Beam simulations for the nano beam scheme in SuperKEKB

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SuperB workshop, Annecy, France

16-19 Mar., 2010

Early studies with weak-strong simulations

Parameters for Super B Factories

a) b-b simulation, b) geometrical

	SuperKEKB	NanoBeam A2	NanoBeam A4 CW	NanoBeam A5 NCW	NanoBeam A6
εx (nm) (L/H)	24/18	2.8/2.0	2.8/2.0	33.6/10.7	2.8/2.0
εy(pm)	240/90	33.6/10.7	33.6/10.7	51.8/24.1	13.4/23.3
κ (%)	1/0.5	1.2/0.53	1.2/0.53	1.8/1.2 15	0.49/1.16
βx (mm)	200/200	44/25	44/25	10.7/25	17.8/25
βy (mm)	3/6	0.21/0.37	0.21/0.37	0.20/0.31	0.26/0.26
σx (μm)	69/60	11/7.07	11/7.07	5.47/7.07	7.06/7.07
σy (μm)	0.85/0.73	0.084/0.063	0.084/0.063	0.102/0.087	0.059/0.078
σz (mm)	5/3	5/5	5/5	5/5	5/5
φσz/σx	0/0	14/21	14/21	27/21	21/21
σx/φ(mm)	∞/∞	0.37/0.24	0.37/0.24	0.18/0.24	0.24/0.24
np / ne x10^10	12/5.25	10.7/6.17	10.7/6.17	10.7/6.17	10.7/6.17
Ebp/Ebe (GeV)	3.5/8	3.5/8	3.5/8	3.5/8	3.5/8
I_{beam} (A)	9.4/4.1	3.42/1.97	3.85/2.22	4.12/2.37	3.84/2.21
#bunch/Cir(m)	5000/3016	2011/3016	2266/3016	2418/3016	2252/3016
φ (mrad) (half crossing angle)	0	30	30	30	30
ξy	0.30/0.51	0.090/0.090	0.080/0.080	0.062/0.062	?/?
Lum	5.3×10^{35} a)	8.0×10^{35} a)	8.0×10^{35} a)	8.0×10^{35} a)	$? \times 10^{35}$ a)

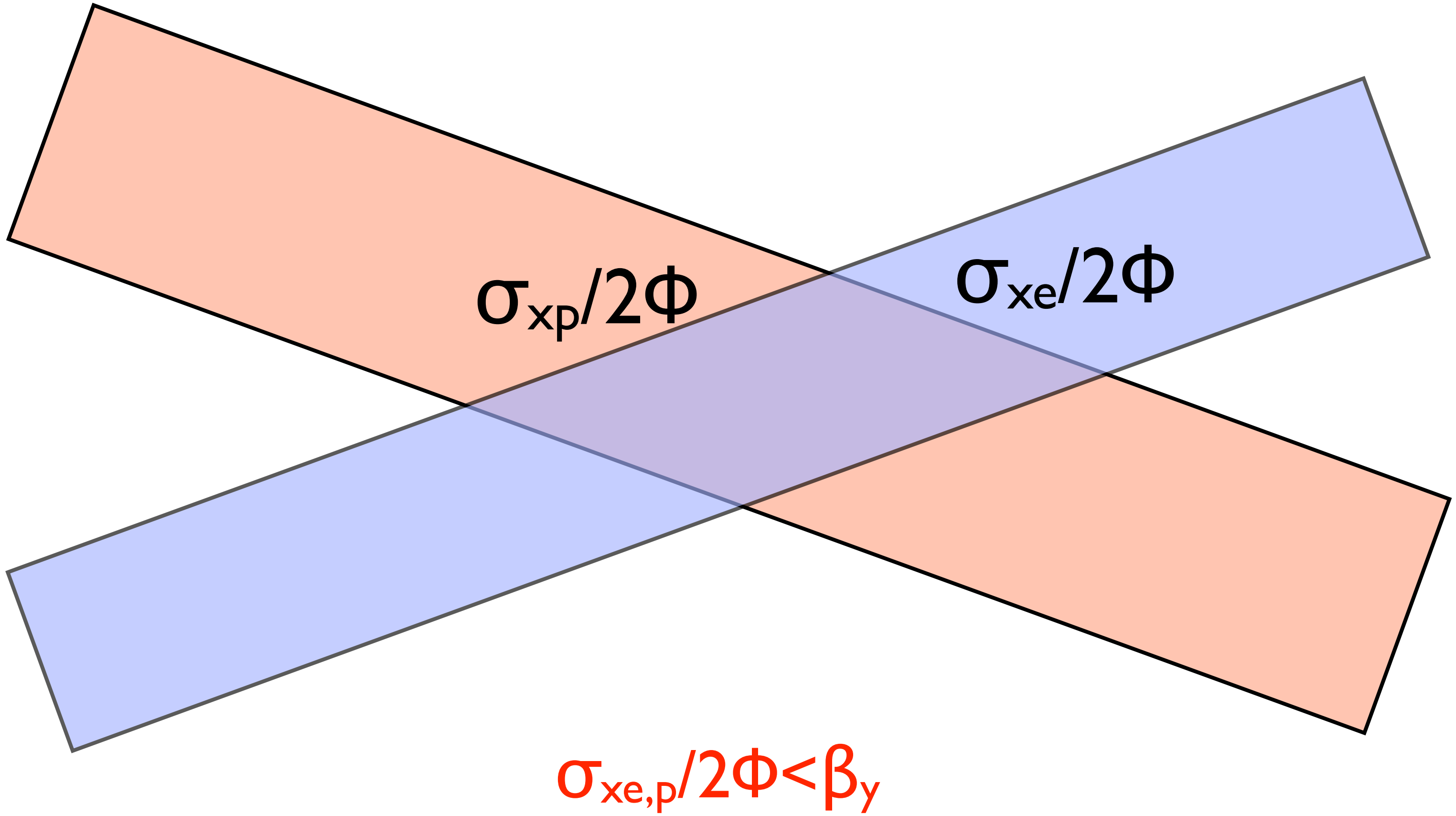
preliminary

$\sigma_{xe,p}/2\Phi < \beta_y$

- L 2.74×10^{35} 7.86×10^{35} 8.00×10^{35}
- L(CW) 8.09×10^{35} 9.67×10^{35} 8.69×10^{35}

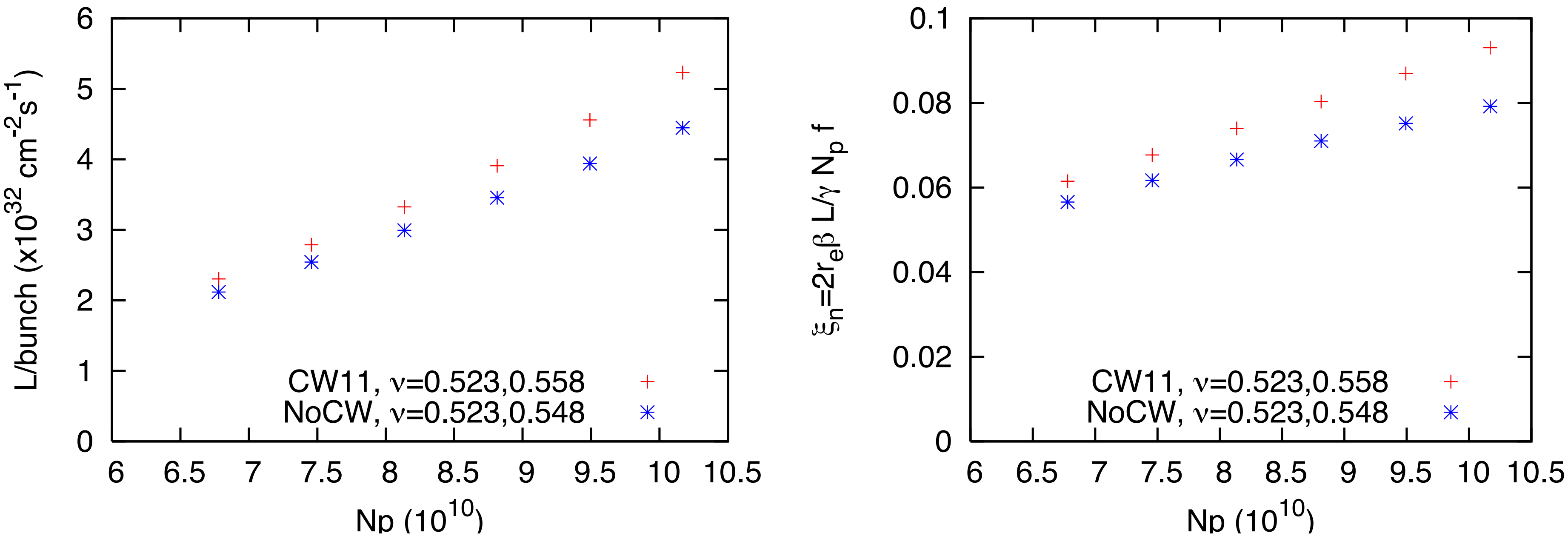
Parameter choice for the nano beam scheme

- HourGlass effect degrades the performance.
- Crab waist recovers the degradation.



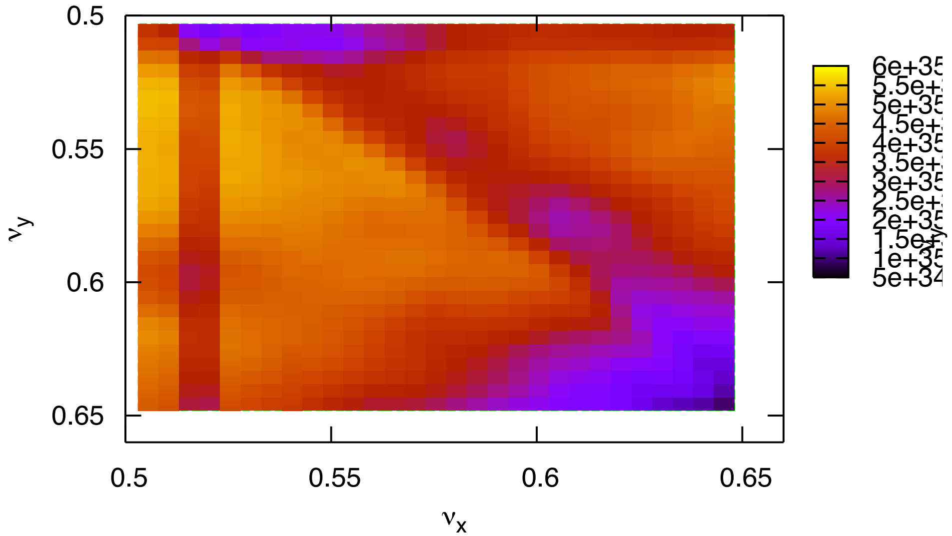
Current dependence

- If the condition is satisfied, NoCW is not bad for ξ<0.1.

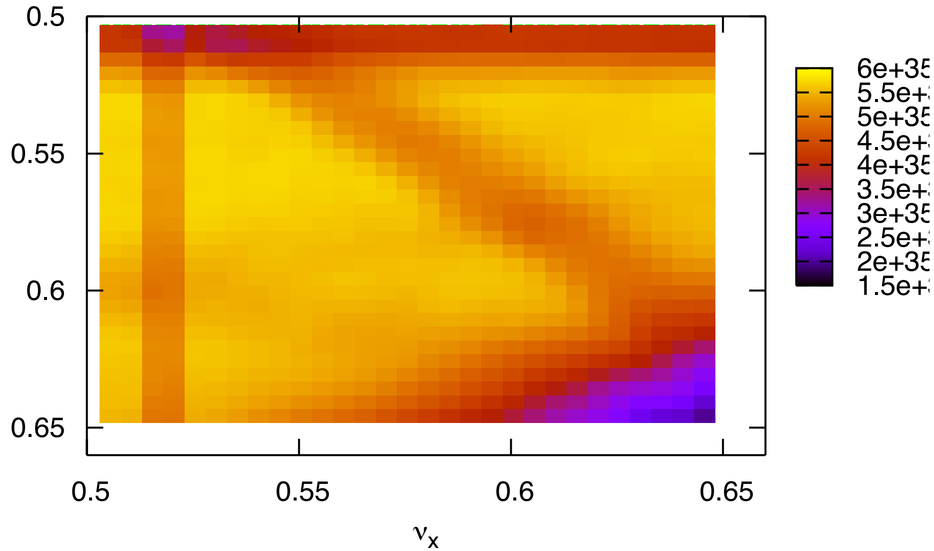


Tune scan with/without crab waist

No crab waist



crab waist



- Crab waist gives better performance.
- Synchro-beta resonance is seen in both cases.
-

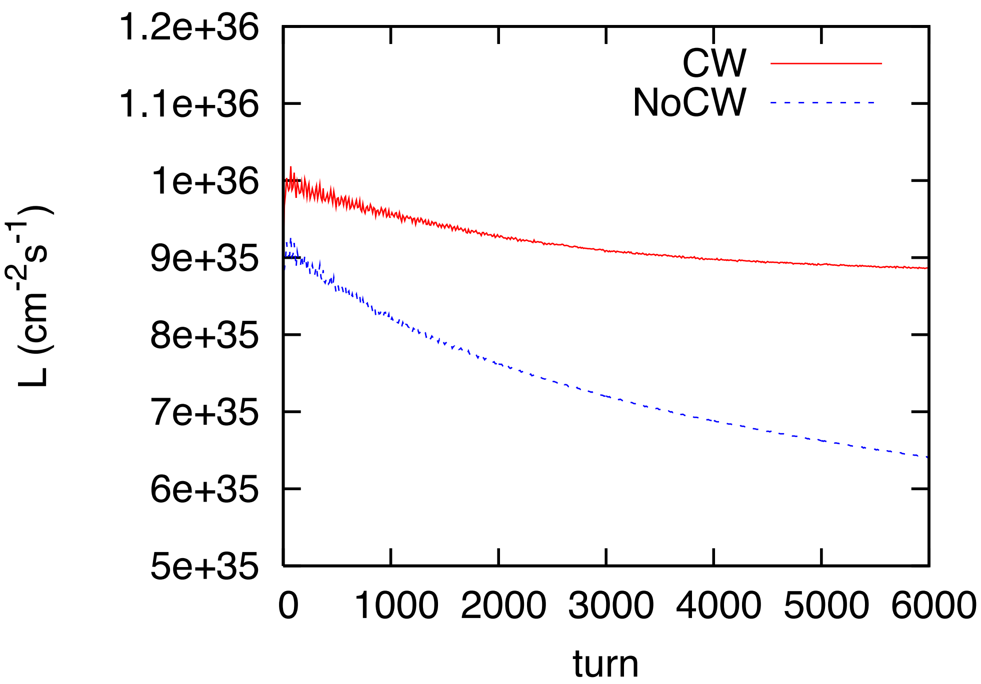
More systematic studies

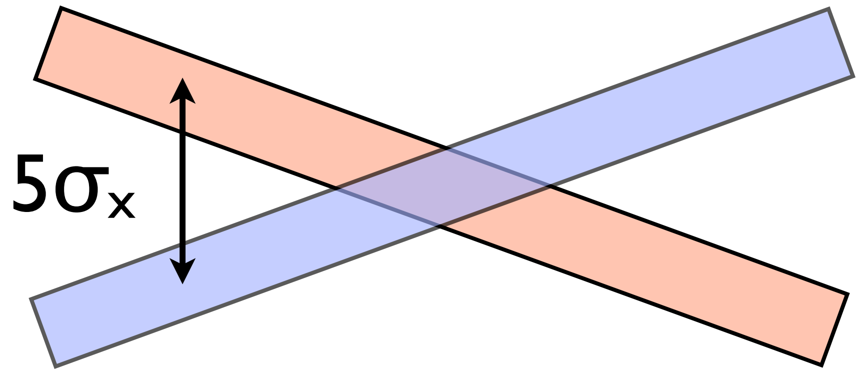
Machine parameters

Parameter	Descript)ion	e^+	e^-
E (GeV)	Beam energy	4.0	7.0
C (m)	Circumference	3016.2	3016.262
β_x^* (mm)	Hor. β at IP	32	25
β_y^* (mm)	Ver. β at IP	0.27	0.41
ε_x (nm·rad)	Hor. emittance	3.29	2.3
ε_y (nm·mrad)	Ver. emittance	17.8	4.7
ε_z (mm·mrad)	Long. emittance	3.89	3.11
ν_x	Hor. tune	45.53	59.529
ν_y	Ver. tune	45.57	41.57
ν_z	Synchrotron tune	0.021	0.0117
σ_z (mm)	Bunch length	4.9	4.9
σ_δ ($\times 10^{-4}$)	Energy spread	7.96	6.34

Tentative strong-strong simulation

- PIC collision if the separation of two slices is closer than $5\sigma_x$, otherwise Gaussian approximation.
- 6000 PIC, 34000 Gaussian approximation per collision (200x200 slices).





Complete Strong-strong simulation

- Multi-mesh
- Shifted Green function
- The code has been developed. The execution time is huge. Expect next supercomputer in KEK or new type of computers.

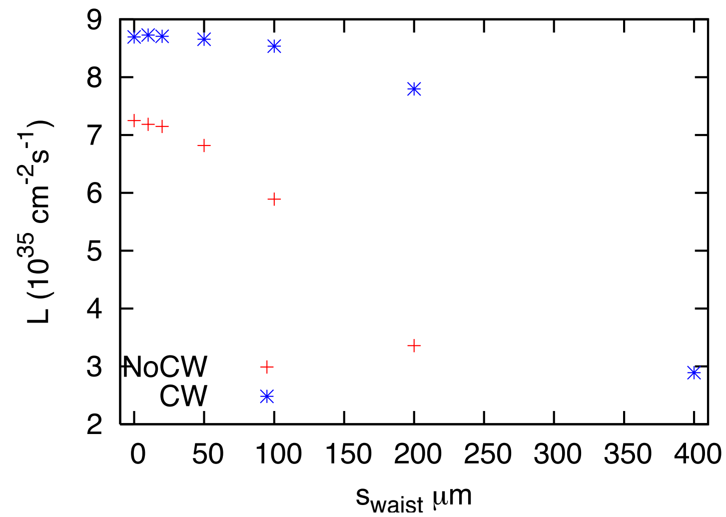
Errors and noise tolerances

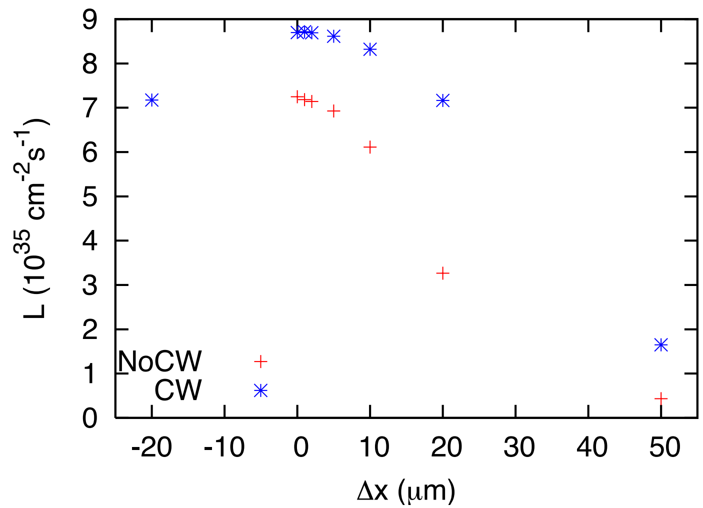
- The tolerances are evaluated with the weak-strong simulation.

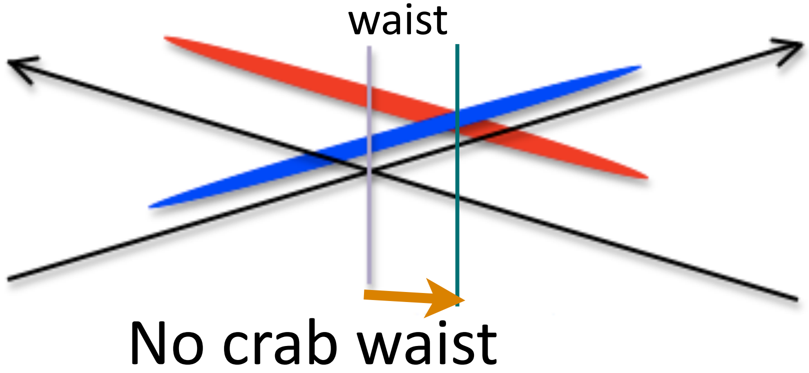
- Collision offset and waist deviation
- x-y coupling and their chromatic aberrations
- Fast noise

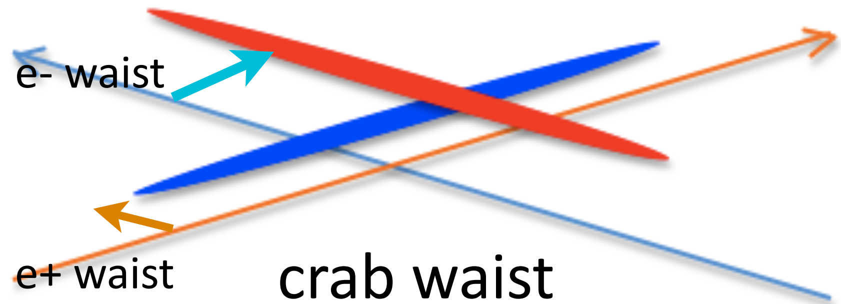
Tolerance of collision condition
Horizontal collision offset and waist

- Horizontal offset and waist are related to each other.
- The cross point of the waist is only one in x-z plane for the crab waist scheme.

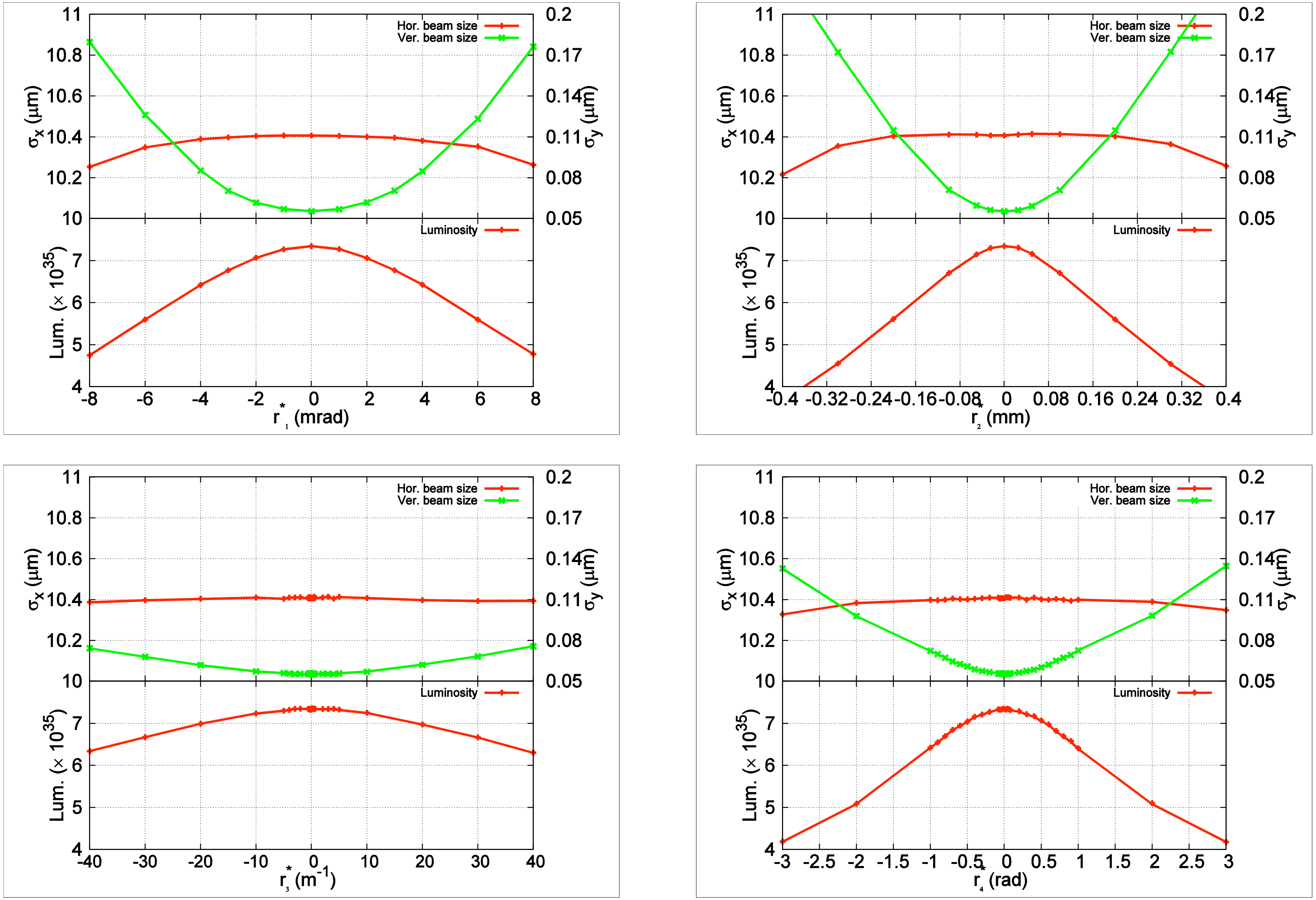




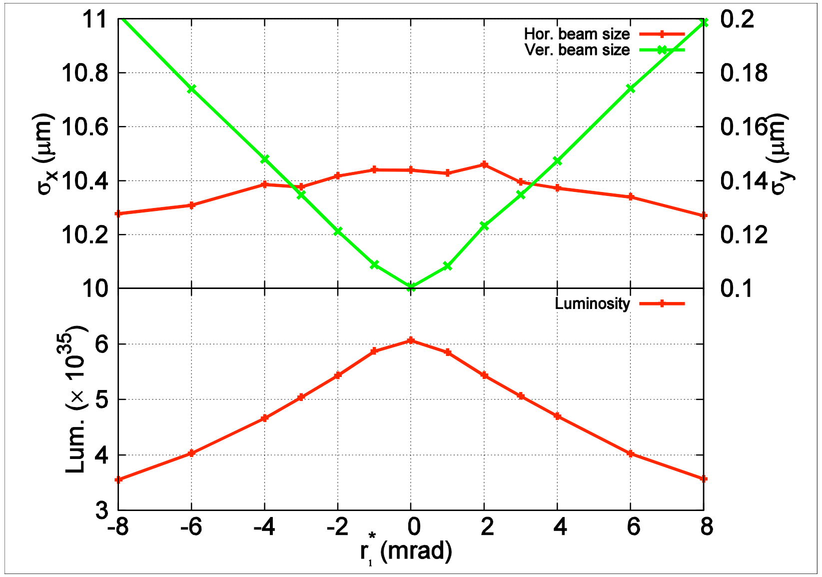


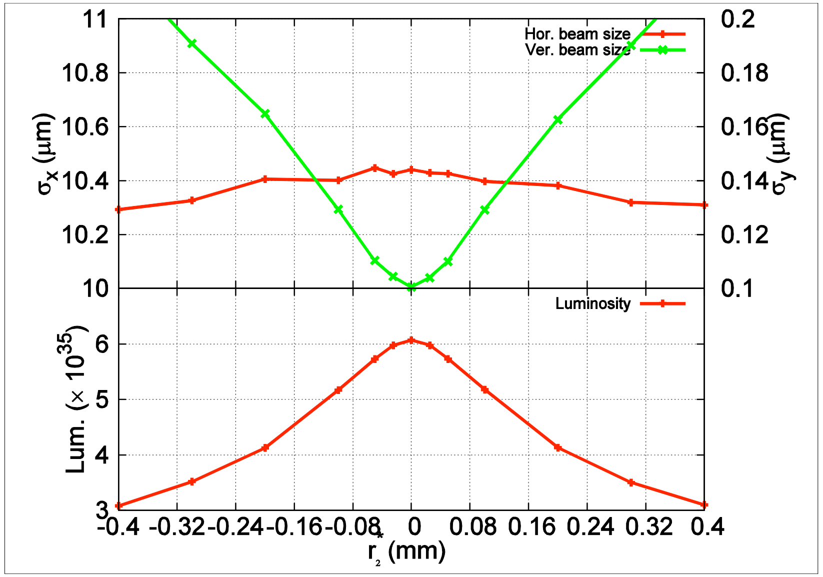


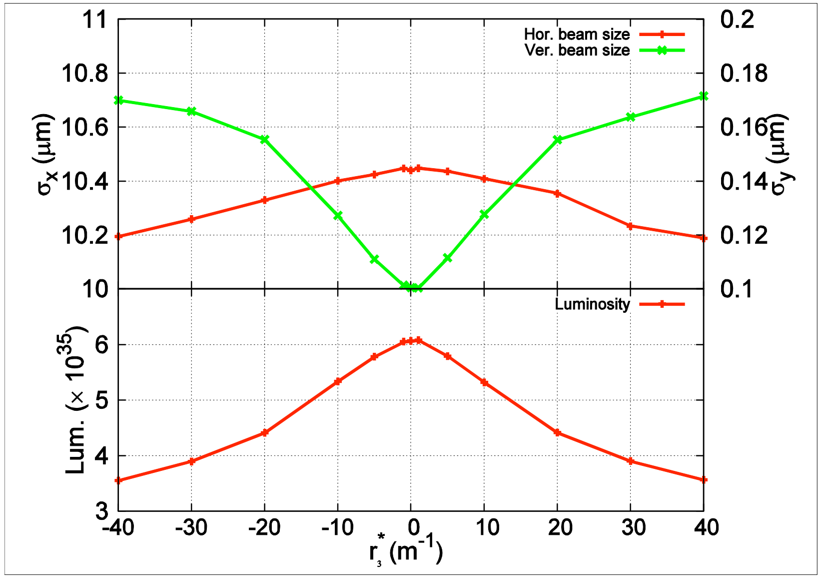
X-Y coupling w/ crab waist

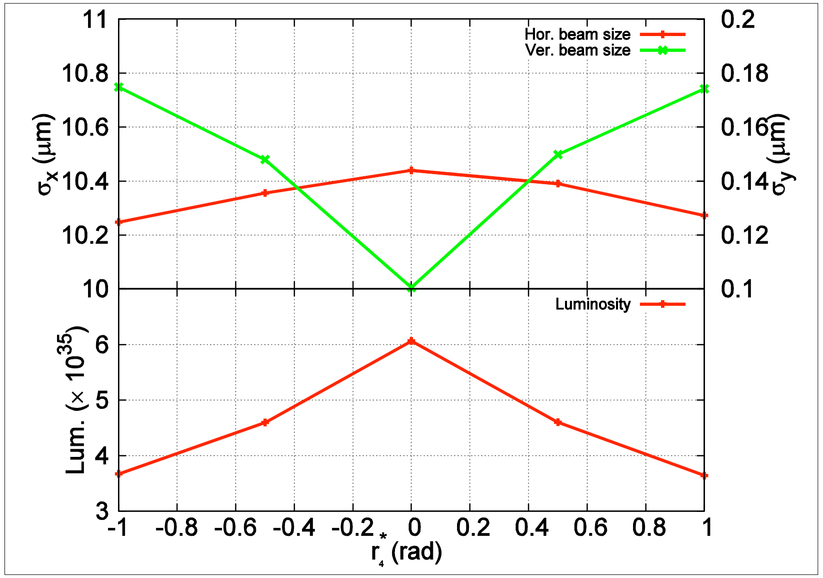


X-Y coupling w/o crab waist

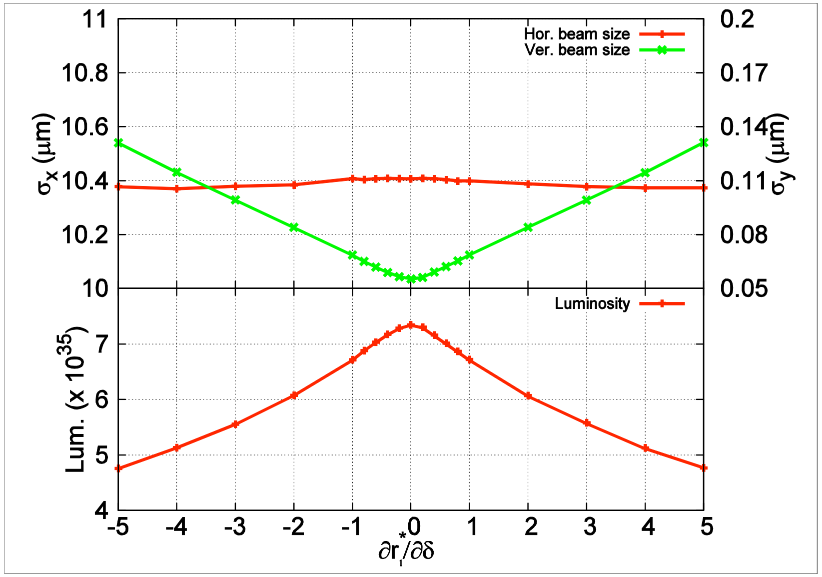


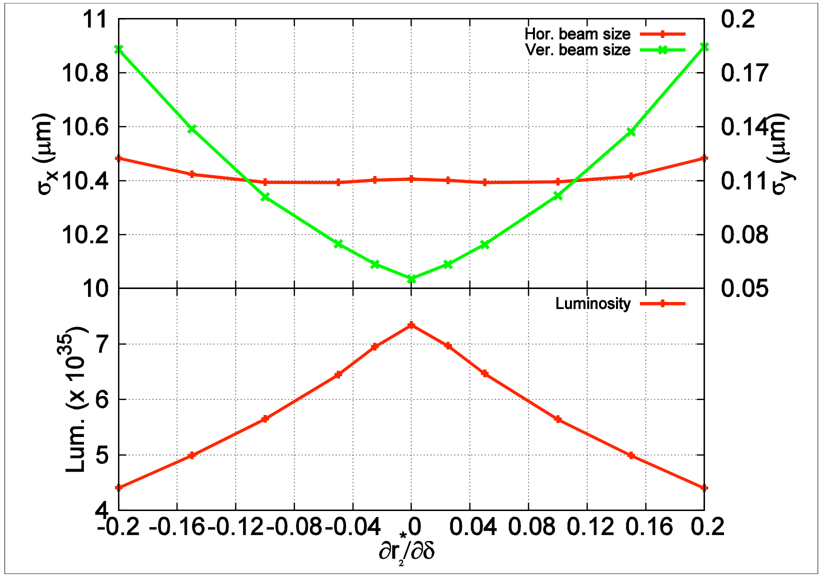


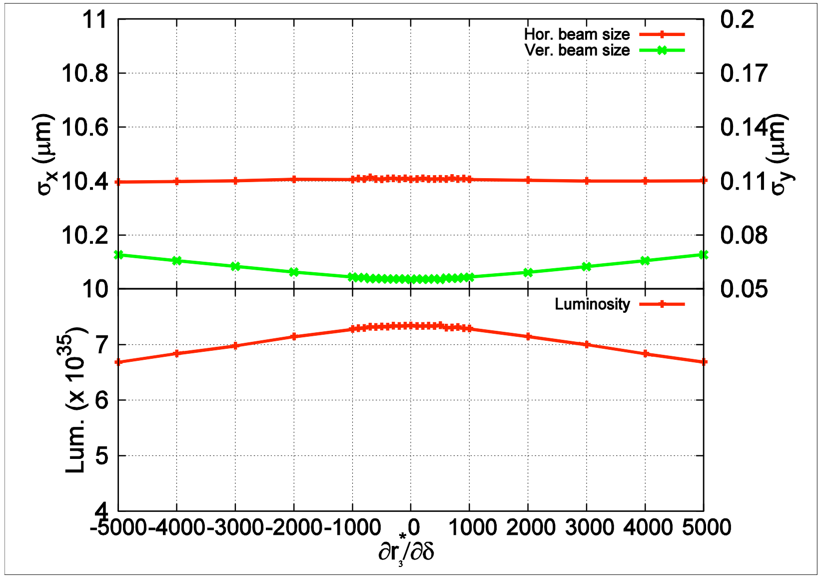


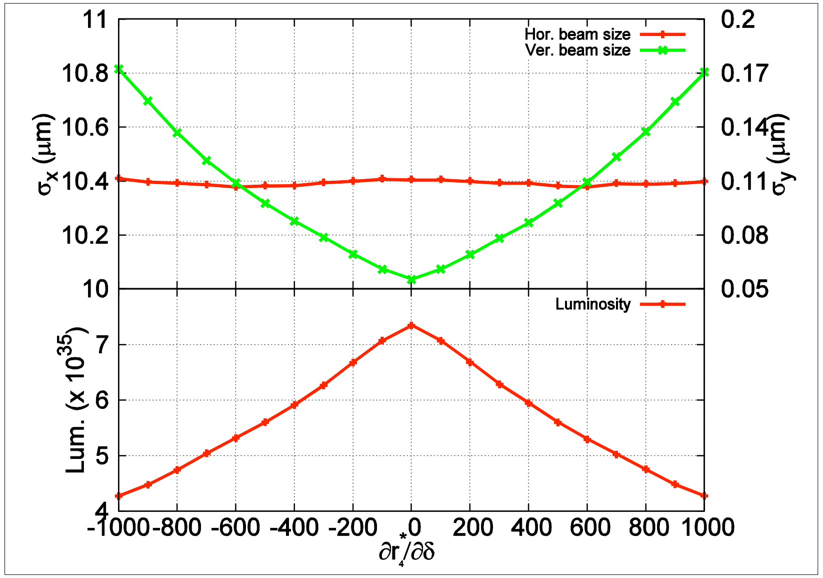


Chromatic X-Y w/ crab waist

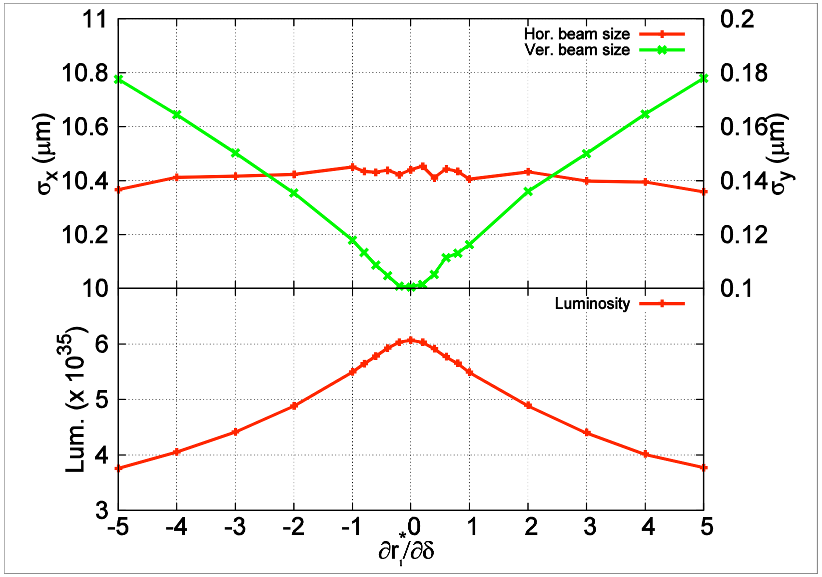


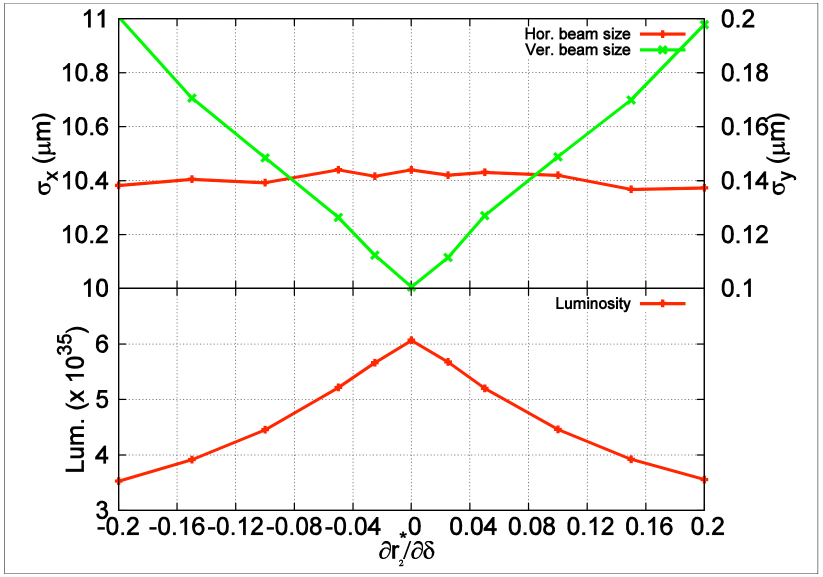


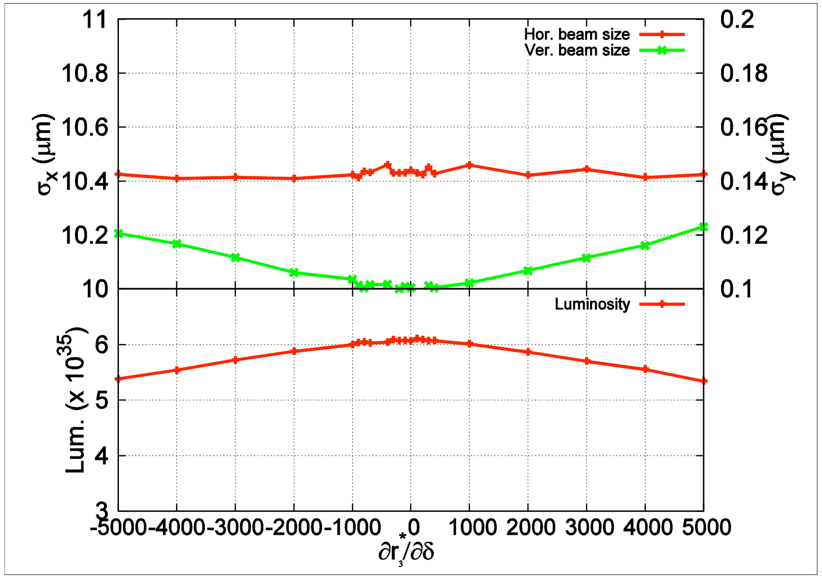


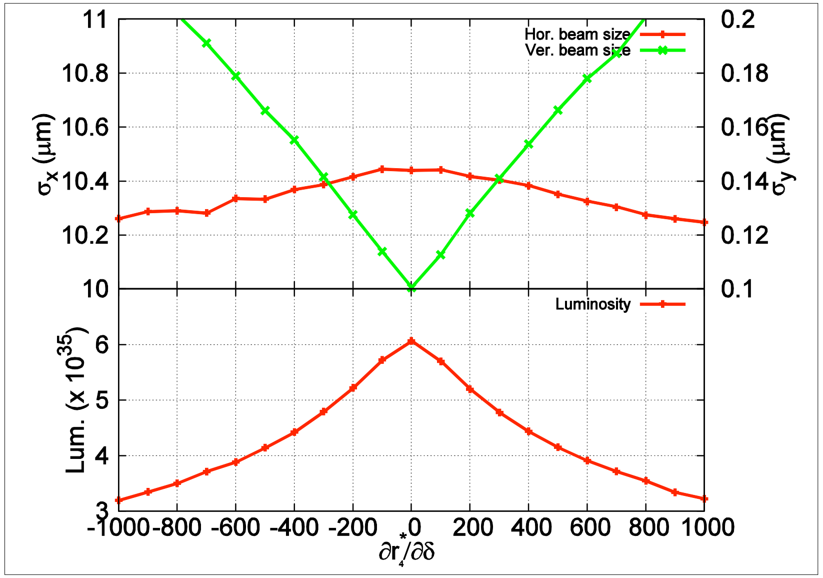


Chromatic X-Y w/o crab waist



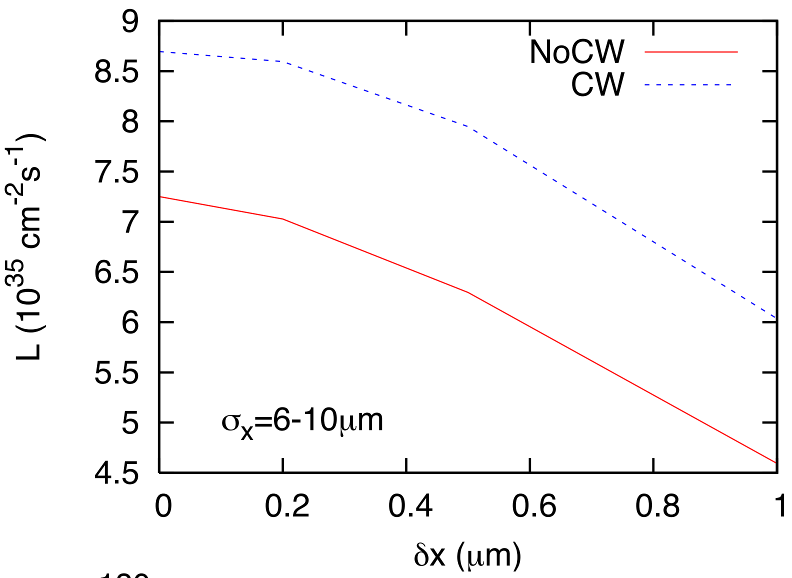


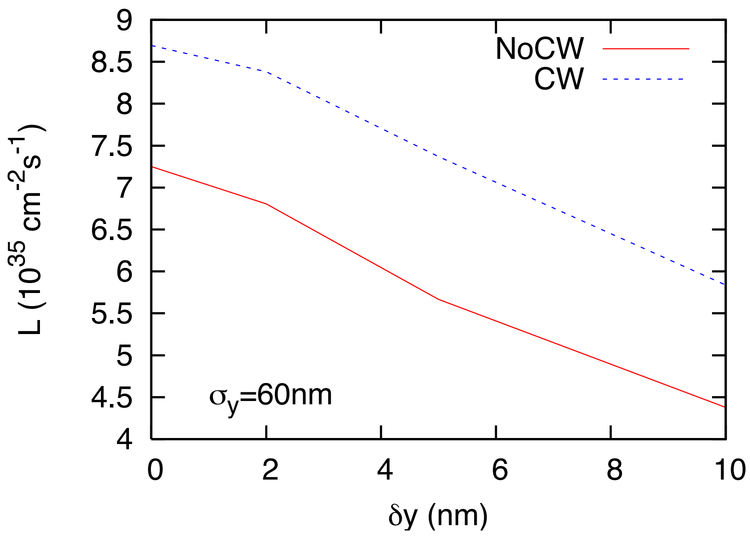


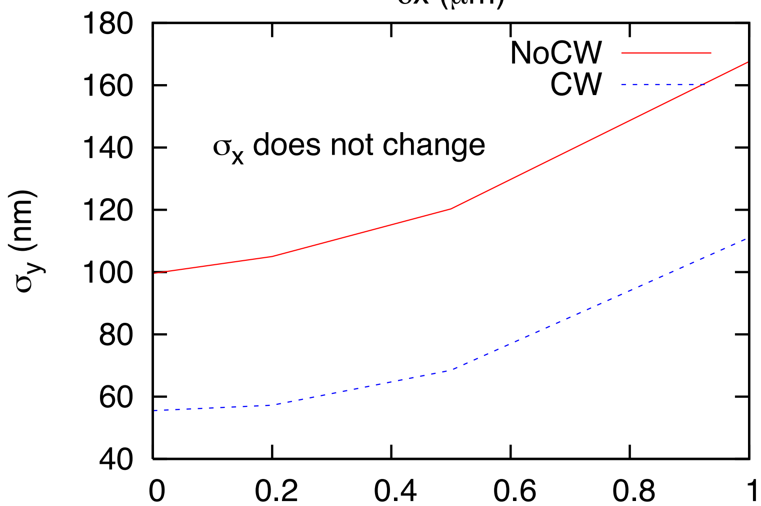


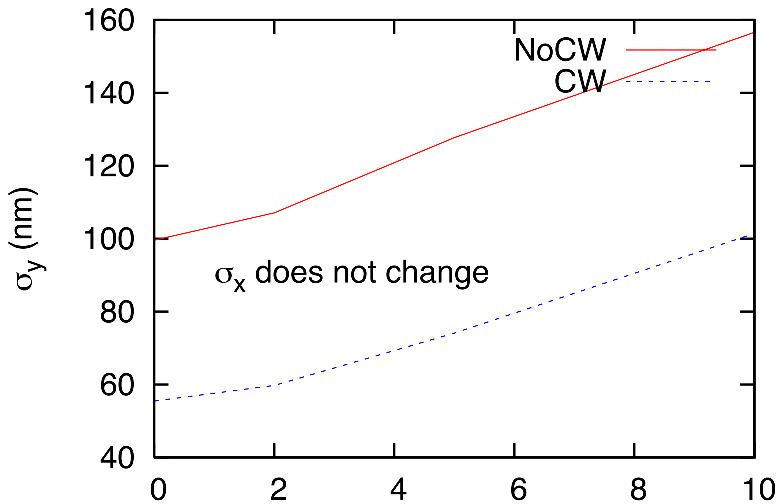
Beam noise

- Turn by turn noise







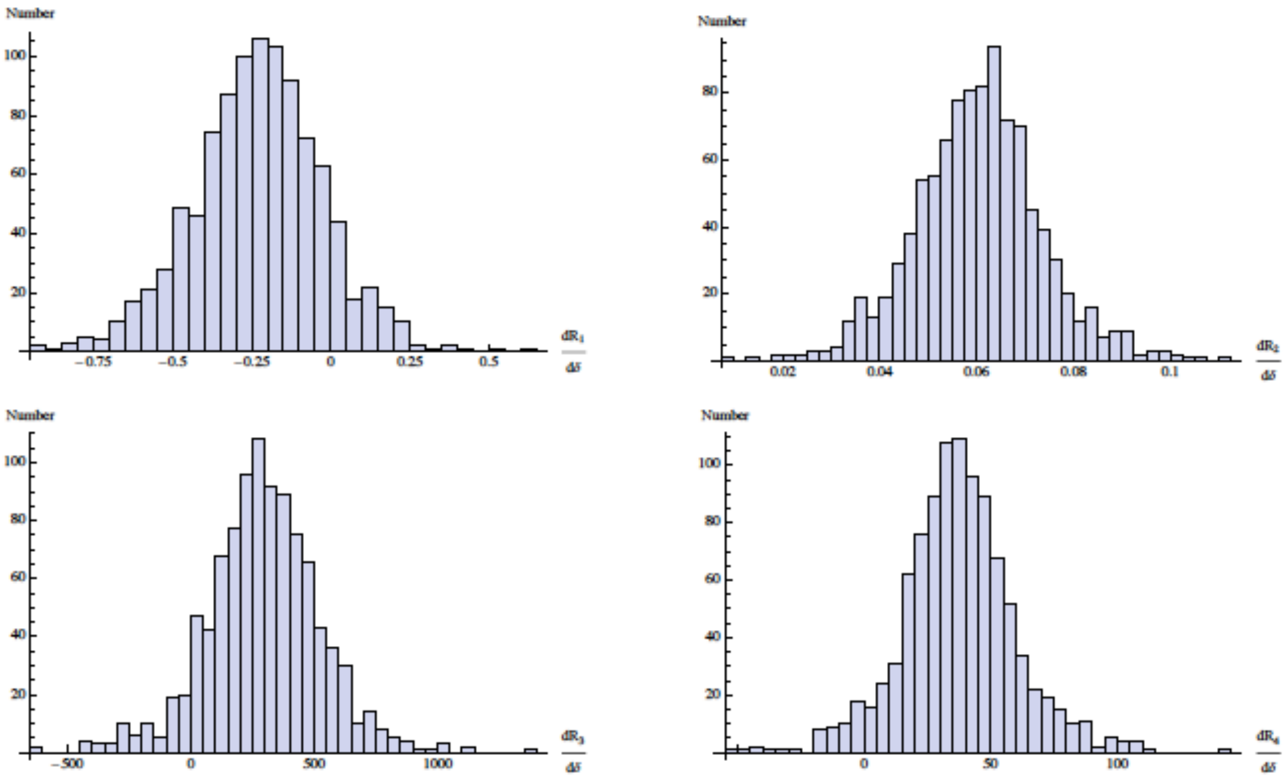


Summary – tolerance for parameters with 20% luminosity degradation

Parameter	w/ crab waist	w/o crab waist
r_1^* (mrad)	±5.3	±3.5
r_2^* (mm)	±0.18	±0.13
r_3^* (m^{-1})	±44	±15
r_4^* (rad)	±1.4	±0.4
$\partial r_1^* / \partial \delta$ (rad)	±2.4	±2.1
$\partial r_2^* / \partial \delta$ (m)	±0.086	±0.074
$\partial r_3^* / \partial \delta$ (m^{-1})	$\pm 1.0\times 10^4$	±8400
$\partial r_4^* / \partial \delta$ (rad)	±400	±290
η_y^* (μm)	±62	±31
$\eta_y'^*$	±0.73	±0.23

Δx (μm) collision offset	10	10
Δs (μm) waist error	100	100
δx (μm) turn by turn noise	0.5	0.5
δy (nm)	4	4

R-chromaticity (LER) with emittance coupling=1%

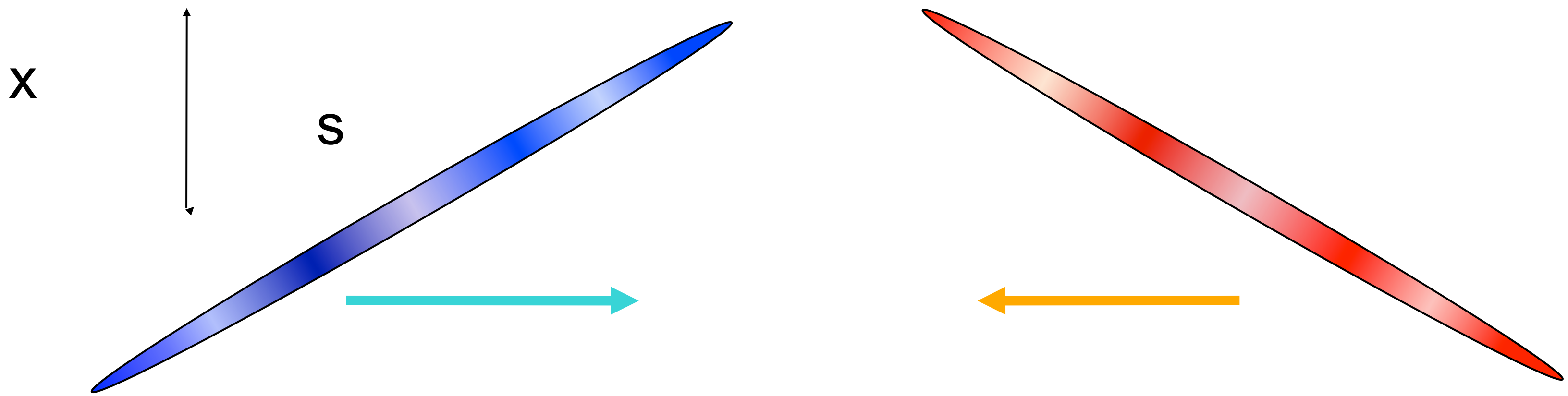


Average and variance of chromaticity (LER, emittance coupling=1%)

Parameter	i=1	i=2	i=3
r_{1i}	-0.23±0.21	-5.9±26.9	-893±2495
r_{2i}	0.06±0.013	-0.98±2.46	-42.9±314
r_{3i}	-292±232	$(-1.71\pm2.25)\times10^4$	$(5.24\pm26.5)\times10^5$
r_{4i}	37.3±22.6	$(-3.61\pm1.51)\times10^3$	$(1.56\pm1.84)\times10^5$
η_{yi}	-0.004±0.017	-0.3±3.52	-73±278
η'_{yi}	11.8±17.9	-570±1642	$(2.17\pm38.7)\times10^4$

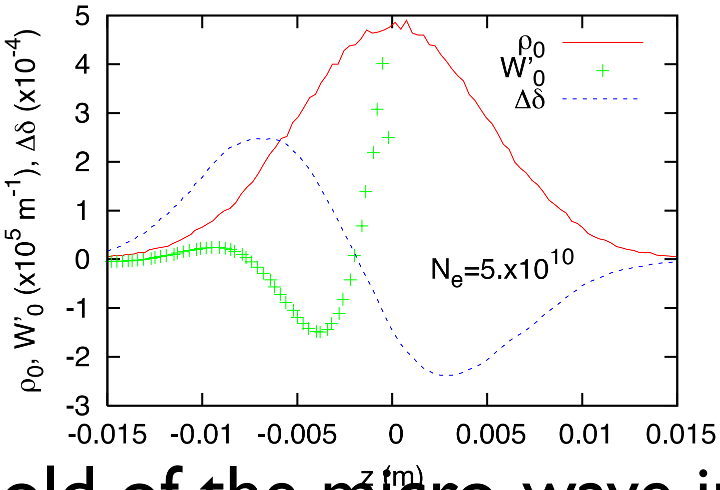
Microwave instability in Nano beam Collision

- Integrated horizontal beam-beam force along bunch length is Bassetti-Erskine type for tri-Gaussian distribution in x-y-z plane.
- When Micro-wave instability arises, transverse beam-beam force is distorted and fluctuated.

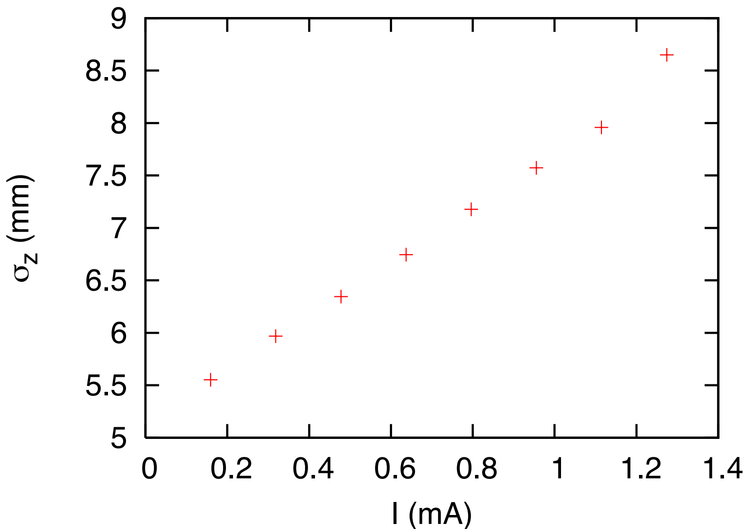


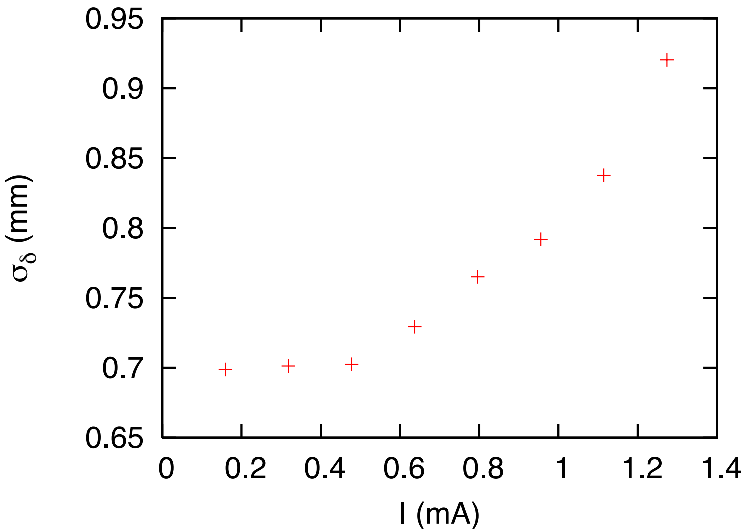
Model wake field

- Low Q resonator model (Y. Cai)



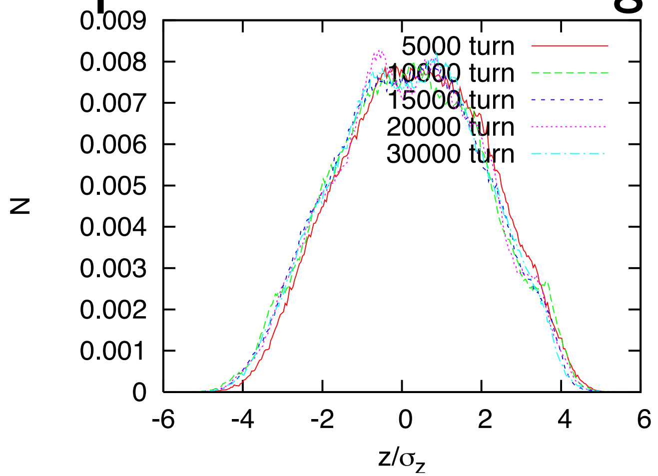
- Threshold of the micro-wave instability is 0.5mA (N_b=3.3x10^{10})





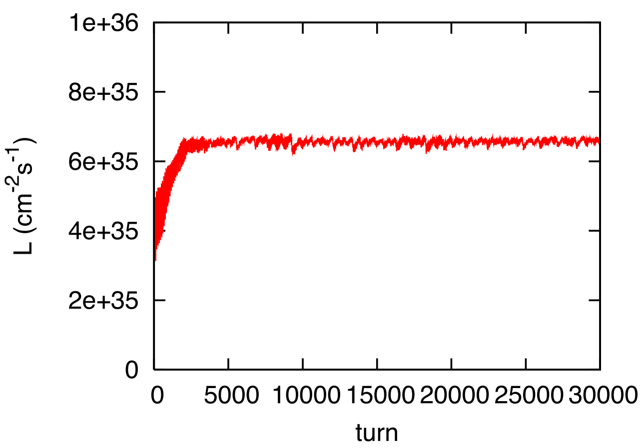
Simulation result of collision under micro-wave instability

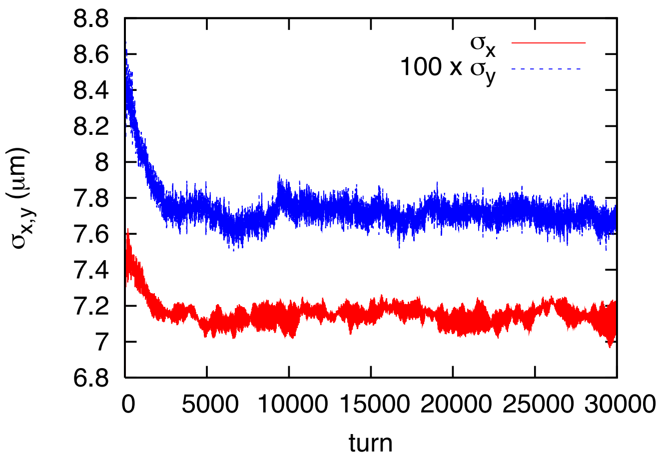
- Longitudinal profile of the strong beam.



The resonator model is mild for instability.

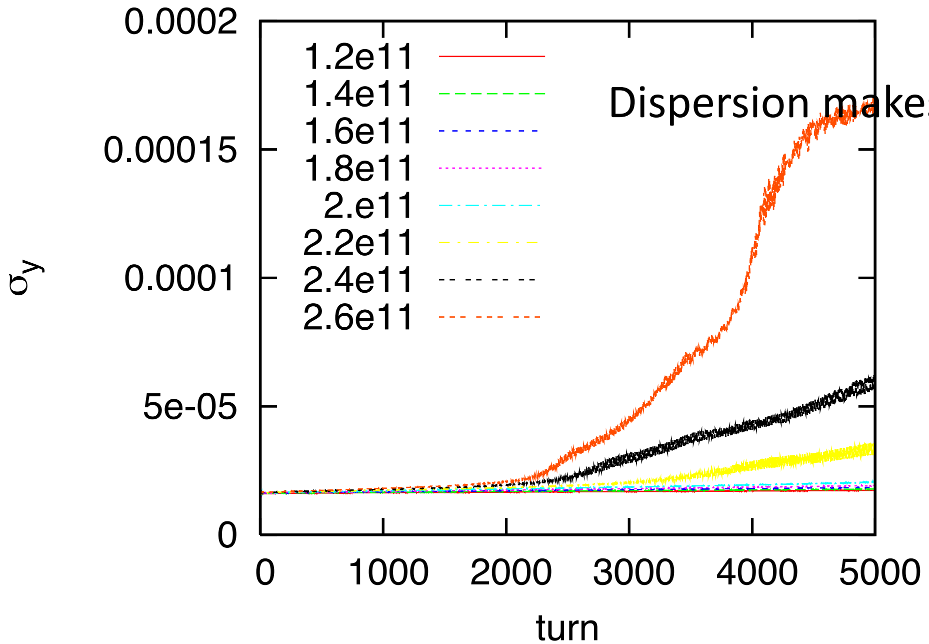
- Luminosity and the beam size of the weak beam. No remarkable effect except for the bunch lengthening in this impedance model.





Electron cloud issue

- Threshold of the fast head-tail instability, ρ_e=1-2x10^{11} cm^{-3}.



Dispersion makes to degrade the 1/2 density.

- Ante-chamber, Solenoid, coating and grove. The density is reduced 3-6x10^{10} cm^{-3}. (Y. Suetsugu)

Summary

- Tentative strong-strong simulation did not show difficulties in the nano beam collision.
- Crab waist gives better performance and loose tolerances. We should consider the crab waist.
- True strong-strong simulation is prepared.
- Errors and noise tolerances are evaluated. The tolerance may be feasible for the beam dynamical issues, if the design lattice is realized.
- All the difficulties are transferred to lattice design and dynamic aperture issues.
- Show stopper will be in the lattice design and dynamic aperture issue, if exist.