DA studies in CEPC by downhill method

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Many Thanks: K. Oide(KEK), Y. Cai (SLAC), D. Zhou(KEK)

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Outline

- Introduction Downhill method & modifications
- Application on CDR lattice
- Application on new lattice with combined magnets (dipole + sextupole) in arcs

Dynamic aperture study in CEPC

- **DA requirement for Higgs** (with errors, crab sextupoles and beam-beam)
  - On-momentum: $20\sigma x \times 30\sigma y$
  - Energy acceptance: 1.5%
- Multi-sextupole optimization
  - Two methods:
    - **Downhill Simplex**, K. Oide@KEK
    - **MODE** (**M**ulti-**O**bjective optimization by **D**ifferential **E**volution), Y. Zhang@IHEP
  - Effects included in DA tracking
    - Synchrotron oscillation
    - SR Damping
    - Sawtooth + tampering
    - Quantum fluctation
- Difference of two methods
  - Downhill: local search, quick convergence, need less cpu.
  - MODE: global search, time consuming, need strong computers.
- Both methods were used on CEPC to complement each other.

Principle of downhill optimization

1. Scan the strength of sextupoles;
2. DA tracking for the energy list
3. Calculate the objective function (DA)
4. Find the minimum of the objective function by the downhill simplex method
5. Go to 1.
6. Optimization stop when

   (fmax-fmin)/(abs(fmax)+abs(fmin)) < Tolerance

Objective function for DA optimization

- Case I: wth $\geq$ 0, optimize the energy bandwidth

$$F = -\left[t + w * Bandwith(0) + w1 * Bandwith(wth) \right]$$

-- t: Touschek lifetime

-- $Bandwith(n)$: DA bandwidth according to $n*\sigma$ DA reference

-- w & $w1$: weight for the DA bandwidth

- Case II: wth < 0, optimize the total DA value

$$F = -\sum_{j=1}^{6} \left(\sum_{i} w(i) * DA_j(i) \right)$$

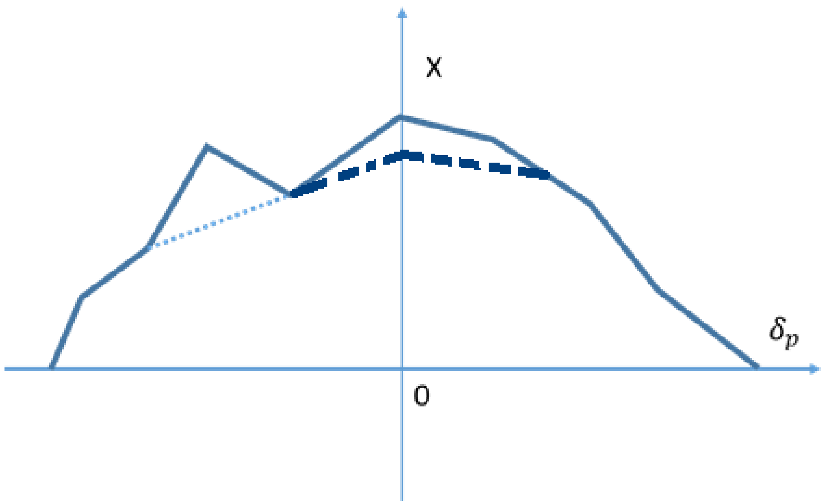
-- $DA_j(i)$: DA for $i*\sigma_\delta$ energy deviation with the j^{th} initial phase (totally 6 phases)

-- $w(i)$: DA weight for $i*\sigma_\delta$ energy deviation

$$w(i) = \exp\left[2 * \left(\frac{|i * \sigma_\delta|}{m * \sigma_\delta} \right) \right] \qquad (i = -m, ..0, ..m.)$$

Downhill Simplex modification

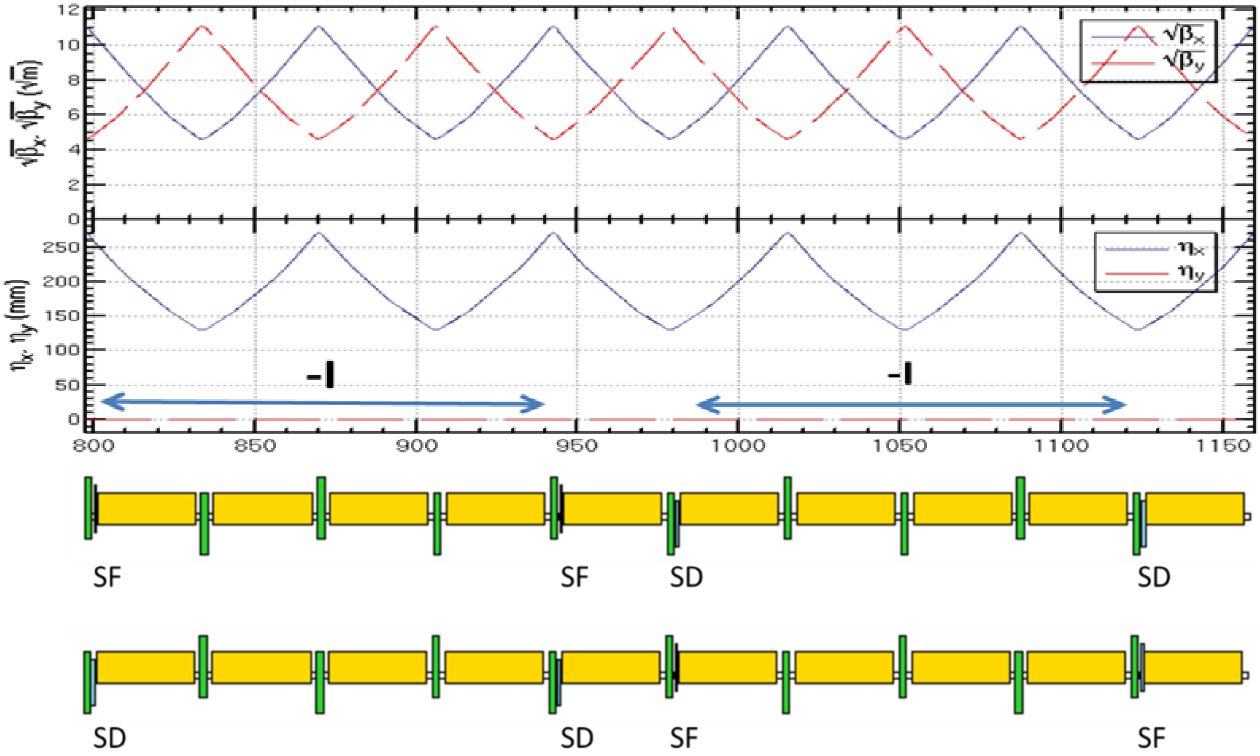
- DA results not stable while opening fluctuation
- Cancel the noise due to fluctuation
- Two methods：
  1. Scan whole DA list (5 seeds) $\rightarrow$ Minimum
  2. Scan DA at center energy (10 seeds) $\rightarrow$ Minimum $\rightarrow$ Clip



So far, we used method 2 to save computer time.

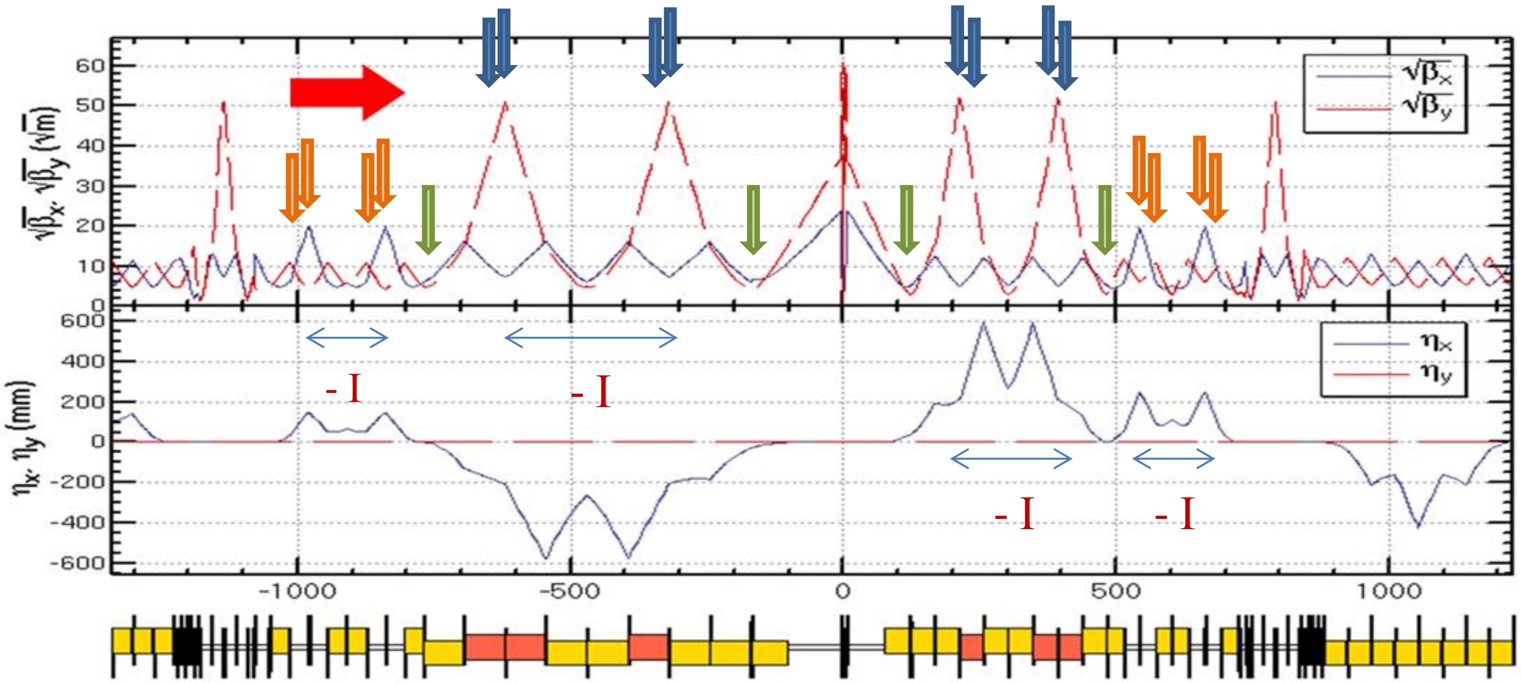
CEPC CDR lattice - arc

- FODO cell, 90°/90°, non-interleaved sextupole scheme
- 224 sextupole pairs in the half ring



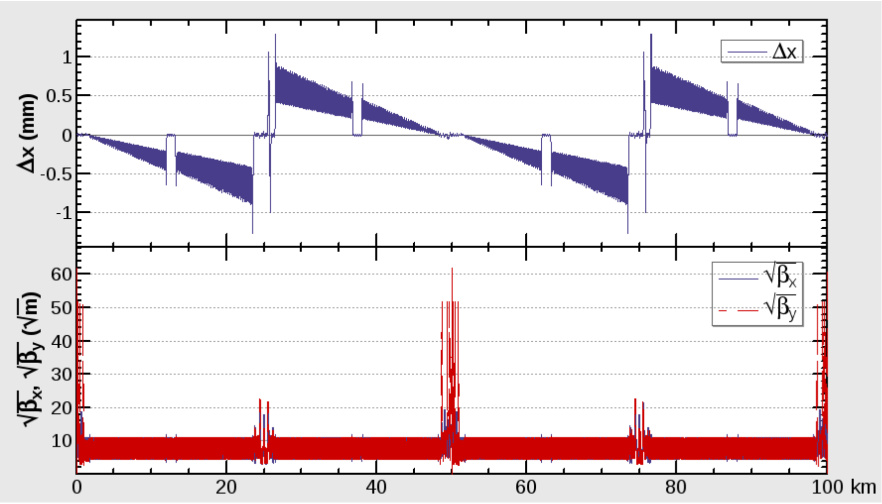
CEPC CDR lattice - IR

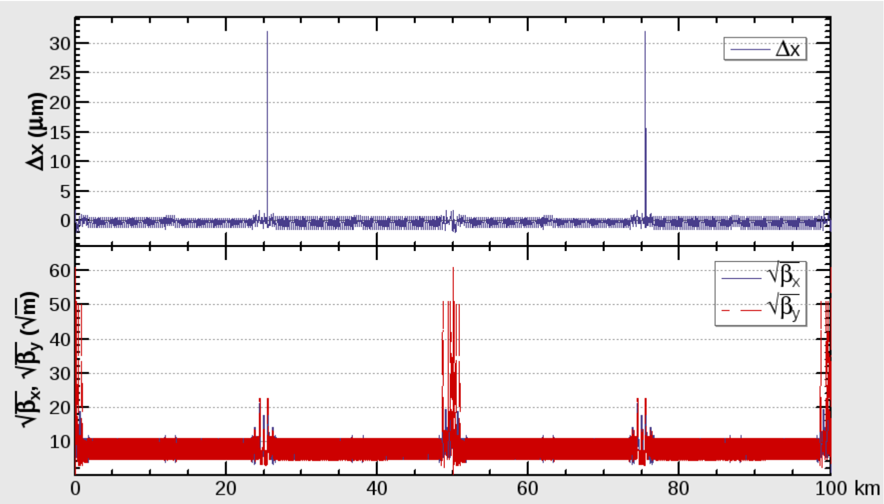
- Final Telescope + CCY + CCX + Matching + crab section
- 10 sextupole pairs in the half ring
  - CCY: 4 pairs → linear chromaticity + sextupole length effect
  - CCX: 4 pairs → linear chromaticity + sextupole length effect
  - Image points: 2 pairs → third order chromaticity (vertical)



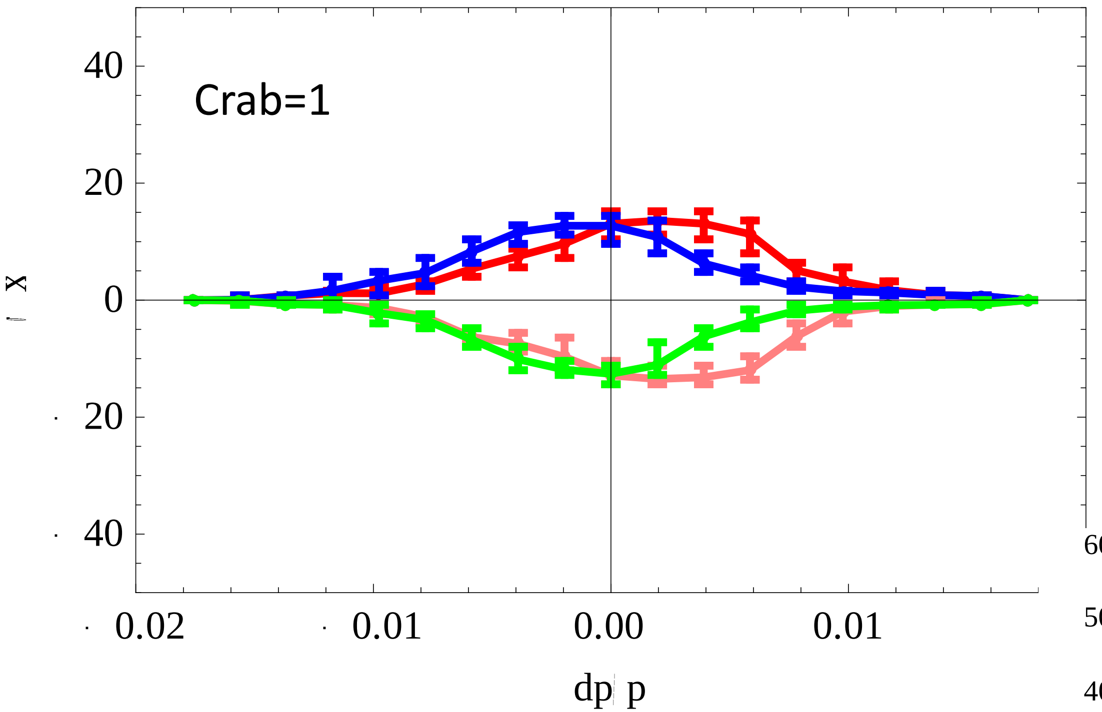
Sawtooth effect

- With only two RF station, the sawtooth orbit : ~1mm
- ~5% distortion of beam optics and DA reduction
- sawtooth orbit after tapering: ~1um
- DA study always include sawtooth + tampering



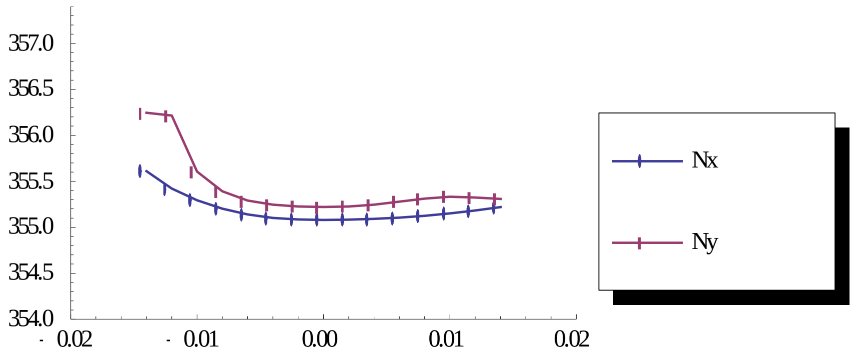


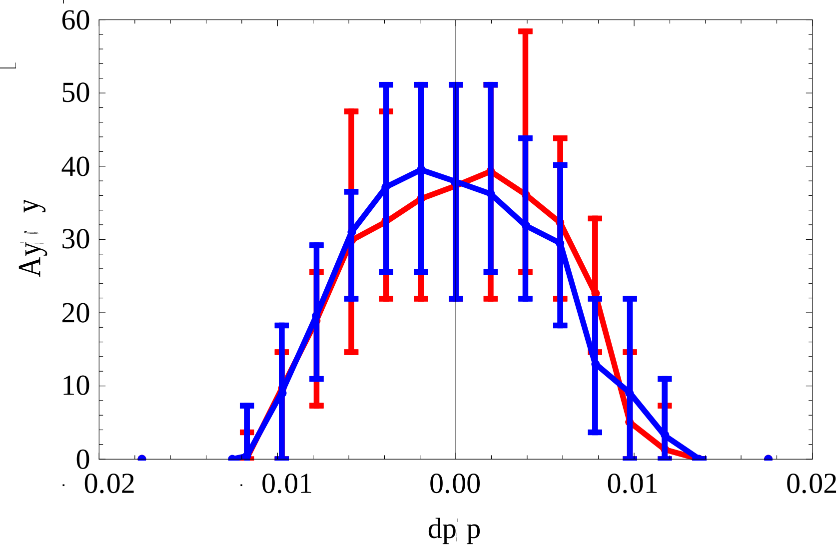
Initial DA



- 100 turns tracking
- 50 seeds

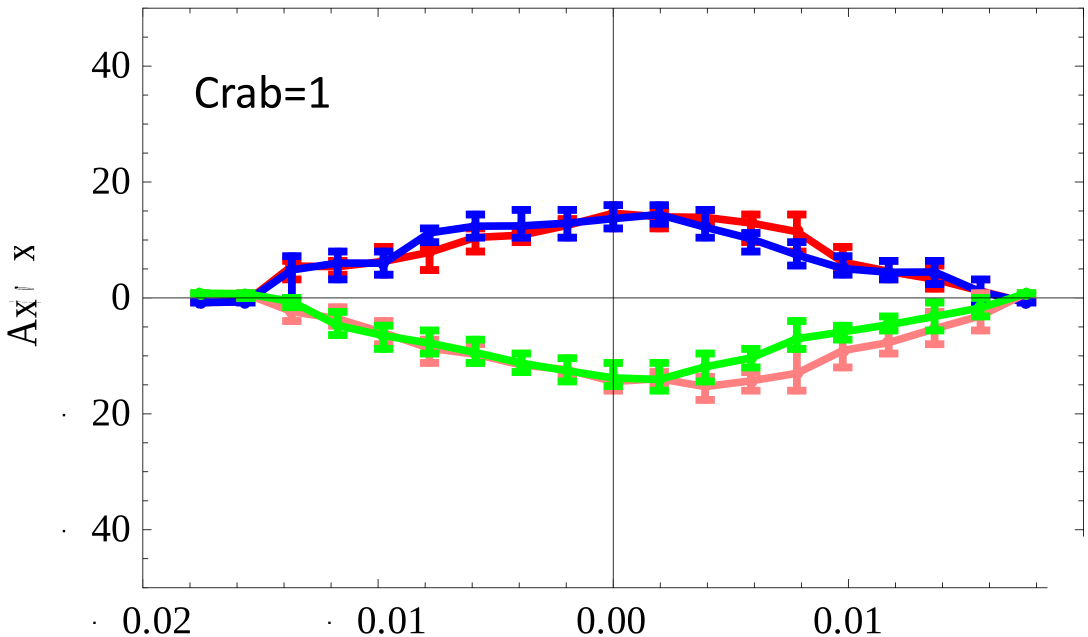
Ax(0): 14 σx
Ay(0): 36 σy
DA bandwith: 1.2%





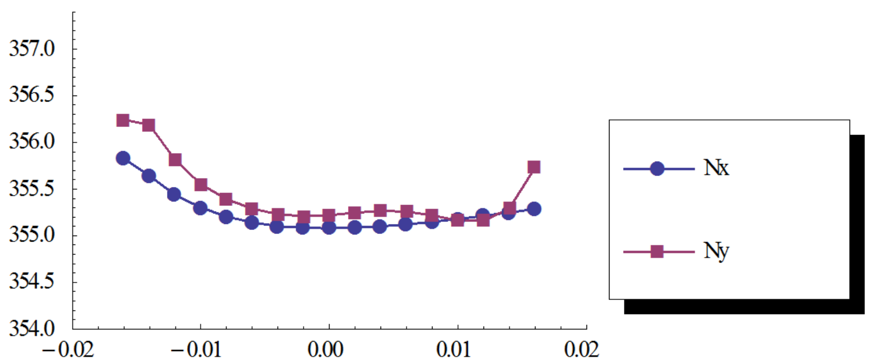
DA-after optimization

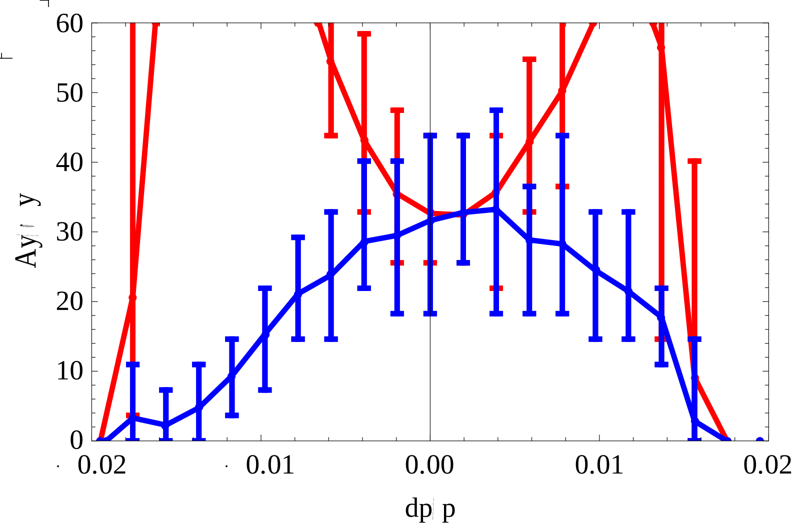
– 234 sextupole knobs (no check for variable redundancy)



- 100 turns tracking
- 50 seeds

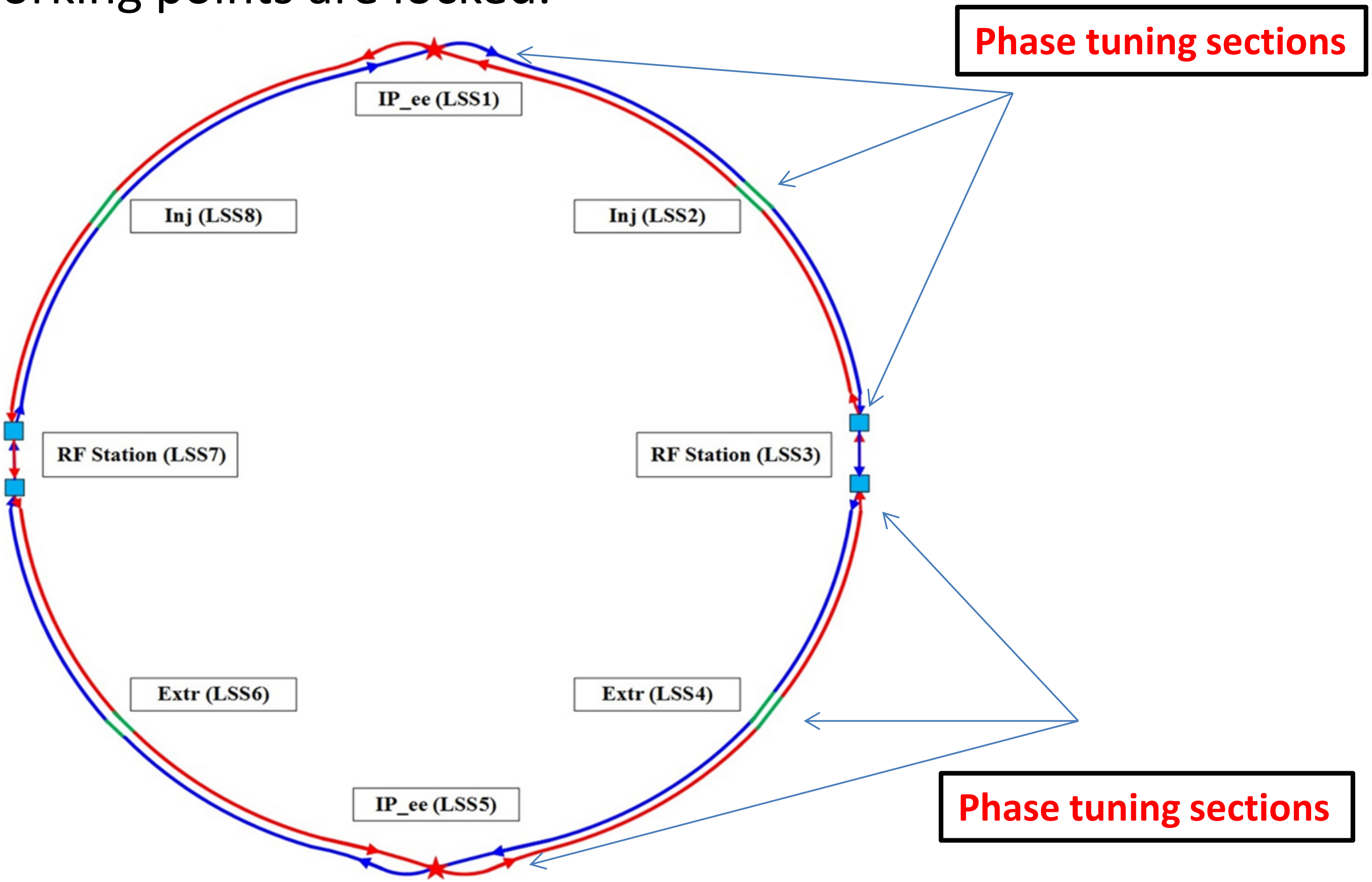
Ax(0): 14 σx
Ay(0): 33 σy
DA bandwith: 1.6%





Quadrupoles optimization in MODE

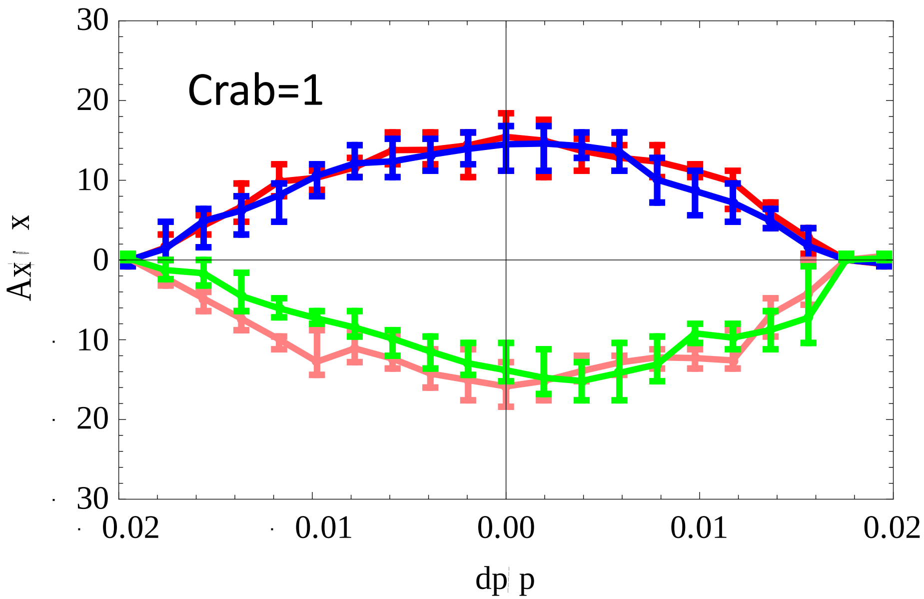
- 12*6 quadrupoles are varied for phase advance tuning
- Working points are locked.



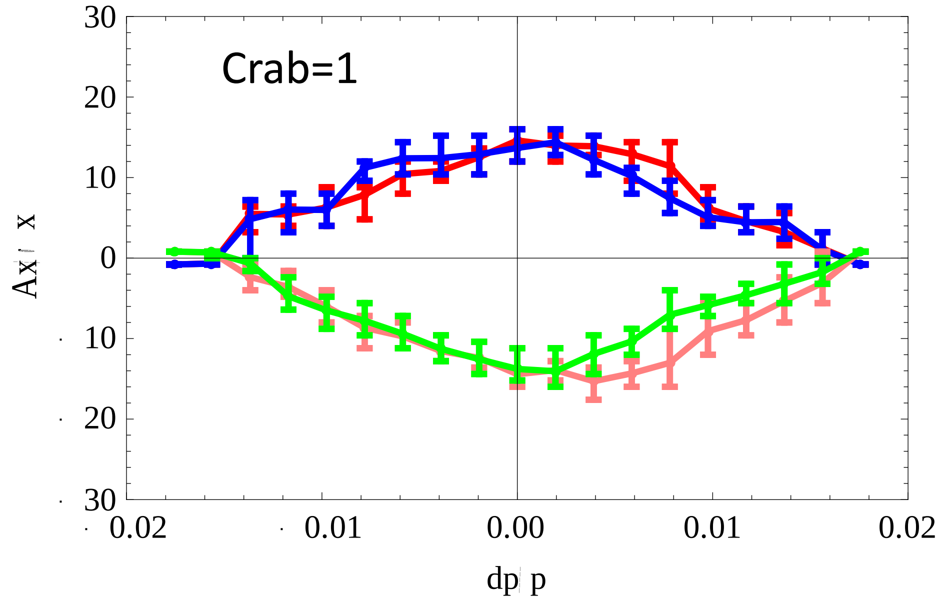
DA optimization with MODE's K1

- Optimization with additional K1 knobs give ~20% DA enlargement.

- 234 K2 knobs
- K1 values from MODE



- 234 K2 knobs



- 100 turns tracking
- 50 seeds

Principle of combined D+S scheme

- The power consumption of the arc sextupoles are too high.
  - Sextupole : 16.7 MW (copper coils)
  - Dipole: 6.5 MW (Al coils)
- Reducing the strength of the stand-alone sextupoles can make help.
- Combined function magnet: dipole + sextupole
  - Combined sextupoles: correct part (all) of the linear chromaticity
  - Stand-alone sextupoles: correct higher order chromaticity

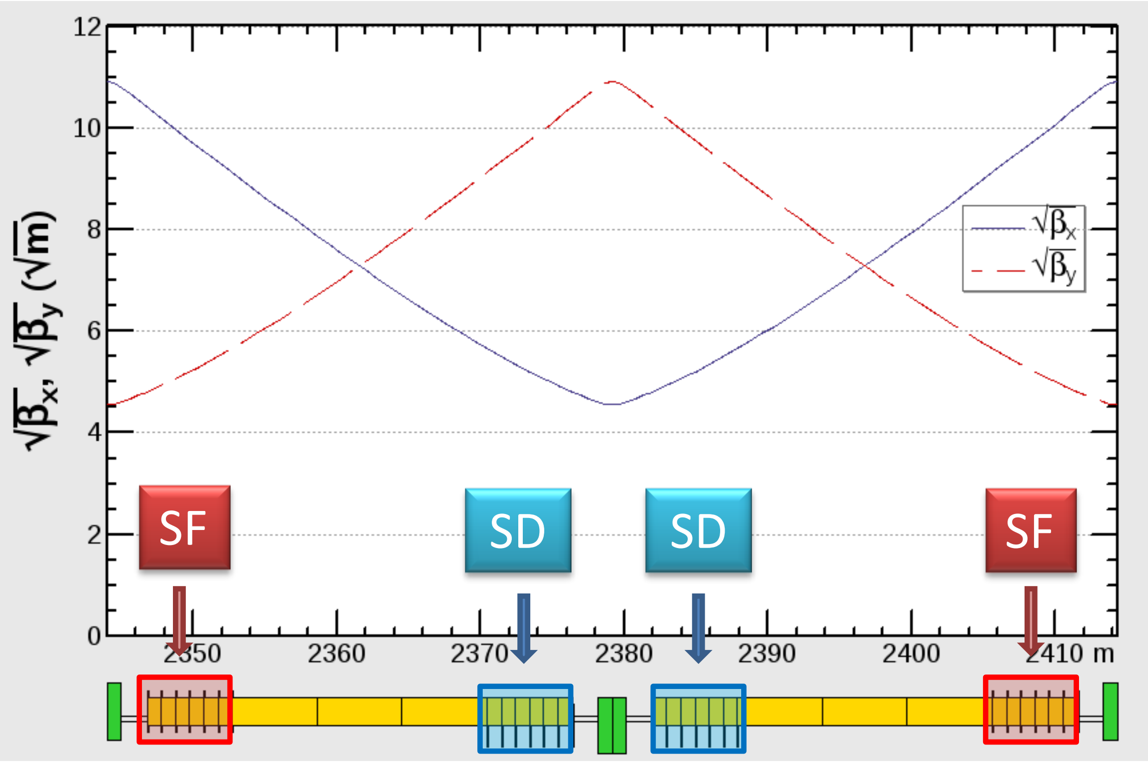
New lattice with combined D+S

- Five dipoles between two quadrupoles in the arc
- Combined sextupoles are on the first and fifth dipoles ($\beta_{x,y} >> \beta_{y,x}$)

  -- one dipole is cut into 6 slices

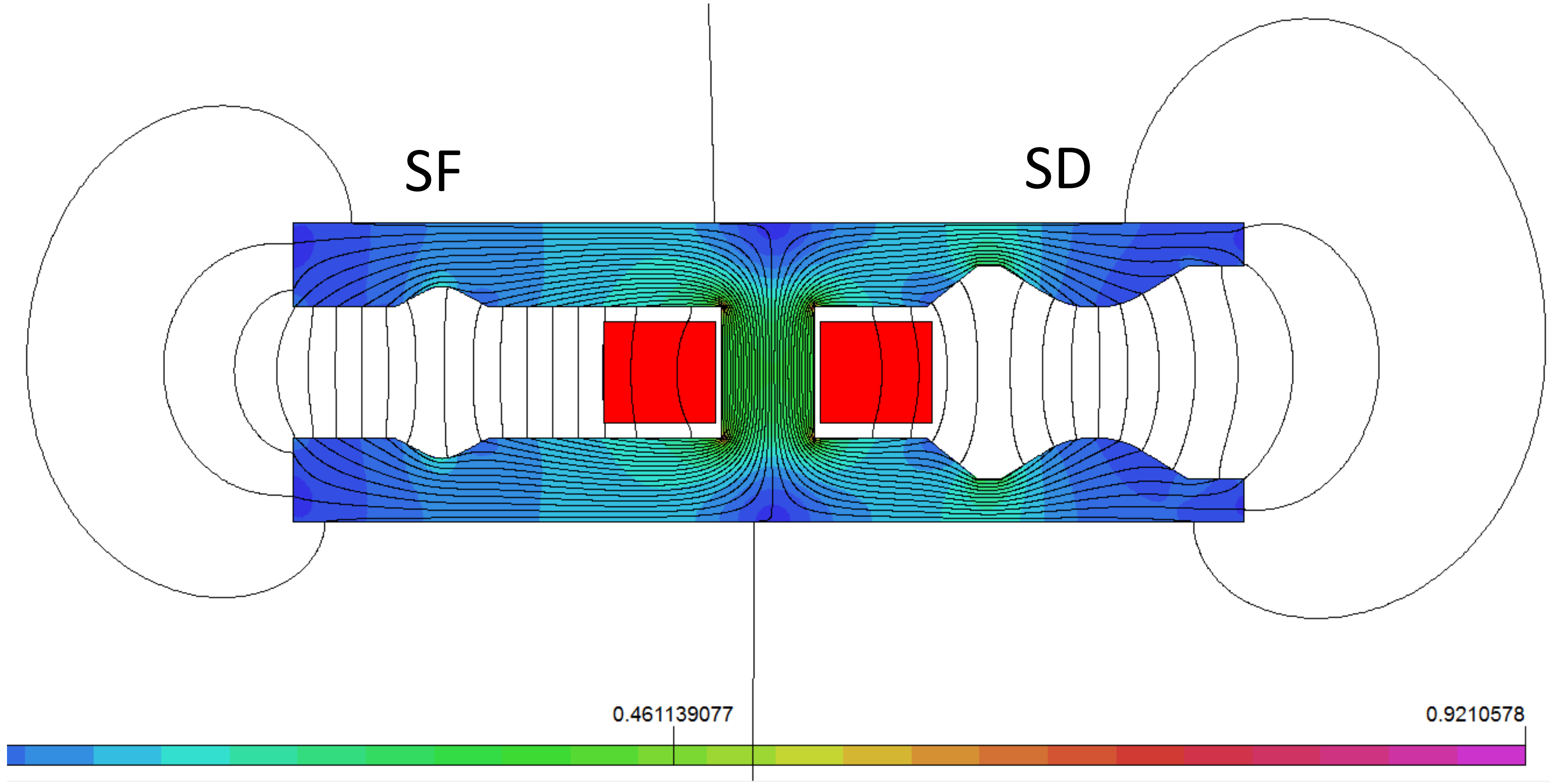
  -- 7 thin sextupoles are insert in one dipole

- No additional power sources for SF and SD



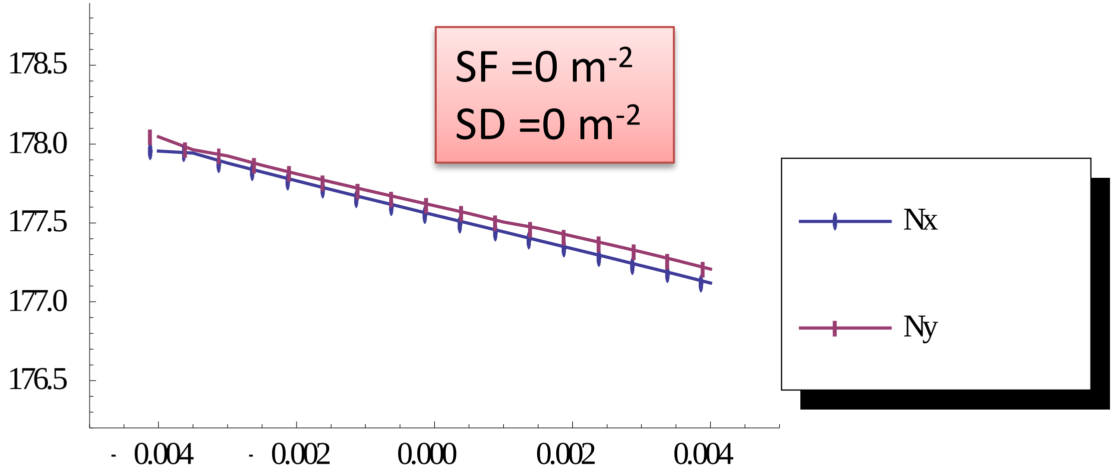
Primary magnet design for combined D+S

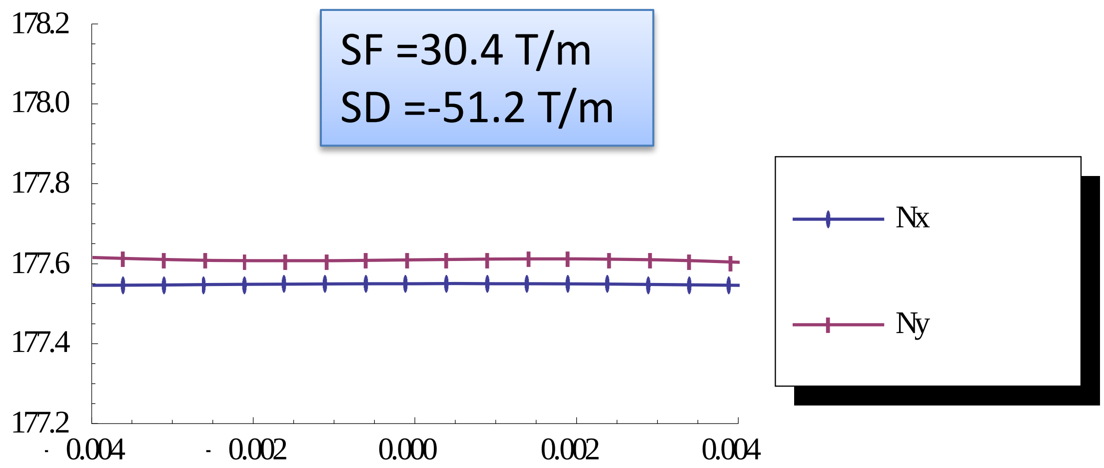
- Twin aperture dipole
- Separation of two ring: 0.35m



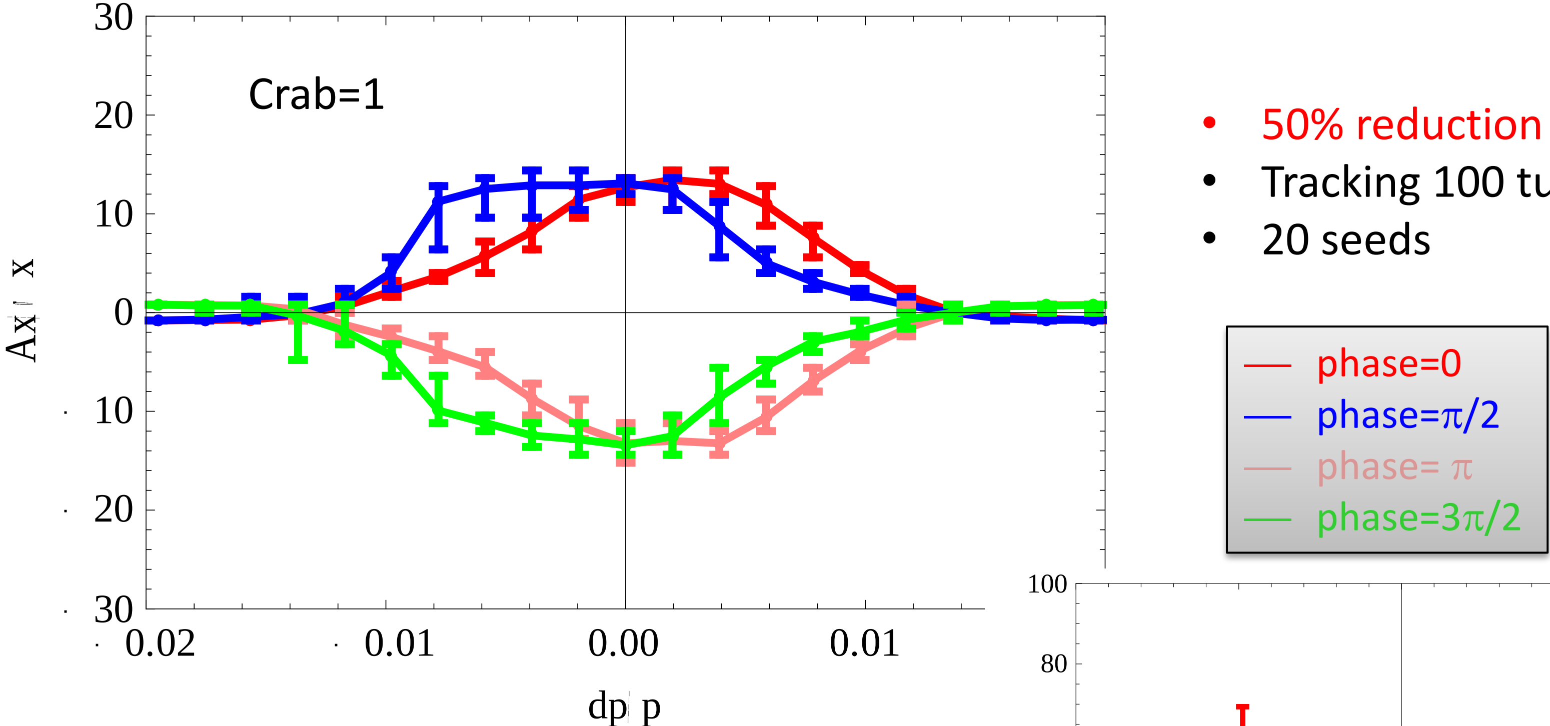
Case I: 50% K2 reduction

- Chromaticity correction with SF & SD

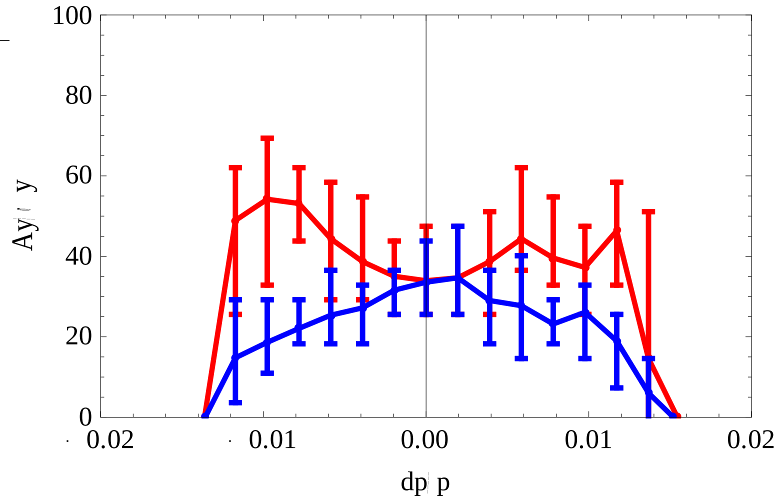




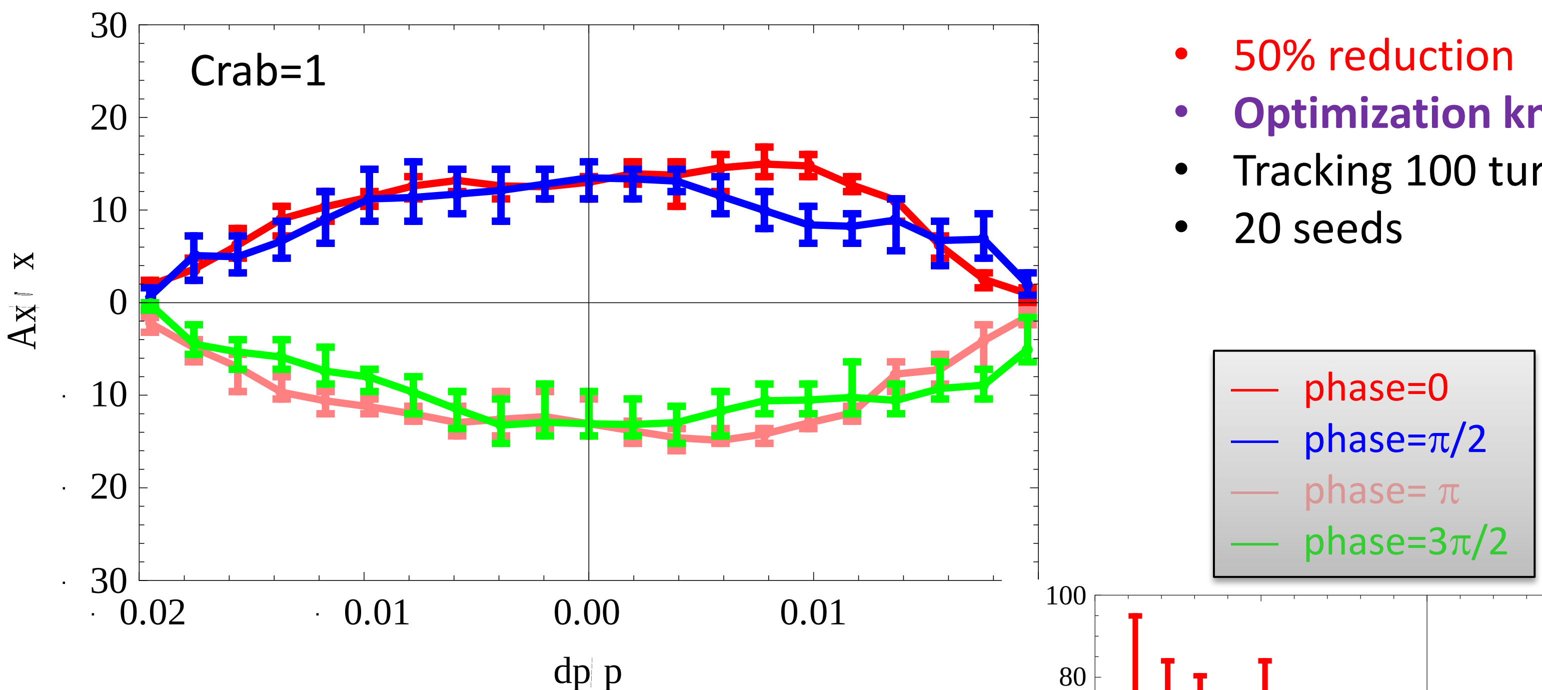
DA before multi-sextupole optimization



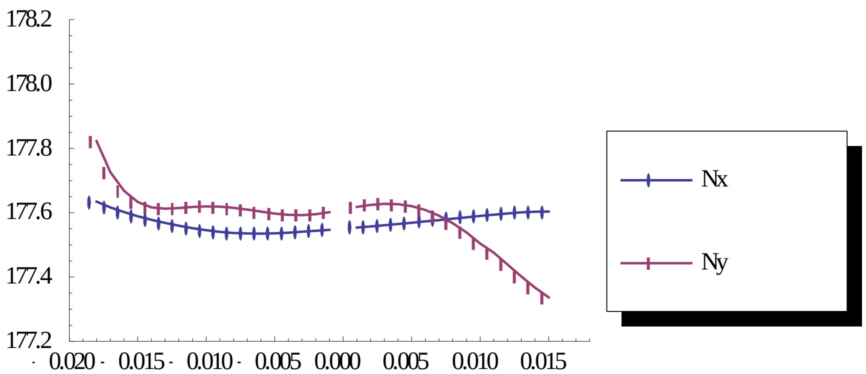
- 50% reduction
- Tracking 100 turns
- 20 seeds

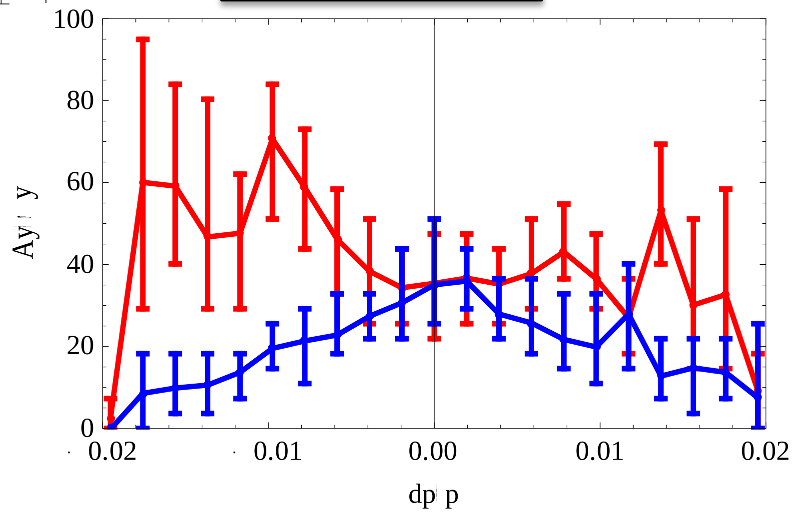


DA after multi-sextupole optimization

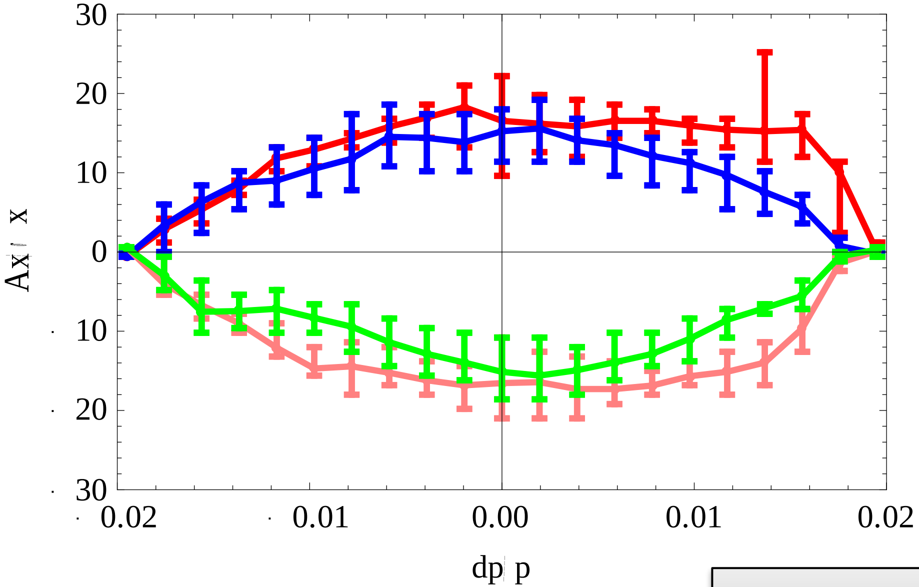


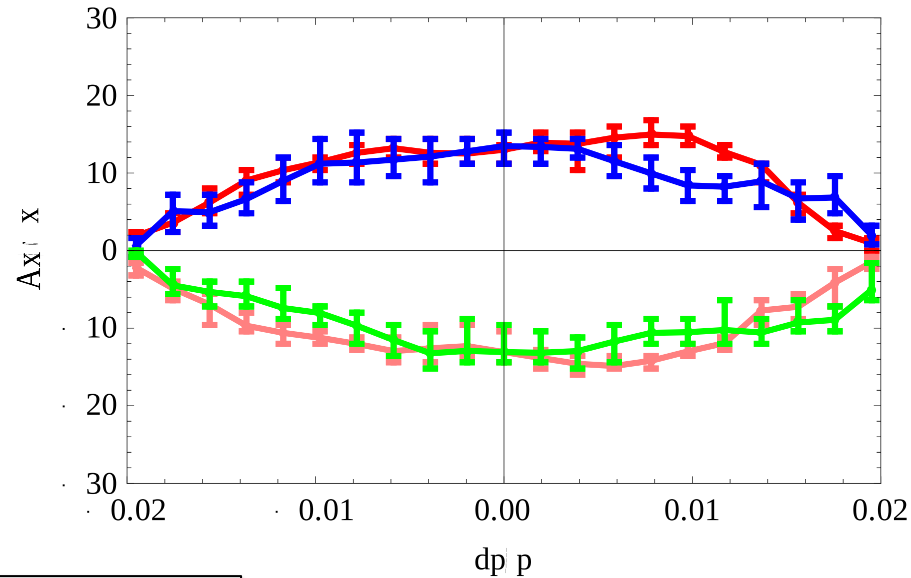
- 50% reduction
- **Optimization knobs: 234 K2s**
- Tracking 100 turns
- 20 seeds





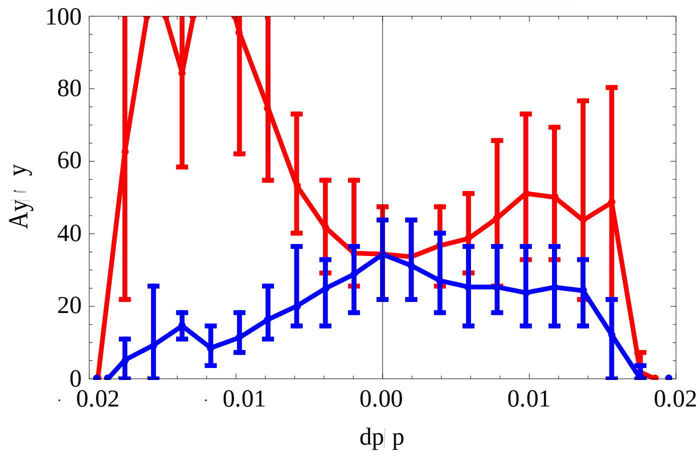
DA comparison



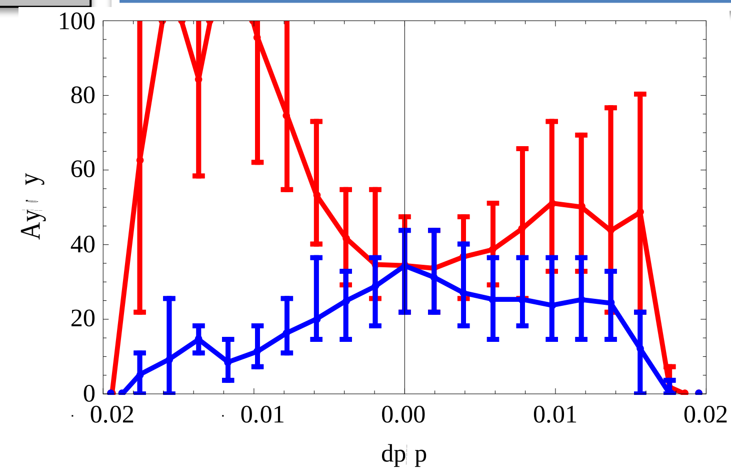


- Tracking 200 turns
- 50 seeds

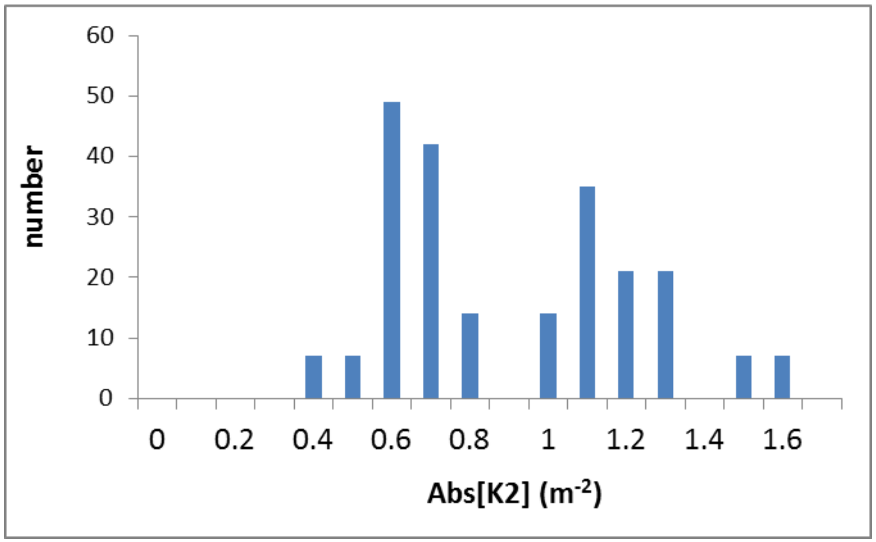
w/o combined D+S



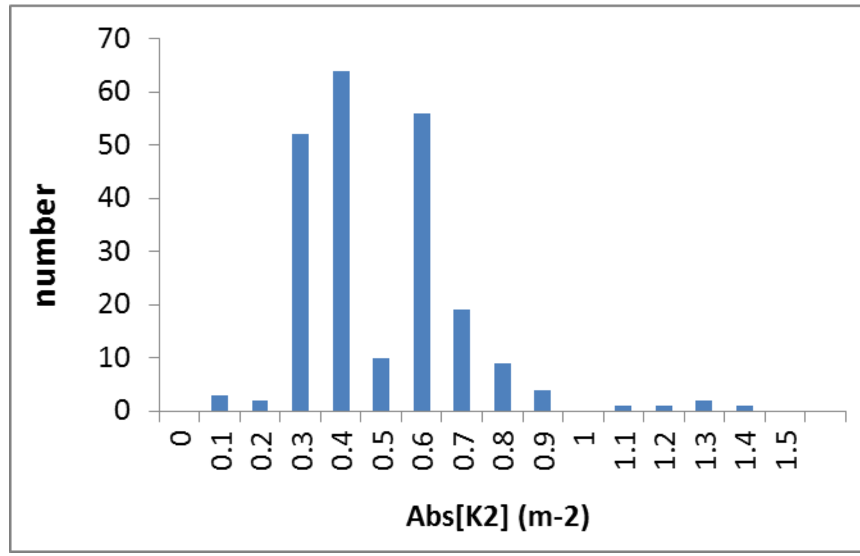
w combined D+S (50% reduction)



Strength of independent sextupoles



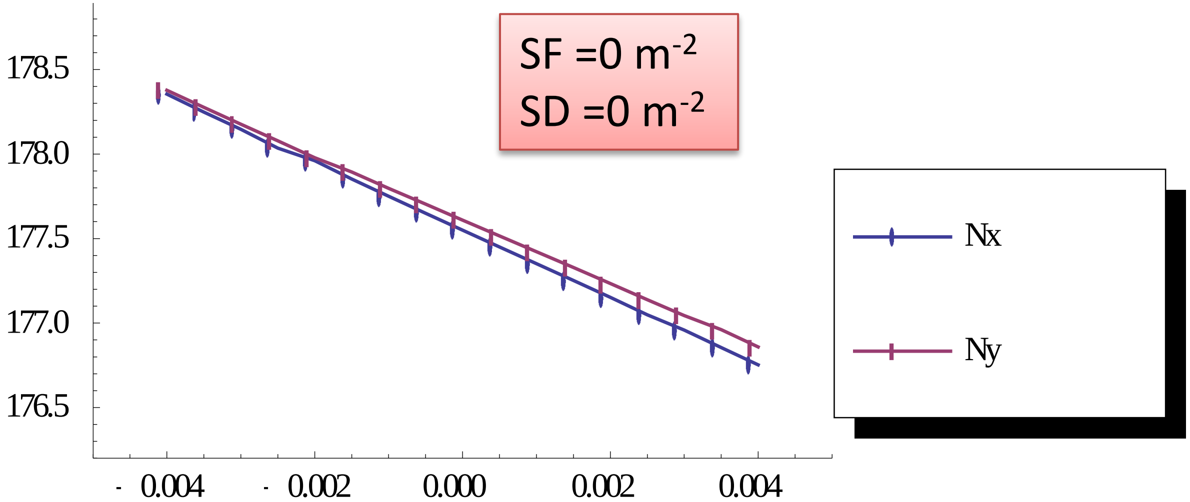
w/o combined D+S

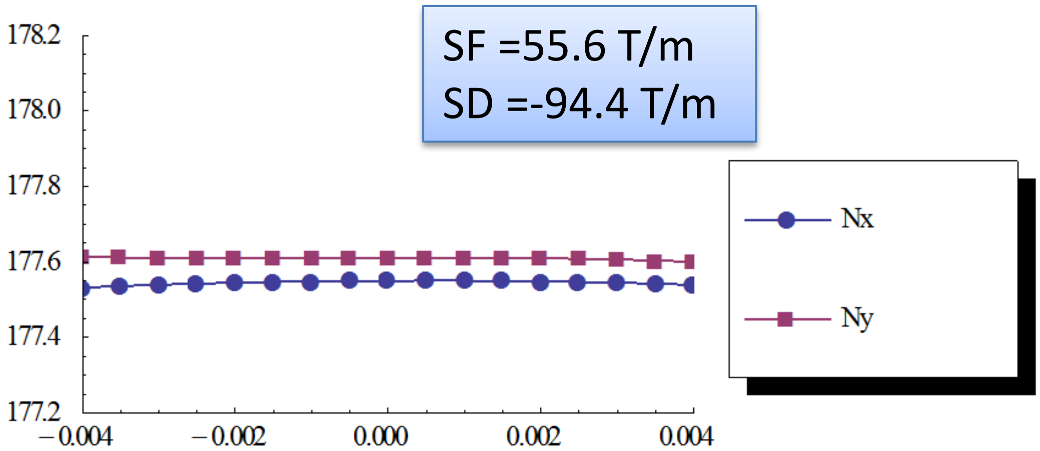


w combined D+S (Case I)

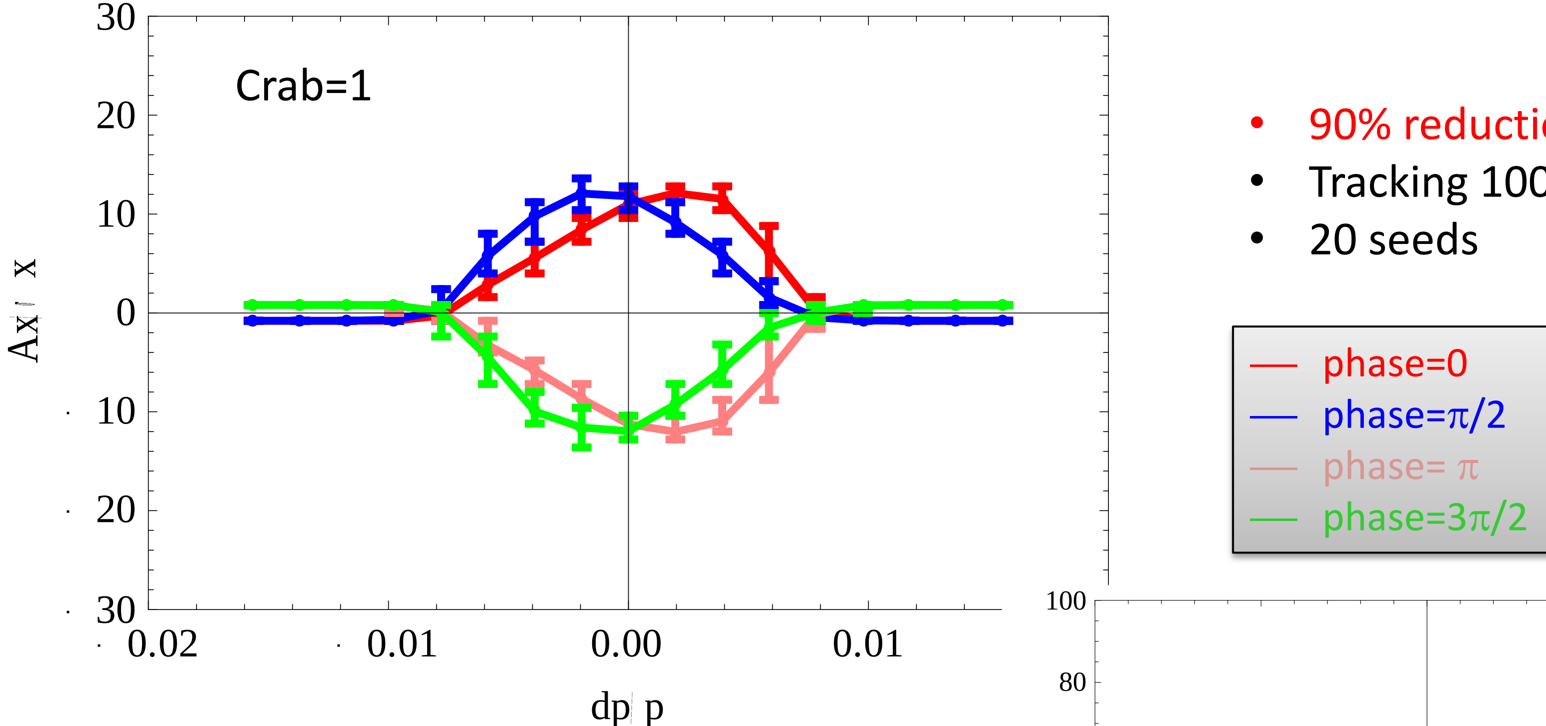
Case II: 90% K2 reduction

- Chromaticity correction with SF & SD

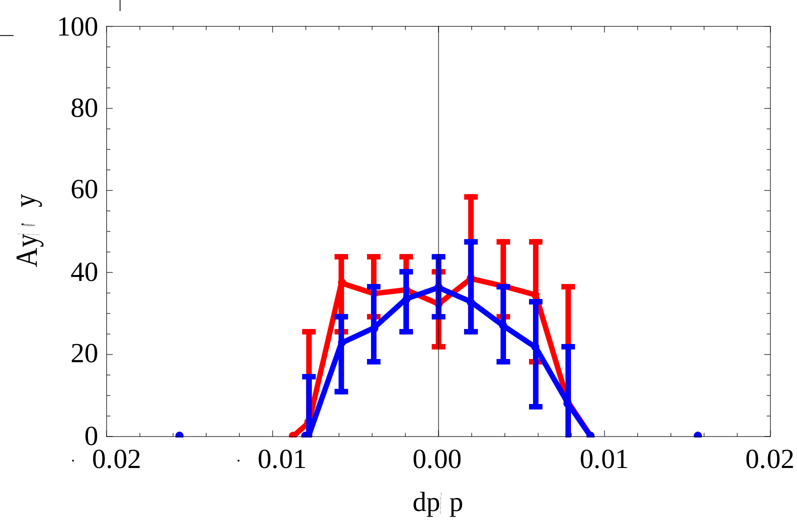




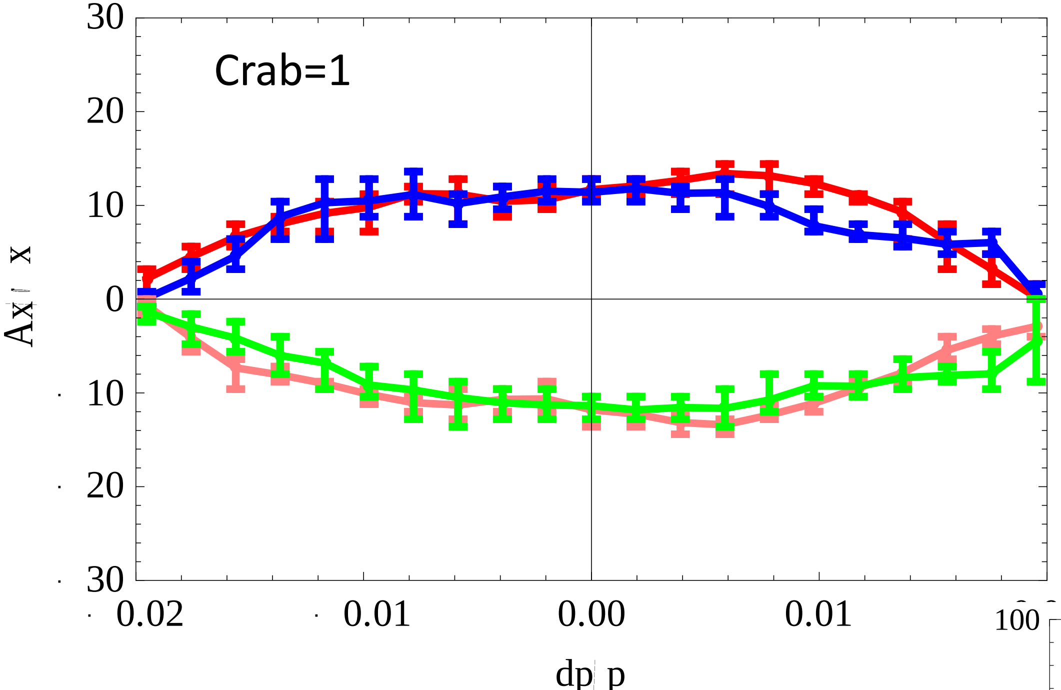
DA before multi-sextupole optimization



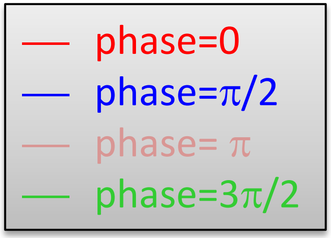
- 90% reduction
- Tracking 100 turns
- 20 seeds

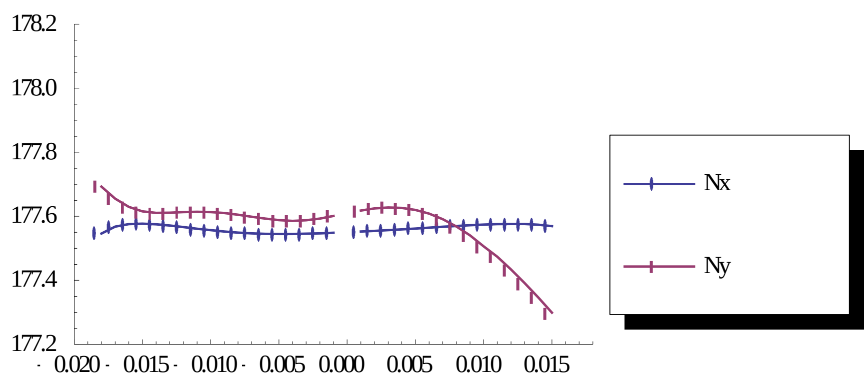


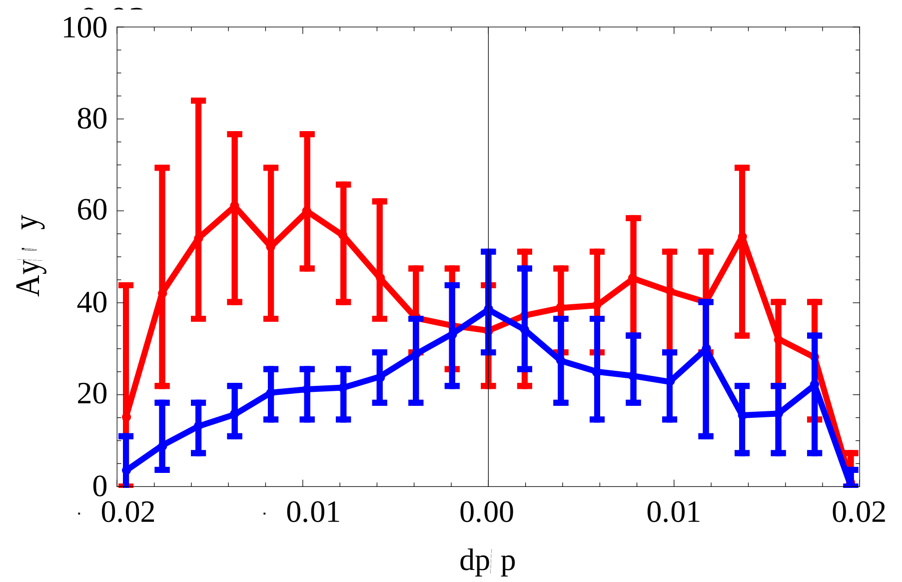
DA after multi-sextupole optimization



- 90% reduction
- **Optimization knobs: 234 K2s**
- Tracking 100 turns
- 20 seeds







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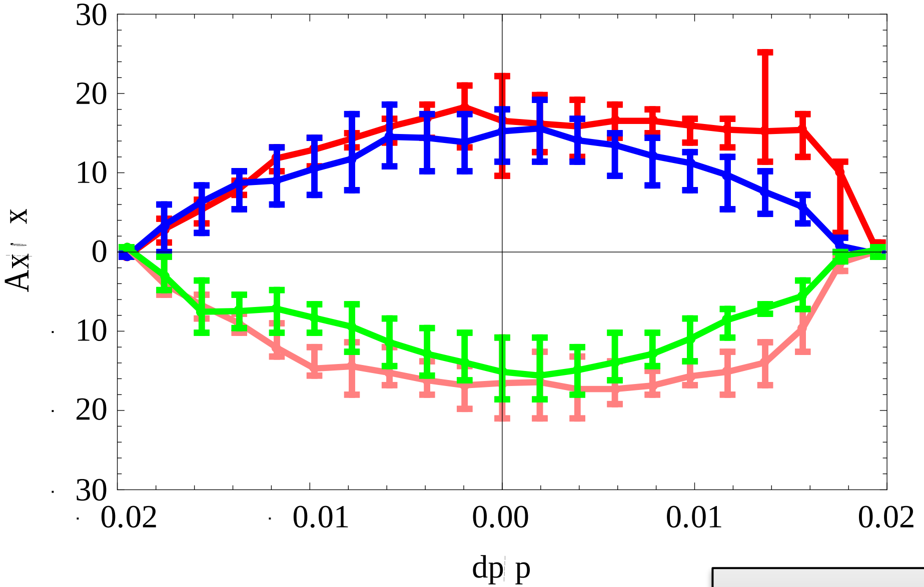
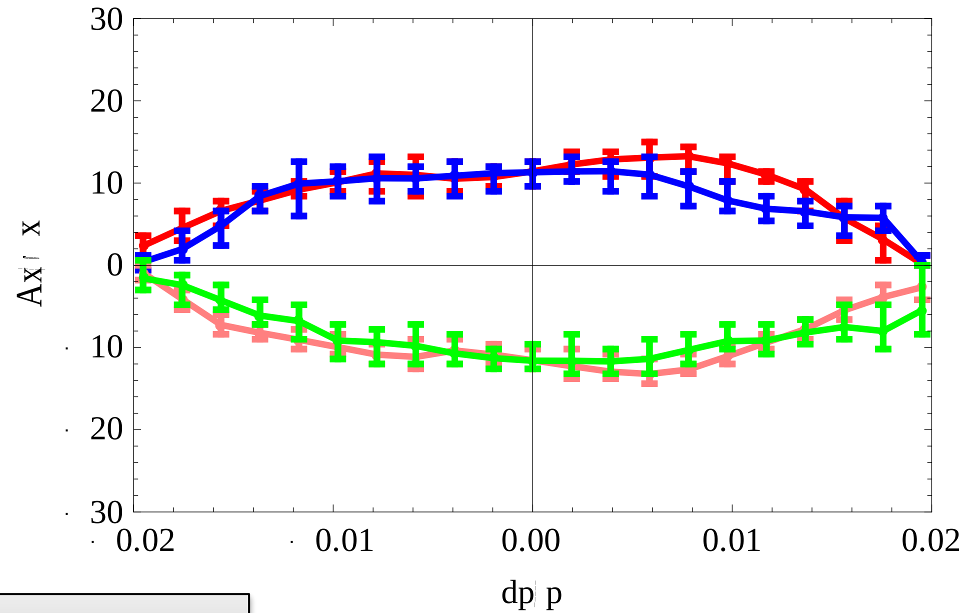
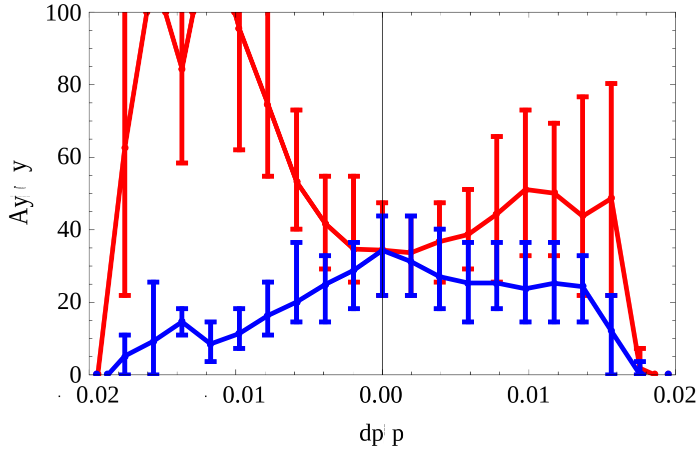


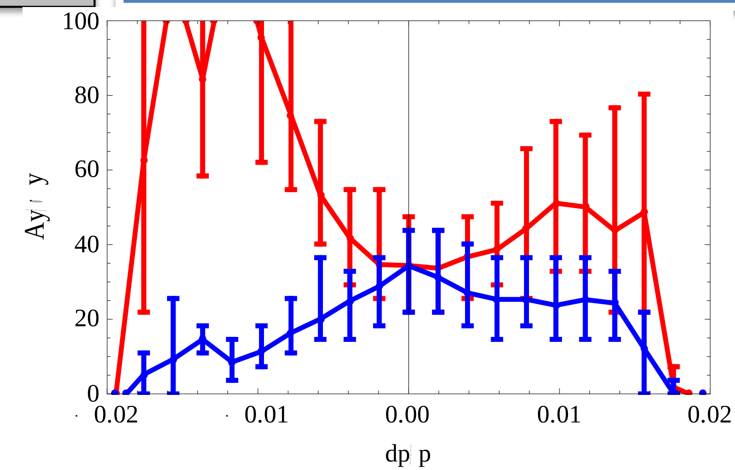


- Tracking 200 turns
- 50 seeds

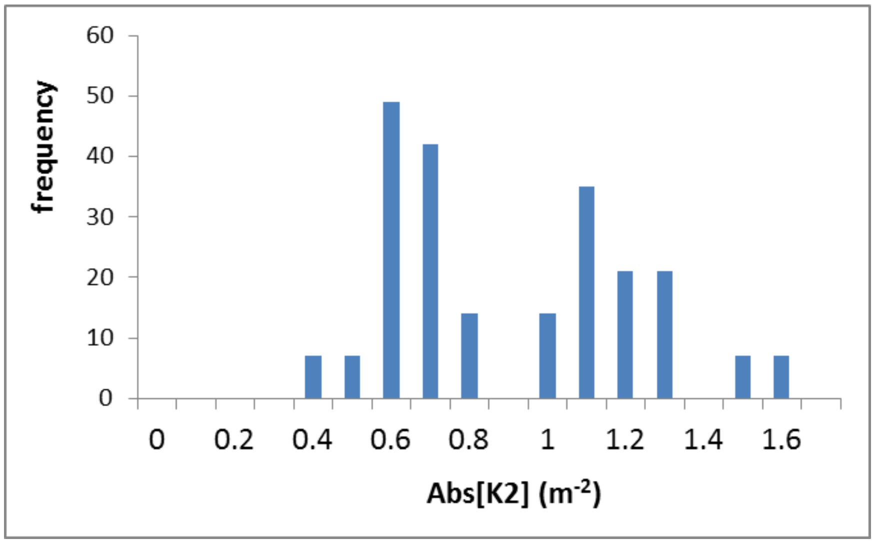
w/o combined D+S

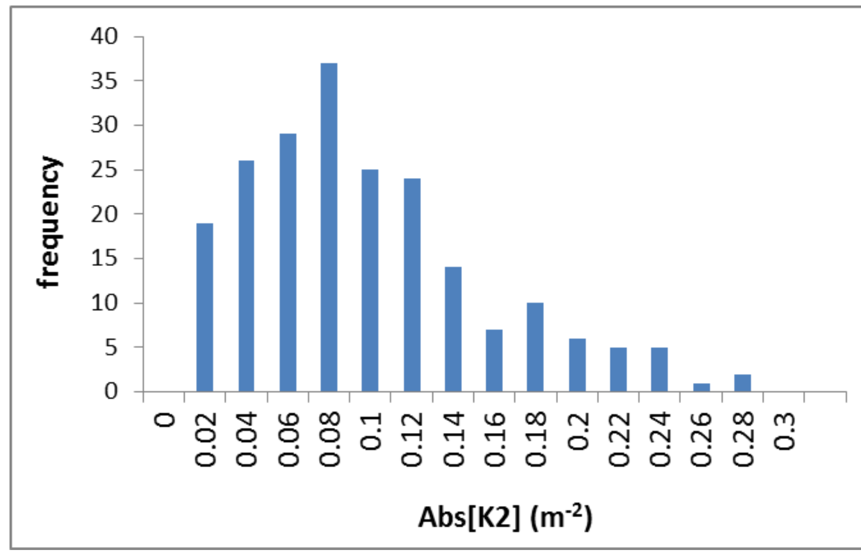
w combined D+S (90% reduction)





Strength of independent sextupoles





w/o combined D+S

w combined D+S (Case II)

Summary

- Both Downhill and MODE were used to complement each other.

- Downhill can give almost same results as MODE.

  -- Plan to introduce K1 knobs in Downhill

- First taste of combined magnet (D+S) looks good.

  -- Power for sextupoles → **¼**, **50%** reduction of independent K2

  -- Still need careful check for the DA results