Future Synchrotron Light Sources Based on Ultimate Storage Rings

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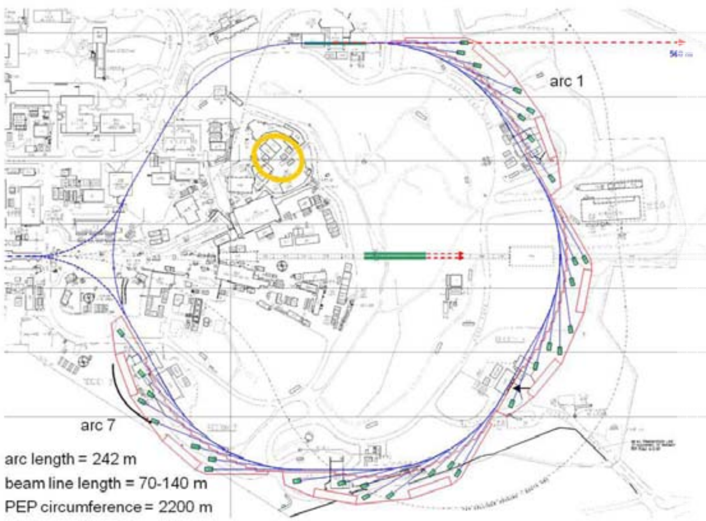
Workshop on Accelerator R&D for Ultimate Storage Rings, Beijing

PEP-X Layout & Parameters

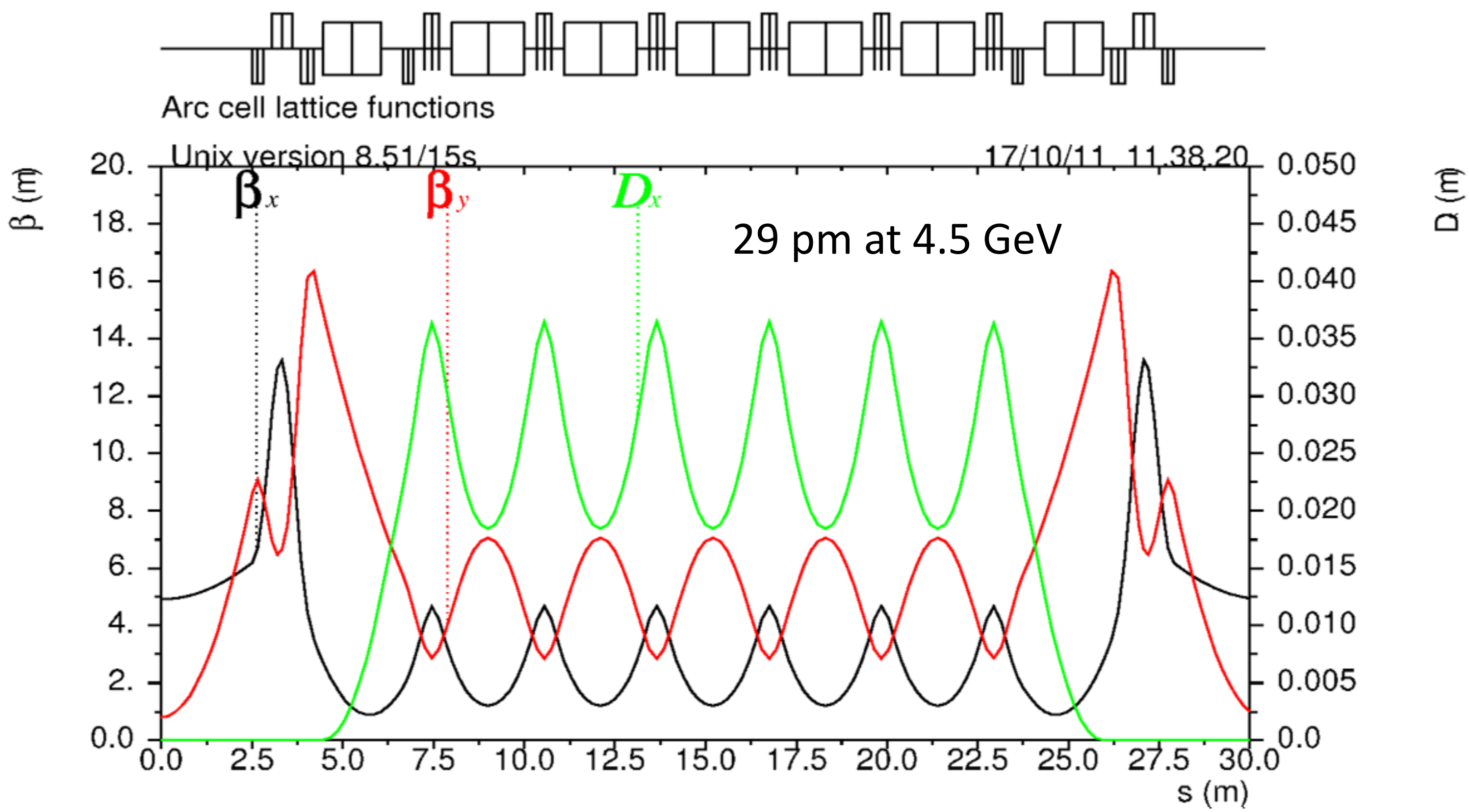
An ultimate storage ring



Energy, GeV	4.5
Circumference, m	2199.32
Natural emittance, pm	11
Beam current, mA	200
Emittance at 200 mA, x/y, pm	12 / 12
Tunes, x/y/s	113.23 /65.14/0.007
Bunch length, mm	3.1
Energy spread	1.25×10^{-3}
Energy loss per turn, MeV	2.95
RF voltage, MV	8.3
RF harmonic number	3492
Length of ID straight, m	5.0
Wiggler length, m	90.0
Beta at ID center, x/y, m	4.92 / 0.80
Touschek lifetime, hour	10
Dynamic aperture , mm	10

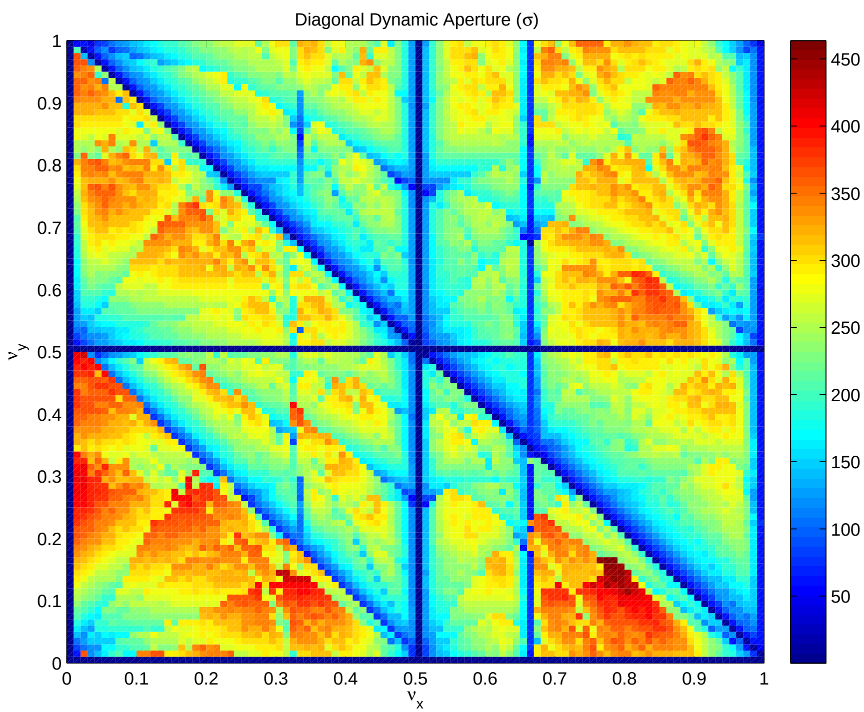
To be Built with 4^{th}-order geometrical achromats in the PEP tunnel.

PEP-X 7 Bend Achromat



Cell phase advances: μ_x=(2+1/8) x 360^0, μ_y=(1+1/8) x 360^0.

Resonance in Storage Rings



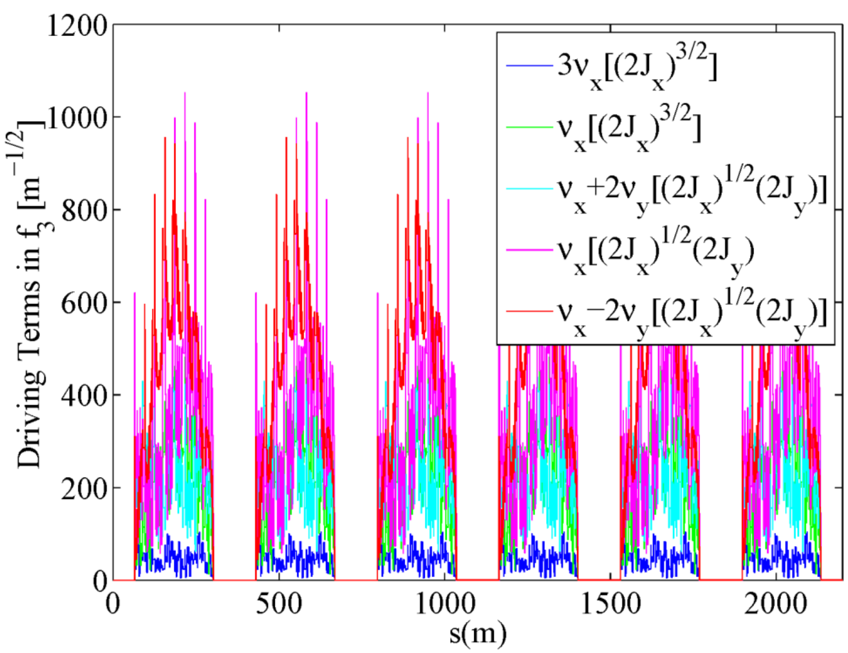
Dynamic aperture in a two-dimensional tune scan for the baseline design of PEP-X (2008).

Where these resonances come from?

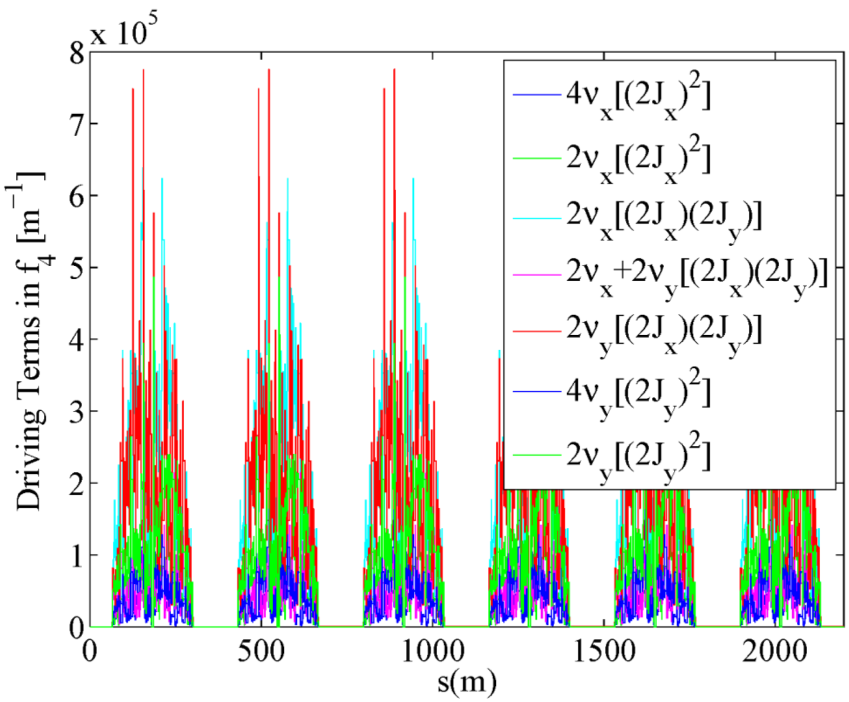
Cancellation of All Geometric 3rd and 4th Resonances Driven by Strong Sextupoles

except $2\nu_x$-$2\nu_y$

Third Order



Fourth Order



K.L. Brown & R.V. Servranckx
Nucl. Inst. Meth., A258:480–502, 1987

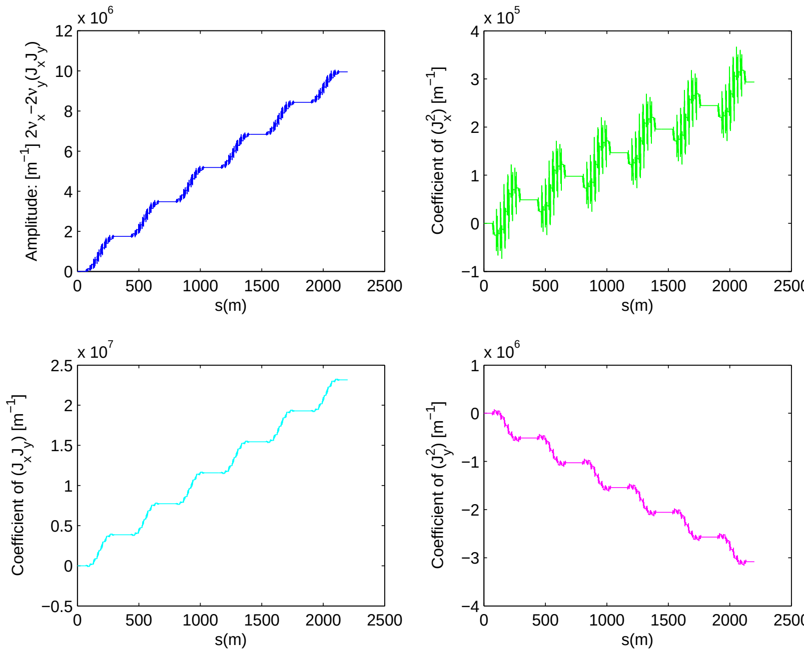
Yunhai Cai
Nucl. Inst. Meth., A645:168–174, 2011.

There are still three tune shift terms.

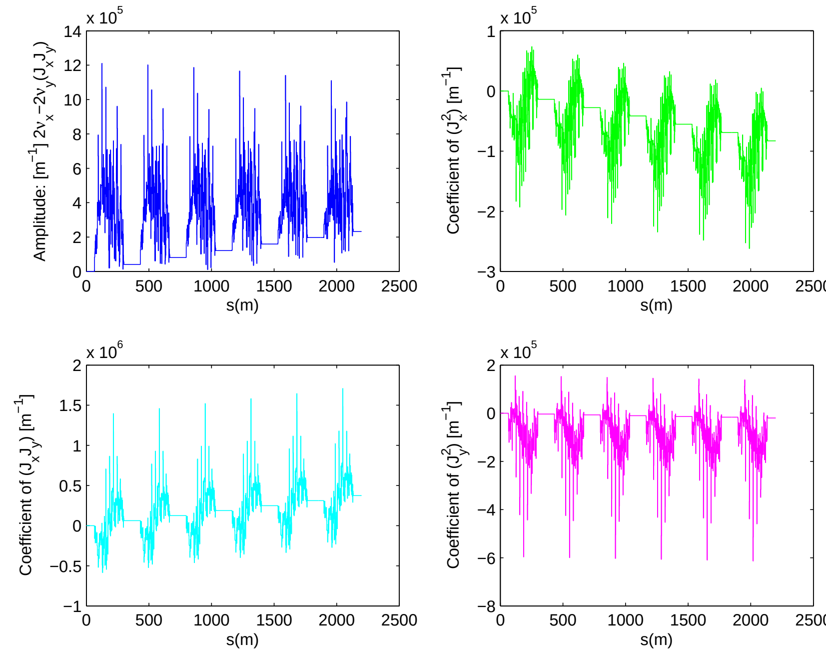
Harmonic Sextupoles

For Tune Shifts and $2\nu_x$-$2\nu_y$ Resonance

Without harmonic sextupoles



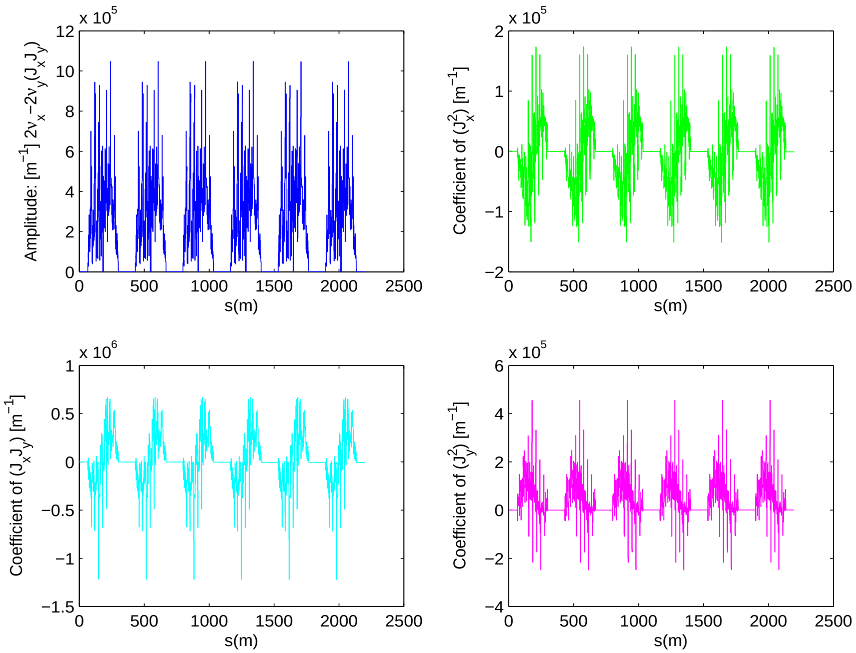
With harmonic sextupoles



OPA is used for optimizing the setting of 10 families of sextupoles. Due to the cancellation of many resonances, the optimization becomes much simpler and easier. OPA is an Accelerator Design Program from SLS PSI developed by A. Streun.

4^{th} Order Geometric Achromat

4^{th} order geometric achromat



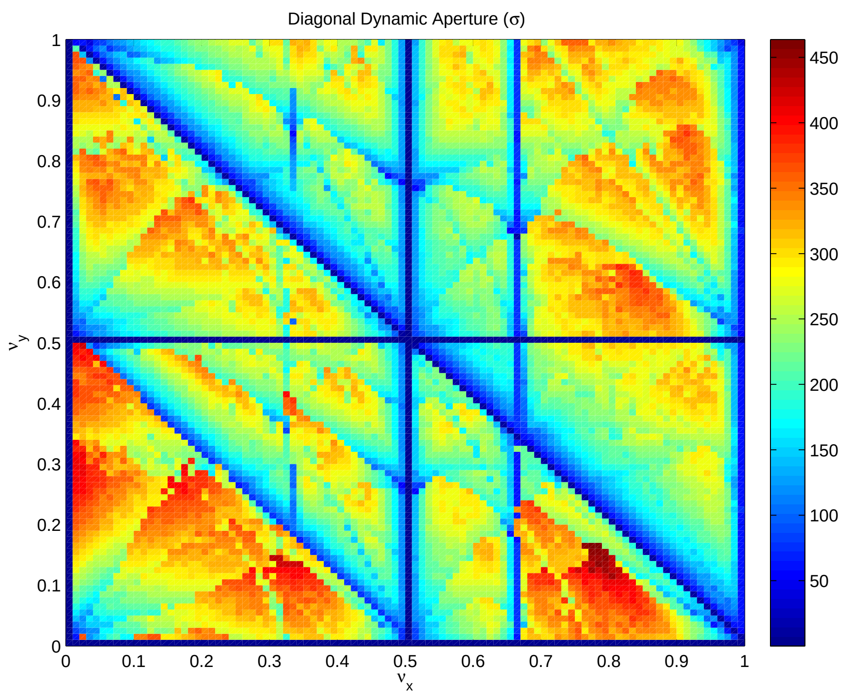
Chromatic effects

$\partial \nu_{x,y} / \partial \delta$	**0,0**
$\partial^2 \nu_{x,y} / \partial \delta^2$	-57,-89
$\partial^3 \nu_{x,y} / \partial \delta^3$	1332,-150
$\eta_{x,y}$	0,0
$\partial \eta_{x,y} / \partial \delta$	0,0

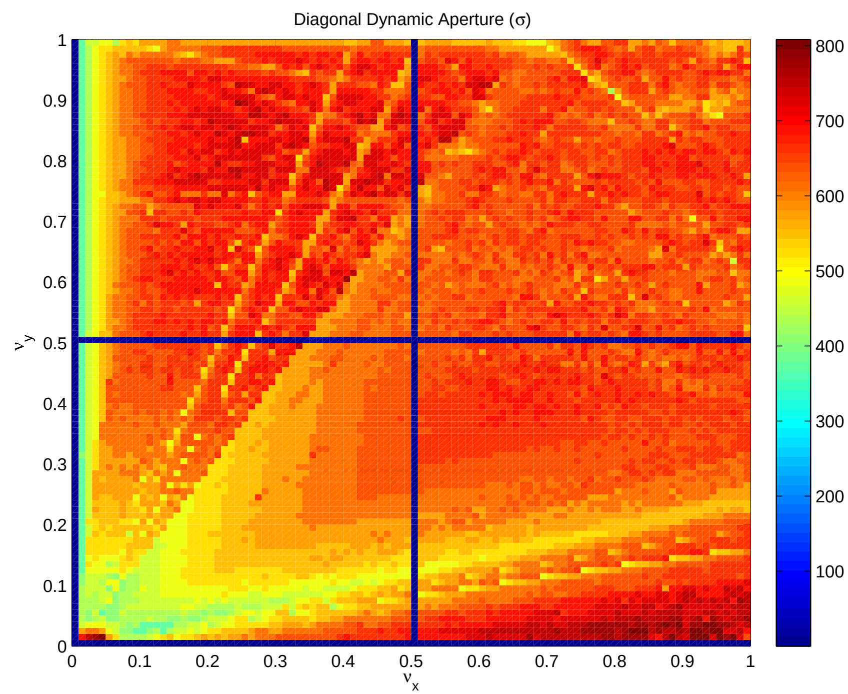
There are 4 families of chromatic sextupoles and 6 families of harmonic ones. The 4^{th} order geometric achromat (f_3=f_4=0) was obtained with the analytical Lie method. It was documented in SLAC-PUB-14785 and submitted to PRSTAB.

Tune Scan of Dynamic Aperture

PEP-X: Baseline (2008)



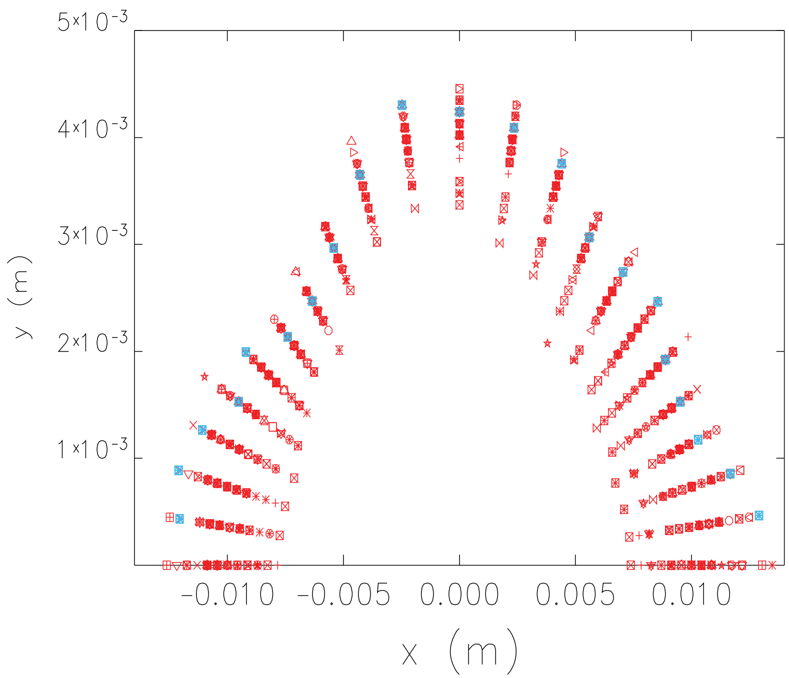
PEP-X: USR (2011)



The dynamic aperture is in unit of sigma of the equilibrium beam size. The USR design is built with 4^{th}-order geometric achromats and therefore no 3^{rd} and 4^{th} order resonances driven by the sextupoles seen in the scan.

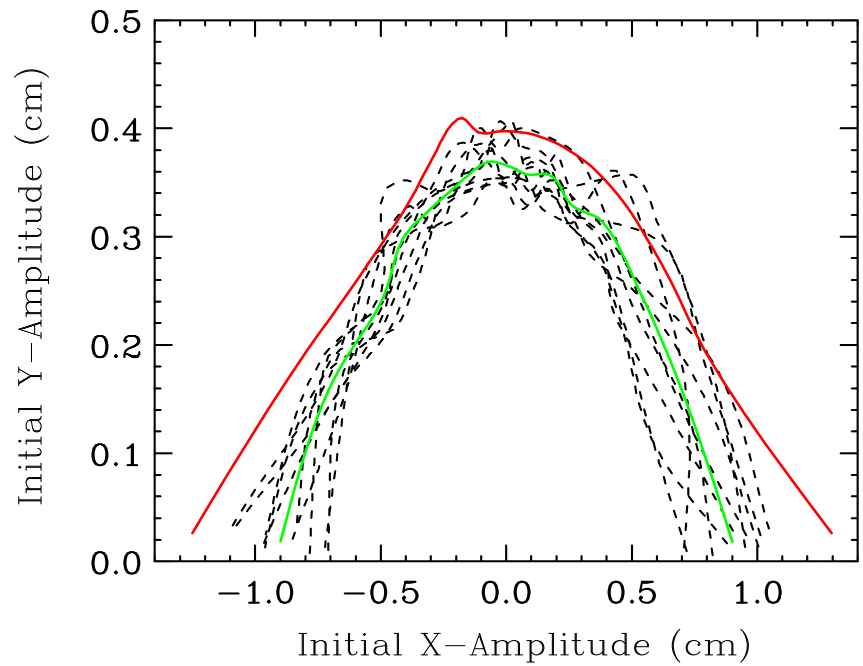
Dynamic Aperture with Machine Errors

ELEGANT Tracking



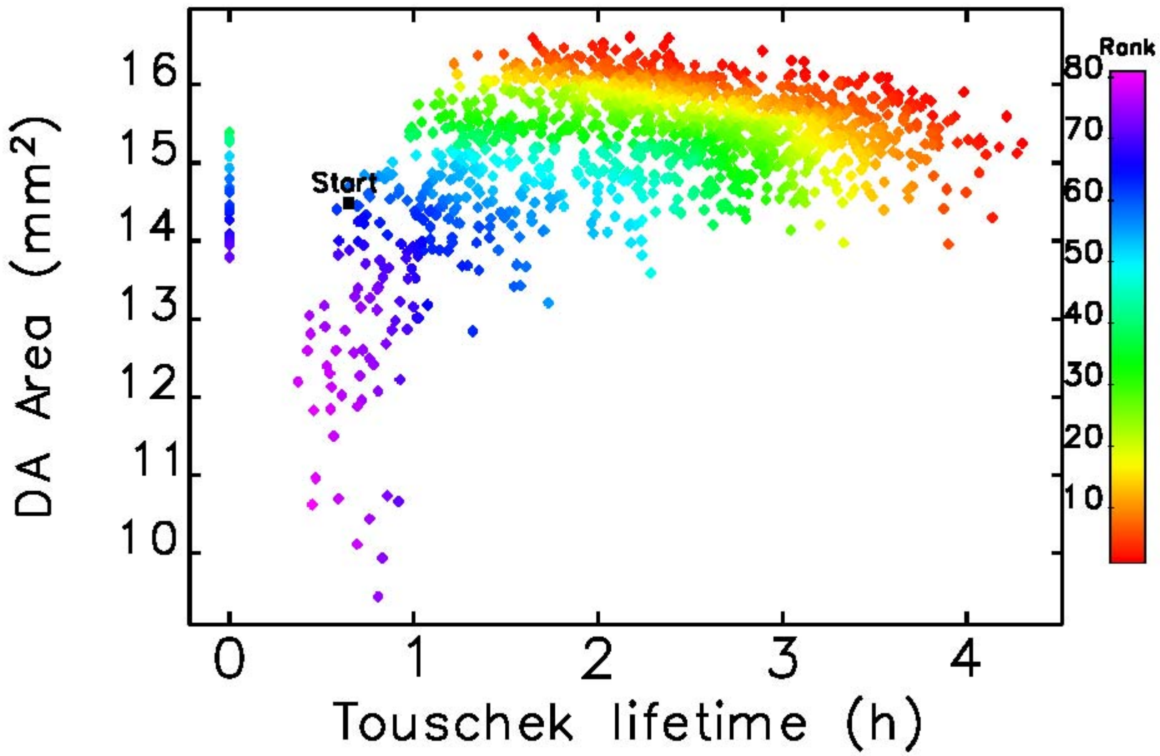
1% coupling & 1% beta beating

LEGO Tracking



Misalignments 20 microns in x.

Optimization Using Elegant



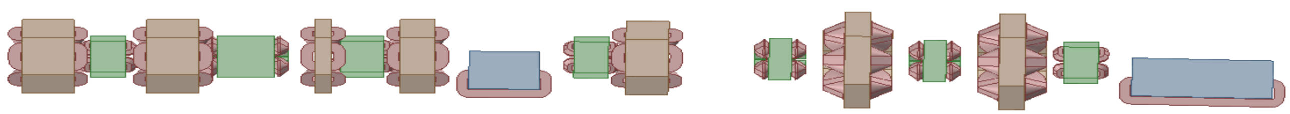
M. Borland et al. *Multi-objective direct optimization of dynamic acceptance and lifetime for potential upgrades of the advanced photon light source*. APS LS 319, Argonne, August 2010.

Achievements

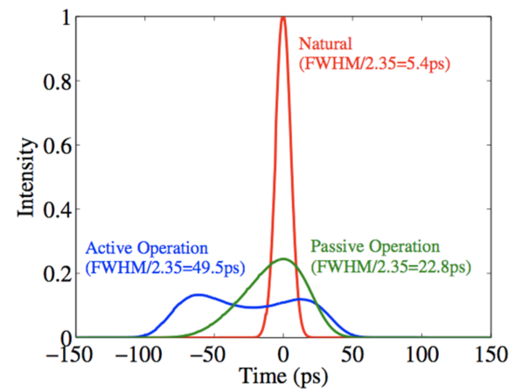
- We have developed an excellent design of an ultimate storage ring
  - Diffraction limit at 1 angstrom
  - Reasonable beam current 200 mA
  - Good beam lifetime 3 hours
  - Good injection with 10 mm acceptance
  - Achievable machine tolerances 20 microns

General R&D Items
for Ultimate Storage Rings

1. Better understanding of beam dynamics
2. How to make a round beam in storage ring
3. New injection scheme for smaller dynamic aperture
4. Compact and strong magnets (sextupoles)



5. Higher harmonic RF system
6. Precise magnet alignment
7. Accurate beam position monitors
8. Undulator with shorter period



Lengthen the beam

Beyond the Ultimate Brightness

Parameter	PEP-X	LCLS-(1.5nm)
Energy [GeV]	4.5	4.3
Normalized emittance [um-rad]	0.1	0.4
Peak current [A]	17	500-3000
Energy spread	1.25×10^{-3}	$(0.5\text{-}3.0) \times 10^{-4}$

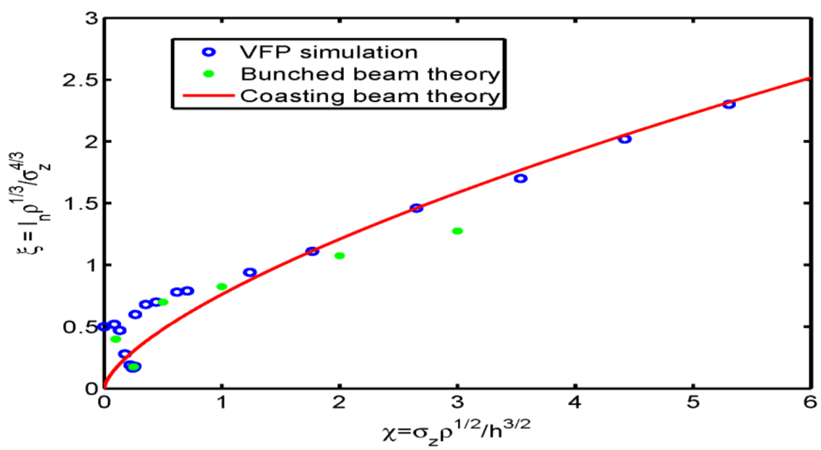
- Increase the peak current by much stronger longitudinal focusing
  - 1.5 GHz, 200 MV CW SCRF
- Any FEL schemes to accommodate larger energy spread?
- Can we achieve lasing or at least partial lasing?

Threshold of Instability Driven by CSR

Based on the bunched beam theory, the threshold can be written as

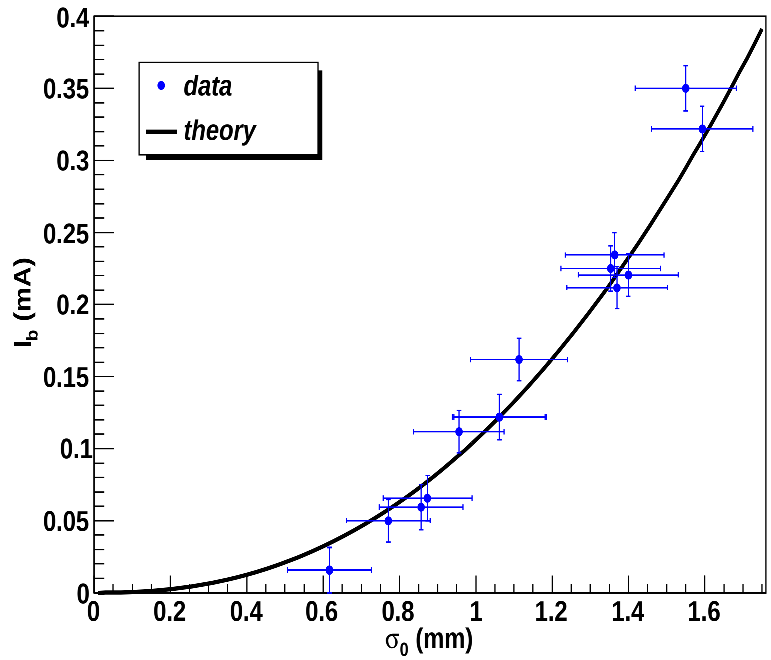
$$\sigma_z^{7/3} = \frac{c^2 Z_0}{8\pi^2 \xi^{th}(\chi)} I_b^{th} \rho^{1/3} / (V_{rf} \cos\varphi_s f_{rf} f_{rev})$$

where ξ^{th} is given by



My talk, IPAC 2011, San Sebastian, Spain

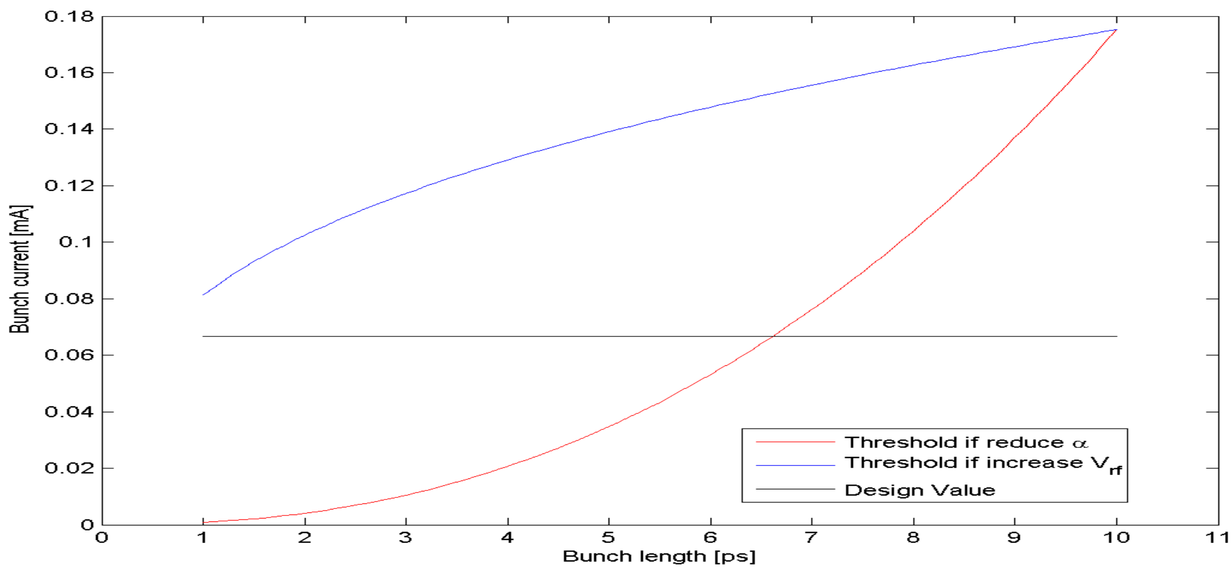
Measured bursting threshold at ANKA
See M.Klein et al. PAC09, 4761 (2009)



(courtesy of M. Klein, ξ^{th}=0.5 used.)

Reduce Bunch Length from 10 ps to 1 ps without reducing bunch current

Calculation of threshold



An illustration using PEP-X nominal parameters: f_{rf} = 476 MHz, V_{rf}=8.3 MV, f_{rev} = 136.312 kHz, σ_z=3 mm, I_b=0.067 mA.

Conclusion

- Diffraction limited (1 angstrom) light source is clearly feasible. Some R&D are necessary to further advance the design for construction.
- High-order achromats can be used in realistic design of ultimate storage rings. This approach significantly simplified the optimization process and improved the dynamic aperture.
- Analytical and numerical methods are complementary to each other. We should spend more time to understand what computers have provided us.
- Longitudinal beam dynamics will be the key to break the barrier of the ultimate brightness in the storage-ring-based light source.

Acknowledgements

- PEP-X-USR design team:
  Karl Bane, Robert Hettel, Yuri Nosochkov,
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