Beam Loss Mitigation in the Oak Ridge Spallation Neutron Source

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HB2012 workshop
Beijing, Sep. 17-21, 2012

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
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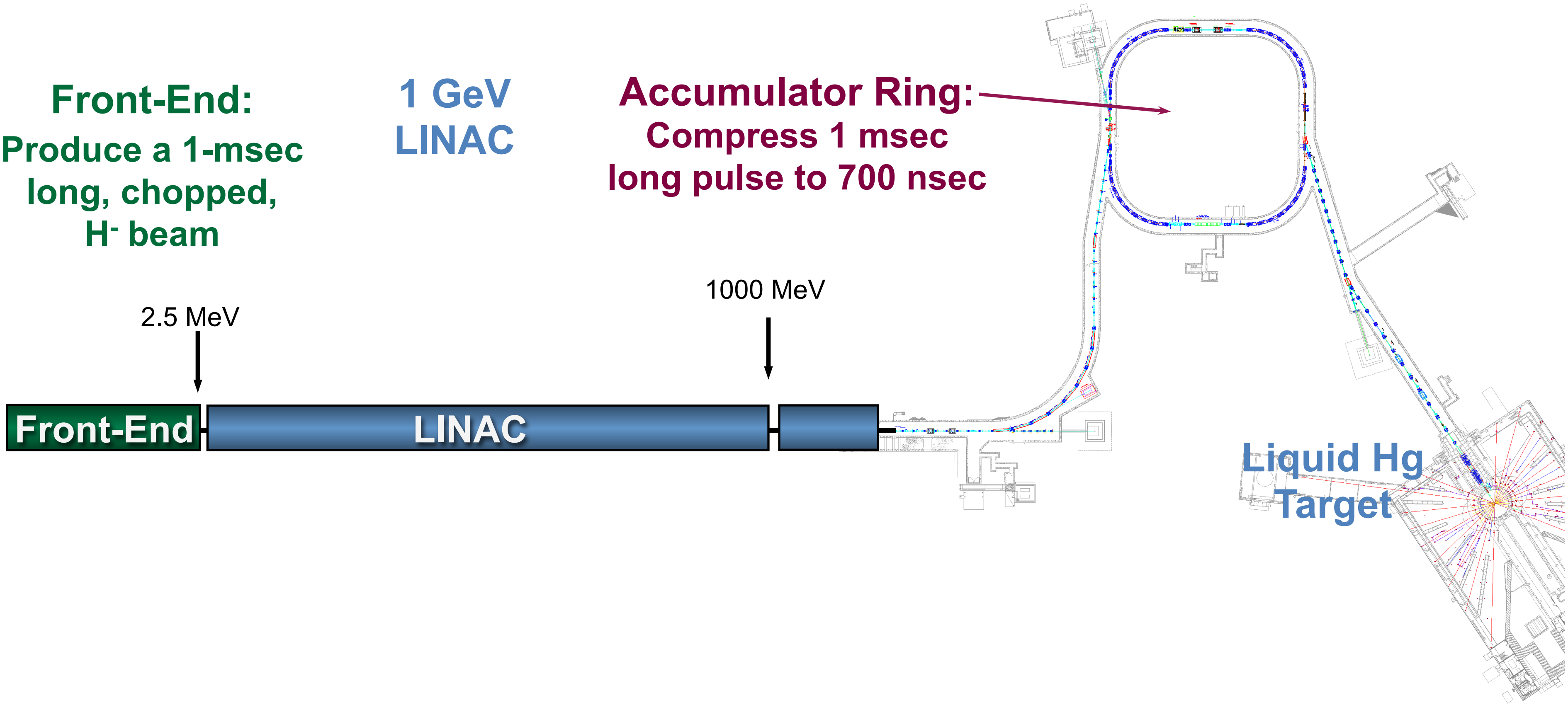
Outline

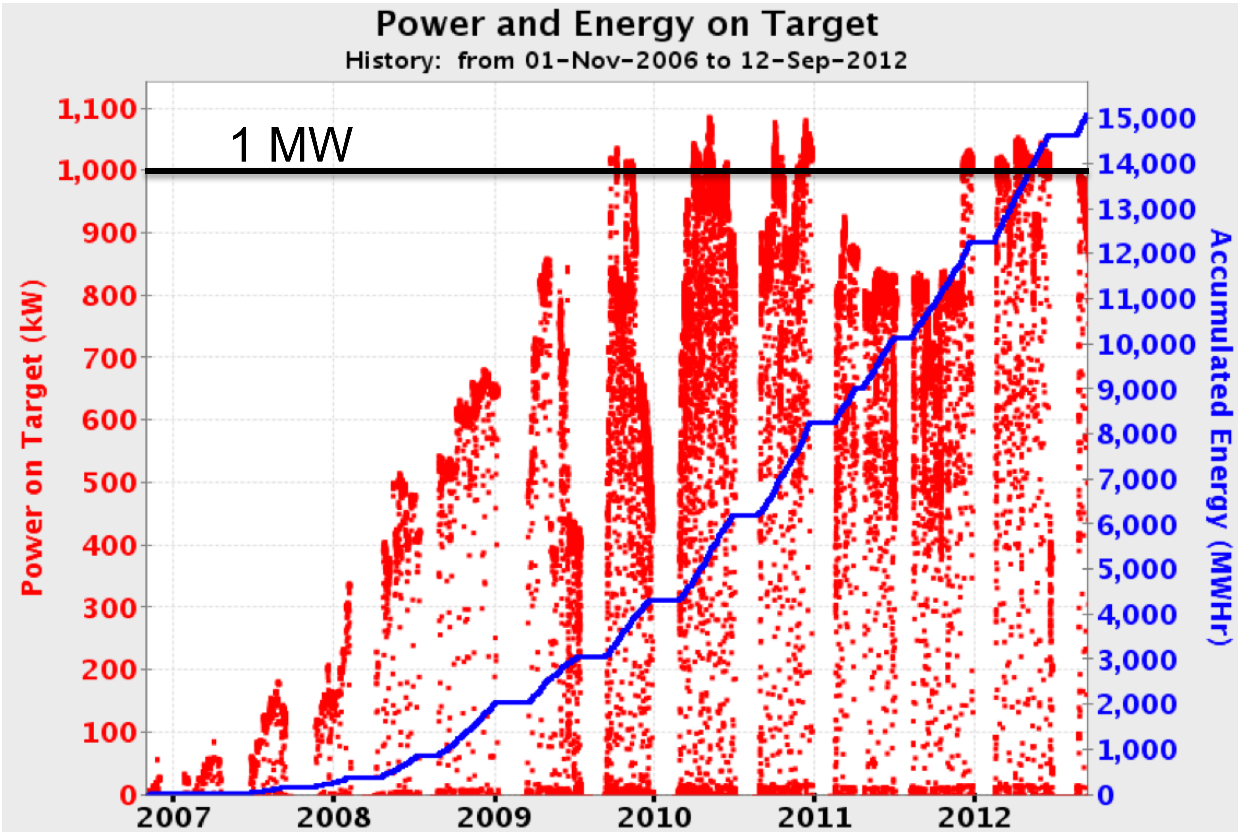
- How we measure beam loss
- Where are the hot spots
- How we mitigate beam loss

SNS Accelerator Complex



Approximately 365 beam loss monitors cover the linac, ring, and transport beam lines

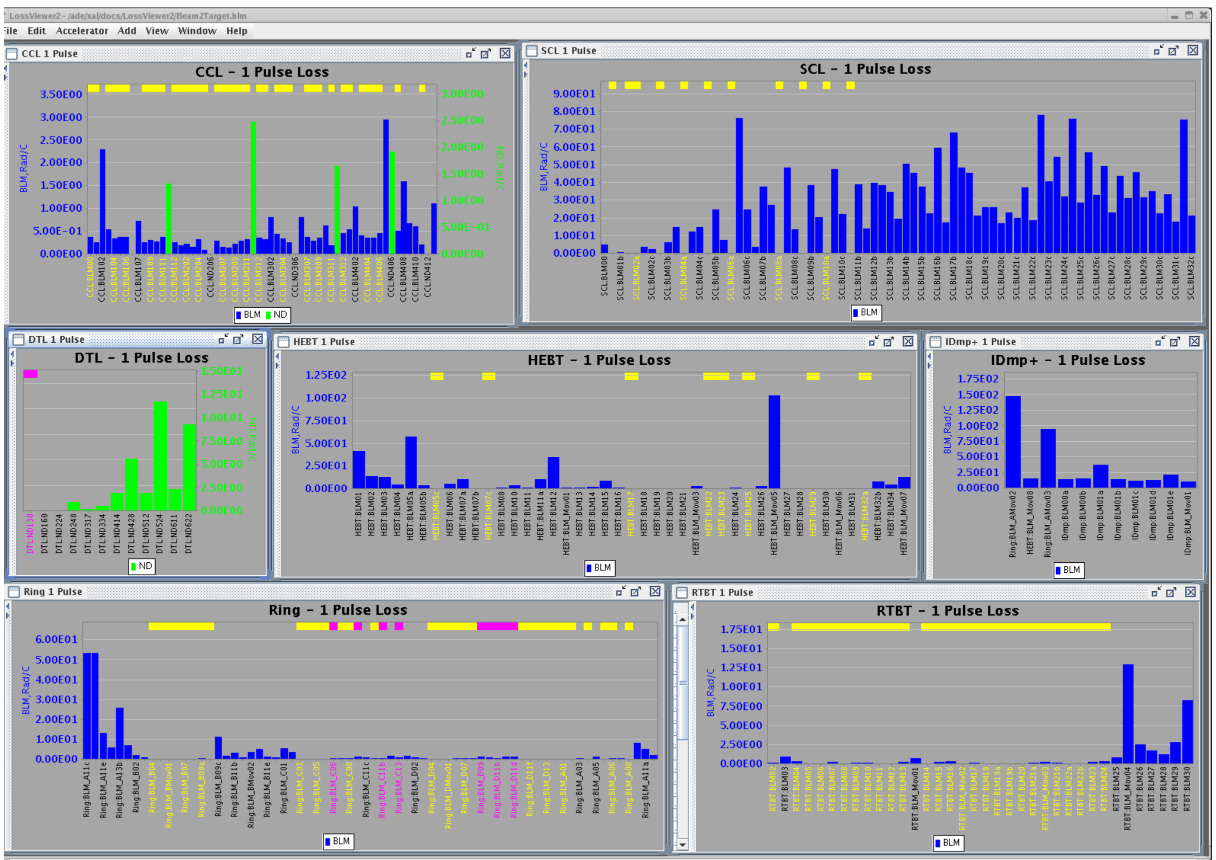
Beam loss measurement and control is critical



- Typical beam power is 1 MW
- Loss should be less than 1 W/m, or 1 part in 10^6 per meter, to limit activation to ~100 mrem/h at 30 cm after 4 hour cool down

How we measure beam loss

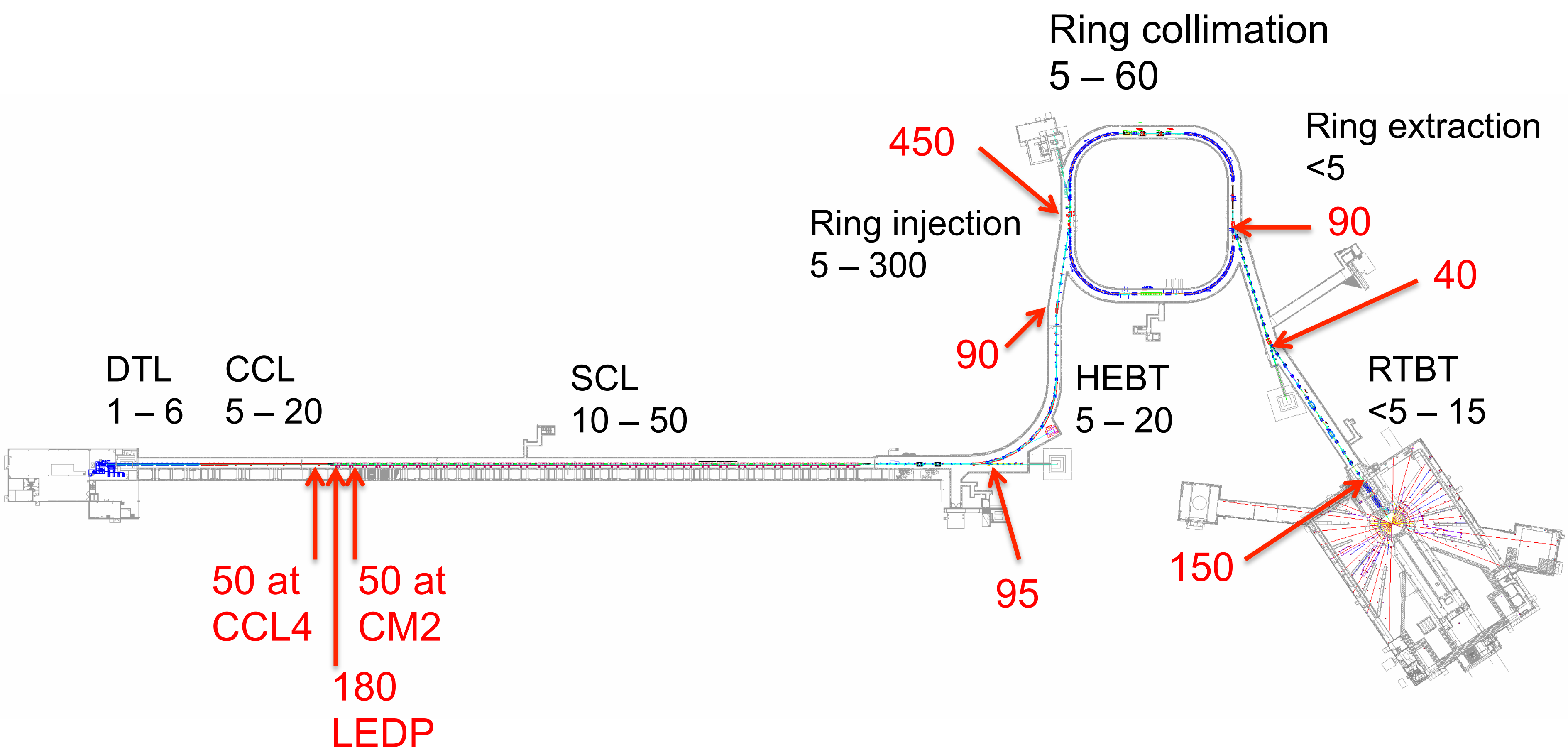
- Argon filled ionization chamber detectors (~307)
- Scintillation detectors with photomultiplier tubes (~55)
  - Neutron detectors - especially useful below ~100 MeV (e.g. DTL)
  - Fast loss detectors



←Typical BLM display

Photo of ionization chamber BLM

Typical activation levels for 1 MW operations



All numbers are mrem/h at 30 cm from beam line after 1 MW operations followed by ~48 hours of low-power studies

(divide by 100 to get mSv/h)

Beam loss mitigation

- Scraping – best done at low beam energies
- Increase beam size in superconducting linac, to reduce intrabeam stripping
- Adjust quadrupole magnet and RF phase setpoints to empirically reduce losses

Beam loss reduction by scraping

Almost never used

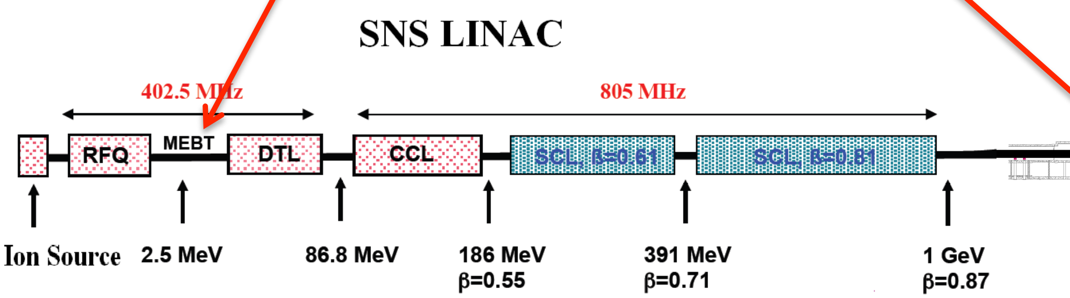
In Ring:
Four scrapers (0, 45, 90, 135 deg.)
Three collimators

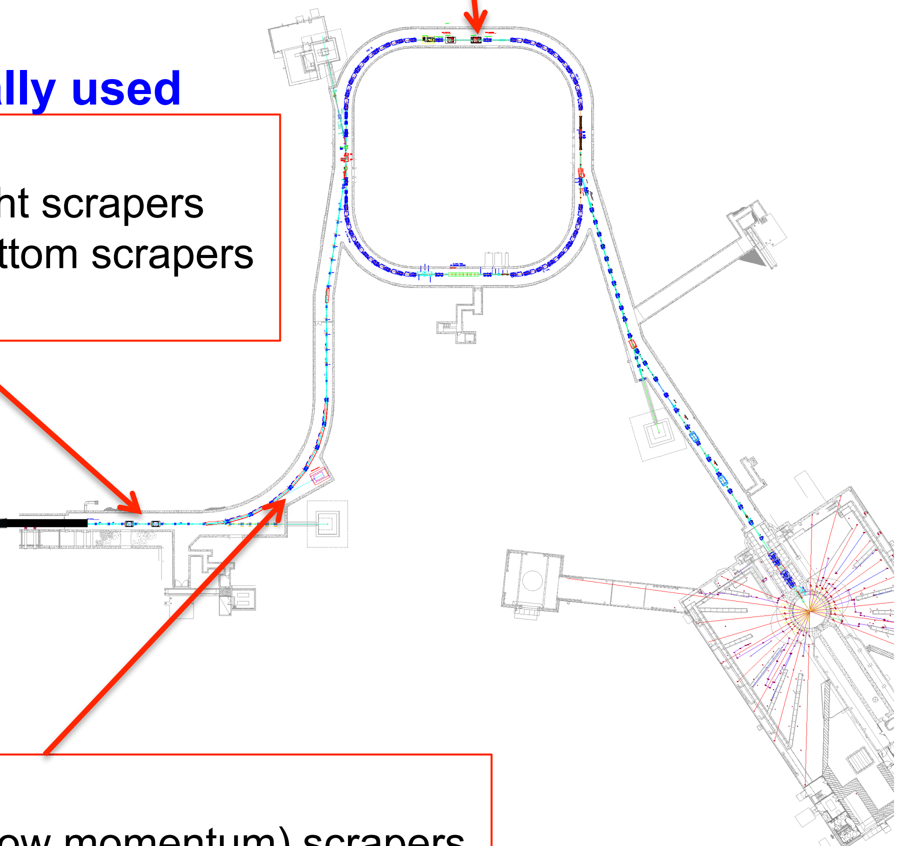
Most effective

In MEBT:
Left-right scrapers
Chopper target also used for top scraping

Occasionally used

In HEBT:
Two pairs of left-right scrapers
Two pairs of top-bottom scrapers
Two collimators





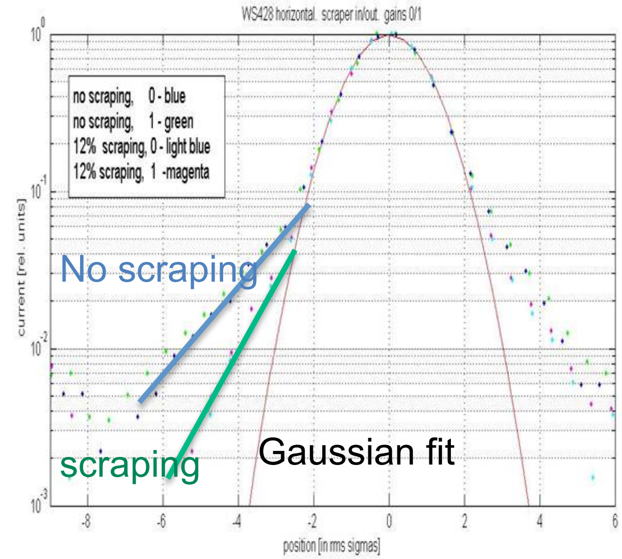
Rarely used

In HEBT:
Left-right (high and low momentum) scrapers
Followed by beam dump

MEBT Scraping

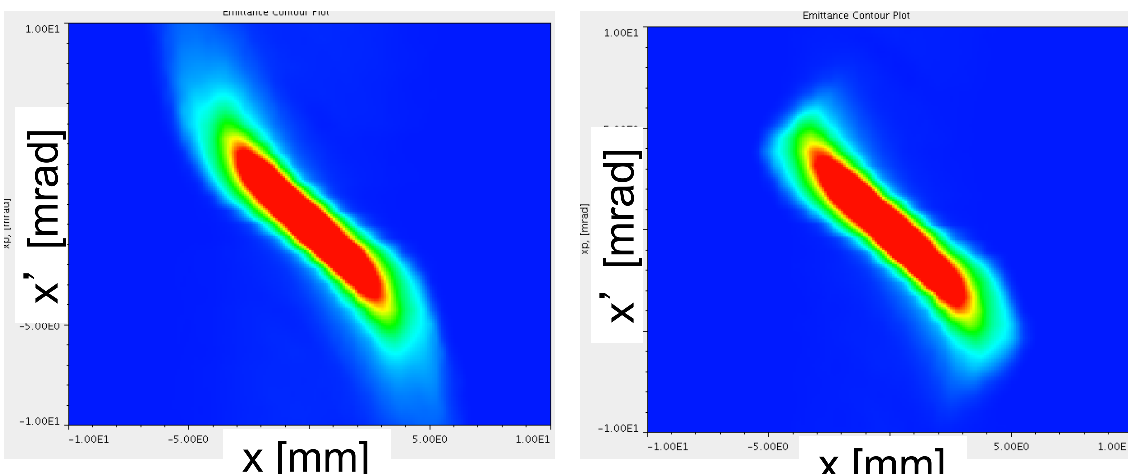
- 2 horizontal MEBT scrapers
  - Standard part of production
  - Reduces linac and injection dump losses by up to ~60%
  - Effectiveness in loss reduction varies from source to source

DTL profile, log scale

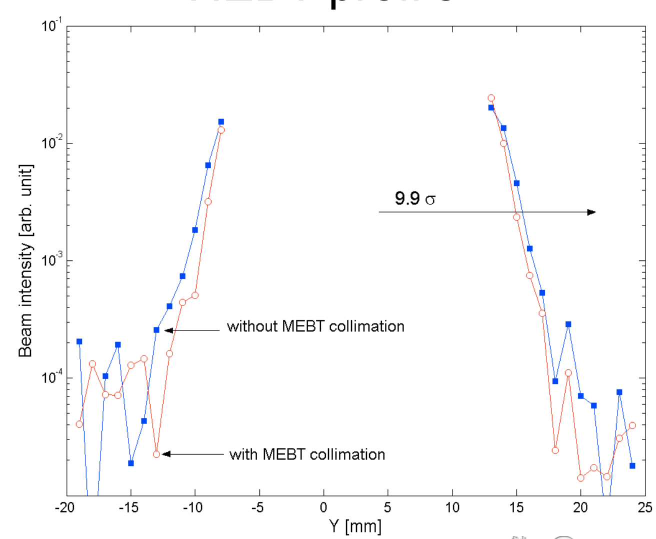


MEBT Emittance without scraping

MEBT Emittance with scraping



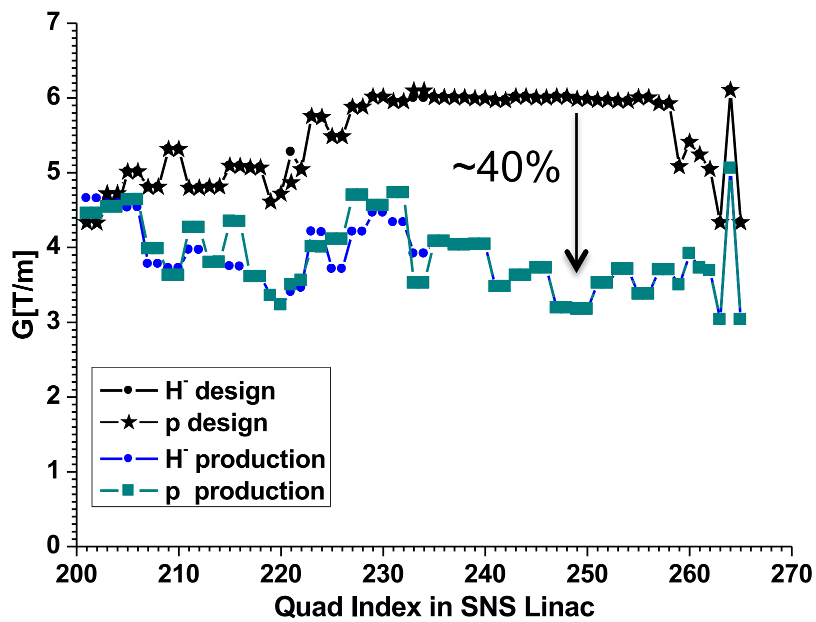
HEBT profile

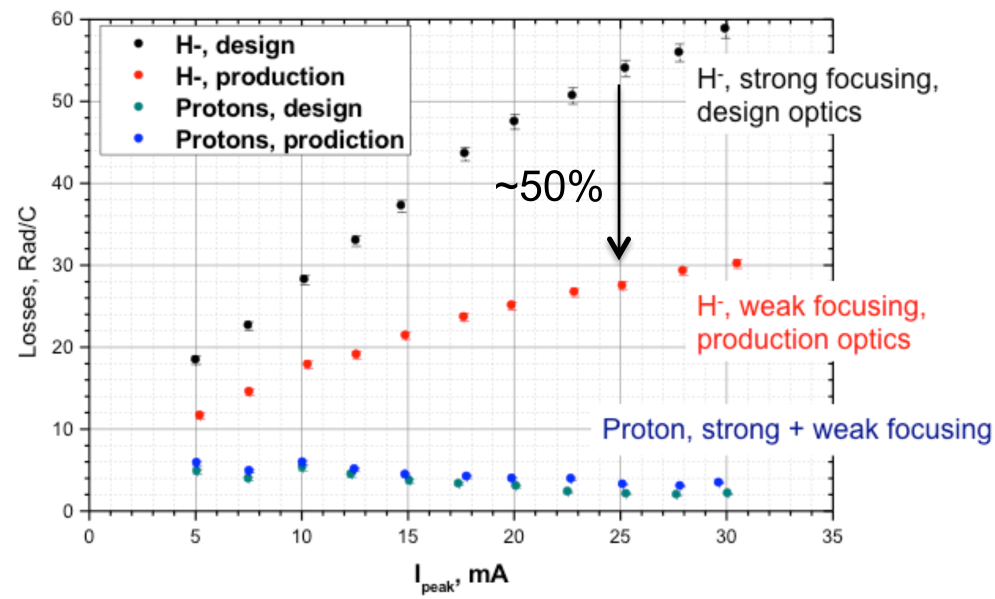


Courtesy A. Aleksandrov

Beam loss reduction by increasing the beam size in the SCL

- Most of the beam loss in the SCL is due to intra-beam stripping ($H^- + H^- \rightarrow H^- + H^0 + e$)
- IBSt reaction rate is proportional to (particle density)^2



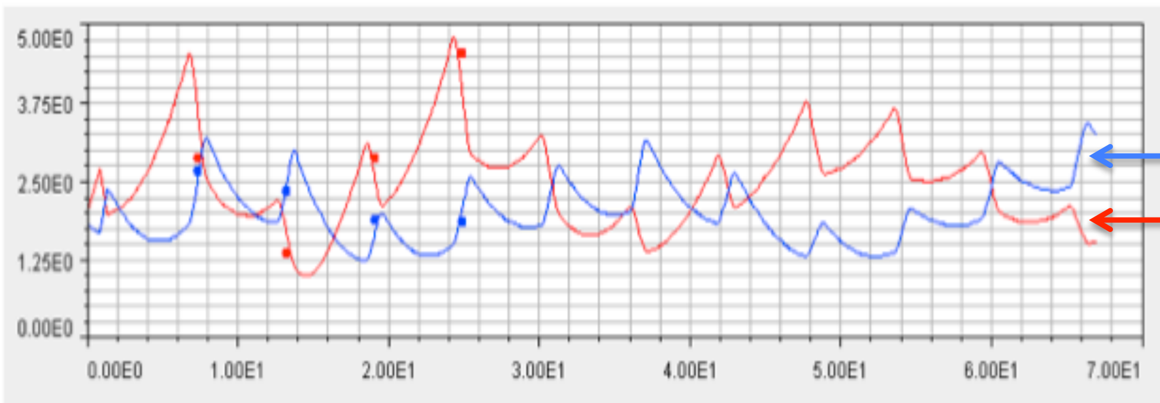


Beam loss reduction by empirically adjusting magnets and RF phase

- Best beam loss is obtained by empirical changes that sometimes results in beam that is transversely mismatched at lattice transitions (e.g. CCL to SCL, SCL to HEBT)
- RF phases that have been determined by simulation codes do not give good beam loss
  - Biggest deviation from simulations are at entrance to SCL
  - One degree phase changes can approx. double the beam loss at some places
  - Typical phase changes are 1 to 10 deg.

Mis-match in the linac and transport line

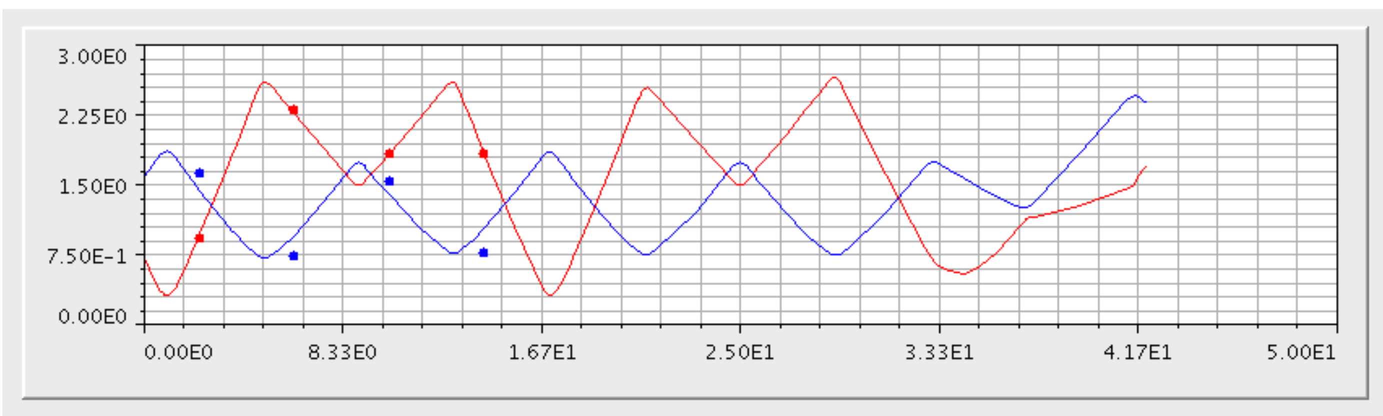
Low-loss tune is mis-matched at beginning of SCL



Vert. size

Horiz. size

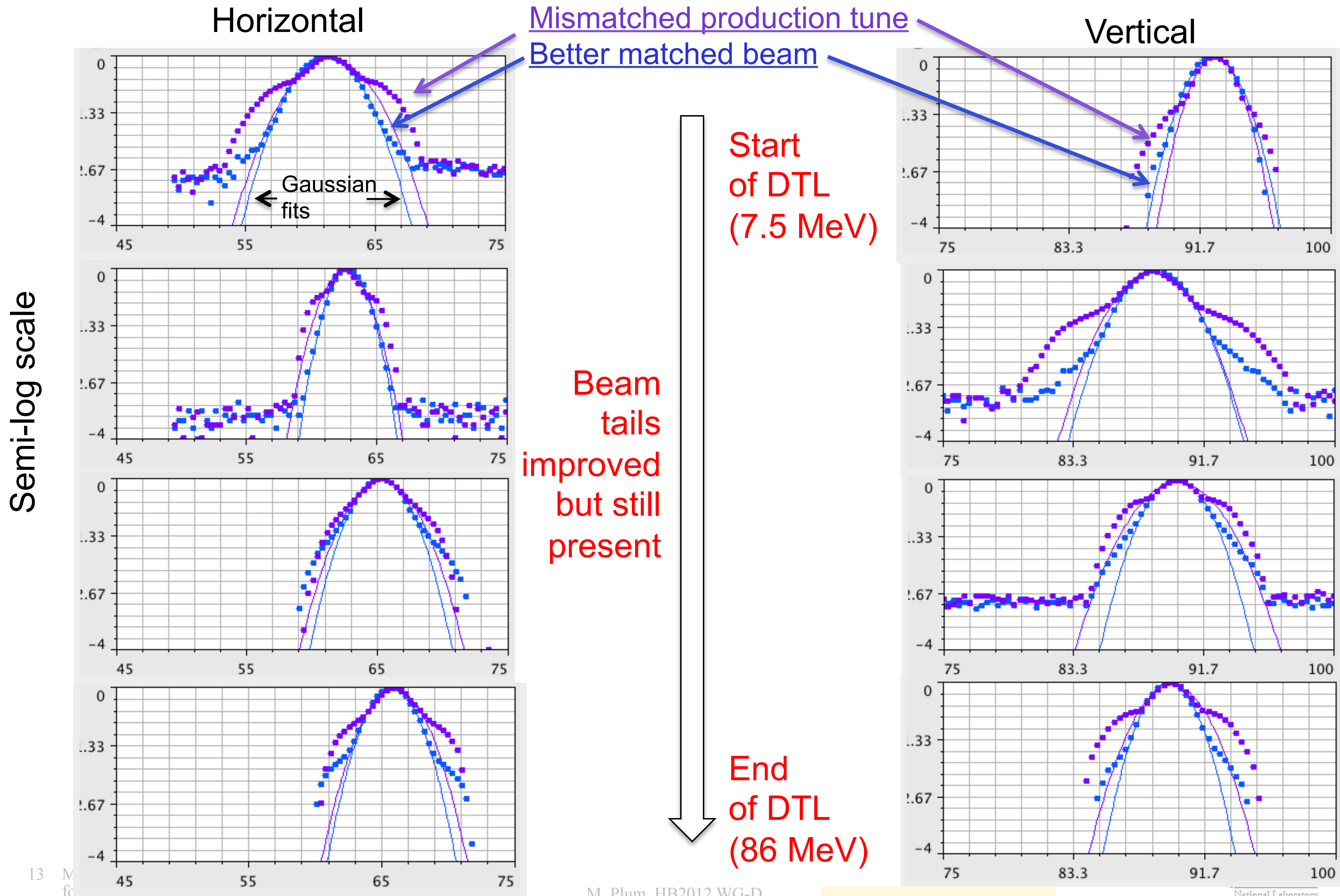
Low loss tune is mis-matched at beginning of HEBT



These are FODO lattices

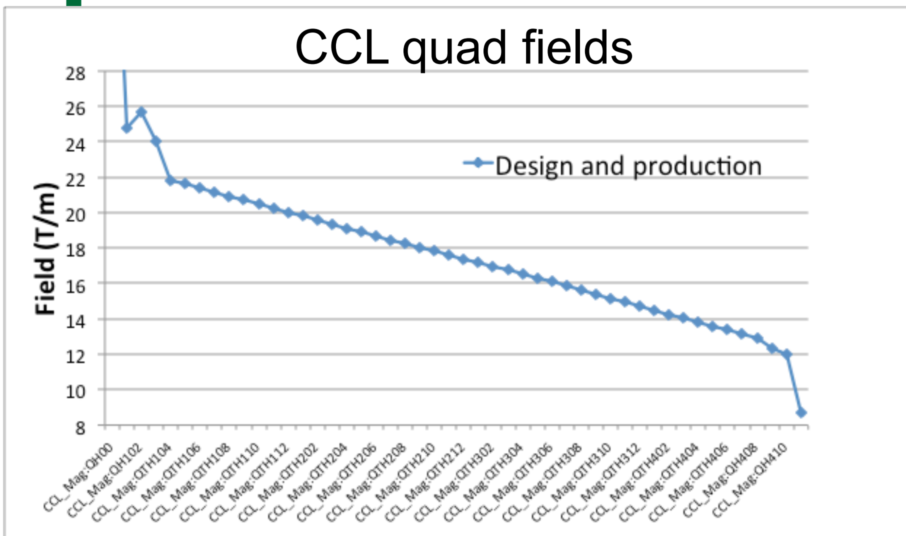
The low-loss tune is mis-matched in the SCL and HEBT

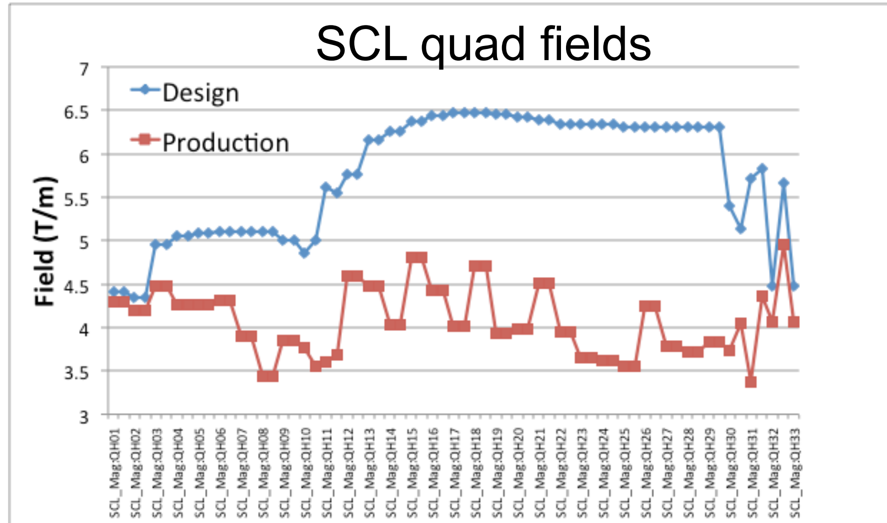
Example: beam tails are created in DTL

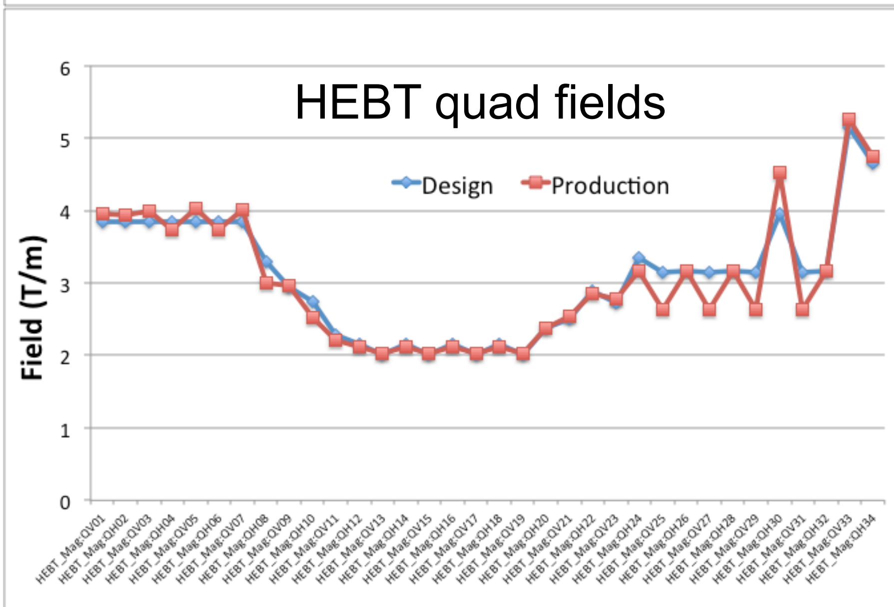


Courtesy C. Allen

SNS Linac Transverse Lattice: Design vs. Operation

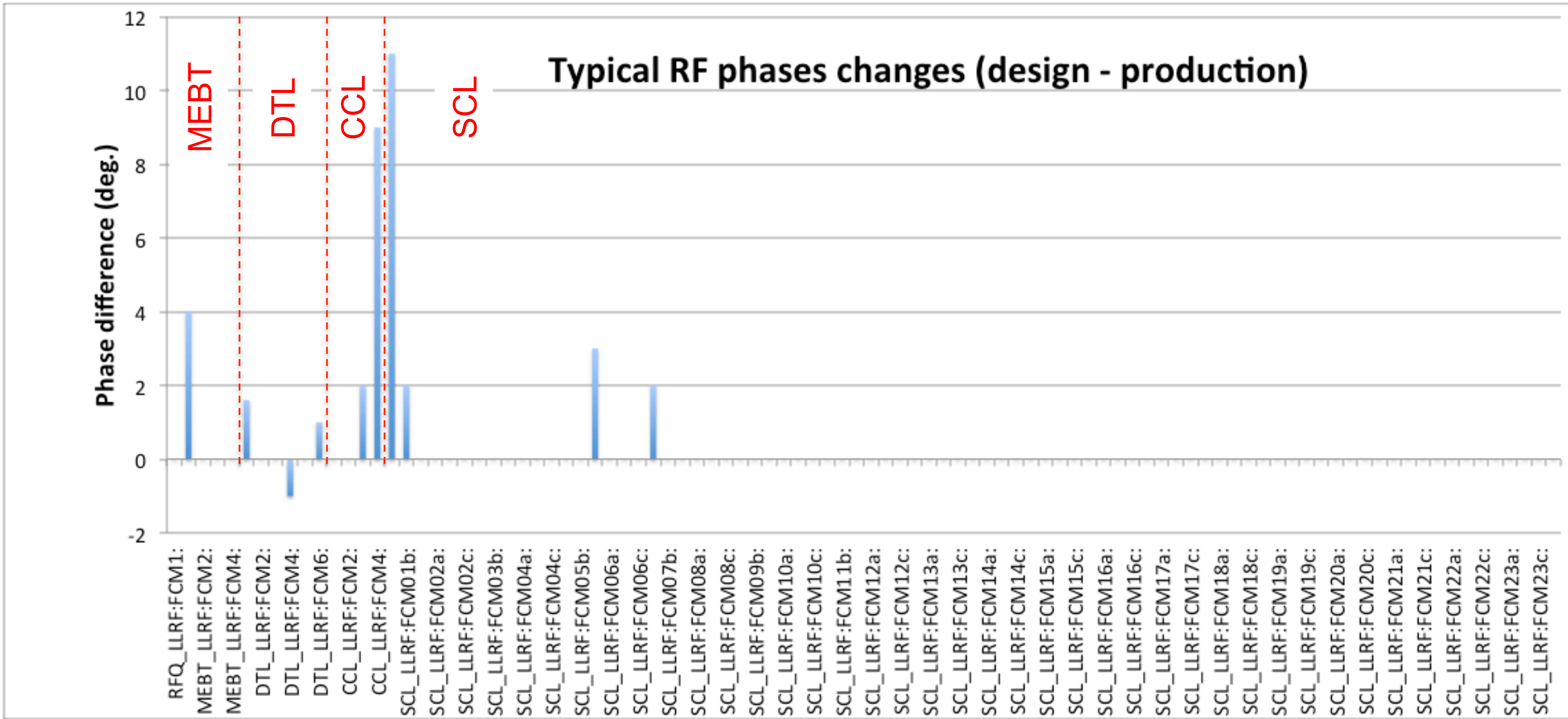






- **Warm linac CCL quads are equal to design**
- **SCL quads run much lower than design**
- **HEBT is run close to design**

Linac RF phases design vs production



Some RF phases must be empirically adjusted to achieve the low-loss tune

Hypothesis

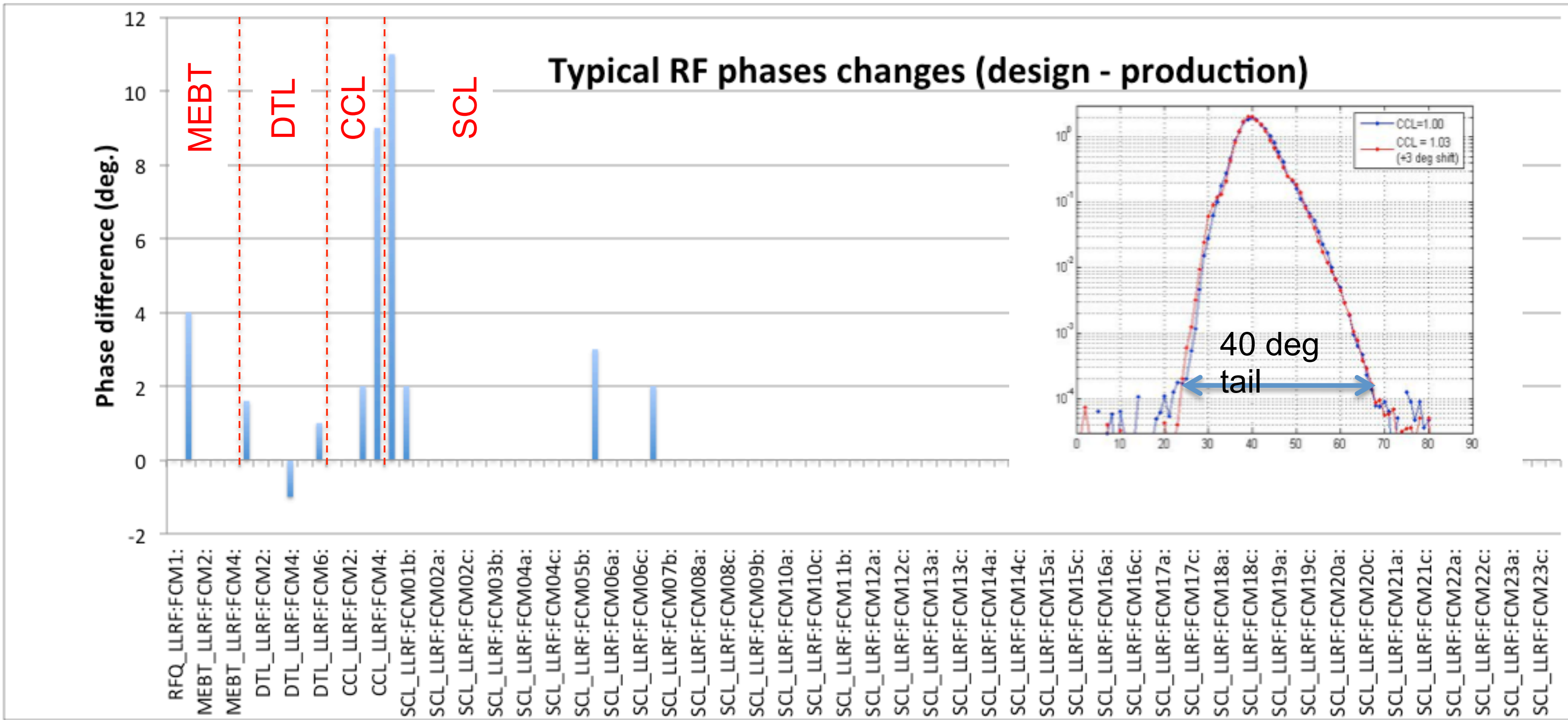
- The empirically-derived low-loss tune shows a mis-matched core throughout the linac and transport lines
- Beam halos/tails are what cause the beam loss, and they are present at the 0.01% to 30% level
- Due to space charge effects, ion source effects, etc., the Twiss parameters of the tails are different than the core of the beam
- The low-loss tune is the one which best transports the halos/tails of the beam, and which may cause strange results (e.g. mis-matched) for beam-core measurements

Summary

- There are some large differences between the design and production set points in the SNS accelerator
- Beam loss is caused by halos/tails, not by the core of the beam
- Scraping at low beam energy (2.5 MeV) is our most effective method of beam loss reduction, after first reducing the loss by empirical tuning
- If the Twiss parameters of the halo/tails is different than the core, it may be better to tune up the accelerator to best transmit the halos/tails rather than the core
- The exact amount of scraping, and the exact empirical tuning set points change a bit when we change ion sources and the machine lattices

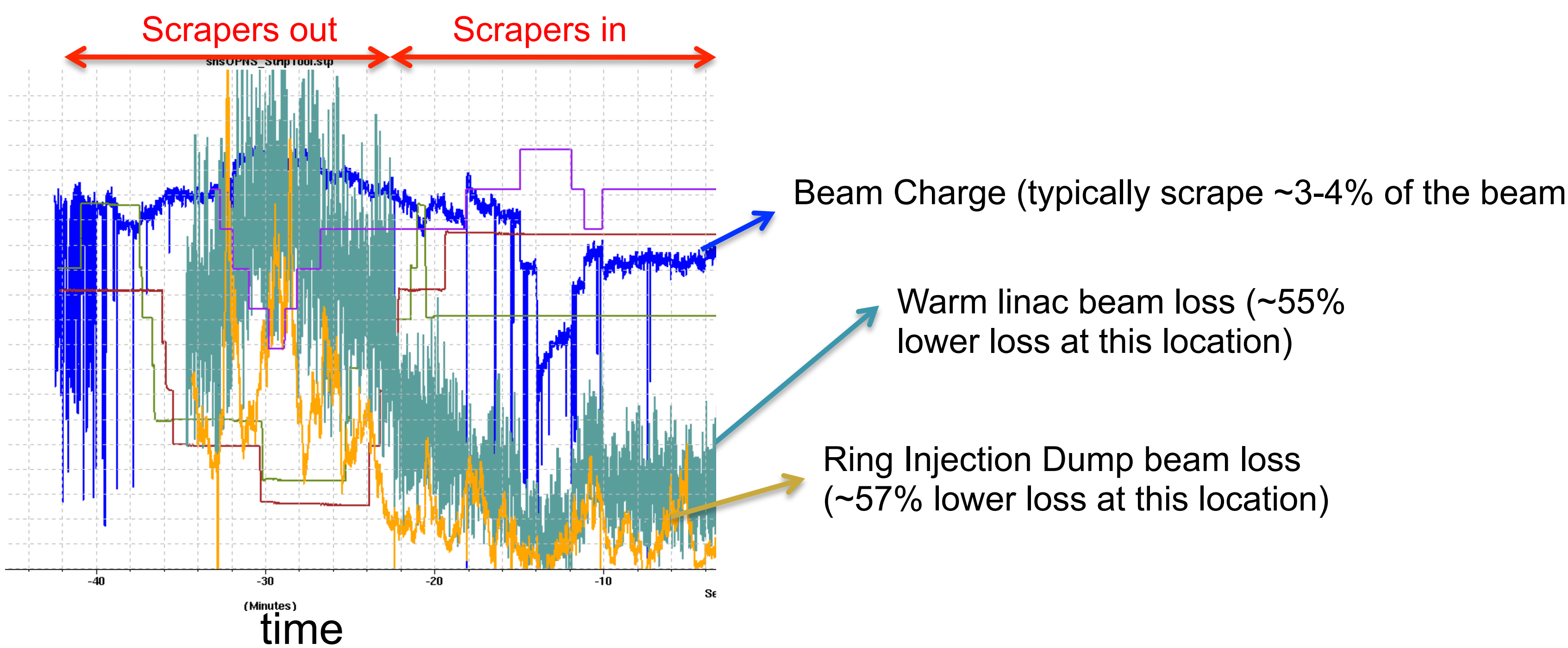
Back up slides

Linac RF phases design vs production



BSM data courtesy A. Aleksandrov

Scraping at low beam energy (2.5 MeV)



- The effectiveness of the MEBT scrapers varies with the ion source and the machine lattice
- We are working to reduce tails/halo by optimizing the match of the beam into the DTL, CCL, SCL, and HEBT

Courtesy J. Galambos