Linac Beam Dynamics Progress

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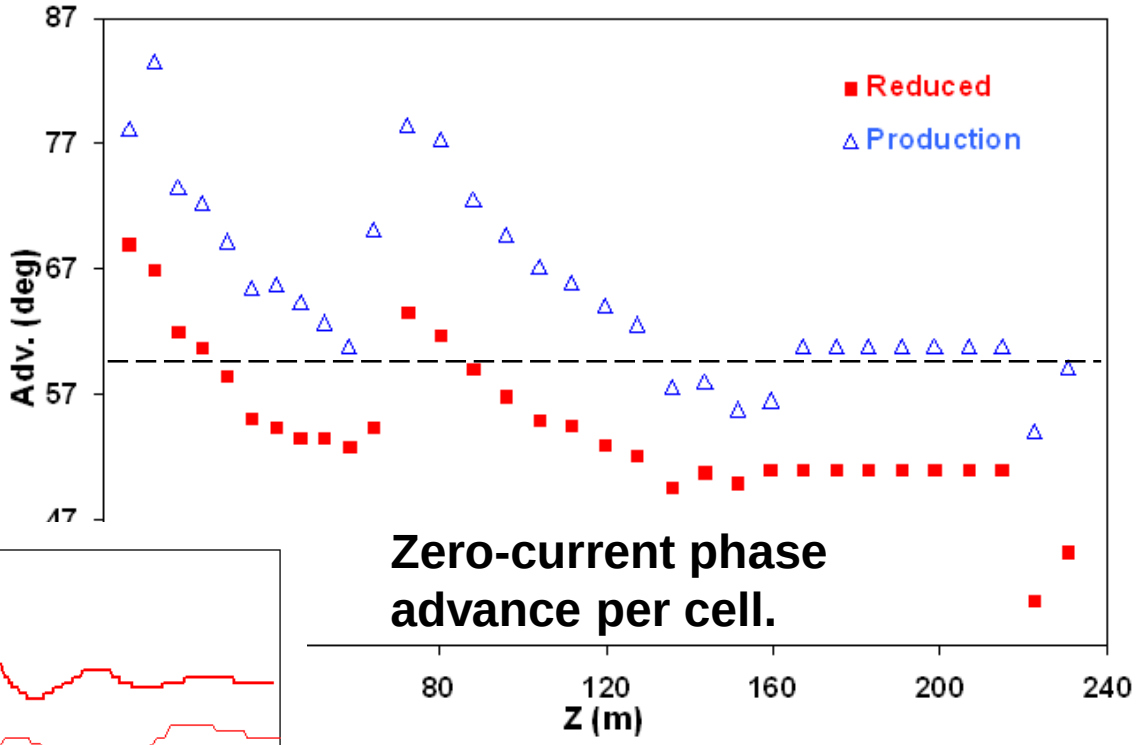
Spallation Neutron Source AAC, February 03, 2010

Outline

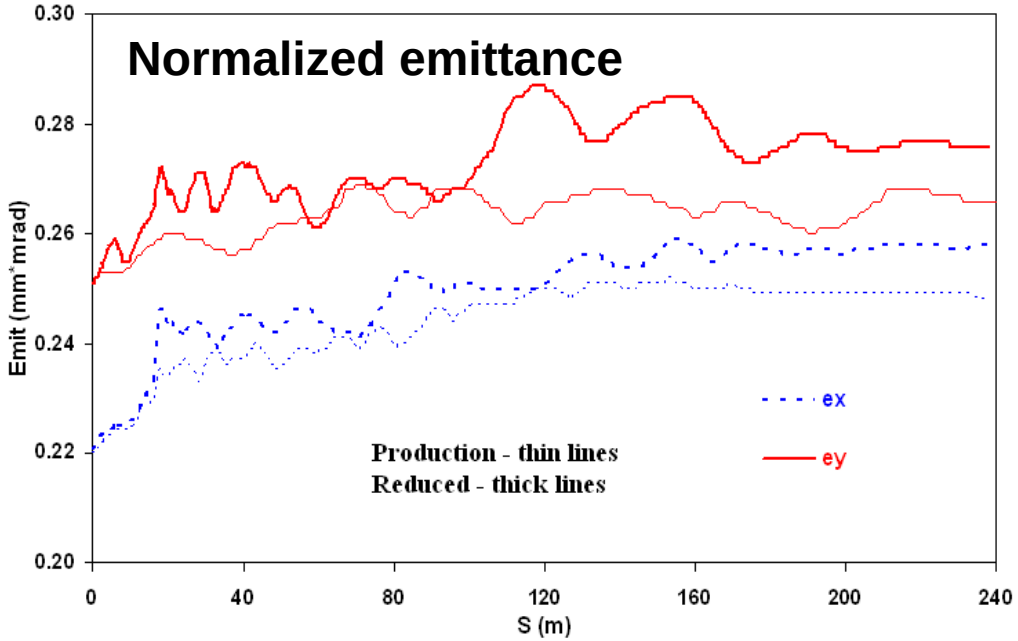
- SCL Beam Loss Reduction
- Weak Resonance at 60° Phase Advance
- Beam Emittance Measurement
- Transverse Beam Matching Progress
- Linac Lattice & Model Limitations
- Summary

SCL Beam Loss Reduction

In March 2009, SCL phase advance was reduced from the baseline design to ~50°, and the SCL loss was reduced by ~50%, so as the residual activation



Zero-current phase advance per cell.



No big difference to beam emittance, in simulations with IMPACT

Multipole Components of the SNS Linac Quads

$$B(r,\theta) = \sum_{m=1}^{\infty} C_m \cdot \left(\frac{r}{R_{ref}}\right)^{m-1} \cdot \sin[m \cdot (\theta - \alpha_m)]$$

$$k_m = \frac{1}{B \cdot \rho}(m-1)! C_m \cdot \left(\frac{1}{R_{ref}}\right)^{m-1}$$

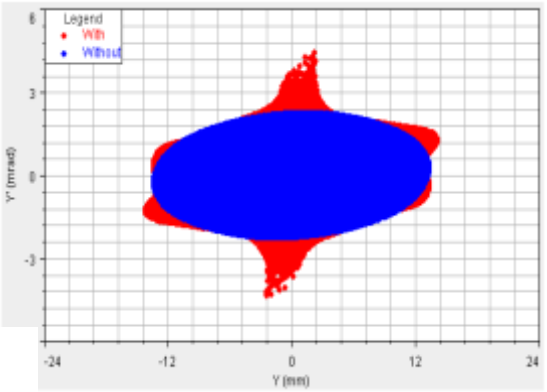
J.G. Wang

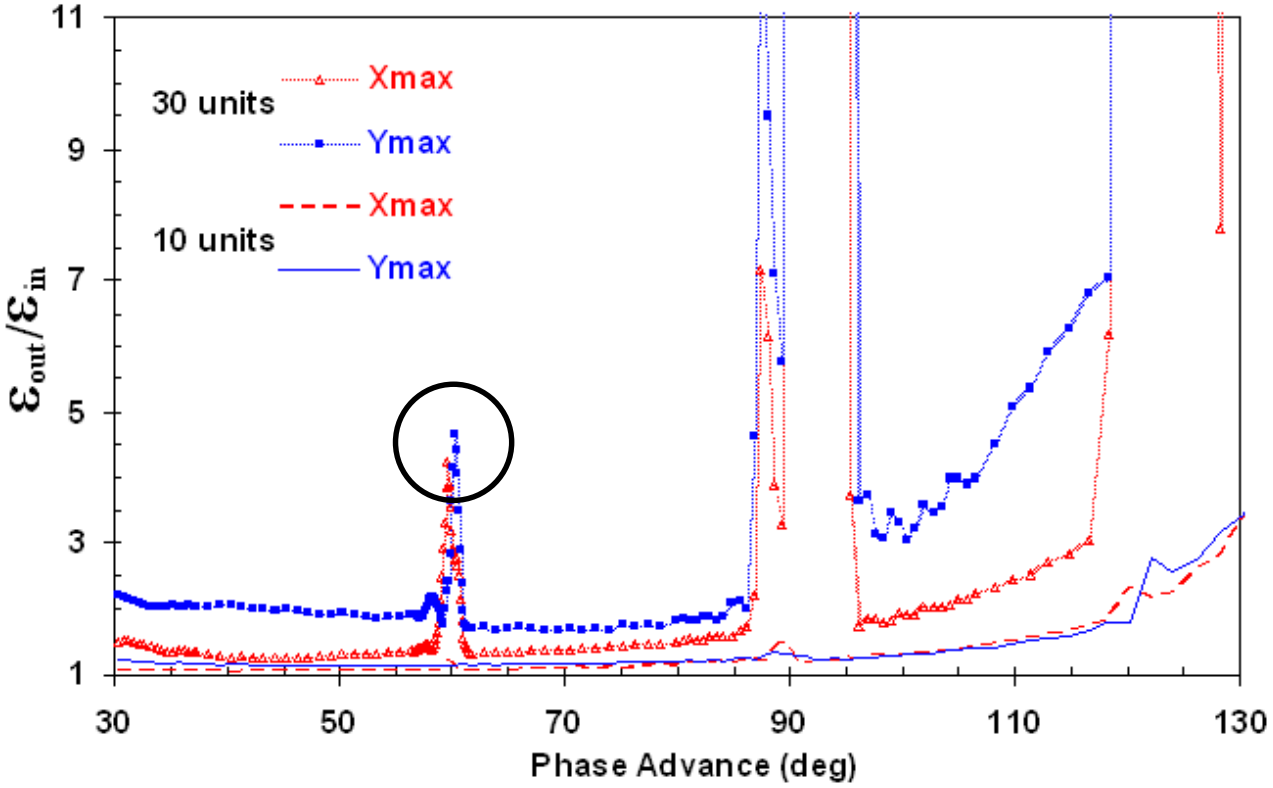
Multipole (units: 1×10^{-4})	m = 6	m = 3	m' = 3 From dipole
CCL R_{REF} 1.3 cm	59.04 37.95	3.72 (2.91)*	
SCL R_{REF} 3.0 cm	28.86 (4.20)*	-6.89 (-1.29)*	193.46 (207.93)*

*** Skew term**

Weak Resonance at 60° Phase Advance

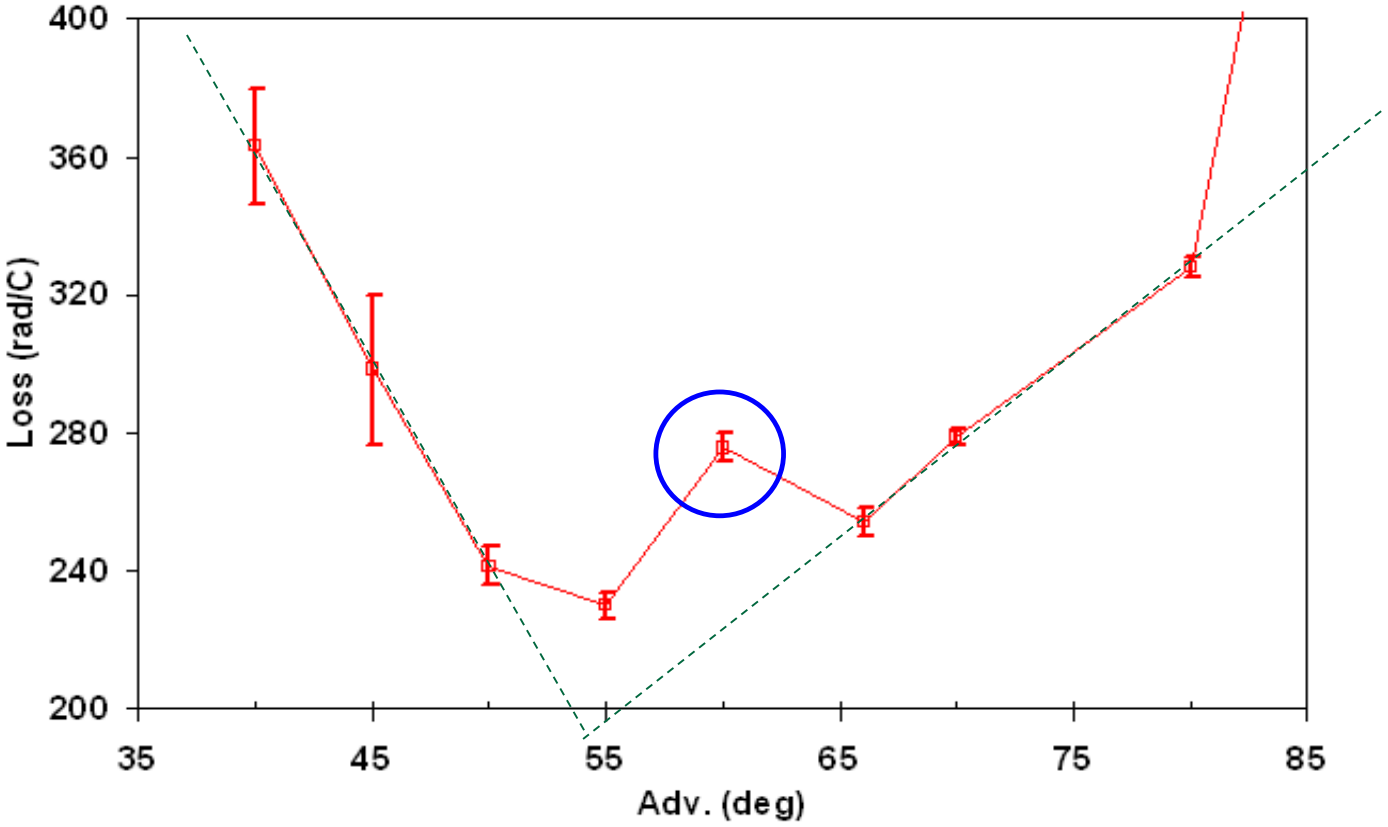
Maximum beam emittance increase in a doublet lattice versus transverse phase advance in simulations with ORBIT, no RF, no space-charge.





6-order resonance is very weak, but if the duodecapole component is large enough, and linac lattice is not too short, it appears.

Turned all SCL cavities off, and set all correctors to zero, transport 186 MeV beams through a doublet-lattice, and measure beam loss with all the SCL beam loss monitors. No RF, no longitudinal focusing, and space charge effect can be ignored. Duodecapole driven resonance at 60°

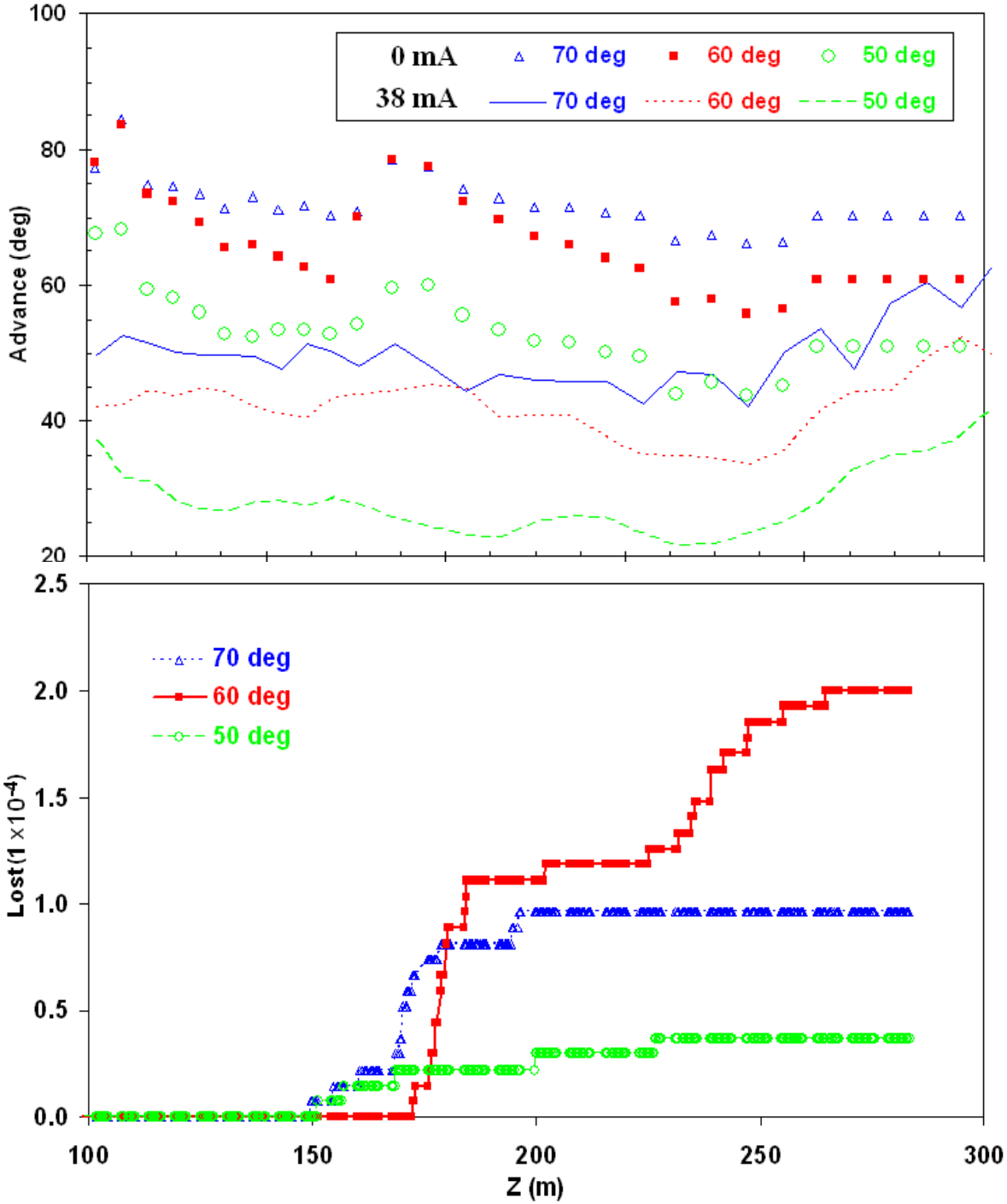


Measured total SCL beam loss versus phase advance

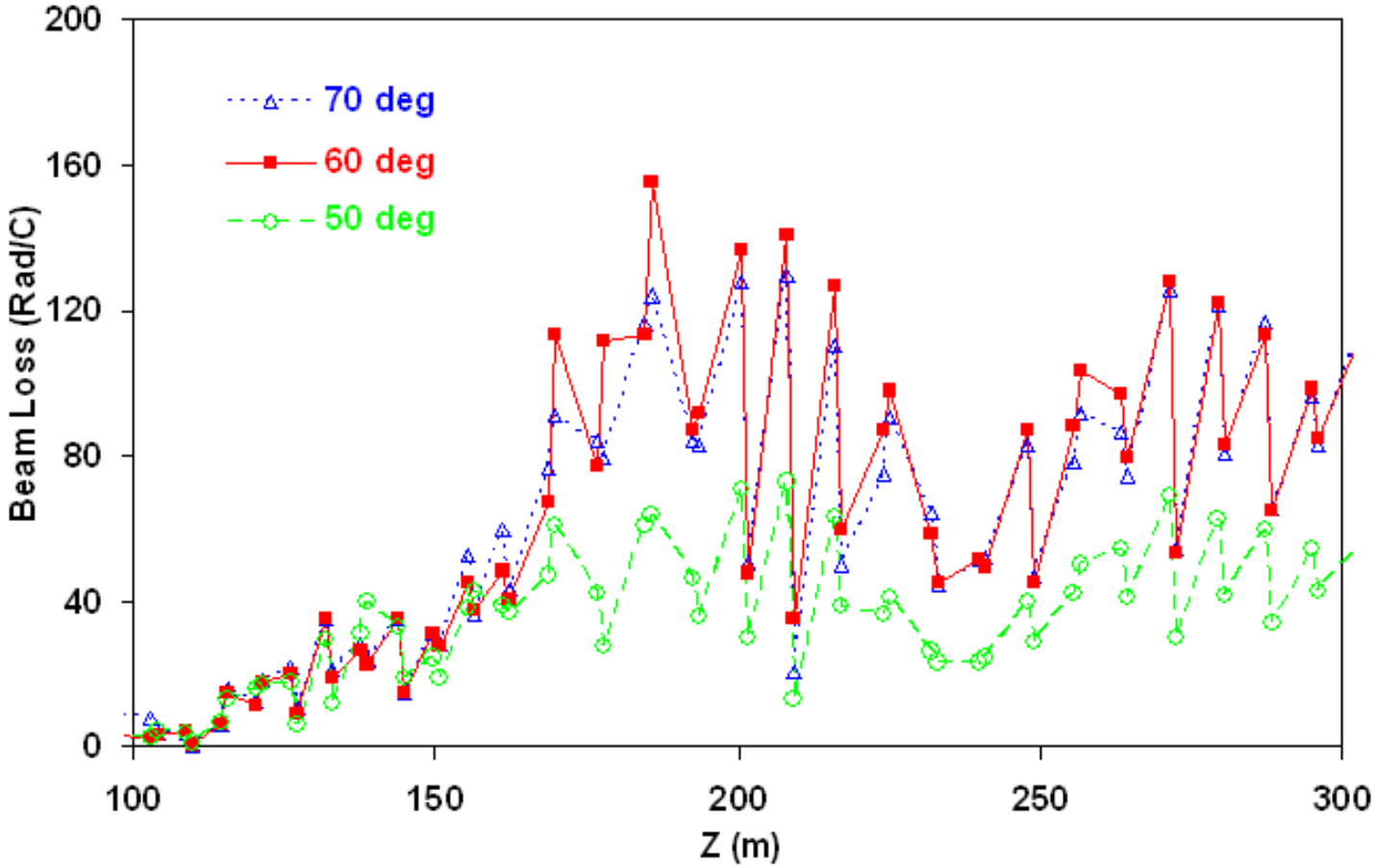
Transverse phase advance for zero current (markers) and 38mA (lines)

60° lattice is the baseline design case, but beam loss is the worst in simulations, because of the 60° resonance

Total fractional SCL beam loss in simulations with PARMILA, 30-unit duodecapole term is included, for 38 mA design beams



SCL Beam Loss Measurements With RF On



In measurements, 70° lattice reduces loss by 10%, 50° by 50%; while model predicted 50% and 80%, respectively. The weak 6-order resonance shows a measurable effect in the SCL loss. However, beam loss, particularly in the medium-beta section, may also from other factors, e.g, longitudinal halo.

Beam Emittance Measurement

- **CCL Longitudinal (S. Cousineau, A. Aleksandrov)**

  Measure bunch size with 3 BSMs in CCL1, and then fit BSM data with linac models (XAL or PARMILA). Normalized emittance ~0.4 mm*mrad in September 2009.
  (In different measurements, it varies from 0.4 to 0.8 mm*mrad)

- **SCL Longitudinal**

  Scan beam injection energy and phase across the longitudinal acceptance, measure beam current at the exit of the linac. Normalized emittance ~0.5 mm*mrad in October 2009.
  (It also varies from 0.4 to 0.8 mm*mrad in different runs, or even during a single operation routine)

- **Design ~ 0.3 mm*mrad**

  Measured longitudinal emittance is 1 to 3 times that of the design, due to ion source and RF drifts; no obvious effect on beam loss.

Beam Emittance Measurement

- Transverse

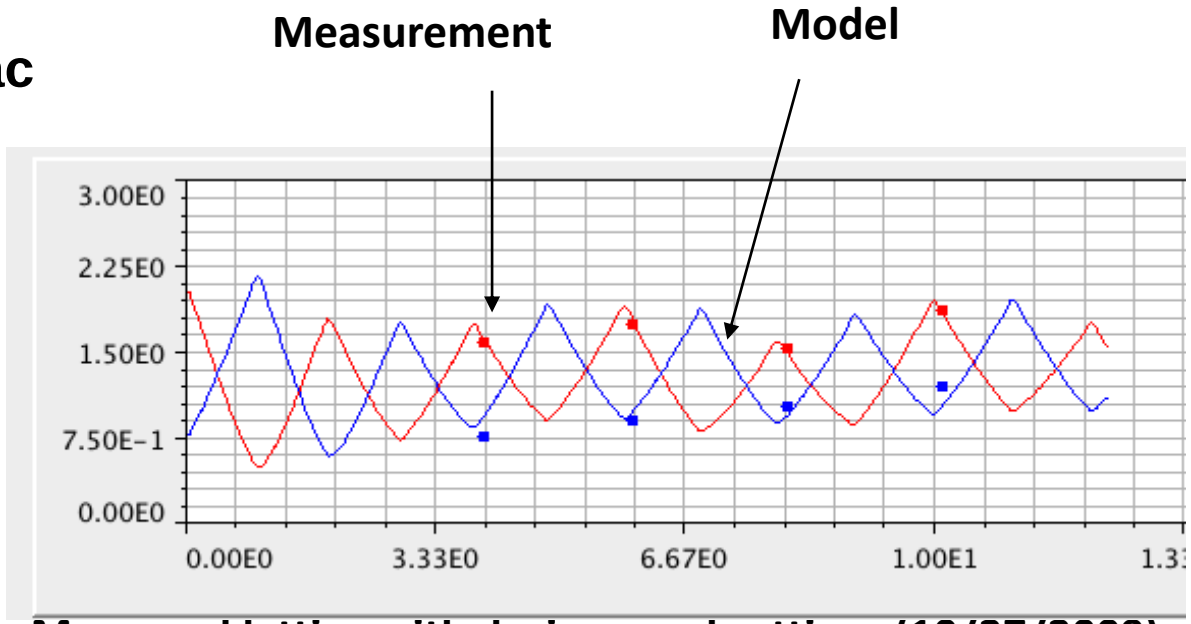
CCL	Design Values	Design Quads (10/27/2009)		Production (12/22/2009)	
α_x	-3.3	-3.5	(6%)	-4.7	(42%)
β_x (m)	3.9	4.0	(3%)	5.1	(31%)
ε_x (π-mm-mrad)	.33	.30	(9%)	.39	(18%)
α_y	.81	.41	(49%)	.08	(90%)
β_y (m)	.77	.61	(21%)	.34	(56%)
ε_y (π-mm-mrad)	.33	.44	(33%)	.37	(12%)

SCL	Design	Production (10/01/2009)	
α_x	-1.57	-1.8	(15%)
β_x	8.13	6.5	(20%)
ε_x	.33	.44	(33%)
A_y	.68	.71	(4%)
β_y	8.63	6.87	(20%)
ε_y	.33	.29	(12%)

HEBT	Design	Production (09/30/2009)	
α_x	.97	1.08	(11%)
β_x	3.67	3.59	(2%)
ε_x	.41	.45	(10%)
α_y	-1.95	-1.96	(1%)
β_y	9.38	12.13	(29%)
ε_y	.41	0.50	(22%)

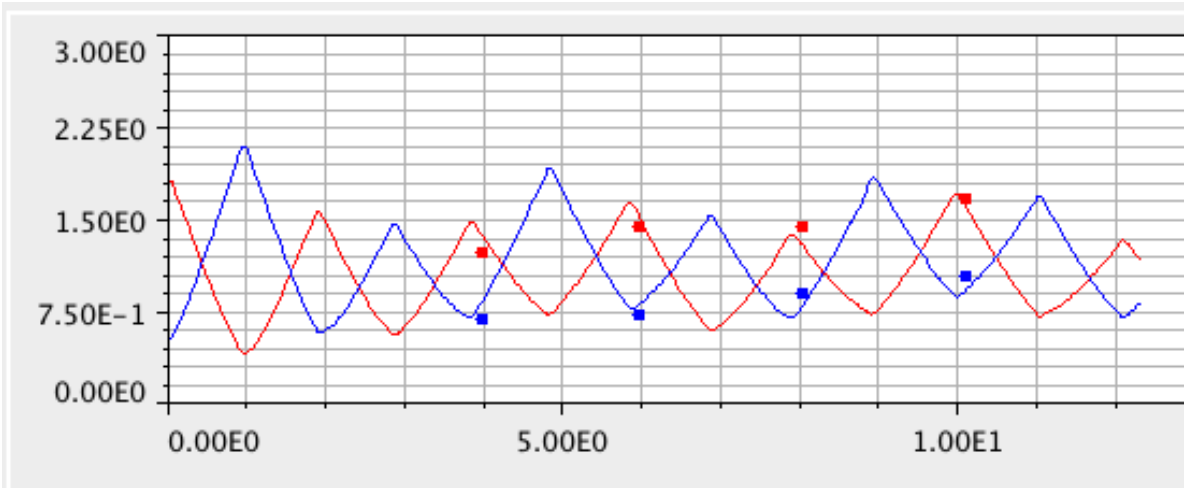
Transverse Beam Matching Progress

- **Warm Linac**



Measured lattice with design quad settings (10/27/2009)

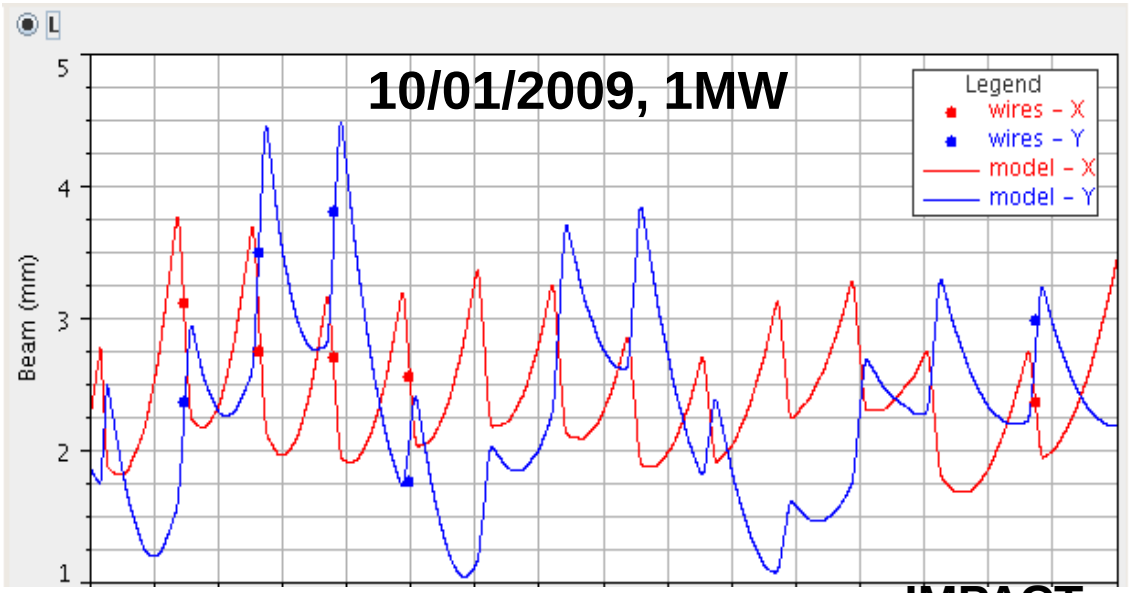
CCL1



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

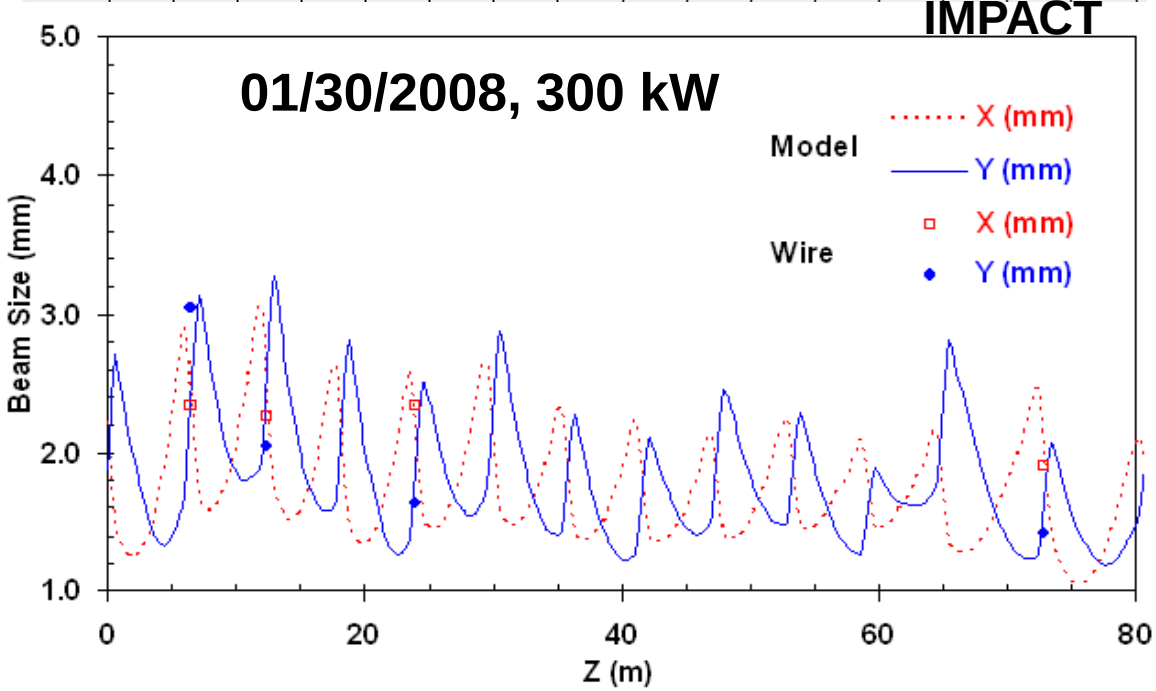
Transverse Beam Matching Progress

- **SCL**



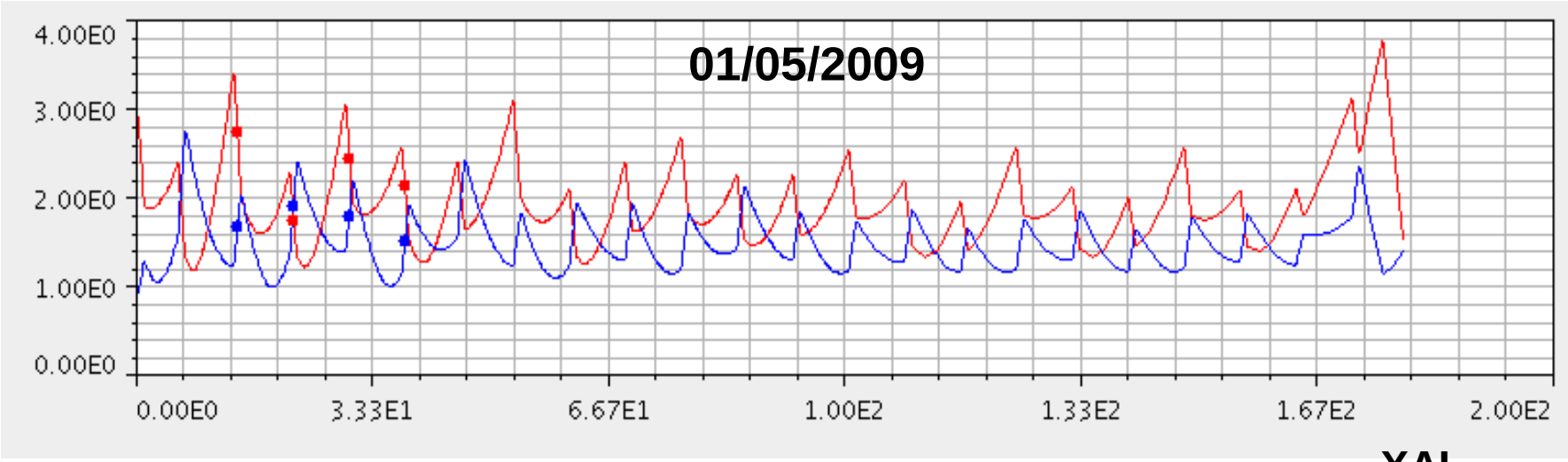
Less progress:

1) **No effect on loss**
2) **Has not been systematically used for beam matching**
3) **Model problems**
4) **Measurements**

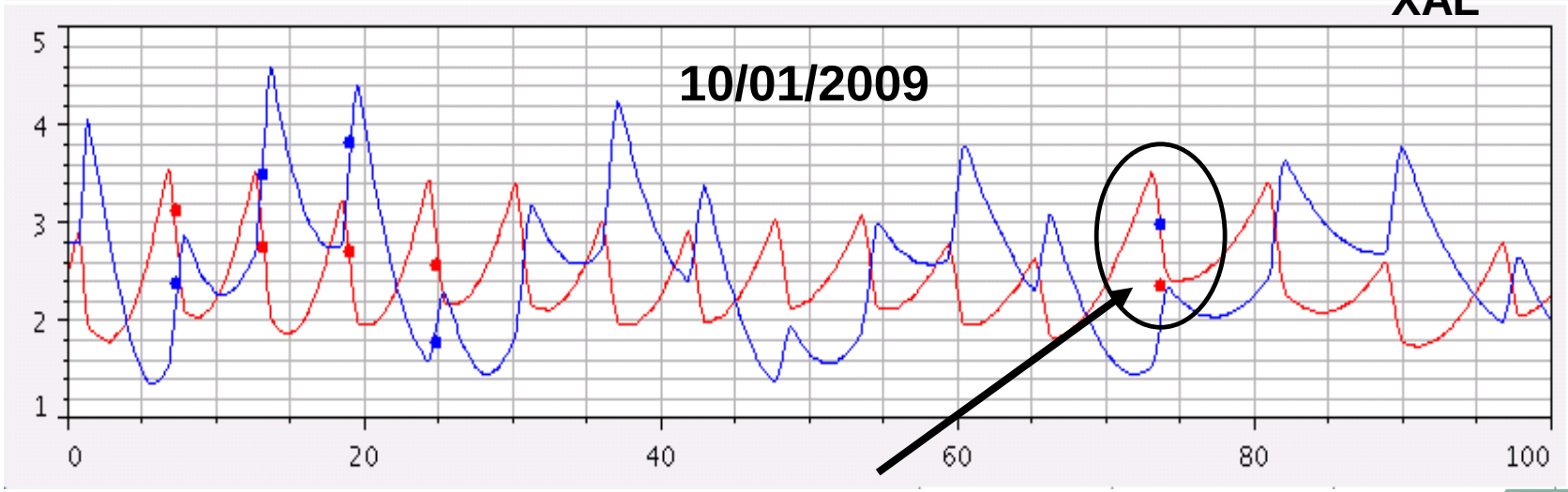


Transverse Beam Matching Progress

- Model



XAL



On-line envelope model is not very helpful when the involved linac lattice exceeds several periods

Transverse Beam Matching Progress

- **Model** — Initial Twiss, 11/16/2009

IMPACT

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%
	~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%

Transverse Beam Matching Progress

- **Measurements (11.16.2009 Y. Liu)**

Short pulse 20 us, measurement starts at 5 us.

With and without ~4 mm steering at the entrance of SCL

LW	Without	With	LW	Without	With	
1x	2.77	2.76	1y	2.77	2.98	~7%
2x	1.51	1.59	2y	2.07	2.20	~6%
3x	4.03	3.95	3y	2.55	2.71	~6%
4x	4.79	4.82	4y	2.00	2.20	~10%

Long pulse 500 us, measurement starts at 100 us.

LW	Short	Long	LW	Short	Long	
1x	2.85	2.76	1y	2.88	2.62	~10%
2x	1.29	1.47	2y	2.23	2.82	~25%

In ion source transient or LLRF AFF learning stage, beam is not very stable, profile measurements in the first 20 to 30 us could be problematic, both longitudinal and transverse.

Linac Lattice & Model Limitations

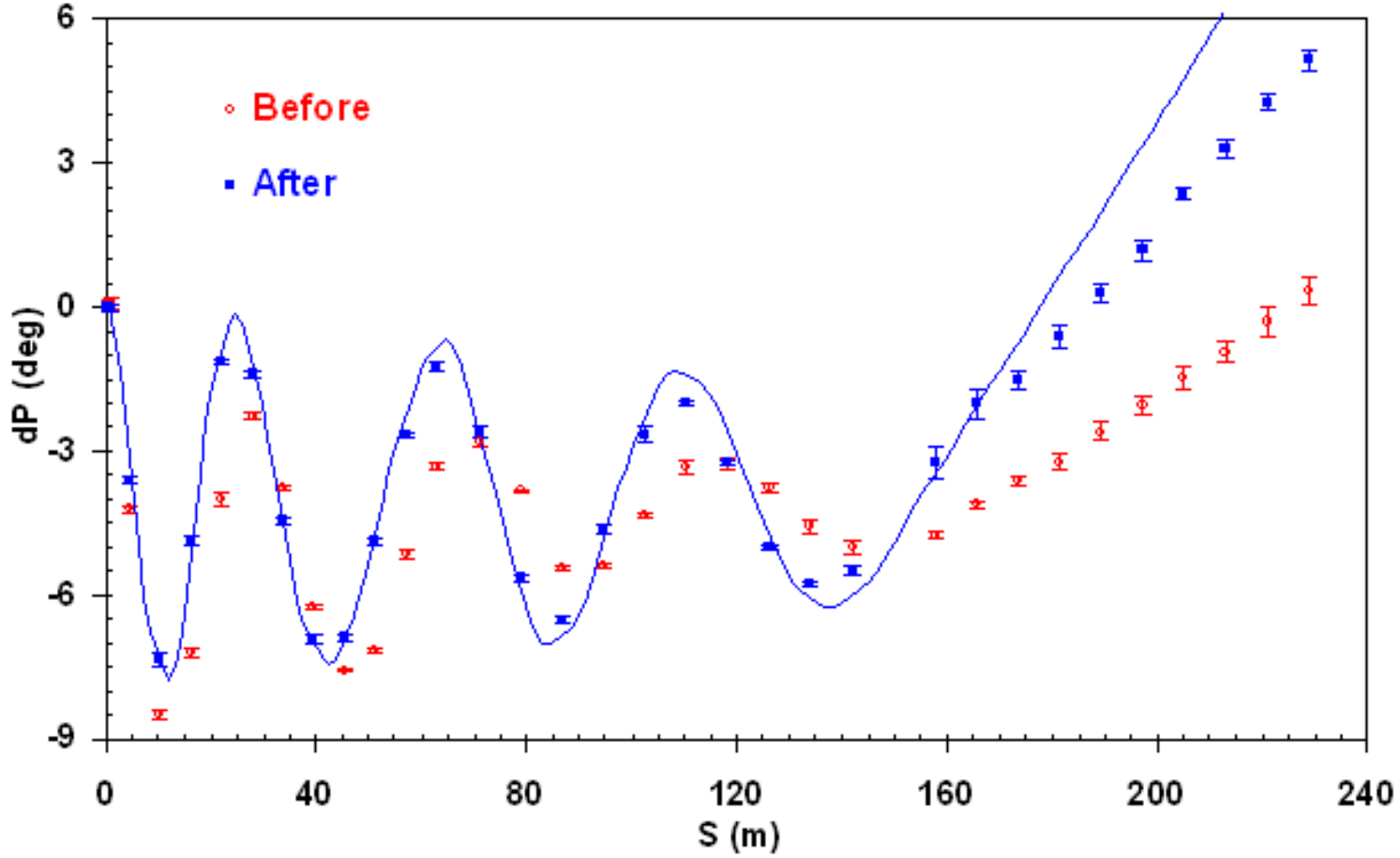
- **Linac Cavity Phase Tuning, July 2009 (Units: degree)**

Cavity	Production setting	Sunday (Diff.)	Tuesday (Diff.)
DTL1	-153	7.3	7.3
DTL2	129.5	3.8	3.8
DTL3	84.7	9.9	9.9
DTL4	156.8	11	11
DTL5	106.1	11	11
DTL6	39	9.6	9.6
CCL1	143.2	15.8	15.8
CCL2	170.8	16.4	16.4
CCL3	-110.9	10	10
CCL4	-112.8	8.1	4.5
SCL01a	-120.3	1.7	8.4
SCL01b	162.5	4.1	10.3
SCL01c	-130.9	2.7	40.3
SCL02a	-52.0	9.2	15

Phase differences in warm linac up to 16°, and in SCL from 8° to over 100°, but beam loss is almost exactly the same.

Linac Lattice & Model Limitations

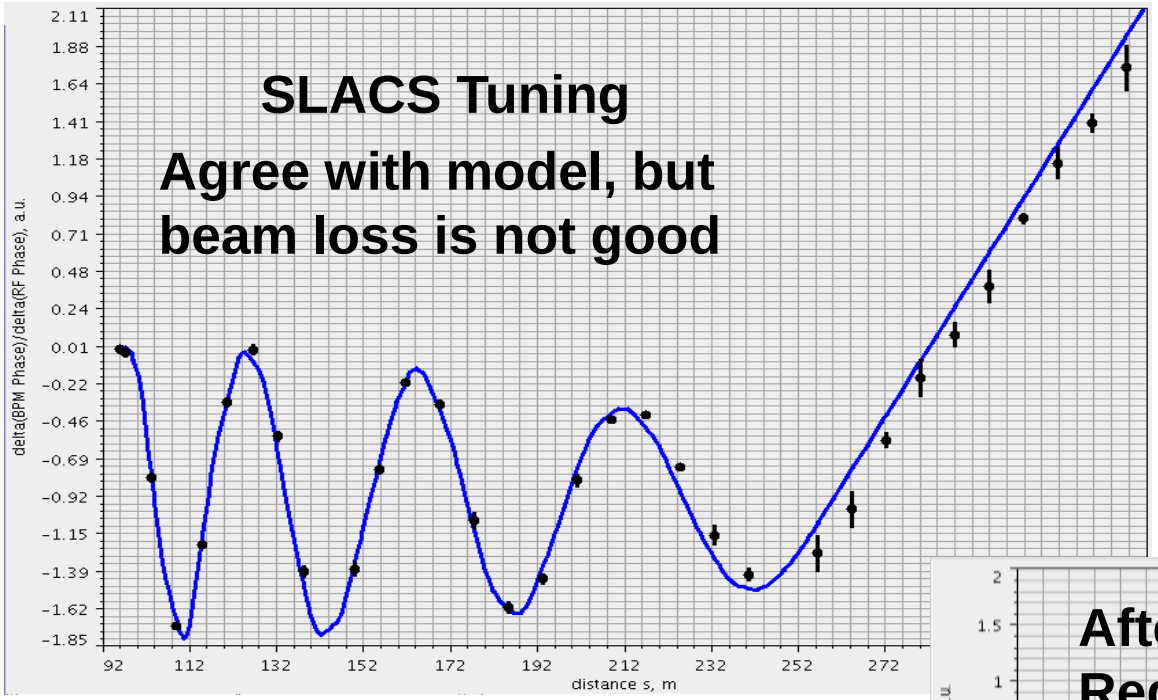
- **SCL RF Shaking** **March, 2009**

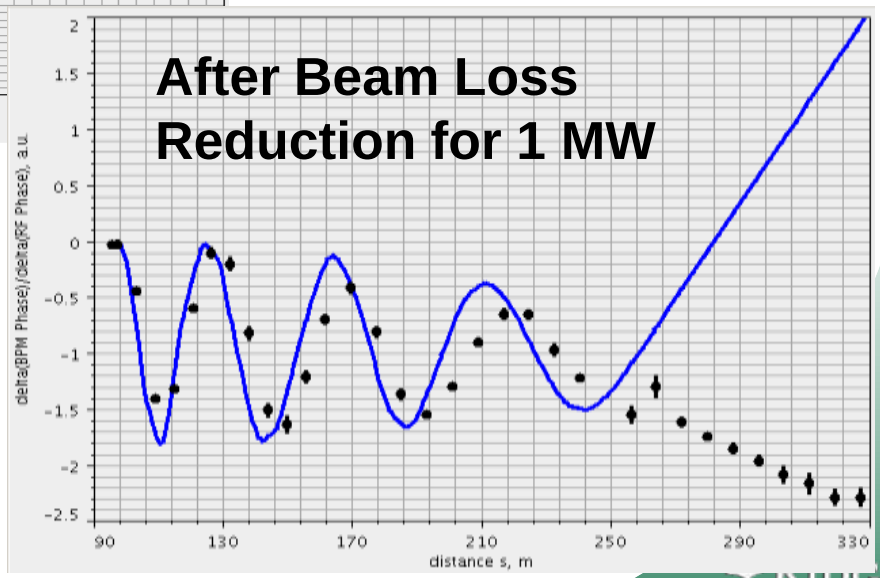


Before and after CCL4 phase reduced by 3°; after the change, agrees better with model, and SCL beam loss is also reduced

Linac Lattice & Model Limitations

- **SCL RF Shaking** **Oct. 2009**



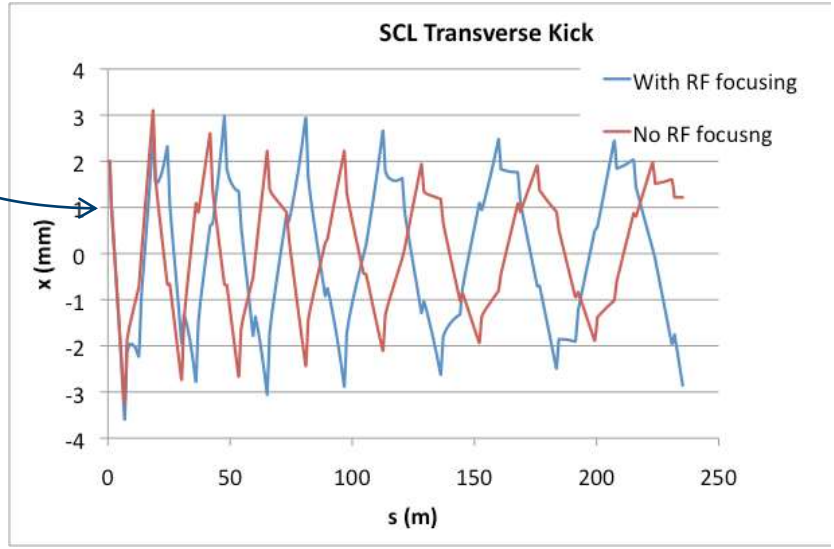


We cannot arrive at a minimum loss solely from any model, as the loss involves a halo of only ~ 10^{-5} of the total beam.

Linac Lattice & Model Limitations

- **SCL Beam Trajectory Response (A. Shishlo)**

•Transverse kick at the start of the SCL: RF defocusing has a large effect

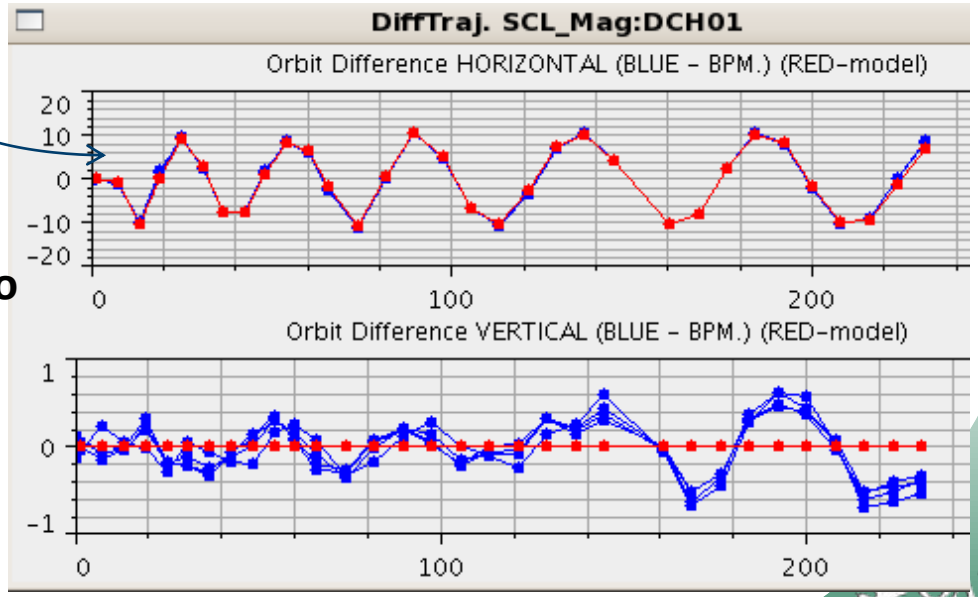


•Trajectory difference from dipole kick at the start of the SCL: Red = envelope model, blue = BPM measurements

•Envelope model with thin lens approximation requires ~ 5% correction on the RF defocusing strength

•Finely sliced cavity field maps in IMPACT may do a better job – no correction required for high gradient SC cavity.

•None of the models predict x-y coupling



Summary

- ✓ SCL beam loss is reduced by 50% or more
- ✓ Weak resonance at 60° is demonstrated
- ✓ Beam emittances in the linac are measured
- ✓ Transverse matching: warm linac, and SCL
- ✓ Identified a few limitations of current model
- ✓ Problems in the linac lattice, and in different models need further investigations
- ✓ Thanks…