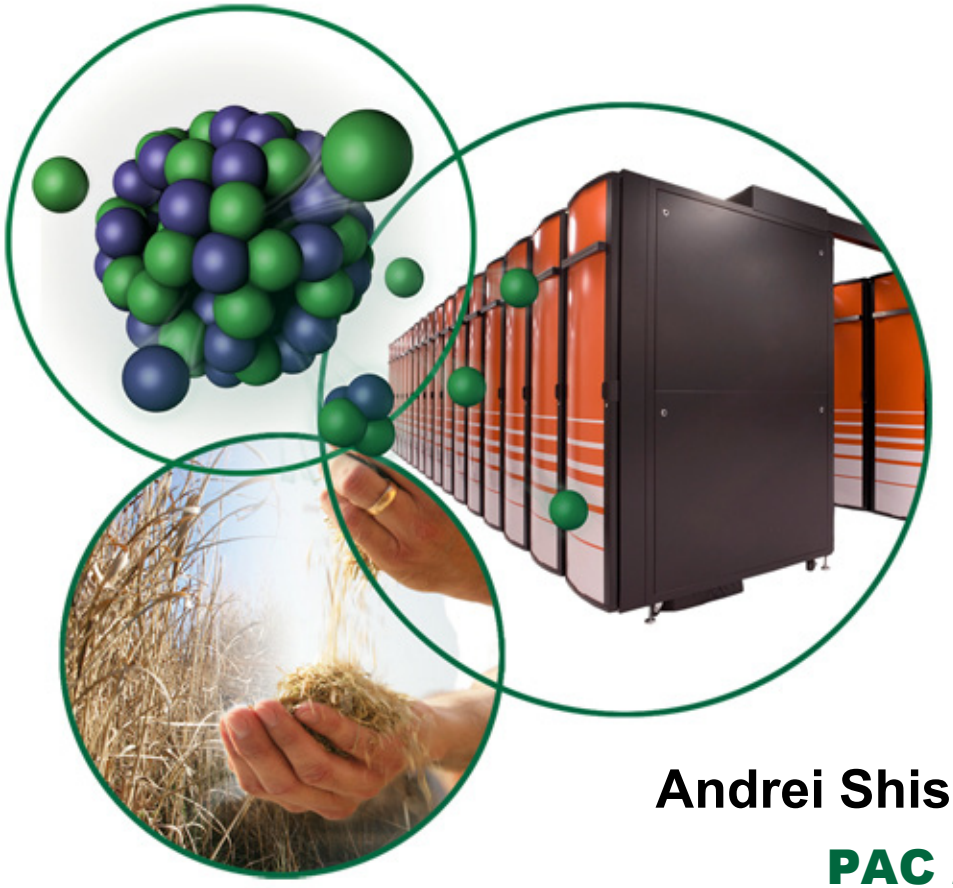
Beam Dynamics Issues in the SNS Linac



Andrei Shishlo on behalf of SNS Group

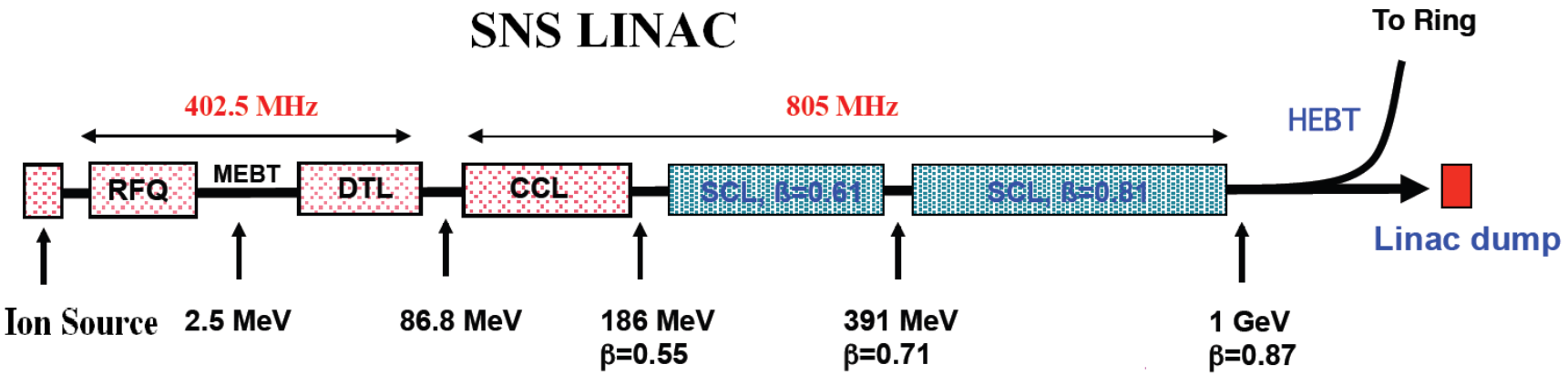
PAC 2011, New York, NY

March 28, 2011

Outline

- Introduction
- SNS Linac design and losses estimation
- Design vs. live machine
  - Live losses vs. estimation
  - Chopping and collimation
  - SCL Losses: absolute value, losses vs. quad fields, “flashlight” experiment
- Conclusions

SNS Linac Structure



DTL – Drift Tube Linac
CCL – Coupled Cavity Linac
SCL – Super Conducting Linac

H^- linac
Length: 330 m (Superconducting part 230 m)

Production run parameters:
Peak current: 38 mA
Repetition rate: 60 Hz
Macro-pulse length: 0.8 ms
Average power: 1 MW

SNS Linac Design

Design to avoid halo generation (Los Alamos):

- zero-current phase advances per period never exceed 90 deg (to avoid envelop instabilities).
- transverse and longitudinal phase advances do not cross (avoiding second order parametric resonance)
- phase advances per meter are smooth functions along the linac
  - minimizes possible mismatches
  - peak current independent design

Warm Linac
- geometry defines the longitudinal dynamics – no flexibility

Superconducting Linac
- set of independent RF cavities – flexible
- can accommodate amplitude changes

SNS Linac Beam Sizes and Apertures, Losses Expectations

E. Tanke et al. SNS, Tech. memo , 16-March-2001
N. Catalan-Lasheras et al. SNS/AP Tech. Note 07

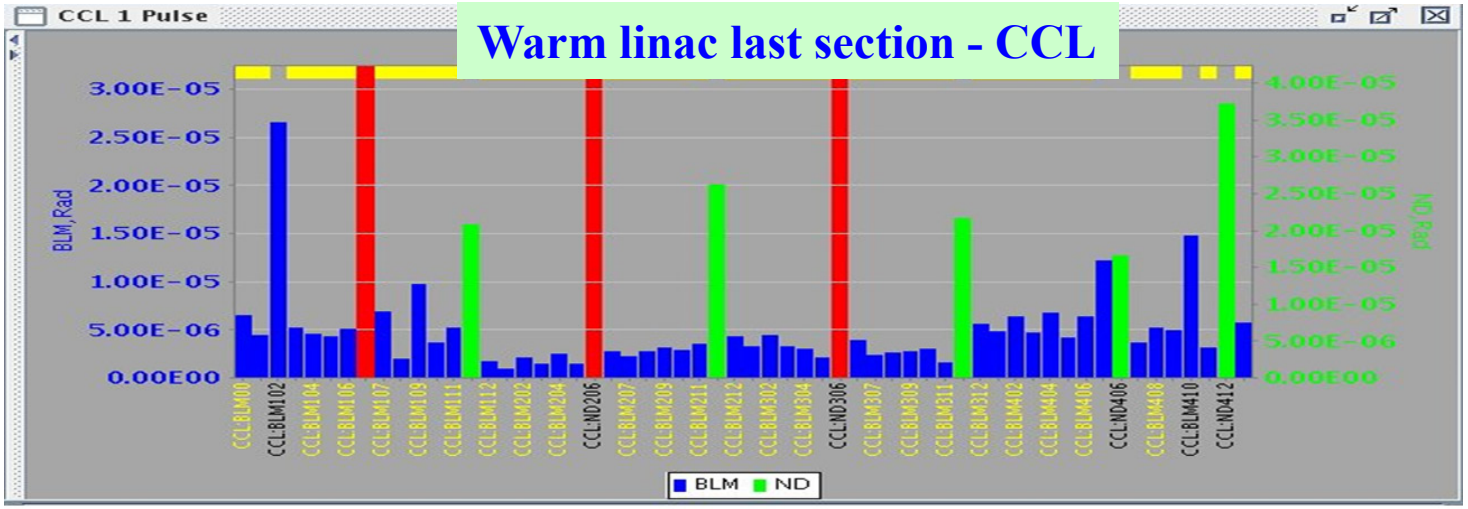
Section	Fractional losses	Half Aperture, mm	Half Aperture (rms size)	Mechanism of Losses
DTL	9.0×10^{-5}	12.5	6	Emittance growth
CCL	6.7×10^{-5}	15	5	Emittance growth + stripping on residual gases
SCL	3.7×10^{-6}	37	10	Emittance growth In cold sections the vacuum is better Hydrogen instead of nitrogen

Quotation about Super Conducting Linac (SCL):

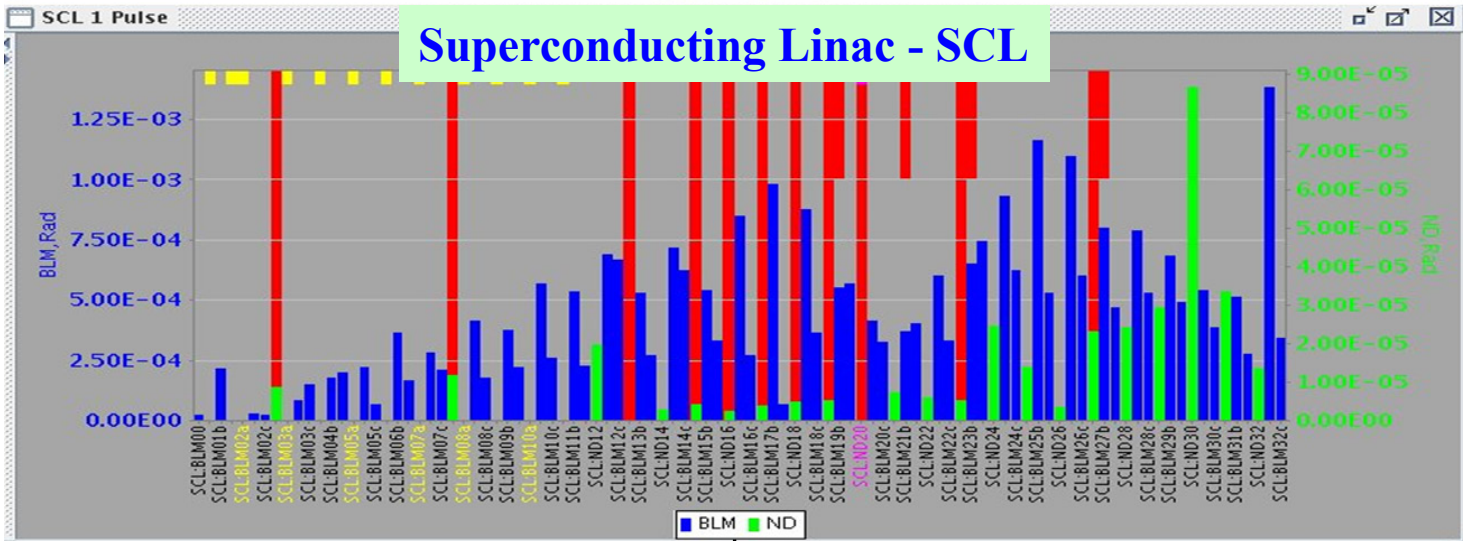
"Simulations and stripping calculations give a negligible amount of losses. On the other hand, one should be very cautious with our expectations as there is no experience with superconducting proton linac up to now."

Production Losses

Losses



Losses



Losses in the cold linac are higher than the predictions

SNS is not limited by SCL losses!

Real Machine vs. Design

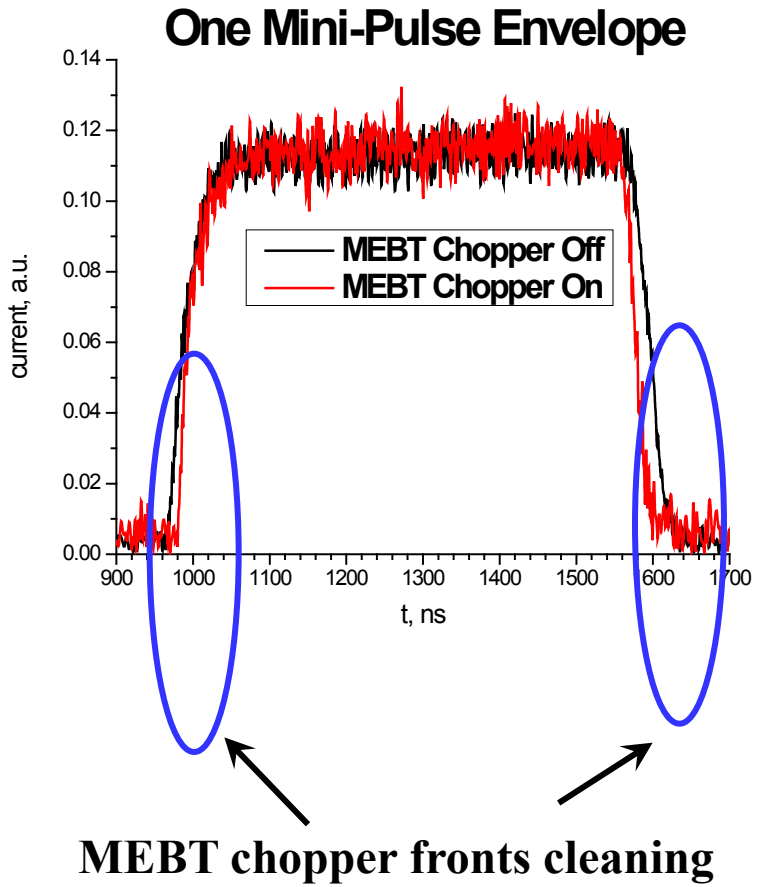
- It works (most important)
- The room temperature linac is tuned according to the design

- The MEBT chopper is mechanically different
- SCL cavity amplitude variation is much greater than expected
- The Intra-Beam Stripping loss mechanism was not considered (only IB Scattering)

MEBT Chopper

SNS has two stage chopping system:

- **LEBT chopper before RFQ: slow - rise time about 50 ns**
- **MEBT chopper (2.5 MeV): rise time is 15 ns, and it cleans the gap once again**



The original faster MEBT chopper (analog of Los Alamos PSR system) was damaged two times and was replaced.

We have a lot of partially chopped beam:

6 - 4% bunches have less than 50% of max charge.

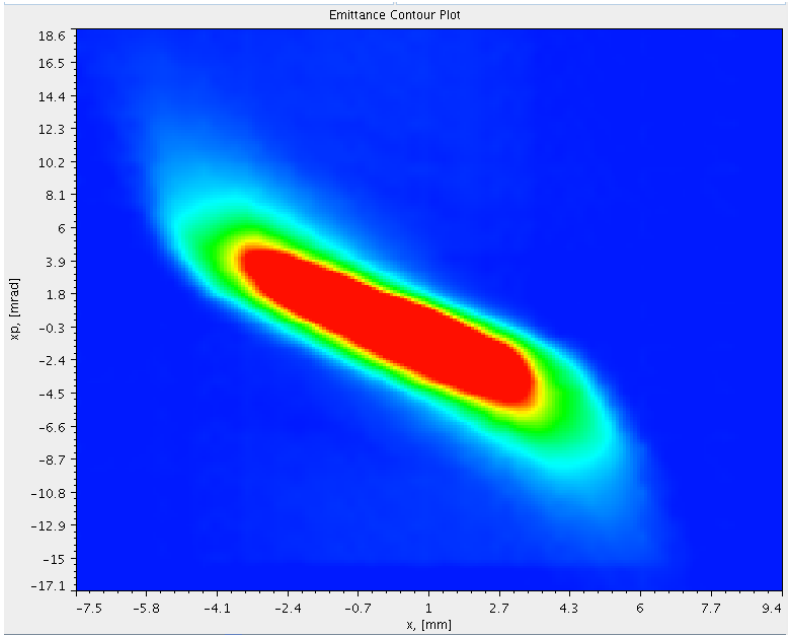
No big effect on linac losses, but it improves extraction losses in the ring

Transverse Emittance and Chopping

LEBT Chopper	RMS Horizontal, norm. mm*mrad	RMS Vertical, norm mm*mrad
On	0.40	0.22
Off	0.29	0.19

MEBT Horizontal Emittance (scales are the same)

X’



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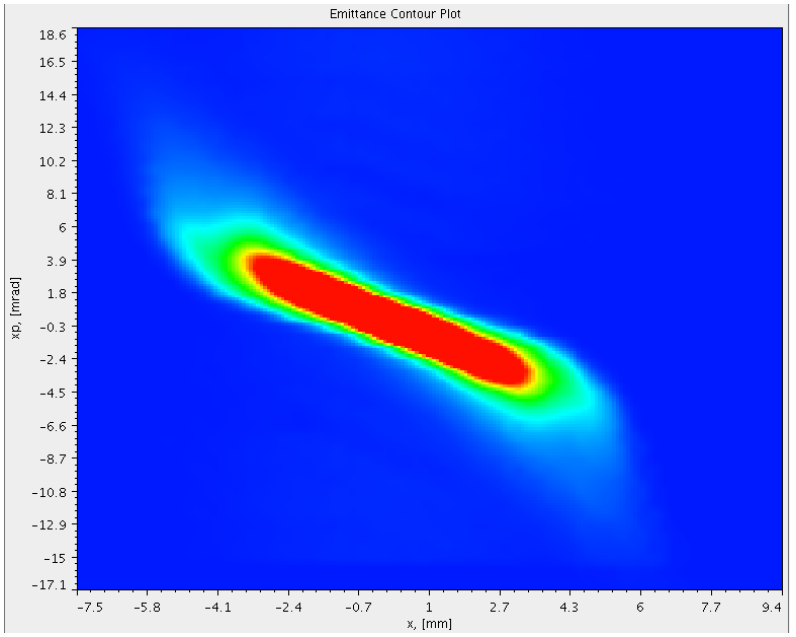
LEBT Chopper On



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LEBT Chopper Off

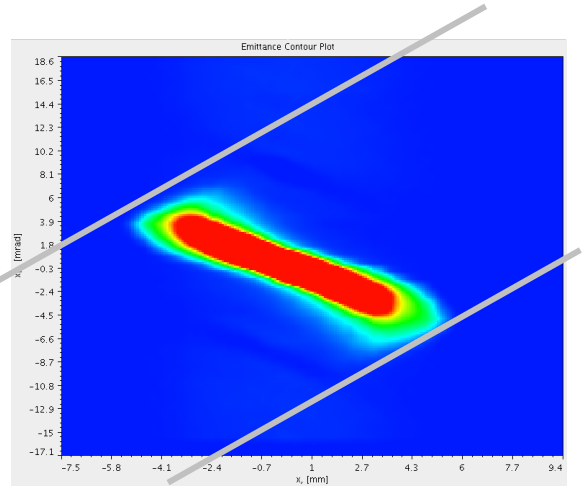
MEBT Scraping

MEBT has:

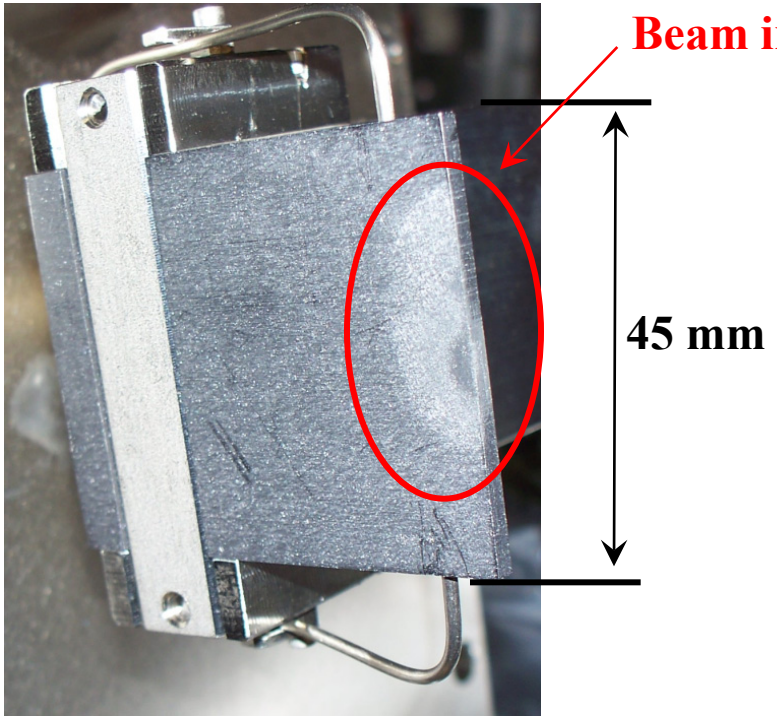
- 2 horizontal scrapers
- MEBT Chopper target is used as a scraper

- MEBT scraping definitely helps in the loss reduction tuning, but the effect is different for different ion sources.

- Usually we are scraping 1-3% of the beam



MEBT Horizontal Emittance



MEBT Scraper Left Blade

- Discoloration occupies considerable part of the MEBT aperture (3 cm diameter)

- Asymmetric in the vertical direction – the second upper spot - MEBT chopper effect

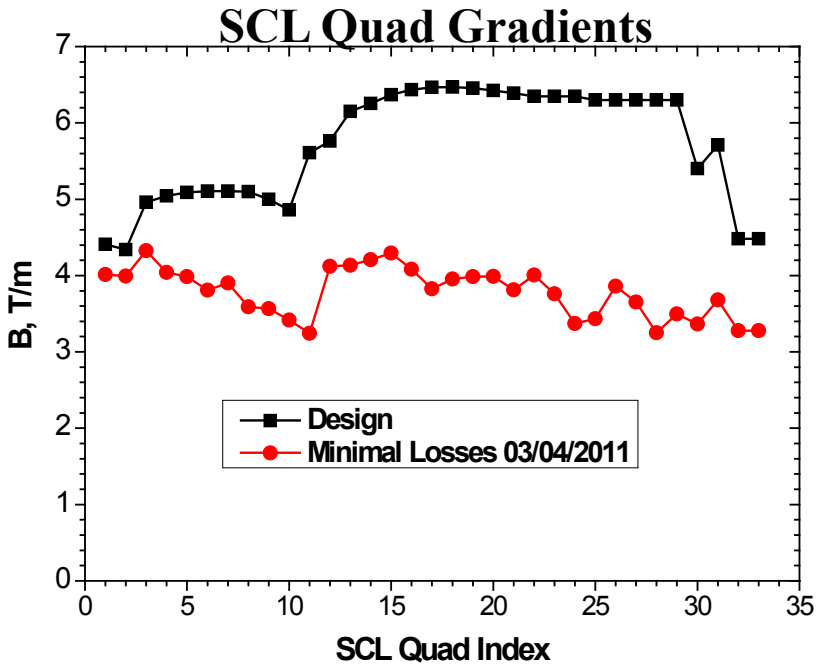
SCL Losses

The better chopping and beam scraping help in the local loss reduction and cannot significantly reduce the level of SCL losses.

- History of SCL loss reduction
- Loss estimation based on Intra Beam Stripping mechanism
- Fractional SCL losses measurements
- “Flashlight” experiment

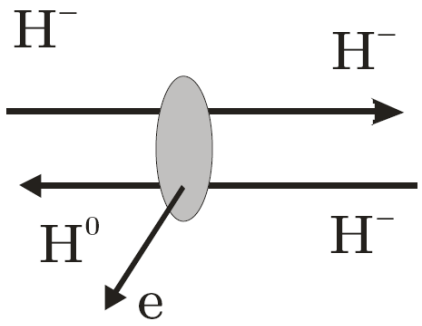
History of SCL Losses Reduction

- Before the end of 2008 the cold linac losses and activation followed our power ramp up.
- At the end of 2008: SCL loses are created by off-energy particles. By reducing the focusing in the lattice we can transport them downstream.
- The start of the campaign to lower the SCL quad fields to reduce losses.
- By lowering SCL quads' fields the losses were reduced to an acceptable level.



2010: SCL losses can be caused by Intra Beam Stripping of H^- (Valeri Lebedev, FNAL)

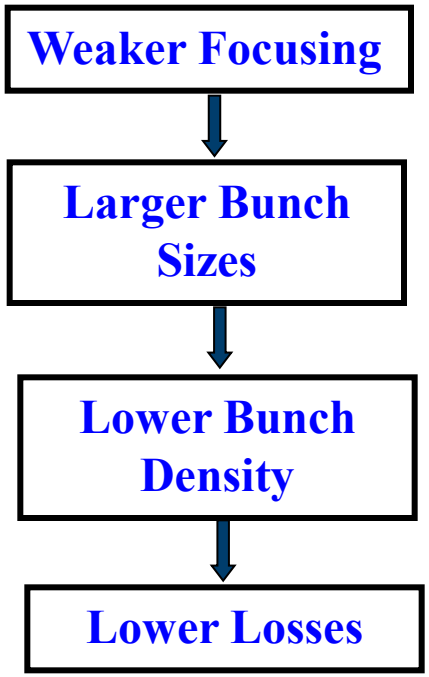
Intra Beam Stripping (Valeri Lebedev, FNAL)



(Talk at SNS, ORNL, October 2010)

$$\frac{1}{N}\frac{dN}{dt} \propto \frac{N}{V}$$

Loss rate is proportional to the bunch density.



Fractional SCL losses estimation: 4×10^{-5}

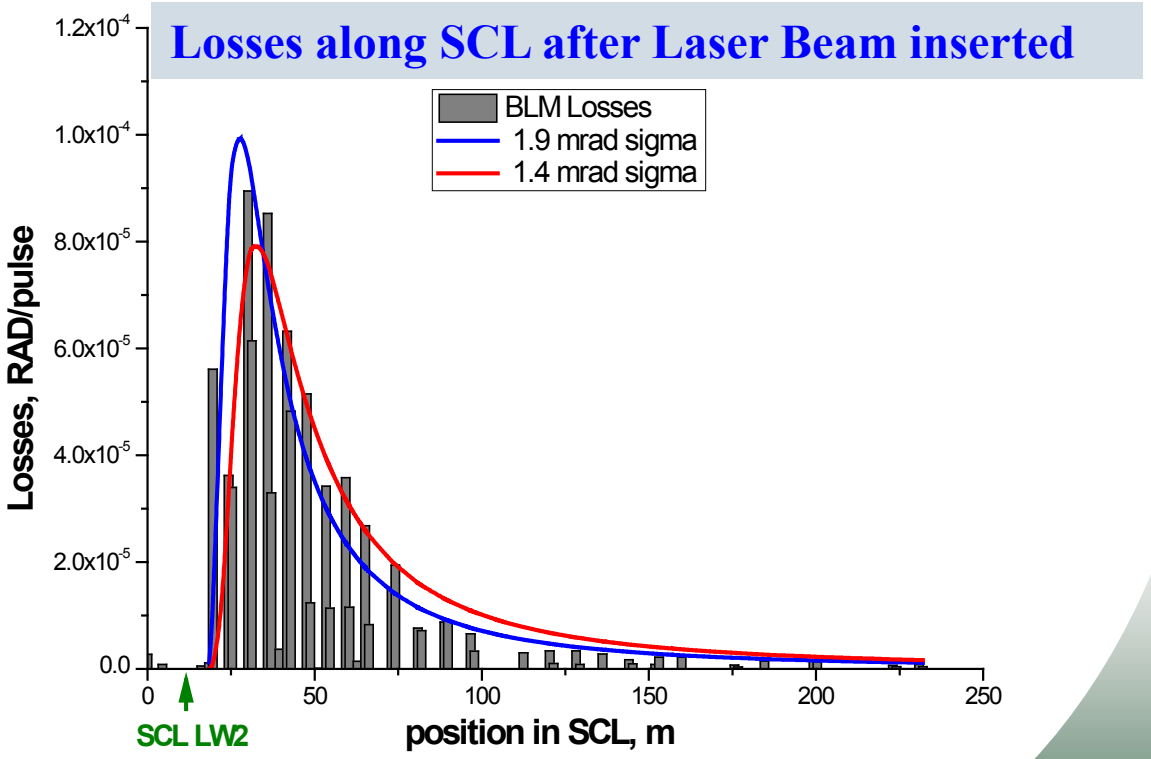
Experimental SCL Total Loss Estimation

Initially was estimated by J. Galambos : 1.0×10^{-4}

- Cold linac has 9 laser wire profile monitors
- Laser beam makes a distributed spill after $H^- \rightarrow H^0 + e^-$ conversion
- Laser beam strips about 10^{-6} of total number of H^- in macro pulse
- We know total losses and additional losses -> can figure out total losses

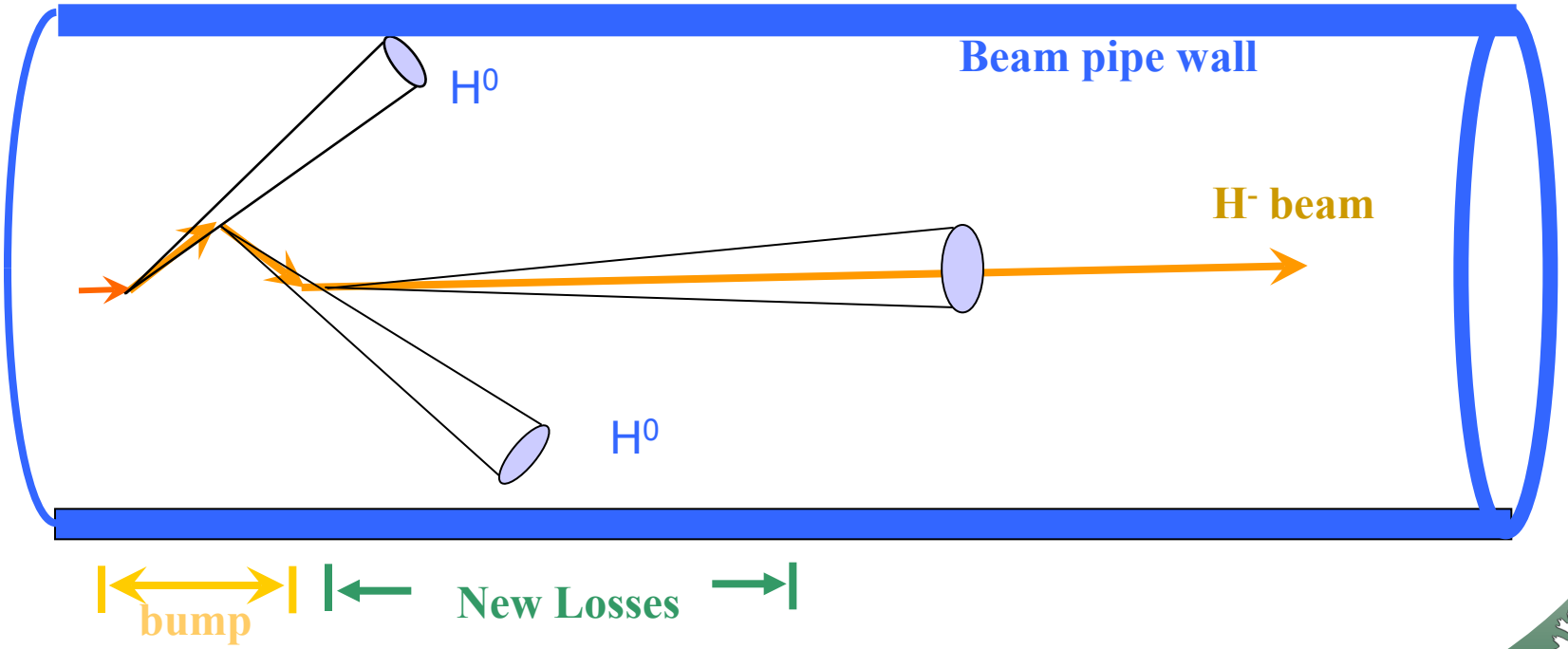
Fractional SCL losses
$(2 - 7) \times 10^{-5}$

This estimation does not prove the mechanism of the losses!



Flashlight Experiment – Rationale (1)

- From the early days:
  - local closed trajectory bump in SCL creates downstream losses (J. Galambos, C. Allen)
- The initial explanation:
  - the off energy particles are disturbed by the bump and thrown onto the beam pipe surface downstream
- Later:
  - H^0 created by the Intra Beam Stripping along the beam can be directed (closed bump in the trajectory) to different downstream points.

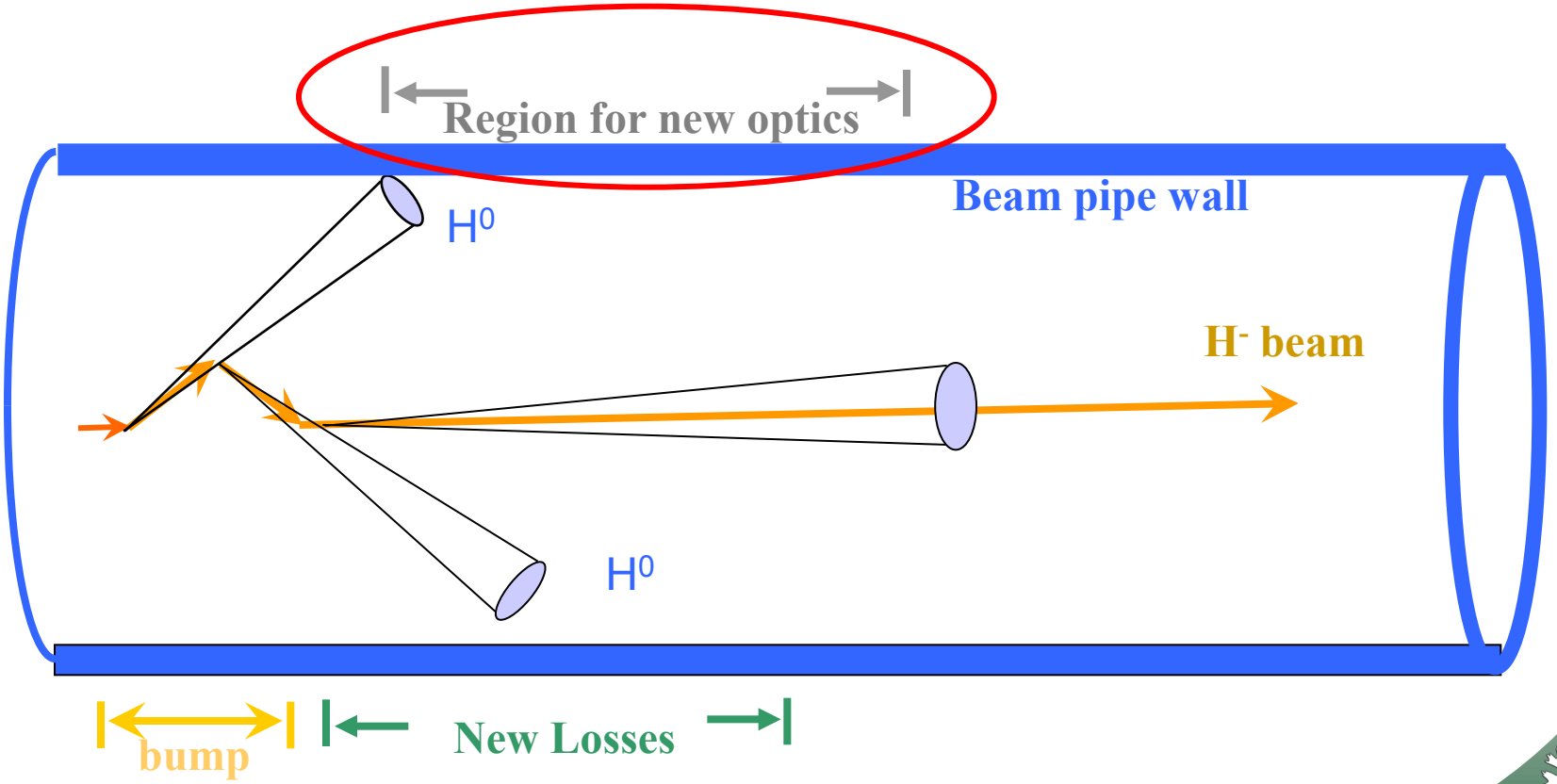


Flashlight Experiment – Rationale (2)

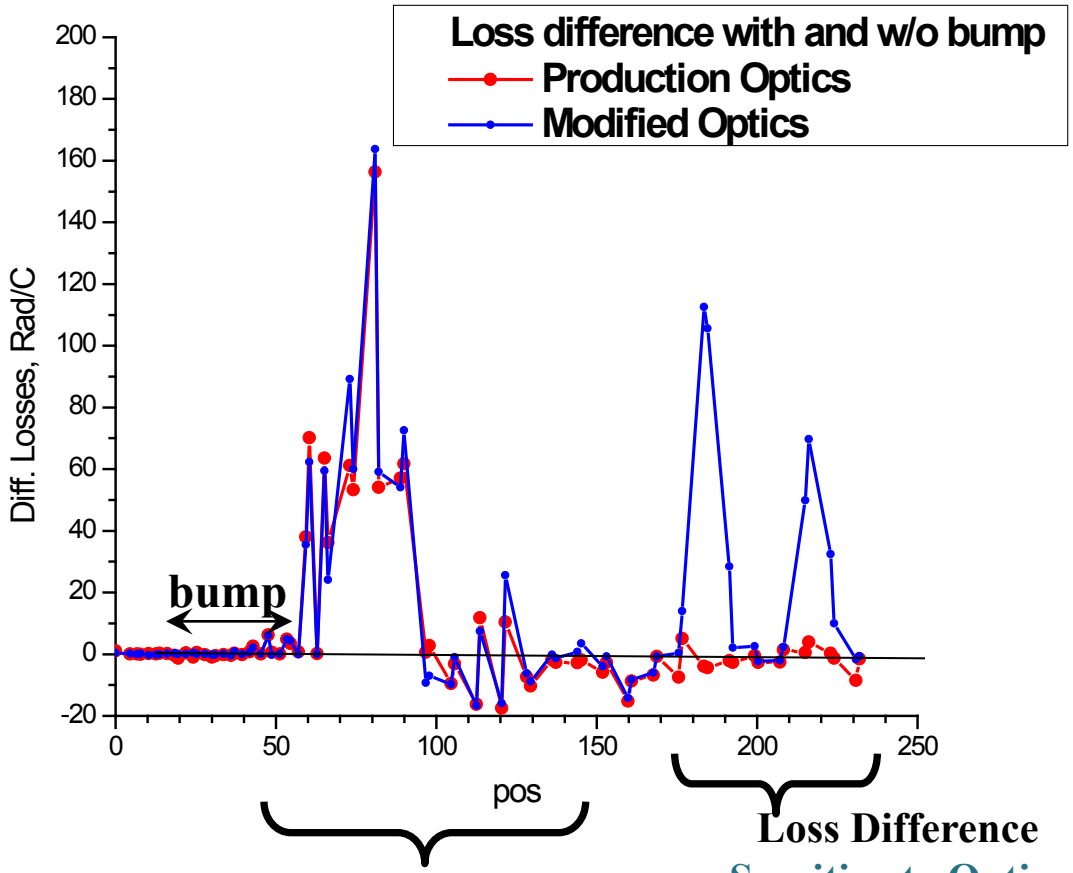
The difference between two mechanisms:

- **H^- are affected by lattice optics downstream of the bump**
- **H^0 are not**

We can compare the change in losses for two optics.
If the changes in losses are the same : we have H^0
If not : we have H^-



Flashlight Experiment – Loss Differences after Closed Trajectory Bump



Question:
Why we always see the positive net change in losses?

Could it be explained by loss monitor sensitivity to the incoming angle of the H^0? Needs additional studies. Simulations?

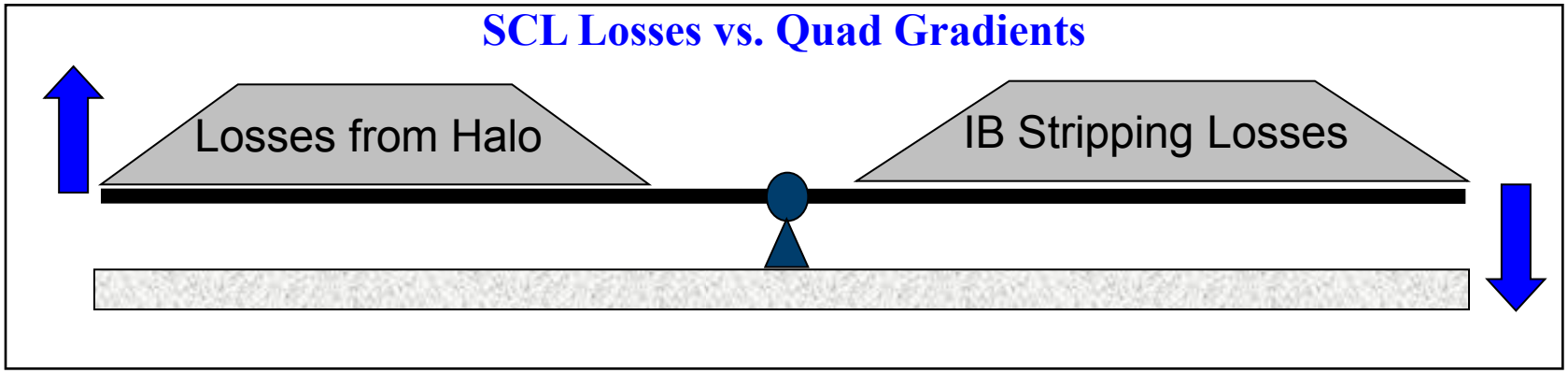
We see the loss component created by Intra Beam stripping

SCL Loss Reduction

If we are right about sources of SCL Losses

- **Transverse or longitudinal halo**
- **Intra Beam Stripping**

Situation today



If we think Intra Beam Stripping creates significant contribution to losses, we can reduce them:

- **by increasing the transverse beam size**
- **by increasing longitudinal beam size**
- **by avoiding the transverse size beating in SCL (matching)**

We reported at HB2010 and Linac10 conferences that we have difficulties in finding the initial Twiss parameters at the entrance of SCL. New error analysis and the experiment planning now give us accurate Twiss parameters.

We are ready to perform the matching procedure in SCL.

Conclusions

- SNS linac delivers routinely 1 MW beam with acceptable losses and activation.
- The wide range of peak current does not create noticeable distributed losses.
- Up to this day, the main tool for the SCL beam loss reduction is the reducing the quadrupole gradients.
- There are strong evidences that the Intra Beam Stripping mechanism is responsible for significant part of the SCL losses.
- There is a progress has been made in our knowledge about matching process in SCL and we will continue to work in that direction.

Thanks for your attention!