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APS 1-nm Lattice Design

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Magnet Layout

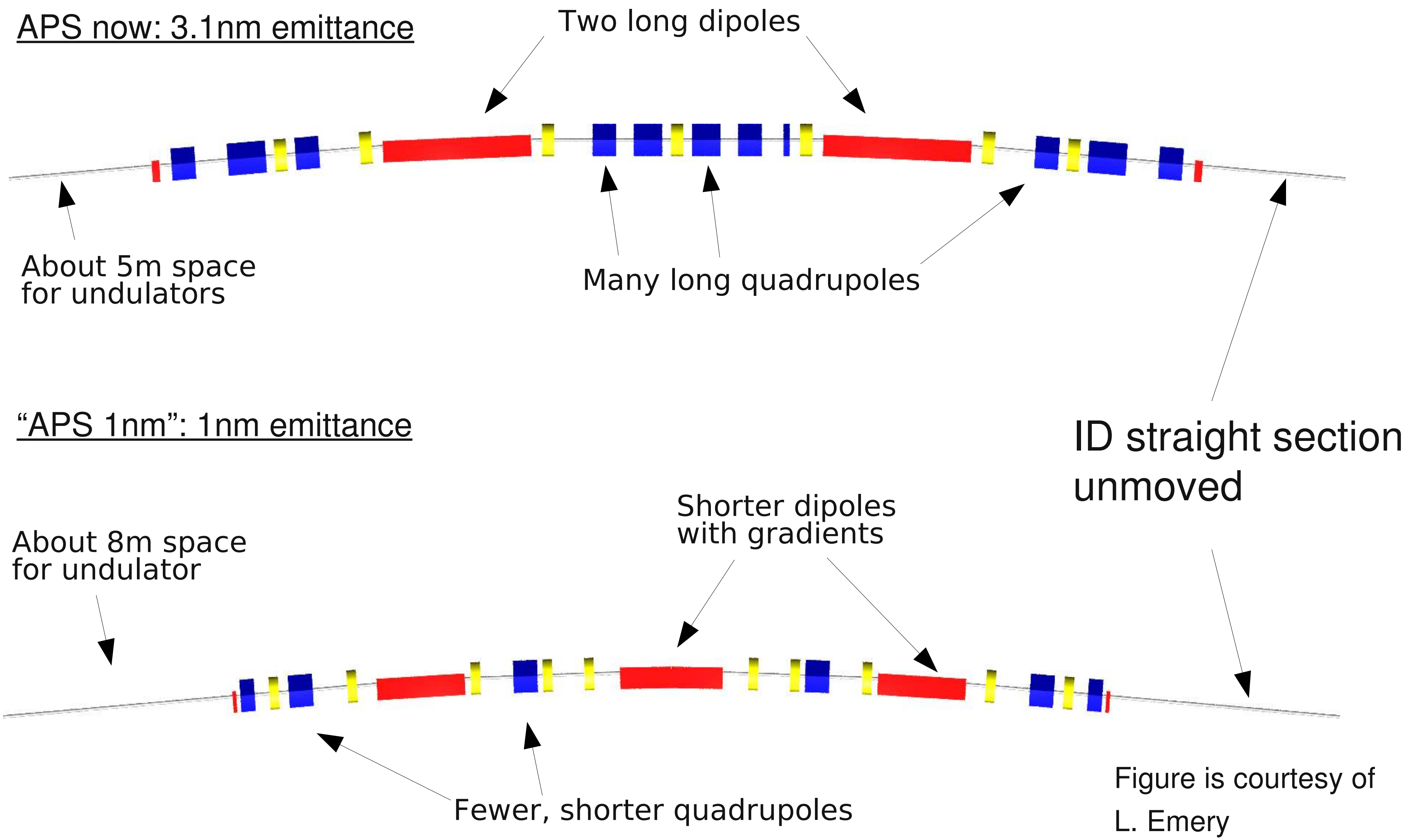
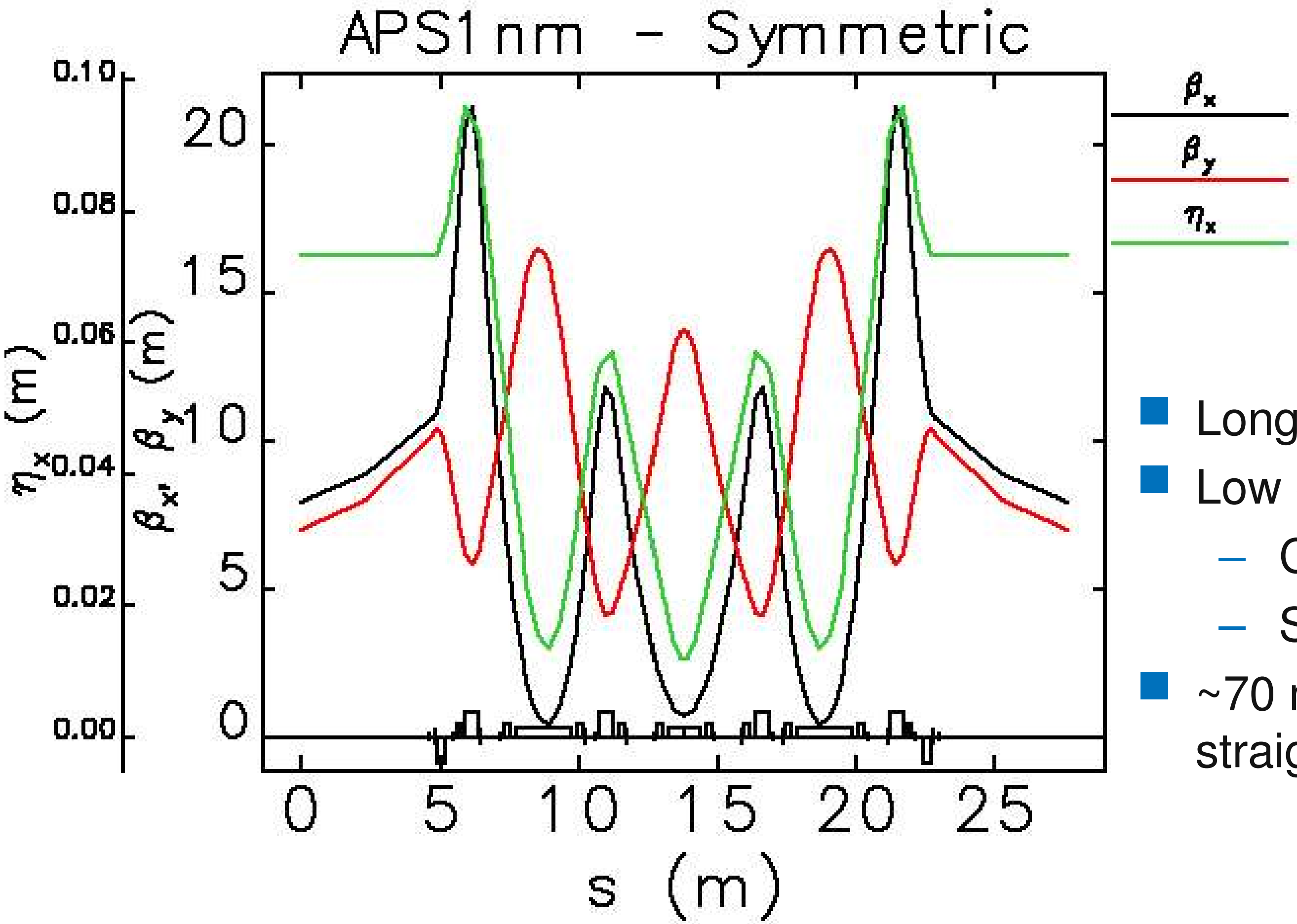


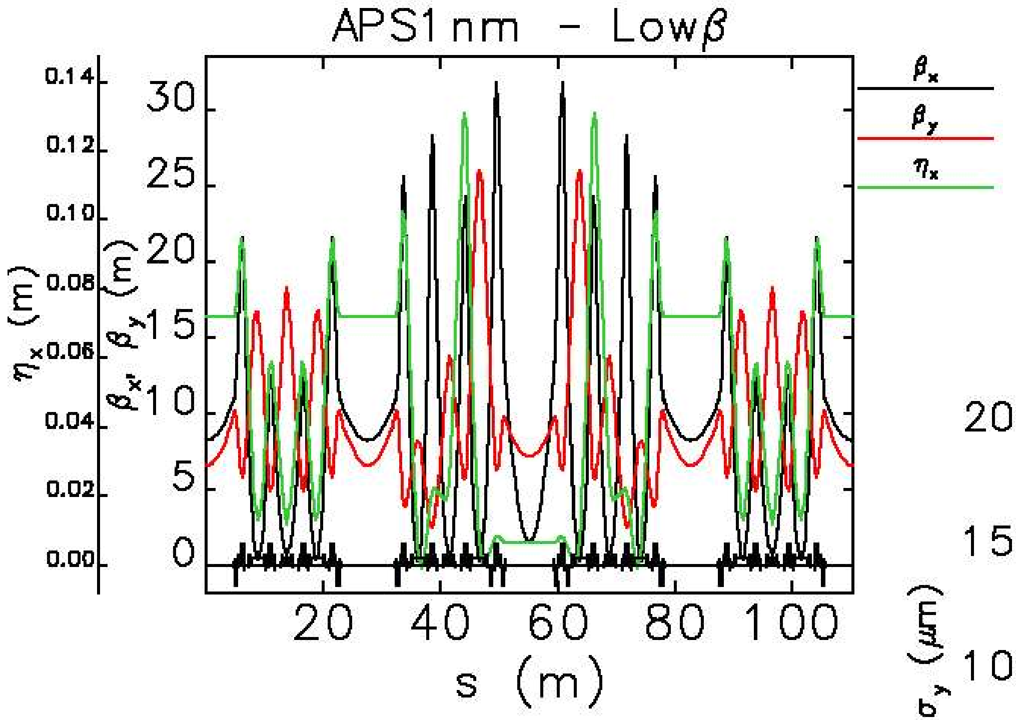
Figure is courtesy of L. Emery

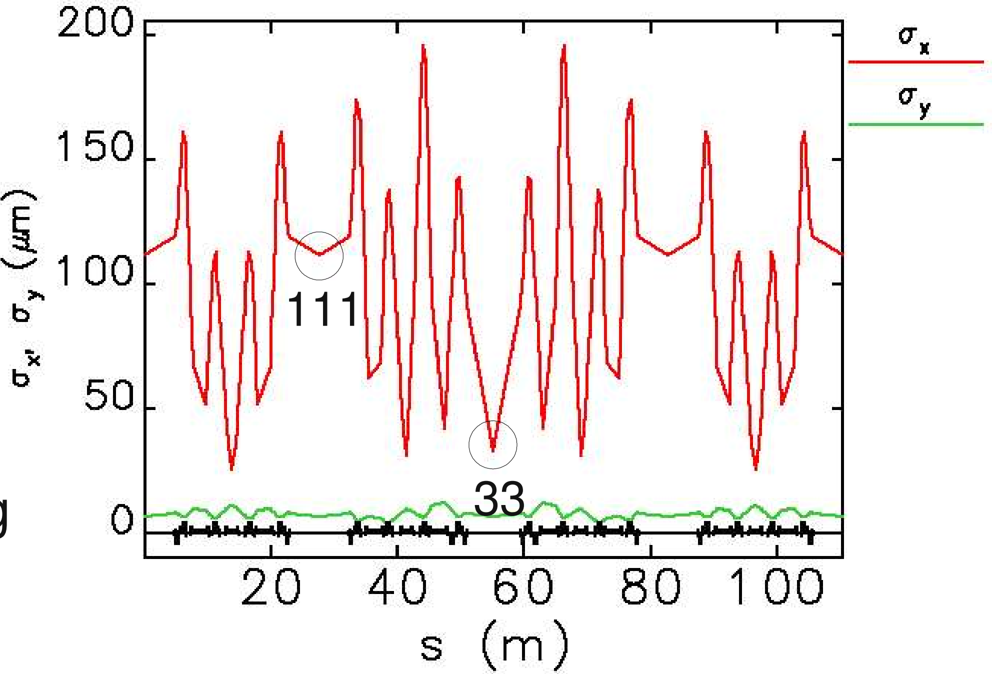
Symmetric Lattice – Optical Function



- Longer straight section ~ 8m
- Low effective emittance
  - Combined function magnet
  - Stronger focusing
- ~70 mm dispersion at ID straight section

Low-β Lattice – Optical Function





Total 4 low-β insertions around ring

General Parameter

	Symmetric	Low-Beta	APS
Energy (GeV)	7	7	7
Effective emittance (nm rad)	0.89	1	3.1
Betatron tune X	57.3	59.4	36.2
Betatron tune Y	21.4	21.23	19.26
Chromaticity X	-127.4	-153.8	-92
Chromaticity Y	-45.1	-48	-45
Energy spread	1.16×10^{-3}	1.15×10^{-3}	0.96×10^{-3}
Energy loss per turn (MeV)	6.5	6.5	5.4
Momentum compaction	1.04×10^{-4}	1.01×10^{-4}	2.81×10^{-4}

Bend

Table 2: Combined-function Bending Magnet Strength for APS1nm Lattice

			APS1nm - Sym.	APS1nm - Lowβ
Name	$L[m]$	$Angle[rad]$	$K1[m^{-2}]$	$K1[m^{-2}]$
B0	2	0.061	-0.277	-0.268
B1	1.132	0.035	-0.372	-0.384

Harder

Quadrupole

Table 3: Quadrupole Strength for APS1nm Lattice

		APS1nm - Sym.	APS1nm - Lowβ		
			Normal	Type-A	Type-B
Name	$L[m]$	$K1[m^{-2}]$	$K1[m^{-2}]$	$K1[m^{-2}]$	$K1[m^{-2}]$
QI1	0.3	-1.185	-1.199	-1.612	-1.023
QI2	0.5	1.413	1.419	1.633	1.463
QDF	0.5	1.698	1.702	1.659	1.675

2.35

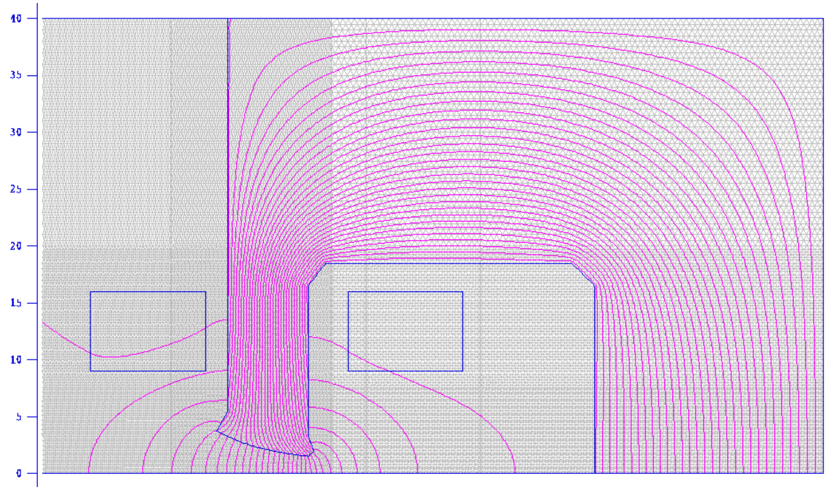
Sextupole

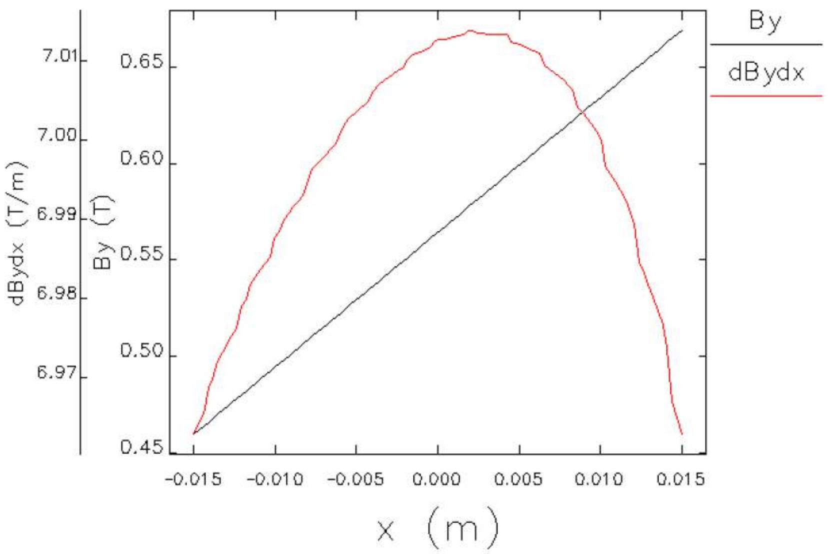
Table 4: Sextupole Strength for APS1nm Lattice

		APS1nm - Sym.	APS1nm - Lowβ		
			Normal	Type-A	Type-B
Name	$L[m]$	$K2[m^{-3}]$	$K2[m^{-3}]$	$K2[m^{-3}]$	$K2[m^{-3}]$
S1	0.2	56.8	71.0	66.5	47.3
S2	0.2	-101.8	-121.2	-93.3	-65.1
SD	0.2	-85.0	-89.4	-84.4	-99.0
SE	0.2	-98.2	-100.1	-51.4	-90.9
SF	0.2	136.8	132.5	87.9	130.0

175

Automated Design Results for Combined Bending Magnets[1]

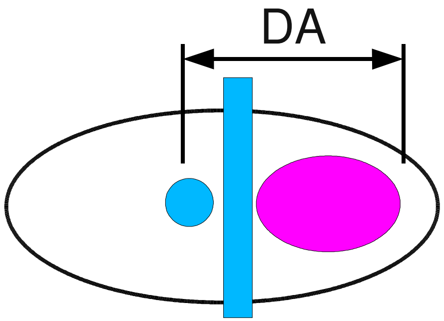




For K1=0.38, it's difficult to get enough good field region.
We are still working on it.

[1]OAG-TN-2006-028 by M.Borland et al.

Dynamic Aperture Requirement

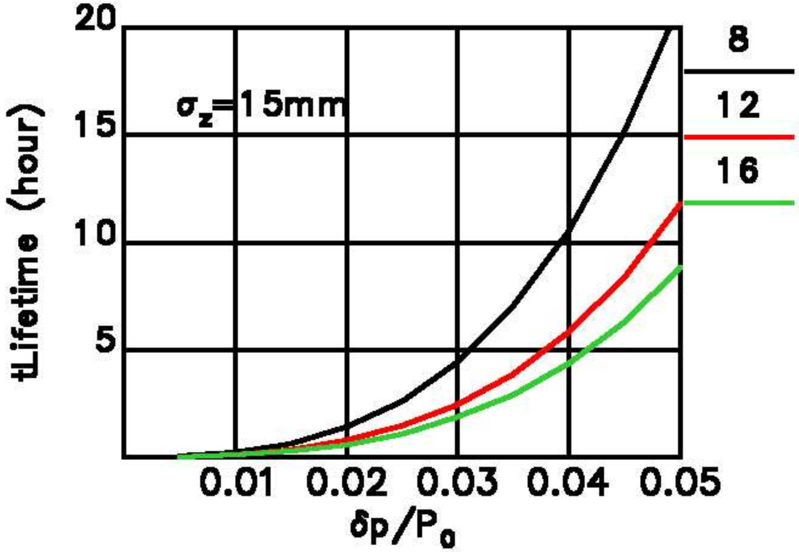


- The required dynamic aperture for injection:

$$6\sigma_{inj} + 3\sigma_{store} + 2\,\mathrm{mm}(\mathrm{septum}) + 0.5\,\mathrm{mm}(\mathrm{margin}) = 6.8\,\mathrm{mm}(@\,65\,\mathrm{nm-rad}, \beta_x = 7\,\mathrm{m})$$

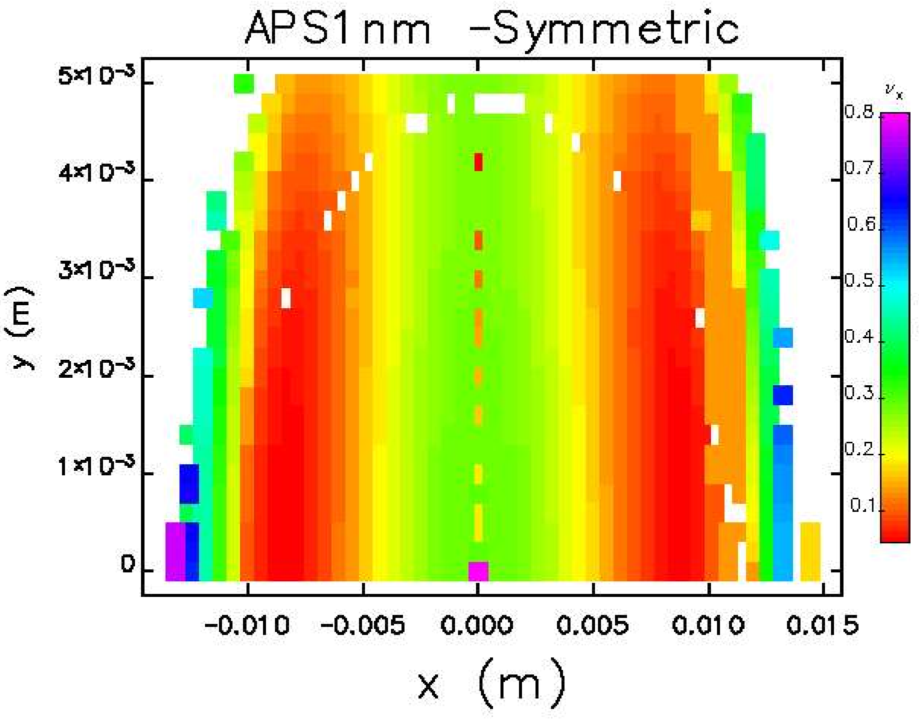
$$6\sigma_{inj} + 3\sigma_{store} + 2\,mm(septum) + 0.5\,mm(margin) = 5.3\,mm(@\,22\,nm-rad, \beta_x = 8\,m)$$

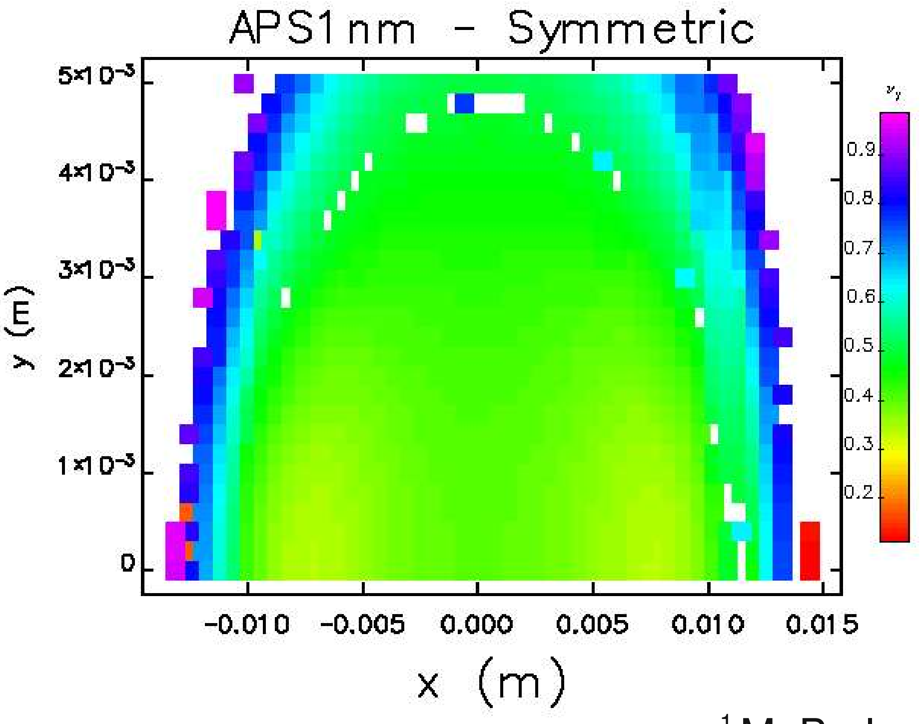
- Touscheck Lifetime:
  - 8.3 mA/bunch for 200 mA in 24 bunches
  - 5 hours lifetime requires 3.2% of momentum dynamic aperture



Symmetric Lattice – FMA

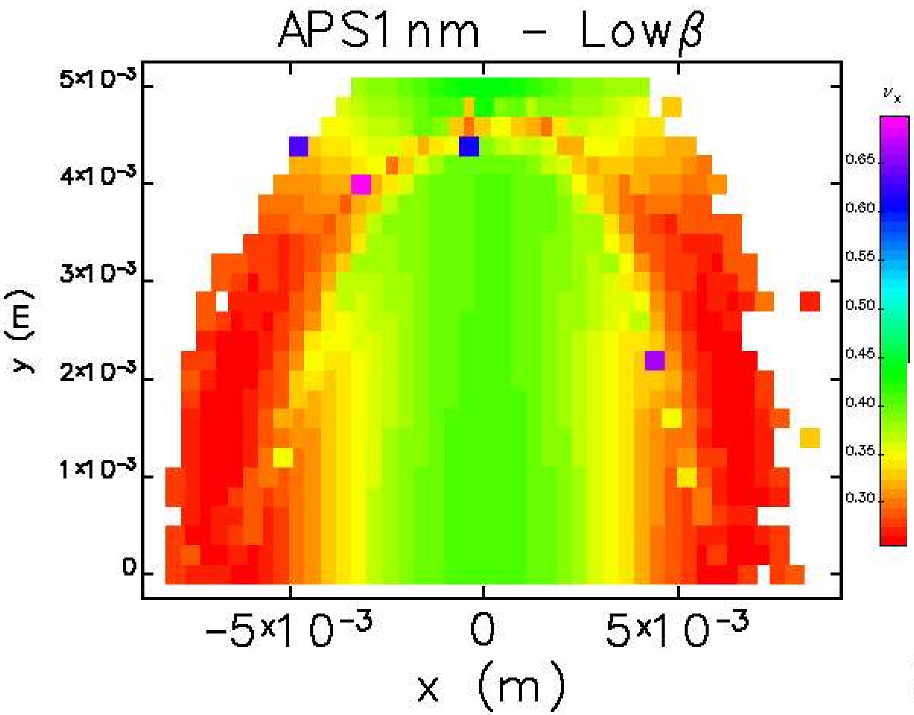
- Dynamic aperture is optimized by using geneticOptimizer [1]
- Tunes, sextupole strength and positions are parameters to change
- Track many particles with dynamic aperture distribution and maximize the number that survive 50~100 turns
- For this case, the 500-turn dynamic aperture is lager than ±10mm

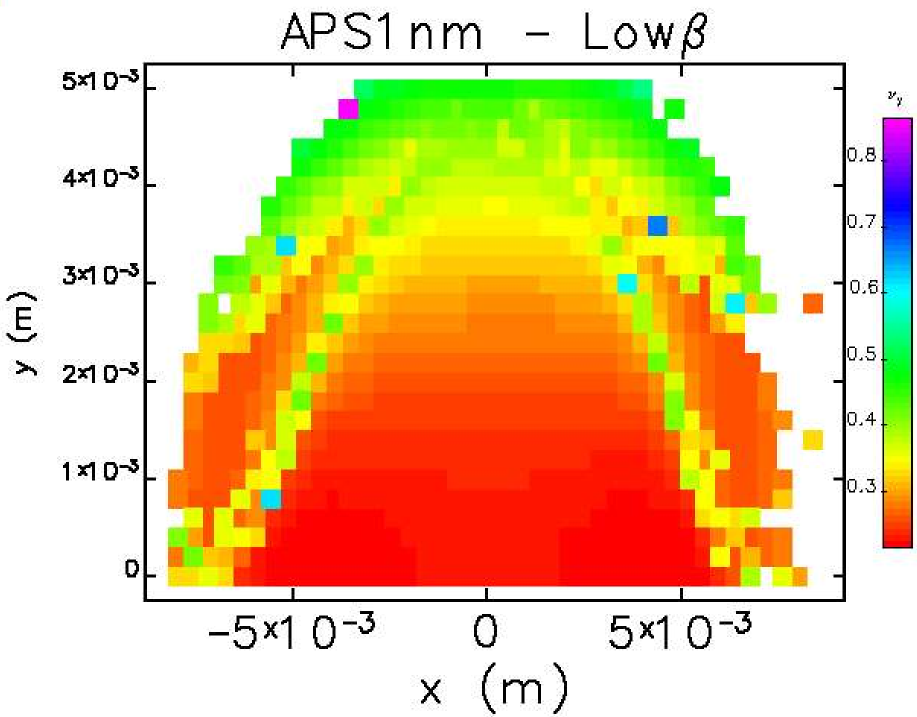




[1] M. Borland

Low-β Lattice – FMA

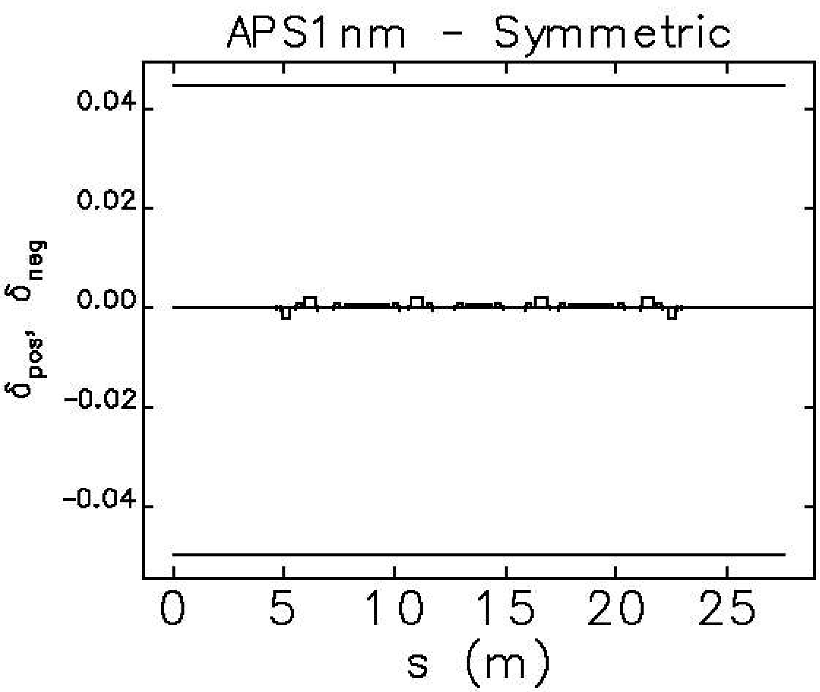


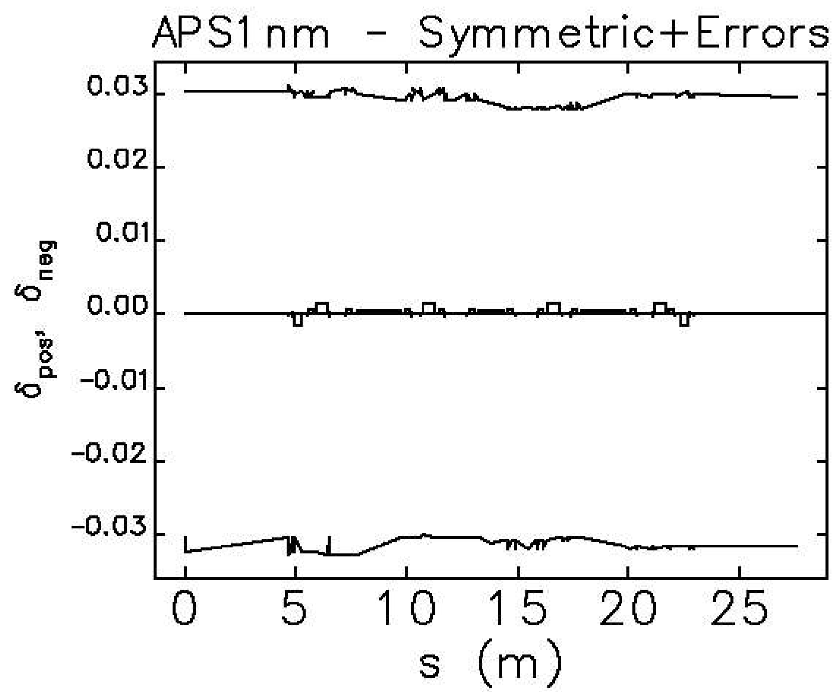


Dynamic aperture is lager than ±8mm

Symmetric Lattice – Momentum Aperture

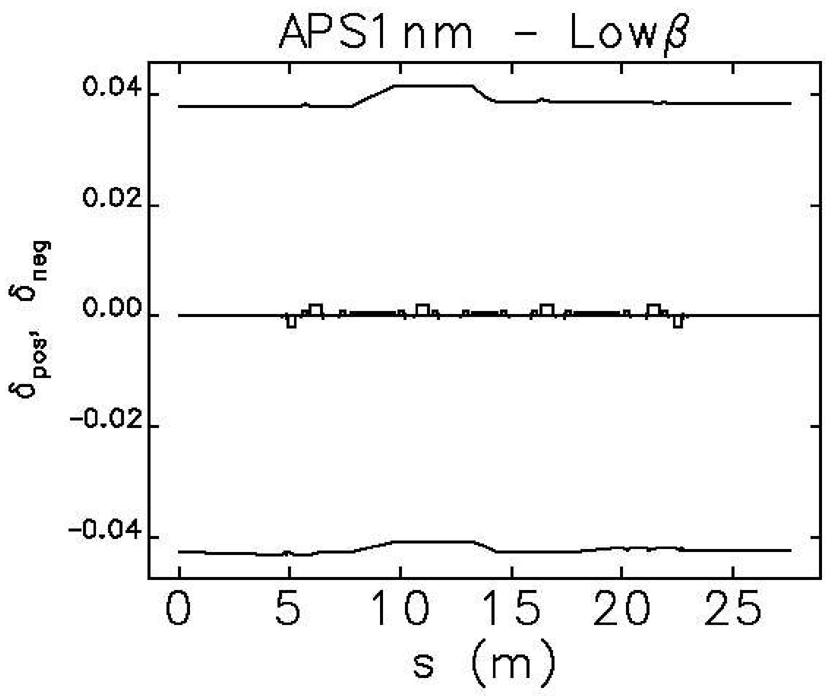
- Momentum aperture is calculated using **elegant**
- Zero displaced particle with momentum deviation at “s” has been tracked for 500 turns for determine local momentum aperture
- Without error, it's limited by RF acceptance (5% for 10MV RF)
- With error (1 seed, 10% of beta beating), ~3% of momentum aperture, which sufficient Touschek lifetime (~5 hrs for 8mA bunch beam)

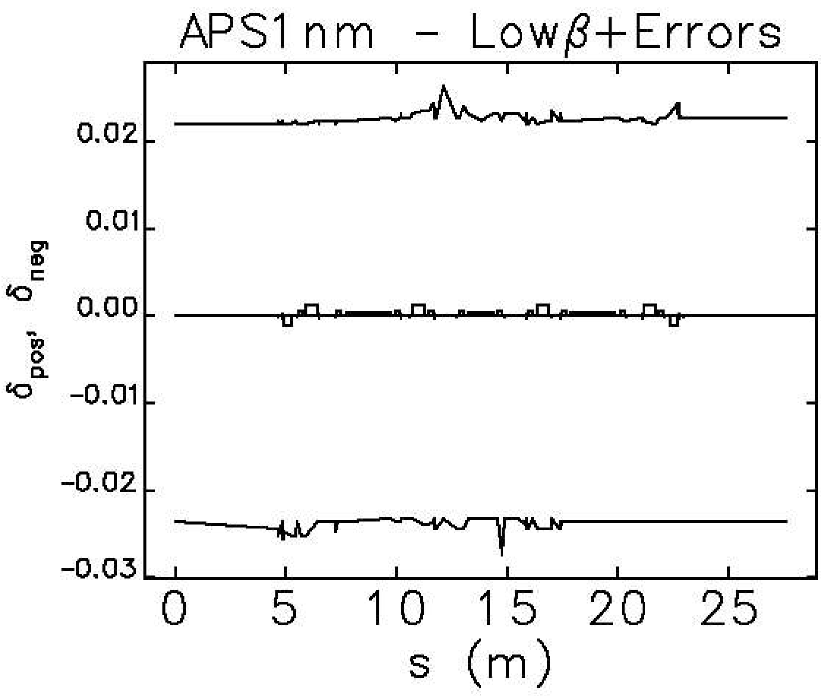




Low-β Lattice – Momentum Aperture

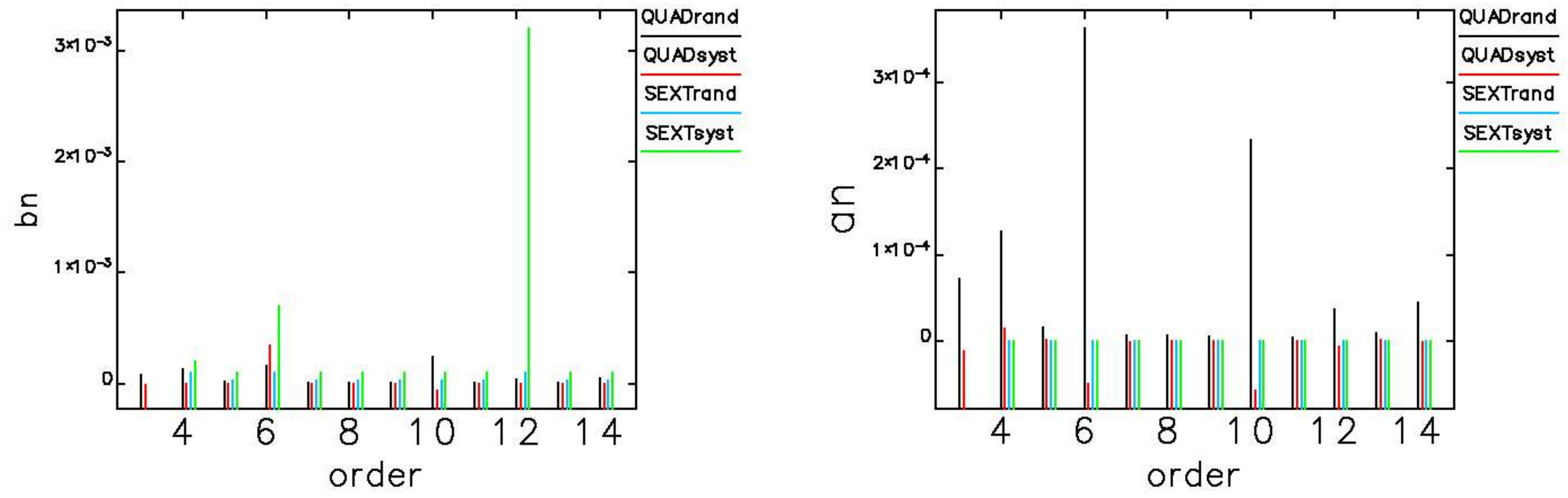
- Without errors, ~4% momentum aperture
- With errors (1 seed, 10% beta beating), ~2% momentum aperture. Not satisfied yet (~1.5 hrs for 8mA bunch beam)





Symmetric Lattice – Error Effects

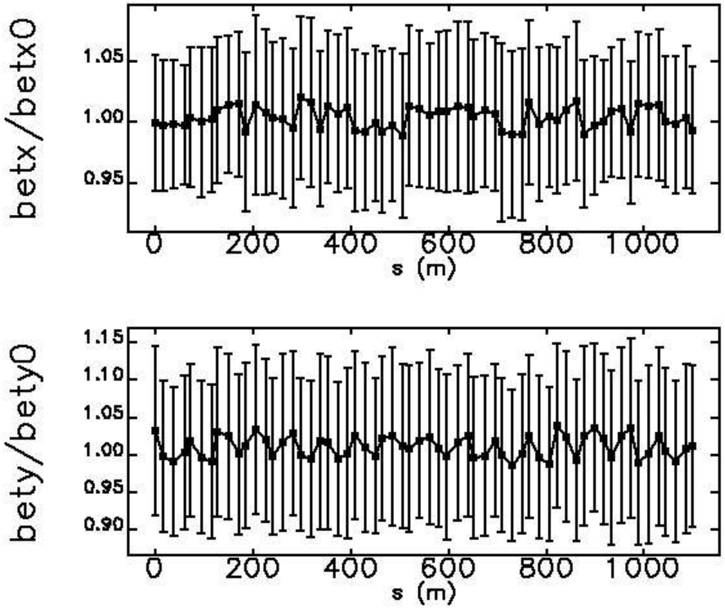
- 50 random seeds
- Multipole errors as ILC damping ring

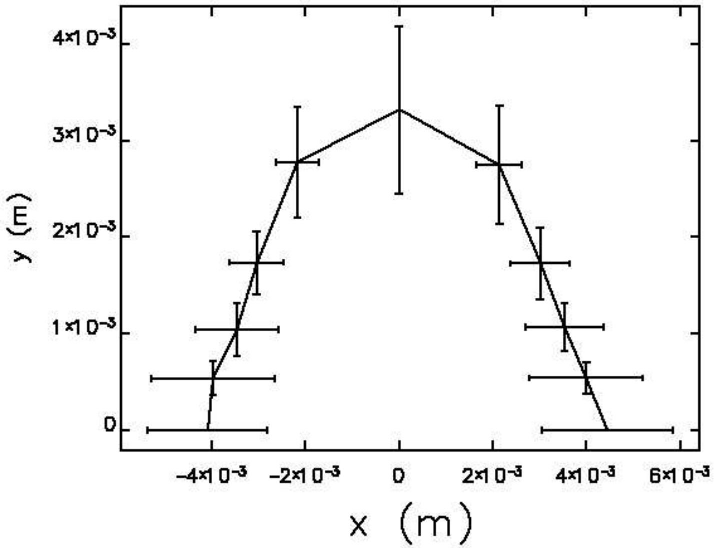


- Full nominal APS error
  - 10^{-4} m alignment error
  - 10^{-4} rad roll
  - 10^{-4} relative field error

Symmetric Lattice with Full Errors

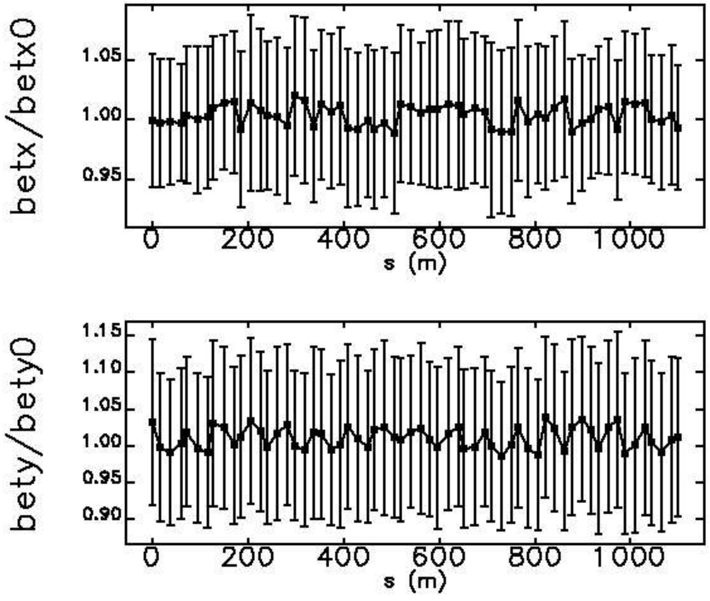
- Full error strength has been used in this simulation
- Trajectory had been corrected first to get stored beam
- Tune and chromaticity corrected to design value by 2 sets of quadrupoles and sextupoles
- RMS beta beating is ~ 15% horizontal, ~30% vertical
- Dynamic aperture is small, but we can get stored beam for optical correction

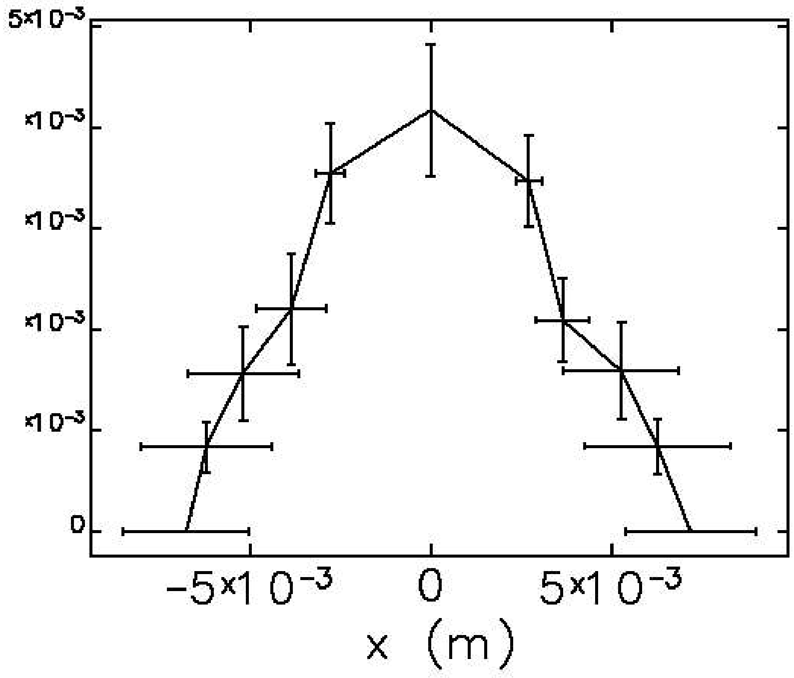




Symmetric Lattice – Reduced Error Effects

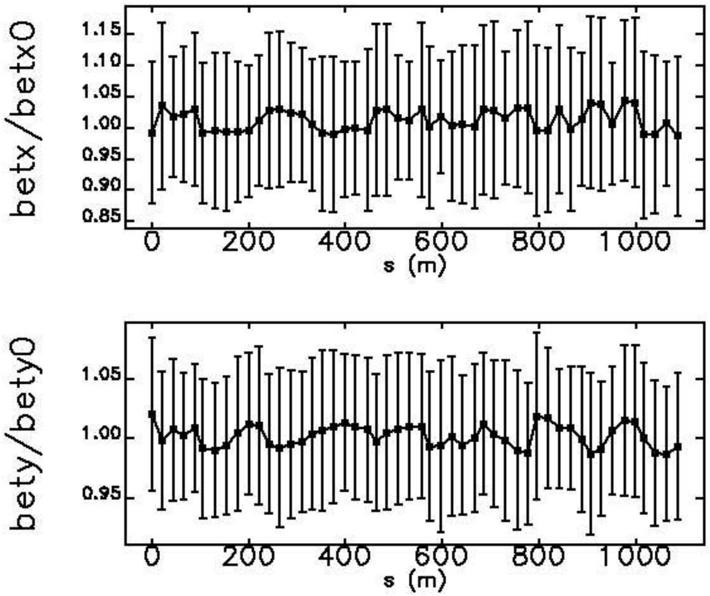
- The error strength has been reduced to 60% level
- Same correction strategy had been used before tracking
- RMS beta beating is ~ 9% horizontal, ~15% vertical
- About 7 mm dynamic aperture. Enough to accommodate beam from current booster
- We can do better optical correction than this

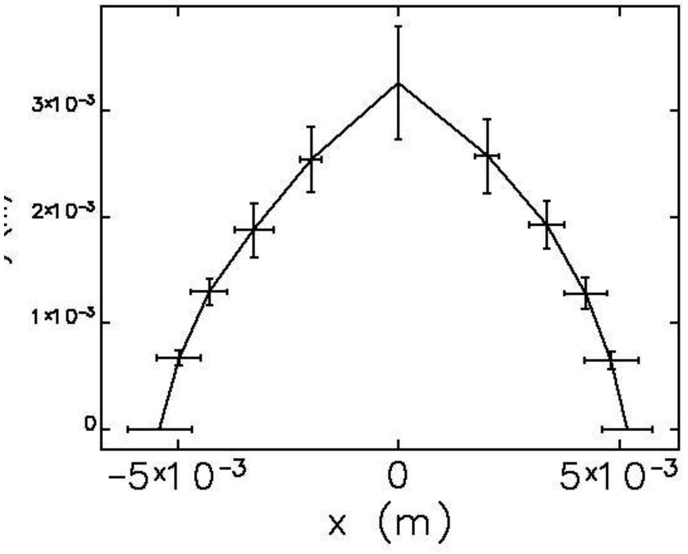




Low-β Lattice – Error Effects

- The error strength has been reduced to 50% level
  - we think this is justified since we will commission symmetric lattice first and correct most of optical errors
- Same correction strategy used before tracking
- RMS beta beating is ~ 15% horizontal, ~9% vertical
- Smaller dynamic aperture indicates an upgrade Booster is needed





Summary

- A 1nm lattice w/o customized beam size insertion has been designed for APS upgrade.
- All ID beamlines have been kept to their current position configuration.
- Simulation study shows promising results on symmetric lattice configuration
  - Has ability of using current booster beam for injection
  - Touschek lifetime is longer enough for top-up operation
- With customized beam size insertion (low-β), dynamic aperture shrinks due to less symmetry and larger natural chromaticities
  - Need booster upgrade for good injection efficiency
- The machine can operate with nominal APS errors with efforts on orbit and optics correction
  - Low-β lattice can be tuned after symmetric one is done