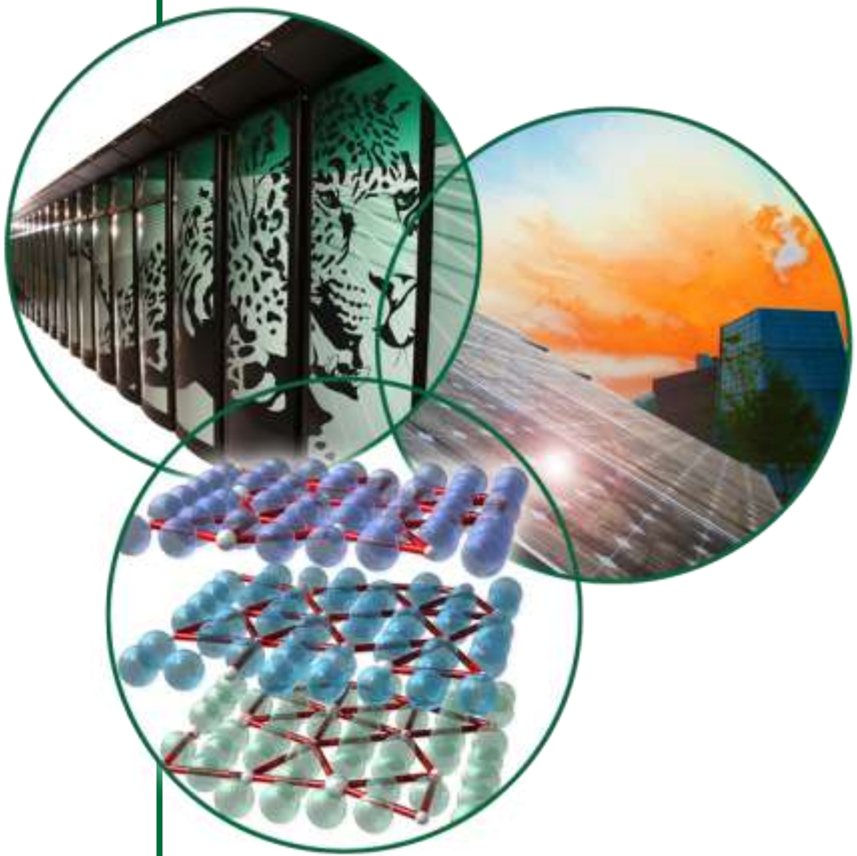
HEBT/Ring/RTBT Overview



AAC, Jan. 10, 2012

by Mike Plum

Ring Area Manager

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Table of contents

HEBT/Ring/RTBT Overview

- We've been at ~1 MW since the last AAC meeting, and we're still at that power
- Our focus has shifted from increasing the beam power to
  - Ironing out the kinks in the subsystems (e.g. inj. kickers, injection dump aperture increase, dipole corrector xfer fcns)
  - Improving day-to-day operations (e.g. lower beam losses, improve beam shape & density on target)
  - Improve our understanding of beam dynamics (e.g. transverse coupling, magnetic multipoles, space charge, instabilities)
  - Preparing for the future (e.g. beam power increase to 1.4 MW, PUP, 2nd target station)

2010 - 2011 Highlights

- New momentum dump installed and commissioned. First beam Aug. 2010.
- Injection dump beam line aperture increase to lower beam loss. First beam Feb. 2011.
- Injection dump beam line added two BPMs to speed up beam steering to the dump. First beam Feb. 2011.
- Routine operation at 1 MW
- Beam loss per Coulomb continues to improve
- Stripper foil lifetime can be an entire 5-month run cycle

Key issues

- Look ahead for high power operation. Biggest question is will the stripper foil survive?
  - On-going stripper foil development program
- No profile / position measurement at injection dump vacuum window / face of dump
  - Risk of vacuum window and/or dump failure if beam density is too high and/or too far off center
- Beam tails / halo formation and control
  - More halo = more stripper foil hits = higher activation
- Primary stripper foil mechanism sometimes hangs up and does not allow a new foil to be inserted
- Also convoy electrons are not properly collected
  - A new mechanism and new electron collector is being fabricated

Overall ring performance

- Availability and reliability of HEBT/Ring/RTBT systems is very good. These systems account for a small fraction of the total down time.
  - In FY'11 the HEBT/Ring/RTBT accounted for 3.5% of the total down time
- Set up time is fast and reproducible
  - A few minutes to restore the settings and cycle the relevant magnets
  - Less than a shift at the start of a run cycle to adjust the trajectory, measure the energy, adjust the beam size, etc.
  - Low loss tuning can take several shifts and involves mainly the linac and HEBT

HEBT/Ring/RTBT Operations Planned Improvements

- New primary stripper foil changer with independent horizontal & vertical control, bigger view ports, better lighting
- New electron collector with larger acceptance and proper placement
- New secondary stripper foil mechanism, with one single wider foil and wider view screen, and larger view port
- We are considering an app to more easily tune the beam size on the target independently of the beam size in the Ring
  - This will allow us to more easily achieve the low loss tune in the Ring

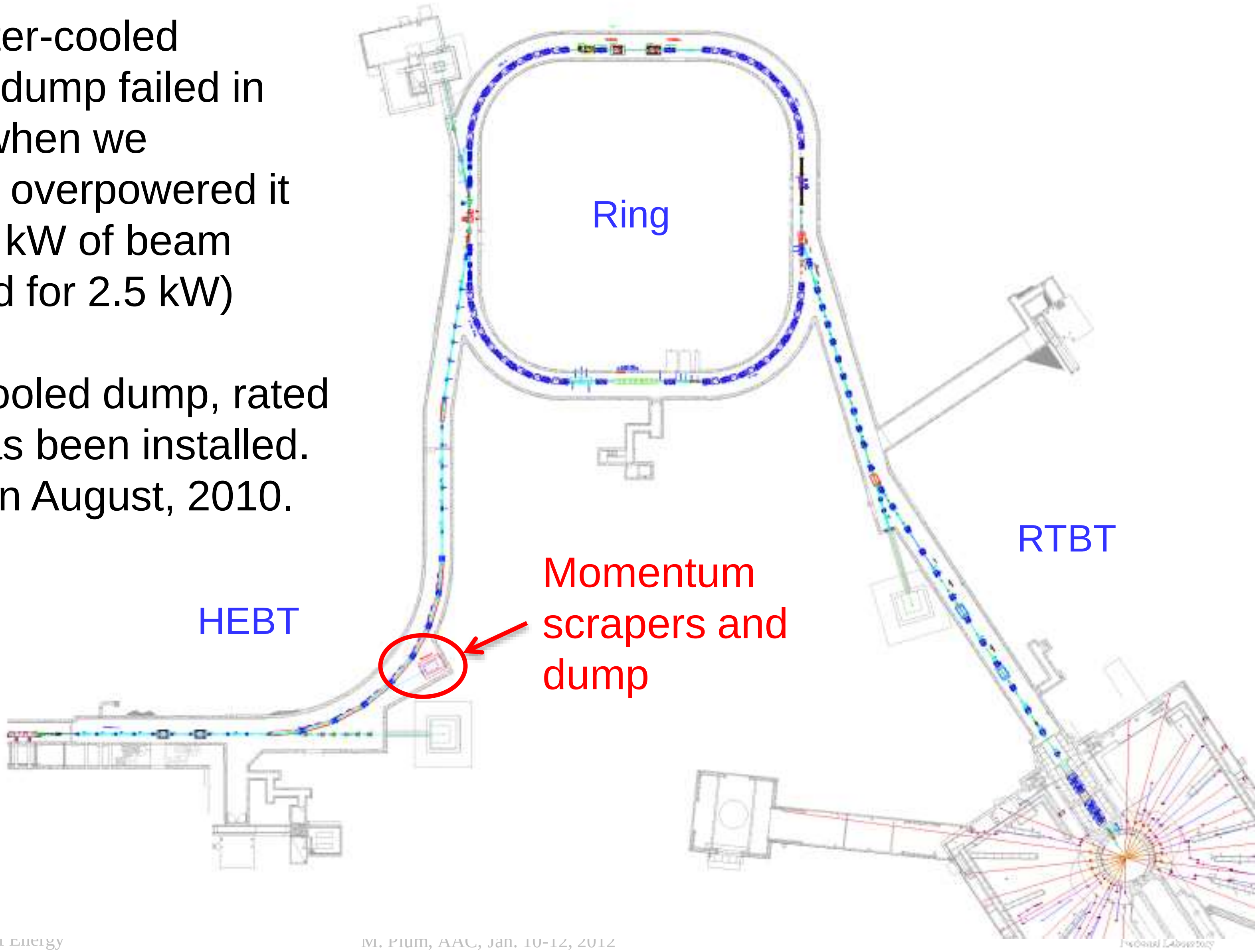
HEBT/Ring/RTBT Operations Planned Improvements (cont.)

- There is a kink in the beam trajectory at end of the HEBT, in the approach to the foil, mainly in the horizontal plane
  - This complicates quad adjustments
  - We are exploring our options that will probably involve moving the magnets
- Improvements on hold due to lack of funds
  - Injection dump view screen, needed to up to 150 kW of beam power
  - Vertical steering magnet & additional BPMs in extraction region, desirable to more easily tune the extraction region

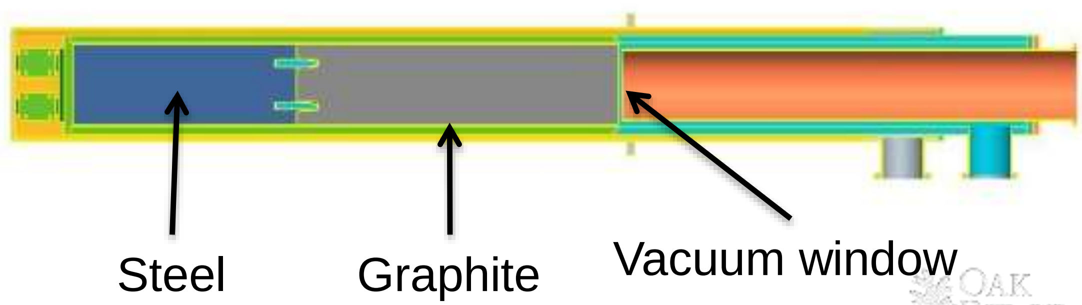
Momentum dump

Original water-cooled momentum dump failed in April 2008 when we accidentally overpowered it with 8 to 10 kW of beam power (rated for 2.5 kW)

A new air-cooled dump, rated for 5 kW, has been installed. First beam in August, 2010.



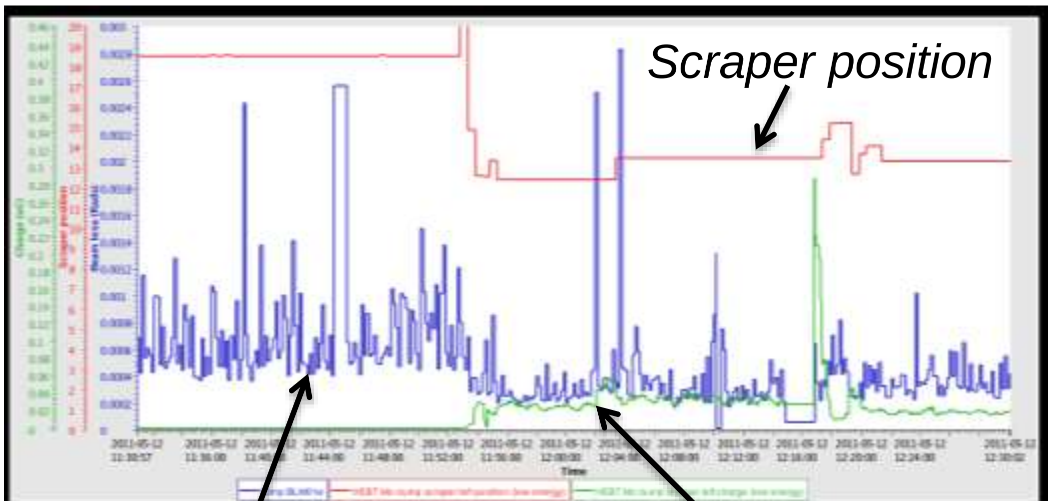
New air-cooled momentum dump



Installed summer 2010
First beam August 2010

New momentum dump (cont.)

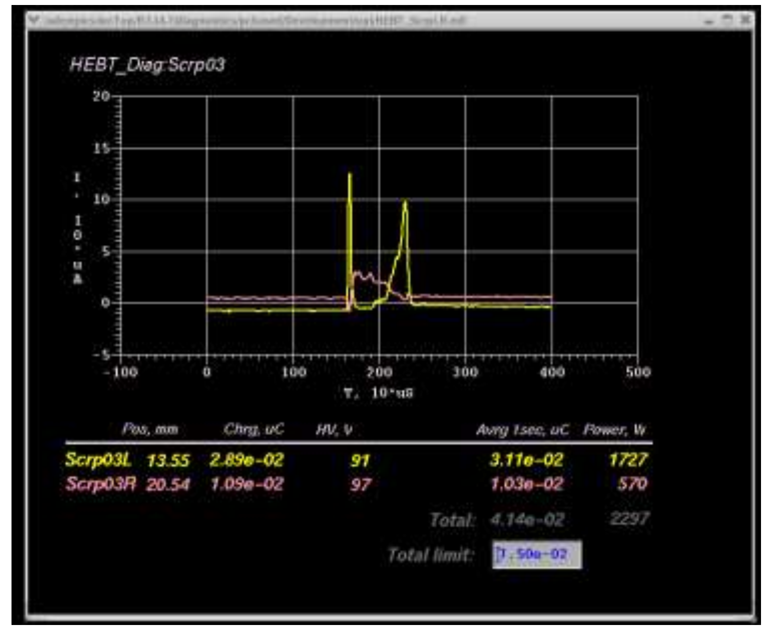
- When we have momentum tails the dump works well and it is effective
- The typical beam these days does not have substantial momentum tails and so the momentum dump is rarely used



IDmp beam loss

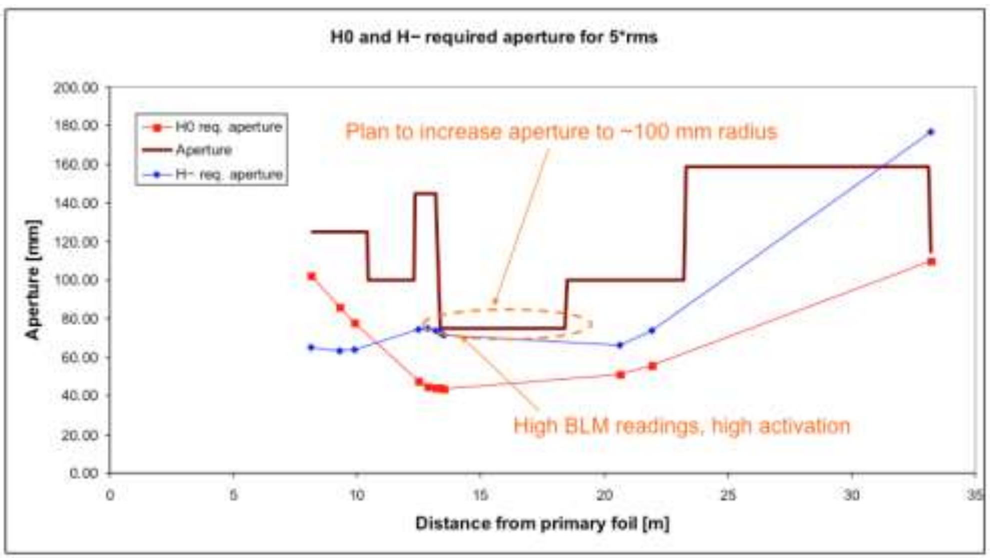
Charge intercepted by scraper

Scraper SEM signals



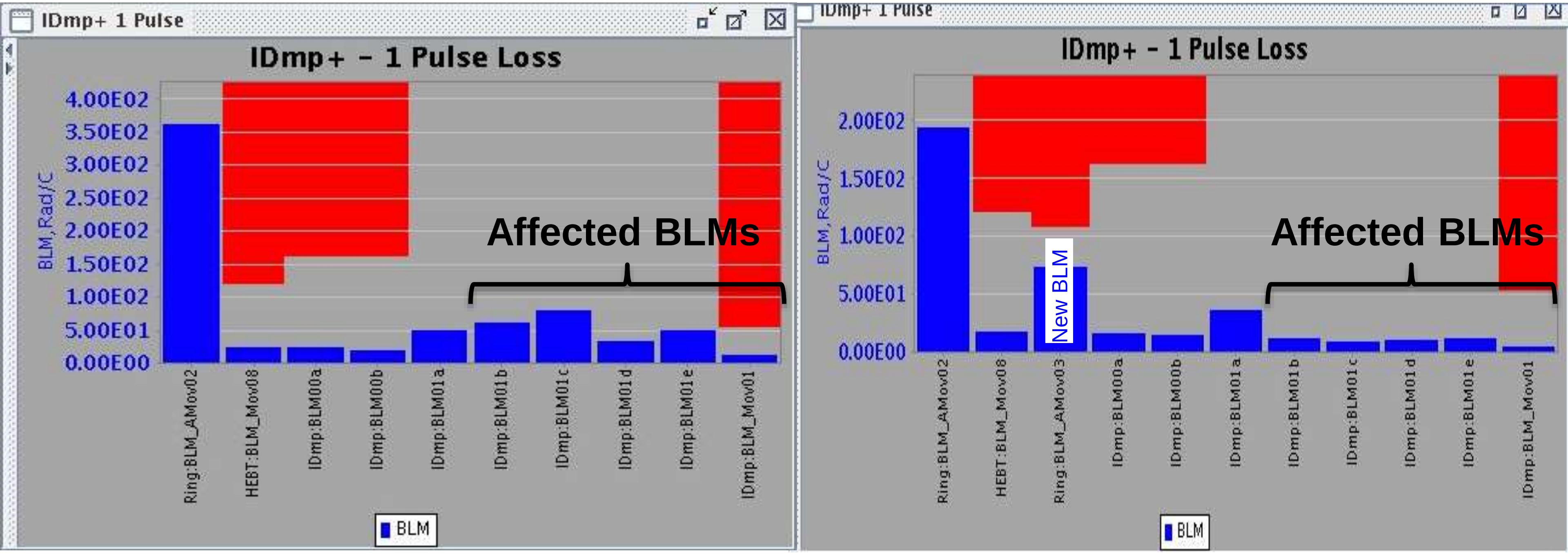
Injection dump aperture increase

- Original beam line had a choke point mainly due to size of available fast valves
- New beam line relieves this aperture limitation
- We also replaced 1 and added 2 new BPMs so we now have 3 high precision BPMs in a row to extrapolate a straight line trajectory to the dump in a single shot



Inj dump aperture increase (cont.)

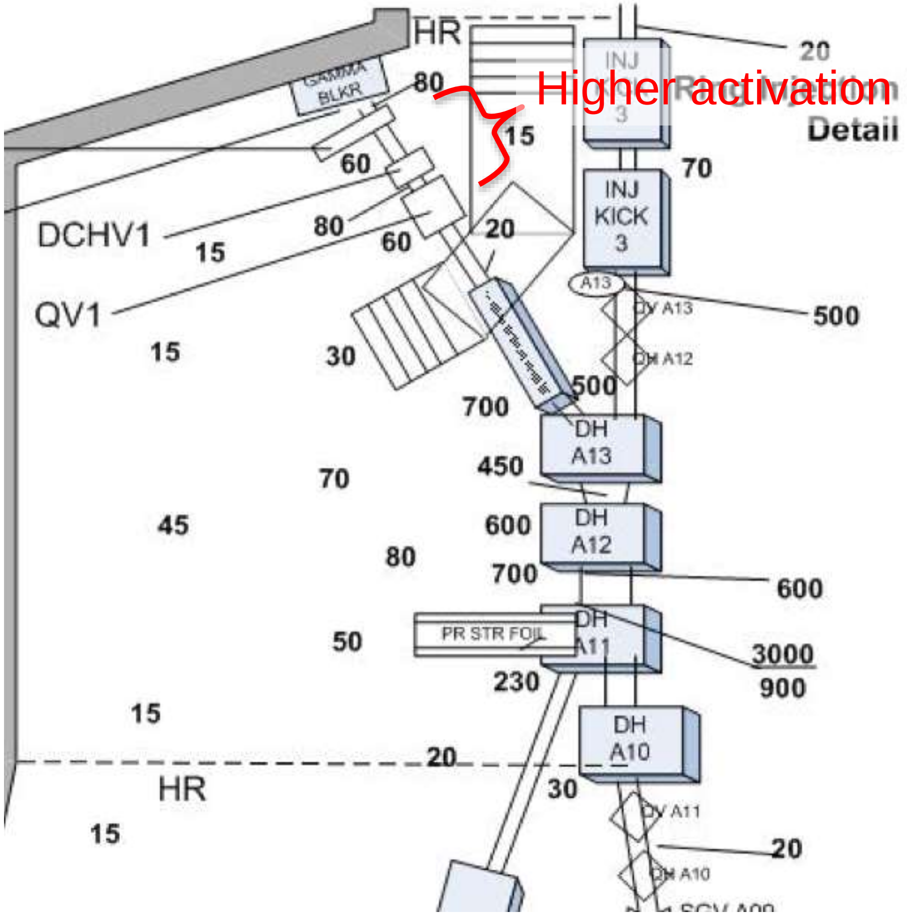
- **Beam loss before and after**



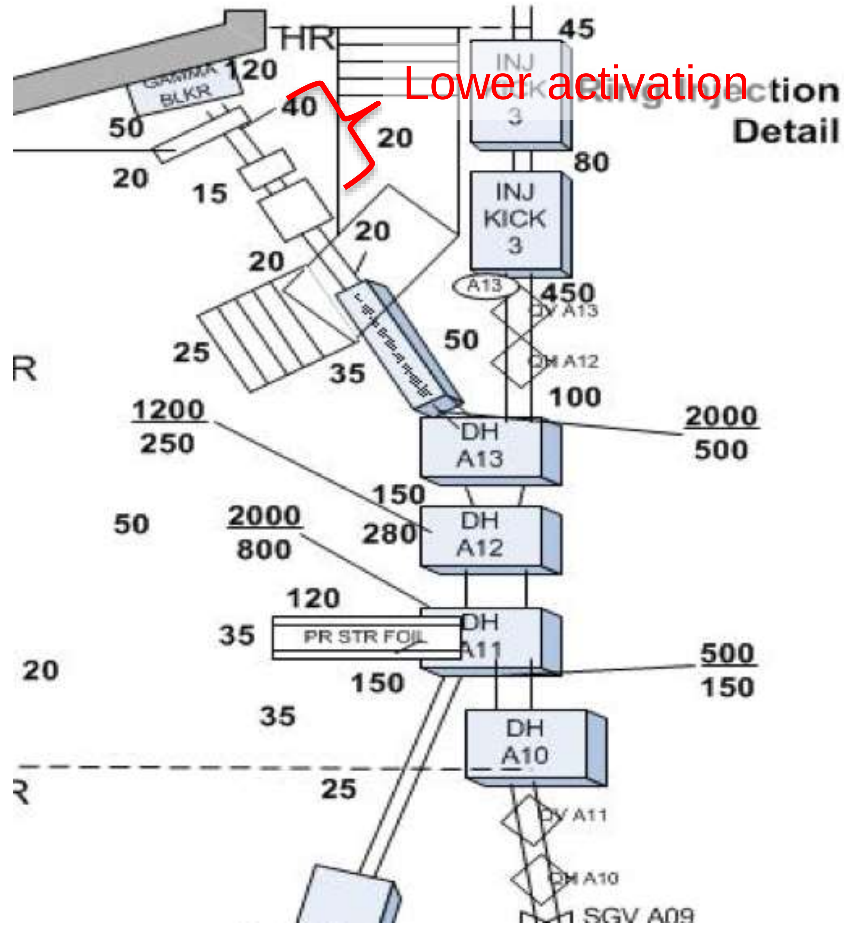
BEFORE (Dec. 2, 2010; 1 MW) AFTER (Dec. 19, 2011; 1 MW)

Injection dump aperture increase (cont.)

- **Activation before and after**



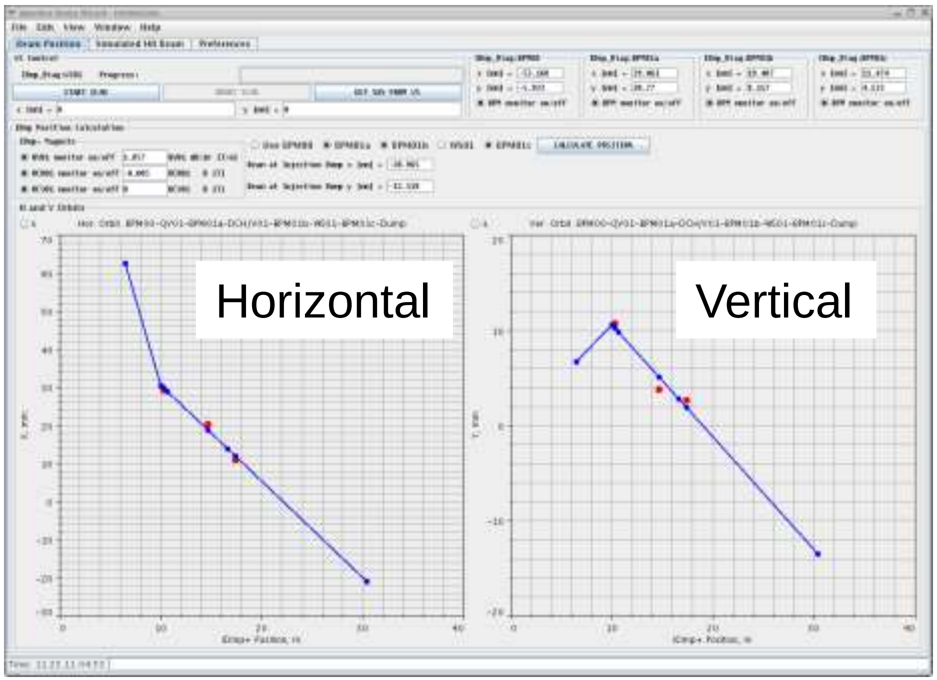
BEFORE (Dec. 24, 2010; 1 MW)



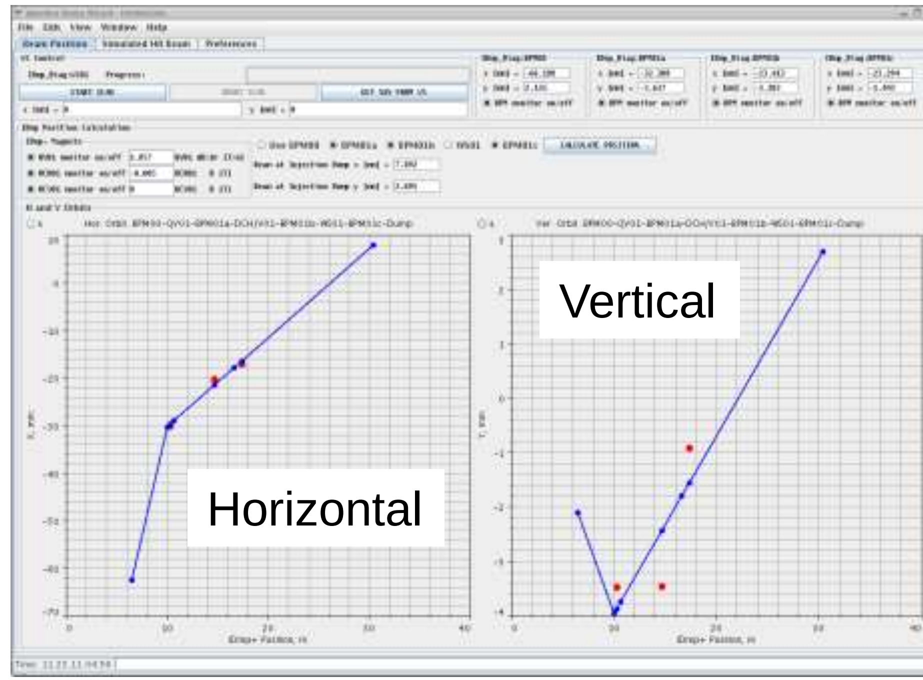
AFTER (Nov. 22, 2011; 0.8 MW)

Injection Dump beam steering

- <u>Old beam line:</u> One BPM and one wire scanner. Tune up could take hours.
- <u>New beam line:</u> Three high precision BPMs in a drift space to extrapolate the beam position on the dump, with wire scanner for back up & redundancy. Tune up takes a few minutes.



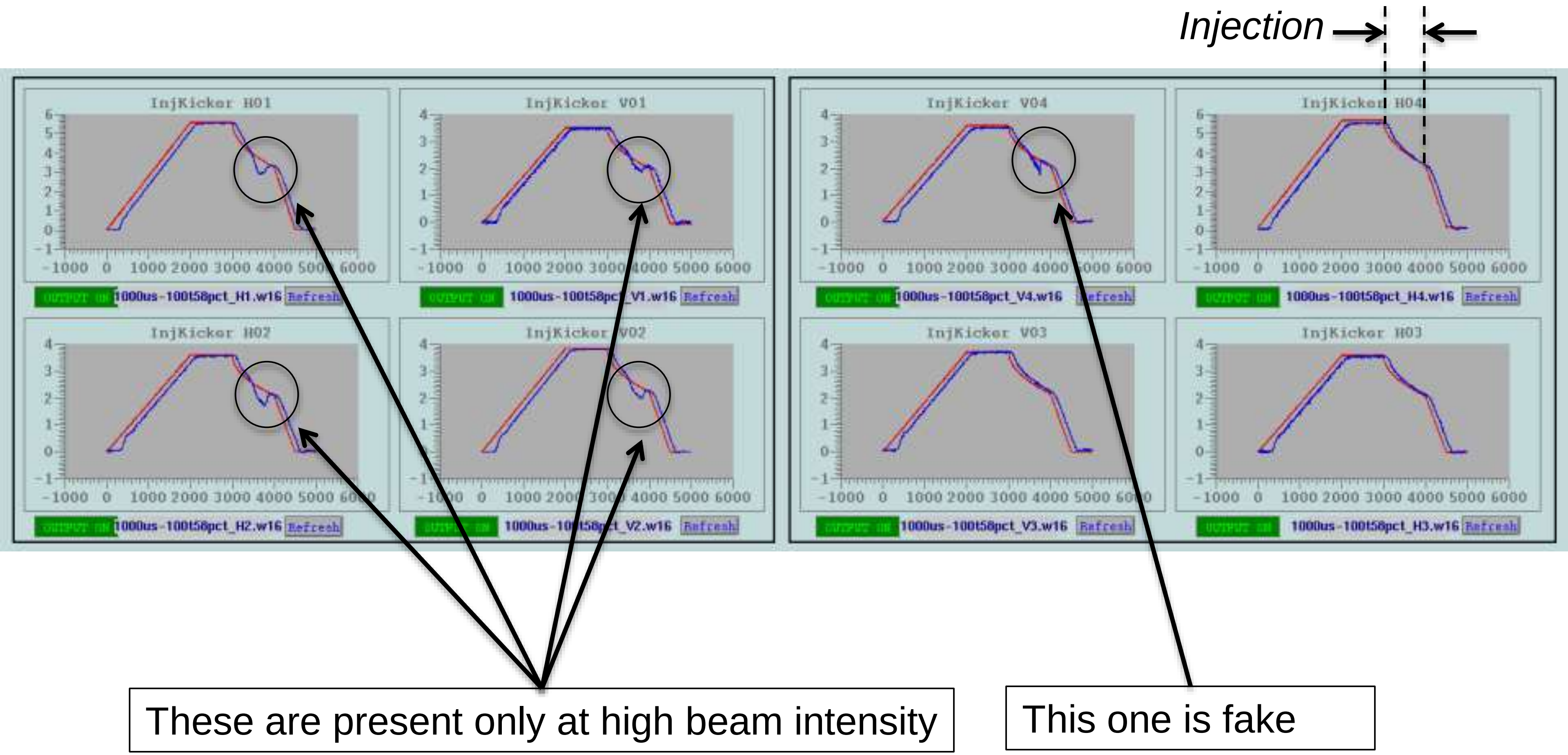
Simulated H^- beam trajectory



Simulated H^0 beam trajectory

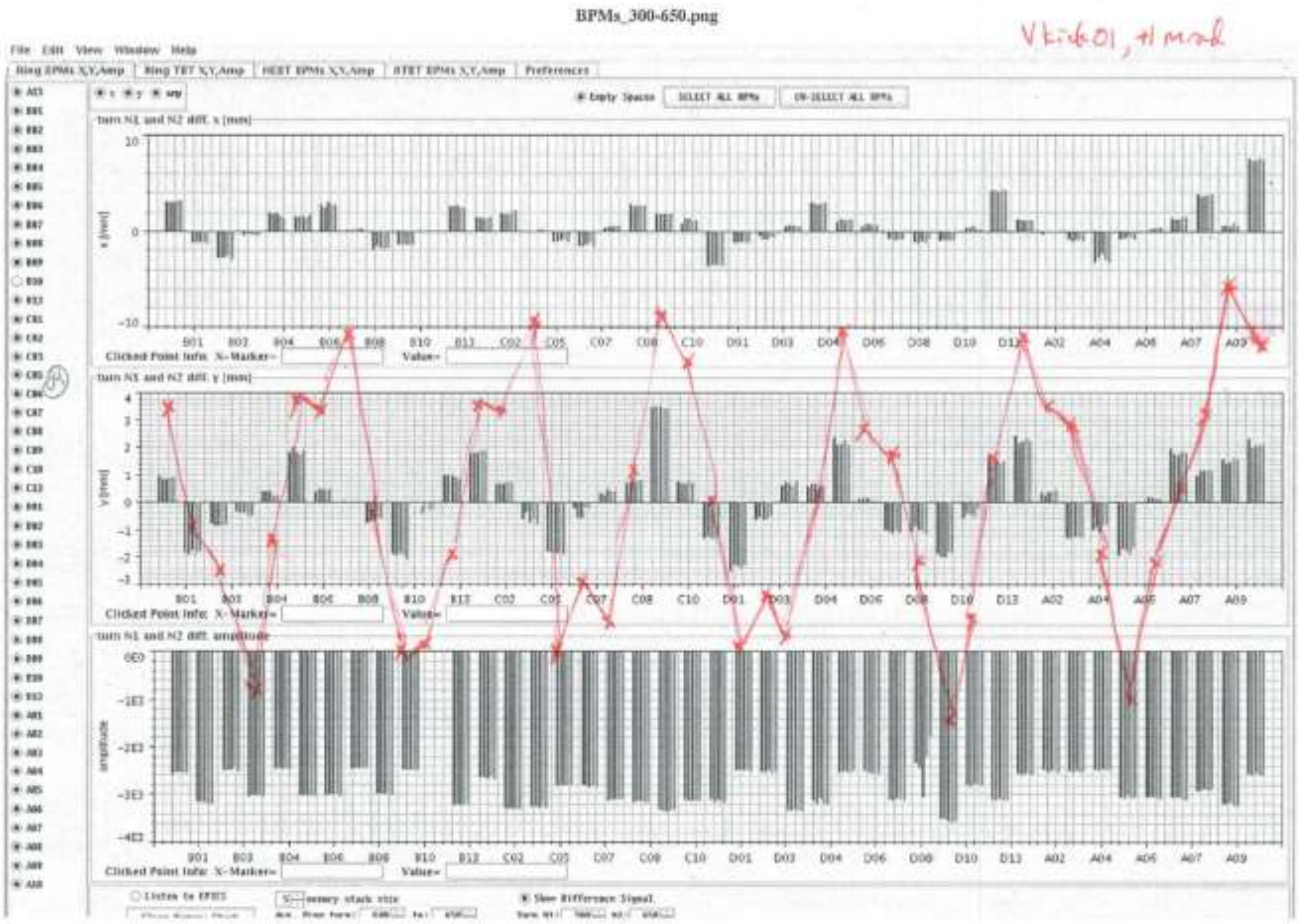
Injection kicker waveform distortion

- Distorted waveforms cause closed orbit distortions that consume the available aperture in the ring



Inj. kicker waveform distortion (cont.)

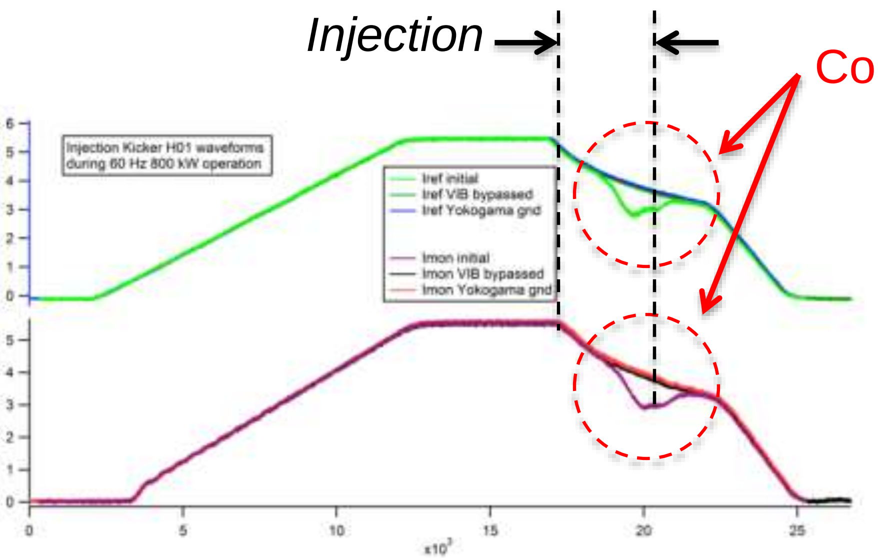
Trajectory distortion wave around the ring is consistent with a MAD simulation of a kick at the Vkick 01 to 02 locations

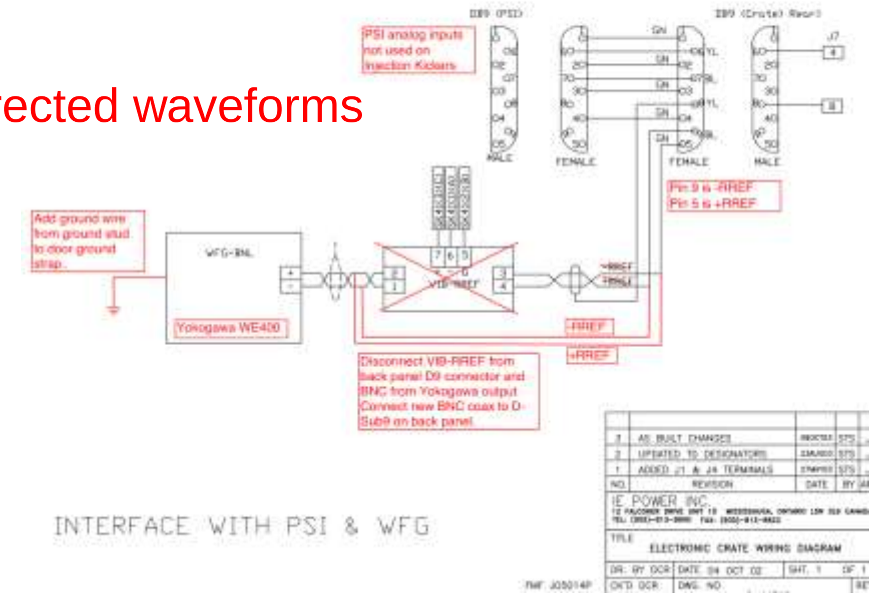


Data from Oct. 3, 2011. Turn 300 – turn 650.

Injection kicker waveform correction

- **Problem traced to beam noise getting into the Voltage Isolation Board. Bypassing this board made a huge improvement. Implemented Oct – Nov 2011.**
- **Also added a ground wire between the waveform generator and power supply frame**





Courtesy R. Saethre

Stripper foil program and status

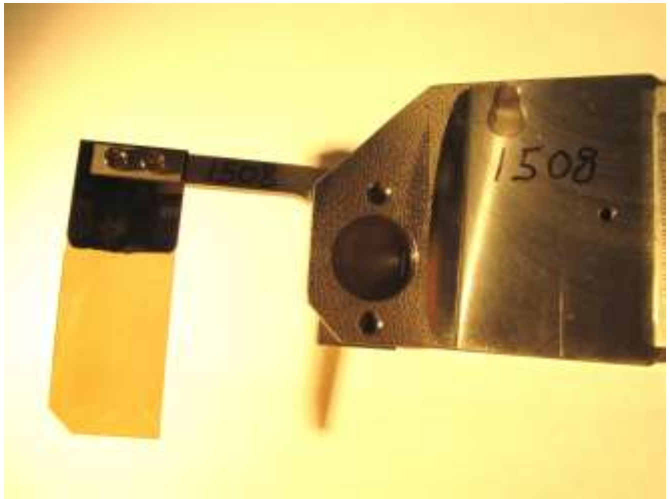
- At the last AAC in Feb. 2010 we presented the analysis of the sudden onset of foil failures in May 2009, and their cures. We had demonstrated that a single foil will survive for an entire run cycle (Sept. – Dec. 2009) including some time at 1 MW.
- Since that time
  - We have repeated the demonstration of a single foil for an entire run cycle (almost entirely at 1 MW)
  - Changed our standard foil to a corner cut shape (still nanocrystalline diamond)
  - We now change foils after ~1 month, even if not necessary, to have the nice straight foil edges we need to minimize the beam loss
  - Our foil changer mechanism has developed problems. It sometimes hangs up when moving from one foil to the next.

Stripper foils (cont.)

- **Biggest foil issues now:**
  - **Foils become wrinkled and twisted, losing the straight edges we need to get the minimum beam loss**
  - **Foil flutter / shaking. We tend to move beam away from corner to stop it, but this increases the beam loss.**
  - **Faulty foil changer mechanism & incorrect electron catcher loc'n**

Photos by C. Luck

This foil lasted the entire Feb. – June 2010 run cycle

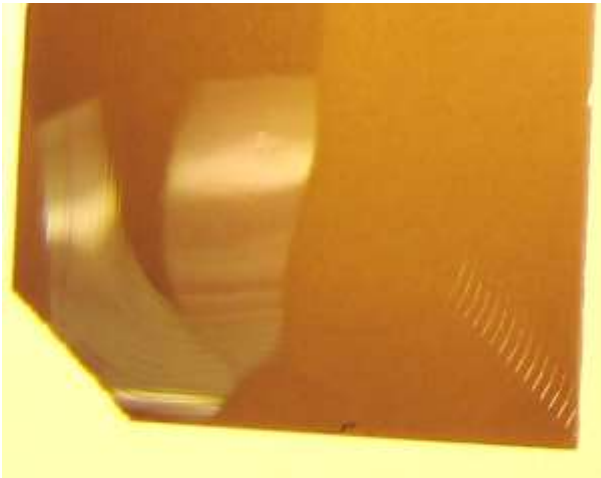


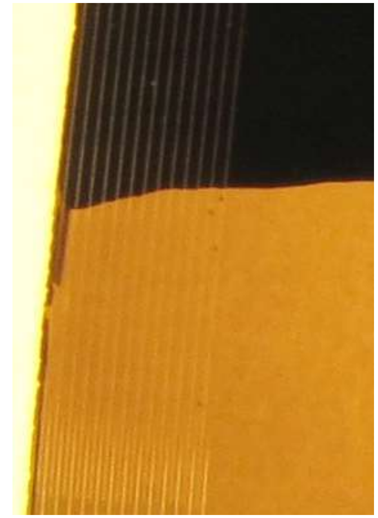
Now standard foil
U-shaped corrugations, corner cut off

Stripper foils (cont.)

- Foil shaking video

Foil corners and corrugations



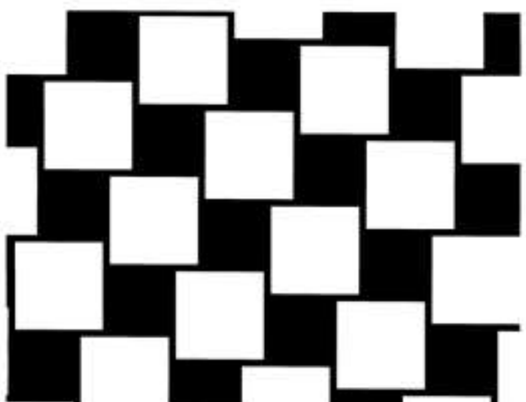


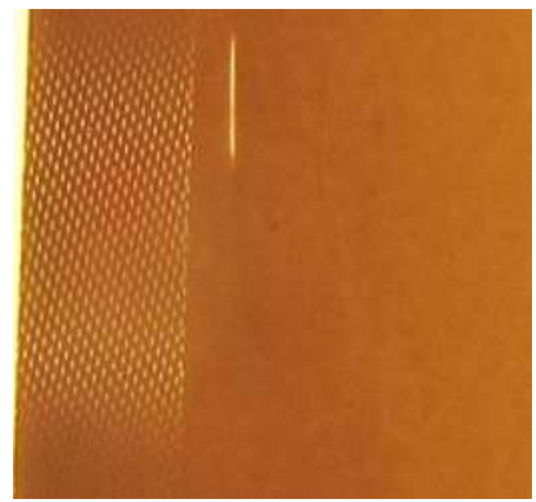
Cutting off the corner tends to lower the beam loss and seems to prevent foil shaking

Standard corrugation pattern

Photos by C. Luck

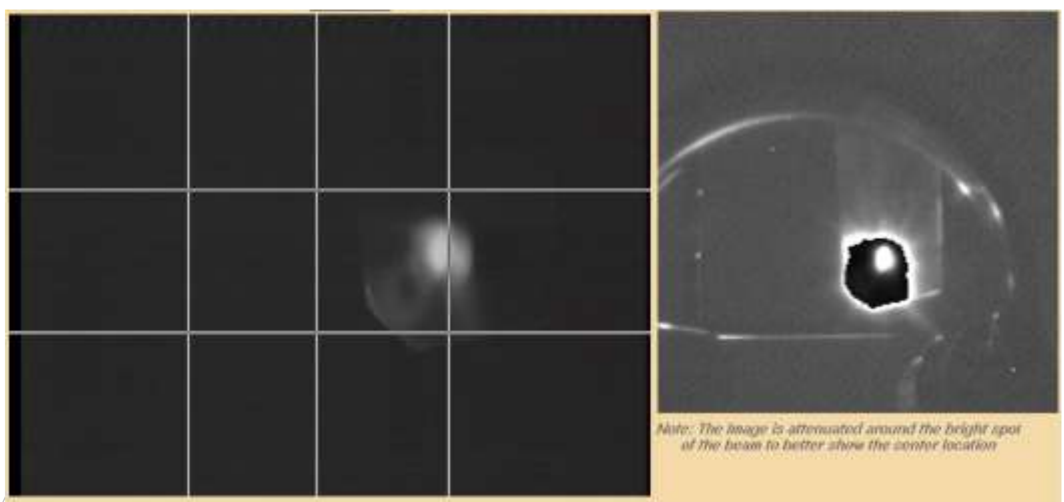
Promising new corrugation pattern may keep straight edges better





High intensity foil test

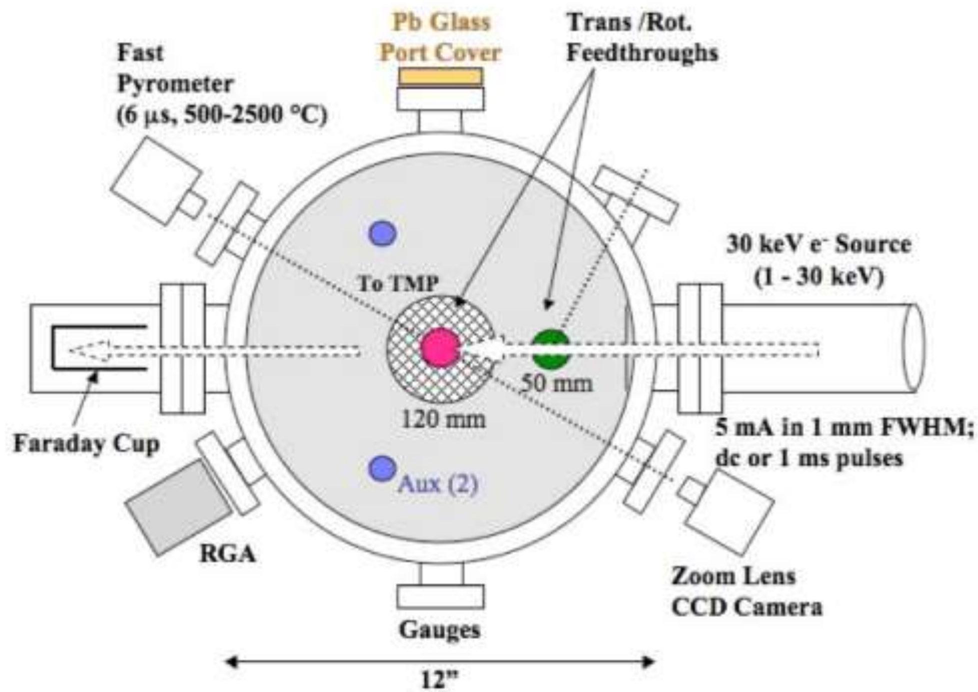
- **We've simulated the 1.5 MW total heat load on the foil by pushing the foil further into a 1 MW beam until the total foil hits (beam loss) increased ~60%**
- **The foil survived ~6 hours, until the end of the test, in good shape**
- **Next step is to simulate the 1.5 MW hit density rather than just the total hits. ORBIT simulations now underway to determine best way to do this**



Camera images of the foil at 1 MW beam power and 1.5 MW total heat load (22/Dec/2011)

Stripper foil electron beam test stand

- The electron beam test stand is now ready for use
- Electron beam energy deposition is equivalent to 1.5 MW ring operation
- Grad student will start working with it in next couple of months
- We plan to test microcrystalline & nanocrystalline diamond, HBC, C nanotube, boron-doped, etc., foils



Stripper foils future plans

- Continue to develop more conductive foils
  - Development of boron doping is in progress here at ORNL
- Develop and test new corrugation patterns
  - E.g. the checkerboard pattern looks promising
- Develop and test new foil technologies
  - E.g. the HBC foil. Visit by Yasuhiro Takeda for 2 years should help with this effort.
- Utilize the electron beam test stand to develop and test foils
- Replace both the primary and secondary stripper foil mechanisms

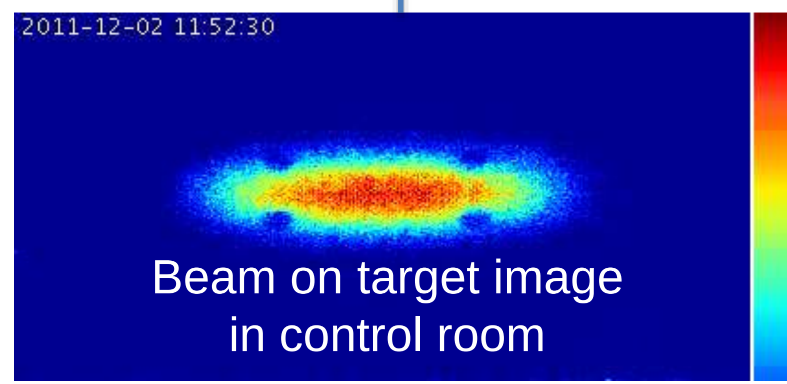
HEBT/Ring/RTBT Action items from the 2010 AAC

- **Development of HBC-like foils is also an option under consideration. The HBC foil developed at KEK has excellent lifetime in proton beams such as the LANL PSR and is expected to have good conductivity. It should be tested at SNS.**
  - The only HBC foil we've tested to date had a much higher stripping efficiency and beam loss caused by scattering than we expected (i.e. higher than expected effective thickness).
  - In April 2012 a J-PARC stripping foil expert (Yasuhiro Takeda) will join us for two years, and during that time we hope to test another HBC foil more suitable for SNS.
- **The Committee strongly encourages a focus on development of higher conductivity foils with long lifetimes. The electron beam test stand is an essential tool for evaluation of foil developments.**
  - We are working on developing boron doped nanocrystalline diamond foils. Two foils produced by a collaborator (Fraunhofer) did not meet our requirements. We are now working on fabricating our own.
  - The electron beam test stand is almost ready to produce meaningful results. It should soon benefit from additional resources (UT grad student Eric Barrowclough and J-PARC visitor Yasuhiro Takeda)

RTBT / Target interface

- We have two methods to determine the beam size, position, and peak density on the target
- The new TIS is in routine use and is an important monitor for neutron production

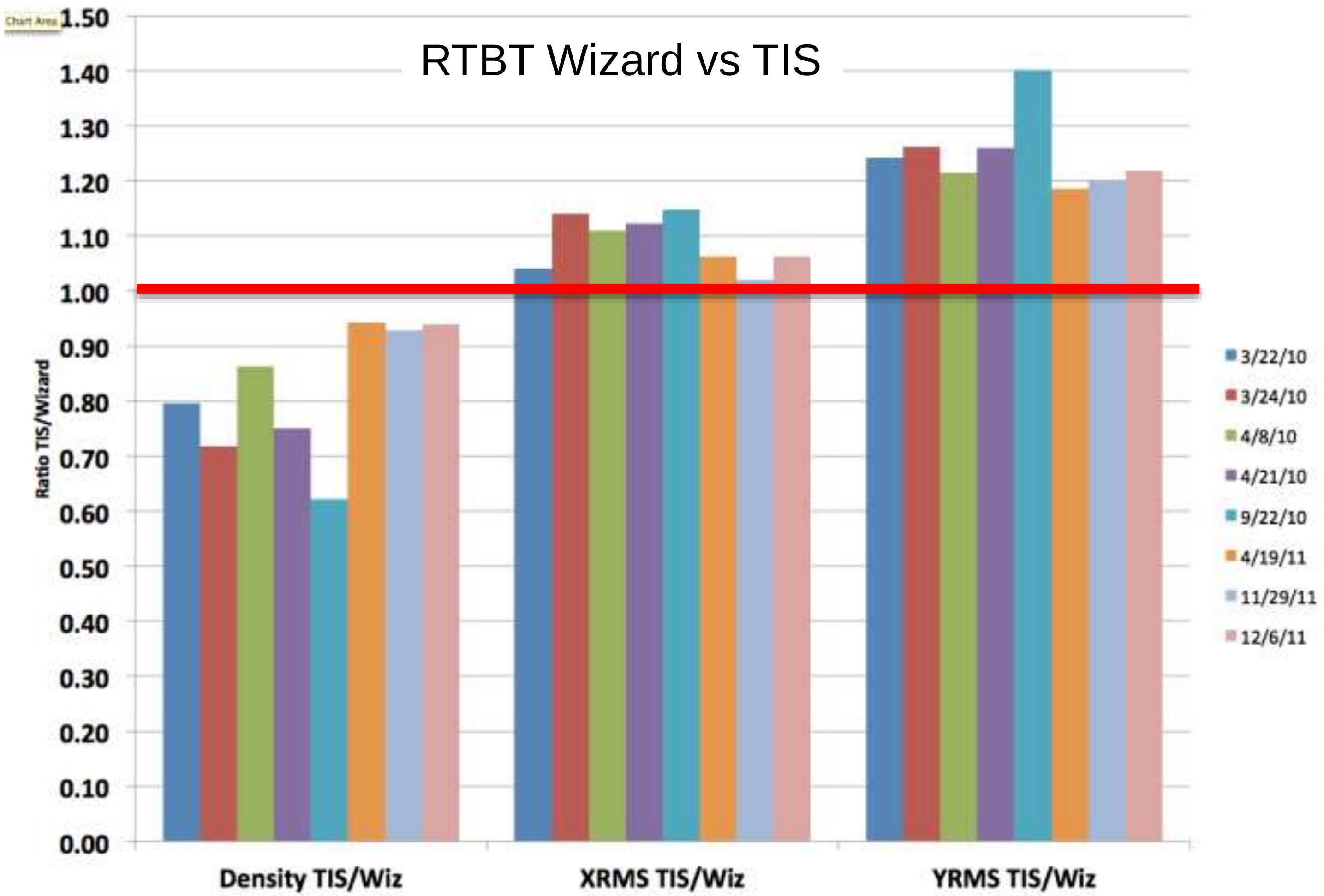
RTBT Wizard, based on wire scanners and harp in RTBT



The new target imaging system

RTBT / Target interface (cont.)

- There are unresolved discrepancies, up to ~40%, between the TIS and the RTBT Wizard. Funding for resolution is not available.



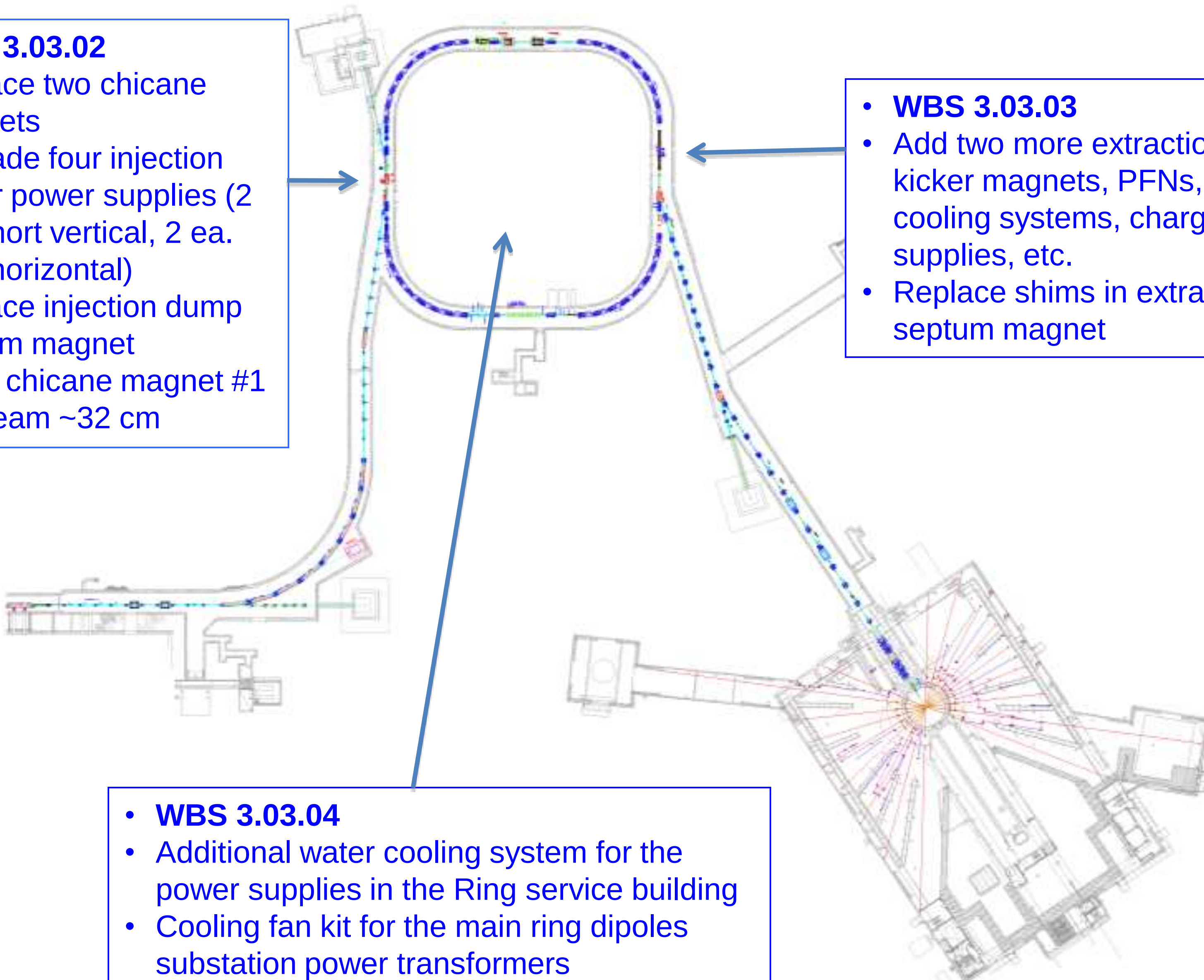
Courtesy T. Shea

RTBT / Target interface (cont.)

- We rely on the TIS for centering the beam on the target, but we still use the beam size and density extrapolated from upstream beam line diagnostics
- We trust the target imaging system for centering the beam on the target.
  - The error budget in beam size involves both the size and the position
  - If we can reduce the position error budget we can increase the beam size, thus lowering the peak density which should translate to longer proton beam window lifetimes and possible longer target lifetimes

The Power Upgrade Project Ring scope

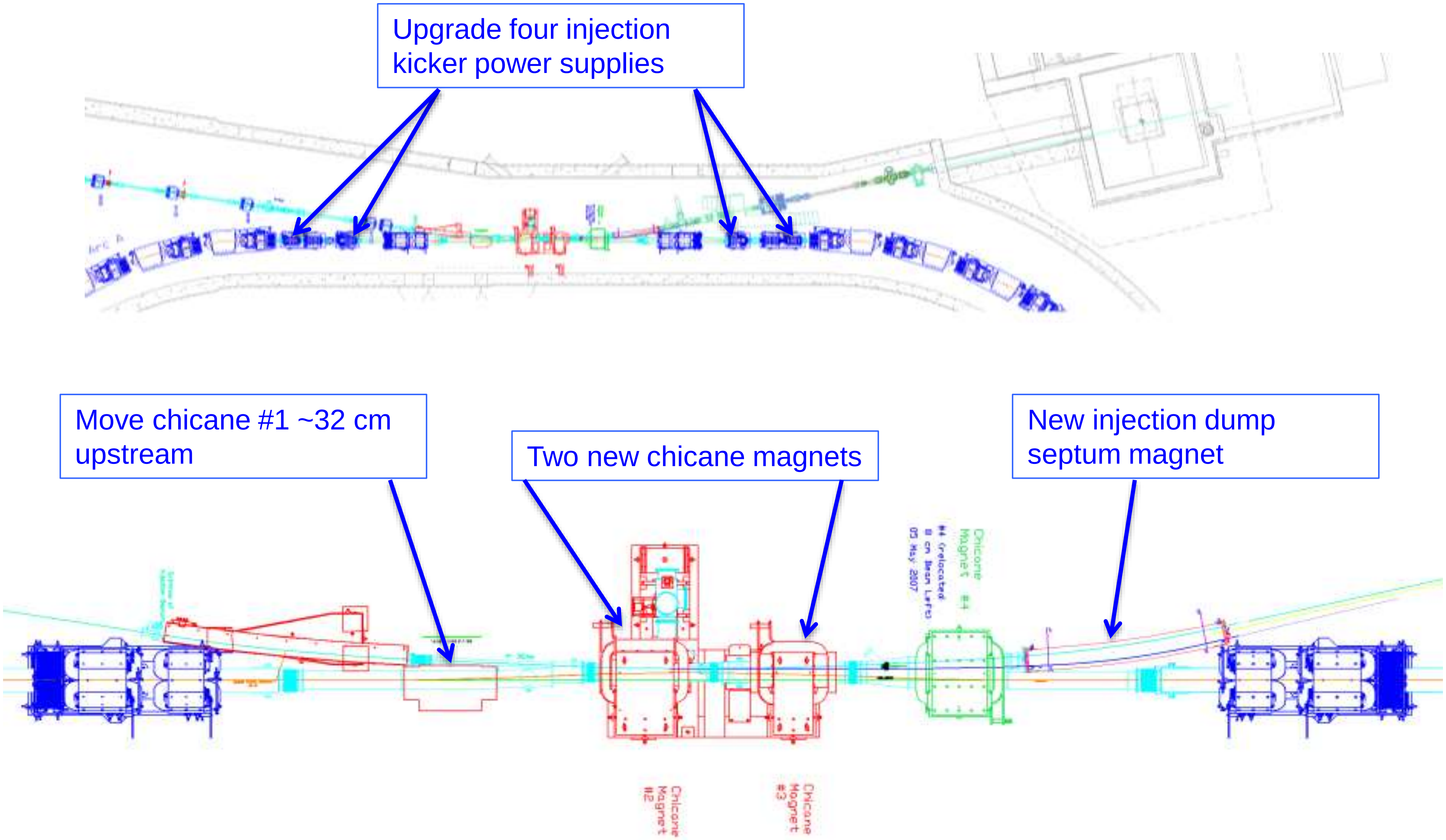
- **WBS 3.03.02**
- Replace two chicane magnets
- Upgrade four injection kicker power supplies (2 ea. short vertical, 2 ea. long horizontal)
- Replace injection dump septum magnet
- Move chicane magnet #1 upstream ~32 cm



- **WBS 3.03.03**
- Add two more extraction kicker magnets, PFNs, oil cooling systems, charging supplies, etc.
- Replace shims in extraction septum magnet

- **WBS 3.03.04**
- Additional water cooling system for the power supplies in the Ring service building
- Cooling fan kit for the main ring dipoles substation power transformers

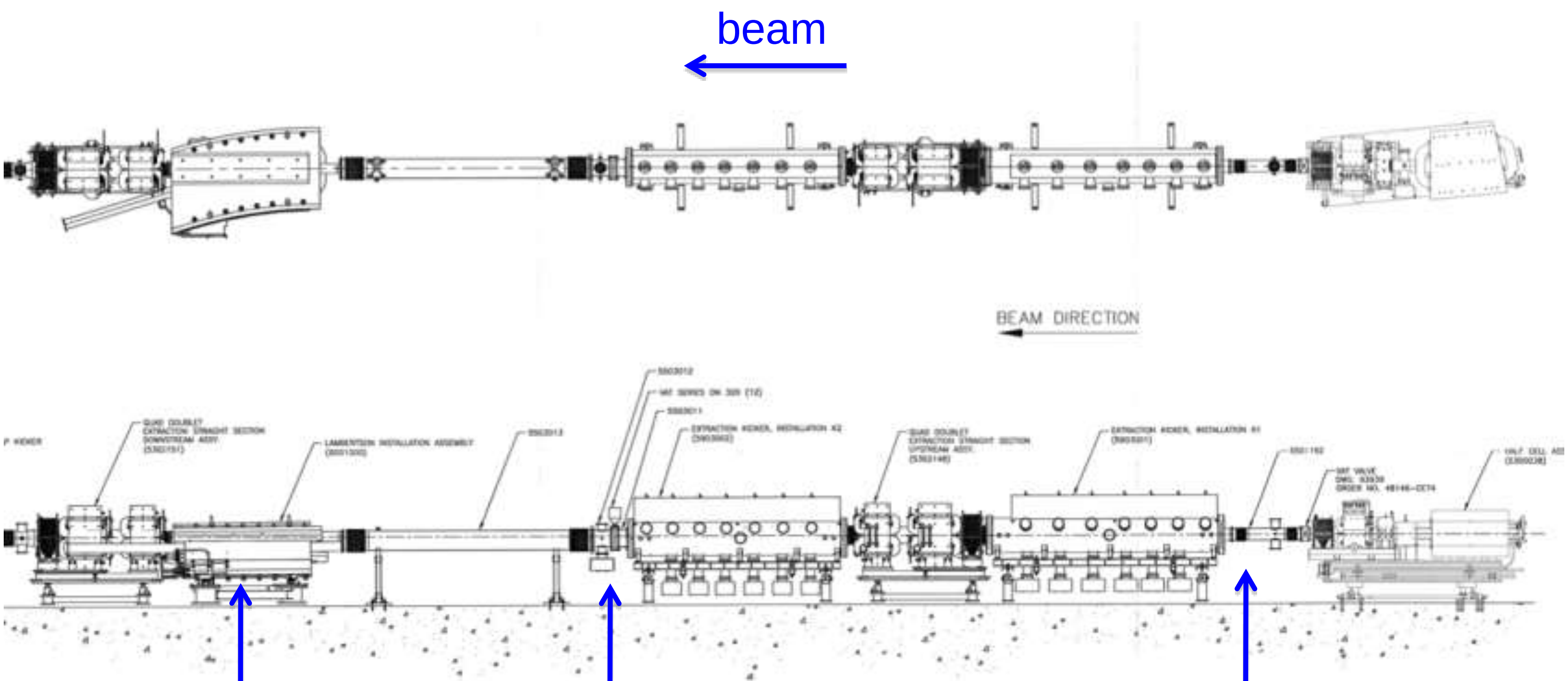
Ring injection PUP scope



Power Upgrade Project

- **For the Ring portion of the Power Upgrade Project, the highest risk area is Ring injection**
  - **There are many constraints that need to be simultaneously satisfied, and some are conflicting**
  - **Biggest constraints are the low magnetic fields required for H^- stripping and H^{0*} control, vs. achieving the bend angles needed for the chicane bump and avoiding magnetic field overlap**
  - **We developed a new design that will work at 1.0 to 1.3 GeV and will address all the issues we've identified with our present design**
  - **The new design was optimized using 3D magnetic field simulations and we are now testing it using particle tracking simulations and the tools we developed to understand the existing injection issues**

Ring extraction PUP scope



Replace shims in extr. septum magnet

Extend extraction kicker tanks, add one kicker magnet to each tank

Looking to the future

- Magnet design for injection dump septum magnet for 1.3 GeV
  - To be followed by particle tracking studies to qualify the design
- Stripper foil lifetime tests to simulate the 1.5 MW hit density, and then the 1.3 GeV, 3 MW peak heat load
- H0* tracking simulations and measurements for the 1.3 GeV chicane magnets, for both 1.0 and 1.3 GeV beam energies
- Possible beam paths (through the ring vs. around the ring) for the second target station

Summary

- The HEBT/Ring/RTBT working very well, and reliability and availability is very good
- The path to 1.4 MW appears to be straightforward
  - Biggest uncertainty is foil survival
  - Next-biggest uncertainties are e-p instability and space charge effects that could lead to higher beam loss per Coulomb

Thank you for your attention!