Commissioning of the SNS Accelerator Systems

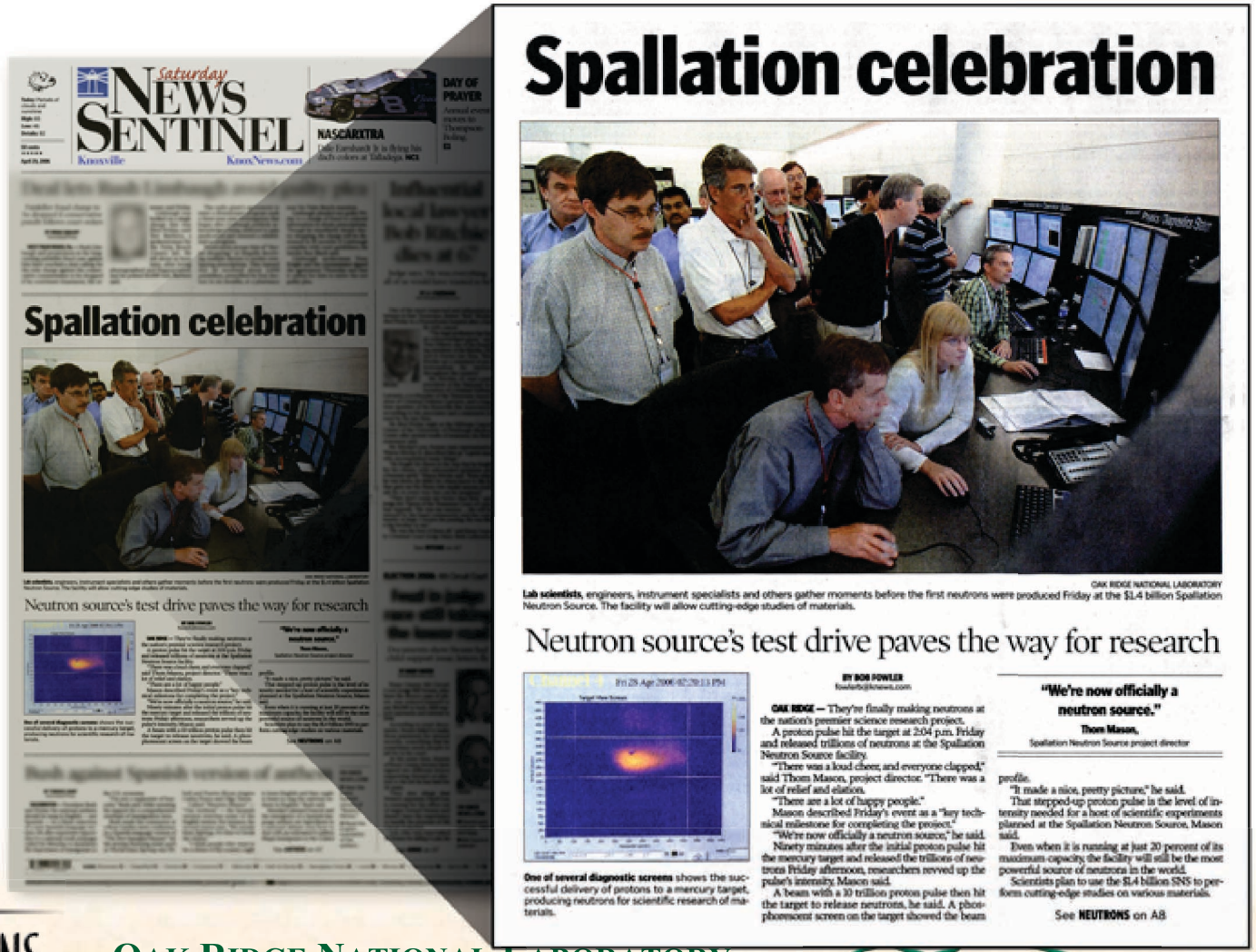
by Michael Plum
on behalf of the commissioning team

PAC2007
Albuquerque, NM
June 25-29, 2007

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

First Beam on Target, First Neutrons and Technical Project Completion Goals Met April 28, 2006

- Beam and Neutronics Project Completion goals were met
  - 10^{13} protons per pulse delivered to the target
- Formal Project Completion in June 2006



Saturday NEWS SENTINEL

Spallation celebration

Neutron source's test drive paves the way for research

Spallation celebration

OAK RIDGE NATIONAL LABORATORY

Lab scientists, engineers, instrument specialists and others gather moments before the first neutrons were produced Friday at the $1.4 billion Spallation Neutron Source. The facility will allow cutting-edge studies of materials.

Neutron source's test drive paves the way for research

BY BOB FOWLER
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OAK RIDGE — They're finally making neutrons at the nation's premier science research project.

A proton pulse hit the target at 2:04 p.m. Friday and released trillions of neutrons at the Spallation Neutron Source facility.

"There was a loud cheer, and everyone clapped," said Thom Mason, project director. "There was a lot of relief and elation.

"There are a lot of happy people."

Mason described Friday's event as a "key technical milestone for completing the project."

"We're now officially a neutron source," he said.

Ninety minutes after the initial proton pulse hit the mercury target and released the trillions of neutrons Friday afternoon, researchers revved up the pulse's intensity, Mason said.

A beam with a 10 trillion proton pulse then hit the target to release neutrons, he said. A phosphorescent screen on the target showed the beam profile.

"It made a nice, pretty picture," he said.

That stepped-up proton pulse in the level of intensity needed for a host of scientific experiments planned at the Spallation Neutron Source, Mason said.

Even when it is running at just 20 percent of its maximum capacity, the facility will still be the most powerful source of neutrons in the world.

Scientists plan to use the $1.4 billion SNS to perform cutting-edge studies on various materials.

See NEUTRONS on A8

One of several diagnostic screens shows the successful delivery of protons to a mercury target, producing neutrons for scientific research of materials.

"We're now officially a neutron source."
Thom Mason,
Spallation Neutron Source project director

Neutron Sciences
HFIR
SNS
SPALLATION NEUTRON SOURCE

SNS Accelerator Complex

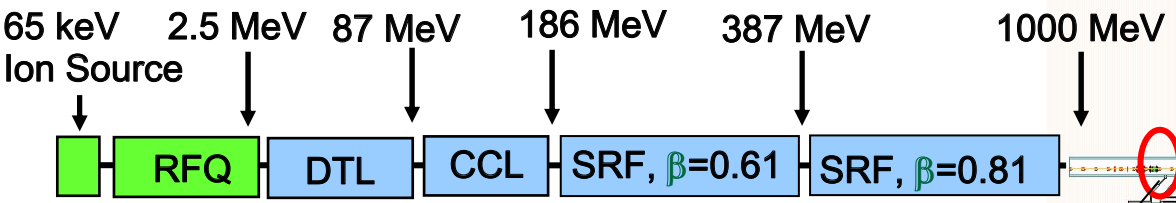
Front-End: Produces a 1-msec long, chopped, H^- beam

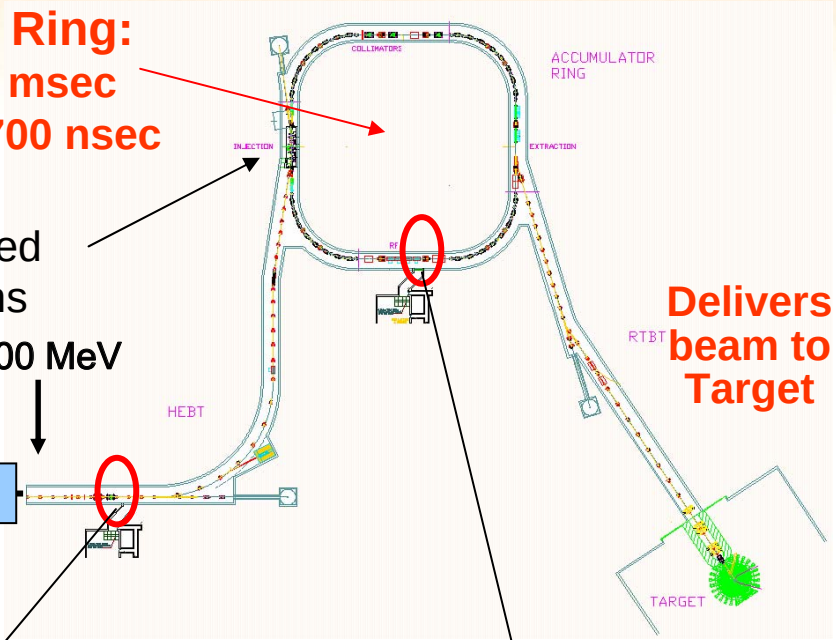
LINAC: Accelerates the beam to 1 GeV

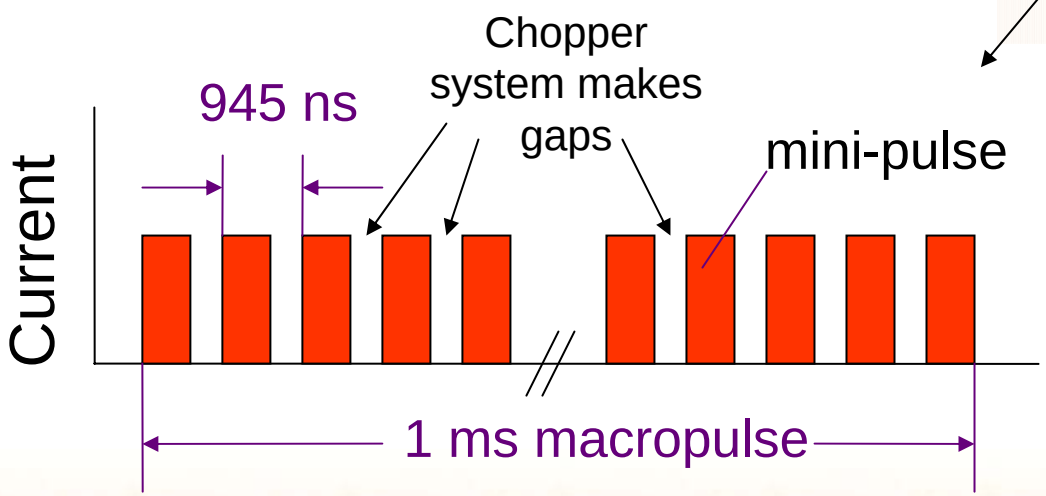
Accumulator Ring: Compresses 1 msec long pulse to 700 nsec

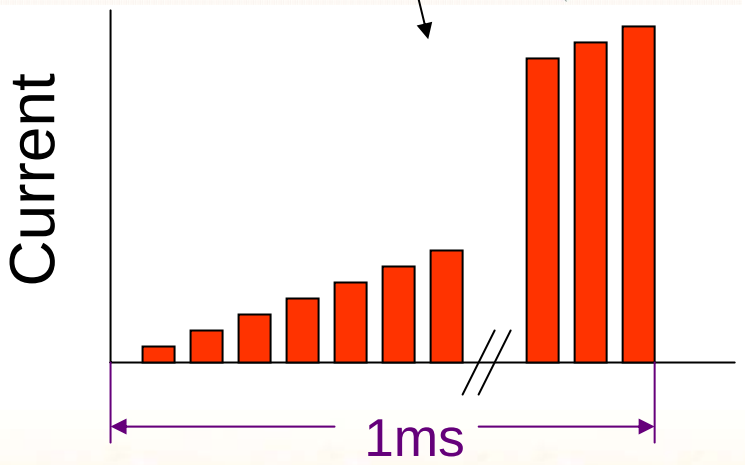
H^- stripped to protons

Delivers beam to Target

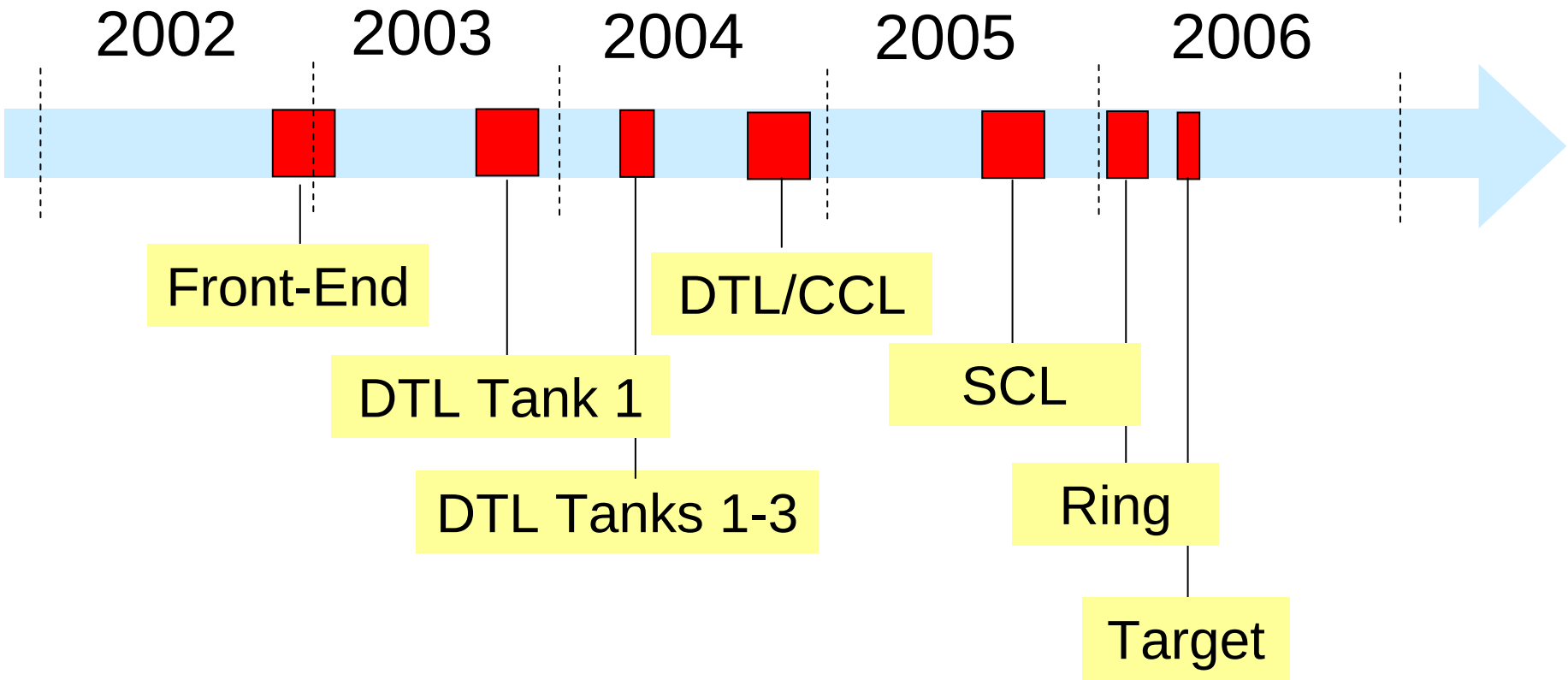








Commissioning Timeline

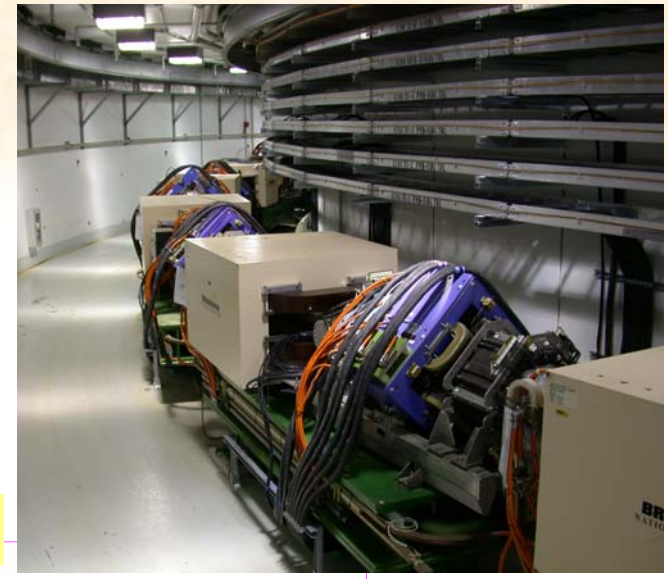


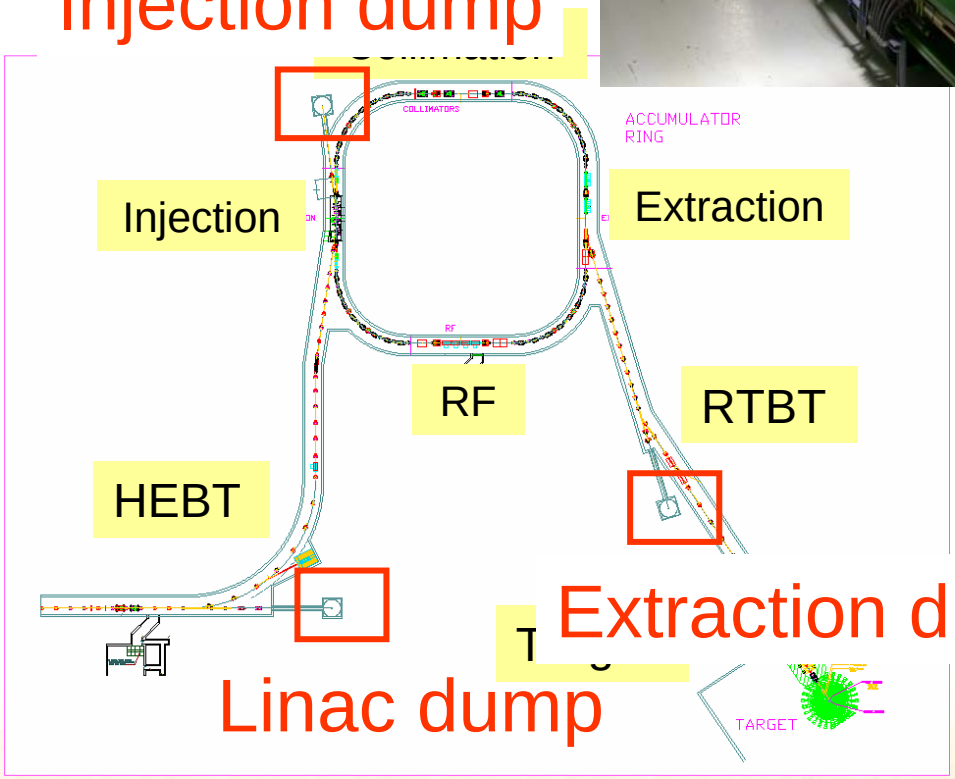
Linac commissioning and operation

- A. Aleksandrov, TUPAS074, ”Performance of the SNS Front End and Linac”
- I. Campisi, WEPMS072, “Status and Performance of the Spallation Neutron Source Superconducting Linac”
- Max beam energy to date is 1.01 GeV (design value is 1.0 GeV)
- Max beam power to date is 90 kW (design value is 1440 kW)
- Max beam rep rate to date is 30 Hz (design value is 60 Hz)
- Now operating with 75 of 81 superconducting RF cavities

Accumulator Ring and Transport Lines

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





Ring/RTBT/Target Commissioning Timeline

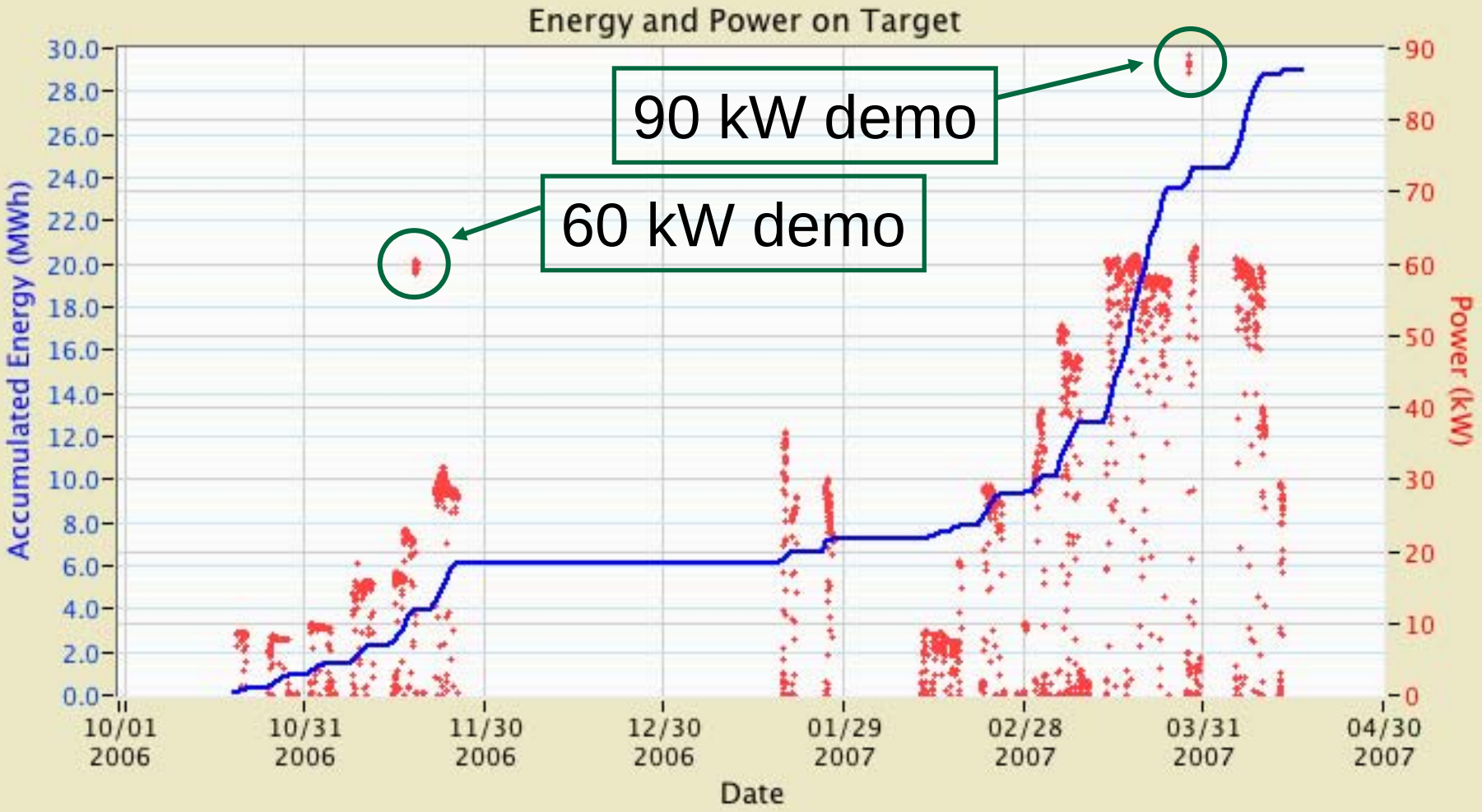
2006:

Jan. 12:	**Received approval for beam to Extraction Dump**
Jan. 13:	**First beam to Injection Dump**
Jan. 14:	**First beam around ring**
Jan. 15:	**>1000 turns circulating in ring**
Jan. 16:	**First beam to Extraction Dump**
Jan. 26:	**Reached 1.26×10^{13} ppp to Extraction Dump**
Feb. 13:	**End of Ring commissioning run**
April 3-7:	**Readiness Review for RTBT/Target**
April 27:	**Received approval for Beam on Target**
April 28:	**First beam on target and CD4 beam demonstration**
Nov 17:	**23.5 kW at 5 Hz to target, making SNS the highest peak flux n source**
Nov. 30:	**Highest stored bunched beam charge to date 15 uC (9.6×10^{13} ppp)**

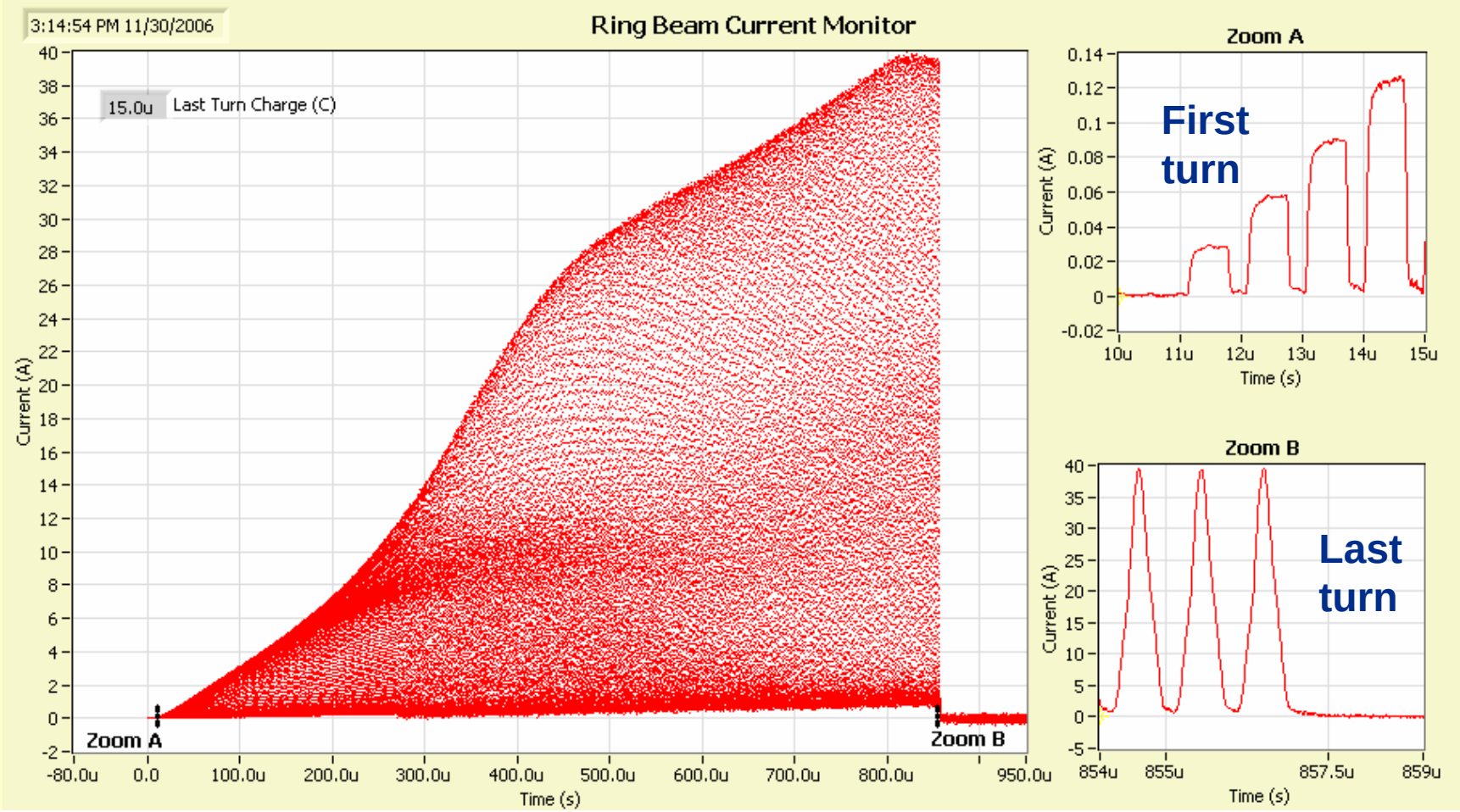
2007:

Feb. 19:	**Highest linac beam energy to date 1010 MeV, new world record**
Mar. 28:	**Highest beam power to date 90 kW at 15 Hz**
Apr. 12:	**Highest beam rep rate to date 30 Hz**

Beam power ramp up



High intensity study: Accumulation of 9.6×10^{13} ppp



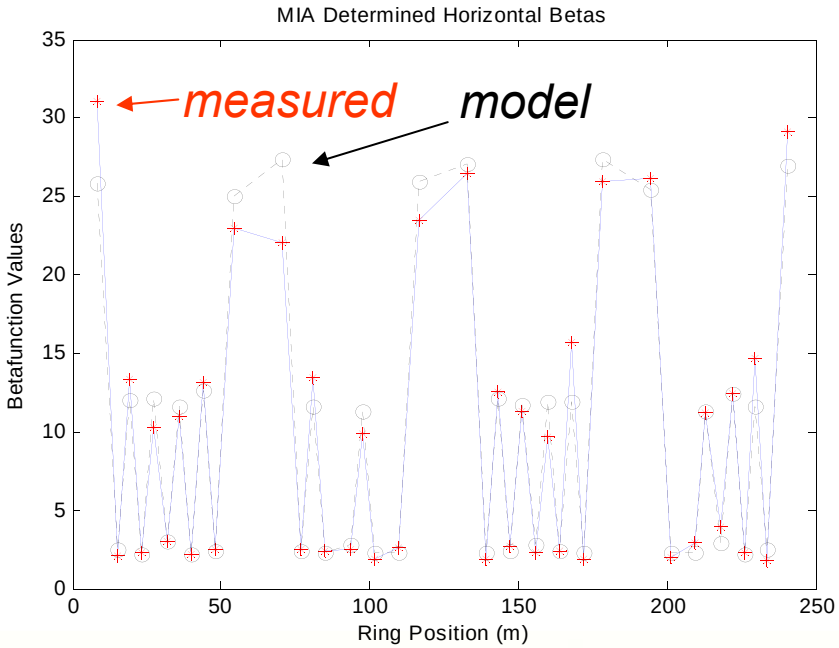
No signs of instabilities observed when stored this beam for 1100 turns

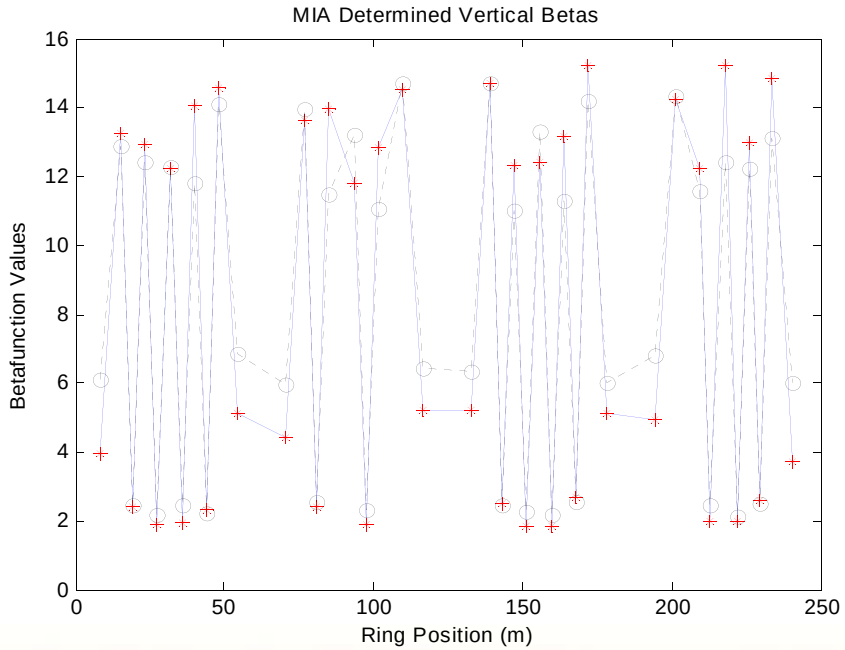
Model independent β fcn measurement (S. Cousineau, S. Thorson)

$$B = USV^T = \sum_{i=1}^{n} \sigma_i u_i v_i^T \quad *$$

temporal matrix (U) eigenvector (S) spatial matrix (V)

Determines β functions with arbitrary scale factor

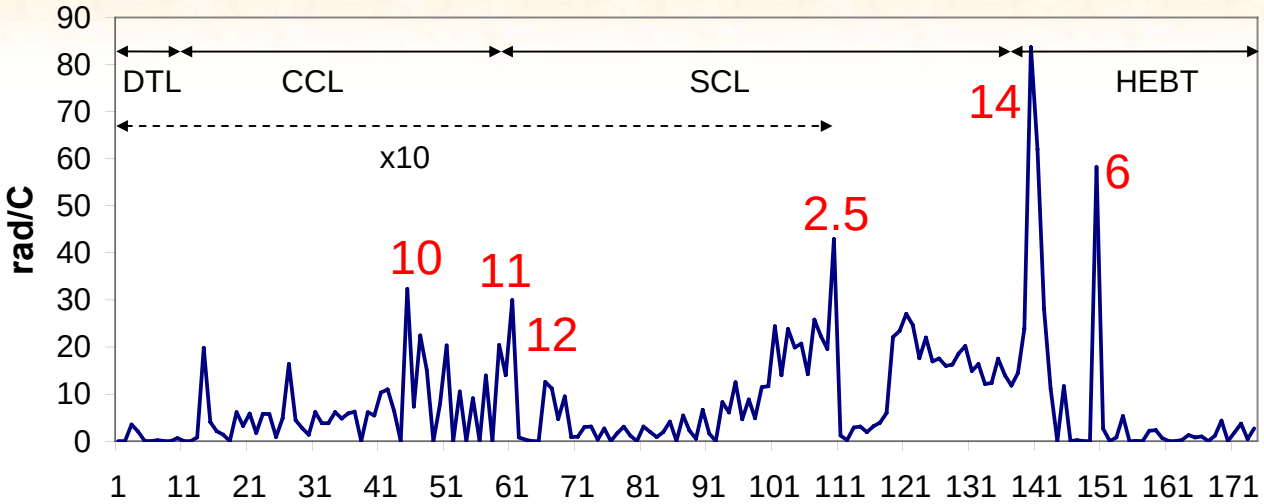




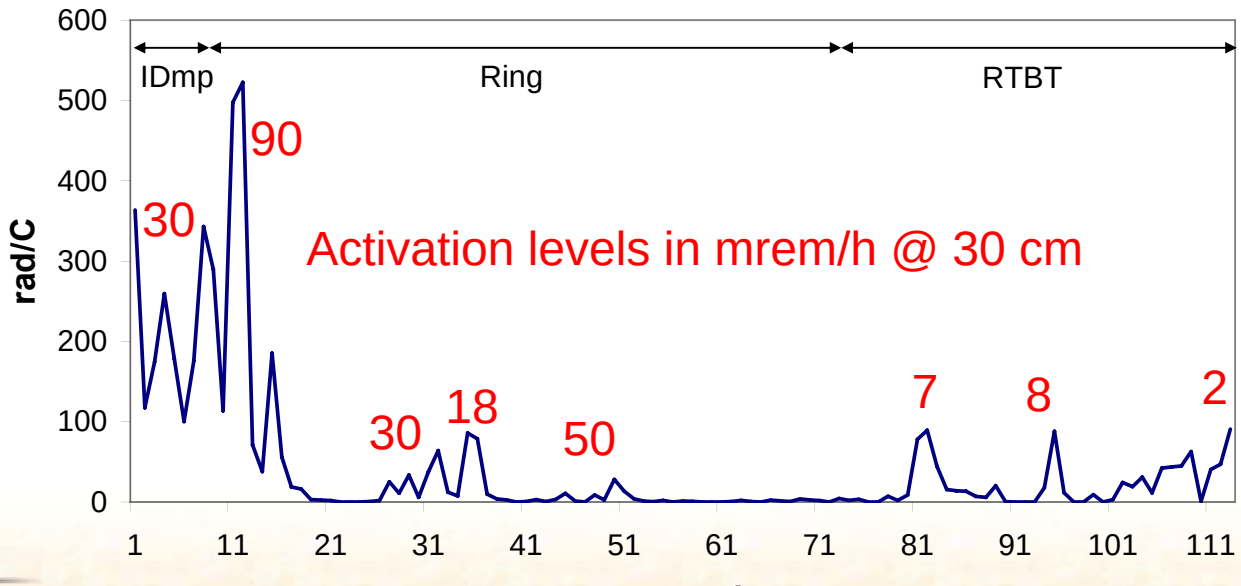
* Wang et al., PRSTAB vol. 6, 104001 (2003)

BLM signals and activation levels

BLM signals and activation levels from a recent 10 day run at 60 kW
(15-25/Mar/07)



Activation levels measured ~29 h after end of production run
(26/Mar/07)



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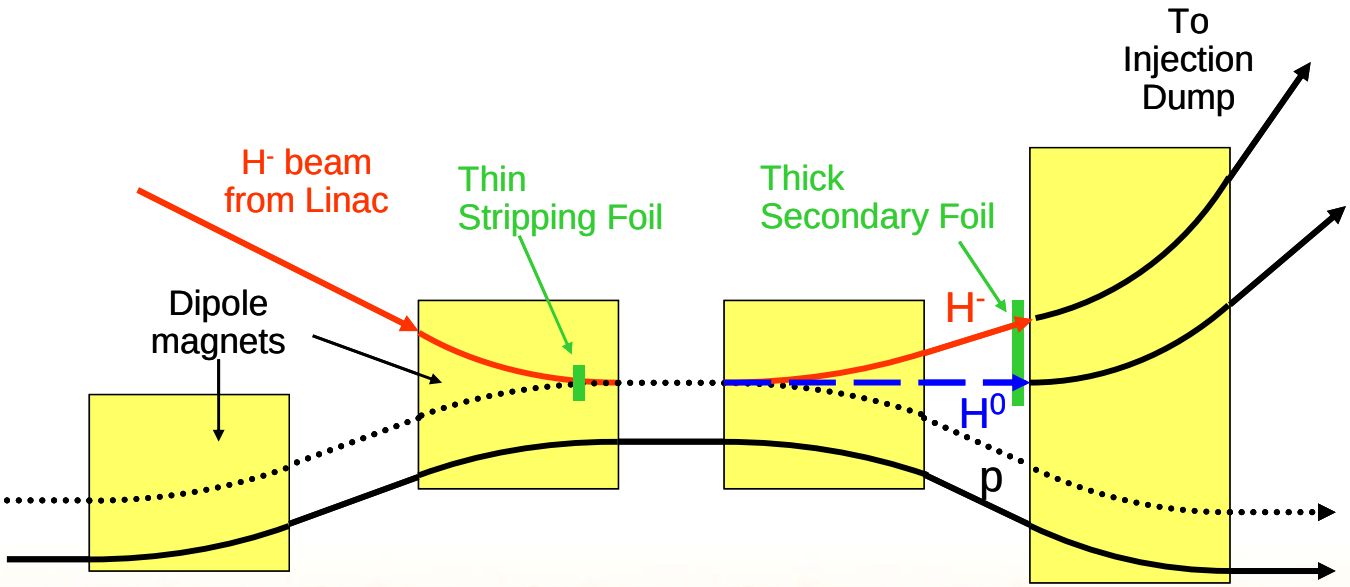
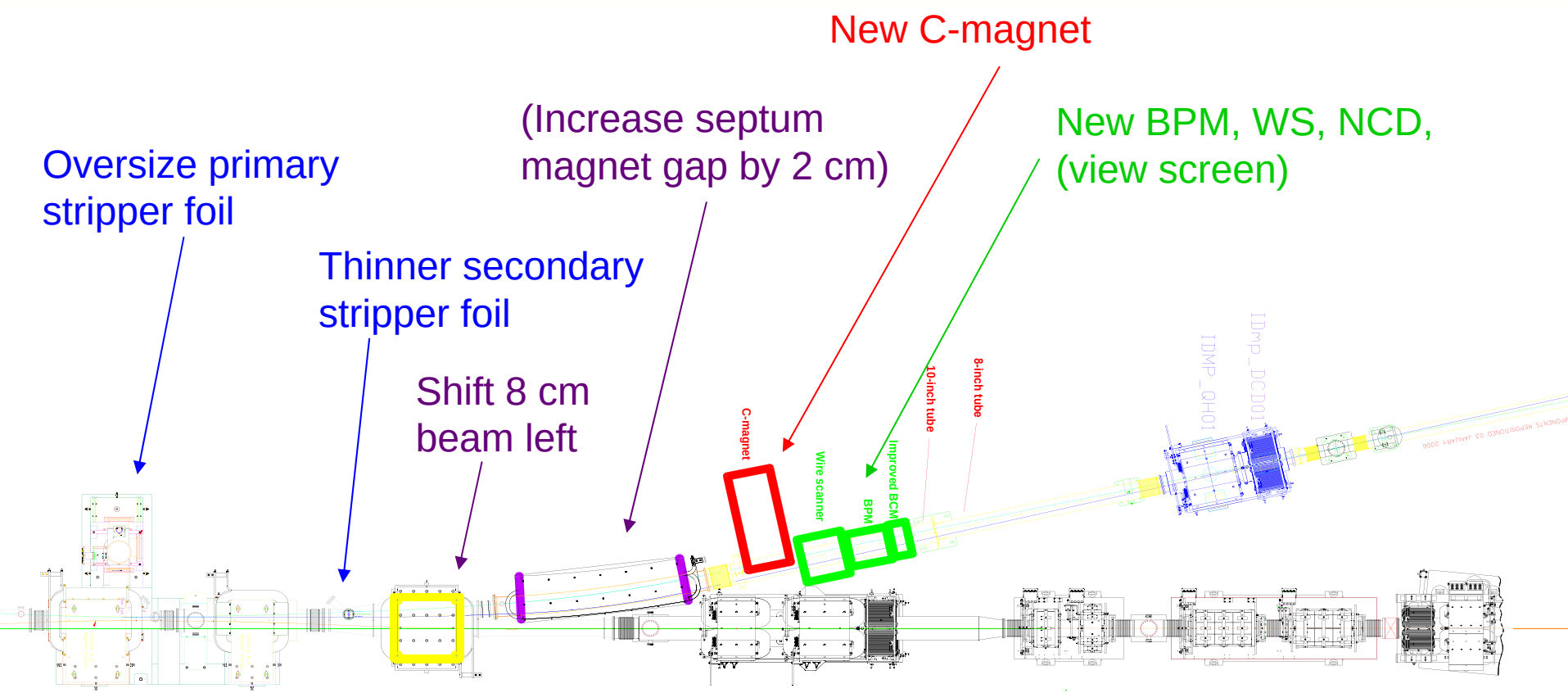
UT-BATTELLE

Issue: Injection dump beam line

- **In 2000 a design change was made in the injection chicane magnet bend angles. This change was not incorporated into the injection dump design. A consequence is that we do not have good transmission of the H^0 and H^- waste beams.**
- **Re-design of the injection dump beam line is in progress**

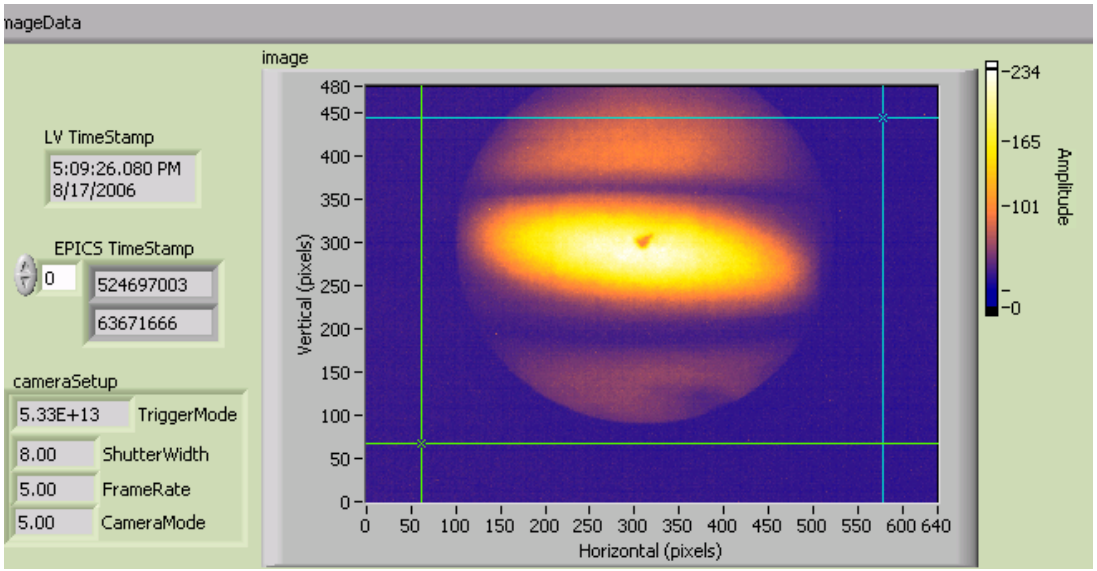


Short and mid-term inj. dump line modifications



Issue: Beam profile on the target

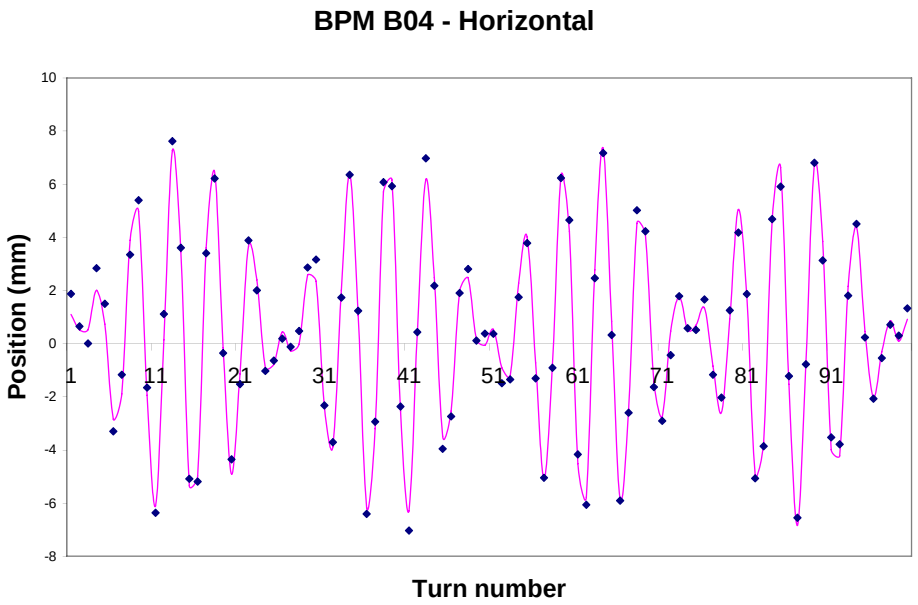
- **A temporary view screen mounted to the face of the mercury spallation target provided very useful beam position and distribution information up through August 2006**
- **The beam profile on the target appears to have a tilt of about 3º, possibly due to transverse coupling in the beam transport line**

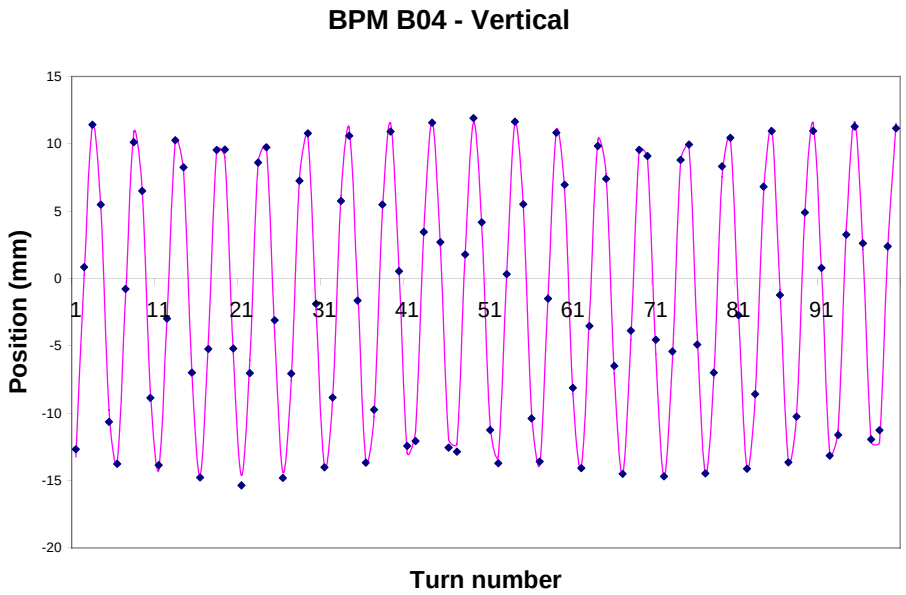


Beam profile for highest intensity pulse on target to date (5.3×10^{13} ppp)

Issue: transverse coupling in Ring

- **Measure transverse coupling by injecting a single minipulse with a large vertical offset and small horizontal offset relative to the closed orbit.**





Transverse coupling (cont.)

- **Following formalism of D. Sagan & D. Rubin (e.g. PRSTAB 074001 (1999))**

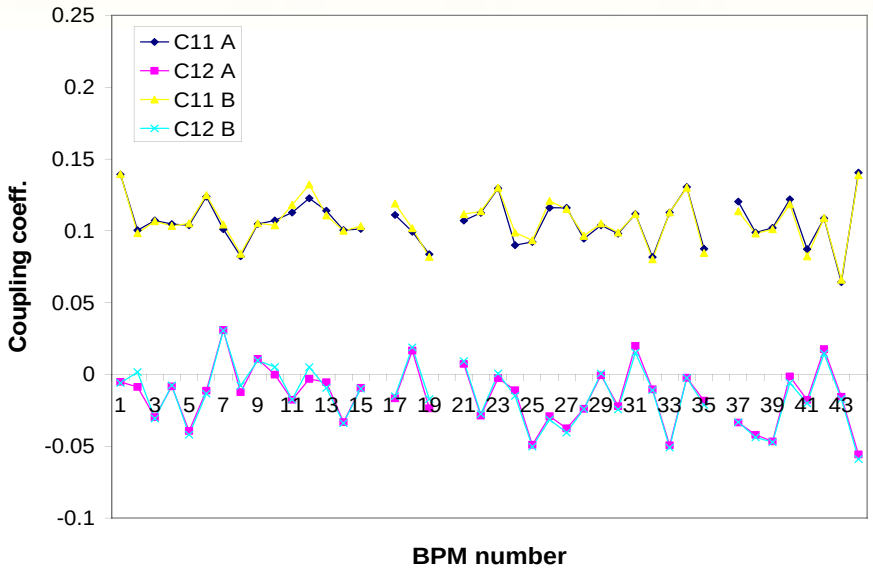
$$\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} A_x\sqrt{\beta_x}\cos\psi_x + A_y\sqrt{\beta_x}(\overline{C_{11}}\cos\psi_y - \overline{C_{12}}\sin\psi_y) \\ -A_x\sqrt{\beta_y}(\overline{C_{22}}\cos\psi_x + \overline{C_{12}}\sin\psi_x) + A_y\sqrt{\beta_y}\cos\psi_y \end{pmatrix}$$

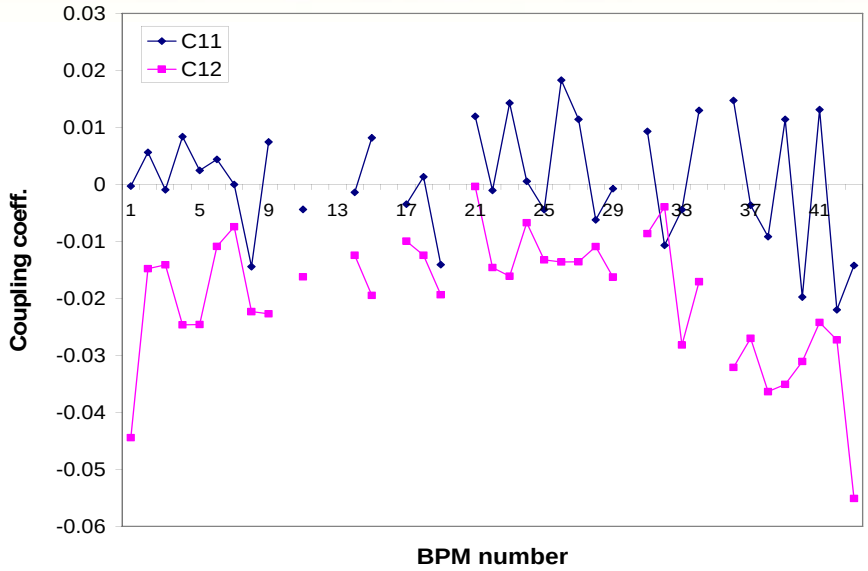
$\psi = n\omega + \phi$

$\overline{C_{11}}$ = amount of in-phase oscillations coupled in from the vertical plane. $|\overline{C_{11}}| \leq 1$.

$\overline{C_{12}}$ = amount of out-of-phase oscillations coupled in from the vertical plane. $|\overline{C_{12}}| \leq 1$.

Measured and corrected coupling coeff.





Before correction

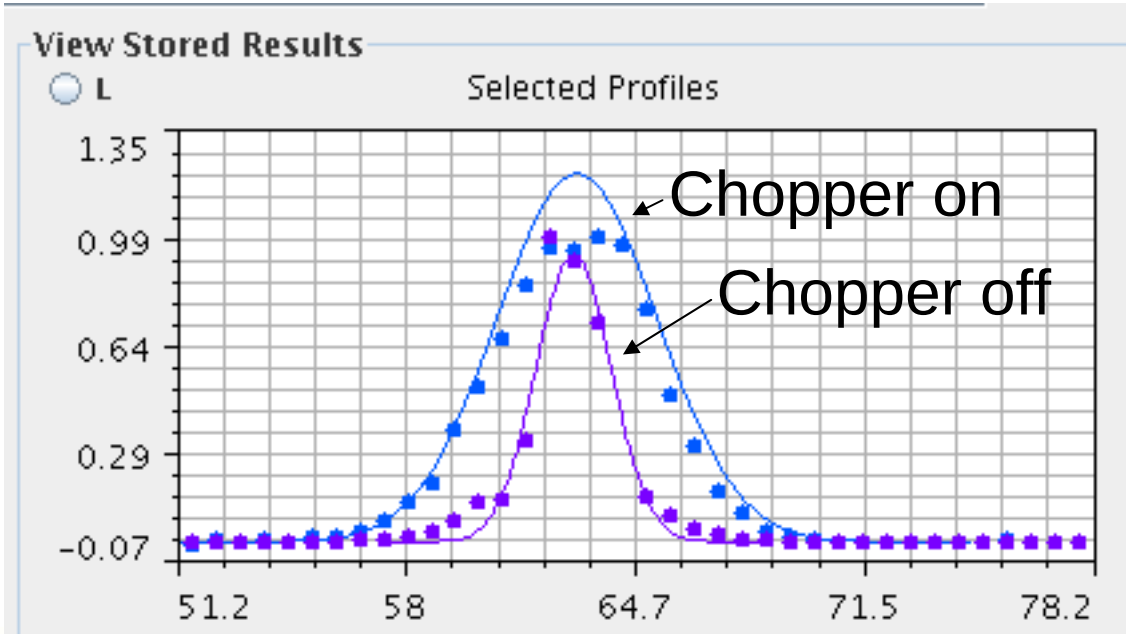
After correction

(6 vert. skew quadrupole correctors set to 4.7 A)

Residual coupling is not a problem at this time

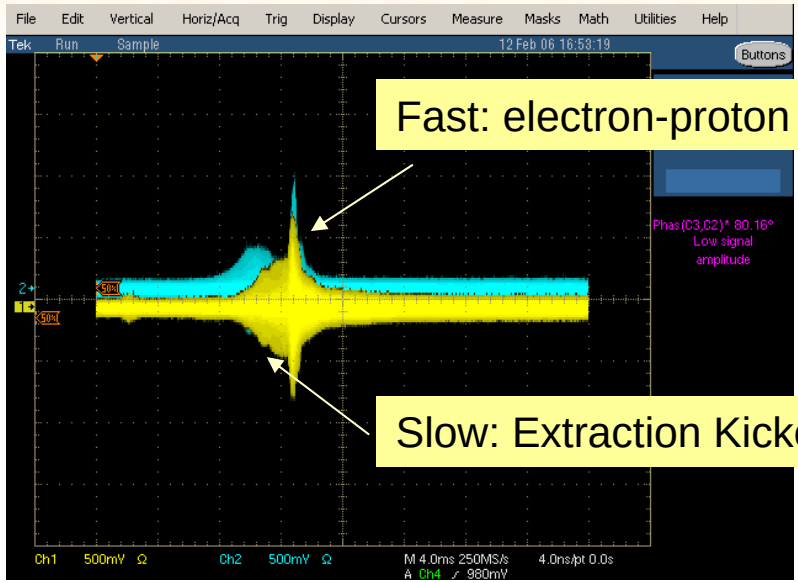
Issue: Effect of degraded LEBT chopper

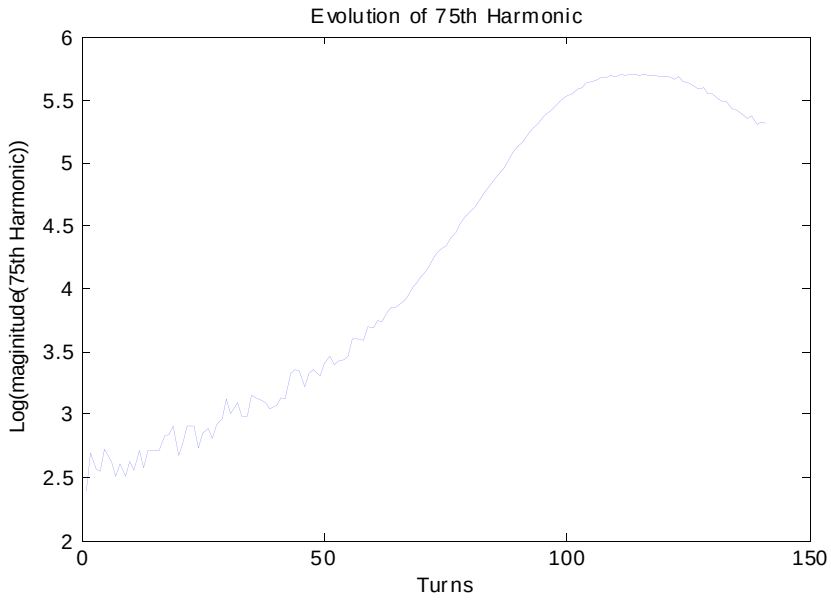
- Increased resistor values installed in LEBT chopper in January 2007 to protect chopper from arcs in ion source lenses
- Causes significant increase in effective beam size



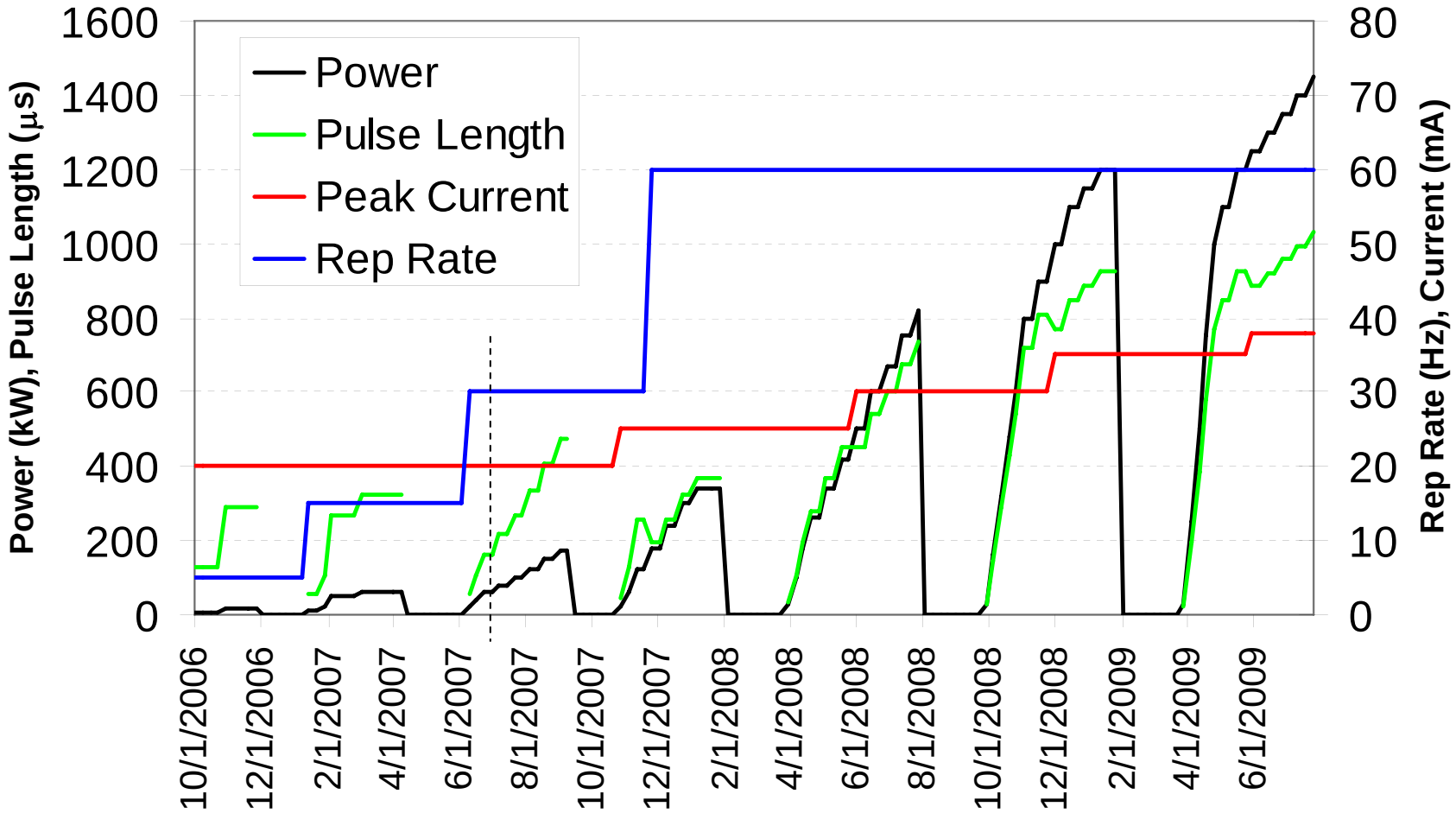
High intensity study: Instabilities

- **No instabilities seen thus far in "normal" conditions**
- **We searched for instabilities by i) delaying extraction, ii) operating with zero chromaticity, iii) storing a coasting beam**
- **First instability observed with central frequency 6 MHz, growth rate 860 μs, for 10^{14} ppp driven, as expected by extraction kicker impedance**
  - Z_{calc} ~22-30 kOhm/m
  - Z_{meas} ~28 kOhm/m
- **Scaling these observations to nominal operating conditions predicts threshold > 2 MW for extraction kicker (as previously predicted)**
- **In coasting beam see very fast instability at 0.2-1x10^{14}, consistent with e-p.**
  - Growth rate 20-200 turns
  - f ~30-80 MHz depending on beam conditions





Beam power ramp up plan



Summary

- Commissioning was completed in 7 beam runs, amounting to more than 1 year of dedicated beam commissioning and operating time
- Achieved beam and neutron project completion requirements within project schedule and within budget
- Major beam quality goals have been met
- Some of the issues we faced during ring commissioning:
  - tilted beam at the target
  - transverse coupling in the Ring
  - waste beam transmission in the ring injection dump beam line
  - beam loss
- We are working to ramp up the beam power of the SNS accelerator complex, with a short-term goal of 180 kW on target by September 2007