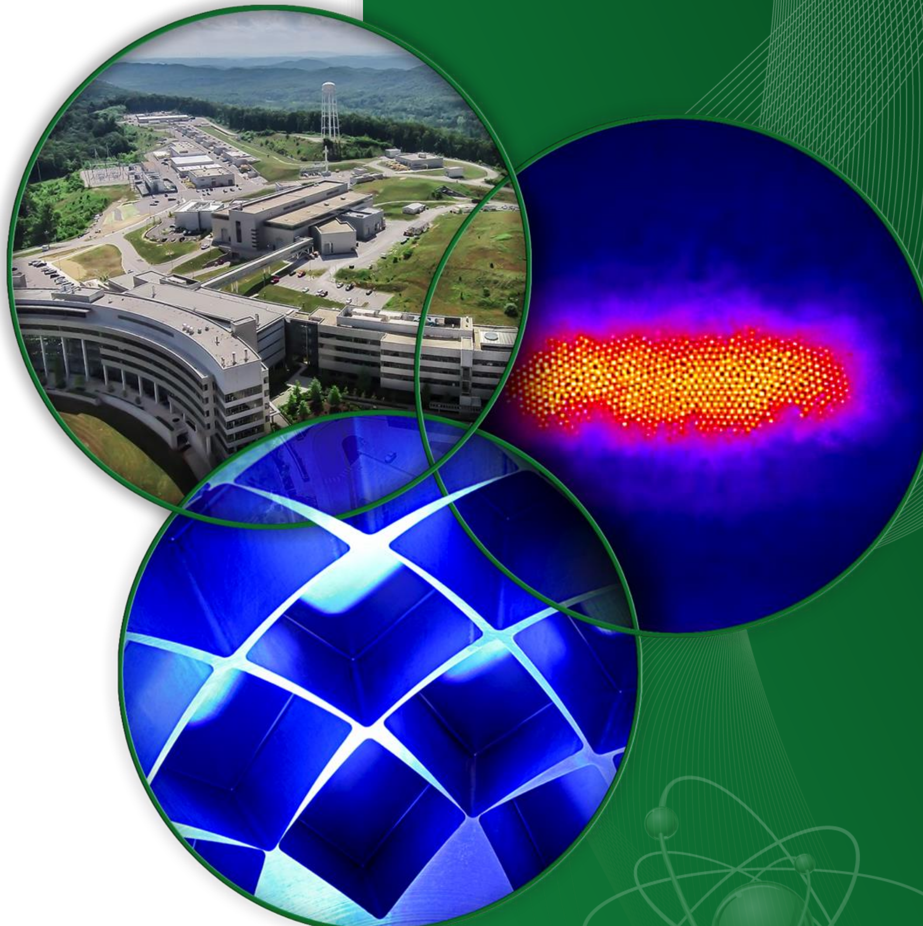
Accelerator Physics and Foil Development



M. Plum (S. Cousineau)

SNS AAC Review

March 24-25, 2015

ORNL is managed by UT-Battelle
for the US Department of Energy

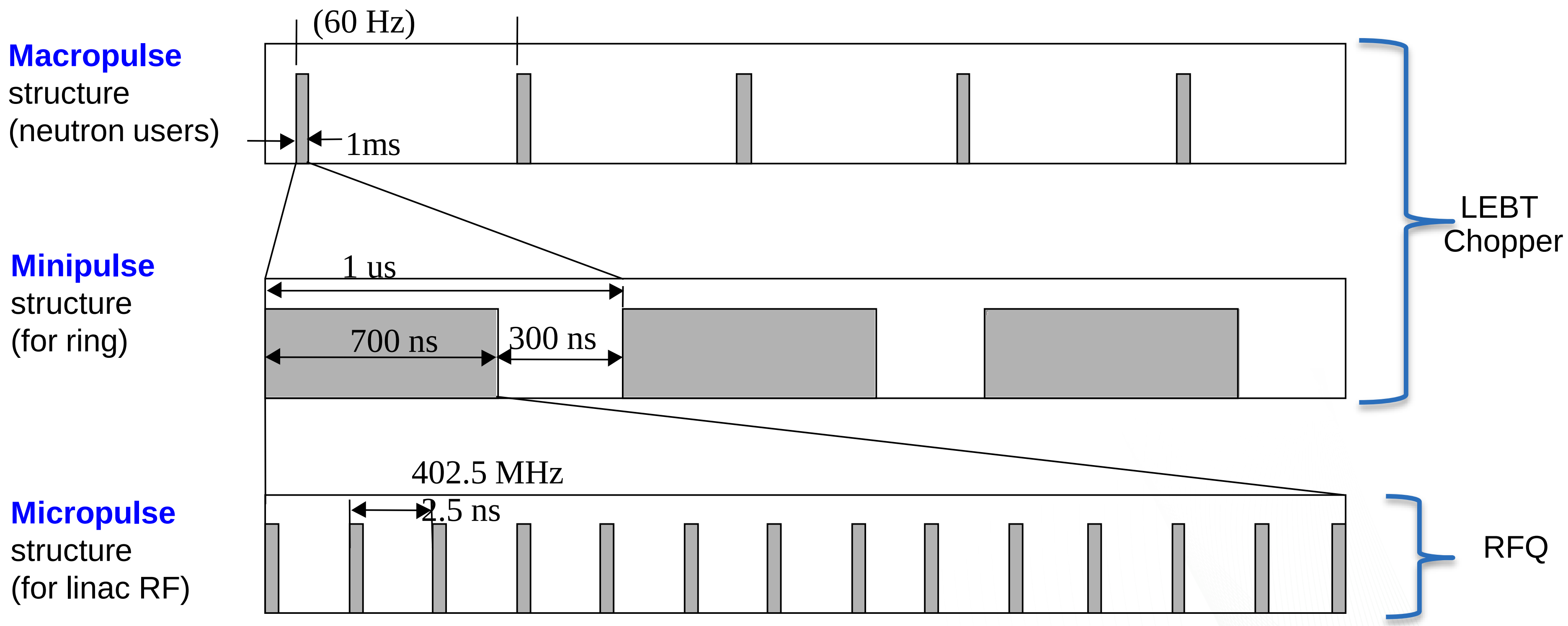
OAK RIDGE National Laboratory | SPALLATION NEUTRON SOURCE

Part I:
Accelerator Physics Efforts

2.4845 ns (1/402.5 MHz)

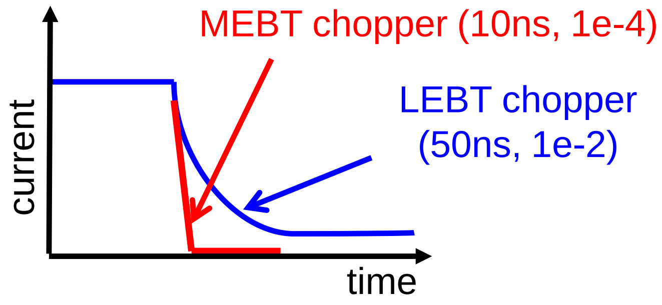
Time Structure of Chopped Beam

- RFQ provides micropulse structure
- LEBT chopper provides mini and macropulse structure



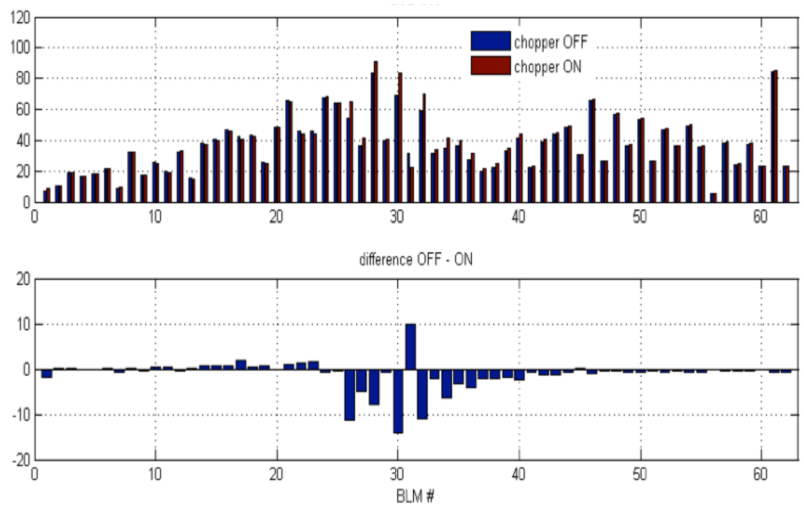
MEBT Chopper Taken Out of Service

- Used to clean minipulse tails, gap.
- Used only intermittently.
- Did not result in significant linac loss reduction.
- Loss reduction in ring collimation, extraction, but losses low already there.
- Removed after MEBT chopper target leak.

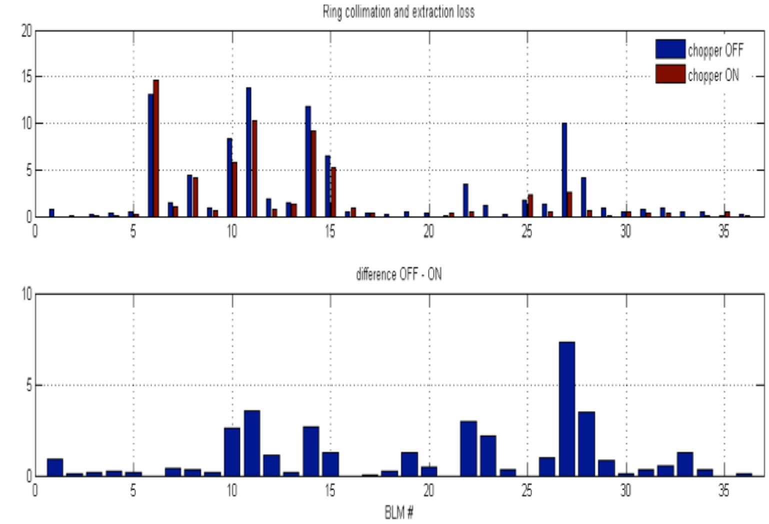


No major impact from MEBT chopper out of service

Effect on SCL Losses



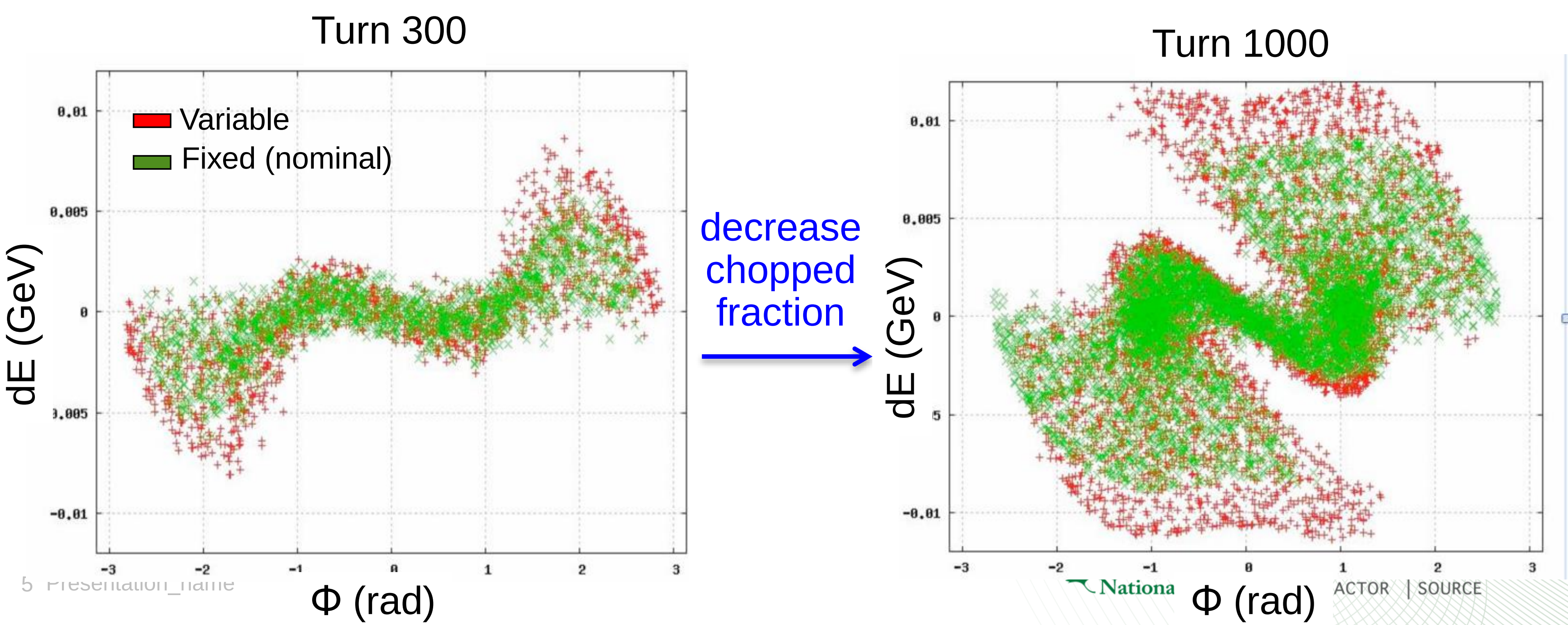
Effect on Ring collimation & extraction losses



Studies on Extending Chopped Beam Fraction in Ring

- Results from simulation
- Upcoming hardware modifications to allow experiments (summer, 2015).

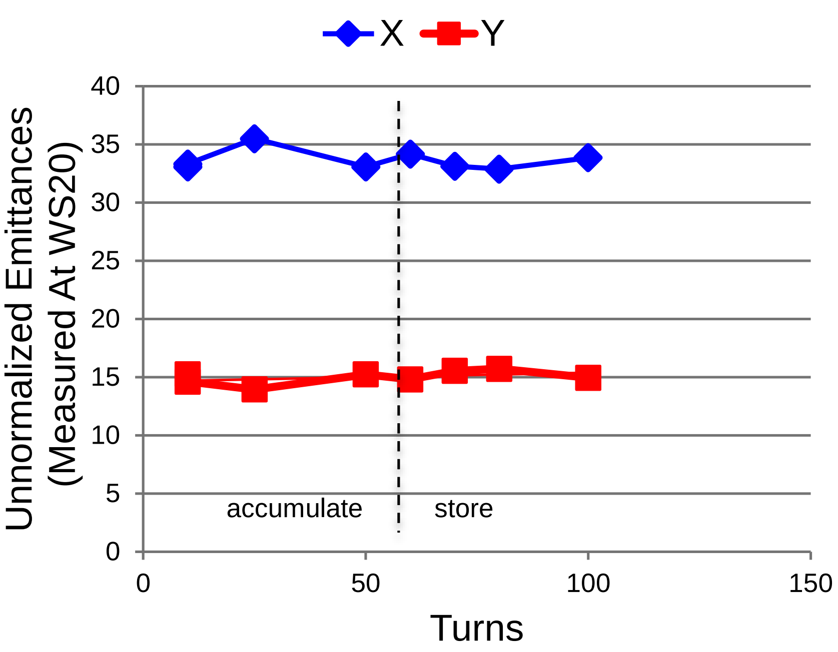
Method	Predicted Increase Beam Current	Turns Storage Required
RF Ramping	8%	200 (~20% increase injection loss)
Chopper waveform painting	11%	None



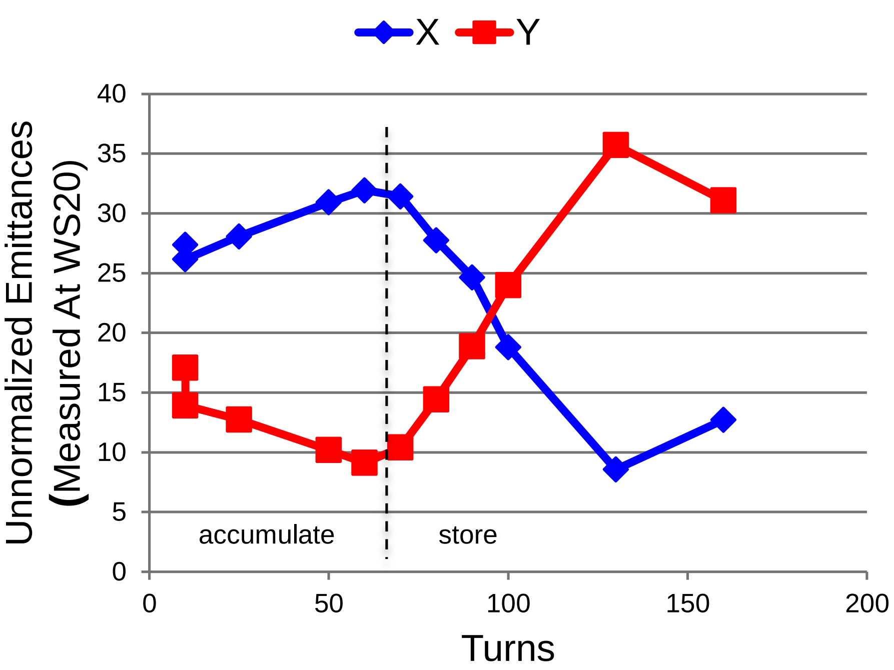
Study of Coupling Resonance in the Ring

- Investigating space charge driven transverse coupling for small tune split (Montague resonance).
  - Production working point near equal tunes (Q_x=6.23, Q_y=6.20).
  - Causes lack of independent control in transverse profile.
  - Ongoing thesis work, R. Potts

H and V tunes spilt by 0.03:



Equal H and V tunes:



PyORBIT Status Update

- PyORBIT: multi-particle simulation open source code
  - Linac and Ring
- Development started at SNS as a new implementation of the ORBIT code
  - Uses modern software tools
- Collaborative project with contributors from CERN and GSI
  - Contributors: Sarah Cousineau, Jeff Holmes, Timofey Gorlov, Andrei Shishlo (SNS ORNL), Hannes Bartoski (CERN), Oliver Boine-Frankenheim and Sabrina Appel (GSI)
  - Used at SNS, CERN,GSI, ISIS and Los Alamos
- Applications
  - SNS
    - Linac and beam dynamics simulations (Shishlo)
    - Ring and transfer line beam dynamics simulations (Cousineau, Holmes)
    - Laser-stripping calculations (Gorlov)
    - Montague space charge resonance ring simulations (Potts)
  - CERN
    - High intensity beam dynamics studies for LHC injectors: PS Booster, PS, and SPS (Bartosik)
  - GSI
    - Simulations of CIS-18 (Sabrina Appel), Design studies for FAIR (Sabrina Appel)

Open XAL Status
Overview

- Active international collaboration among accelerator facilities including SNS, ESS, MSU FRIB, CSNS and TRIUMF
- Derived from SNS XAL with major architectural redesign plus algorithm and performance improvements
- Framework for developing accelerator physics applications, scripts and services
- Common shared core includes machine representation, online model and algorithms
- Customization via shared and site specific applications, extensions, plugins and resources

Open XAL Status
Major Milestones

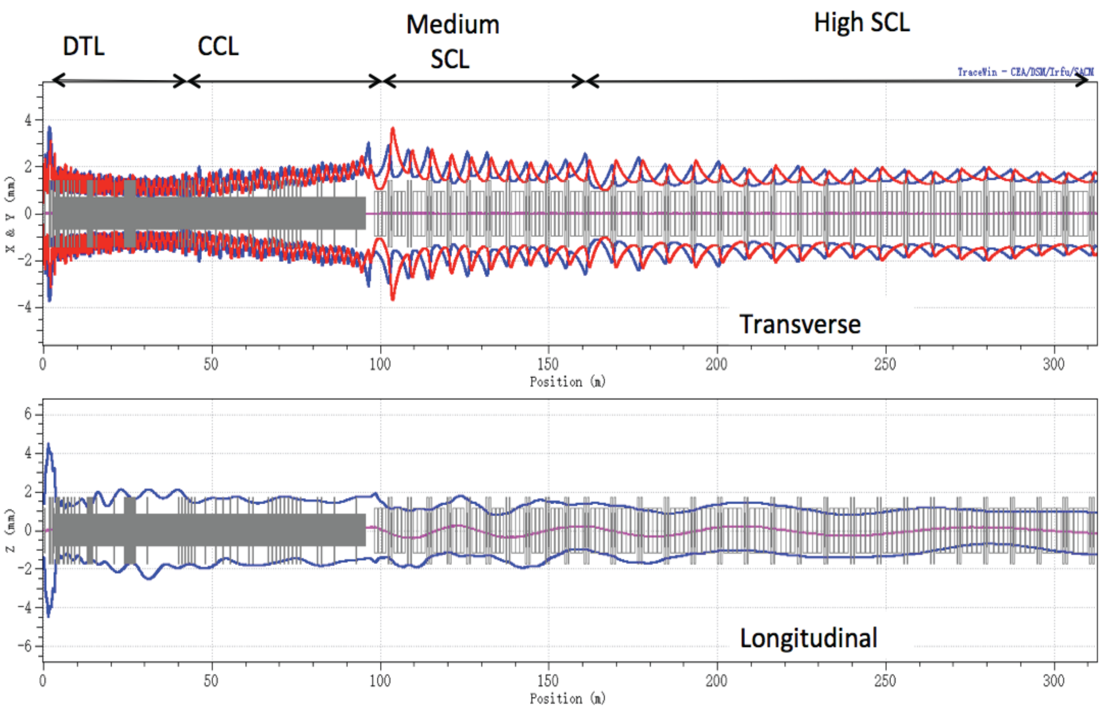
Milestone	Status
Implement new site customizable, zero configuration build system	Complete
Classify XAL tools as core, extensions and plugins	Complete
Port common core, extensions, plugins, applications, scripts and services	Complete
Fix all compiler warnings (Java 7 & 8)	Complete
JSON based services framework	Complete
Refactor Online Model	Complete
Support script applications	Complete
Migration to Open XAL for operations	Progressing
Verification and bug fixing	Progressing

Second Target Station AP Activities

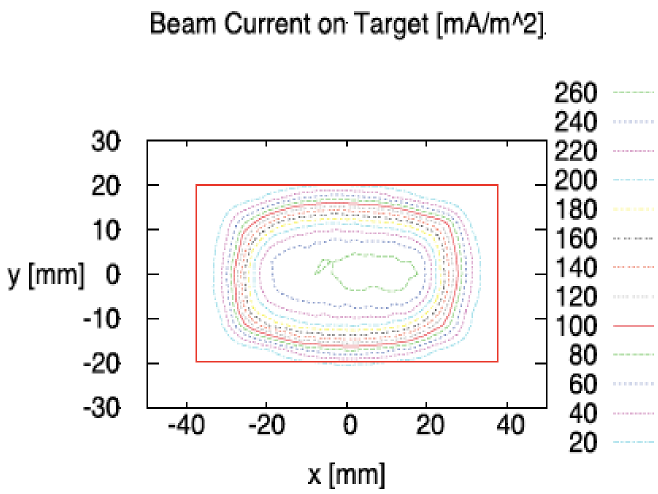
- Extraction scheme: RTBT to new “R2T2” beam-line
  - Redirect 1 of 6 pulses
- New R2T2 lattice
  - Horizontal and vertical achromats
- Beam dynamics / multi-particle simulations
  - Linac
    - Additional cryomodules
    - Higher energy and current
  - Ring
    - Higher energy and current

STS Beam Simulations

Beam envelopes through the SNS linac

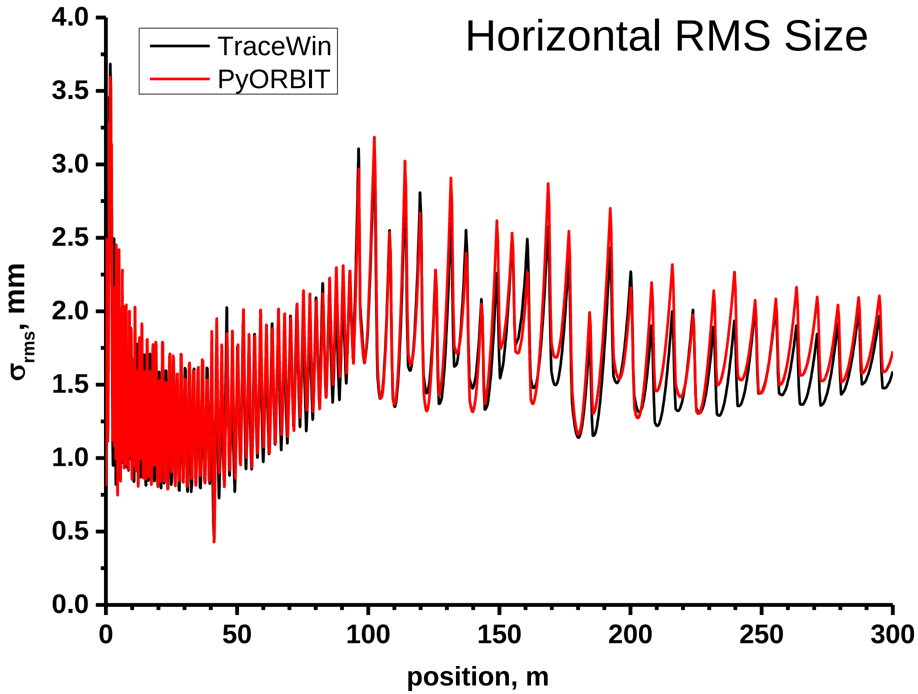


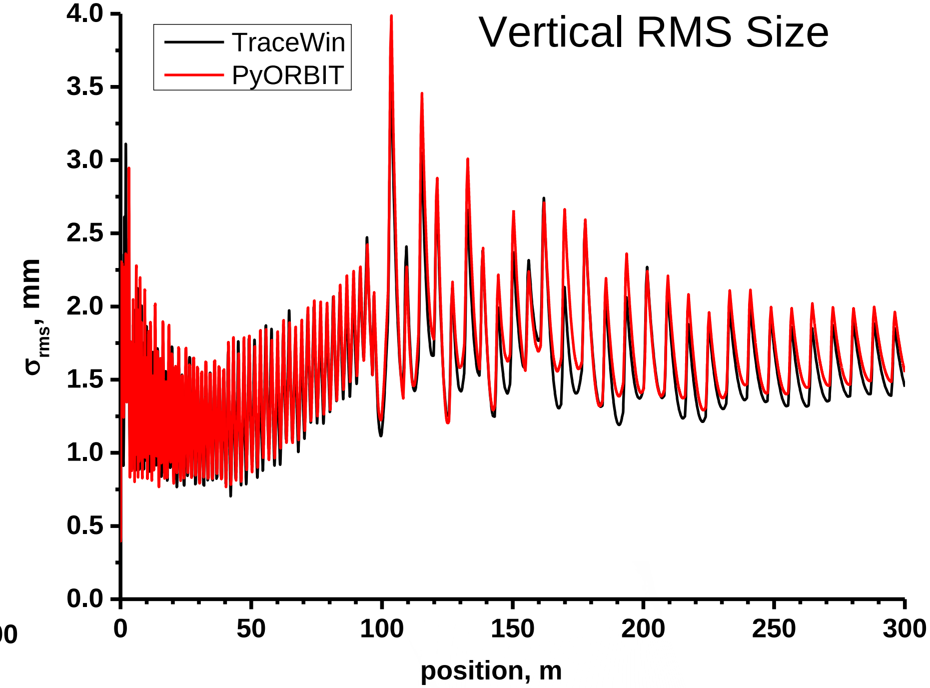
Beam distribution on the STS target

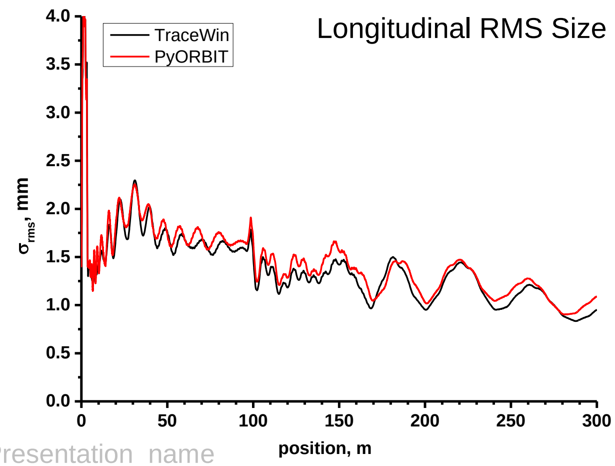


- Multi-particle beam simulations for linac and ring performed
  - No alarm bells
  - May require tweaking lattice bare tune to avoid coupling

PyORBIT – TraceWin : SNS STS Upgrade MEBT-SCL End-to-End Linac Simulations





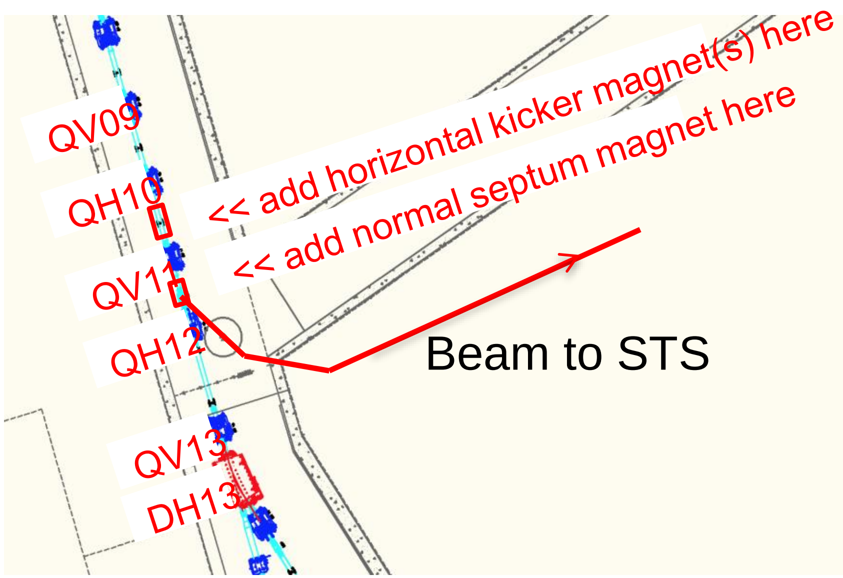


PyORBIT and TraceWin:
No beam loss found

Peak current 50 mA

E_{out} = 1376 MeV

STS Activities : Kicker Scheme



- Horizontal kicker scheme developed to direct pulses from existing RTBT to STS
- Requires replacing one quad in RTBT.
- After evaluating options, decided on a scheme with a normal septum magnet.

Option	Normal septum
Required beam deflection, septum entrance	137 mm
Achieved beam deflection septum entrance	143 mm
Kick angle per kicker	1.4 deg
Kicker / septum center displacement	98 mm
Required quad aperture radius	124 mm
Existing 21Q40 aperture radius	~100 mm

AP Outreach Activities (2013, 2014)

- USPAS
  - Chair and members curriculum committee, prize committee
  - 6 instructors covering 3 courses:
    - Accelerator Physics Fundamentals, 2013
    - Control Room Accelerator Physics, 2013
    - Beam Loss and Accelerator Protection, 2014
- PRSTAB editorial board
- Organizing, Scientific Program Committees
  - IPAC15, IPAC16, ICAP, ICFA HB workshop
- 8 invited talks
- 5 Accelerator Review Committees
- Student support
  - 3 graduate students
  - 10 undergrad interns
  - ORNL classical mechanics course

Part II:
Stripper Foils Update

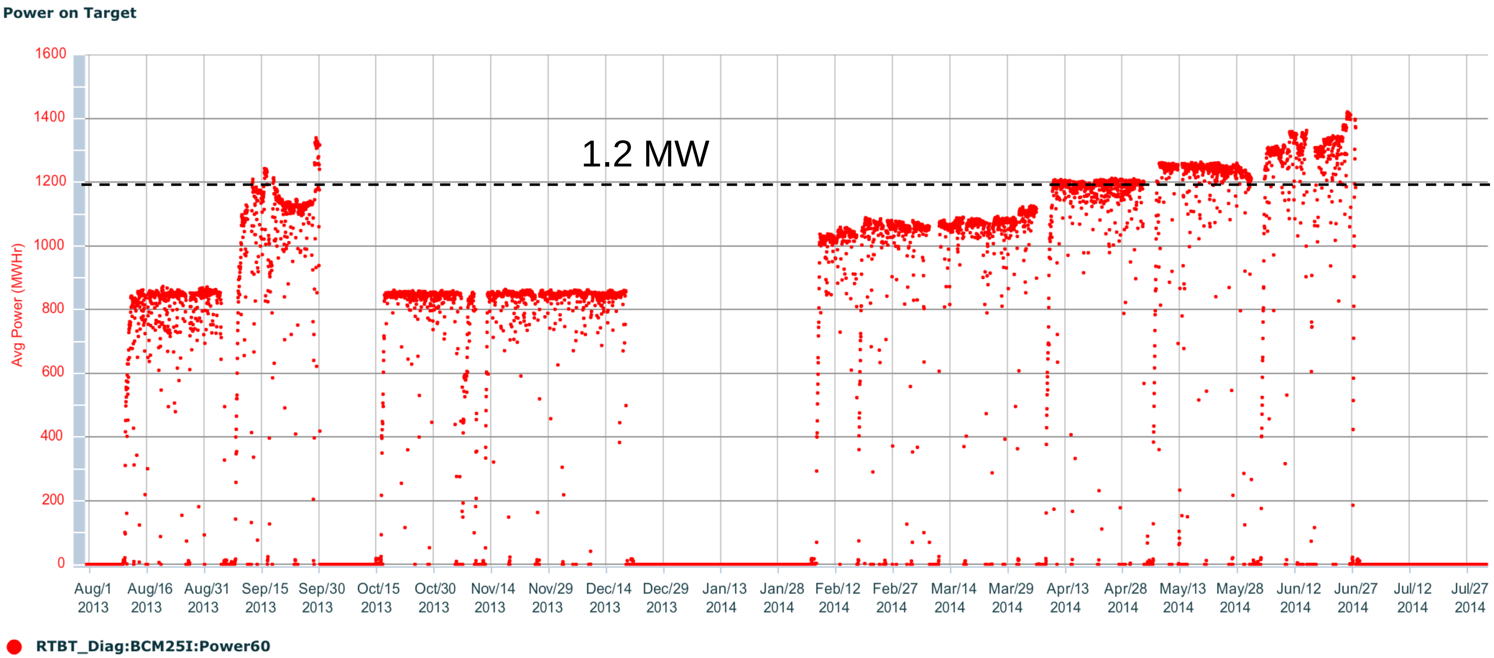
Stripper foil update

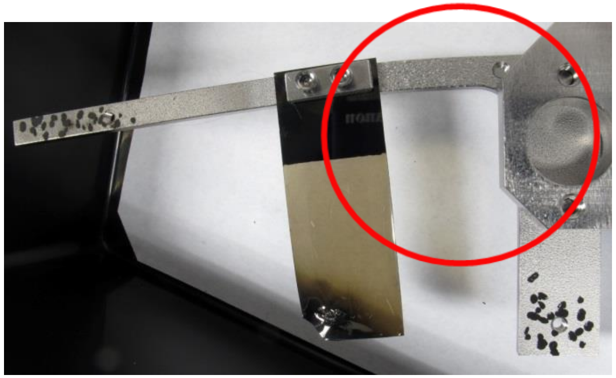
- Successes: Since 2009 (last foil system modification)
  - Standard nano-crystalline diamond foils work at 1.4 MW !
  - Tested 2 HBC (J-PARC) foils – failed quickly
  - Biggest problem: foil shaking

- Problems: Beginning with the Spring 2014 run
  - Serious damage to the foil bracket due to reflected convoy electrons
  - Investigating and mitigating this bracket damage

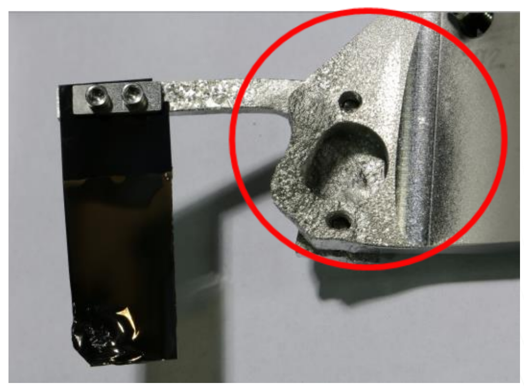
Beam power and foil plot: 2014

- Consistent signs of damage to brackets at >=1.2 MW





#1839, used for 1.1 – 1.2 MW for a few weeks, then 1.4 MW demonstration for a few minutes, and then 1.3 MW for ~32 hours.

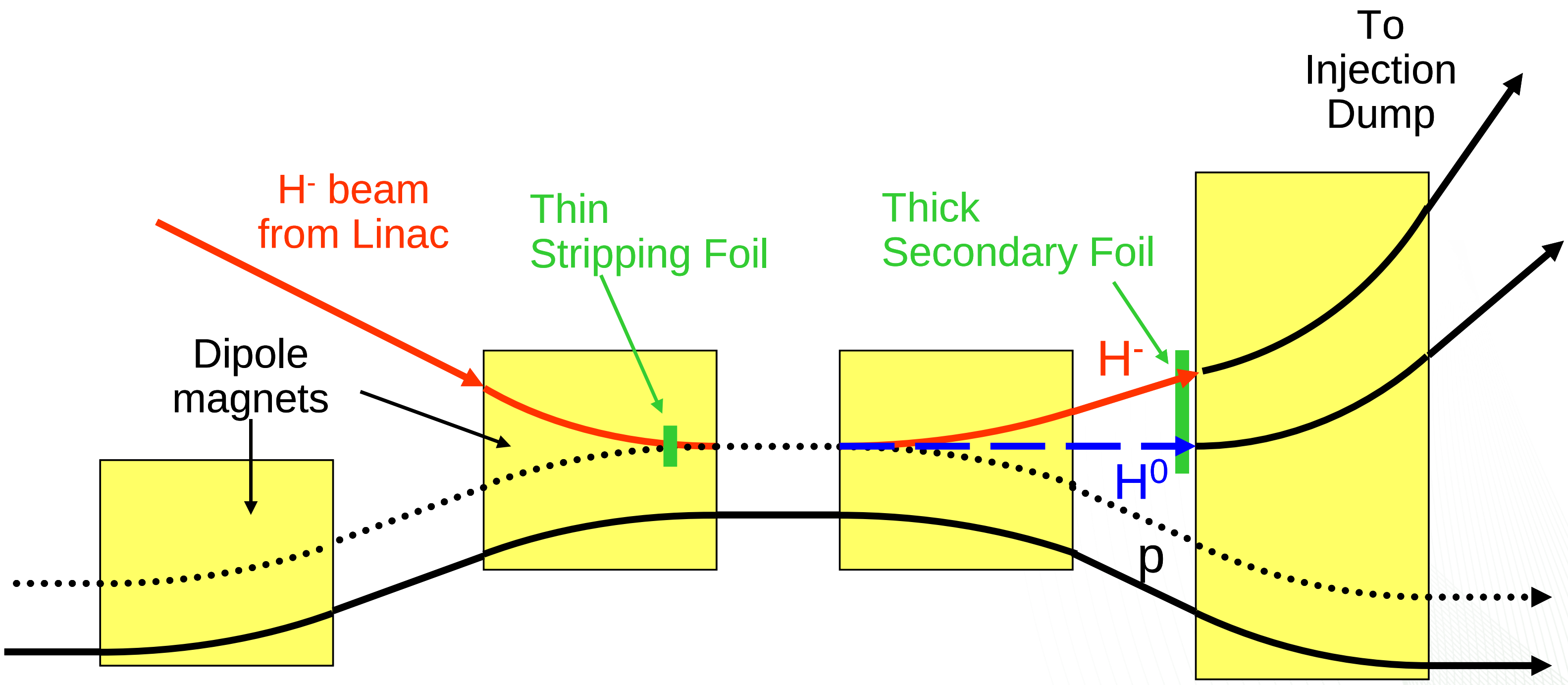


#1872, up to 1.4 MW. 3 months at 1.1 to 1.4 MW.

BW-18. ~24 days at ~1.2 MW

SNS injection schematic

- Multi-Turn Charge-Exchange Injection to accumulate high intensity
- Stripping foil removes 2 electrons, injected protons merged with previously accumulated beam.
- The Secondary foil strips residual H^- and H^0 which survive the first foil.

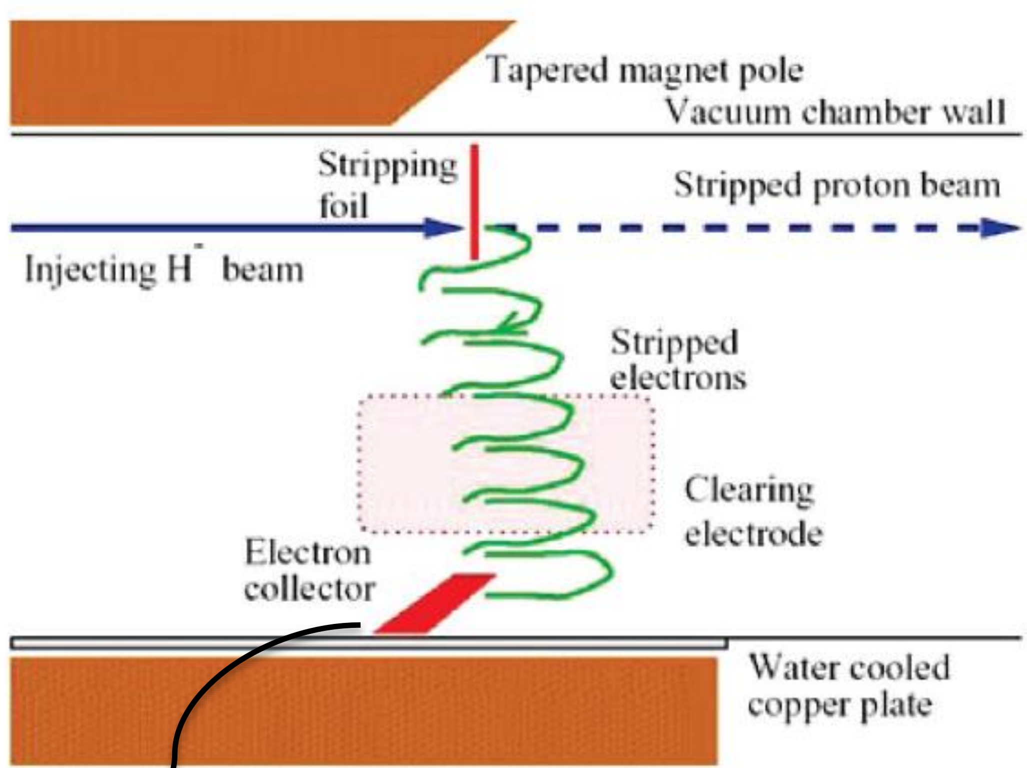


Electron Catcher Design

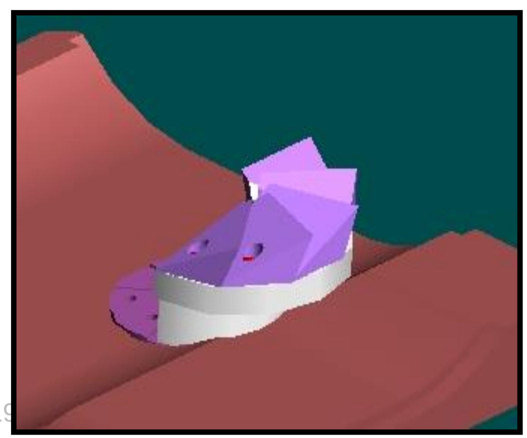
- Field tilt directs electrons downward
- Nominally, electrons should impact underside of electron catcher wedges

1 GeV H^- convoy electrons

- 545 keV energy
- ~ 2 kW
- Gyroradius: 12 mm,
- Period: 0.29 ns,
- Pitch: ~16 – 23 mm

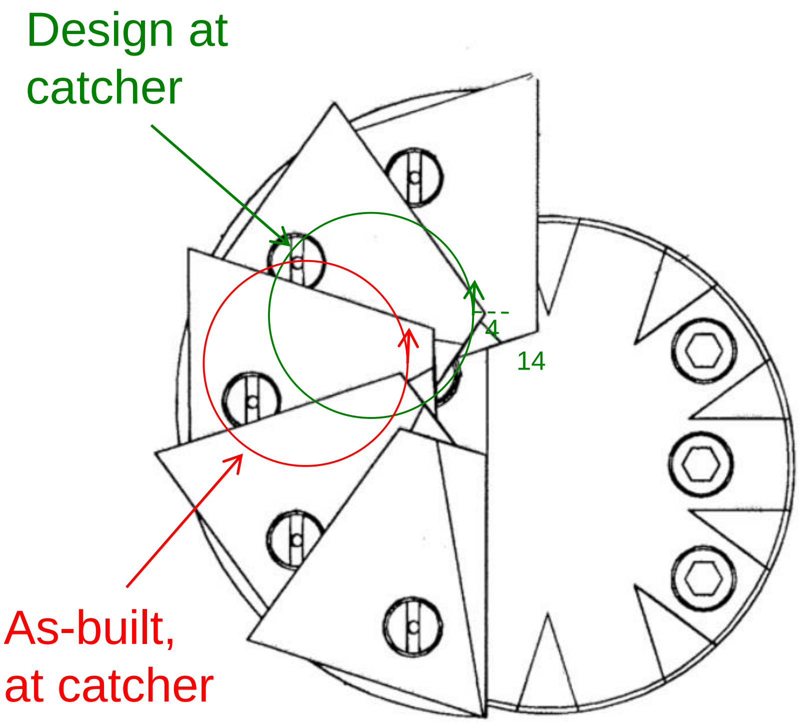


Electron Catcher



Efficient electron catching: catcher and foil need to be properly aligned

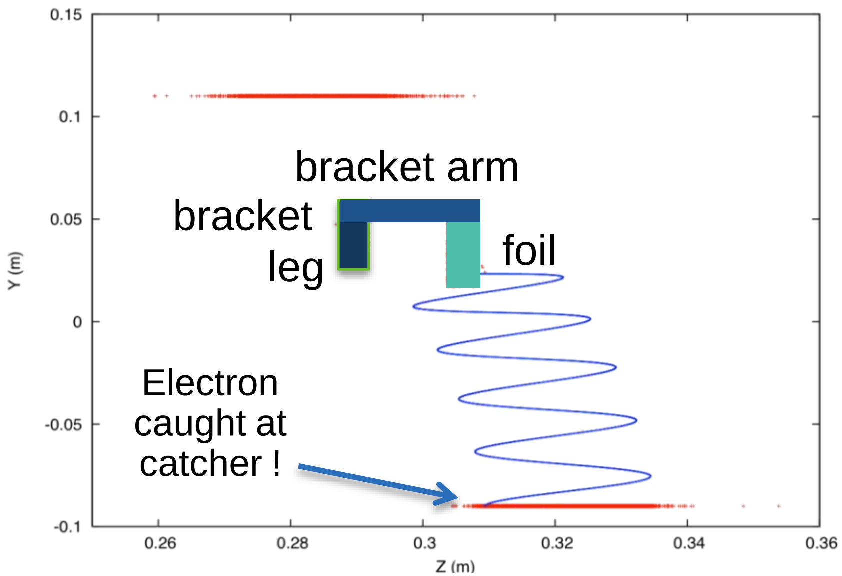
Electron catcher is not at the proper location w.r.t. the foil

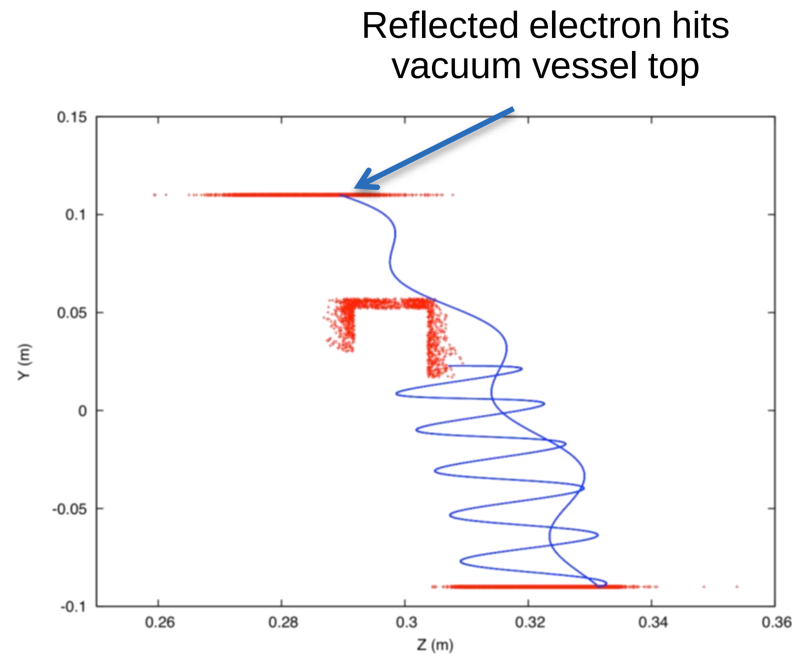


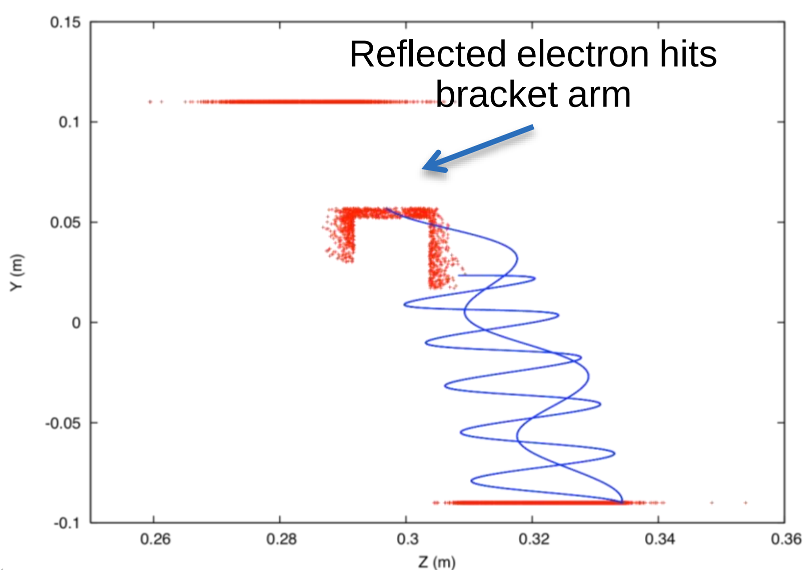
- Initial installation was misaligned. Foil moved three times to address injection loss and bracket damage issues.
- The catcher is not and has never been positioned within design tolerance.

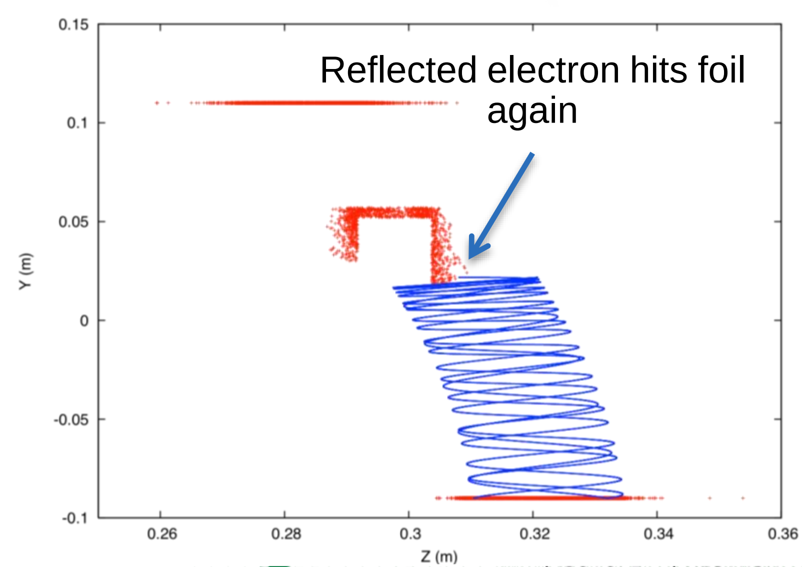
	As built error [mm]	Tolerance [mm]**
Horizontal	8	A few
Vertical	3	±6.5
Longitudinal	6.4	6.5

Example Convoy Electron Simulated Trajectories

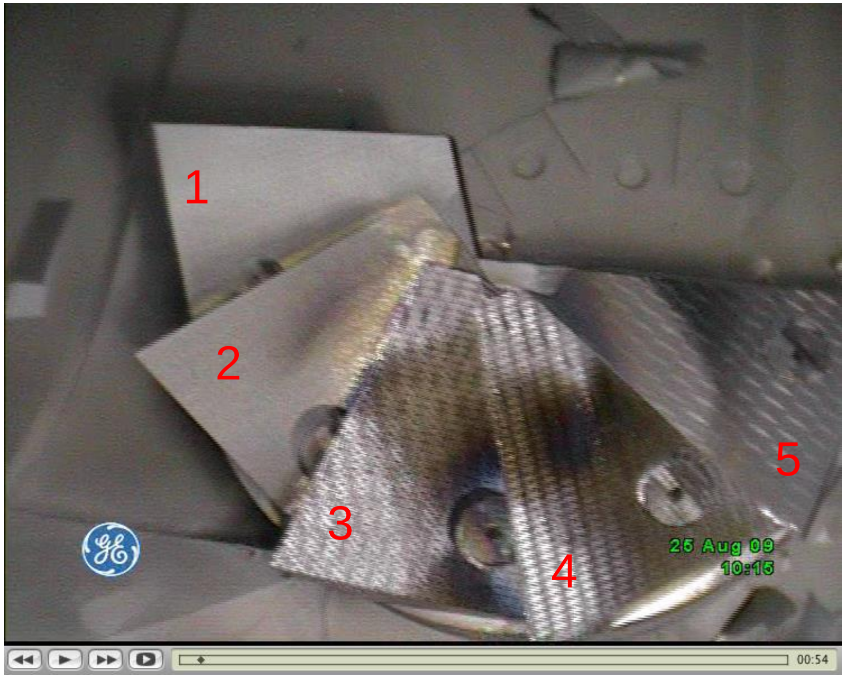


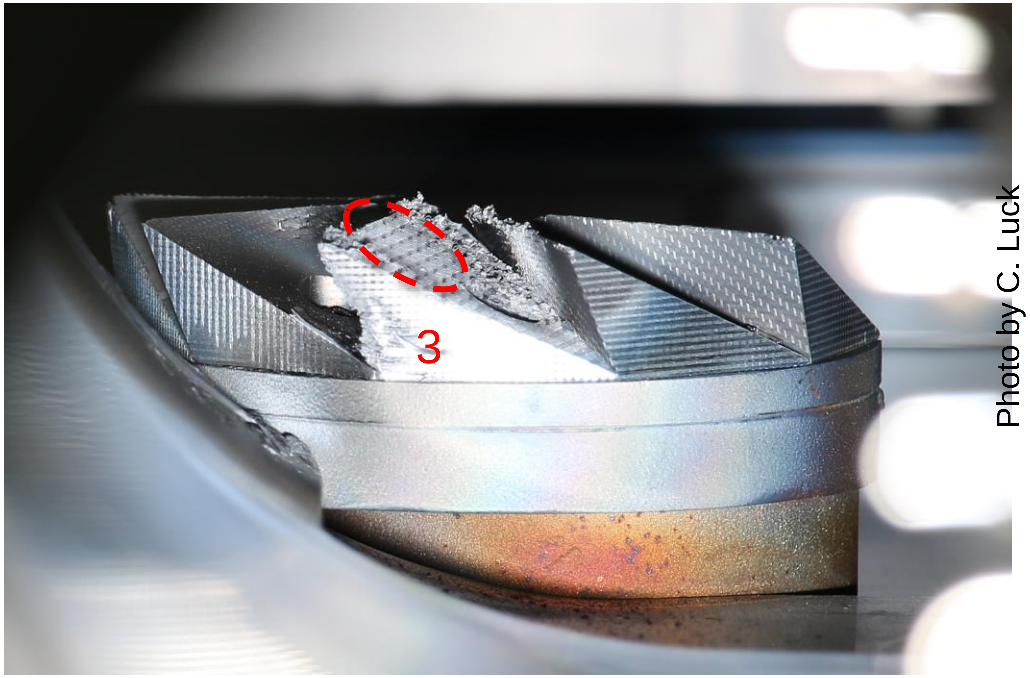






Electron catcher: Electrons striking top?



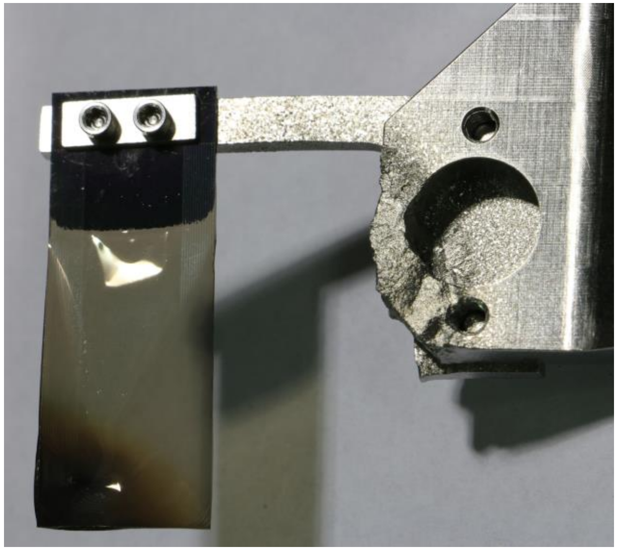


<u>August 2009</u>
Carbon-carbon wedges coated by aluminum from foil brackets, then sputtered / evaporated off by convoy electrons. Electrons appear to be striking tops of wedges #3 and #4.

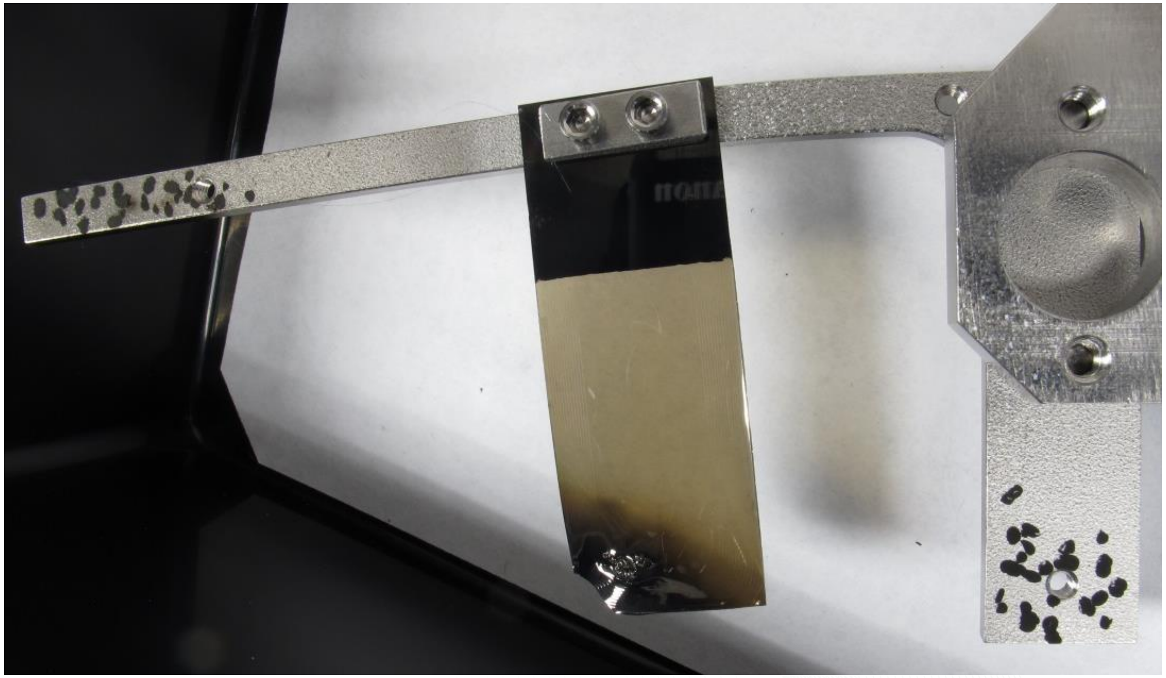
<u>July 2014</u>
Damage to top of wedge #3 shows circular electron trajectory. Electrons also appear to be striking underside of wedge #3 (as they should), and top edge of wedge #4.

Two foils with similar beam power histories

More evidence that a longer bracket leg could be useful



BW-18, 24 days at 1.2 MW, April-May 2014



#1839, ~16 days at 1.2 MW, ~32 h at 1.30 – 1.35 MW, a few minutes at 1.4 MW, Sept. 2013

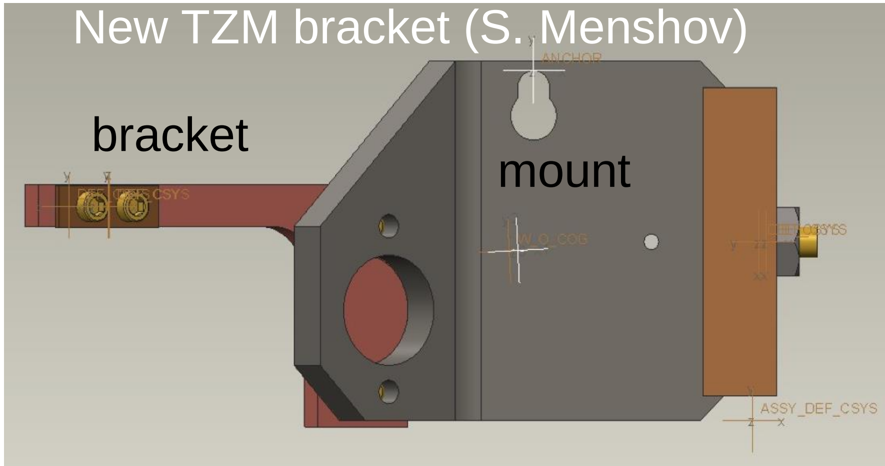
Photos by C. Luck

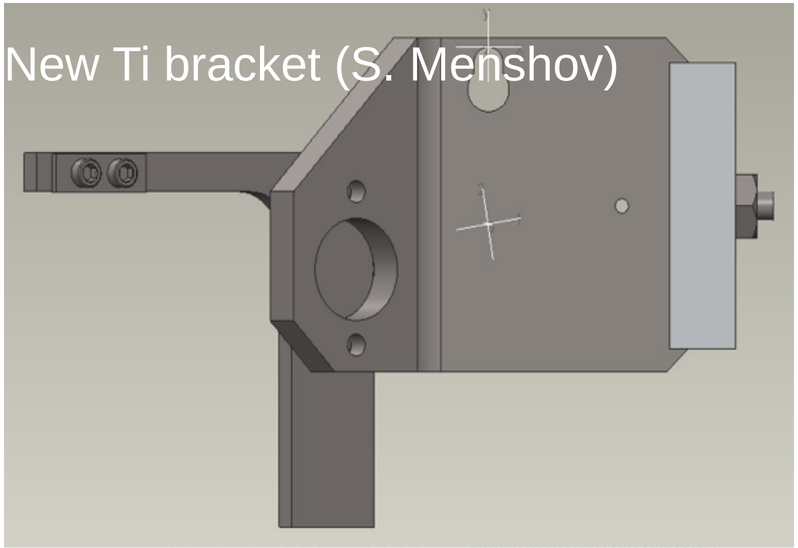
Mount and bracket changes for 2015

- Two design change ideas:

1. Change to more robust material:
   - TZM bracket & mount (99% Mo, 0.5% Ti, 0.08% Zr, some C).
   - Still use Ti nuts and screws to ~match CTE
2. Change the geometry:
   - Use standard Ti brackets / mounts, but increase leg length

- 2 new Ti bracket types installed now (12 total)
  - 1 used





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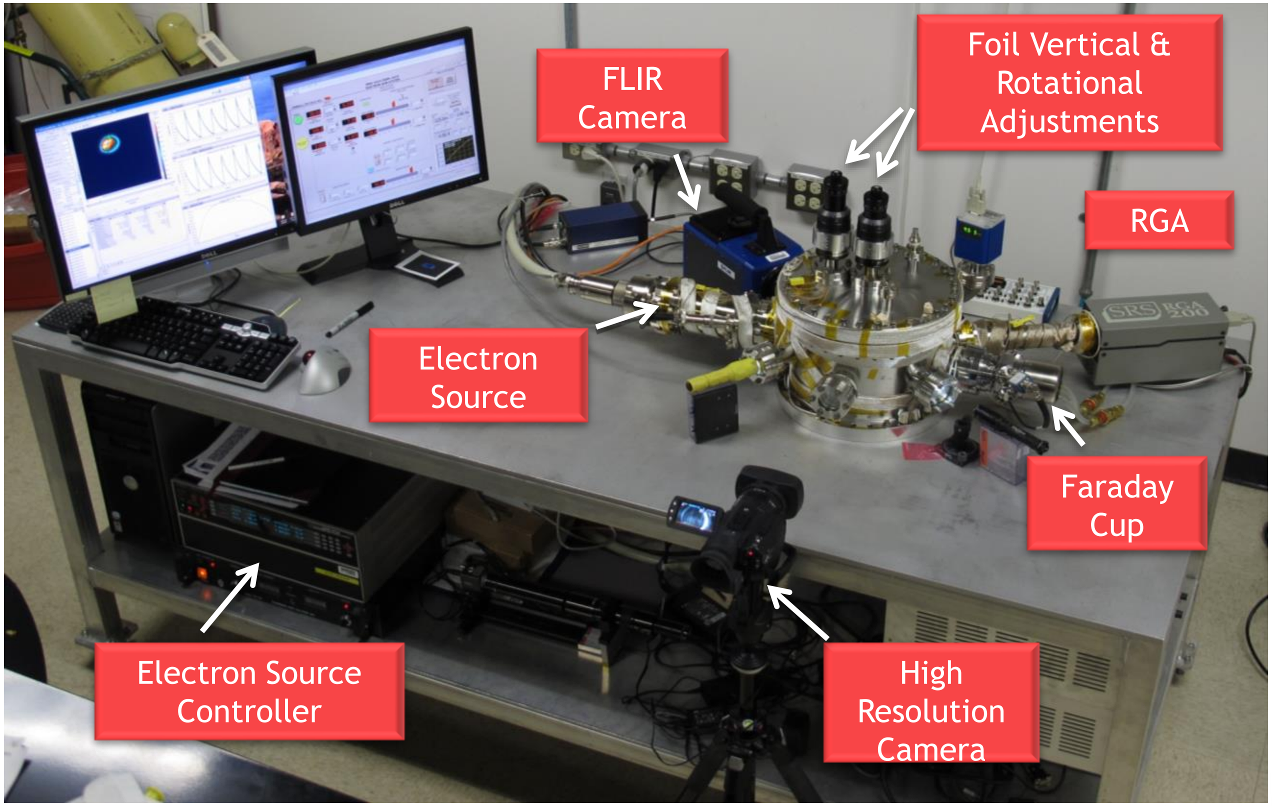
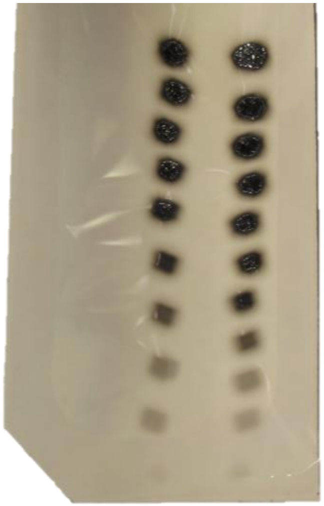
New: Foil Test Lab



Example: Systematic power density variation

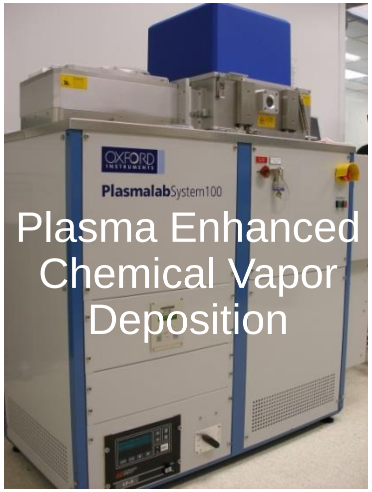


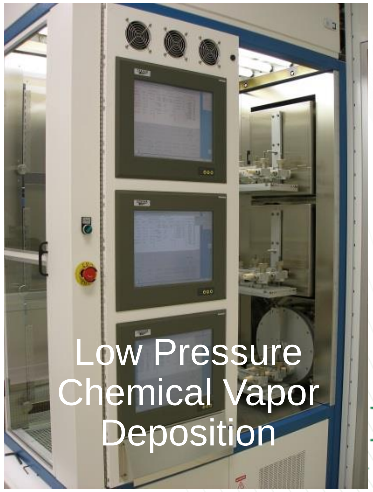
- Use 30 keV e-beam to simulate foil heating
  - Replicates thermal load (1.4 MW H- at 1 GeV = 1.6 mA/mm^2 e- at 30 keV)
  - Offline study foil material, flutter, lifetime, temp. distribution

Foil Fabrication

- Nano-crystalline diamond foils are fabricated at Chemical Science lab at ORNL
  - One personnel retiring, other key personnel maintained
- Moving production to Center for Nanophase Material Science (CNMS, on SNS site) in 2015
  - State of art facility, added capabilities
  - Initially overlap capabilities
  - $600K transfer cost

Equipment at CNMS



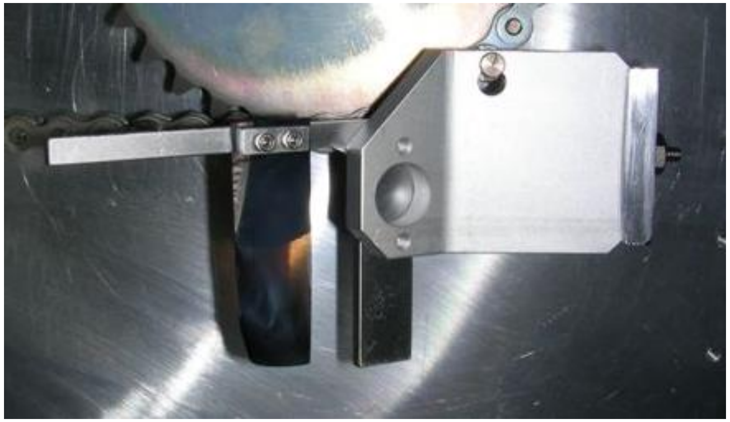


Summary

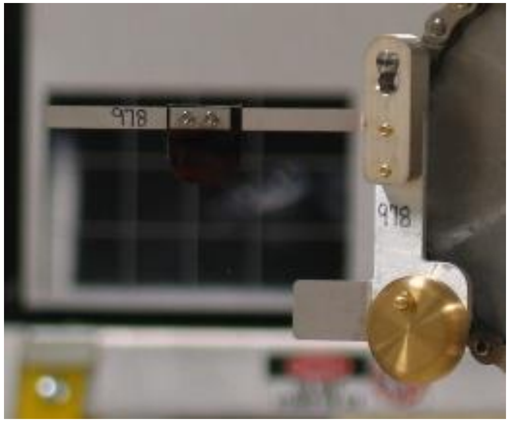
- Accelerator Physics supports SNS and the community in a variety of ways
  - Understanding our machine
  - Software tool support
  - Education
- Need to stay on top of the foil systems
  - Higher power concerns (brackets)
  - Foil fabrication

Auxiliary Slides

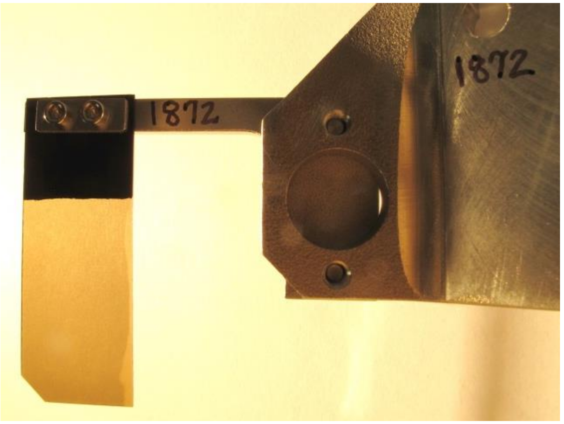
Brief history of foil brackets / mounts



1st gen., used thru Jan/09
(3rd gen same as this one but leg is cut off, used May-Sep 2009)



2nd gen., used Mar/09 to May/09



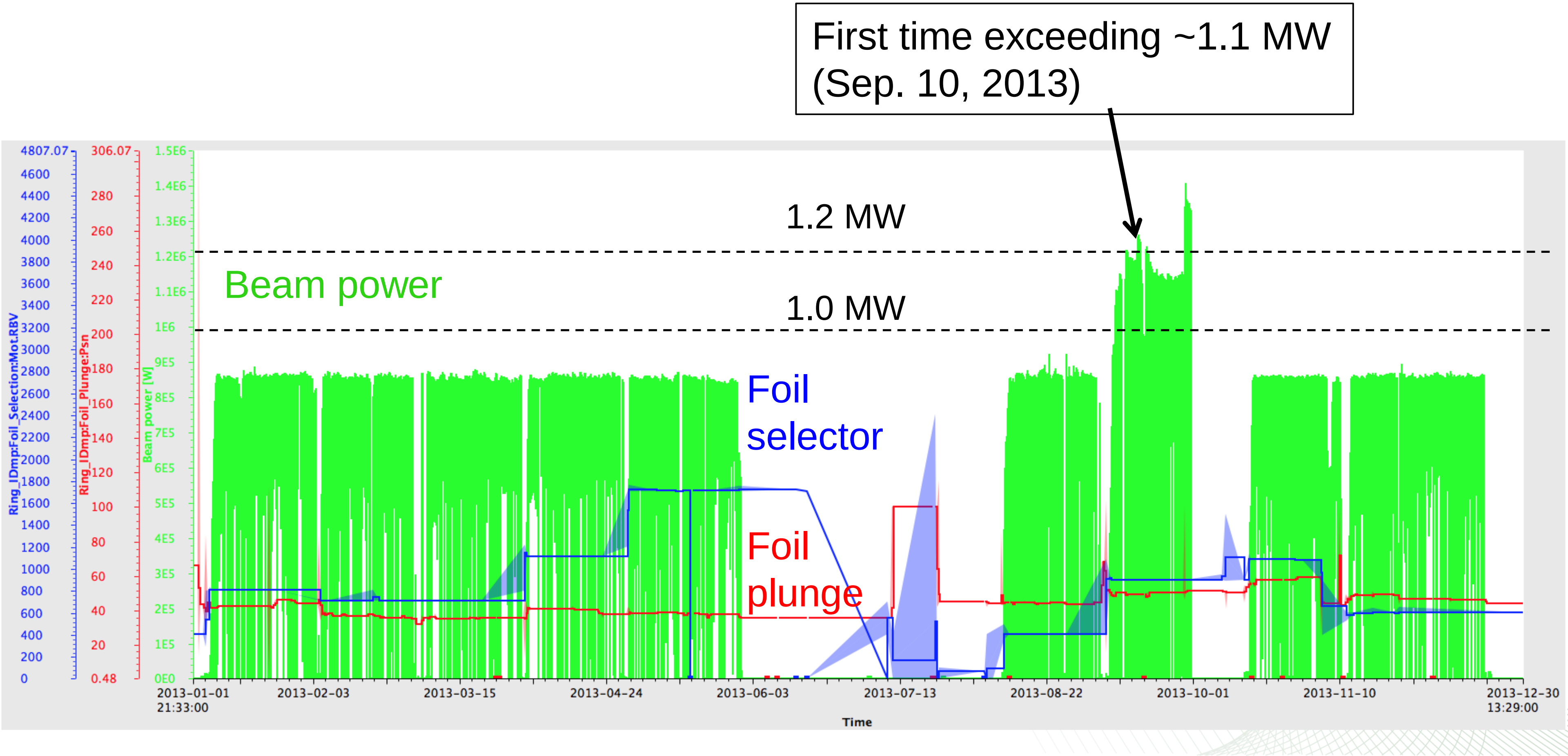
4th gen., used from Sep/09

- Switch from Al to Ti
- Move foil 1 cm out
- Cut off excess arm and leg
- **No significant problems until Spring 2014**

Photos by C. Luck

Beam power plot: 2013

- Foils are surviving well up to 1.4 MW
- First signs of damage to brackets at 1.2 MW



Foil removed from Aug. – Dec. 2013 run

Fiber supported standard diamond foil. Test to see if fibers could suppress foil shaking. Bracket thickness = 0.093” vs. normal 0.125”.

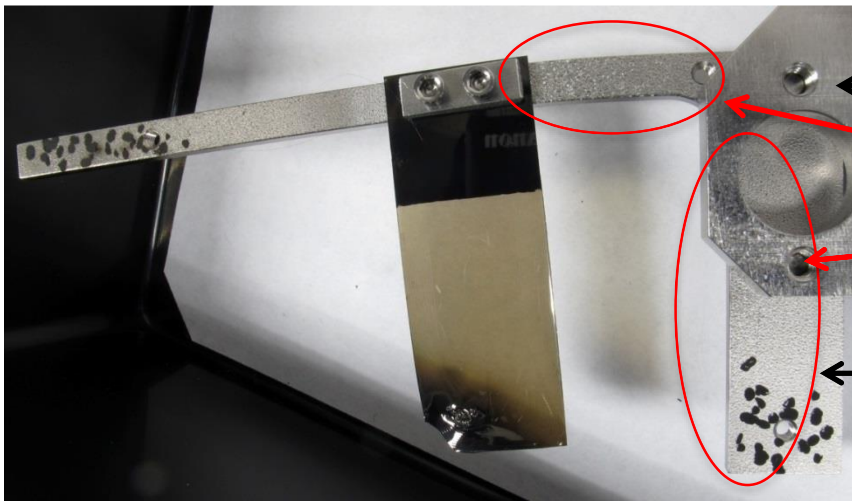
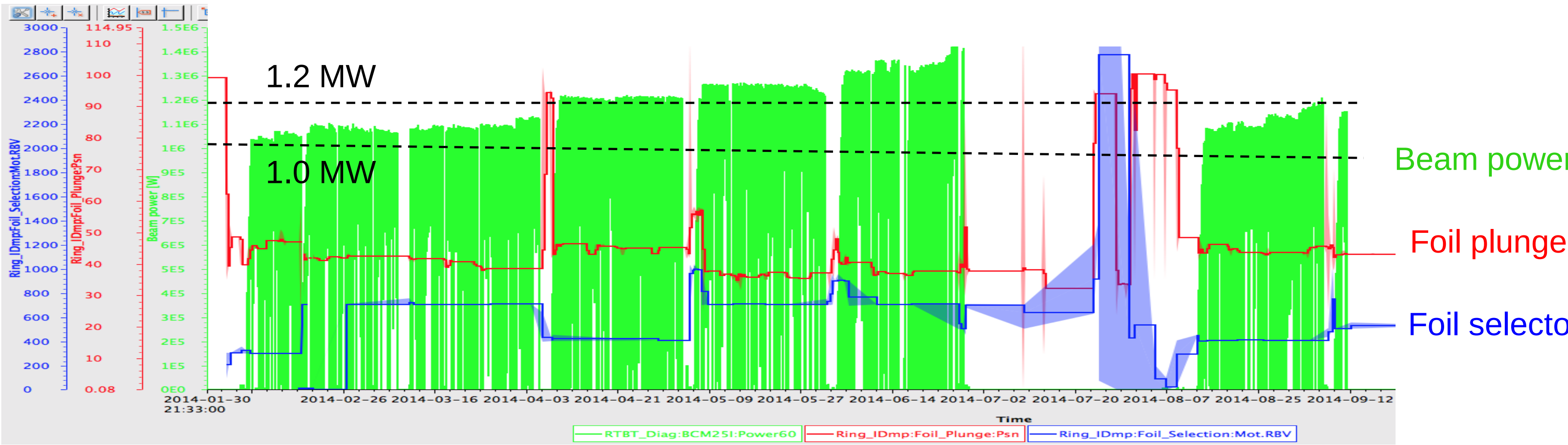


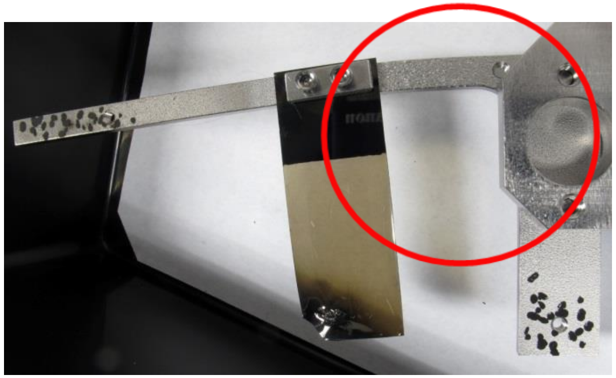
Photo by C. Luck

#1839, used for 1.1 – 1.2 MW for a few weeks, then 1.4 MW demonstration for a few minutes, and then 1.3 MW for ~32 hours.

Beam power and foil plot: 2014

- Consistent signs of damage to brackets at >=1.2 MW





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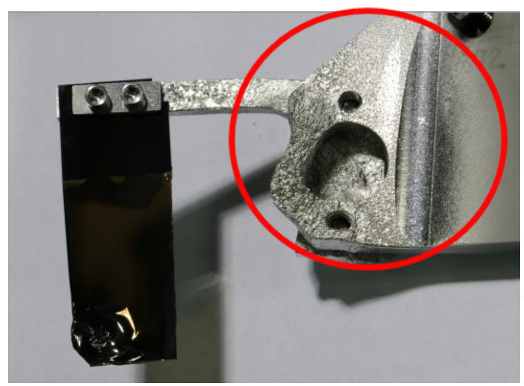
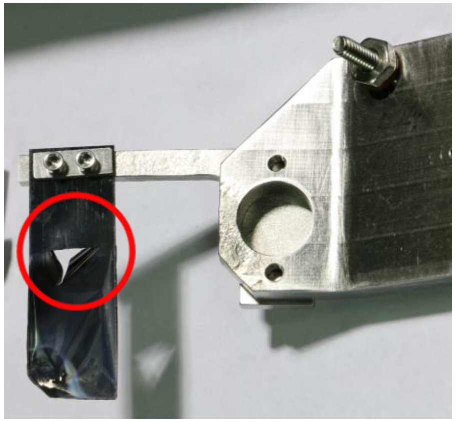


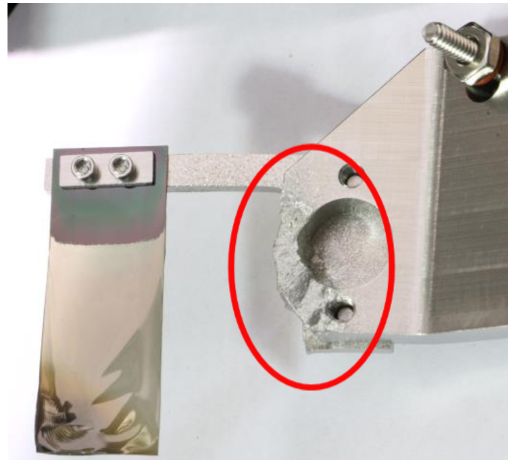
#1872, up to 1.4 MW. 3 months at 1.1 to 1.4 MW.

BW-18. ~24 days at ~1.2 MW

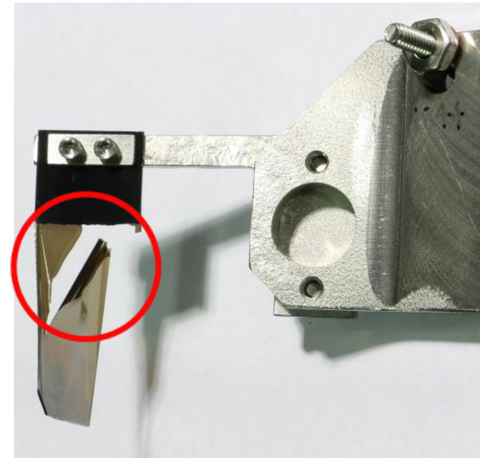
Foils from Feb-June 2014 run: more signs of distress



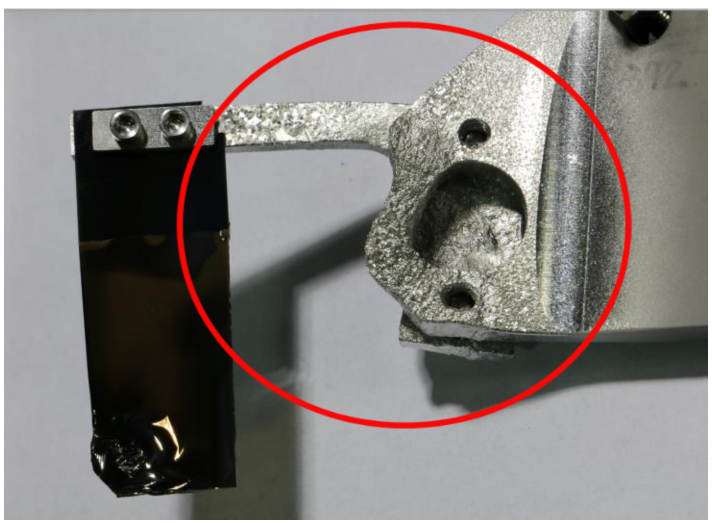
#2024, 4 days, beam high on foil - positioning error. ~2 days at ~1.3 MW.



BW-18. ~24 days at ~1.2 MW



#1844, fast ramp test 12.25 h to 1.4 MW, + ~6 hours at 1.4 MW. Difficulties recovering from IDmp steering.



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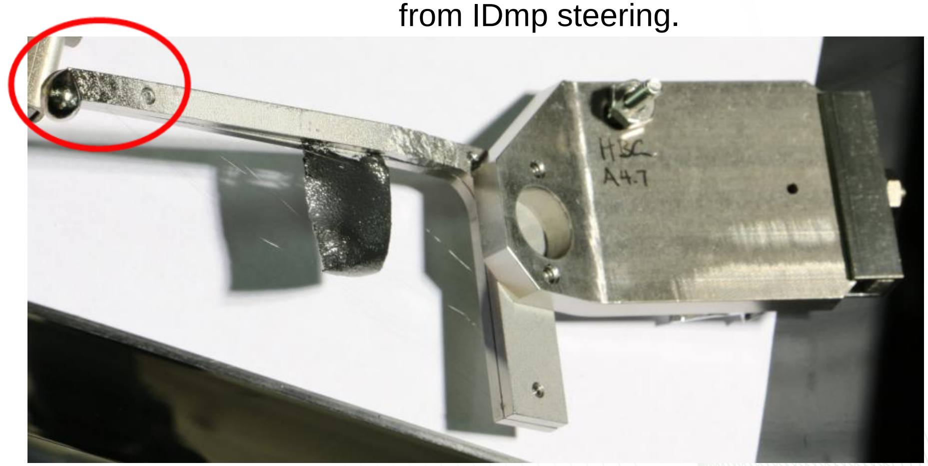
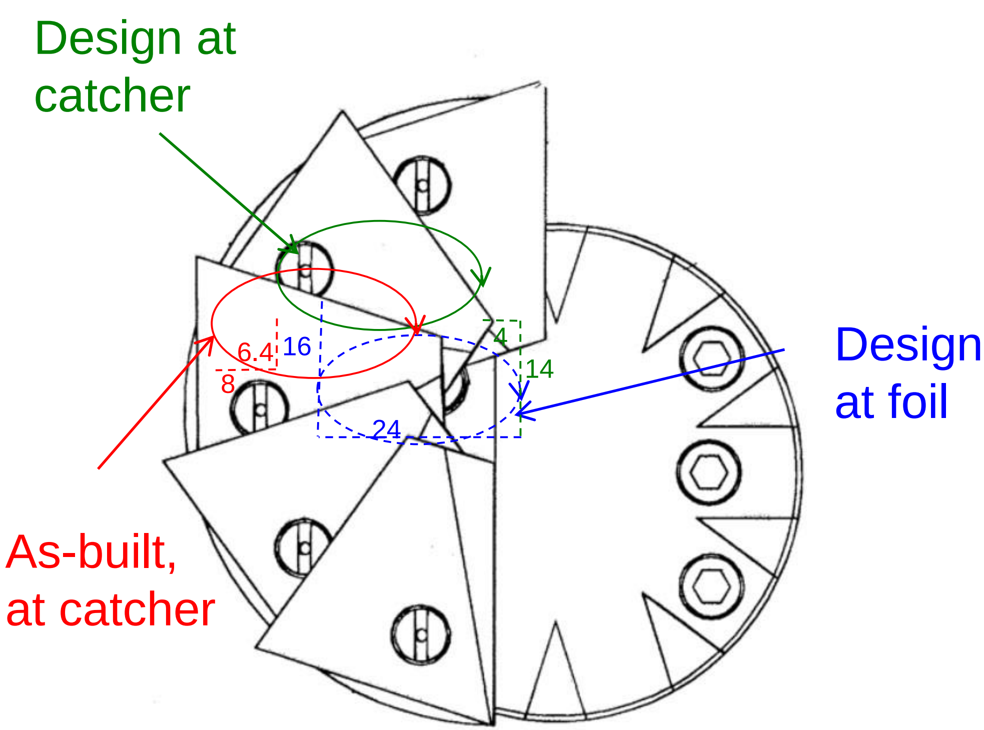


HBC A-4.7. End melted when adjacent foil raised for IDmp steering studies? Or RCE from adjacent foil? ~13.5 hours at 1.2 MW.

Photos by C. Luck

Electron catcher is not at the proper location w.r.t. the foil



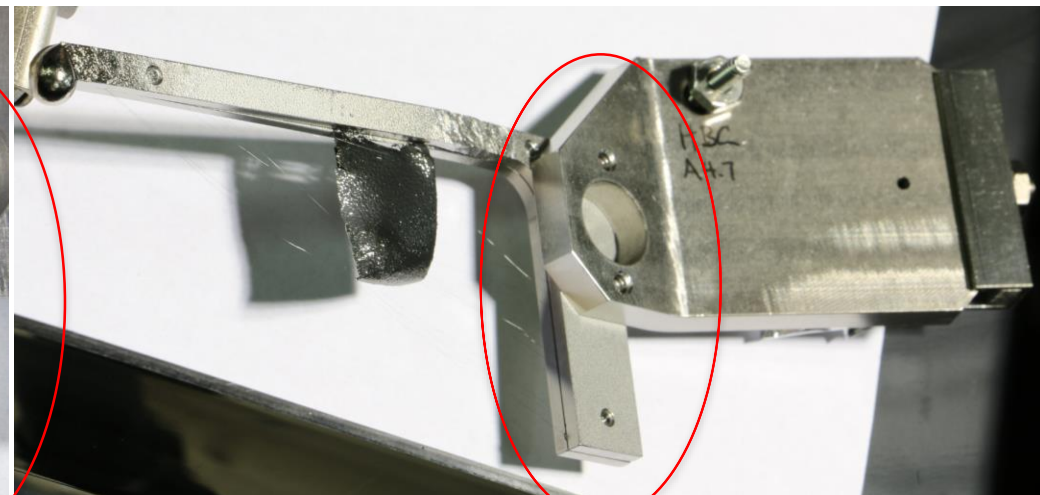
	As built error [mm]	Tolerance [mm]**
Horizontal	8	A few
Vertical	3	±6.5
Longitudinal	6.4	6.5

- From day 1, the foil is is-aligned due to the mechanical fit-up of the as-delivered components (14 mm too far upstream w.r.t. catcher)
- In ~2007, injection point moved ~7 mm beam left to improve ring operation
- 2009: foil moved 1 cm out along bracket arm (equiv. to 5 mm downstream)
- 2012: replaced foil changer and moved injection point 2.6 mm downstream
- Improperly caught electrons are reflected (RCE)

Long Leg on Bracket Seems to Help

The two brackets that have the long leg show much less damage to the mount

Used for 1.1 – 1.2 MW for a few weeks, then 1.4 MW demonstration for a few minutes, and then 1.3 MW for ~32 hours



Used ~13.5 hours at 1.2 MW. Not much, but enough to see damage at the usual place on the bracket.

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