Beam-beam, lattice nonlinearity and space charge at SuperKEKB

D. Zhou

Acknowledgements: Y. Funakoshi, H. Koiso, A. Morita, K. Ohmi, Y. Ohnishi, K. Oide, H. Sugimoto

ICFA Mini-Workshop on Commissioning of SuperKEKB and e+e- Colliders, KEK, Nov. 12, 2013

Outline

- Introduction
- Beam-beam (BB) and luminosity
  - Lum. tune scan
- Lattice nonlin. (LN)
  - Interplay with BB; Beam tail
- Space charge (SC)
  - Linear tune shift; Interplay with beam-beam
- Summary

1. Introduction

➤ Scaling SuperKEKB/KEKB

	LER			HER		
	SKEKB	KEKB*	Factor	SKEKB	KEKB*	Factor
E(GeV)	4.0	3.5	1.14	7.007	8	0.876
I_b(mA)	1.44	1.03	1.4	1.04	0.75	1.4
ε_x(nm)	3.2	18	0.18	4.6	24	0.19
ε_y(pm)	8.64	180	0.048	11.5	240	0.048
β_x^*(m)	0.032	1.2	0.027	0.025	1.2	0.021
β_y^*(mm)	0.27	5.9	0.046	0.3	5.9	0.051
$\alpha_p(10^{-4})$	3.25	3.31	0.98	4.55	3.43	1.33
$\sigma_\delta(10^{-4})$	8.08	7.73	1.11	6.37	6.3	0.96

*Machine parameters on Jun.17, 2009

1. Introduction

➤ **Features of SuperKEKB with nano-beam scheme:**

- Large crossing angle
- Small vertical emittances
- Small beam sizes at IP
- Complicated IR
- … …

➤ **The machine performance will be more sensitive to various perturbations to the beams in SuperKEKB than in KEKB**

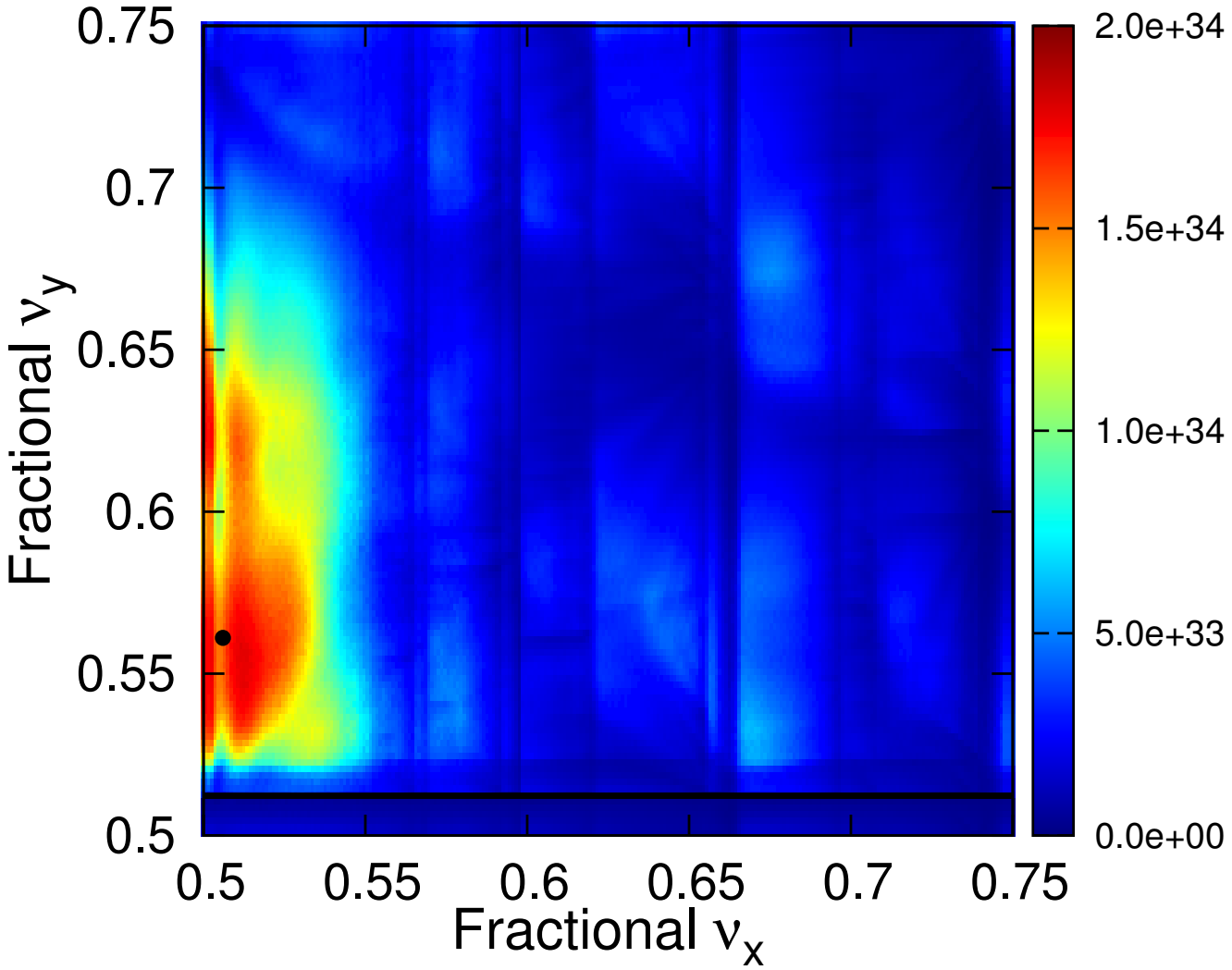
➤ **Some important issues in SuperKEKB:**

- Beam-beam
- Lat. nonlin.: Beam-beam + Lat. nonlin.
- Space charge: Beam-beam + Lat. nonlin. + Space charge
- … …

2. BB and luminosity

➤ KEKB with machine parameters on Jun.17, 2009

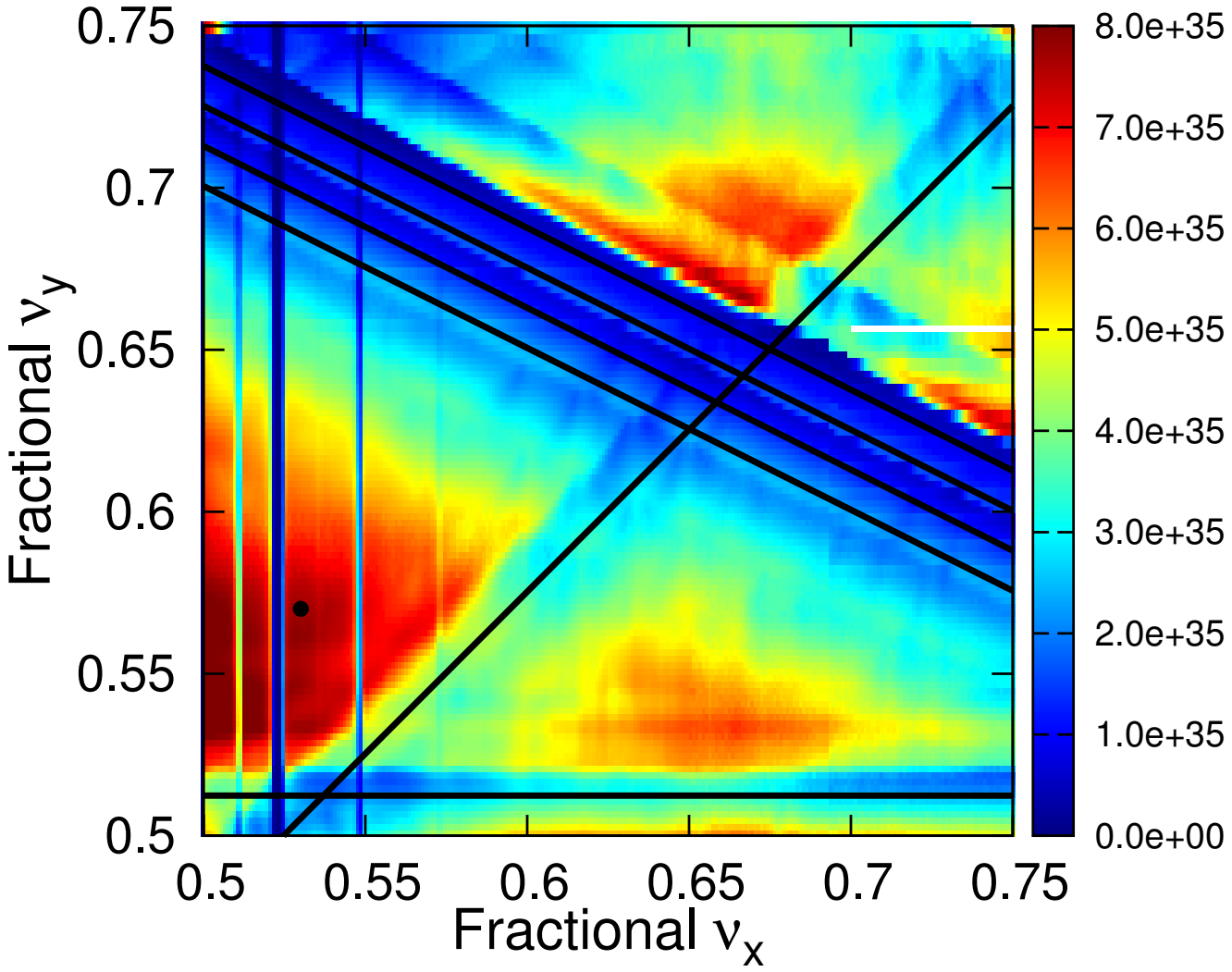
- **Lum. tune scan by BBWS (K. Ohmi)**



2. BB and luminosity

➤ SuperKEKB LER w/o crab waist

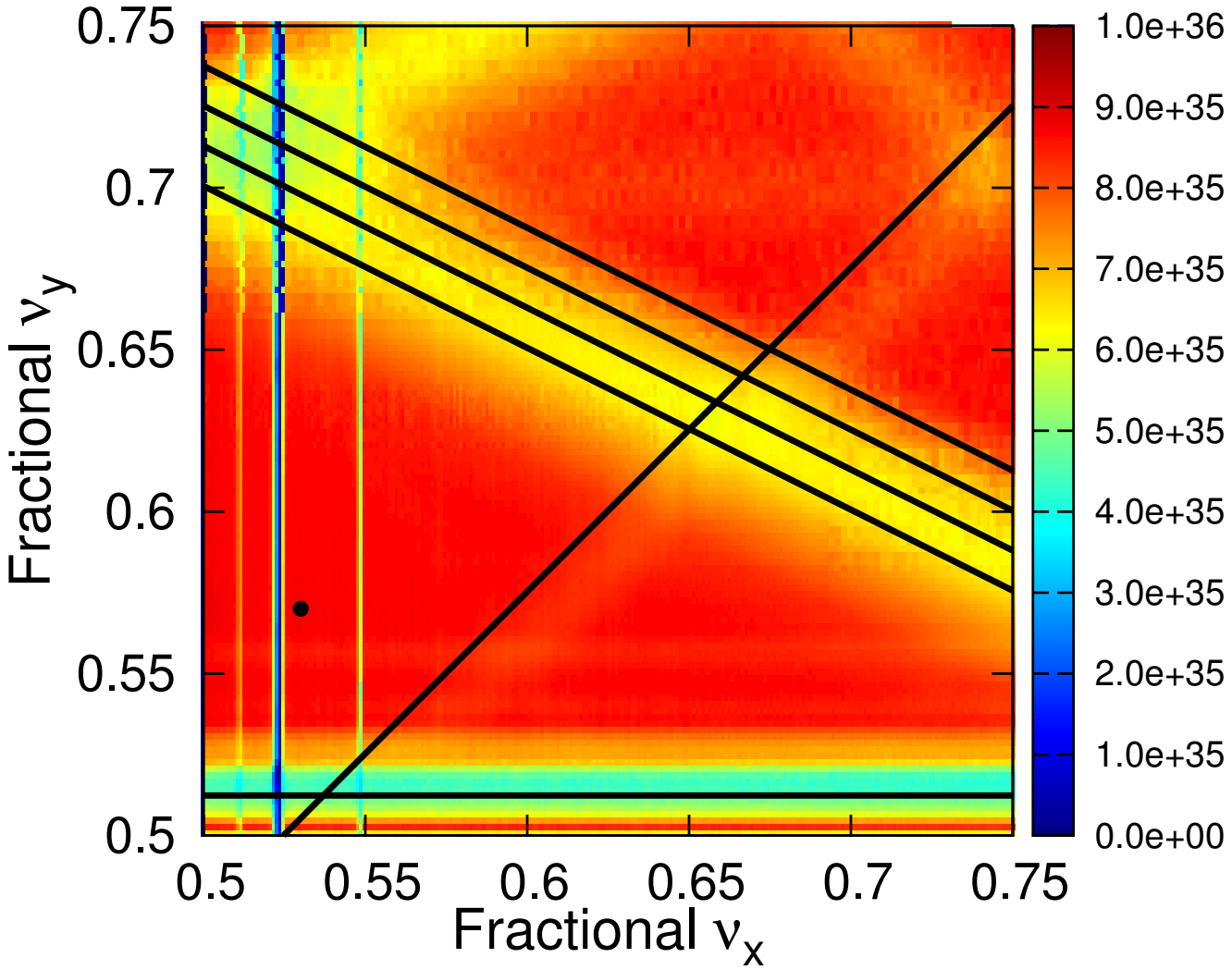
- **Lum. tune scan by BBWS (K. Ohmi)**



2. BB and luminosity

➤ SuperKEKB LER w/ crab waist

- **Lum. tune scan by BBWS (K. Ohmi)**

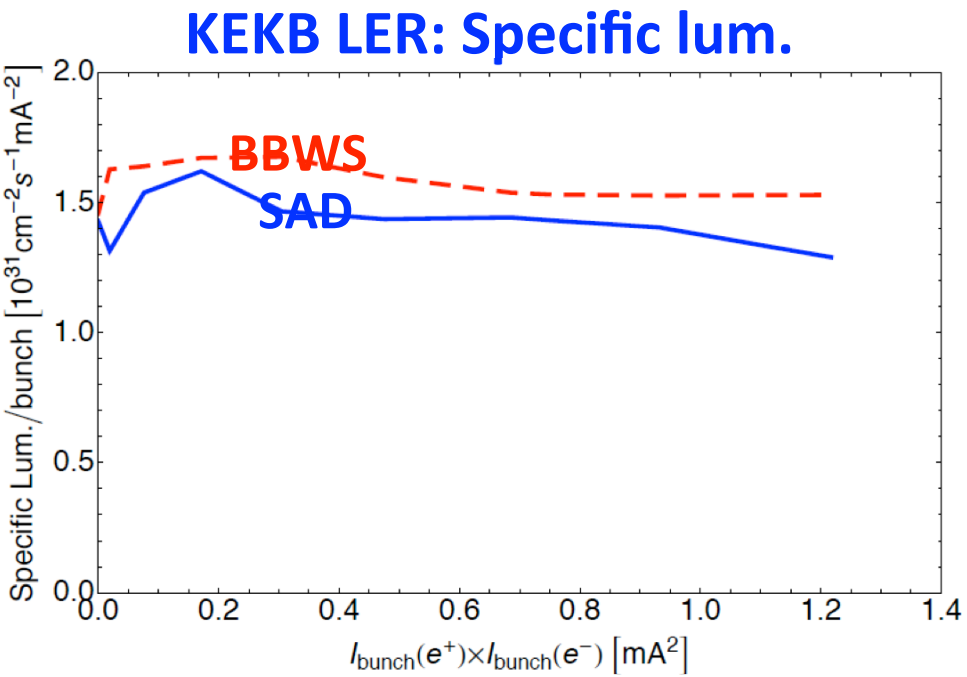


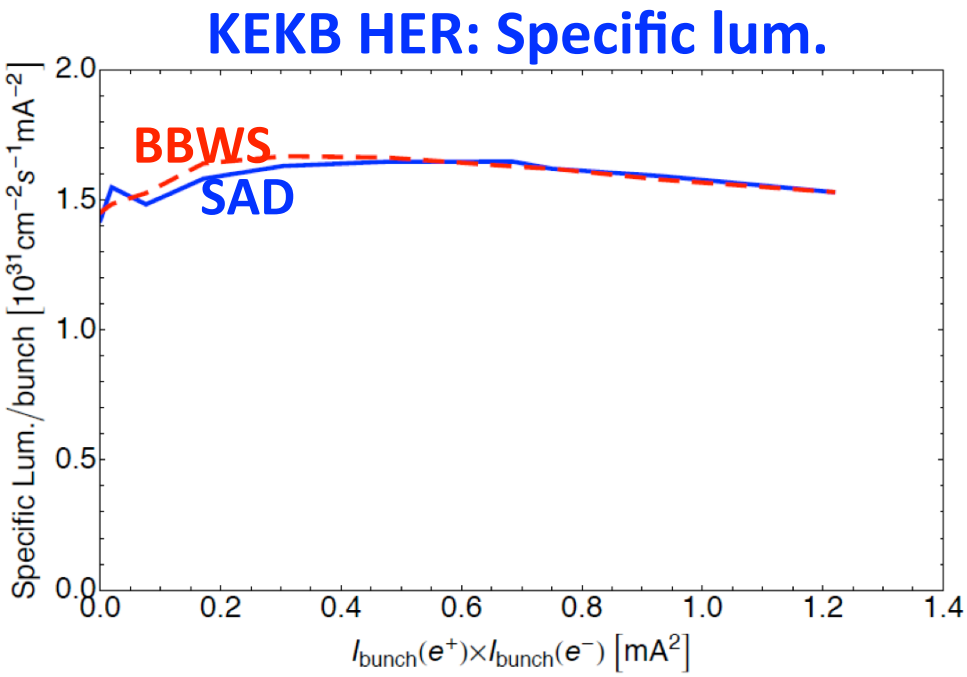
3. LN: Case of KEKB

➤ LN crosstalk with beam-beam

➤ BB simulations were done using BBWS, BBSS and SAD

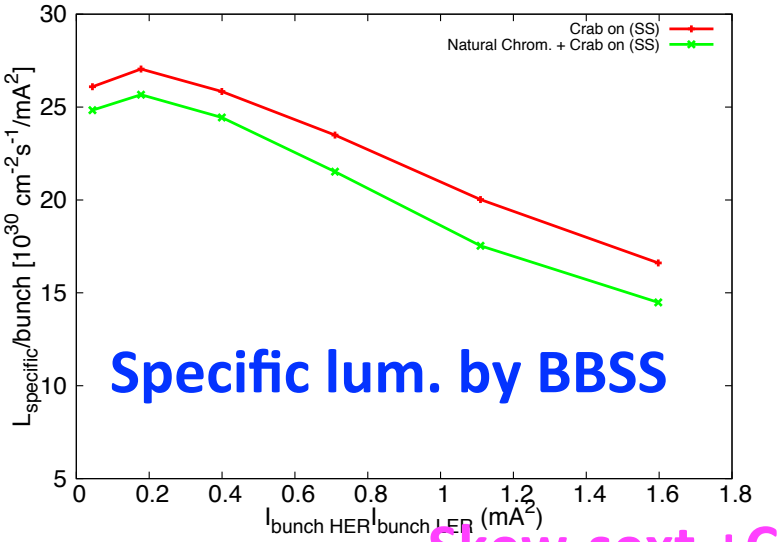
➤ Only chromatic coupling were found to be important (see next page)

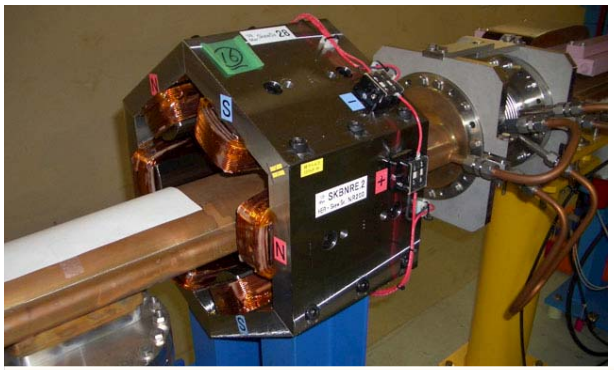




3. LN: Case of KEKB

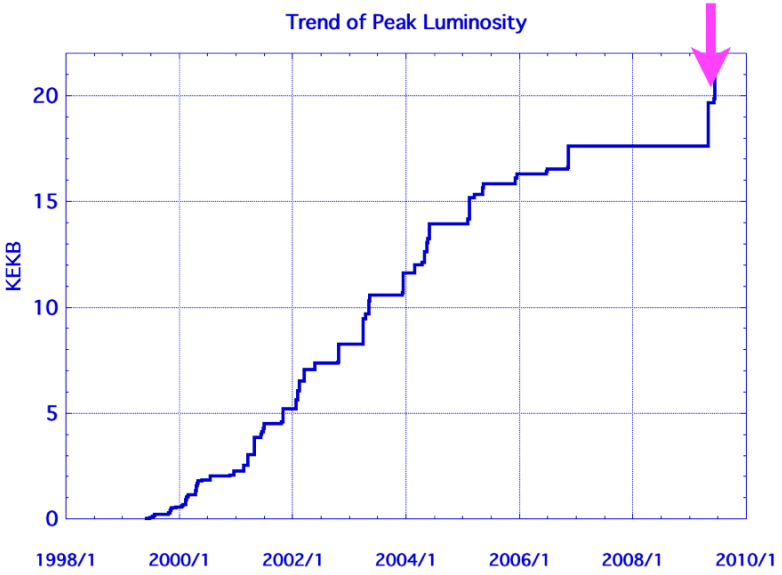
➤ **Chromatic coupling was important in both cases of crab cavity on and off**

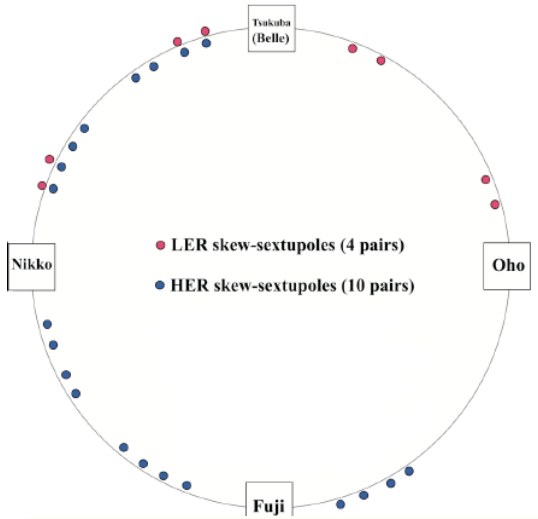




Skew sext., Masuzawa et al.

Skew-sext.+Crab cavities

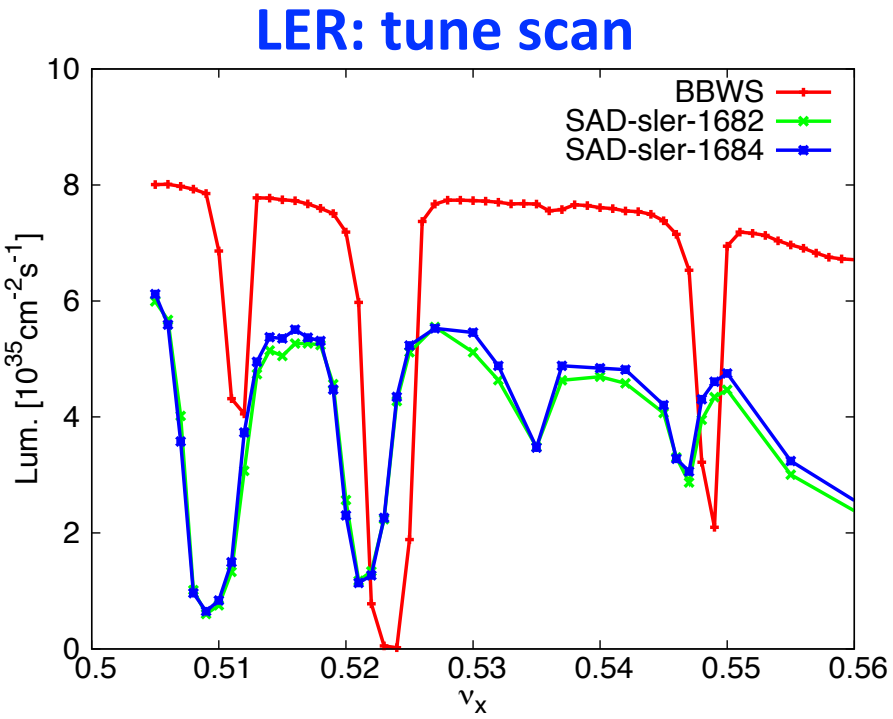


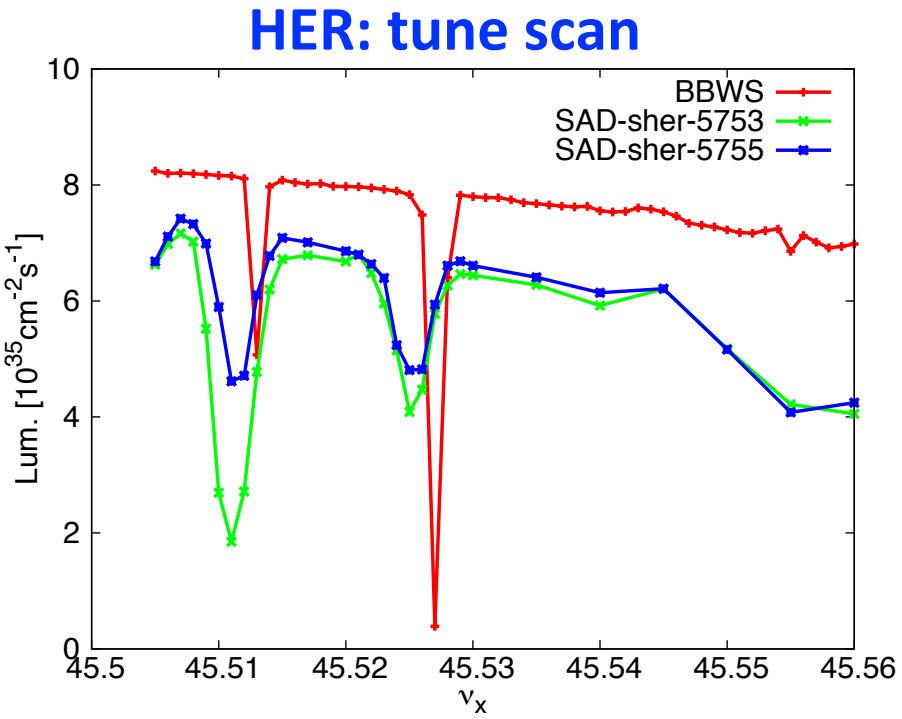


Optics, A. Morita et al.

3. LN: Case of SuperKEKB

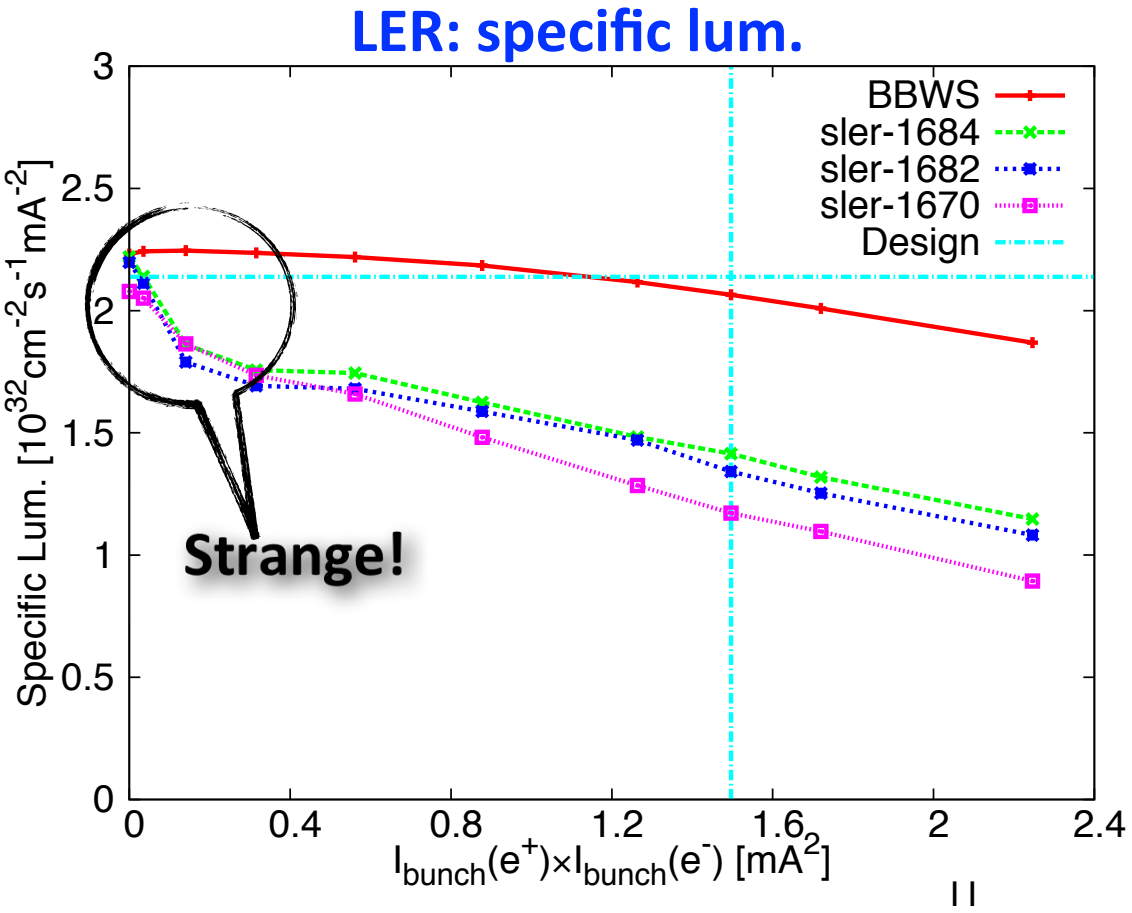
- ➤ Simulations done by BBWS and SAD
- ➤ Significant lum. loss observed
- ➤ LN enhance synchro-betratron resonances (BB: x^2z^2)
- ➤ Loss rate depend on optics design

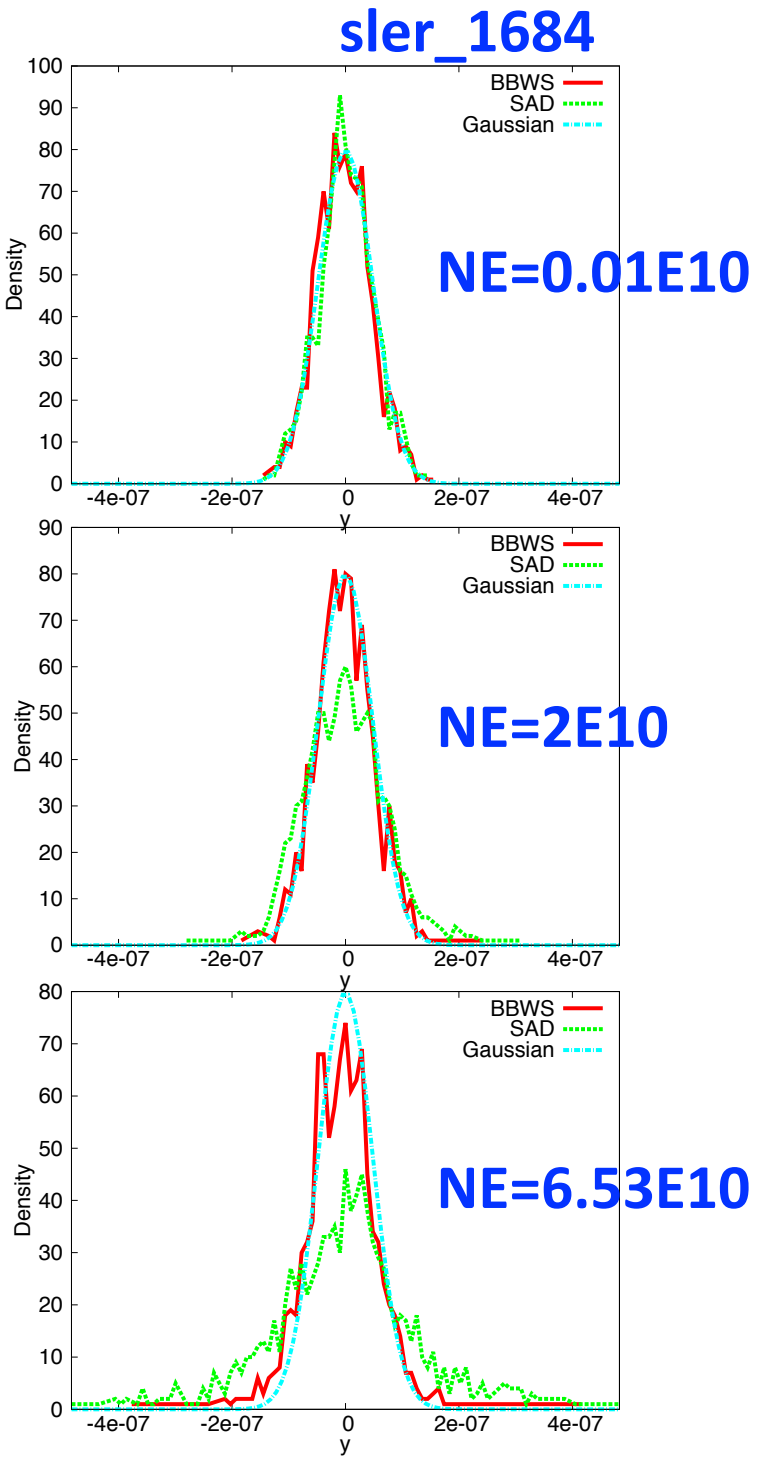




3. LN: Case of SLER

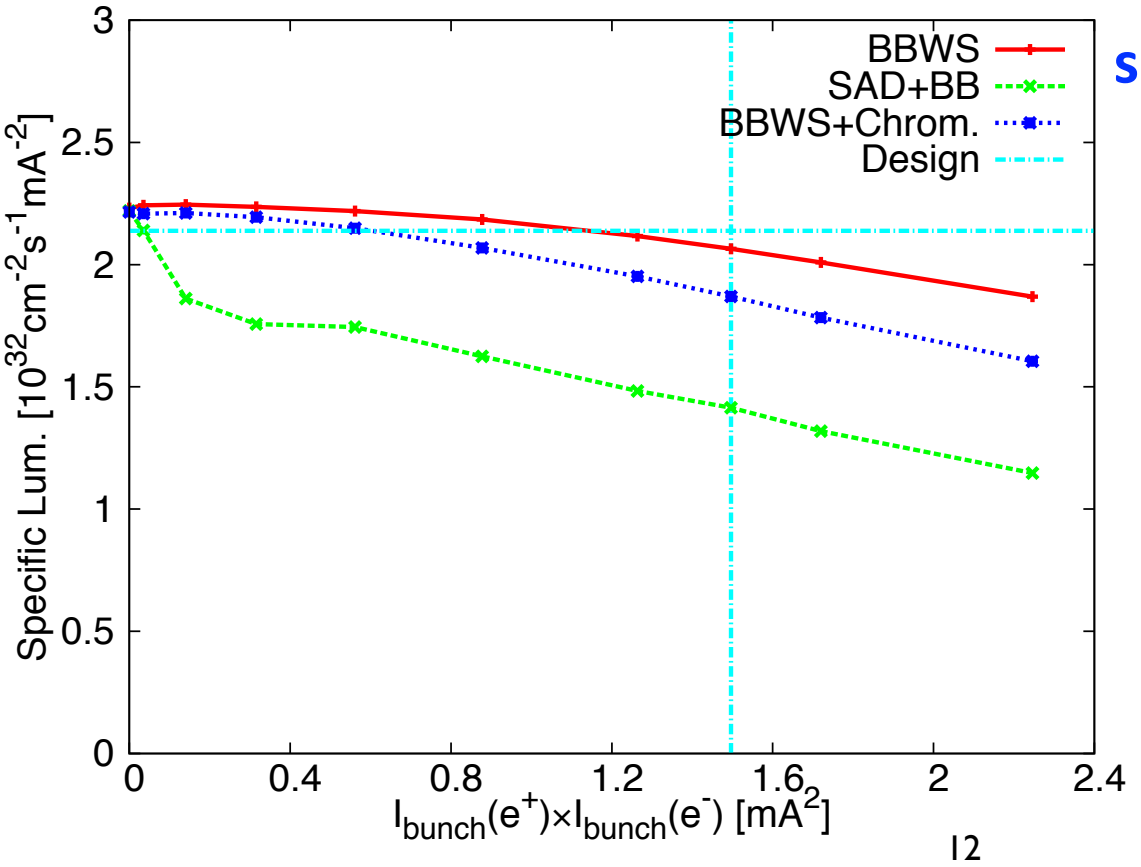
- ➤ Simulations by SAD
- ➤ Direct vert. emit. growth
- ➤ Current dependent





3. LN: Case of SLER

- ➤ Chromatic effect: KEKB experiences
- ➤ Mom. nonlin. controlled in lattice design
- ➤ Chromatic effect can not explain the lum. loss
- ➤ Amplitude-dependent nonlin. more important?



sler_1684

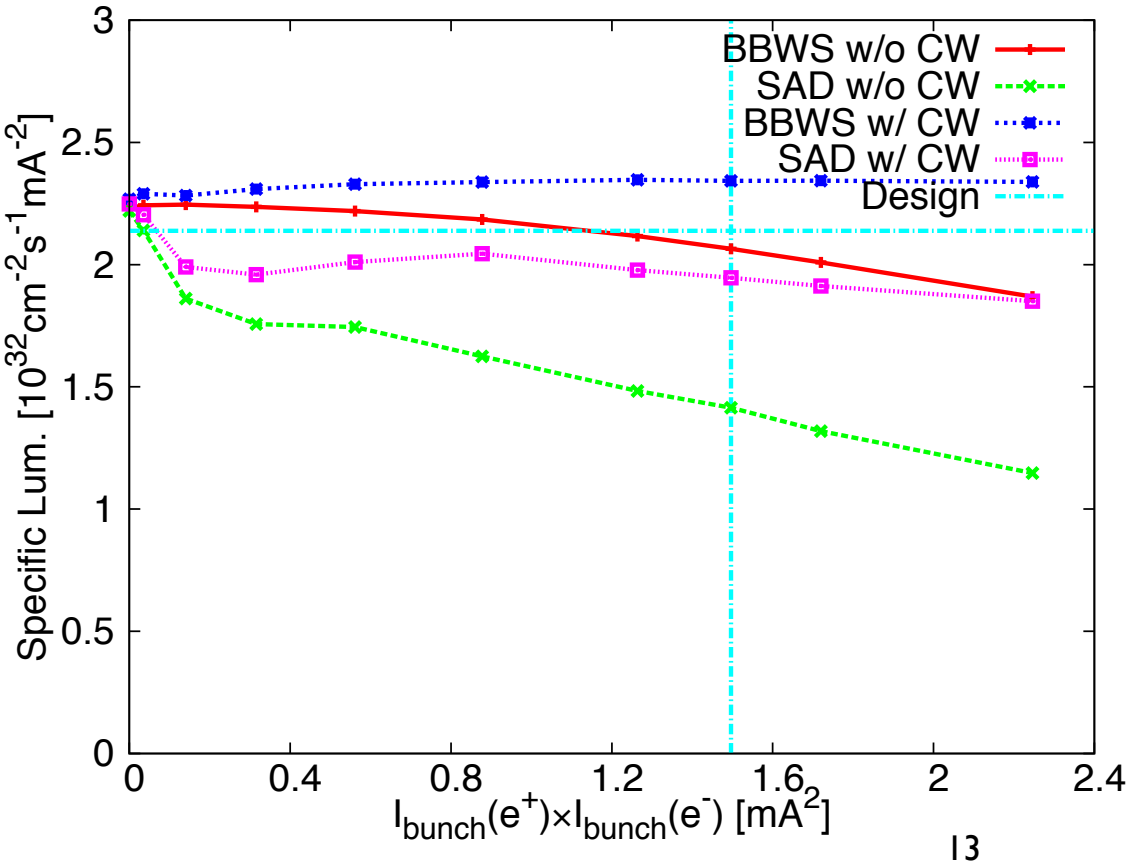
sler_1684

3. LN: Case of SLER: with crab waist

➤ Simple map for crab waist at IP

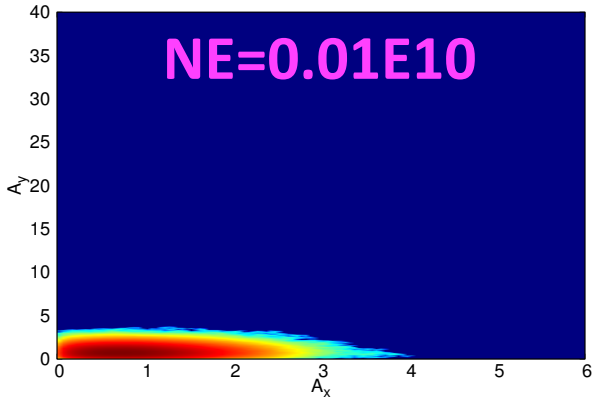
$$p_{x1} = p_{x0} - \frac{1}{2\mathrm{Tan}(2\phi)} p_{y0}^2$$

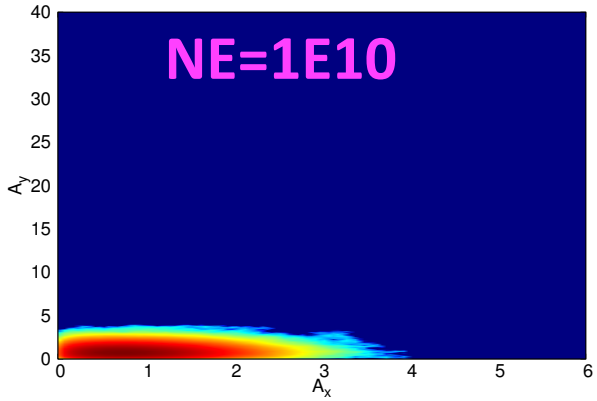
$$y_1 = y_0 + \frac{1}{\mathrm{Tan}(2\phi)} x_0 p_{y0}$$

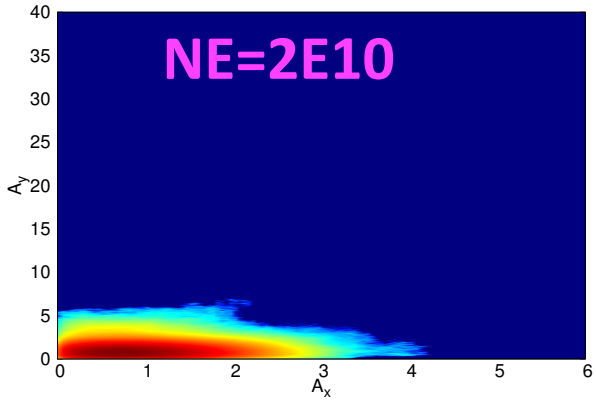


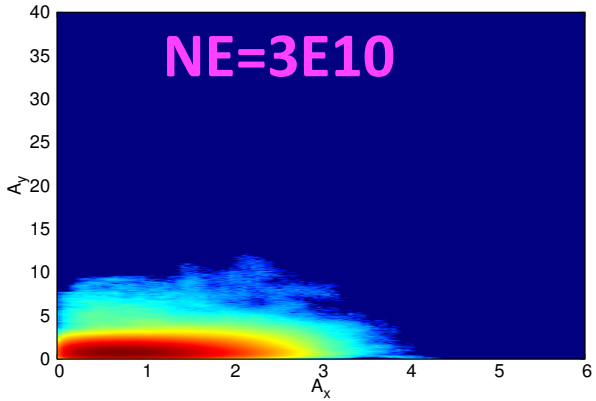
3. LN: Case of SLER

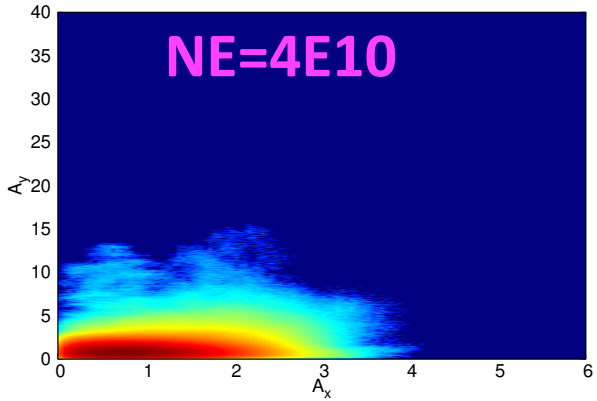
➤ Beam tail w/ BB by BBWS

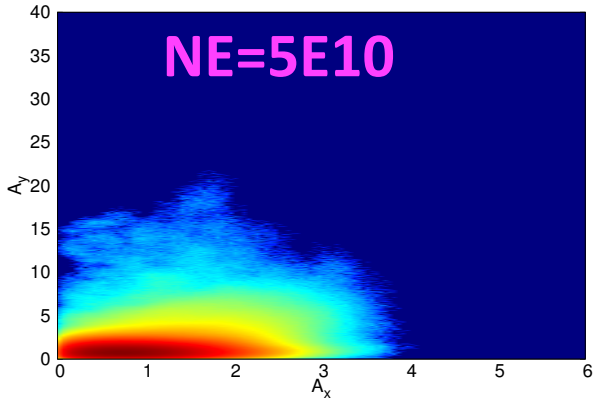


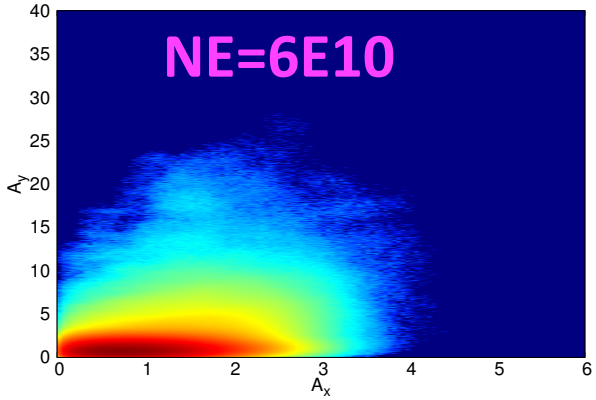


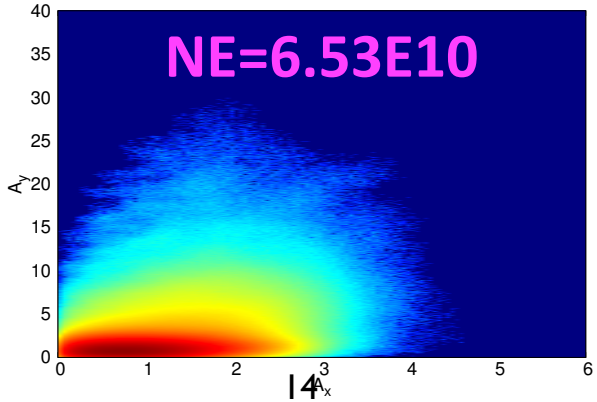












3. LN: Case of SLER

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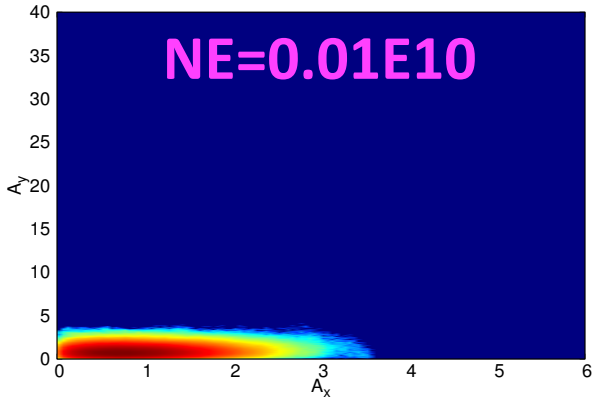
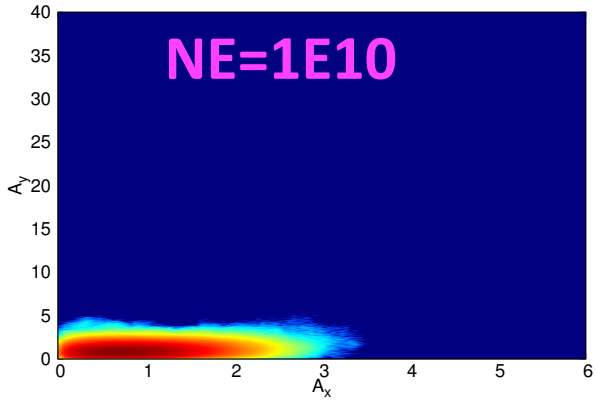
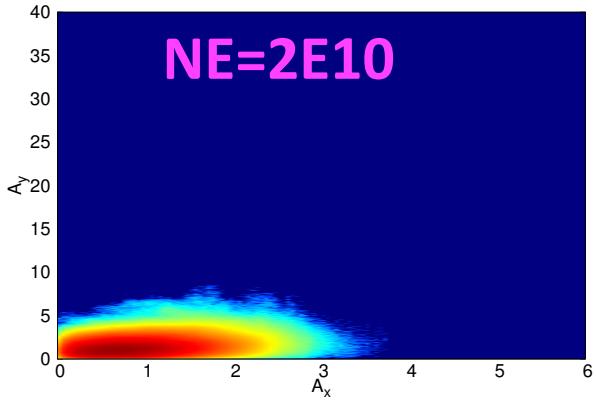
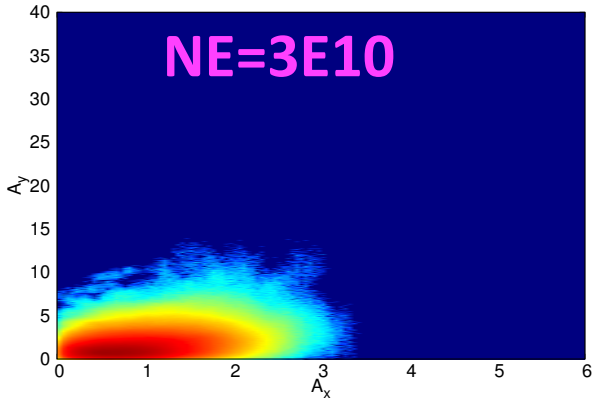
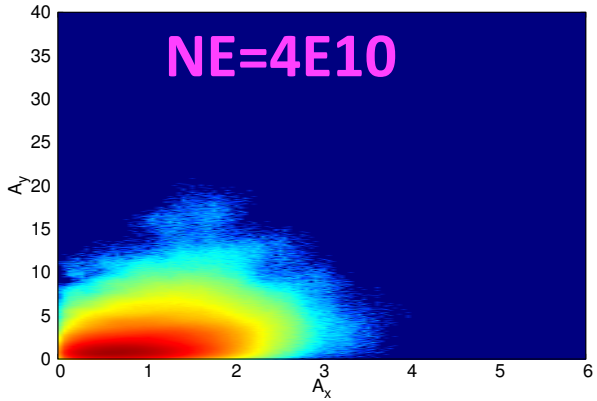
➤ Beam tail w/ BB+LN by SAD

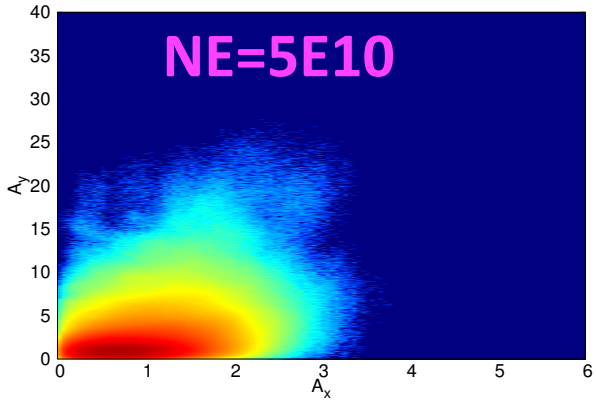


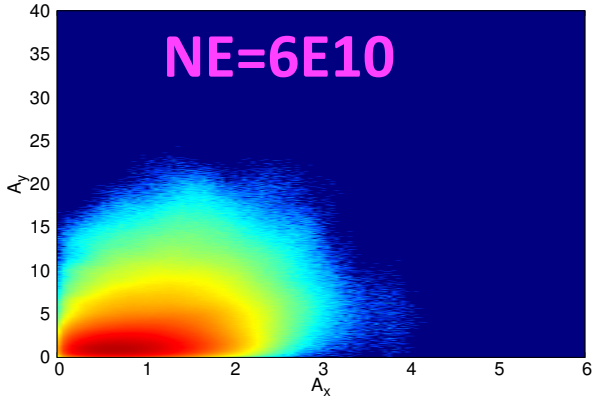


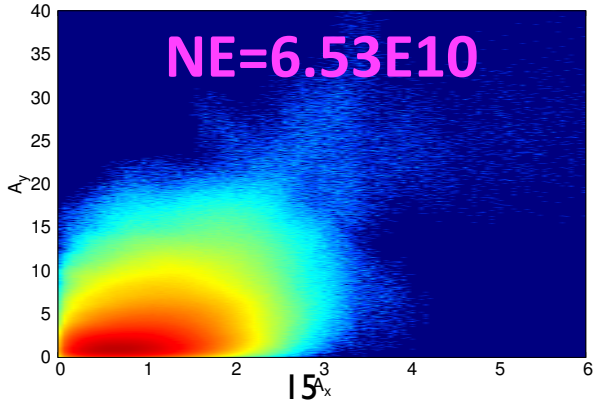






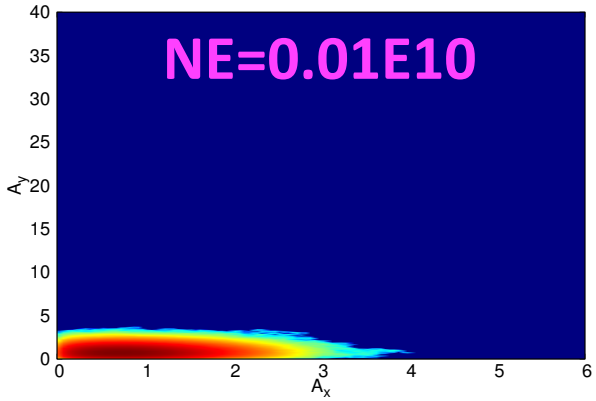


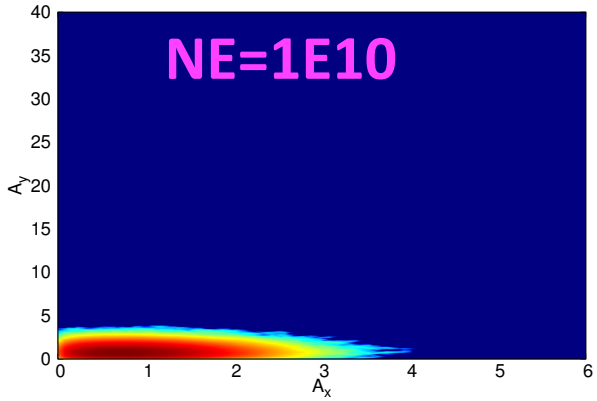


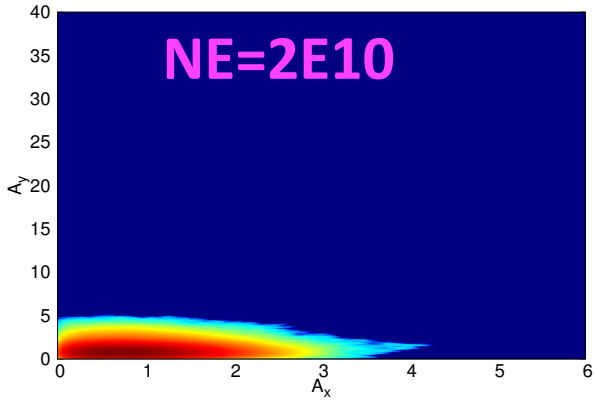


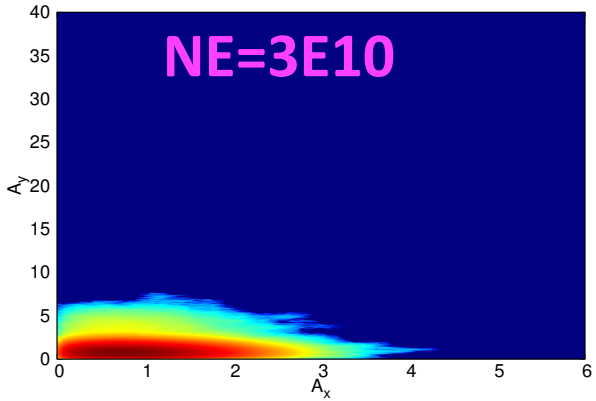
3. LN: Case of SLER

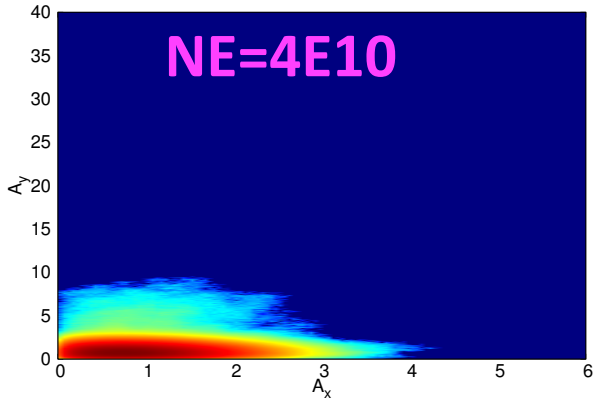
➤ Beam tail w/ BB+CW by BBWS

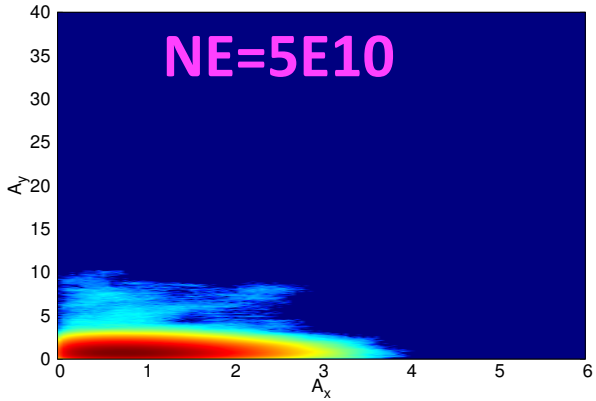


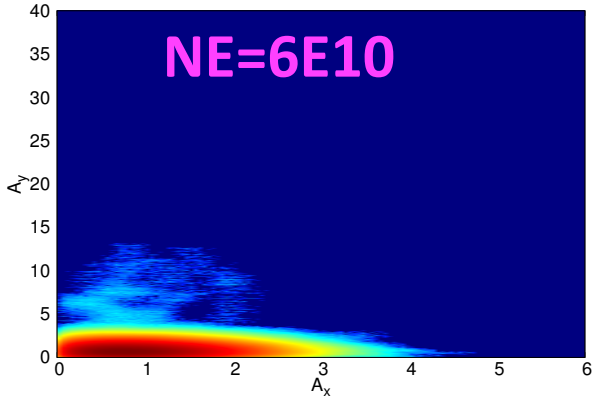


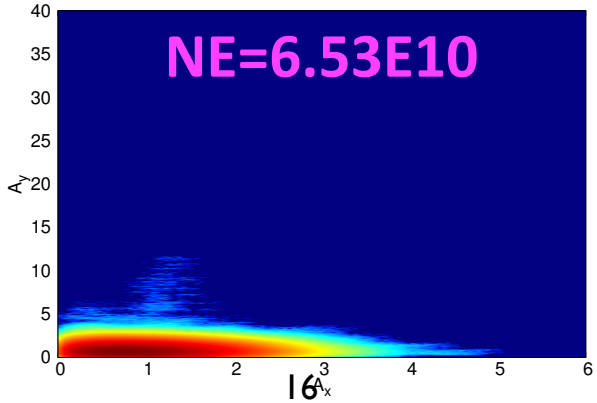








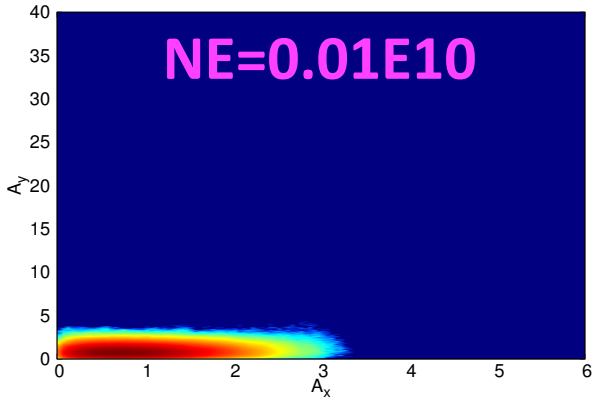


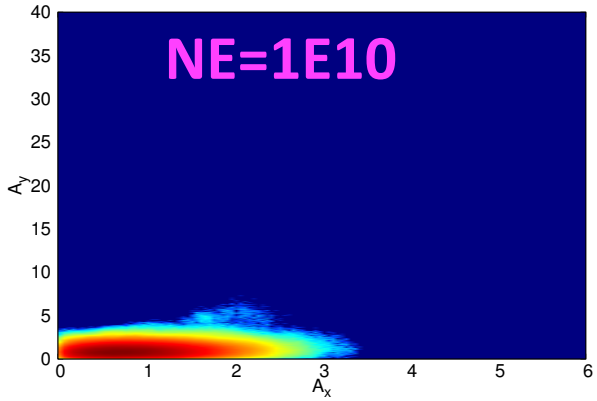


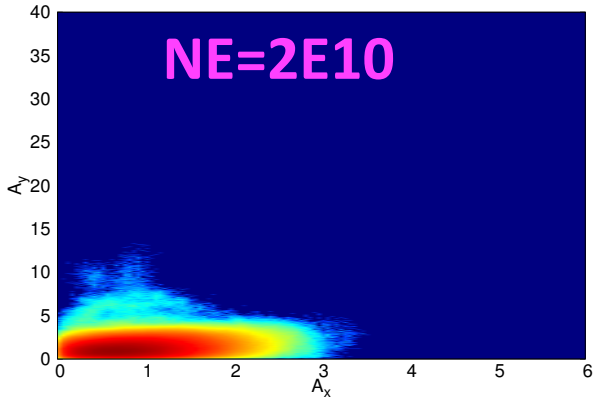
3. LN: Case of SLER

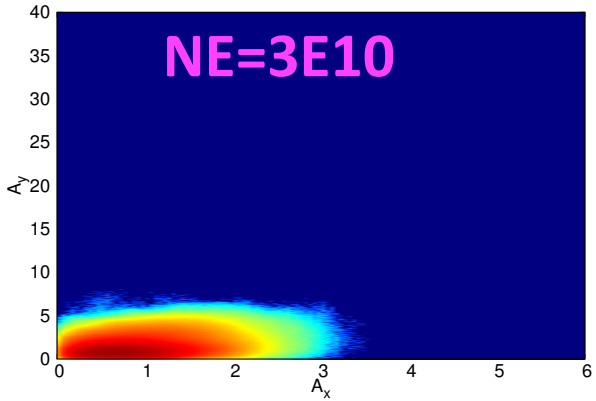
sler_1684

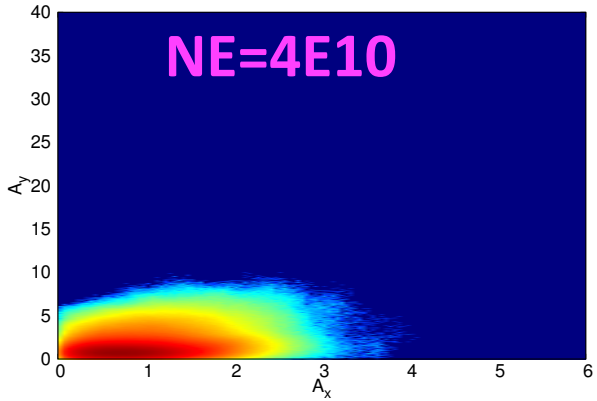
➤ Beam tail w/ BB+CW+LN by SAD

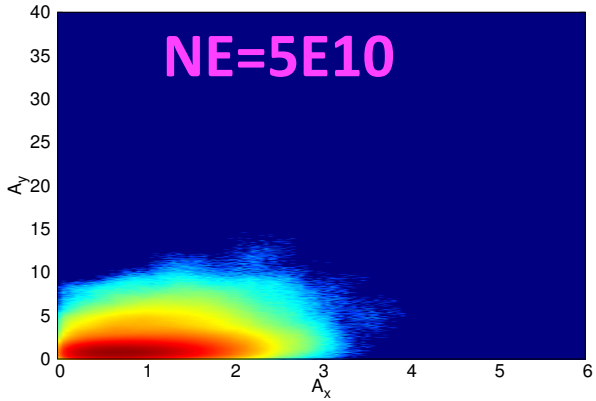


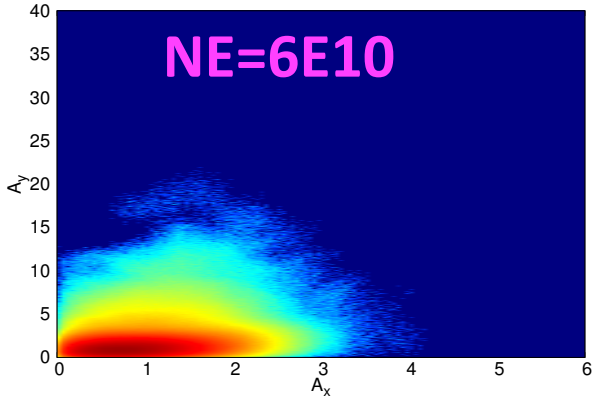


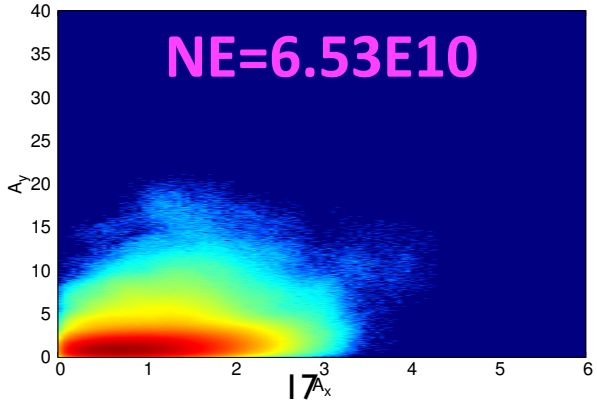








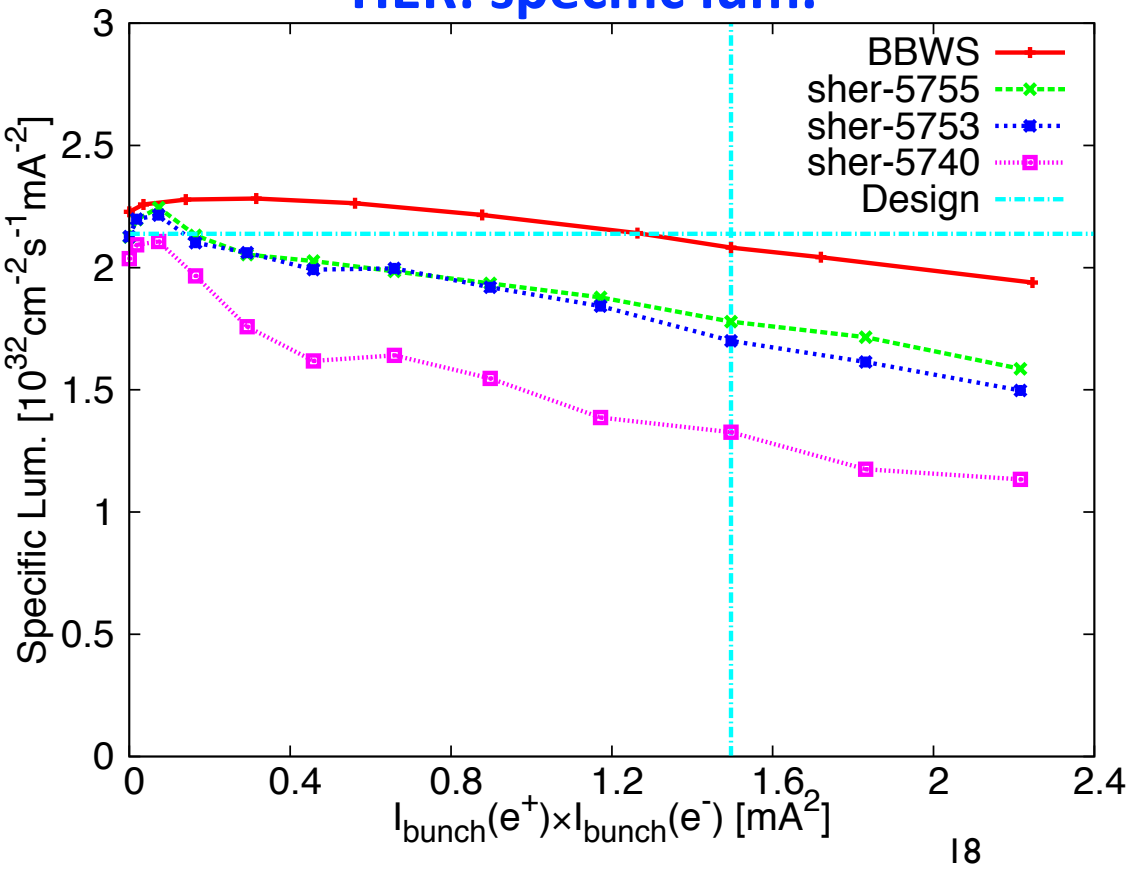




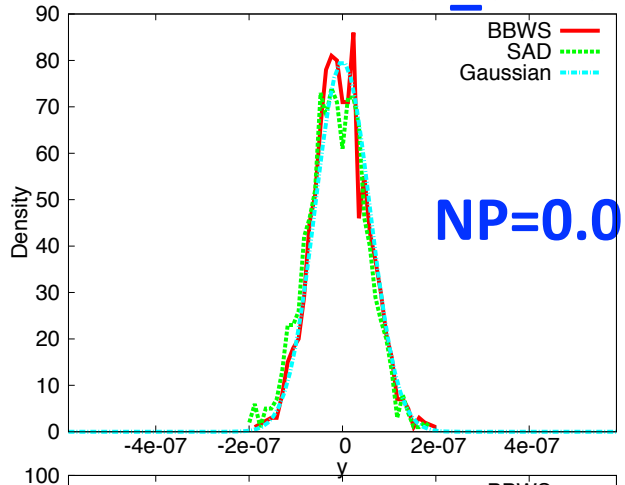
3. LN: Case of SHER

- ➤ Simulations by SAD
- ➤ Direct vert. emit. growth
- ➤ Current dependent

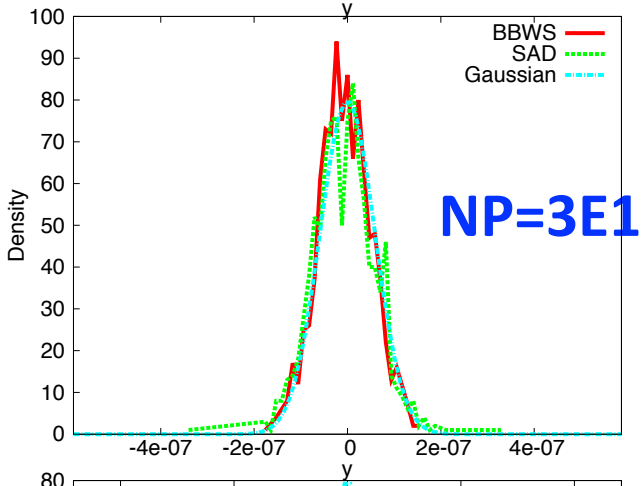
HER: specific lum.



sher_5755



NP=0.01E10



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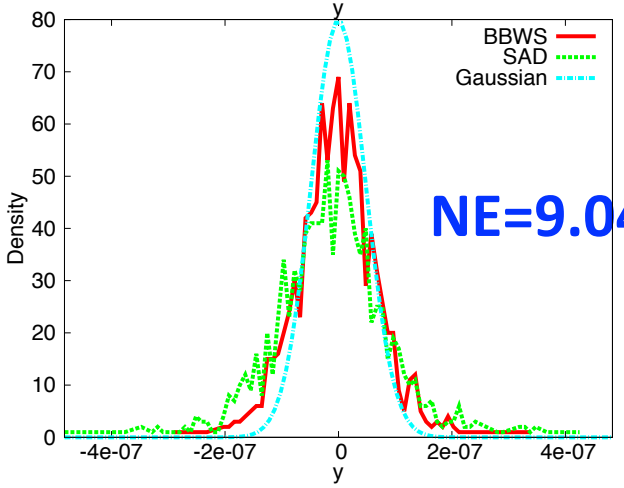
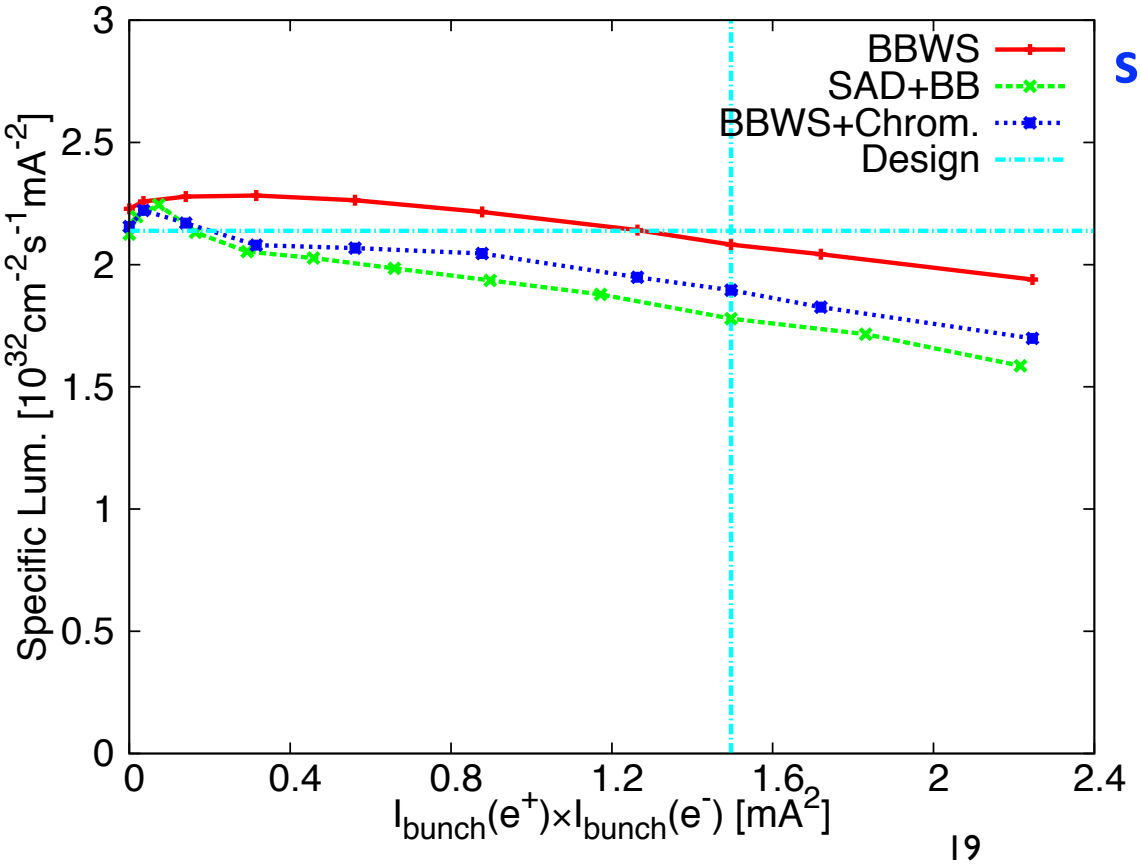


NE=9.04E10

3. LN: Case of SHER

- ➤ Chromatic effect: KEKB experiences
- ➤ Mom. nonlin. not controlled in lattice design
- ➤ The lum. loss is mainly due to chromatic effect



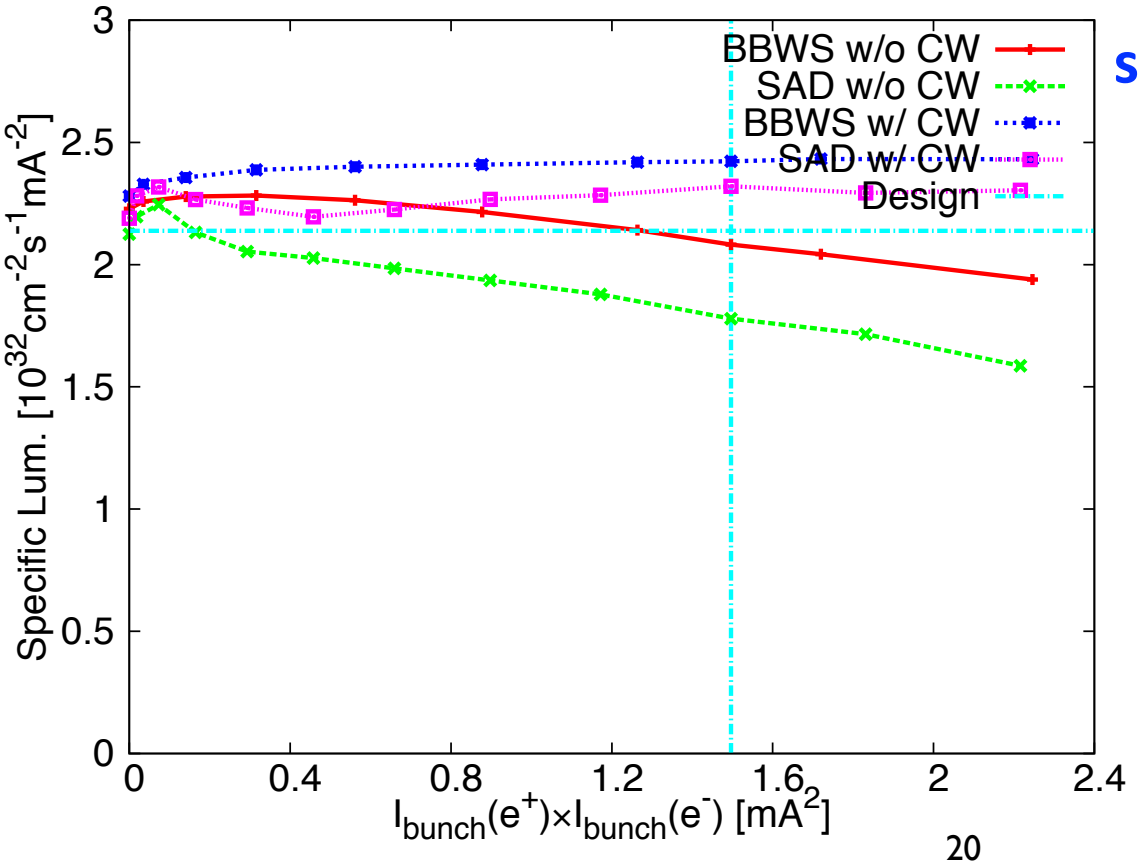
sher_5755

3. LN: Case of SHER: with crab waist

➤ Simple map for crab waist at IP

$$p_{x1} = p_{x0} - \frac{1}{2\mathrm{Tan}(2\phi)} p_{y0}^2$$

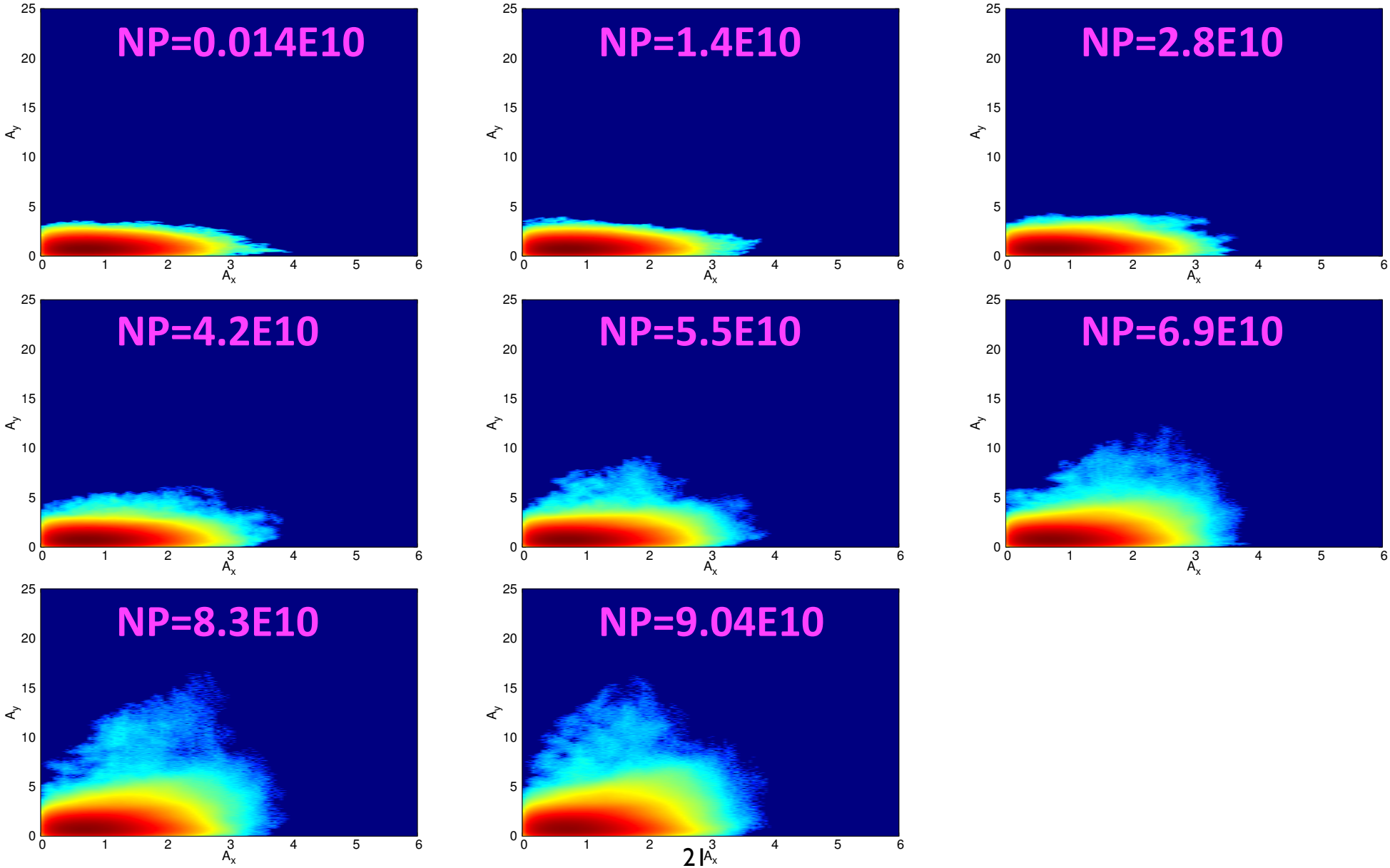
$$y_1 = y_0 + \frac{1}{\mathrm{Tan}(2\phi)} x_0 p_{y0}$$



sher_5755

3. LN: Case of SHER

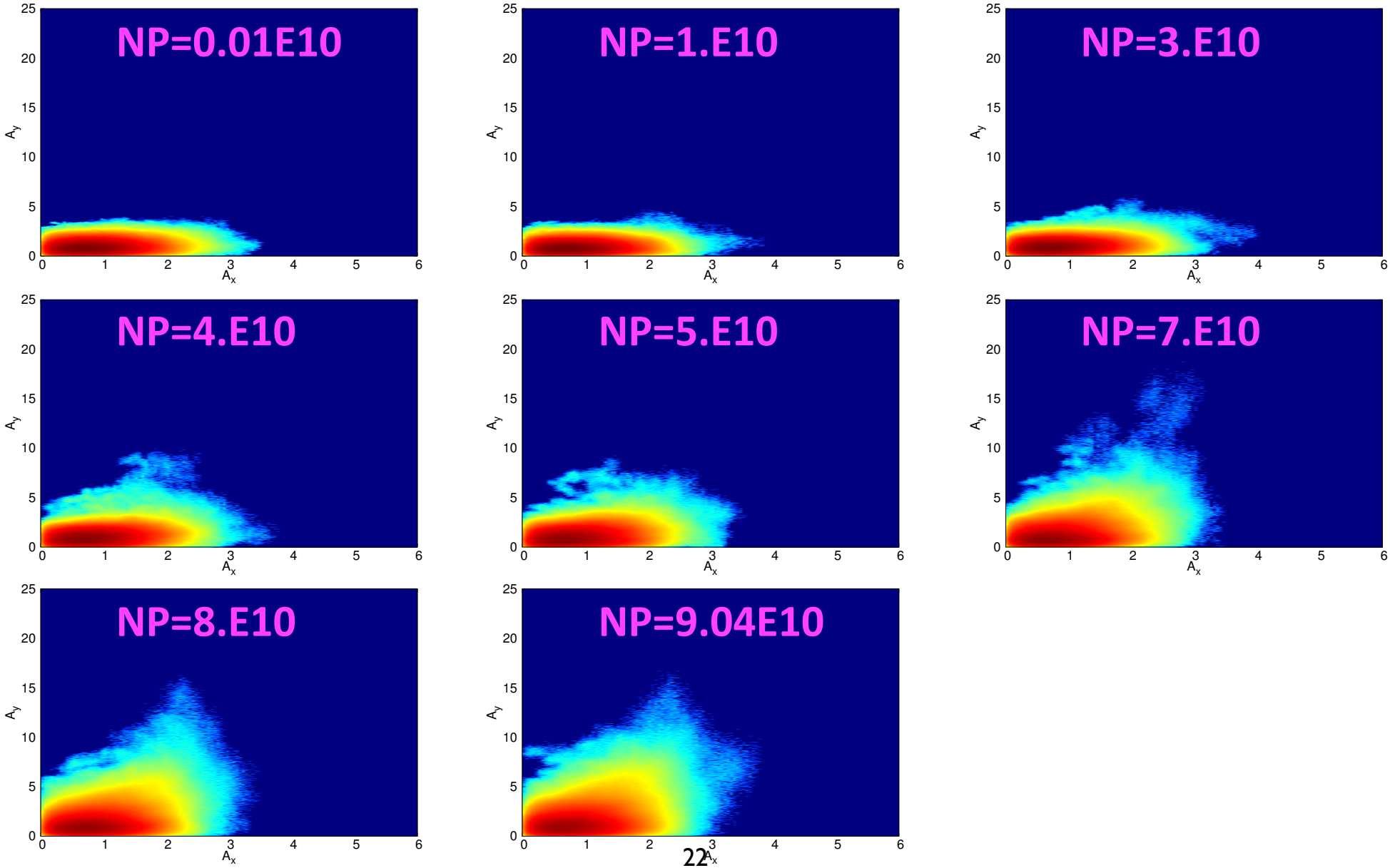
➤ Beam tail w/ BB by BBWS



3. LN: Case of SHER

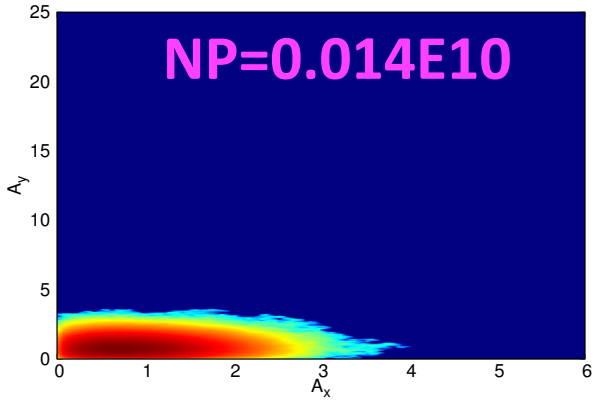
sher_5755

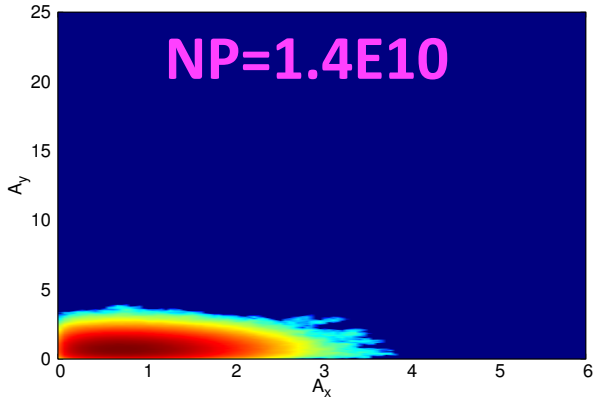
➤ Beam tail w/ BB+LN by SAD

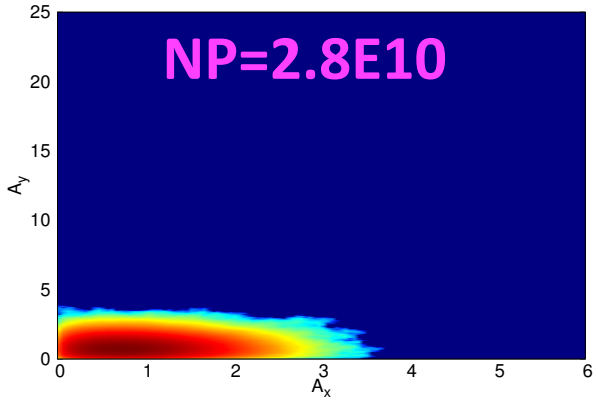


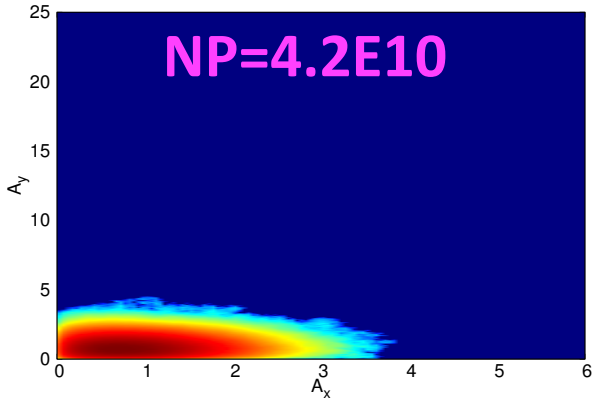
3. LN: Case of SHER

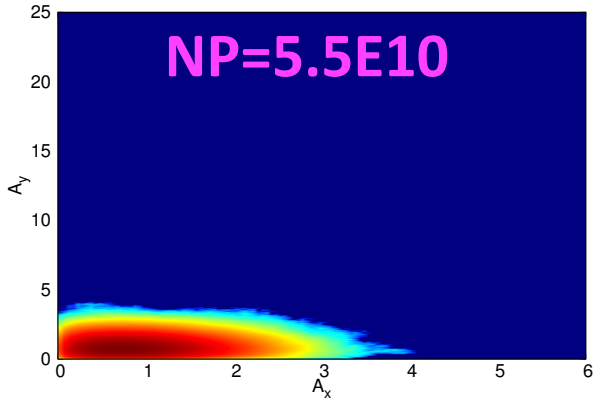
➤ Beam tail w/ BB+CW by BBWS

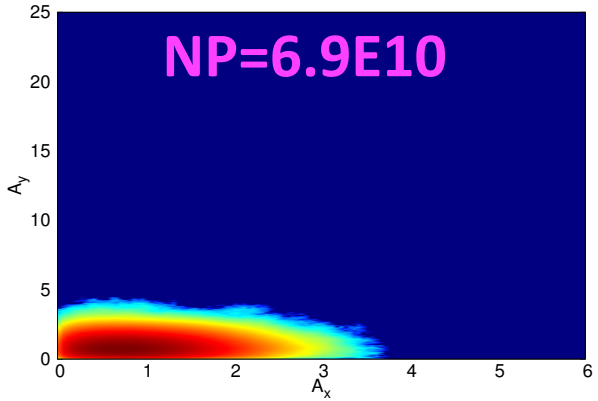


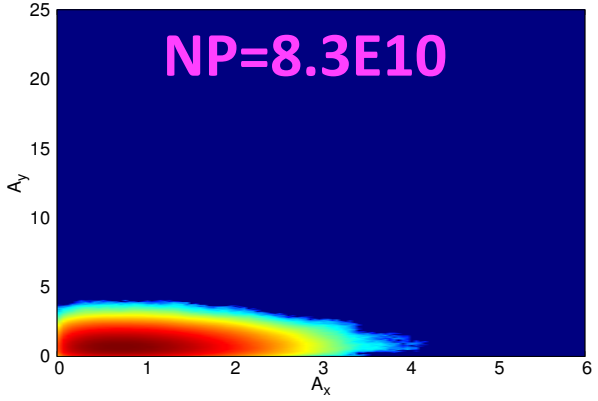


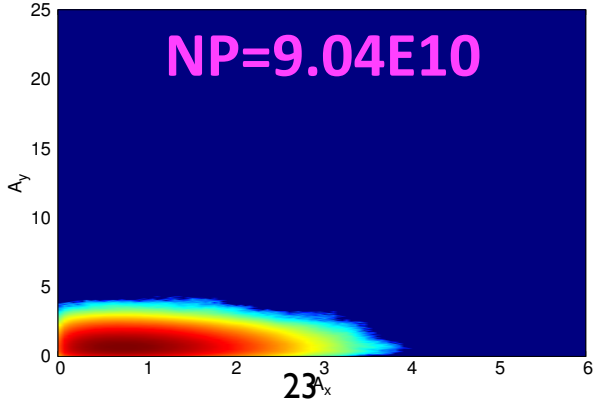








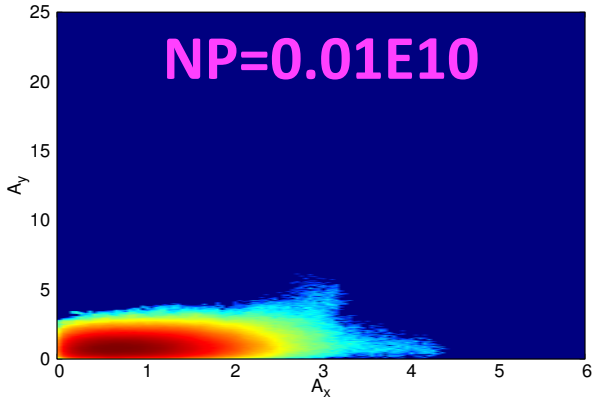


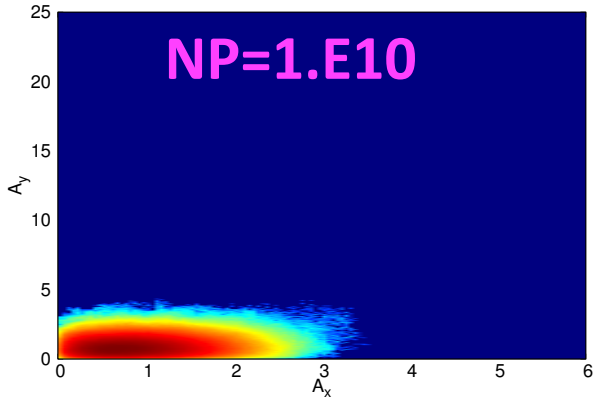


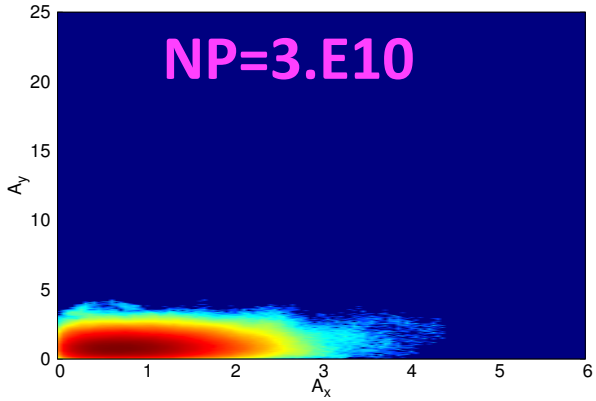
3. LN: Case of SHER

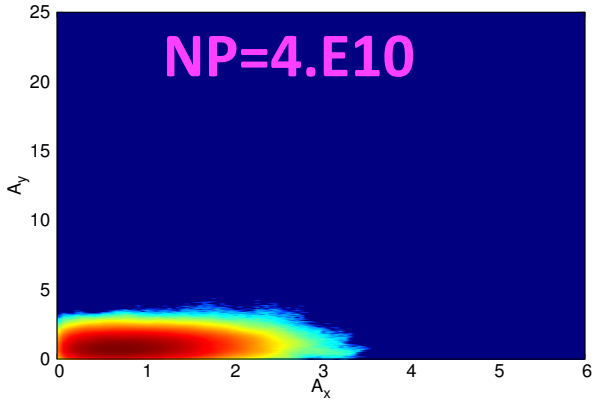
sher_5755

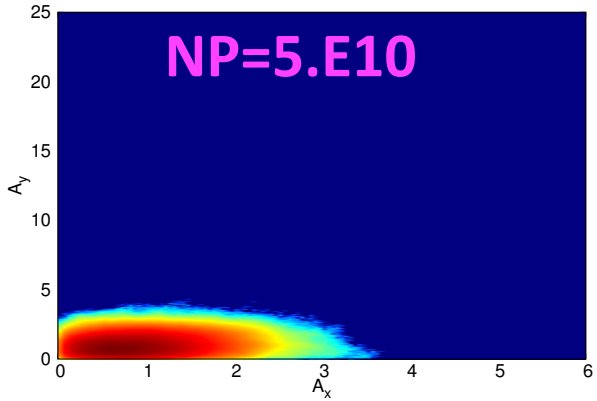
➤ Beam tail w/ BB+CW+LN by SAD

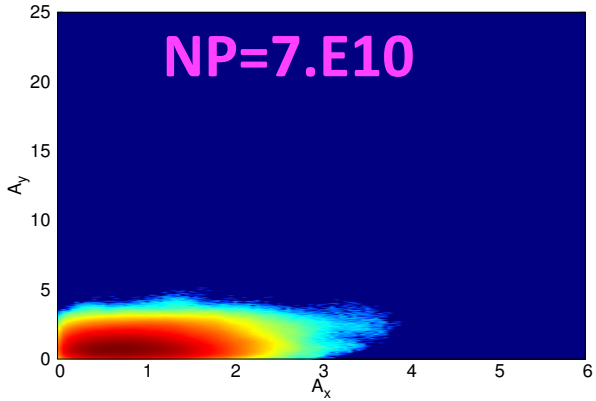


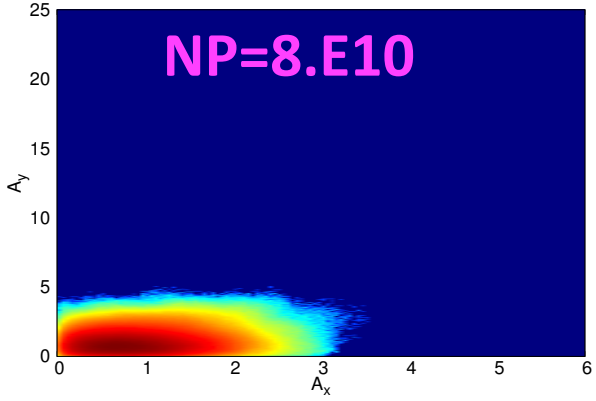


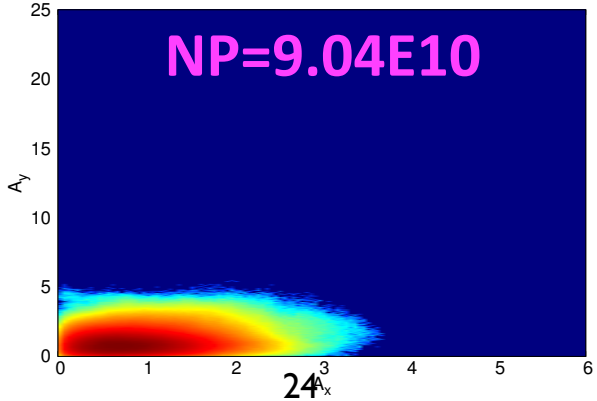












4. SC: Case of SuperKEKB LER

➤ **Linear tune shift**

- Same order for SC and BB
- But with opposite signs

$$\Delta\nu_i = -\frac{1}{4\pi}\frac{2r_e}{\beta^2\gamma^3}\int_0^C \frac{\lambda\beta_i}{\sigma_i(\sigma_x+\sigma_y)}ds$$

$$i = x, y \qquad \lambda(s) = N/\sqrt{2\pi}\sigma_z(s)$$

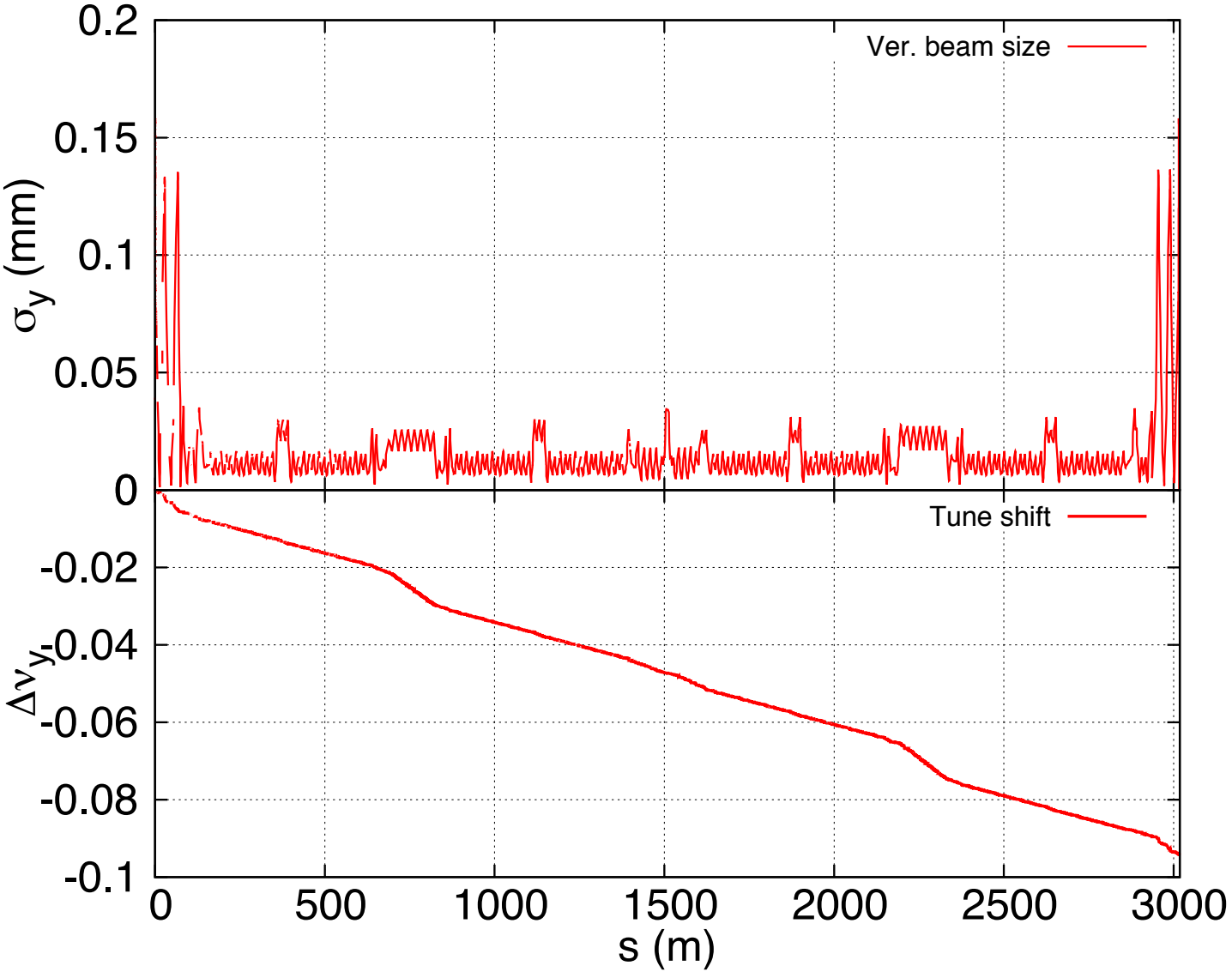
$$\sigma_x^2 = \epsilon_x\beta_x + \langle\delta^2\rangle D^2$$

	SuperKEKB[1]		KEKB[4]	
	LER[2]	HER[3]	LER	HER
ε_x (nm)	3.2	4.6	18	24
ε_y (pm)	8.64	11.5	180	240
ξ_x	0.0028	0.0012	0.127	0.102
ξ_y	0.0881	0.0807	0.129	0.09
$\Delta\nu_x$	-0.0027	-0.0004	-0.0005	-3.00E-05
$\Delta\nu_y$	-0.0943	-0.0121	-0.0072	-0.0004

[1] Main paraperters from Y. Ohnishi et al., Prog. Theor. Exp. Phys. 2012;
[2] sler_1682; [3] sher_5753; [4] Lattice used on Jun.17, 2009.

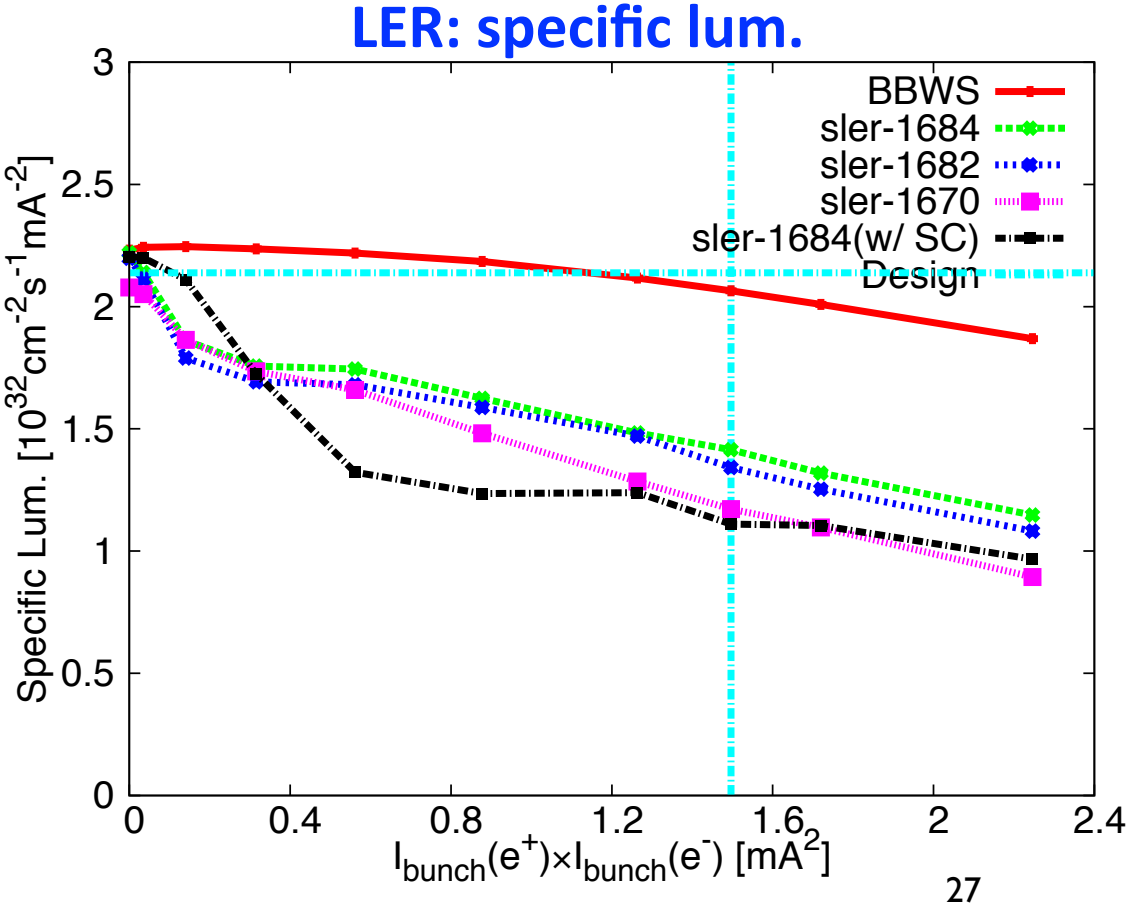
4. SC: Case of SuperKEKB LER

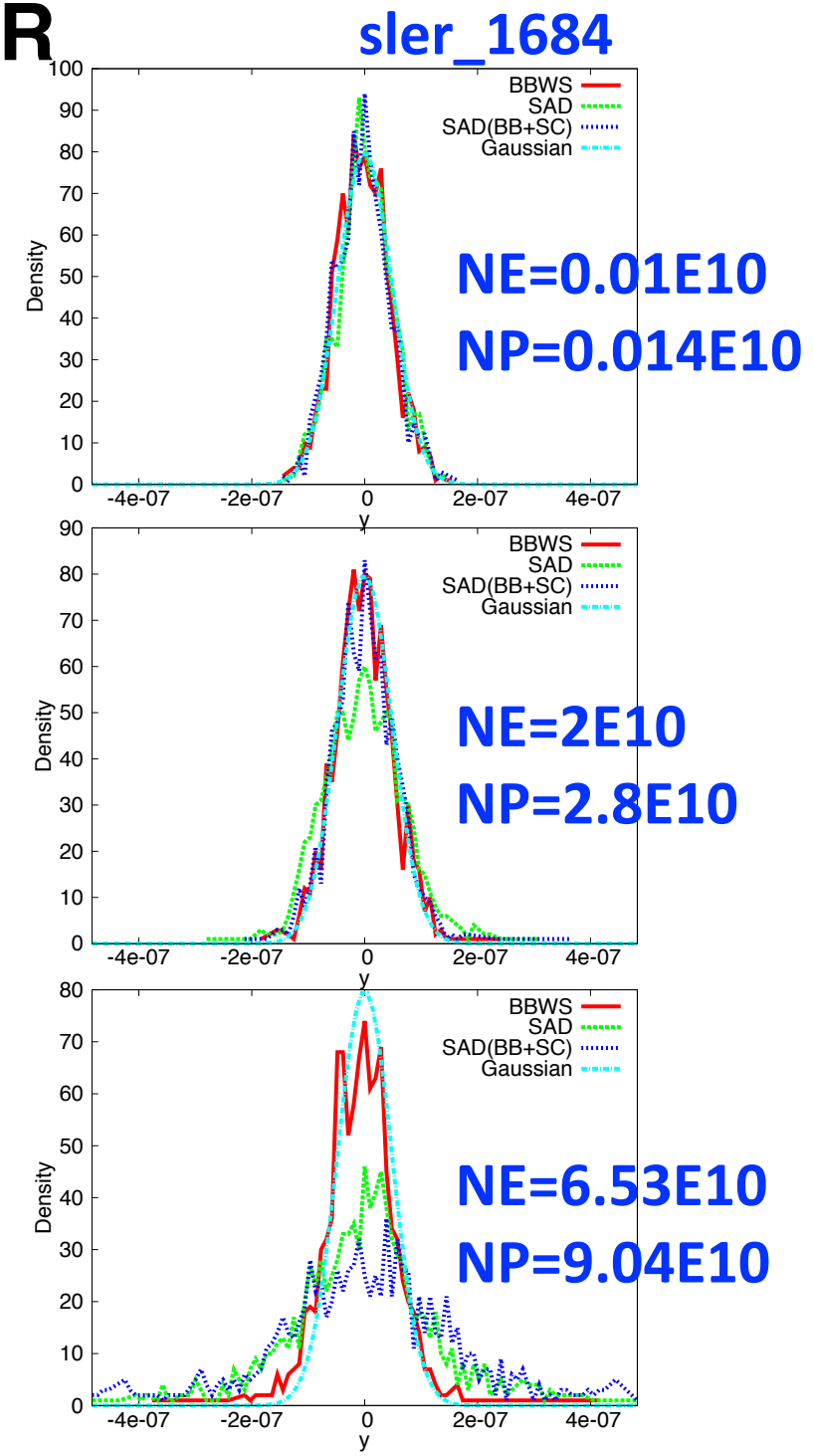
➤ SC tune shift along the ring



4. SC: Case of SuperKEKB LER

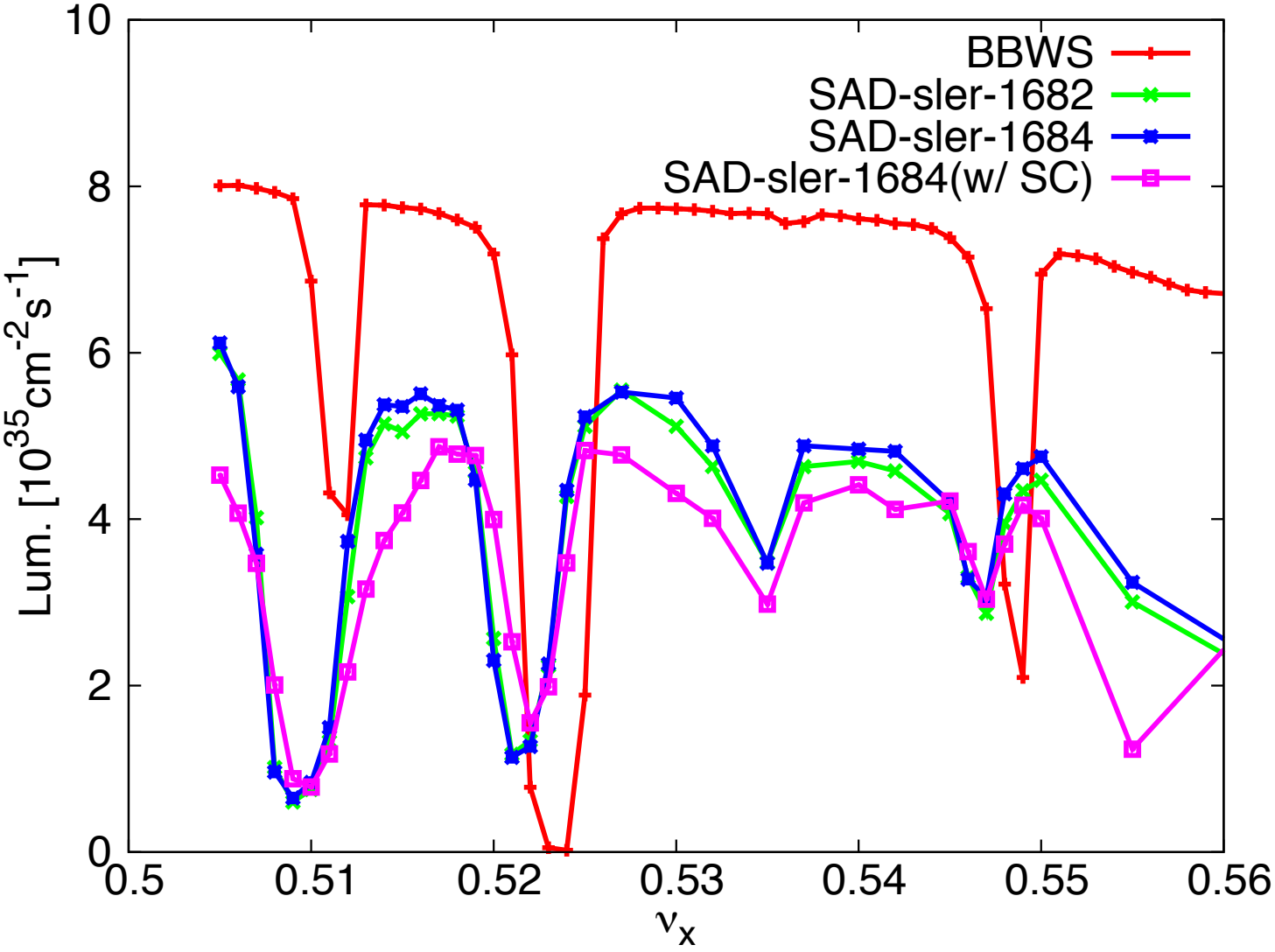
- SC causes lum. degradation
- BB + SC: compensate at low currents?





4. SC: Case of SuperKEKB LER

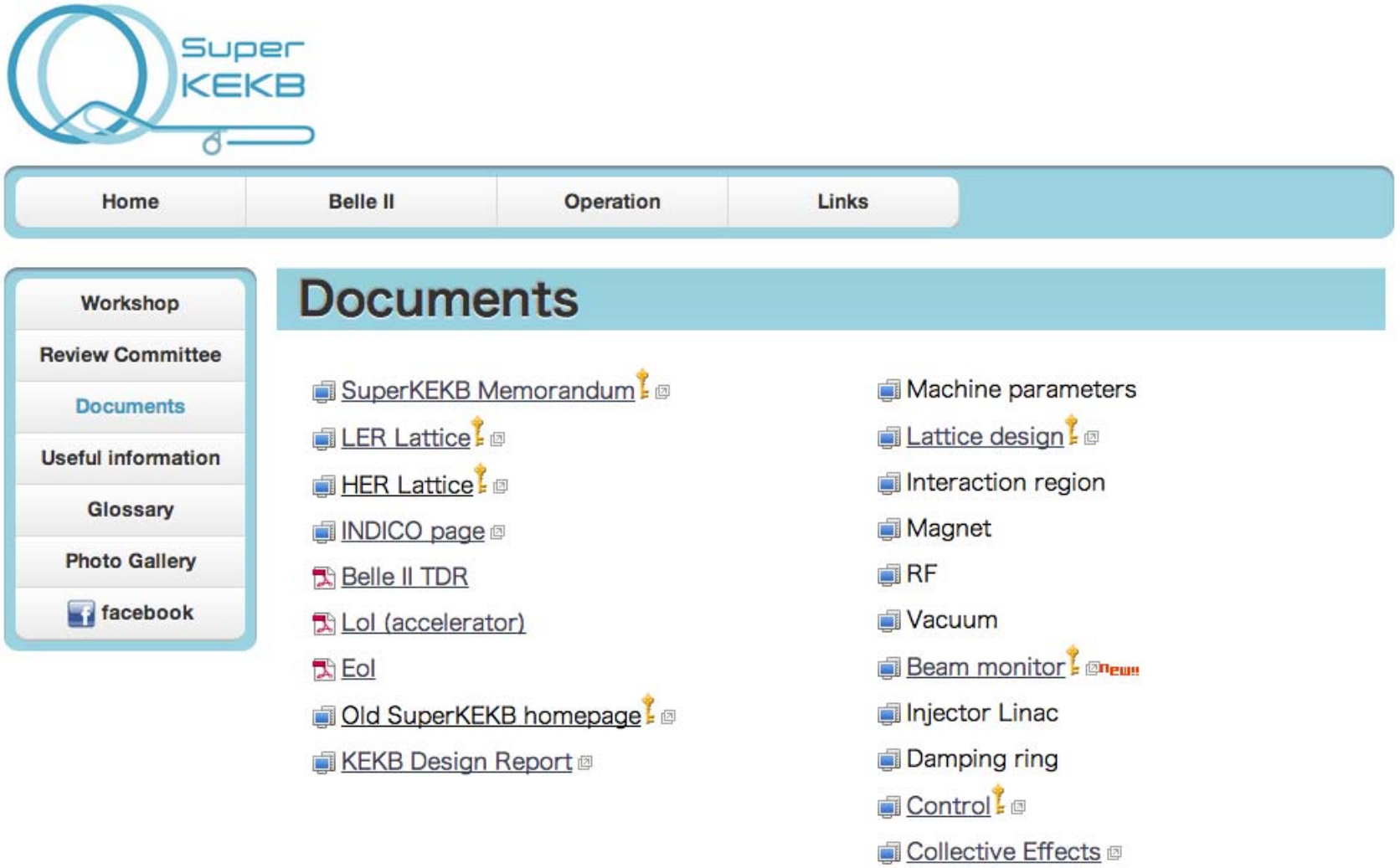
➤ Hor. tune scan



5. Summary and future plan

- **Lattice nonlinearity**
  - Interplay with beam-beam and cause lum. loss
  - Play a role even with crab waist
- **Space charge**
  - Distort footprint in tune space
  - Cause lum. loss
- **Crab waist**
  - Suppress beam-beam resonances
  - Suppress beam tail
  - Performance degraded by LN
- **Future plan**
  - Better understand LN in LER and HER
  - Investigate compensation schemes for SC
  - Collaborate with BINP, IHEP and SLAC teams

➤ **For more information, please look at the SuperKEKB website: http://www-superkekb.kek.jp/documents.html**



Thanks for your attention!