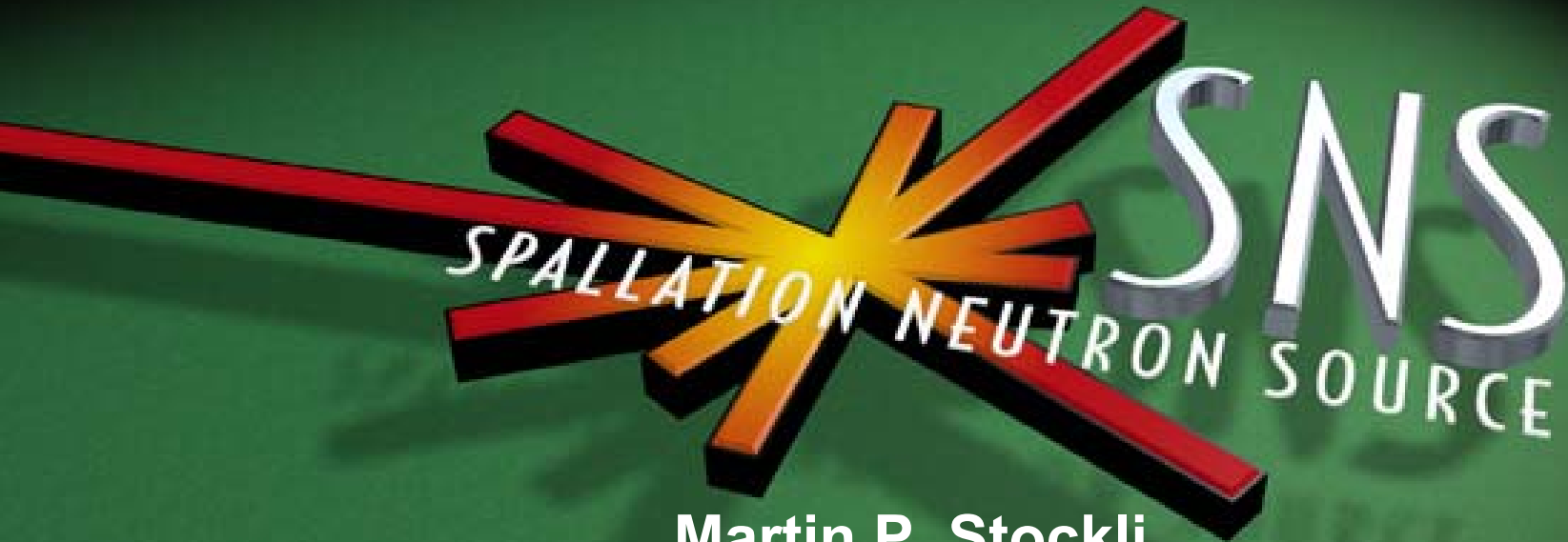# Preparing the SNS Injector for feeding the Spallation Neutron Source

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Ion Source Group Leader

ORNL-SNS-ASD

Fermi National Accelerator Laboratory

Batavia, IL November 10, 2005

Content

- The SNS accelerator
- The ion source and LEBT
- What is moving so slowly in East Tennessee?
- Emittance, the holy grail
- Ghost signals? But Halloween is over!
- Can we meet the ion source current specs?
- Lets get working on the upgrade!
- Summary

The SNS Parameter List

Ion Source: Ion Specie	H$^-$
❯Peak Current	~50 mA
❯Beam Energy	65 keV
❯Frequency	60 Hz
❯Pulse length	1.23 ms
❯Emittance	0.2 π·mm·mrad
❯Mean time between major maintenance	3 weeks
RFQ/MEBT: Peak Current	38 mA
❯Beam Energy	2.5 MeV
DTL: Beam Energy	86.8 MeV
CCL: Beam Energy	185.6 MeV
SCL: Beam Energy	1.0 GeV
Ring: Ion Specie	p
❯Number of injections:	1060
❯Peak current	50 A
Target: Material	Hg
❯proton per pulse	1.5×10^{14}
❯Proton pulse length on target	695 ns
❯Average power on target	1.4 MW
❯Ambient/cold moderators	1/3
❯Neutron beam shutters	18
❯Initial instruments	5

The SNS Accumulator Ring

• *The ring accumulates the ion beam.*
• *The stripper foil converts the negative H⁻ ions into protons and merges them with the protons already in the ring!*
• *Accumulating up to 1060 turns brings the ion beam current from tens of mAmps in the LINAC to tens of Amps in the ring before it is dumped onto the target.*

stripper
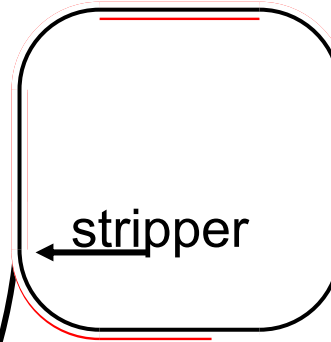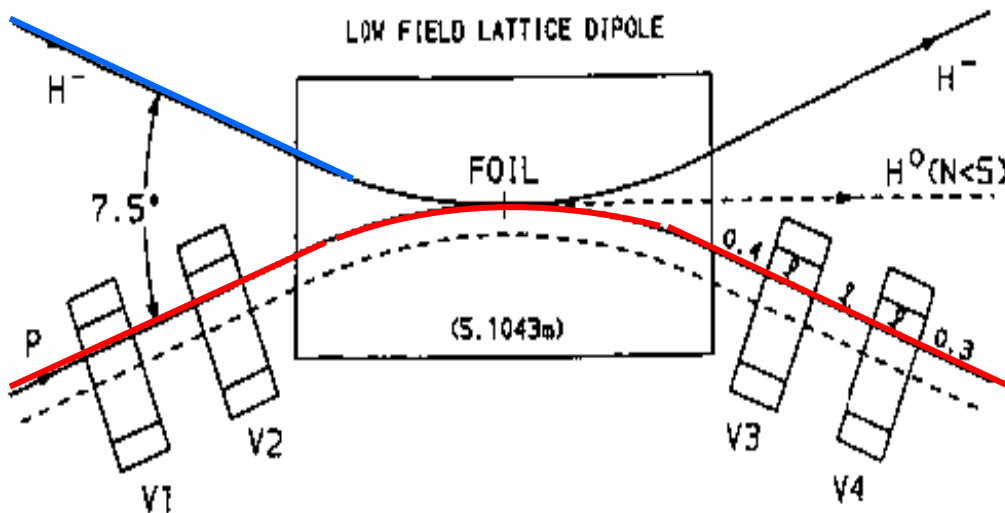
Beam accumulation requires a polarity change. We need negative ions!

LOW FIELD LATTICE DIPOLE

H⁻

7.5°

FOIL

H⁻

H⁰(N<5)

P

(5.1043m)

0.4

0.3

V2

V3

V1

V4

Front-End Systems
(Lawrence Berkeley)

Accumulator Ring
(Brookhaven)

Target
(Oak Ridge)

Linac
(Los Alamos and Jefferson)

Instrument Systems
(Argonne and Oak Ridge)

*SNS is a collaboration of six U.S. national laboratories:
• Argonne National Laboratory (ANL)
• Brookhaven National Laboratory (BNL)
• Thomas Jefferson National Accelerator Facility (TJNAF)
• Los Alamos National Laboratory (LANL)
• Lawrence Berkeley National Laboratory (LBNL)
• Oak Ridge National Laboratory (ORNL).

00-04492E/hrb

Central Helium Liquefaction Building

Front-End Building

Klystron Building

Linac Tunnel

Ring

Target

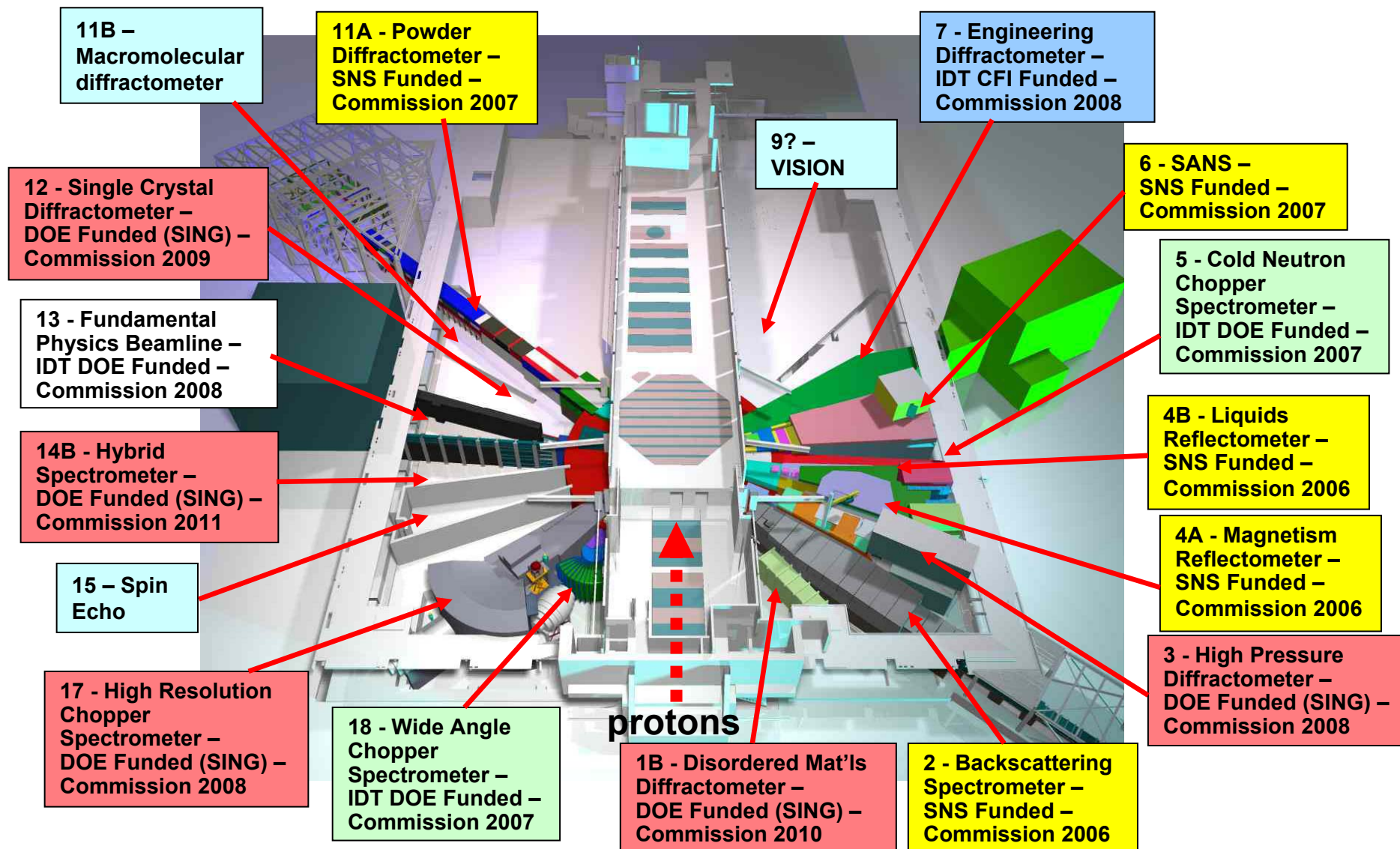**Radio-Frequency Facility**

Support Buildings

Central Laboratory and Office Complex

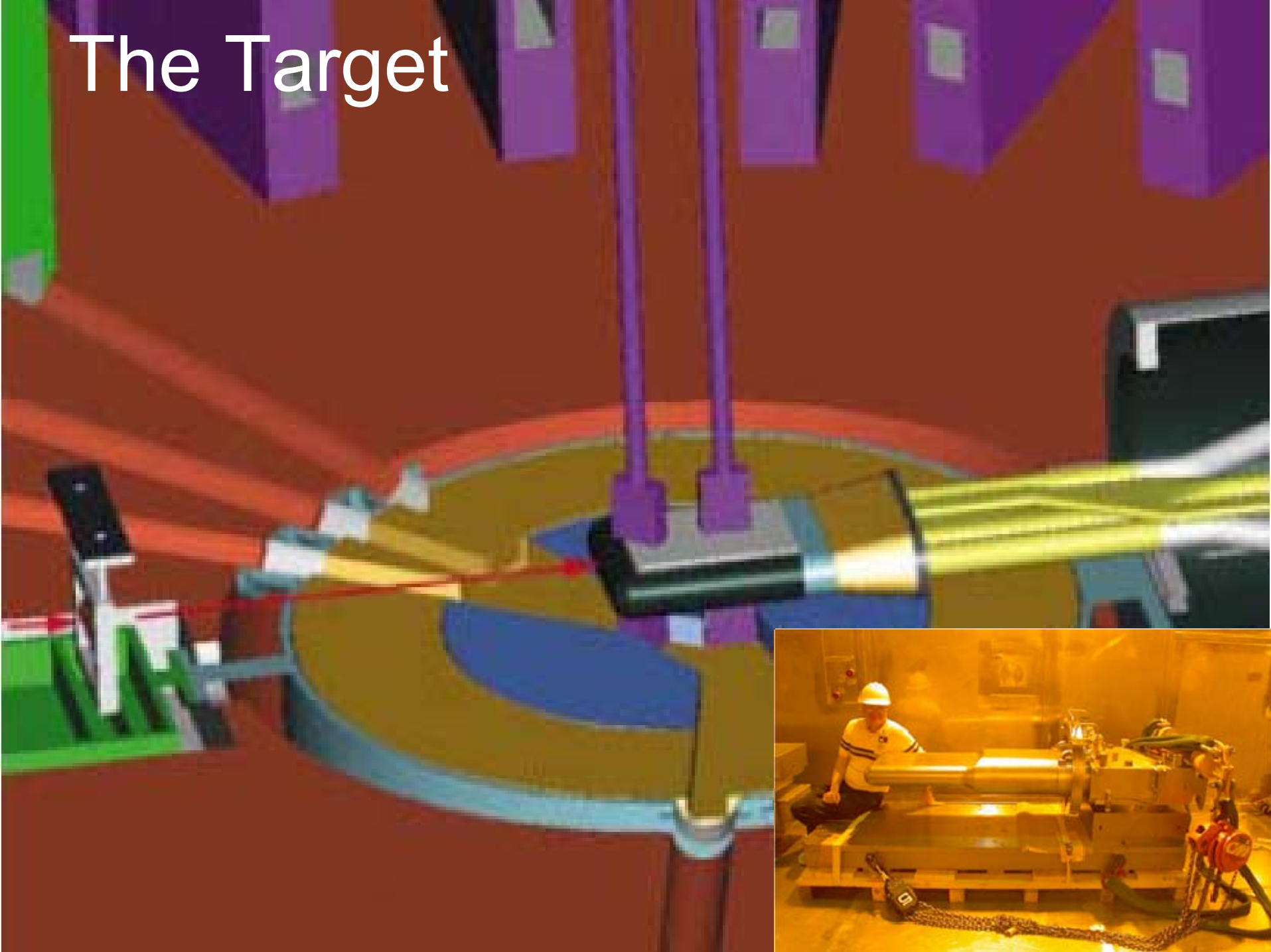**Center for Nanophase Materials Sciences**

- The SNS construction project will conclude in 2006
- At 1.4 MW it will be ~8x ISIS, the world's leading pulsed spallation source
- The peak neutron flux will be ~20-100x ILL
- SNS will be the world's leading facility for neutron scattering
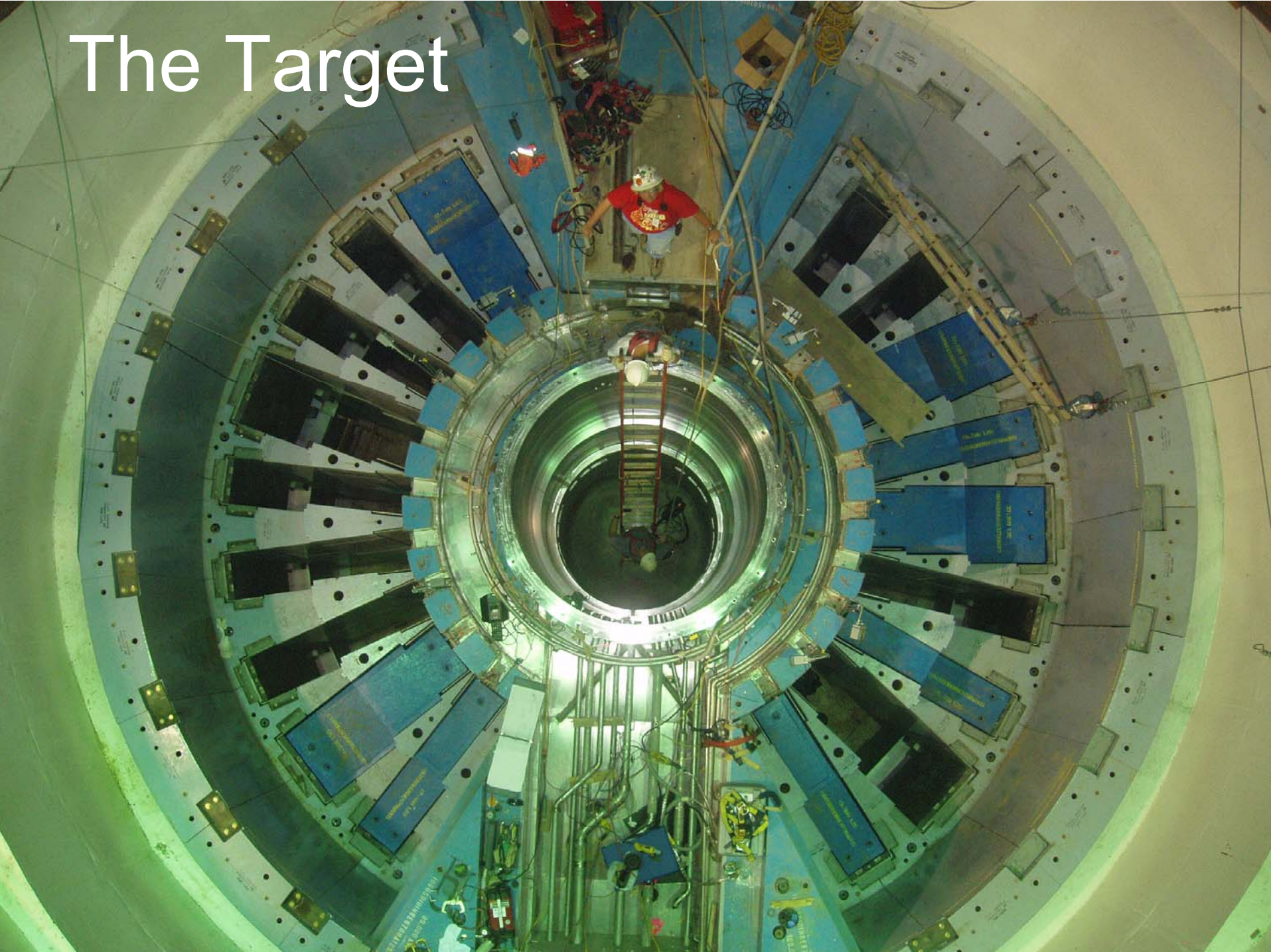- It is close to HFIR, a reactor source with a flux comparable to the ILL

04-06610/arm

Instrument Layout

SNS ▮ (yellow) SING ▮ (pink/red)
UNIV ▮ (green) NUC-PH ▮ (white)
CANADA ▮ (blue) Other ▮ (light blue)

11B – Macromolecular diffractometer

11A - Powder Diffractometer – SNS Funded – Commission 2007

7 - Engineering Diffractometer – IDT CFI Funded – Commission 2008

9? – VISION

6 - SANS – SNS Funded – Commission 2007

12 - Single Crystal Diffractometer – DOE Funded (SING) – Commission 2009

5 - Cold Neutron Chopper Spectrometer – IDT DOE Funded – Commission 2007

13 - Fundamental Physics Beamline – IDT DOE Funded – Commission 2008

4B - Liquids Reflectometer – SNS Funded – Commission 2006

14B - Hybrid Spectrometer – DOE Funded (SING) – Commission 2011

4A - Magnetism Reflectometer – SNS Funded – Commission 2006

15 – Spin Echo

3 - High Pressure Diffractometer – DOE Funded (SING) – Commission 2008

17 - High Resolution Chopper Spectrometer – DOE Funded (SING) – Commission 2008

18 - Wide Angle Chopper Spectrometer – IDT DOE Funded – Commission 2007

1B - Disordered Mat'ls Diffractometer – DOE Funded (SING) – Commission 2010

2 - Backscattering Spectrometer – SNS Funded – Commission 2006
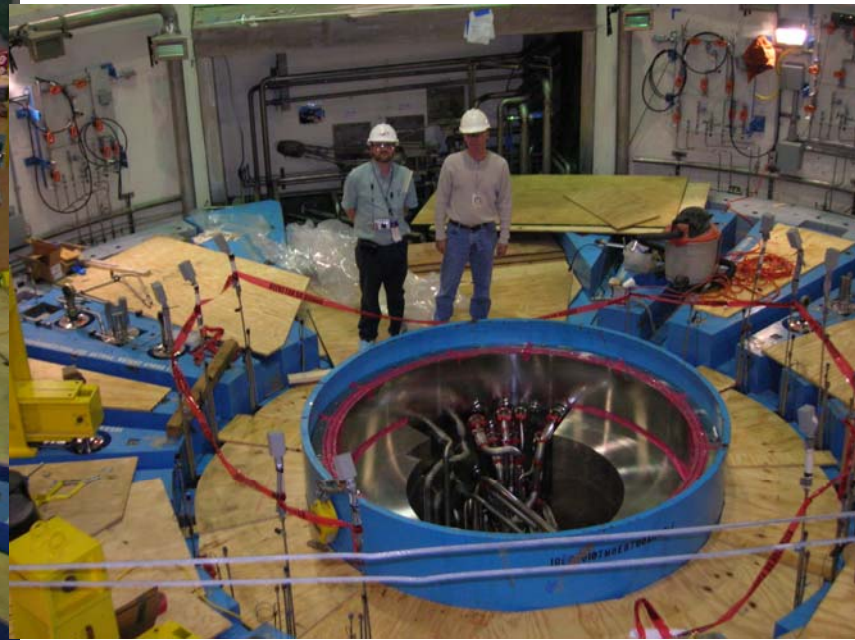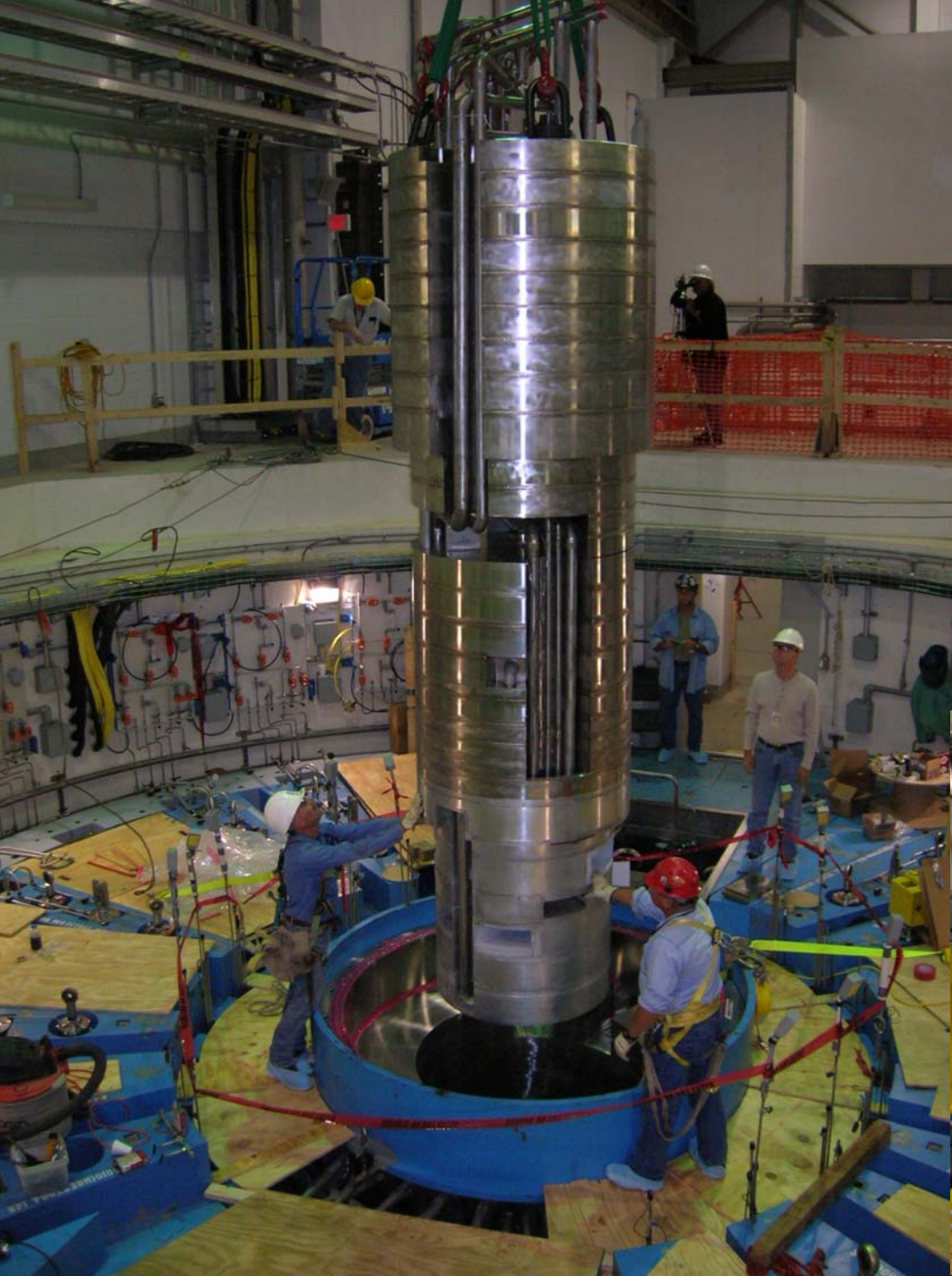
protons

The Target

The Target

The Target

Inner reflector plug installed!

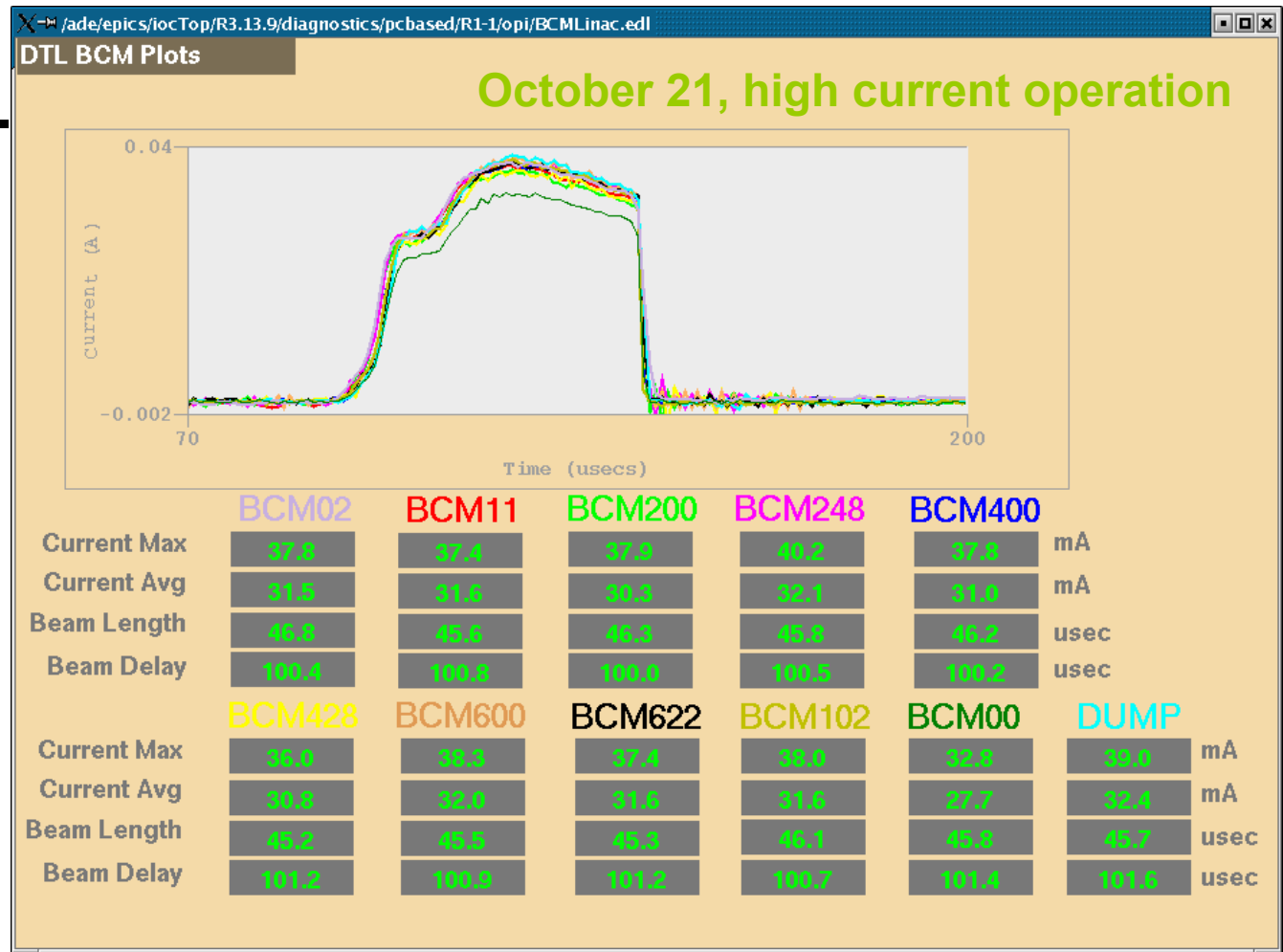October 20, 2005

The Accelerator Systems Division

DTL and CCL

- The RFQ, DTLs, and CCLs 1-3 have been operating since September 7th.

- Field gradients and full pulse length have been achieved.

- All diagnostics installed and operating.

- The DTL – CCL layout will include the whole linac as one PPS area.

- Decided to install shielding wall between CCL and SCL to minimize interference with conditioning, commissioning, and SCL installation and testing. Originally not in the plan.

- DTLs and CCLs are commissioned.

DTL3-6/CCL1-3 commissioning

- **Started beam for DTL/CCL1-3 on Sept. 7, 04. 100% transmission after setting all correctors to zero.**

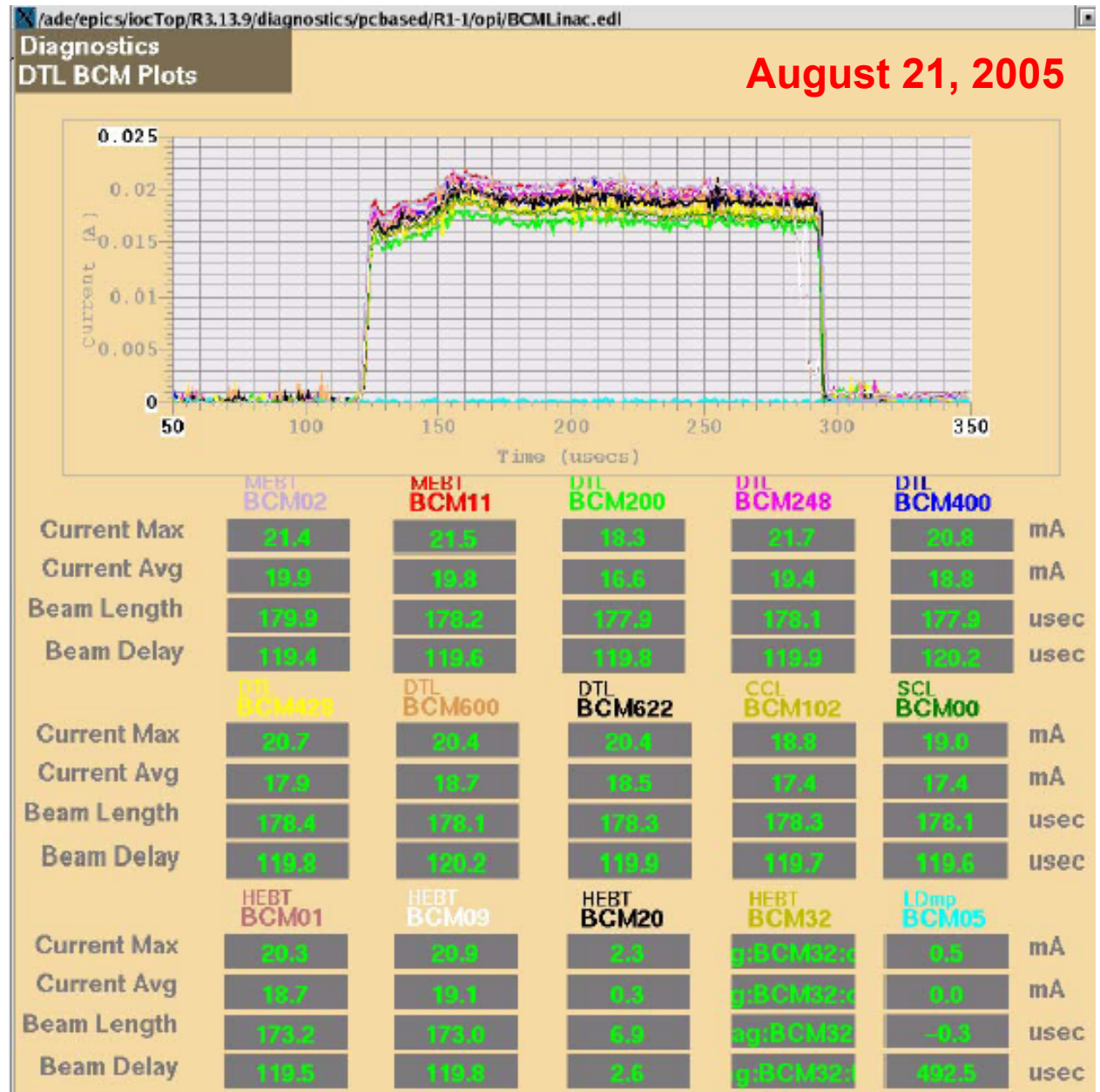- **High current operation demonstrated with very good transmission.**

October 21, high current operation

DTL BCM Plots

/ade/epics/iocTop/R3.13.9/diagnostics/pcbased/R1-1/opi/BCMLinac.edl

	BCM02	BCM11	BCM200	BCM248	BCM400	
Current Max	37.8	37.4	37.9	40.2	37.8	mA
Current Avg	31.5	31.6	30.3	32.1	31.0	mA
Beam Length	46.8	45.6	46.3	45.8	46.2	usec
Beam Delay	100.4	100.8	100.0	100.5	100.2	usec

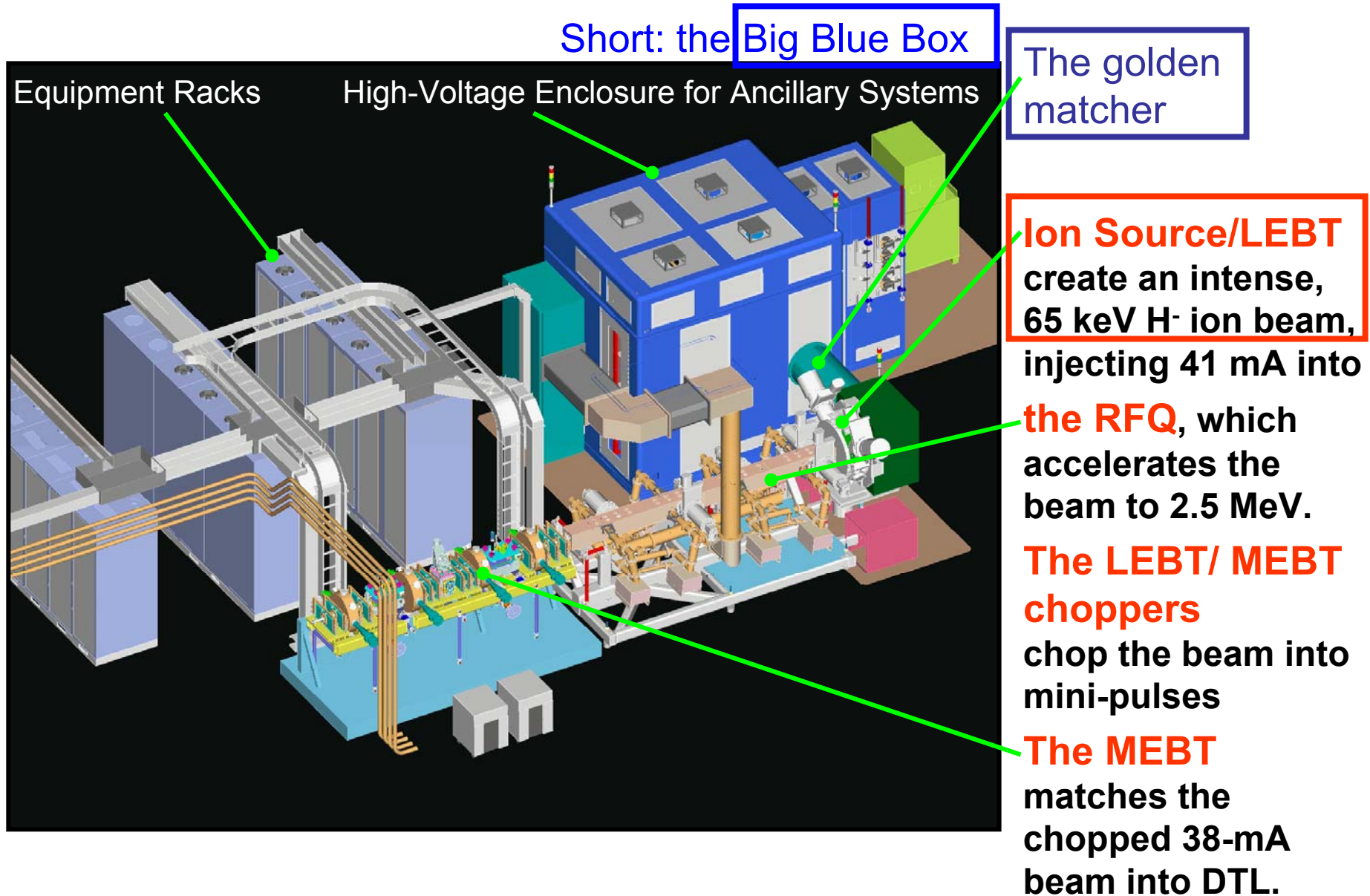|	BCM428	BCM600	BCM622	BCM102	BCM00	DUMP	
Current Max	36.0	38.3	37.4	38.0	32.8	39.0	mA
Current Avg	30.8	32.0	31.6	31.6	27.7	32.4	mA
Beam Length	45.2	45.5	45.3	46.1	45.8	45.7	usec
Beam Delay	101.2	100.9	101.2	100.7	101.4	101.6	usec

SCL

Last Cryomodule delivered March 16.
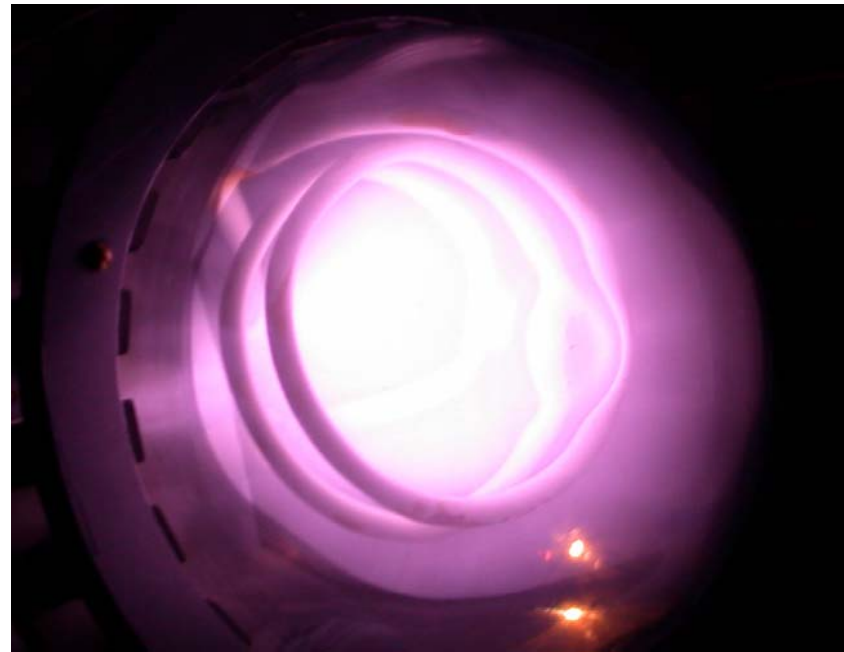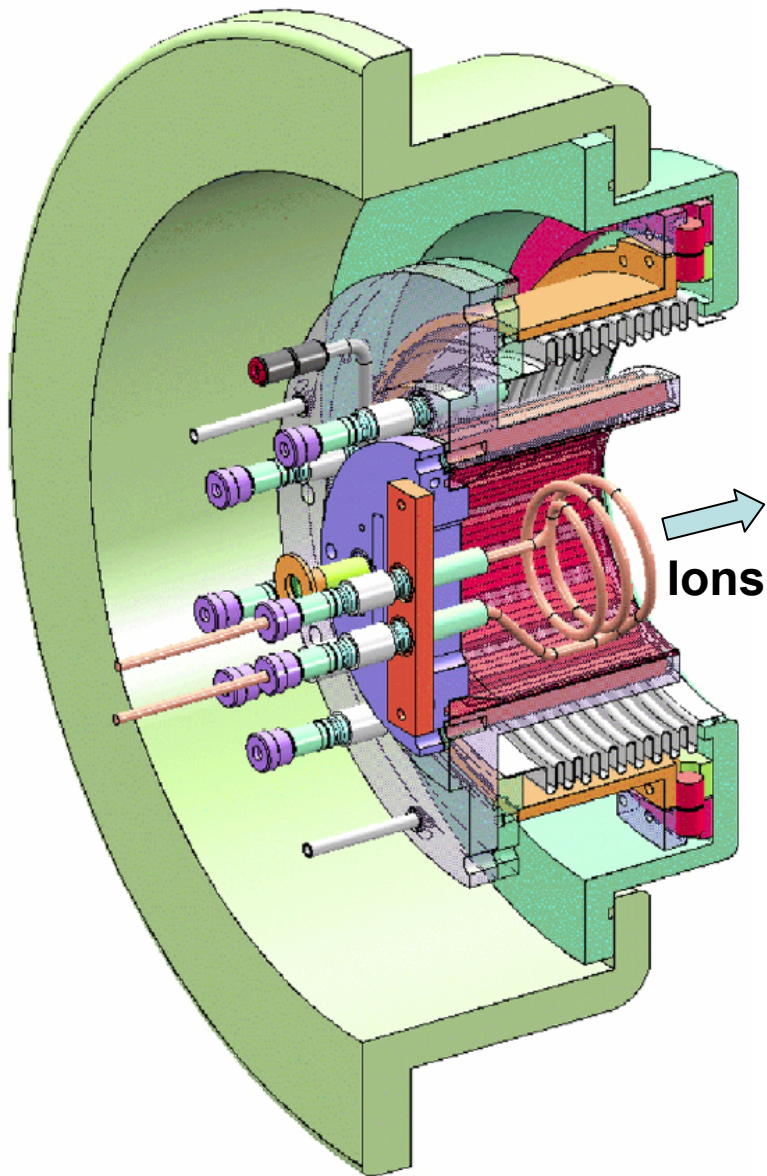
CCL4-6 & SCL commissioning

- **Restarted accelerator mid July. Started SCL commissioning on 8-05-05.**

- **Reached 865 MeV.**

- **Demonstrated 2×10^{13} H$^-$ on LINAC beam dump on 8-21-05.**

- **Very good transmission.**

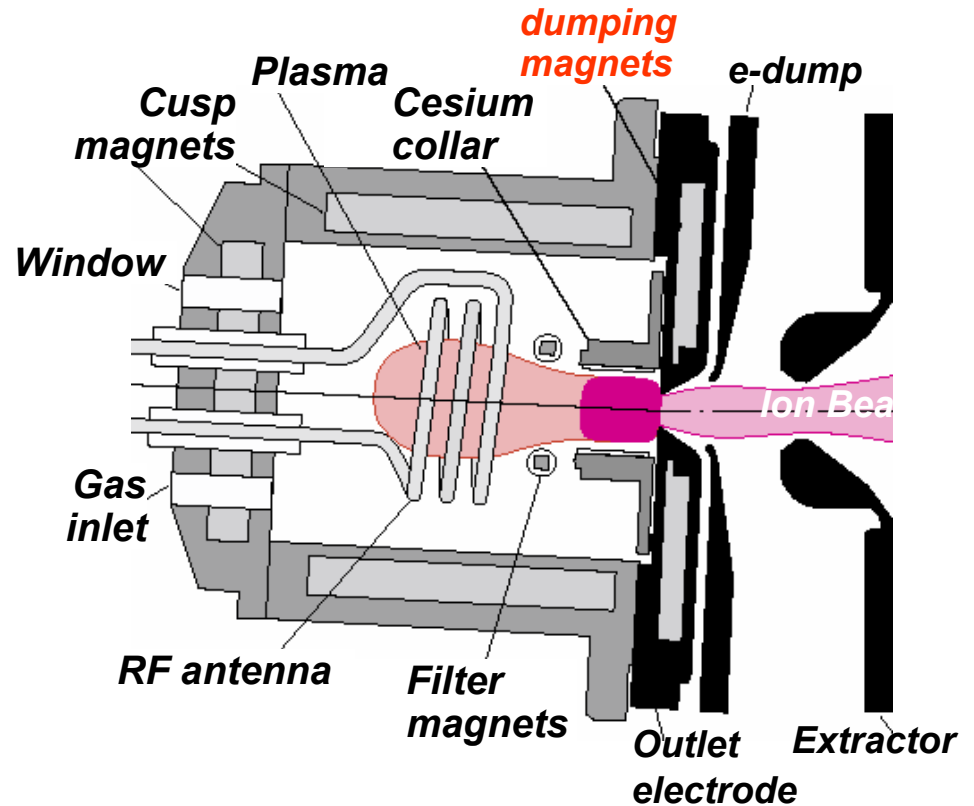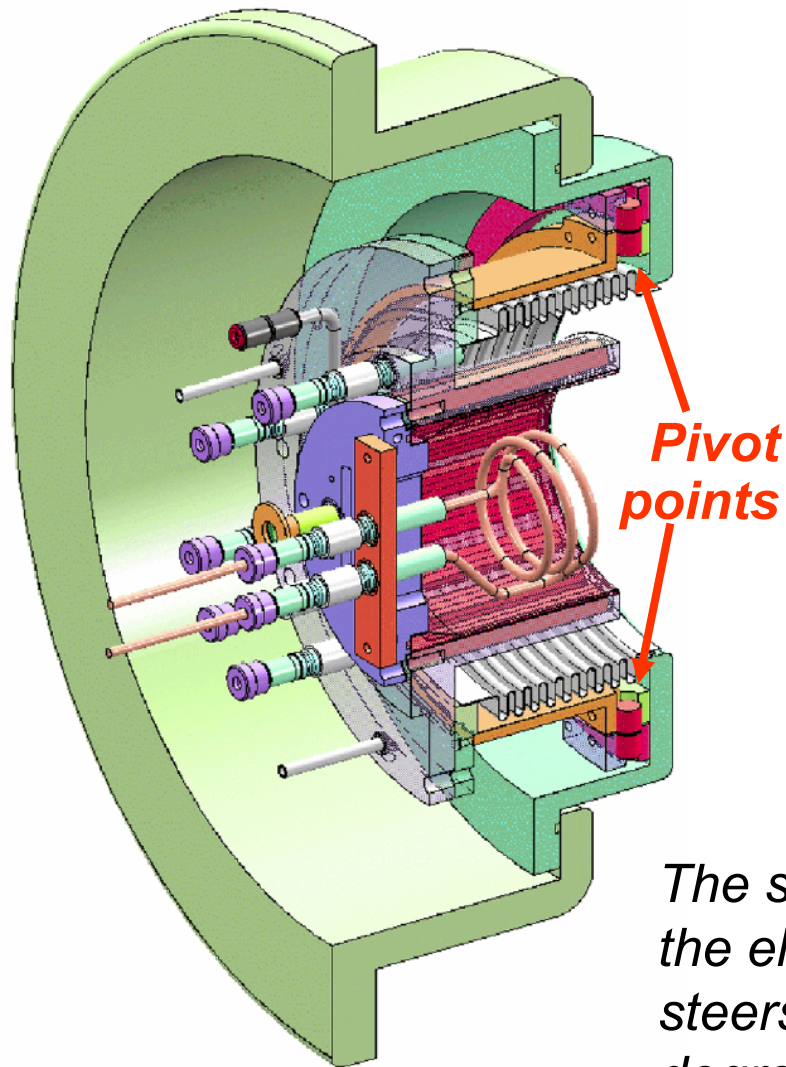- **Demonstrated 8×10^{13} 912 MeV H$^-$ on LINAC beam dump early September.**

/ade/epics/iocTop/R3.13.9/diagnostics/pcbased/R1-1/opi/BCMLinac.edl

Diagnostics
DTL BCM Plots

August 21, 2005

	MEBT BCM02	MEBT BCM11	DTL BCM200	DTL BCM248	DTL BCM400	
Current Max	21.4	21.5	18.3	21.7	20.8	mA
Current Avg	19.9	19.8	16.6	19.4	18.8	mA
Beam Length	179.9	178.2	177.9	178.1	177.9	usec
Beam Delay	119.4	119.6	119.8	119.9	120.2	usec

	DTL BCM420	DTL BCM600	DTL BCM622	CCL BCM102	SCL BCM00	
Current Max	20.7	20.4	20.4	18.8	19.0	mA
Current Avg	17.9	18.7	18.5	17.4	17.4	mA
Beam Length	178.4	178.1	179.3	178.3	178.1	usec
Beam Delay	119.8	120.2	119.9	119.7	119.6	usec

	HEBT BCM01	HEBT BCM09	HEBT BCM20	HEBT BCM32	LDmp BCM05	
Current Max	20.3	20.9	2.3	g:BCM32:c	0.5	mA
Current Avg	18.7	19.1	0.3	g:BCM32:c	0.0	mA
Beam Length	173.2	173.0	6.9	ag:BCM32	-0.3	usec
Beam Delay	119.5	119.8	2.6	g:BCM32:l	492.5	usec

The SNS Front End

Short: the Big Blue Box

The golden matcher

Equipment Racks

High-Voltage Enclosure for Ancillary Systems

Ion Source/LEBT create an intense, 65 keV H⁻ ion beam, injecting 41 mA into

the RFQ, which accelerates the beam to 2.5 MeV.

The LEBT/ MEBT choppers chop the beam into mini-pulses

The MEBT matches the chopped 38-mA beam into DTL.

The SNS Ion Source

Ions

A 2.5 turn antenna converts the RF into the ionizing electric field that drives the plasma. Typically ~150 W from a 600 W, CW 13.5 MHz generator maintains a low density plasma. Whenever requested by a timing signal, ~50 kW from a 80 kW, 2 MHz RF amplifier increases the plasma density to produce the intense H- beam.

The SNS Ion Source

Pivot points

Cusp magnets
Plasma
dumping magnets
e-dump
Cesium collar
Window
Gas inlet
Ion Beam
RF antenna
Filter magnets
Outlet electrode
Extractor

The strong electron dumping magnets steers the electrons on the e-dump. The magnet also steers the ion beam to the side by several degrees. This horizontal bend is compensated with a manually adjustable tilt of $3\pm3^\circ$.

The SNS Ion Source and LEBT
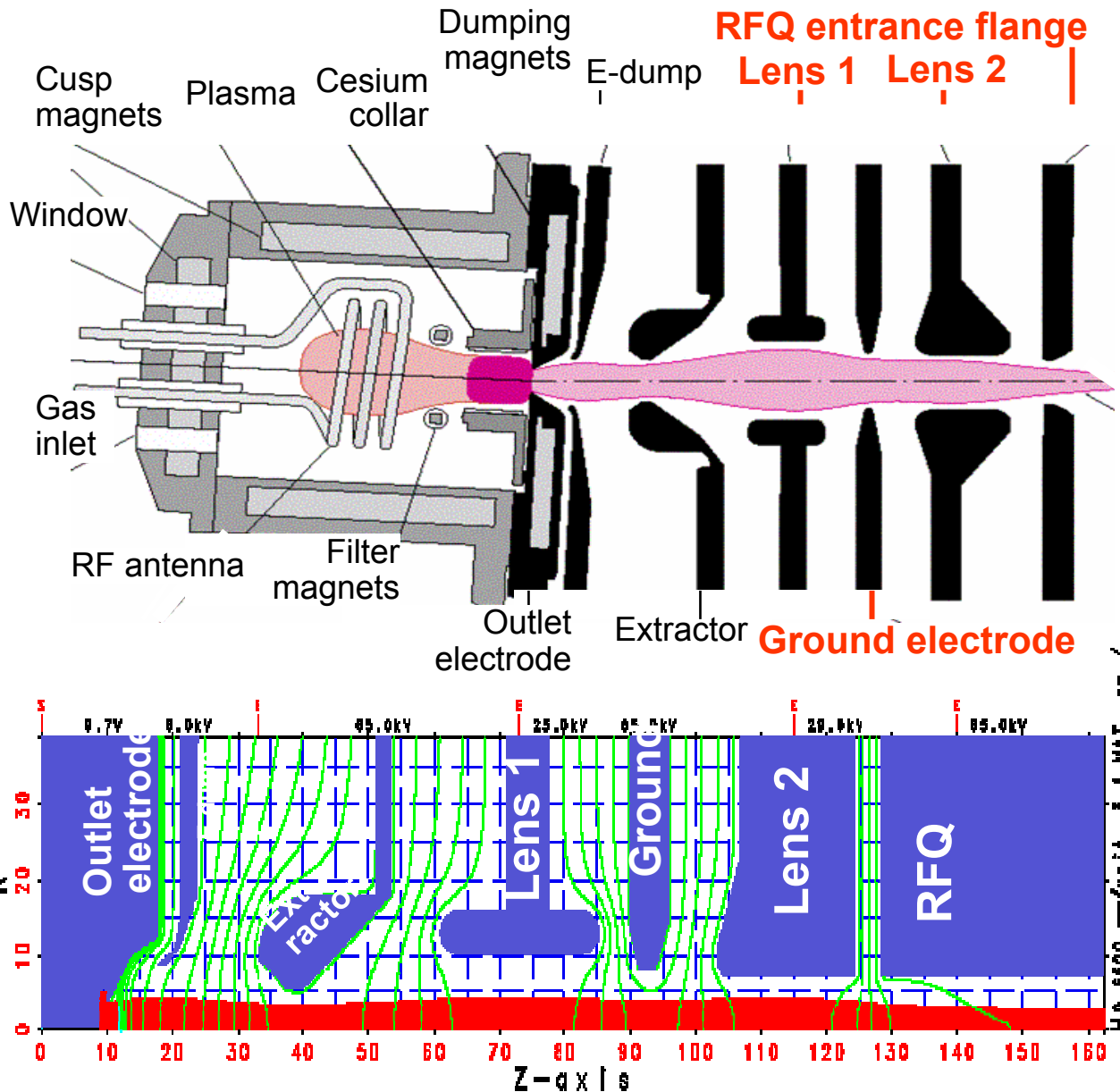
•*To minimize emittance growth of the high intensity, 65 kV beam, the SNS LEBT was designed as short as possible. A 12-cm long, two-lens electrostatic telescope forms a convergent ion beam with a waist a few cm inside the RFQ, where the RFQ captures the beam. Telescopes allow for adjusting the beam waist diameter and convergence angle without changing the waist's location.*

The SNS Ion Source and LEBT

To allow for adequate pumping (2100 l/s H_2), the LEBT is installed inside a 30"$\varnothing$ chamber. The ion source and LEBT can be aligned against the RFQ under vacuum by moving the isolation flange with a sliding seal on the LEBT chamber.
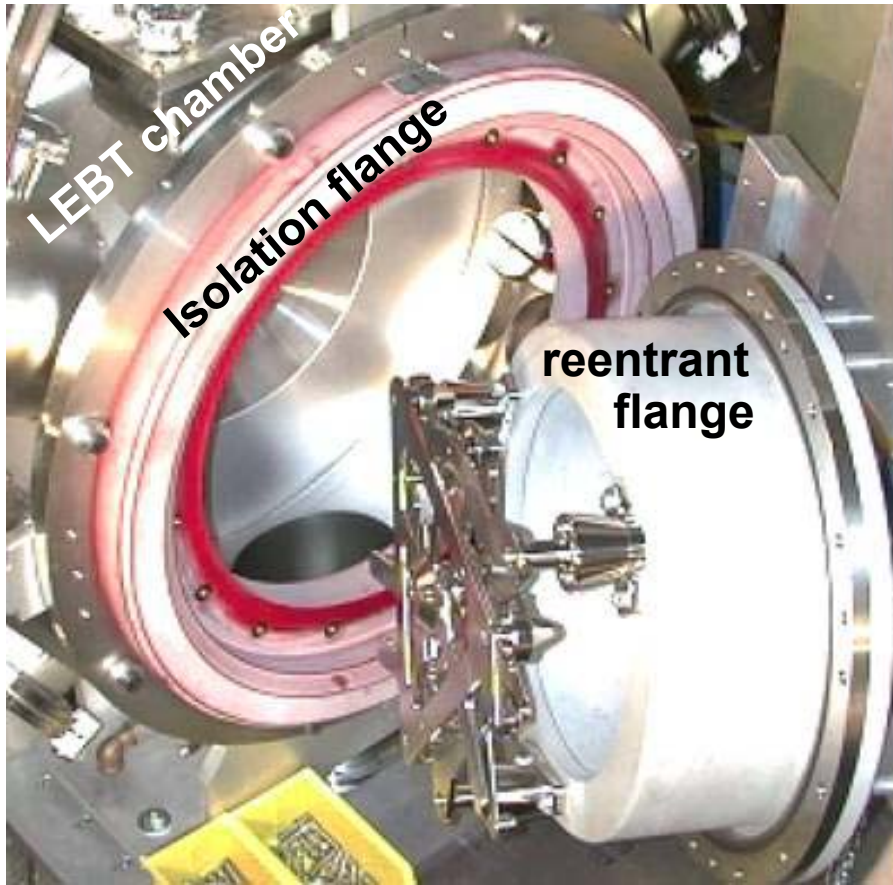
About ~10,000 lbs of air push the reentrant flange against the LEBT chamber. Large cranks with a high gear ratio enable smooth controlled displacements.
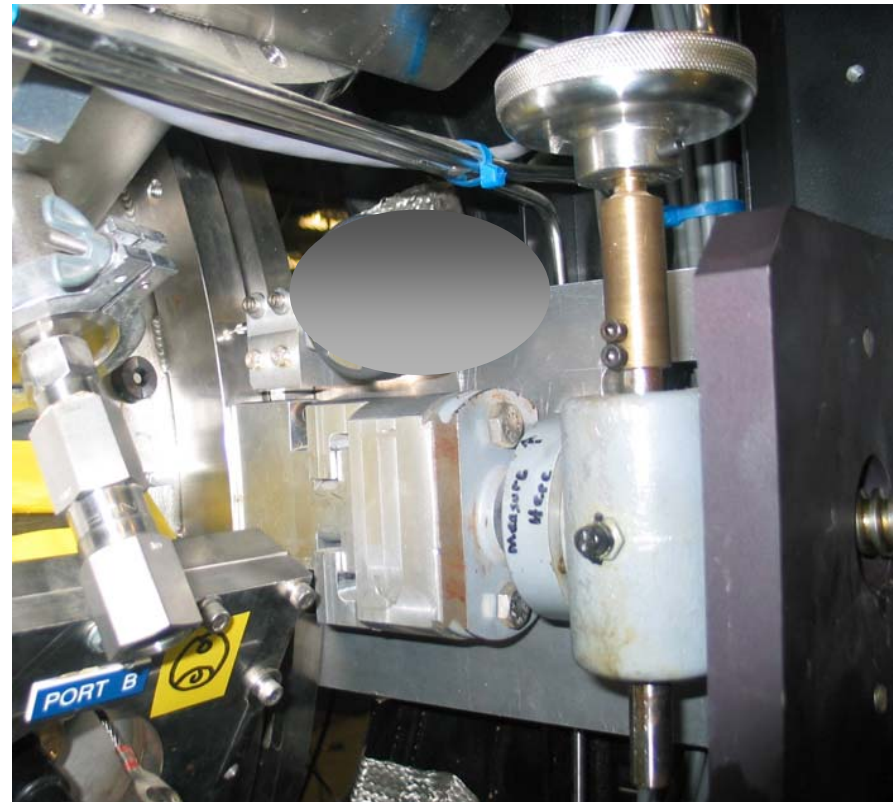
What is moving so slowly in East Tennessee?

Early in '03, we kept trying to align the ion source and LEBT by maximizing the beam current out of the RFQ. This process was repeated many times with inconsistent results as something appeared to drift.

At 1:20 AM we decided to do an experiment:

Do nothing and watch.

Beam Position Monitor 1

Beam position [mm]

Average horizontal position

Average vertical position

Plasma died, no beam

initial 0.5mm rightward displacement of the IS/LEBT flange

1-15-03

Time [minutes]
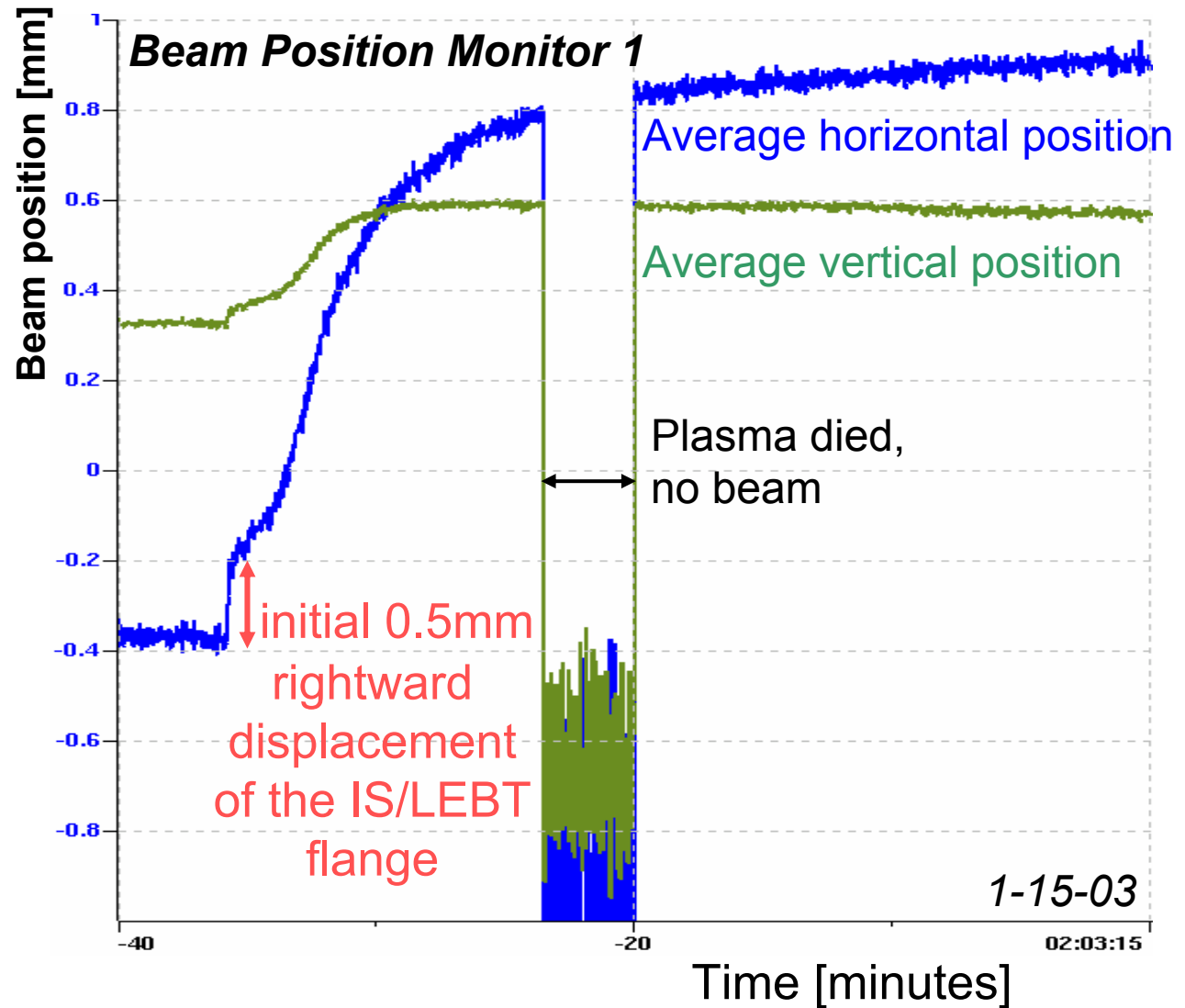
To identify the cause we did an off-line experiment:

What is moving so slowly in East Tennessee?
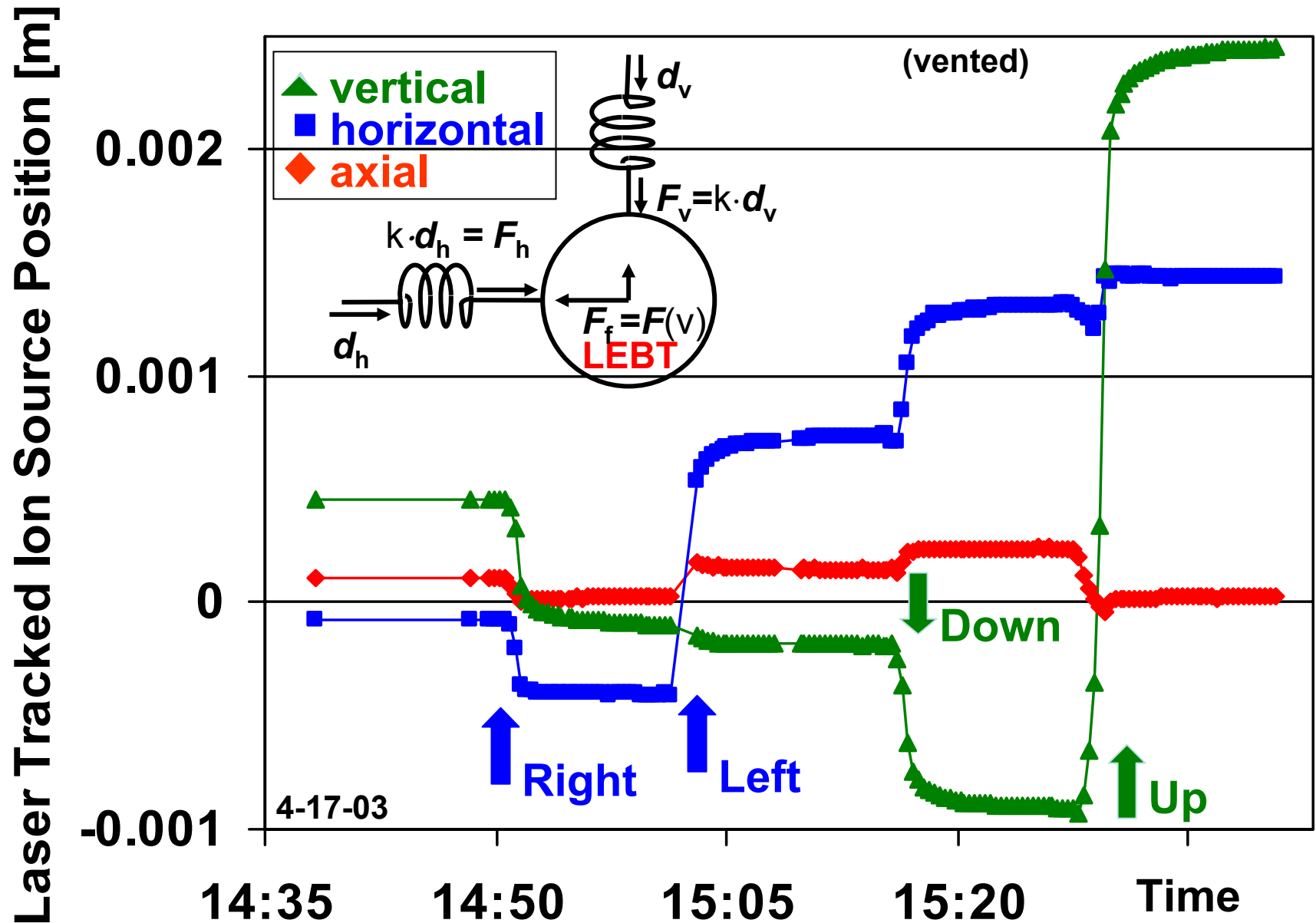
What is moving so slowly in East Tennessee?
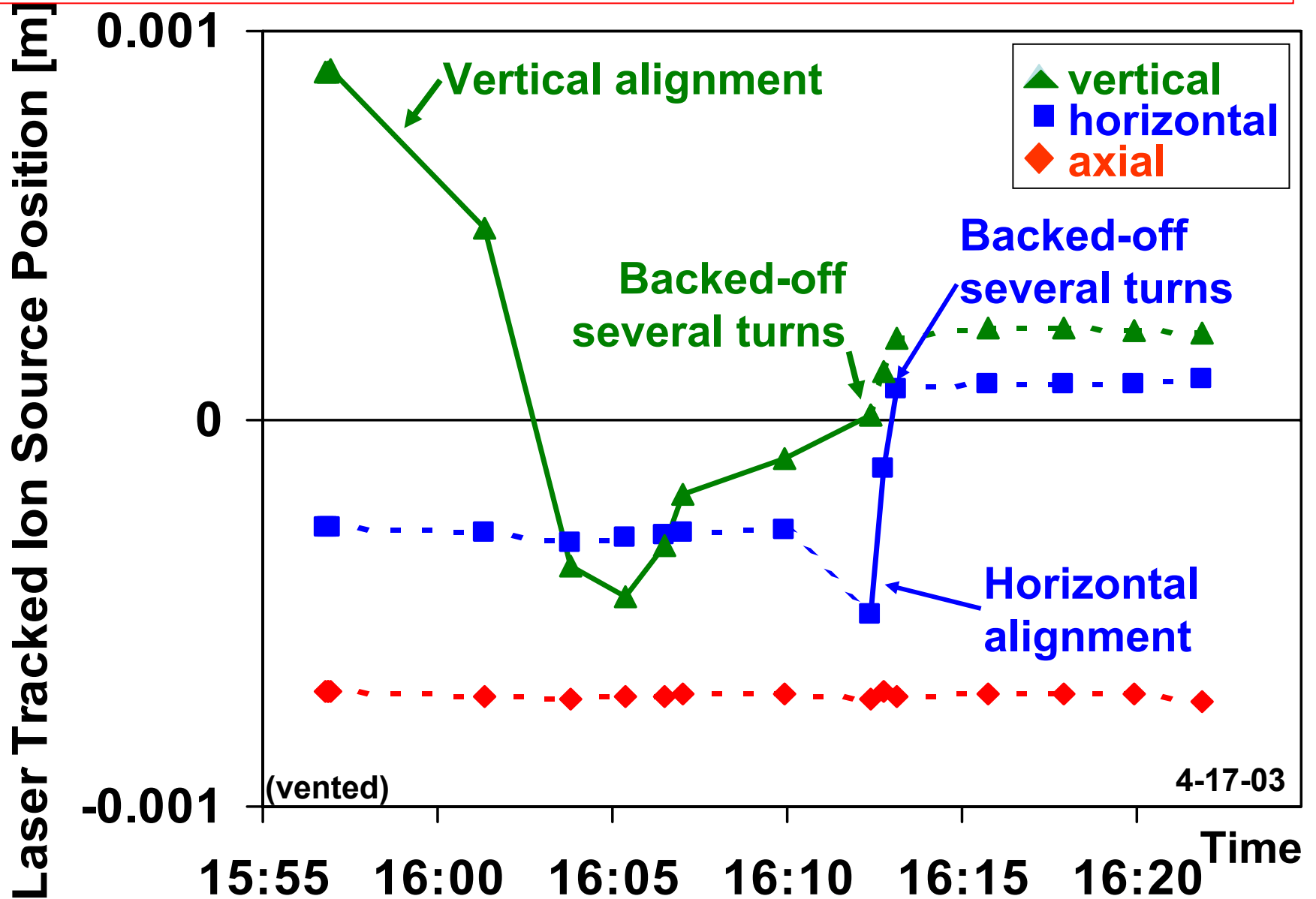
This allowed for aligning the LEBT optically within 0.2 mm.

The SNS Ion Source and LEBT

However, the beam exited the RFQ with an angle!

To allow for beam-based alignment we installed dial indicators end of '04. They give instantaneous position and tilt feedback.
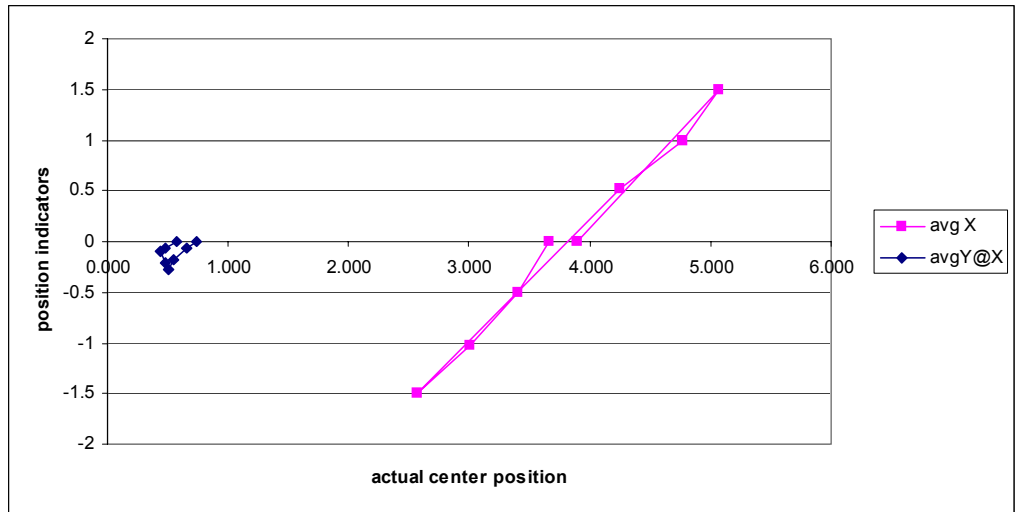

Dial-indicator

Tilt-indicators

BCM02Avg

tilt angle

horizontal position

Legend:
- 30-35
- 25-30
- 20-25
- 15-20
- 10-15
- 5-10

rms-emittance

tilt angle

horizontal position

Legend:
- 5.4-5.6
- 5.2-5.4
- 5-5.2
- 4.8-5
- 4.6-4.8
- 4.4-4.6
- 4.2-4.4
- 4-4.2
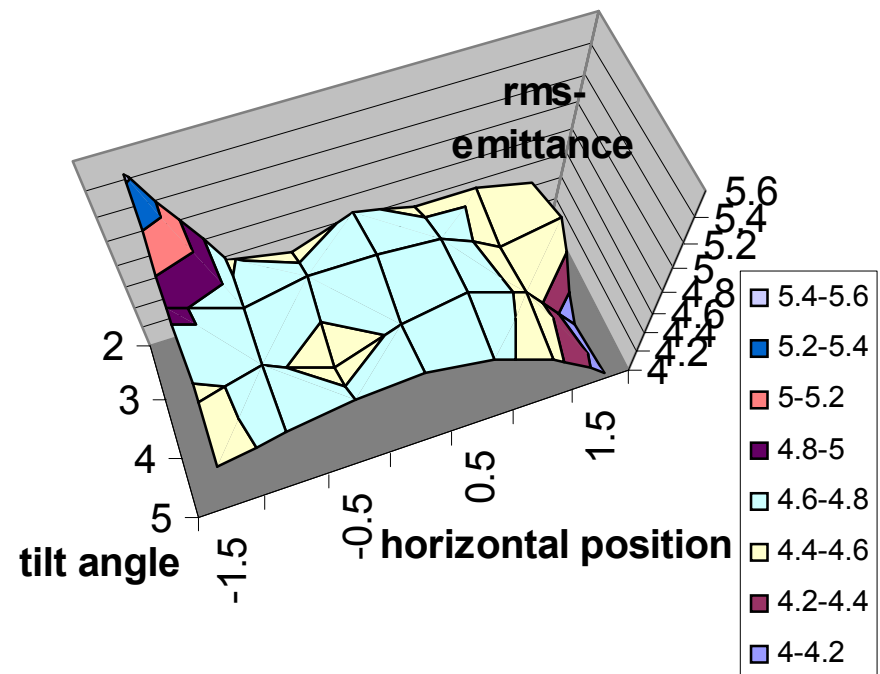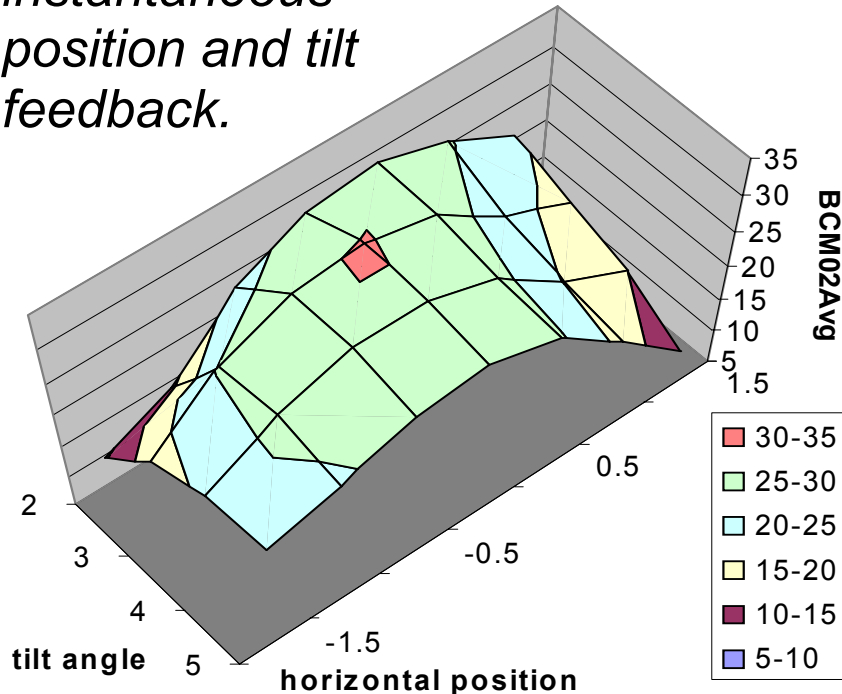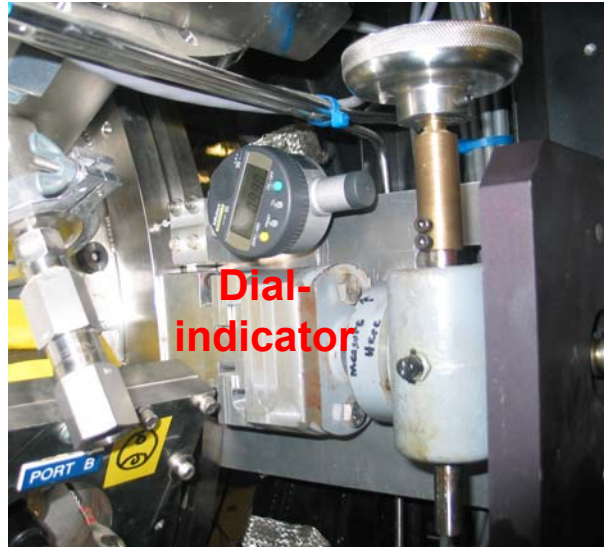
The SNS Ion Source and LEBT

Mid '05, ion source position and tilt were laser tracked and compared to dial indicators
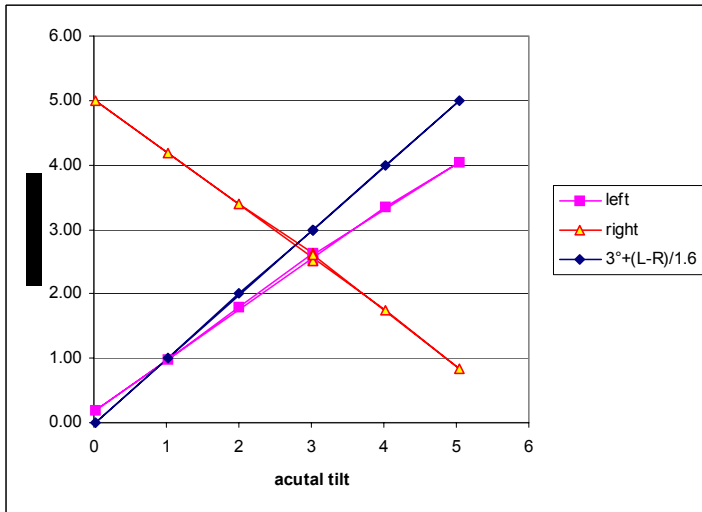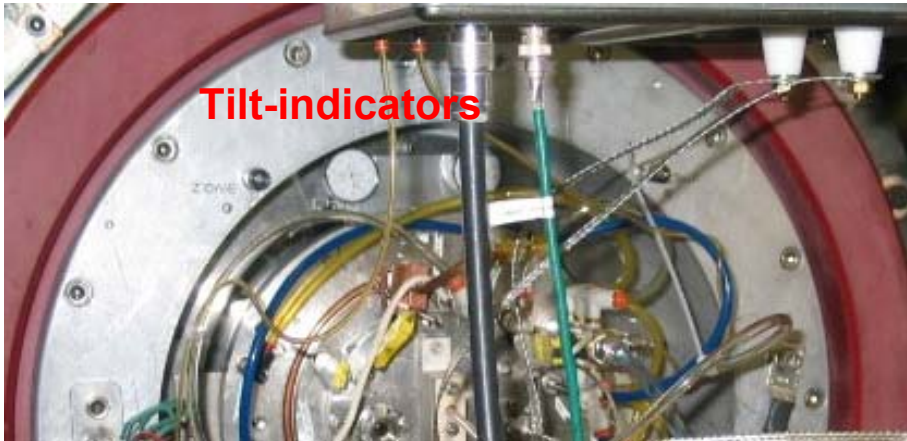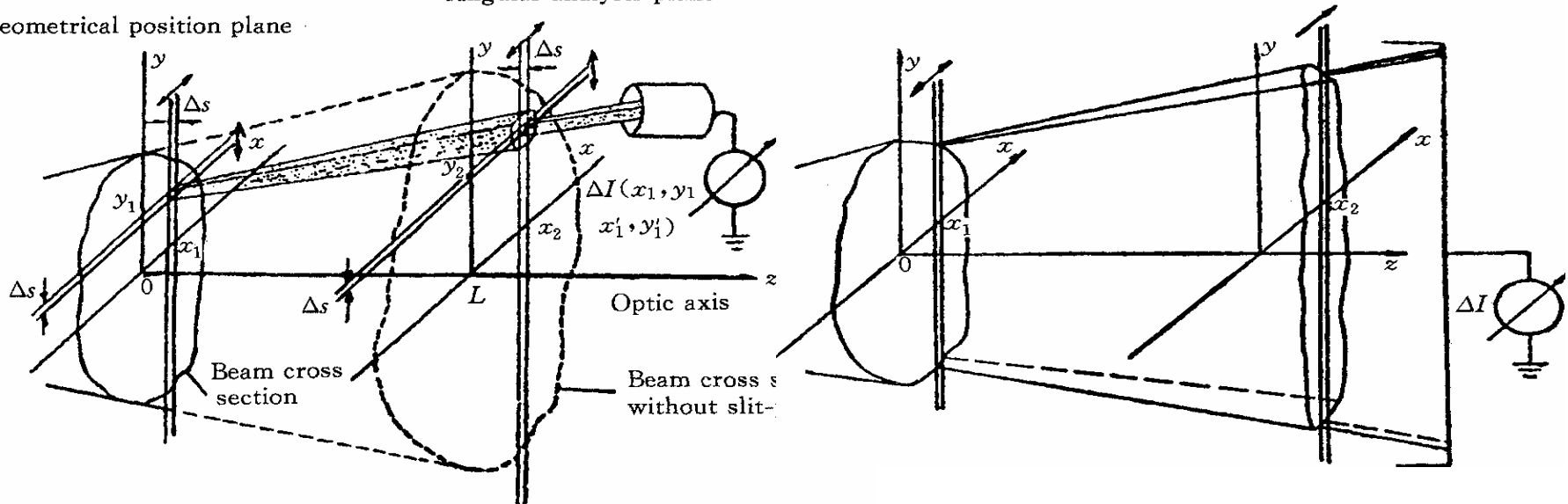

Tilt-indicators

Tilt indicator within 0.01°.

Position indicators within 0.2 mm.
Needs to be improved!

Emittance, the Holy Grail of Beam Transport

Louisville's theorem: a particle beam's 6 dimensional emittance is conserved under conservative forces !

The emittance in the trace space:

$$\varepsilon_{xyz} = \iiint dx \cdot dy \cdot dz \cdot dx' \cdot dy' \cdot dz'$$

or

$$\varepsilon_x = \iint dx \cdot dx' \quad \text{and} \quad \varepsilon_y = \iint dy \cdot dy'$$

These are areas having units of mm·mrad or equivalent.

However, it is common to write π·mm·mrad.

With $\beta = v/c$ and $\gamma = (1 - \beta^2)^{-1/2}$, the normalized emittance becomes

$$\varepsilon^* = \beta\gamma \iint dx \cdot dx' \quad \text{and} \quad \varepsilon_y^* = \beta\gamma \iint dy \cdot dy'$$

Two dimensional Emittance Distributions

LBNL

x (mm) x' (mrad)
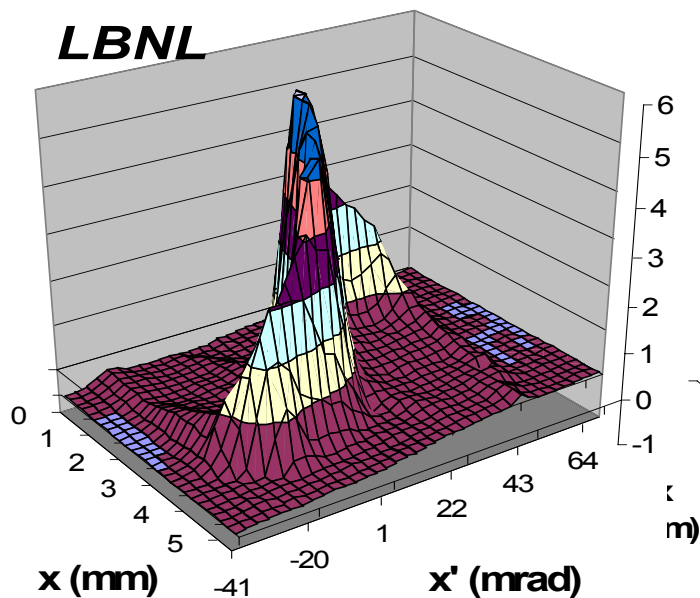
LBNL evaluated their normalized rms emittance as >0.2 mm·mrad. But we needed ≤ 0.2 mm·mrad.

JAERI
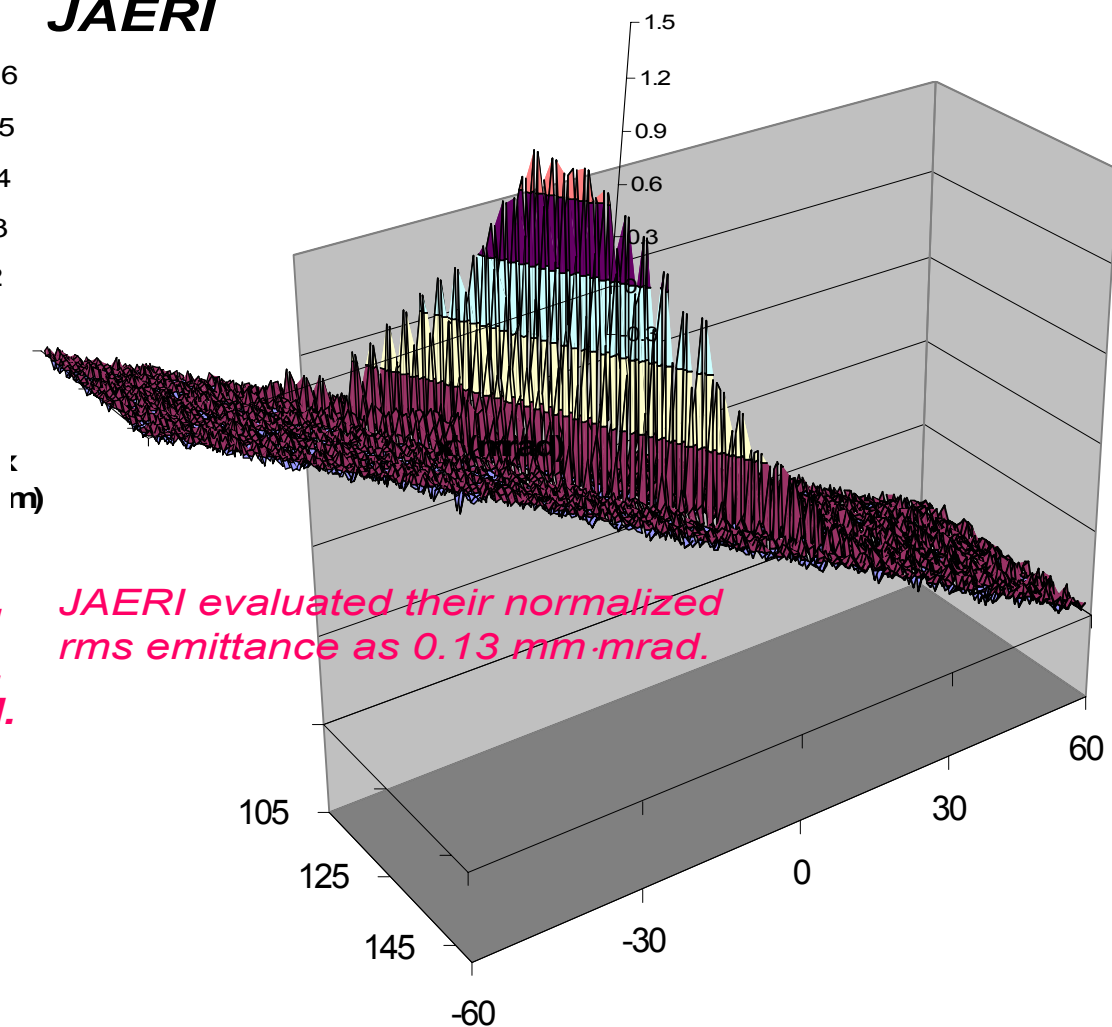
JAERI evaluated their normalized rms emittance as 0.13 mm·mrad.

The ultimate Reduction: The RMS Emittance

The Twiss parameters are:

$$\alpha = -\frac{\langle xx' \rangle}{\varepsilon}$$

$$\beta = \frac{\langle x^2 \rangle}{\varepsilon}$$

$$\gamma = \frac{\langle x'^2 \rangle}{\varepsilon}$$

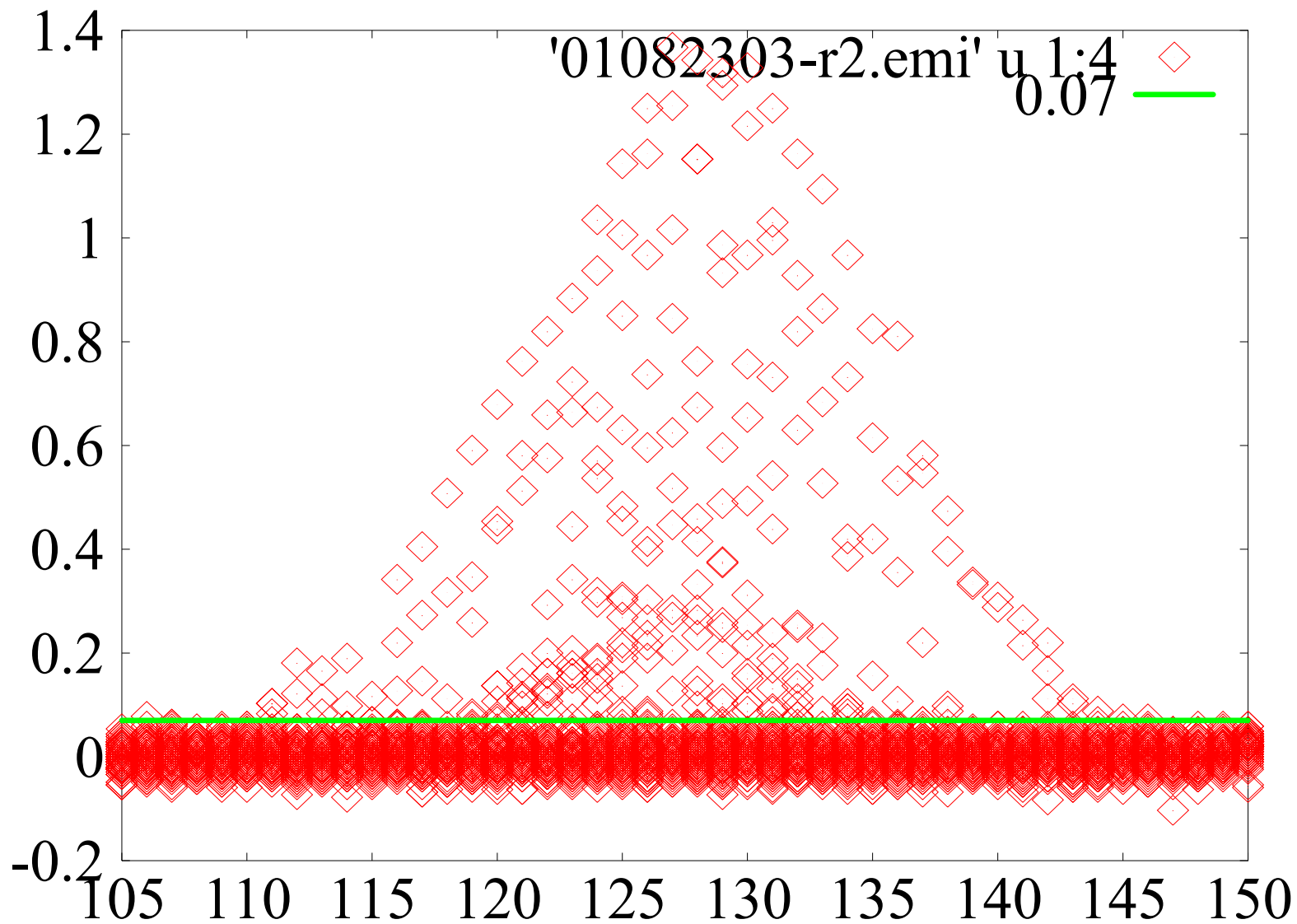$$\varepsilon_{rms} = \sqrt{\langle x'^2 \rangle \langle x^2 \rangle - \langle xx' \rangle^2}$$

where

$$\langle xx' \rangle = \frac{\sum_{all} xx' c(x,x')}{\sum_{all} c(x,x')}$$

$$\langle x^2 \rangle = \frac{\sum_{all} x^2 c(x,x')}{\sum_{all} c(x,x')}$$

$$\langle x'^2 \rangle = \frac{\sum_{all} x'^2 c(x,x')}{\sum_{all} c(x,x')}$$

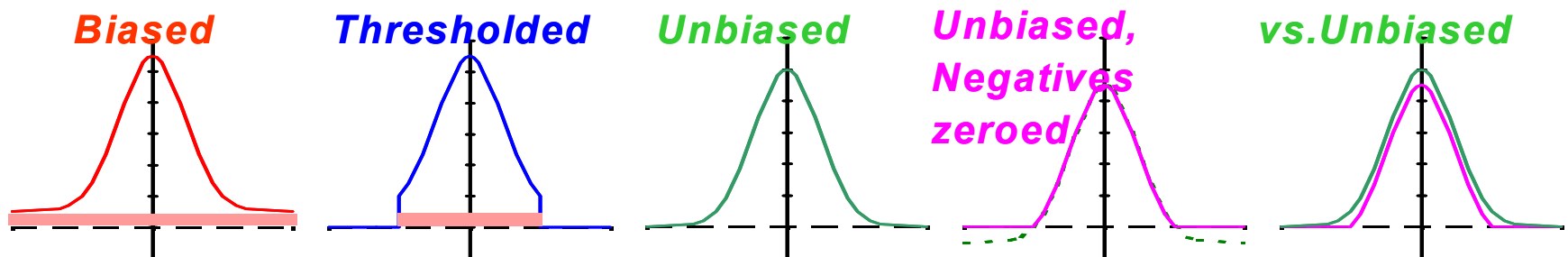*where c(x,x') is the current measured for position- and velocity-coordinates x, x'.*
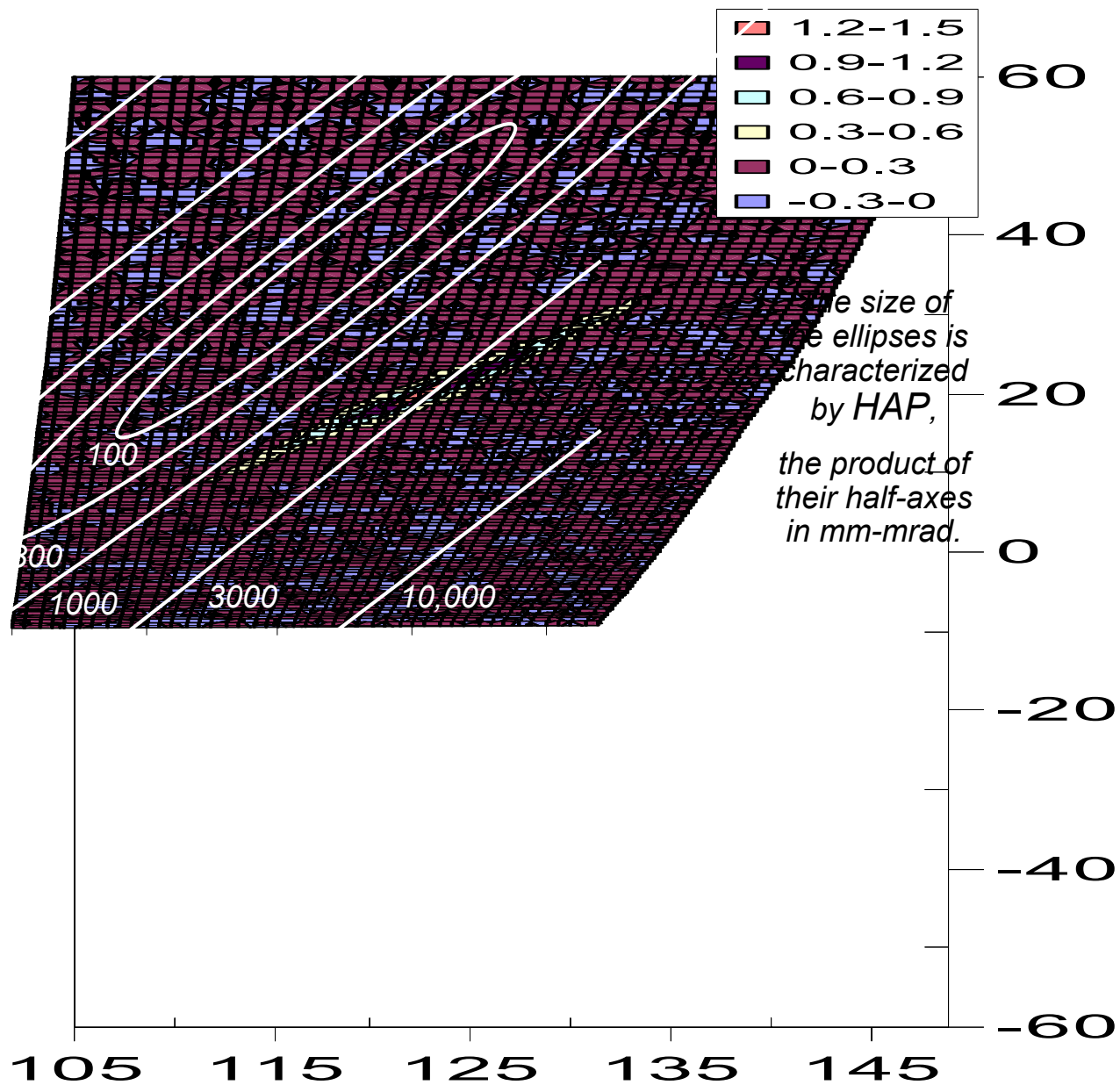
RMS Emittance evaluation at JAERI

'01082303-r2.emi' u 1:4   ◇
0.07 ——

Courtesy of A. Ueno, KEK

There were many ways to evaluate RMS Emittances

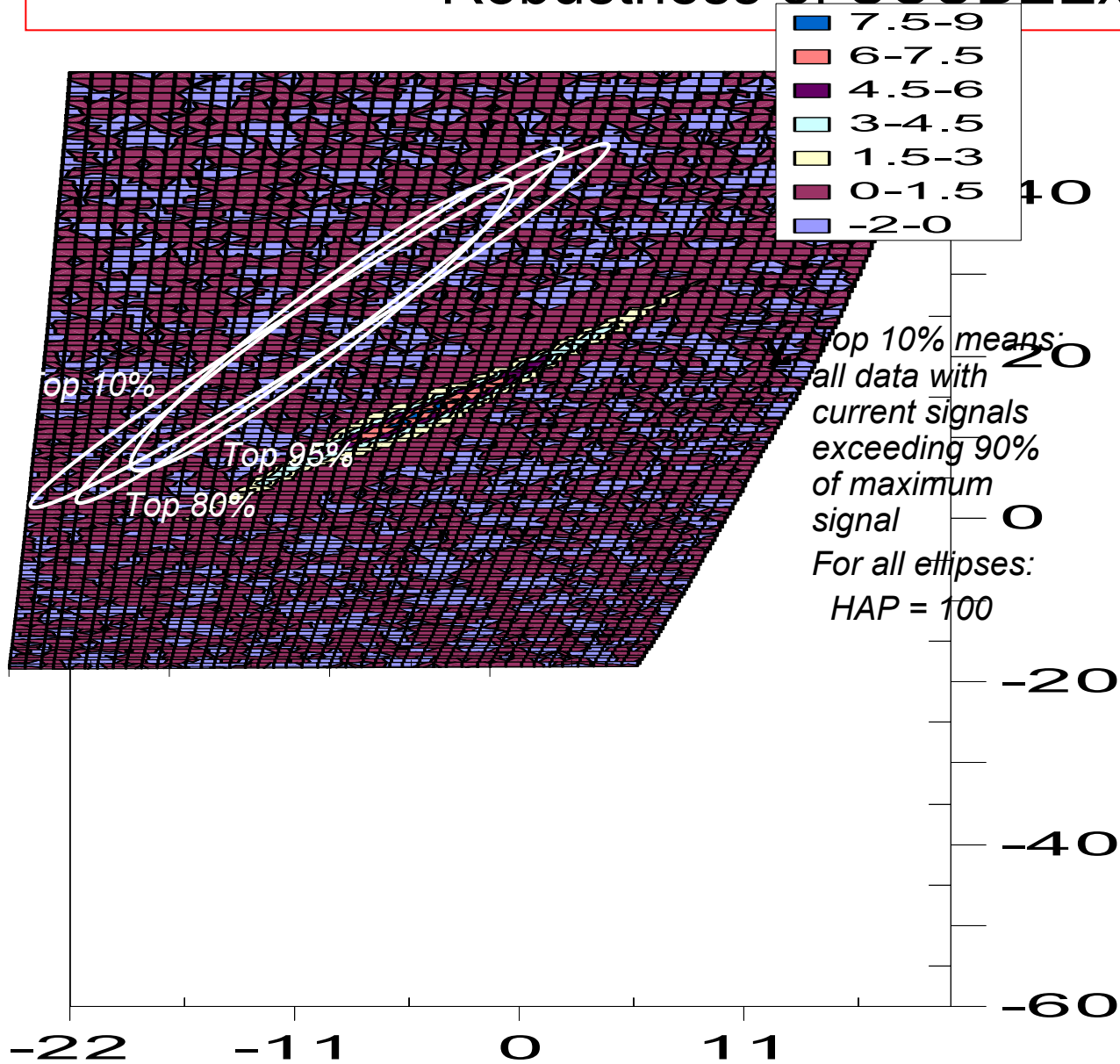| Method: *lab estimate	LBNL data mm·mrad	JAERI data mm·mrad
Raw data	(≥0) 0.192*	1.24
Threshold, histogram	(8%) 0.097	(6.7%) 0.145
Threshold, change of slope	(8%) 0.097	(5%) 0.194
Threshold, change of α	(15%) 0.079	(5%) 0.194
Bias subtraction	(0.16 ± 0.04 %) 0.182 ± 0.003	(0.164 ± 0.007 %) 0.28 ± 0.05
Bias subtraction, negative numbers suppressed	(1.3%) 0.152	(5.1%) 0.13*

Biased **Thresholded** **Unbiased** **Unbiased, Negatives zeroed** **vs.Unbiased**

Self Consistent Unbiased Elliptical Exclusion Analysis

Legend:
- 1.2–1.5
- 0.9–1.2
- 0.6–0.9
- 0.3–0.6
- 0–0.3
- −0.3–0

The size of the ellipses is characterized by *HAP*, the product of their half-axes in mm-mrad.

Contour labels: 100, 300, 1000, 3000, 10,000

Self Consistent UnBiased Elliptical Exclusion Analysis

Average current outside ellipse

Top 90% ellipse

Bias = -0.08% ± 0.1%

Emittance of outside current subtracted data

$\varepsilon_n = 0.20 \pm 0.02$

This is self-consistent!!

What ellipse ??

Top 90% ellipse

Norm. RMS-Emit. [mm*mrad]

0.05

0

-0.05

0.2

0.1

0

0   1000   2000   3000

Included elliptical HAP

Robustness of SCUBEEx

Legend:
- 7.5-9
- 6-7.5
- 4.5-6
- 3-4.5
- 1.5-3
- 0-1.5
- -2-0

Top 10% means: all data with current signals exceeding 90% of maximum signal

For all ellipses: HAP = 100

Top 10%
Top 95%
Top 80%

Robustness of SCUBEEx

Average current outside ellipse

Top 10% ellipse

Bias = -0.08% ± 0.1%

aver. outside current [%]

Emittance of outside current subtracted data

$\varepsilon_n = 0.20 \pm 0.02$

Top 10% ellipse

Top 95% ellipse

Top 90% ellipse

Top 80% ellipse

Norm. RMS-Emit. [mm*mrad]

0.05

0

-0.05

0.2

0.1

0

0   1000   2000   3000

Included elliptical HAP

Estimate robust !!

It's about the same, says SCUBEEx

Method: *lab estimate	LBNL data mm·mrad	JAERI data mm·mrad
Raw data	(≥0) 0.192*	1.24
Threshold, histogram	(8%) 0.097	(6.7%) 0.145
Threshold, change of slope	(8%) 0.097	(5%) 0.194
Threshold, change of α	(15%) 0.079	(5%) 0.194
Bias subtraction	(0.16 ± 0.04 %) 0.182 ± 0.003	(0.164 ± 0.007 %) 0.28 ± 0.05
Bias subtraction, negative numbers suppressed	(1.3%) 0.152	(5.1%) 0.13*
SCUBEEx	0.18 ± 0.01	0.20 ± 0.02

No, Scooby Doo, it's not you, it's SCUBEEx!!!

Lesson learned:

A lesson learned from this and the crooked E case:

ENRON
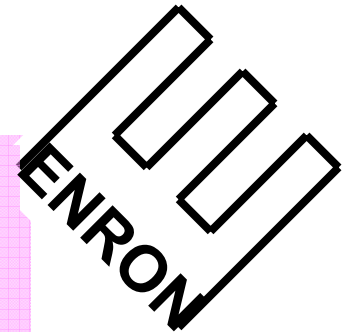
Zeroing negative numbers is a bad idea, unless the applied method maintains a zero net balance !!

Electric Sweep Scanners

- P. Allison developed in the early 1980s a hybrid emittance scanner at LANL, known today as Allison scanner.
- A stepper motor scans the entire unit through the beam to sample position x with entrance slit.
- Saw-tooth voltages of opposite polarity are applied to the deflector plates located between the two set of slits to sample angle x'.
- A suppressed Faraday cup measures the beam passing through both slits.
- Allison scanners are in use at LANL, LBNL, ORNL, Triumph, etc.
- The Allison scanners shown here were designed by LBNL's M. Leitner in the early days of the SNS project.
- They are currently on loan at ORNL and need to be returned to LBNL.
- They are measuring the emittance at the exit of the Test LEBT.
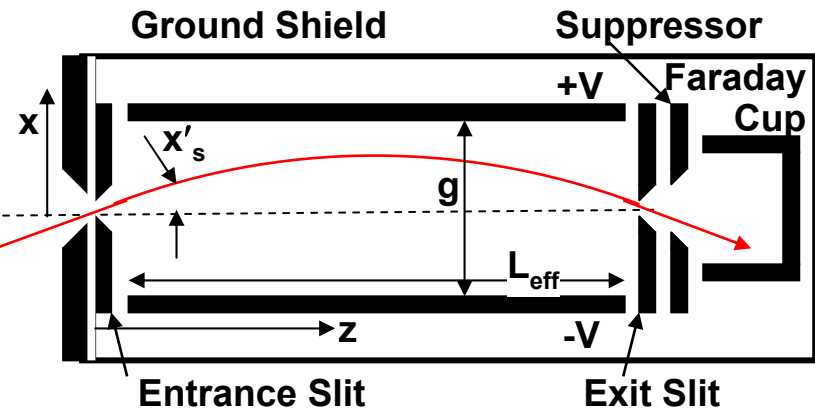
$$x = \iint a_x \cdot dt^2 = -2 \cdot \iint dt^2 \cdot q \cdot V/g$$

With $2 \cdot q \cdot U \cdot dt^2 = m \cdot dz^2$

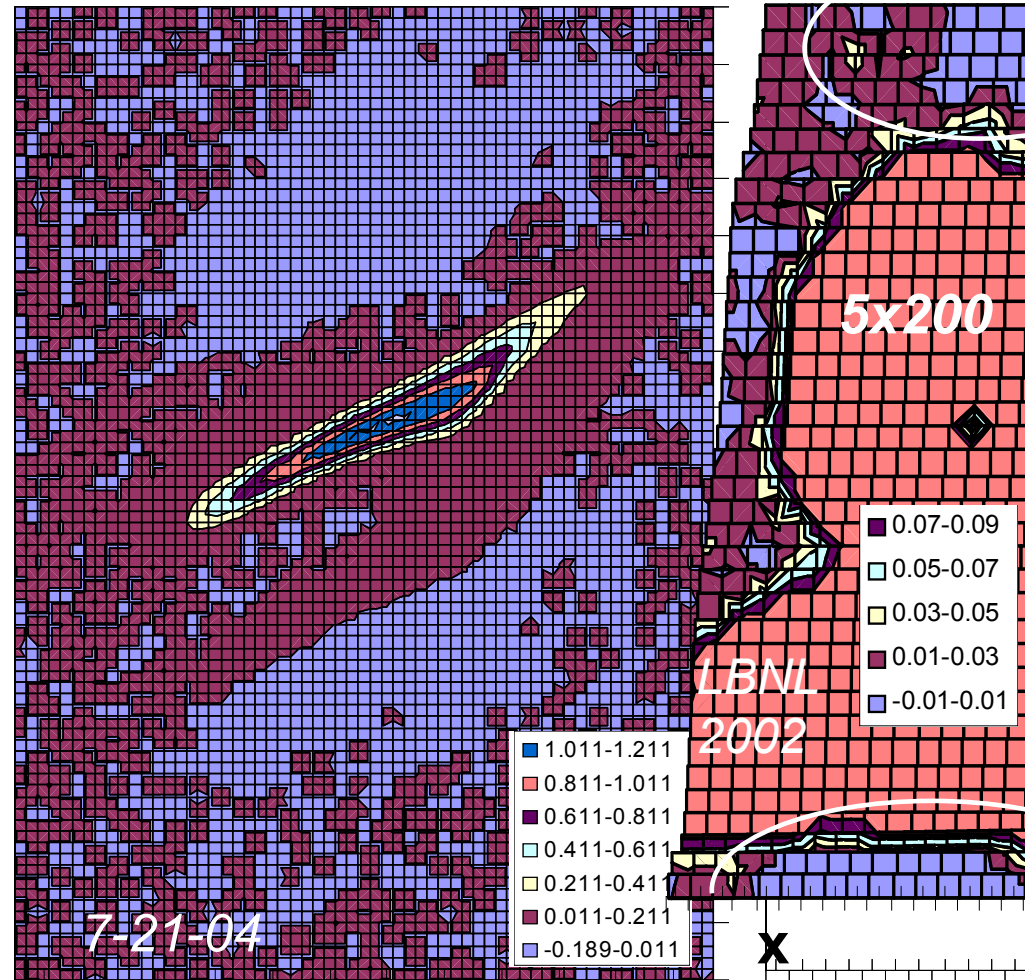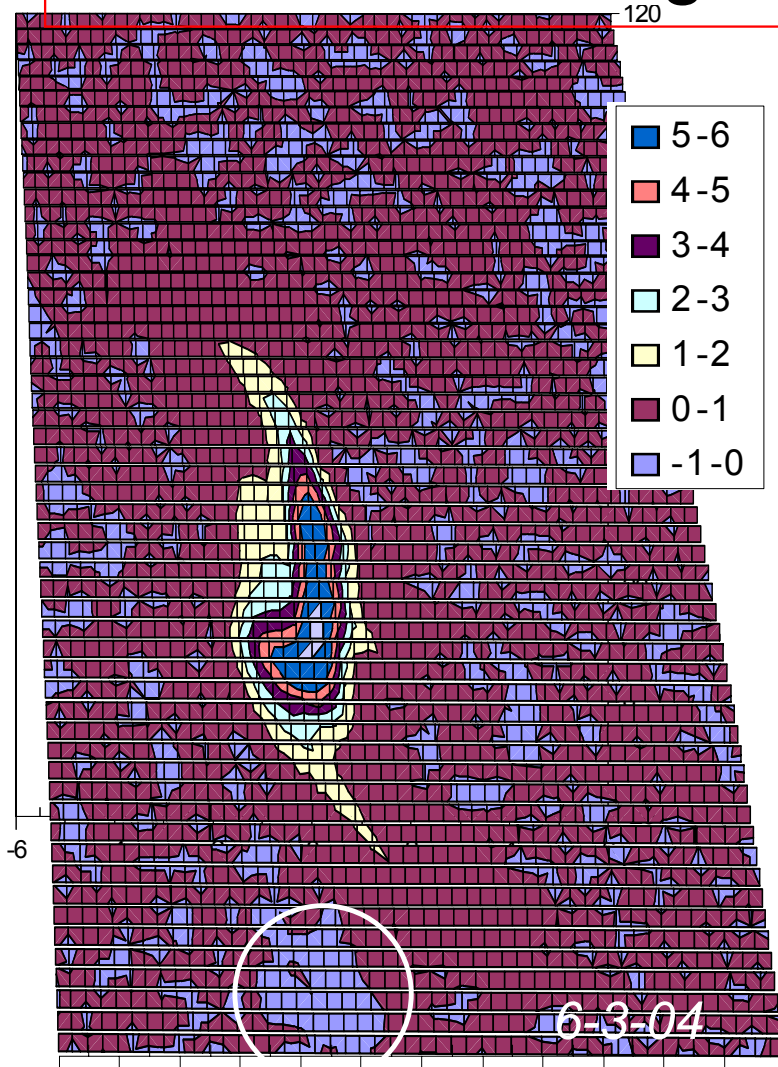$$x = x'_s \cdot z - V \cdot z^2/(2 \cdot g \cdot U)$$

For $x(z = L_{eff}) = 0$: $x'_s = V \cdot L_{eff}/(2 \cdot g \cdot U)$

And for $x < g/2$: $x' < x'_{max} = 2 \cdot g/L_{eff}$

5x200

LBNL
2002

6-3-04

7-21-04

■	5 - 6
■	4 - 5
■	3 - 4
■	2 - 3
■	1 - 2
■	0 - 1
■	-1 - 0

■	0.07-0.09
■	0.05-0.07
■	0.03-0.05
■	0.01-0.03
■	-0.01-0.01

■	1.011-1.211
■	0.811-1.011
■	0.611-0.811
■	0.411-0.611
■	0.211-0.411
■	0.011-0.211
■	-0.189-0.011
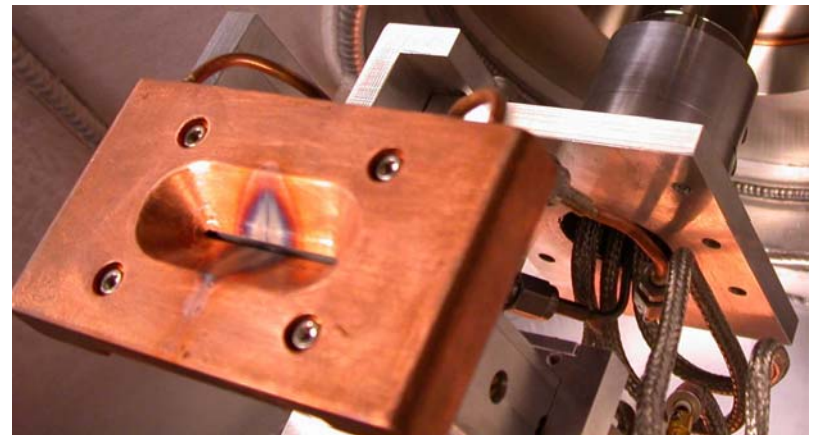
➤ *Normally we measure the emittance of the strongly focused beam way it is injected into the RFQ.*
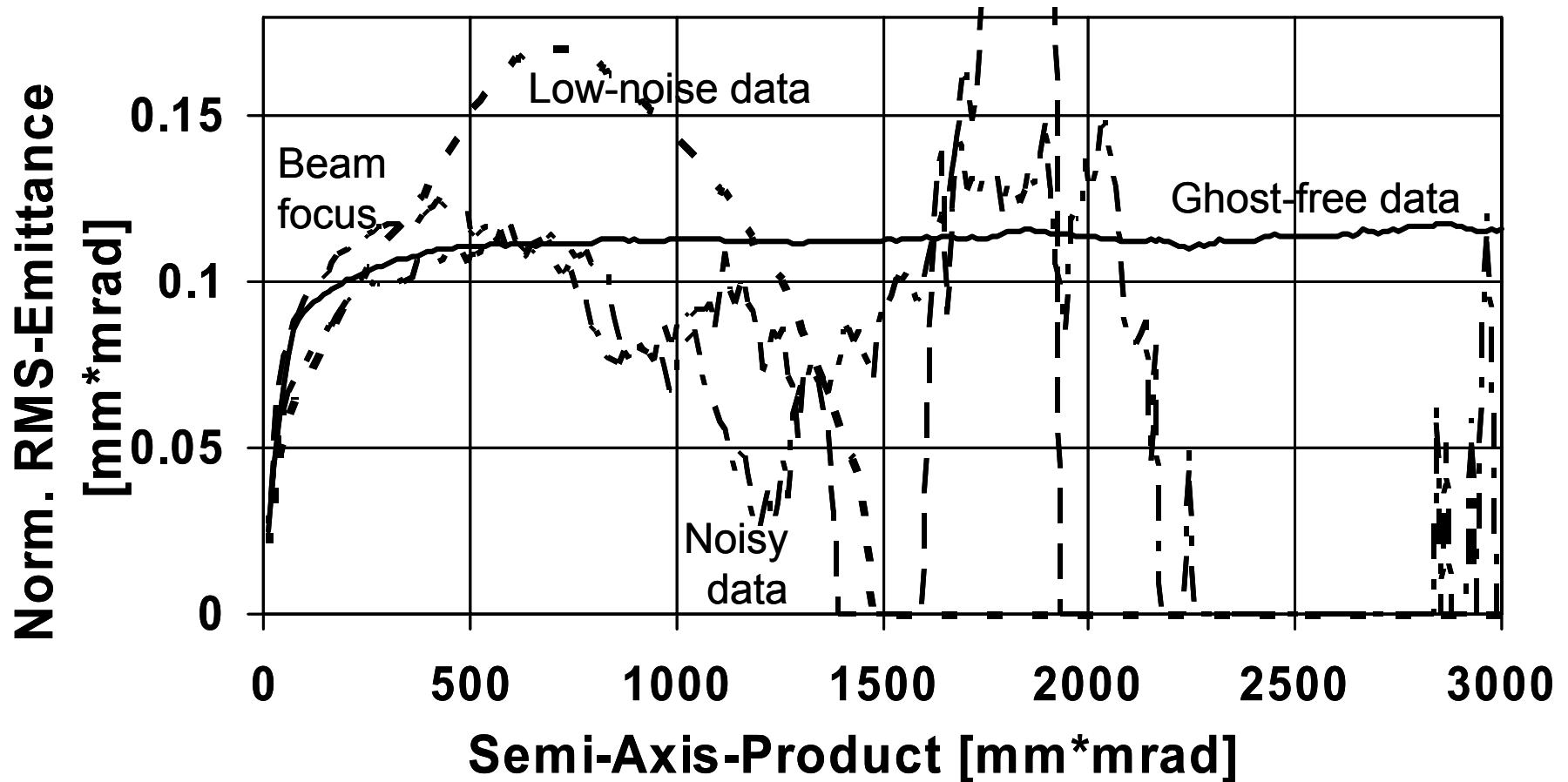
➤ *Last July, Doug Moehs (FNAL) tuned an almost parallel beam wh*

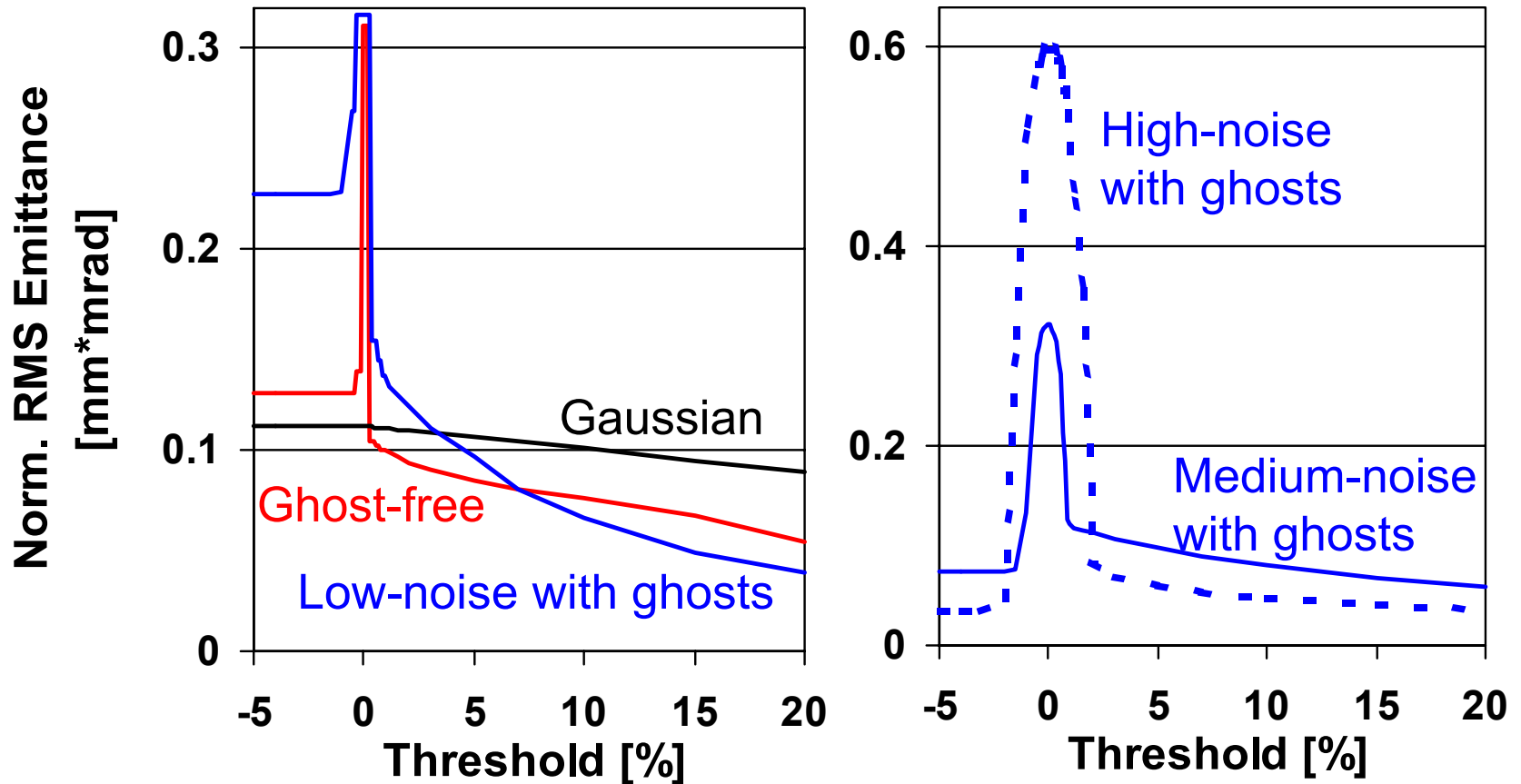# Testing Emittance Data for Ghost Signals
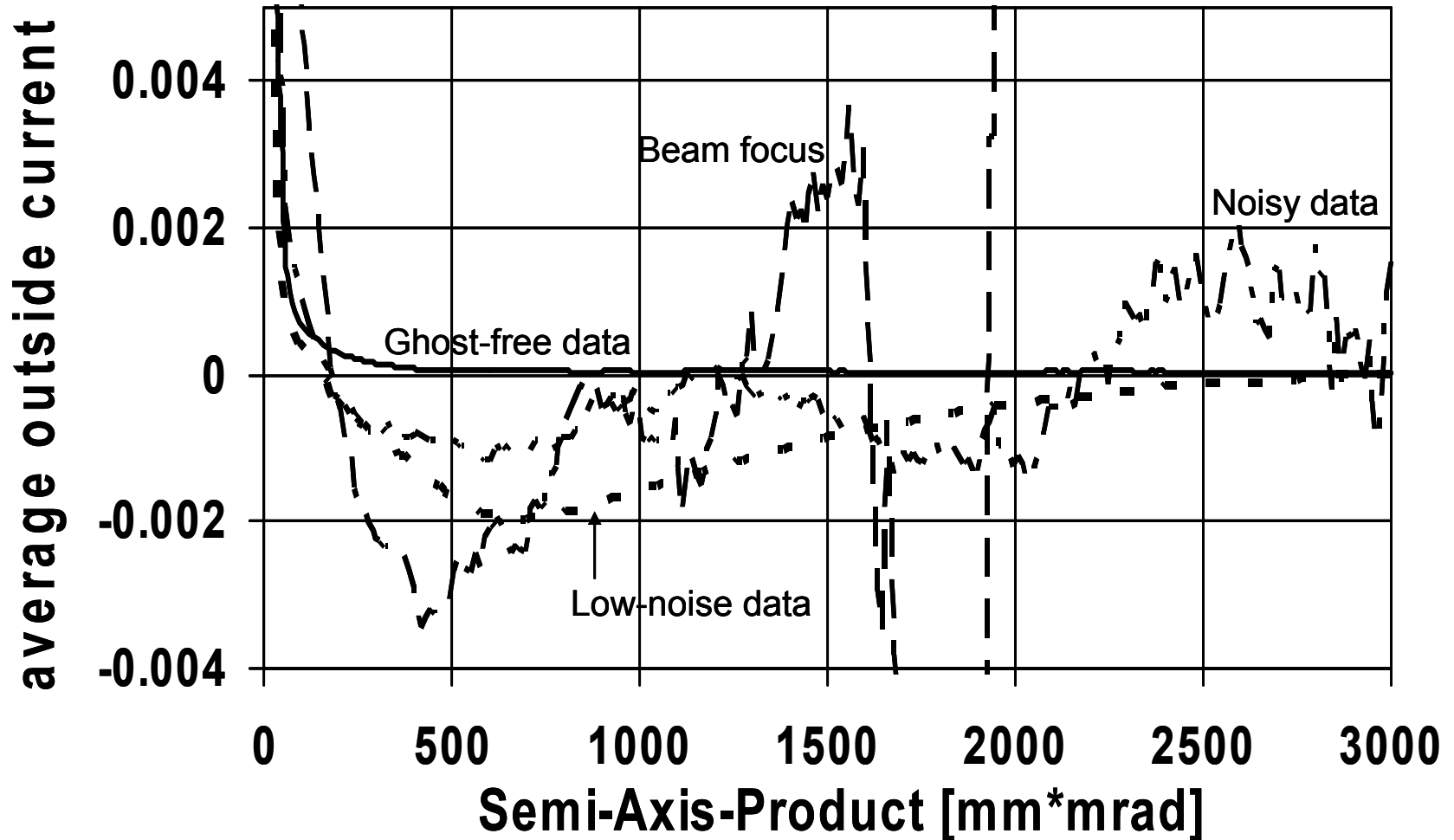
➤ **Ghost signals cause the average outside current to under-shoot and interfere with the self-consistent bias estimation!**

Ghost Signals affect RMS Emittances

> **Ghosts signals cause rms emittances to be under-, then over-, then under-estimated with increasing ellipse size!**

Ghost Signals affect RMS Emittances

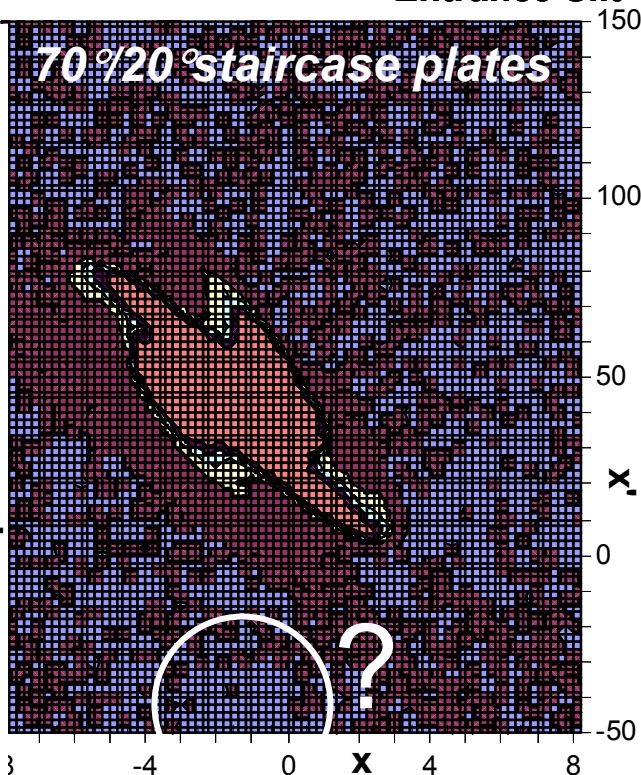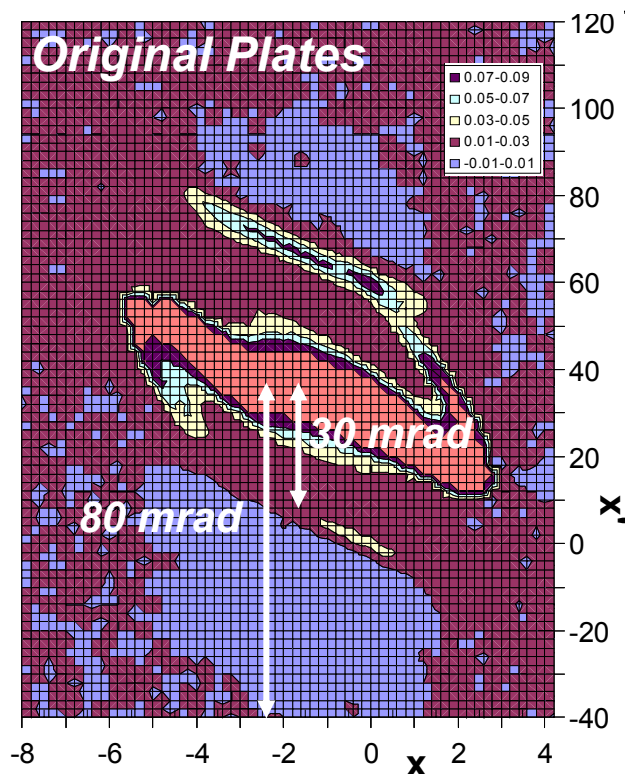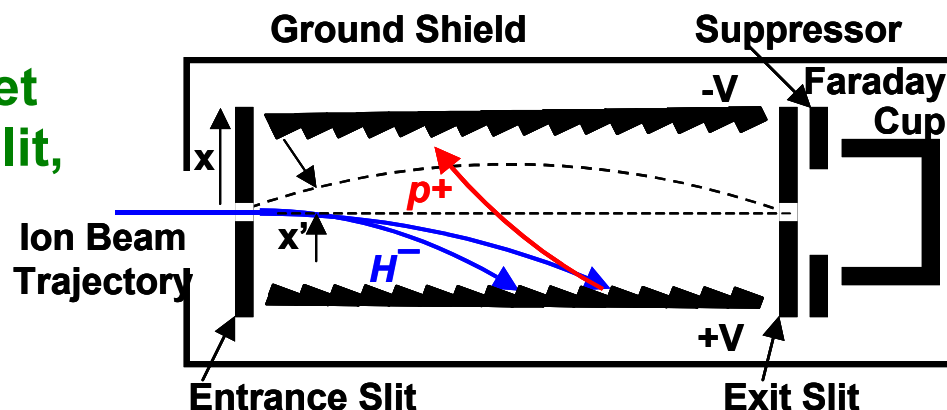➢**Ghosts signals skew rms-emittances and make them even more sensitive to thresholds!**

> **The ghosts need to go!**

> **Lets call the Ghostbusters!**

Is Ghost Busting Trickery?

The symmetry with respect to the beamlet passing through the entrance slit, and the 30 mrad ghost-free gaps suggested protons backscattered from the deflector plates.

Ground Shield **Suppressor**

-V **Faraday Cup**

x

p+

Ion Beam Trajectory

x'

H⁻

+V

Entrance Slit **Exit Slit**

Original Plates

- 0.07-0.09
- 0.05-0.07
- 0.03-0.05
- 0.01-0.03
- -0.01-0.01

30 mrad

80 mrad

x

70 %20° staircase plates

?

X

x

▸**Using deflector plates with a staircase shaped surface changes the impact angles to close to normal, stopping the forward momentum.**

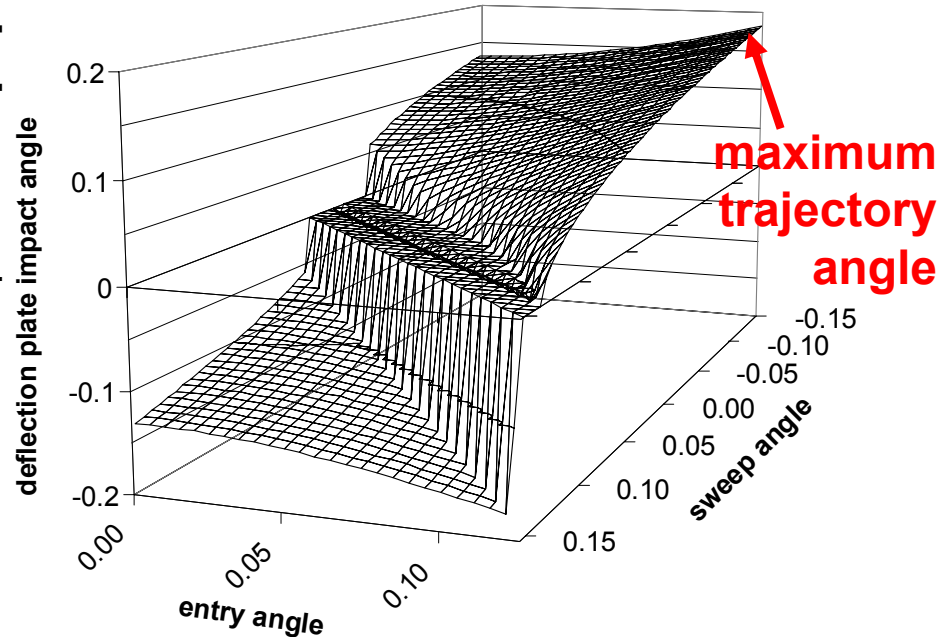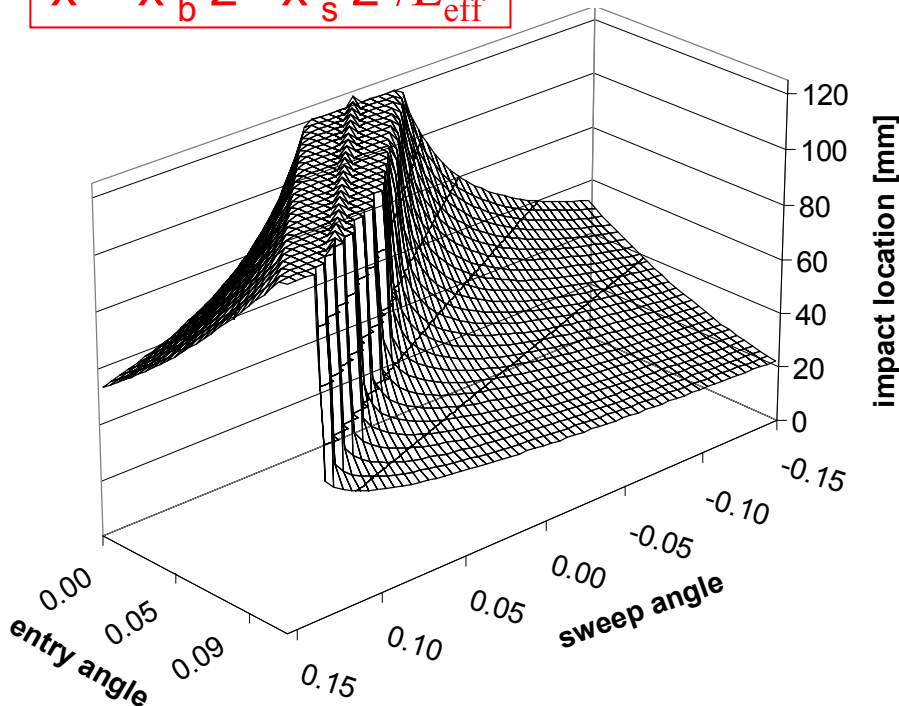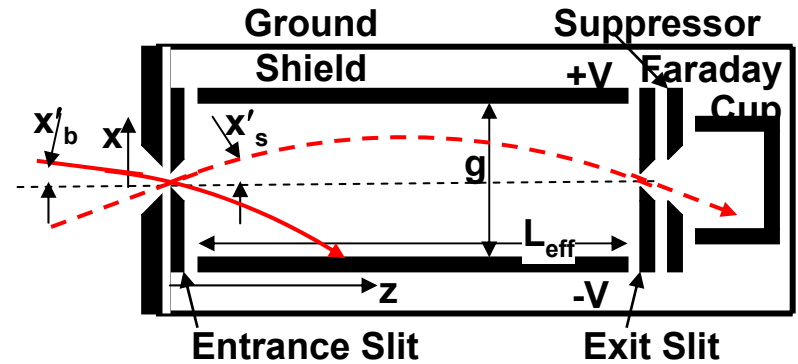But are the ghost signals completely gone?

No, Ghost Busting is Science!

$$x = x'_s \cdot z - V \cdot z^2/(2 \cdot g \cdot U)$$

For $x(z = L_{eff}) = 0$: $x'_s = V \cdot L_{eff}/(2 \cdot g \cdot U)$

And for $x_{max} = g/2$: $x'_{max} = 2 \cdot g/L_{eff}$

$$x = x'_b \cdot z - x'_s \cdot z^2/L_{eff}$$

Exit slit: $z_{ie} = L_{eff}$ for $|x'_s - x'_b| \leq g/(2 \cdot L_{eff})$ $x'_{ie}(z = L_{eff}) = x'_b - 2 \cdot x'_s$

Upper plate: $z_{iu} = (x'_b - (x'^2_b - 2 \cdot x'_s \cdot g/L_{eff})^{1/2}) \cdot L_{eff}/(2 \cdot x'_s)$ $x'_{iU} = (x'^2_b - 2 \cdot x'_s \cdot g/L_{eff})^{1/2}$

Lower plate: $z_{iL} = (x'_b + (x'^2_b + 2 \cdot x'_s \cdot g/L_{eff})^{1/2}) \cdot L_{eff}/(2 \cdot x'_s)$ $x'_{iL} = -(x'^2_b + 2 \cdot x'_s \cdot g/L_{eff})^{1/2}$

The Ghostbusters did it again!

The largest reasonable trajectory angle at impact is **$(8)^{1/2} \cdot g / L_{eff}$**.

➤ It occurs when beamlets with $x'_b = \pm 2g / L_{eff}$ (the geometrical acceptance limit) are scanned with $x'_s = -x'_b$, the opposite geometrical acceptance limit.

Ground Shield — Suppressor — +V — Faraday Cup — x'_b — x — x'_s — g_{eff} — L_{eff} — z — -V — Entrance Slit — Exit Slit

➤ For our scanner this is ~10°, less than the 20° staircase angle of our new deflection plates.

⇒ **All particles impact on the faces of the stairs!**
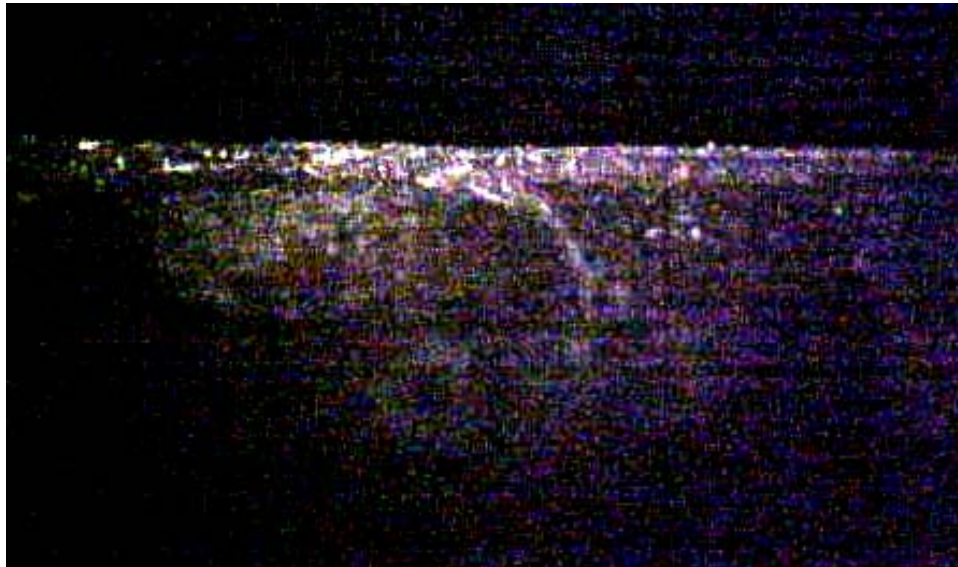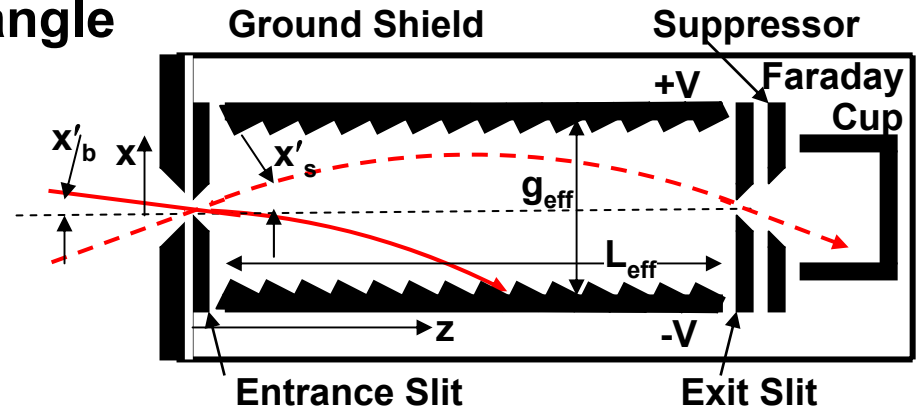
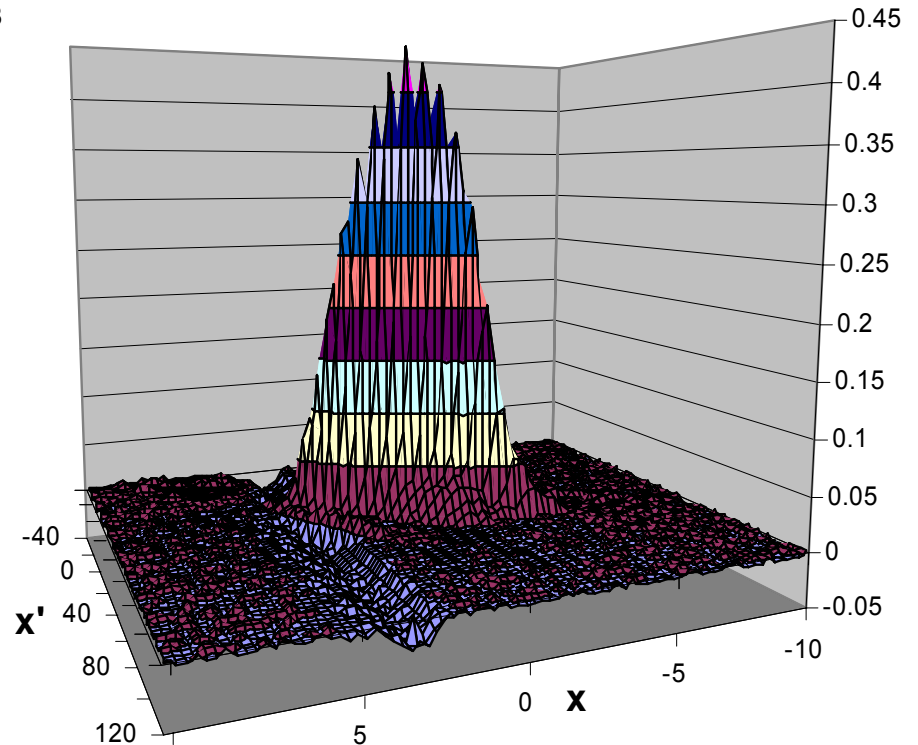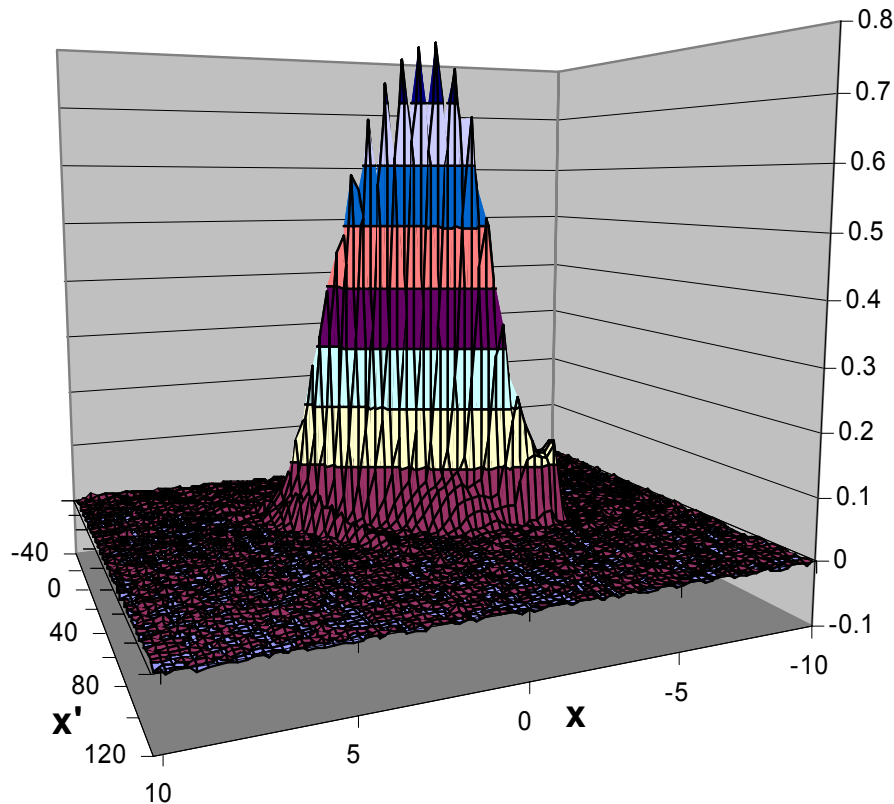➤ An optical comparator suggest rough edges with a width of ~1 mil.

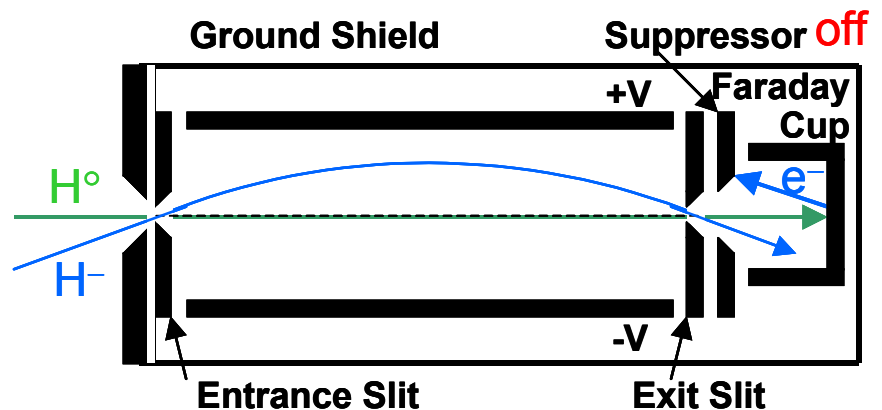➤ The steps are 1 mm high, ~115 mils apart.

⇒ **>99% of ghosts eliminated!**

A 10° staircase angle could reduce the ghosts by another factor of 2!

Neutral Beam Detection with Allison Scanners

Switching off the suppressor reveals the neutral beam and possible alignment problems!

Ramping up SNS

Accelerator Availibility and Operation
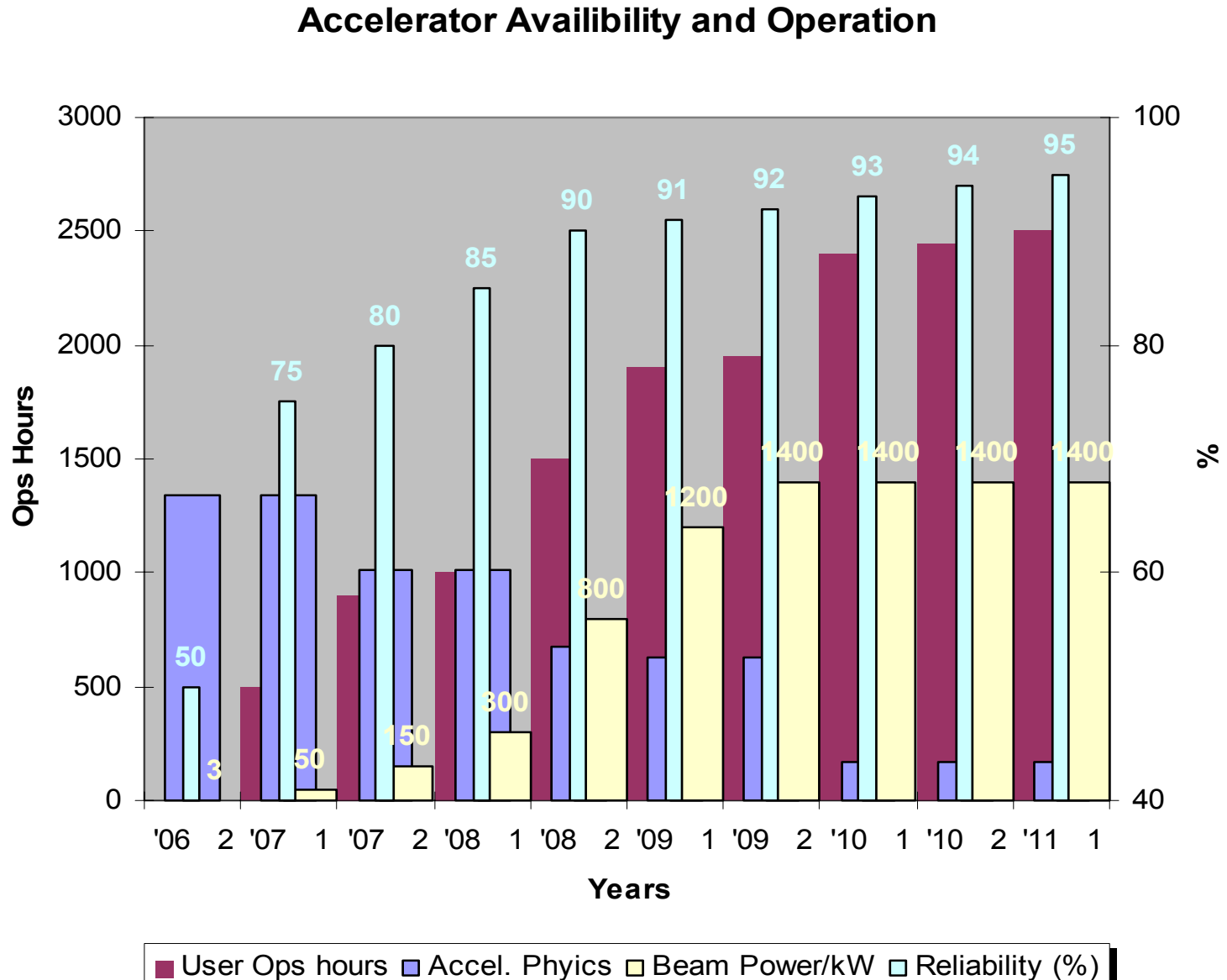
The Ion Source Test Stand

- The SNS ion source group's main job is to support operation of the Front-End ion source and LEBT.
- In our spare time (and with a spare budget) we duplicate the ion source and LEBT.
- The controls group implements computer control and archiving in their spare time.
- The built-up test stand became our work horse thanks to unattended operation. Tests can run 24 hours a day, 7 days a week.

Front-End Test Stand

Front-End Building

- When a problem is sensed, the system turns off in a fail-safe manner.
- In emergencies it can also be stopped and isolated from the outside.
- It is used to test new configurations, new cesiation procedures, new diagnostics, and to test the ion source and LEBT for 1.4 MW operations.
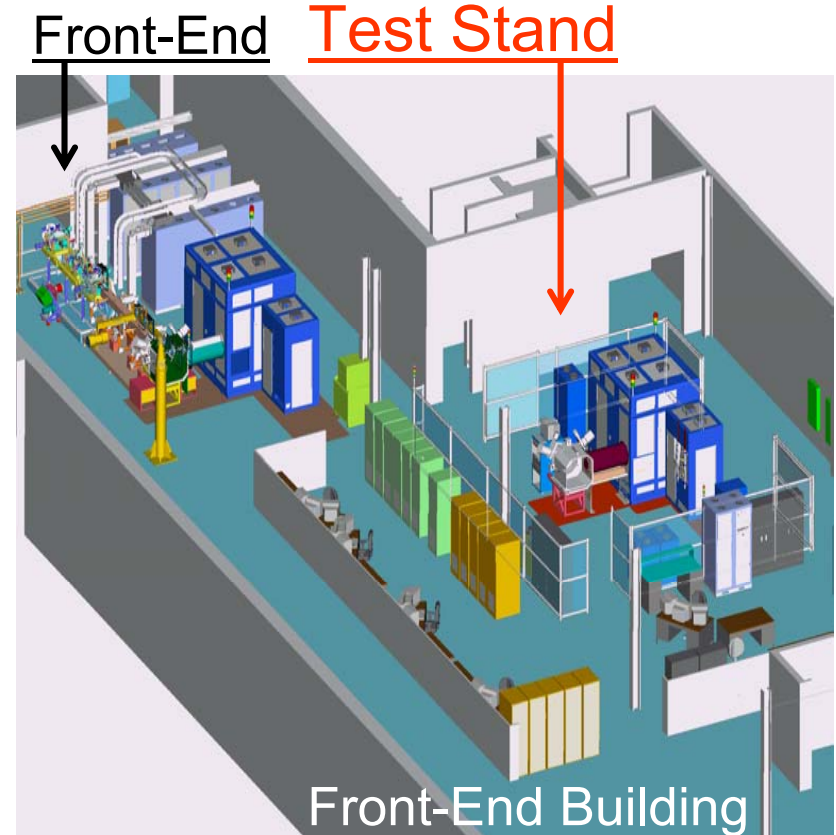
Ramping up the Ion Source on the Test Stand
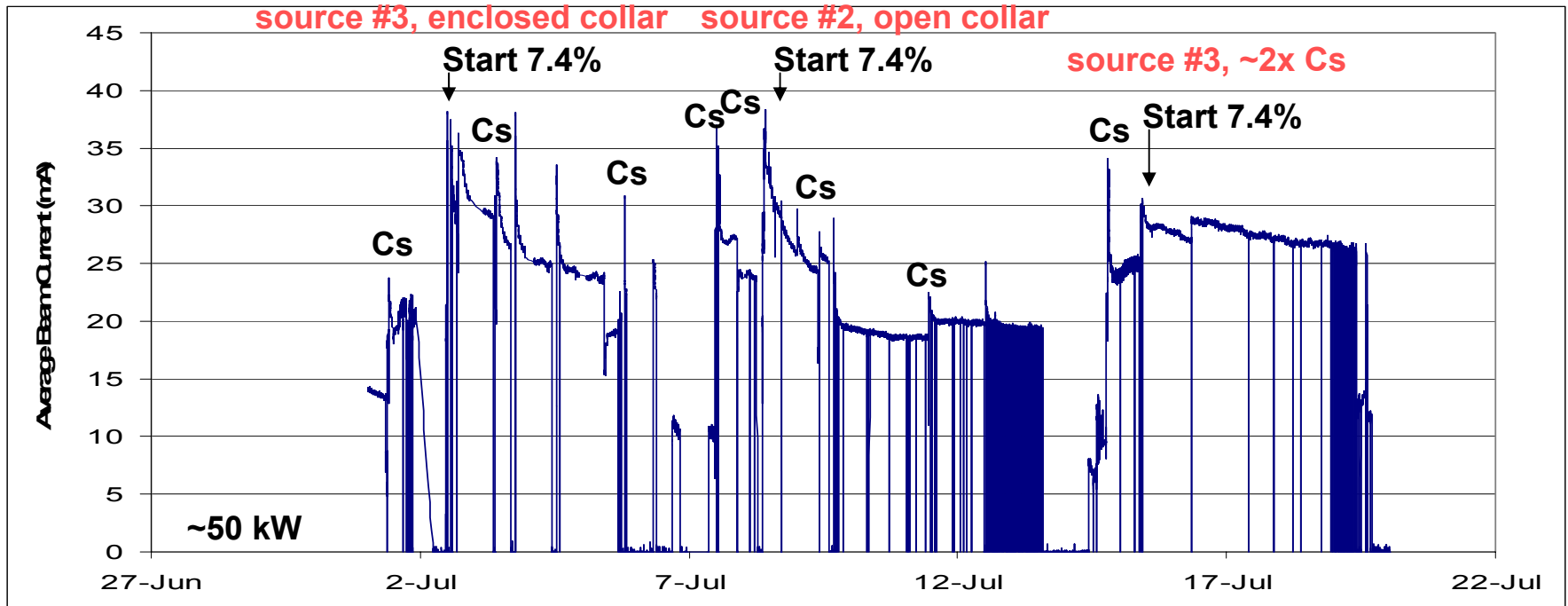
- MEBT peak currents of ~50 mA have been measured for short pulses.
- 40 mA LEBT currents have been measured for 1.23 ms pulses.
- But when operating at 60 Hz and 1.23 ms, the source produced only 20 to 30 mA for a few hours to a few days.
- Problem: Cs is supplied by heating the Cesium collar to ~ 550 C.
- Highest ion output expected ~ 300 C.
- However, above 200 C, $CsCrO_4$ reacts with O, N, H_2O, etc.

Ramping up the Ion Source on the Test Stand

Keeping the cesium collar below 200 C solves the problem:
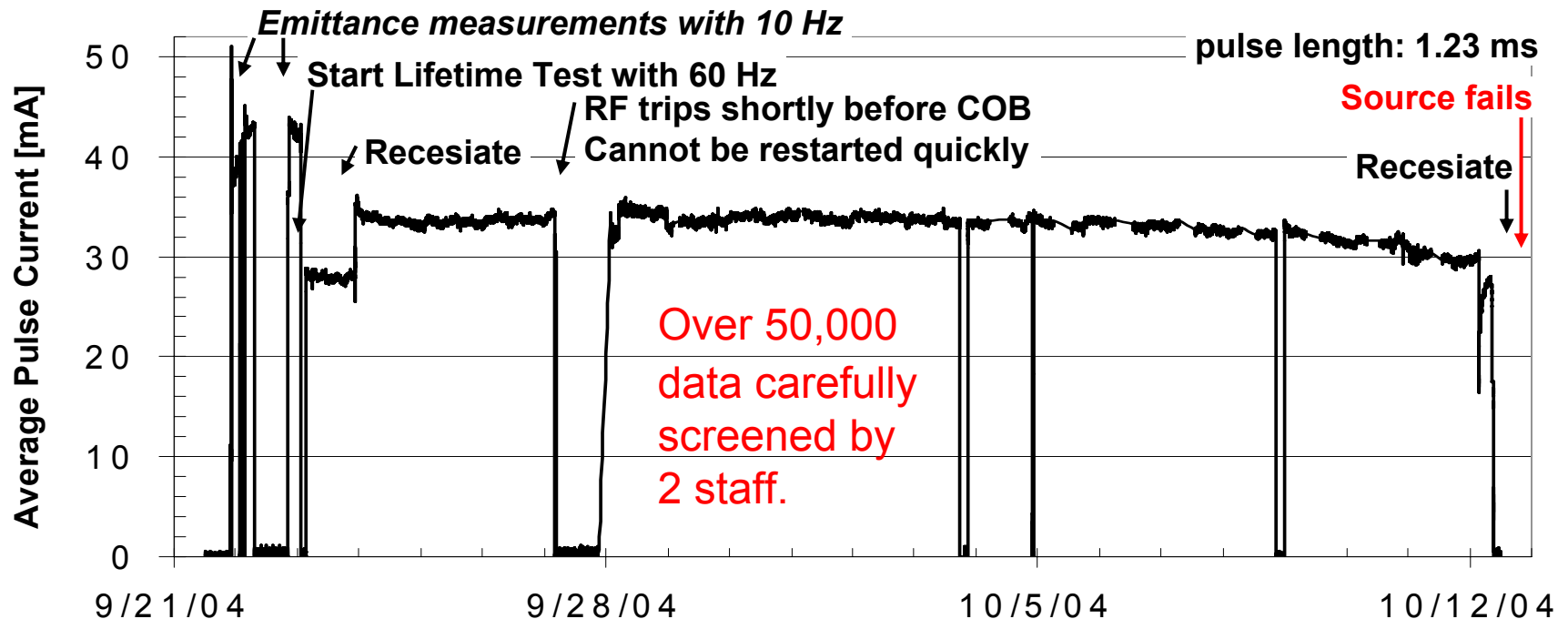
- Increasing to 60 Hz reduces ~40 mA output to ~ 30 mA.
- Only 4 trips during 19.2 day lifetime test.
- 16.4 effective days with $\geq$ 30 mA, with an average of 33.3 mA.
- Current varies by only $\pm$1.0% over 24 hour period ($\pm 1\sigma$).
- $\geq 85 \cdot 10^6$ flawless pulses extracted with $\geq$ 30 mA.

SNS Power Upgrade

Table 1. SNS baseline, upgrade, and ultimate parameters

	Baseline	Upgrade	Ultimate
Kinetic energy, E_k [MeV]	1000	1300	1400
Beam power on target, P_{max} [MW]	1.4	3.0	5.0
Chopper beam-on duty factor [%]	68	70	70
Linac beam macro pulse duty factor [%]	6.0	6.0	6.0
Average macropulse H- current [mA]	26	42	65
Peak current from front-end system	38	59	92
Linac average beam current [mA]	1.6	2.5	3.9
SRF cryomodule number (med-beta)	11	11	11
SRF cryomodule number (high-beta)	12	12 + 8 (+1 reserve)	12 + 8 (+1 reserve)
Number of SRF cavities	33+48	33+80 (+4 reserve)	33+80 (+4 reserve)
Peak gradient, E_p (β=0.61 cavity) [MV/m]	27.5 (+/- 2.5)	27.5 (+/- 2.5)	27.5 (+/- 2.5)
Peak gradient, E_p (β=0.81 cavity) [MV/m]	35 (+2.5/-7.5)	31	34
Ring injection time [ms]/turns	1.0 / 1060	1.0 / 1100	1.0 / 1110
Ring rf frequency [MHz]	1.058	1.098	1.107
Ring bunch intensity [10^{14}]	1.6	2.5	3.8
Ring space-charge tune spread, ΔQ_{sc}	0.15	0.15	0.2
Pulse length on target [ns]	695	691	683

(Assuming 4% injection loss to dump, 4% target window loss, and linac maximum of 20° phase.)

SNS Power Upgrade

Transfer line in tunnel + Waveguide chases already in place

131 ``

Tunnel + Klystron Gallery 1 GeV point

HEBT Service Building
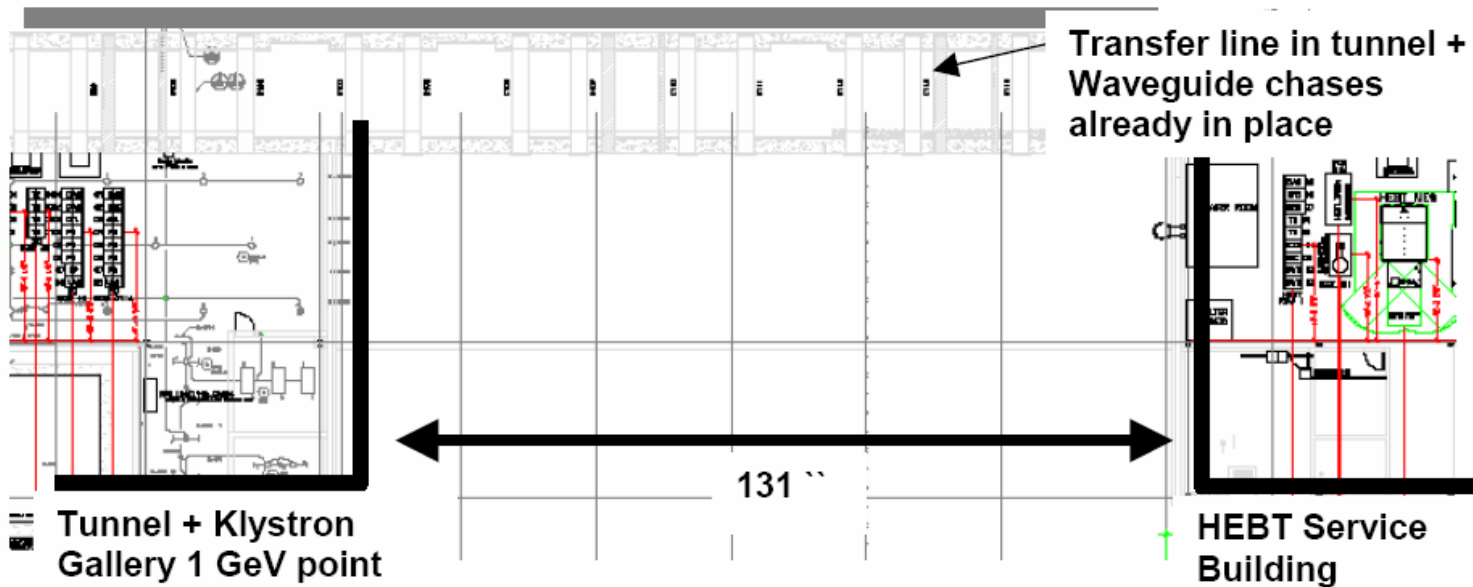
Fig. 1: This January photo shows the gap in the klystron gallery between the linac and the high-energy beam transport (HEBT) Service Building. The existing gallery wall (left) and the HEBT service-building wall (right) are visible. The concrete slab and waveguide chases in the klystron gallery, as well as the complete helium distribution line in the tunnel, are already in place.

Beam Current requirements for SNS Power Upgrade

PARMTEQ and TOUTATIS predict for our RFQ a transmission that decreases with input current and emittance.

Our best emittance measurements show the LEBT output emittance to increase roughly linear with beam current.

RFQ transmission for different input beam emittance

Emittance = .1;.15;.2;.25;.3;.35;.4 mm mrad

PARMTEQ
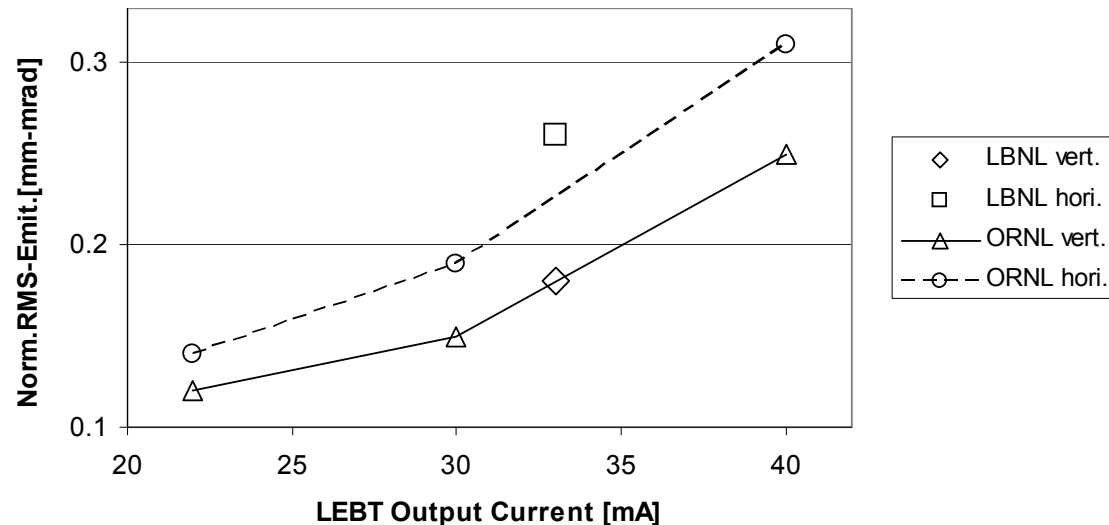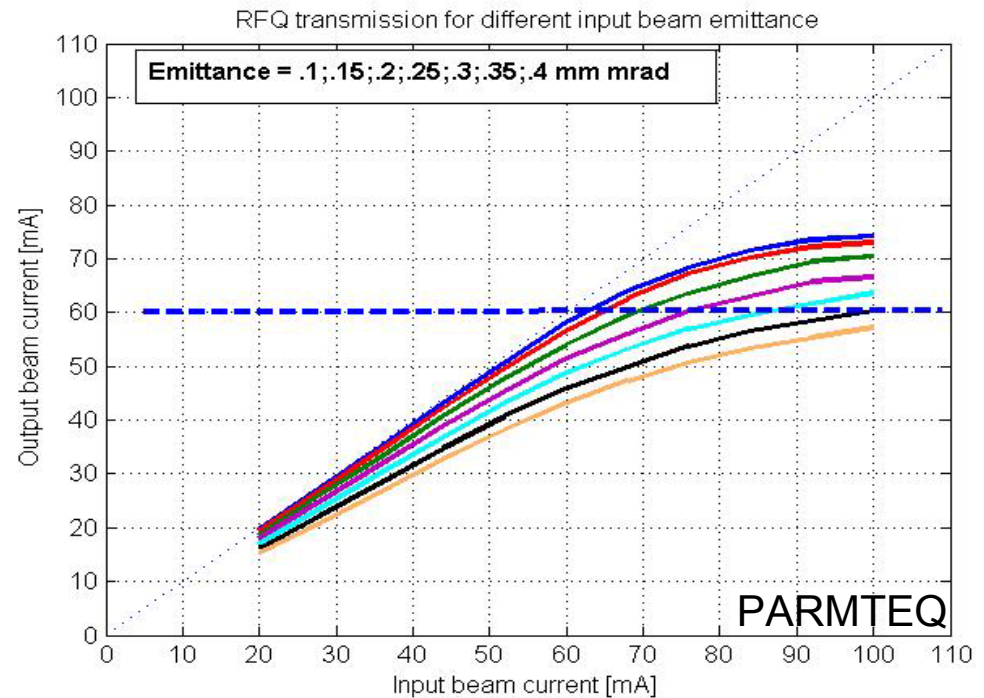
Beam Current requirements for SNS Power Upgrade
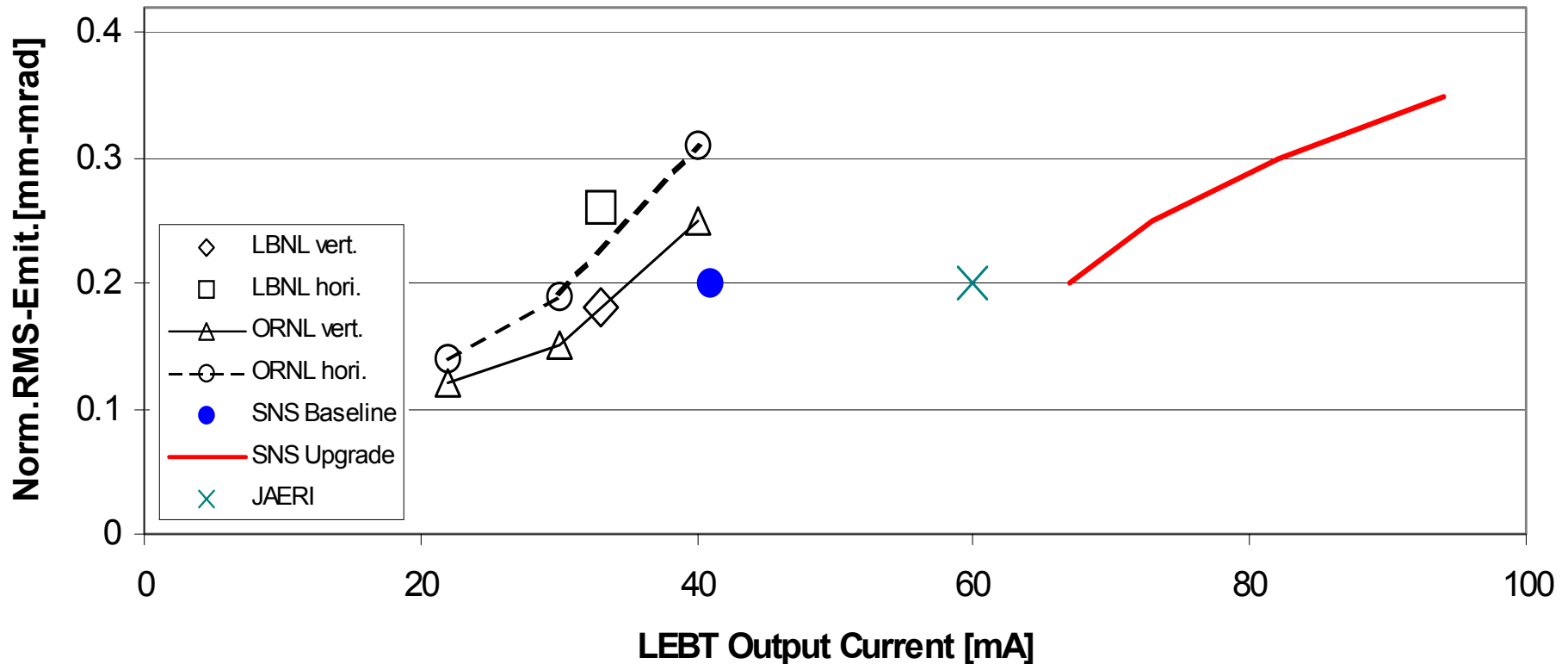
> The required LEBT output current depends strongly on the emittance.
> Our baseline ion source and LEBT are not on track to meet the requirements.
> The JAERI source may meet the requirements. Emittance was measured without LEBT.
> We need to measure the emittance of our source without LEBT!

H⁻ Ion Source and LEBT Upgrade: The 2-source option

Ion source

Quad 1

Quad 2

Extraction & pump cross

Diagnostics & pump cross

3 sets of scrapers

Double focusing switching magnet

3 pairs of vertical deflectors

Diagnostics & pump cross

Gate valve

Solenoid lens

Chopper

Existing RFQ
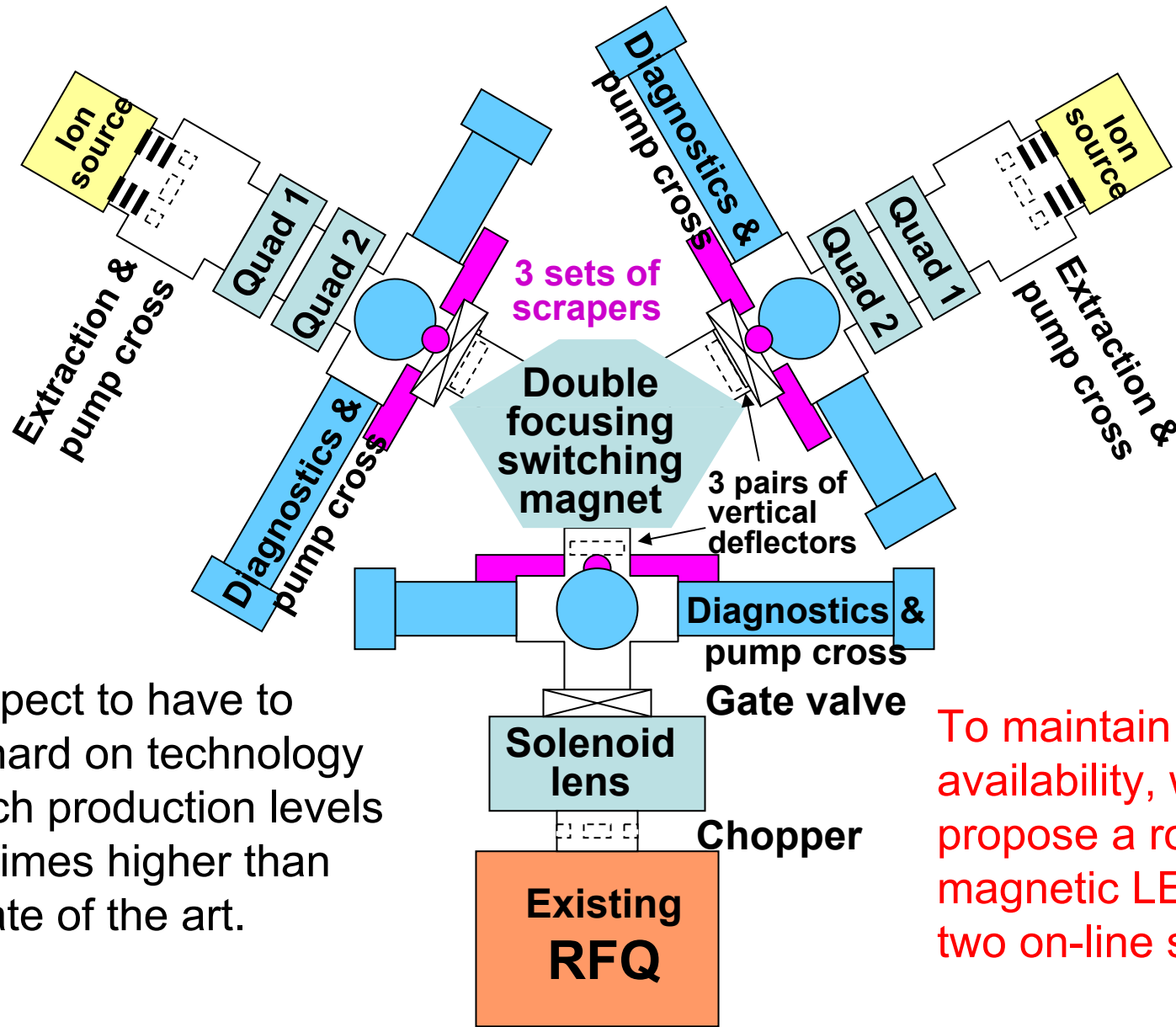
We expect to have to push hard on technology to reach production levels three times higher than the state of the art.

To maintain a high availability, we propose a robust magnetic LEBT with two on-line sources!

H⁻ Ion Source and LEBT Upgrade: The 2-source LEBT

BEAM AT NEL1=   1

H A= 0.00   B=0.588E-01
V A= 0.00   B=0.588E-01

2.000mm x 20.000mrad

Z A= 0.00   B=0.740E+08

180.000Deg x 100.000KeV

NP1=   1   15.00 mm (Horizontal)********* Deg. (Longitudinal)

I=   0.0 mA
W=   0.0650   0.0650 MeV
FREQ= 425.00 MHz   WL=   705.39 mm
EMITI= 17.000   17.000   0.00
EMITO= 17.000   17.000   0.00
N1=   1   N2= 12

MATCHING TYPE =   8
DESIRED VALUES (BEAMF)
          alpha   beta
x   1.7900   0.0700
y   1.7900   0.0700

MATCH VARIABLES (NC=4)
MPP MPE   VALUE
 1   2   -1.95926
 1   4   3.76160
 1   6   47.28532
 1   10   3430.29632

P B O Lab T R A C E
DATE: 05-05-2005
TIME: 17:17:51

Perfect
match for a fully neutralized beam!

1st order

BEAM AT NEL2= 11

H A= 1.79   B=0.700E-0
V A= 1.79   B=0.700E-0

2.000mm x 40.000mra

Z A=0.148E-06 B=0.286E+1

25.000Deg x 10.000KeV

NP2= 12

Length=   1361.80 mm

Q   Q   E   B   E   SOL

1   2 3 4   5   6   7   8   9   10   11 12

15.00 mm (Vertical)

The Ion Source, a Multi-energy-source system
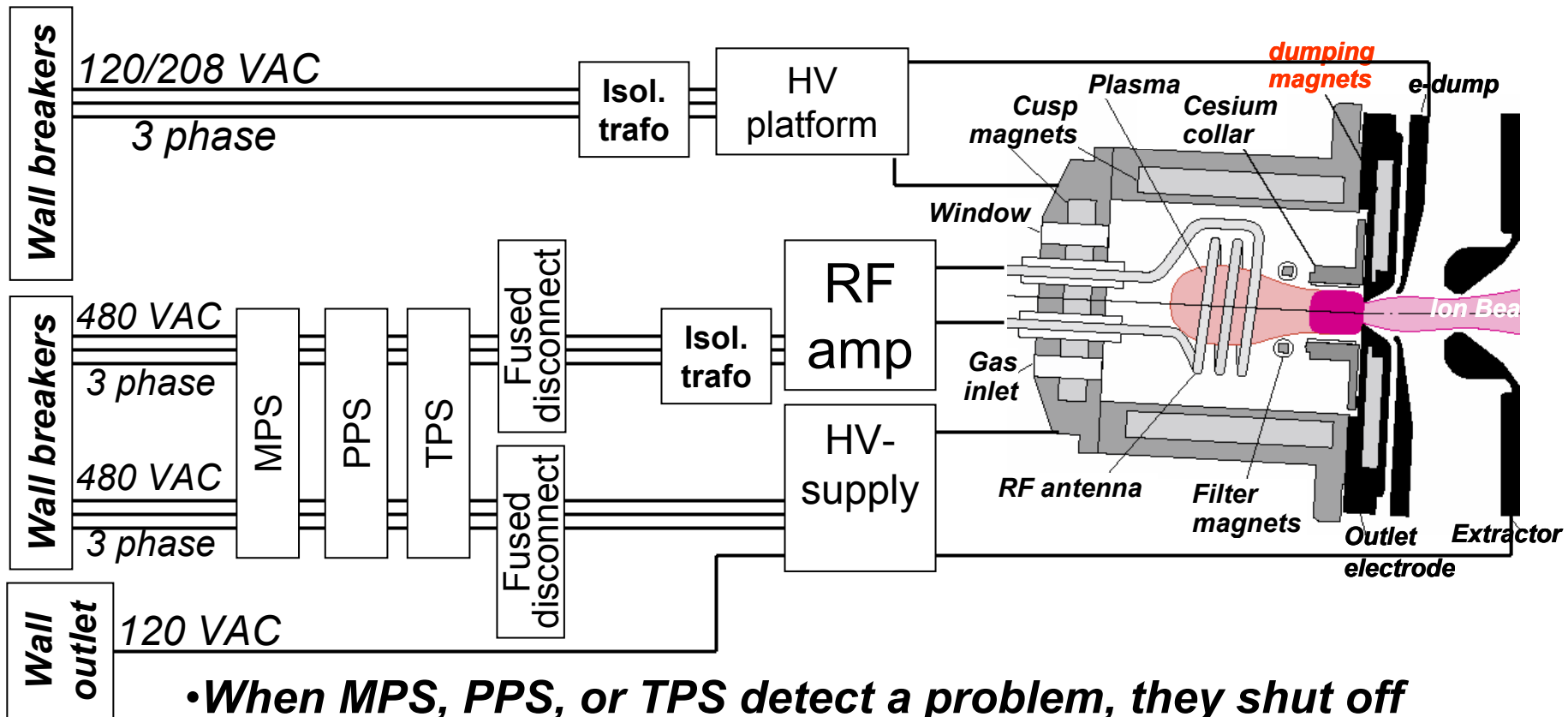
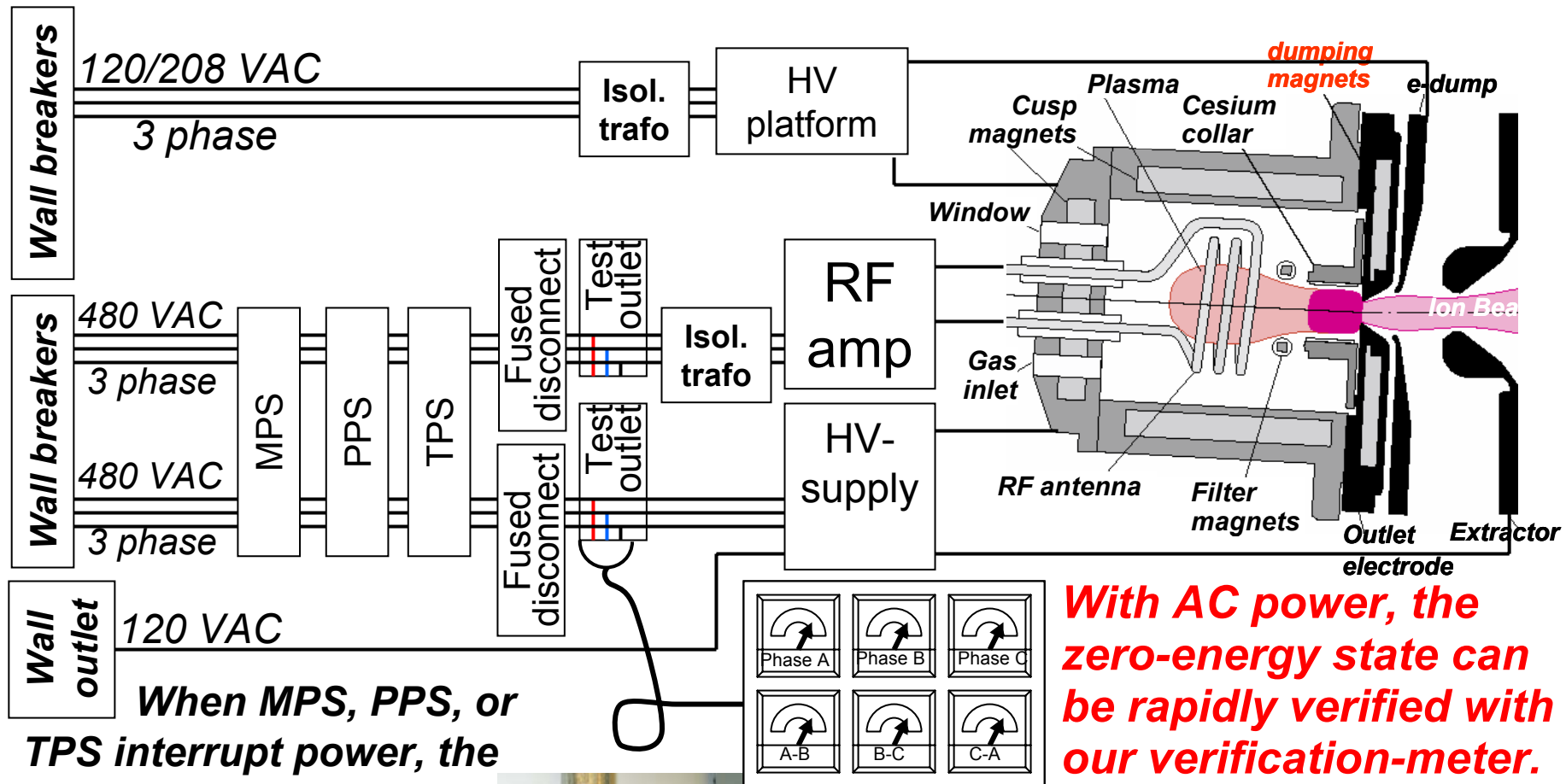- **When MPS, PPS, or TPS detect a problem, they shut off the beam by interrupting the AC to the source HV and RF.**
- **Such power interruptions during the LOTO verification process could lead to false verifications!**
- **The Electrical Group recently installed downstream disconnects.** *We have re-established the ultimate veto!*

Finger-safe LOTO accelerates Troubleshooting!

Wall breakers
120/208 VAC
3 phase

Wall breakers
480 VAC
3 phase
480 VAC
3 phase

Wall outlet
120 VAC

Isol. trafo

HV platform

MPS

PPS

TPS

Fused disconnect

Test outlet

Isol. trafo

RF amp

Fused disconnect

Test outlet

HV-supply

dumping magnets

e-dump

Plasma

Cusp magnets

Cesium collar

Window

Ion Beam

Gas inlet

RF antenna

Filter magnets

Outlet electrode

Extractor

Phase A | Phase B | Phase C

A-B | B-C | C-A

When MPS, PPS, or TPS interrupt power, the fused disconnect needs to be visually verified, wearing required PPE. Downstream test outlets were installed!

With AC power, the zero-energy state can be rapidly verified with our verification-meter.

After verification, multi-meter needs to be verified at an active outlet.

This is finger-safe! It is faster! It is safer!

Conclusions

➢ In 2006 SNS will start to operate at low power to test out the target, the instruments, and to do physics experiments.

➢ First users are welcome in 2007. The power and reliability will be ramp up over several years.

➢ Around 2009 we will shut down for ~6 month to double the neutron yield.

➢ After 2009 the ion source group should be able to sleep through the night because we can fix the source first thing in the morning.

➢ We will continue our efforts to increase output and reliability, while reducing the emittance.

Thank you for your attention!

11TH INTERNATIONAL SYMPOSIUM ON THE PRODUCTION AND NEUTRALIZATION OF NEGATIVE IONS AND BEAMS

SANTA FE, NEW MEXICO USA

13–15 SEPTEMBER 2006

However, to make this a truly international meeting, we need travel support for our colleagues from less fortunate countries!