Sources of Nano-beams – a comparison between ATF, TESLA and NLC Damping Rings

Sources of vertical emittance
Emittance tuning
Global and local
Collective effects

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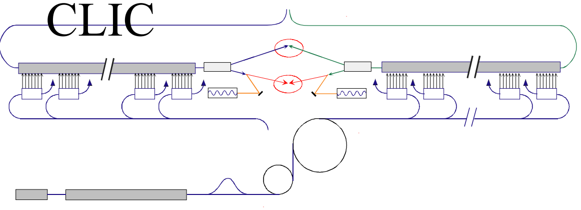
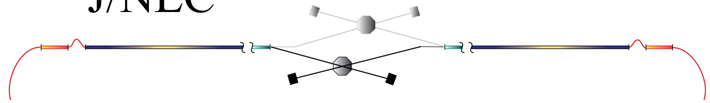
Wednesday, June 26, 2002

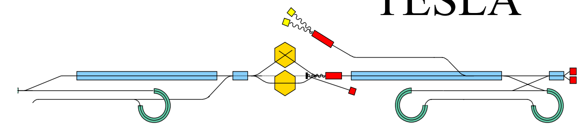
CLIC



J/NLC



TESLA



Ring Parameters

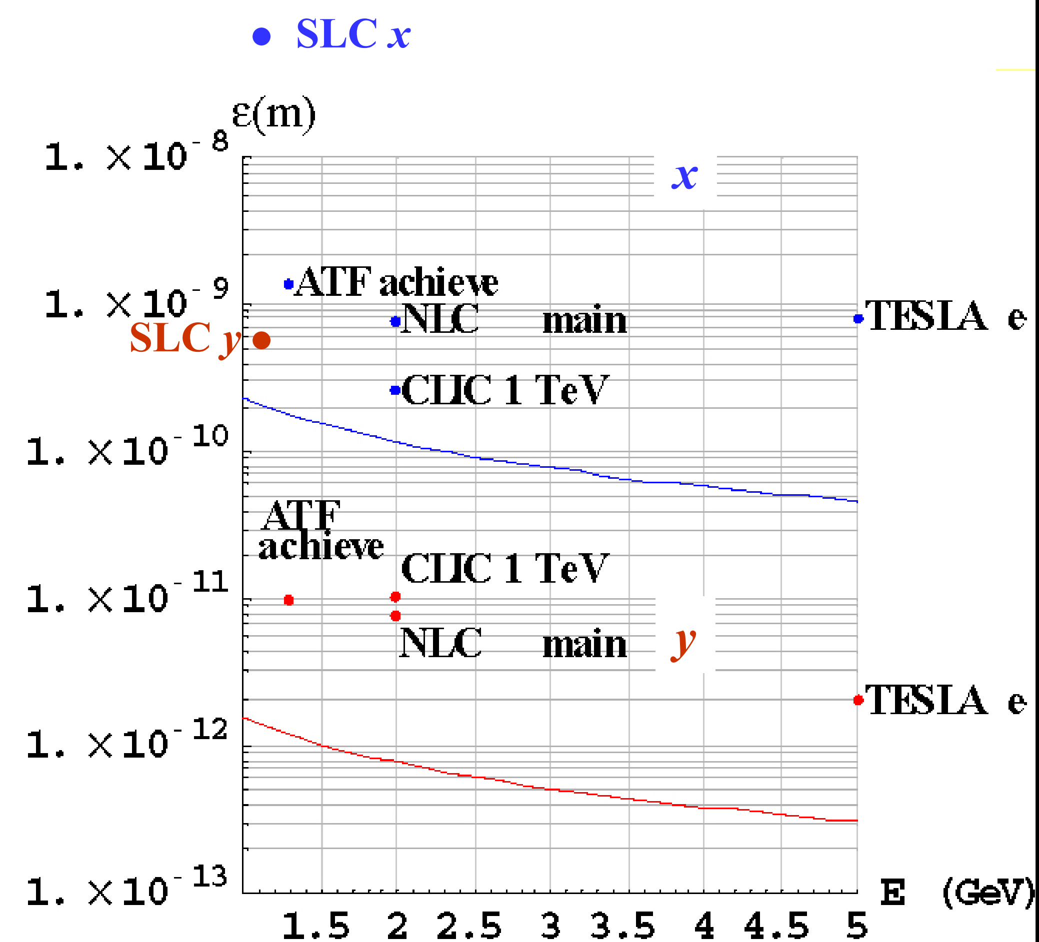
	ATF achieved	TESLA e^+ Ring	NLC MDR
Energy	1.3 GeV	5.0 GeV	1.98 GeV
Relativistic Factor	2544	9785	3875
Store Time		200 ms	25 ms
Damping Time	10/12 ms	28.0 ms	5.00 ms
Normalized Injected Emittance	100 μm rad	0.01 m rad	150 μm rad
Normalized Extracted Emittance		0.02 μm rad	0.02 μm rad
Normalized Equilibrium Emittance	0.038 (0.02) μm rad	0.0138 μm rad	0.0132 μm rad
Geometric Equilibrium Emittance	15 (7.5) pm rad	1.41 pm rad	3.40 pm rad

ATF results – single bunch

(low I result)

ATF needs about a factor ~3 to achieve LC goals

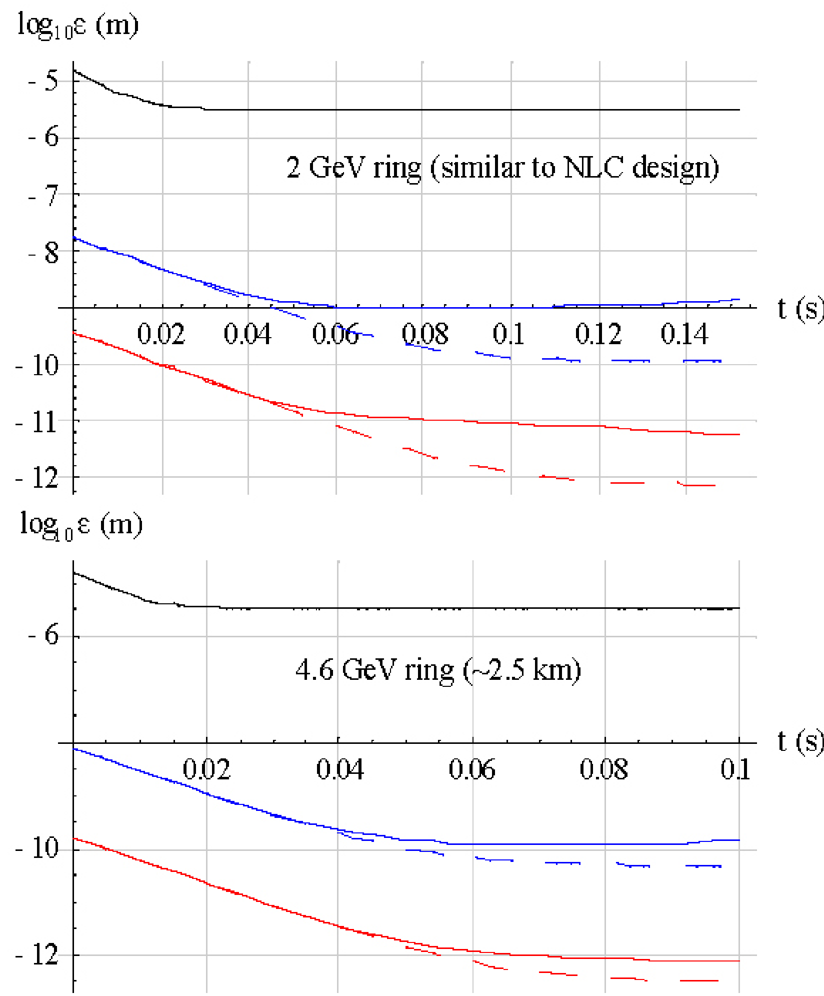
Damping ring comparison



Geometric emittances vs E for LC DR's

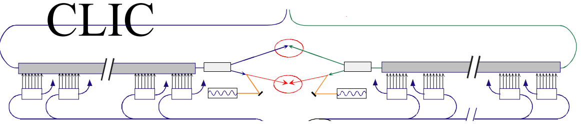
(J. Jowett – PAC01)

CLIC Damping ring studies – showing importance of IBS for DR designs



z, x, y emittance *vs* time – 2 CLIC DR designs (dashed – low I – no IBS)

CLIC



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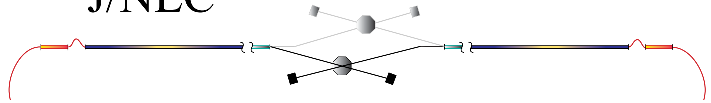
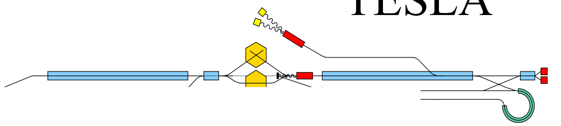
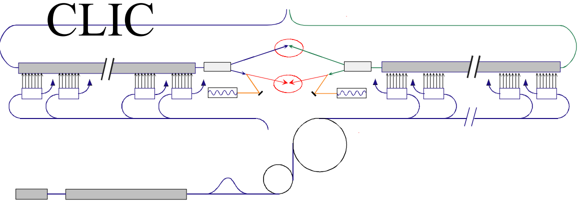


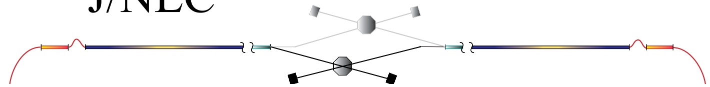
TESLA

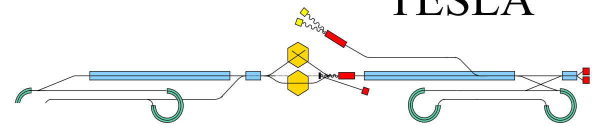


Salient features

- Tesla
  - 90% damping from wiggler
  - Non-planar
  - Very long straight sections
  - Skew quads for coupling insertion
- NLC
  - 60% damping from wiggler
- ATF
  - Wiggler usually not used
  - Low energy (1.3 GeV)
  - *exists*







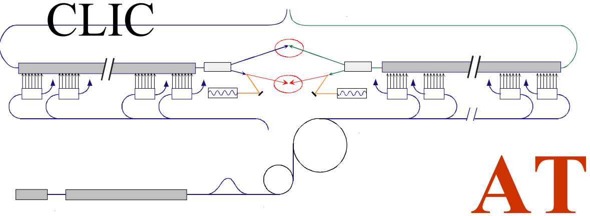
Minimum ε_y

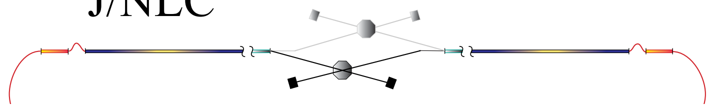
Due to the opening angle ‘geometric part’ of synchrotron radiation

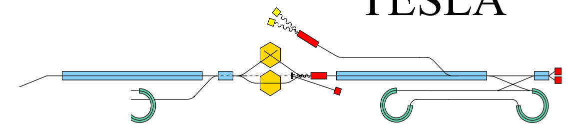
- TESLA 0.42 pm-rad
- NLC 0.14pm-rad
- ATF (similar to NLC)

$$\varepsilon_{y,\min} = \frac{C_q \langle \beta_y \rangle}{2J_y} \frac{I_3}{I_2}$$

- Minimum achieved at ATF 5 pm – rad at low current

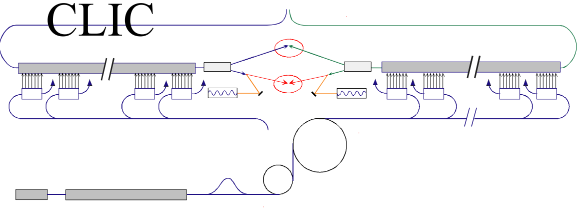


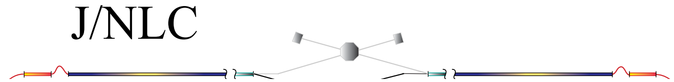


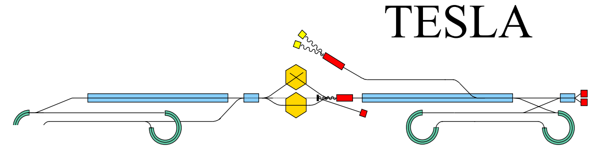


ATF emittance chronology

- 1997 50 pm-rad
- 1998 35 pm-rad
- 1999 35 pm rad
- 2000 15 pm rad (low I)/ 23 pm rad (nom I)
- 2001 10 pm rad (low I) / 17 pm rad (nom I)
- 2002 <10 pm rad (low I)







Sensitivity estimates for vertical COD, η_y

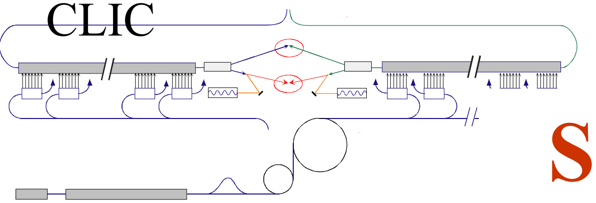
Work in progress → use only as a rough guide

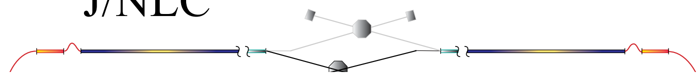
For uncorrelated misalignments:

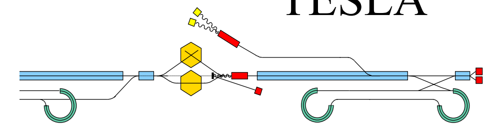
$$\left\langle y_{co}^2 \right\rangle \approx \frac{\left\langle \beta_y \right\rangle}{8 \sin^2 \pi \nu_y} \left(\sum_{\text{quadrupoles}} \beta_y (k_1 l)^2 \right) \left\langle \Delta Y_{\text{quadrupole}}^2 \right\rangle$$

$$\left\langle \eta_y^2 \right\rangle \approx \frac{\left\langle \beta_y \right\rangle}{2 \sin^2 \pi \nu_y} \left(\sum_{\text{quadrupoles}} \beta_y (k_1 l \eta_x)^2 \right) \left\langle \Delta \Theta_{\text{quadrupole}}^2 \right\rangle$$

$$\left\langle \eta_y^2 \right\rangle \approx \frac{\left\langle \beta_y \right\rangle}{8 \sin^2 \pi \nu_y} \left(\sum_{\text{quadrupoles}} \beta_y (k_2 l \eta_x)^2 \right) \left\langle \Delta Y_{\text{sextupole}}^2 \right\rangle$$

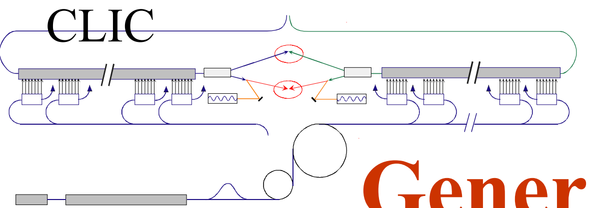


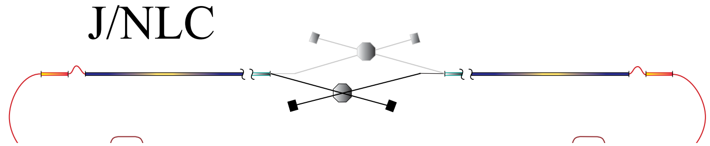


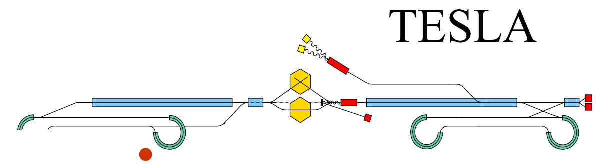


Sensitivity Parameters

		ATF	TESLA e^+ Ring	NLC MDR
Vertical Tune	ν_y	8.7589	41.1915	11.1357
Mean Beta Function at BPMs	$\langle \beta_y \rangle$	4.6 m	12 m	7.1 m
Quadrupole Orbit Factor	$\sum_{\text{quadrupoles}} \beta_y (k_1 l)^2$	338 m^{-1}	563 m^{-1}	507 m^{-1}
Quadrupole Dispersion Factor	$\sum_{\text{quadrupoles}} \beta_y (k_1 l \eta_x)^2$	2.88 m	82.6 m	2.42 m
Sextupole Dispersion Factor	$\sum_{\text{sextupoles}} \beta_y (k_2 l \eta_x)^2$	486 m^{-1}	4250 m^{-1}	1300 m^{-1}

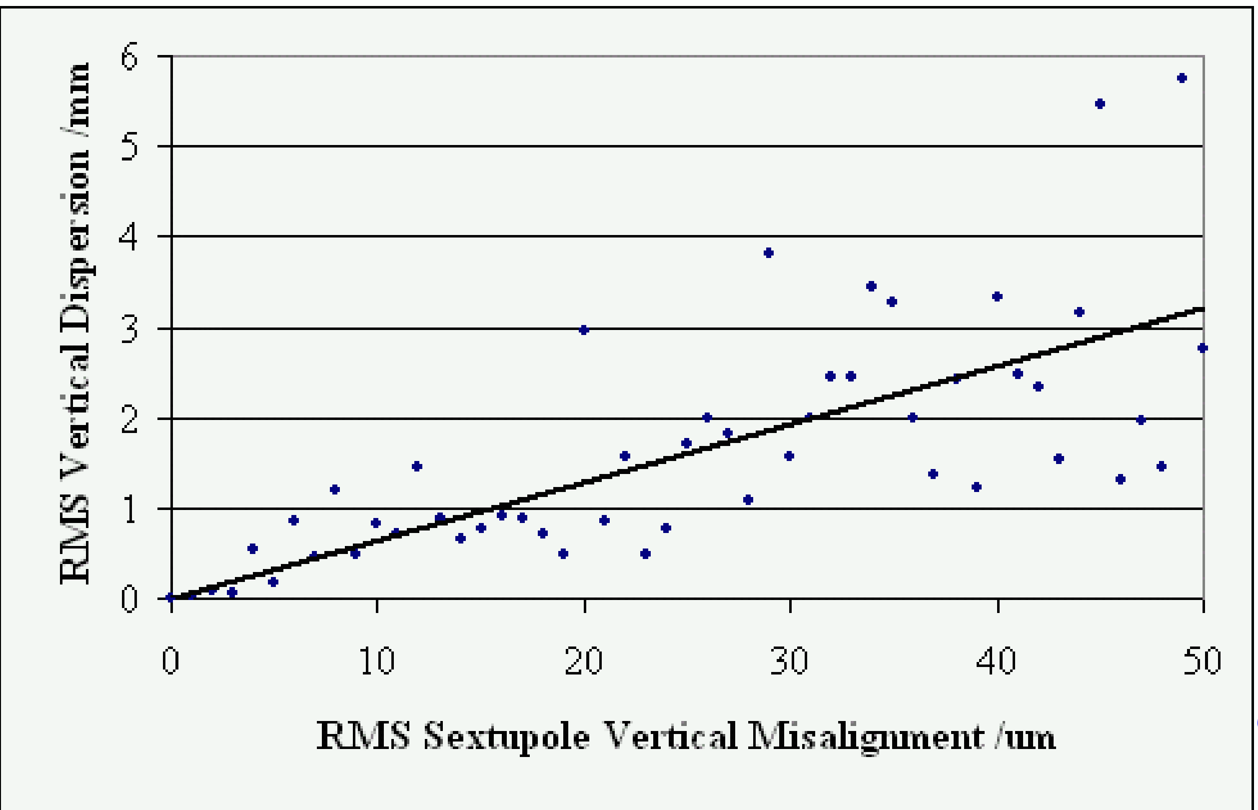




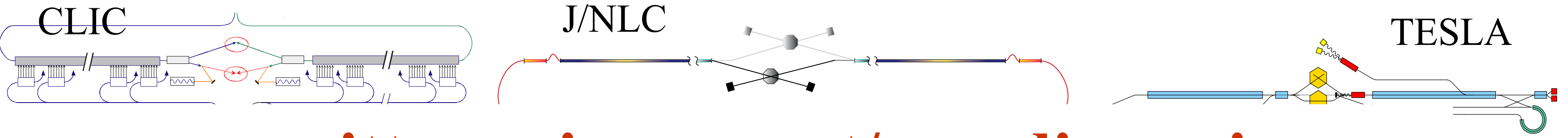


Generation of vertical dispersion

Lattice	$\sqrt{\langle \eta_y^2 \rangle} / \sqrt{\langle \Theta^2_{\text{quadrupole}} \rangle}$	$\sqrt{\langle \eta_y^2 \rangle} / \sqrt{\langle \Delta Y^2_{\text{sextupole}} \rangle}$
ATF	6 m	130
TESLA	40 m	140
NLC	9 m	100



C

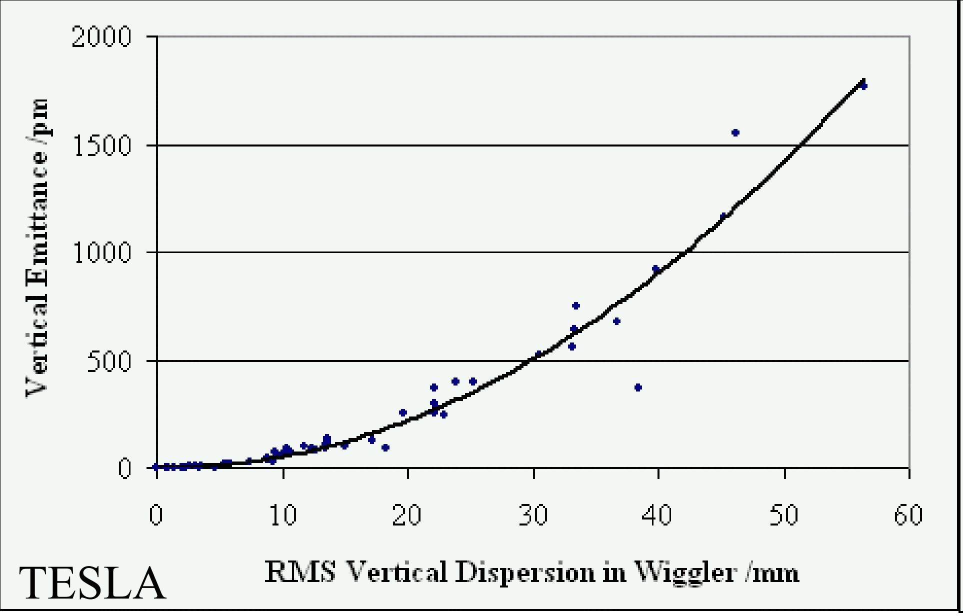


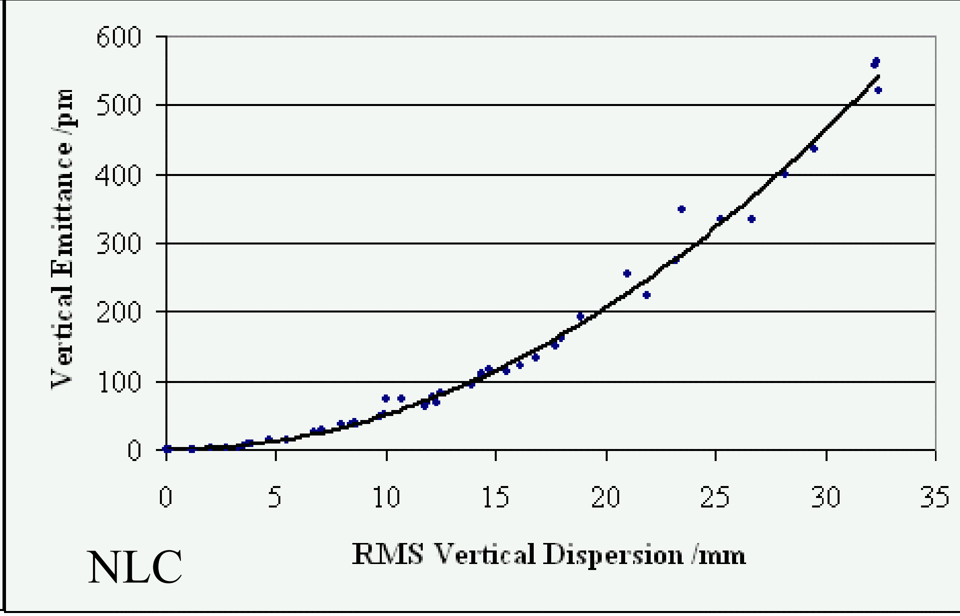
emittance increment/rms dispersion

$$\varepsilon_y = 2J_\varepsilon \frac{\langle \eta_y^2 \rangle}{\langle \beta_y \rangle} \sigma_\delta^2$$

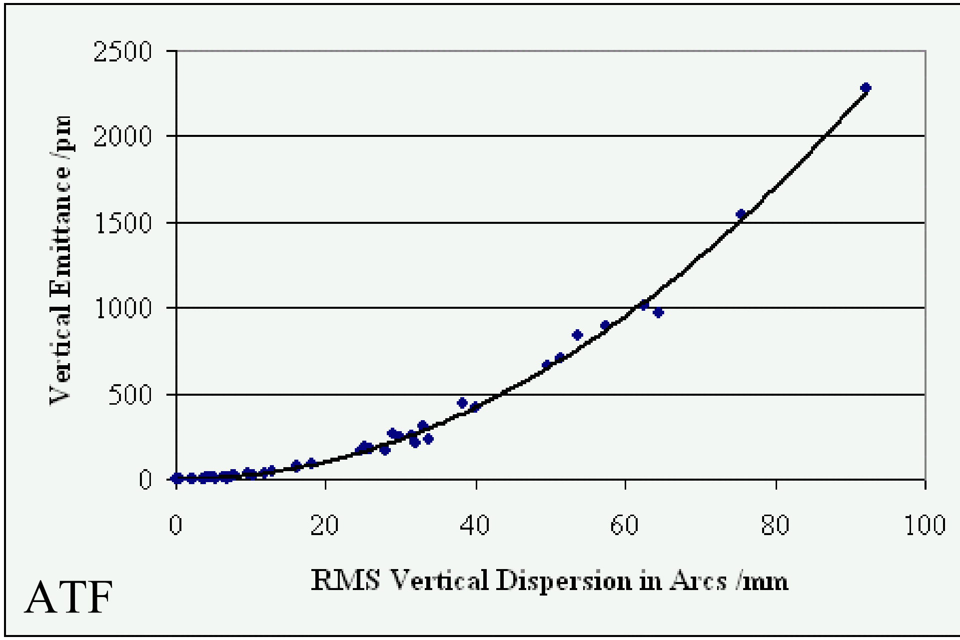
Lattice and region of energy loss	$\varepsilon_y / \langle \eta_y^2 \rangle$	max σ_{η_y}
ATF arcs	2.7×10^{-7} m^{-1}	
TESLA wiggler	5.6×10^{-7} m^{-1}	1.5 mm
NLC full lattice	4.6×10^{-7} m^{-1}	3.5 mm

- Since dispersion correction to better than 1 mm is generally required, and energy variation is limited to the order of 0.1%, the BPM resolution must be 1 µm or better.





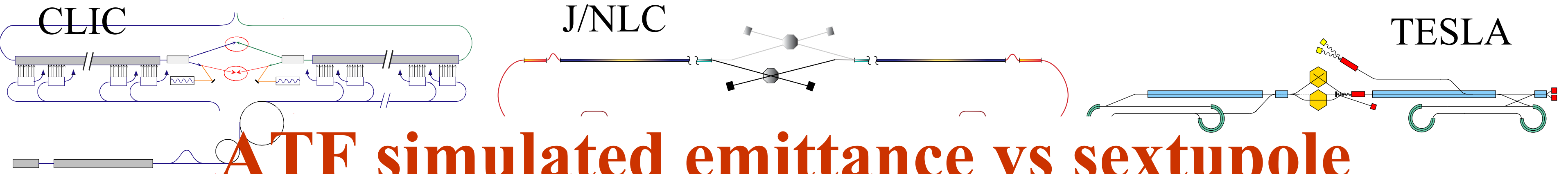
Emittance generated by η_y



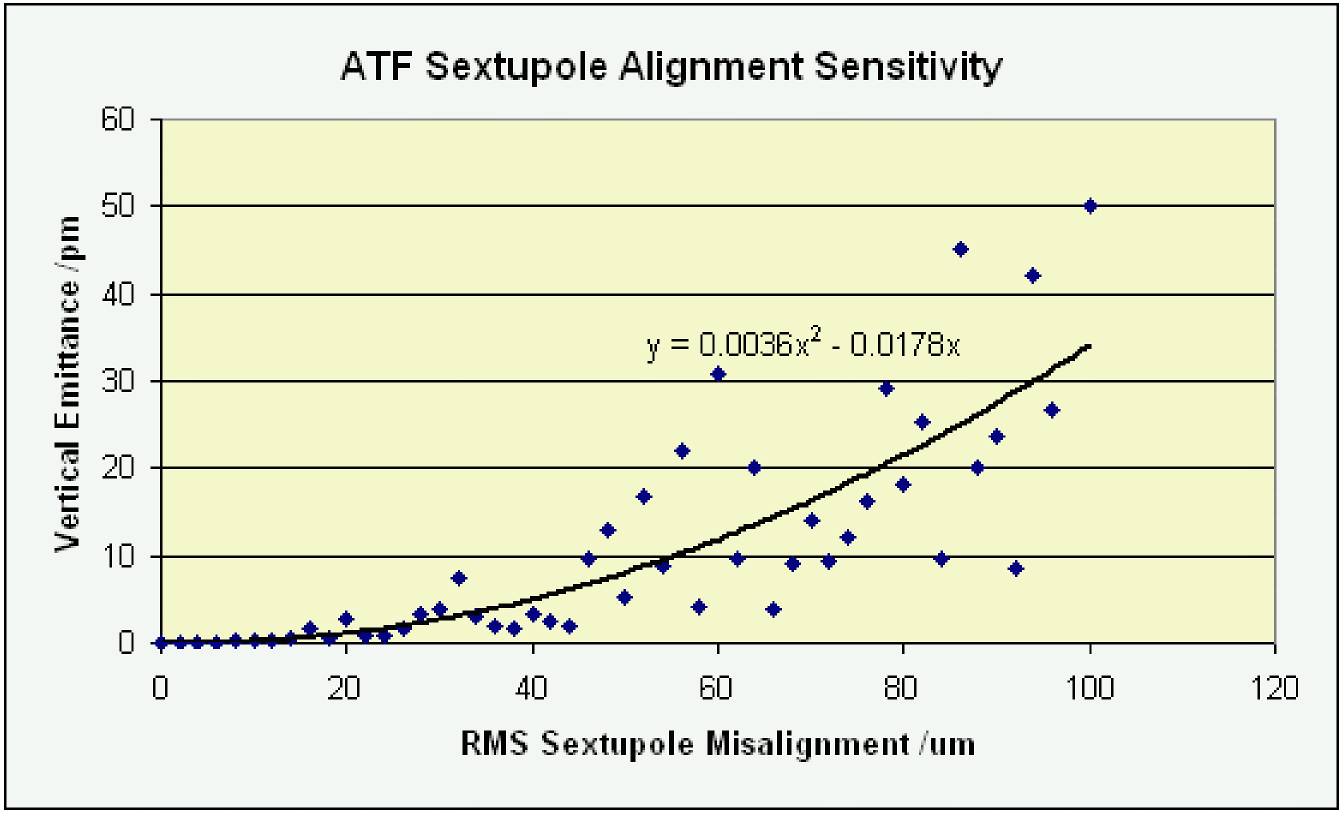
Comparison of analytic estimates of alignment sensitivities and results of simulations

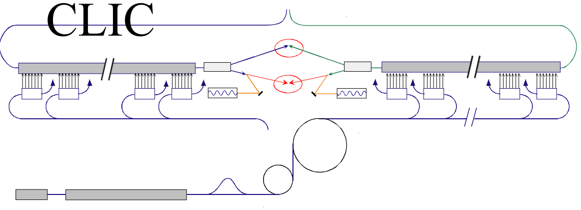
		TESLA e^+ Ring		NLC MDR	
		Analytic	Simulation	Analytic	Simulation
Vertical Emittance	$\varepsilon_y / \langle \eta_y^2 \rangle$	5.63×10^{-7} m^{-1}	5.90×10^{-7} m^{-1}	4.60×10^{-7} m^{-1}	4.83×10^{-7} m^{-1}
Quadrupole Vertical Alignment	$\sqrt{\langle y_{co}^2 \rangle / \langle \Delta Y^2 \rangle}$	112	115	50.9	46.0
Quadrupole Roll	$\sqrt{\langle \eta_y^2 \rangle / \langle \Delta\Theta^2 \rangle}$	86.0 m	87.0 m	7.04 m	
Sextupole Vertical Alignment	$\sqrt{\langle \eta_y^2 \rangle / \langle \Delta Y^2 \rangle}$	309	304	52.7	64.1

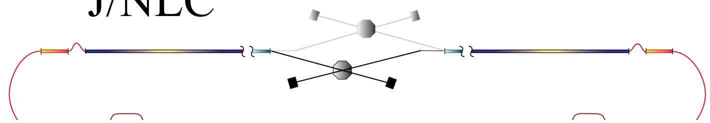
The quadrupole vertical alignment, is of limited significance for the vertical emittance, since the uncorrected closed orbit is typically dominated by the principal betatron modes, and the beam offset in the sextupoles is correlated around the ring as a result.

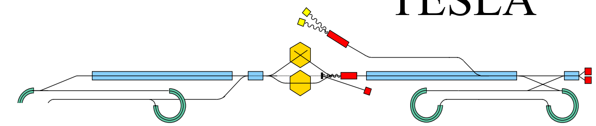


ATF simulated emittance vs sextupole offsets



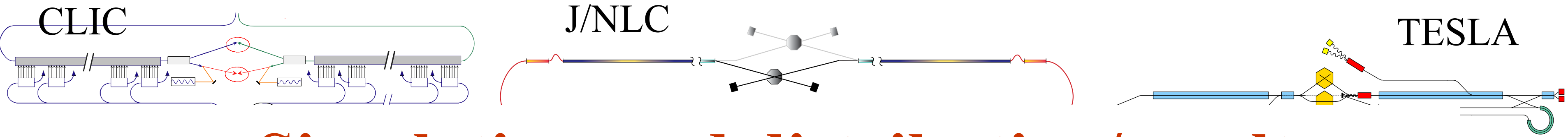






Emittance Tuning

- Dependence on beam based alignment strategy and systematic errors
  - BPMs and BPM location; local lattice
- BBA consists of two pieces
  1. Determination of BPM / magnet center offset
  2. Determination of component alignment

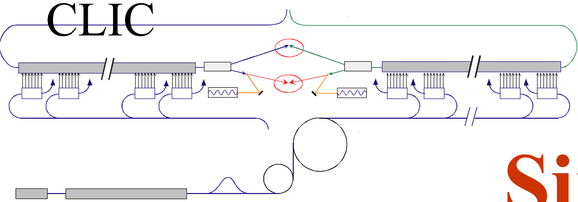


Simulation seed distribution/results

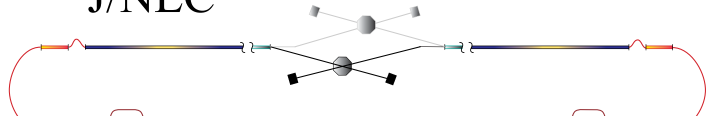
	NLC	TESLA
Quadrupole vertical misalignment rms	100 μm	100 μm
Quadrupole roll rms	100 μrad	100 μrad
Sextupole vertical misalignment rms	100 μm	100 μm
BPM resolution	0.5 μm	1 μm
Energy variation for dispersion measurement	±0.1%	±0.2%
Correction effectiveness	90%	70% (85%)

(correction effectiveness w/o coupling bumps) → algorithm development in process

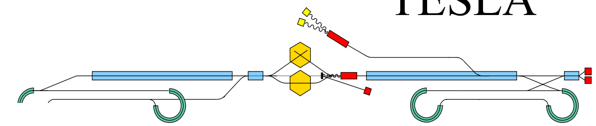
CLIC



J/NLC



TESLA



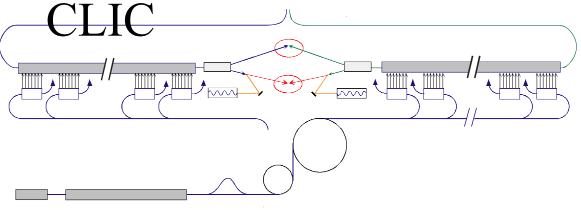
Simulation qualifications

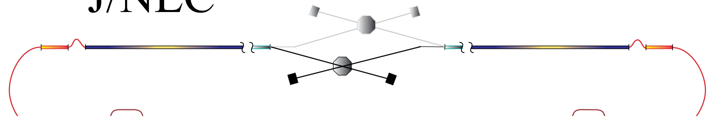
Included:

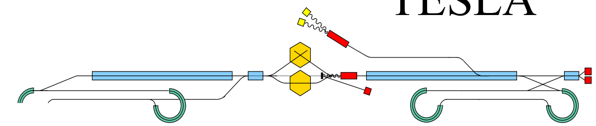
- quadrupole vertical alignment errors;
- quadrupole rotations about the beam axis;
- sextupole vertical alignment errors;
- limited BPM resolution.

***Not* included:**

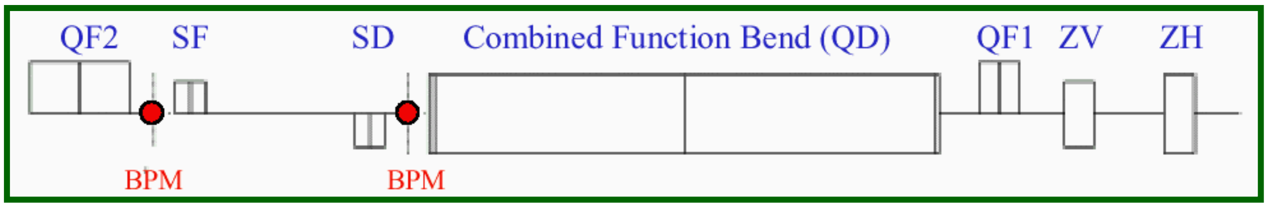
- dipole vertical alignment and rotation errors;
- horizontal orbit and dispersion errors;
- optics errors arising from focusing variations;
- BPM rotations;
- effects of nonlinear wiggler fields;
- limitations from malfunctioning BPMs and correctors;
- tuning of the skew quadrupoles used to implement beam coupling in the TESLA damping ring.







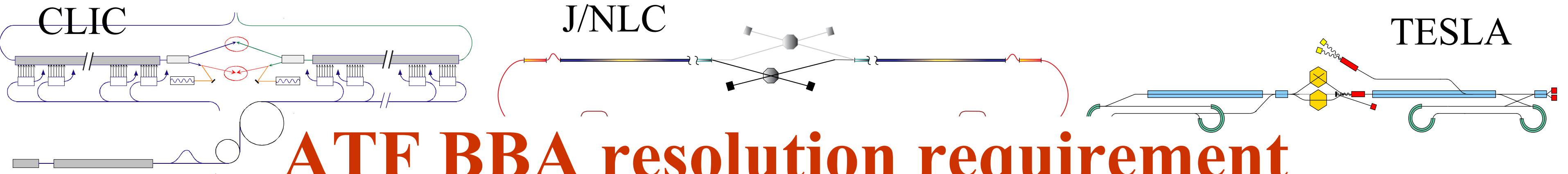
ATF BBA



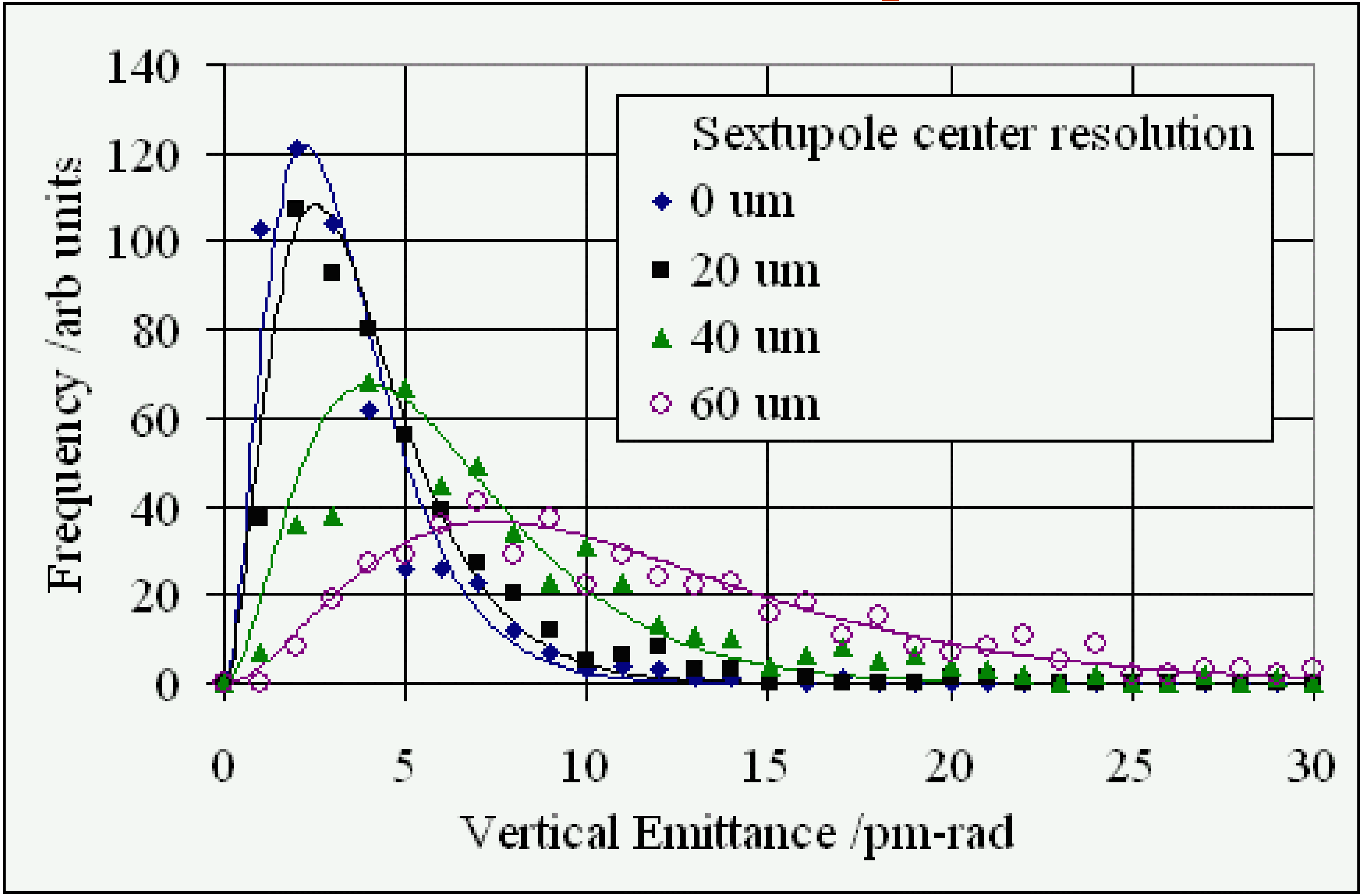
ATF arc cell

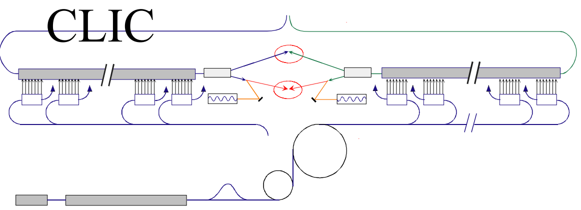
- ATF does not have one BPM/Quad (~ BPM/sextupole)
- The arrangement allows for systematic checks on BBA

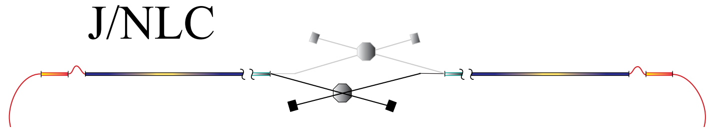
- Response matrix techniques not yet tried
  - TESLA response matrix is large compared to existing machines where the technique has been used

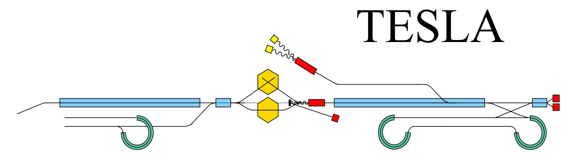


ATF BBA resolution requirement



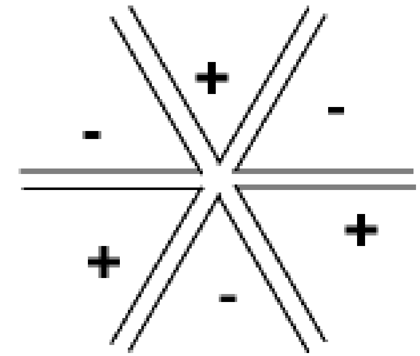


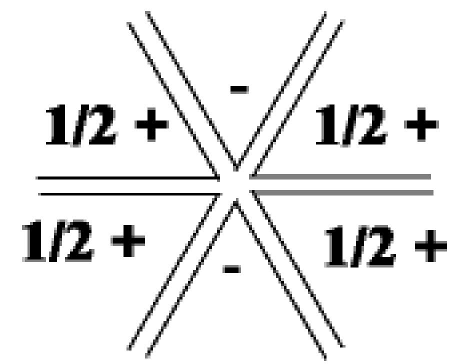




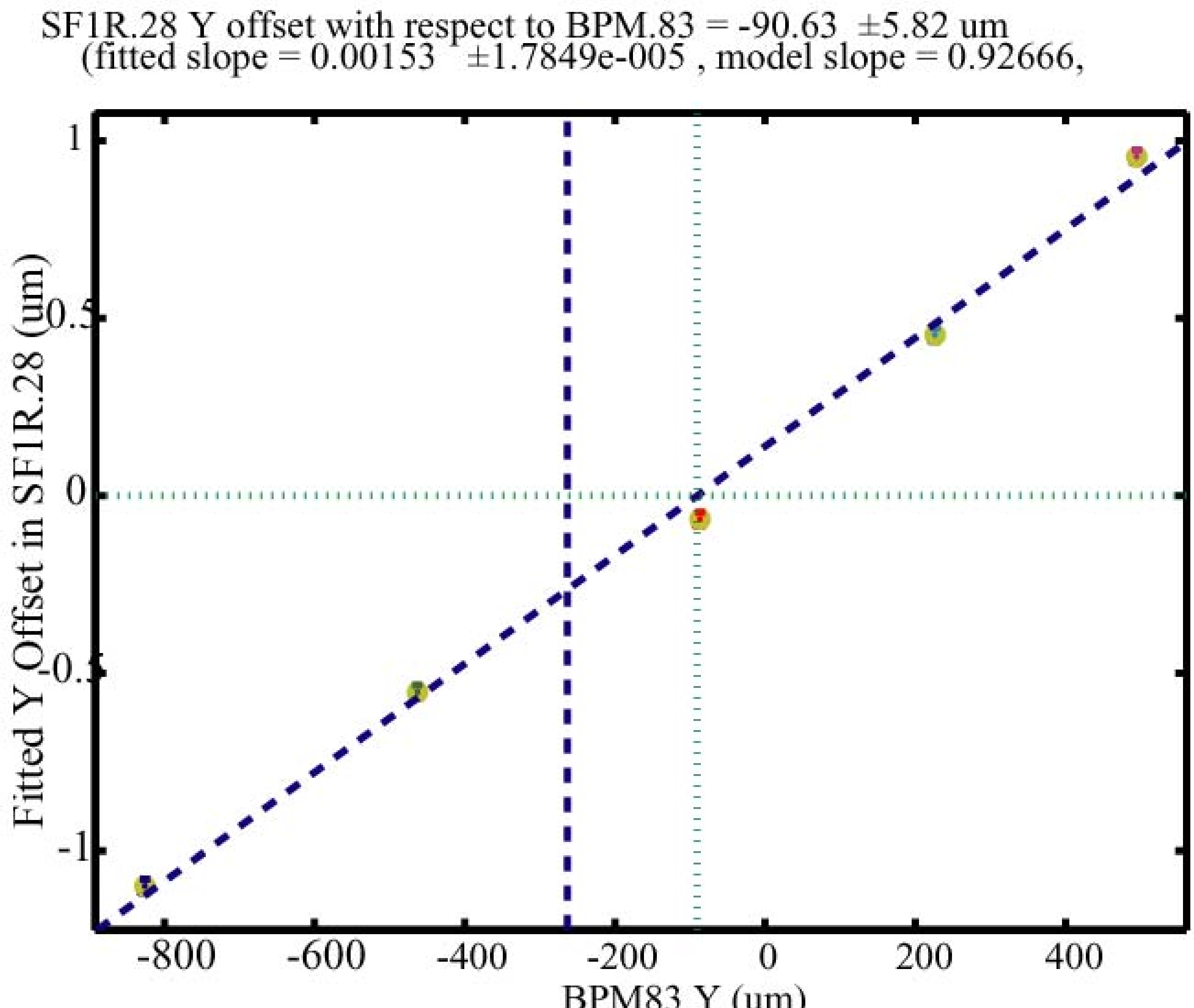
BBA (1) Strategies:

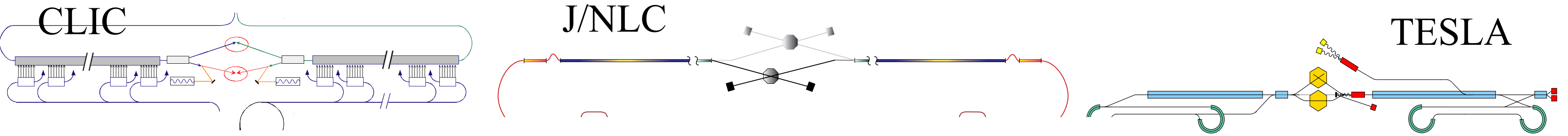
- Most involve tedious shunt technique
  - How good is this?;/ How can we improve?
  - ATF – skew quad/sextupole hysteresis
    - Hysteresis gives residual horizontal kick
- ATF:
  - Strong gradient bend
  - No component movers
- NLC
  - Gradient bend



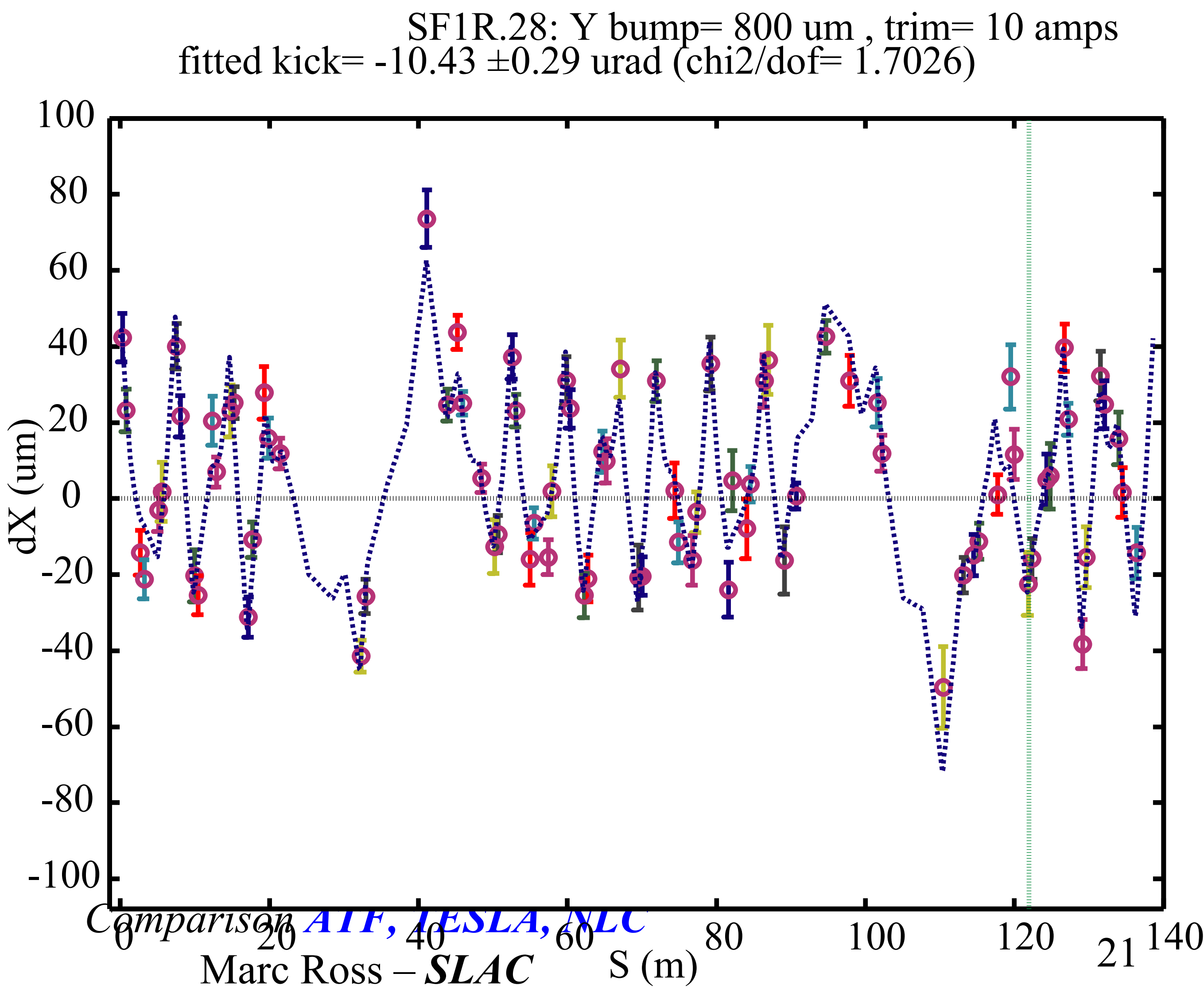


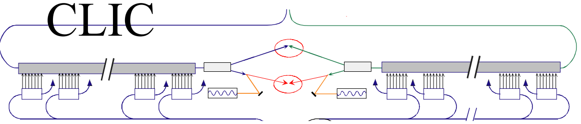
ATF BBA 'BPM offset' determination

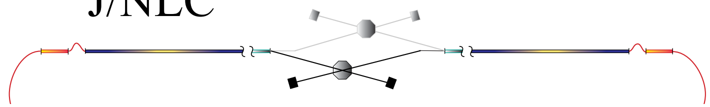


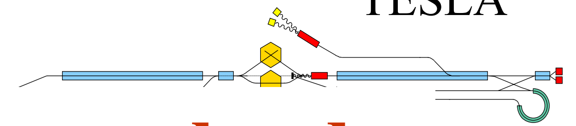


ATF BBA – basic 'good' difference orbit









Collective effects – IBS & electron cloud

Or: How much 'global' tuning is forced?

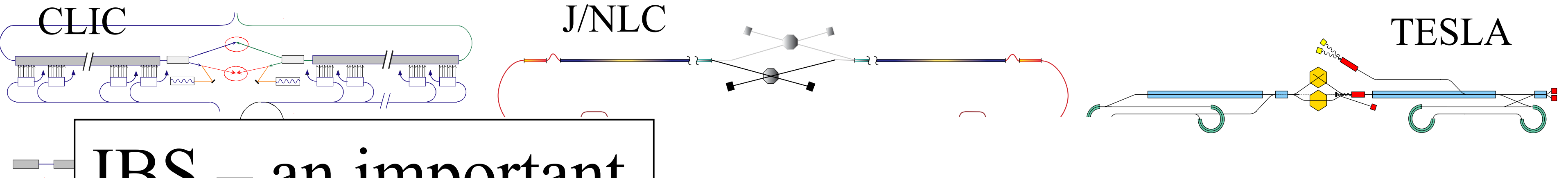
•tune shifts (from a number of sources) impact the emittance correction algorithms

• practical difficulties separating:

  • emittance growth from collective effects ←→

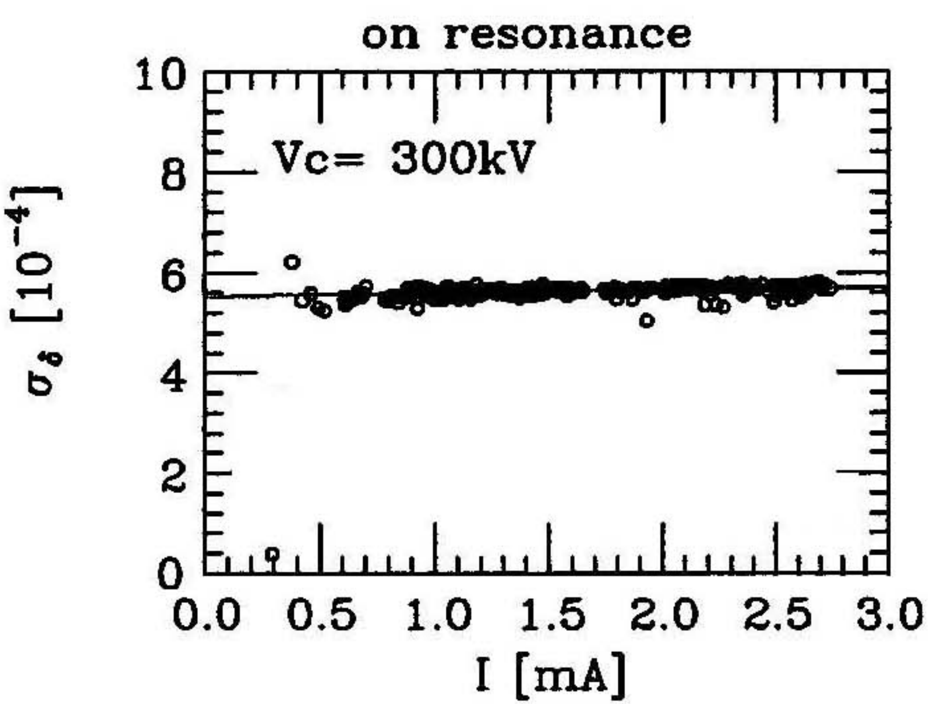
  • emittance growth resulting from magnet misalignments

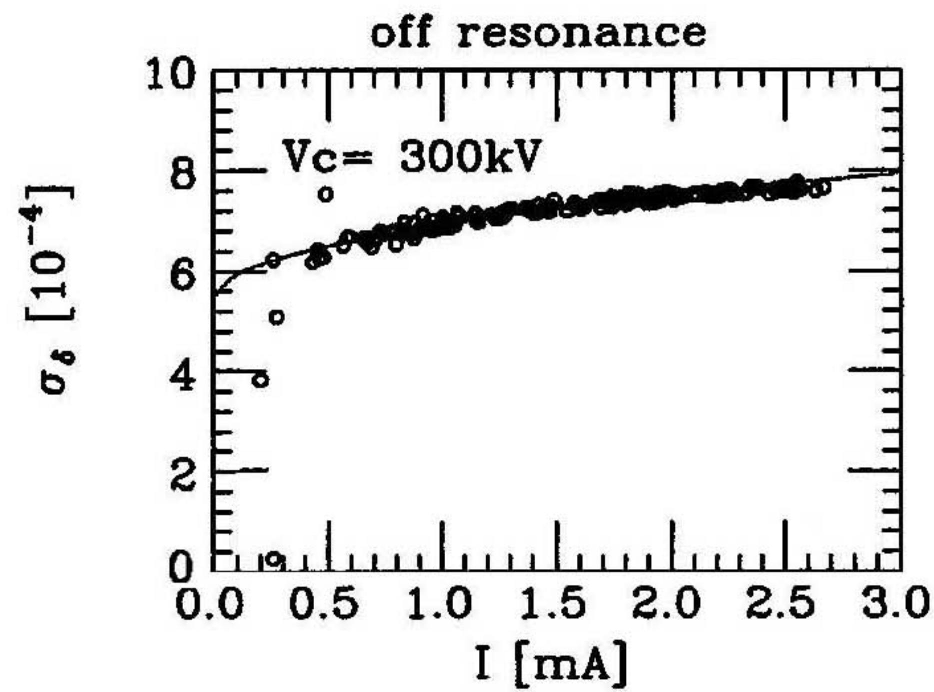
<u>Avoid GLOBAL TUNING as much as possible</u>



IBS – an important effect at NLC/ATF

Energy spread on/off ν_x=ν_y coupling resonance – showing IBS effect

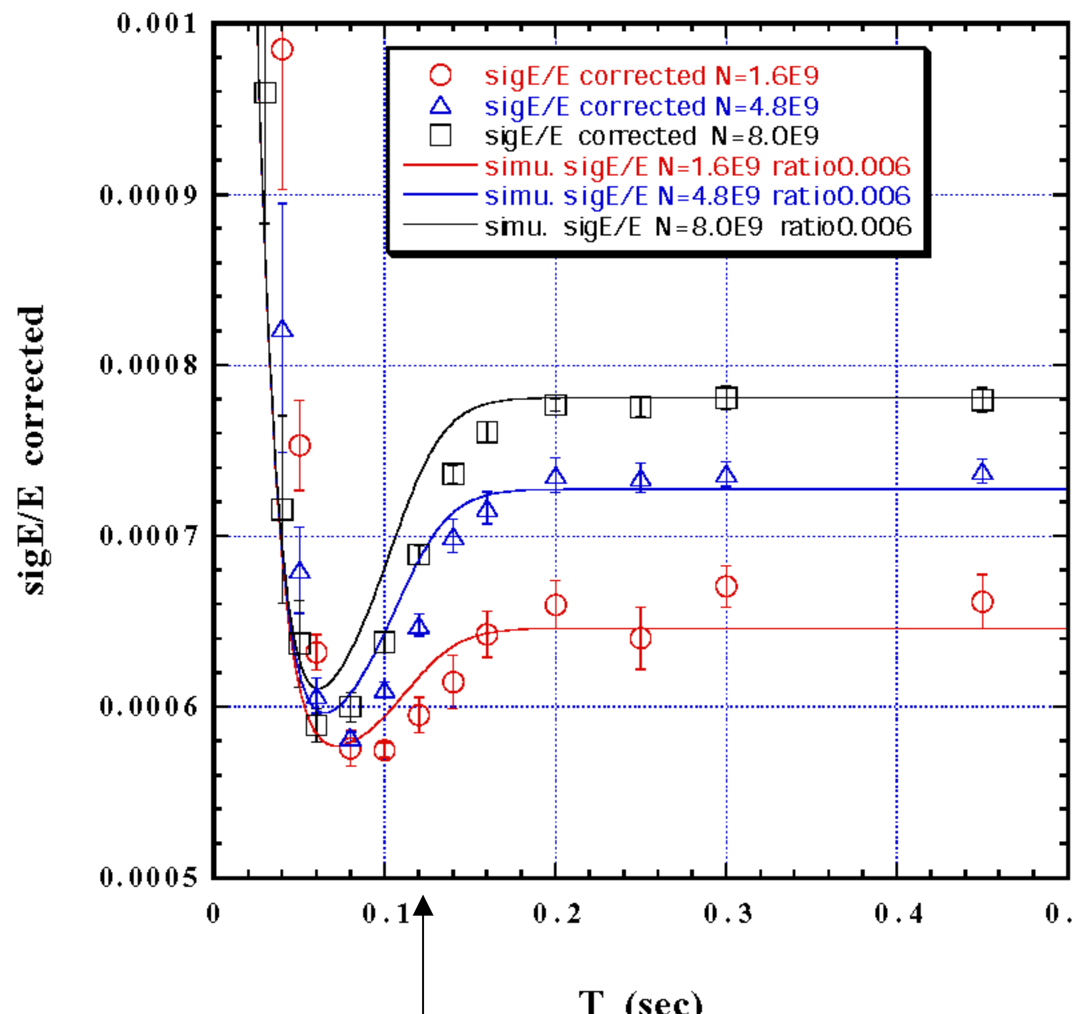




Evidence for IBS at ATF – vertical coupling into σ_E

Evolution of energy spread following injection for I :

1.6e9	4.8e9	8.0e9
0.6	1.7	2.8 mA



Sequence:

- Vertical still large – no effect on *x* and *E*
- Vertical damped – increase in *x* and *E*
- minimum at 70ms (2.5 τ_rad)

Nominal extraction time for NLC DR – IBS growth < equilibrium

Simulation consistent when coupling →

$$\varepsilon_y / \varepsilon_x = 0.006$$

IBS – relative *y/x* growth rate

$$H = \left[\eta^2 + (\beta\eta' + \alpha\eta)^2\right]/\beta$$ *dispersion invariant*

$$\frac{\varepsilon_{y0}}{\varepsilon_{x0}} = \frac{\langle H_y \rangle_B J_x}{\langle H_x \rangle_B J_y}$$

Zero current emittance – determined by SR in bends

$$\frac{d\varepsilon_y}{d\varepsilon_x} = \frac{\langle H_y \rangle J_x}{\langle H_x \rangle J_y}$$

Emittance growth from IBS – determined by dispersion throughout

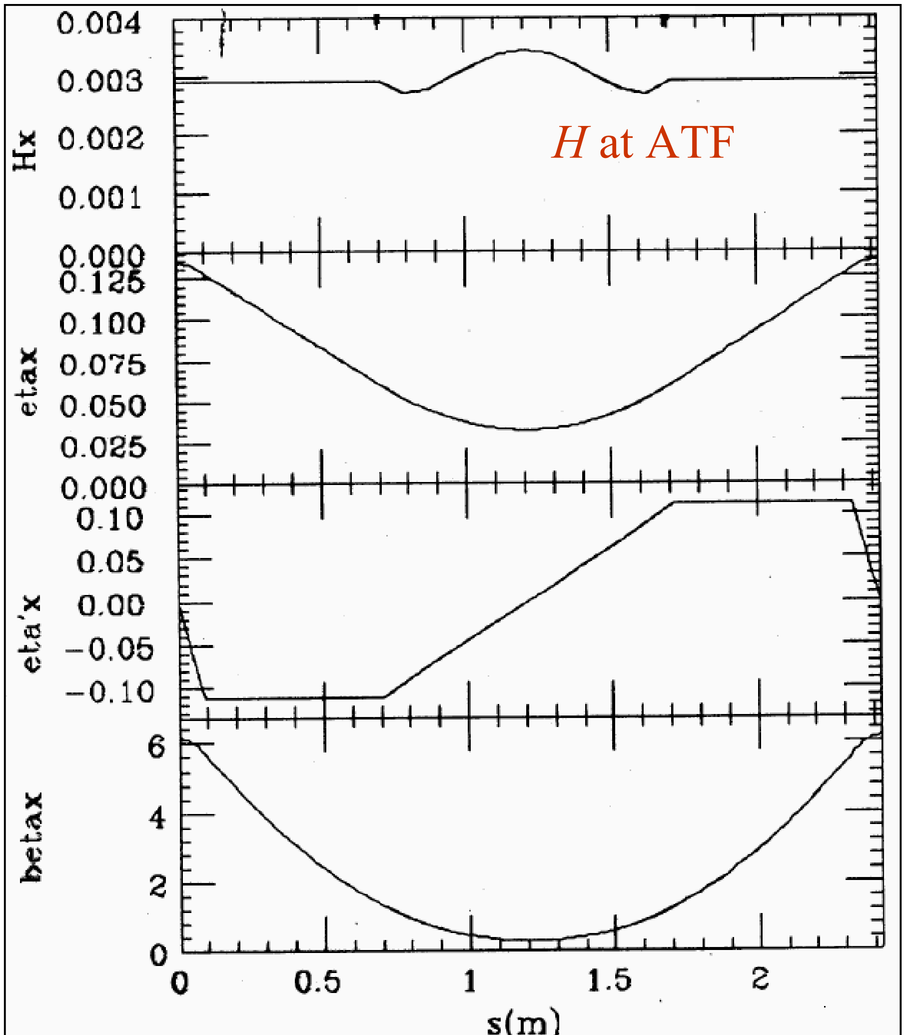
for emittance generated through residual η as opposed to residual coupling

Divide and assume that there is nothing special about η_y in the bends $\langle H_y \rangle_B \approx \langle H_y \rangle$

$$\frac{\langle H_x \rangle_{bends}}{\langle H_x \rangle} = \frac{(\varepsilon_y - \varepsilon_{y0})/\varepsilon_{y0}}{(\varepsilon_x - \varepsilon_{x0})/\varepsilon_{x0}}$$

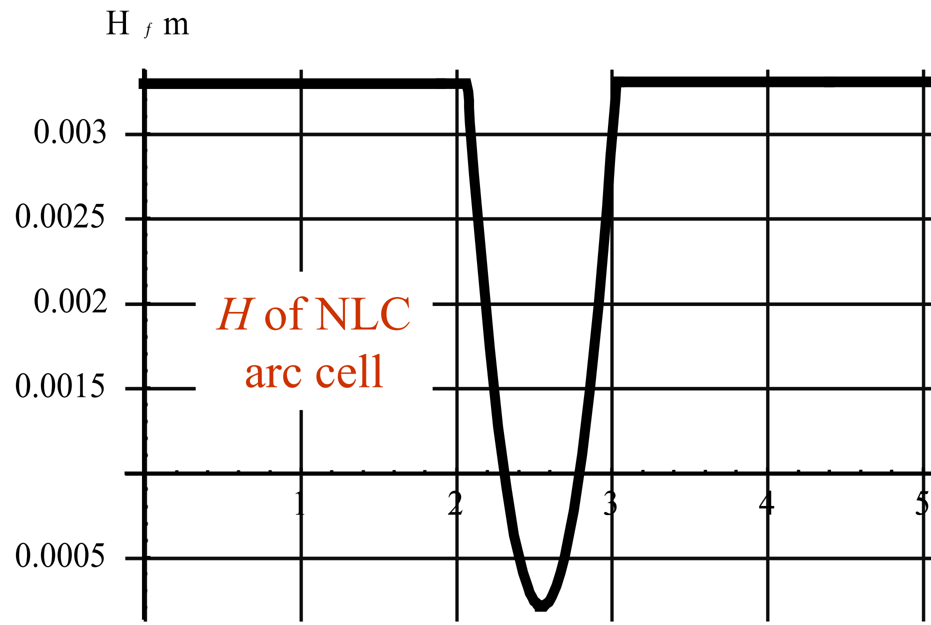
(Tor & Kubo)

Dispersion invariant – *H* – for ATF and NLC design



$$\frac{\langle H \rangle_{bends}}{\langle H \rangle} = 1.6 @ ATF$$

$$\frac{\langle H \rangle_{bends}}{\langle H \rangle} = 0.64 @ NLC$$



NLC DR – A. Wolski (LBL)

Emittance results

- ε_y0 extrapolation is poor
- Observed energy spread & horizontal emittance growth indicates a 2 - 3 x smaller vertical emittance than observed
- Growth ratio shows a similar factor
- measurements made 4/00 to 6/01

Table of emittance measurements: (e-9/e-11 *x/y*, not normalized)

		e_x0	e_x	e_y0	e_y	r
extracted	wires 4/00	1	1.85	1	3	2.35
extracted	Dec-00	1.1	2.2	1.7	4	1.35
extracted	Feb-01	1.1	2.2	0.7	2.8	3.00
extracted	Apr-01	1	2.4	1.2	2.5	0.77
extracted	Jun-01	1.2	2.1	0.9	2.3	2
ring	L wire	1.1	2.2	0.7	1.9	1.71

- IBS: $1 < r < 1.6$ (ATF)
  x/y cpl η_y

$$r = \frac{(\varepsilon_y - \varepsilon_{y0})/\varepsilon_{y0}}{(\varepsilon_x - \varepsilon_{x0})/\varepsilon_{x0}}$$

Electron cloud density (e+) simulation

Ecloud ~ threshold effect

NLC:

- no magnetic field
- Could be worse in wiggler

Tesla:

- straight only
- Arcs ignored
- Bunch spacing