Touschek Lifetime and Higher Order Multipole Requirements for NSLS-II.

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BNL, NSLS-II
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Overview

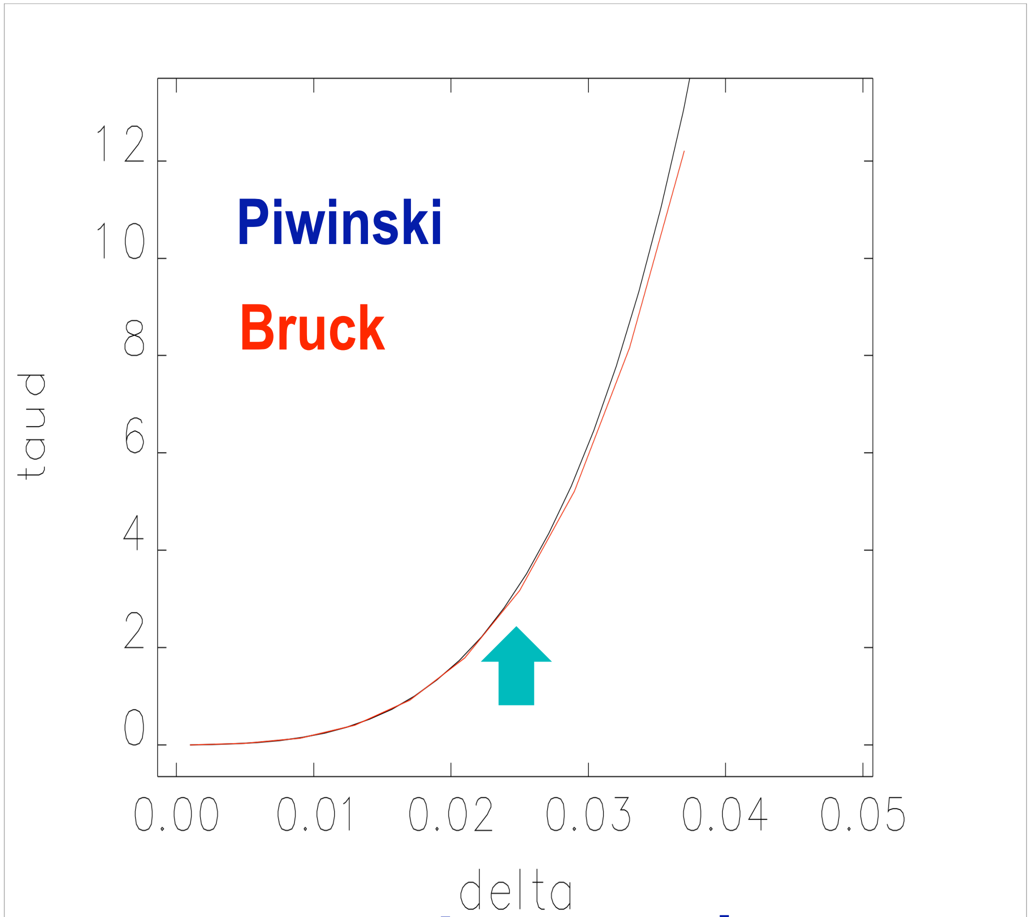
- Touschek Lifetime
- Momentum Aperture Requirements
- Expected Magnet Multipole Errors
- Impact of Multipole Errors on Momentum Aperture
- Other Effects that will Limit Momentum Aperture
- Conclusions

Touschek Lifetime requirement is τ > 3 hr

$$\frac{1}{\tau} = \left\langle \frac{r_0^{\,2} c N}{8\pi\gamma^3 \sigma_x \sigma_y \sigma_s \sigma_{x'} \delta_{acc}^{\;\;2}} C(\varepsilon_m) \right\rangle$$

$$\varepsilon_m = \frac{\delta_{acc}^{\;\;2}}{\gamma^2 \sigma_{x'}^{\;\;2}}$$

$$C(\varepsilon_m) = \int_0^1 \left(\frac{1}{u} - \frac{1}{2} \ln \frac{1}{u} - 1 \right) e^{-\frac{\varepsilon_m}{u}} du$$

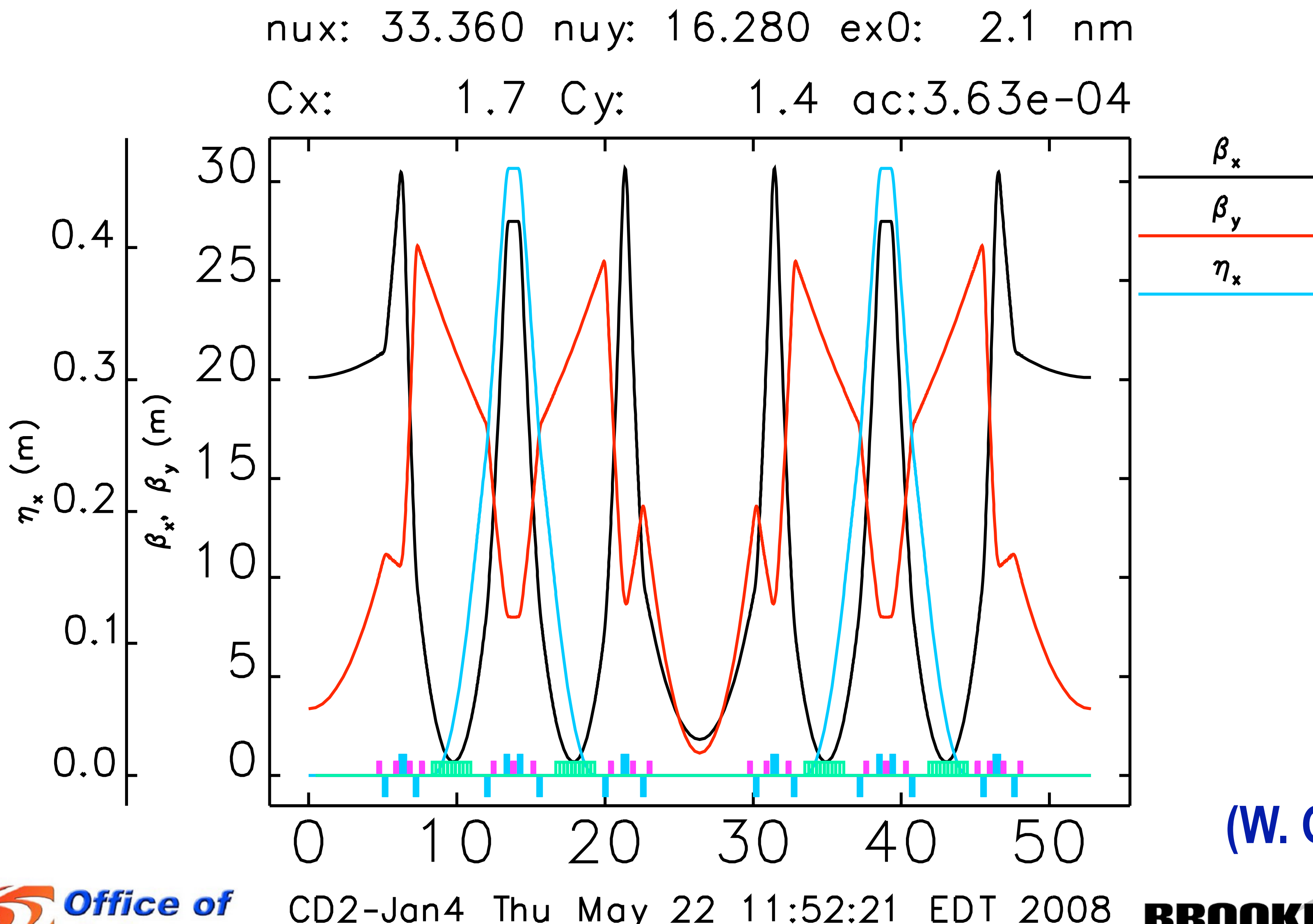


eps_x = 1nm   sig_s =4.5 mm

eps_y = 10pm   Q=1.3nC

δ_acc = 2.5% gives τ=3hr

δ_RF = 3%.


nux: 33.360 nuy: 16.280 ex0: 2.1 nm
Cx: 1.7 Cy: 1.4 ac:3.63e-04
β_x
β_y
η_x
η_x (m)
β_x, β_y (m)
0.0
0.1
0.2
0.3
0.4
0
5
10
15
20
25
30
0
10
20
30
40
50
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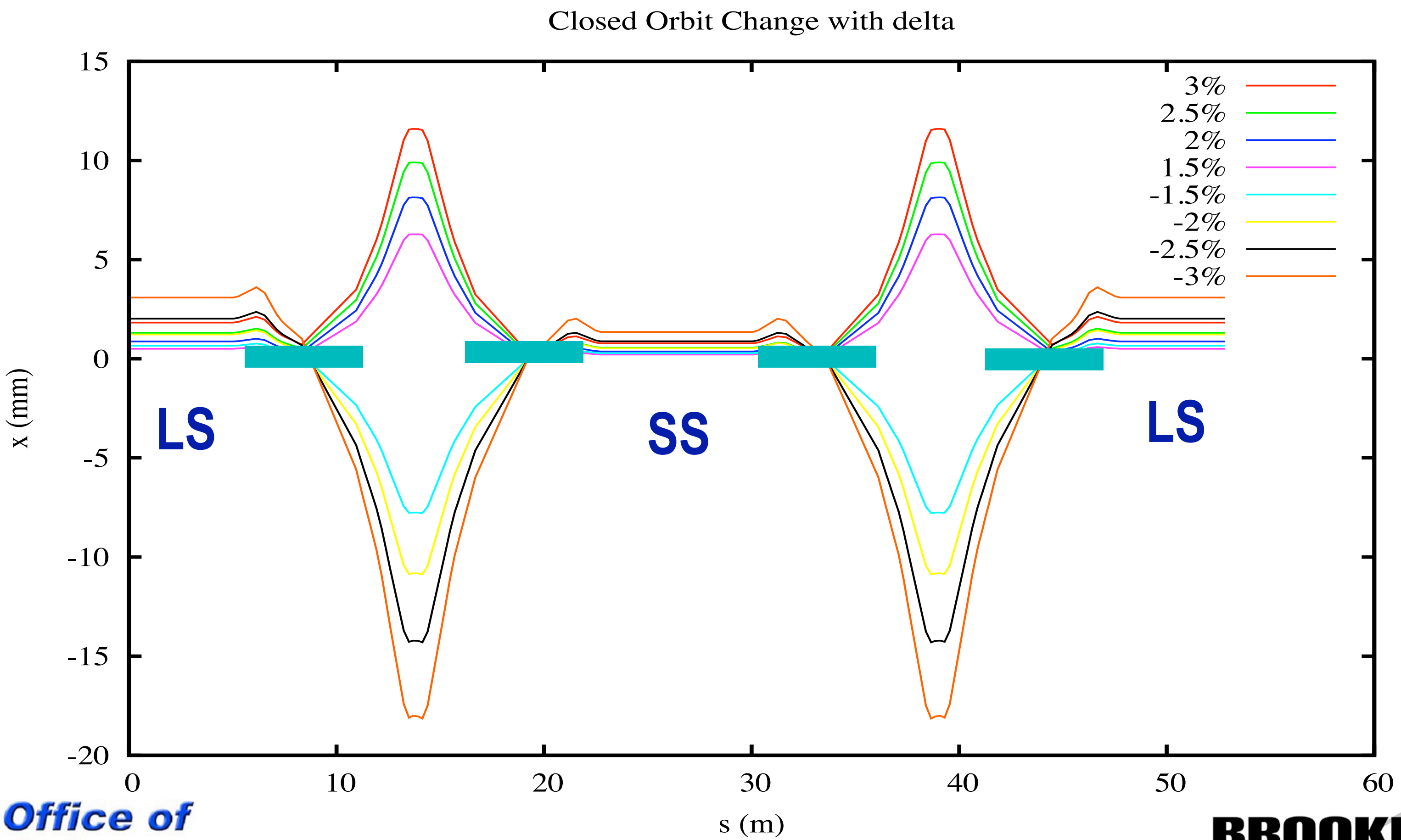
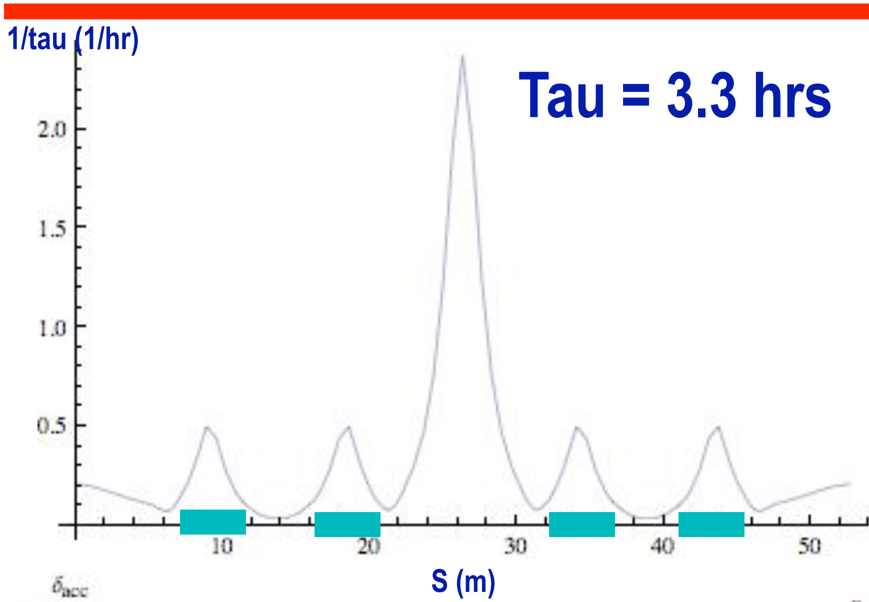
(W. Guo)

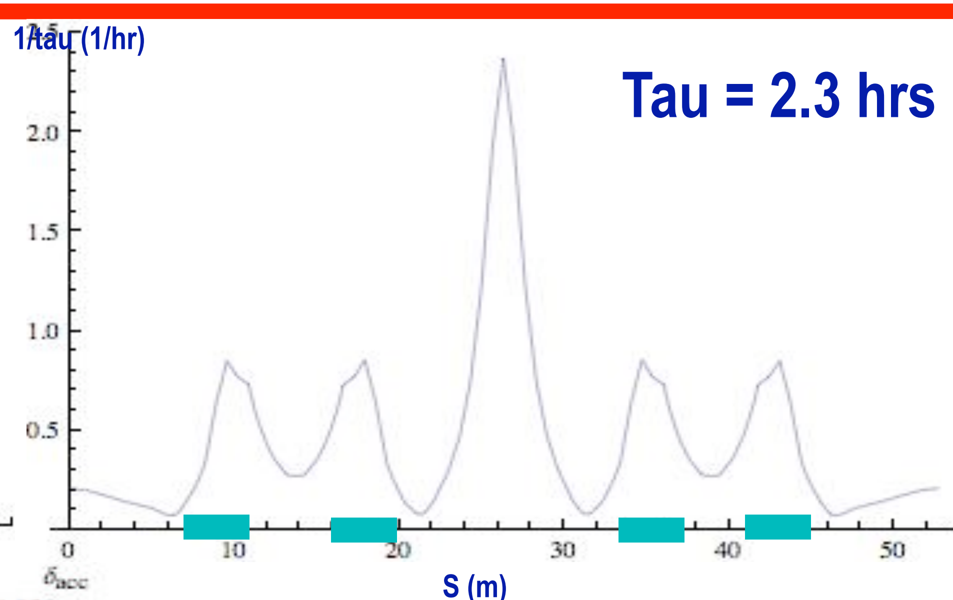
Momentum Acceptance varies around the ring

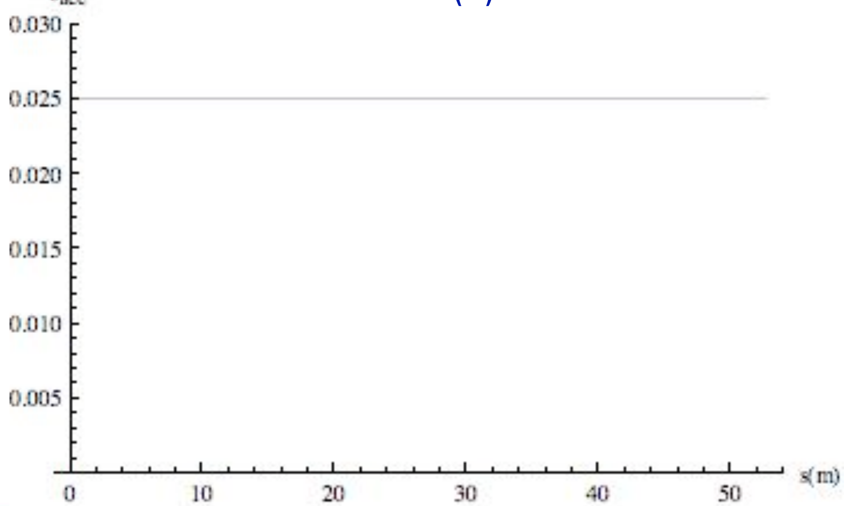
- Dispersion (linear + non-linear) sets resulting amplitude of oscillation for Touschek scattered particle.

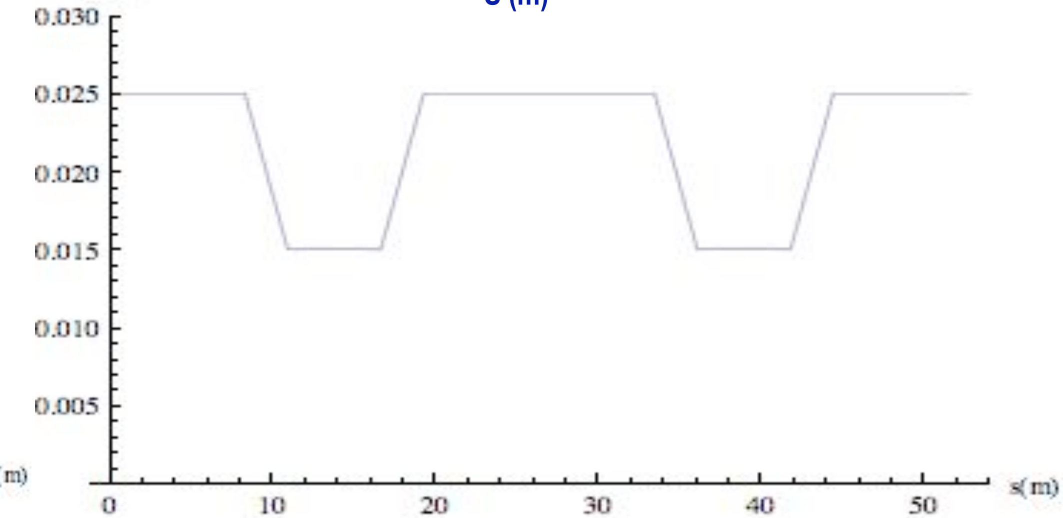


Local Touschek Scattering Rate









δ_acc(str)	δ_acc(disp)	τ (hr)
3%	3%	6.2
3%	2.5%	5.5
3%	2.0%	4.6
3%	1.5%	3.3
2.5%	2.5%	3.3
2.5%	2.0%	2.9
2.5%	1.5%	2.3

Magnetic Field Multipole Expansion

$$(B_y + iB_x)(r,\phi) = B\rho \sum_n (b_n + ia_n) r^{n-1} e^{i(n-1)\phi}$$

b_1 = dipole, b_2 = quadrupole, b_3 = sextupole

a_n = skew components

$$(B_n + iA_n)(R) = \frac{1}{2\pi} \int_0^{2\pi} (B_y + iB_x)(\phi; R) e^{-i(n-1)\phi} d\phi$$

Measured by

Rotating coil

$$B_N{}^n = \frac{\int_0^L B_n(s;R)ds}{\int_0^L B_N(s;R)ds} \propto R^{n-N}$$

Field ratio of given harmonic to design field

at a given radius. Here we use R = 25 mm.

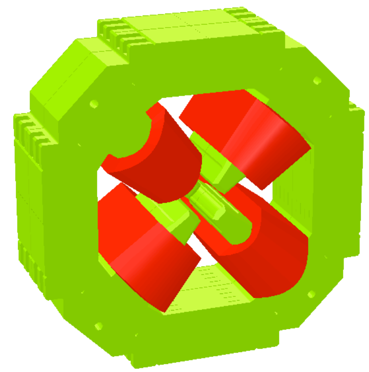
Sources of Systematic and Random Multipole Errors

- For ideal, symmetric magnets, higher order multipoles consistent with symmetry (“allowed multipoles”): N(2m+1), m=0,1,2,…

  dipole: 1,3,5,7, …

  quadrupole: 2, 6, 10, 14, …

  sextupole: 3, 9, 15, 21, …



- Random Errors from manufacturing tolerances

Specifications for systematic and Random Multipole Errors (Apr. 28)

Random quad

1	0.00E+00	1.00E-04
2	0	0.00E+00
3	3.00E-04	1.00E-04
4	1.00E-04	1.00E-05
5	1.00E-05	1.00E-05
6	0	1.00E-05
7	1.00E-05	1.00E-05
8	1.00E-05	1.00E-05
9	1.00E-05	1.00E-05
10	0.00E+00	1.00E-05
11	1.00E-05	1.00E-05
12	1.00E-05	1.00E-05
13	1.00E-05	1.00E-05
14	0.00E+00	1.00E-05
15	1.00E-05	1.00E-05
16	1.00E-05	1.00E-05
17	1.00E-05	1.00E-05
18	1.00E-05	1.00E-05
19	1.00E-05	1.00E-05
20	1.00E-05	1.00E-05

Random sextupole

1	1.00E-03	1.00E-04
2	0	1.00E-04
3	0.00E+00	1.00E-04
4	1.00E-04	1.00E-04
5	5.00E-05	1.00E-05
6	5.00E-05	1.00E-05
7	5.00E-05	1.00E-05
8	1.00E-05	1.00E-05
9	0.00E+00	1.00E-05
10	2.00E-05	1.00E-05
11	2.00E-05	1.00E-05
12	2.00E-05	1.00E-05
13	2.00E-05	1.00E-05
14	2.00E-05	1.00E-05
15	0.00E+00	1.00E-05
16	1.00E-05	1.00E-05
17	1.00E-05	1.00E-05
18	1.00E-05	1.00E-05
19	1.00E-05	1.00E-05
20	1.00E-05	1.00E-05

Low disp. systematic

Q	6	1.00E-04	0
	10	3.30E-04	0
	14	3.50E-04	0
S	9	1.00E-04	0
	15	1.00E-04	0
	21	4.00E-04	0

High disp. systematic

Q	6	1.00E-04	0.00E+00
	10	5.00E-05	0
	14	1.00E-05	0
S	9	5.00E-05	0
	15	5.00E-05	0
	21	5.00E-05	0

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(R=25 mm)

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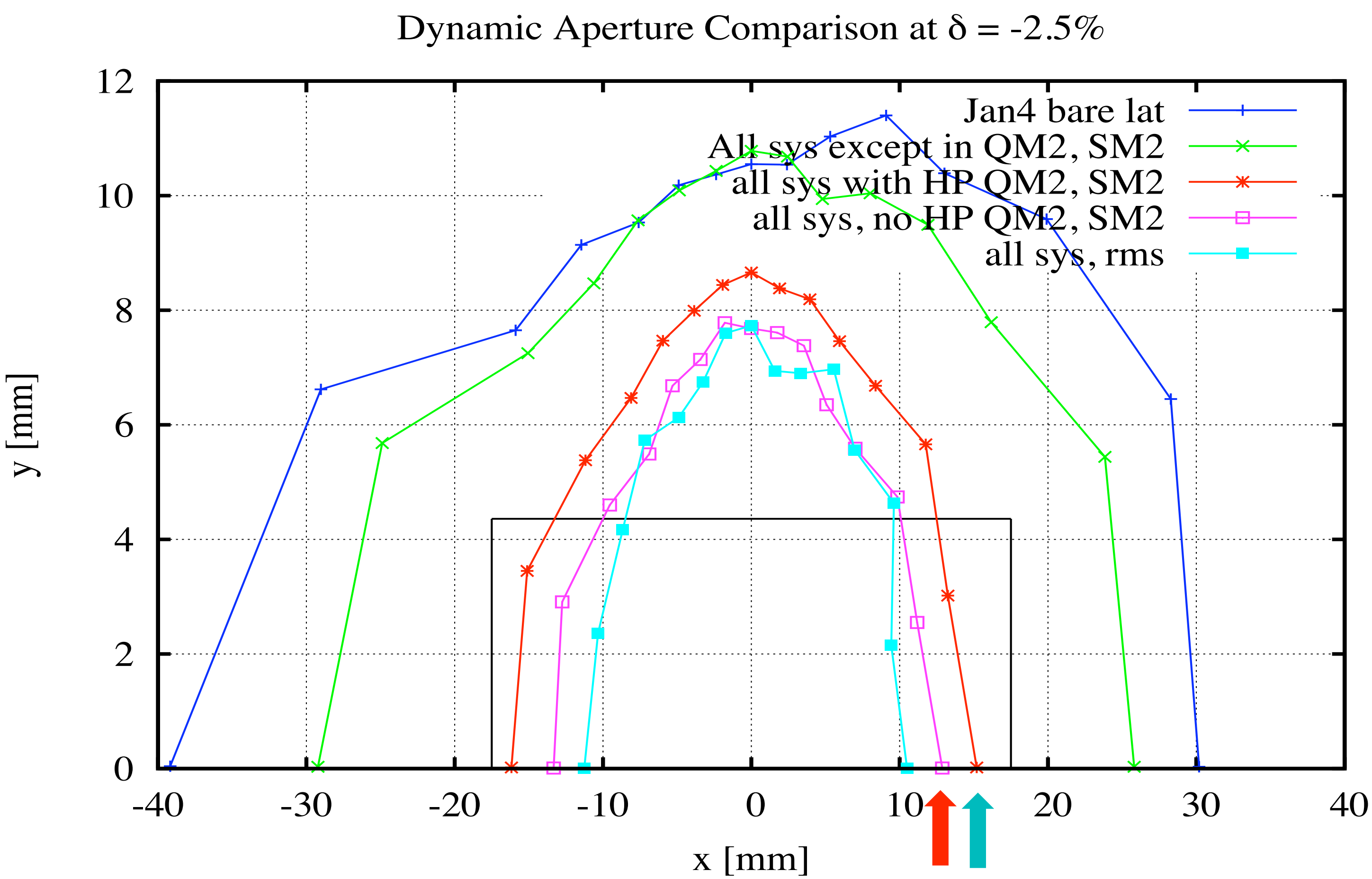
Systematic Multipole Errors

	NSLS-II regular	NSLS-II HP	SOLEIL	CELLS	SLS
B_2^6	1	1	1	2	1.1
B_2^{10}	3.3	0.5	0.2	4	-2.5
B_2^{14}	3.5	0.1	0.1		
B_3^9	1	0.5	-1	5	-2
B_3^{15}	1	0.5	-0.5	7	6.9
B_3^{21}	4	0.5			

R = 25 mm

Impact of multipole errors on off-momentum DA



Tightening tolerances increases DA by ~3mm

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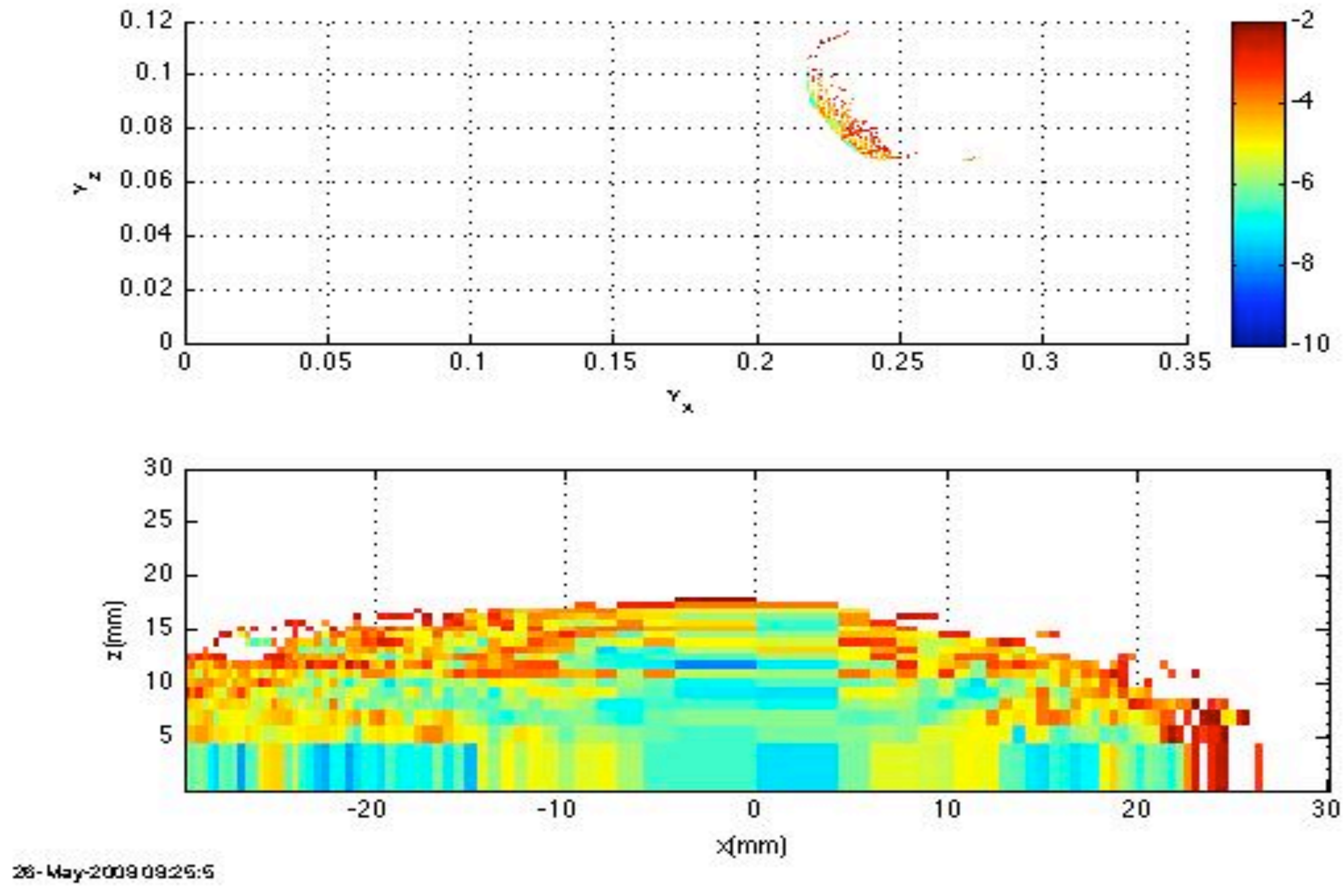
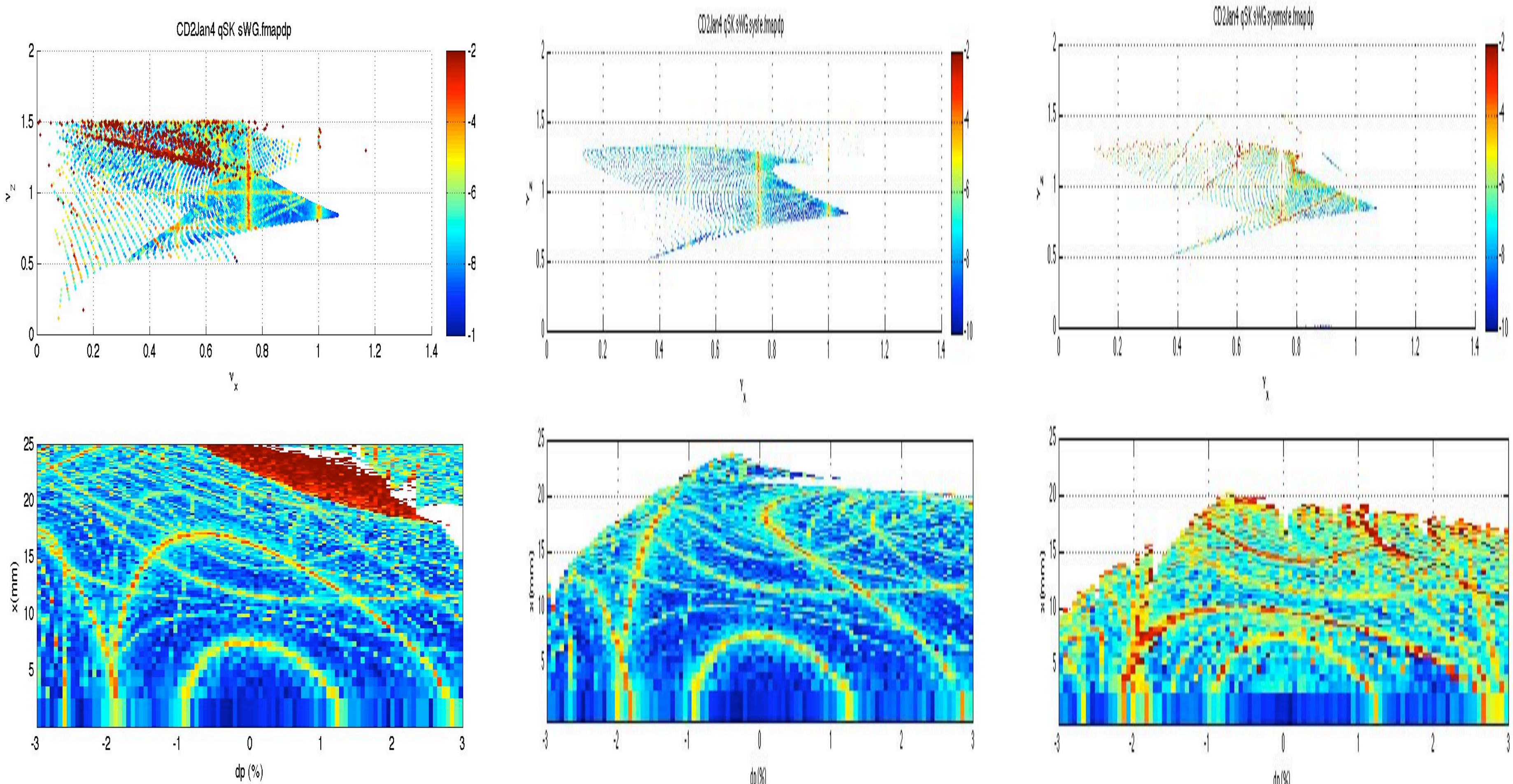
Bare Lattice On-Momentum Frequency Map



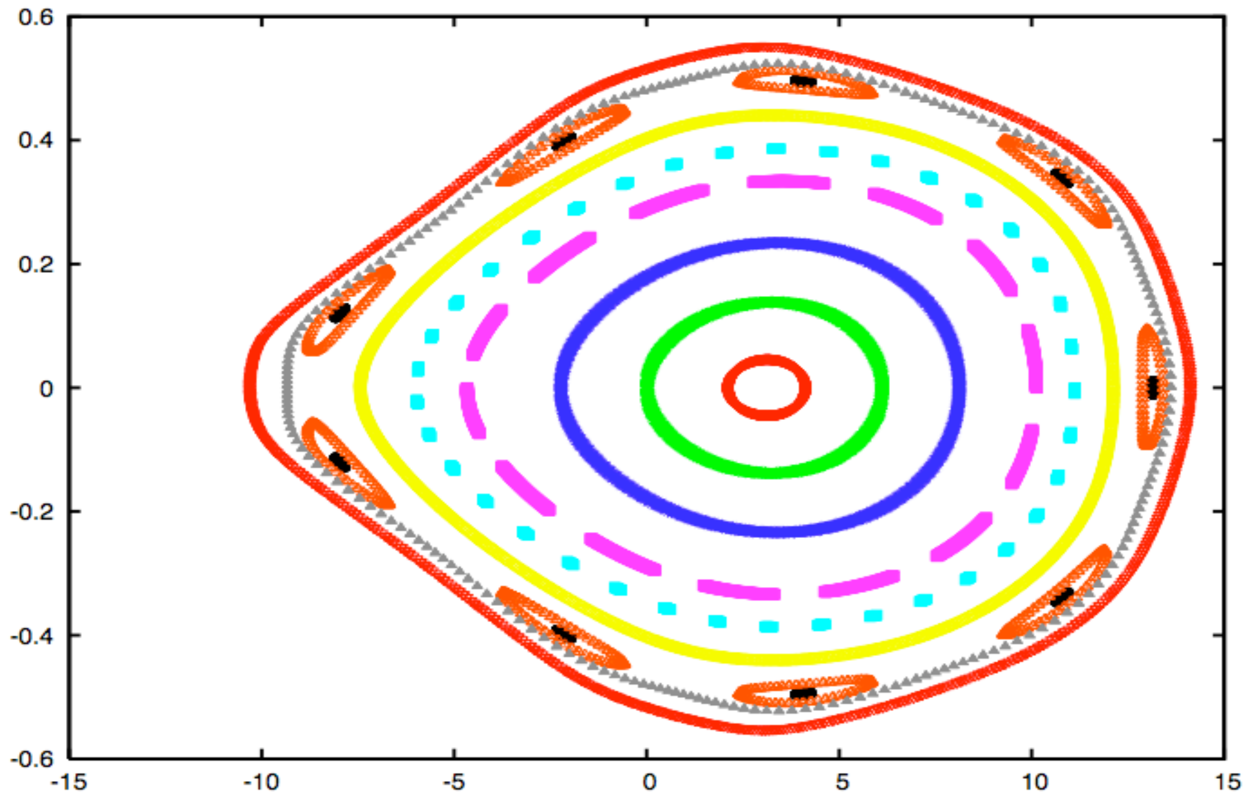
X-δ Frequency Map



No errors   Systematic errors   Sys + Rand errors

(Tracy 3 w/ NAFF)

Orbits (δ = −3%) Approaching Unstable Boundary



X’ (mrad)

X (mm)

Effects that Impact Momentum Aperture

- **Physical Apertures**

Horizontal: vacuum chamber, absorbers…

Vertical: IVU (+/- 2.5 mm)

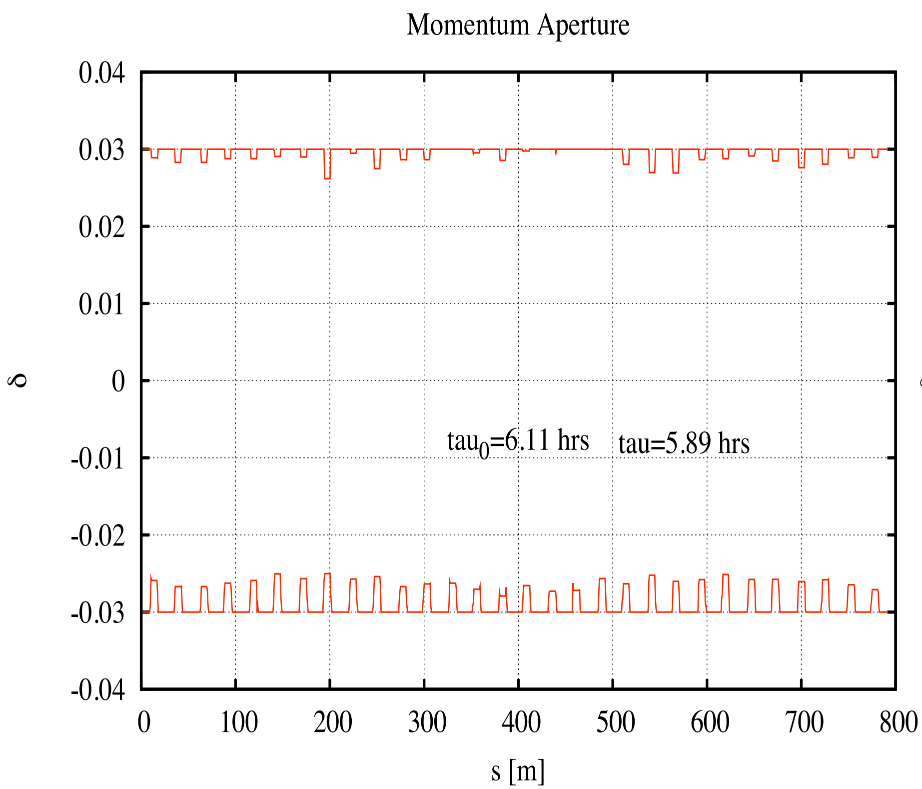
- **Dynamic Aperture**

Further non-linearities:

ID's: DW's, IVU's, EPU, etc.

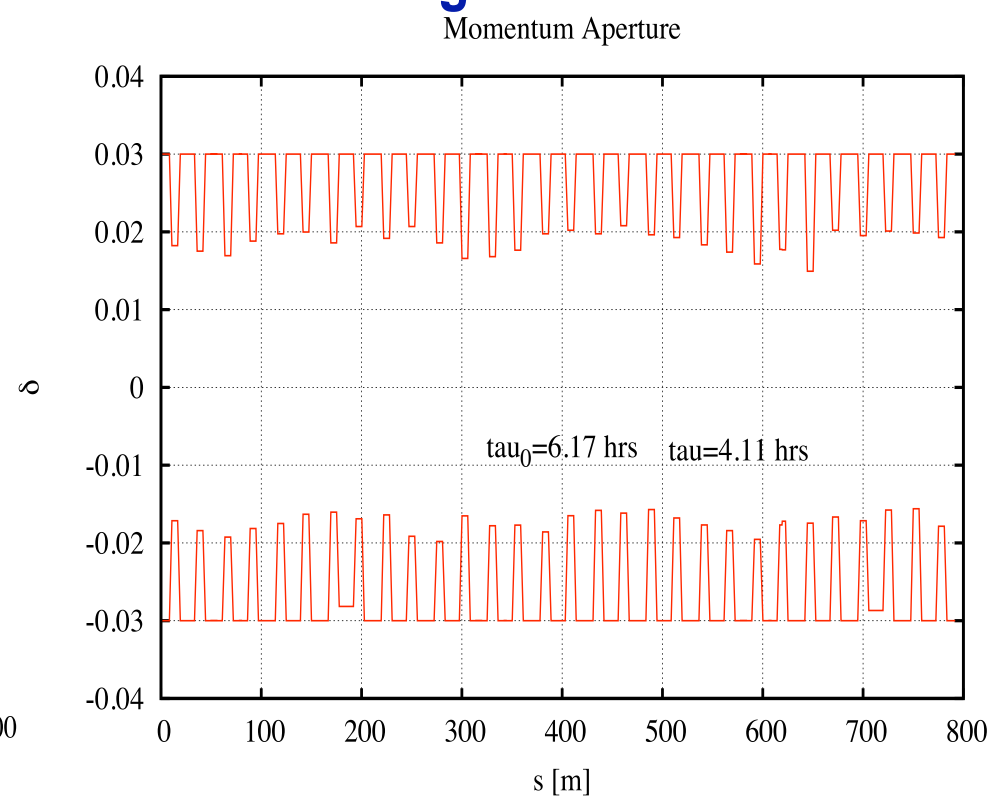
Momentum Aperture Results

- Field errors



Also add:

- 3 DW, 3 IVU
- +/- 2.5 mm IVU gap
- Align err + Correction



(DW: λ=90mm, B=1.8T,n=78)
(IVU: λ=20mm, B=1.2T,n=160)

Conclusions

- 3 hour Touschek Lifetime requires sufficient momentum acceptance
- Most scattering occurs in short straight section where the beam size is small. Fortunately, dispersion is small here, due to achromatic condition.
- $\delta\_acc(str) = 2.5\%$, $\delta\_acc(disp) = 1.5\%$ still allow $\tau > 4$ hr, with Landau cavity.
- Multipole errors (particularly in disp. region and for $dp < 0$) decrease off momentum dynamic aperture.
- Random multipole errors cause degradation of frequency map which can reduce DA when additional errors are added. More study on expected errors needed.
- Increasing high dispersion quadrupole/sextupole aperture decreases impact of higher order multipole errors.
- Touschek lifetime calculation/analysis is going on in parallel with lattice optimization. This is an iterative process.

Extra Slides

Compare Systematic Multipole Errors

Regular Quadrupoles	BNL Bn/B2		SLS/BINP Bn/B2	SLS/BNL Bn/B2	SOLEIL Bn/B2		SPEAR Bn/B2	CELLS "sqrt(An^2+Bn^2)/B2"	CELLS Bn/B2	
	Calculated*	Specs	Measured		Measured	Calculated	Measured	Specs	Calc scaled 20 mm	high precision BNL
n	25 mm	25 mm	25 mm	25 mm	25 mm	25 mm	25 mm	25 mm	25 mm	
3										
4										
5										
6	2.18	1.00	1.14	1.83	1.16		2.41	2.0	3.05	-0.55
10	-4.54	4.50	-2.50	-2.50	0.16	0.33	1.16	4.0	-2.98	-0.43
14	-3.74	4.00			0.10	0.08				0.02

Regular Sextupoles	BNL Bn/B2		SLS/BINP Bn/B2	SLS/BNL Bn/B2	SOLEIL Bn/B2		SPEAR Bn/B2	CELLS "sqrt(An^2+Bn^2)/B2"	CELLS Bn/B2	
	Calculated*	Specs	Measured		Measured	Calculated	Measured	Calculated	Calc scaled 20 mm	high precision BNL
n	25 mm	25 mm	25 mm	25 mm	25 mm	25 mm	25 mm	25 mm	25 mm	
1	-5.0	10.00	-13.17	6.65						
4										
5										
9	0.52	1	-2.08	-1.17	-1.07	-0.80	1.40	5.0	3.81	0.23
15	0.5	1	6.88	6.94	-0.47	-0.39	0.56	7.0	-14.55	-0.22
21	-3.5	4								0.51

(M. Rehak)