Dynamic Aperture of CEPC

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Many thanks: K. Oide(KEK), Y. Cai(SLAC)

Outline

- Introduction
- Dynamic Aperture
  - β_y^* (2mm, 1.5mm, 1mm)
  - More knobs
  - Combined Function Dipole(+Sextupole)
  - Beam-Beam Effect
- Summary

MODE:

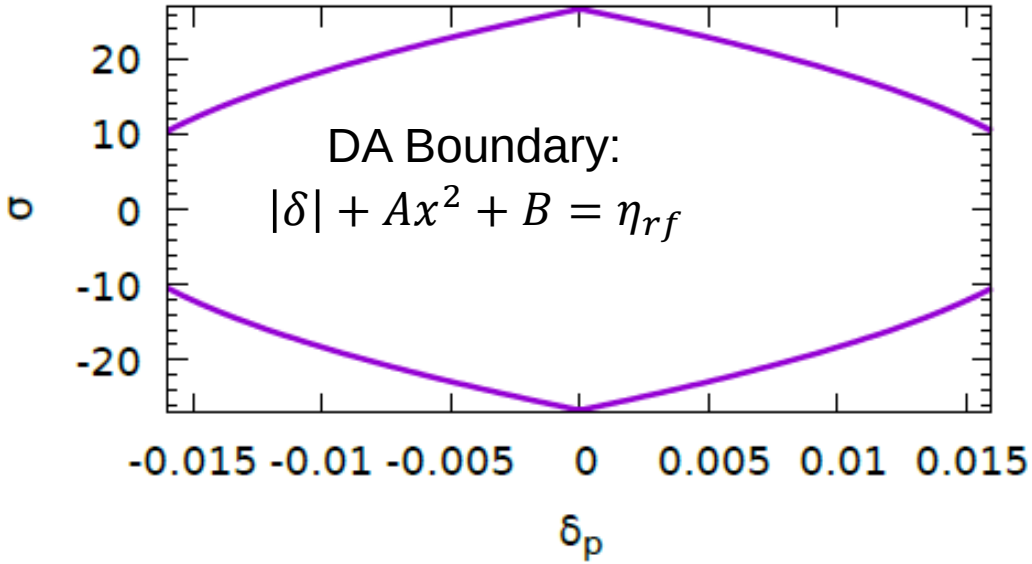
Multi-**O**bjective optimization by **D**ifferential **E**volution

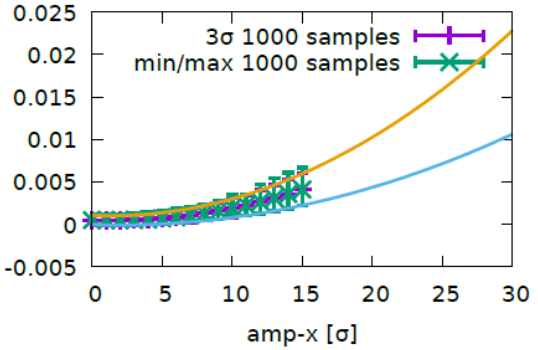
The parallel algorithm is referencing to J. Qiang(IPAC'13)

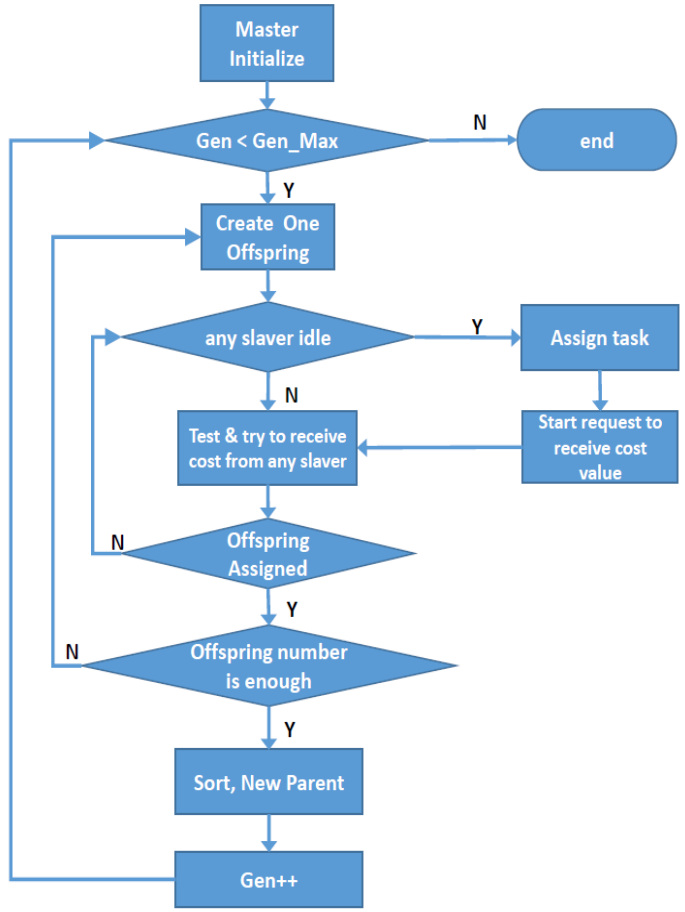
High Parallel + High Scalability

- Even the time taken by different task is different
- Even some node is very busy

The difference between the DA boundary and real DA is defined as the objective cost value







DownhillSimplex in SAD

- Try to optimize the total DA

$$F = -\sum_{j=1}^{6}\left(\sum_{i} w(i) * DA_j(i)\right) \qquad w(i) = \exp\left[2 * \left(\frac{|i * \sigma_\delta|}{m * \sigma_\delta}\right)\right] \qquad (i = -m, ..0, ..m.)$$

-- $DA_j(i)$: DA for $i*\sigma_\delta$ energy deviation with the jth initial phase (totally 6 phases)

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

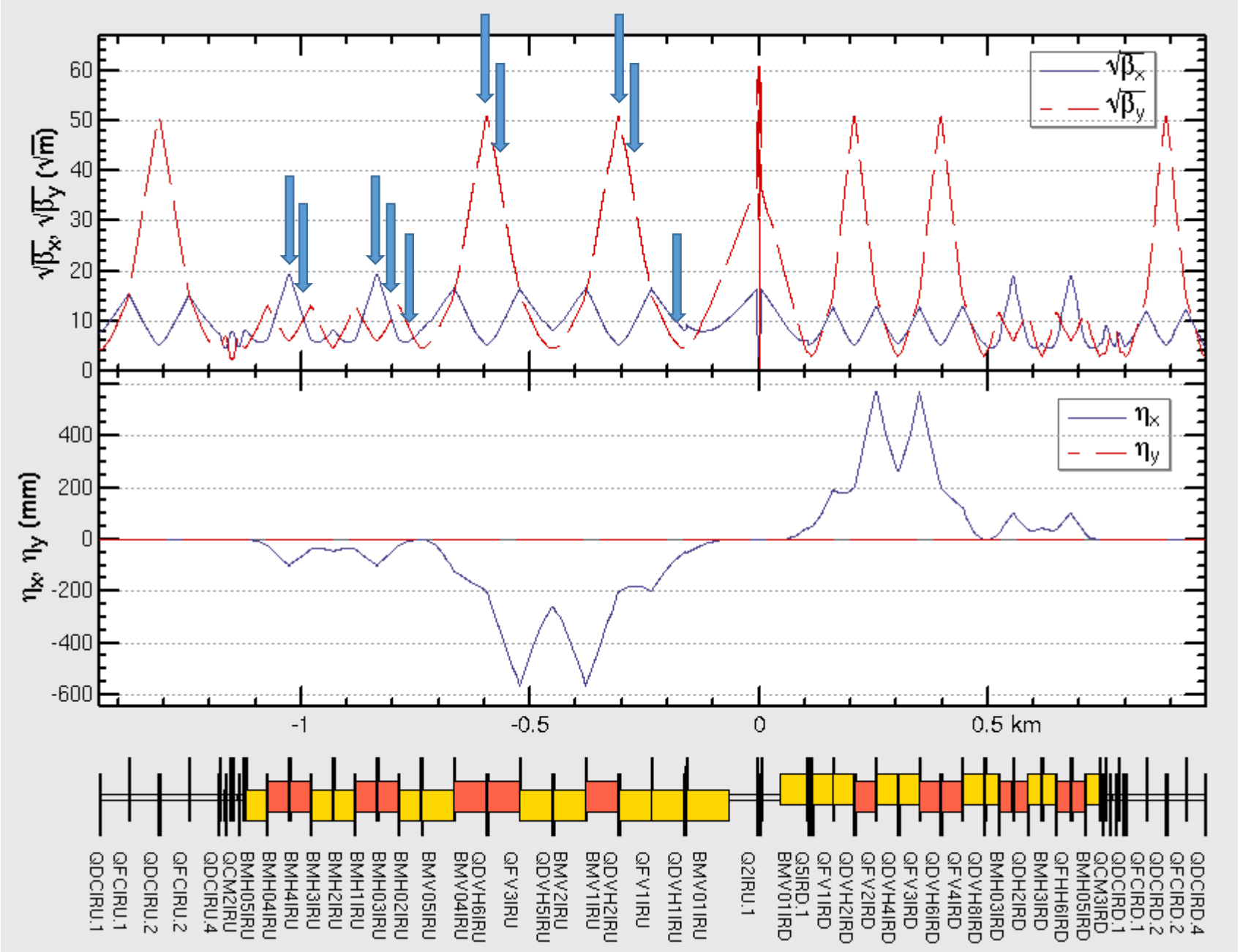
1. Scan the strength of sextupoles;
2. DA tracking for the energy list
3. Calculate the objective function (DA)
4. Find the minimum of the objective function by the downhill simplex method
5. Go to 1.
6. Optimization stop when

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

CEPC DA Optimization Knobs

50(234) knobs in total

- IR sextupoles: (10)
- Arc Sextupole (32) (or 56*4)
- Phase advance (8)



IR knobs

- Main Chromaticity Sextupoles (2)
- Neighbor weaker sextupole to correct finite length effect (2)

A. Bogomyagkov, ArXiv:0909.4872

- Sextupole to correct higher order chromaticity in vertical direction (1)

Y. Cai, PRAB.19.111006

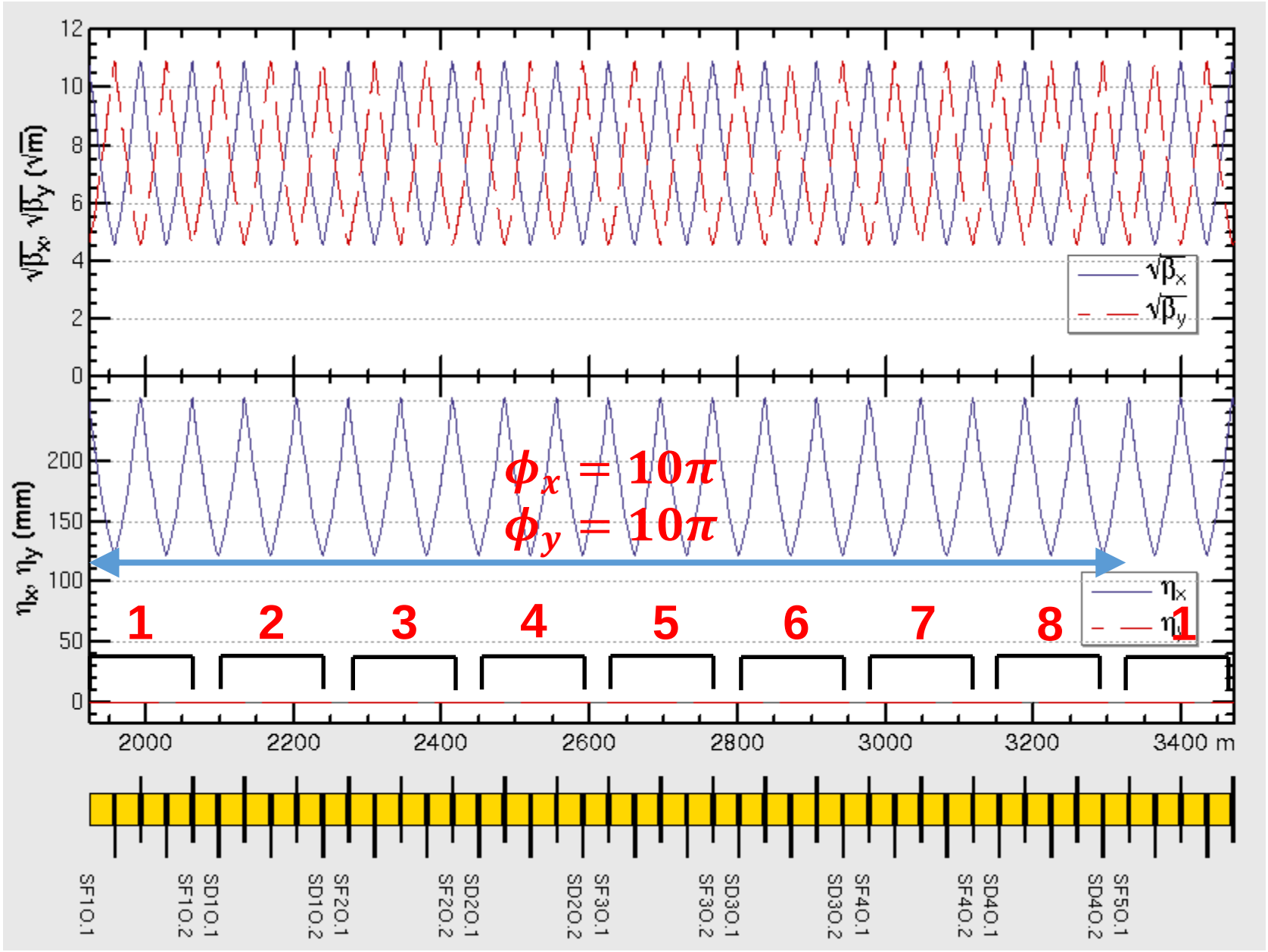
Different strength between Upstream and Downstream of IP.

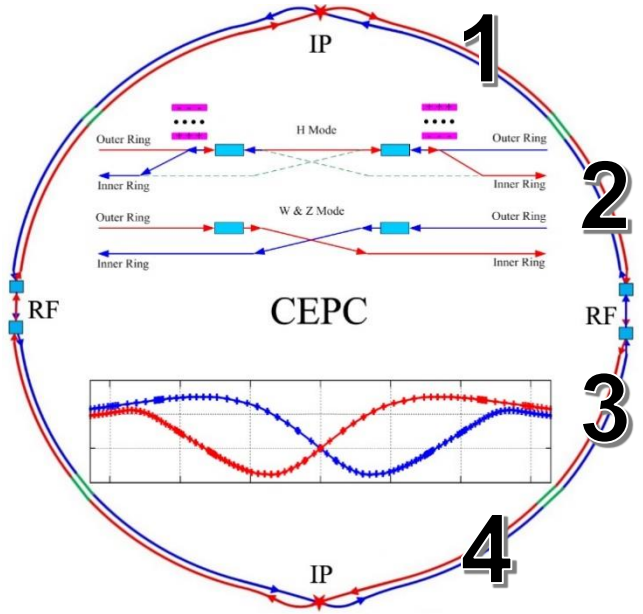
10 knobs in IR.

Arc sextupole

- 90/90 FODO
- Non-interleave sextupole scheme
- 4 SF + 4 SD sextupole configurations in one arc section
- 7 sub-period in in one arc section,
- 4 arc section in half ring

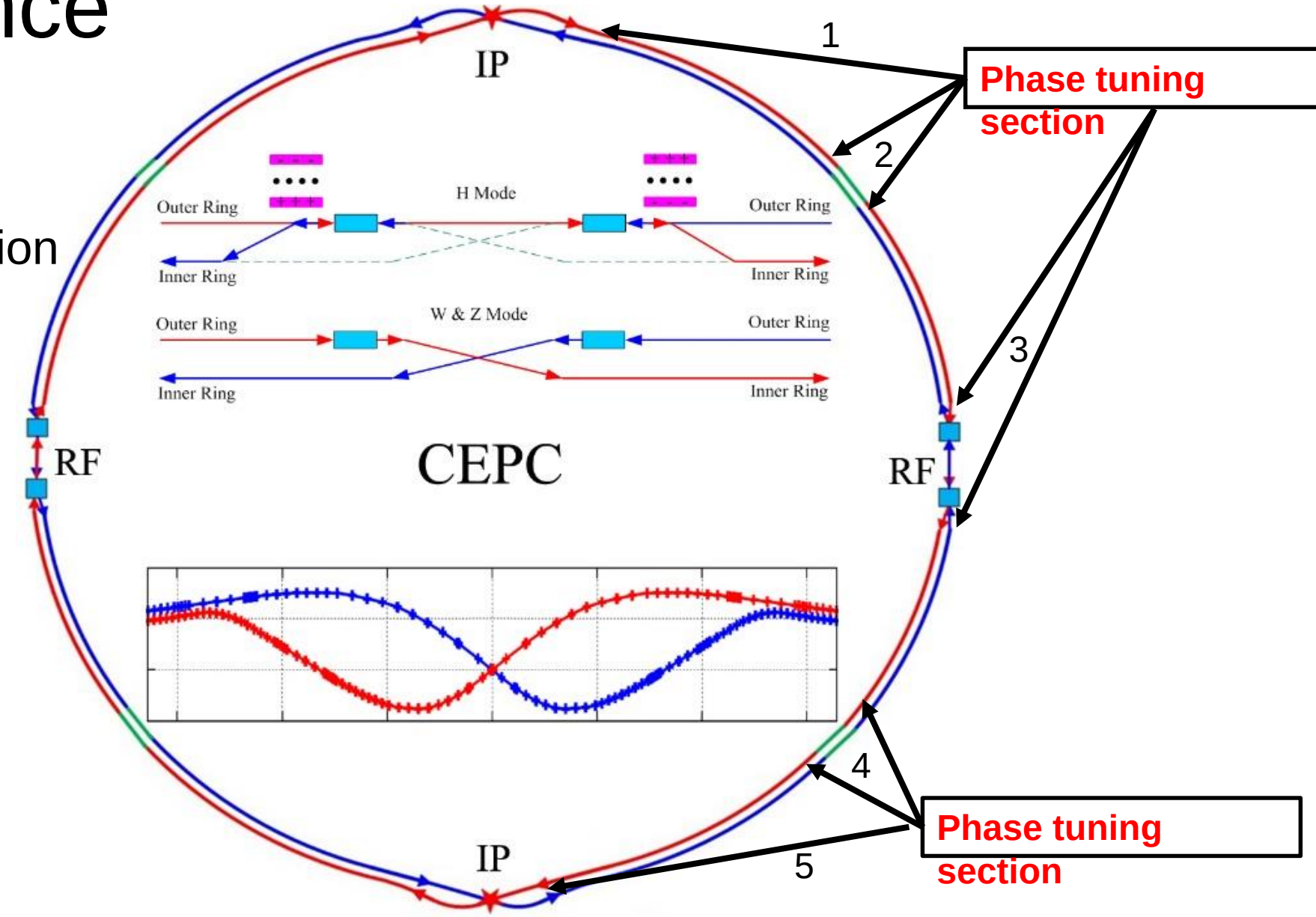
Total knobs: 32





Phase Advance Tuning

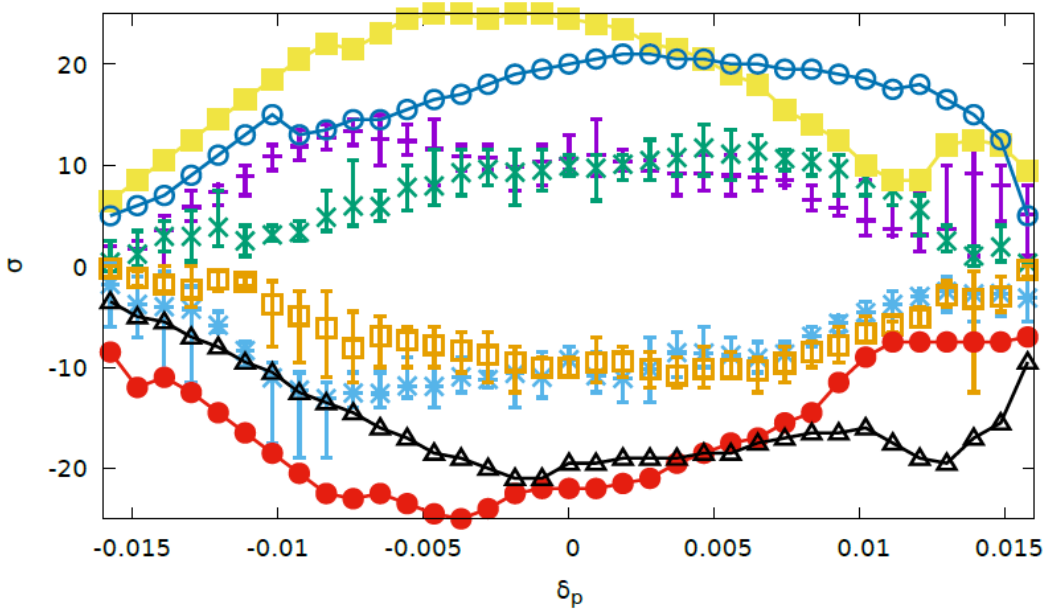
- 10 knobs in x/y direction
- Keep tune fixed
- Only 8 free knobs



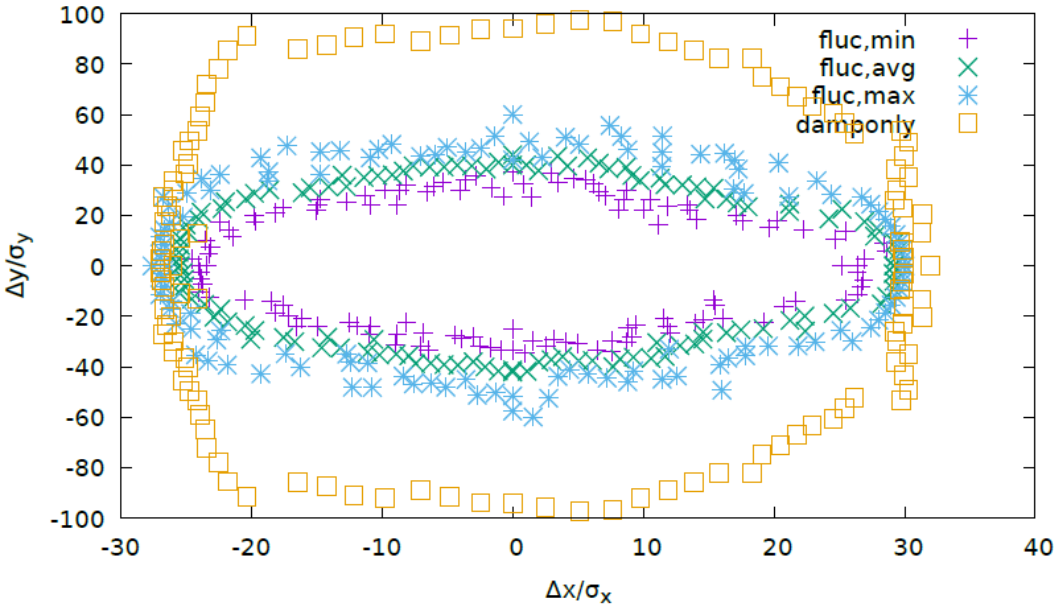
Model used in DA tracking

SAD:

Synchrotron motion, synchrotron radiation in dipoles, quads and sextupoles, tapering, Maxwellian fringes, kinematical terms, crab waist are included.

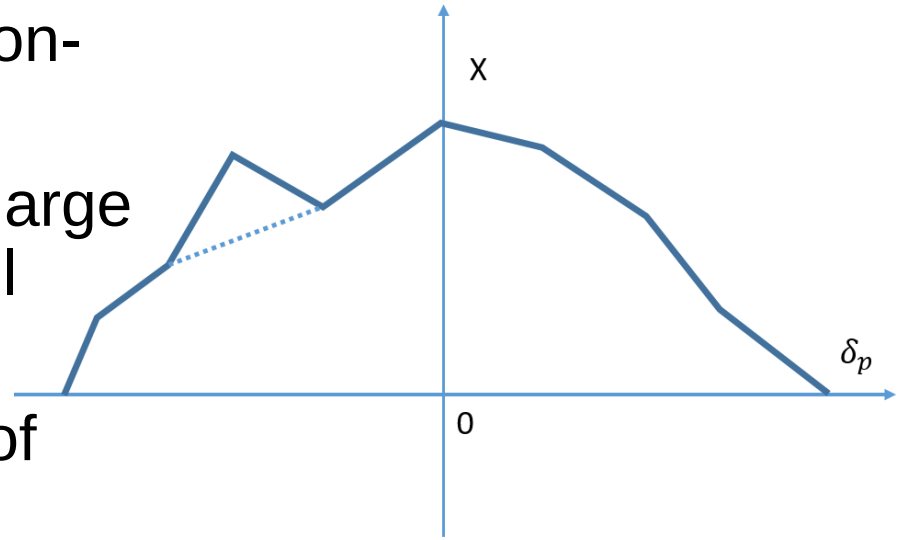


DAMPONLY vs SR Fluctuation



Suppress noise of DA with SR fluctuation

- DA is tracked with different initial phase: $\left(0, \frac{\pi}{2}, \pi, \frac{3\pi}{2}\right)$ for different energy
- 10 more times survey for on-momentum particle is tracked, and the minimum value is treated as the on-momentum DA
- Tracked DA result will be clipped to ensure DA at large momentum deviation will be less than that at small deviation
- Only two objective: min-DA of $(0, \pi)$ and min-DA of $\left(\frac{\pi}{2}, \frac{3\pi}{2}\right)$

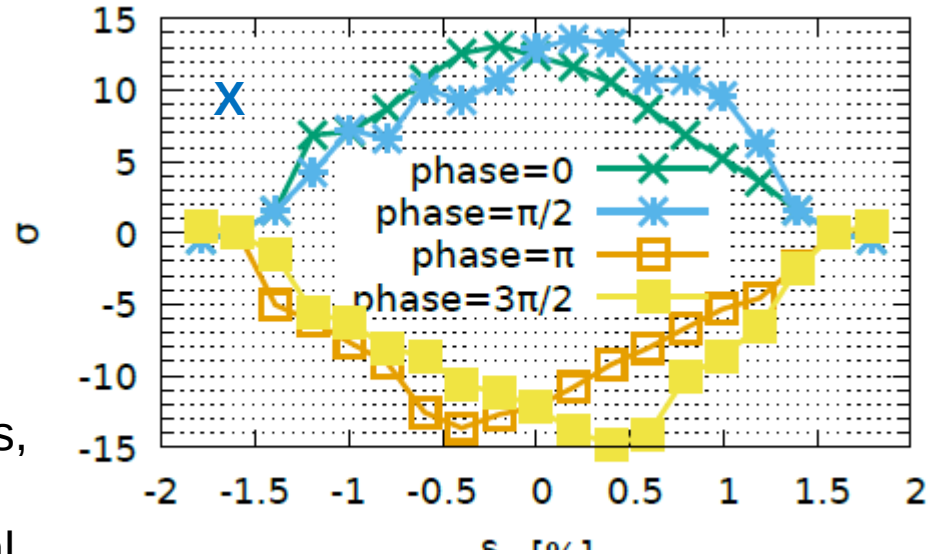


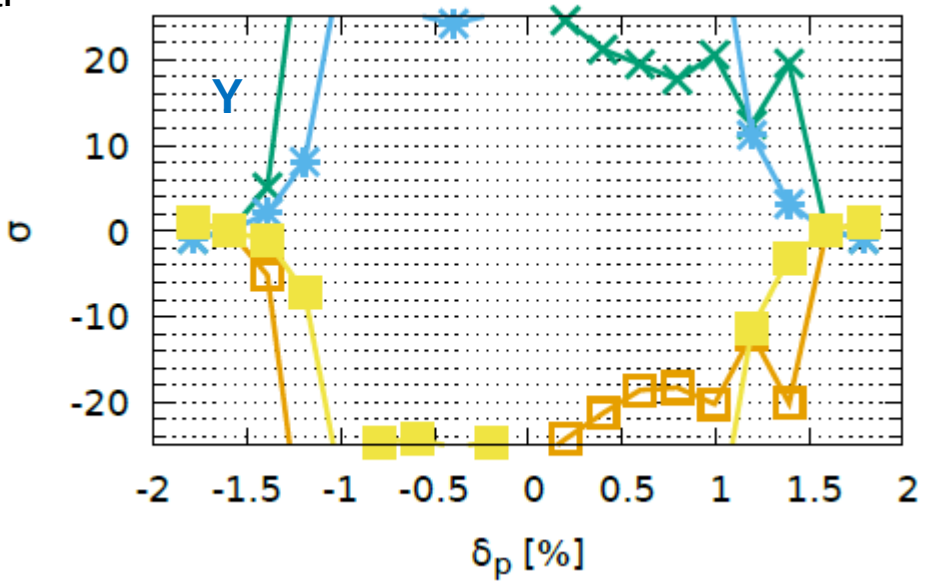
D. Wang

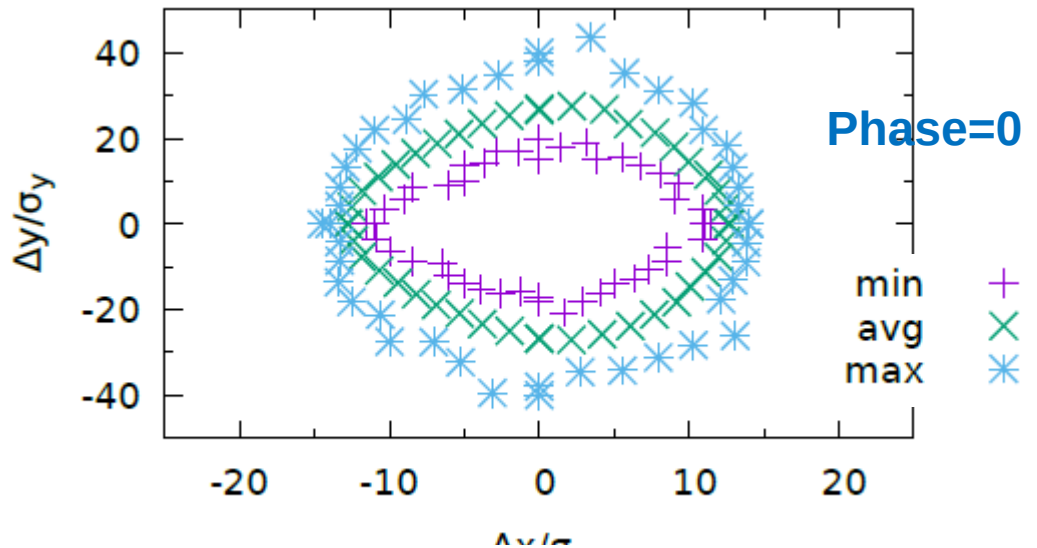
Optimized at IP. DA at INJ shown.

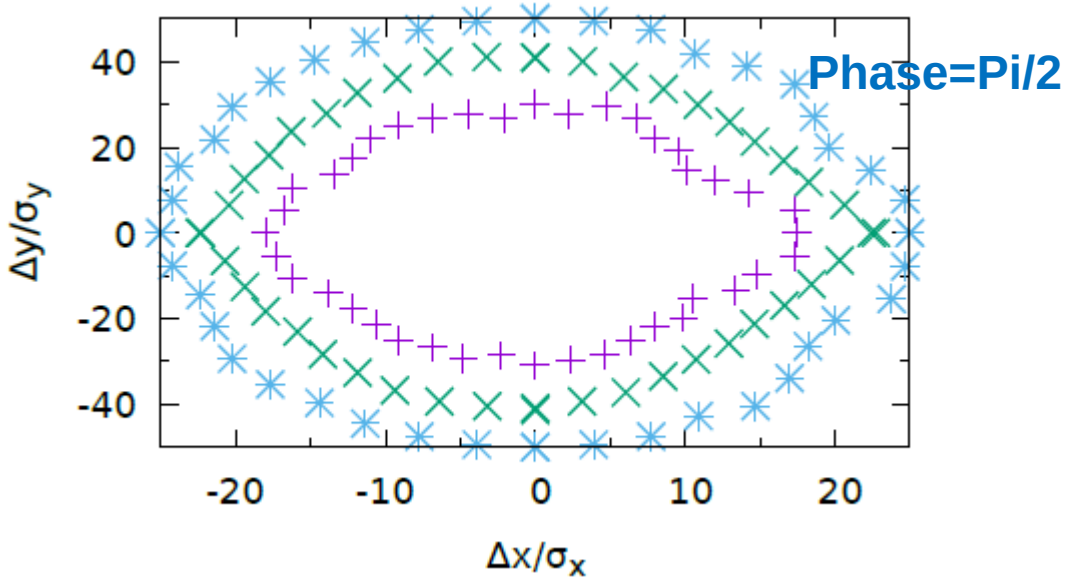
By=2mm, DownhillSimplex (234 knobs)

100 samples,
200 turns,
90% survival





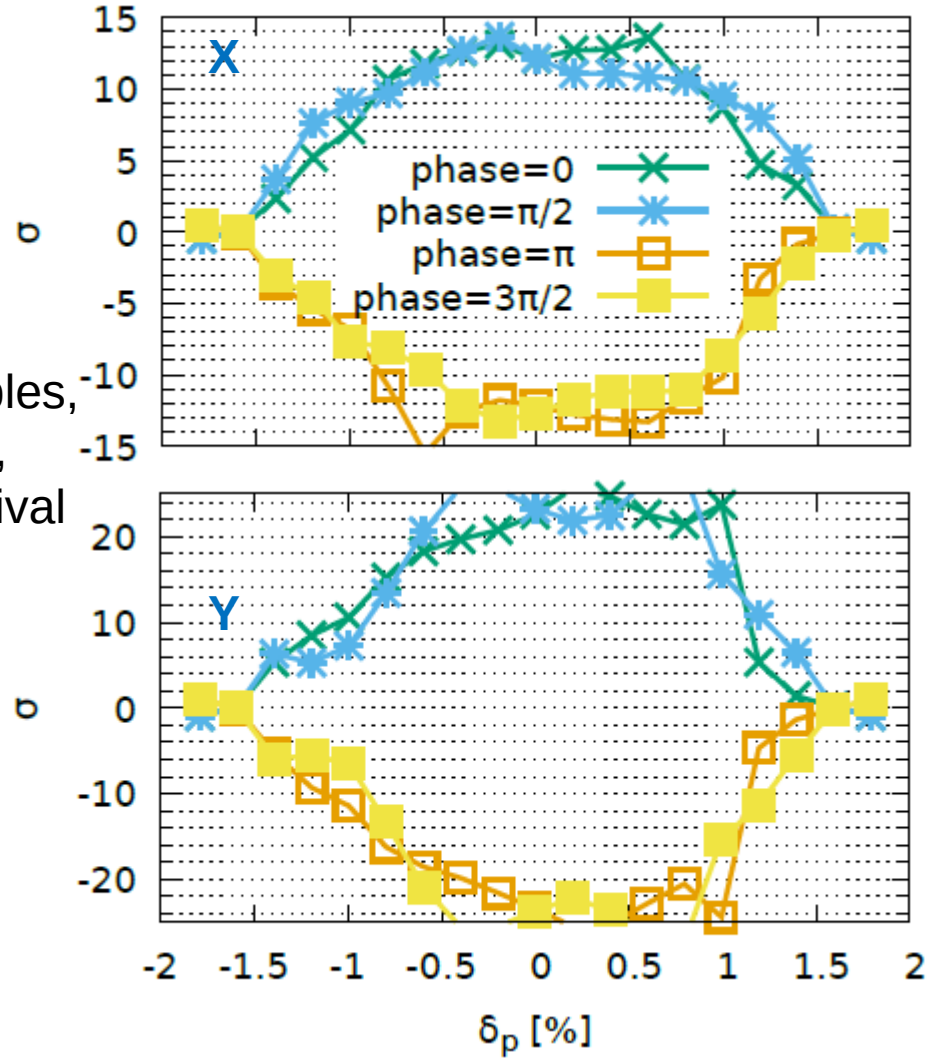


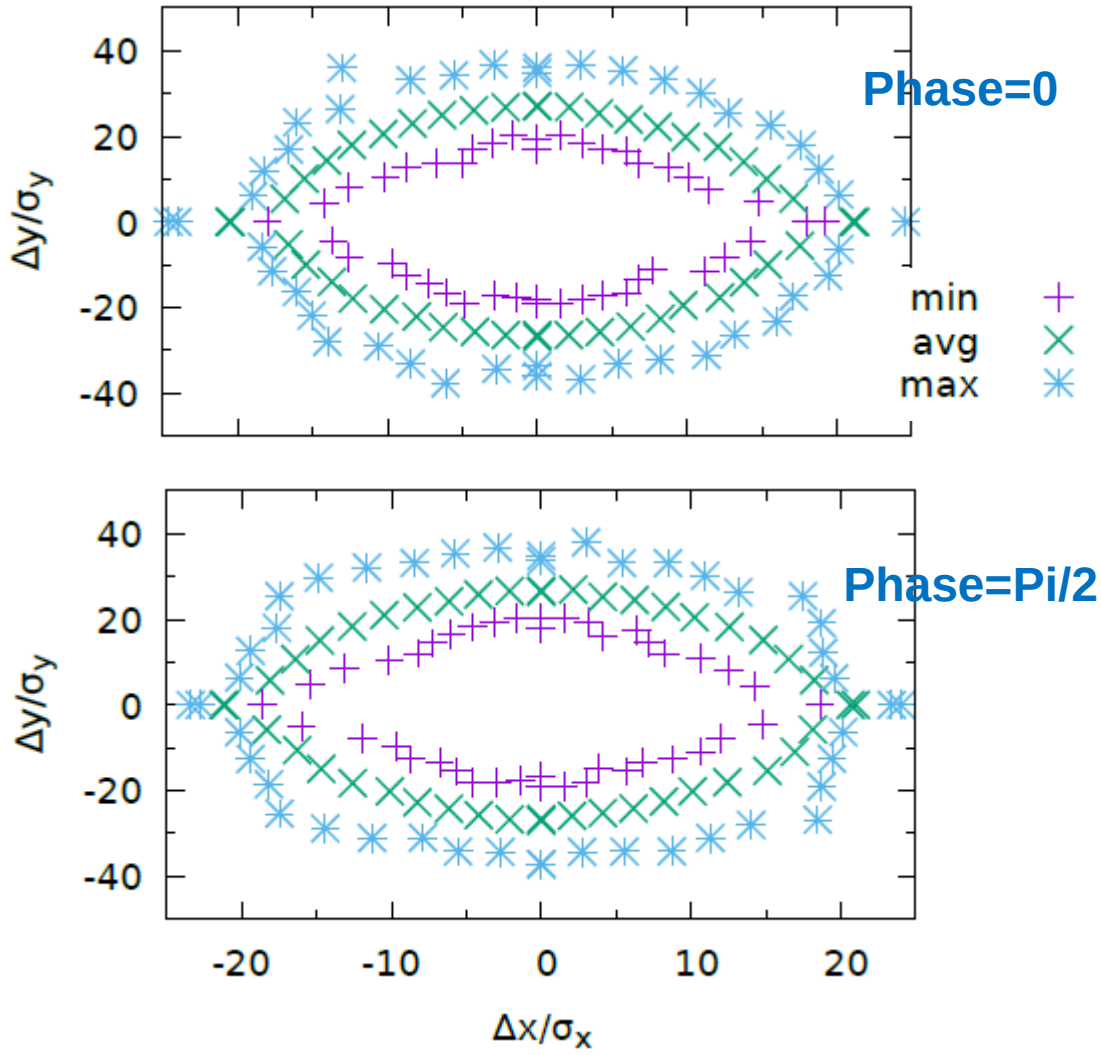


By=2mm, MODE (50 knobs)

Optimized at INJ.

100 samples,
200 turns,
90% survival





Older version lattice,

By=2mm, MODE (50 knobs)

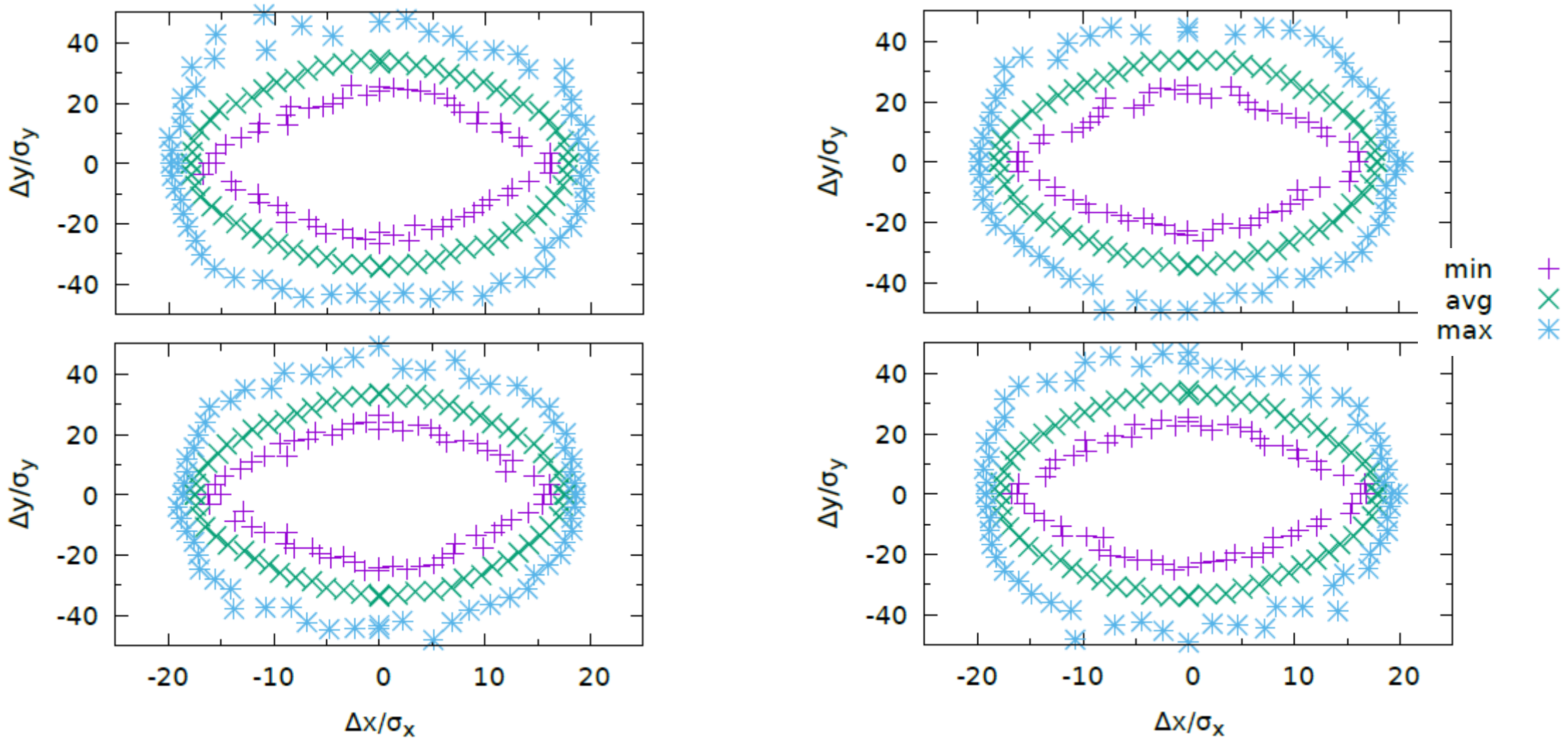
Optimized at IP. DA at INJ shown.

IP

INJ

Phase=0

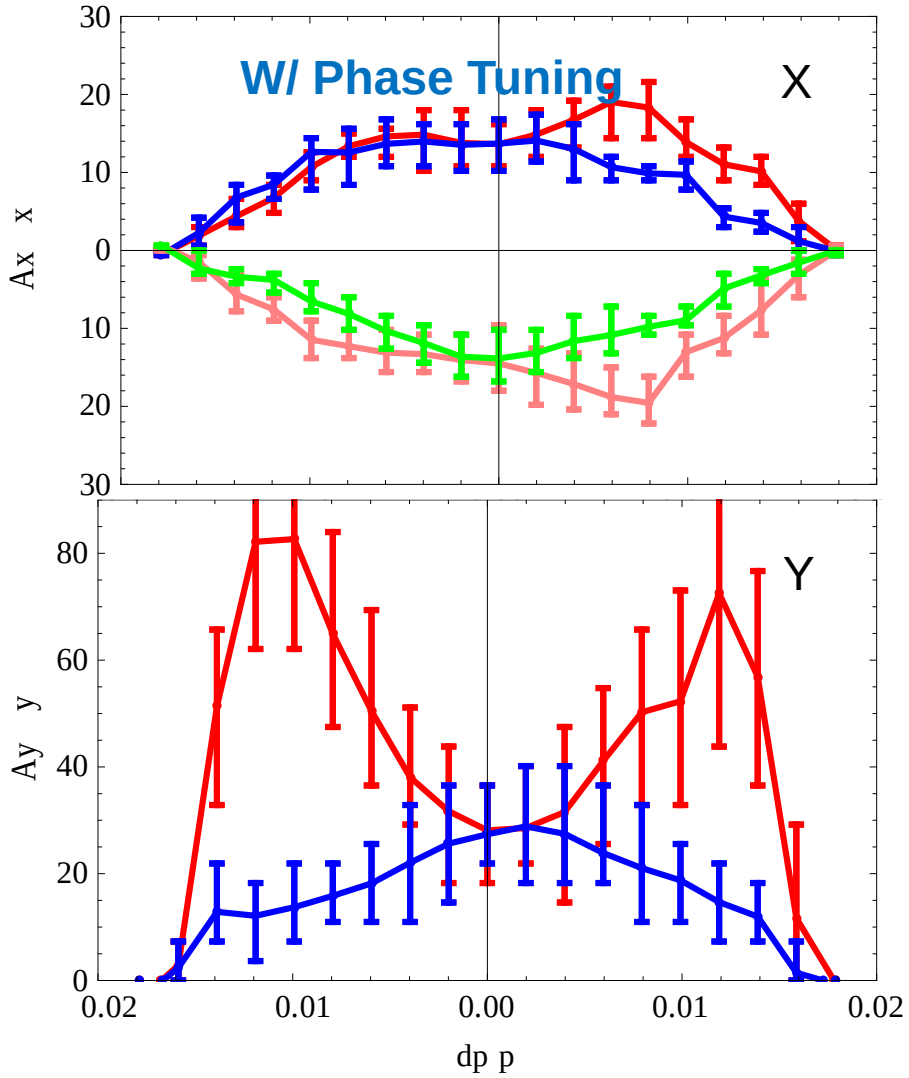
Phase=$\pi/2$



D. Wang

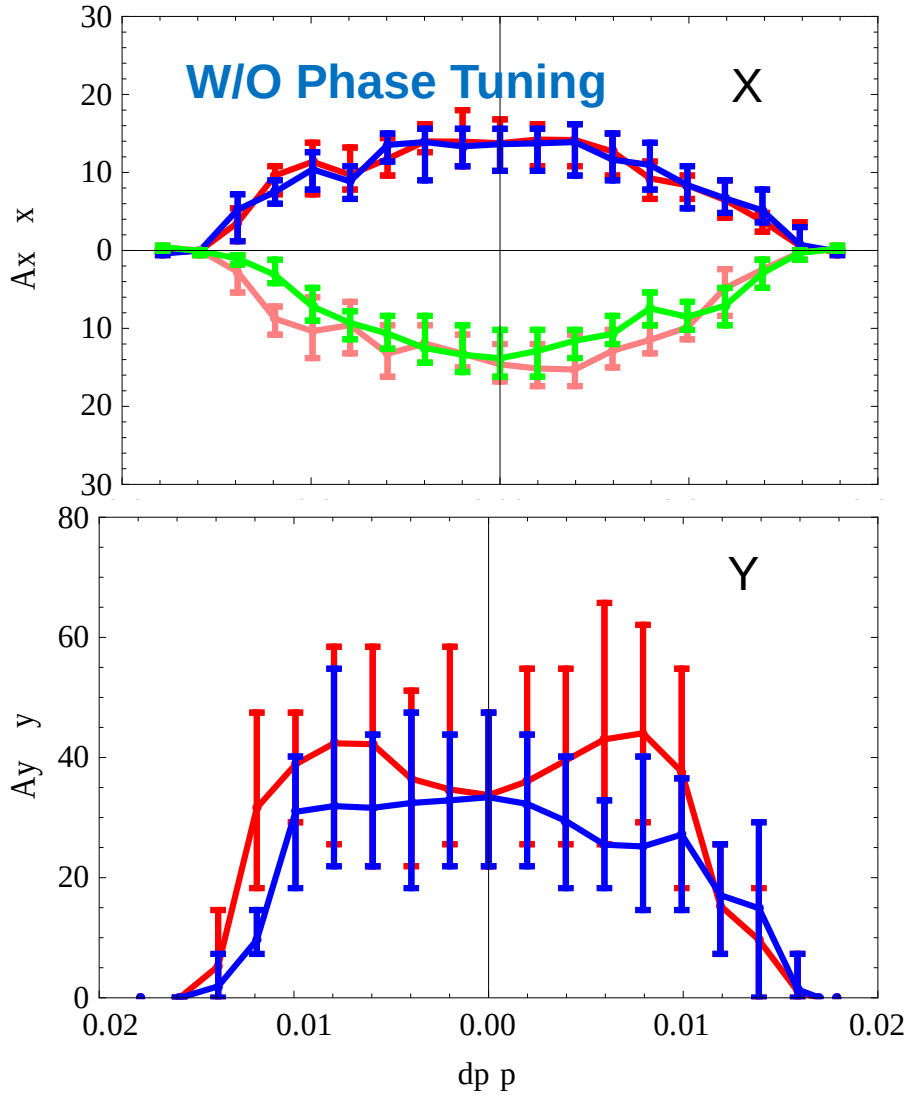
Arc Phase Tuning

by=2mm, DownhillSimplex(234 knobs)



Objective

Not Objective so far

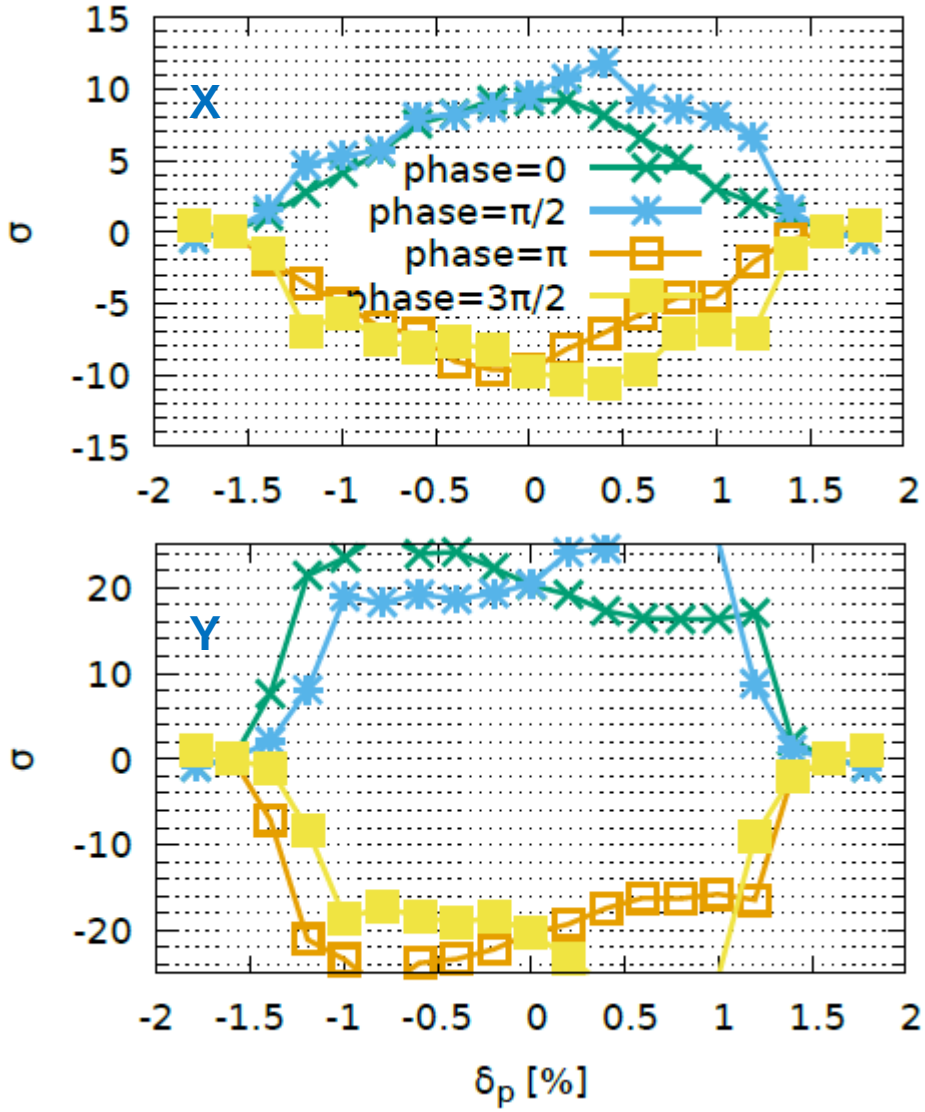


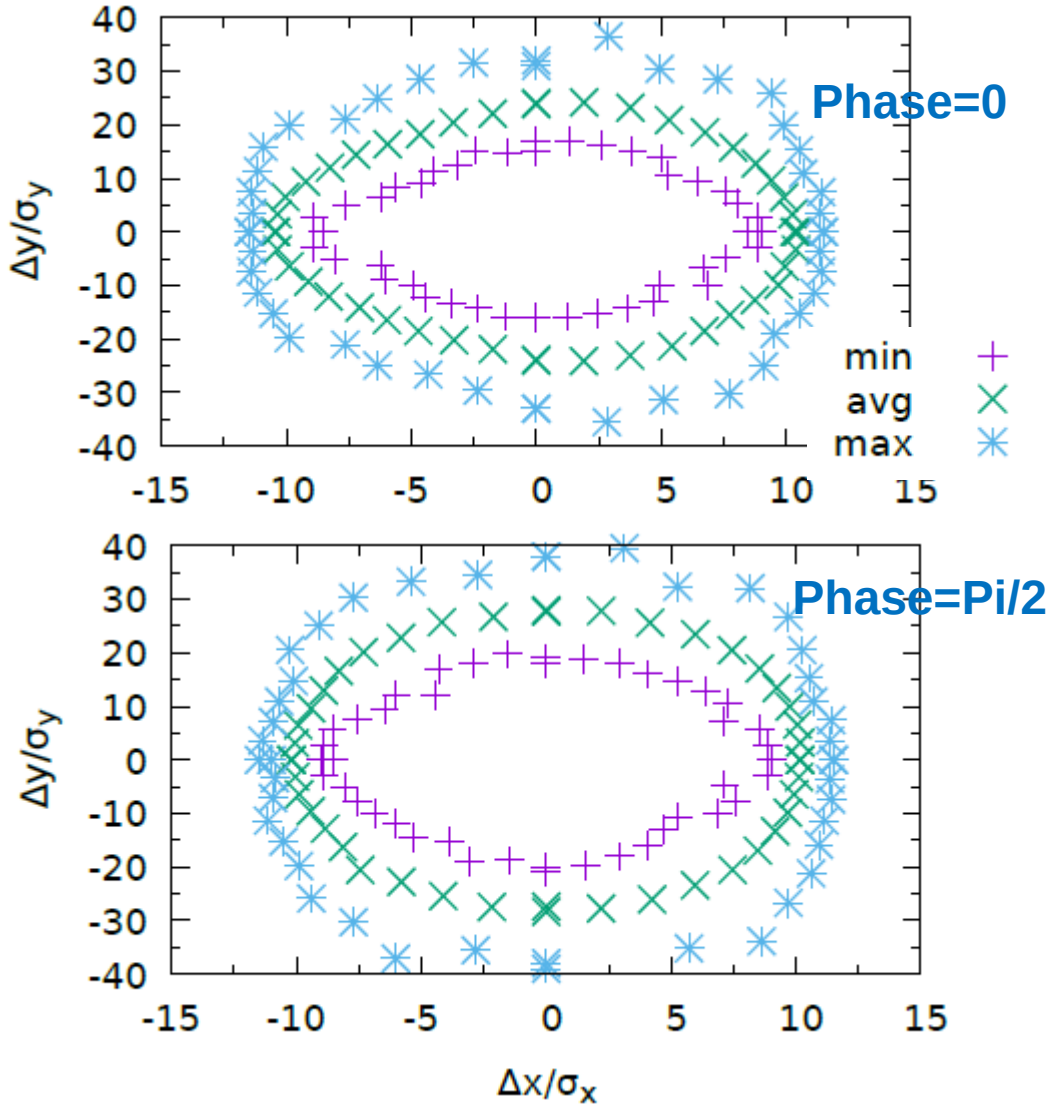
D. Wang

Optimized at IP. DA at INJ shown.

By=1.5mm, DownhillSimplex (234 knobs)

100 samples,
200 turns,
90% survival

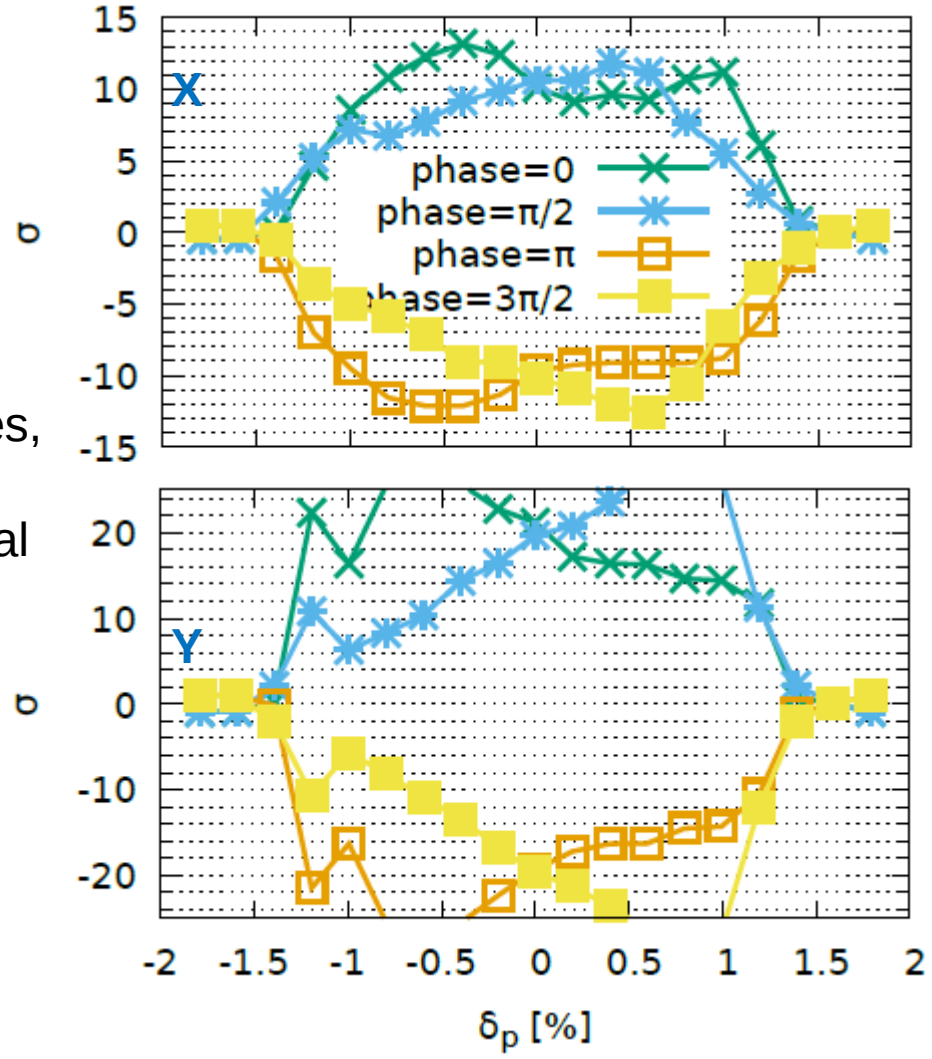


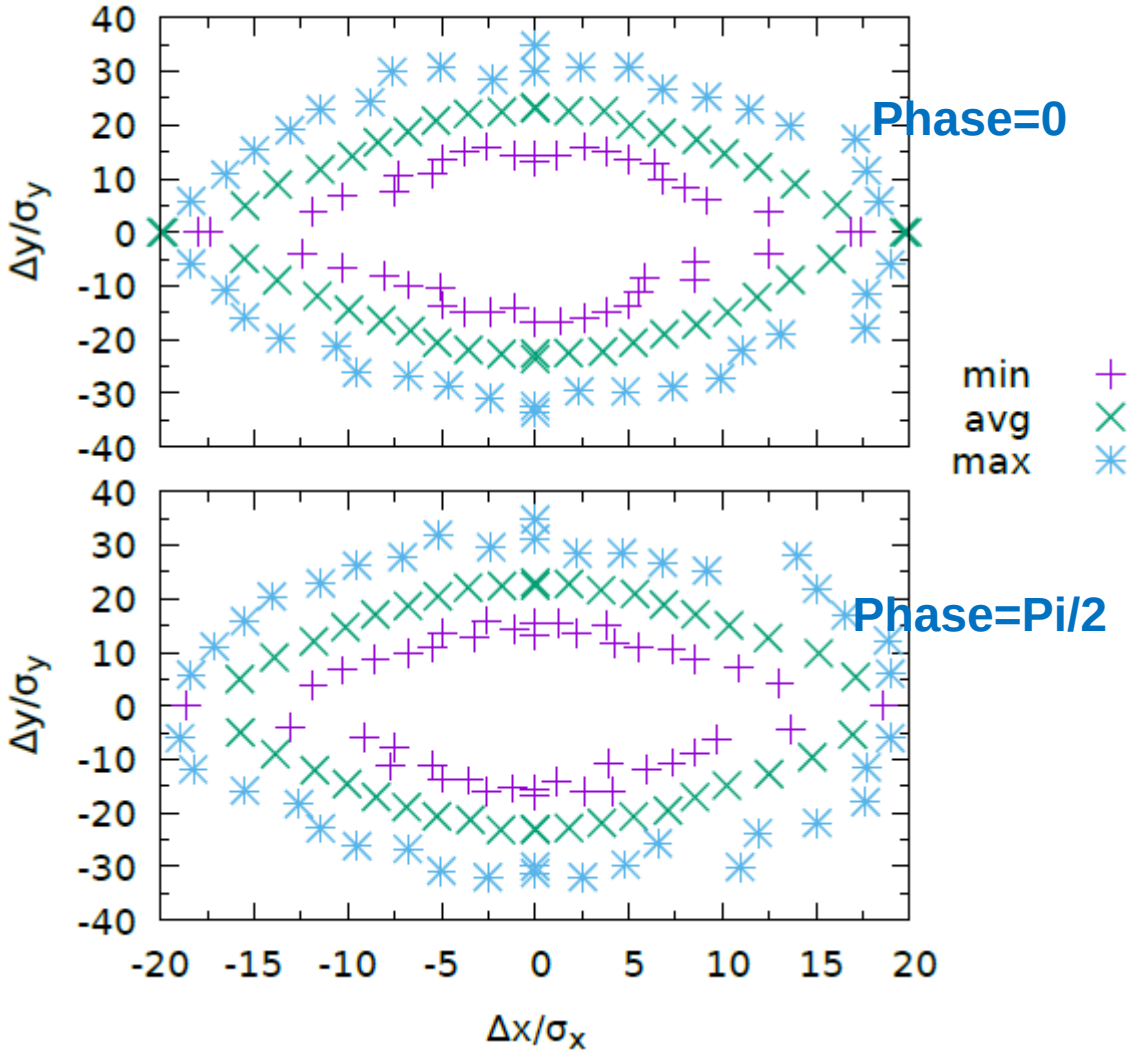


By=1.5mm, MODE (50 knobs)

Optimized at INJ.

100 samples,
200 turns,
90% survival



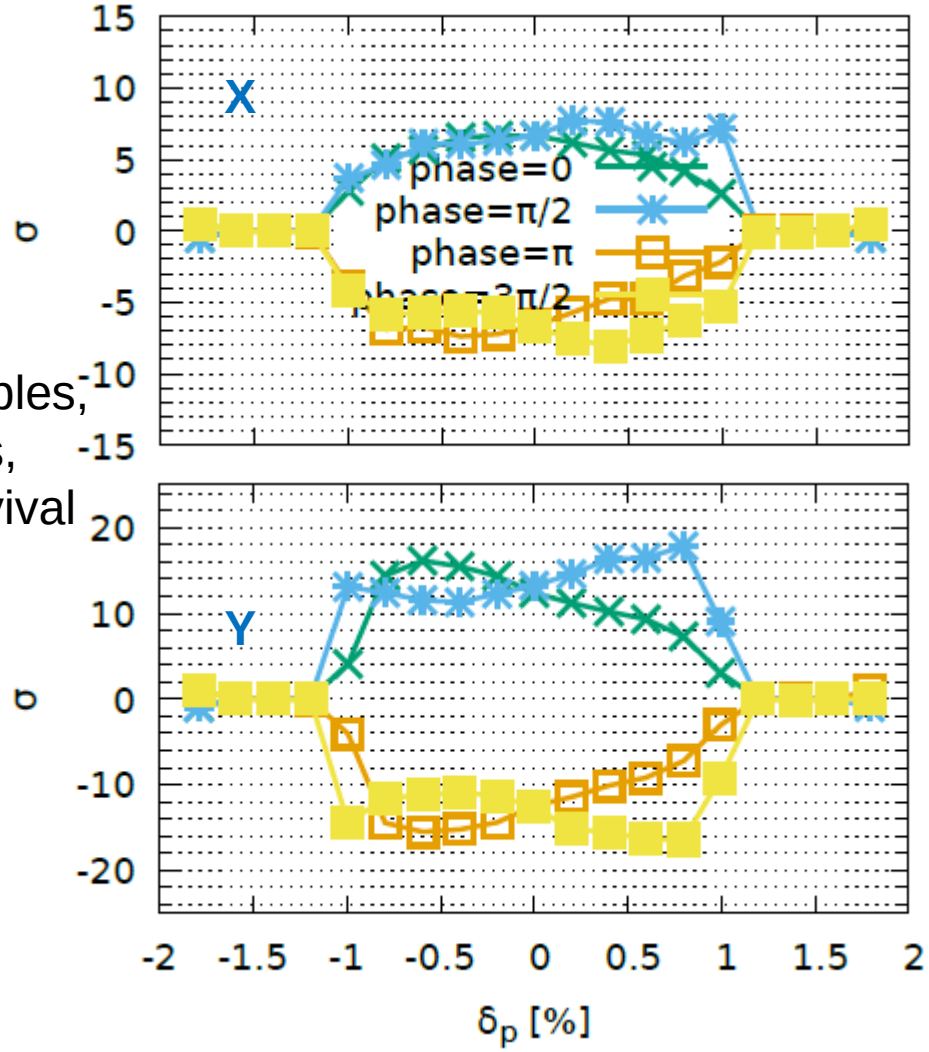


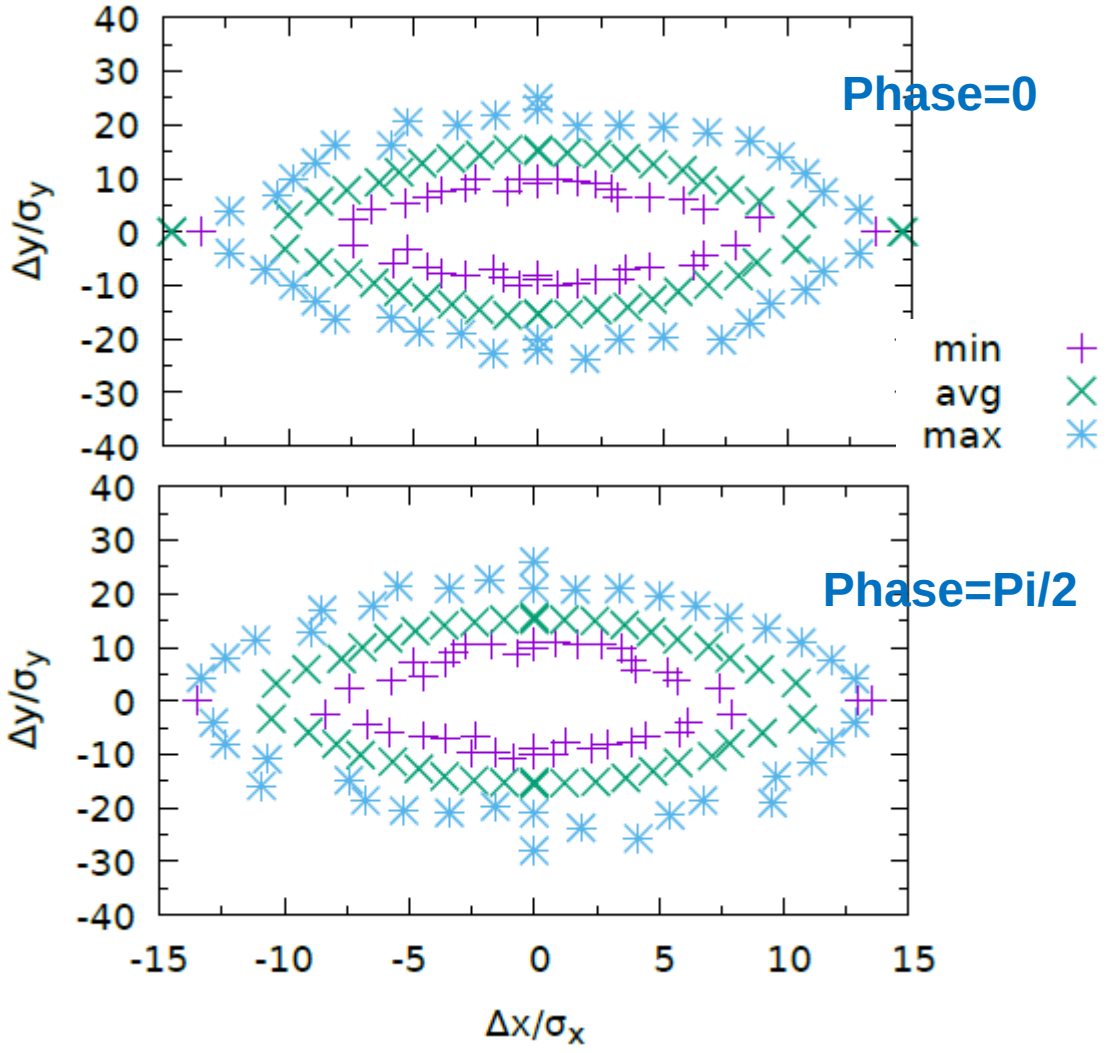
D. Wang

Optimized at IP. DA at INJ shown.

By=1mm, DownhillSimplex (234 knobs)

100 samples,
200 turns,
90% survival

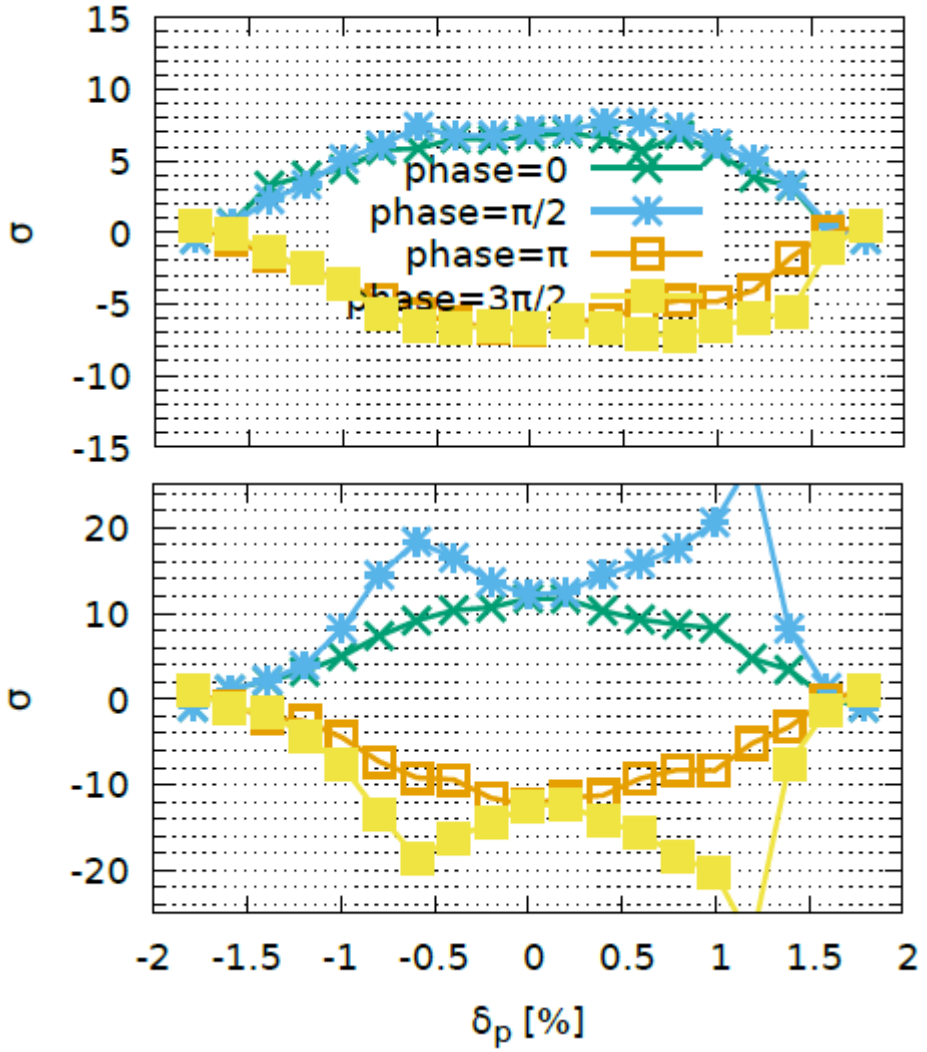


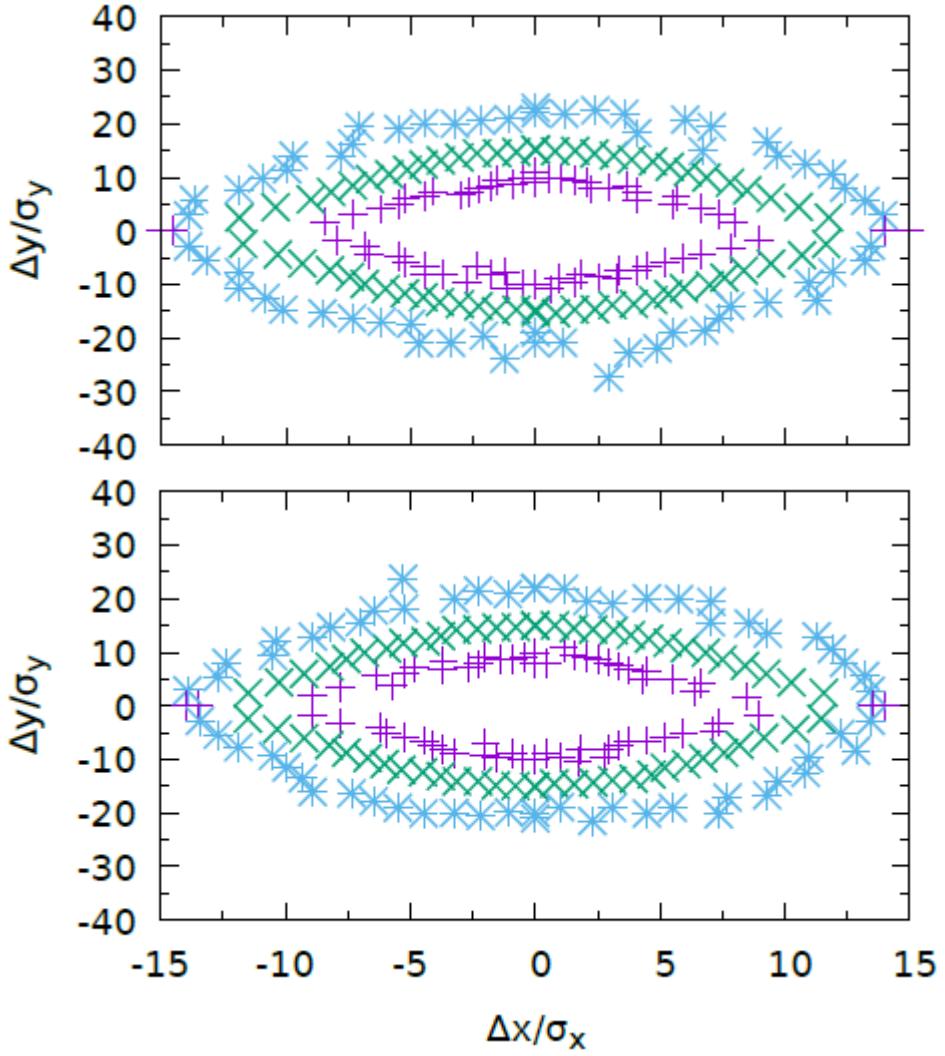


By=1mm, MODE (50 knobs)

Optimized at INJ.

100 samples
200 turns,
90% survival



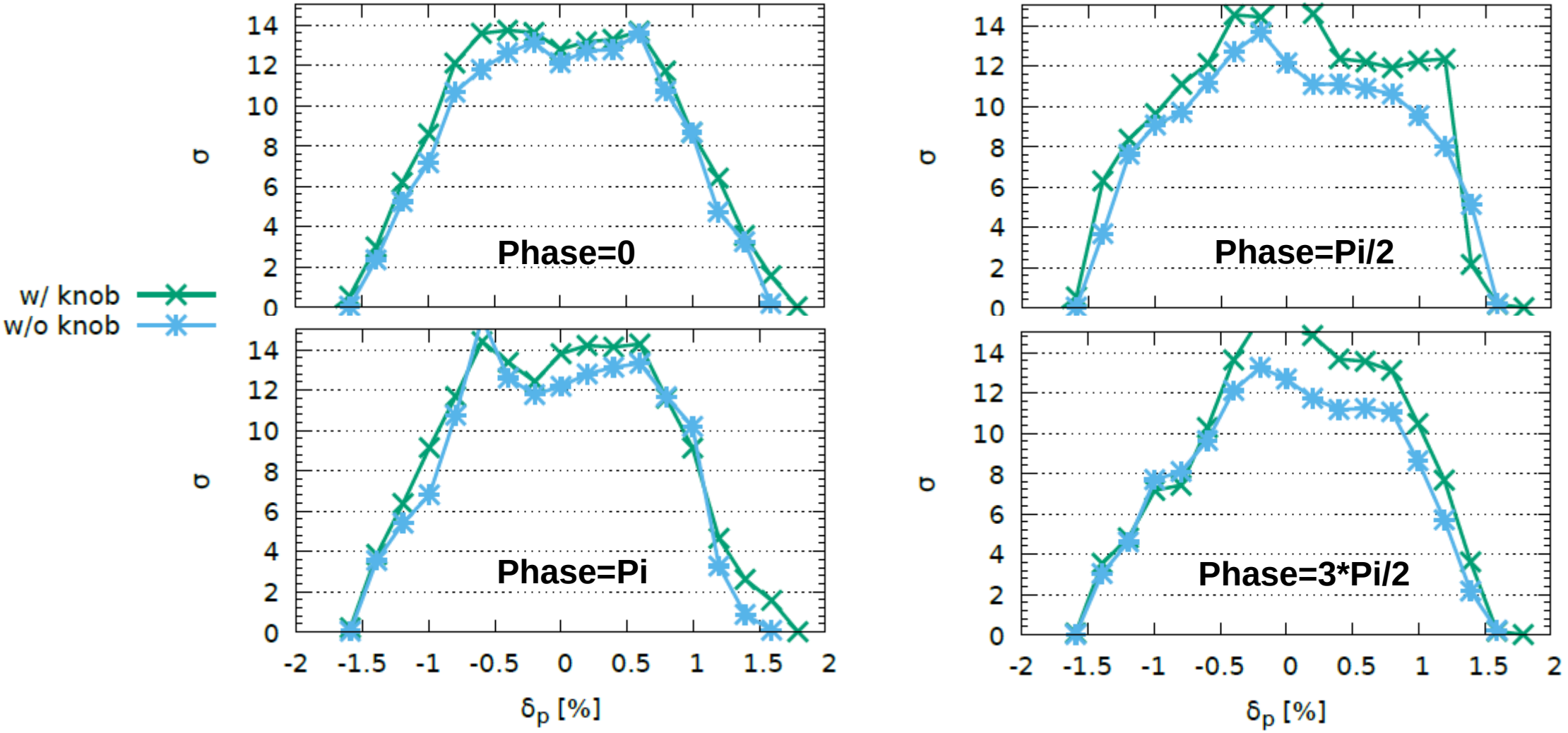


More knobs (20)

- The octupole magnets in the immediate vicinity of the FF quadrupoles (QD0 and QF0) (4) slac-pub-12716
- Octupoles are added to ccs sextupoles for the optimization (4) K. Oide
- Non-interleave sextupole pair in RF region(2)
- Octupole to correct higher order chromaticity in vertical direction (2) Y. Cai
- More sextupole in dispersive region(8)

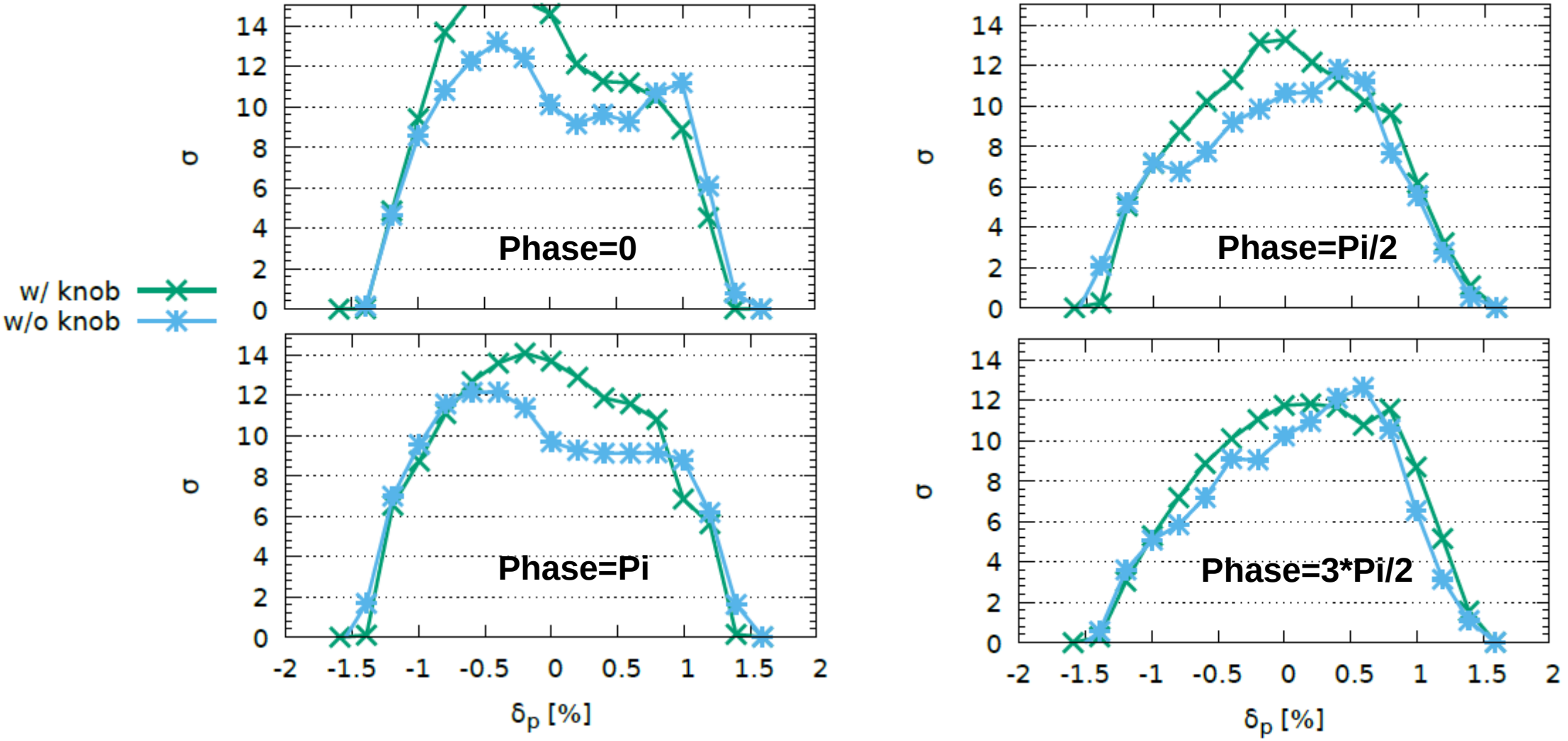
20 more knobs: by=2mm

(1-2 sigma enlargement at small momentum deviation)



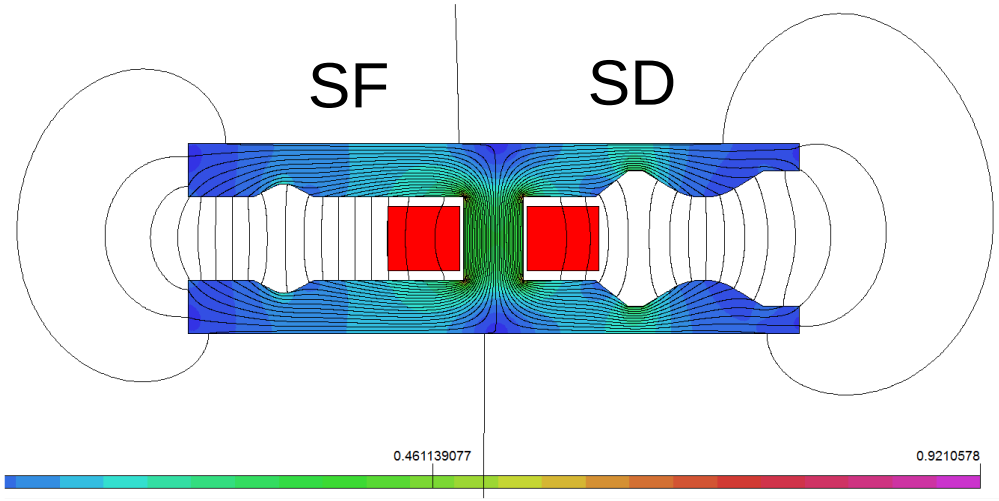
20 more knobs: by=1.5mm

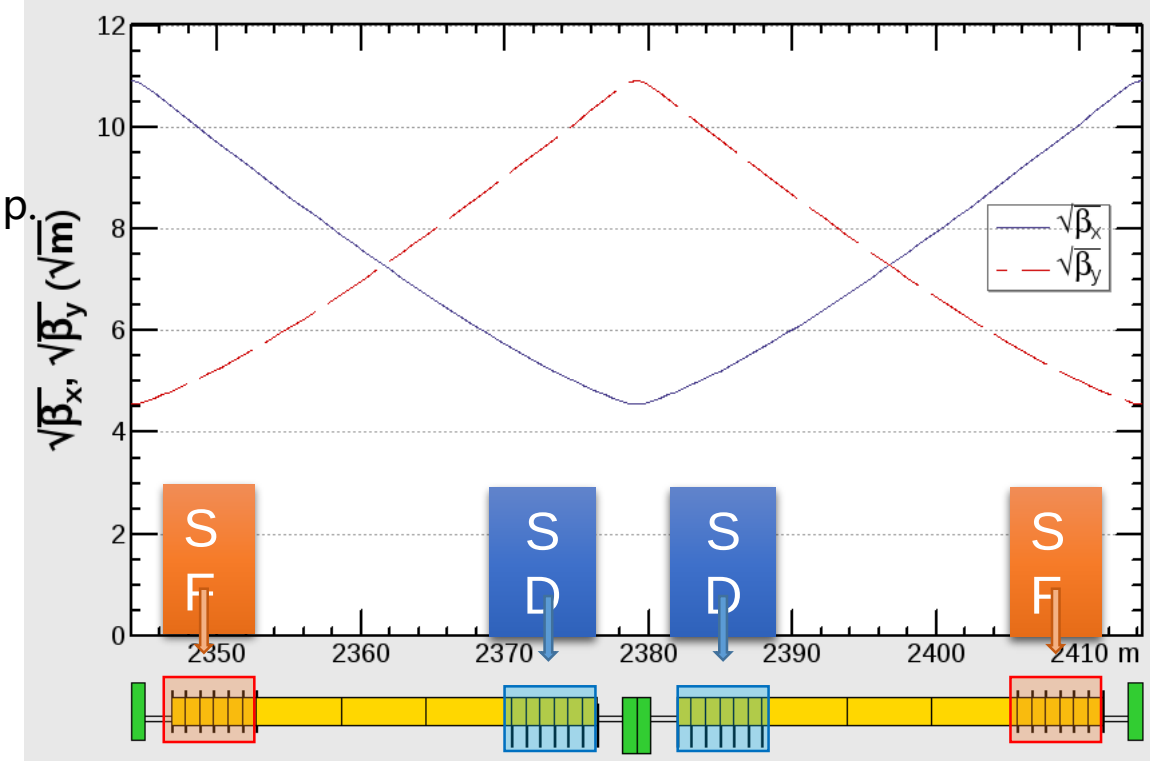
(1-2 σ enlargement at small momentum deviation)



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 help.
- Combined function magnet: dipole + sextupole
  - Combined sextupoles: half of linear chromaticity
  - Stand-alone sextupoles: Chromaticity and DA
- No additional power sources for combined SF and SD

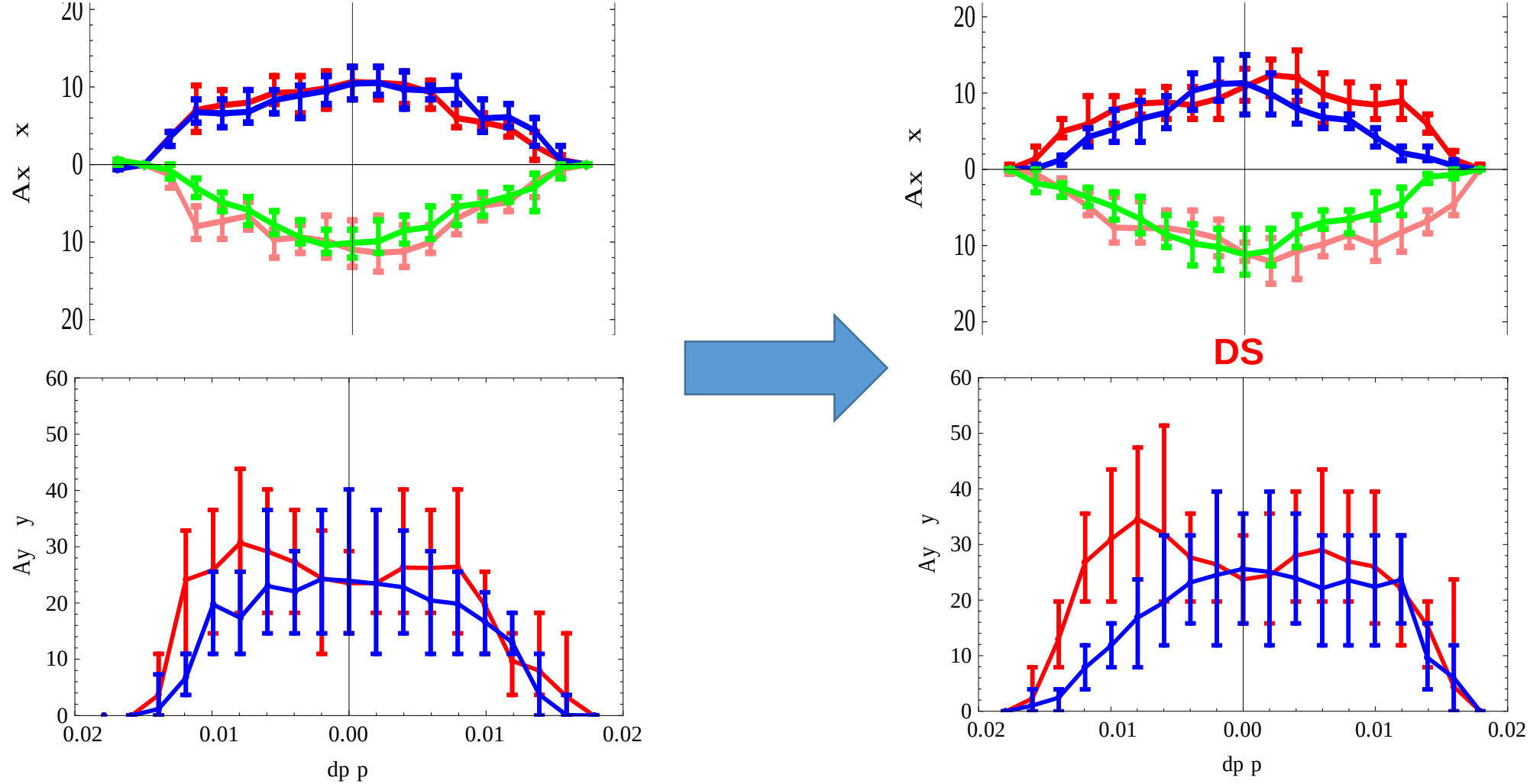




D. Wang

DA of DS Scheme

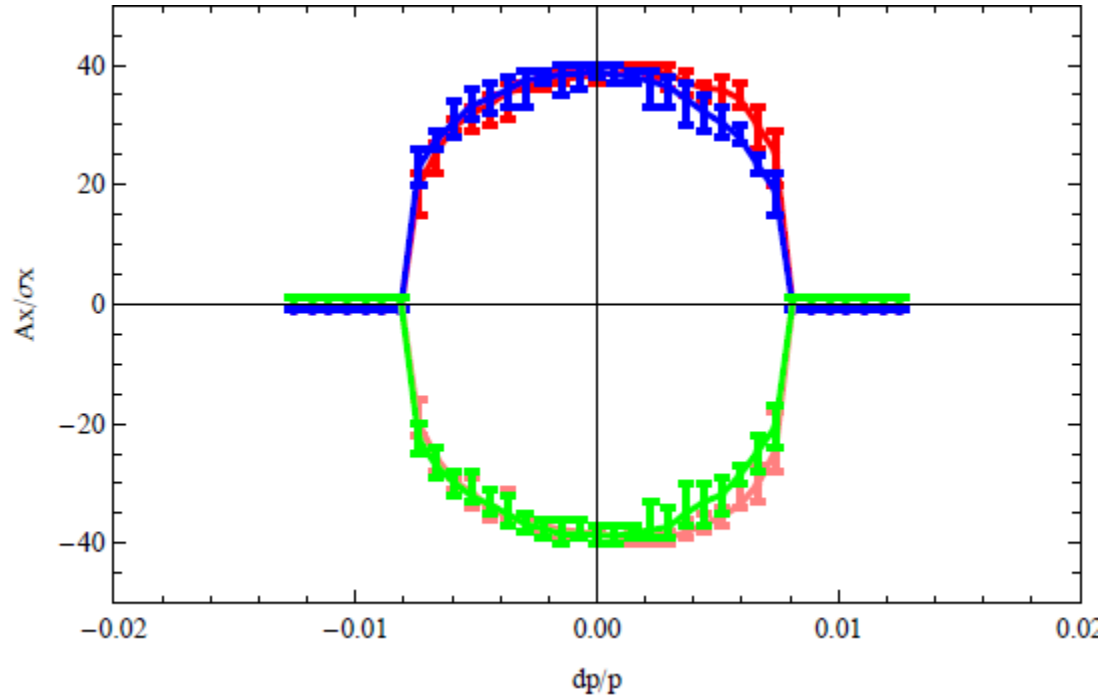
By=1.5mm, DownhillSimplex (234 knobs)

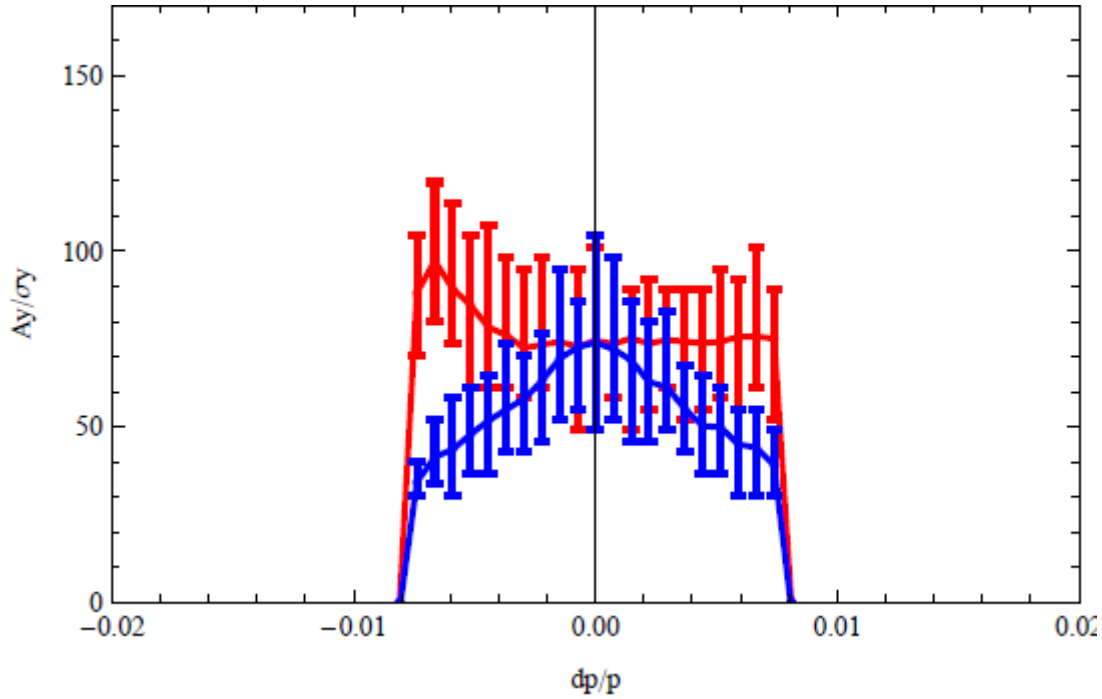


D. Wang

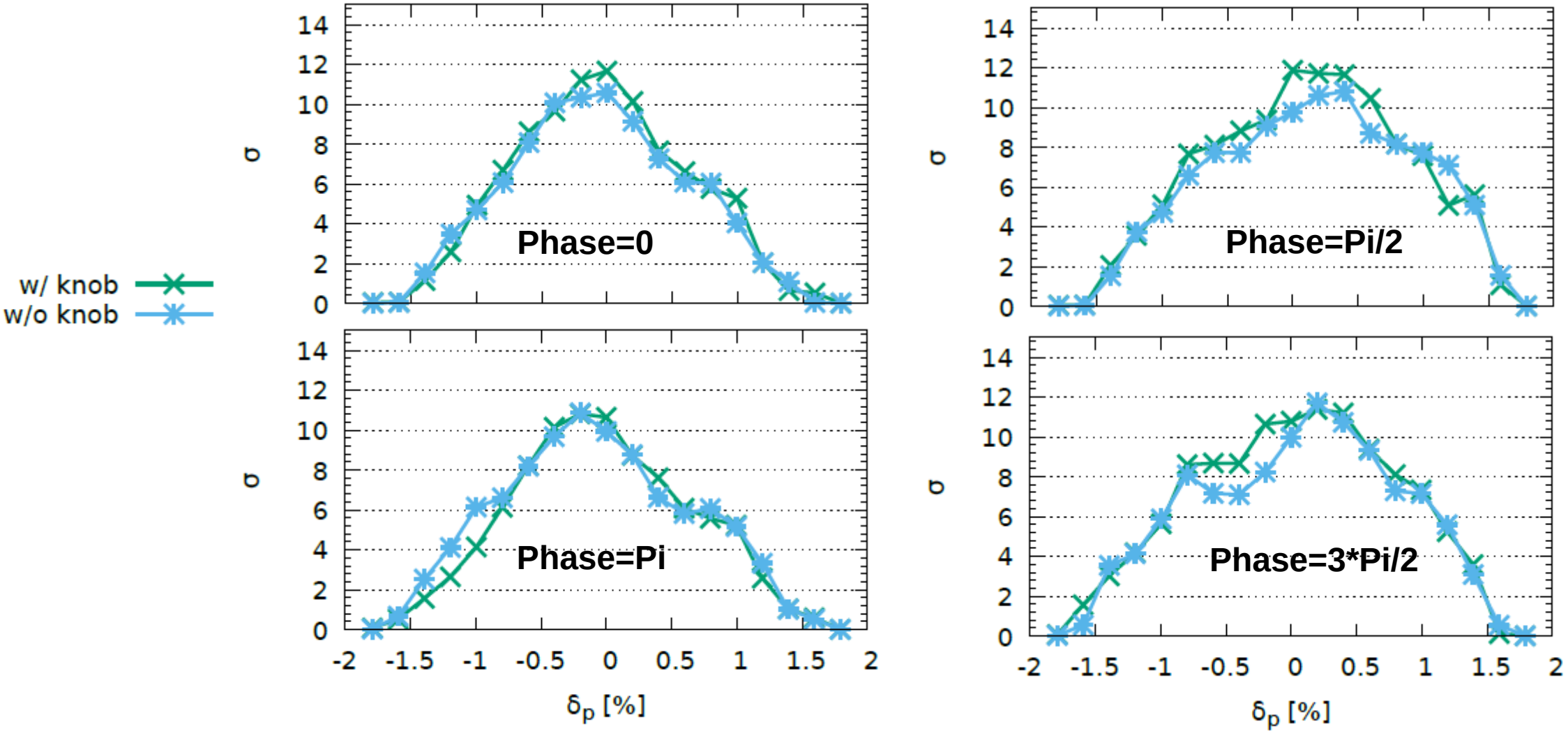
DA at Z with combined DS

We do not need to worry about the break of non-interleave sextupole scheme

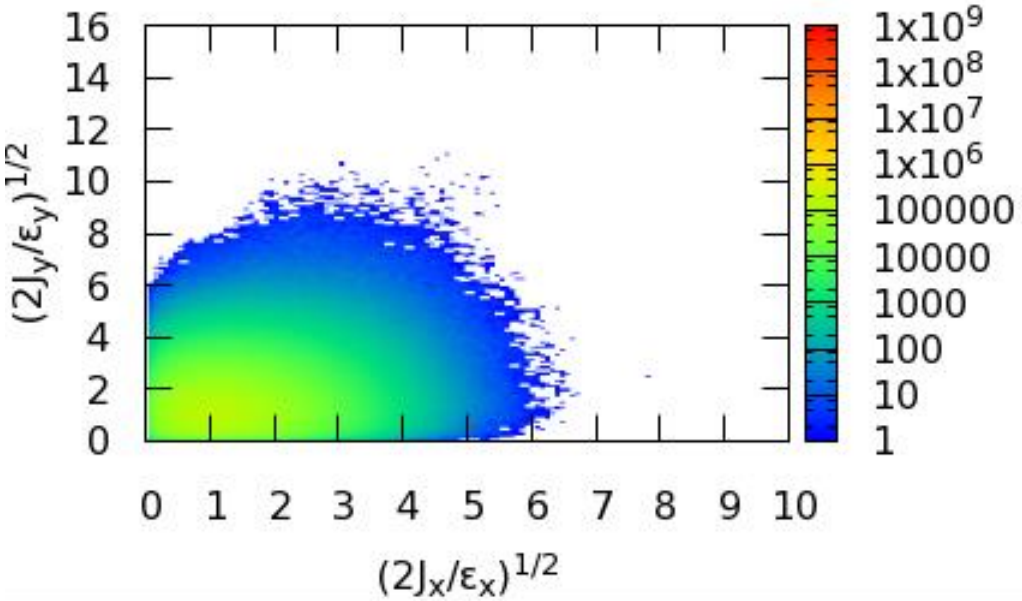


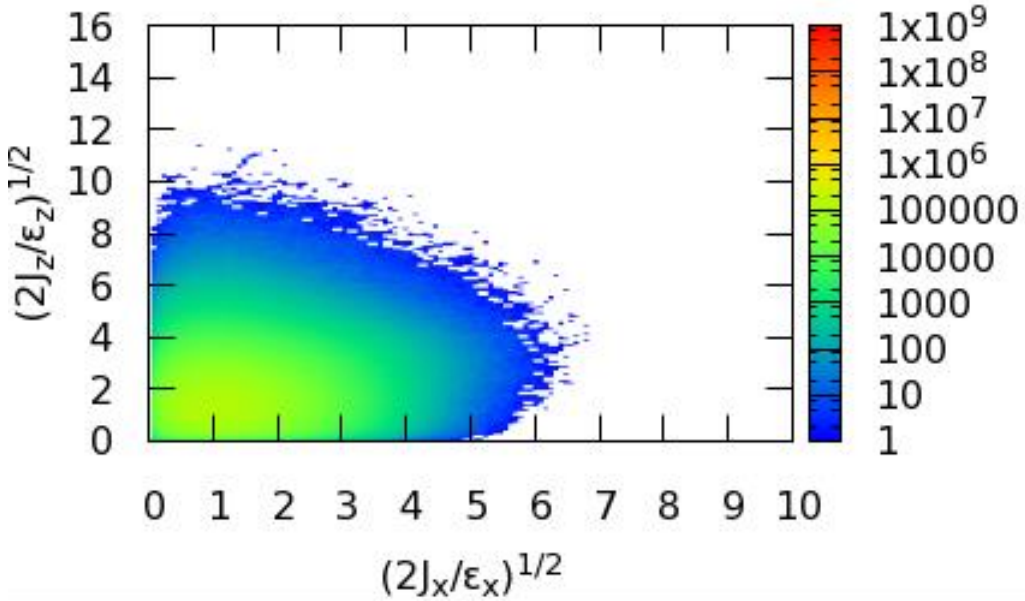


20 more knobs: by=1.5mm DS Scheme
(no so clear contribution from 20 more knobs)

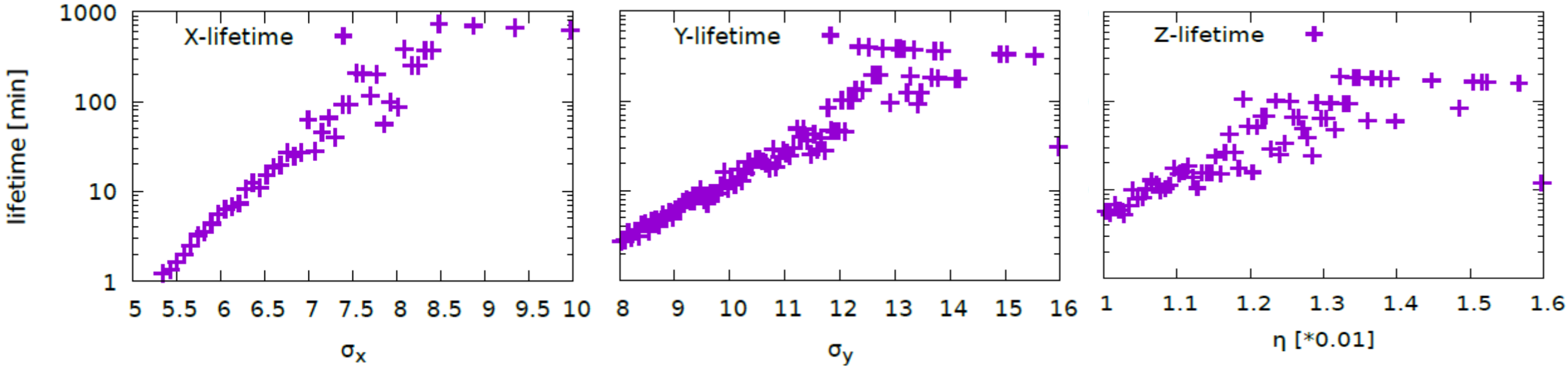


Beam Distribution: by=1.5mm
Lattice + Beamstrahlung + SR Fluctuation





Beam Lifetime: by=1.5mm
Lattice + Beamstrahlung + SR Fluctuation



100min, DA requirement: $7.5\sigma_x$, $12.5\sigma_y$, 0.0135

Achieved DA: ~$15\sigma_x$, ~$15\sigma_y$, ~0.015

Summary & Discussion

- By*=1.5mm, The DA requirement (lifetime/injection) is met without error, nearly no margin so far.
- We only focus on the delta-x aperture in optimization, but the vertical phase is also tuned, which may breaks the symmetry in delta-y space.
- We only focus on the DA at one point in the ring. Free all the sextupoles(56*4) in arc may bring worse symmetry.
- 20 more knobs could help enlarge the transverse DA
- Combined function Dipole(+S) may enlarge the momentum acceptance. But the conclusion is not finalized, since cutting long dipole into 5 pieces may help.