Beam Intensity Challenges at the Spallation Neutron Source



August 25, 2008

42nd ICFA Advanced Beam Dynamics Workshop on High-Intensity, High-Brightness Hadron Beams

Nashville TN, USA

J. Galambos – on behalf of the SNS team

SNS Accelerator Complex

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

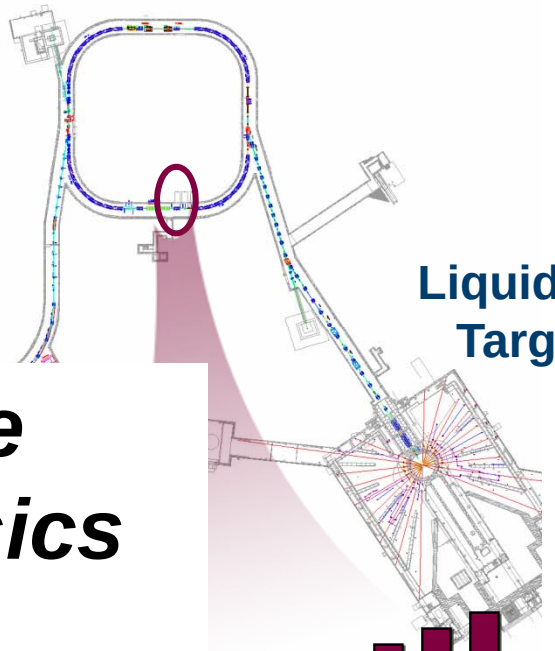
Accumulator Ring:
Compress 1 msec long pulse to 700 nsec

1 GeV LINAC

2.5 MeV

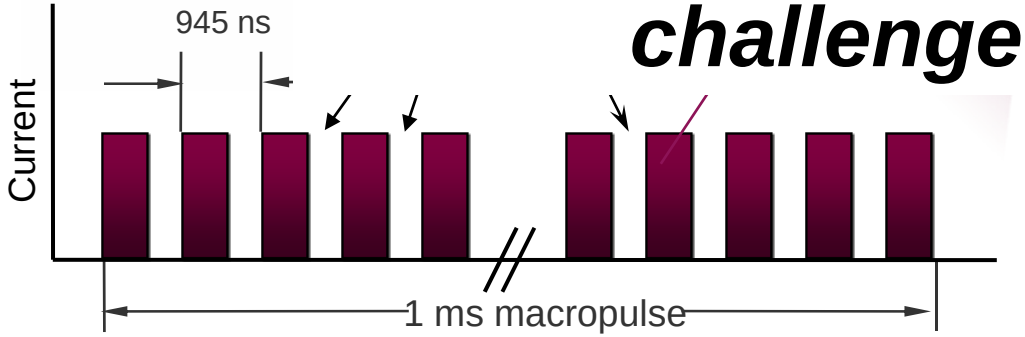
1000 MeV

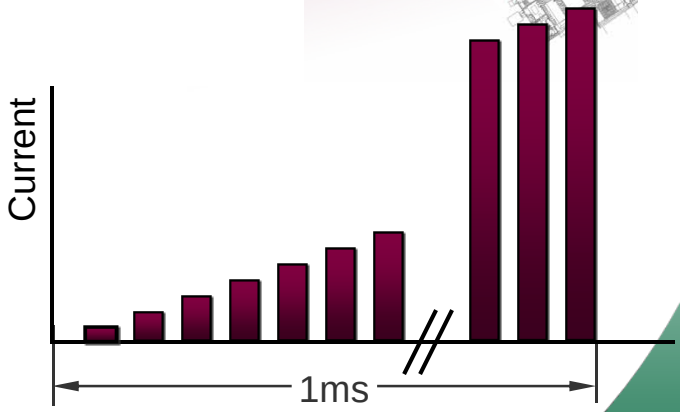




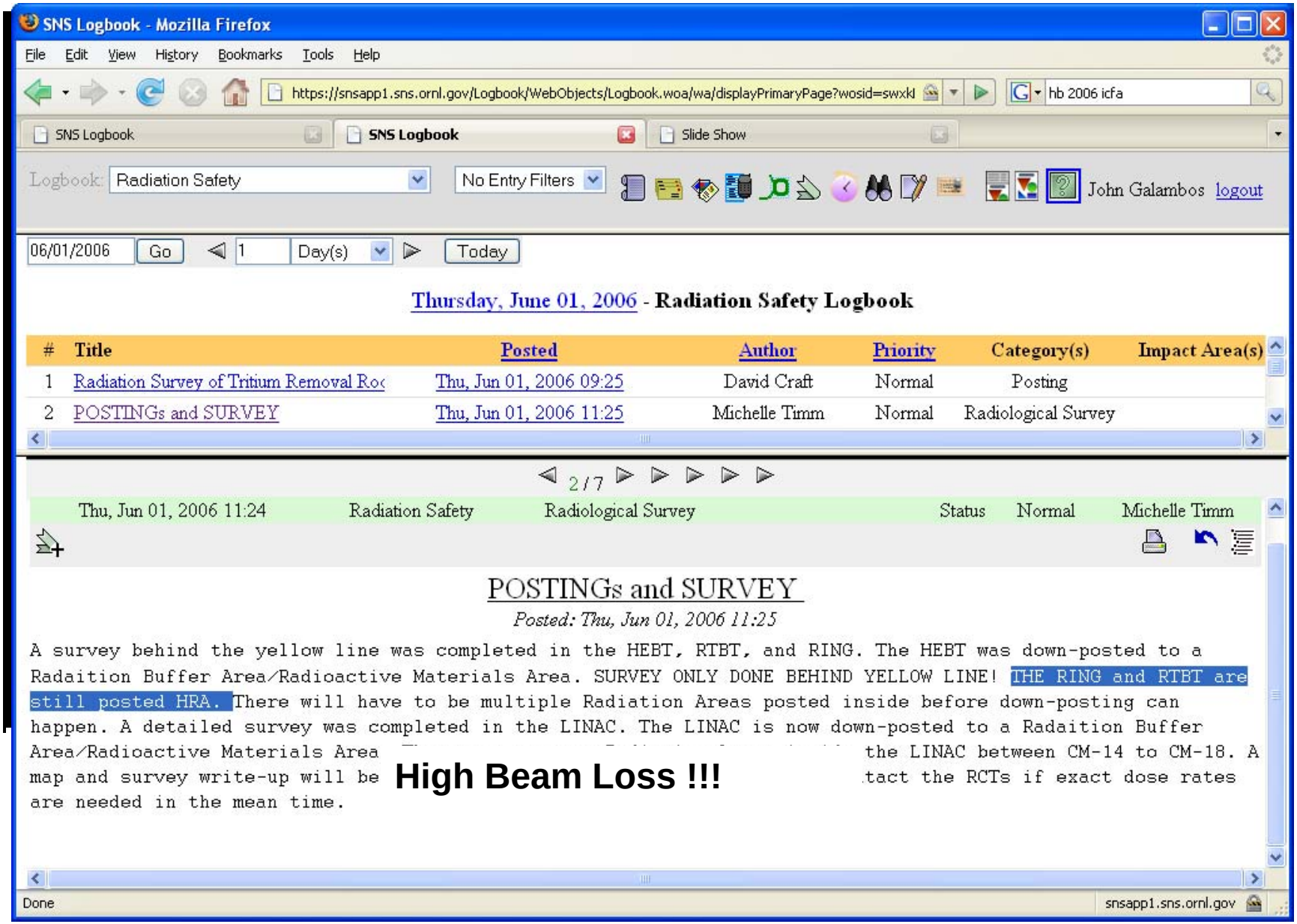
Liquid Hg Target

Beam Loss is the primary beam physics challenge

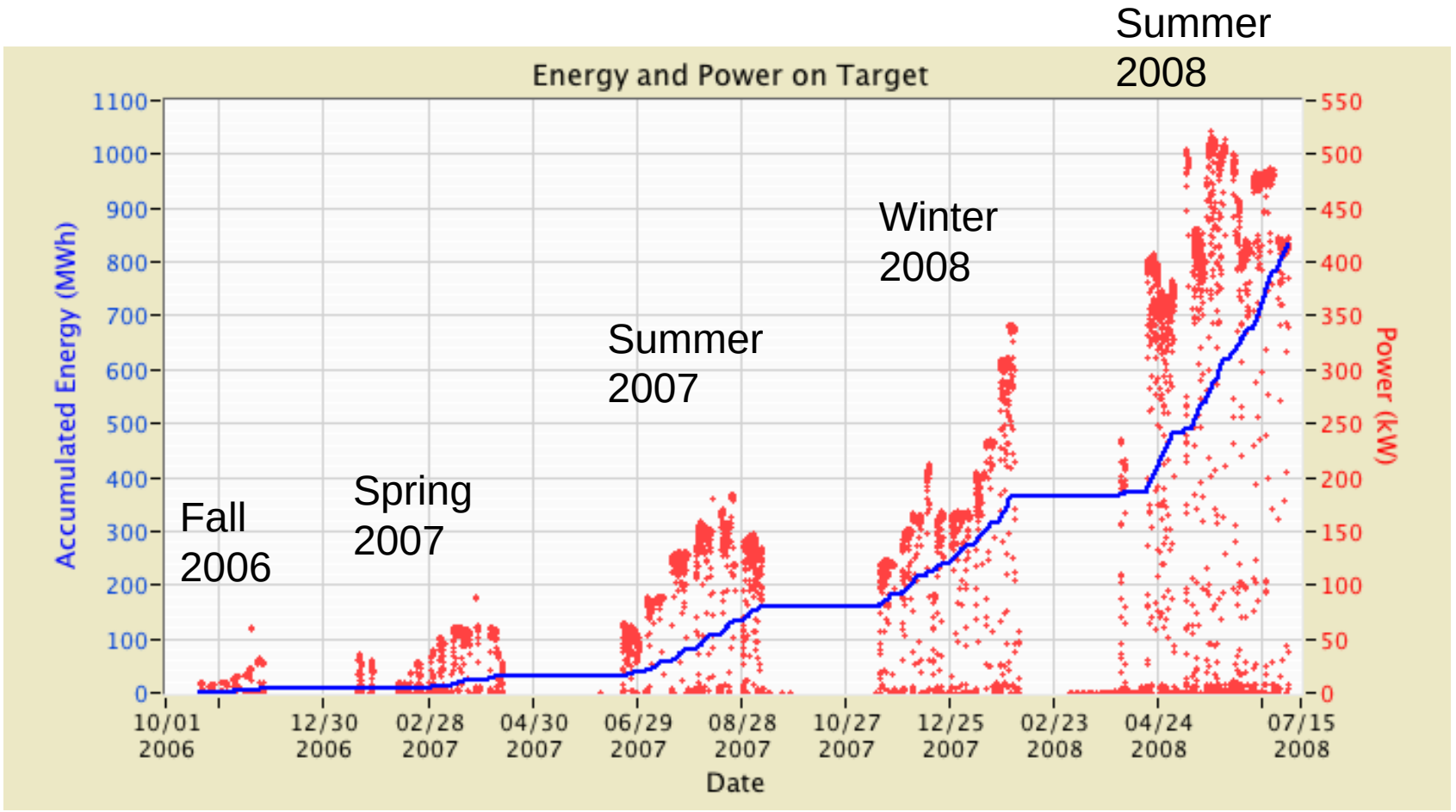




May 29 2006: An Important Date!



Power Ramp-up: 0.5 MW to date

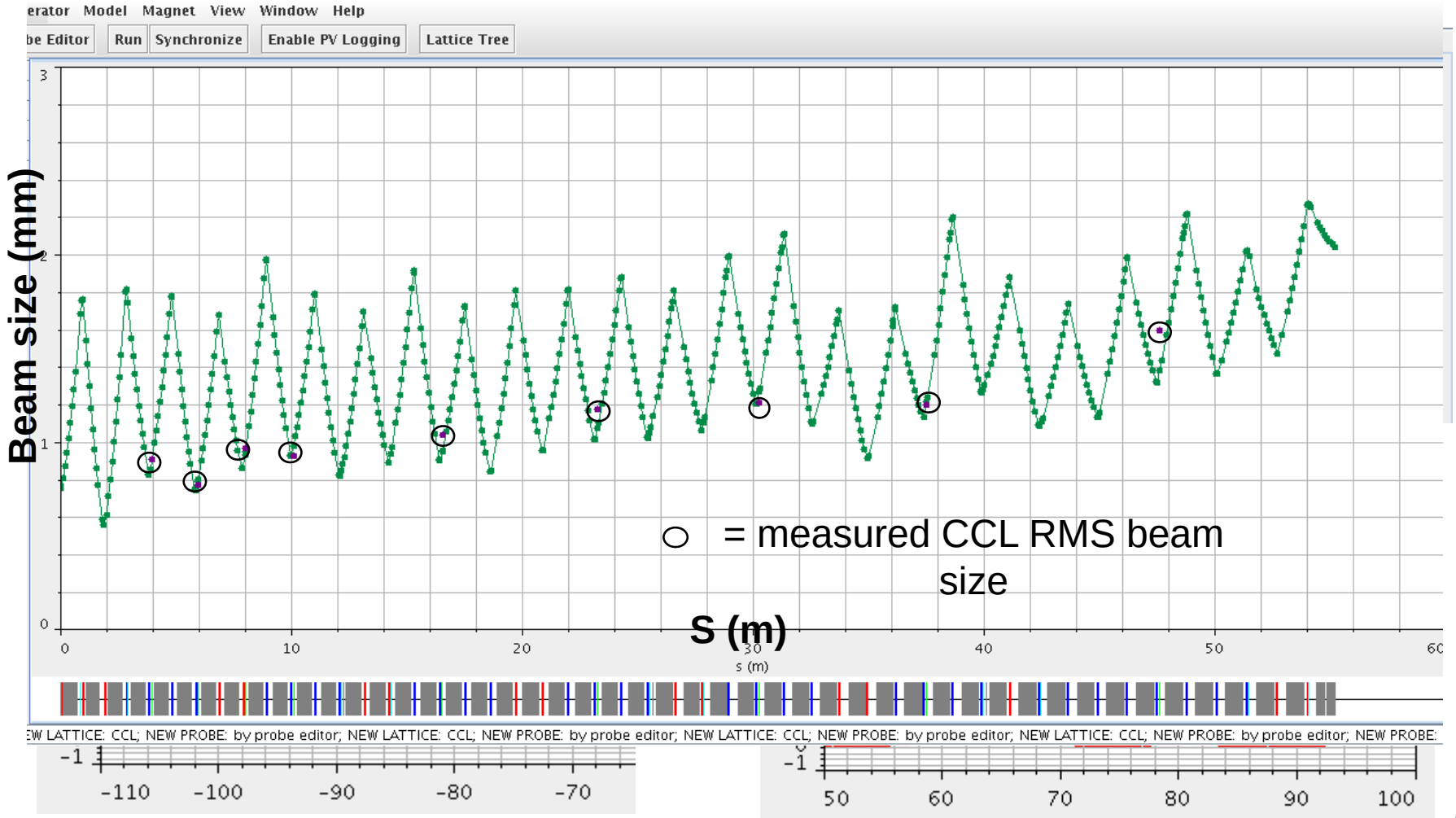


- **Did manage some increase in the beam power the past 2 years**

High Level Beam Parameters Achieved

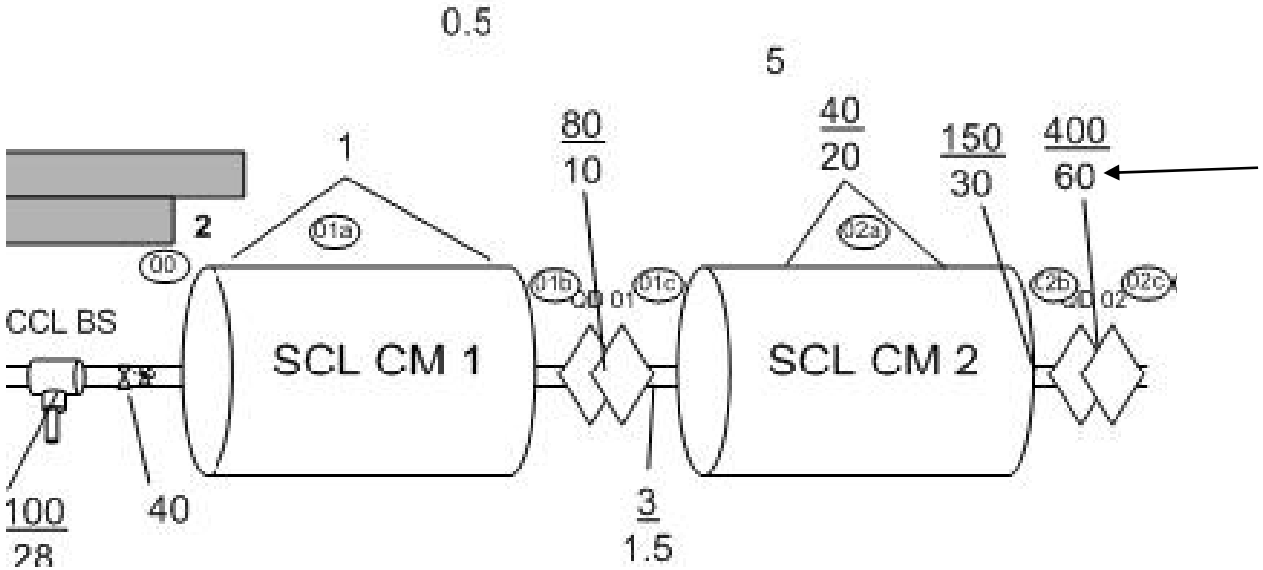
	Design	Best Ever (Not Simultaneous)	Highest Power Run (Simultaneous)
Pulse Length (μSec)	1000	1000	600
Beam Energy (MeV)	1000	1010	890
Peak Accelerated Current (mA)	38	40	32
Average Accelerated Current (mA)	26	22	17
Repetition Rate (Hz)	60	60	60
Beam Power (kW)	1440	520	540

Linac Beam Quality – Transverse Profiles



- **Beam transverse profiles looks clean at exit of warm linac (Gaussian / halo free)**
  - **To the resolution of wire scans**
- **Measured optics are close to that expected with online-model (except 33% increased emittance) using design quadrupole settings**
- **In practice we perturb quadrupoles a few percent to reduce beam loss**

There is Beam Loss in the Superconducting Superconducting Linac Warm Sections (*Galambos, Popova WG-D*)



Residual dose rate at 30 cm, 24hrs. after production run

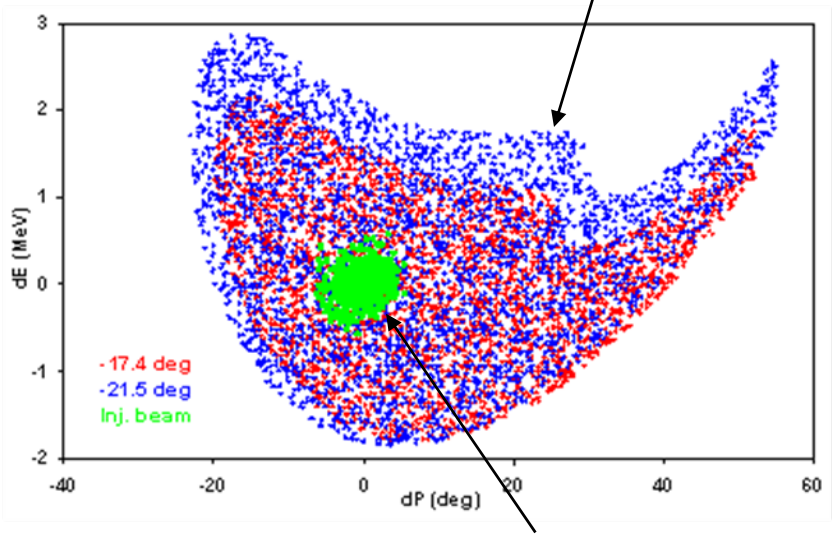
- **Activation became noticeable as beam power exceeded ~ 50 kW**
- **Moved BLMs closer to beam pipe to observe the loss**
- **Where is it coming from: leading candidate is longitudinal tails**
  - **More sensitive to warm linac RF settings than quadruple settings**
- **Loss is greater than expectation, which was close to zero**
  - **Residual activation is not limiting maintenance – but equipment robustness to radiation is a concern**

Fractional Beam Loss Measurements
(Galambos WG-D, Joint WG D-F, Zhukov – WG-C)

- **Design criteria is 1W/m uncontrolled beam loss**
  - **At 1 MW: 10^{-6} fractional beam loss/m**
- **The Challenge: spill a small amount of beam (<< 10^{-3} of a full production pulse), near Beam Loss Monitors, in a similar way as loss occurs during production**
- **Superconducting Linac: < 2x10^{-6} beam / warm section**
  - **Medium β: uncertainty $\pm$ factor of 3**
  - **High β: uncertainty $\pm$ factor of 2**
- **Ring Injection: < 6x10^{-4}**
  - **Close to expected loss fraction for operational conditions**

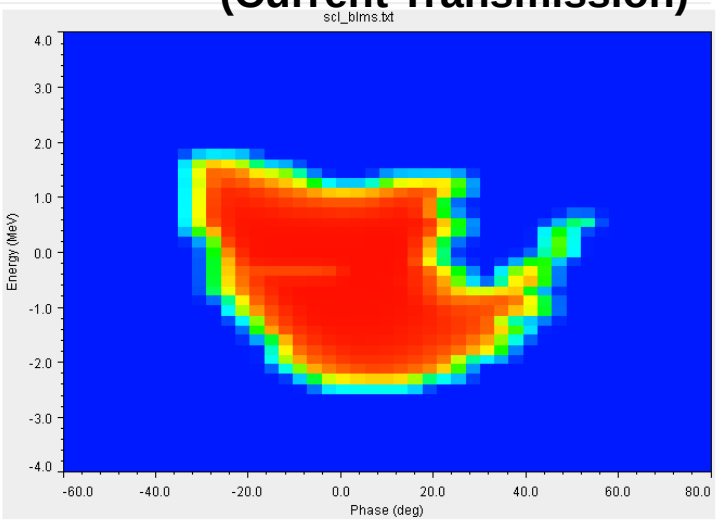
SCL Longitudinal Acceptance
(Y. Zhang, WG-B)

Model Predicted Acceptance

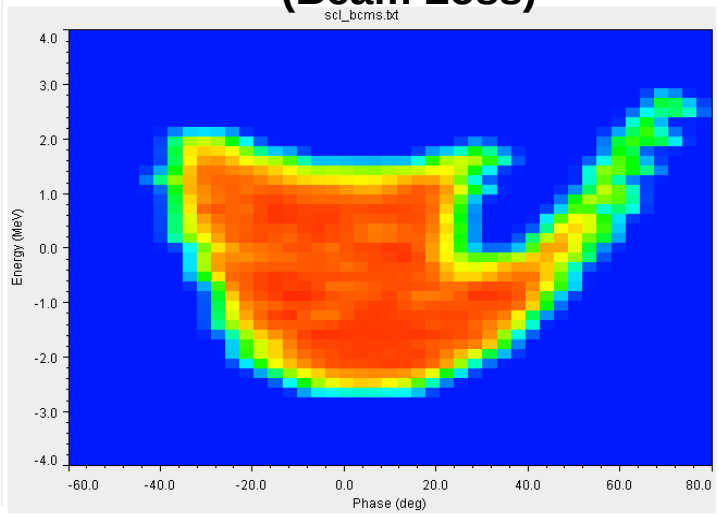


Model beam emittance

Measured Acceptance (Current Transmission)

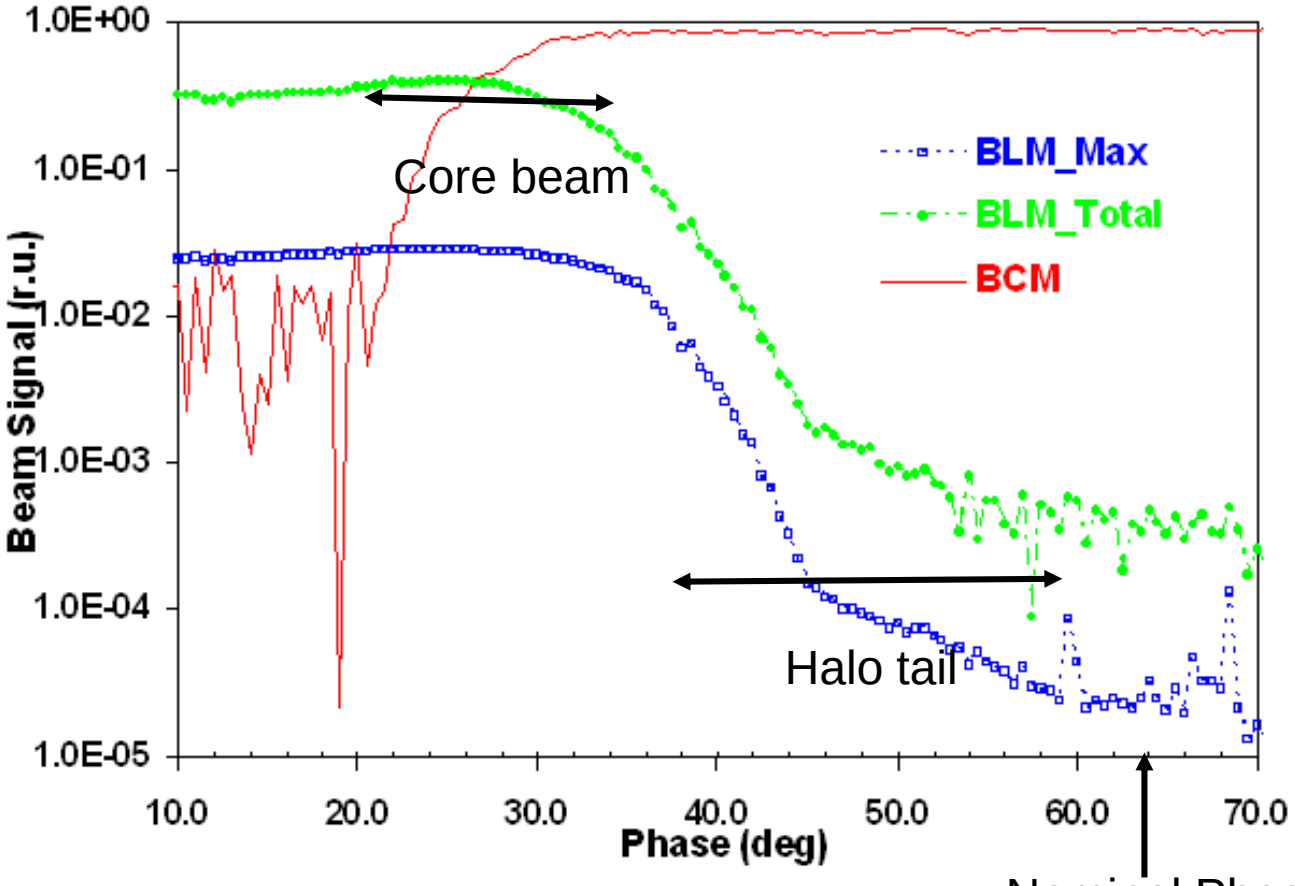


Measured Acceptance (Beam Loss)



- **Beam should fit well into the nominal acceptance**
- **SCL Longitudinal Acceptance measurement indicates normal acceptance**

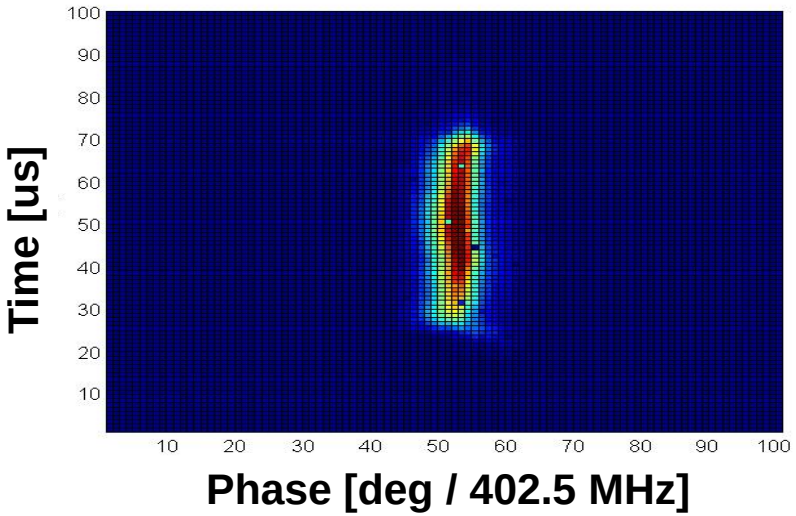
Flexible SCL RF Set-up Facilitates Scans in Phase and Amplitude *(Y. Zhang)*

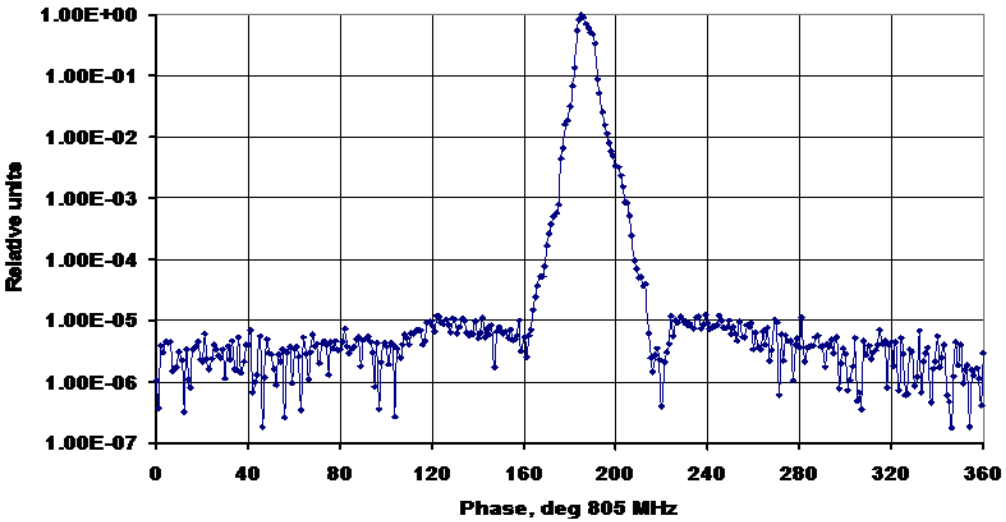


- **Independently powered SCL cavities facilitates model based scans in phase and energy**
- **Used to construct longitudinal acceptance measurements**
- **Indicates the possibility of longitudinal halo**

Bunch Shape Measurement

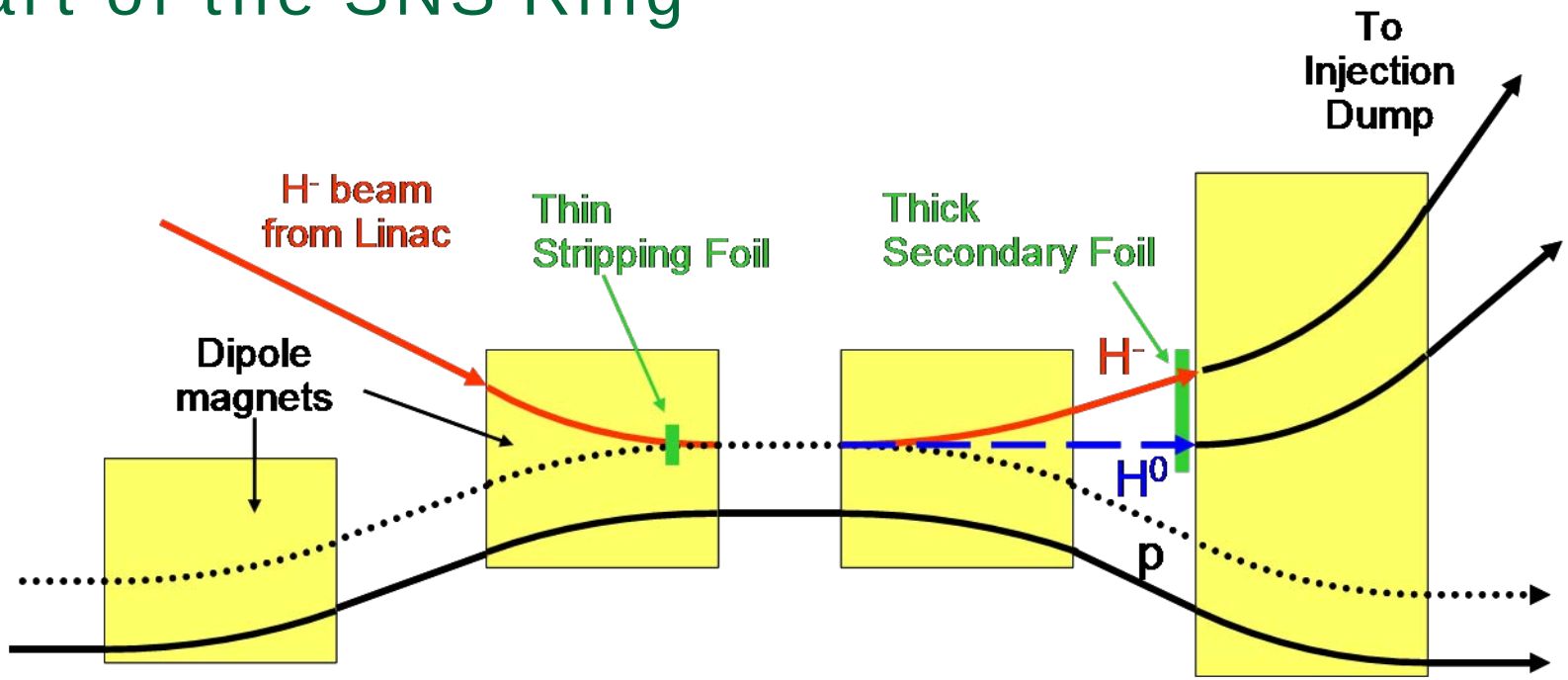
S. Aleksandrov, S. Feshenko, et.al.





- **Measurements of individual RF bunch lengths in the CCL indicate an RMS bunch length up to 30% too long.**
  - **Not enough RMS increase to explain SCL beam loss**
- **Very little tail at the entrance to the CCL**

The Injection Region is the Most Complicated Part of the SNS Ring



- **Injection losses are at full energy, and this is the highest beam loss area in the machine**
- **The ring injection straight is expected to be a high loss area due to foil scattering**
- **It is the highest beam loss area at SNS**

Injection Area Modifications
(*M. Plum, WG-C, J.G. Wang WG-C)*

Radiation monitor on vacuum window water cooling return pipe

New C-magnet

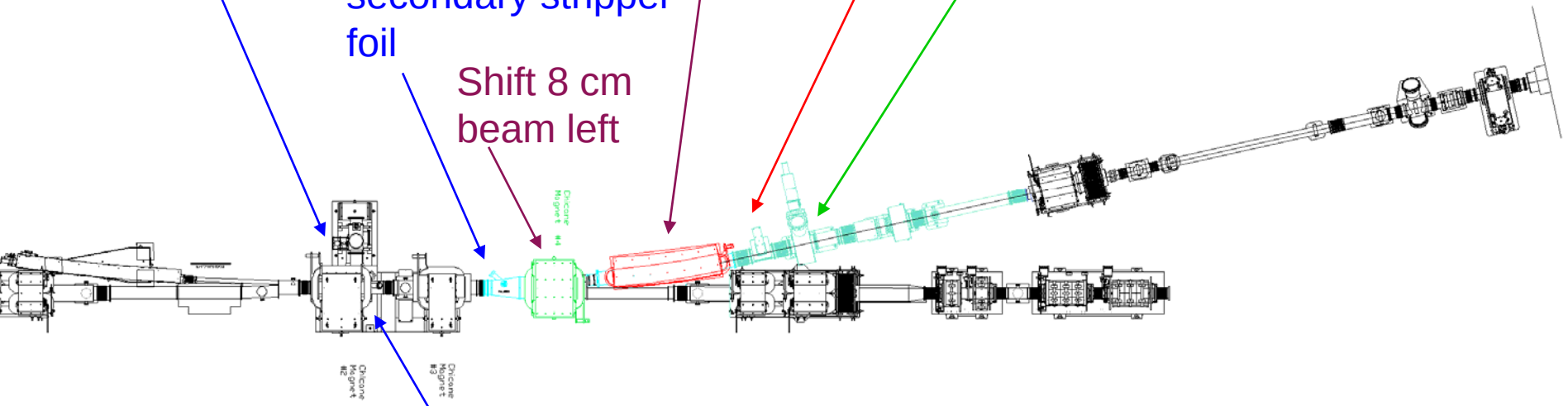
Increase septum magnet gap by 2 cm

Oversize & thicker primary stripper foil

New WS, view screen, BPM, NCD (ridicules)

Thinner, wider secondary stripper foil

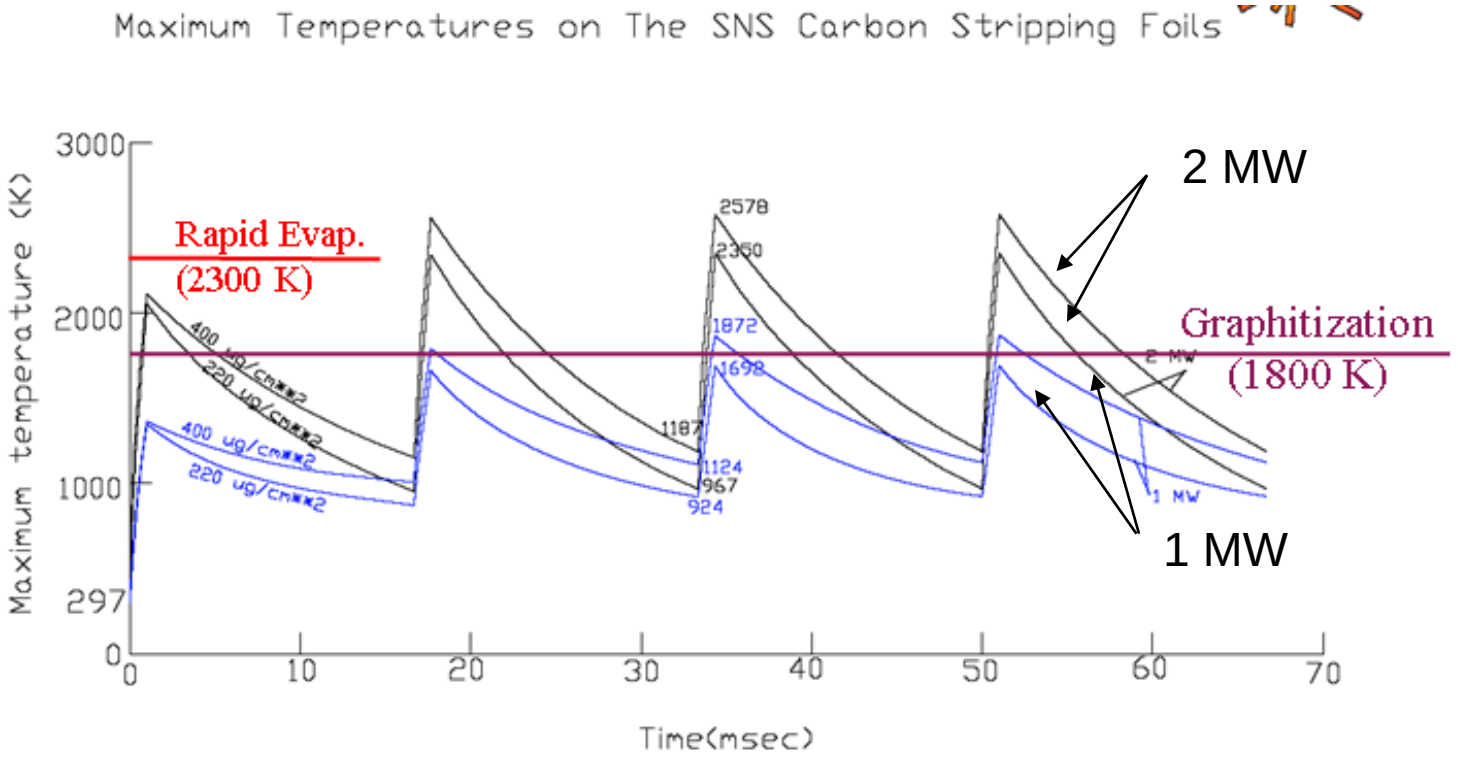
Shift 8 cm beam left



Electron catcher IR video

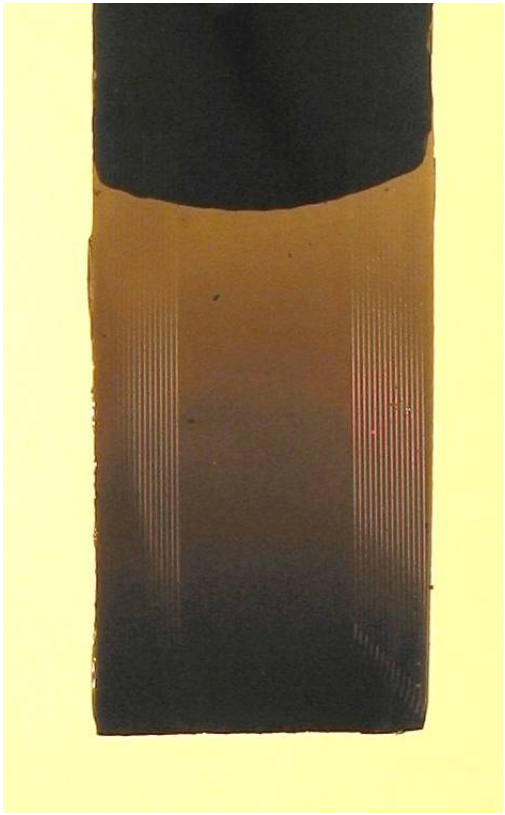
beam line drawing from J. Error

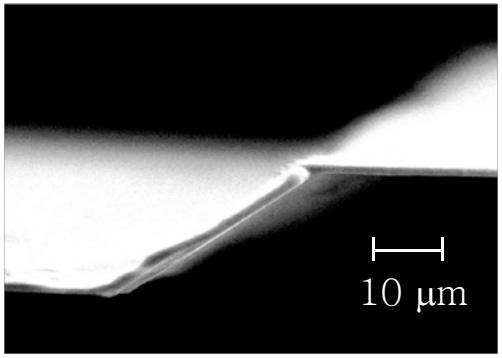
Foil Survivability is a Concern



- **Predictions are that we are approaching foil survivability limits somewhere between 1 and 2 MW**

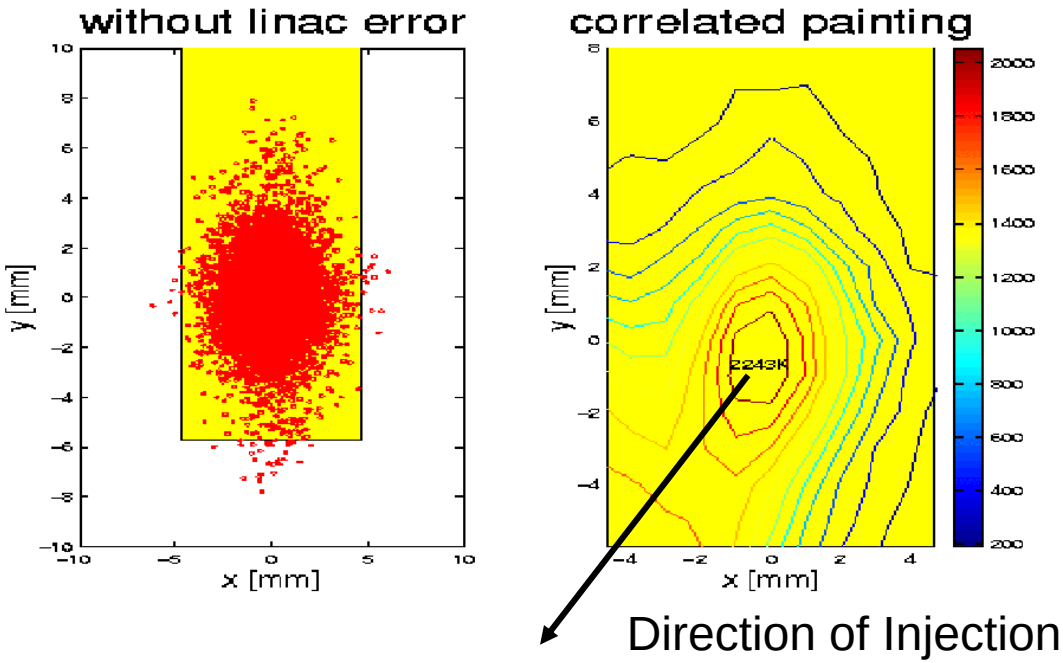
Foil Development at ORNL *(R. Shaw et.al.)*





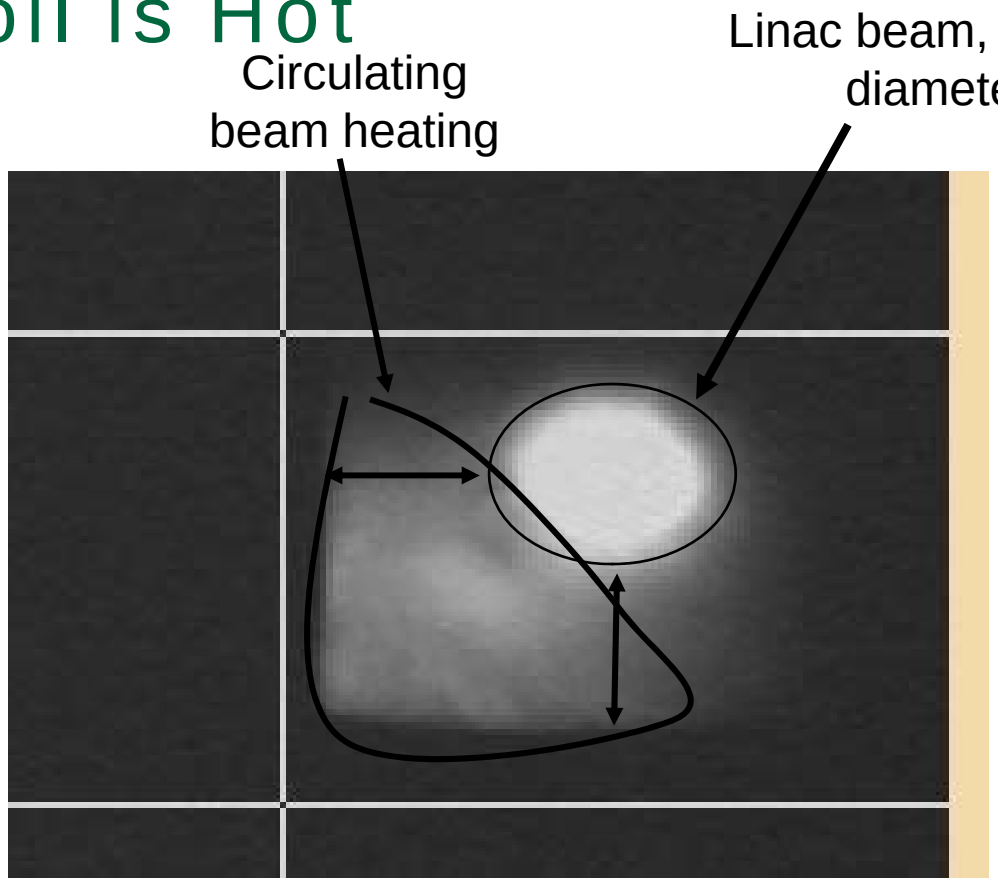
- SNS is using a nano-crystalline foil, 1% CH4, 90% Ar, 350 mg/cm^2 developed at ORNL
- Corrugated pattern around edge provides mechanical strength

Design Beam / Foil Interaction
(Joanne Beebee-Wang, BNL)



- **Nominally 2 % beam misses foil**
  - **Nominal foil size = 20x12 (mm), practice beam size = 25x17 (mm)**
  - **Practice << 1% misses foil**
- **Nominally 3 % is not fully stripped**
  - **Nominal Foil thickness = 300 μg/cm^2, practice thickness = 450 μg/cm^2**
  - **Practice ~ 1.5% is not fully stripped**
- **Foil changes introduced to reduce beam transported to the Injection dump**

The SNS Foil is Hot

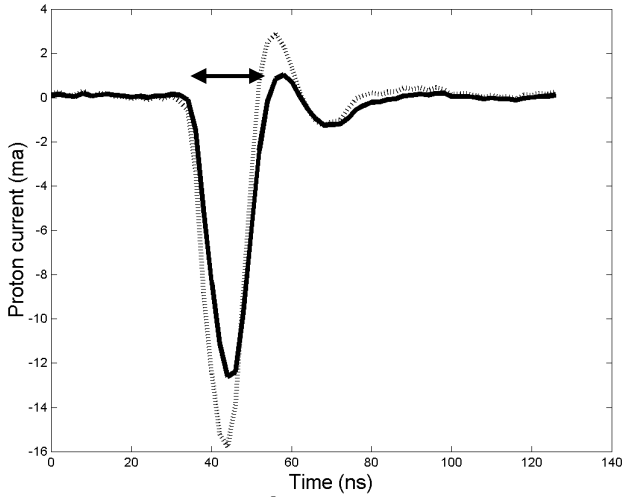


- **Image of the foil during a 480 kW production run**
  - **All light is from the foil (C glow starts at ~ 1100 C)**
  - **Hot spot is the linac beam, dimmer light is from injection painted circulating beam**
- **Need to reduce linac halo, and position the linac beam closer to the foil edge to reduce foil hits**
  - **Design is ~ 7 foil traversals/proton, measurement indicates ~ 20 traversals/proton**
- **How much more beam can the foils take?**
  - **1 foil failure to date (infant)**

Laser Stripping Proof-of-Principle Experimental Results *(Danilov – WG-C)*

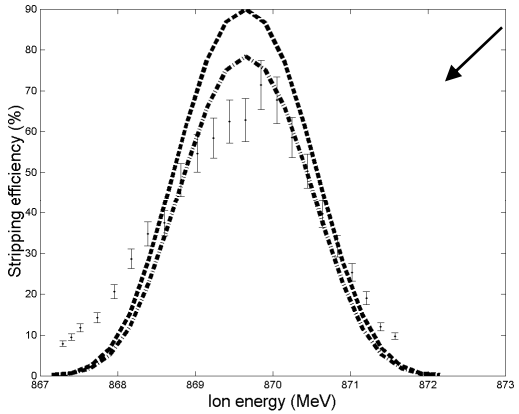
- Since HB2006 successful proof-of-principle of full laser stripping of H^- (90% efficiency)
- Now investigating demonstration stripping for longer pulse lengths
  - Key issues are efficient use of laser light

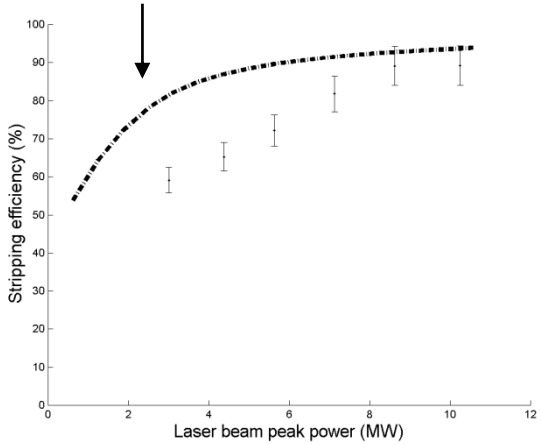
Laser on



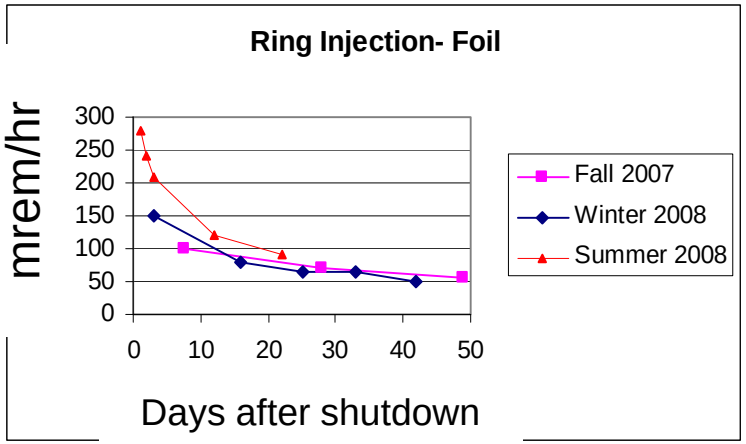
time

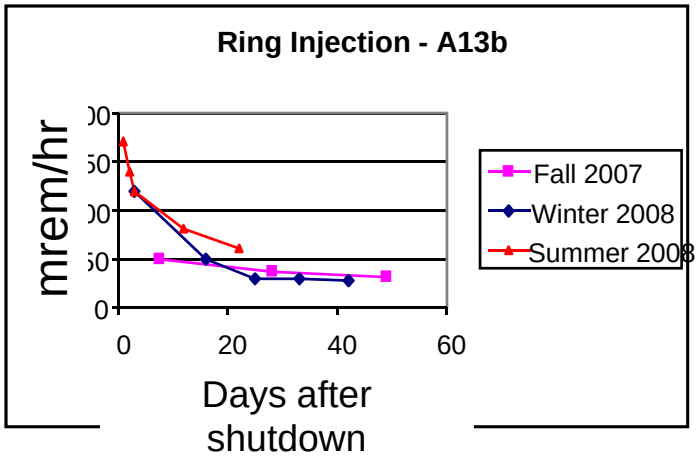
Energy and power dependence

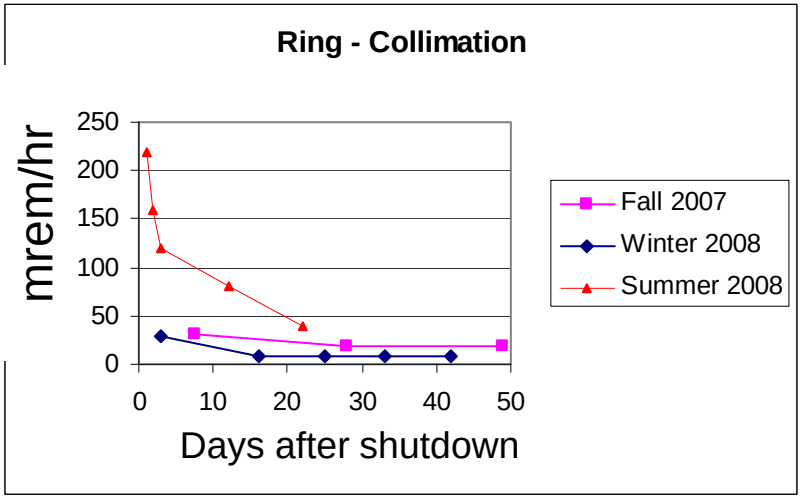


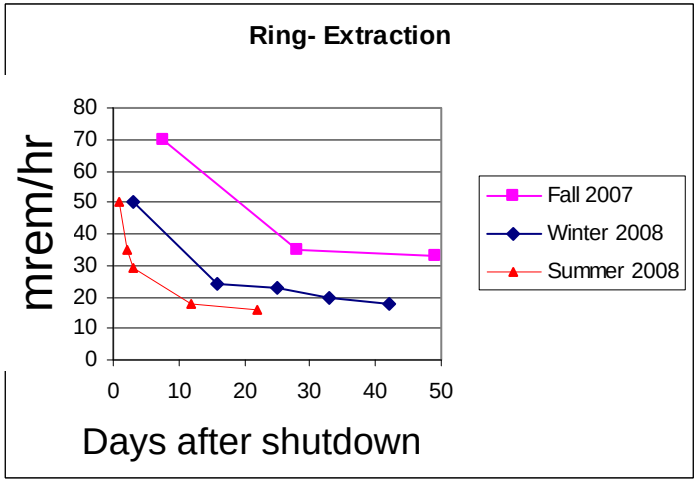


Ring Residual Activation Decay History (*Galambos WG-D*)



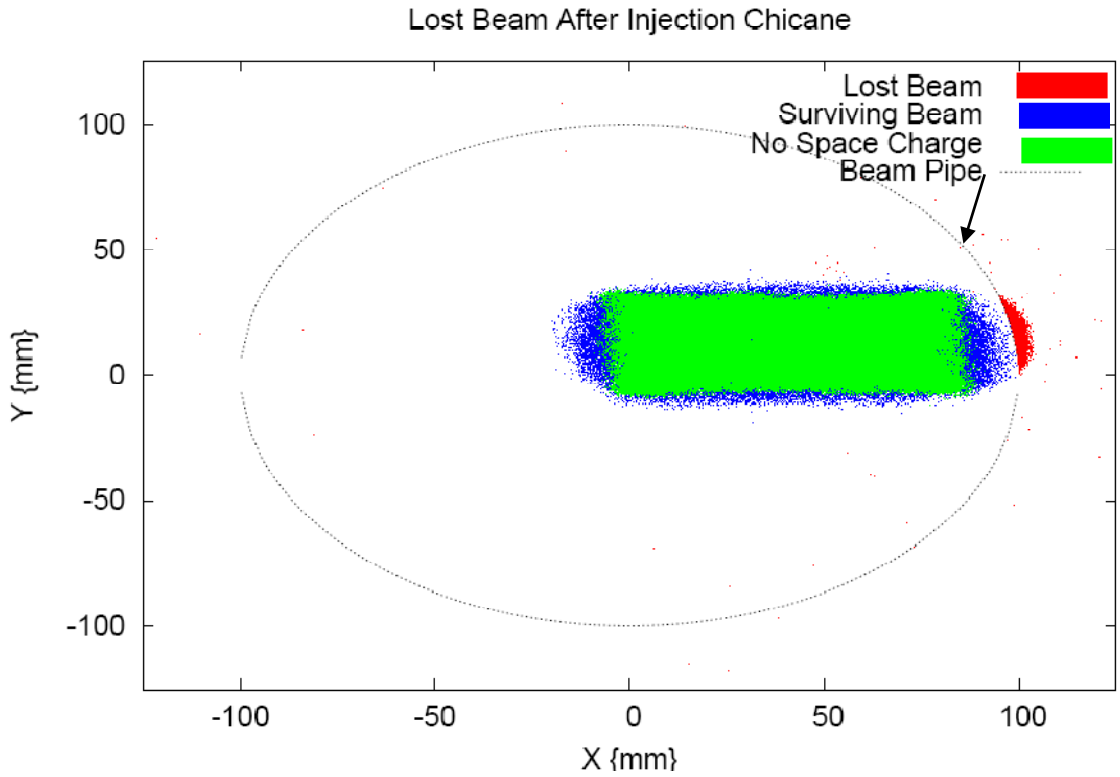






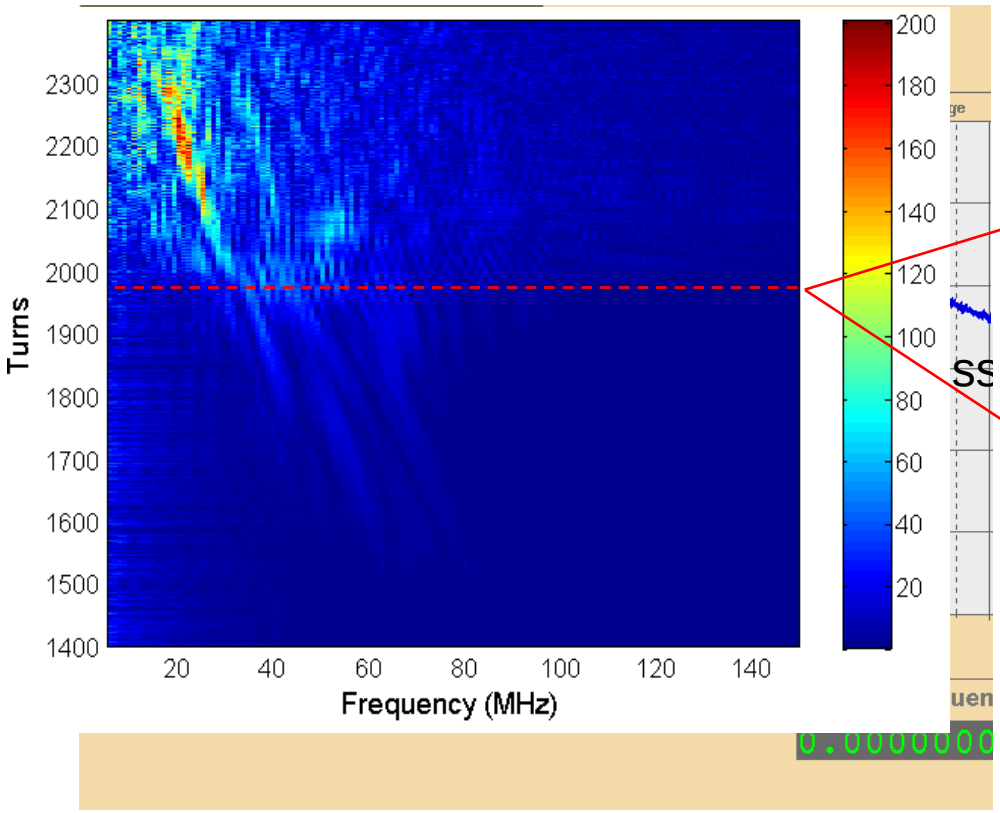
- **Despite increasing the beam power by factor of 2.5, the long term residual activation buildup is not increasing proportionally**

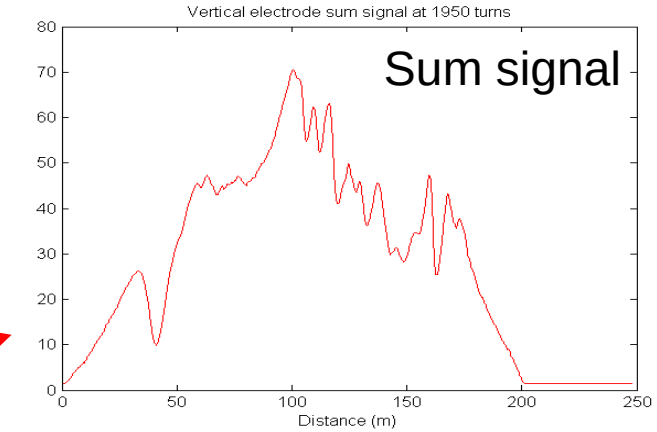
Modeling Beam Loss – Details Become Important *(J. Holmes: WG-A)*

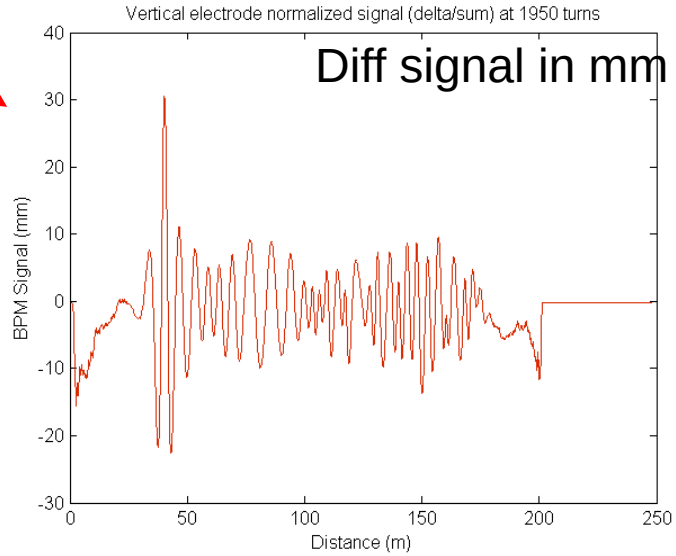


- **Modeling beam loss at an aperture reduction in the injection region**
- **Details are important: e.g. space charge**
- **ORBIT code is used to study loss**

Collective Effects / e-P Instability
(Cousineau (WG-A)



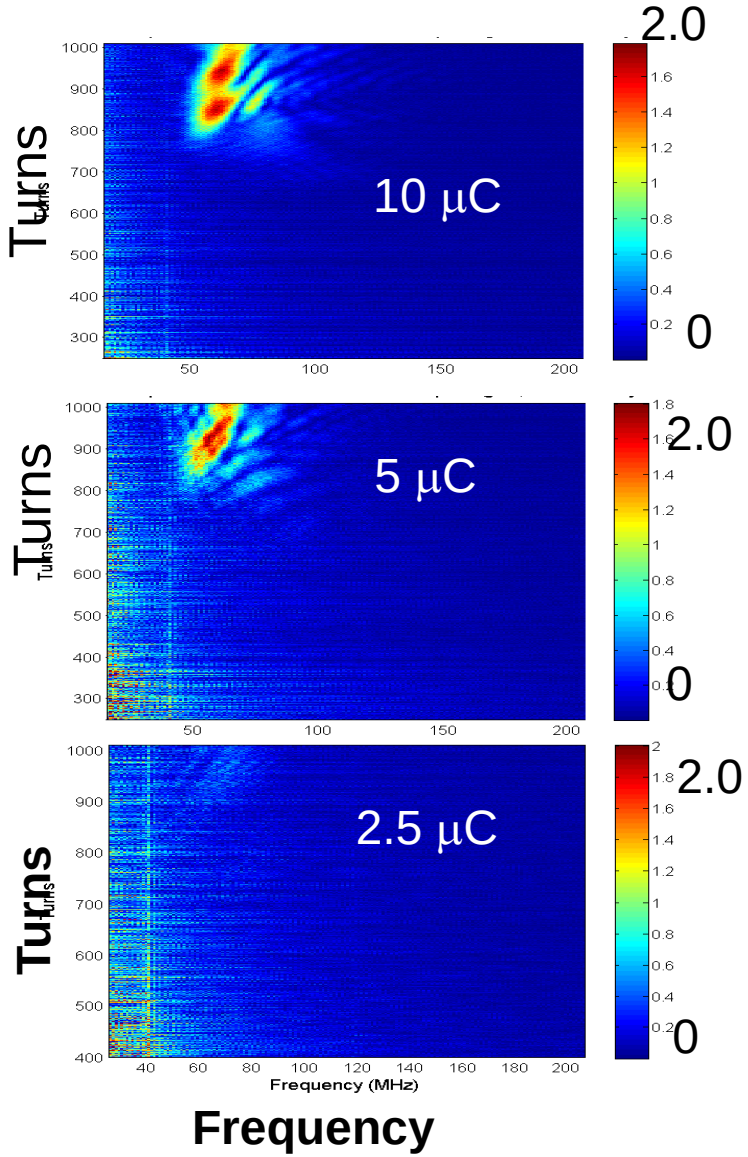




- **Extending the storage time and reducing the RF amplitude can see e-P signature for latest production beam**

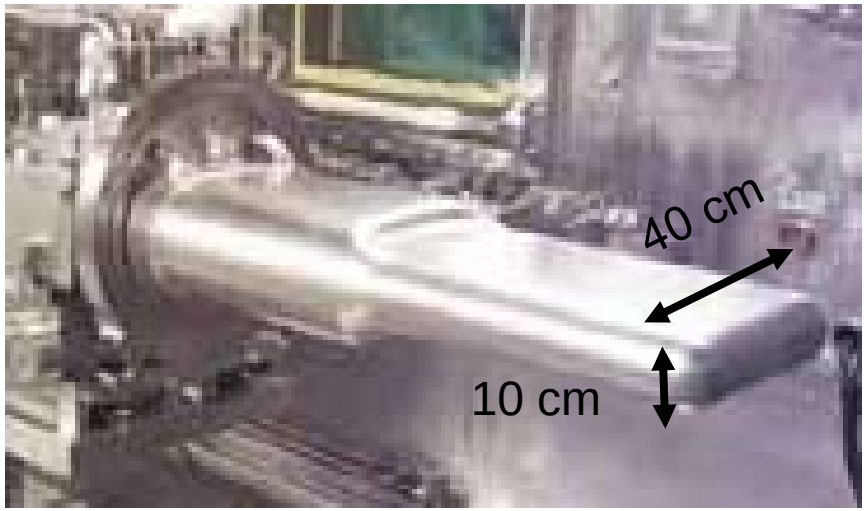
OAK RIDGE National Laboratory

E-p signature is also evident at lower intensities

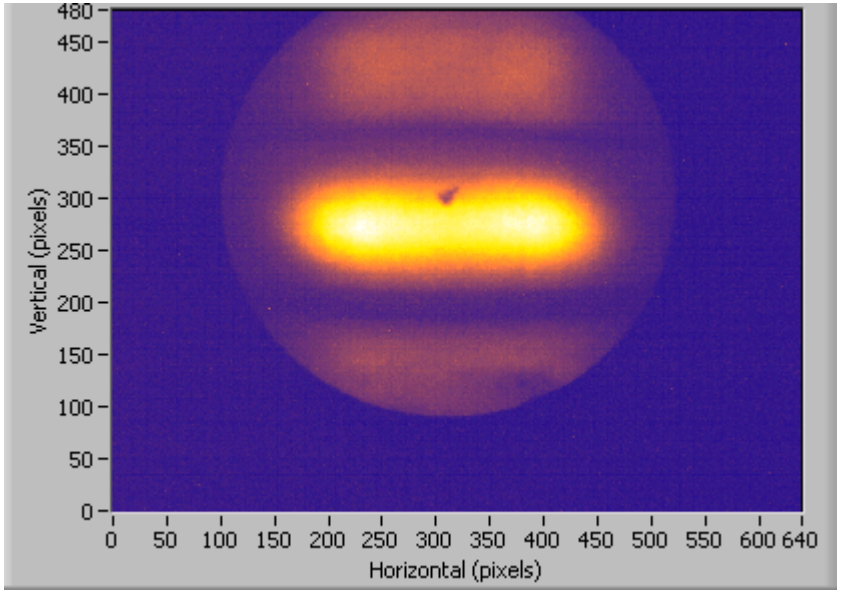


- **e-P signature can be seen at low intensities with no measureable reduction in beam current**
- **Magnitude of the oscillation is small compared to the beam size**
- **Effect on beam loss for this "small scale collective" behavior is uncertain**
- **We are implementing a damper system *(C. Deibele et. al.: WG-F)***

Beam On Target Concerns
(Plum – WG- C)

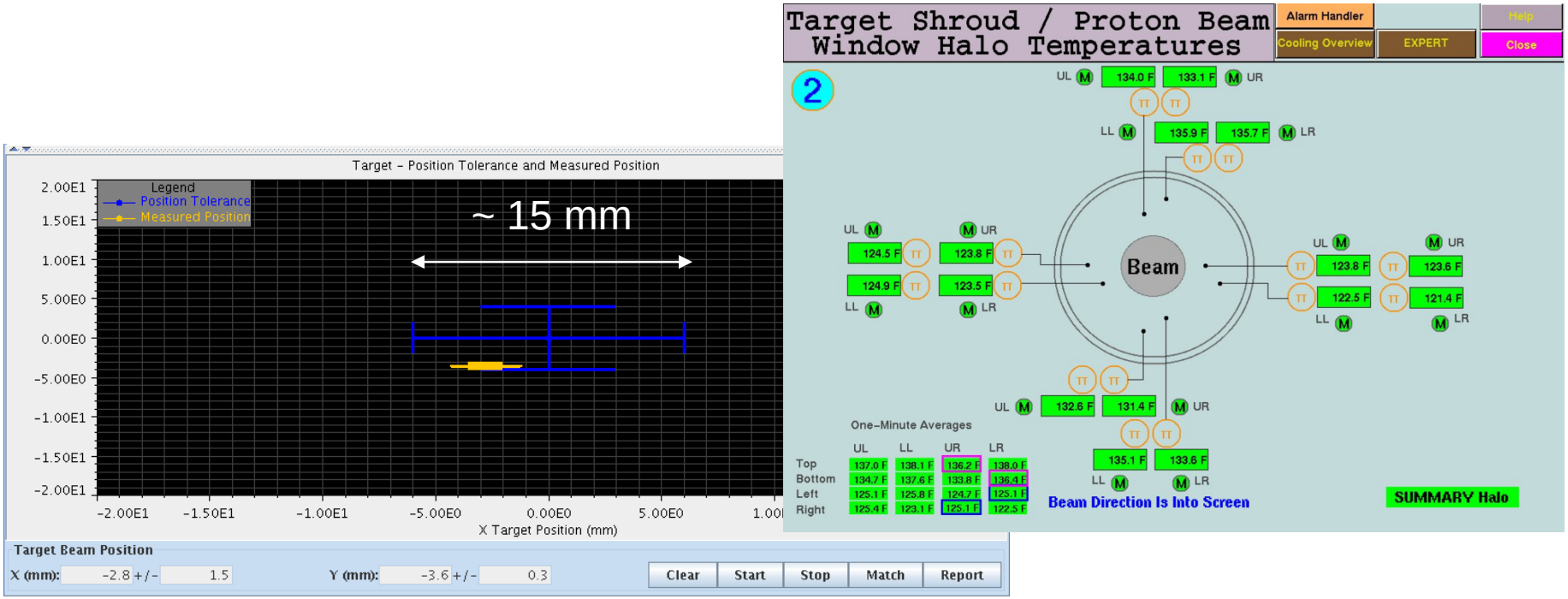


Beam on Target - phosphor screen



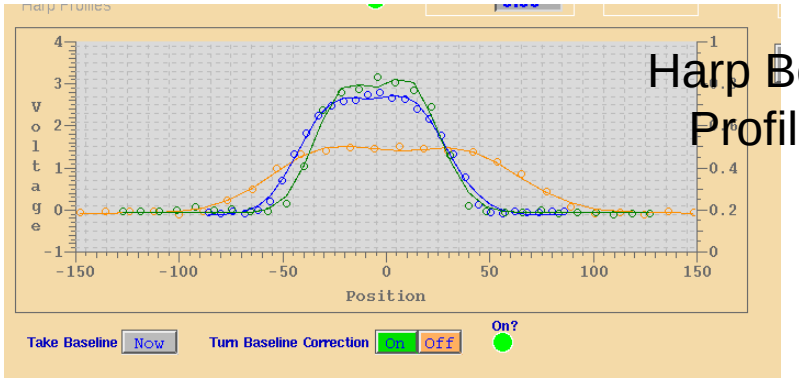
- **There are strong limits on peak power density on the Target and upstream vacuum window (dependence on rep-rate)**
- **Limits on the fraction of beam missing the target**
- **Ensuring that the beam on Target center**
- **Ensuring that the waste beams from incomplete foil stripping hit the injection dump**

Beam centering on the target



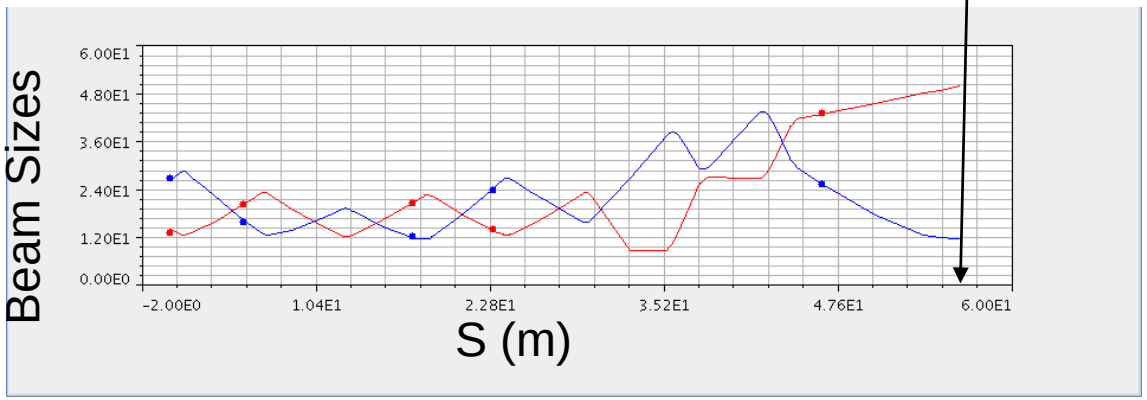
- **Last BPMs are located ~ 10 m upstream from the Target**
- **Extrapolate beam position to the Target**
- **Use thermocouples on the Target shroud to do final centering**
- **Fast machine protection limits magnet currents and loss monitor signals in the Ring extraction and transport line to the Target (errant beam control)**
  - **Fine line between safe protection and excessive false trips**

Beam Power Density Calculations



Harp Beam Profiles

Target

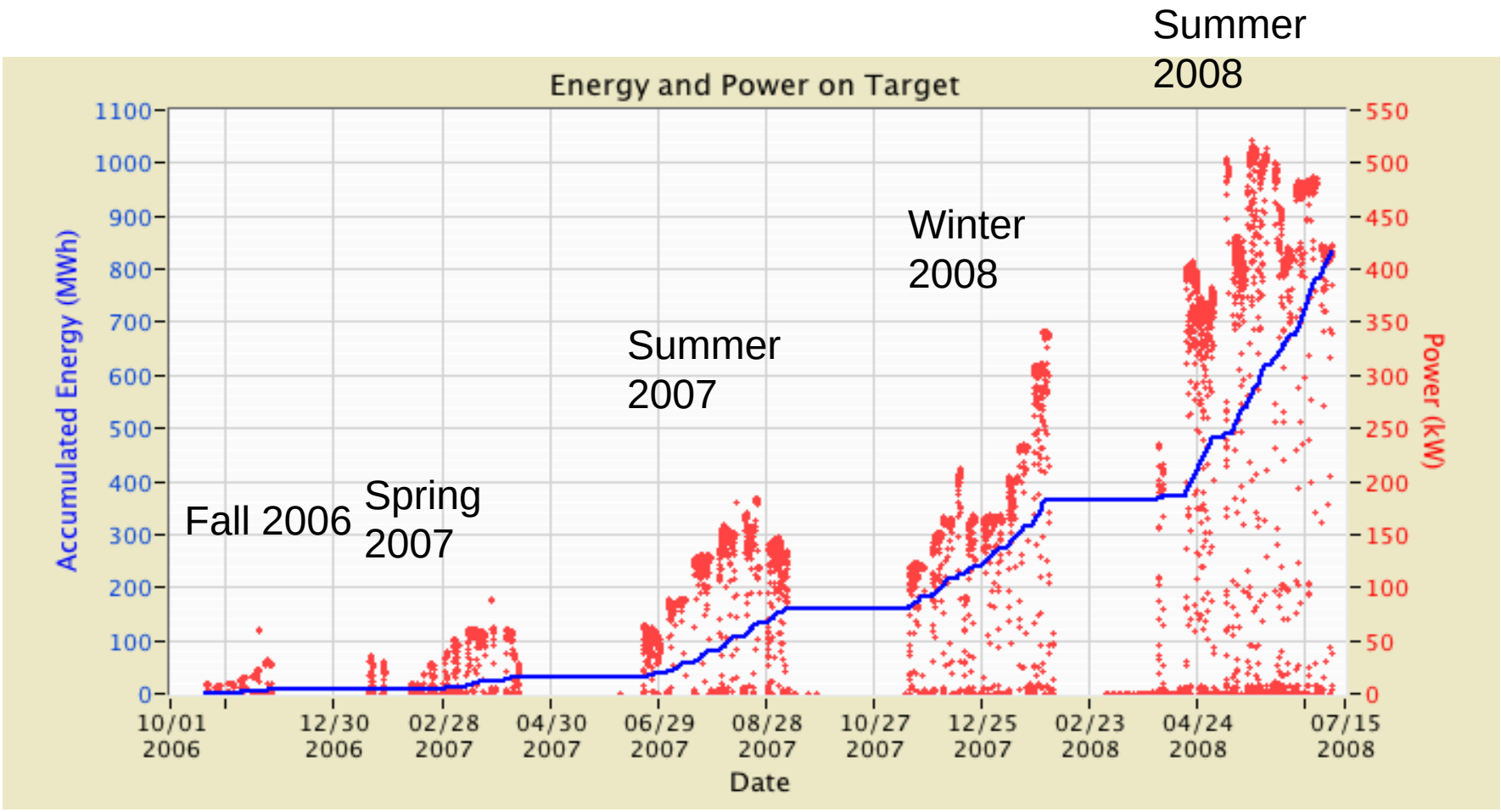


- **Measure beam sizes at wires and a harp upstream of the target**
- **Use a model to extrapolate the peak target density to the window / Target**
- **Acceptable target power density profiles are not the same as minimum beam loss profiles**

Other Areas of Challenge

- **Collimation: HEBT collimation starts to become effective at high intensity, but performance repeatability is not consistent**
- **Machine protection: balance between good protection and high availability *(Galambos WG-D)***
- **High level software: ability to effectively utilize diminishing beam study time *(Shishlo WG B & D)***
- **Diagnostics: Robust loss detection, halo measurements, non-intercepting diagnostics *(Assadi, Zhukov, Gorlov WG-F)***
- **Availability *(Galambos WG-D)***

Summary



Thanks for your attention