PEPX-type BAPS Lattice Design and Beam Dynamics Optimization

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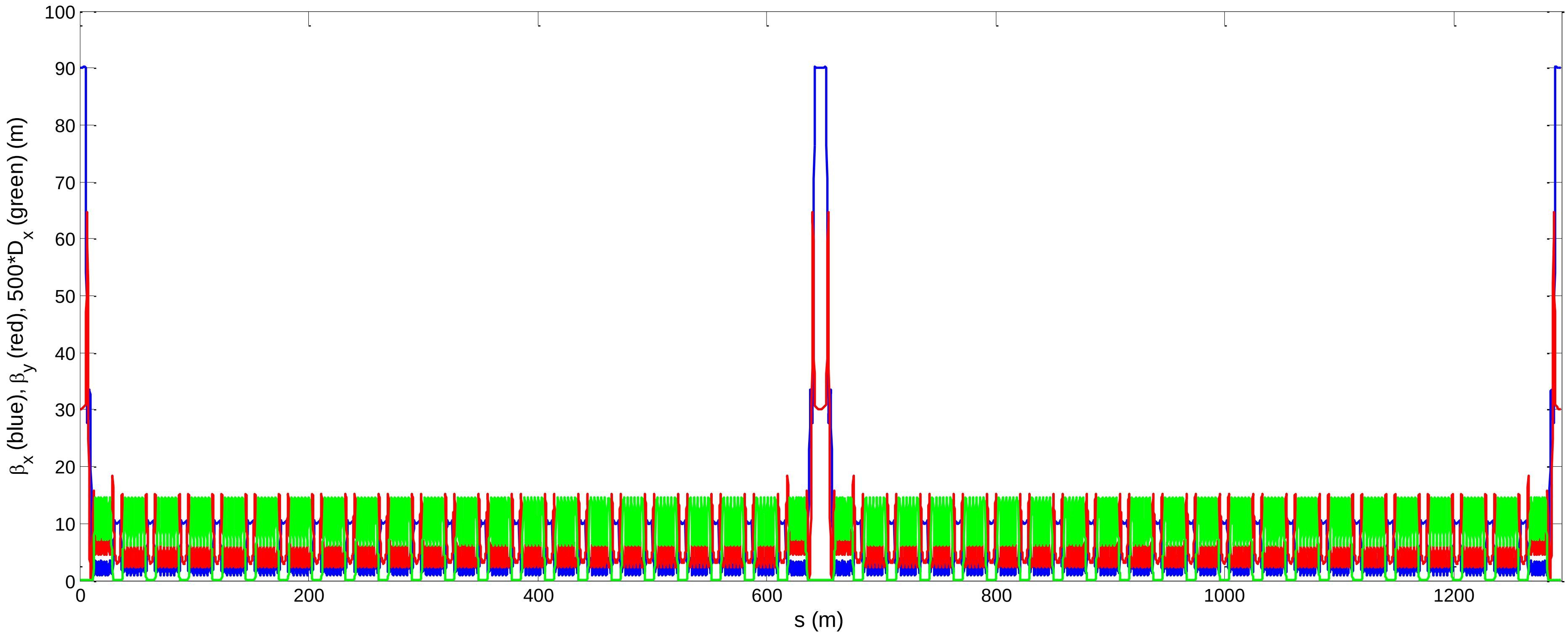
PEPX-type lattice, 6 GeV, ~1.3 km, ~90 pm

参数	幅度	单位
Beam energy E_0	6 (5)	GeV
Beam current I_0	200	mA
Bunch number n_B	2000	
Circumference	**1294.2**	**m**
Horizontal damping partition number $J_x / J_y / J_z$	2.05/1./0.95	
Natural emittance	**88 (61)**	**pm**
Working point (x/y/z)	93.14/49.40/0.0058	
Natural chromaticity (x/y)	-112/-107	
Number of 7BA achromats	**44**	
Number of high-beta **10-m** injection sections	2	
Beta functions in high-beta injection section (x/y)	90/30	m
Number of low-beta **5-m** ID sections	42	
Beta functions in low-beta straight section (x/y)	10/3	m
Damping times (x/y/z)	11.2/23.0/24.3	ms
Energy loss per turn, U_0	2.25	MeV
Energy spread σ_δ	0.001	
Momentum compaction	5.9×10^{-5}	
RF voltage, V_{rf}	**10**	**MV**
RF frequency, f_{rf}	500.36	MHz
Harmonic number	2160	
Natural bunch length σ_z	2.2	mm

Linear lattice design

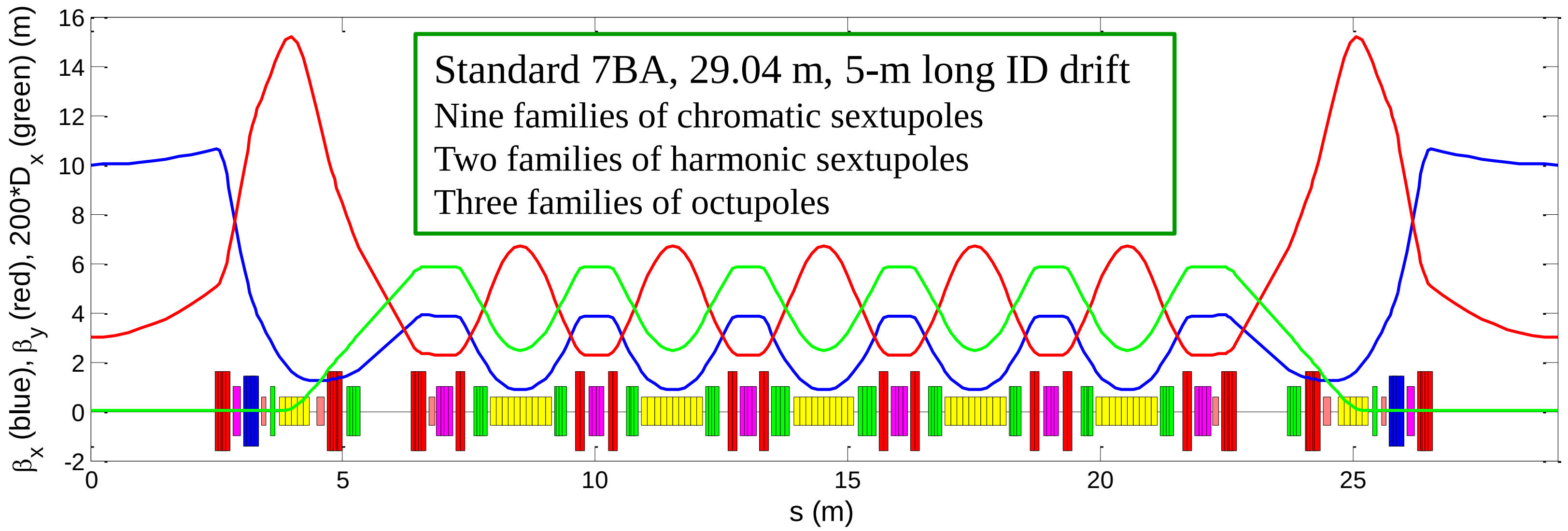


40 standard 7BAs + 4 non-standard 7BAs (for injection)

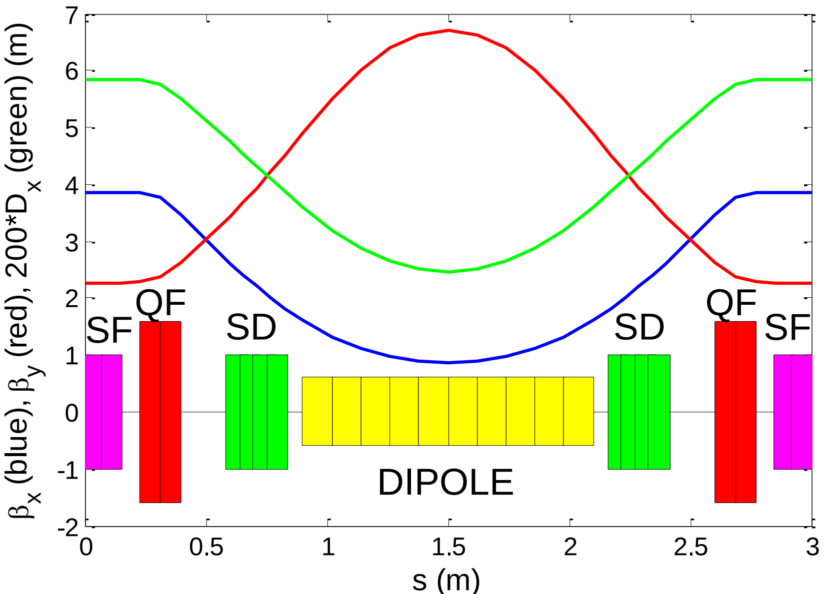
Similar to PEP-X design (Cai, et al., PRST-AB 2012, 054002), each standard 7BA, phase advance is about ($4\pi + \pi/4$, $2\pi + \pi/4$), thus every 8 such 7BAs form a quasi-3th order achromat (to cancel the nonlinearities as much as possible).

For each non-standard 7BA, high-beta, 10-m long straight section is designed for injection, the phase advance is matched to (4π, 2π) to restore the symmetry of the beam optics.

Standard 7BA

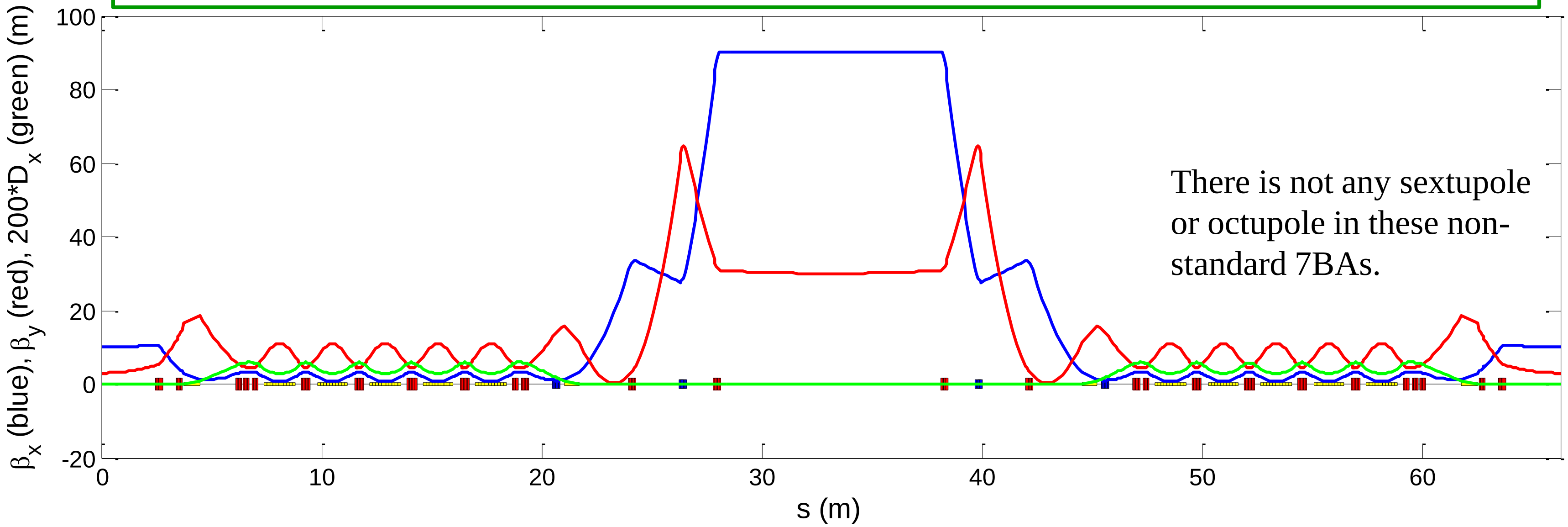


- Unit cell, compact design, horizontal defocusing gradient combined in dipole, total length 3 m.
- Magnet aperture (radius 12.5 mm), vacuum chamber inner radius 11 mm.
- Reserve room for correctors (between SD and QF).
- QF gradient: < 80 T/m, QD gradient in dipole: < 20 T/m, sext. gradient: < 11400 T/m^2, oct. gradient: < 10^6 T/m^3



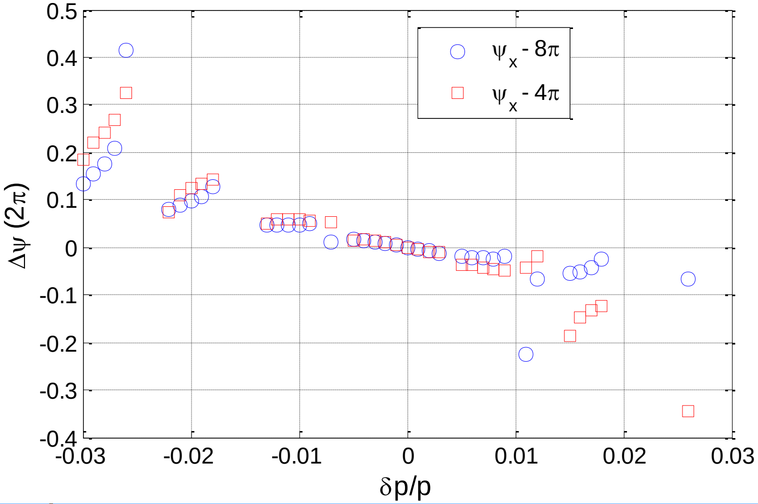
Non-standard 7BAs

Two non-standard 7BAs, 10-m long drift for injection, phase advance are (8π, 4π).



There is not any sextupole or octupole in these non-standard 7BAs.

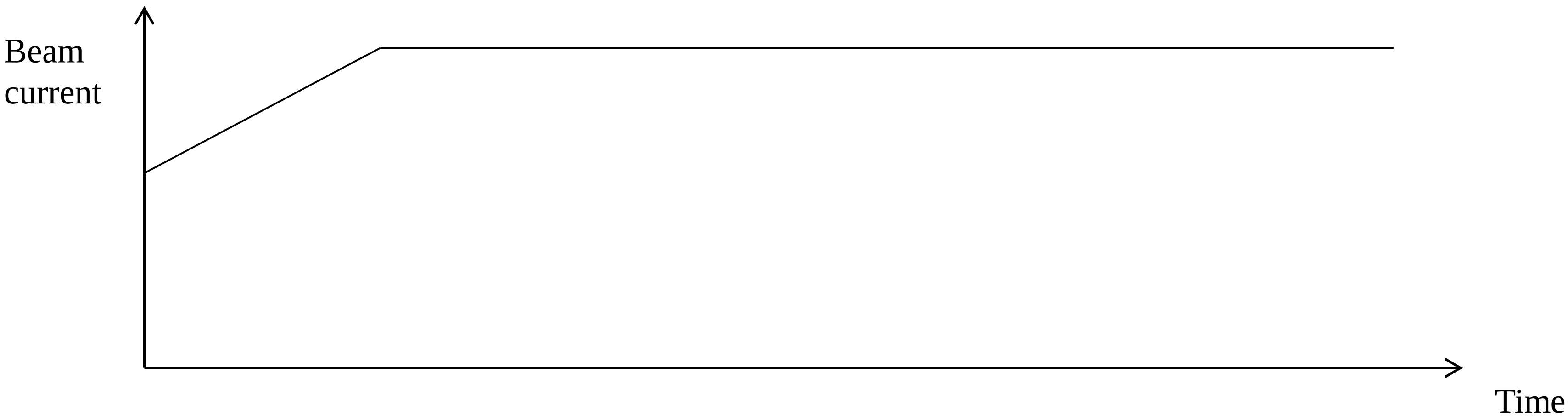
- High beta functions result in relatively large dynamic aperture, promising both off-axis and on-axis injection.
- However, the phase advance will deviates from $2n\pi$ for off-momentum particles, leading to difficulty in optimizing the momentum acceptance.

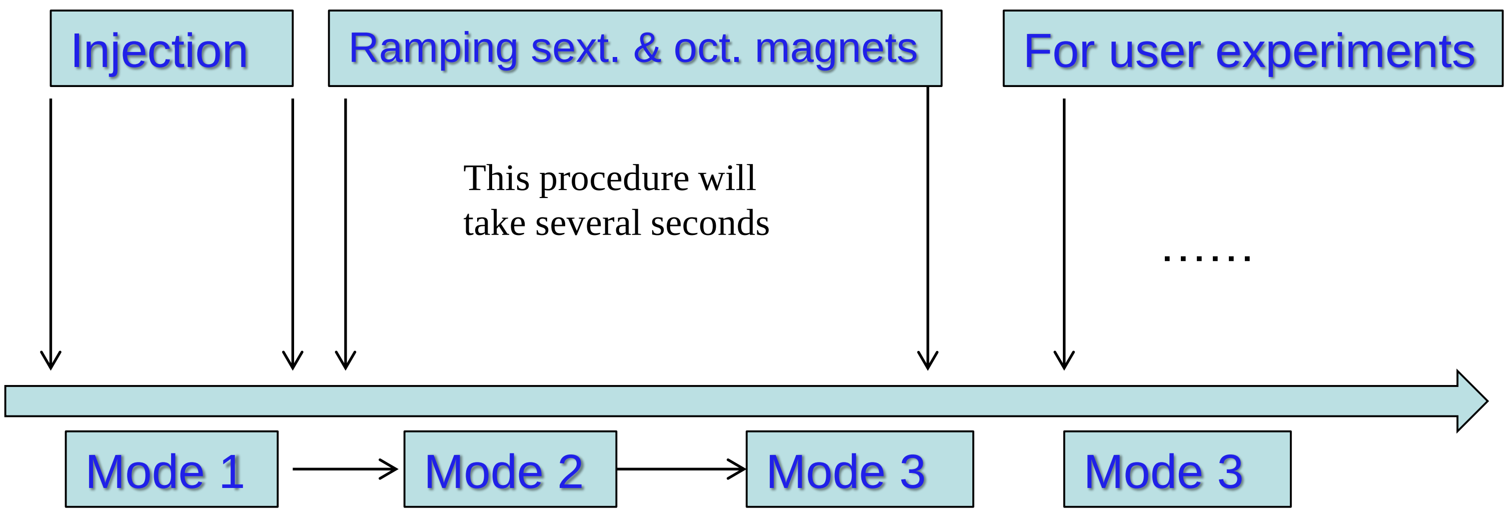


Nonlinear optimization

- Strong nonlinearities caused by the chromatic sextupoles make it hard to obtain a large dynamic aperture and a large momentum acceptance at the same time.
- The deviation of the phase advance of the injection section from $2n\pi$ adds the difficulty of the optimization.
- Three modes (only different in sextupole and octupole strengths) are explored, and are used to inject and store the beam, respectively.
  - Mode 1, horizontal dynamic aperture (DA) >+/- 11 mm, momentum acceptance (MA) ~1%
  - Mode 2, horizontal dynamic aperture (DA) ~+/- 10 mm, momentum acceptance (MA) ~1.8%
  - Mode 3, horizontal dynamic aperture (DA) ~+/- 5 mm, momentum acceptance (MA) ~3%

Mode 1 for injecting & Mode 3 for storing beam



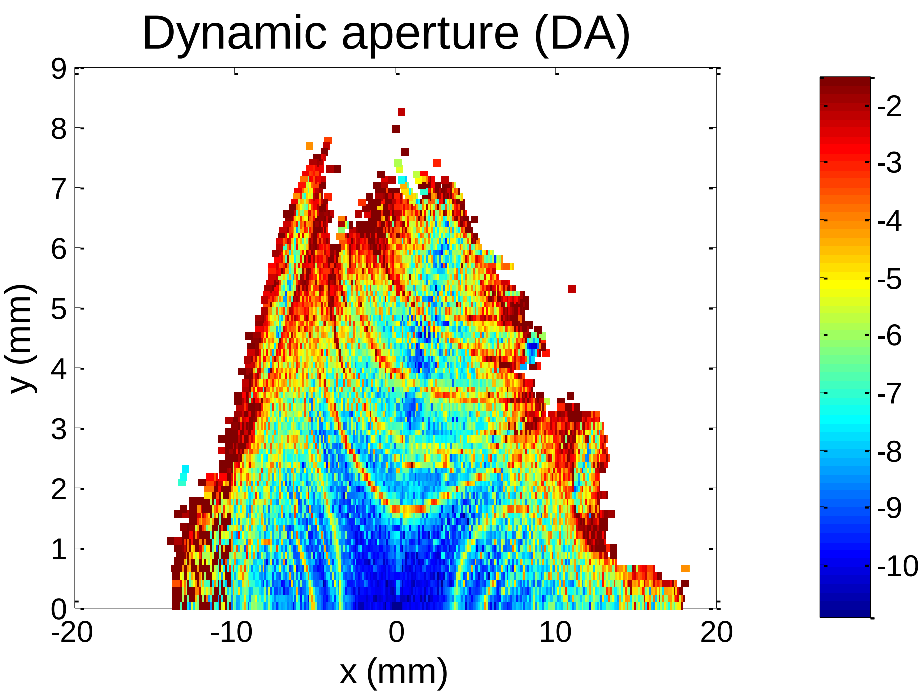


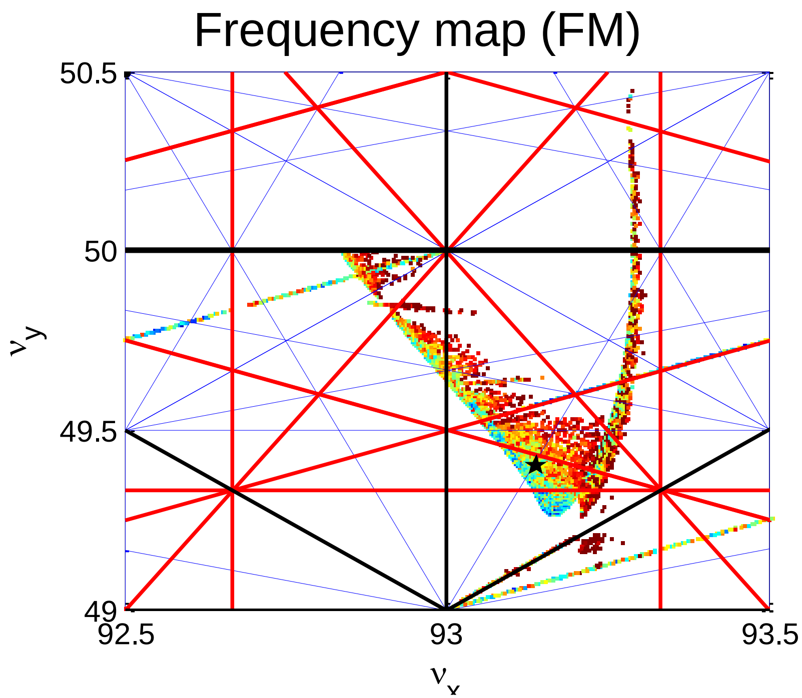
Three modes are different only in sextupole and octupole strengths

Mode 1, Dynamic aperture, Frequency map

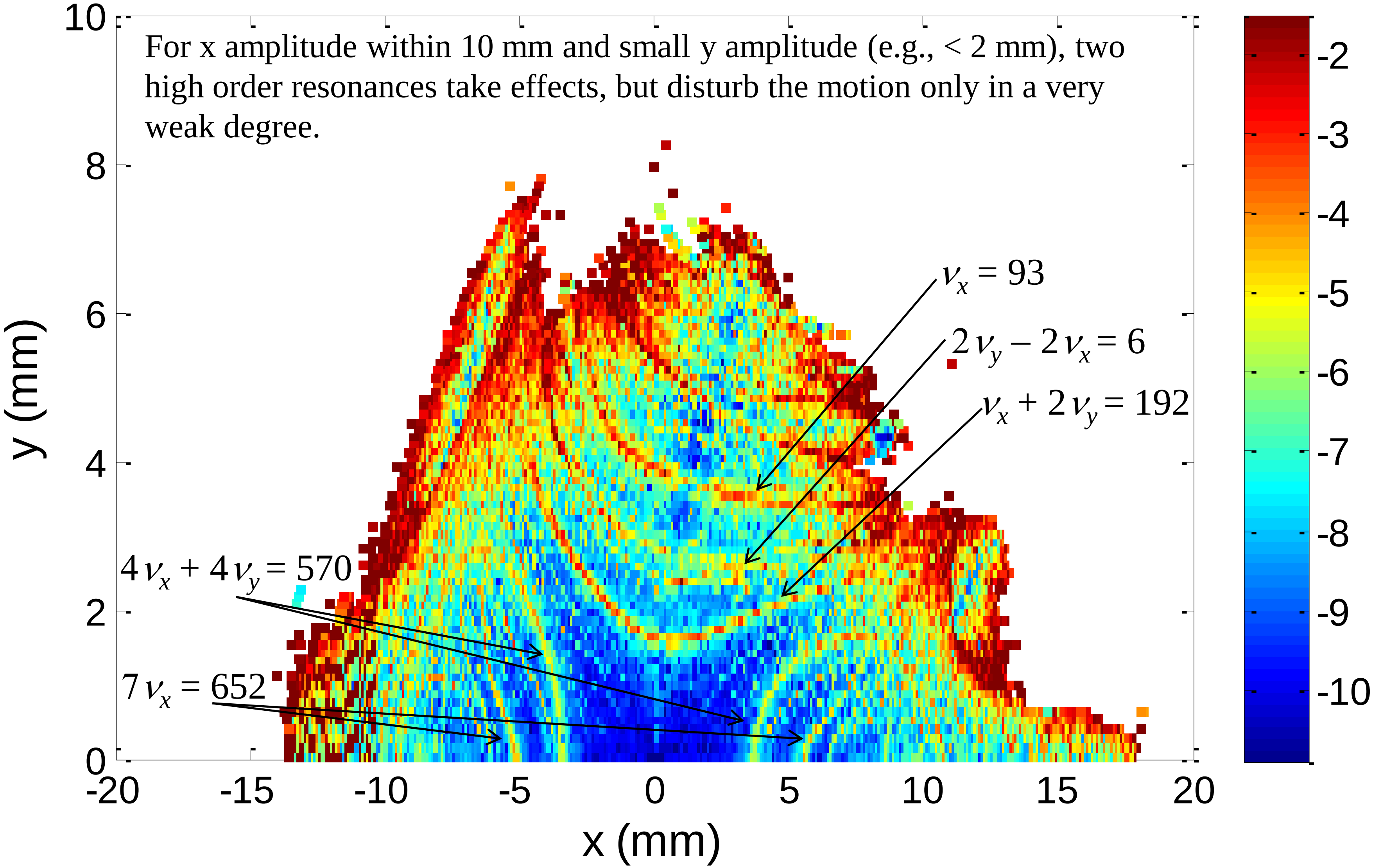
Mode 1 is designed specifically for injection

Large horizontal dynamic aperture (larger than the physical aperture, +/– 11 mm), and robust beam dynamics (clear of low order resonances as horizontal amplitude increases).



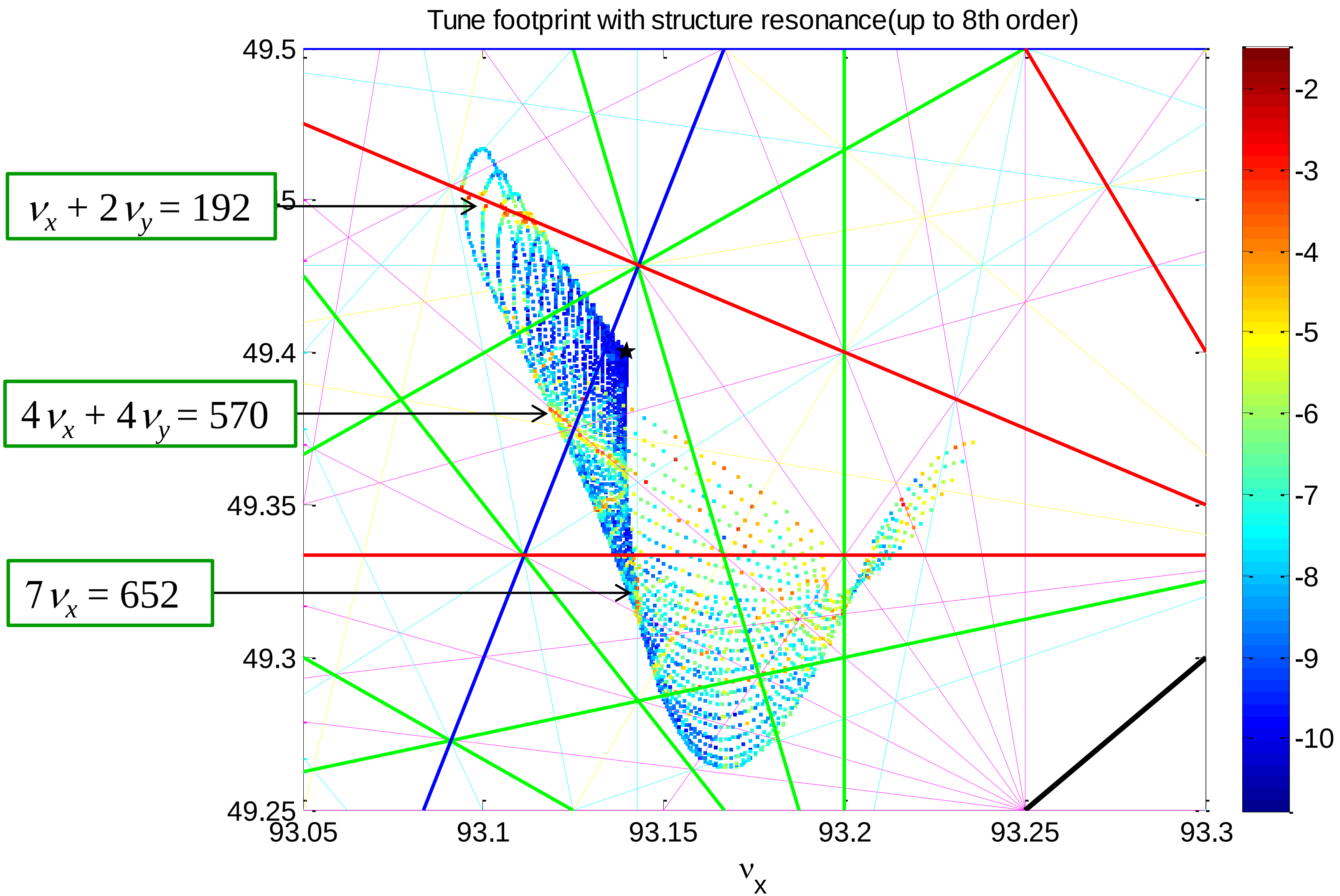


Mode 1, resonance analysis

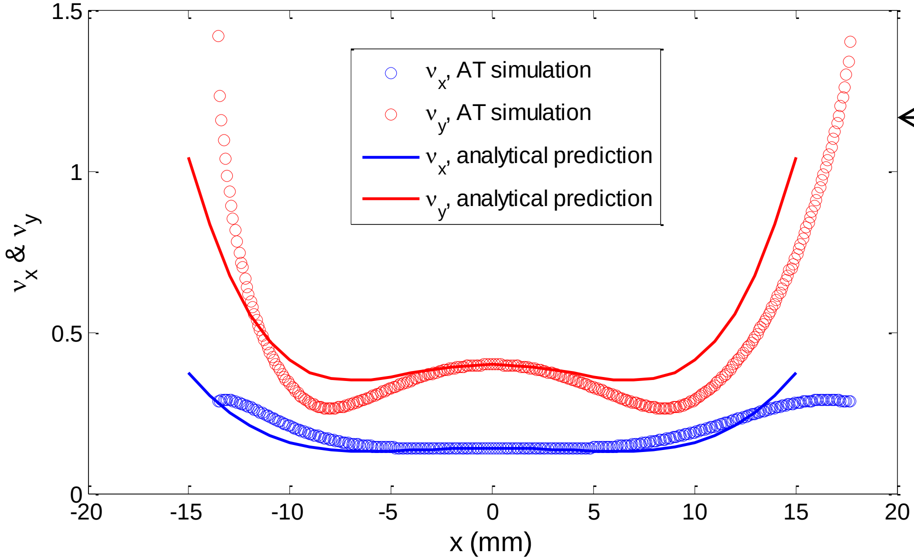


Mode 1, frequency map for the injection area

with |x| < 10 mm & |y| < 2 mm

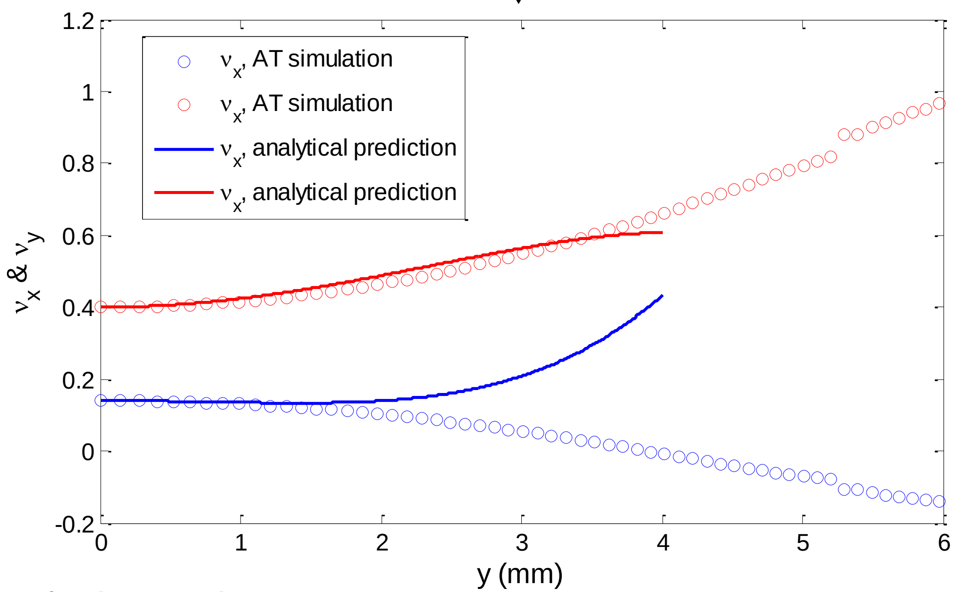


Mode 1, detune curves



Tune shift with x amplitude

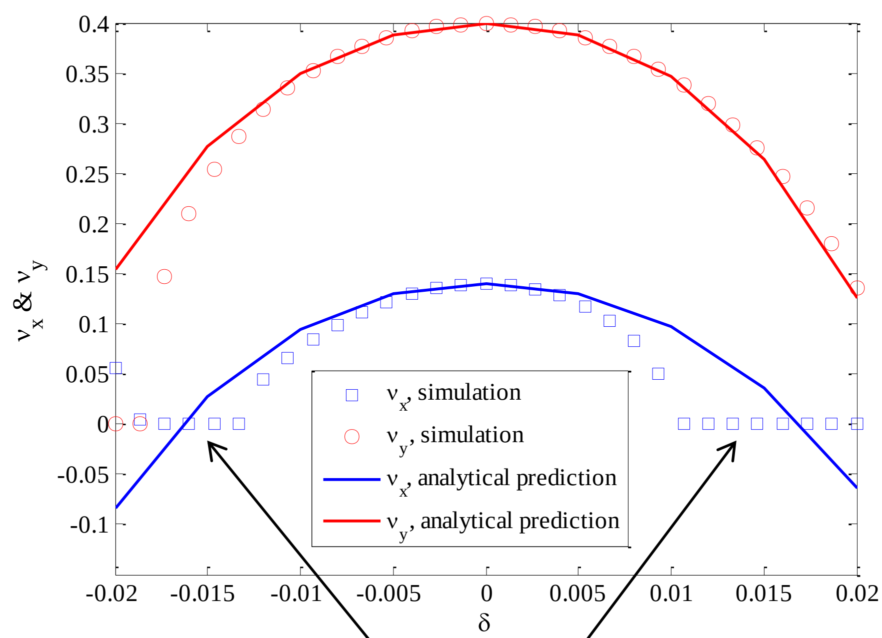
Tune shift with y amplitude



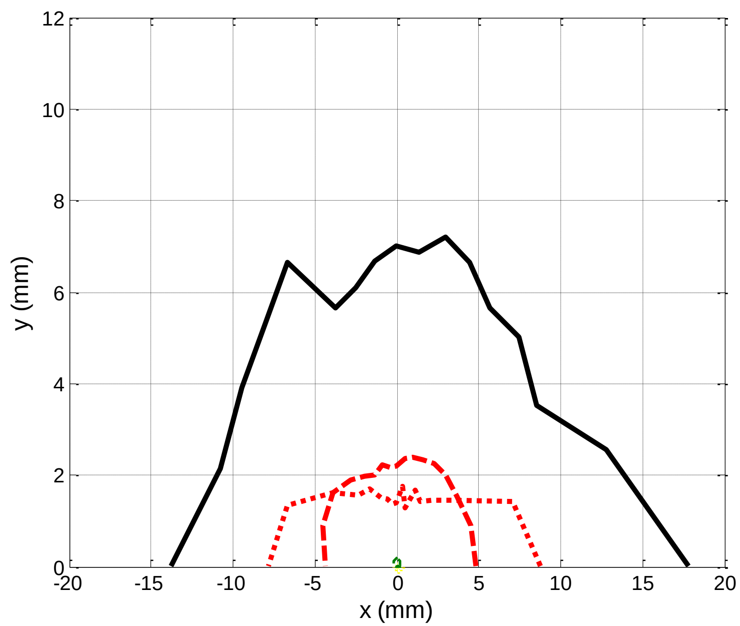
AT tracking results agree reasonably well with the analytical predictions, especially in horizontal plane! Detune terms are well controlled!

Mode 1, chromatic curve

Due to extremely strong sextupole and octupole strengths, it is very difficult to obtain reasonably small detune terms and well control the high order chromatic terms at the same time. For mode 1, the available maximum momentum acceptance (MA) is ~ 1%.



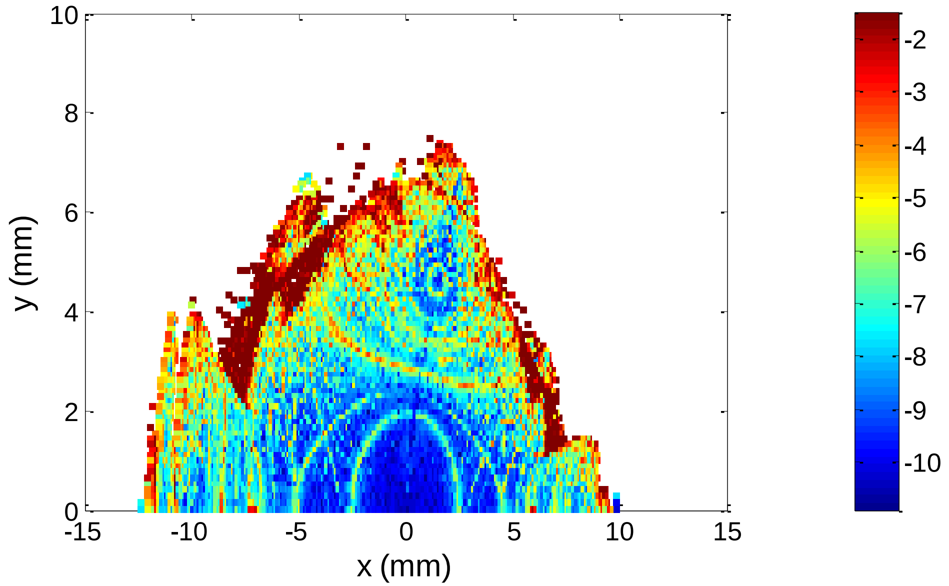
Also due to the inj. section phase advance deviates from $2n\pi$ as $\delta p/p \neq 0$

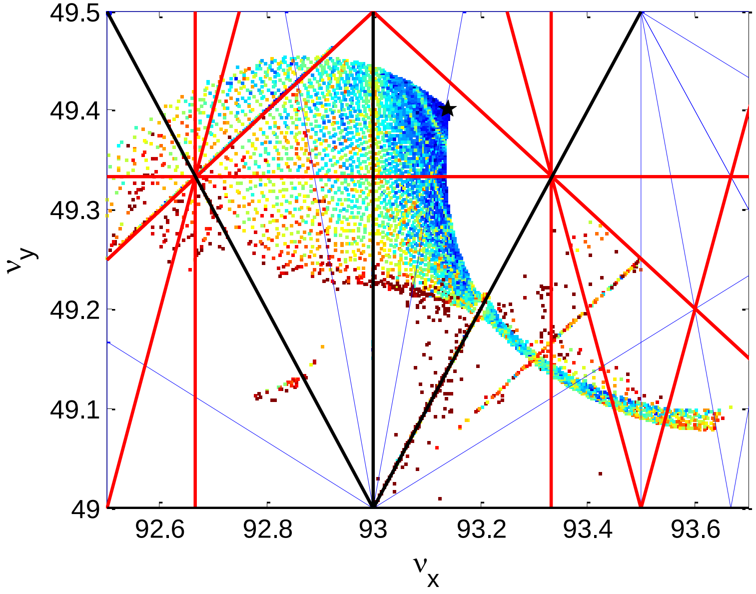


Black solid: δp/p = 0,
red dashed: 1%, red dotted: -1%

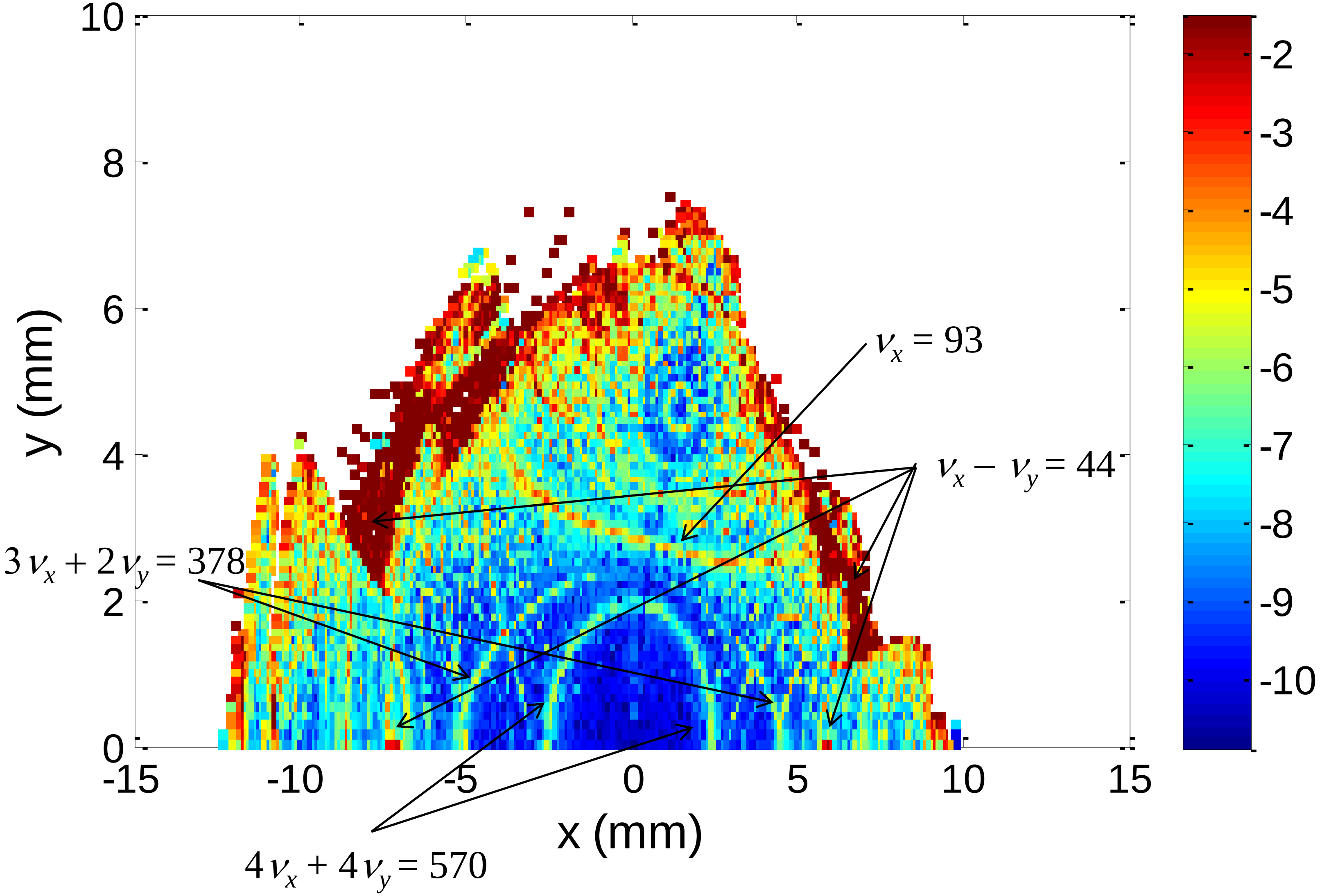
Mode 2, moderate DA & MA

Mode 2
Horizontal dynamic aperture (~ +/–10 mm),
Coupling resonance $\nu_x - \nu_y = 44$ take effects (occurs at x ~ 6 mm),
Momentum acceptance is ~ 1.8%.

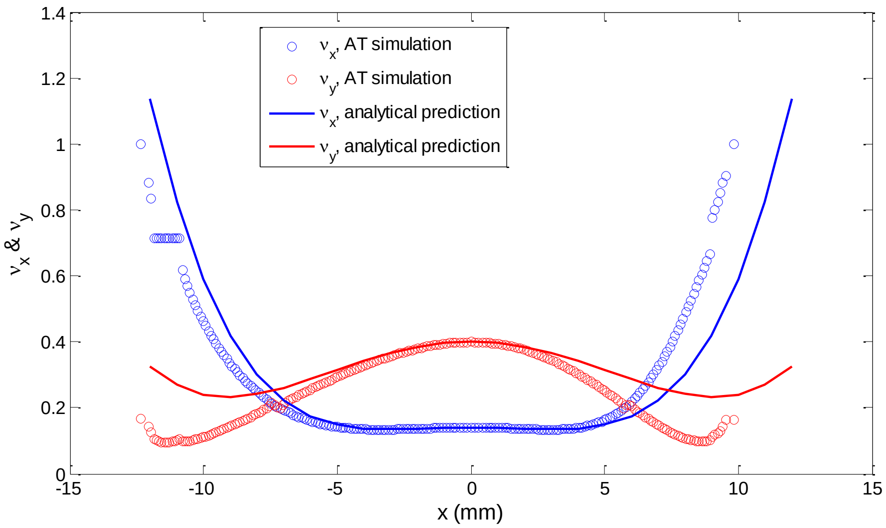


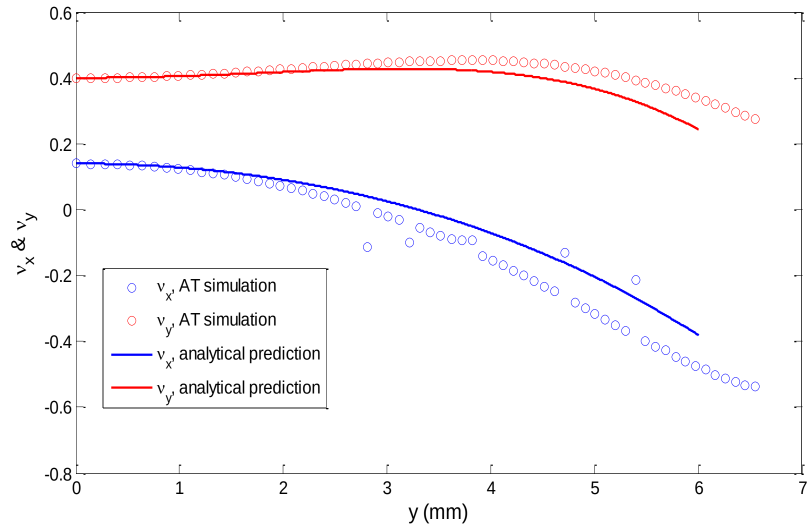


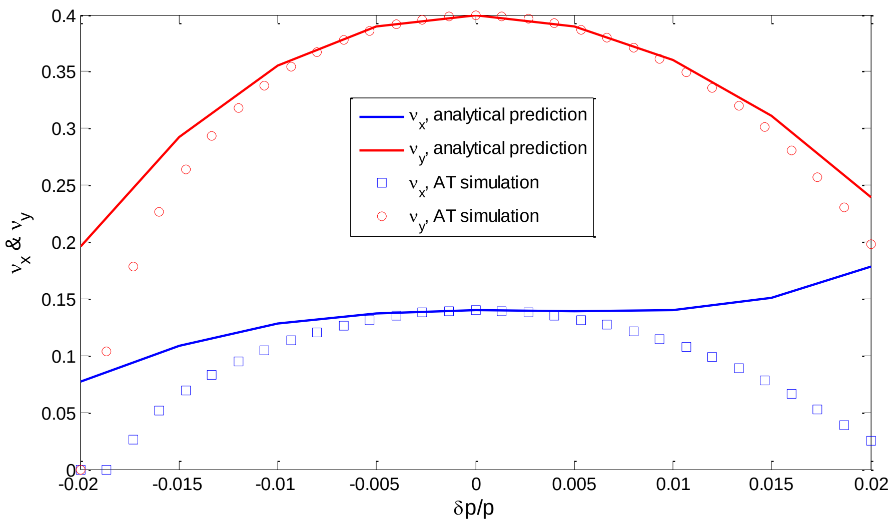
Mode 2, resonance analysis



Mode 2, detune & chromatic curves







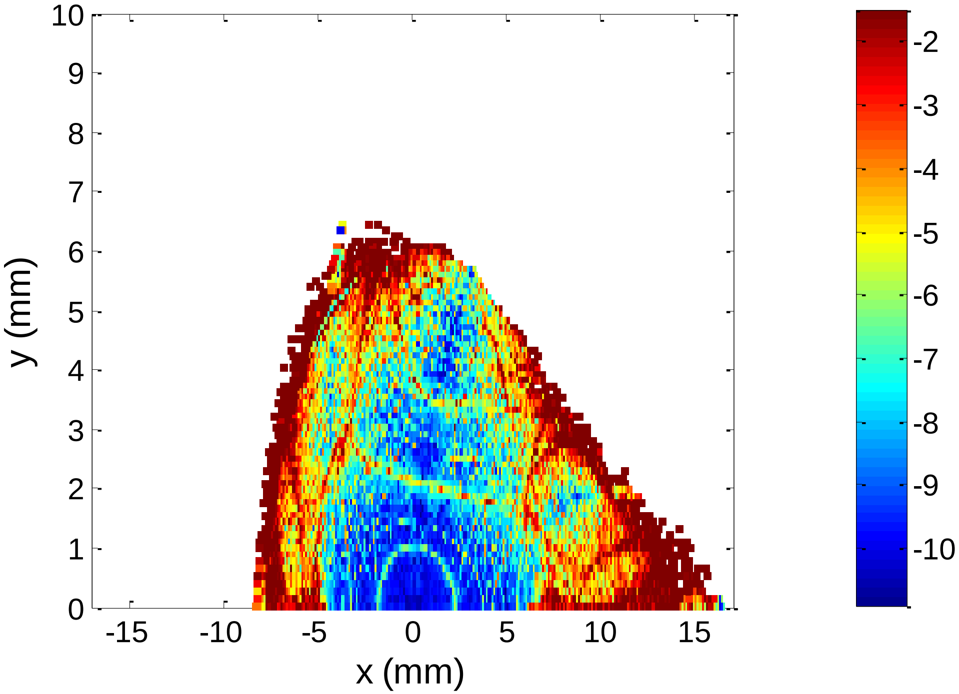
Detune curves: simulation results agree well with the analytical prediction;

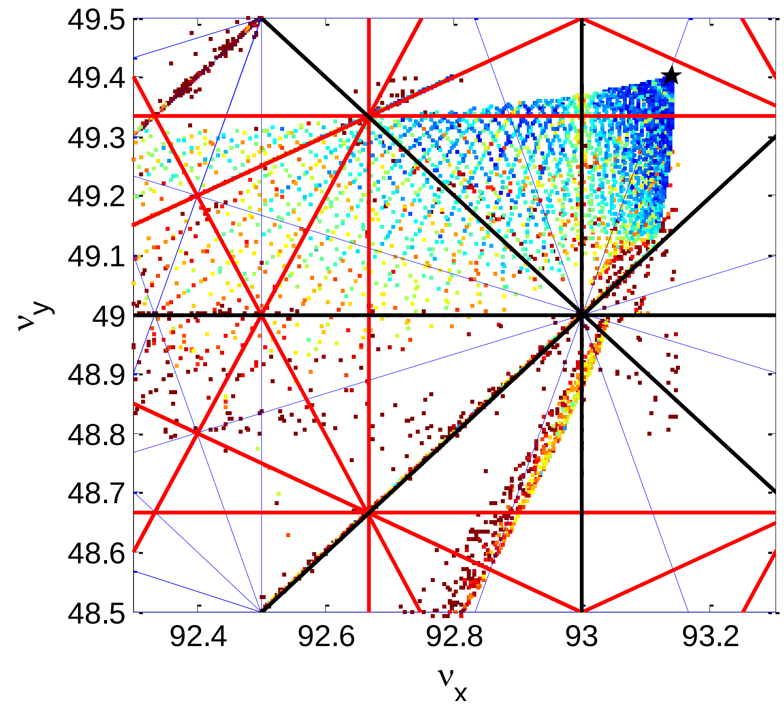
Chromatic curves: although the analytical results predict MA > 2%, but actually at $\delta p/p = -2\%$, ν_x & ν_y tend to integer.

Mode 3, large MA but relatively small DA

Mode 3 is used to store the beam after injection

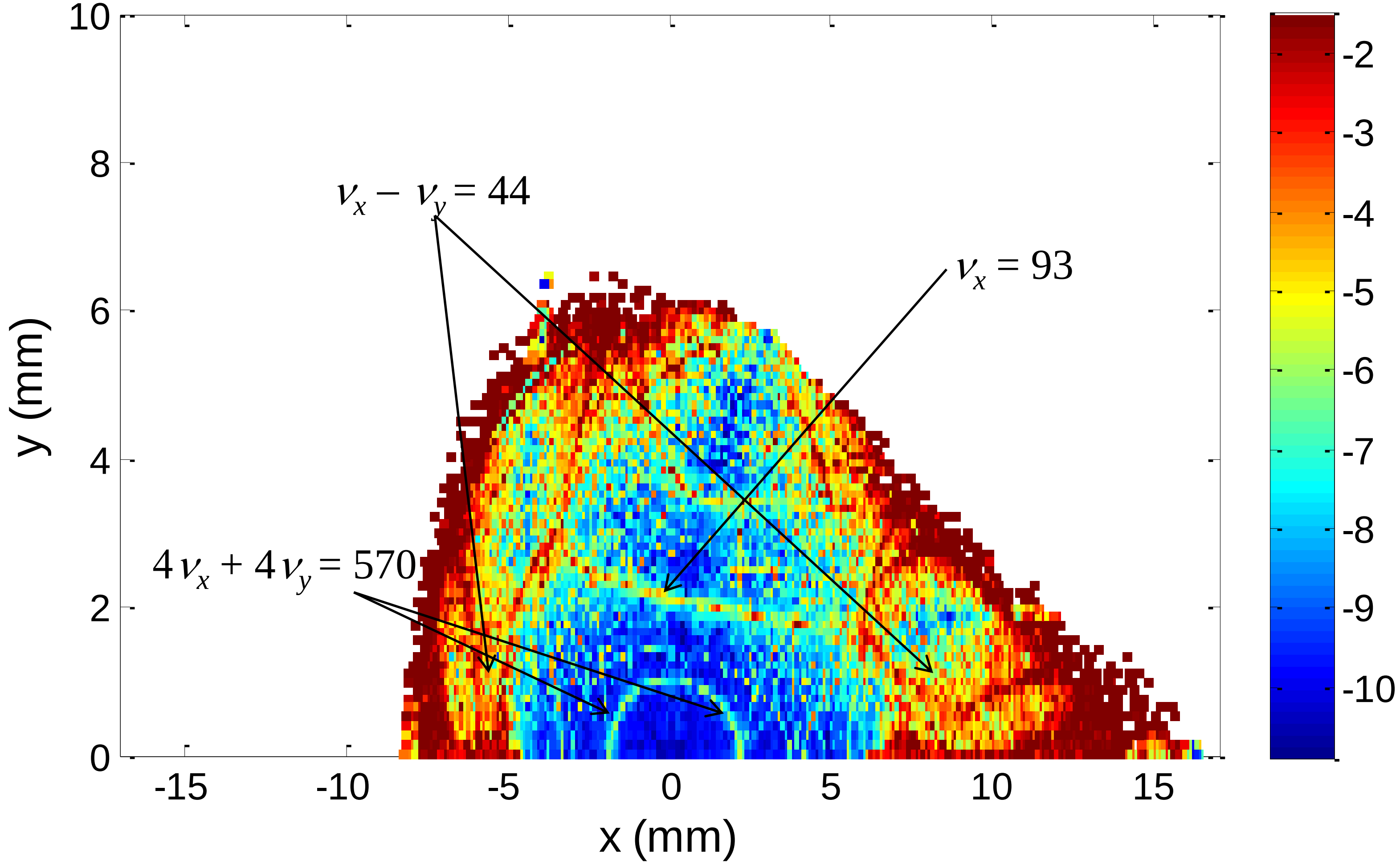
Large enough dynamic aperture (stable area of x ~ +/–5 mm & y ~ +/–2 mm) to store the beam and large momentum acceptance (>3%), promising long enough Touschek lifetime.





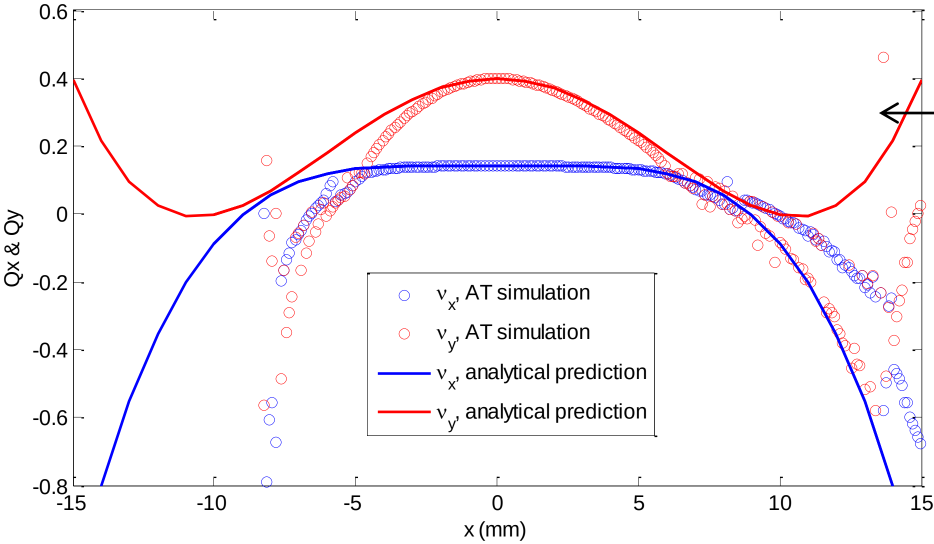
The coupling resonance $\nu_x - \nu_y = 44$ and the integer resonance $\nu_x = 93$ dominate the beam dynamics in *x* and *y* planes, respectively. Due to large detune terms, the motion reaches these two resonances at relatively small amplitudes.

Mode 3, resonance analysis



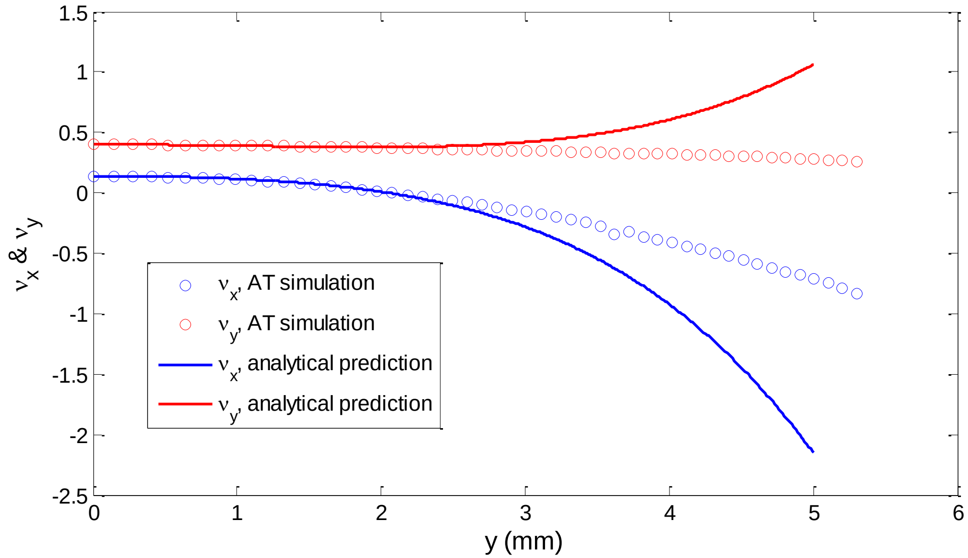
The area of $|x| < 4$ mm (about $40\sigma_x$) and $|y| < 2$ mm (about $40\sigma_y$) is enough to store the beam, where only a 8th order resonance $4\nu_x + 4\nu_y = 570$ slightly distorts the motion.

Mode 3, detune terms



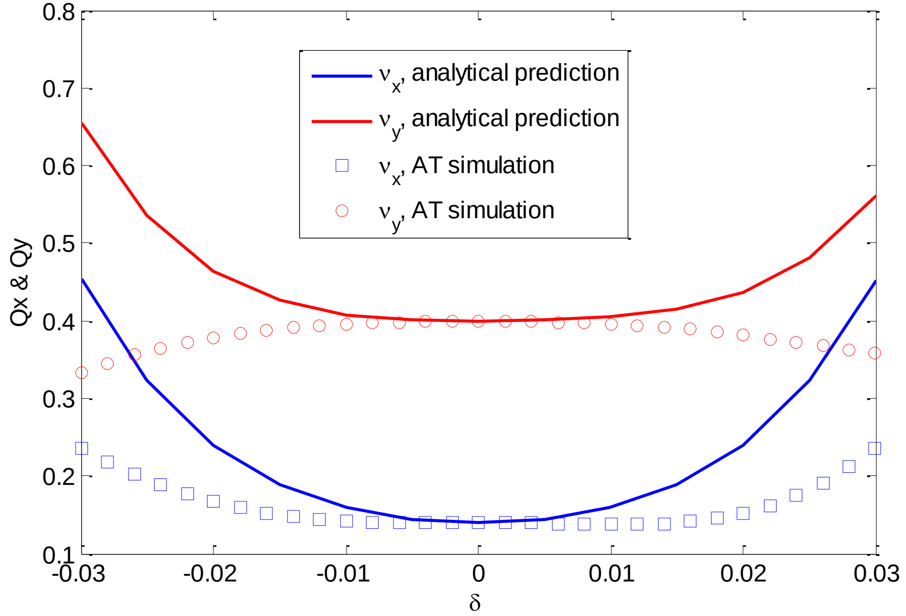
Tune shift with x amplitude

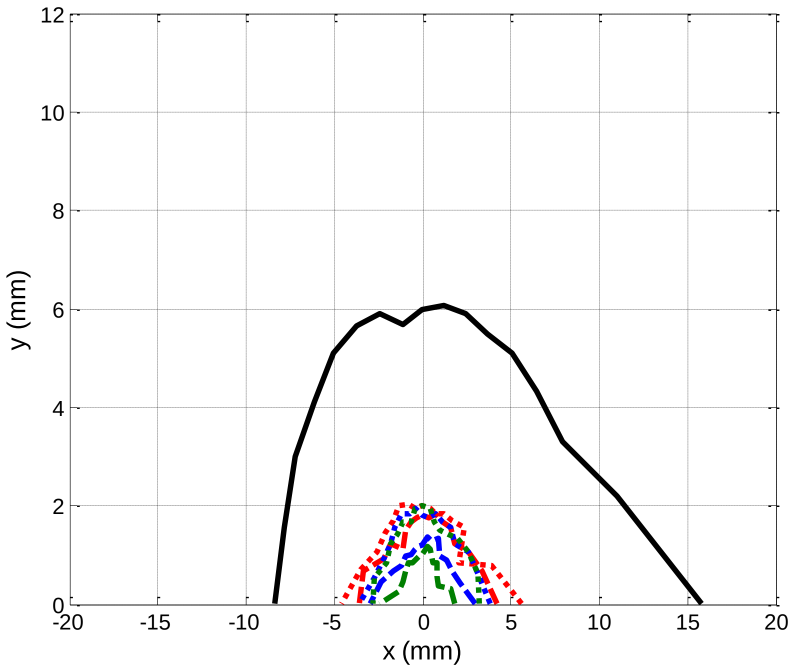
Tune shift with y amplitude



The detune terms are larger than those of mode 1 and mode 2.

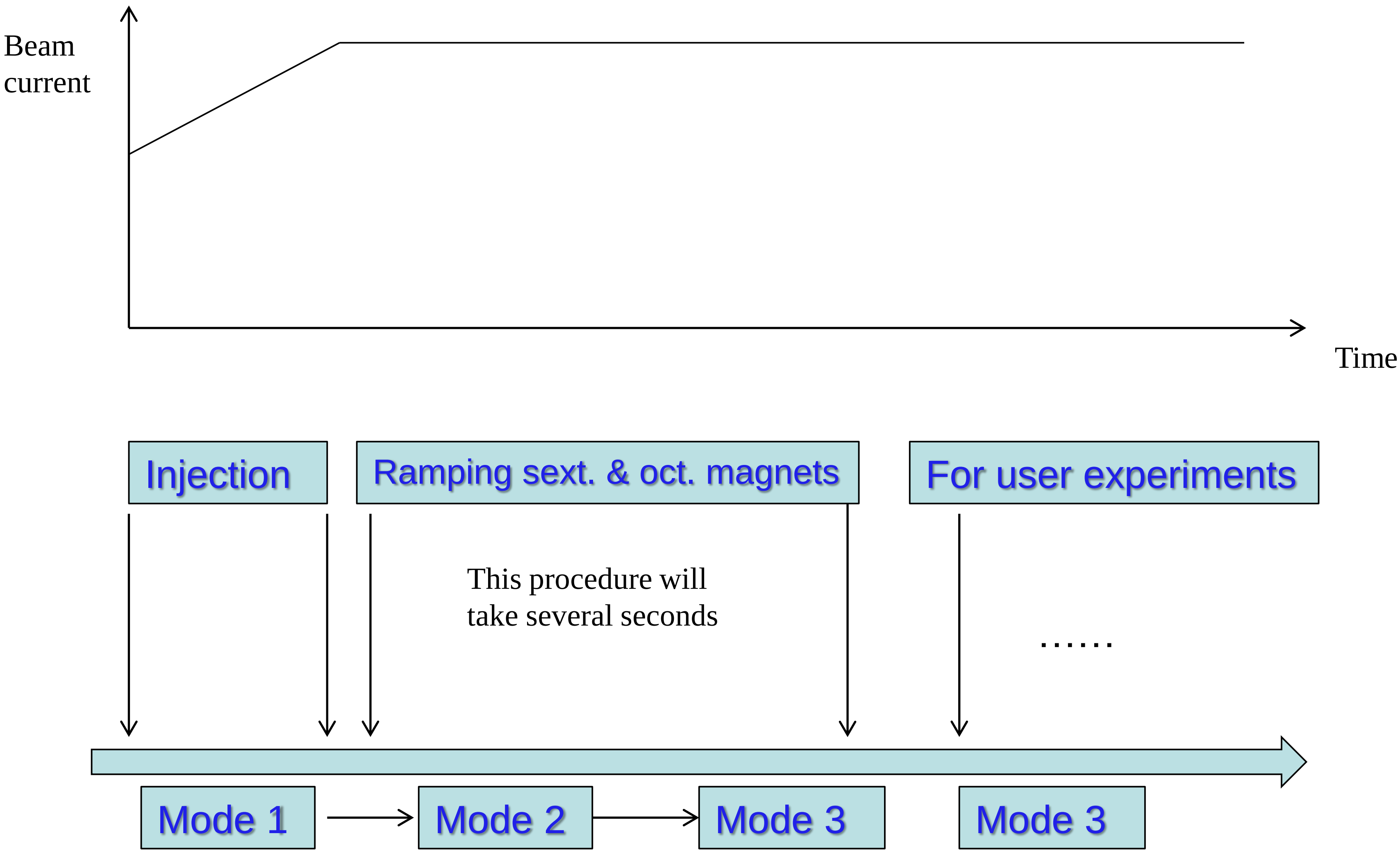
Mode 3, chromatic curves





Black solid: δp/p = 0,
red dashed: 1%, red dotted: -1%,
blue dashed: 2%, blue dotted: -2%,
green dashed: 3%, green dotted: -3%

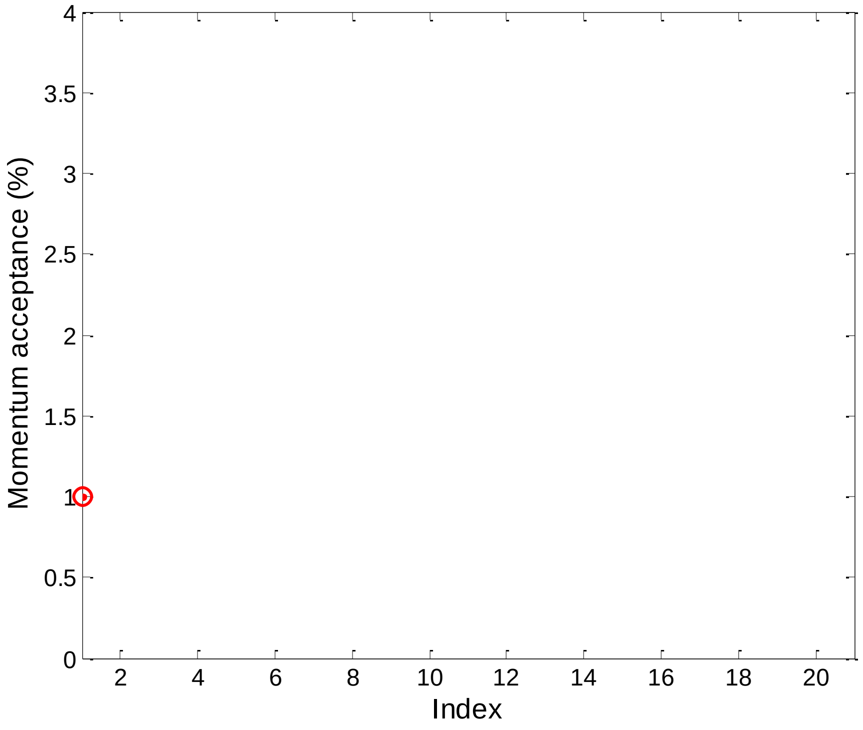
Mode 1 for injecting & Mode 3 for storing beam

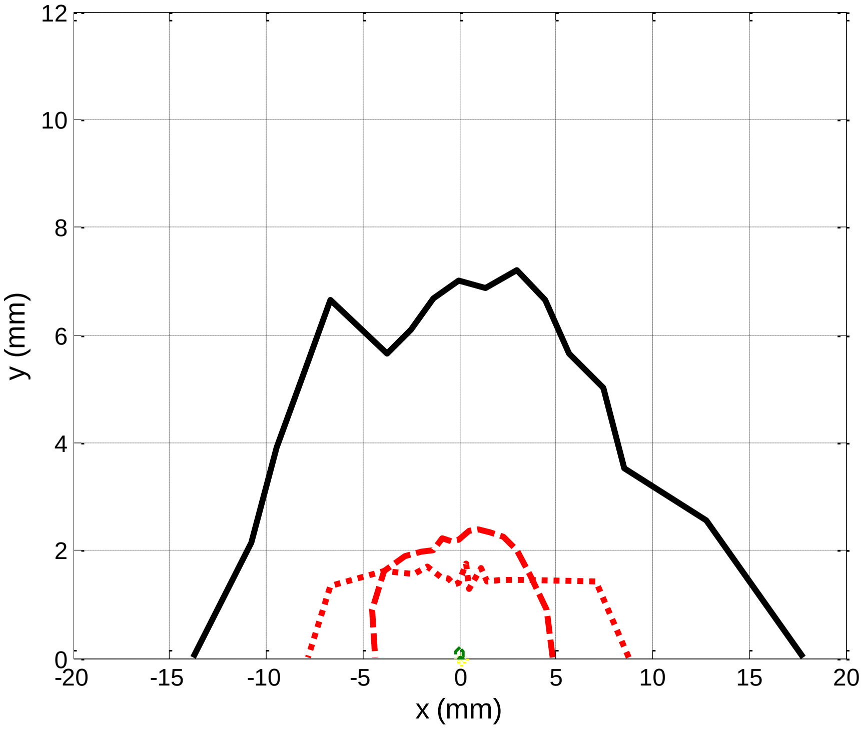


Three modes are different only in sextupole and octupole strengths

From Mode 1 to 2, then to 3

* Assume the sext. & oct. strengths are varied averagely from one mode to another, totally 21 steps. No. **01**/**21**.



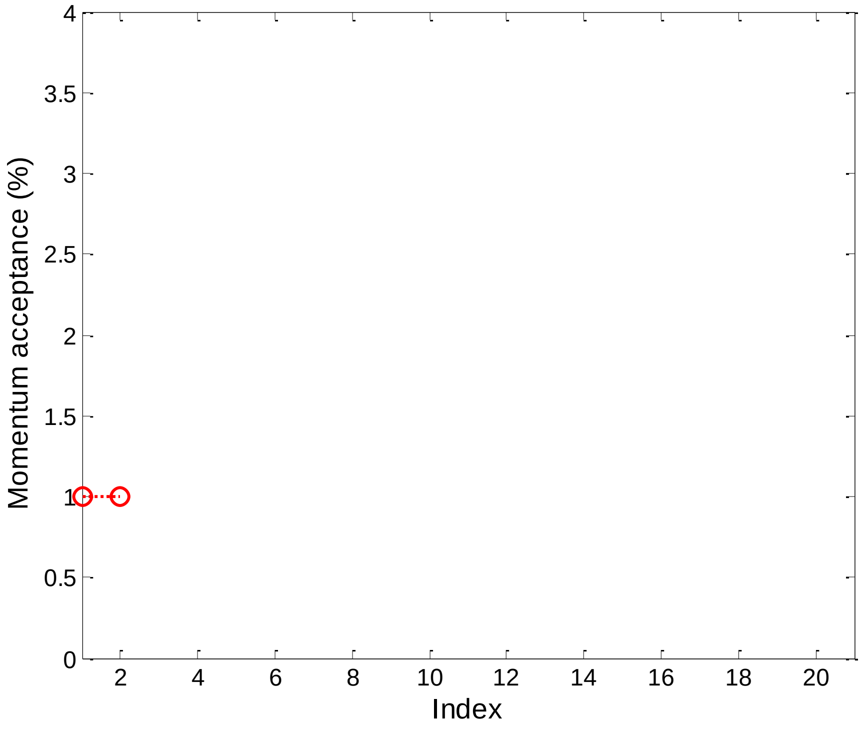


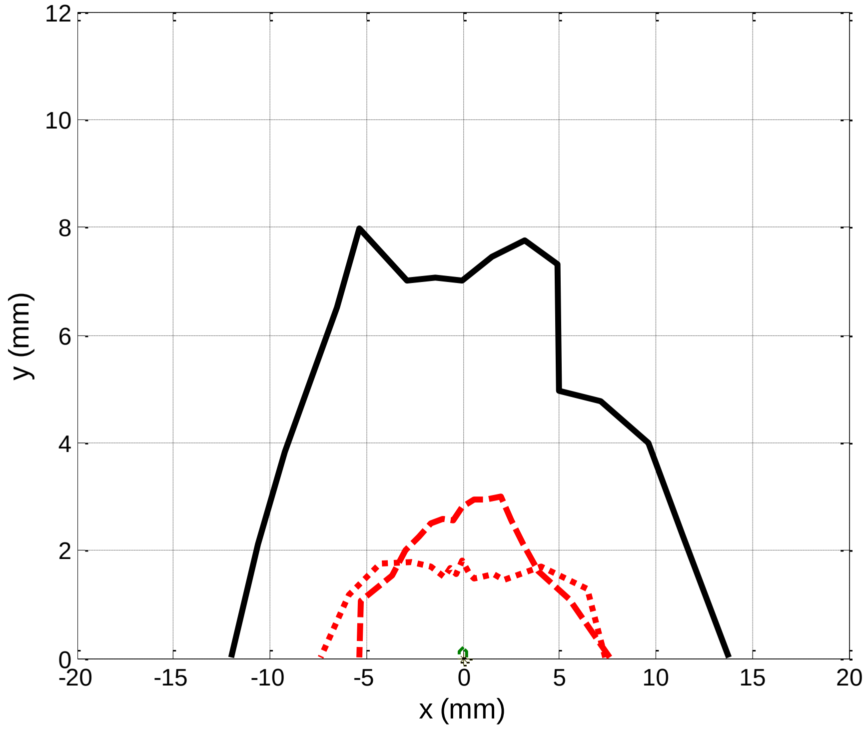
Mode 1

Black solid: 0, red dashed: 1%, red dotted: -1%, blue dashed: 2%, blue dotted: -2%, green dashed: 3%, green dotted: -3%

From Mode 1 to 2, then to 3

* Assume the sext. & oct. strengths are varied averagely from one mode to another, totally 21 steps. No. **02/21**.

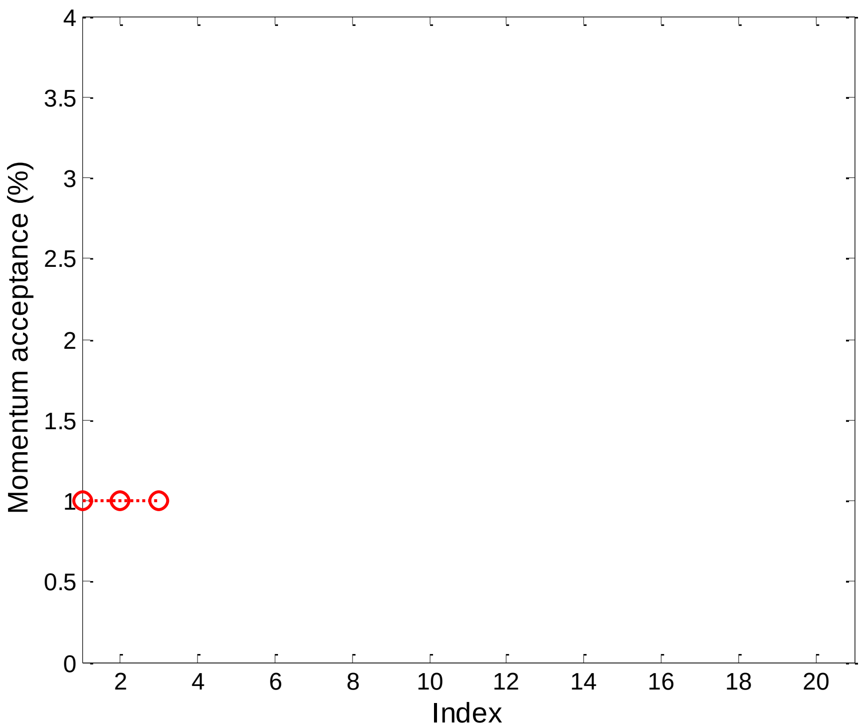


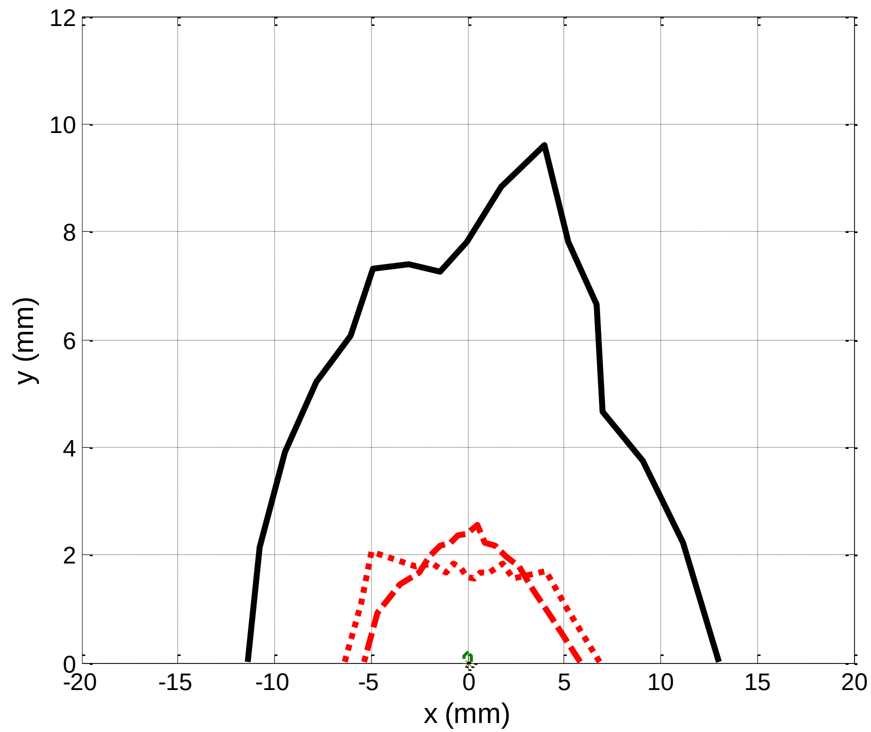


Black solid: 0, red dashed: 1%, red dotted: -1%, blue dashed: 2%, blue dotted: -2%, green dashed: 3%, green dotted: -3%

From Mode 1 to 2, then to 3

* Assume the sext. & oct. strengths are varied averagely from one mode to another, totally 21 steps. No. **03/21**.





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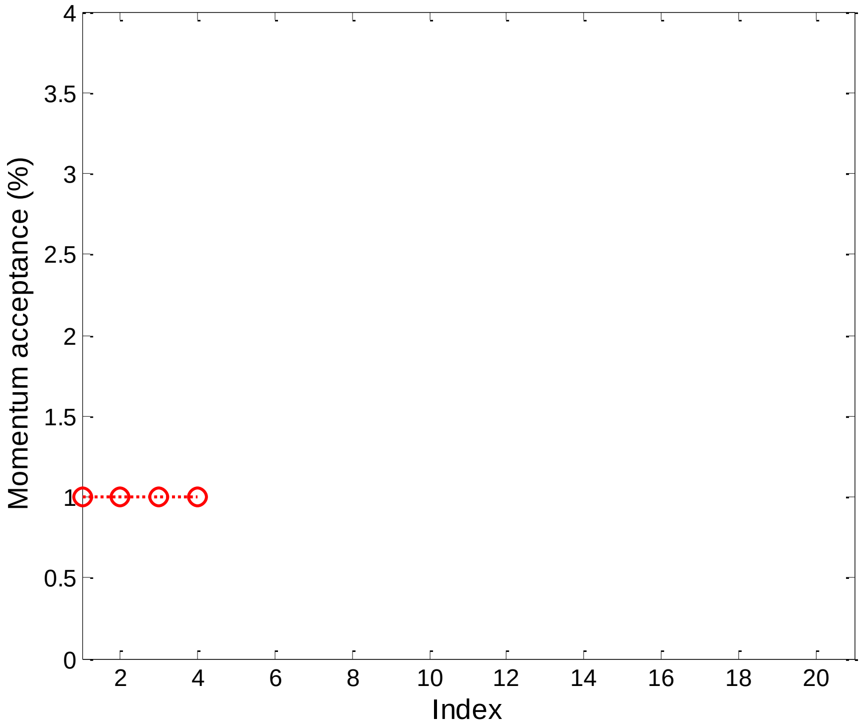
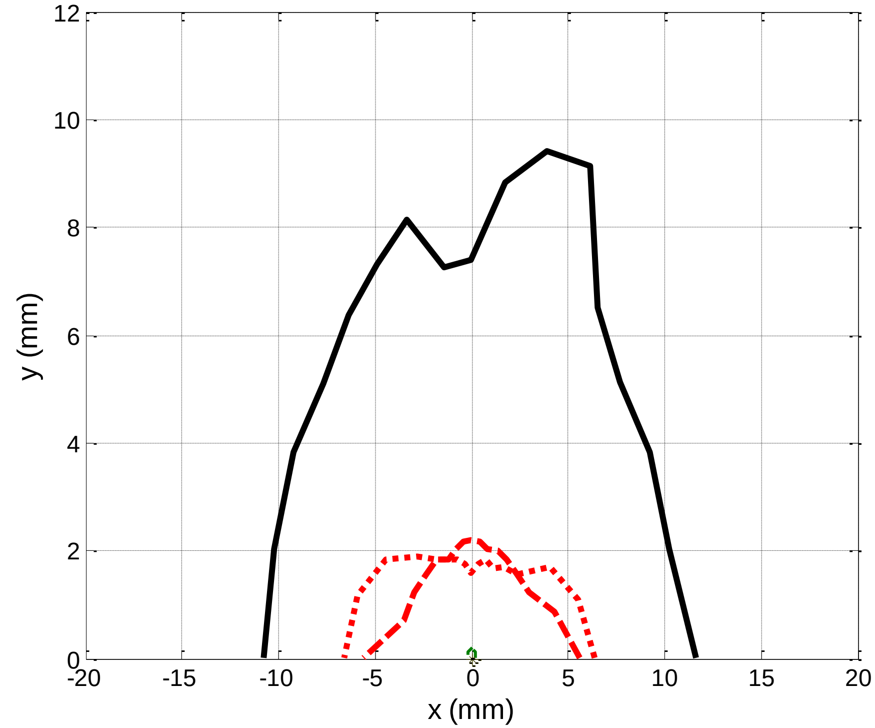
From Mode 1 to 2, then to 3

* Assume the sext. & oct. strengths are varied averagely from one mode to another, totally 21 steps. No. **04/21**.

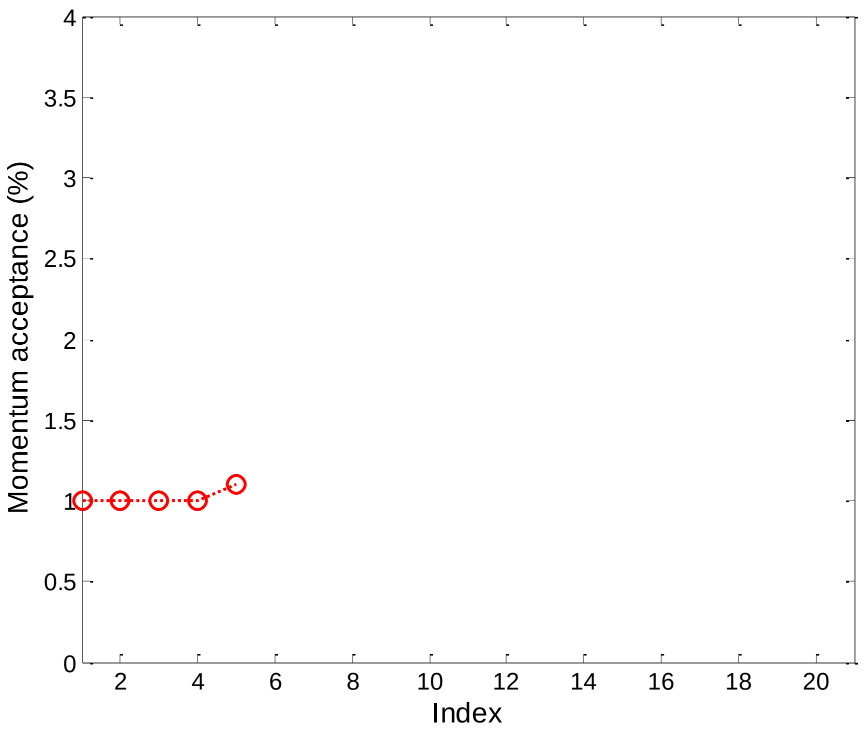


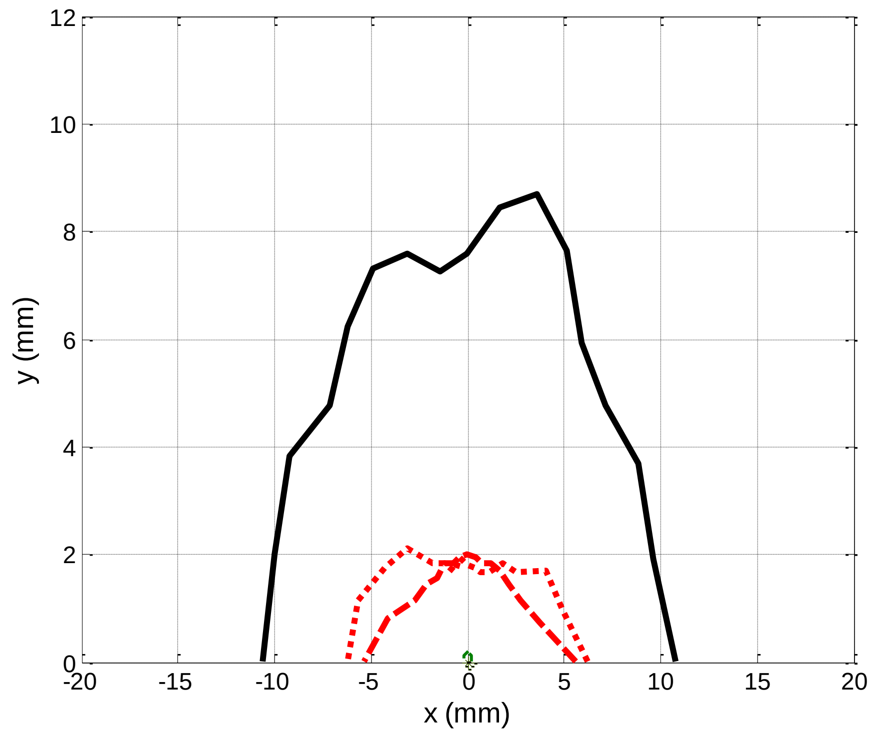


Black solid: 0, red dashed: 1%, red dotted: -1%, blue dashed: 2%, blue dotted: -2%, green dashed: 3%, green dotted: -3%

From Mode 1 to 2, then to 3

* Assume the sext. & oct. strengths are varied averagely from one mode to another, totally 21 steps. No. **05/21**.

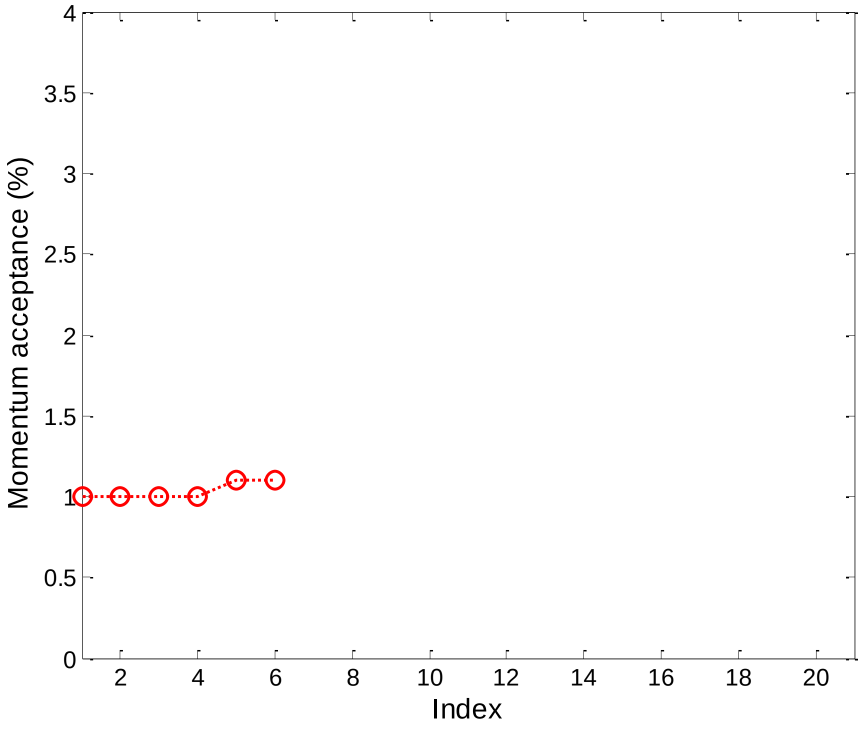


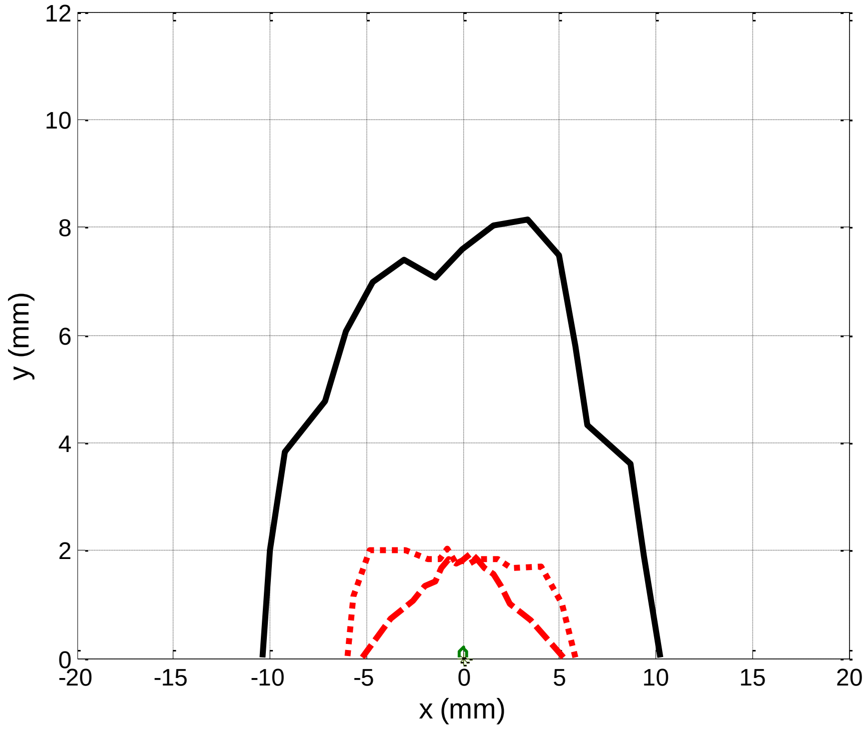


Black solid: 0, red dashed: 1%, red dotted: -1%, blue dashed: 2%, blue dotted: -2%, green dashed: 3%, green dotted: -3%

From Mode 1 to 2, then to 3

* Assume the sext. & oct. strengths are varied averagely from one mode to another, totally 21 steps. No. **06/21**.

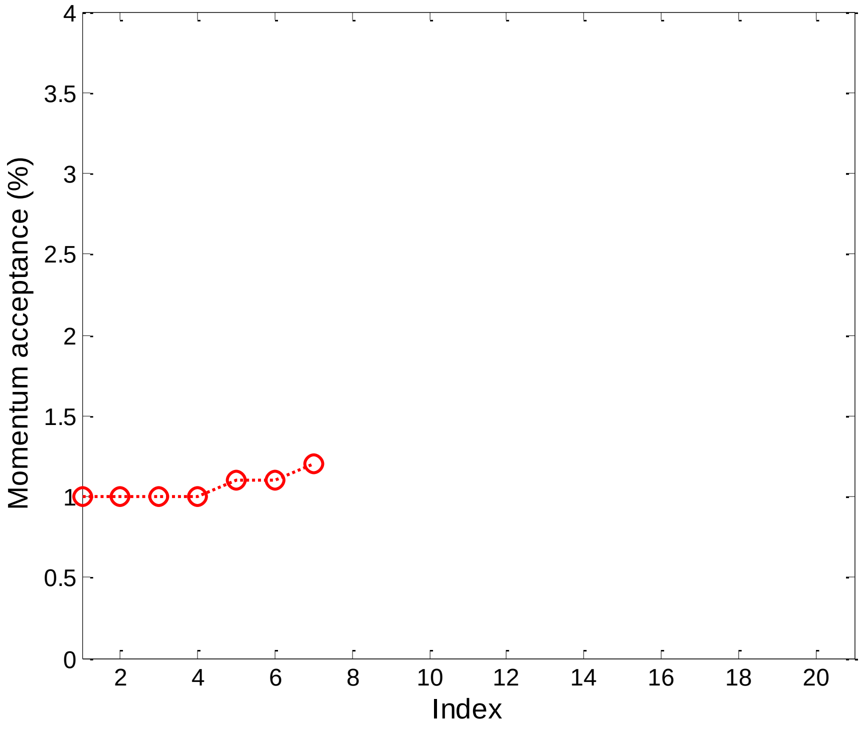


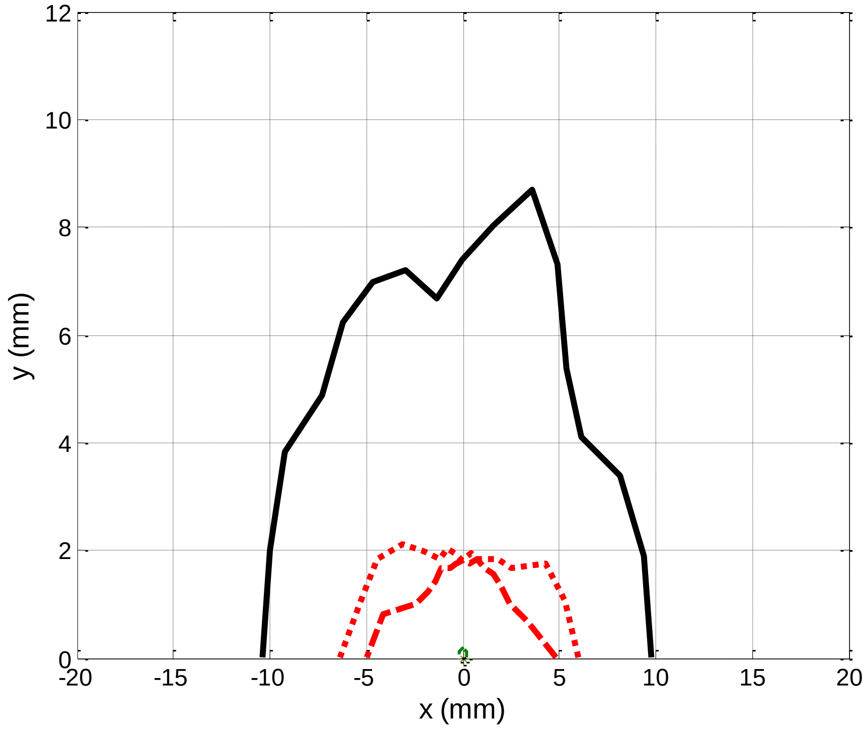


Black solid: 0, red dashed: 1%, red dotted: -1%, blue dashed: 2%, blue dotted: -2%, green dashed: 3%, green dotted: -3%

From Mode 1 to 2, then to 3

* Assume the sext. & oct. strengths are varied averagely from one mode to another, totally 21 steps. No. **07/21**.

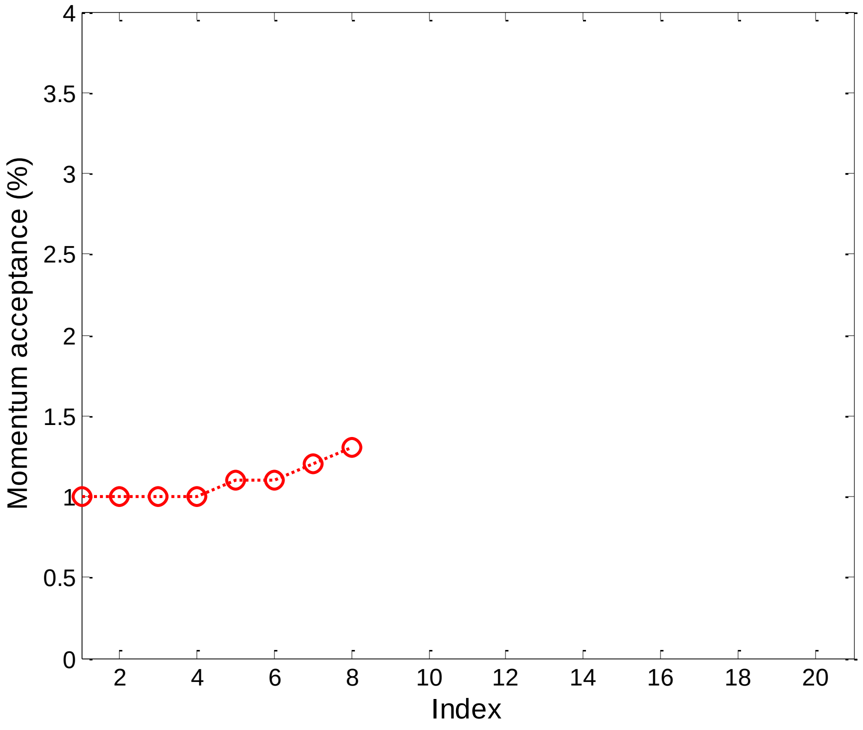


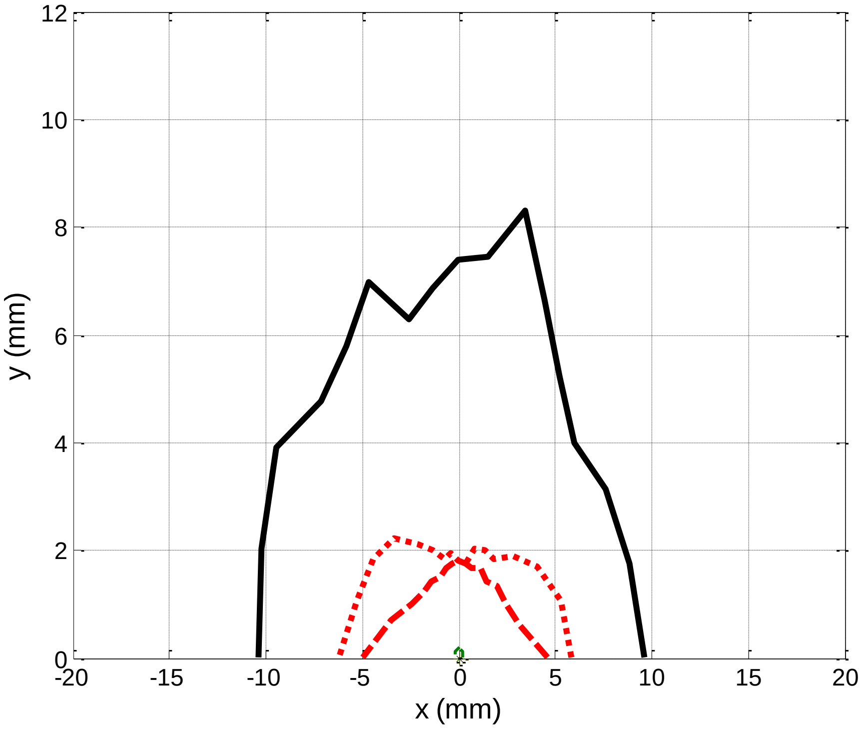


Black solid: 0, red dashed: 1%, red dotted: -1%, blue dashed: 2%, blue dotted: -2%, green dashed: 3%, green dotted: -3%

From Mode 1 to 2, then to 3

* Assume the sext. & oct. strengths are varied averagely from one mode to another, totally 21 steps. No. **08/21**.

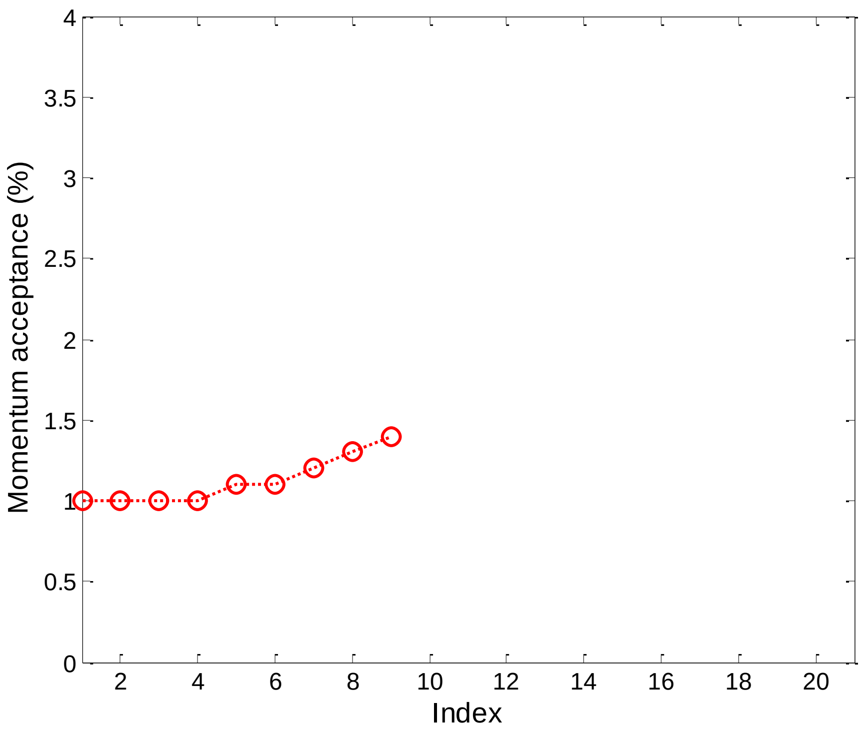


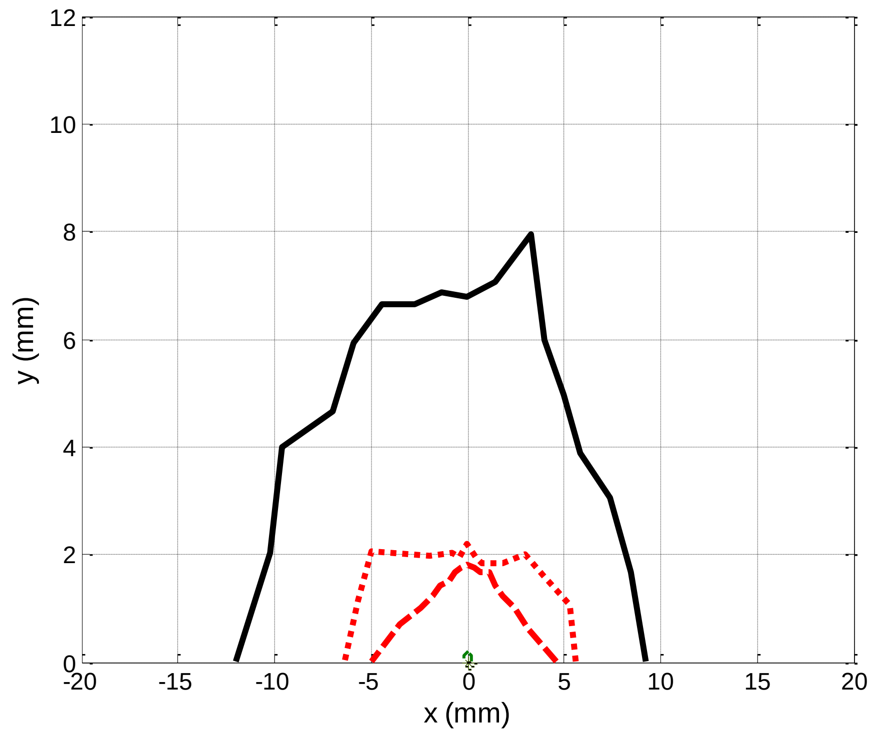


Black solid: 0, red dashed: 1%, red dotted: -1%, blue dashed: 2%, blue dotted: -2%, green dashed: 3%, green dotted: -3%

From Mode 1 to 2, then to 3

* Assume the sext. & oct. strengths are varied averagely from one mode to another, totally 21 steps. No. **09/21**.

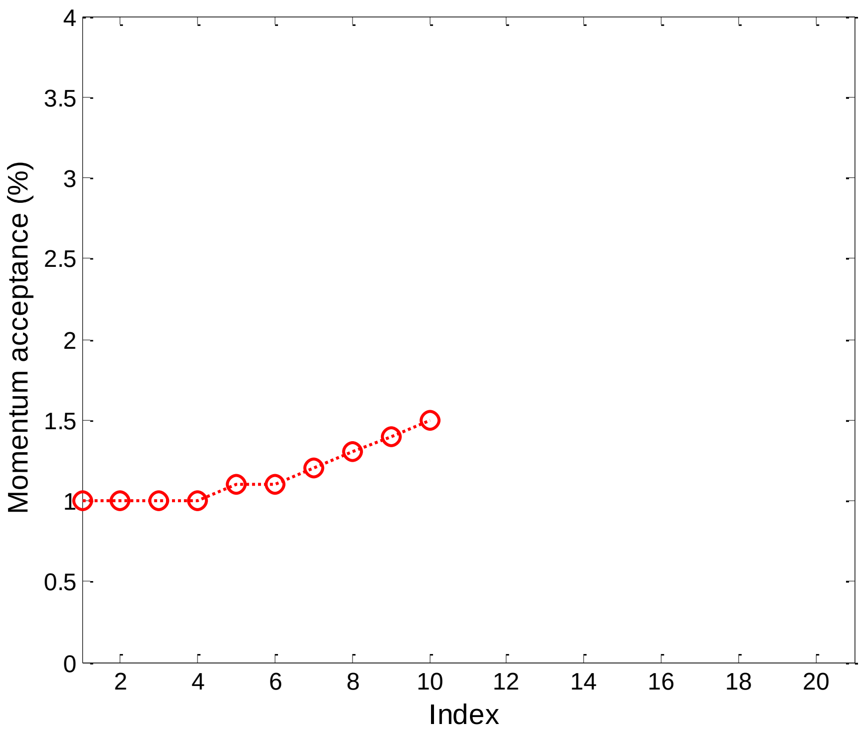


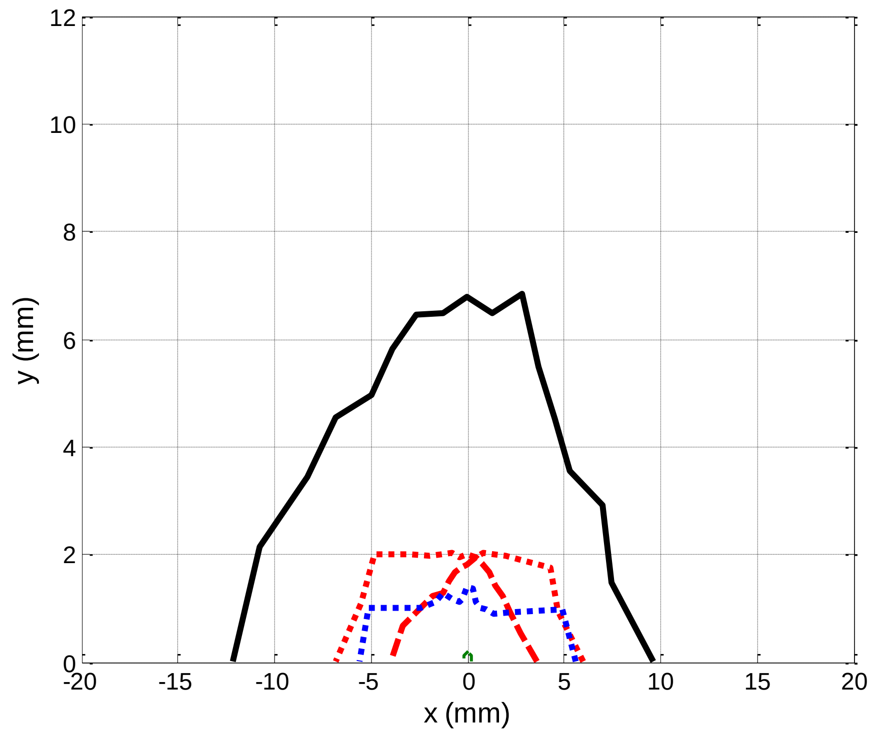


Black solid: 0, red dashed: 1%, red dotted: -1%, blue dashed: 2%, blue dotted: -2%, green dashed: 3%, green dotted: -3%

From Mode 1 to 2, then to 3

* Assume the sext. & oct. strengths are varied averagely from one mode to another, totally 21 steps. No. **10/21**.

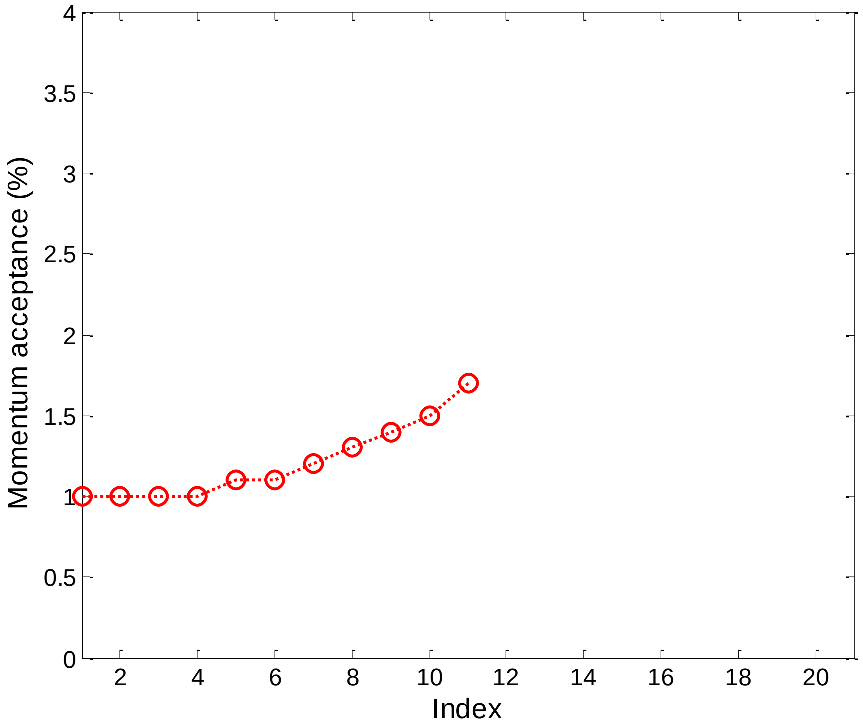


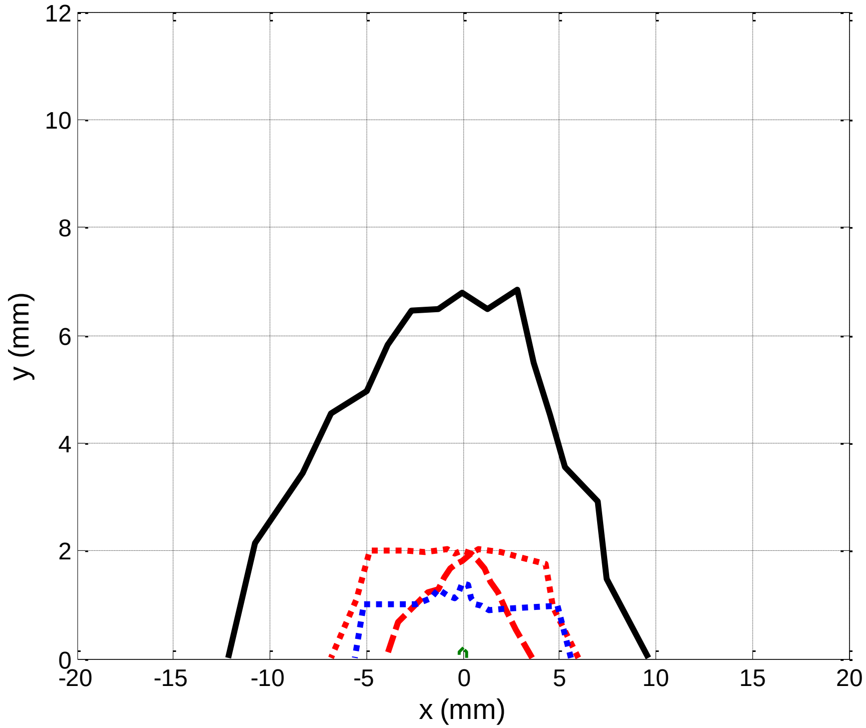


Black solid: 0, red dashed: 1%, red dotted: -1%, blue dashed: 2%, blue dotted: -2%, green dashed: 3%, green dotted: -3%

From Mode 1 to 2, then to 3

* Assume the sext. & oct. strengths are varied averagely from one mode to another, totally 21 steps. No. **11**/**21**.



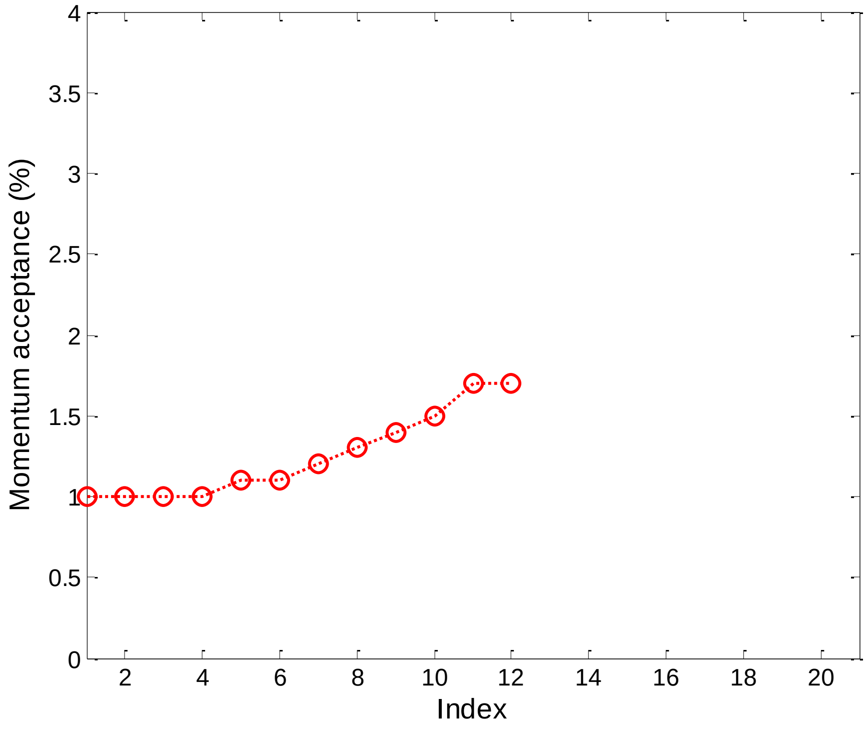


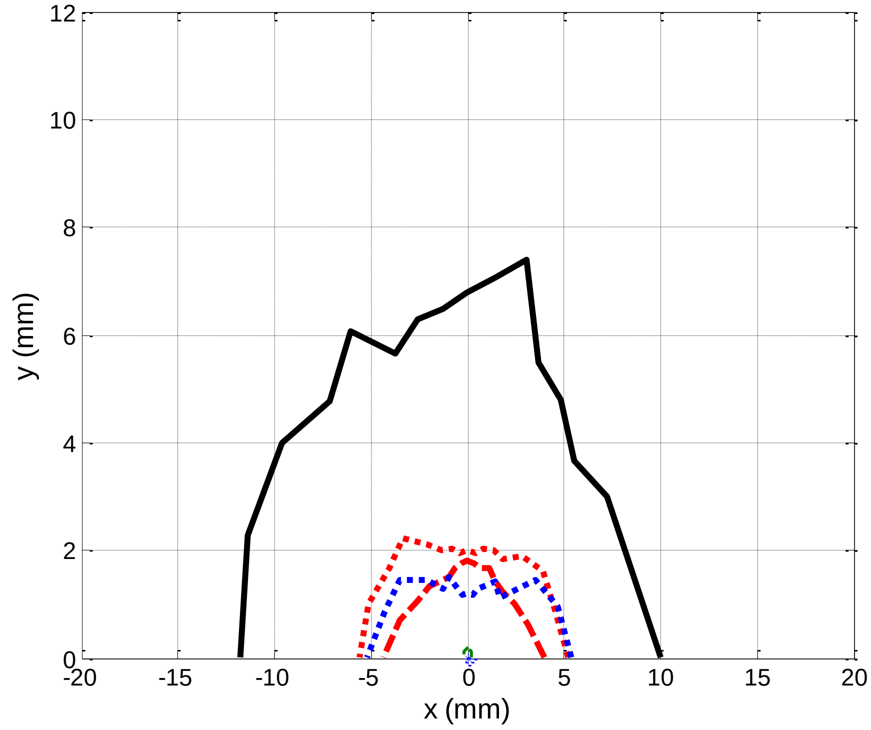
Mode 2

Black solid: 0, red dashed: 1%, red dotted: -1%, blue dashed: 2%, blue dotted: -2%, green dashed: 3%, green dotted: -3%

From Mode 1 to 2, then to 3

* Assume the sext. & oct. strengths are varied averagely from one mode to another, totally 21 steps. No. **12/21**.

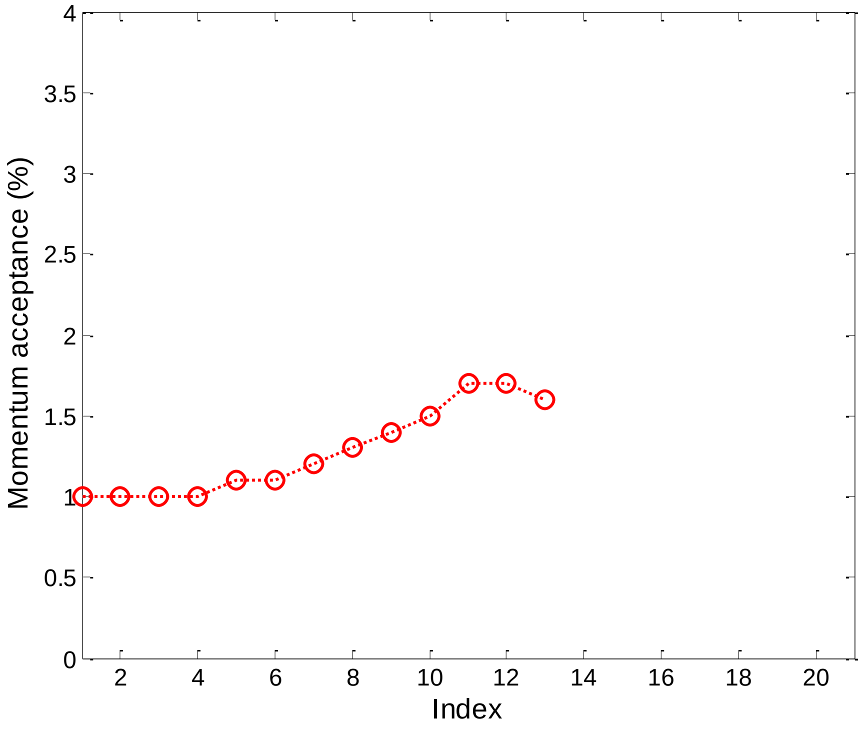


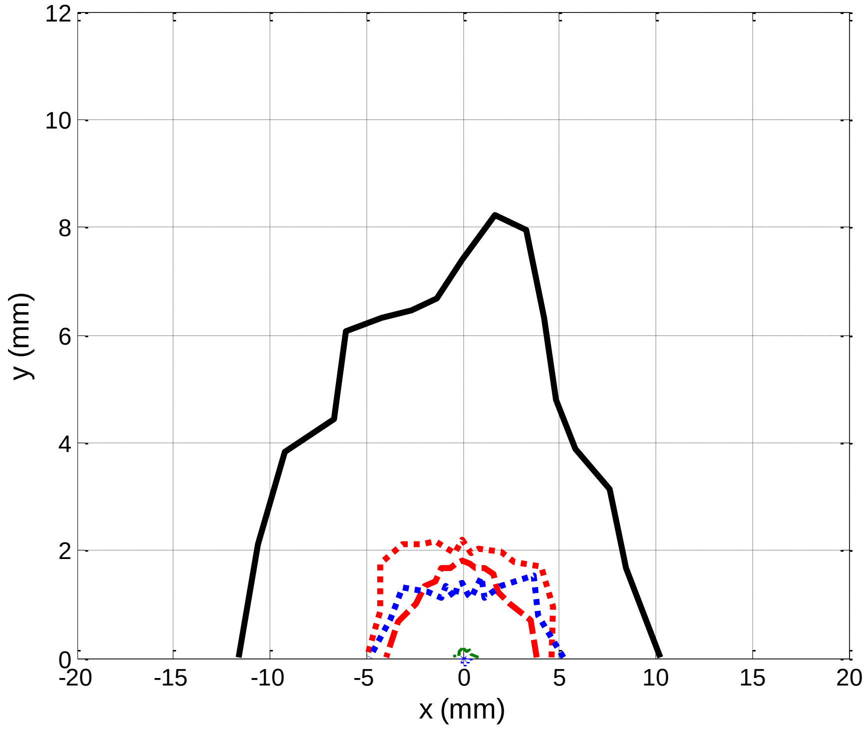


Black solid: 0, red dashed: 1%, red dotted: -1%, blue dashed: 2%, blue dotted: -2%, green dashed: 3%, green dotted: -3%

From Mode 1 to 2, then to 3

* Assume the sext. & oct. strengths are varied averagely from one mode to another, totally 21 steps. No. **13/21**.

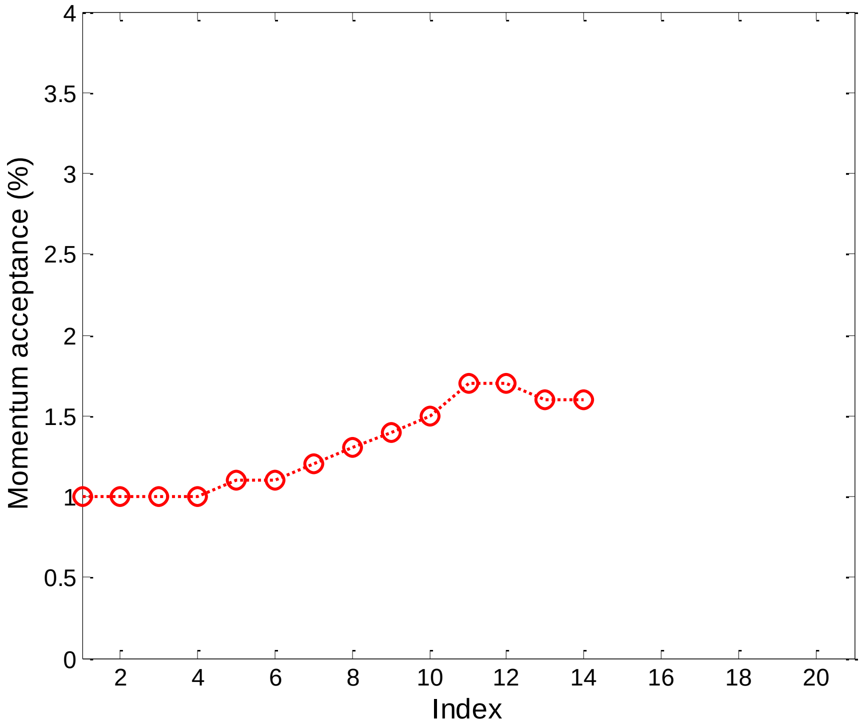


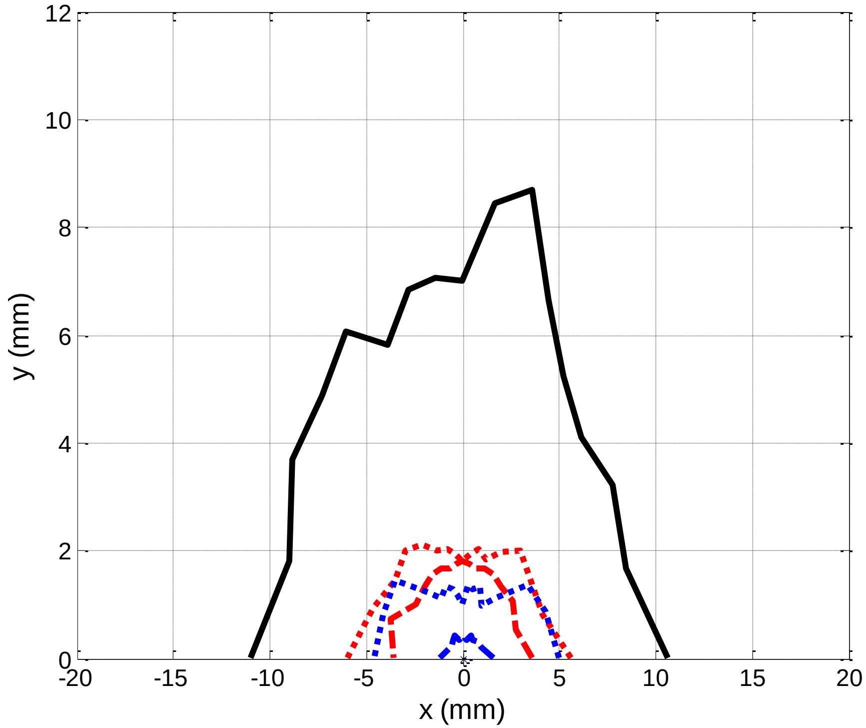


Black solid: 0, red dashed: 1%, red dotted: -1%, blue dashed: 2%, blue dotted: -2%, green dashed: 3%, green dotted: -3%

From Mode 1 to 2, then to 3

* Assume the sext. & oct. strengths are varied averagely from one mode to another, totally 21 steps. No. **14/21**.

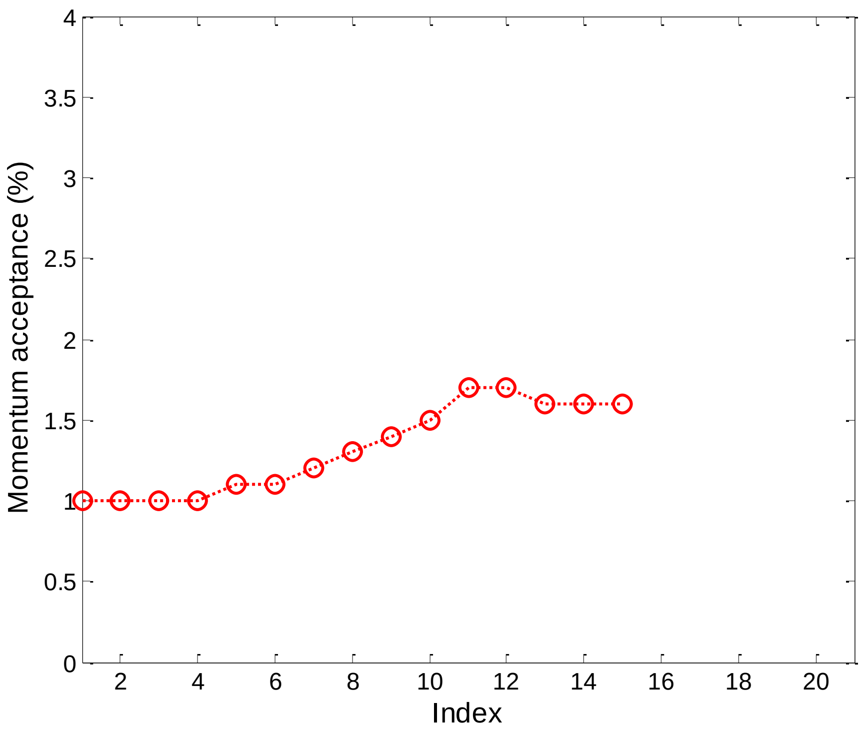


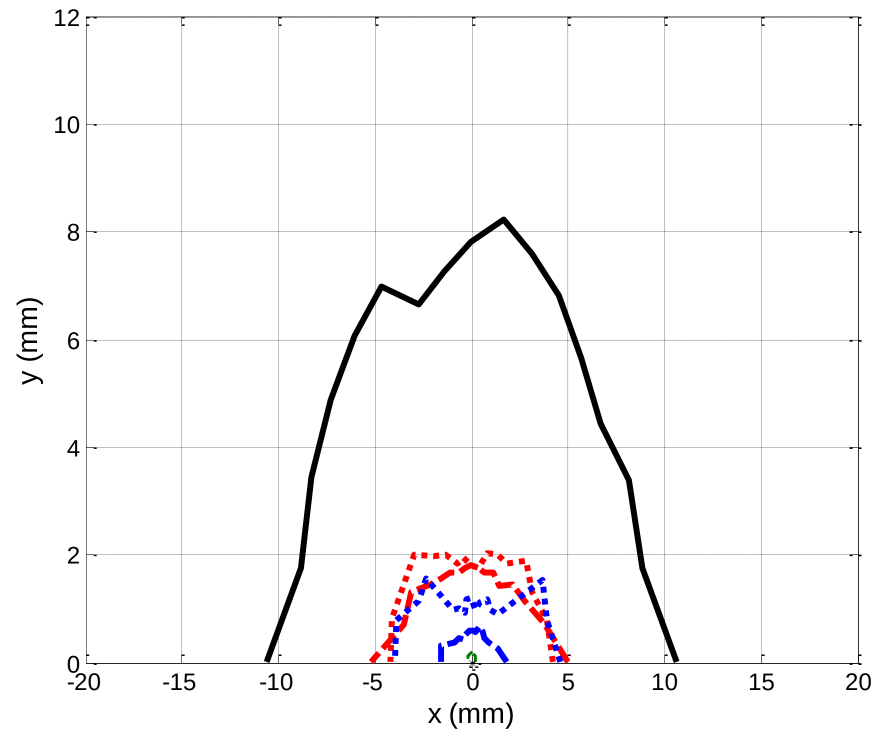


Black solid: 0, red dashed: 1%, red dotted: -1%, blue dashed: 2%, blue dotted: -2%, green dashed: 3%, green dotted: -3%

From Mode 1 to 2, then to 3

* Assume the sext. & oct. strengths are varied averagely from one mode to another, totally 21 steps. No. **15/21**.

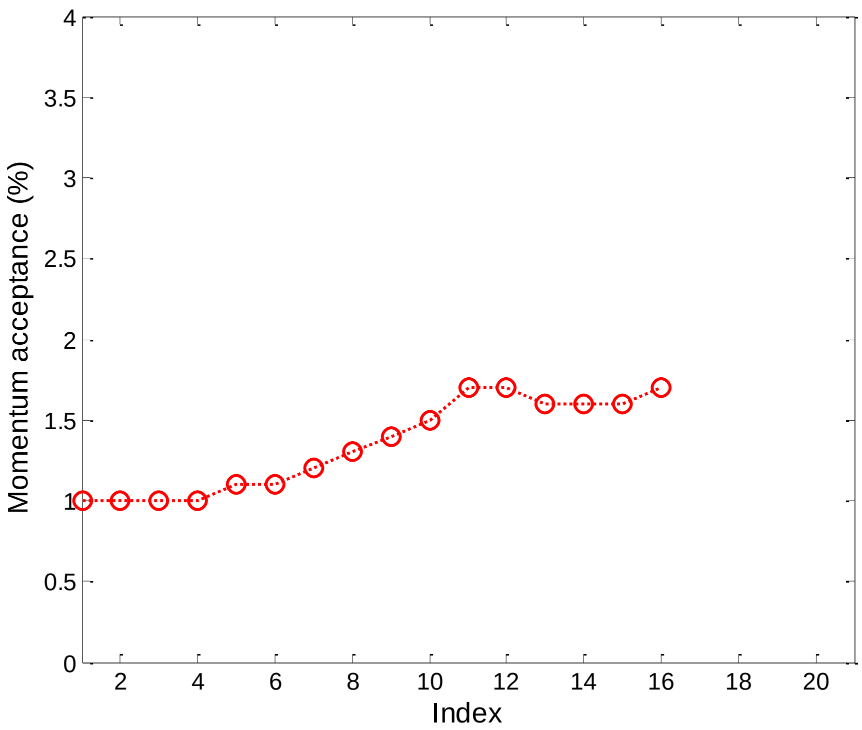


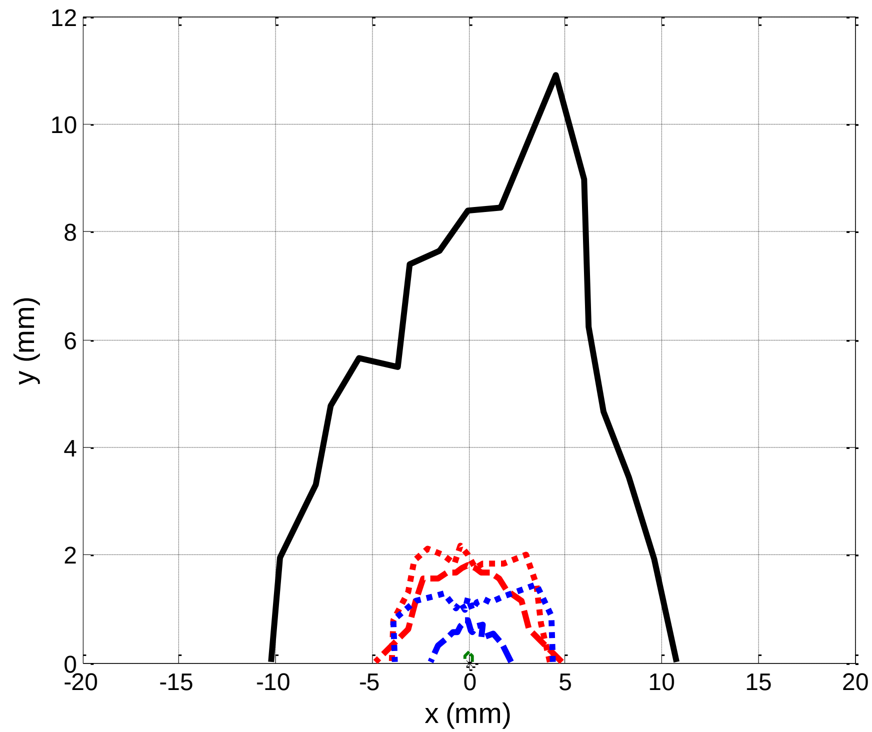


Black solid: 0, red dashed: 1%, red dotted: -1%, blue dashed: 2%, blue dotted: -2%, green dashed: 3%, green dotted: -3%

From Mode 1 to 2, then to 3

* Assume the sext. & oct. strengths are varied averagely from one mode to another, totally 21 steps. No. **16/21**.

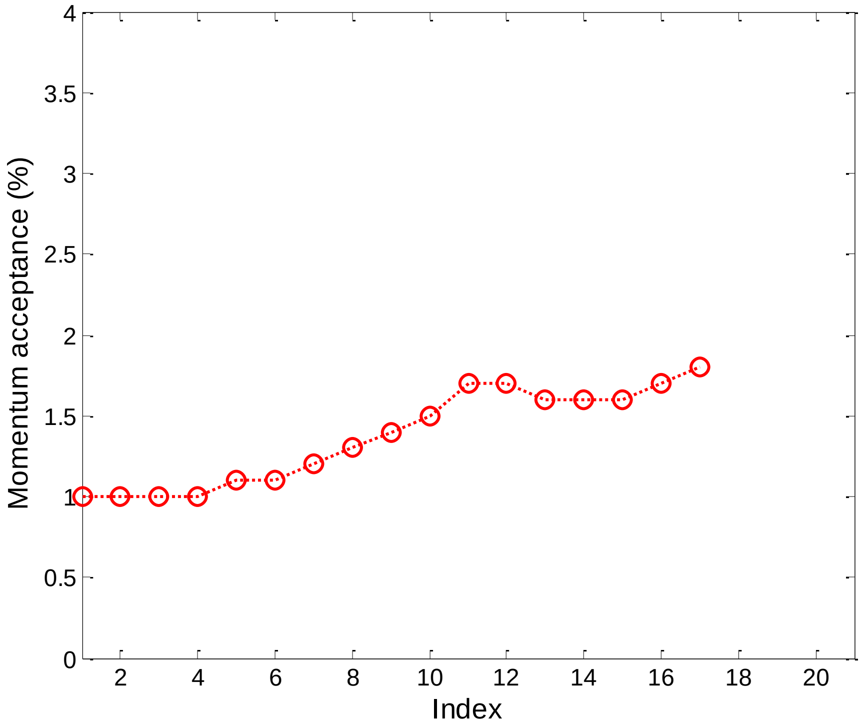


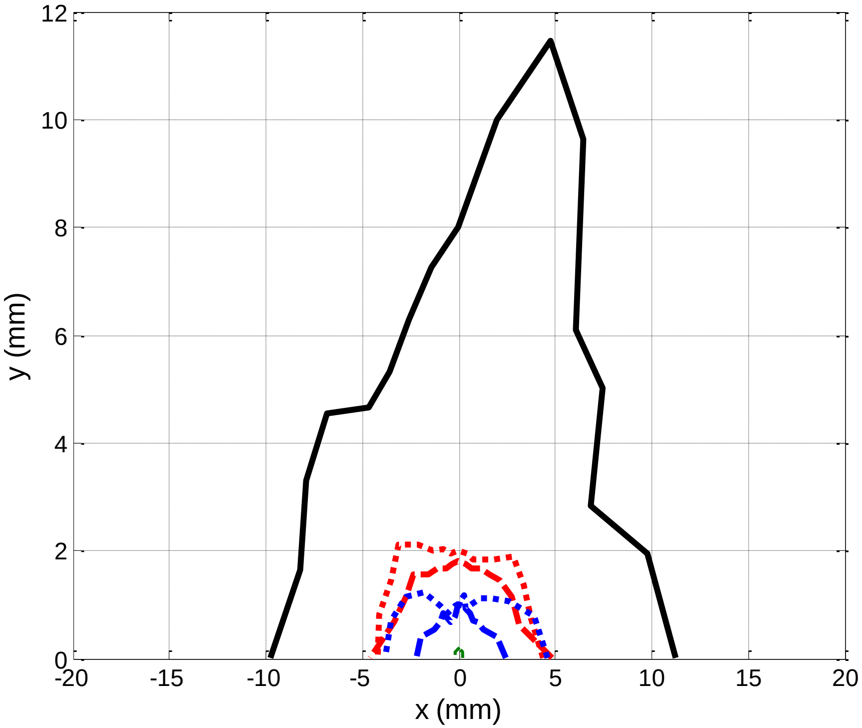


Black solid: 0, red dashed: 1%, red dotted: -1%, blue dashed: 2%, blue dotted: -2%, green dashed: 3%, green dotted: -3%

From Mode 1 to 2, then to 3

* Assume the sext. & oct. strengths are varied averagely from one mode to another, totally 21 steps. No. **17/21**.

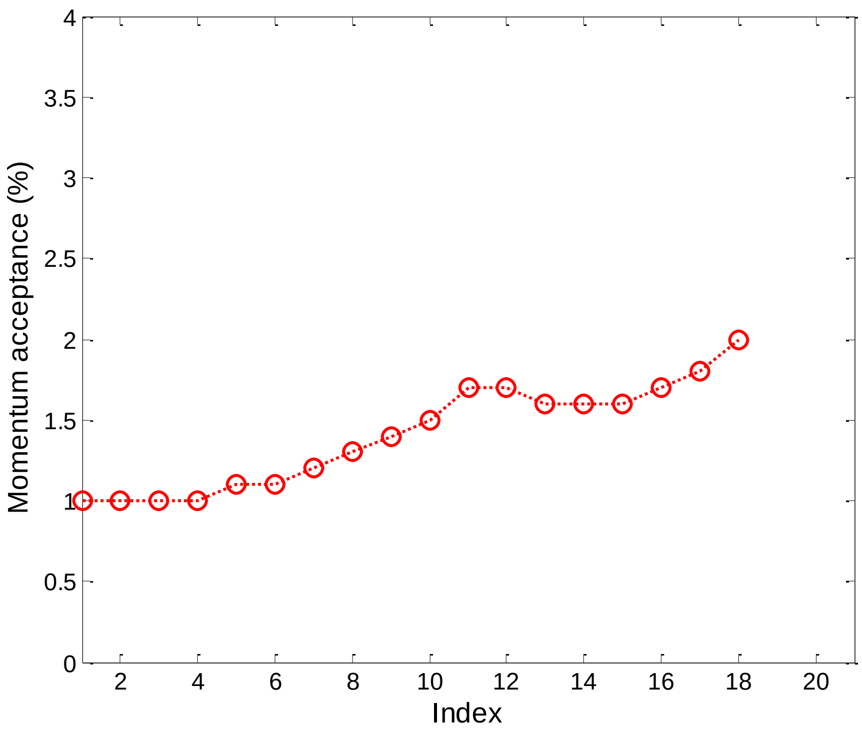


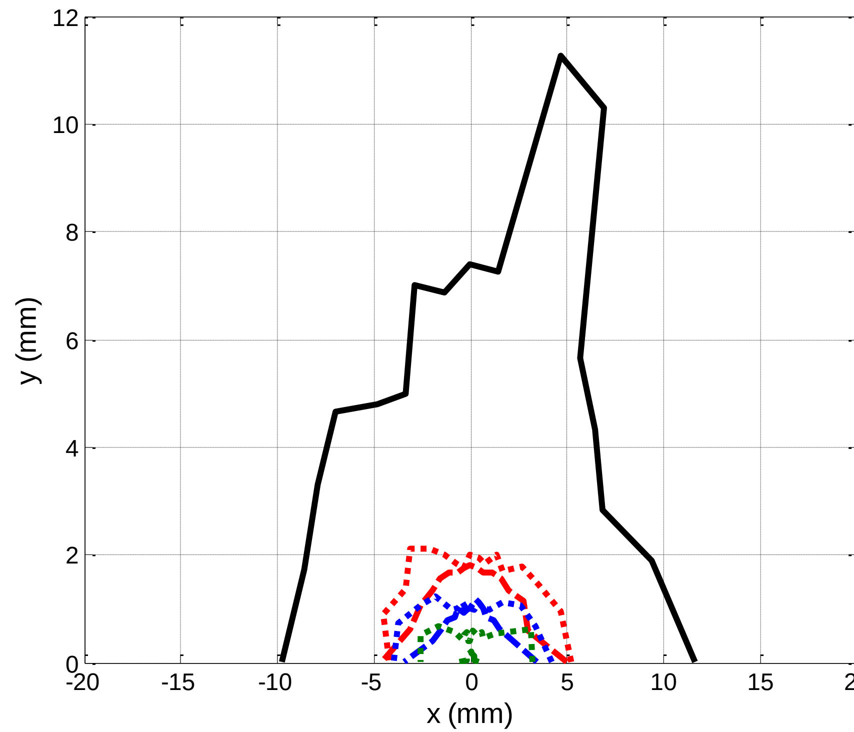


Black solid: 0, red dashed: 1%, red dotted: -1%, blue dashed: 2%, blue dotted: -2%, green dashed: 3%, green dotted: -3%

From Mode 1 to 2, then to 3

* Assume the sext. & oct. strengths are varied averagely from one mode to another, totally 21 steps. No. **18/21**.

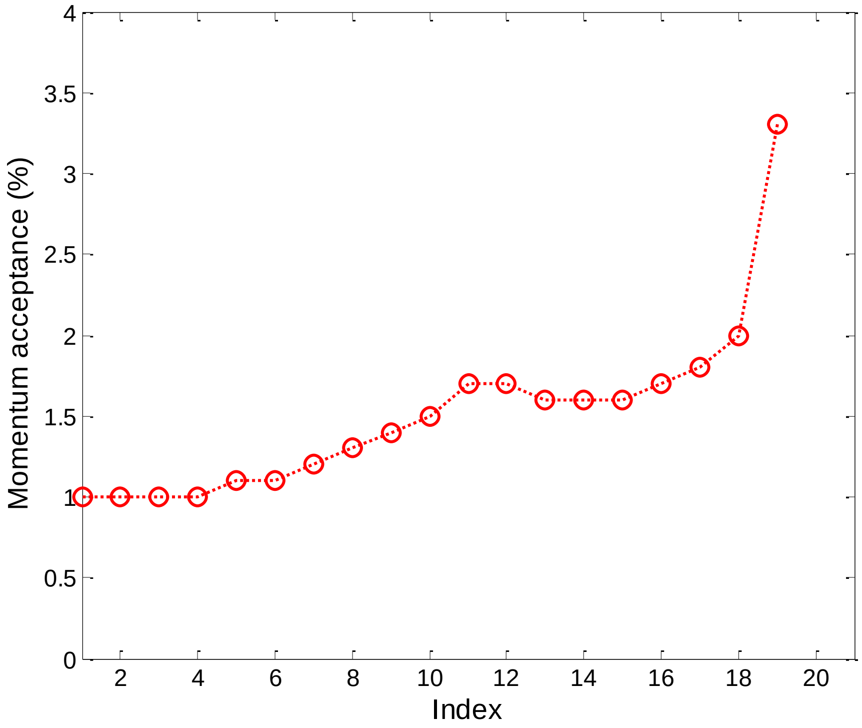


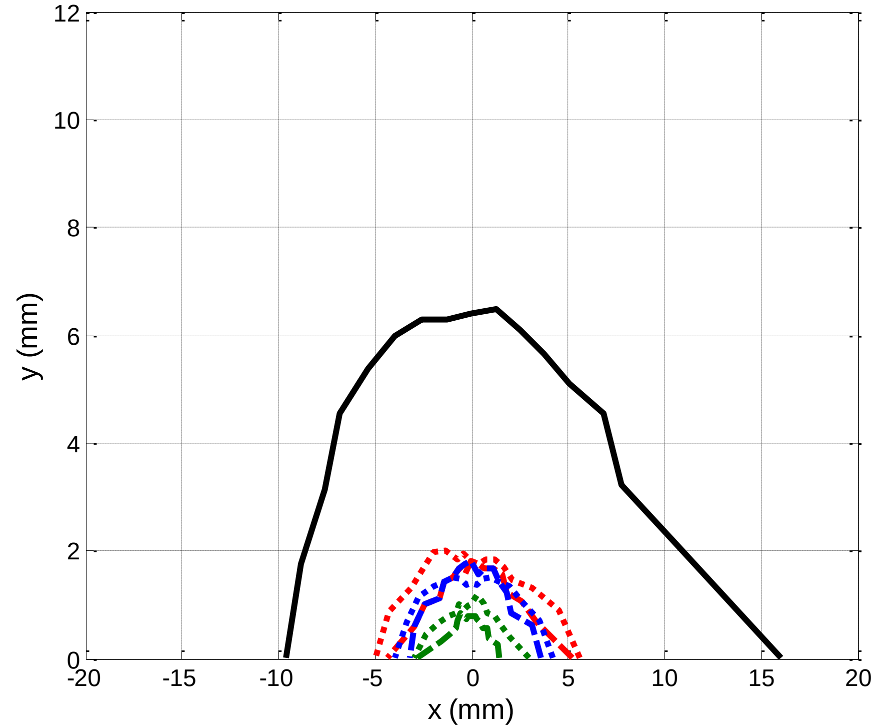


Black solid: 0, red dashed: 1%, red dotted: -1%, blue dashed: 2%, blue dotted: -2%, green dashed: 3%, green dotted: -3%

From Mode 1 to 2, then to 3

* Assume the sext. & oct. strengths are varied averagely from one mode to another, totally 21 steps. No. **19/21**.

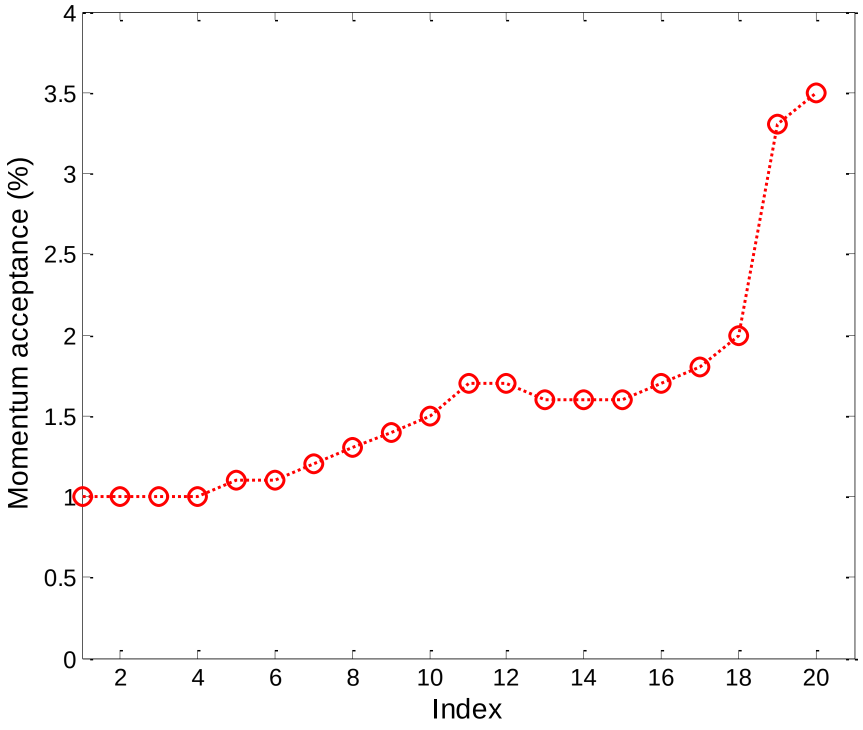


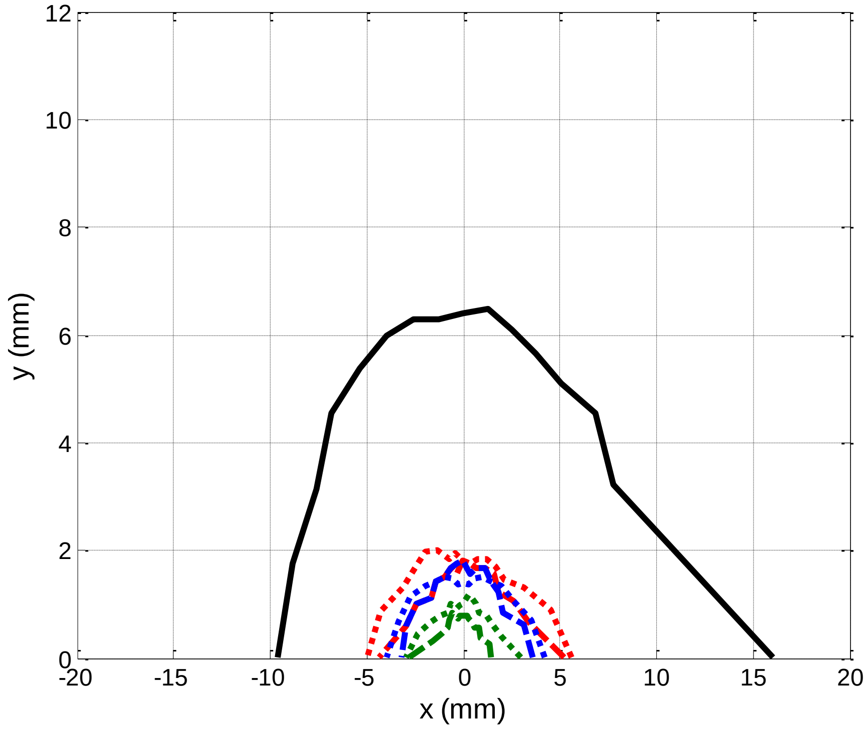


Black solid: 0, red dashed: 1%, red dotted: -1%, blue dashed: 2%, blue dotted: -2%, green dashed: 3%, green dotted: -3%

From Mode 1 to 2, then to 3

* Assume the sext. & oct. strengths are varied averagely from one mode to another, totally 21 steps. No. **20/21**.

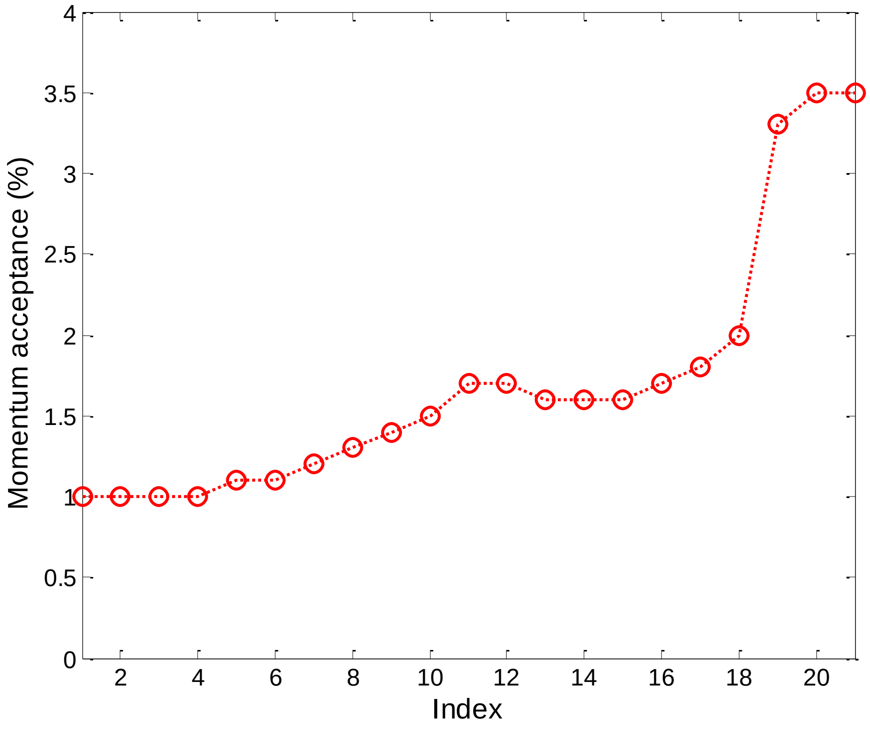


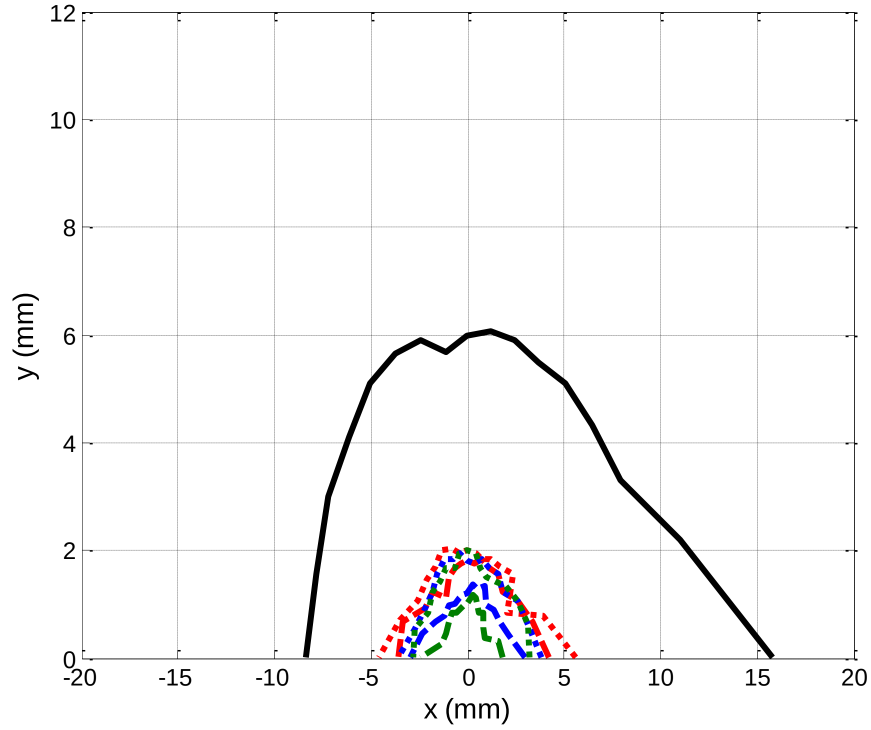


Black solid: 0, red dashed: 1%, red dotted: -1%, blue dashed: 2%, blue dotted: -2%, green dashed: 3%, green dotted: -3%

From Mode 1 to 2, then to 3

* Assume the sext. & oct. strengths are varied averagely from one mode to another, totally 21 steps. No. **21/21**.





Mode 3

Black solid: 0, red dashed: 1%, red dotted: -1%, blue dashed: 2%, blue dotted: -2%, green dashed: 3%, green dotted: -3%

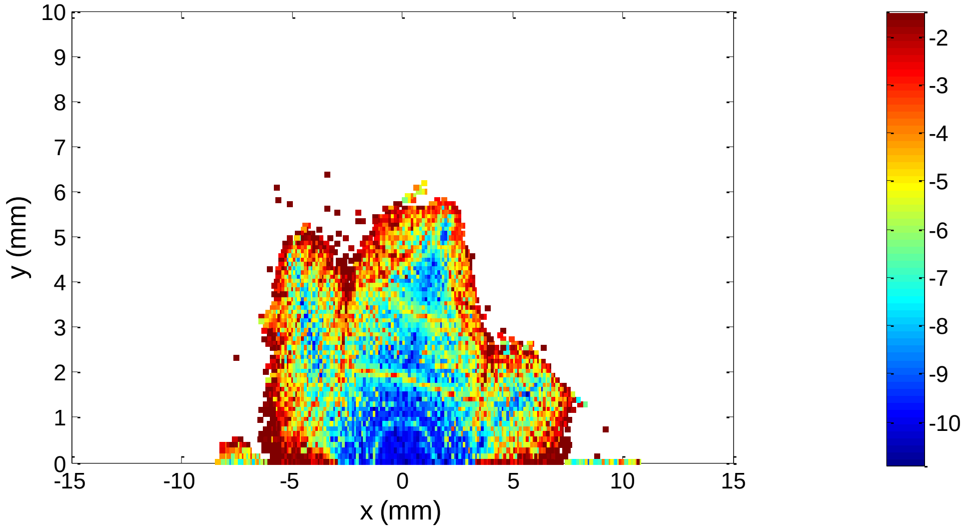
Conclusion

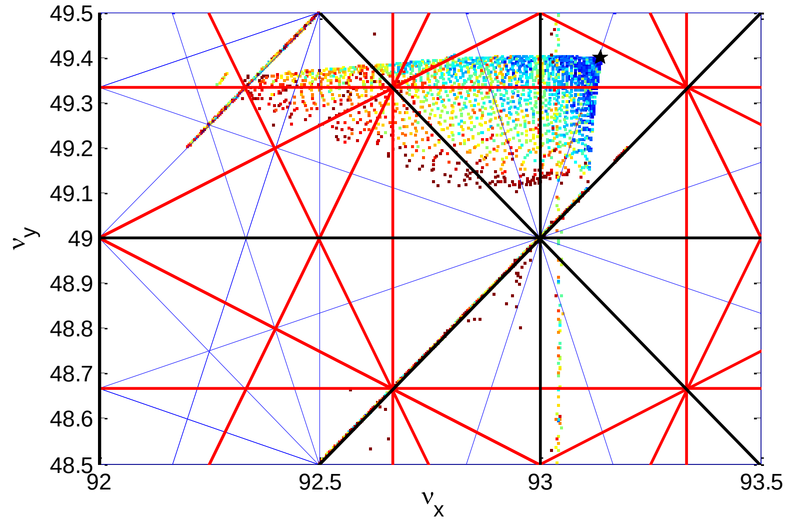
- Linear lattice of 1.3 km BAPS ring, with natural emittance of ~90 pm @ 6 GeV has been designed.
- Due to strong chromatic sextupole strengths and specifically designed injection section, the nonlinear optimization is difficult, and it is barely to well control the detune, chromaticity, and resonance driving terms at the same time.
- A solution is to inject the beam at one mode with large dynamic aperture, and store the beam at another mode with large momentum acceptance.
- Simulation shows that during the transportation from the injection mode to the storage mode, the beam dynamics keeps stable.

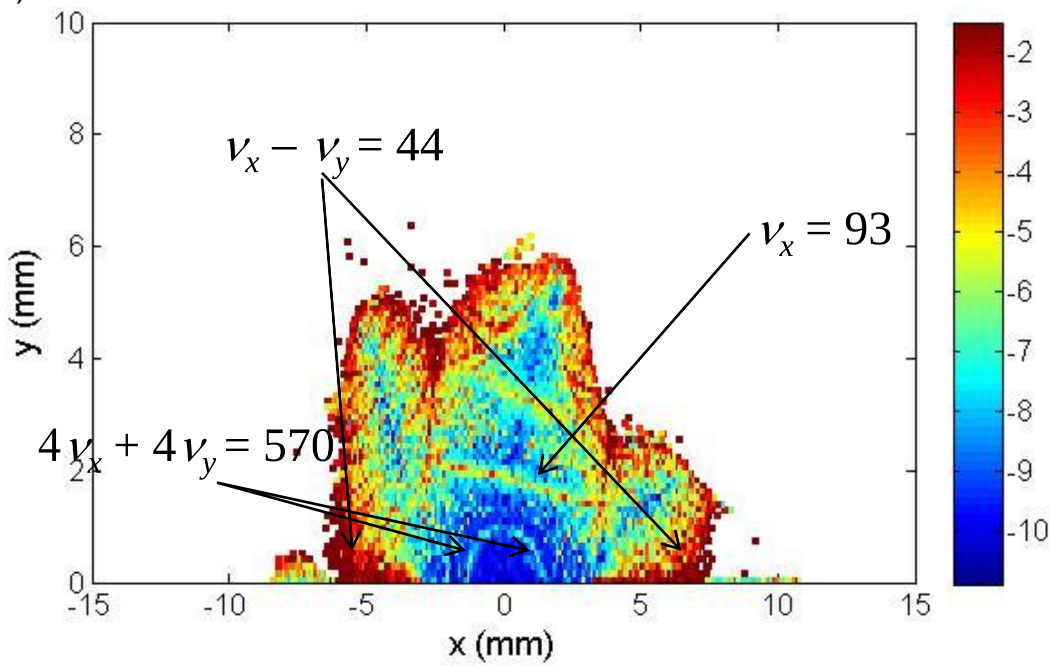
Thanks for your attention!

Backup slides

DA & FM with only two families of sext. & oct.







Detune & chromatic results