Linac Frontend Upgrade Report

C.Y. Tan
8 Dec 2010
Proton Source Retreat

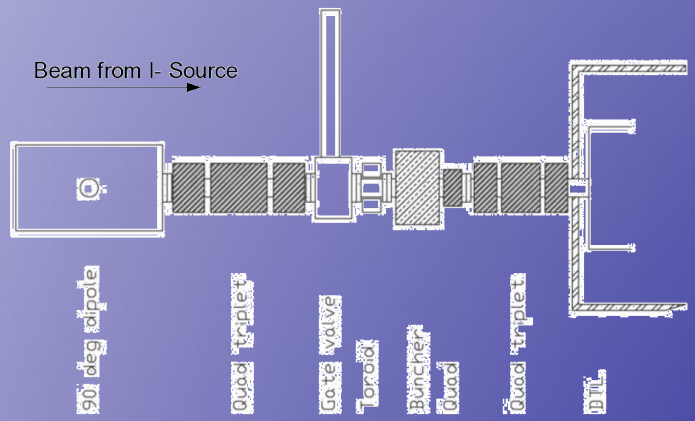
Fermilab,
P.O. Box 500
Batavia, IL 60510

cytan@fnal.gov

People *(Additional Help – Needed/Requested)*

- AD people:
  - W. Pellico (head of proton source), C.Y. Tan, J. Lackey, D. Bollinger, K. Duel, R. Riley, V. Scarpine.
- TD people:
  - G. Velev, V. Kashikhin, A. Makarov
- Thanks to BNL pre-injector group
  - J. Alessi, D. Raparia, M. Okamura, V. Lodestro.

Present Injector – Vintage 1968 Hardware



- Magnetron Source
  - 35 keV ribbon beam
  - Current about 50-60mA
- Cockcroft Waltons
  - 750keV
  - Current about 45 - 55 mA
- MEBT section
  - Quads and buncher before Tank 1
  - Dipole to accommodate another H- source + Cockcroft Walton

Reasons for Upgrade

- The components are getting harder to maintain
  - Critical personnel have retired.
  - Components getting harder to find and replace
    - Critical failure of I- column in early 2010 which required a rebuild.
- As system ages, more time and attention required to maintain reliability of system.
- Going to RFQ system should increase beam quality and system reliability.
  - Very good results from BNL when they switched from Cockcroft-Walton to RFQ system. Done in 1989. (21 years late to the party)

Quote from D. Lowenstein (BNL)

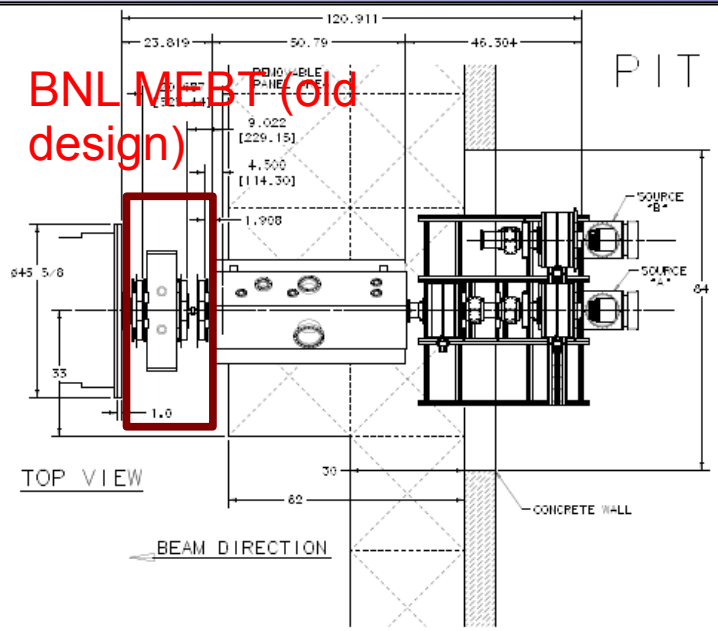
"We have been very pleased with the operational reliability of the BNL RFQ. It has worked very well since day one. In fact, the downtime attributed to the RFQ has been negligible (less than 10 hours) since it was commissioned." – D. Lowenstein (former chairman of C-AD) , BNL. Source: Fermi Today 30 Nov 2010 edition.

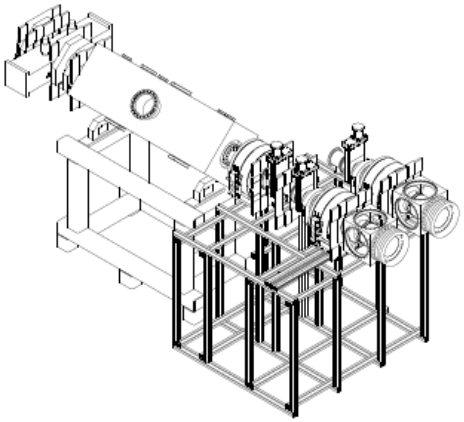
Objectives

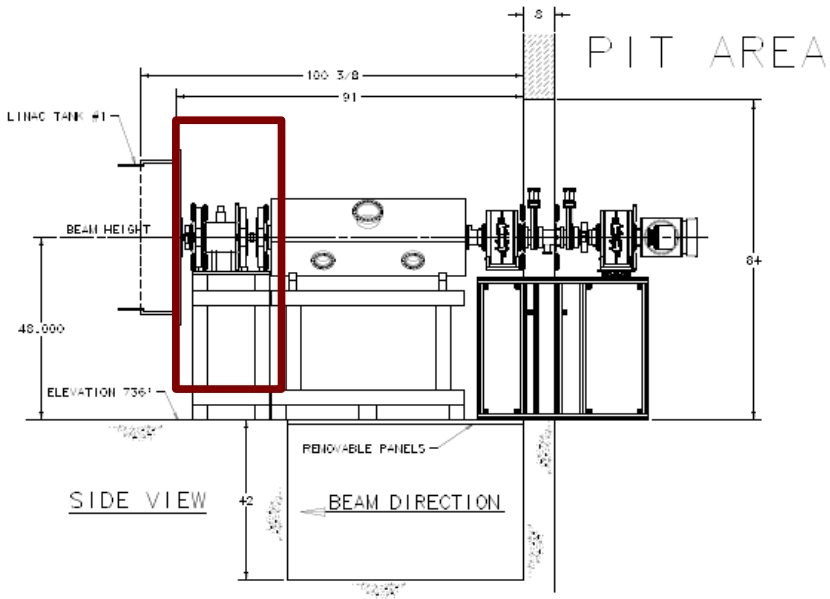
- This is not an R&D project
- Copy as much as possible from an existing injector
  - BNL injector is used as basis of design.
- Use as much as possible existing infrastructure, technology and expertise.
  - Convert slit magnetron source to round magnetron source
    - BNL style source. Very good reliability and performance > 90mA at 500 us, more than 6 months before any change required.
    - 750keV RFQ 60mA 200MHz (not technology limited)
- Better performance
  - At least 10-15% improvement in efficiency to Booster.
- Support future operations – Nova, Mu2E, MicroBooNE, G-2, RunIII

Overall Mechanical Design

BNL MEBT (old design)







PREACCELERATOR
PRELIMINARY
LAYOUT

NOVEMBER 16, 2010

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UNITED STATES DEPARTMENT OF ENERGY

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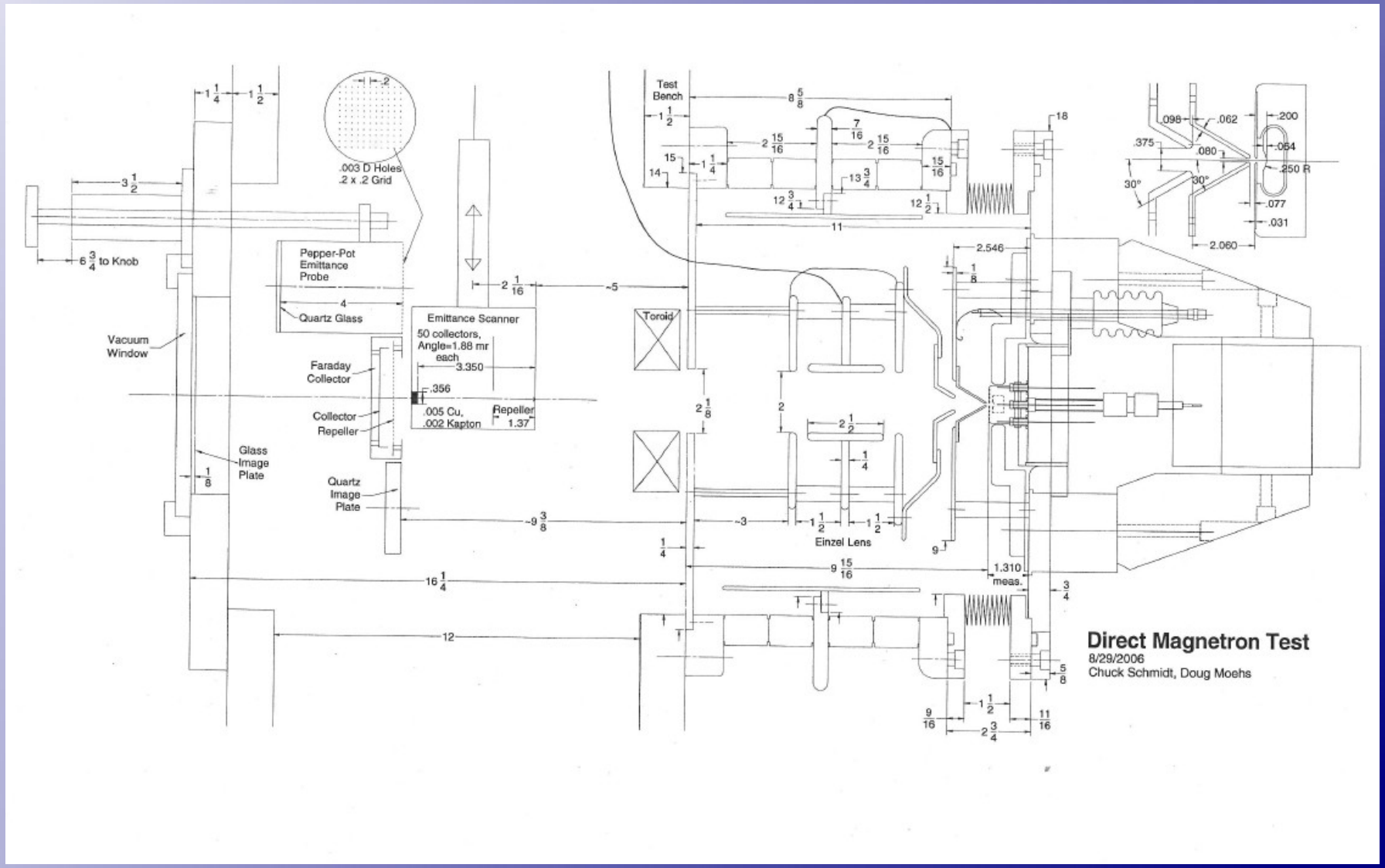
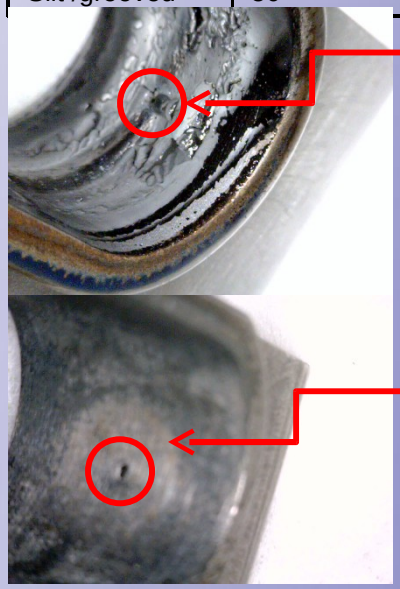
Test Stand Setup



Why Round(Dimple) Source

BNL improvements in magnetron power efficiency					
Cathode	H- (mA)	Arc I (A)	Arc V (V)	Pwr effic (mA/kW)	Lifetime (months)
Slit/flat	50	150	150	2.2	N/A
Slit /grooved	50	50	150	6.7	N/A
Circular/dimpled	100	10	150	67	6-9 months

FNAL magnetron power efficiency					
Cathode	H- (mA)	Arc I (A)	Arc V (V)	Pwr effic (mA/kW)	Lifetime (months)
Slit/flat	50	150	150	2.2	N/A
Slit /grooved	50	50	120	8.3	3.5 (average)

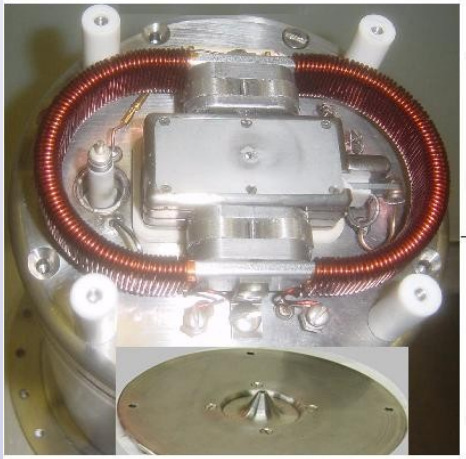


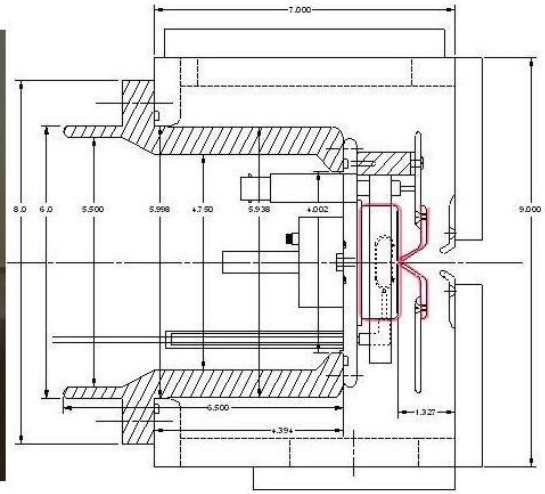
Cathode material blocking the cesium inlet opening in anode

New anode showing cesium inlet

We have to run high arc currents ~ 50A in order to get 50mA+ of H- out of the source for Linac operations. This causes increased cathode erosion and reduced source lifetime. BNL needs only 10A of arc current to get 100mA of H- beam current. Their cathode erosion is greatly reduced which leads to longer source lifetimes.

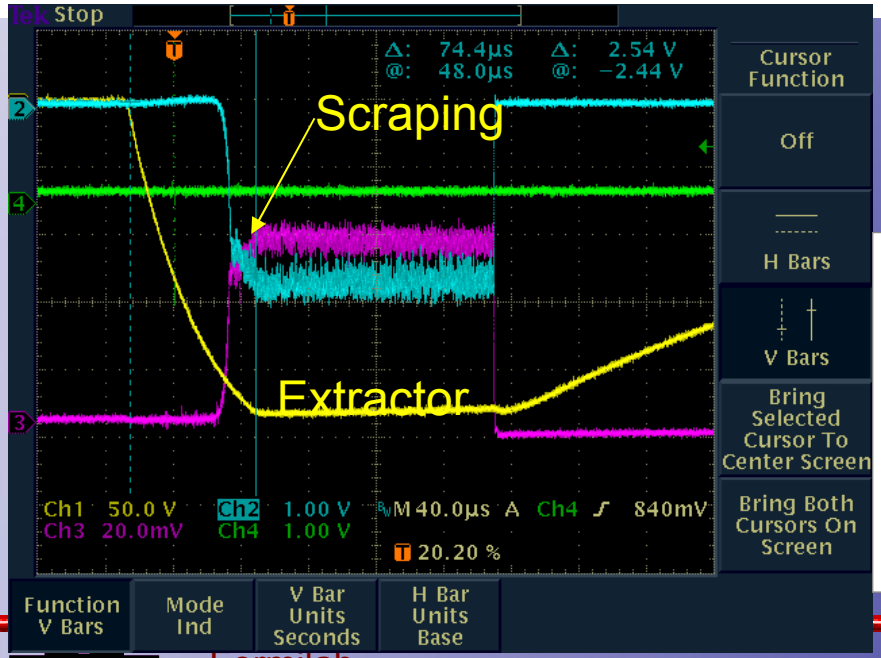
The H- Test Source

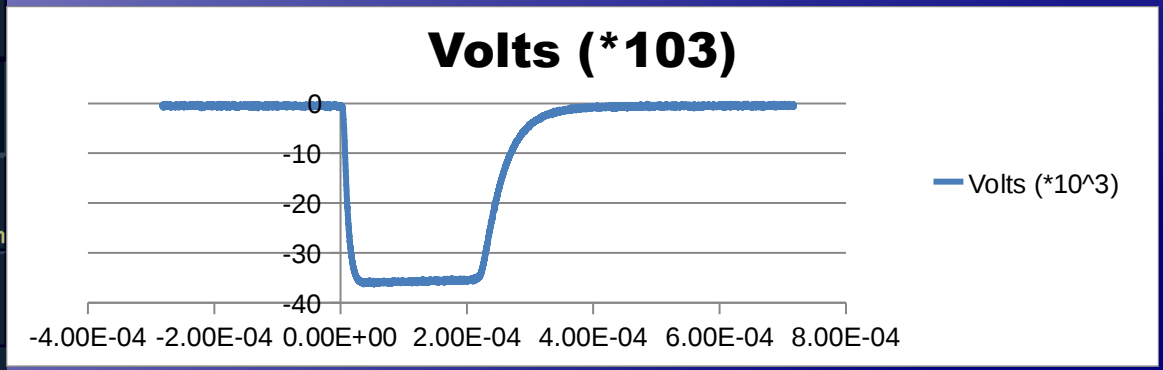




H- source test source (modified from HINS) source at 35keV

- 40mA at extraction
- Wrong cone.
- Should get 90mA at 35kV extraction.





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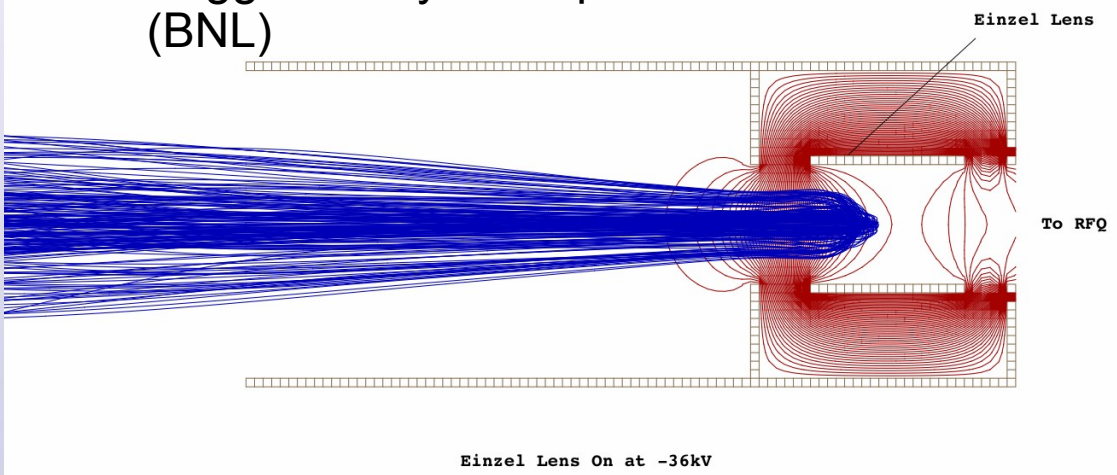
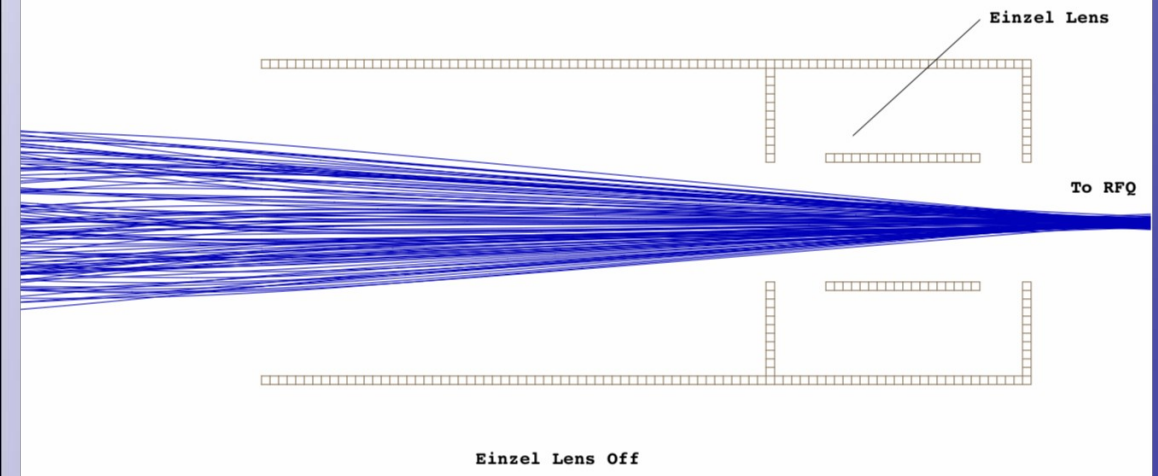
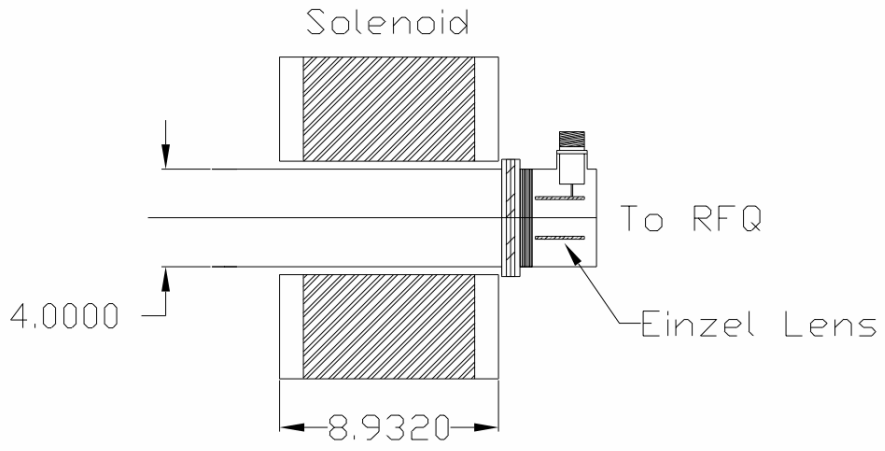
P.O. Box 500
Batavia, IL 60510

Chopper

Suggested by D. Raparia (BNL)





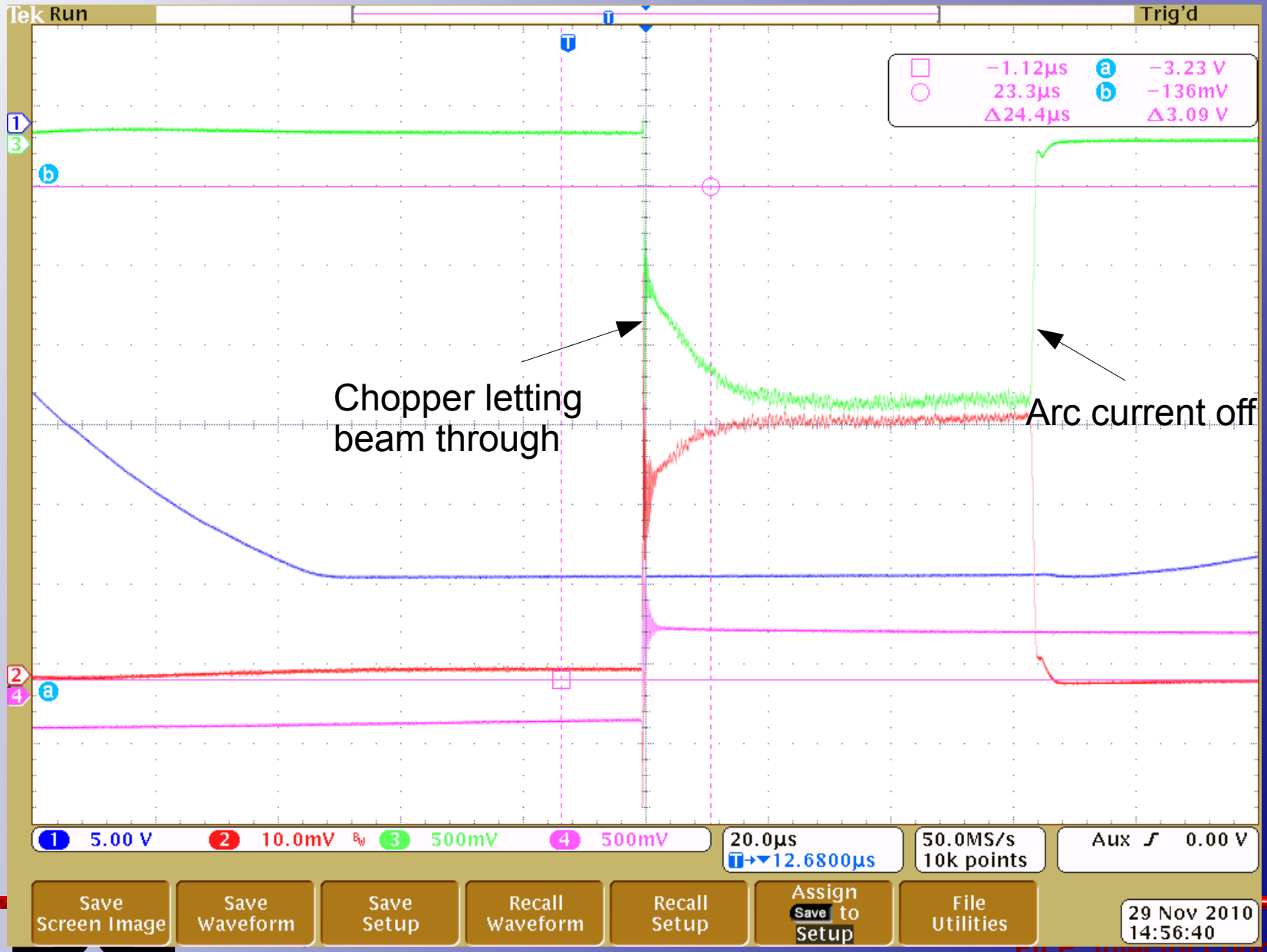


Present experiments have shown that Einzel lens will not spark at 37kV with or without H-

Reason for chopper

- Want rise/fall time of H- < 1us.
- Want control of length of pulse.
- Want to neutralize the LEBT before chopping.

First results



Green: Faraday cup

Red: toroid

Blue: Extractor voltage

Magenta: chopper pulser

16 averages

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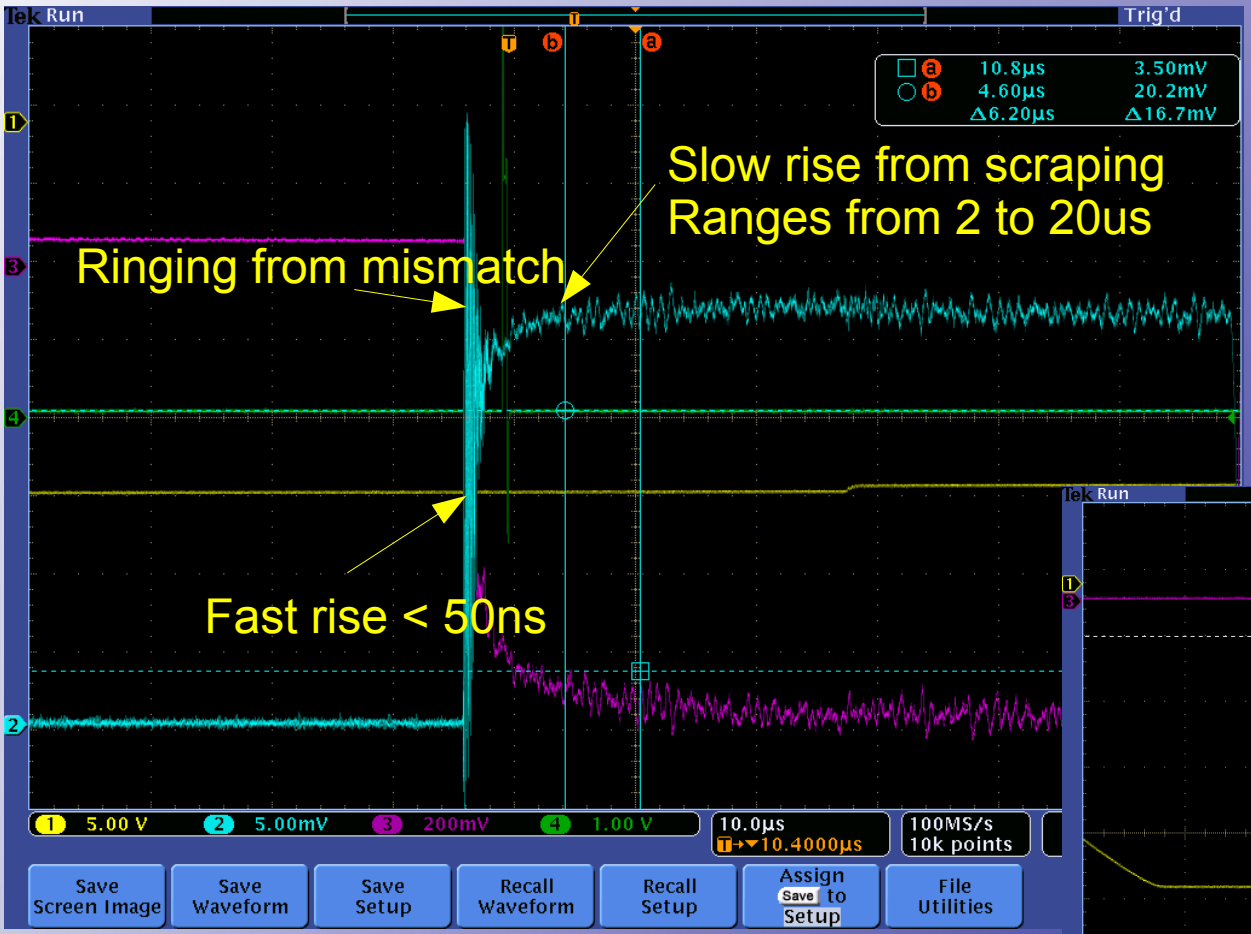
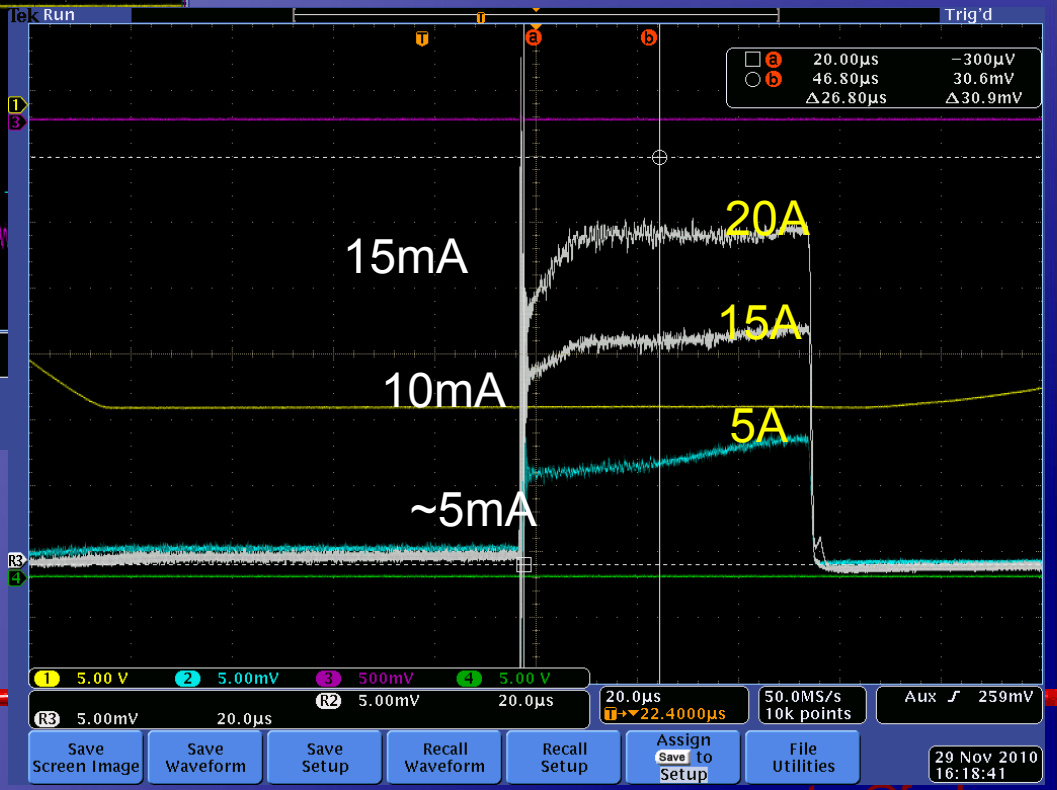
Zoomed in view





Note: no solenoidal focusing.
Beam is blowing up from space charge

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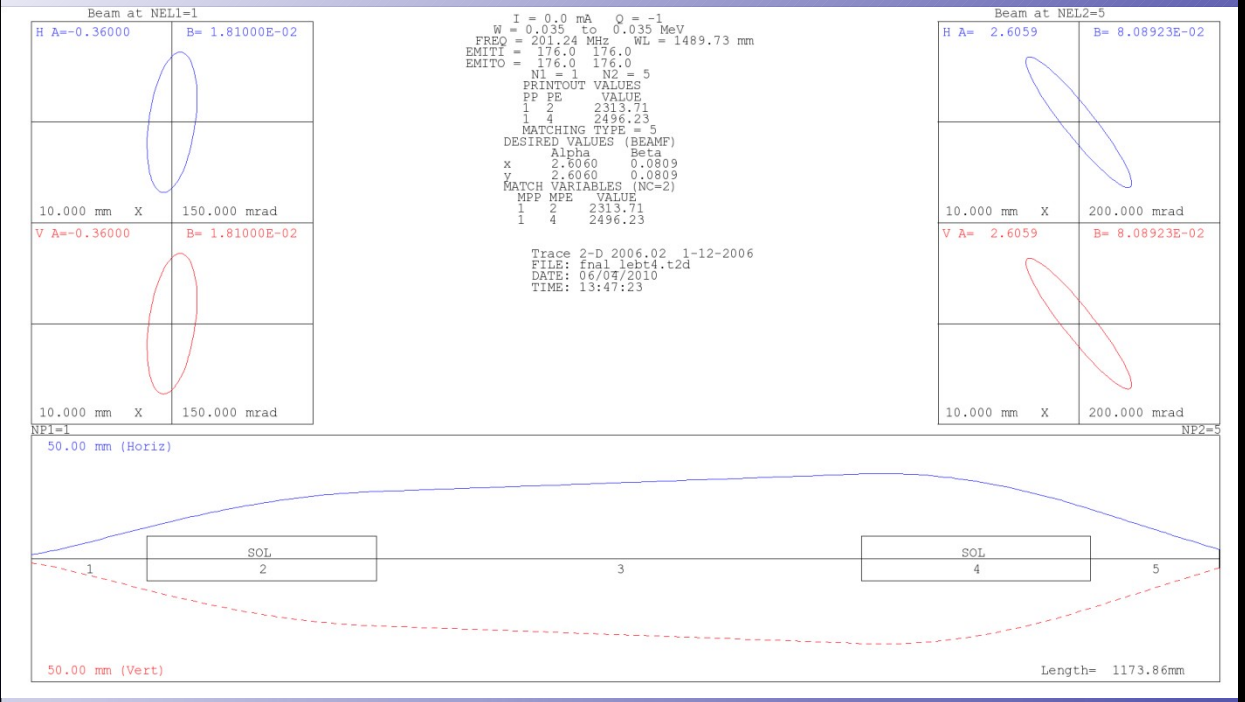
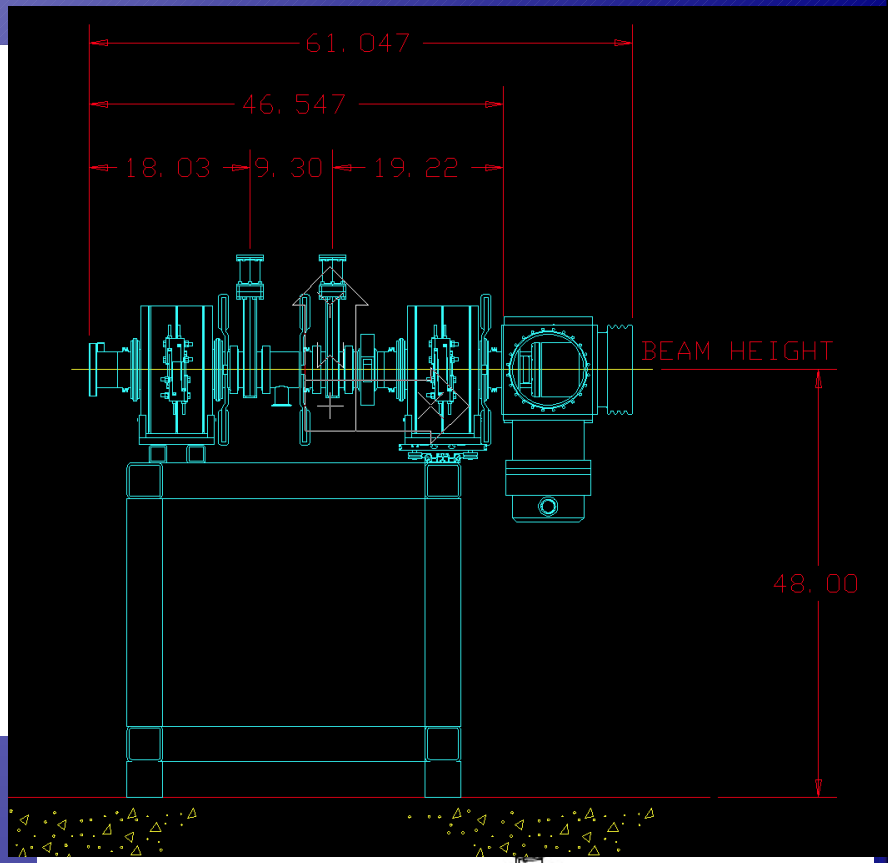
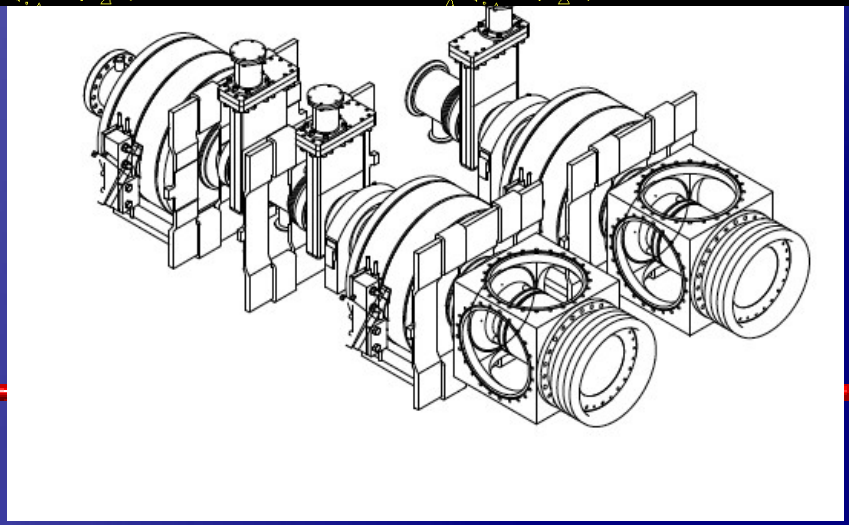
LEBT





- LEBT < 1.2 m long
- 2 sources for reliability.
- Will probably use Xe gas neutralization of H-
- Solenoids are being built right now. Delivery expected by early 2011.



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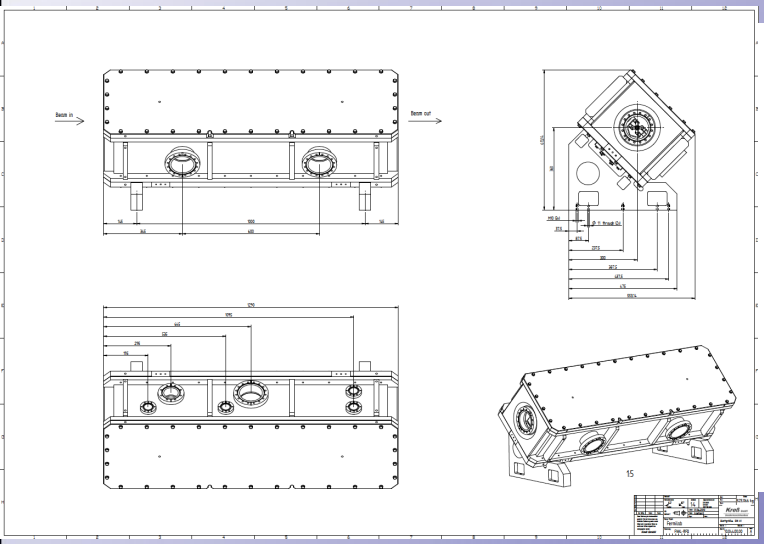
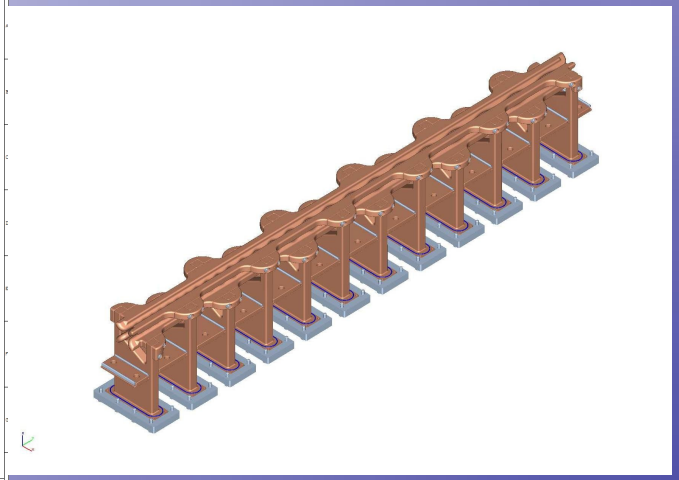
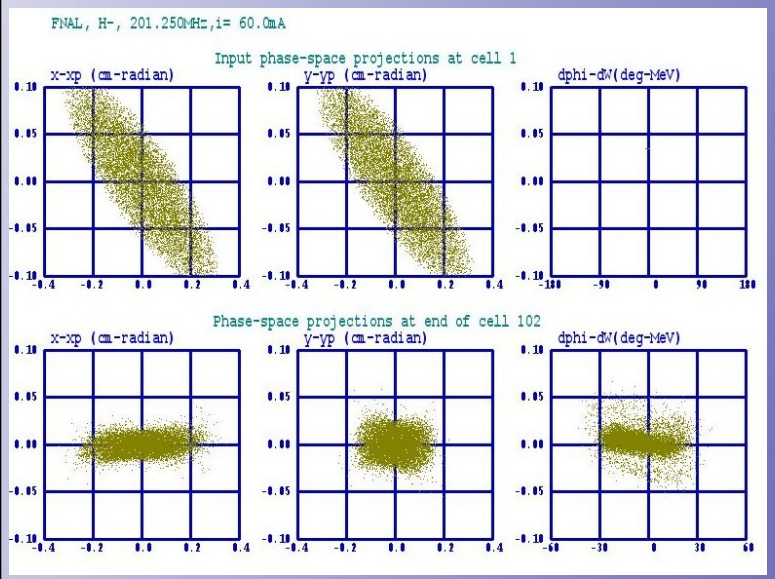
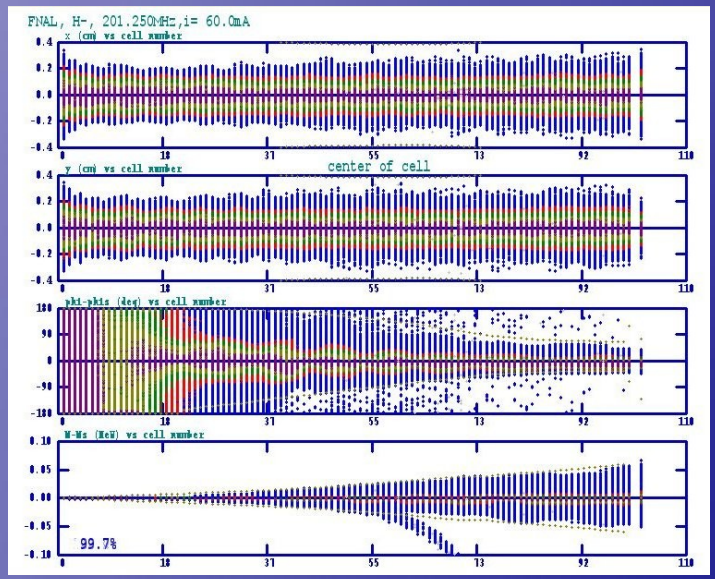
RFQ





- 750keV RFQ.
- 60mA beam current
- 1.3m long.
- Rod design.
- Alwin Schempp designer
- Expected delivery, early 2011





RFQ Params

60mA beam

Input: α = 1.5, β=5.1 cm/rad ϵ=210 pi mm mrad

Output:

α_x = -0.18, β_x = 12.5 cm/rad, ϵ_x (rms norm)= 0.37

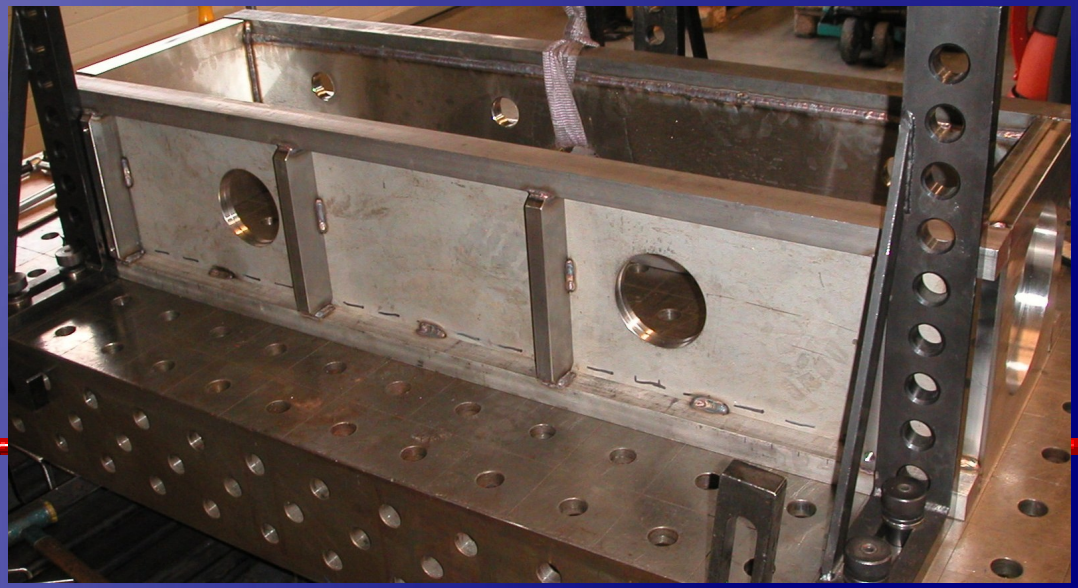
α_y = 0.07, β_y = 5.5 cm/rad, ϵ_y (rms norm)= 0.35

α_z = 0.21, β_z = 1170 deg/MeV, ϵ_z (rms unnorm) = 0.14 π MeV deg.

2.0 BAISC OPERATING SPECIFICATIONS

Operating Frequency	201.25 MHz
Frequency Tuning Range	+/- 100KHz (slug tuning range)
Input Energy	35 KeV
Output Energy	750 KeV
Repetition Rate	15 Hz
Design Beam Current	60 mA
Pulse Length	up to 100 us
Input Transverse Emittance	0.3 π mm-mrad RMS Normalized
Output Transverse Emittance	0.3 π mm-mrad RMS Normalized
Output Longitudinal Emittance	< 50 KeV deg Normalized 6sigma
Input Twiss Parameters*	$\alpha_x = \alpha_y$, $\beta_x = \beta_y$ equal within +/-10%
Output Twiss Parameters*	Need to be developed and checked
Acceleration Efficiency	>95% @ full beam current
Power Consumption	100 kW + Beam Power
Sparking Rate	< 10^{-4} sparks/pulse @ design power
Vacuum Pressure (Operating)	<3 x 10^{-7} torr @ design power
X-Ray Emission	<5mrem/hr @ 1foot
Expected Lifetime	20 years

RFQ Tank Waiting to be Copper Plated



"Grooves" are an artifact of compression. Not there in real life.

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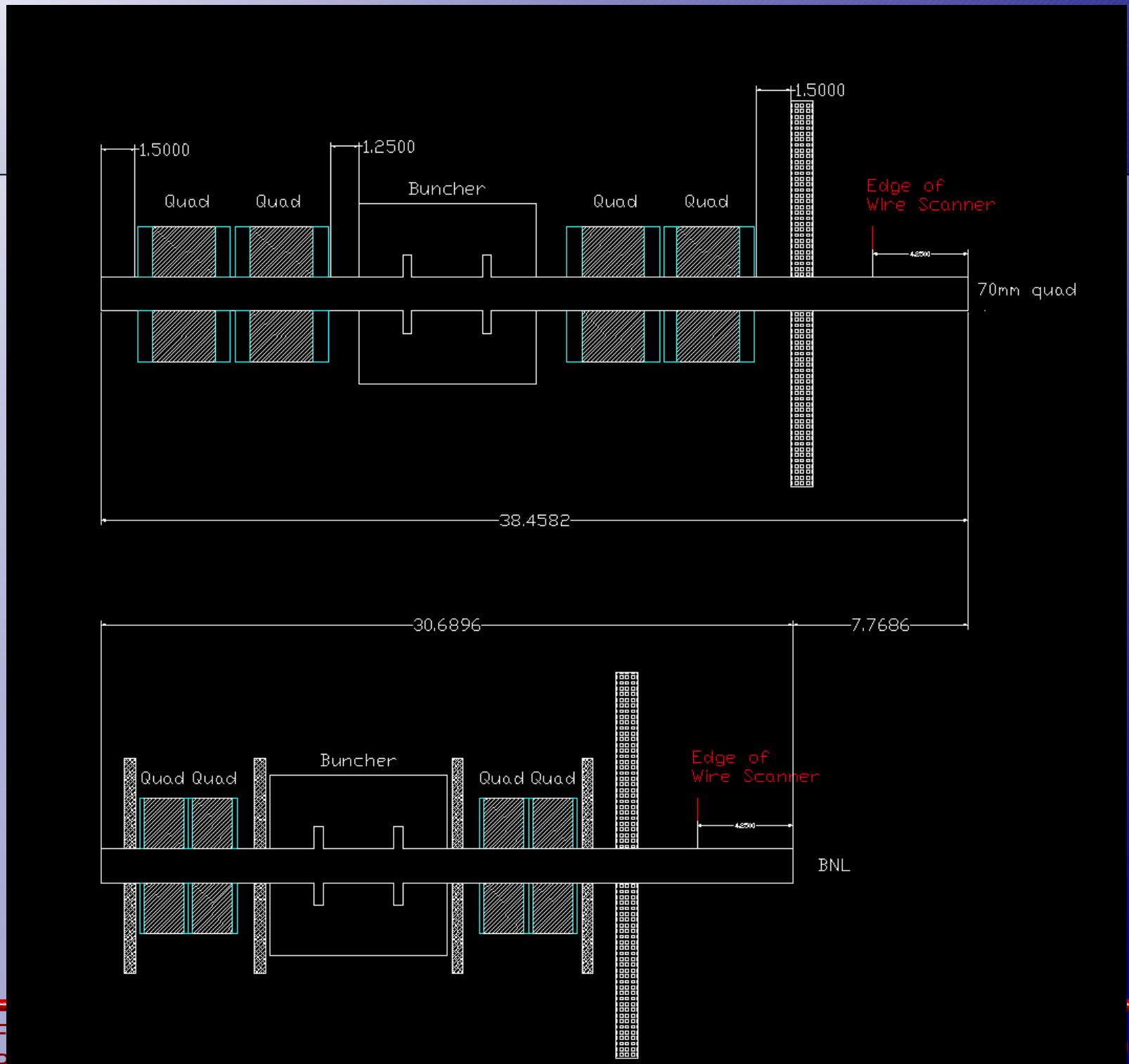
MEBT

The beam is approximately round coming out of the RFQ

- Use doublets to focus the beam before and after buncher
- Must be very short from BNL experience
- Use some of BNL's design
- Quads are a problem because they run very hard.
  - 2 designs available
    - BNL quads are 45mm (~55 physical length) water cooled.
      - » Don't know whether can run at our rep rate of 15Hz
    - FNAL quads are 70mm (105mm physical length) but includes dipole correctors and air cooled.
    - Both give comparable capture at the end of Tank 1
    - Note: work is being done at TD to shorten the quads to ~55 physical length and use water cooling with built in dipoles.


1.5000
1.2500
1.5000
Quad
Quad
Buncher
Quad
Quad
Edge of
Wire Scanner
70mm quad
38.4582
30.6896
7.7686
Quad Quad
Buncher
Quad Quad
Edge of
Wire Scanner
BNL

MEBT Quad Strengths

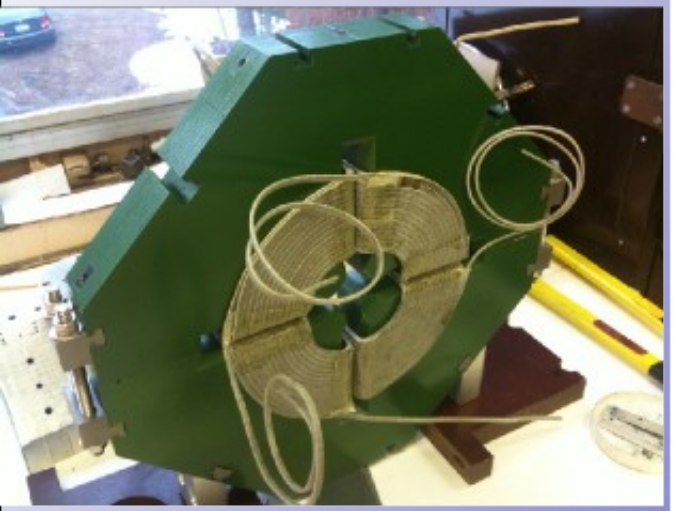
FNAL doublets (using 70mm magnetic length)

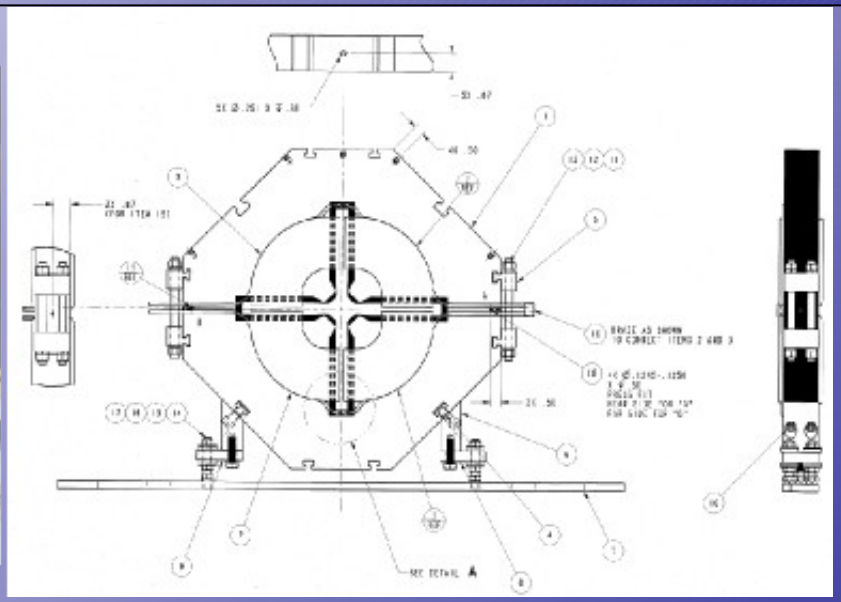
- Quad1: 26.8 T/m
- Quad2: 22.9 T/m
- Quad3: 17.6 T/m
- Quad4: 16.7 T/m

BNL doublets (using 45mm magnetic length)

- Quad1: 54.0T/m
- Quad2: 47.3 T/m
- Quad3: 40.3 T/m
- Quad4: 37.9 T/m

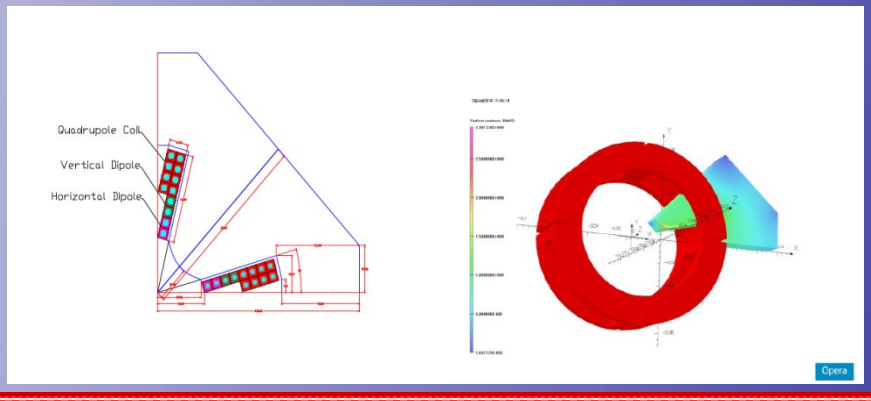
MEBT Quads

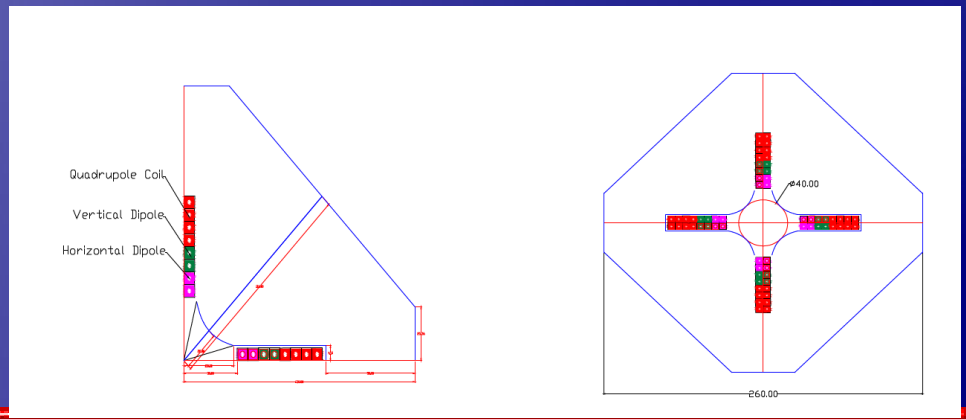




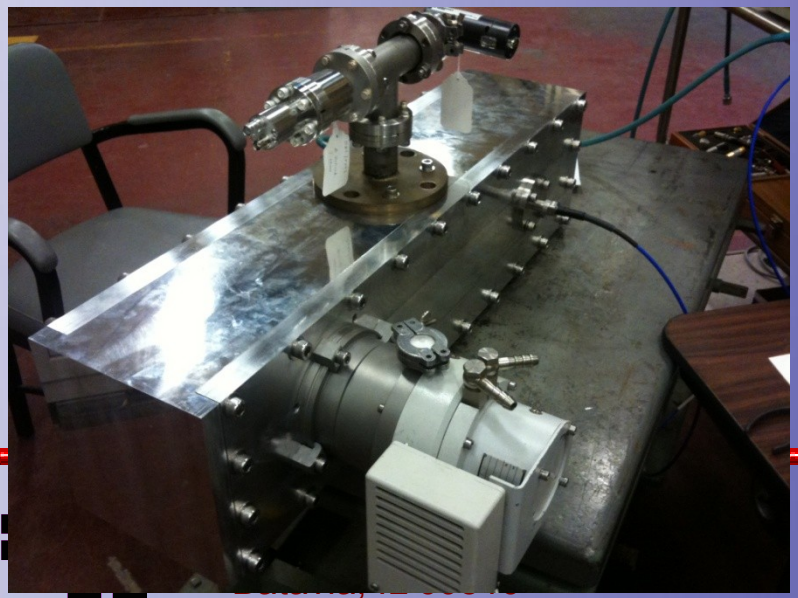
BNL style

FNAL style



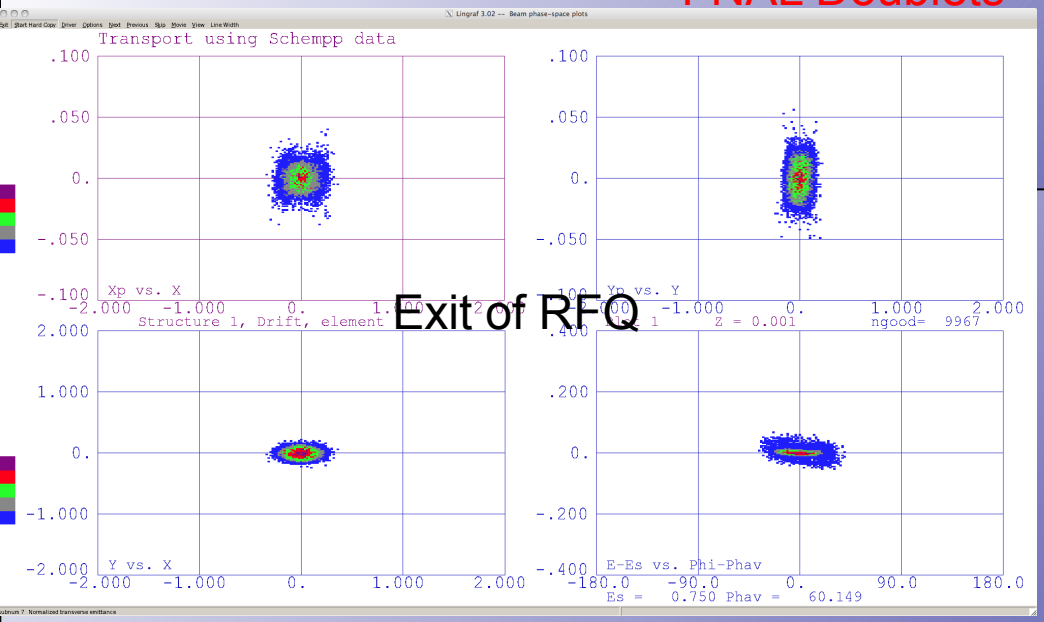


Buncher

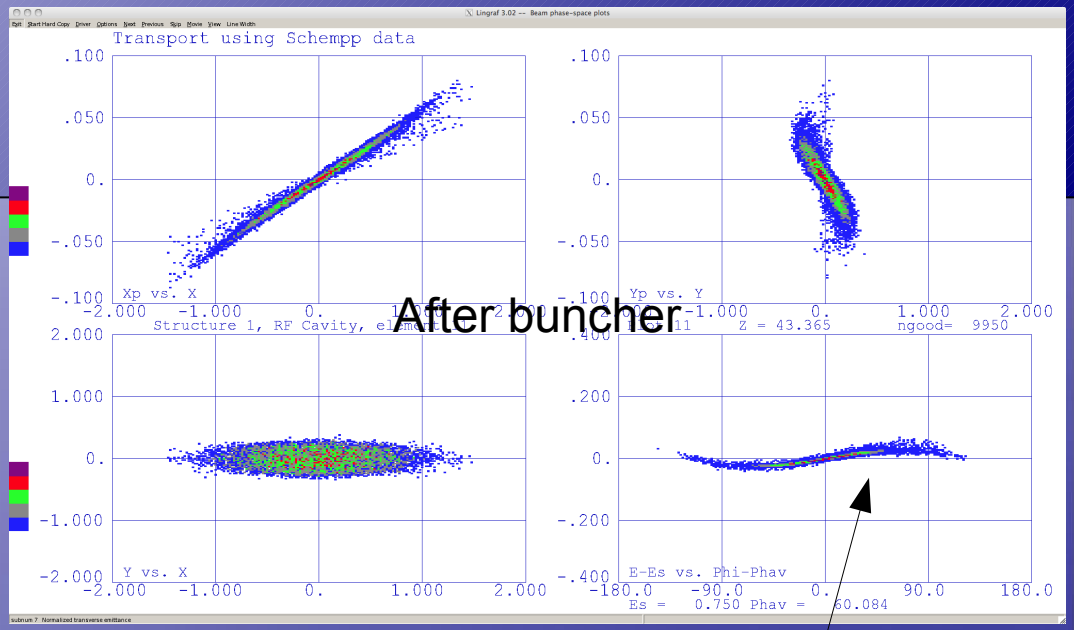


Pictures from BNL.
Thanks to M. Okamura (BNL).

FNAL Doublets



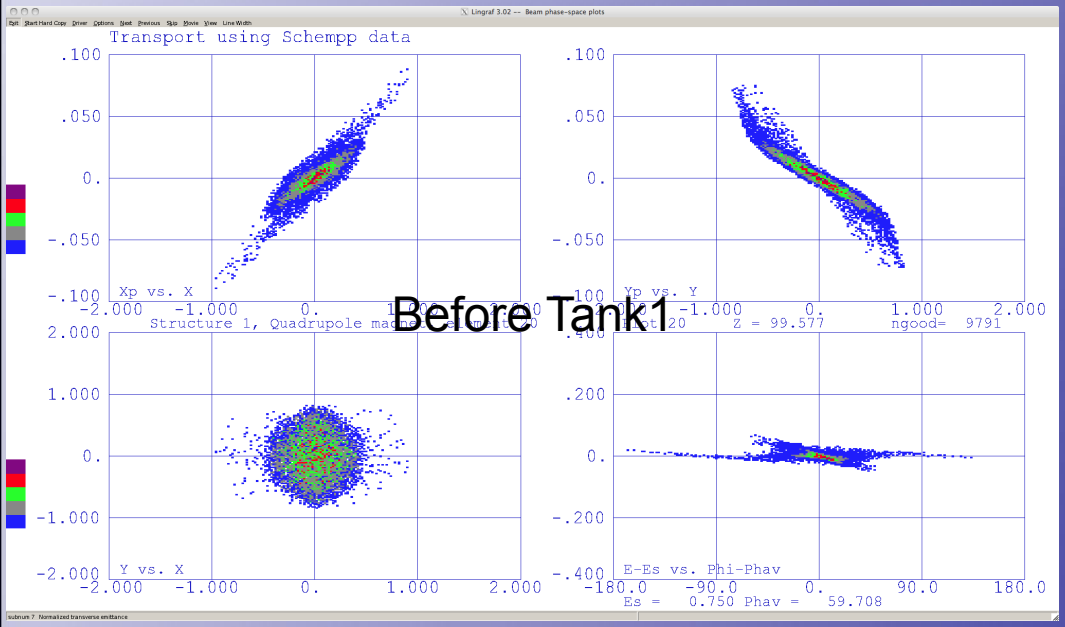
Exit of RFQ



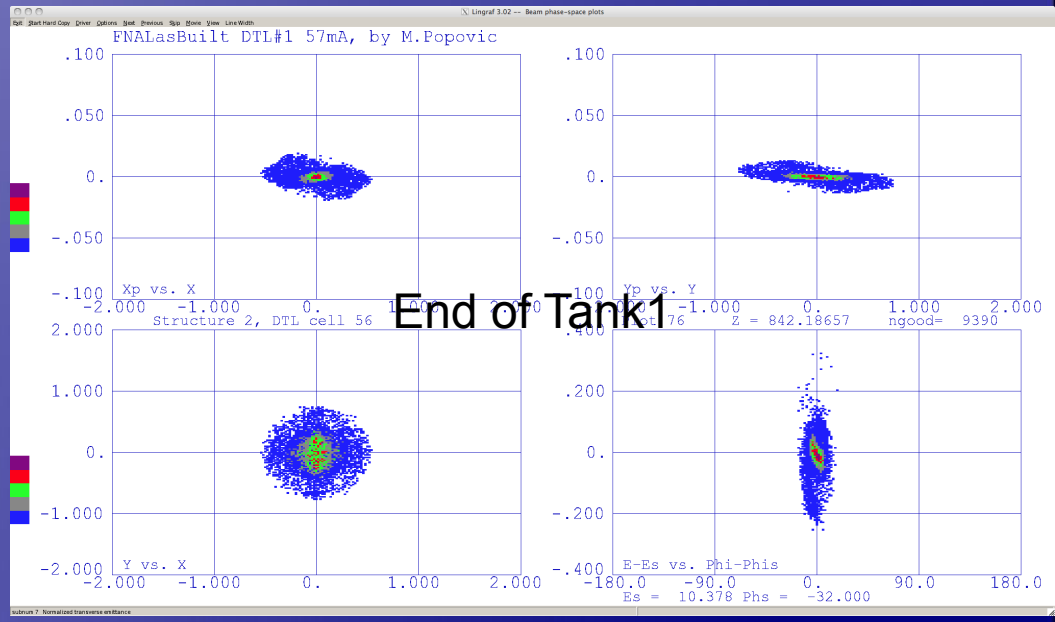
After buncher

Capture is 94.2% at end of Tank 1

Tails are much longer than when we use BNL doublets

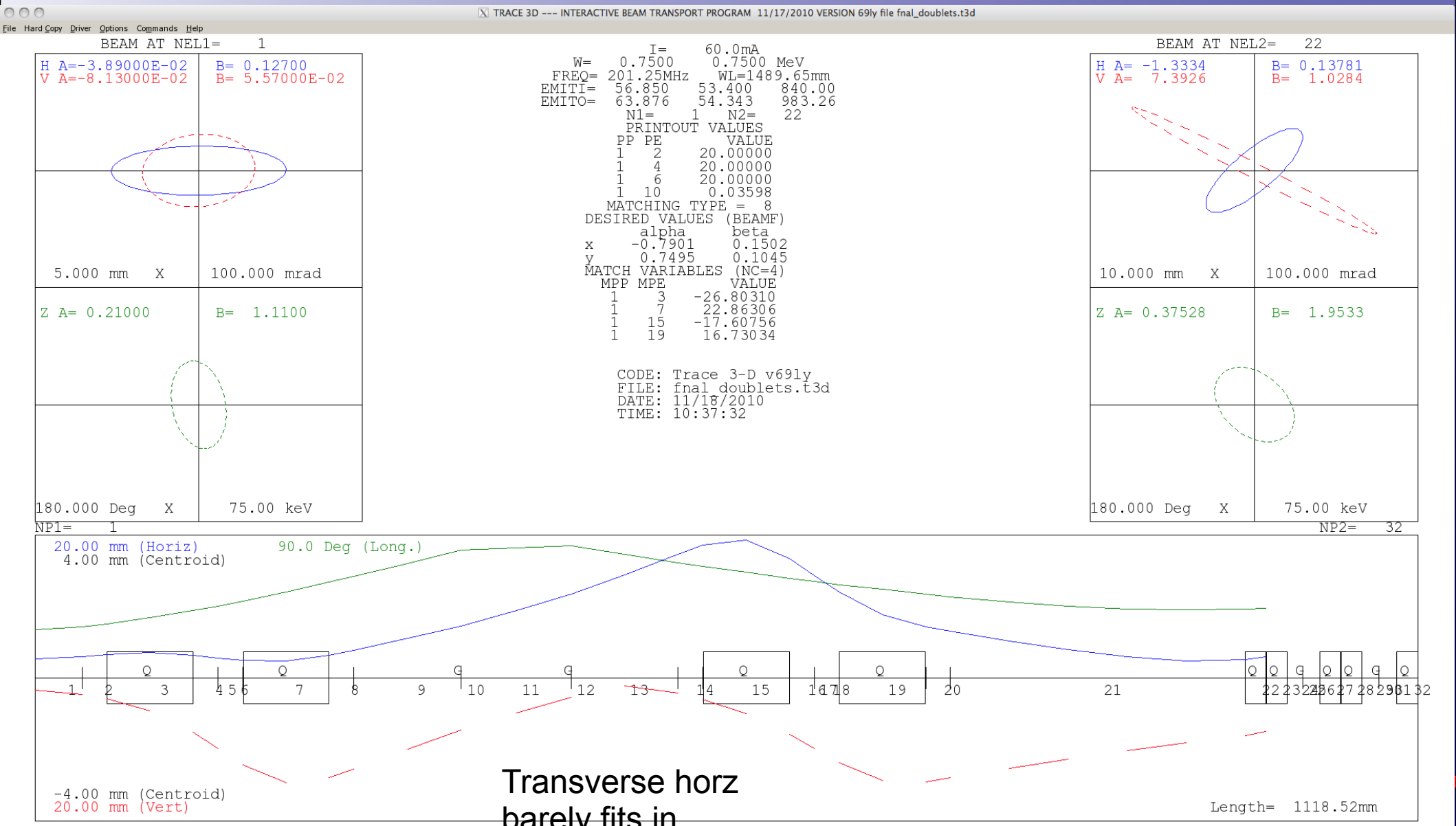


Before Tank1



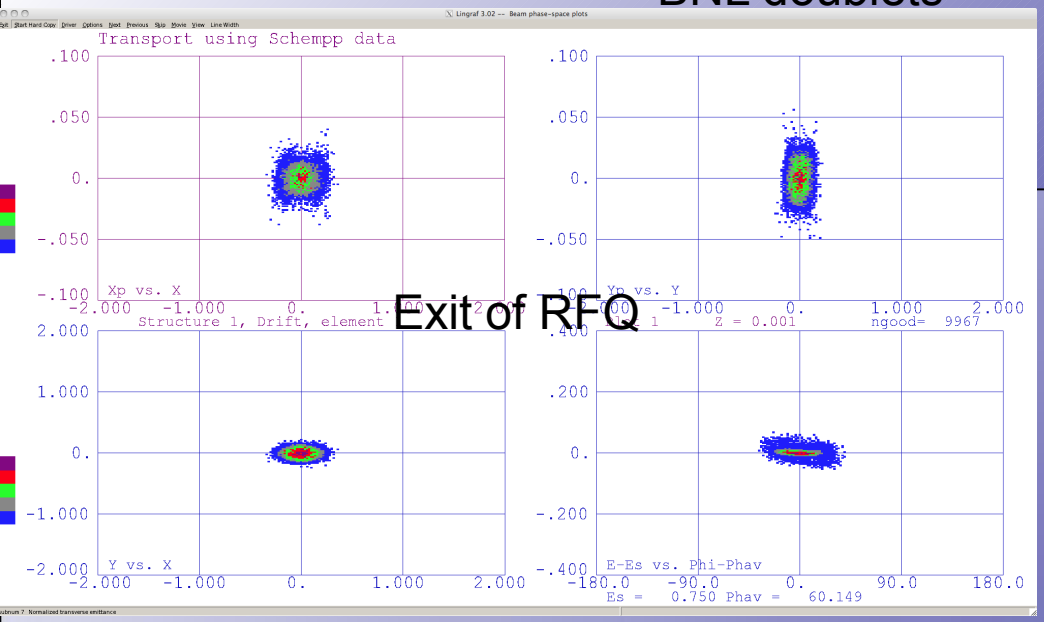
End of Tank1

FNAL Trace3D

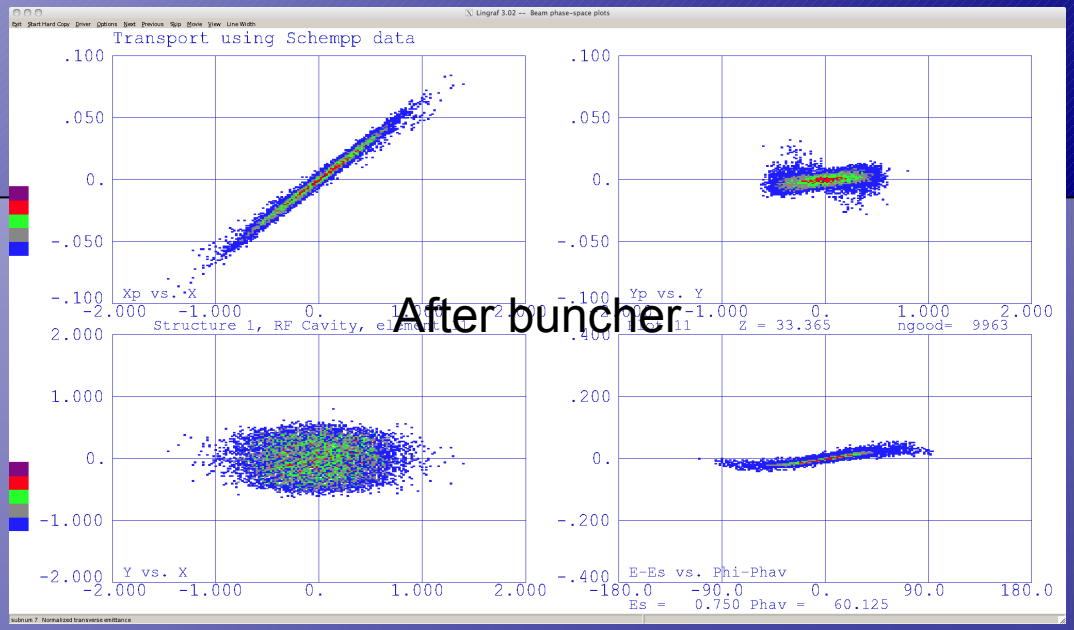


Transverse horz barely fits in beampipe

BNL doublets

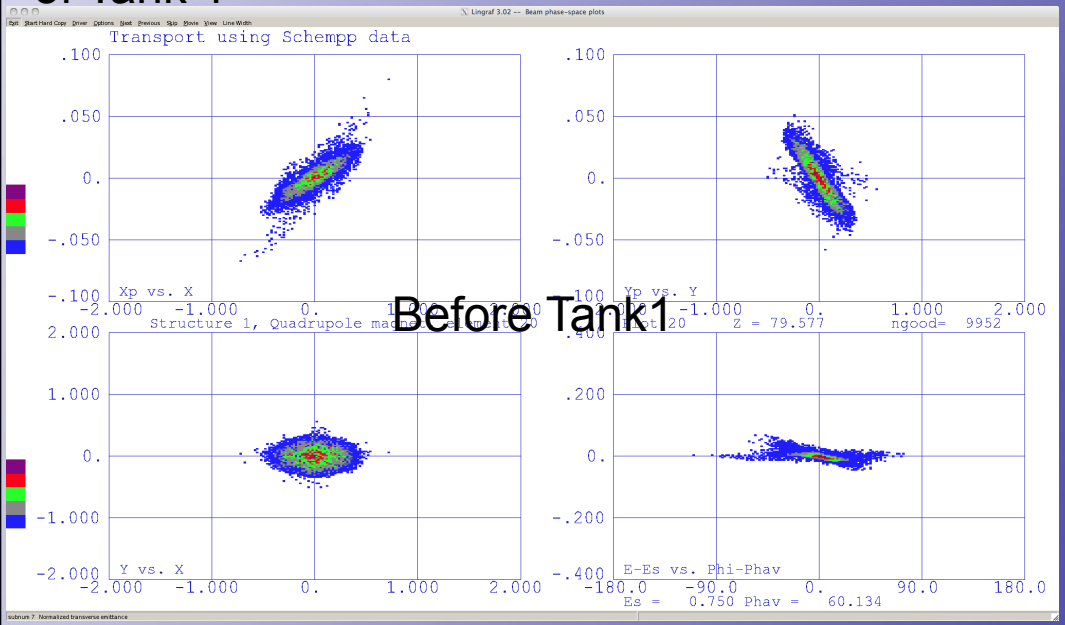


Exit of RFQ

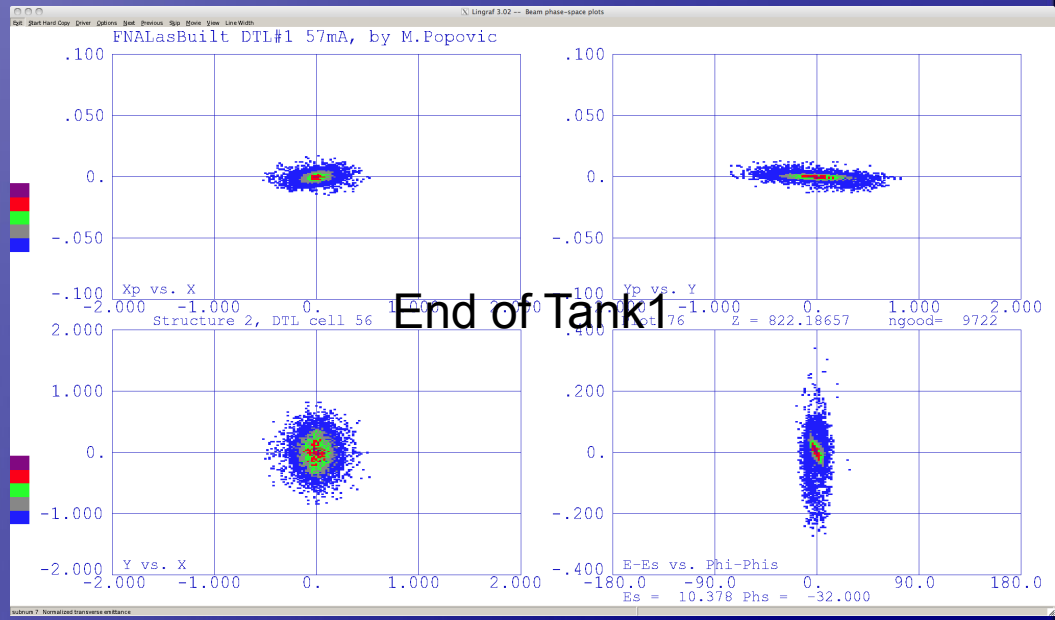


After buncher

Capture is 97.5% at end of Tank 1

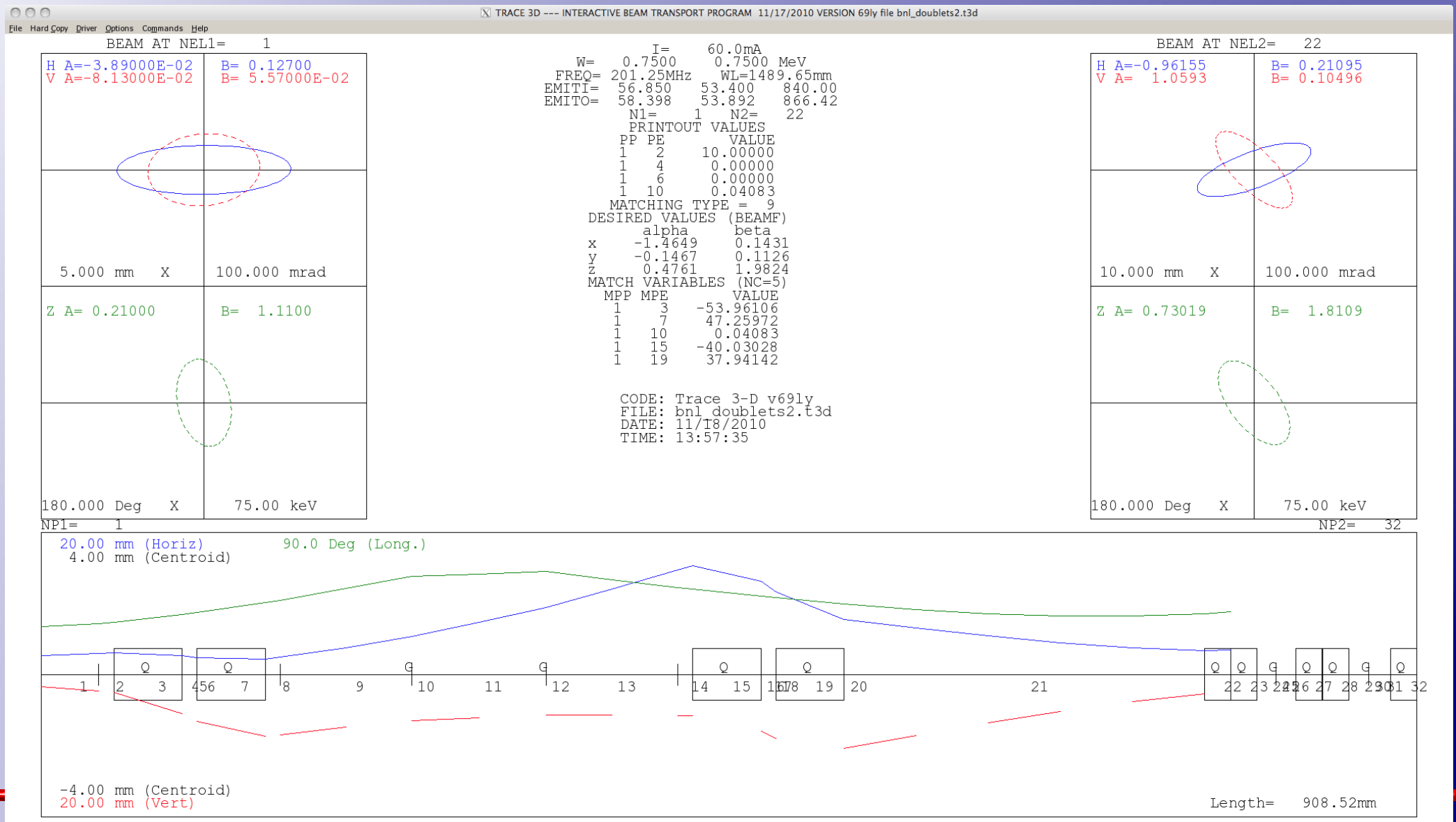


Before Tank1



End of Tank1

BNL Trace3D



P.O. Box 500
Batavia, IL 60510
cytan@fnal.gov

Conclusion

- Goal is to complete testing of injector before the shutdown of 2011.
  - Installation will probably take 3 months in 2012.
- Lots of things to do before then
  - Complete commissioning of the H- source
  - Complete testing of Einzel lens as chopper.
  - Check and condition buncher.
  - Check and condition RFQ
  - Have test stand ready for beam test
  - Build and complete solenoids.
  - Build and complete quadrupoles.
    - Choice has to be made between BNL and FNAL quads