Next Generation B-factories

Mika Masuzawa (KEK)

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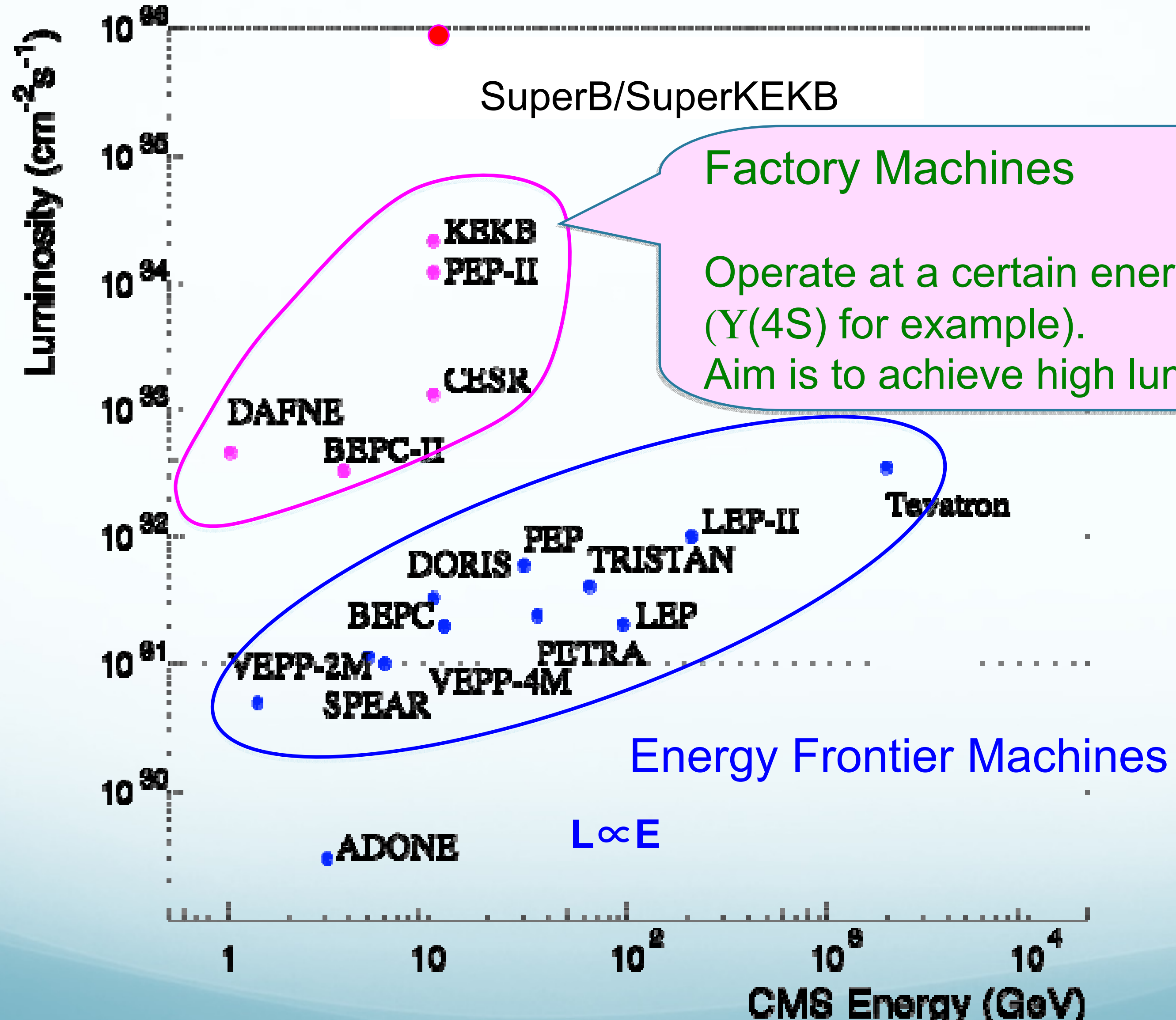
PEP-II & KEKB



Factory Machines

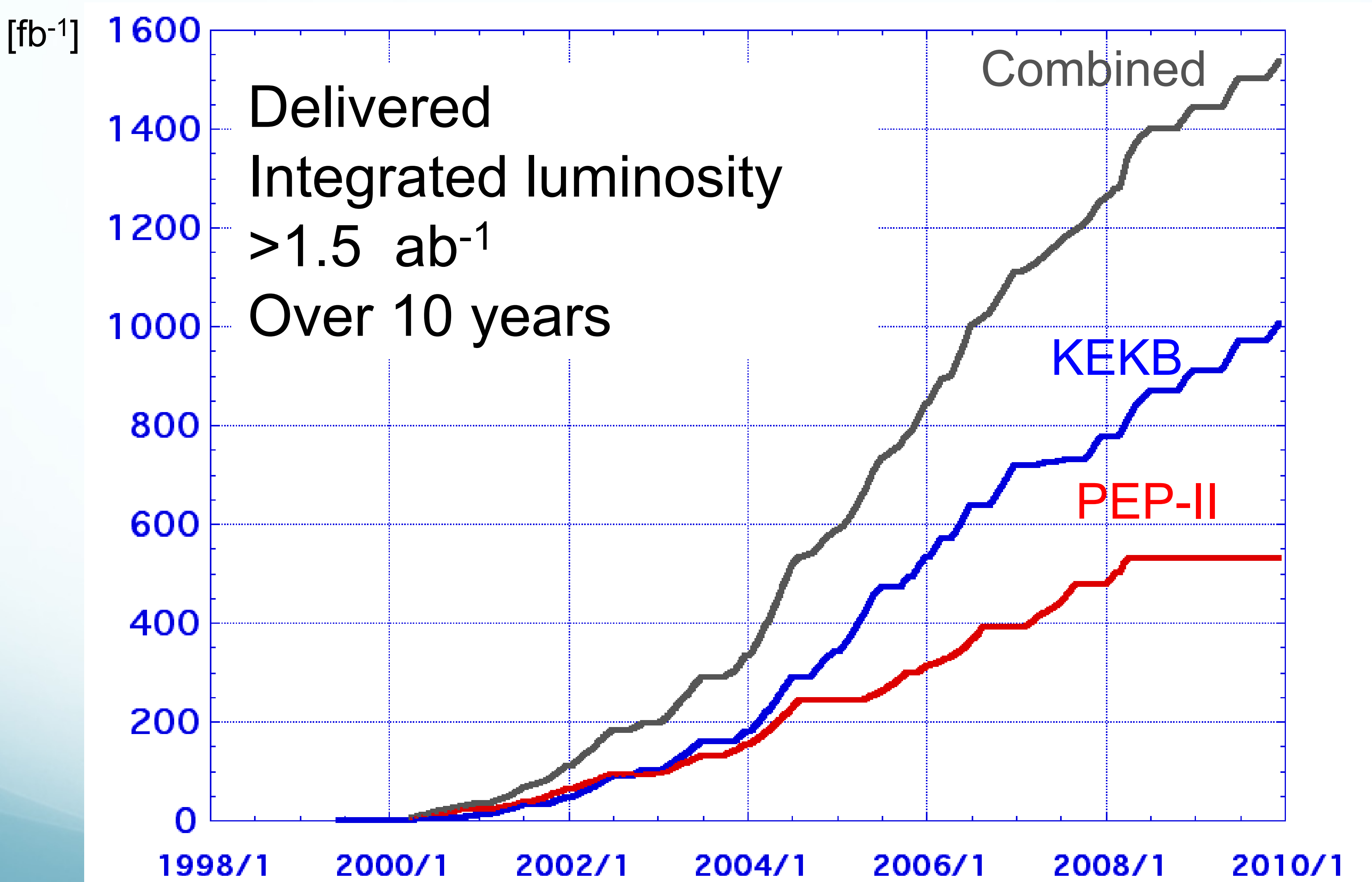
Operate at a certain energy (Υ(4S) for example).
Aim is to achieve high luminosity.

What we, PEP-II and KEKB, have achieved

We have operated the world's highest luminosity e^+e^- colliders with stored beam currents > 1A.

- Establishment of technology of key components, such as RF, vacuum and beam monitors, to handle multi-ampere beam currents.
- Operation with crossing angle, and crab cavities (KEKB).
- Proof that IR configuration with permanent magnets (PEP-II) / superconducting magnets (KEKB) works.
- Detector backgrounds at manageable level with continuous (trickle-charge) injection scheme.
- Demonstration of effectiveness of solenoids against electron clouds.
- Benchmarks for simulations made and further understanding of beam dynamics obtained.

What we, PEP-II and KEKB, have achieved



Next Generation B-factories

Q: How many years would we need to accumulate 50 ab^{-1}
(the target given by the physics community)
IF we kept running the present KEKB?

A: With the current peak luminosity of $2 \times 10^{34}\ cm^{-2}s^{-1}$
⇒0.3 ab^{-1}/year (assuming 1.5×10^7 seconds/year running)
⇒167 years.

Need for much higher luminosity machines:
Next Generation B-factories

⇒Two projects:

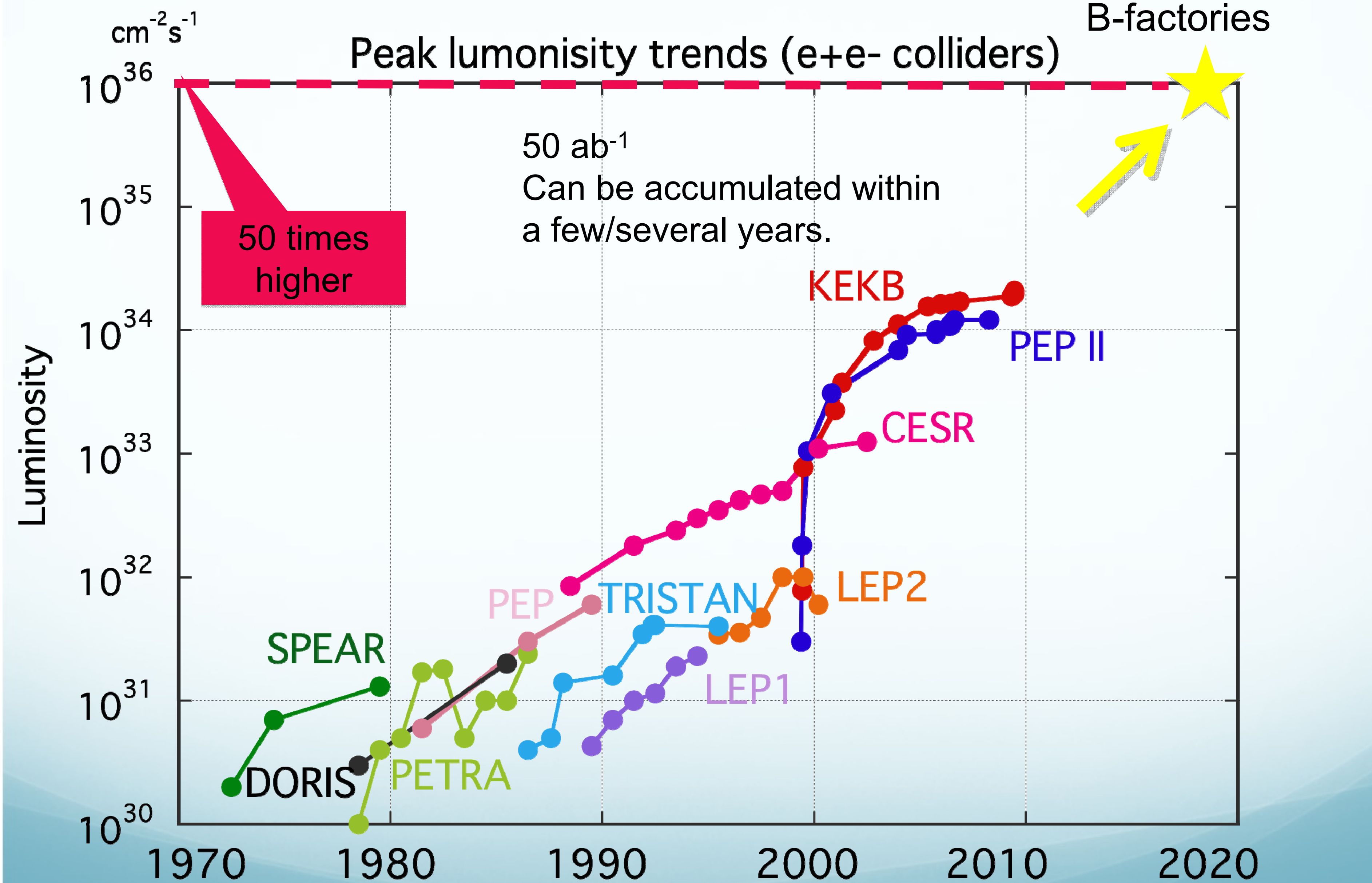
SuperB and SuperKEKB

Next Generation B-factories

Global efforts for Next Generation B-factories

Our mission

Next Generation B-factories



Strategies for higher luminosity

- The design work has been going on for a while for both SuperB and SuperKEKB.
- The designs and parameters are not yet finalized.
- Information is being exchanged between the two groups, learning from each other and improving the designs.
- Please note that all the numbers are still somewhat preliminary.

Three major factors determining luminosity:

Stored current:

1.7 / 1.4 A (e^+/ e^- KEKB)

Beam-beam parameter:

0.09 (KEKB)

Lorentz factor

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

Classical elec. radius

Beam size ratio

Geometrical correction factors due to crossing angle and hour-glass effect

Luminosity:

0.21 $\times 10^{35}$ $cm^{-2}s^{-1}$ (KEKB)

Vertical β at the IP:

5.9 /5.9 mm (e^+/ e^- KEKB)

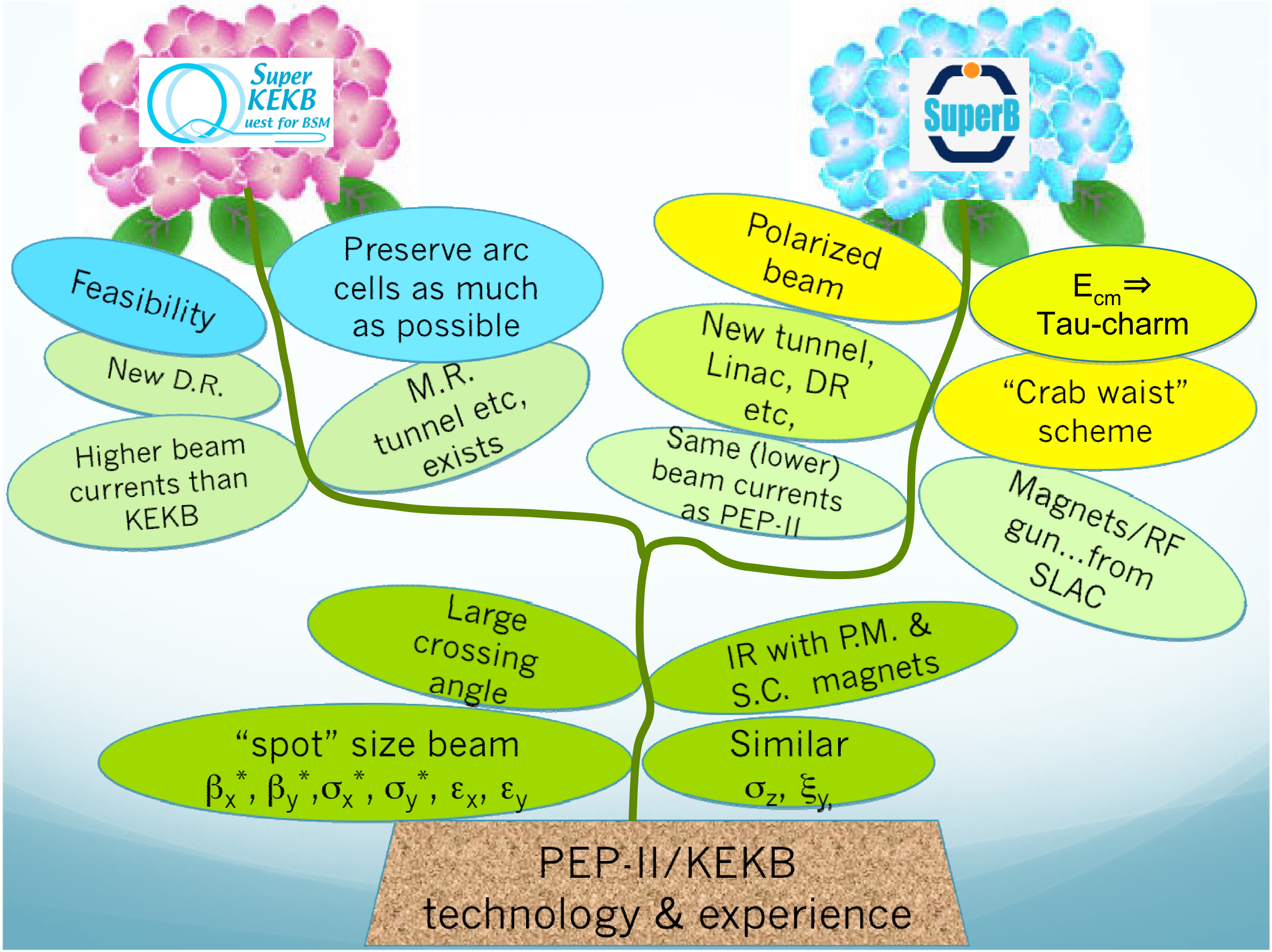
Design concepts

Our initial approaches :
Extrapolations of PEP-II & KEKB

More beam currents ⇒ larger power consumption
Crab crossing
Higher ξ_y
Somewhat reduced β_y^*
Shorter bunch length ⇒ Challenges from HOM heating.
⇒ Bunch lengthening due to Coherent Synchrotron Radiation (CSR).

Low emittance ("nano-beam") scheme
⇒ first proposed by P. Raimondi for SuperB.

Collision with very small spot-size beam.



Super KEKB Quest for BSM
SuperB
Feasibility
New D.R.
Higher beam currents than KEKB
Preserve arc cells as much as possible
M.R. tunnel etc, exists
Polarized beam
New tunnel, Linac, DR etc,
Same (lower) beam currents as PEP-II
$E_{cm} \Rightarrow$ Tau-charm
"Crab waist" scheme
Magnets/RF gun...from SLAC
Large crossing angle
IR with P.M. & S.C. magnets
"spot" size beam $\beta_x^*, \beta_y^*, \sigma_x^*, \sigma_y^*, \varepsilon_x, \varepsilon_y$
Similar $\sigma_z, \xi_y,$
PEP-II/KEKB technology & experience

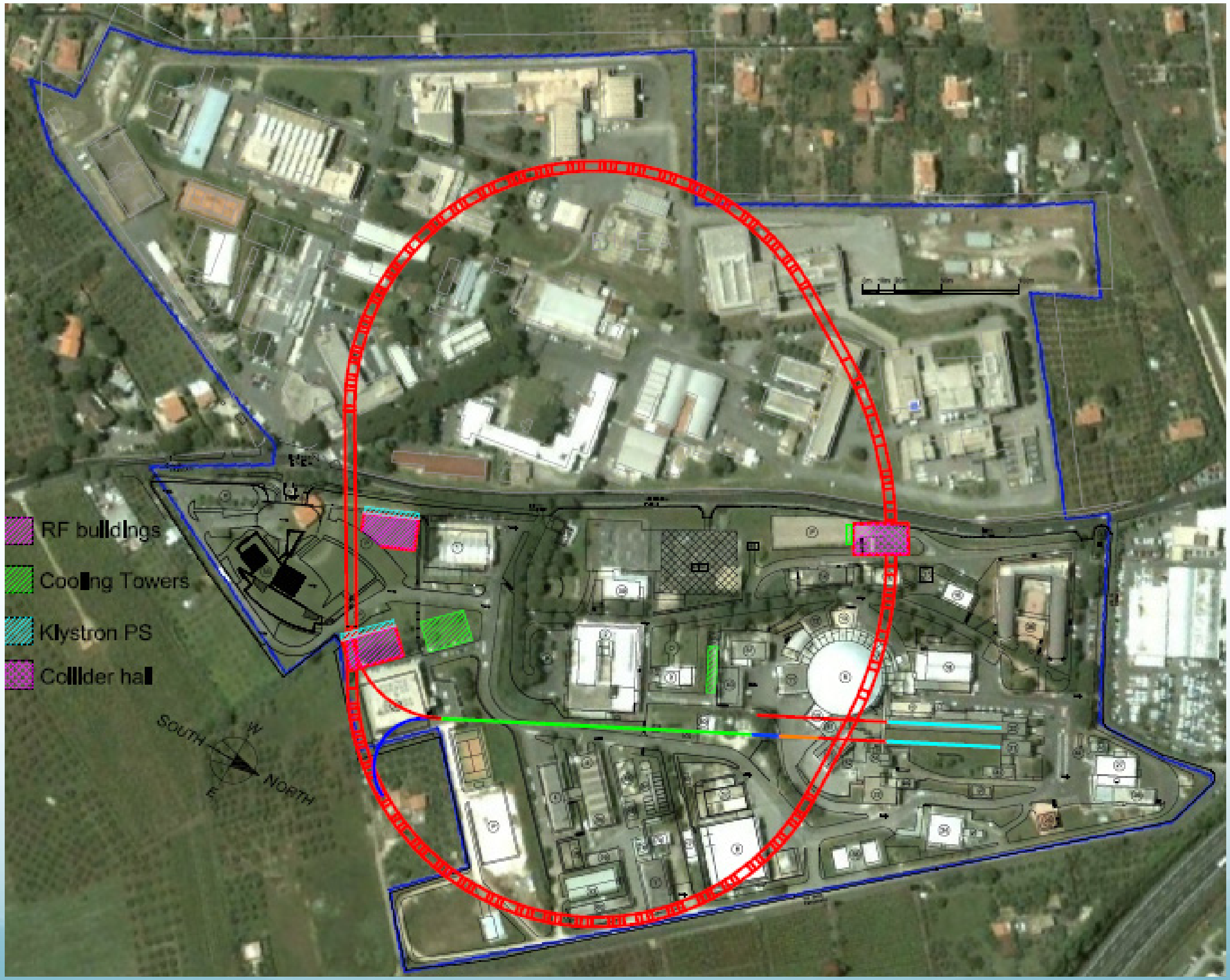
Introduction to SuperB

SuperB Project

- SuperB aims at the construction of a very high luminosity ($1x\ 10^{36}\ cm^{-2}\ s^{-1}$) asymmetric e^+e^- flavor factory with a possible location on or near the campus of the University of Rome at Tor Vergata or the site of the INFN Frascati National Lab.
- Aims:
  - Very high luminosity ($\sim 10^{36}$)
  - Flexible parameter choices.
  - High reliability.
  - Longitudinally polarized beam (e^-) at the IP (>80%).
  - Ability to collide at the Charm threshold.

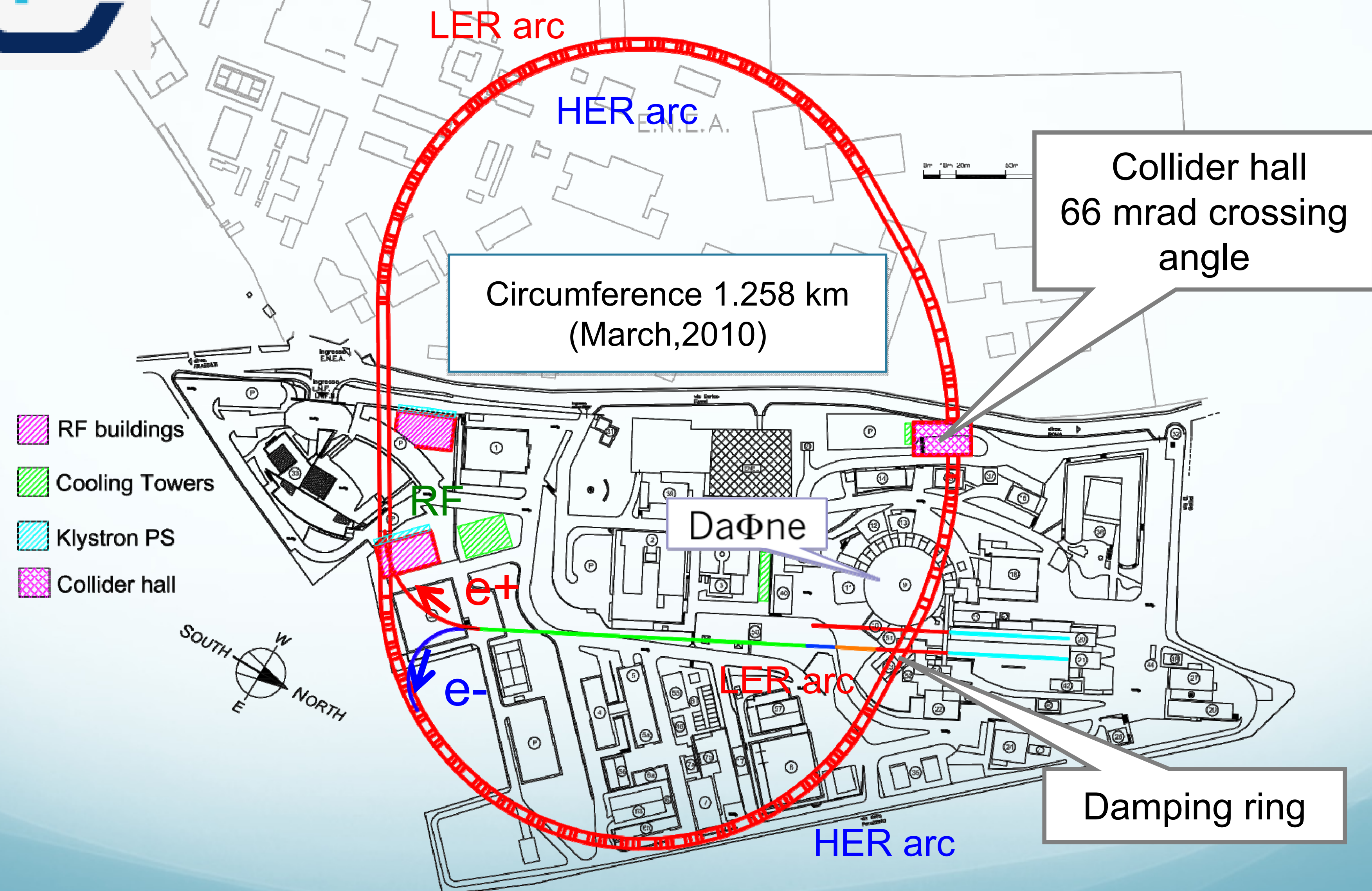
Slide by P. Raimondi at SuperB WS Dec.9, modified.

Super-B layout at LNF



From M. Biagini

SuperB at Frascati



HER and LER arcs are parallel to each other in the H-plane, separated by 2.1 m.

SuperB parameters

Flexible lattice:

The following 4 sets of parameters were presented at the last SuperB workshop.

1. Baseline
2. High current
3. Low emittance
4. Tau-charm in the vicinity of $E_{c.m.}$ = 3.8 GeV

SuperB Parameters

Parameter	Units	Base Line		Low Emittance		High Current		Tau/Charm (prelim.)	
		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	
Piwinski angle	rad	22.88	18.60	32.36	26.30	14.43	11.74	8.80	7.15
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
ε_x (without IBS)	nm	1.97	1.82	1.00	0.91	1.97	1.82	1.97	1.82
ε_x (with IBS)	nm	2.00	2.46	1.00	1.23	2.00	2.46	5.20	6.4
ε_y	pm	5	6.15	2.5	3.075	10	12.3	13	16
σ_x @ IP	μm	7.211	8.872	5.099	6.274	10.060	12.370	18.749	23.076
σ_y @ IP	μm	0.036	0.036	0.021	0.021	0.054	0.054	0.092	0.092
Σ_x	μm	11.433		8.085		15.944		29.732	
Σ_y	μm	0.050		0.030		0.076		0.131	
σ_L (0 current)	mm	4.69	4.29	4.73	4.34	4.03	3.65	4.75	4.36
σ_L (full current)	mm	5	5	5	5	4.4	4.4	5	5
Beam current	mA	1892	2447	1460	1888	3094	4000	1365	1766
Buckets distance	#	2		2		1		1	
Ion gap	%	2		2		2		2	
RF frequency	Hz	4.76E+08		4.76E+08		4.76E+08		4.76E+08	
Harmonic number		1998		1998		1998		1998	
Number of bunches		978		978		1956		1956	
N. Particle/bunch		5.08E+10	6.56E+10	3.92E+10	5.06E+10	4.15E+10	5.36E+10	1.83E+10	2.37E+10
Tune shift x		0.0021	0.0033	0.0017	0.0025	0.0044	0.0067	0.0052	0.0080
Tune shift y		0.0970	0.0971	0.0891	0.0892	0.0684	0.0687	0.0909	0.0910
Long. damping time	msec	13.4	20.3	13.4	20.3	13.4	20.3	26.8	40.6
Energy Loss/turn	MeV	2.11	0.865	2.11	0.865	2.11	0.865	0.4	0.166
σ_E (full current)	dE/E	6.43E-04	7.34E-04	6.43E-04	7.34E-04	6.43E-04	7.34E-04	6.94E-04	7.34E-04
CM σ_E	dE/E	5.00E-04		5.00E-04		5.00E-04		5.26E-04	
Total lifetime	min	4.23	4.48	3.05	3.00	7.08	7.73	11.41	6.79
Total RF Power	MW	17.08		12.72		30.48		3.11	

Tau/charm threshold running at 10^{35}

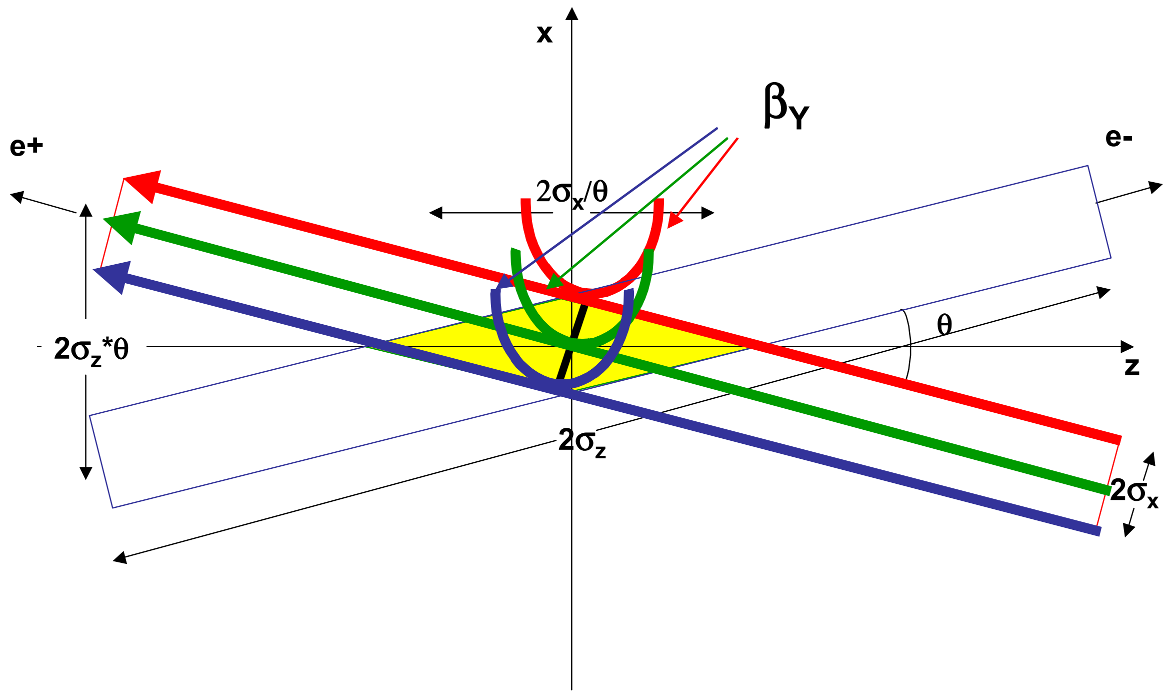
Baseline + other 2 options:
- Lower y-emittance
- Higher currents (twice bunches)

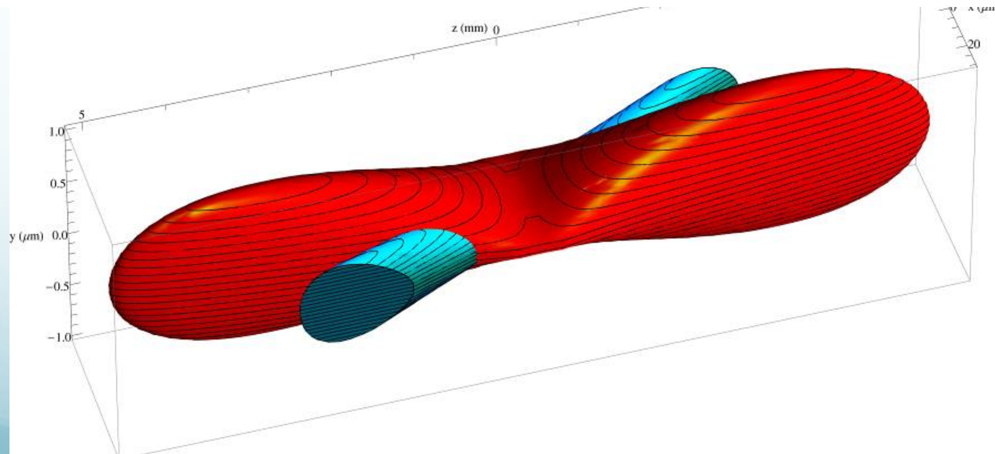
Baseline:
- Higher emittance due to IBS
- Asymmetric beam currents

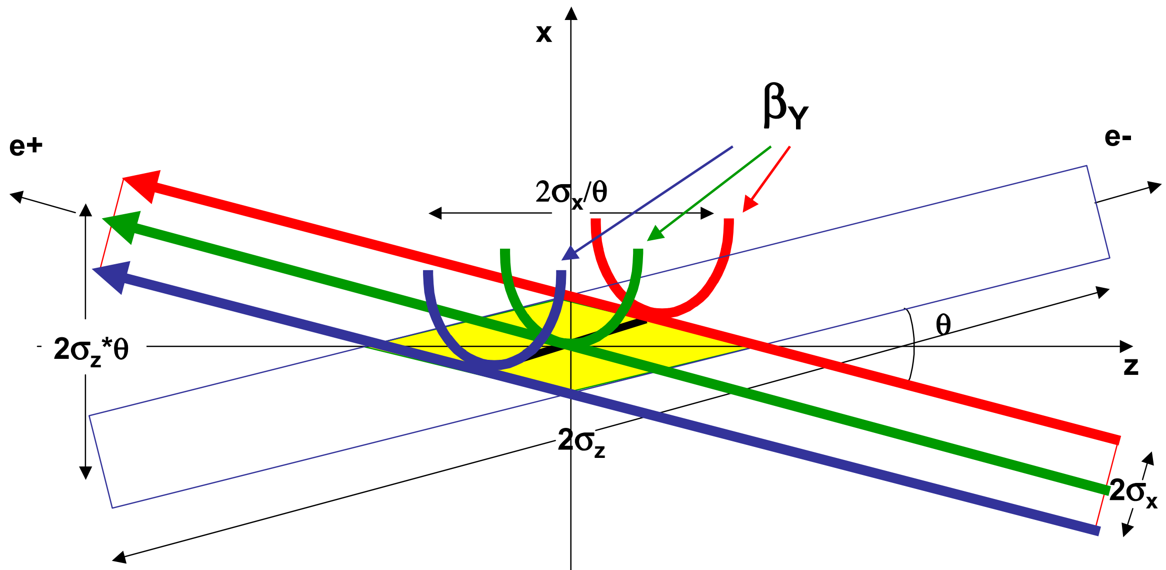
RF power includes SR and HOM

Presented at SuperB WS in Mar., 2010

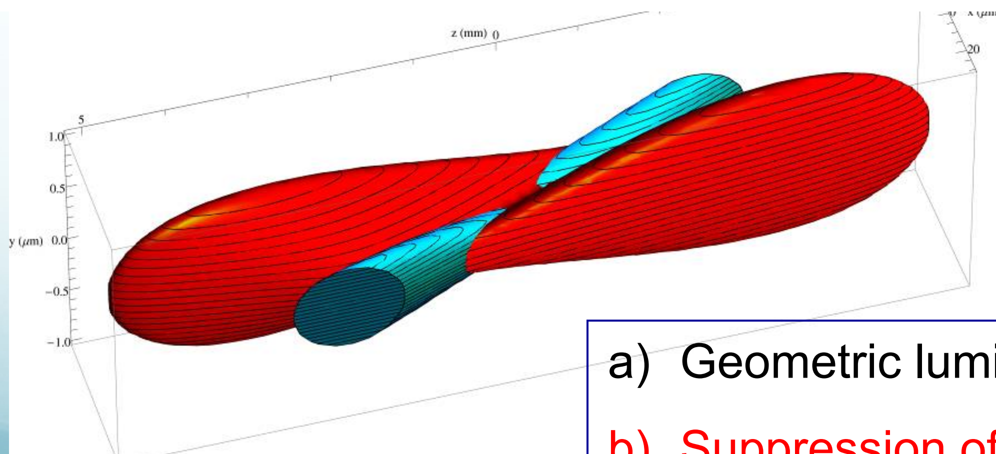
Collision scheme with large crossing angle & crab waist


x
βY
e+
e-
2σx/θ
2σz*θ
θ
z
2σz
2σx


z (mm)
y (μm)



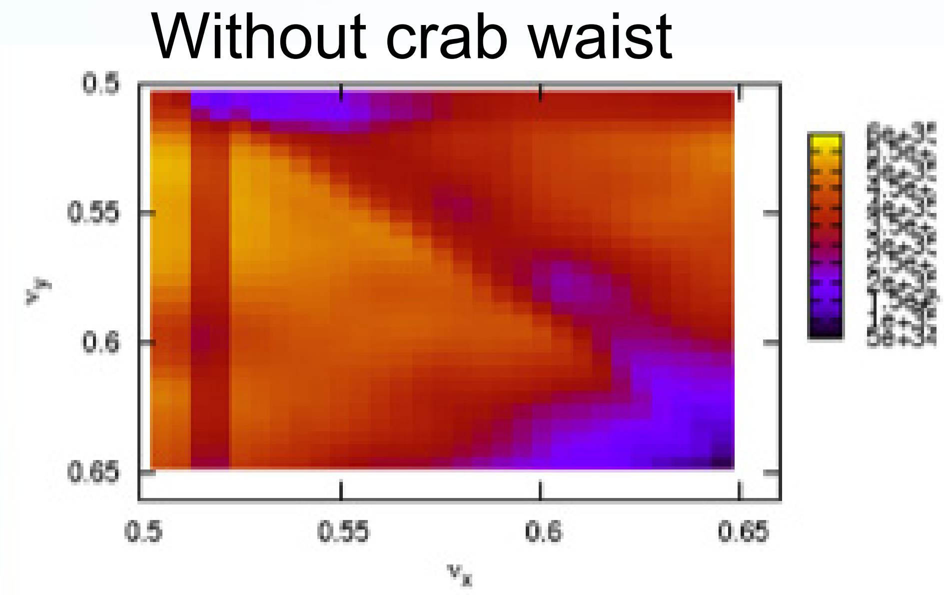
All particles from both beams collide in the minimum β_y region, with a net luminosity gain

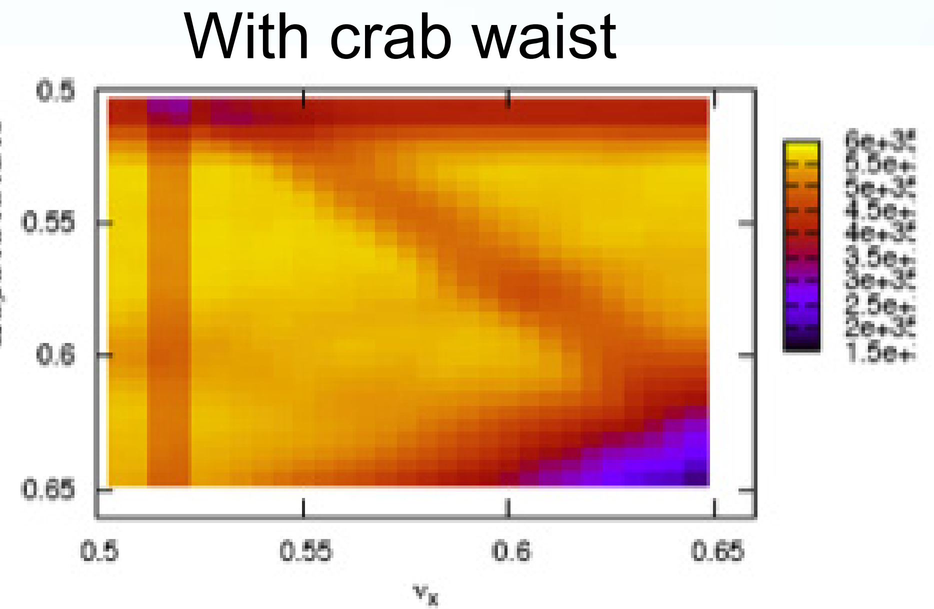


a) Geometric luminosity gain

b) Suppression of X-Y betatron and synchro-betatron resonances

Beam-Beam simulation tune scan

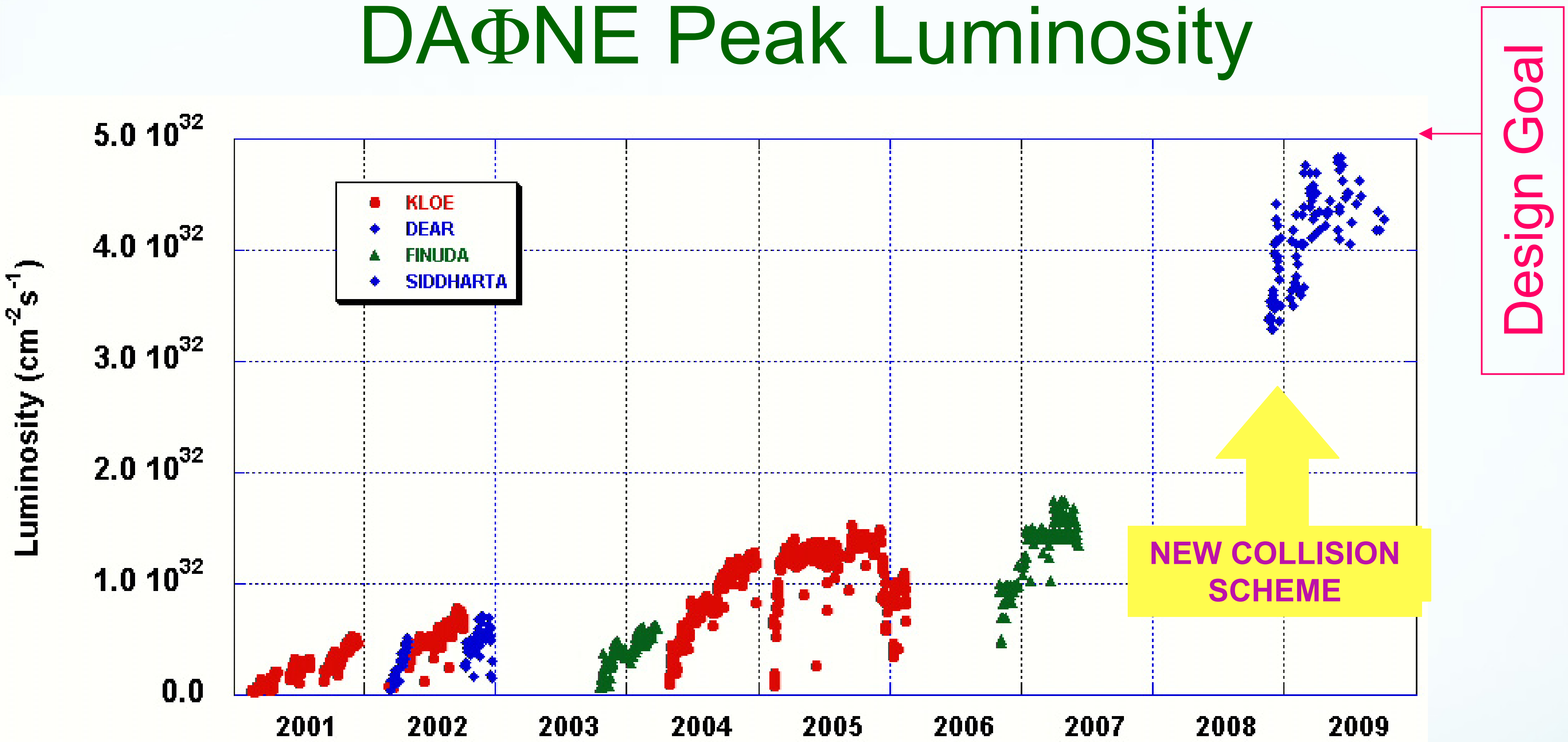


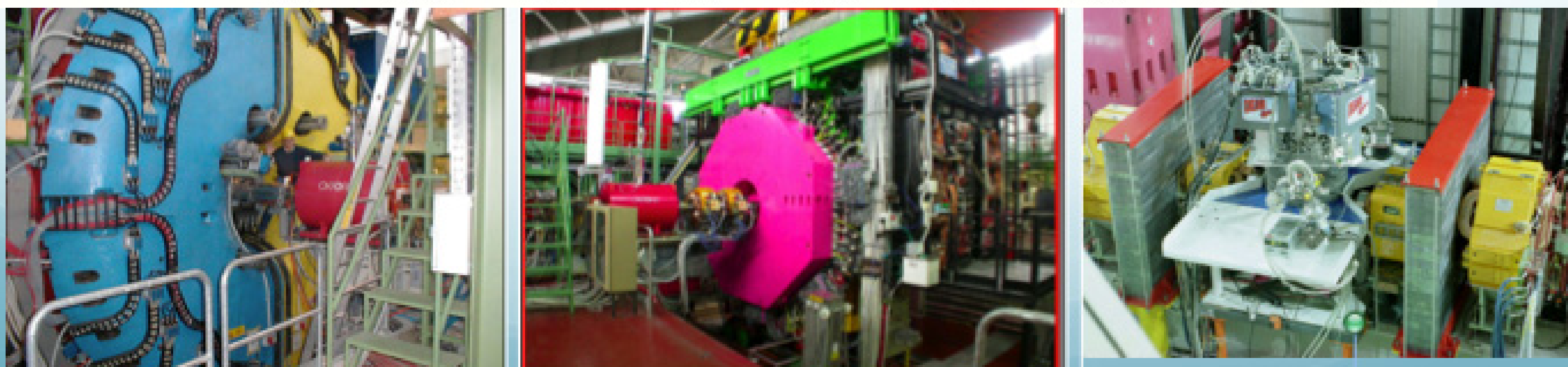


Crab waist gives
Higher luminosity &
suppression of X-Y betatron and synchro-betatron resonances.
A clear suppression of "ν_x-ν_y = integer" line is seen in this simulation with a certain set of parameters for SuperKEKB.

K.Ohmi at SuperB Workshop, March.2010

DAΦNE Peak Luminosity





P. Raimondi at SuperB WS, Dec. 2009

DAΦNE Test Results Conclusions

- Large Piwinski Angle & Crab Waist work well
- Crab waist sextupoles are of great importance for the collider luminosity increase
- DAΦNE scientific program has been approved for the next 3 years with the KLOE detector.

Polarized LER (e-)

requirement from physics

Polarized electrons in the LER.

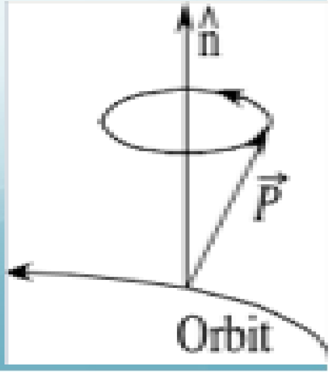
- Spin rotators are easier to accommodate.
- Spin depolarization time in the LER is longer.

e- gun

- SLAC has a long and rich experience with polarized e- guns.
  SLC, etc.

Spin rotator

- Polarized beam in the ring is vertical but needs to be longitudinal at the IP.



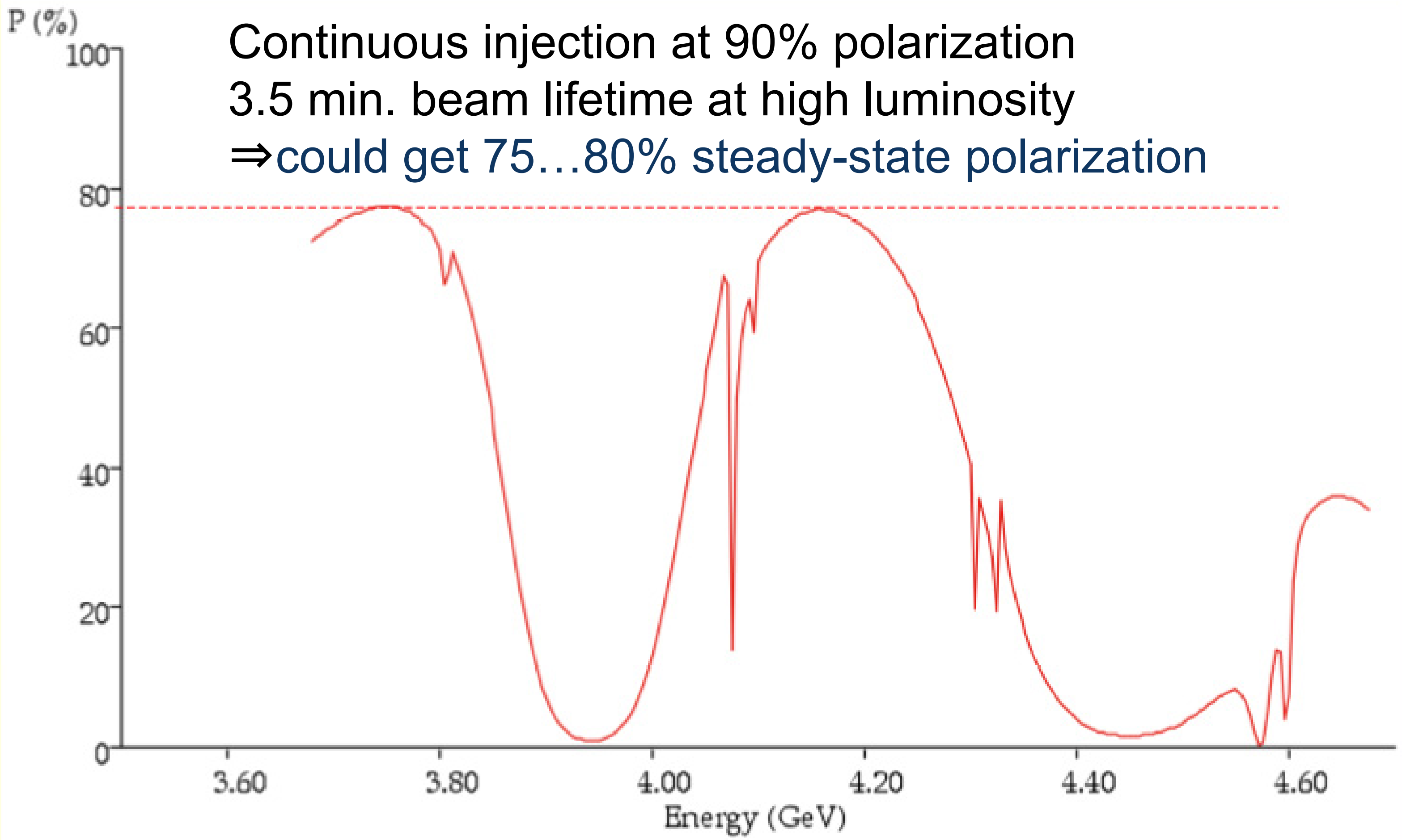
Mini-MAC PARAMETER REQUIREMENTS FROM PHYSICS

Parameter	Requirement	Comment
Luminosity (top-up mode)	10^{36} cm^{-2}s^{-1} @ $\Upsilon(4S)$	
Integrated luminosity	75 ab^{-1}	Based on a "New Snowmass Year" of 1.5 x 10^{7} seconds (PEP-II experience-based)
CM energy range	From just below charm ≈τ threshold to $\Upsilon(5S)$	For a better study of CP violation in Charm and for B_S measurements.
Minimum boost	$\beta\gamma$= 0.28 (4x7 GeV)	1 cm beampipe radius. First measurement at 1.5 cm
e^- Polarization	60-85%	Enables τ *CP* and *T* violation studies, measurement of τ *g*-2 and improves sensitivity to lepton flavor-violating decays. Detailed simulation, needed to ascertain a more precise requirement, are in progress.

Polarization (P_{inj} = 90%)

Jly-09 lattice, SLICK

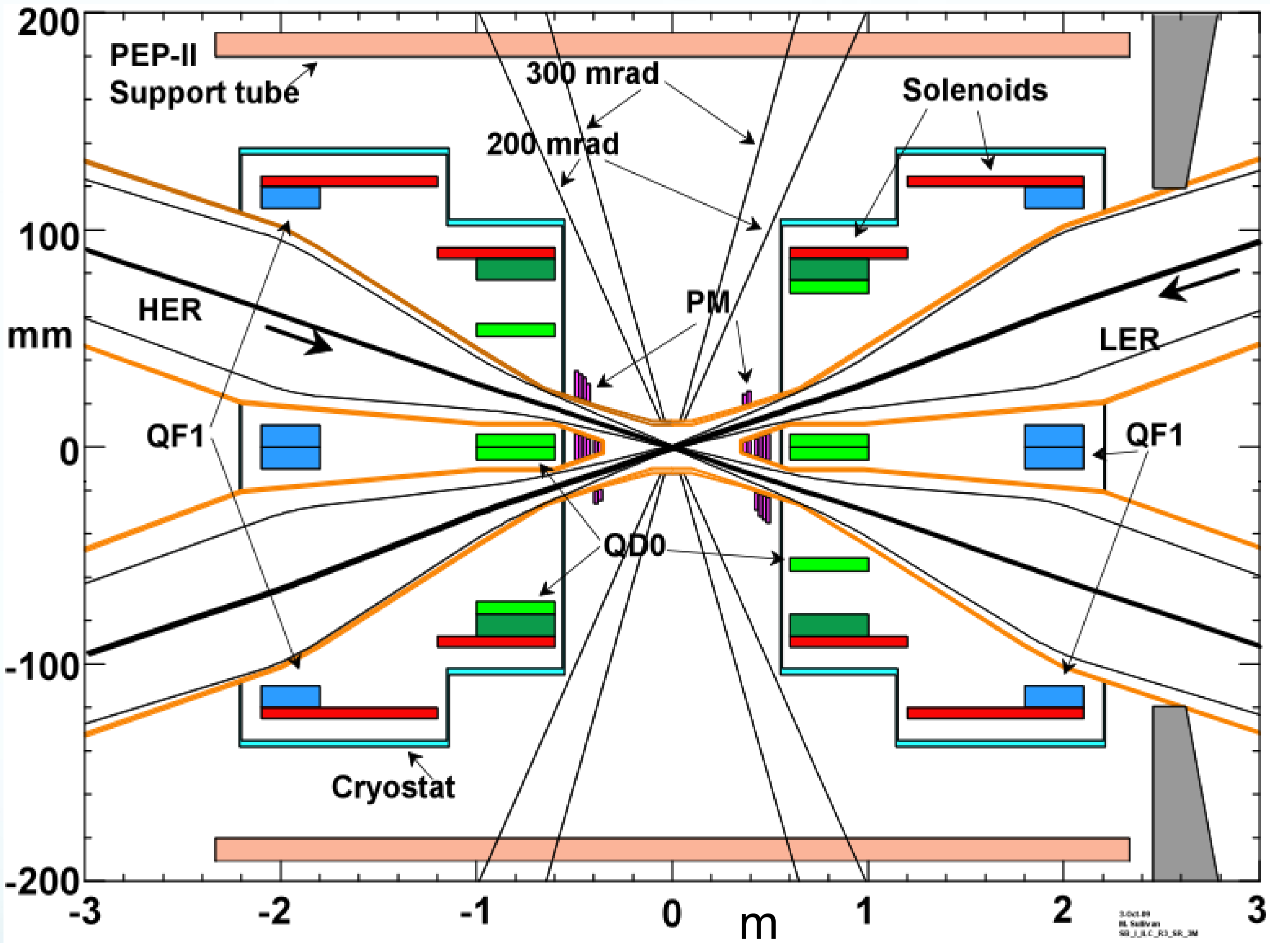
Continuous injection at 90% polarization
3.5 min. beam lifetime at high luminosity
⇒could get 75…80% steady-state polarization



The Interaction Region

- The interaction region design has to accommodate the machine needs as well as the detector requirements
  - Final focus elements as close to the IP as possible
  - As small a detector beam pipe as backgrounds allow
  - As thin as possible detector beam pipe
  - Adequate beam-stay-clear for the machine
    - Low emittance beams helps here
  - Synchrotron radiation backgrounds under control
  - Adequate solid angle acceptance for the detector
  - Twin bore IR quadrupoles

Baseline IR design

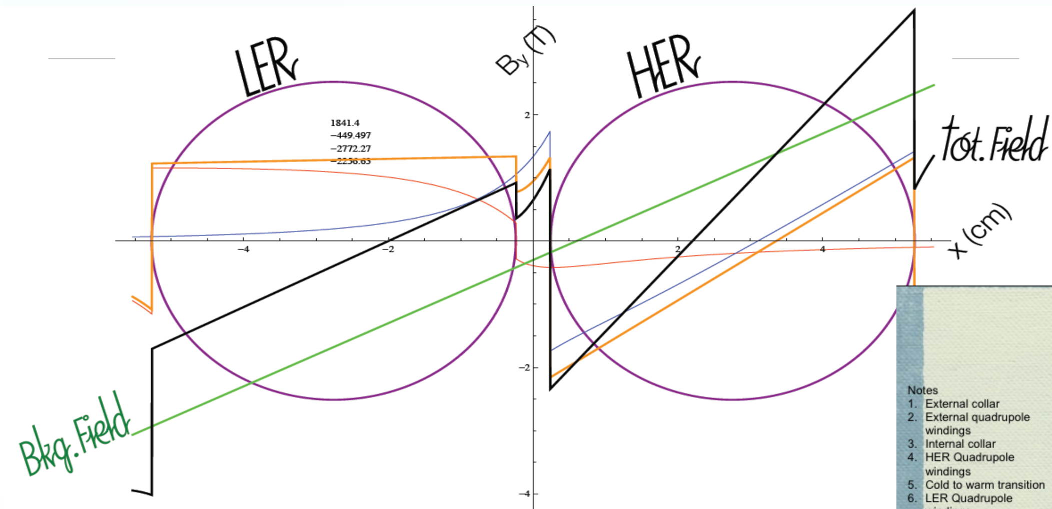


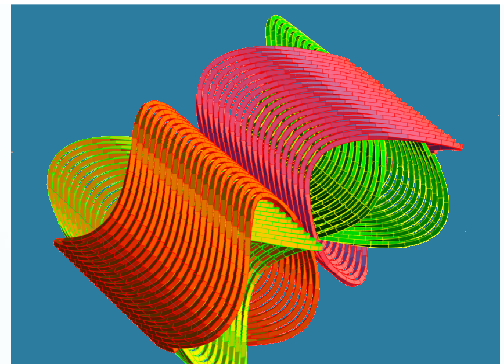
Crossing angle ± 33 mrad
QD0 & QF1 Superconducting magnets
Cryostat has a warm bore
Permanent magnet in front of QD0

M. Sullivan et al.

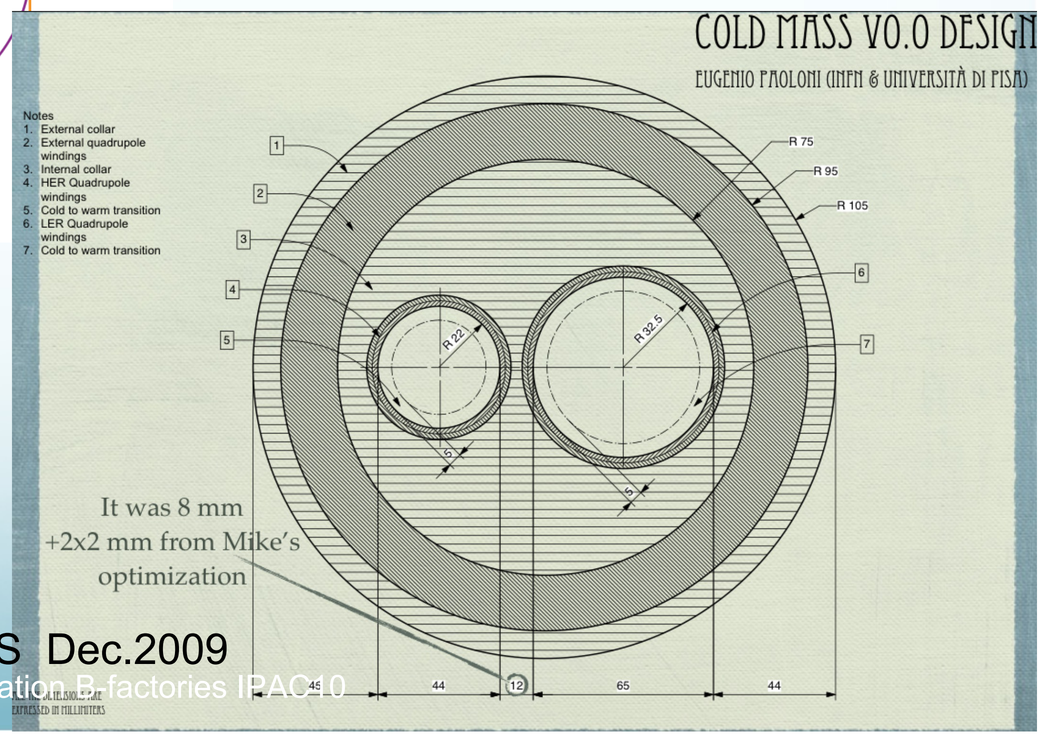
R&D on twin bore superconducting Quadrupoles (QD0) at the IP

Total field in black



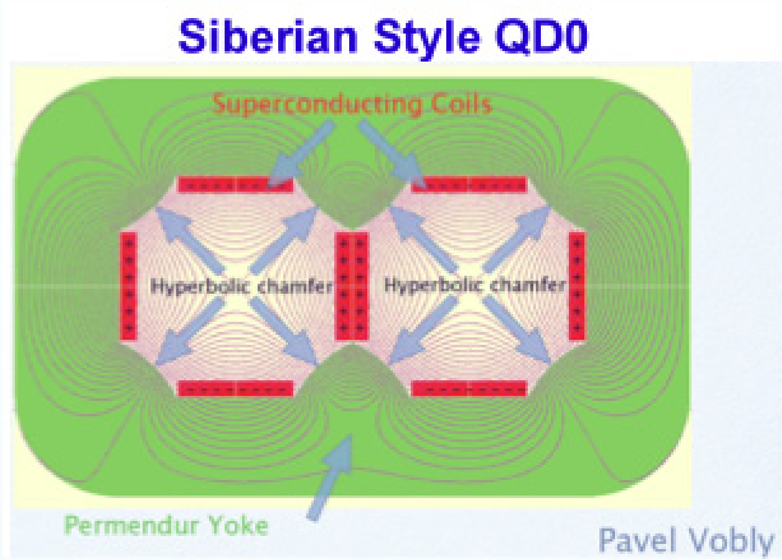


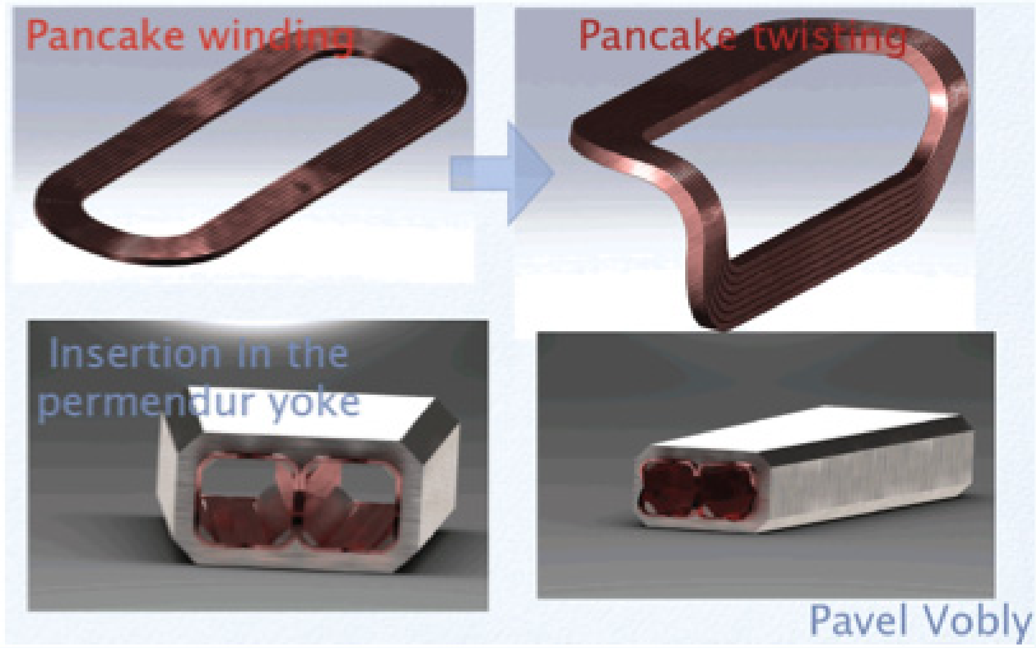
Coils array



E. Paoloni (Pisa),S. Bettoni (CERN) SuperB WS Dec.2009

Alternative QD0: Super-ferric QD0 DESIGN





The iron yokes mean the maximum B field in the magnet iron can not exceed 2T

The initial suggested design used cold beam pipes (80K) which we can not do because of SR fans from the last soft bend but we can try to increase the space for these magnets so a warm bore works

The magnetic field gradients have to be the same value for the LER and HER and the aperture is square

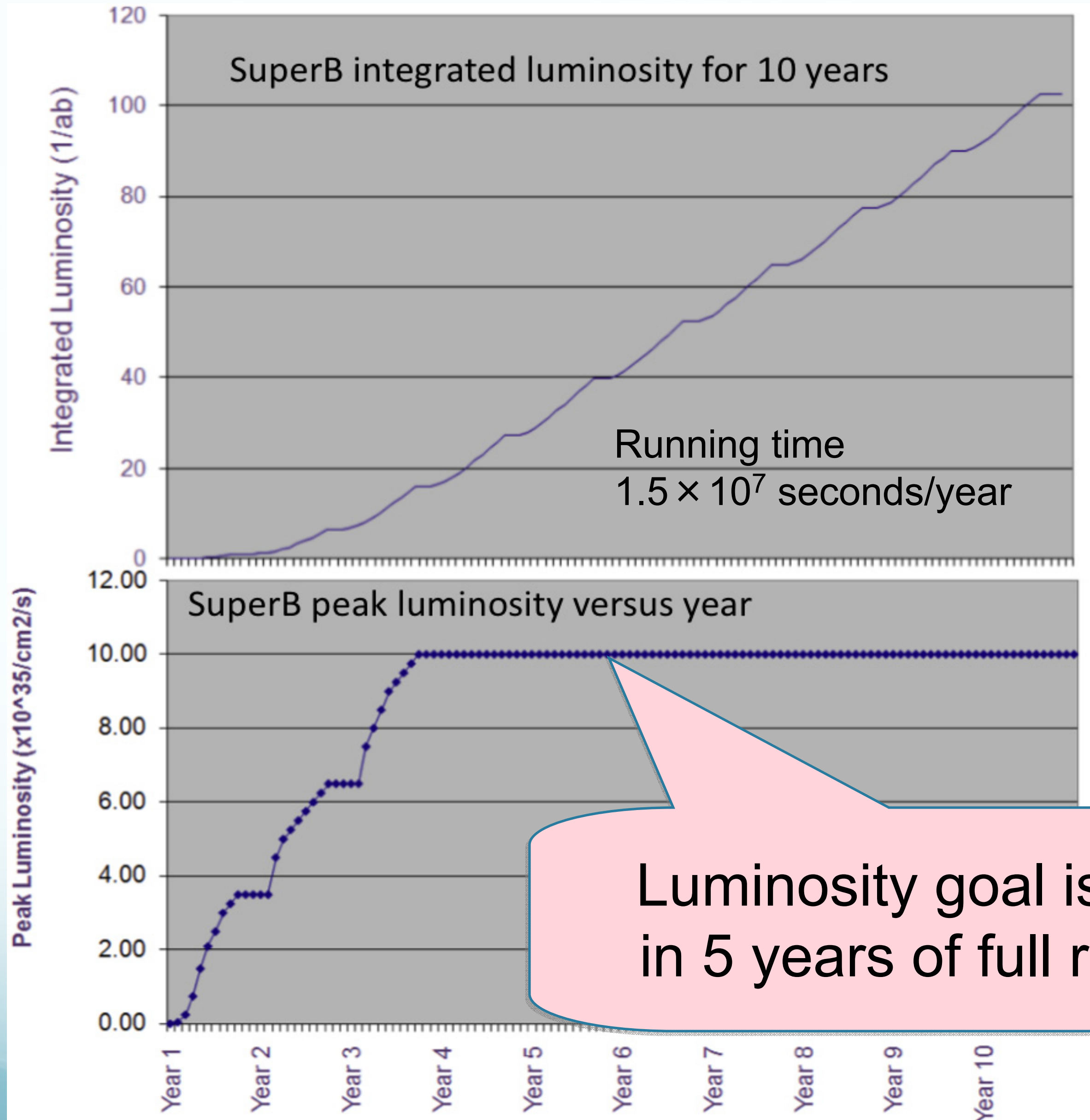
There are several advantages to being able to use this design and work has started on developing an IR design using these magnets

SuperB Status (March 2010)

- Accelerator design is converging with all aspects starting to look feasible.
- Lattice and parameter optimization is continuing for better performance and with added flexibility.
- More subtle beam dynamics issues are being studied (e.g. IBS, FII, emittance diffusion, beam-beam effects, feedbacks).
- Component and lattice tolerances with corrections are being studied.
- Polarization is progressing: beam-beam depolarization, trying to simplify the polarized gun, spin measurements.

J. Seeman Summary at SuperB Workshop, March 2010

Luminosity projection



Luminosity goal is 75 /ab in 5 years of full running.

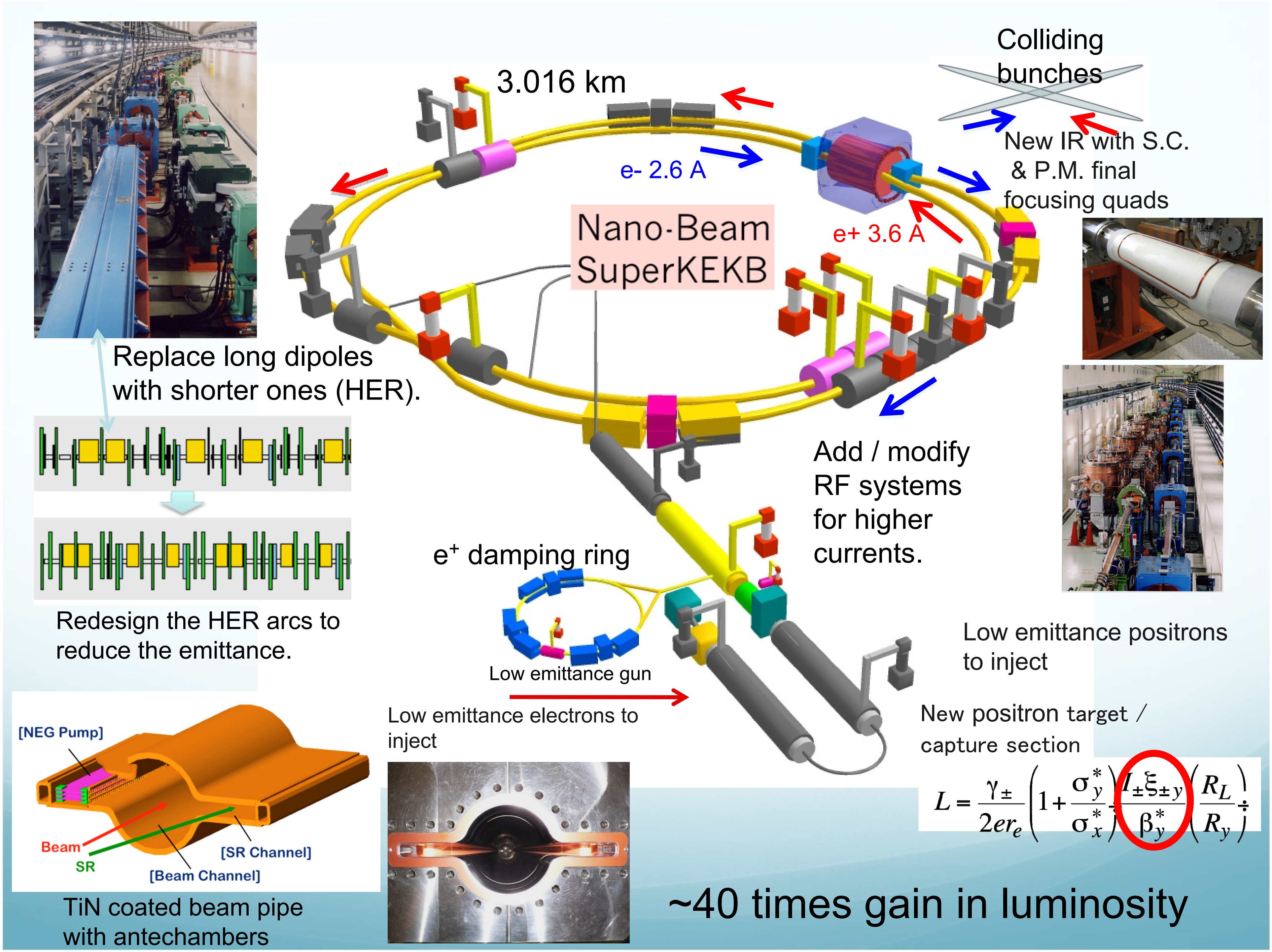
M. Biagini

Introduction to SuperKEKB

SuperKEKB Project

- The KEKB B-Factory will be upgraded to SuperKEKB using the same tunnel as KEKB. The upgrade is based on the “Nano-Beam” scheme, which was first proposed for the Super B factory in Italy.
- Squeeze β_y^* to be as small as possible: 0.27/0.41 mm (LER/HER).
- Assume beam-beam parameter = 0.09, which has already been achieved at KEKB.
- Change beam energies 3.5 / 8 (KEKB)⇒ 4 /7 GeV to achieve longer Touschek lifetime and mitigate the effect of intra-beam scattering in LER. Also it helps lowering the emittance in the HER.
- Try to reuse the KEKB components as much as possible.

From BELLE-II TDR



Colliding bunches
3.016 km
e- 2.6 A
e+ 3.6 A
New IR with S.C. & P.M. final focusing quads
Nano-Beam SuperKEKB
Replace long dipoles with shorter ones (HER).
Redesign the HER arcs to reduce the emittance.
Add / modify RF systems for higher currents.
e+ damping ring
Low emittance gun
Low emittance positrons to inject
Low emittance electrons to inject
New positron target / capture section
[NEG Pump]
Beam
SR
[SR Channel]
[Beam Channel]
TiN coated beam pipe with antechambers
$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm\xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$
~40 times gain in luminosity

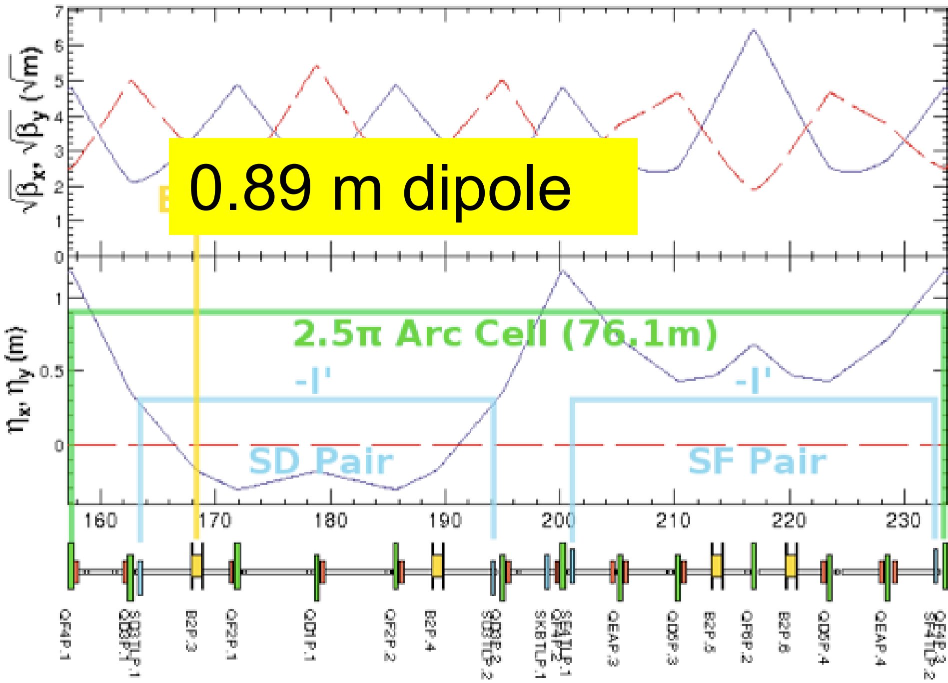
SuperKEKB parameters compared with SuperB

		SuperB (Baseline)		SuperKEKB	
Parameter	units	HER (e+)	LER (e-)	HER (e-)	LER (e+)
Circumference	m	1258.4		3016.3	
Energy	GeV	6.7	4.18	7	4
X angle (full)	mrad	66		83	
β_x at IP	cm	2.6	3.2	2.4	3.2
β_y at IP	cm	0.0252	0.0206	0.041	0.027
ε_x	nm	2.0	2.41	2.4	3.1
Emittance ratio	%	0.25	0.25	0.35	0.40
σ_z (full)	mm	5	5	5	6
I	mA	1892	2410	2620	3600
σ_x at IP	µm	7.211	8.782	7.75	10.2
σ_y at IP	µm	0.035	0.035	0.059	0.059
ξ_x		0.0021	0.0033	0.0028	0.0028
ξ_y		0.0978	0.0978	0.0875	0.09
Luminosity	$cm^{-2}\ s^{-1}$	$1x10^{36}$		$0.8x10^{36}$	

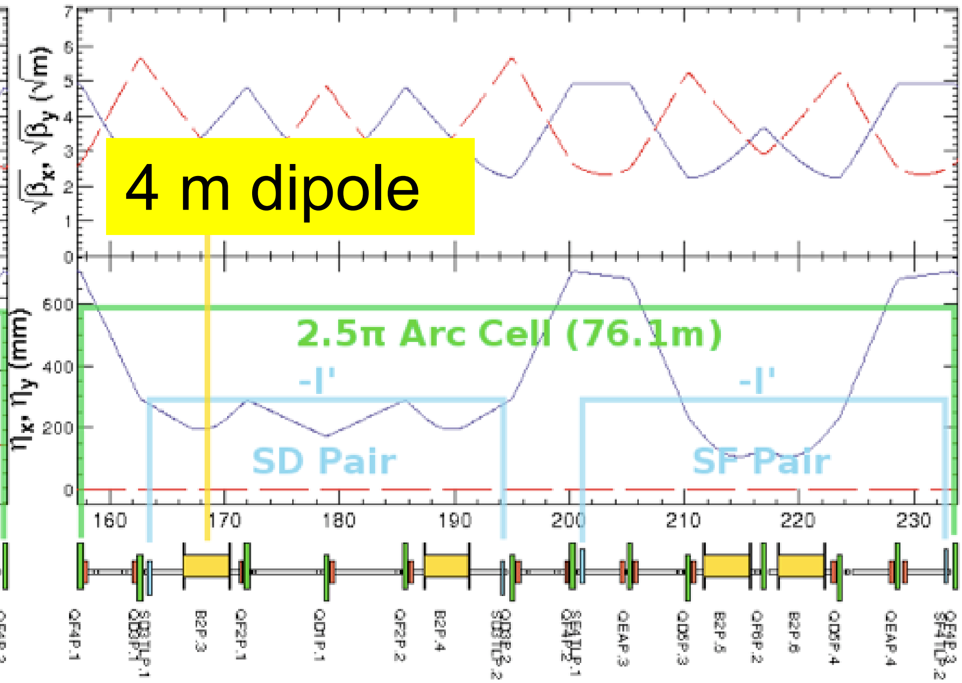
Major items to upgrade

- New Ante-chamber beam pipes for both rings:
  - 3 km x 2 in total.
  - Al/Cu for LER/HER.
  - Mitigation techniques for suppression of electron cloud.
- New IR optics.
  - New superconducting/permanent magnets around IP.
  - Optimization of the compensation solenoid.
- Additional normal magnets to reduce emittance.
  - Replace dipoles & change the wiggler layout for LER.
- New HER arc lattice
- More precise magnet setting ⇔ power supplies.
- Rearrangement of existing ARES cavities with additional power sources.
- Positron damping ring and new positron target.
- New RF gun for electrons with reduced emittance.

Achieving low emittance with minimum change



KEKB LER

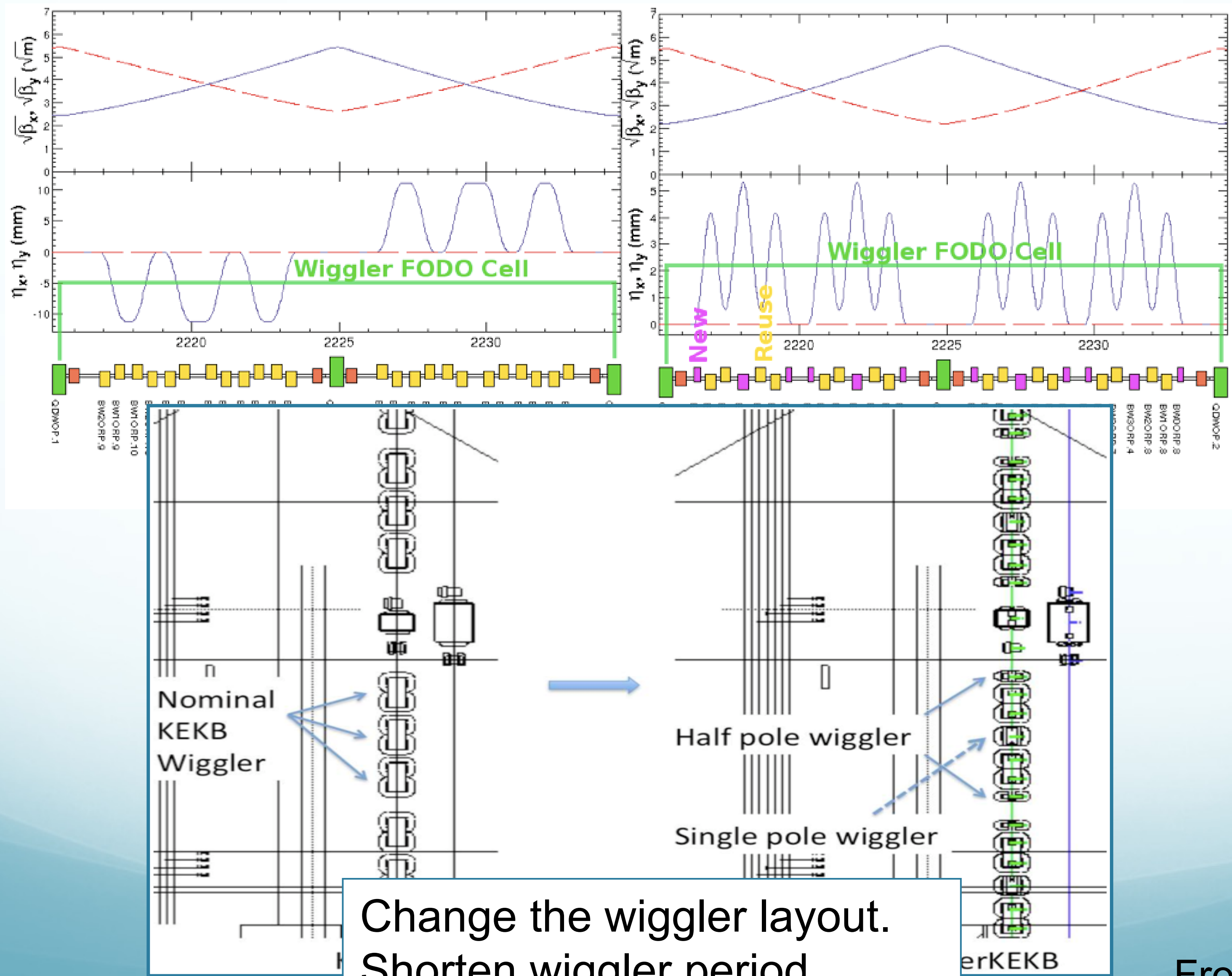


SuperKEKB LER

Replacing ~100 dipole magnets in the arc sections from 0.89 m to 4 m dipoles.

From BELLE-II TDR

Achieving low emittance with minimum change

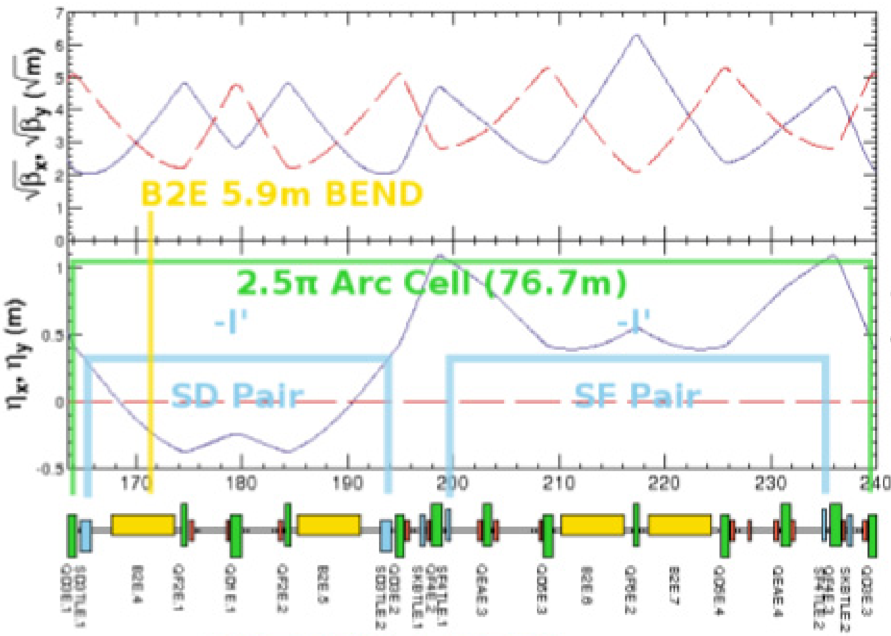


Change the wiggler layout.
Shorten wiggler period.

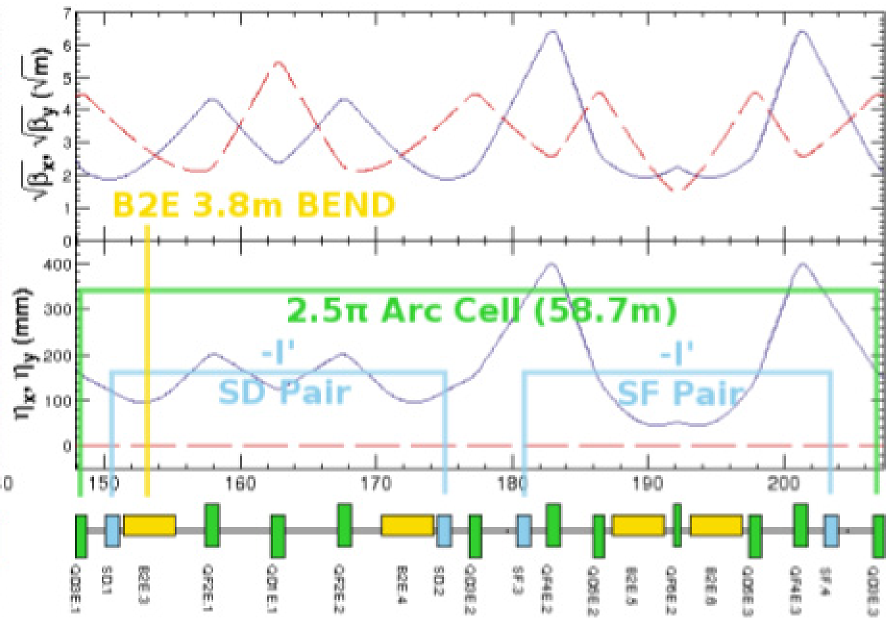
From BELLE-II TDR

Achieving low emittance with minimum change

HER Arc Cell Changes



KEKB HER

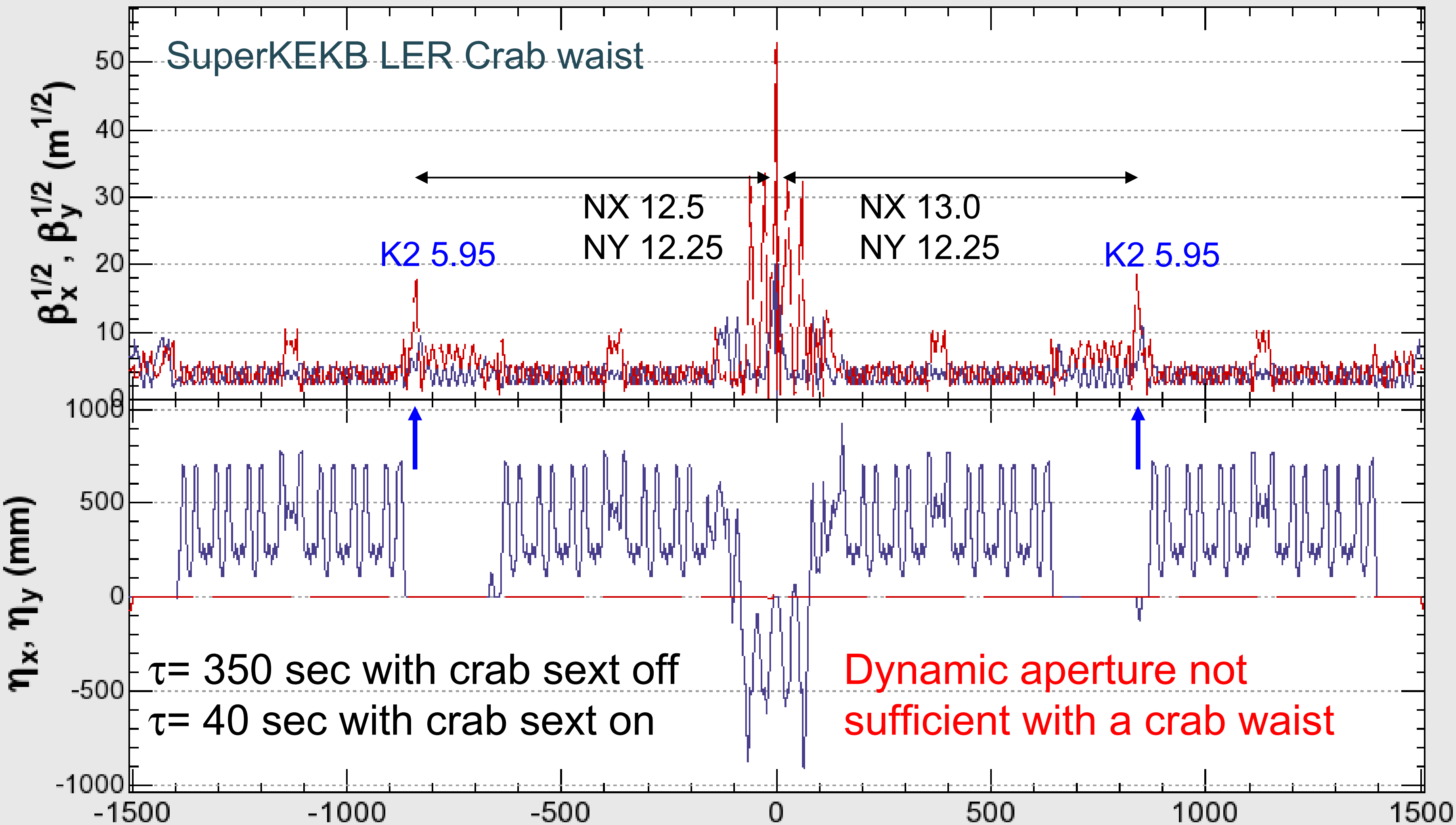


SuperKEKB HER

The number of cells for 1/4 arc section is increased from 6.5 to 8.5 to make the horizontal dispersion smaller in order to reduce the emittance, replacing the main dipole magnets of 5.9 m with ones 3.8 m long.

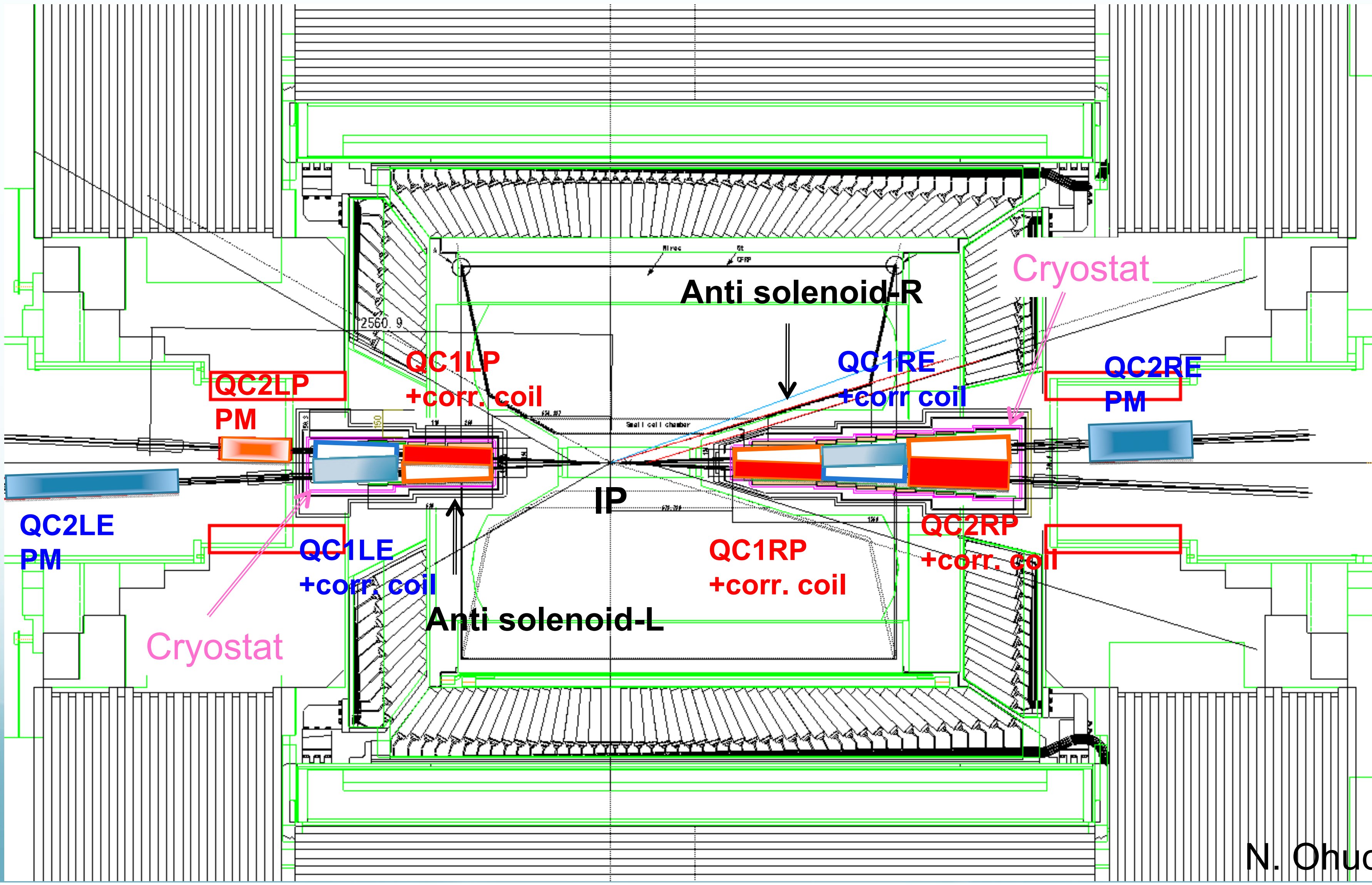
From BELLE-II TDR

Crab waist scheme for SuperKEKB



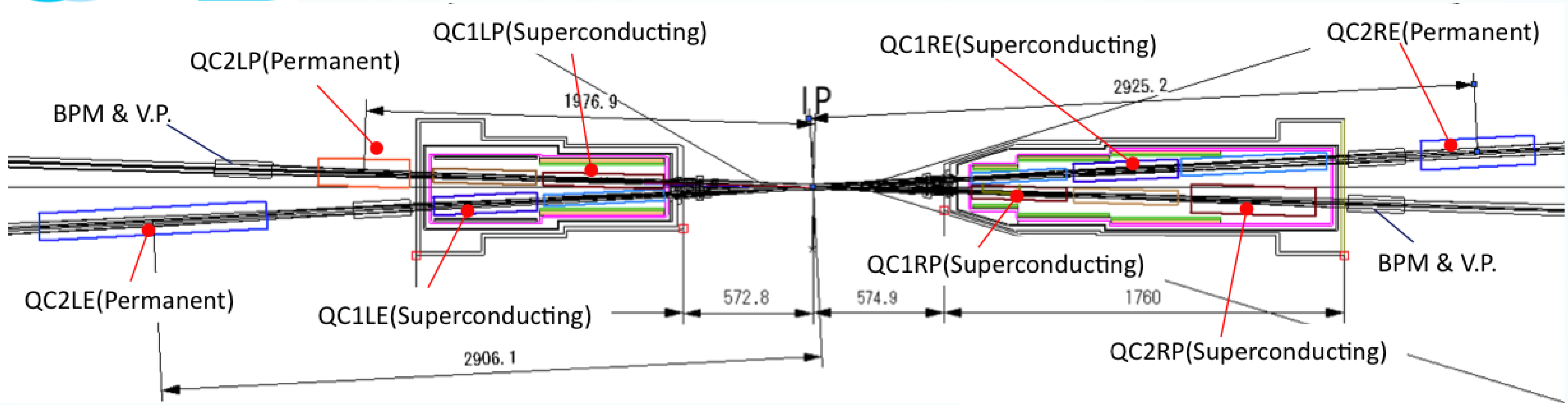
H. Koiso Apr. 2010

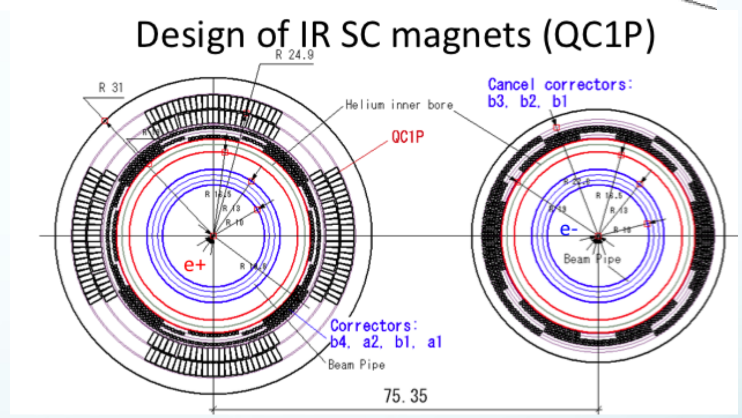
IR design with superconducting & permanent magnets



N. Ohuchi

IR design





Superconducting magnets

- Leakage fields of superconducting magnets are canceled by correction windings on the other beam pipe
- Warm bore

Permanent magnets

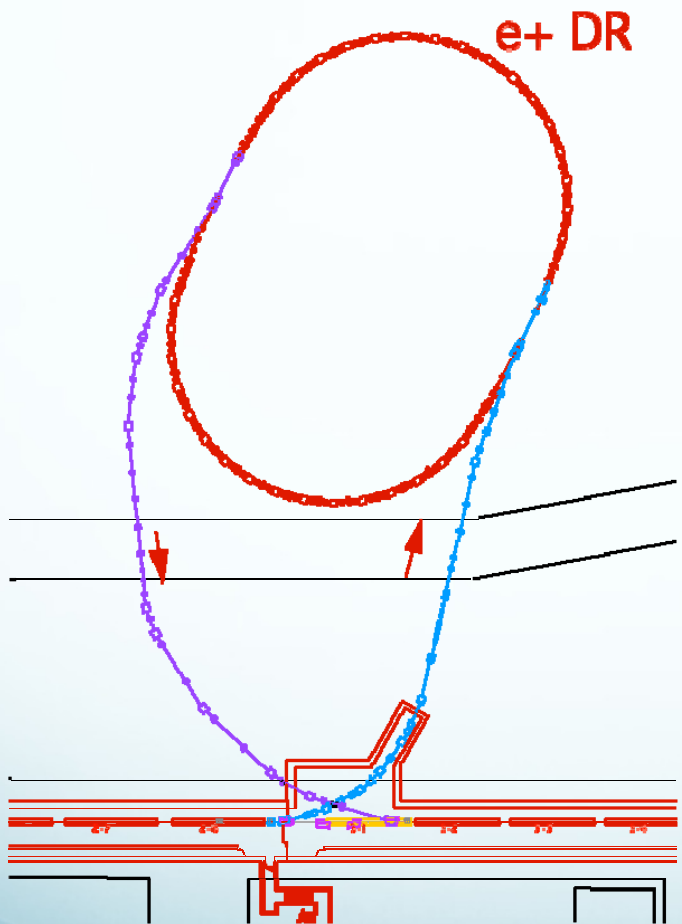
- Cryostats can be made smaller
- Assembly of vacuum chamber can be simpler
- Vacuum pumps can be located nearer IP
- R&D work needed for developing permanent magnets
- Temperature dependence
- Tunability (an additional magnet is needed when changing the energy)

 BELLE-II TDR N.Ohuchi, M.Tawada

Damping ring

- The injected beam should have very low emittance because of poor dynamic aperture of the main rings
- We have decided to construct a damping ring for positron beam and a low emittance RF-gun for electrons.

Positron Damping Ring



Energy	1.1		GeV
Number of bunch trains	2		
Number of bunches / train	2		
Circumference	135.50207		m
Maximum stored current	70.8		mA
Energy loss per turn	0.091		MV
Horizontal damping time	10.87		ms
Injected-beam emittance	1700		nm
Equilibrium emittance (h/v)	41.4 / 2.07		nm
Coupling	5		%
Emittance at extraction (h/v)	42.5 / 3.15		nm
Cavity voltage	0.5	1.0	MV
Bucket height	0.81	1.24	%
Energy spread	5.5×10^{-4}		
Synchrotron tune	0.0152	0.0216	
Equilibrium bunch-length	11.01	7.74	mm
Threshold due to CSR	9.51	8.46	nC / bunch
Phase advance/cell (h/v)	64.39 / 64.64		deg
Momentum compaction factor	0.0141		
Bend-angle ratio	0.35		
Number of normal-cells	40		
RF frequency	509		MHz
Chamber diameter(normal cell)	34		mm

Electron cloud will be mitigated by TiN coating and solenoid windings.
Founded for some components such as magnets.

Vacuum challenges

Higher beam currents
(a factor of 2 larger than KEKB)

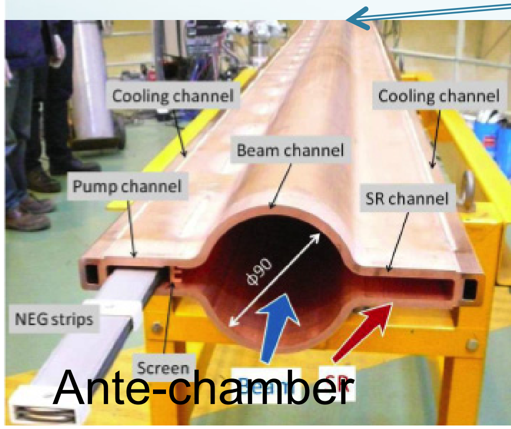
Higher bunch current
Short bunch length
(though the same as KEKB)

Synchrotron Radiation power
Higher photon density
Higher heat & gas load

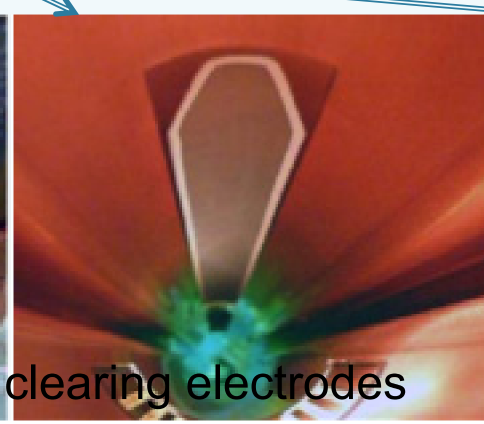
Higher Oder Mode
(HOM) heating

Electron cloud instability, heating of components, etc.

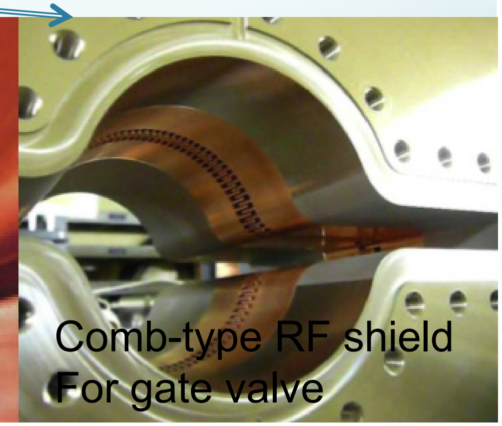
Damaged RF finger



Ante-chamber



Ante-chamber with clearing electrodes

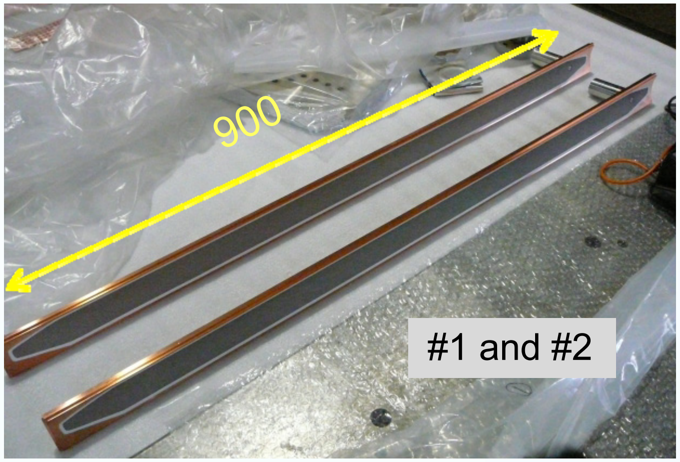


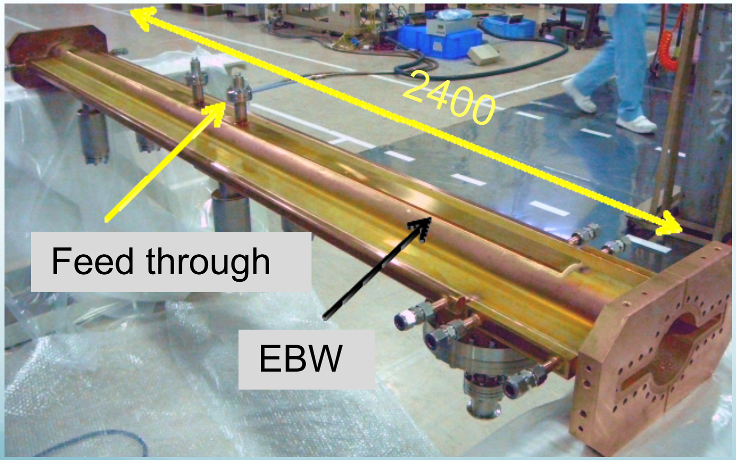
Comb-type RF shield
For gate valve

Application to a beam pipe with antechamber

- Final check of heating of electrode and feed through [2009]
  - Beam pipe with antechamber will be used for the wiggler section of SuperKEKB.

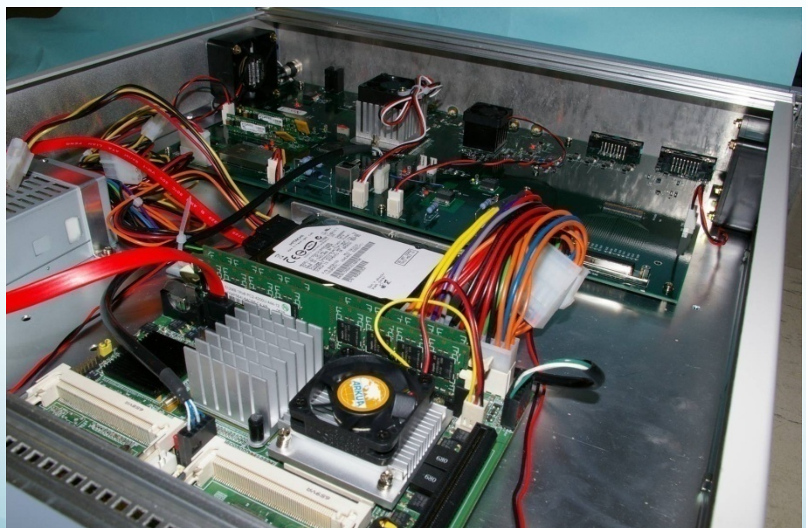
- The beam pipe was installed at a magnetic field-free region.
  - But the length was adjusted to fit the real wiggler magnet.
  - Length = 950 mm, width = 32 mm.





Y. Suetsugu IPAC10 WEOAMH01

Bunch-by-bunch Feedback system

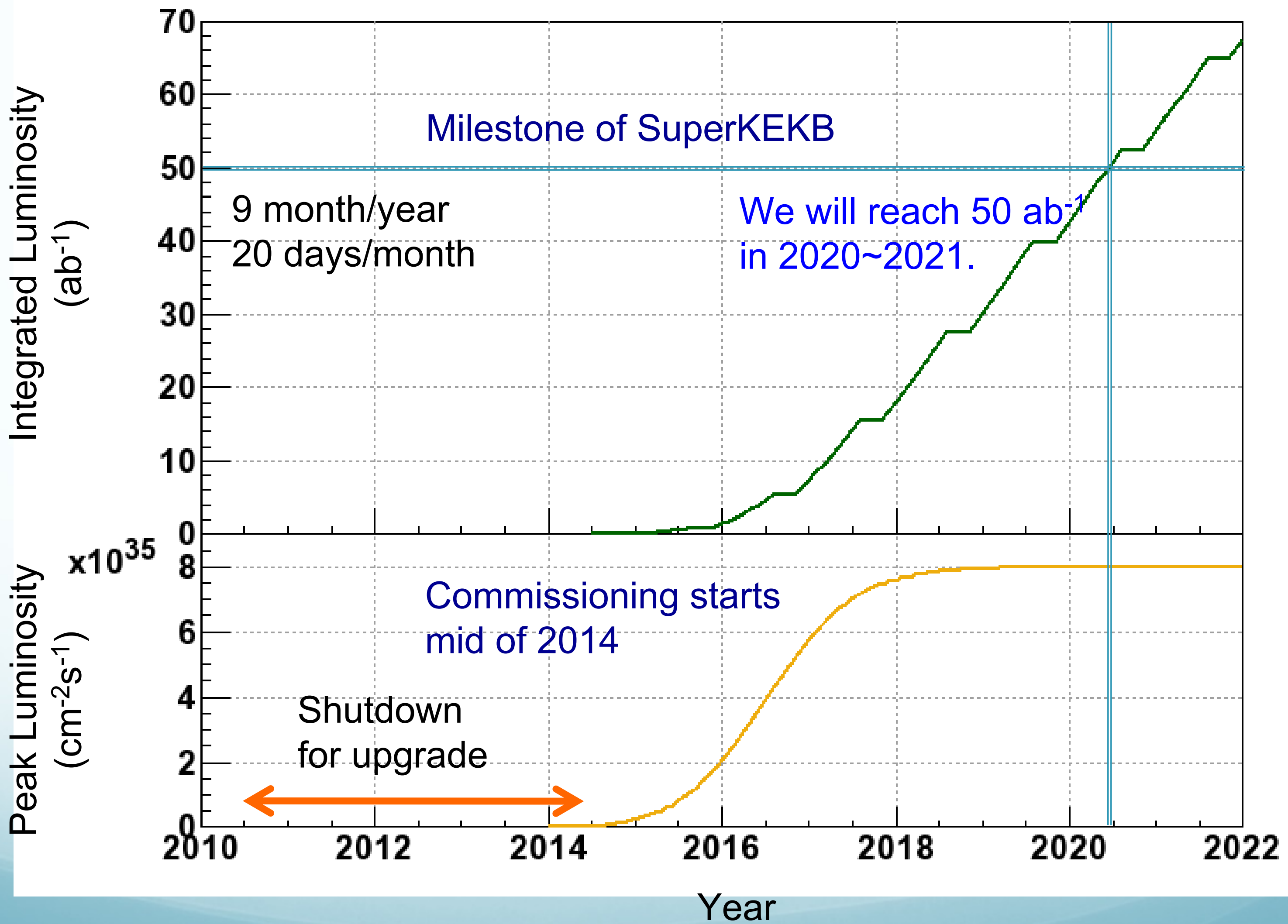


A new digital bunch-by-bunch feedback system (iGp) has been developed as a result of collaboration between SLAC, KEK and INFN, and successfully tested at KEKB, KEK ATF, KEK PF, SLAC, DAFNE and CesrTA.

SuperKEKB Status

- A decision to change the strategy from the high current scheme to the nano-beam scheme was made.
- Design work is making steady progress in that direction.
  - IR
  - Intensive feasibility study with simulations.
  - Efforts not to touch the arc sections of the rings.
    - We may have recently found a solution that permits us to keep the HER arc lattice as it is.
  - Reuse of the KEKB hardware as much as possible.
  - We have not found a solution for the SuperKEKB lattice that provides sufficient dynamic aperture with a crab waist.
- The R&D work originally for the high current scheme (Vacuum, RF, etc.) is still valid and indispensable with the new scheme as the current will be still a factor of 2 larger than KEKB. A good amount of work has been done.

Luminosity upgrade projection



Y. Ohnishi

Summary

- Physics requires next generation of B factories to achieve 40-50 times the present peak luminosity.
- SuperB and SuperKEKB are in advanced stages of design to meet these goals.
- Design have converged somewhat from different starting points, but still retain individual differences.
- The two machine groups are trading notes in an open manner.

To the success of both projects!

End

IPAC logo by Claudio Federici

Special thanks to SuperB colleagues for helping with this talk.

Crab Waist Advantages

1. Large Piwinski angle

$$F = tan(\theta)\sigma_z/\sigma_x$$

- a) Luminosity gain with N
- b) Very low horizontal tune shift

2. Vertical beta comparable with overlap area

$$\beta_y \approx \sigma_x/\theta$$

- a) Geometric luminosity gain
- b) Lower vertical tune shift
- c) Vertical tune shift decreases with oscillation amplitude
- d) Suppression of vertical synchro-betatron resonances

3. Crabbed waist transformation

$$y = xy'/(2\theta)$$

- a) Geometric luminosity gain
- b) Suppression of X-Y betatron and synchro-betatron resonances