Optics modeling and low-emittance tuning with MIA – The PEP-II experiences

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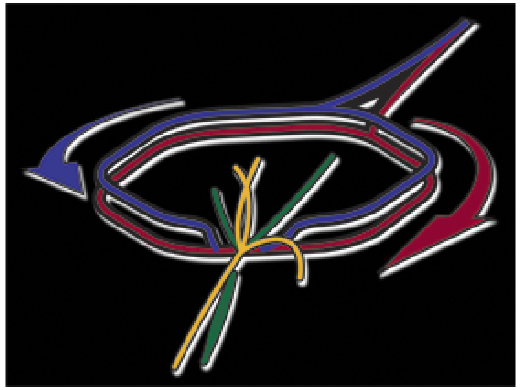
PEP-II: Asymmetric B Factory

- two electron storage rings

--- HER (9 GeV)

--- LER (3.1 GeV)



- optics complication from IR

--- detector solenoid causes strong LER coupling

--- 6 local skews in each side of IR

PEP-II was shut down in April this year.

Optics modeling and correction

Other than time consuming online tuning, the PEP-II optics correction has been centered on MIA modeling. We review activities related to MIA model.

MIA

- a series of MATLAB programs
  -- robust for PEP-II optics modeling and correction..

- a model-independent analysis (MIA) of turn-by-turn BPM orbit data
- an auto SVD-enhanced fitting process
  --- brings the real hardware storage ring to a computer -- the virtual machine

- approachable better virtual machine for the real machine to follow.

- MIA passes the optics model to MAD / LEGO for optics and beam-beam studies.

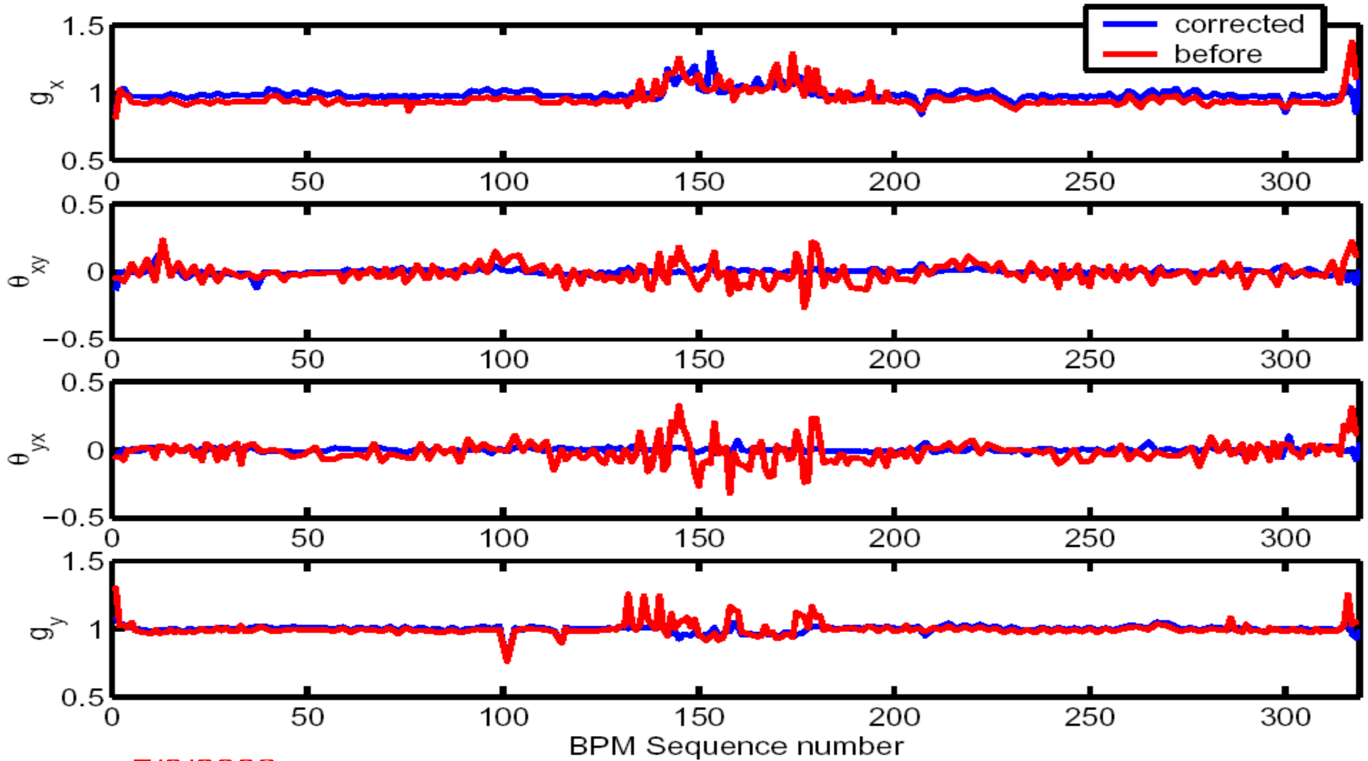
- MIA passes the optics model to online.

- MIA has helped PEP-II overcome optics improvement milestones
  --- For example, MIA brought PEP-II LER to half-integer working point to enhance 40% luminosity in 2003, which would have been very difficult or almost impossible without MIA at that time

PEP-II MIA measurement

- BPM turn-by-turn data acquisition
  –- 3 resonance excitations: 2 transverse + longitudinal

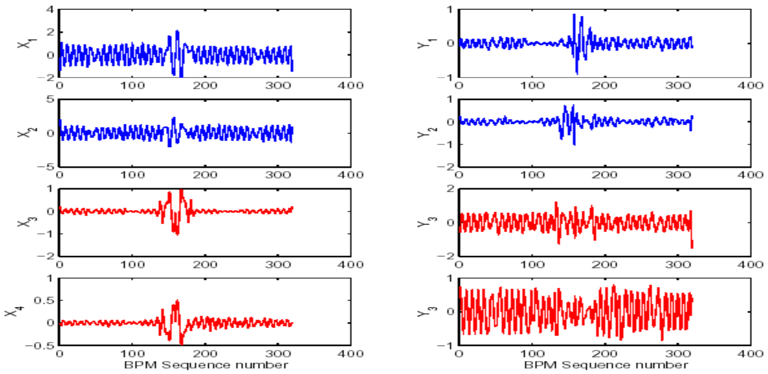
- Validation of MIA data
  –- symplecticity and noise check
  –- good bases for selecting reliable BPM data
  –- have helped PEP-II correct and improve BPM performance.



MIA can figure out BPM errors - 2004

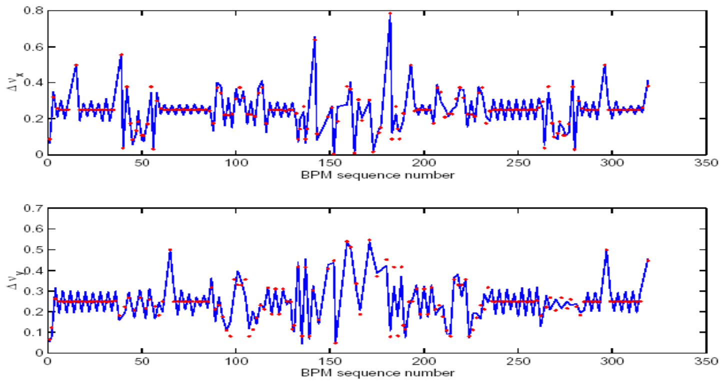
PEP-II MIA measurement

- BPM turn-by-turn data acquisition
  - –- 3 resonance excitations.
  - –- four independent linear orbits
  - –- dispersion (ac synchrotron mode)
  - –- phase advances
  - –- beta functions
  - –- Eigen ellipses – linear couplings



4 independent orbits determines the linear optics.

For each double-view BPM, one can trace the MIA extracted high-resolution real-space orbits to obtain a coupling ellipse in real space for each resonance (Eigen) excitation. Shown in Figure 2 are typical Eigen ellipses projected in the real X-Y plane.



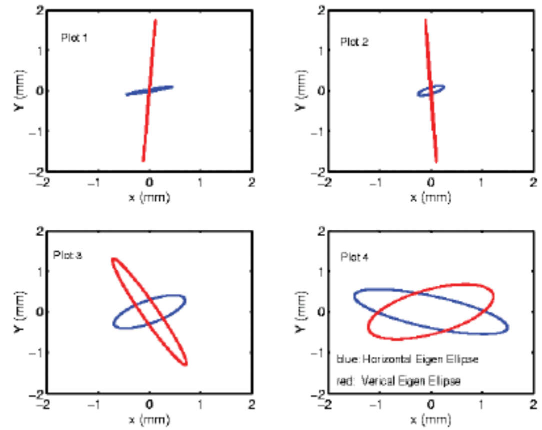


Figure 2: Eigen-mode coupling ellipses projected on the transverse x-y plane at 4 double-view BPM locations of PEP-II LER. The top 2 are at the two BPMs beside the IP, which show little coupling, while the bottom 2 are at the tenth BPMs from IP in each side, which show large couplings as the axis ratios of the short axis vs the long axis are large. (data acquired on September 30, 2003).

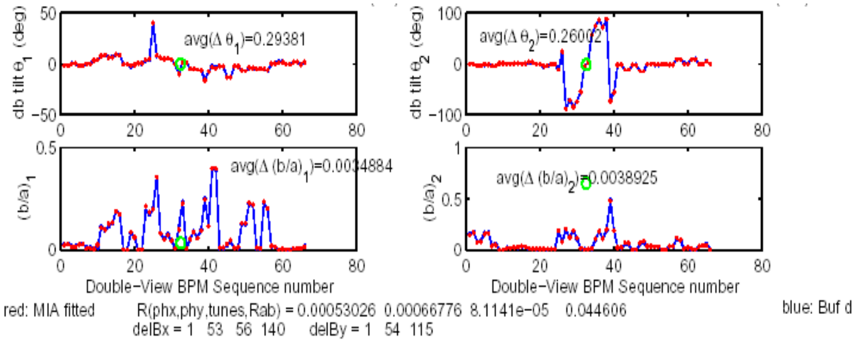
This is before MIA fitting

PEP-II MIA modeling

- auto SVD-enhanced fitting of phase advances, Green's functions, and dispersions among BPMs
  - Semi-Infinite Greens' functions for enough constraints that add on fitting accuracy
  - Eigen ellipses' parameters not used in fitting but reserved for checking fitting accuracy

$$\left(x_1^a x_2^b - x_2^a x_1^b\right)/Q_{12} + \left(x_3^a x_4^b - x_4^a x_3^b\right)/Q_{34} = R_{12}^{ab}$$
$$\left(x_1^a y_2^b - x_2^a y_1^b\right)/Q_{12} + \left(x_3^a y_4^b - x_4^a y_3^b\right)/Q_{34} = R_{32}^{ab}$$
$$\left(y_1^a x_2^b - y_2^a x_1^b\right)/Q_{12} + \left(y_3^a x_4^b - y_4^a x_3^b\right)/Q_{34} = R_{14}^{ab}$$
$$\left(y_1^a y_2^b - y_2^a y_1^b\right)/Q_{12} + \left(y_3^a y_4^b - y_4^a y_3^b\right)/Q_{34} = R_{14}^{ab}$$

R is a function of BPM gain and BPM cross-plane coupling.

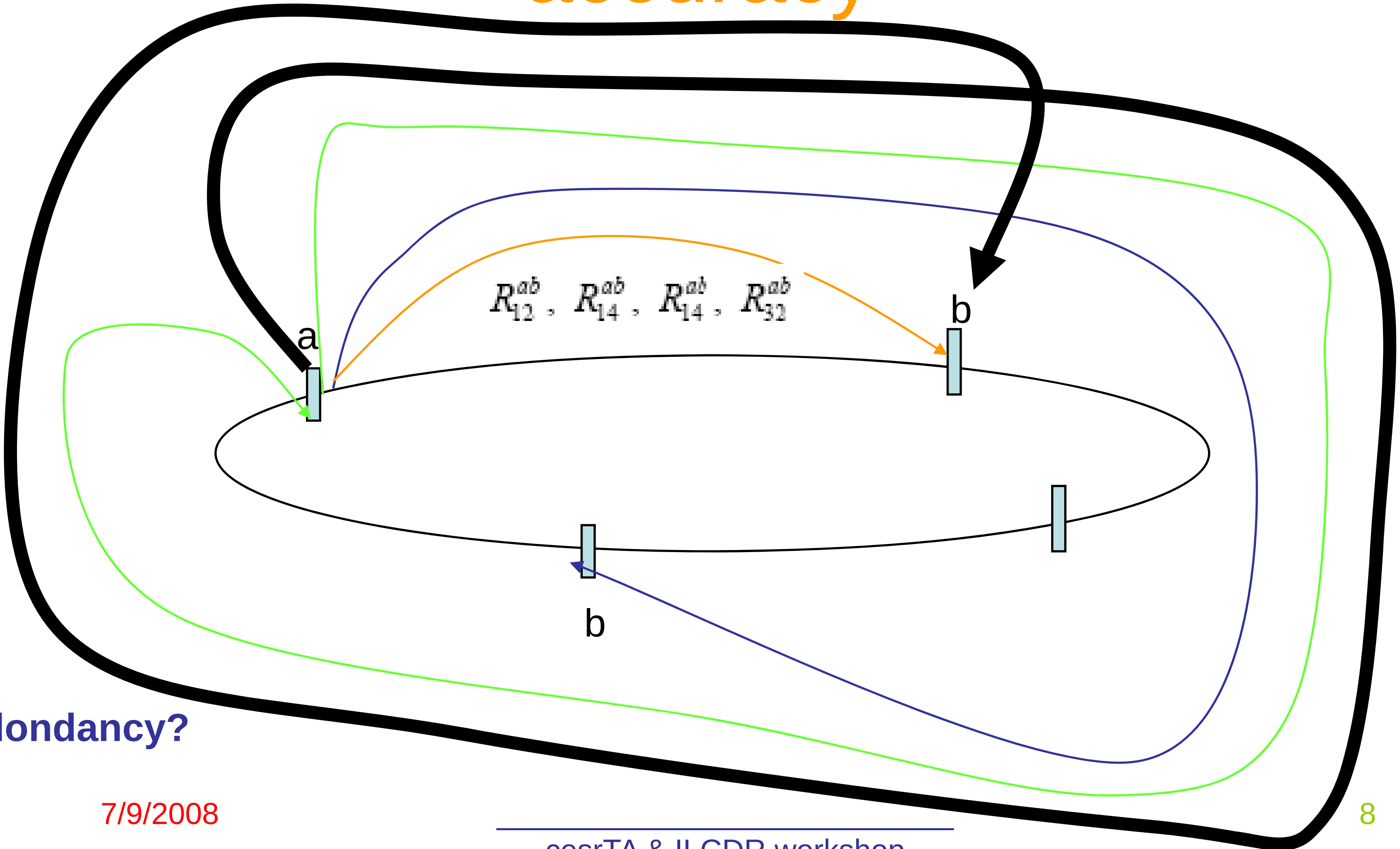


Q12 and Q34 are the two invariants representing the excitation strength..

That Eigen ellipses' parameters match well between model and measurement shows reliable model

MIA does not trust the BPM accuracy – MIA figures out BPM gain and cross coupling errors.

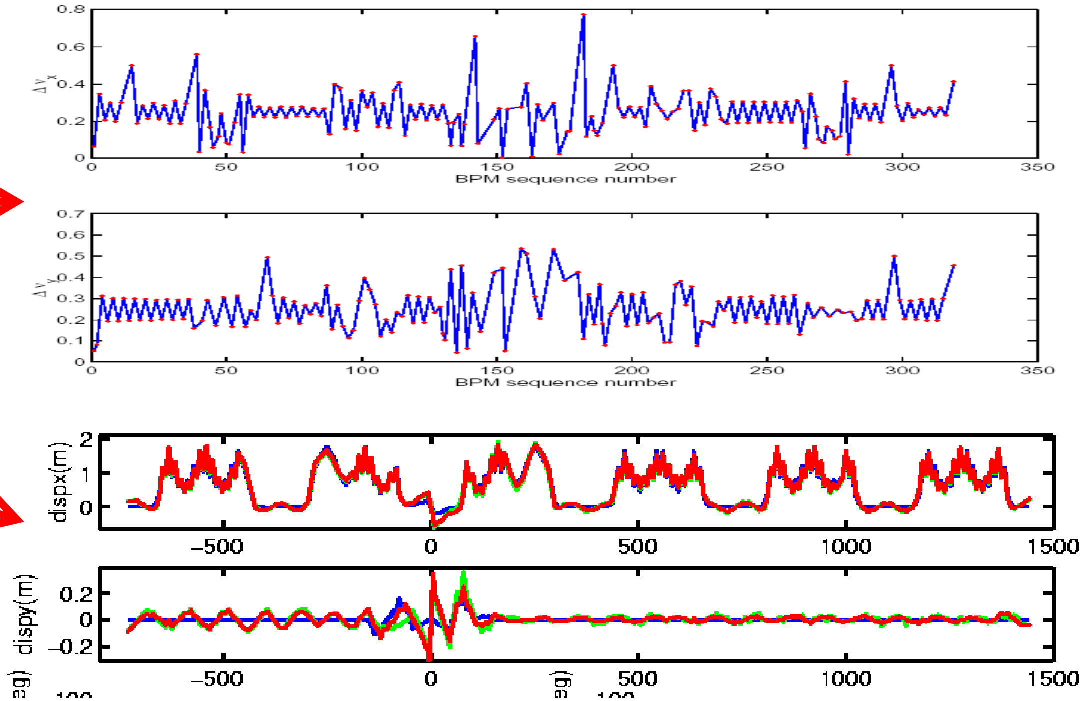
Semi-Infinite Greens' functions for enough constraints that add on accuracy

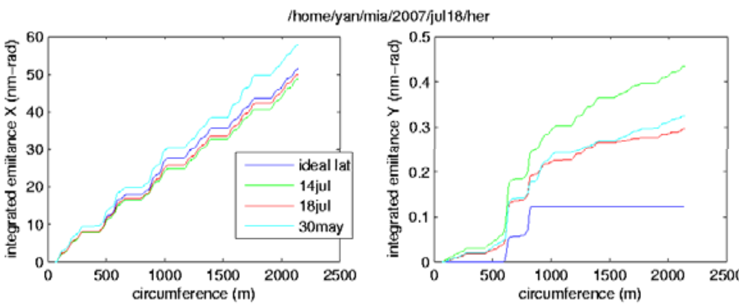


Redondancy?

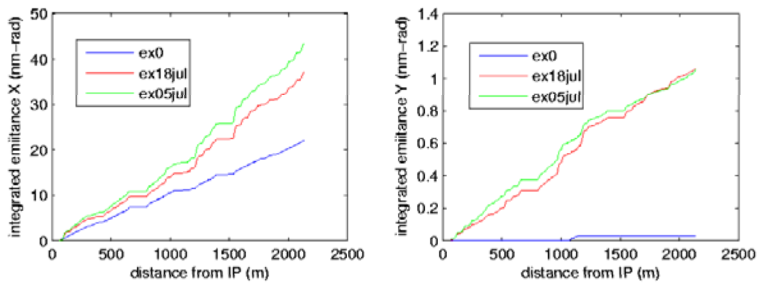
PEP-II MIA modeling

- Virtual machine → more accurate calculation of
  - –- Phase advances
  - –- Beta functions
  - –- Linear couplings
  - –- Dispersions
  - –- Emittance
  - –- Estimate of Luminosity



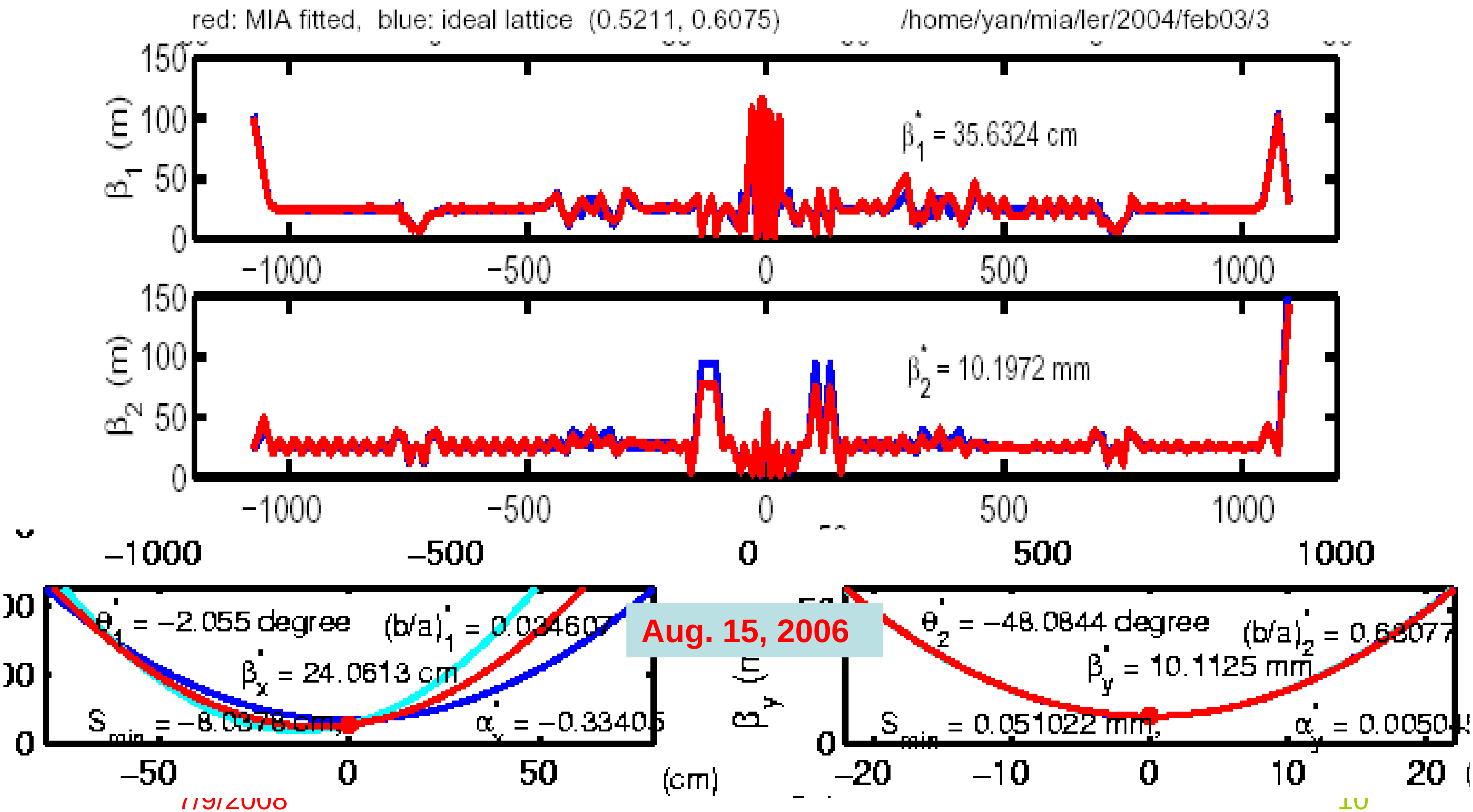


HER emiitance integration on July 18, 2007



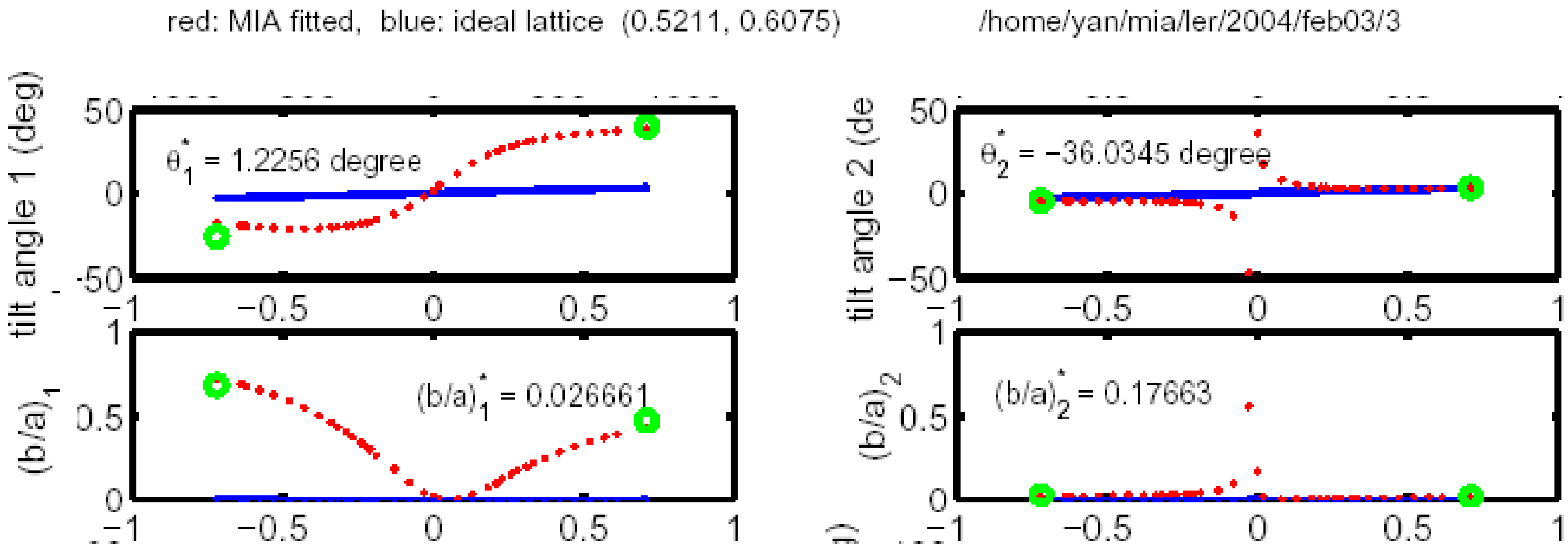
LER emiitance integration on July 18, 2007

A typical β-function plots from MIA

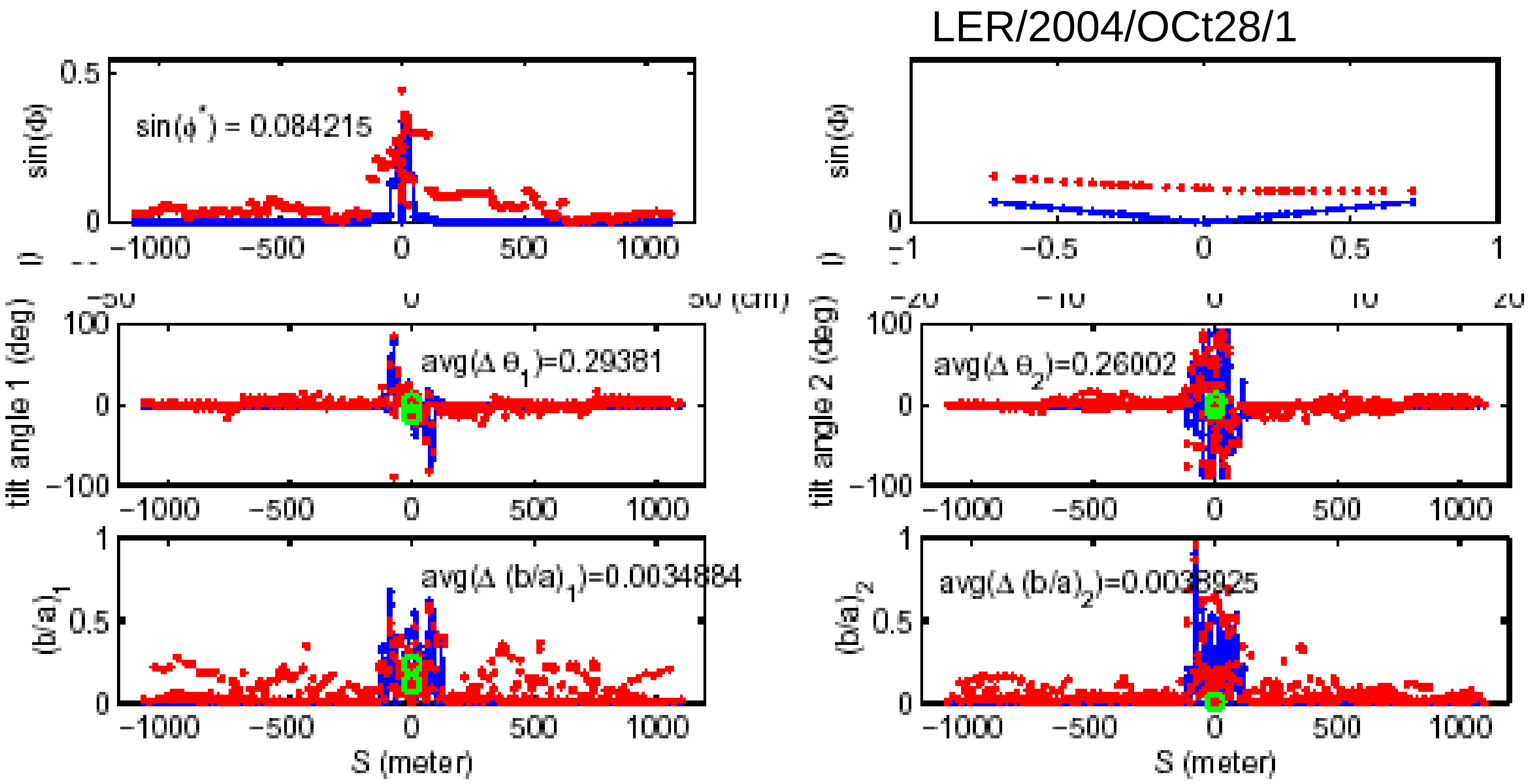


A typical linear coupling plots near IP

from PEP-II MAC2004



A complete appraisal of the LER linear coupling



PEP-II Optics correction with MIA model

- Once we have the virtual machine, the model can be kept with MIA for an optics correction solution and/or brought to MAD/LEGO for beam-beam and optics studies .

- we can select a limited number of key magnets for fitting to get a wanted model. We then generate a knob for dialing into the machine. The "cold" machine responded to our expectation very well

  --- fix beta beat

  --- reduce linear coupling

  --- emittance tuning

  --- IP match improvement

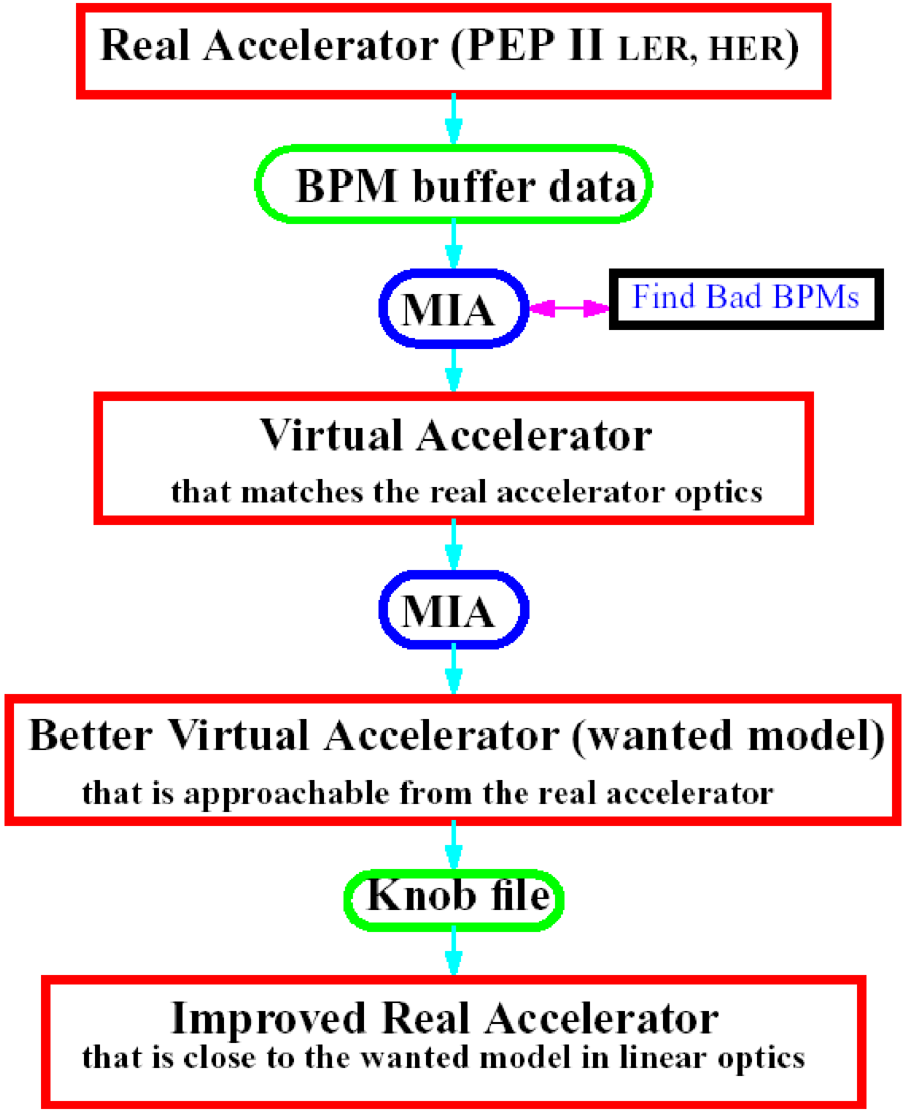
  --- help orbit steering successful

  --- …

MIA constraints and weights for wanted machine – an example

Initial Residuals			constraint # start	end	weight start	end	snap-shot residuals	special quantities	
0.00041393	1	Tunex	1	1	1000	5000	0.0019588	38.5064	Tune
0.000169228	2	Tuney	2	2	1000	5000	0.00485956	36.581	
0.000245875	3	nux	3	28	100	100	0.000305344	0.499811	- l
0.00375321	4	nuy	29	54	100	100	0.00387669	0.496279	
26.9007	5	Betax	55	425	0.5	1	10.7411	37.0005	Beta Beat
4.88197	6	Betay	426	796	0.3	1	4.55298	24.0697	
2.06367	7	axay	797	1538	0.3	1	0.836578	5.15022	
0.306315	8	tiltxy	1539	2280	10	25	0.329449	0.330447	coupling
0.116435	9	axisRatio	2281	3022	10	25	0.151386	0.169479	
0.0872007	10	sinPsxt	3023	3393	10	25	0.0806435	0.110078	
0.0550547	11	bx**IP	3394	3394	1000	1000	0.00382164	0.306178	Beta* IP waist
0.0016697	12	by*IP	3395	3395	5000	200	0.0021166	0.0096224	
0.604155	13	ax*IP	3396	3396	300	2000	0.02563	0.0256379	
0.00224	14	ay*IP	3397	3397	300	10000	0.000989	0.000989447	
0.0468993	15	Tiltx*IP	3398	3398	100	5000	0.002646	0.00264634	IP coupling
1.52045	16	Tilty*IP	3399	3399	100	1000	0.00710	0.00710003	
0.06326	17	bax*IP	3400	3400	100	1000	0.0133853	0.0133853	
0.564624	18	bay*IP	3401	3401	100	200	0.425895	0.425895	
0.17073	19	sinP0*IP	3402	3402	100	100	0.0533182	0.0533182	
0.192546	20	eta13SF	3403	3506	20	30	0.163688	0.425425	dispersio
0.165198	21	eta13SD	3507	4144	20	30	0.146349	0.381311	
0.0716958	22	eta1234IP	4145	4148	100	30	0.0571557	0.0571557	
0.0675275	23	eta1234SKEW	4149	4212	20	500	0.0667764	0.282782	
0.0636338	24	eta1234INJ	4213	4220	20	2000	0.032879	0.43337	

MIA flow chart



Optics correction with MIA – PEP-II experience

- We tried MIA optics correction for PEP-II (without any confidence at all) for the first time in late 2002. PEP-II luminosity (then at about 3 – 4 x 10^{33} $cm^{-2}s^{-1}$) increased 20%. We could not judge if it is real MIA contribution or just very lucky. Nonetheless, this gave us a big green light for more MIA MD time.

- But this is not a free meal.
- Very soon, we lost that privilege with two consecutive failures in increasing PEP-II luminosity although machine geometric optics responded to MIA very well.

- Now, we know why it failed. Although the machine geometric optics responded to MIA prediction very well, MIA had no dispersion information then. (now MIA has the dispersion).

optics correction - continued

- It was until several failed tries without using MIA for bringing LER working tune to near half integer, MIA got the opportunity again on April 29, 2003.

- MIA successfully brought LER to a half integer working tune and improve LER beta beats and linear coupling.

  -- LER became way too strong for the HER. Nonetheless, consequently, PEP-II luminosity increased over 40% , achieved its record peak luminosity at 6.5 X 10^{33} /cm^2/s in the beginning of June, 2003.

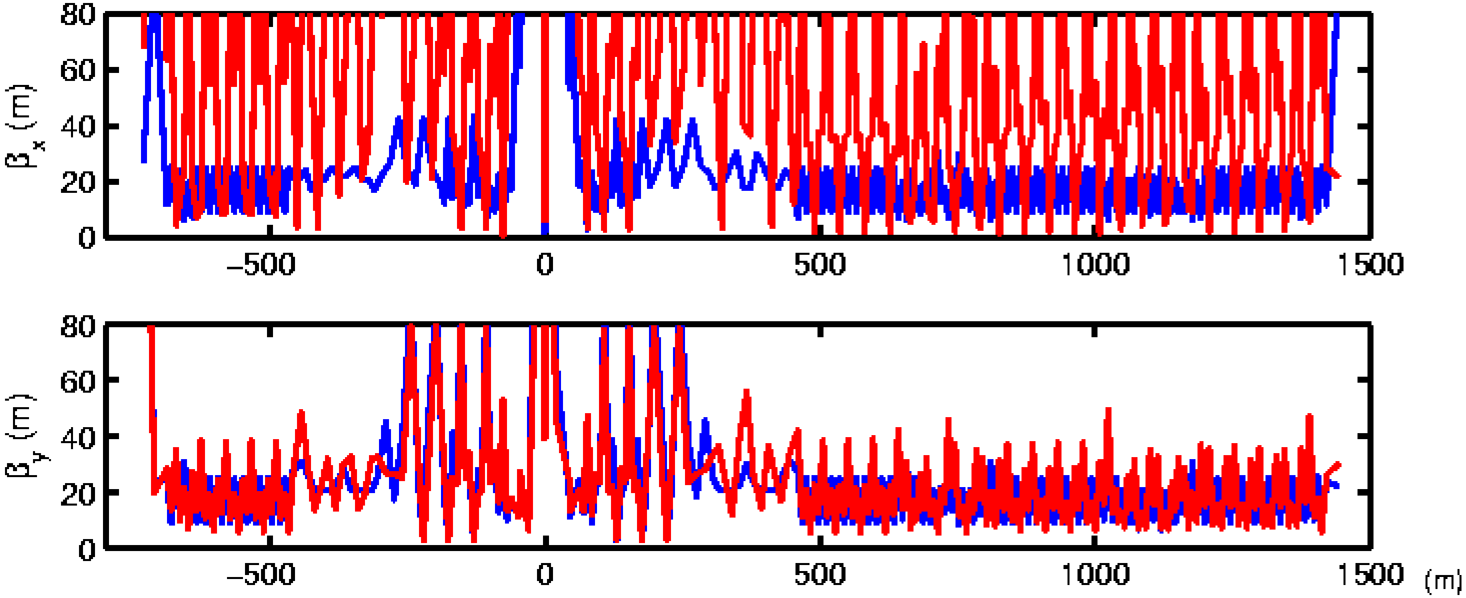
optics correction - continued

- After we enjoyed good 2003, 2004 for bringing PEP-II luminosity up to 10^{34} $cm^{-2}s^{-1}$, we had a PEP-II crisis in 2005 due to an accident. PEP-II was shut down for about half a year in 2005.

- We faced the so-called P-5 reviews both in 2005 and 2006. Even worse, when we turned on PEP-II again, our machines are not cooperating.

Virtual HER – Feb 1, 2006

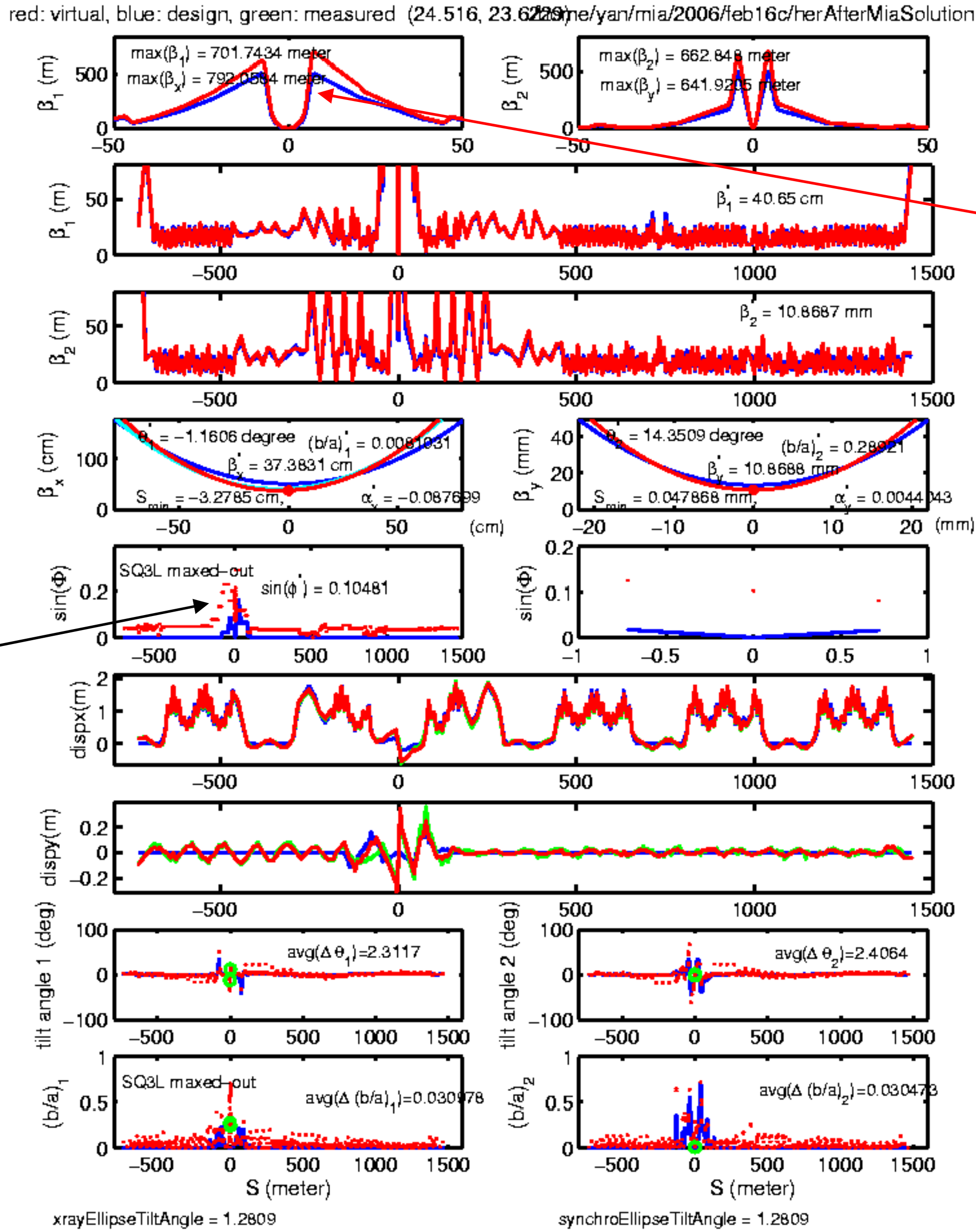
comparing beta function bewteen the machine and the ideal lattice



We had a very strong HER X beta beat during the beginning period of this run. We could have fixed it right away, however, due to more urgent problems, this high beta beat fix was postponed till mid-February, 2006.

Virtual HER after one-shot MIA correction– Feb 16, 2006

- Beta beating fixing mainly from QF5 (we use only the left one).
- We had also added trombones, local and global skews to simultaneously improve couplings, dispersion, and IP optics.
- We had a max-out of SQ3L that caused an imperfection of the offline solution. Thanks to Pantalio Raimondi who helped me find this max-out then.
- Since then we had enjoyed an HER record-low residual from the ideal lattice till we ramped the currents at later stage of the run.



Now, we have an updated ideal lattice at BetaX* =33 cm.

mac2006

Y. Yan

Successful LER major orbit steering

- One of the key improvement for PEP-II optics in 2006 run was the successful LER major orbit steering.
- It is usually difficult to correct the optics after a major steering for the coupled LER.
- We rely on offline modeling (MIA) after the steering to generate wanted approachable optics model and dial in the solution for restoring the linear optics.

MIA HER emittance improvement in 2007

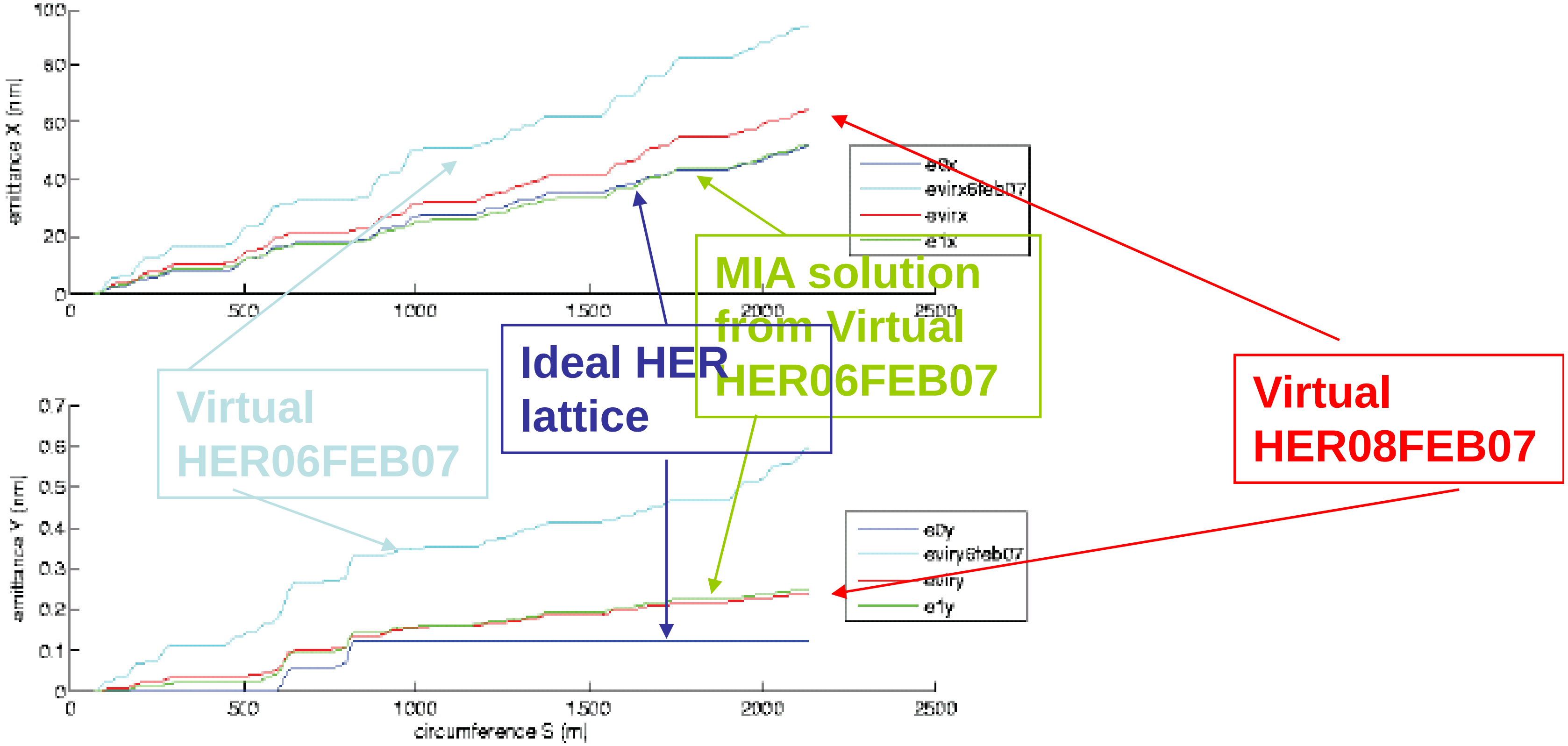
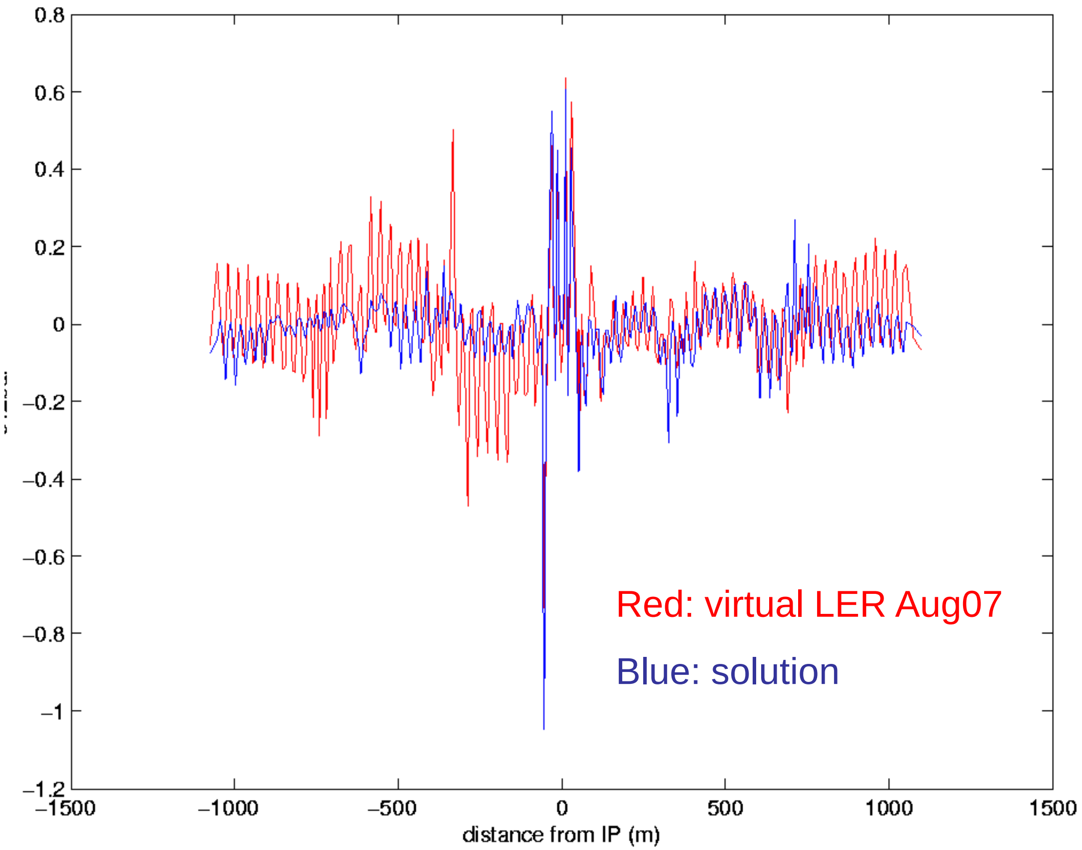


Figure 13: Comparison of PEP-II HER X emittance (top plot) and Y emittance (bottom plot) contribution through circumference for the virtual machine on Feb 6, 2007 (evirx6feb07, eviry6feb07), the virtual machine on Feb 8, 2007 (evirx, eviry), the wanted model for the new half solution derived from the virtual HER on Feb 8, 2007 (e1x, e1y), and the ideal lattice of HER (e0x, e0y).

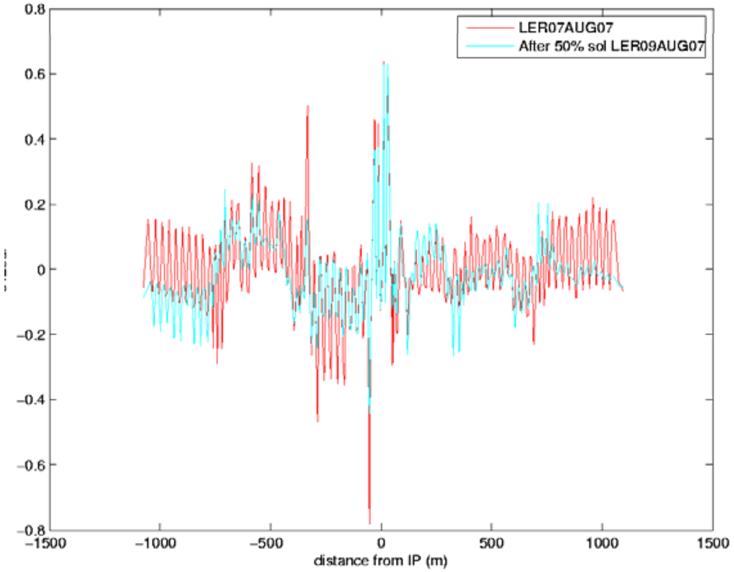
Reducing LER coupling – dimensionless C12 : Lacey Kitch's summer science project

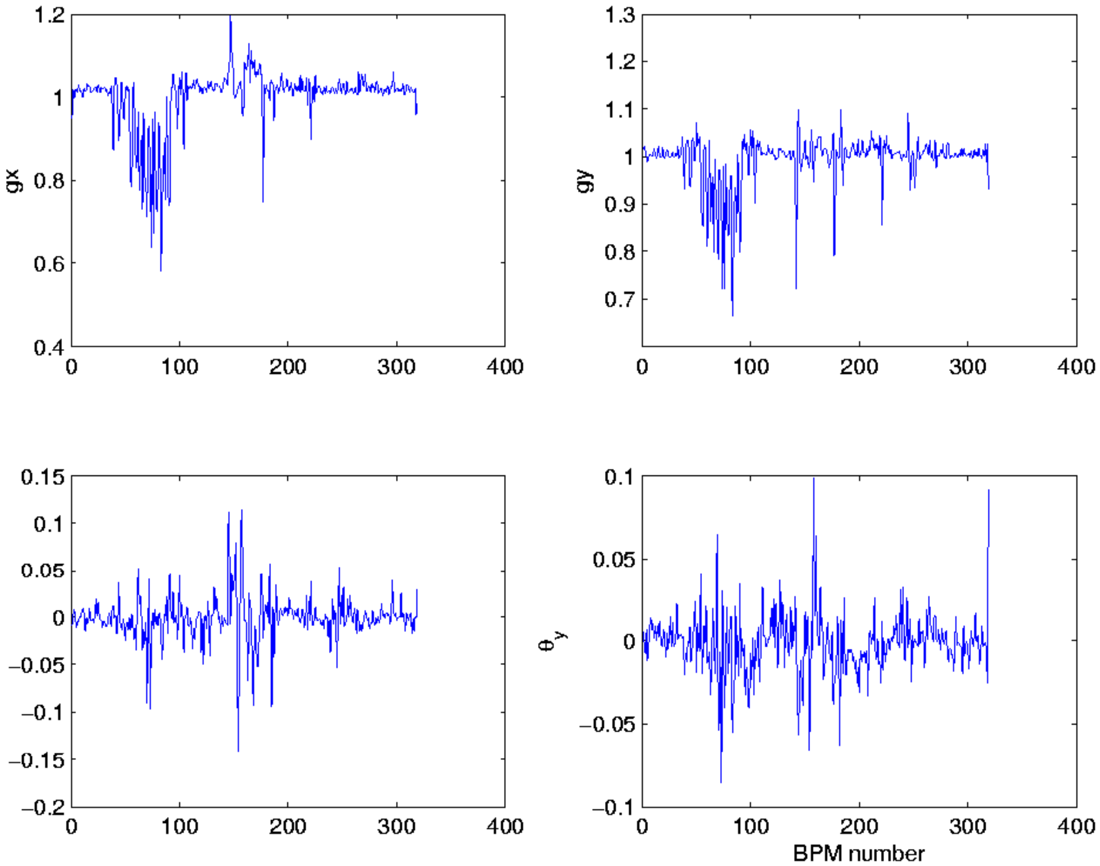
$M = A\ C\ R\ C^{-1}\ A^{-1}$

With Aug. 7 MIA LER data, my summer science student, Lacey was helped to get a MIA model and find a solution that reduced LER c12 with vertical symmetric sextupole bumps.



Reducing LER coupling – C12bar : Lacey's summer science project





We were able to manage dialing in 50% of the solution.

Regional BPM problem caused inaccuracy.

Test of HER 60 degree to HER 90 degree

- Toward the end of 2007 run, we tried to test converting HER 60 degree lattice to HER 90 degree lattice aiming at shorter bunch length.
- We got HER MIA data, came up with MIA model and pass to MAD. Then Wittmer used MIA2MAD to find a dialing-in solution.
- HER 90 degree was successfully achieved with one-shot dialing in.

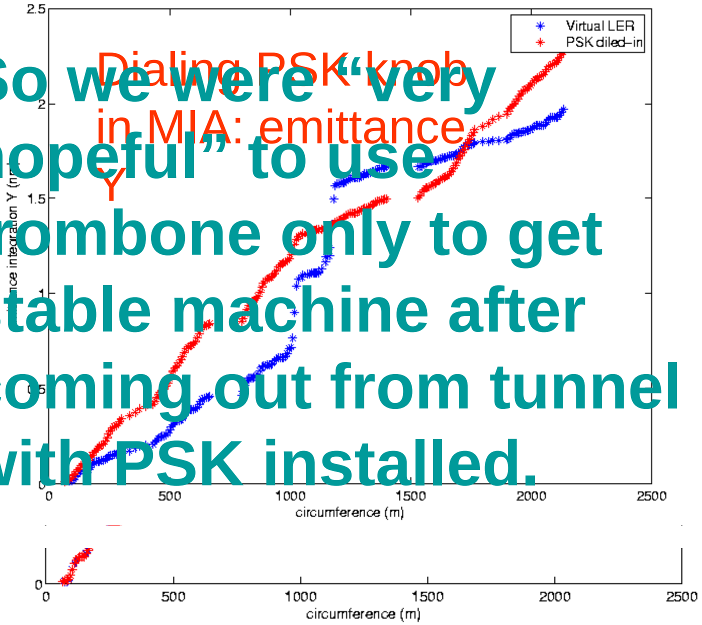
Installation of permanent skews in LER

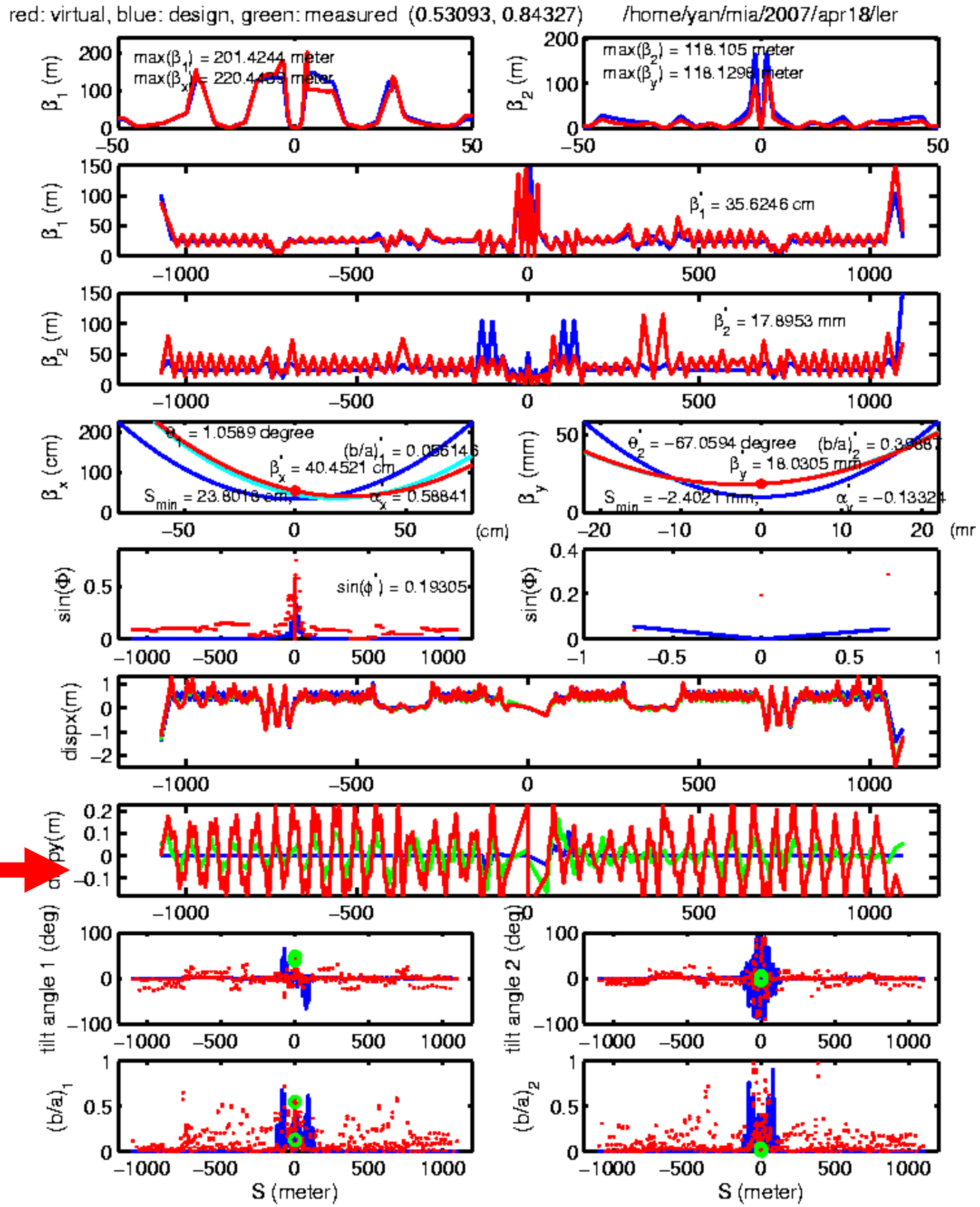
- We knew we could improve the LER ideal lattice by adding local skew quads in IR to reduce the coupling, thereby, reduce the vertical emittance dramatically.
- The ideal LER vertical emittance is 0.5 nm.rad while the real LER best vertical emittance from MIA measurement was 1.4 nm.rad on August 15, 2006 when we had the peak luminosity.
- But we have no $ for regular skew quads. Franz-Josef Decker came up with the idea of very cheap permanent Skews (PSK).

Dialing PSK knob in MIA for Virtual LER on Apr 17, 2007

So we were "very hopeful" to use trombone only to get stable machine after coming out from tunnel with PSK installed.

Dialing PSK knob in MIA: emittance Y





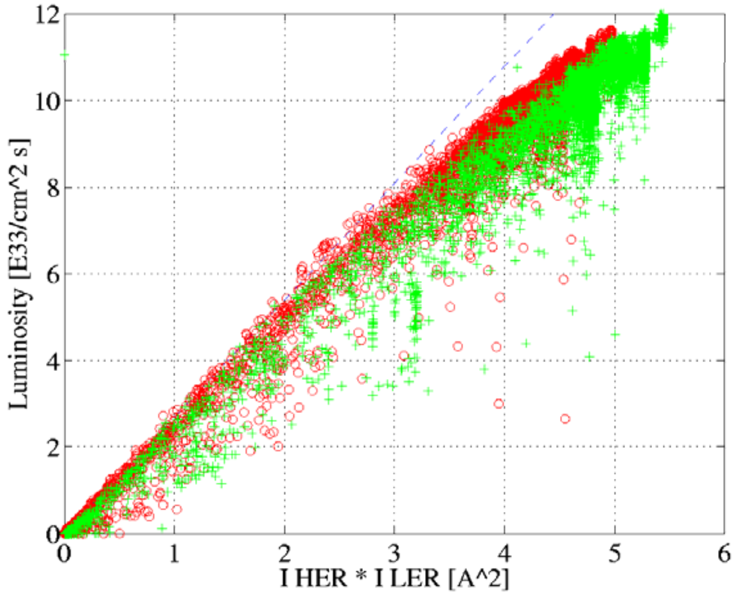
MIA model showed that we could fix the machine, at the 1st step, with trombone and global skews although vertical dispersion was not good yet. However it could be easily fixed with asymmetric sextupole bumps at a later time

Dialing PSK knob in MIA for Virtual LER - continued

- Got MIA LER virtual machine and then dialing PSK installation to MIA virtual machine, finding a correction Knob. -- Installing PSK (permanent skew quarupole) successful. LER vertical emittance dropped from previous best 1.4 nm.rad to 0.8 nm.rad.

- We could further reduce the LER vertical emittance. But we faced a weaker HER.

- So running at Lower LER current, we managed to get record peak specific luminosity (red as shown in the plot) at high current but not the luminosity in 2007.



Summary

- We are able to get accurate models for PEP-II "cold machine" with MIA.
  --- side mentioning: MIA model helped light monitor commissioning – coupling ellipse tilt angle in each Eigen plane.

- MIA can provide approachable model for optics correction – lower emittance
  --- beta beat correction
  --- bringing operation to half integer
  --- linear coupling reduction – vertical emittance reduction
  --- IP optics improvement
  --- dramatic conversion into a new configuration.

- Challenges still not overcome:
  - Warm machine vs. cold machine.
  - Beam-beam effect on the model.
  - Orthogonal and dynamical IP knob dialing technique.
  - And more

MIA procedures may apply for cesrTA for low emittance tuning