H^- Ion Source and LEBT development

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Project X Collaboration Meeting

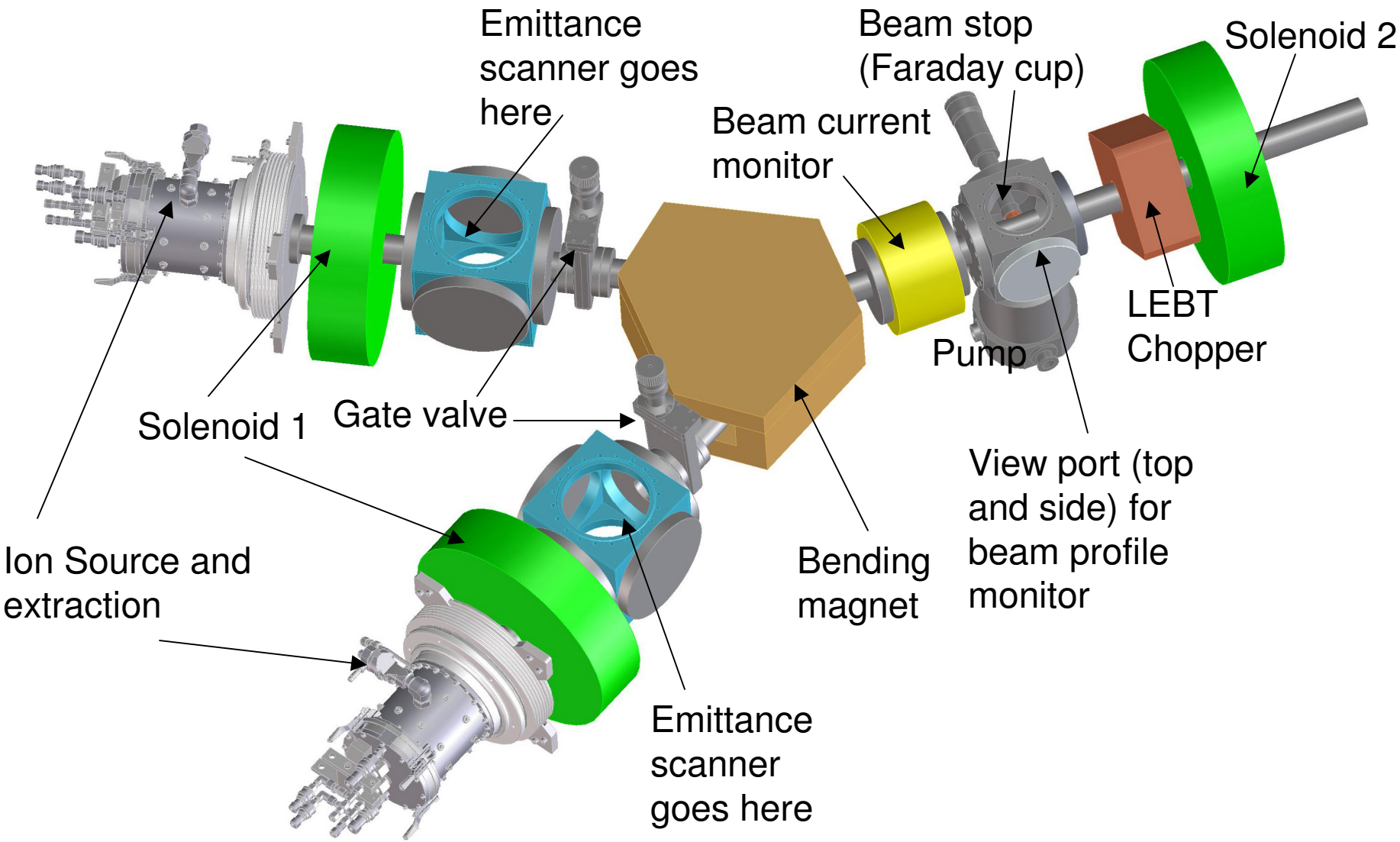
Specifications of Project X H^- Ion Source and LEBT

- **H^- Ion Source**
  - cw operation
  - 10 mA -> 5 mA
  - normalized rms emittance < 0.2 π mm mrad
  - Pulsed H^- beam at 10Hz, with 5 ms pulse width, 0.5 ms pulse ramping up and down, with variable beam intensities of adjacent pulses
- **LEBT**

	Previous RFQ Design	Current RFQ Design
Freqency (MHz)	325	**162.5**
Injection Energy (keV)	35	**20**
Twiss parameter	α = 0.9	**α = 2**
	β = 0.02 m/rad	**β = 0.06 m/rad**

  - normalized rms emittance < 0.25 π mm mrad

Ion Source and LEBT Beam line and Diagnostics



H^- Ion Source

Filament-discharge H^- Ion Source

- Project X 5 mA baseline H^- ion source identified.
  - DC filament, Penning, and RF H^- ion source evaluated.
  - D-Pace filament-driven H^- ion source ordered.
- Filament driven H^- source provides a rapid-entry, low risk solution
  - Having this source can expedite R&D of LEBT
  - Emittance should meet specifications at 5mA of output beam current
    - normalized 4rms emittance ~ 0.6 π mm mrad
  - cw 5 mA, proven technology
  - No Cs
  - Limited lifetime (~ 500 hrs)
    - Two ion sources with a switching magnet shorten downtime significantly
  - Present beam extraction system was optimized for 28 keV beam injection energy
    - optimization for 20 keV beam injection energy needed

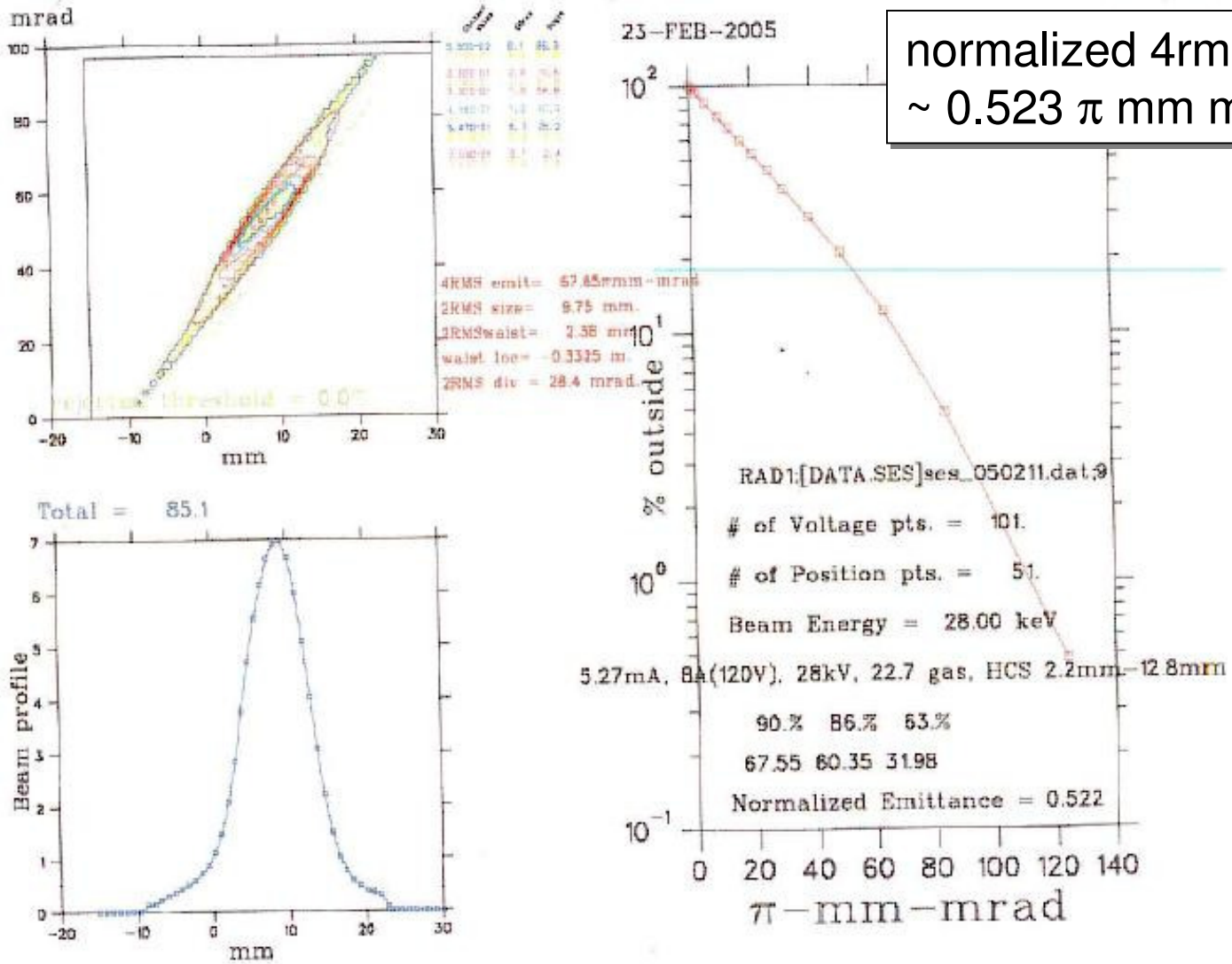
Source operation from prior work

I Injection (µA)	H^2 Flow sccm	Varc V	I arc I	V pull V	I pull mA	V es V	I es A
1011.1	11.0	120.0	4.7	2400.0	3.1	4.7	1.2
1053.0	11.0	120.0	1.9	2200.0	5.2	2.0	0.6
2030.0	11.0	120.0	3.1	2100.0	18.4	1.9	0.9
3026.0	11.0	120.0	4.2	1900.0	5.7	2.7	1.5
4042.7	11.0	120.0	5.6	2100.0	11.1	2.9	2.0
5030.9	11.0	120.0	7.0	2300.0	14.2	3.3	2.5
6066.1	11.0	120.0	8.5	2700.0	17.8	3.7	3.1
7052.0	11.0	120.0	10.1	3000.0	22.8	4.0	3.8
8074.0	11.0	120.0	11.9	3000.0	31.7	4.2	4.4
9028.2	11.0	120.0	13.8	3100.0	40.1	4.6	5.2
100016.0	11.0	120.0	16.2	3200.0	49.3	5.0	6.2
11028.0	11.0	120.0	19.2	3200.0	53.9	5.6	7.7
12013.0	11.0	125.0	23.3	3200.0	95.3	5.8	9.0
13079.0	15.5	125.0	22.5	3400.0	77.2	4.8	7.7
14035.0	15.5	125.0	25.0	3500.0	105.5	4.8	8.3
15000.0	20.6	130.0	30.0	3900.0	120.0	4.7	9.2

Courtesy of Morgan Dehnel, D-Pace, Inc.

Emittance Measurement (5.27 mA @ 28kV)

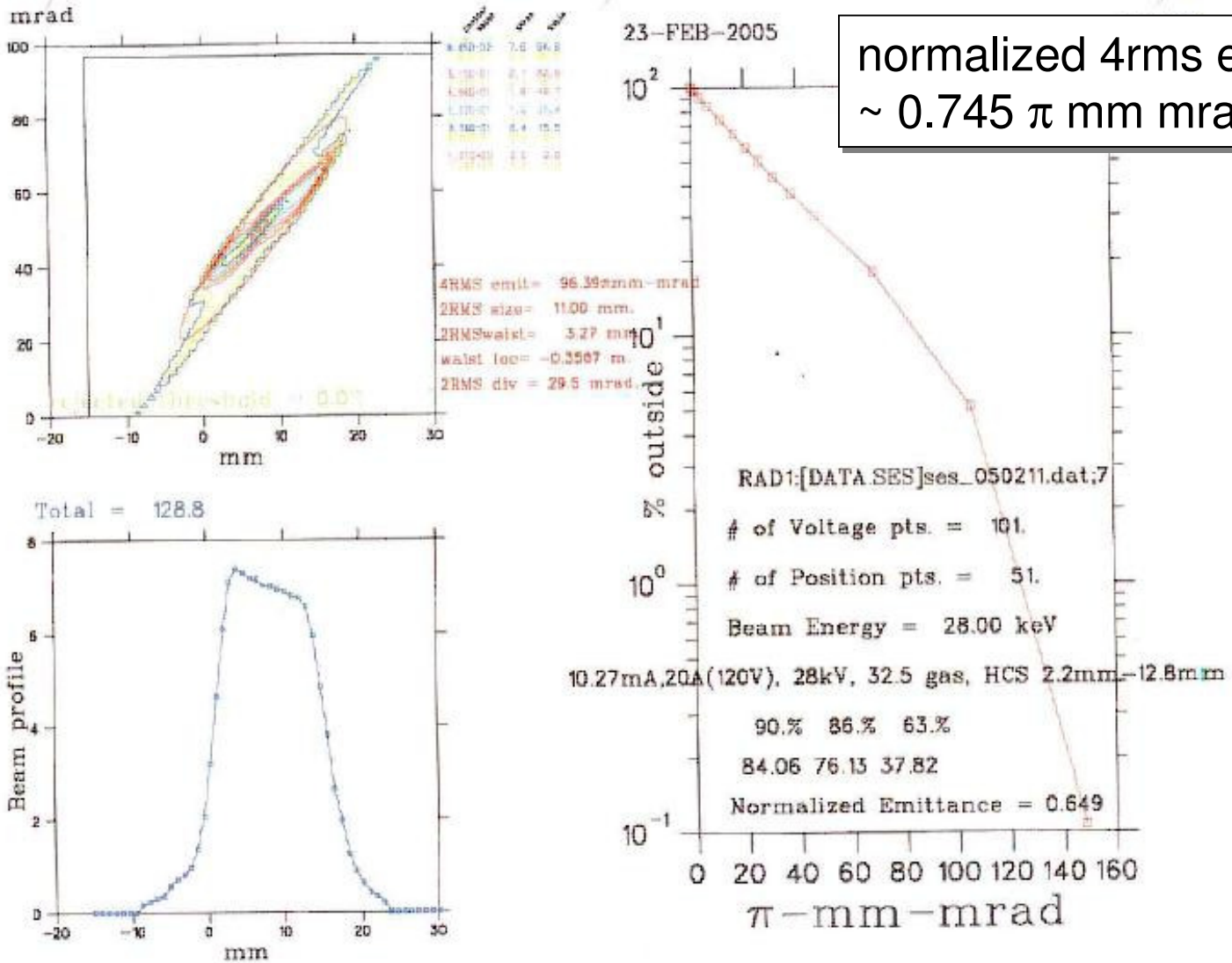
normalized 4rms emittance
~ 0.523 π mm mrad



Courtesy of Morgan Dehnel, D-Pace, Inc.

Emittance Measurement (10.27 mA @ 28kV)

normalized 4rms emittance
~ 0.745 π mm mrad



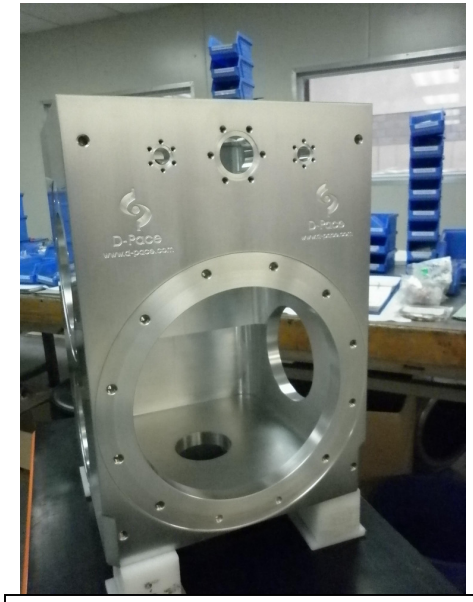
Courtesy of Morgan Dehnel, D-Pace, Inc.

Status of D-Pace Ion Source Manufacturing

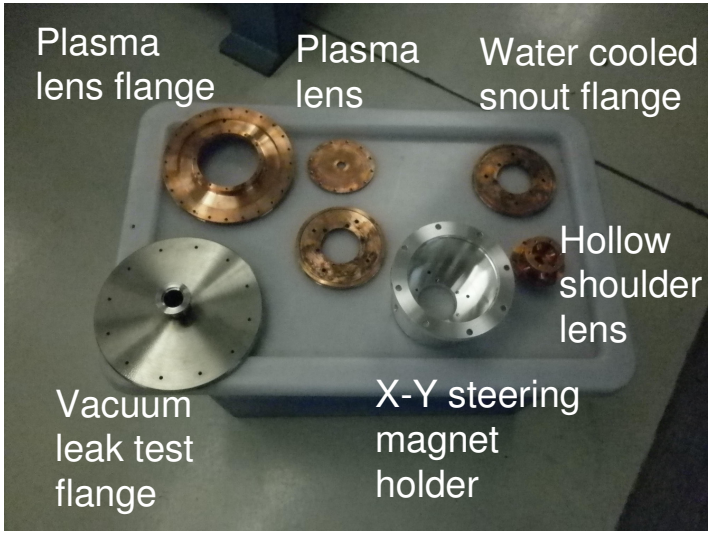
- D-Pace ion source fabrication is on track to have the ion source assembled by the last week of April. Parts that have been received and delivered to the machine shop:
  - All the permanent magnets
  - The grounding strips
  - The quartz tubes
  - The ion source inner housing
  - The wire for the filaments
  - D-Pace specific jigs and tool required to make and assemble certain parts of the ion source
  - D-Pace Ion Source specific vacuum leak test flanges
  - Packing materials for spare Filament sets

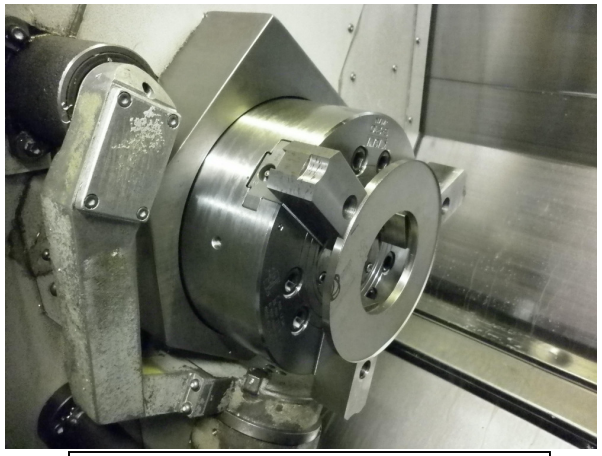
commercial parts and hardware in the rack trolley

D-Pace H$^-$ Ion Source: work in progress



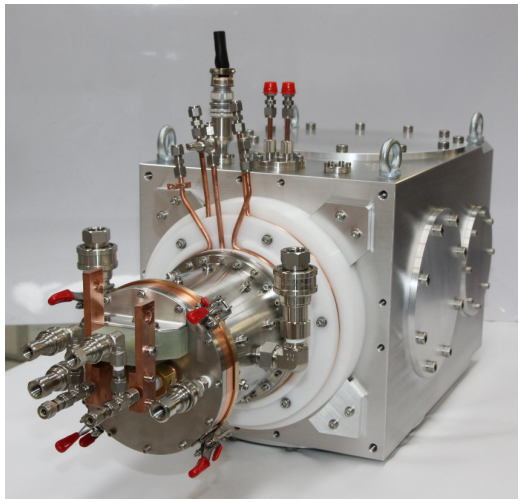
Vacuum Box completed





Seal plate in machining

Expected Ion Source Assembly



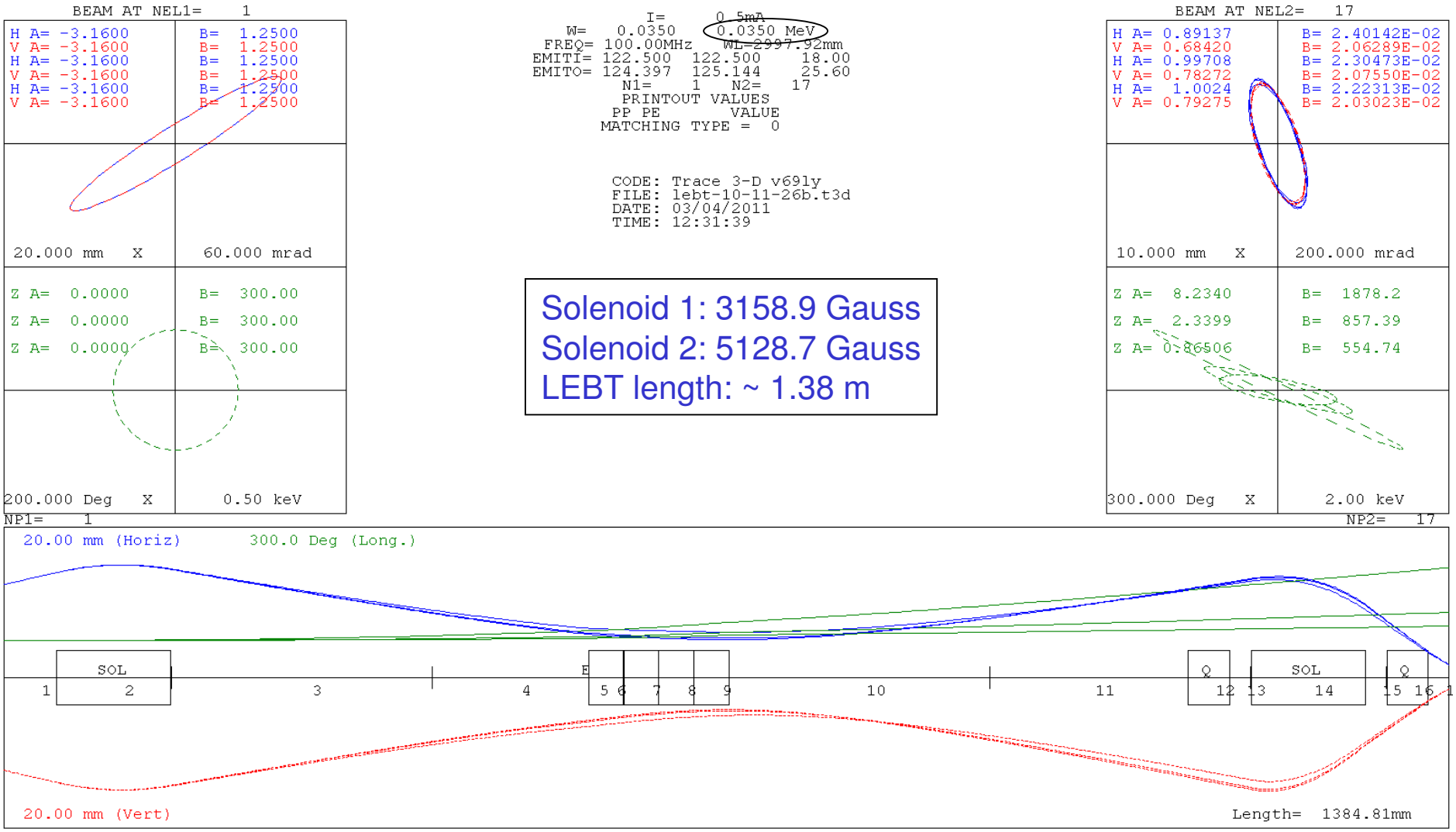
D-Pace Ion Source Acceptance Test

- **Factory acceptance tests performed at the machine shop (by D-Pace Inc.)**
  - Vacuum leak testing of entire assembly
  - Electrical isolation test
  - Verification of the magnetic fields in the Ion Source Body, Back Plate and Extraction Lens
  - XY Steering Magnet: electrical isolation, temperature and voltage, magnetic field direction tests and magnet current and magnetic flux densities.
  - Cooling water flow rate test
- **Ion source assembly and installation in TRIUMF (by D-Pace Inc.)**
- **Beam tests at TRIUMF (May 9, 2011 – May 13, 2011)**
  - **Day 1:** Check and make sure Ion Source has pumped down sufficiently. Turn on cooling water, H2 gas, and power supplies. Ramp up the power supplies slowly to "condition" the new filament. Try to get up to max beam current (~10mA due to test stand limitations), tune the beam, record tune and take emittance scan.
  - **Day 2:** Run beam and record tunes in ~1mA increments starting at ~ 1mA up to max capable on Ion Source test stand (~10mA). Take an emittance scan for each tune.
  - **Day 3:** Continue emittance measurement
  - **Day 4:** Beam stability test
  - **Day 5:** Remove Ion Source and extraction lenses from test stand. Reassemble in crate with vacuum box. Repackage for shipping. Reinstall TRIUMF Ion source on test stand. Move Ion Source to shipping department for delivery to client.
- **The results of all the FAT's, the certificate of conformance, and ion source tuning data and emittance scans will be included in the appendices of the final copy of the Ion Source user manual.**

LEBT

Previous LEBT Design (for 35keV RFQ Injection Energy)

With new input twiss parameters: α=-3.16, β=1.25



Solenoid 1: 3158.9 Gauss
Solenoid 2: 5128.7 Gauss
LEBT length: ~ 1.38 m

Changes in RFQ design

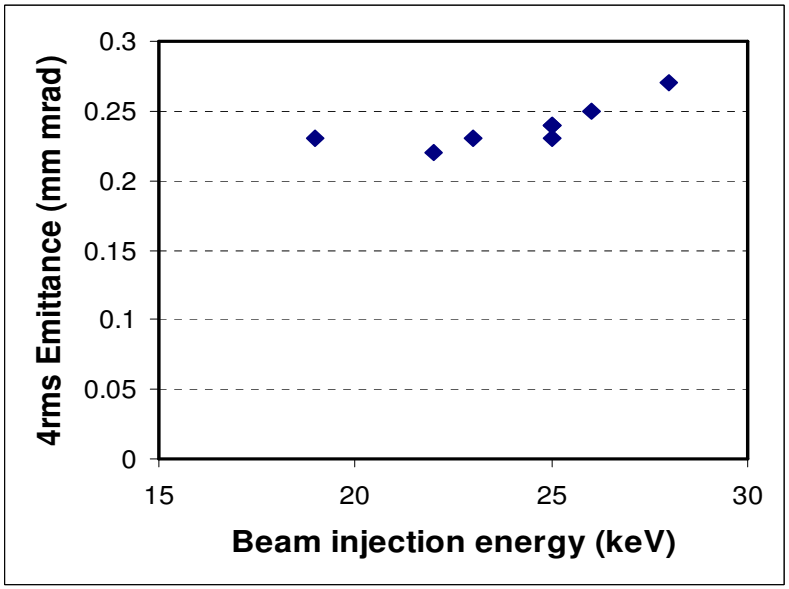
	Previous RFQ	Current RFQ
Freqency (MHz)	325	162.5
Injection Energy (keV)	35	20
Twiss parameter	α=0.9	α=2
	β=0.02 m/rad	β=0.06 m/rad

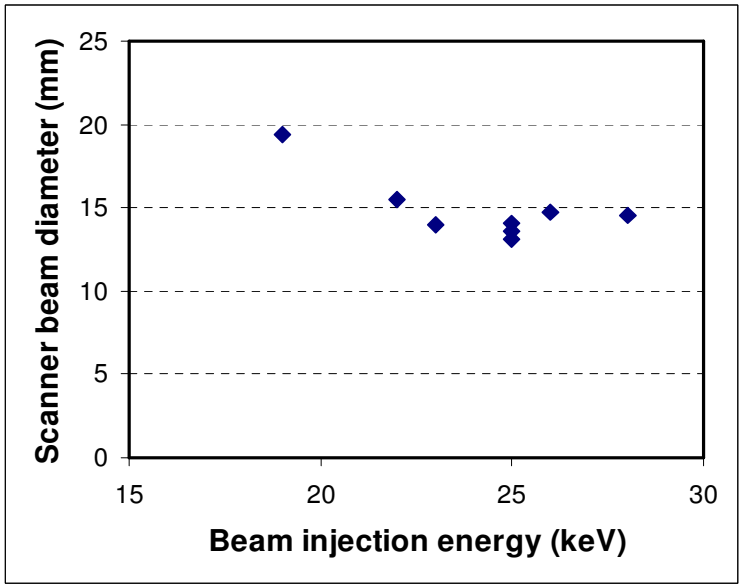
Emittance vs. Beam Injection Energy

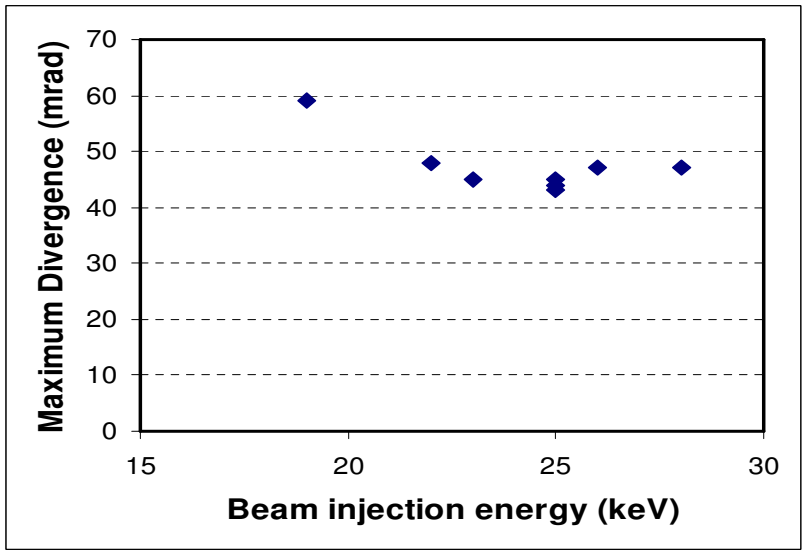
Beam injection Energy (keV)	Normalized 4rms emittance (mm mrad)	unnormalized 4rms emittance (mm mrad)	Maximum Divergence (mrad)	Scanner beam diameter (mm)	Output beam current (mA)
28	0.27	34.94	47	14.5	1.897
26	0.25	33.58	47	14.7	1.897
25	0.24	32.87	45	14.1	1.86
25	0.23	31.50	43	13.1	1.907
25	0.24	32.87	44	13.6	1.916
23	0.23	32.84	45	14	1.897
22	0.22	32.12	48	15.5	1.785
19	0.23	36.14	59	19.4	1.766

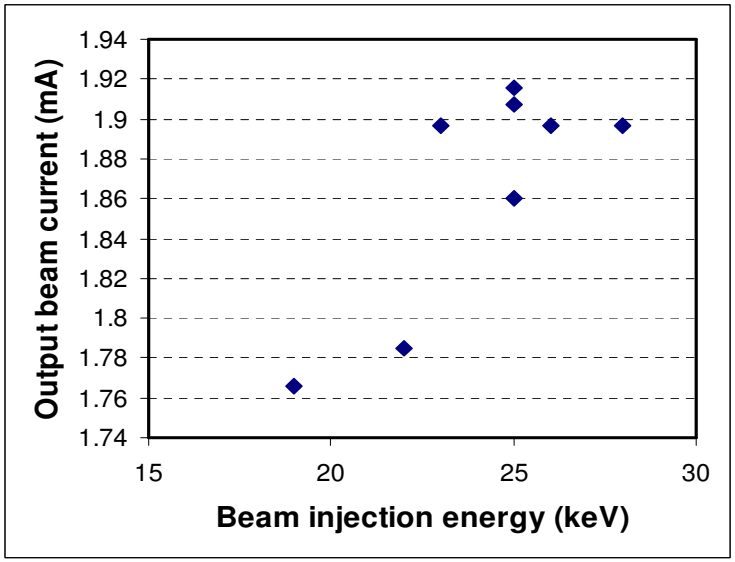
Morgan Dehnel's PhD thesis. Data was taken on a low current filament-discharge H- ion source, which the current D-Pace source is based on.

Emittance vs. Beam Injection Energy



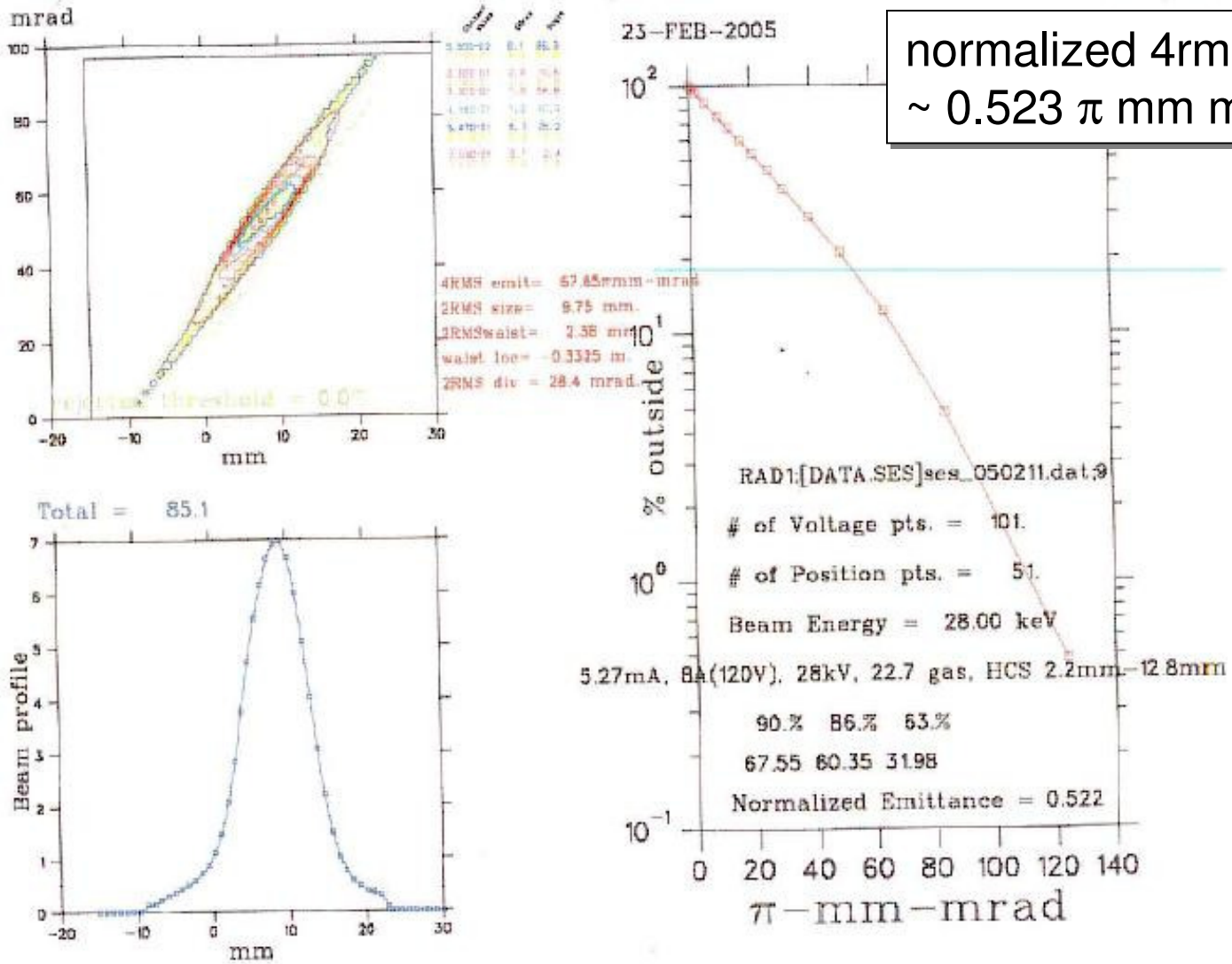






Emittance Measurement (5.27 mA @ 28kV)

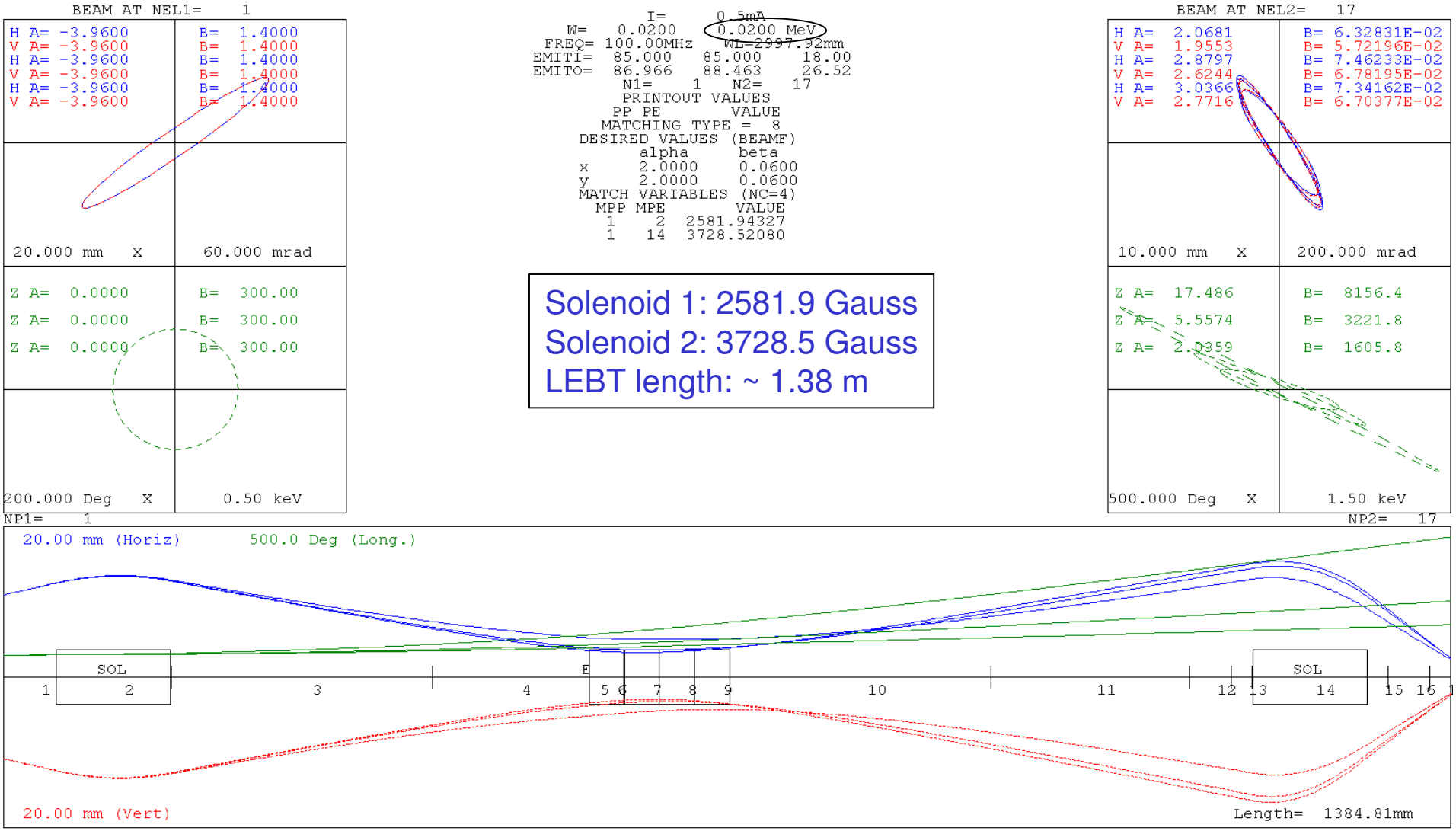
normalized 4rms emittance
~ 0.523 π mm mrad



Courtesy of Morgan Dehnel, D-Pace, Inc.

Current LEBT Design (for 20keV RFQ Injection Energy)

With new input twiss parameters: α=-3.96, β=1.4 (5.27mA/28kV scan)



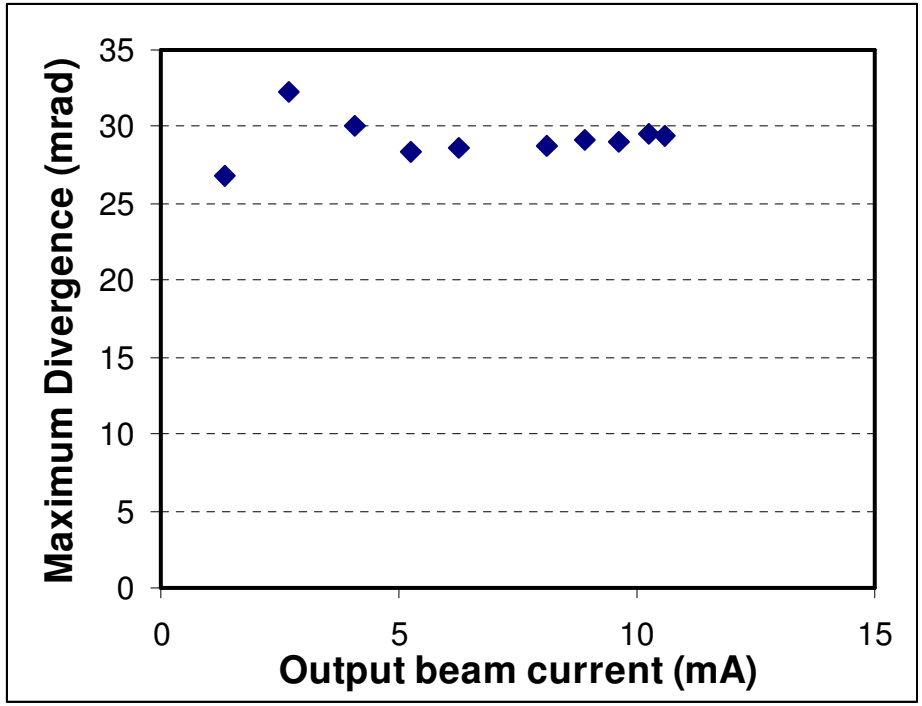
Solenoid 1: 2581.9 Gauss
Solenoid 2: 3728.5 Gauss
LEBT length: ~ 1.38 m

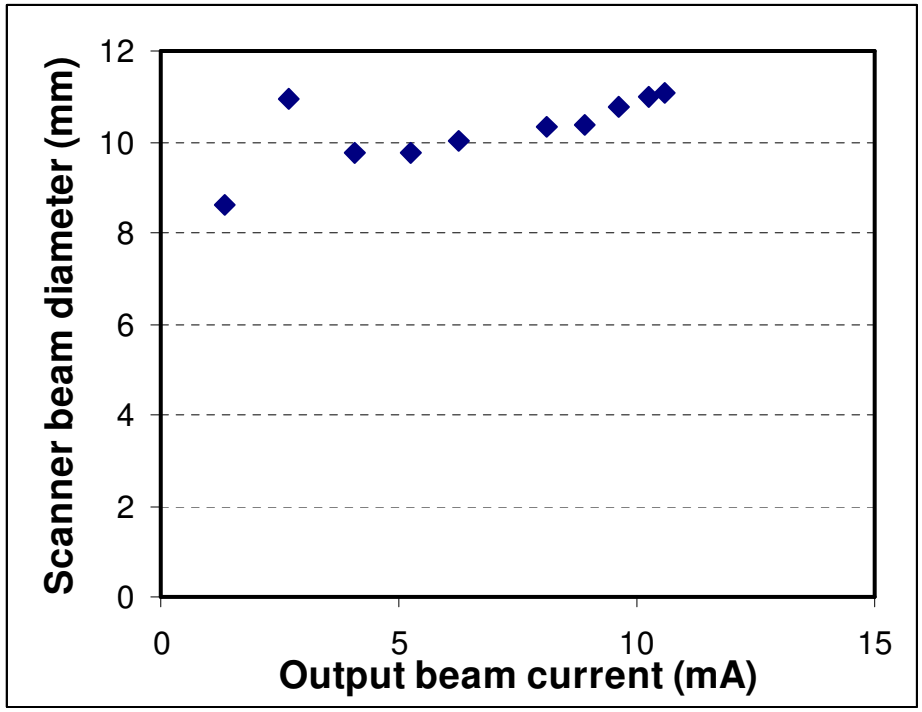
D-Pace Ion Source Performance

Output beam current (mA)	Normalized 4rms emittance (mm mrad)	Maximum Divergence (mrad)	Scanner beam diameter (mm)	Bias voltage (kV)
1.35	0.751	26.8	8.6	28
2.71	0.503	32.3	10.96	28
4.09	0.502	30	9.77	28
5.27	0.523	28.4	9.75	28
6.28	0.569	28.6	10.04	28
8.11	0.658	28.8	10.33	28
8.92	0.701	29.1	10.37	28
9.64	0.712	29	10.77	28
10.27	0.745	29.5	11	28
10.6	0.758	29.4	11.08	28

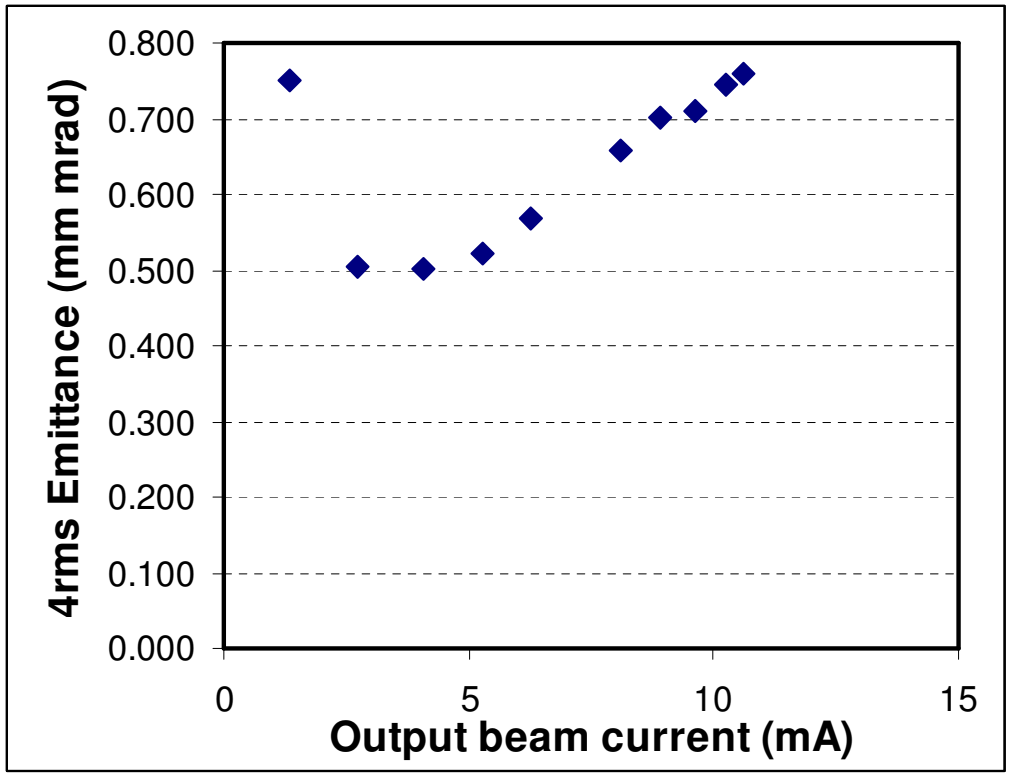
Courtesy of Morgan Dehnel, D-Pace, Inc. Data was taken in 2005 on a delivered D-Pace ion source.

Beam size and divergence angle vs. beam current





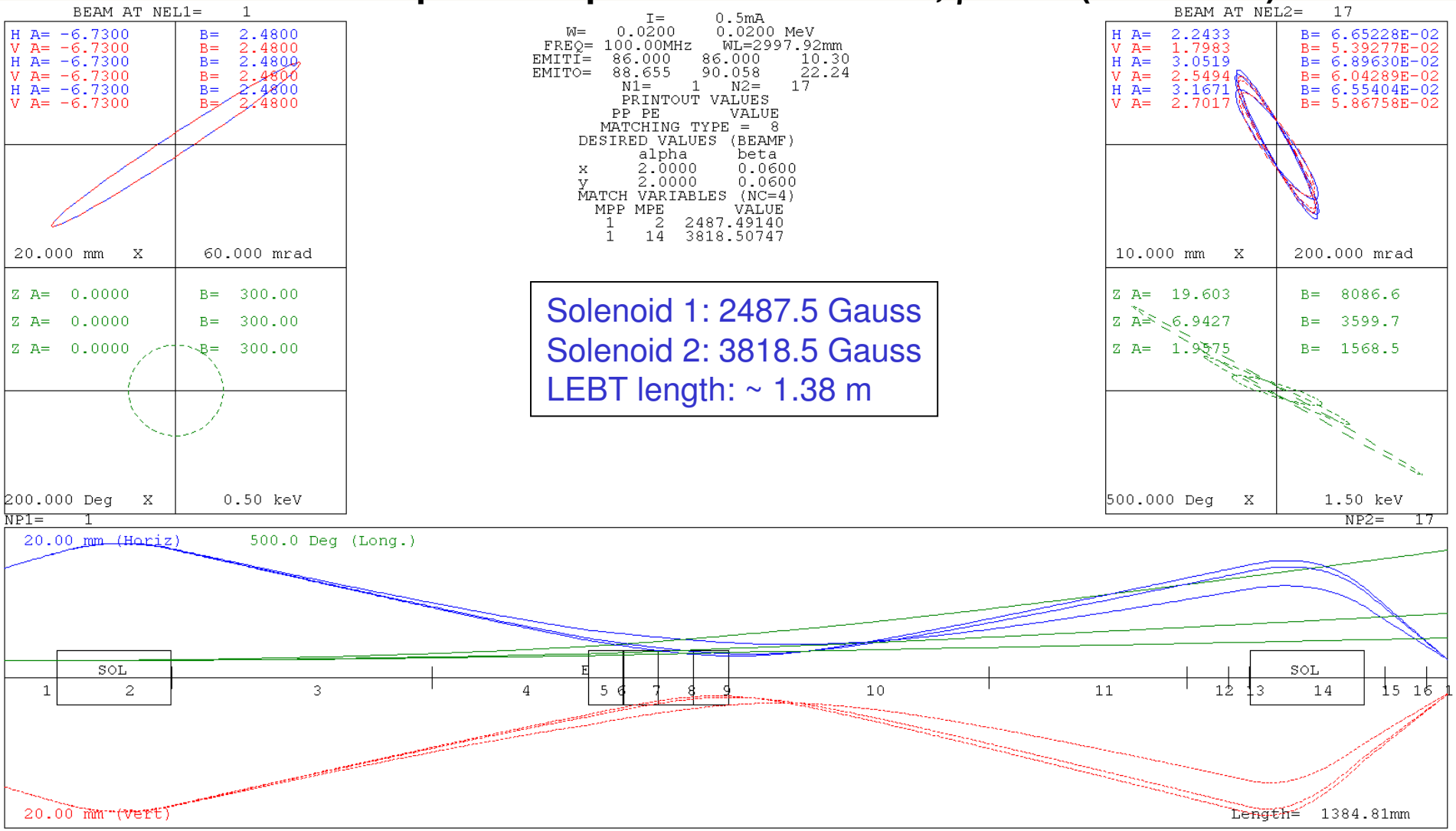
Beam emittance vs. output current



	2mA		5mA	
	19kV	28kV	19kV	28kV
4rms normalized emittance (mm mrad)	0.23	0.27	0.446	0.523
Maximum divergence (mrad)	59	47	35.651	28.4
Beam diameter (mm)	19.4	14.5	13.045	9.75

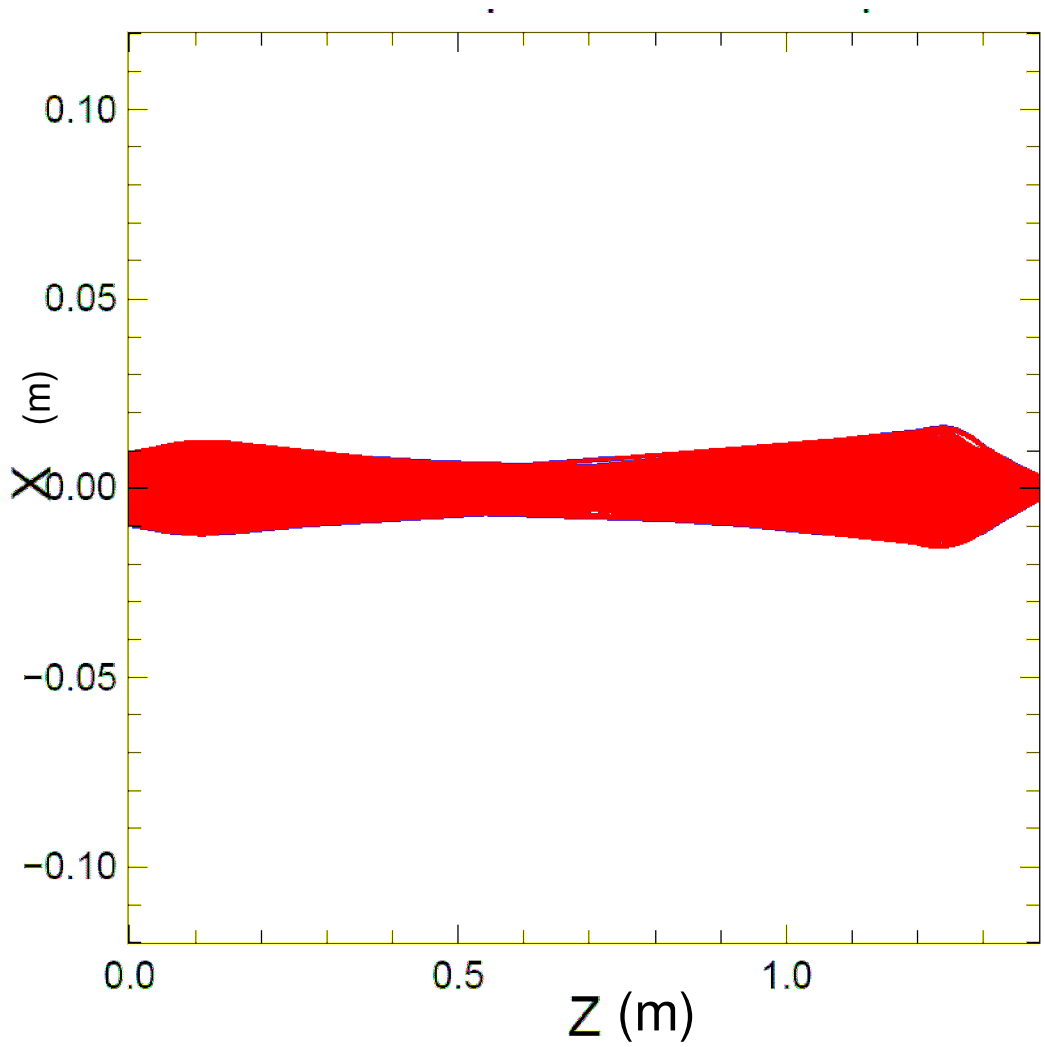
Current LEBT Design (for 20keV RFQ Injection Energy)

With new input twiss parameters: α=-6.73, β=2.48 (5mA/20kV)

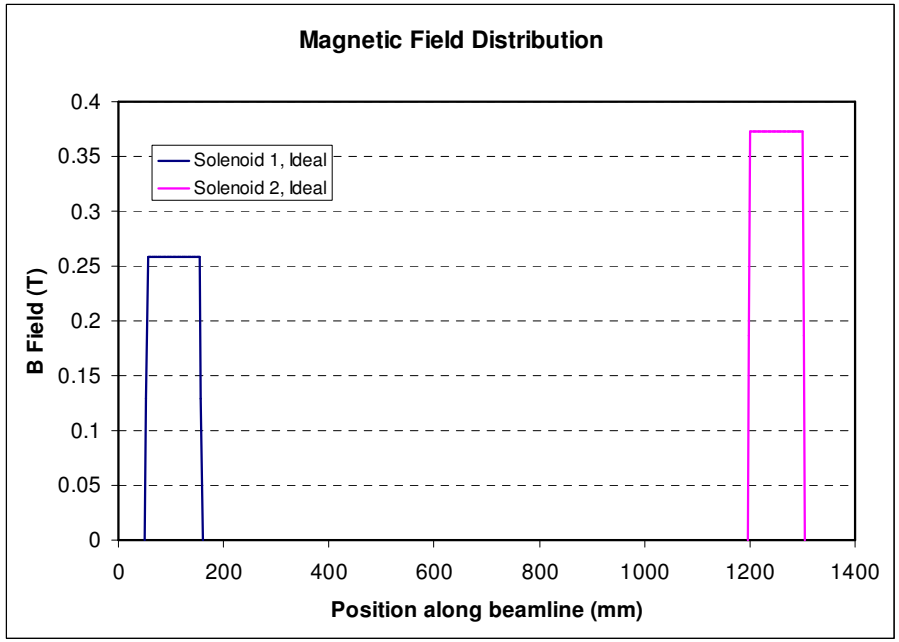


Solenoid 1: 2487.5 Gauss
Solenoid 2: 3818.5 Gauss
LEBT length: ~ 1.38 m

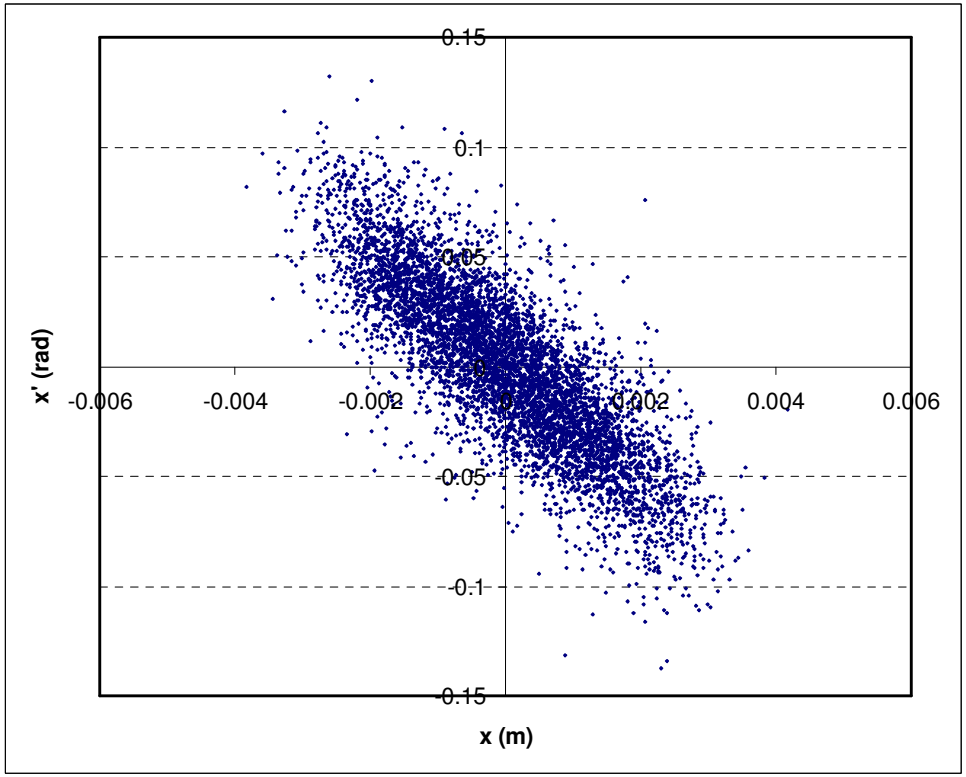
WARP Simulation (Two Solenoids, no bending magnet)



WARP Simulation (Sharp-edge axial magnetic field)

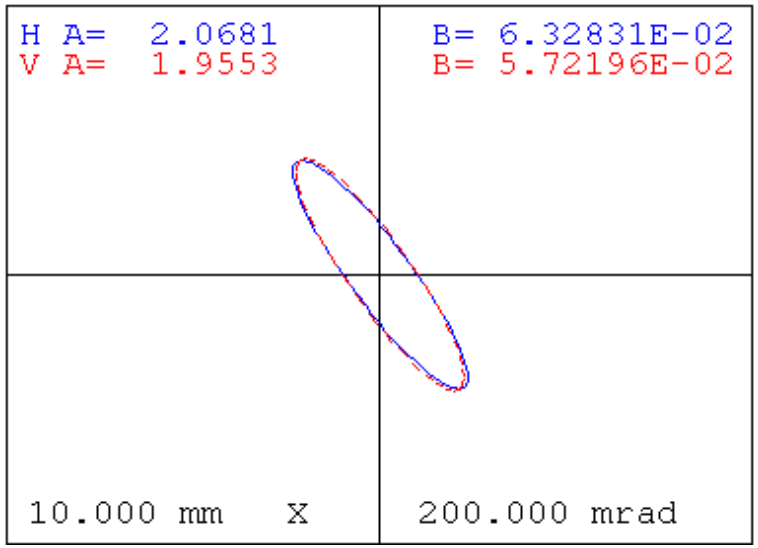


90% space charge neutralization



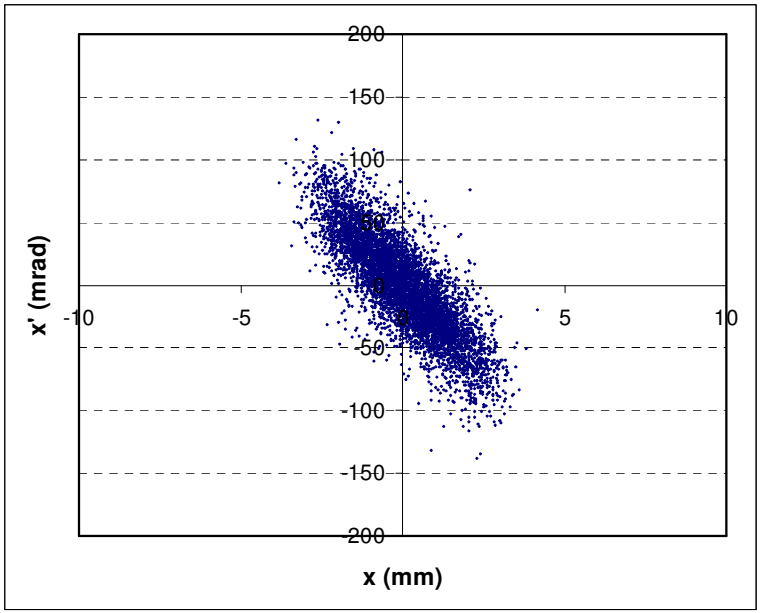
TRACE 3D vs. WARP

Trace 3D



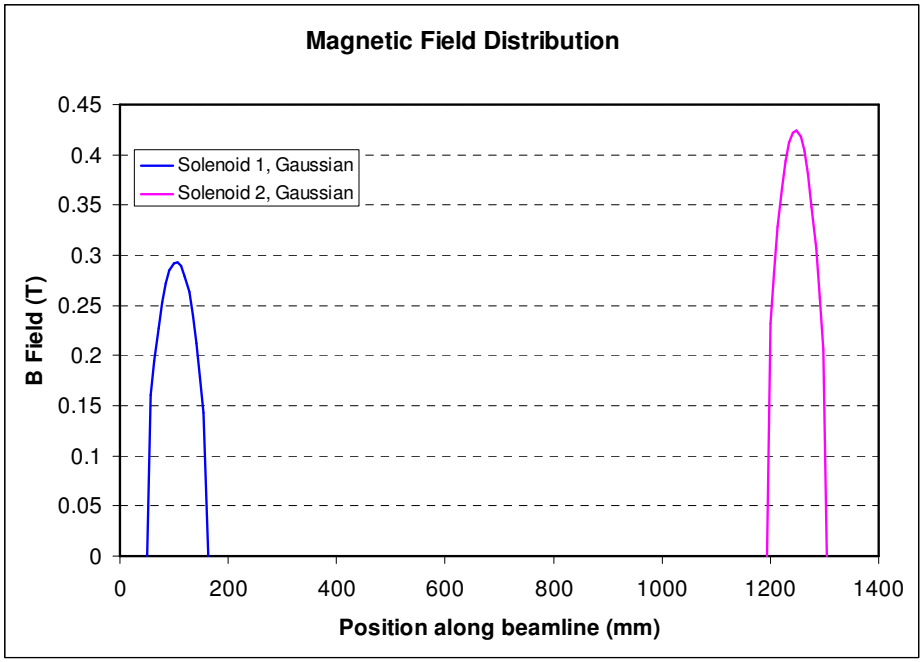
$\alpha = 2.0$, $\beta = 0.063$ m/rad

WARP

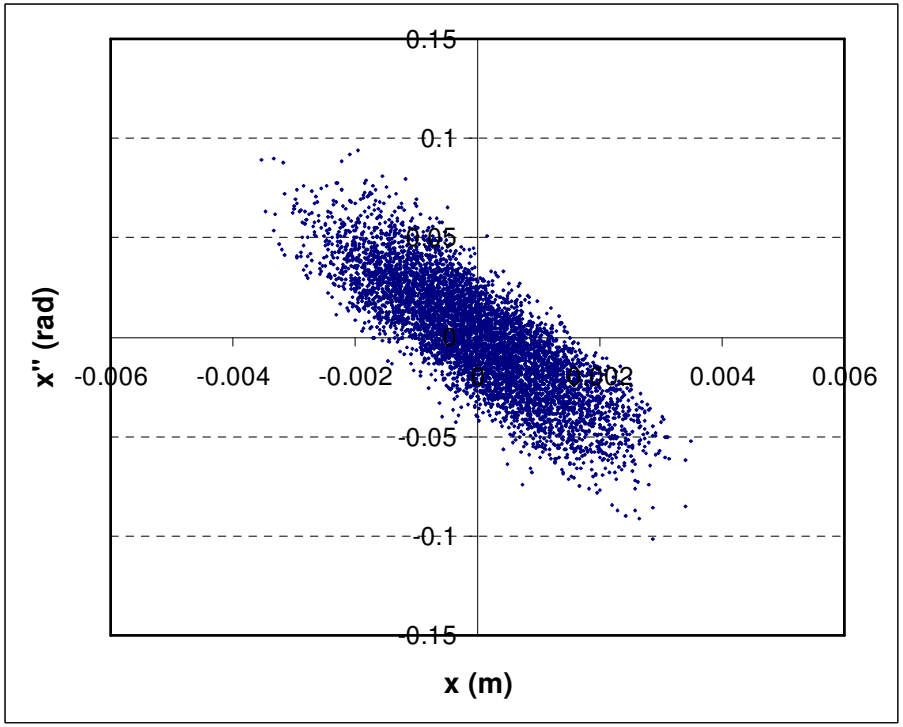


$\alpha = 1.47$, $\beta = 0.059$ m/rad

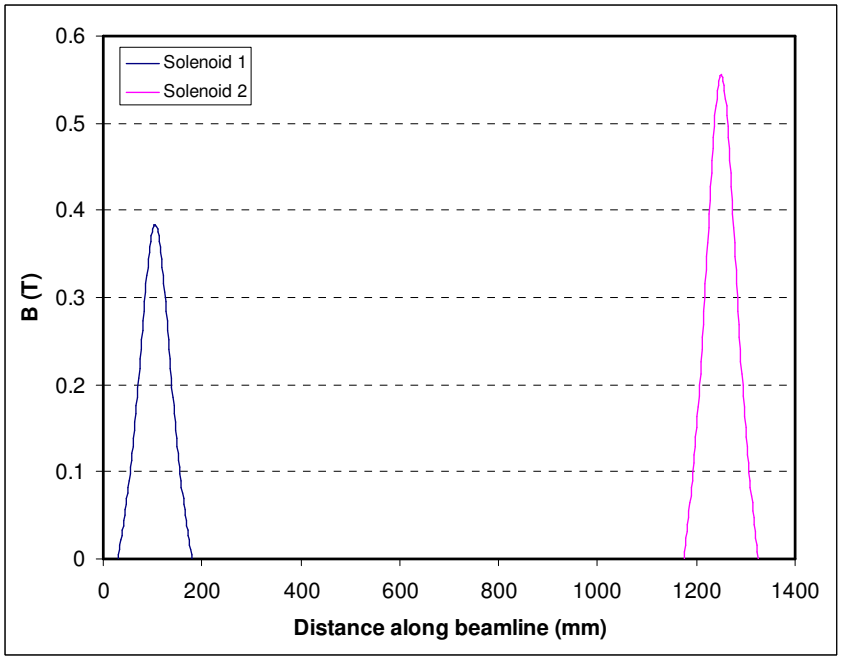
WARP (magnetic field - Truncated Gaussian distribution)



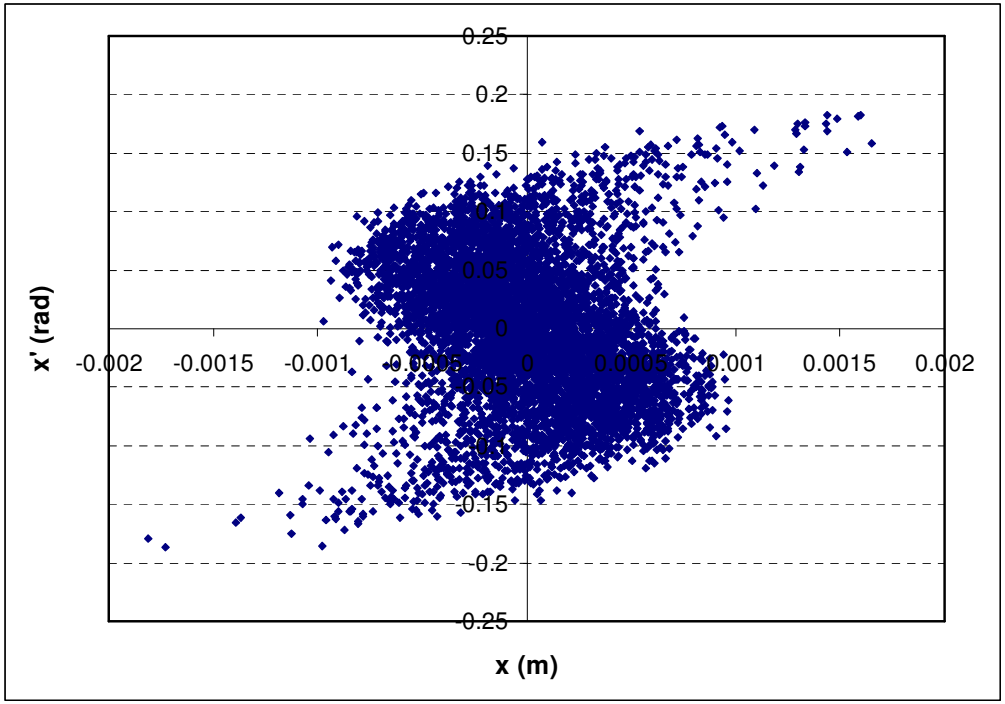
$\alpha = 1.42$, $\beta = 0.07$ m/rad



WARP (magnetic field - Gaussian distribution)

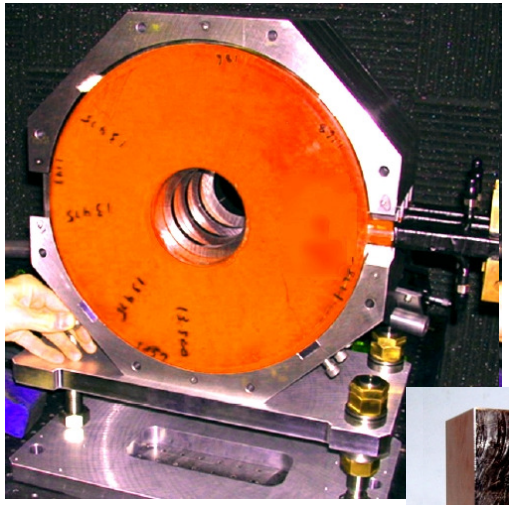


$\alpha = 0.14$, $\beta = 0.006$ m/rad



Magnets: Solenoid and Dipole magnets

from RadiaBeam Technology

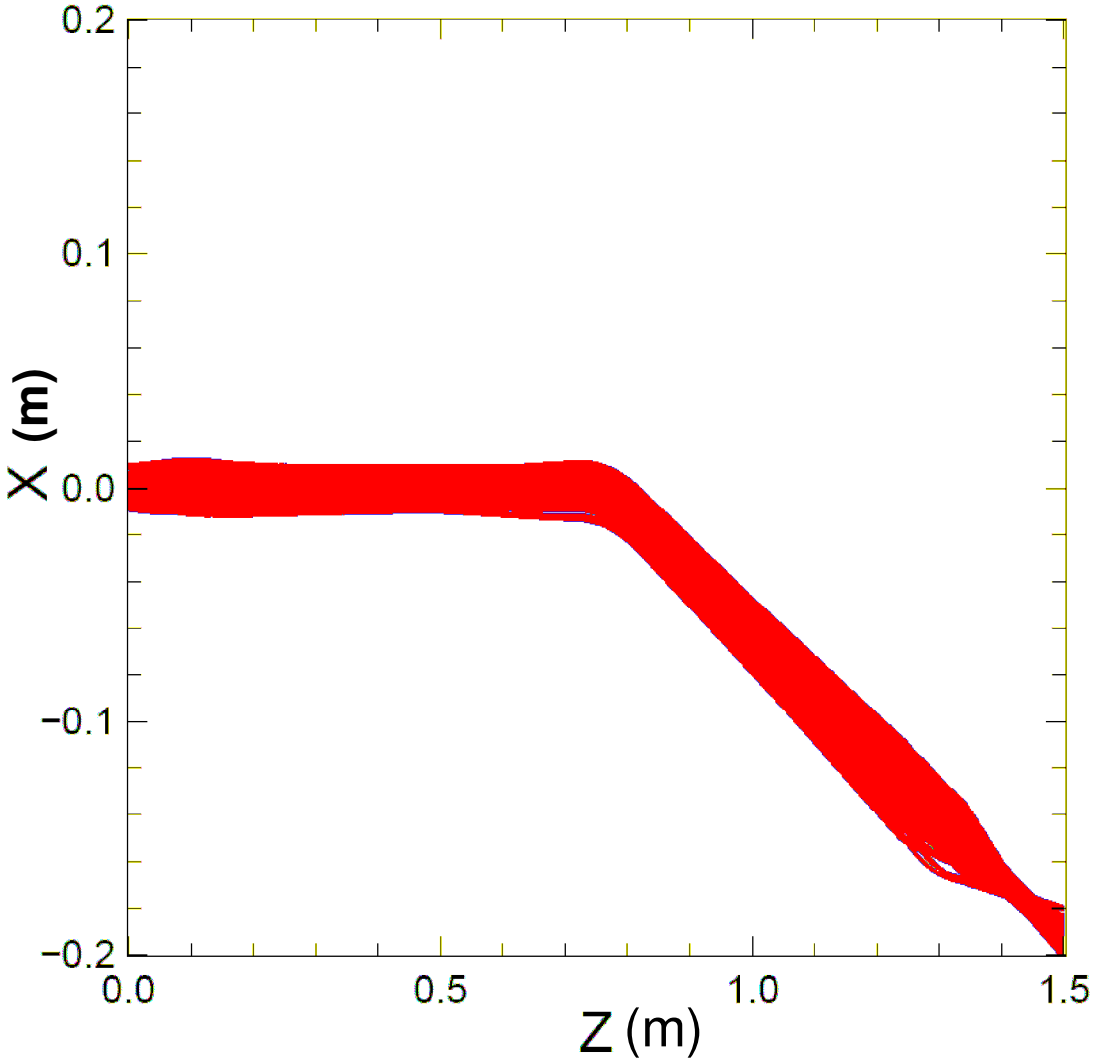


http://www.radiabeam.com/products/Magnets.html

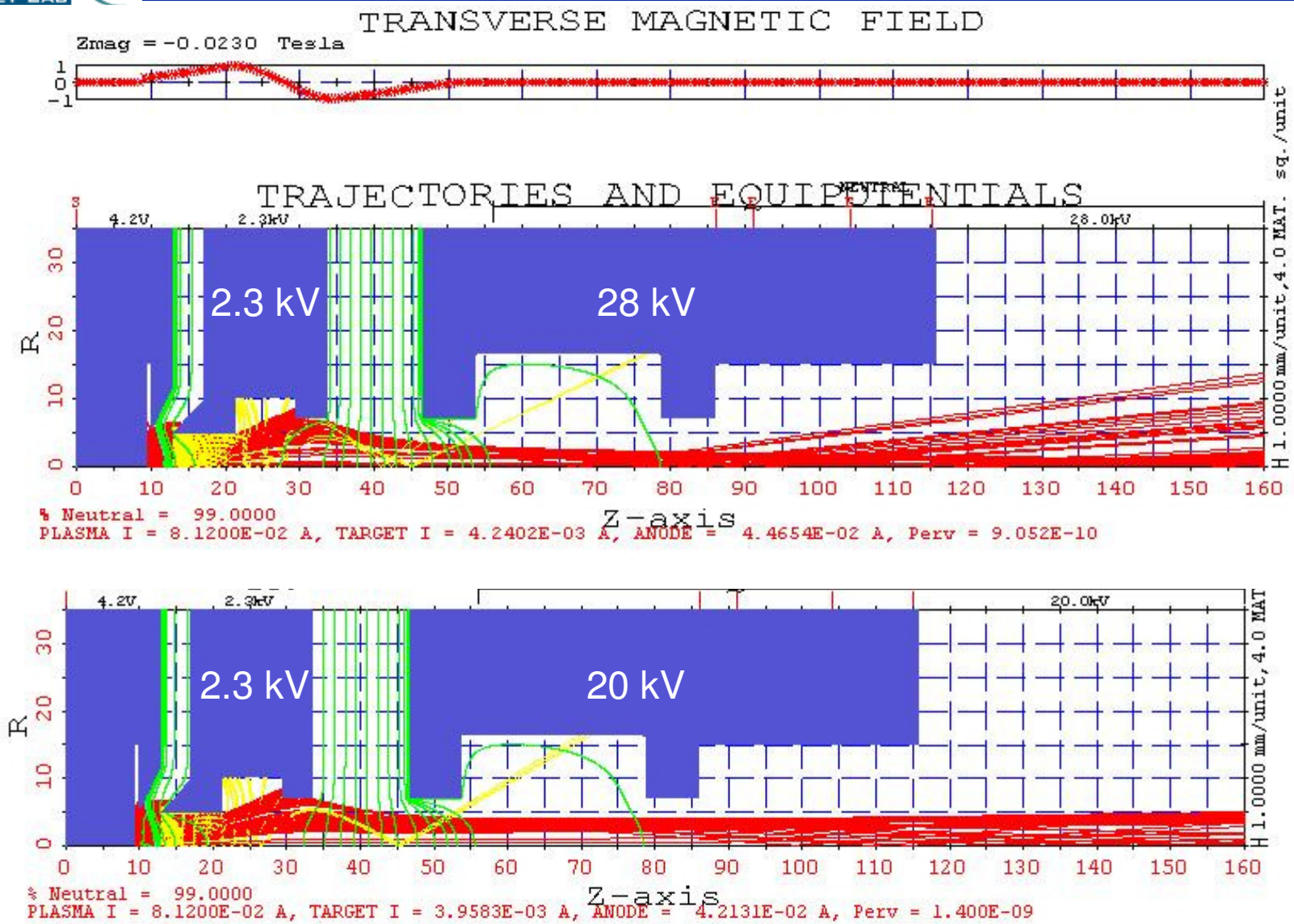
from D-Pace

http://www.d-pace.com/products_magnets.html

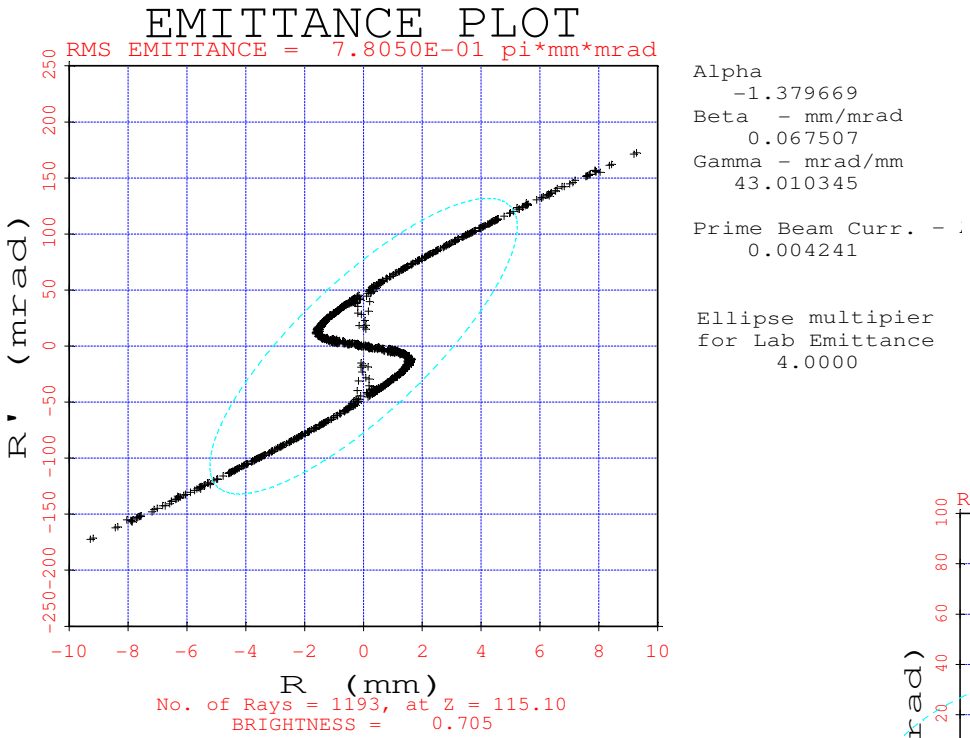
WARP Simulation (Two Solenoids, with bending magnet)



PBGun Simulation of D-Pace Ion Source Extraction

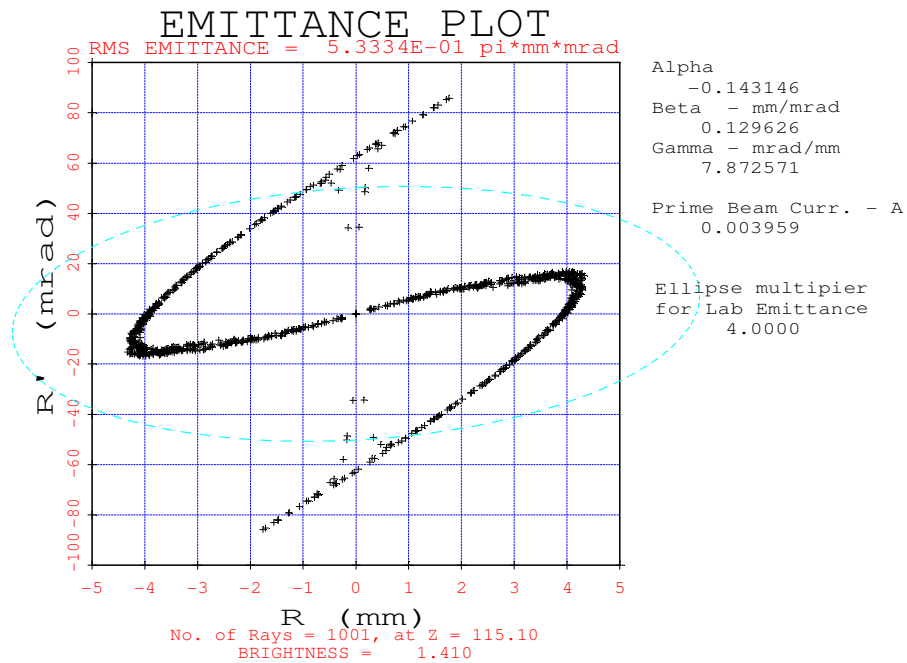


PBGun Simulation Results: Emittance



28 kV

20 kV



Ion Source and LEBT testing

D-Pace 15mA H^- ion Source Power supplies

- ✓ Arc: 45A, 150V (10A, 150V for 5mA operation)
- Filament: 375A, 10V
- ✓ Plasma: 30A, 10V (Plasma lens is positively biased relative to the source body)
- ✓ Extraction: 100mA, 5kV(Extraction lens is positively biased relative to the source body)
- ✓ Bias: 40mA, -30kV(Bias supply is negative output)
- ✓ X steering: 6A, 10V
- ✓ Y steering: 6A, 10V

Available Vacuum Components at LBNL

- Two turbo pumps in house: 1000 l/s
  - (suggested)Upstream pump
    - Pfeiffer HiPace 2300
    - Hydrogen pumping speed of 1850l/s,
    - with inlet DN250, outlet DN ISO40-K
  - (suggested)Downstream pump
    - Turbo recommended or Cryo pump with 2500l/s
- Roughing pump
- Isolation transformer
- Faraday cup
- Emittance scanner

Available Power Supplies at LBNL

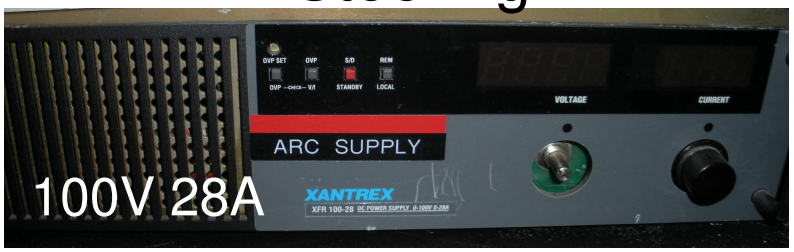
Plasma Electrode

Extraction

Arc power supply

Bias

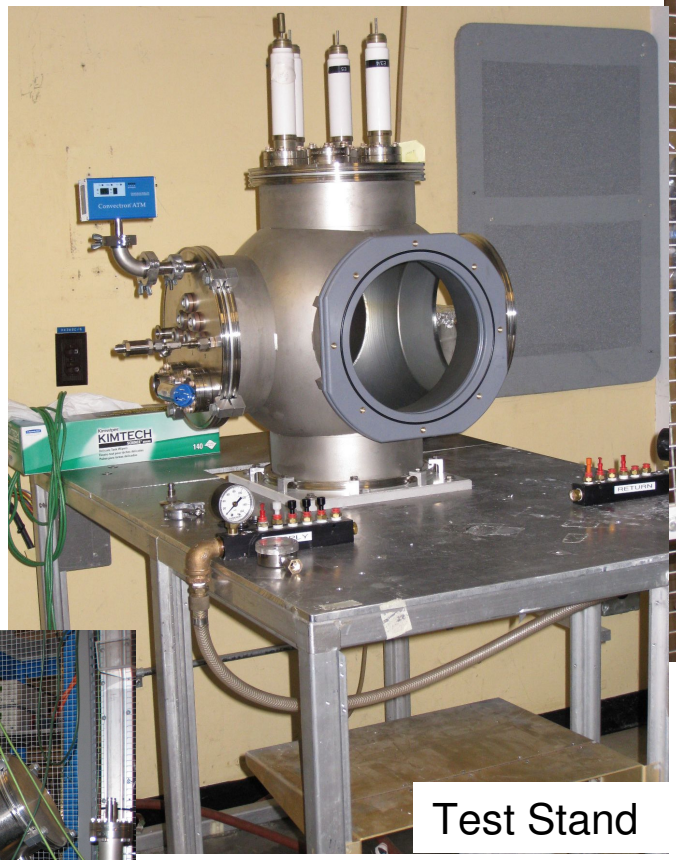
X Steering



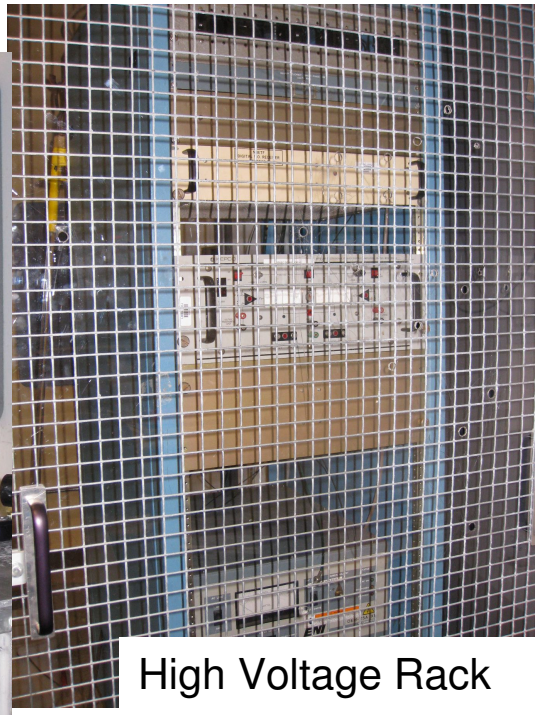
Y Steering

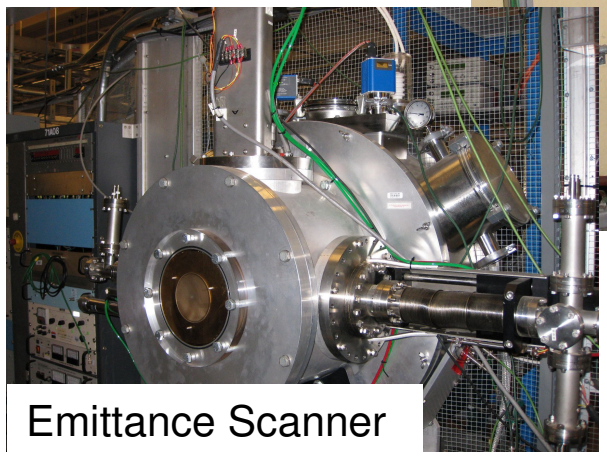
Setting up H^- Ion Source Test Stand

Control Rack



Test Stand


High Voltage Rack


Emittance Scanner

Summary

- Project X baseline H^- ion source is identified and a filament-discharge H^- ion source has been purchased.
- Ion source acceptance test has been planned.
- A two-solenoid magnetic lens LEBT system has been designed.
- Simulations of 5 mA 20keV beam transportation have been carried out using various codes.
- Plan to construct a production prototype LEBT and test with the D-Pace ion source.