SNS Transfer Lines

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Outline

- HEBT

  Functions, Optics, Energy Jitter Correction, Energy Spread, Transverse Emittance, Collimation, Diagnostics

- RTBT

  Functions, Optics, One kick failure, collimation, diagnostics, Window Scattering, Distribution at Target,

- Summary

Acknowledgements

- Contributors:
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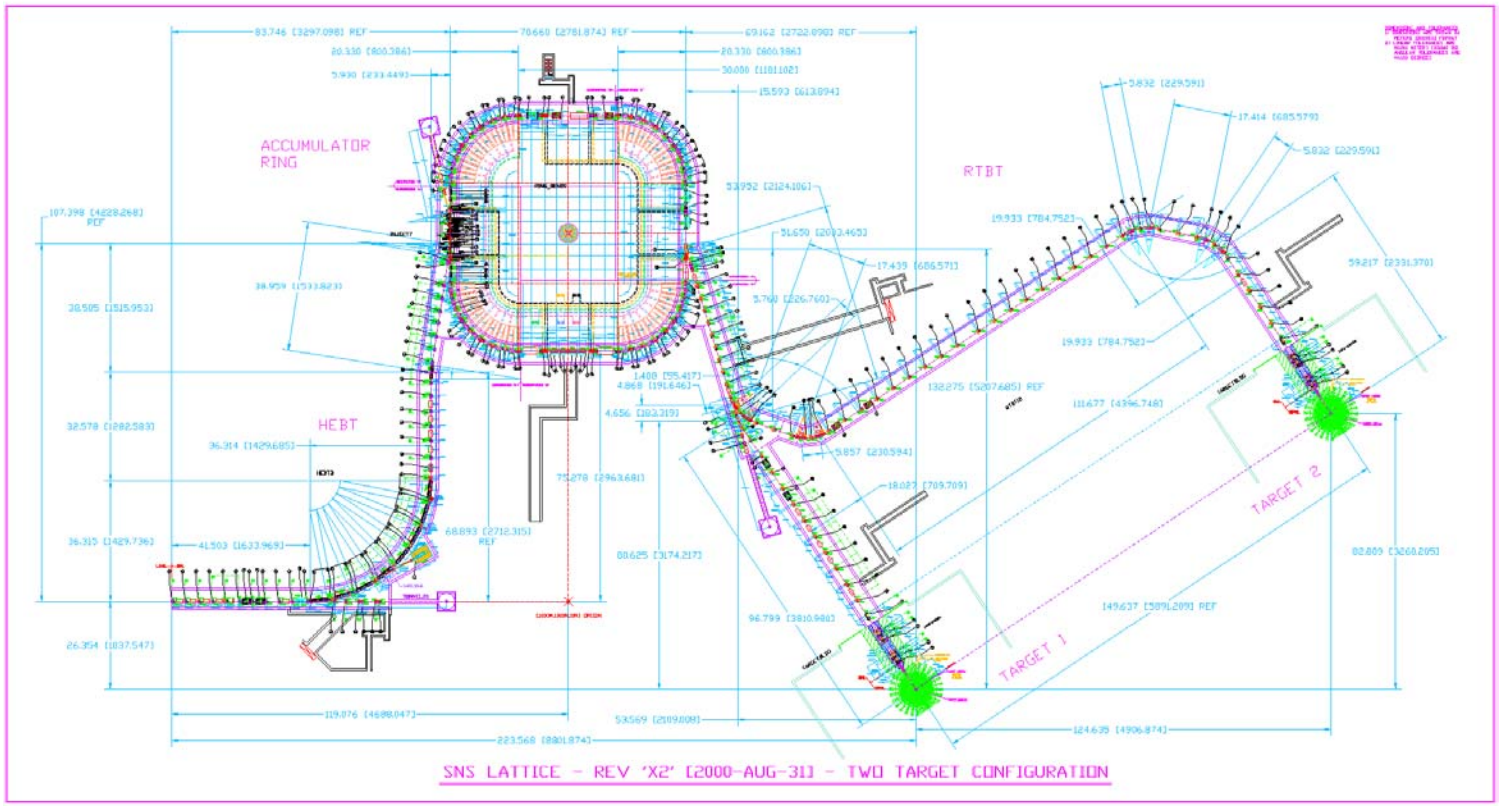
  A. V. Fedotov, Y.Y. Lee, W.T. Weng,
  J. Wei, N. Tsoupas

Transfer Lines & Ring



Requirements

- Matching from Linac to Ring
- Low Uncontrolled Beam Losses (<nA/m)
- Beam Characterization
- Detect Fault Conditions to Protect Ring

	Linac	Ring
Transverse Emit.(rms, Nor)	<0.5	<0.5 pi mm rad
Energy Centroid Error	+- 1.5	<0.2 MeV
Energy Spread	+- 0.3(rms)	+- 4 (Full) MeV
Beam Chopper Gap	<1.0E-4	<1.0E-4

Linac to HEBT IDD

Flange, Valve, beam height, vacuum (10^{-8} T), etc.
LANL responsible for diagnostics to the linac dump
Current, energy, pulse width, rep rate, etc.
Signals

Transverse emittance	< 0.5 pi mm mrad (norm, rms)
off normal	> 0.5 pi mm mrad (norm, rms)
Energy spread	±0.3 MeV (rms)
Bunch spread	±1.5 deg (rms)
Energy centroid error	± 1.5 MeV max
Phase centroid error	± 2 degrees
Beam halo outside 5 sigma	$<10^{-4}$
off normal	3×10^{-4}
Beam chopper gap	$< 10^{-4}$
off normal	3×10^{-4}

RF energy corrector and energy spreader cavities provided by LANL

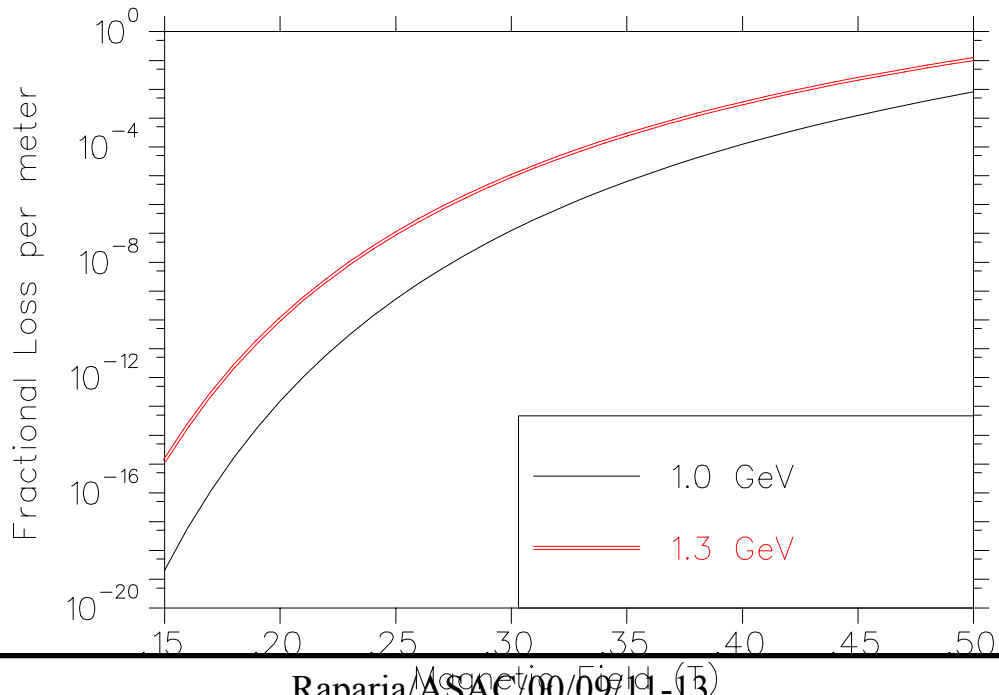
Functions of HEBT
More Than a Transfer Line !

- Optical and Dispersion Matching to Linac and Ring
- Linac Energy Jitter Correction
- Increase Energy Spread (ARMS)
- Characterization of the Linac Beam(L-Dump)
- Cleans Halo, Protect Ring injection
- Cleans momentum tail from linac
- Diagnostics

H Minus Stripping

$$fractional_loss_per_meter \approx \frac{B}{A_1} e^{-\frac{A_2}{\beta\gamma c B}}$$

Where B=dipole field(T); $A_1 \sim 8 \times 10^{-6}$ V*s/m; $A_2 \sim 4.3 \times 10^9$ V/m



Lorentz Stripping of H^- in HEBT

$$\approx \frac{B}{A_1} e^{-\frac{A_2}{\beta\gamma c B}}$$

Where B=dipole field(T); $A_1 \sim 8 \times 10^{-6}$ V*s/m; $A_2 \sim 4.3 \times 10^9$ V/m

	T=1000 MeV	**T=1300 MeV**
$\beta\gamma$	1.81	2.17
Magnetic filed for loss rate of 1.3E-7 per meter	0.3 Tesla	0.252 Tesla
Magnet length to bend 3 degrees	1 meters	1.42 meters

Vacuum Stripping

HEBT Vacuum < 5x 10^{-8} Torr.

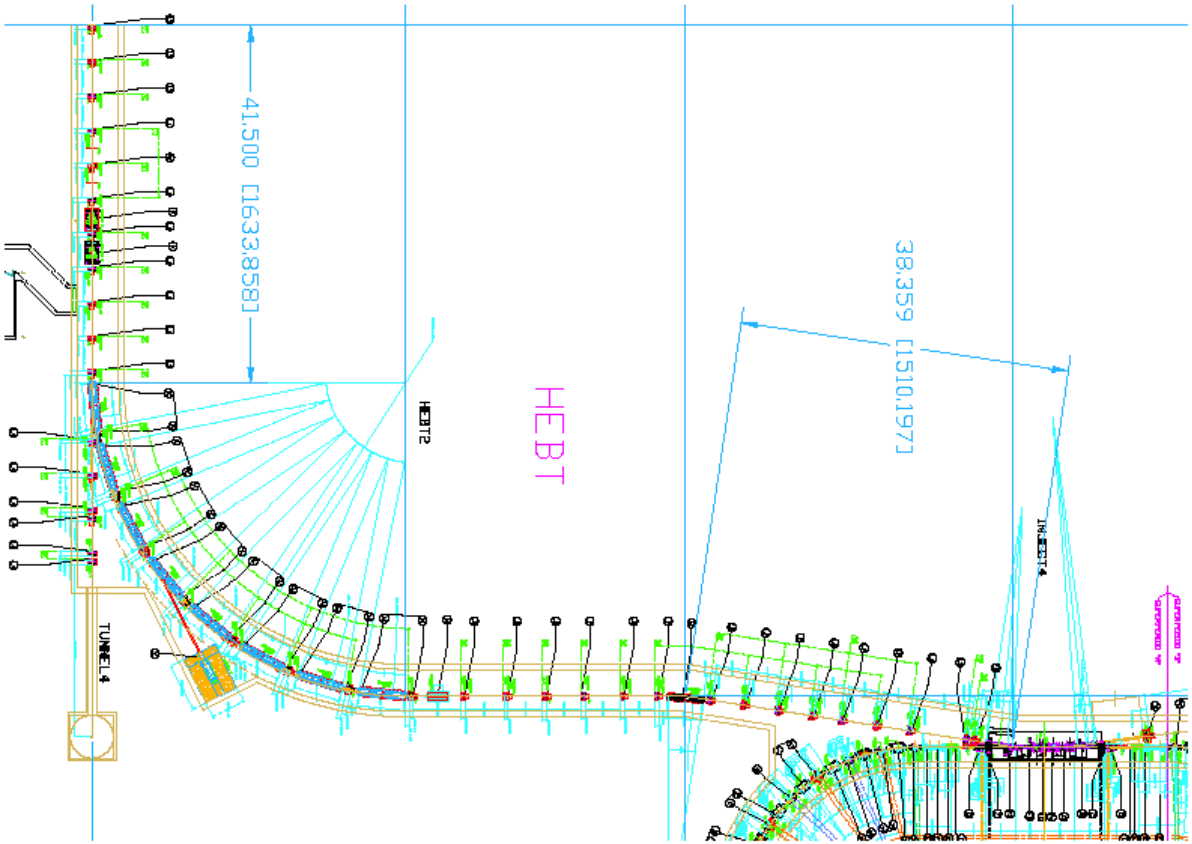
Assuming

50% Hydrogen ($\sigma = 10^{-19}$ cm^2 /atom)

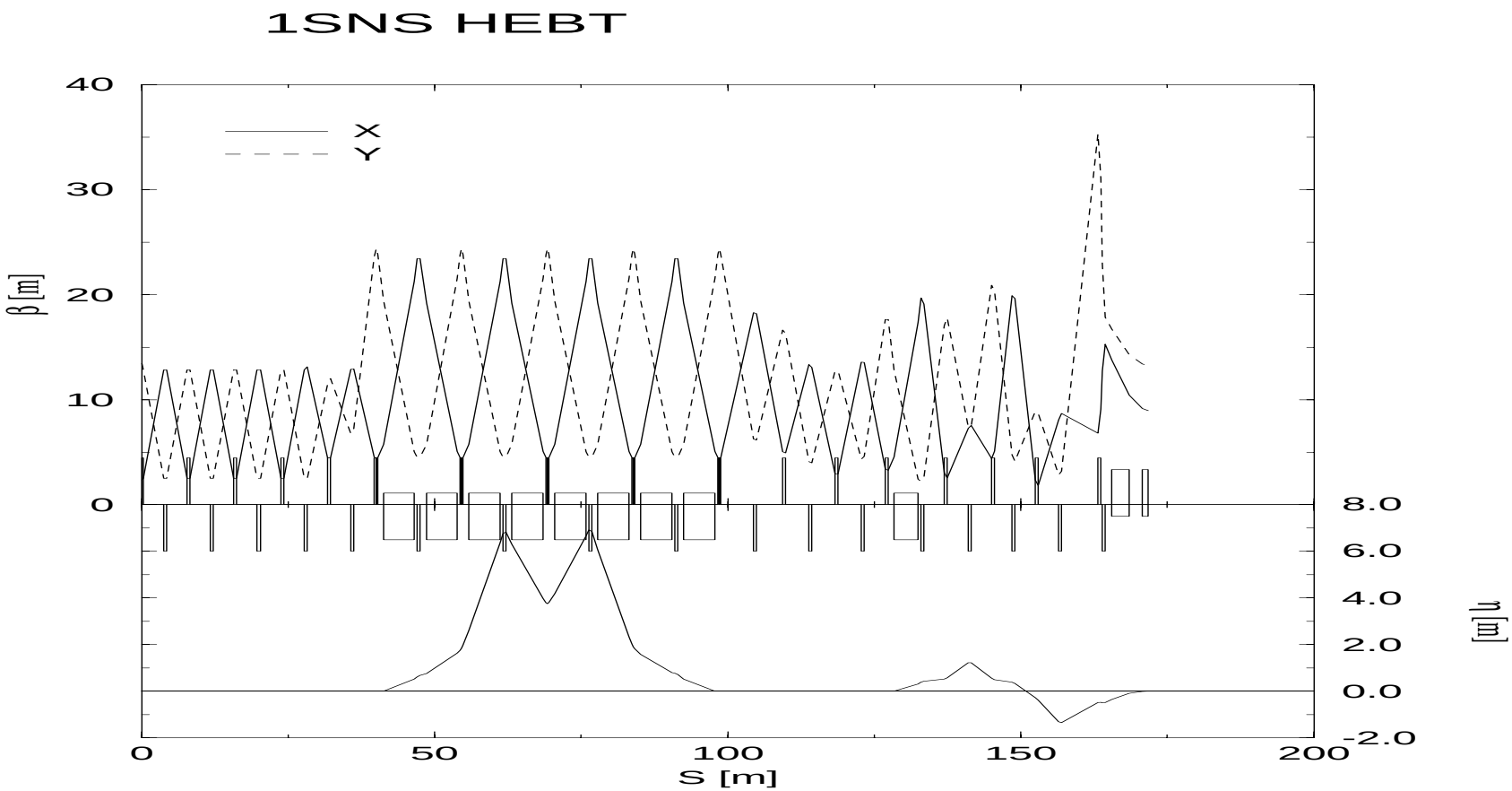
50% oxygen/nitrogen($\sigma = 10^{-18}$ cm^2 /atom)

Losses 0.18 nA/m

Layout of HEBT



Transport Output for HEBT



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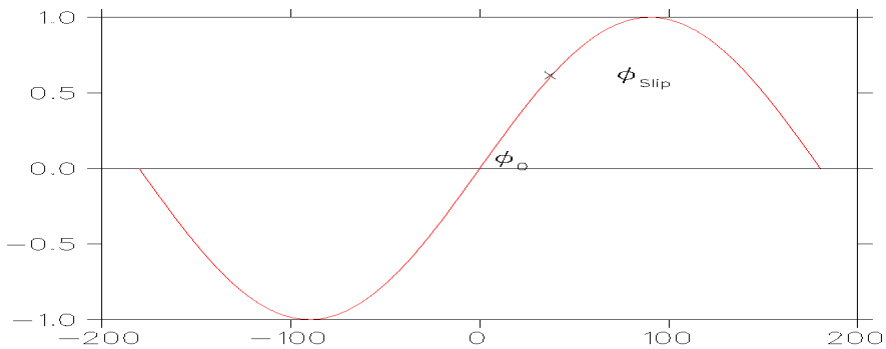
Phase and Energy Jitter Out of Linac

	Phase Jitter (degrees)	Energy Jitter (MeV)
SC linac	± 2.0	± 1.5

For ±0.5 degrees phase error and ±0.5% Amplitude error

Working of ECC

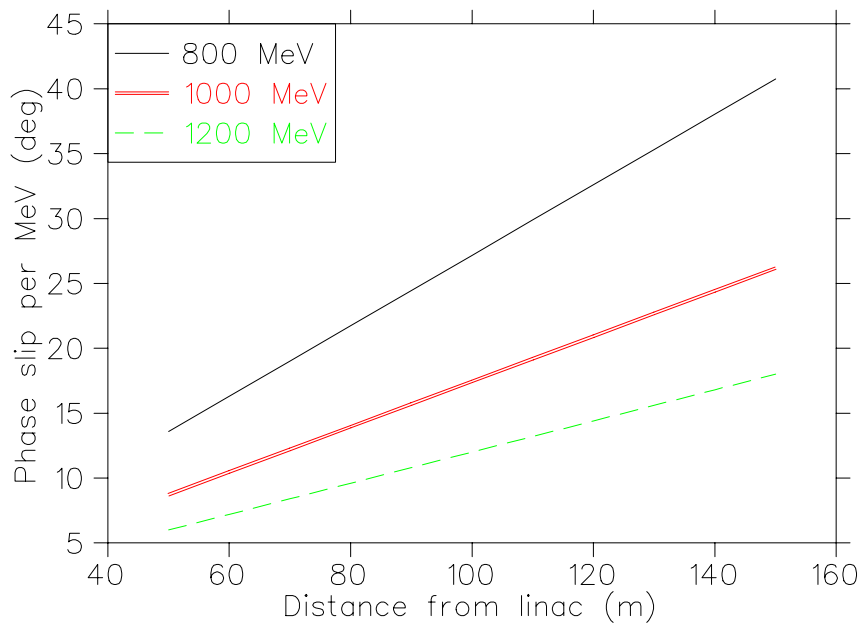


$$\Delta E = V_0 \sin(\phi_{Slip}) \Rightarrow V_0 = \Delta E / \sin(\phi_{Slip})$$

$$\phi_{Jitter}(max) = \sin^{-1}(\Delta E_{aecc}/V_0)$$

Phase Slips per MeV as function of Distance

$$\Delta\phi_L \equiv \frac{\gamma}{\gamma(\gamma+1)}\frac{\Delta T}{T}\frac{L}{\beta c}2\pi f$$



Phase Slips at the Energy Corrector Cavity

Energy Corrector cavity has move before the achromat

Cavity Location	~92 m
Phase Slip per MeV	18 Degrees
Require Cavity Voltage	3.2 MV

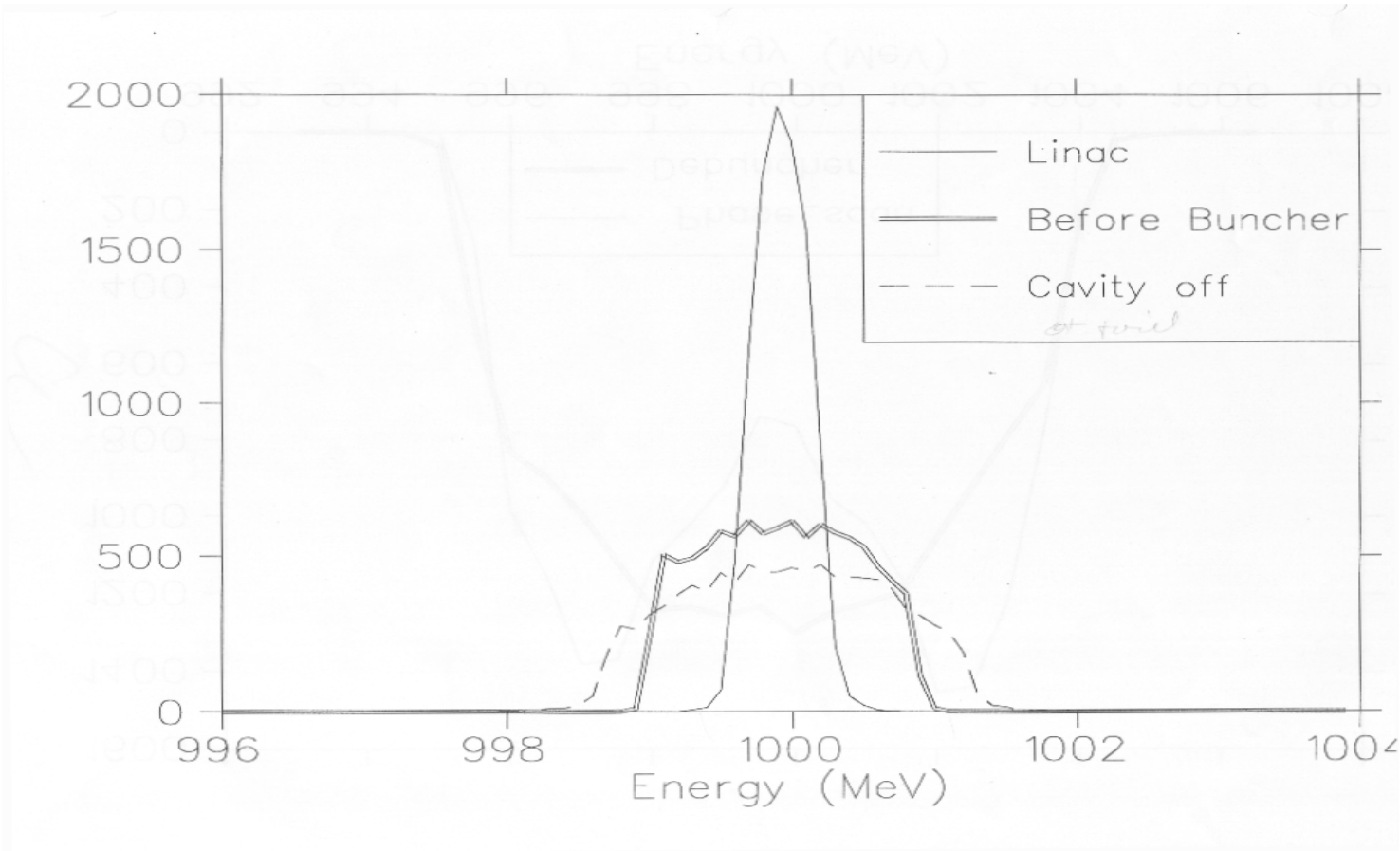
Energy Corrector Cavity

Linac phase and amplitude error of 0.5 deg in phase and 0.5% in amplitude ➡ ± 1.5 MeV (max) energy error which has to be corrected

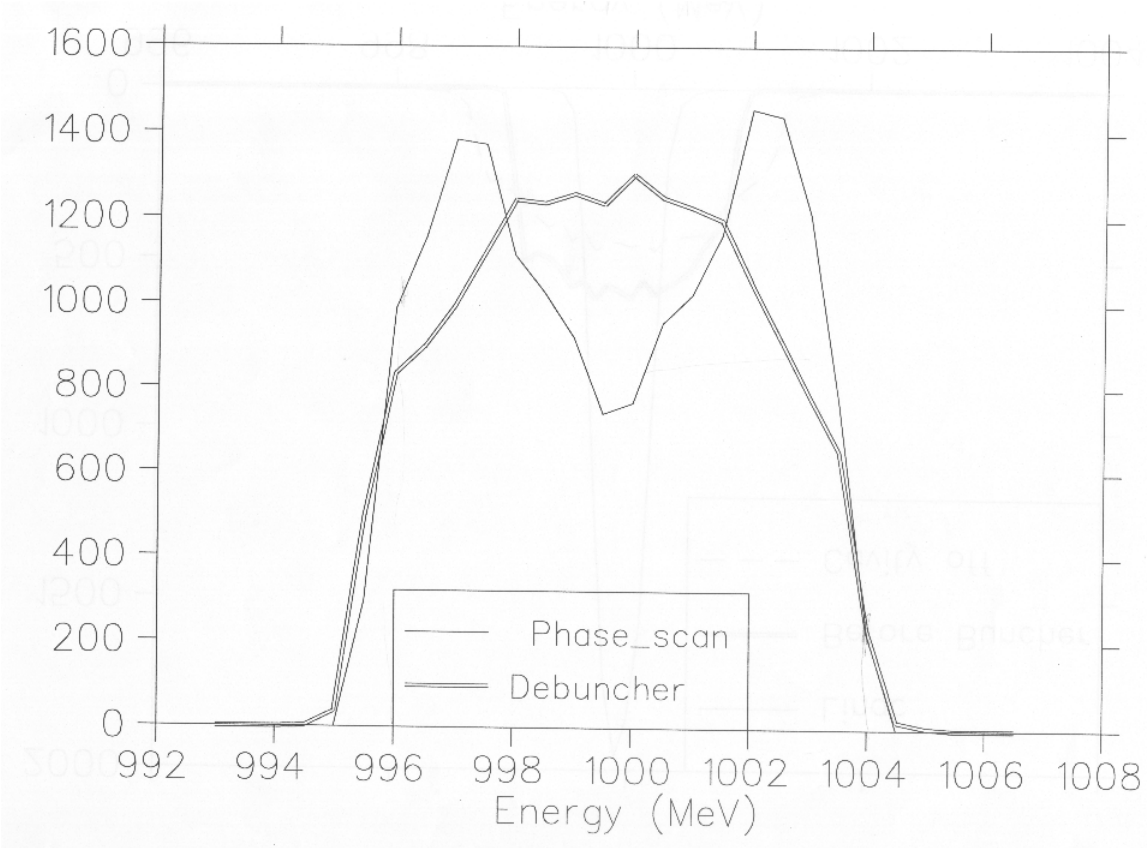
RF cavity (805 MHz) before the achromat
92 m from the linac ➡ phase slip 18 deg/MeV ➡
Required voltage = 3.2 MV

Cavity is similar to cavity of the CCL
1.3 m long, 5.0 cm diameter aperture

Energy Spread in the HEBT



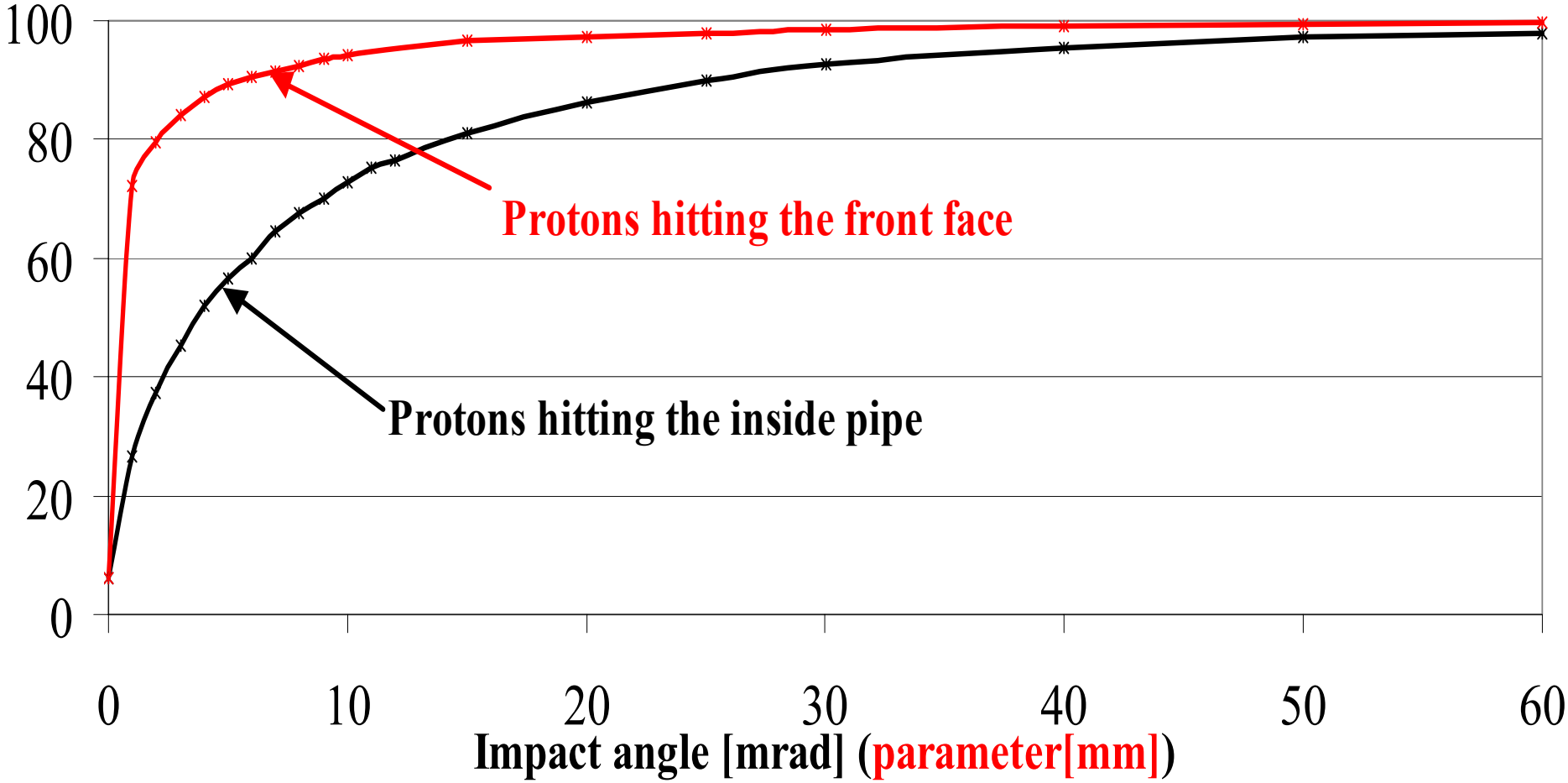
Energy Spread by Phase Scan

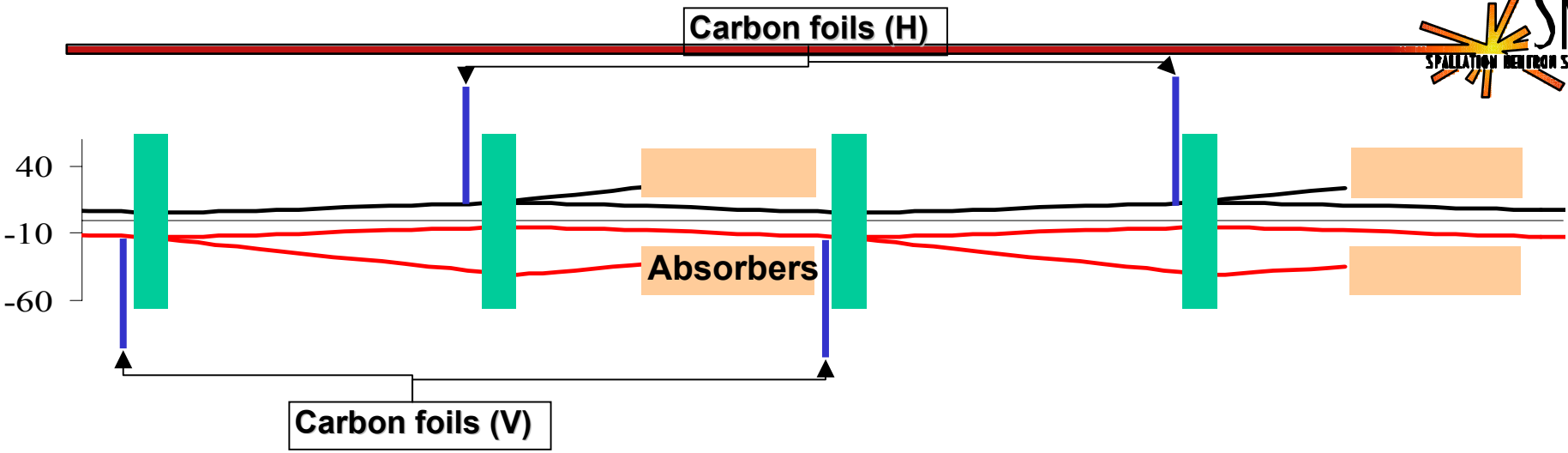


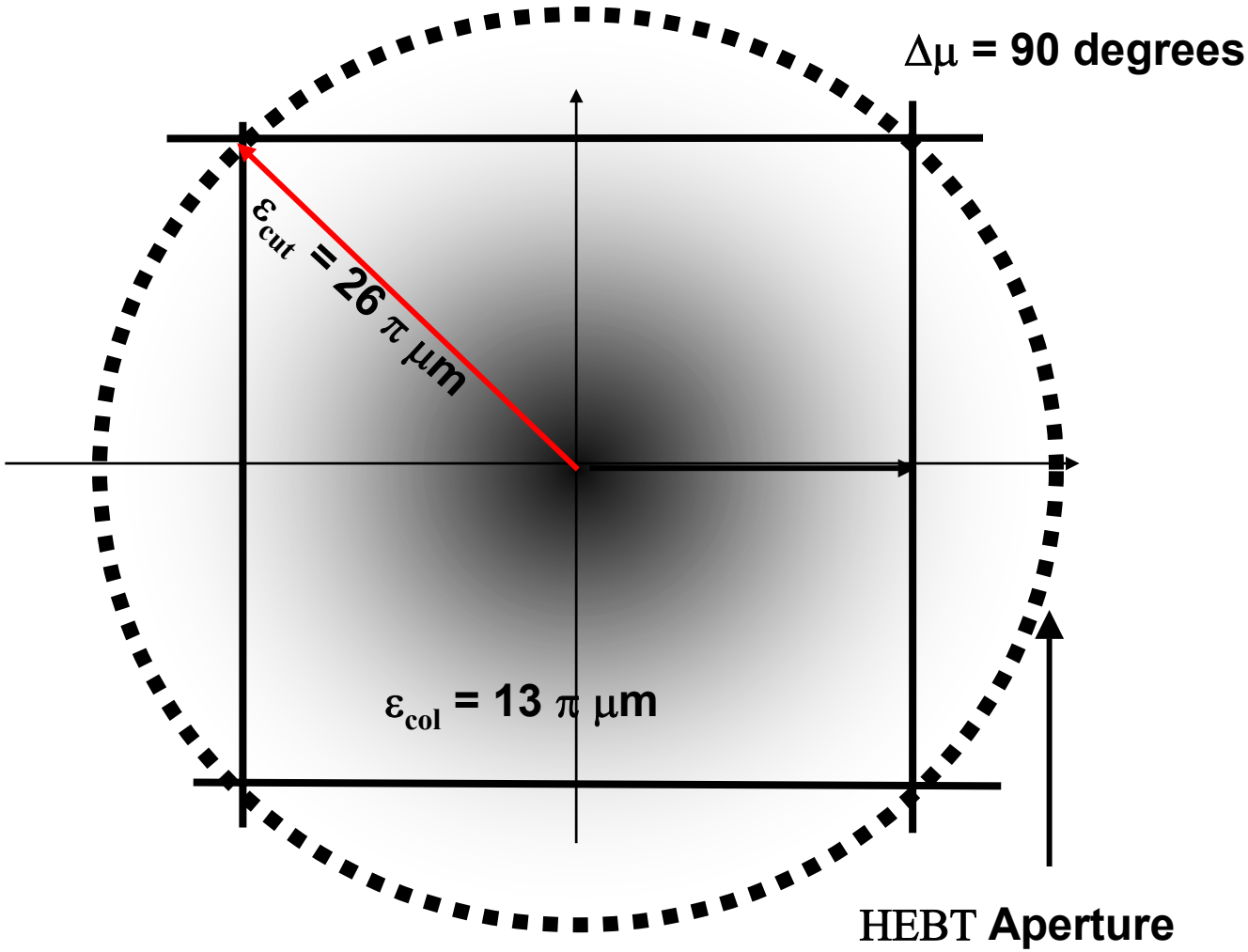
Energy Spreader Cavity

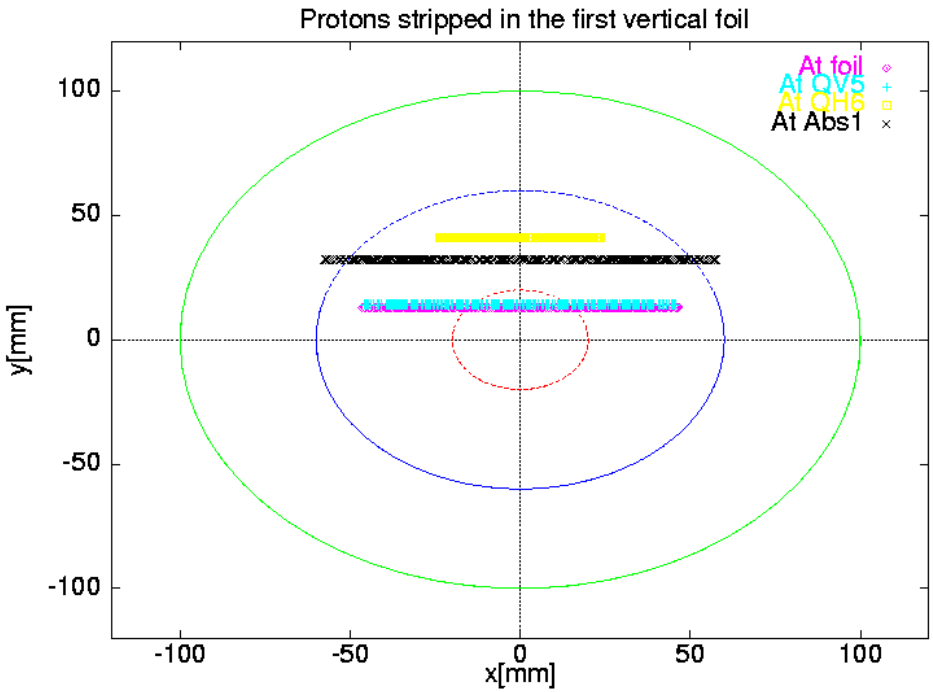
Energy spreader cavity is also in the first half cell after the achromat and is similar to the last cavity of the CCL

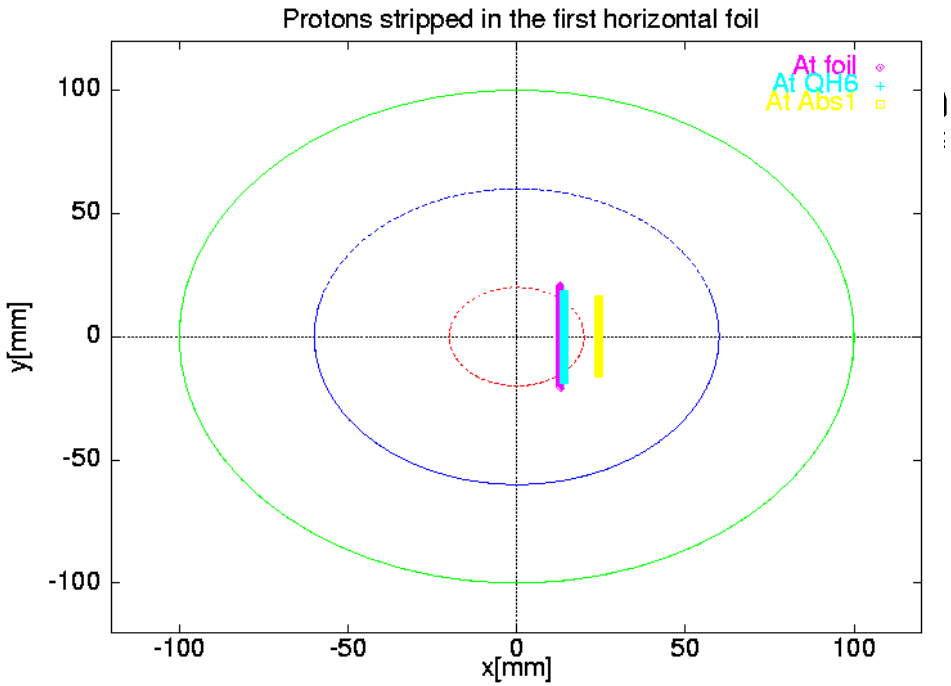
Length	1.3 meter
Aperture (diameter)	5.0 cm
Frequency	805 MHz ±100 kHz
Required voltage	3.5 MV


100
80
60
40
20
0
0
10
20
30
40
50
60
Protons hitting the front face
Protons hitting the inside pipe
Impact angle [mrad] (parameter[mm])

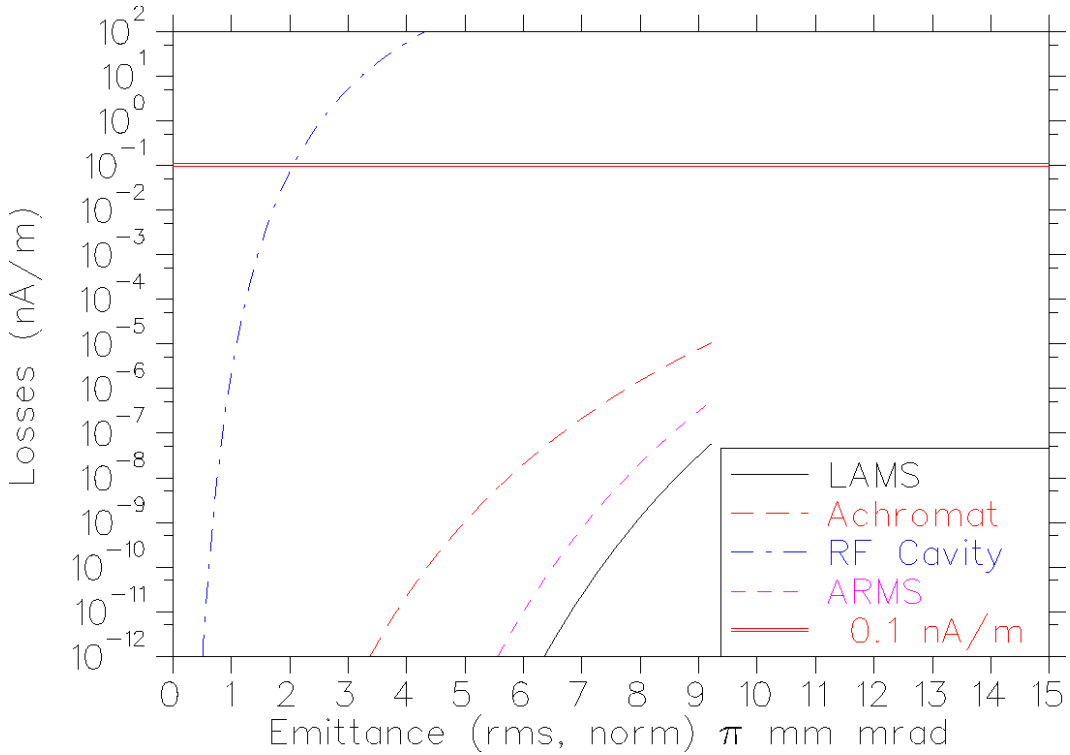

Carbon foils (H)
40
-10
-60
Absorbers
Carbon foils (V)


Δμ = 90 degrees
ε cut = 26 π μm
ε col = 13 π μm
HEBT Aperture


Protons stripped in the first vertical foil
At foil
At QV5
At QH6
At Abs1
y[mm]
x[mm]
100
50
0
-50
-100
-100
-50
0
50
100

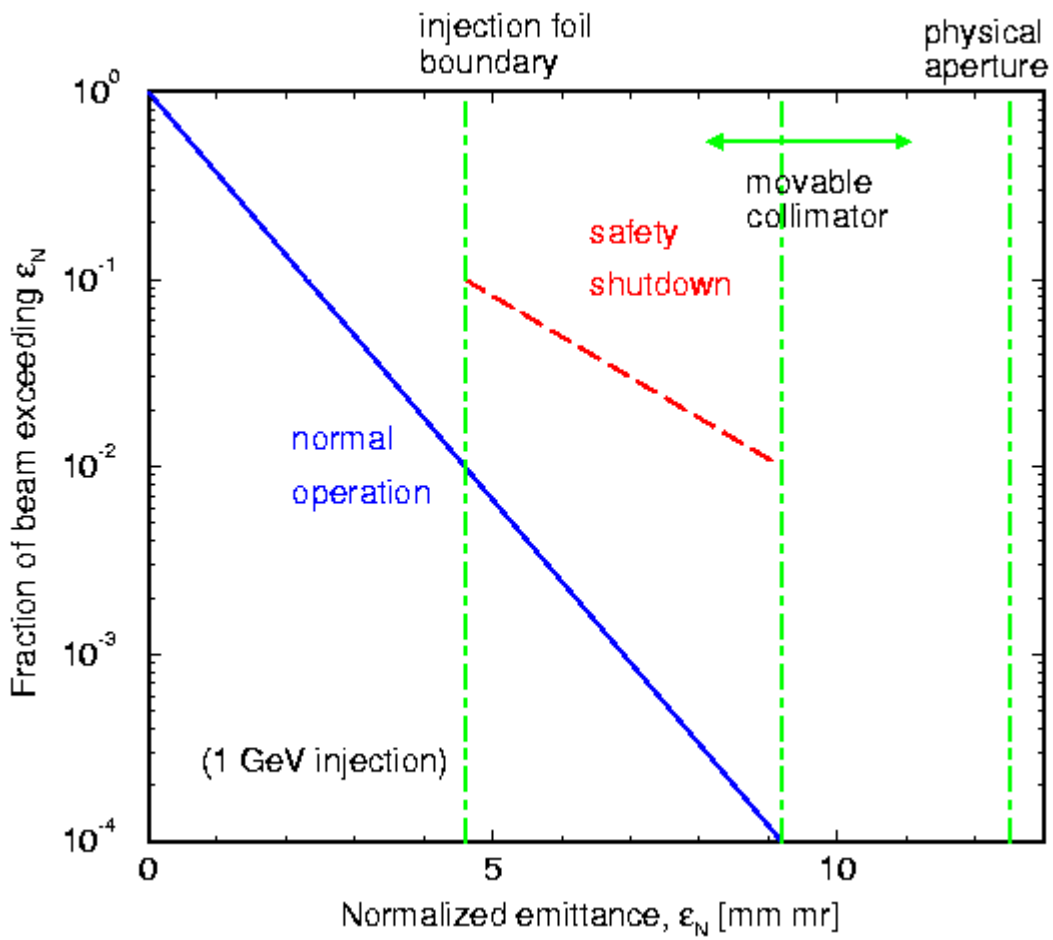

Protons stripped in the first horizontal foil
At foil
At QH6
At Abs1
y[mm]
x[mm]
100
50
0
-50
-100
-100
-50
0
50
100

Transverse Emittance (HEBT)



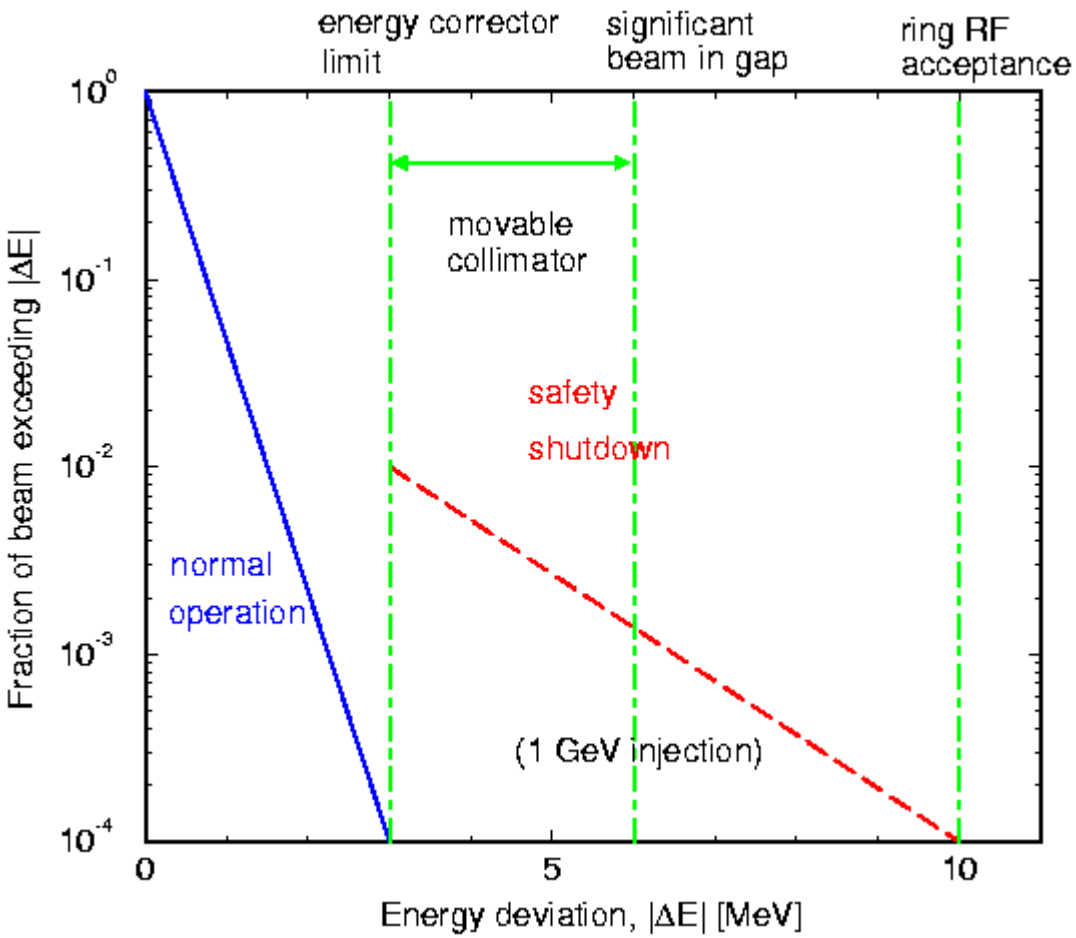
Without Collimator

Linac/HEBT interface (trans.)



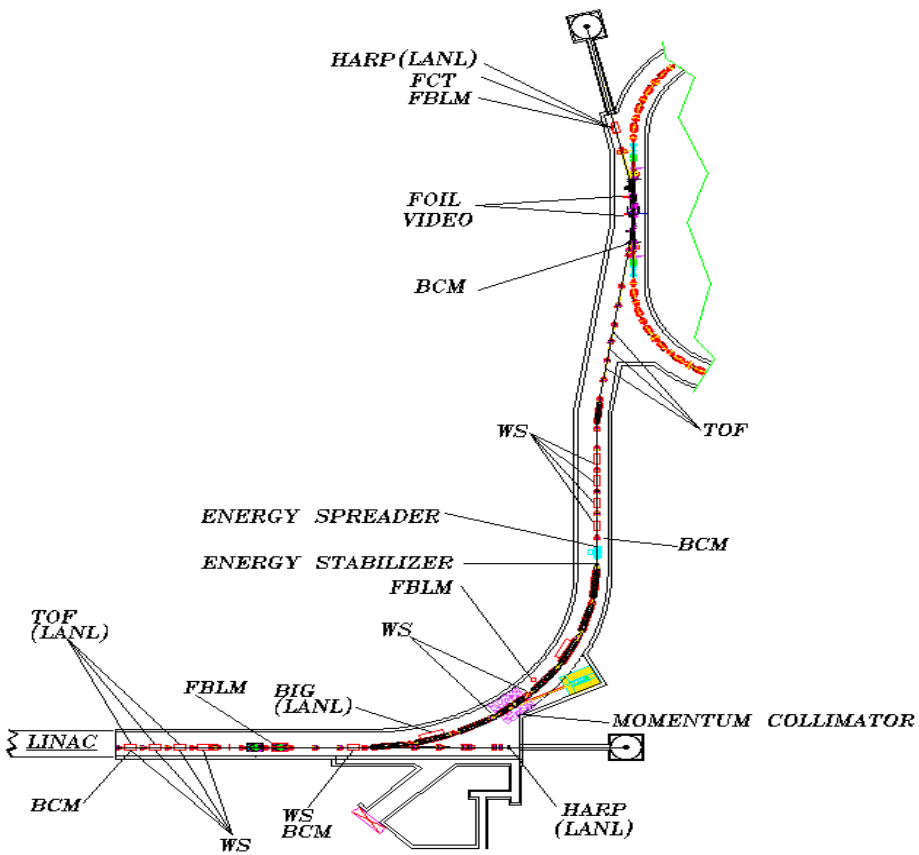
- Nominal norm. rms emittance: 0.5 mm mr
- Larger emittance compromises power & loss/activation
- Injection dump accepts 10% power
- Movable transverse collimator for protection; takes 1% power
- Chamber aperture: HEBT rf cavity …

Linac/HEBT interface (long.)



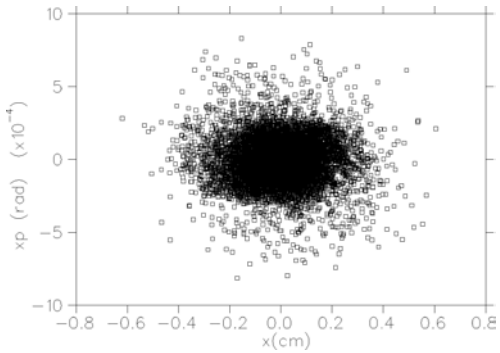
- Nominal energy jitter limit: +/- 2.2 MeV
- Nominal rms energy spread: 0.3 MeV
- Impact of beam loading, Lorentz detuning, and microphonics (under study) 1-on-1 controlled
- Movable energy collimator; corrector limit & ring acceptance
- Two locations of energy corrector reserved (present & future)

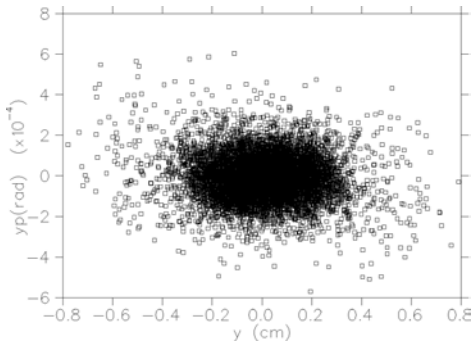
HEBT Beam Instrumentation

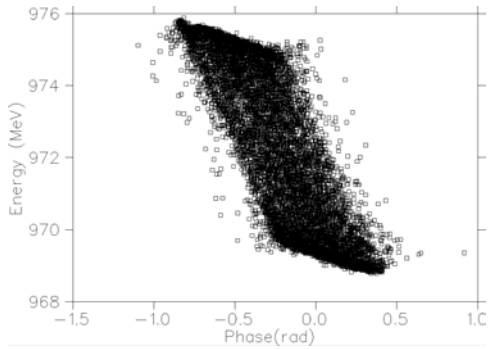


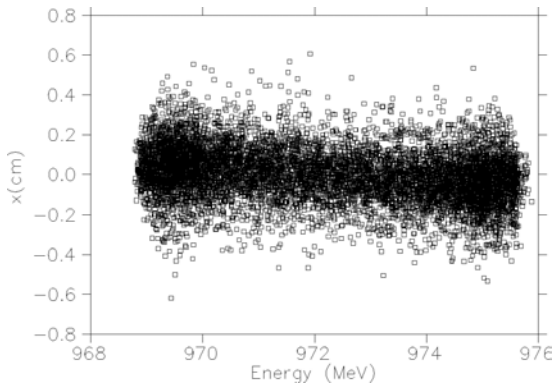
Detectors	BNL	LANL
BIG	0	1
BPM	41	0
TOF	0	2
BLM	52	0
FBLM	3	0
BCM	5	0
WS	11	0
Foil Video	2	0
HARP	0	2

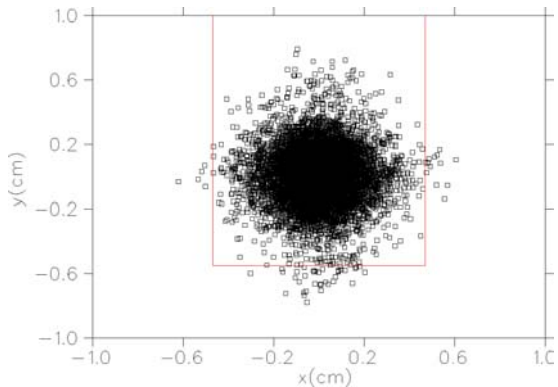
Phase Spaces at Foil(NE)



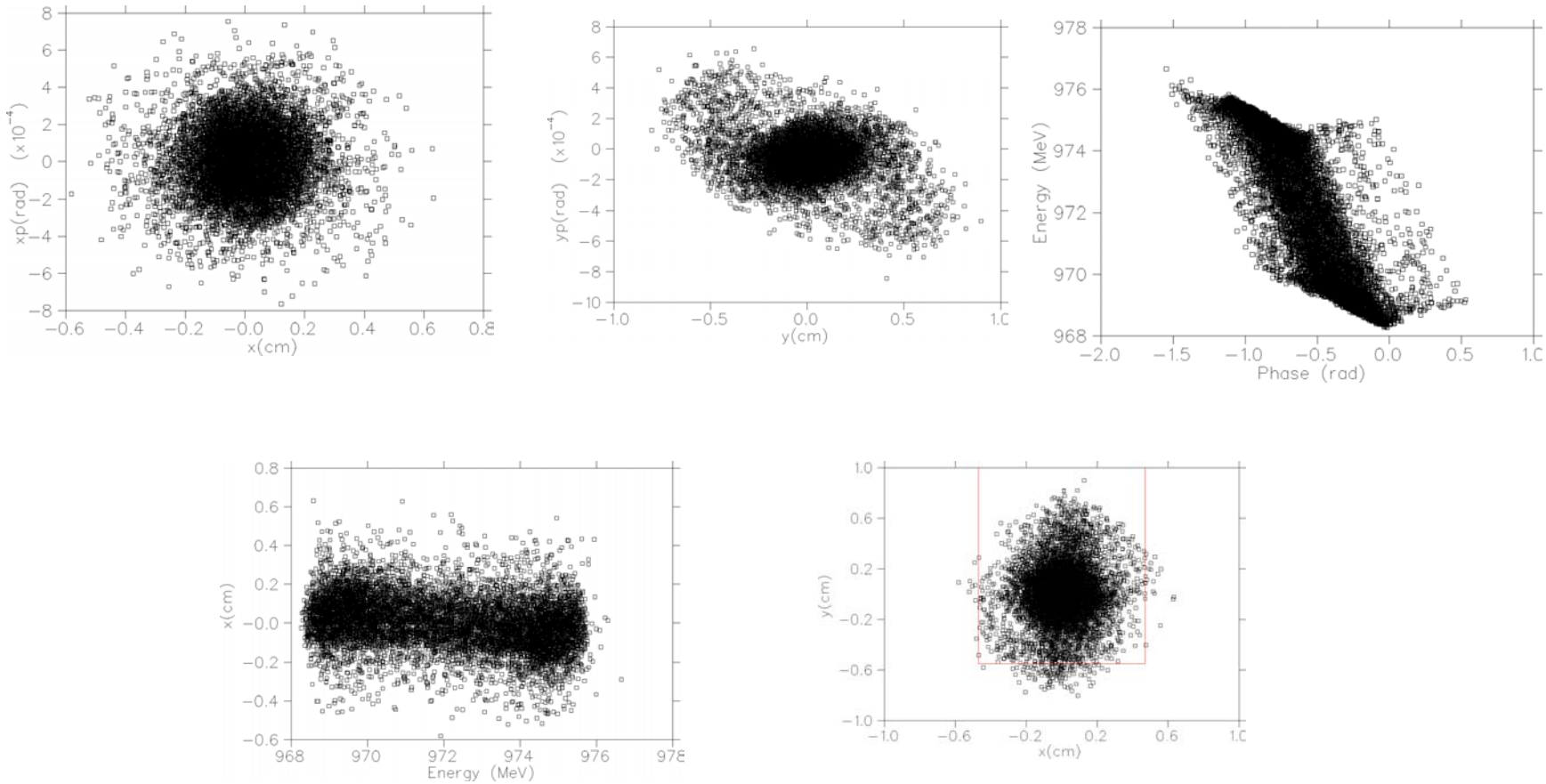




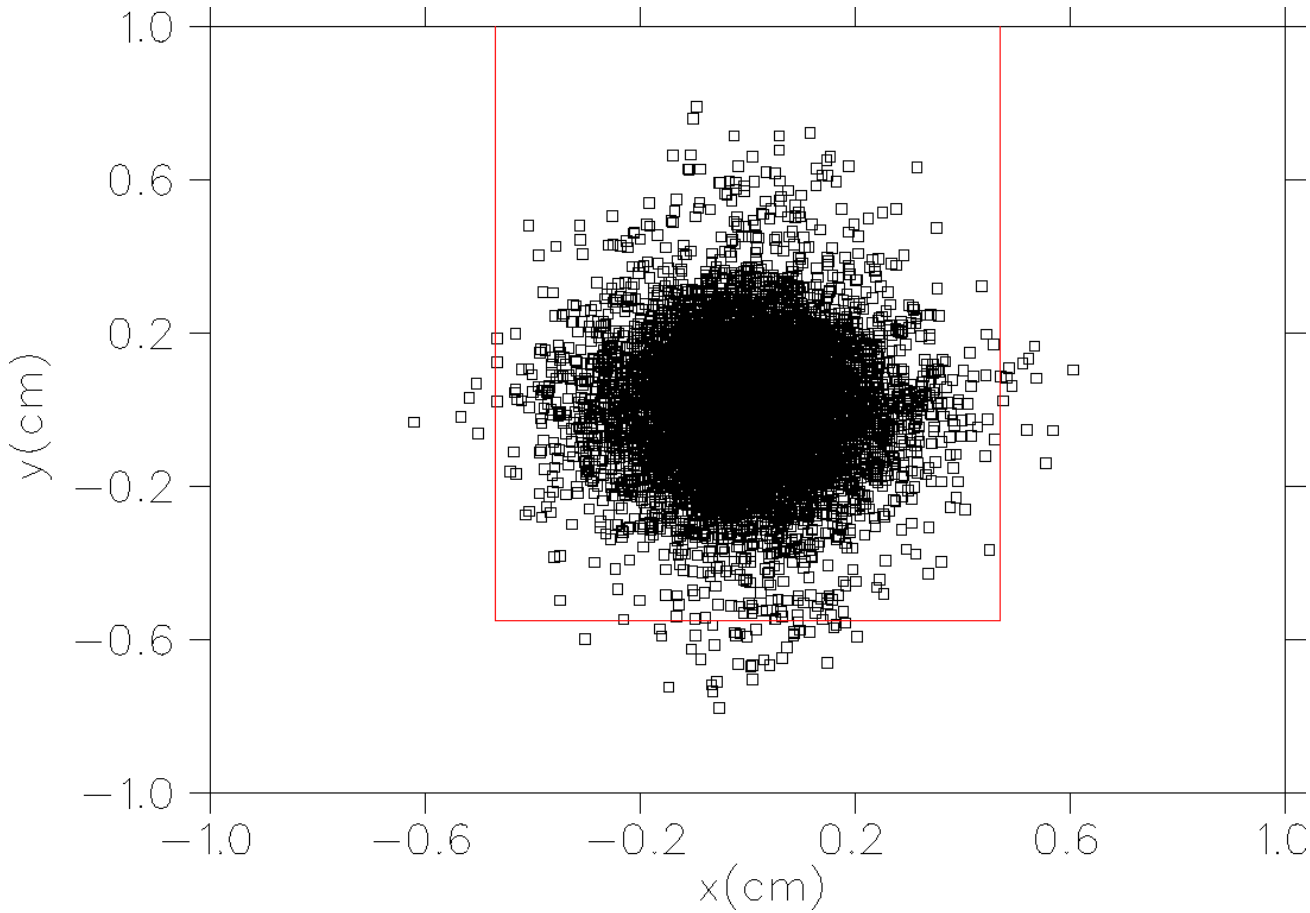




Phase space at Foil (Err)



Particle Distribution at Foil



End-to-end Simulations

	No Error	run1	run2	run3	run4	run5	run6	run7	run8	run9	run10
Number of particle	9160	9269	9442	9354	9395	9415	9536	9498	9394	9288	9408
Ex nor.rms (pi mm mr)	0.351	0.416	0.426	0.444	0.439	0.382	0.401	0.412	0.465	0.398	0.423
EY nor.rms (pi mm mr)	0.328	0.447	**0.538**	0.413	0.432	0.421	0.385	0.382	0.458	0.395	0.478
EZ rms (pi MeV deg)	0.357	0.367	0.6056	0.4506	0.4126	0.4312	0.4137	0.4402	0.445	0.3598	0.446
p0 (Deg)	0	1.105	**-4.74**	2.36	-0.661	**4.14**	1.96	1.33	0.543	-1.49	-1.27
e0 (MeV) @ Linac	0	0.374	1.5	1.57	1.18	0.0795	-0.076	0.31	-1.05	-0.519	1.3
E0(MeV) @ Foil	0	0.0534	**-0.251**	0.115	-0.0669	**0.228**	0.121	0.0813	0.023	-0.108	-0.096
Loss %	**0**	**0**	**0**	**0.011(T)**	**0.096(T)**	**0.04(T)**	**0.05(T)**	**0.04(T)**	**0.01(T)**	**0.01(T)**	**0.04(T)**
Miss Foil (%)	0.485	1.553	1.338	0.378	0.637	0.442	0.529	0.583	1.413	0.744	0.658
EX nor,rms (pi mm mr)	0.376	0.429	0.44	0.506	0.483	0.405	0.437	0.448	0.45	0.436	0.461
EY nor,rms (pi mm mr)	0.329	0.445	**0.587**	0.418	0.446	0.445	0.393	0.39	0.474	0.392	0.495
Del Ex (%)	7.122507	3.125	3.286385	**13.96396**	10.02278	6.020942	8.977556	8.737864	-3.22581	9.547739	8.983452
Del Ey (%)	0.304878	-0.44743	9.107807	1.210654	3.240741	5.700713	2.077922	2.094241	3.49345	-0.75949	3.556485

RTBT to Target IDD

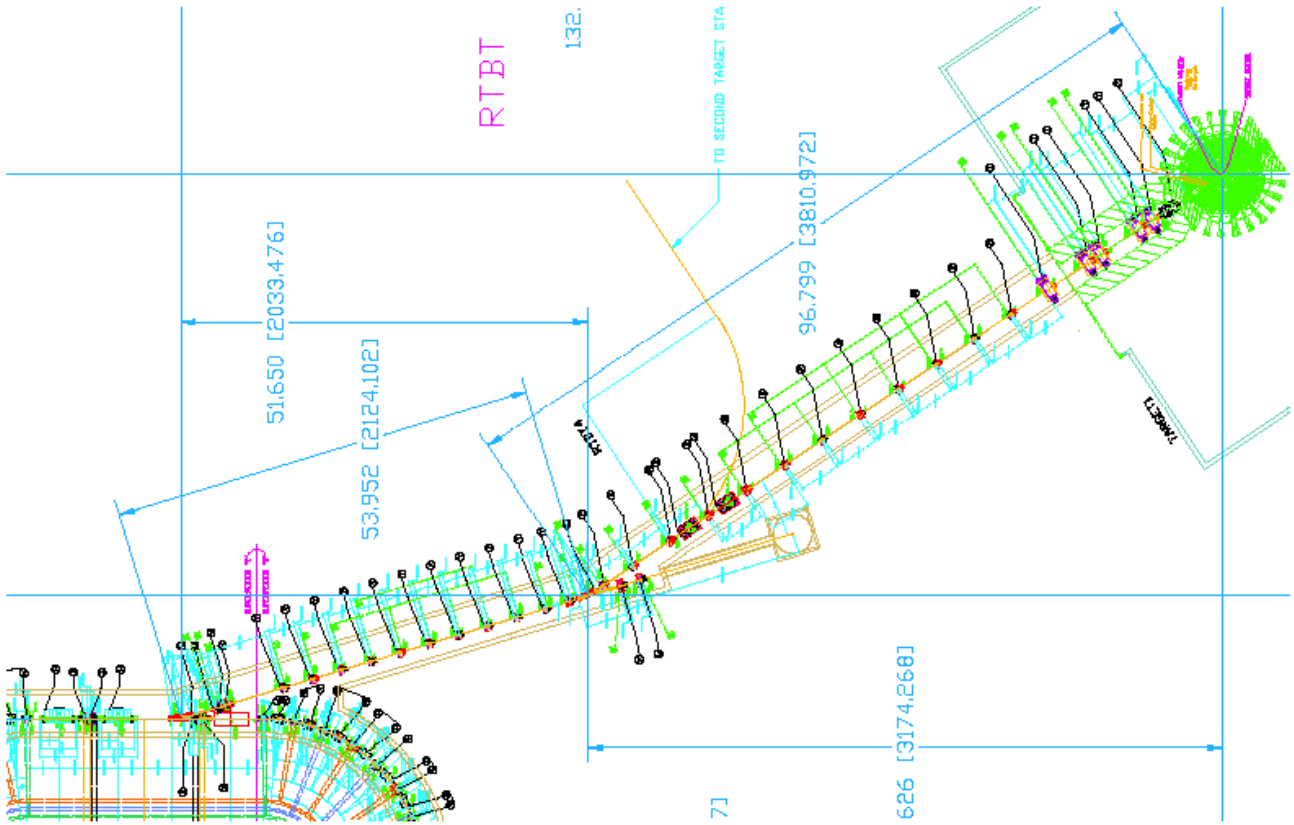
	Normal Condition	Off-Normal	Duration of fault
Target cross section	404 mm x 104 mm		
Beam spot	200 mm x 70mm		
Beam power within target and outside nominal footprint	≤ 10%	≤ 50% power out side spot	≤ 2 pulses
Beam power outside target cross section	< 0.5 %	Prevented by Collimation	
Time-average beam current density, over foot print	0.143 A/m^2		
Normal peak current density	0.25 A/m^2		10 seconds
Normal single pulse peak density	2.57E+16 protons/m^2	3.20E+16 protons/m^2	2 pulses max
Unscheduled beam off > 5s	50 per day		
Unscheduled beam off >300 s	10 per day		
Tolerance on beam centroid H,V	± 2mm , ± 2 mm		

Beam window 2 m in front of target,

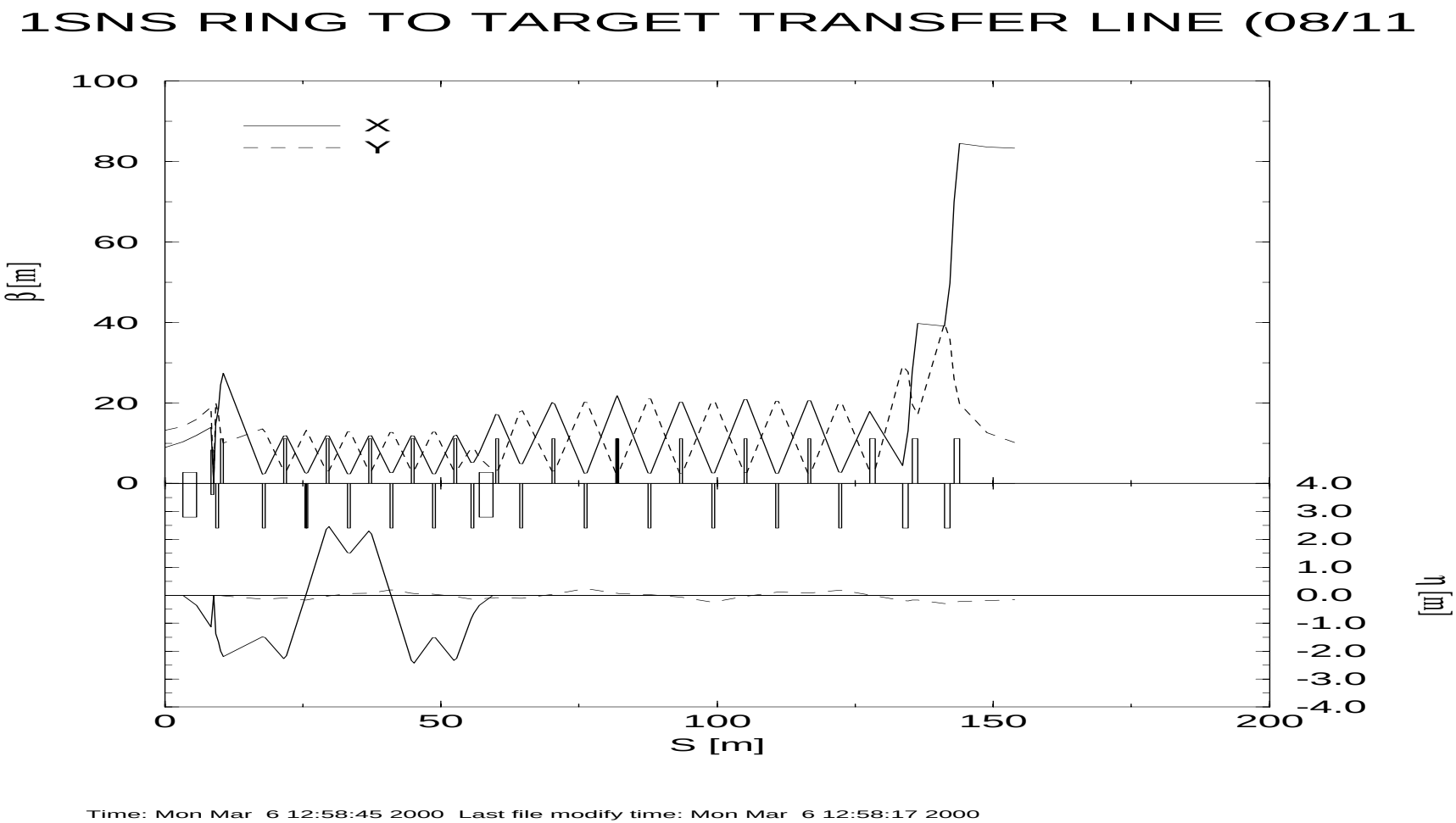
Functions of RTBT

- Extraction (6 cells, 90º/cell)
- Extraction Beam Dump (Two quads)
- Transport (6 cells/ 90º/cell)
- Beam Spreader (Last 5 quads)
- Minimize the Beam motion on the target in case of one or two kickers fails
- Diagnostics

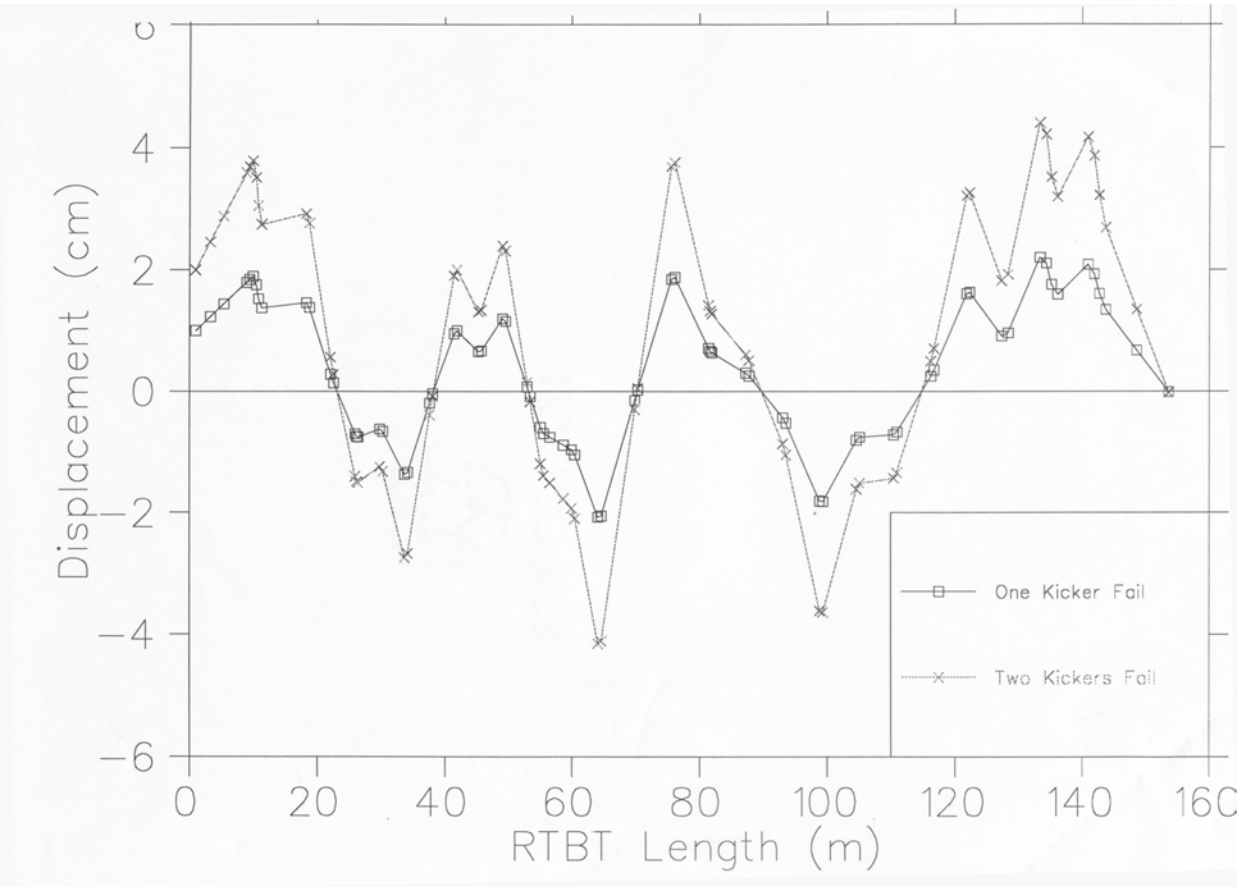
Layout of RTBT

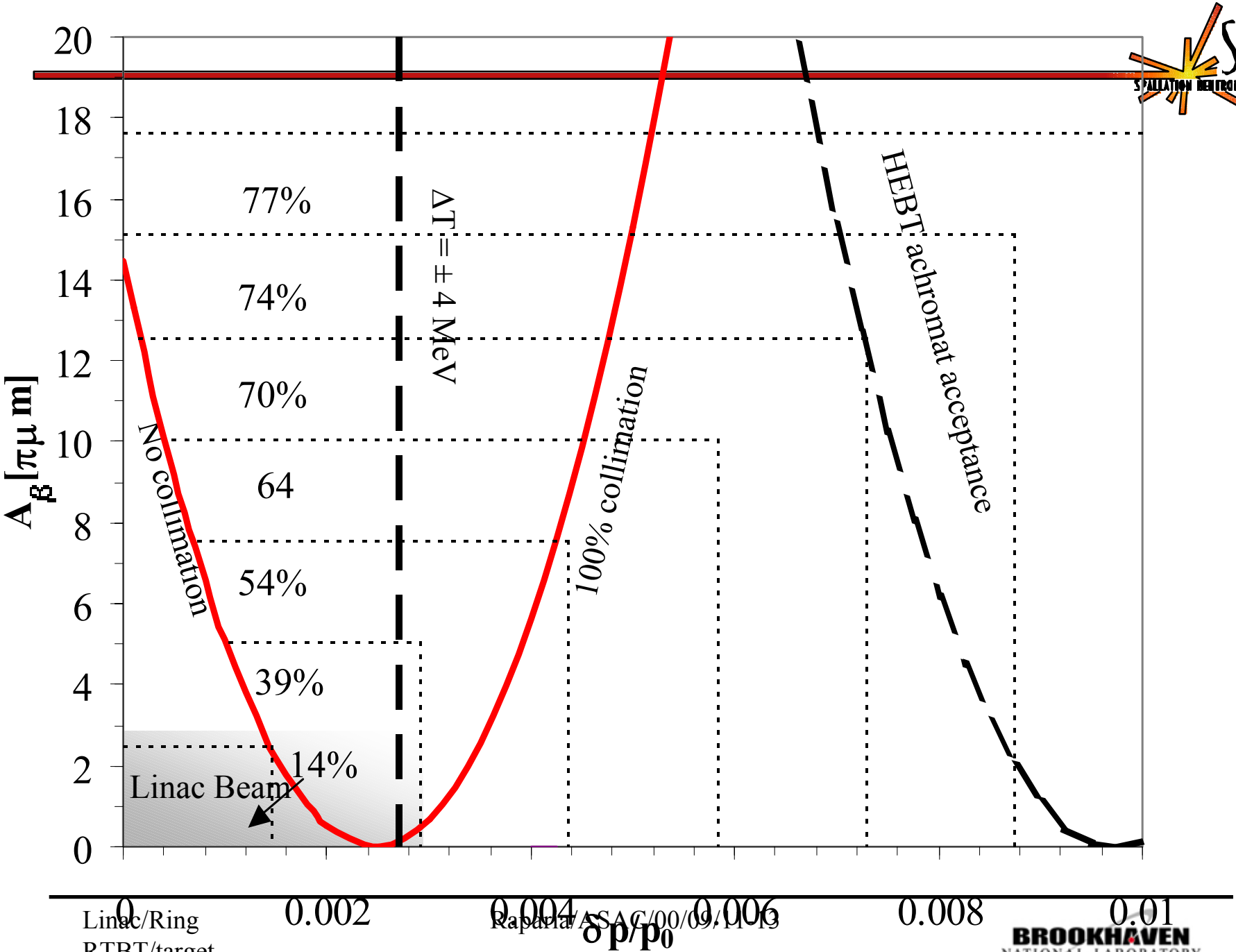


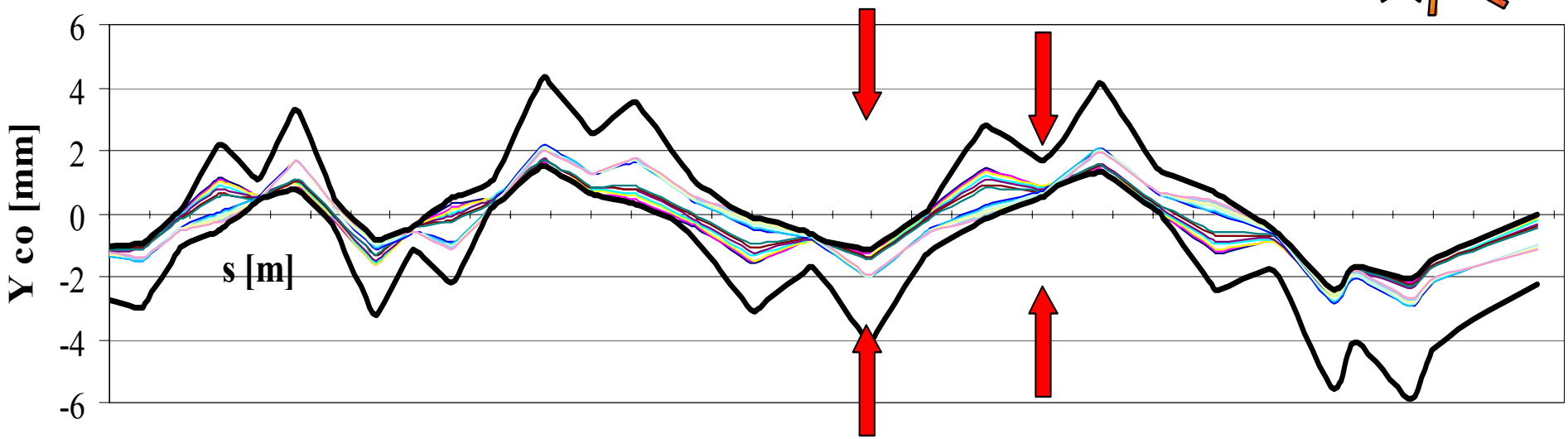
Transport Output for RTBT



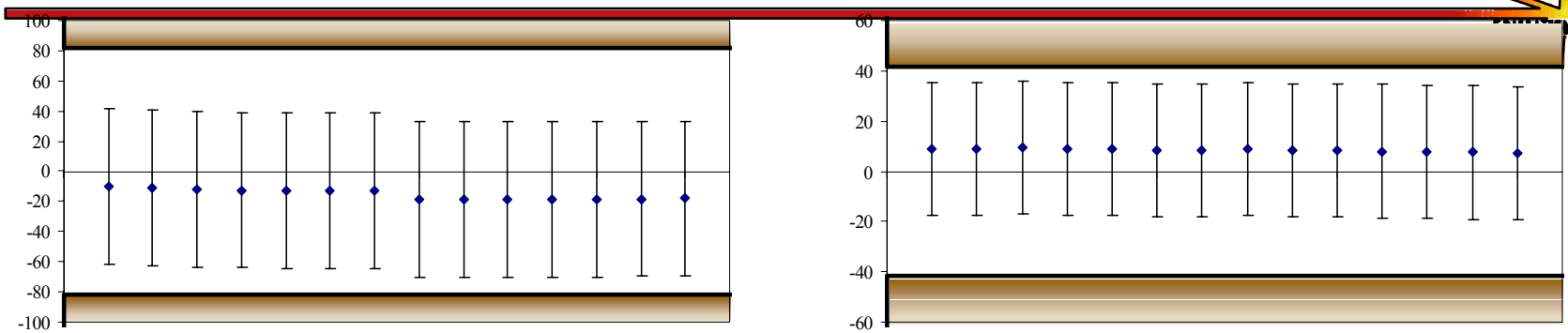
Target Beam Position Immune to Kicker Failure



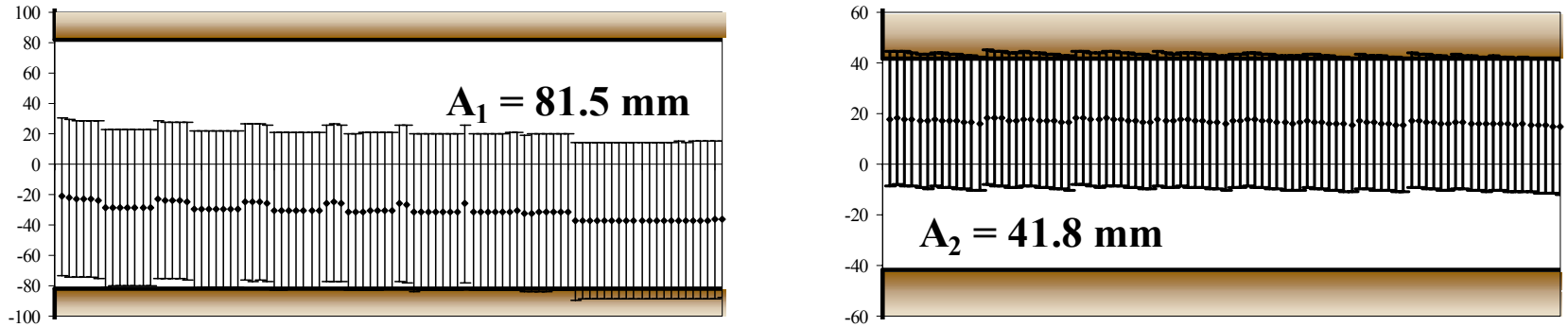

20
18
16
14
12
10
8
6
4
2
0
$A_\beta [\pi\mu m]$
77%
74%
70%
64
54%
39%
14%
Linac Beam
No collimation
ΔT=∓4 MeV
100% collimation
HEBT achromat acceptance
0
0.002
0.004
0.006
0.008
0.01
$\delta p/p_0$


6
4
2
0
-2
-4
-6
Y co [mm]
s [m]

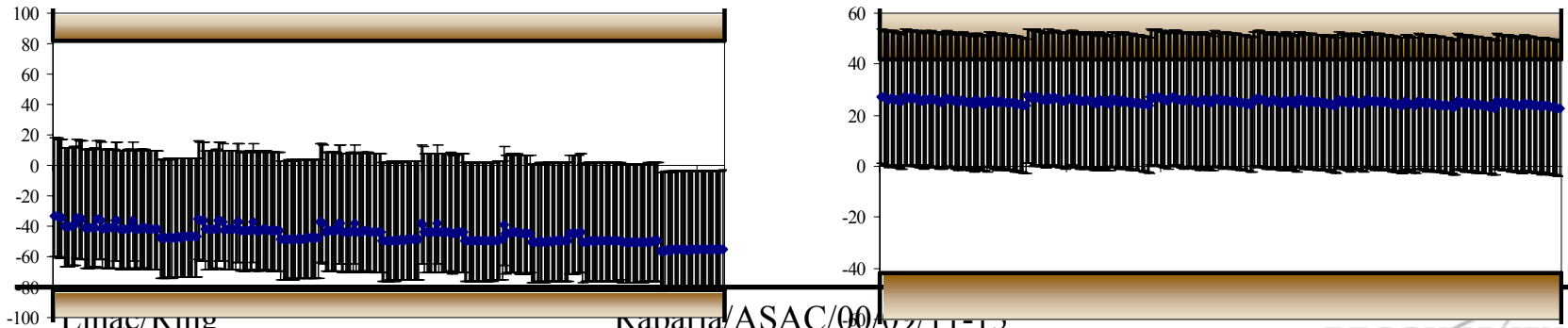
One kicker failure



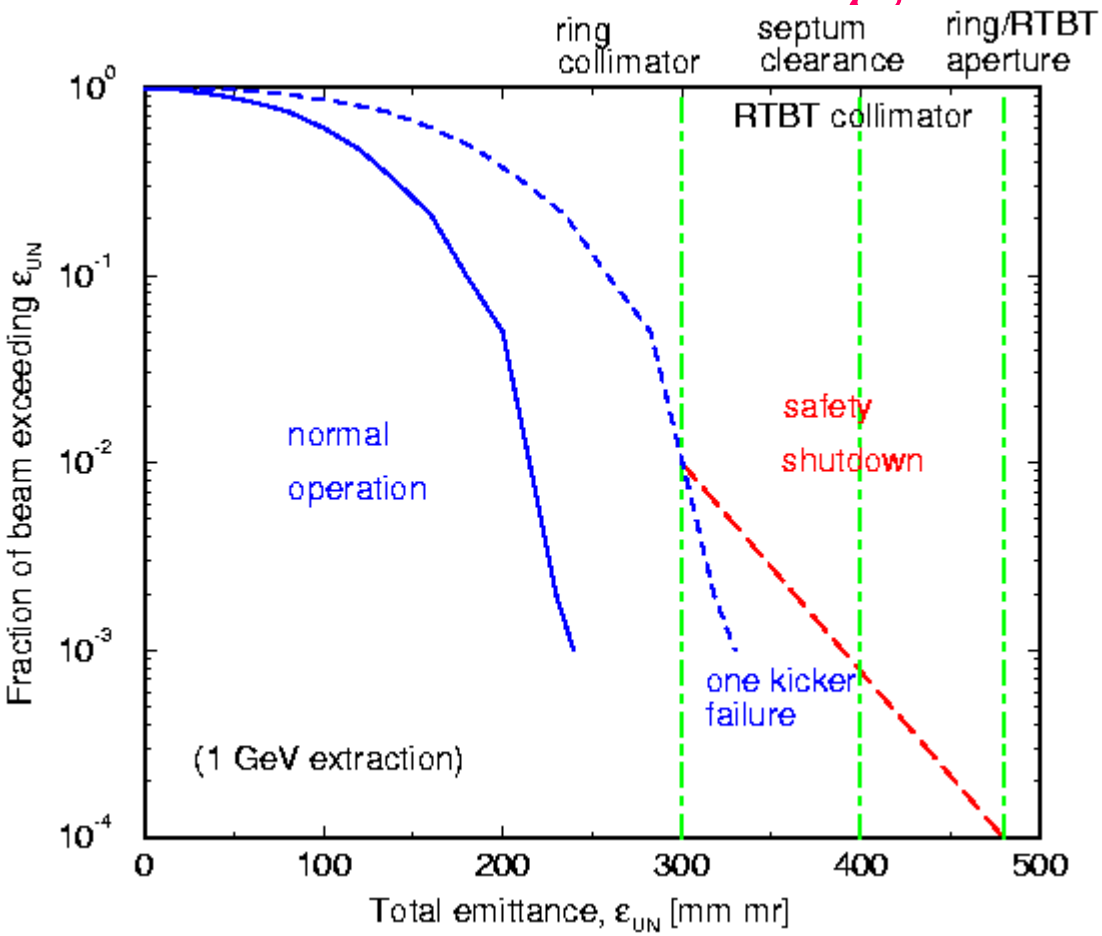
Two kickers failure



Three kickers failure



RTBT/Target interface



- Tolerable to one extraction kicker failure
- Beam position on target not moved upon kicker failure
- RTBT collimator for accident protection
- Accelerator-target interface involves many aspects: painting, halo, window scattering, collimation, ...

Beam Spreading

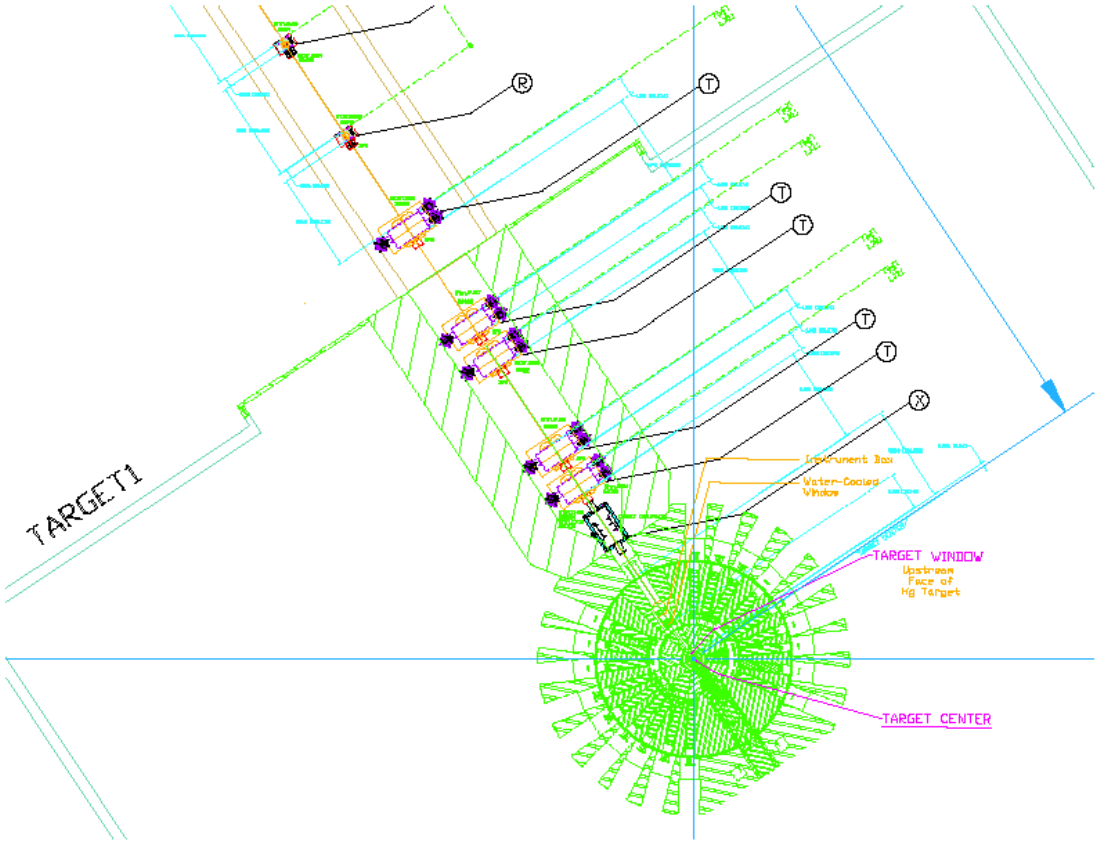
The beam spreader consists of five 36 cm diameter quadrupoles near the end of the RTBT, to provide the desired beam size the target (70 mm x 200 mm)

The flatting of the beam density distribution on target is achieved by providing a uniform distribution out of ring, through painting in the x and y planes at injection.

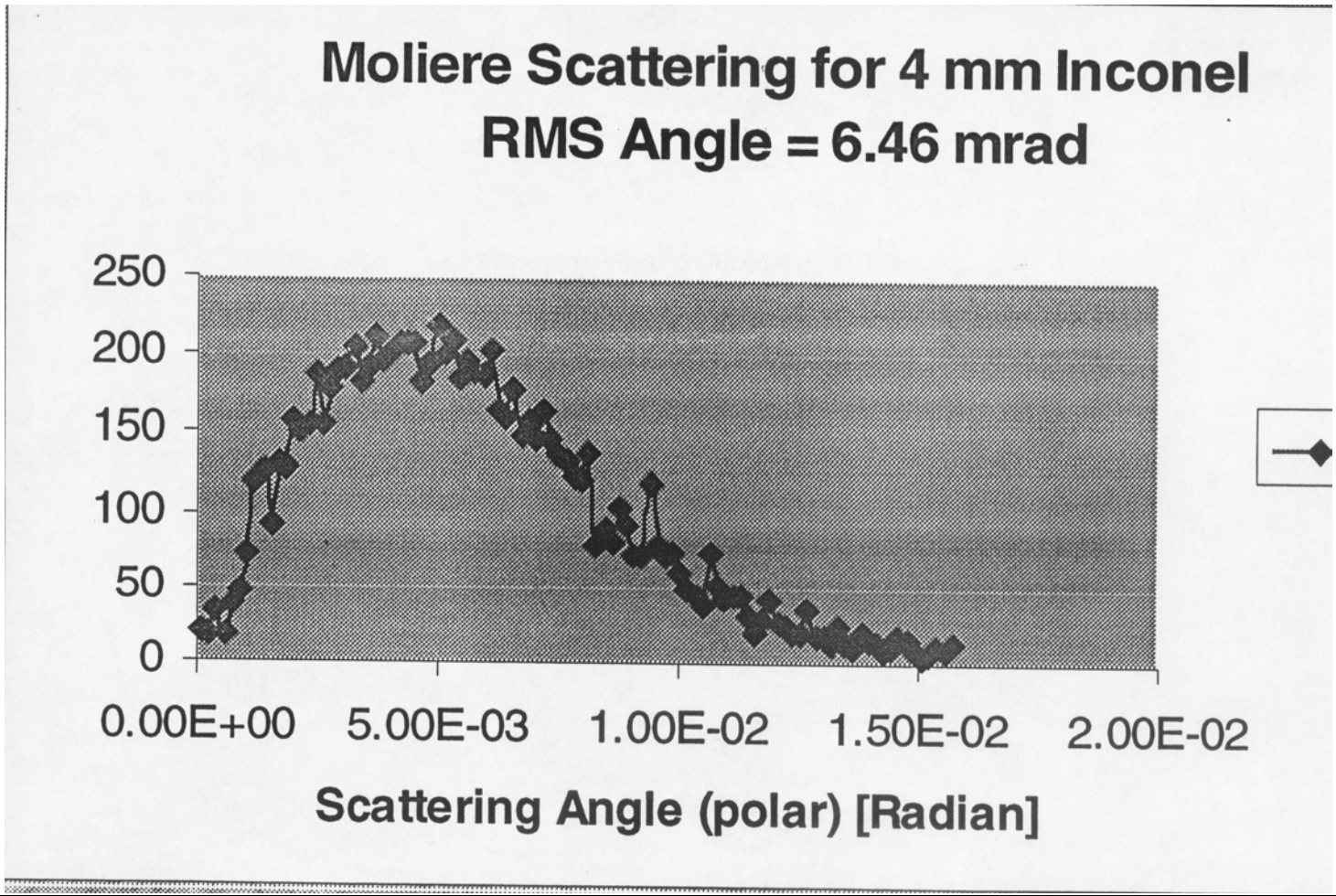
The calculation of the distribution on the target includes the effects of scattering in the 4 mm inconel window, located 2 m in front of the target.

A profile monitor in front of the target will monitor the target density distribution and trigger a fast beam abort if the density exceeds a threshold.

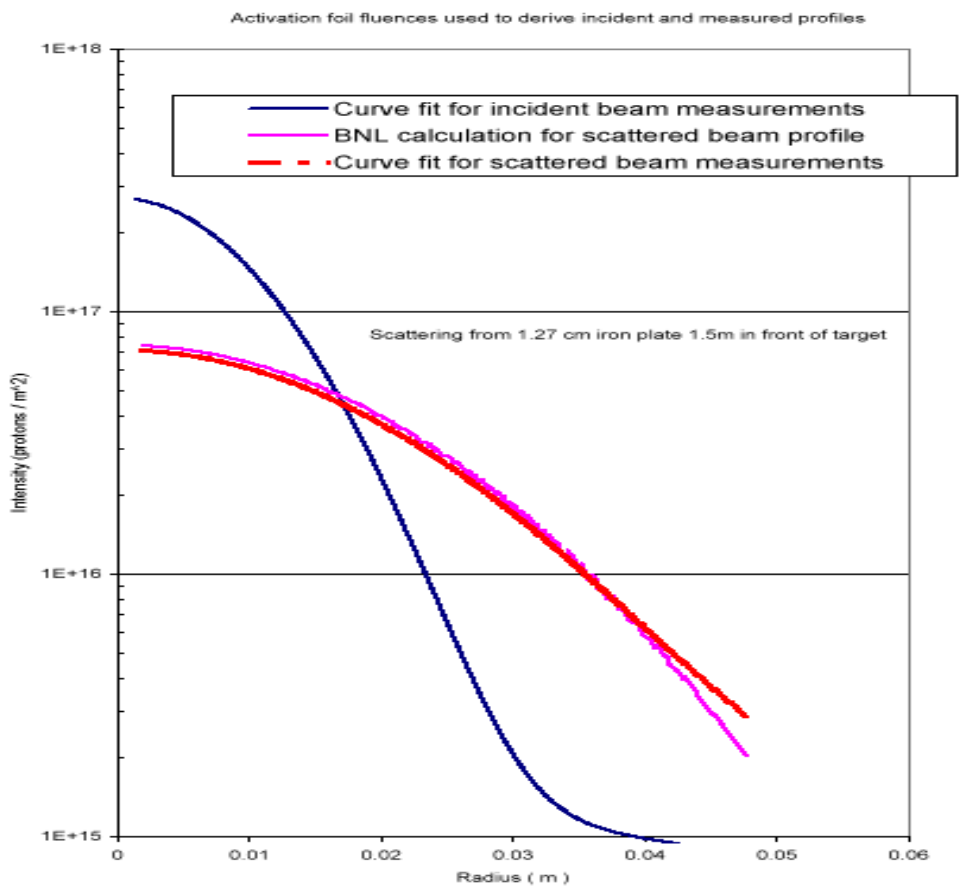
RTBT-Target


TARGET1
R
T
T
T
T
T
X
Instrument Box
Water-Cooled Window
TARGET WINDOW
Upstream Face of Hg Target
TARGET CENTER

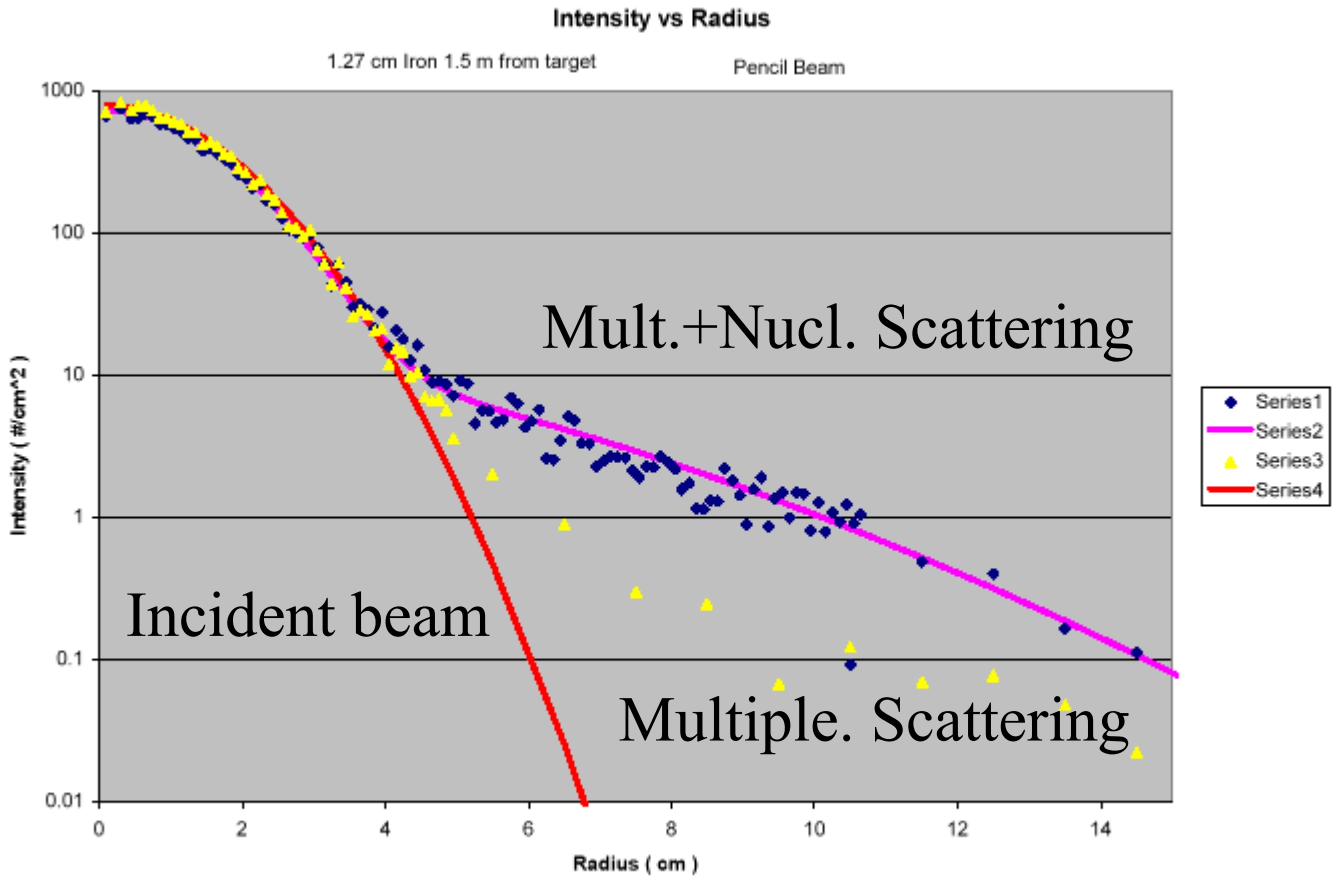
Scattering From Windows



Scattering From Windows

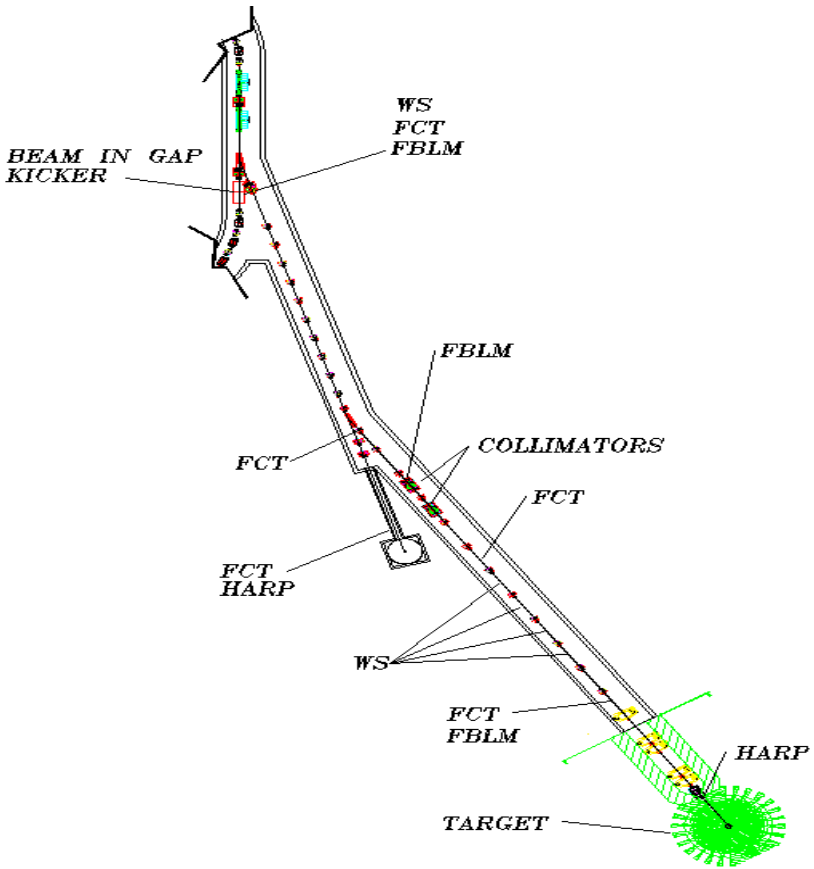


Scattering From Windows

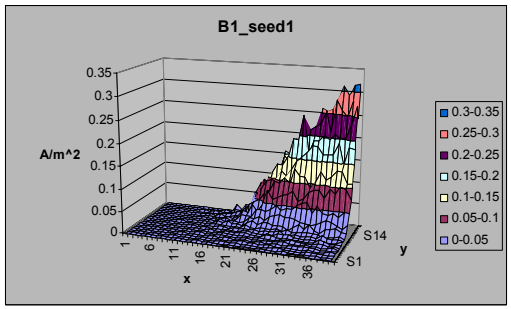


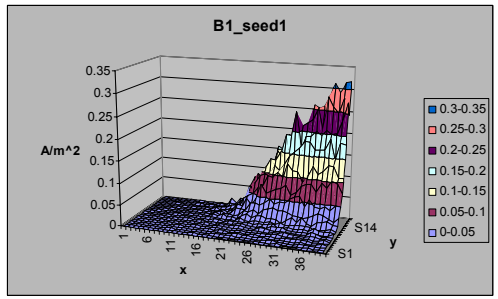
RTBT Beam Instrumentation

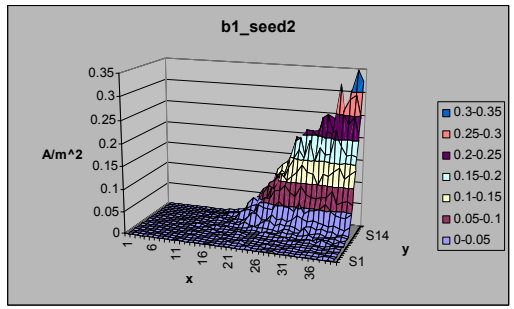
Detectors	BNL	LANL
BPM	32	0
BLM	40	0
FBLM	3	0
HARP	0	2
WS	5	0
BCM (FCT)	5	0

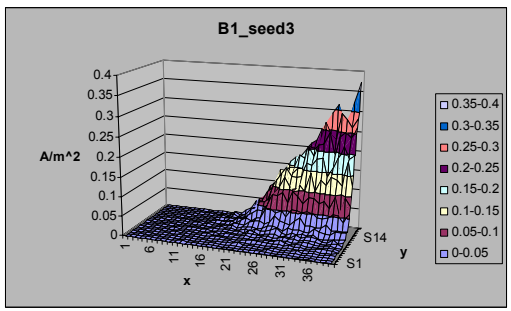


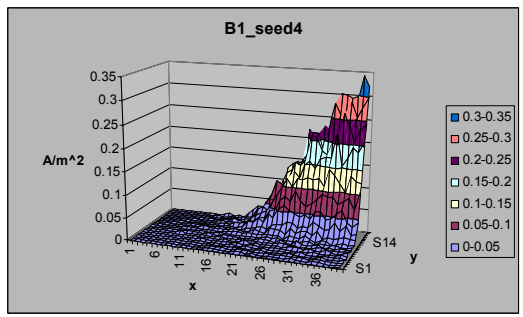
Current Density at target (bump1)

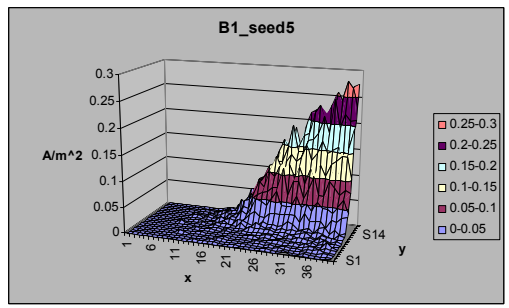




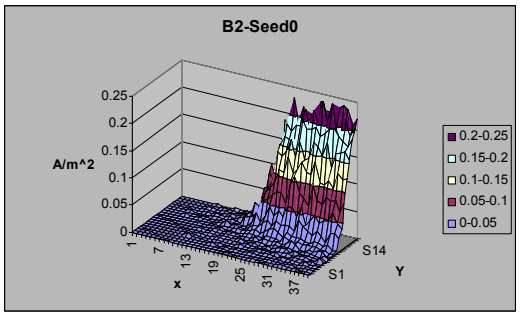


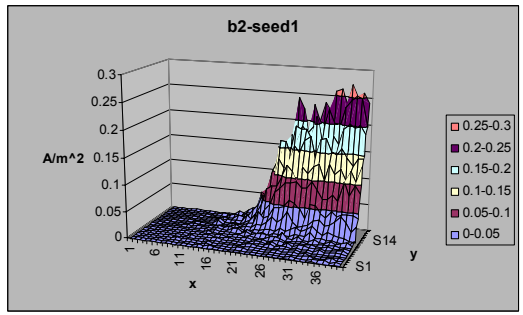


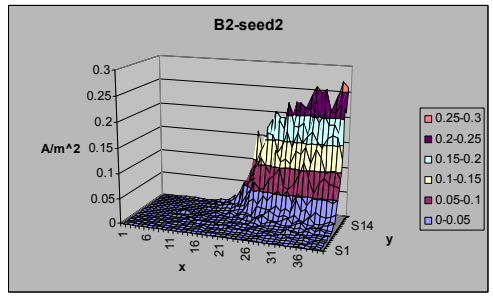


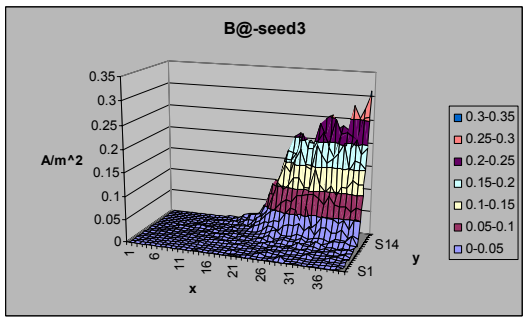


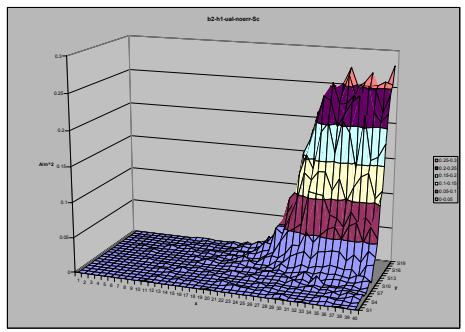
Current Density at Target (bump2)

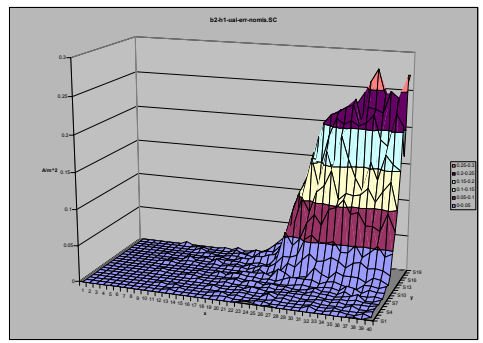












Constraints on bump function

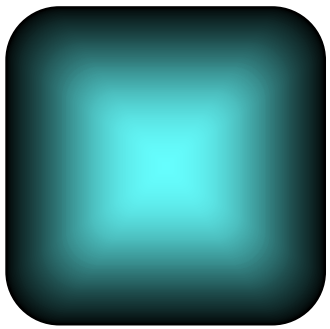
Bump function	Low-loss at primary collimator	Space-charge tune shift	Target requirement
1. Results in a beam distribution close to Gaussian	**Good:** Can achieve loss at 10^{-3} level	**Bad:** Large tune shift (close to 0.3)	**Bad:** Density is too big
2. Results in a beam distribution close to Uniform	**Bad:** Very large loss: around 10^{-2} level	**Good:** Can get tune shift below 0.2	**Good:** Can get close to target requirements

Injection Bump Optimization

(J. Beebe-Wang et al.)

Work is in progress in developing injection bumps that optimize between the goals:

Beam profile without SC



Example bump function: exp(-t/τ) with τ=0.3msec

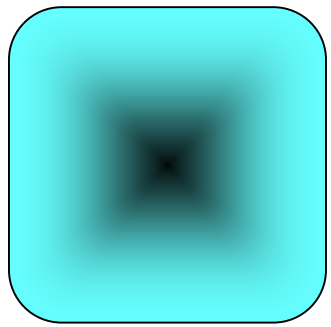
Meeting target requirement

Reducing loss

Reducing space charge tune shift

Reducing foil-hitting rate (depends on details)

Beam profile without SC



Example bump function: Sq-root

0.3 msec ← τ (time constant) → 0.6 msec

Constraints on bump function

- Bump optimization requires to find the best between 3 constraints:

  Low-loss at primary scraper

  Space-charge tune shift

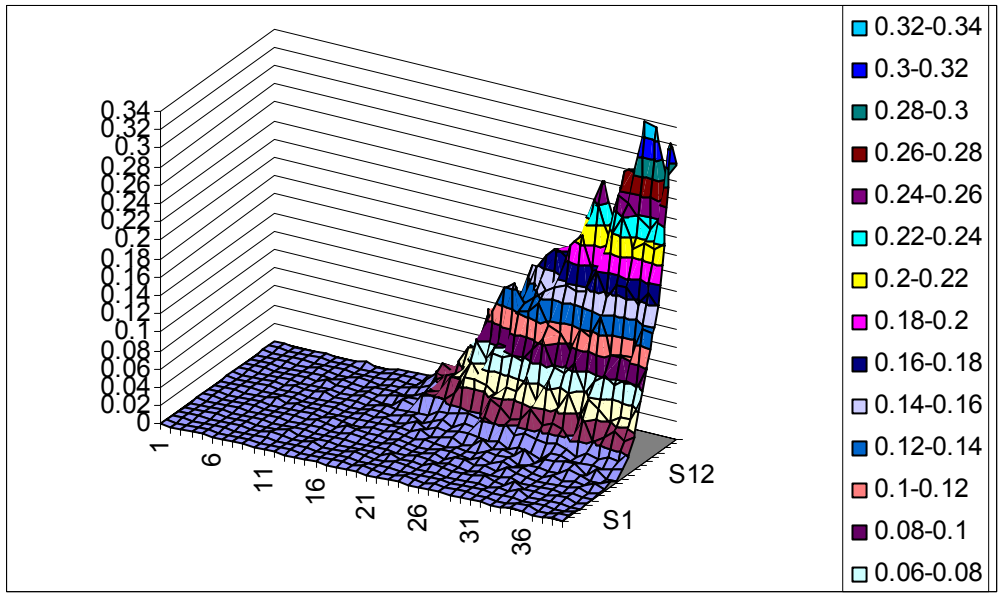
  Target requirement

Strategy: Based on bump#2 approach get as close to Target requirement as possible. Then paint to smaller emittance until you achieve low-loss requirement with primary scraper located as far as possible. This will increase space-charge tune shift but we start with relatively small tune shift (below 0.2). So, by relaxing space-charge constraint we can try to satisfy both Target and Collimation requirements.

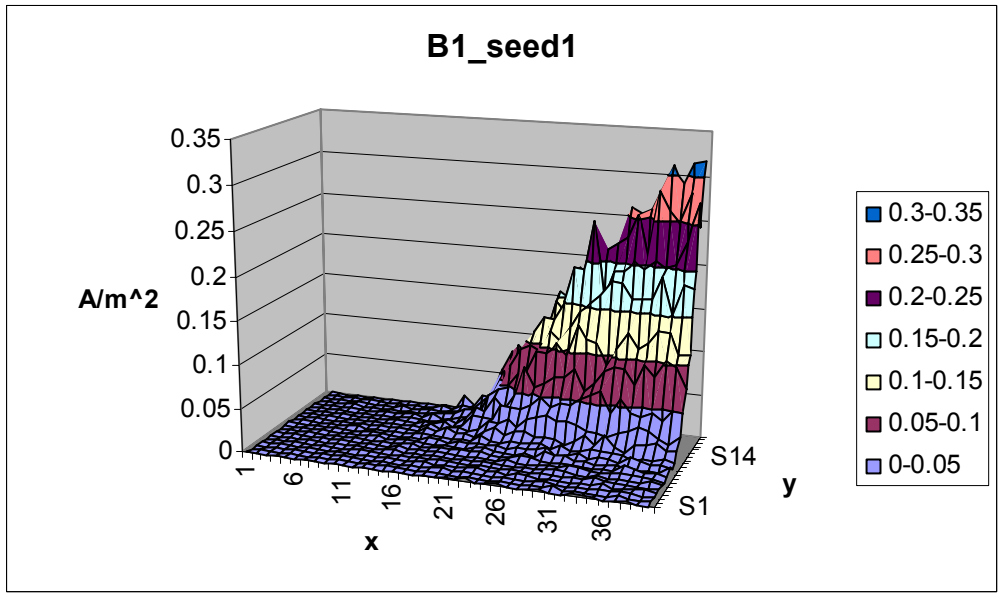
Summary

- Linac/Ring Interface:
  - No major concerns
  - Collimation, energy correction and energy spread are the unique feature of this line
- RTBT/Target Interface:
  - The beam position on the target is immune to case one or two kickers failure
  - Compromise between beam spread on target and low losses in the ring are still under study

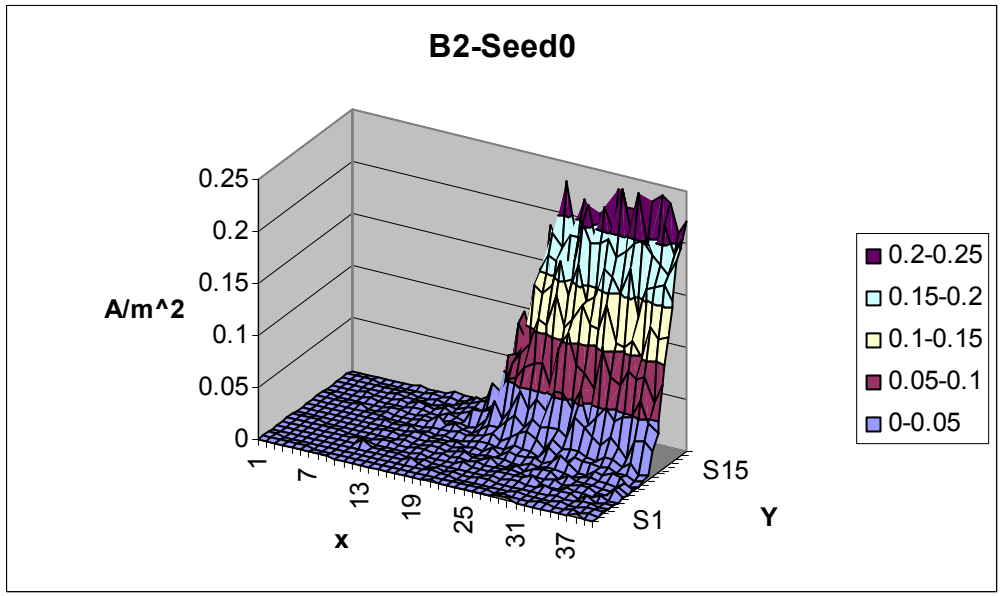
Current Density Distribution at Target (B1,Seed0)



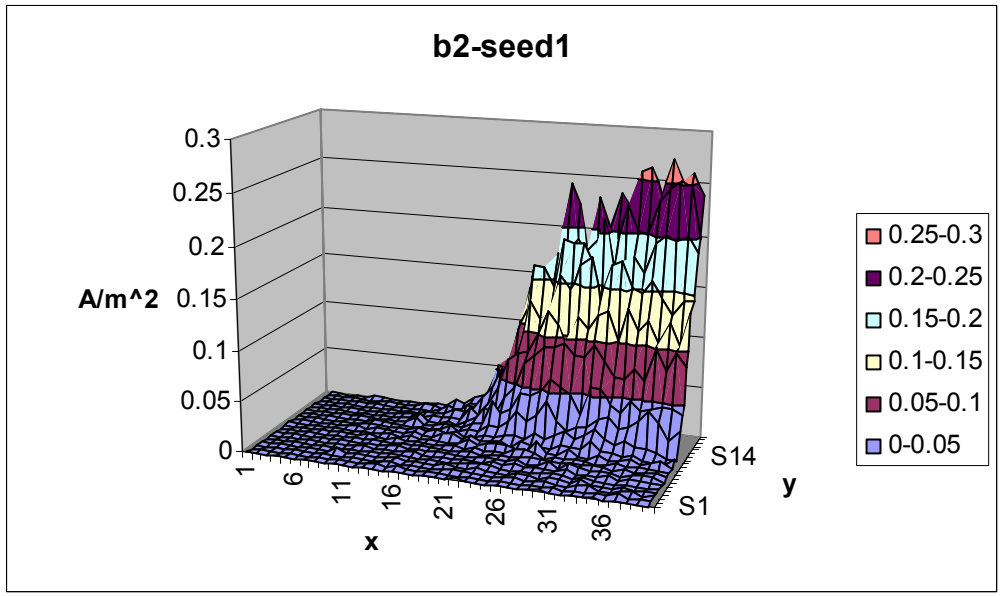
Current Density Distribution at Target (B1, Seed1)



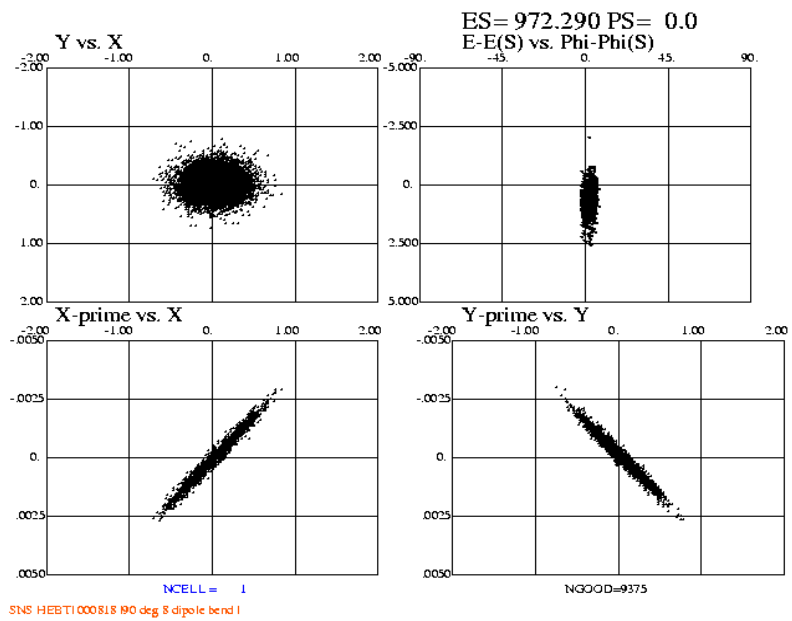
Current Density Distribution at Target (B2, Seed0)



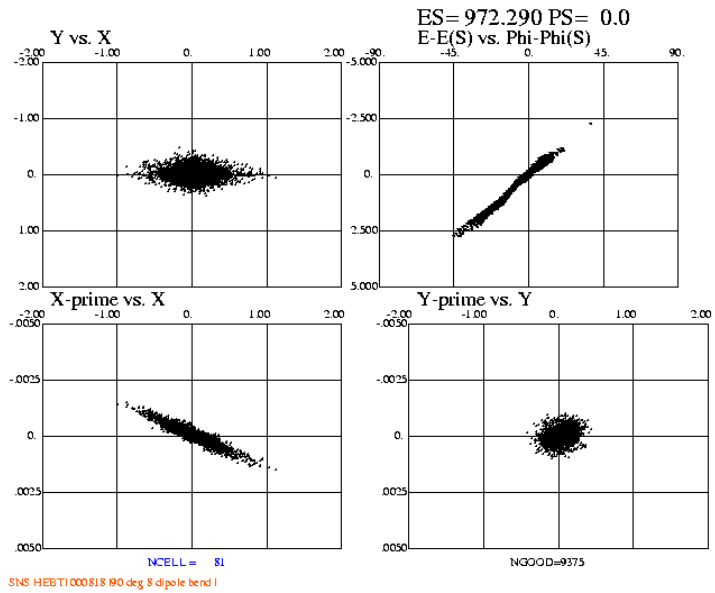
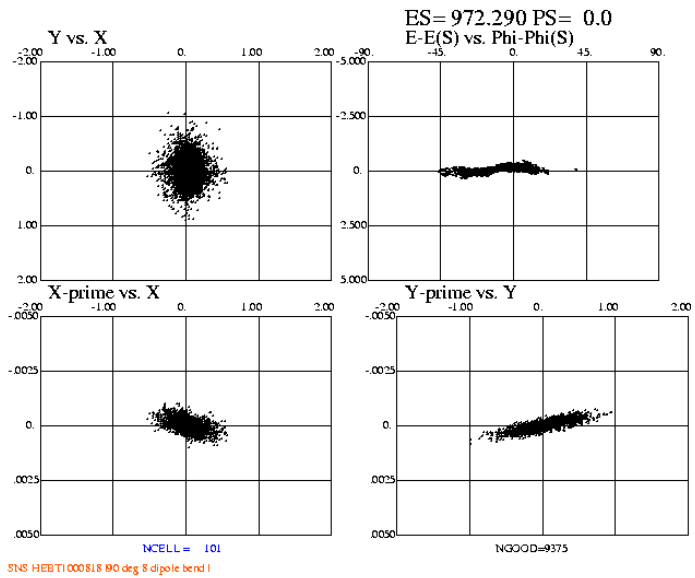
Current Density Distribution at Target (B2, Seed1)



Phase Space at end of Linac



Phase Space before the Corrector



Phase Space after the Corrector Cavity