SNS Transfer Lines

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April 8-12, 2002

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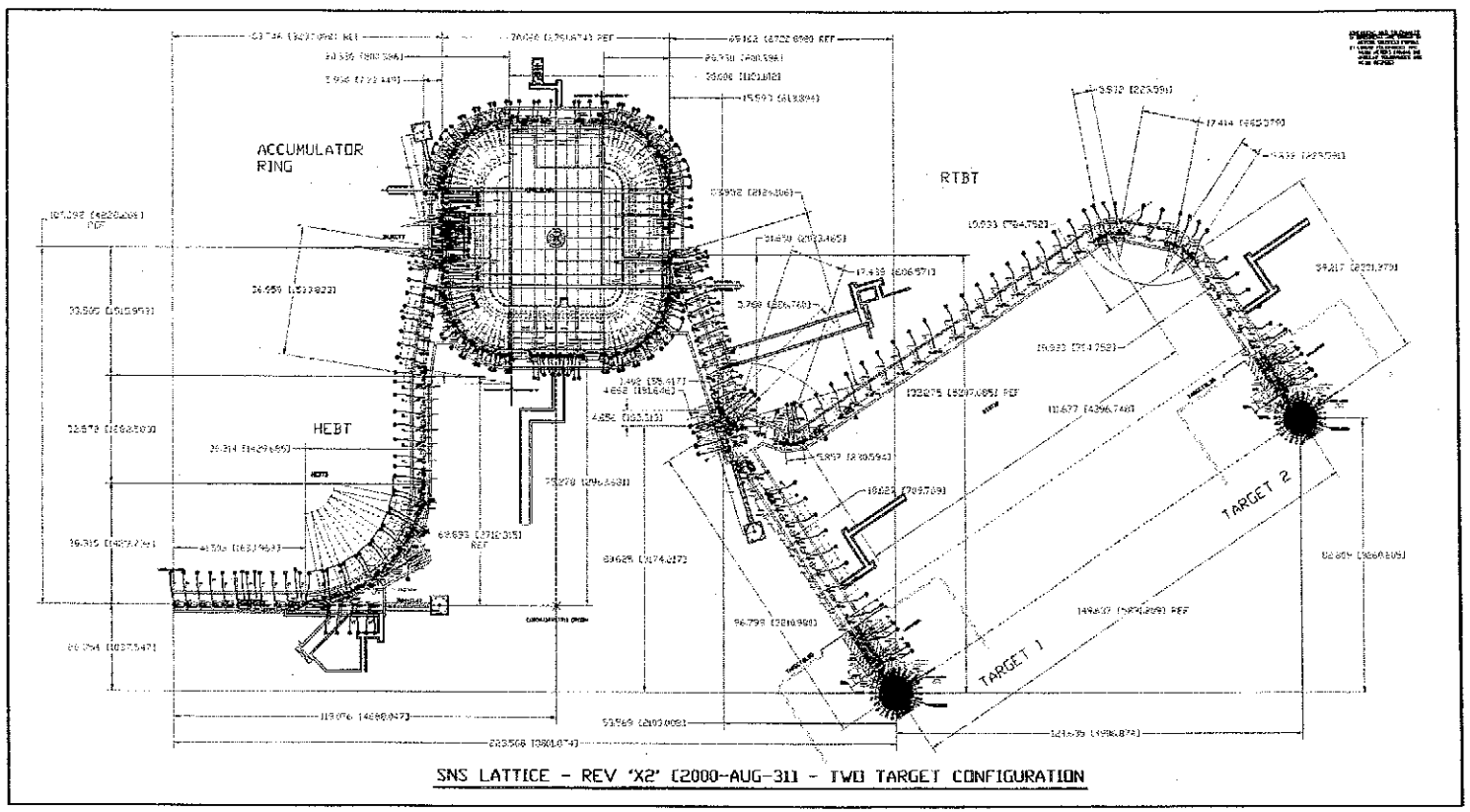
  A. V. Fedotov, Y.Y. Lee, W.T. Weng,
  J. Wei, N. Tsoupas

Transfer Lines & Ring



ISSUES

- VERY HIGH PROTON POWER
- UNPRECEDENTED NUMBER OF PROTON ACCUMULATION 2 X 10^{14}
  - LOSS AND COLLIMATIO
- HANDS ON MAINTENANCE
  - LIMIT LOSS TO < 1 WATT / m (10^{-4} LOSS)
- STRICT PROTON DISTRIBUTION REQUIREMENTS AT THE TARGET
  - INJECTION PAINTING
- RELIABILITY, AVAILABILITY AND MAINTAINABILITY

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

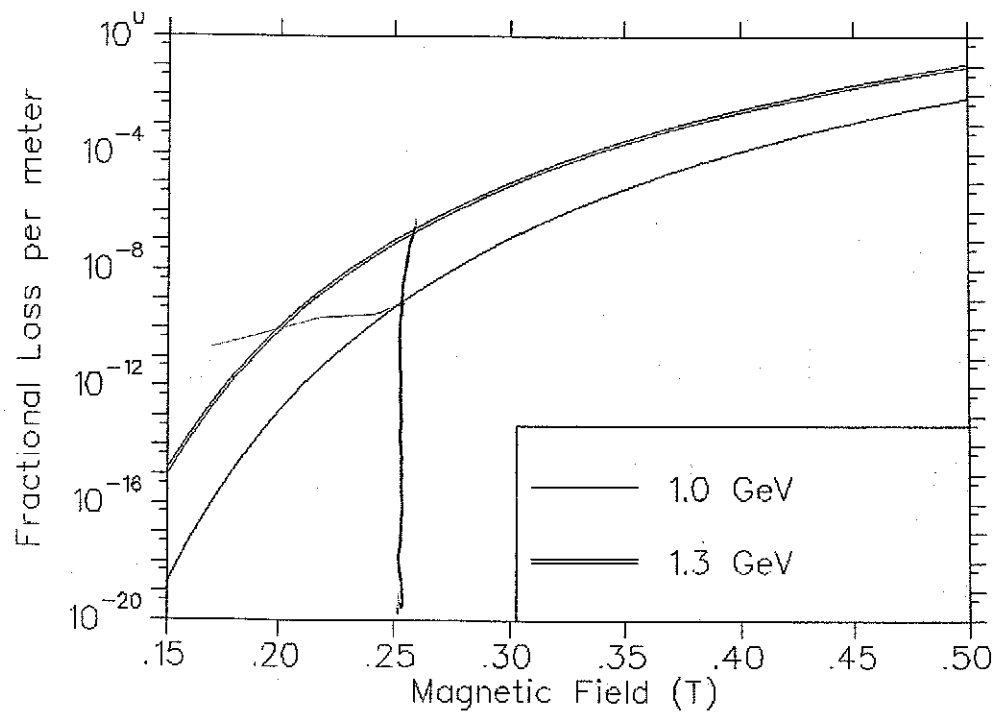
Functions of HEBT
More Than a Transfer Line !

- 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

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

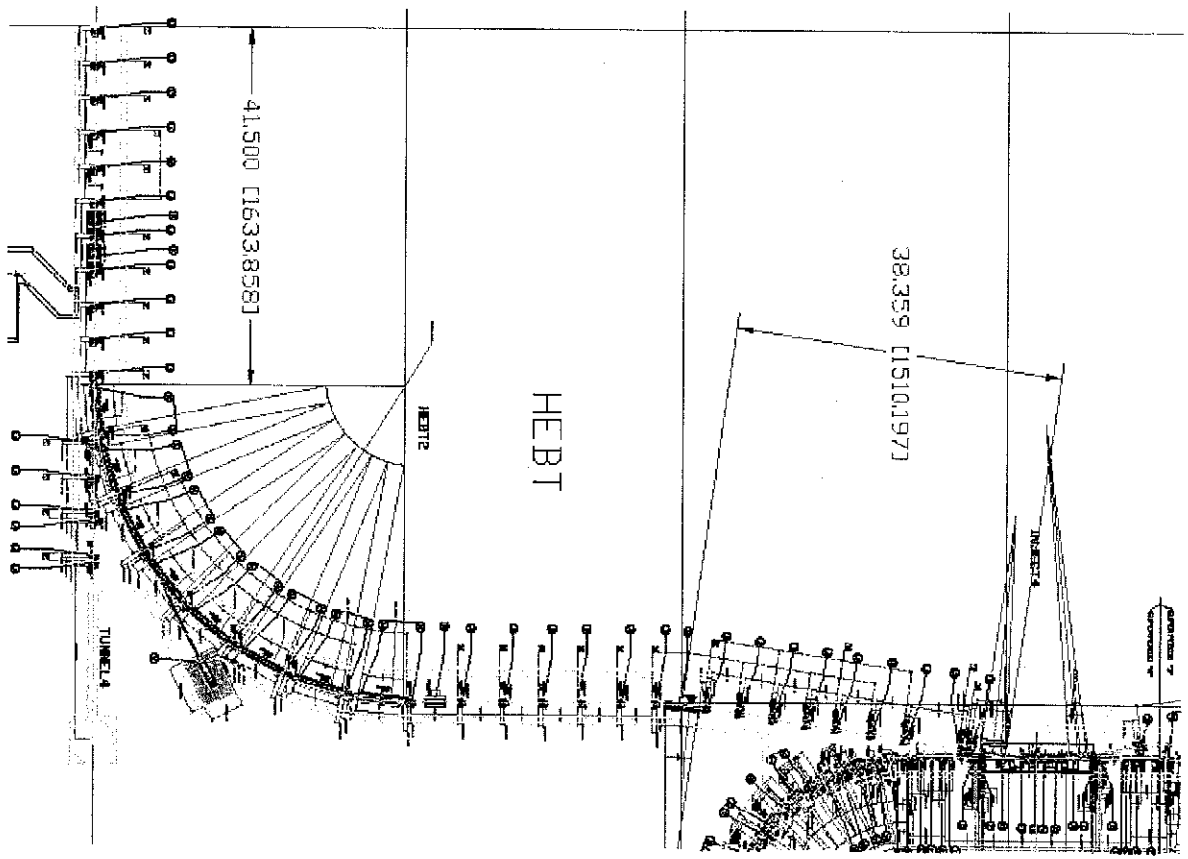
Where B=dipole field(T); $A_1 \sim 8 \times 10^{-6}$ V*s/m; $A_2 \sim 4.3 \times 10^9$ V/m

	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

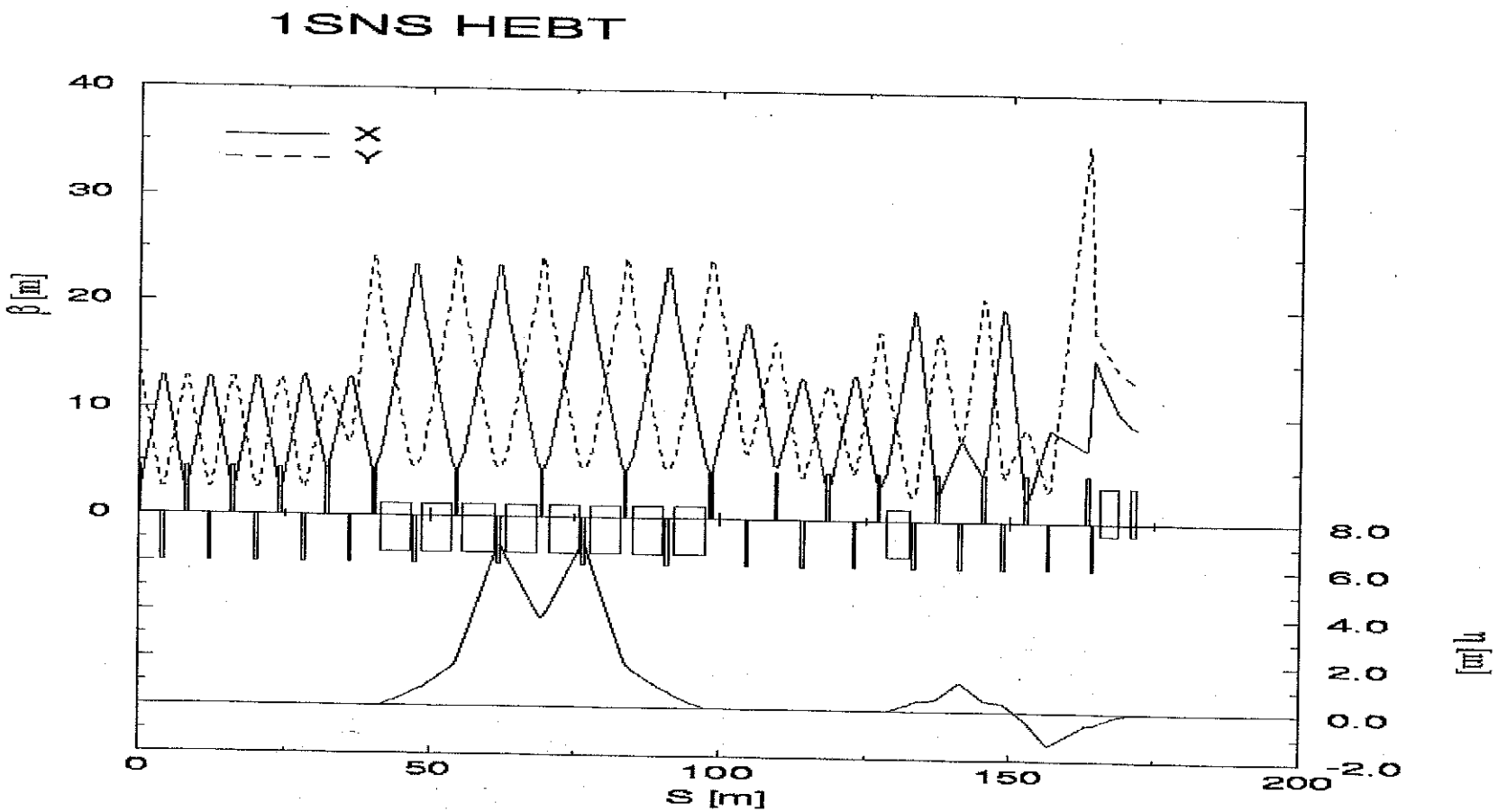
Vacuum Stripping

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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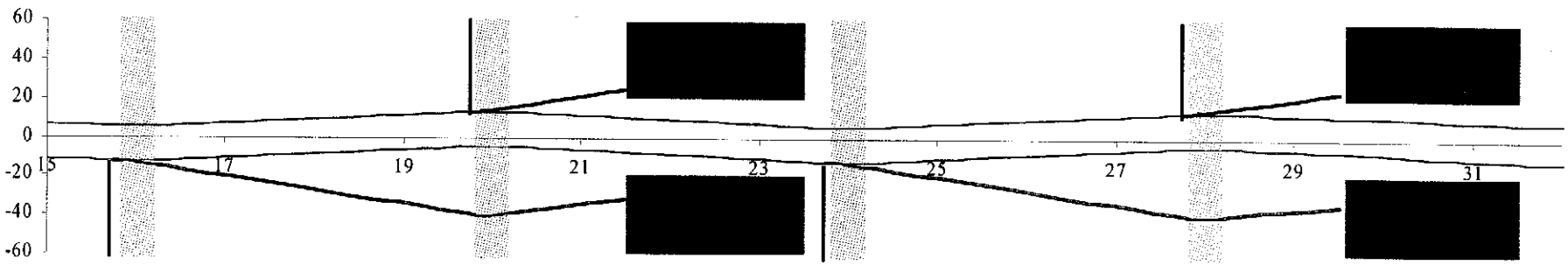
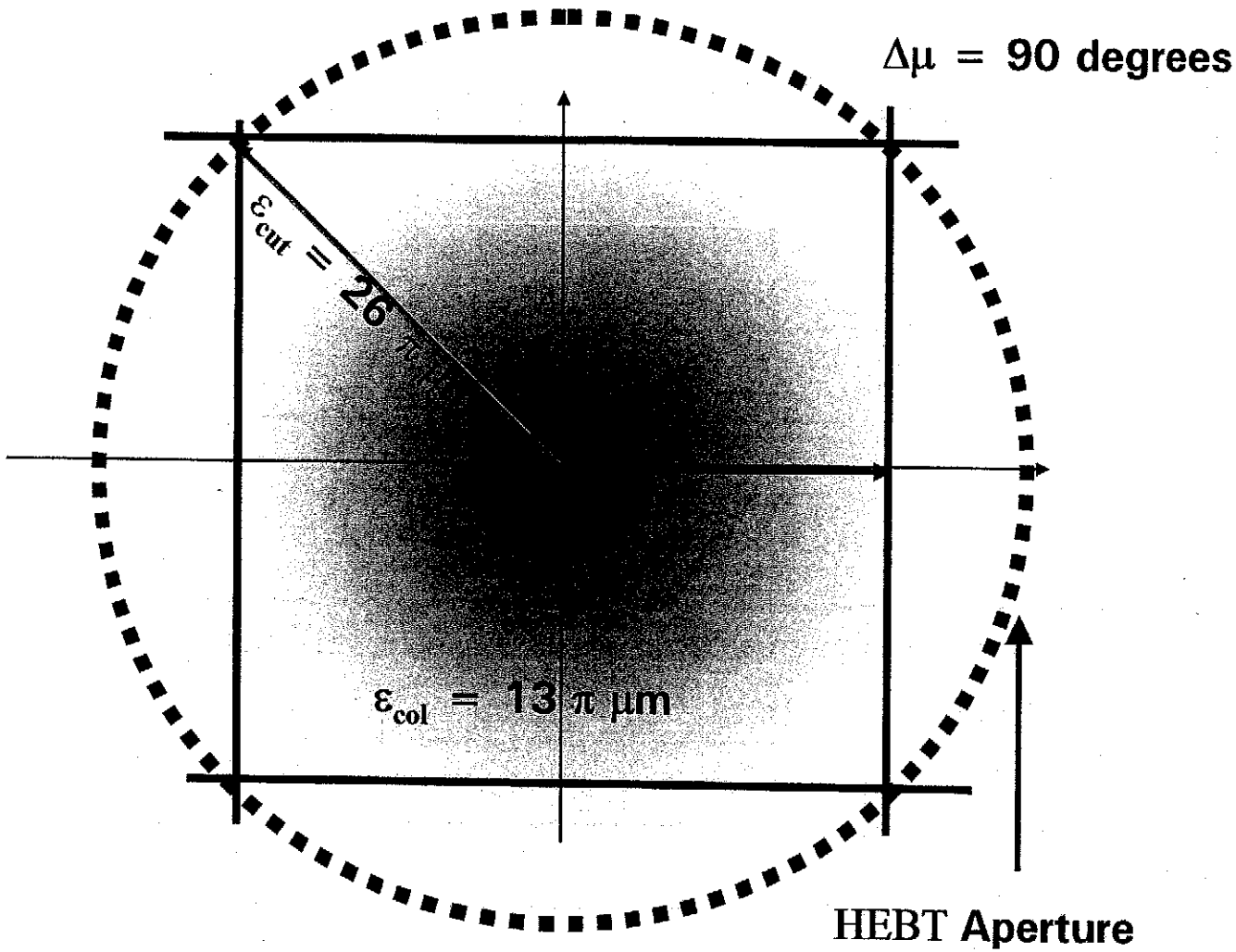
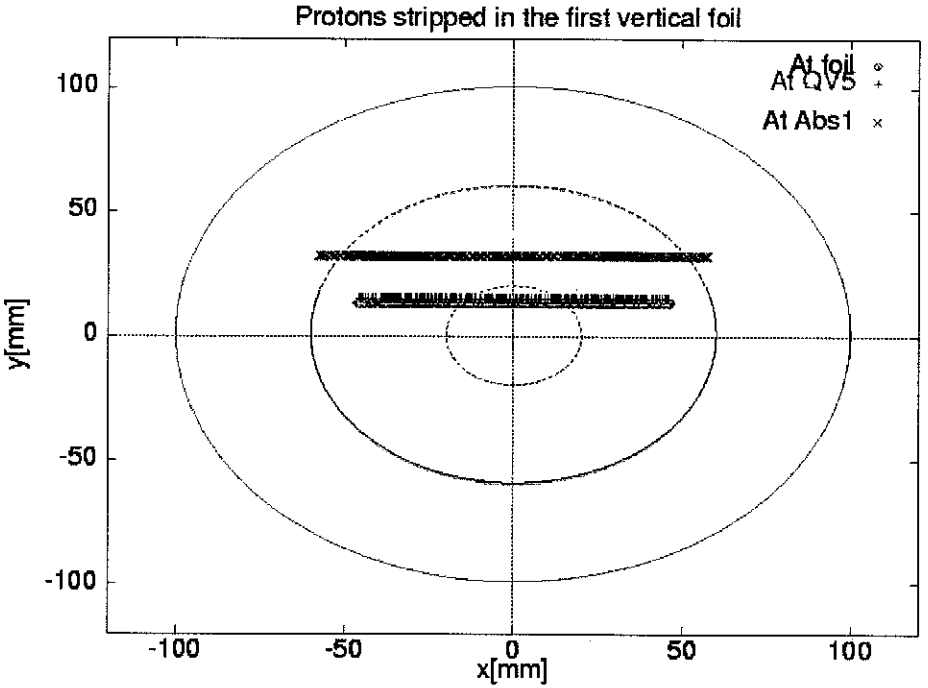
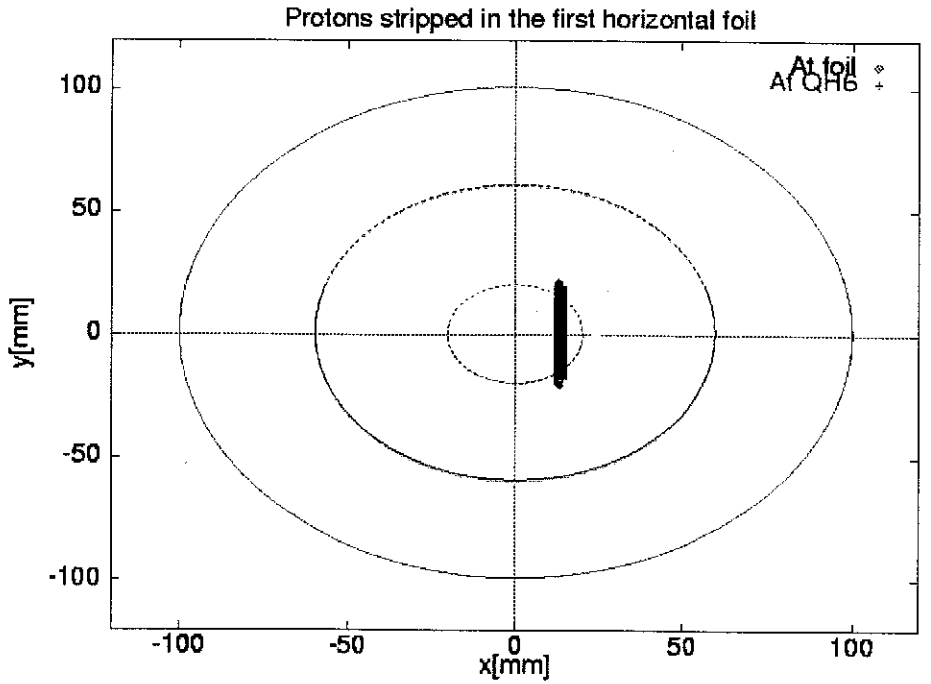
Impact parameters and efficiency



Name	Aperture [mm]	Impact parameter [mm]	/ [mrad]	Efficiency [%]	
Scr 1 U/D	13	12.3	-5.9	95.5	To abs1
Scr 1 L/R	17	4.3	6.7	92.5	To abs1
Scr 2 U/D	13	15.0	-4.1	96.7	To abs2
Scr 2 L/R	17	3.3	6.1	91.0	To abs2


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 Abs1
100
50
0
-50
-100
y[mm]
-100
-50
0
50
100
x[mm]

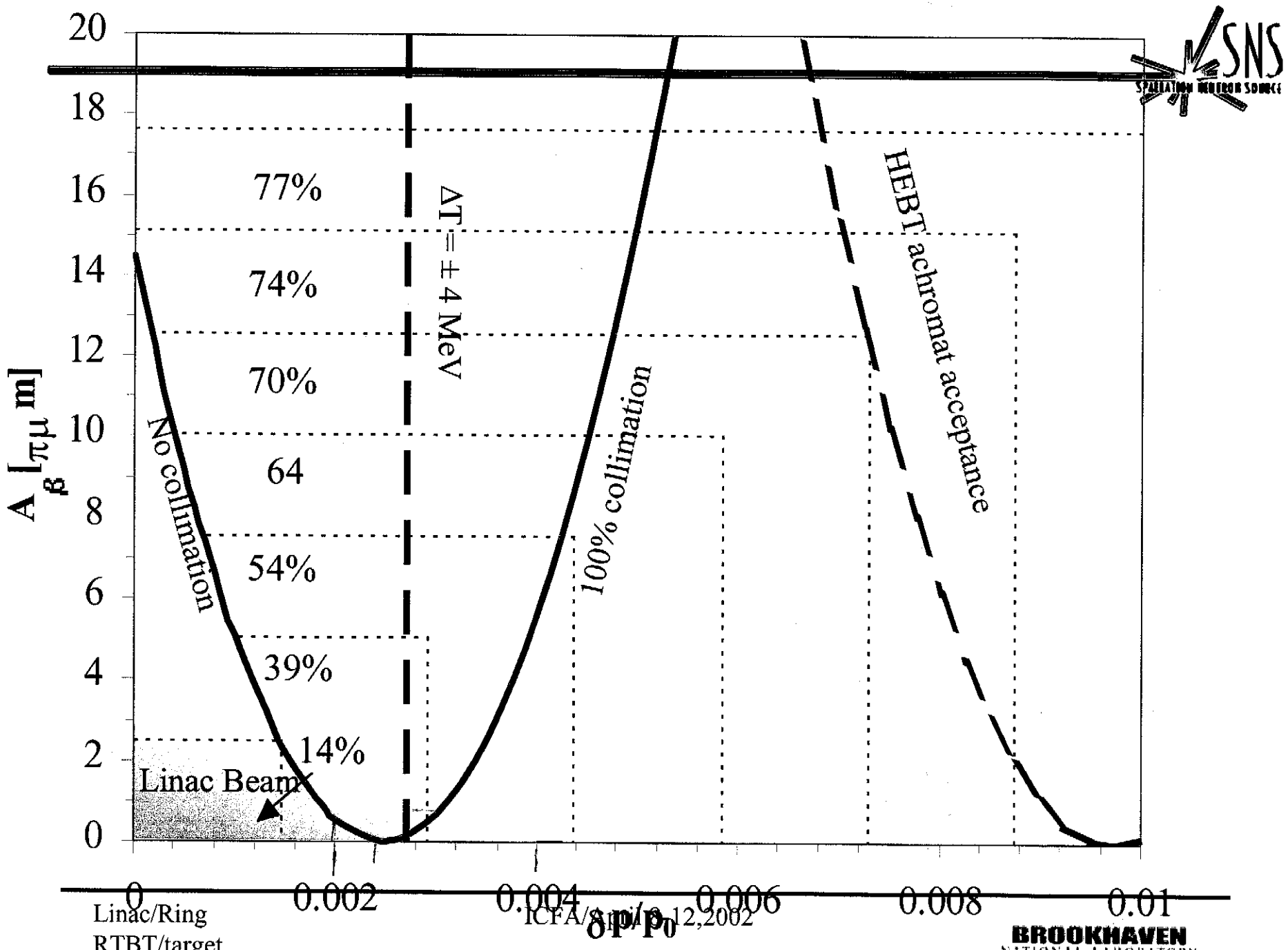

Protons stripped in the first horizontal foil
At foil
At QH6
100
50
0
-50
-100
y[mm]
-100
-50
0
50
100
x[mm]

Achromat
Momentum Tail Clean Up

- Total Phase advance 360 degrees.
- Resolution

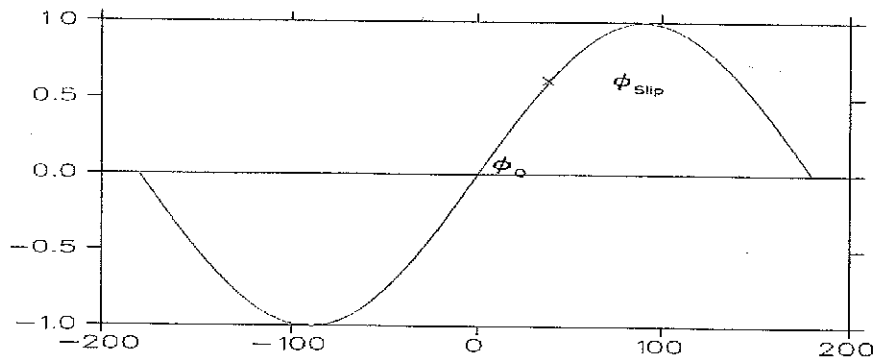
$$R_1 \equiv \frac{R_{16}}{2X_0 R_{11}} \equiv \frac{6.4}{2\times\sqrt{21\times 1.4\times 10^{-6}}\times 1} \cong 5.9\times 10^2$$

- Energy resolution ~4.3mm/MeV
- Momentum Acceptance $\pm 1\%$



20
18
16
14
12
10
8
6
4
2
0
A_β [$\pi\mu$ m]
77%
74%
70%
64
54%
39%
14%
No collimation
ΔT = ± 4 MeV
100% collimation
HEBT achromat acceptance
Linac Beam
0
0.002
0.004
0.006
0.008
0.01
$\delta p/p_0$
Linac/Ring
RTBT/target
ICFA/Sept/9-12,2002
BROOKHAVEN
NATIONAL LABORATORY

Working of ECC



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

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

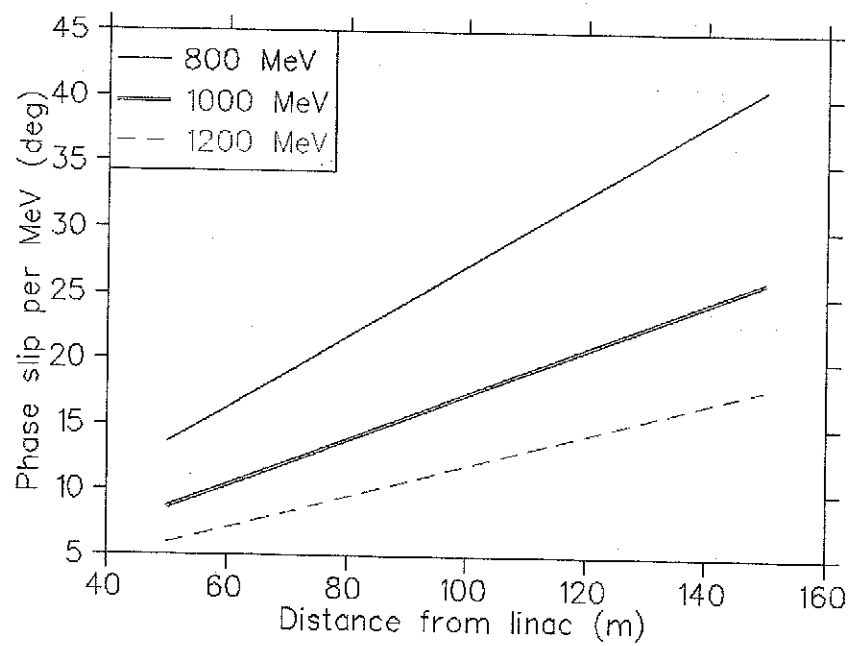
Phase and Energy Jitter Out of Linac

	Phase Jitter (degrees)	Energy Jitter (MeV)
SC linac	$\pm$ 2.0	$\pm$ 1.5

For $\pm$0.5 degrees phase error and $\pm$0.5% Amplitude error

Phase Slips per MeV as function of Distance

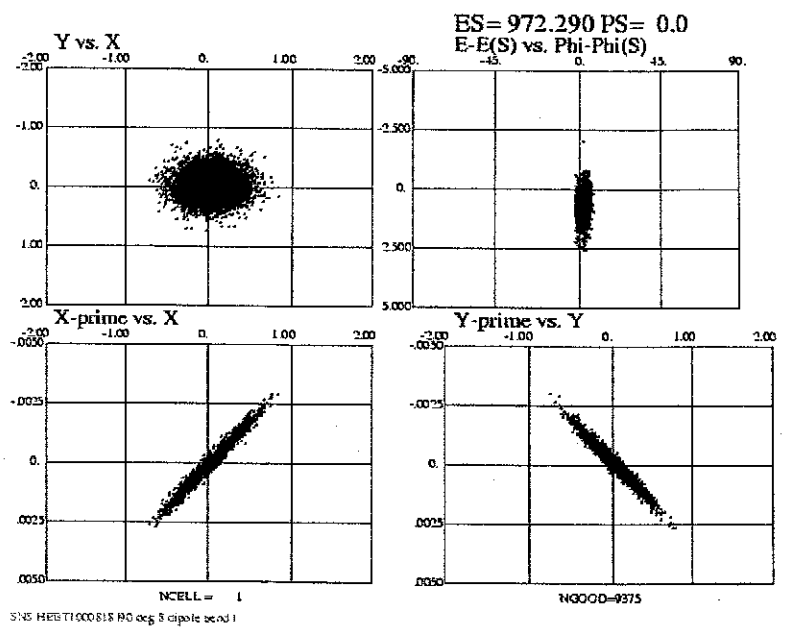
$$\Delta\phi_L \equiv \frac{\gamma}{\gamma(\gamma+1)}\frac{\Delta T}{T}\frac{L}{\beta c}2\pi f$$



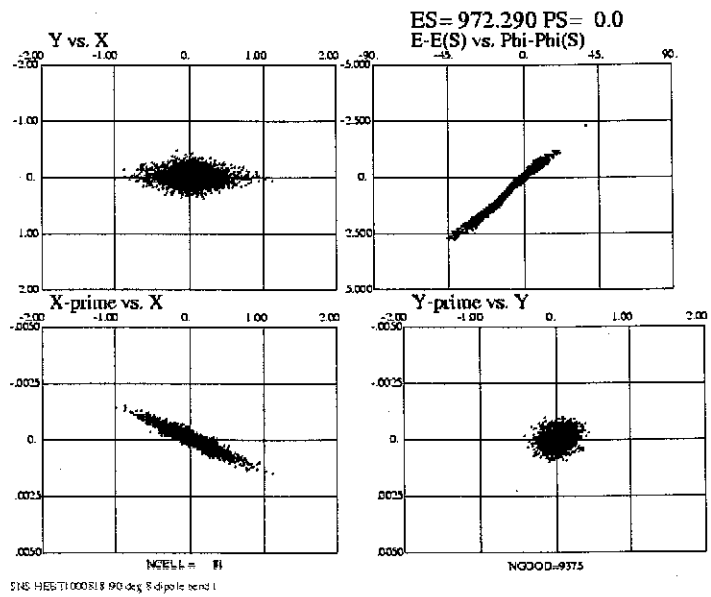
Phase Slips at the Energy Corrector Cavity

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

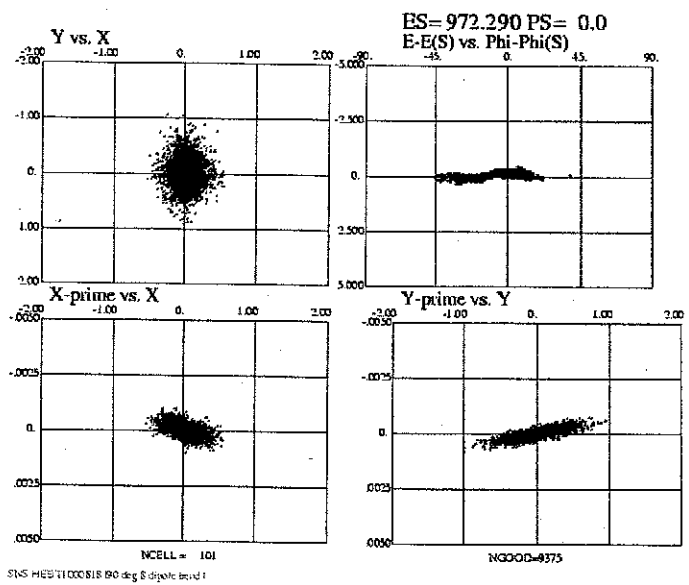
Phase Space at end of Linac



Phase Space before the Corrector



Phase Space after the Corrector Cavity



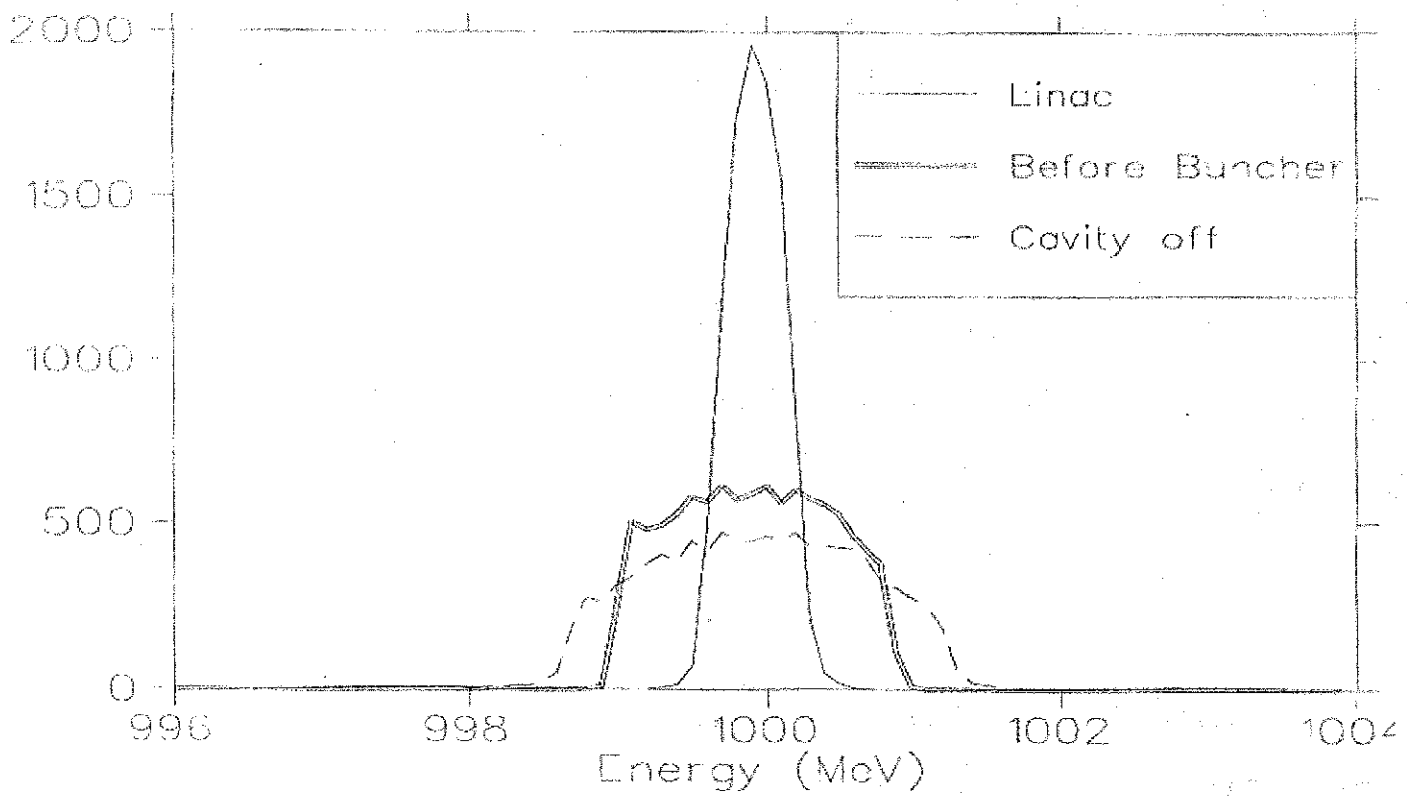
Energy Corrector Cavity

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

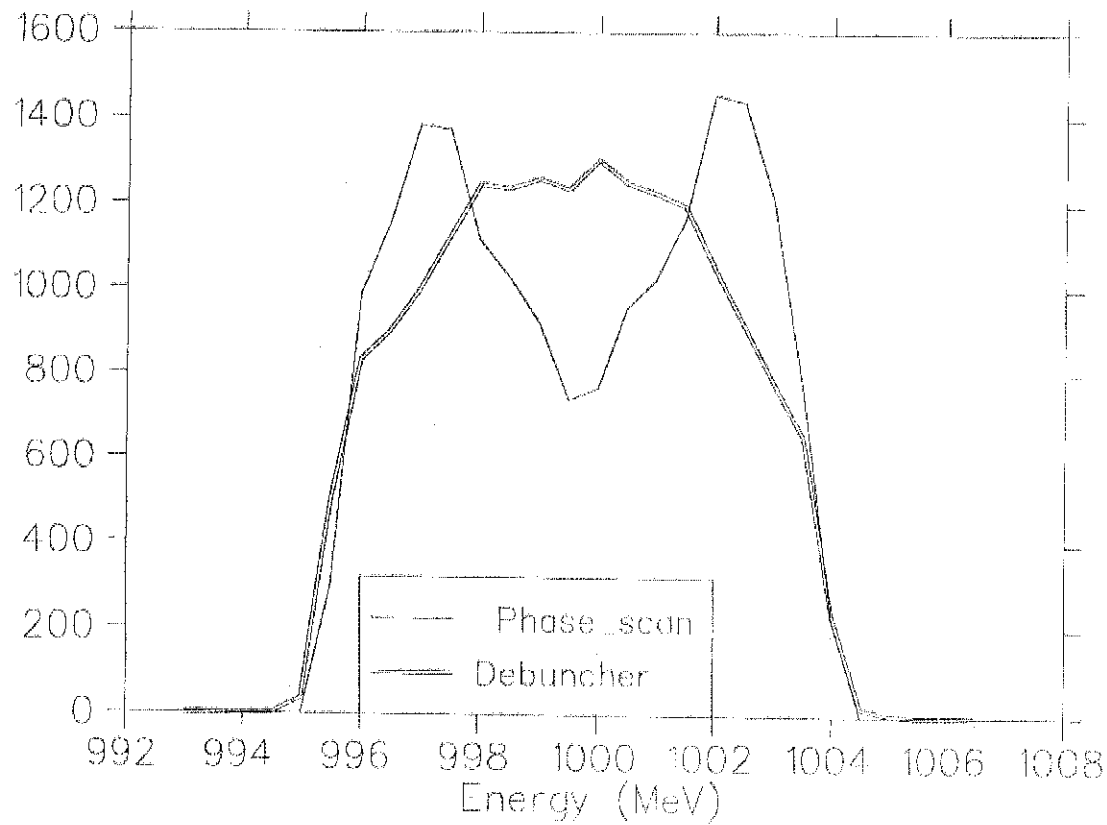
RF cavity (805 MHz) before the achromat
92 m from the linac ➡ phase slip 18 deg/MeV ➡
Required voltage = 3.2 MV

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

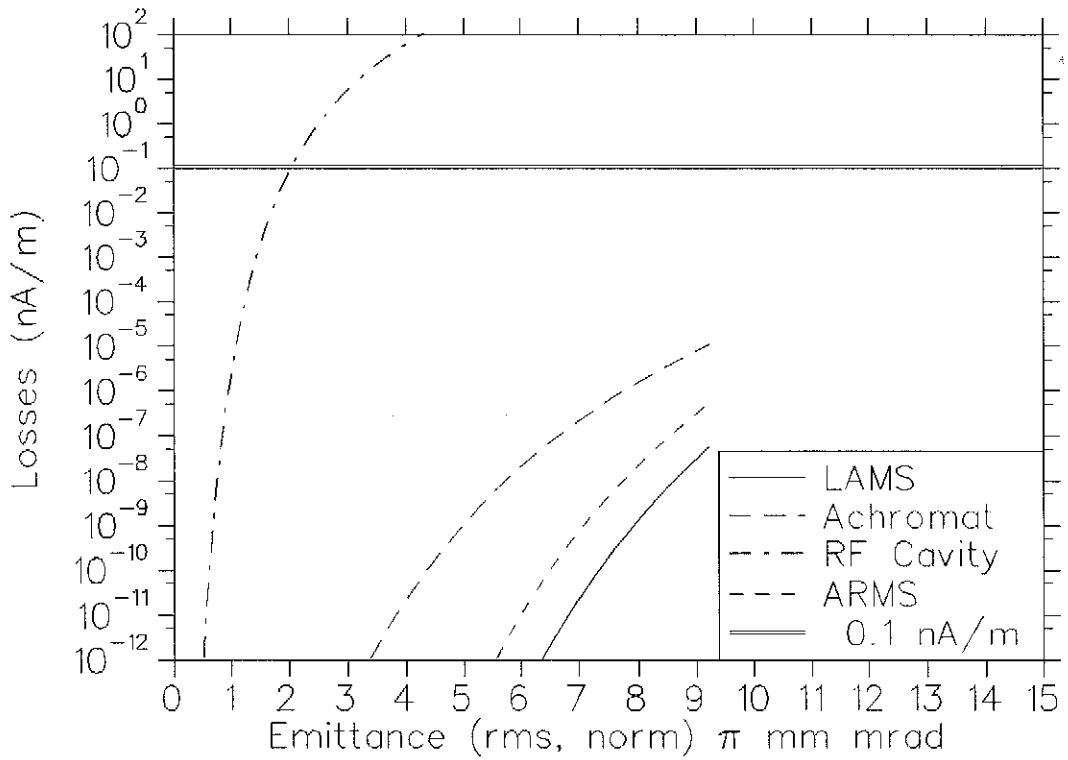


Energy Spreader Cavity

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

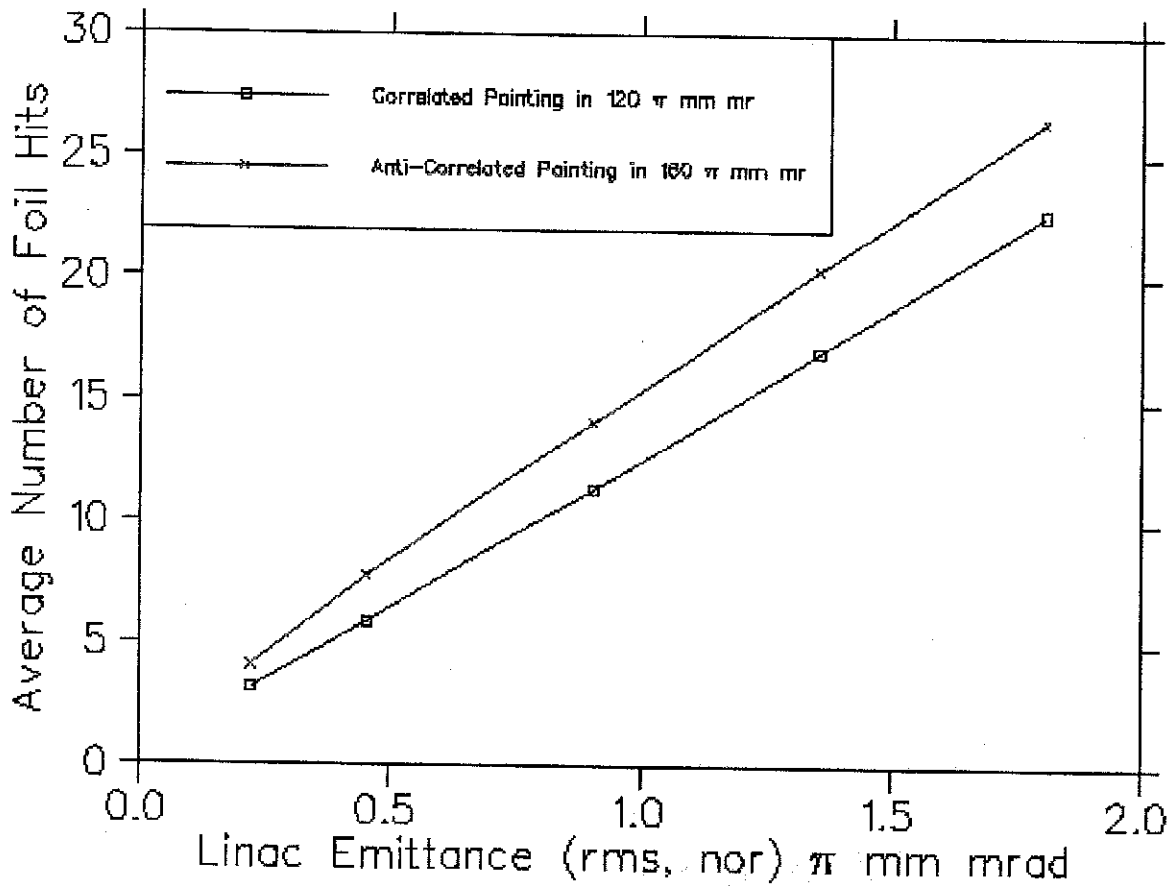
Length	1.3 meter
Aperture (diameter)	5.0 cm
Frequency	805 MHz ±100 kHz
Required voltage	3.5 MV

Transverse Emittance (HEBT)

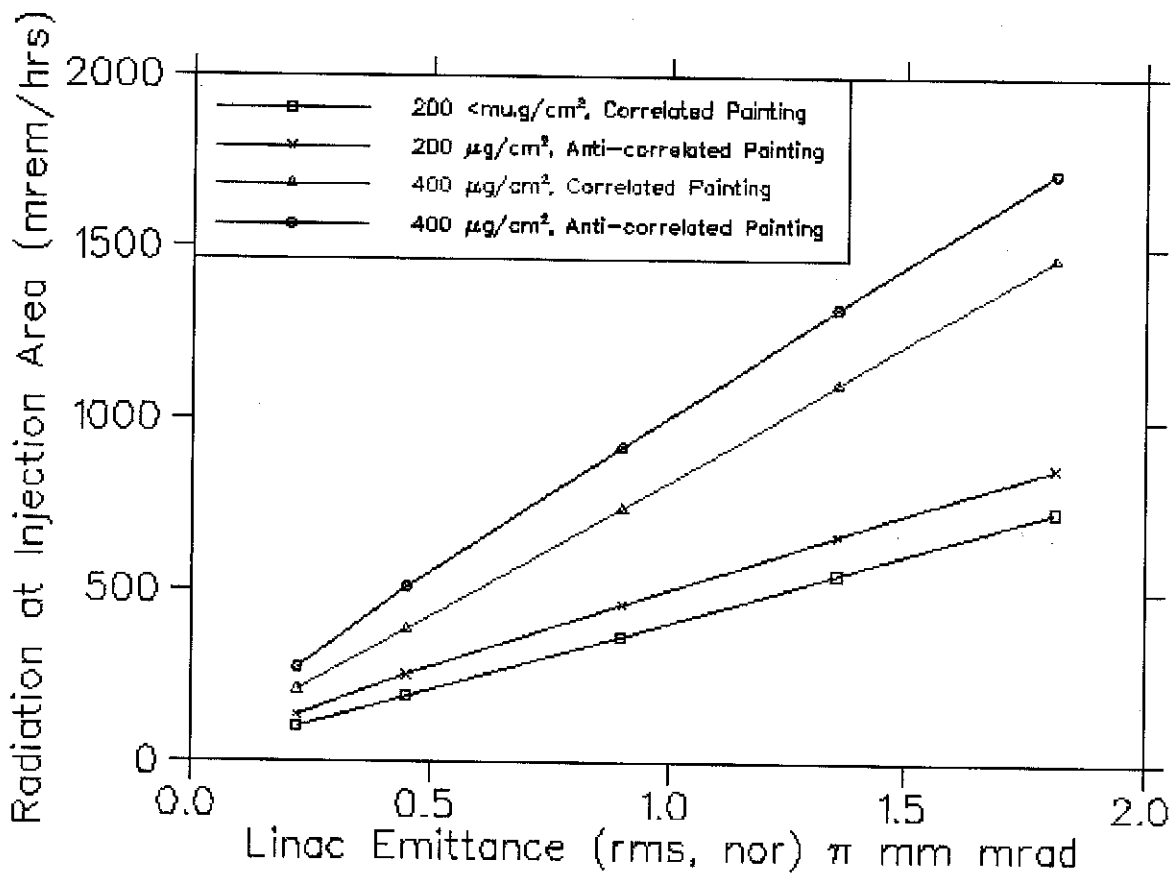


Without Collimator

Transverse Emitance (Cont.)



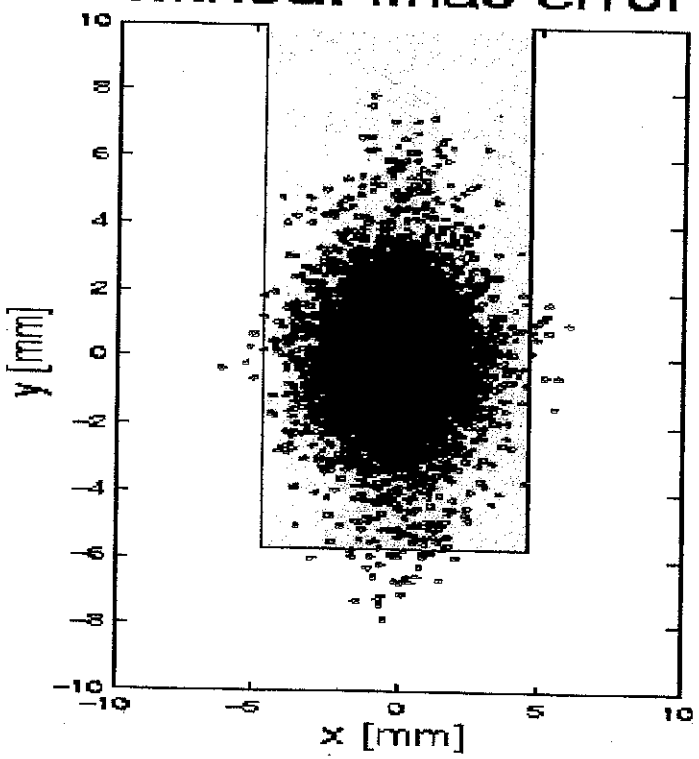
Transverse Emittance (Cont.)



Foil Heating & Foil Miss

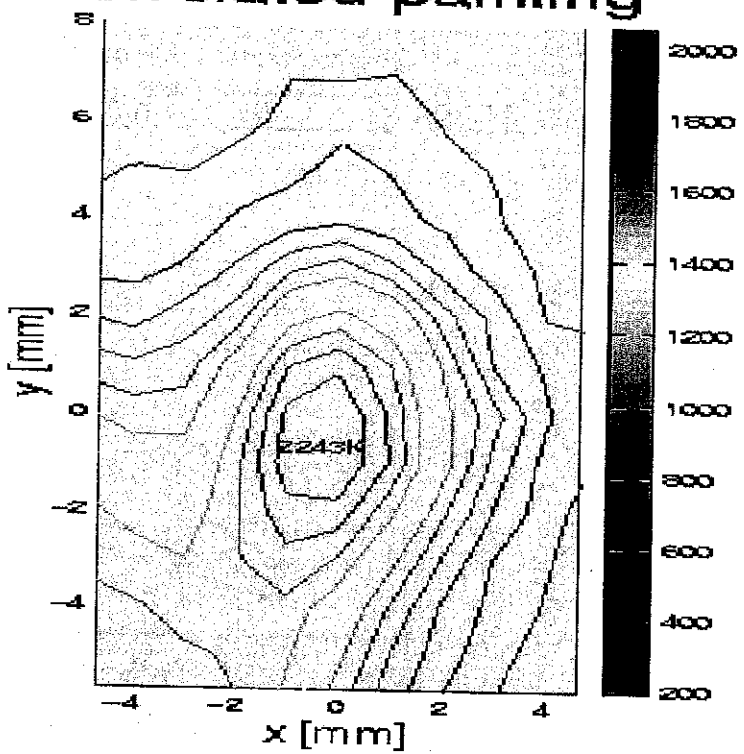
Injected Beam Distribution

without linac error

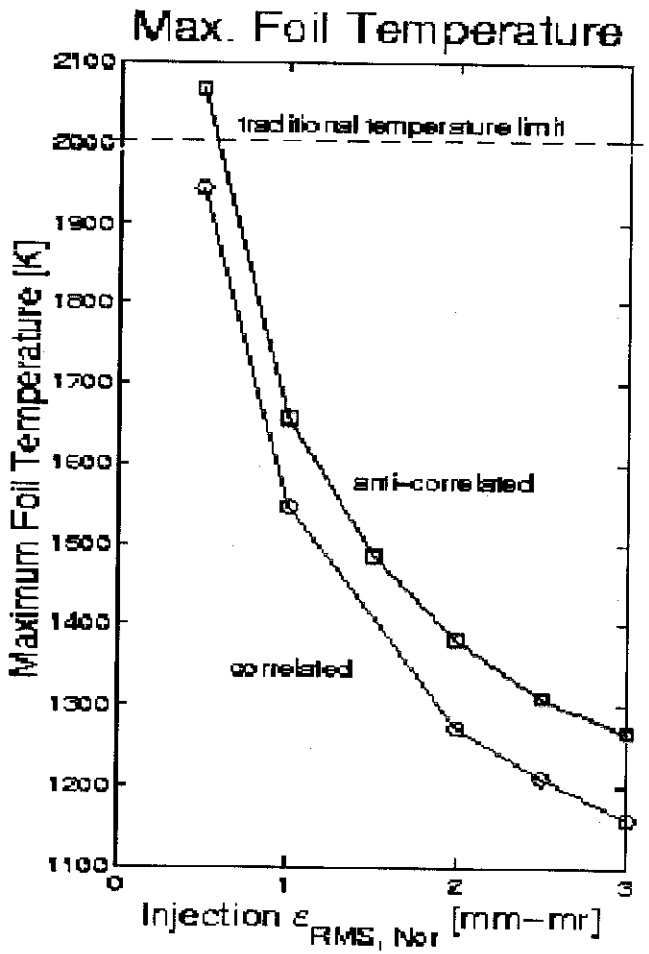


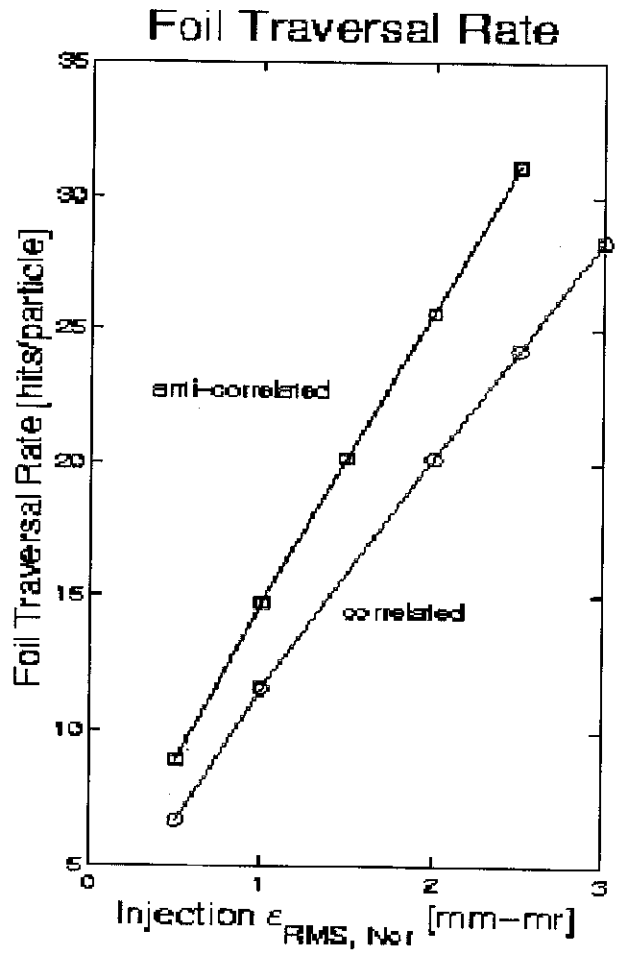
Foil Temperature [K]

correlated painting

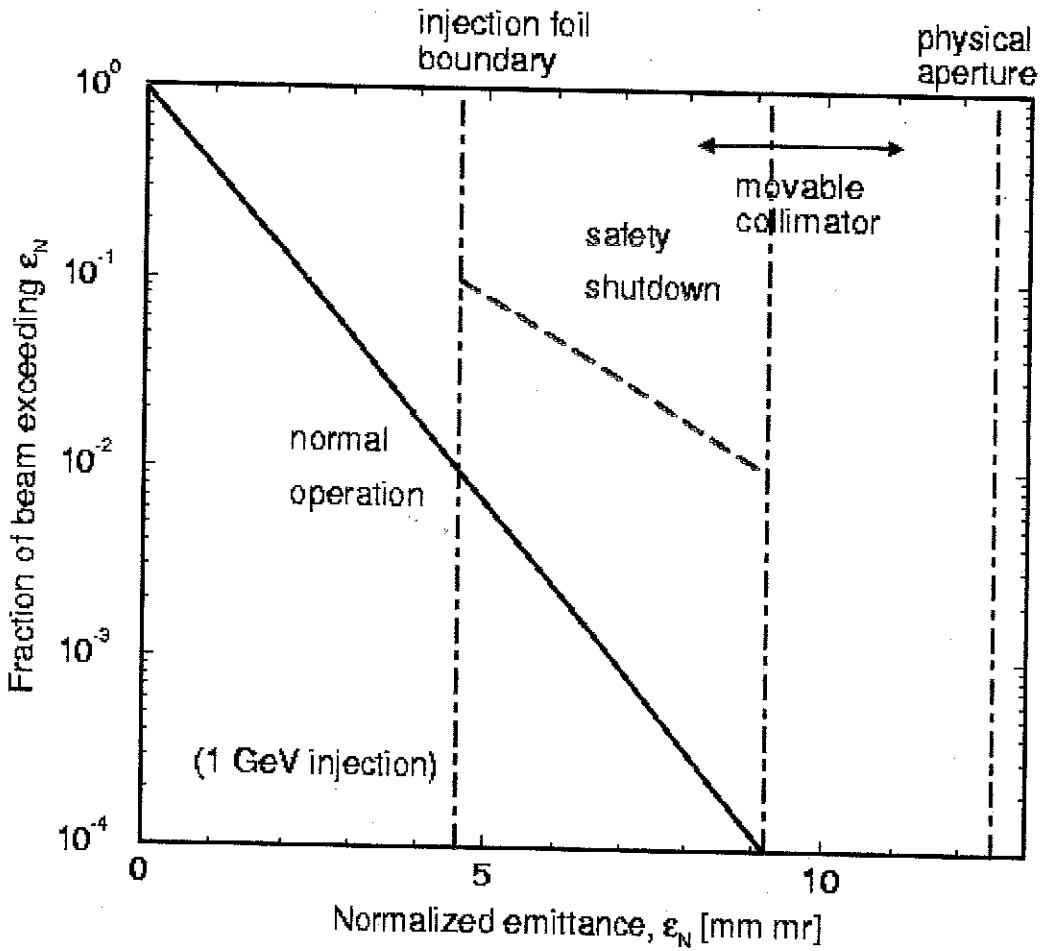


Foil Heating & Scattering



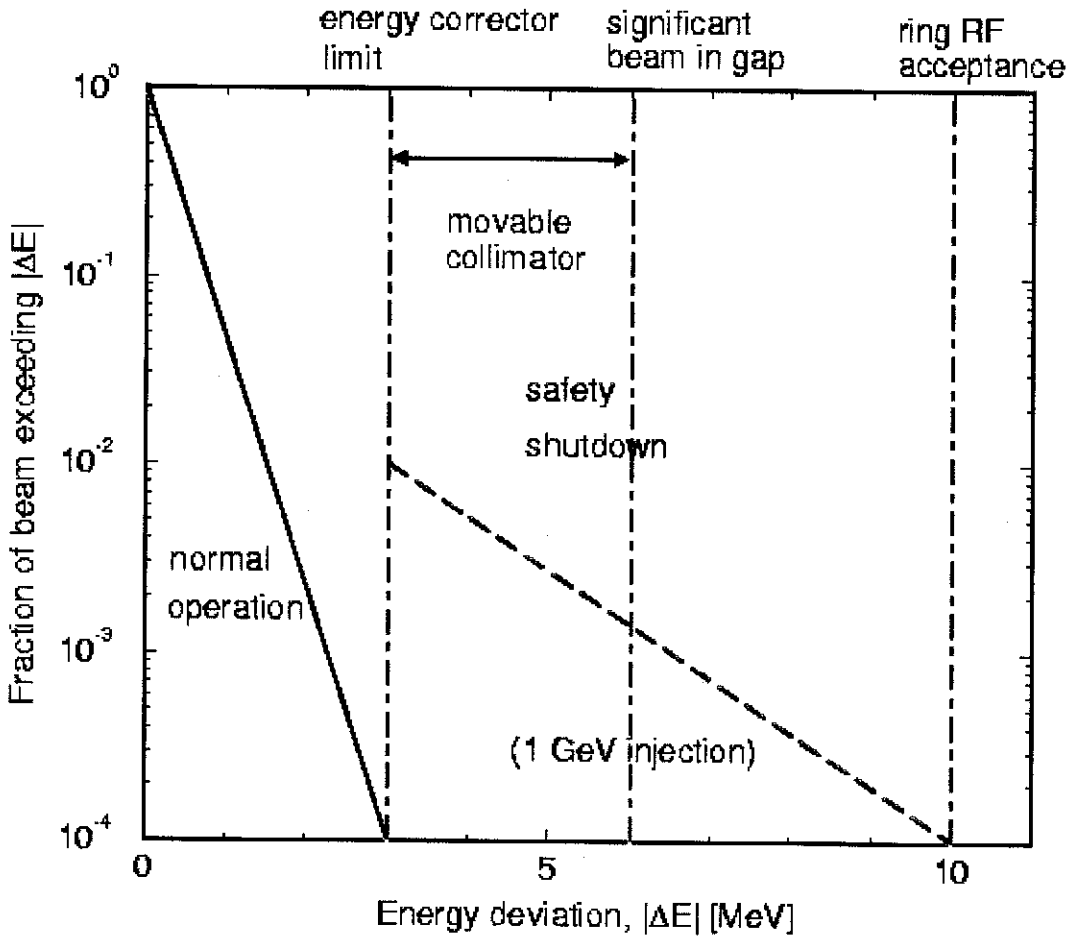


Linac/HEBT interface (trans.)



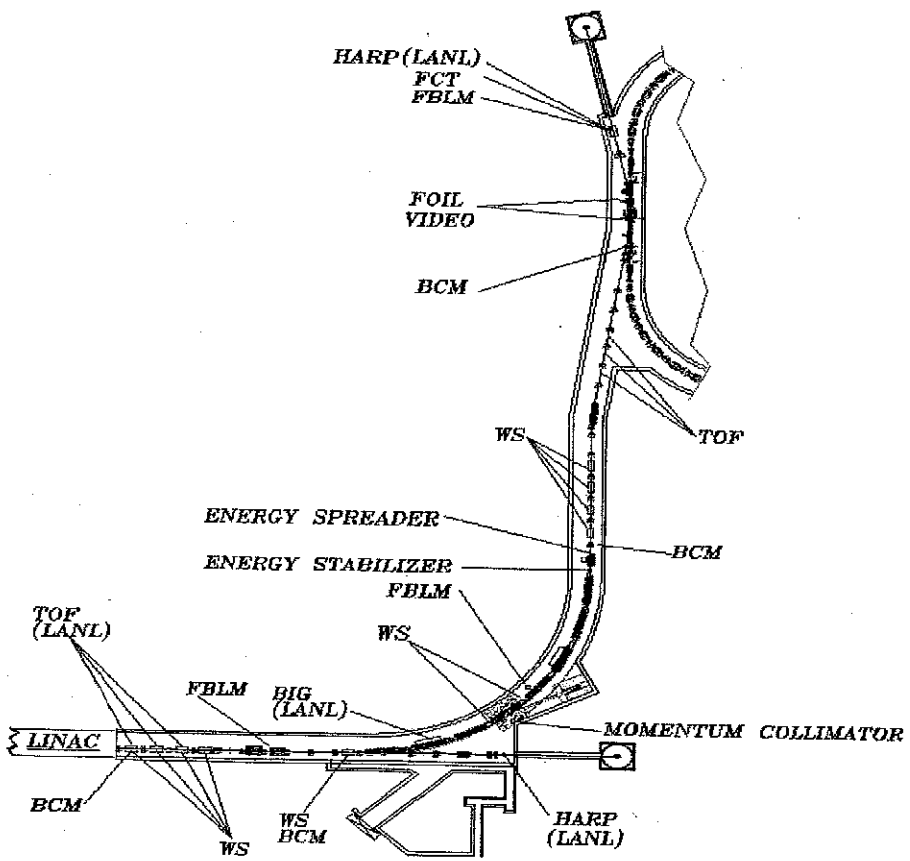
- Nominal norm. rms emittance: 0.5 mm mr
- Larger emittance compromises power & loss/activation
- Injection dump accepts 10% power
- Movable transverse collimator for protection; takes 1% power
- Chamber aperture: HEBT rf cavity …

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

RTBT to Target IDD

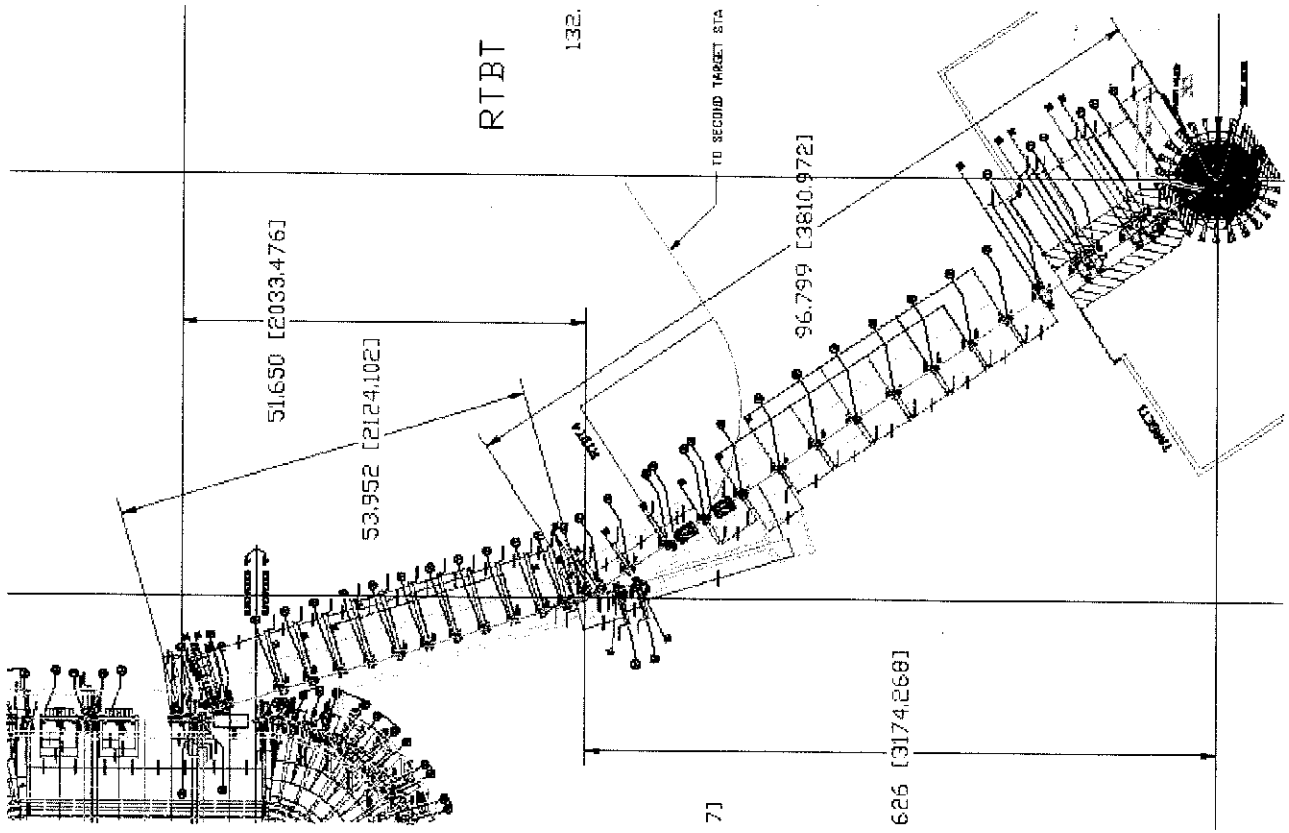
	Normal Condition	Off-Normal	Duration of fault
Target cross section	404 mm x 104 mm		
Beam spot	200 mm x 70mm		
Beam power within target and outside nominal footprint	≤ 10%	≤ 50% power out side spot Prevented by Collimation	≤ 2 pulses
Beam power outside target cross section	< 0.5 %		
Time-average beam 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,

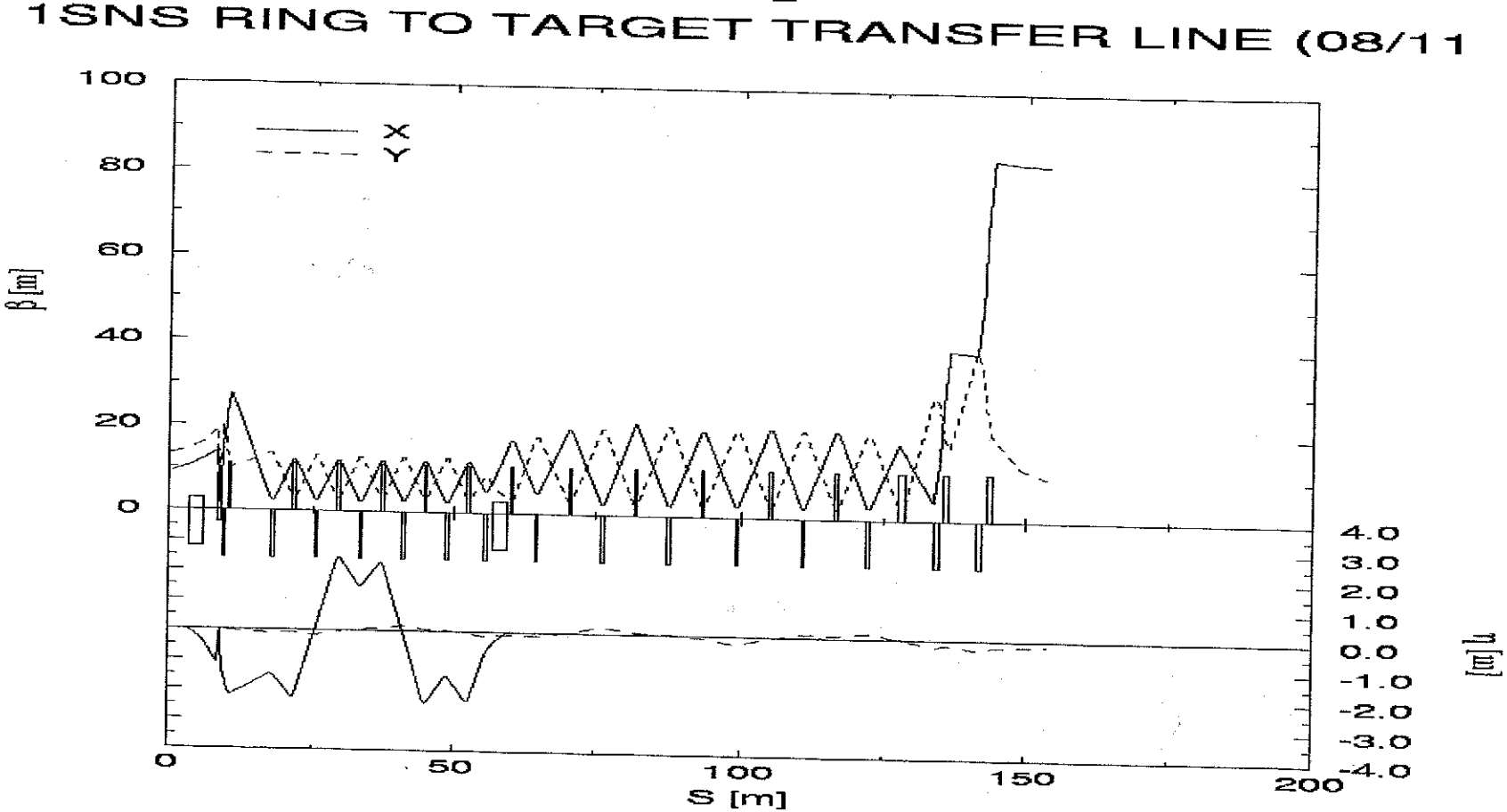
Functions of RTBT

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

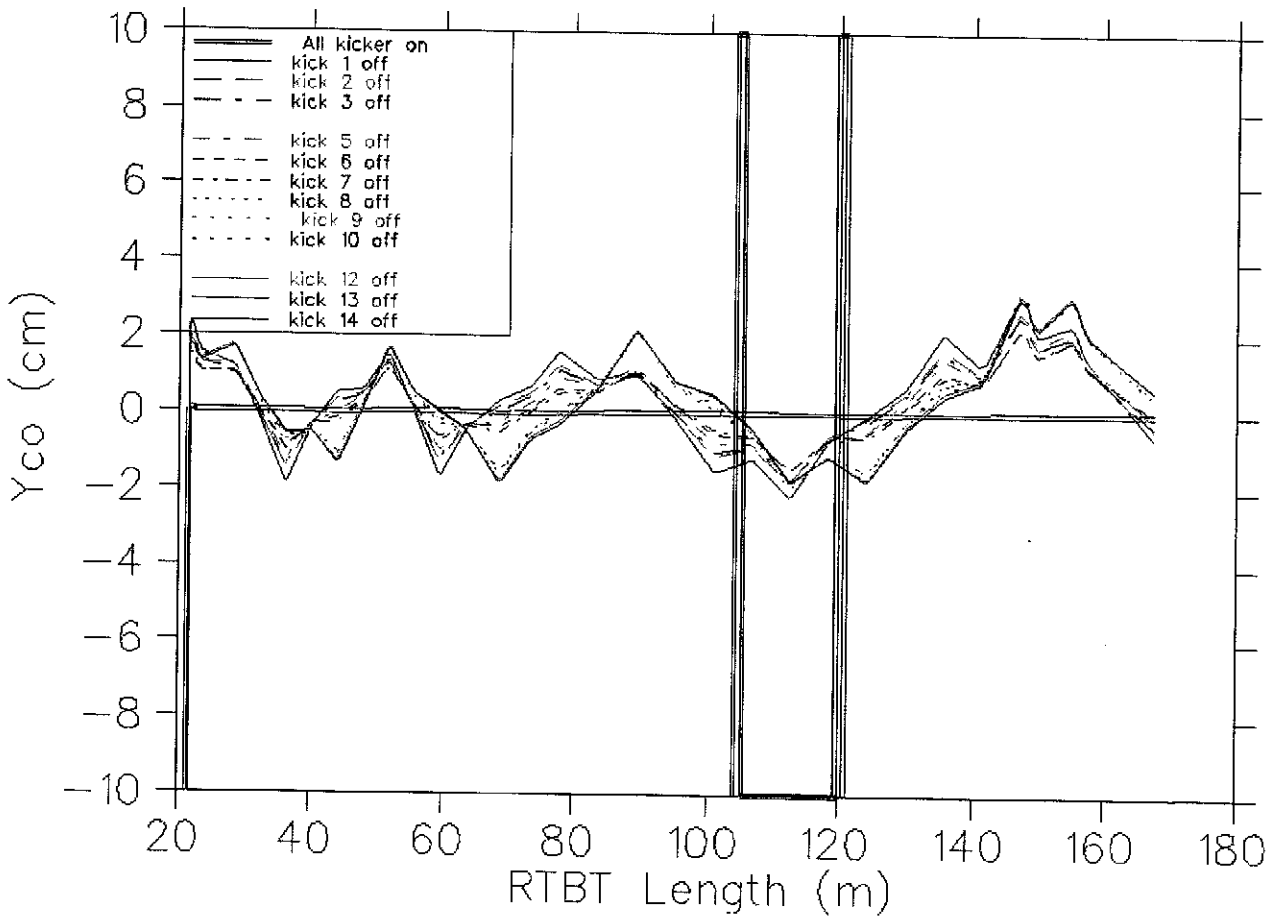
Layout of RTBT



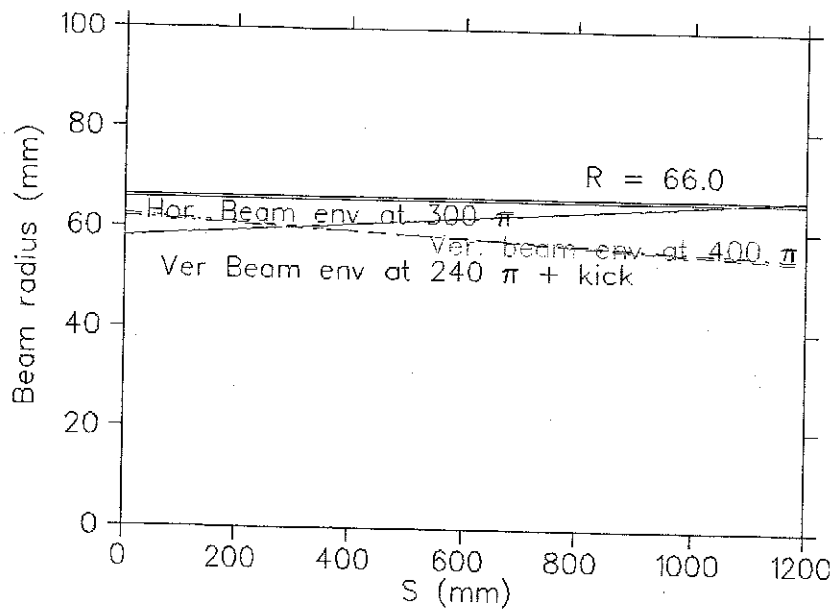
Transport Output for RTBT

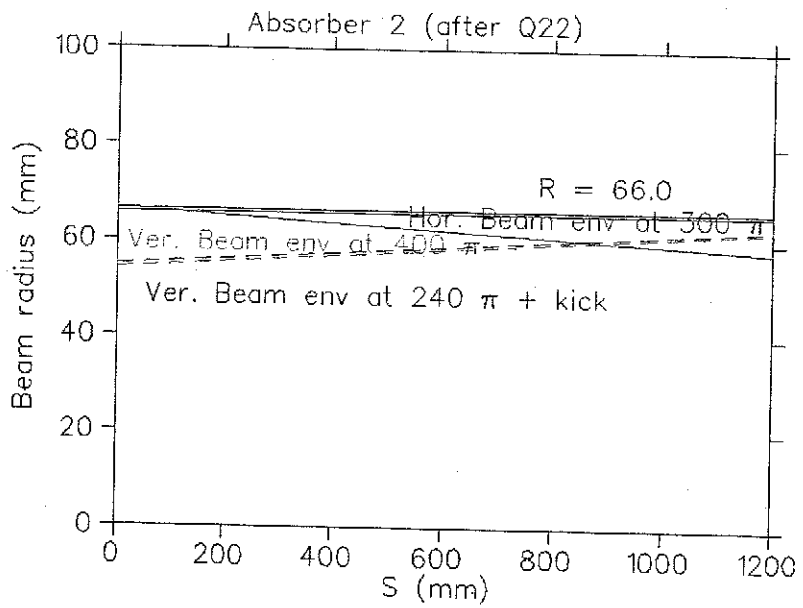


Target Beam Position Immune to Kicker Failure

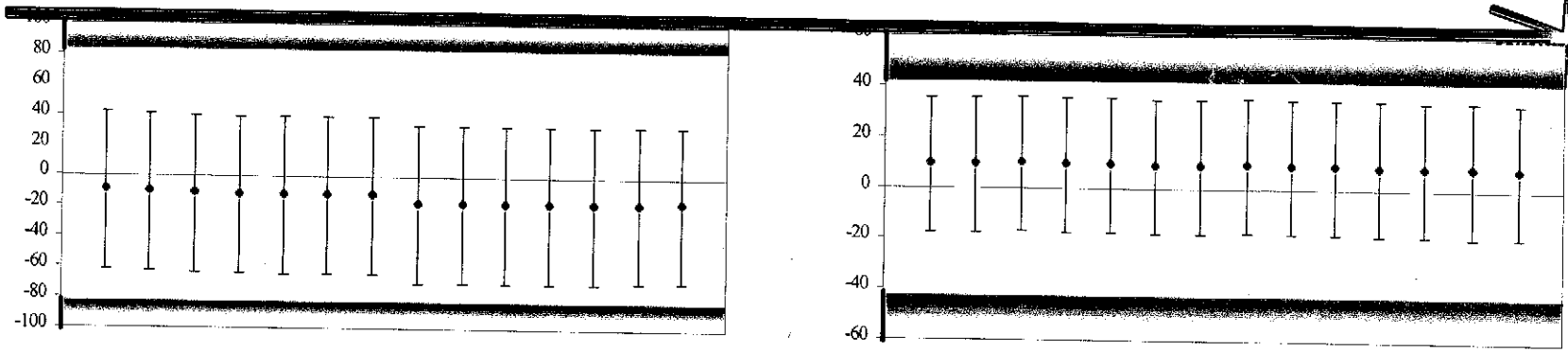


RTBT Collimators

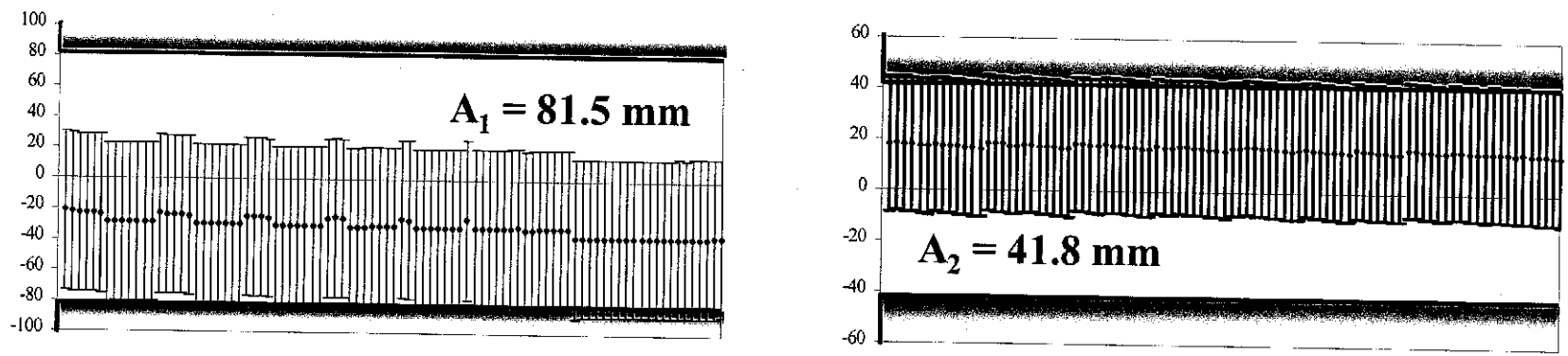




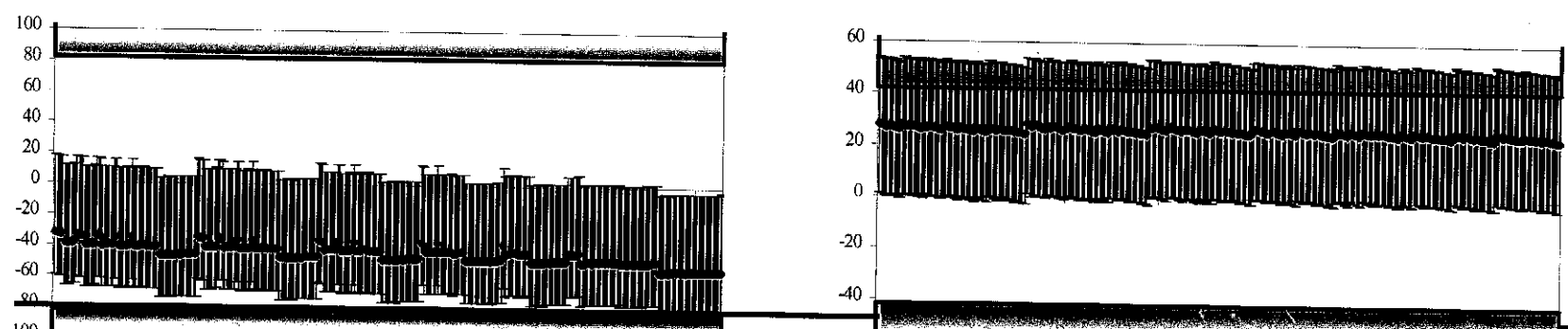
One kicker failure



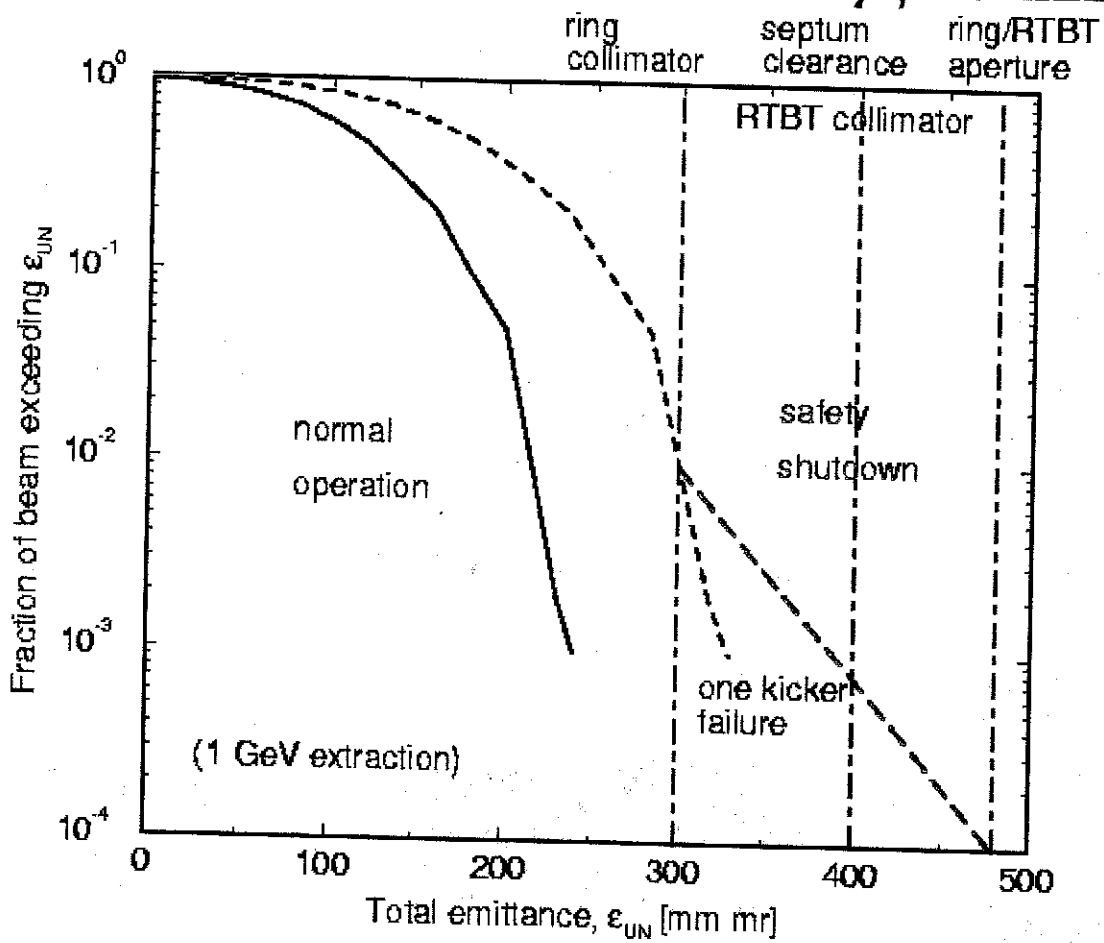
Two kickers failure



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

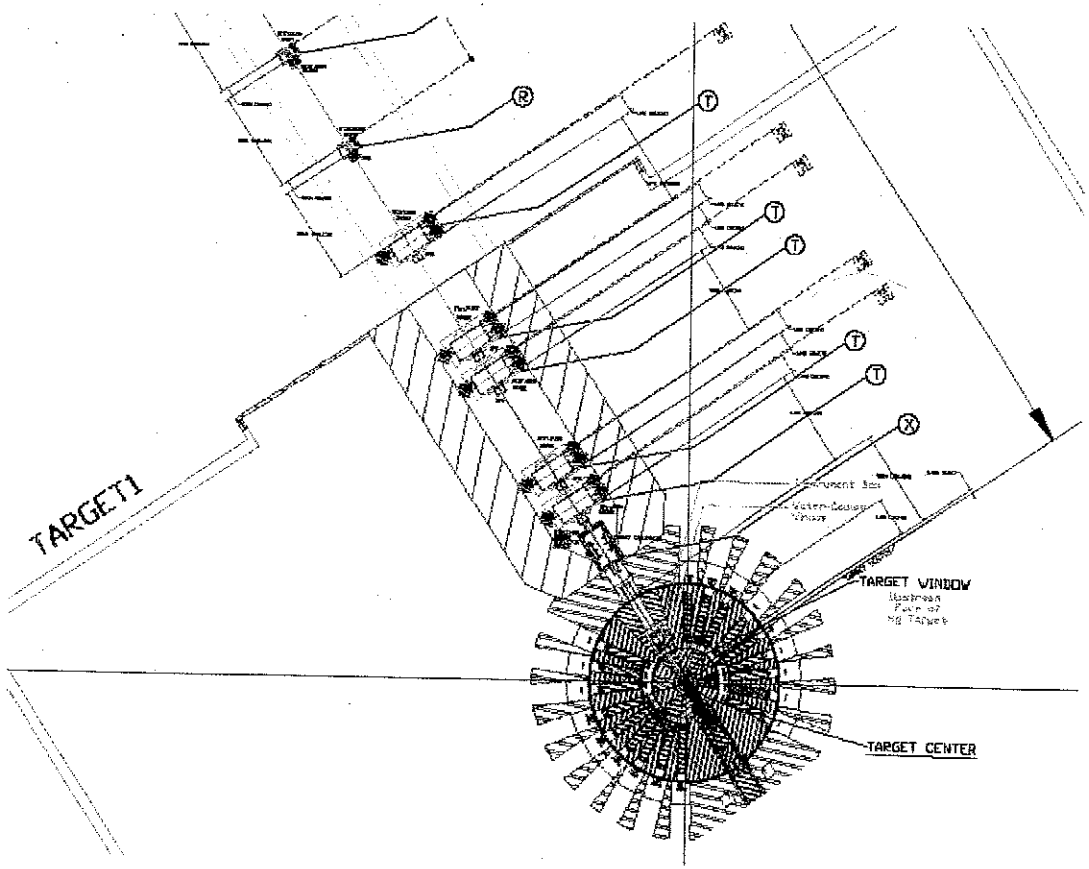
The beam spreader consists of five 36 cm diameter quadrupoles near the end of the RTBT, to provide the desired beam size the target (70 mm x 200 mm)

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.

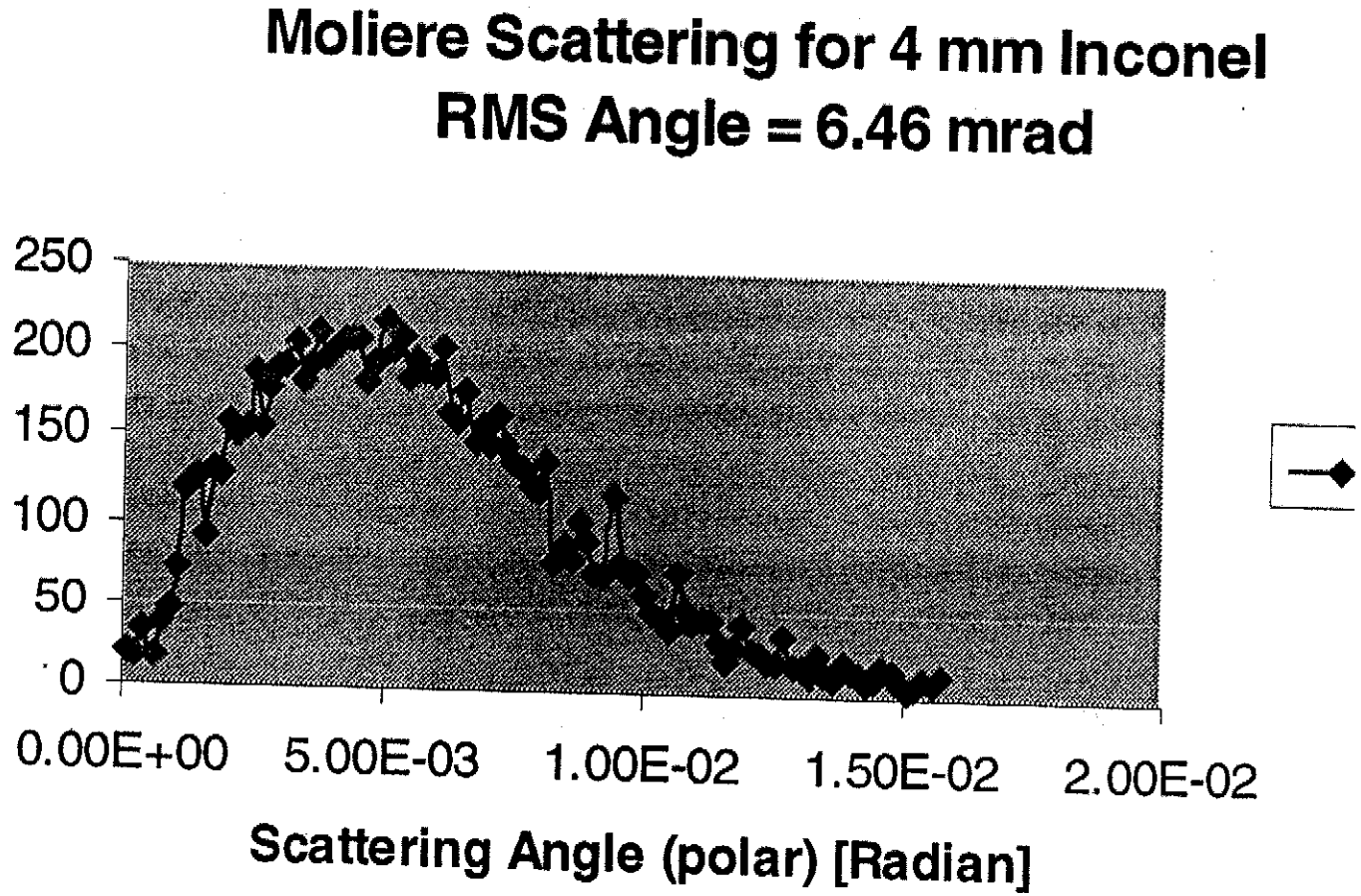
The calculation of the distribution on the target includes the effects of scattering in the 4 mm inconel window, located 2 m in front of the target.

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.

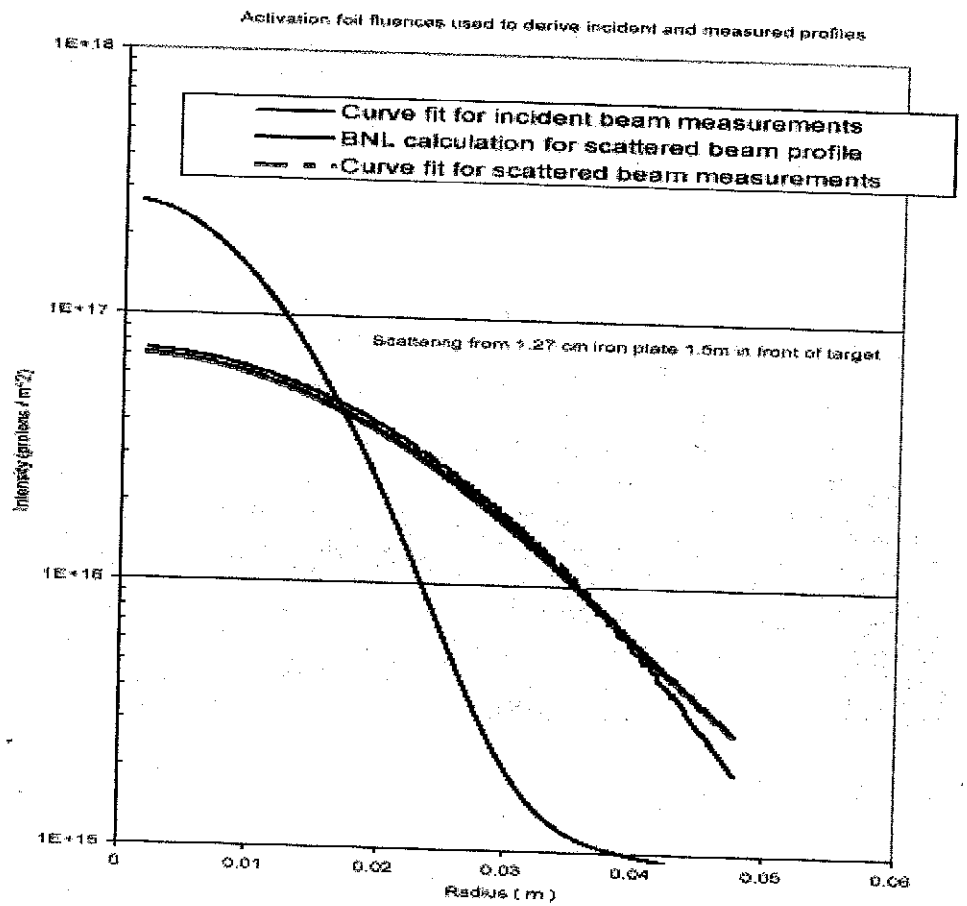
RTBT-Target



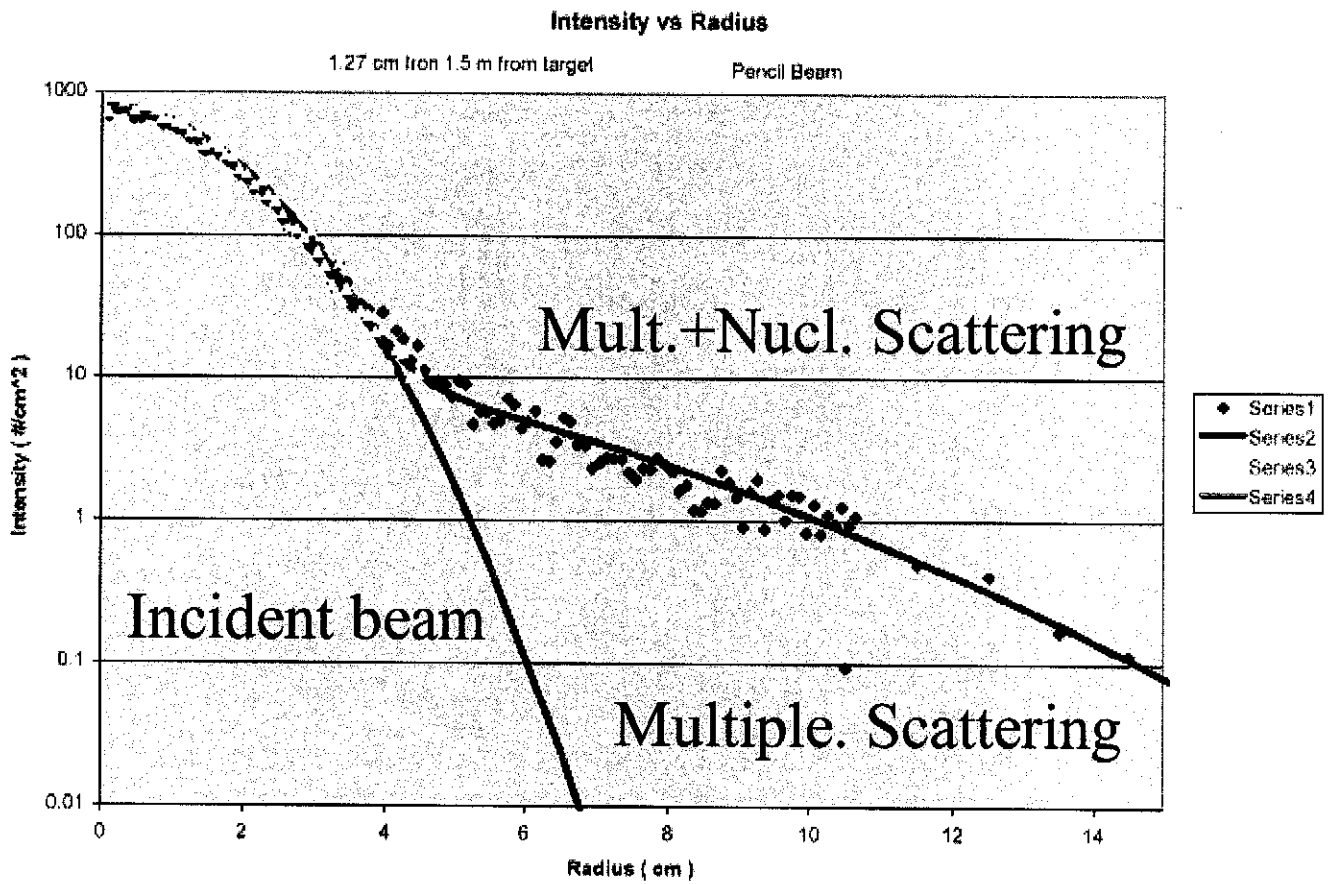
Scattering From Windows



Scattering From Windows

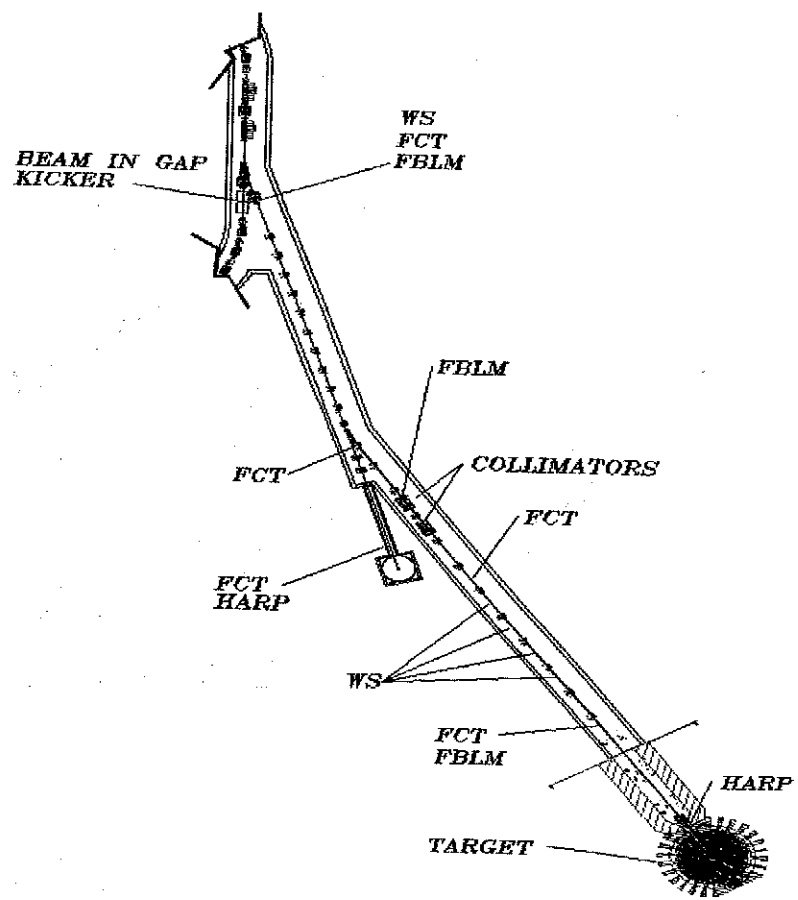


Scattering From Windows

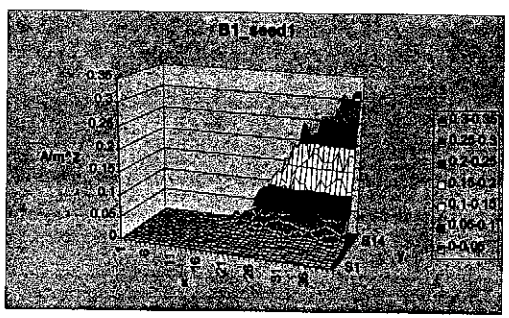


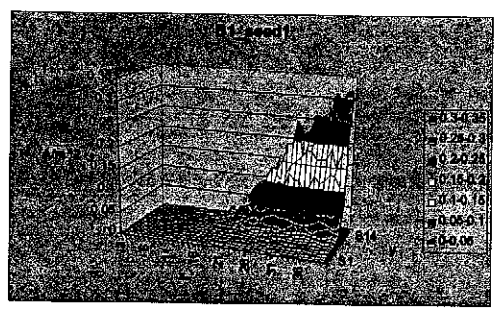
RTBT Beam Instrumentation

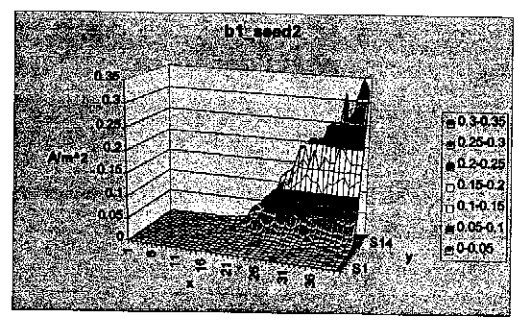
Detectors	BNL	LANL
BPM	32	0
BLM	40	0
FBLM	3	0
HARP	0	2
WS	5	0
BCM (FCT)	5	0

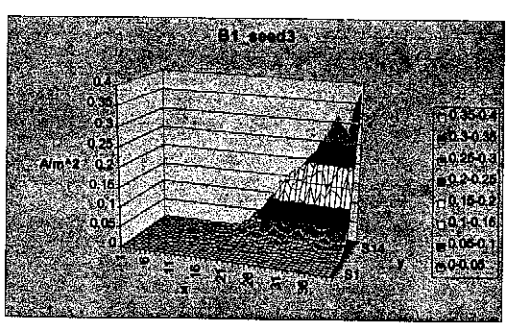


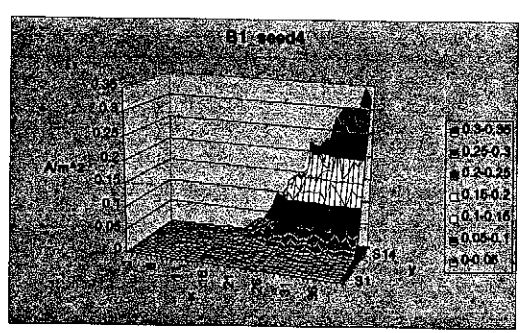
Current Density at target (bump1)

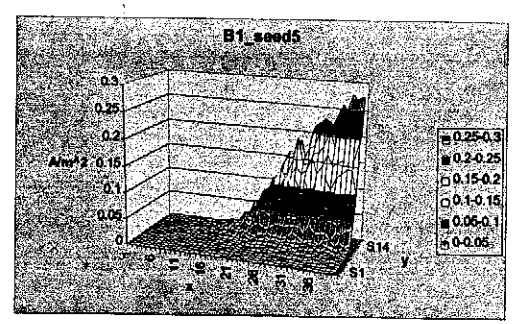




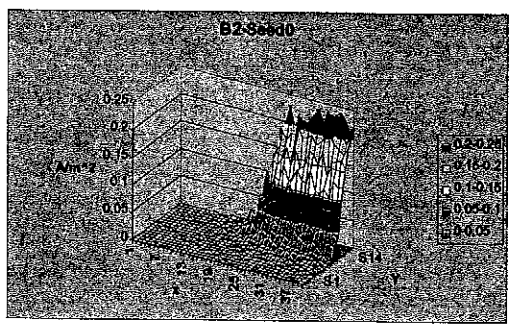


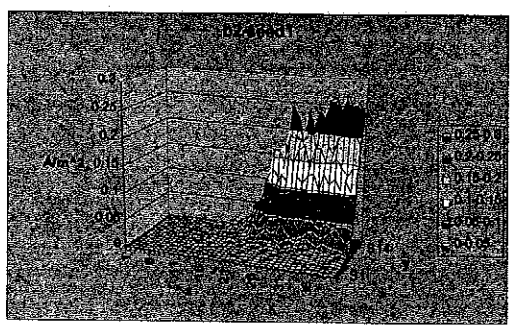


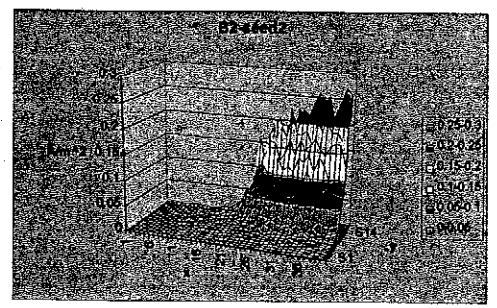


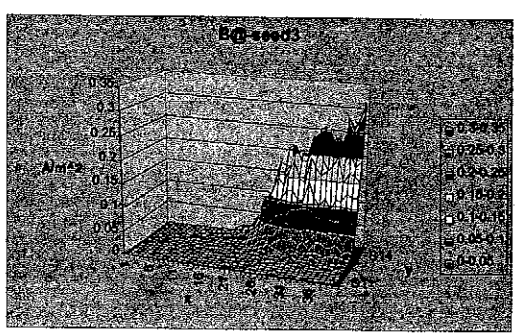


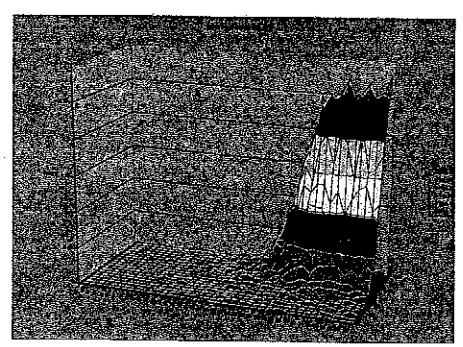
Current Density at Target (bump2)

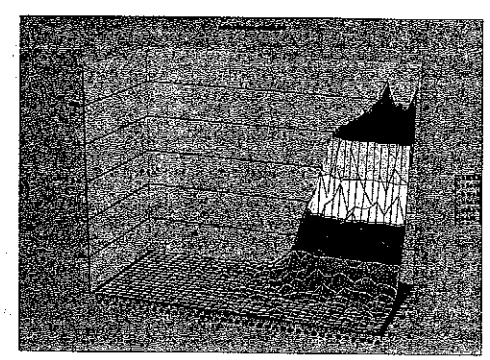




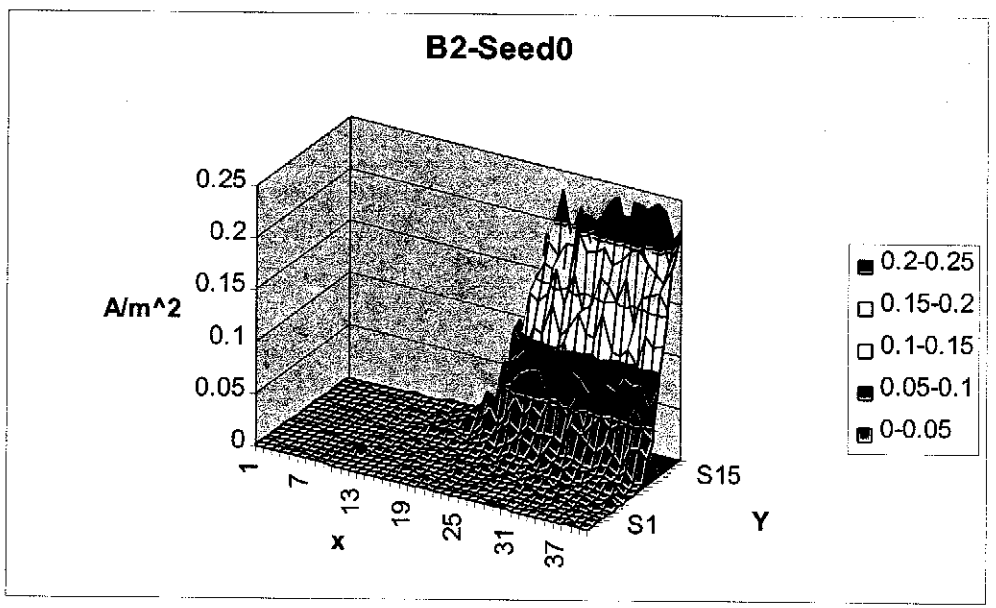








Current Density Distribution at Target (B2, Seed0)

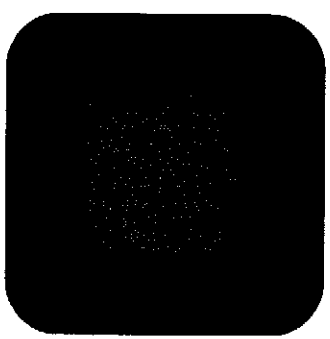


Injection Bump Optimization

(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

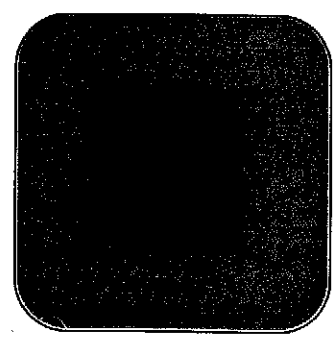
Meeting target requirement

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

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