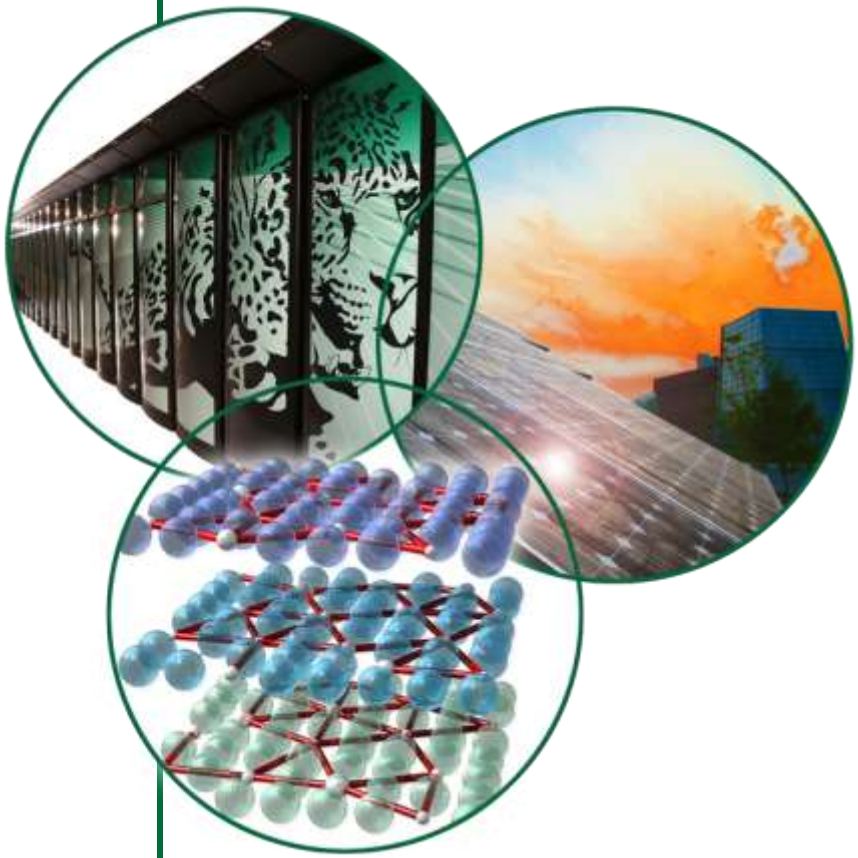
Accelerator Physics Overview

J. Galambos

Accelerator Advisory Committee

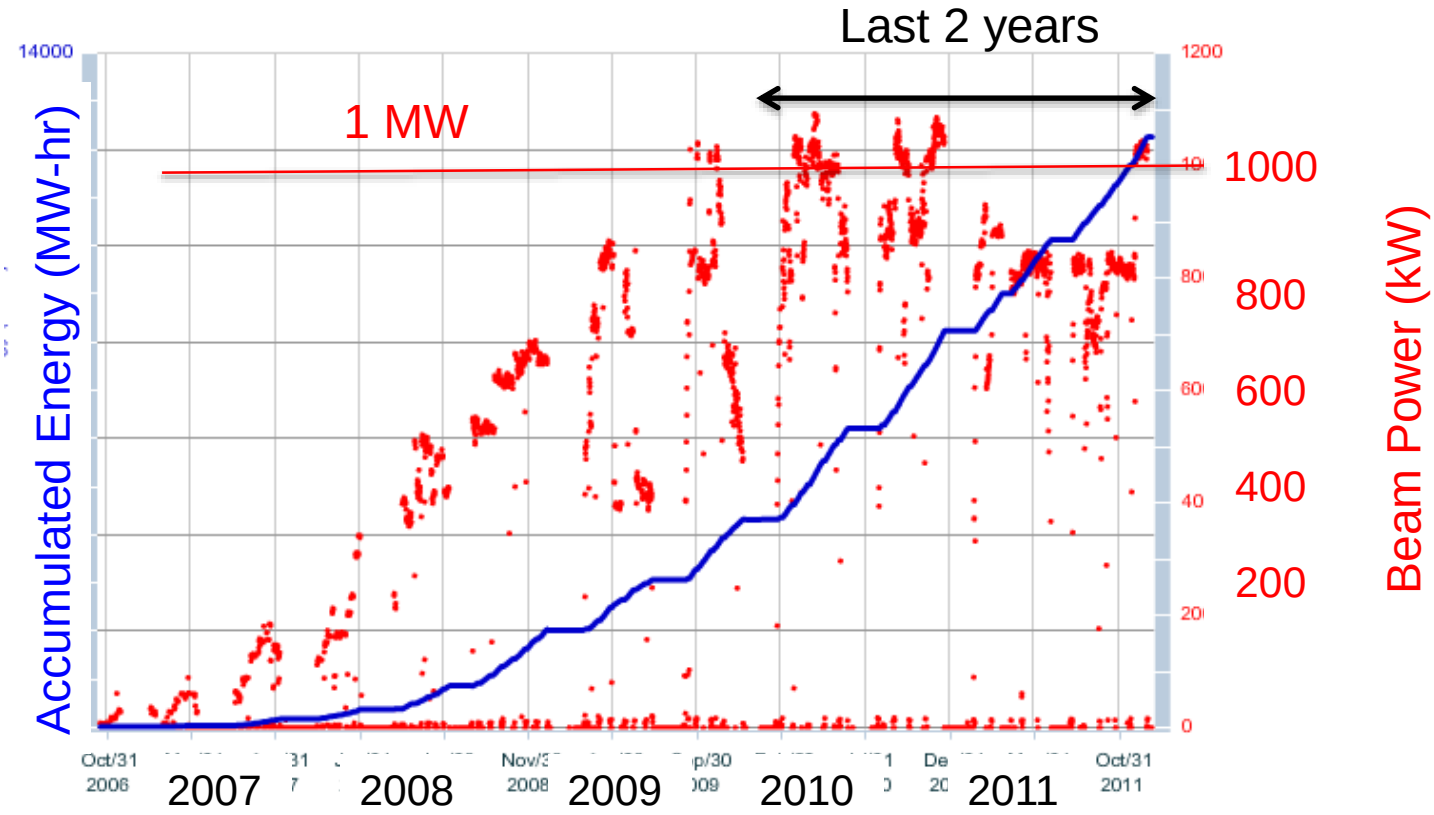
Jan. 10-12, 2012



U.S. DEPARTMENT OF ENERGY

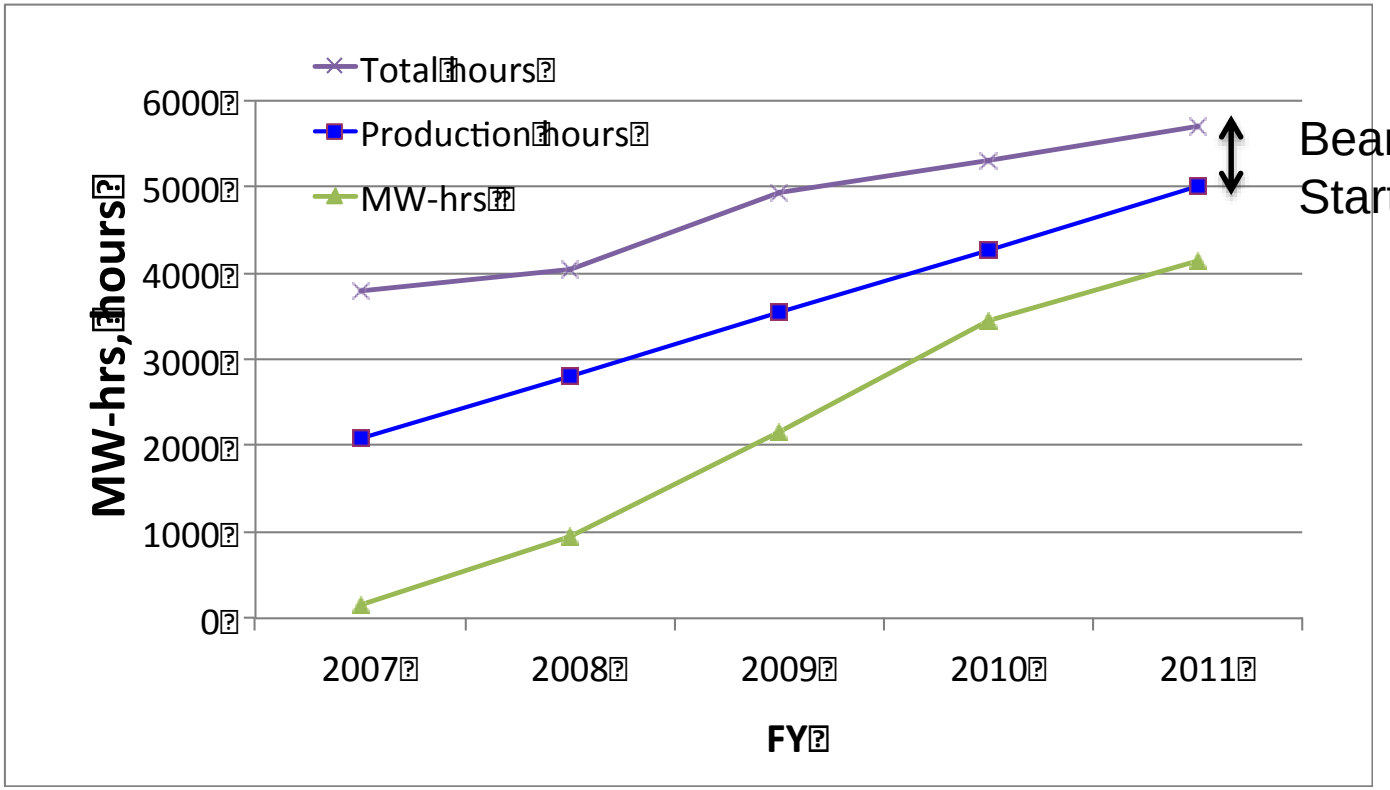
OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

SNS Operates at ~ 1 MW



- **Have not increased the beam power in the last 2 years**
  - **Steady high power operation**
  - **Simpler beam restoration (shutdown / maintenance)**

Approaching Final Annual Operational Hour Goal



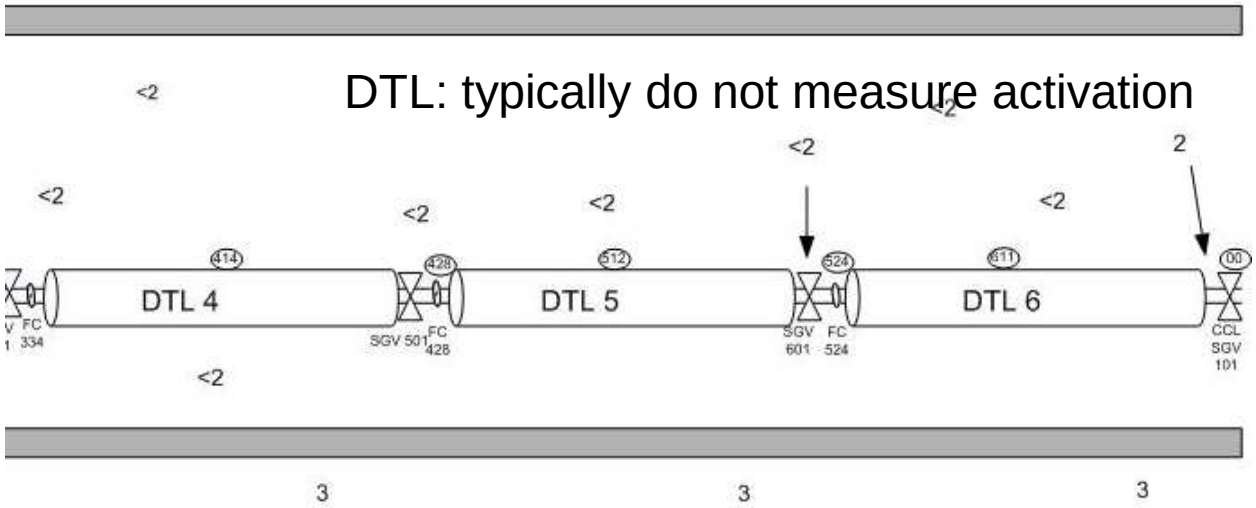
- There is less time available for beam studies / startup
  - Approaching Steady-state
  - Adequate time for beam studies

Production Beam Setup

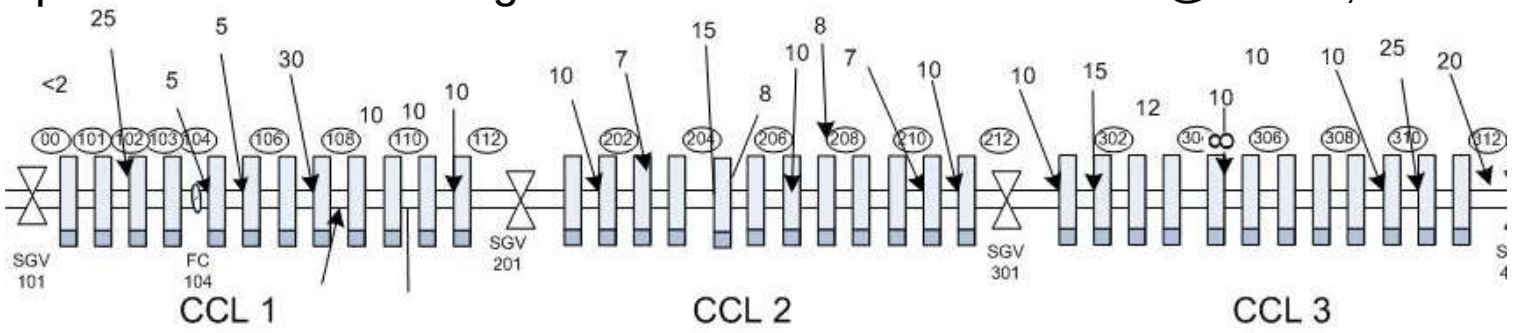
- Reproducing a “golden” setup – easier than constant power increases
  - Restoration after extended outages faster
  - Restoration after maintenance days by operations staff
- High level applications help (XAL)
  - Snapshot capabilities for beam in transverse and longitudinal space along the linac
  - Good for diagnosing equipment problems
- Should avoid a false sense of security!
  - Power increases (to 1.4 MW and beyond) will not be so easy

Activation in the Warm Linac

October 2011 Activation surveys

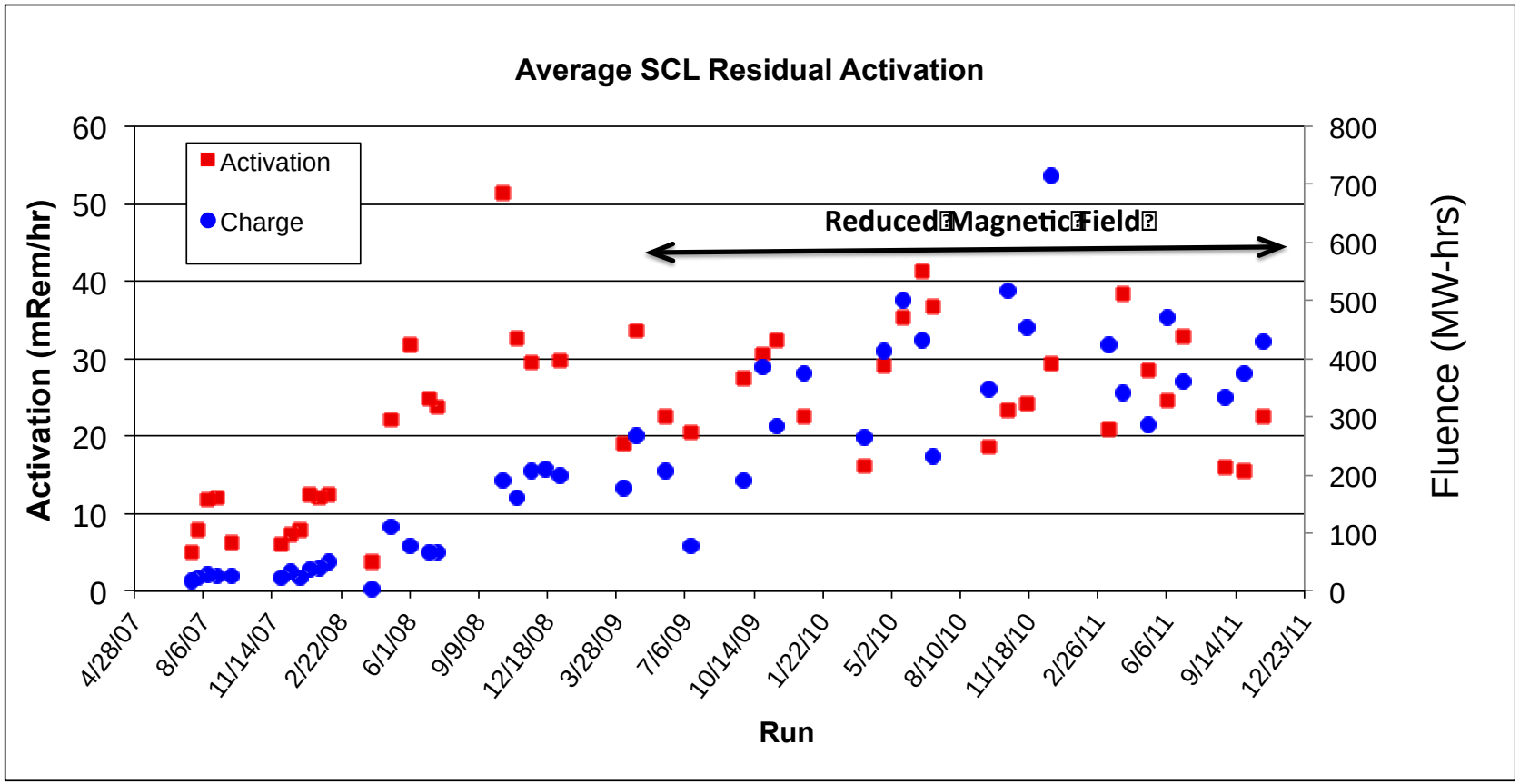


CCL: Spots between CCL segments show 10-50 mRem/hr -@30 cm, 24 hr cooldown



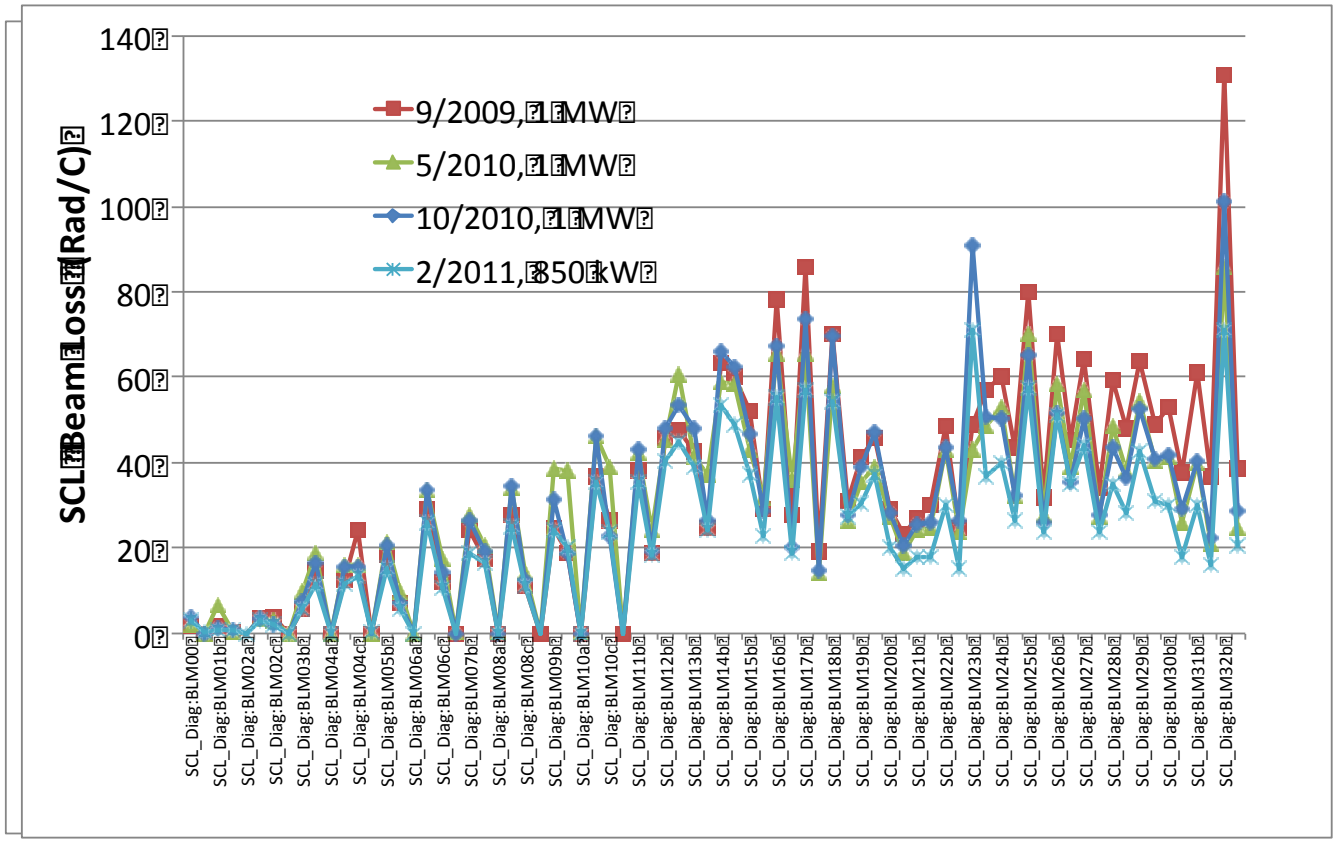
- **Warm linac beam loss is not a constraint**

Beam Loss in the Superconducting Linac



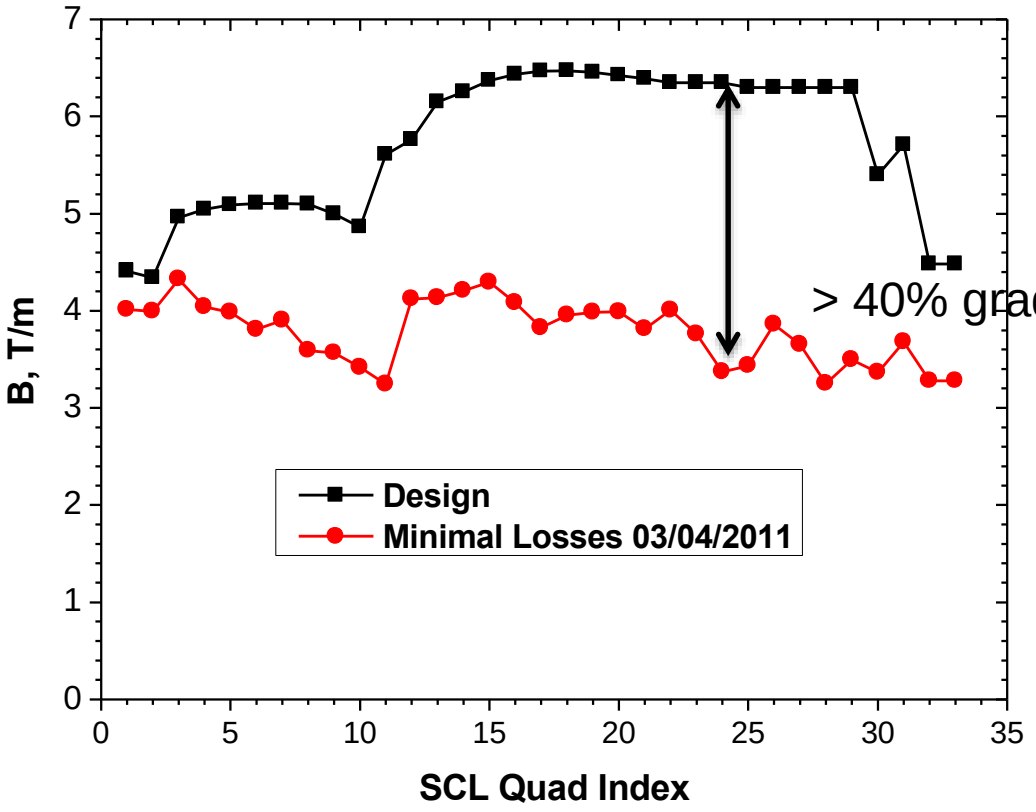
- **SNS observed a low level of beam loss / machine activation**
  - **Unexpected!**
  - **OK for 1 MW, does not restrict operations, but unexplained**

SCL Beam Loss



- Consistent loss pattern observed over years
- Reduction corresponds to reduced focusing strength

Reduced Focusing Strength in the SCL

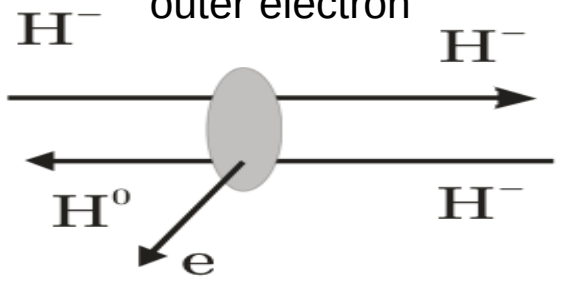


- Beam loss was reduced by lowering the SCL quadrupole strengths
  - Motivation was thought that off energy beam may be better transported
  - The large SCL aperture permits increased beam size

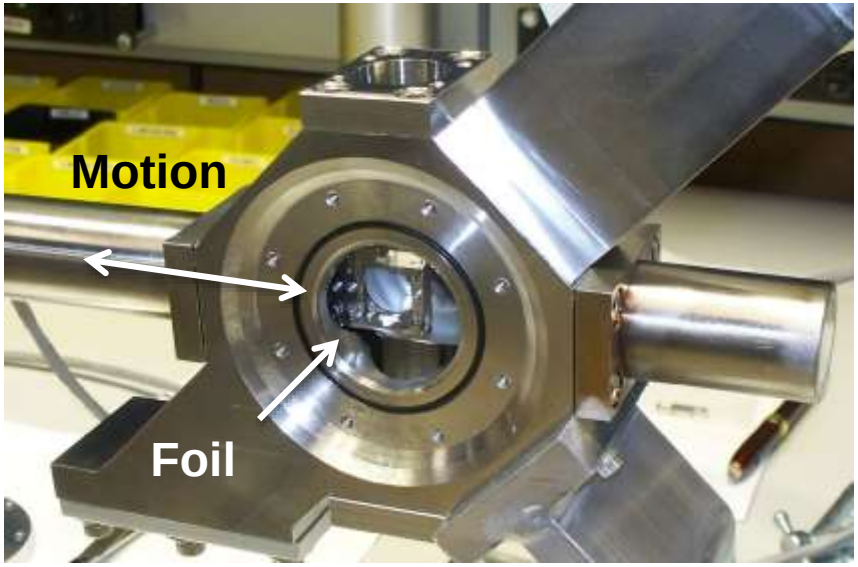
Proton Beam Experiment at SNS

- SNS beam loss explanation: related to H^- stripping by self collisions
  - V. Lebedev, FNAL

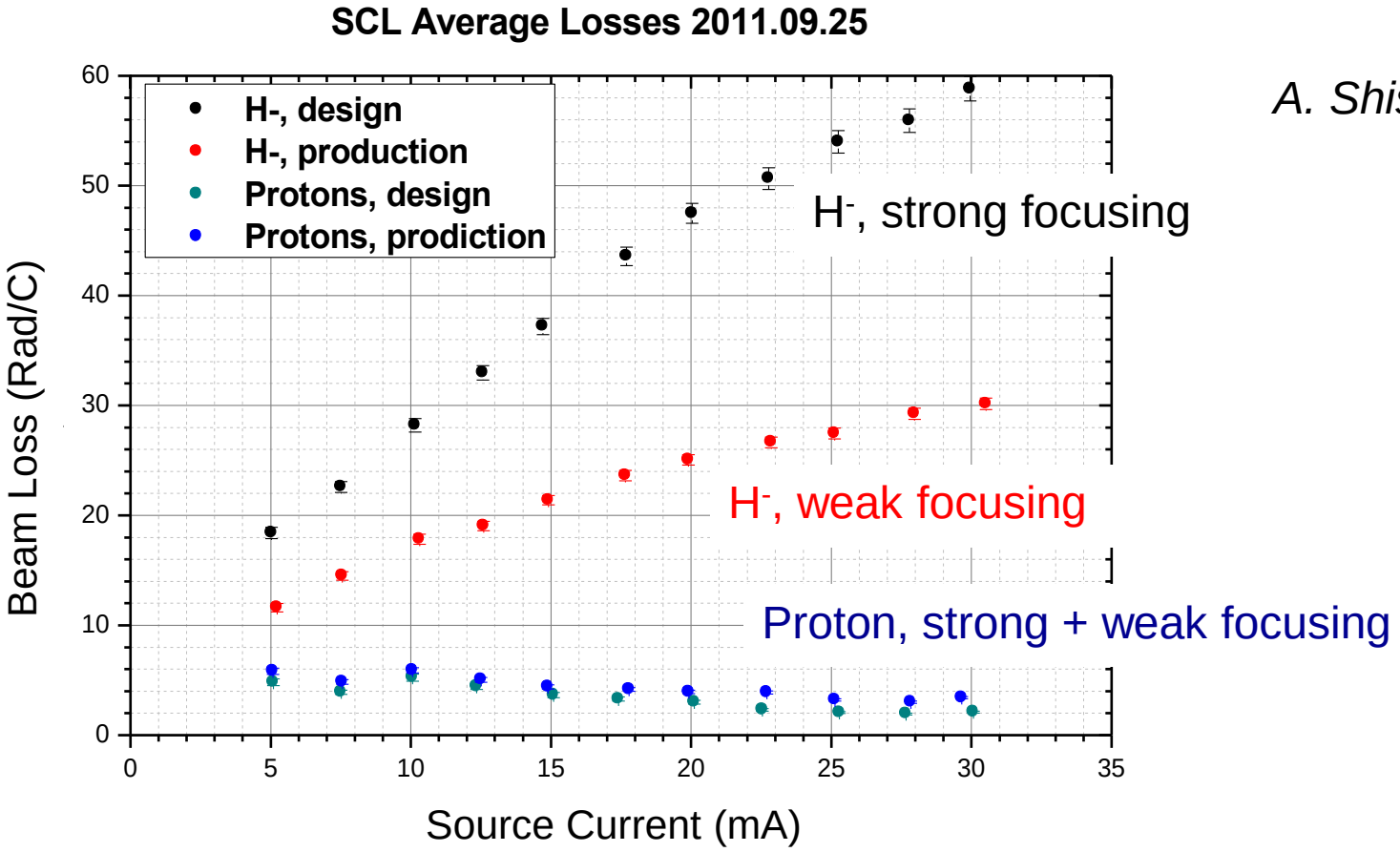
Collisions between H- in the accelerated bunch can strip the outer electron



- Recently added an insert-able thin foil upstream in the SNS linac (A. Shishlo)
  - Converts H^- to protons
  - Adjust a few quadrupoles and flip all RF by 180 degrees:
    - A proton linac!!!



Proton Beam Loss is much lower than H^-



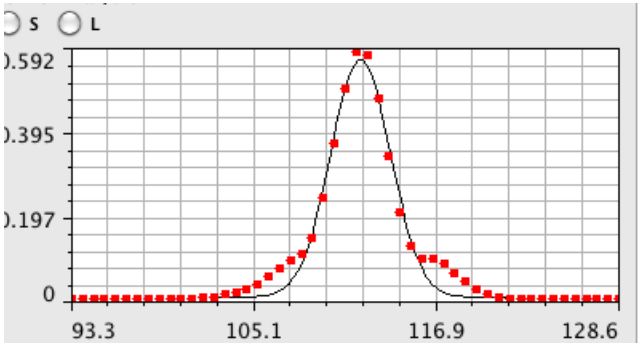
A. Shishlo et al.

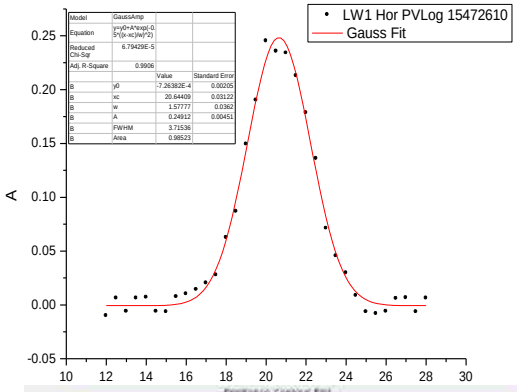
- **Measured beam loss in the SNS linac is much lower for protons than for H^-**
  - **Trends are consistent with "Intra-beam stripping"**
  - **Submitted to PRL**

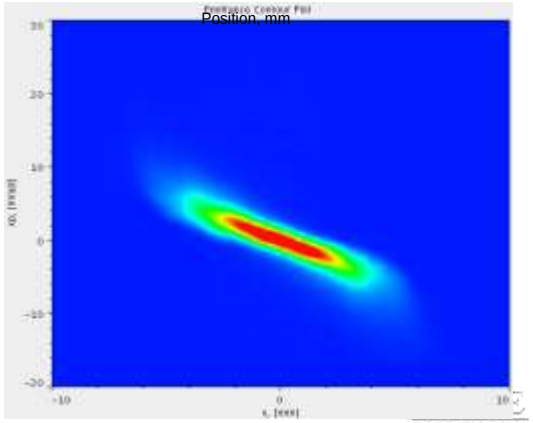
Linac Beam Dynamics

- Focus has been on beam envelope RMS size (intra-beam stripping)
  - But there are significant tails / halo in the linac beam
- Laser profile measurements in the SCL are becoming less expert based tools (see S. Aleksandrov's talk)
- Have implemented emittance measurements in the MEBT and HEBT (see S. Aleksandrov's talk)
  - Should be a valuable combination

H^-







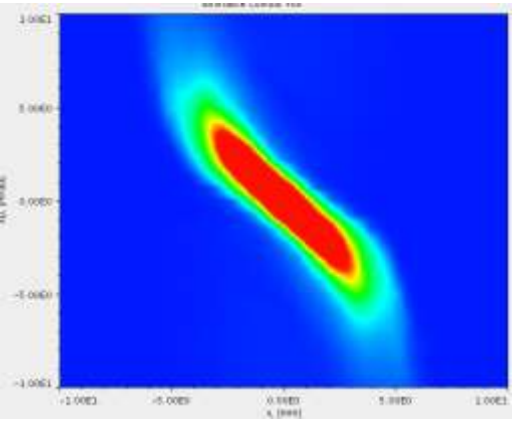
SCL RF Setup

- Have developed beam based tool to facilitate setup
- "Automated" RF setup application
  - 3 hours to setup all 80 cavities
  - faster than the 10 warm linac cavity setup!!!
- Model based scaling to accommodate cavity gradient reductions
  - Have to do this during operations occasionally

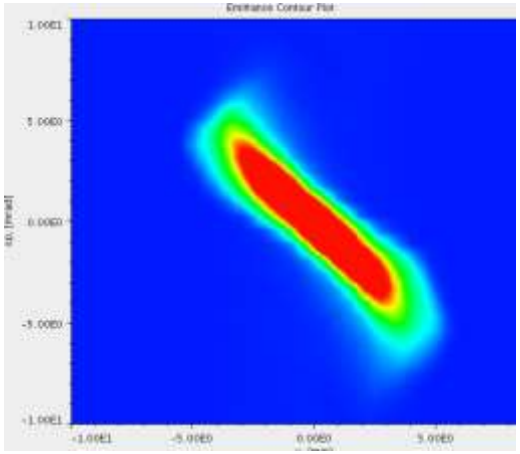
MEBT Scraping

- **2 horizontal MEBT scrapers**
  - **Standard part of production**
  - **Reduces linac and injection dump losses**
  - **Effectiveness in loss reduction varies from source to source**

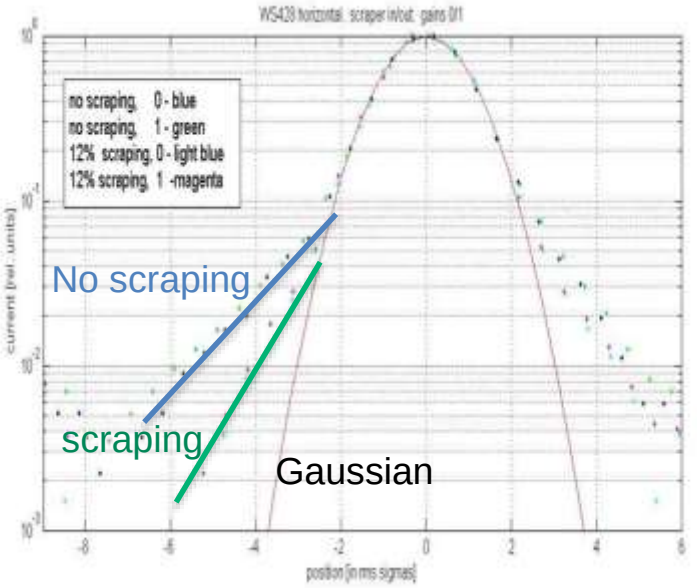
MEBT Emittance without scraping



MEBT Emittance with scraping

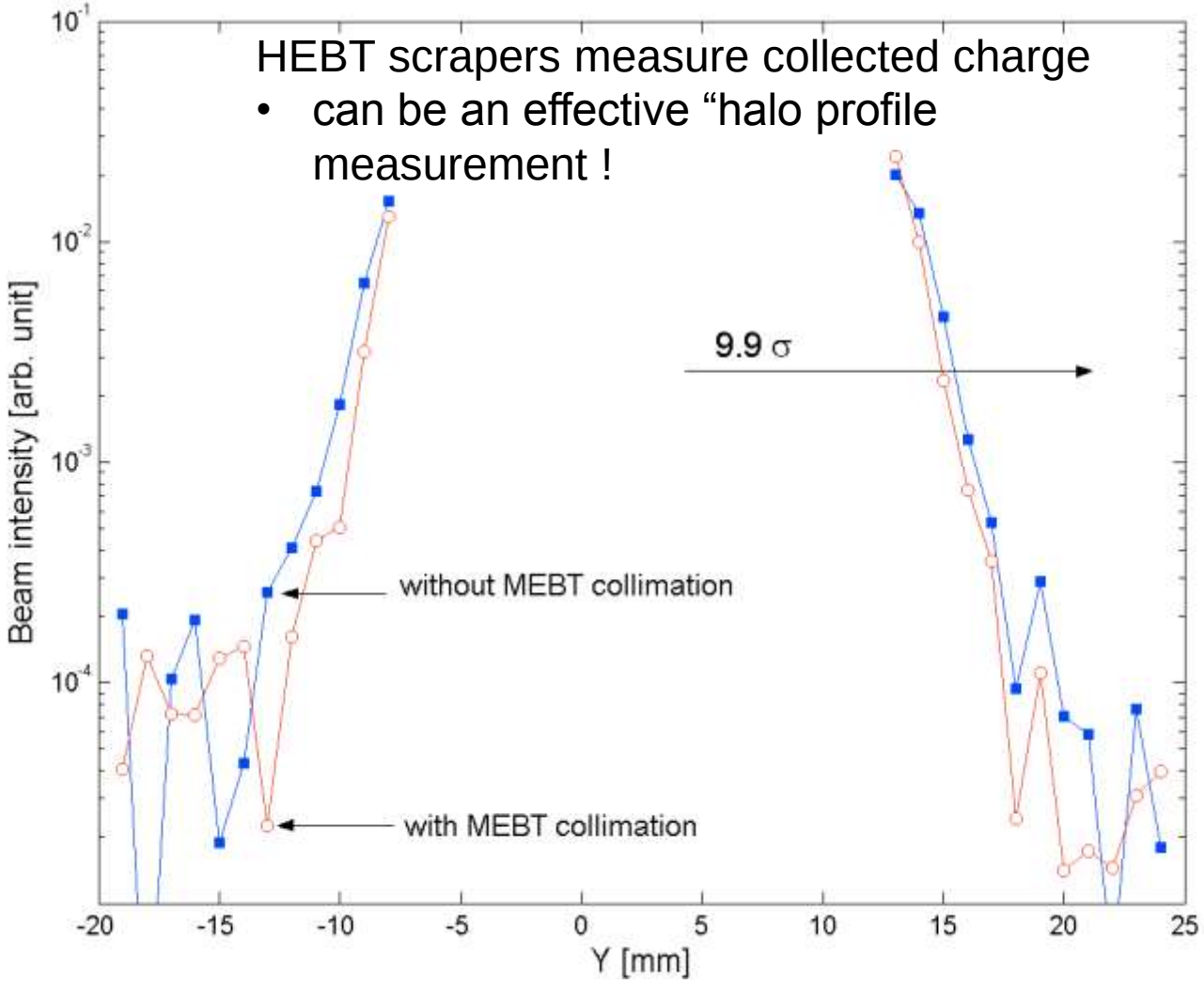


DTL profile, log scale

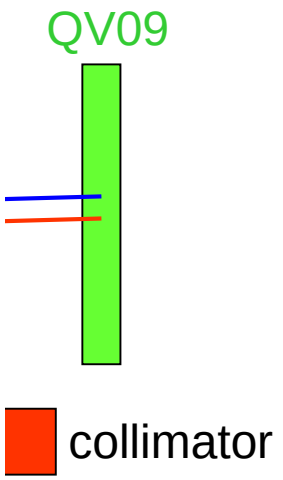


HEBT Scraping

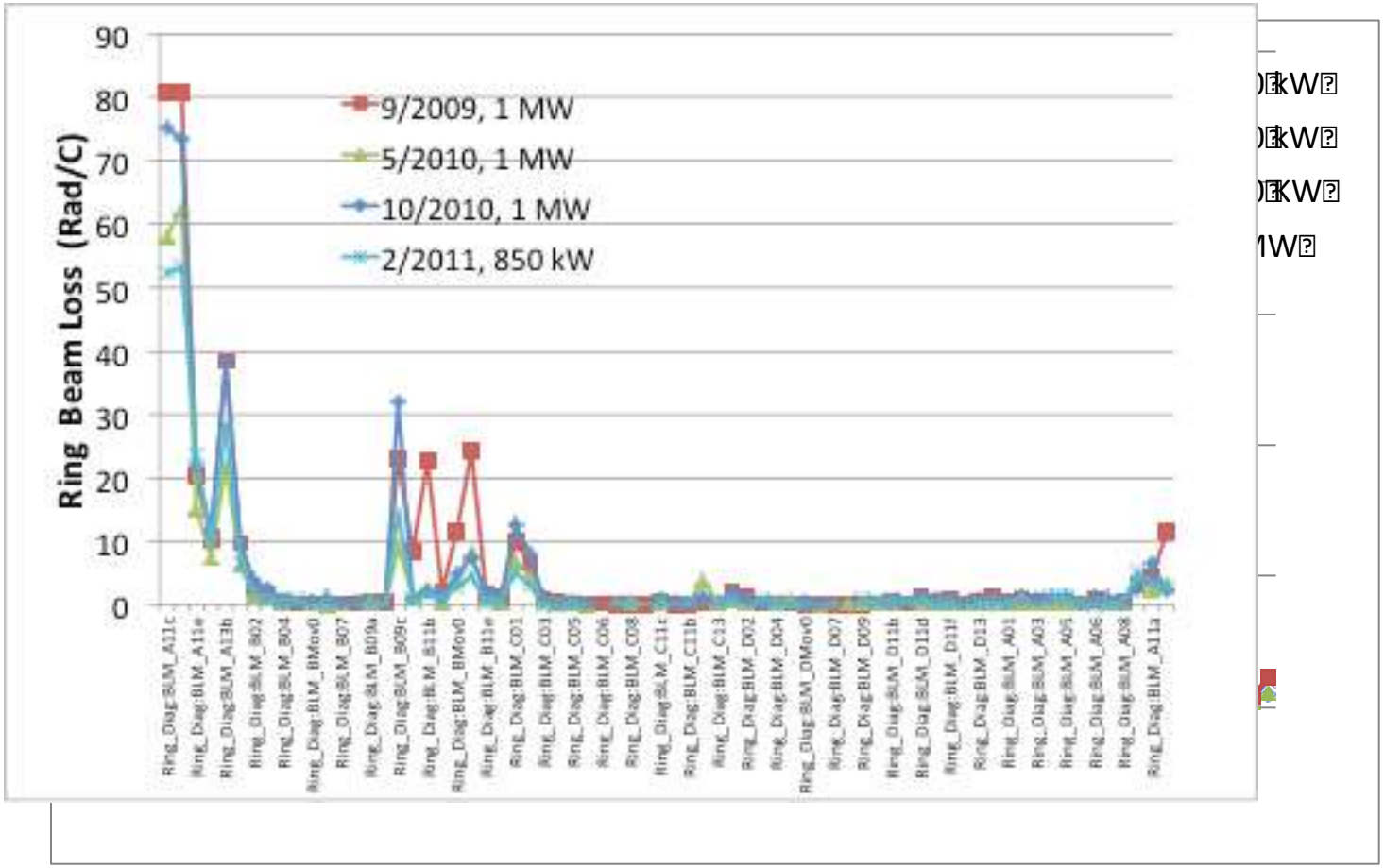
- **HEBT vertical and momentum scraping is effective in**
-



predictions

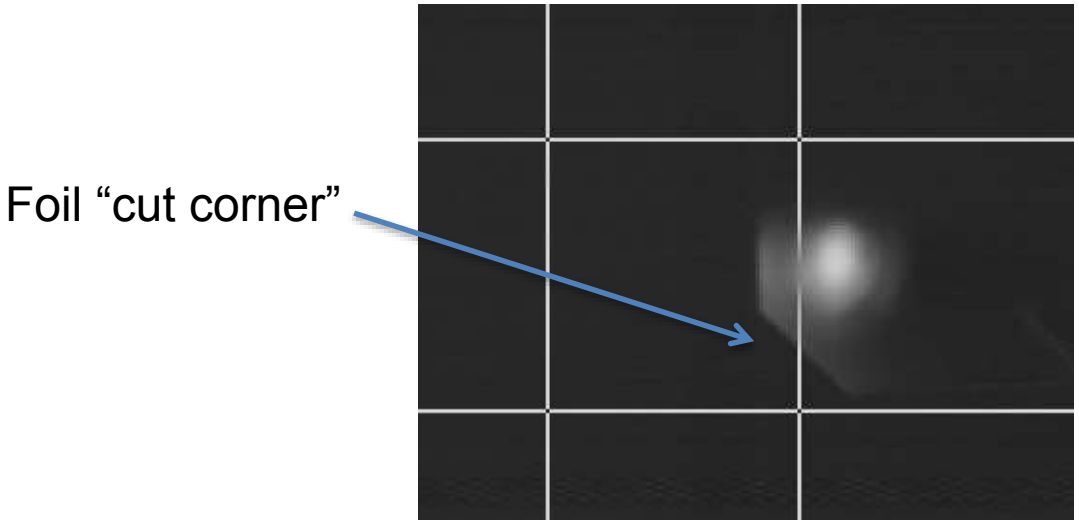


Ring Beam Loss



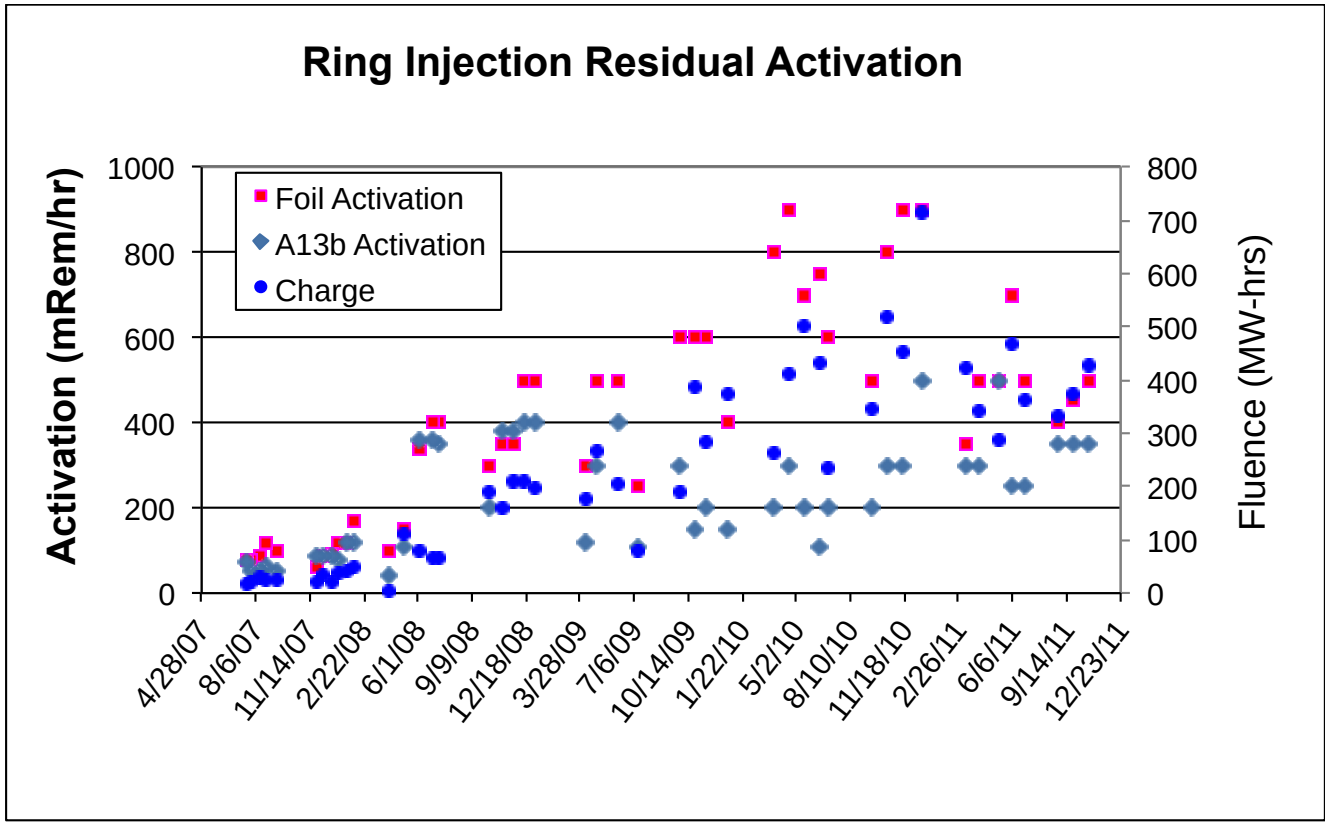
- Ring injection is where the losses are
- Still making modest gains in reducing the beam loss

Ring Injection Stripper Foil
(M. Plum's talk)



- **Cut corner reduces circulating beam hits (and loss at injection)**
- **Would like to pull the beam even closer to the edge**
  - **Foil stability is an issue**
  - **Transport of "tails" to the I-dump**
  - **50 kW "self-imposed" beam power limit to the dump**

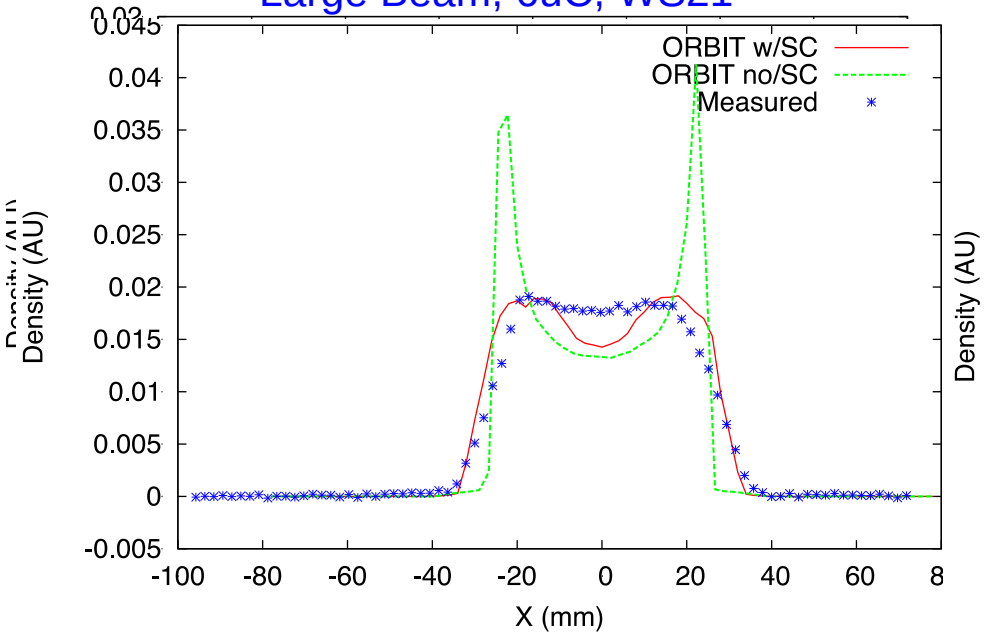
Ring Residual Activation Buildup



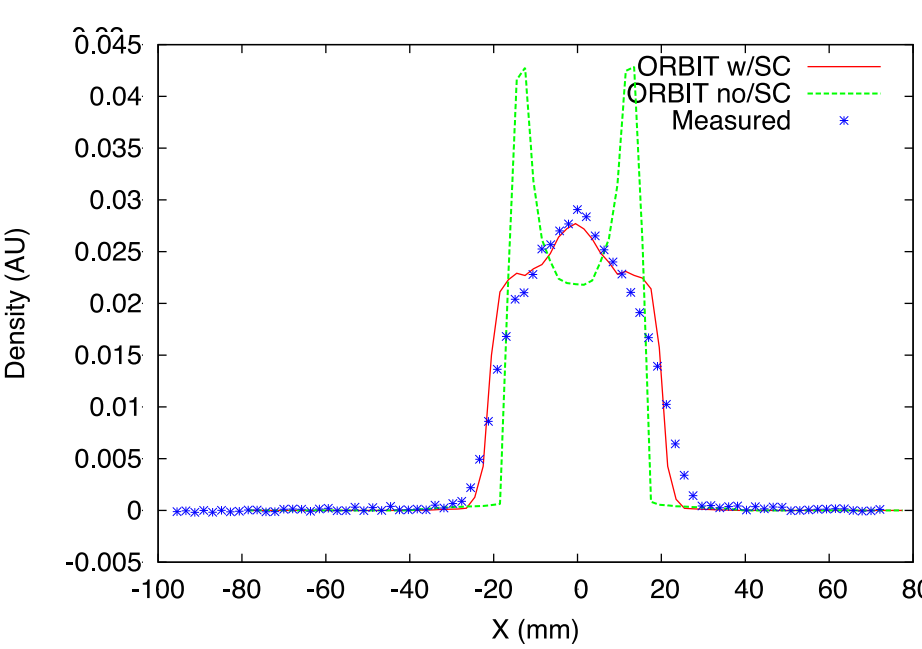
- Activation near the foil is highest in the accelerator
  - Close to design expectations
- Activation is not increasing with extended operation at high power

Ring Beam Profile Benchmark: Model (ORBIT) vs. Measurements (*S. Cousineau*)

Large Beam, 6uC, WS21



Small beam, 12uC, WS21



<u>Comparing measurement and model is useful</u>

Lessons learned:

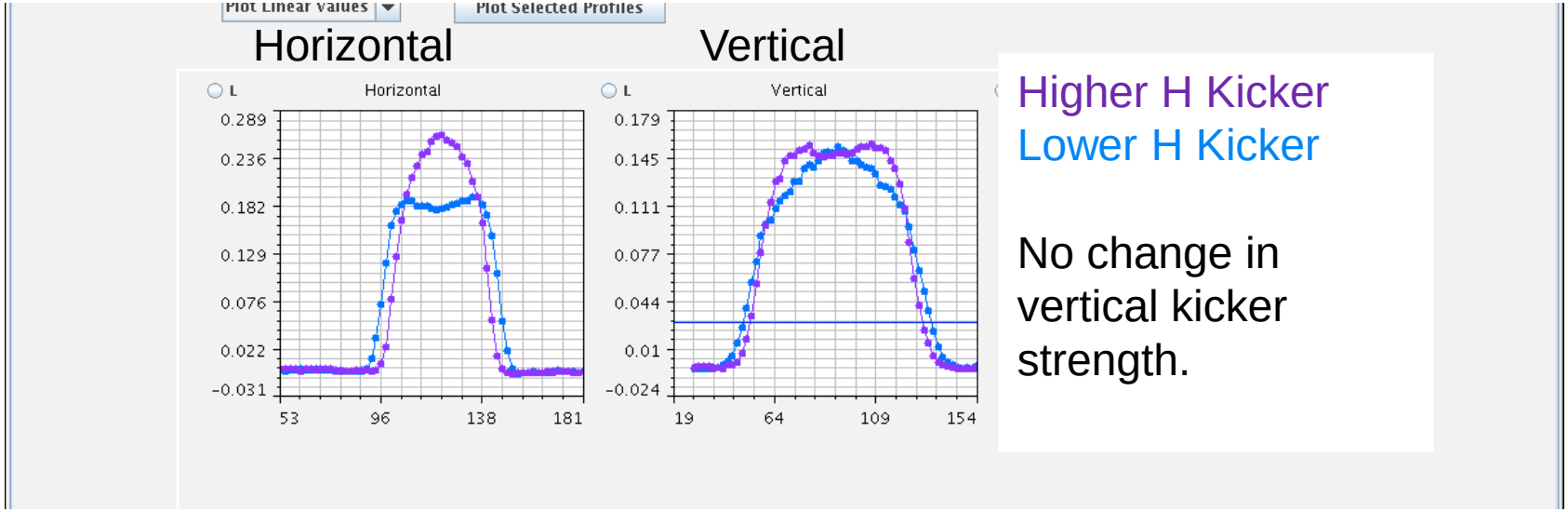
- Model: RTBT optics details, ORBIT fringe field model due to off axis injection.
- Hardware: RTBT beam tilt and Injection kicker timing offset issue.

Beam Simulation Code: ORBIT

- Developed at SNS – used worldwide
  - CERN, KEK- J-PARC, ISIS, LANL, FNL, CSNS, …
  - Open source (Google distribution)
  - Outsider developed modules
  - Scripted interface / C++ / parallel processing …
- Modernizing the scripting interface to use Python
  - Easier to build
- Applying to linacs

There are Ring Issues We do not Understand: Transverse Coupling in the Ring

WS20 Data for Near Betatron Tunes **Qx=6.21, Qy=6.19**



Horizontal inj. Kicker change resulted in vertical profile shape change.

High Intensity Ring Physics

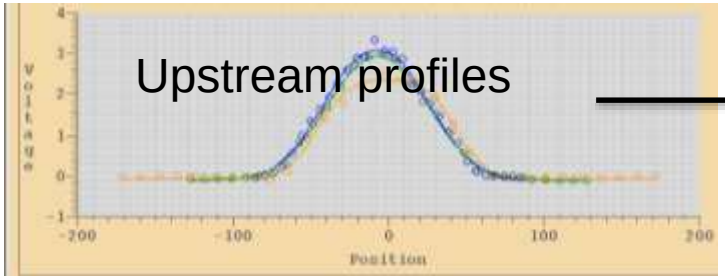
- SNS: world record intensity (1.55×10^{14} ppp)
- E-p is a concern (S. Cousineau's talk)
  - Sometimes run with low level e-p instability signature evident
    - But no increased beam loss
    - Longitudinal profile matters – (Z. Liu thesis)
    - Instability onset scaling more involved than simple RF power
- Working on a damper system
  - Have pickup, amplifier, kicker installed
  - S. Aleksandrov and S. Cousineau talks

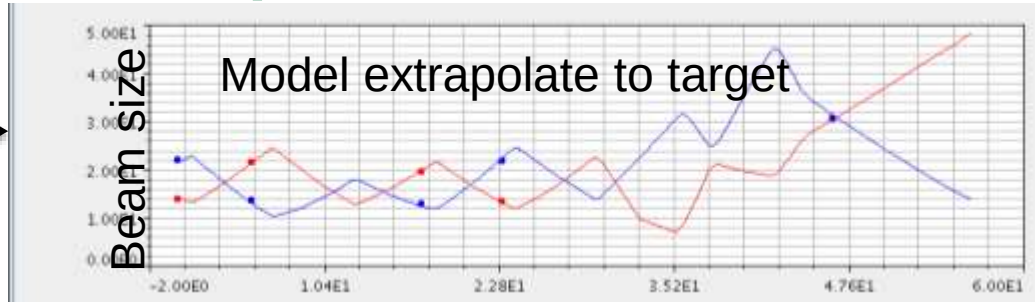
Laser Stripping Status

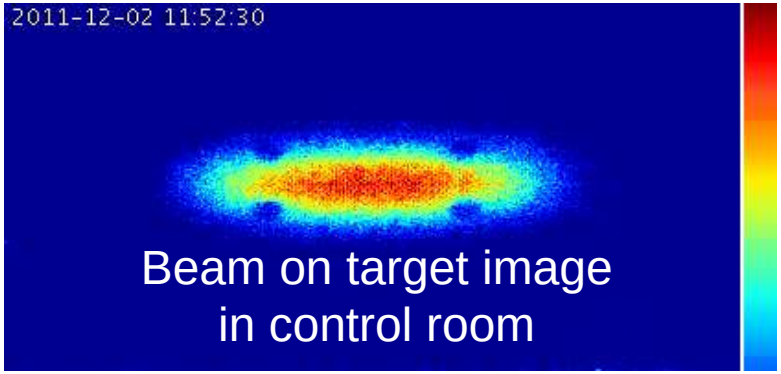
- Did 10 ns POP demonstration in 2006
- Held laser stripping workshop at SNS in April 2011
  - Follow-up to 2009 workshop
- Aim to do 10 μs demonstration next, in HEBT
  - Laser is in house
  - Fabray-Perot recycling development proceeding
  - Some required beam instrumentation being development
- Vacuum vessel insert for stripping apparatus is stalled
  - Looking for R&D funding

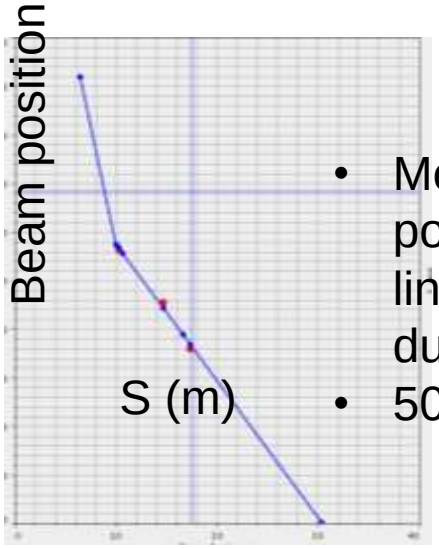
Note: laser stripping now in Tigner's Accelerator Handbook

High Power Target / Dump Interfaces(M. Plum's talk)





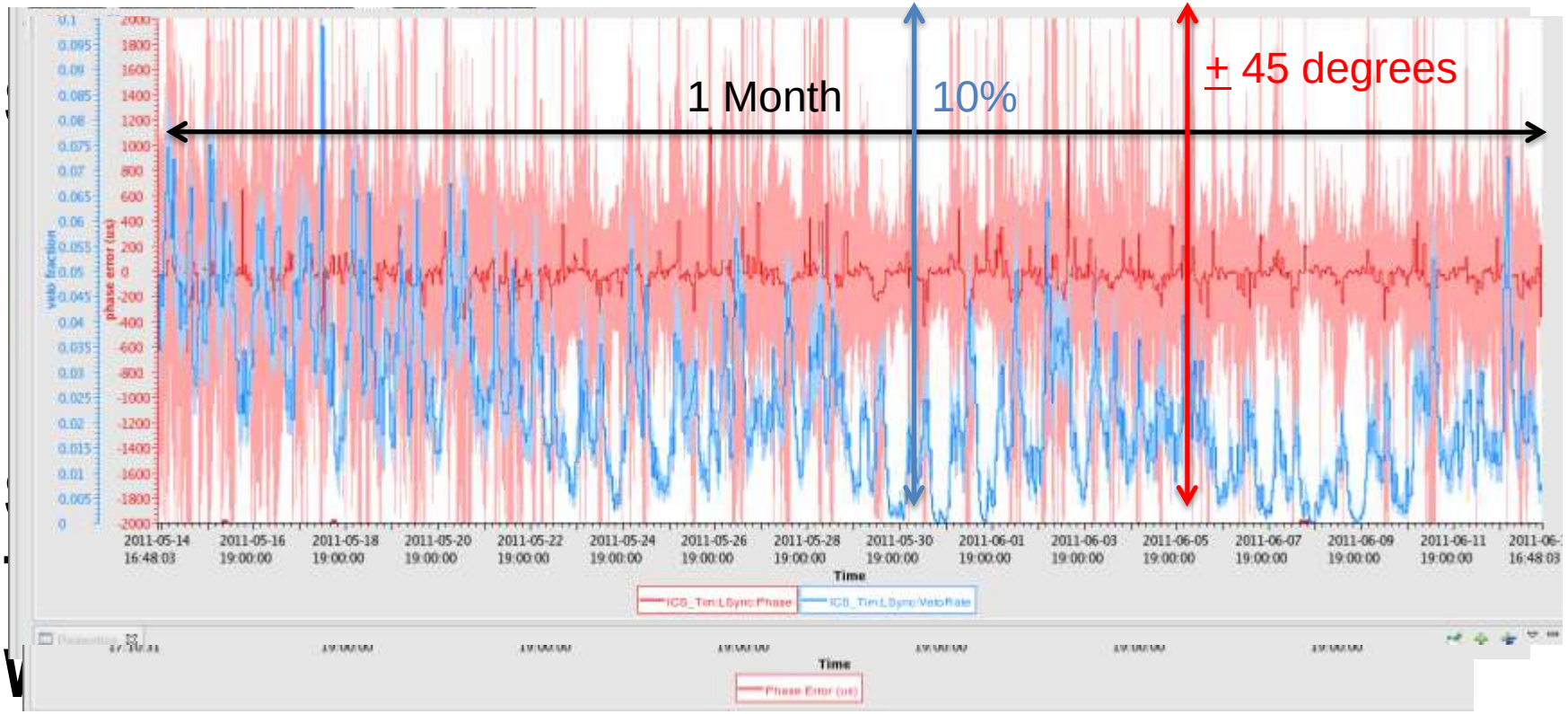




- Measurement of beam position in Injection dump line and extrapolation to the dump
- 50 kW beam!!!!

- **Control of the target beam interface is critical**
- **Instrumentation in high radiation areas is challenging**

Fixed Frequency Operation

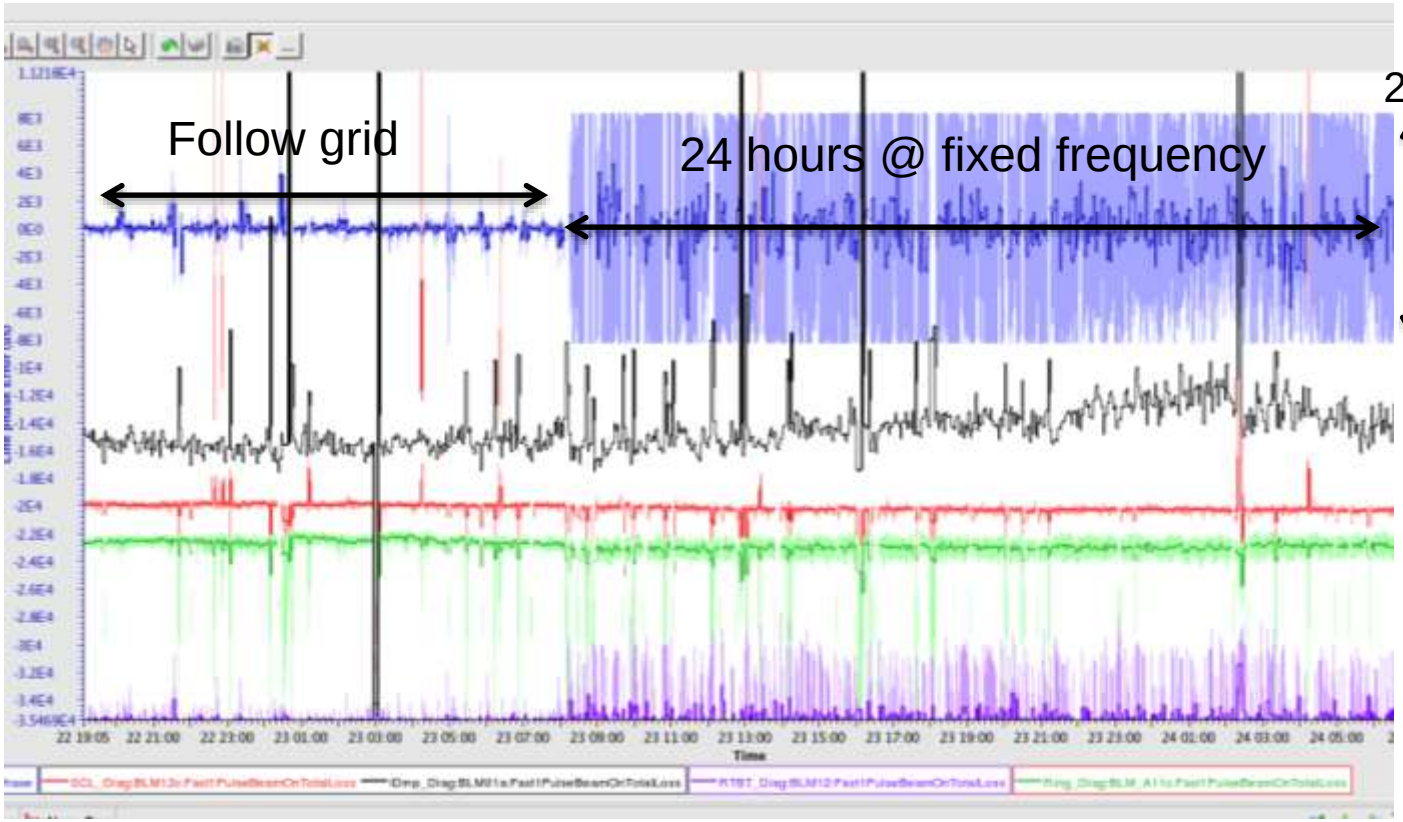


-
-
-

with the “grid phase error”

  - Cause has been faulty equipment

Fixed Frequency Demo: 24 hrs @ full power



- **No adverse effect on accelerator running asynchronously to the grid**

XAL – High Level Control Roon Application Software

- Toolset is mature, and an integral part of beam studies and operational setup
- Other institutions want to use it (FRIB, ESS, CSNS)
  - Is an informal collaboration development
- Are developing a new "generalized" version with no SNS specific features
- Uses modern software technology
  - Java, databases, …
- Open source!!!!
  - Sourceforge

Where We Are Going

	Operational Value	Design	3 MW
Power (MW)	1	1.4	3
Energy (MeV)	925	1000	1300
Repetition rate (Hz)	60	60	60
Pulse length (ms)	0.8	1	1
<macro-pulse current> (mA)	23	26	42
Beam duty factor (%)	4.8	6	6
Stored beam intensity (ppp)	1.1×10^{14}	1.5×10^{14}	2.5×10^{14}

- **Significant challenges in physics and equipment to reach the ultimate accelerator potential**

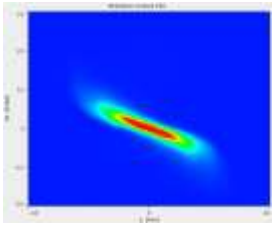
Accelerator Physics Staff

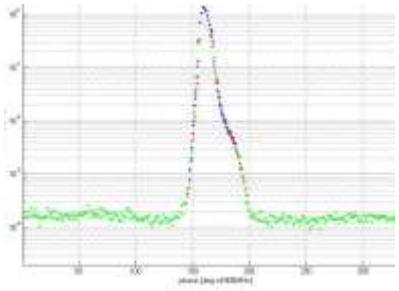
Post Commissioning	Fall 2010	Jan. 2012
FTE staff	12.5	9
Post Doc	1	0
Grad students	2	1

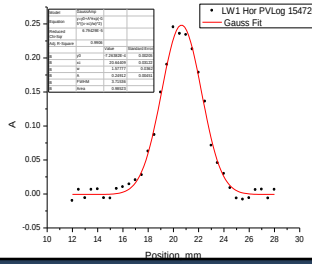
- **AP staff is smaller**
  - **Some reduction is natural as we move to operations**
  - **1.5 FTE due to SRF group split**
- **Need to retain people to manage longer term / power rampup**

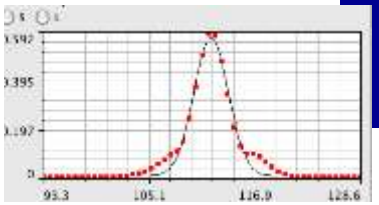
Accelerator Physics R&D Focus

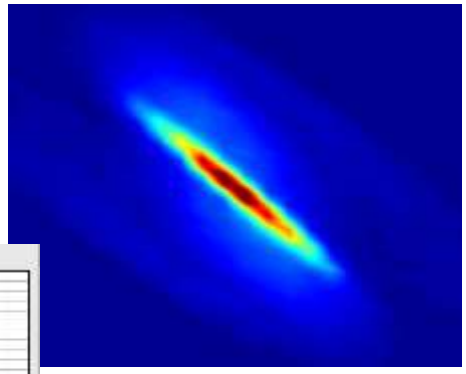
- **Still a lot to learn from the SNS beam**
  - **Well instrumented high intensity linac (model-measurement comparison)**
  - **High intensity ring: e-p, laser stripping**
- **Looking for outside R&D funding**
  - **Get no accelerator R&D funds from BES**
  - **Applying to HEP, ideas?**











Front-End	Warm Linac	SCL	HEBT-1
5 transverse profiles 1 transverse emittance	14 transverse profiles 4 longitudinal profiles	9 transverse profiles	9 transverse profiles 1 transverse emittance

Integrable Optics - Danilov

- Non-linear lattice, fundamental paradigm shift for lattics design
  - Advantages for high intensity - huge tune spread, no resonance

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 13, 084002 (2010)

Nonlinear accelerator lattices with one and two analytic invariants

V. Danilov
Spallation Neutron Source Project, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830, USA

S. Nagaitsev

- FNAL is pursuing this idea
  - Integrable Optics Test Accelerator (IOTA) ring is being designed

FERMILAB-CONF-11-114-AD-APC

RING FOR TEST OF NONLINEAR INTEGRABLE OPTICS

A. Valishev, S. Nagaitsev, V. Kashikhin FNAL, Batavia, IL 60510, U.S.A.
V. Danilov SNS, Oak Ridge, TN 37830, U.S.A.

Abstract In this report we discuss the choice of parameters and

Summary

- Still learning about our beam
  - IBST in the SCL
  - Better understanding of the ring beam
  - Better understanding leads to reduced beam loss
- Beam based tools have improved beam setup and problem diagnosis
- Still alot to do !!!