Crab Crossing design and Simulations

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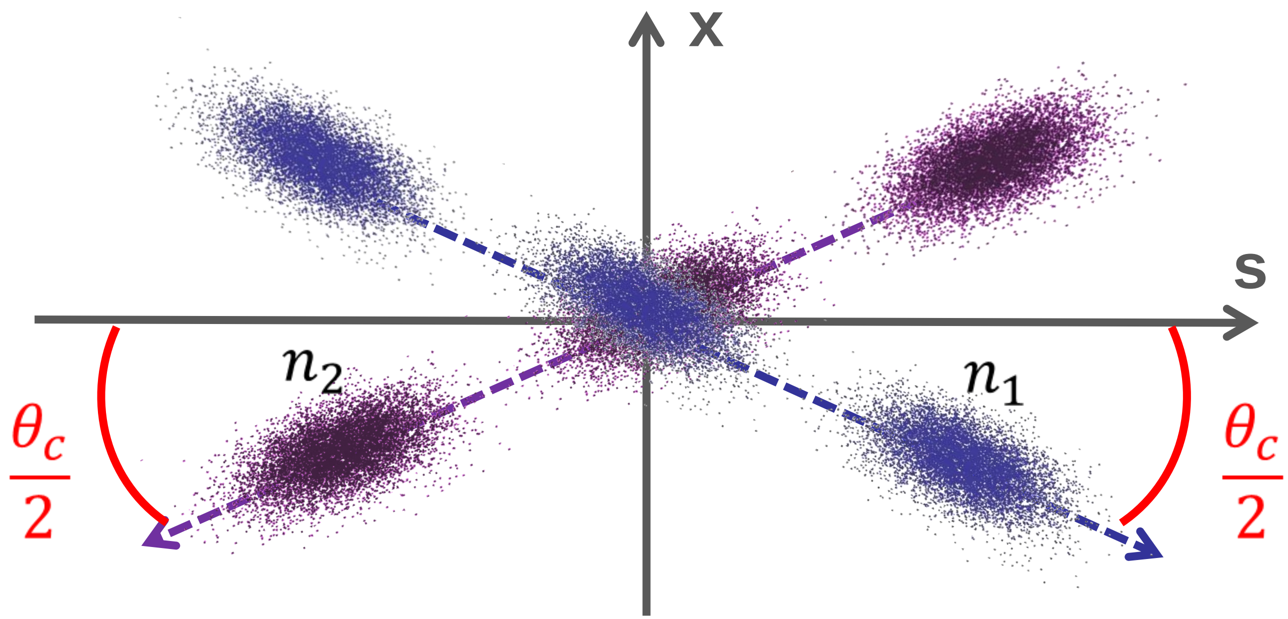
Outline

- Crab Crossing concepts and considerations for JLEIC
- Preliminary self-consistent set of crab crossing parameters
- Crab Crossing simulations
- Future Plans

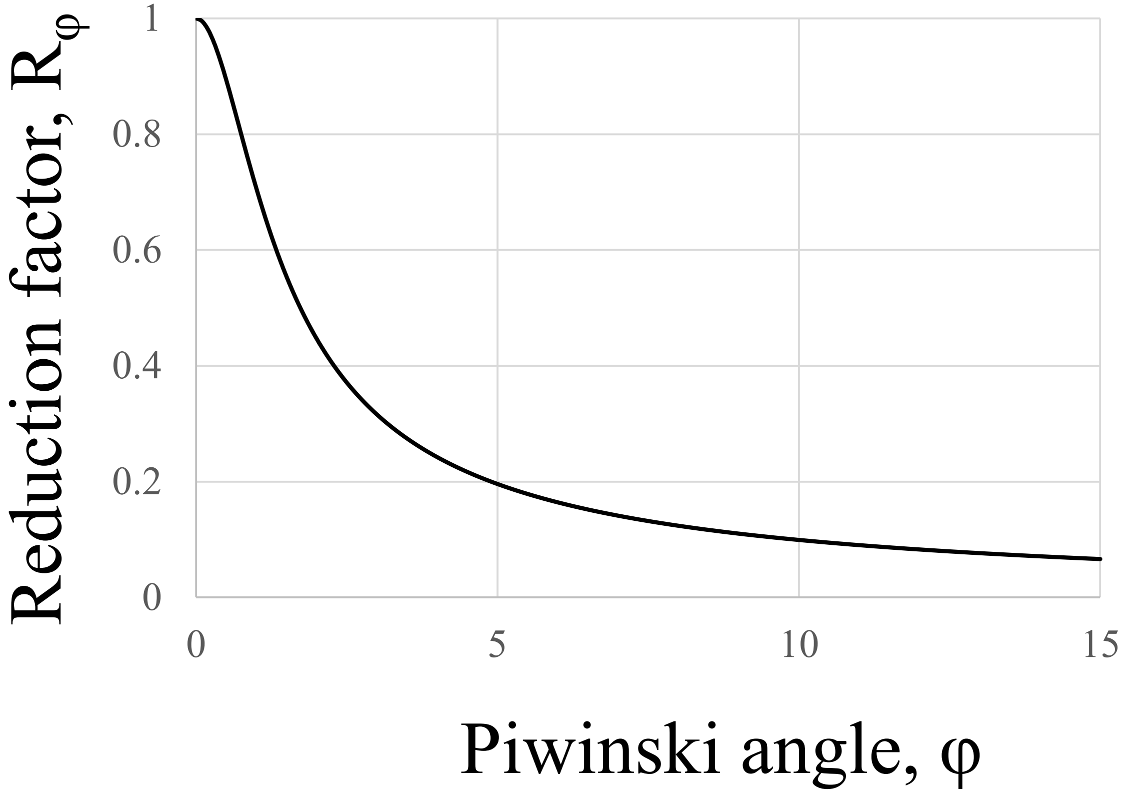
Beam Crossing Angle

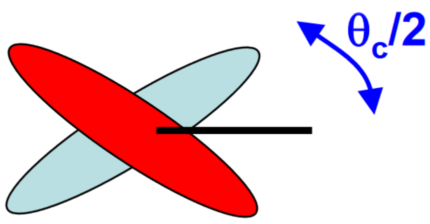
- Reduce parasitic collisions
- Reduce long range beam-beam effects



Luminosity Reduction Factor @ JLEIC

$$R_\phi = \frac{1}{\sqrt{1+\phi^2}}; \quad \phi \equiv \frac{\theta_c \sigma_z}{2\sigma_x}$$ *"Piwinski angle"*





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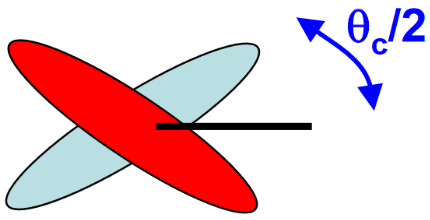


Crossing beam parameters		
θ_c	50	mrad
σ_z	9.08	mm
σ_x	18.04×10^{-3}	mm
φ	**12.5**	**rad**

$$R_\varphi \approx 0.0797$$

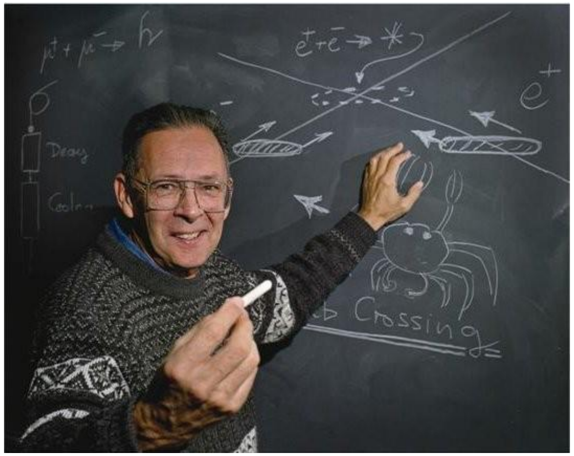
Roughly 8% of Luminosity

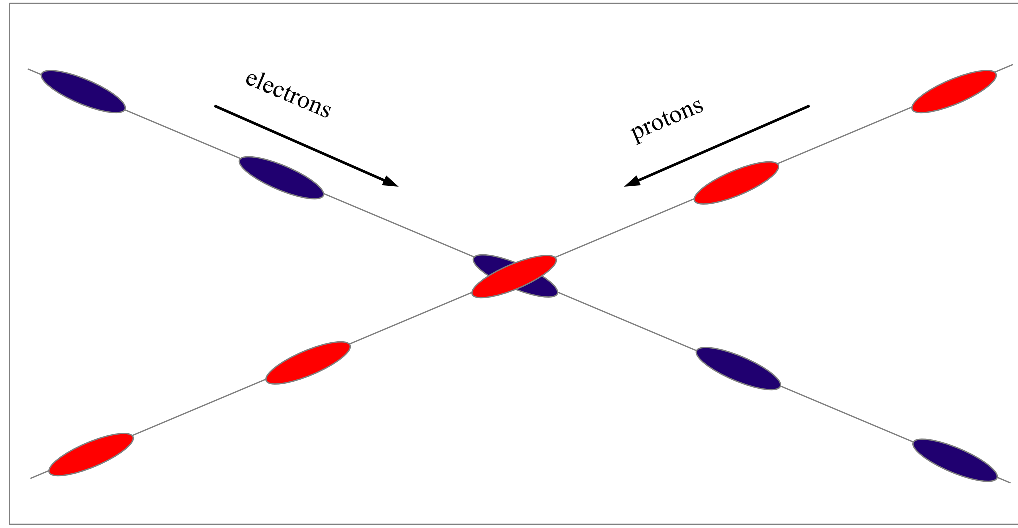
JLEIC Luminosity Approach

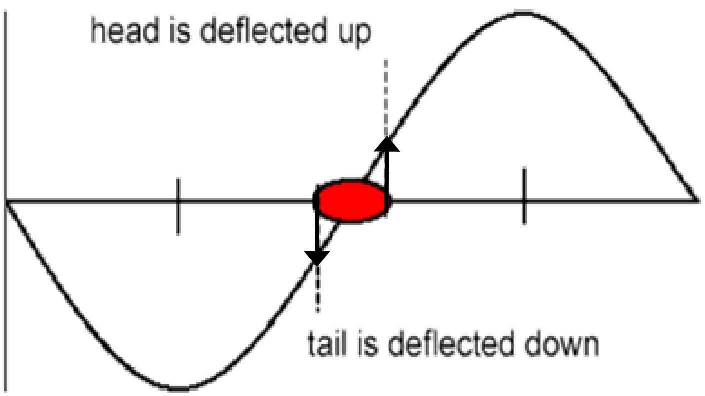
- Short bunches for both ion and electron beams
- Small transverse emittance
- Ultrahigh collision frequency
- Staged electron cooling
- Small final focusing β^*
- Large beam-beam tune shift
- **Crab crossing of colliding beam**s

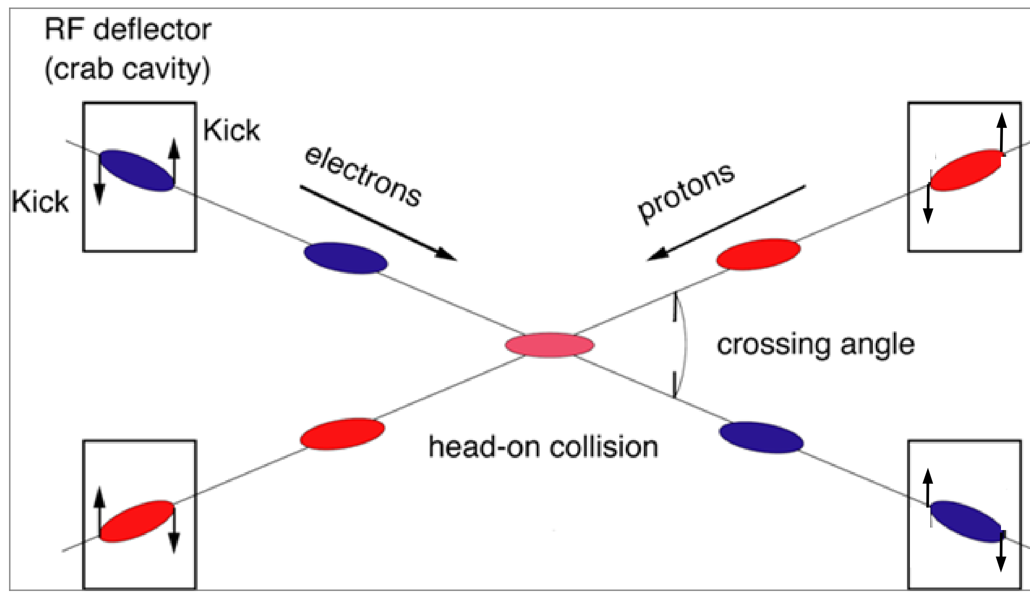
$$\mathscr{L} = \frac{N_1 N_2 f n_b}{4\pi\varepsilon\sqrt{\beta_x^*\beta_y^*}} \cdot \frac{1}{\sqrt{1+\left(\frac{\sigma_z}{\sigma_x}\tan\frac{\theta_{cross}}{2}\right)}}$$

The Crabbing Concept









*R. Palmer, SLAC-PUB-4707 (1988).

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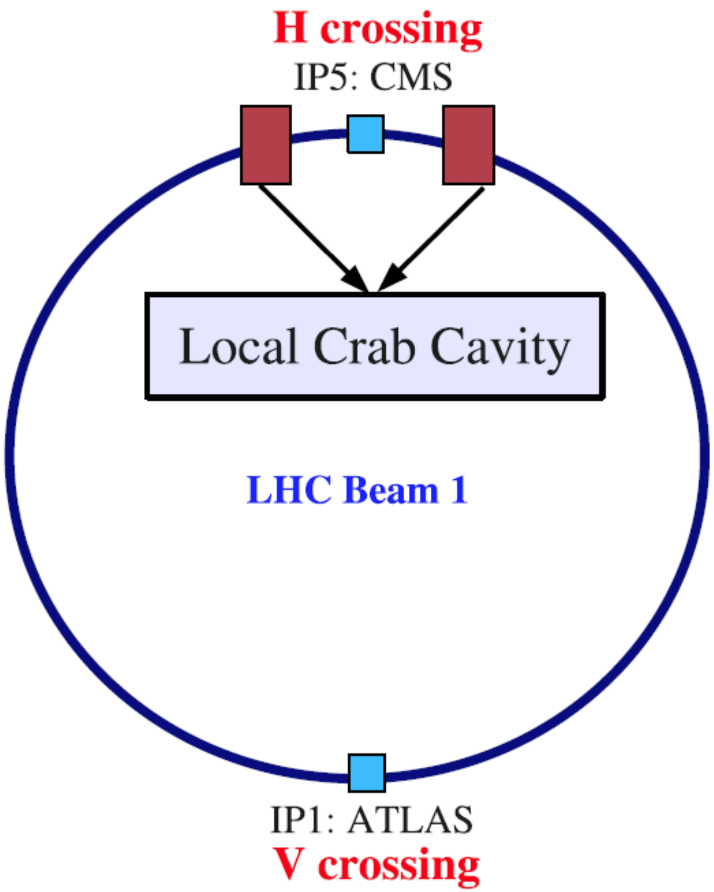
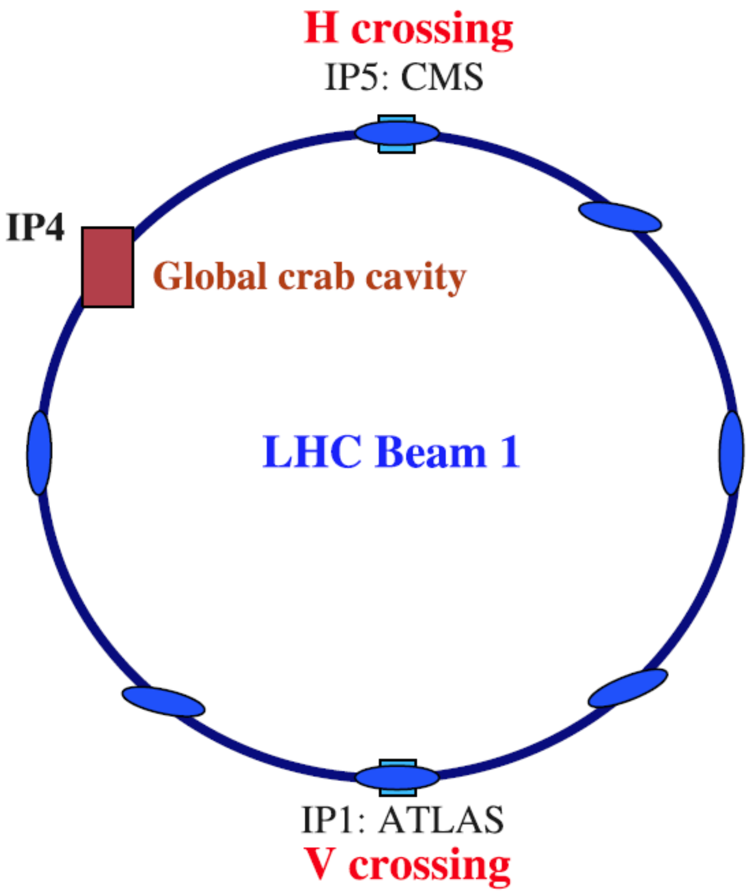
Crabbing Schemes: Local & Global





Y.-P. Sun et. Al, Phys. Rev. ST. Accel. Beams, 12, 101002

- Local crabbing:
- $(2n+1)\pi/2$ phase advance between crab cavities

Crabbing by deflecting cavity

- Use of a transverse electric field to impart a "kick" on the bunch

$$V_{da} = \frac{cE_b \tan\frac{\varphi_{cross}}{2}}{e2\pi f\sqrt{\beta_{crab}\beta^*}}$$

E_b = beam energy

f = RF frequency

β_{crab} = beta function at CC location

β^* = beta function at IP

φ_{cross} = beam crossing angle

S. Ahmed, et al. in Proceedings of IPAC2011, WEPC047

Crabbing by dispersive cavity

- Convetional accelerating/bunching cavity located in a region of dispersion D(s)

$$V_a = \frac{cE_b\varphi_{crab}}{e2\pi f\sqrt{\beta_{crab}\beta^*}D'}$$

E_b = beam energy

f = RF frequency

β_{crab} = beta function at CC location

β^* = beta function at IP

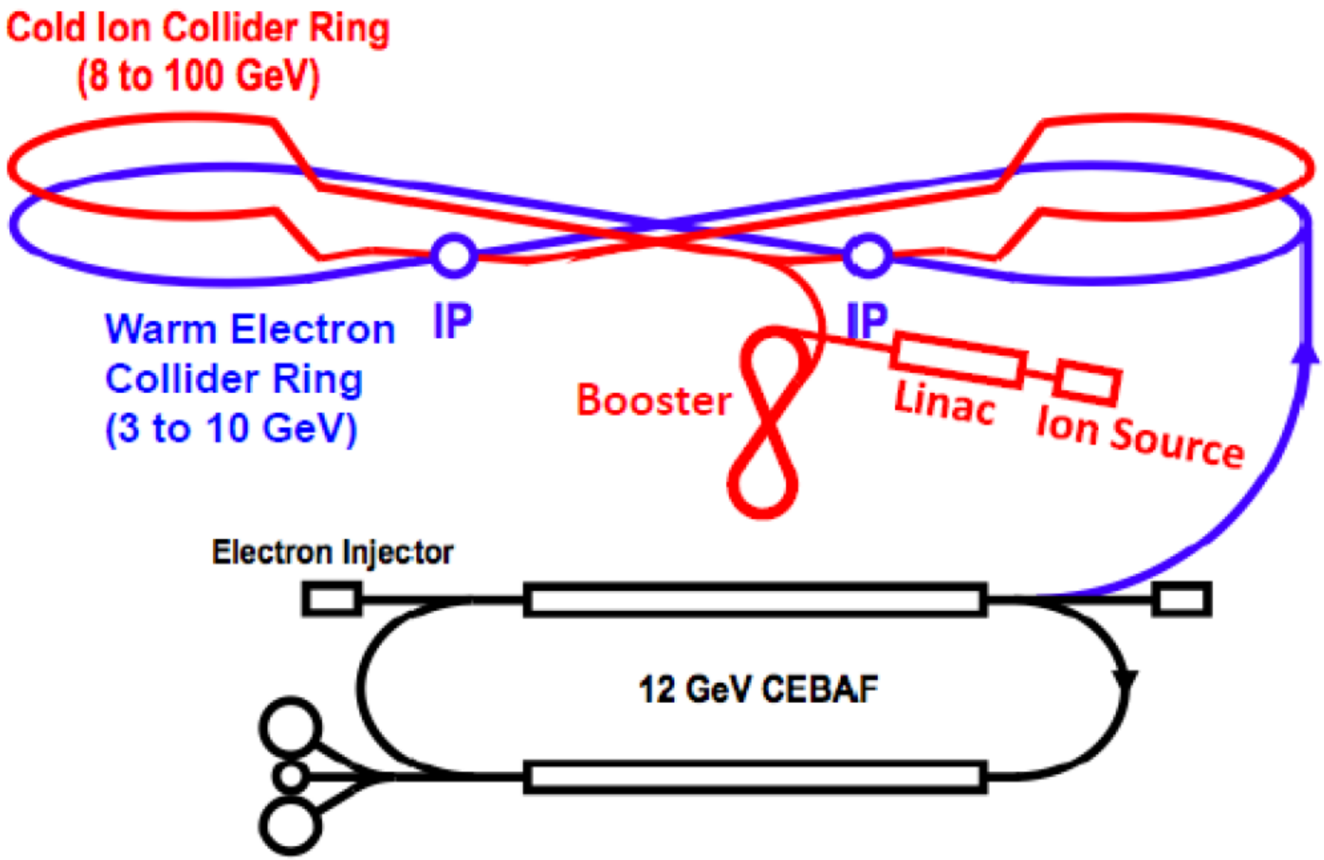
φ_{crab} = crab angle

D' ≤ 0.3 (from ion ring lattice simulation)

Dispersive crab voltage larger than deflecting crab voltage.

S. Ahmed, et al. in Proceedings of IPAC2011, WEPC047

JLEIC layout

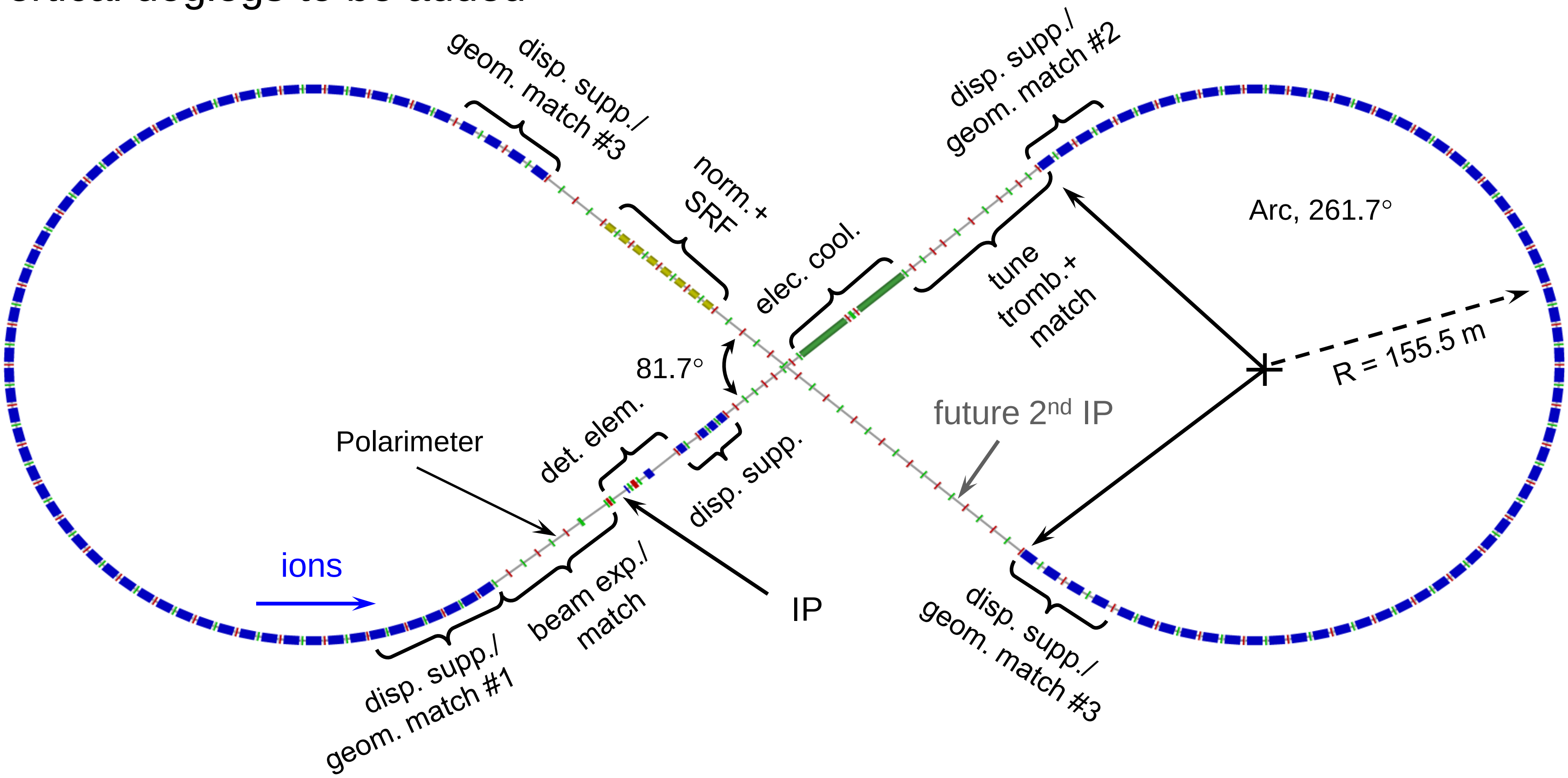


C.M. energy - $\sqrt{s} = 15 - 65$ GeV

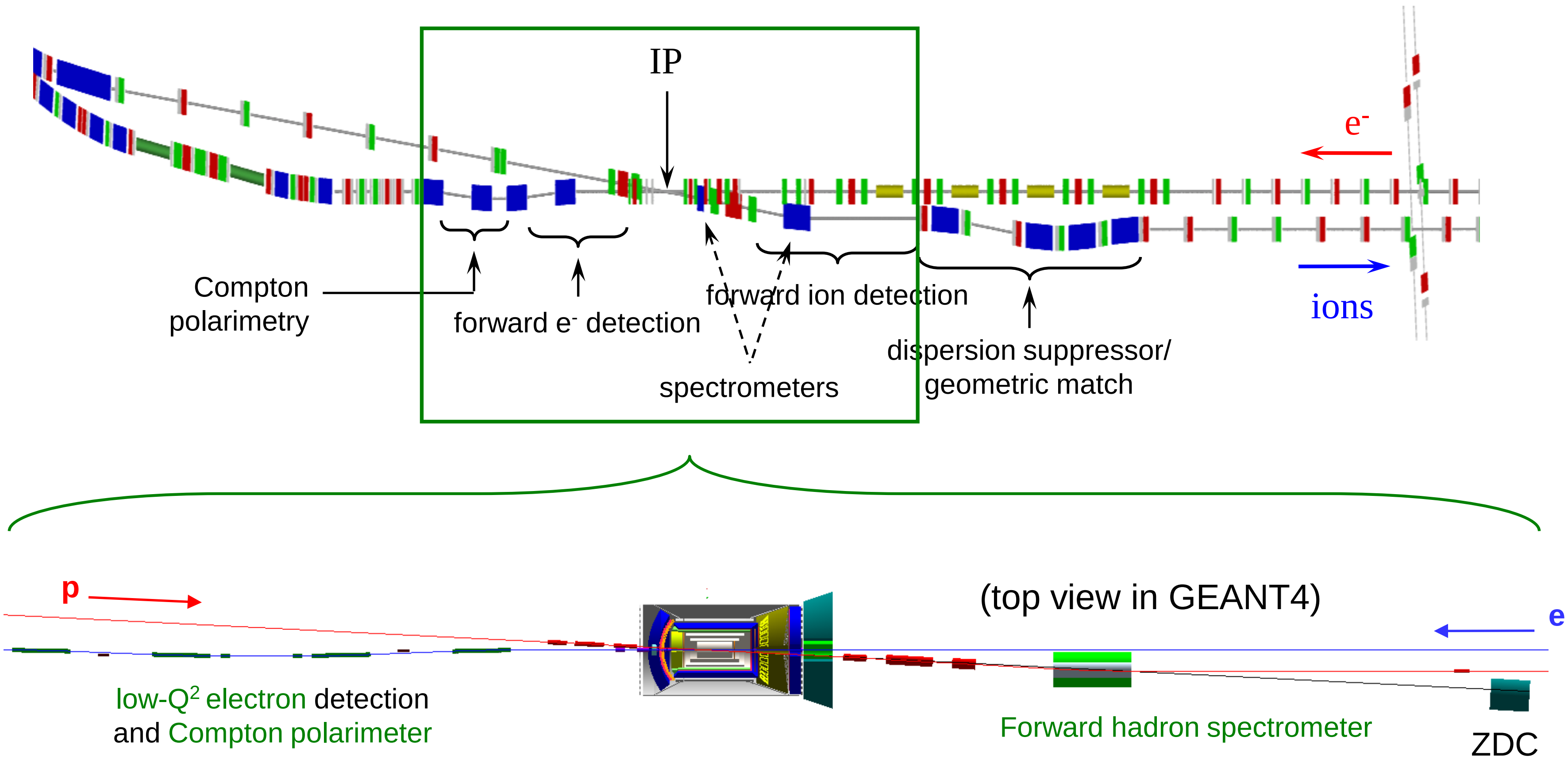
$L \approx 10^{33}\ cm^{-2}s^{-1}$, optimized around 45-50 GeV

Ion Collider Ring

- Figure-8 ring with a circumference of 2153.9 m
- Two 261.7° arcs connected by two straights crossing at 81.7°
- Vertical doglegs to be added

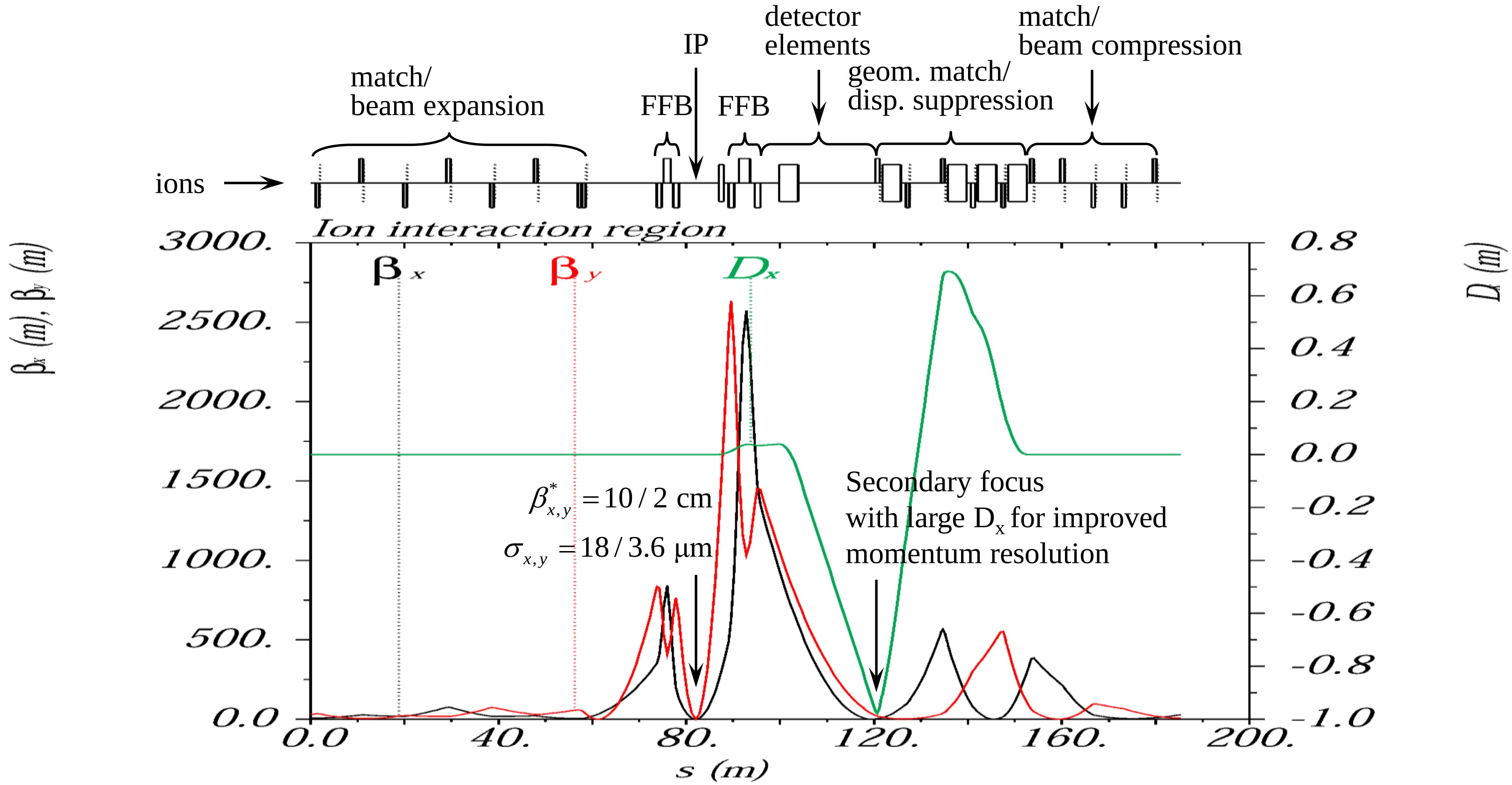


Detector Region Layout

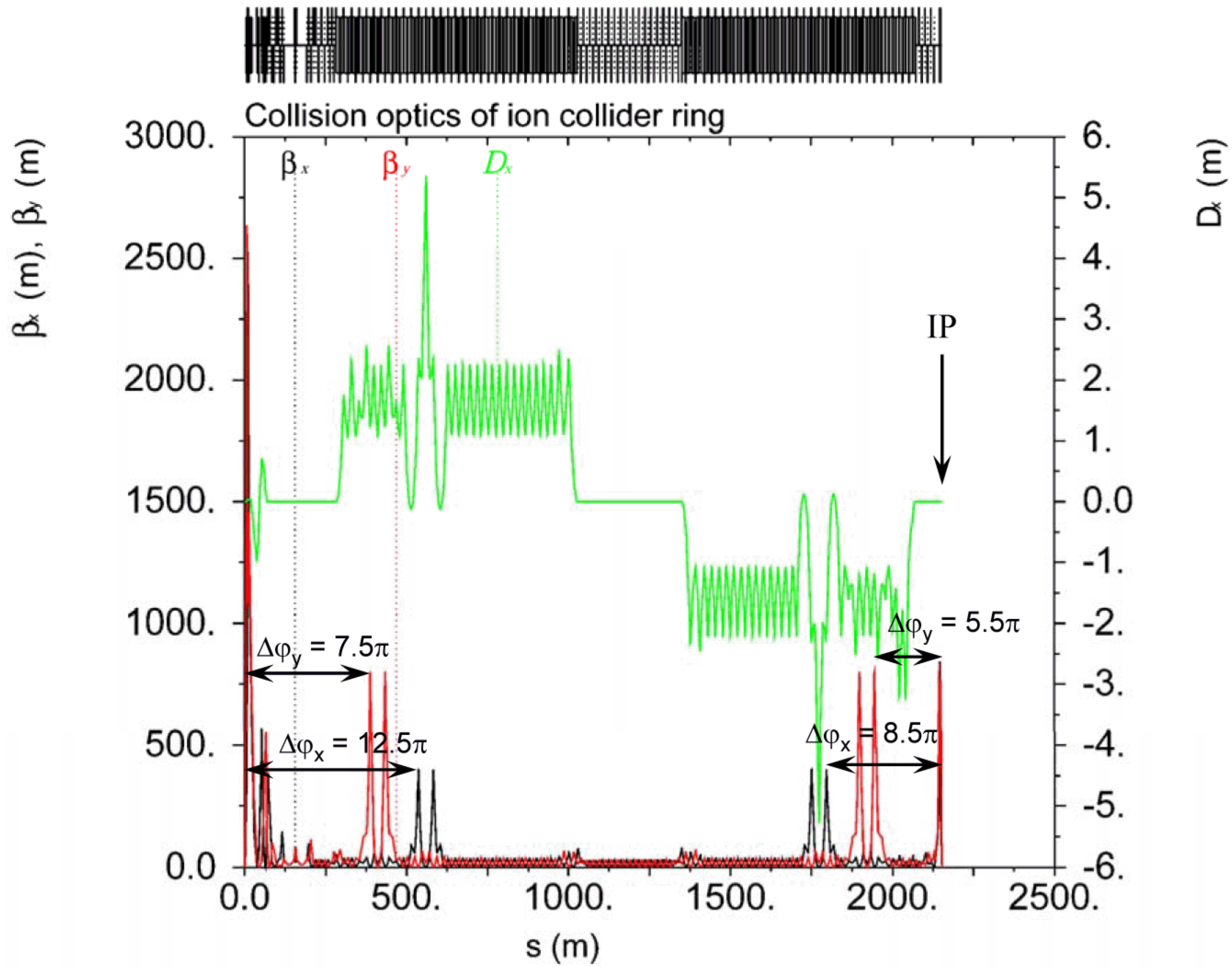


Baseline Ion IR Optics

- IR design features
  - Modular design
  - Based on triplet Final Focusing Blocks (FFB)
  - Asymmetric design to satisfy detector requirements and reduce chromaticity
  - Spectrometer dipoles before and after downstream FFB, second focus downstream of IP
  - No dispersion at IP, achromatic optics downstream of IP



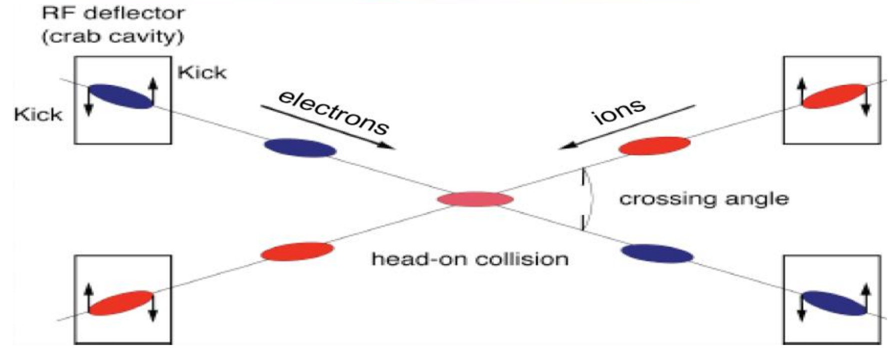
Collision optics of JLEIC ion collider ring

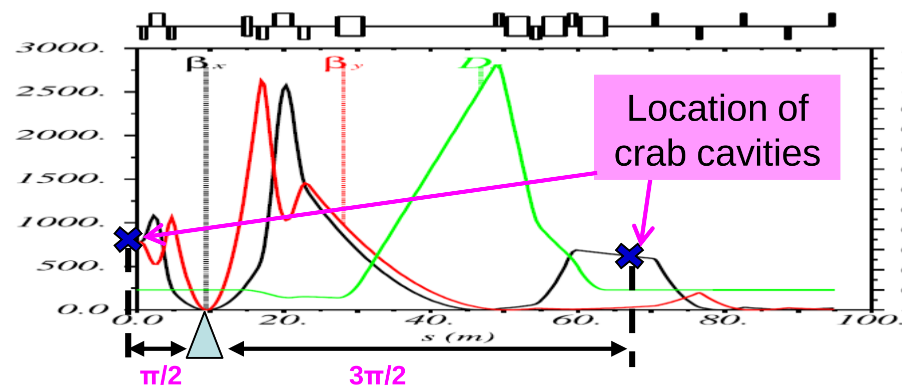


β_x peaks from CCB sextupoles adequate for crab cavity locations.

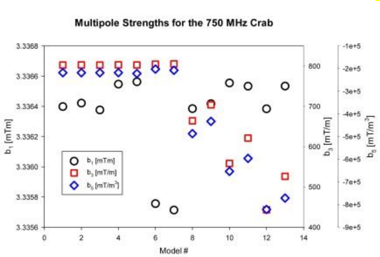
Crab Crossing at JLEIC

- Effective head-on bunch collisions restored with 50 mrad crossing angle
- Local crab scheme
- Two cavities are placed at $(2n+1)\pi/2$ phase advance relative to IP
- Optimal β_x at locations of crab cavities for minimizing the required kicking voltage
- Deflective crabbing using transverse electric field of SRF cavities (as at KEK-B)
  - Design and analysis completed
  - Prototype fabricated and characterized
  - Final testing with promising results

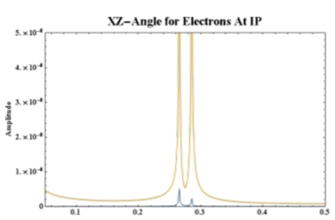


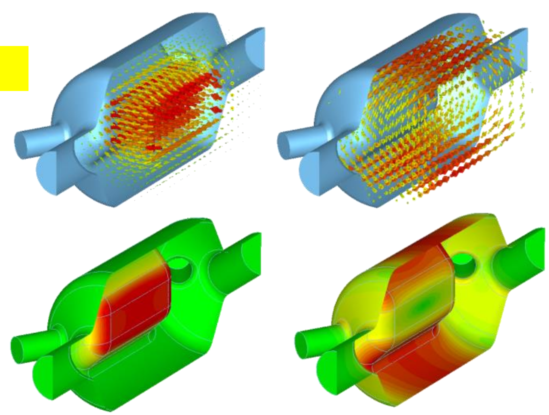


Multipole Tailoring



Beam Dynamics Studies





Crab crossing Design Parameters

Parameter	Unit	Electron	Proton
Energy	**GeV**	**10**	**100**
Frequency	**MHz**	**952.6**	
Crossing angle	**mrad**	**50**	
β^*	**cm**	**10**	
β_x @ crab cavity location	**m**	**200**	**400**
Integrated kicking voltage	**MV**	**2.8**	**19.81**

Deflecting voltage:

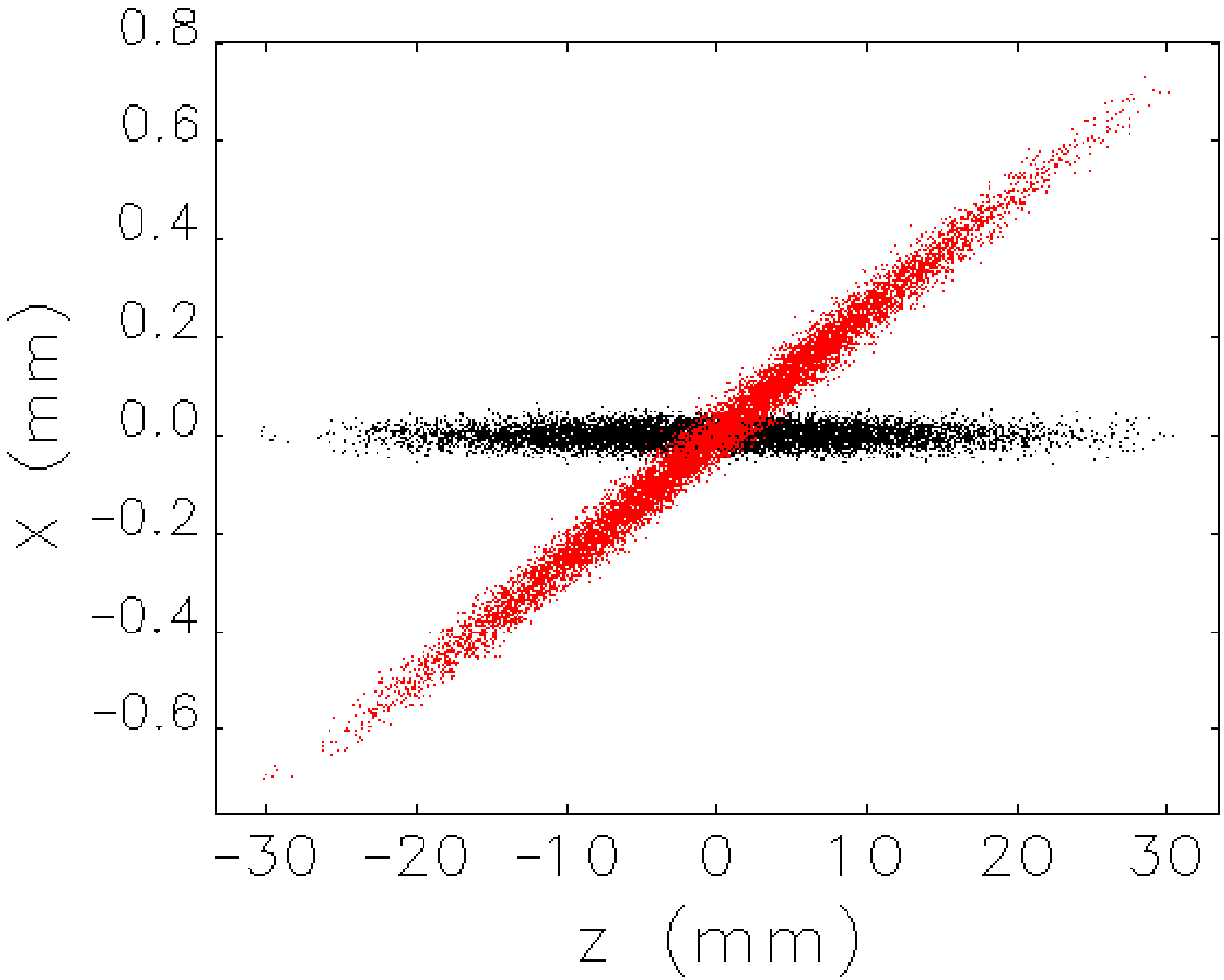
$$V_{da} = \frac{cE_b \tan\frac{\varphi_{cross}}{2}}{e2\pi f\sqrt{\beta_{crab}\beta^*}}$$

S. Abeyratne et al, MEIC Design Summary, 2015

Bunch at IP with and w/o crabbing

Bunched Beam parameters	
N particles	10,000
ε_{nx}	0.35 µm
dp/p	$3e^{-4}$
σ_s	1 cm
Gaussian distribution 3 - sigma	

Crab angle ≈ 25 mrad

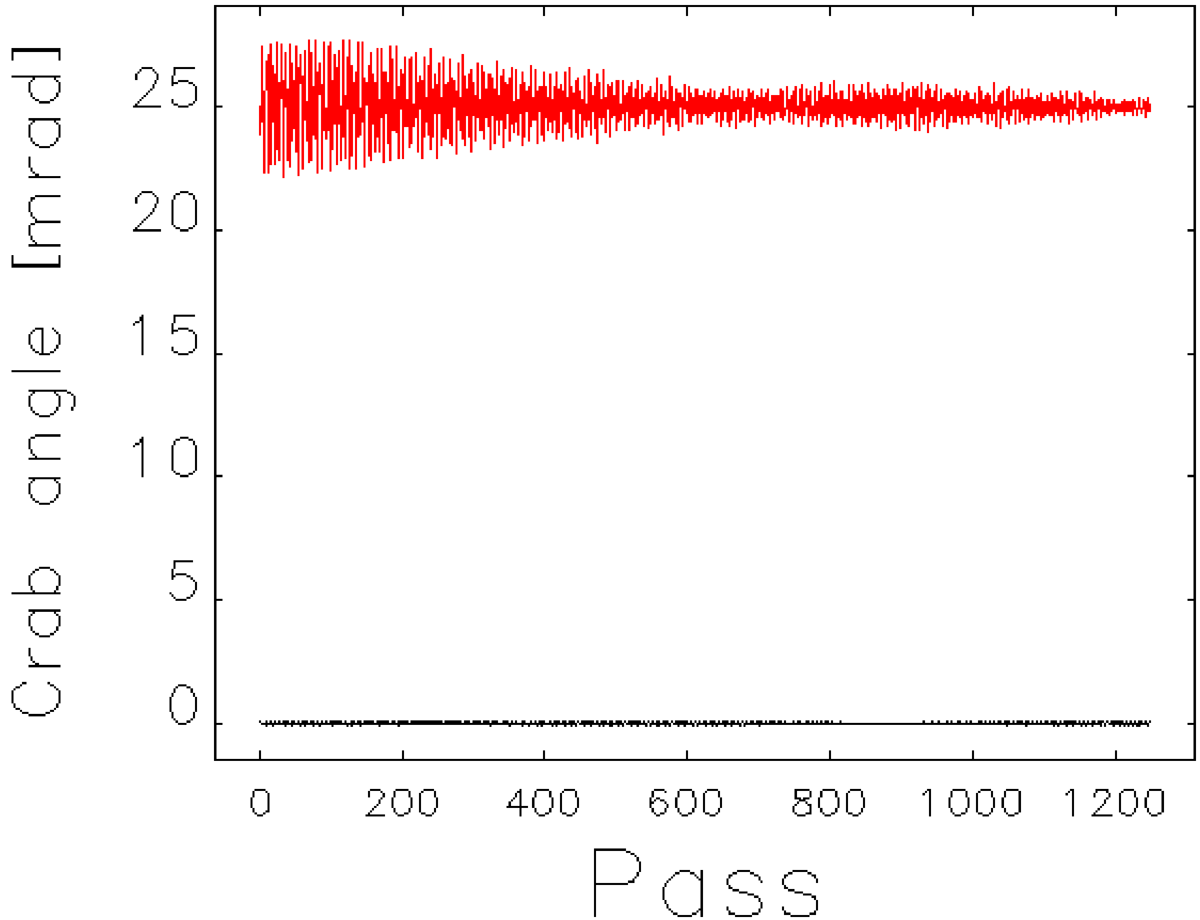


Crab stability with time

- Calculated as

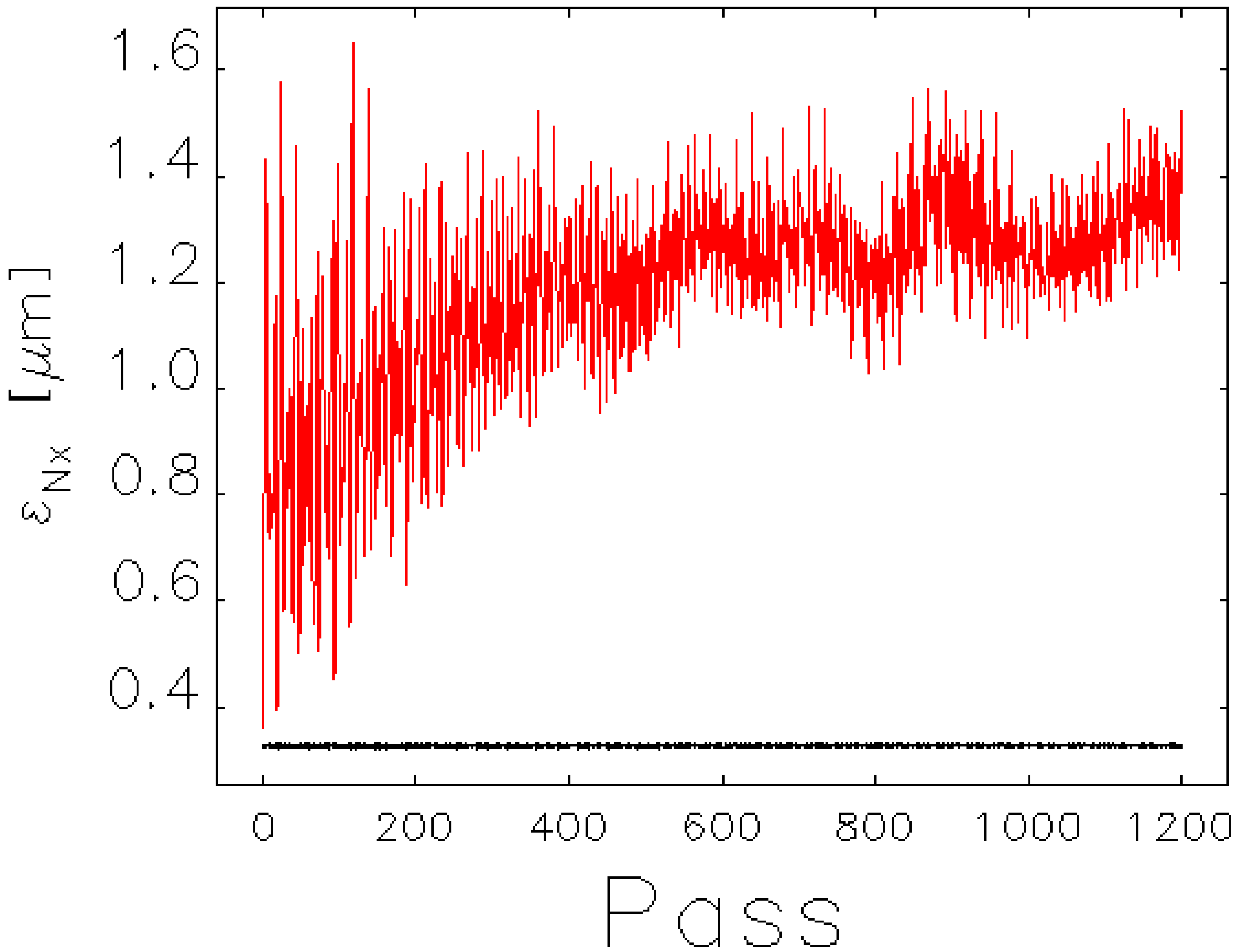
$$\varphi_{crab} = \frac{\langle xz \rangle}{\langle zz \rangle}$$

- $x = x_{rc} + z \tan \varphi$

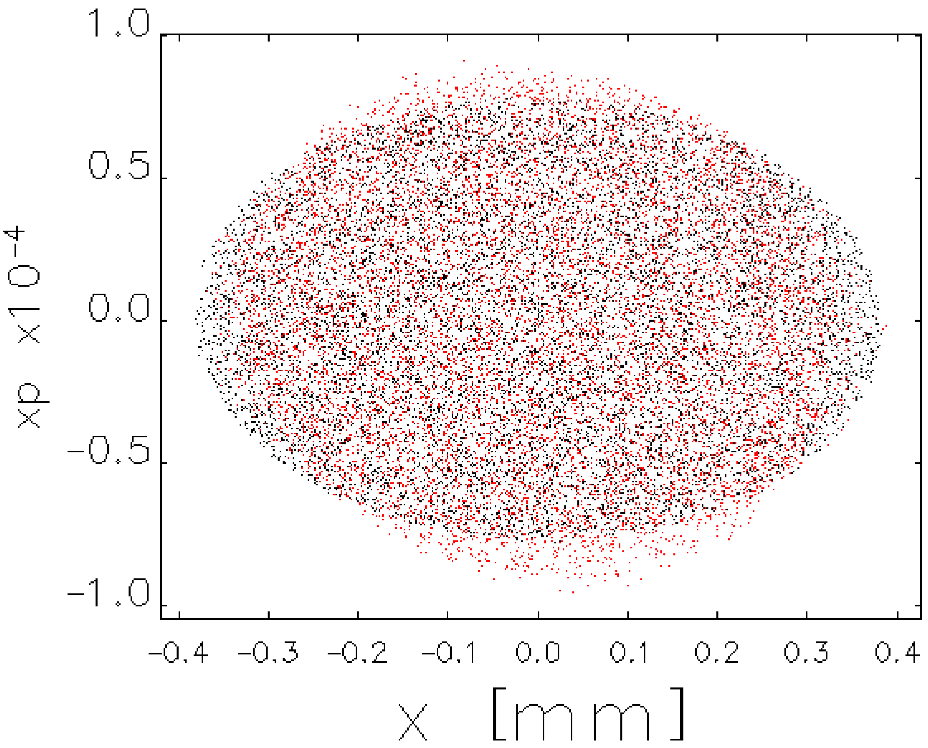


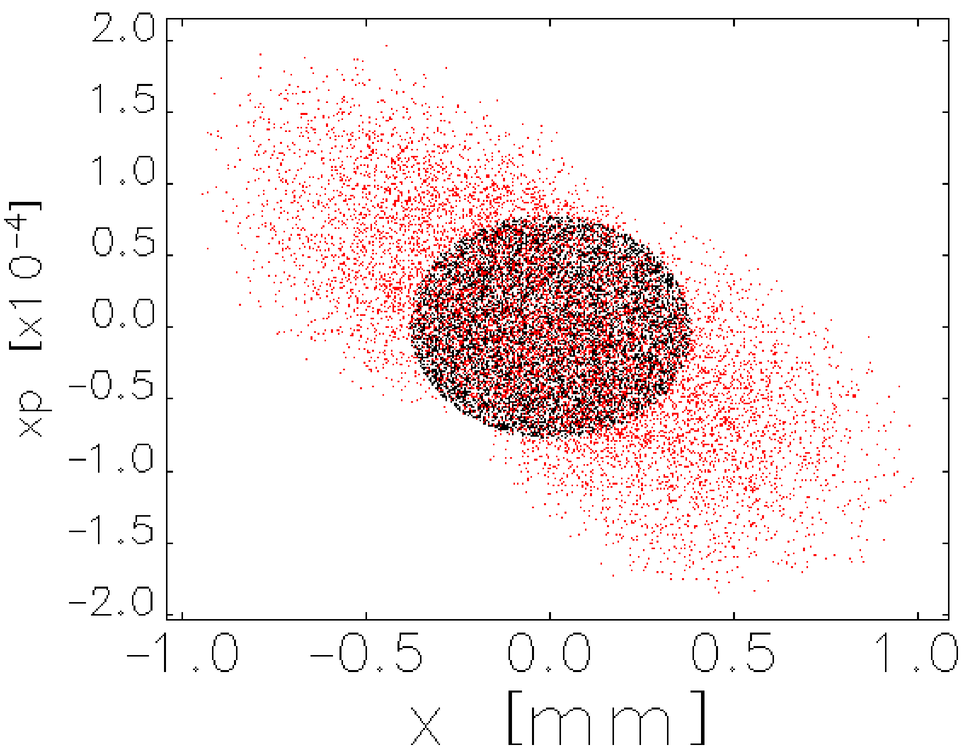
Crab angle jitter suppression, required for beam stability and minimum emittance impact.

Emittance growth with crabbing



Bunch matching in ion ring lattice

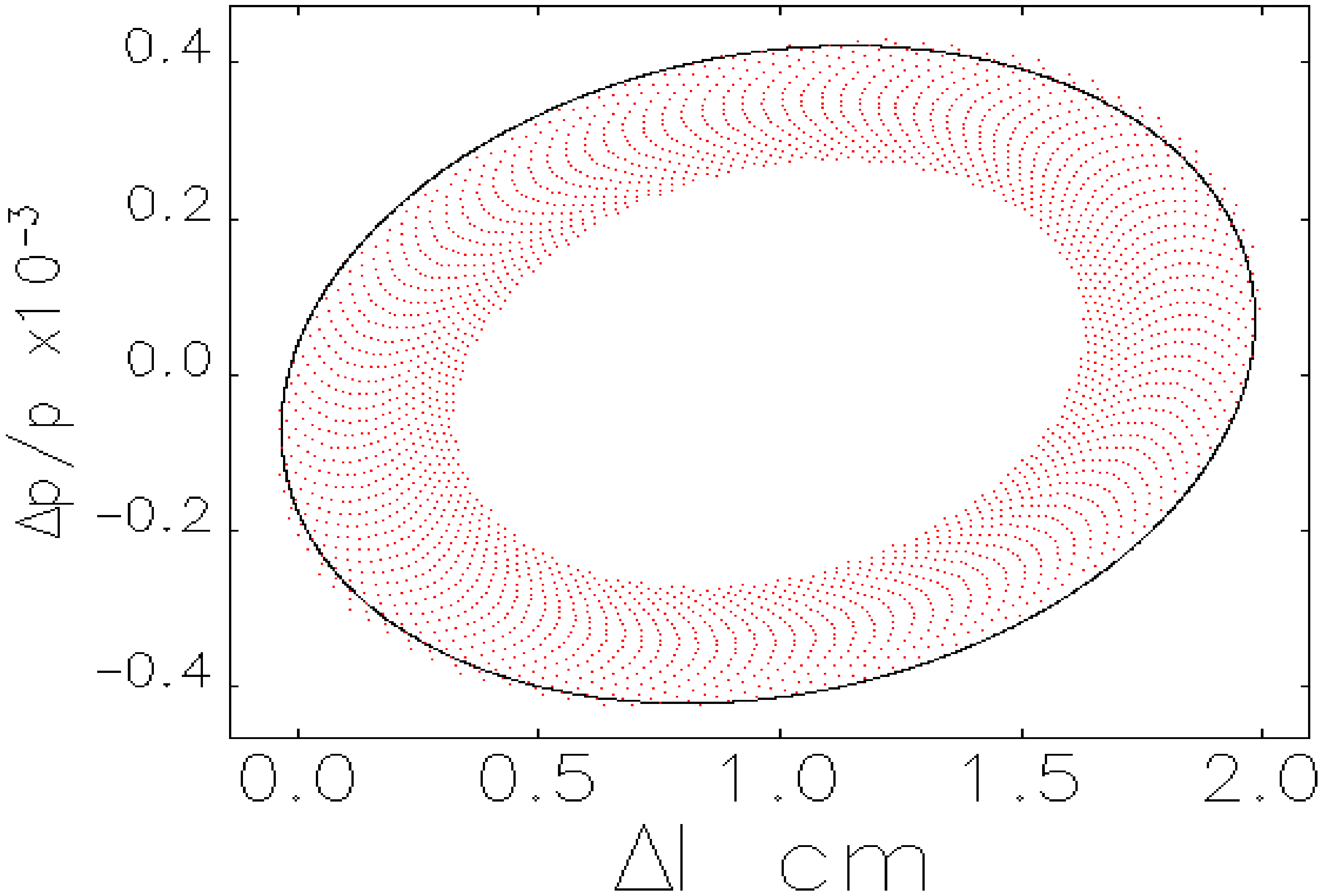




Crabbing OFF:
Particle distributions are matched after 1 turn.

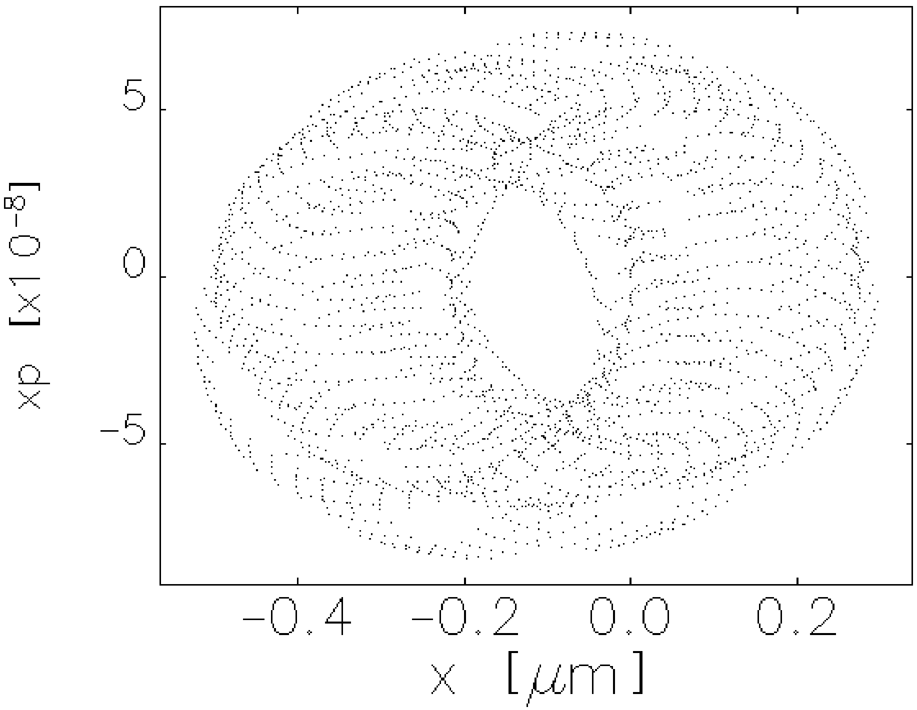
Crabbing ON:
Particle distribution is not matched after 1 turn.

Momentum spread in Phase Space

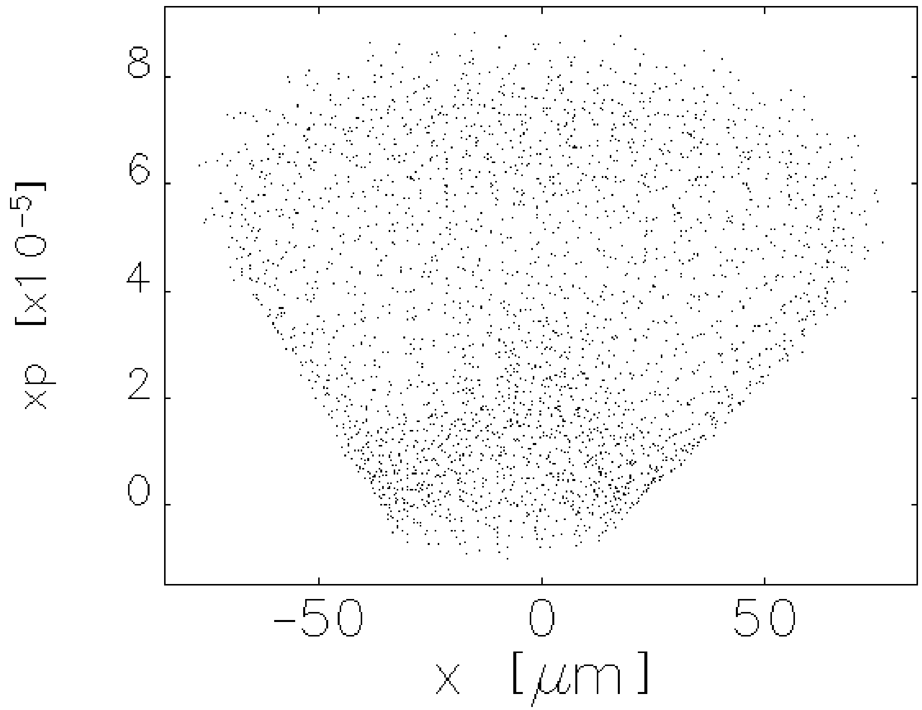


Phase space

Of 1 particle over 3000 turns, crabbing off and on



Crabbing OFF



Crabbing ON

Crab crossing plan

- **Avoid sextupoles in crabbed beam region by switching optics sections**
- **Optimize the crabbing system for best beam stability and minimum emittance impact**

- Study effects of and specify tolerances on crab cavity errors such as misalignment, amplitude and phase instability
- Study and specify tolerances on cavity multipole components by estimating impact on the ring's dynamic aperture
- Specify high-order mode requirements
- Specify requirement on the beam parameters such as maximum bunch length
- Evaluate and optimize impedance of the crab cavities
- Complete beam dynamics simulation using an optimized field map satisfying the determined requirements

Acknowledgements

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