Beam measurement and simulation at the SNS

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ICFA-HB 2010, Morschach, Switzerland

September 30, 2010

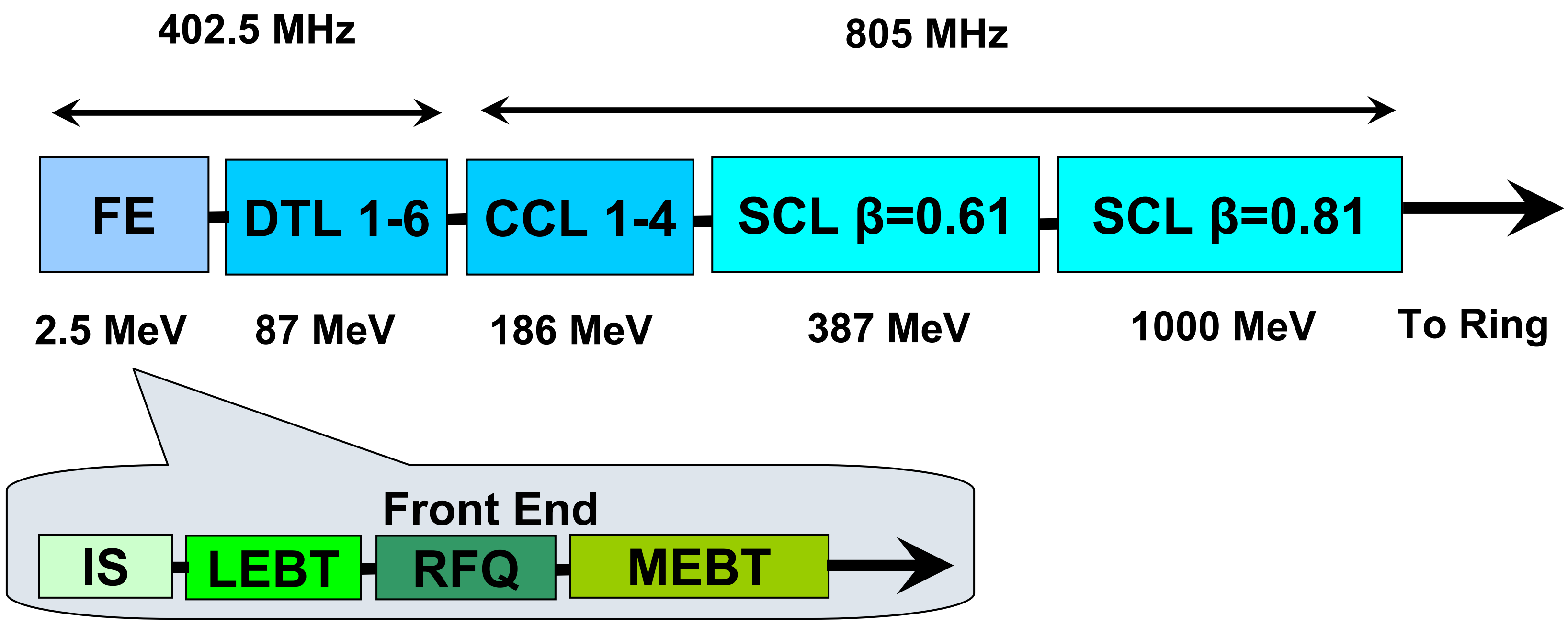
Outline

- **SNS linac structure**
- **Models**
- **Single Particle Beam Dynamics**
- **Twiss Parameters, Matching**
- **Losses and Models**
- **Intra Beam Stripping**
- **Conclusions**

SNS Linac Parameters

Parameter	Design	Best	Production
Energy, GeV	1.0	1.0	0.93
Peak Current, mA	38	50	35-40
Pulse Length, ms	1.0	1.0	0.8
RF Duty Factor, %	8	7	7
Average Power	1.44	1.08	0.9-1.08

SNS Linac Structure



- **In DTL and CCL tanks geometry defines the longitudinal dynamics – no flexibility**
- **SCL Medium and High beta – set of independent RF cavities - flexible**

Design to avoid halo generation:

- The zero-current phase advances (transverse and longitudinal) per period never exceed 90 deg.
- To avoid the second order parametric resonance, the transverse and longitudinal phase advances.
- The transverse and longitudinal phase advances per meter are smooth functions along the linac. This feature minimizes possible mismatches and helps to create a current independent design

SNS Linac Diagnostics

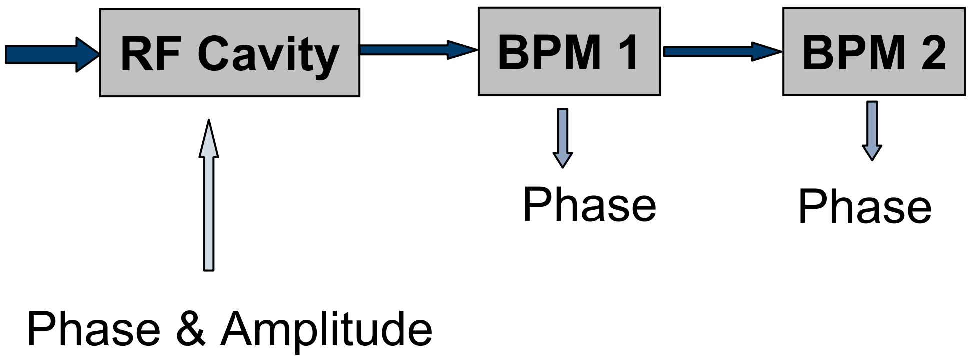
- **60 Beam-Position Monitors (BPM). They are sensitive to transverse and longitudinal (phase) bunch center position.**
- **Beam profile monitors. Wire Scanners (WS) in MEBT, DTL, and CCL. Laser Wire (LW) scanners in SCL.**
- **Beam Loss Monitors (BLM). 137 in the linac.**
- **4 Bunch Shape Monitors in CCL**

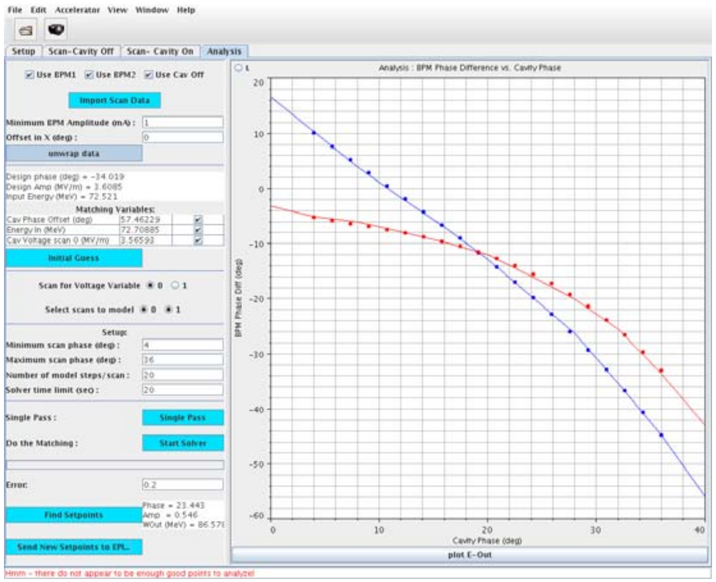
•Beam Current Monitors (BCM) are noisy. We do not use them for precise measurements.
•Emittance device in MEBT is not fully tested yet.

Models

XAL Online Model	A part of XAL programming framework. Envelop and Single Particle Dynamics, inherited from Trace-3D and PARMILA
PARMILA	It was used for the SNS linac design. Now PARMILA is occasionally used as an online tool for matching the beam into DTL and CCL (under MATLAB GUI script) and for offline analysis.
IMPACT	It is a parallel computer PIC accelerator code which includes 3D space charge calculations. At SNS it is used for offline analysis.
Trace-3D	Envelope Model. The algorithms were migrated to XAL online model.

Longitudinal Dynamics of Beam Center

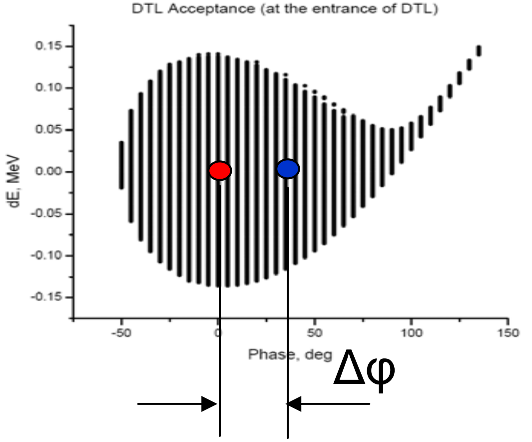


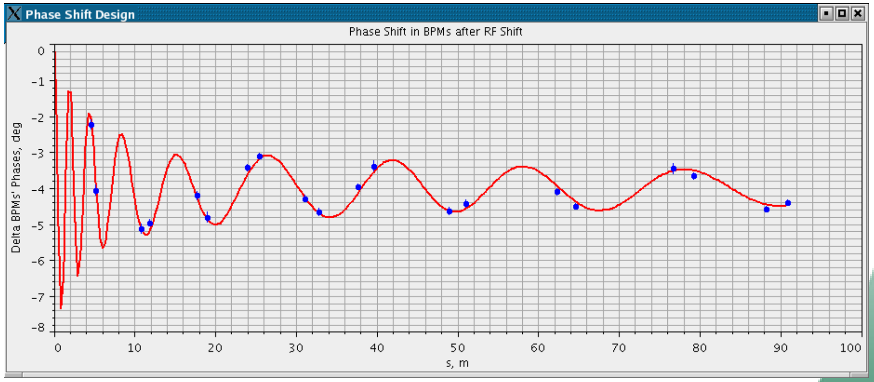


XAL Online Model

Phase Signature Matching – XAL PASTA Application

Control: XAL RF Phase Shaker





DTL and CCL
Points are BPMs response
Red curve is a model

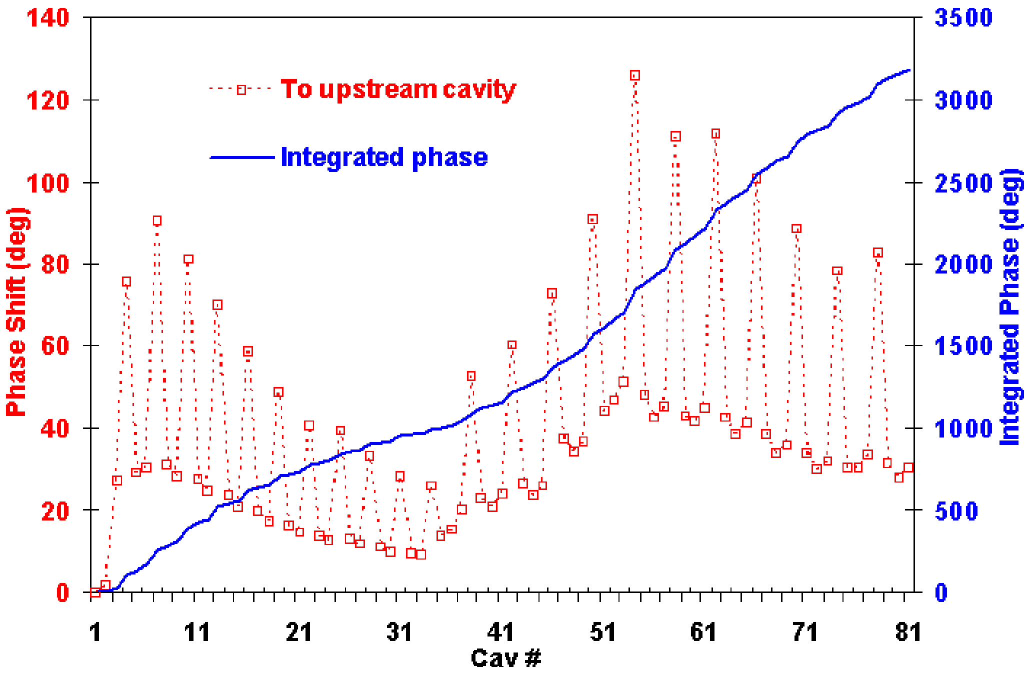
SCL Phase Scaling

Technique was developed by John Galambos

After tuning SCL we know:
(Real SCL RF Phase,Amplitude) <-> (Model)

Was used:

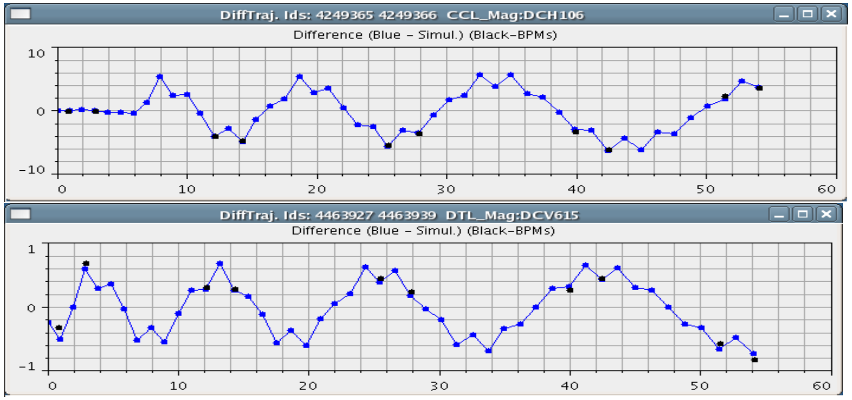
- **SCL RF Cavity failure or Amplitude change**
- **New longitudinal tune settings or energy change**



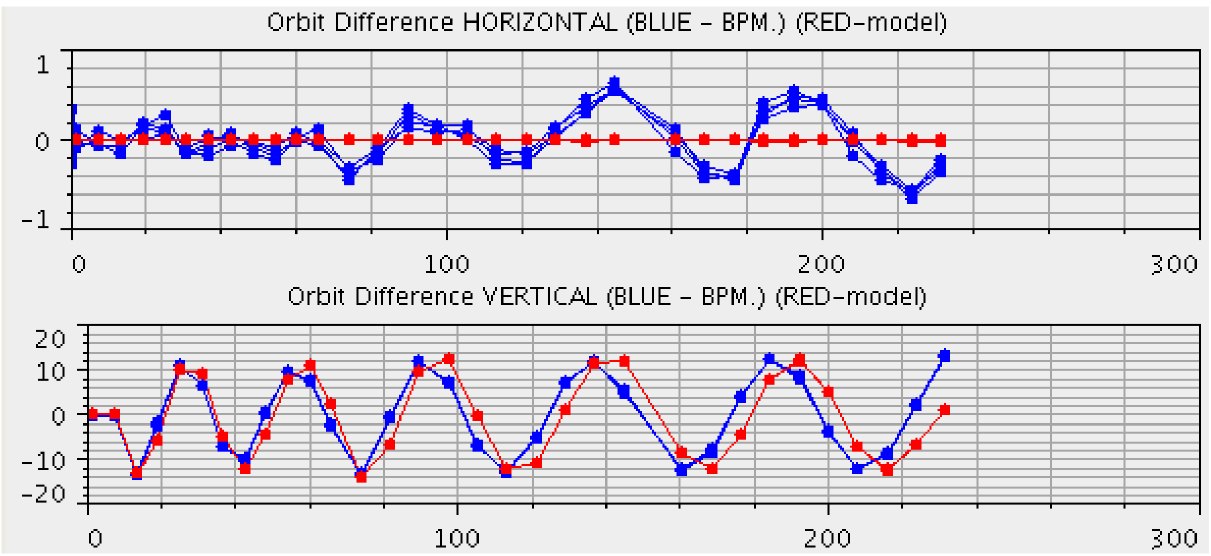
Scaling for 900 MeV to 1 GeV

Courtesy of Yan Zhang

Orbit Simulation and Correction



Orbit excitation in CCL. Blue Line – model. Points are BPM readings. Average difference < 0.1 mm



SCL
Not so good.

Coupling H & V

Cannot reproduce exactly

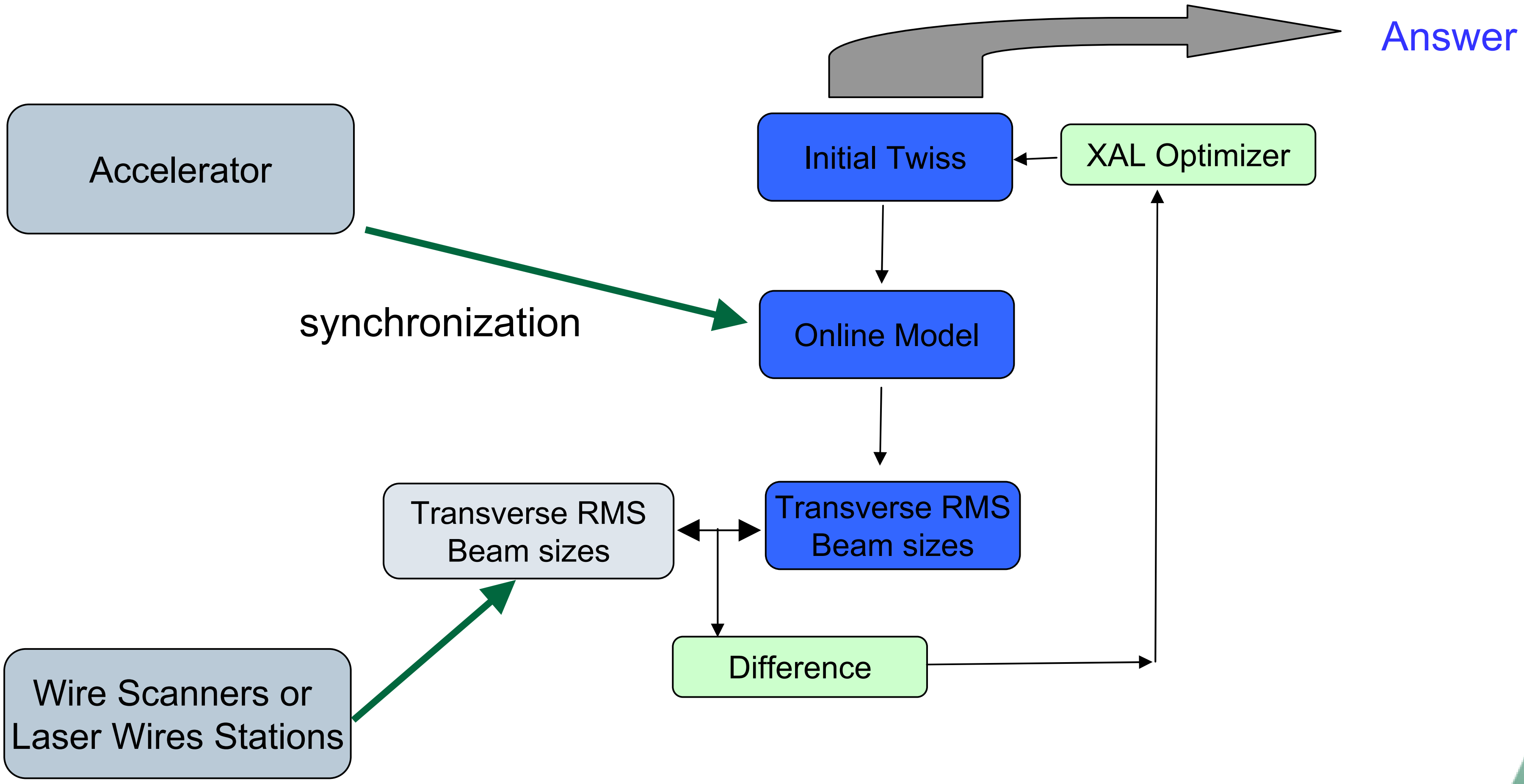
XAL Online Model, we did not try IMPACT, PARMILA

Single Particle Dynamics

- **We have good understanding of this type of dynamics.**
- **Can control the center of the beam.**

Envelope Transverse Dynamics

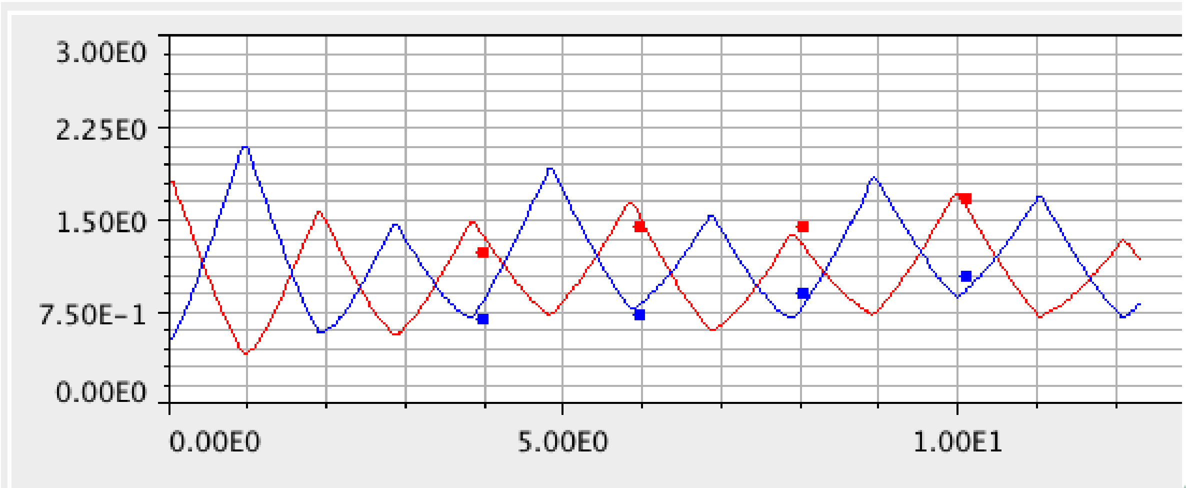
XAL Wire Analysis application (S. Cousineau)



The same scheme is used for IPMACT

Envelope Transverse Dynamics in CCL

CCL	Design Values	Production (12/22/2009)	
α_x	**-3.3**	**-4.7**	**(42%)**
β_x (m)	**3.9**	**5.1**	**(31%)**
ε_x (π-mm-mrad)	**.33**	**.39**	**(18%)**
α_y	**.81**	**.08**	**(90%)**
β_y (m)	**.77**	**.34**	**(56%)**
ε_y (π-mm-mrad)	**.33**	**.37**	**(12%)**



Measured beam size for production setup (12/22/2009)

Matching in SCL

IMPACT — **Courtesy of Yan Zhang**

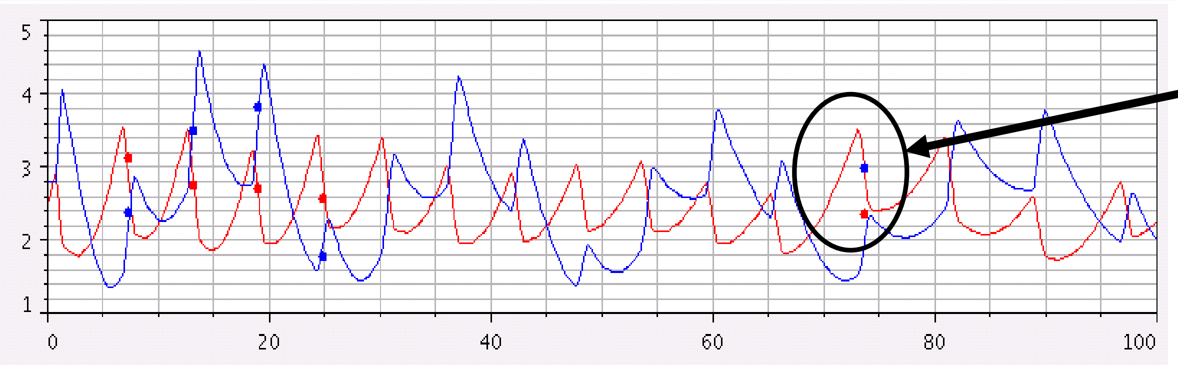
Case No.	Alpha_x	Beta_x	Emit_x	Alpha_y	Beta_y	Emit_y
Round 1	-2.49	6.50	0.27	2.98	5.78	0.21
Round 2	-2.61	6.45	0.23	2.94	5.81	0.21
Round 3	-2.54	6.52	0.40	3.01	5.76	0.24
Round 4	-2.65	6.36	0.22	3.01	5.78	0.20
Average	-2.57	6.46	0.28	2.98	5.78	0.22
Difference	<3%	~1%	~26%	~1%	<1%	~6%

Difference	~25%	~34%	~40%	~90%	~3%	~70%

XAL (S. Cousineau)

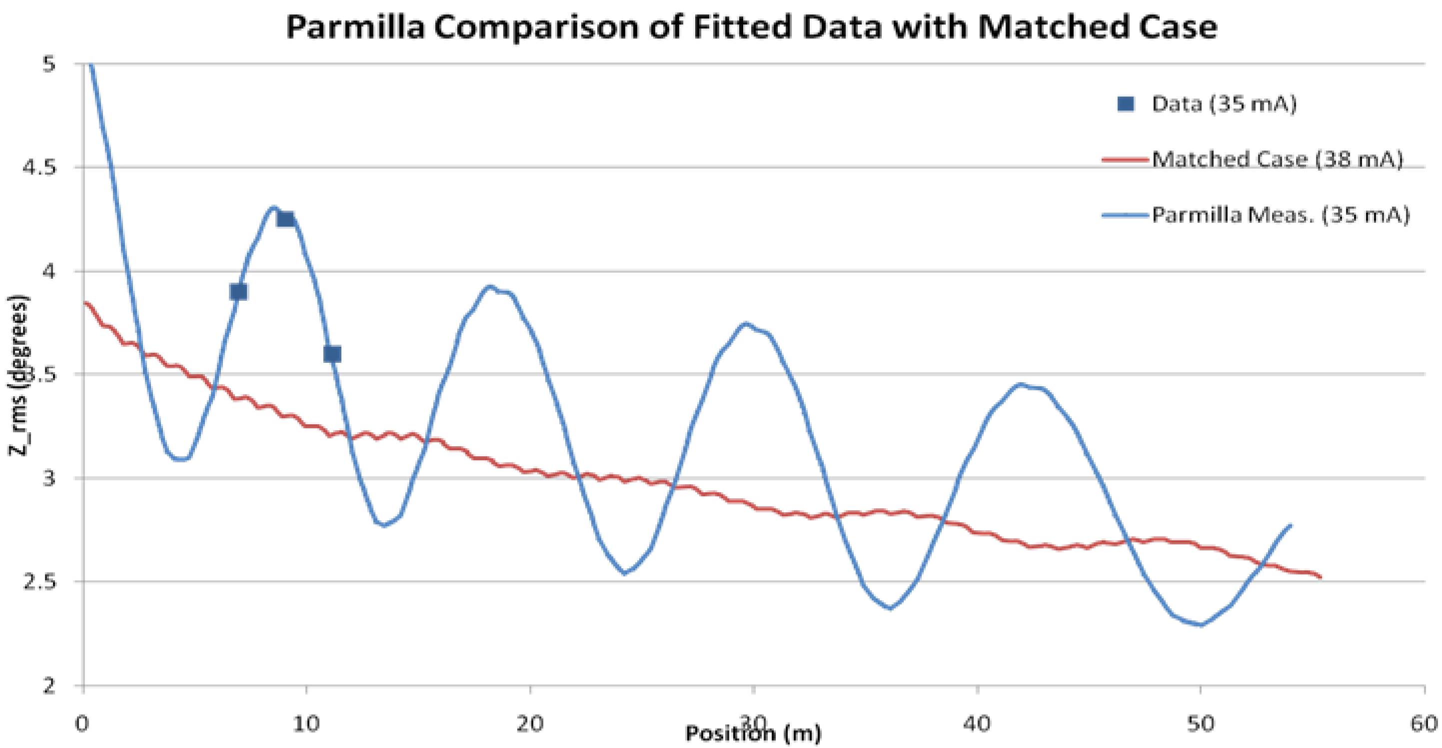
Round 1	-1.50	11.14	0.37	0.87	6.30	0.47
Round 2	-1.60	10.27	0.36	2.00	8.02	0.43
Round 3	-2.12	5.97	0.50	1.22	5.10	0.45
Round 4	-2.74	8.47	0.47	0.38	4.56	0.46
Average	-1.99	8.96	0.42	1.09	5.97	0.45
Difference	~22%	~25%	~16%	~46%	~21%	~2%

Different results for XAL IMPACT



XAL and Data
No agreement

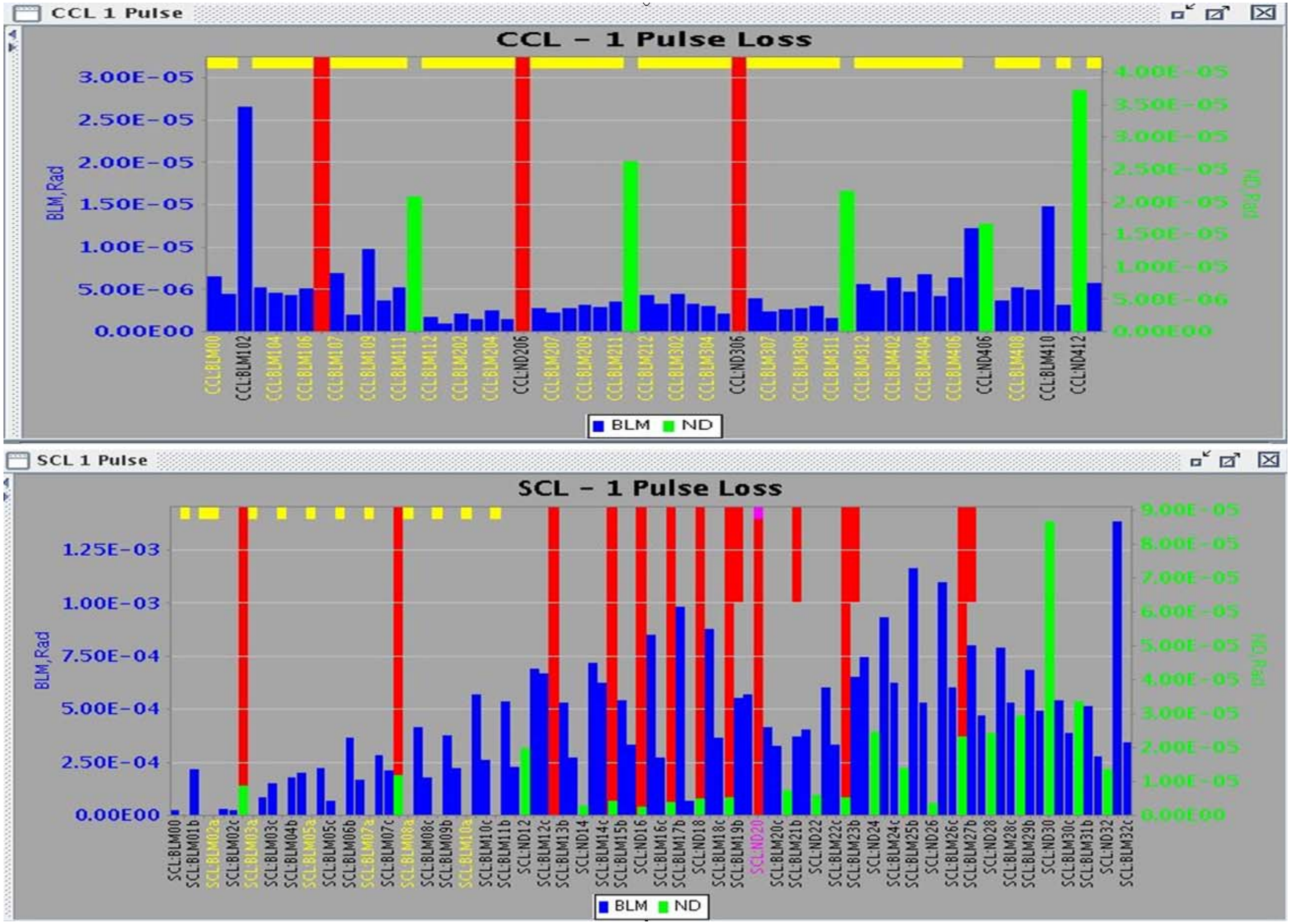
Longitudinal Beam Size in CCL



Courtesy Sarah Cousineau

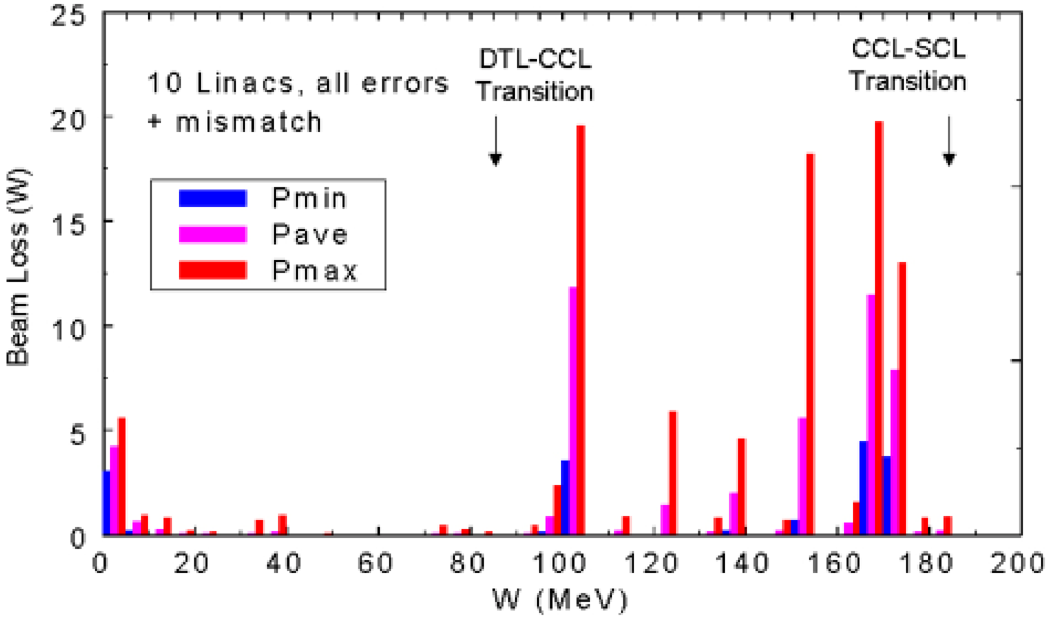
Design longitudinal emittance 0.4 deg*MeV, measured 0.53 deg*MeV

Losses

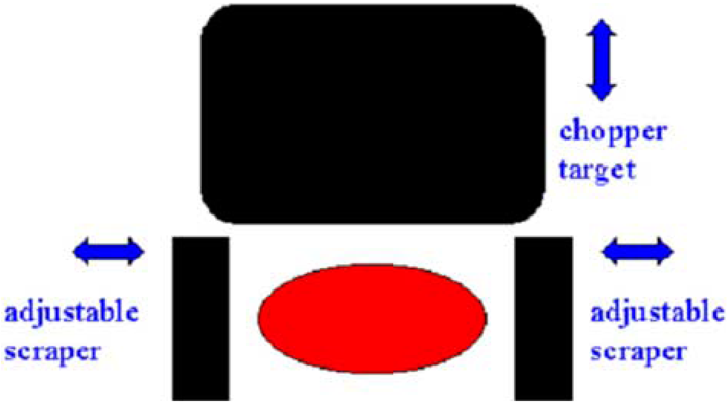


Goal: Final tuning should reduce losses with the same beam quality for the SNS ring.

Losses Predictions for DTL and CCL



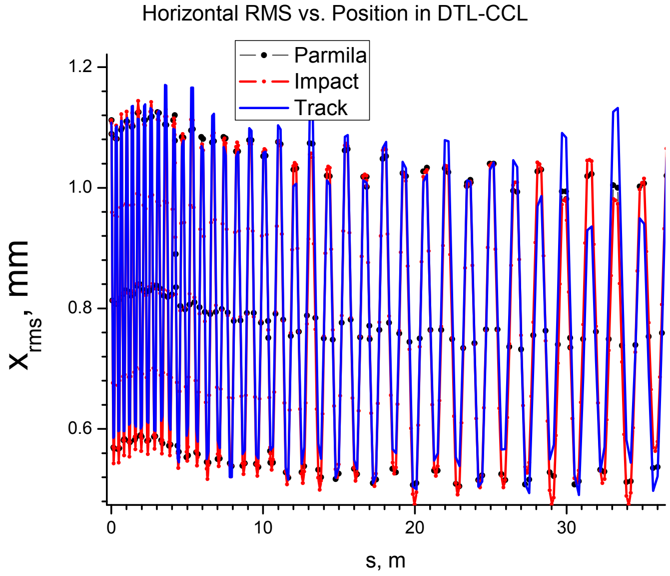
PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS, VOLUME 5, 094201 (2002)
Formation and mitigation of halo particles in the Spallation Neutron Source linac.
D. Jeon, J. Stovall, A. Aleksandrov,J. Wei, J. Staples, R. Keller, L. Young, H. Takeda, and S. Nath4

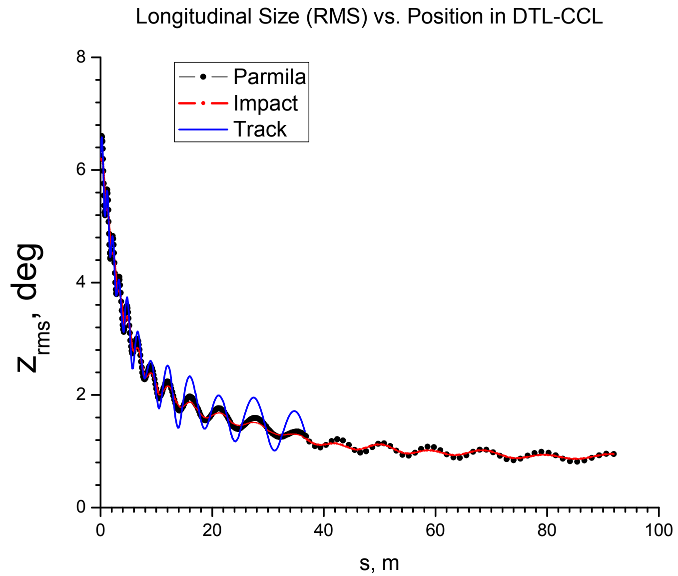


"Halo is reduced by 84%. This means that 84% of the beam with *radius* < 9 mm is removed.
CCL bore radius is 1.5 cm."

No losses predictions for SCL, bore R=5 cm

PARMILA, IMPACT, TRACK – Benchmark I



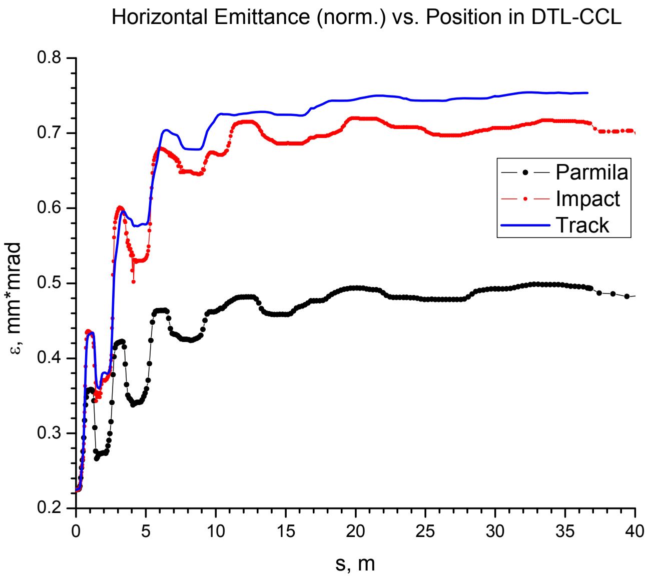


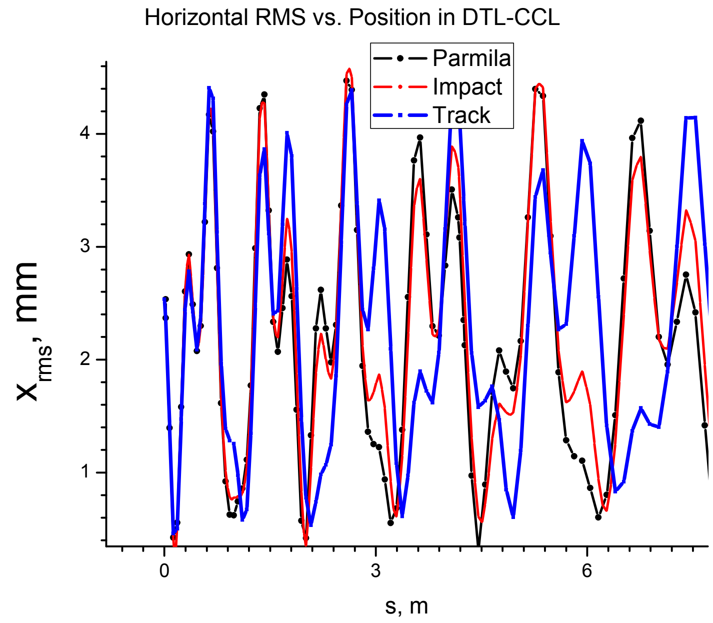
PARMILA – A. Shishlo, IMPACT – Yan Zhang, TRACK – Dong-O Jeon

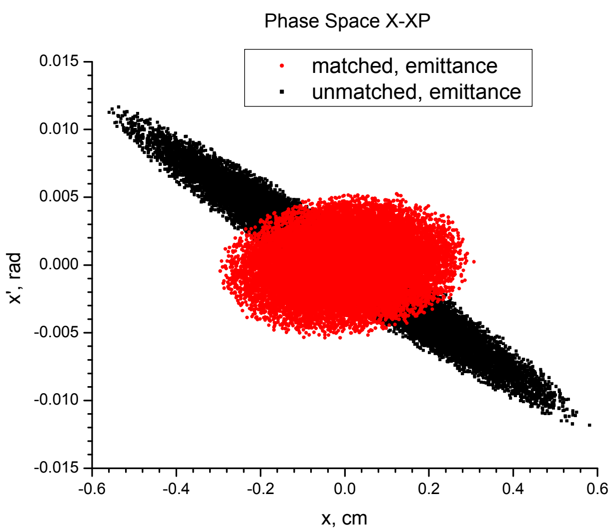
Matched beam at the DTL entrance gives a good agreement between codes

NO SPACE CHARGE !

PARMILA, IMPACT, TRACK – Benchmark II



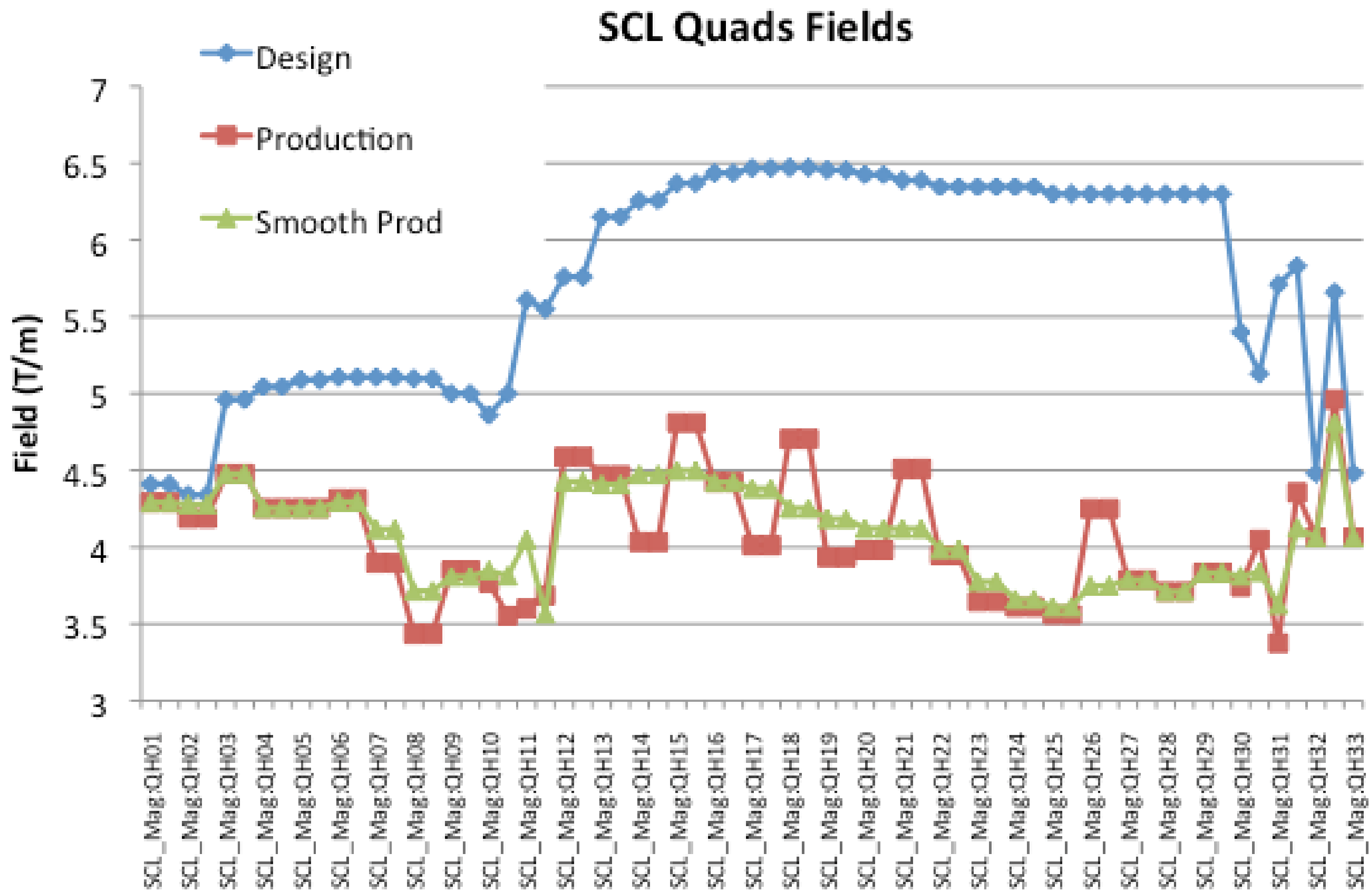




- Unmatched beam at the entrance gives different predictions from codes.
- Reason: beam too big, particles almost on the bore radius. Models for RF fields are not reliable.
- Losses calculations: that is exactly the same particles that we are interested in.

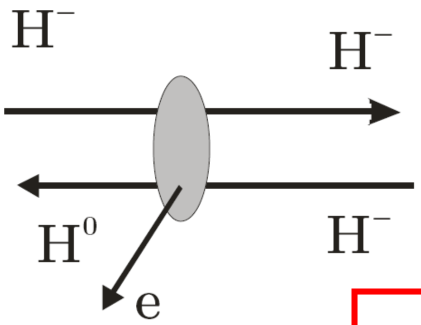
We do not have the model for losses!

SCL Quads for Minimum (?) Losses



Courtesy of John Galambos

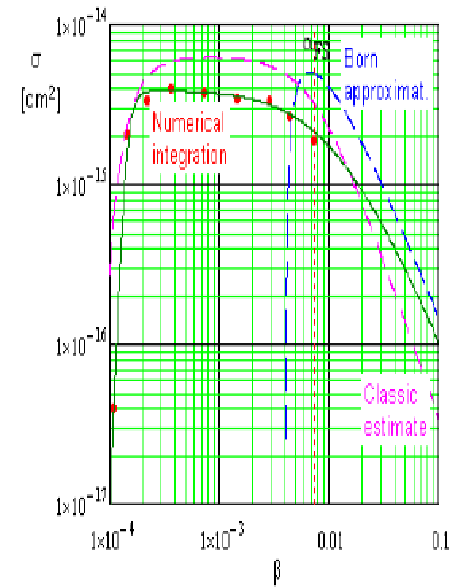
Intra Beam Stripping (Valeri Lebedev, FNAL)

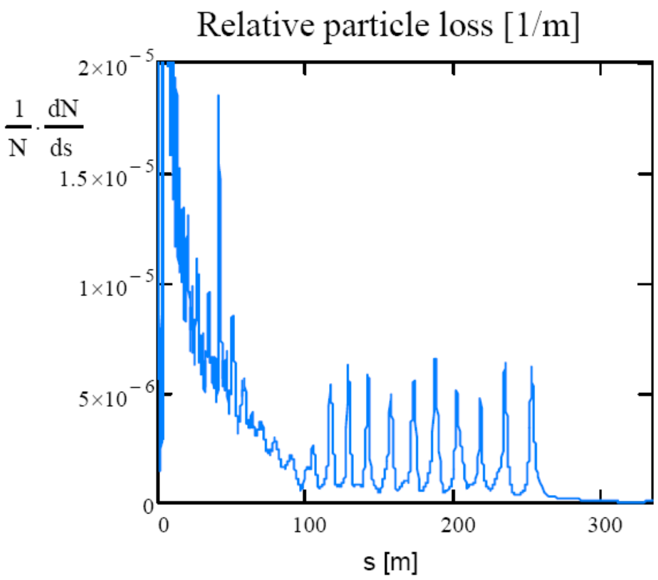


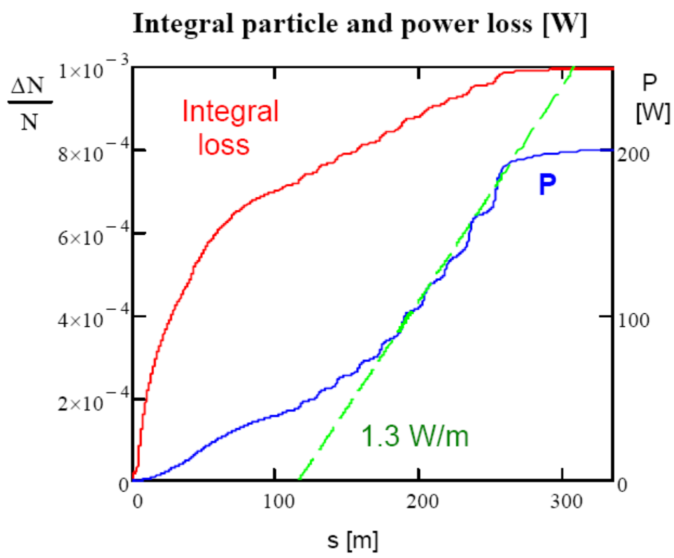
(Talk at SNS, ORNL, March 2010)

$$\sigma_{strip} = 120 a_0^{\,2}\left(\frac{\alpha_{FS}}{\beta+\alpha_{FS}}\right)^2 \frac{(\beta-\beta_m)^6}{(\beta-\beta_m)^6+\beta_m^{\,6}} \ln\left(3.2\left(\frac{\beta+\alpha_{FS}}{\alpha_{FS}}\right)^2\right) ,$$

$$\beta \ge \beta_m = 7.5\cdot 10^{-5}$$





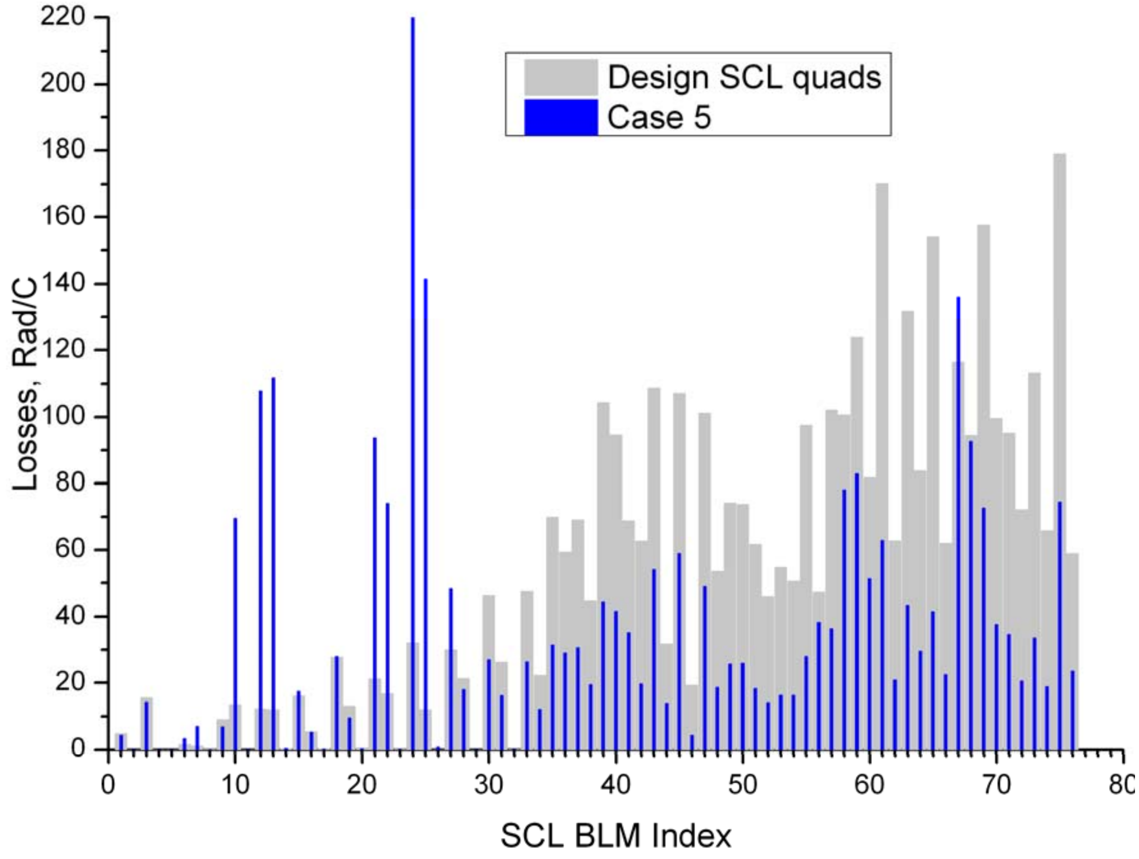


Reduced Quads Experiment (J. Galambos)

data from 3/1/2010 at ~ 8:00 AM - see ELog at 10:15 AM

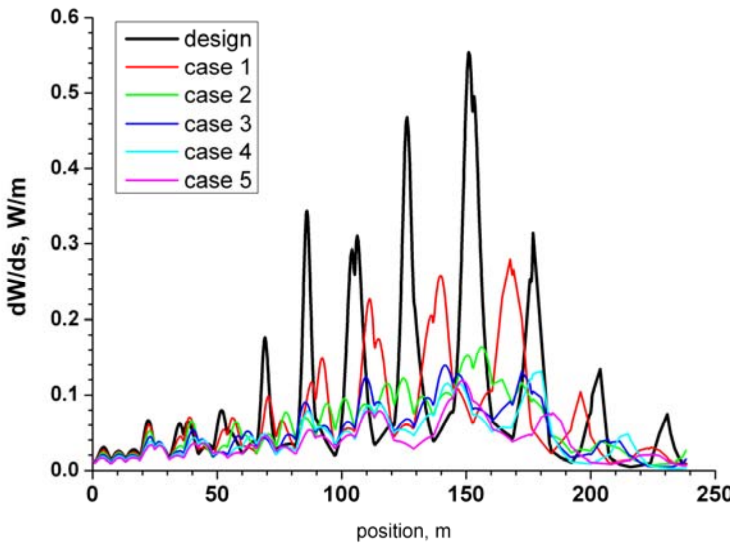
- **Try the following field reduction scaling:**
  - **$B = B_{design} * C_1 * (1 – C_2*s/L)$: L < 160 m**
  - **$B = B_{design} * C_1 * (1 – C_2)$:L < 160 m**
    - **S = distance from start of SCL**
    - **L = 160 m (last accelerating cavity)**
- **Cases:**
  - **1: $c_1 = 0.975$, $c_2 = 0.05$**
  - **2: $c_1 = 0.95$, $c_2 = 0.1$**
  - **3: $c_1 = 0.925$, $c_2 = 0.15$**
  - **4: $c_1 = 0.90$, $c_2 = 0.2$**
  - **5: $c_1 = 0.875$, $c_2 = 0.25$**

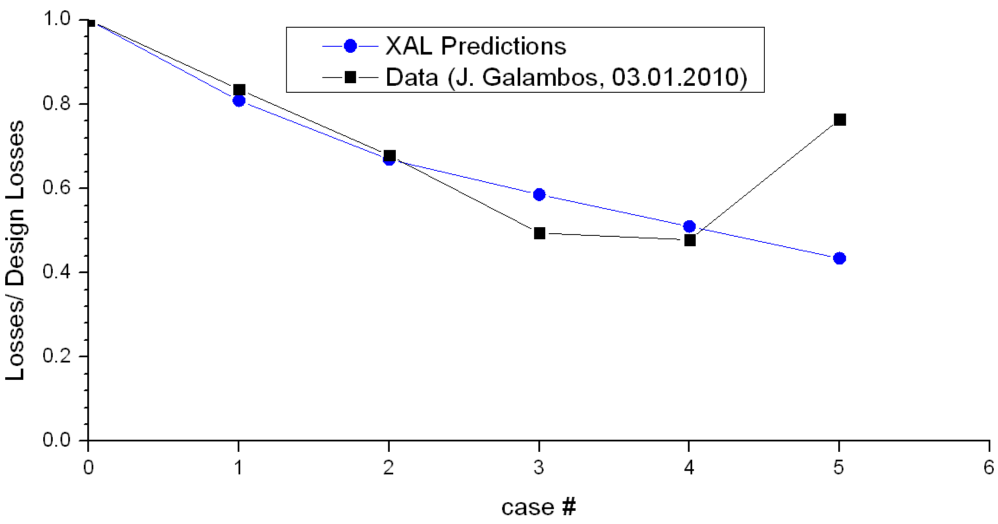
Losses for Reduced Quads



Losses go down with
Quad strength reduction

Simulation with XAL



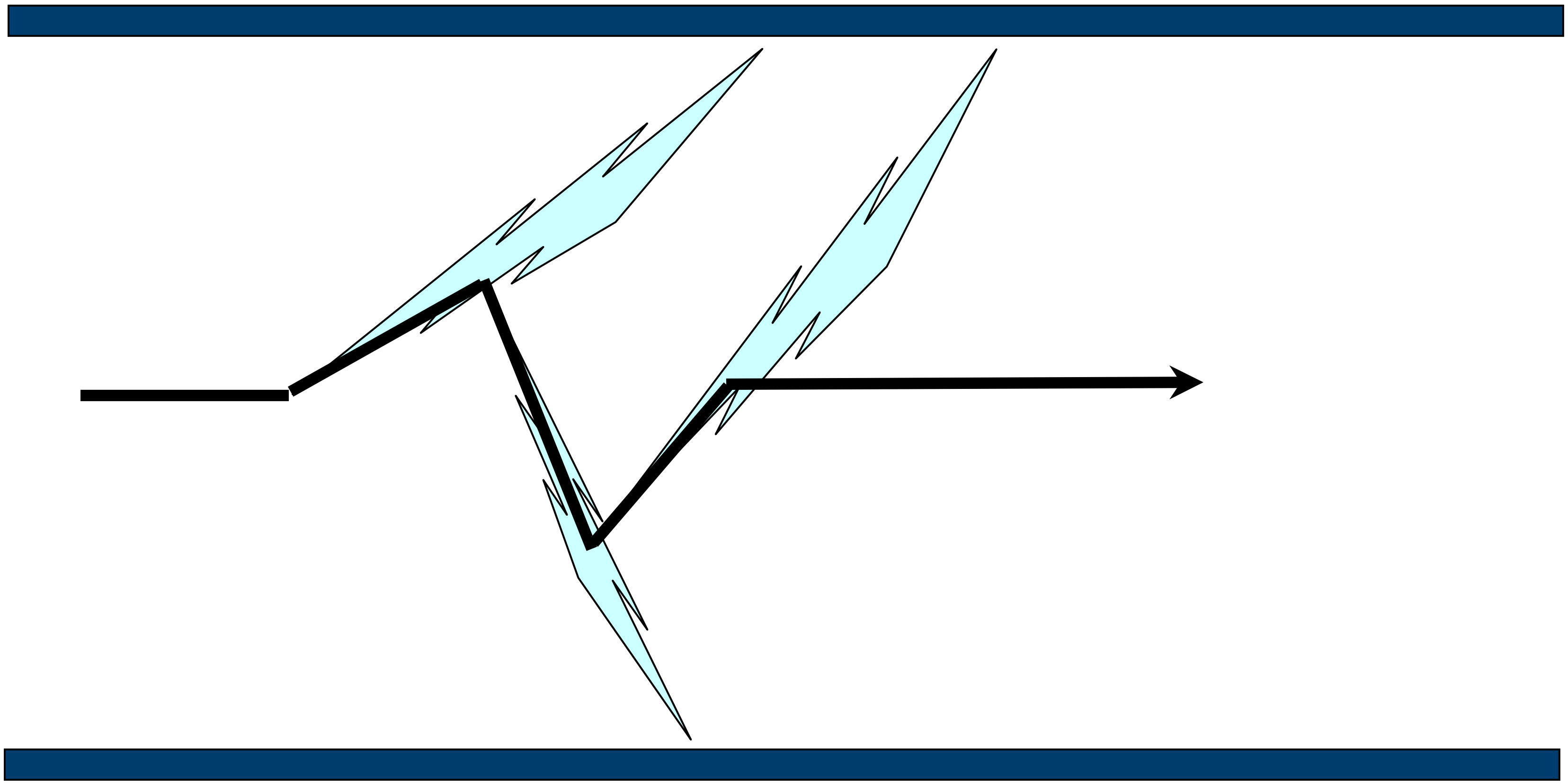


Conclusions

- **We have good understanding of the single particle beam dynamic.**
- **We cannot get matched beam in SCL. XAL online model does not work, IMPACT is difficult to use, and the losses is not improving.**
- **We does not have a good model for losses.**
- **IBS should be included.**

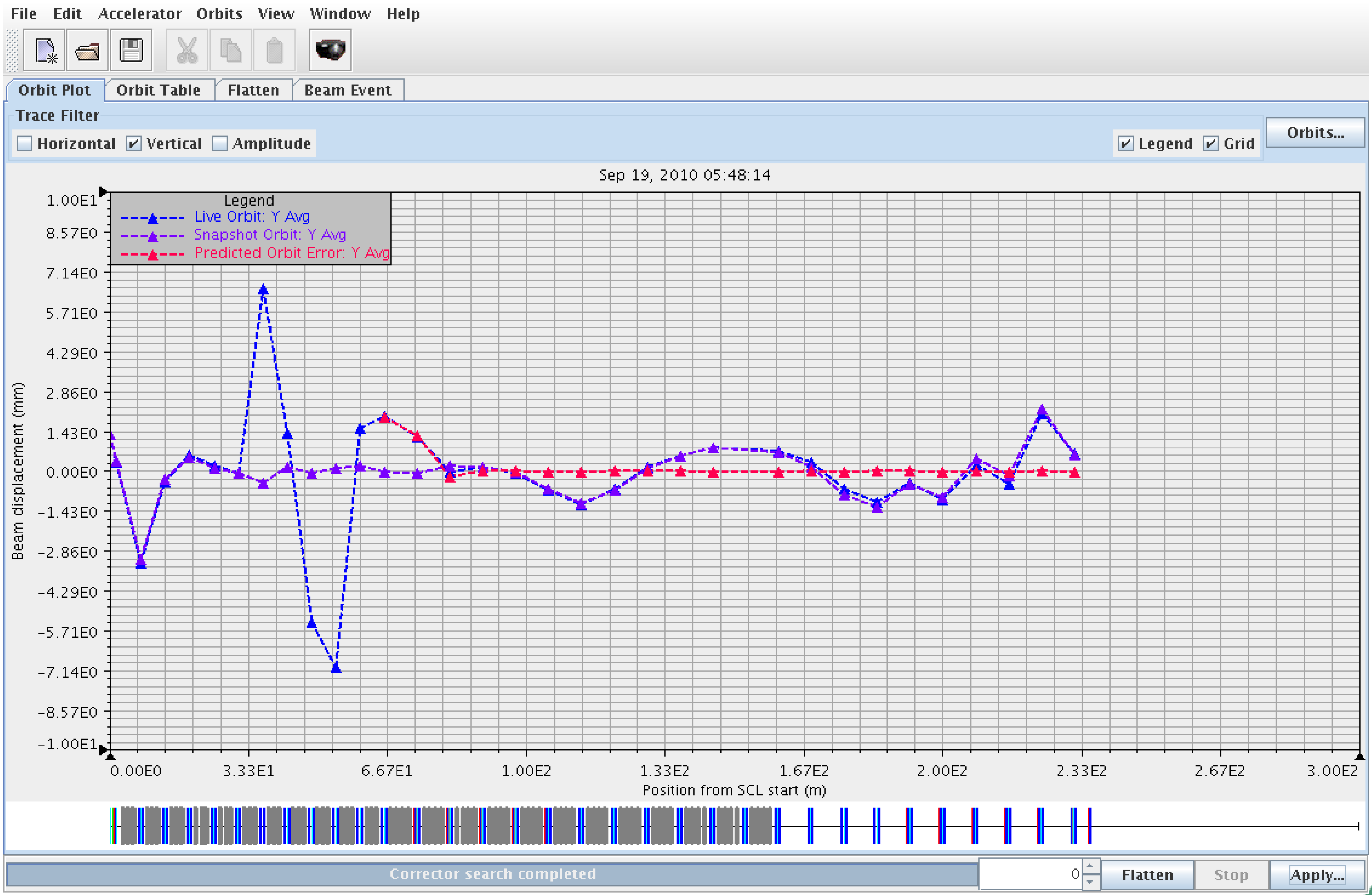
Additional Slides

IBS Flash Light Experiment

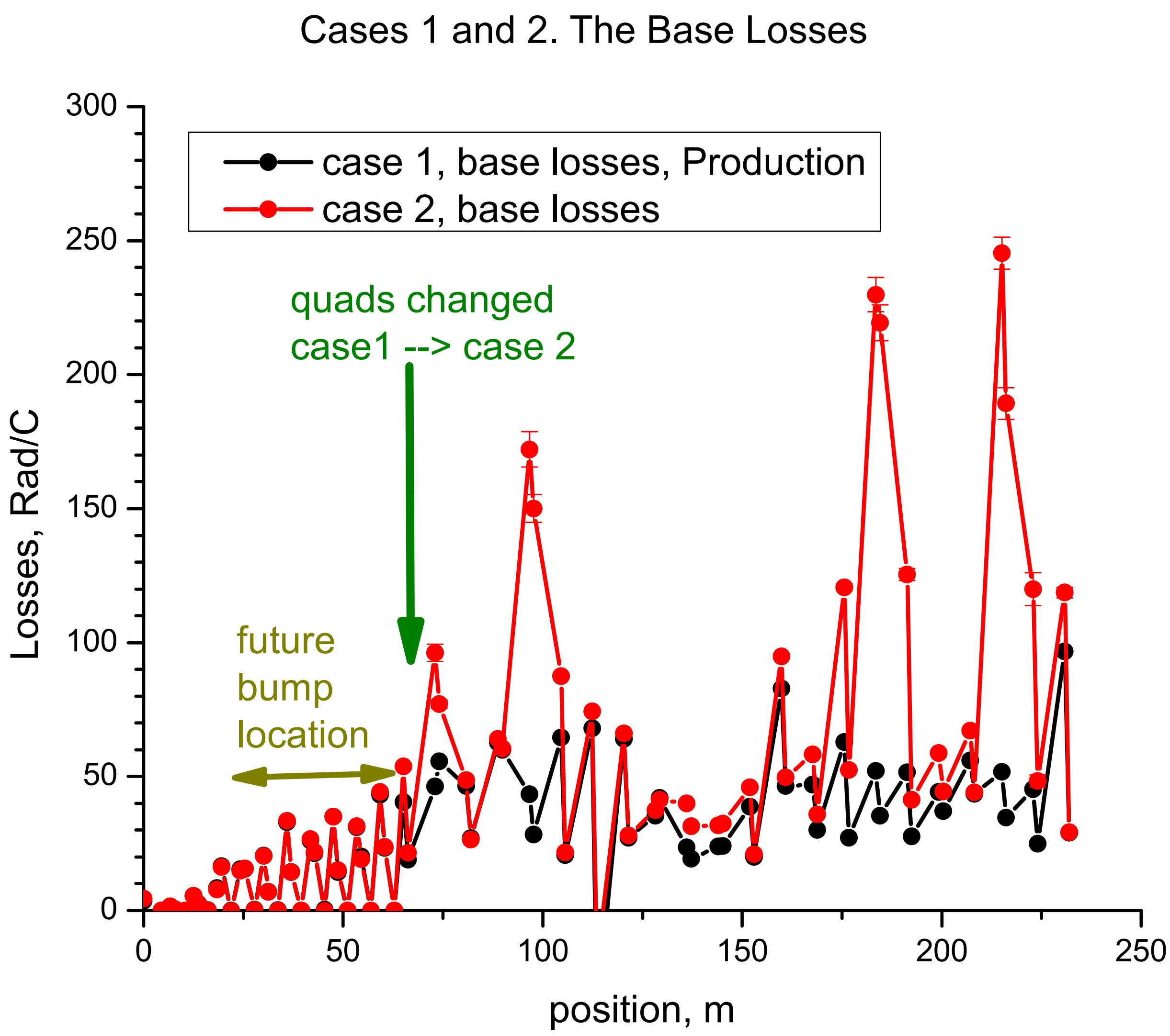


We create a local bump and change its amplitude. We will see the losses downstream and moving.
They should not be affected by downstream optics – they are H^0!

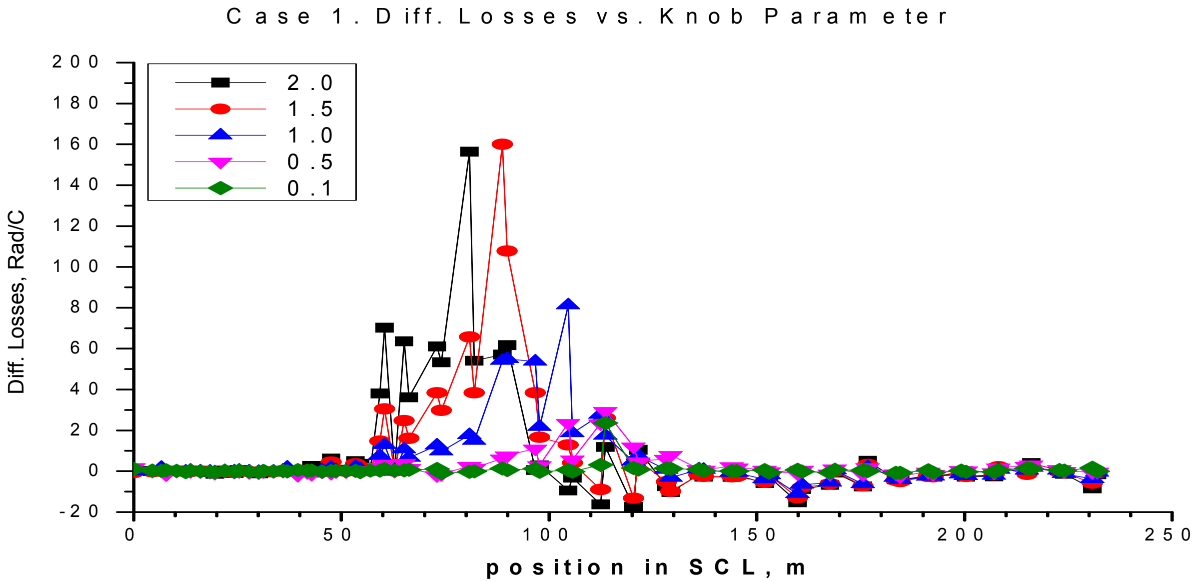
Bump for Knob Value 2.0

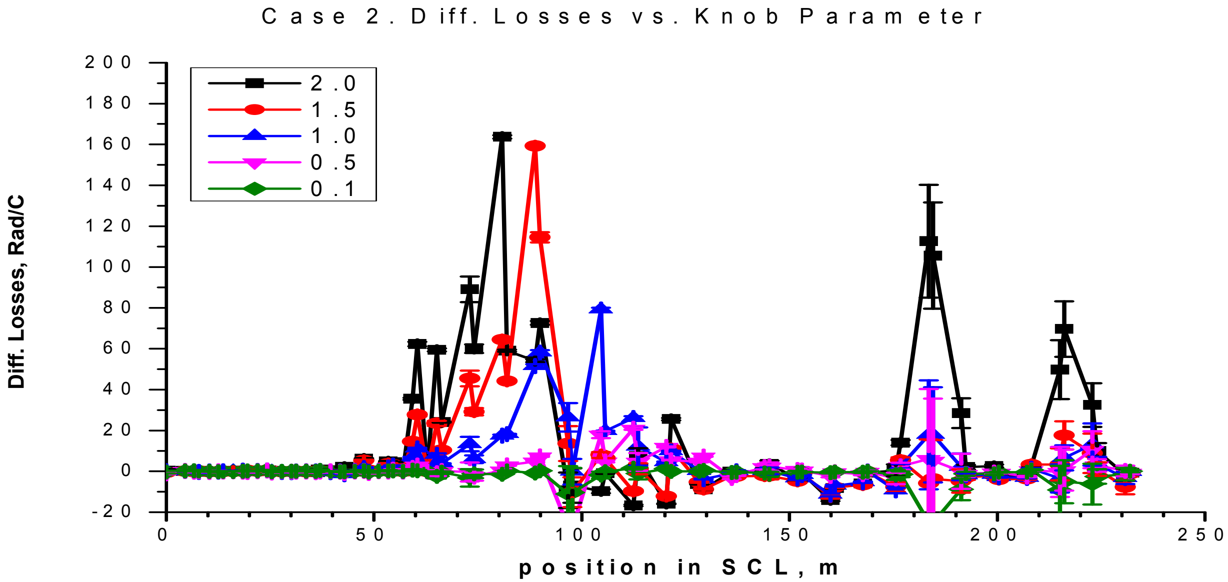


Two Cases – Quads are Different after Q10



Differential Losses Cases 1,2





Beam Time Structure of the SNS Linac

Macro-pulse Structure (made by the Ion Source)

Mini-pulse Structure (made by the choppers)

Micro-pulse structure (made by the RFQ)