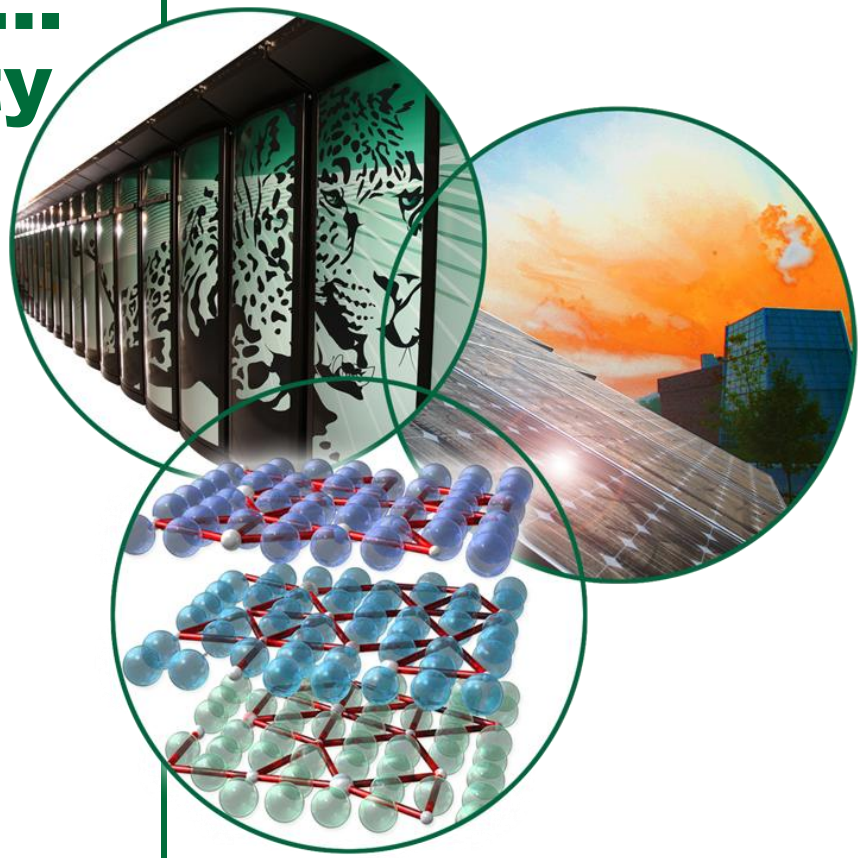
SNS High Power Operation: Great Expectations.... and a Dose of Reality



J. Galambos – on behalf of the SNS team

Sept. 27, 2010

46th ICFA Advanced Beam Dynamics Workshop on High-Intensity and High-Brightness Hadron Beams

Morschach Switzerland

U.S. DEPARTMENT OF ENERGY

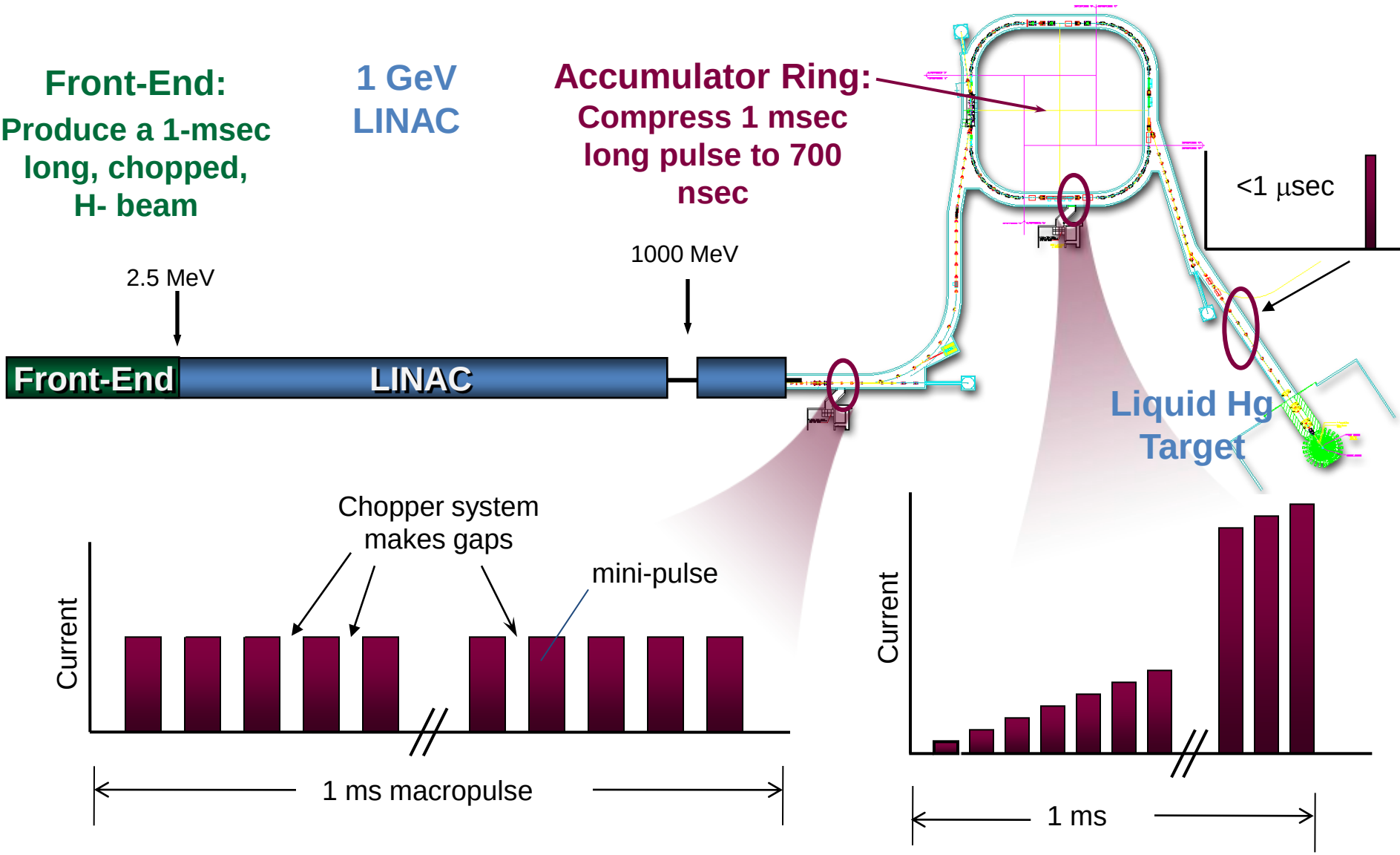
OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

SNS Accelerator Complex

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

1 GeV LINAC

Accumulator Ring:
Compress 1 msec long pulse to 700 nsec



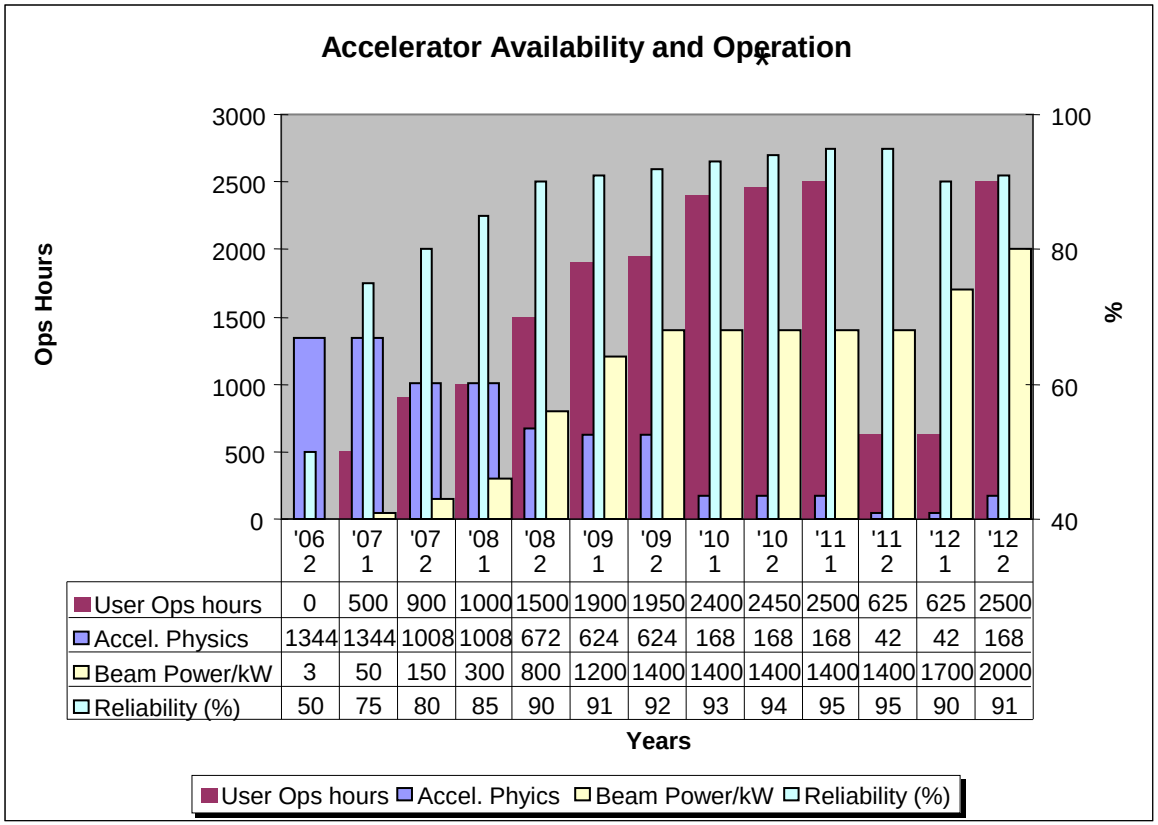
Beam Power Ramp-up: Expectations vs. Reality

- The high level operational goals
- The equipment
- The beam

Power Ramp-up Expectations: circa 2006

- **Initial impression: somewhat overwhelmed by the height of the MW-mountain we were climbing**

Transition to Operations: Initial Expectations *DOE Semi-annual Review, May 2-3, 2006**

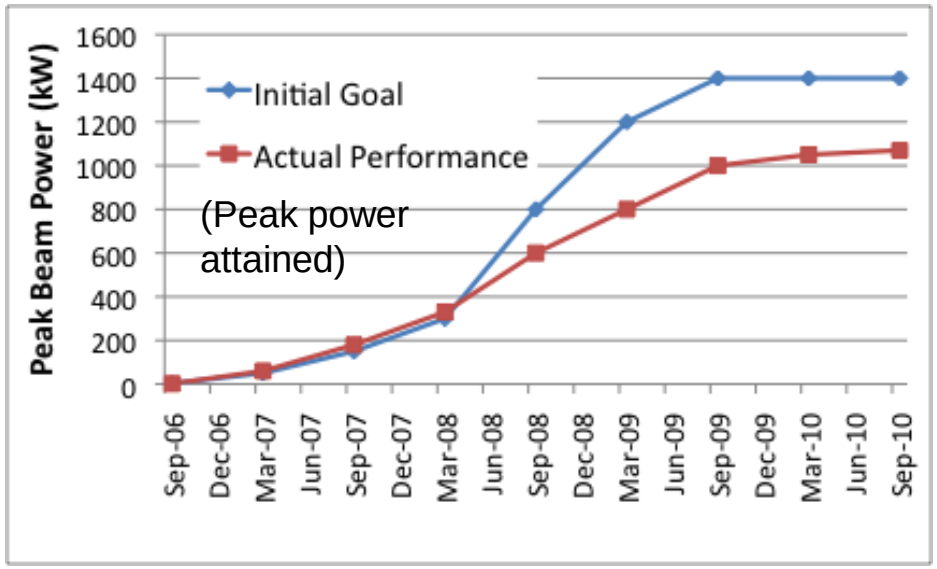


	'06 2	'07 1	'07 2	'08 1	'08 2	'09 1	'09 2	'10 1	'10 2	'11 1	'11 2	'12 1	'12 2
User Ops hours	0	500	900	1000	1500	1900	1950	2400	2450	2500	625	625	2500
Accel. Physics	1344	1344	1008	1008	672	624	624	168	168	168	42	42	168
Beam Power/kW	3	50	150	300	800	1200	1400	1400	1400	1400	1400	1700	2000
Reliability (%)	50	75	80	85	90	91	92	93	94	95	95	90	91

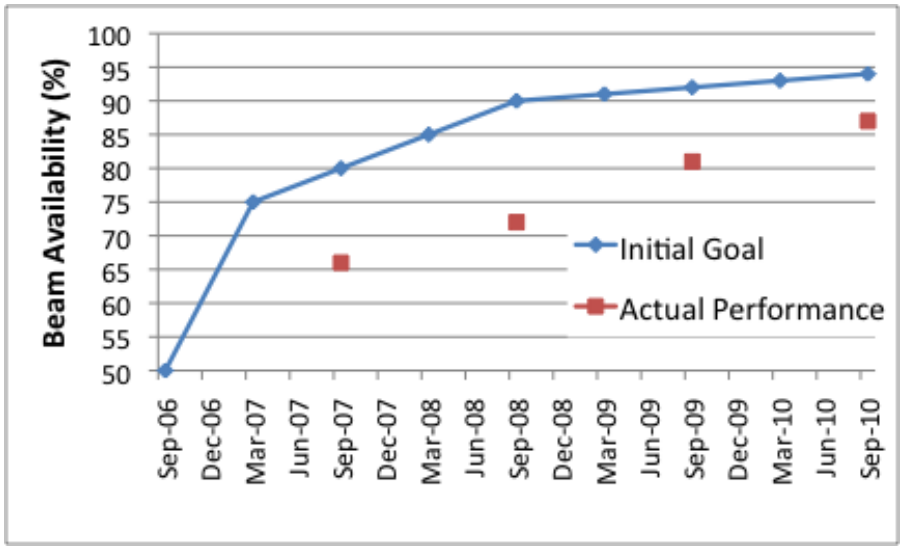
* Mason & Holtkamp

Rapid transition from accelerator physics to neutron production

Operation Metrics Record

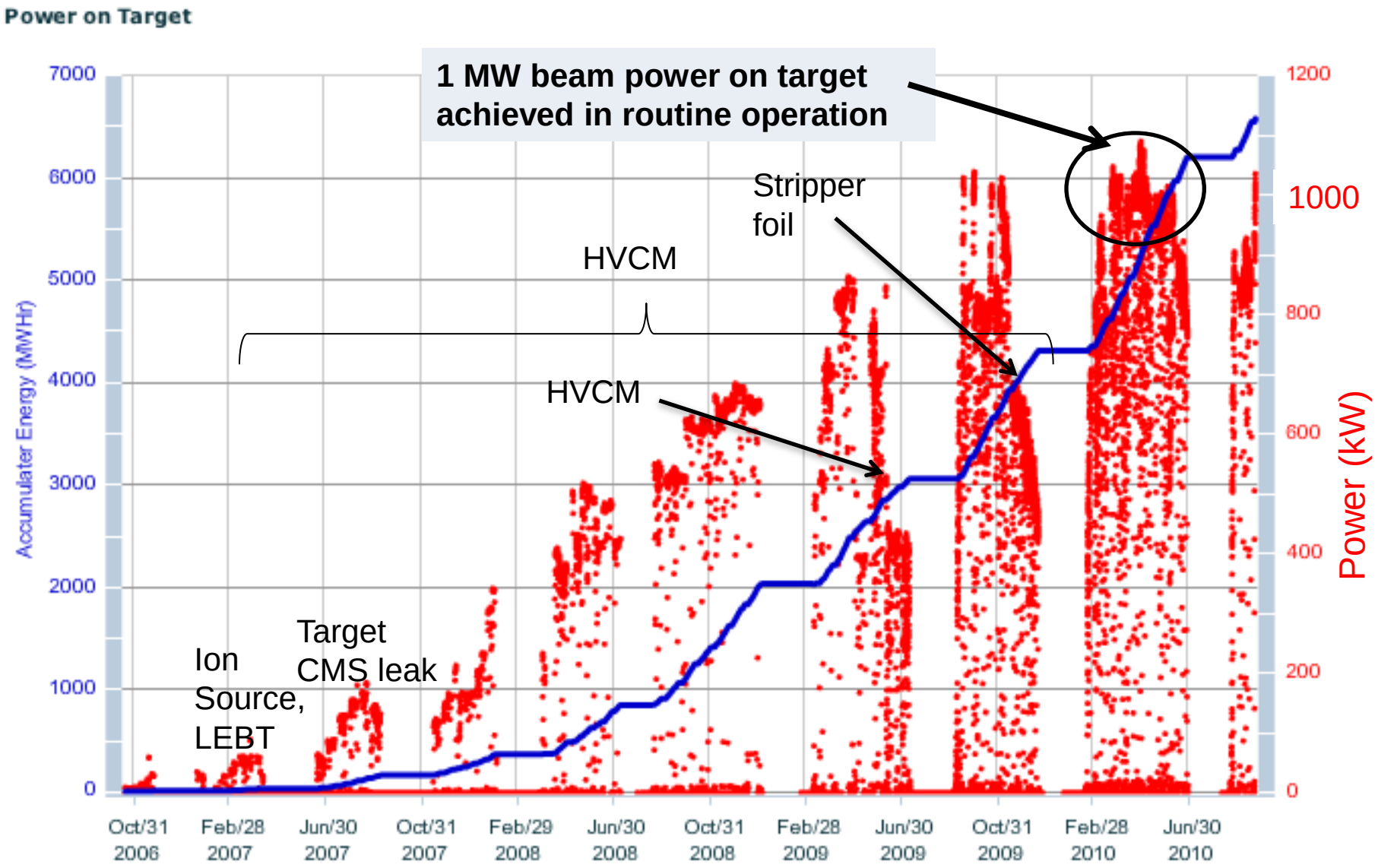


- **Beam power: kept up initially, but leveled off at ~ 1 MW after fall 2009**



- **Availability is a more difficult goal, and stronger driver for operational parameters**
  - **We could run at higher powers, but the availability may suffer**

History of Beam Power on Target



Expectations vs. Reality: The Equipment

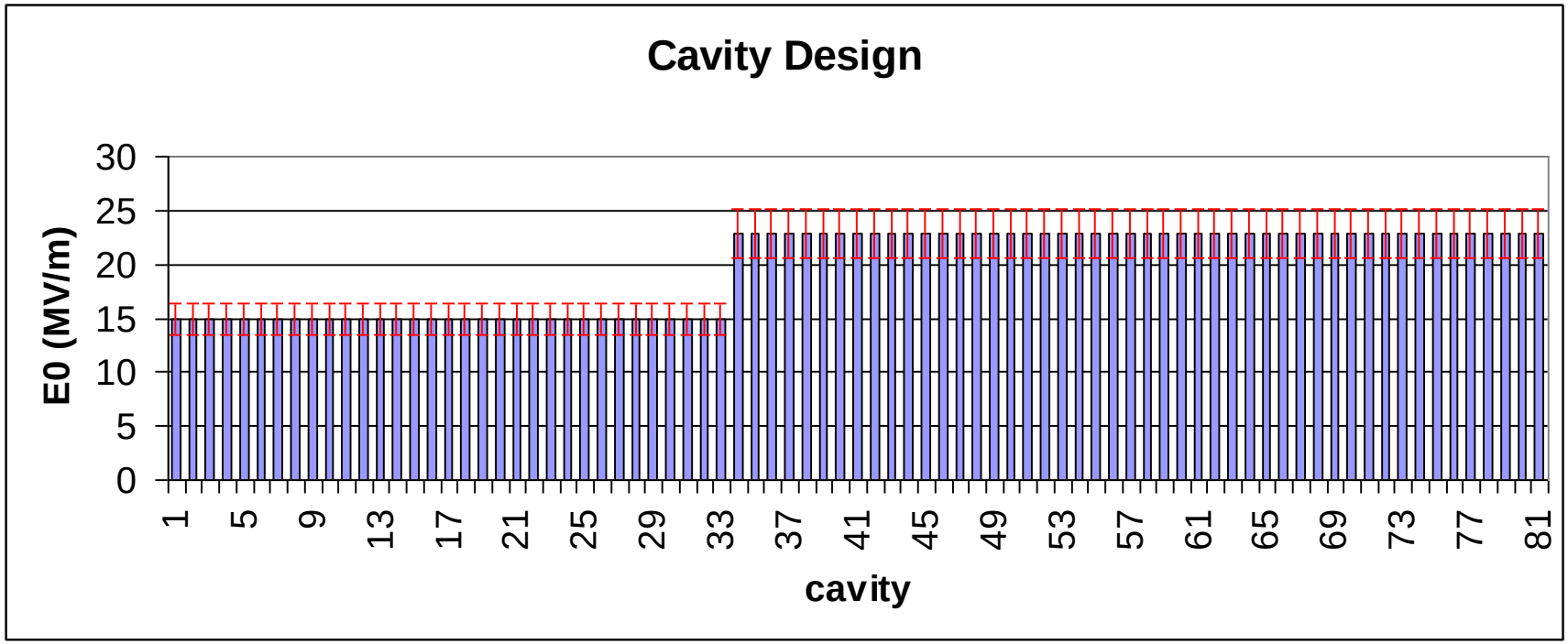
Physicist view of how equipment should work: Speficy requirements and turn it on

Expectations vs. Reality: The Equipment

Reality: Stuff does not always work as expected

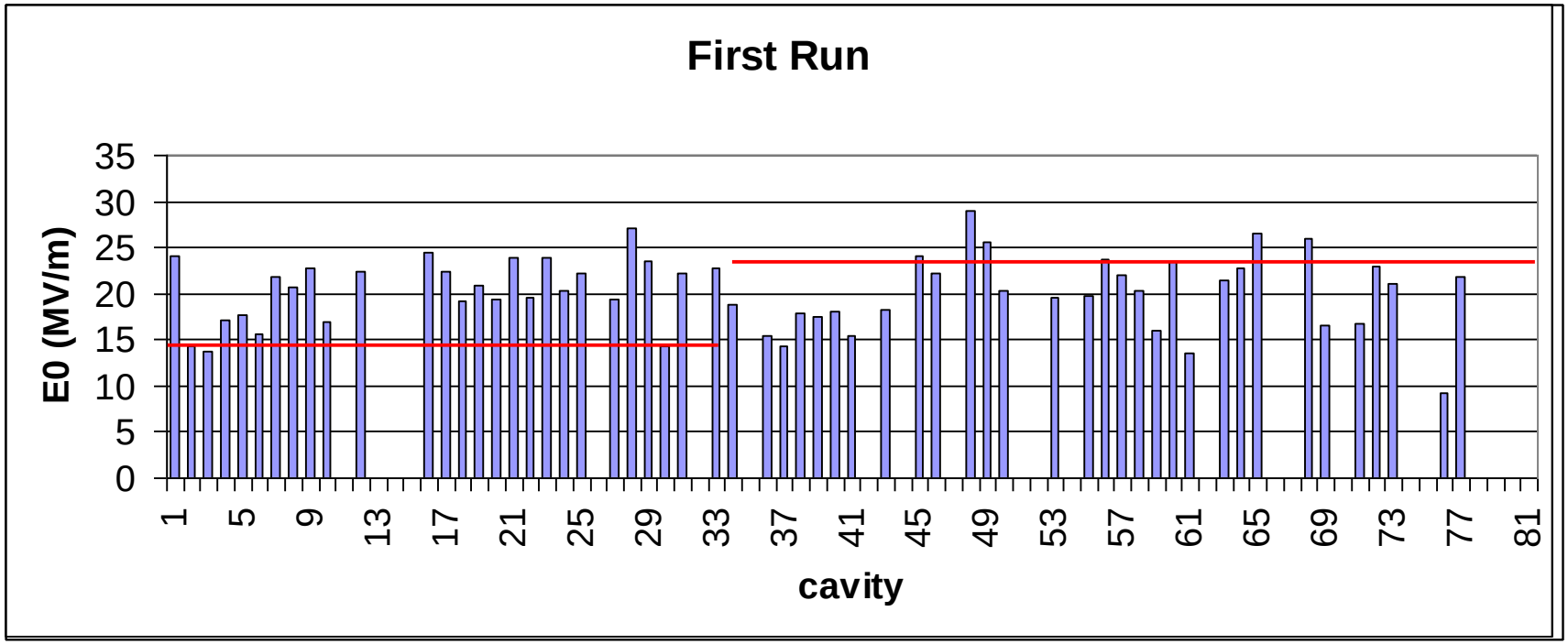
- Modulators
- Superconducting RF cavities
- Choppers
- Stripper foils
- ….

Superconducting Cavity Amplitudes



- **SCL cavity gradient levels were not what we expected**
  - **We grossly underestimated the gradient variability**
  - **But the SCL is operationally quite flexible !!**

Superconducting Cavity Amplitudes



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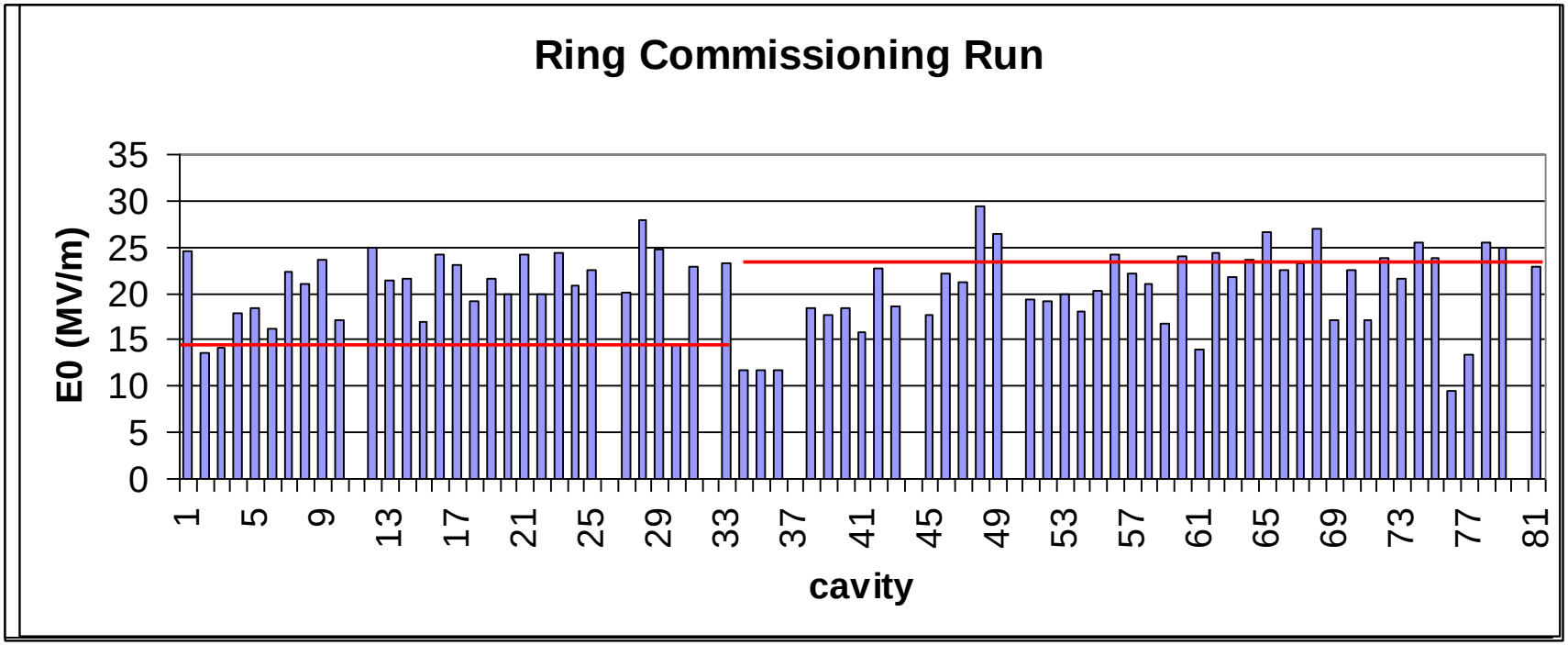

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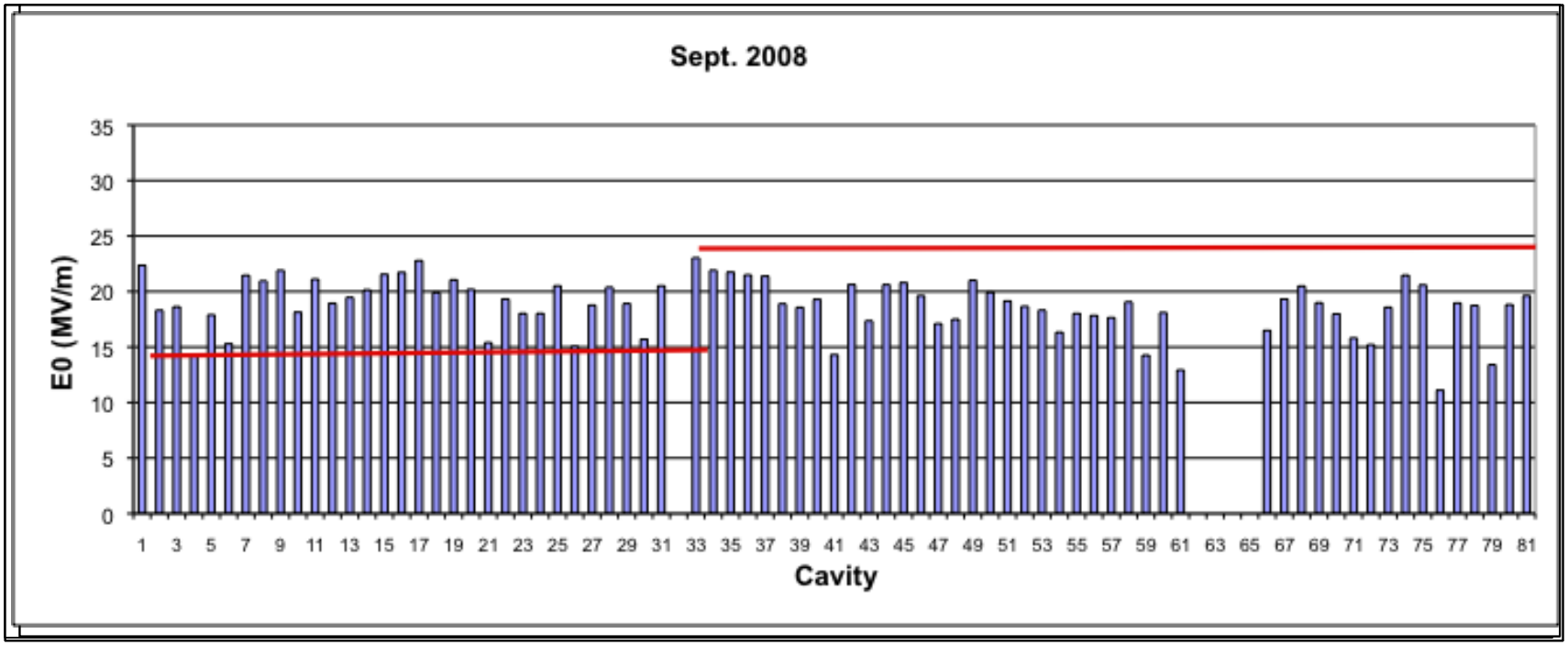

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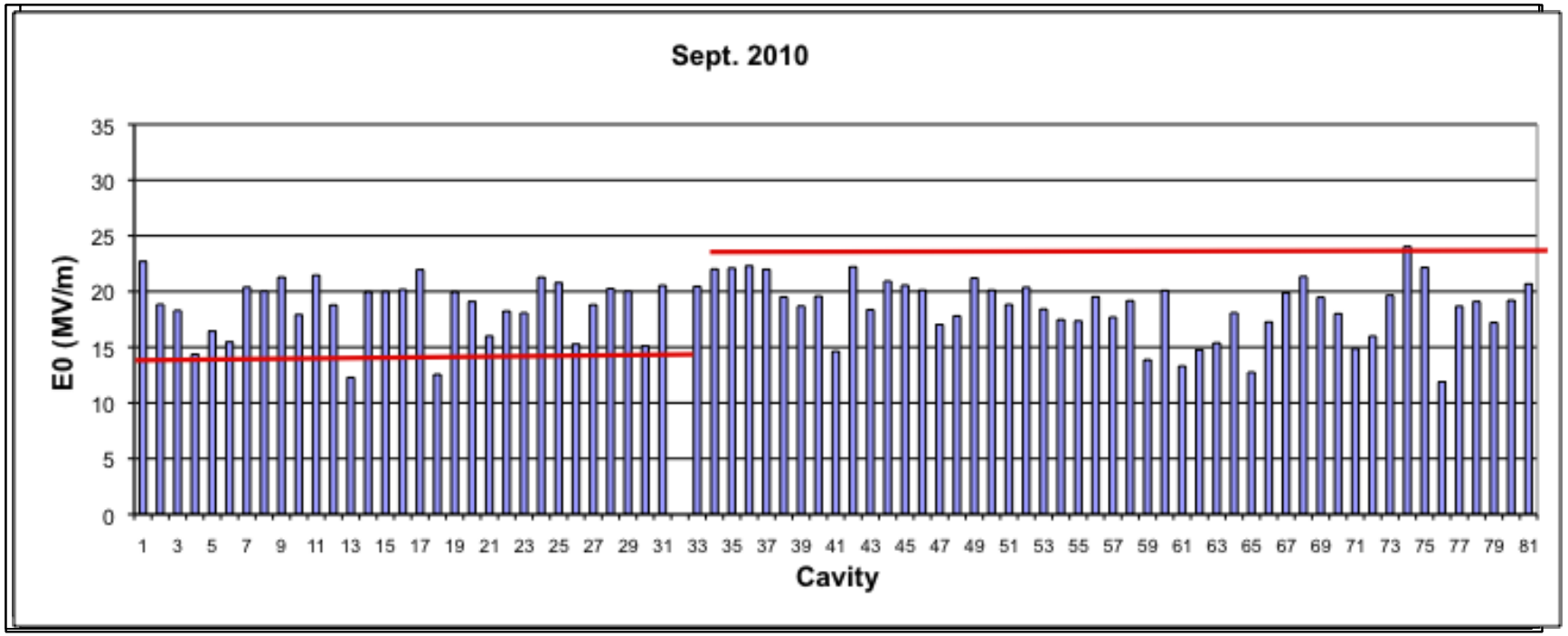

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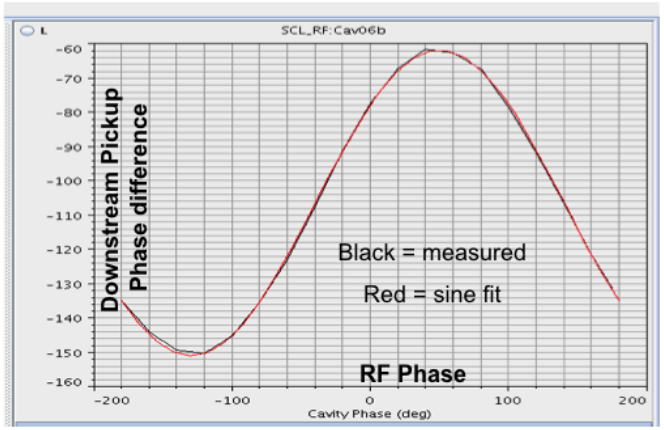
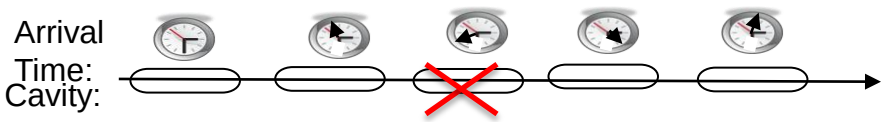
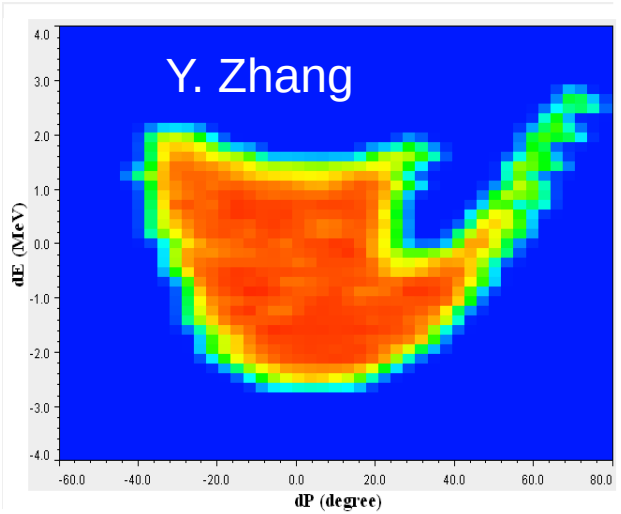
SCL: Independent Cavity Control = Flexibility

Model based re-phasing of downstream cavities after “cavity failure” *: reliability*



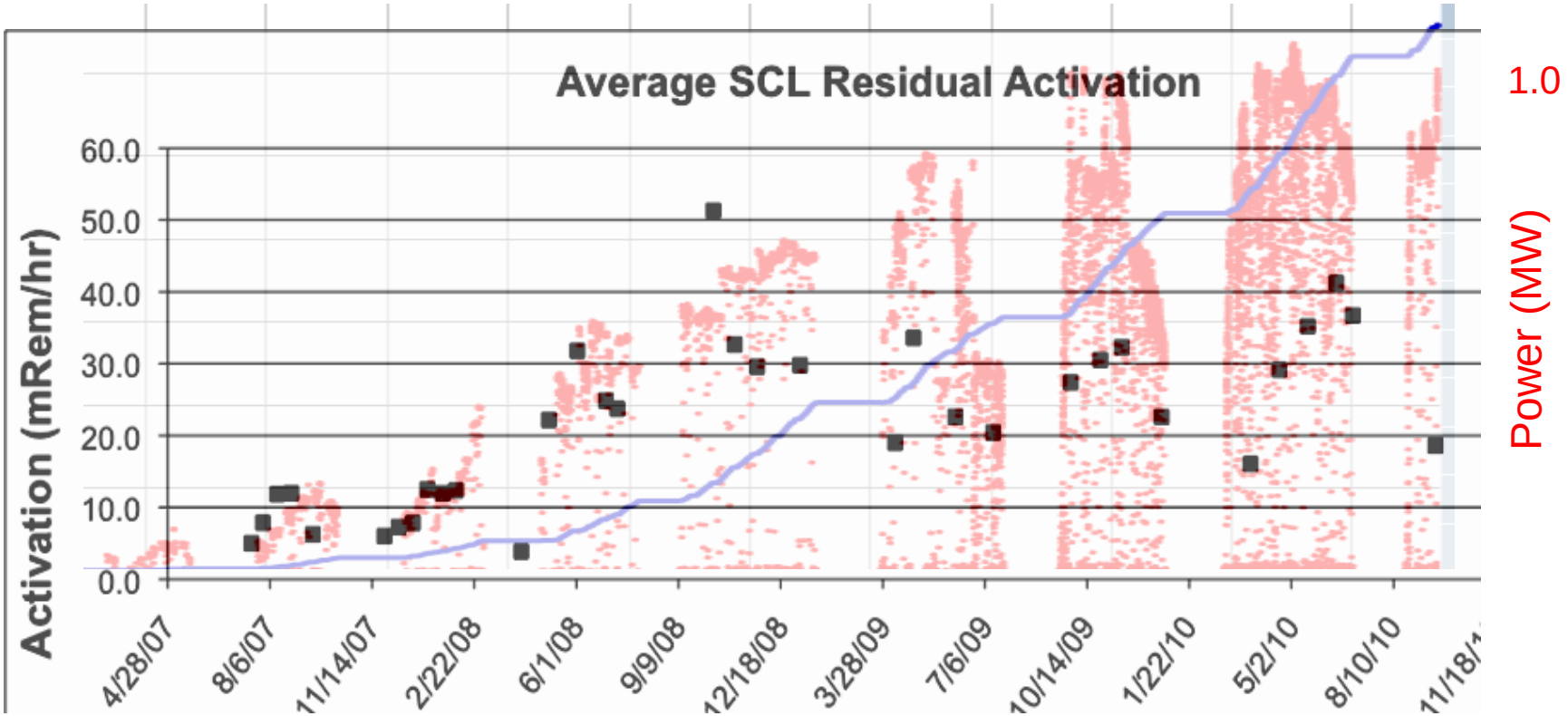




Beam response from a 6 cell SC cavity is like an ideal kick

Scans in phase and energy: *diagnostic capability*

SCL Activation: How are we doing?



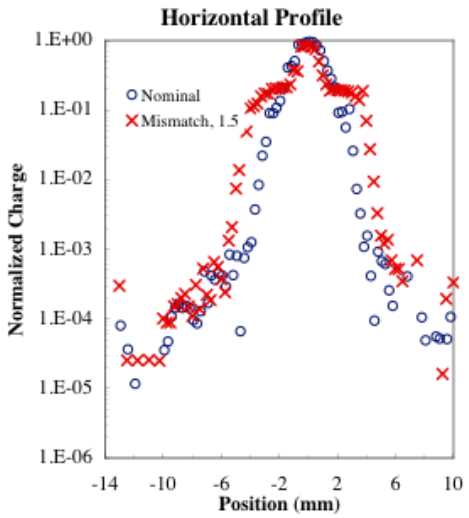
- **Expectation: Modeling during the design stage indicated no beam loss in the SCL**
- **30-40 mRem/hr at 1 MW operation is typical**
- **SNS operations has not been limited by beam loss – but 10 MW is a problem**

How Much Beam is Lost in the SNS SCL ???

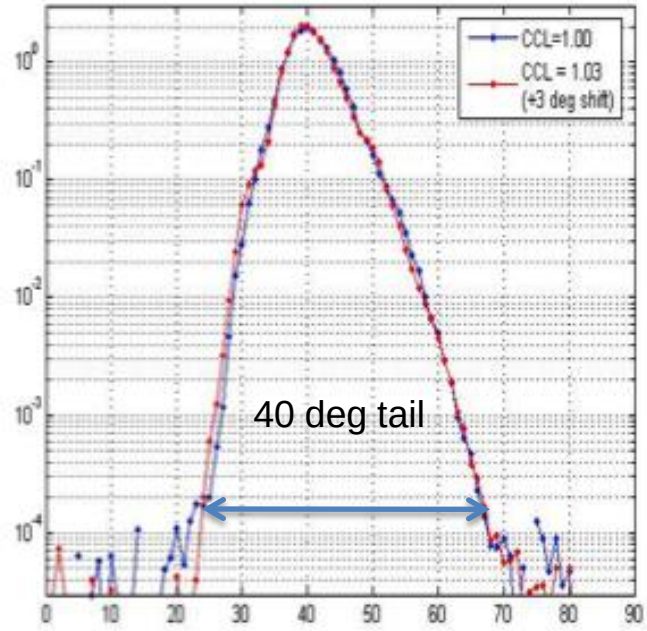
- We did not know what to expect (models indicated no loss)
- Activation measurements indicate < 1 W/m in the warm sections (x 32 warm sections < 100 W or 10^{-4} of the beam)
- Laser profile device turns out to be a good way to create controlled beam spills of 10^{-6} beam
  - Increases the integrated beam loss about 10% (or we are nominally losing 10^{-5} throughout the linac)
- Measurements in the 10^{-5} fractional beam level are difficult
  - Loss monitors are quite sensitive, but do not tell you much about why you lost beam

Beam Distributions at 10^{-5} Levels

- Large dynamic range measurements are difficult
- Typically expert based systems, measuring beam distributions in a limited number of 6-D cross sections
- What should we use as initial distributions for the models????

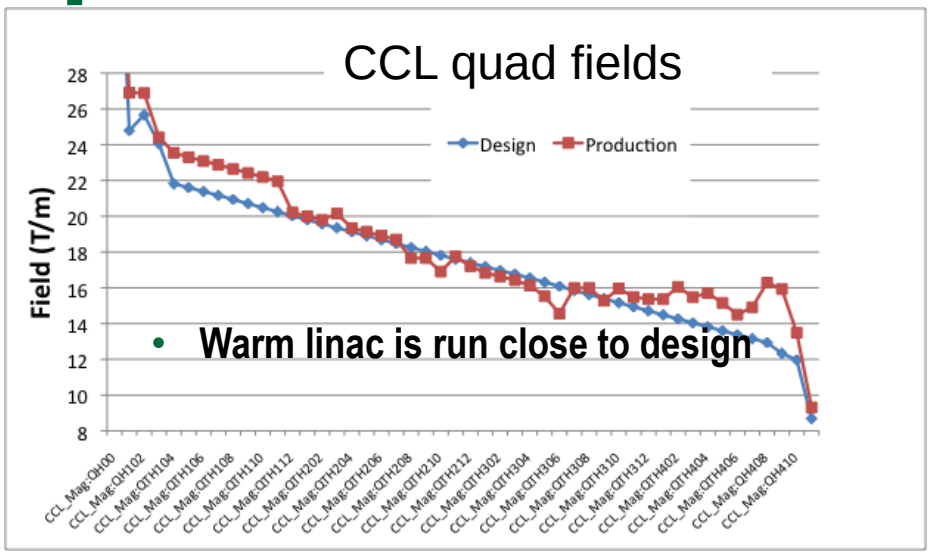


LEDA measurement – Gilpatrick et. al.

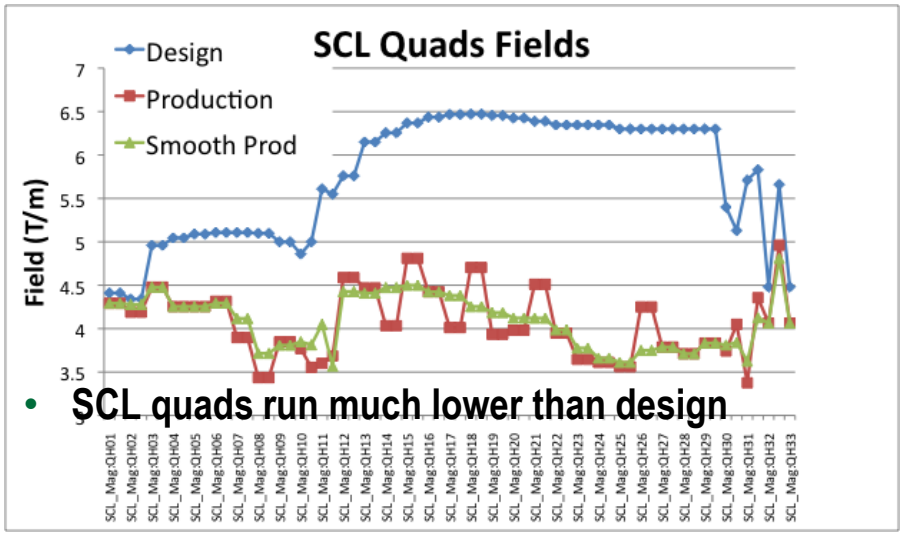


Longitudinal BSM, S. Aleksandrov

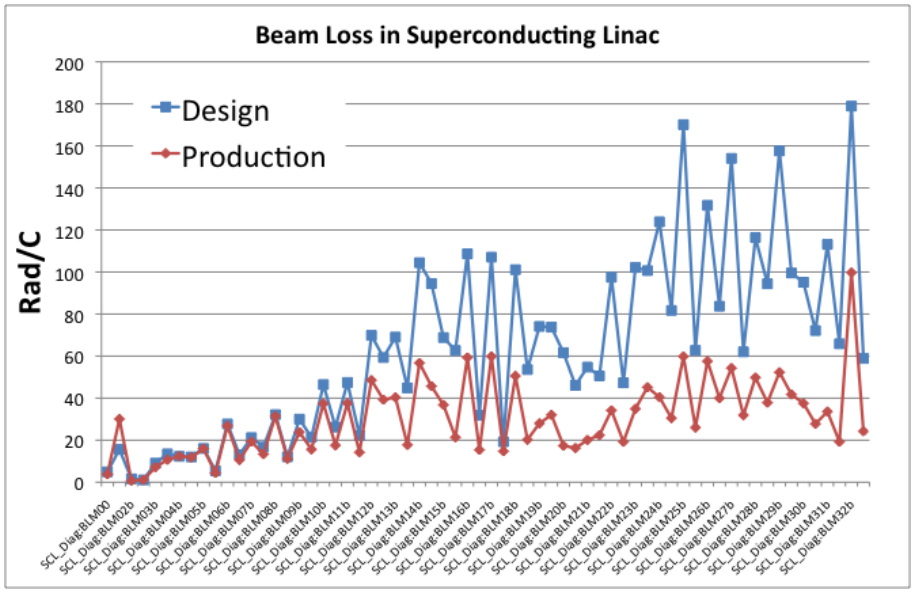
SNS Linac Transverse Lattice: Design vs. Operation



- Warm linac is run close to design

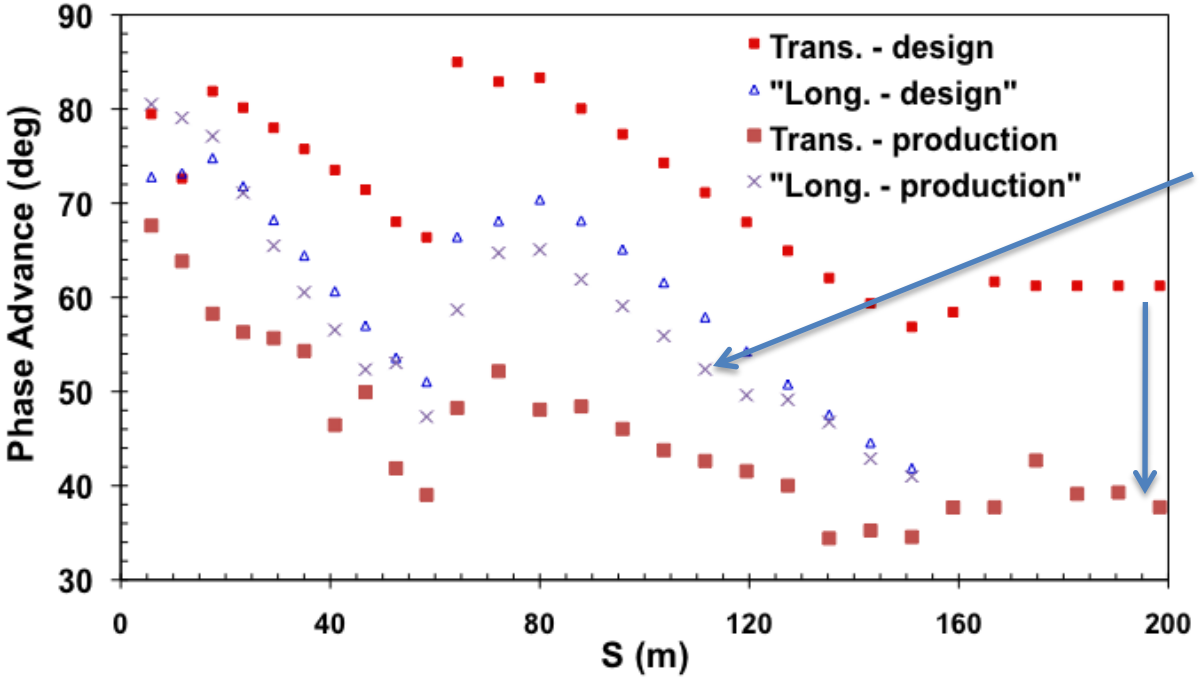


- SCL quads run much lower than design

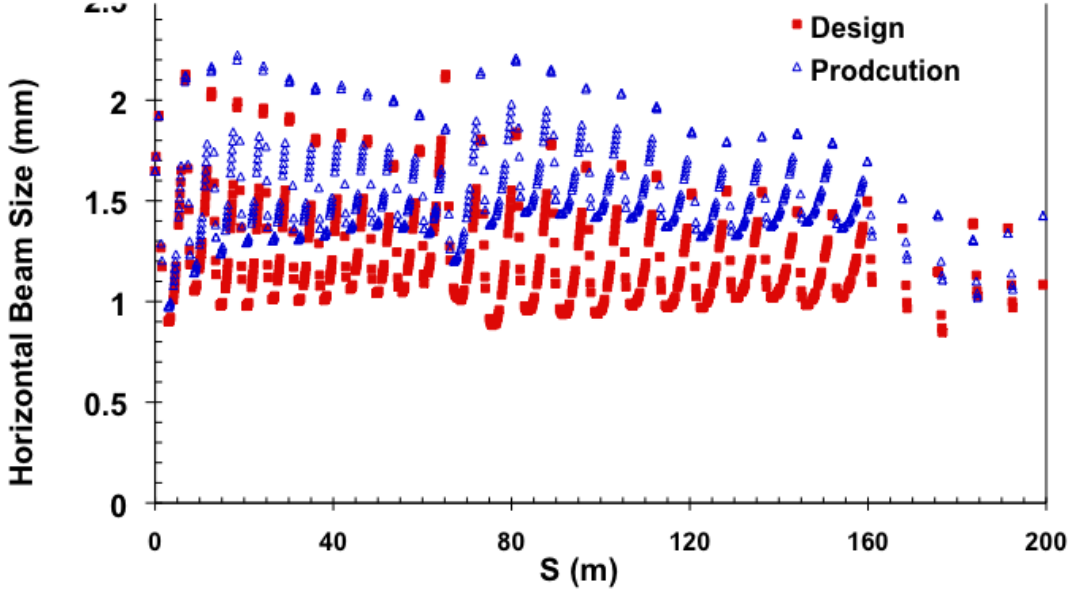


- SCL beam loss is significantly lower for the reduced field settings!!
- Empirically derived

Linac Lattice: Production vs. Design



- Longitudinal phase advance close to design
- Large decease in the transverse phase advance

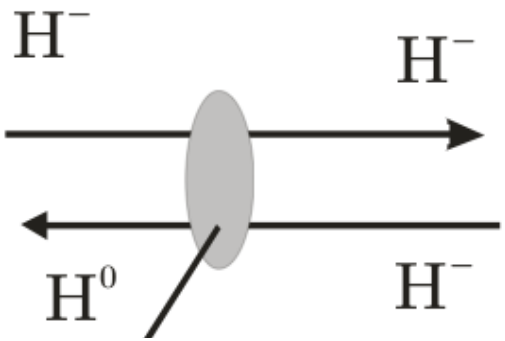


- "Production" beam is bigger
- Large aperture offers flexibility – not considered in the design

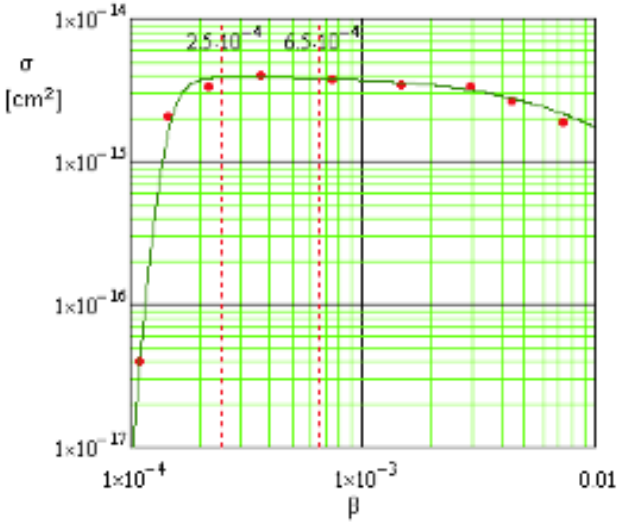
Intra-Beam-Scattering Beam Loss

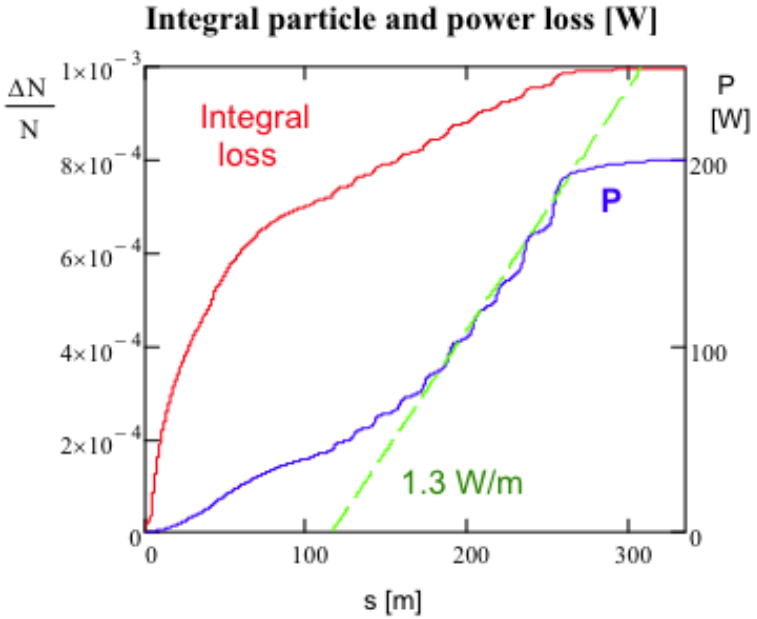
V. Lebedev, FNAL

Collisions between H- in the accelerated bunch can strip the outer electron



Stripping probability is known :

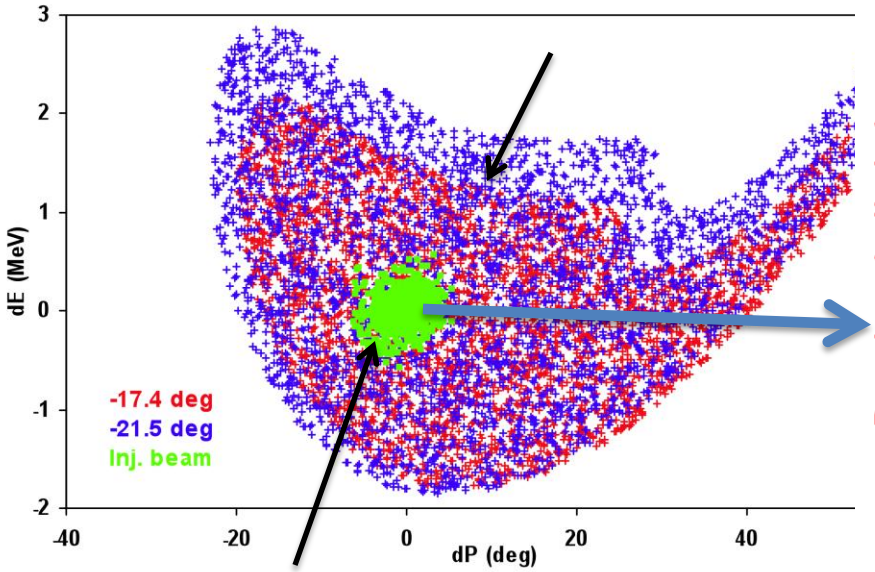




- **Simple estimates indicate this could be a loss contributor at SNS**
- **Only an issue for H^- beams**
- **SNS will test a proton source (Dec. 2010)**

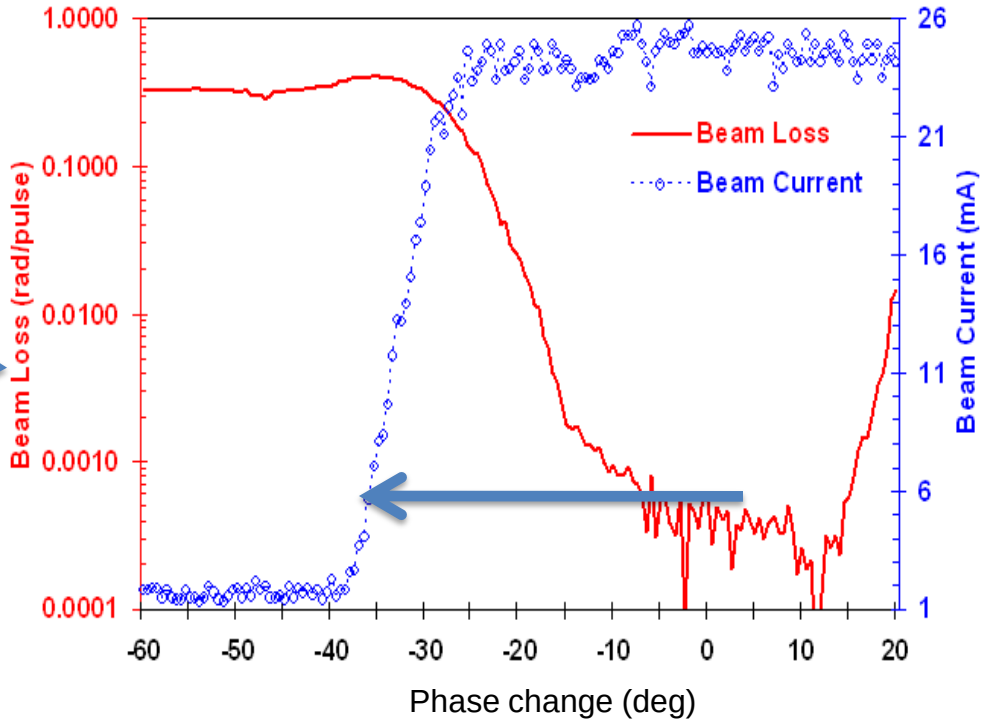
Longitudinal Beam Loss
(Y. Zhang)

Longitudinal RF acceptance is large



Model beam input distribution with enhanced tails

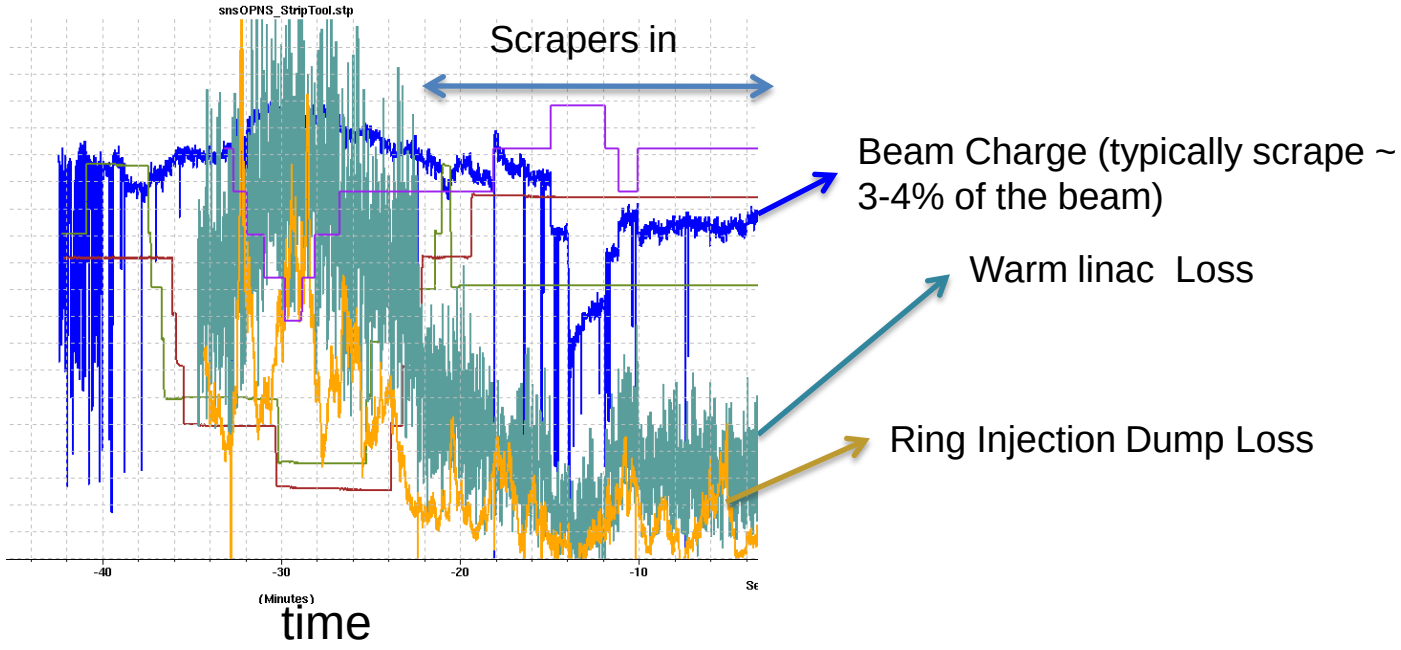
Longitudinal tail measurement: SNS SCL linac entrance



- **Longitudinal scans indicate presence of very small tails**
- **Tails can generate off-energy beam, which is not well matched to the nominal focusing channel**

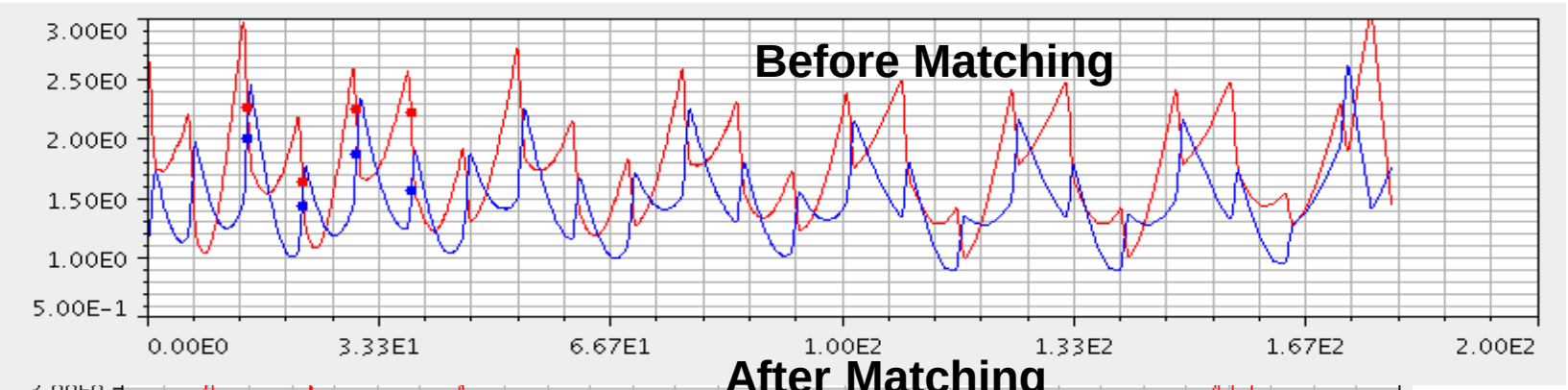
Halo Collimation – Useful Insurance

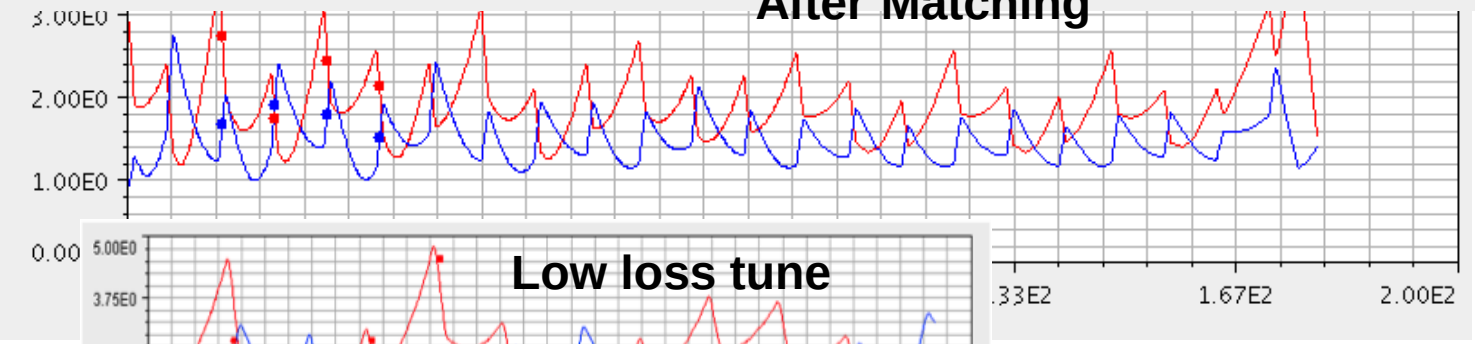
Scraping at the SNS linac entrance helps reduce loss in the linac

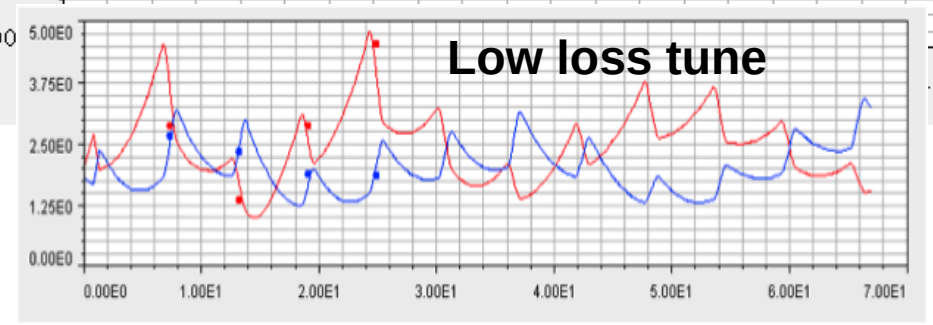


- **Scraping tails of the input beam helps reduce loss in the linac**
- **Not reproducible, setup to setup**

Transverse Matching - SCL







- **Tend to run with miss-matched beam in the SCL to reduce beam loss**

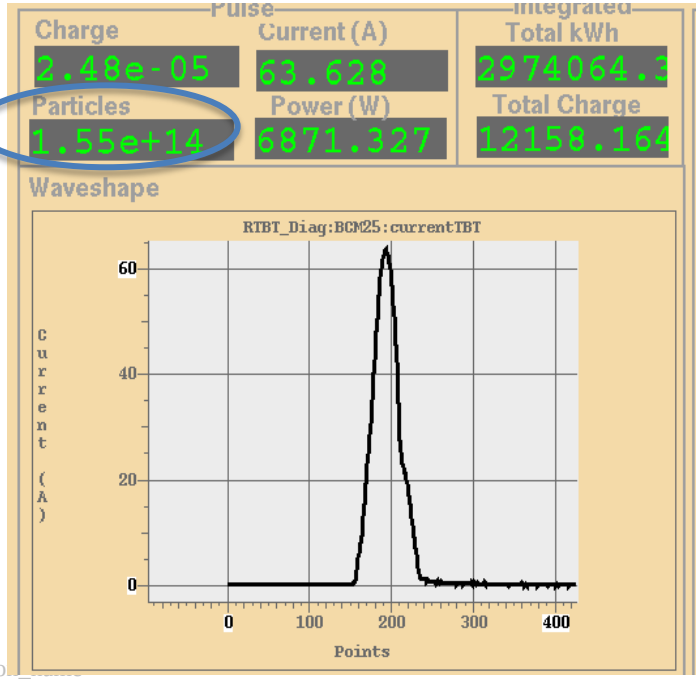
Linac Beam Loss Situation

- SNS has unexpected beam loss in the SCL
  - OK for 1 MW, not acceptable for 10 MW
  - There is a suit of measurement tools available at SNS
    - see S. Aleksandrov's talk
  - Challenge is to measure the 6-D initial beam distributions down to halo levels
  - And understand measured beam loss
- We should use the existing machines to understand the nature of this loss

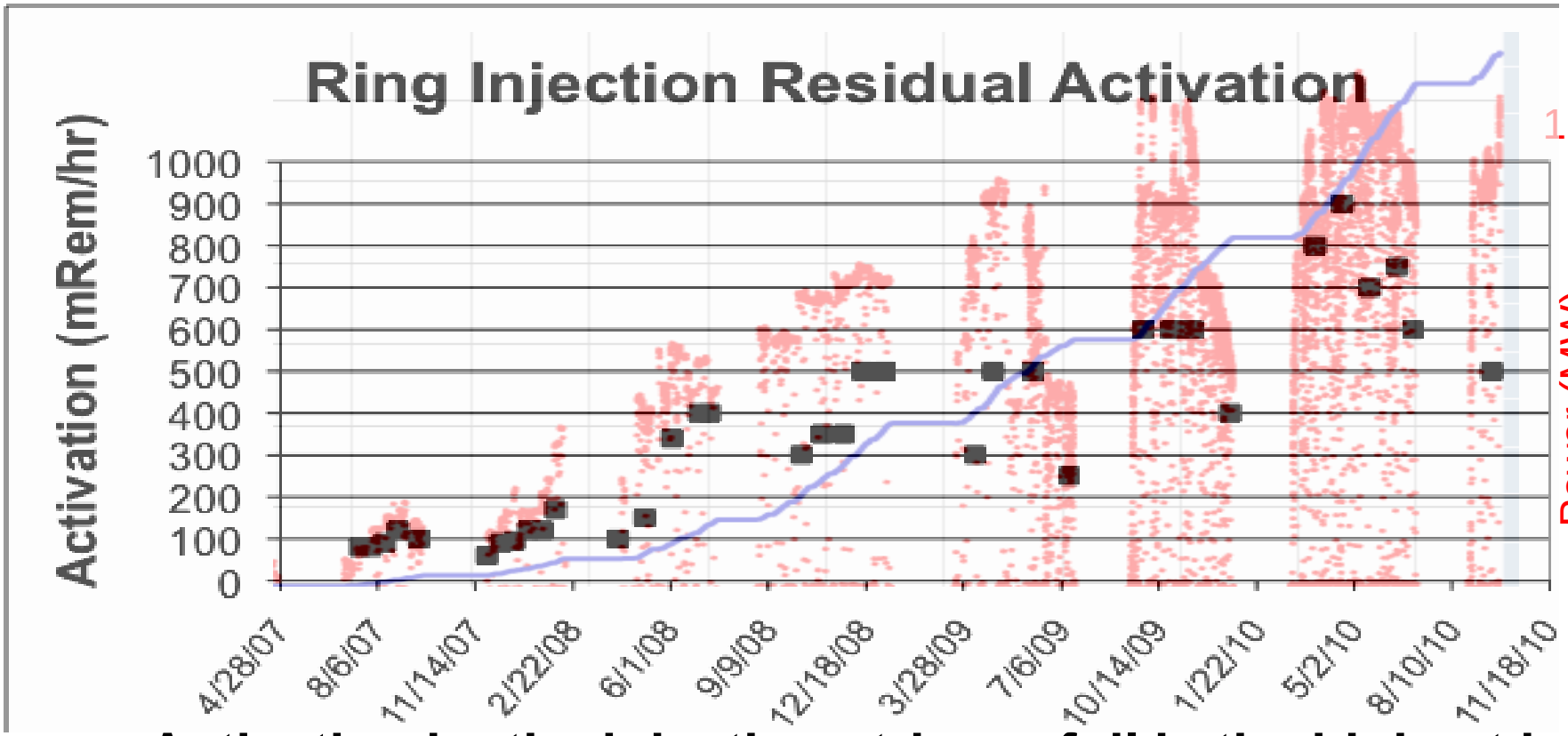
Ring Expectations / Experiences

- **For the most part the Ring has fewer surprises than the linac**
  - **We are running close to design settings, using the design tune, and painting schemes close to those planned**

We have accumulated the full design intensity (1.5 x 10^{14}) in a beam study period

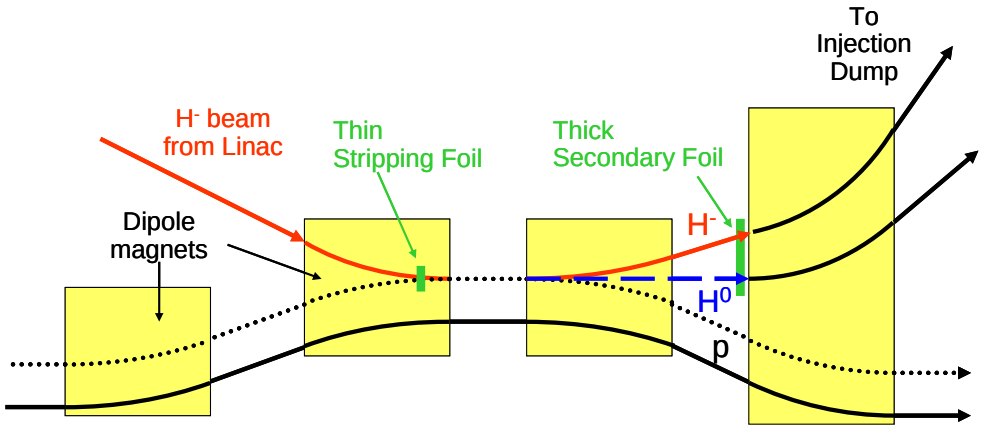


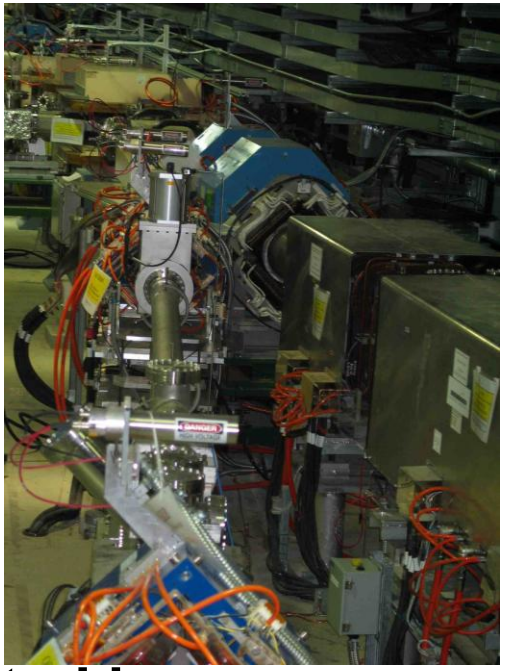
Ring Activation History



- **Activation by the injection stripper foil is the highest in the SNS accelerator**
- **Close to activation expectations**
- **~ Monotonic increase with beam power**

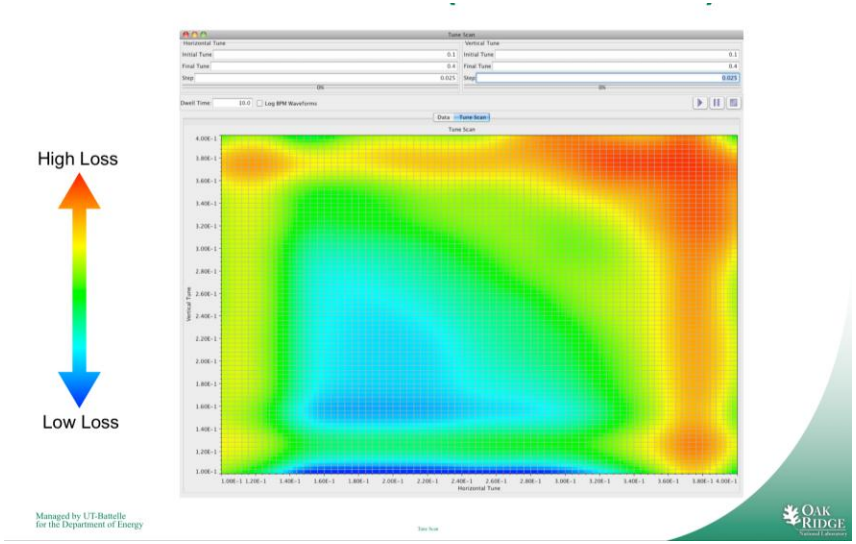
Ring Injection: More Difficult than Originally Envisioned





- Need to handle clean transport of injected beam, circulating beam, un-stripped H- beam and partially stripped H0 beam
  - Not much space
  - Careful treatment of beam transport through 3-D fields
  - Fair amount of re-work in this area at SNS

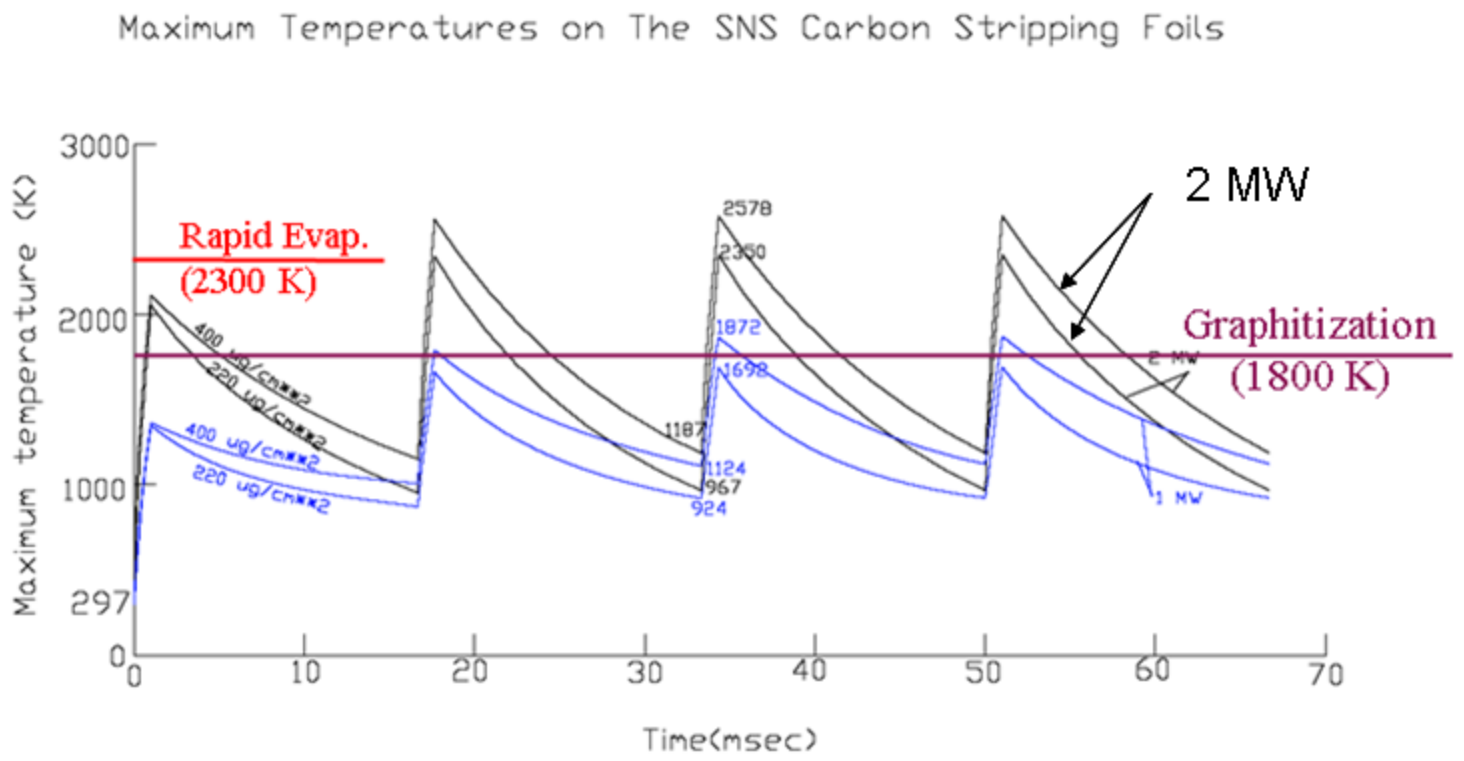
Ring Losses with Tune: Resonance Diagram (Tom Pelaia)



- **We are running at the design tune**

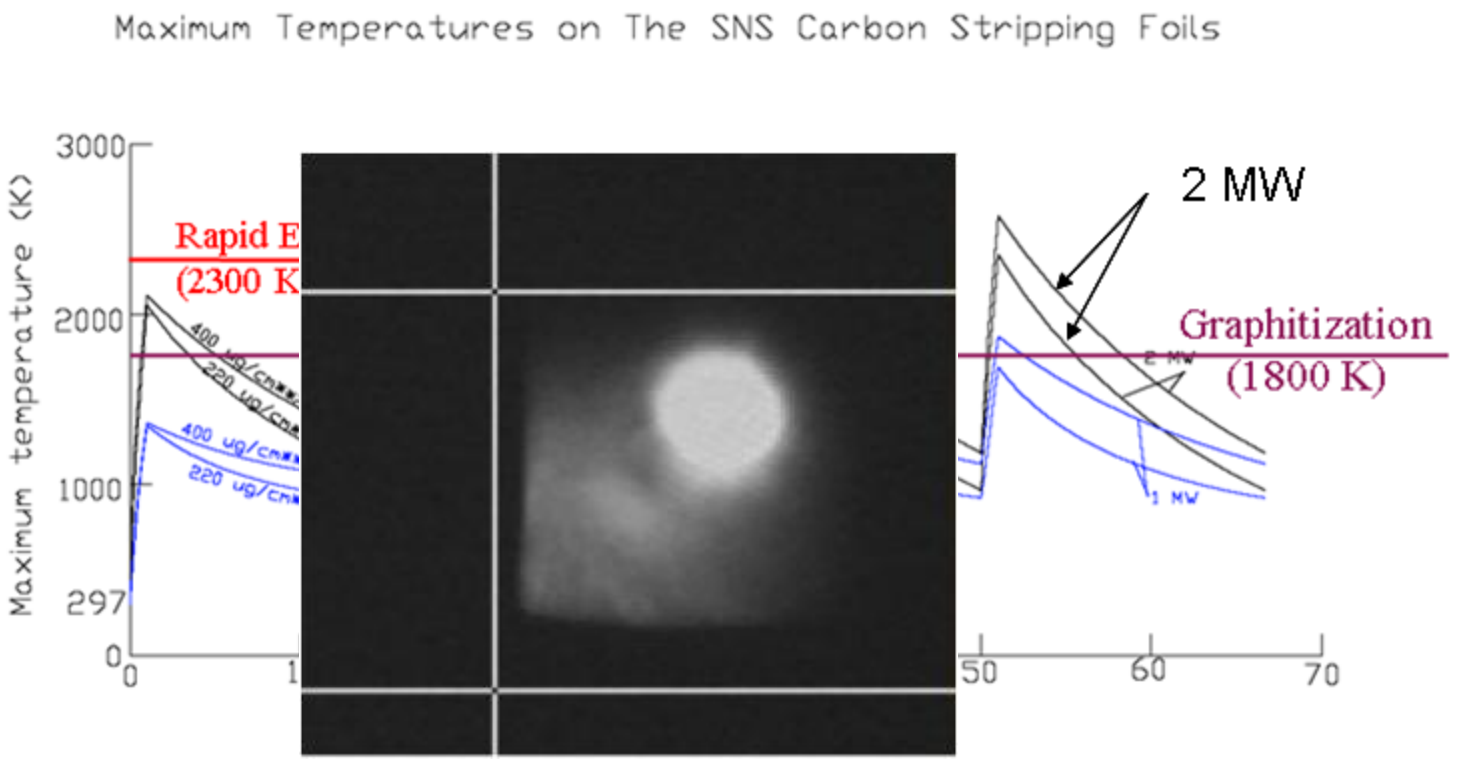
Presentation_name

Stripper Foil Surprises



- We worried about foil temperature driven foil lifetime issues in the design stage
- We did consider “convoy “ electrons

Stripper Foil Surprises



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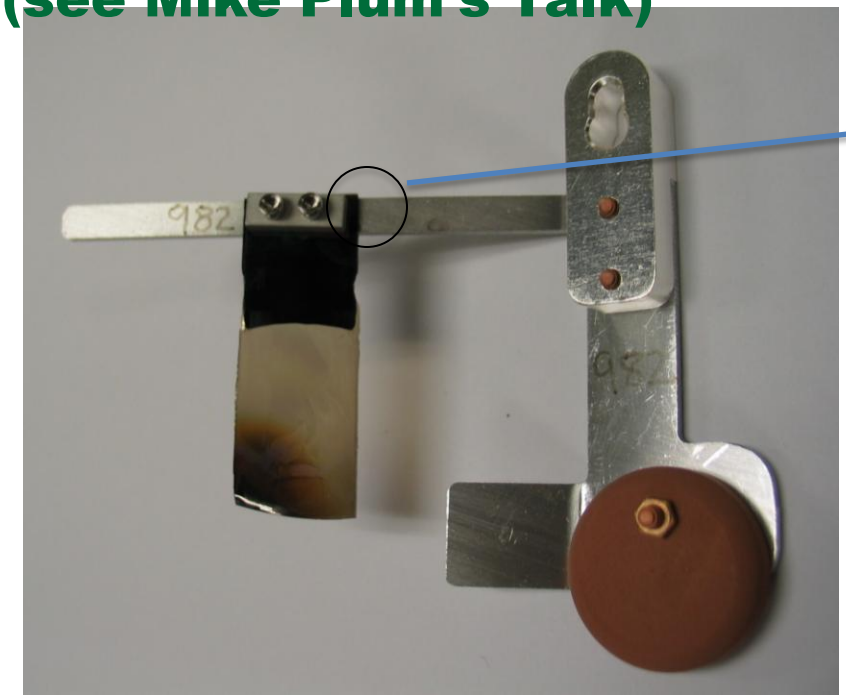
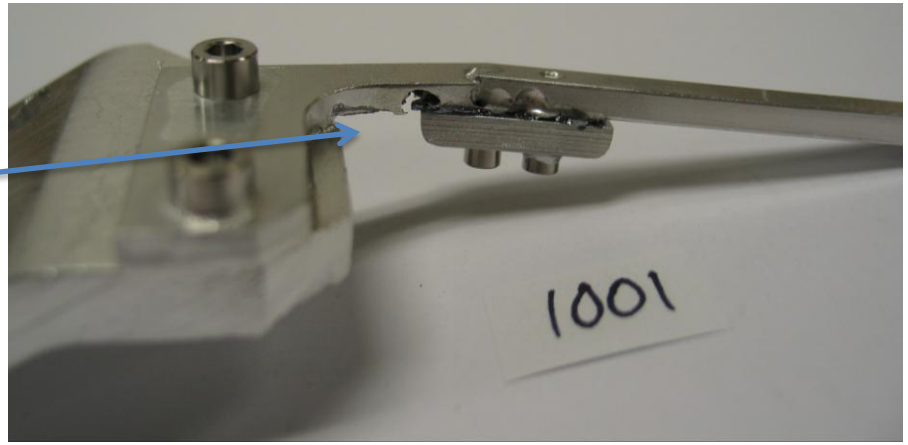
Foil - problems
(see Mike Plum's Talk)

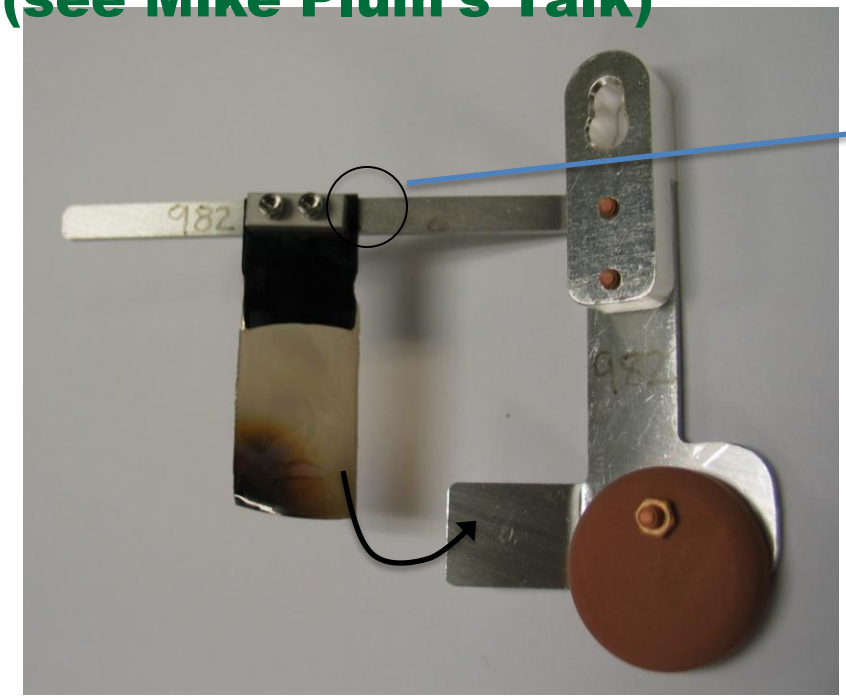


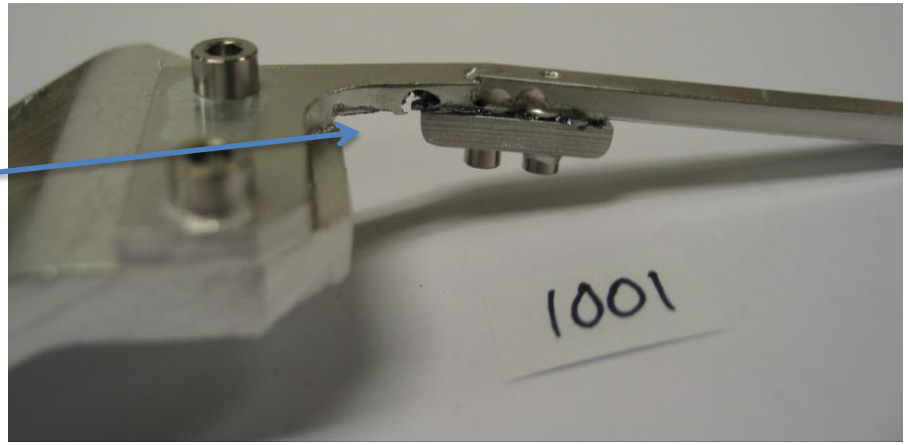


Discharge between foil / bracket

- **Foil mounting is critical**
- **Careful consideration of electron effects is important**

Foil - problems
(see Mike Plum's Talk)





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"Convoy" electron direct impact

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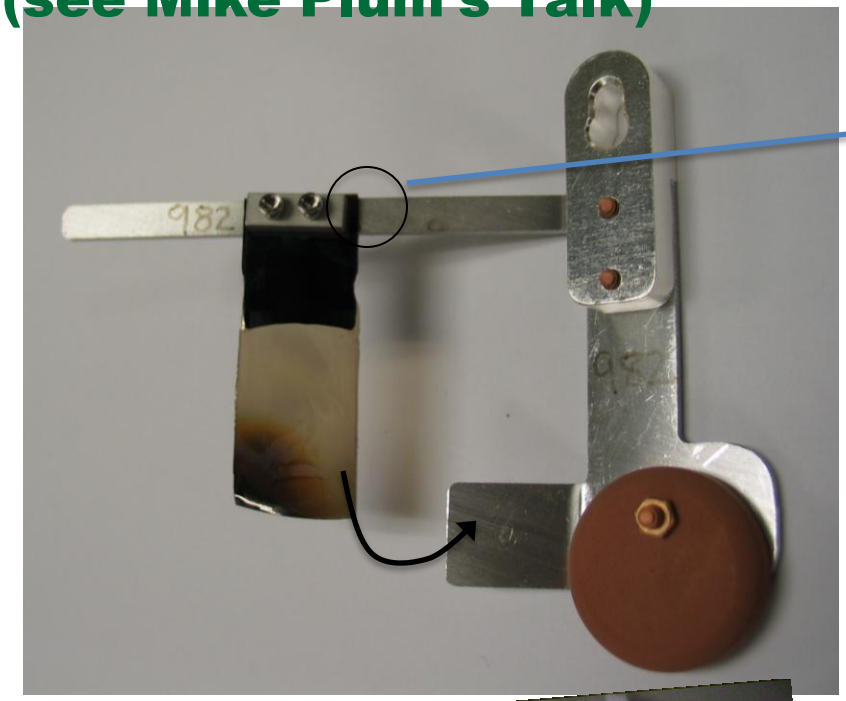

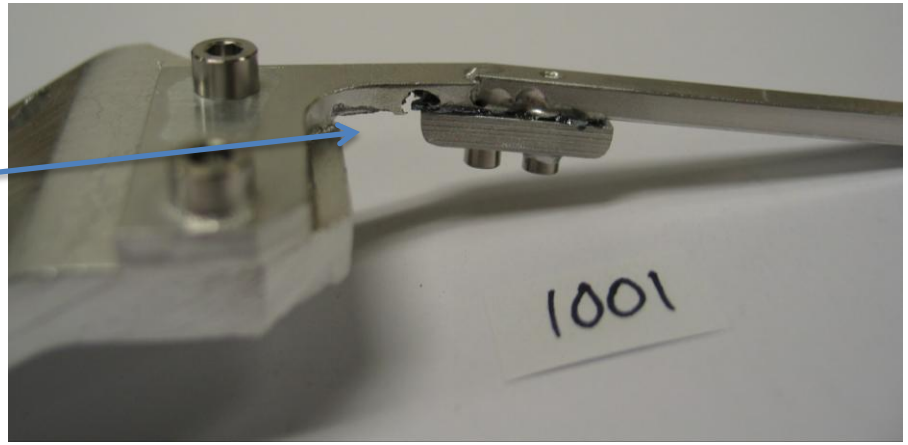

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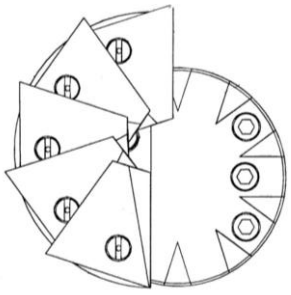
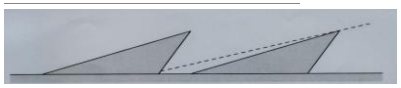
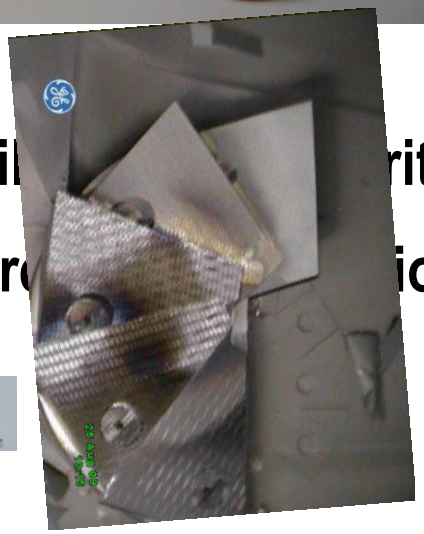






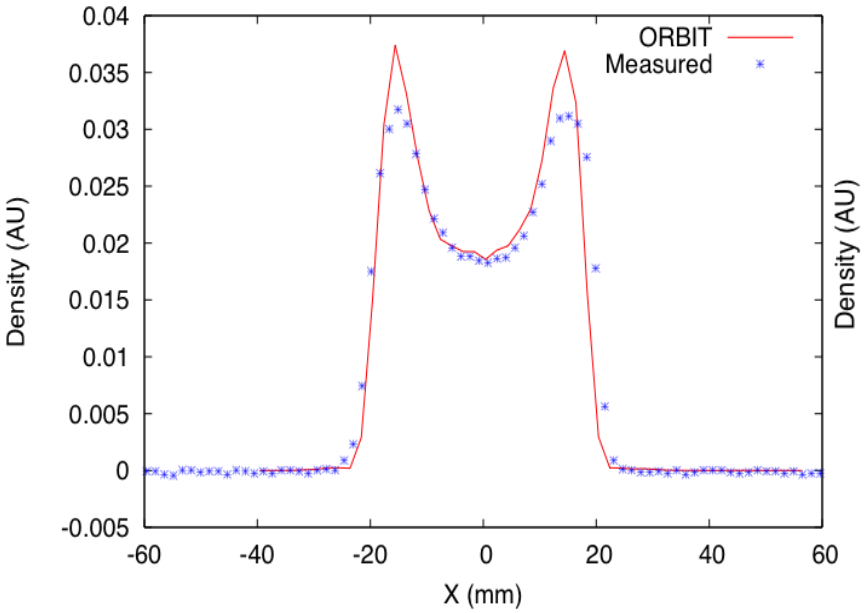
Foil ritica

Car ion of electron effects is important

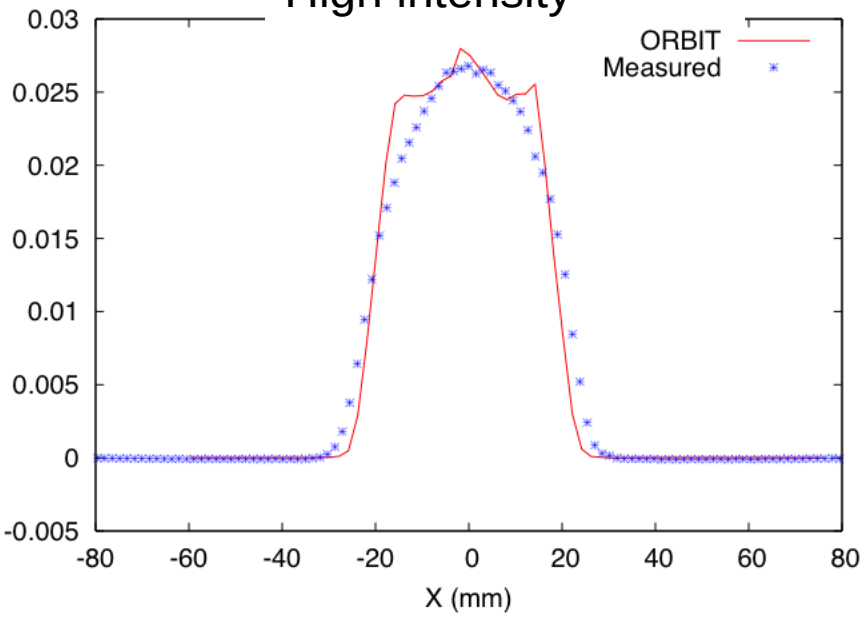
Electron "catcher" designed to capture stripped electrons – shows signs of heating on top surface

Space Charge Effects in the Ring
(S. Cousineau)

Low intensity



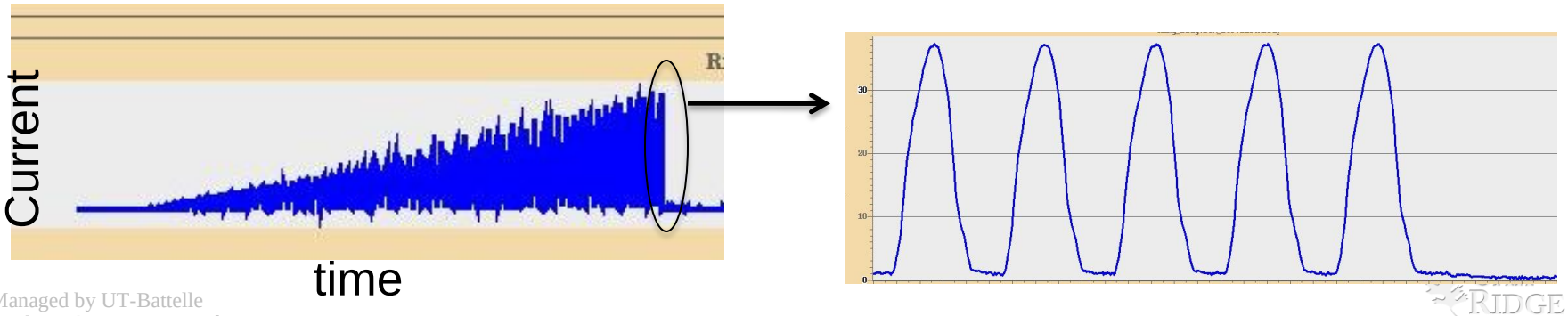
High intensity



- **Space charge effects were identified as an issue**
- **Effects are as expected, at least to "first order" - profile measurements vs. models**
  - **Benchmarks are useful for identifying equipment issues**

Clean Extraction from the Ring: No Problem

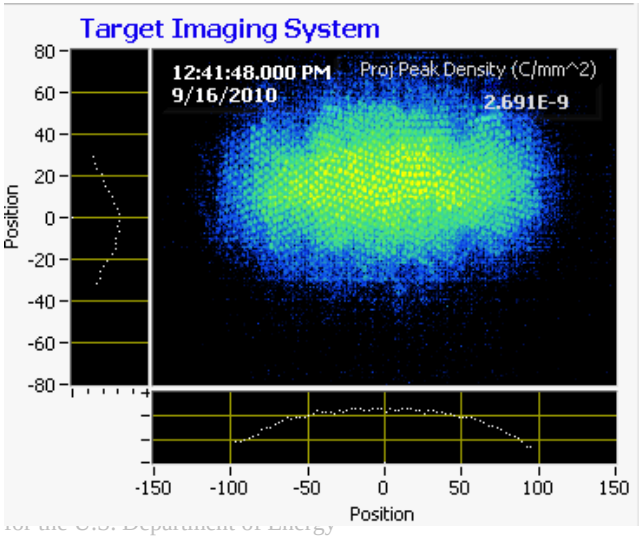
- We have only used second stage chopping for the past ~ one year
  - 1st chopper stage is slow rise time (~100 nsec) LEBT chopper
- We never implemented a planned "Beam-in-Gap" kicker to clean the gap
- We are running a smaller gap than initially planned (up to 75% beam vs. 68% beam)



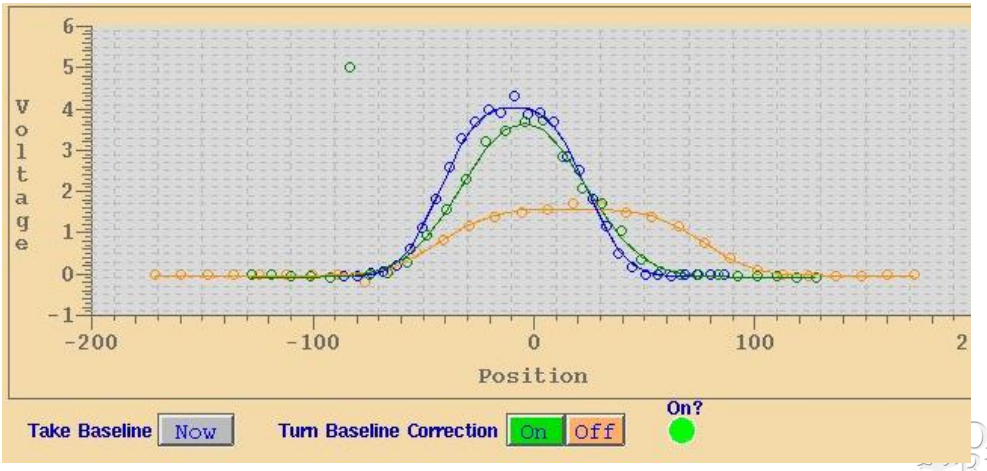
Targets, Dumps, Collimators: More trouble than we imagined

- **High power operation requires good understanding and control of primary and waste beams**
- **Redundant safety systems – avoid excessive nuisance trips**

Direct measurements (beam position, power density, …) are easier than….

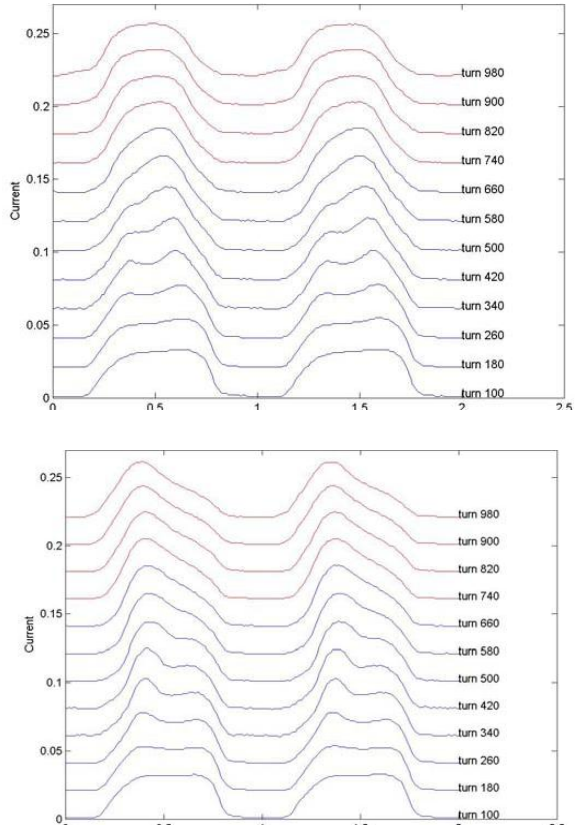


Model based extrapolations from upstream measurements

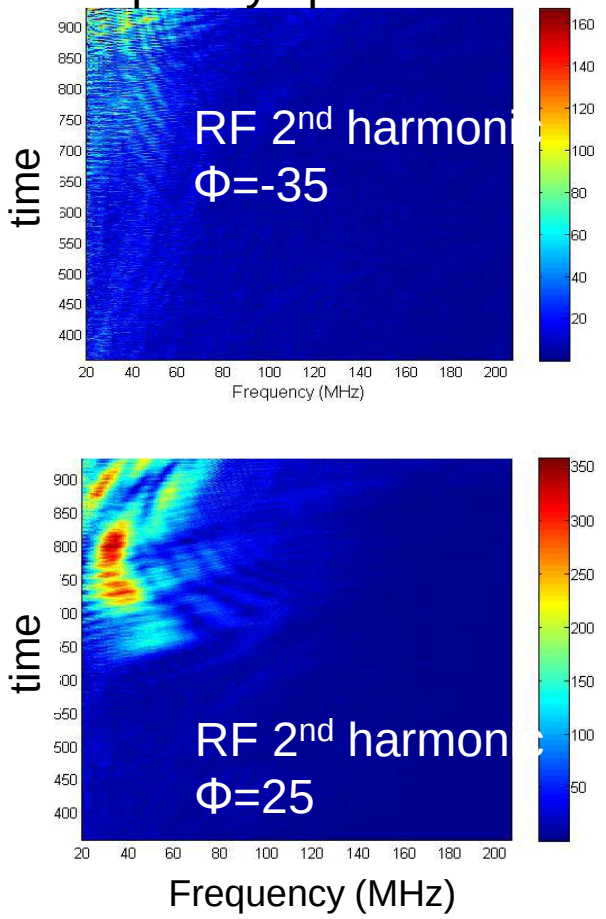


E-p Instability: yes, we can observe it!

Bunch shape during accumulation



Frequency spectra of beam motion



- E-p does not limit normal beam operation
- We can produce conditions to study it
  - Bunch shape matters !

Summary

- The SCL has offered surprises
- The Ring is challenging, but running close to design
- The future
  - Still have 40 – 50% more margin in existing equipment
  - We are embarking on a power upgrade
    - 1.3 times energy increase: funded project
    - 50% current increase
  - Second target station

Post-facto View of the SNS Ramp-up Experience

Post-facto View of the SNS Ramp-up Experience

- **We (accelerator community) understand how to build and operate pulsed MW class devices**