SuperB and Super KEKB
The "Precision Frontier"

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I am indebted to M. Iwasaki and to M. Masuzawa, KEK, for providing me with material on Super KEKB

Outline

- Introduction
- The Crab Waist
- The SuperB proposals
- Conclusion

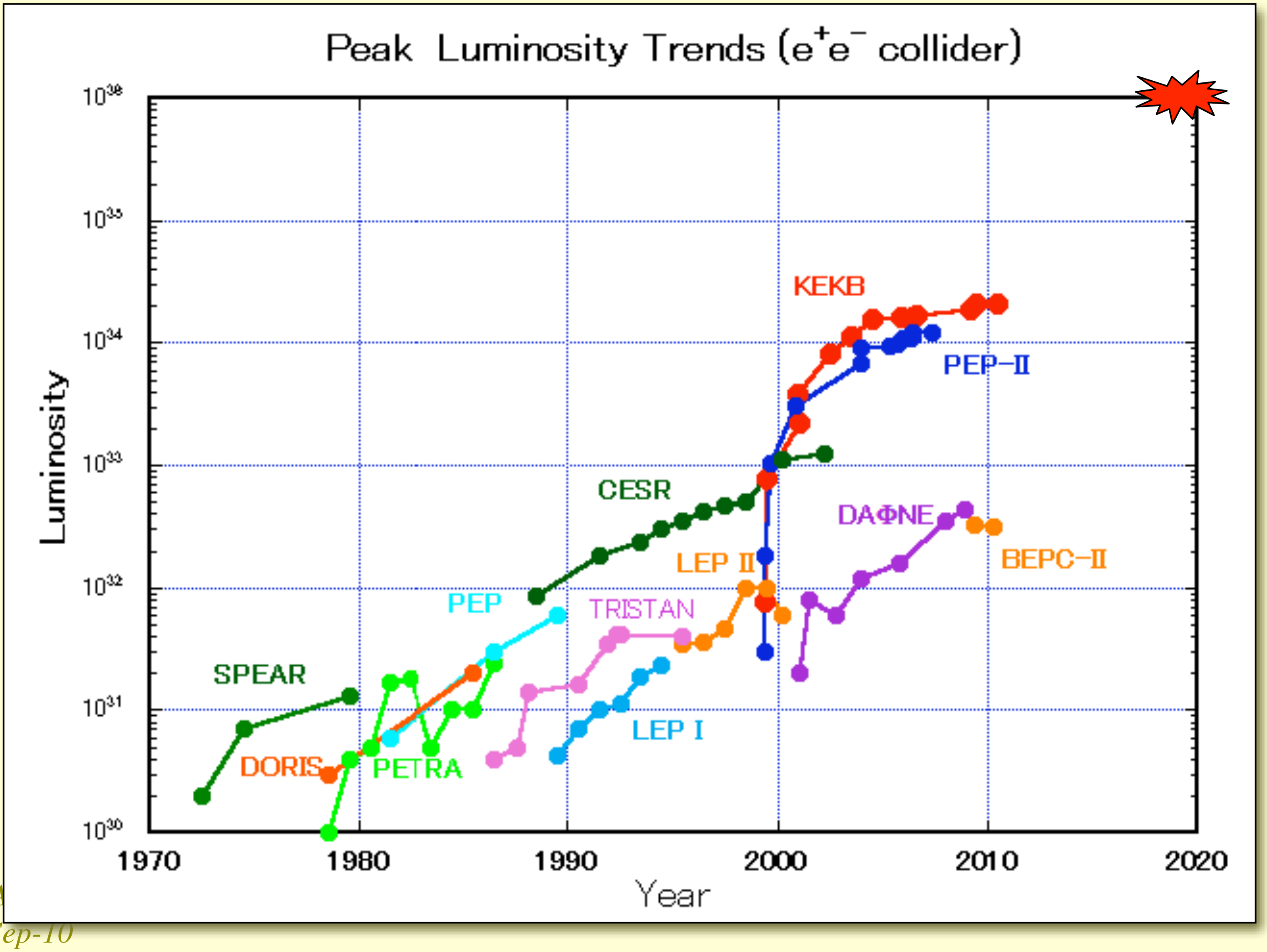
B-Factories: Success Story

- PEP-II: 1.2 $10^{34}/\mathrm{cm}^2/\mathrm{s}$, about 0.5 ab^{-1}
- KEKB: 2.1 $10^{34}/\mathrm{cm}^2/\mathrm{s}$, about 1 ab^{-1}
- PEP-II/BaBar together with KEKB-Belle:
  - Definitive measurement of sin(2β), solid foundation for CKM formalism
  - Exceeded their physics goals
  - Proved that multi-ampere beam currents can be handled
    - up to 3.2 A @ 3.1 GeV; 2 A @ 9 GeV in PEP-II
  - Proved that background is manageable
    - s.r. background as well as lost-particle background
  - Proved that high overall efficiency can be maintained
    - PEP-II/BaBar reached >85% up time

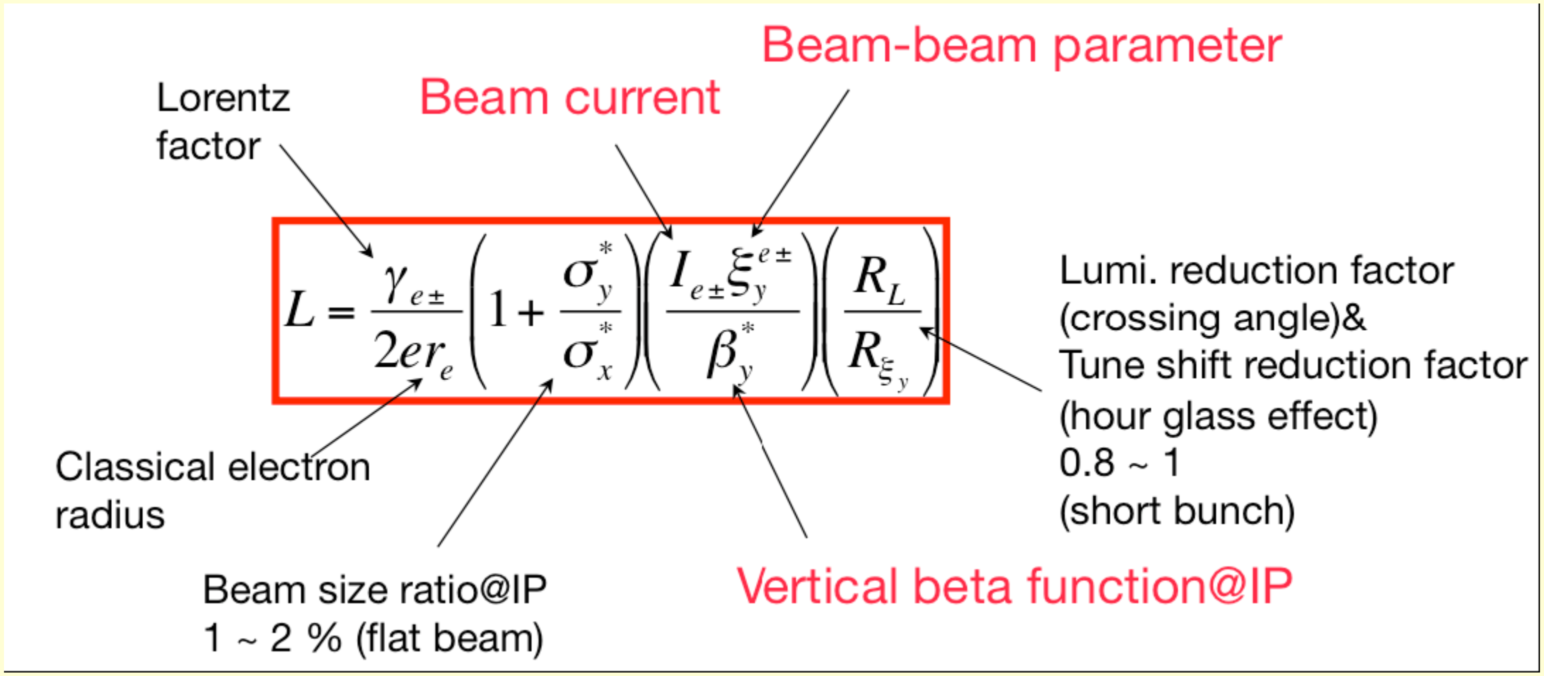
Super *B*-Factories

- A growing momentum has built up to expand on the program and push for new reach on the "precision frontier"
- This physics reach is possible with 50…100 ab^{-1} of data
- In order to gather such an amount in a reasonable time, a peak luminosity of $\approx 10^{36}\ \text{cm}^{-2}\text{s}^{-1}$ is necessary

$e^+ e^-$ Luminosity Trend



Luminosity Equation



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

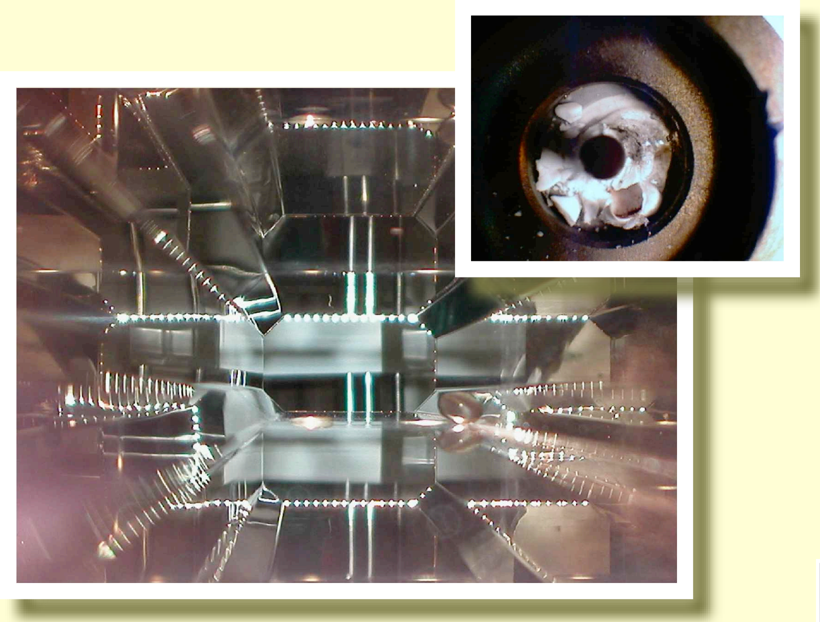
- It then follows that, for fixed beam-beam parameter ξ, one needs higher beam current and/or lower β_y*.

Strategies

- Head-on collisions (R_L=1): hourglass becomes important
  - $\sigma_l \geq 2$ mm
  - > $\beta^* \geq 2$ mm => need O(10) A beam current ☹
- Crossing angle (horizontal):
  - foreshortens the IP => ß* ≤ σ_l is possible
  - > synchro-betatron coupling due to beam-beam 😐
- "Crab Waist" can reduce or eliminate the effect of crossing angle ☺
  - Raimondi, LNF, based on earlier work by Balakin, BINP
  - Successfully operated at DAΦNE, Luminosity gain ≈ *2.5.

High Beam Current/Short Bunches

- Problems of high beam current for short bunches:



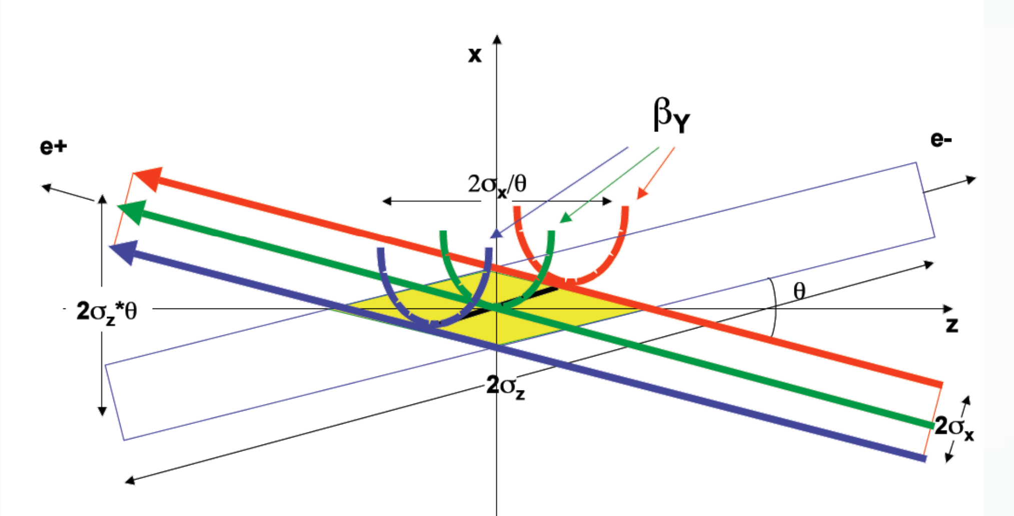
BPM damage due to overheating

Rf seal damage

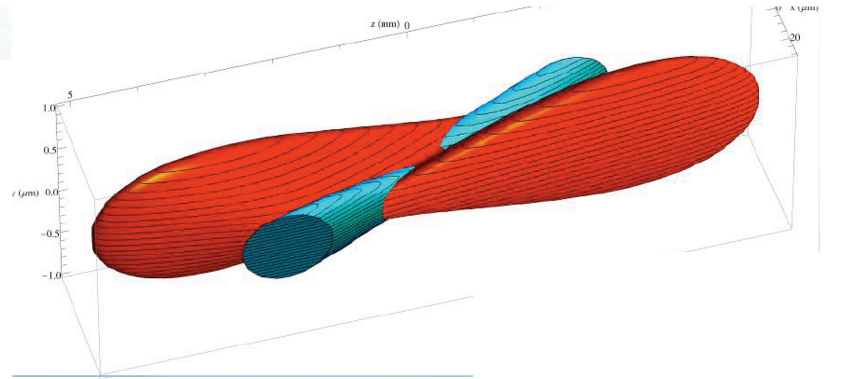
Crab Waist

Raimondi

Graphics by
E. Paoloni

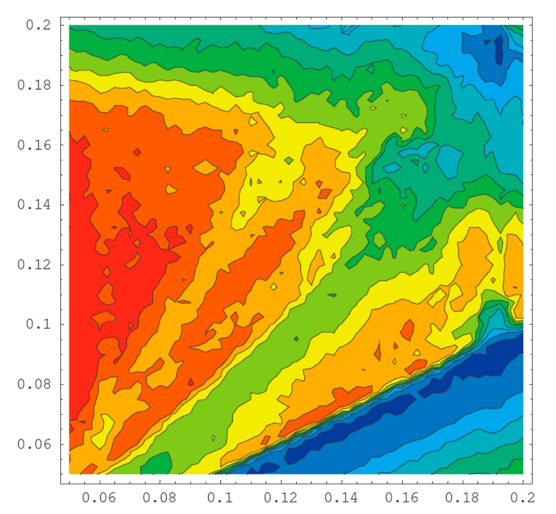


All particles from both beams collide in the minimum β_y region, with a net luminosity gain

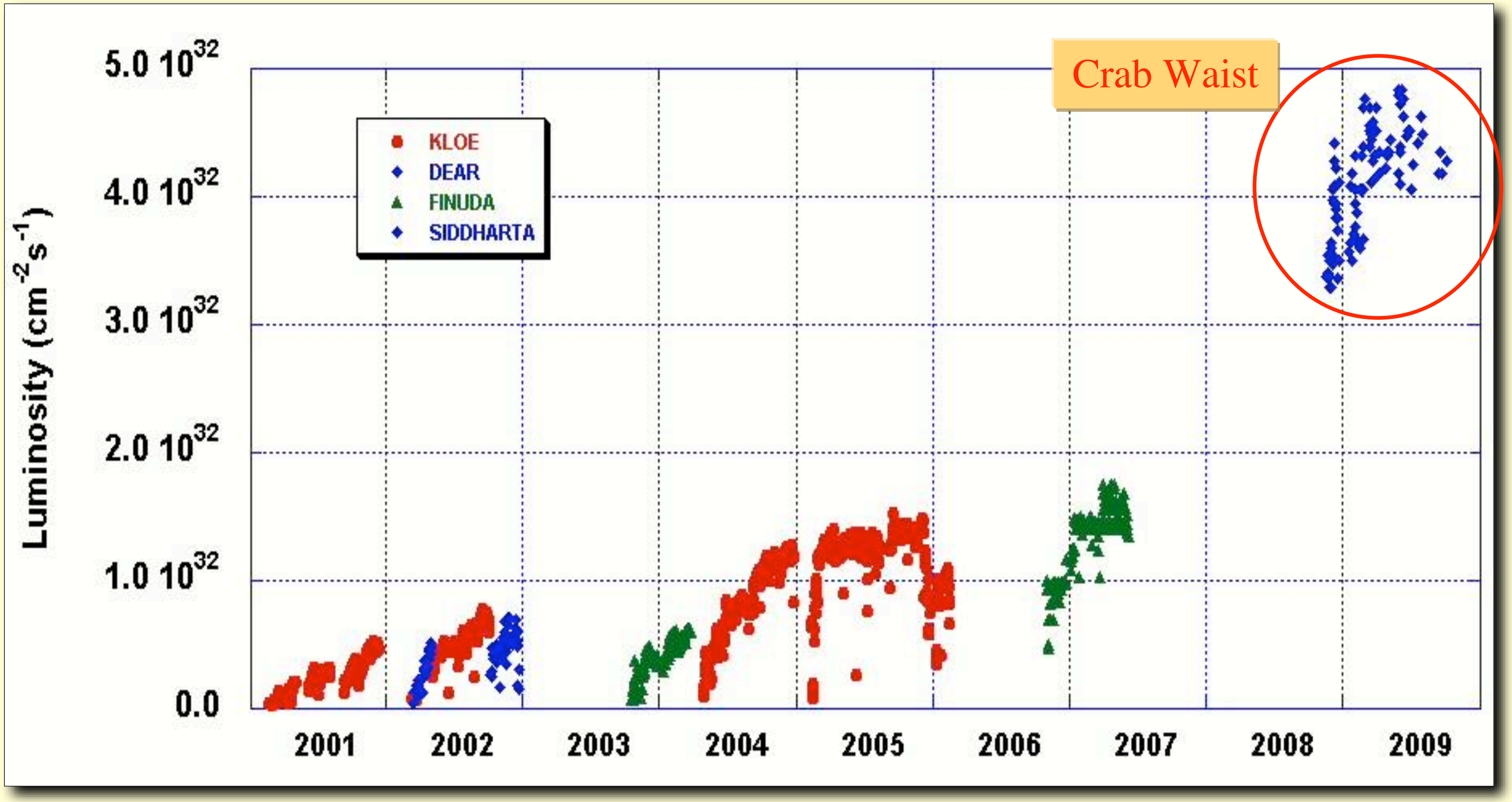


Crab sextupoles: nπ in x; (n+1/2)π in y from IP

Tune scan, red=higher luminosity



DAΦNE Luminosity



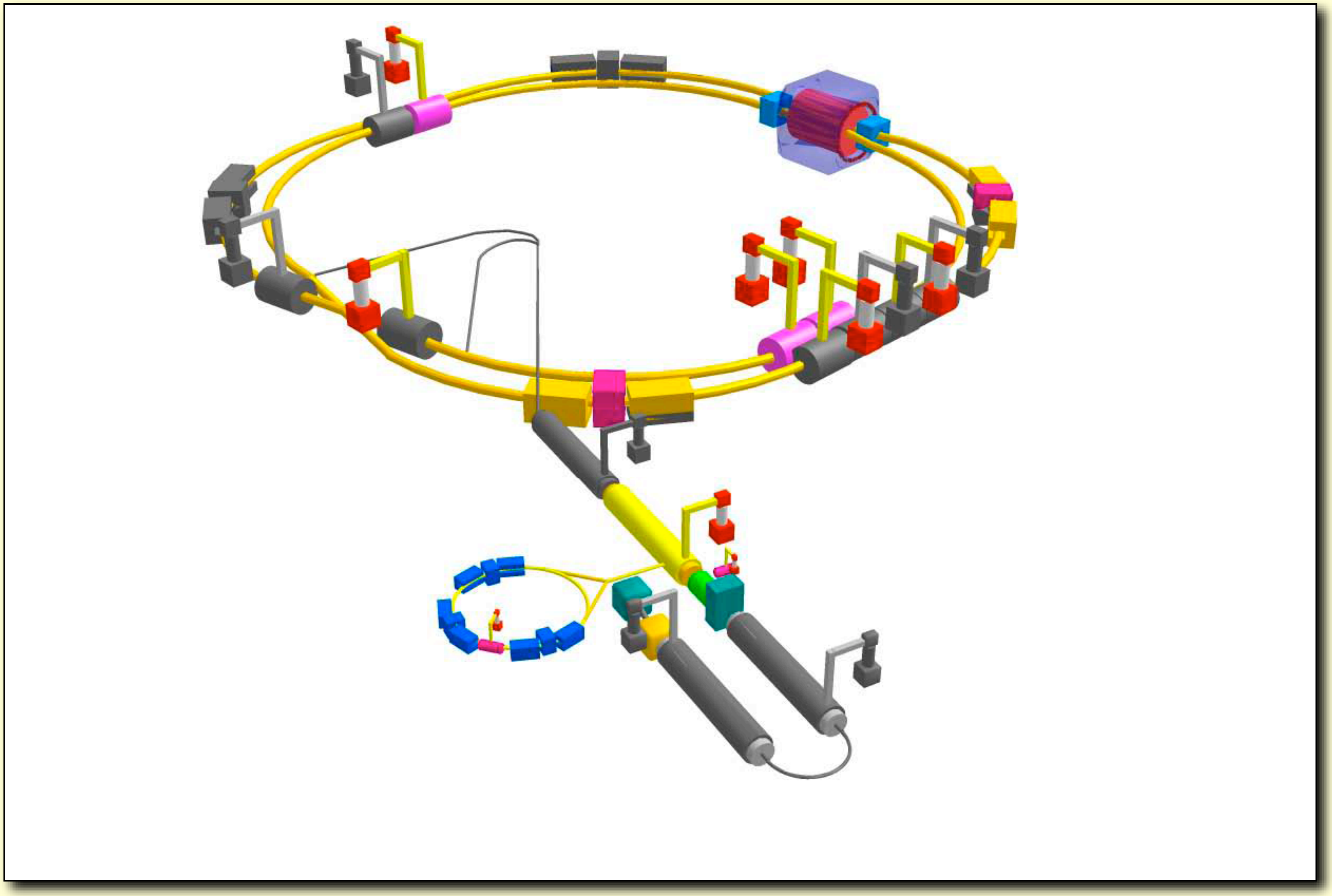
Towards next-Generation *B*-Factories

- Both *B*-Factory teams have proposed upgrades exploiting this scheme:
  - Super KEKB: Upgrade of existing KEKB
  - Super*B*: New facility, to be built at LNF in a collaboration of LNF, SLAC, several European Laboratories and BINP Novosibirsk.
- While the challenges are similar for both facilities, they differ in the details:
  - Super KEKB: ≈3 km circumference (KEKB tunnel), no polarized beam, KEKB hardware
  - Super*B*: 1.25 km circumference, polarized electrons, PEP-II hardware

Common Features

- Energy asymmetry: 4 on 7 GeV
- Crossing angle: 2* 41.5 mr, 2*30 mr
- Small beam emittances (nmr in *x*, pmr in *y*)
  - Beam aspect ratios ≈ 1/100
- Beam currents up to ≈ 3.5 A or less
- Bunch length ≈ 5 mm
- Short beam lifetime (≈ 5 min)
  - continuous injection (“trickle charge”)

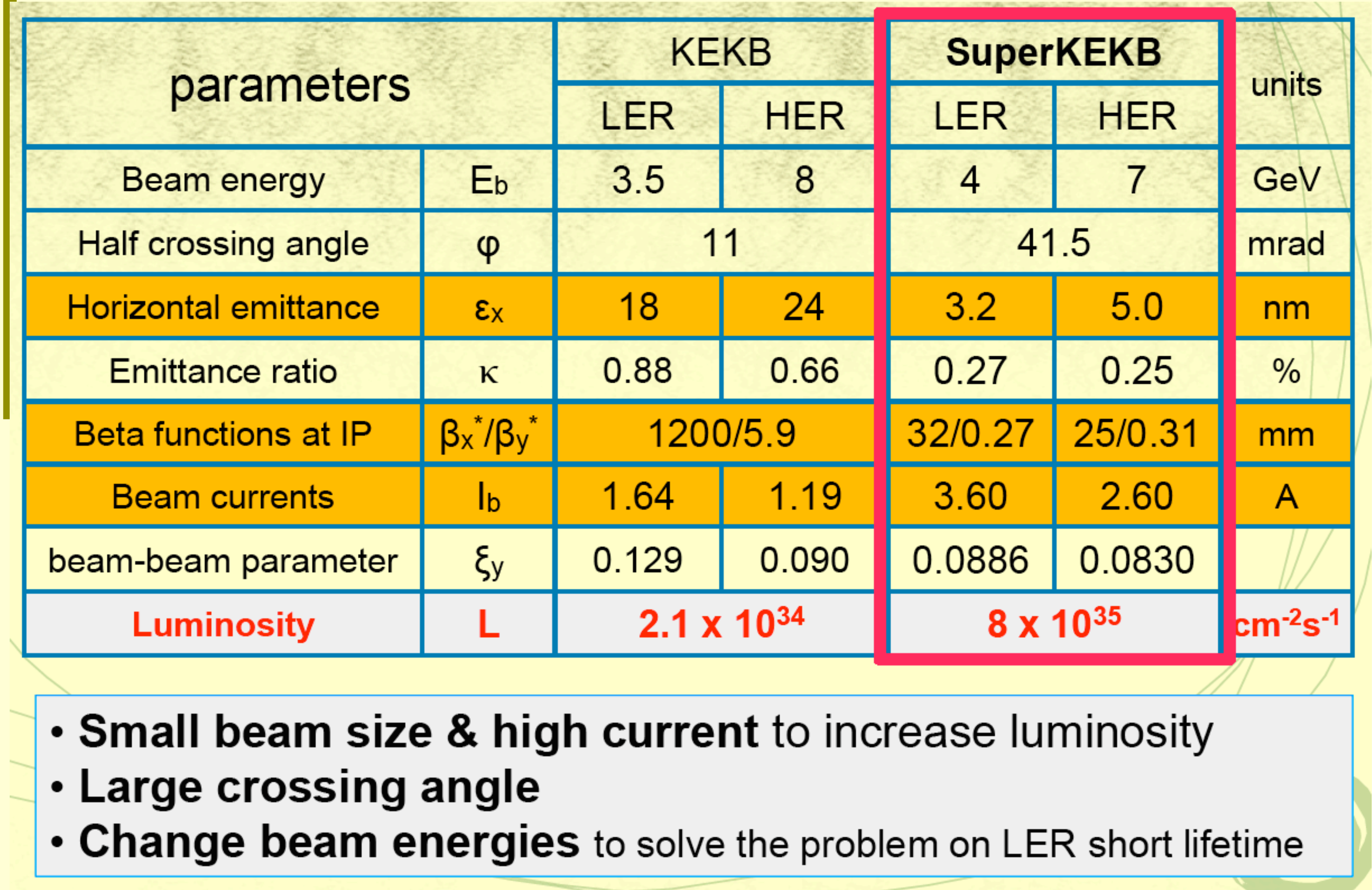
KEKB/SuperKEKB



U. Wienands, SLAC
U. de Paris, 16-Sep-10

KEKB Site

Super KEKB Parameters

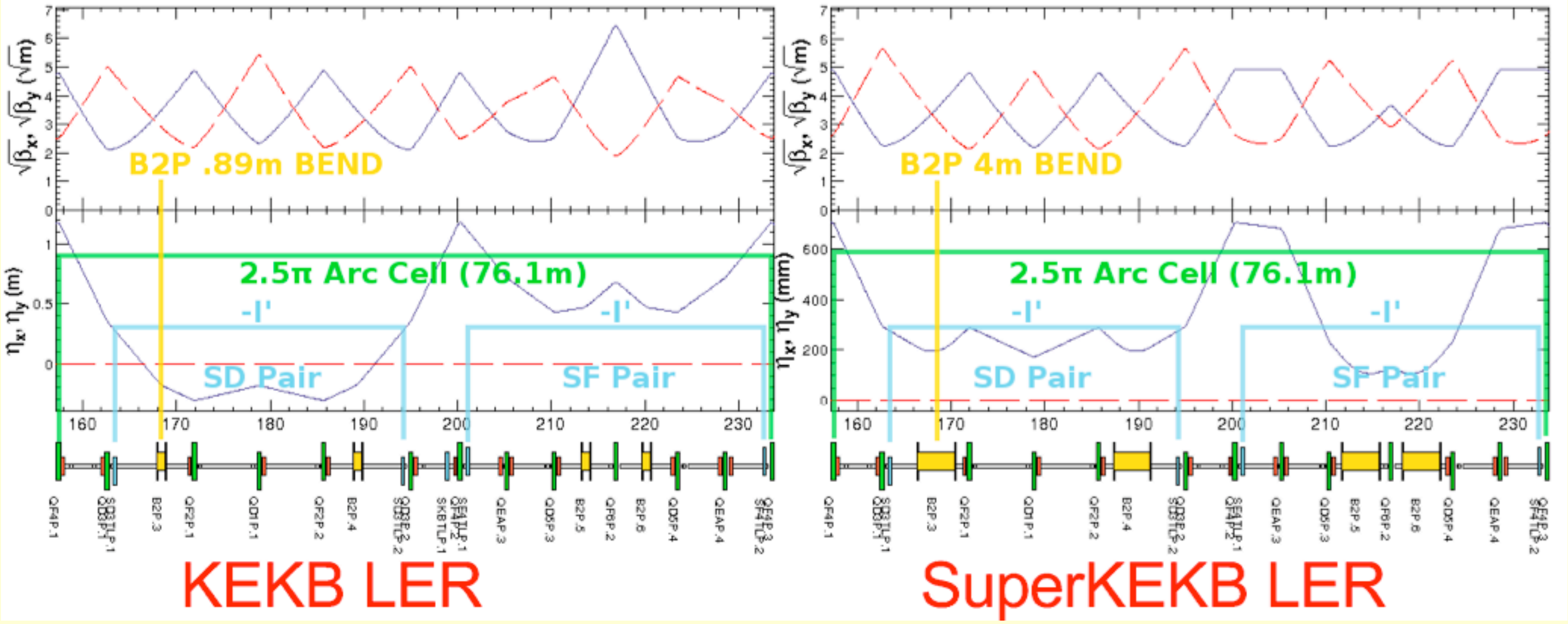


parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7	GeV
Half crossing angle	φ	11		41.5		mrad
Horizontal emittance	ε_x	18	24	3.2	5.0	nm
Emittance ratio	κ	0.88	0.66	0.27	0.25	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.31	mm
Beam currents	I_b	1.64	1.19	3.60	2.60	A
beam-beam parameter	ξ_y	0.129	0.090	0.0886	0.0830	
Luminosity	**L**	**2.1 x 10^{34}**		**8 x 10^{35}**		$cm^{-2}s^{-1}$

- **Small beam size & high current** to increase luminosity
- **Large crossing angle**
- **Change beam energies** to solve the problem on LER short lifetime

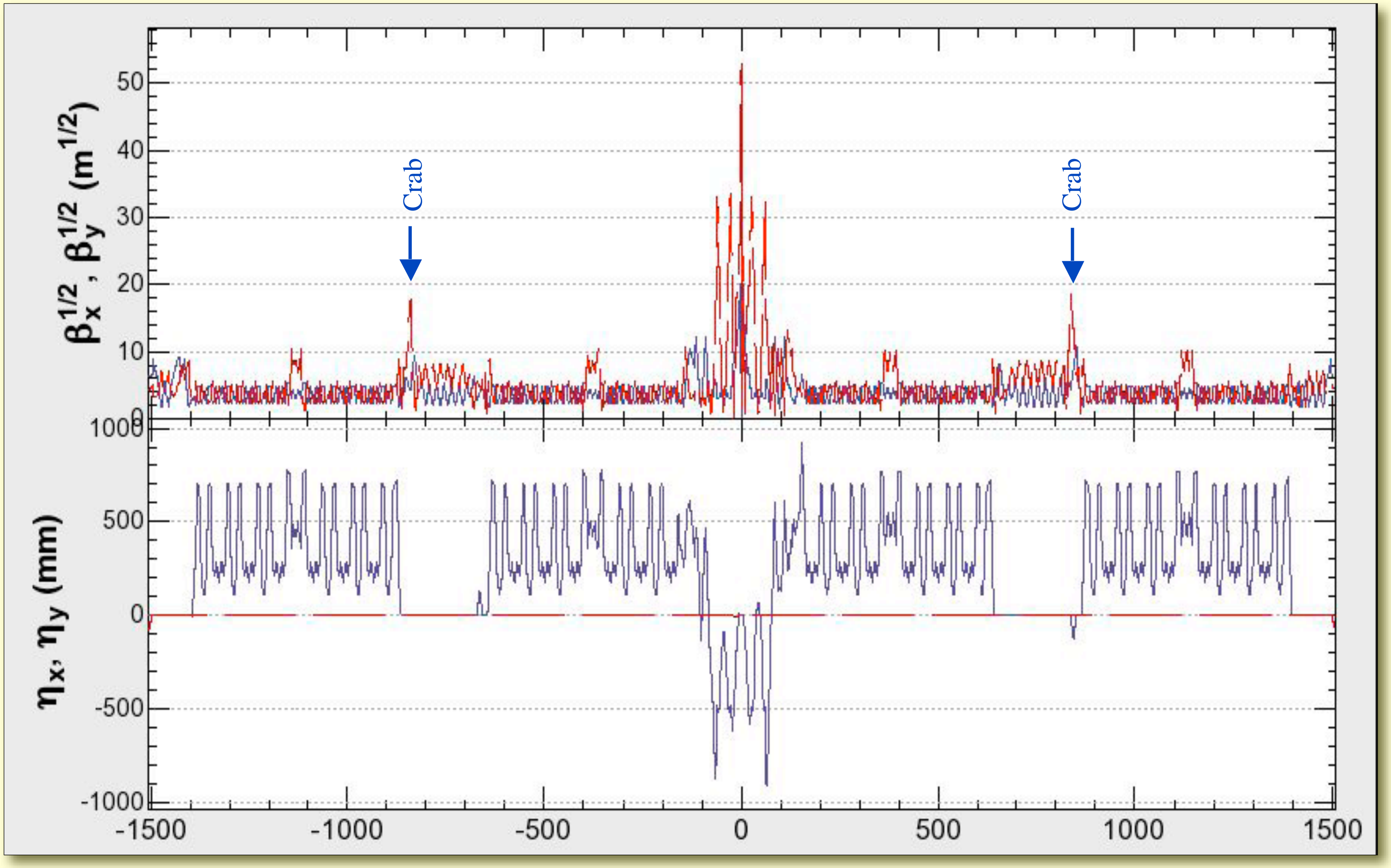
Low Emittance Lattice

- Achieving low emittance with minimum change
  - Replace short dipoles with longer ones for LER



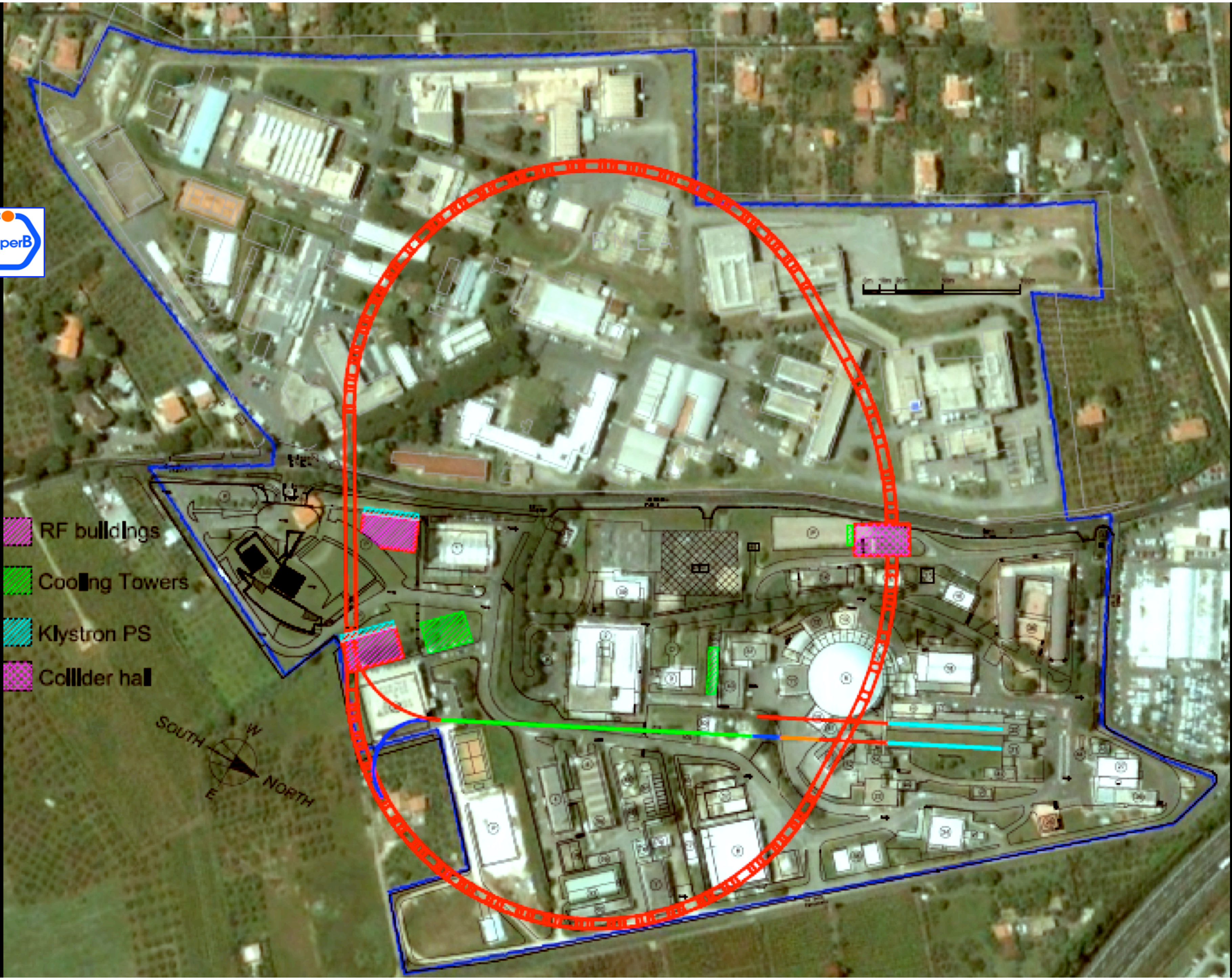
≈100 0.89 m dipoles replaced with 4 m ones.

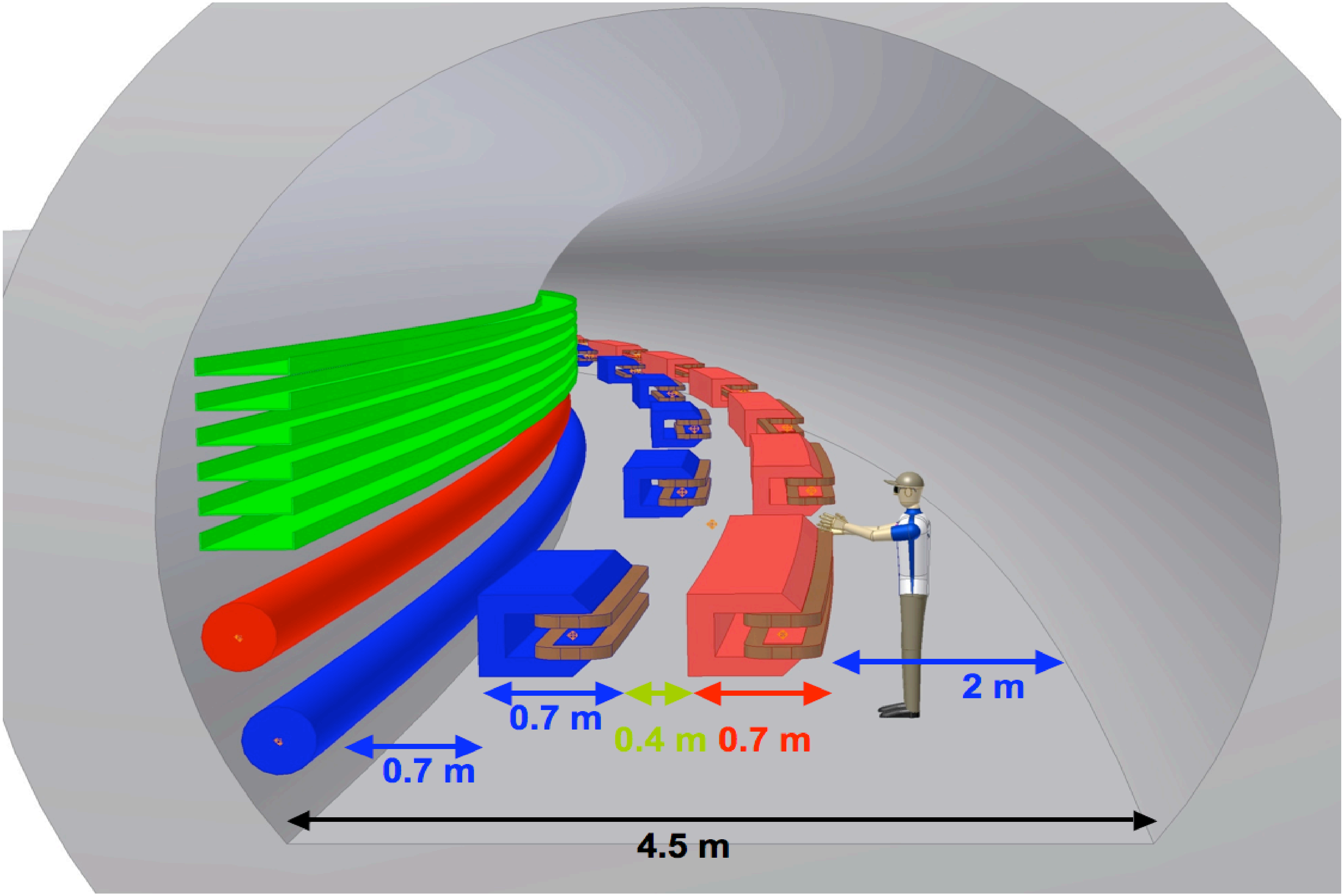
SuperKEKB Lattice



Super*B* Parameters

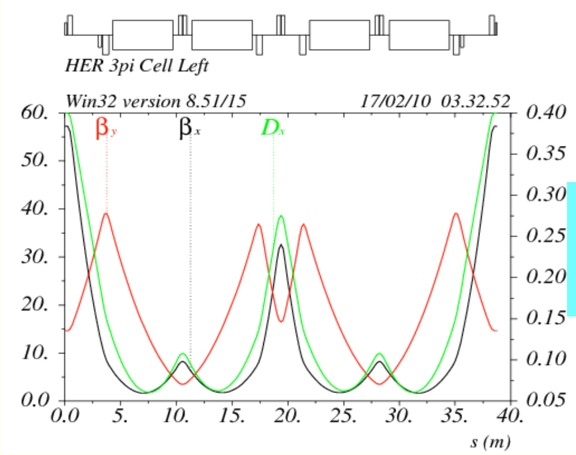
Energy:	6.78 (e^+) on 4.18 (e^-) GeV		
Half crossing angle:		30 mr	
Horiz. emittance:	2	on	2.5 nmr
Vertic. emittance:	5	on	6 nmr
β_x/β_y at IP:	26/0.25 on		32/0.21 mm
Beam currents:	1.9	on	2.5 A
Beam-beam parameter ξ_y:		0.097	
Beam lifetime:	4.2	on	4.5 min
Luminosity:		1×10^{36} cm^{-2}s^{-1}	


RF buildings
Cooling Towers
Klystron PS
Collider hall
SOUTH
W
E
NORTH

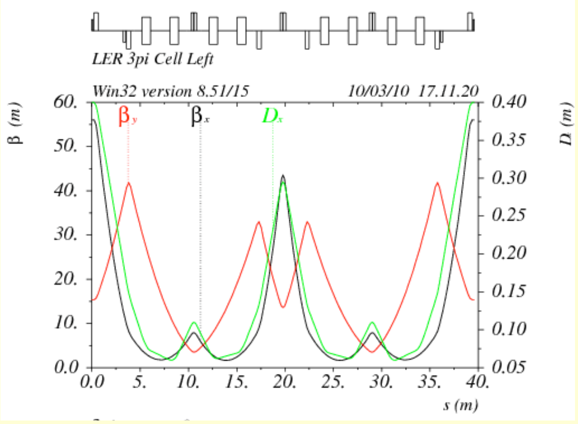


SuperB: Storage Ring Tunnel Occupanc

Low Emittance Lattice



$\mu_x = 3\pi$, $\mu_y = \pi$
Cell in HER

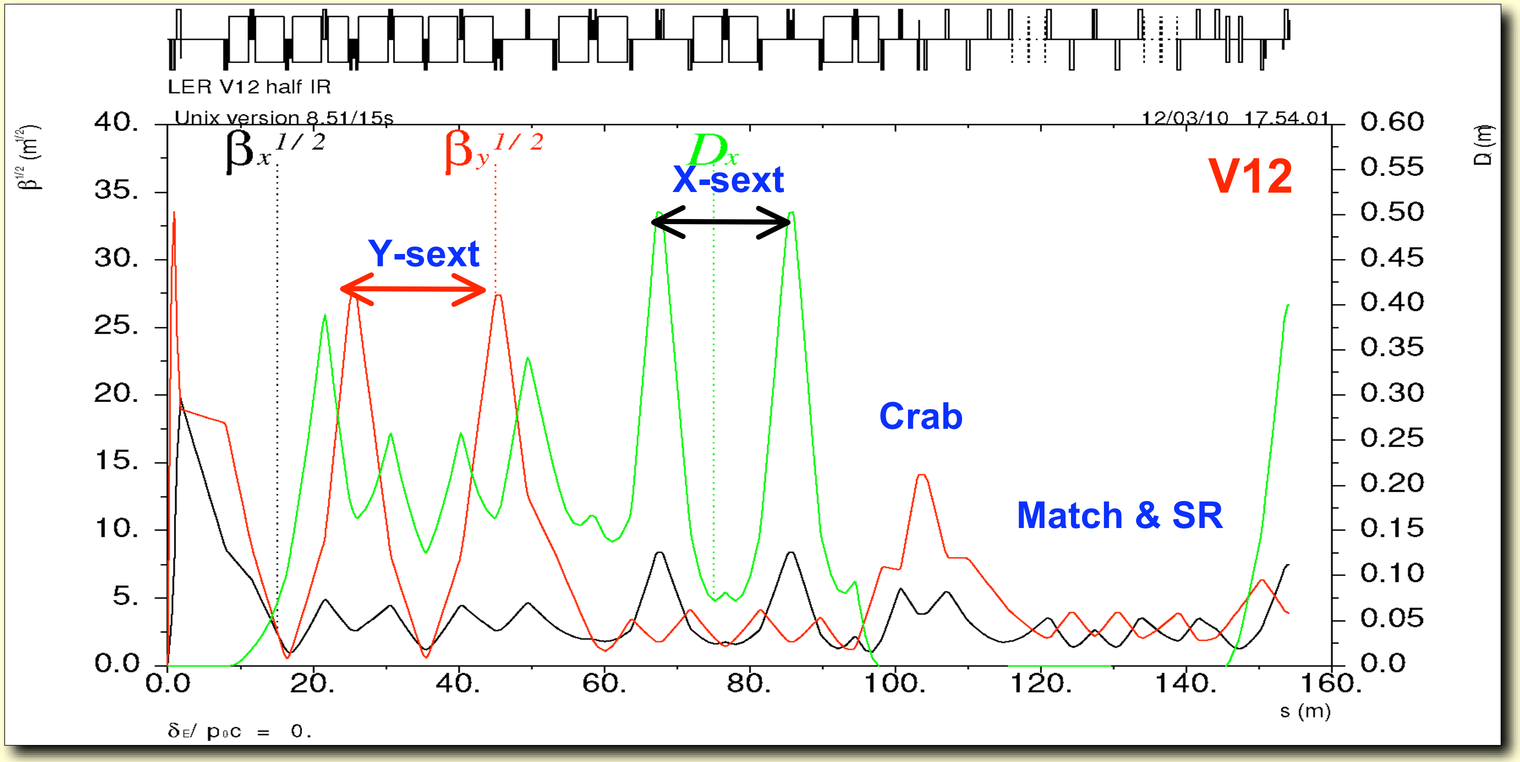


$\mu_x = 3\pi$, $\mu_y = \pi$
Cell in LER

- Lattice near TME
  - synch.-rad. type design
- In the LER, dipole position adjusts the emittance
- ≈ 5 mm bunch length
  - acceptable

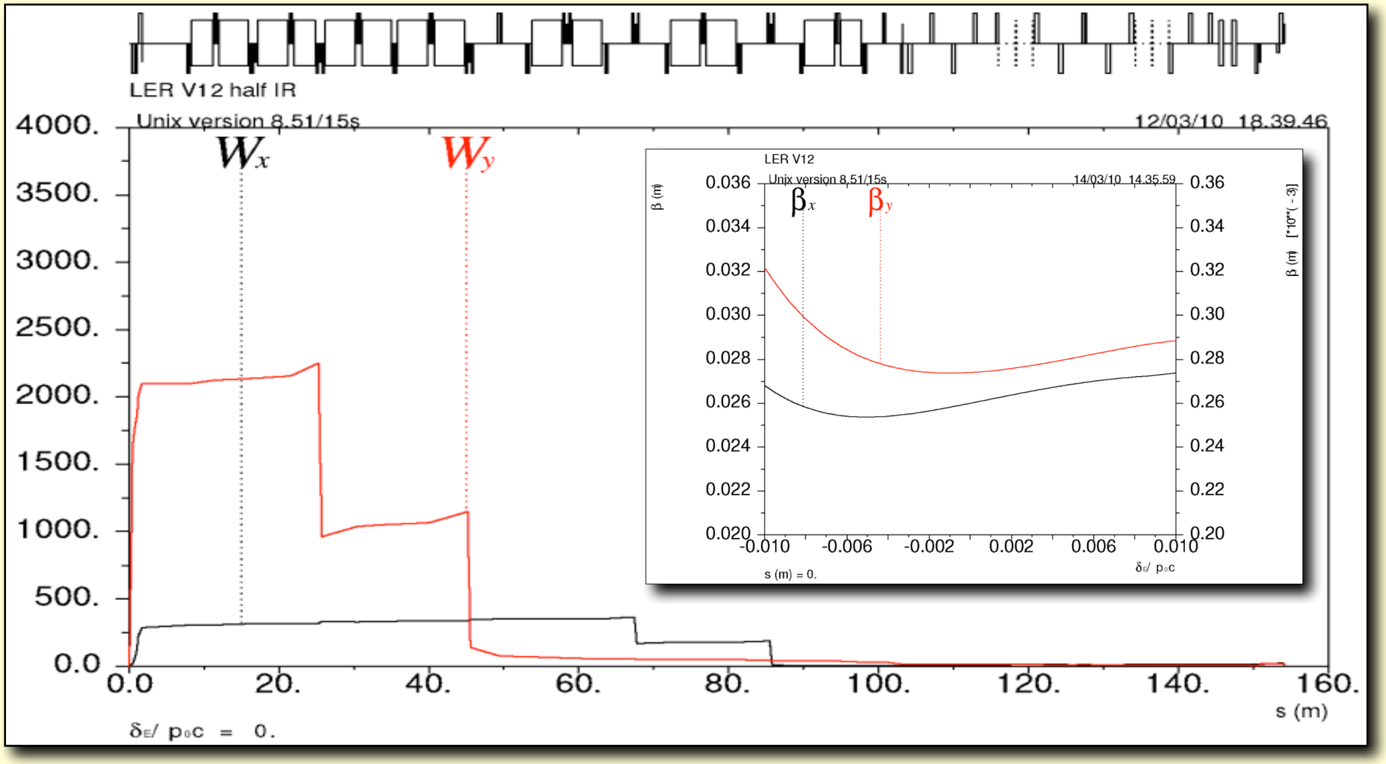
LER Interaction Region

- Spin Rotator outside local chromaticity correction



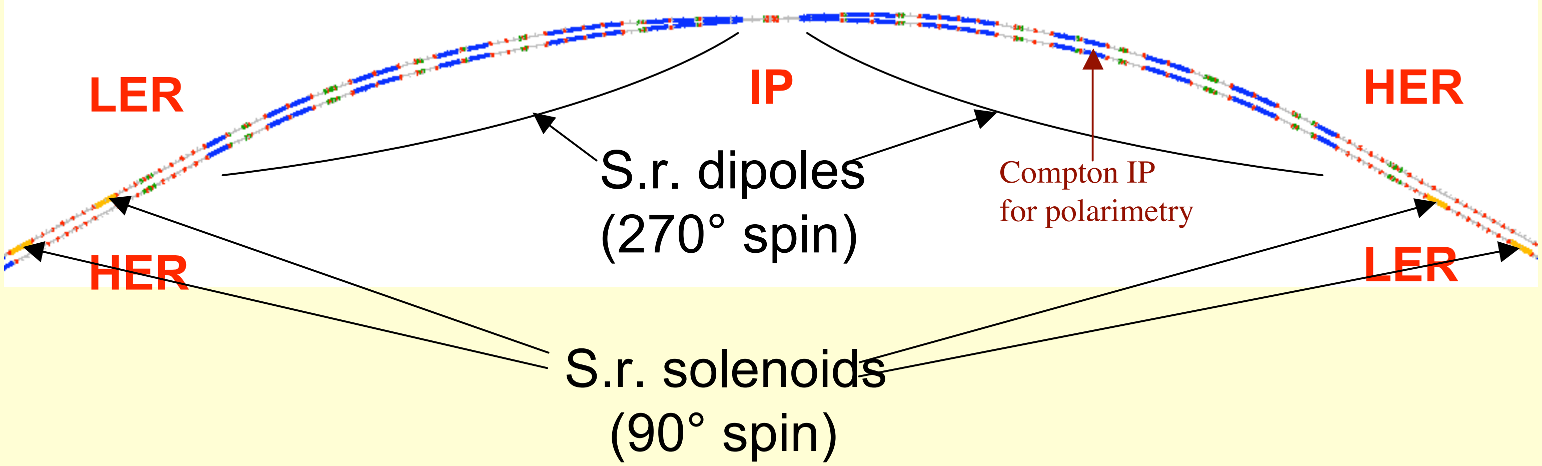
Chromatic behaviour of the IP

- β chromaticity (W) corrected at IP
  - necessary condition for high momentum bandwidth



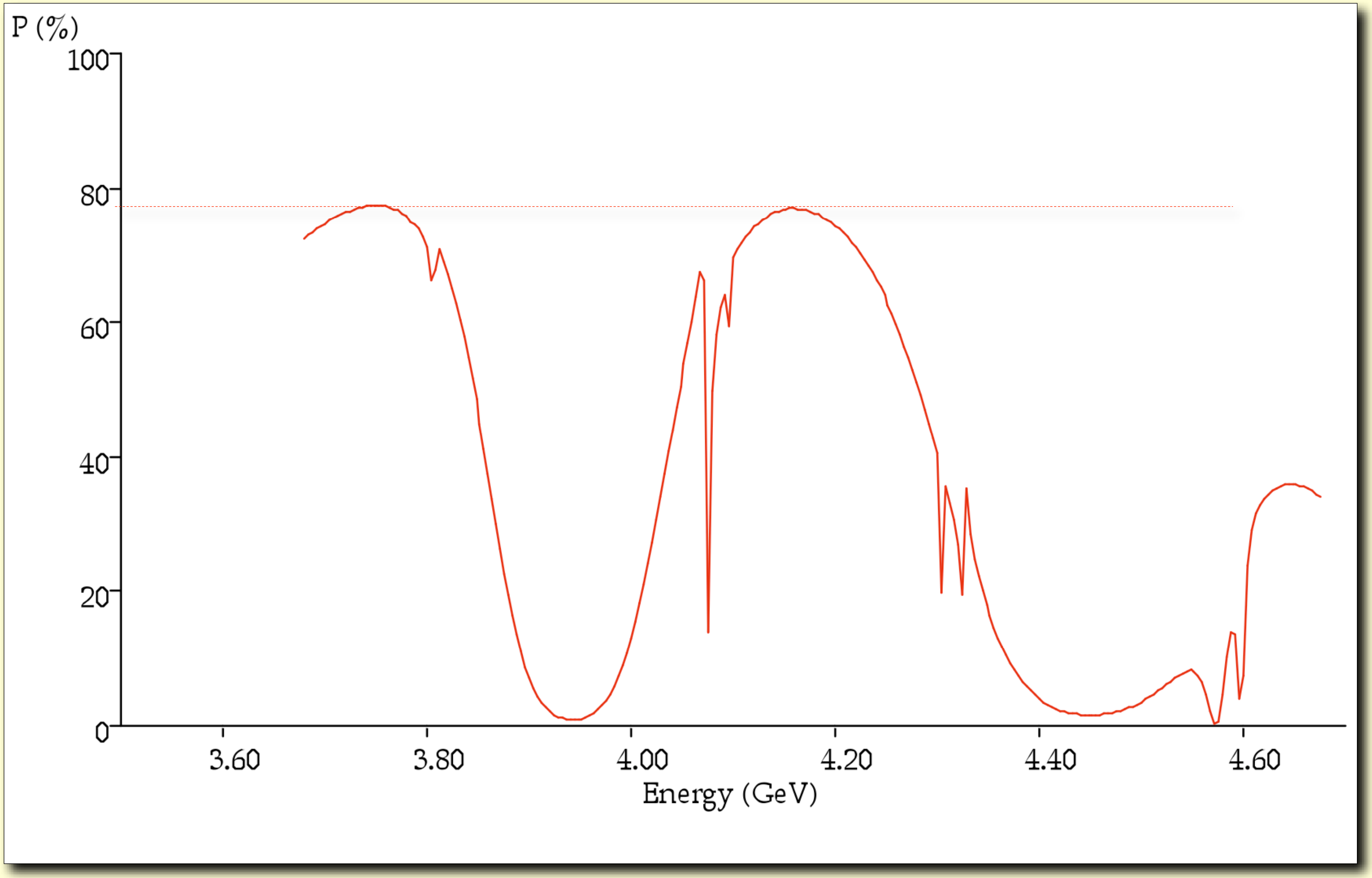
SuperB LER Spin Rotation

- 90° spin rotation about x axis
  - 90° about z followed by 270° about y
- “flat” geometry => no vertical emittance growth
- Solenoid scales with energy => LER more economical
- Solenoids are split & decoupling optics added.



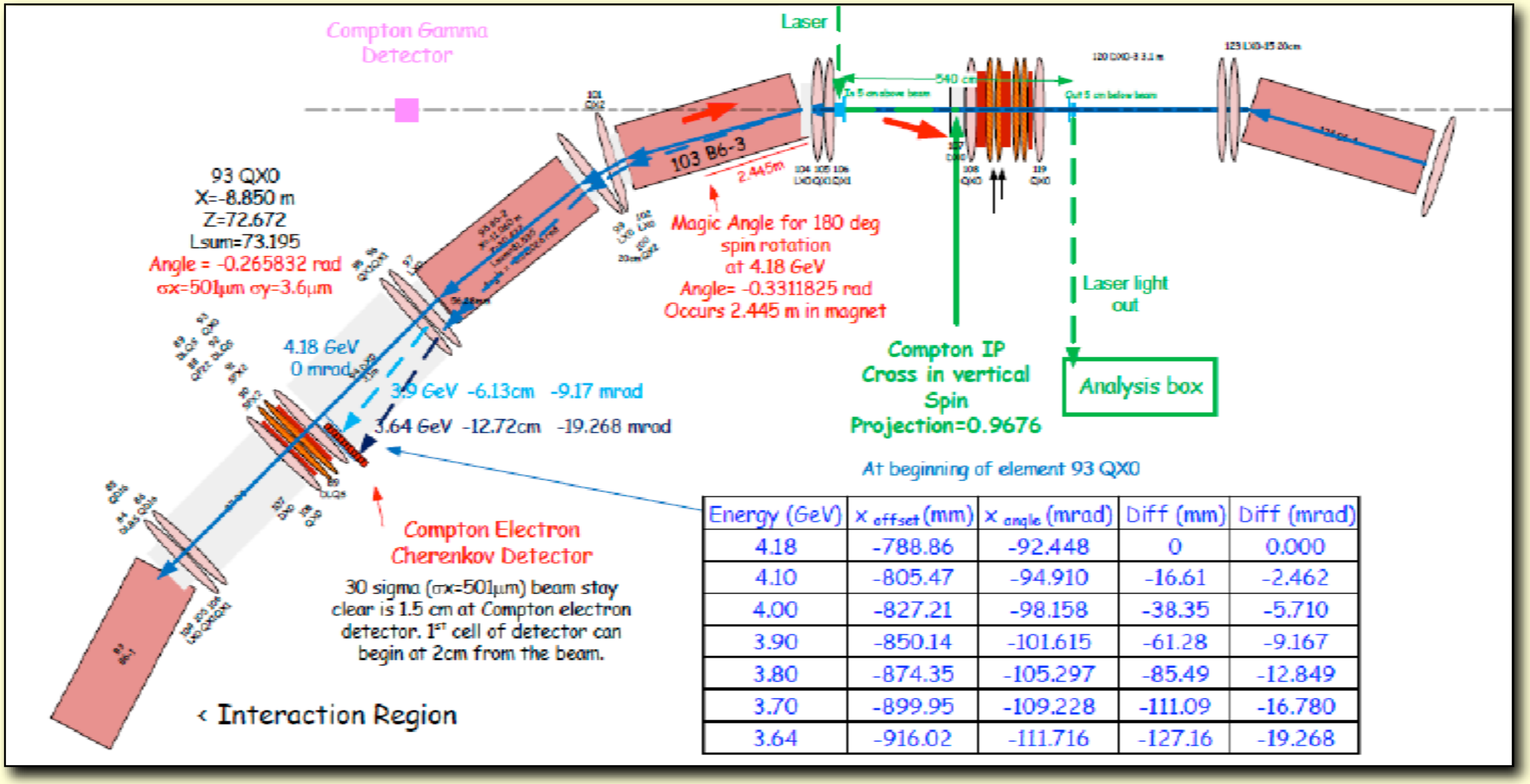
SuperB LER Polarization

3.5 min
beam
lifetime



Polarimetry

- Compton polarimeter, γ and e^- detection
  - bunch-by-bunch, < 1% systematic error



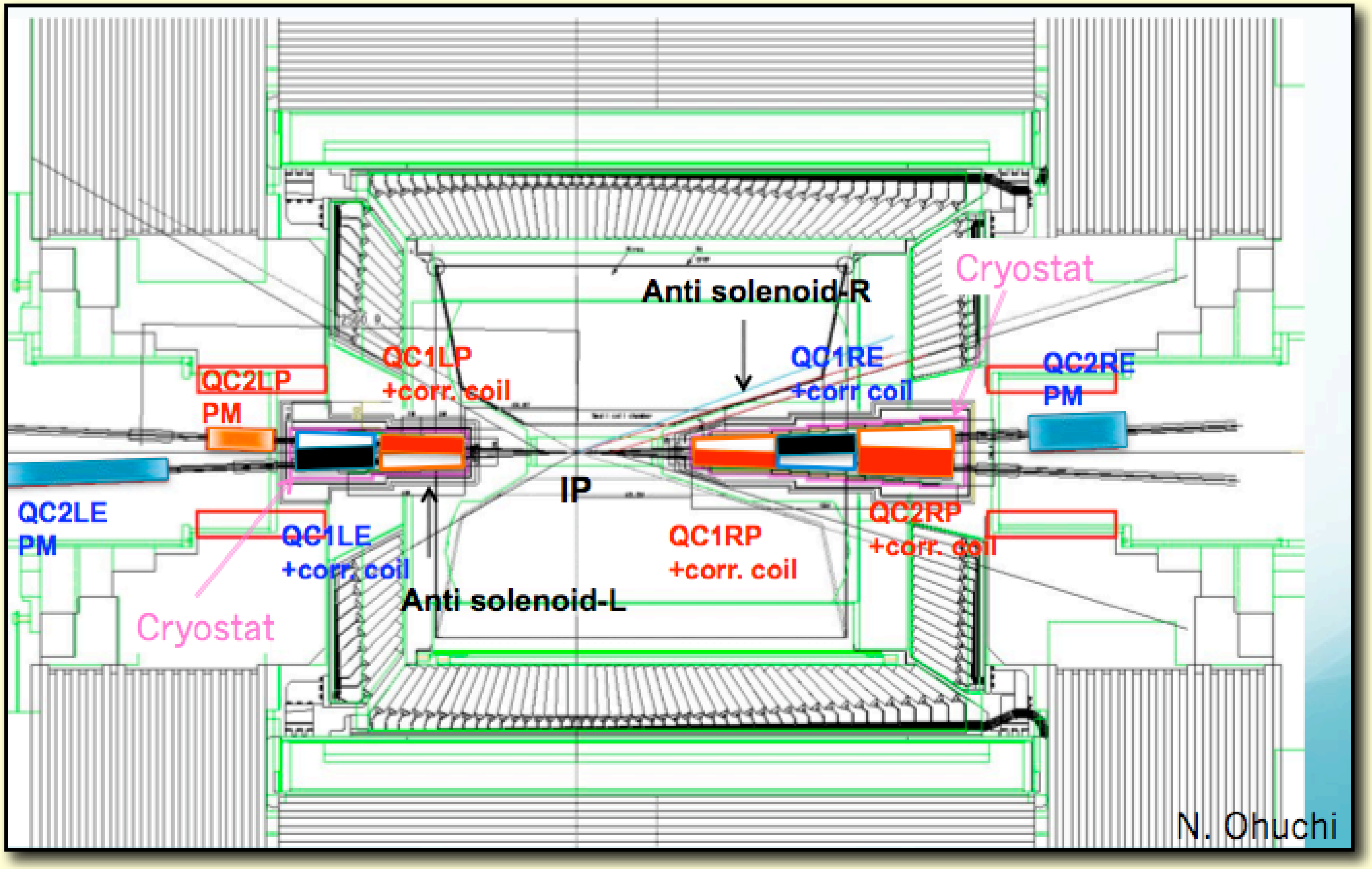
30 sigma (σx=501μm) beam stay clear is 1.5 cm at Compton electron detector. 1st cell of detector can begin at 2cm from the beam.

At beginning of element 93 QX0

Energy (GeV)	x_{offset} (mm)	x_{angle} (mrad)	Diff (mm)	Diff (mrad)
4.18	-788.86	-92.448	0	0.000
4.10	-805.47	-94.910	-16.61	-2.462
4.00	-827.21	-98.158	-38.35	-5.710
3.90	-850.14	-101.615	-61.28	-9.167
3.80	-874.35	-105.297	-85.49	-12.849
3.70	-899.95	-109.228	-111.09	-16.780
3.64	-916.02	-111.716	-127.16	-19.268

Super KEKB Final-Focusing system

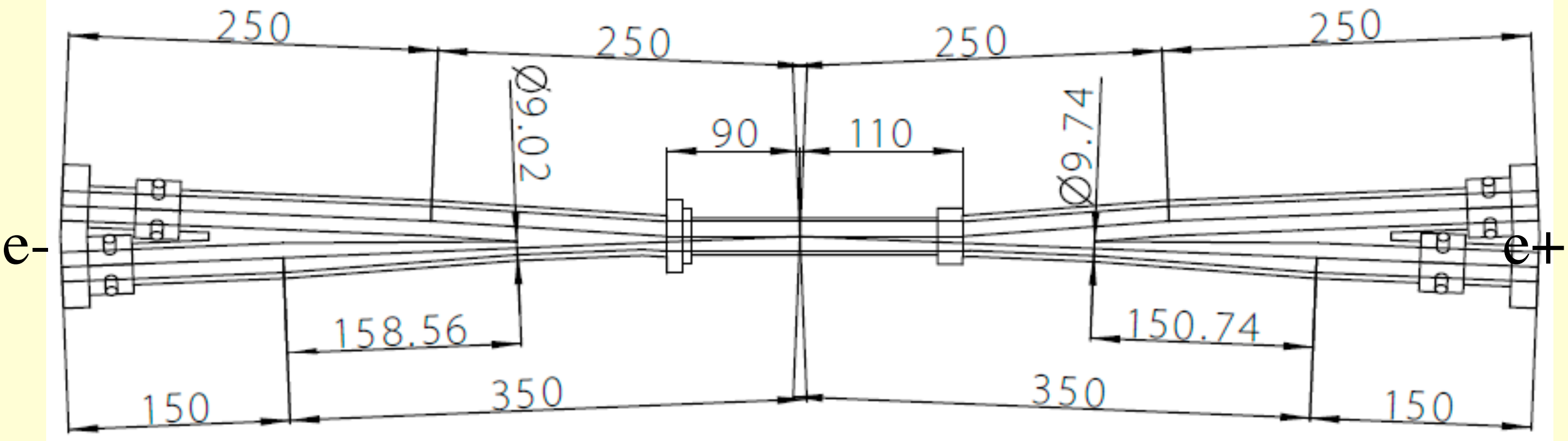
- Crossing angle 83 mrad to make the FF magnets close to IP



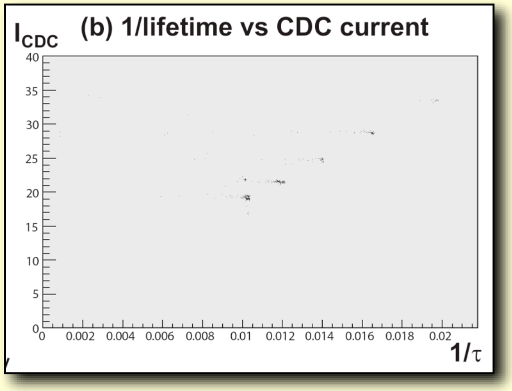
N. Ohuchi

Super KEKB IR Beam Pipe

- Crotched structures (Two FF Q-magnets in both sides)
- 1cm radius of vtx chamber



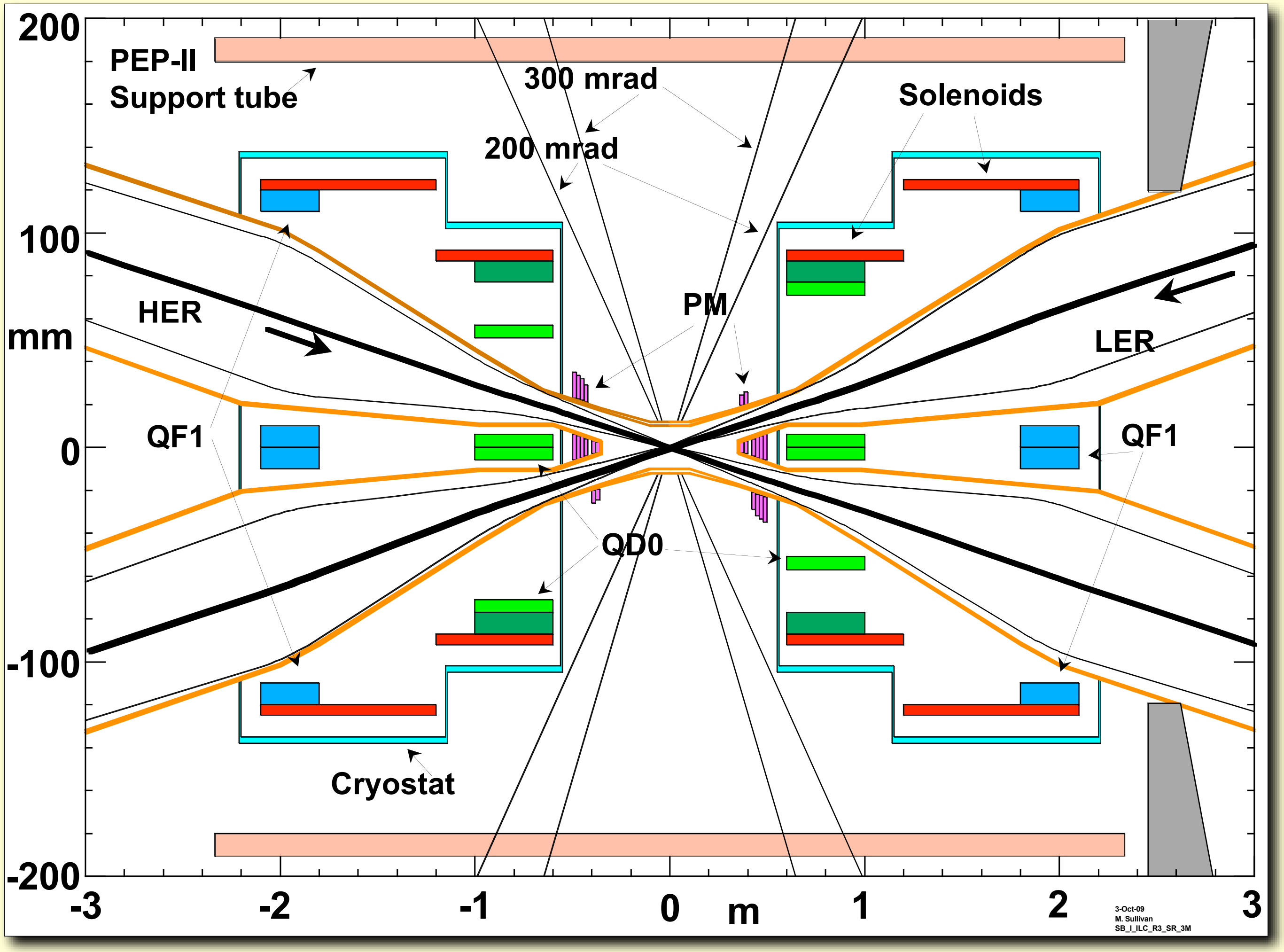
Detector Background



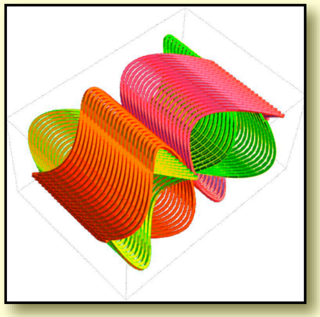
- SR background
  - not worse than present *B*-Factories;
- Lost-particle background
  - Touschek factor 20-30 higher (SuperKEKB est.)
  - beam collimation can help (Super*B*)
- Radiative Bhabhas ($\propto$ Luminosity)
  - Shielding (*n*), optics (e^+,e^-) to deal with
  - SuperKEKB Study: can be reduced by factor 40 c.f. KEKB

Super KEKB S/C Magnet R&D

SuperB IR Layout



SuperB IR Quad Designs

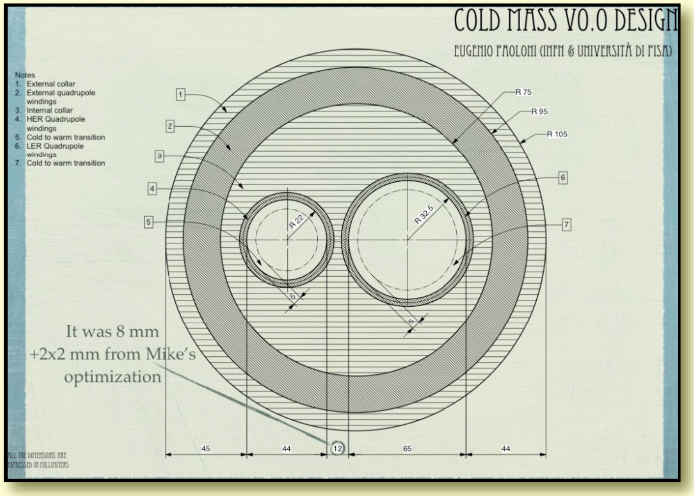


Scalloped solenoid magnets

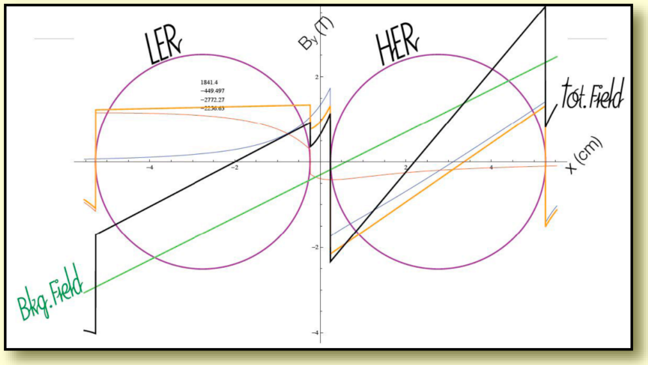
3 coils x 2 (to cancel solenoid)

⇒different fields possible

E. Paoloni, S. Bettoni

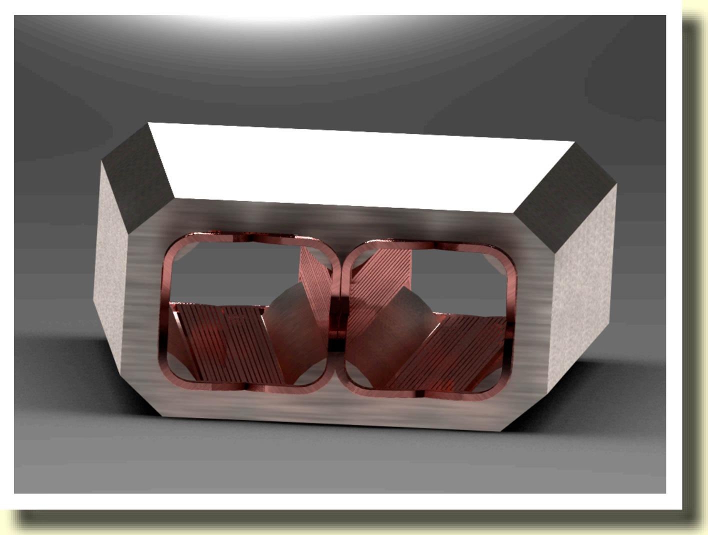


It was 8 mm
+2x2 mm from Mike's
optimization



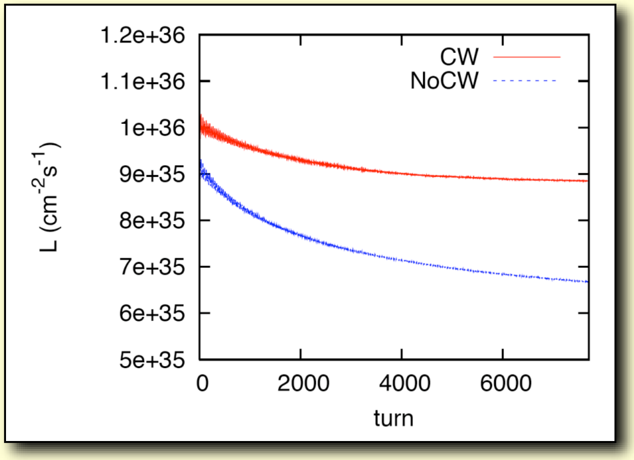
Alternative QD0: Superferric

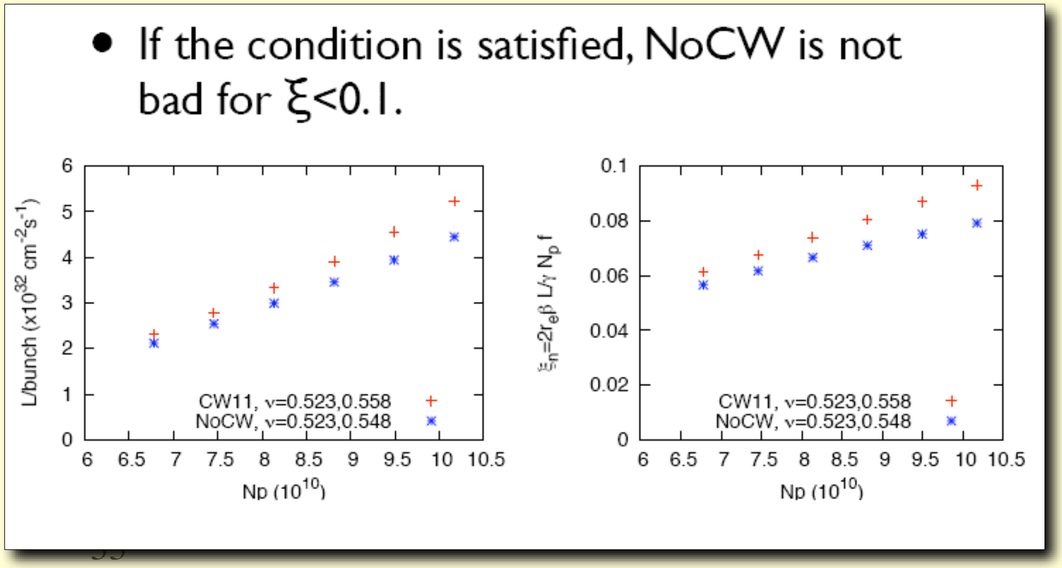
(P. Vobly, BINP)



Beam-Beam (Ohmi)

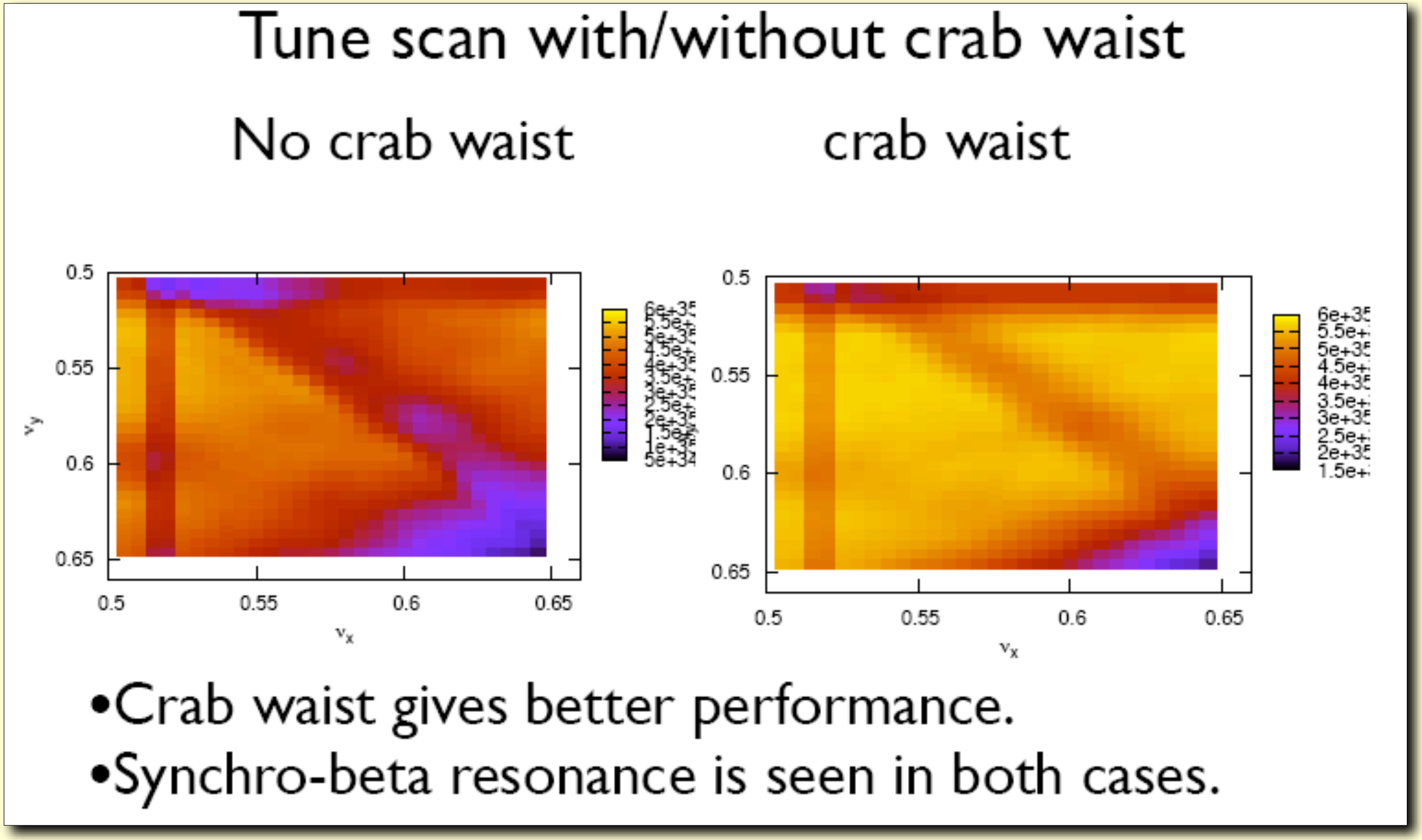
- Strong-strong simulation for SuperKEKB
  - crab waist increases L from ≤7 to ≤9 1035.





- If the condition is satisfied, NoCW is not bad for ξ<0.1.

Beam-Beam (cont'd)



Tune scan with/without crab waist

No crab waist

crab waist

- Crab waist gives better performance.
- Synchro-beta resonance is seen in both cases.

Misalignments (Luzzio, Super*B*)

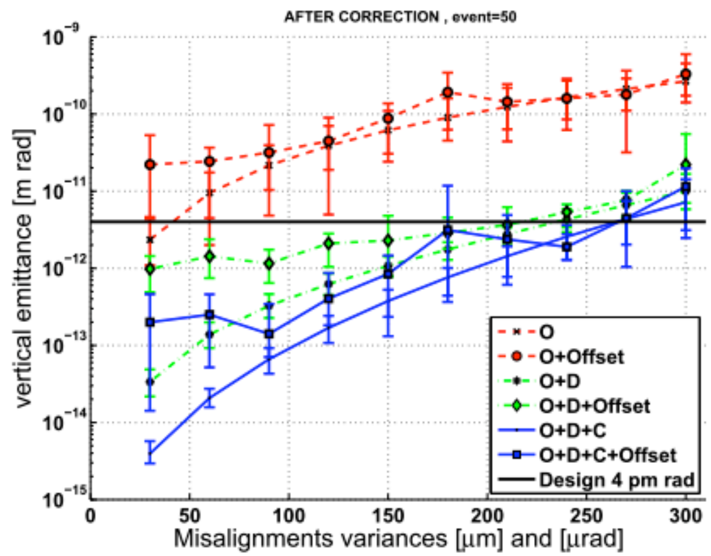


Figure 2: Vertical emittance (m) for machine misalignment from 30 to 300μm H and V for Sext and Quad and qudrupole Tilts of 30-300 μrad. Orbit (O), Dispersion (D) and Coupling and Beta-beating (C) Free Steering are compared

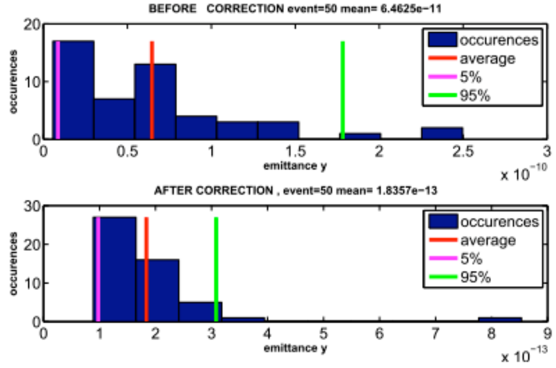


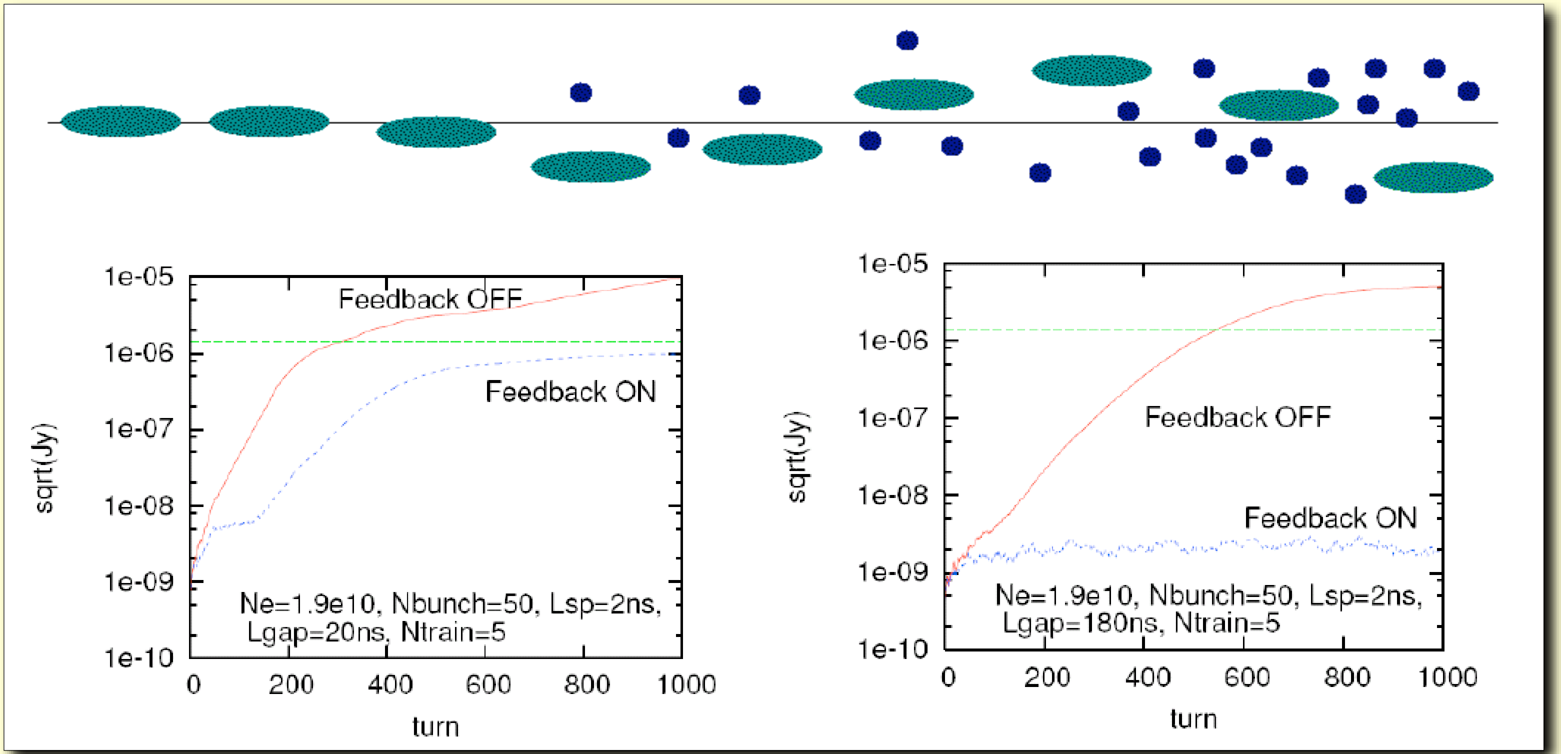
Figure 4: Vertical emittance for 50 simulation with misalignment and tilts from Table 1.

Table 1: Tolerances; values of the combined tolerated displacements, tilts and monitor offsets.

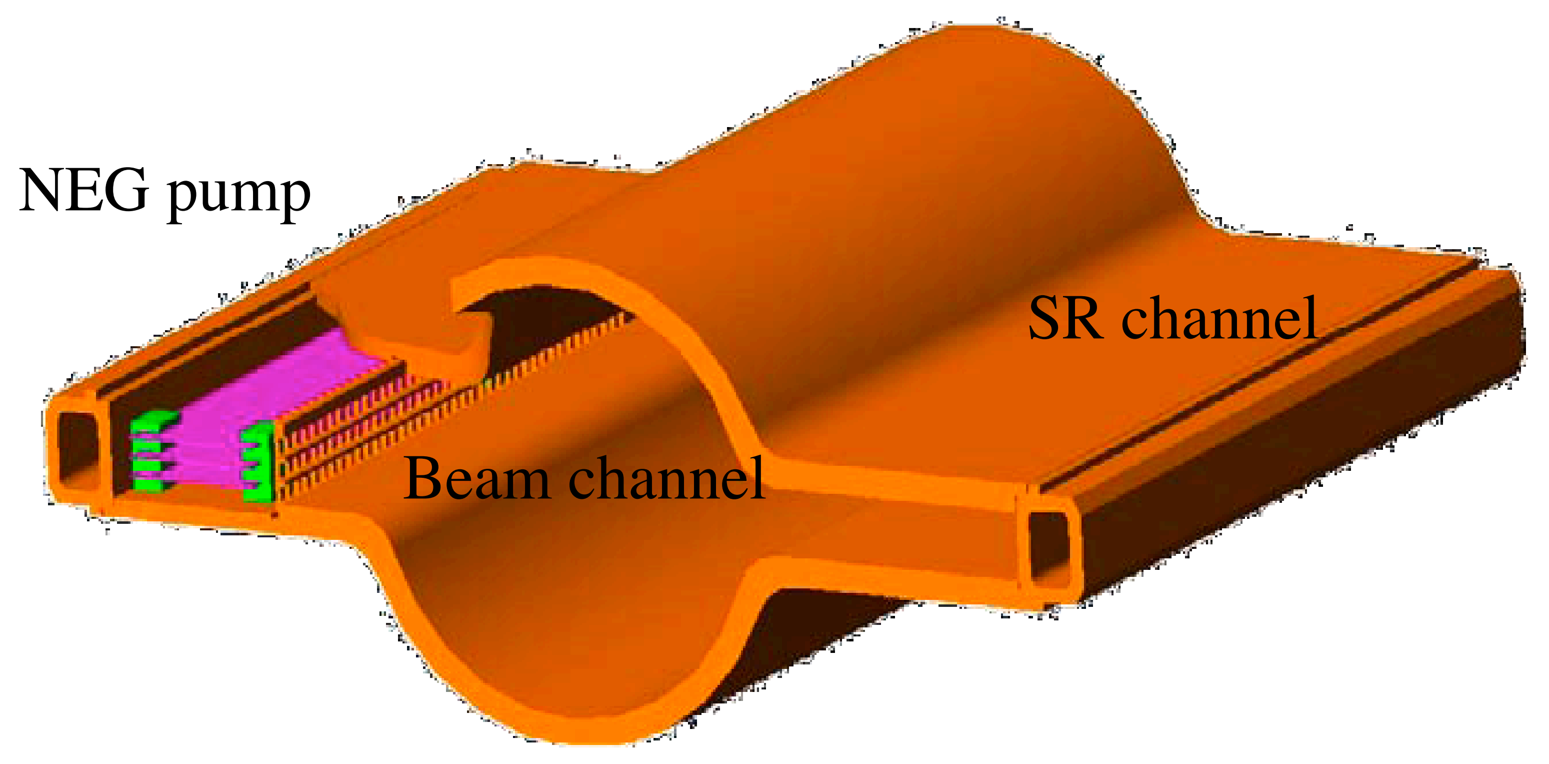
error	tolerance
quadrupole Y	300 μm
quadrupole X	300 μm
quadrupole tilt	300 μrad
sextupole Y	150 μm
sextupole X	150 μm
BPM OFFSET	400 μm
vertical emittance	<1 pmrad

e-Cloud Simulations (Demma, Super*B*)

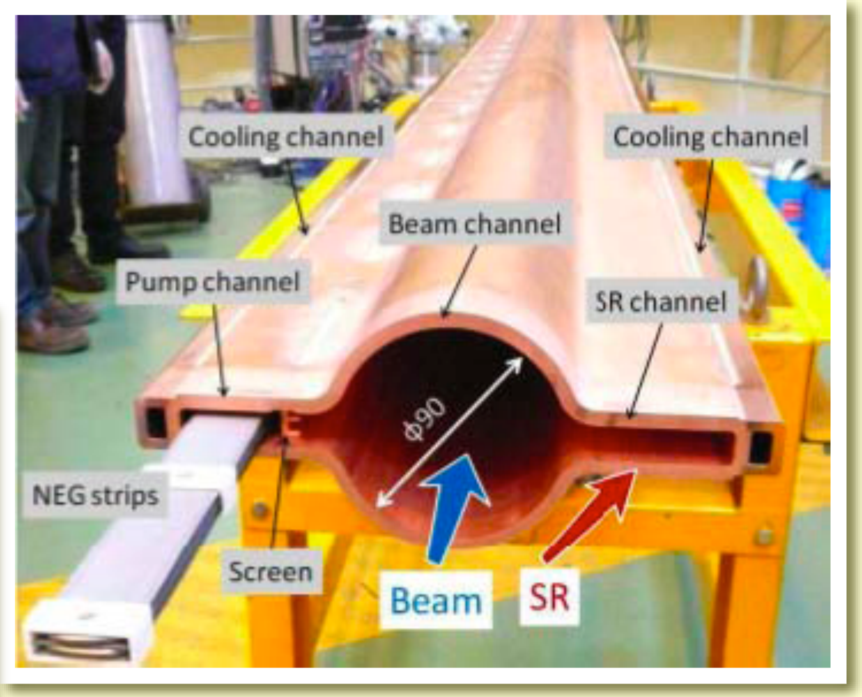
- *e*-Cloud was seen in both KEKB and PEP-II
  - details differ somewhat (PEP-II: mostly *x*, KEKB: mostly *y*)
  - successfully mitigated with beam-line solenoids
  - strongly dependent on bunch pattern, vac. syst. (ante-chamber)



Super KEKB Vacuum Chamber



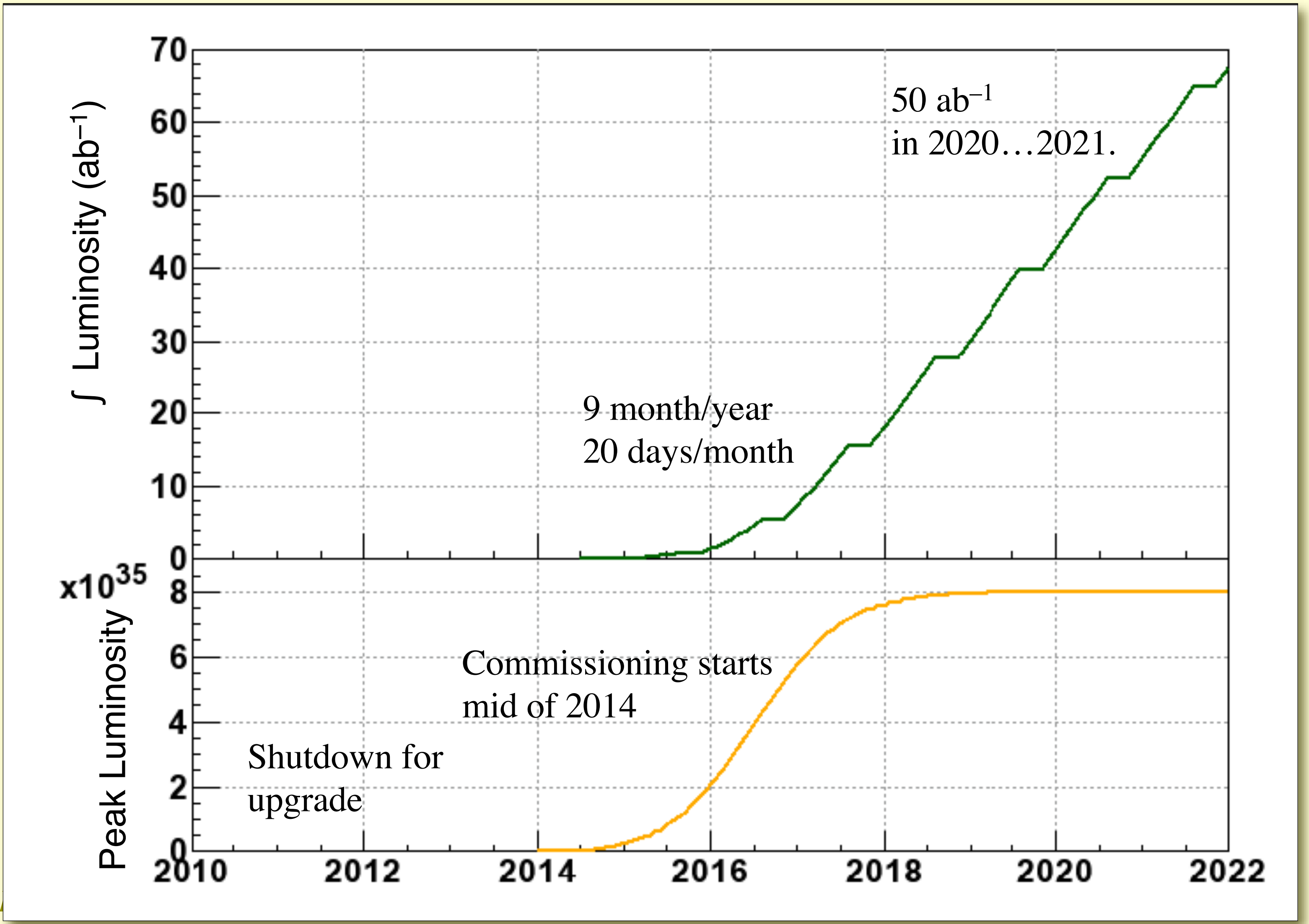
Super KEKB Chamber Prototypes



SuperKEKB

- New Ante-chamber beam pipes
  - Mitigation techniques for suppression of electron cloud.
- -New IR design
  - New superconducting/permanent magnets around IP.
  - Optimization of the compensation solenoid.
  - Local Chromaticity correction sections for both rings.
- -New low emittance optics for both e+e-rings
  - Replace dipoles, change wiggler layout for e^+ ring
- -New low emittance beam injections
  - New damping ring & target for e^+
  - New RF gun for electrons
- -Higher beam currents
  - Add / modify the RF systems
- -Precise beam diagnostics and tunings
  - More precise magnet setting ⇔power supplies.

SuperKEKB Projection



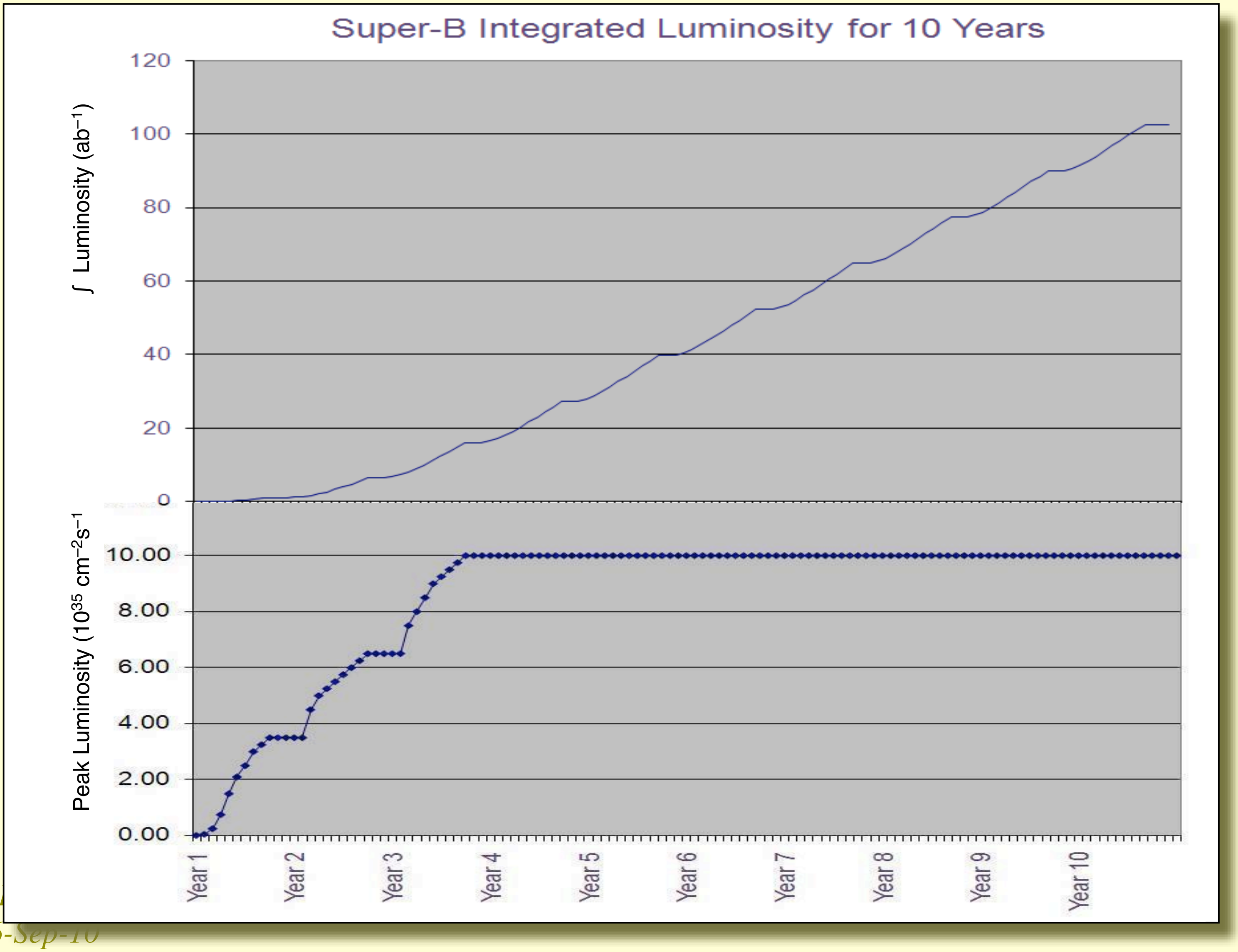
50 ab^{-1}
in 2020…2021.

9 month/year
20 days/month

Commissioning starts
mid of 2014

Shutdown for
upgrade

SuperB Projection



Conclusion

- Two next-generation *B*-Factories are in an advanced design stage.
  - Both use a large crossing angle and have provisions for a crab-waist sextupole pair
  - The crab waist was proposed and successfully operated at DAFNE
  - Super*B* add polarized electrons as an integral component of the design
- Direct evolution of the extremely successfull *B*-Factories (about 1.5 ab^{-1} combined data set).