AAC - HEBT/Ring/RTBT Overview

Jan. 22 – 24, 2008

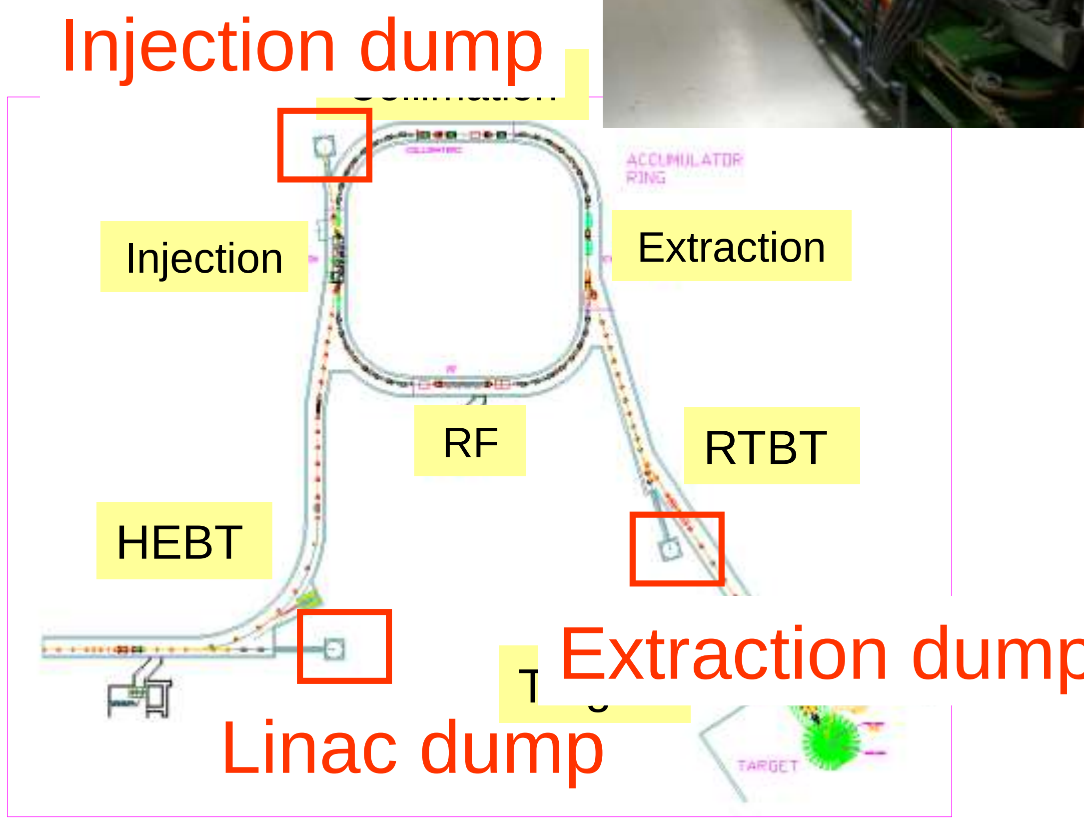
by Mike Plum

Ring Area Manager

Managed by UT-Battelle
for the Department of Energy

Accumulator Ring and Transport Lines

Circumference	**248 m**
Energy	**1 GeV**
f_{rev}	**1.06 MHz**
Q_x, Q_y	**6.23, 6.20**
Accum turns	**1060**
Final Intensity	**1.5×10^{14}**
Peak Current	**52 A**



Accomplishments in HEBT/Ring/RTBT

- **Except for RTBT optics issue, HEBT/Ring/RTBT on track for power ramp up**
- **Activation levels are presently acceptable and beam loss per Coulomb continues to drop (Galambos)**
- **Record beam power (213 kW)**
- **Record beam charge ($1.08x10^{14}$ ppp)**
- **Beta functions measured and found to be OK (Holmes)**
- **Transverse coupling measured and corrected (Holmes)**
- **IDmp problem being managed***
- **Method of single minipulse profile reconstruction* (Holmes)**
- **Identified source of RTBT cross-plane coupling (ExSptm)***
- **New stripper foil technology is working well***
- **Instability thresholds measured (3 types) (Danilov)**

Primary issues in the HEBT/Ring/RTBT

- **Injection dump poor beam transmission**
- **Cross plane coupling in the RTBT**
- **Beam optics control in the RTBT and peak density on the proton beam window**
- **Activation hot spots**

Other issues in the HEBT / Ring / RTBT

- **Transverse matching from SCL to HEBT to Ring**
- **Secondary stripper foil is thicker than we'd like**
- **Lack of diagnostics**
  - **Pinger**
  - **Transverse profile monitor**
  - **Target profile monitor**
  - **Convoy electron collector IR video**
  - **Electron cloud detector**
  - **Dipole and quadrupole kicker and pickup**

What stands between us and 1.5 MW?

- **Activation per Coulomb needs to come down about a factor of 2 to 3 near the stripper foil. Also have hot spots at beginning of HEBT arc, upstream end of Ikick V03.**
- **IDmp waste beam transmission and waste beam delivery to center of dump**
- **Cut peak beam density on proton beam window in half**
- **Errant beam controls on injection and extraction kickers**
- **Functional MEBT chopper**
- **Would like to reduce cross-plane coupling in RTBT**
- **Would like to check convoy electron catcher**
- **Would like to replace hoses on rad-hard quads with ceramics**

Modifications since start of commissioning

- **Wider, thinner secondary stripper foils (July/06 - May/07)**
- **Wider, taller, thicker primary stripper foils (Nov/06)**
- **Chicane magnet #4 8 cm shift beam left (May/07)**
- **C-magnet in IDmp beam line (May/07)**
- **BPM, WS, nano-Coulomb detector in IDmp beam line (May/07)**
- **Errant beam controls for RTBT magnets and RTBT BLMs (Jul/07 - ??)**
- **View screen in IDmp beam line (Oct/07)**
- **Mu-metal added in 3 locations in injection straight (Oct/07)**
- **Physics software applications and EPICS improvements**
- **All Griswold water flow control valves removed from Ring (2006 – 07)**
- **Replaced ceramic breaks on rad-hard RTBT quad water cooling (May/07)**

Modifications now in progress

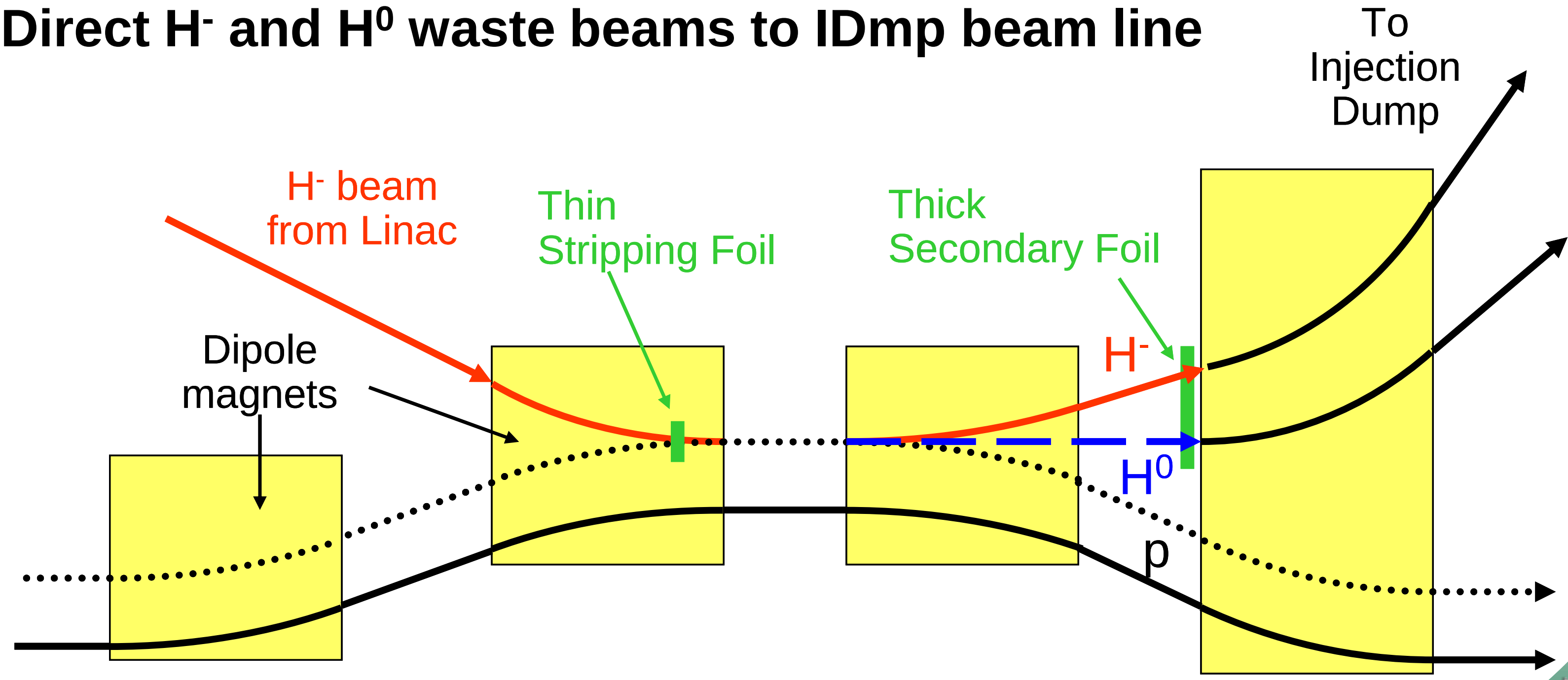
- **Injection dump septum magnet with increased aperture**
- **New primary and secondary stripper foil mechanisms and vacuum chambers**
- **Errant beam controls for injection and extraction kickers**
- **Remote handling vacuum clamps for collimators**
- **Beam in gap and pinger systems**
- **Electron beam and gas ionization profile monitors for Ring**
- **View screen in RTBT**
- **Convoy electron collector IR video**
- **RTBT harp actuator**
- **Beam profile on target system**

Issue: Injection dump beam line

- In 2000 a design change was made in the injection chicane magnets. This change caused a 14 mm offset in the closed orbit and prevented waste beam transmission to the dump.
- We have adjusted the chicane magnet bend angles to give good injection into the ring
- But we did not have good transmission or control of the H^0 and H^- waste beams.
- Chicane #4 also caused large vertical deflection of the H^- waste beam
- Re-design of the injection dump beam line is in progress

Functions of chicane magnets

- Closed orbit bump of about 100 mm
- Merge H^- and circulating beams with zero relative angle
- Place foil in 2.5 kG field and keep chicane #3 peak field <2.4 kG for H^0 excited states
- Field tilt [arctan(By/Bz)] >65 mrad to keep electrons off foil
- Funnel stripped electrons down to electron catcher
- Direct H^- and H^0 waste beams to IDmp beam line



Short and mid-term IDmp modifications

Radiation monitor on vacuum window water cooling return pipe

New C-magnet

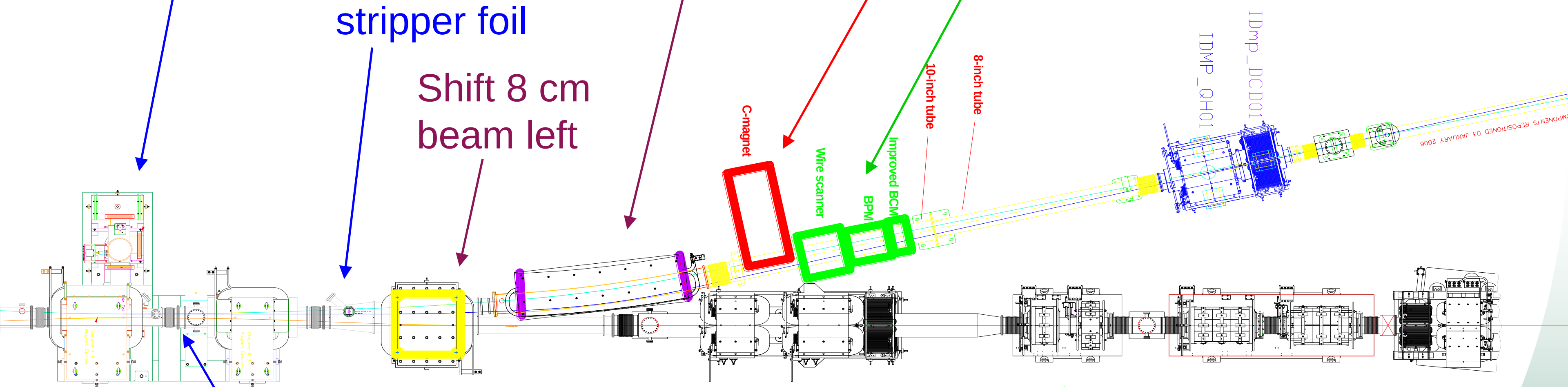
(Increase septum magnet gap by 2 cm)

New WS, BPM, NCD, view screen

Oversize primary stripper foil

Wider, thinner secondary stripper foil

Shift 8 cm beam left



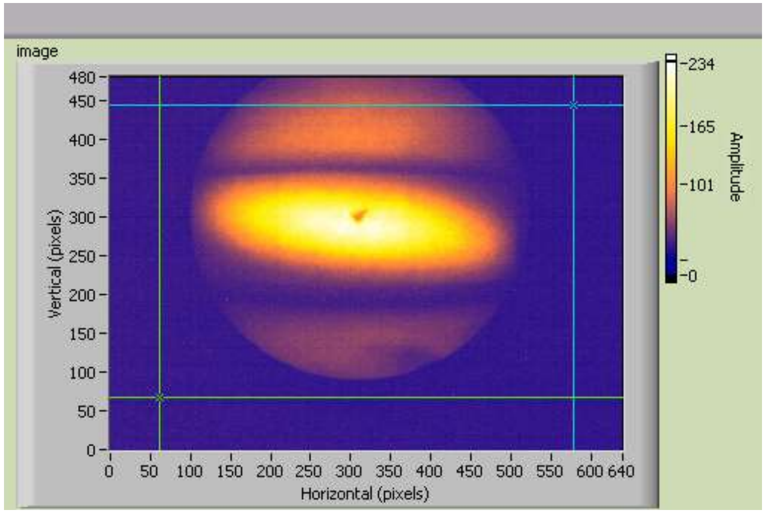
(Electron catcher IR video)

Injection dump beam line plan

- Chicane #4 shifted 8 cm beam left, and the C-magnet, have made big improvements
- The new diagnostics have been a big help to improve our understanding of the beam line.
- We have empirically evolved to an improved tune for the ring injection, with the injection point about 1 cm beam left of design, but we still need more improvements
- Install spare IDmp septum magnet, modified to have larger aperture, in February 2008
- May need to add a quadrupole
  - ORBIT simulations now in progress
  - A spare 30Q44 or 30Q58 could work nicely

Issue: cross plane coupling in the RTBT

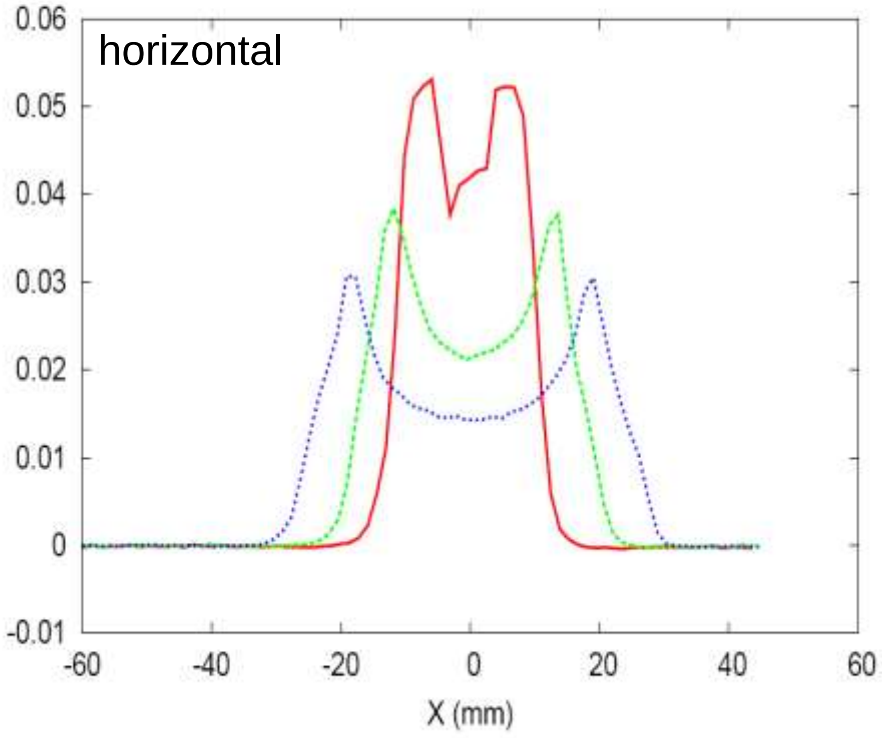
- **Early measurements with the target view screen showed tilted beam at the target**
- **Wire scanners in the RTBT consistently showed strange profiles that could not be explained with simulations**
- **Vertical extraction kickers cause large horizontal oscillations in the RTBT**

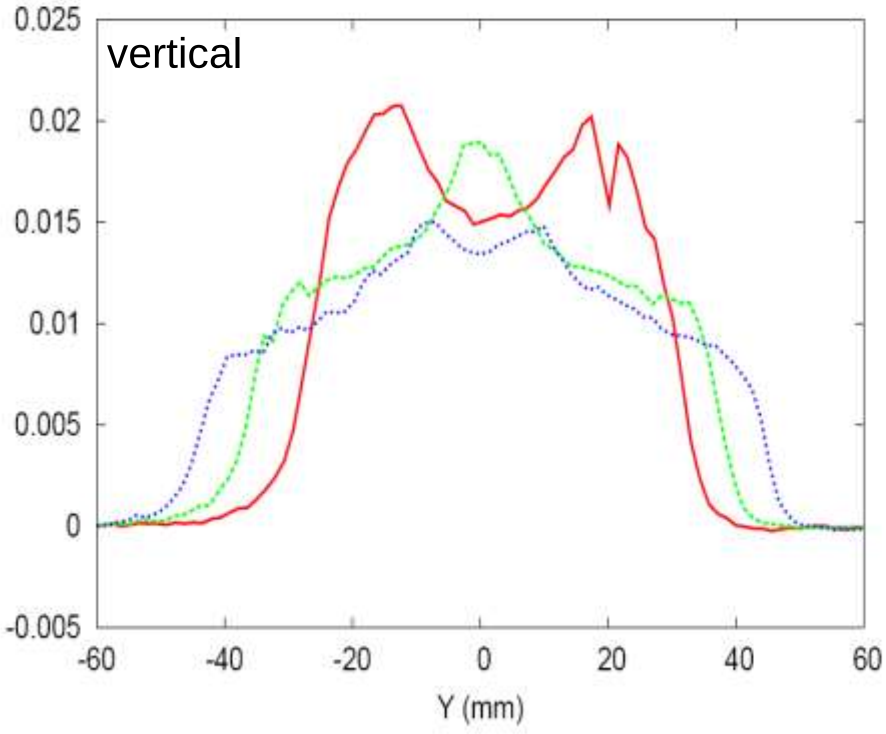


- **Single minipulse profile reconstruction (new technique) conclusively showed tilted beam in the RTBT**
- **The source of the coupling has been narrowed down to a large skew quad component inside the extraction Lambertson septum magnet**

Beam profiles in the RTBT

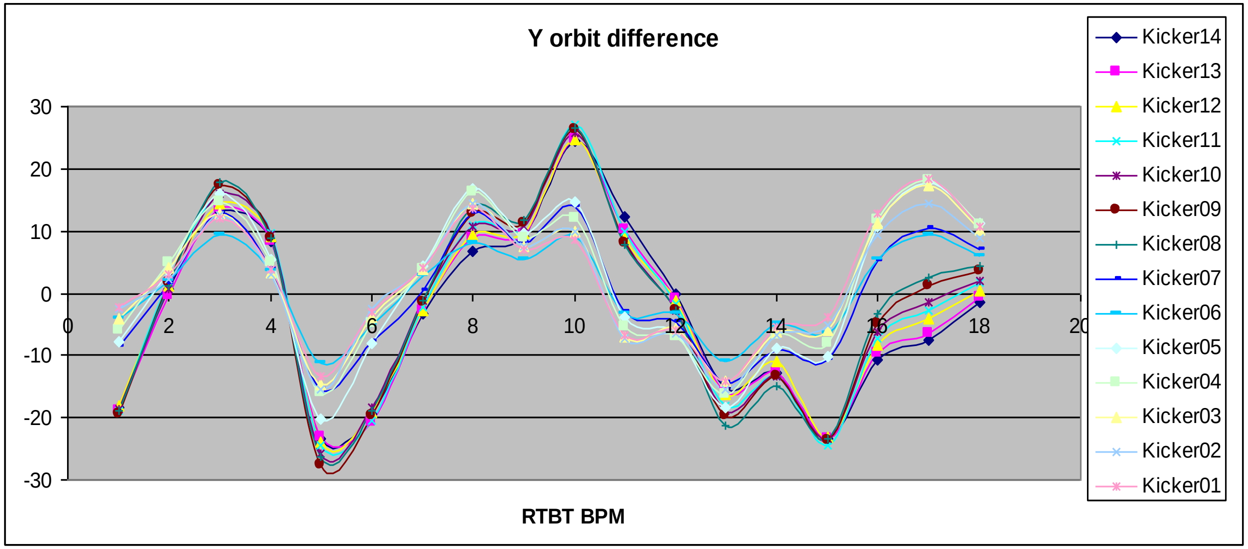
For no painting (flat-topped kickers), expected hollow profiles with independent control of x and y planes. One wire scanner for three different horizontal injection kicker amplitudes is shown.

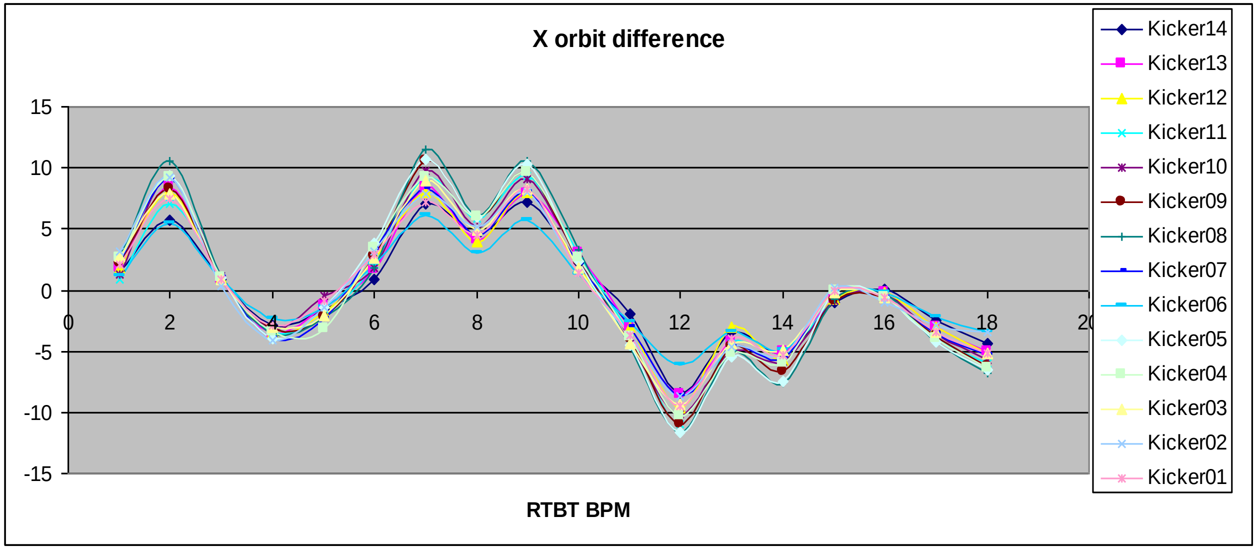




Courtesy S. Cousineau

Orbit Difference by Extraction kicker on & off





All Ext kickers affect beam both in X and Y planes

This demonstrates:

- A source of coupling exists

- The source is unlikely to be one or two extraction kickers (all kickers produce same H wave)

Courtesy D. Jeon

OAK RIDGE National Laboratory

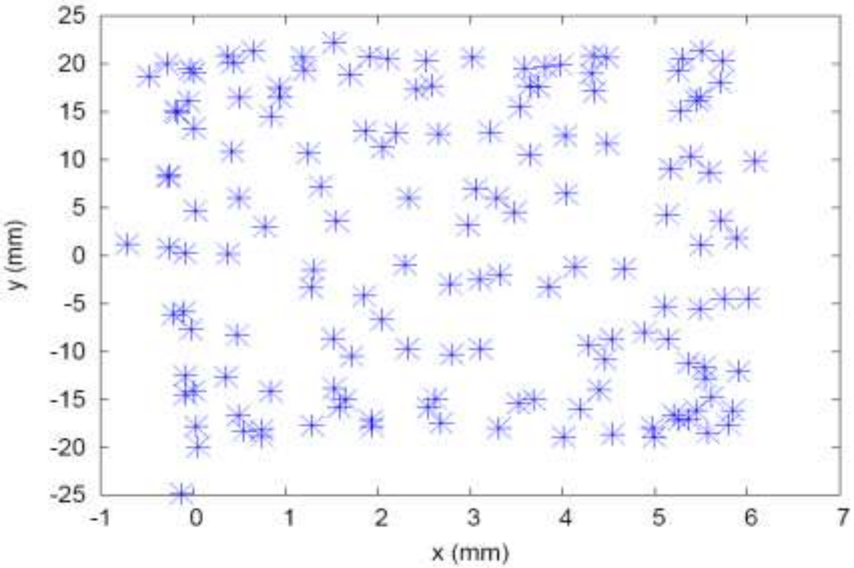
BPM Beam Profile Measurement in the RTBT

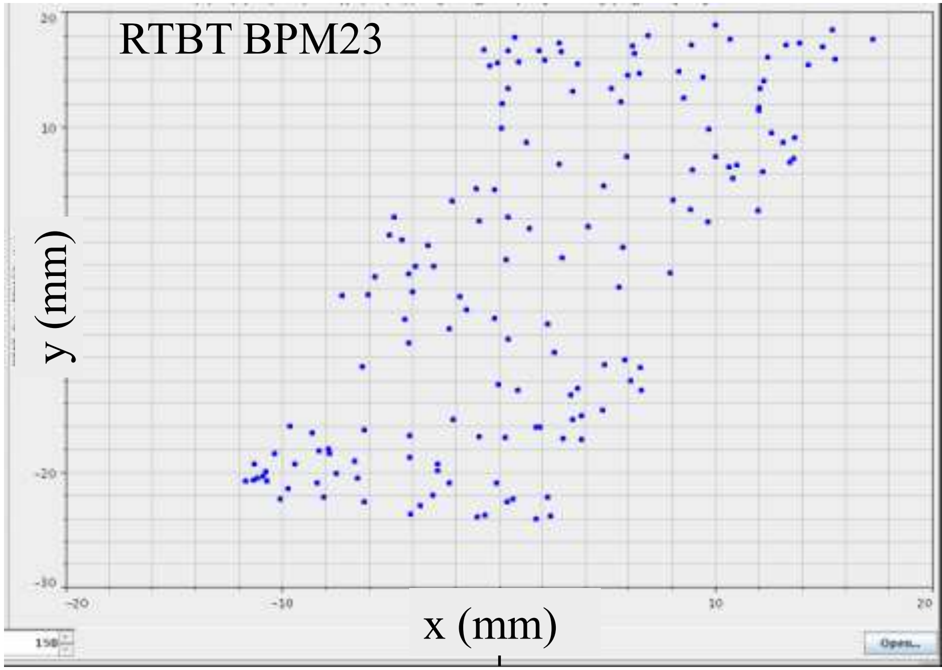
Procedure for creating a "PDM" ("Pelaia Distribution Monitor"):

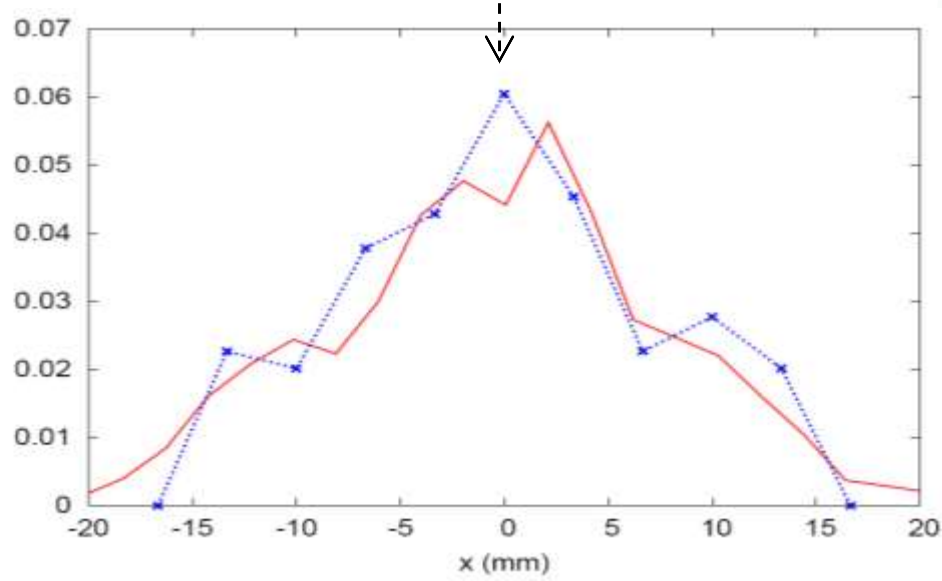
1) Setup flat top injection kickers
2) Set chromaticity to zero using sextupoles to suppress decoherence
3) Inject single mini-pulses and scan through the extraction kicker delays (storage time) by integer turns
4) For each delay setting, record the beam positions at the RTBT BPMs
5) For each BPM, aggregate the mini-pulse beam position data over the delay settings to reconstruct a macro-pulse beam distribution. In other words, plot all of the BPM measurements together to reconstruct the x vs y distribution.

Single minipulse profile reconstruction

Ring BPM B03







- Very little tilt seen in Ring
- Large tilt seen in RTBT

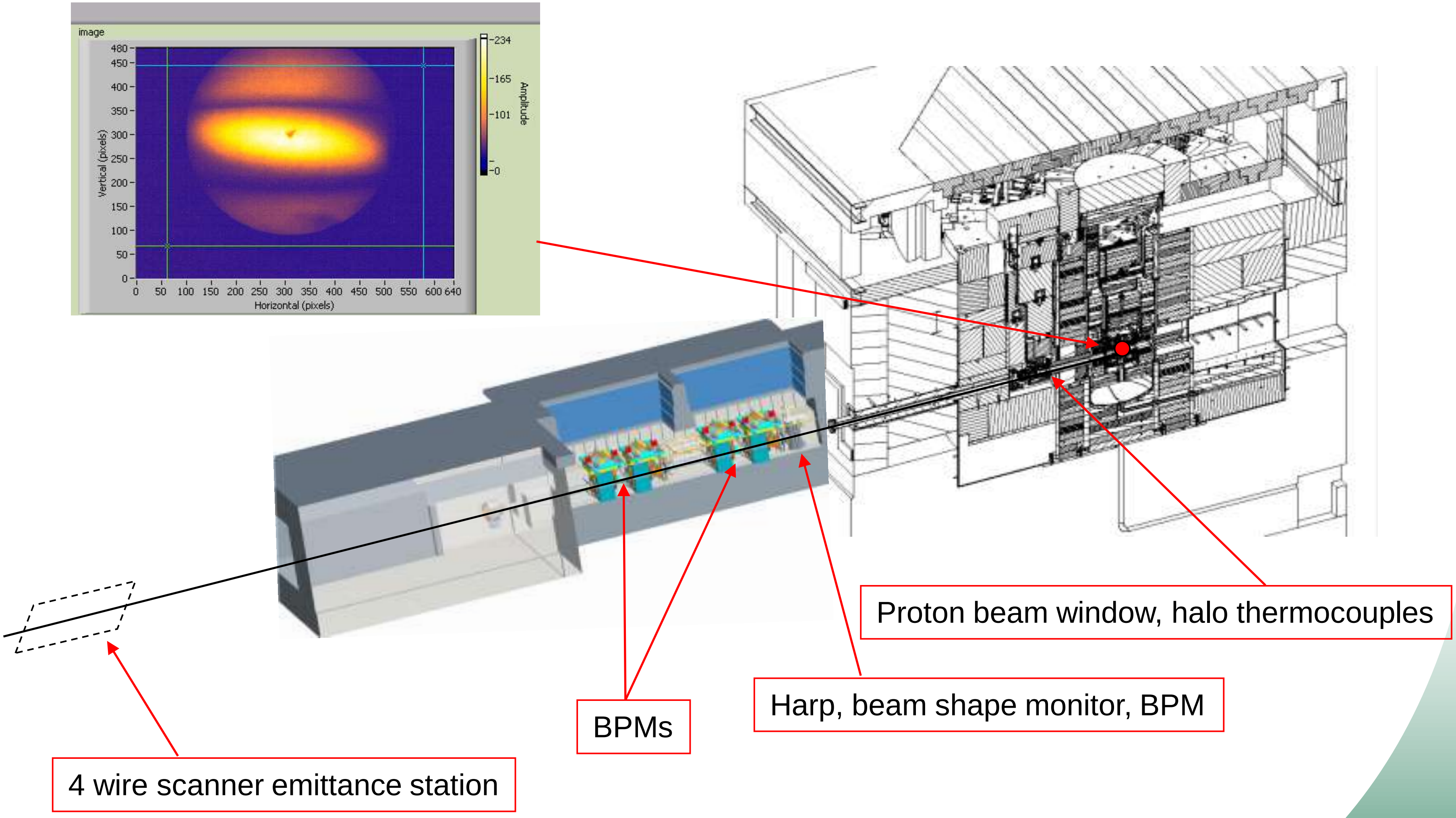
Coupling source localized to extraction septum magnet

T. Pelaia & S. Cousineau

Plan for cross plane coupling in RTBT

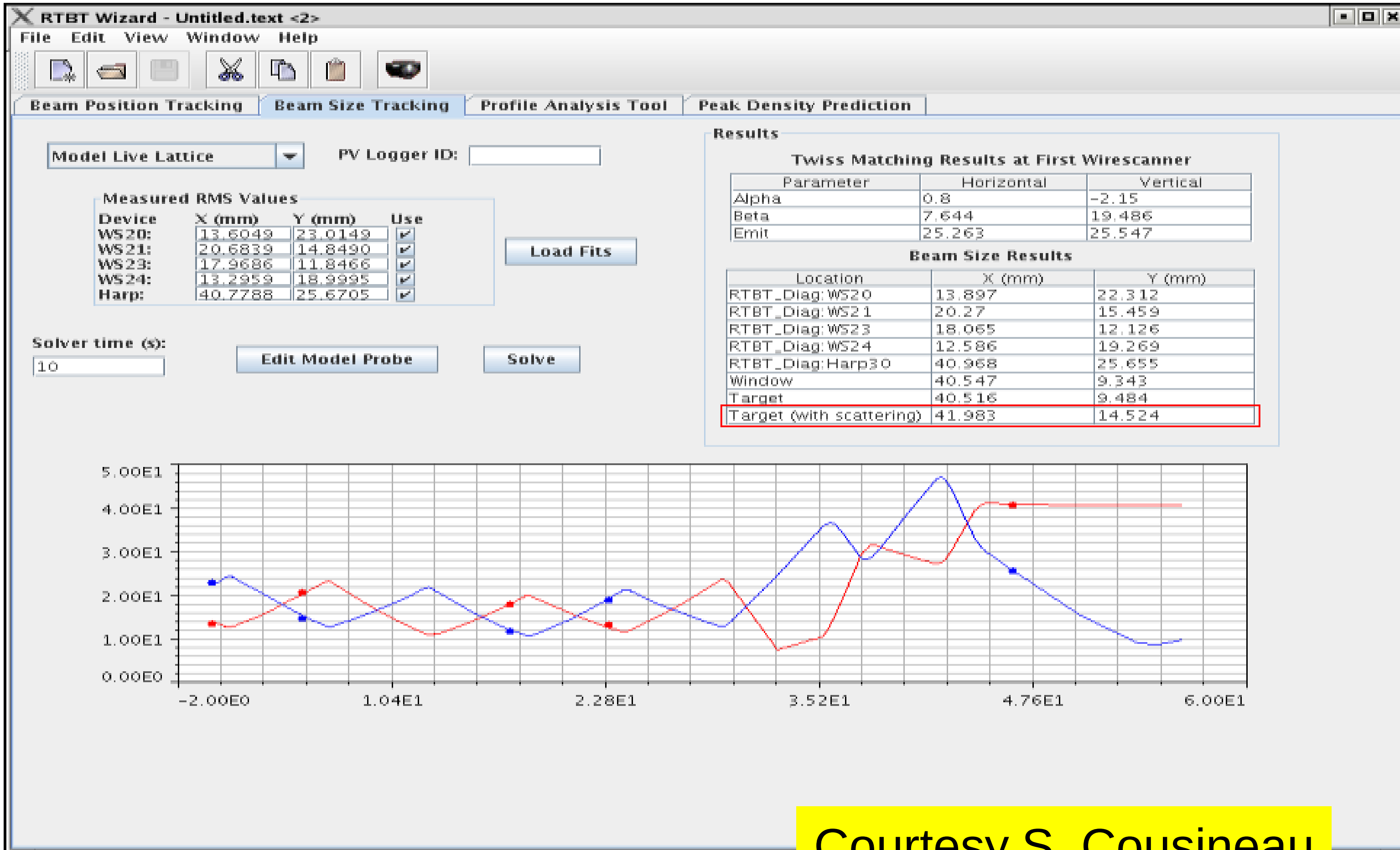
- **ORBIT simulations now in progress to determine how many skew quads are needed, where they should be located, and how strong they need to be**
- **Add skew quads as necessary. This will probably take 1 to 1.5 years.**
- **In parallel we are modifying our physics apps to include cross plane coupling. We may be able to improve the RTBT optics.**

Beam size, density, and position on target and Proton Beam Window



Beam size measurement on target and PBW

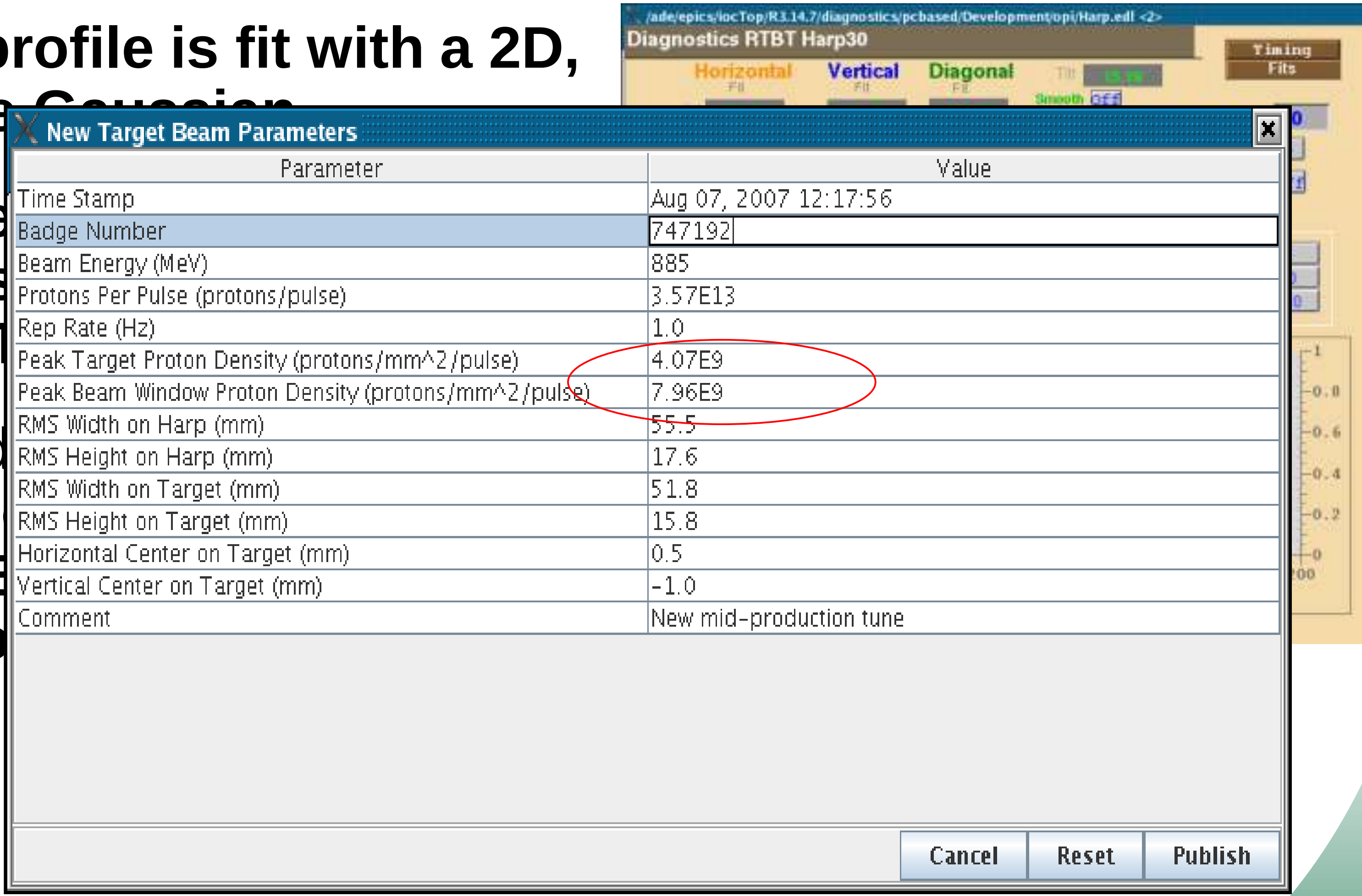
- The RMS of the wires and harp are found by statistical RMS or double Gaussian fits.
- The online model is used to match the envelope to the RMS data.
- The match gives a prediction of beam size on target (we include window scattering).
- Benchmark of the application gave agreement within 10% of viewscreen measurement.



Courtesy S. Cousineau

Peak density measurement on target and PBW

- Harp profile is fit with a 2D, double Gaussian
- The pe… harp is… and RT…
- Peak d… extrap… and PB… envelo…



Parameter	Value
Time Stamp	Aug 07, 2007 12:17:56
Badge Number	747192
Beam Energy (MeV)	885
Protons Per Pulse (protons/pulse)	3.57E13
Rep Rate (Hz)	1.0
Peak Target Proton Density (protons/mm^2/pulse)	4.07E9
Peak Beam Window Proton Density (protons/mm^2/pulse)	7.96E9
RMS Width on Harp (mm)	55.5
RMS Height on Harp (mm)	17.6
RMS Width on Target (mm)	51.8
RMS Height on Target (mm)	15.8
Horizontal Center on Target (mm)	0.5
Vertical Center on Target (mm)	-1.0
Comment	New mid-production tune

Issue: peak density on target and PBW

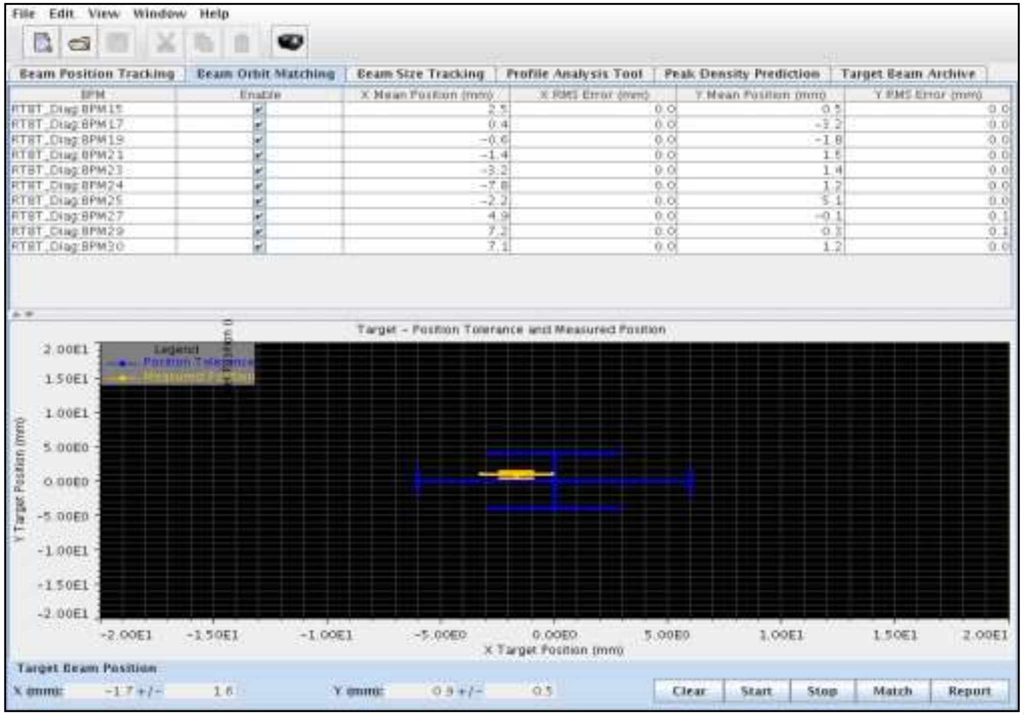
- **The measured peak density on the target has, until recently, been ~3x higher than expected**
- **This has caused the beam power at 30 Hz to be limited to ~160 kW.**
- **The measured peak density at the proton beam window was also ~3x higher than expected**
- **In early January 2008 the cause was finally traced to swapped vertical and diagonal profiles on the RTBT harp**
- **Measured peak density on target is now fine, but peak density at PBW is still ~2x higher than expected**

Plan for peak density control

- **Develop ability to control RTBT optics in a predictable and reproducible fashion**
  - **May require correction of cross-coupled beam**
  - **May require improved physics model of RTBT that includes cross coupling**
- **Adjust optics to reduce peak density at PBW**
- **Check when get the target profile monitor system working (see McManamy talk)**

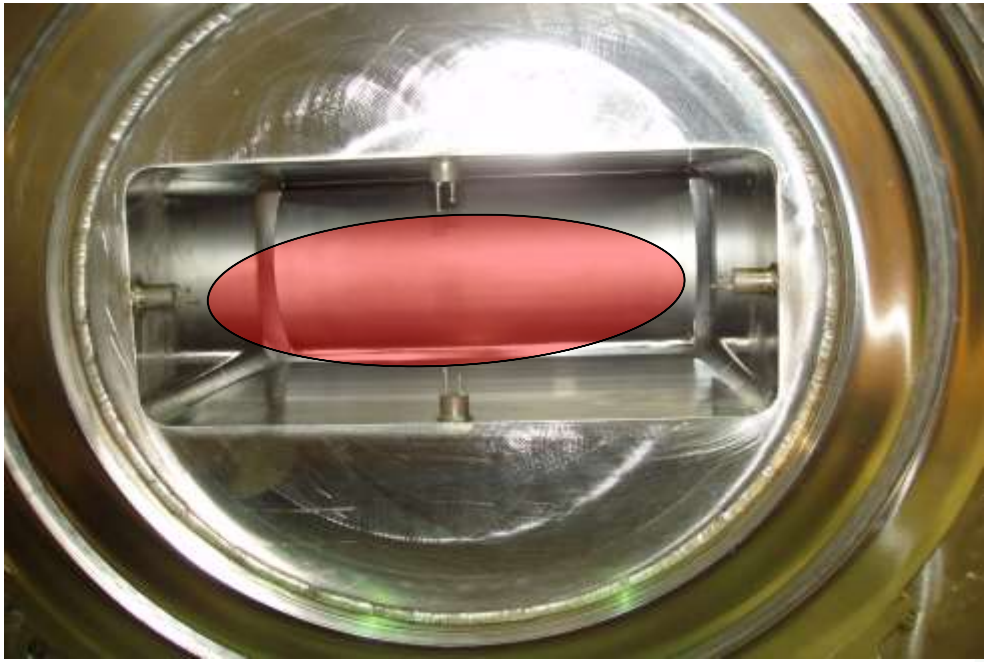
Target beam position measurement

- **Prior to November 2007 we had been using the RTBT BPMs to extrapolate the beam position on target**
  - **Tested using archived target view screen data**
  - **Two different methods developed, but each needed arbitrary scale factors and offsets**
  - **When BPMs indicated beam centered on target, PBW halo thermocouples indicated off center**



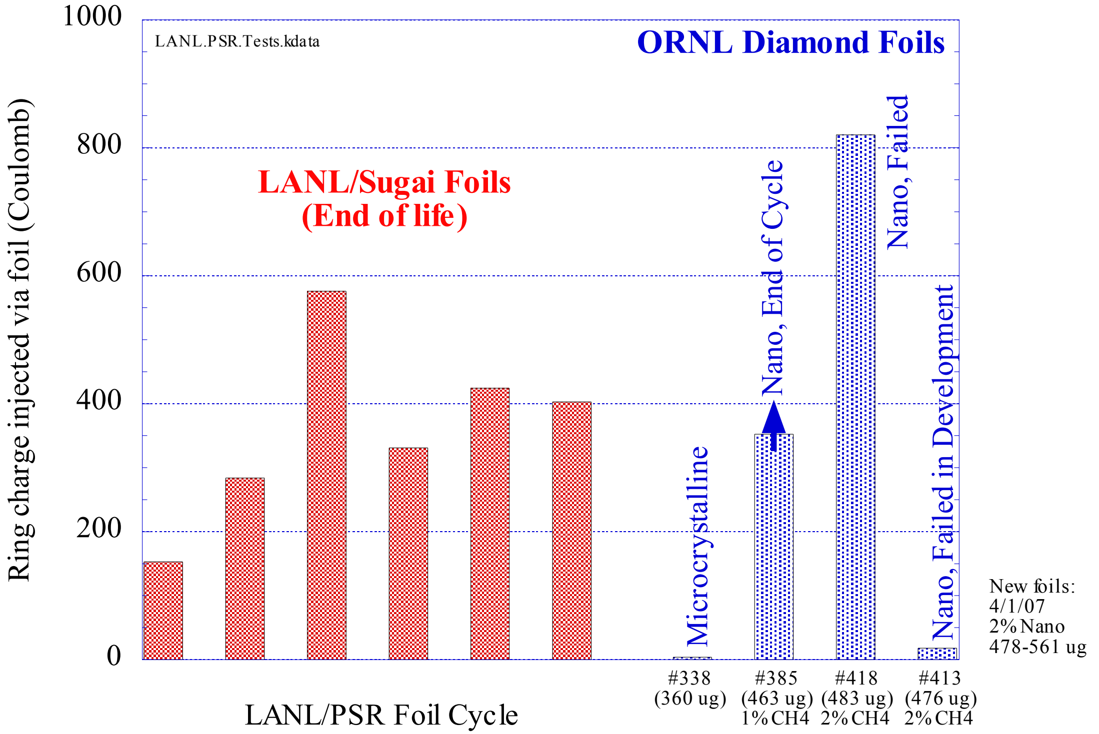
Target beam position measurement cont.

- In November 2007 we began using PBW halo thermocouples to center the beam
- We believe this is more accurate, although lower resolution
- Better to be approximately correct than exactly wrong
- A new beam imaging system is being developed for the target (see McManamy talk)
- We will check our target centering when that system is installed



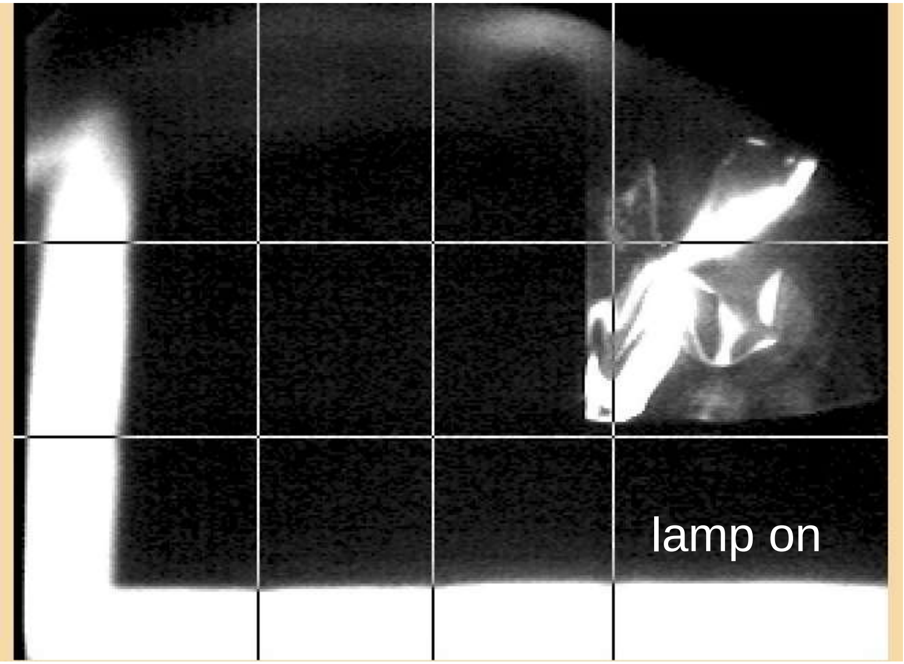
Status of the primary stripper foils

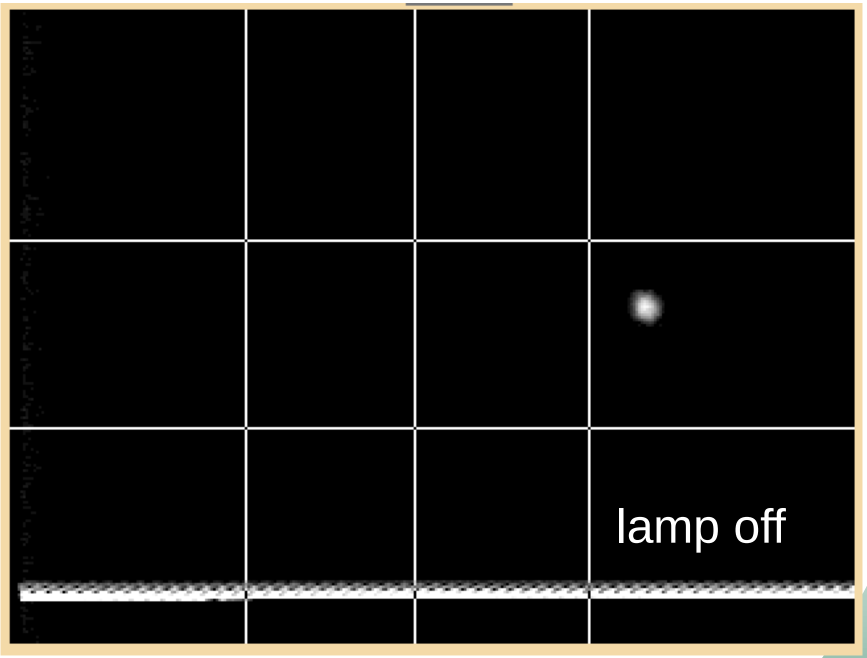
- **Diamond foil development program started at ORNL in 2001**
- **Foils tested at PSR, BNL, FNAL, KEK, RIKEN, TIT**
  - **PSR tests are the most relevant to SNS**
  - **Show that diamond foils last about same time as PSR-style, maybe a bit longer, but fail under extreme conditions (e.g. PSR to WNR mode)**



Status of the primary stripper foils cont.

- Diamond foils appear to be the best option for SNS
  - Although we are still considering PSR-style and HBC foils
- Per pulse beam intensity on foil is now ~28% of 1.44 MW design





160 kW, 30 Hz, 4/Jan/08

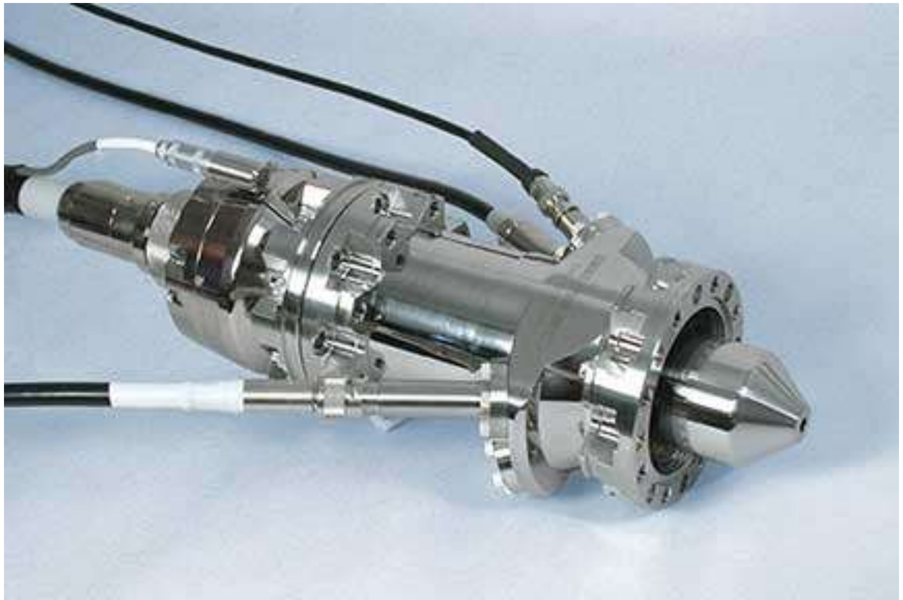
Status of the primary stripper foils cont.

- **No foil failures to date for production conditions, although 1 foil was removed Oct/07 with a curled corner**
- **Integrated injected charge delivered to target was 312 μC**

Foil #601, from position #6, removed 29/Oct/07. Curl is toward upstream.

Status of the primary stripper foils cont.

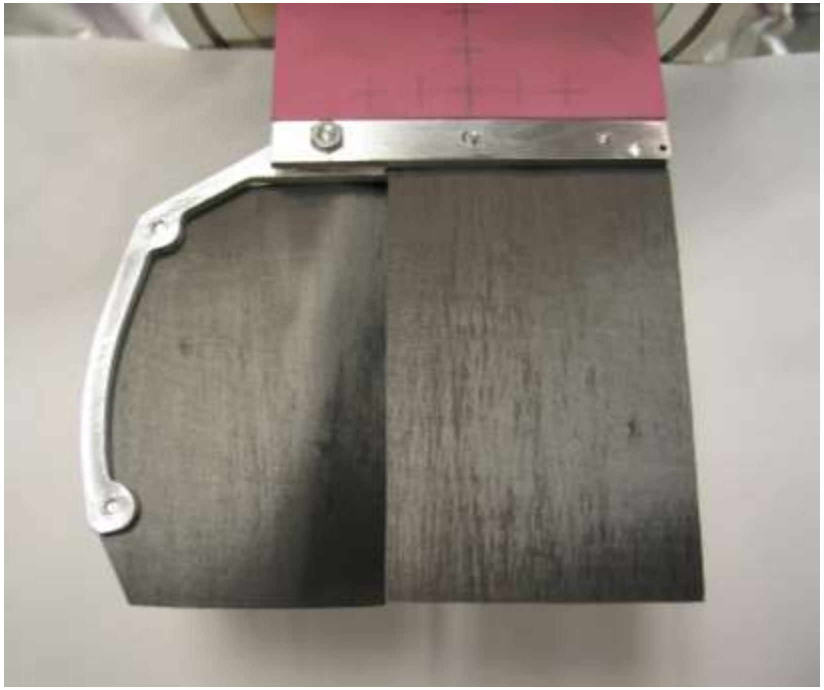
- **We're building an electron beam foil test facility**
  - **Estimate that we need 1.6 mA/mm^2 of 30 keV electrons to simulate the 1.4 MW, 1 GeV case**
  - **Purchase in progress for a 30 keV, 5 mA electron gun with a 1 mm spot size**
  - **Optical pyrometry system is also planned**
  - **The system should be assembled by the fall of 2008**



Customized version of this EMG-4212 gun

Status of the secondary stripper foils

- Started with 25 mg/cm^2 carbon-carbon foil
- Not wide enough, so developed a two-part swinging mechanism. This will eventually be replaced.
- Much thicker than required for stripping
  - Mechanically robust, but causes excessive scattering & beam loss, and may get too hot
- We have changed vendors, and we are now using 18 mg/cm^2 carbon-carbon foils
- We are searching for a 1 mg/cm^2 solution

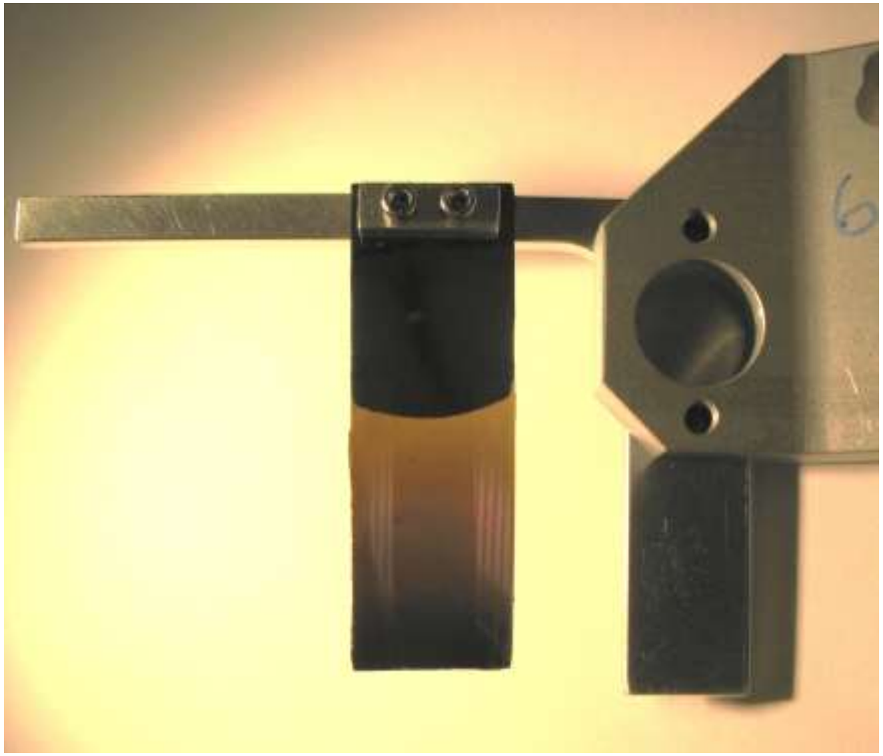


Summary

- HEBT / Ring / RTBT are on track for the power ramp up
- We are aggressively addressing issues with
  - Injection dump waste beam transport
  - Cross plane coupling in RTBT
  - Beam density on proton beam window
  - Beam loss reduction
- Stripper foil technology is continuing to advance
  - Diamond foils are working well for us

- **Backup slides**

Reason for shorter foils



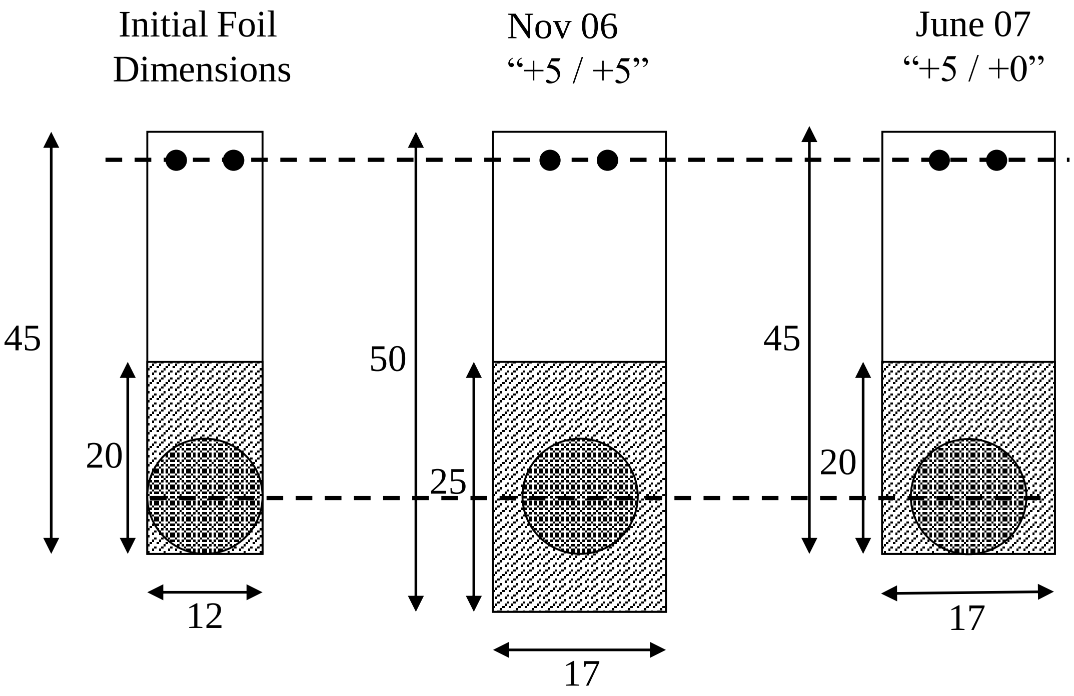
Foil #601, now installed in pos'n #6,
in use since Nov/06

Foil #648, now installed
in pos'n #9

Photos by Chris Luck

Primary foil size evolution

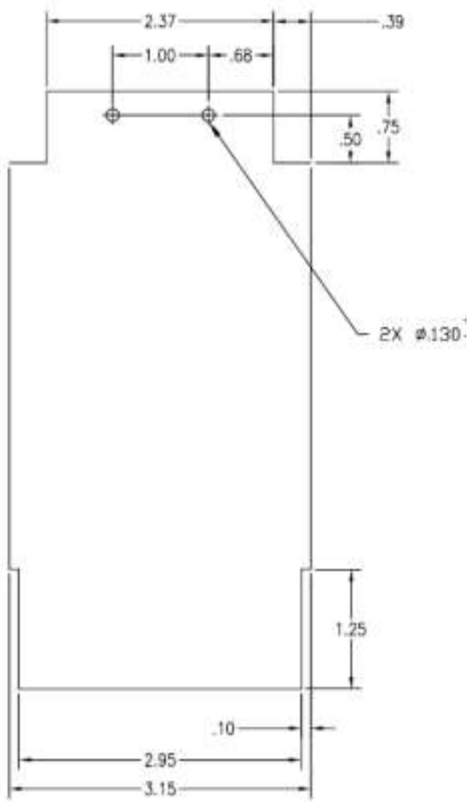
SNS Diamond Stripping Foils



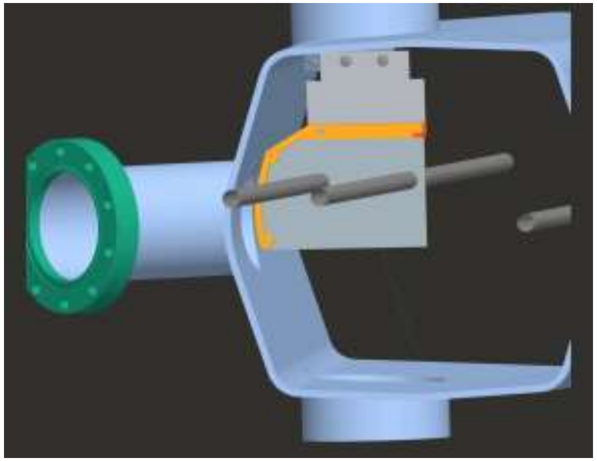
Drawing from R. Shaw

Secondary stripper foil

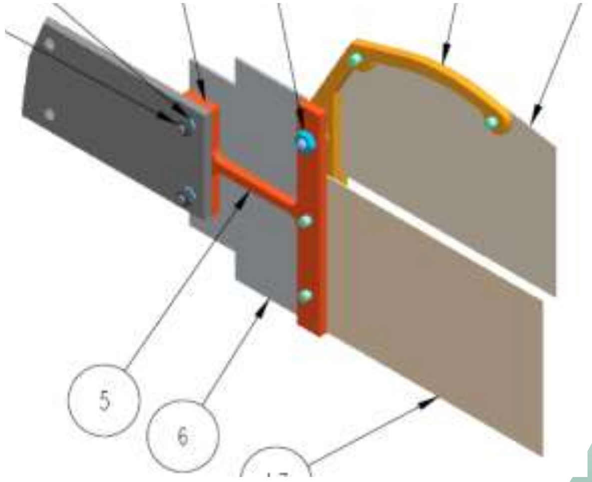
Used Jan – May 2006
25 mg/cm² C-C



Used Jun/06 – Apr/07
Two-part hinged foil to extend beam left side.
25 mg/cm² C-C

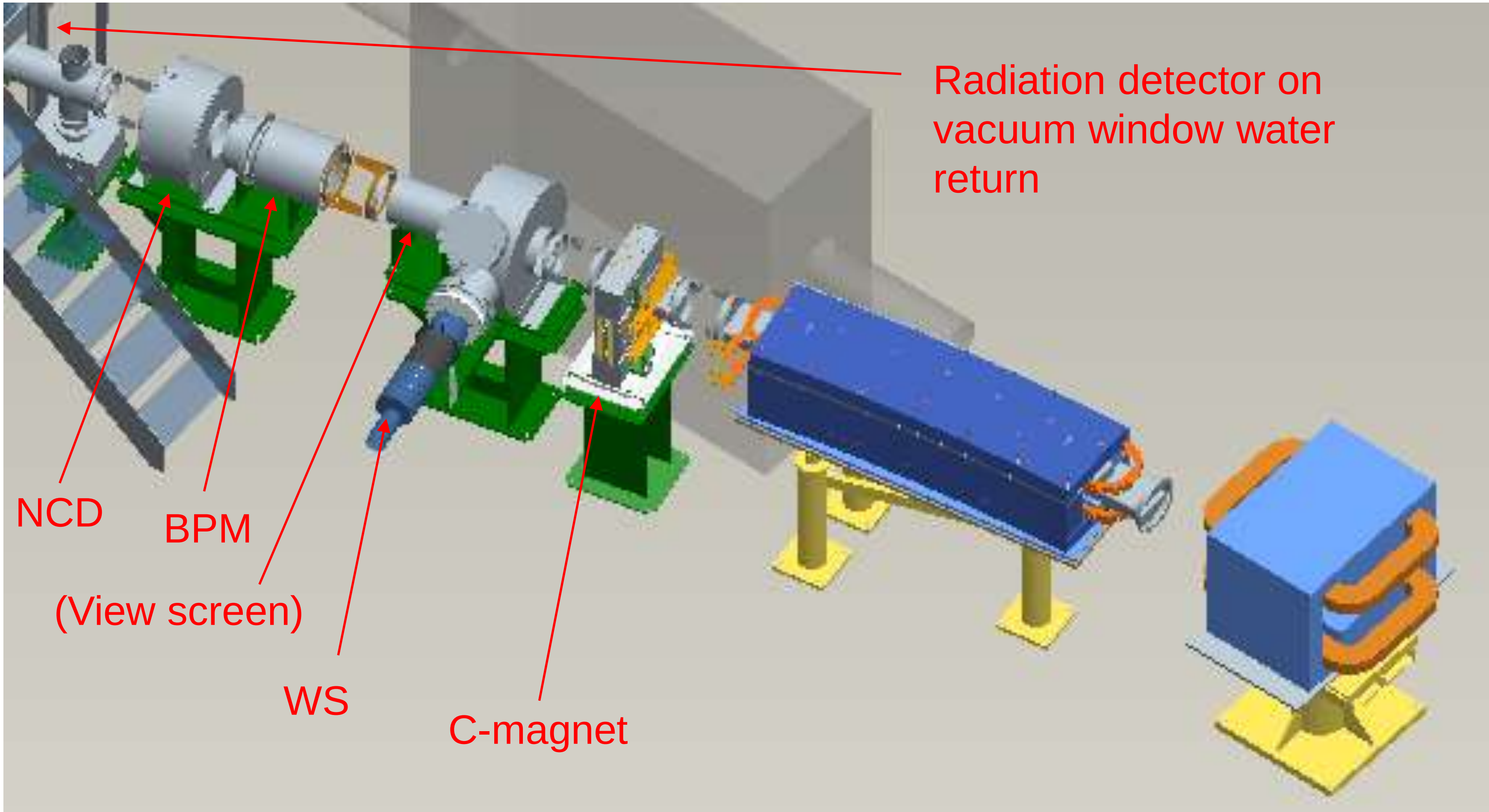


Used Jun/07 – ???
Two-part hinged foil, thinner.
?? mg/cm²

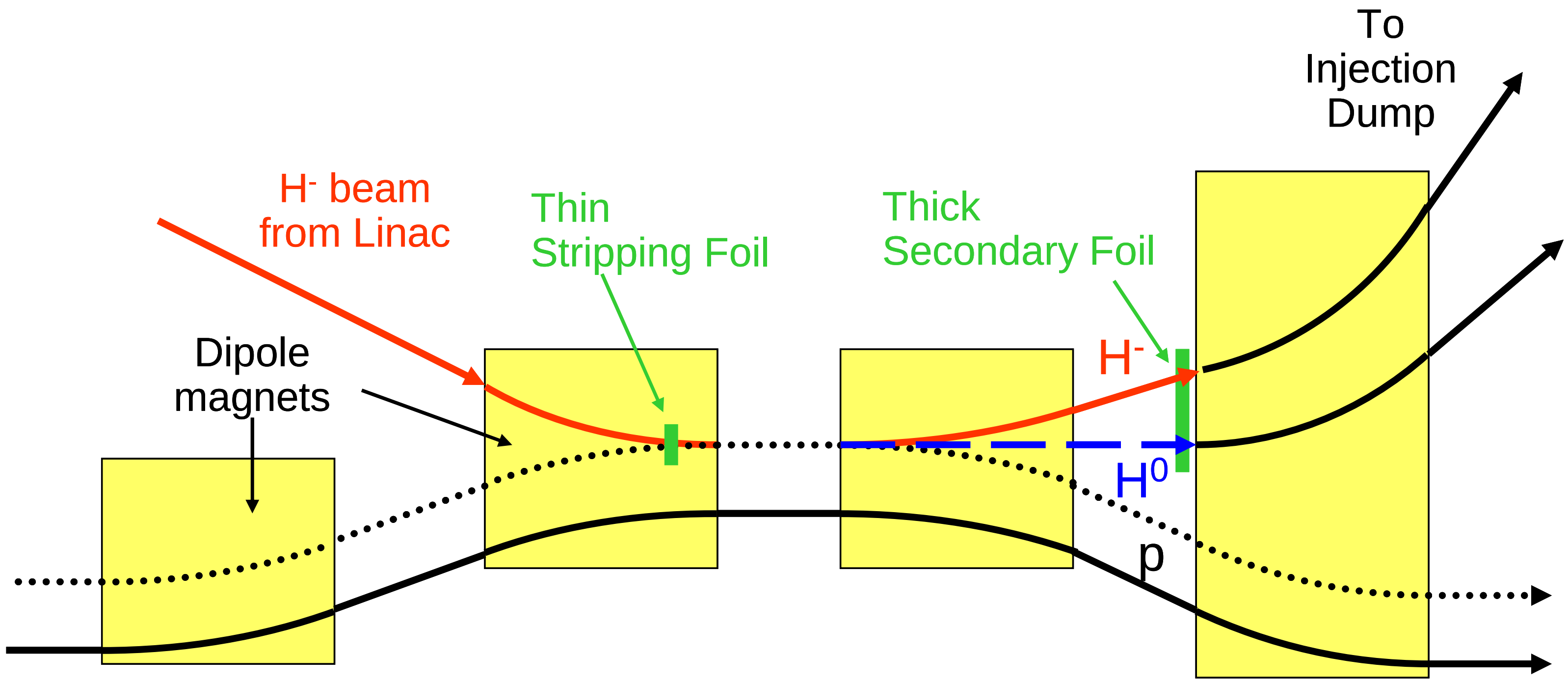


Images from K. Potter / J. Safieh

New injection dump beam line diagnostics



Chicane bend angles



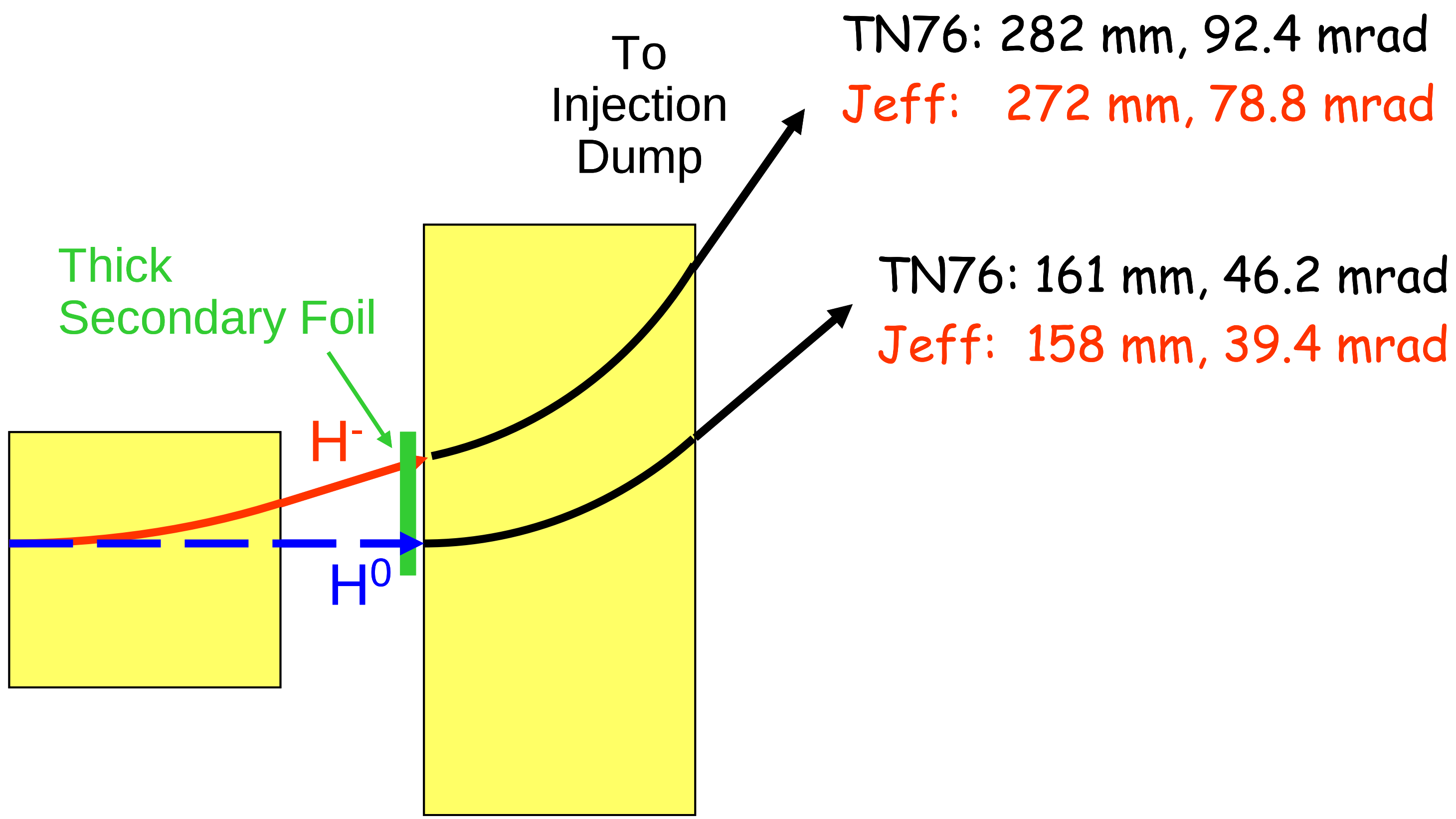
TN76: 42 mrad
Deliv: 42 mrad
Jeff: 42 mrad

TN76: 46.2 mrad
Deliv: 53.1 mrad
Jeff: 53.1 mrad

TN76: 42 mrad
Deliv: 35.6 mrad
Jeff: 28.3 mrad

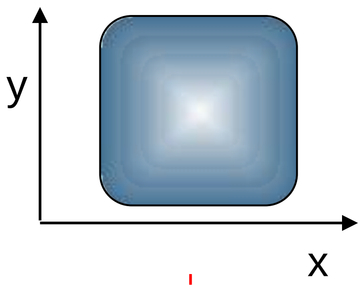
TN76: 46.2 mrad
Deliv: 46.2 mrad
Jeff: 39.4 mrad

H^0 and H^- beams exiting chicane #4

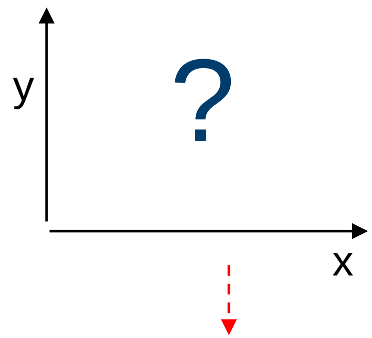


Recap from September AP Talk

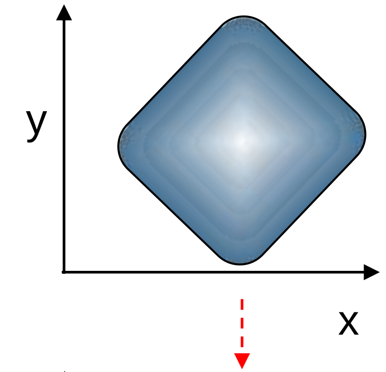
We expected this:

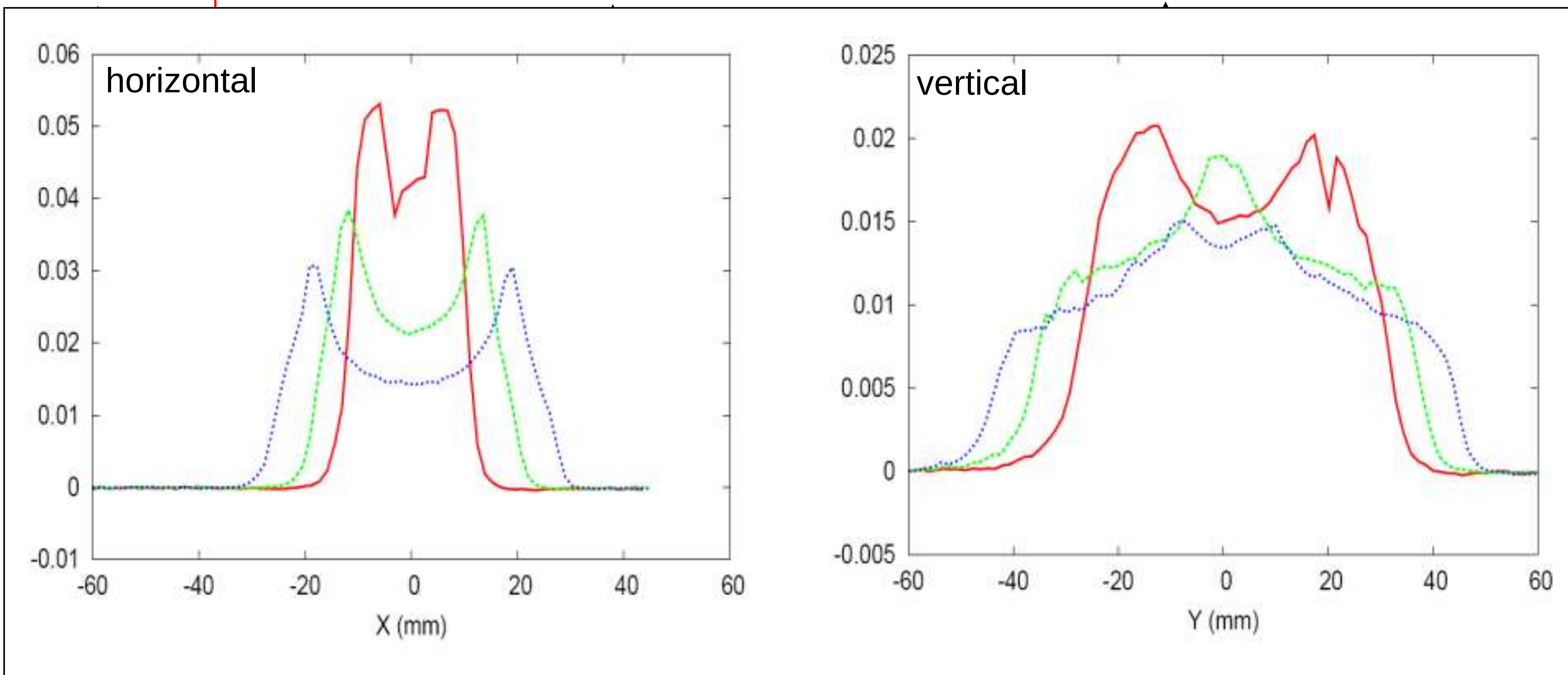


We saw this:



We proposed this:





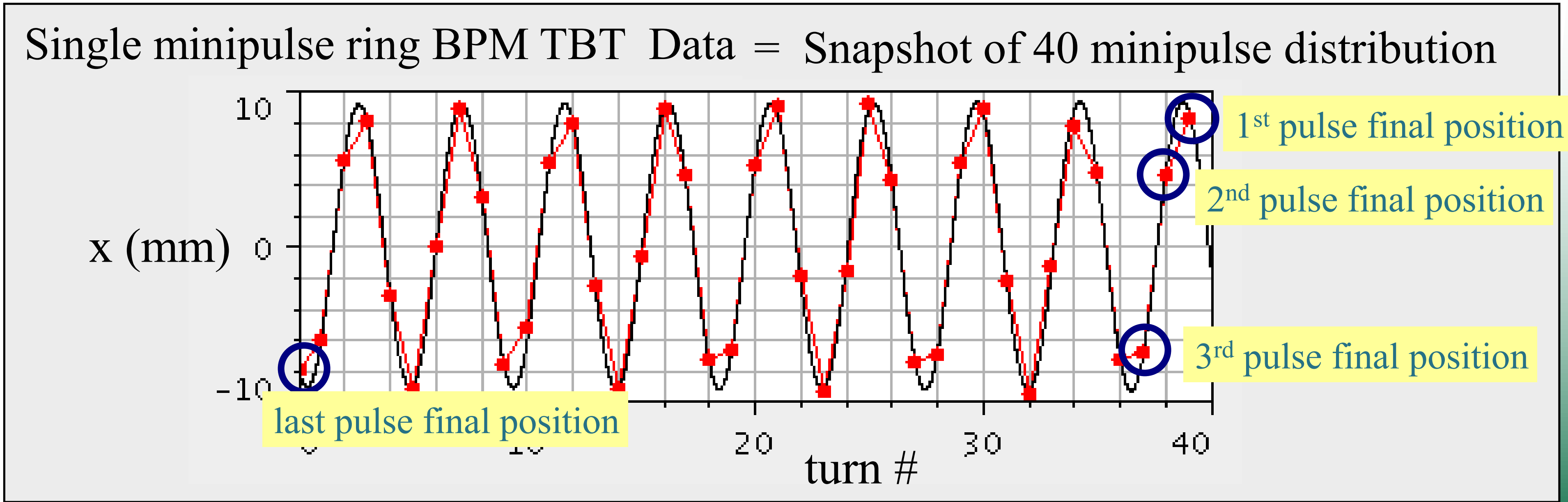
Mini-pulse Motion in the Ring

If we don't paint, then each mini-pulse enters the ring with the same initial position and momentum and experiences the same optics.

- **In the absence of decoherence and collective effects, turn by turn motion of a mini-pulse is well defined and varies predictably with ring tune**
- **For cases with no injection painting, the orbit of each successive mini-pulse is the same as the previous one shifted in phase by one turn**

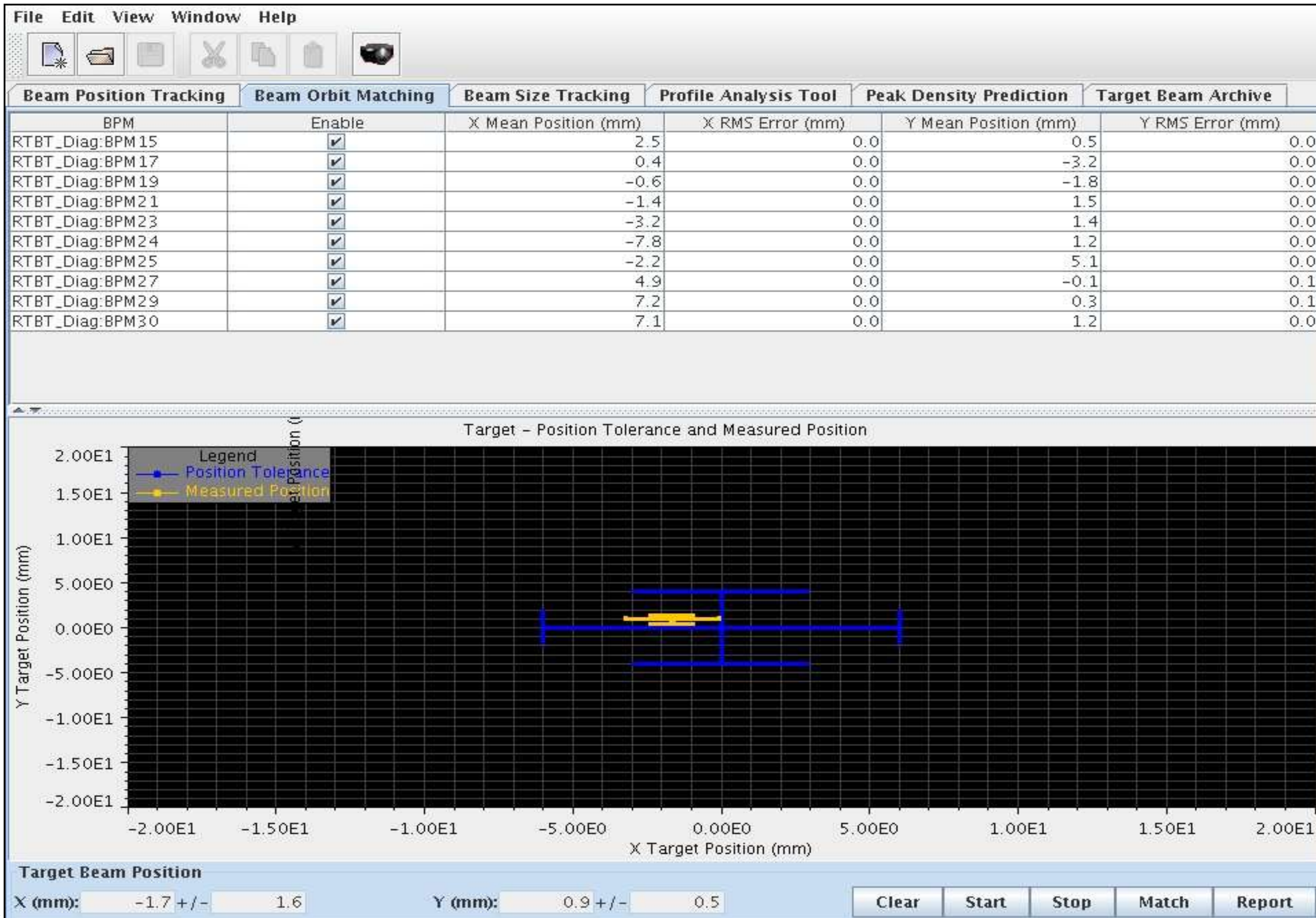
A macro-pulse is an aggregate of minipulses injected sequentially.

- **We can measure the macropulse all at once – as the harp does – or we can measure each piece separately and plot them together at the end.**



Target Beam Position Prediction

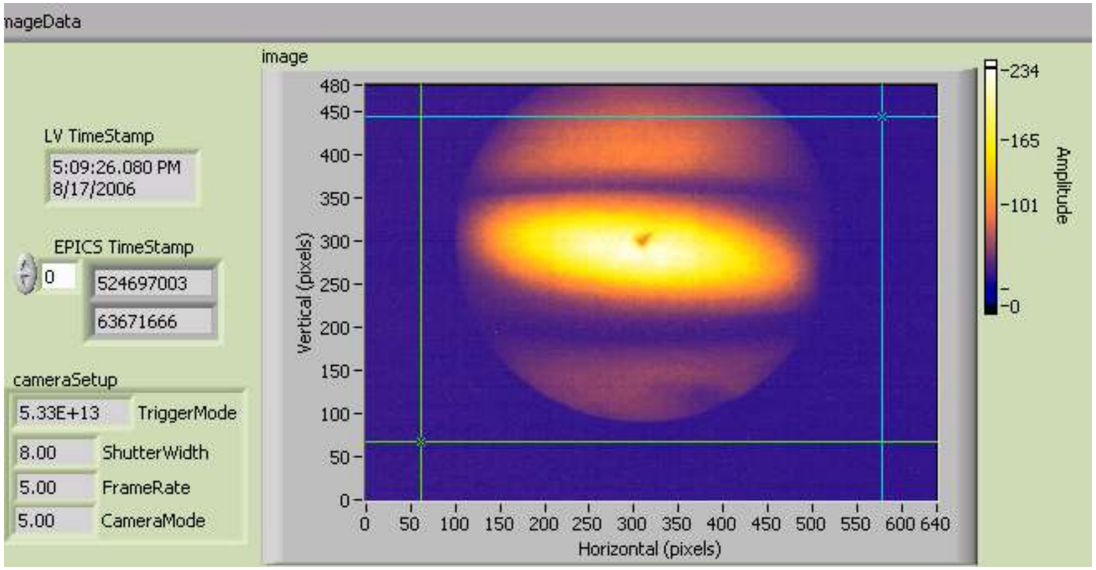
- We use the RTBT BPMs downstream of DH13 to fit the beam trajectory and predict the beam position on the target.
- Method requires slope and offset to match VS data taken in August, 2006.



BPM	Enable	X Mean Position (mm)	X RMS Error (mm)	Y Mean Position (mm)	Y RMS Error (mm)
RTBT_Diag:BPM15	✔	2.5	0.0	0.5	0.0
RTBT_Diag:BPM17	✔	0.4	0.0	-3.2	0.0
RTBT_Diag:BPM19	✔	-0.6	0.0	-1.8	0.0
RTBT_Diag:BPM21	✔	-1.4	0.0	1.5	0.0
RTBT_Diag:BPM23	✔	-3.2	0.0	1.4	0.0
RTBT_Diag:BPM24	✔	-7.8	0.0	1.2	0.0
RTBT_Diag:BPM25	✔	-2.2	0.0	5.1	0.0
RTBT_Diag:BPM27	✔	4.9	0.0	-0.1	0.1
RTBT_Diag:BPM29	✔	7.2	0.0	0.3	0.1
RTBT_Diag:BPM30	✔	7.1	0.0	1.2	0.0

Beam profile on the target

- **A temporary view screen mounted to the face of the mercury spallation target provided very useful beam position and distribution information up through August 2006**
- **The beam profile on the target appears to have a tilt of about 3º, possibly due to transverse coupling in the beam transport line**



Beam profile for highest intensity pulse on target to date (5.3×10^{13} ppp)