Emittance: Linac and Booster

D. Raparia

2009/07/15

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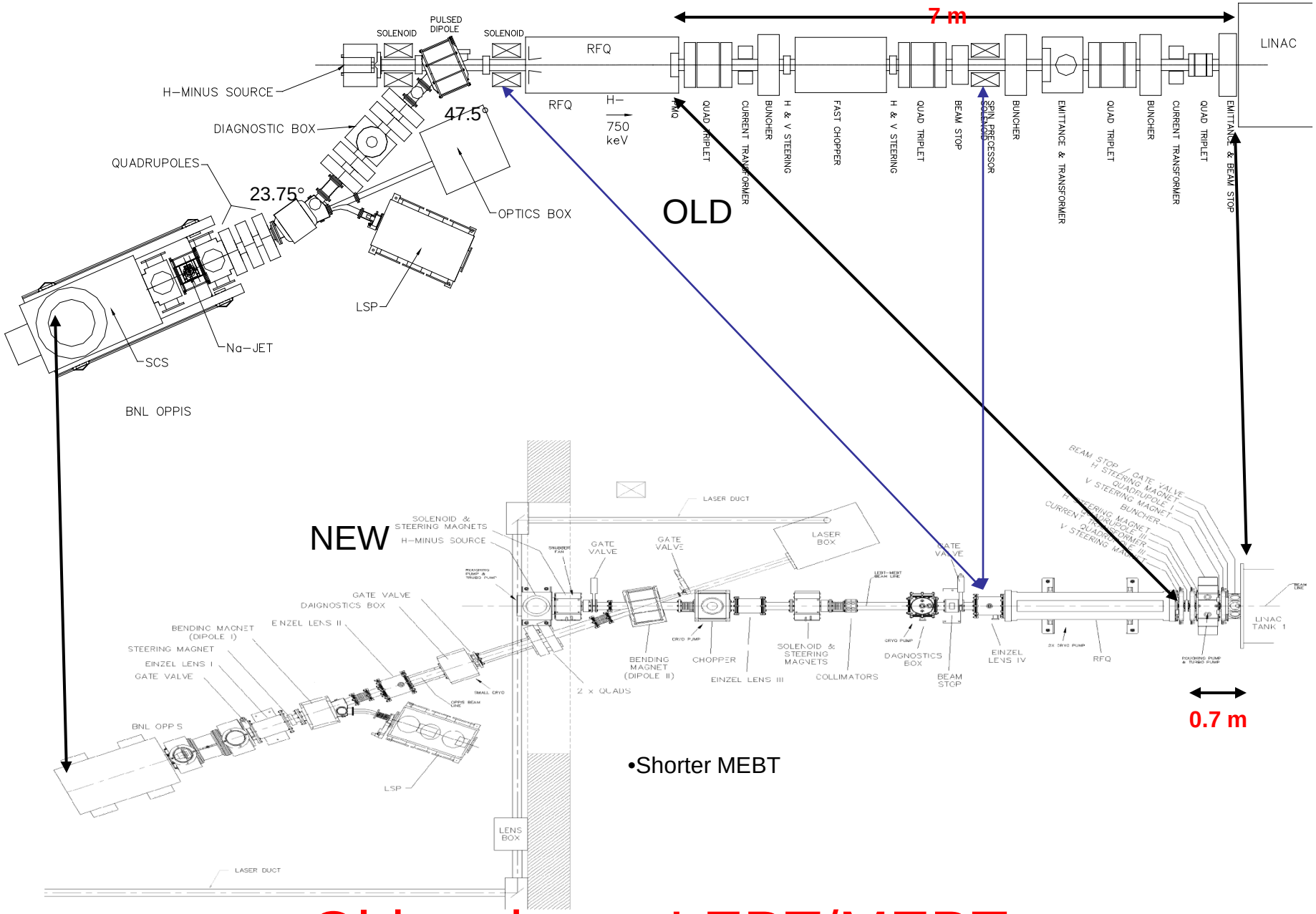
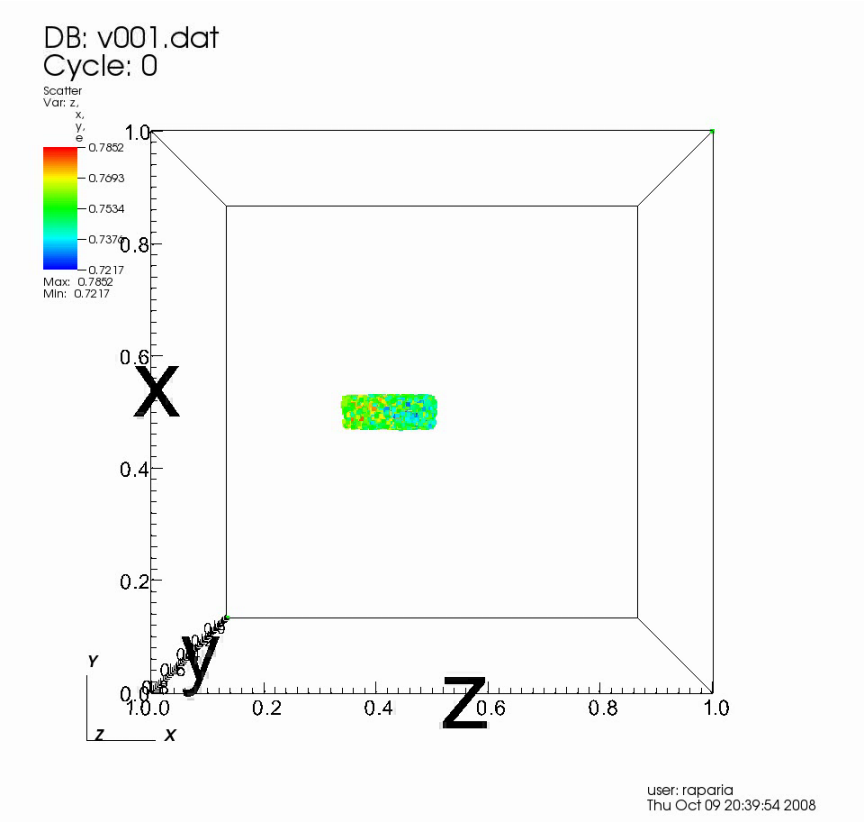
Outlines

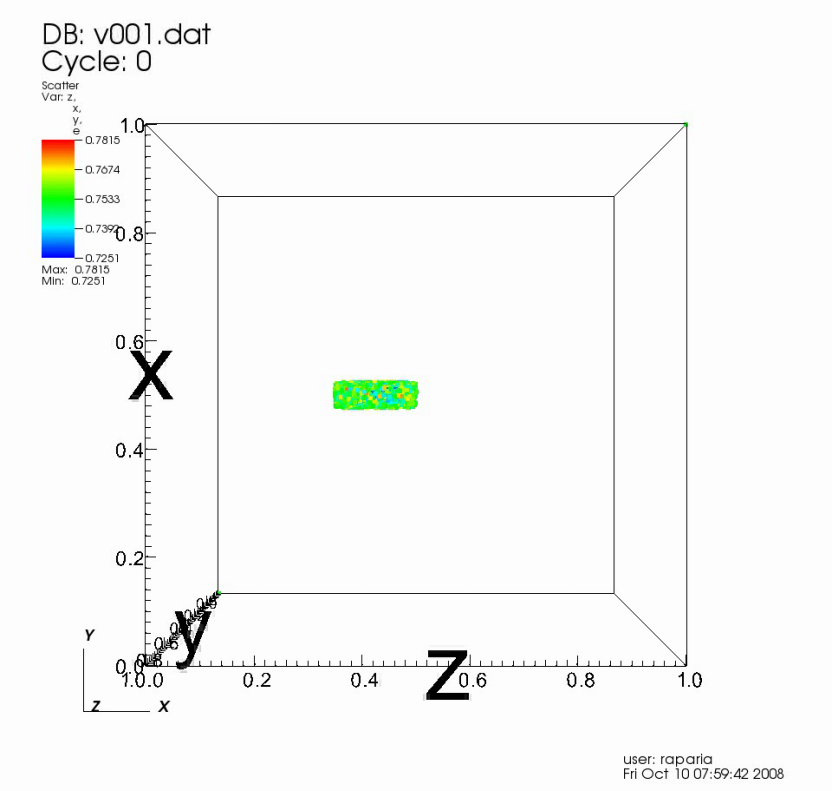
- LEBT and MEBT Layouts
- Linac Transverse Emittance
- Impact on polarization due to LEBT/MEBT reconfiguration
- Changes for 2010 and beyond
- Injection Foils
- Booster Transverse Emittance
- Summary



Old and new LEBT/MEBT

Old and New Linac





Transverse Emittance 2009

090206_0640_F6.sem **Feb 06 2009, 06:40**

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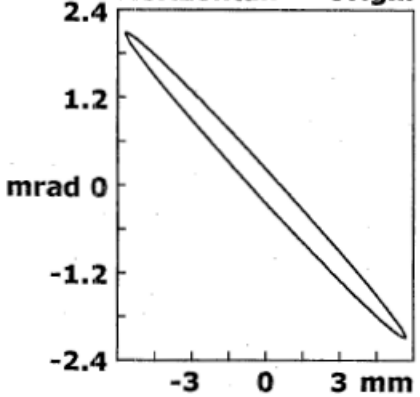
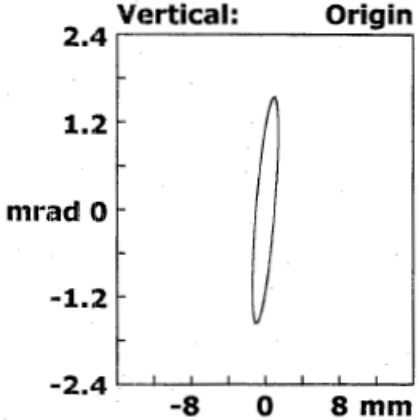
Horizontal: Origin



Emittance: 1.3222 ¶ mm·mrad Standard deviation: 10.3 %

ID	Center mm	Sigma mm	x mm	x' mrad	R(x,x')	Gamma mrad/mm	Beta mm/mrad	Alpha
Origin			5.690	2.091	-0.9938	3.3077	24.4897	8.9446
H1	37.70	4.975	4.907	1.131	0.9712	0.9670	18.2111	-4.0755
H2	39.40	3.514	3.506	1.860	-0.9792	2.6162	9.2958	4.8291
H3	34.91	2.526	2.530	1.907	0.9617	2.7493	4.8410	-3.5085
H4	37.83	2.071	2.604	1.498	-0.9408	1.6974	5.1273	2.7755

Vertical: Origin



Emittance: 1.5815 ¶ mm·mrad Standard deviation: 5.1 %

ID	Center mm	Sigma mm	y mm	y' mrad	R(y,y')	Gamma mrad/mm	Beta mm/mrad	Alpha
Origin			1.407	1.566	0.6966	1.5516	1.2521	-0.9710
H1	30.72	6.183	6.173	1.971	-0.9915	2.4568	24.0946	7.6286
H2	34.40	1.426	1.584	0.998	-0.0090	0.6302	1.5869	0.0090
H3	37.53	2.708	2.647	0.643	0.3699	0.2614	4.4313	-0.3981
H4	39.71	11.719	11.720	2.190	0.9981	3.0325	86.8594	-16.1988

Summary Linac Emittance and Transmission Efficiencies

Year	H	V	H(95%)	V (95%)	H(N, (95%)	V(N,95%)
2007	3,2	3.5	16.0	17.5	11.04	12.075
2008	3.1	4.6	15.5	23.0	10.69	15.87
2009	1.3	1.6	6.5	8.0	4.5	5.5

Measurement in the LTB , MW 35 and MW 105

H	4.0
V	4.5

Source to Tank9 transmission	
2008	50-55%
2009	65-70%

Source emittance	> 2 π
RFQ Acceptance	~2 π
Linac output	~5 π

Can be improved further

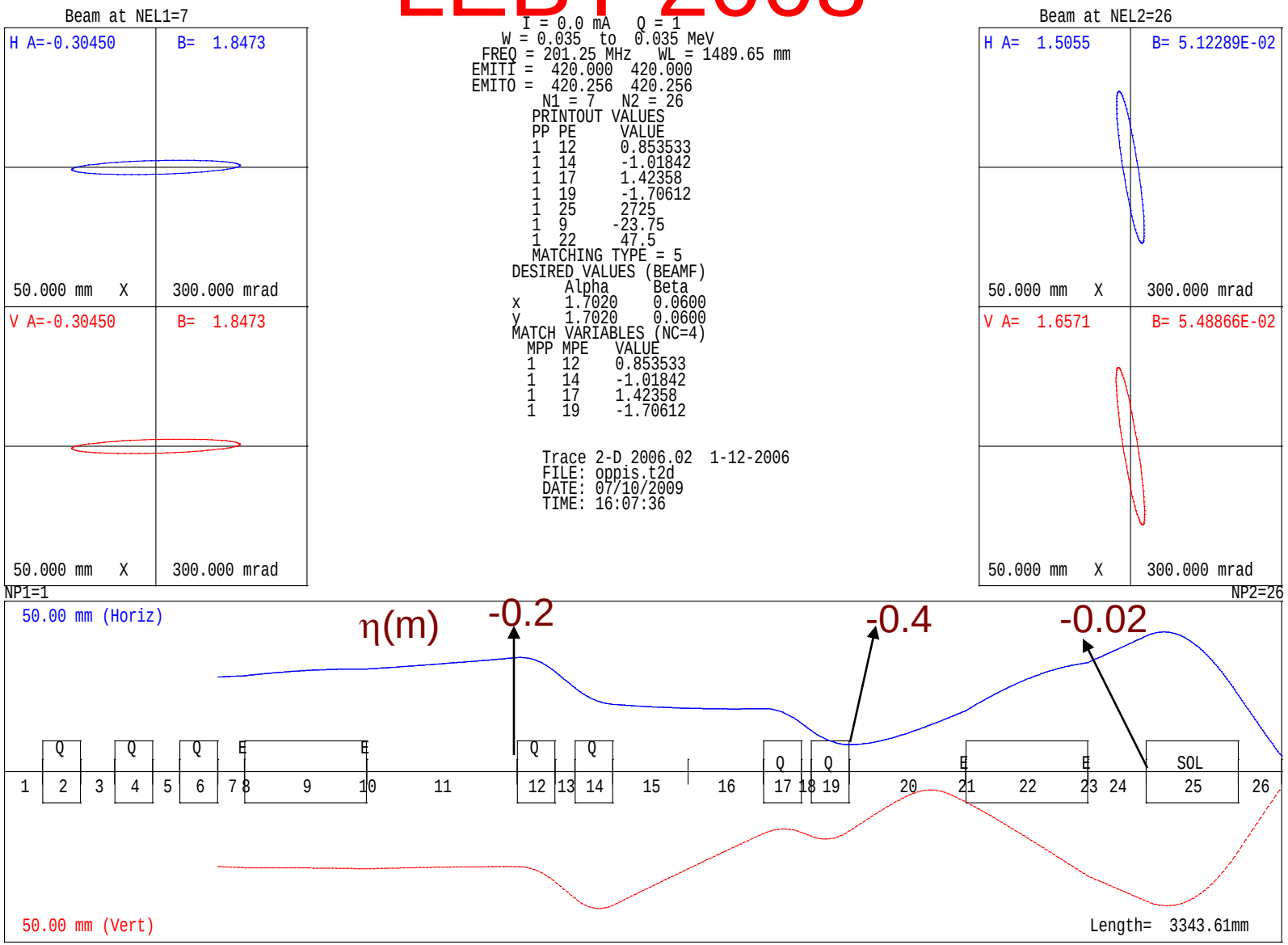
$\beta\gamma$@ 200 MeV =0.69

Emittance=π mm mrad

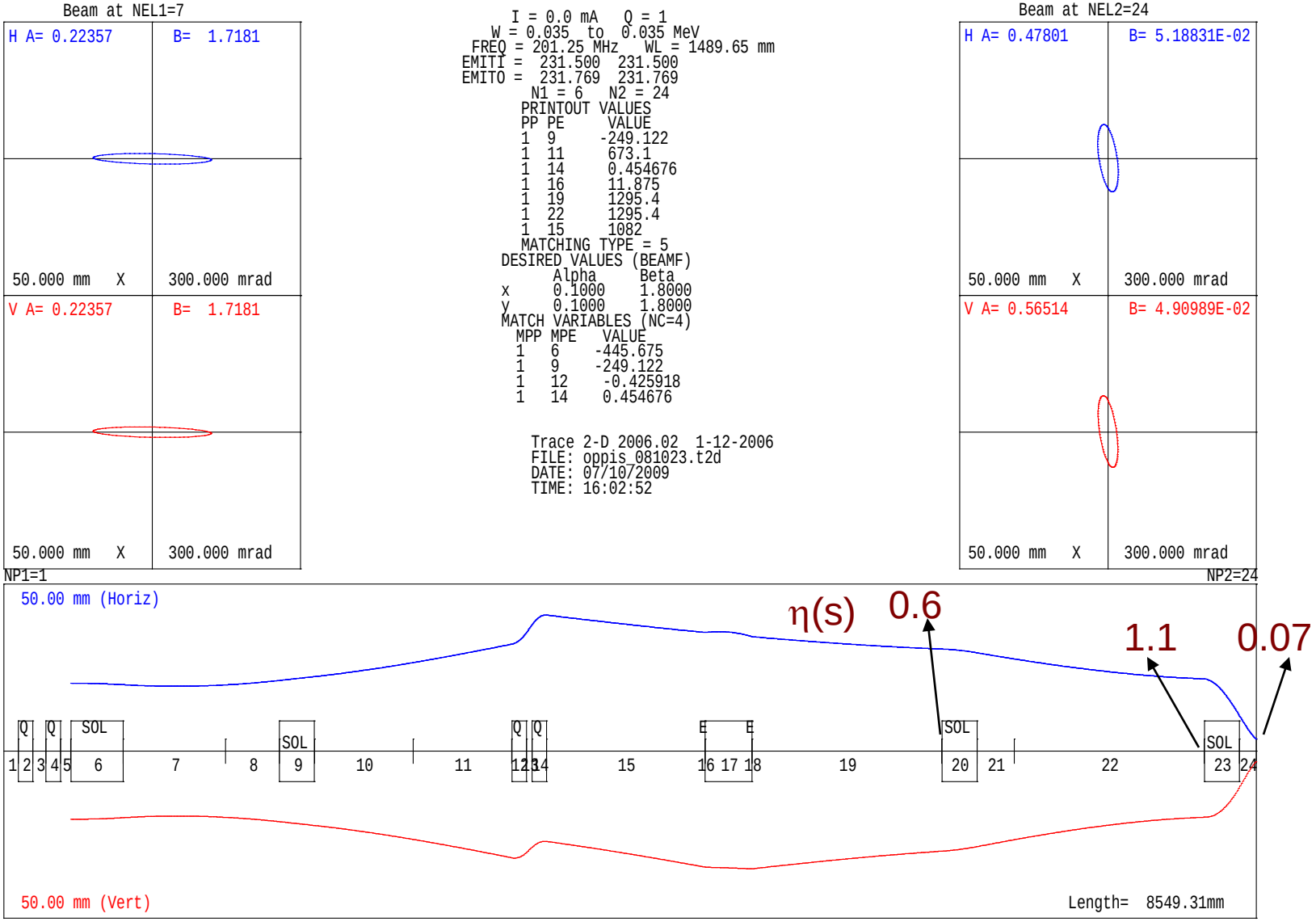
Molecular Component

- ECR -> H or H_2 at 3 keV
- H_2 break up in H and its energy is 1.5 keV and after extraction from OPPIS, its energy is 33.5 keV instead of 35 keV and is un-polarized , this component can be as high as 20%
- LEBT should be design such that it reject this molecular component

LEBT 2008

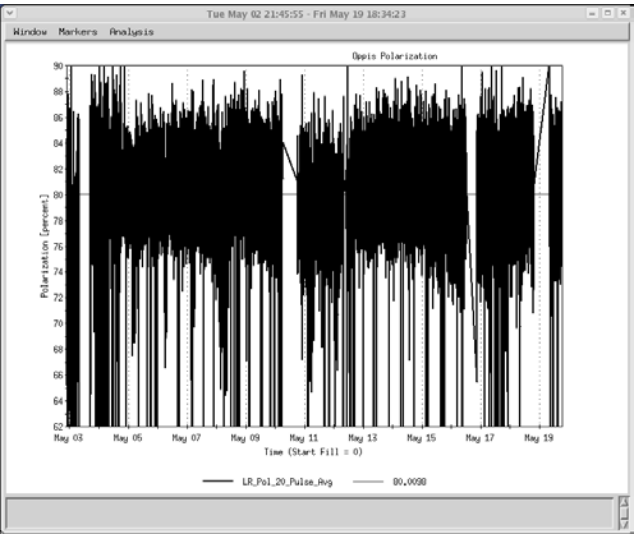

Beam at NEL1=7
H A=-0.30450
B= 1.8473
50.000 mm X
300.000 mrad
V A=-0.30450
B= 1.8473
50.000 mm X
300.000 mrad
NP1=1
I = 0.0 mA Q = 1
W = 0.035 to 0.035 MeV
FREQ = 201.25 MHz WL = 1489.65 mm
EMITI = 420.000 420.000
EMITO = 420.256 420.256
N1 = 7 N2 = 26
PRINTOUT VALUES
PP PE VALUE
1 12 0.853533
1 14 -1.01842
1 17 1.42358
1 19 -1.70612
1 25 2725
1 9 -23.75
1 22 47.5
MATCHING TYPE = 5
DESIRED VALUES (BEAMF)
Alpha Beta
x 1.7020 0.0600
y 1.7020 0.0600
MATCH VARIABLES (NC=4)
MPP MPE VALUE
1 12 0.853533
1 14 -1.01842
1 17 1.42358
1 19 -1.70612
Trace 2-D 2006.02 1-12-2006
FILE: oppis.t2d
DATE: 07/10/2009
TIME: 16:07:36
Beam at NEL2=26
H A= 1.5055
B= 5.12289E-02
50.000 mm X
300.000 mrad
V A= 1.6571
B= 5.48866E-02
50.000 mm X
300.000 mrad
NP2=26
50.00 mm (Horiz)
η(m)
-0.2
-0.4
-0.02
0.05
Q Q Q E E Q Q Q Q E E SOL
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
50.00 mm (Vert)
Length= 3343.61mm

LEBT 2009

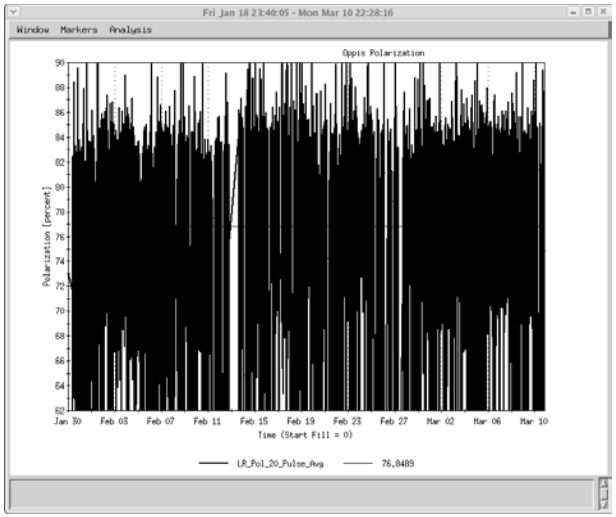

Beam at NEL1=7
H A= 0.22357
B= 1.7181
50.000 mm X
300.000 mrad
V A= 0.22357
B= 1.7181
50.000 mm X
300.000 mrad
NP1=1
I = 0.0 mA Q = 1
W = 0.035 to 0.035 MeV
FREQ = 201.25 MHz WL = 1489.65 mm
EMITI = 231.500 231.500
EMITO = 231.769 231.769
N1 = 6 N2 = 24
PRINTOUT VALUES
PP PE VALUE
1 9 -249.122
1 11 673.1
1 14 0.454676
1 16 11.875
1 19 1295.4
1 22 1295.4
1 15 1082
MATCHING TYPE = 5
DESIRED VALUES (BEAMF)
Alpha Beta
x 0.1000 1.8000
y 0.1000 1.8000
MATCH VARIABLES (NC=4)
MPP MPE VALUE
1 6 -445.675
1 9 -249.122
1 12 -0.425918
1 14 0.454676
Trace 2-D 2006.02 1-12-2006
FILE: oppis_081023.t2d
DATE: 07/10/2009
TIME: 16:02:52
Beam at NEL2=24
H A= 0.47801
B= 5.18831E-02
50.000 mm X
300.000 mrad
V A= 0.56514
B= 4.90989E-02
50.000 mm X
300.000 mrad
NP2=24
50.00 mm (Horiz)
η(s)
0.6
1.1
0.07
Q
Q
SOL
SOL
Q
Q
E
E
SOL
SOL
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
50.00 mm (Vert)
Length= 8549.31mm

Polarization@ 200 MeV 2006, 2008 2009

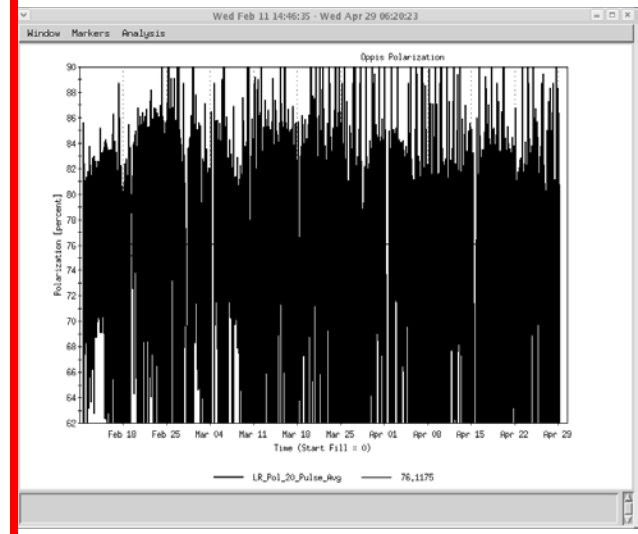
2006 80.0%



2008 76.8%



2009 76.1%



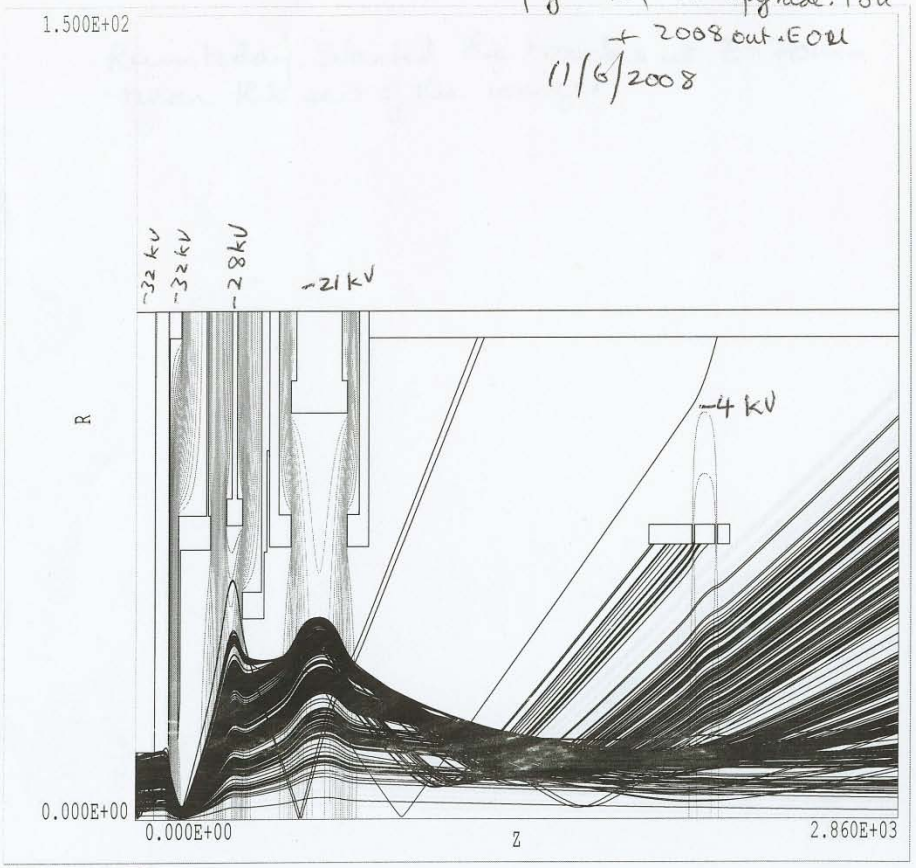
E-log entry

Comment: Apr-29-2009 13:53 In today's spin meeting, we discussed about the source polarization over past a few years. Here are examples of the source polarization over past a few years in run6 (left, May 2-19), run8 (middle, Jan 30-Mar10) and run9 (Feb. 15-April 29). The vertical scales are the same. A simple average of all visible points showed 80.0% for run6, 76.8% for run8 and 76.1% for run9. One significant difference is that the variation of measured polarization is large since run8. **Haixin**

OPPIS Optics 2008

4/22/09

2008\Lebt Upgrade\Lebtupgrade.Tou
+ 2008 out.EOU
11/6/2008



Total orbits: 2000
Plotted range
NOrbMin: 1
NOrbMax: 2000
Plot mode: ZR
Magnification: ON
Orbit range
XMin: -7.895E+01
XMax: 8.977E+01
YMin: -8.859E+01
YMax: 8.521E+01
ZMin: 0.000E+00
ZMax: 2.860E+03
RMin: 3.009E-02
RMax: 9.000E+01

Plot type: Contour
Quantity: Phi

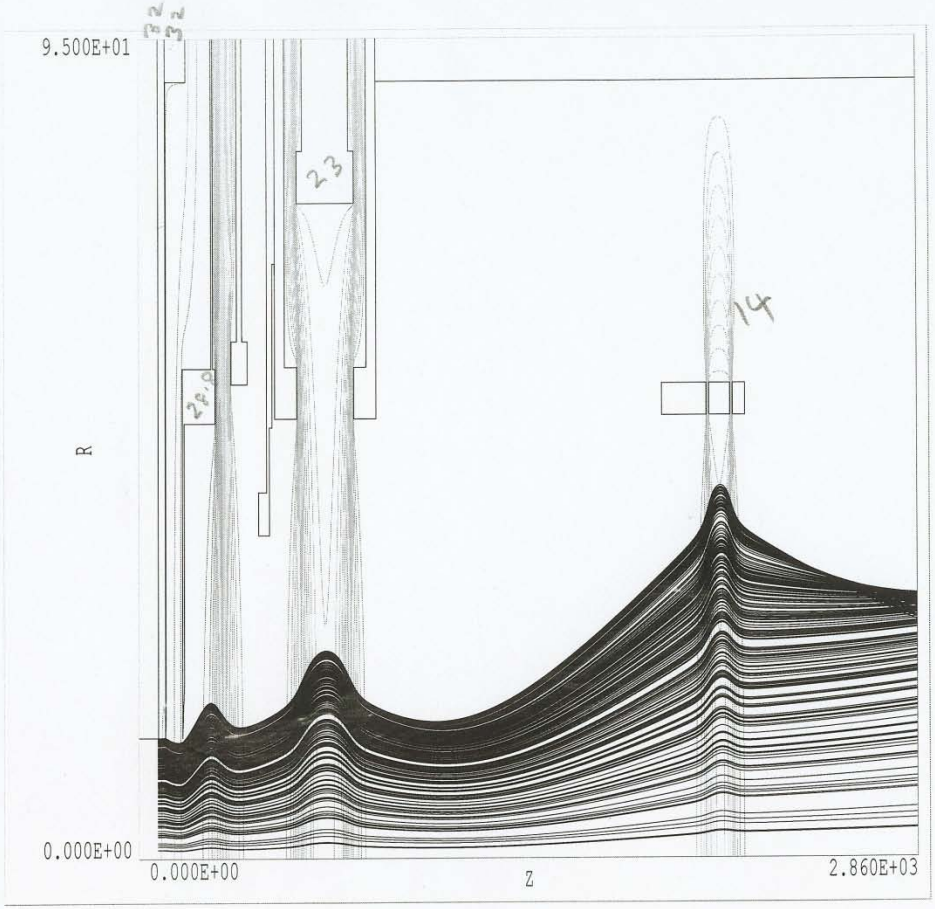
Minimum value: -3.200E+0
Maximum value: 0.000E+0

-2.933E+04
-2.667E+04
-2.400E+04
-2.133E+04
-1.867E+04
-1.600E+04
-1.333E+04
-1.067E+04
-8.000E+03
-5.333E+03
-2.667E+03
0.000E+00

↑
Start
Z=0mm

OPPIS Optics 2009

4/29/09



Total orbits: 200
Plotted range
NOrbMin: 1
NOrbMax: 200
Plot mode: ZR
Magnification: ON
Orbit range
XMin: -4.272E+01
XMax: 4.290E+01
YMin: -4.233E+01
YMax: 3.975E+01
ZMin: 7.000E+01
ZMax: 2.860E+03
RMin: 9.645E-01
RMax: 4.314E+01

Plot type: Contour
Quantity: Phi

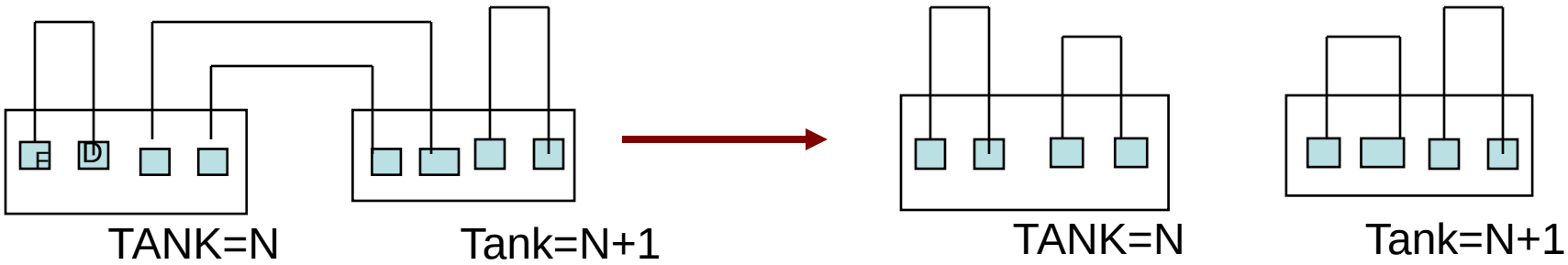
Minimum value: -3.199E+0
Maximum value: 0.000E+0

-2.933E+04
-2.666E+04
-2.399E+04
-2.133E+04
-1.866E+04
-1.600E+04
-1.333E+04
-1.066E+04
-7.998E+03
-5.332E+03
-2.666E+03
0.000E+00

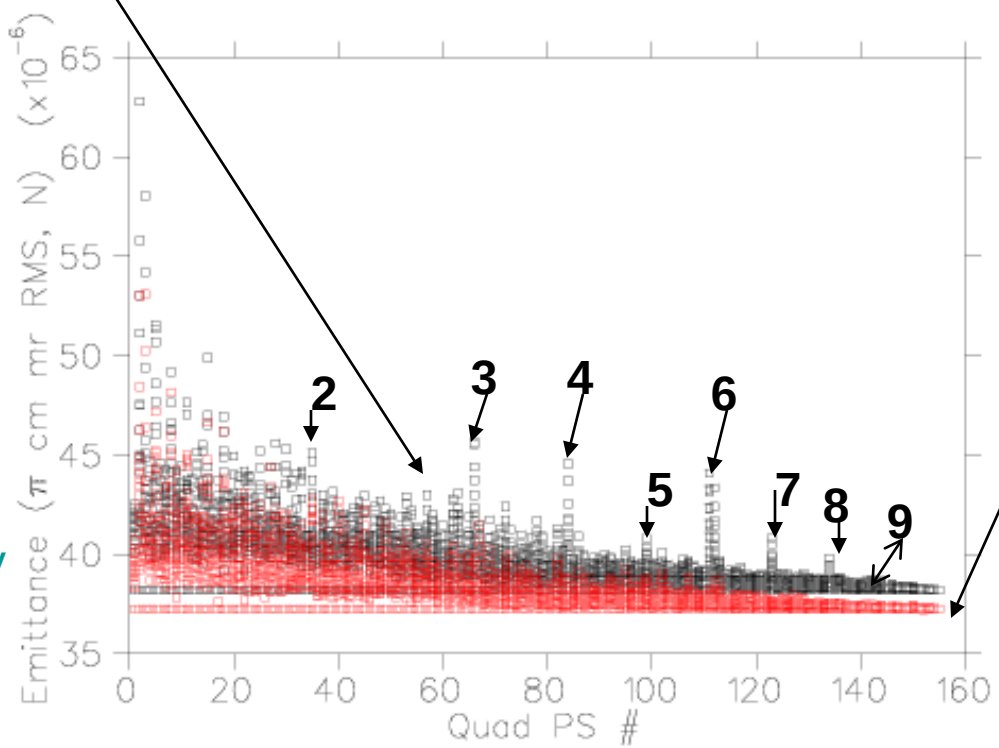
Changes for 2010 and beyond

- Reduce the LEBT length by 50% for High intensity
- Add Einzel lens to improve discrimination of molecular component
- Tank quad PS reconfiguration to improve emittance
- Add fast chopper in polarized LEBT
- Install LPM after Tank 9
- Incorporate Einzel lens inside last solenoid

Tank-Quad Reconfiguration



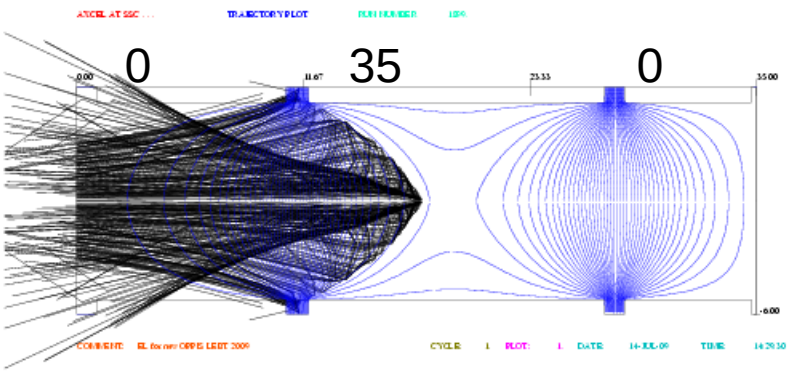
Total # quad 295
Total # PS 155



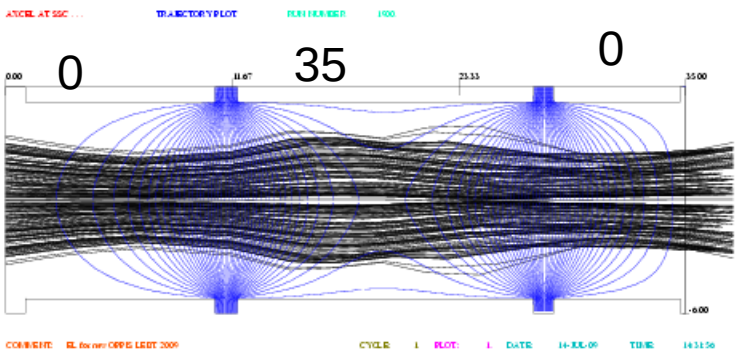
Varying PS by ± 5%

Estimated reduction in emittance growth is about 20-25%

New Einzel Lens for Molecular Component (33.5 keV) Discrimination

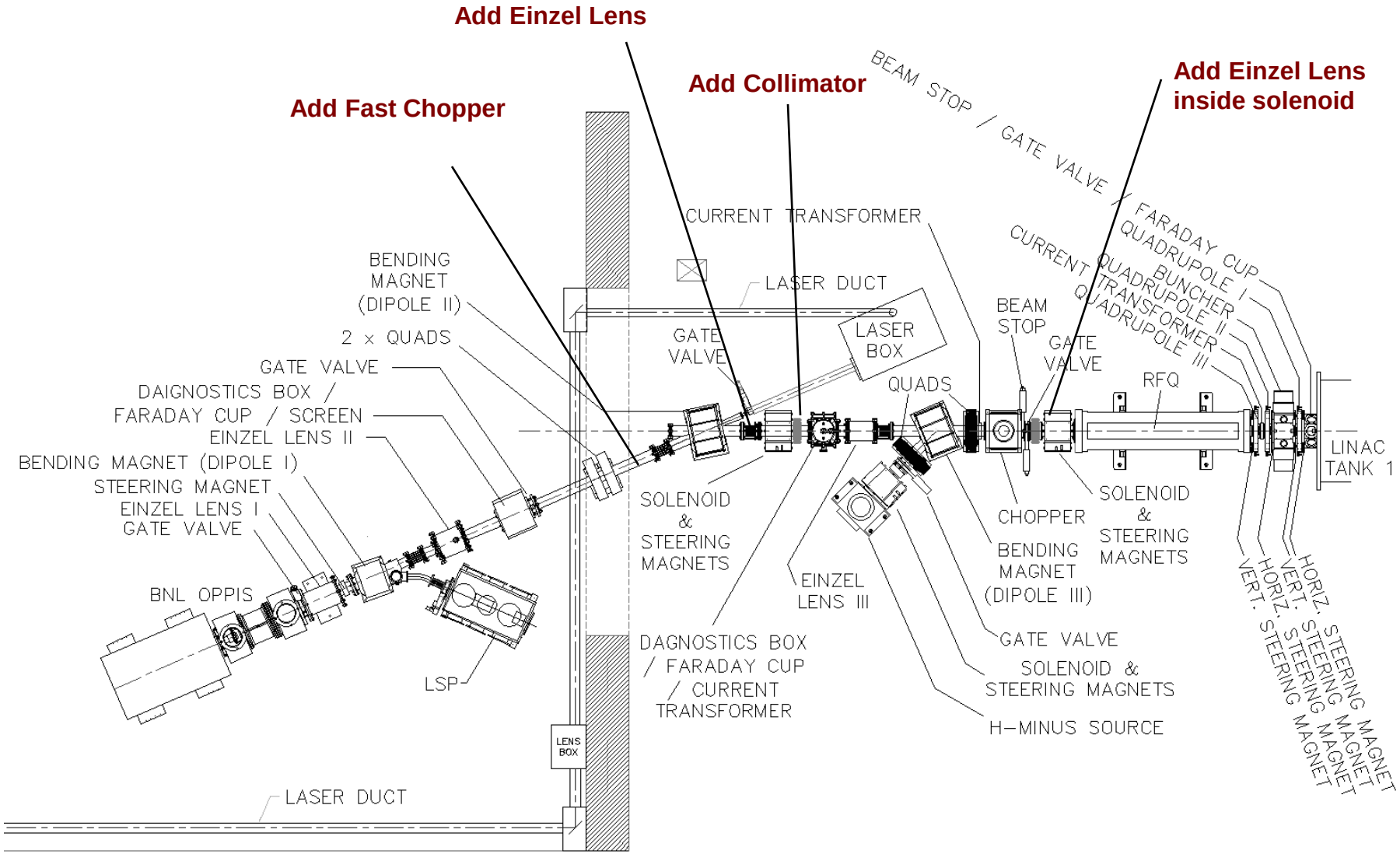


T=33.5 keV



T=35.0 keV

Changes for 2010 and beyond



Booster

Emittance Growth due to Foil Traversal

Assuming only source for emittance growth in the Booster is multiple scattering due to the foil traversal

Emittance growth due to multiple scattering

$$\Delta\varepsilon \equiv 0.5\, n\beta_{Foil}\, \theta^2$$

N=number of traversal: Pulse Length, Size, Painting Scheme

β= Beta function at foil: ring lattice, (matching etc)

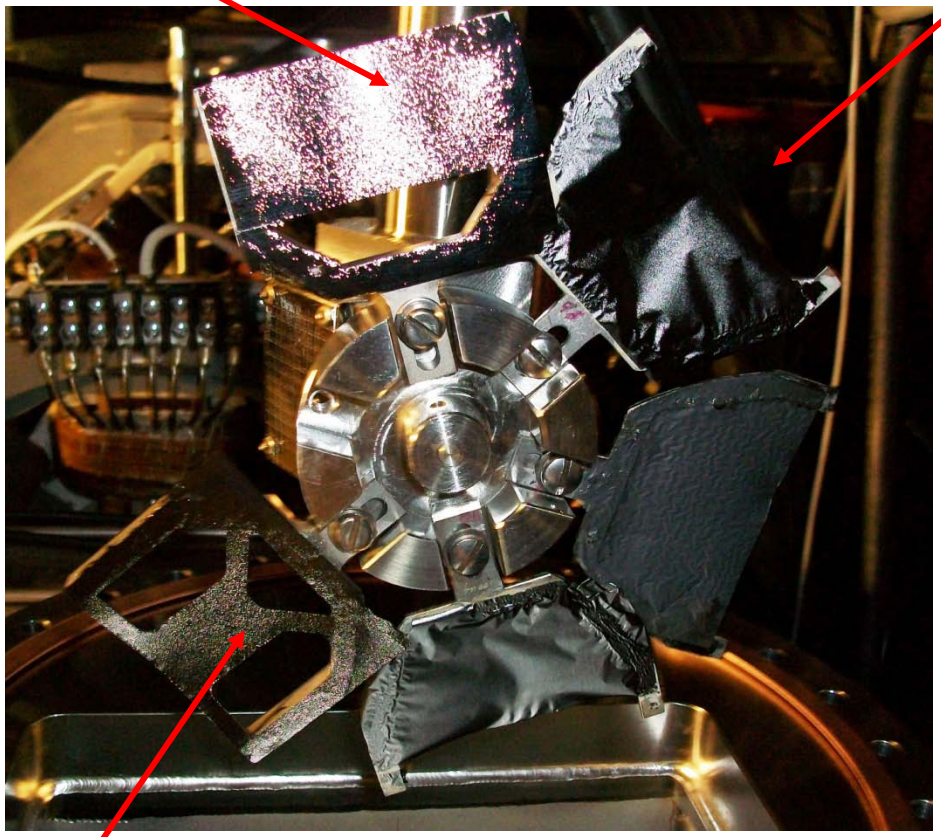
θ= Scattering angle: Material of foil, Thickness

$$\sigma = 14.2 z \frac{\sqrt{x/X_0}}{p\beta}\left[1 + 0.088 \log_{10}\left(xz^2/X_0\beta^2\right)\right].$$

Foils

Foil 6 (Strip)
127 μg/cm2

Foil 5
100 μg/cm^2



Foil 2 (Stamp)
127 μg/cm2

Table 1: Available foils on foil wheel.

No.	Thickness ($\mu g/cm^2$)	Edge location Inches from R_0	Type
1	No Foil	na	
2	130	-1.00	stamp
3	100	-1.00	full
4	200	-1.00	full
5	100	-1.00	full
6	130	-1.00	strip

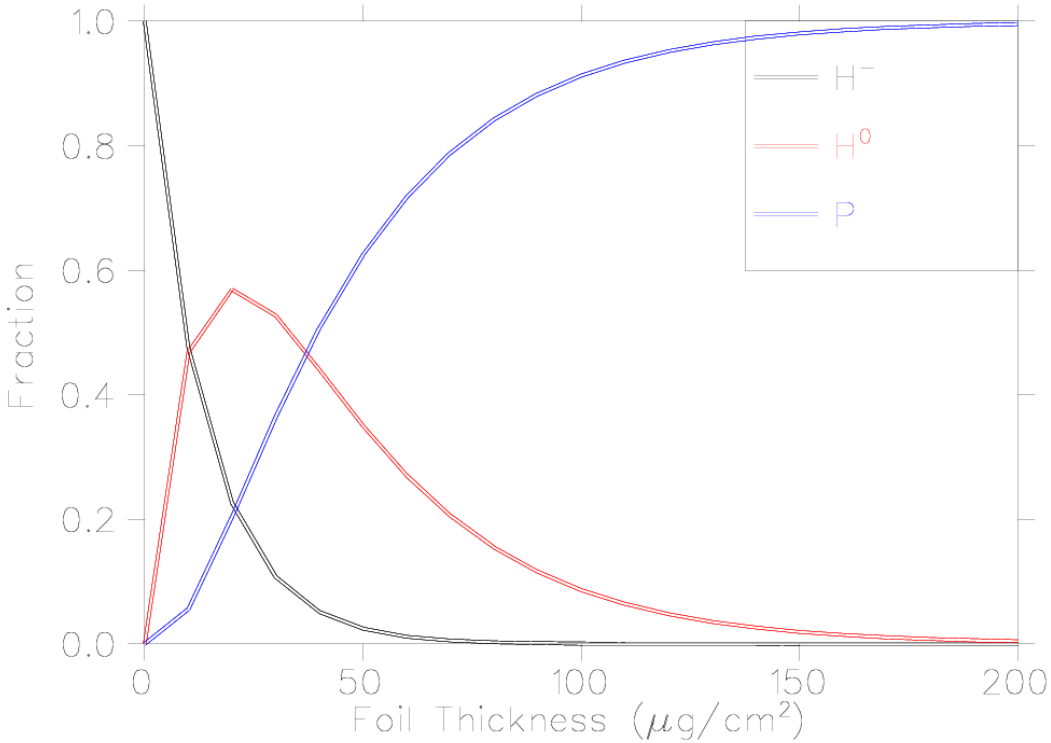
Stamp & Strip foil behave very similar

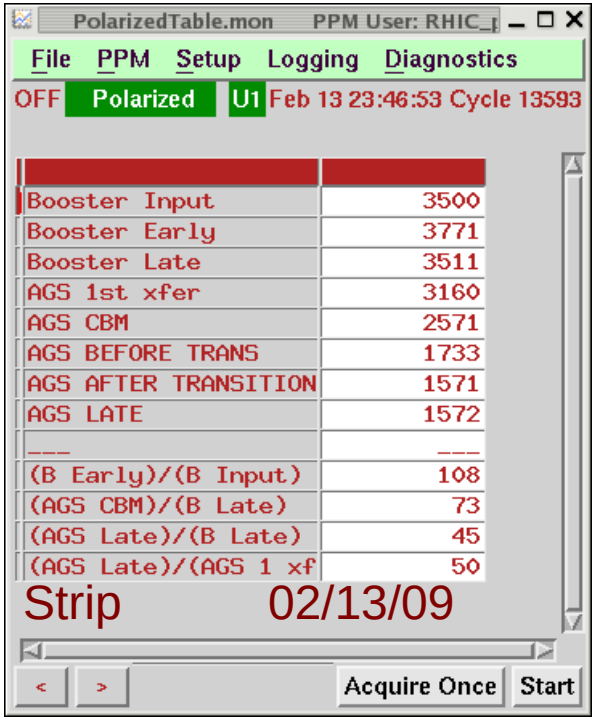
Stripping Efficiencies

Thin Foil

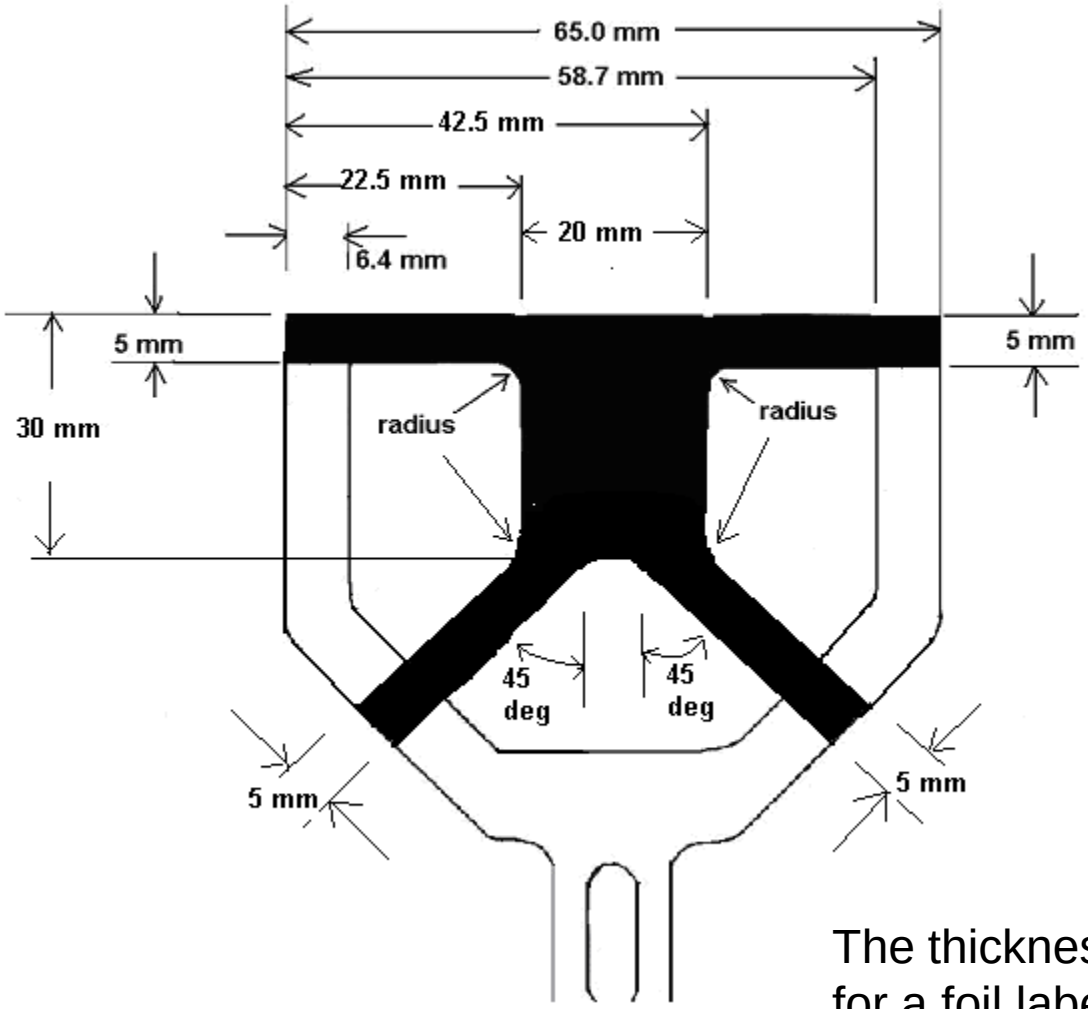
$$\sigma = 14.2 z \frac{\sqrt{x/X_0}}{p\beta}[1 + 0.088 \log_{10}(xz^2/X_0\beta^2)].$$

Foil thickness	eff. H- to P
200 ug	0.99458
130 ug	0.96459
100 ug	0.91296





Foil 2

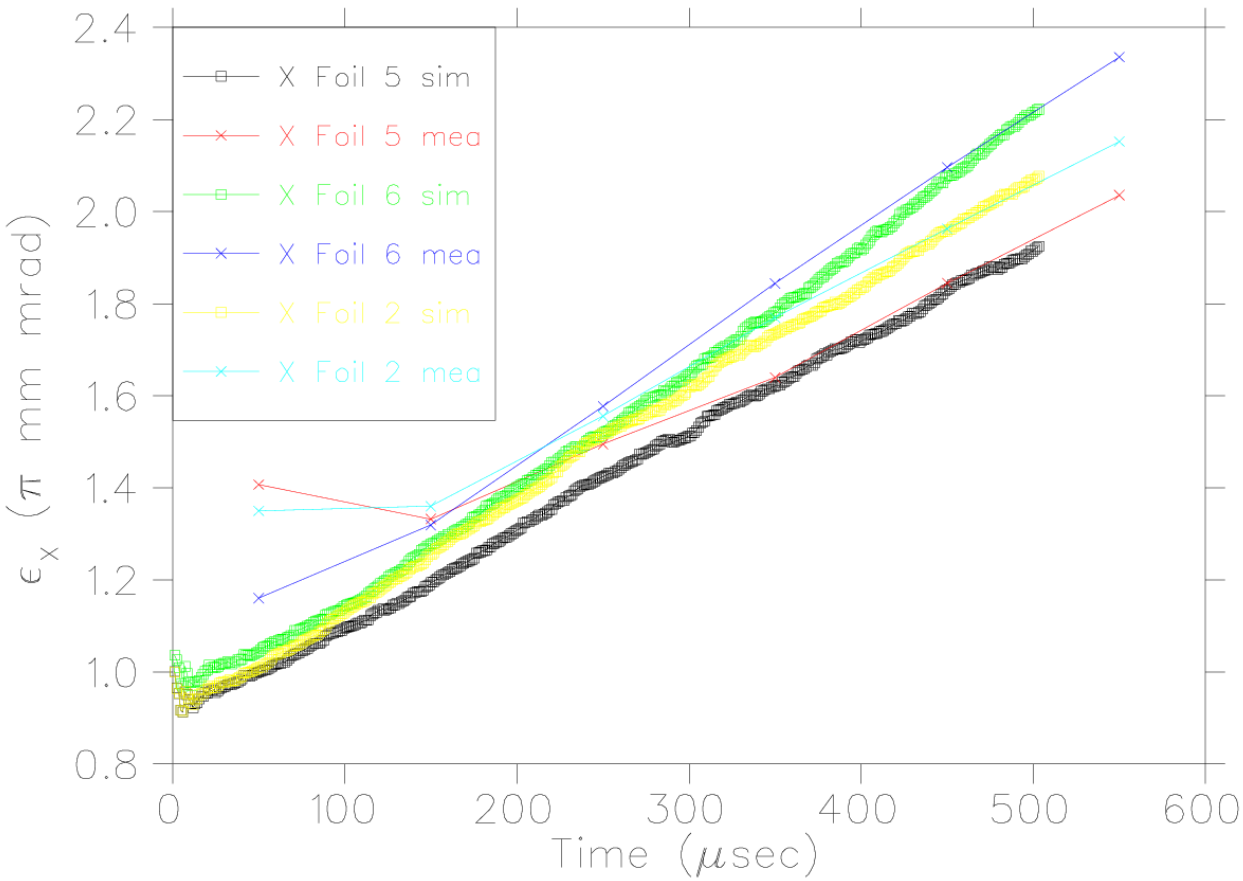


The thickness that I measured is 127 μg/cm^2 for a foil labeled as 0.55 μm.
This gives a density of 2.31 g/cm^3.

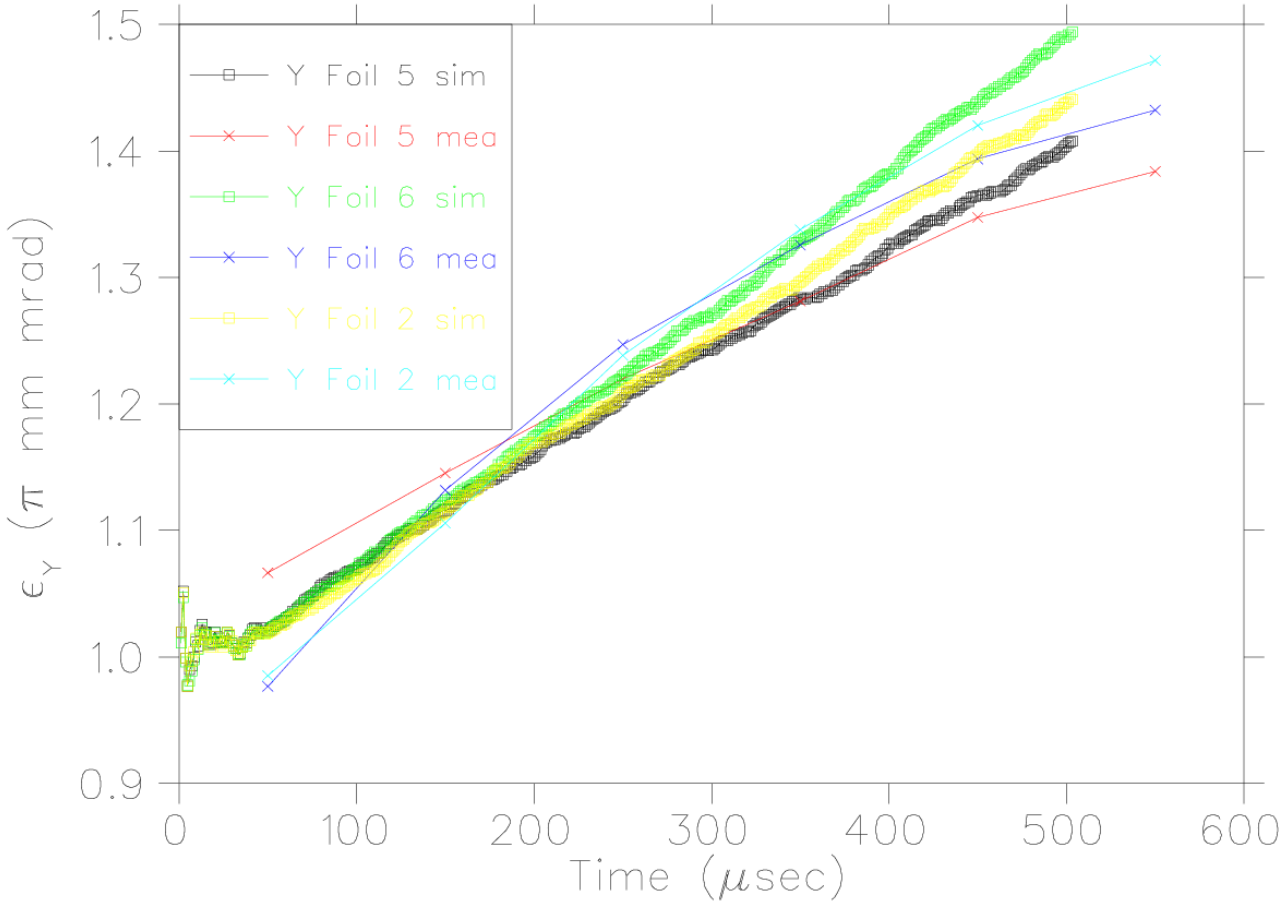
Emittance Measurement at BTA MW006

- Beam was injected in the Booster for 50μs
- Beam was kept on the foil for 100, 200, 300, 400 μs
- Then measure the beam profile in BTA at MW006
- Assuming we know the beta function at MW006, beam emittance was calculated

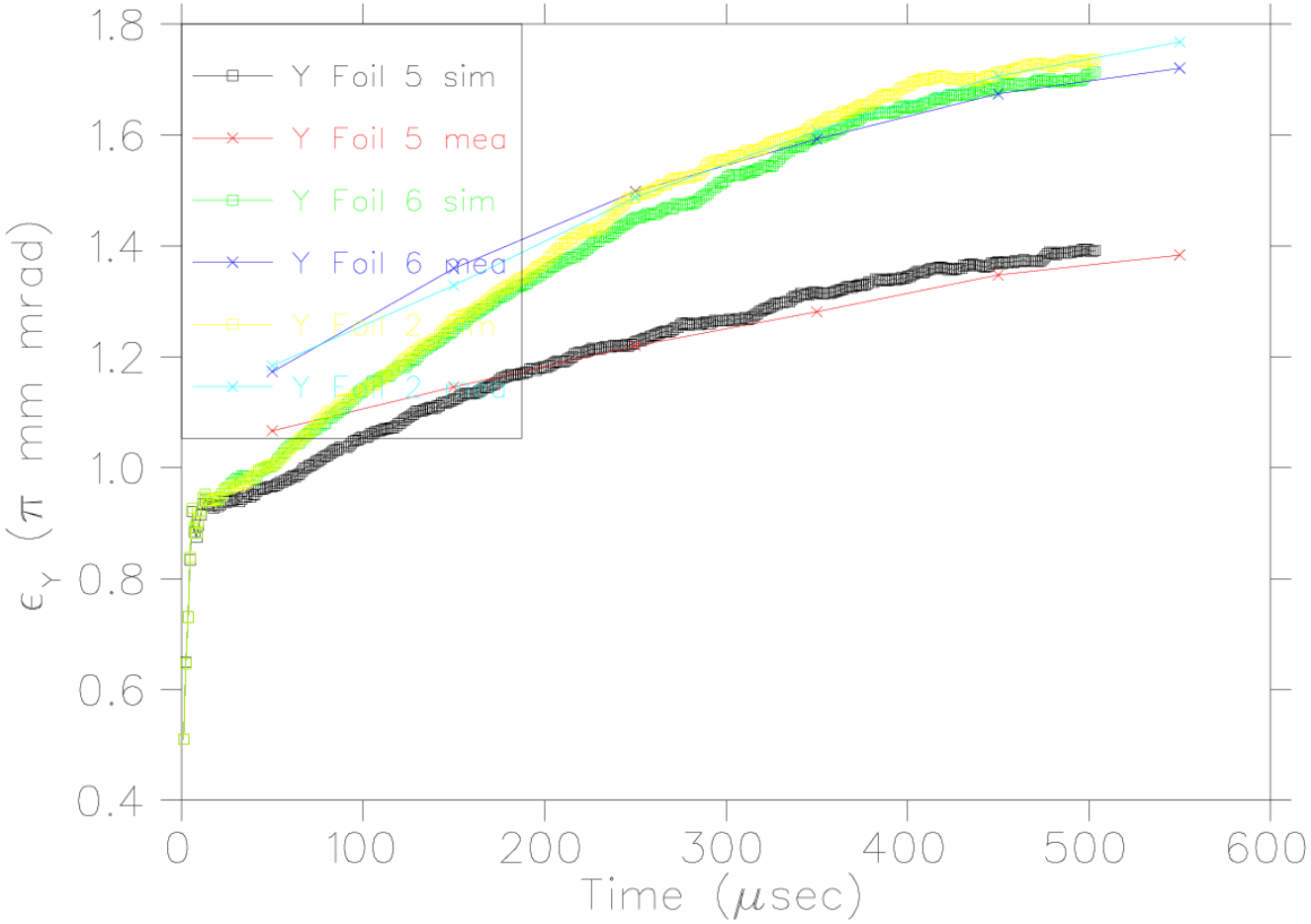
Comparison Horizontal Normal Lattice in Booster



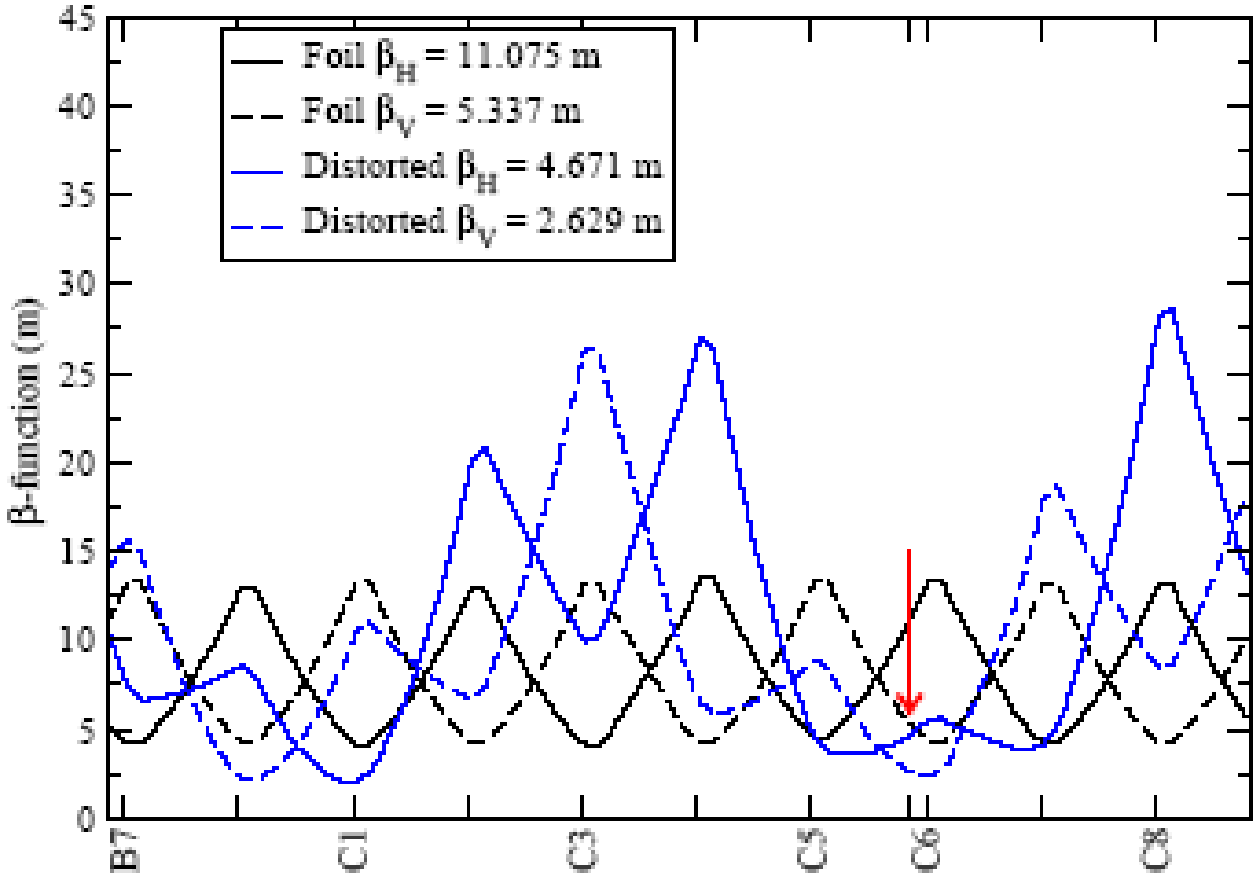
Comparison Vertical Normal Lattice in Booster



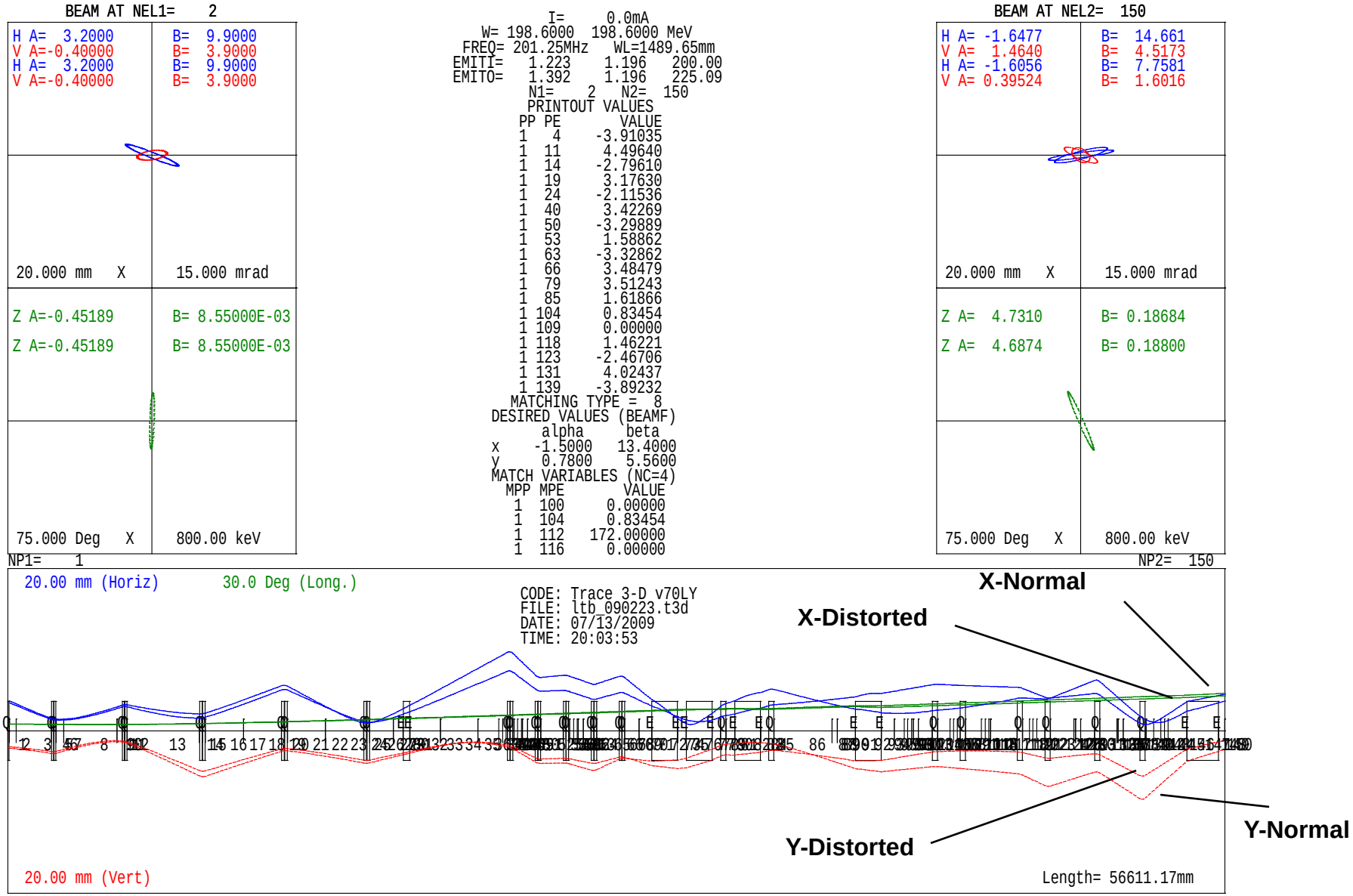
With steering error and aperture Normal Lattice in Booster



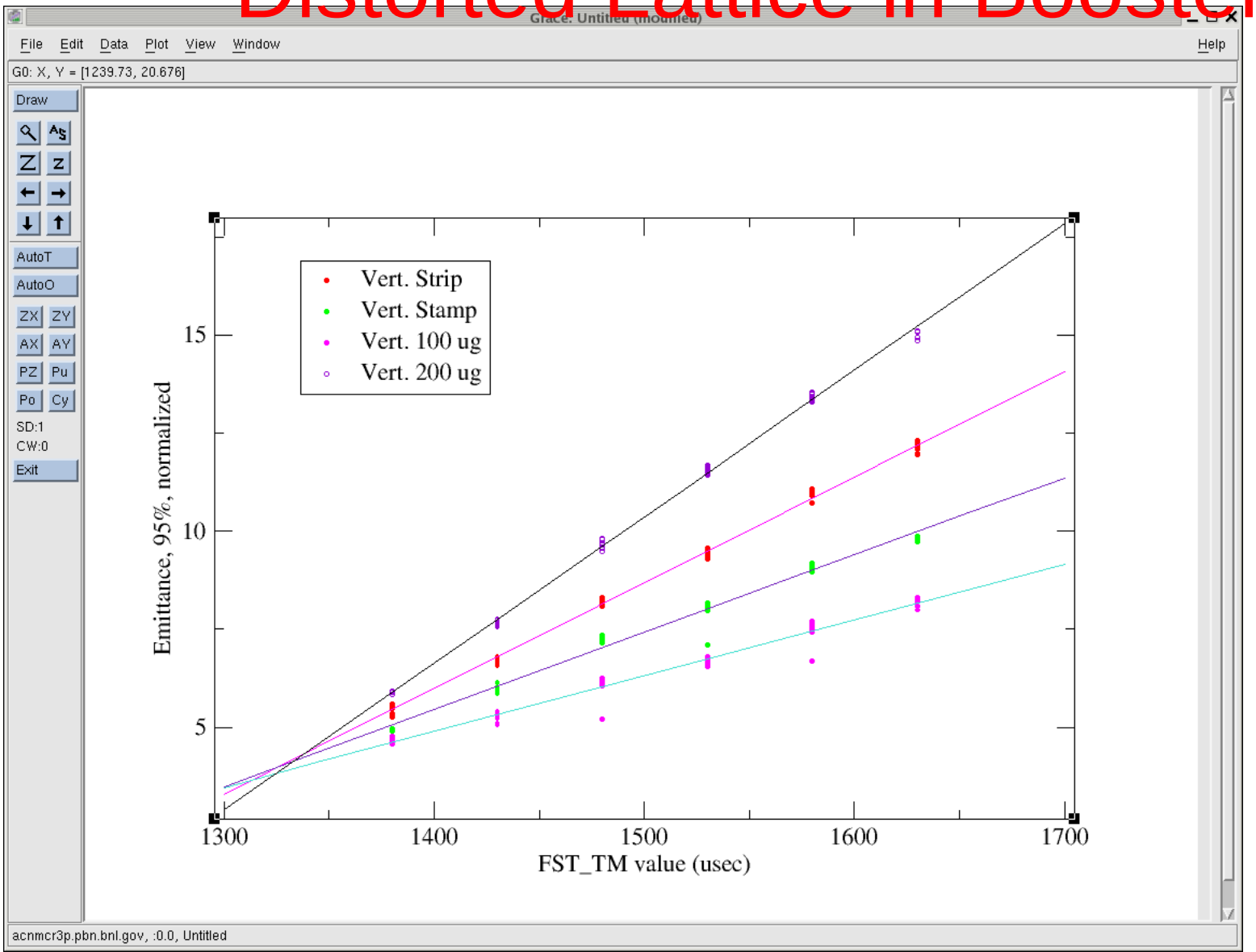
Modified Booster Lattice



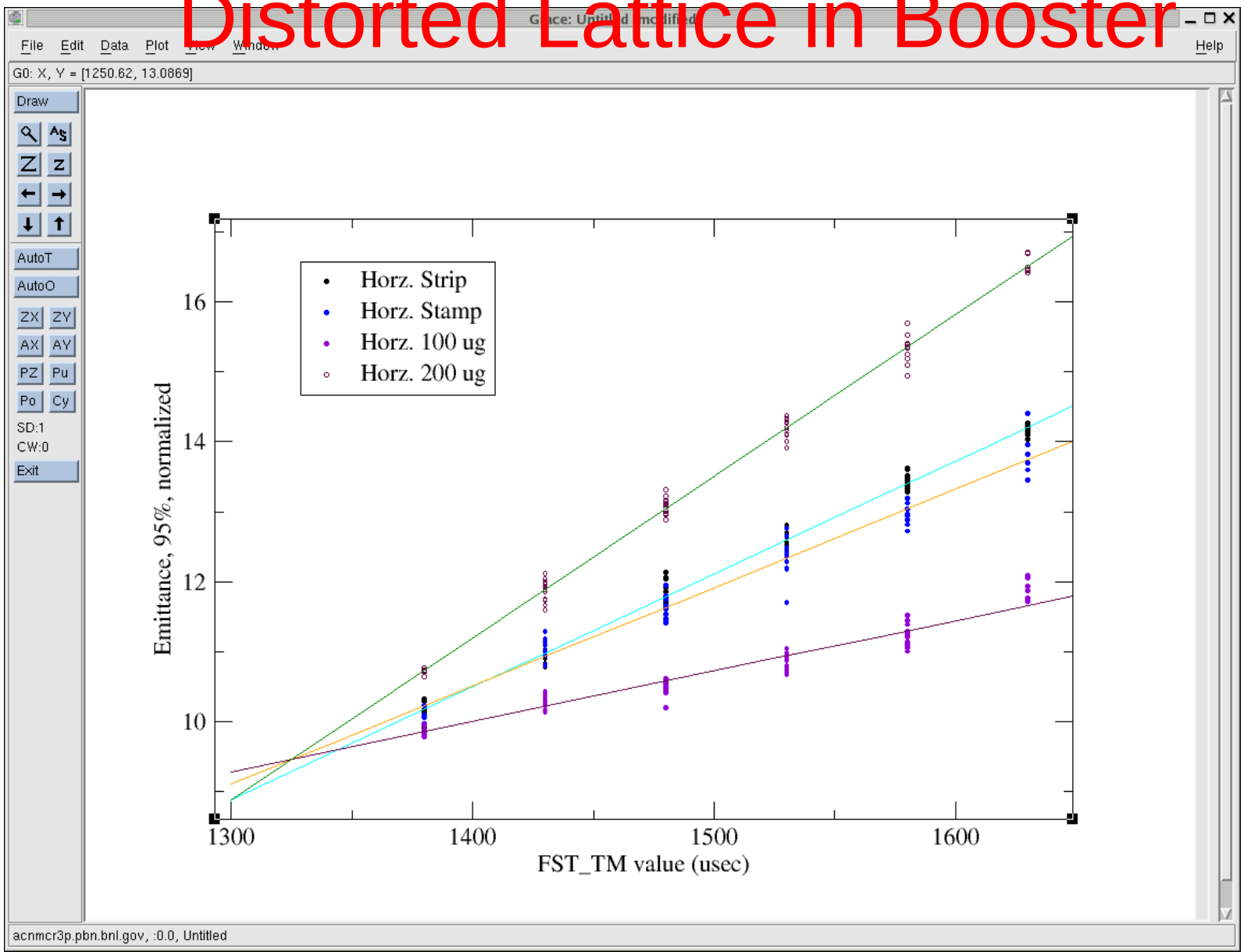
LTB Normal/Distorted



042109
Distorted Lattice in Booster



2009/04/21
Distorted Lattice in Booster



Relative Foil Thickness

- $\Delta\varepsilon \equiv n\beta\theta^2 \sim n\beta t$

Foil	X: ratio of n*t Mea.	Y: ratio of n*t Mea.
200μg	2.54	2.45
Strip	1.71	1.81
Stamp	1.62	1.34
100 μg	1.00	1.00

Ratio of Beta-Functions

- $\Delta\varepsilon \equiv n\beta\theta^2 \sim n\beta t \Rightarrow \beta_X / \beta_Y = \Delta\varepsilon_x / \Delta\varepsilon_y$

Foil	β_y / β_x Mea	(x,y switch during ramp)
100 μg	0.66	
200 μg	0.67	
Strip	0.60	
Stamp	0.81	

Expected/Measured Emittance After LEBT/MEBT Upgrade

- **At end of linac** — Measured (w/o Scrapping)

H	5 π mm mrad (N, 95 %)	**4-5**
V	5 π mm mrad (N, 95 %)	**5-6**

- **At end of booster**

assuming matched (we are matched),
present booster lattice

H	12 π mm mrad (N, 95 %), $\Delta\varepsilon_x$=7	**10-12**
V	8 π mm mrad (N, 95 %), $\Delta\varepsilon_y$=3	**8-11**

- With low beta lattice at injection (assuming matched)

H /V	8 π mm mrad (N, 95 %), $\Delta\varepsilon_x$=3	**9-11**
V /H	7 π mm mrad (N, 95 %), $\Delta\varepsilon_y$=2	**6-7**

- With low beta lattice at injection with scrapping

H /V	π mm mrad (N, 95 %),	**8-9** (Scrapping)
V /H	π mm mrad (N, 95 %)	**2.5-3** (Scrapping)

Booster transmission efficiencies increased by ~ 15%

Pulse length

2008	400 μs
2009	300 μs

Summary

- Reduced linac output emittance by more than factor of two.
- Increased transmission efficiency from source to Tank 9 by 10-15%.
- **No impact on polarization due to new LEBT/MEBT configuration**
- Linac reliability > 97%
- Radiation due to losses were low every where.
- Changes next year and beyond

  - Reduce LEBT length for high intensity
  - Add Einzel lens to increase discrimination of molecular component
  - Reconfigured tank quad to reduce emittance by 20-25%
  - Incorporate Einzel lens inside 2nd solenoid to reduce depolarization
  - Add fast chopper in polarized LEBT
- New foil thickness and shape has increase the over all booster efficiencies (15%) and reduced emittance growth
- Modified booster lattice with low beta function at foil has reduce the emittance out of booster
- Want to reduce stamp foil size further
- **Contrary to general perception the average current on BLIP target for last several month was more than last year.**

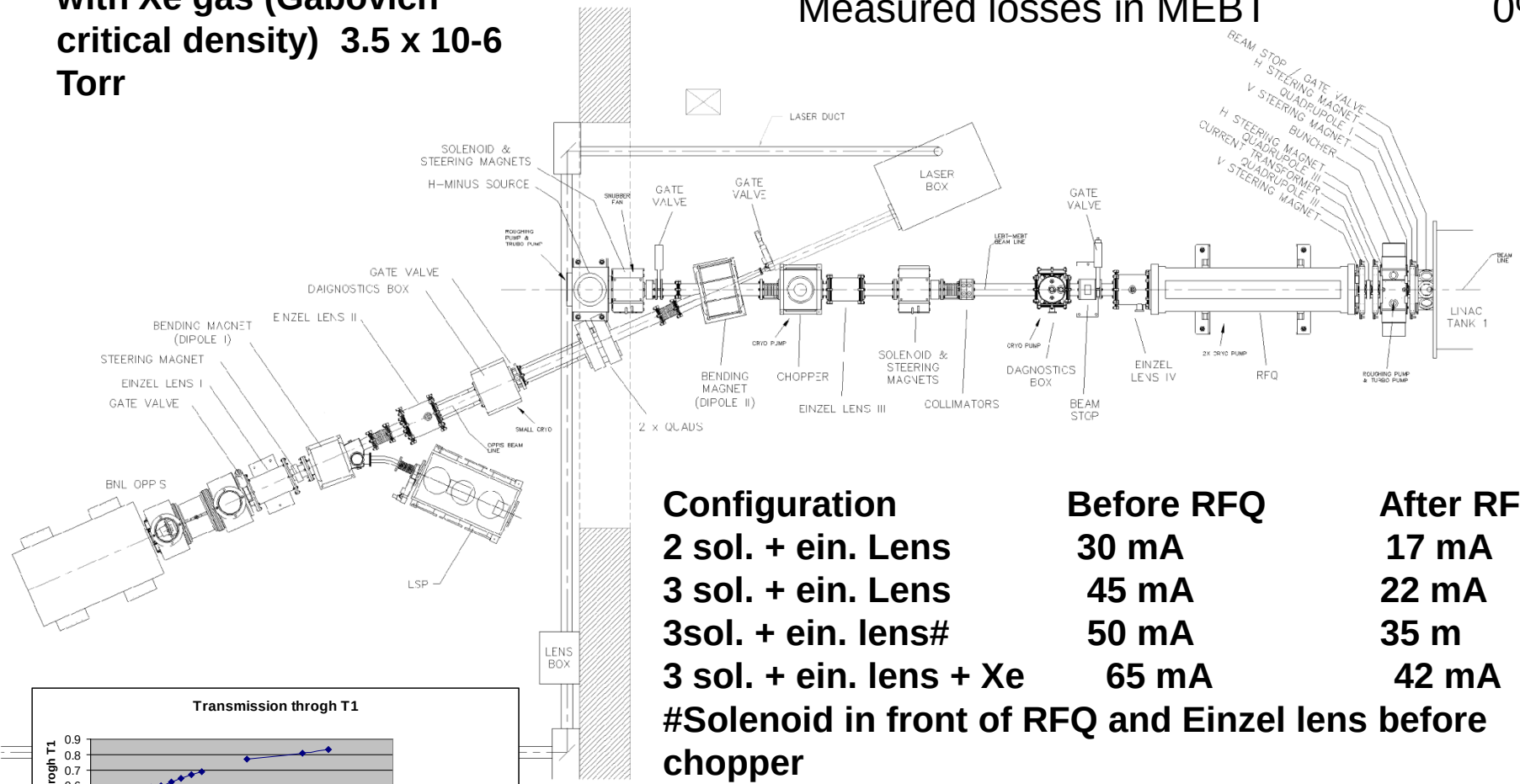
Yes

This was an upgrade

Average pressure in the LEBT 3.5 x 10-6 Torr. Pressure required for complete neutralization with Xe gas (Gabovich critical density) 3.5 x 10-6 Torr

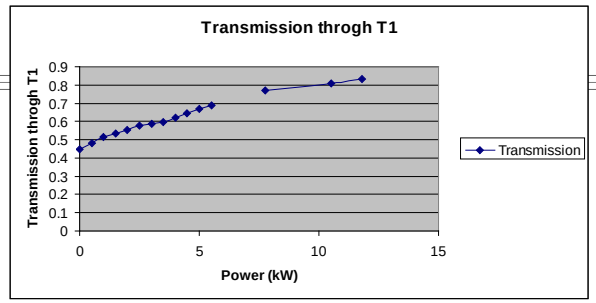
BLIP

Calculated neutralization time	38 μs
Measured neutralization time	~ 40 μs
Measured losses in the LEBT	20%
Calculated Stripping losses	10%
Measured losses in MEBT	0%

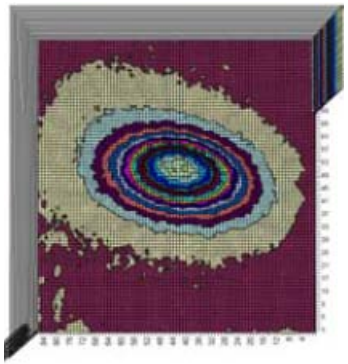
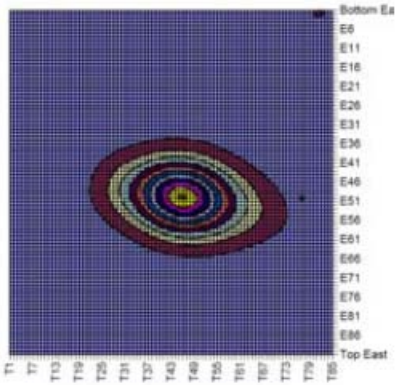


Configuration	Before RFQ	After RFQ
2 sol. + ein. Lens	30 mA	17 mA
3 sol. + ein. Lens	45 mA	22 mA
3sol. + ein. lens#	50 mA	35 m
3 sol. + ein. lens + Xe	65 mA	42 mA

#Solenoid in front of RFQ and Einzel lens before chopper

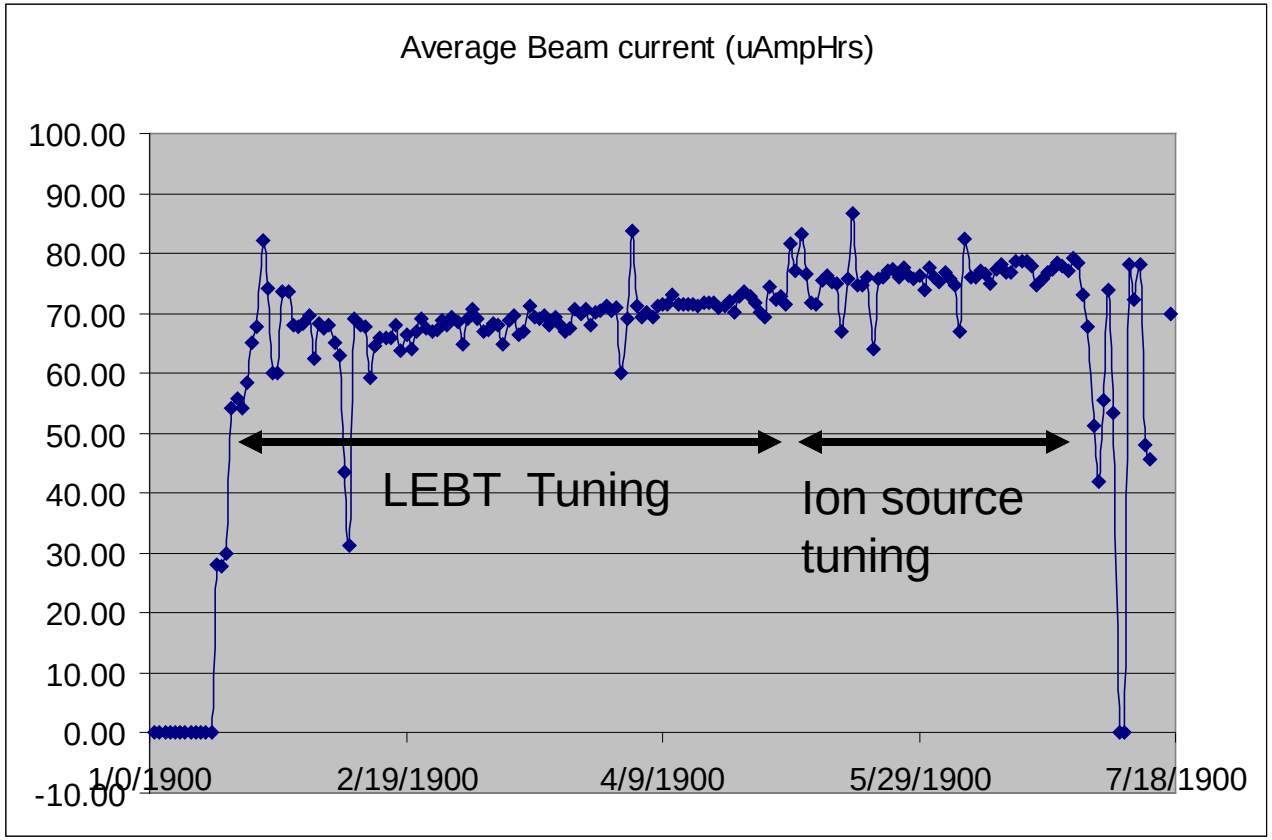


BLIP

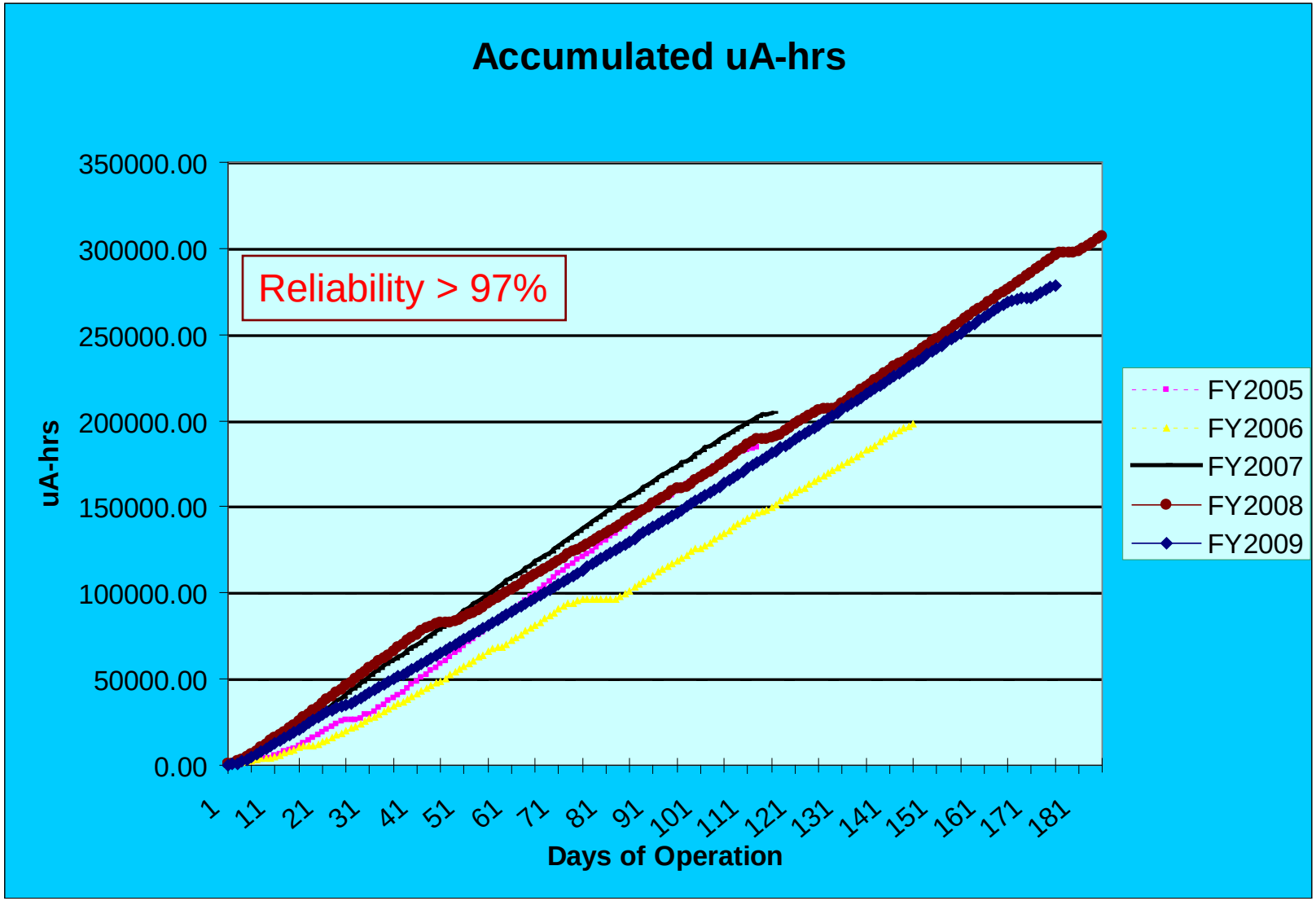
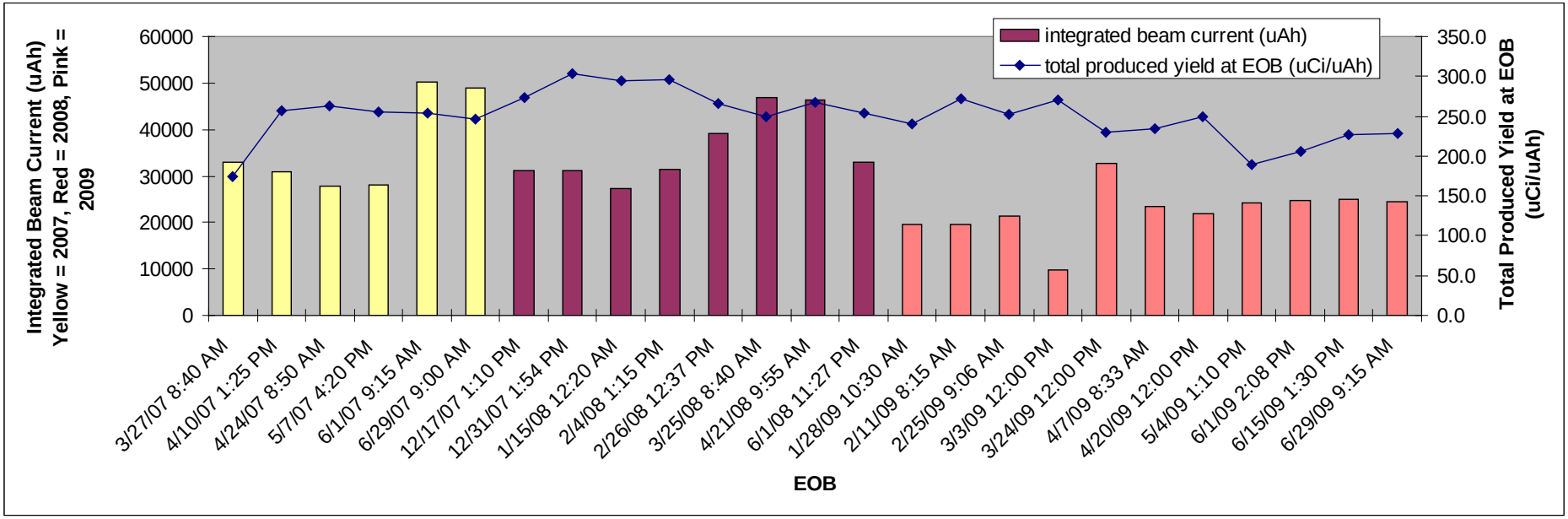
Parameters	2008	2009
Beam Foot print @ Target		
Linac RR (Hz)	6.67	6.67
DF with PP	0.85[#]	0.92[*]
Pulse width@ base (μs)	412	440
Pulse height @Max (mA)	38	35
Beam outside target (%)	8	0
Collimator temp (°C)	160	70
Current within target (μA)[$]	71	79

[*]2 pulse every 4.07 sec
[#]Every 7th pulse
[$]Calibration in current integration
Measured by BLIP

Average Current 2009



Accumulated current



Yield/current