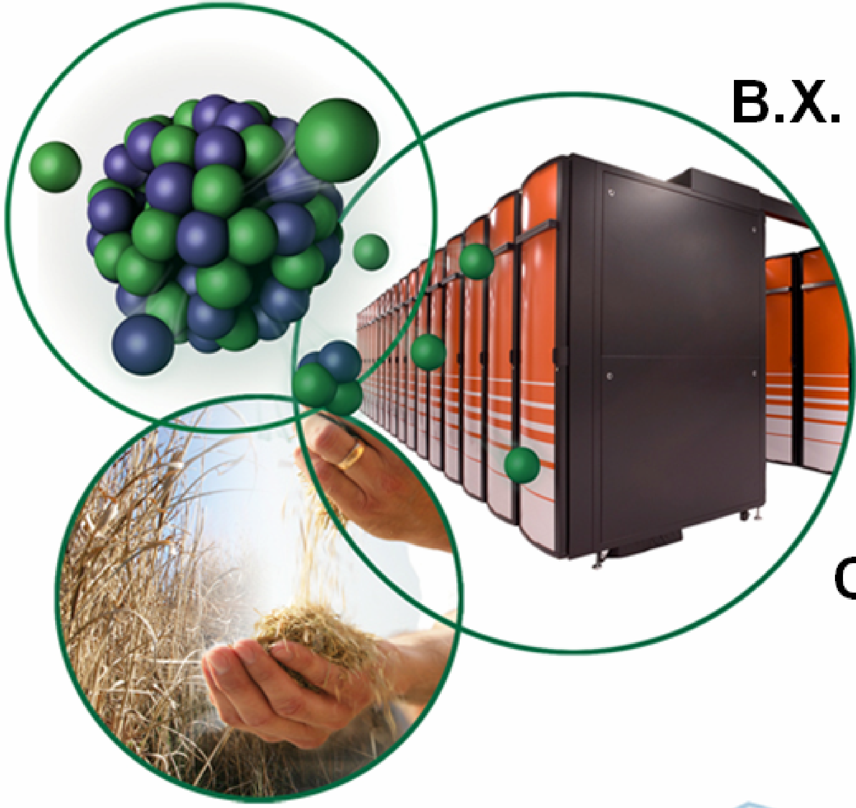
Doubling the SNS Beam Current with the Baseline LBNL Ion Source



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OAK RIDGE National Laboratory

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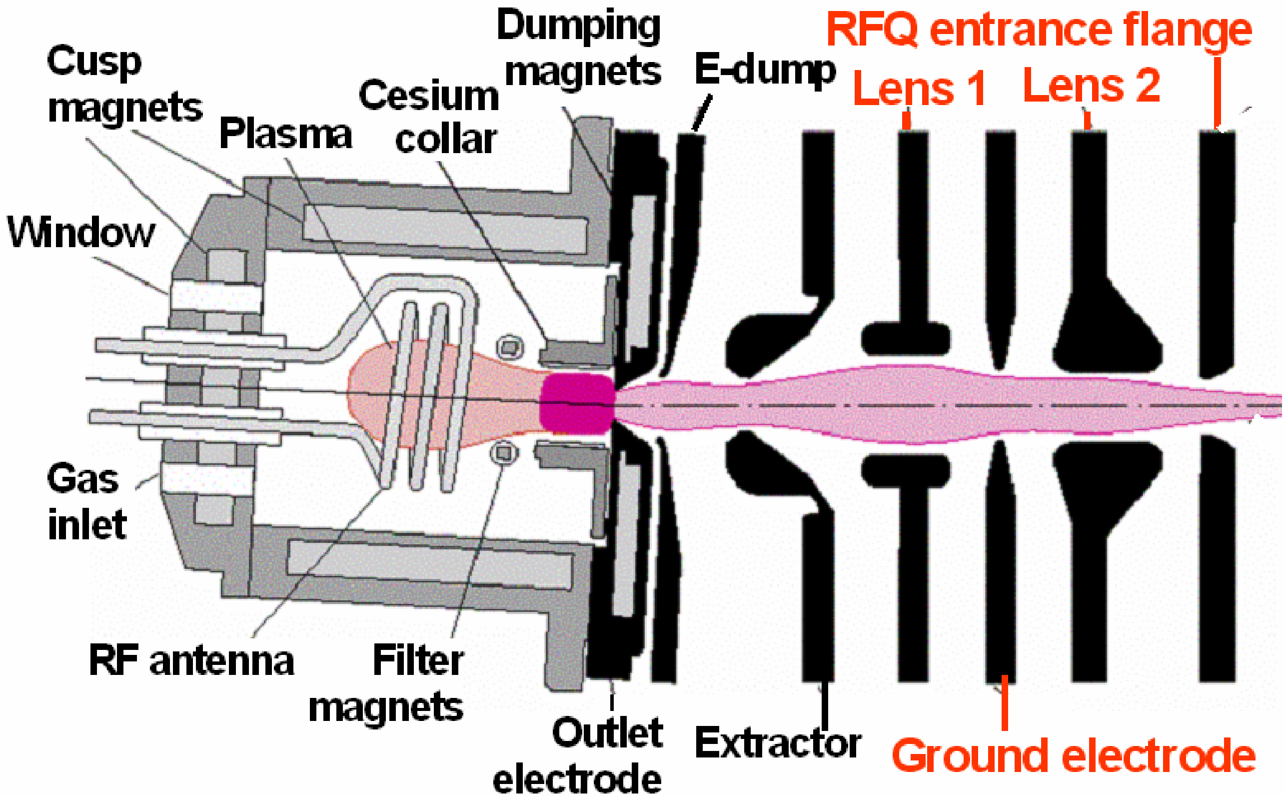
The SNS Baseline Ion Source and LEBT



LBNL developed the SNS baseline ion source, a cesium-enhanced, multicusp ion source. Typically 250 W from a 600-W, 13-MHz-amplifier generate a continuous low power plasma. The high current beam pulses are generated by superimposing 30-70 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.

Ion Source and LEBT Plan and Performance

Production Run	Duty factor	Pulse length	mA required	mA in MEBT	RF [kW]	%Availability	Comments
2006-1		~.1 ms	20	28-20	~70	99.9	1 ion source, 1 cesiation, raise collar temp
2007-1	0.2	~.25ms	20	30-16	~70	99.98	1 ion source, 1 cesiation + 24h @115°C
2007-2	0.8	~0.4ms	20	20-10	60-80	70.6	Arcing LEBT; antenna puncture after 37 days, start 2-week source cycles
2007-3	1.8	~0.5ms	20	13-20	80	97.2	Modified lens-2; e-target failures; tune for long pulses
2008-1	3.0	~0.6ms	25	25-30	35-50	99.65	modified Cs collar
2008-2	3.6	~0.6ms	25/30	25-37	uncal.	94.9	Beam on LEBT gate valve
2008-3 2009-1	4.0	0.69ms	32	32-38	48-55	99.22	Start 3-week source cycles, Ramp up e-dump
2009-2	5.0	0.8 ms	35	35			
2010-1	5.6	0.9 ms	38				
2010-2	6.2	1.0 ms	38				

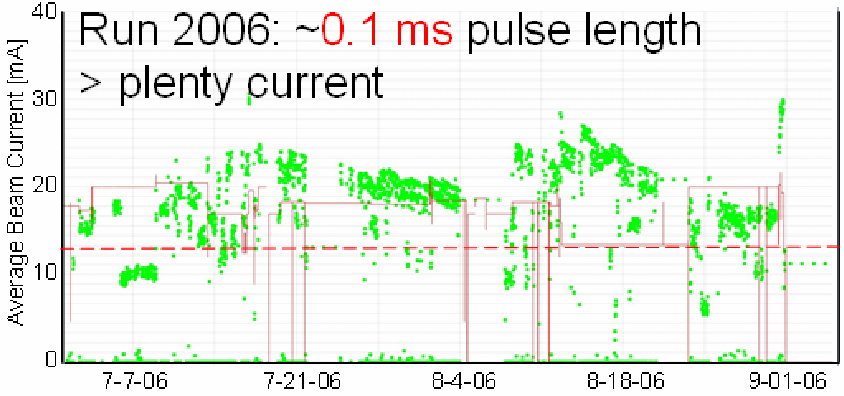
The SNS Power Ramp Up Plan is simple:

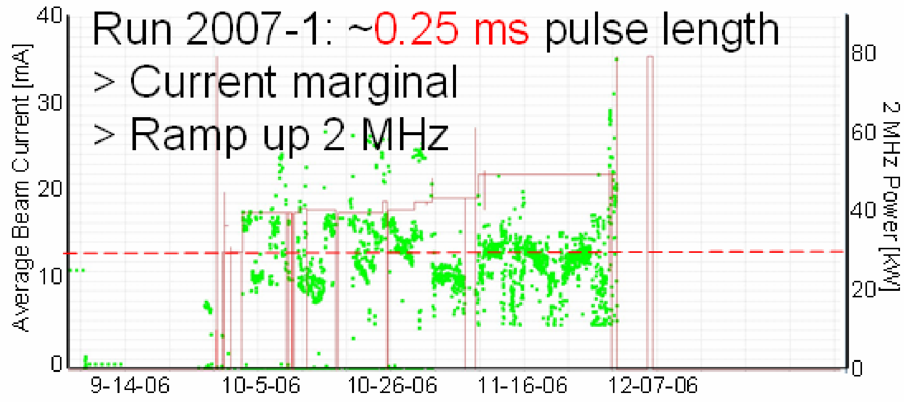
1) With every run ramp up pulse length and duty factor - up to 1 ms and 6%.
2) Start with accelerating 20 mA, then ramp by ~5 mA with every run up to 38 mA.
3) Simultaneously ramp up Source & LEBT availability from 95% to 99.54%.

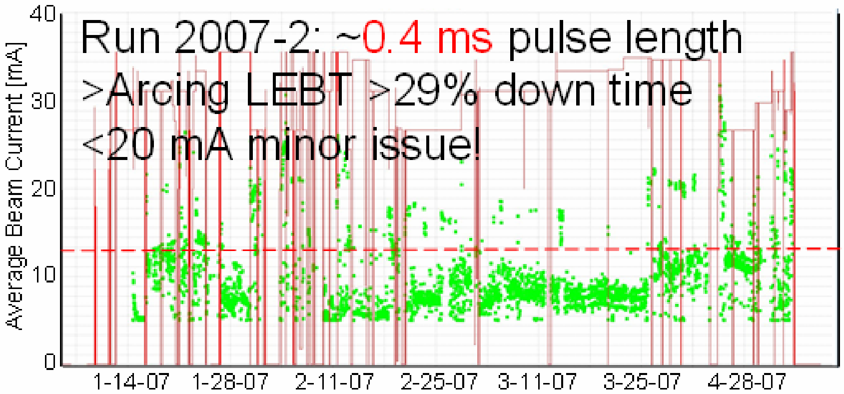
So far the plan has mostly worked, except for a few things that went wrong.

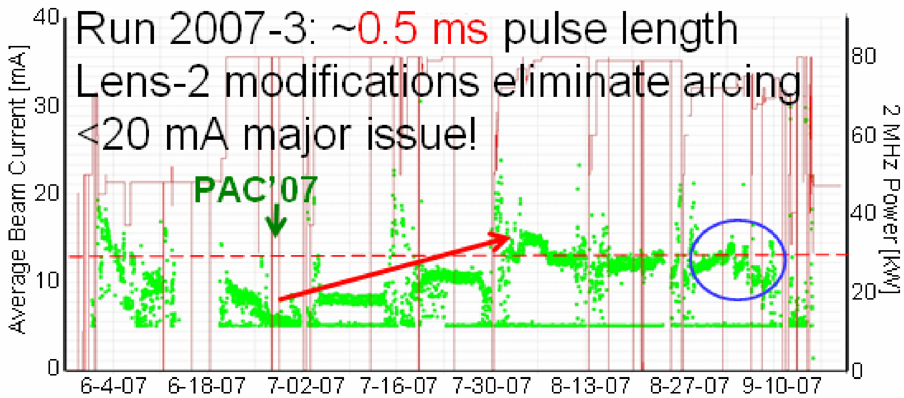
However, all major failures are well understood; mitigations were implemented to make recurrences extremely unlikely.

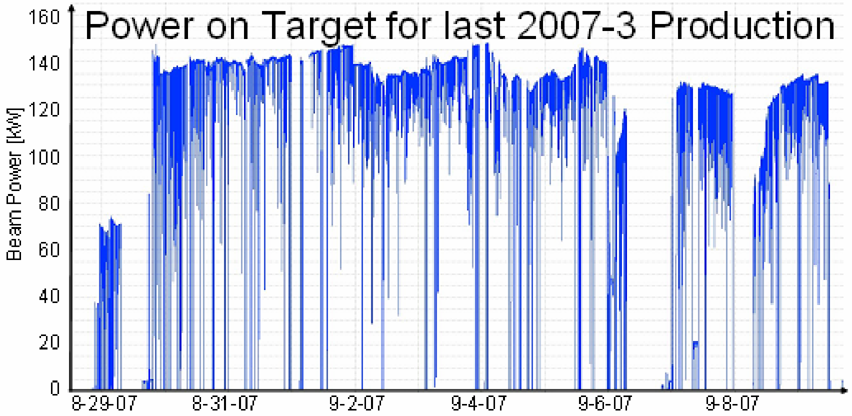
The 20 mA Challenge: (~13 mA average chopped)











- Learning to tune for long pulses allowed us to again meet the 20 mA challenge!
- However, with maxed-out 2 MHz, the beam power depends completely on ion source mood swings.
- To regulate the beam current requires a production with <<70 kW RF!

But the next run required 25 mA!
Need to increase efficiency!

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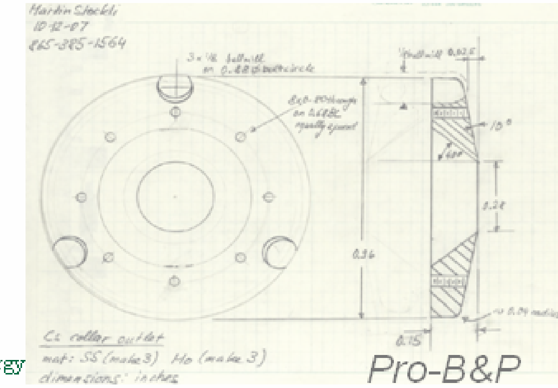
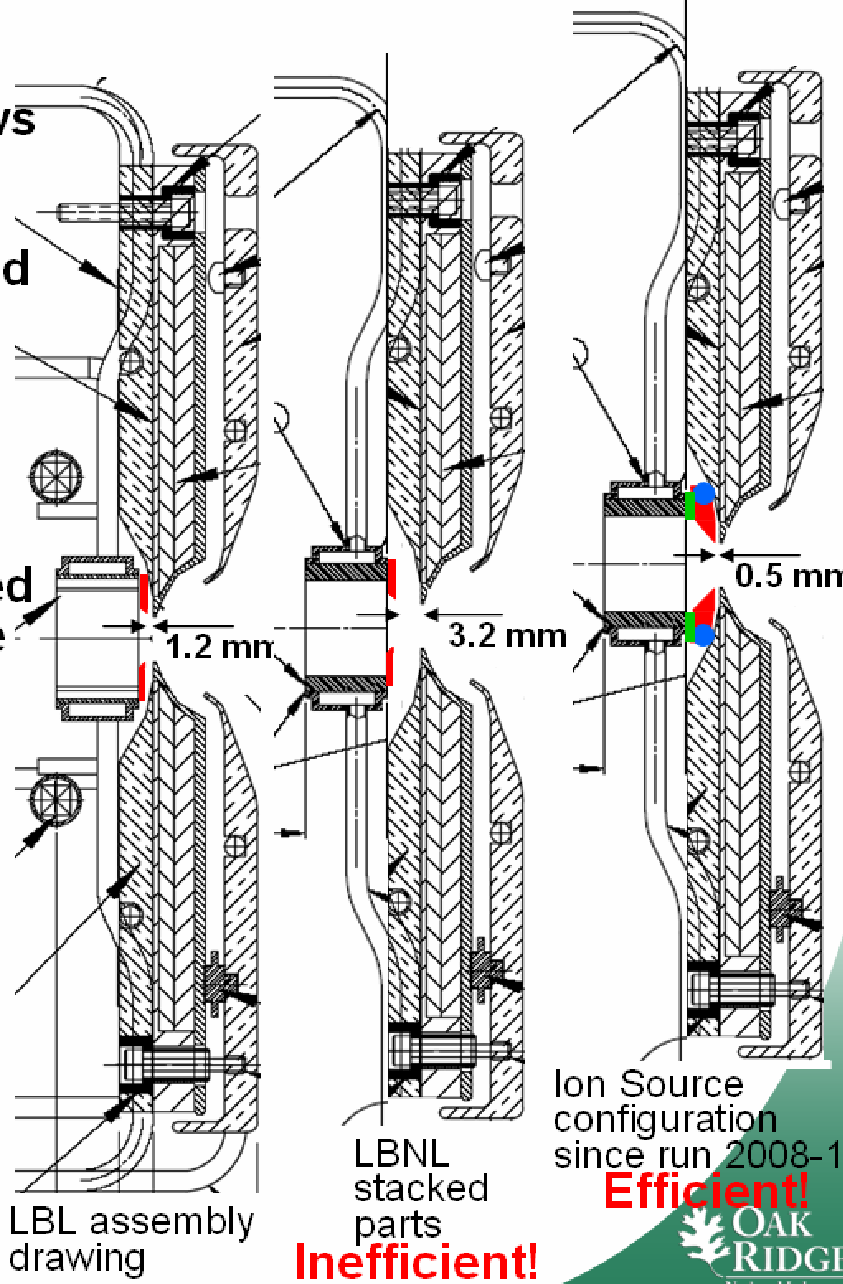
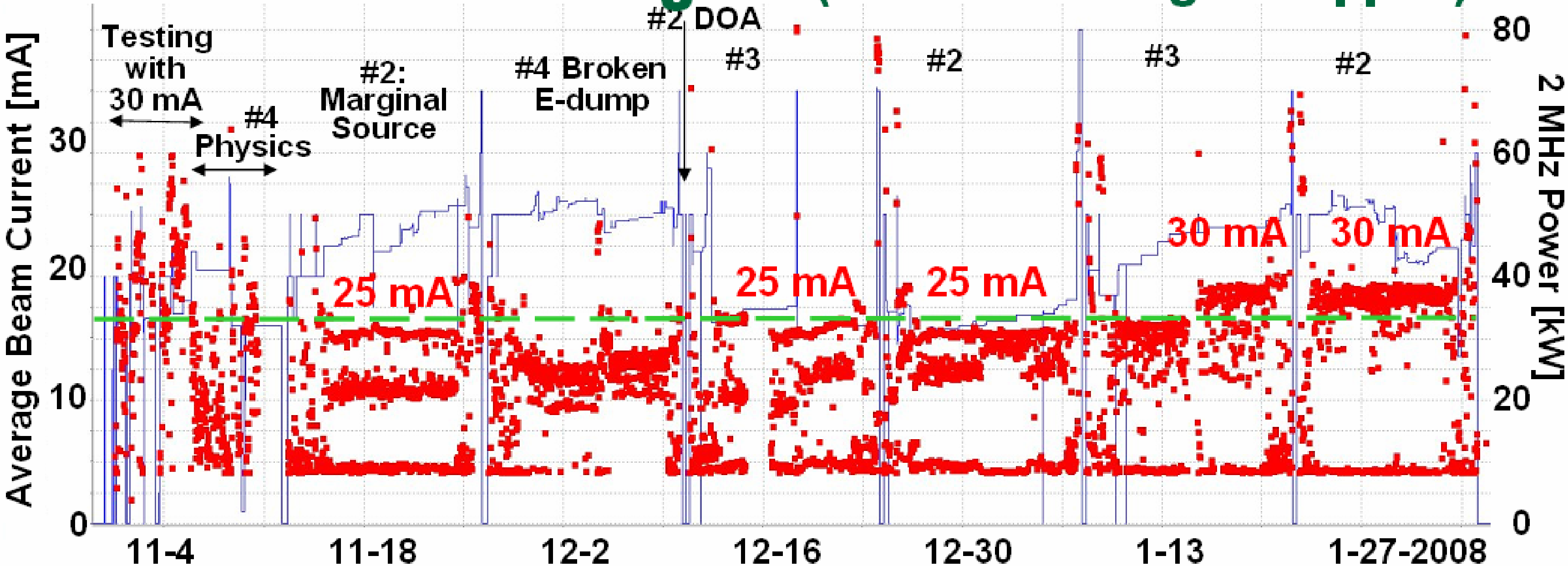
The Cs Collar Position:

- The LBNL assembly drawing shows a 1.2 mm gap between the cesium collar outlet and the source outlet.
- Correctly fabricated and assembled LBNL parts leave a 3.2 mm gap.
- Refabricating the Cs collar would take ~4 weeks with only ~5 weeks before having to deliver 25 mA!
- In the remaining 5 weeks 13 different configurations were tested before settling on a simple change that increased the yield by ~50%.
- It features a 4 mm thick Mo aperture with ceramic balls (blue) that guarantee a ~0.5 mm gap and use an existing groove to center.





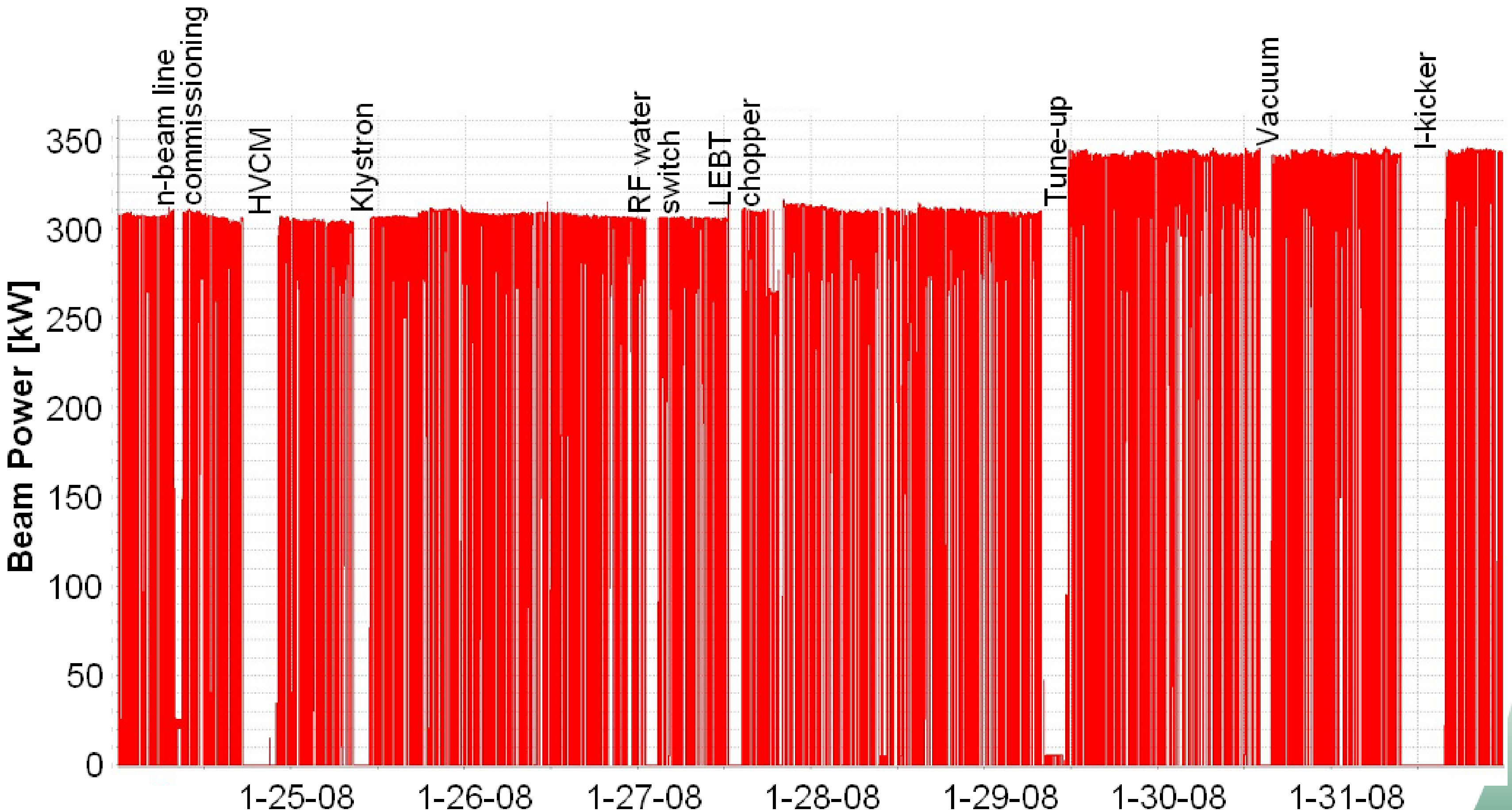
The 25 mA Challenge: (~16 mA average chopped)



- In the 5 days before run 2008-1 three source configurations were tested with ~30 mA on the Front End before deciding on the ball-centered Mo collar outlet as workhorse for this run.
- 6th and 7th sources made 25 mA with <40 kW.
- 8th and 9th sources made 30 mA with ~50 kW.

- **30 mA Challenge was met 5.5 month ahead of schedule!**

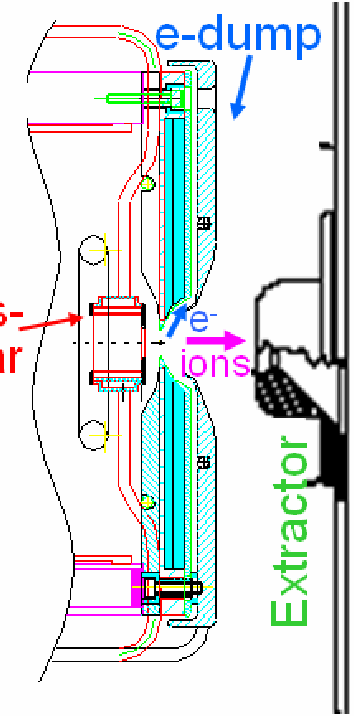
The last Production Cycle of Run 2008-1



Without being maxed out, Operations can use the 2 MHz power to maintain the beam power at a constant level!

The 30 mg Cs System:

The LBNL H- source has a outlet electrode assembly that
1. extracts the ions and forms a beam
2. deflects the co-extracted electrons onto the e-dump
3. adds surface-produced H- ions to the beam

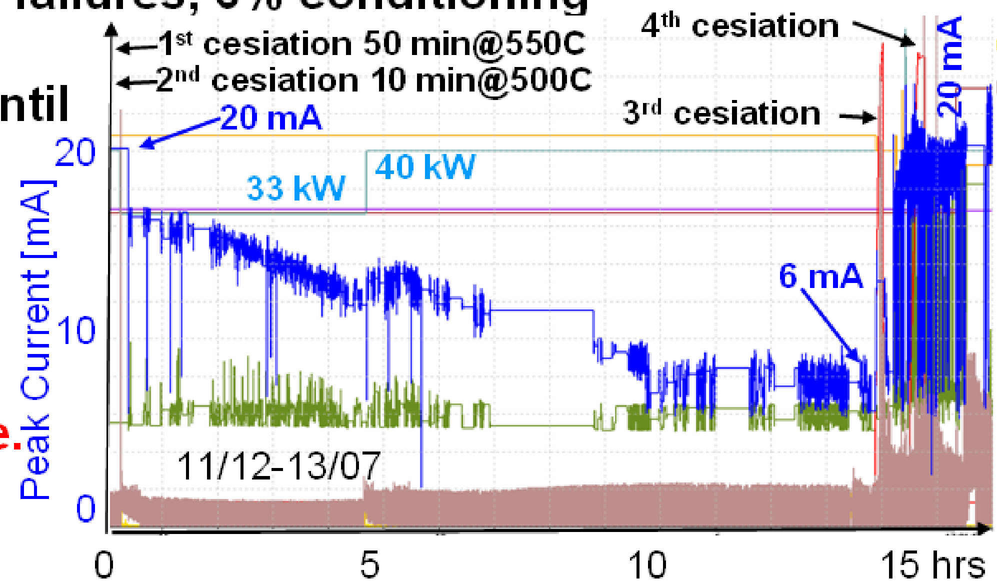


To minimize Cs-induced arcing in the ultra-compact LEBT and the nearby RFQ, LBNL introduced 8 Cs_2CrO_4 cartridges (SAES Getters), which together contain <30 mg Cs. They are contained in the Cs collar, where the temperature can be controlled between ~30 and ~400°C with compressed air.

When being heated with plasma to ~550°C, the Cs_2CrO_4 reacts with the getter St 101 and releases Cs.

- To reduce the risk of antenna failures, 6% conditioning was limited to ½ hour.
- The Cs collar was kept cold until raising temperature to 550°C, following a recommendation presented at PAC'05 (which turned out to be incorrect).
- **Results, however, remained inconsistent and unpredictable.**

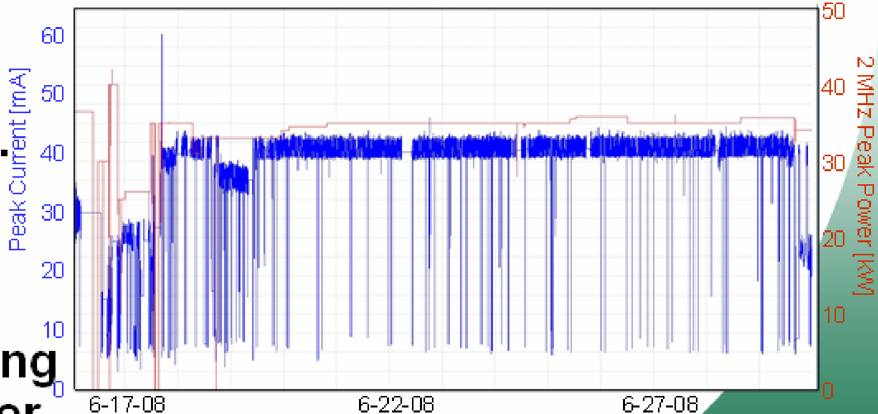
Clearly, a new analysis was needed!



The 30 mg Cs System:

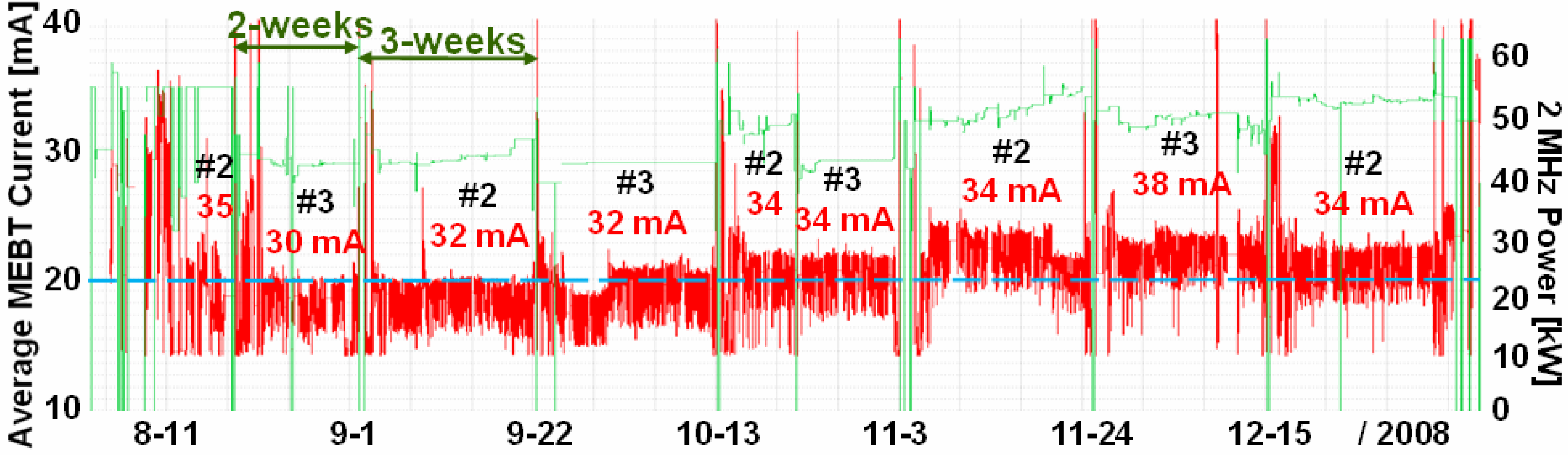
- RGA- and other observations suggested that conditioning with a cold Cs collar fails to de-gas the Cs_2CrO_4 and St101 powder. Apparently, after being heated to 550°C, the St101 reacted for the 1st 20-100 minutes with the surface contaminants, before starting to reduce the Cs_2CrO_4.
- Conditioning with ~130°C, and then gradually increasing the temperature to 350 C before raising the temperature to 550°C allows for consistently releasing ~10 mg Cs during the 30-minute, 550°C cesiation.
- Increasing the ~6%-duty-factor conditioning from 0.5 to ~2.5 hours appears to have resolved the persistence problem. Apparently, the Cs deposited on a insufficiently sputter-cleaned surface is sputtered away.
- At ~4% duty factor the change in the beam current over 10-20 days is normally too small to be assessed. This leaves two logical explanations:

1) There are many mono-layers of Cs and the sputtering is too slow to drop below 1 mono-layer.
2) All excess Cs atoms are rapidly sputtered away except for those Cs atoms bonding with 3 neighboring surface atoms, leaving a very stable fractional mono-layer.



The 30 mg Cs could last for years!

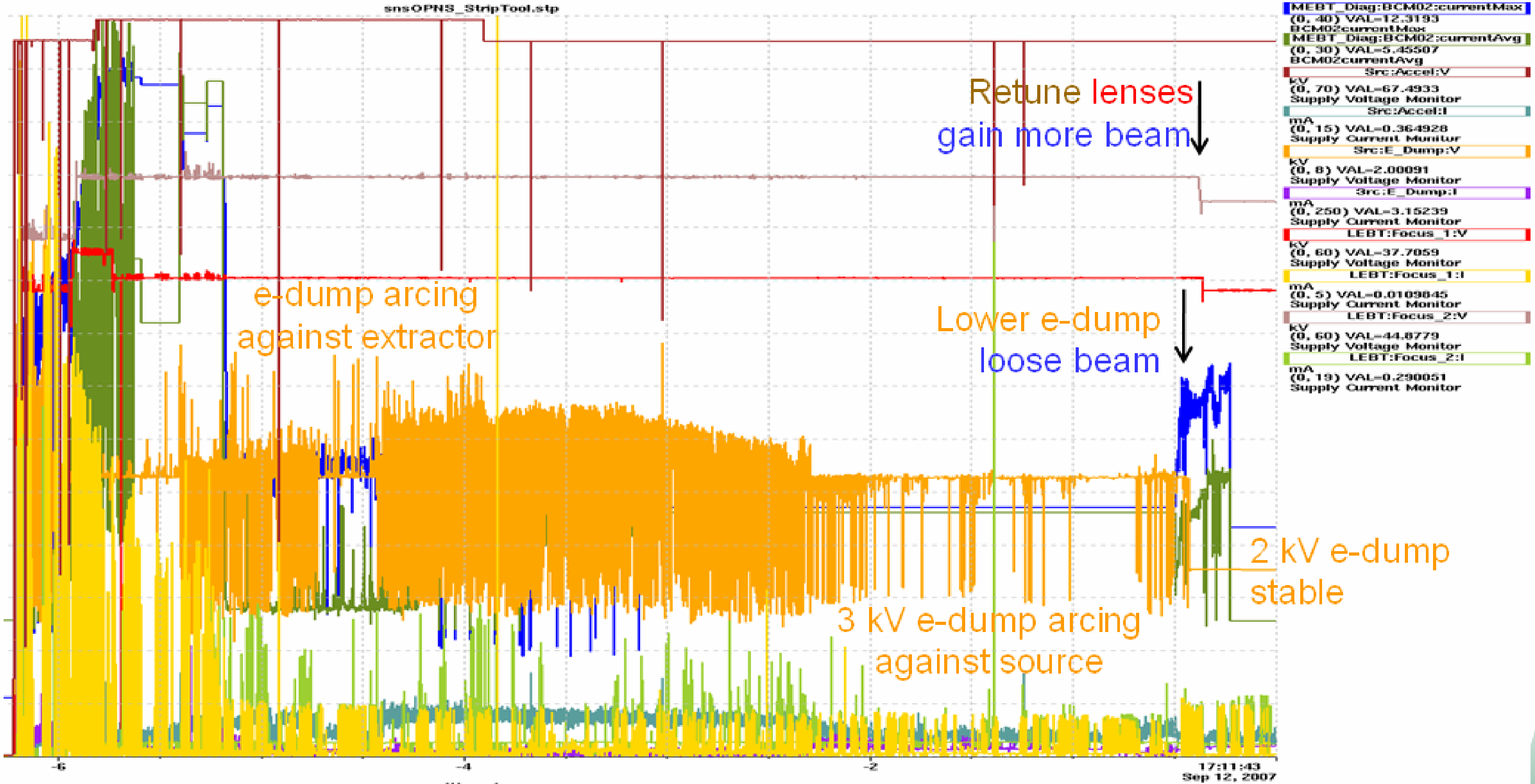
The 3-week & 32 mA Challenge: (~20 mA average chopped)



- A 5-week lifetime test on the test stand supported the implementation of a 3-week source cycle starting September 1, 2008.
- Run 2008-3 /2009-1 required routinely 32 mA, ~the level that was barely achieved at the end of run 2008-2.
- Without knowing the exact benefits, every new source was tuned with a 1 kV higher e-dump voltage and 20°C higher Cs collar temperature, carefully watching for e-dump arcing and beam degradation. This validated problem-free operations with up to 6.2 kV e-dump and up to 160°C.

A 3-week production run utilized 38 mA, the requirement for 2010!

The Electron-Dump Story



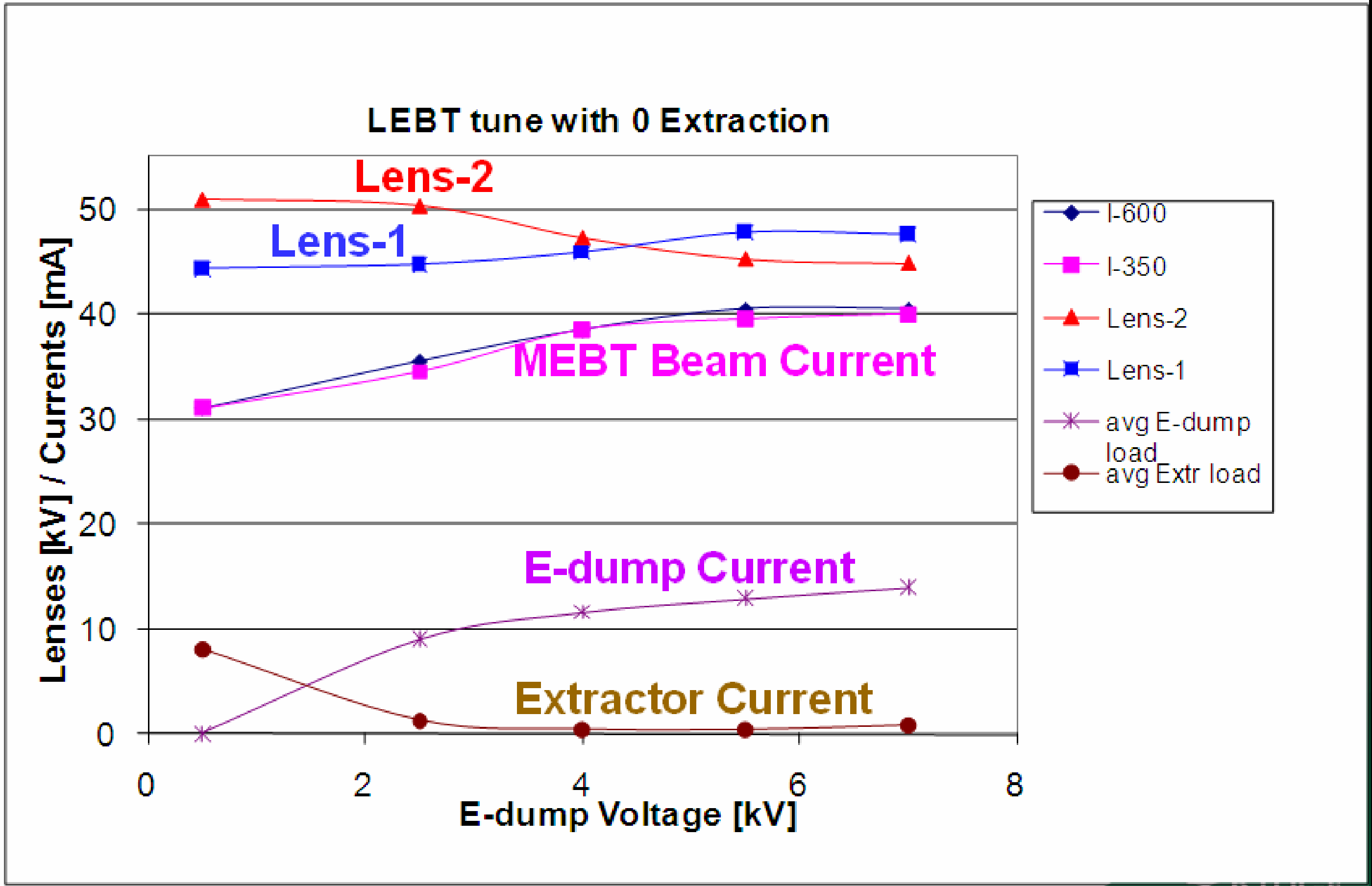
In the past the e-dump voltage was normally set to <3 kV to avoid frequent e-dump arcs. Its voltage did not appear to affect the MEBT beam current: Small changes did not give more beam. Large changes yielded less beam, which could be recovered by retuning the lenses.

In spring 2008 we replaced the Vespel insulators with ceramic ones and started to use low-profile screws.

The Electron-Dump Story

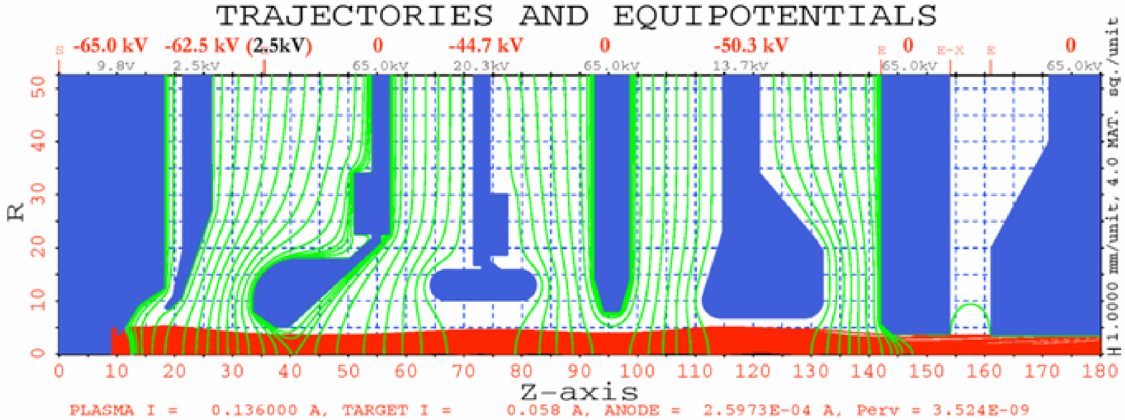
•After establishing that the e-dump can reliably be operated with voltages >5kV, and having a stable source, a maintenance day was used to explore different LEBT tunes. The study showed clearly that the e-dump can increase the MEBT beam current by ~15% if the lenses are carefully adjusted. It further showed that more electrons would impact on the e-dump rather than on the extractor.

Increasing the e-dump voltage enabled the 38 mA run!

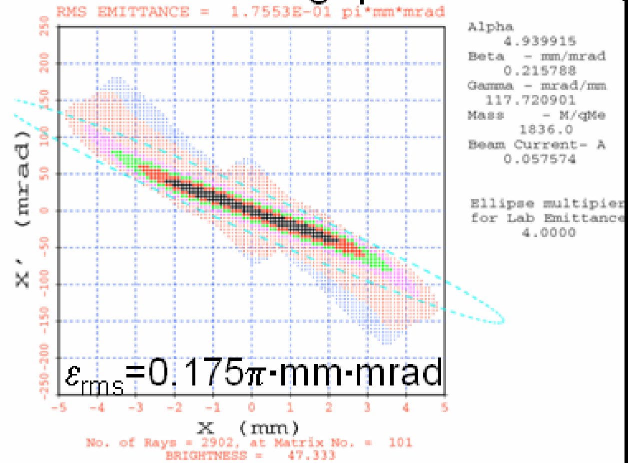


The Electron-Dump Story

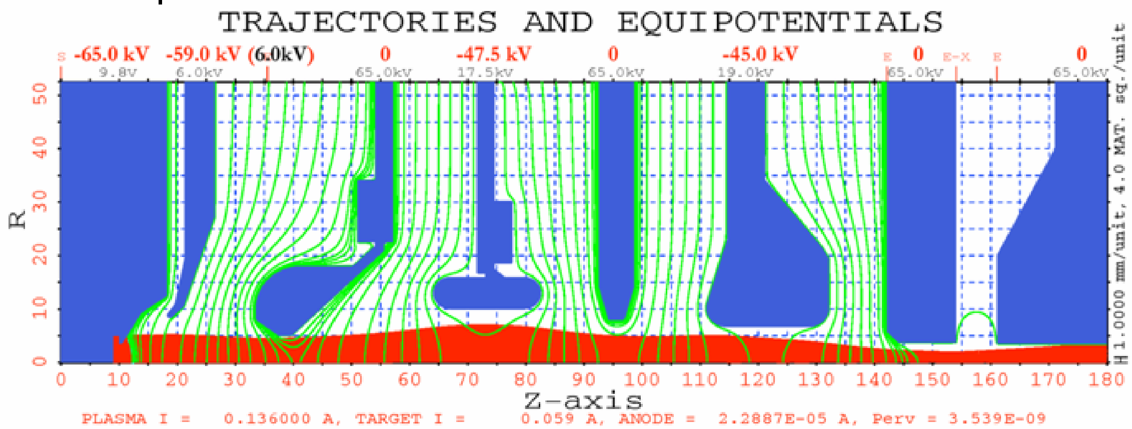
E-dump = 2.5 kV

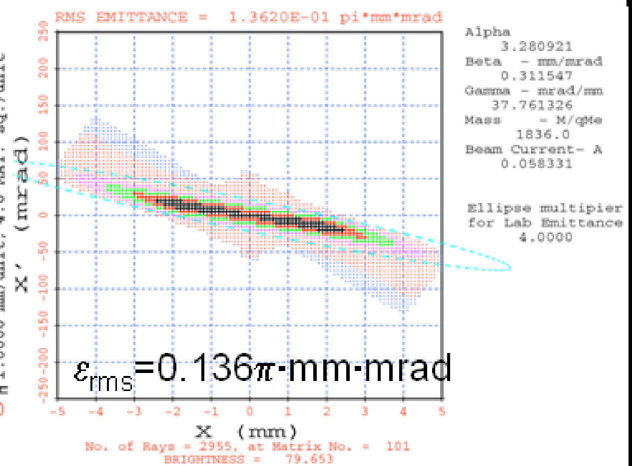


Emittance in extraction gap



E-dump = 6.0 kV

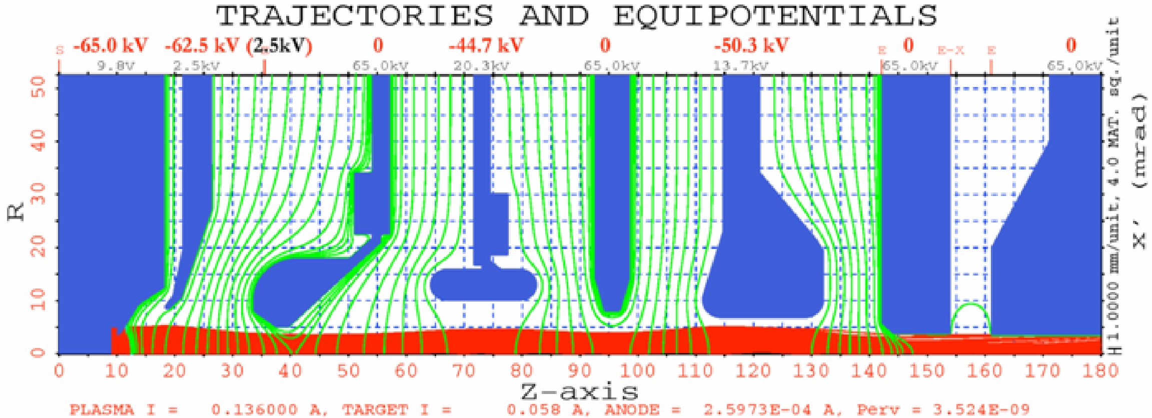




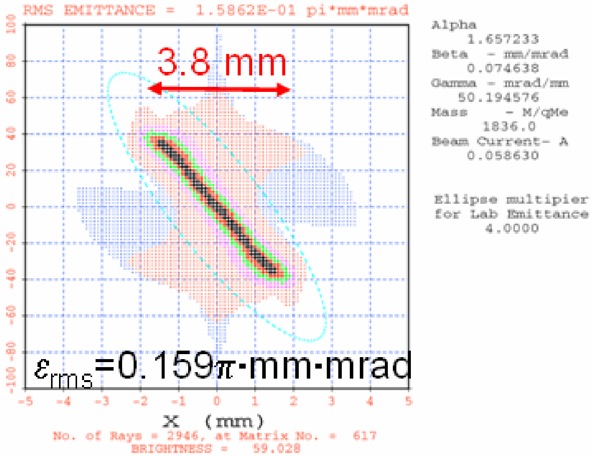
PBGUNS simulations suggest that the higher E-dump voltages extract the beam with less convergence.

The Electron-Dump Story

E-dump = 2.5 kV



Emittance at RFQ entrance



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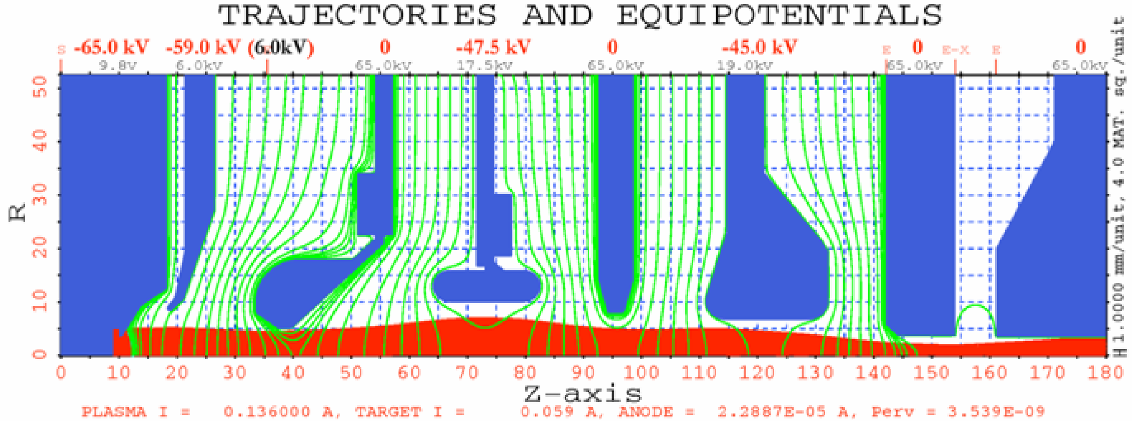

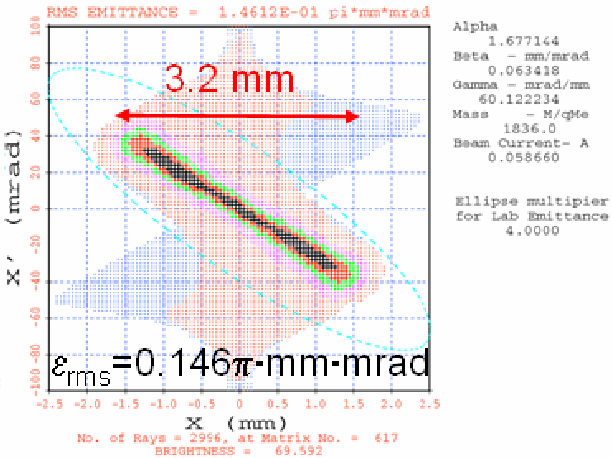

PBGUNS simulations suggest that the higher E-dump voltages extract the beam with less convergence. The larger beams in the LEBT can be better compressed by the telescope, yielding smaller beams at the RFQ entrance.

A safety-certified MEBT beam stop!

- The compactness of the LBNL LEBT allows for no beam current diagnostics before the RFQ.
- Source tuning and development required a secured LINAC tunnel, which was very limiting.
- Early in 2008, SNS implemented a safety-certified MEBT beam stop, which allows running the RFQ while work is performed in the LINAC tunnel.
- This has drastically increased the ion source testing time on the Frontend.

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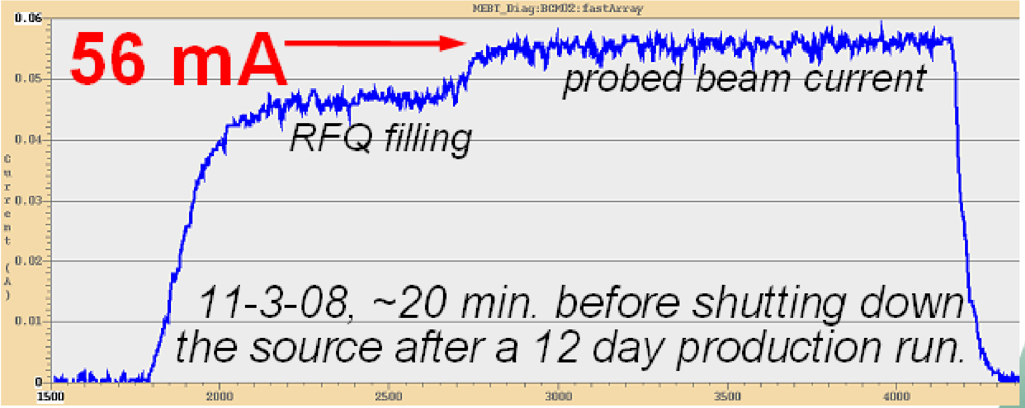
- This has drastically increased the ion source testing time on the Frontend.
- In the MEBT beam stop mode, the source is started before the RFQ. An adjustable delay allows for accelerating any 50 μs slice of the ion source pulse.



- This yielded **56 mA** MEBT beam current halfway through 0.69 ms long pulses at 60 Hz after a 12 day production run.

This is close to the 59 mA needed for 3 MW operation!

Summary and Conclusions

- We have learned to operate the modified LBNL H^- source in an efficient and reliable manner. We normally meet and exceed the requirements for the SNS Power Ramp-Up.
- A neutron production run has utilized 38 mA, which is the requirement for 1.4 MW operations.
- We have demonstrated 56 mA in the MEBT, which is close to the 59 mA requirement for 3 MW operations.
- Our revised source conditioning, cesiation, and startup procedure yields consistently high beam currents with nearly perfect persistence. Subsequent cesiations normally do not increase the beam current, even not after 20 days.
- There were no antenna defects in the last 5 sources of the last run. However, the 6^{th} to last source had to be replaced due to an antenna defect.
- We continue our efforts to lower the required RF power by making our sources more efficient and reliable.

Thank you for your attention!