Brief introduction to SuperKEKB and issues on possible upgrade with polarized electron beam

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On behalf of the SuperKEKB team

Acknowledgements:

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First meeting on polarized electron beam for SuperKEKB

KEK, Feb. 6, 2018

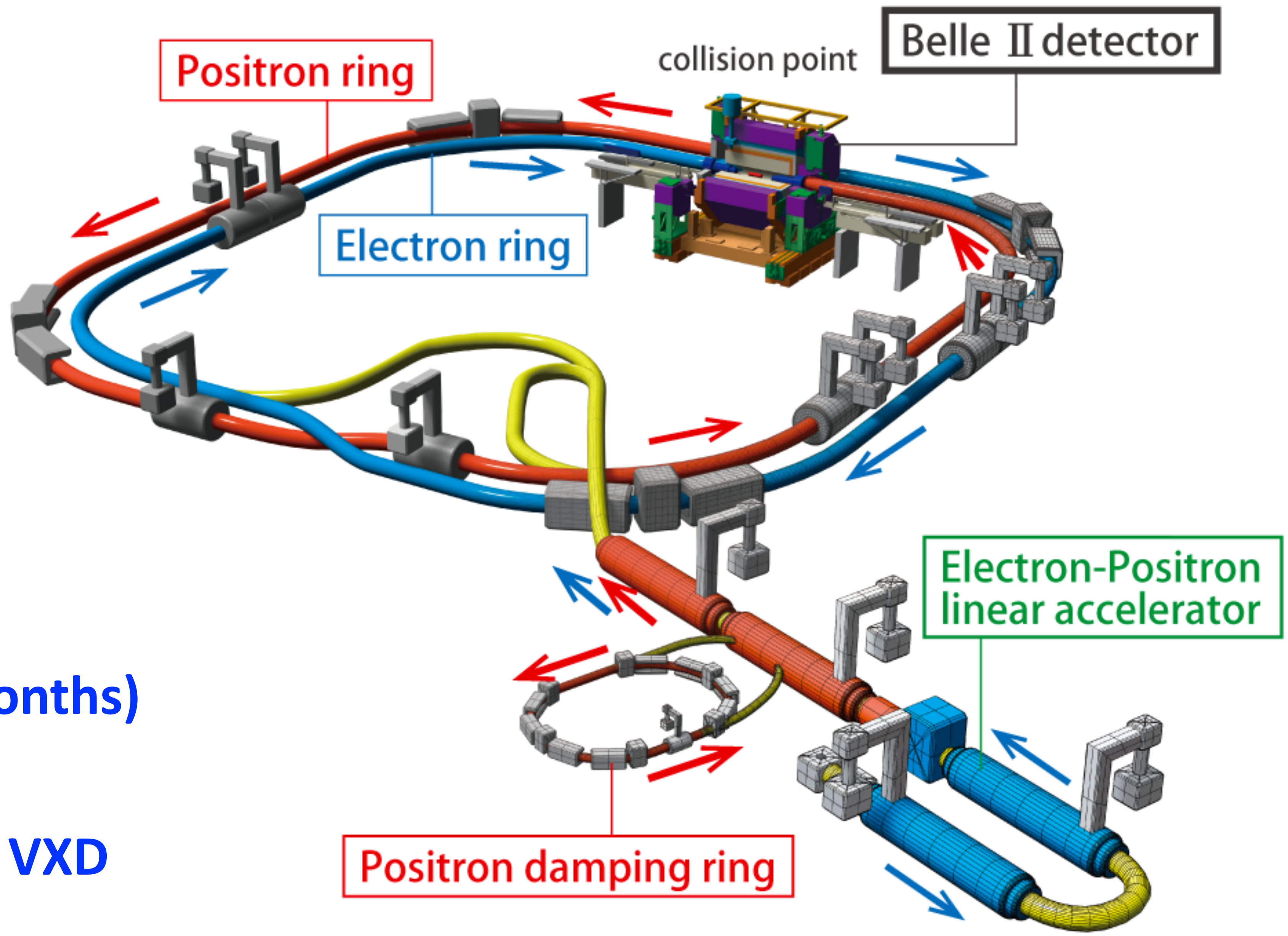
Outline

- **Introduction**
- **Issues on polarized electron beam**
  - Lattice translation
  - Polarized beam source
  - Ring optics design
- **International collaboration**
  - Investigation team
  - Resources

1. Introduction

- **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 I**
  - w/o QCS and Belle-II
  - Feb. - Jun., 2016
- **Phase II**
  - w/ QCS and Belle-II
  - w/o Vertex detector
  - Around Feb. 2018 (~5 months)
- **Phase III**
  - w/ Full Belle-II including VXD
  - After summer of 2018

NO damping ring for electron beam



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	0: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	$7.92(7.53)\times10^{-4}$	$6.37(6.30)\times10^{-4}$		0:zero current
V_c	9.4	15.0	MV	
σ_z	6(4.7)	5(4.9)	mm	0: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

➤ Ring parameters (SuperB)

Table 1: SuperB parameters for baseline, low emittance and high current options, and for τ/charm running.

		Base Line		Low Emittance		High Current		τ-charm	
Parameter	**Units**	**HER (e+)**	**LER (e-)**	**HER (e+)**	**LER (e-)**	**HER (e+)**	**LER (e-)**	**HER (e+)**	**LER (e-)**
LUMINOSITY	$cm^{-2}\ s^{-1}$	**1.00E+36**		**1.00E+36**		**1.00E+36**		**1.00E+35**	
Energy	**GeV**	6.7	4.18	6.7	4.18	6.7	4.18	2.58	1.61
Circumference	**m**	1258.4		1258.4		1258.4		1258.4	
X-Angle (full)	**mrad**	66		66		66		66	
β_x **@ IP**	**cm**	2.6	3.2	2.6	3.2	5.06	6.22	6.76	8.32
β_y **@ IP**	**cm**	0.0253	0.0205	0.0179	0.0145	0.0292	0.0237	0.0658	0.0533
Coupling (full current)	%	0.25	0.25	0.25	0.25	0.5	0.5	0.25	0.25
Emittance x (with IBS)	**nm**	2.00	2.46	1.00	1.23	2.00	2.46	5.20	6.4
Emittance y	**pm**	5	6.15	2.5	3.075	10	12.3	13	16
Bunch length (full current)	**mm**	5	5	5	5	4.4	4.4	5	5
Beam current	**mA**	1892	2447	1460	1888	3094	4000	1365	1766
RF frequency	**MHz**	476.		476.		476.		476.	
Number of bunches	**#**	978		978		1956		1956	
Tune shift x		0.0021	0.0033	0.0017	0.0025	0.0044	0.0067	0.0052	0.0080
Tune shift y		0.097	0.097	0.0891	0.0892	0.0684	0.0687	0.0909	0.0910
Total RF Wall Plug Power	**MW**	16.38		12.37		28.83		2.81	

1. Introduction

➤ Machine parameters for Phase 2 and 3

- Phase 2 target: $1x10^{34}$ $cm^{-2}s^{-1}$

Parameters	symbol	Phase 2.x		Phase 3.x		unit
		LER	HER	LER	HER	
Energy	E	4	7.007	4	7.007	GeV
#Bunches	n_b	1576		2500		
Emittance	ε_x	2.0	4.6	3.2	4.6	nm
Coupling	$\varepsilon_y/\varepsilon_x$	5	5	0.27	0.28	%
Hor. beta at IP	β_x^*	128	128	32	25	mm
Ver. beta at IP	β_y^*	2.2	2.2	0.27	0.30	mm
Beam current	I_b	1.0	0.8	3.6	2.6	A
Beam-beam	ξ_y	0.0228	0.0246	0.088	0.081	
Hor. beam size	σ_x^*	16	24	10	11	µm
Ver. beam size	σ_y^*	470	711	48	62	nm
Luminosity	L	$1x10^{34}$		$8x10^{35}$		$cm^{-2}s^{-1}$

Courtesy of Y. Ohnishi, 24th B2GM, Jun. 2016

1. Introduction

➤ Injector parameters

Required injector beam parameters

Stage	KEKB (final)		Present Phase-I		SuperKEKB (final)	
Beam	e+	e–	e+	e–	e+	e–
Energy	3.5 GeV	8.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV
Stored current	1.6 A	1.1 A	1 A	1 A	3.6 A	2.6 A
Life time	150 min.	200 min.	100 min.	100 min.	6 min.	6 min.
Bunch charge	Primary e-10nC → 1 nC	1 nC	Primary e- 8nC → 0.4 nC	1 nC	Primary e-10nC → 4 nC	5 nC
Norm. Emittance (γβε) (μrad)	2100	200	2400	150	100/20 (Hor./Ver.)	50/20 (Hor./Ver.)
Energy spread	0.125%	0.125%	0.5%	0.5%	0.1%	0.1%
No. of Bunch / Pulse	2	2	2	2	2	2
Repetition rate	50 Hz		25 / 50 Hz		50 Hz	
Simultaneous top-up injection (PPM)	3 rings (KEKB e–/e+, PF)		No top-up		4+1 rings (SuperKEKB e–/e+, DR, PF, PF-AR)	

Injector Linac Upgrade towards SuperKEKB *K.Furukawa, KEK, Jun.2016.* 3

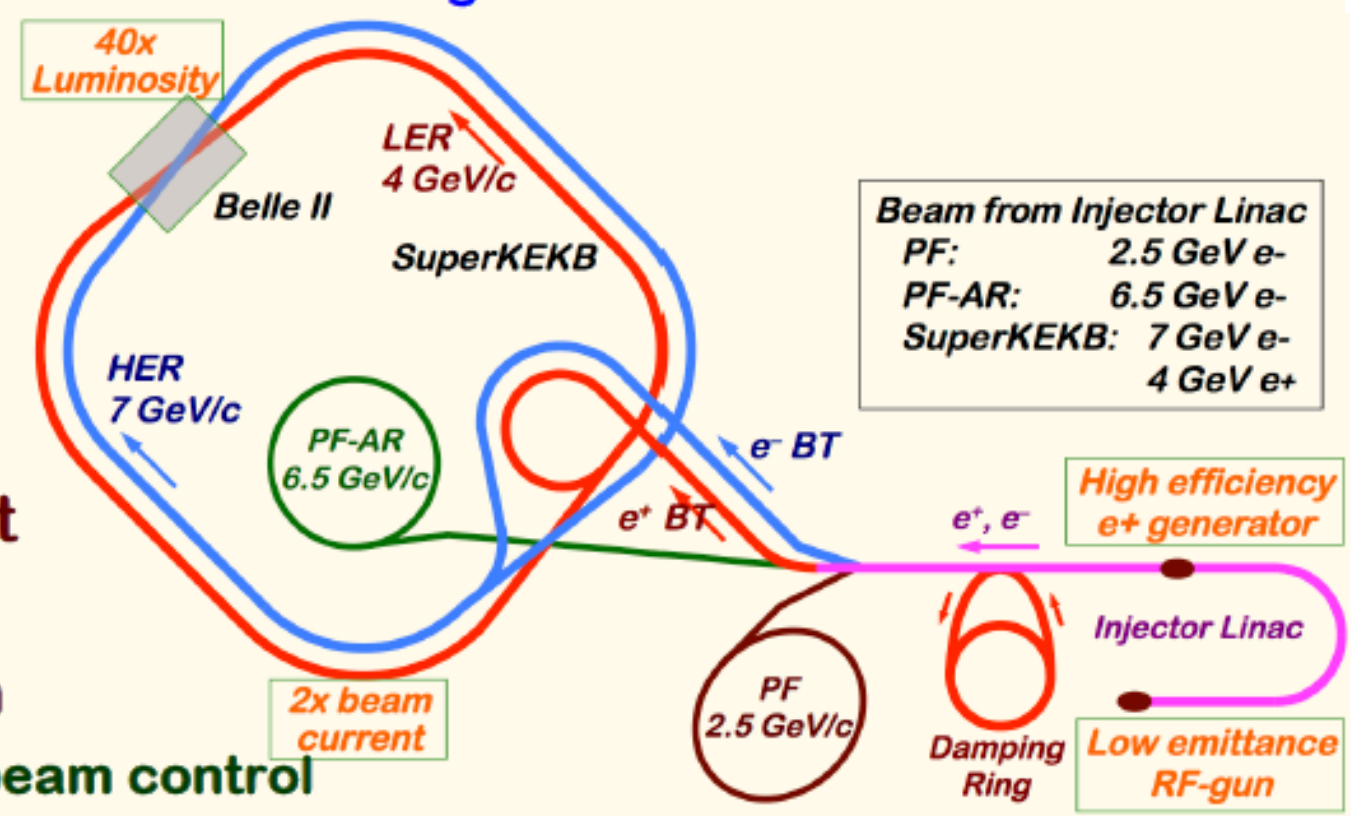
K. Furukawa, http://www-kekb.kek.jp/MAC/2016/

1. Introduction

➤ Injector

Mission of electron/positron Injector in SuperKEKB

- **40-times higher Luminosity**
  - 20-times higher collision rate with nano-beam scheme
    - → Low-emittance even at first turn → Low-emittance beam from Linac
    - → Shorter storage lifetime
  - Twice larger storage beam → Higher beam current from Linac
- **Linac challenges**
  - Low emittance e-
    - with high-charge RF-gun
  - Low emittance e+
    - with damping ring
  - Higher e+ beam current
    - with new capture section
  - Emittance preservation
    - with precise alignment & beam control
  - 4+1 ring simultaneous injection



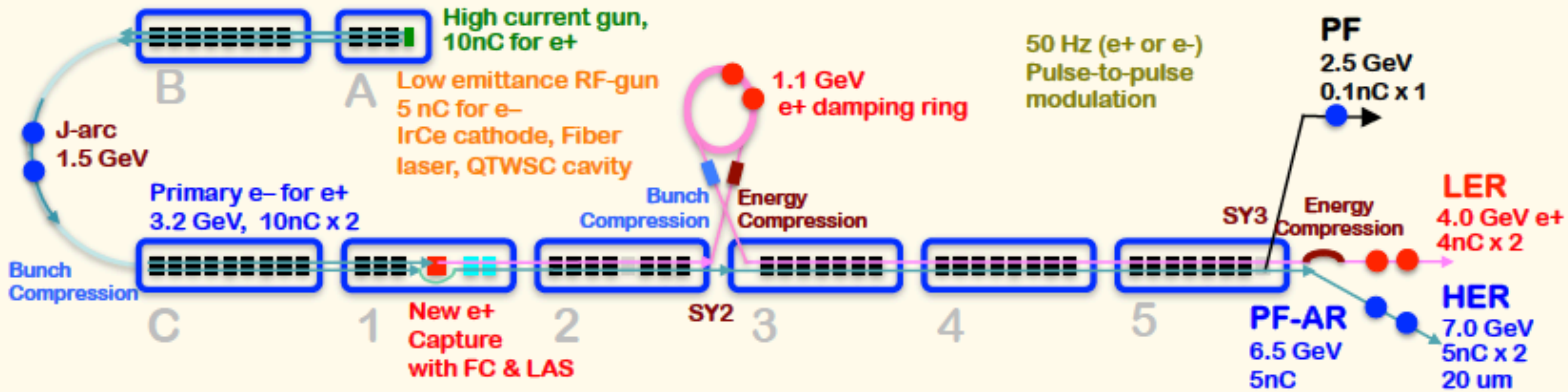
 K. Furukawa, http://www-kekb.kek.jp/MAC/2016/

1. Introduction

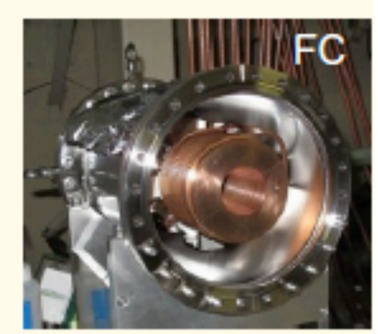
➤ Injector

Linac Overview

Linac Upgrade for SuperKEKB



- **Higher Injection Beam Current**
  - To Meet the larger stored beam current and shorter beam lifetime in MR
  - 4~8-times larger bunch current for electron and positron
- **Lower-emittance Injection Beam**
  - To meet nano-beam scheme in the ring
  - Positron with a damping ring, Electron with a photo-cathode RF gun
  - Emittance preservation by alignment and beam instrumentation
- **Quasi-simultaneous injections into 4 storage rings (PPM)**
  - SuperKEKB e⁻/e⁺ rings, and light sources of PF and PF-AR
  - Improvements to beam monitors, low-level RF, controls, timing, etc



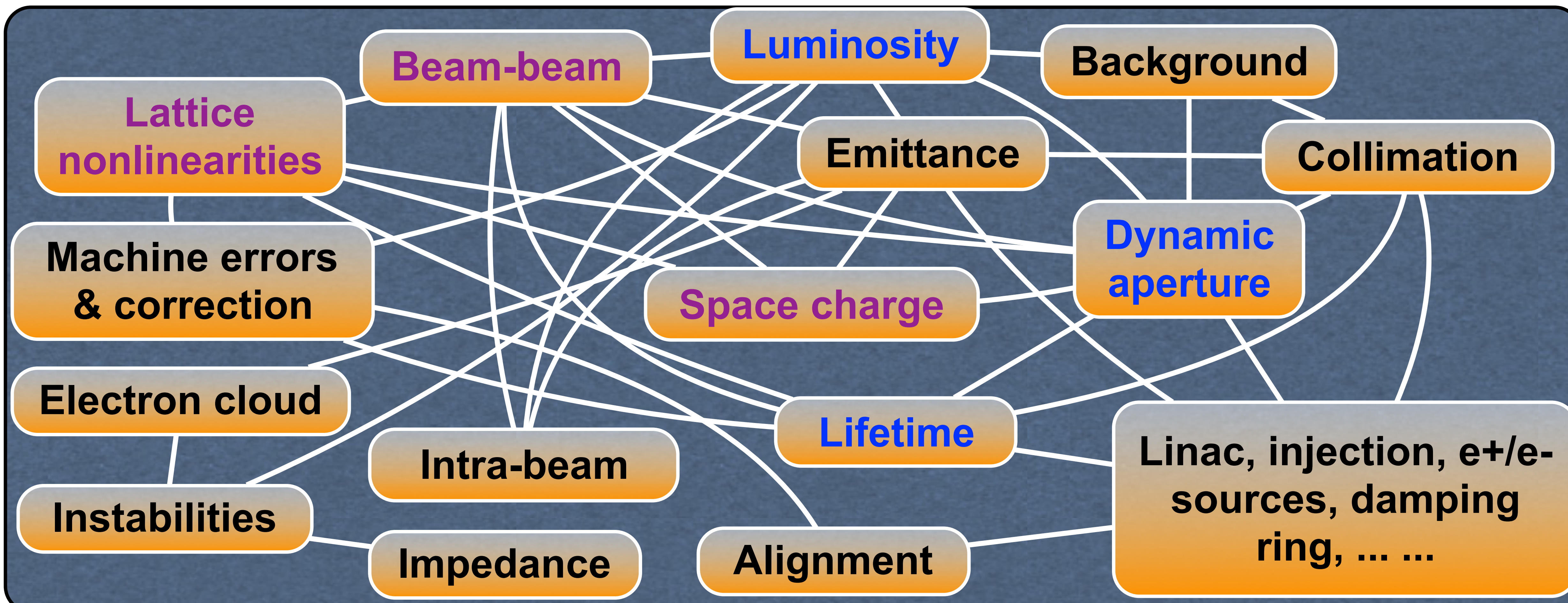
Linac Upgrade towards SuperKEKB *K.Furukawa, MAC review, Feb.2015.* 3

 K. Furukawa, http://www-kekb.kek.jp/MAC/2015/

1. Introduction

➤ Interplay of beam dynamics issues

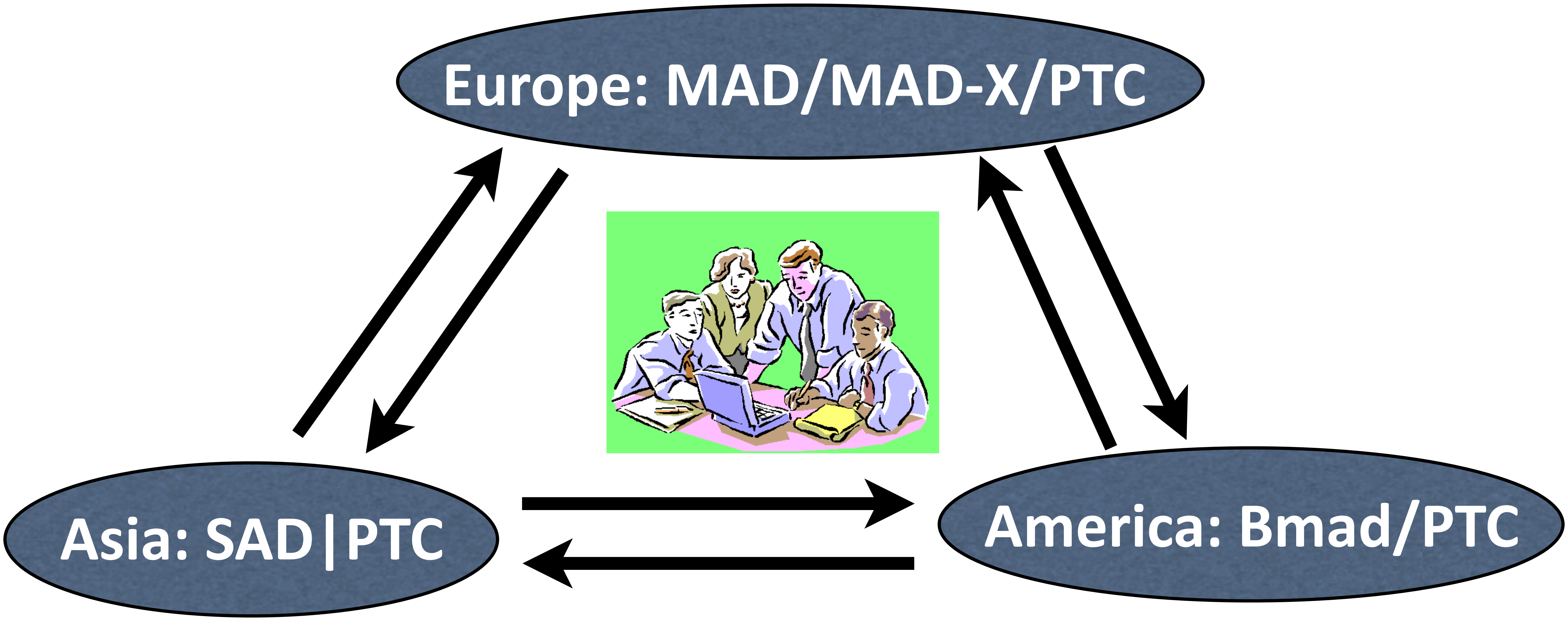
- Luminosity <= Emittance <= Beam-beam, Lattice nonlinearity, Space charge, Impedances, Electron cloud, Intra-beam scattering, etc.
- => Dynamic aperture and lifetime => Beam commissioning => Injection, Detector back ground, Alignments, etc. => Tolerances for hardwares => ...



2. Lattice translation

➤ **Motivation: To improve communications**

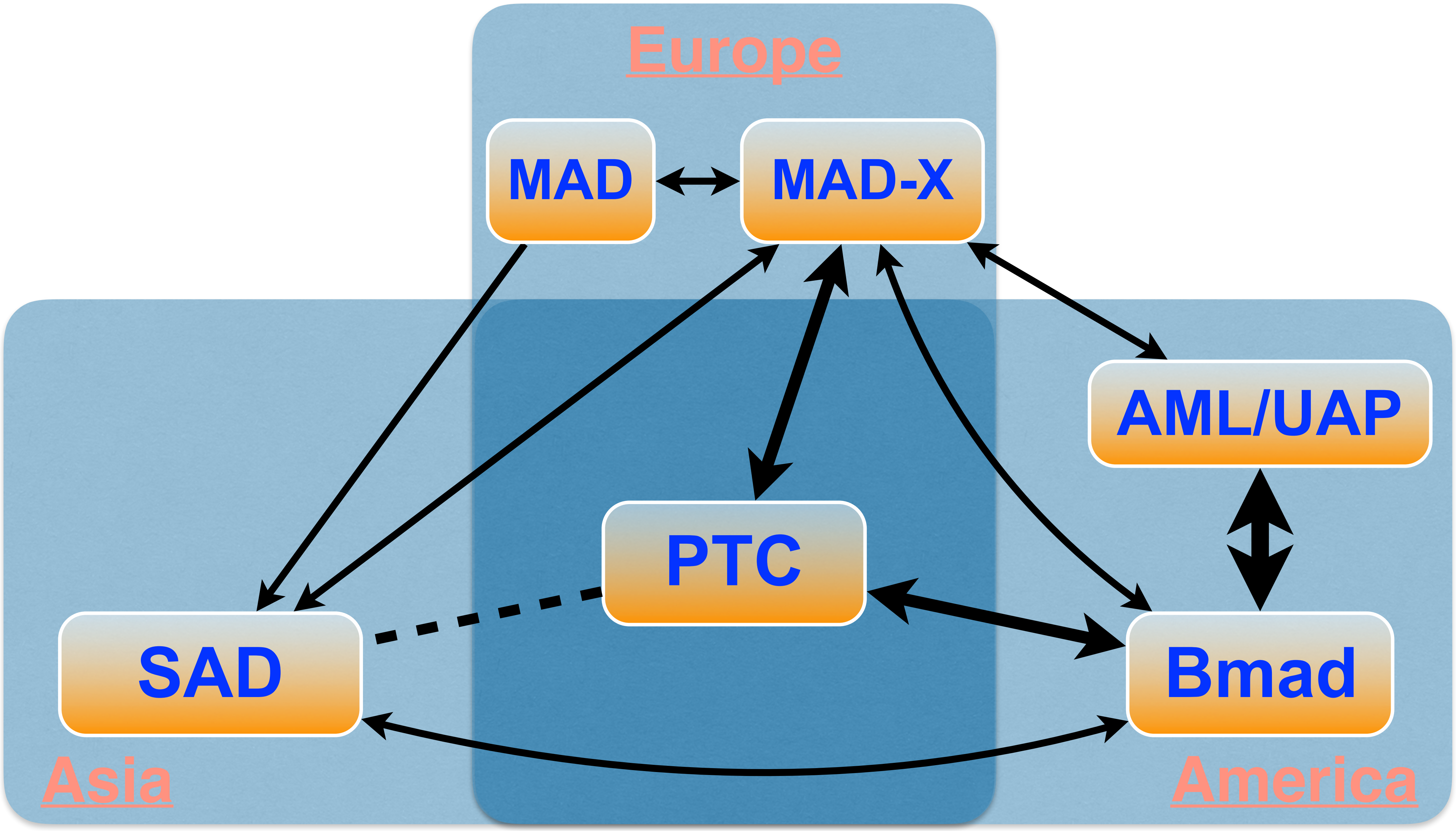
- **SAD: TRISTAN, KEKB, J-PARC, SuperKEKB, …**
- **Bmad: CESR, ERL, …**
- **MAD/MAD-X: PS, LEP, LHC, FCCs, …**



2. Lattice translation

➤ Efforts for lattice translations

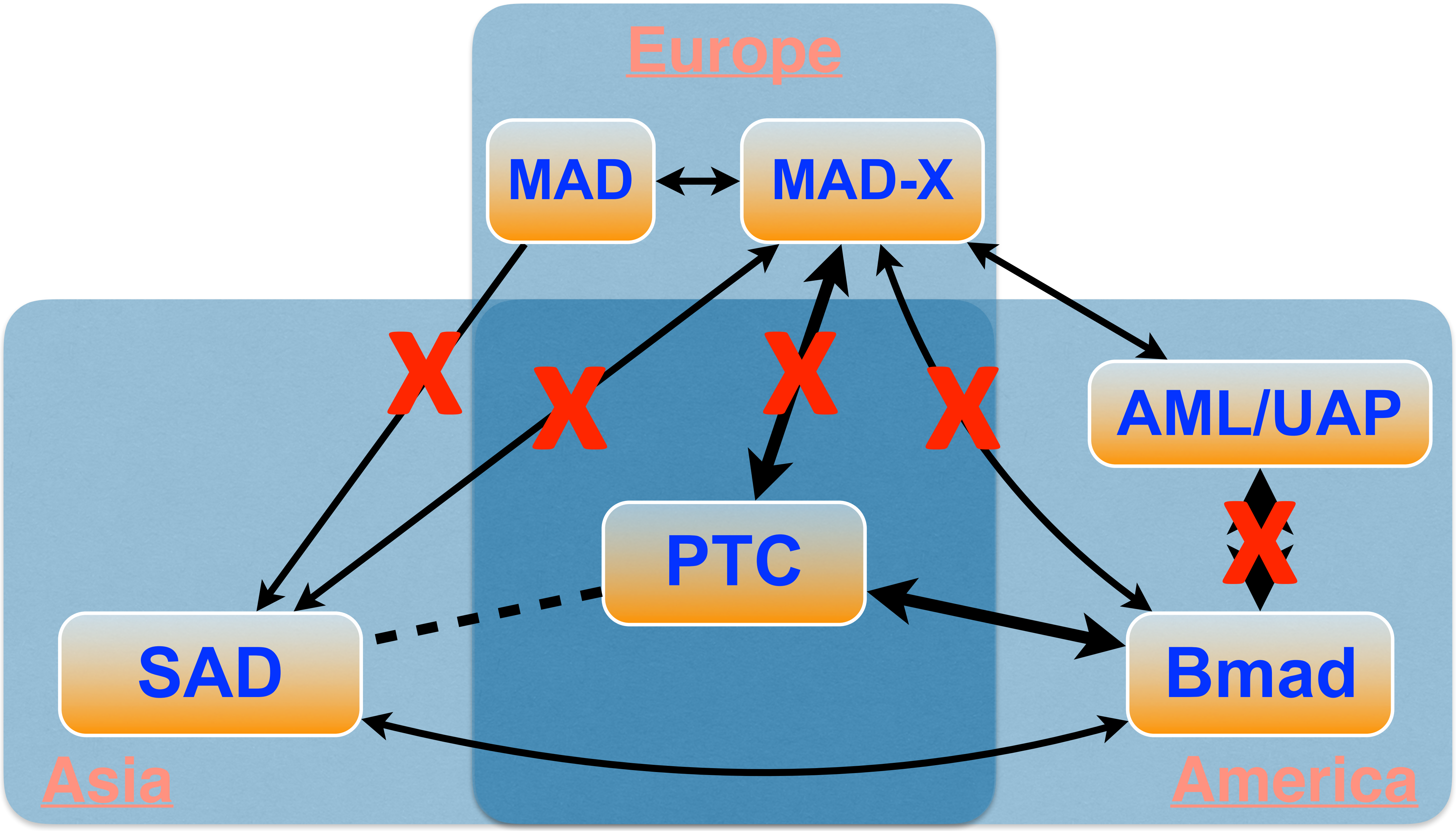
- SAD and PTC: developed at KEK, many shared features (transfer maps, symplectic integrator, ...)
- PTC integrated into MAD-X and Bmad



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: mostly successful**
- **Source of lattice nonlinearities in SuperKEKB identified by PTC**
- **Possible run simulation tools developed based on Bmad and PTC**
- **PTC is perfect tool for simulations of spin dynamics**

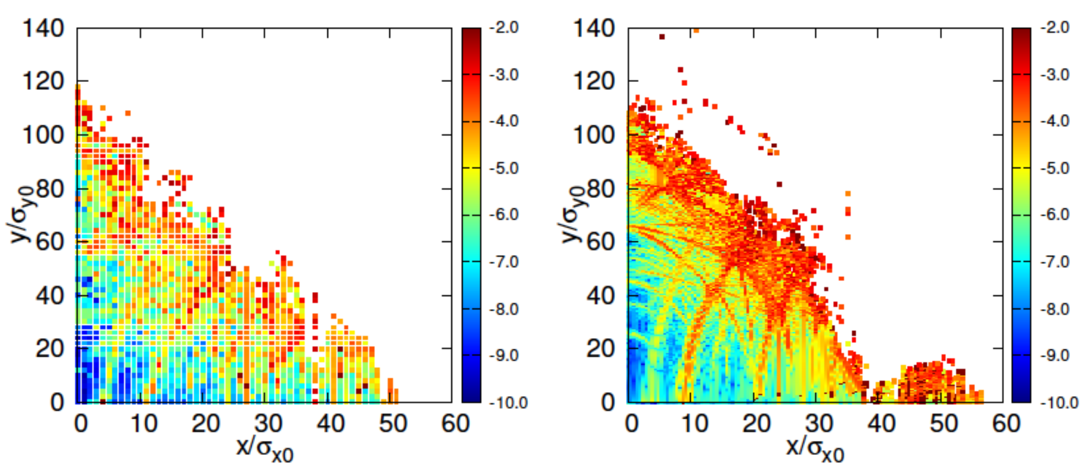


Figure 3: Amplitude-dependent diffusion for a baseline lattice of SuperKEKB LER using SAD (left) and Bmad (right).

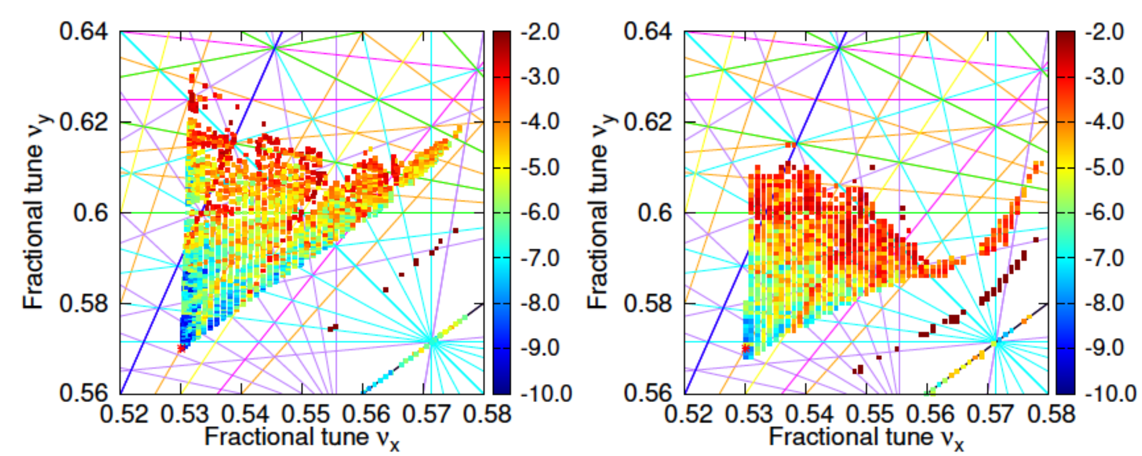


Figure 4: Frequency maps for a baseline lattice of SuperKEKB LER using SAD (left) and Bmad (right). The colored lines indicate various resonance lines.

Ref. D. Zhou et al., IPAC16

3. Polarized beam source

➤ Comments from Dr. Masao Kuriki (Hiroshima Univ.)

- Polarization increases the sensitivity for physics.
- 70% polarization is very easy, because the highest polarization from GaAs super-lattice photo-cathode is 90%. Polarization during the acceleration and transportation can be well controlled. Depolarization should be negligible.
- Issues:
  - ➢ High bunch intensity and low emittance

    Depending on the required emittance, we need electron damping ring. Because the photo-cathode can be used only in DC field, the beam spot size at the cathode could be large due to the low field, depending on the bunch intensity. It leads a large emittance.
  - ➢ Maintain the polarization in the main ring

    As suggested, the polarization vector should be aligned vertically to the orbit plane. If it is not in vertical, the polarization vector do precession. Due to the energy spread, the polarization vector will be randomized.

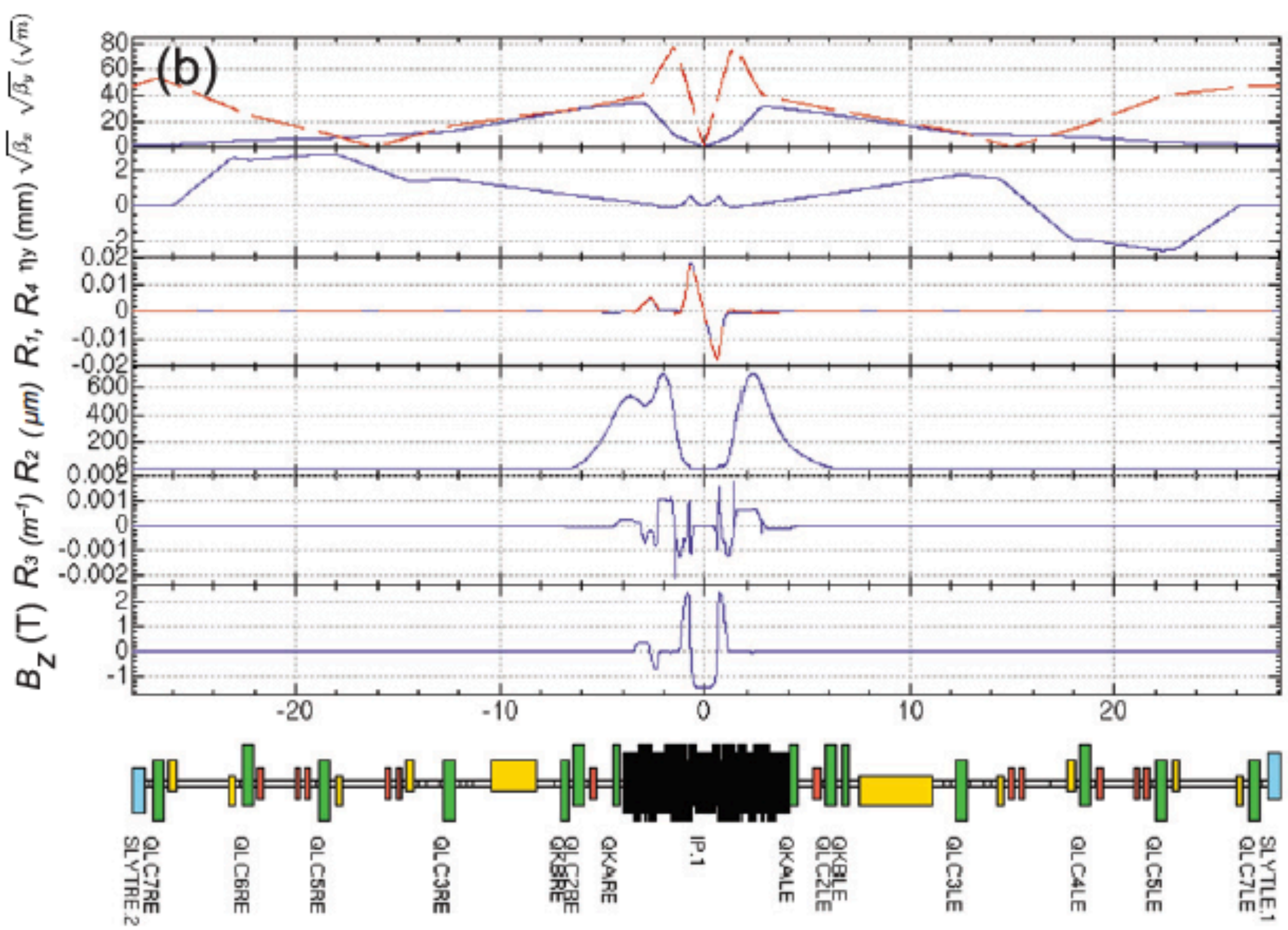
    On the other hand, we need a longitudinal polarization at the collision point. Before and after the collision, we have to rotate the polarization vector as vertical-longitudinal-vertical. It adds another boundary conditions in the ring dynamics, otherwise, the polarization will be randomized over many turns.
- "…it is not easy, but it is possible."

4. Ring optics re-design for HER

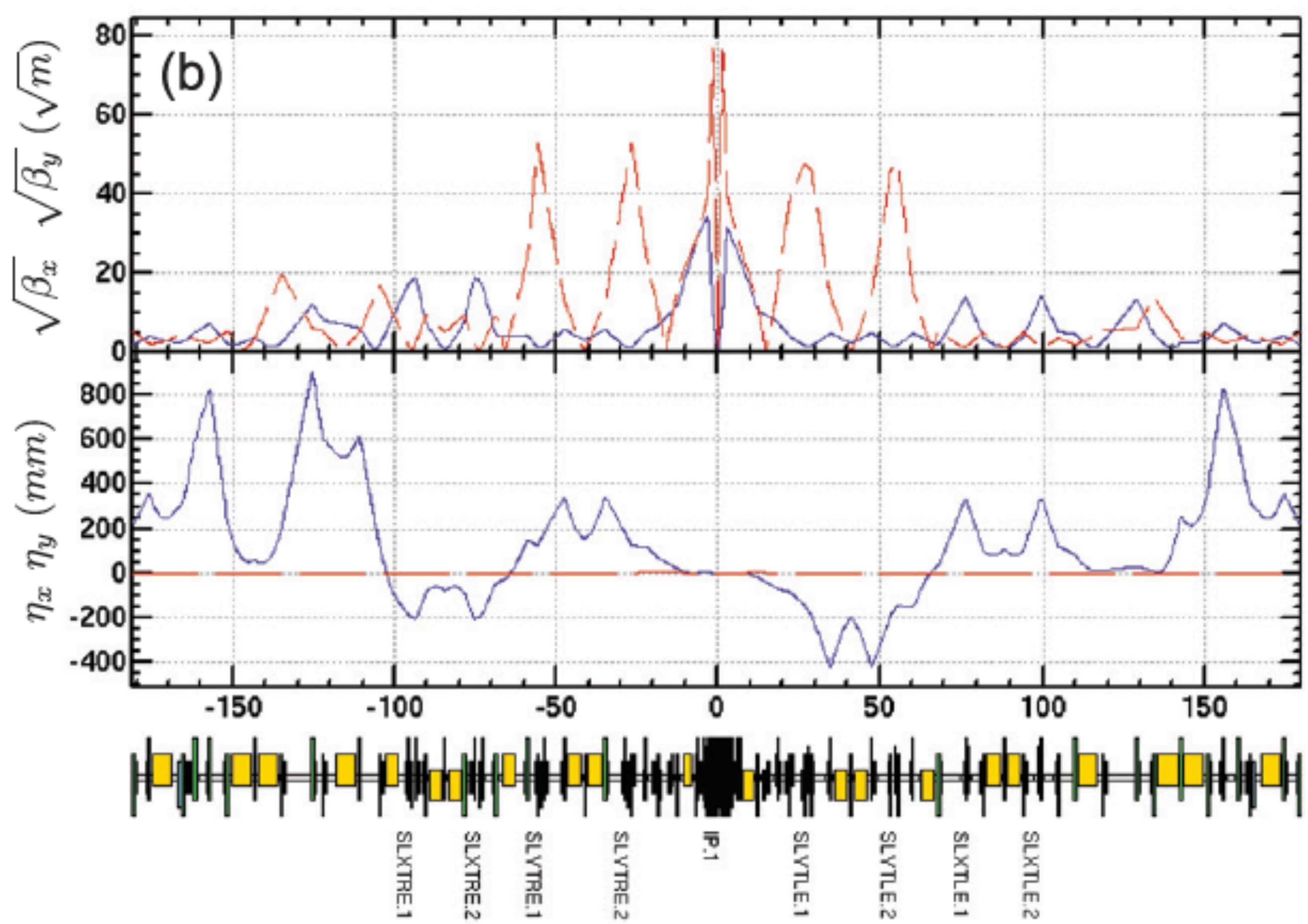
➤ **Issues**

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

IR



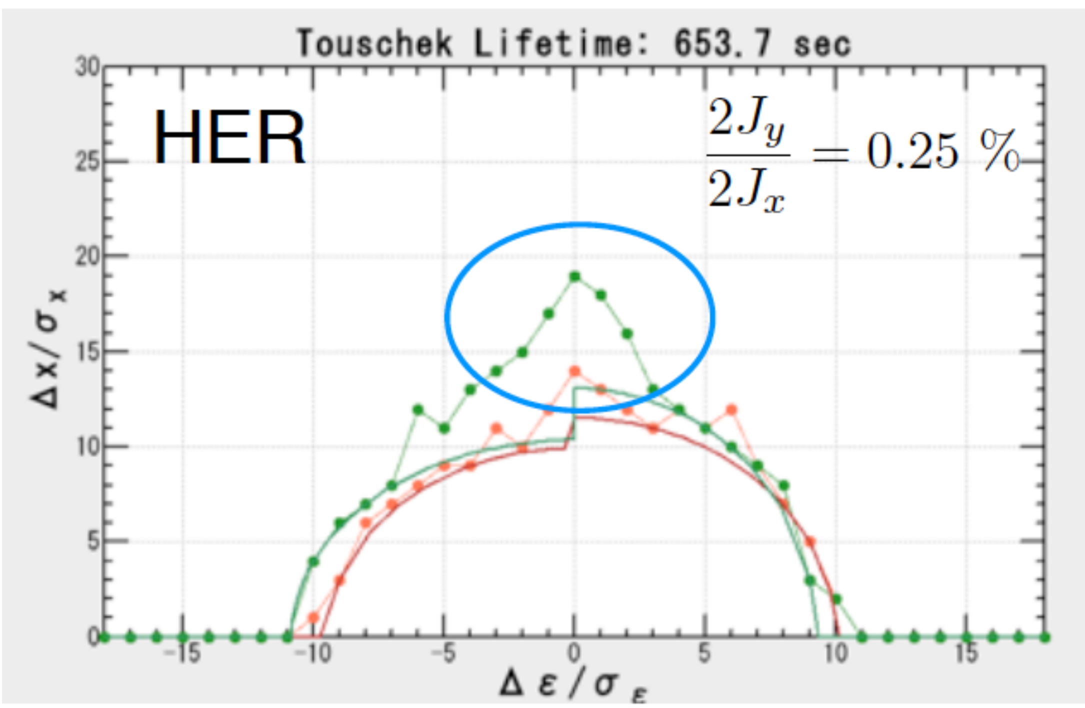
Local chromaticity correction

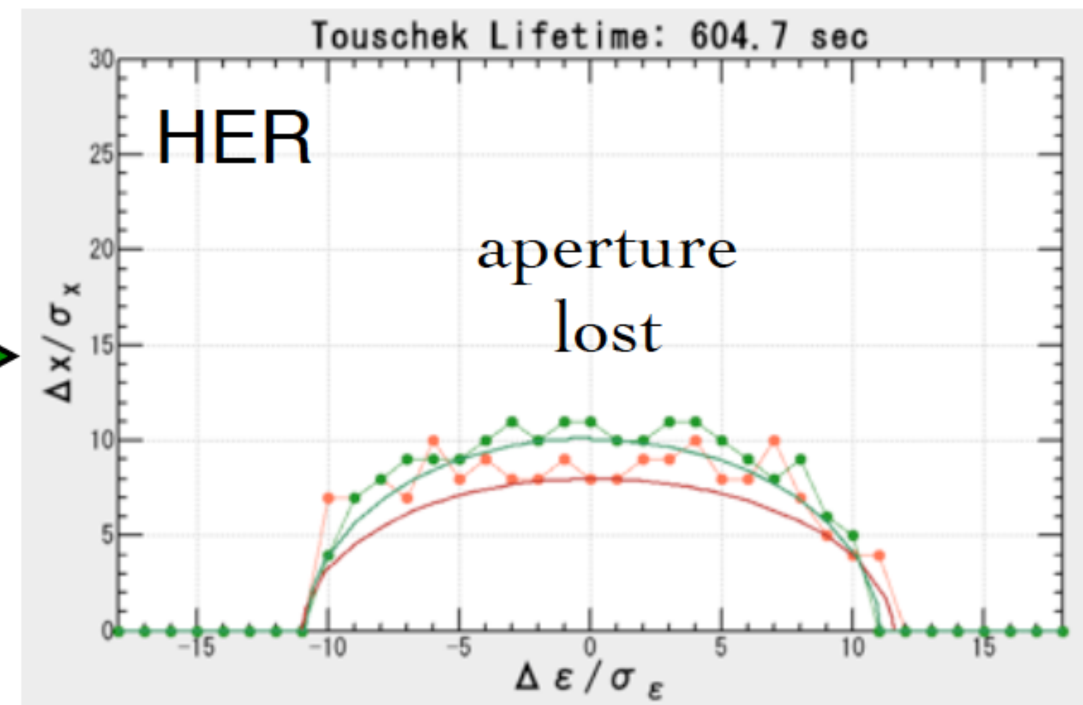


Y. Ohnishi, Accelerator design at SuperKEKB, Prog. Theor. Exp. Phys. (2013) 03A001.

4. Ring optics re-design for HER

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





From Y. Ohnishi

4. International collaboration

- **Investigation team**
  - **KEK: E. Forest, D. Zhou, K. Ohmi, Y. Ohnishi, …**
  - **Japan: M. Kuriki (Hiroshima Univ.), …**
  - **USA: U. Wienands, …**
  - **Canada: M. Roney, …**
- **Resources**
  - **Design tools (accelerator physics): SAD, Bmad, PTC, …**
  - **Electron beam source (damping is a must?)**
  - **Spin rotator**
  - **Compton polarimeter**
- **Task definitions, schedule, …**

4. International collaboration

➤ Tasks for the first meetings (M. Roney)

- a concrete list of questions that would have to be addressed in any feasibility study;
- determine if there are problems that are already known to be completely insurmountable;
- assuming that all problems are, in principle at least, tractable, then compile a list of international experts who might be recruited to help address specific questions at hand;
- determine when it would be reasonable to hold a workshop of accelerator physicists on this;
- identify immediate action items/tasks for each of us that would move us forward to the next step;

- Conceptual Design Phase
- Detailed Design Phase
- Develop Cost Estimate
- Make go-no/go decision on submitting funding request
- Secure funding
- Final Design Phase
- Construction Phase
- Installation Phase
- Commissioning Phase