The Case of the Lost Beam

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U.S. DEPARTMENT OF ENERGY

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The Spallation Neutron Source (SNS) Superconducting RF Linac

- SNS has a superconducting RF linac for H- acceleration
- Designed to accelerate H^- from 186 MeV to 1 GeV
- High power linac (MW)

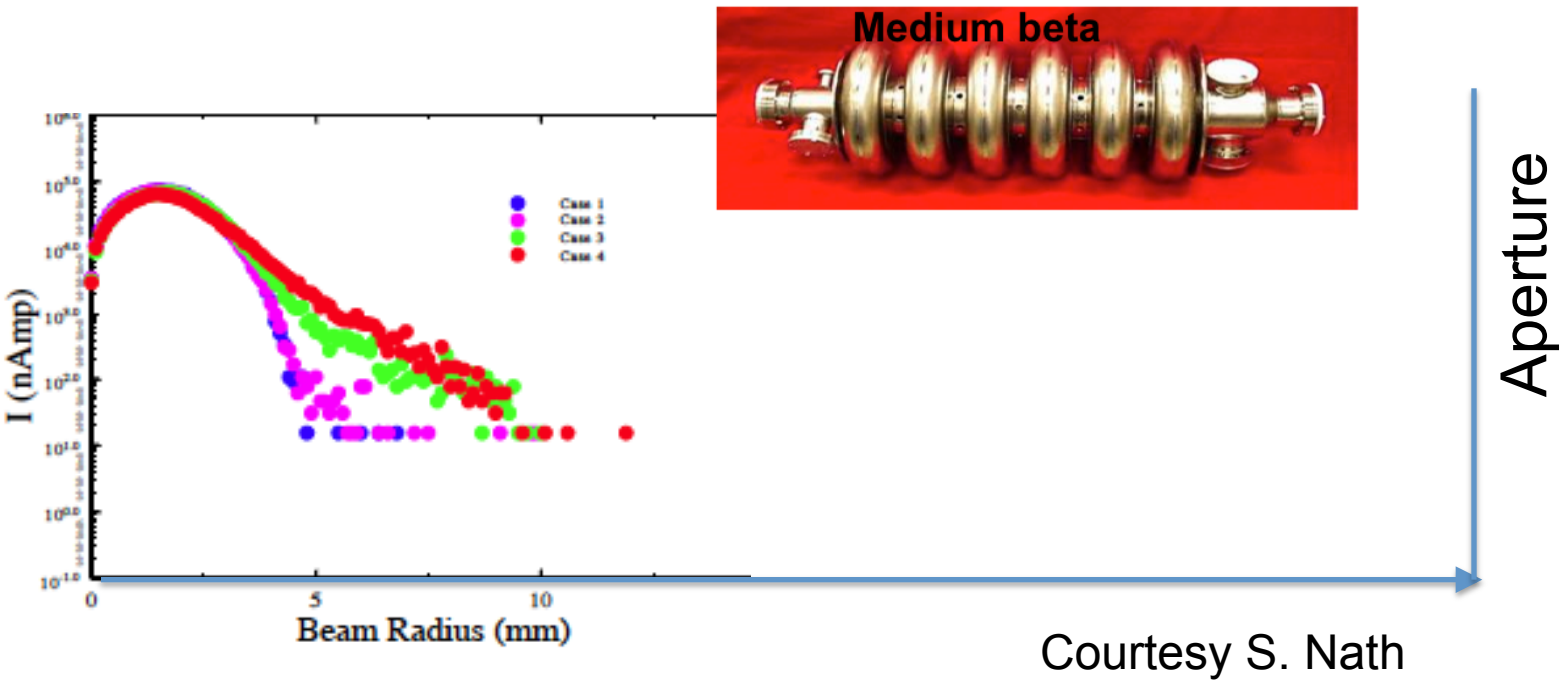
SNS SCL Linac Losses: The Expectation

"Accelerator physics model of expected beam loss along the SNS
a mal operation"

N.

"As for the superconducting linac
much larger than the nominal bea
stripping calculations give a negli he
other hand, one should be very cautious with our expectations as there is no experience with superconducting proton linacs up to now."

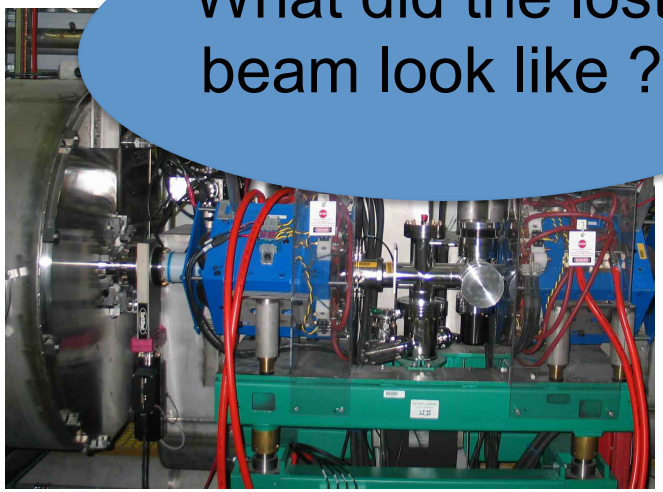
SNS design stage: The Expectation

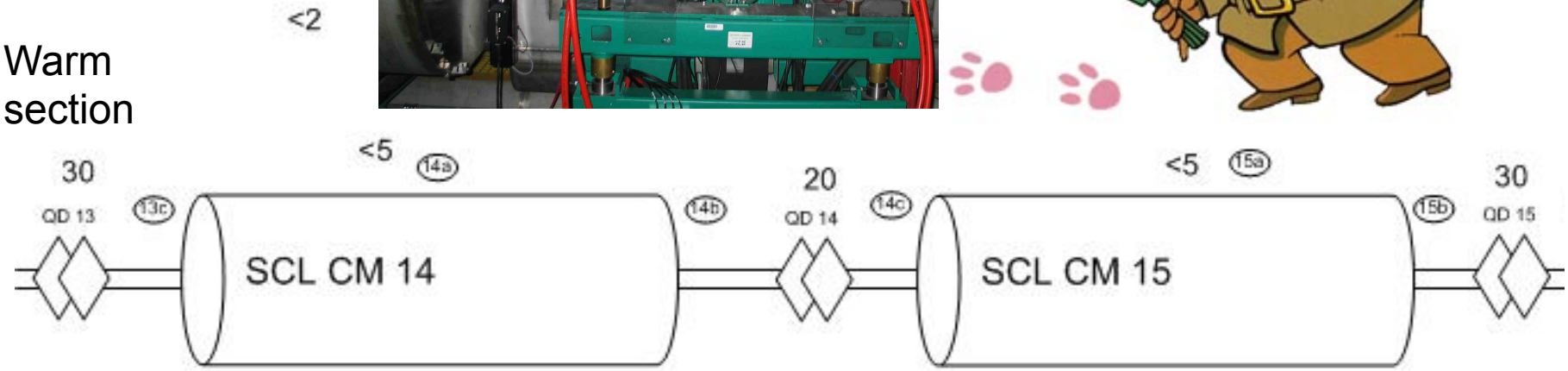


Courtesy S. Nath

- Multi particle simulations did not predict beam loss
  - Maximum extent was far from aperture

Nature of the Beam Loss

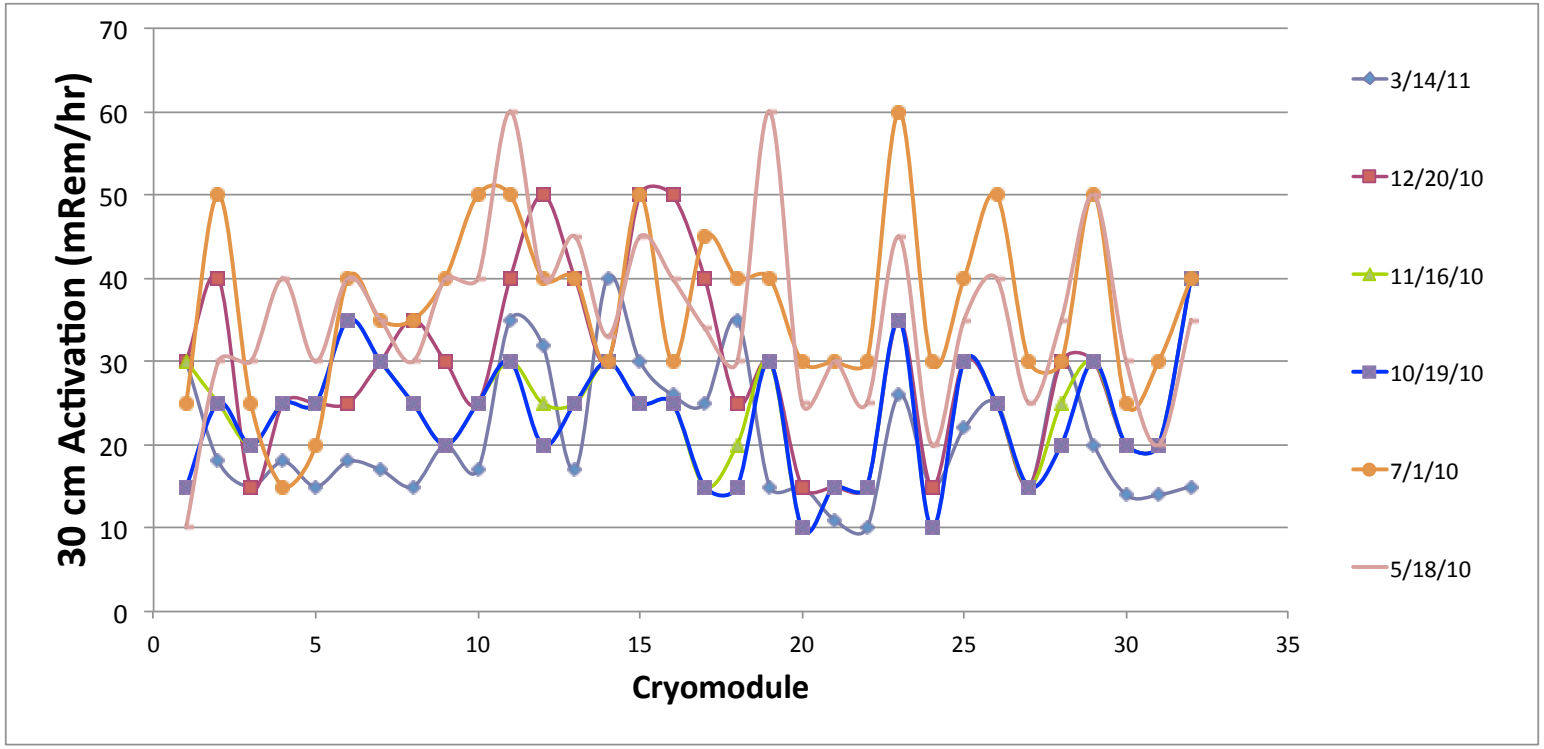




- The activation pattern: local hot spots are in warm sections between cryomodules

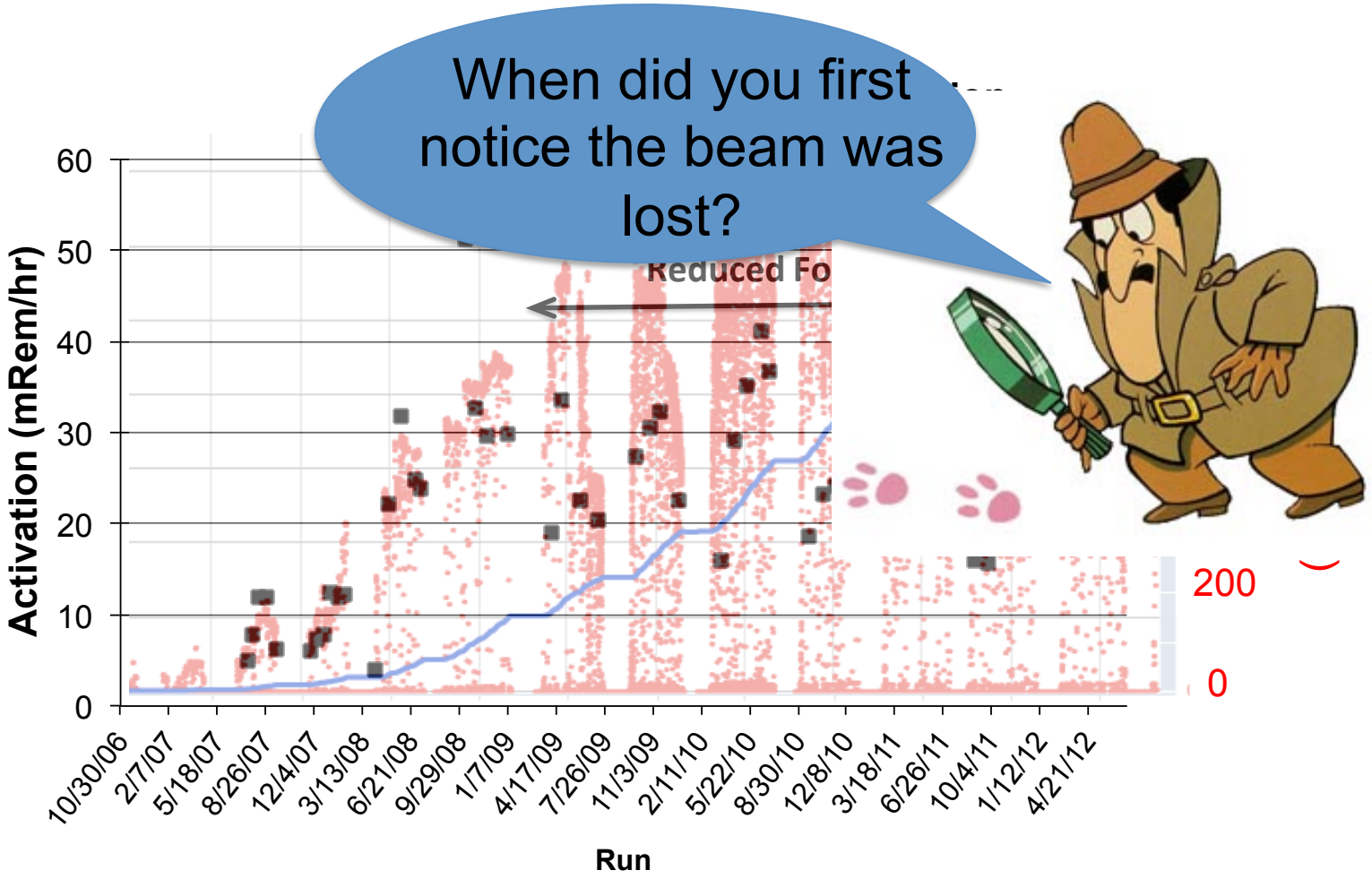
SCL Residual Activation Global Distribution

Activation in warm sections along the SCL



- **Remarkably uniform!**

SCL Activation: The History

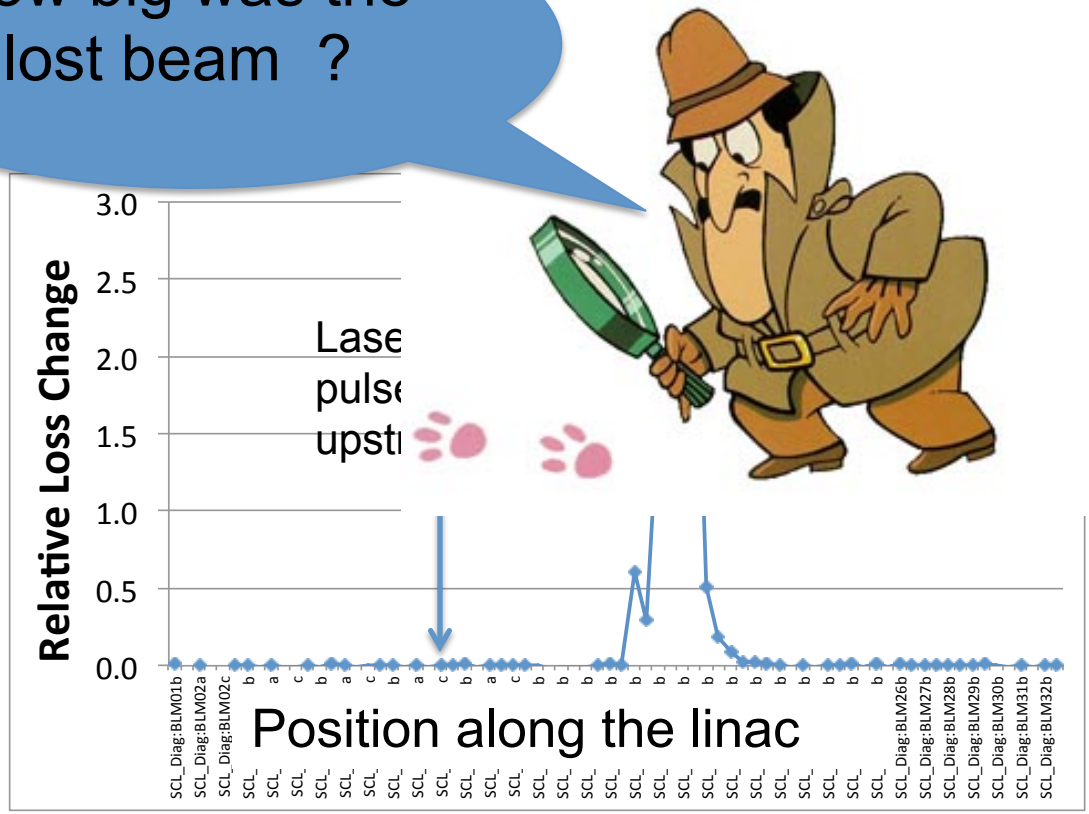


- **Even at low beam power, we began to measure SCL activation from beam loss**
  - **Does not limit operational power**

How much beam is really lost??

It's difficult to create a [illegible] that produces similar loss re[illegible]

How big was the lost beam ?



Solution: Use available pulsed laser pulses to strip 10^{-6} of the beam

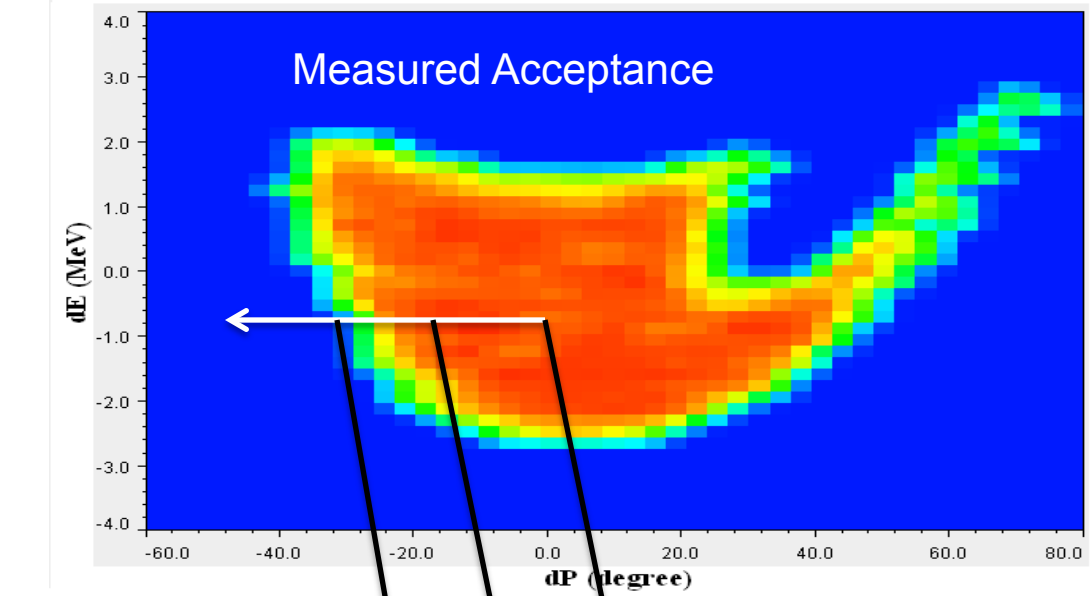
- **Implication is that not much beam is lost: ~ 5×10^{-5} throughout the superconducting linac**

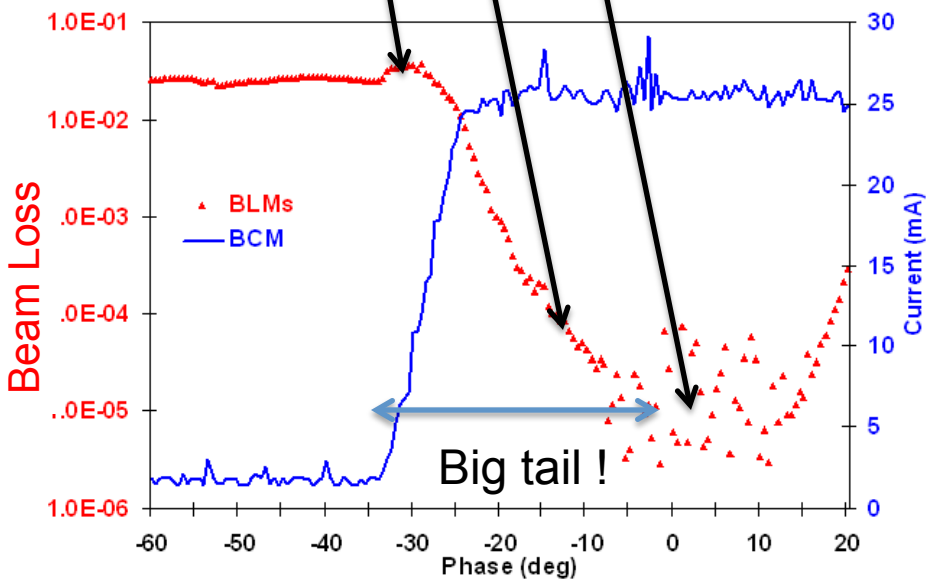
How Is Beam Getting Lost ???

- **Possible beam**
  - **Longitudinal halo**
  - **Transverse halo from the source**
  - **Transverse mis-match**
  - **H^- stripping**
  - **Non-linear fields**

Longitudinal Halo Impact on Beam Loss

- We have measured a long (30-40 deg) longitudinal tail at the SCL entrance
- Loss is sensitive to warm linac RF setup



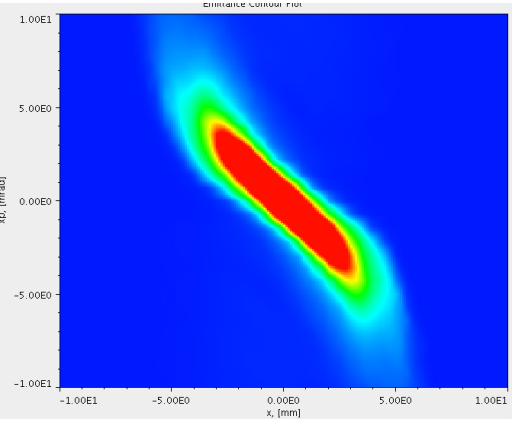


Courtesy Y. Zhang

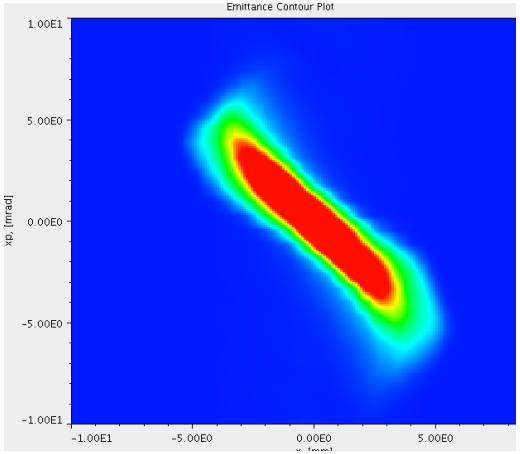
Transverse halo: MEBT scraping

- **2 horizontal MEBT scrapers at SNS**
  - **Reduces lattice transition and ring injection dump losses – no uniform reduction throughout the SCL**
  - **Effectiveness in loss reduction varies from source to source**

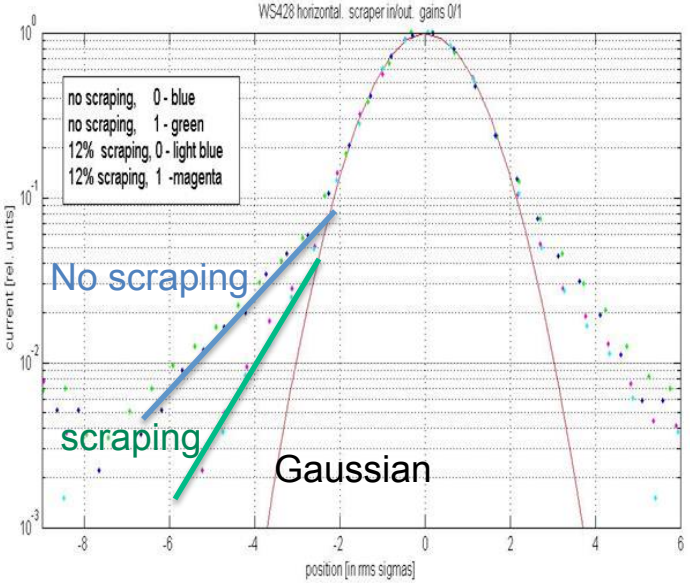
MEBT Emittance without scraping



MEBT Emittance with scraping



DTL profile, log scale

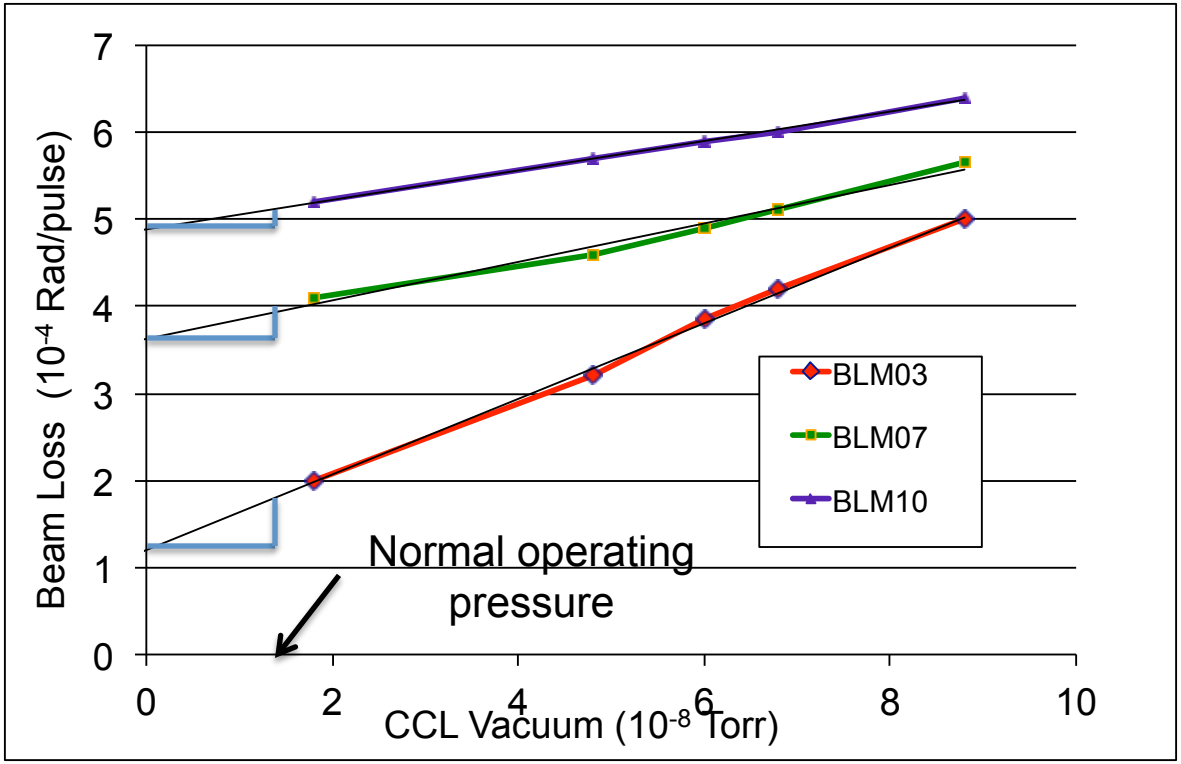


Courtesy A. Aleksandrov

H^- Stripping Loss Contribution

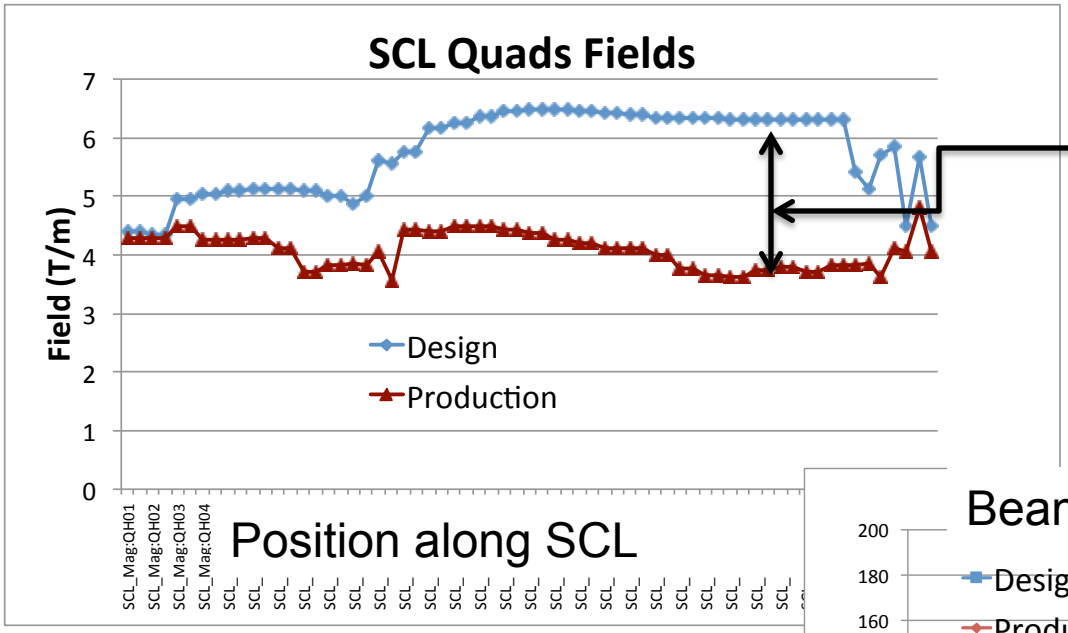
- Magnetic stripping, RF field stripping, calculated to have small effect

Residual gas stripping:
Measured beam loss sensitivity to upstream vacuum level:



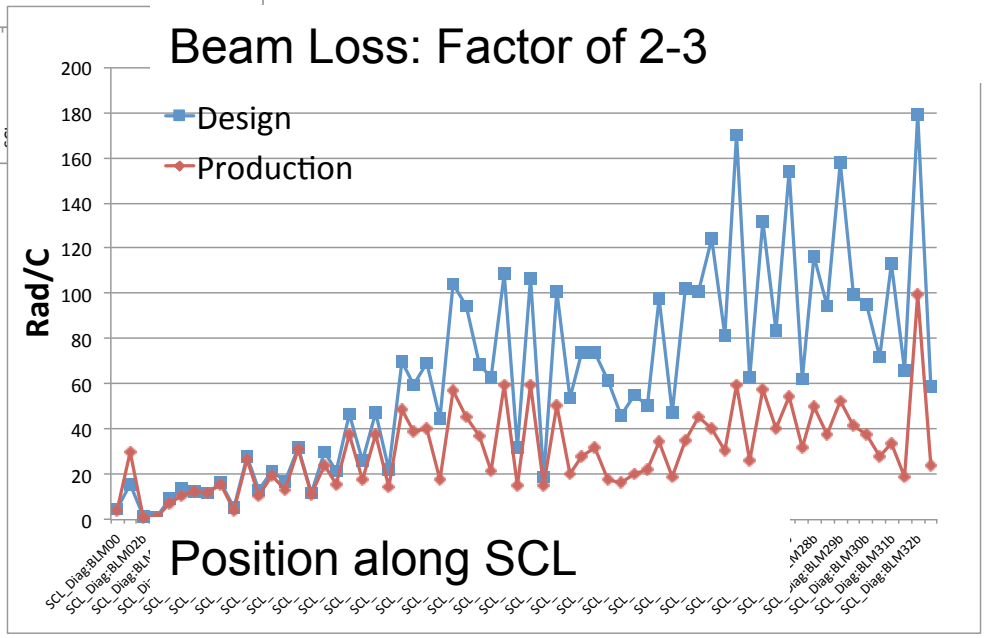
Minimal impact on beam loss from residual gas stripping

A clue: reduced transverse focusing lowers beam loss !



40% reduction in focusing strength results in:

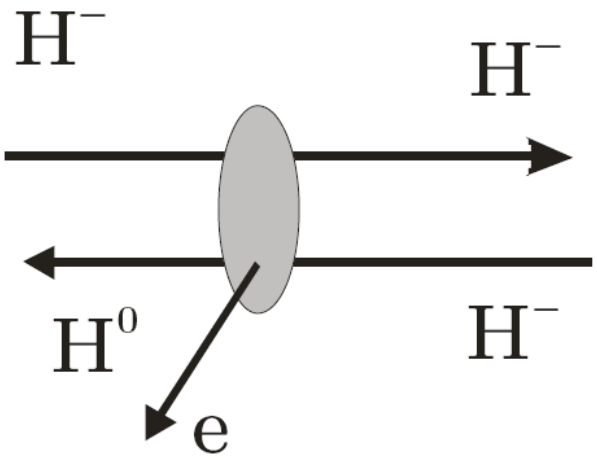
- **Why does making the beam bigger reduce loss ???**

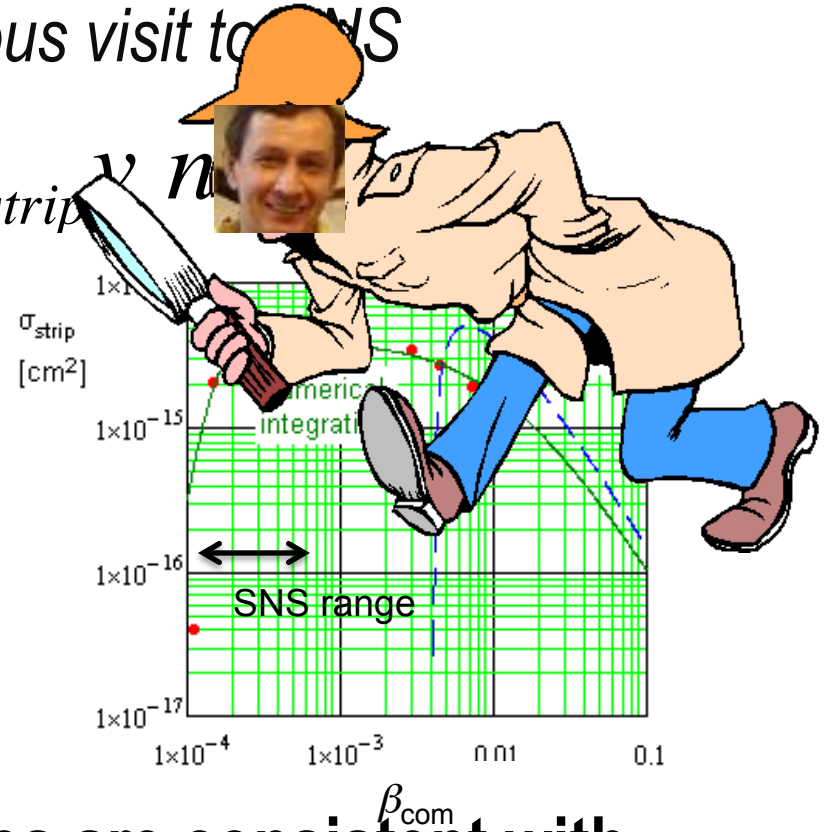


The Insight: intra-beam stripping (IBSt)

V. Lebedev's fortuitous visit to SNS

$$dn/dt \propto \sigma_{strip} \, v \, n^2$$





- **Simple estimates of loss rates are consistent with measured loss levels**
  - **Observed at CERN in 1980's**
- **Predicted loss magnitude is right order for SNS**

IBSt really seems to make sense, but …

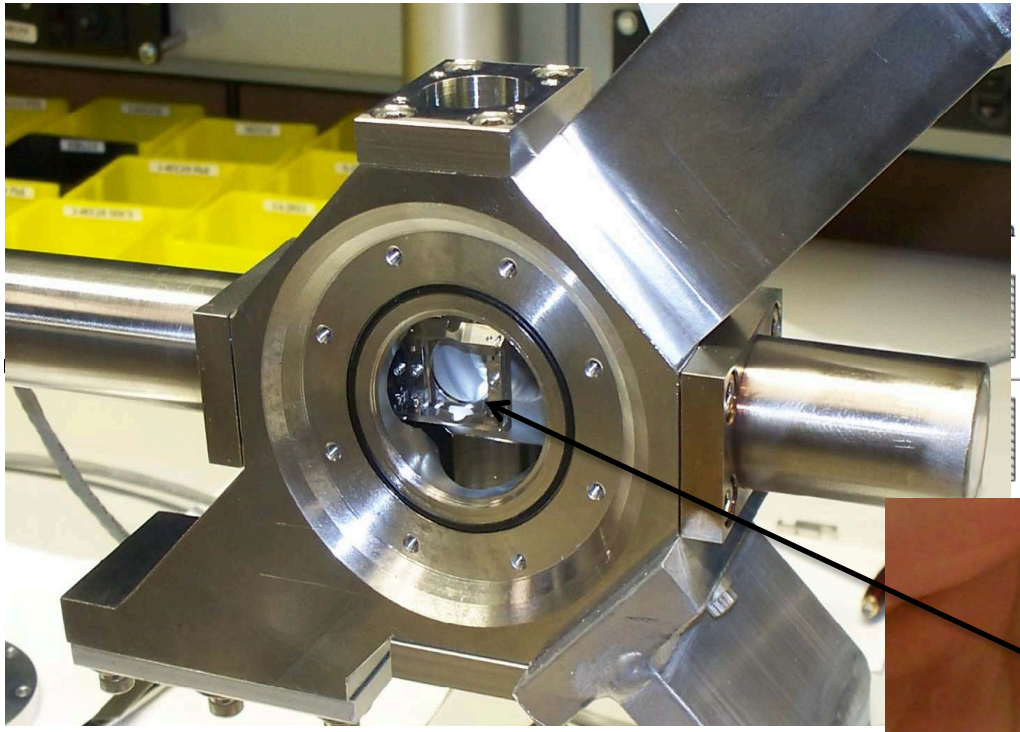
Доверяй, но проверяй (trust, but verify)

So, let's put a proton beam in the SNS SCL

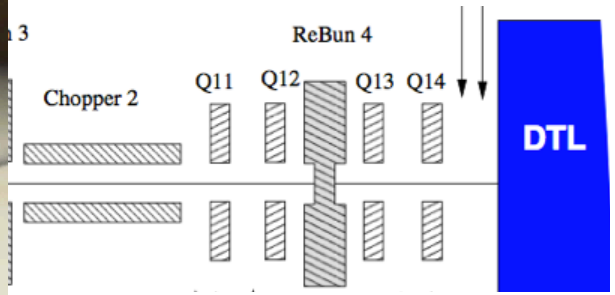
- **Tried to convert an H^- source to an H^+ source: no luck**
- **Use an insertable stripper foil upstream of the DTL**
  - **Use 10 independent focusing power supplies in the transport from RFQ to (permanent magnet) DTL for transverse match**
  - **Move RF phases 180 degrees**

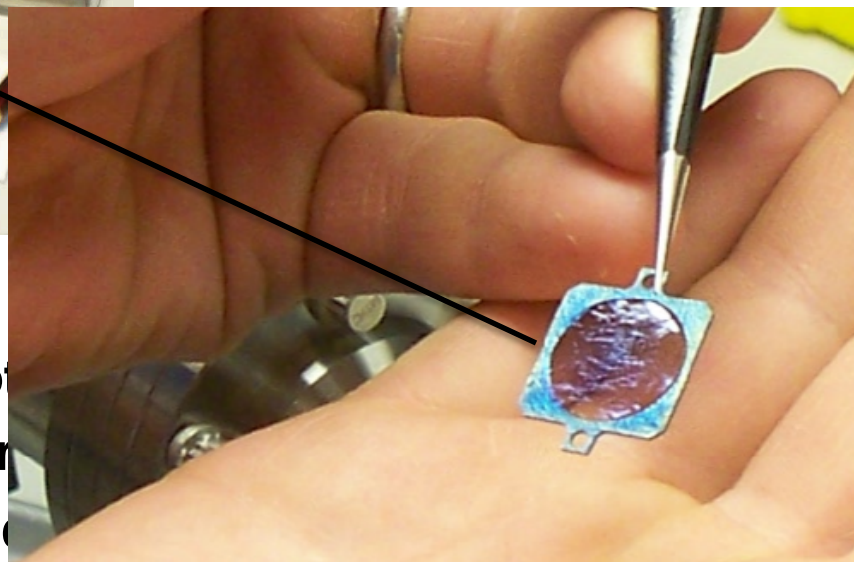
Proton Beam at the SNS Linac

H-



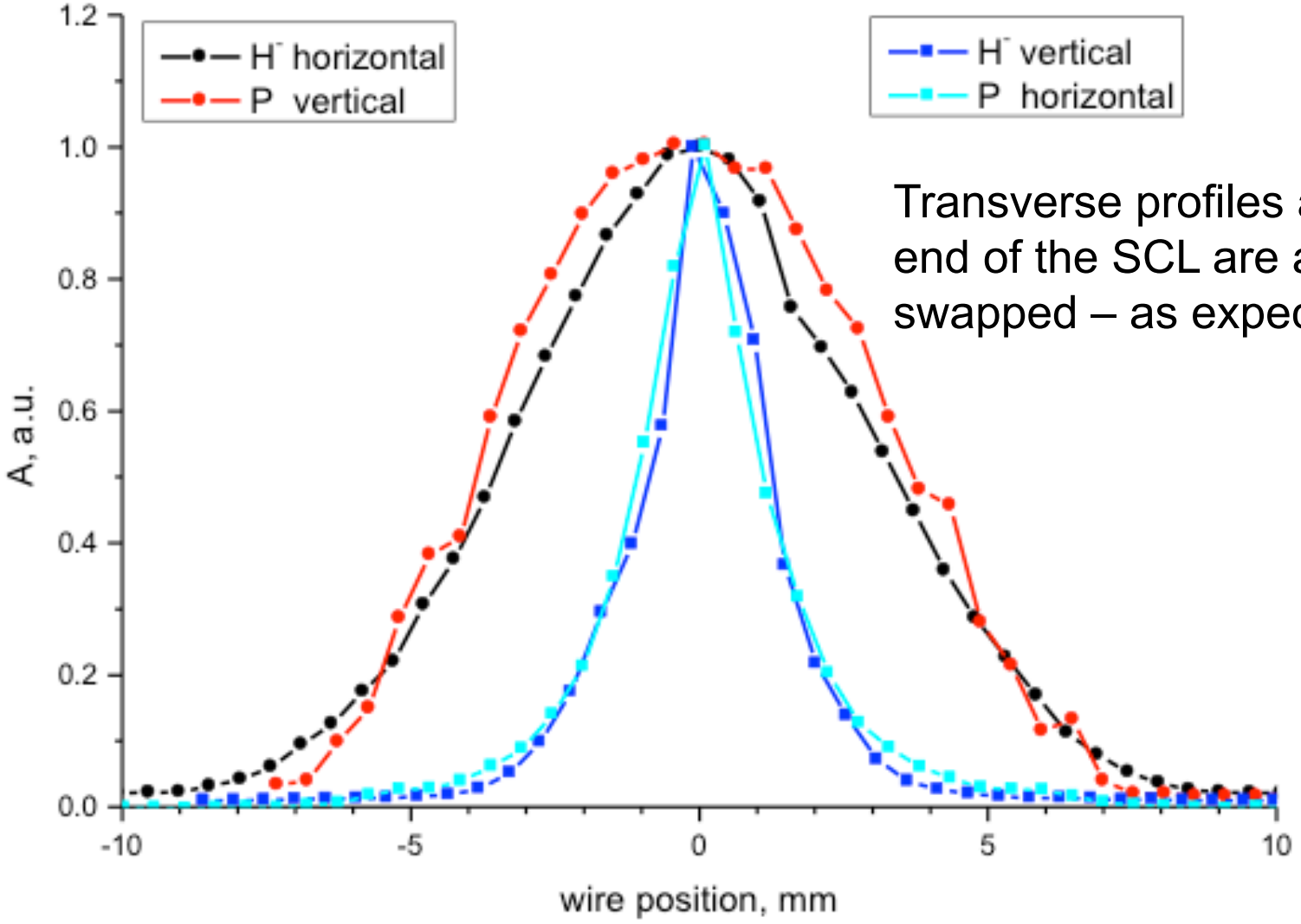
Swap H- and proton
Twiss parameters here





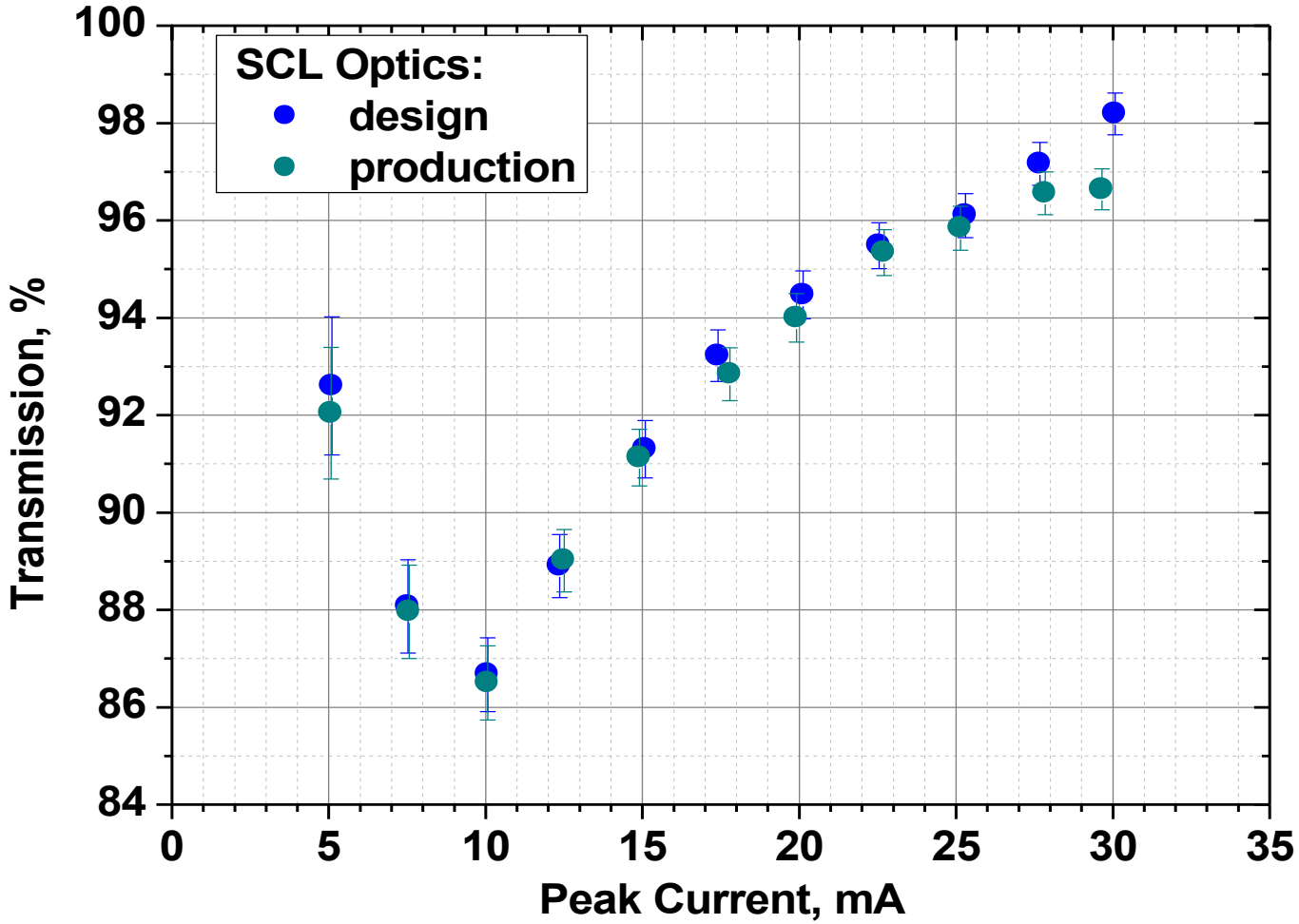
- 5 μg/cm^2 carbon foil will strip >
  - 0.6 keV kinetic energy loss for pro
  - 12 % emittance growth expected fr
  - ~50 μs pulse without damaging th

Measured Twiss Parameters at the End of SCL for H- and Protons



Transverse profiles at the end of the SCL are also swapped – as expected

Measured Proton Transmission to SCL



Proton transmission is not 100%

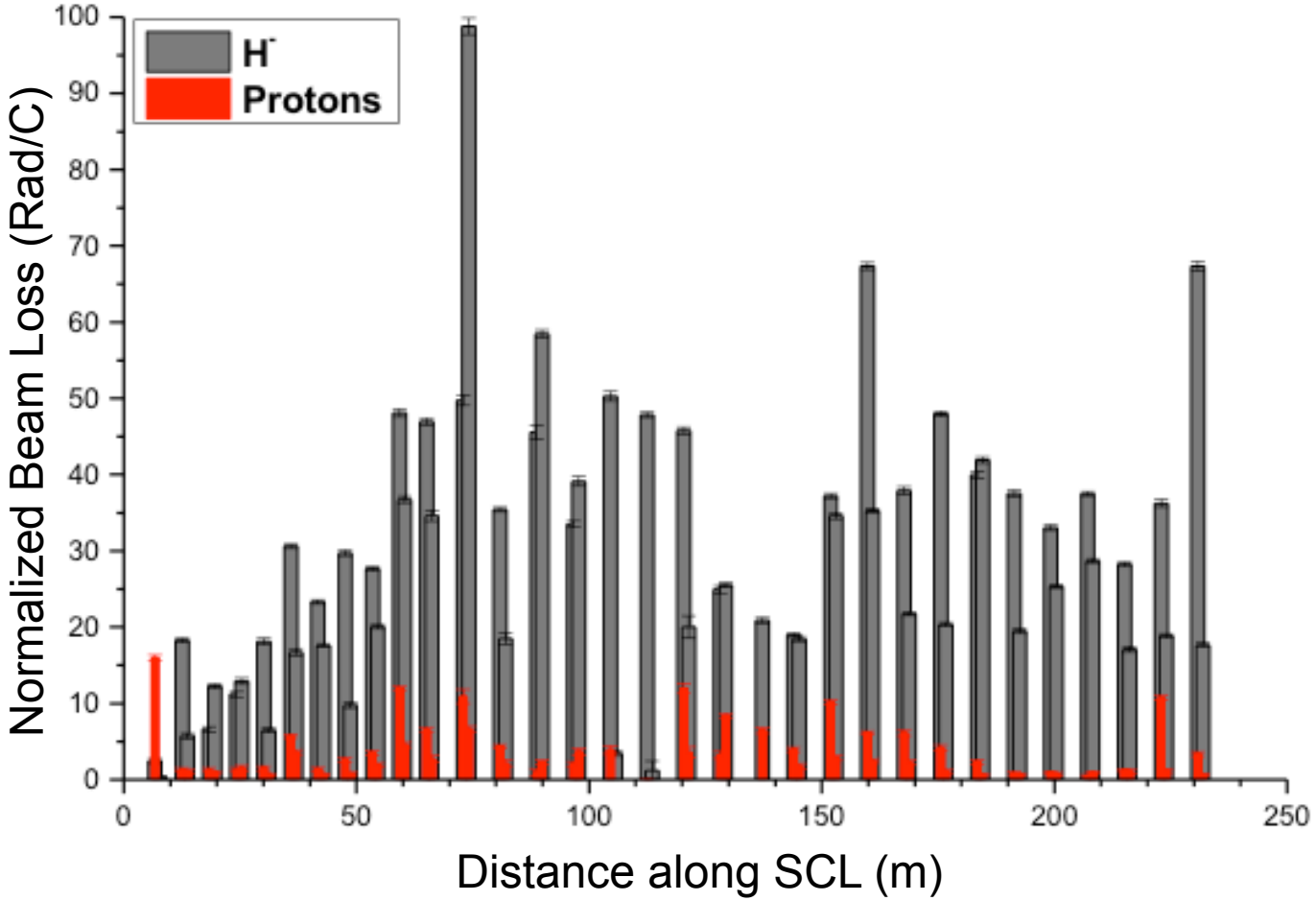
It is peak current dependent

We lose beam in MEBT-DTL

Transmission to SCL, 2011.09.25

Measured SCL Losses Protons vs. H-

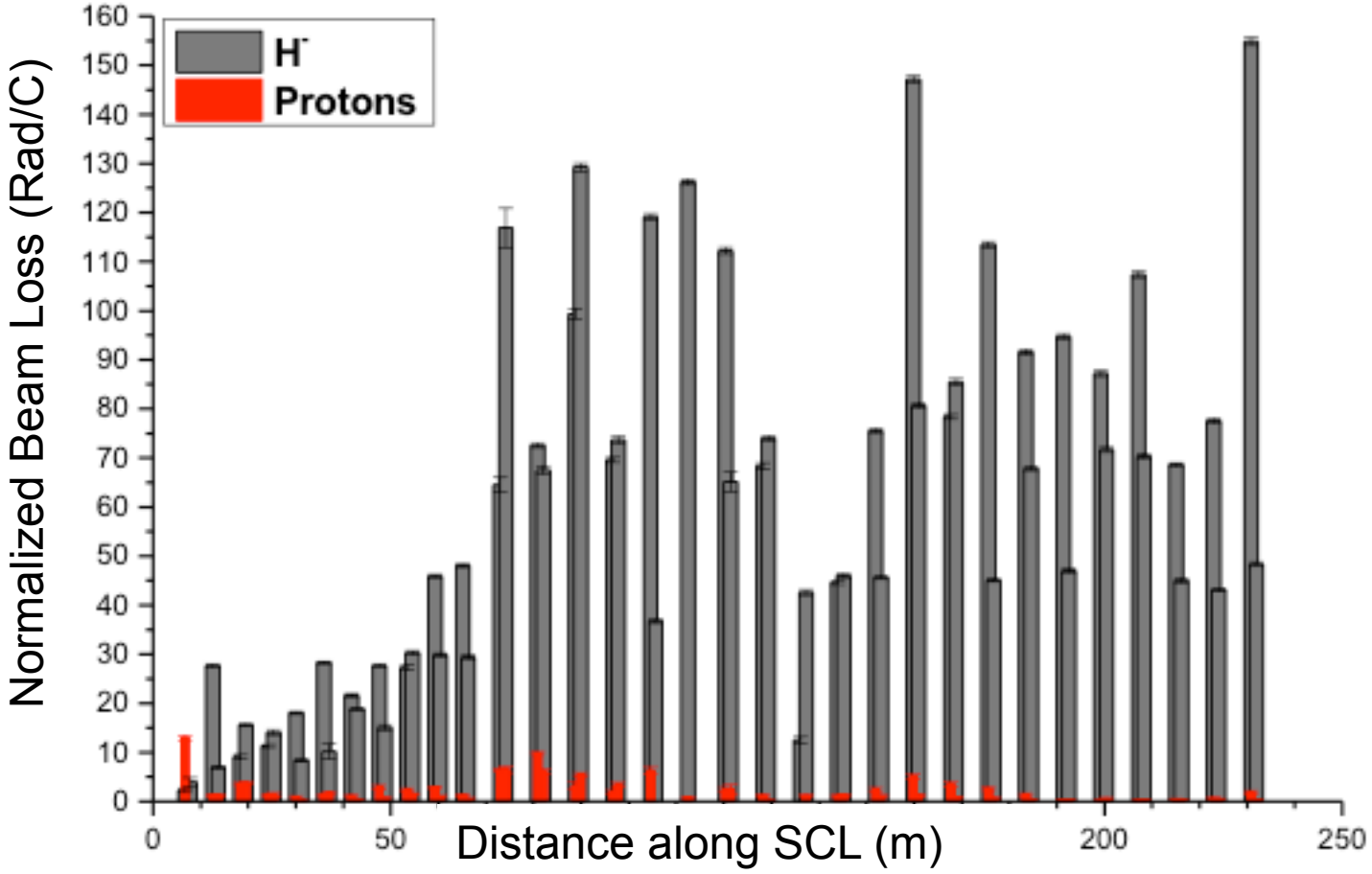
30 mA, production lattice (weak focusing)



- Significant reduction in loss for the proton beam

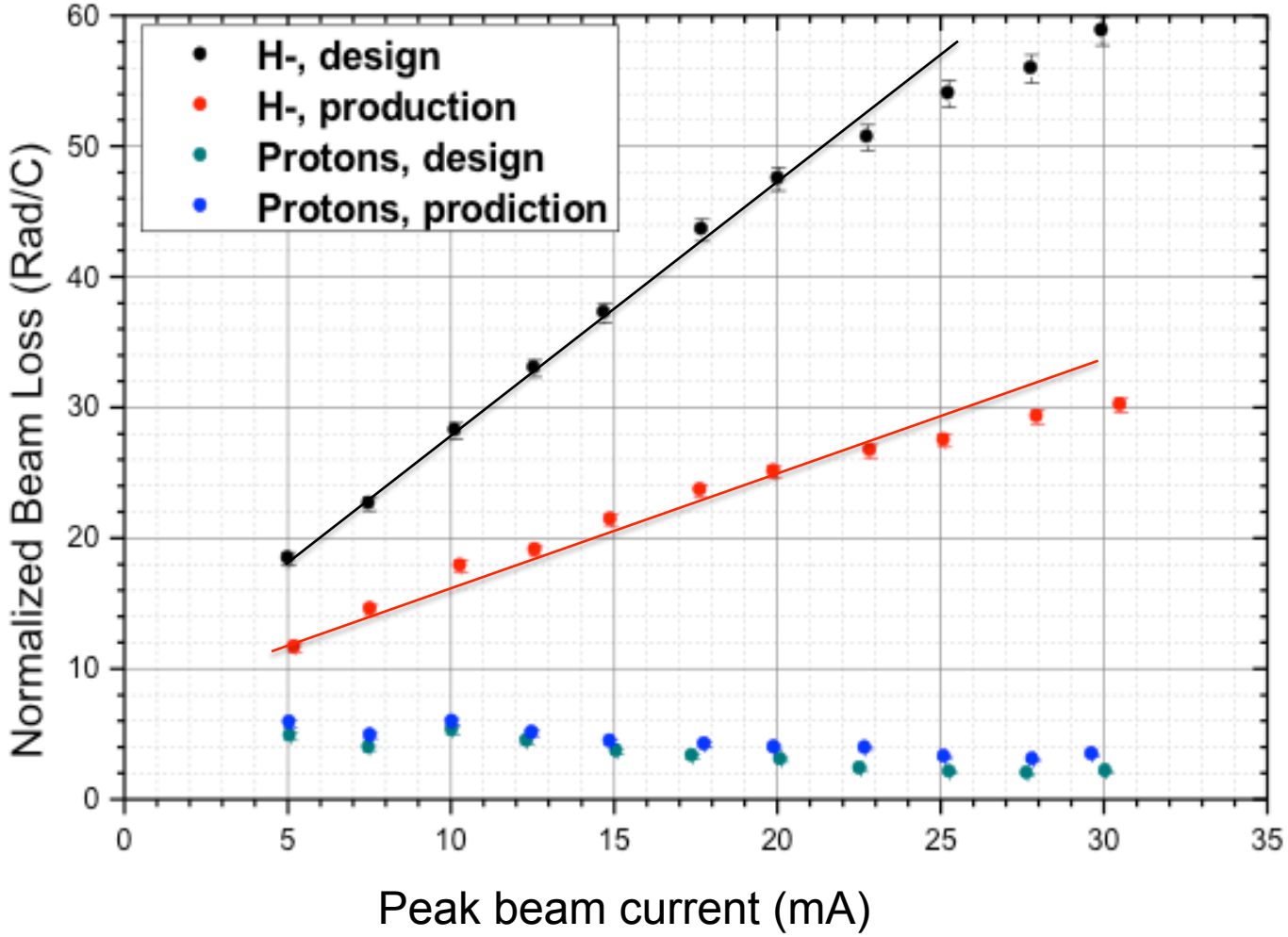
Measured SCL Losses Protons vs. H-

30 mA, design lattice (strong focusing)



- Even more significant reduction in loss for the proton beam

SCL Losses vs. Beam Current



- H- normalized loss shows linear dependence on current
  - Consistent with IBSt scaling
- Proton normalized loss is independent on intensity

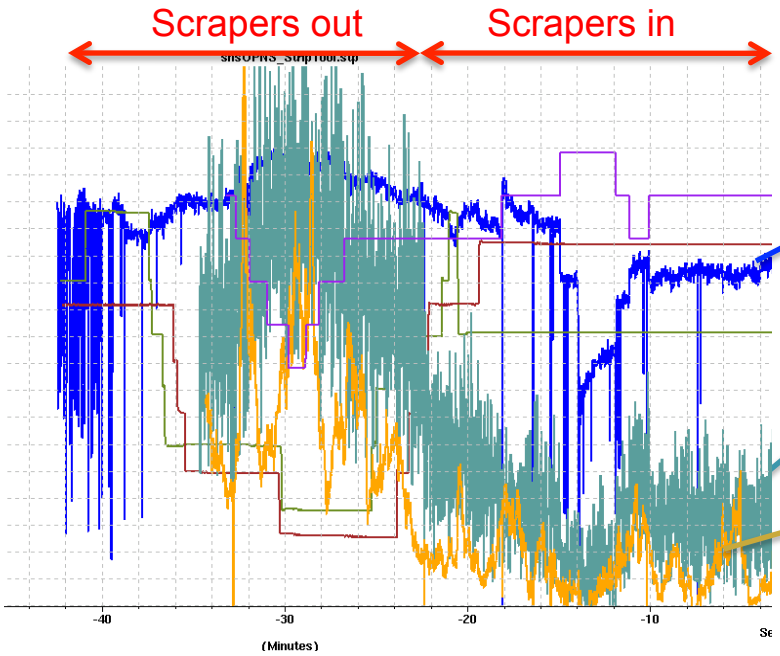
A New H^- Beam Loss Mechanism is Identified

- IBSt seems to be the primary contributor to beam loss in the SNS SCL
- This loss mec d in future high power ion acc
  - Situation is g
- Direction for S
  - Reduce trans attempt to make the beam even b
  - Add more transverse scrapers

Thanks!

Backup

Upstream Halo Scraping Impact Loss at Isolated Locations



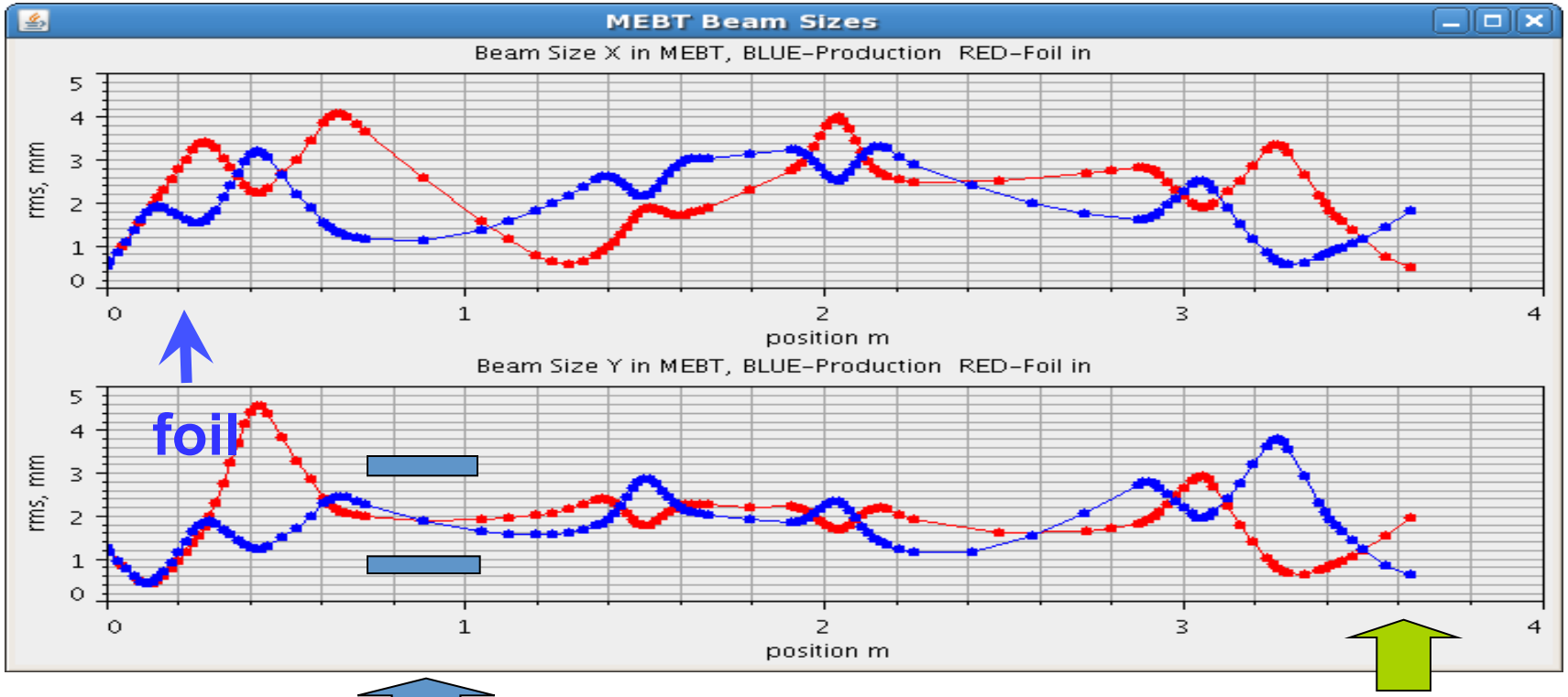
Beam Charge (typically scrape ~3-4% of the beam)

Warm linac beam loss (~55% lower at this point)

Ring Injection Dump beam loss (~57% lower at this point)

- **The effectiveness of the scrapers varies with the ion source and the machine lattice**

MEBT Sizes: Production vs. Optimized



Chopper Plates, 18 mm distance

X and Y Twiss parameters are switched

- Prediction: Horizontal beam size at the foil will change from about 1.7 mm to 2.6 mm due to the QH01 field change from 34.5 to 2.5 T/m. The vertical size will be almost the same.
- Not a problem: the foil is big enough to accommodate this!