Modeling and Guidelines

ASAC Review April 23 – 24, 2007

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Outline

1.0 Matching Sections: Quadruplets vs. Triplets

The DBA have 6 constraints:

- **linear achromat ($\eta_x = \eta'_x = 0$ at the entrance),**
- **small emittance ($\min(\mathcal{H}) \Rightarrow (\alpha_x, \beta_x)$ fixed at the entrance),**
- **and symmetric ($\alpha_{x,y} = 0$ at the center).**

Similarly, the two matching sections have 10 constraints:

- **symmetric ($\alpha_{x,y} = 0$ at the center),**
- **$\beta_{x,y}$ at the center,**
- **$\beta_{x,y}$ at the center of the DBA and symmetric ($\alpha_{x,y} = 0$),**
- **and the cell tune $\nu_{\text{cell}, x, y}$.**

Rank Conditions for the Matching Sections

Observation:

	System				
	Gradients			Gradients and Placement	
	Quadruplets	Triplets		Quadruplets	Triplets
Singular Values	10×8	10×7		10×(8+8)	10×(7+7)
	3.5E+00	3.3E+00		3.4E+00	3.3E+00
	2.1E+00	1.9E+00		2.1E+00	1.9E+00
	1.3E+00	1.0E+00		1.2E+00	1.0E+00
	4.0E-02	3.5E-02		3.3E-02	3.5E-02
	1.1E-02	5.9E-03		1.0E-02	6.0E-03
	2.7E-04	3.6E-04		3.1E-04	3.6E-04
	3.1E-05	3.4E-05		3.2E-05	3.4E-05
	3.8E-06			4.6E-06	6.7E-07
				5.8E-07	1.1E-07
				1.1E-07	3.2E-07
				4.4E-27	2.0E-17
				0.0E+00	0.0E+00
				0.0E+00	0.0E+00
				0.0E+00	0.0E+00
				0.0E+00	
				0.0E+00	

Solution: simplify to triplets and add a quadrupole at the center of the DBA.

2.0 Hard X-Ray Sources

Problem: not enough (hard) X-ray sources.

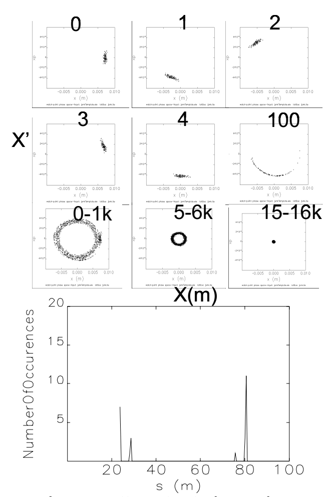
Solution:

- **Start from the SOLEIL concept (A. Nadji et al "A Modified Lattice for SOLEIL with a Larger Number of Straight Sections" SSILS, 2001).**
- **Improve (S. Krinsky).**

3.0 Injection Studies

(I. Pinayev, T. Shaftan, L.-H. Yu)

- Machine model:
  - RF cavity ON
  - Damping ON
  - QF ON
  - Apertures:
    - H(-30mm,17.5mm) in 8m straight
    - V(-2.5mm,2.5mm) in 5m straight
  - Misalignments in Quads only (100 um)
  - Field error 0.5×10^{-3} in quads
  - Tune correction with Q11,Q44. Orbit correction.
  - No rolls; no sextupole mis.
  - No coupling correction yet
  - No IDs
- Study
  - Tracking for 512 to 16000 turns (4 damping time with IDs) at 3GeV
  - Test loss patterns with large emittance and 0.5mrad roll error without coupling correction
  - Injection misalignment tolerance analysis
  - Compare booster emittance of 15nm and 34 nm showing 34 nm acceptable



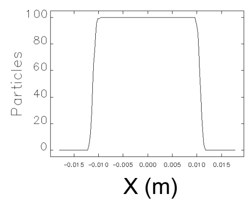
Loss pattern test shows loss at 5 m straight entrance and exit

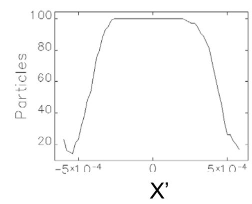
FIG. 1. Injection Tracking with ELEGANT (L.-H. Yu).

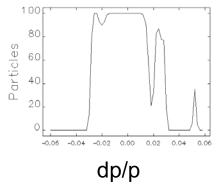
Injection Tracking with ELEGANT

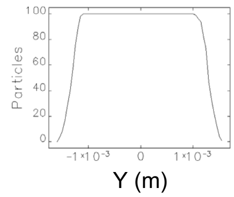
(L.-H. Yu)

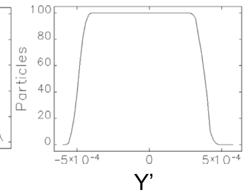
- X: 7.7mm→10mm
- X': 0.2mrad
- Y: 1mm
- Y':0.3mrad
- delta :-1.8%→1%







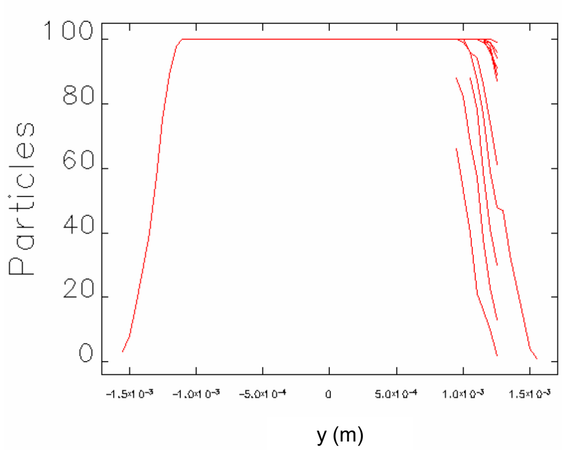




Injection Misalignment Tolerance in *y*

(L.-H. Yu)

Q1=-0.649, nux=32.32599, nuy=16.29031, npass=2040



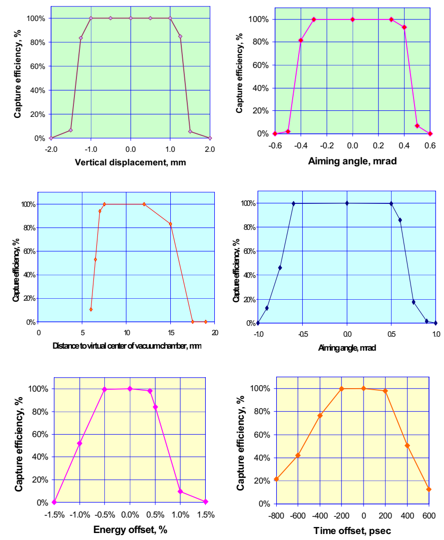
20 random seeds used to track between 0.9mm to 1.3mm of injection offset

Revealed that the tolerance of y as 1mm with error of +/-0.2mm when track with 100 particles

Simulation Parameters (Tracy-2)

(I. Pinayev)

- 200 particles, 500 turns for transverse misalignments, 10000 turns for longitudinal (one damping time)
- 2.5 MV RF (3% acceptance), synchrotron radiation is on
- Alignment errors (from CDR with rolls), vertical dispersion wave 20 mm amplitude (courtesy B. Nash), multipole field errors according to BINP data
- ε_x=34 nm, ε_y=3.4 nm
- σ_E/E=0.1%, σ_t=50 ps
- β_x=5 m, X_0=9.0 mm, X'_0=0
- β_y=3 m, Y_0=0.0 mm, Y'_0=0
- Vertical aperture at ID location ±2.5 mm
- Horizontal apertures at septum -30 mm and +17.5 mm
- Other apertures: ±50 mm horizontal and ±25 mm vertical
- Septum edge at 6.4 mm
- ν_x=0.3523, ν_y=0.2803 (correction with q33 and q44)



Estimation for Allowable Beam Envelope

(I. Pinayev)

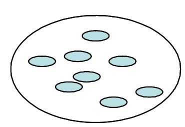
$$f_i(x,x',y,y',\delta E,t) \sim \exp\left(-\frac{(x-x_{0i})^2}{2\sigma_\varepsilon^2}\right) f_i^{x'}(x') f_i^{y}(y) f_i^{y'}(y') f_i^{\delta E}(\delta E) f_i^{t}(t)$$

$$g(x_0) \sim \exp\left(-\frac{x_0^2}{2\sigma_{x_0}^2}\right) \quad \sigma_{eff}^2 = \sigma_\varepsilon^2 + \sigma_{x_0}^2$$

$$\sigma_{xeff} = 1.11\,mm \quad \sigma_{x'eff} = 0.22\,mrad$$

$$\sigma_{yeff} = 0.27\,mm \quad \sigma_{y'eff} = 0.09\,mrad$$

$$\sigma_{Eeff} = 0.2\% \quad \sigma_{teff} = 100\ ps$$



For 500 particles tracked for 10000 turns capture efficiency was 97.7%±1.6% for 25 seeds of alignment errors

Tolerances for the aiming of the injected beam with specified parameters are:

$$\sigma_{x_0} = 1\,mm \quad \sigma_{x'_0} = 0.2\,mrad$$

$$\sigma_{y_0} = 0.25\,mm \quad \sigma_{y'_0} = 0.08\,mrad$$

$$\sigma_{E_0}/E_0 = 0.17\% \quad \sigma_t = 85\,p\sec$$

4.0 Magnet TQM

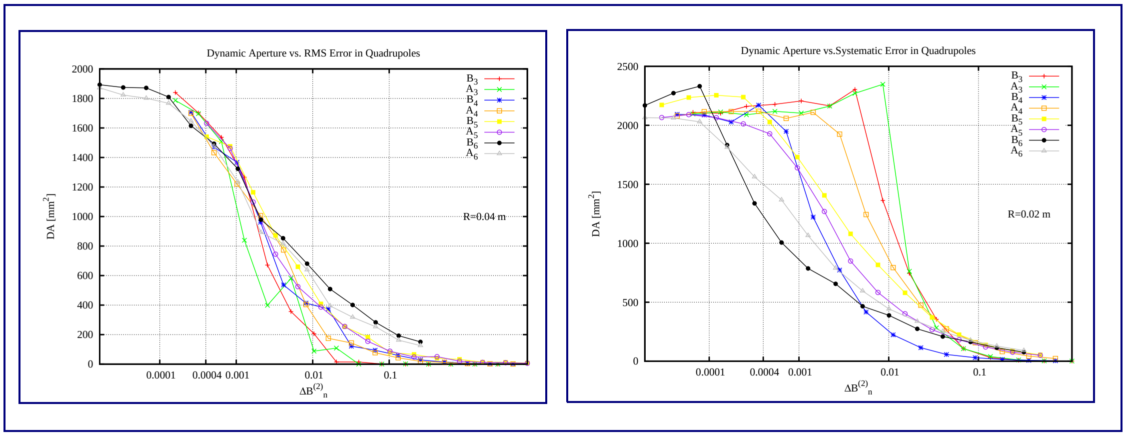


FIG. 2. Impact of Random and Systematic Multipole Errors in the Quadrupoles (B. Nash)

4.1 Magnet Design Plan

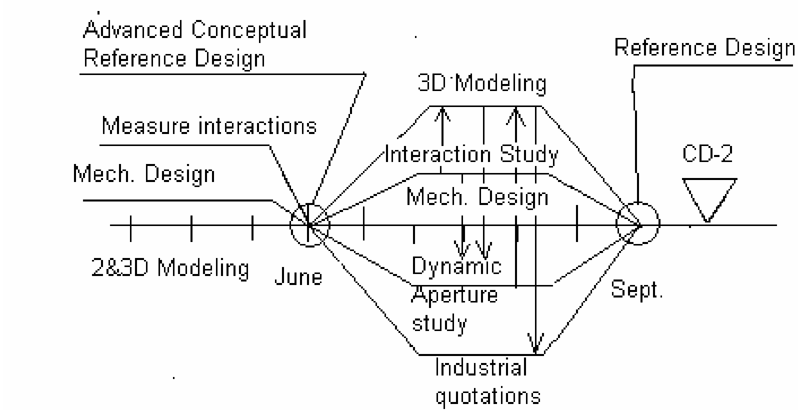
(J. Skaritka, W. Meng, R. Gupta)

A systematic closed loop iterative approach

- Magnet systems and Accelerator physics adopts a consistent set of definitions and multipole conventions.
- Advanced conceptual design of the lattice magnets along with 2&3D modeling and Interaction studies using loaned SLS magnets shall be performed.
- As designs mature estimates of harmonic content from Systematic and Random errors shall be provided to Accelerator physics for Dynamic Aperture Calculation.
- Results of Dynamic Aperture Calculations shall be used to refine the magnet designs.
- Refined magnet designs with performance specifications shall be provided to Industry for quotations.
- Cost & performance optimization shall result in a reference designs for to CD-2.

Magnet Design Plan Diagram

(J. Skaritka)



This systematic closed loop approach will allow the magnet design process to rapidly converge into optimized magnet reference designs and reliable cost estimates.

“Magnets for Johan”

(J. Skaritka)

4.2 Model Validation: the Lie Generators (CDR)

Table 6.1.6 Residual Normalized Lie Generators.

Lie Generator	Effect	Normalized Value
$\lvert h_{11001}\rvert$	$\partial\nu_x/\partial\delta$	1.6×10^{-11}
$\lvert h_{00111}\rvert$	$\partial\nu_y/\partial\delta$	1.3×10^{-12}
$\lvert h_{10002}\rvert$	$\partial\eta_x/\partial\delta$	3.3×10^{-6}
$\lvert h_{20001}\rvert$	$\nu_x \pm \nu_z$	6.0×10^{-7}
$\lvert h_{00201}\rvert$	$\nu_y \pm \nu_z$	3.5×10^{-8}
$\lvert h_{21000}\rvert$	ν_x	6.4×10^{-7}
$\lvert h_{10110}\rvert$	ν_x	1.5×10^{-7}
$\lvert h_{30000}\rvert$	$3\nu_x$	2.1×10^{-8}
$\lvert h_{10020}\rvert$	$\nu_x - 2\nu_y$	5.4×10^{-8}
$\lvert h_{10200}\rvert$	$\nu_x + 2\nu_y$	7.1×10^{-7}
$\lvert h_{20110}\rvert$	$2\nu_x$	2.2×10^{-8}
$\lvert h_{31000}\rvert$	$2\nu_x$	8.8×10^{-8}
$\lvert h_{40000}\rvert$	$4\nu_x$	7.4×10^{-9}
$\lvert h_{20020}\rvert$	$2\nu_x - 2\nu_y$	3.4×10^{-7}

Lie Generator	Effect	Normalized Value
$\lvert h_{20200}\rvert$	$2\nu_x + 2\nu_y$	1.3×10^{-9}
$\lvert h_{11200}\rvert$	$2\nu_y$	5.5×10^{-8}
$\lvert h_{00310}\rvert$	$2\nu_y$	1.5×10^{-7}
$\lvert h_{00400}\rvert$	$4\nu_y$	2.3×10^{-8}
$\lvert h_{22000}\rvert$	$\partial\nu_x/\partial J_x$	1.1×10^{-6}
$\lvert h_{11110}\rvert$	$\partial\nu_{x,y}/\partial J_{y,x}$	1.3×10^{-7}
$\lvert h_{00220}\rvert$	$\partial\nu_y/\partial J_y$	6.9×10^{-7}
$\lvert h_{22001}\rvert$	$\partial^2\nu_x/\partial J_x\partial\delta$	7.0×10^{-7}
$\lvert h_{11111}\rvert$	$\partial^2\nu_{x,y}/\partial J_{y,x}\partial\delta$	3.7×10^{-7}
$\lvert h_{00221}\rvert$	$\partial^2\nu_y/\partial J_y\partial\delta$	7.6×10^{-8}
$\lvert h_{11002}\rvert$	$\partial^2\nu_x/\partial\delta^2$	3.9×10^{-6}
$\lvert h_{00112}\rvert$	$\partial^2\nu_y/\partial\delta^2$	1.1×10^{-7}

Remote Beam Studies and On-Line Control at the SLS

(A. Streun et al, 02/22/05, 02/21/07)

Machine development

(Andersson, Pedrozzi, Streun)

Summary (detailed evaluation will follow):

- Test of a new sextupole setting (optics F4TJB calculated by J.Bengtsson, BNL): better injection efficiency (100% without any optimization!) (due to larger horizontal DA) but lower lifetime (due to larger 2nd order chromaticity). Tests for various tunes and chroma - quite promising optics.

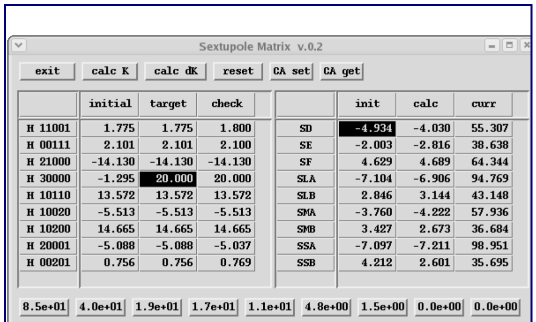


FIG. 3. The Sextupole Response Matrix.

5.0 Modeling of Realistic Insertion Devices

Options:

- Generalized Halbach basis for the Tracy-2 first order explicit symplectic integrator (E. Forest, K. Ohmi, KEK, 1992).
- Radia kick maps (P. Elleaume, EPAC92).
- Generalized Halbach basis and generating function (J. Bahrdt, G. Wüstefeld EPAC92).

Considerations:

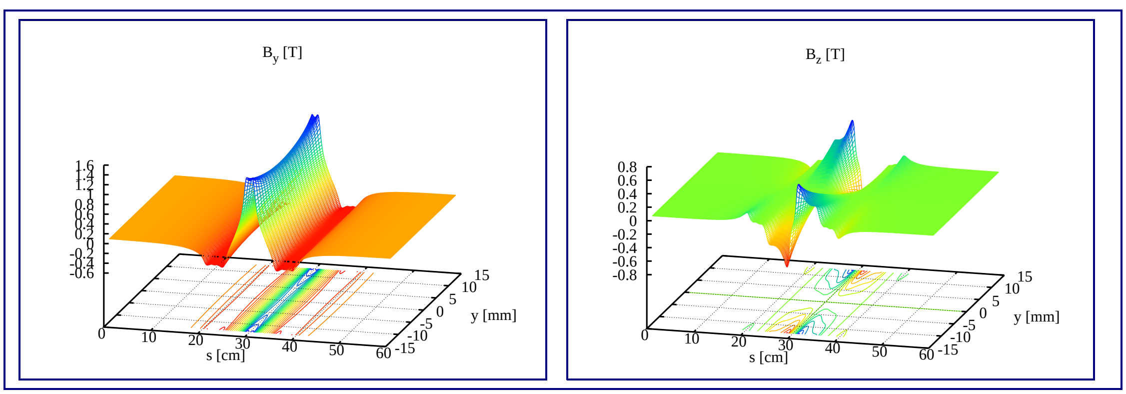
- modeling of the 3-pole wiggler,
- how to determine the dynamic aperture

Choice:

- use generalized Halbach basis with fitted coefficients (simple, efficient),
- and implement infrastructure to import arbitrary 3D field maps (complete).

Impact of the 3-Pole Wiggler

(field map by T. Tanabe)



	ν_x	ν_y	ε_x
Bare Lattice	32.3472	16.2803	2.04
with 15 TPWs	32.3485	16.2843	2.27

Hamiltonian for EPUs

General Hamiltonian:

$$\langle H\rangle_{\lambda u}=\frac{p_x^2+p_y^2}{2(1+\delta)}-\frac{\left\langle\left(\frac{q}{p_0}A_x\right)^2\right\rangle}{2(1+\delta)}-\frac{\left\langle\left(\frac{q}{p_0}A_y\right)^2\right\rangle}{2(1+\delta)}-\delta+0(p^4)$$

Halbach expressions for undulator fields:

$$\frac{q}{p_0}A_x=\frac{B_o}{k}\cos(k_1x)\cos h(k_2y)\sin(kz)-\frac{k_4G_0}{kk_3}\sin h(K_3x)\sin(k_1y)\sin(kz+\varphi)$$

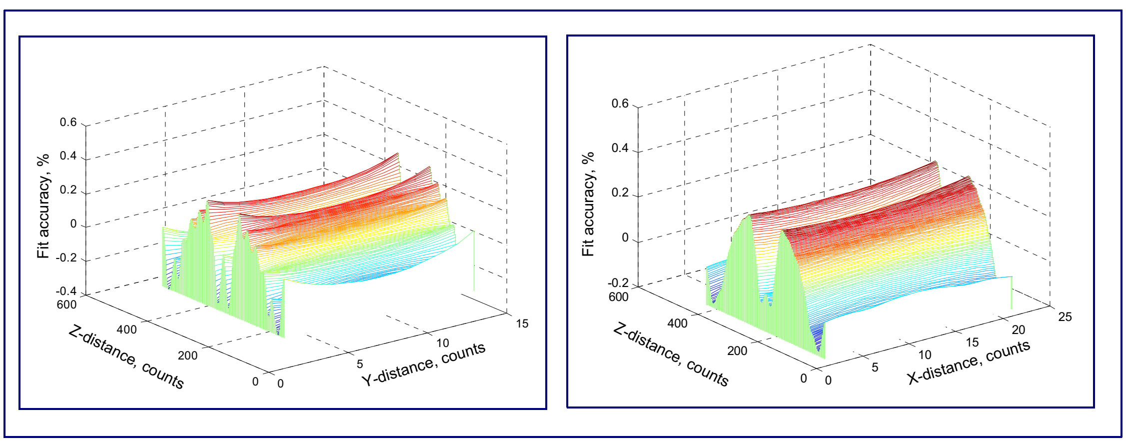
$$\frac{q}{p_0}A_y=\frac{B_ok_1}{kk_2}\sin(k_1x)\sin h(k_2y)\sin(kz)-\frac{G_0}{k}\cos h(k_3x)\cos(k_1y)\sin(kz+\varphi)$$

Hamiltonian for EPU ($k_1=k_4=0$):

$$\langle H\rangle_{\lambda u}\approx\frac{p_x^2+p_y^2}{2(1+\delta)}-\frac{B_0^2y^2+G_0^2x^2}{4(1+\delta)}+\frac{k^2}{12(1+\delta)}(B_0^2y^4+G_0^2x^4)-\delta+O(p^4).$$

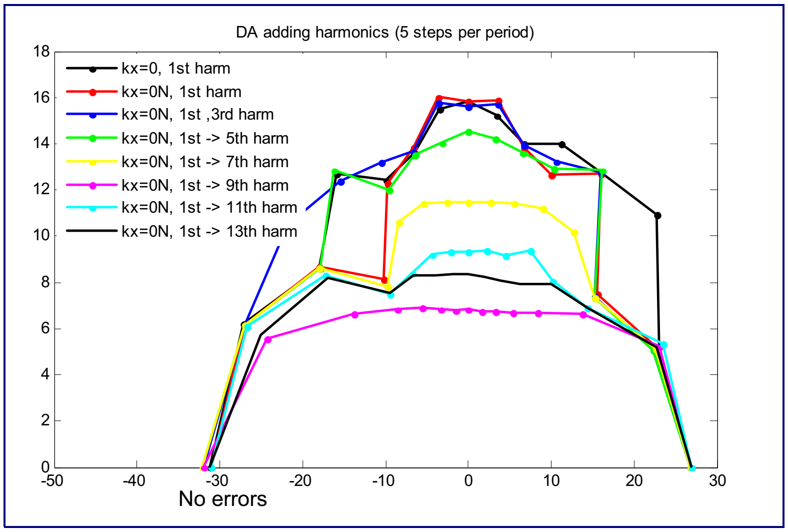
DW80: Fit Quality $\Delta B_y/B_y$ [%].

(T. Shaftan, T. Tanabe)



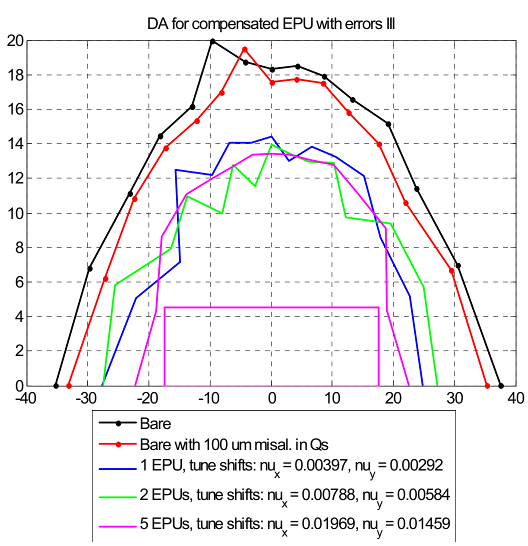
Impact of one Damping Wiggler on DA

(T. Shaftan, T. Tanabe)



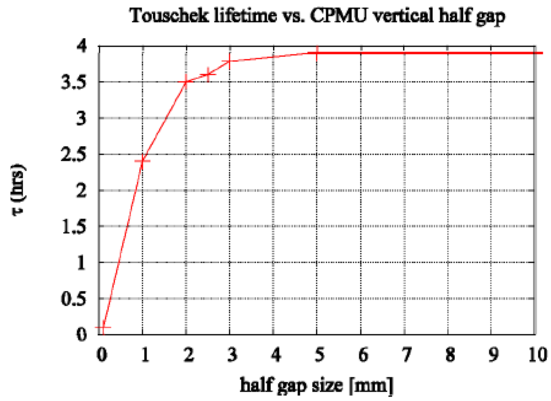
Impact of EPUs

(T. Shaftan, T. Tanabe)



6.0 Touschek Lifetime

Add 5 CPMU's to CDR Lattice:



Parameters:

$$Q = 1.3\ \mathrm{nC}$$
$$\epsilon_x = 10^{-9}\ \mathrm{m}$$
$$\epsilon_y = 10^{-11}\ \mathrm{m}$$
$$\sigma_z = 5\ \mathrm{mm}$$
$$\sigma_\delta = 10^{-3}$$
$$\delta_{\mathrm{RF}} = 3\%$$

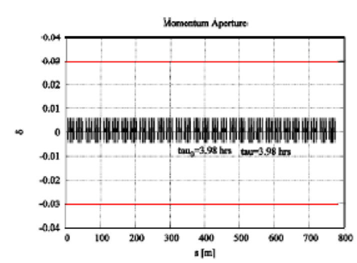
Misalignments + Orbit correction w/ girders

FIG. 4. Effect of ID gaps on Touschek Lifetime (B. Nash).

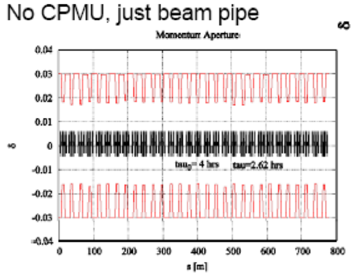
Effect of CPMUs on Momentum Aperture

(B. Nash)

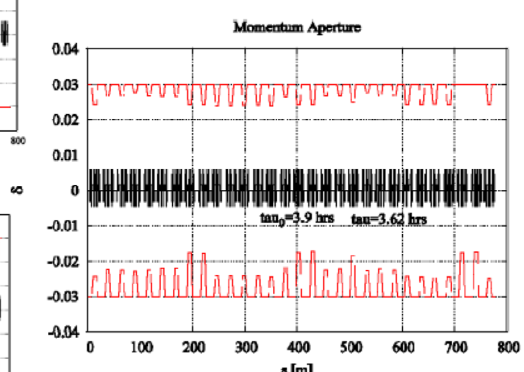
$\delta_{\mathrm{RF}} = 3\%$



No CPMU, just beam pipe



No CPMU's, +/- 2.5 mm apertures

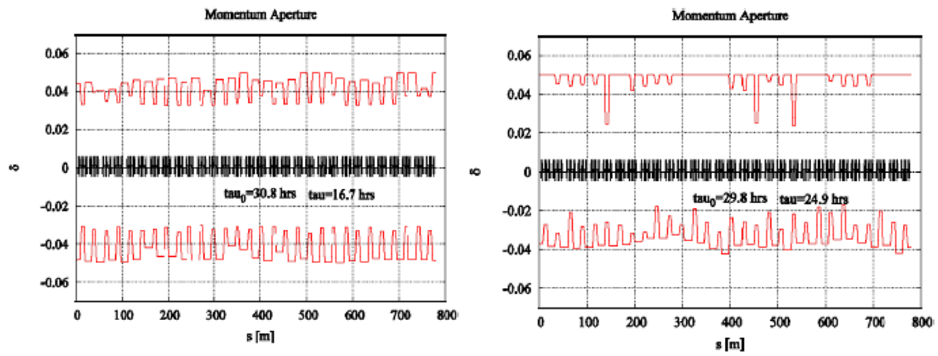


5 CPMU, +/- 2.5 mm apertures

Effect of One DW on Momentum Aperture

(B. Nash)

$\delta_{\mathrm{RF}} = 5\%$



No DW

Now add 1 DW (corrected)

7.0 Conclusions

- We have presented a snapshot of on-going modeling and design activities.
- We believe that we now have the necessary infrastructure for a timely, pro-active delivery on a CD2 design. In particular: modeling based on 3D field maps, TQM for the magnet reference design, and self-consistent approach for realistic Touschek lifetime estimates.
- While there are many issues that need to be evaluated and addressed, we do not see any show stoppers from the preliminary results.
- However, the relatively strong impact of a realistic damping wiggler is a concern, i.e., requires care.

8.0 To Do List

- Complete modeling of insertion devices and provide guidelines on tolerances.
- Evaluate Touschek life time for a realistic lattice (self-consistent approach).
- Evaluate the feasibility to increase the momentum aperture goal to 3+% (by beam studies at the SLS).
- Evaluate tolerance for positive linear chromaticity.
- Validate the magnet reference design.
- Evaluate the merit of introducing octupoles.