Progress in Super B-Factories

Kazunori AKAI
KEK
IPAC13

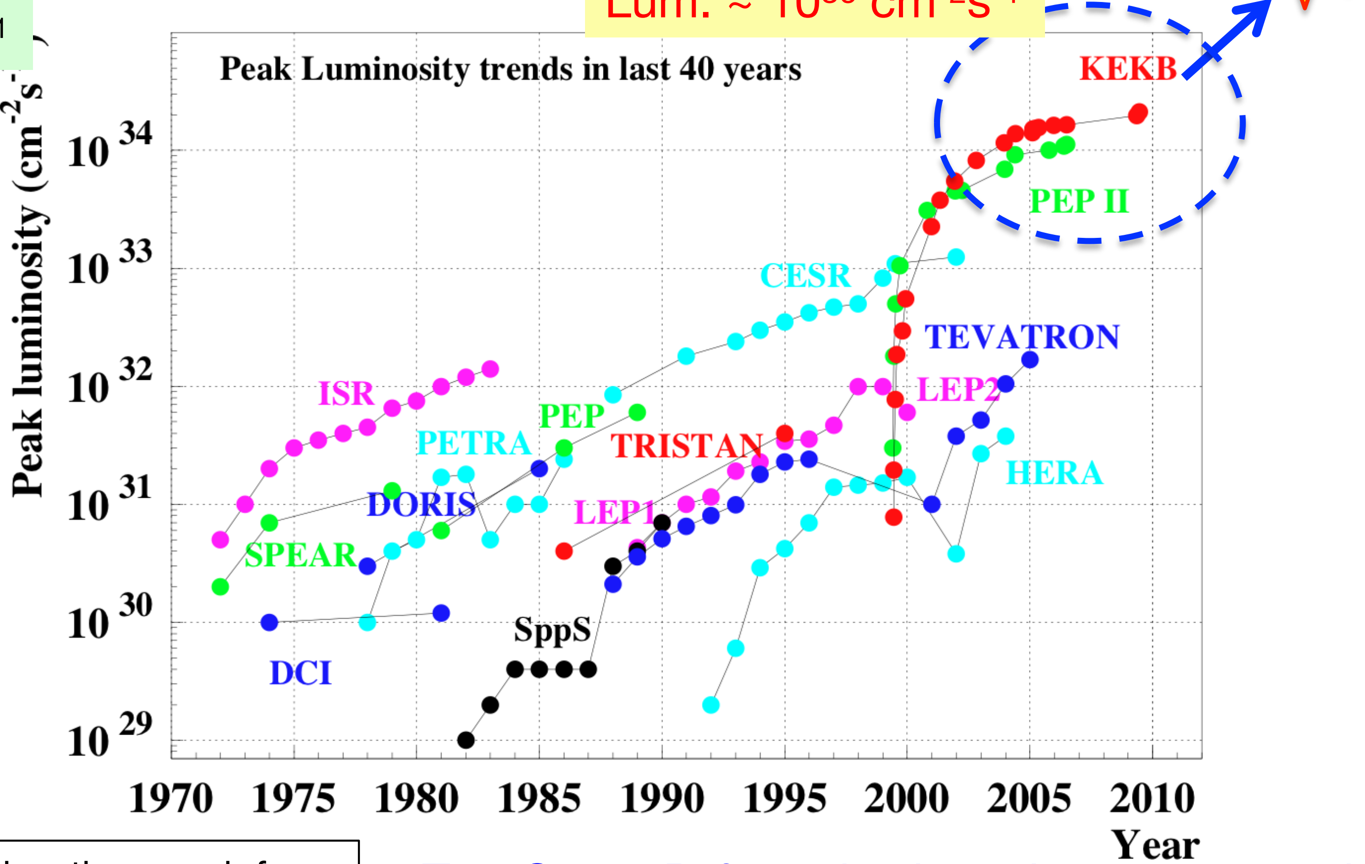
B-factories to Super B-factories

PEP-II: 1997 — 2008
KEKB: 1998 — 2010

Luminosity ~ 10^{34} $cm^{-2}s^{-1}$

Super B-factories

Lum. ~ 10^{36} $cm^{-2}s^{-1}$



With the success of B-factories, the search for "new physics" beyond the Standard Model has become an urgent program in particle physics.

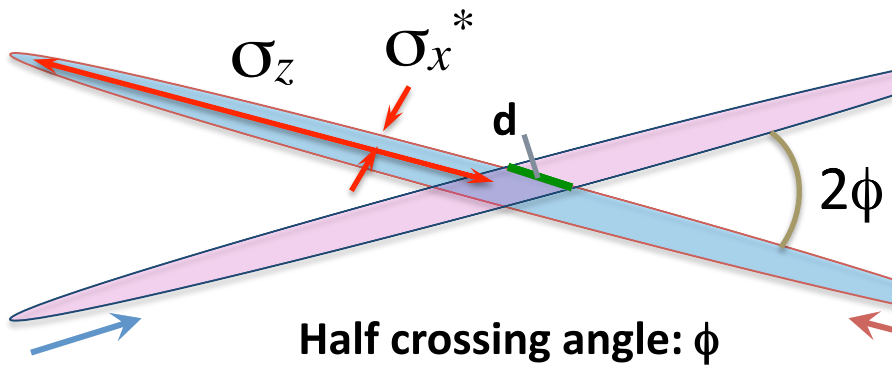
Two Super B-factories have been proposed.

- SuperB / INFN, Cabibbolab
- SuperKEKB / KEK

Nano-Beam Scheme

The designs of both Super B-factories are based on the Nano Beam Scheme.

Large angle crossing



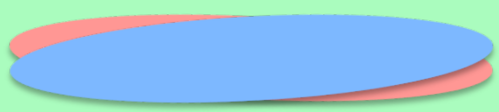
$$\beta_y^* \geq \frac{\sigma_x^*}{\phi} = d$$

~200-300 μm

The hourglass effect is reduced, and β_y^* can be reduced to a very small value.

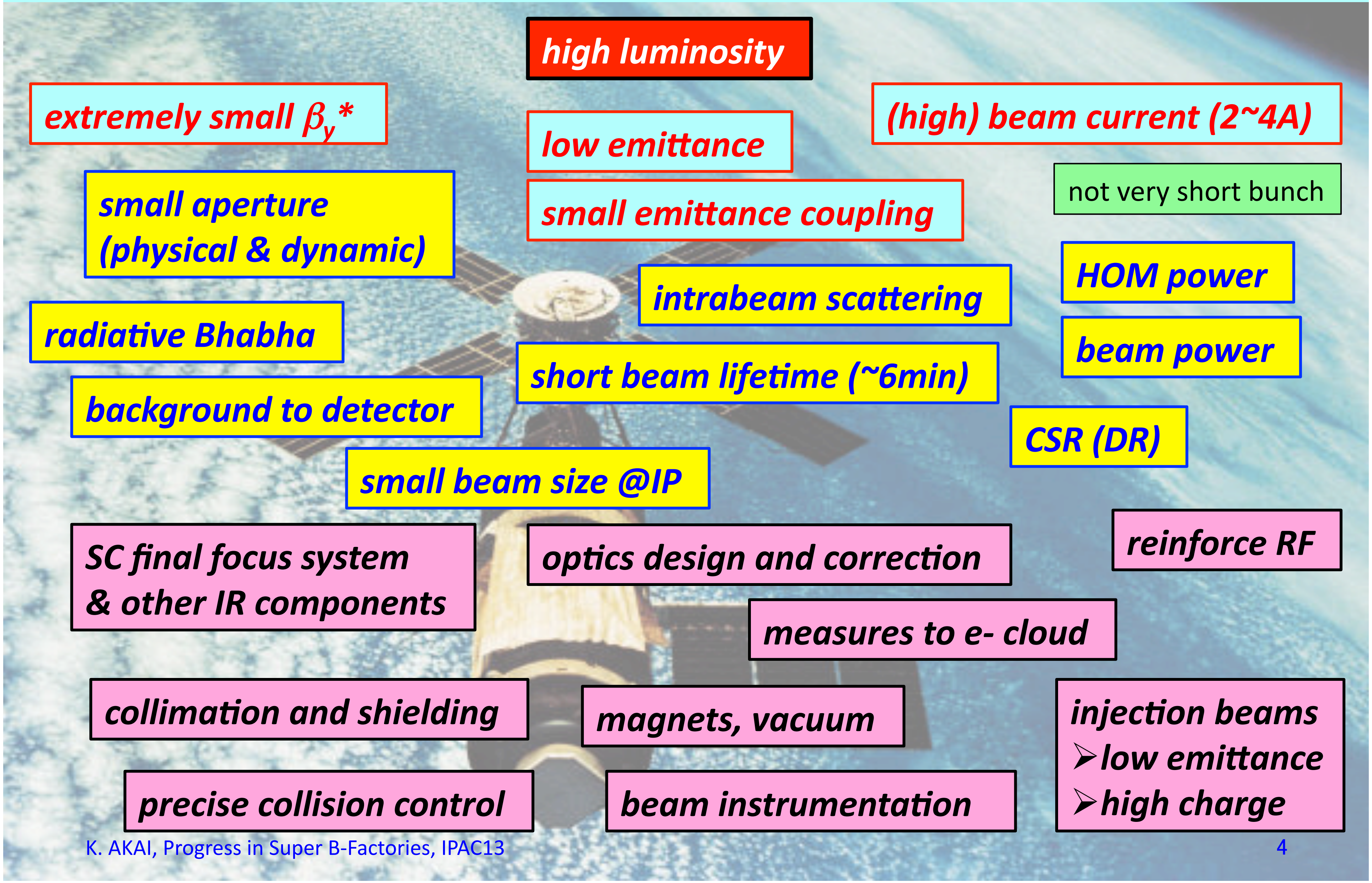
$$L = \frac{N_{e+}N_{e-}f}{4\pi\sigma_x^*\sigma_y^*}R_L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm\xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

cf. small-angle crossing



P. Raimondi, 2nd SuperB Meeting, Frascati (2006).

Challenges for Super B-factories



SuperKEKB

- In KEK Roadmap 2009-2013 (2008.01)

  KEKB / Belle upgrade as a future plan

- 2010: project was partially approved.
  KEKB / Belle upgrade started.
- 2011: project was fully approved.
  → SuperKEKB / Belle II

- Design Improvements
- Construction Status
- Commissioning Scenario

Upgrade of KEKB / Belle

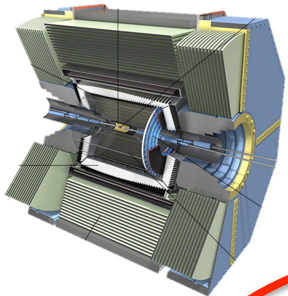
	KEKB		SuperKEKB
Luminosity:	2.1×10^{34}	$\rightarrow$	8×10^{35} (x 40)
Total Data:	1 ab^{-1}	$\rightarrow$	> 50 ab^{-1} (x50)

Parameters of KEKB and SuperKEKB

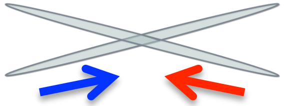
parameters		KEKB(@record)		SuperKEKB		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7.007	GeV
Crossing angle (full)	ϕ	22		83		mrad
# of Bunches	N	1584		2500		
Horizontal emittance	ε_x	18	24	3.2	4.6	nm
Emittance ratio	κ	0.88	0.66	0.27	0.28	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
Max. beam currents	I_b	2.0	1.4	3.6	2.6	A
Beam-beam param.	ξ_y	0.129	0.090	0.0881	0.0807	
Bunch Length	σ_z	6.0	6.0	6.0	5.0	mm
Horizontal Beam Size	σ_x^*	150	150	10	11	um
Vertical Beam Size	σ_y^*	0.94		0.048	0.062	um
Luminosity	L	2.1×10^{34}		8×10^{35}		$cm^{-2}s^{-1}$

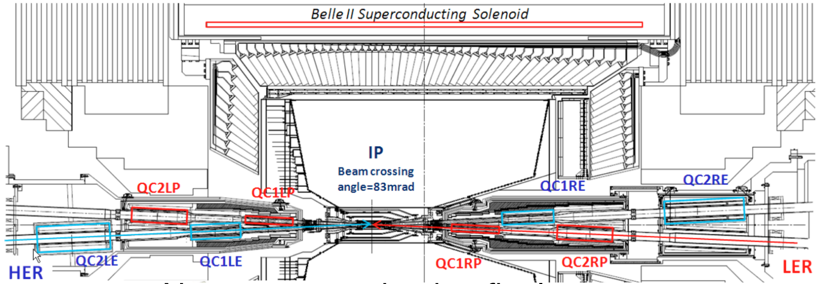
Intra-beam scattering is included.

Upgrade to Belle II detector



Colliding bunches





New superconducting final focusing magnets near the IP

e^+ 3.6A

e^- 2.6A

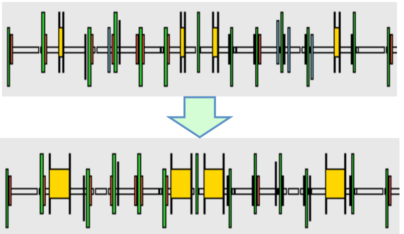
KEKB to SuperKEKB

- ◆Nano-Beam scheme
  - extremely small β_y^*
  - low emittance
- ◆Beam current double

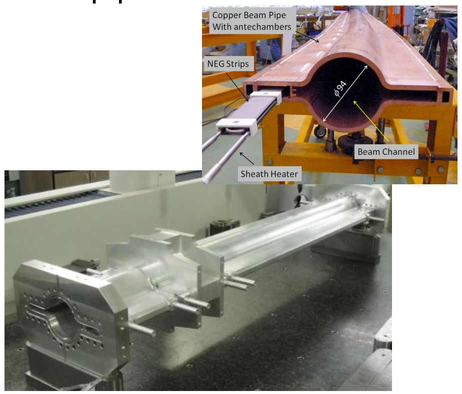
$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

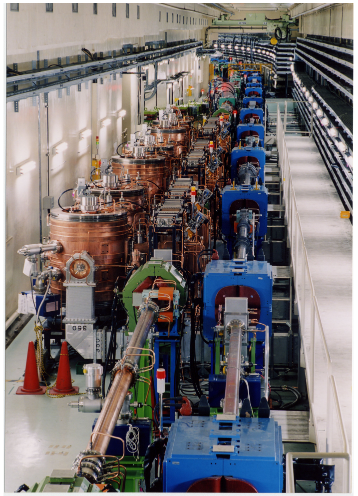
40 times higher luminosity
2.1×10^{34} --> 8×10^{35} $cm^{-2}s^{-1}$

Redesign the lattice to squeeze the emittance (replace short dipoles with longer ones, increase wiggler cycles)



Replace beam pipes with TiN-coated beam pipes with antechambers



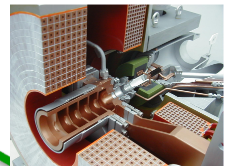


Reinforce RF systems for higher beam currents

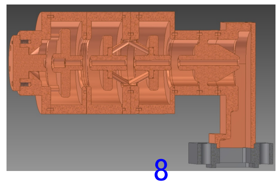
Improve monitors and control system

Injector Linac upgrade

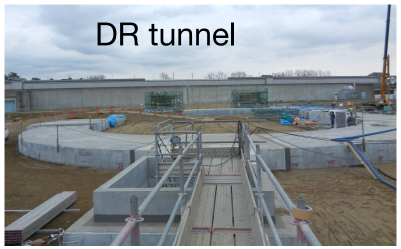
Upgrade positron capture section



Low emittance RF electron gun



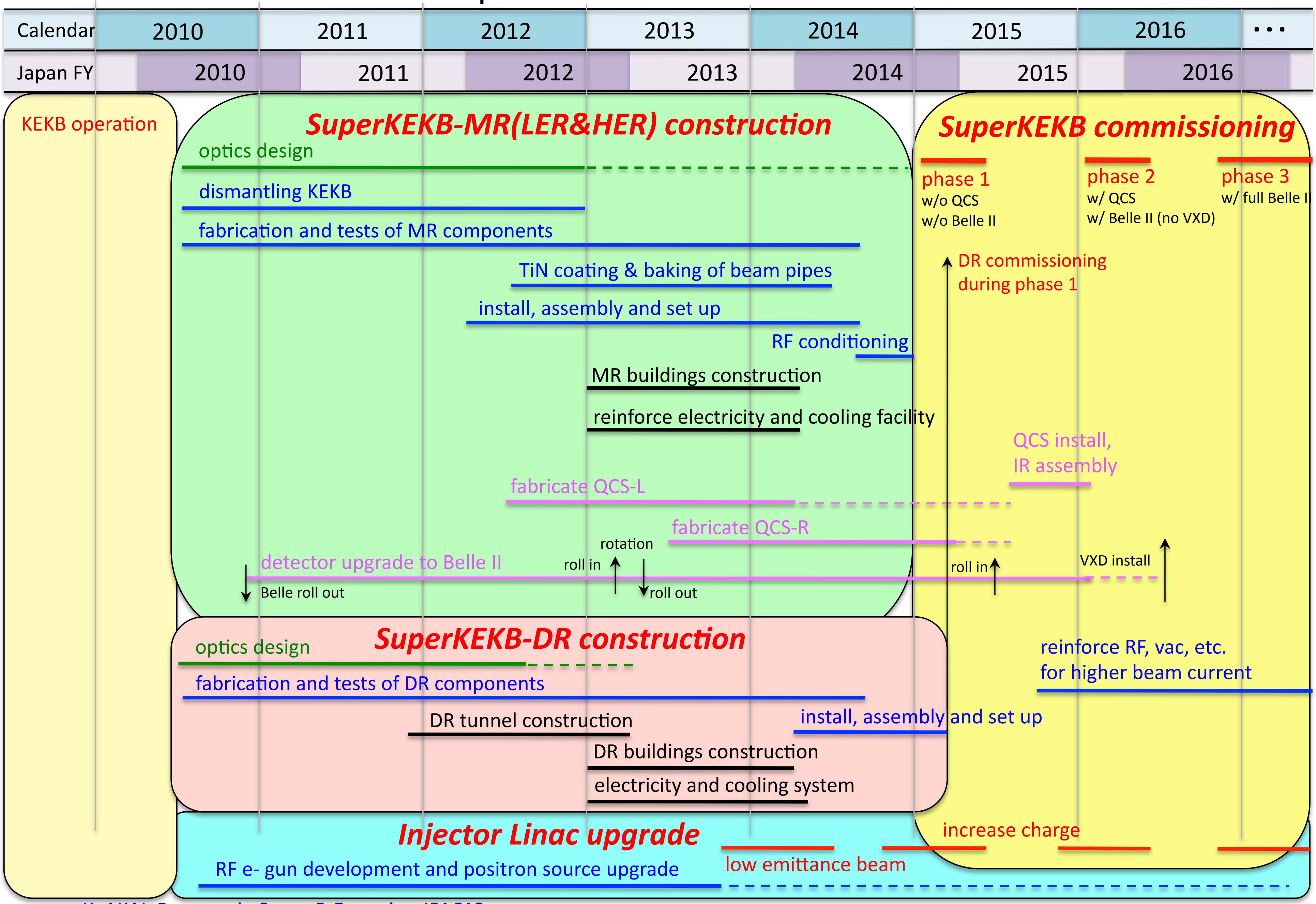
DR tunnel



New e+ Damping Ring

K. AKAI, Progress in Super B-Factories, IPAC13

SuperKEKB master schedule

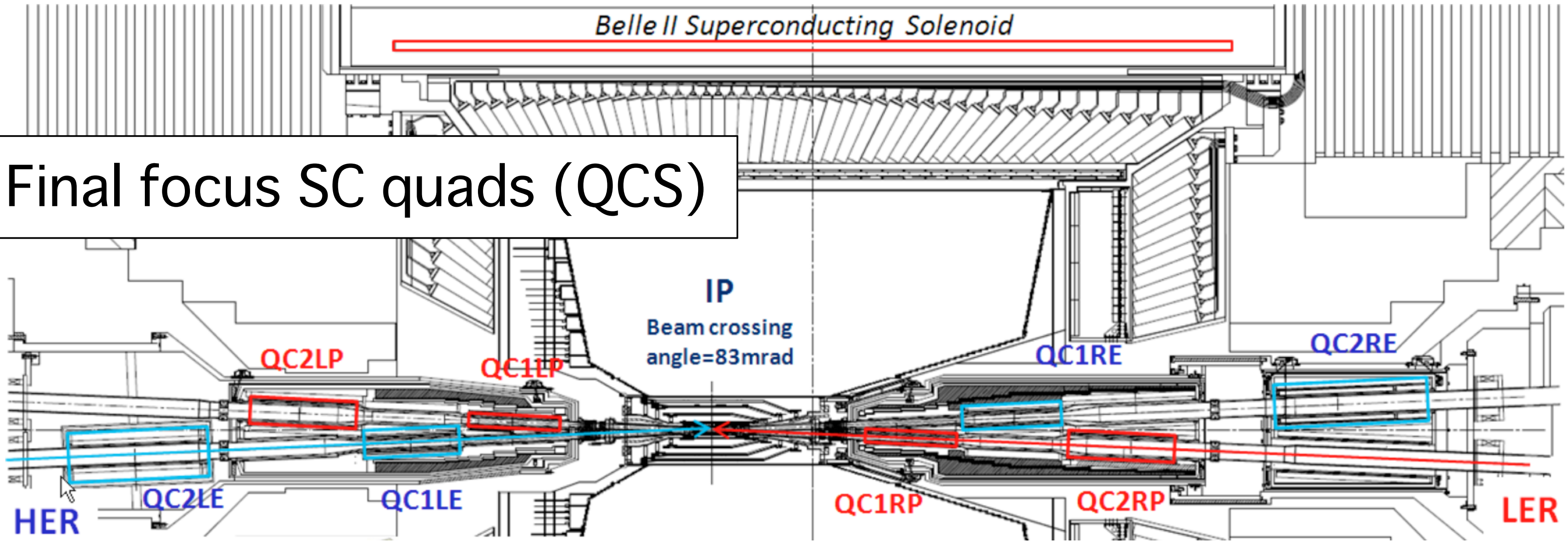


Design Improvements

While construction proceeds, the design work continues to finalize the most critical region, including the IR.

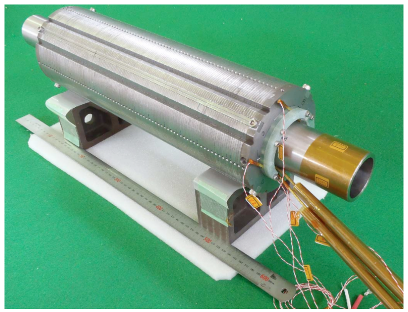
- IR-related issues
  - Optics design to obtain a sufficiently large dynamic aperture and long beam lifetime.
  - Evaluation of the beam background (BG) at the Belle II detector and various measures to reduce the BG such as collimation and shielding.
  - Design optimization of magnets, beam pipes, and other hardware components.
  - Mechanical support and assembly procedure in very tight spaces.
  - Beam motion due to ground motion and measures.
- Beam loss and collimation
  - Estimation of beam loss due to Touschek, beam-gas, radiative Bhabha process.
  - Optimization of layout of movable collimators, and hardware design.

Final focus SC quads (QCS)



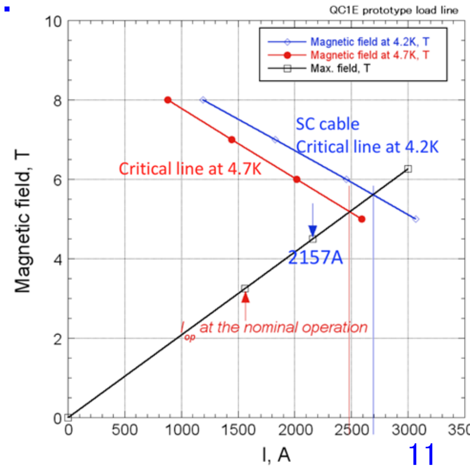
- Eight final focus QCS with 40 corrector coils are to be used.
- Fabrication of QCS-L started in July 2012, and will be completed in JFY2013.
- Fabrication of QCS-R is scheduled in JFY2013 and 2014.
- Prototype magnet was made at KEK. Test results show sufficient margin for operation.
- Corrector coils are being wound at BNL under BNL/KEK collaboration.

QC1LE prototype magnet



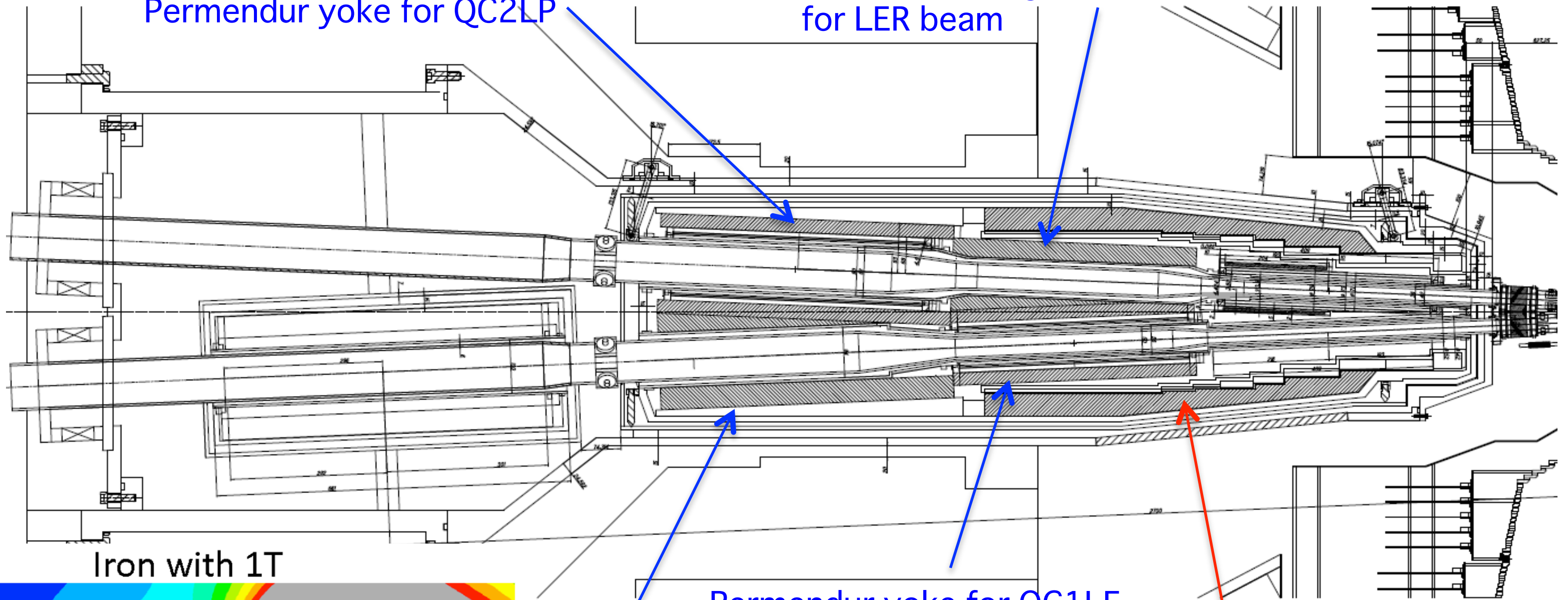
Successfully tested without any quench up to 2157A, well over the design current (1560A) for nominal operation.

$I_{4S}/I_{c@4.7K}$ = 62.8%
$I_{12GeV}/I_{c@4.7K}$ = 87.0%
Sufficient margin for operation

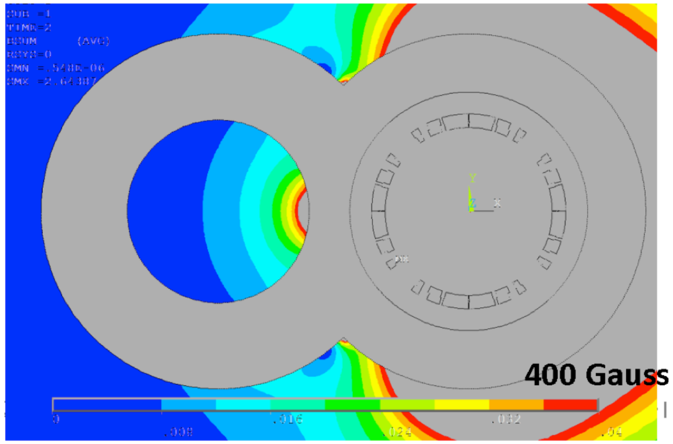


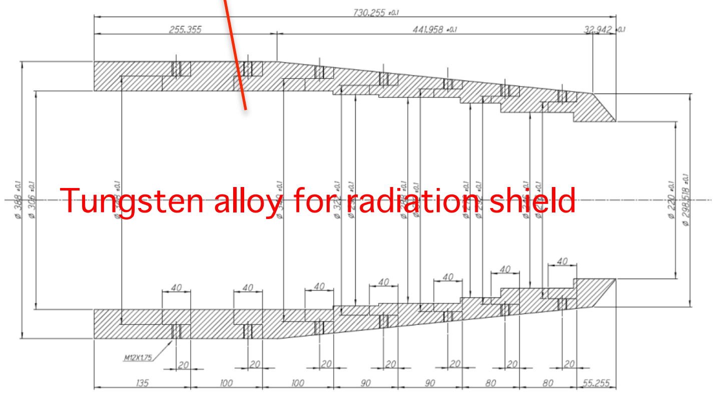
K. AKAI, Progress in Super B-Factories, IPAC13

Improvements for the IR design



Iron with 1T



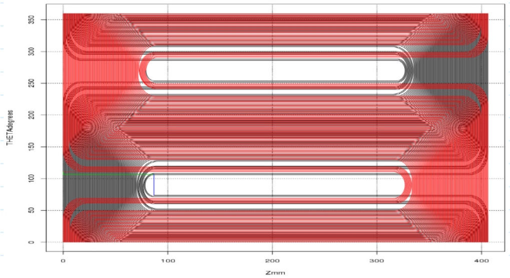


(2) To reduce leakage field on the other beam line, Permendur yokes and shields are adopted, instead of Iron.

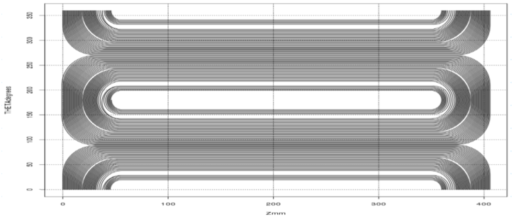
(1) To reduce BG due to radiative Bhabha, Tungsten shield is added inside the cryostat as much as possible.

Corrector coils for QCS

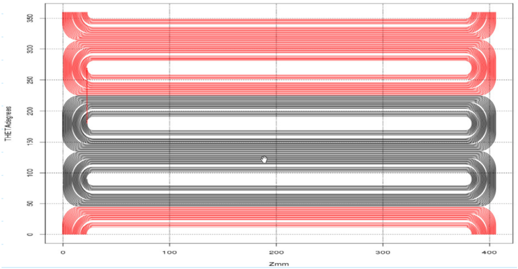
QC1LE – b1 coil



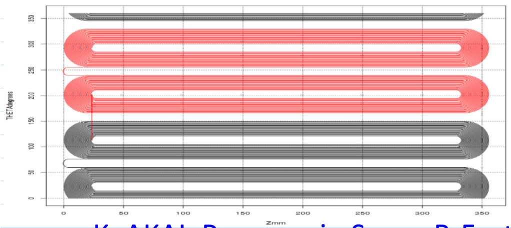
QC1LE – a1 coil



QC1LE – a2 coil

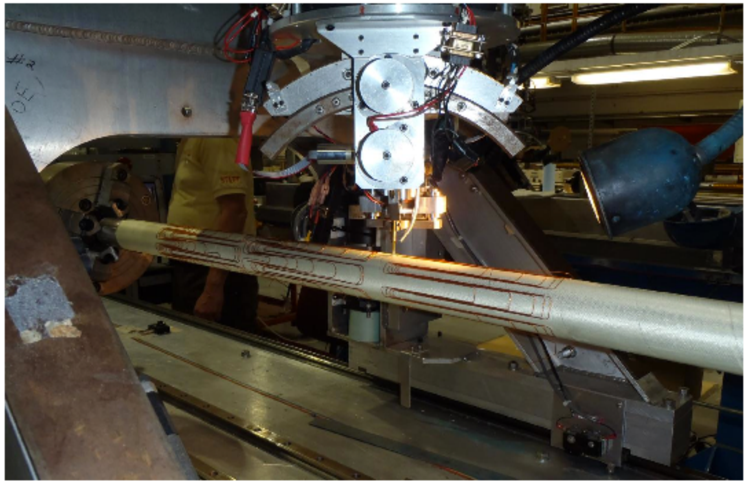


QC1LE – b4 coil



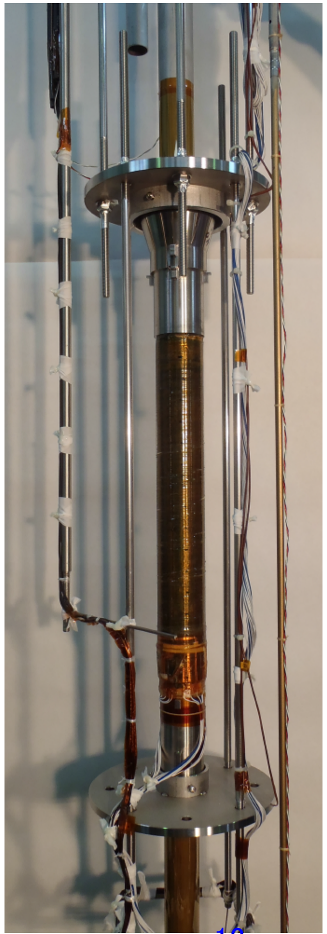
- Corrector coils are being wound at BNL under BNL/KEK collaboration.
- Each main quadrupole has correction coil windings of:
  - a1 and b1: to correct horizontal and vertical misalignments
  - a2: to correct rotation error
  - b4 (and/or a3): to optimize dynamic aperture

Leak field cancel coil
in a direct winding machine at BNL



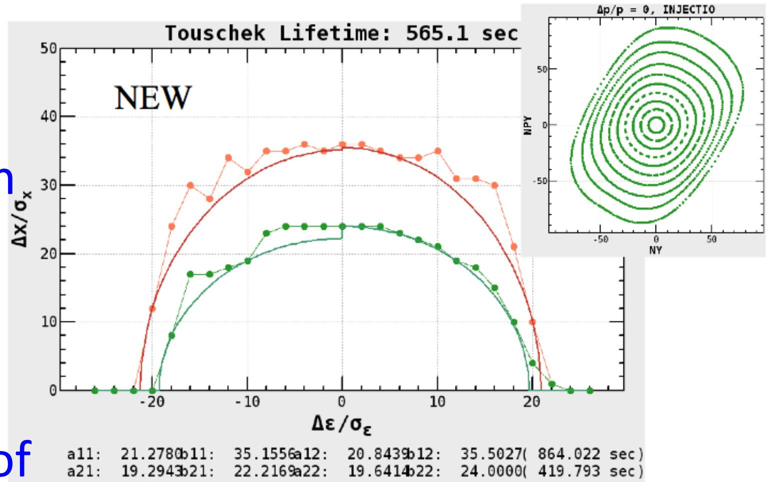
B. Parker et al., IPAC12

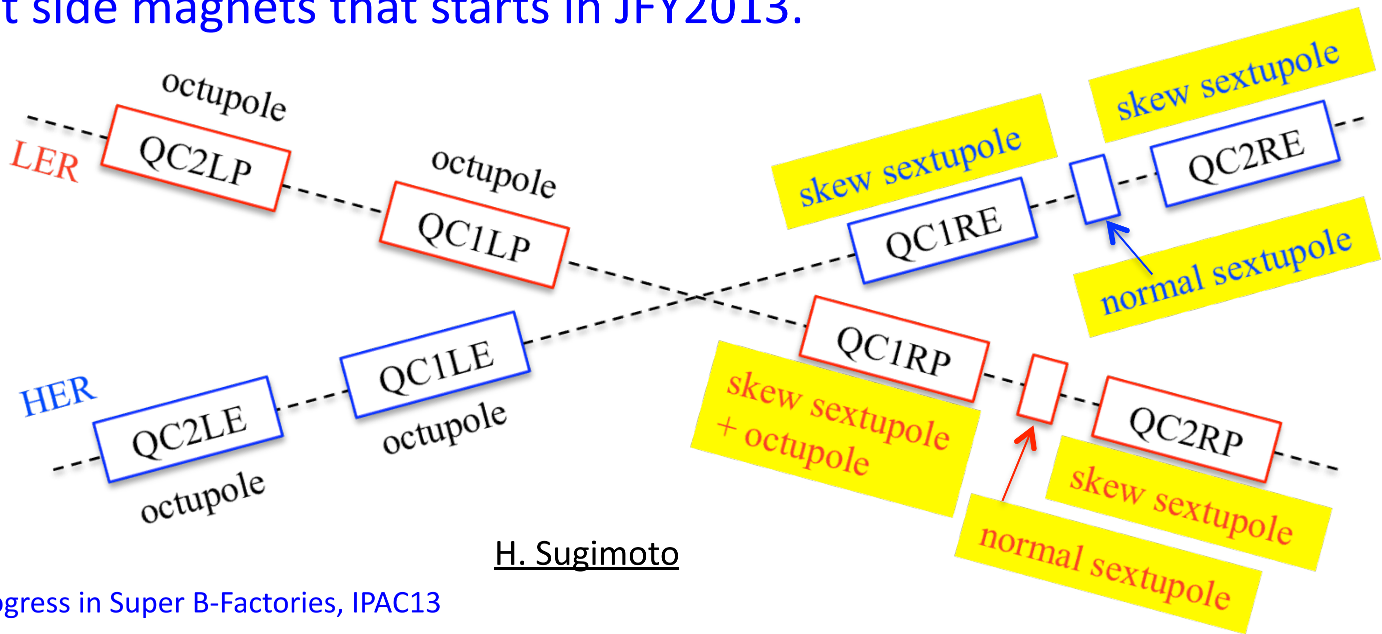
Corrector coil for QC1LP in a test stand at KEK



Layout change of corrector coils

- It was found that a possible sextupole error field in QC1 seriously deteriorates the dynamic aperture.
- The original design did not include sextupole correction coils. Since fabrication of the left side magnets already had started, possible ideas for changing the right side magnet design have been studied.
- The result showed that by adopting normal and skew-sextupole correction coils, the dynamic aperture recovers.
- This scheme will be adopted for the fabrication of the right side magnets that starts in JFY2013.





H. Sugimoto

Beam loss simulation and collimator design

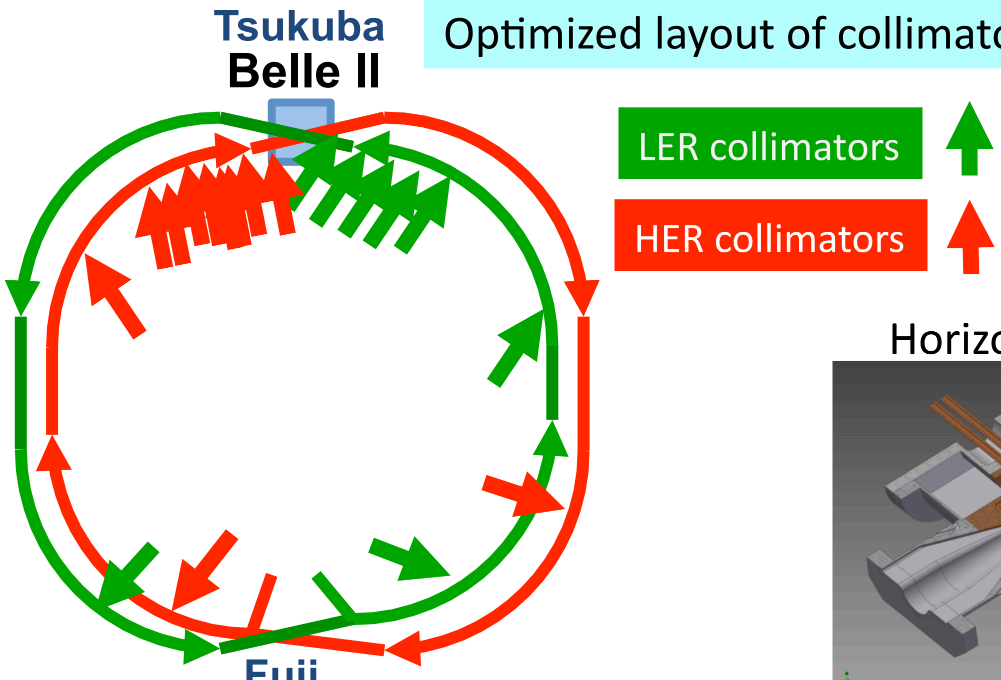
	KEKB (design)		SuperKEKB (design)	
	LER	HER	LER	HER
Radiative Bhabha	21.3 h	9.0 h	28 min.	20 min.
Beam-gas	45 h	45 h	25 min.	46 min.
Touschek	10 h	-	10 min.	10 min.
Total	5.9 h	7.4 h	6 min.	6 min.
@Beam current	2.6 A	1.1 A	3.6 A	2.6 A

High luminosity

low emittance, small aperture @IR

Y. Ohnishi and Y. Funakoshi

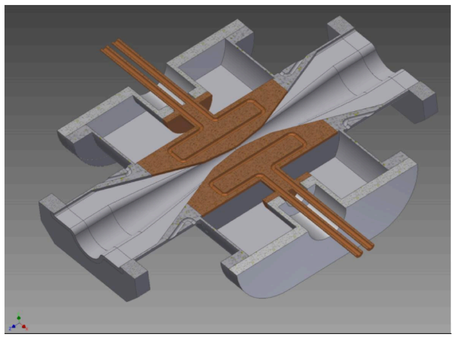
Optimized layout of collimators



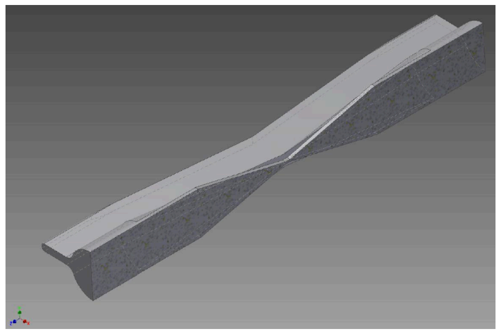
New movable collimator design

T. Ishibashi et al.

Horizontal



Vertical



Construction Status

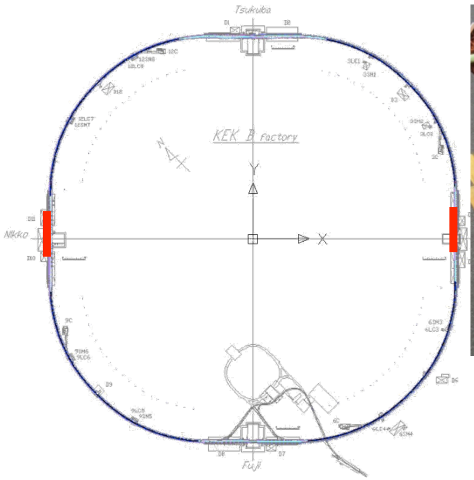
- Vacuum system
- Magnet system
- Monitor and control system
- RF system
- Facilities and infrastructure
- Damping ring
- Injector Linac upgrade

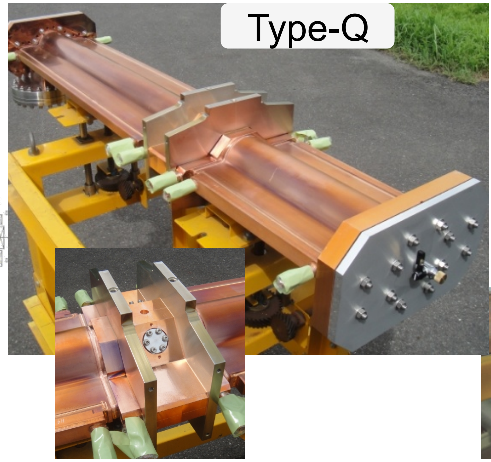
Beam pipes

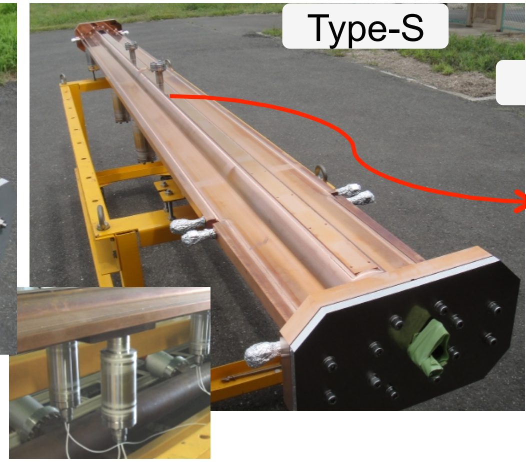
Measures for e- cloud issues:

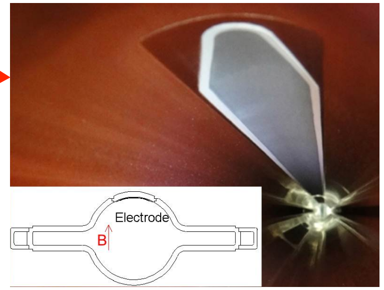
- Antechamber + TiN coating
- + electrode (wiggler sections)
- + groove (bent pipes)
- + solenoids

Copper beam pipes for LER and HER wigger sections

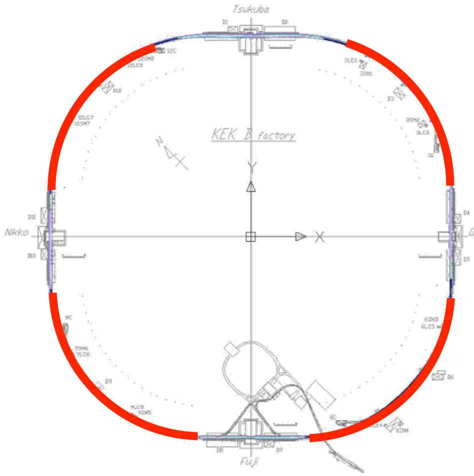


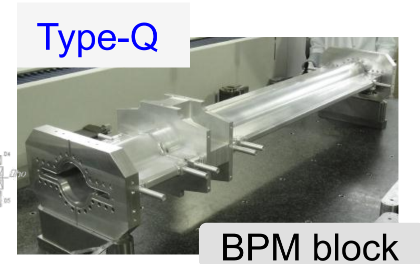


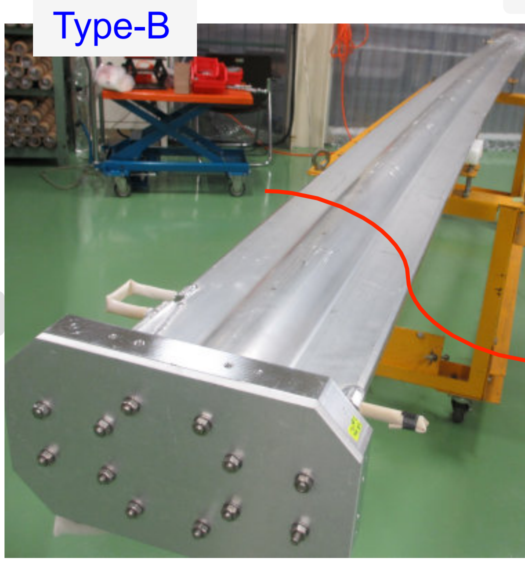


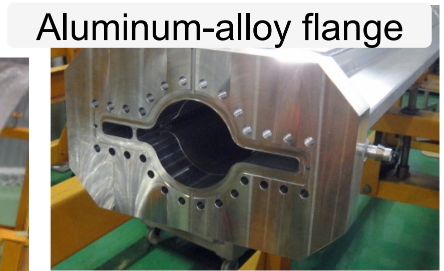


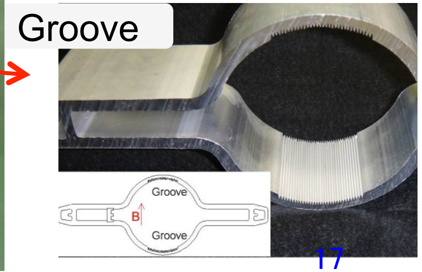
Aluminum antechamber beam pipes for LER arc sections





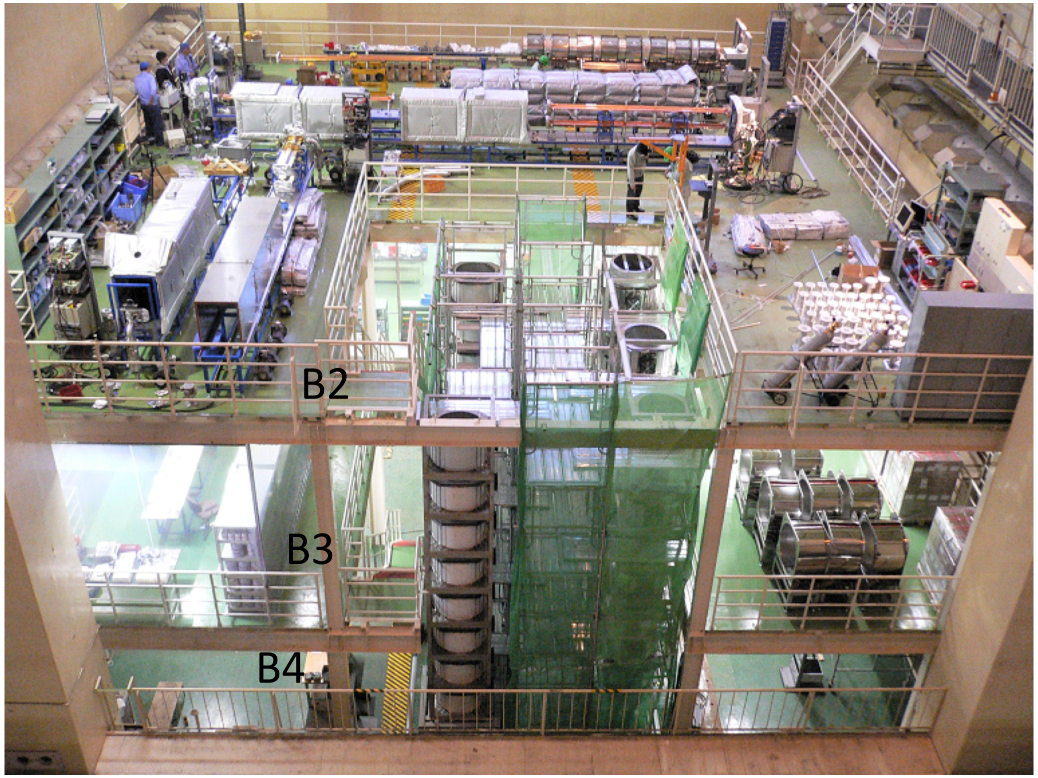




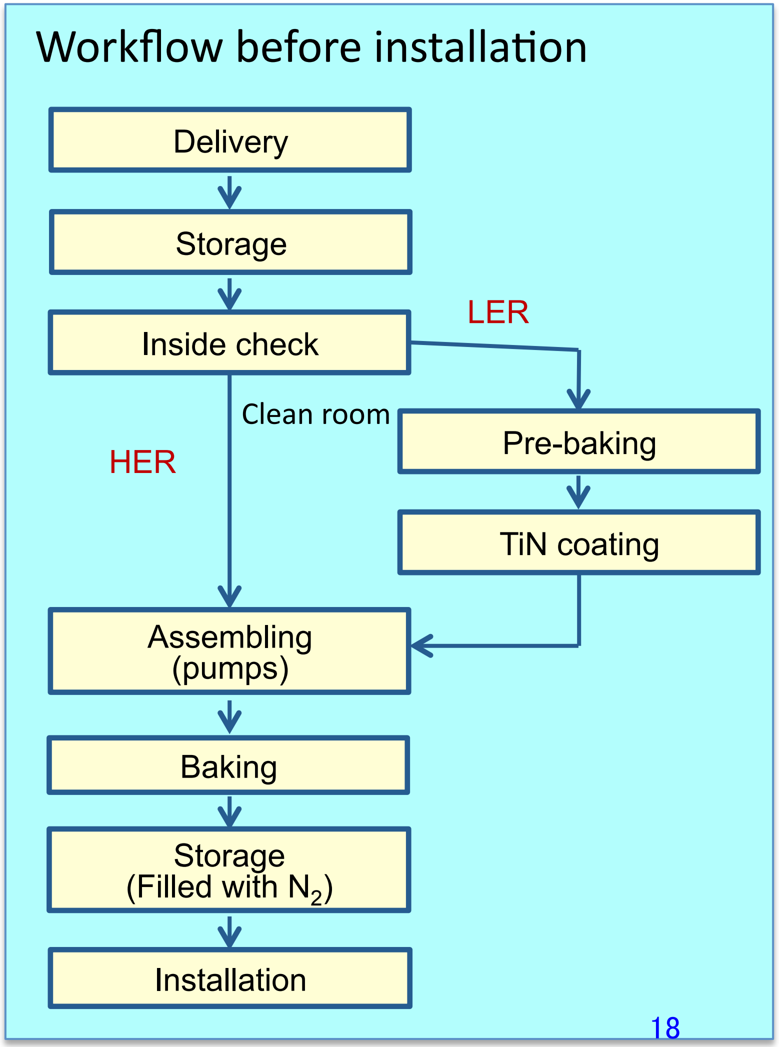


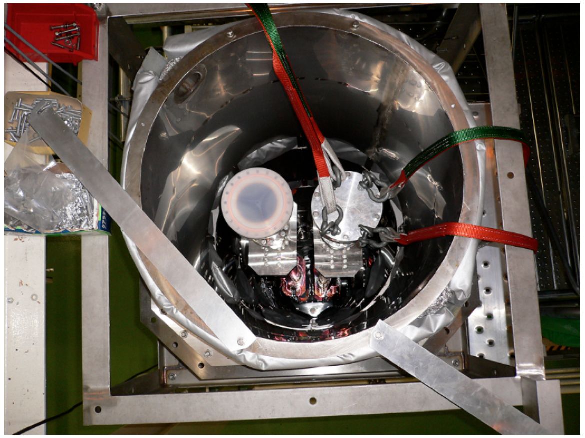
Beam pipes treatments

- Baking and TiN coating system have been constructed at Oho experimental hall in KEK. Treatment of beam pipes is well ongoing.



●Four baking systems and horizontal TiN coating systems on the upper floor (B2).
●Checking and preparation work on the middle floor (B3).
●Five vertical TiN coating systems from B4 to B2 through.





(upper): Inserting ante-chambers into a vertical TiN coating system. (lower): Top-side view of ante-chambers in two lines set in the coating system.

(upper and lower): Copper and Aluminum beam pipes after baking and TiN coating. They are temporary stocked in Oho B4 until moved to tunnel or other stock houses.

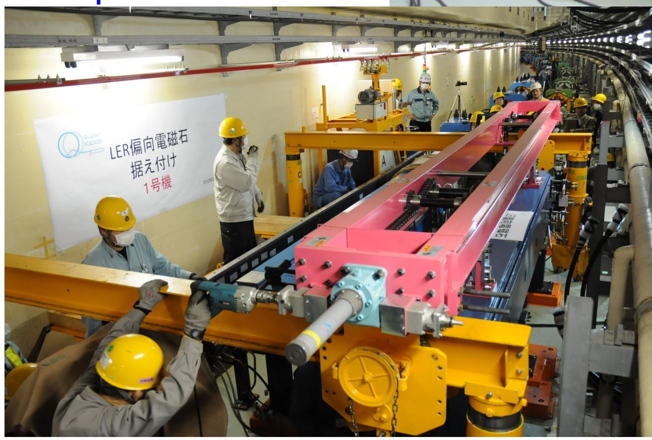
Installation of 100 new LER 4m bend magnets completed.

field measurement

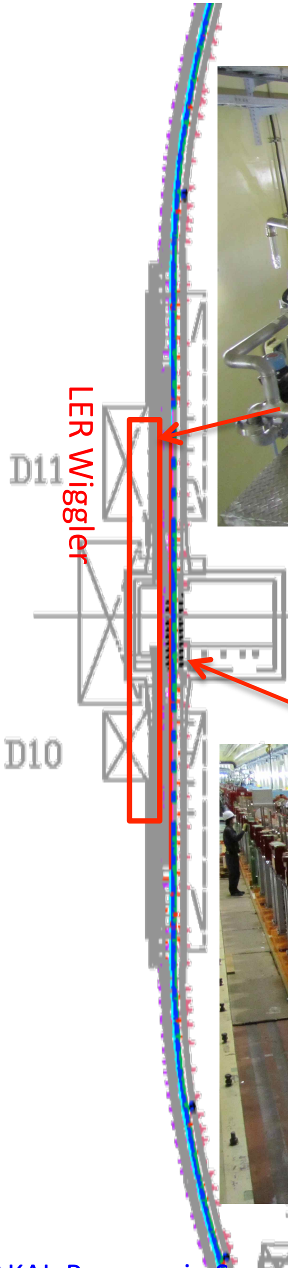
move into tunnel

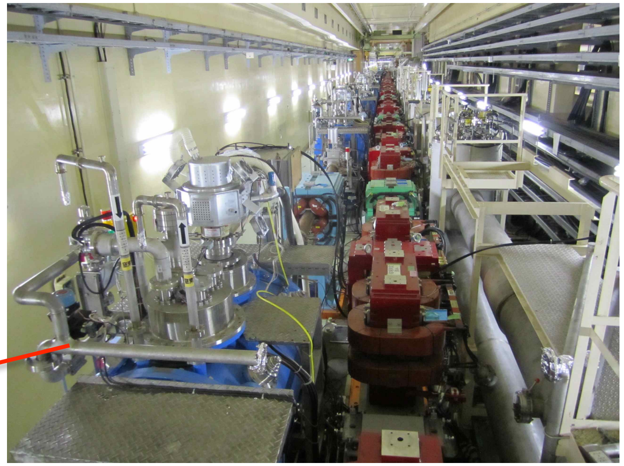
carry on an air-pallet

carry over existing HER dipole

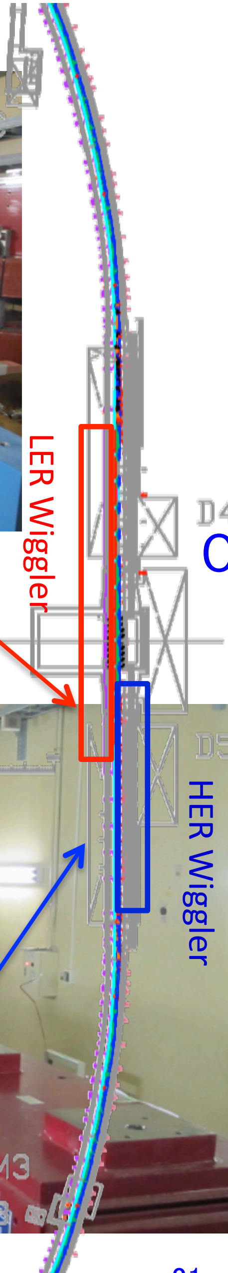


Wiggler sections

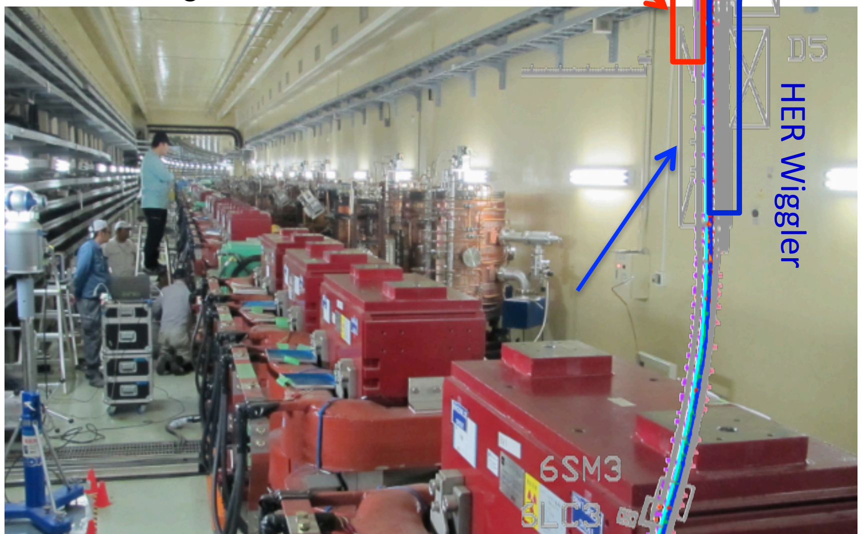




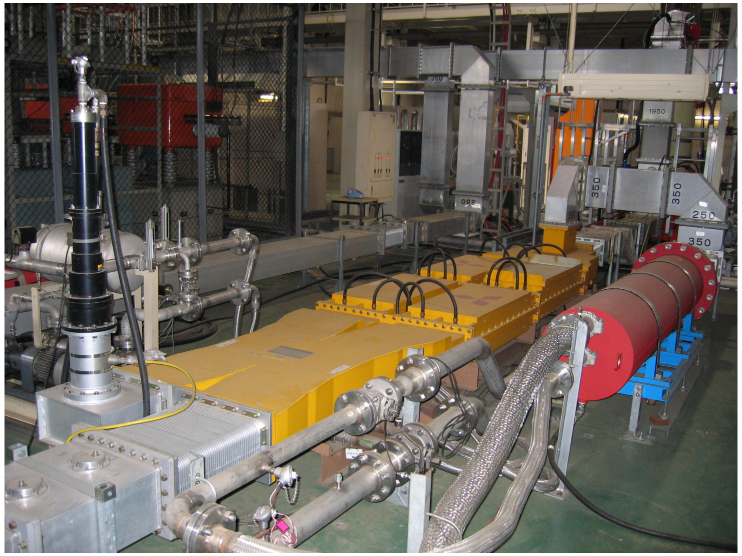
Installation of LER wiggler chambers in Nikko and Oho straight sections will be completed in March.



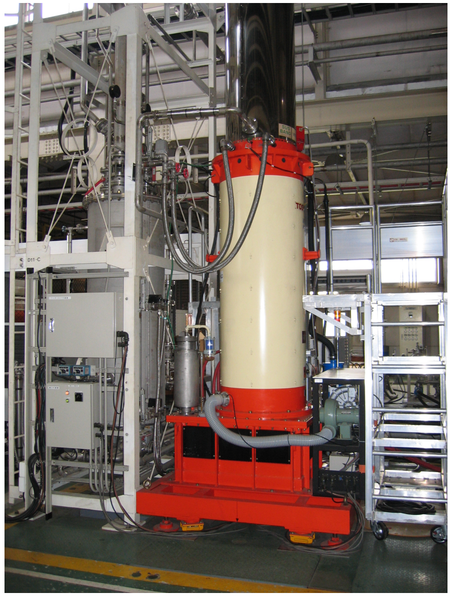
Installation of HER wiggler chambers in Oho straight section is done.



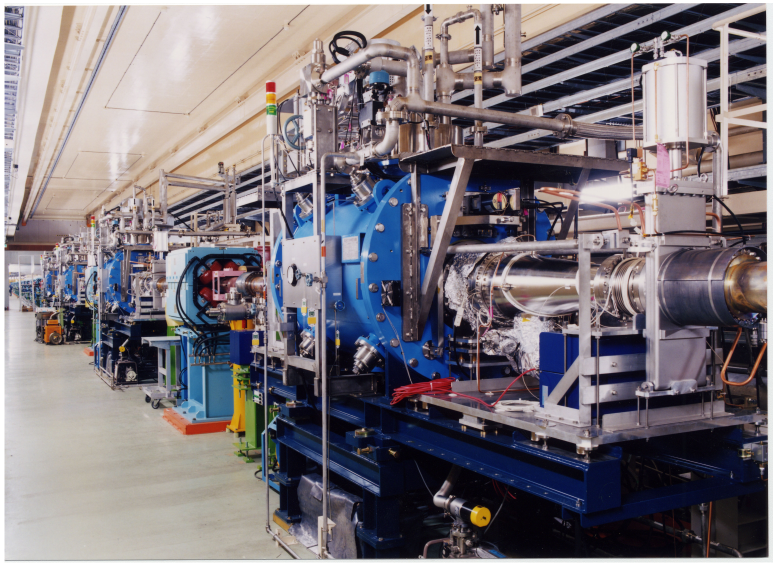
RF syetem



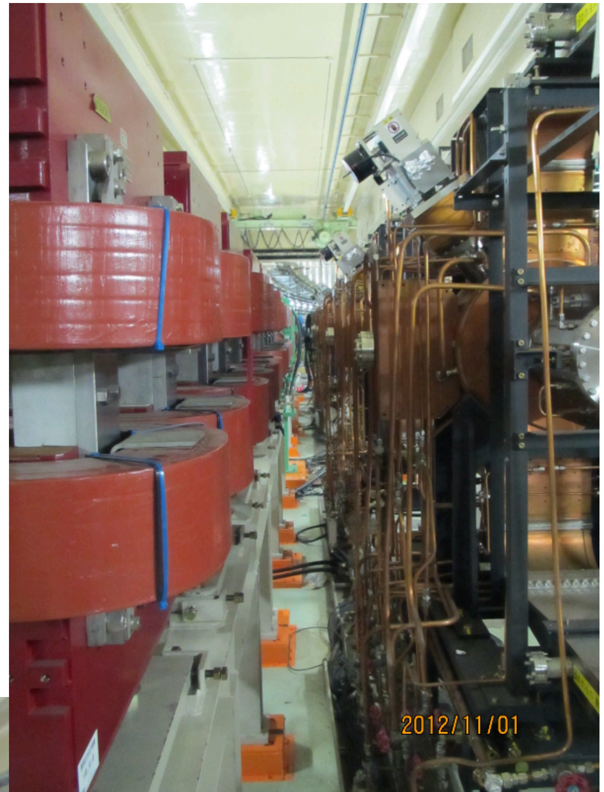
RF high power system



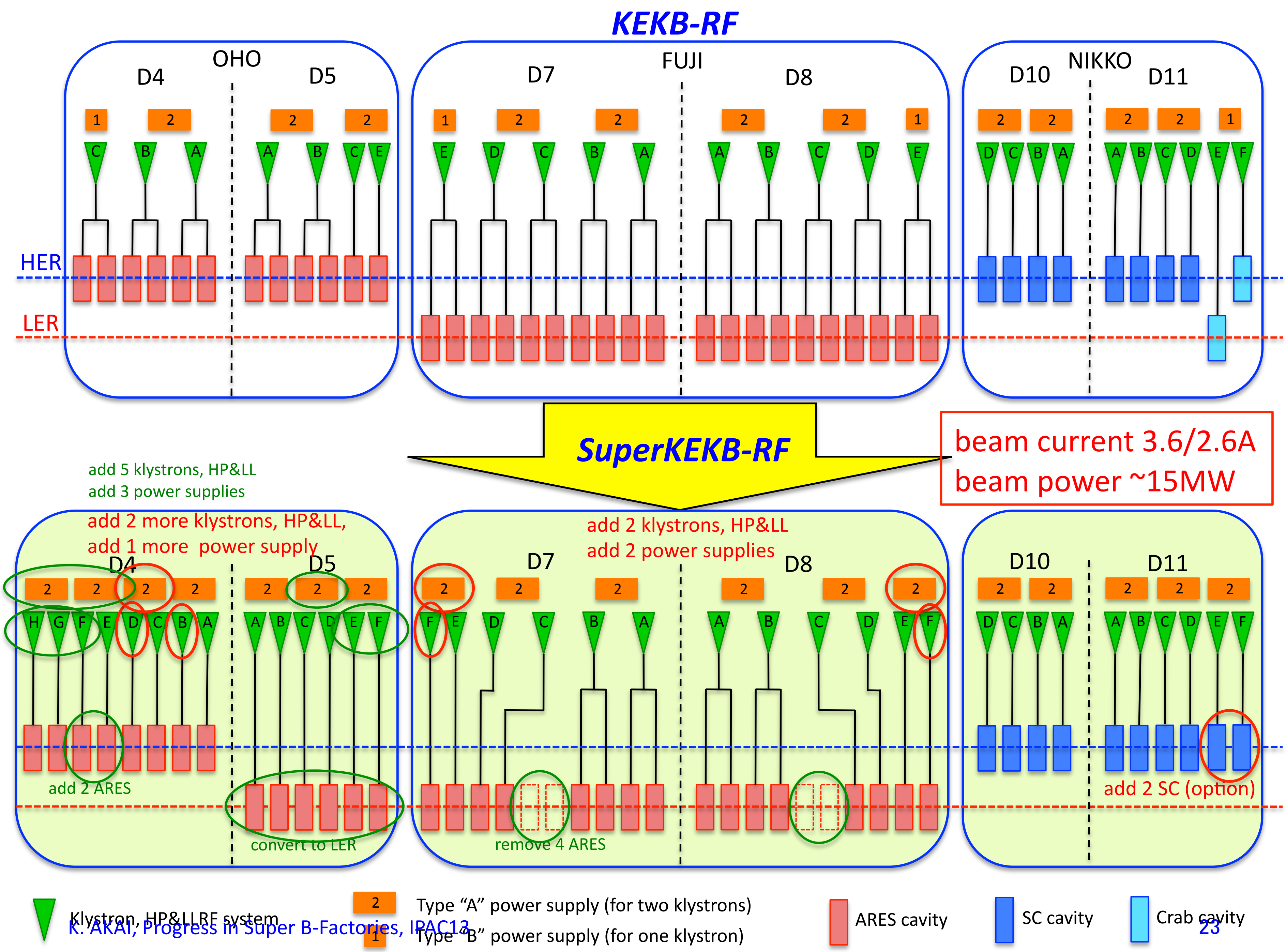
1.2MW CW kystron



Superconducting cavities



Six ARES cavities in D5 moved from HER to LER. HER wiggler magnets were installed close to the ARES.

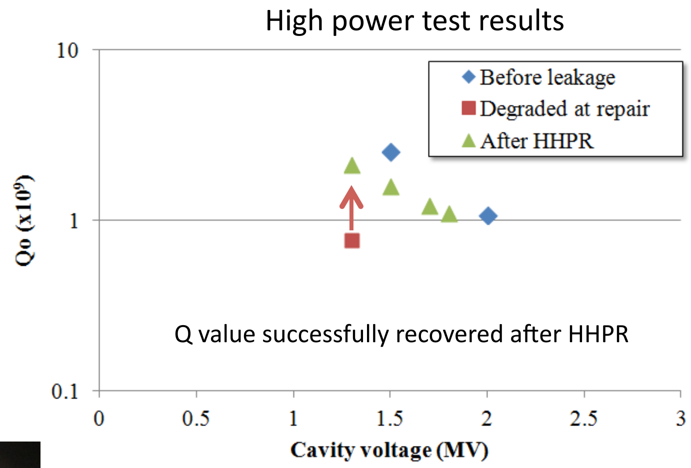


KEKB-RF
OHO
D4
D5
FUJI
D7
D8
NIKKO
D10
D11
HER
LER
SuperKEKB-RF
beam current 3.6/2.6A
beam power ~15MW
add 5 klystrons, HP&LL
add 3 power supplies
add 2 more klystrons, HP&LL,
add 1 more power supply
add 2 klystrons, HP&LL
add 2 power supplies
add 2 ARES
convert to LER
remove 4 ARES
add 2 SC (option)
Klystron, HP&LLRF system
Type "A" power supply (for two klystrons)
Type "B" power supply (for one klystron)
ARES cavity
SC cavity
Crab cavity

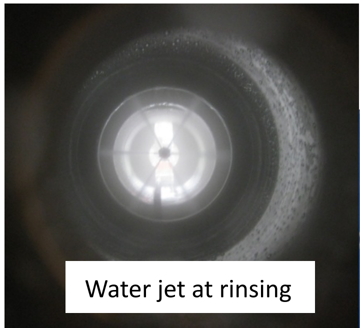
Horizontal high pressure rinsing (HHPR) for cavity performance recovery

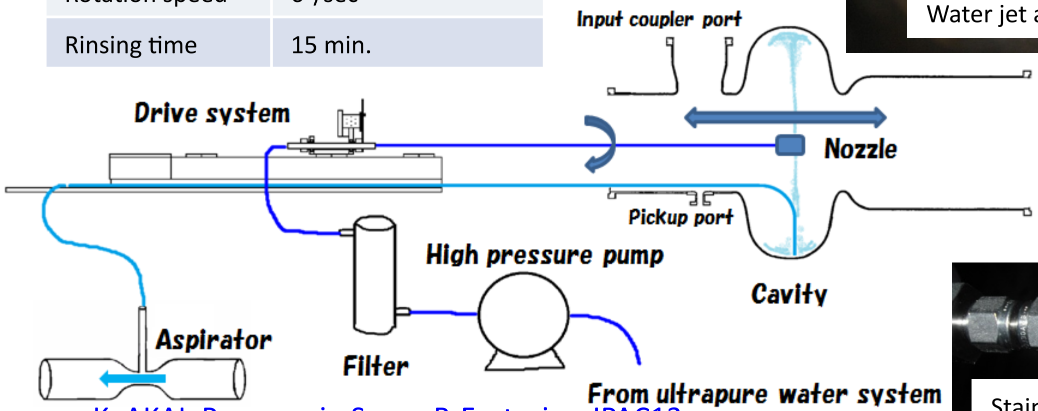
Y. Morita et al.

High pressure water rinsing is an effective method to clean up the cavity surface. In order to recover RF performance of Q-degraded cavity, we have developed a horizontal high pressure water rinsing (HHPR) . A high pressure water nozzle is horizontally inserted into the cavity and wasted water is extracted by an aspirator. This method makes it possible to clean the cavity surface without disassembling the cryomodule. We applied the HHPR to our degraded cavity contaminated by air dusts at indium seal repair and successfully recovered its RF performance.

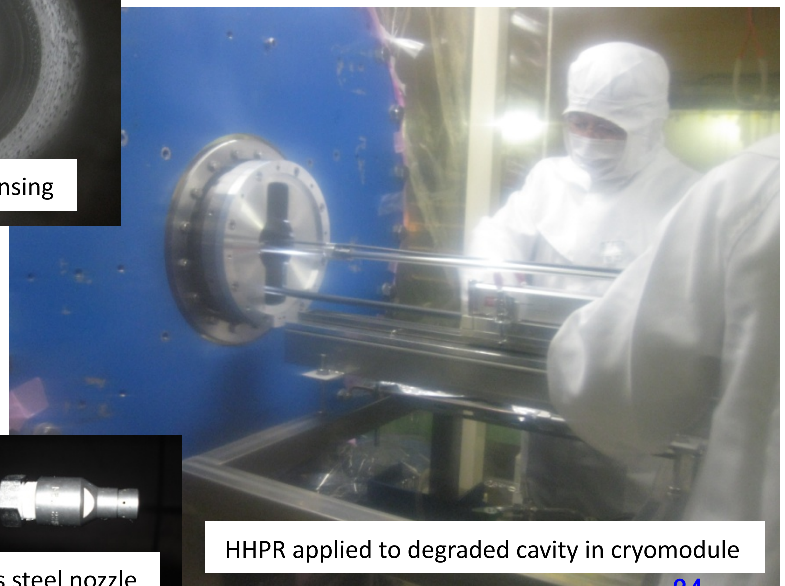


HHPR parameters	
Water pressure	7 MPa
Nozzle	Stainless steel Φ0.54 mmX 6 holes
Driving speed	1 mm/sec
Rotation speed	6°/sec
Rinsing time	15 min.


Water jet at rinsing



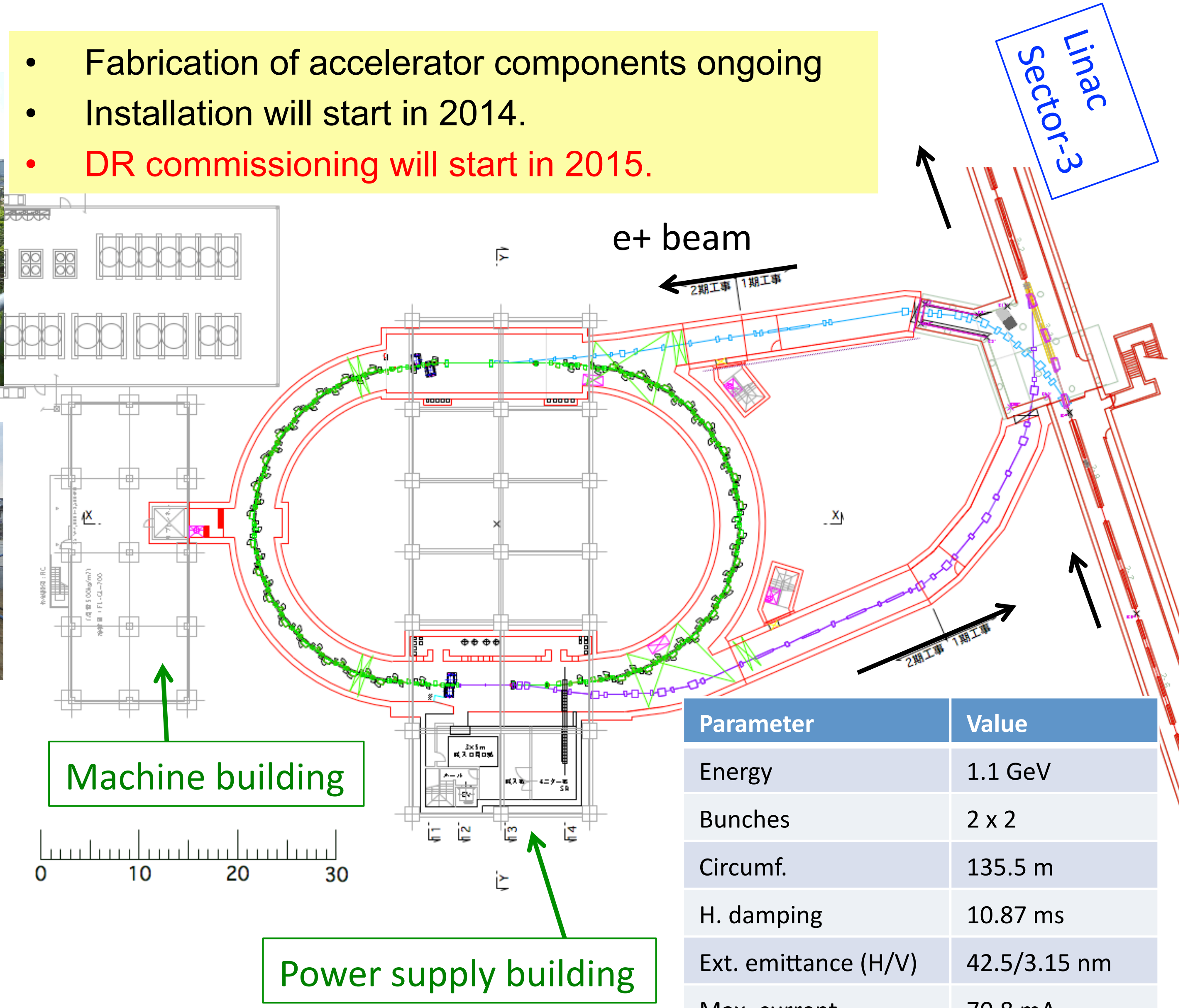

Stainless steel nozzle


HHPR applied to degraded cavity in cryomodule

New Damping Ring for positrons

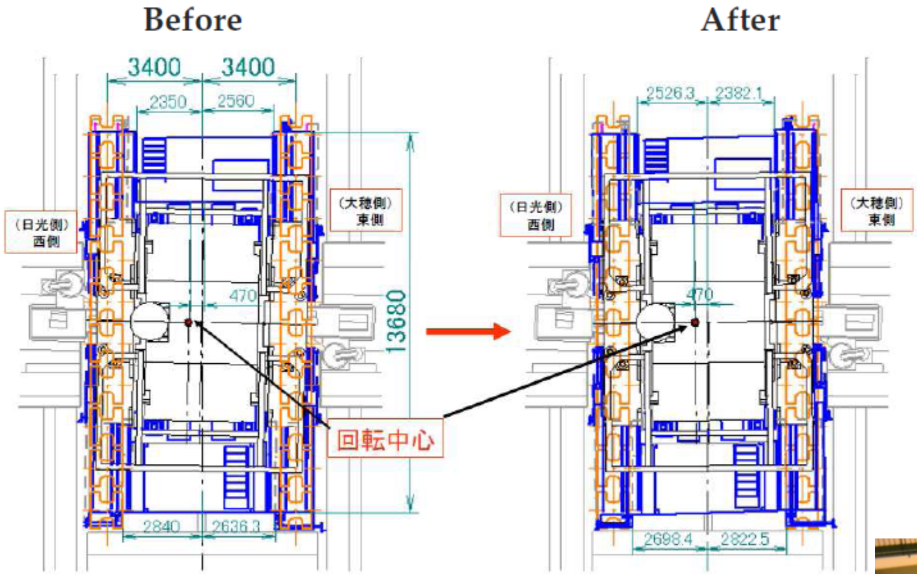
DR tunnel construction

- Fabrication of accelerator components ongoing
- Installation will start in 2014.
- DR commissioning will start in 2015.

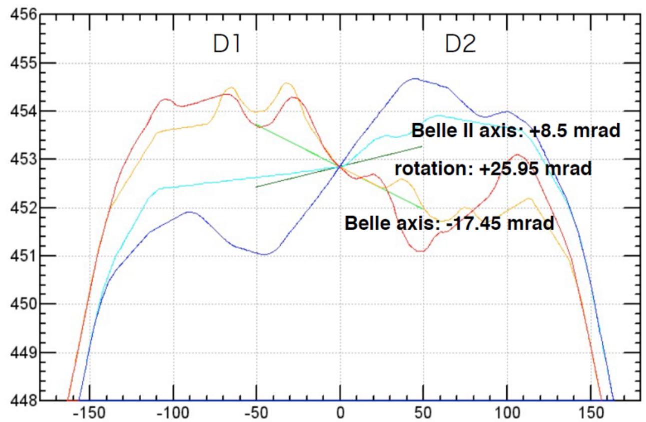


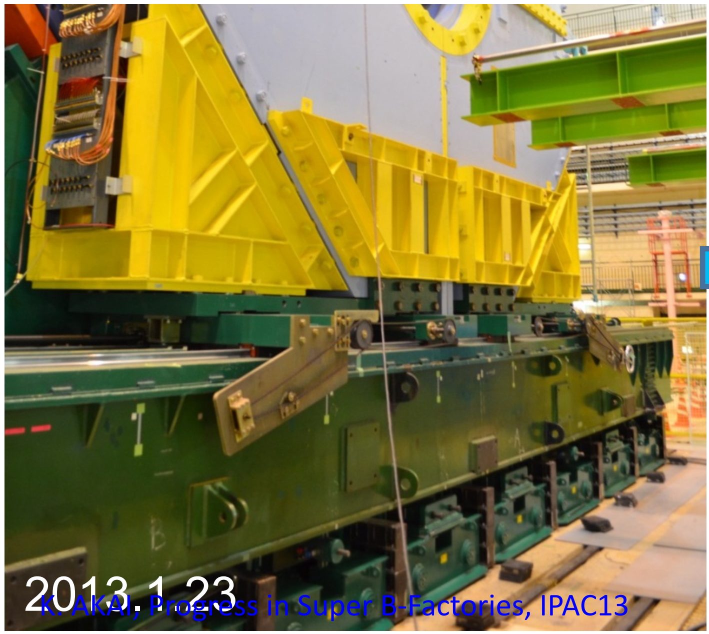
Parameter	Value
Energy	1.1 GeV
Bunches	2 x 2
Circumf.	135.5 m
H. damping	10.87 ms
Ext. emittance (H/V)	42.5/3.15 nm
Max. current	70.8 mA

Belle Rotation Completed



Rotation by 26 mrad required from SuperKEKB optics



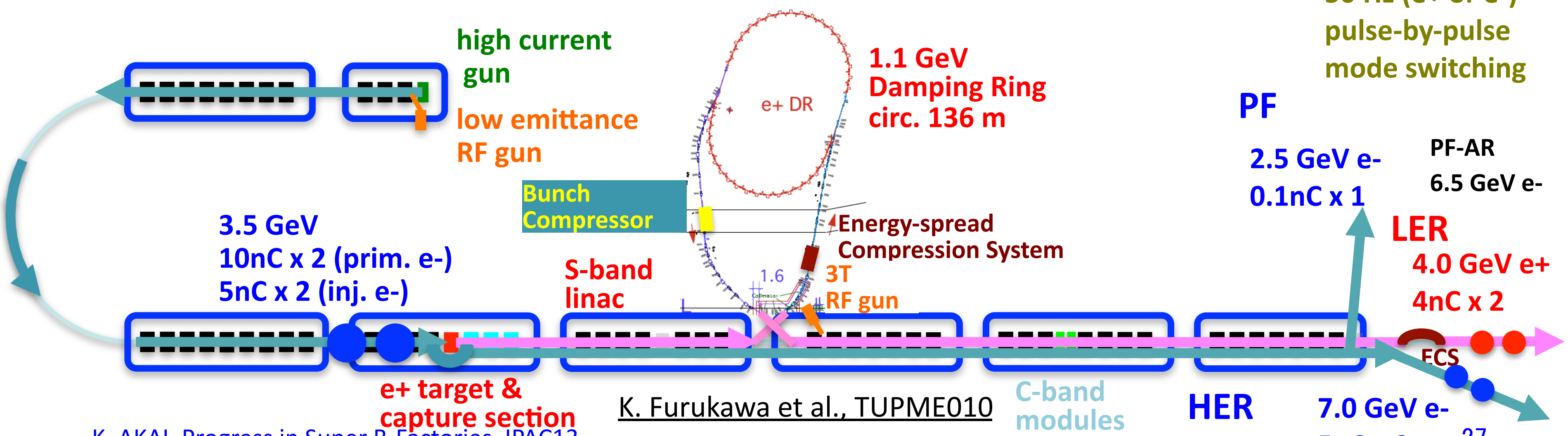


Injector Linac Upgrade

- RF low emittance gun
  - Low emittance
  - High charge (5nC)
- Improve positron source
  - Increase charge (4nC)

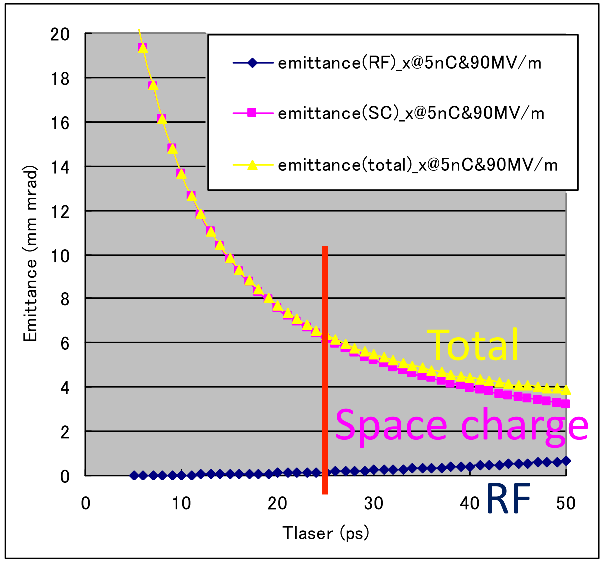
	KEKB obtained (e+ / e-)	SuperKEKB required (e+ / e-)
Beam energy	3.5 GeV / 8.0 GeV	4.0 GeV / 7.0 GeV
Bunch charge	e- → e+ / e- 10 → 1.0 nC / 1.0 nC	e- → e+ / e- 10 → 4.0 nC / 5.0 nC
Beam emittance (γε)[1σ]	2100 μm / 300 μm	6 μm / 20 μm

- Improve emittance preservation
  - Alignment tolerance is 0.1 mm locally and 0.3 mm globaly.

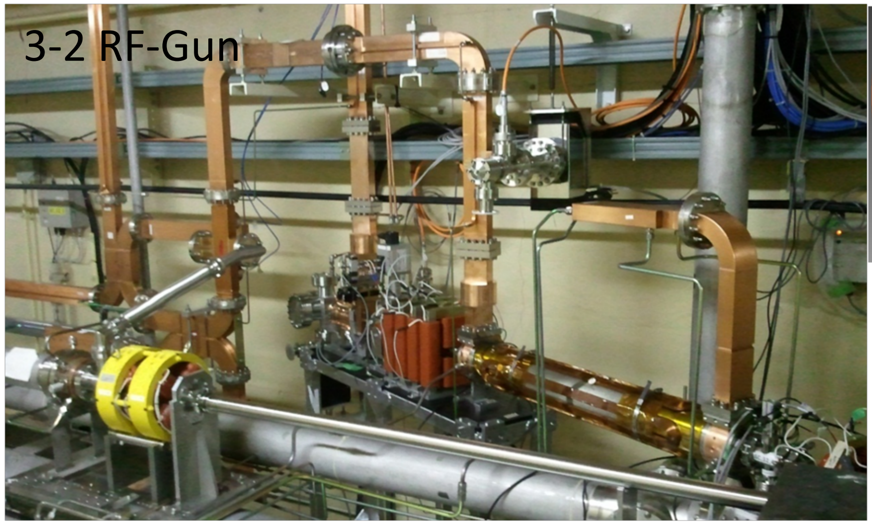


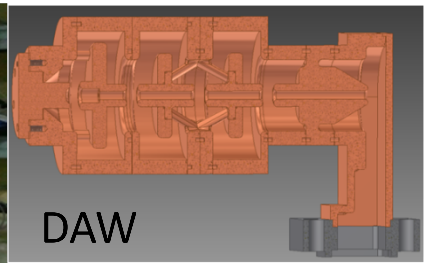
RF-Gun for 5 nC

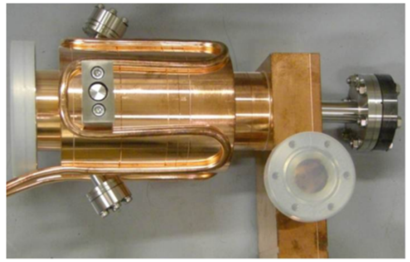
- Space charge is dominant.
  - Longer pulse length : 20 - 30 ps
- Stable operation is required.
  - Lower electric field : < 100MV/m
- Strong focusing field is required.
  - Solenoid focus causes the emittance growth.
  - **Electric field focus preserve the emittance.**



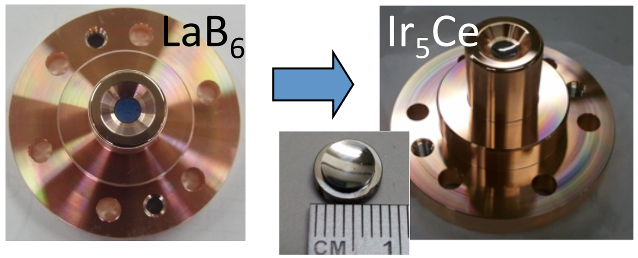
Annular coupled cavity ： Disk and washer / Side couple







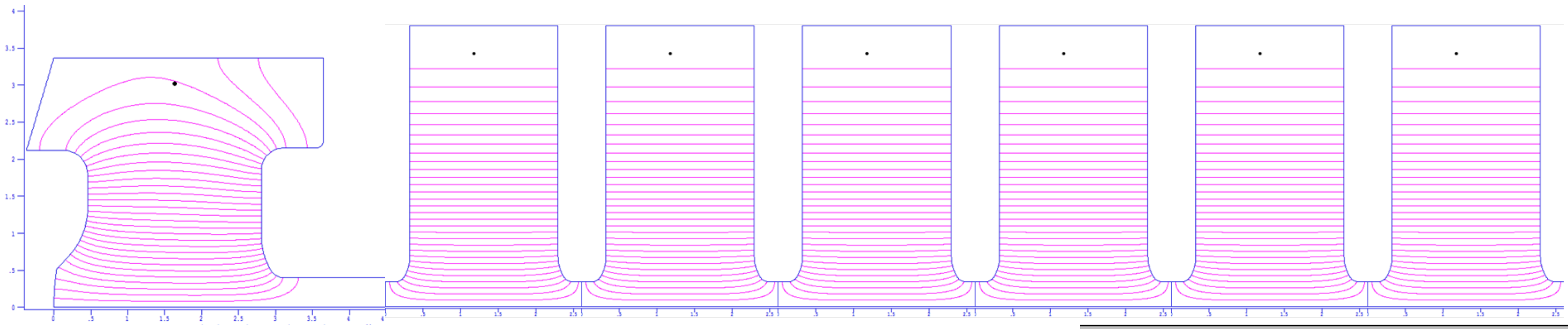
Cathode LaB6 => Ir5Ce（2012/03)

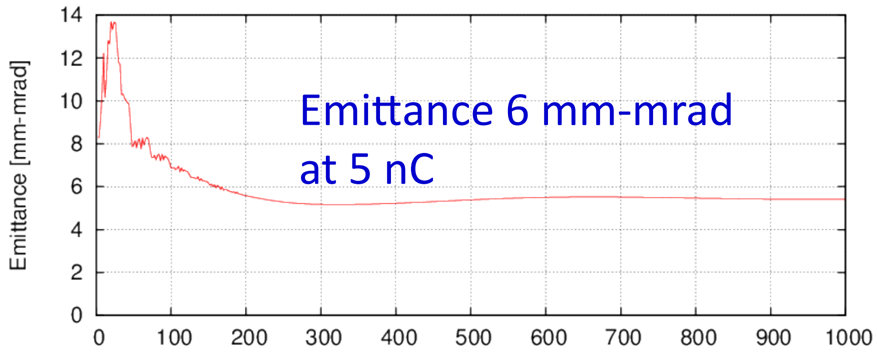


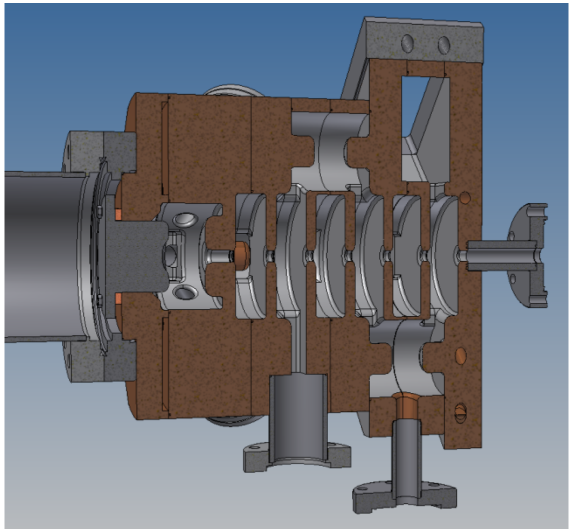
5nC@gun, 4.4nC@Linac end obtained.

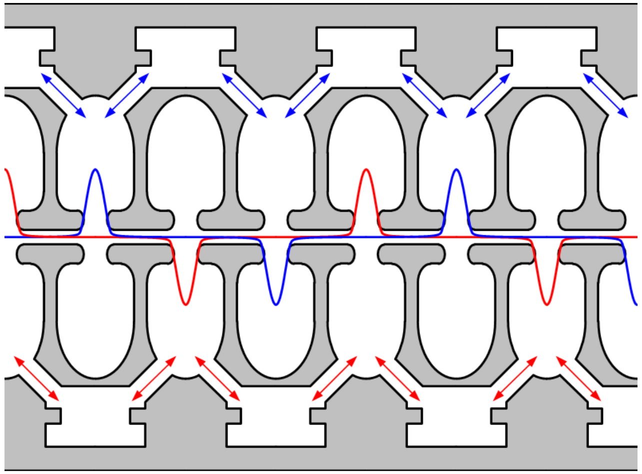
M. Yoshida et al., TUPFI004
D. Satoh et al., MOPFI023

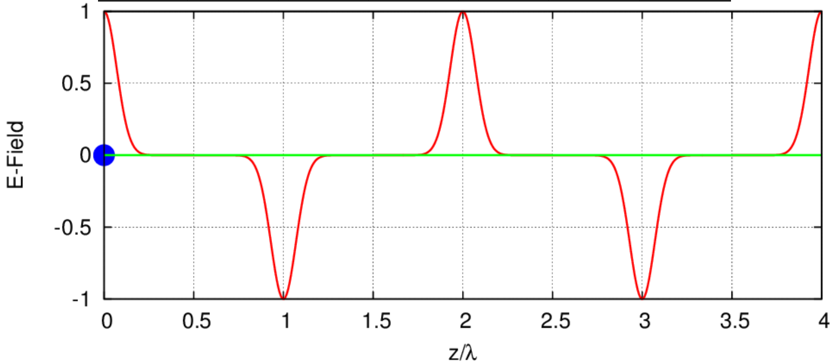
Quasi traveling wave sidecouple structure is also being developed.





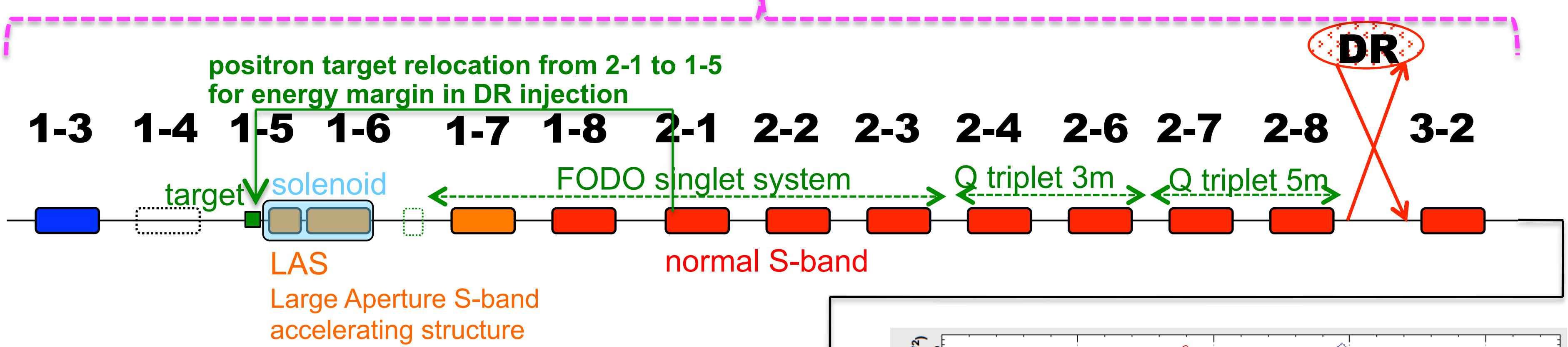


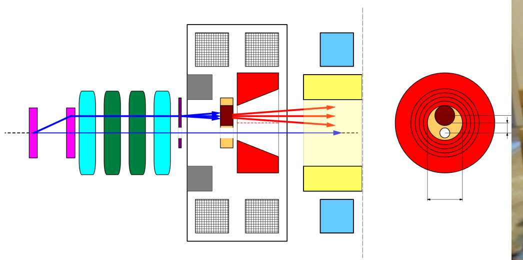




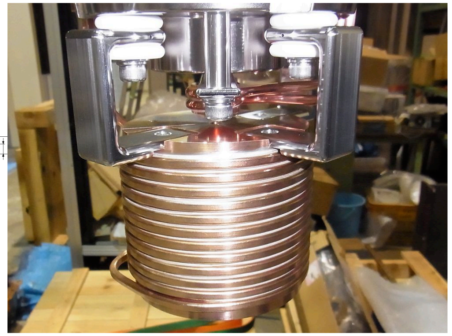
T. Natsui et al., TUOCB103

Positron source upgrade



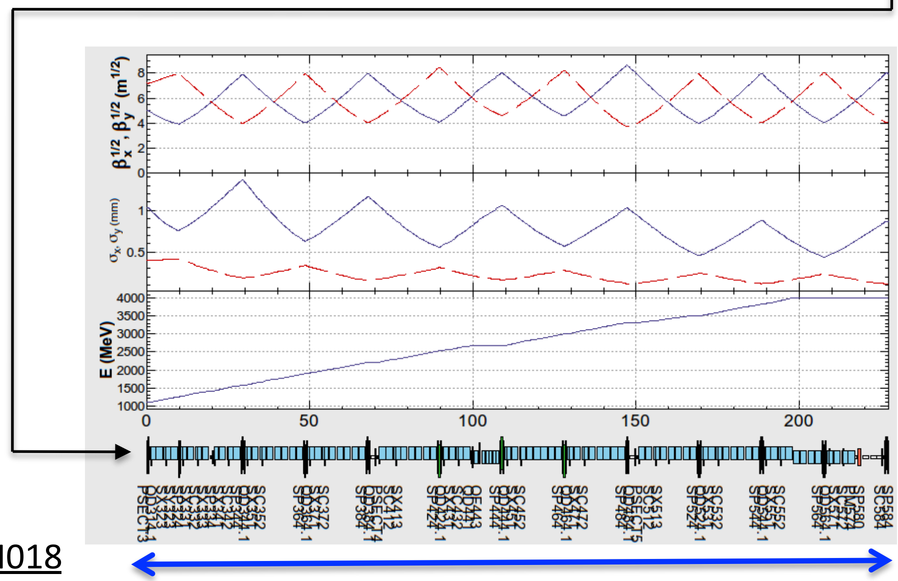


Positron target



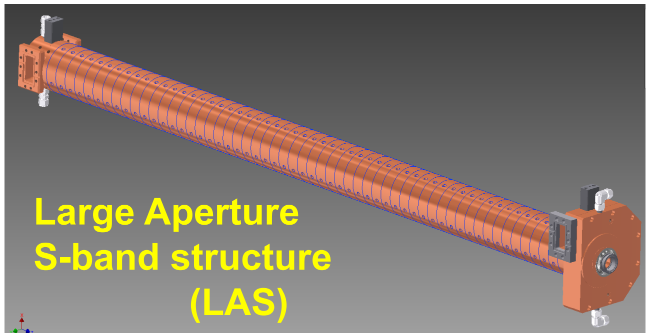
Flux concentrator

L. Zang et al., MOPFI018



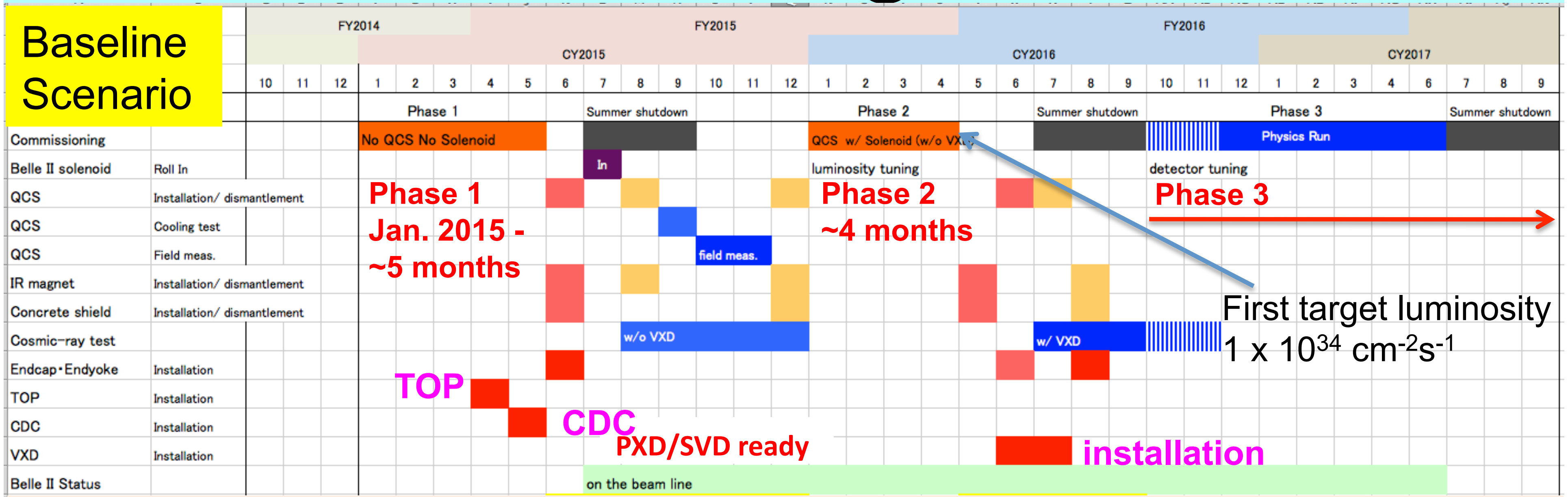
sector - 3, 4, 5

- to switch optics flexibly for e+/e-/PF/AR, pulse quads are preferable
- triplets are replaced by FODO and beam pipe aperture will be reduced to half to relax pulse quad specification and cost



K. AKAI, Progress in Super B-Factories, IPAC13

Commissioning Scenario



[Phase 1] No QCS, No Belle II

- Basic machine tuning, Low emittance tuning
- Vacuum scrubbing (0.5 ~ 1.0 A, >1 month)
- DR commissioning start (~Apr. -)

[Phase 2] With QCS, With Belle II (without Vertex Detector)

- Small x-y coupling tuning, Collision tuning
- βy^* will be gradually squeezed
- Background study

[Phase 3] With Full Belle II

- Increase beam current with adding more RF
- Increase luminosity

From SuperB to τ/charm

Following slides on the Italian τ/charm project: courtesy of M. Biagini, INFN-LNF

M. Biagini

Introduction – From SuperB to τ/charm

- In 2012, after a careful costing review of the SuperB project a decision was taken by INFN to cancel it, due to the insufficient budget allocated by the Italian Governement. The Nicola Cabibbo Laboratory, entity in charge of building SuperB, has then started in 2013 a study for a dedicated high luminosity (10^{35} cm^{-2} s^{-1}) τ/charm factory
- This program was already planned as a second phase of SuperB, by decreasing the beams energies, so most of the work done in the past years for SuperB can be used for the new project
- The scope of the present design is to have a dedicated and optimized project, re-using all the competences, studies and tools developed for SuperB, keeping costs in the allocated budget (250 Meuro)
- The possibility to use the injection Linac for a SASE FEL facility is still valid and is part of the design

τ/charm Factory main features

- Energy tunable in the range **E_{cm} = 1-4.6 GeV**
- **10^{35} cm^{-2} s^{-1}** peak luminosity at the τ/charm threshold and upper
- **Symmetric beam energies**
- Longitudinal polarization in the electron beam (60-70%)
- Possibility of e^-e^- collisions (to be studied)
- Beam parameters for reasonable lifetimes and beam currents
- Damping times of the order of 30-50 msec (wigglers are needed at lower beam energy)
- Low power consumption → lower running costs
- Injection system scaled from the SuperB one

Table of parameters
@ 2 GeV/beam
for L = 1×10^{35}
and L = 2×10^{35}

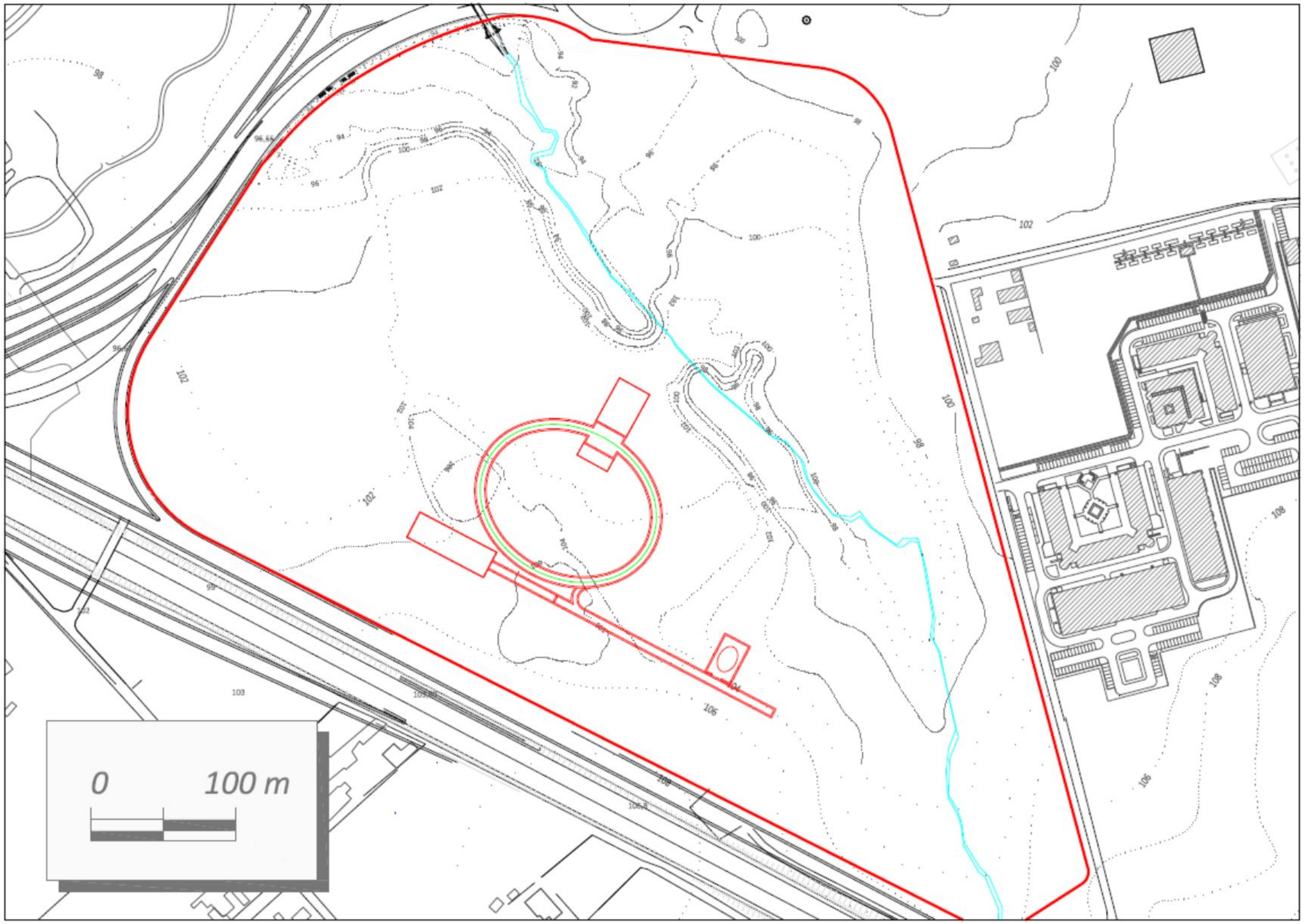
M. Biagini

K. AKAI, Progress in Super B-Factories, IPAC13

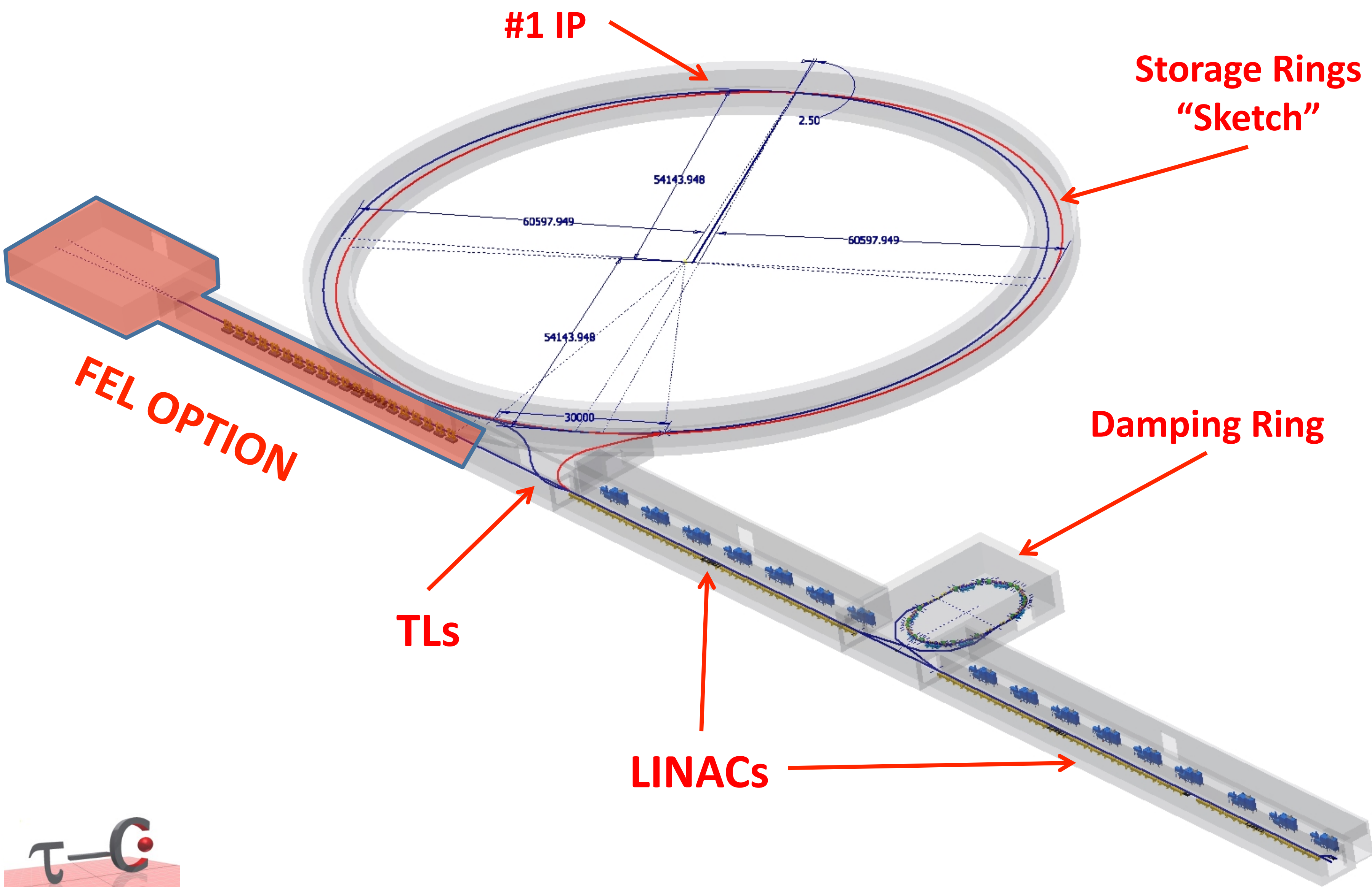
Parameter	Units	HER=LER	HER=LER
LUMINOSITY	cm^{-2} s^{-1}	1.00E+35	2.00E+35
cm Energy	GeV	4.0	4.0
Beam Energy	GeV	2.0	2.0
Boost		0	0
Circumference	m	325.43	325.43
X-Angle (full)	mrad	60	60
Piwinski angle	rad	9.50	9.54
Hourglass reduction factor		*0.86*	*0.86*
Tune shift x		0.005	0.007
Tune shift y		0.097	0.131
β_x @ IP	cm	6	6
β_y @ IP	cm	0.06	0.06
σ_x @ IP	microns	17.69	18.56
σ_y @ IP	microns	0.088	0.093
σ'_x @ IP	microrad	295	309
σ'_y @ IP	microrad	147	155
Coupling (full current)	%	0.25	0.25
Emittance x (no IBS)	nm	2.93	2.93
IBS factor		1.78	1.96
Emittance x (with IBS)	nm	5.22	5.74
Emittance y (with IBS)	pm	13.0	14.4
Bunch length (full current, with IBS)	mm	5.6	5.9
Bunch length (full current, no IBS)		4	4
Beam current	mA	1570	2340
Buckets distance	#	1	1
Ion gap	%	2	2
RF frequency	Hz	4.76E+08	4.76E+08
Revolution frequency	Hz	9.21E+05	9.21E+05
Harmonic number	#	517	517
Number of bunches	#	506	506
Bunch current	mA	3.10	4.62
N. Particle/bunch	#	2.11E+10	3.14E+10
Average bending radius	m	15	15
E loss/turn	MeV	0.09	0.09
Beam power	MW	0.15	0.22
Transverse damping times (no wigg)	msec	33/47	33/47
Total number of particles		1.07E+13	1.59E+13
Bhabha cross section	mbarn	166	166
Bhabha beam lifetime	min	10.7	8.0
Tau tou (rough scaling)	*min*	*20.0*	*16.3*
Tau Tot (rough scaling)	*min*	*6.9*	*5.4*
Tau depol	sec	*1435*	*1435*
Polarization	%	*62*	*65*

Tau-Charm Layout @ Tor Vergata

M. Biagini



τ-Charm Pictorial View



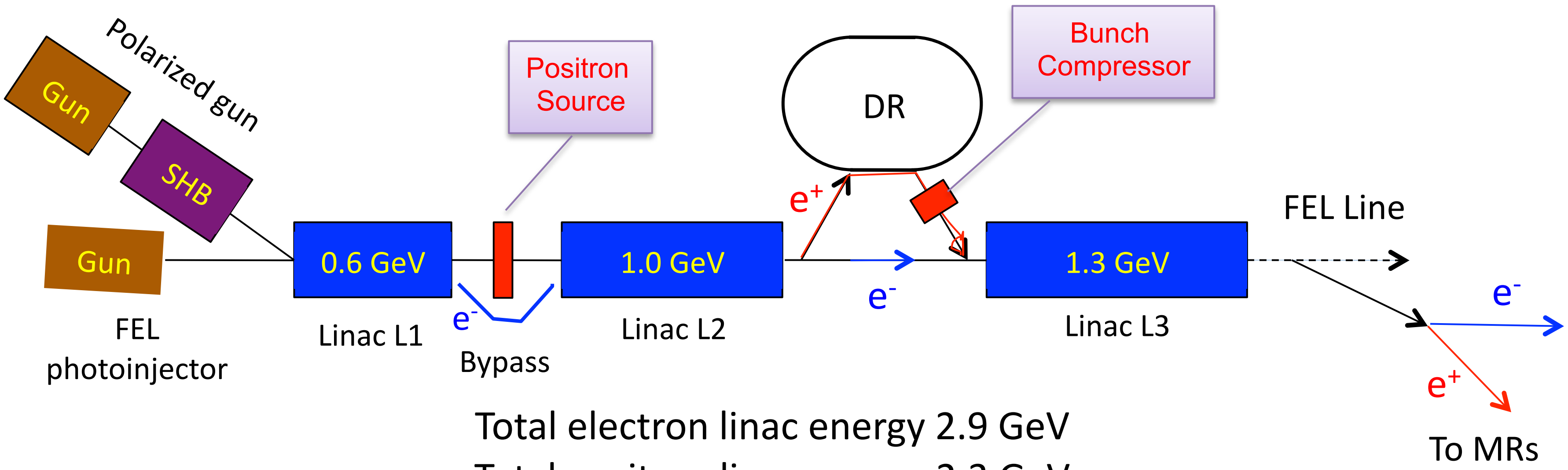
M. Biagini

Rings lattice @ 2 GeV

- The lattice has to provide the minimum emittance in order to reach the goal luminosity
- The arcs layout is similar to the SuperB lattice
- The number of magnets and their layout is similar to the ESRF arc cell, where minimum emittance is obtained
- Some of the dipoles have a gradient component, so X and y damping times are different
- The Final Focus has been optimized for the lower energy and to have beams passing as much as possible on-axis in the first doublet to avoid SR in the detector
- The present FF design includes octupoles to compensate for the first doublet fringing fields
- Optimization of the dynamic aperture is in progress

S. Guiducci et al.

Tau-Charm Injection System layout

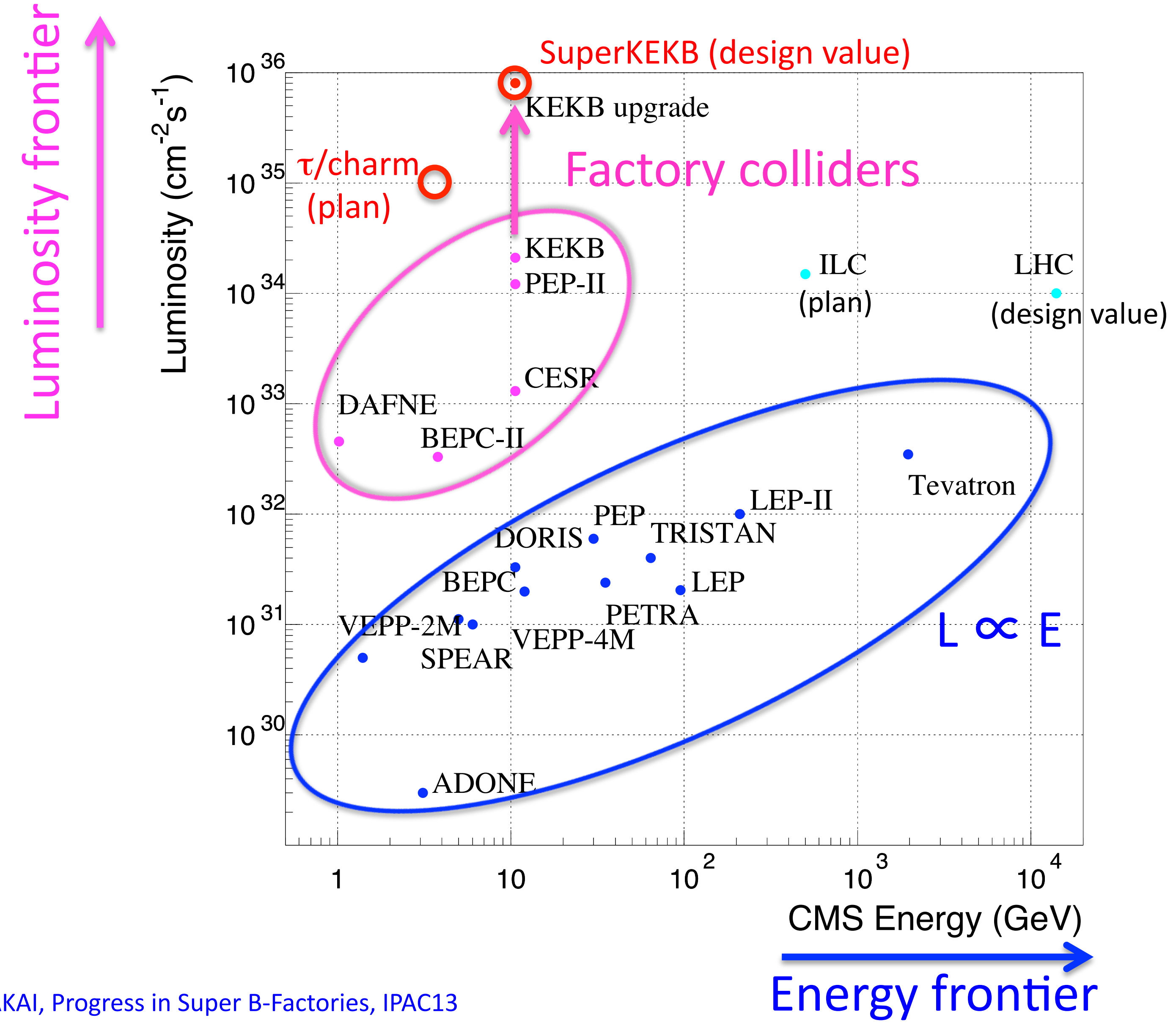


Total electron linac energy 2.9 GeV
Total positron linac energy 2.3 GeV

	Linac L1	Linac L2	Linac L3
N. of klystrons	3	6	7
N. of cavities	9	18	21
Max. Energy (GeV)	0.62	1.24	1.45

The number of klystrons and cavities allows to reach the maximum positron energy of 2.3 GeV also with one klystron off

Frontier of colliders



Summary

- Construction of SuperKEKB is underway, and the commissioning is scheduled early 2015. Finalizing the design is also in progress for the most critical region, in particular for the IR.
- SuperB has been cancelled due to budget issues, but a design for a τ/charm factory has started, based on the previous work done for the SuperB.
- These colliders address very challenging tasks, and will open new luminosity frontier.