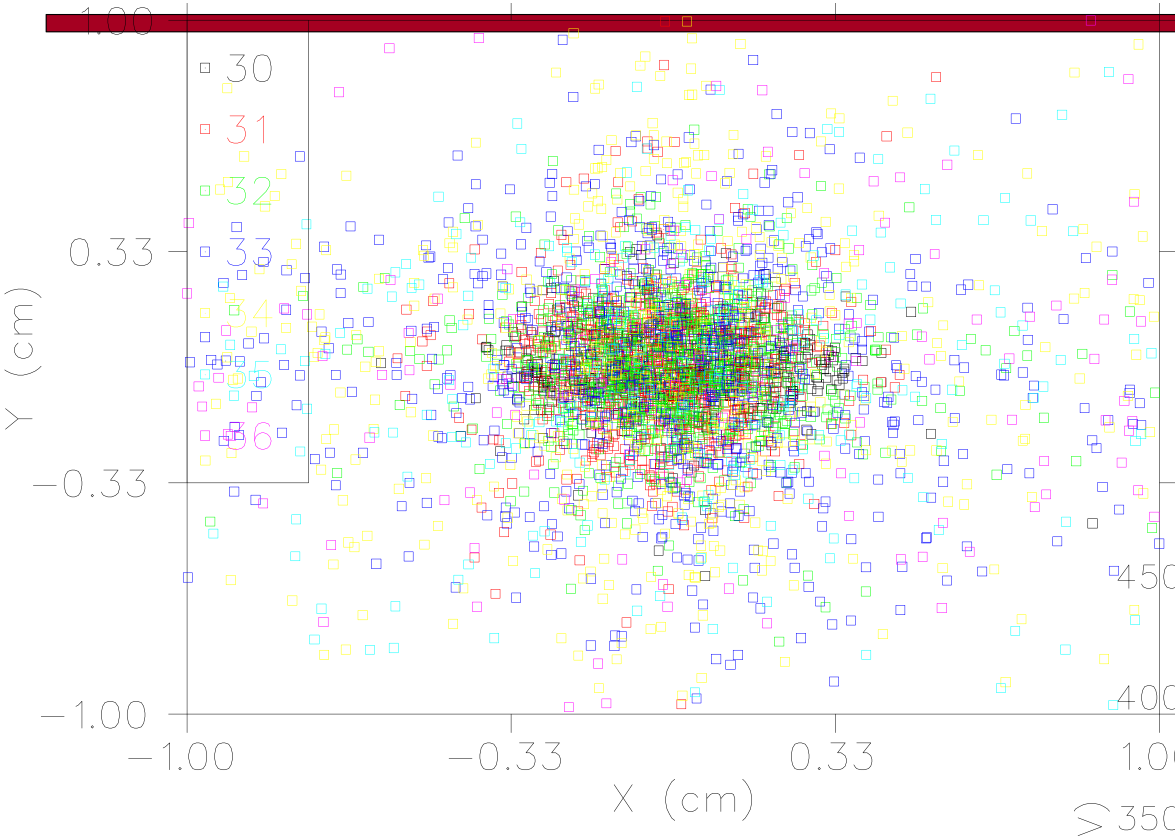


0.40
0.13
−0.13
−0.40
Y (cm)
−0.40
−0.13
0.13
0.40
X (cm)
29
30
31
32
33
34
35
36
37
38
39

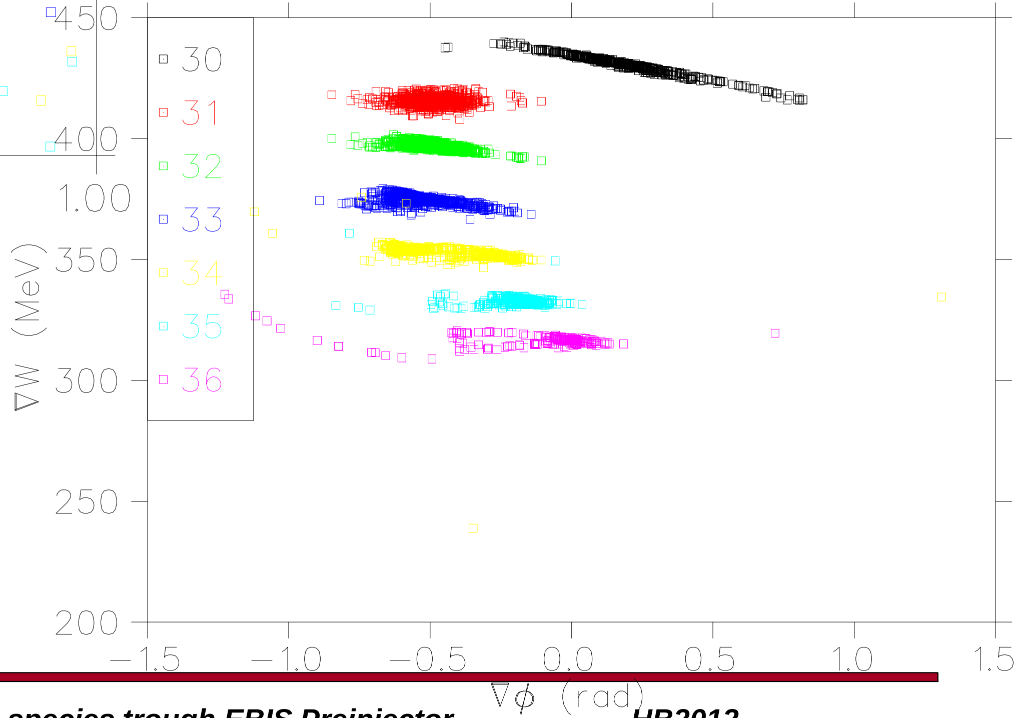


70.0
63.3
56.7
50.0
∇ W (MeV)
2.0
3.3
4.7
6.0
∇φ (rad)
+29
+30
+31
+32
+33
+34
+35
+36
+37
+38

At Linac

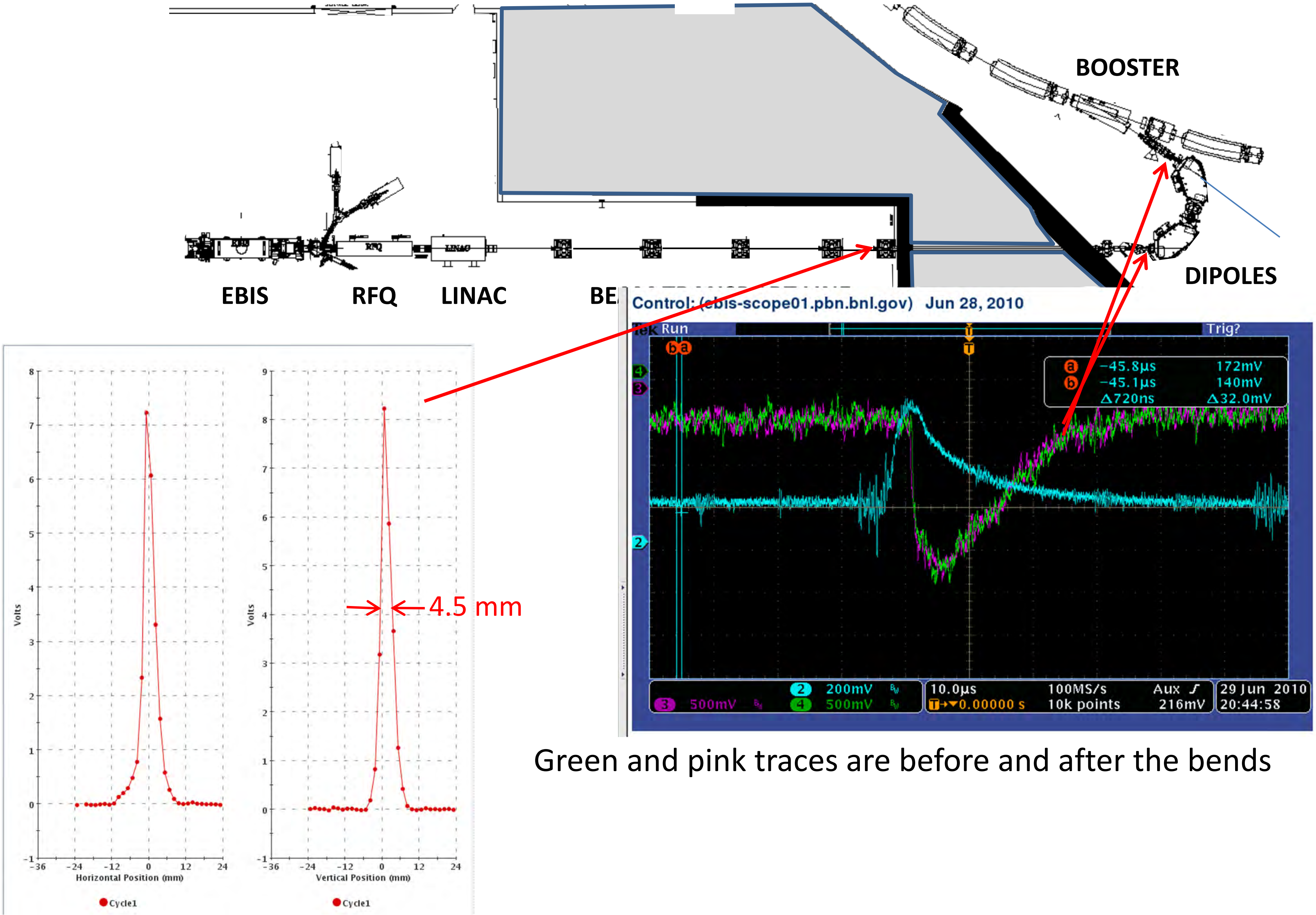


1.00
0.33
−0.33
−1.00
−1.00
−0.33
0.33
1.00
X (cm)
Y (cm)
30
31
32
33
34
35
36



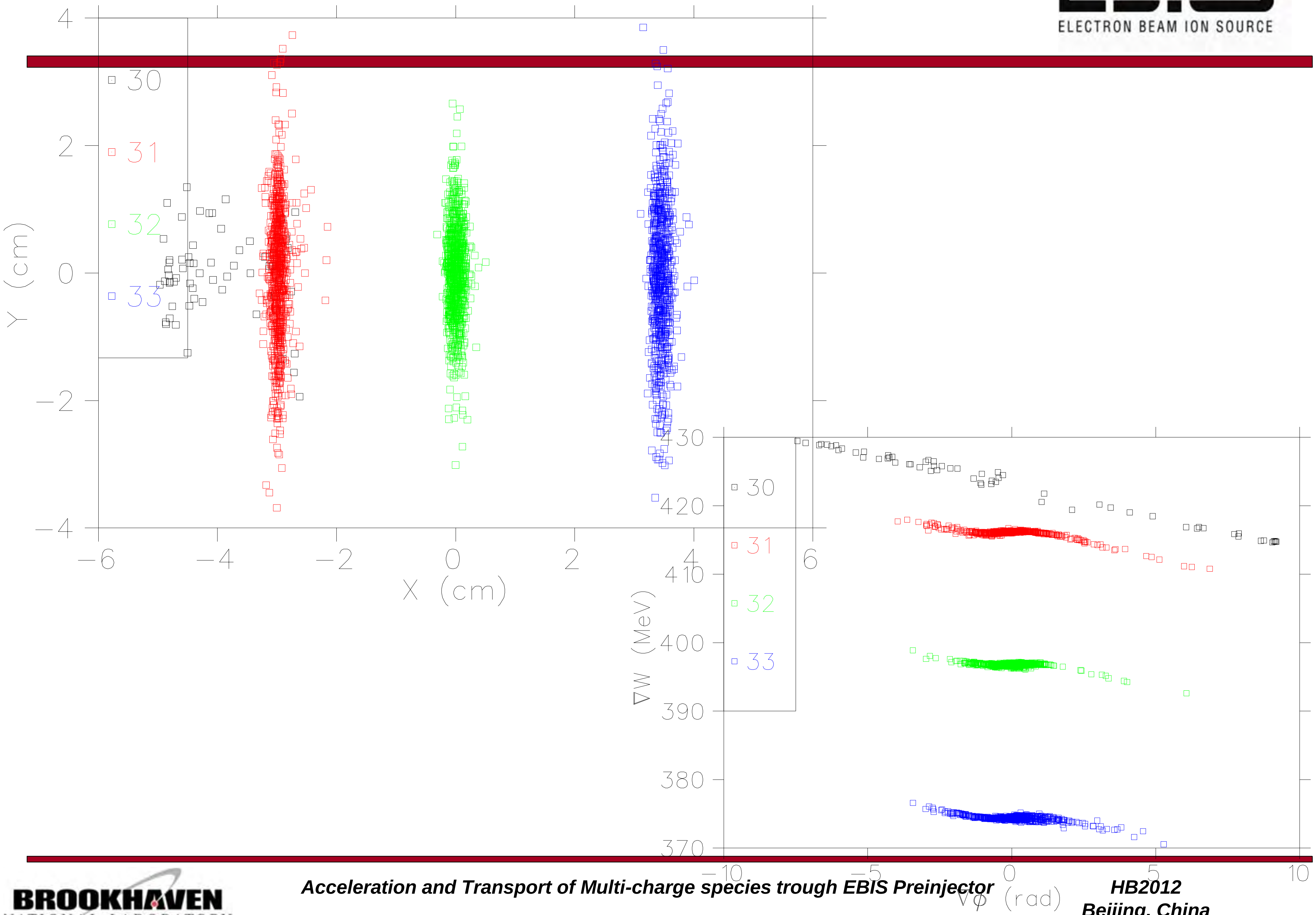
450
400
350
300
250
200
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
∇φ (rad)
∇W (MeV)
30
31
32
33
34
35
36

He^{1+} – first beam from EBIS transported to Booster

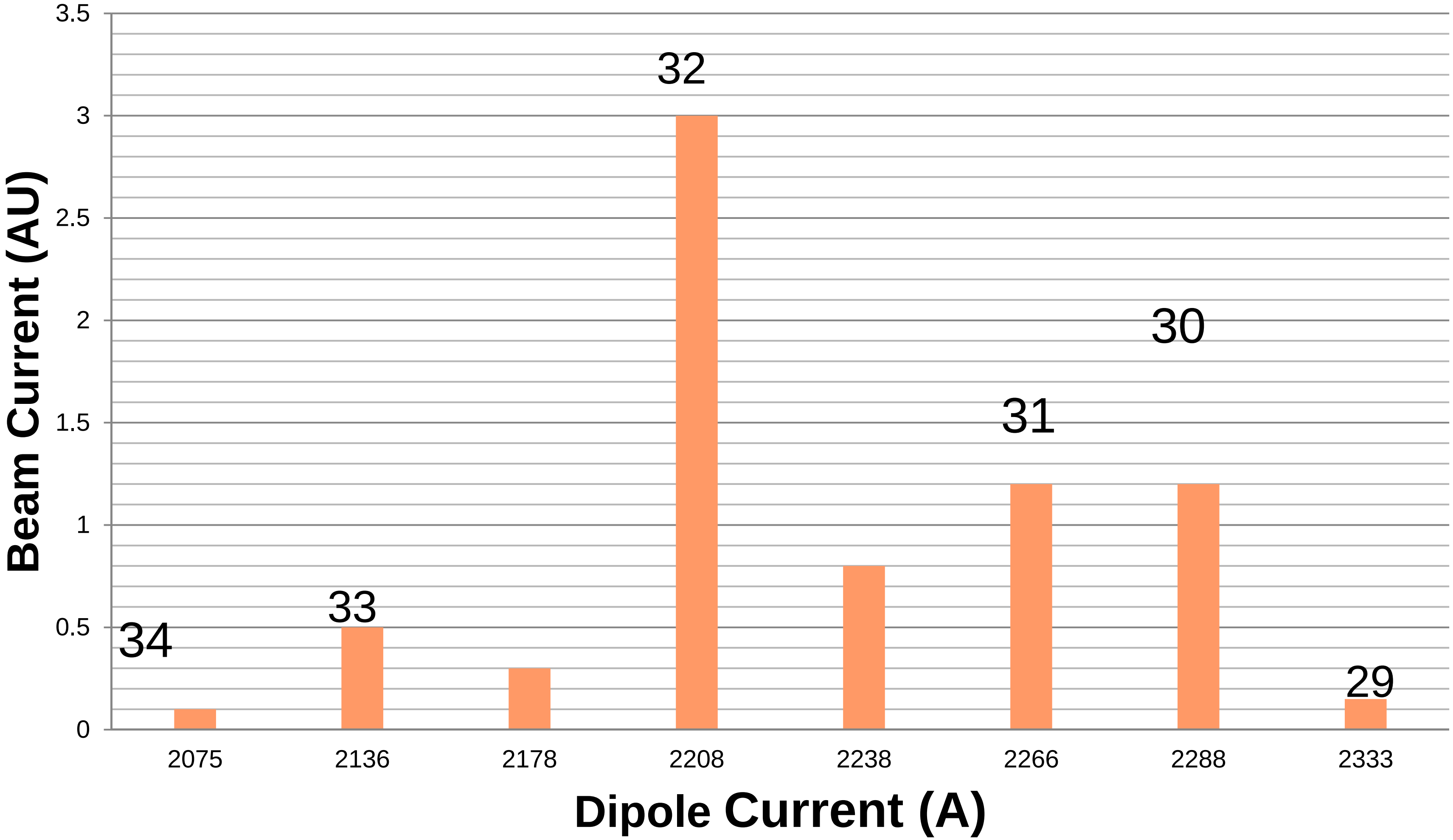


Green and pink traces are before and after the bends

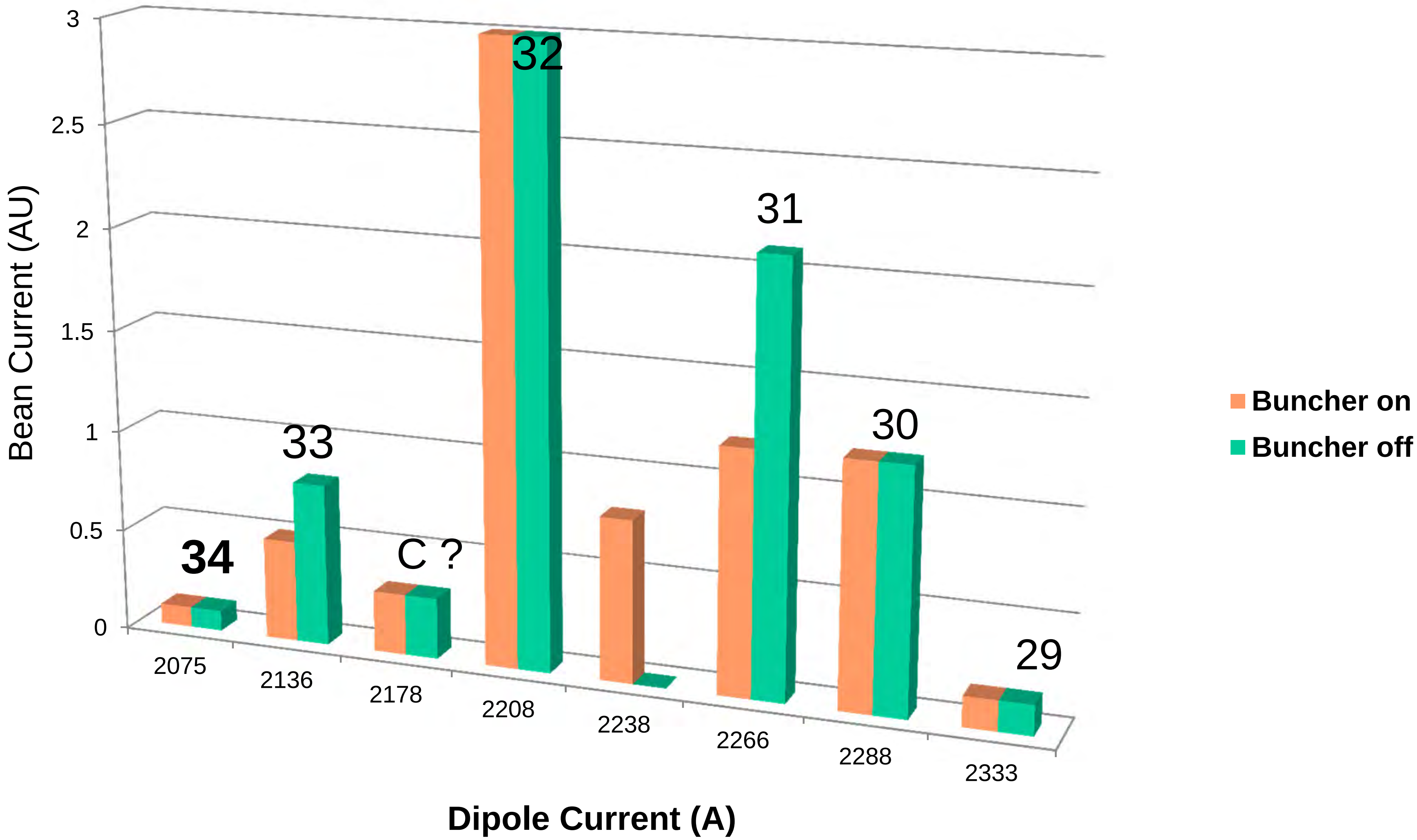
Middle of the Bend



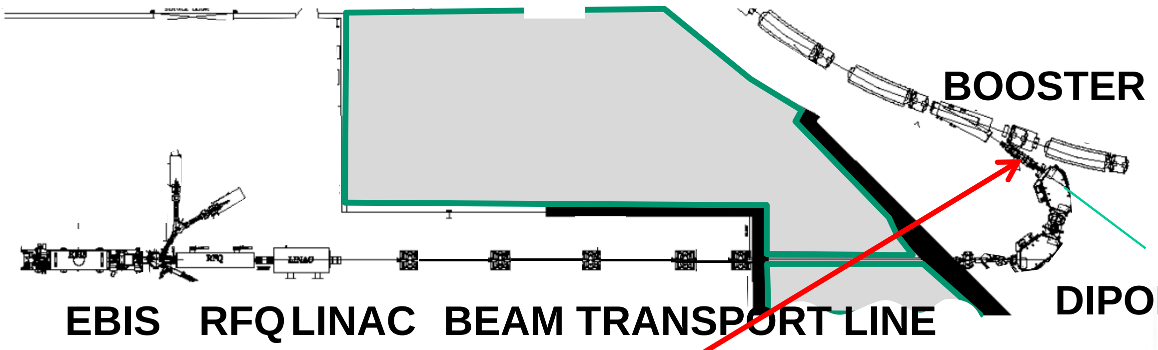
Gold at Middle of Bend



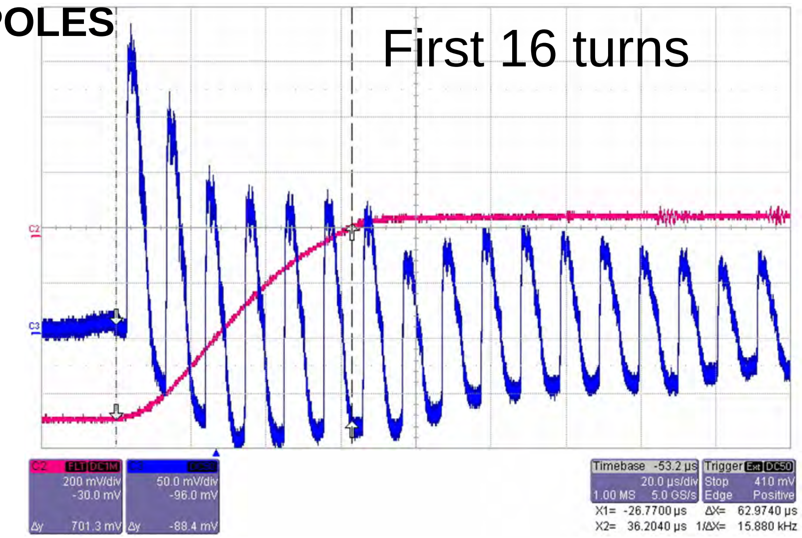
Gold at Middle of Bend: Buncher On/Off

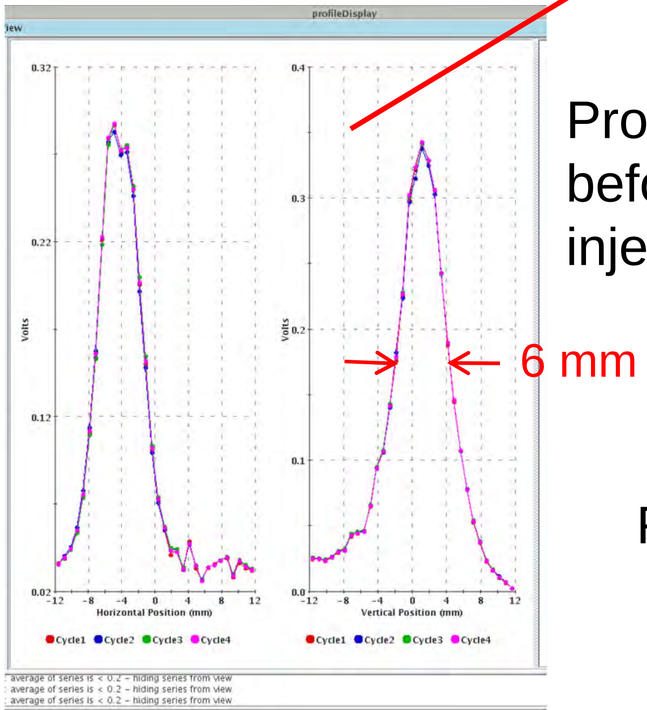


EBIS Beam circulating in the Booster



He+ beam from EBIS circulating in the Booster





Profiles right before the Booster injection

From the measure of the beam debunching time in Booster

$\Delta p/p = 2.0\times10^{-4} \pm 1.0\times10^{-4}$

(Requirement $\leq 5.0 \times 10^{-4}$)

EBIS beams transported to middle of bend (2 MeV/u)

He^{+1}	Conf. Time	2.5 ms
	RFQ Power	40 kW
	Linac Power	76 kW
	Pulse width	<20 μs
	Intensity	7×10^{10} ions / pulse

Transmission (helium):

RFQ Input FC	1.4 mA (18.5 nC)	
RFQ Output FC	1.4 mA (15.0 nC)	T=100%,(T=81% charge)
XF14 (after linac)	1.1 mA	T=79%
XF 89 (before bend)	1.1 mA	T=100%
XF108 (after ***both*** bends)	1.1 mA	T=100%

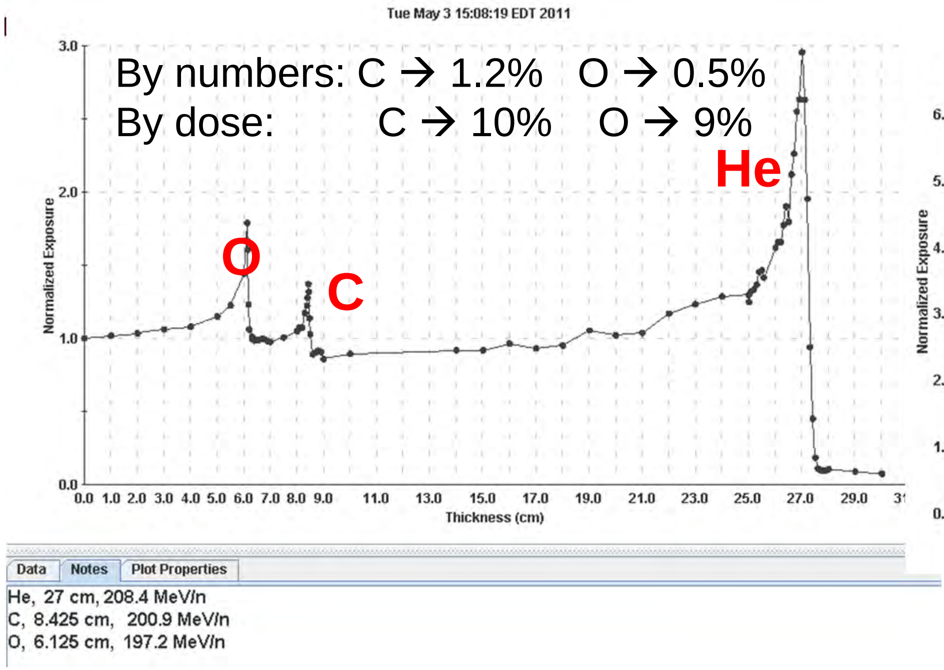
Gold Transmission to booster injection

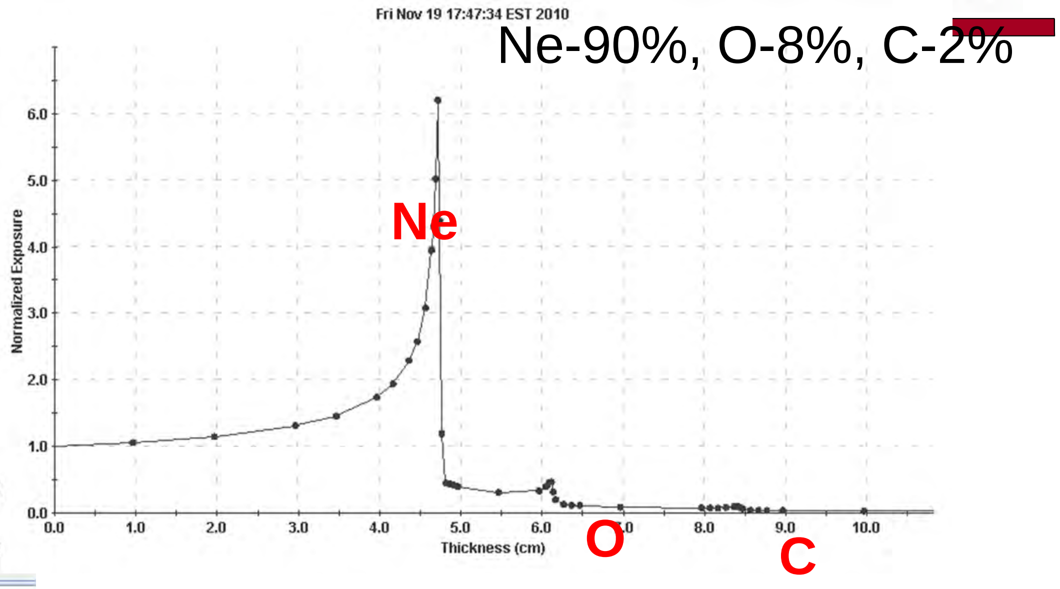
Charge		EBIS# (Measu)	RFQ	Linac	Bend	B INPUT
26	1.2	0.033622	0	0	0	0
27	7.5	0.044829	0	0	0	0
28	20	0.064041	0	0	0	0
29	45	0.092859	0.000464	0	0	0
30	80	0.108229	0.060933	0.044206	0.005698116	0
31	111	0.120077	0.107589	0.106748	0.105307397	0
32	124	0.128082	0.123727	0.123727	0.123599103	0.123599
33	111	0.120077	0.096182	0.091499	0.085134486	0
34	80.5	0.112072	0.07139	0.062872	0	0
35	49	0.076049	0.028975	0.021598	0	0
36	25.5	0.048031	0.015754	0.008357	0	0
37	11.5	0.03202	0.005487	0	0	0
38	4.5	0.020013	0.003162	0	0	0
		1	0.513662	0.459008	0.123599	0.123599
Sim (nC)		54.5	27.9945	25.01659	6.7362	6.7362
Measu (nC)		54.5	29.6	16.2	7.4	5.8
Ratio		1.000	1.05735	0.647	1.10	0.86

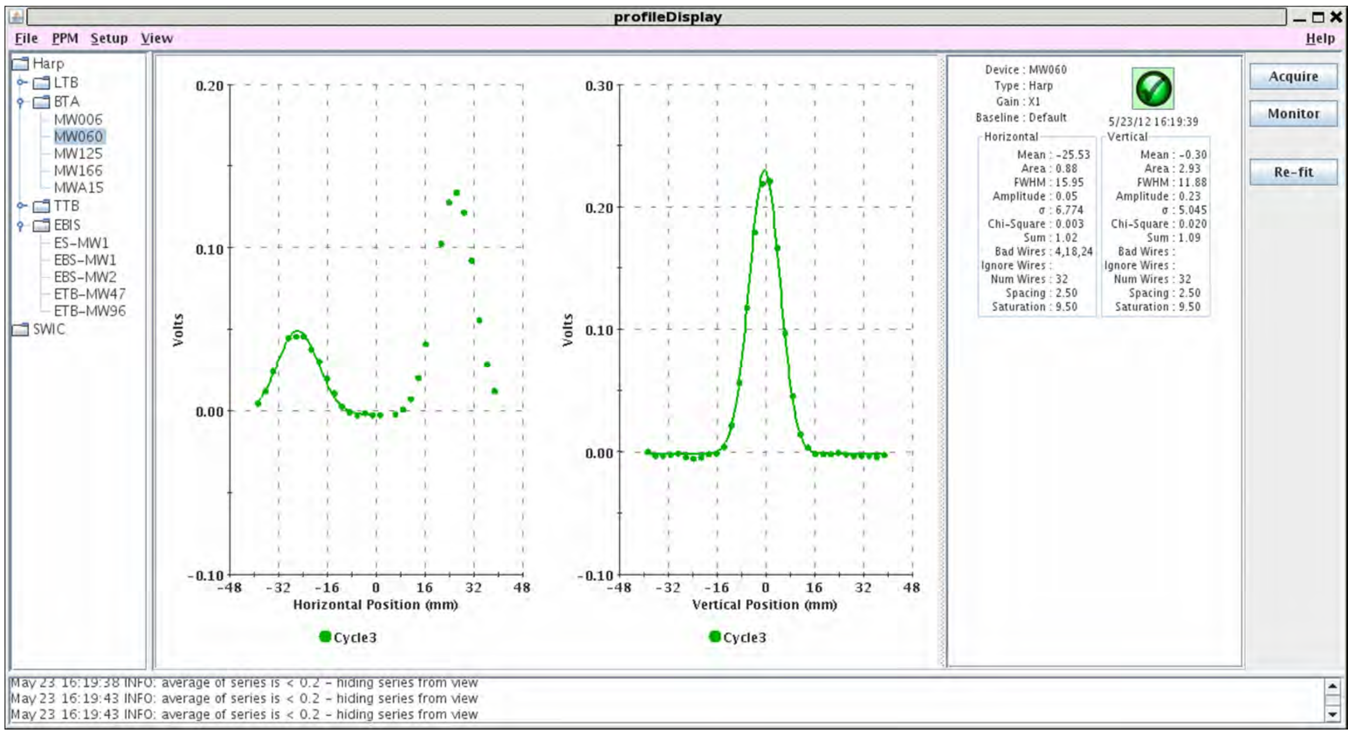
Electron current 7.5 A

Design	Achieved	Ratio
0.81*.128*54.5		5.8/5.7
=5.7 nC	5.8 nC	=1.02

Multiple ion Species seen after Booster







Beam profile in BTA

~ 60% Cu^{+11}

~ 40% Ar^{+7}

Tuning procedure with Multiple Charge Species (PLAN vs Real)

ELECTRON BEAM ION SOURCE

We have studies the tuning procedure for the linac. Summary as follows:
Set all the quad to calculated values and bunchers off

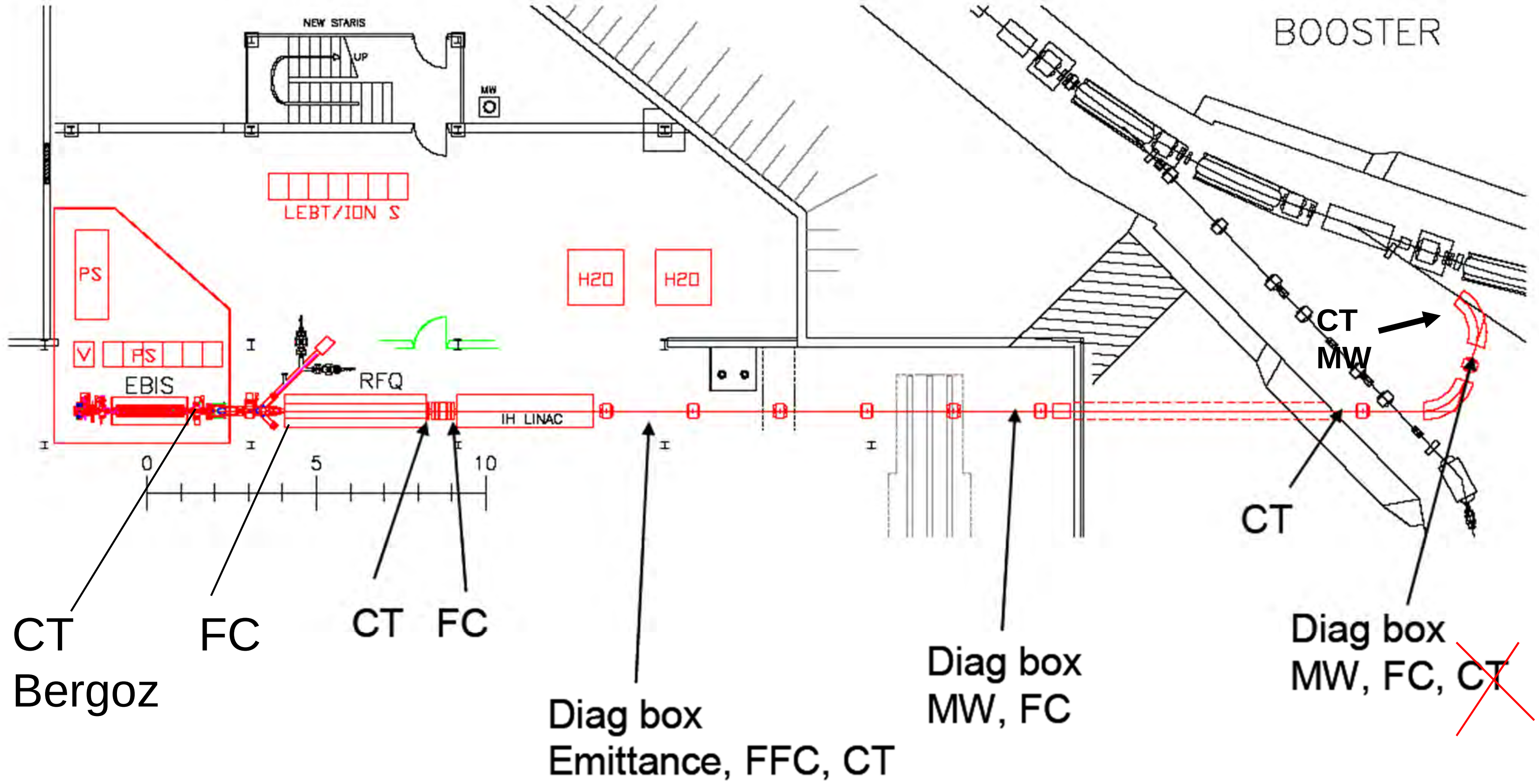
- **LEBT**
  - -With TOF maximize beam current for desire charge state (NOT practiced)
  - -Maximize beam current after RFQ to find the match into RFQ
- **RFQ**
  - -Since RFQ will be commissioned about 1.5 years earlier than linac, (NOT done) we will set up analyzing magnet to set the correct amplitude (e. g Au^{+32})
- **IH Linac**
  - Maximizing the beam current for desire ☑charge state using Booster to set phase and amplitude of IH Linac
- **MEBT**
  - -Maximizing current after IH Linac, by tuning quads and buncher (using Booster)
- **HEBT**
  - -Minimize the energy spread by tuning buncher amplitude and looking beam size with profile monitor at high dispersion at the bend (using Booster)

-Verify bend magnet setting with Booster

Conclusions

- EBIS pre-injector provided Au and Cu beam for RHIC Run 12 and tens ions species to NSRL
- Acceleration and transport of multi ion species seen in the EBIS pre-injector and Booster
- EBIS pre-injector is very stable, reliable and reproducible

Diagnostics



CT=current transformer; FC= Faraday cup; FFC=fast Faraday cup; MW=multiwire.

Diagnostics

- Exit of EBIS: CT (Bergoz), depends on the voltage on nearby electrostatic grid lens
- RFQ Input: FC, diameter 13 mm, can collect +/- 30% delQ/Q
- RFQ Output: CT, lot of noise due to RF of RFQ, and pulse quadrupole, NOT USED
- MEBT Output: FC, Not biased, electron suppression due to magnetic field of quad
- Linac Output: CT (XF14), sensitive to EBIS voltage configuration

  FFC: due to multiple charge, not much used
- Middle of HEBT: FC47, diameter 30mm, not much used due to its size , beam diameter is much bigger

  MW47: Used to determine emittance with multiple charge species

Diagnostics (cont.)

- Before the bend: CT, (XF89)
- Middle of the bend: FC96, 30 mm diameter, sensitive to ion species since biased is limited to few kV, read higher for lower q/m not used in transmission calculation

  MW96: very useful, scanning magnetic filed see all the ion species,

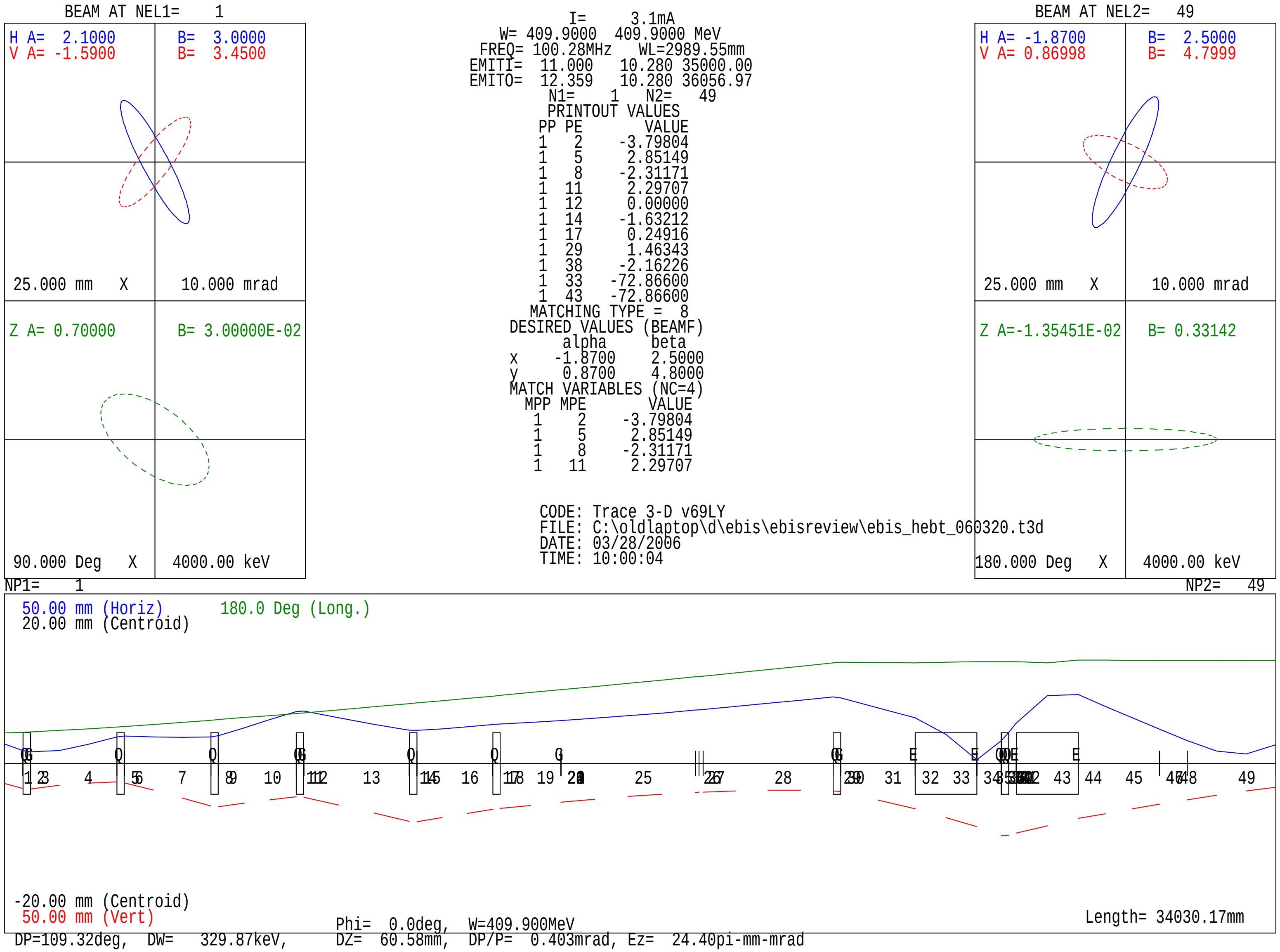
  scrapers, Very important to stop other charge
- Input of booster: CT (XF108), very important to determine injection efficiencies

- Looking for diagnostics to distingious charge states

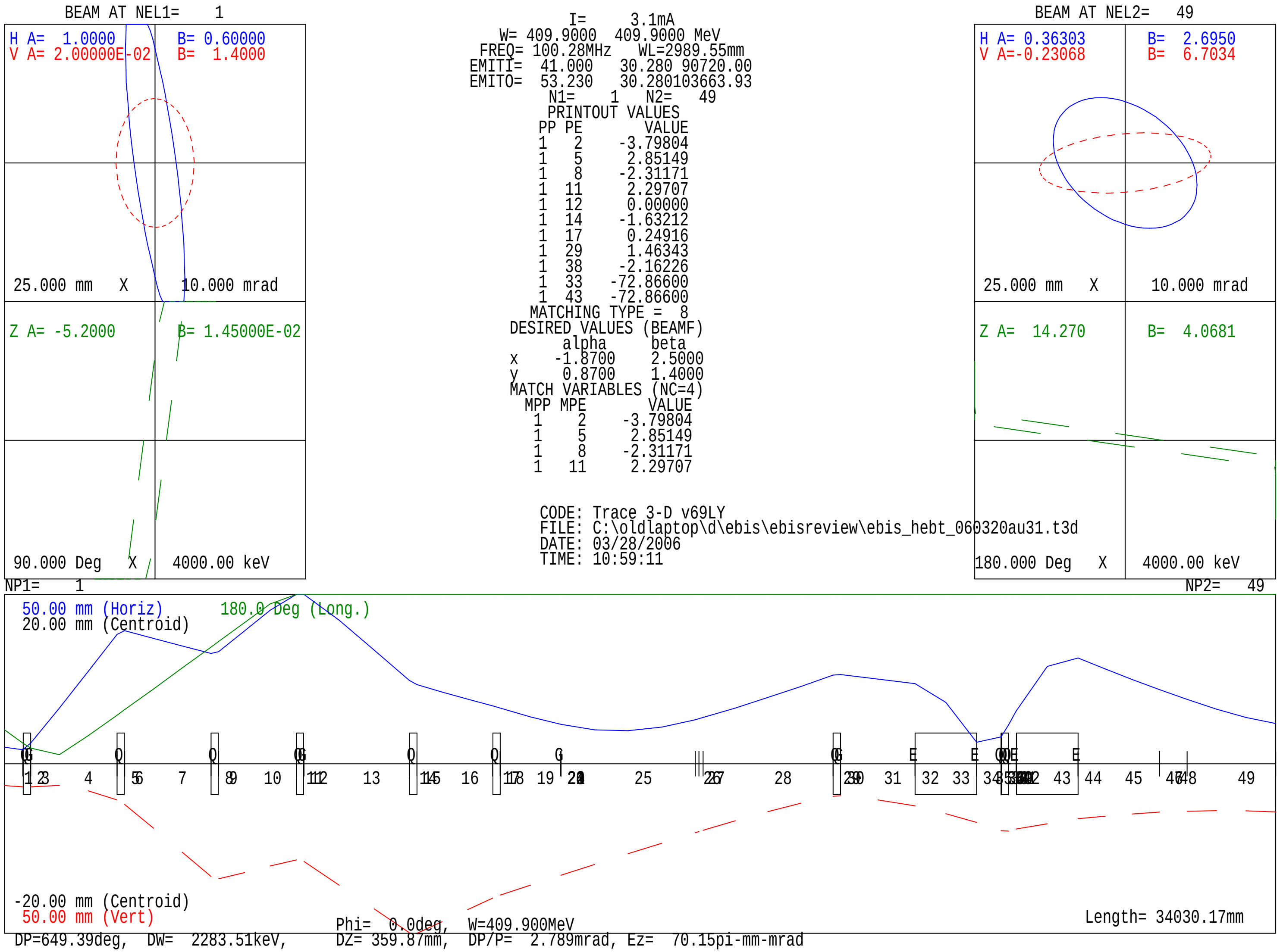
Optics of the Transport line to the Booster

Quad#	G T/m
1	3.8
2	2.9
3	2.3
4	2.3
5	1.6
6	0.3
7	1.5
8	2.2

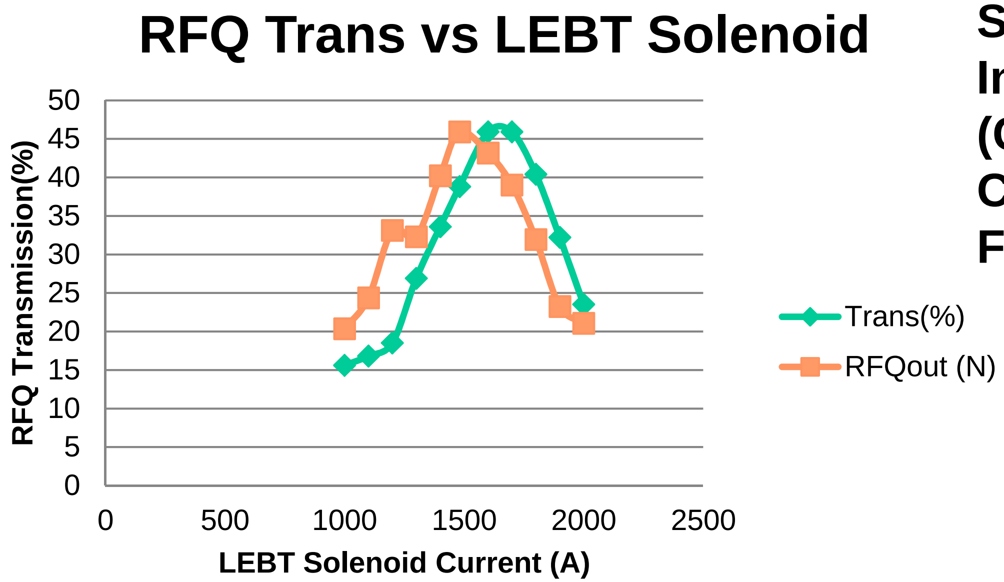
Buncher	V kV
1	0
2	33



Beam Envelop for Au^{+31}

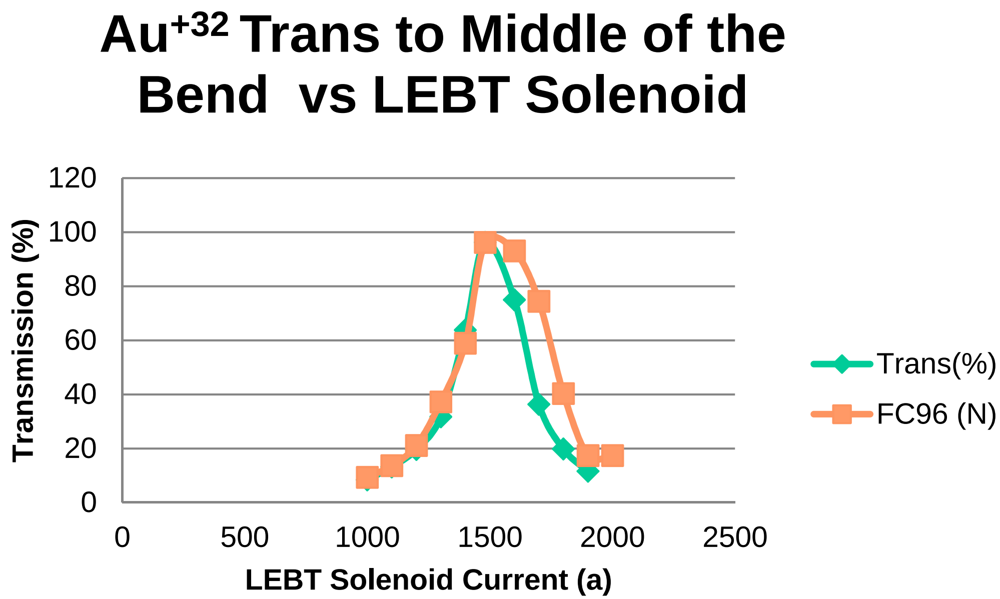


Transmission of Au ions



Simulation done using TRACK
Input included Au^{32} and $\Delta p/p = \pm$ 10%
(C^2, N^3, O^3, $Ne^{3\text{-}4}$) at EBIS voltage of 104 kV.
Current was measured at end of MEBT by Faraday cup

TRACK, PARMILA, and LORAS codes were used in simulations to transport Au^{+32} ions to the middle of the bend. Current was measured by Faraday cup (FC96) in the middle of the bend.

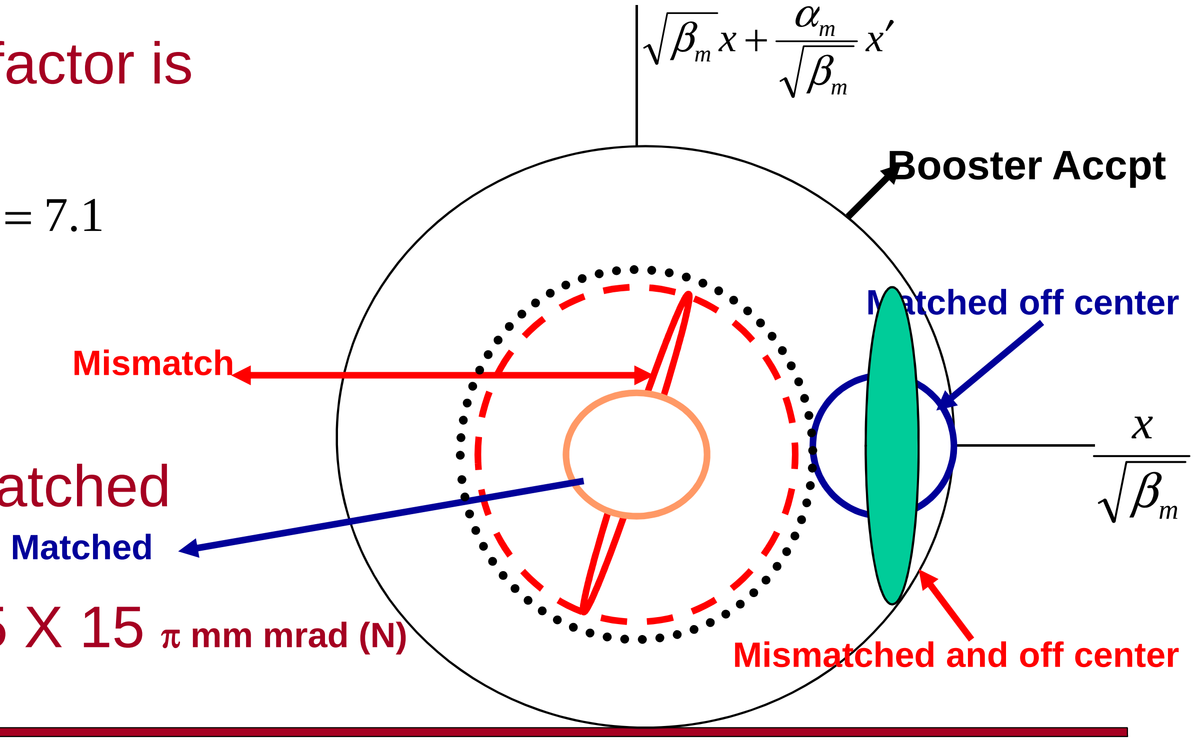


Inflector Aperture

- Inflector gap is 17 mm and 2.2 meter long **(BNL #159, Gardner)**
  => Geometric acceptance 29 π mm mrad, α_H=-1.87, β_H=2.5m
  Infector acceptance 1.9 π mm mr (N)
- Lattice function at exit of inflector are α_H=-1.72, β_H=11m, η_X=-2.4 m
- Full beam size $2a = 2\sqrt{\varepsilon_{90}\,\beta_H + (\eta_x \frac{\Delta p}{p})^2}$ =22.1 mm for matched injection
- Mismatch emittance dilution factor is

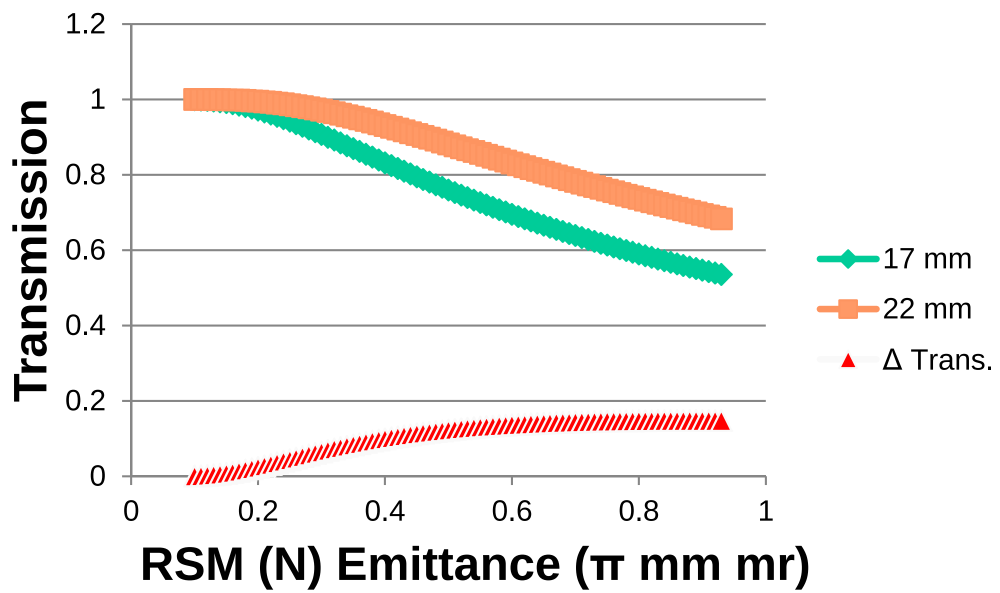
$$\frac{\varepsilon_i}{\varepsilon_m} = \frac{\sigma_i^2}{\sigma_m^2} = \frac{1}{2}(\beta_m \gamma_i + \beta_i \gamma_m - 2\alpha_i \alpha_m) = 7.1$$

- Linac emittance of 0.7(norm) will result in 5 π mm mrad
  R=15, 3.31 matched. 2.6 mismatched
- Incoherent tune shift 0.08
- Booster acceptance (VXH) 4.5 X 15 π mm mrad (N)



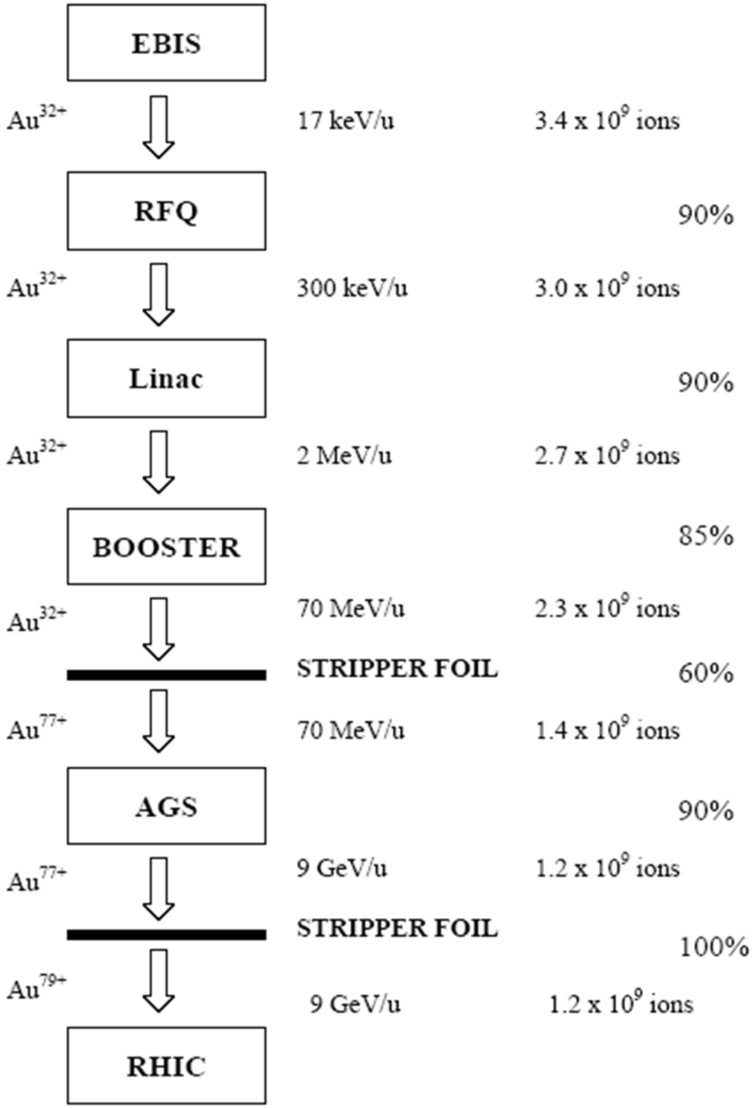
Emittance at Inflector

Last December inflector aperture was increase to 22 mm from 17 mm
The transmission was increase about 85% from 70% percent



=> Emittance (rms ,N) about 0.55 (π mm mr)

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



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

Pikin

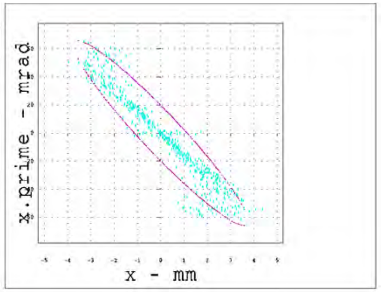
2-D simulation with TRAK

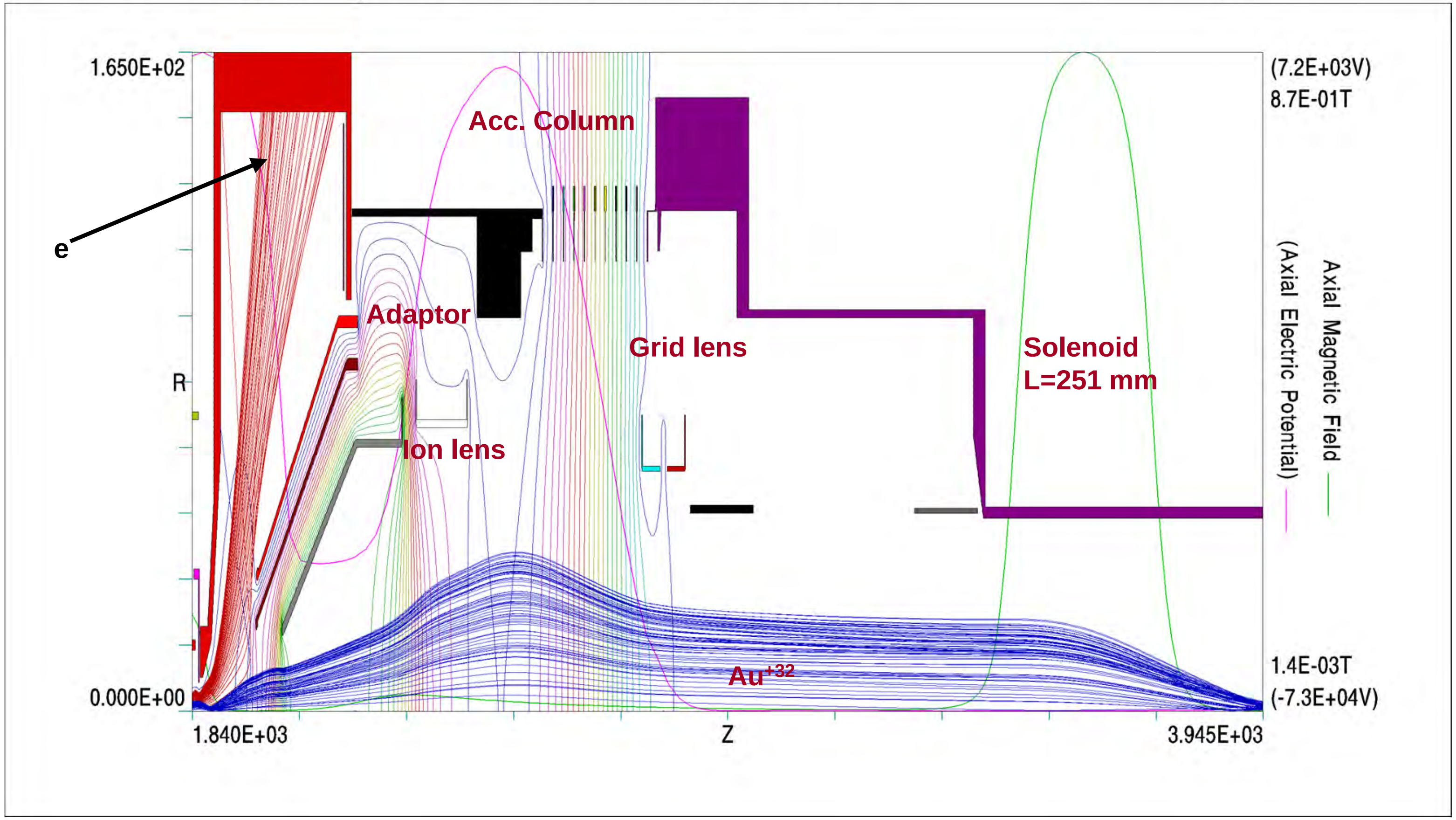
This Plot Created On: March 24, 2006

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

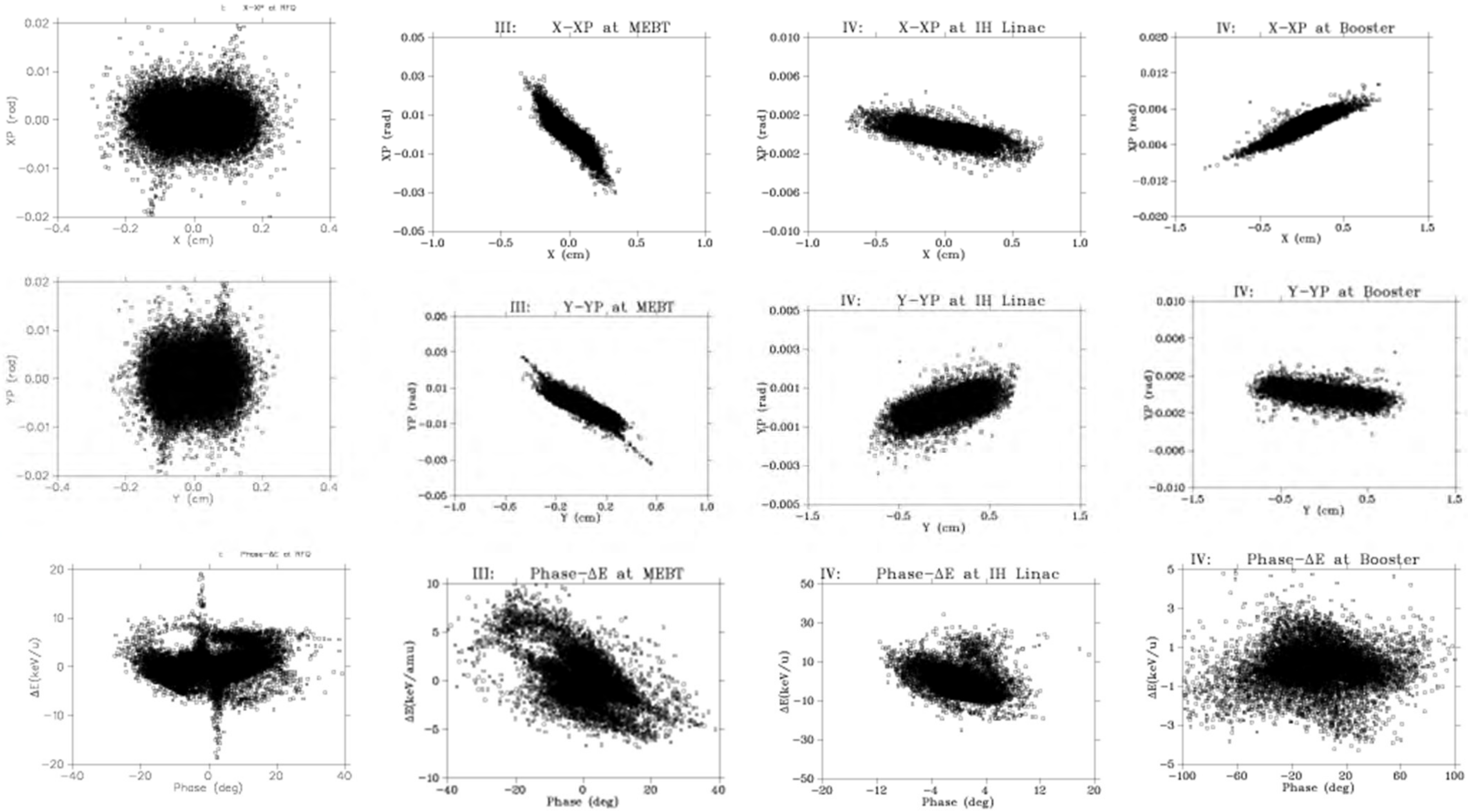
ELECTRON BEAM ION SOURCE

RFQ MEBT IH HEBT

X-XP

Y-YP

ΔW-Δφ

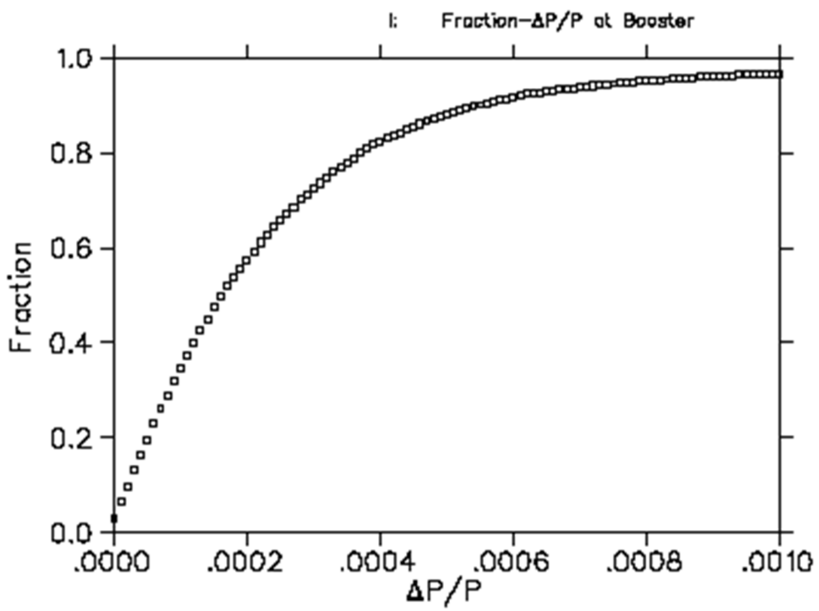


End-to-End Simulations

ELECTRON BEAM ION SOURCE

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.($\Delta p/P$=0.1%)	0.960
	T.($\Delta p/P$=0.05%)	0.896

End-to-End Simulations with error tolerances

- 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

ELECTRON BEAM ION SOURCE

- 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

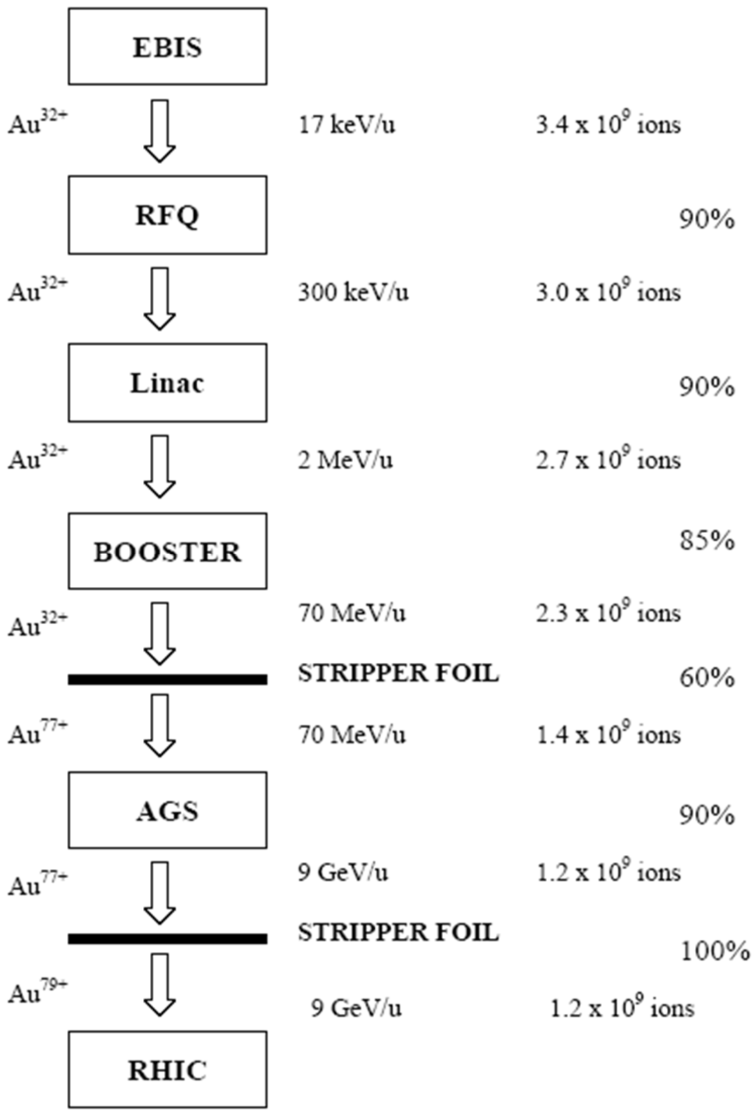
End-to-End Simulations with Errors

- 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



Simulations

Au^{+32}

97.6%

94.9%

93.3%¥, §

§ ΔP/P =0.05% **¥ Longitudinal only**

Performance Requirements of the EBIS

ELECTRON BEAM ION SOURCE

Species	He to U
Output (single charge state)	≥1.1 x 10^{11} charges
Intensity (examples)	3.4 x 10^{9} Au^{32+} / pulse (1.7 mA) 5 x 10^{9} Fe^{20+} / pulse (1.6 mA) 6.3 x 10^{10} He^{1+} / pulse (2.0 mA)
Q/m	≥ 0.16, depending on ion species
Repetition rate	5 Hz
Pulse width	10 - 40 μs
Switching time between species	1 second
Output emittance (Au^{32+})	< 0.18 π mm mrad,norm,rms
Output energy	17 keV/amu
ΔP/P	<0.05 %

Space Charge in LEBT

ELECTRON BEAM ION SOURCE

Current 10 mA

	Z	A	Q	Q/m	vext	EPS(un)	Perv(gen)	ET	SCT	Ratio	Debye Len
P	1	1	1	1.00	16.2	67	0.00296	0.0019	0.1971	104.5375	0.000436
He3	2	3	2	0.67	24.4	67	0.00197	0.0019	0.1314	69.69164	0.000534
D	1	2	1	0.50	32.5	67	0.00148	0.0019	0.0985	52.26873	0.000616
Si	14	28	12	0.43	37.9	67	0.00127	0.0019	0.0845	44.80177	0.000665
Au	79	197	32	0.16	100.0	67	0.00048	0.0019	0.0320	16.9807	0.001081

Measurement for 1.7 mA Au^{+25} (n,rms) =0.125 π mm mrad @ 20keV

Calculated(n,rms) =0.125 π mm mrad

Envelope equation

$$R''+k_0^2R-\frac{(4\varepsilon_{rms})^2}{R^3}-\frac{K}{R}=0$$

Gen. Perv. (K)= QI/(2 π ε0 m c^3 $\beta^3\gamma^3$)

Debye Length(λD) = 2 ε^2rms/K=(1/8)(R/λD)^2

Energy = 17 keV/u
β=0.006017
γ=1.000018
R= 15 mm