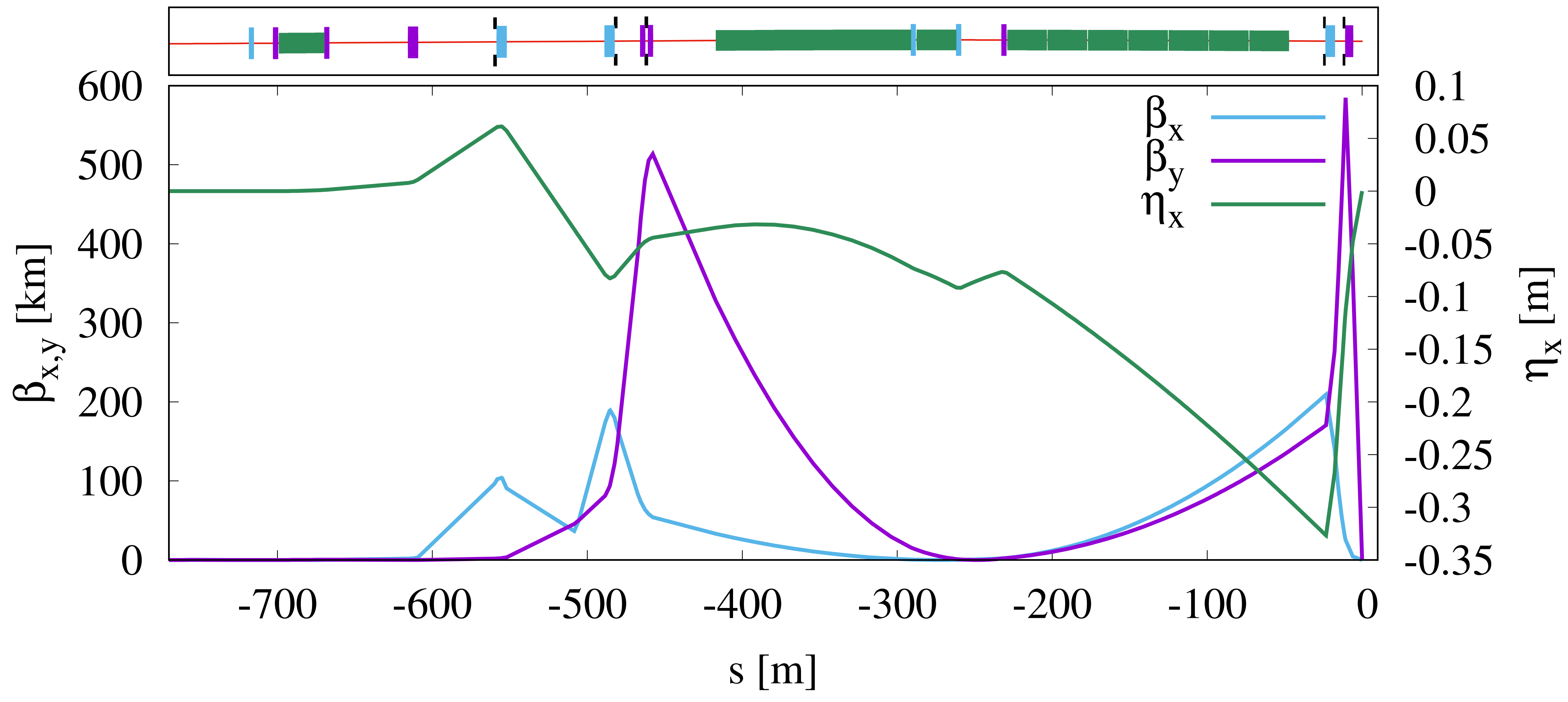
New FFS tuning techniques and sensitivity to energy and BPM calibration

Jim Ögren

Linear Collider Workshop 2018 (LCWS18), October, 2018
Arlington, TX

The 380 GeV Final focus system

- The final focus system (FFS):
  - Local chromaticity correction scheme
  - L* = 6 m (new baseline)



Norm. emittance (end of linac) $\gamma\epsilon_x/\gamma\epsilon_y$	[nm]	900 / 20
Norm. emittance (IP) $\gamma\epsilon_x/\gamma\epsilon_y$	[nm]	950 / 30
Beta function (IP) β_x^*/β_y^*	[mm]	8.2 / 0.1
Target IP beam size σ_x^*/σ_y^*	[nm]	149 / 2.9
Bunch length σ_z	[μm]	70
rms energy spread δ_p	[%]	0.35
Bunch population N_e	[10^9]	5.2
Number of bunches n_b		352
Repetition rate f_{rep}	[Hz]	50
Luminosity $\mathcal{L}_{total}$	[10^{34}cm^{-2}s^{-1}]	1.5
Peak luminosity $\mathcal{L}_{1\%}$	[10^{34}cm^{-2}s^{-1}]	0.9

FFS System:
- 780 m
- 20 quadrupole magnets
- 22 Beam-position monitors (BPMs)
- 6 sextupole magnets
- 2 octupole magnets

Tuning of the Final focus system

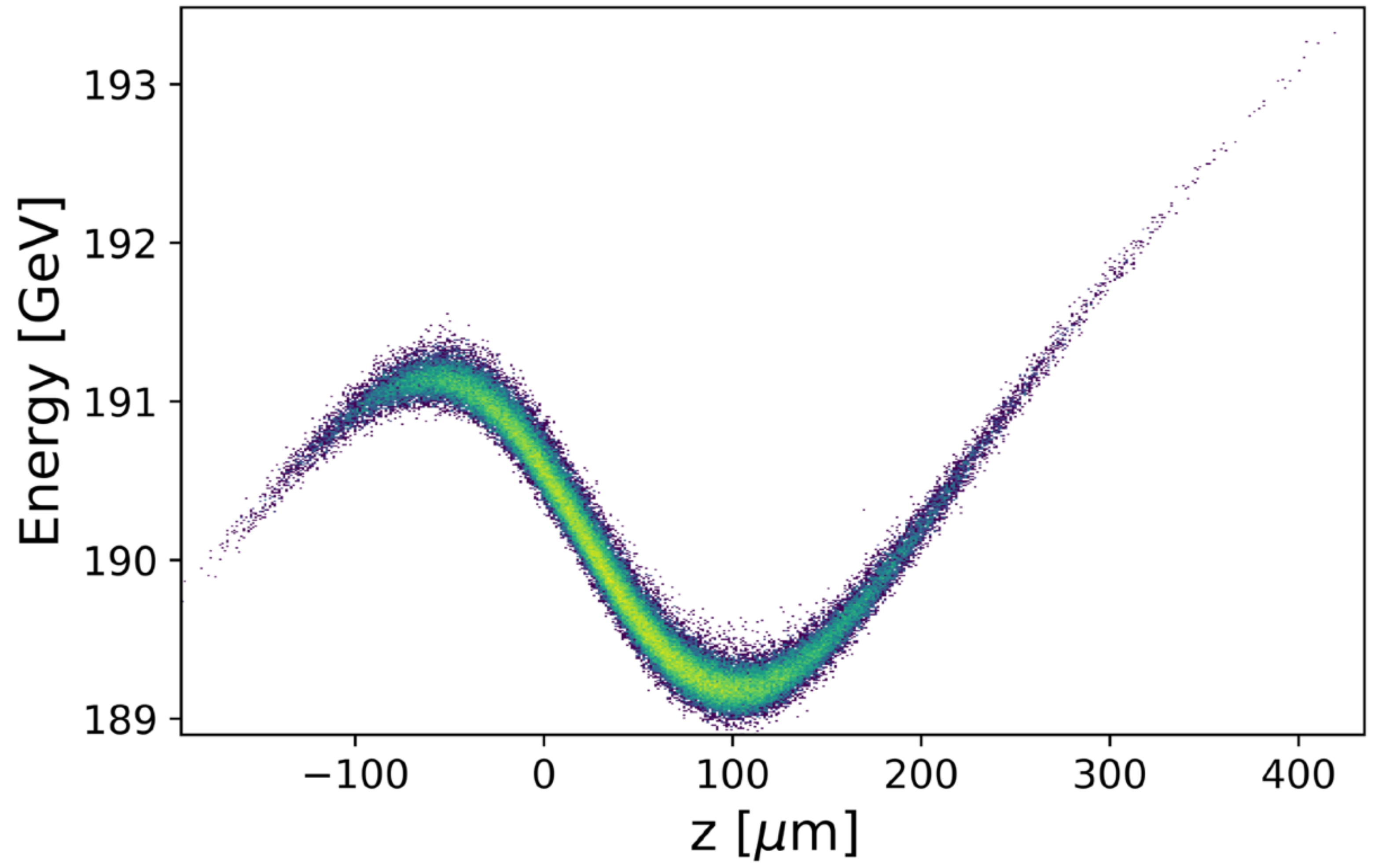
- Tuning = reaching performance for a machine with imperfections
  - Studied extensively for CLIC
  - For 3 TeV machine: two-beam tuning, static and dynamic imperfections (work by E. Marin)
  - Can we improve? Lower the tuning time (number of luminosity measurements)

- Simulation setup
  - Tracking in PLACET
  - Guinea-pig for computing the luminosity

- What is new?
  - New method for aligning the sextupoles
  - Using beam from integral simulation (RTML+ML+BDS)

- The challenge
  - Complicated, interleaved system with many effects
  - Stuck in local optima
  - Separate functions and correct subsystems independently

Beam energy profile at end of main linac



Static imperfections

Imperfection	Specified tolerance (rms error)	Elements
Resolution	20 nm	BPMs
Transverse misalignments	10 μm	BPMs, quadrupoles, multipoles
Roll errors	100 μrad	BPMs, quadrupoles, multipoles
Relative strength error	10^{-4}	Quadrupoles, multipoles

Monte Carlo simulations

- Generate machines with random imperfections
- Tuning goal: 90% of machines to be successfully tuned

Single-beam tuning simulation

Procedure:

- Perform BBA
    - Multipoles OFF
    - Use BPMs as signal

- Align sextupoles 1-by-1
    - Use luminosity as signal
    - Single-beam tuning = the beam is mirrored

- Sextupole knobs
    - Move sextupoles together = ’knobs’
    - Close to orthogonal
    - Use luminosity as signal

- Octupole knobs
    - Similar to the sextupole knobs

Beam-based alignment (BBA)

- Correct the linear part of the system
  - Trajectory and dispersion
  - Multipoles OFF

- Measure the response matrix on the misaligned machine

- Use movement of quadrupoles or dedicated steering magnets

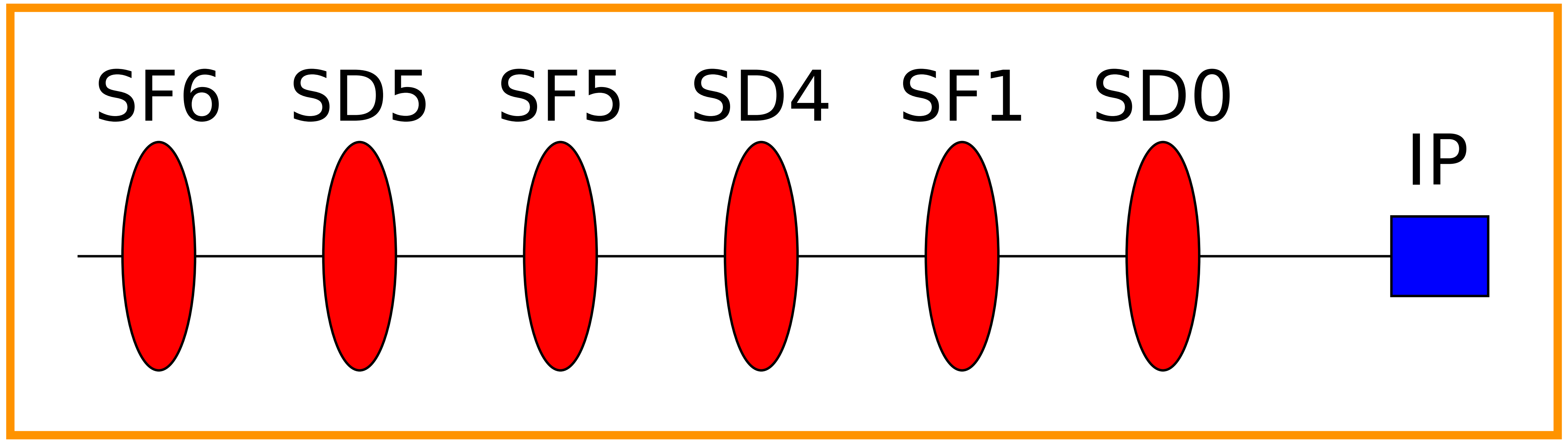
$$\begin{bmatrix} \vec{y}_{\mathrm{traj}} \\ w\vec{y}_{\mathrm{disp}} \\ \vec{0} \end{bmatrix} = \begin{bmatrix} R_{\mathrm{traj}} \\ wR_{\mathrm{disp}} \\ \beta I \end{bmatrix} \begin{bmatrix} \Delta\vec{x} \\ \Delta\vec{y} \end{bmatrix}$$

- Weight on dispersion, beta to condition matrix

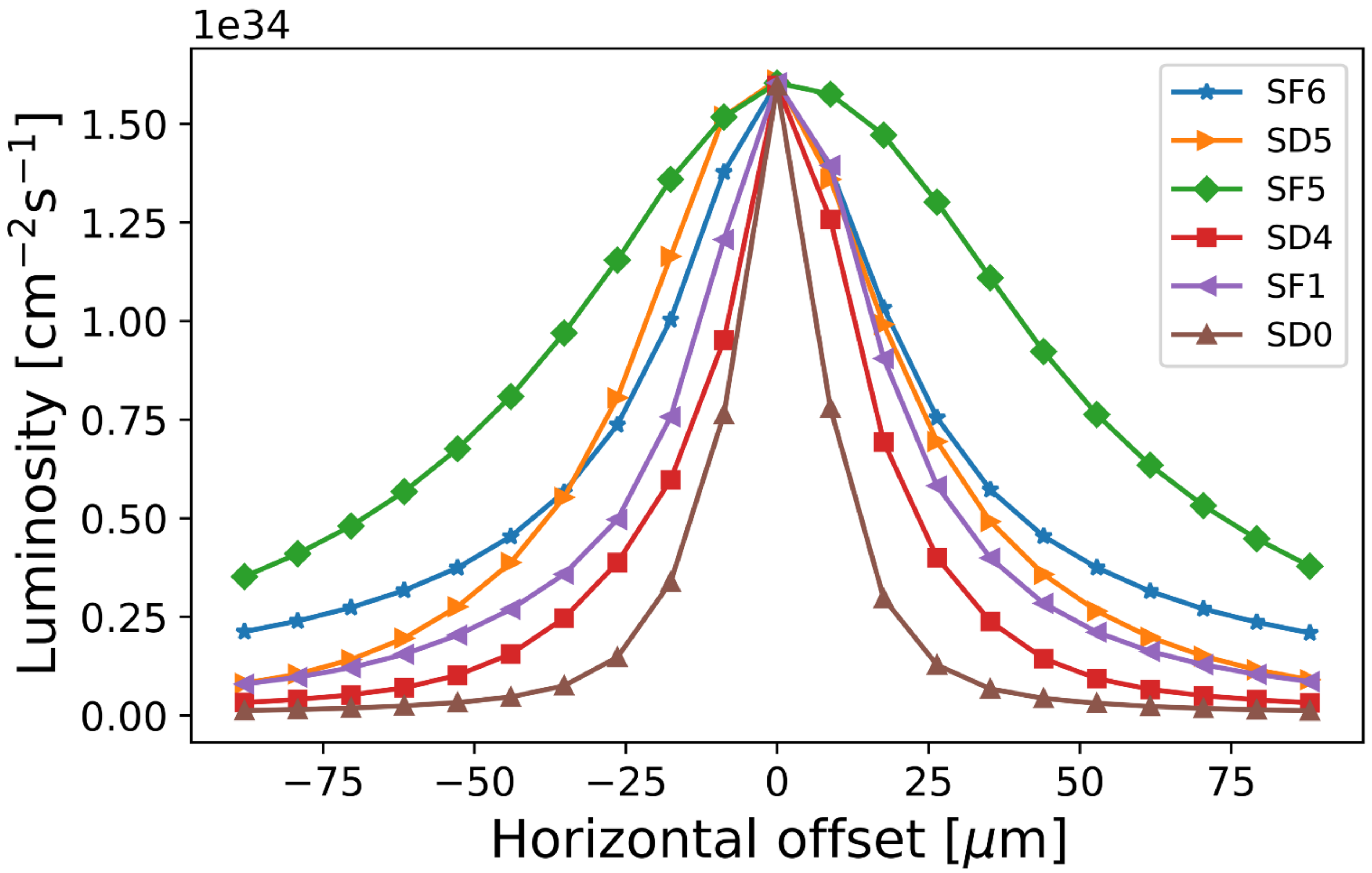
- Invert system to match target trajectory and dispersion

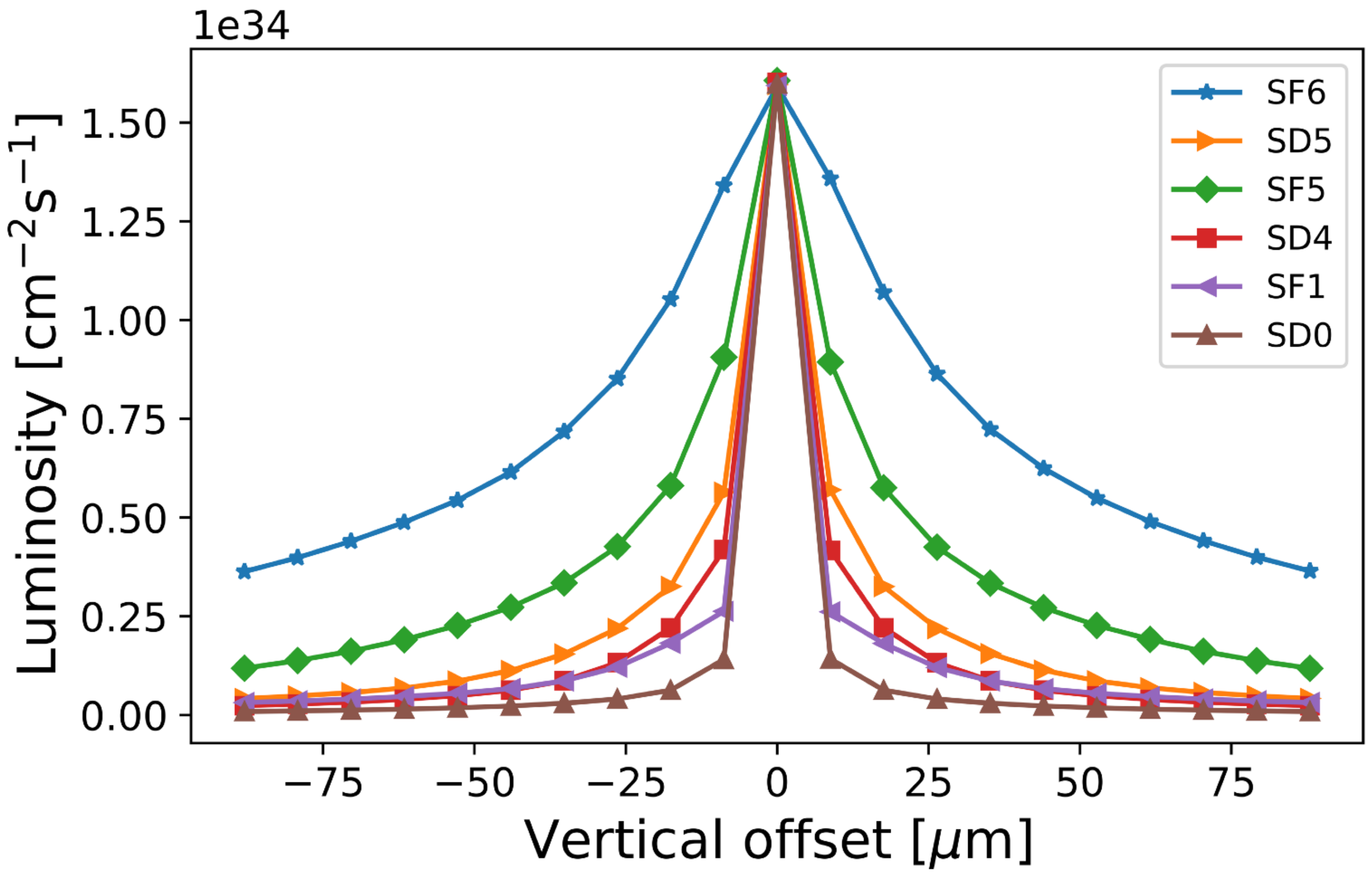
Aligning the sextupoles

- Sextupole transverse offsets
  - Quadrupole and dipole kicks
  - Impacts sextupole knobs tuning
  - Impact on trajectory small
  - difficult to use BBA method



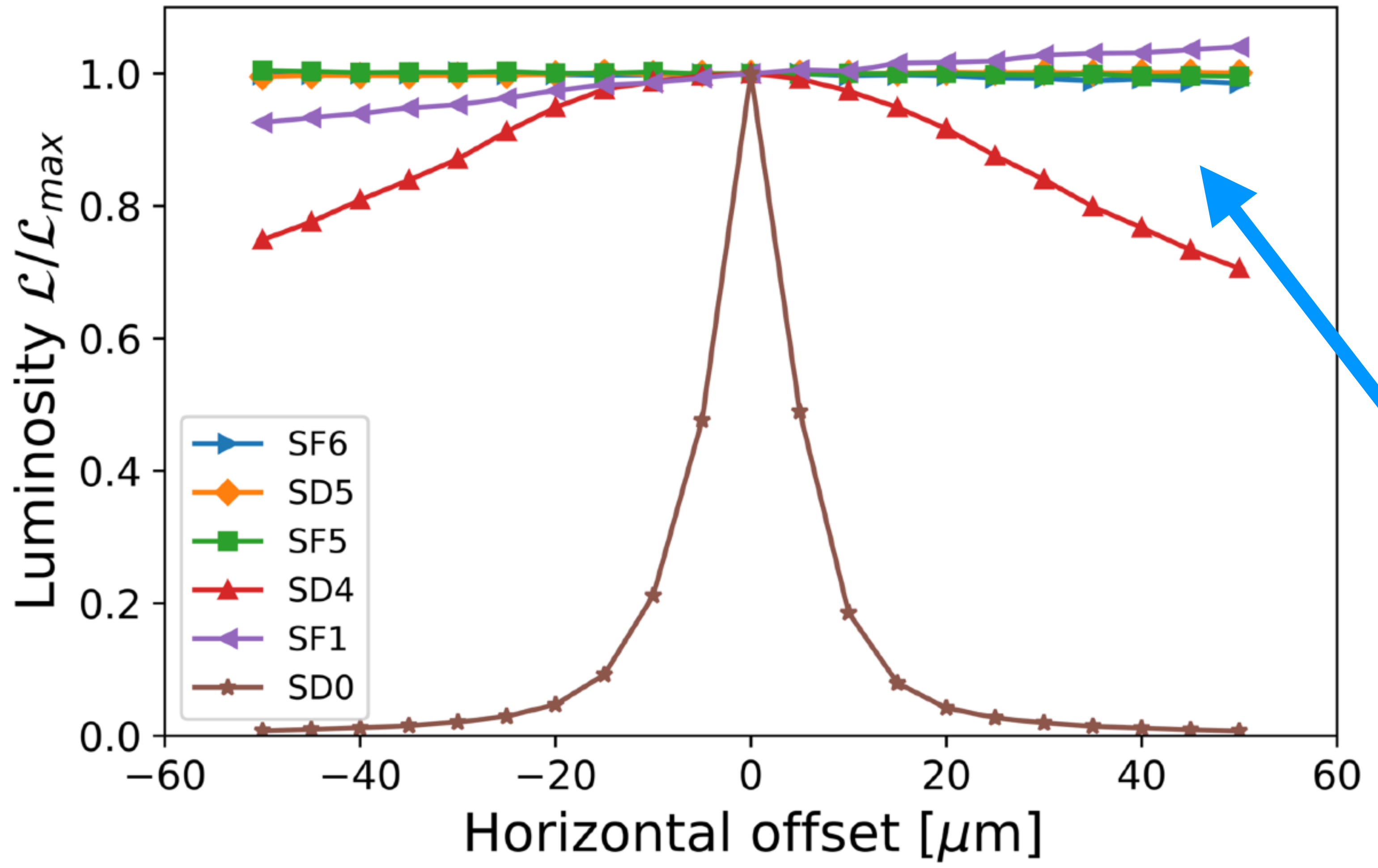
- Luminosity and sextupole offsets (perfect machine)

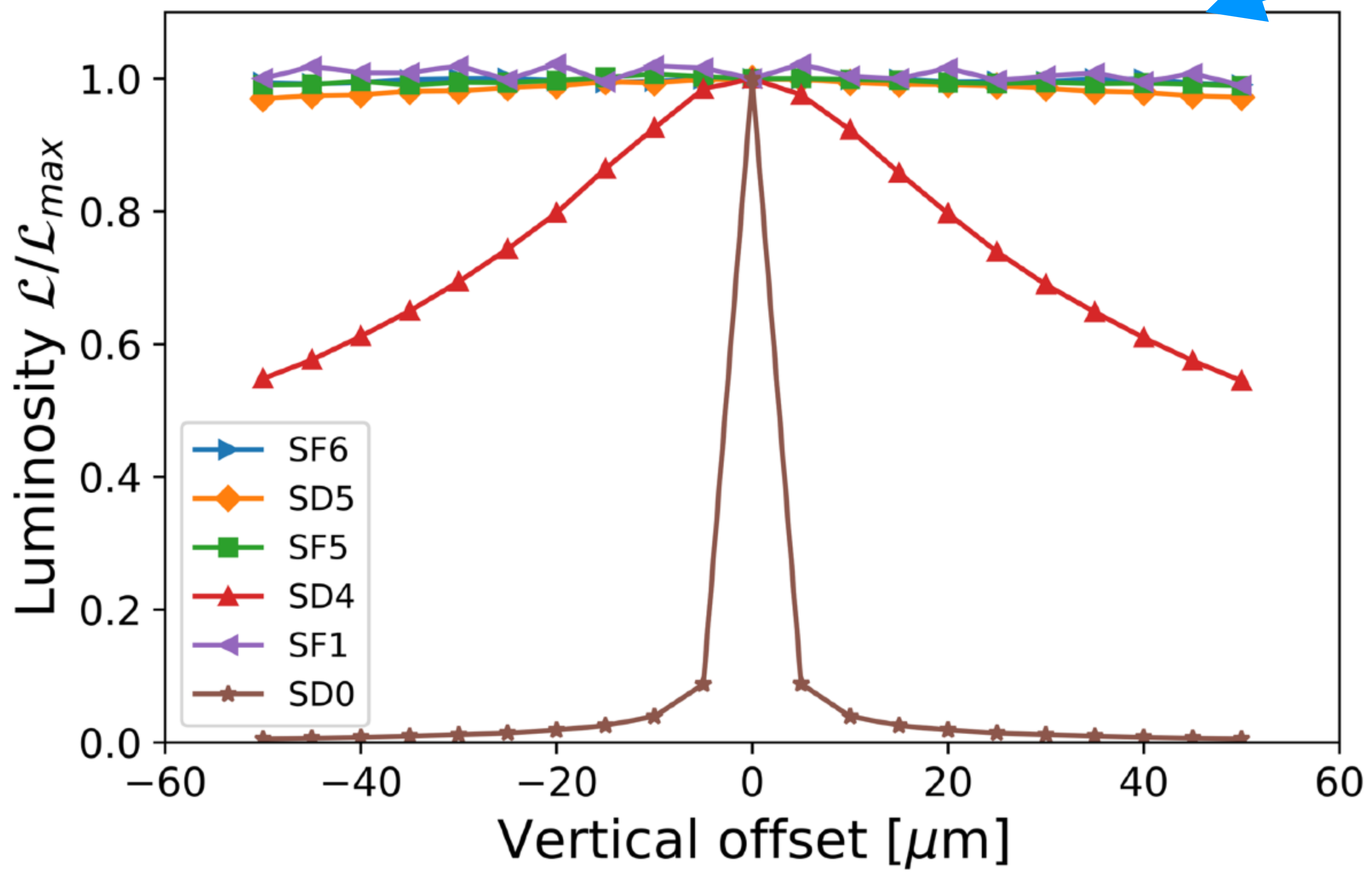




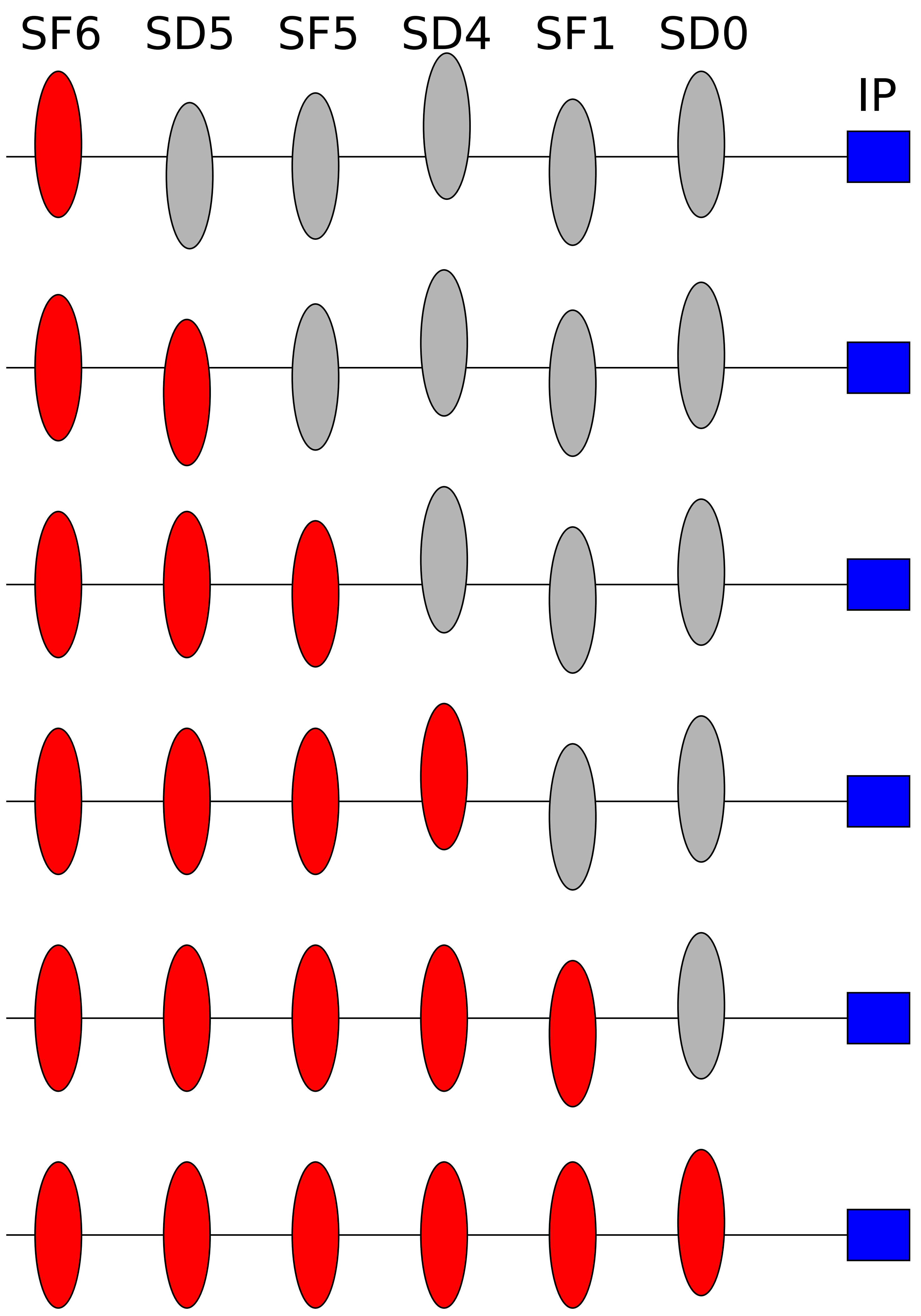
Aligning sextupoles 1-by-1: **downstream**

Relative luminosity change vs offset:



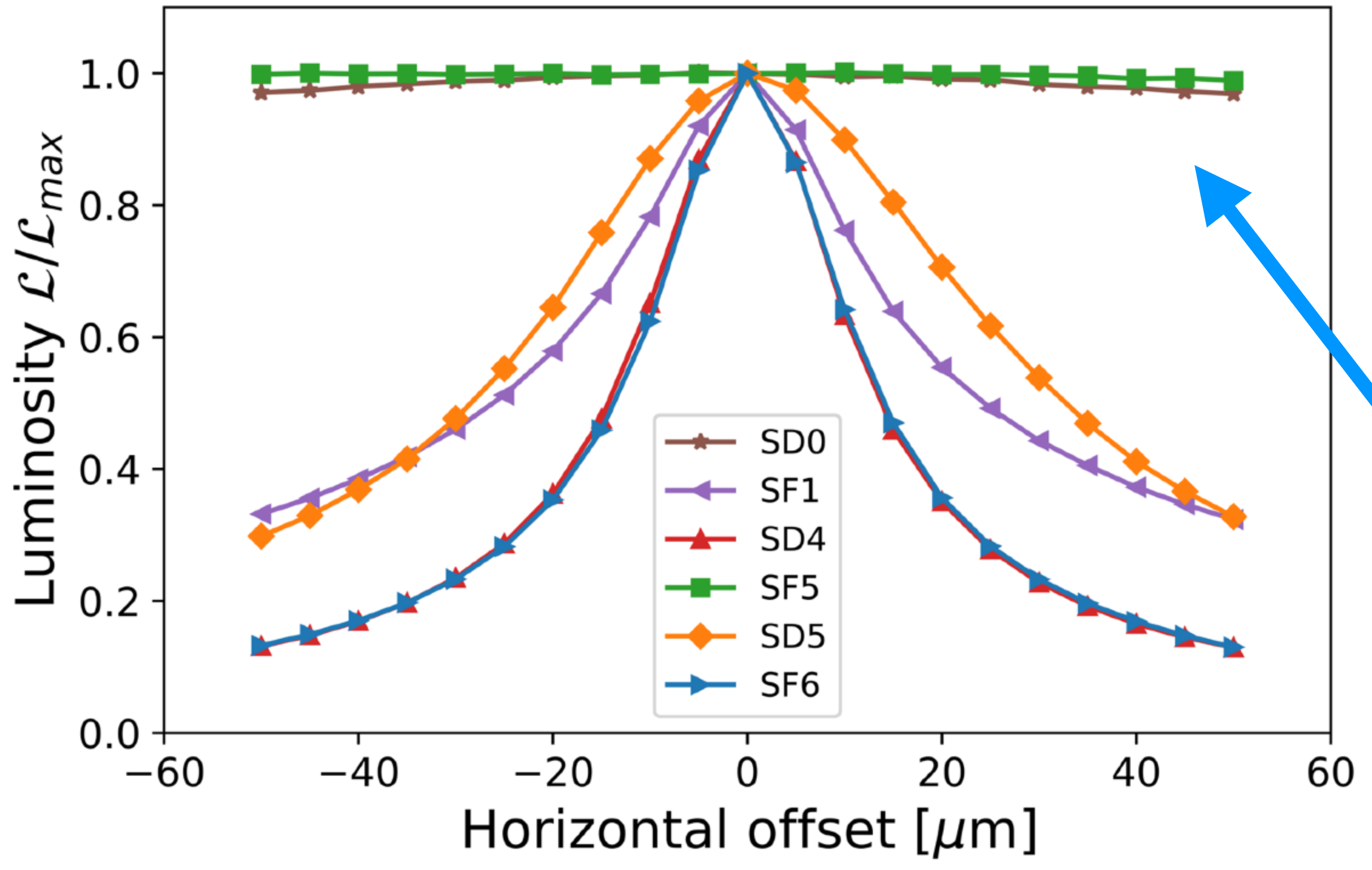


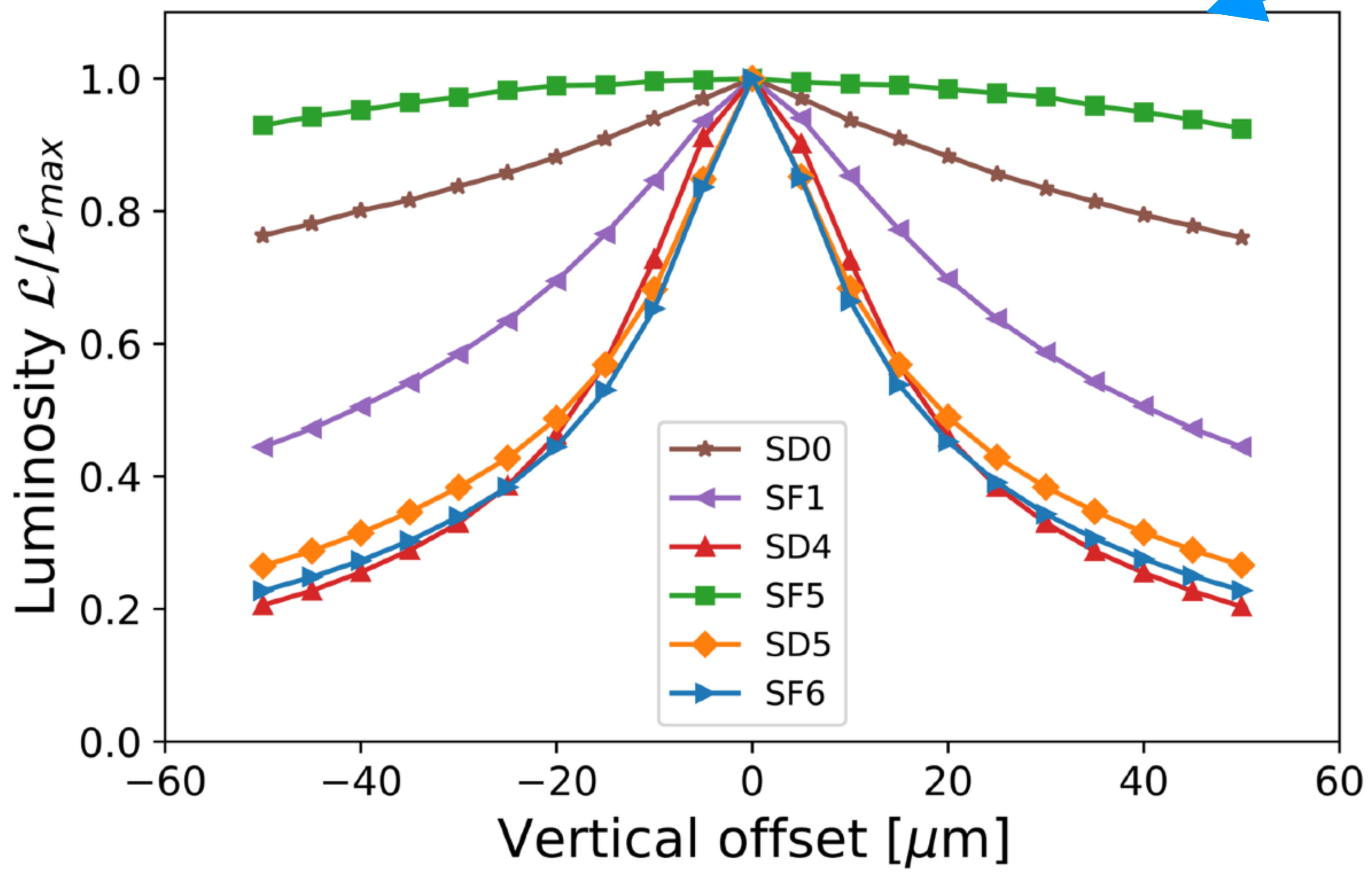
No sensitivity for 4 of the sextupoles



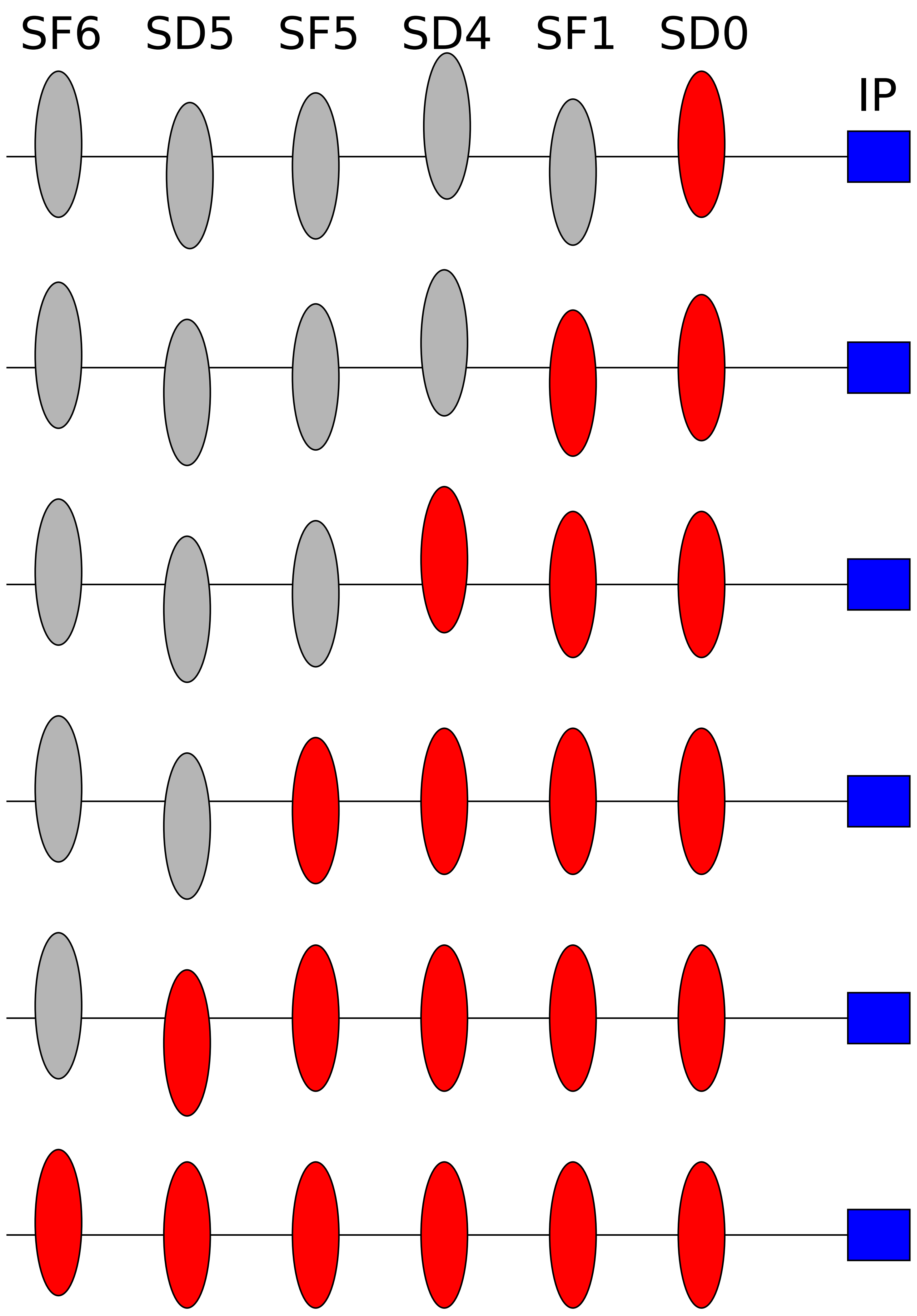
Aligning sextupoles 1-by-1: **upstream**

Relative luminosity change vs offset:



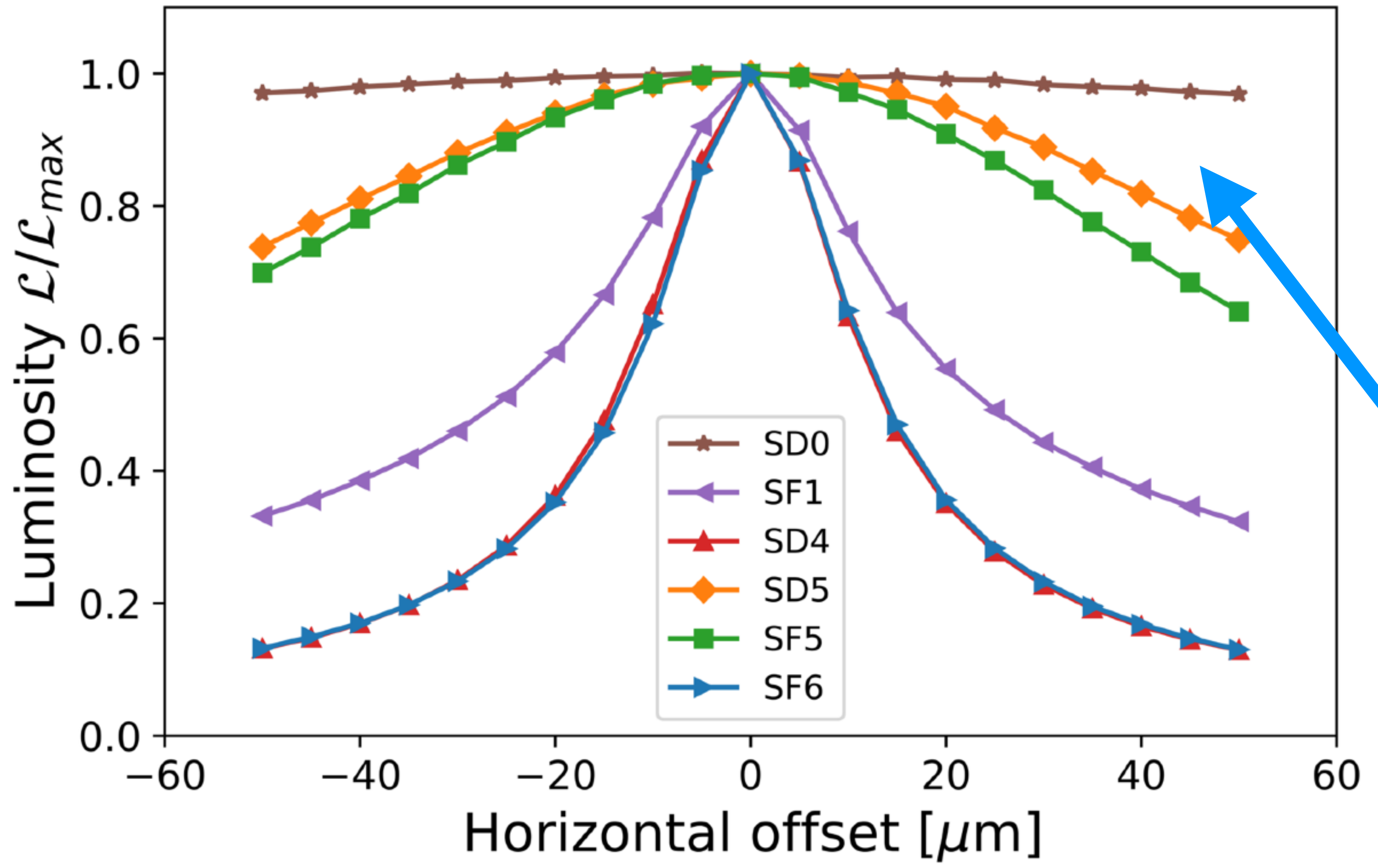


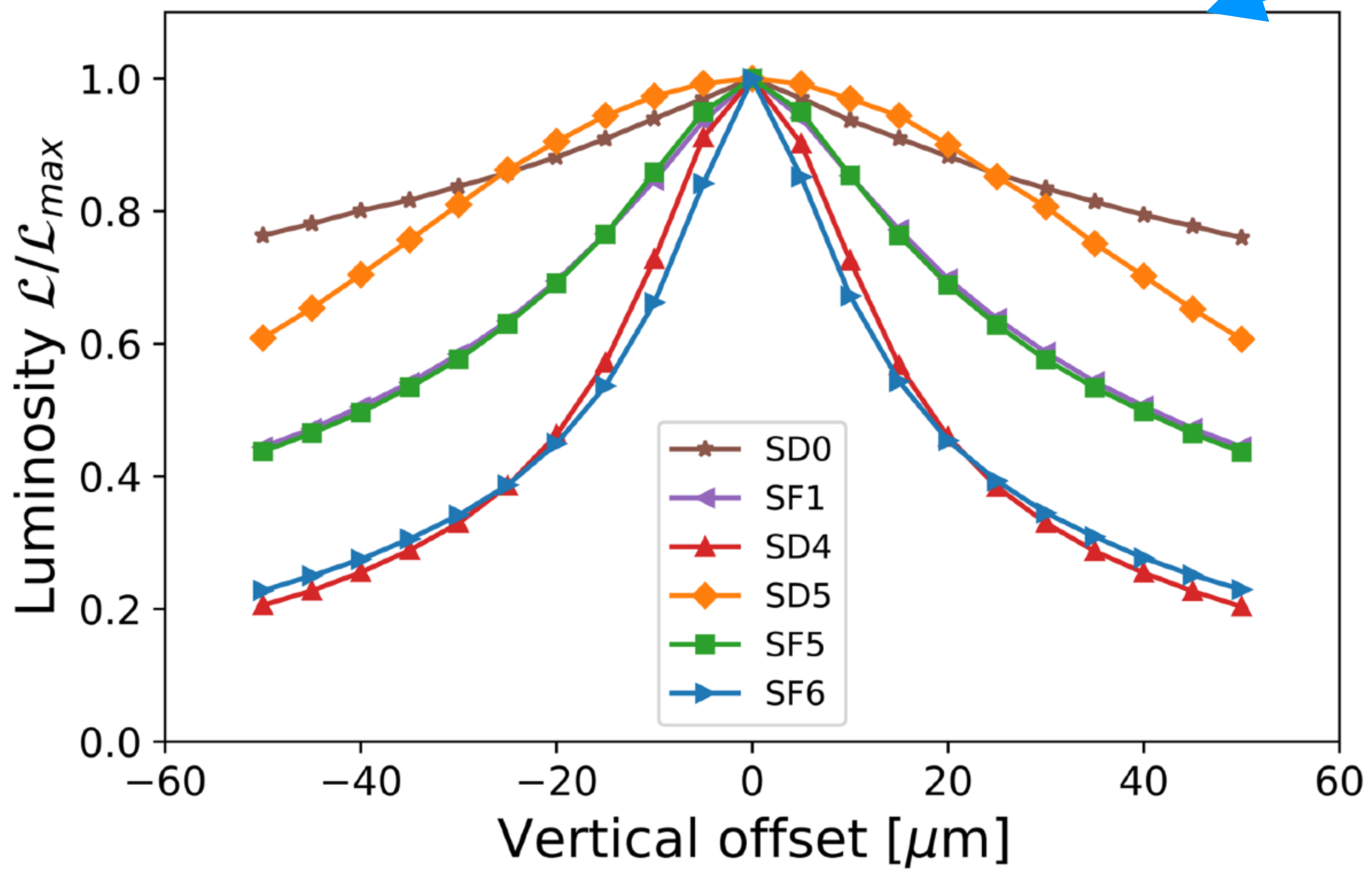
Improved sensitivity



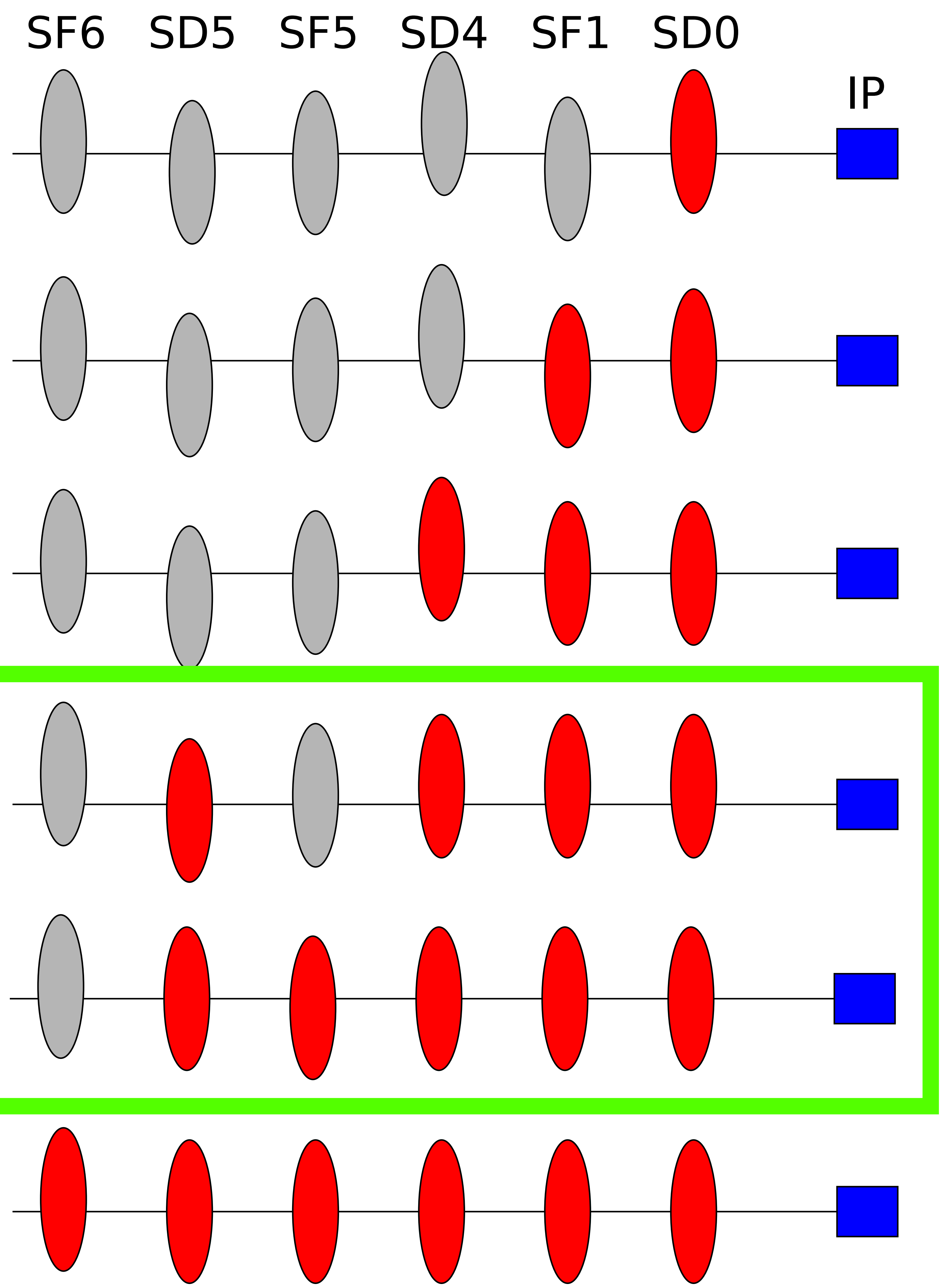
Aligning sextupoles 1-by-1: **optimum**

Relative luminosity change vs offset:





Further improved sensitivity by swapping order of SF5 and SD5



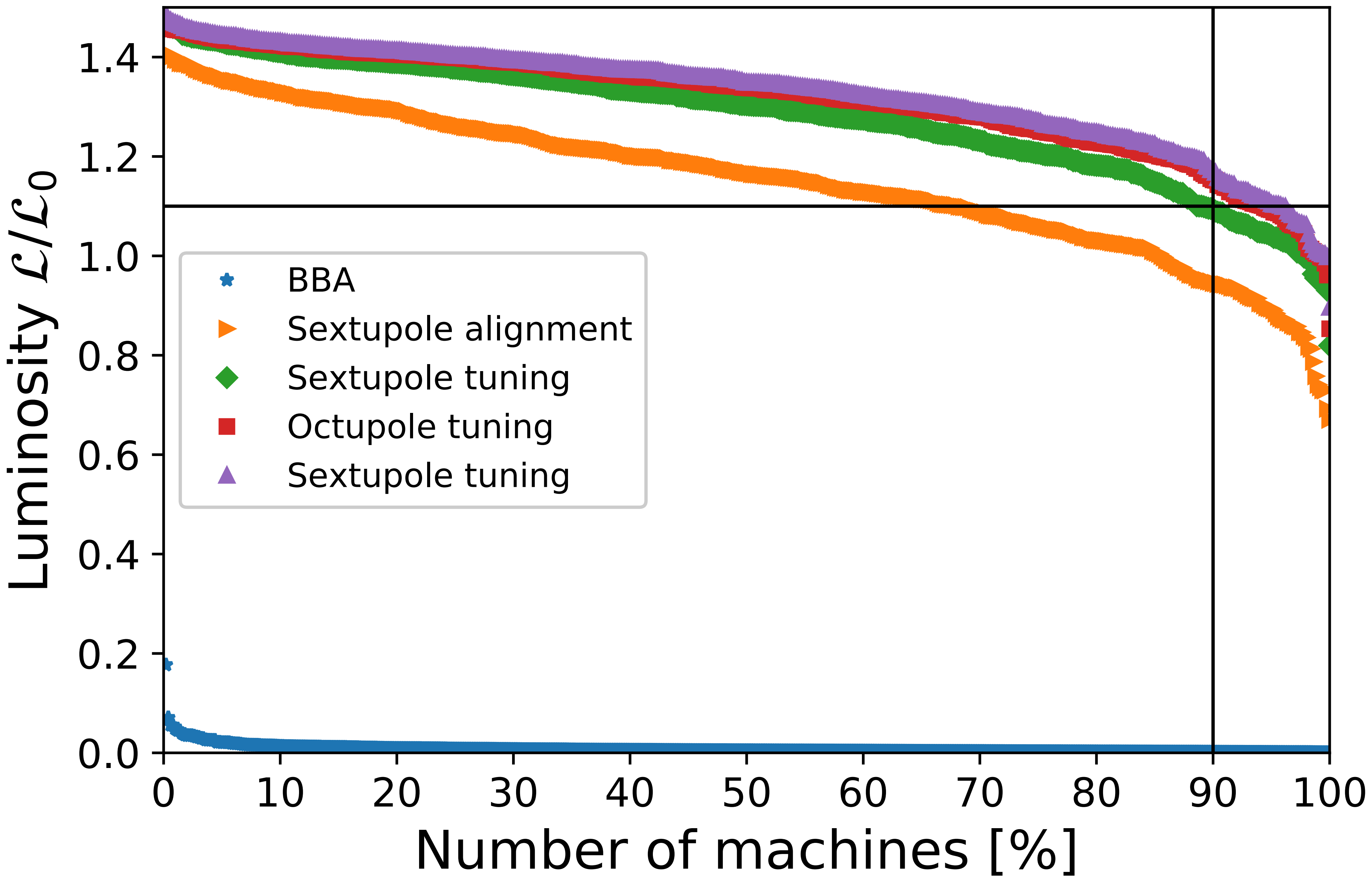
Sextupole knobs - 1st order

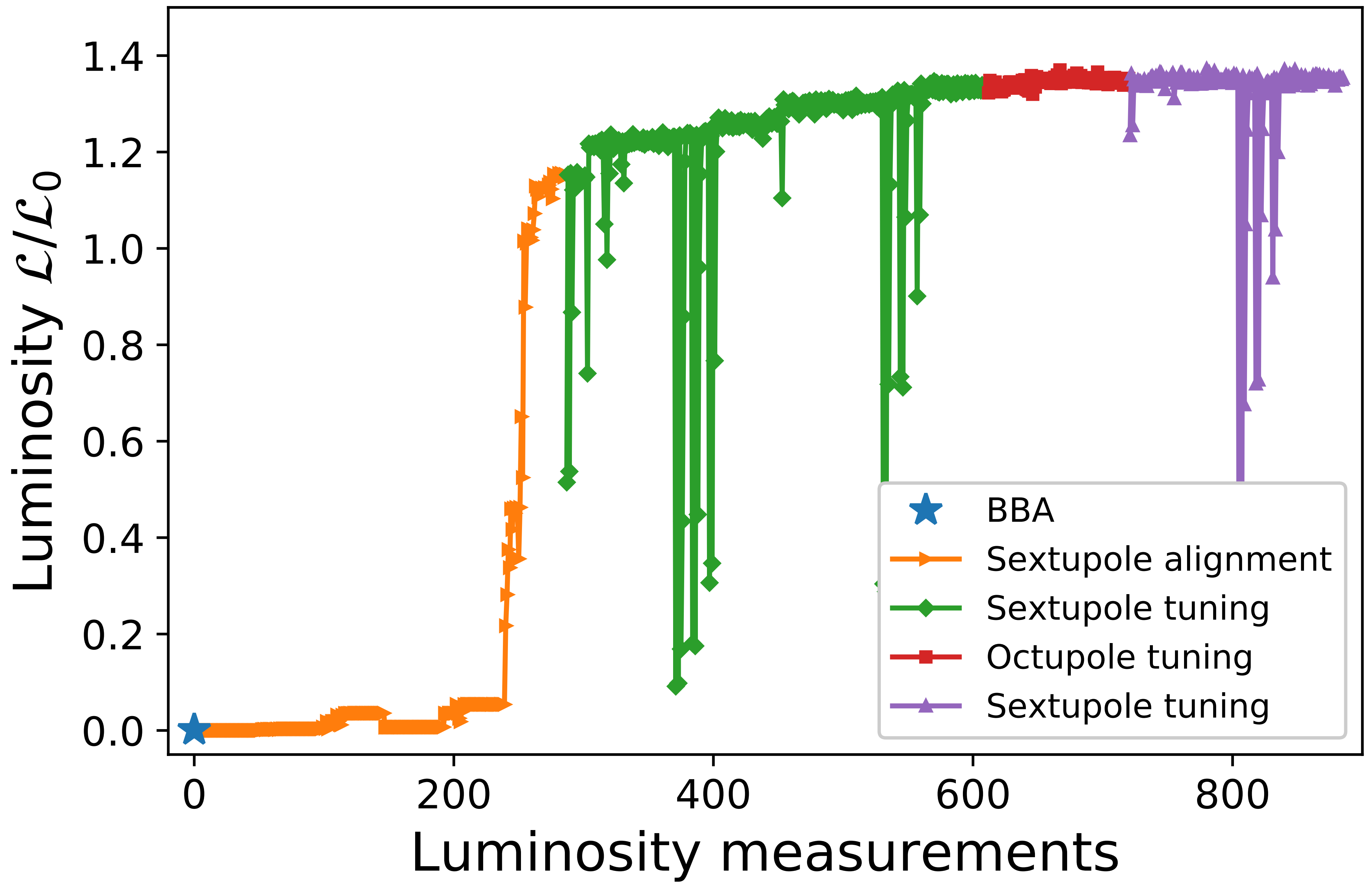
- Use transverse movement of sextupoles
- Track the perfect lattice and offset one sextupole
- The response matrix contain the 2^{nd} order moments of the beam distribution at IP
- Use SVD to find orthogonal 'knobs' (vectors from matrix V)

$$U\lambda V^T = R$$

- Each knob is scanned over some range and luminosity is maximized
- Similarly for the octupoles

Tuning results





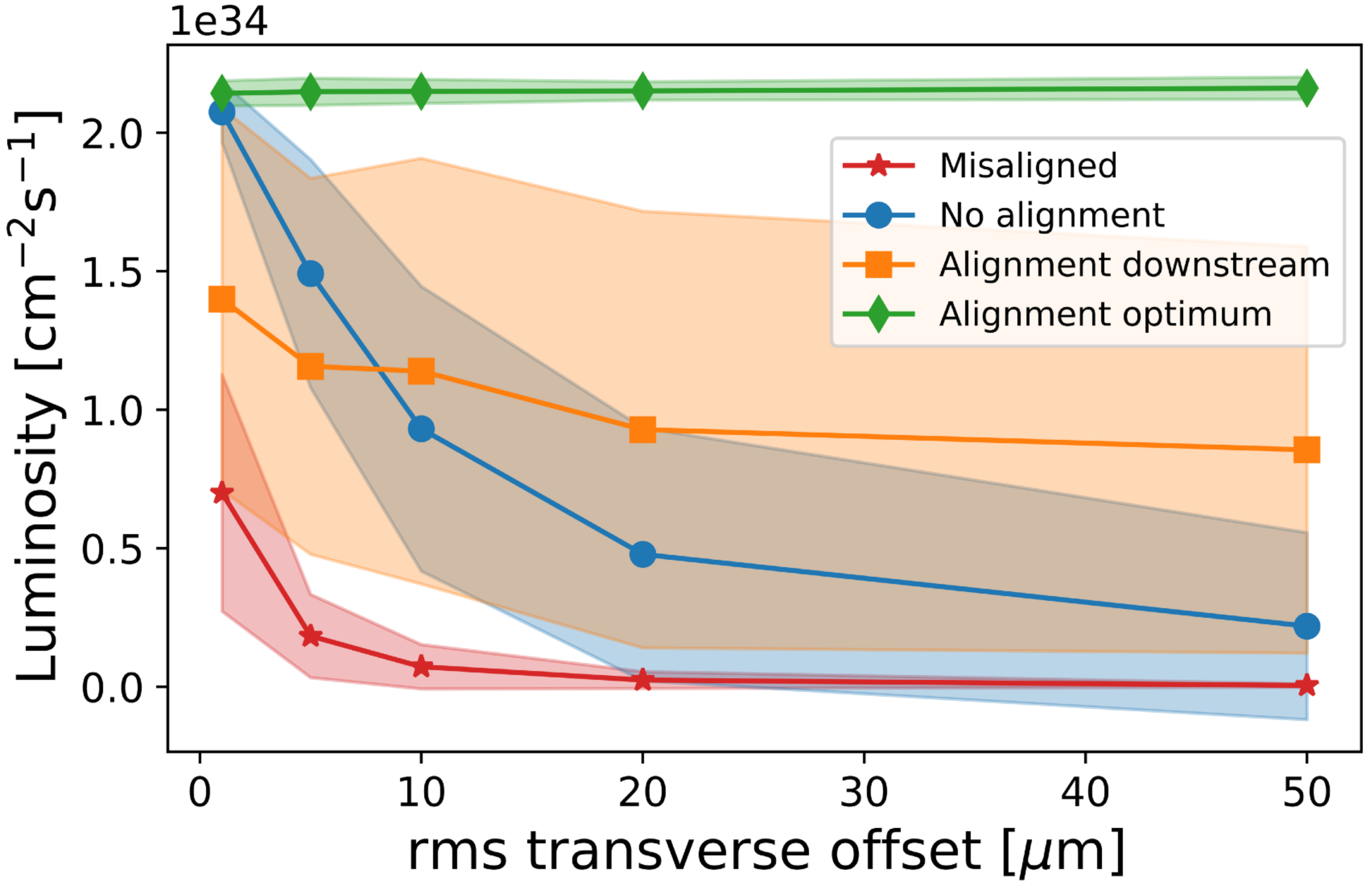
500 machines, randomly distributed imperfections

- Left: 95% of machines reach goal of 110% of L_0
- Right: Luminosity evolution for the median machine

Importance of the sextupole alignment

Perfect lattice, only offset sextupoles

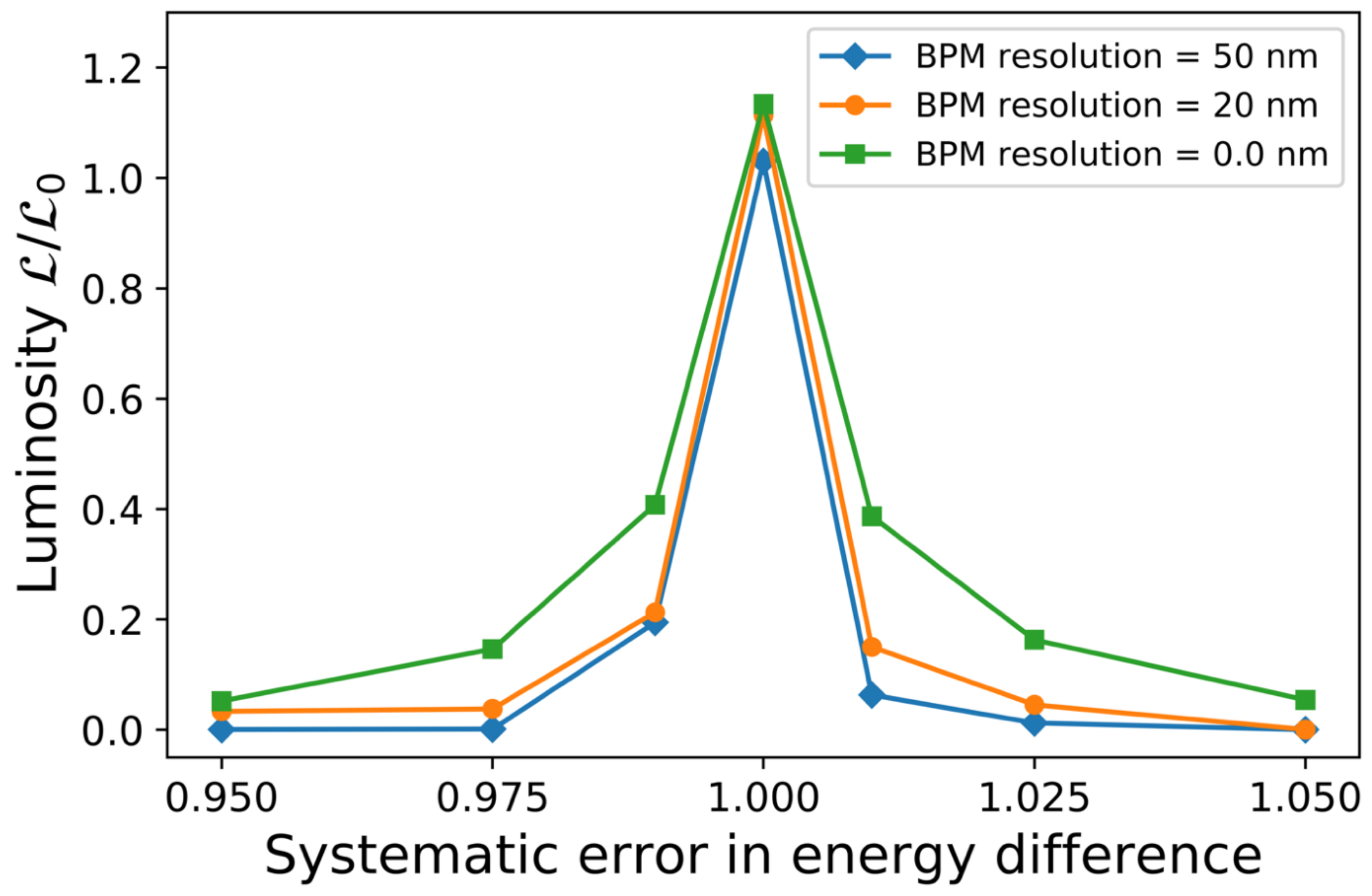
- Compare three methods
  - 1) Sextupole knobs only
  - 2) Alignment downstream + sextupole knobs
  - 3) Alignment optimum order + sextupole knobs
- Random sextupole offsets:
  - rms = 1, 5, 10, 20 and 50 μm
- Average over 10 machines:
- Big impact on tuning efficiency of the sextupole knobs
- Alignment downstream order is far less robust



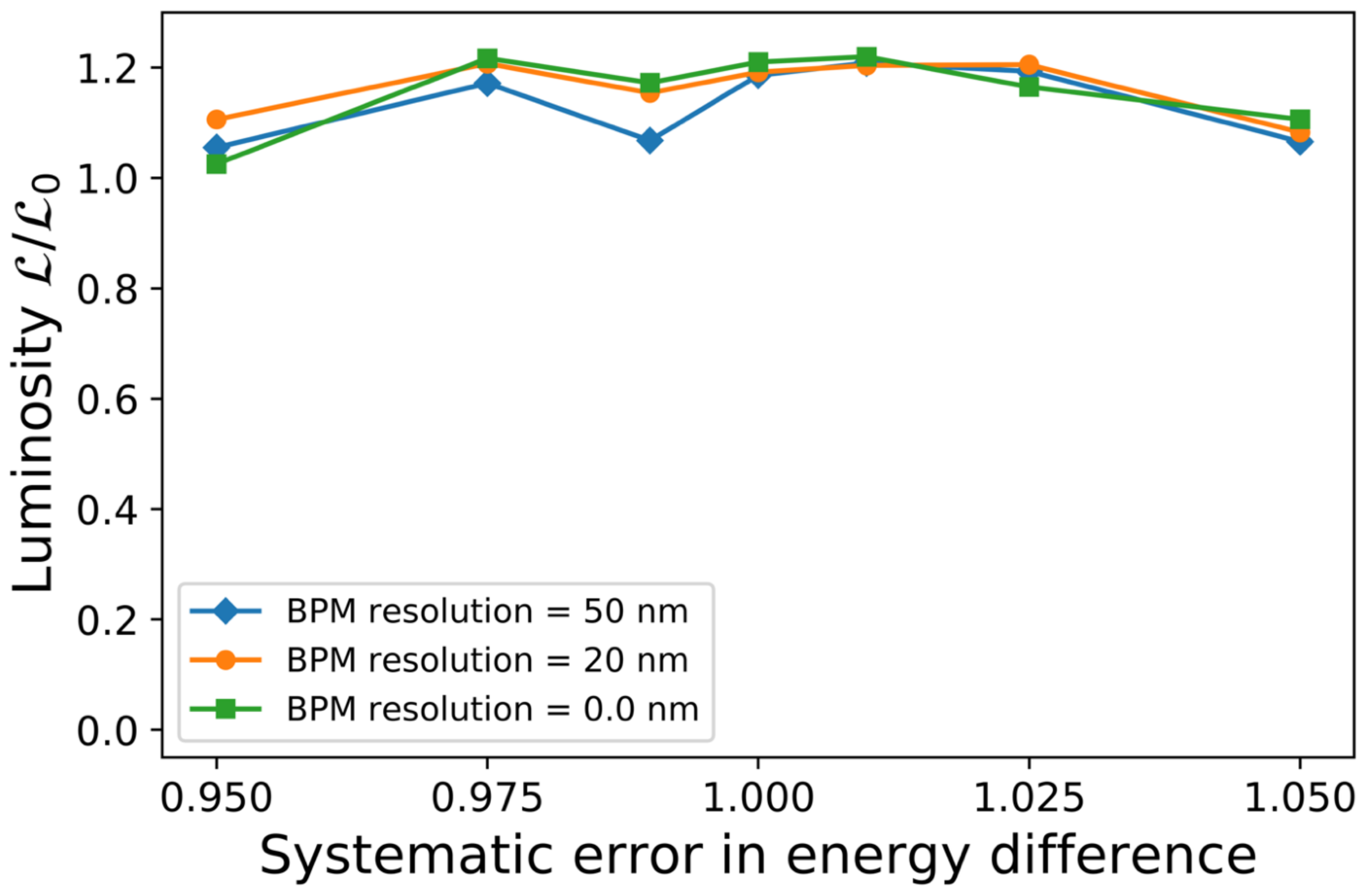
Importance of the BBA

- Test with different BPM resolutions
- Systematic errors in energy difference
- Average over 10 machines (BBA + sextupole alignment + sextupole knobs)
- Put more weight on non-dispersive locations

$$\eta_x = \frac{x^{(2)} - x^{(1)}}{\delta}$$



Dispersion correction to target profile



Zero-dispersion correction

Conclusions

- New method for sextupole alignment
    - Align sextupoles one-by-one and optimize for luminosity
    - Order matters
    - Robust and effective, good starting point for the sextupole knobs
- Tuning results
    - 95% of machines reach tuning goal.
    - Can tolerate larger initial misalignments
    - Substantial improvement on the number of luminosity measurements
- Importance of BBA
    - Put more weight on nondispersive sections
- Future work
    - Two-beam tuning
    - Including dynamic imperfections
    - Experimental test at ATF2