SuperKEKB upgrade with polarized electron beam - Beam optics and spin tracking software

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Acknowledgements:

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Belle 2 collaboration meeting

KEK, Oct. 23, 2019

Outline

- **Introduction**
- **Studies to be done for the CDR of SuperKEKB with polarized e- beam**
  - **Lattice translation**
  - **Ring optics design with spin rotators**
  - **Spin tracking**
- **Summary**

1. Introduction

NO damping ring for electron beam

➤ **Nano-beam scheme**

- E (LER/HER): 3.5/8 ➟ 4/7 GeV
- β_y^* (LER/HER): 5.9/5.9 ➟ 0.27/0.3 mm
- I_{beam} (LER/HER): 1.7/1.4 ➟ 3.6/2.6 A
- ξ_y: 0.09 ➟ 0.09
- Crab waist: optional
- $\mathcal{L}$: 2.1 ➟ 80 $\times 10^{34}$ cm^{-2}s^{-1}

➤ **Phase 1**

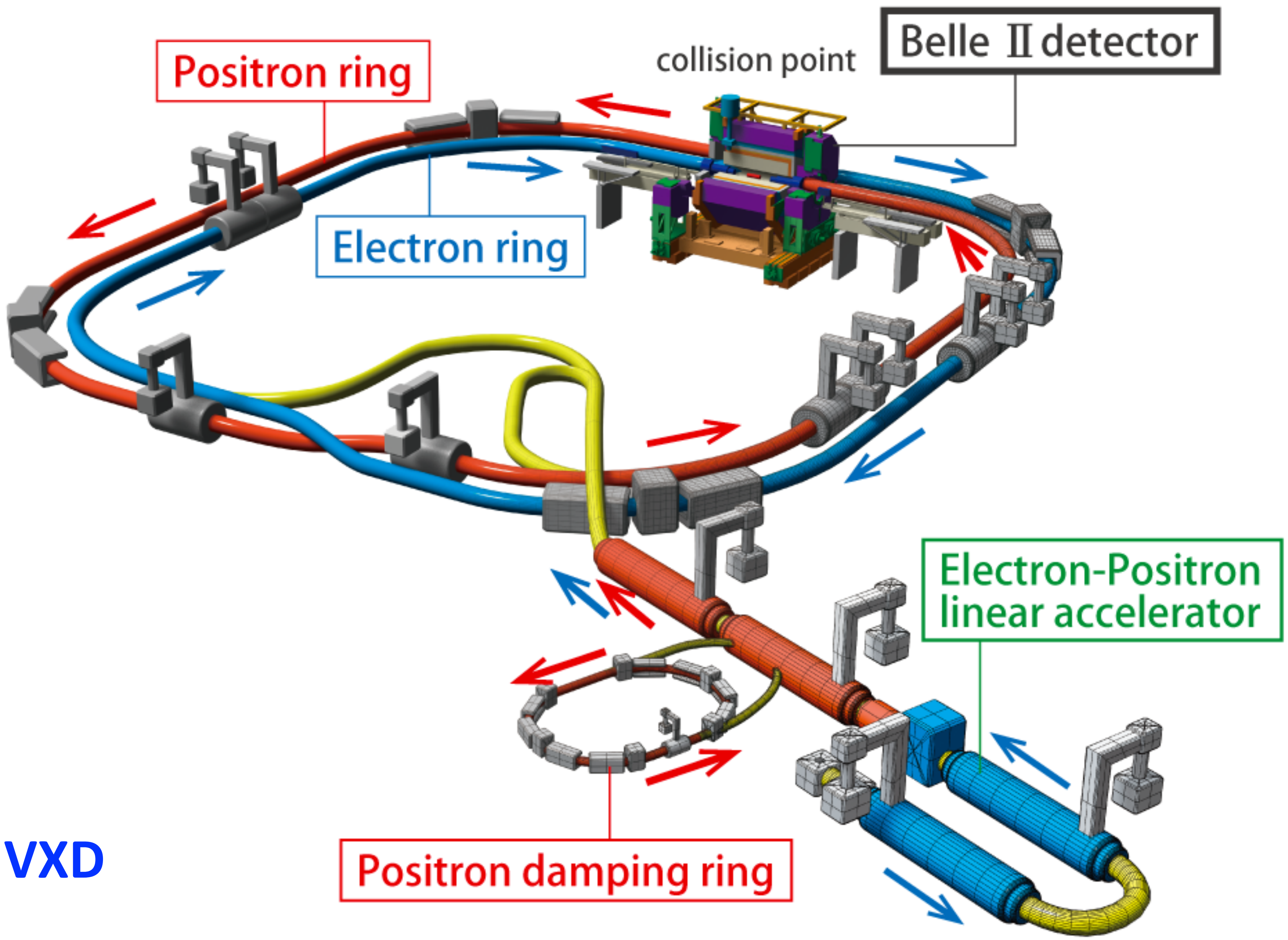
- w/o QCS and Belle-II
- Feb. - Jun., 2016

➤ **Phase 2**

- w/ QCS and Belle-II
- w/o Vertex detector
- Mar. 2018 - Jul. 2018

➤ **Phase III**

- w/ Full Belle-II including VXD
- Mar. 2019 -



1. Introduction

➤ Ring parameters

NO damping ring for electron beam

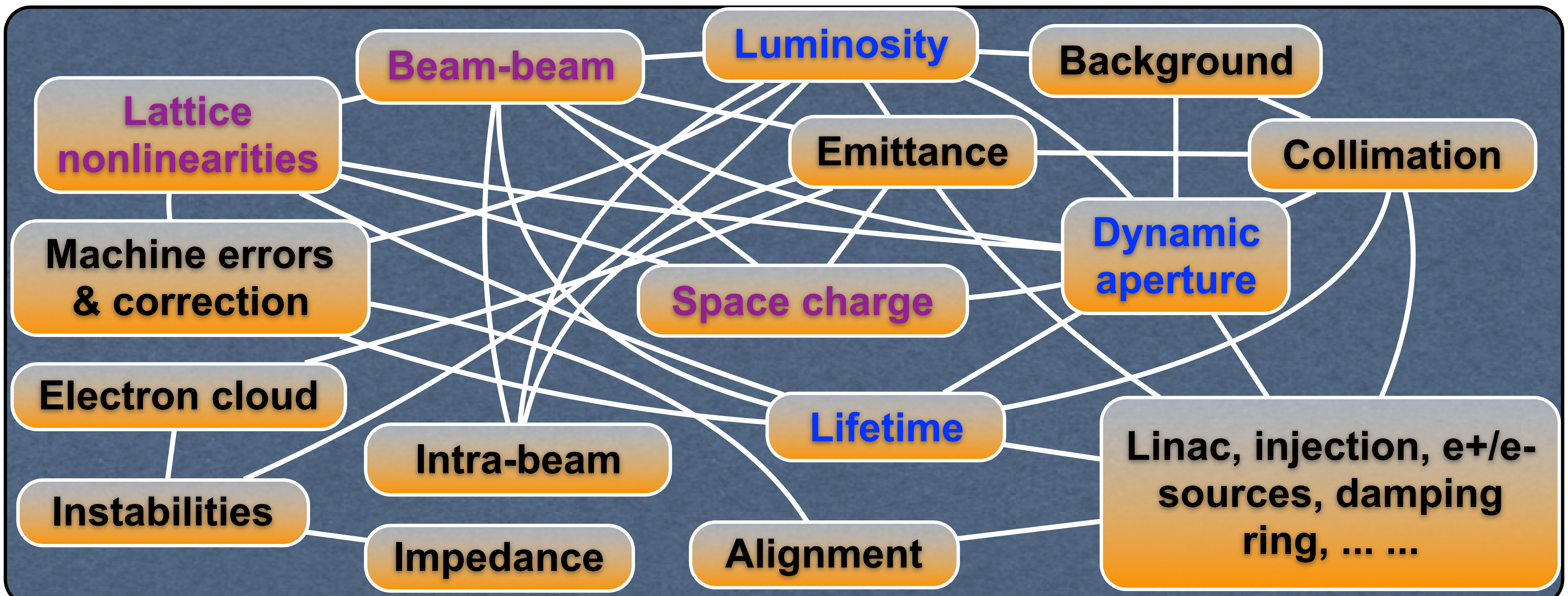
2017/September/1	LER	HER	unit	
E	4.000	7.007	GeV	
I	3.6	2.6	A	
Number of bunches	2,500			
Bunch Current	1.44	1.04	mA	
Circumference	3,016.315		m	
$\varepsilon_x/\varepsilon_y$	3.2(1.9)/8.64(2.8)	4.6(4.4)/12.9(1.5)	nm/pm	():zero current
Coupling	0.27	0.28		includes beam-beam
β_x^*/β_y^*	32/0.27	25/0.30	mm	
Crossing angle	83		mrad	
α_p	3.20×10^{-4}	4.55×10^{-4}		
σ_δ	$7.92(7.53)\times10^{-4}$	$6.37(6.30)\times10^{-4}$		():zero current
V_c	9.4	15.0	MV	
σ_z	6(4.7)	5(4.9)	mm	():zero current
ν_s	-0.0245	-0.0280		
ν_x/ν_y	44.53/46.57	45.53/43.57		
U_0	1.76	2.43	MeV	
$\tau_{x,y}/\tau_s$	45.7/22.8	58.0/29.0	msec	
ξ_x/ξ_y	0.0028/0.0881	0.0012/0.0807		
Luminosity	8×10^{35}		$cm^{-2}s^{-1}$	

http://www-superkekb.kek.jp/index.html

1. Introduction

➤ Interplay of beam dynamics issues

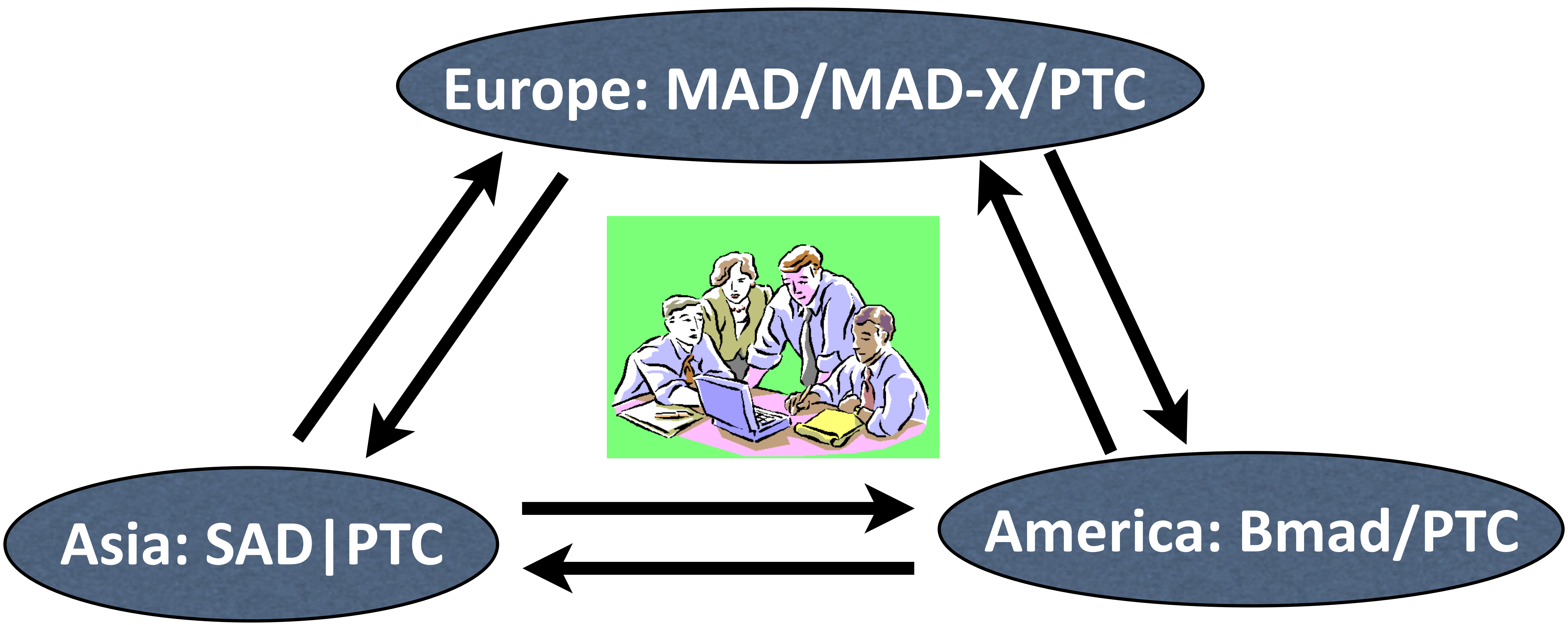
- Luminosity <= Emittance <= Beam-beam, Lattice nonlinearity, Space charge, Impedances, Electron cloud, Intra-beam scattering, etc.
- => Dynamic aperture and lifetime => Beam commissioning => Injection, Detector back ground, Alignments, etc. => Tolerances for hardwares => …



2. Lattice translation

➤ **Motivation: To improve communications and establish collaborations**

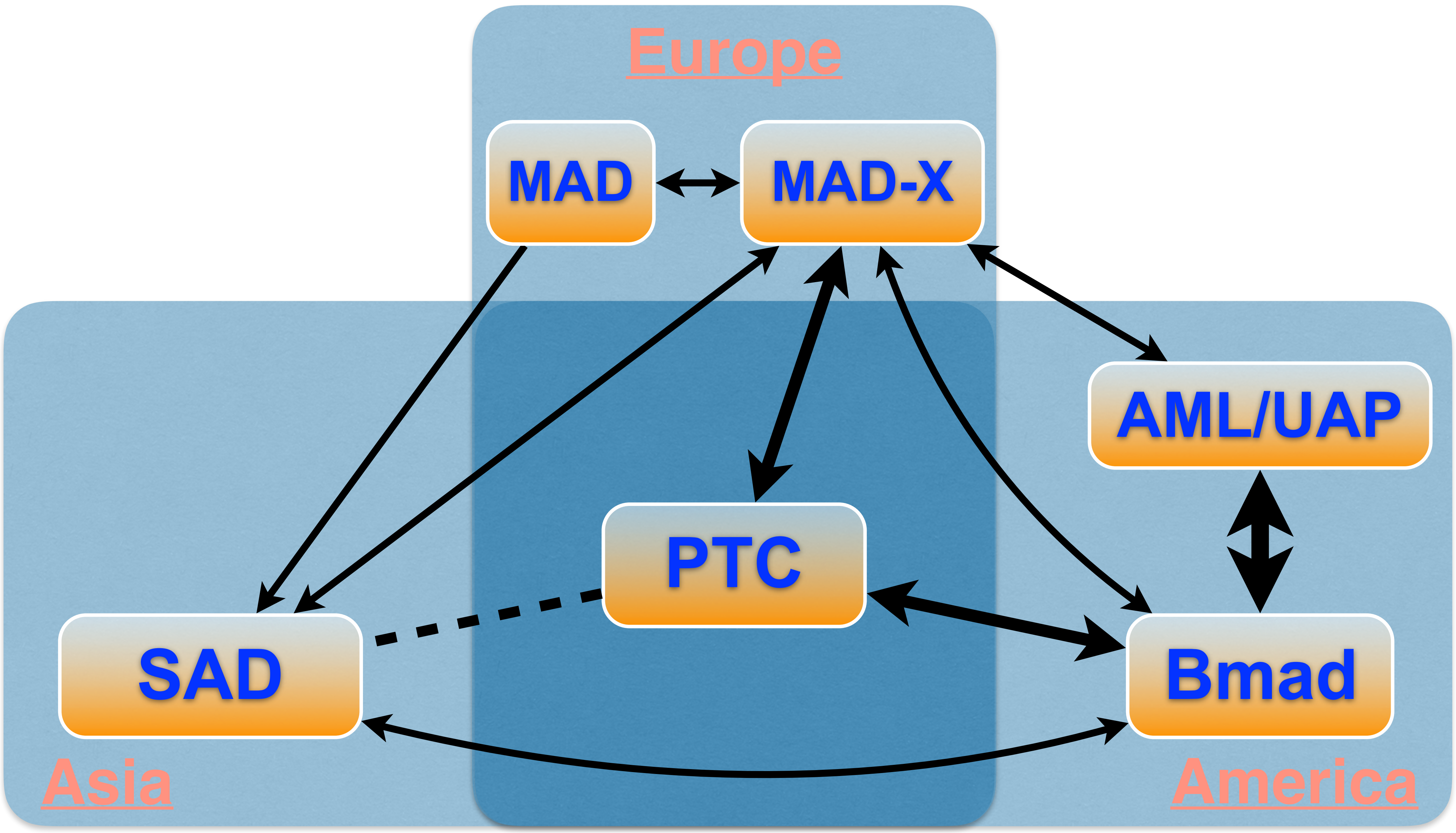
- **SAD: TRISTAN, KEKB, J-PARC, SuperKEKB, …**
- **Bmad: CESR, ERL, …**
- **MAD/MAD-X: PS, LEP, LHC, FCCs, …**



2. Lattice translation

➤ **Efforts for lattice translations**

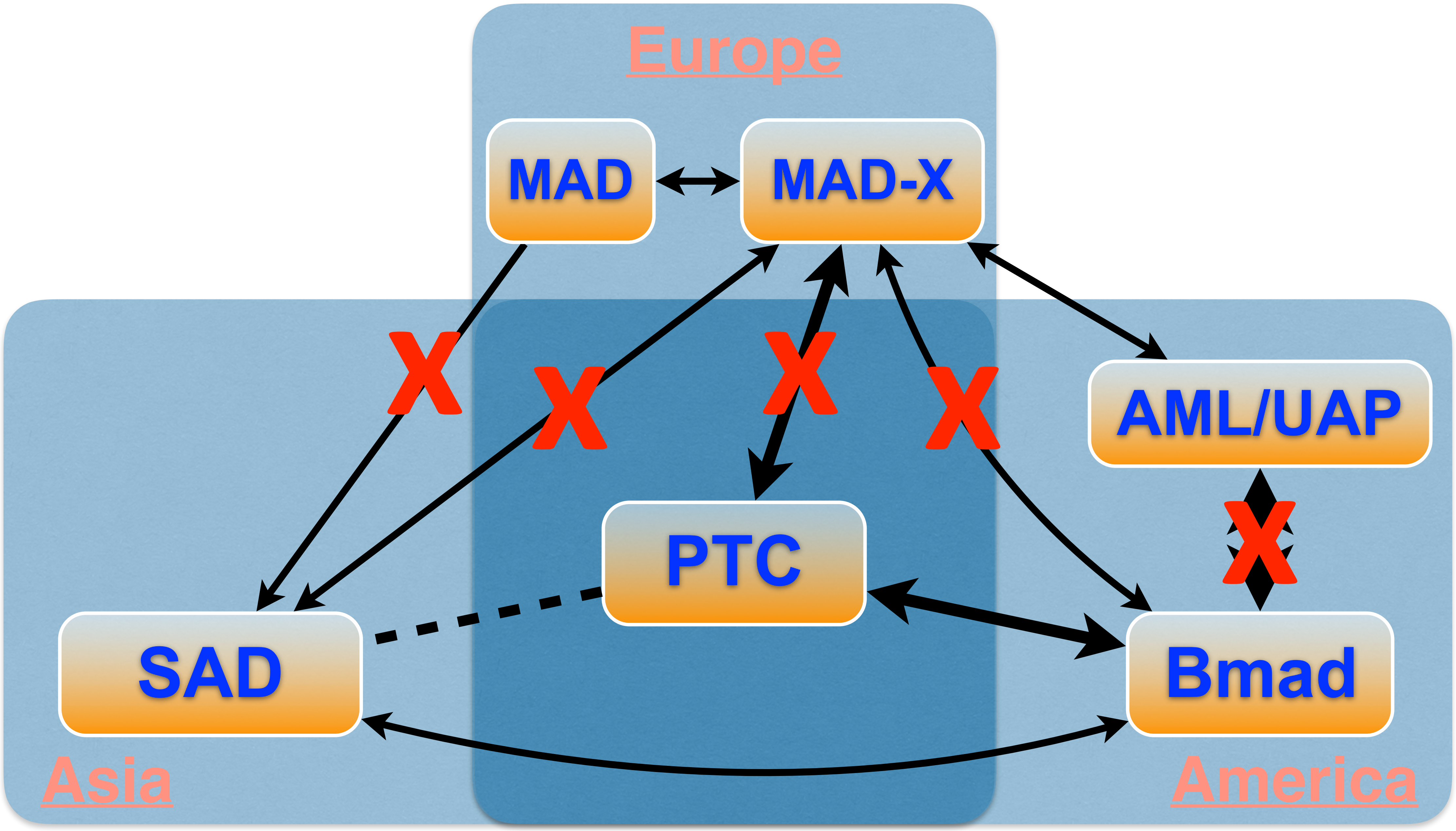
- **SAD and PTC: developed at KEK, many shared features (transfer maps, symplectic integrator, ...)**
- **PTC integrated into MAD-X and Bmad**



2. Lattice translation

➤ **Efforts for lattice translations**

- **But for SuperKEKB, so far only SAD, Bmad and PTC can interpret the lattices because of complicated IR**



2. Lattice translation

➤ **To start collaborations, SuperKEKB lattices have to be translated to other codes**

- **SAD to Bmad and then to PTC: very successful now**
- **Source of lattice nonlinearities in SuperKEKB identified by PTC**
- **Possible run simulation tools developed based on Bmad and PTC**
- **PTC is the best tool for simulations of spin dynamics**

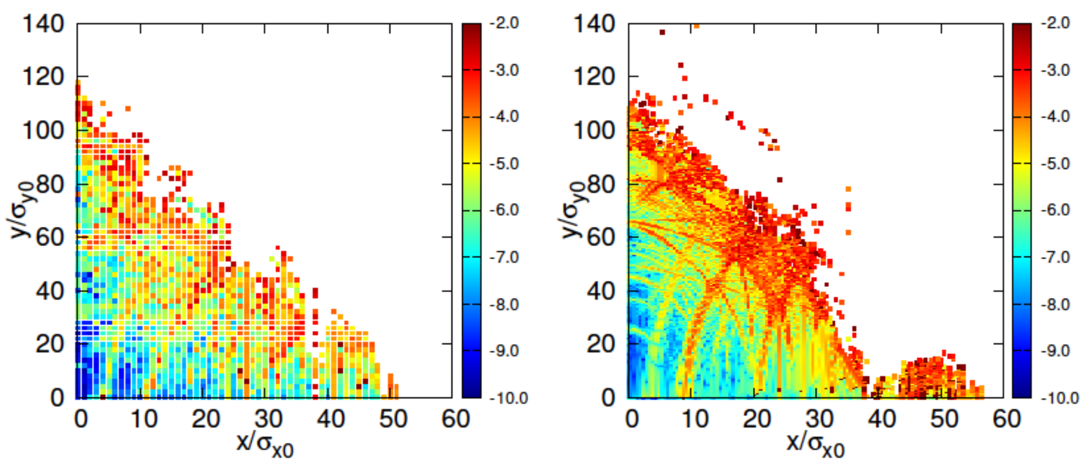


Figure 3: Amplitude-dependent diffusion for a baseline lattice of SuperKEKB LER using SAD (left) and Bmad (right).

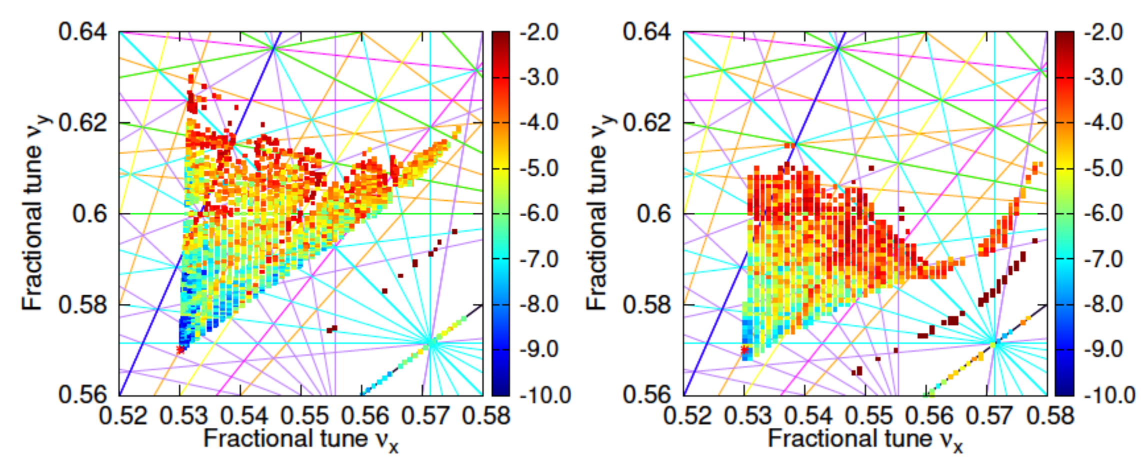


Figure 4: Frequency maps for a baseline lattice of SuperKEKB LER using SAD (left) and Bmad (right). The colored lines indicate various resonance lines.

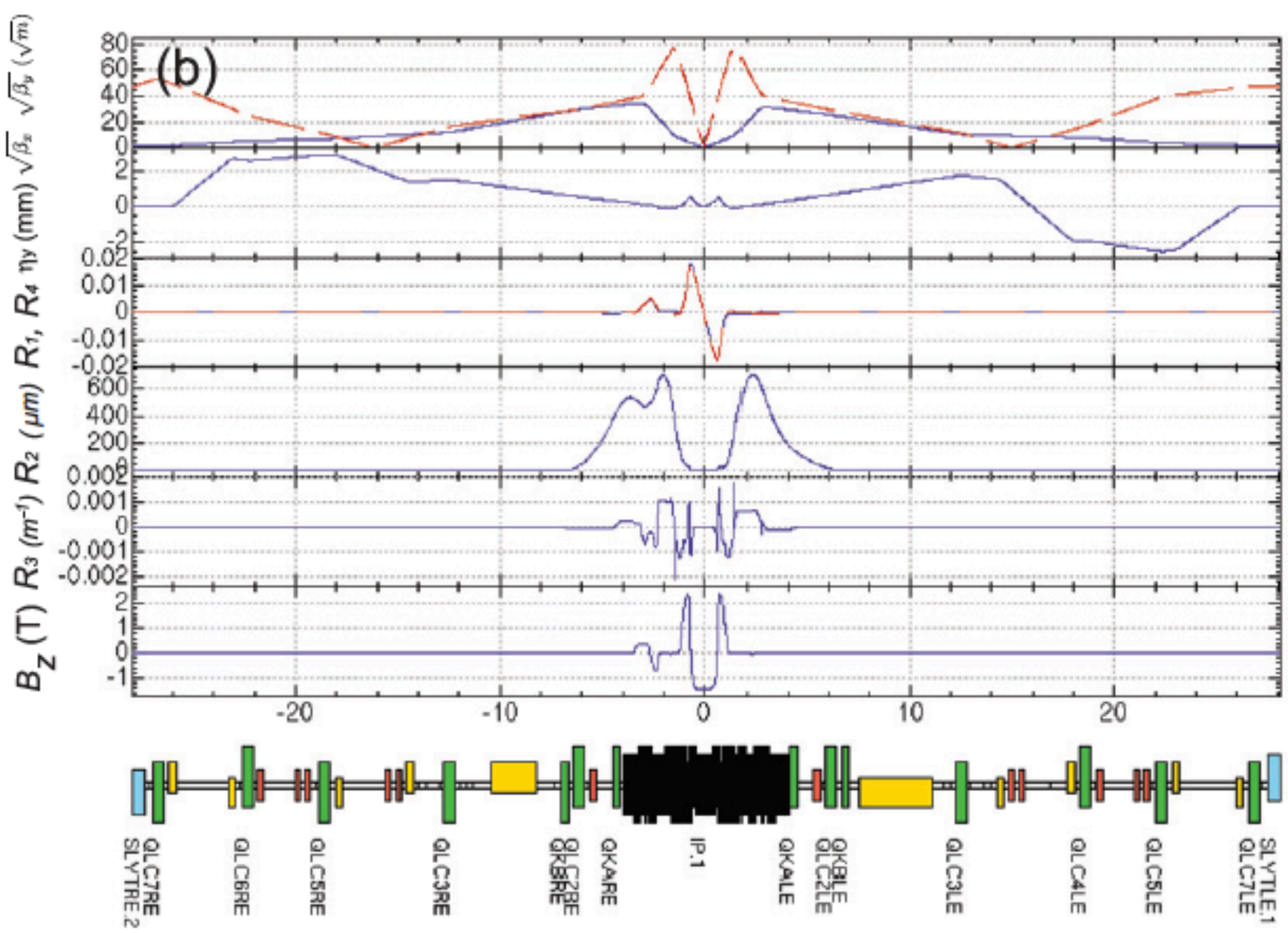
Ref. D. Zhou et al., IPAC16

3. Ring optics design for HER

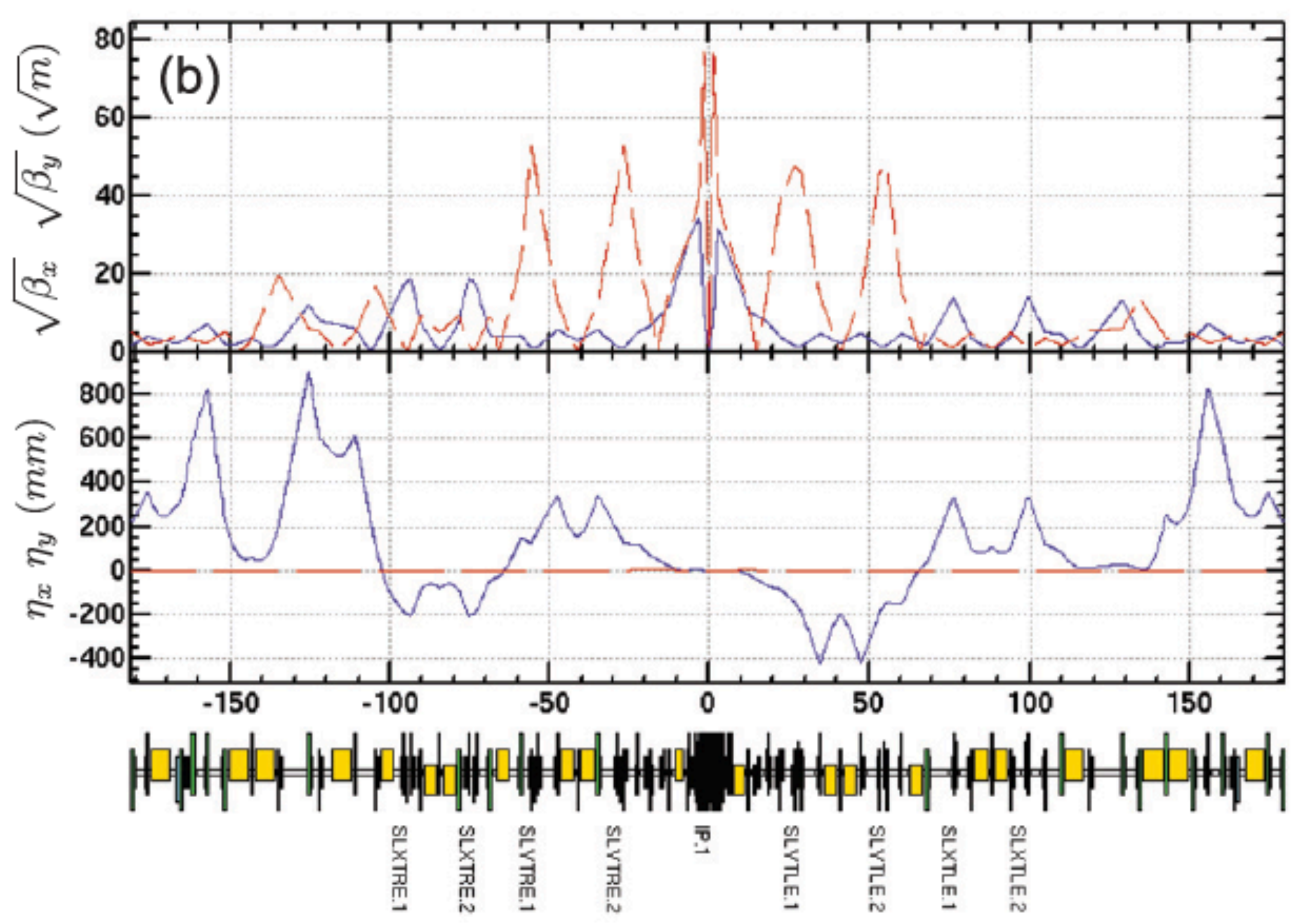
➤ **Issues**

- **Available spaces for spin rotator?**
- **Additional constraints to the optics => Effects on DA, lifetime, etc.**

IR



Local chromaticity correction



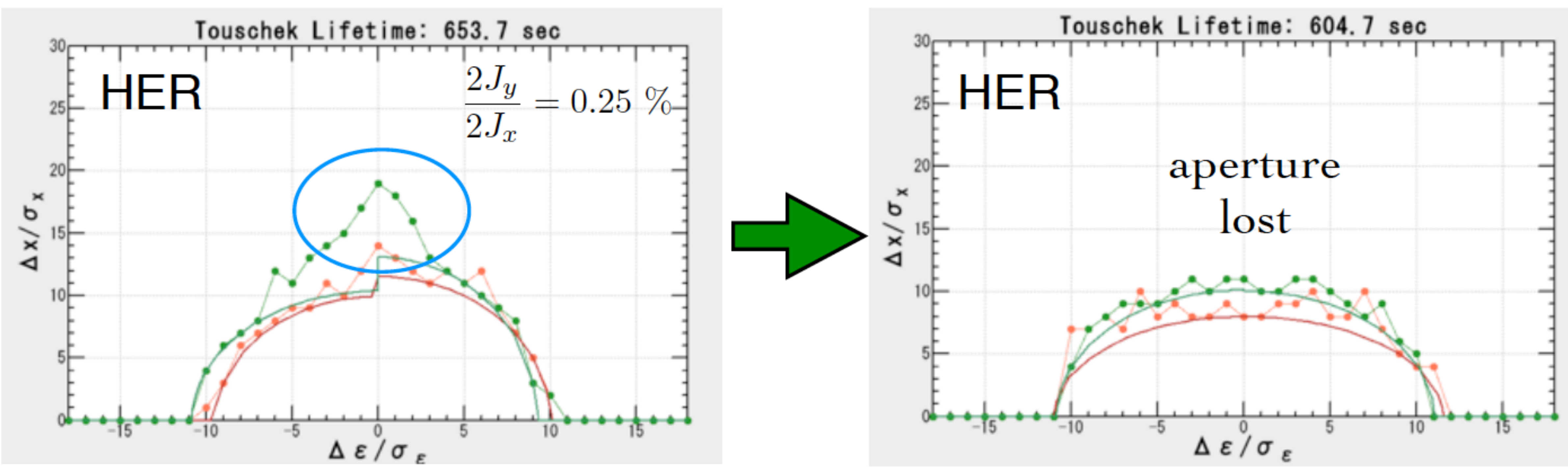
Y. Ohnishi, Accelerator design at SuperKEKB, Prog. Theor. Exp. Phys. (2013) 03A001.

3. Ring optics design for HER

➤ **DA and lifetime are sensitive to beam-beam interaction**

- **The case of SuperKEKB final design**
- **Including crab waist is even challenging**
- **Spin rotators set more constraints => Loss of variables for DA optimizations**

Effect of beam-beam on DA and lifetime



From Y. Ohnishi

4. Spin tracking

➤ The only tool available: PTC

- Spin tracking is not implemented (or lost) into SAD
- Long-term developments of PTC for spin tracking (based on international collaborations)
- SuperKEKB lattice translatable to PTC (then to MAD-X and Bmad with necessary interfaces)

➤ Brief history of PTC [Ref. D.T. Abell, PTC Library User Guide]

- Late 1980s, DA (Differential Algebra) package by M. Berz. E. Forest developed LieLib on top of DA
- Early 1990s, Forest and Bengtsson developed ideas of the fundamental blocks of PTC
- Middle to late 1990s, Forest developed LieLib into FPP. Then the PTC-proper (the integrator)
- …

4. Spin tracking

➤ Brief history of PTC [Ref. E. Forest, Talk to SAD Workshop 2019 at KEK]

History

- Start FPP around 1998/Start PTC around 2000
- Put into MAD-X with help of Frank Schmidt and Eric Macintosh completed by 2002
- Spin added around 2007 in FPP and PTC (Barber pressure)
- Magnet modulation added in FPP and PTC (Schmidt pressure)
- Continuous collaboration with David Sagan since the beginning: FPP/PTC fully added in the early 2010 in BMAD
- PTC painfully added in ORBIT under the guidance Alexander Molodozhentsev (It is unfortunately a “hack” but it worked)
- Made SAD compatible under the guidance of David Sagan
- Analysis tools fully “complexified”, old Fortran 77 routines are obsolescent (Deniau pressure)

4. Spin tracking

➤ **Important issues to be investigated [private point view of beam dynamics]**

- Layout of a SuperKEKB lattice with spin rotators
- Simulations of spin dynamics with full lattice including spin rotators
- Interplay of lattice nonlinearity, beam-beam and spin rotators: Dynamic aperture and beam lifetime

5. Summary

- **Design/simulation tools for SuperKEKB with polarized e-beam are ready (Users of Bmad/PTC)**
- **Detailed investigations to be performed based on a framework of international collaboration**