CESR-c Wiggler Experience

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for the CESR-c Operations Group

Second ILC Accelerator Workshop
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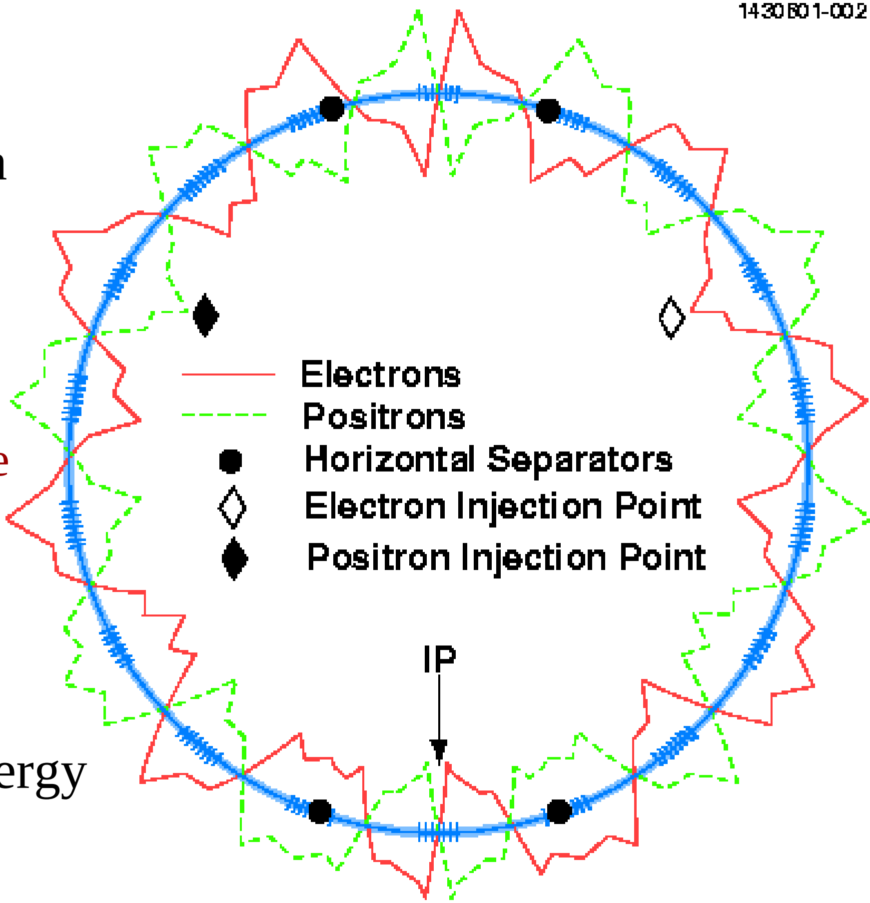
Outline

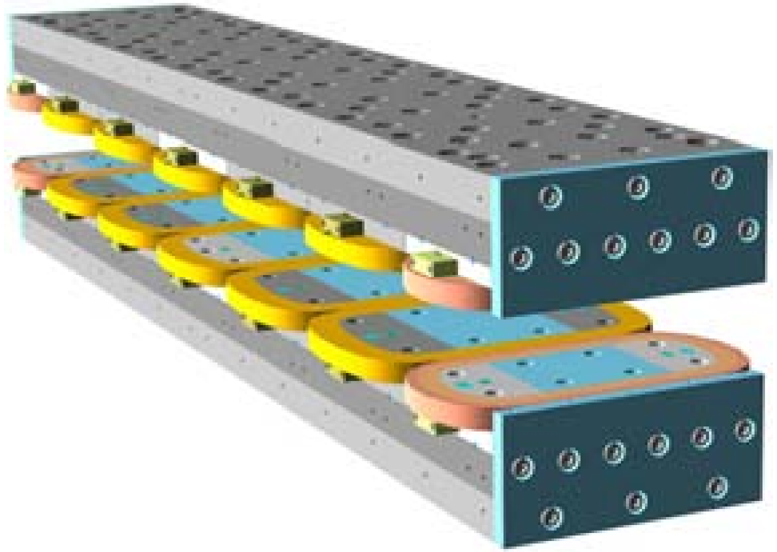
- CESR-c Overview
- Wiggler Overview
- Wiggler Modeling and CESR-c Optics Design
- Wiggler Beam-Based Benchmarking
- Conclusion

CESR-c Overview

- CESR-c Conversion (2001 Decision)
  - Move from 5.3 GeV/beam luminosity operation to 1.5-2.5 GeV/beam operation
    - J/ψ (3.1 GeV CM)
    - Charm threshold (3.77 GeV CM)
    - Above $D\bar{D}$ threshold (4.2-5.0 GeV CM)
  - Preserve 5.3 GeV Operations
    - Cornell High Energy Synchrotron Source
    - Vacuum scrubbing
- Wiggler-dominated storage ring
  - 768m ring
  - ~19m of superferric wigglers to provide >90% of synchrotron radiation at low energy
- Up to 9 5-bunch trains in each beam
  - Presently operating with 8 x 5
  - Electrostatic separation to accommodate counter-rotating trains
  - ±~3 mrad horizontal crossing angle at IP



Wigglers



- Superferric wigglers
  - Lower damping time:
    570ms ⇨ 55ms @ 1.88 GeV
  - Provide control of horizontal emittance
- Repetition rate for transfer from synchrotron limited by damping time in storage ring

Exact scaling subject to debate

Single- and multi-bunch instability thresholds: $\sim\tau^{-1}$

Beam-beam tune shift limit: $\sim\tau^{-1/3}$

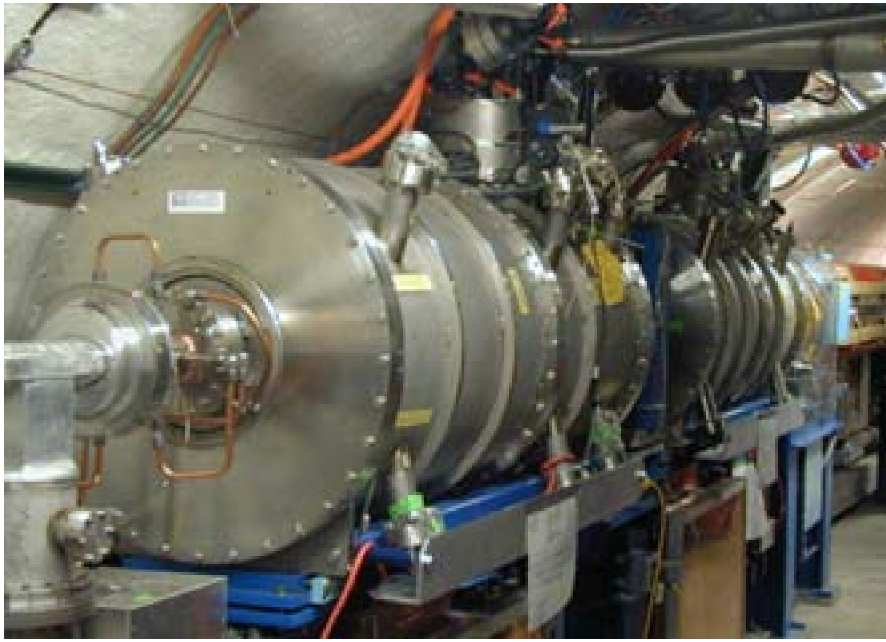
Tolerance to parasitic beam-beam effects: $\sim\tau^{-1/3}$

Beam-beam current limit: $\sim\varepsilon_h$

Wigglers

- Wigglers
  - 2.1 T peak field vs. 0.2 T max bending field
    - Peak field represents compromise between damping, energy spread, and total length
  - Uniform over 9 cm horizontal aperture
    - Linearity requirements are driven by CESR pretzel operation with 20 mm amplitude orbit excursions
  - Long period (40 cm) to minimize vertical cubic nonlinearity

    ΔQ_y ~ 0.1 integer per wiggler
  - 7.62 cm pole gap ⇨5 cm vertical beam aperture
  - 1.3 m individual wiggler active length
  - 12 wigglers in full complement
  - 8-pole wigglers presently in use
    - Also have used 2 7-pole versions
    - Primary reason for 8-pole selection: better field quality for varying excitations
  - 3kW/wiggler synchrotron radiation with I_{beam} = 200 mA @1.88 GeV



- Wiggler Cryogenic Performance

  ~1.3 W @ 4 K

  ~ 40 W @ 77 K

Further details:

PAC03 Paper (D. Rice *etal)*

http://accelconf.web.cern.ch/accelconf/p03/PAPERS/TOAB007.PDF

WIGGLE05 talk (A. Temnykh)

http://www.lnf.infn.it/conference/wiggle2005/talks/Temnyk.pdf

Wiggler Production

- Fabrication
  - Largely in house to control costs and schedule
- Pipelined Process (3 wigglers at various stages of fabrication/assembly at the same time)
- Production Line
  - 1 wiggler every 3 weeks
  - Manpower
    - Sr. Technical & Supervisory: **5** FTE
    - Technical support: **13** FTE
- Parts and Outside Fabrication Costs:

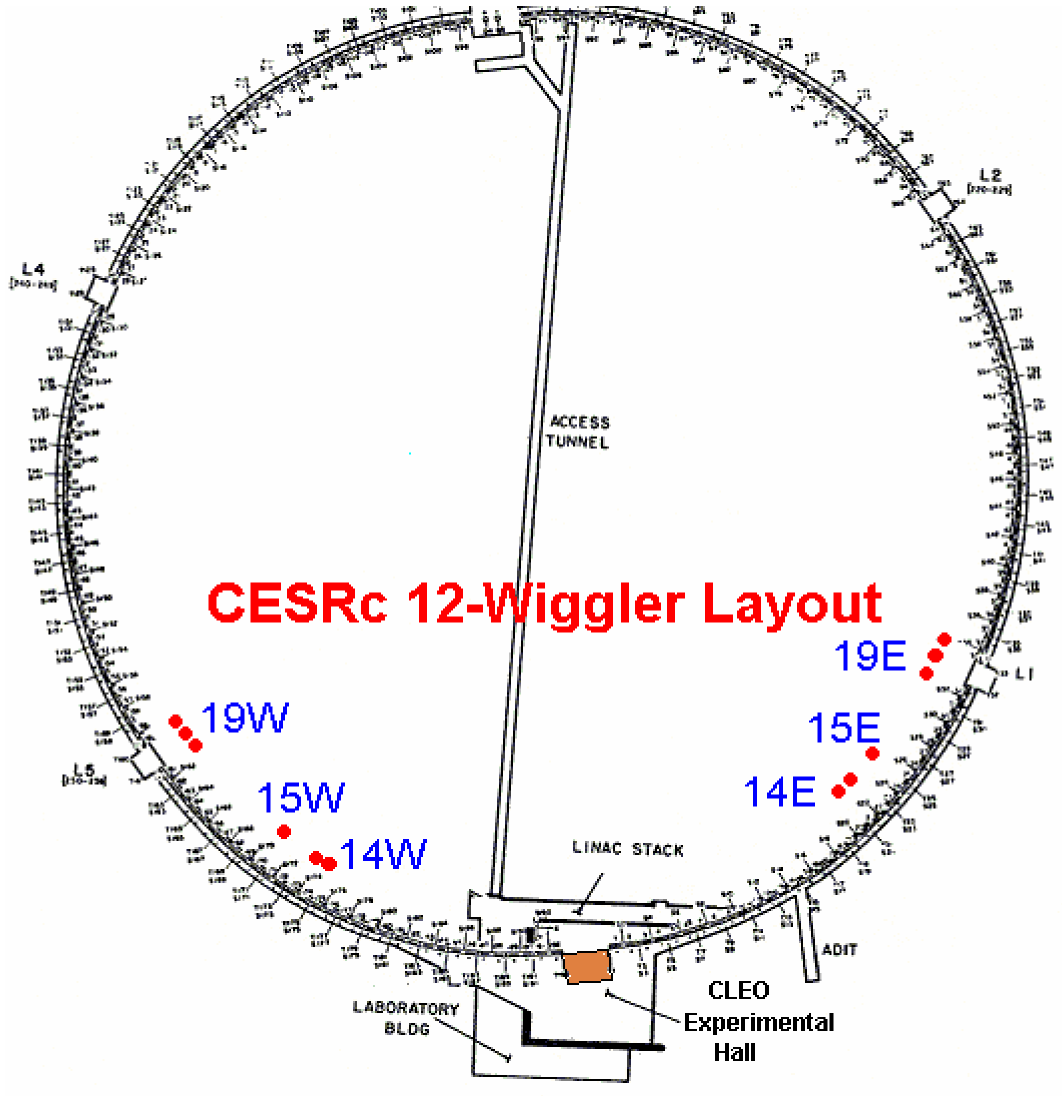
~$80K per wiggler

Wiggler Quality Control

- Production Testing
  - Vigilance during coil winding
  - Warm flux test on each wound pole
    - Sensitive to turn-to-turn shorts/missing turns
    - Sensitive to O(0.1 mm) geometry errors in coil shapes (a1 problem – see below)
  - Frequent electrical insulation/vacuum leak checks
  - Final cold operational test and field mapping
    - Precision Hall Probe measurement for point-by-point fields
    - Flip coil measurement for first integral of field
    - "Twisted" flip coil measurement for second integral of field
    - See A. Temnykh, WIGGLE05 presentation for detailed discussion
- No failures encountered after 1st unit
- One significant multipole issue encountered during production
  - Skew quad moment (a1)
  - Traced to variations in geometry of wound coils
  - Warm flux measurement and careful "shuffling" of poles ameliorated problem
    - See A. Temnykh, WIGGLE05 presentation for detailed discussion

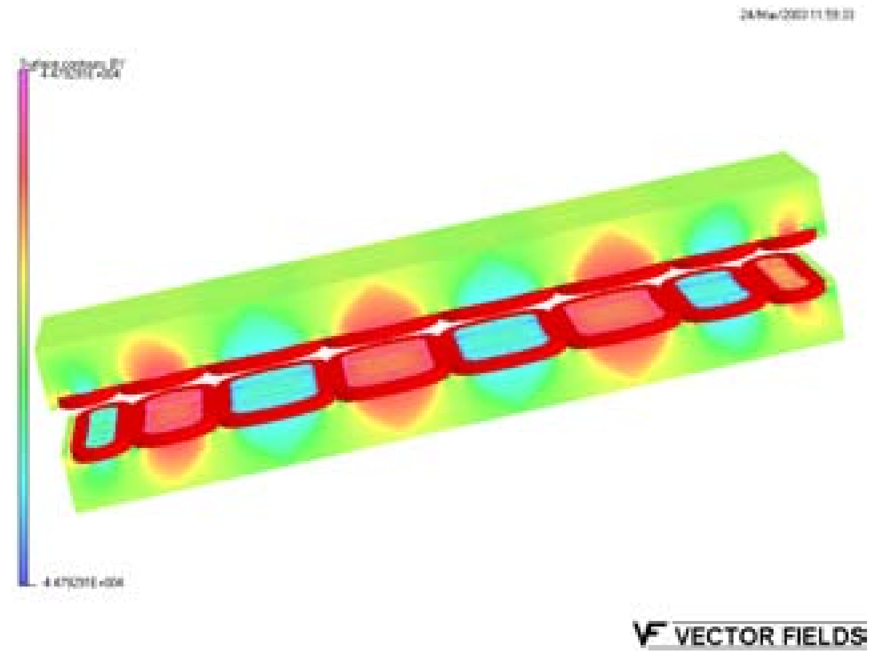
Final Wiggler Layout

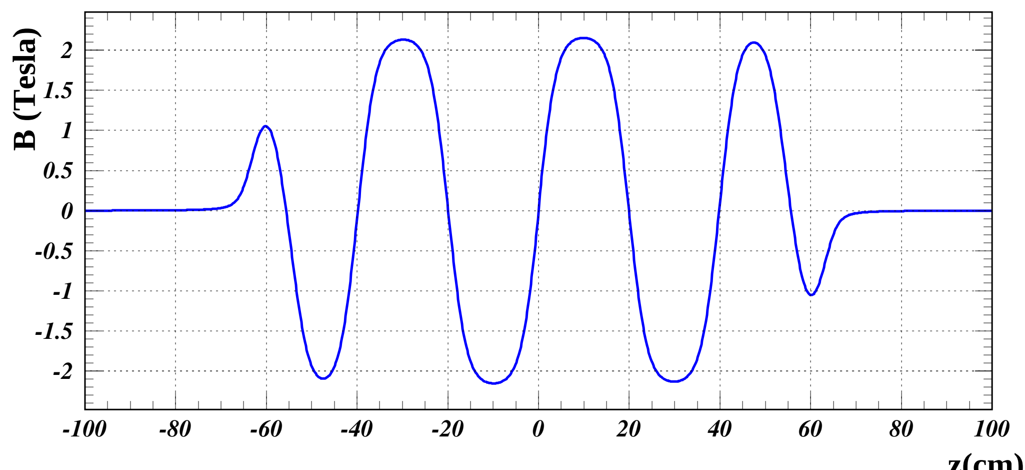
Full complement of 12 wigglers installed during summer 2004 shutdown



Wiggler Modeling

- Phase space mapping through wigglers required for simulation of dynamical effects
- Mapping is based on detailed 3D modeling using Vector Fields Opera

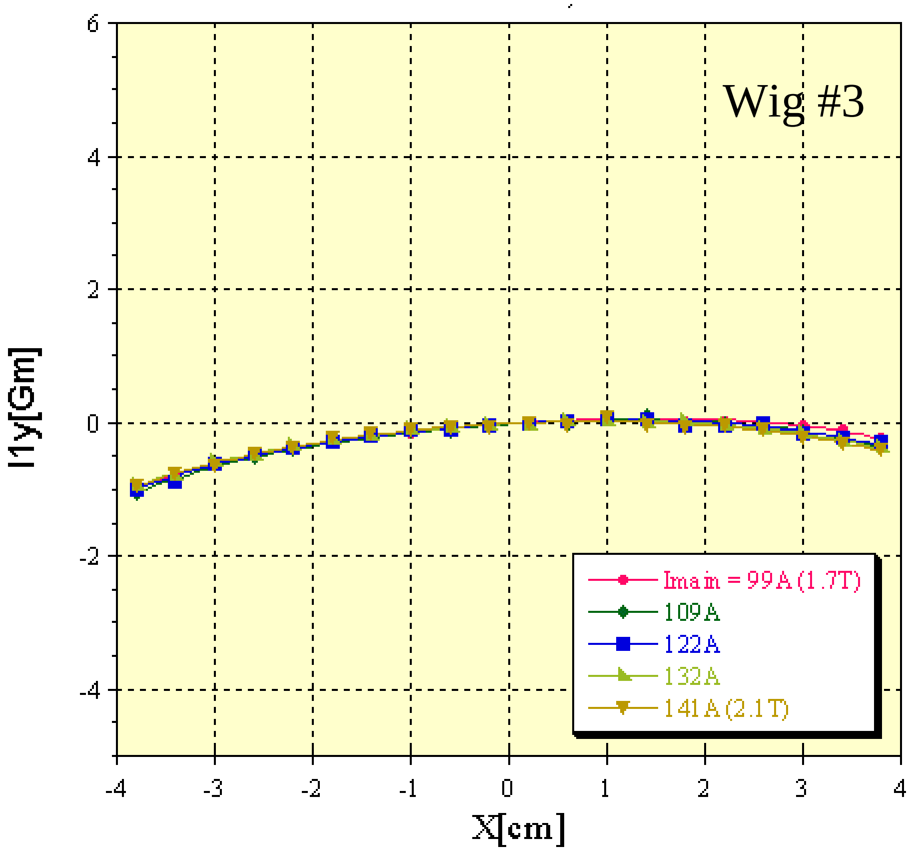




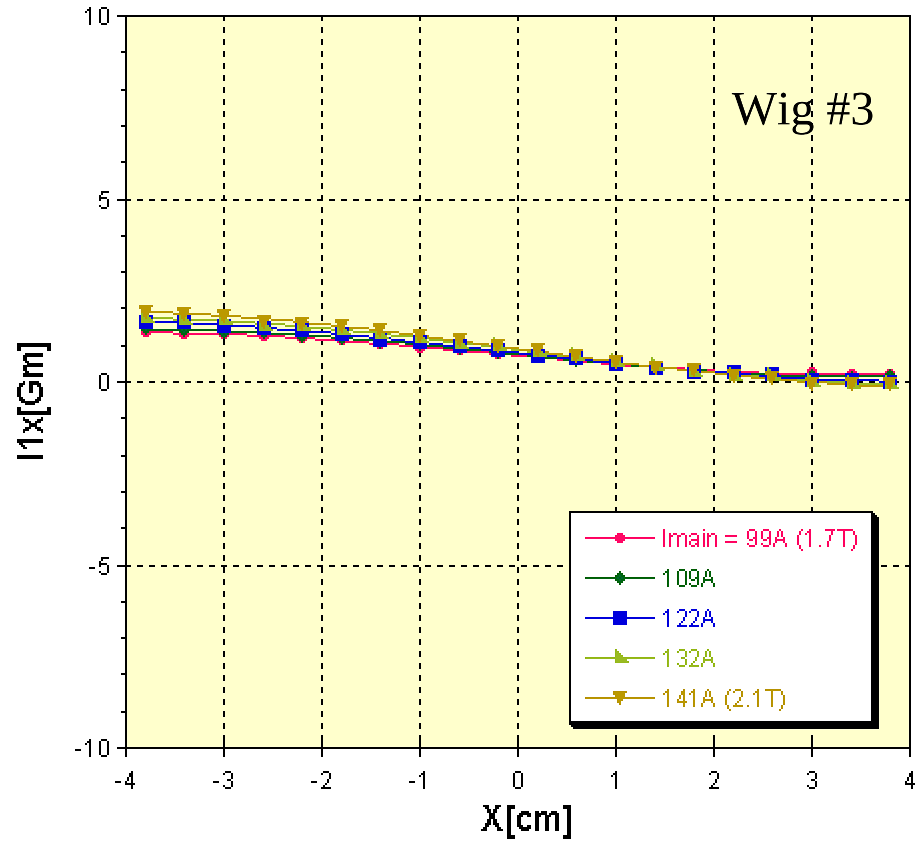
Field Measurement

Flip-coil measurement of field integrals

- Integrated vertical component B_y (Gm)
- ~15μrad/Gm @ 1.88 GeV



- Integrated horizontal component B_x (Gm)
- Linear horizontal dependence ↔ skew quad



Field Maps

- 3D field table from modeling
- Fit table with analytical form
- Analytic form of Hamiltonian
  - ⇨ symplectic integration
  - ⇨ taylor map

$$B_{fit} = \Sigma_{n=1}^{N} B_n(x, y, s; C_n, k_{xn}, k_{yn}, k_{sn}, \phi_n)$$

$$B_n x = -C\frac{k_x}{k_y}\sin(k_x x)\sinh(k_y y)\cos(k_s s + \phi_s)$$

$$B_n y = C\cos(k_x x)\cosh(k_y y)\cos(k_s s + \phi_s)$$

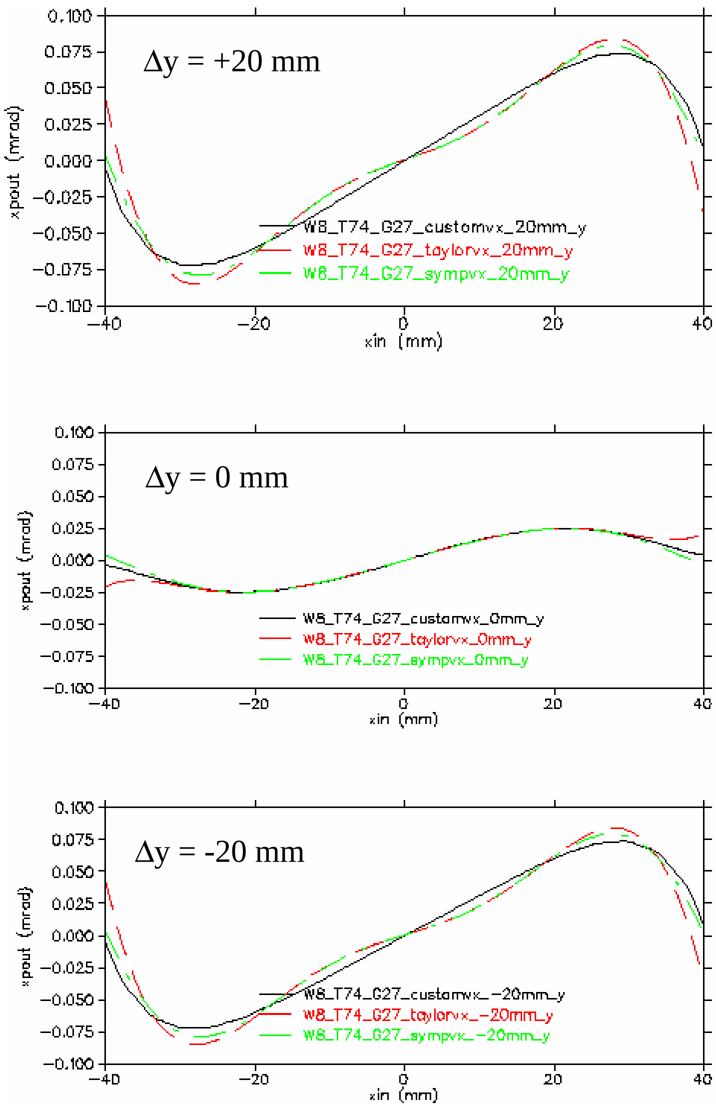
$$B_n s = -C\frac{k_s}{k_y}\cos(k_x x)\sinh(k_y y)\sin(k_s s + \phi_s)$$

with $k_y^2 = k_x^2 + k_s^2$

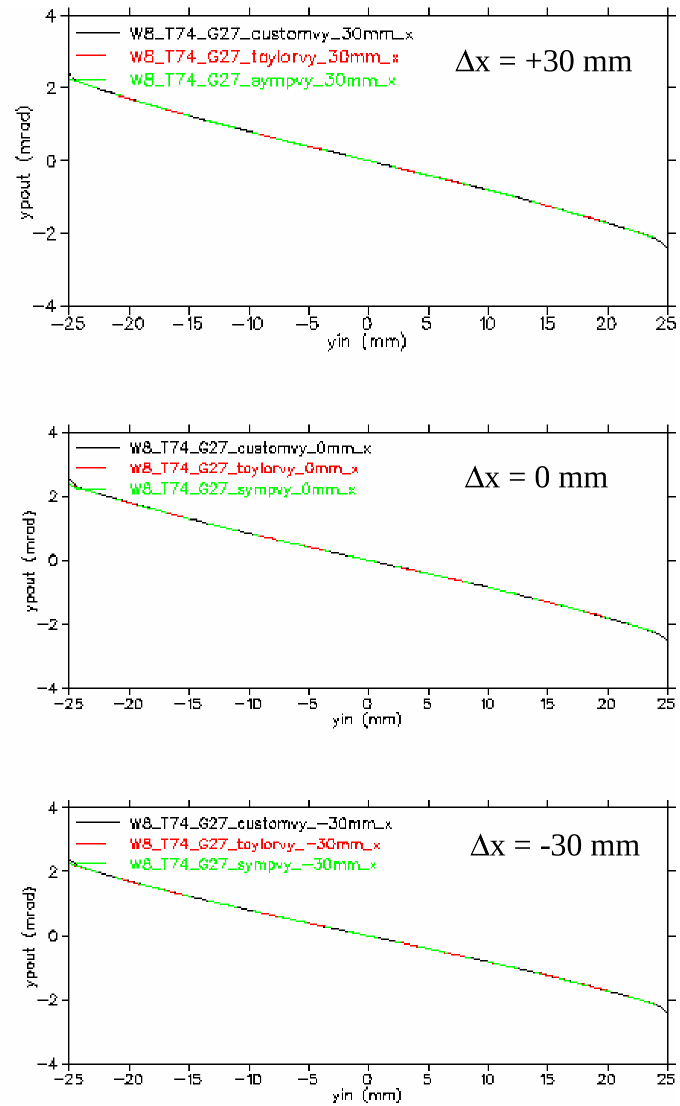
Beam Simulations based on the BMAD package (D. Sagan):
http://www.lns.cornell.edu/~dcs/bmad

Phase Space Mapping

x transfer function vs y displacement



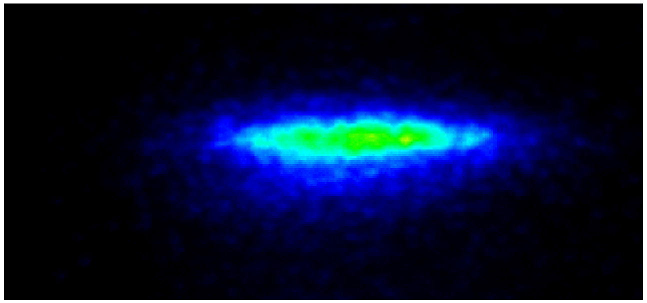
y transfer function vs x displacement

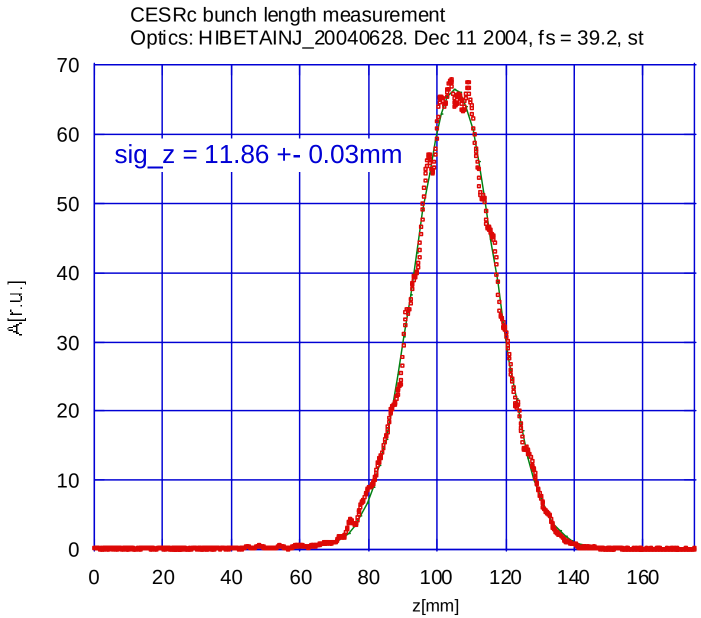


Beam-Based Benchmarking

- Beam-based probe of wiggler and model agreement
  - Bunch length and beam energy spread
  - Tune variation with wiggler field
  - Tune variation with beam position in wiggler
  - Tune variation with amplitude (octupole moment)
- Beam dynamics modeling and application also probes wiggler performance
- Provides full front-to-back check of local tools and hardware

Bunch Length and Beam Energy Spread





Streak camera measurement

$$\frac{\sigma_E}{E} = \frac{2\pi f_s}{\alpha c}\sigma_z;\ f_s \simeq 39kHz,$$

$$\alpha = 0.011, \sigma_z = 11.86mm$$

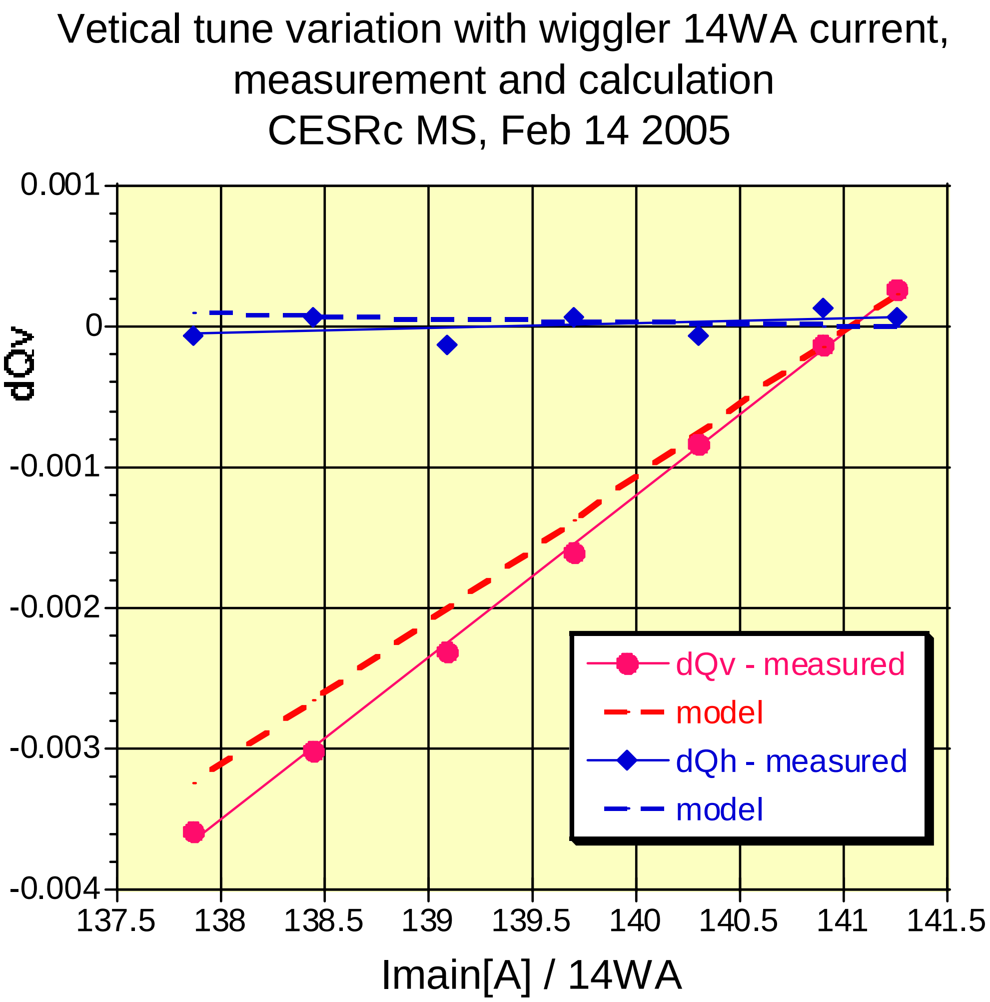
$$\Rightarrow \frac{\sigma_E}{E} = 8.62\times 10^{-4}$$

Model prediction: $\frac{\sigma_E}{E} = 8.47\times 10^{-4}$

(72% from wigglers)

A. Temnykh – WIGGLE05

Tune vs Wiggler Current



Tune variation with wiggler (14WA) current.

$$\Delta Q \simeq \frac{1}{4\pi}\beta\frac{1}{f}$$

$$\frac{1}{f} = \frac{dy'}{dy} \propto \left(\frac{B(I)}{B}\right)^2$$

	Value	Error
dQh/dI (model)	-2.97e-5	6.7e-13
dQh/dI (measl)	3.5e-5	2.9e-5
dQv/dI (model)	0.00102	2.0e-11
dQv/dI (meas)	0.00115	1.67e-05

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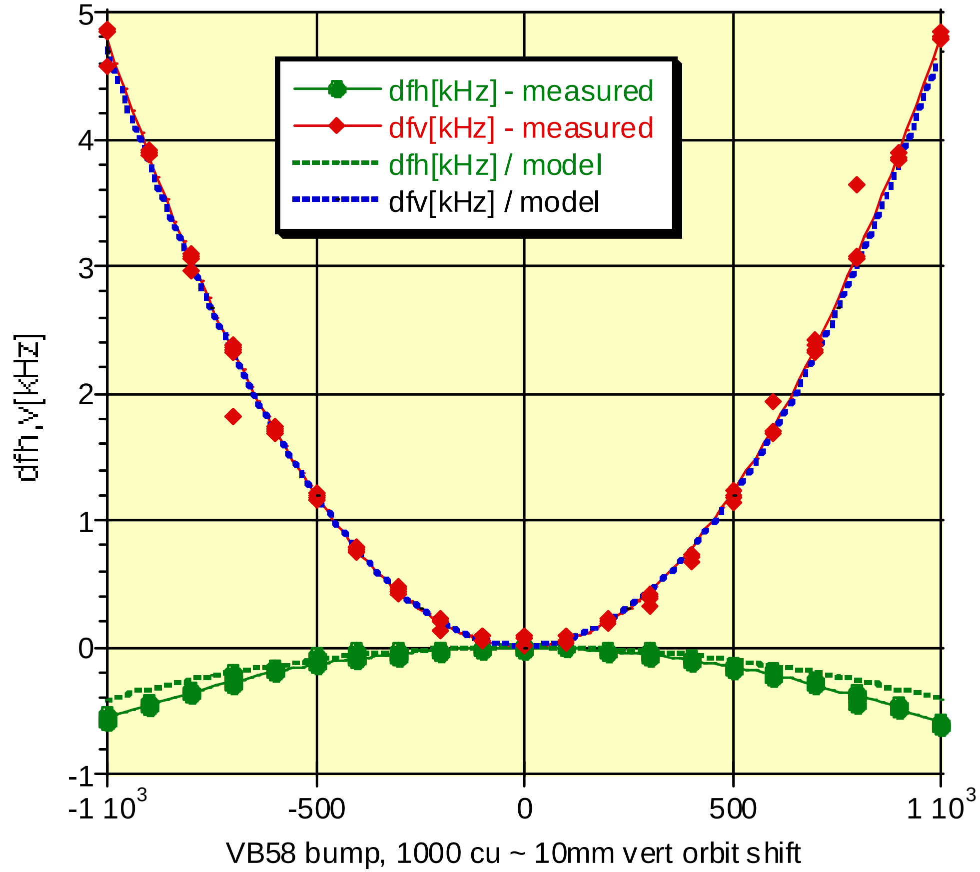
Tunes Versus Vertical Position in Wigglers

Tune variation with beam position in 19E cluster (3wigglers).

Vertical and horizontal tunes measured as a function of vertical orbit position in wigglers

$$df_{h,v} = 1kHz \;\Rightarrow\; dQ_{h,v} = 0.0025$$

Vertical and horizontal tune versus vertila beam position at three 8-pole wigglers cluster, VB 58. (ST, Aug 21 2003)



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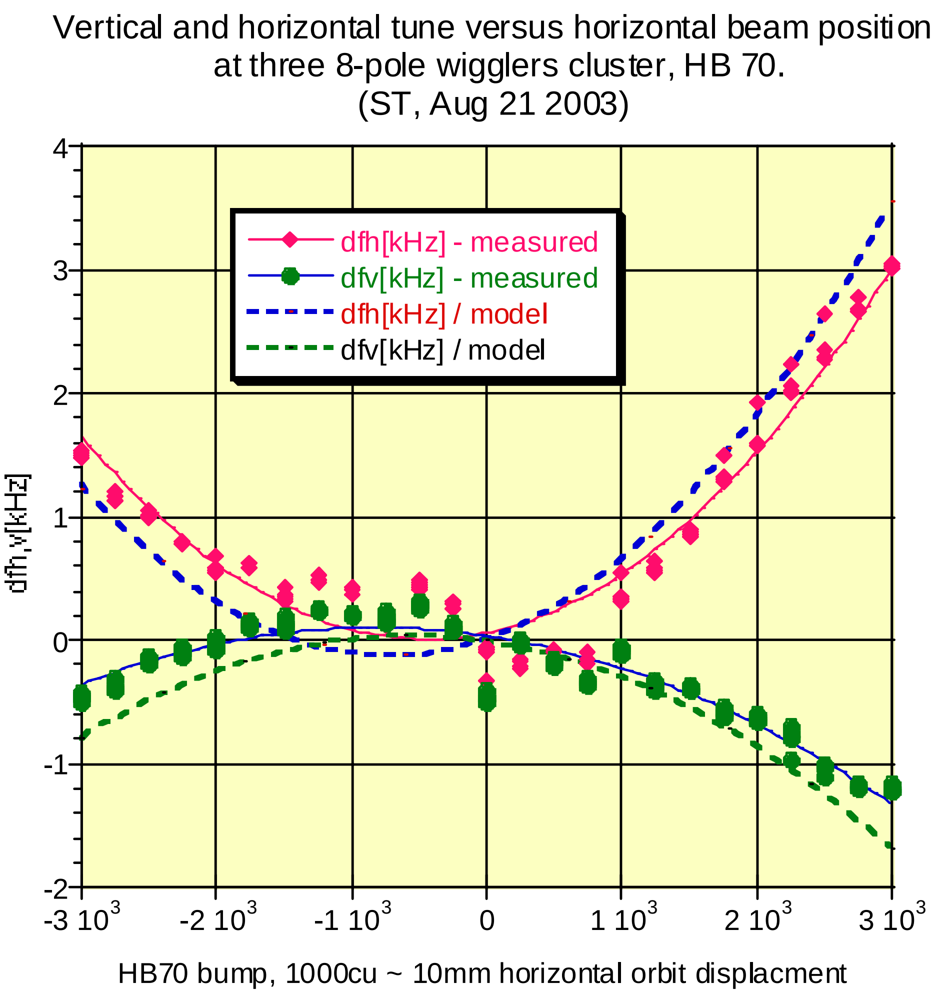
Tunes Versus Horizontal Position in Wigglers

Tune variation with beam position in 19E cluster (3wigglers).

Vertical and horizontal tunes measured as a function of horizontal orbit position in wigglers

$$df_{h,v} = 1kHz \quad \Rightarrow \quad dQ_{h,v} = 0.0025$$



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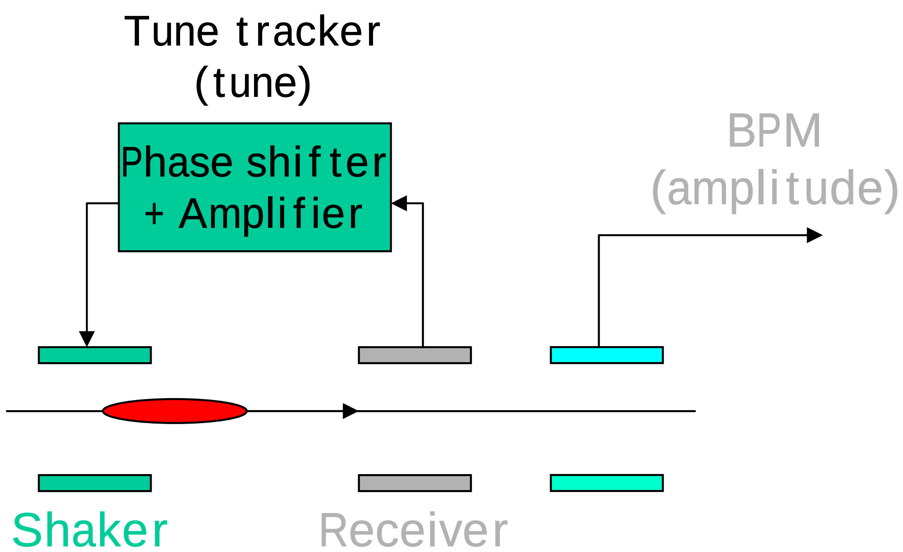
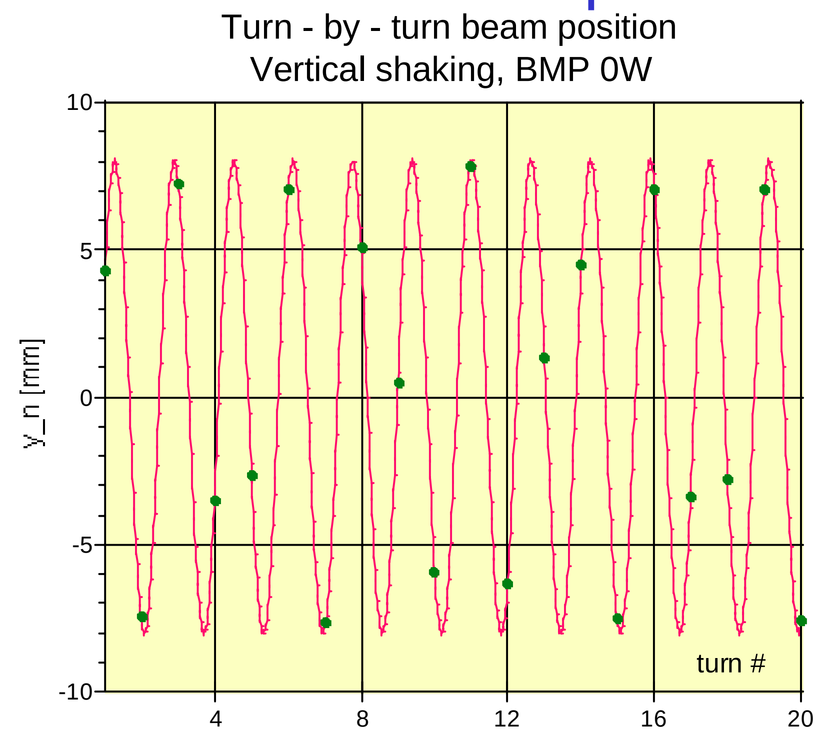
Characterization of Wiggler Octupole Component

Setup for measurement of tune variation with amplitude.





y = Ay*cos((m0-m2)*360*Qy)		
	Value	Error
Ay[mm]	8.007	0.062
m2	4.5137	0.0030
Qy	0.61565	0.0002

Tune tracker provides beam resonance shaking with stable amplitude horizontal/vertical plane.

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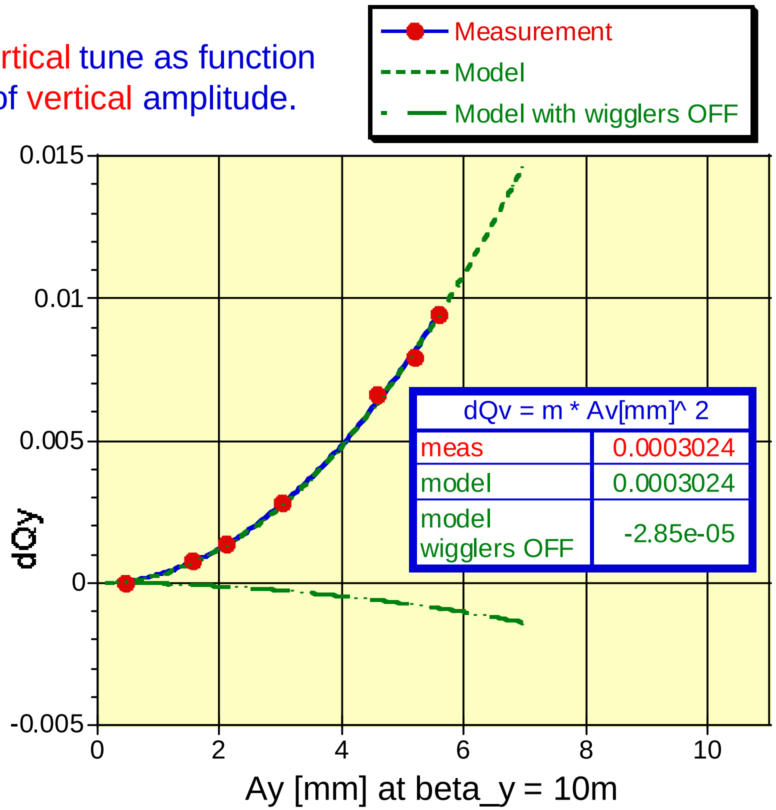
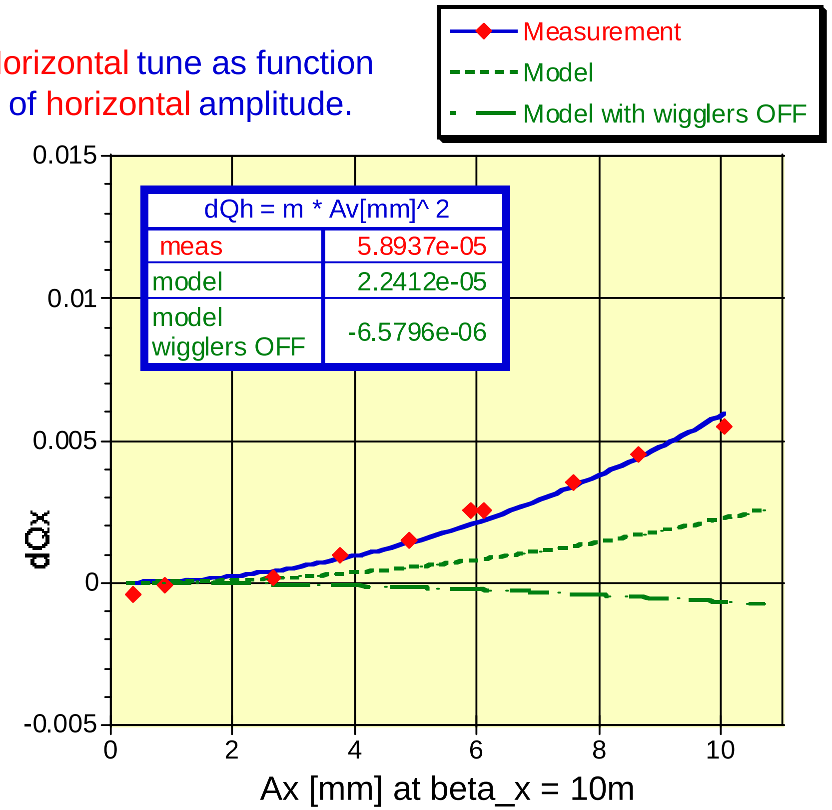
Characterization of Wiggler Octupole Component

Measured and calculated dependence of vertical/horizontal tune versus vertical/horizontal amplitude

Vertical tune as function of vertical amplitude.



Horizontal tune as function of horizontal amplitude.



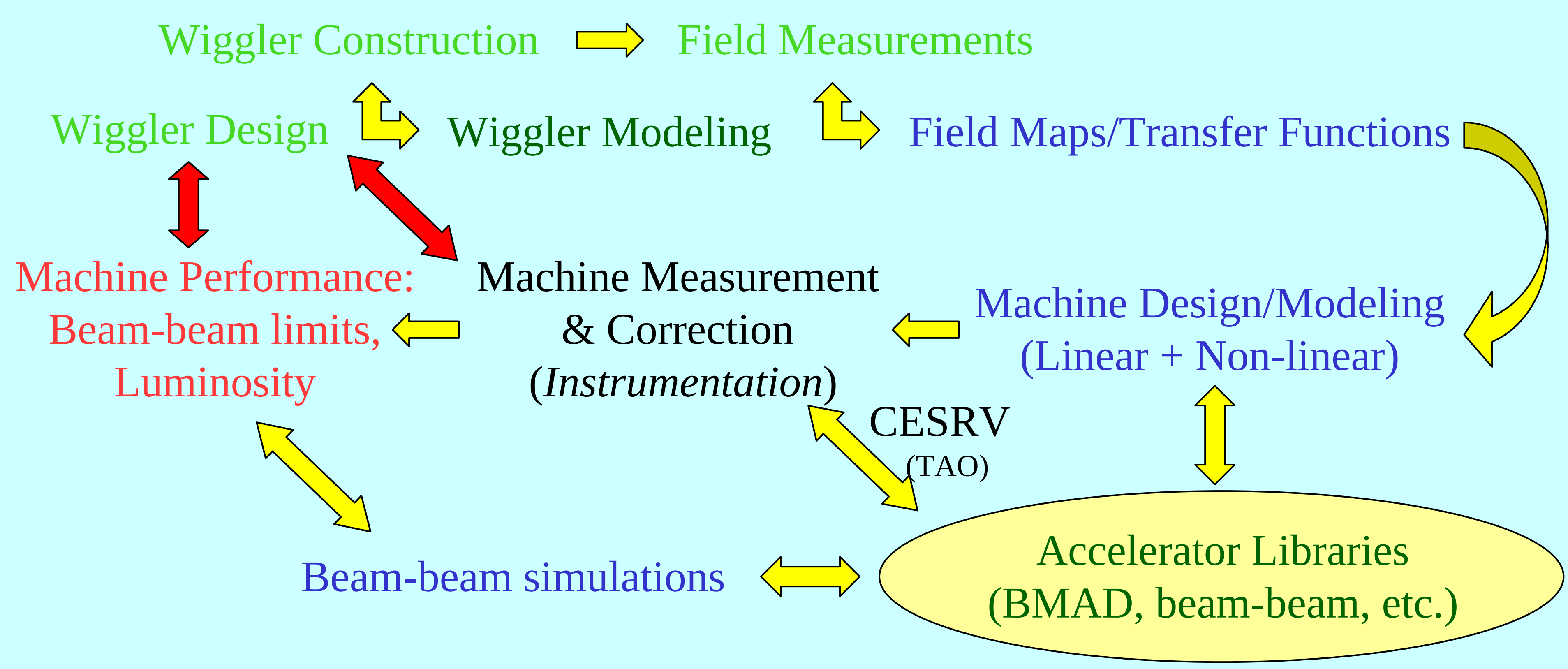
A. Temnykh – WIGGLE05

Conclusions

- The CESR group has obtained substantial (*good*) experience with building and operating a set of 12 superconducting wigglers
- Agreement between model and machine performance of wigglers is quite good
- This experience and infrastructure is currently being applied to ILC DR issues (see talk by J. Urban)

Benefits for ILC DR Design

- Fully characterized machine/wigglers and benchmarked tools



⇨ **Confidence in new development!**

Acknowledgements

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Dave Rice

A. (Sasha) Temnykh

Jim Crittenden

CESR Wiggler Production Team

S. Chapman	G. Codner
J. Crittenden	R. Gallagher
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N. Mistry	T. Moore
E. Nordberg	D. Rice
S. Richichi	D. Rubin
E. Smith	K Smolenski
A. Temnykh	W. Trask

CESR Design Parameters

Beam Energy [GeV]	1.55	1.88	2.5	5.3
Luminosity [÷10^{30}]	150	300	500	1250
i_b [mA/bunch]	2.8	4.0	5.1	8.0
I_{beam} [mA/beam]	130	180	230	370
ξ_y	0.035	0.04	0.04	0.06
ξ_x	0.028	0.036	0.034	0.03
σ_E/E_0 [x10^3]	0.75	0.81	0.79	0.64
$\tau_{x,y}$ [msec]	69	55	52	22
B_W [Tesla]	2.1	2.1	1.75	1.2
β_y^* [cm]	1.0	1.0	1.0	1.8
ε_x [nm-rad]	230	220	215	220