Ion Source

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Accelerator Advisory Committee Review

Oak Ridge, TN

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- R&D to Replicate Source #3
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SNS AAC Executive Summary 2012

- 1.2 Ion source and LEBT
- The Ion Source group has made good progress over the past two years. Although the downtime from source failures is now the highest among accelerator systems, good progress with the source and LEBT has been made, improving source reliability over the years. Additionally, progress is being made in understanding the performance of the source, which indicates a path toward achieving the needed performance.
- Of the three factors which must be addressed to accomplish the power ramp up to 1.4 MW, one is the stable and predictable operation of the source, at current levels already achieved, but not demonstrated by any of the sources over a period of time. Thus fundamental improvements must be made to the sources.
- We note that there are a number of well thought out, important R&D items for the source that are being considered. In the short term we recommend focusing on the more limited program of thoroughly understanding the issues with the present sources, as this will address issues related to present operation and lay the foundation for proposed future developments.

SNS AAC Review Report 2012

5.1 Findings

- The Ion Source group has made good progress over the past two years. Although the downtime from source failures is now the highest among accelerator systems, good progress with the source and LEBT has been made, improving source reliability over the years. Additionally, progress is being made in understanding the performance of the source, which indicates a path toward achieving the needed performance.
- SNS has been able to implement a 6-week source service cycle which eliminates one source change per run.

5.1.1 Reliability Issues

- The primary cause of source downtime has been antenna failures. The Ion Source Group believes the failures are at the leg bends which penetrate into the plasma. A new design has been implemented and will be tested in early 2012. Source leak and contamination issues have been investigated, and solutions include careful handling of sources in a class 10,000 clean room, and more rigorous procedures.
- RF issues have been addressed by installing a high-voltage insulated RF transformer. A production 2 MHz high voltage isolation transformer has been in operation since July 2010, and there is a plan to provide a 13 MHz transformer to allow operation of the 13 MHz amplifier system at ground potential.
- LEBT reliability has been improving; an ongoing carefully proceduralized approach to maintenance has been implemented and should be tracked to ensure that the trend continues.

5.1.2 Performance Issues

- Ion sources have performed at the levels needed for present operation, and for the 1.4MW ramp-up. However, performance is not predictable, and the different sources, which ostensibly are the same design, behave differently. A carefully developed program to understand these issues is needed, and in fact is being pursued by the ion source group. The components of the program include:
- Careful understanding and documentation of any differences among the existing sources. This includes not only observable differences, but also differences in the way the sources have been handled, which could lead to different surface properties.
- Ongoing careful understanding of LEBT alignment issues. Alignment issues may be behind the differing beam and electrical performance.
- Development of test stands to support the above.

SNS AAC Review Report 2012

5.2 Comments

- With substantial improvements to the reliability of the High Voltage Converter Modules, the ion source has become the leading contributor to downtime in the period from FY2011 to date. While the ion source and LEBT are now the most significant contributor to downtime, this metric masks the fact that improvements have been made in source reliability over the last few years, and the committee acknowledges this progress.
- Additionally, of the three factors which must be addressed to accomplish the power ramp up to 1.4 MW, one is the stable and predictable operation of the source, at current levels already achieved, but not demonstrated by more than one of the sources over a period of time. Thus fundamental improvements must be made to the sources.

5.3 Recommendation

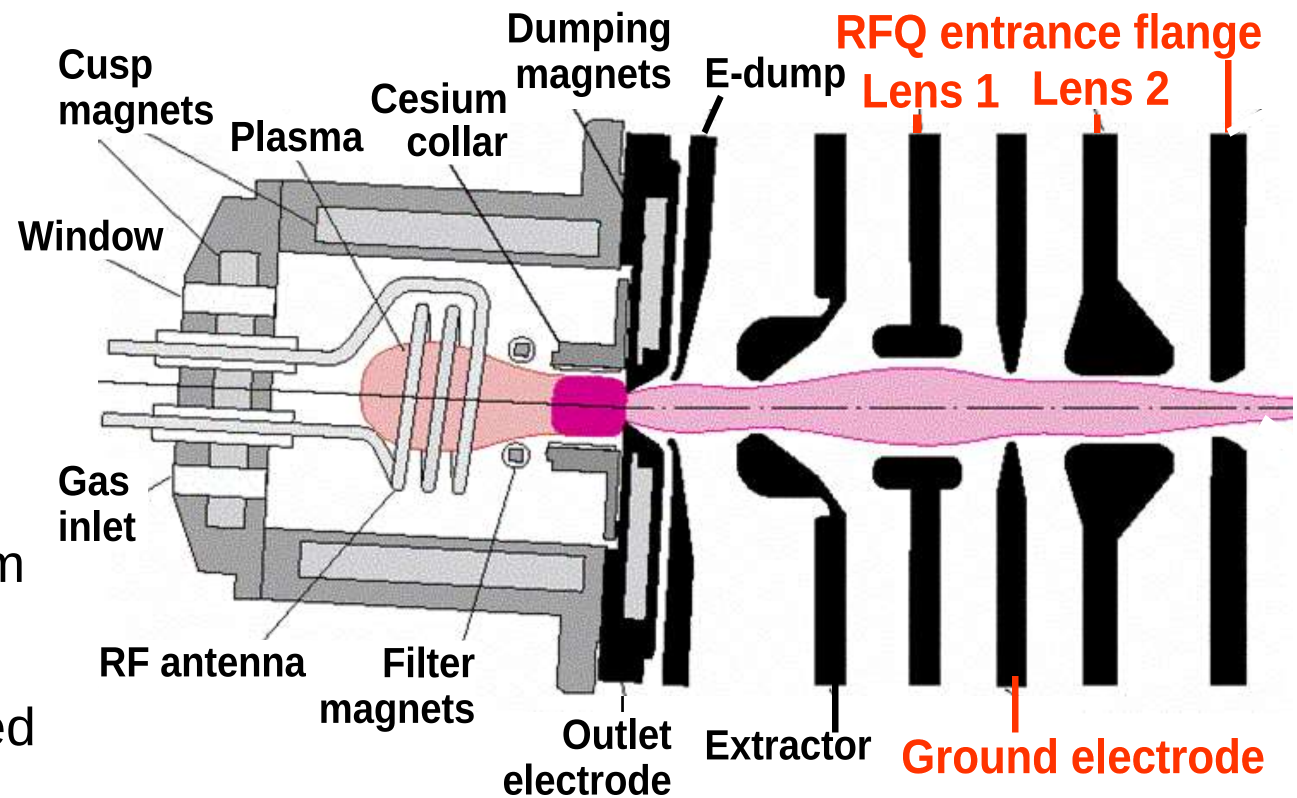
- We note that there are a number of well thought out, important R&D items for the source that are being considered. In the short term we recommend focusing on the more limited program of thoroughly understanding the issues with the present sources as noted above, as this will address issues related to present operation and lay the foundation for proposed future developments.

Production Run (CY)	Duty cycle %	Pulse length ms	mA required	mA in MEBT	RF [kW]	tilt deg	Random Antenna Failures^	%Availability#	Comments
2006-1		~.1	20	28-20	~70	3	0	99.9	1 ion source, 1 cesiation, raise collar temp
2006-2	0.2	~.25	20	30-16	~70	3	0	99.98	1 ion source, 1 cesiation + 24h @115°C
2007-1	0.8	~0.4	20	20-10	60-80	3	1*(37)	70.6	Arcing LEBT; punctured antenna* after 37 days, start 2-week source cycles
2007-2	1.8	~0.5	20	13-20	80	3	0	97.2	Modified lens-2; e-target failures; tune for long pulses
2007-3	3.0	~0.6	25	25-30	35-50	3	0	99.65	modified Cs collar (Mo converter)
2008-1	3.6	~0.6	25/30	20-37	uncal	3	1 (6)	94.9	Restore matching network; new tube; Beam on LEBT gate valve
2008-2	4.0	0.69	32	32-38	48-55	3	1 (9)	99.22	Start 3-week source cycles; Ramp up e-dump & collar temperature
2009-1	5.0	0.8	35	34-38	~50	3	2 ExAn + 1 (8)	97.52	Start "Perfect Tune"; use external antenna$ source for 1st 8 weeks; start 7.2% conditioning
2009-2	5.1	0.85	38	42-26	~55	0	1 (1)	98.84	Start replacing LEBT, slim extractor; start 4-week cycles; 2 MHz degrades; plasma outages at end
2010-1	5.4	0.9	38	39-30	~60	0	1*(11) +1(>4)+ 1(0)	96.80	Repair and tune-up RF; punctured antenna* to beam back in ~6 hours; lens-1 & e-dump breakdowns;
2010-2	5.4	0.9	38	46-36	<55	0	2(10) +1(3) +2(0)	~98.5	Replace 1.6 µH with two 1 µH inductors; start 2 MHz on ground
2011-1	5.4 4.4	0.9 0.73	38	38-30	~60	1.5	1(22) +1(6) +1(2)	98.2	Double LEBT pumping; start frequency hopping; source leaks by electric arc & by plasma heating; start 6% conditioning
2011-2	4.4 5.3	0.73 0.88	38	38-30	~55	0	1*(>5) 1 (9)	98.7	*start of run; contamination of #2 & 4; 6 week #3 run; start rigorous antenna selection & Dc% conditioning
2012-1	5.3	0.88	38	38/34	~60	3	0	99.3	6/2 week cycles with source 3&4
2012-2	5.3	0.88	30-34	30-35	~60	3	0	99.7	start to measure LEBT & converter temperature
2013-1	5.3	0.88	30-34	30-35	~60	0/1.5	1 (11)	99.3*	5.3 week run with #4; *until 4-26-13
^(lifetime of failed antenna)									

2012: No freak leaks or contamination, reduced conditioning duty cycle & improved antenna QA lowered IS & LEBT downtime % by a factor of 3!

The SNS Baseline Ion Source and LEBT

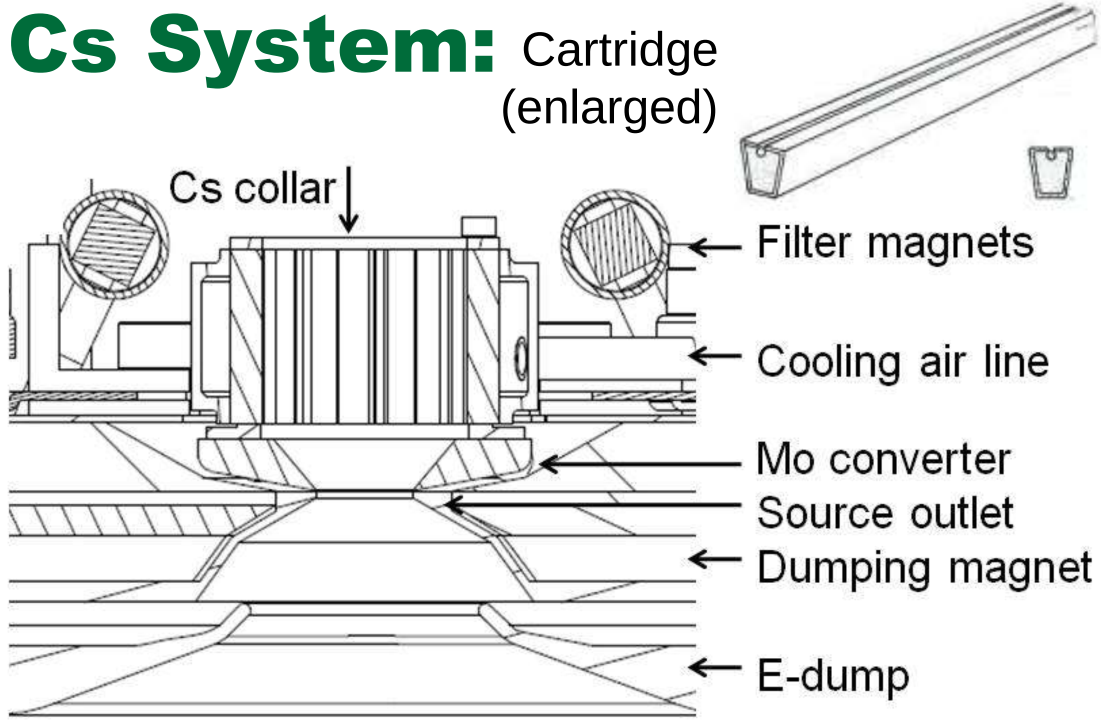
- LBNL developed the SNS H^- ion source, a cesium-enhanced, multicusp ion source.
- Typically 300 W from a 600-W, 13-MHz amplifier generates a continuous low-power plasma.
- The high current beam pulses are generated by superimposing 50-70 kW from a pulsed 80-kW, 2-Mz amplifier.



- The two-lens, electro-static LEBT is 12-cm long. Lens-2 is split into four quadrants to steer, chop, and blank the beam.
- The compactness of the LEBT constrains beam characterizations in front of the RFQ. The beam current is measured after emerging from the RFQ, which equals the LINAC beam current.
- Measuring the chopped beam on the RFQ entrance flange shows ~50 mA being injected into the RFQ under nominal conditions.

While there remain issues, this is a record breaking injector!

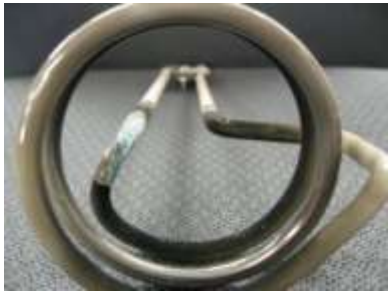
A highly efficient Cs System:



- To minimize Cs-induced arcing in our ultra-compact LEBT and the nearby RFQ, LBNL introduced 8 Cs_2CrO_4 cartridges (SAES Getters), which together contain **<30 mg Cs**. They are integrated into the Cs collar. The system **compactness allows for rapid startups**!
- The Mo ion converter is electrically and thermally attached to the Cs Collar. The temperature of the system is controlled with heated air.
- Right after being evacuated, the system is outgassed at 250°C and the Mo converter is sputter-cleaned for ~3 hours. Then the collar is heated for 12 minutes to 550°C to release **~4 mg of Cs**. Then the temperature is lowered to ~170°C. This appears to produce a nearly optimal monolayer of Cs, which appears to become persistent.
- Sometimes the beam decays a little for a few hours.
- Normally the H^- beam grows a little for a few days.
- Then the beam becomes persistent, free of decay!

In 6-week service cycles we produce >9 kC or >2.5 A·h of H^- ions.

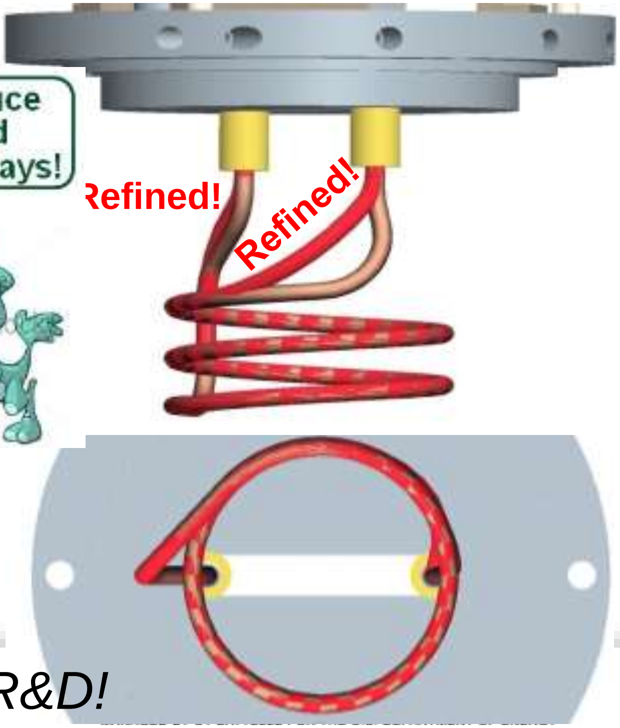
The SNS Antenna Problem



- In 2009 the conditioning duty cycle was raised to 7.2 %.
- In 2010, when the RF **power was raised to ~60 kW and** the source **pulse length to 0.9 ms**, the **antenna failures increased** from ~1 per run **to ~3 per run**.
- Most antennas fail within the first week of operation, long before the end of the typical 4-week service cycle, consistent with **infant mortality**.
- Failure analysis shows that ~77% of antennas fail in the leg bends, which penetrate into the core of the plasma. Apparently **plasma heating** of **high porosity porcelain** can melt and **destroy** the porcelain **insulation**.

To reduce the number of antenna failures we

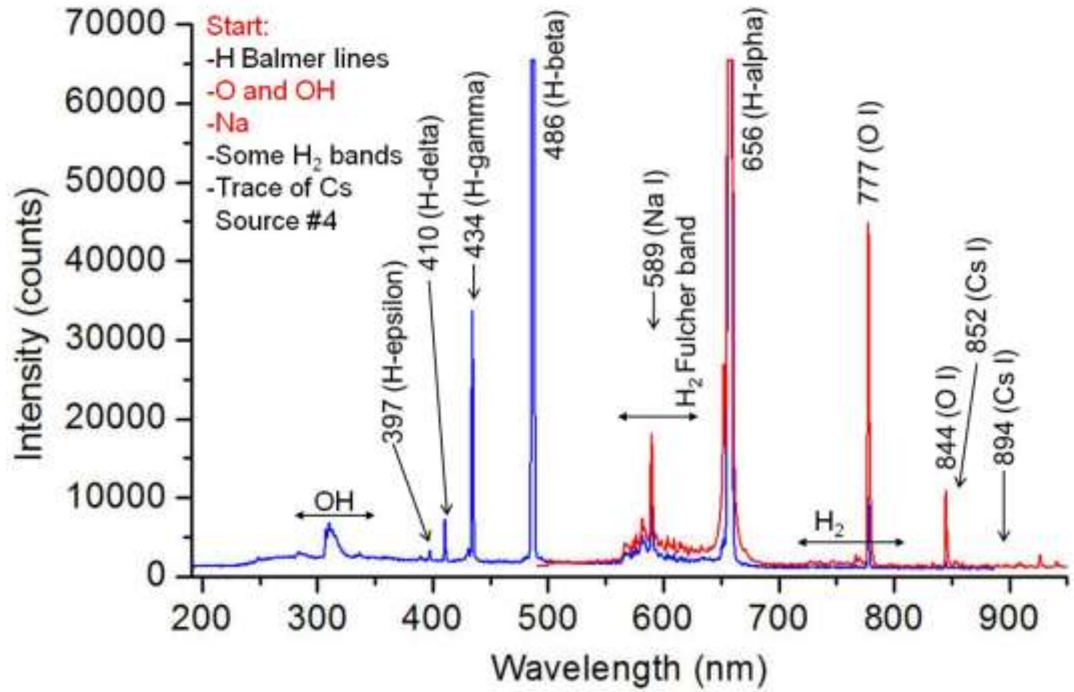
1. Reduced the conditioning duty cycle
2. Select the antenna with the least defects for production runs
3. CP cleaned up the coating process
4. **Try power-testing antennas before production runs** (in progress)
5. **Are developing an external antenna source**
6. Will test refined wide leg antennas where the legs do not penetrate the plasma core
7. Will test thinner porcelain coatings
8. Will try to extend the source service cycle

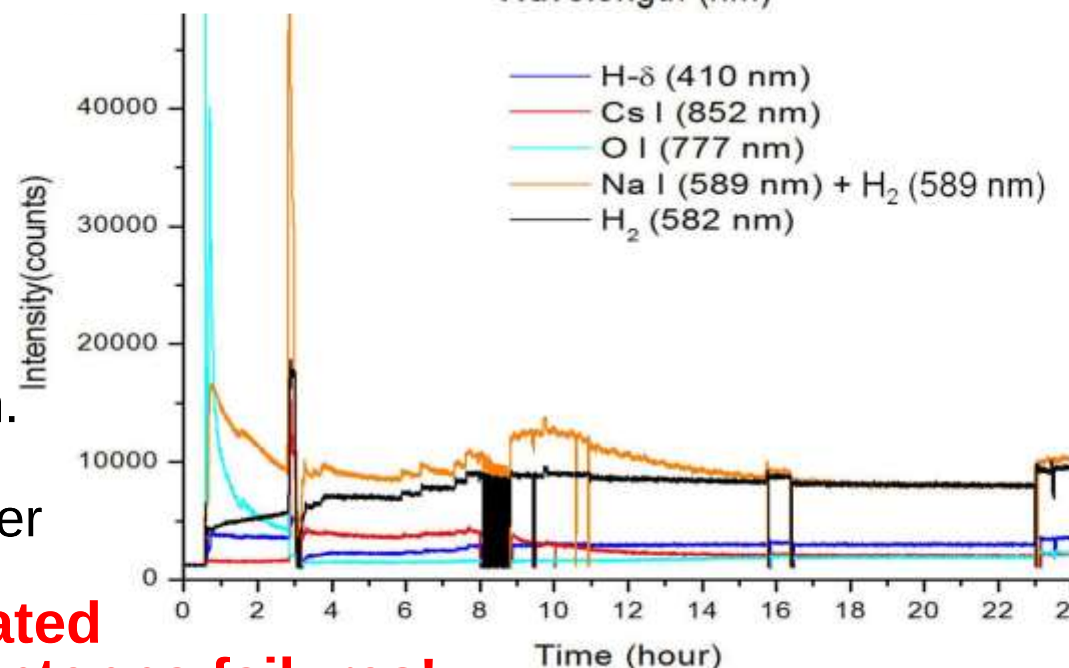


The 2012 focus on performance suspended antenna R&D!

Power Testing Antennas

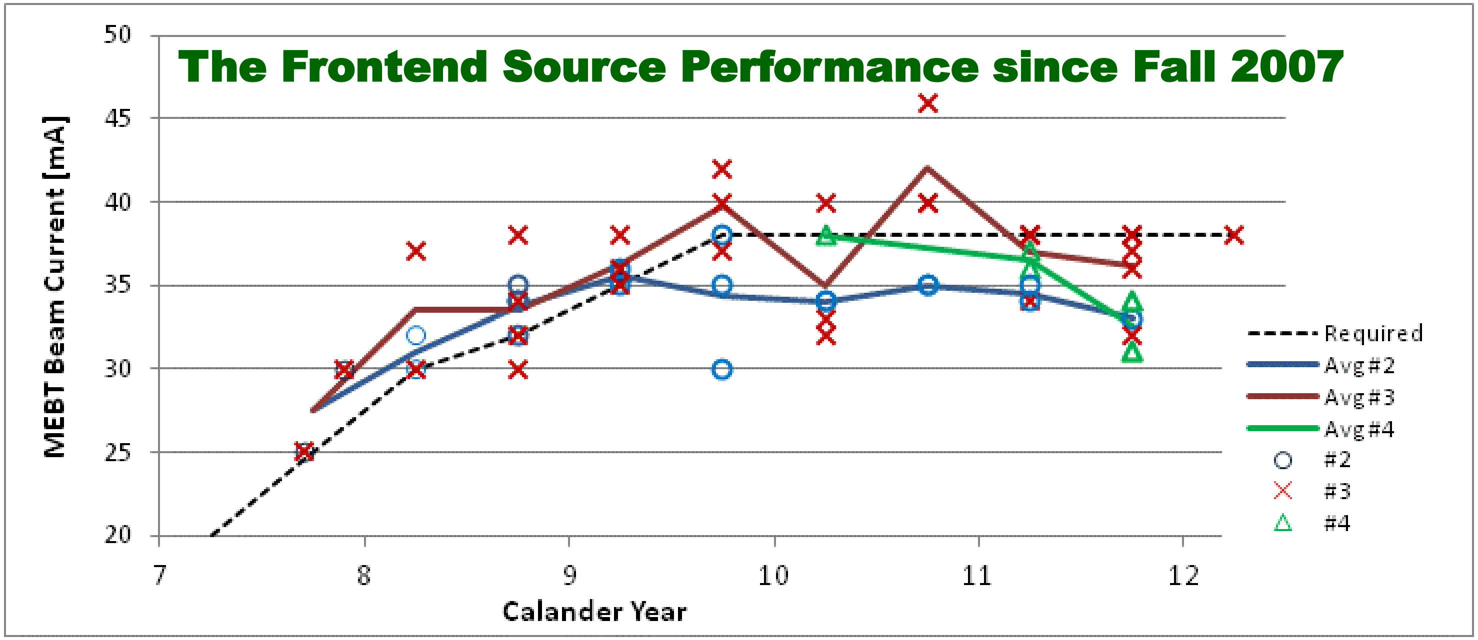
- Plasma emission spectra show a Na line due to antenna sputtering.
- Na is high during conditioning when H_2O is high (O and OH).
- Na is very high during and high after cesiation, when Cs is in the plasma .
- Na disappears after ~1 day when the Cs disappears.
- Apparently antennas do not age beyond ~1 day. They quickly develop a black carbon coating, consistent with a sputter-free environment.
- This may allow for burning-in and power testing antennas before being used for production.
- This could reduce the Na contamination of the Mo converter and thus initial beam losses.





Pretesting antennas at elevated duty cycle could eliminate antenna failures!

The Biggest Ion Source Concern of 2012



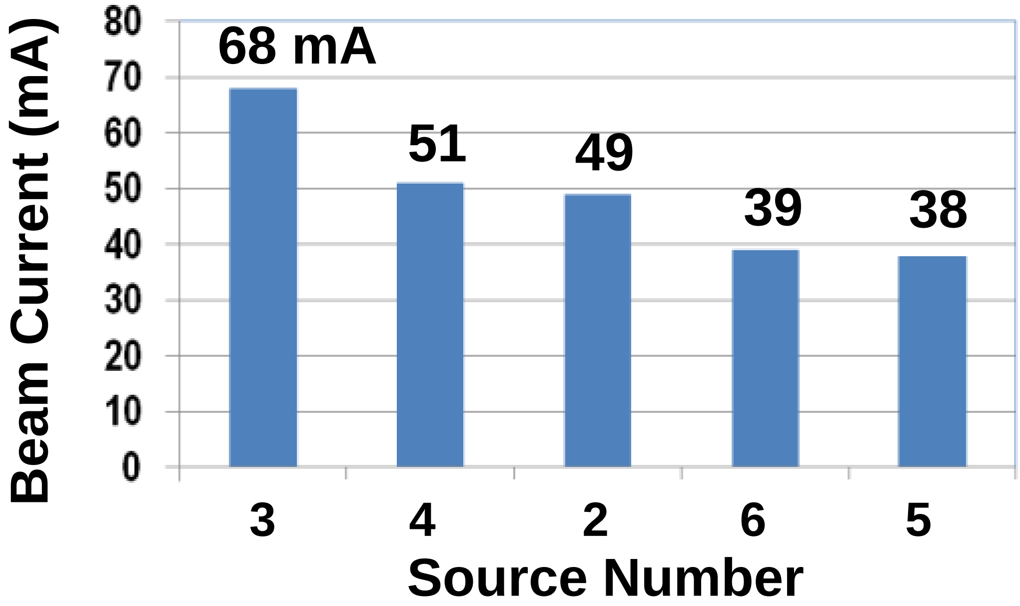
- 2007 - 2009: changes implemented to increase beam current
- ~2010: peak performance
- Significant scatter in source performances
- **Since 2010 a degradation of the Frontend became apparent:**

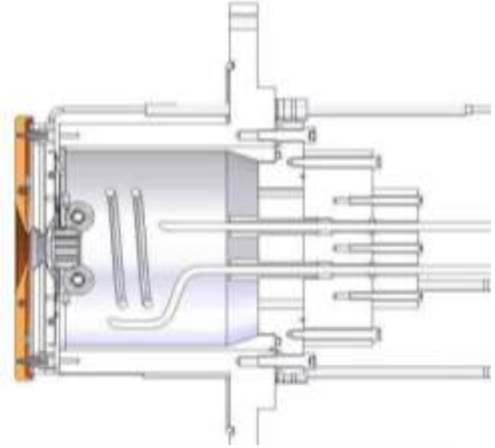
•#3 made easily 38 mA now makes 36 mA after increasing RF

•#4 which made 38 mA now makes 34 mA after increasing RF

•#2 which made 35 mA now makes 32 mA after increasing RF

Baseline Source Performance on Test Stand



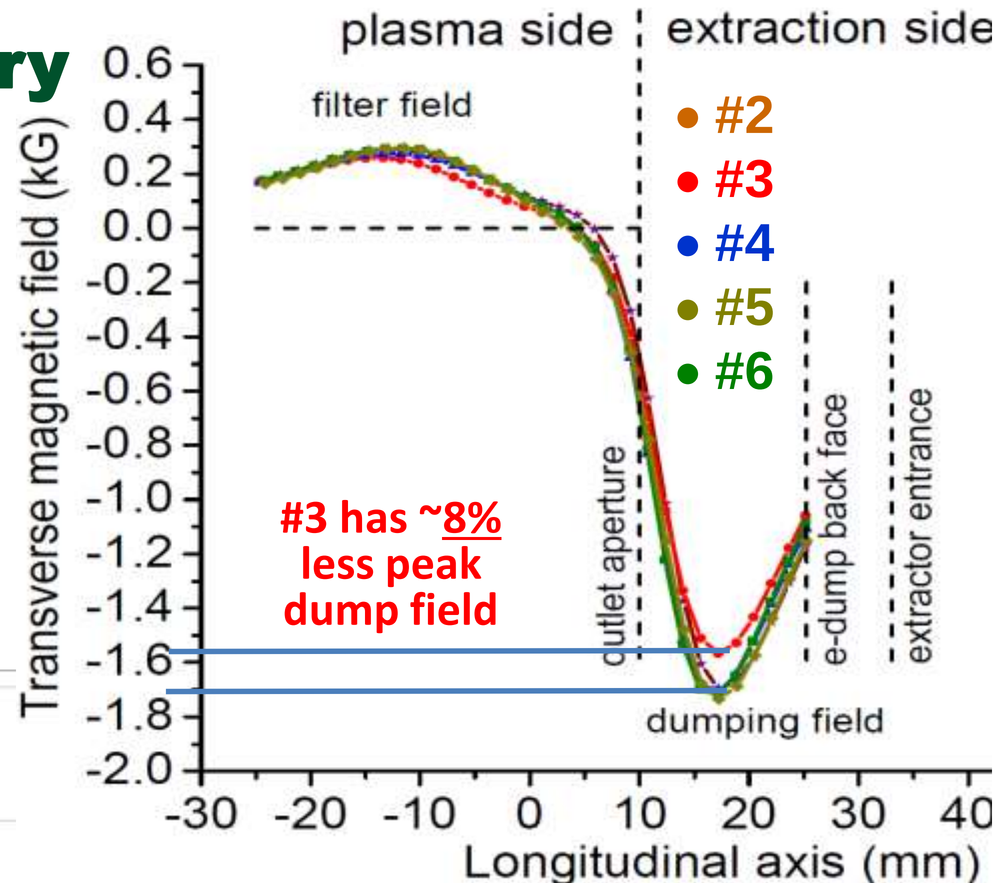


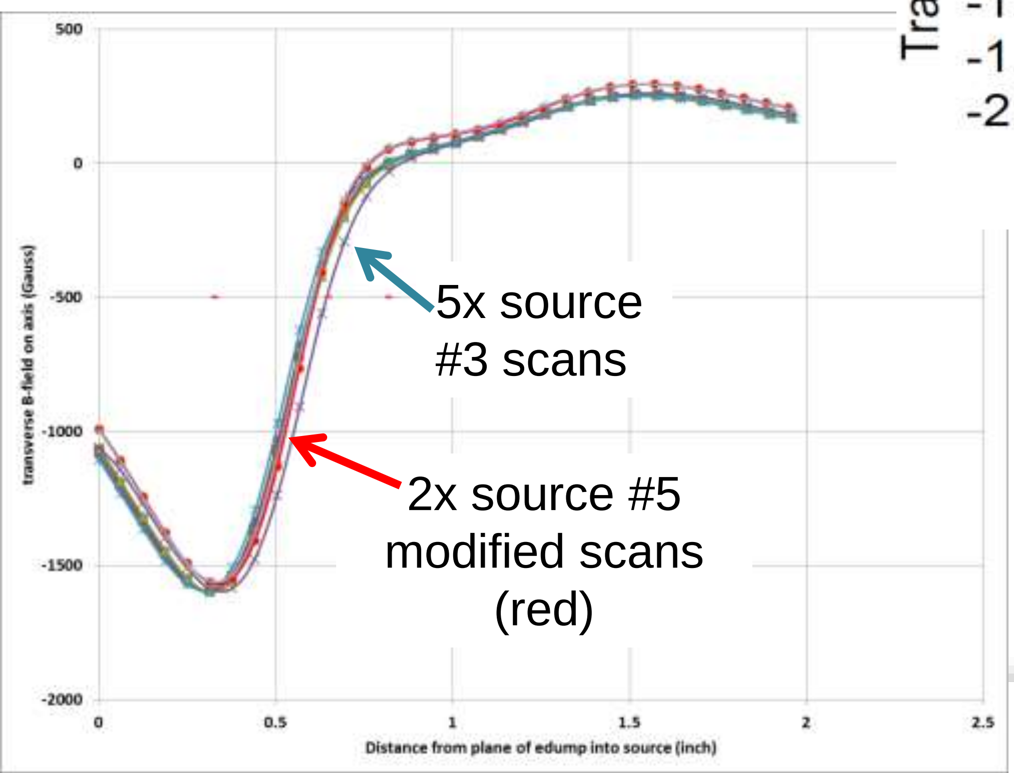
#3: 6-week production workhorse
#4: alternate production source
#2: spare production source
#6: R&D source
#5: R&D source

- Last year the test stand was used to characterize all baseline sources with ~60 kW (2.3 rms antenna current)
- The highest output stable for ≈1 day was evaluated
- No consistent dependence on the position and tilt angle was found
- Two repetitions suggested a reproducibility of a few mA
- Several results were ignored because they made no sense
- **Production workhorse #3** set the records with ~**68 mA**
- **Production sources #4 and #2** yielded ~**50 mA** (~25% less)
- **R&D sources #5 and #6** are new sources and yield only ~**40 mA**

The Dumping Field Story

- Since 2008, the magnetic field of each source is recorded after each use.
- After the filter field deficiency of the source #3 became clear, the magnet company declined to try a reduced magnetization.
- Opera-2 was used to develop a shim that could reduce the field of other sources.





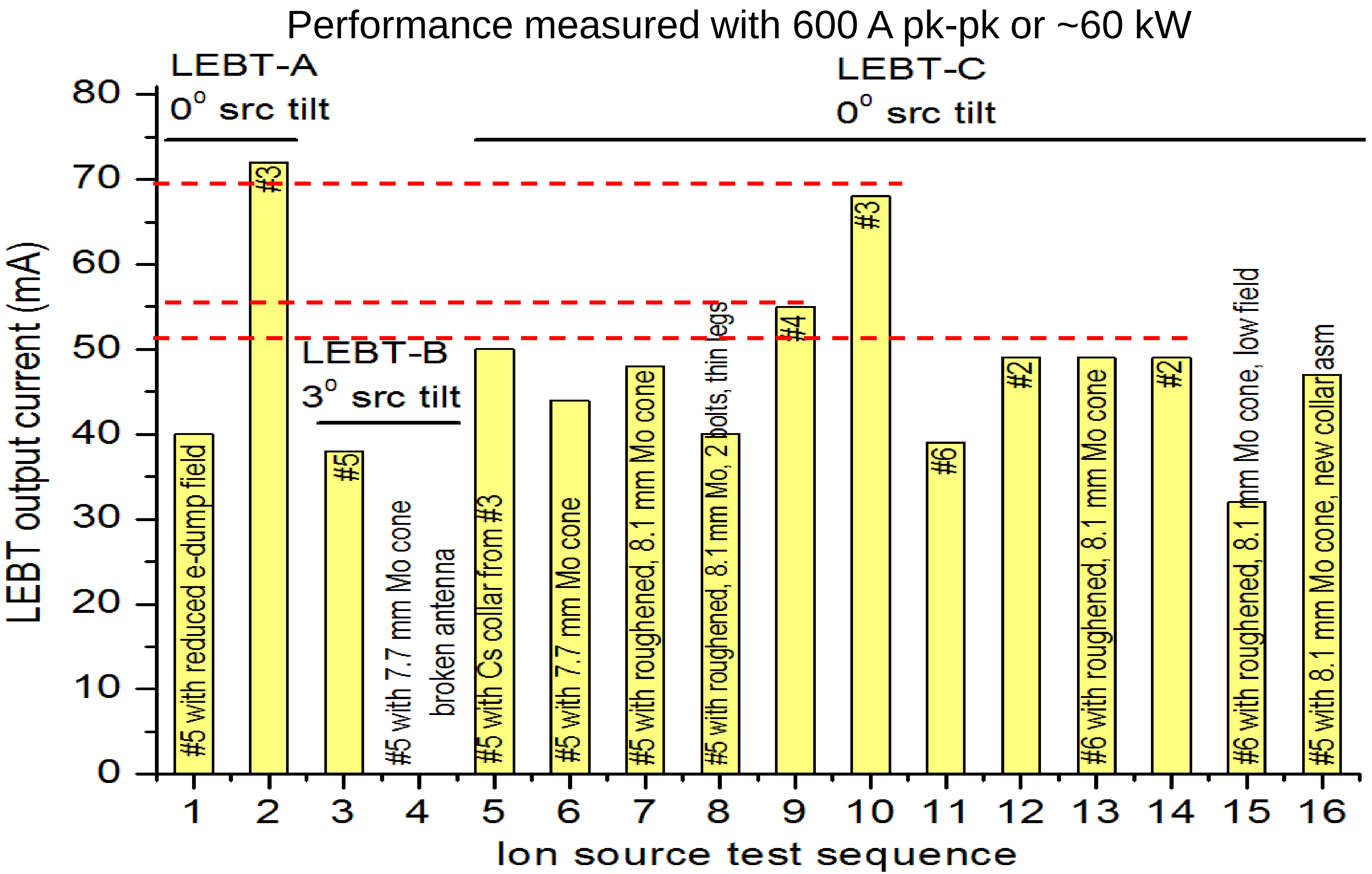
- **Adding a 0.01” thick shim** in front of the dumping magnet changed the field of **source #5** to match the profile of source #3.
- This change **increased** the **current** of source #5 **from 38 to 41 mA**.
- We should duplicate this with #6.
- In the summer outage we can test this change with #2 and #4 on the FE.

Measurement table outlet aperture – baseline source

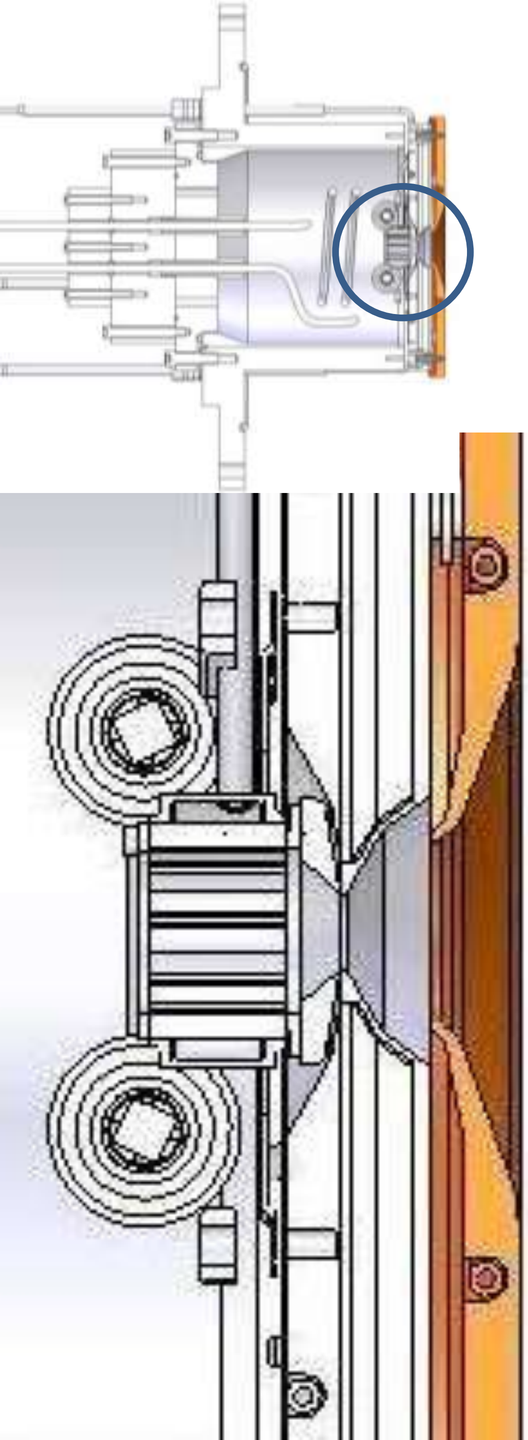
	Filter field, height & separation	Retaining ring Id, thick Mag=(Y/N)	Cs collar Length, height, leg dim, Mag=(Y/N), screw #, protub	Collar washer Id, thick, mag=(Y/N)	Mo converter Id, thick, gap, ecc, mag(Y/N) lg cone dia	Dump magnets & shield, Id, thick, shield thick, mag	SS outlet id, thick (ref for con)	E-dump, id, thick, ecc
Source 2		Id= Thick= Mag=		Id= Thick= Mag=	Id= 7.1 mm Gap=0.5 mm (0.33-0.59mm) Con=0.3 mm Lg cone dia=	Id= Thick= Shield t= Mag=	Id= 7.0 mm H= 8.4 mm	Id= 17.1mm H= 8.3 mm Con=0.15 mm
Source 3	H=16.0 mm Sep=29.7mm	Id=15.4 Thick=0.8 Mag=1.3-1.8	Length=18.7mm Height=19.2 Leg=6.2 x 0.45 mm Pro=.73 mm S#=2; tube=0.02 Mag<1.1	Id=15.2 Thick=1.0 Mag<1.1	Id=7.7mm Gap=0.5 mm (0.31-0.65mm) Con=0.16 mm cone dia=13.4 T=3.7 mm	Id=13.1 mm Thick=11.8 mm Shield t=0.3 mm Mag=yes	Id= 7.1 mm H= 8.1 mm mag<1.016	Id=17.4 mm H= mm Con=0.25 mm Mag<1.01
Source 4		Id=14.5 Thick=0.86 Mag=	Length=18.7mm Height=19.3 S#=2; tube=0.02 Leg=6.2 x 0.62 mm Leg is slotted	Id=15.1 Thick=1.0 Mag=	Id=7.2mm Gap=0.6 (0.24-0.76) Ecc= Lg cone dia=	Id=12.9 Thick=11.69 Shield t=0.5 Mag=	Id=6.9mm H= 8.1	Id= 17.2 mm H= 8 mm Con=
Source 5	H=15.0 mm Sep=26.9 mm	Id=14.8 mm Thick=0.90 mm Mag=yes Perm<1.01u	Length=18.7mm Height=18.9 Leg=6.35 x.69 mm, #=4, Pro=1.27 mm Pm1.1u tube=0.02	Id=15.1mm Thick=1.1 mm Mag=yes Perm<1.02u	Id=7.3 mm H=4.0mm Gap=0.24mm Con=0.19 mm P<1.01u lg dia	Id=12.92 Thick=11.73 Shield t=0.5 mm Mag=	Id=6.9 mm H=7.1 mm Perm<1.03u	Id=17.0mm H=8.0 mm Con=0.07 Perm<1.01u
Source 6		Id=14.3 mm Thick=0.86 mm Mag=yes Perm<1.15u	Length=18.7mm Height=19.1 Leg=6.35 x 0.66 mm #=2, Pro=2.2 mm Perm	Id=15.1mm Thick=1.1 mm Mag=yes Perm<1.03	Id=7.2 mm H=4.1mm Gap=0.4mm Ecc= mag=no P<1u lg dia=	Id= Thick= Shield t= Mag=	Id=7.0mm H=8.5 mm Perm<1.03	Id=16.7mm H=8.6 mm Con= Perm<1.01
Drawings		Id= 15.0 mm Thick=0.9 mm Mag=no	Leg=6.35 x 0.6 mm	Id= 17.3 Thick= 1.0 mm Mag=no	Id=7.1 mm H= 3.8 mm Lg cone dia=	ID=12.9 mm Thick=11.7 mm Shield t = 0.5 mm Mag=no	Id= 7 mm H= 8.1 mm	Id= 16.7 mm H= 7.9 mm Con=

Sources are practically identical, except for **Cs collar legs** and **Mo aperture size!**

LEBT output currents measured on the test stand



On the test stand, sources 3,4,2 make ~70, ~55, ~50 mA!



The Converter Story

In 2007, the 1-mm thin SS converter was replaced with a 4-mm thick Mo converter to increase the beam current.

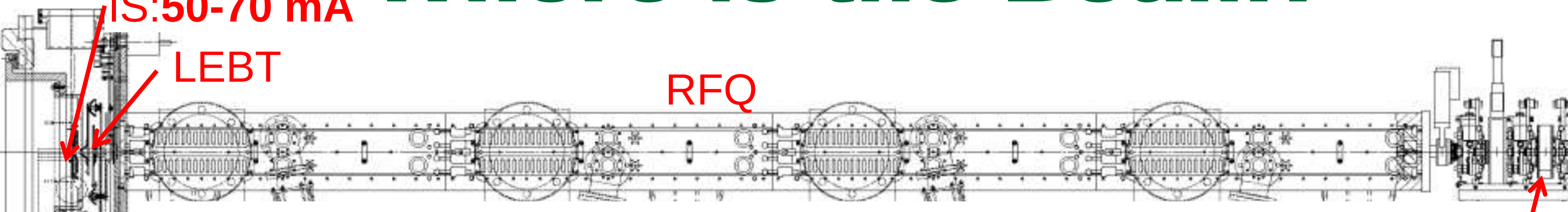
- Apparently source #3 received the first machined converter, which had machine chatter and apparently a oversize aperture (~7.7 mm instead of 7.1 mm).
- The other sources received smoother Mo converter with ~7.1 mm aperture.
- The beam current increased ~20% when source #5 & #6 were equipped with roughened ~8mm ID Mo converters.
- Source #2 & #4 were equipped with roughened ~8 mm ID Mo converter. The MEBT beam current went up a few mA, but <20%.
- The physics is unclear, because the outlet remains 7 mm!

Source #3

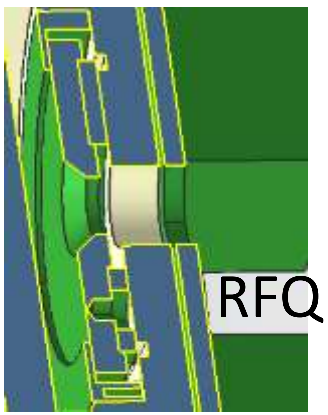
Source #2

#2 & #4 made ~34 mA MEBT current, enough for 1 MW

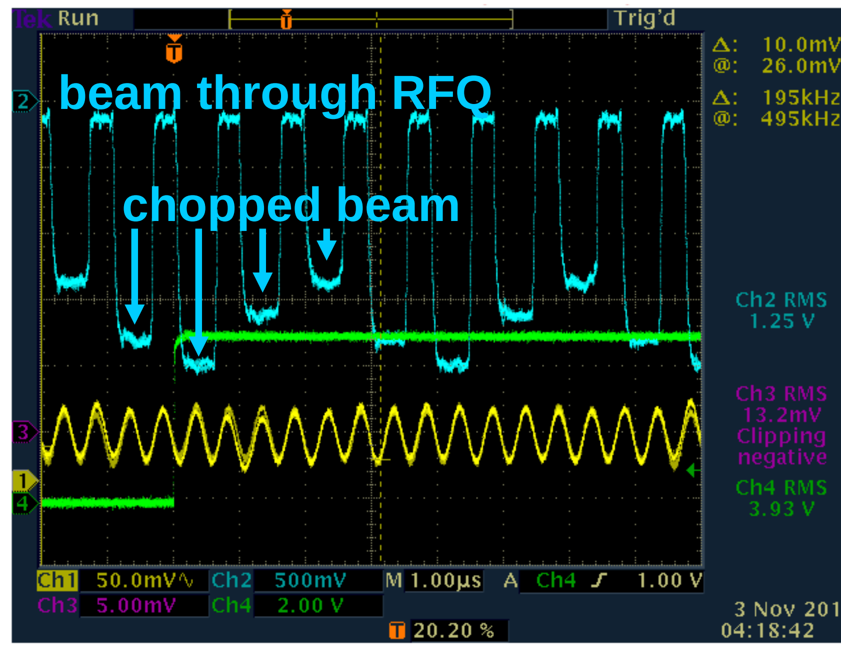
Where is the Beam?

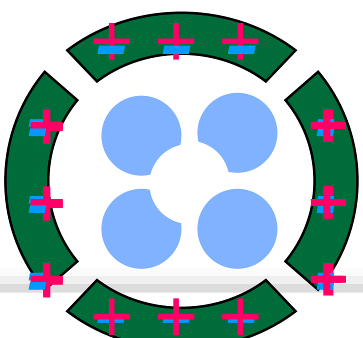


- Test stand shows sources 2-4 to produce 50-70 mA
- However, only 32-36 mA reach the MEBT
- Where are the 18-34 mA lost? (~100 W)



- No beam current monitor in the LEBT
- But RFQ entrance aperture electrically isolated; stops ~70% of chopped beam

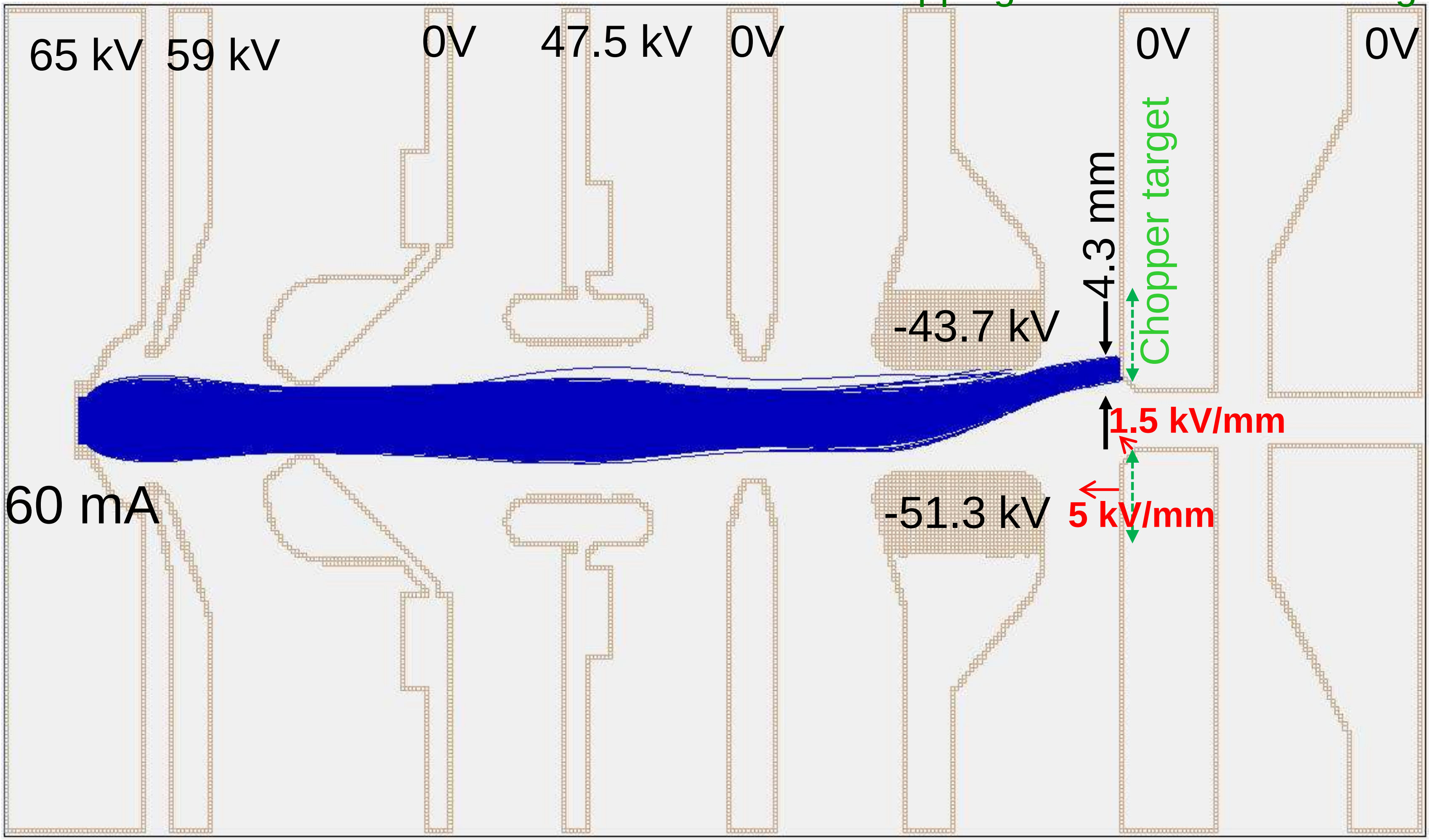




- Beam chopped in 4 diagonal directions

Steerers can drive 1 or 2 chopped beamlets completely on RFQ entrance aperture

The maximum deflection: $\underbrace{2 \times 2.3\ \text{kV}}_{\text{chopping}} + \underbrace{3\ \text{kV}}_{\text{steering}}$



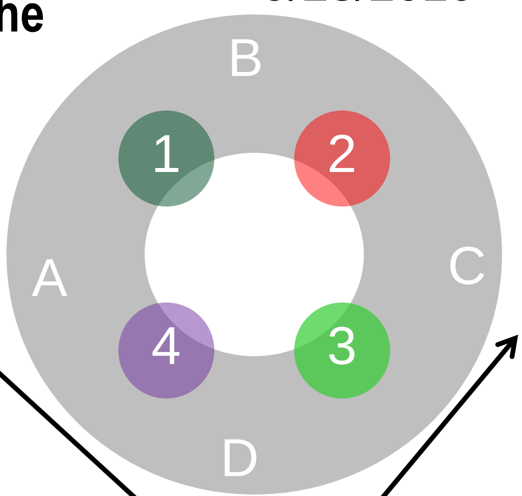
- Using maximum chopping and steering deflection drives centered beams completely on the chopper target!
- The lens-2 field repels secondary electrons <0.015 mm above the surface! They are fully suppressed!

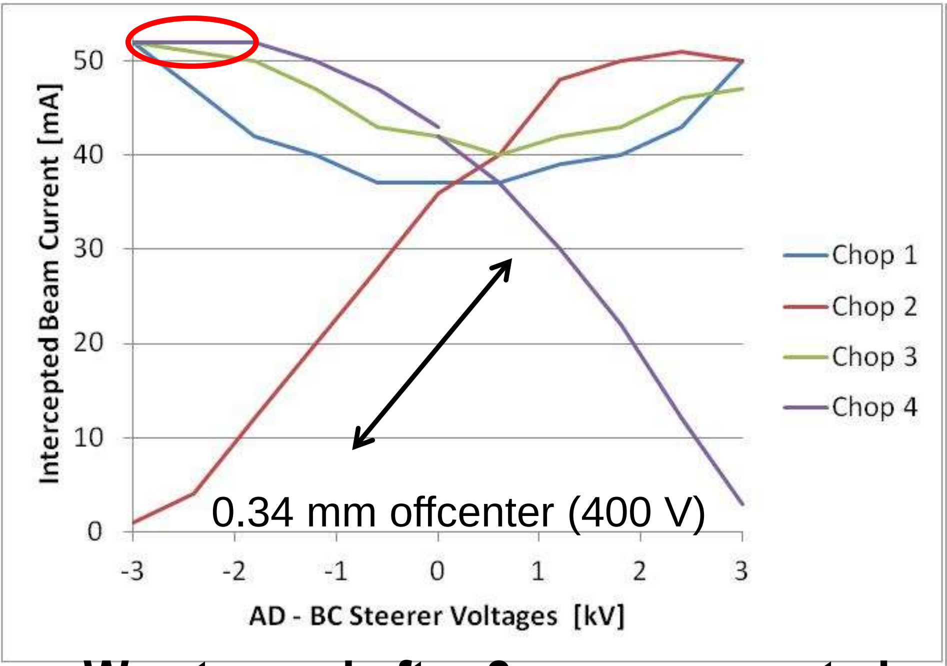
Every mA H- yields 1 mA of signal!

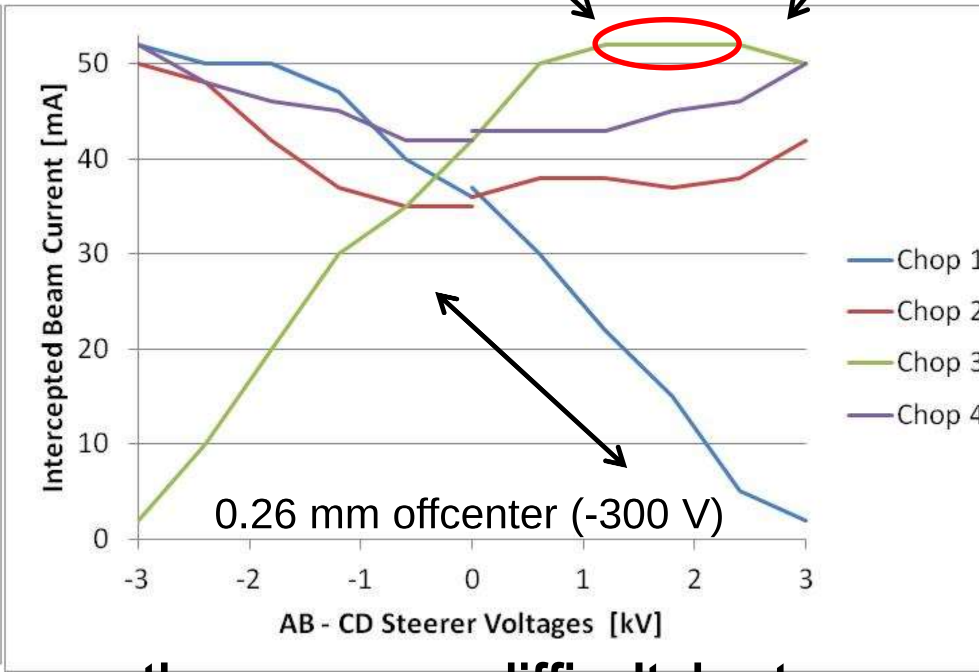
LEBT Chopper Beam Diagnostics

Source #3
9/28/2010

- **Measuring the current on the chopper target while scanning the chopped beamlets allows for identification of the beamlets.**
- The data show better centered beam at RFQ entrance.
- The total beam current appears to be 47*±1 mA.
- 42 mA on BCM02 yields a RFQ transmission of **89*%.**
- 70 to 85% of the beam is normally dumped on the LEBT chopper target.
- Only 0-2 mA changes in beam currents for large deflections. Hitting lens-2 no major issue.





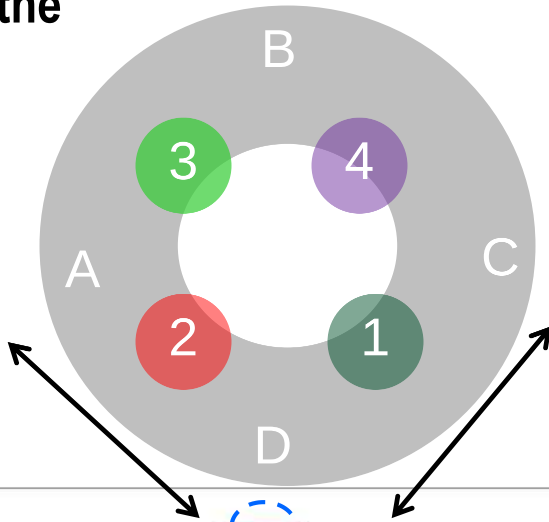


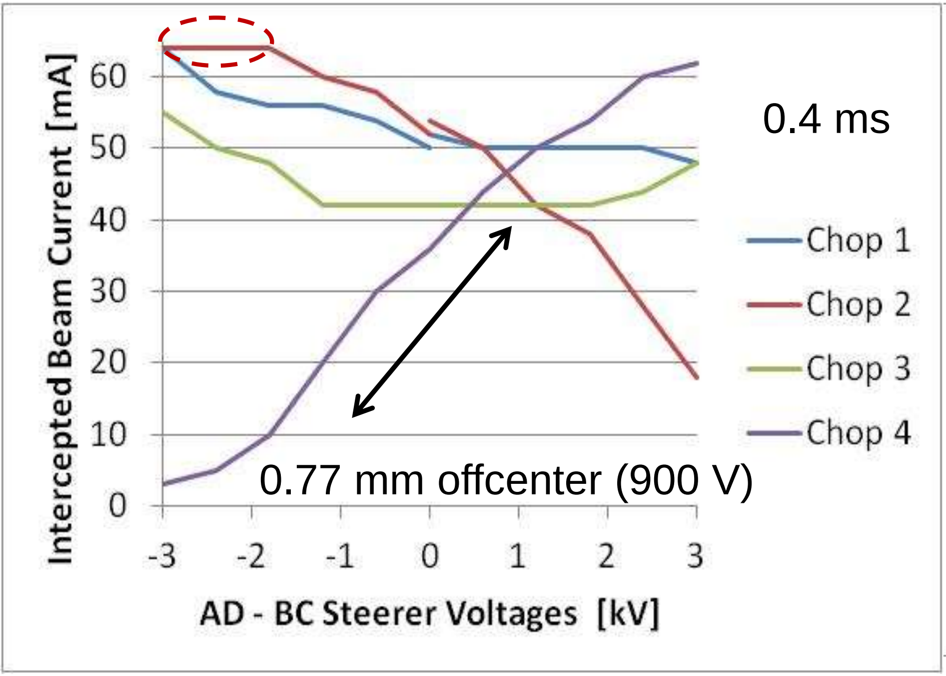
We stopped after 2 measurements because they were very difficult due to rudimentary scope controls! **Flattops confirm complete beam intercepts!**

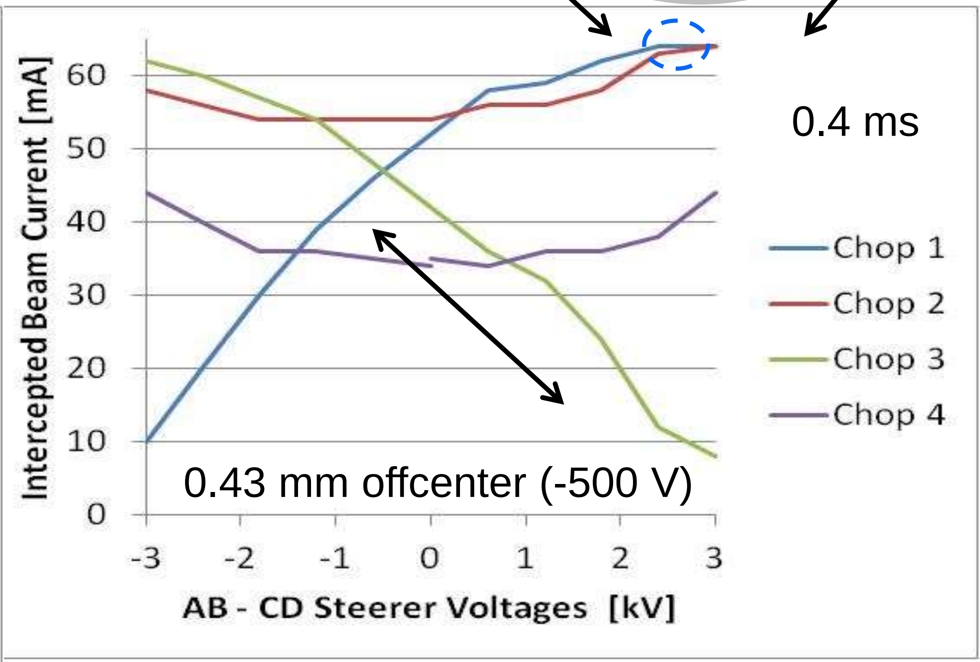
LEBT Chopper Beam Diagnostics

Source #3
10/14/2012

- **Measuring the current on the chopper target while scanning the chopped beamlets allows for identification of the beamlets.**
- The data show off-center beam at RFQ entrance.
- The total beam current appears to be 59*–3 mA.
- 35 mA on BCM02 yields a RFQ transmission of **62*%.**
- 51 to 84% of the beam is dumped on LEBT chopper target.
- No changes in beam current for large deflections of beams not crossing center (Chop 1 and Chop 2).
- Hitting lens-2 no major issue.



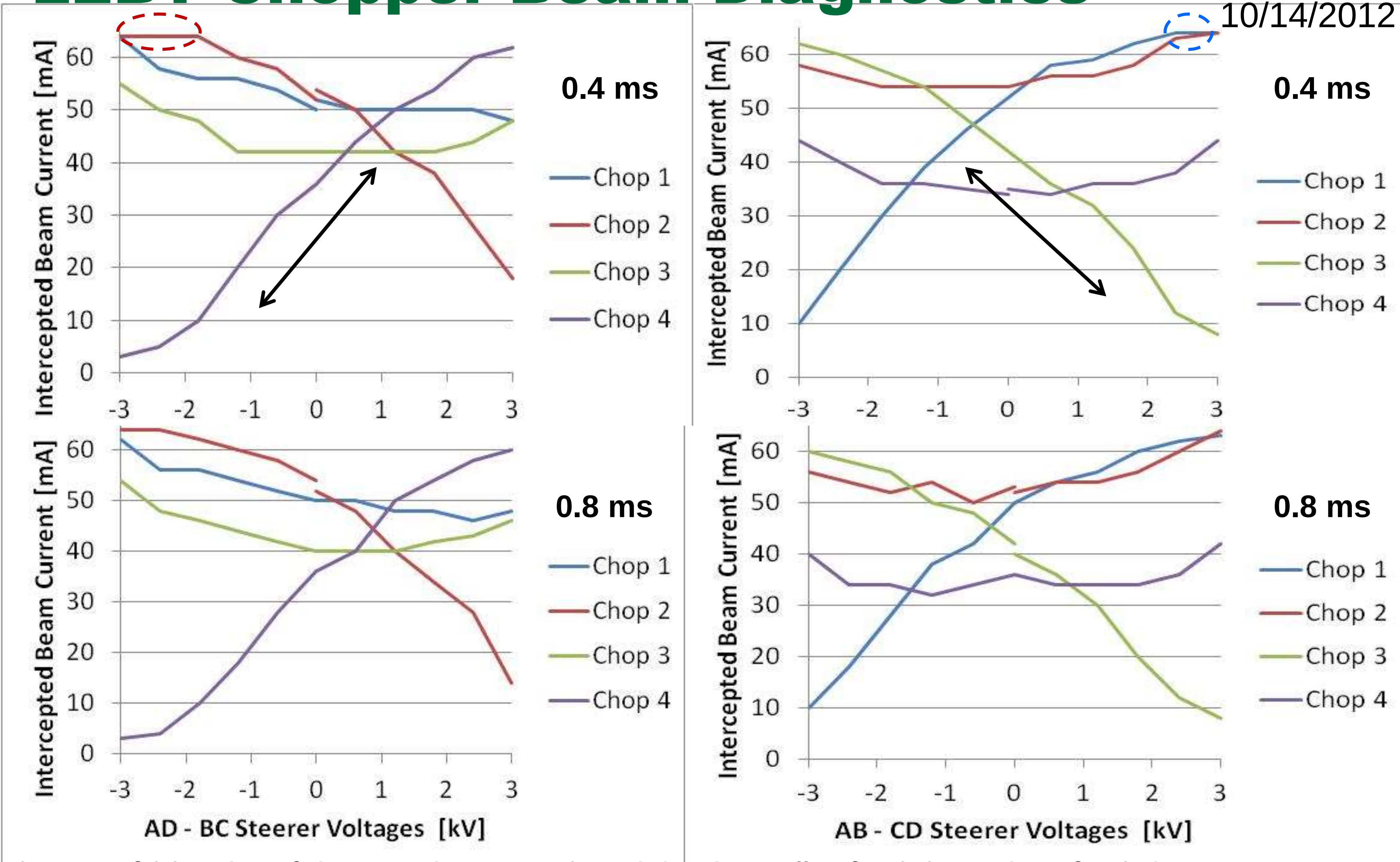




We resumed the measurements in 2012 after Controls implemented a better scope utility!

LEBT Chopper Beam Diagnostics

Source #3
10/14/2012



95 out of 96 pairs of data are between 0 and 4 mA smaller for 0.8 ms than for 0.4 ms.

1)The beam decays by 3.7% between 0.4 and 0.8 ms.

2) The accuracy of the current reading is ±2 mA.

Extensive data sets allows for detailed statistics!

Measured RFQ Transmissions

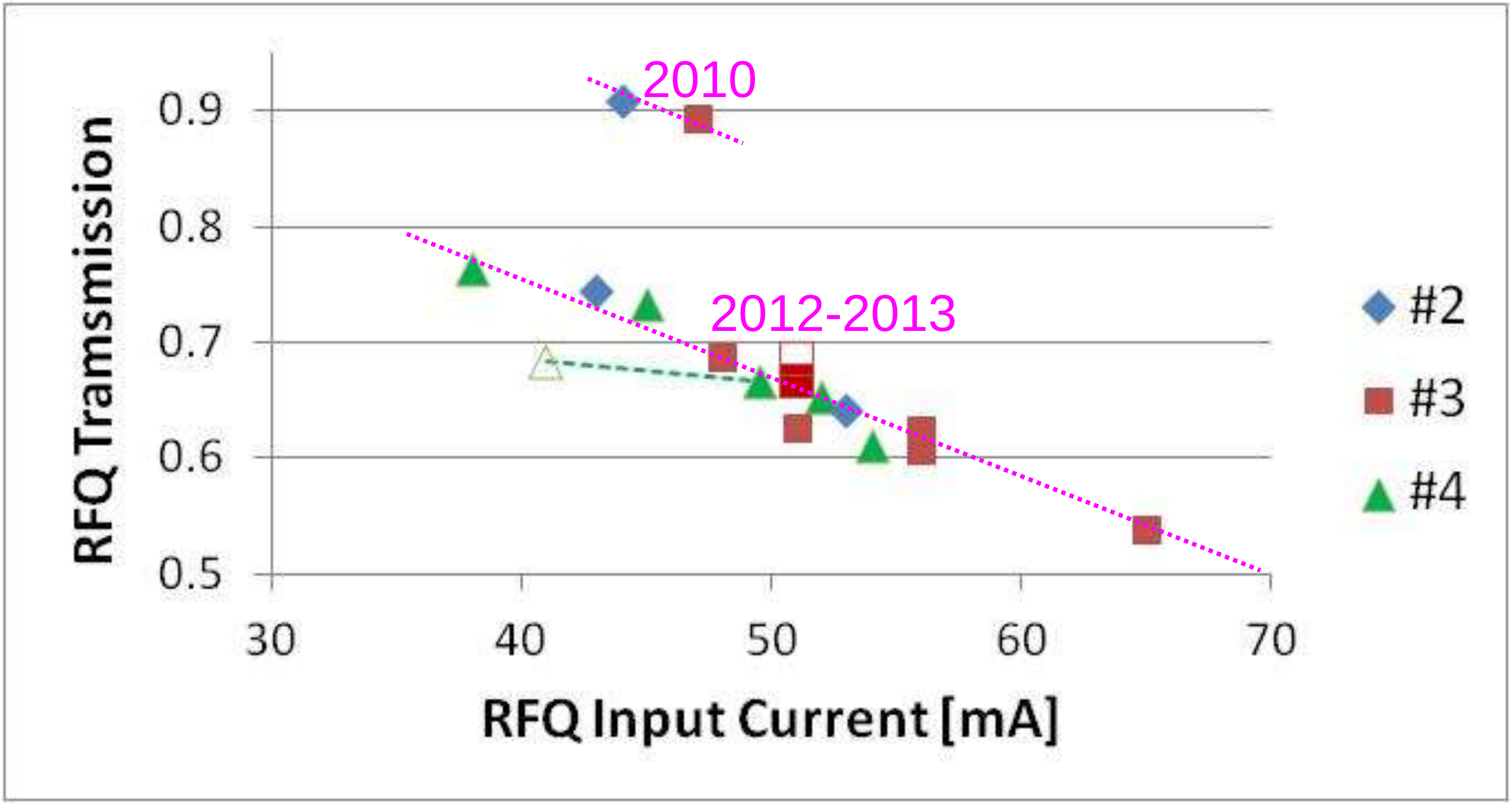
date	Source #	Method	Antenna rms	Test stand (rms scaled)	LEBT beam current [mA] ±5%	BCM02 [mA] ±5%	Ratio ±7%
8/31/10	2	Scan	~2.2	~46	44	40	92
9/28/10	3	Scan	~1.9	~48	47	42	89
9/26/12	4	Max	2.3	~55	56-4	34	65
9/28/12	2	Max	2.4	~54	46-3	32	74
10/4/12	3	Max	2.2	~64	59-3	34	61
10/14/12	3	Scan	2.24	~66	59-3	35	62
10/22/12	2	Scan	2.39	~54	56-3	34	64
11/2/12	4	Scan	2.31	~54	52-2.5	33	67
11/2/12	4	Scan	1.93	~39	43-2	28	68
11/15/12	4	Max	2.33	~56	57-3	33	61
11/19/12	3	Max	2.3	~70	68-3	35	54
12/21/12	3	Max			54-3	32	63
1/29/13	4	Max			47-2	33	73
3/20/13	3	Max			50-2	33	69
4/9/13	4	Max			40-2	29	76

~90%

54 to 76%

We repeated these measurements for #2 and each production source!

Measured RFQ Transmissions



- Full symbols are well tuned and aligned sources, mostly for production!
- Data suggest the RFQ transmission to decrease by ~1% per injected mA

Trying to compensate degraded RFQ transmission, we keep making more beam than in 2010!

What are the Real H- Problems?

Workshop on Performance Variations in H^- Ion Sources 2012: PV H^-12*

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Abstract. This paper briefly summarizes a workshop held in Jyvaskyla the day after NIBS'12. The half-day workshop aimed at globally capturing the issue of performance variations in H^- sources. There was a focus on production facilities and facilities that work under production-like conditions, because there are often high expectations to be met.

18 H- experts from 10 H- labs discussed H- performance variations for ~3 hours.

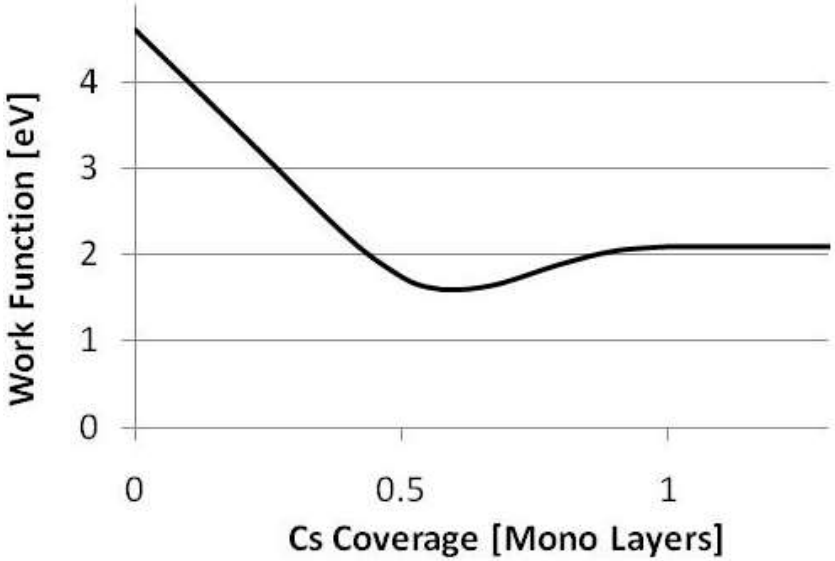
What are the Real H- Problems?

- For H- sources performance variations appear to be the rule.
- This is especially true for production environments where certain performances need to be reached within a rather limited time period.
- Refurbishing and reusing H- sources causes ~±5% variations.
- Different sources delivering different beam currents also appears to be the rule for H- sources and yield larger variations.
- However, the level of SNS source #3 outperforming the other SNS sources is rather unusual.
- Some laboratories run with the highest H- current available.
- Most laboratories adjust some parameters to equalize the performance of each source. E.g. ISIS adjusts the pulse length.
- In the past SNS has used the RF power to equalize the H- currents.
- The present SNS problem is caused by meeting the requirements with little or no margin, a problem that surfaced over the last couple of years.
- The workshop finished with an apparent consensus that the performance variations are predominately caused by inadequate distribution of the Cs!

The goal should be to reduce rather than to eliminate performance variations!

What are the Real H- Problems?

- The cesium is of utmost importance in cesiated H- sources.
- Lowering the work function of surfaces increases the H- beam 2-4 fold.
- The Rasser approximation $\beta^{-}(v_{\perp}) \approx (2/\pi)\cdot\exp[-\pi(\Phi-S)/(2\cdot a\cdot v_{\perp})]$ suggests that 0.1 eV increase in the work function lowers the ion-induced H- surface production by ~10%.



- This is 7.5% of the beam from a source with a 4 fold Cs effect, or 3 mA out of 40 mA of the SNS source.
- The persistence of the SNS beam suggests that most Cs sticks well to the converter and therefore is not sputtered by the ultra high purity hydrogen plasma.
- However, earlier experience suggests that the Cs does not stick well on surface contaminants and is lost within a few hours.

It is not clear how well we may be able to control the work function and/or surface contaminations!

What are the Real SNS H- Problems?

To improve the predictability of the H- beam, we need to increase the margin over the requirements.

- We need to retune the RFQ.
- We need to increase the H- output of the sources.
- We need to improve certain controls.
- The test stand used a QEI amplifier on the 65 kV platform, limiting the stability and accuracy of the performance measurements. It was recently replaced with a **solid state** TOMCO **amplifier on ground**.
- The Cs collar was never locked in place. A new clamp is being tested to **keep the collar centred within 0.1 mm**.
- The thermo couple showed a poor control of the converter temperature after cesiation. We continue trying to improve the thermal contact after cesiation. We expect to redesign the cesium collar for more reliable thermal contacts.

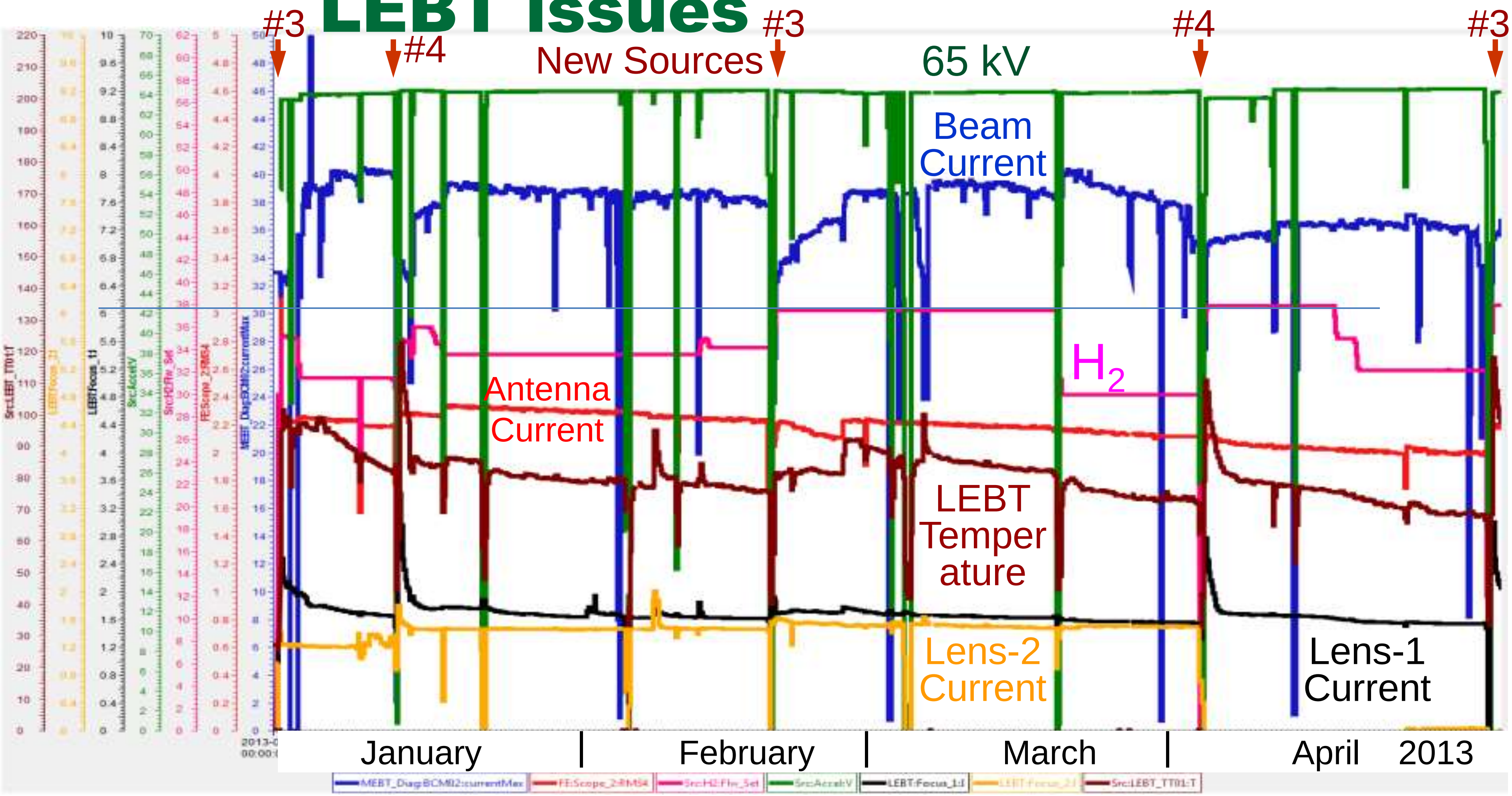
We are working towards increased predictability!

LEBT issues

- Apparently source #3 overheated the LEBT center ground on the test stand, causing it to buckle excessively, snapping screws and insulators.
- Non uniform heating creates non-uniform local expansion stresses!
- LEBT failures cause ~1 day downtime!

- **The mounts were reengineered to double their heat sinking.**
- **A thermo couple was added to understand the issues and reduce the likelihood of future failures!**

LEBT issues



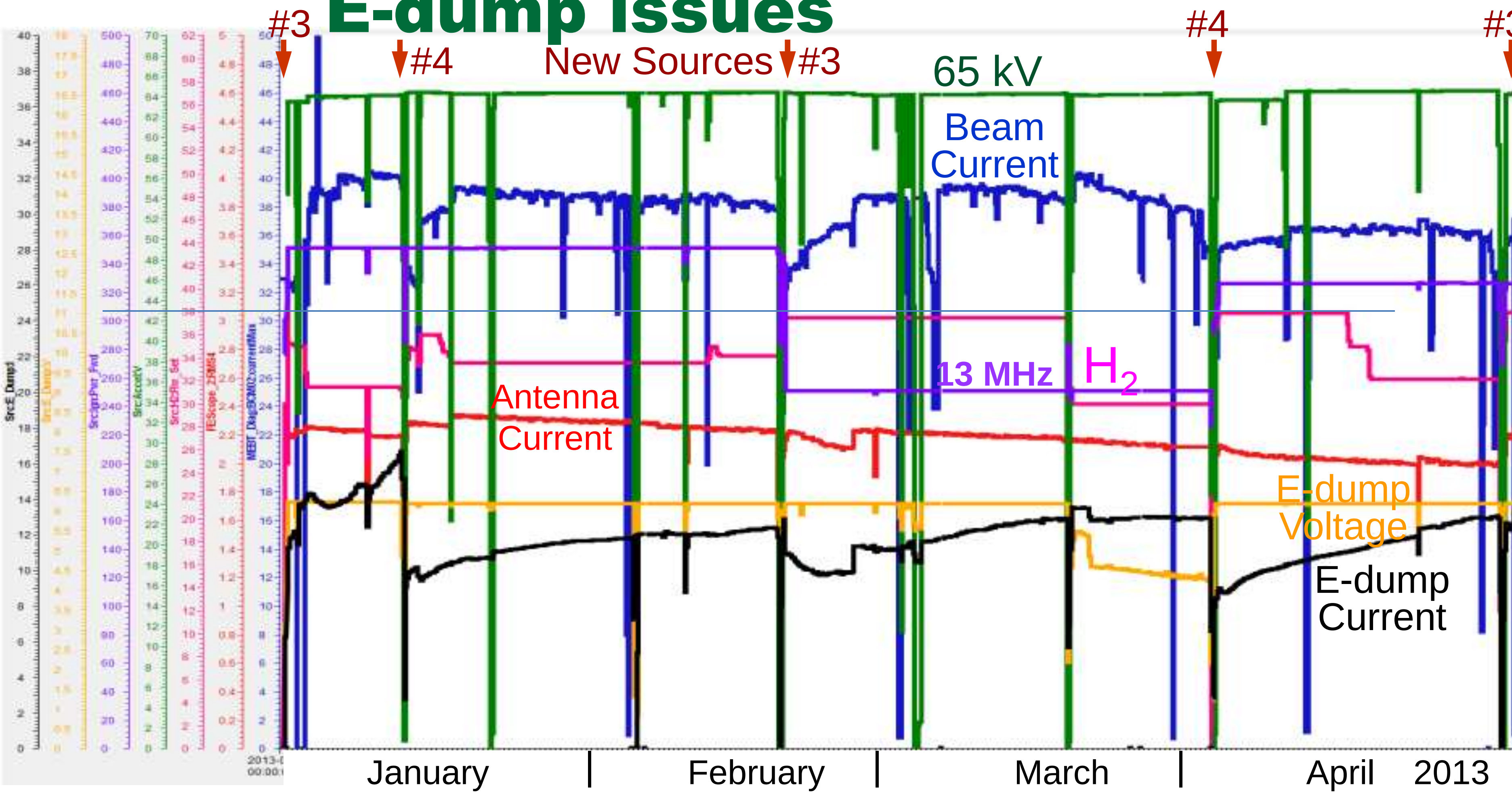
The LEBT center ground can reach up to 130 C. It appears to be heated by

1. 65 kV particles from the source
2. lens-1 discharges, especially after cesiation
3. occasional corona discharges from lens-2

P.S. Model calculations show no LEBT losses

Excessive LEBT temperatures can be avoided by lowering the beam current through detuning the RF!

E-dump issues



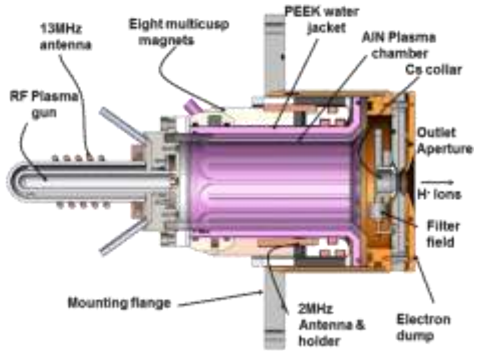
As seen with other RF H- sources, the e-dump current grows with time.

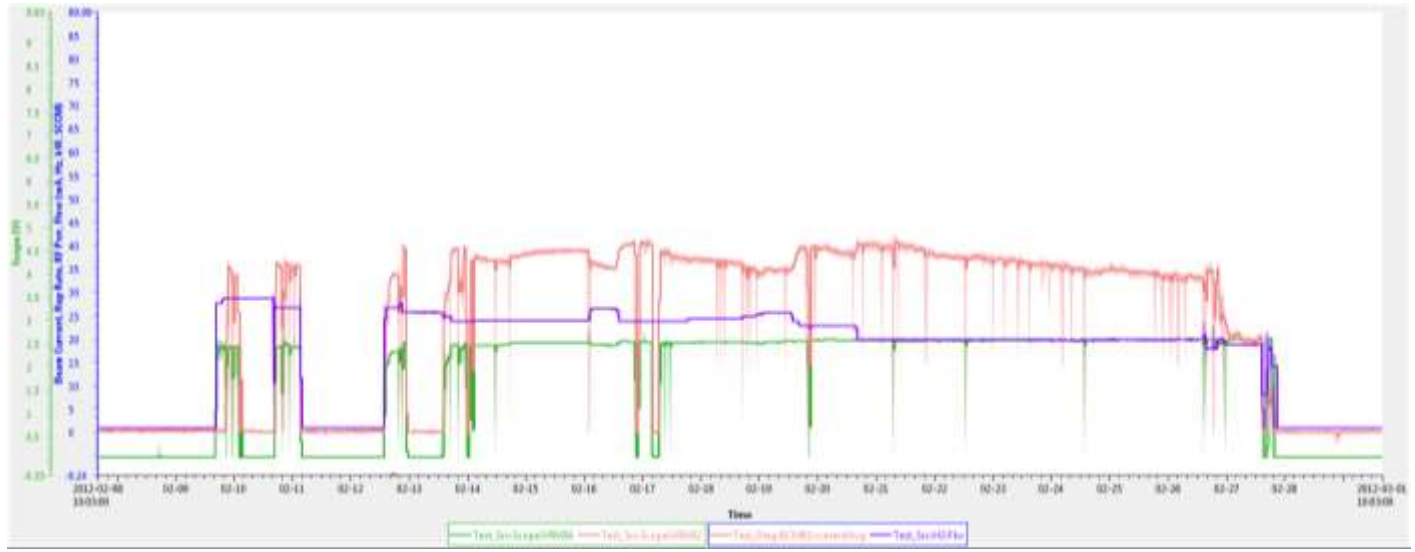
- When the e-dump current exceeds 250 mA, the voltage starts to fluctuate.
- Fluctuations can be reduced by lowering the voltage, which lowers the beam.
- Lowering the 13 MHz lowers the e-dump current, but causes plasma outages.
- Increasing the H_2 flow may stabilize the e-dump, but lowers the beam.
- Peak and average current data are needed for complete assessments.
- We are in the process of testing a 500 mA supply on the test stand.

Better control of the e-dump voltage could enable 8-week source cycles!

The SNS External Antenna Source

- Designed at ORNL in 2007 as a replacement for the baseline source
- Beam decays by ~1mA/day, likely due to emissions from AlN.





Was tested in February 2012 with thoroughly out gassed components:
- AlN source chamber baked to 700C for 6h in high vacuum oven, Al_2O_3 gun chamber and o-rings baked to 220C for several days in vacuum oven
- Used 400 G water-cooled array + vacuum baked ceramics and o-rings
- Produced ~38mA with 45 kW, but decayed ~1mA/day

Testing resumed in 2013 after demonstrating 3 1-MW sources.

Summary and Conclusions

- Resolving the leak and contamination issues and reducing antenna failures **reduced** the source & LEBT **downtime by about a factor of 3**.
- We have improved **source #4 and #2**, which can again **support 1 MW**.
- H- beam current measurements on the RFQ entrance aperture show that the **SNS sources deliver unprecedented H- beams** to the RFQ.
- The measured RFQ transmission of well tuned and aligned sources suggest that the relevant **emittance of all 3 production sources is about equal.**
- On the test stand we have measured the LEBT output current of our three H- production sources, which were comparable to the beam currents measured on the RFQ entrance aperture.
- We have used our R&D sources to study changes reflecting source #3.
- Lowering the e-dump field by ~8% increased the beam by ~8%.
- Increasing the inner diameter of the Mo converter from 7 to ~8 mm increased the beam current by ~20%.
- We will try to implement those changes on sources #2 and #4 during the summer outage.
- Having resolved the most critical concerns, we have resumed long term R&D, including the development of an external antenna source.
- The newly implemented thermocouples have produced invaluable data that are likely to improve the performance of the source and to avoid LEBT failures.

Thank you for your attention!