Beam-beam Study of TLEP H and SuperKEKB

D. Zhou and K. Ohmi

Acknowledgements: Y. Funakoshi, H. Koiso, A. Morita,
Y. Ohnishi, K. Oide, H. Sugimoto, and F. Zimmermann

International Workshop on Future High Energy Circular
Colliders, IHEP, Dec. 16, 2013

Outline

- **Introduction**
- **TLEP H**
  - **Baseline and crab waist designs**
  - **Beam-beam (BB) and luminosity performance**
  - **Beamstrahlung**
- **SuperKEKB**
  - **BB and luminosity performance**
  - **Interplay between lattice nonlinearities (LN) and BB**
  - **Space charge (SC) effects**
- **Summary and outlook**

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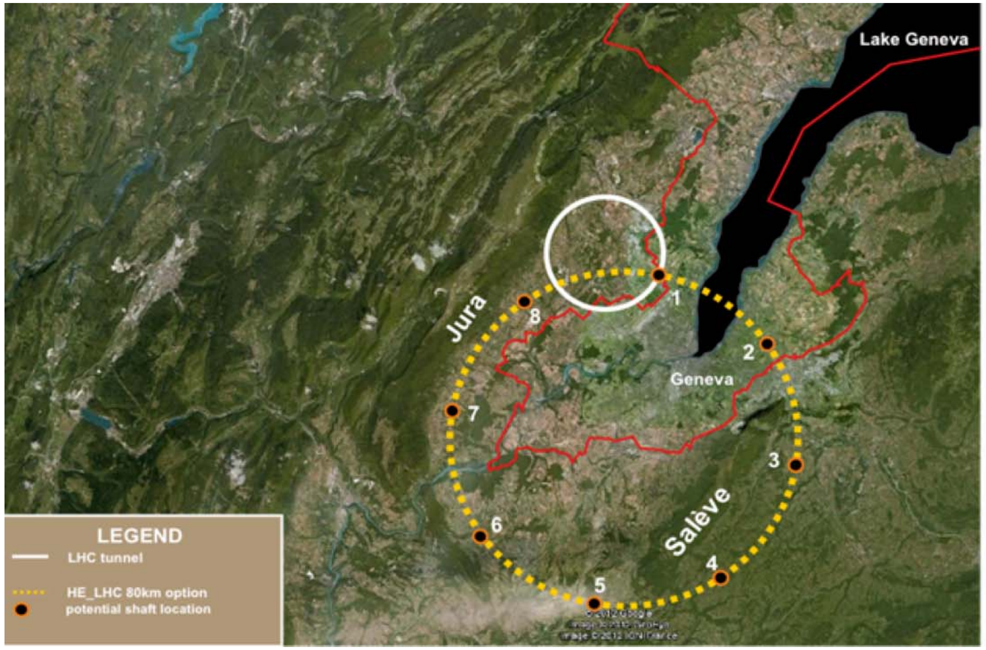
1. Introduction

➤ **TLEP as a future e+e- circular collider to study the Higgs boson and physics at the electroweak scale**

See A. Blondel and F. Zimmermann's talks



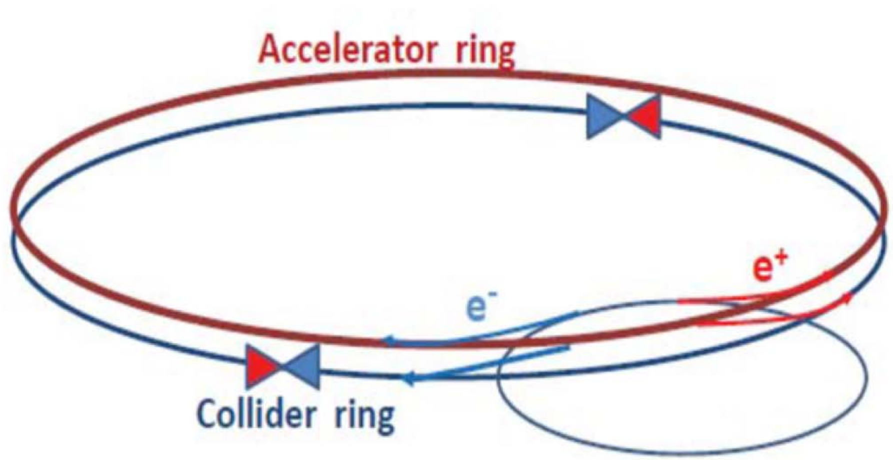
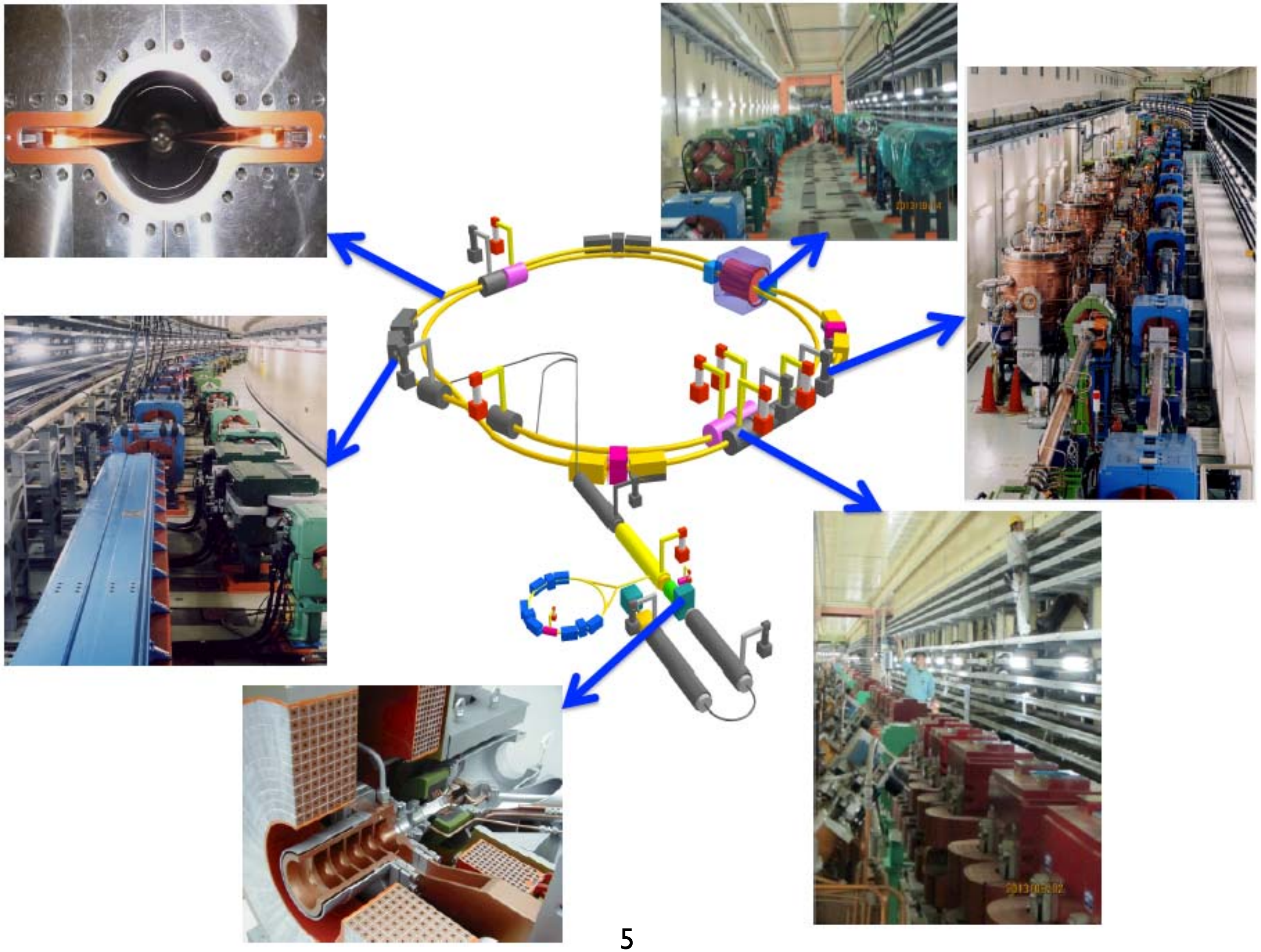


Figure from http://tlep.web.cern.ch/

Possible site and schematic layout for TLEP

1. Introduction

- **SuperKEKB as a B-factory under construction**
- **Beam commissioning starts in Jan. 2015**



Machine parameters

	SuperKEKB[1]		TLEP H	
	LER	HER	Baseline[2]	Crab waist[3]
C(km)	3.016		100	
E(GeV)	4	7.007	120	
# of IPs	1		4	
N_b	2500		167	133
$N_p(10^{11})$	0.904	0.653	3.7	4.5
Xangle	0.083		0	0.07
ε_x(nm)	3.2	4.6	7.5	1
ε_y(pm)	8.64	11.5	15	2
β_x^*(m)	0.032	0.025	0.5	
β_y^*(mm)	0.27	0.3	1	0.8
σ_x(μm)	10.1	10.7	61	22.4
σ_y(μm)	0.048	0.059	0.12	0.04
$\sigma_z(\mathrm{mm})^{SR}$	6	5	0.98	7.5[4]
$\sigma_\delta(10^{-3})^{SR}$	0.808	0.637	1.4	1.4[5]
Lum./IP(10^{34}cm^{-2}s^{-1})	80		5.08	5.5

[1]No crab waist; [2]2013 summer parameters provided by F. Zimmermann; [3]Crab waist option proposed by A. Bogomyakov at TLEP6 Workshop; [4]w/ beamstrahlung; [5]Assumed

1. Introduction

➤ **Features shared by SuperKEKB and TLEP H:**

- **Extremely small vertical emittances**
- **Extremely small vertical beam sizes at IP**
- **Complicated IR**
- **Nonlinear beam dynamics**
- **Sensitivity of machine performance to various perturbations to the beams**
- **… …**

➤ **Challenges in technologies, machine tuning and beam physics will be identified at SuperKEKB**

➤ **The following slides will present a comparison of beam-beam simulations for TLEP H and SuperKEKB**

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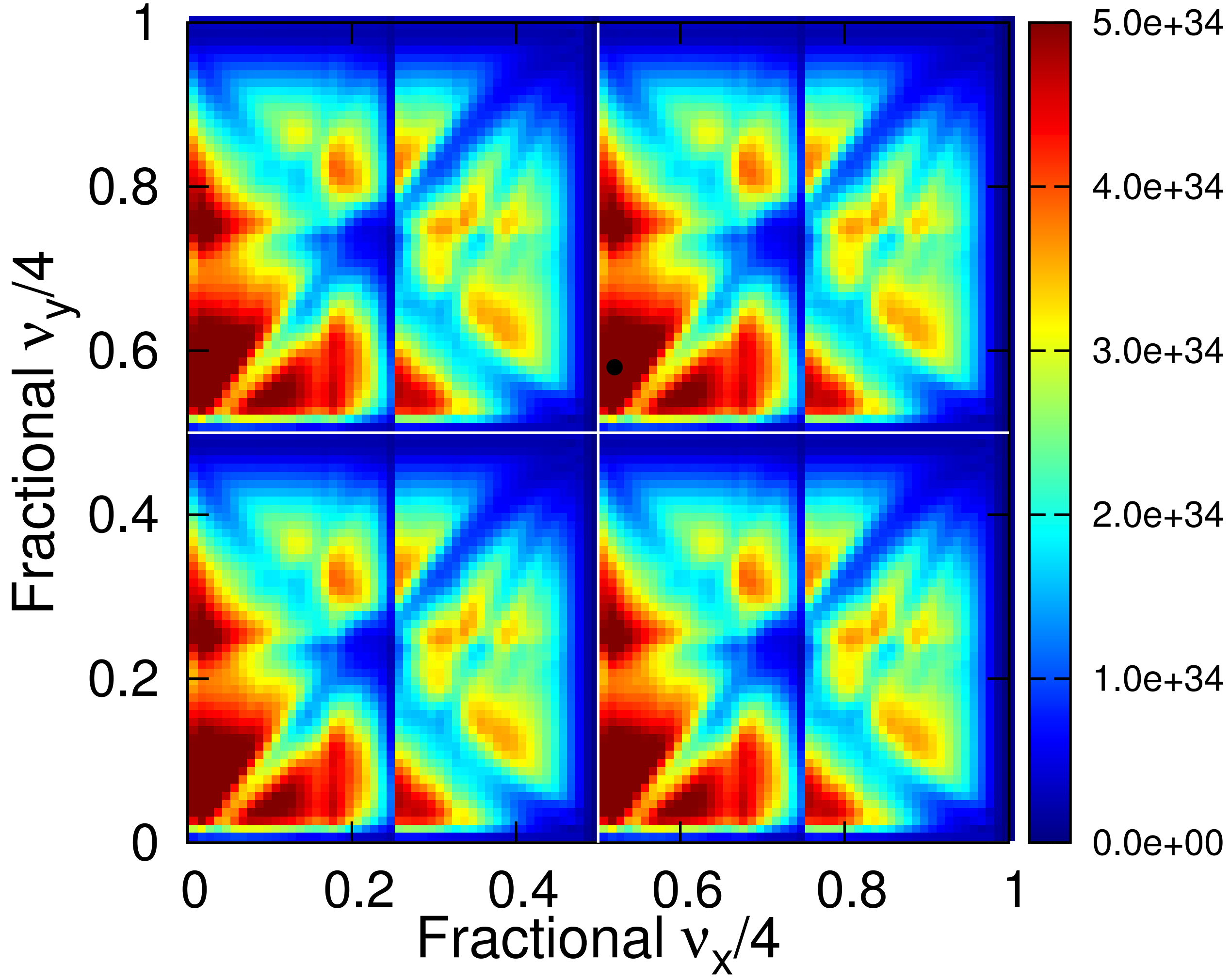
- Summary and outlook

2. TLEP H: Baseline design: Lum. tune scan

➤ **Tune scan for baseline design**

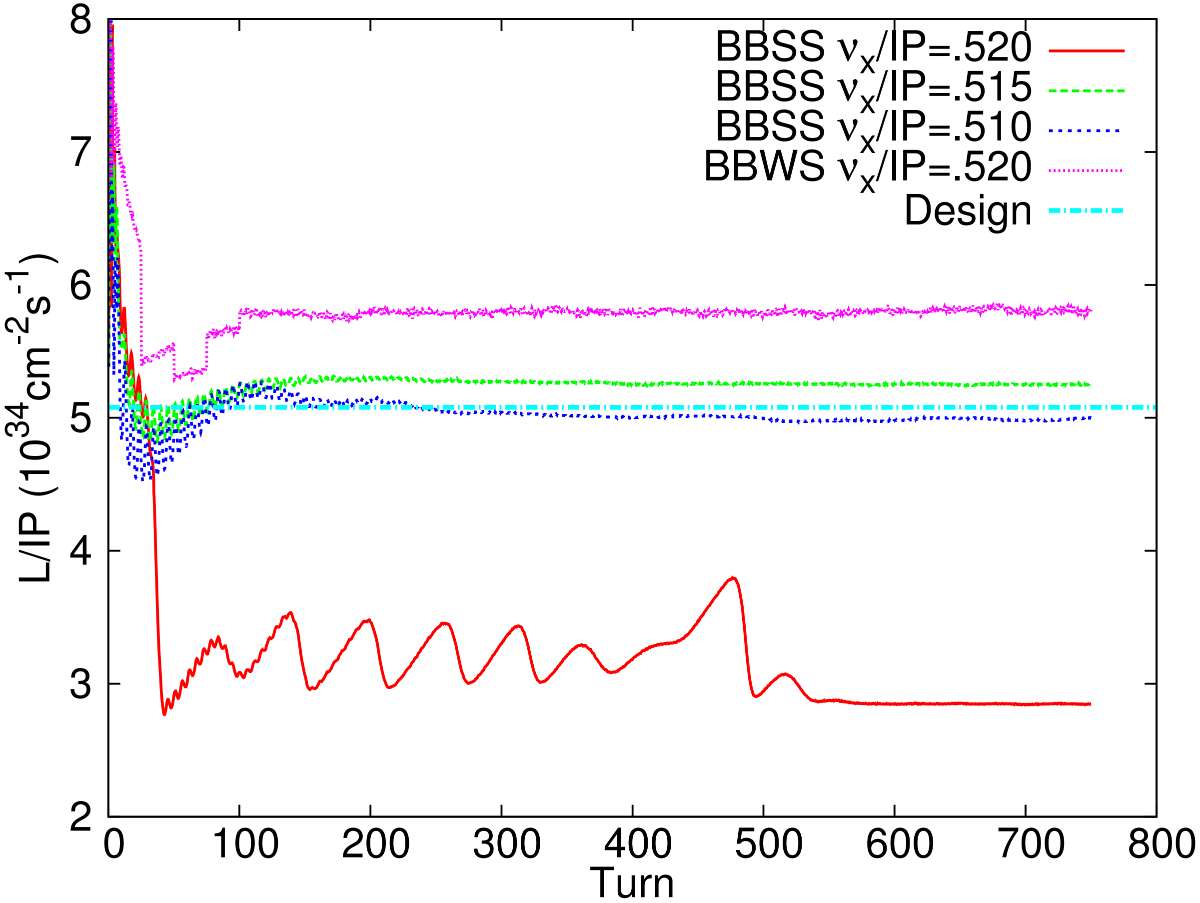
- **Done by BBWS w/ beamstrahlung**
- **Good work point around (.52, .58)×4 IPs**



2. TLEP H: Baseline design: Working point

➤ **Turn-by-turn data for baseline design: luminosity**

- **Done by BBSS w/ beamstrahlung**
- **Beams unstable at work point (.52, .58)×4 IPs**
- **Beams stable at work point (.515, .58)×4 IPs**



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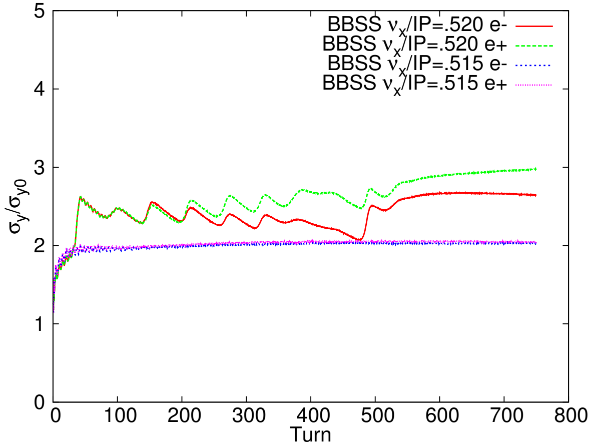
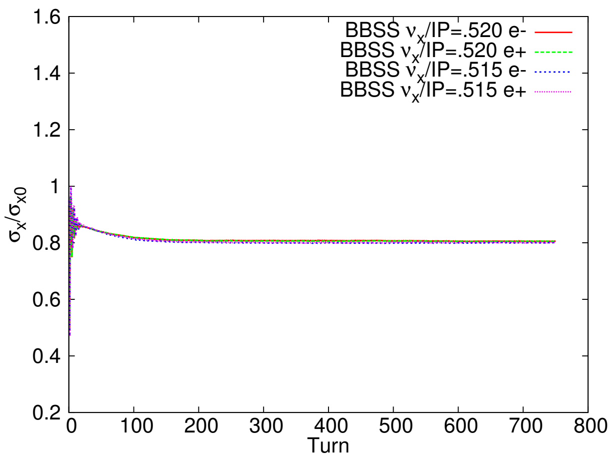
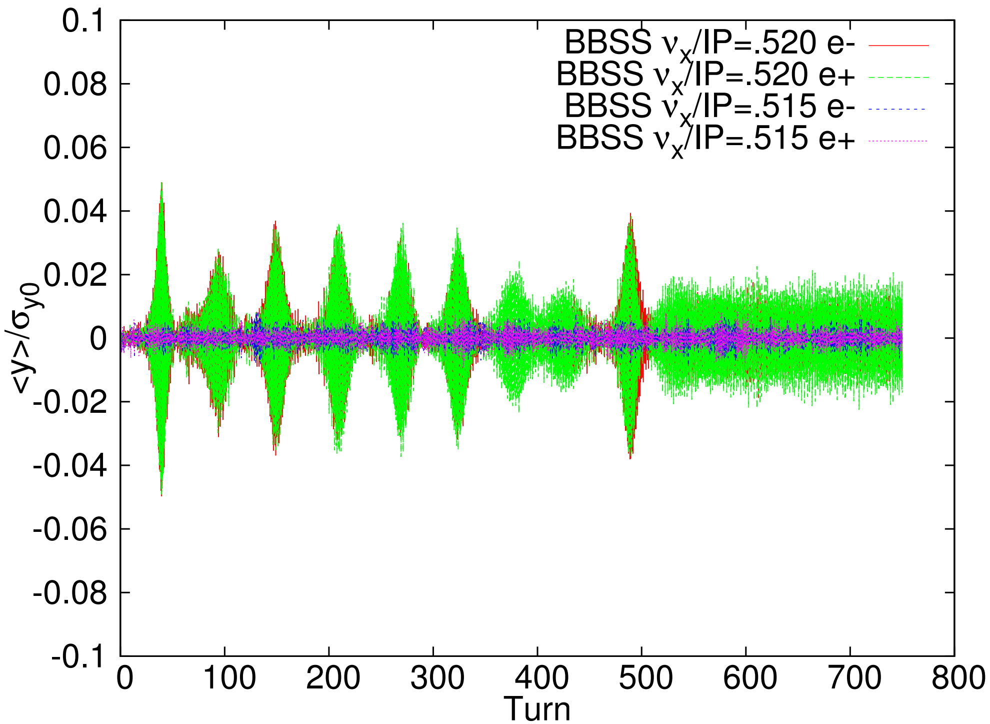


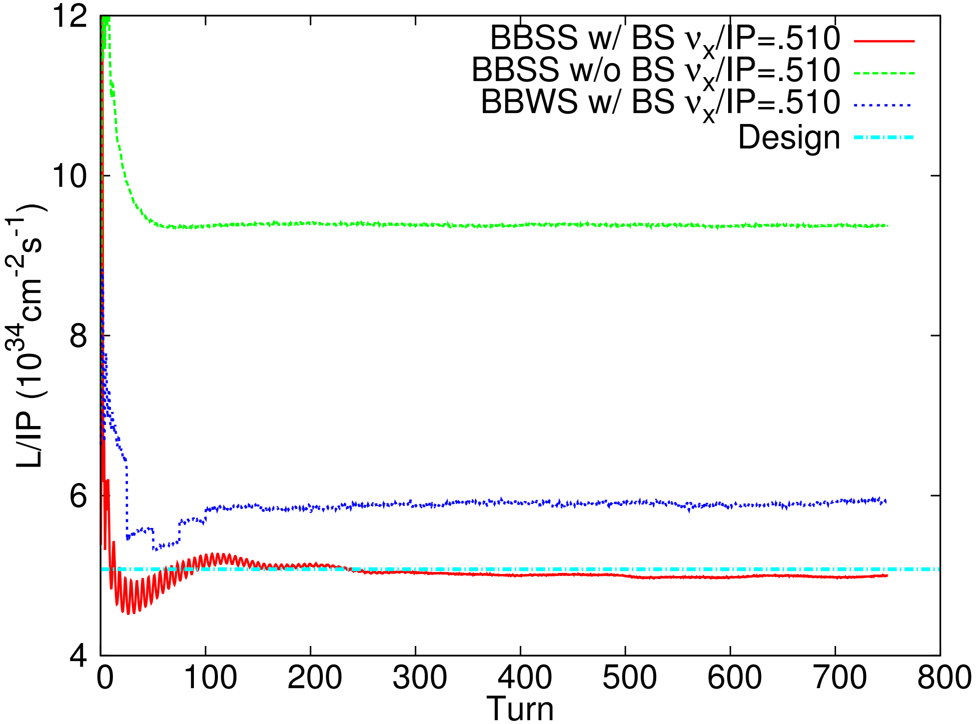


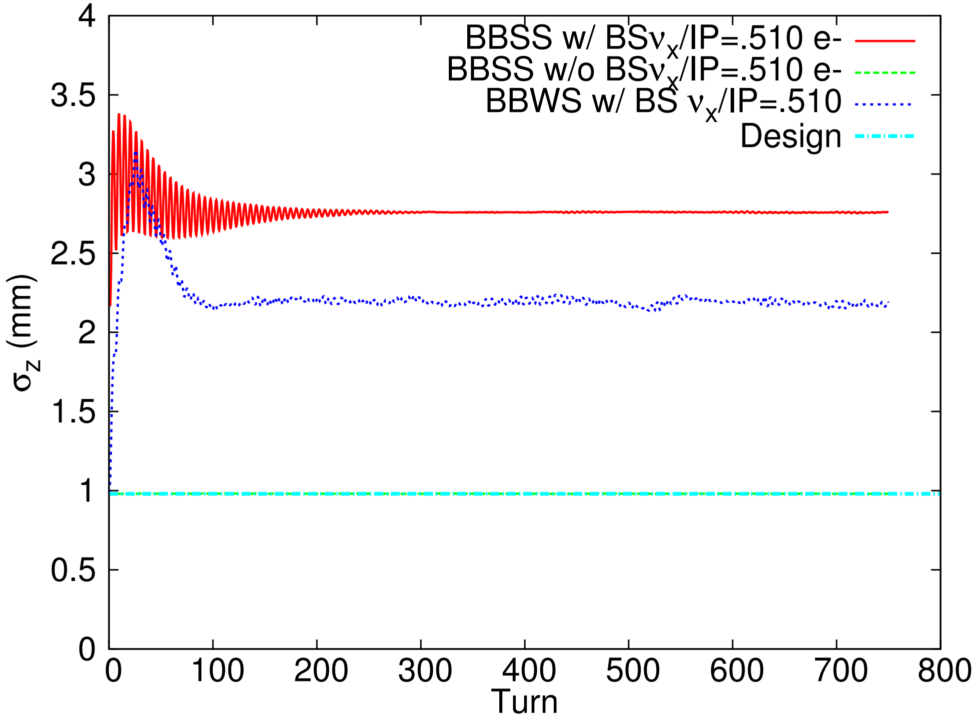


2. TLEP H: Baseline design: Beamstrahlung

➤ **BB induced synchrotron radiation**

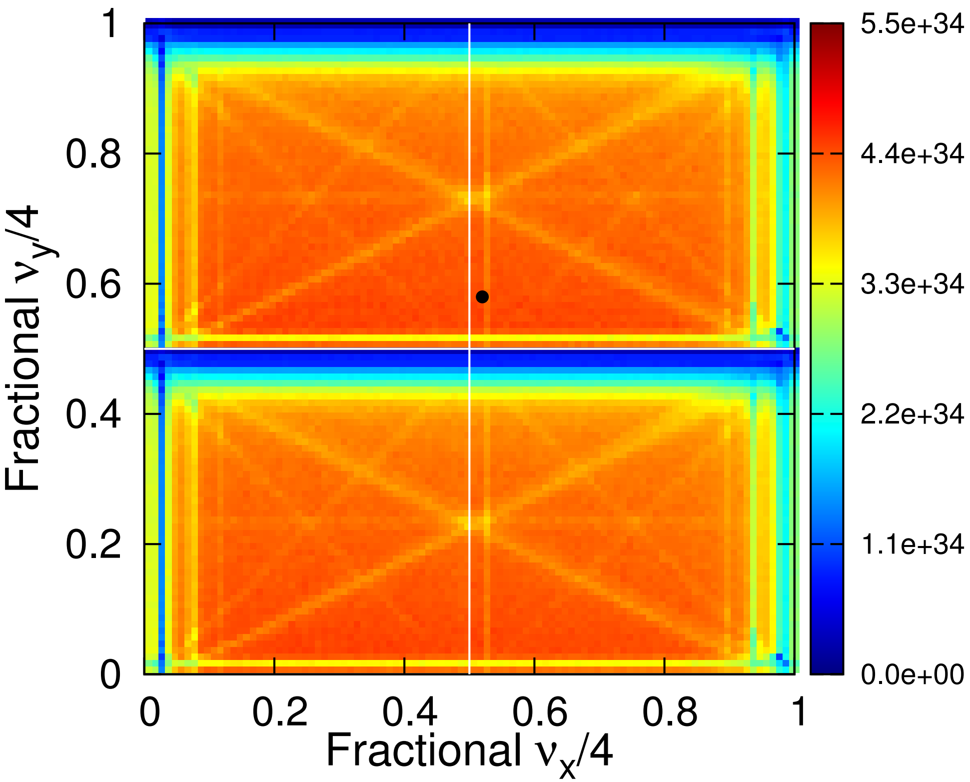
- **Become significant at TLEP**
- **Cause bunch lengthening and enlarge energy spread**
- **Worsen hourglass effect**
- **Vertical beam size blowup**



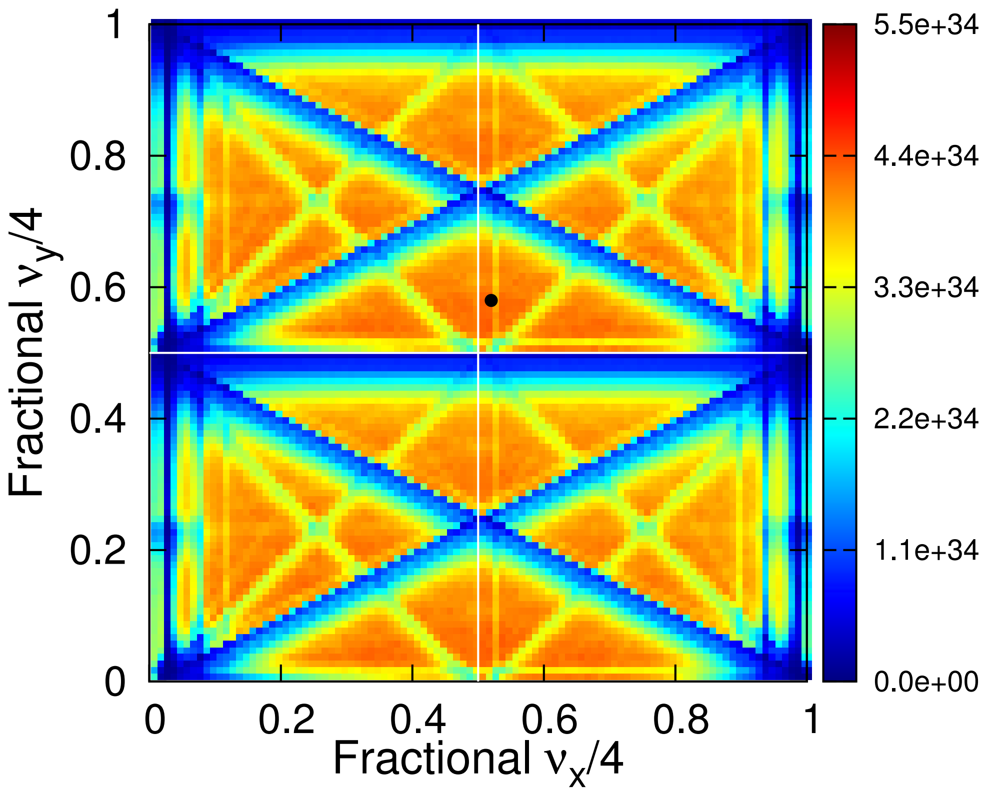


2. TLEP H: Crab waist option: Lum. tune scan

- **Tune scan for crab waist option**
  - **Done by BBWS w/ beamstrahlung**
  - **CW suppress coupling resonances**
  - **Simulated luminosity lower than design because of incorrect bunch length used!**



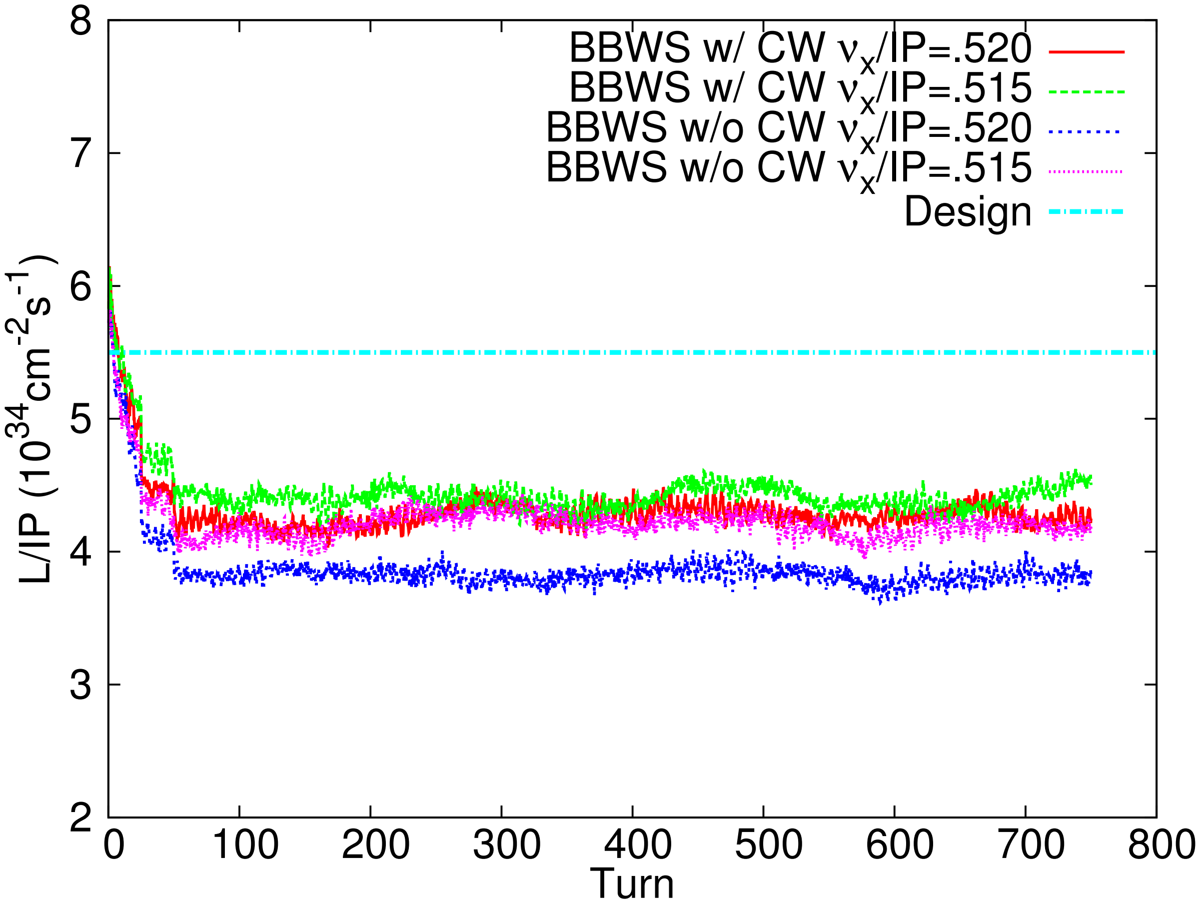
w/ CW



w/o CW

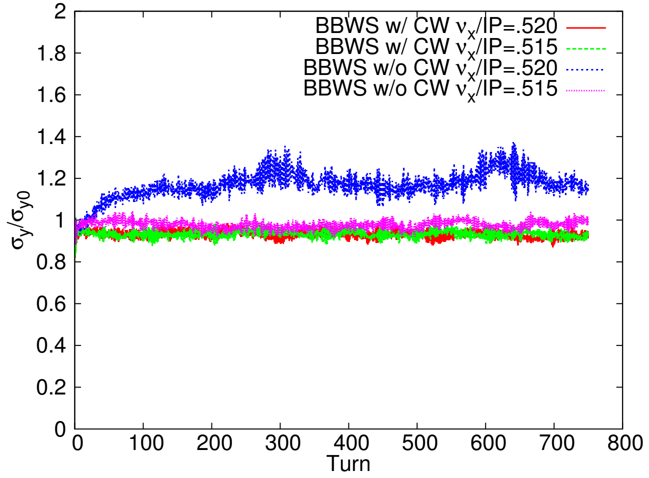
2. TLEP H: Crab waist option: Working point

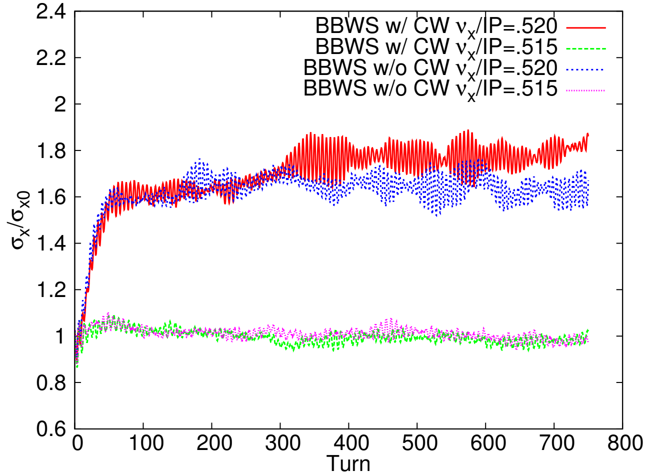
- **Turn-by-turn data for crab waist option: luminosity**
  - **Done by BBWS w/ beamstrahlung**
  - **BBSS simulation not feasible due to long computing time**
  - **Working point (.515,.58) seems to be good**

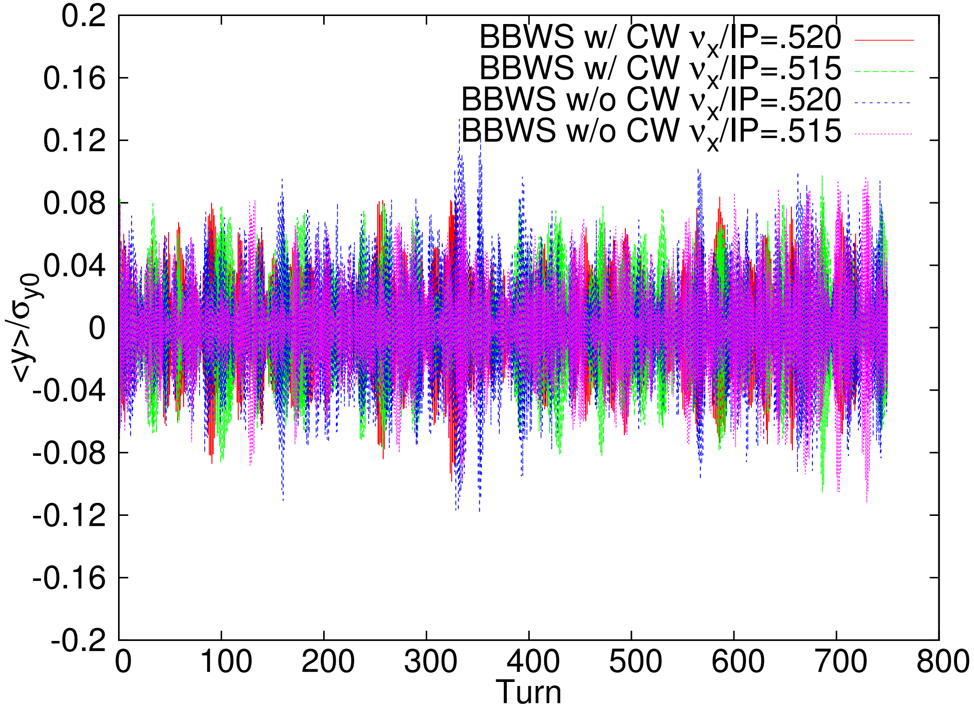


2. TLEP H: Crab waist option: Working point

- **Turn-by-turn data for crab waist option: beam sizes**
  - **Done by BBWS w/ beamstrahlung**
  - **Vert. beam size blowup not serious**
  - **Hor. blowup when working point close to $2\nu_x$-$2\nu_s$=Integer**

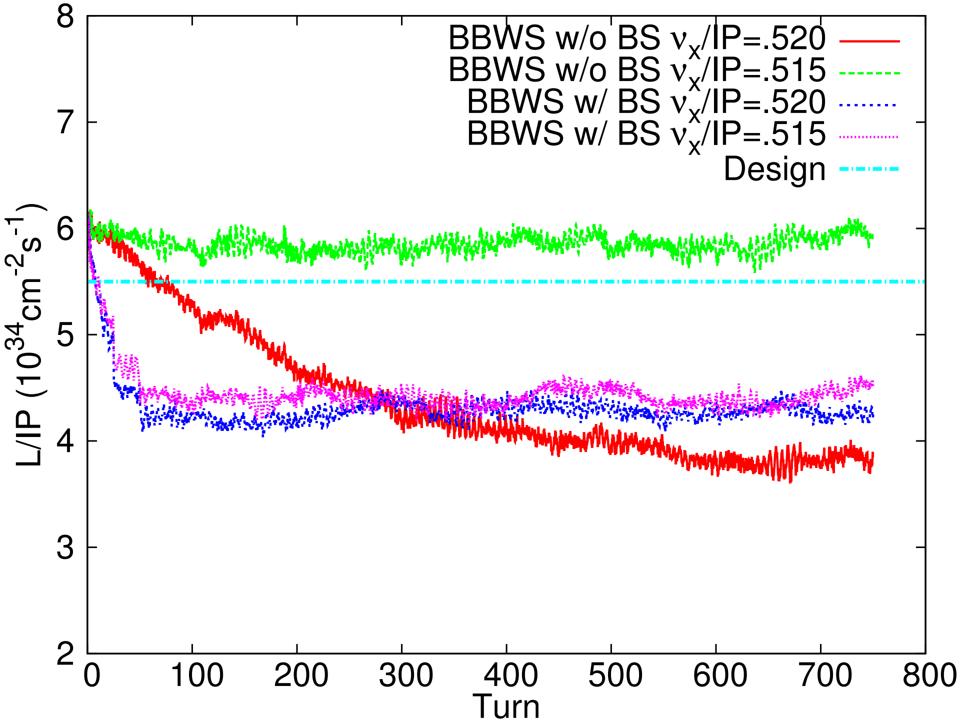


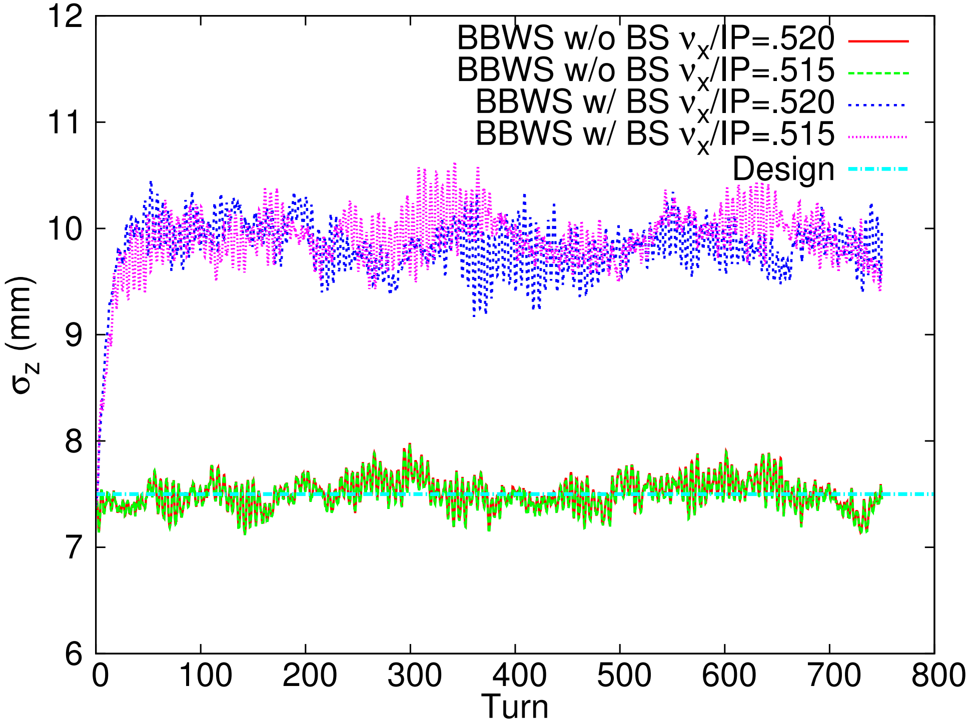




2. TLEP H: Crab waist option: Beamstrahlung

- **BB induced synchrotron radiation**
  - **Become significant at TLEP**
  - **Cause bunch lengthening and enlarge energy spread**





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  - Baseline and crab waist designs
  - Beam-beam (BB) and luminosity performance
  - Beamstrahlung
- ➤ SuperKEKB
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  - Interplay between lattice nonlinearities (LN) and BB
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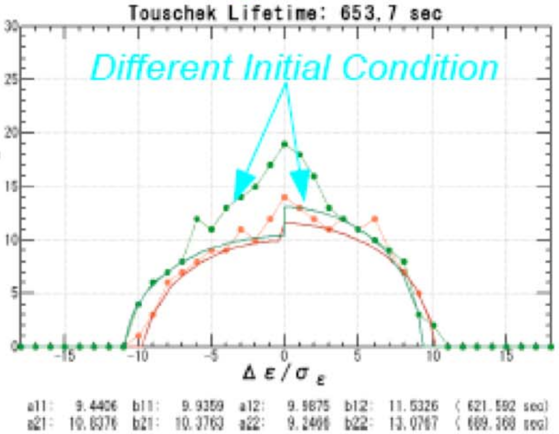
- ➤ Summary and outlook

3. SuperKEKB: Dynamic aperture and lifetime

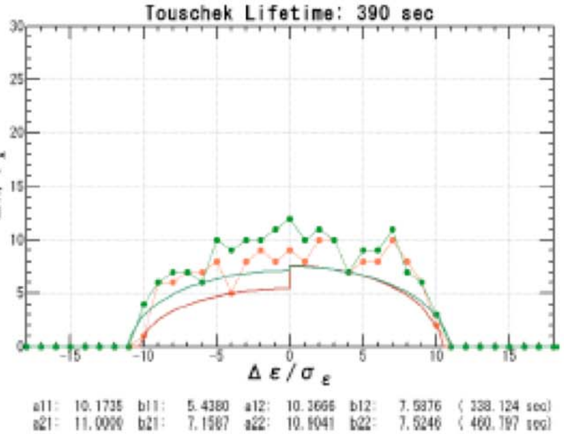
Design Target of Lifetime: 600sec

HER

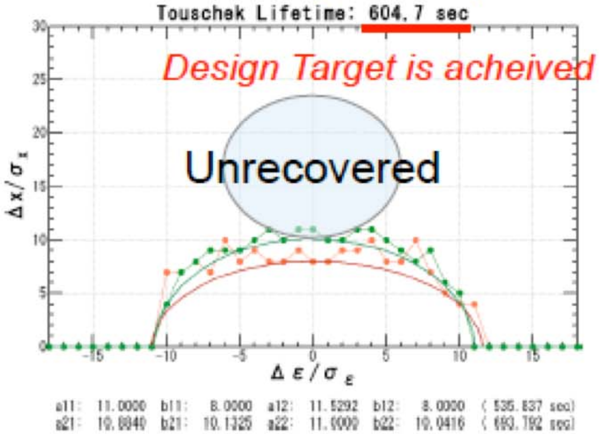
Design Lattice



With Beambeam

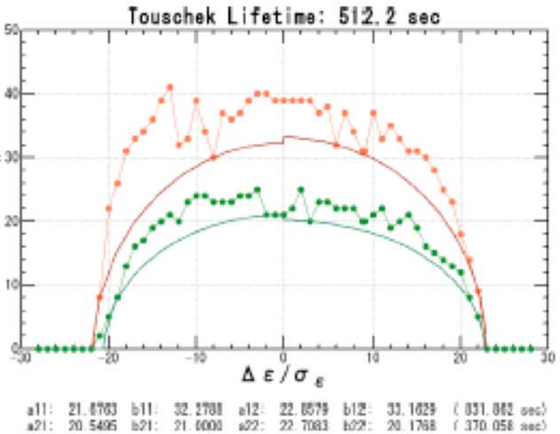


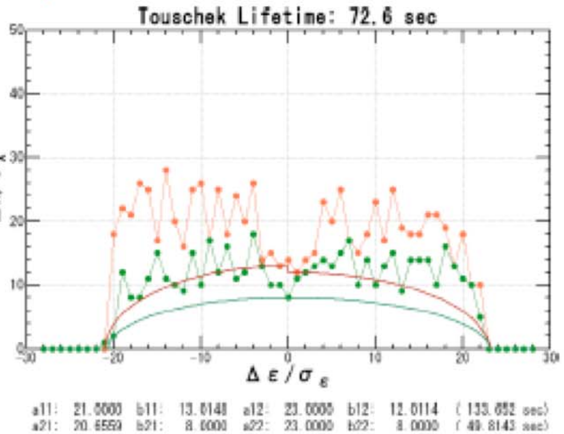
With BB + Re-Optimize(Sext/Oct)

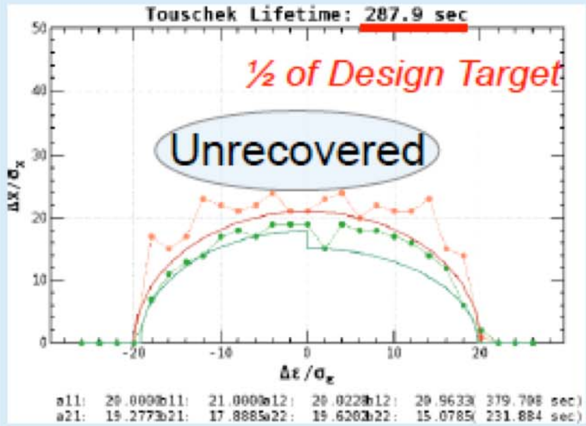


Working point (ν_x, ν_y)=(#.53, #.57)

LER







Different working point (ν_x, ν_y)=(#.61, #.53)

We have to

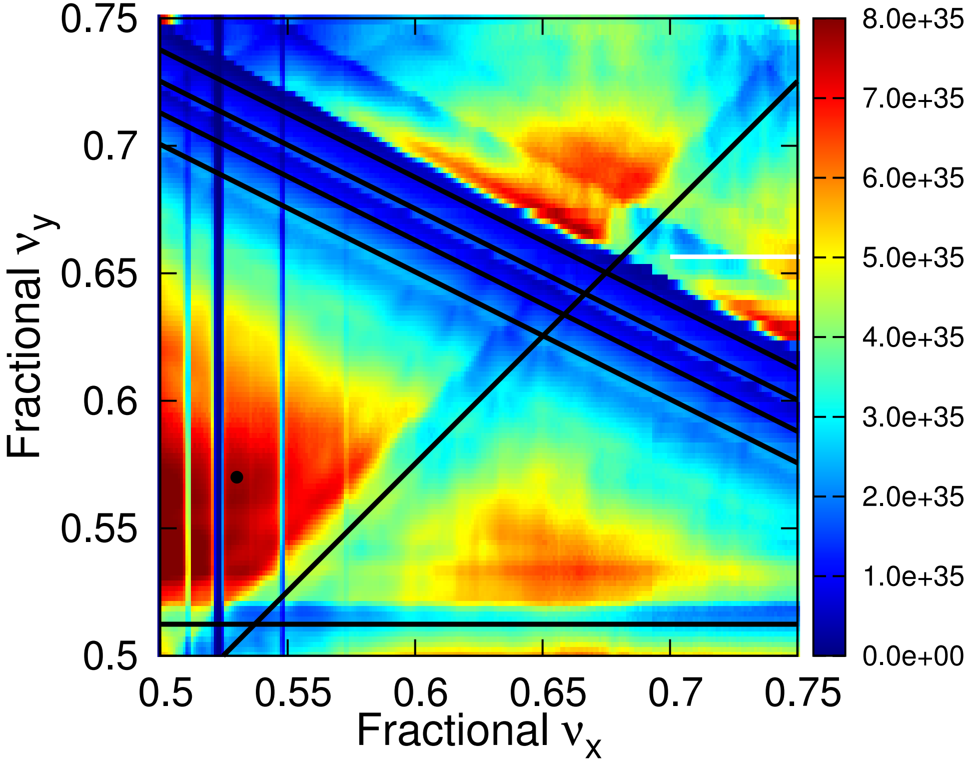
- *understand origin of aperture degradation*
- *find method to cure transverse aperture*

A. Morita, ICFA Mini-Workshop, KEK, Nov.11-13, 2013

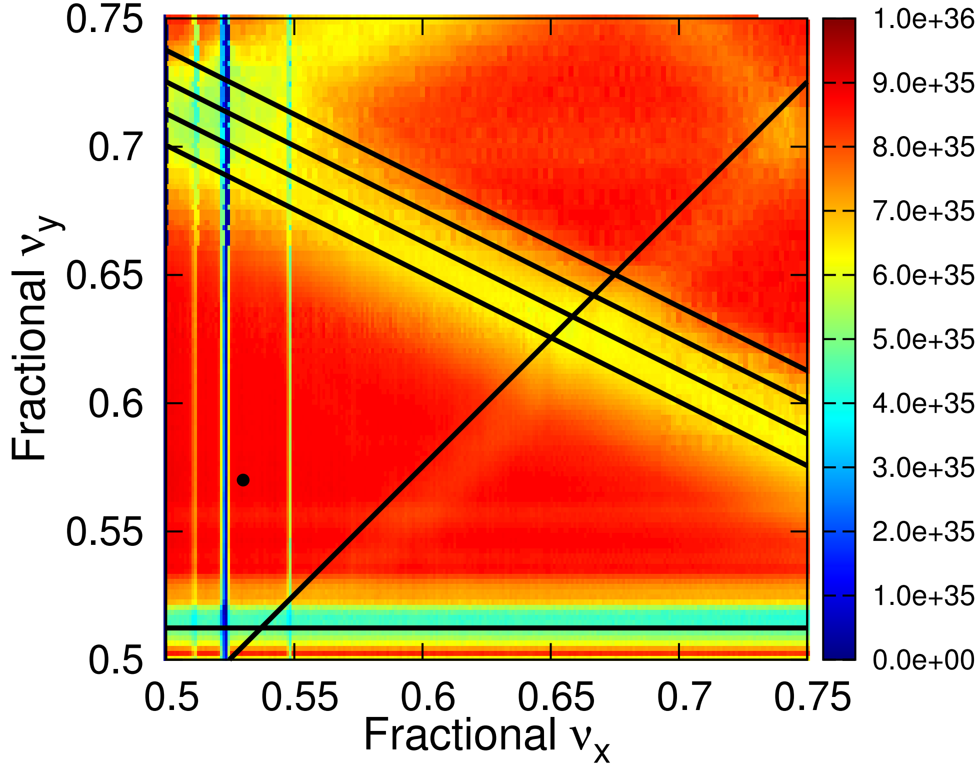
3. SuperKEKB: Lum. tune scan

➤ **Tune scan (LER) w/o and w/ CW**

- **Simulations by BBWS**
- **w/o CW: Good working point(WP) around (.53, .57)**
- **w/ CW: More choices of WP and lum. gain ~20%**



w/o CW



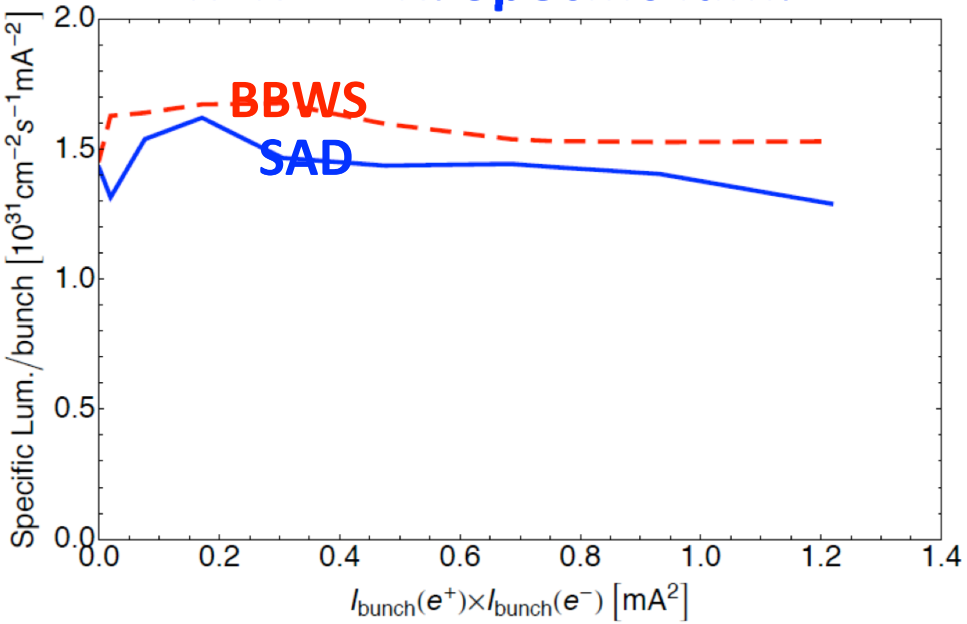
w/ CW

3. SuperKEKB: Lattice nonlinearities

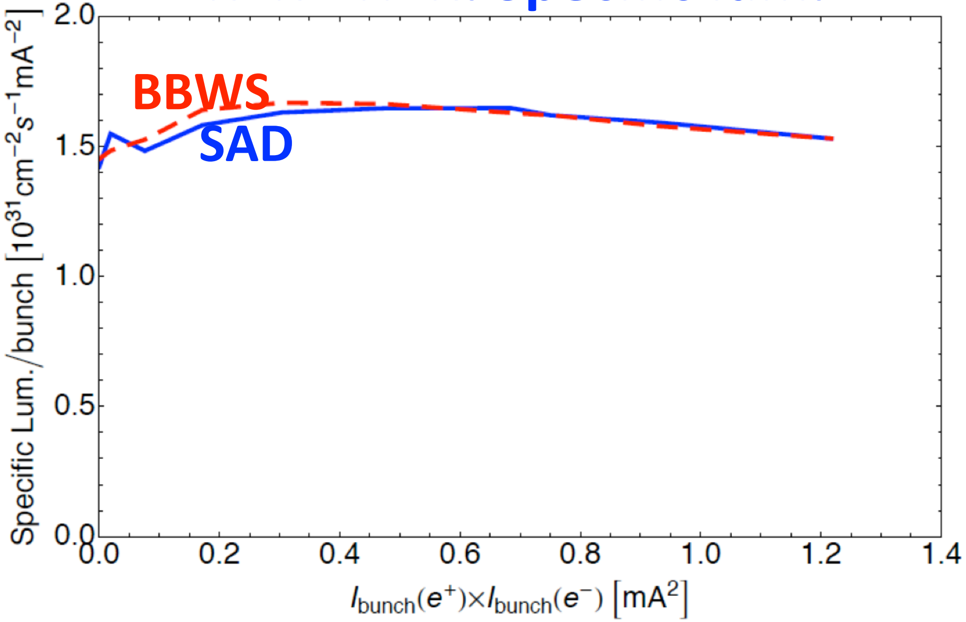
➤ **The case of KEKB:**

- **LN interplays with BB**
- **Simulations were done using BBWS, BBSS and SAD codes**
- **Chromatic couplings cause remarkable lum. loss ~10%**

KEKB LER: Specific lum.



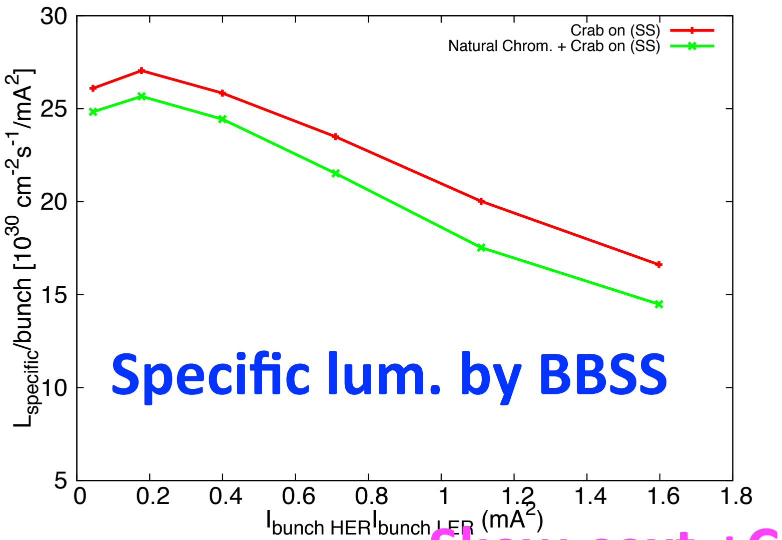
KEKB HER: Specific lum.



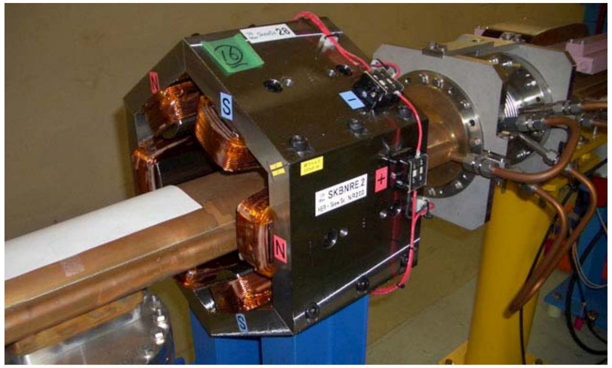
3. SuperKEKB: Lattice nonlinearities

➤ The case of KEKB:

- **Observed lum. gain ~15% independent of crab cavities**

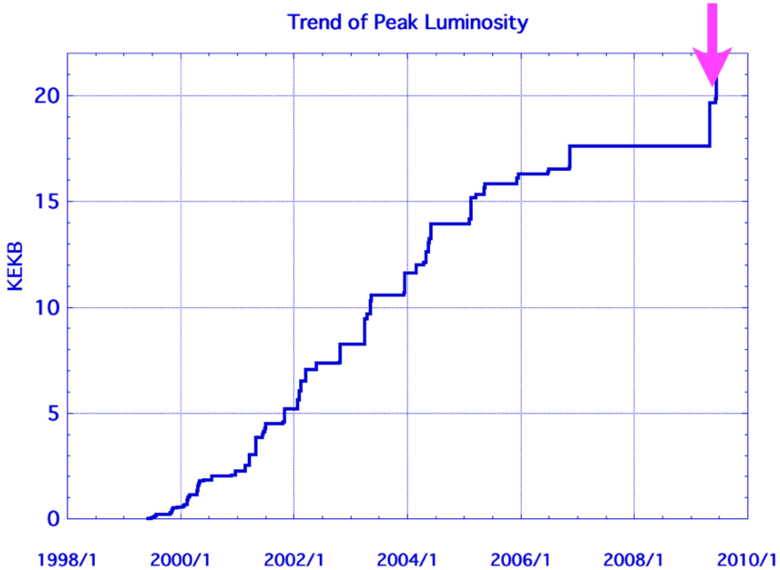


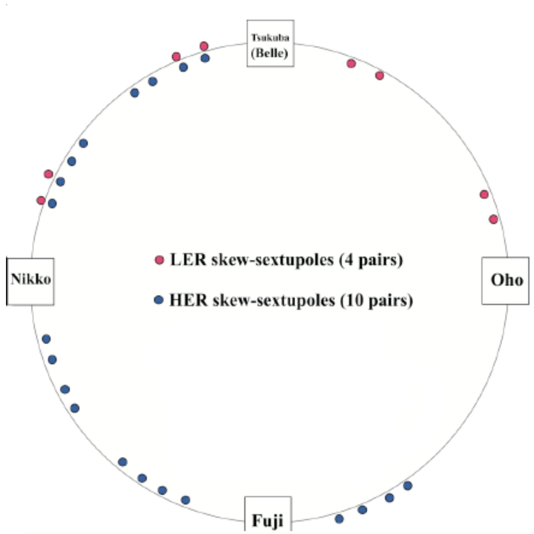
Specific lum. by BBSS



Skew sext., Masuzawa et al.

Skew-sext.+Crab cavities



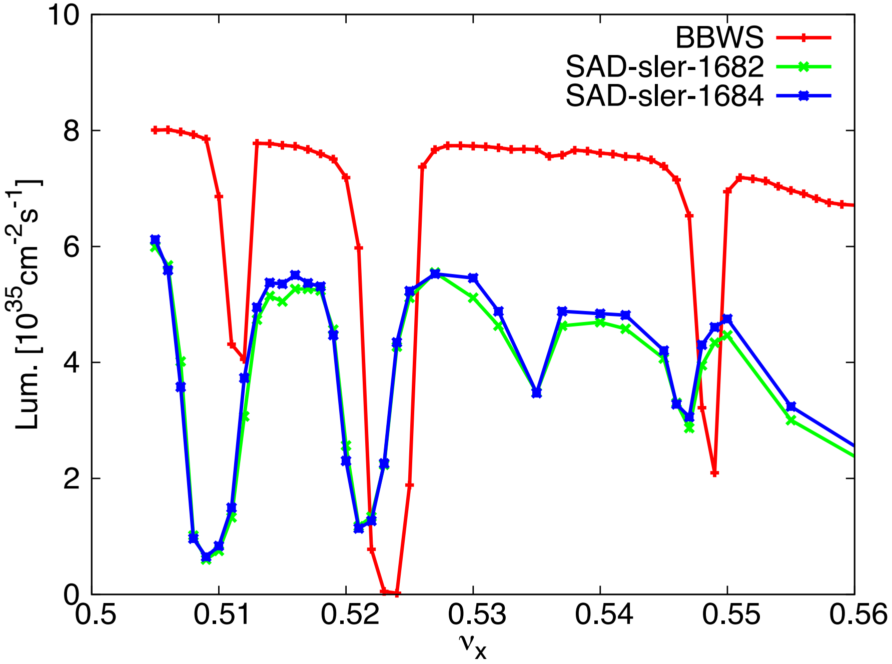


Optics, A. Morita et al.

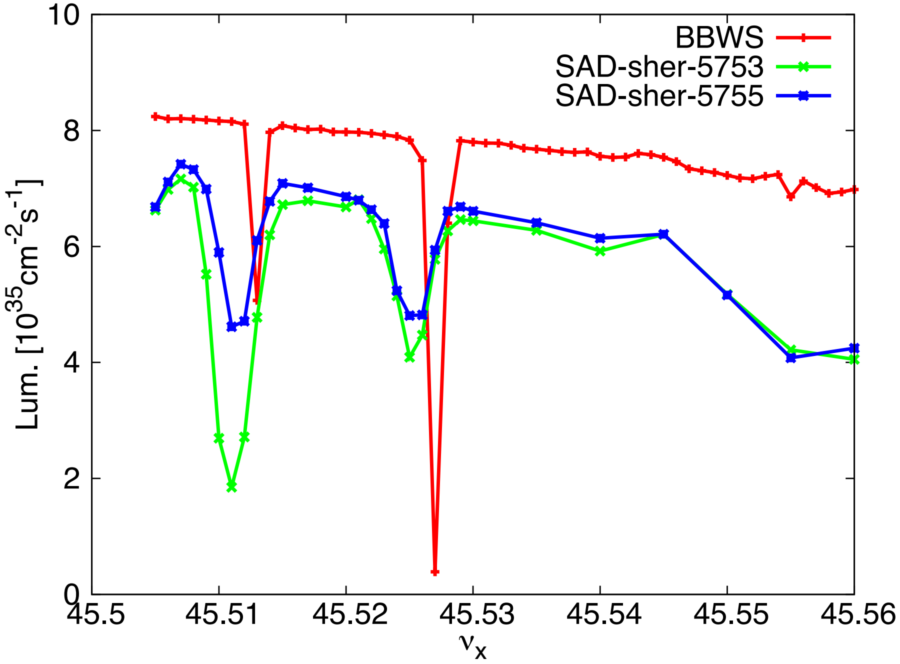
3. SuperKEKB: Lattice nonlinearities

➤ **Simulations by BBWS and SAD**
- **Significant lum. loss ~30% predicted**
- **LN enhance synchro-betatron resonances (BB: x^2z^2)**
- **Loss rate depend on optics designs**

LER: tune scan



HER: tune scan

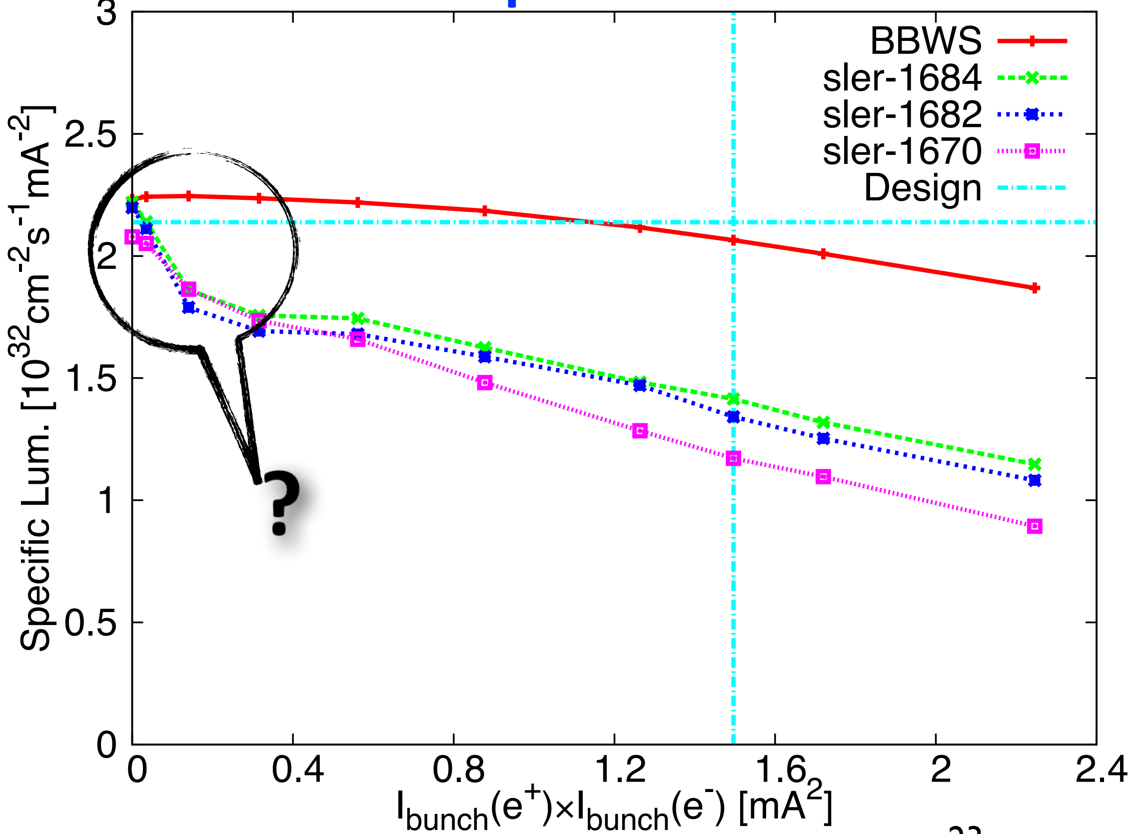


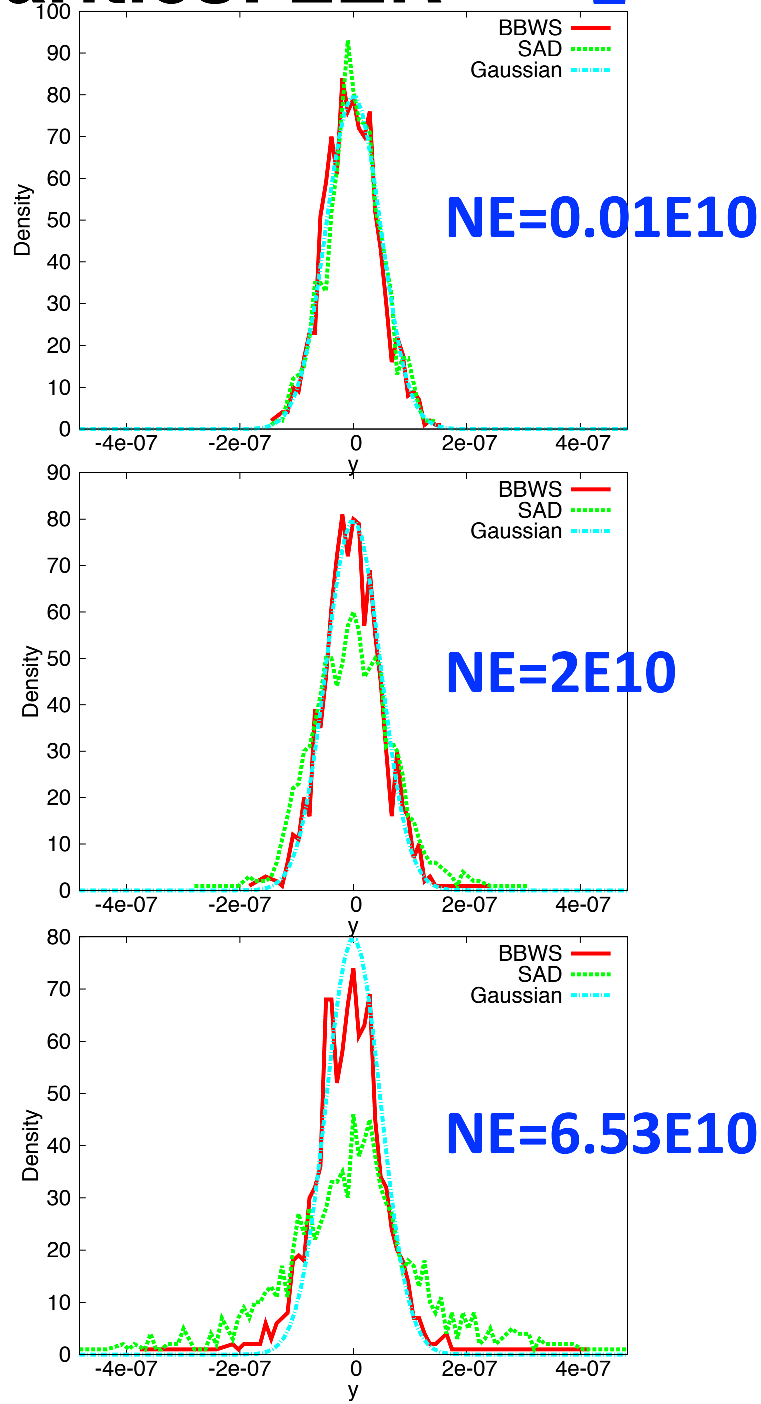
3. SuperKEKB: Lattice nonlinearities: LER

sler_1684

- Simulations by SAD
  - Direct vert. beam size blowup
  - Depend on beam currents

LER: specific lum.

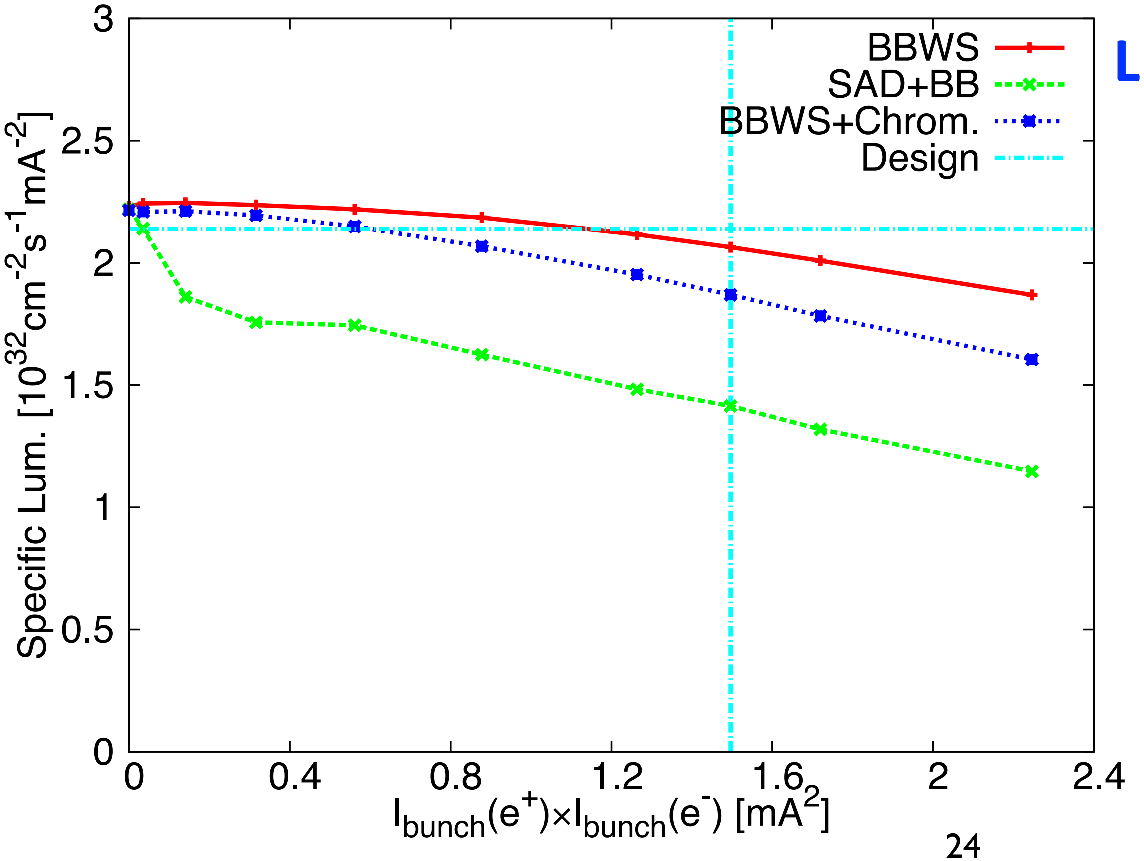




3. SuperKEKB: Lattice nonlinearities: LER

➤ **Check chromatic effects in LER**

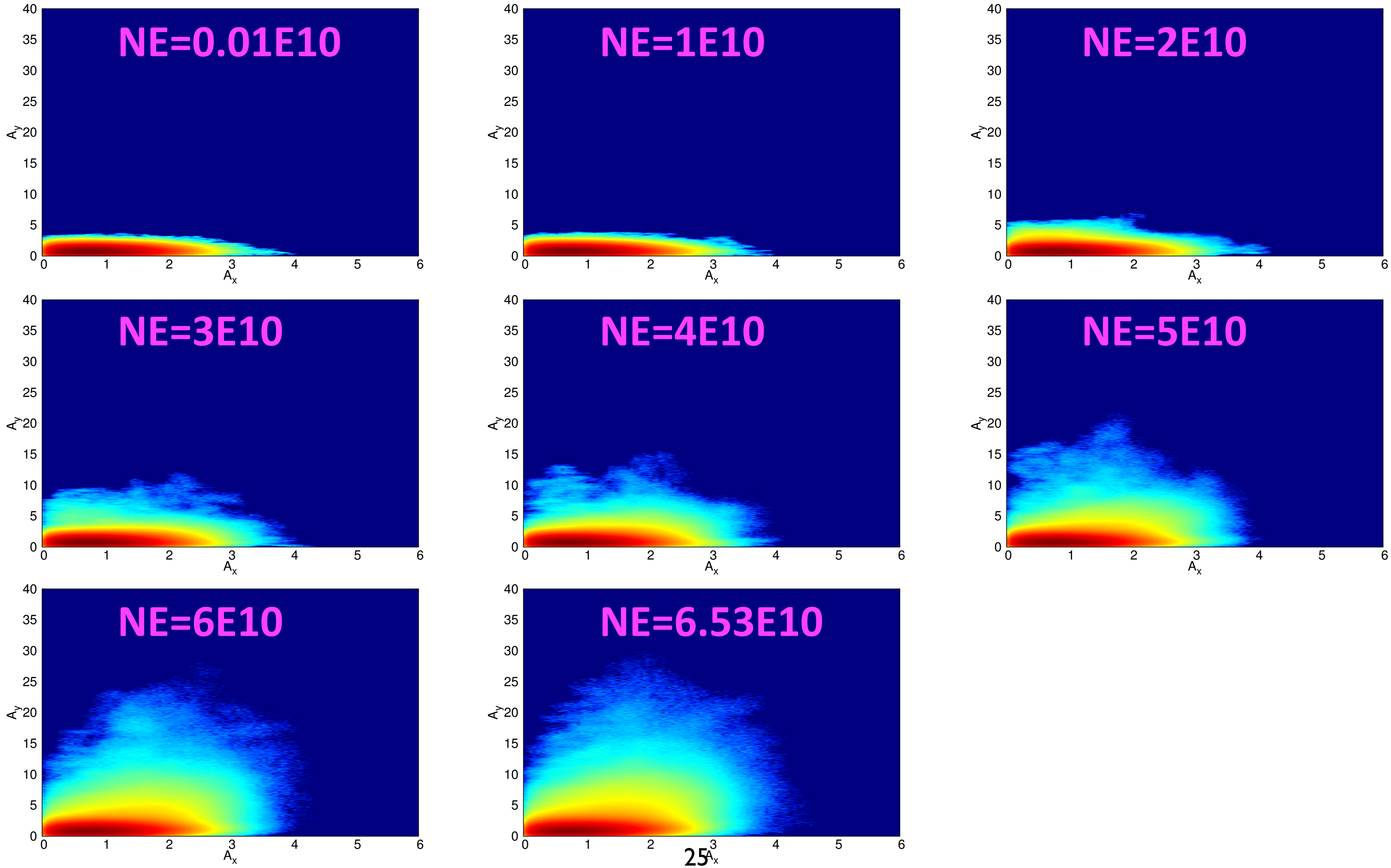
- **Based on KEKB experiences**
- **Fact: Mom. nonlin. controlled in optics design of LER**
- **Finding: Lum. loss not due to chromatic effects**
- **Conclusion: Amp. nonlin. more important (?)**



LER: sler_1684

3. SuperKEKB: Lattice nonlinearities: LER

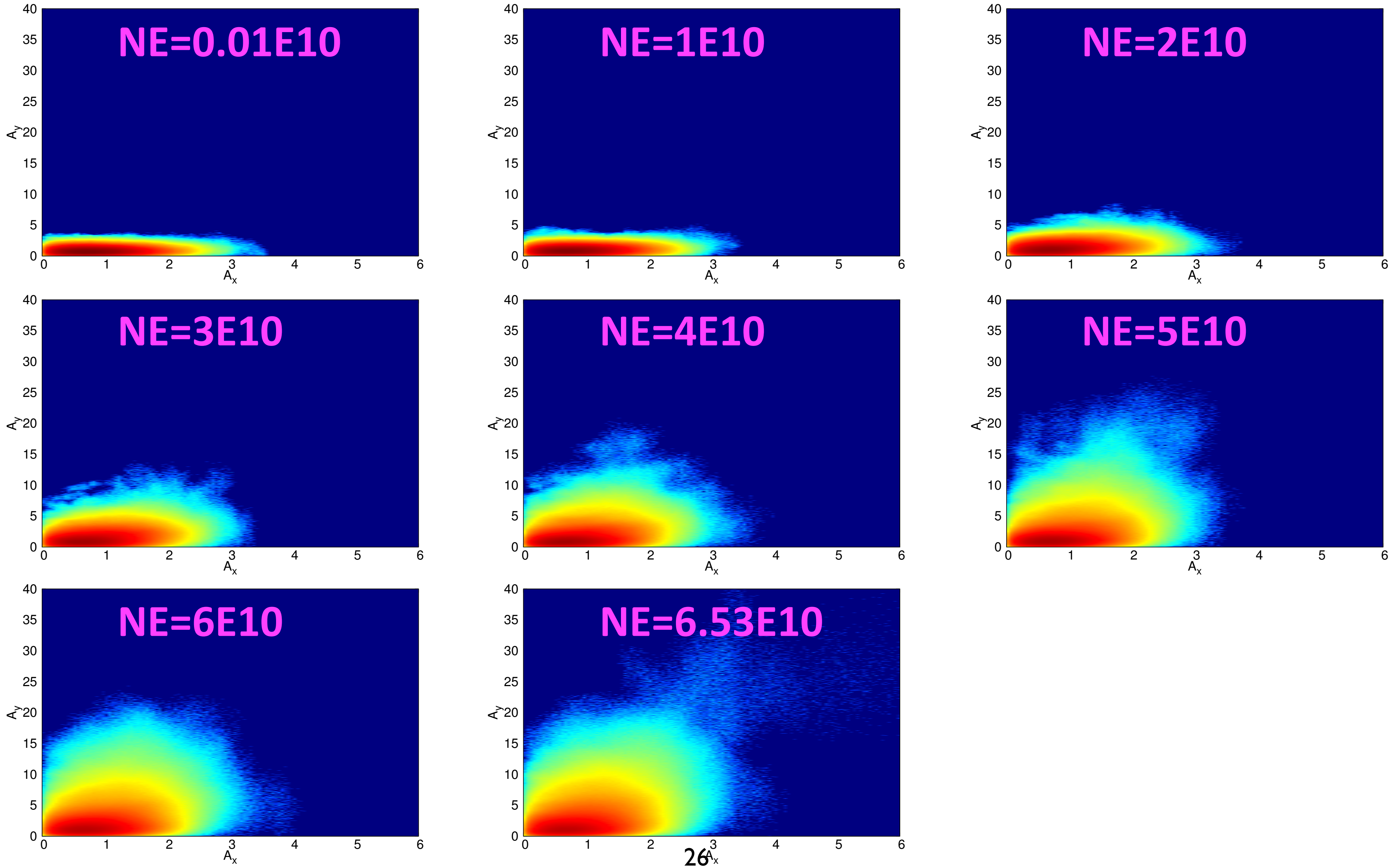
➤ Beam tail by BBWS w/ BB



3. SuperKEKB: Lattice nonlinearities: LER

sler_1684

➤ **Beam tail by SAD w/ BB+LN**

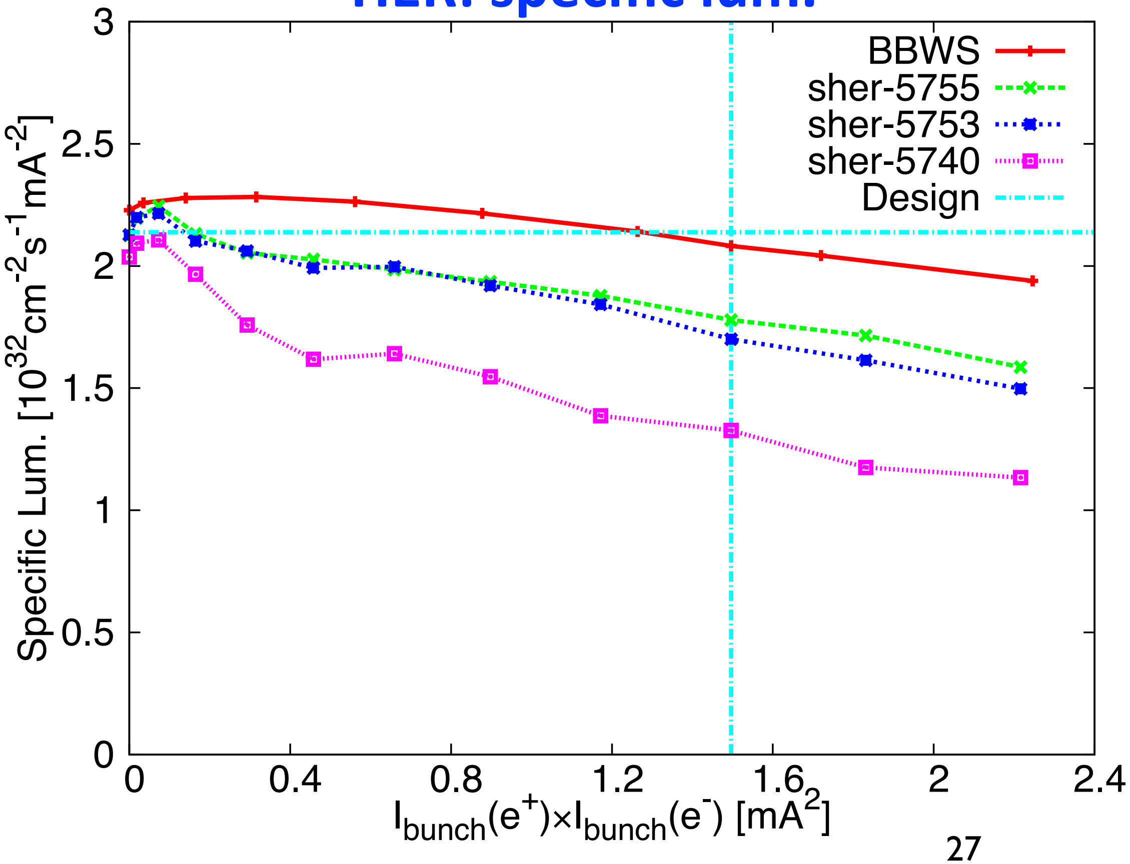


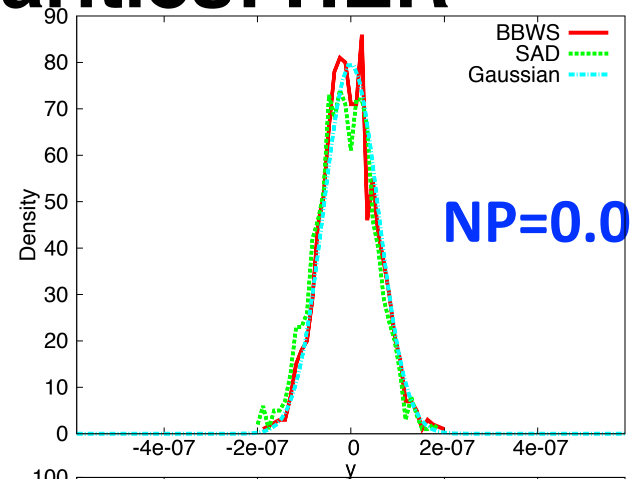
3. SuperKEKB: Lattice nonlinearities: HER

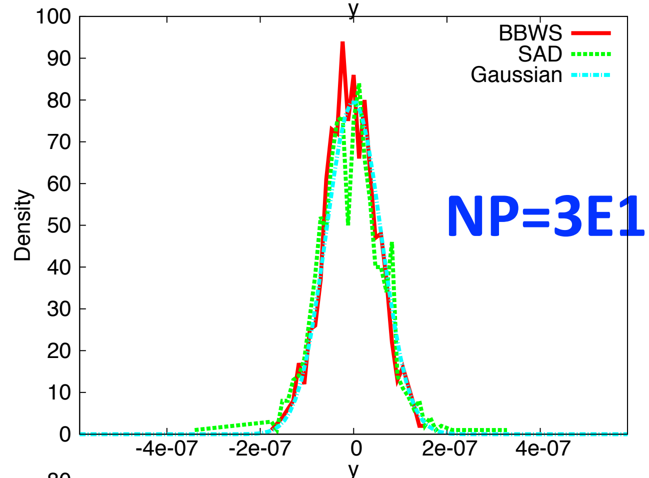
sher_5755

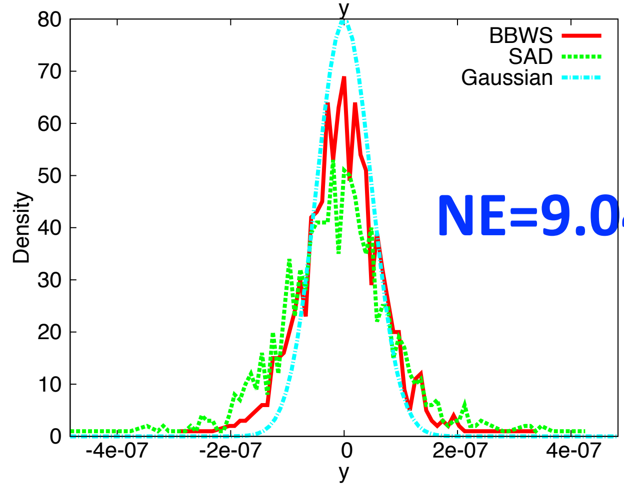
- Simulations by SAD
- Direct vert. emit. growth
- Current dependent

HER: specific lum.



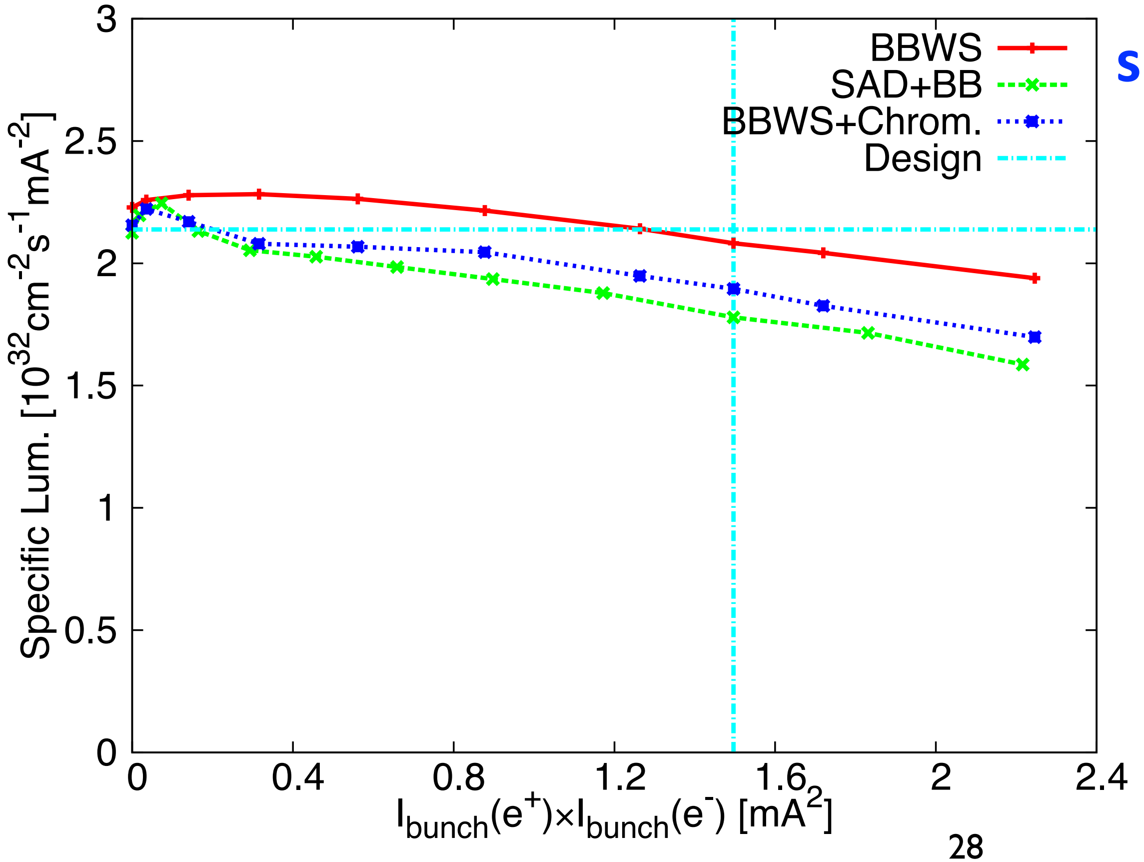






3. SuperKEKB: Lattice nonlinearities: HER

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



sher_5755

3. SuperKEKB: Space charge: LER

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

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

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

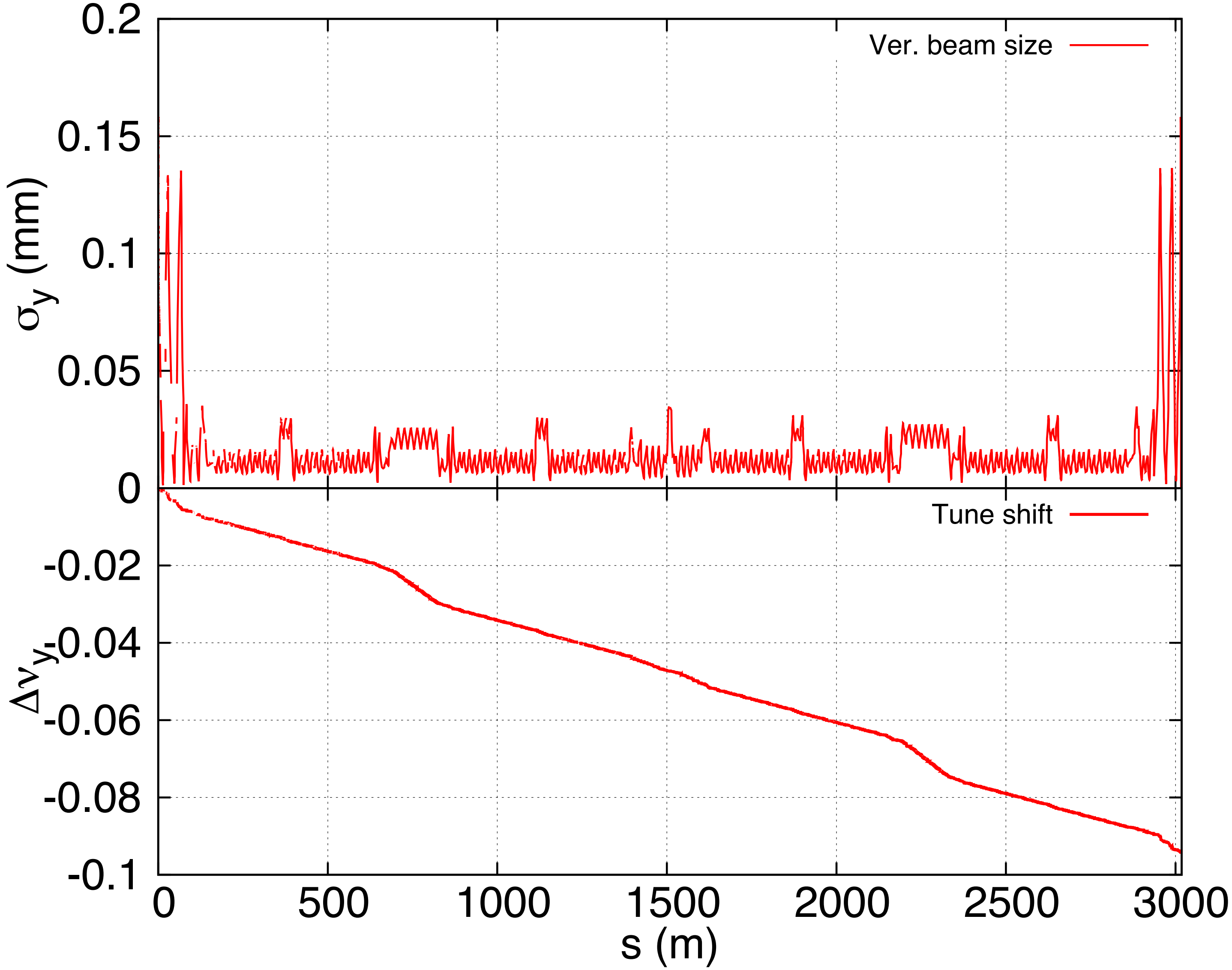
- **Linear tune shift**
  - **Same order for SC and BB**
  - **But with opposite signs**

	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.

3. SuperKEKB: Space charge: LER

➤ SC tune shift along the ring

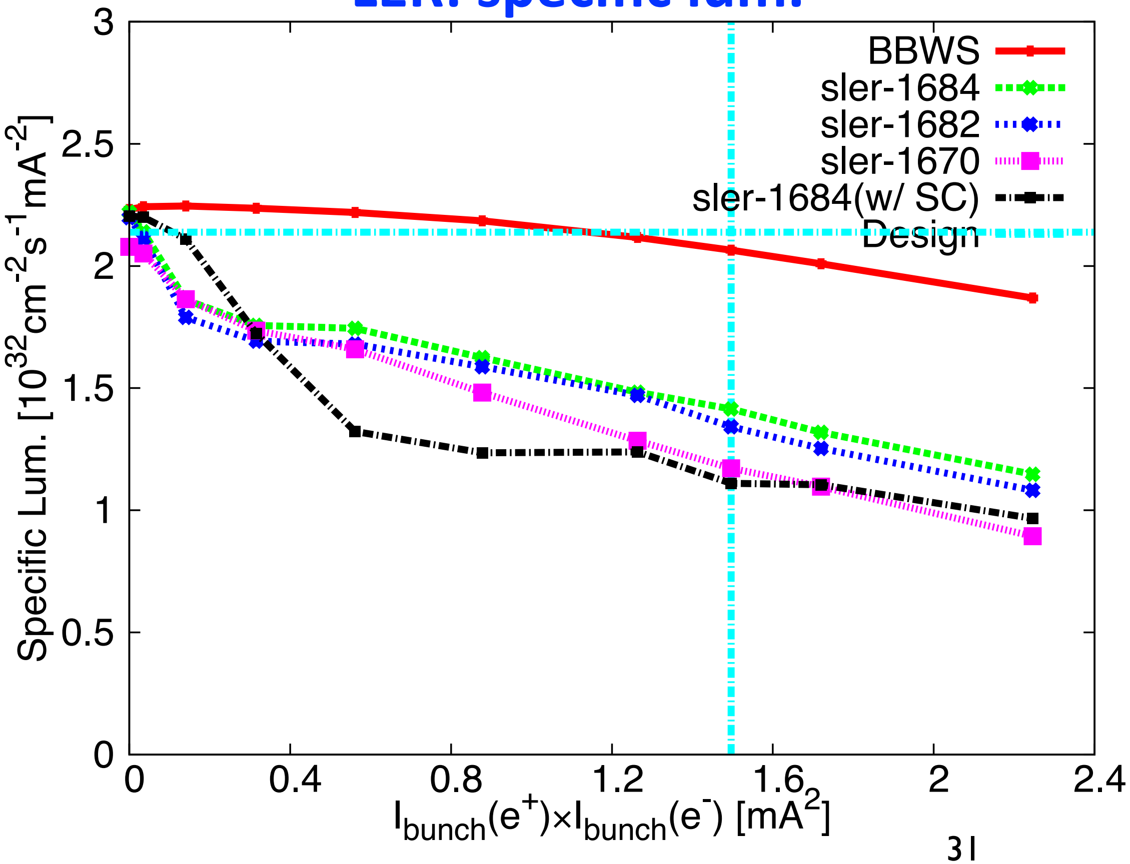


3. SuperKEKB: Space charge: LER

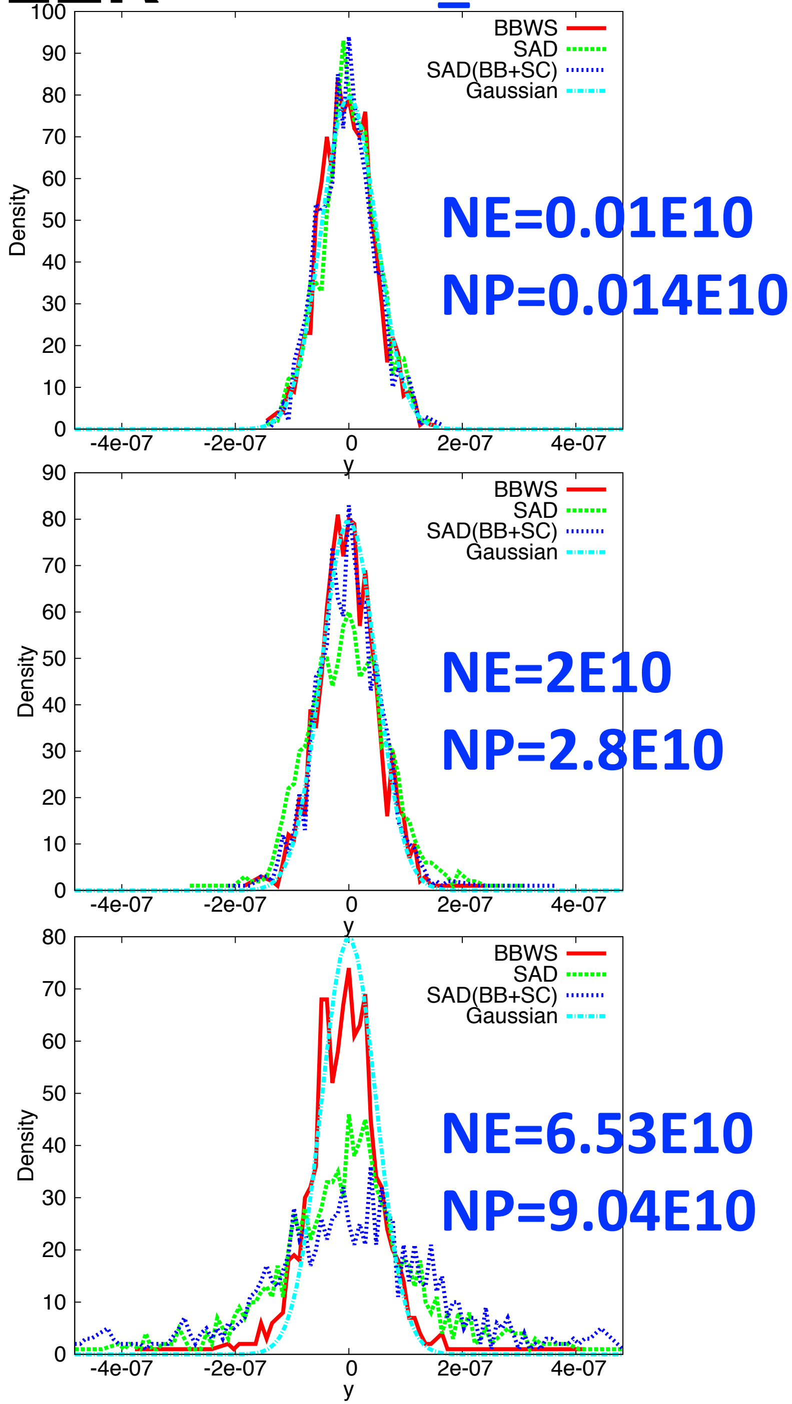
➤ SC causes lum. degradation

➤ SC forces overestimated with weak-strong model

LER: specific lum.

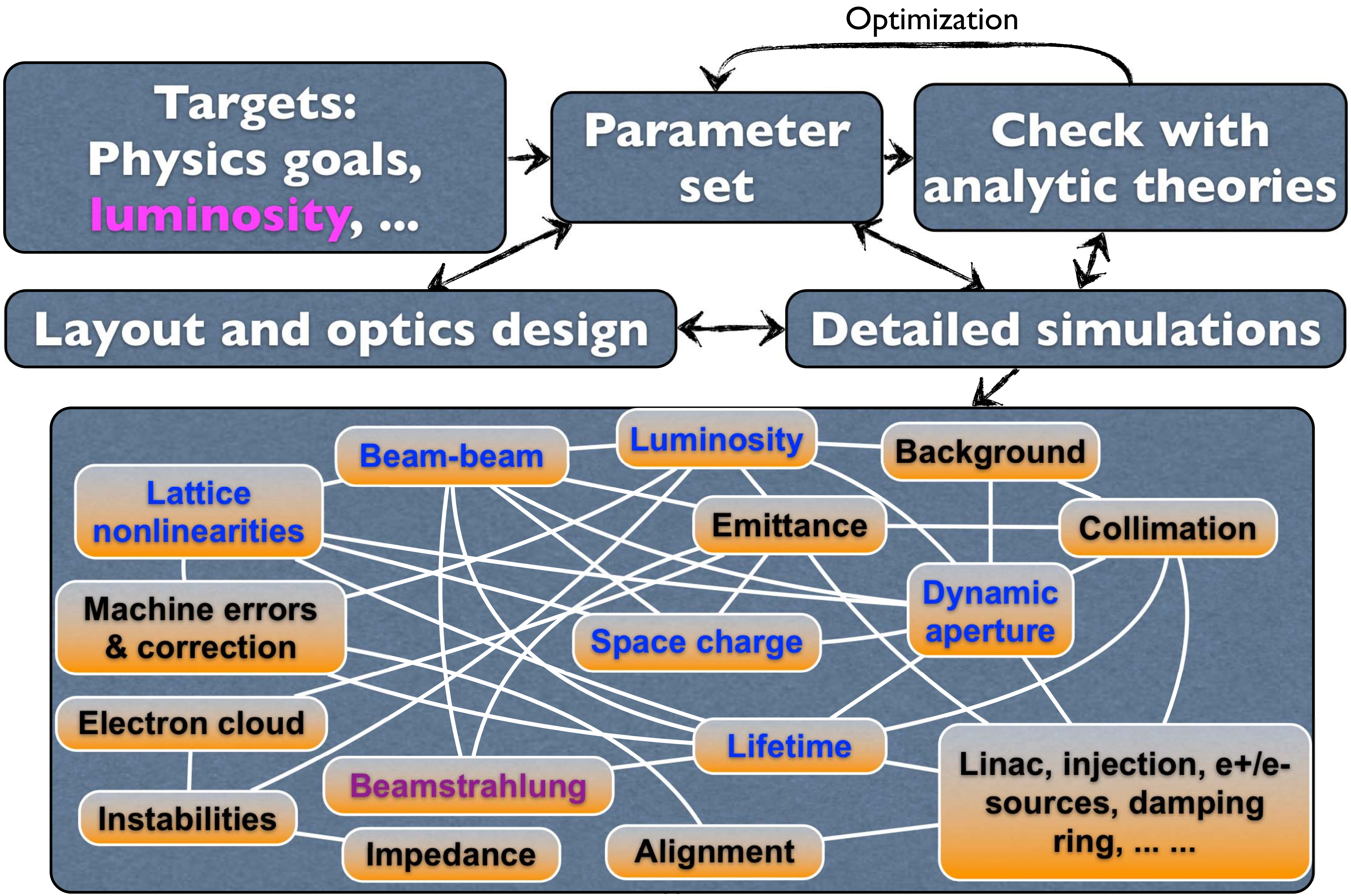


sler_1684



Outline

Workflow of designing a collider



4. Summary: TLEP H

➤ **Baseline design**

- Good working point around (.515,.58) ×4 IPs
- Strong beamstrahlung
- Hourglass effects cause vert. blowup
- $\beta_y^* \approx \sigma_z$ required with head-on collision

➤ **Crab waist option**

- CW suppresses coupling resonances
- Acceptable beamstrahlung
- Hourglass effects relaxed with crossing angle
- $\beta_y^* \ll \sigma_z$ is possible

➤ **More detailed simulations to be done with available lattice designs**

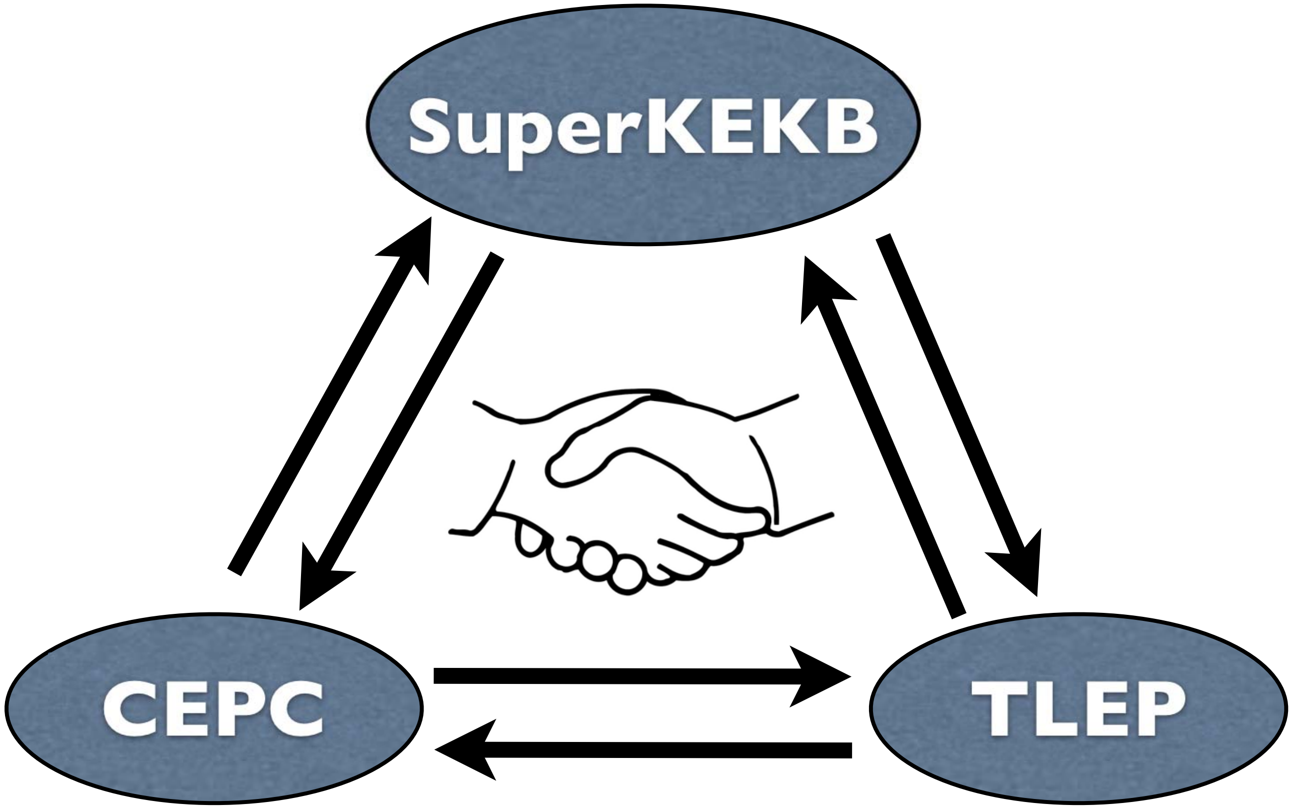
4. Summary: SuperKEKB

- **Lattice nonlinearities**
  - Interplay with beam-beam
  - Reduce dynamic aperture and lifetime
  - Cause lum. loss
  - Momentum-dependent LN in both LER and HER can be controlled by skew-sextupoles
  - Amplitude-dependent LN hard to suppress in LER
- **Space charge**
  - Distort footprint in tune space
  - Possibly cause lum. loss
- **Future plan**
  - Better understand LN in LER
  - Investigate compensation schemes for SC
  - Feasibility of crab waist option

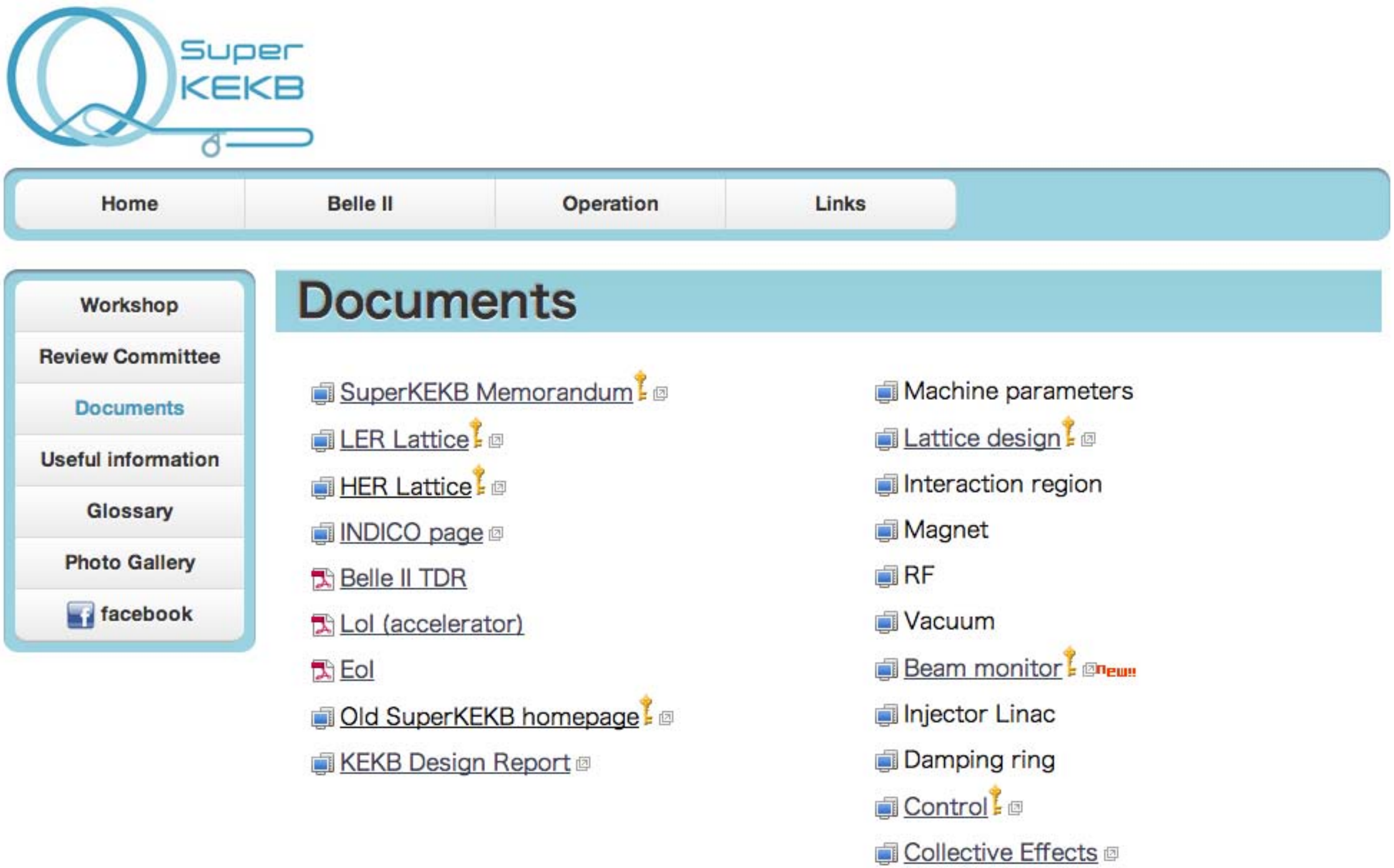
4. Outlook: Possible collaborations

➤ **SuperKEKB => TLEP and CEPC: Technologies, beam commissioning, and accelerator physics**

➤ **TLEP and CEPC => SuperKEKB: Design tools, manpower and collaborations, and accelerator physics**



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



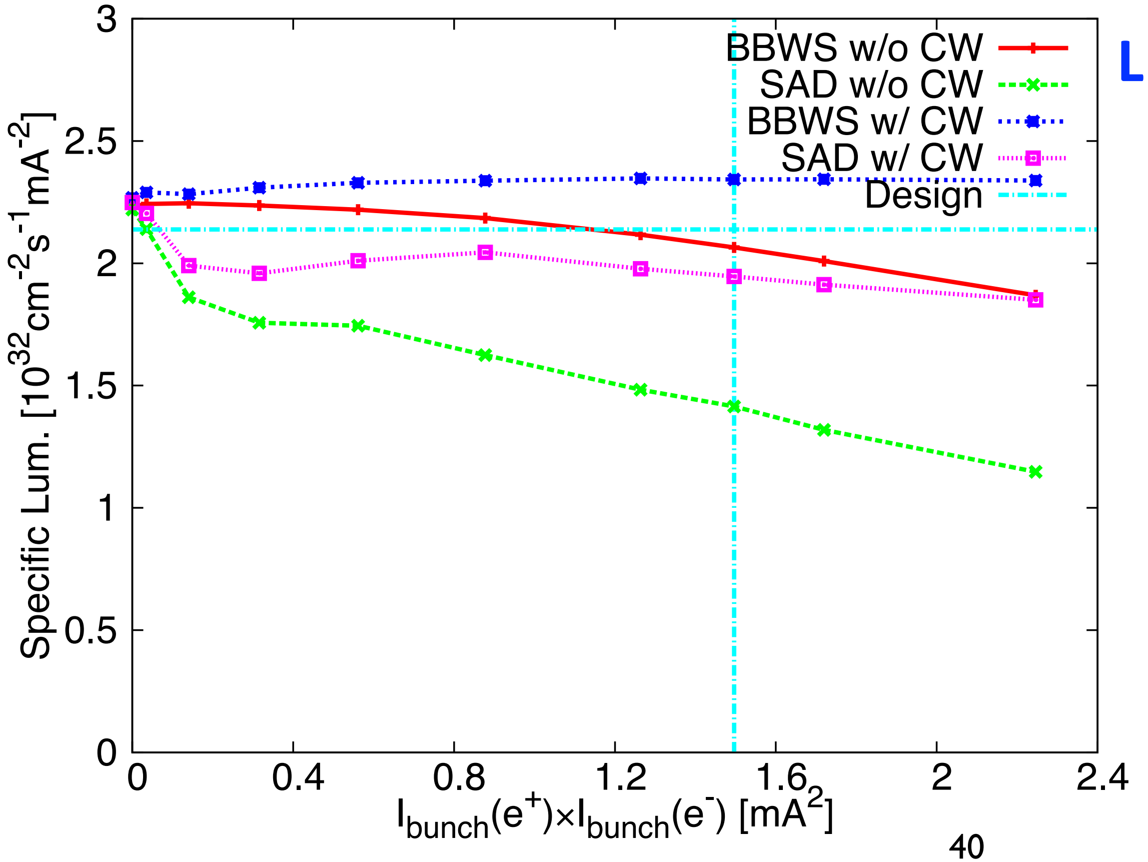
Thanks for your attention!

Backup

3. SuperKEKB: Lattice nonlinearities: LER

➤ **The case of using ideal crab waist in LER**

- **Lum. gain of CW ~20% w/o LN**
- **LN effects partly mitigated**
- **LN decrease CW's power**



LER: sler_1684

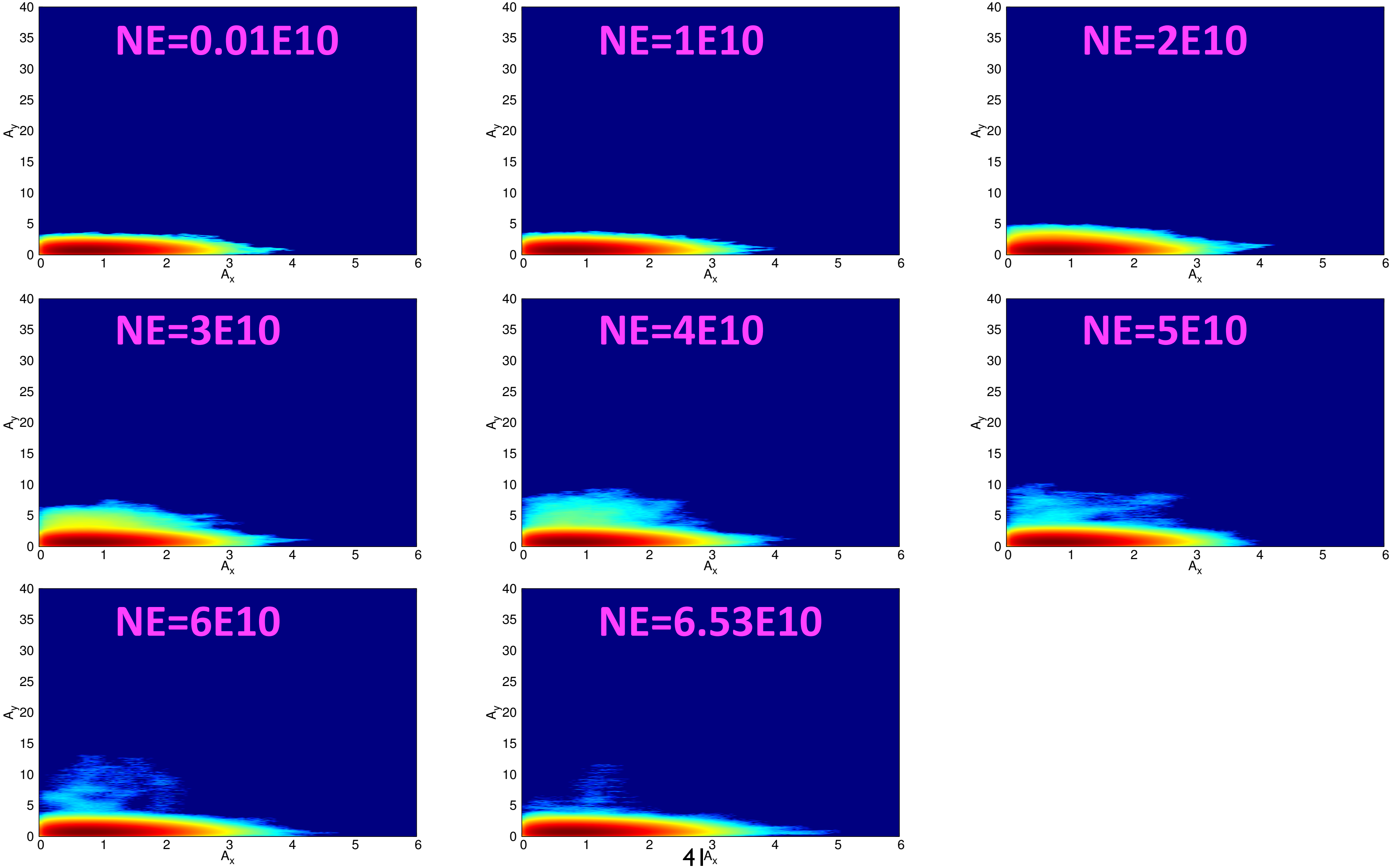
Simple map for CW at IP:

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

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

3. SuperKEKB: Lattice nonlinearities: LER

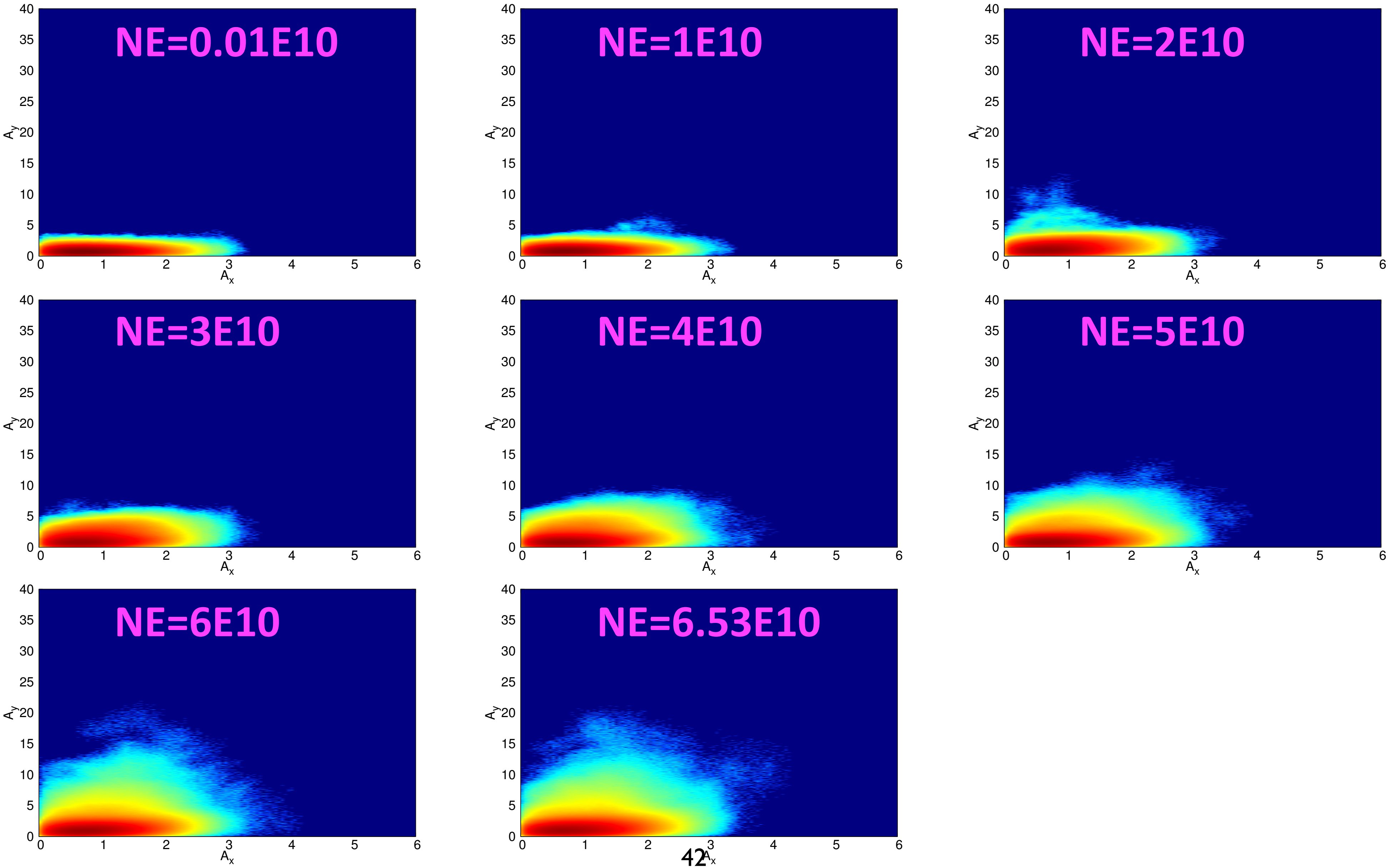
➤ **Beam tail by BBWS w/ BB+CW**



3. SuperKEKB: Lattice nonlinearities: LER

sler_1684

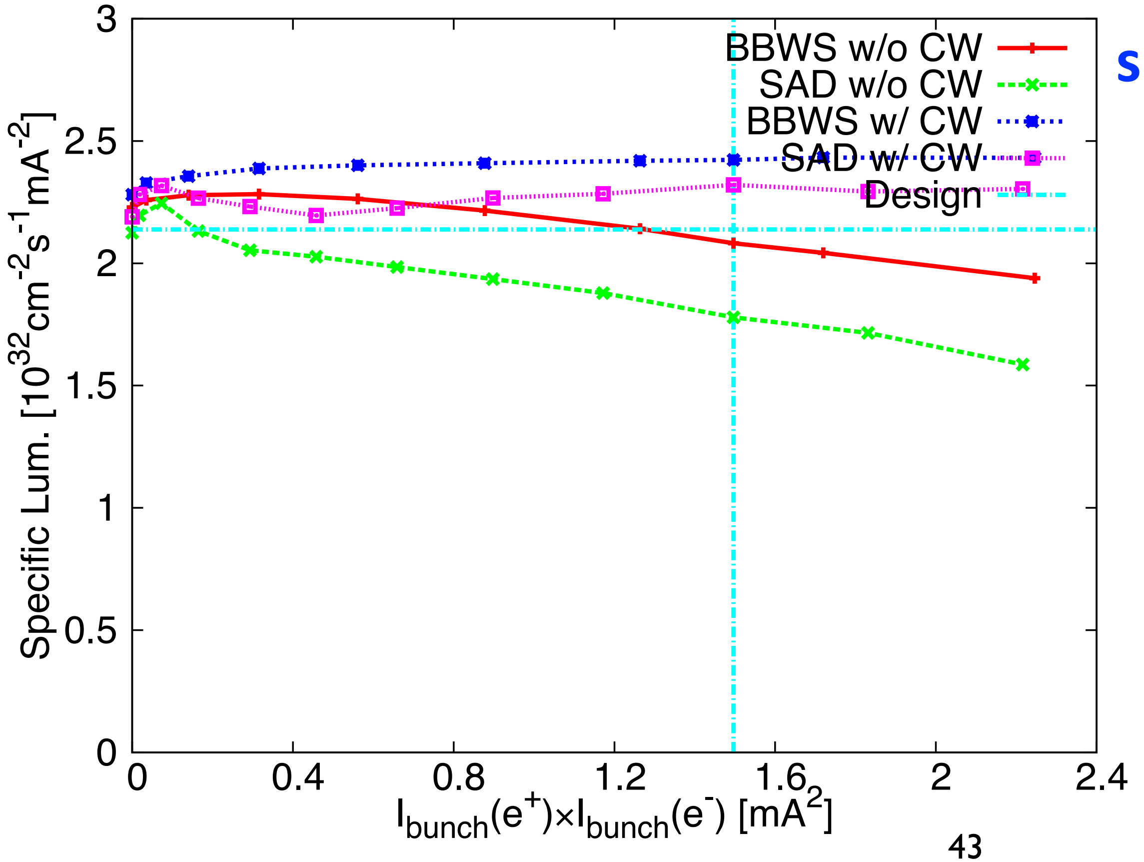
➤ Beam tail by SAD w/ BB+LN+CW



3. SuperKEKB: Lattice nonlinearities: HER

➤ **The case of using ideal crab waist in HER**

- **Lum. gain of CW ~15% w/o LN**
- **LN effects partly mitigated**
- **LN decrease CW's power**



sher_5755

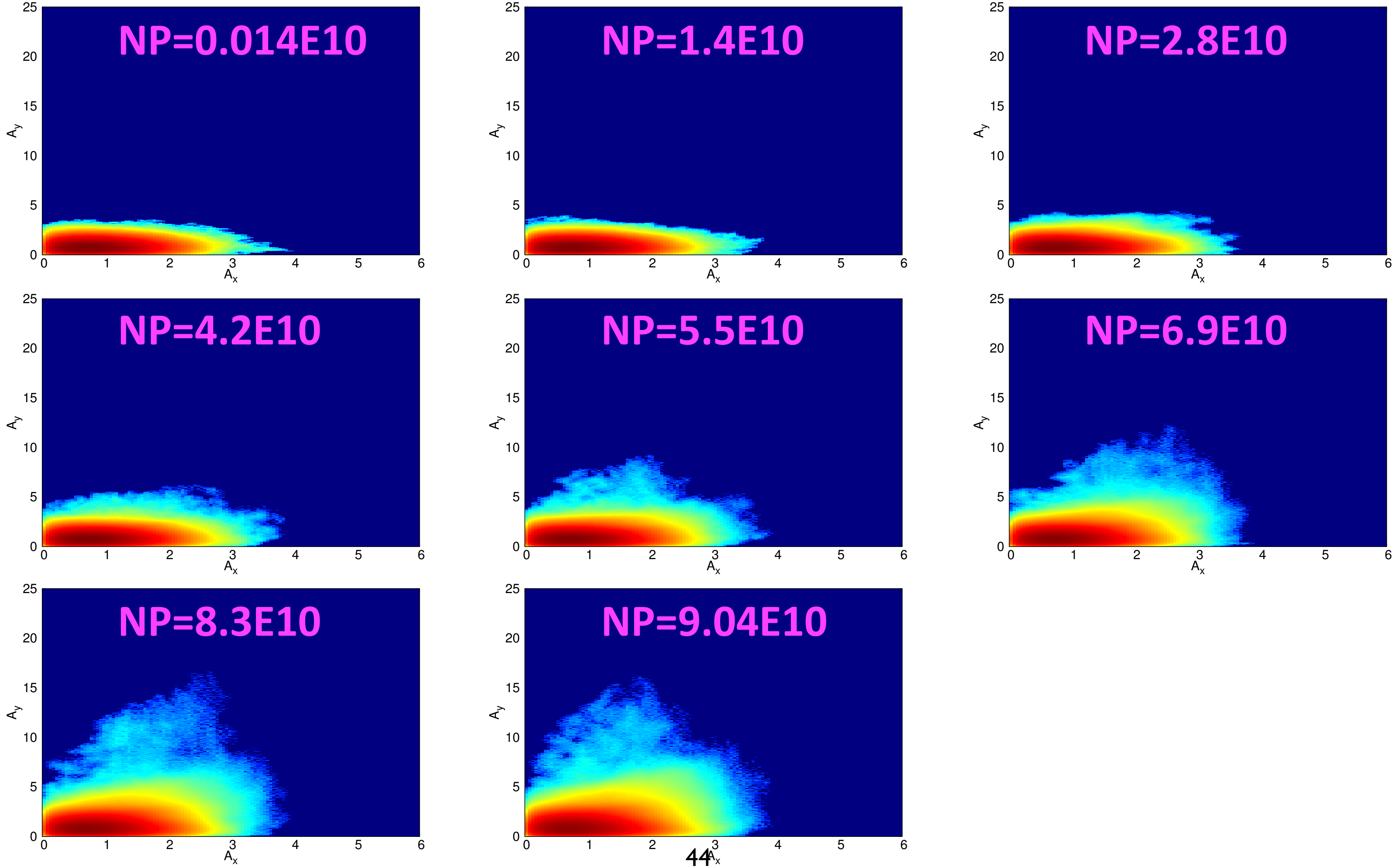
Simple map for CW at IP:

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

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

3. SuperKEKB: Lattice nonlinearities: HER

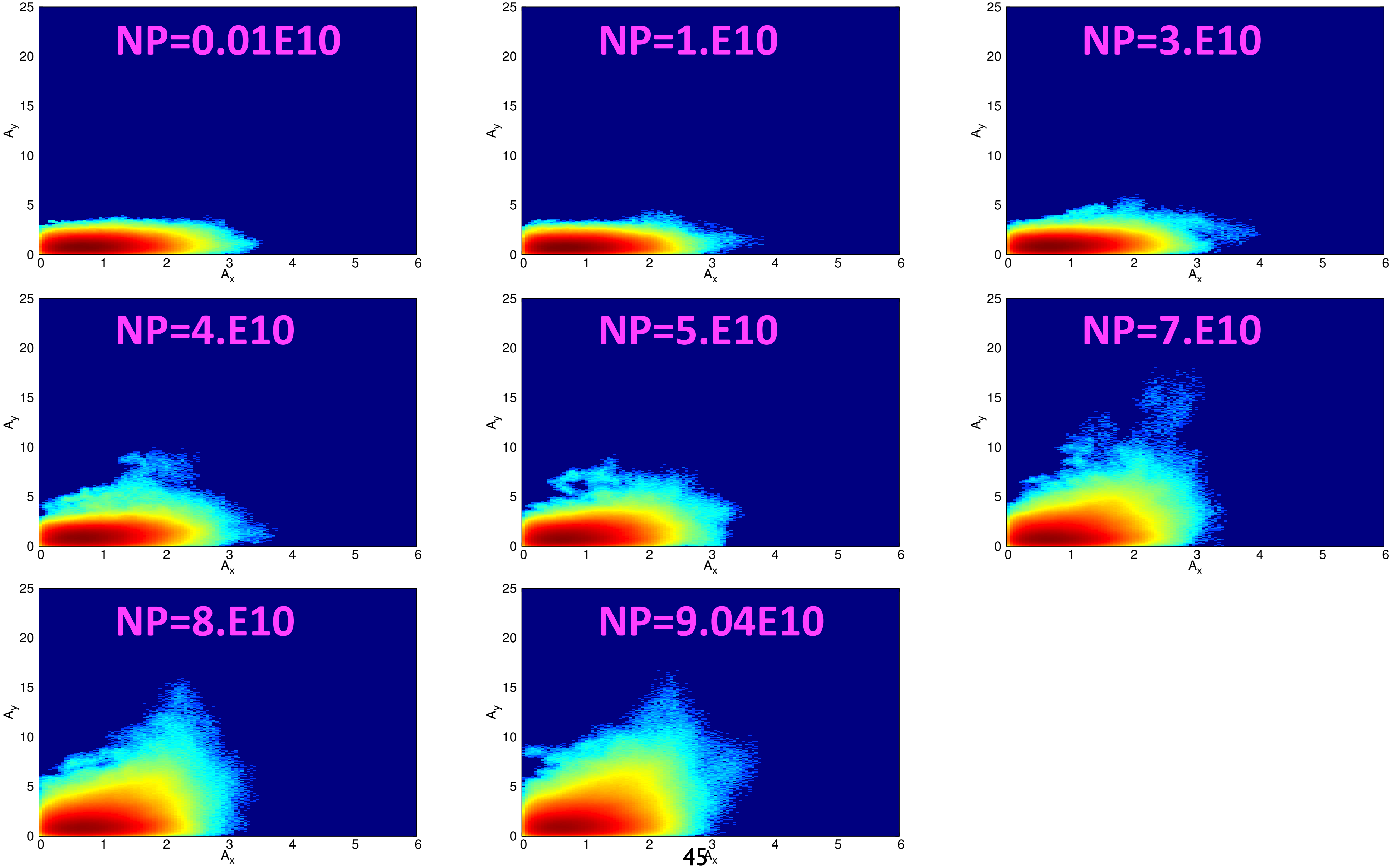
➤ **Beam tail w/ BB by BBWS**



3. SuperKEKB: Lattice nonlinearities: HER

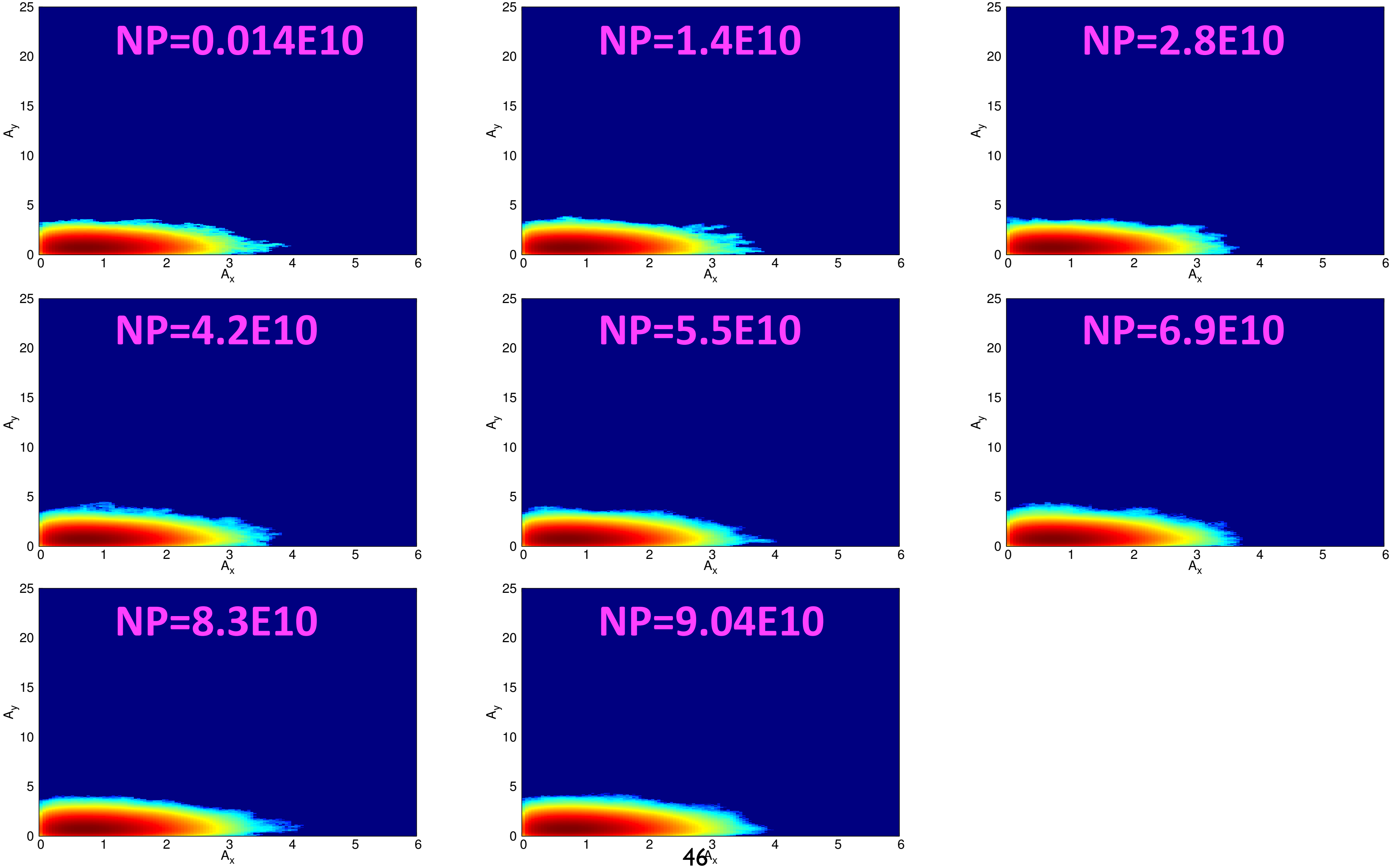
sher_5755

➤ Beam tail w/ BB+LN by SAD



3. SuperKEKB: Lattice nonlinearities: HER

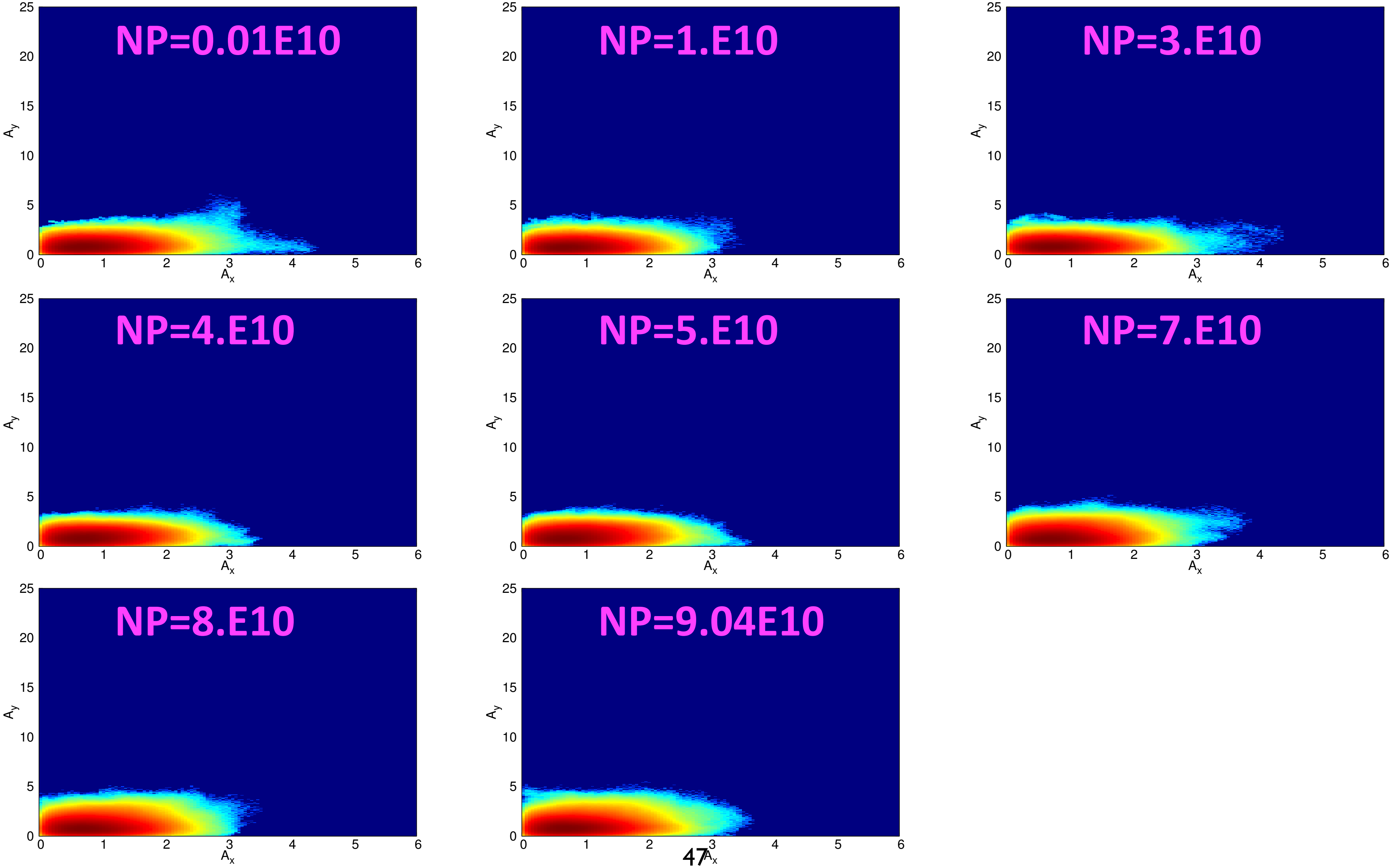
➤ **Beam tail w/ BB+CW by BBWS**



3. SuperKEKB: Lattice nonlinearities: HER

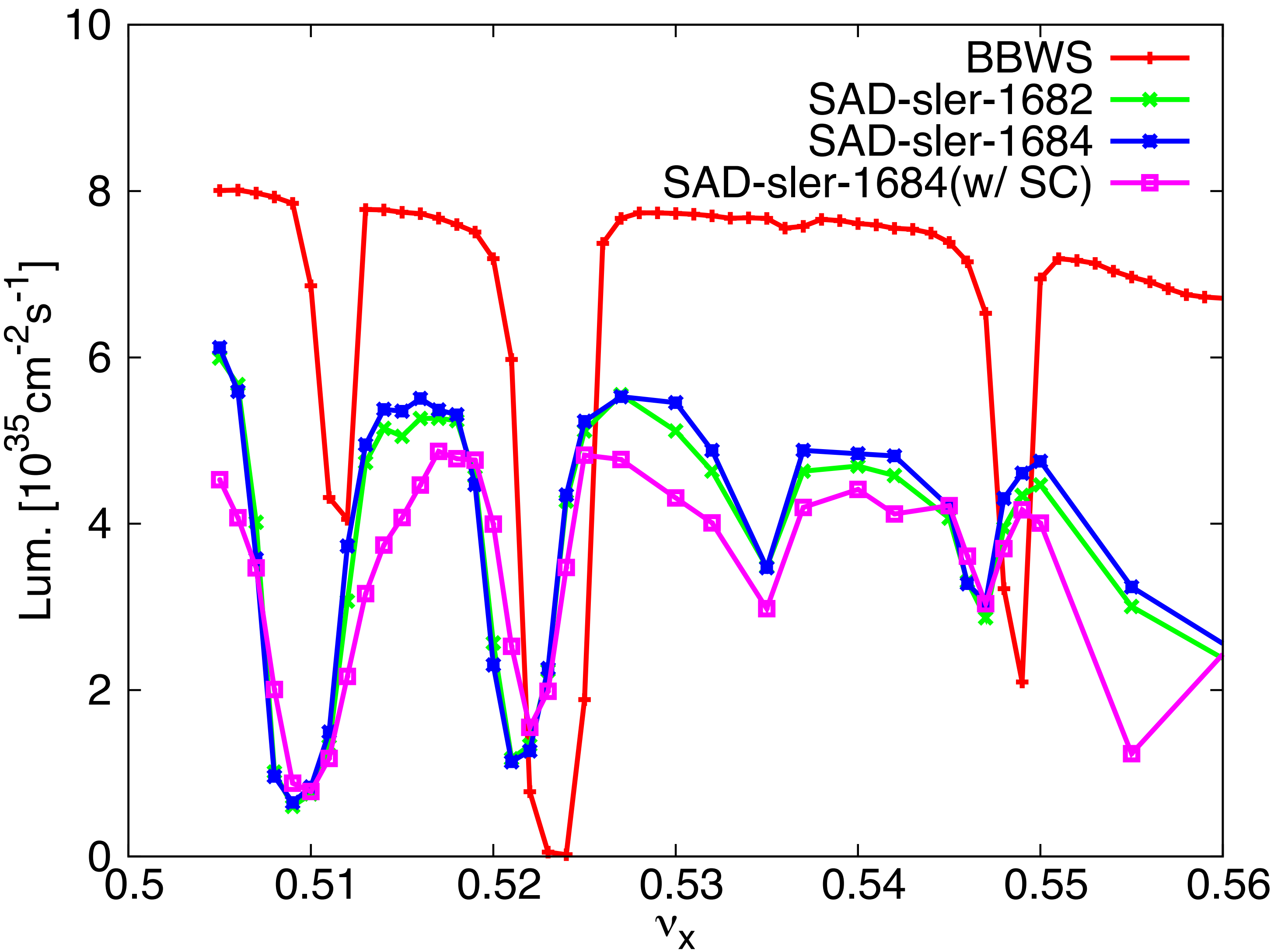
sher_5755

➤ Beam tail w/ BB+CW+LN by SAD



3. SuperKEKB: Space charge: LER

➤ **Hor. tune scan**



2. TLEP H

➤ Specific luminosity