LESSONS FROM B-FACTORY OPERATION
and
SECOND-GENERATION B-FACTORY PROPOSALS

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SLAC National Accelerator Laboratory

PAC 2009 Vancouver, BC
May 4, 2008

Topics

* e+e- colliders at the Upsilon resonance
* Trends of parameters of former or ongoing five colliders leading to two perhaps future colliders:
  - Energy and circumference
  - Factors determining luminosity
  - Number of bunches and beam currents
  - Bunch length and β^*s
  - IP free space and crossing angles
  - Injection
  - Beam-beam tune shifts and luminosity
* Conclusions

Collider Energies and Ring Sizes

*

Collider	e+ energy	e- energy	Circumference
	(GeV)	(GeV)	(m)
DORIS-II	5.28	5.28	288
VEPP-4M	5.28	5.28	366
CESR	5.28	5.28	768
PEP-II	3.1	9.0	2200
KEKB	3.5	8.0	3016
Super-KEKB	3.5	8.0	3016
Super-B	4	7.0	1800

DORIS-II at DESY (~1978-1984)

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VEPP-4M at BINP (1983-1985)

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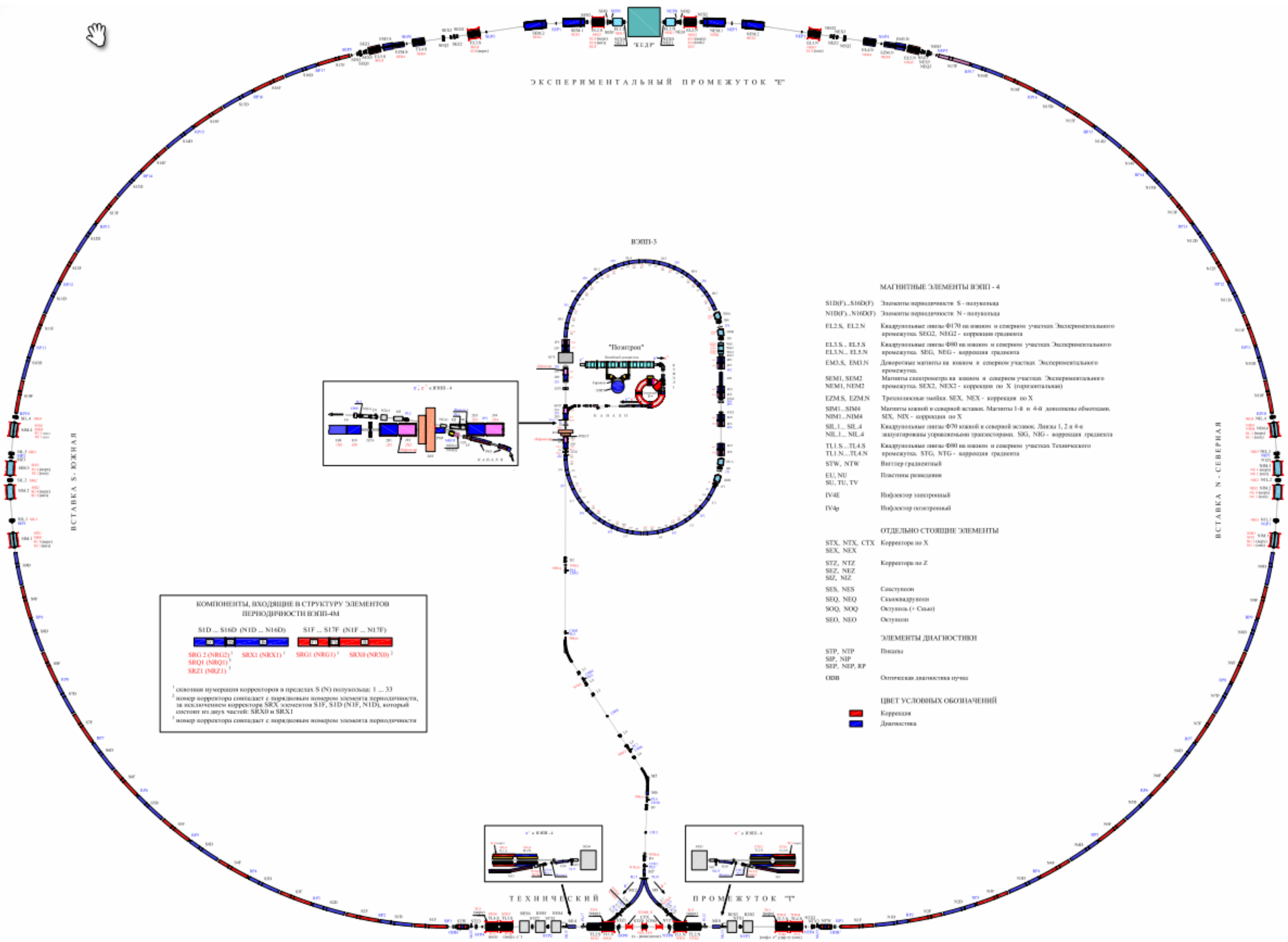

CESR at Cornell (1979-2001)

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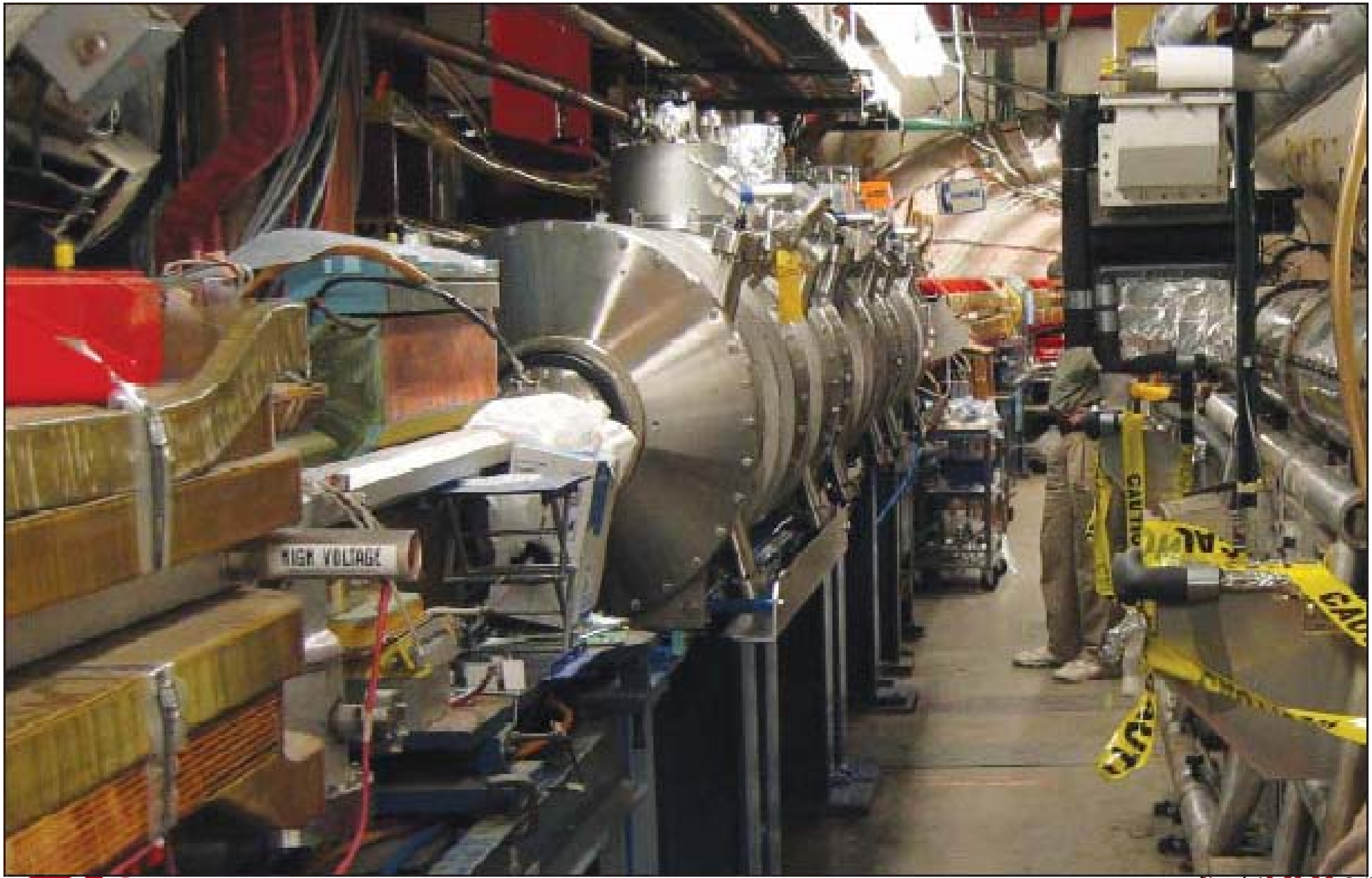

PEP-II at SLAC (1999-2008)

KEKB at Tsukuba (2000-2010)

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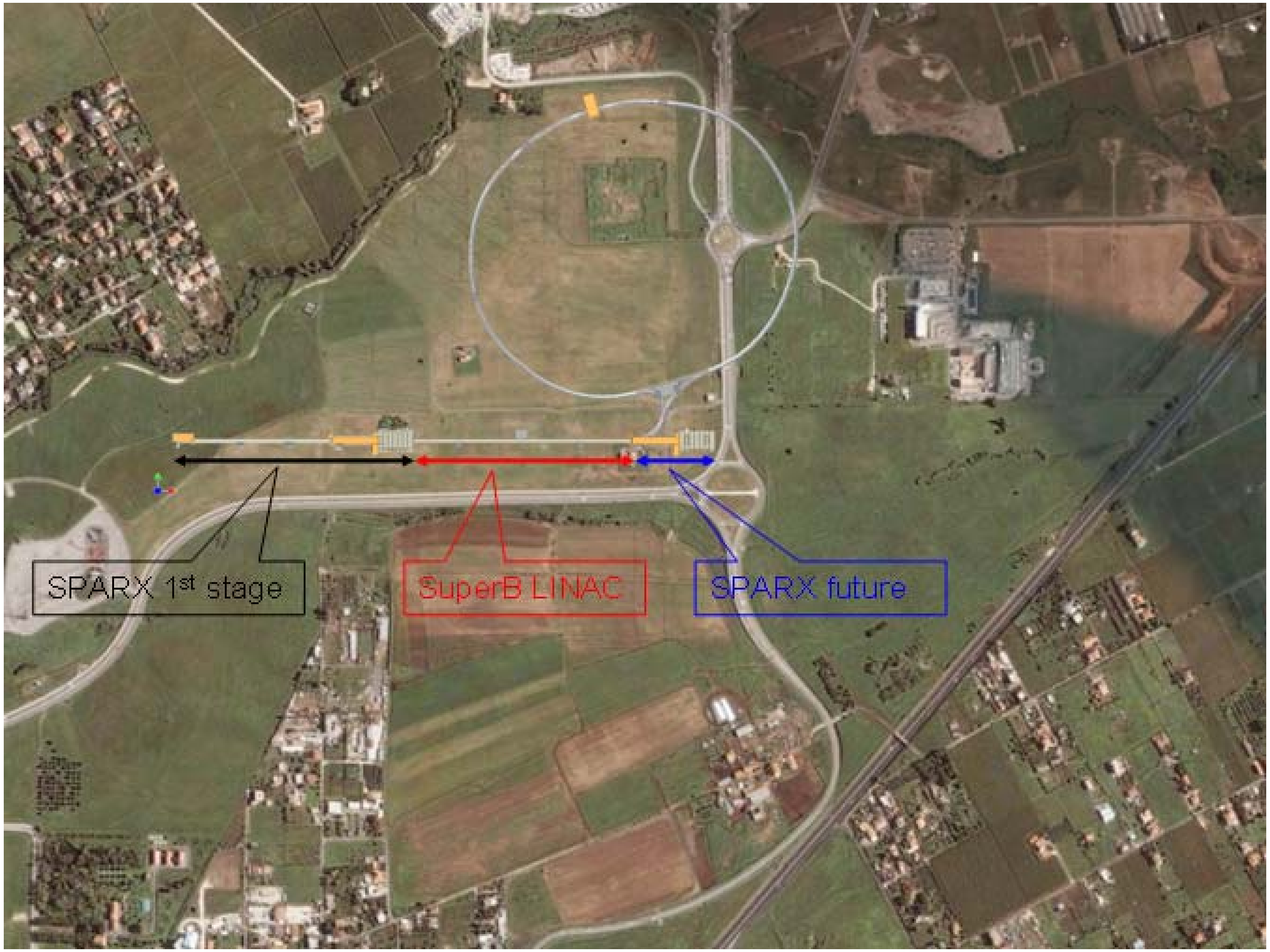
Future: Super-B site at Tor Vergata University near Frascati, Italy

*



Talk by
M. Biagini

Future: Super-KEKB Tsukuba

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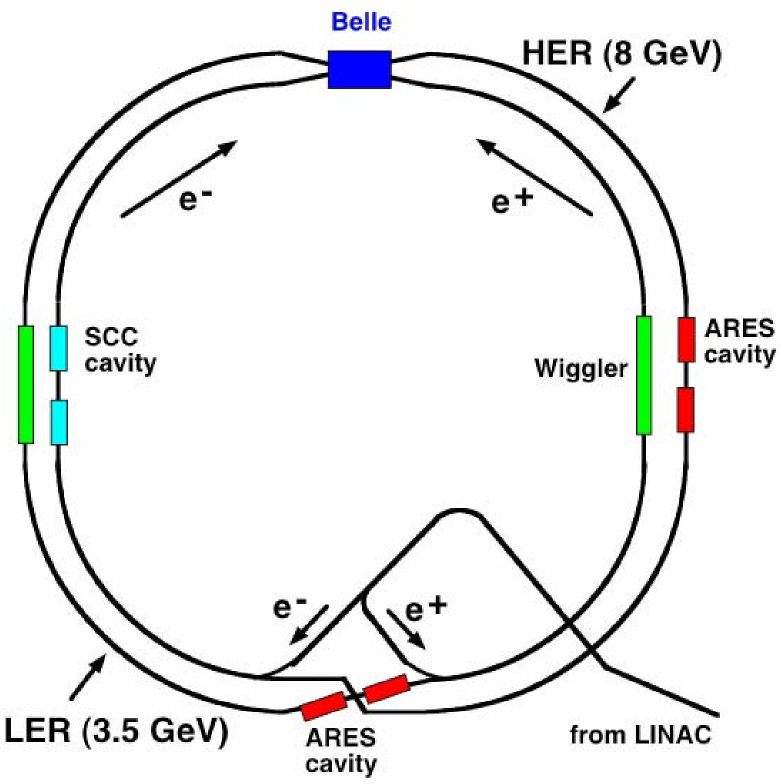

KEKB Ring

Talk by
K. Oide

Luminosity and Beam-Beam Parameter Equations for a Circular e^+e^- Collider

ξ_y is the beam-beam parameter (~0.06)

I_b is the bunch current (1 to 3 mA)

n is the number of bunches (~1700)

β_y^* is the IP lattice optics function (vertical beta) (10 mm)

E is the beam energy (3.1 and 9 GeV) (fixed)

Luminosity (10^{33} cm^{-2} s^{-1})

$$L = 2.17x10^{34} \frac{n \xi_y E I_b}{\beta_y^*}$$

$$\xi_{y,+} = \frac{r_o N_- \beta_{y,+}^*}{2\pi\gamma_+ \sigma_{y,-}^* (\sigma_{x,-}^* + \sigma_{y,-}^*)}$$

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Number of Bunches and Beam Currents

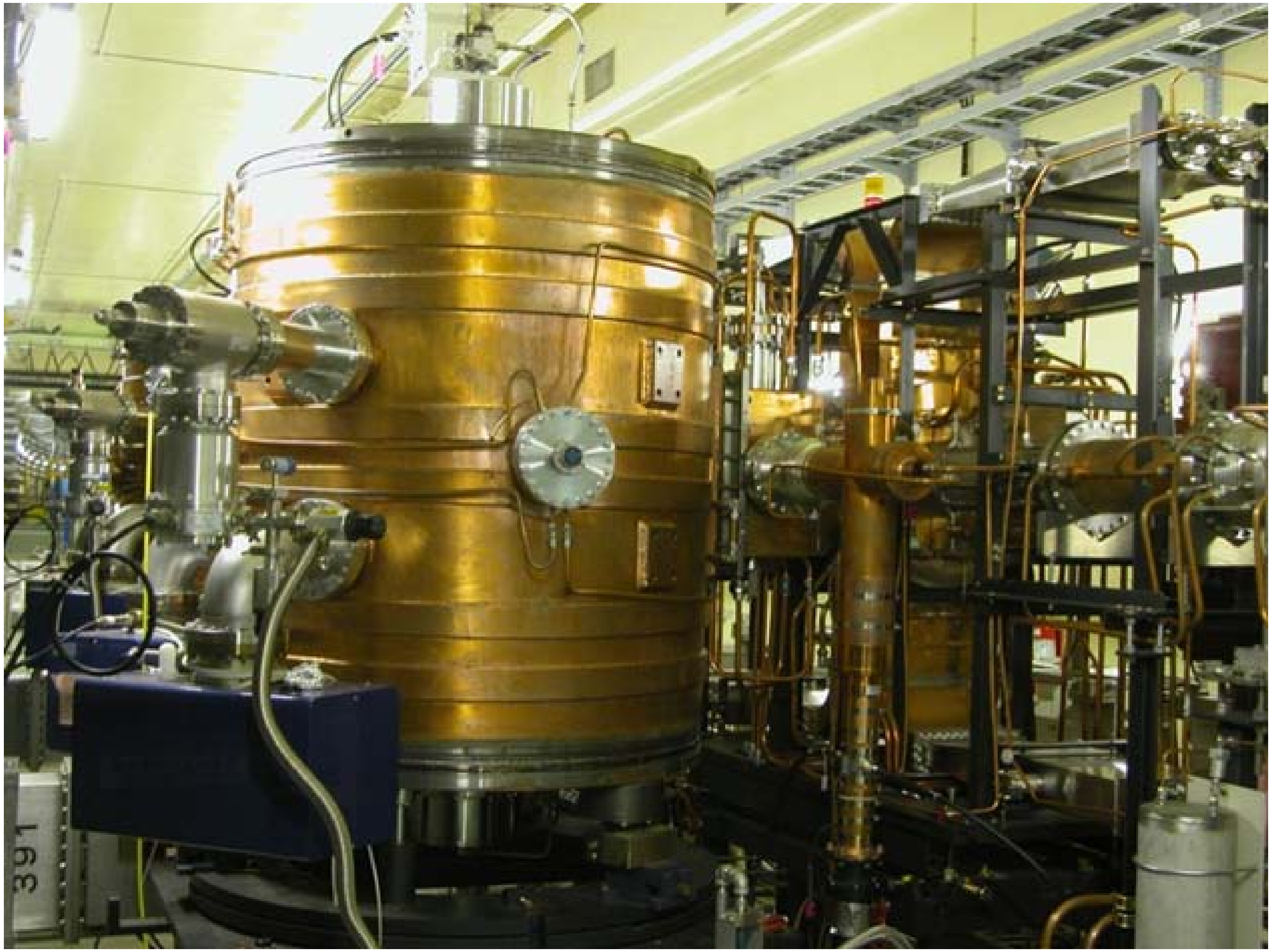
*

Collider	Bunches	e+ current	e- current
		(mA)	(mA)
DORIS-II	1	42	42
VEPP-4M	1	12	12
CESR	5x9=45	375	375
PEP-II	1722	3210	2070
KEKB	1585	1662	1340
Super-KEKB	5018	9400	4100
Super-B	2500	2800	2800

ARES in the KEKB Tunnel

Design Parameters

V_c	0.5MV
R_a/Q_0	15 Ω
Q_0	11x10^5
P_{in}	400kW
P_c	150kW
U_s/U_a	9 → 15



KEKB HER SC RF Cavities

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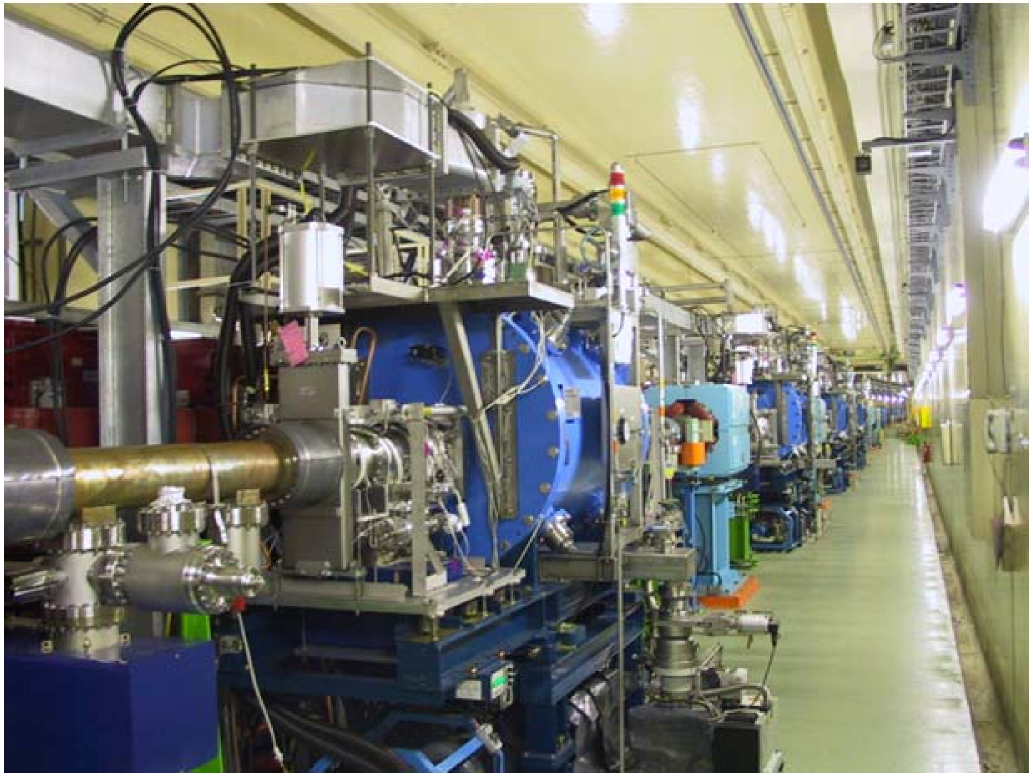
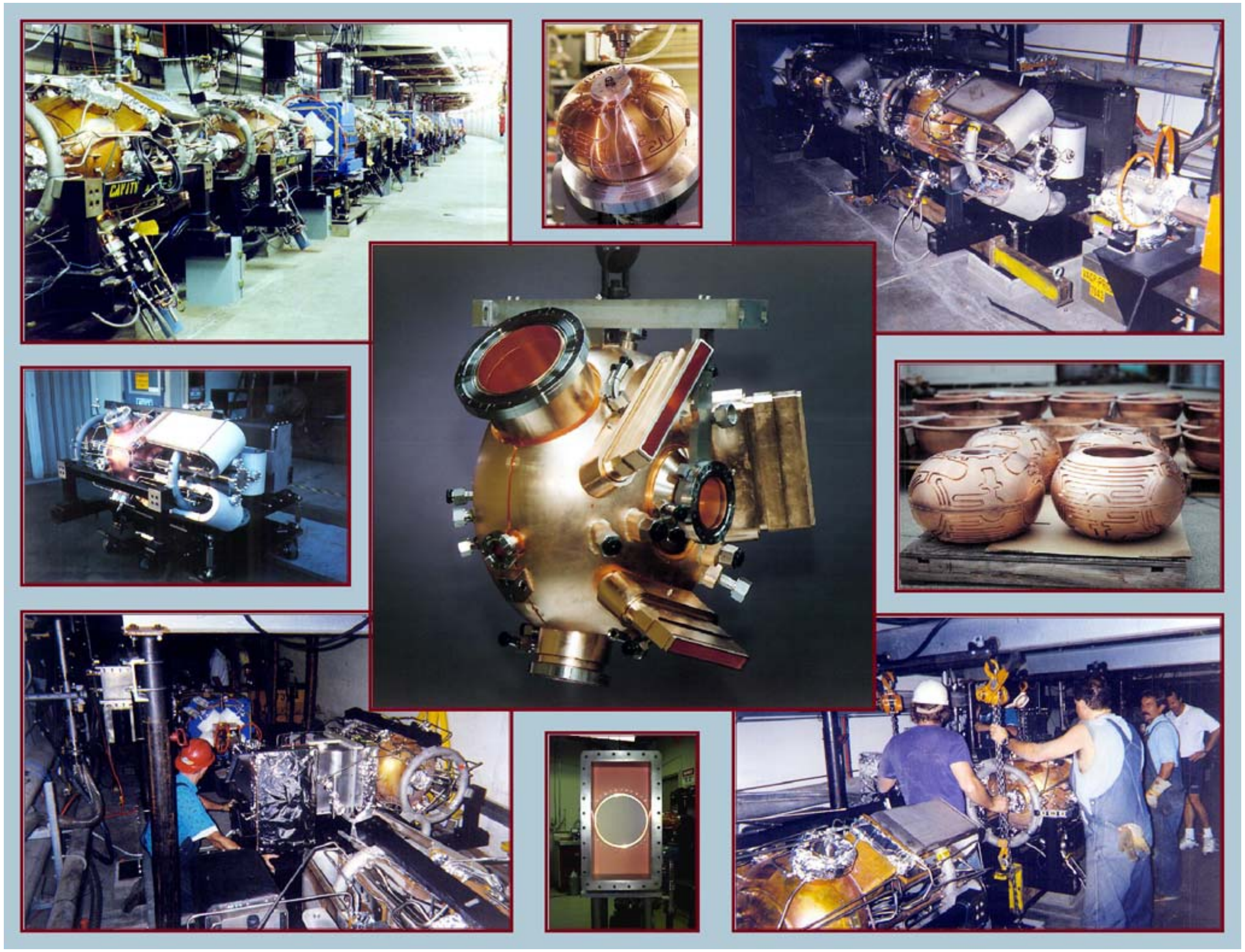
N_b cavity



PEP-II Radio-Frequency RF System



Each cavity:
850 kV
500 kW
476 MHz
HOM loads
Ceramic
windows

B-Factory RF Klystrons (1.2 MW)

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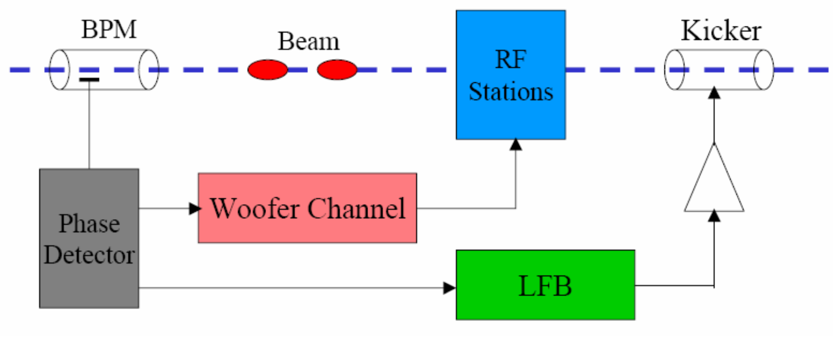
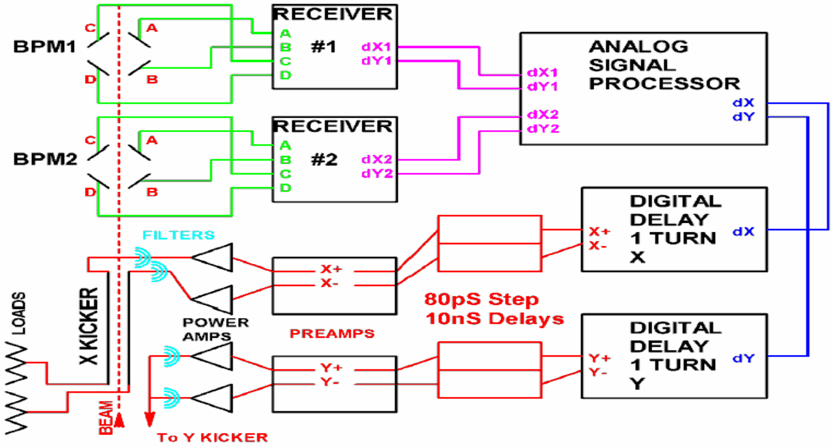
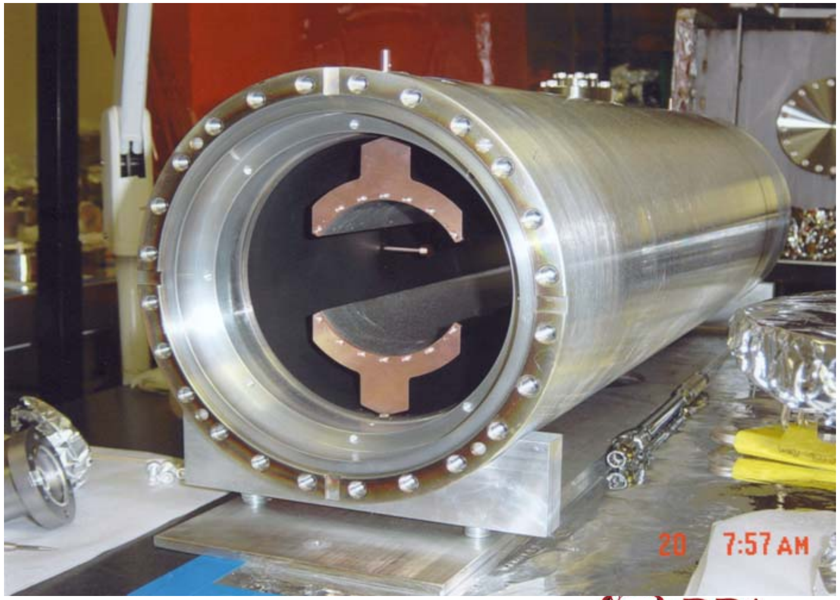
Bunch-by-bunch feedback systems (Fox, Barry)





Frascati longitudinal kicker

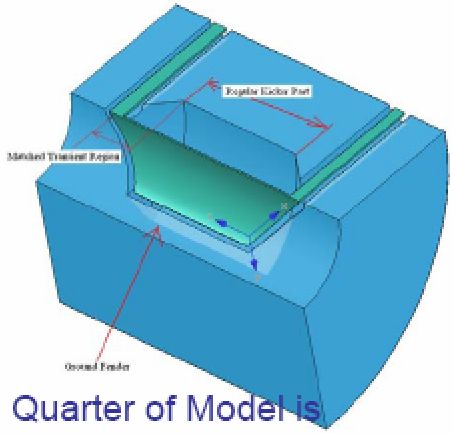


LBL transverse kicker

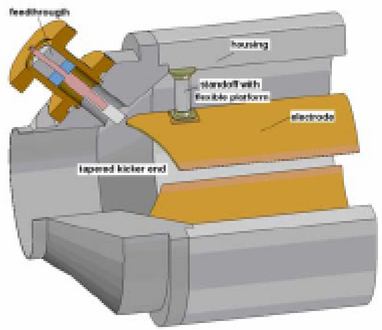
New feedback Kicker design (A. Krasnykh)

*

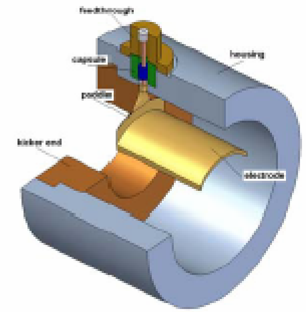
SuperB Kicker Assembly (proposal)



Quarter of Model is shown



PEP TFB Design

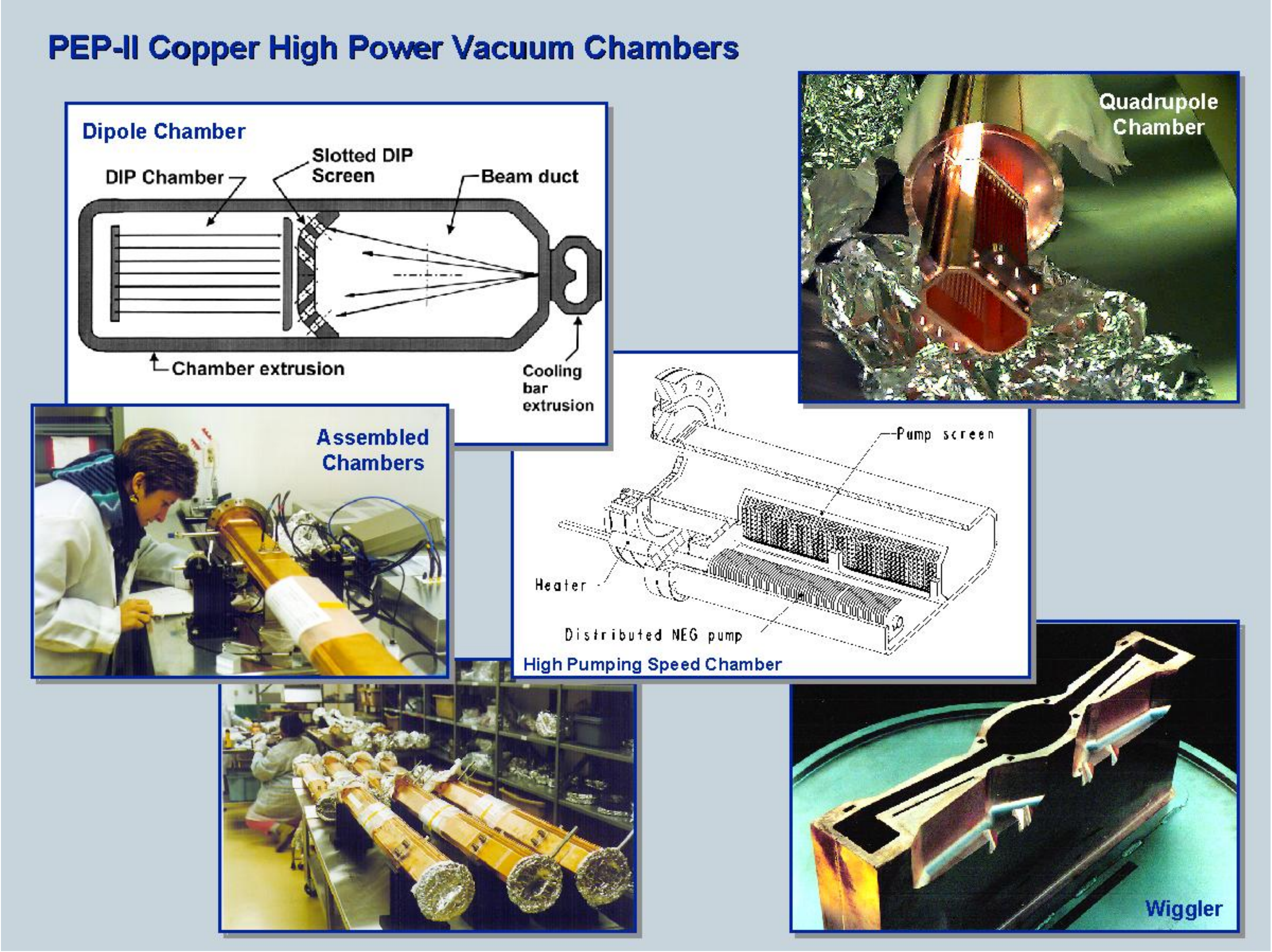


Electrodynamic Structure with:

- Regular Kicker Part
- Two Matched Transition Regions at the Kicker Ends
- Ground Fenders
- Broadband Constant Impedance Feedthrough

20

PEP-II Copper Vacuum System



Cu chambers absorbing 100 W/cm of synchrotron radiation

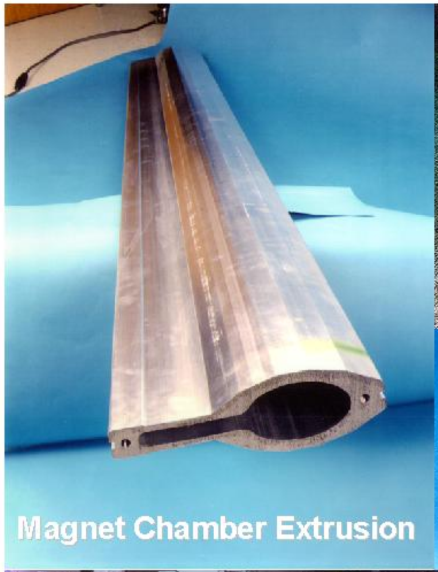
Total SR power = 5 MW in the HER

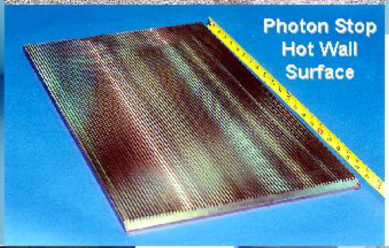
LER Magnets and Aluminum Vacuum System

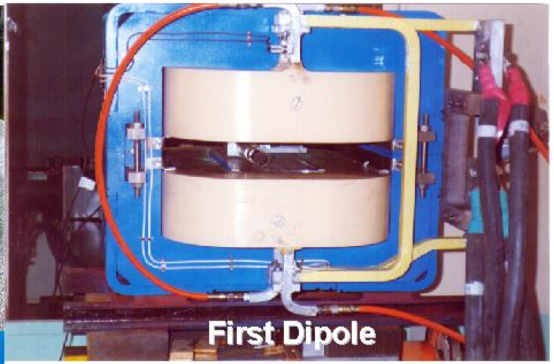
Antechambers Reduce Electron-Cloud-Instability

High power photon stops

LER SR power = 2 MW.







Low Energy Ring

LER Wiggler Chamber (LLNL)

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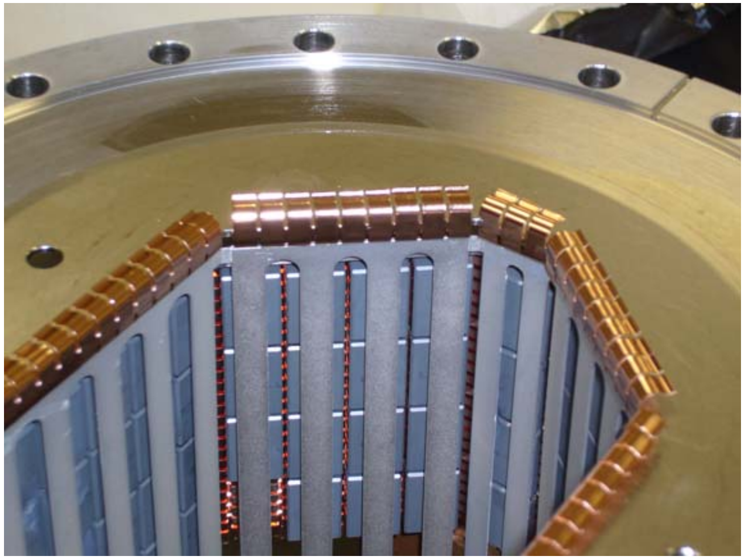
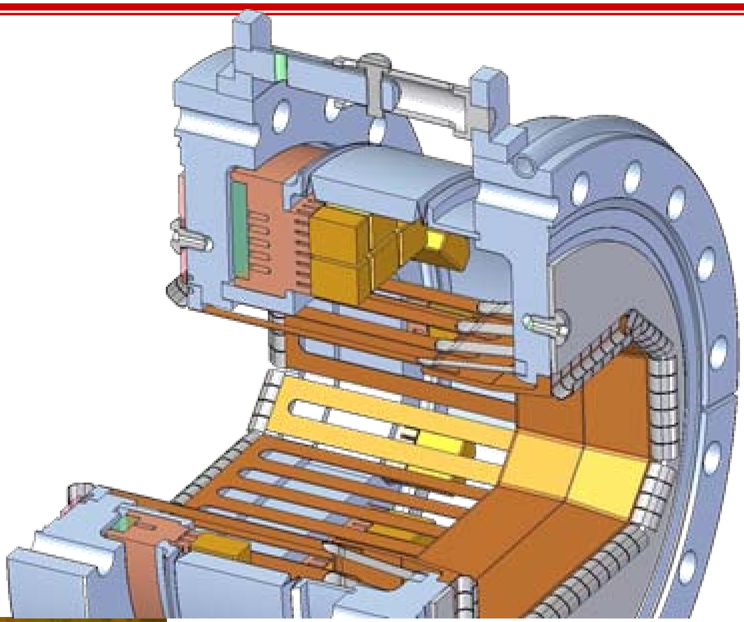
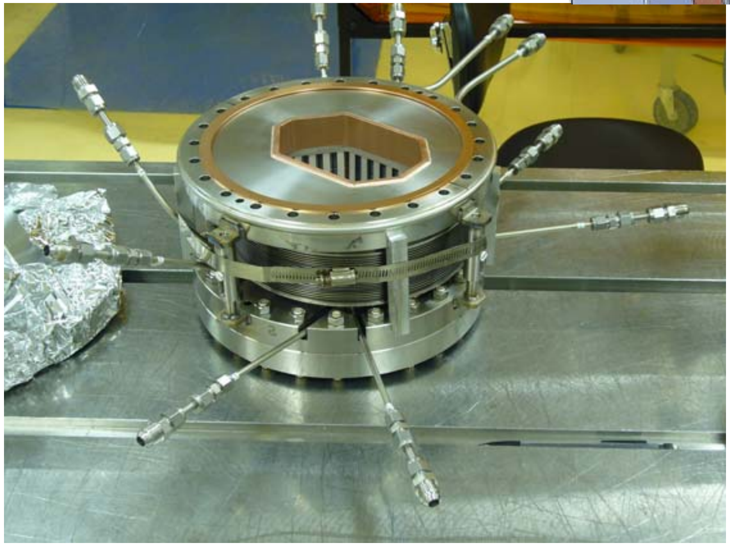
LK_094 Downstream Wiggler Chamber #5 02/03/98

Final sliding bellows solution

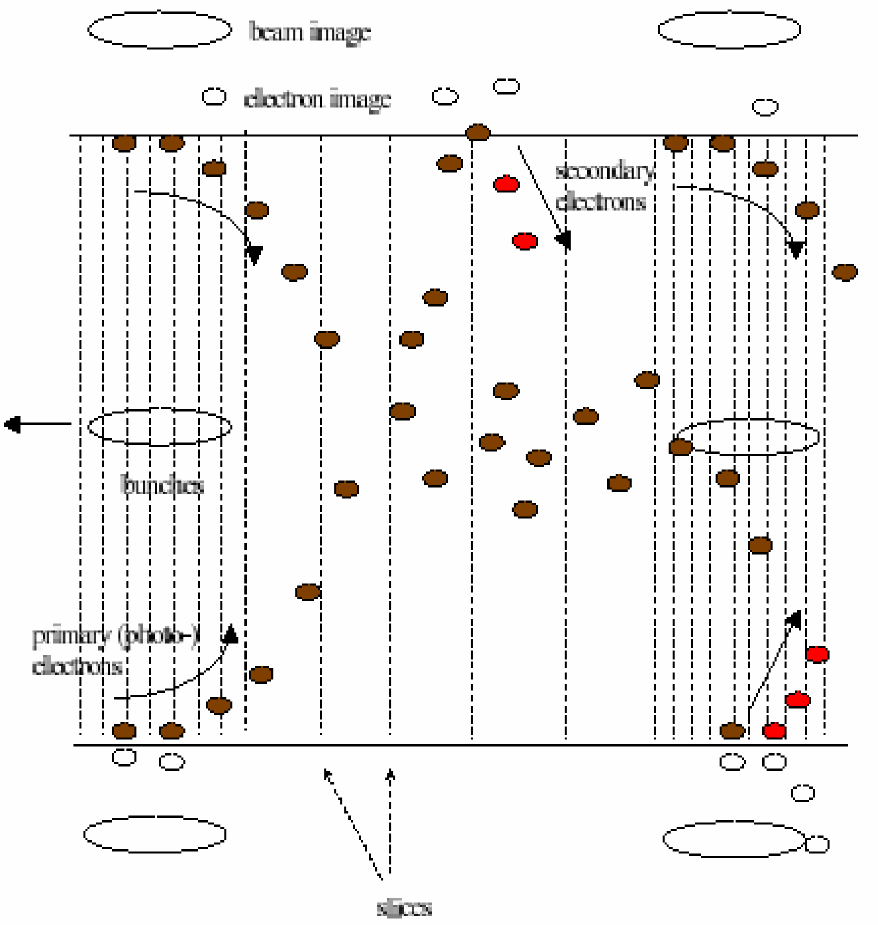


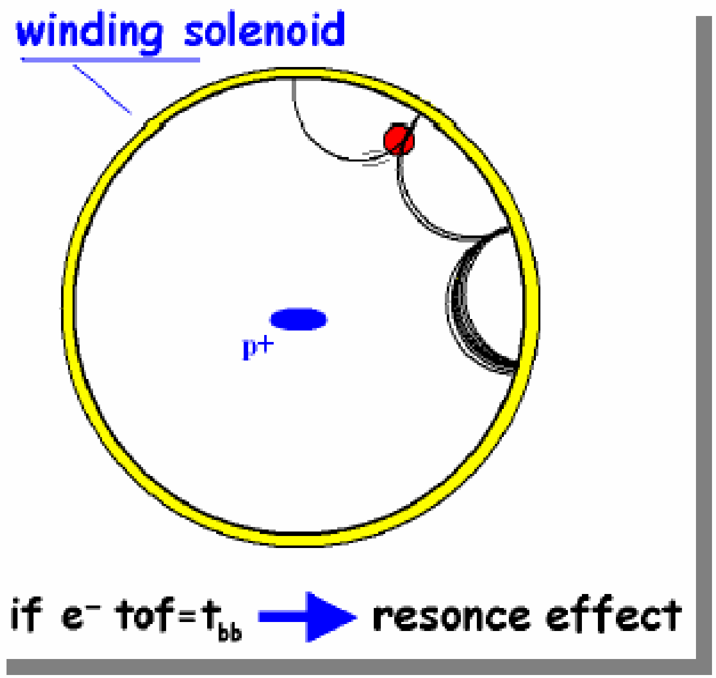




The new MKIII bellows

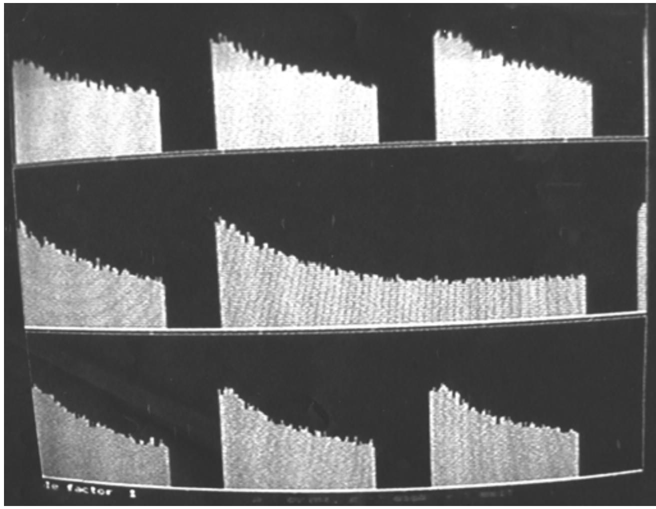
Positrons: Electron Cloud Instability & Multipacting

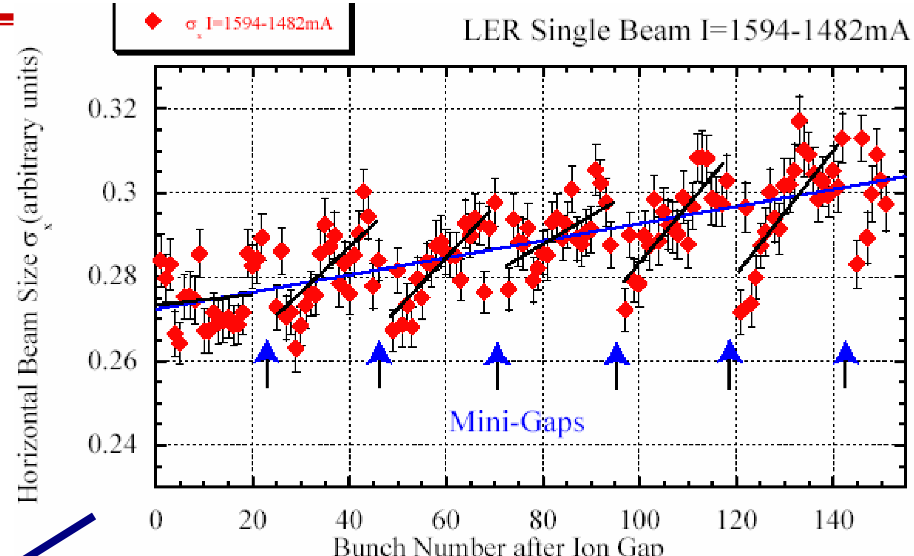




Resonance multipacting in solenoid field when the electron time of flight is equal to the bunch spacing

Luminosity drop in “ long” mini-trains from ECI → Solenoids





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Bunch Lengths and β*s

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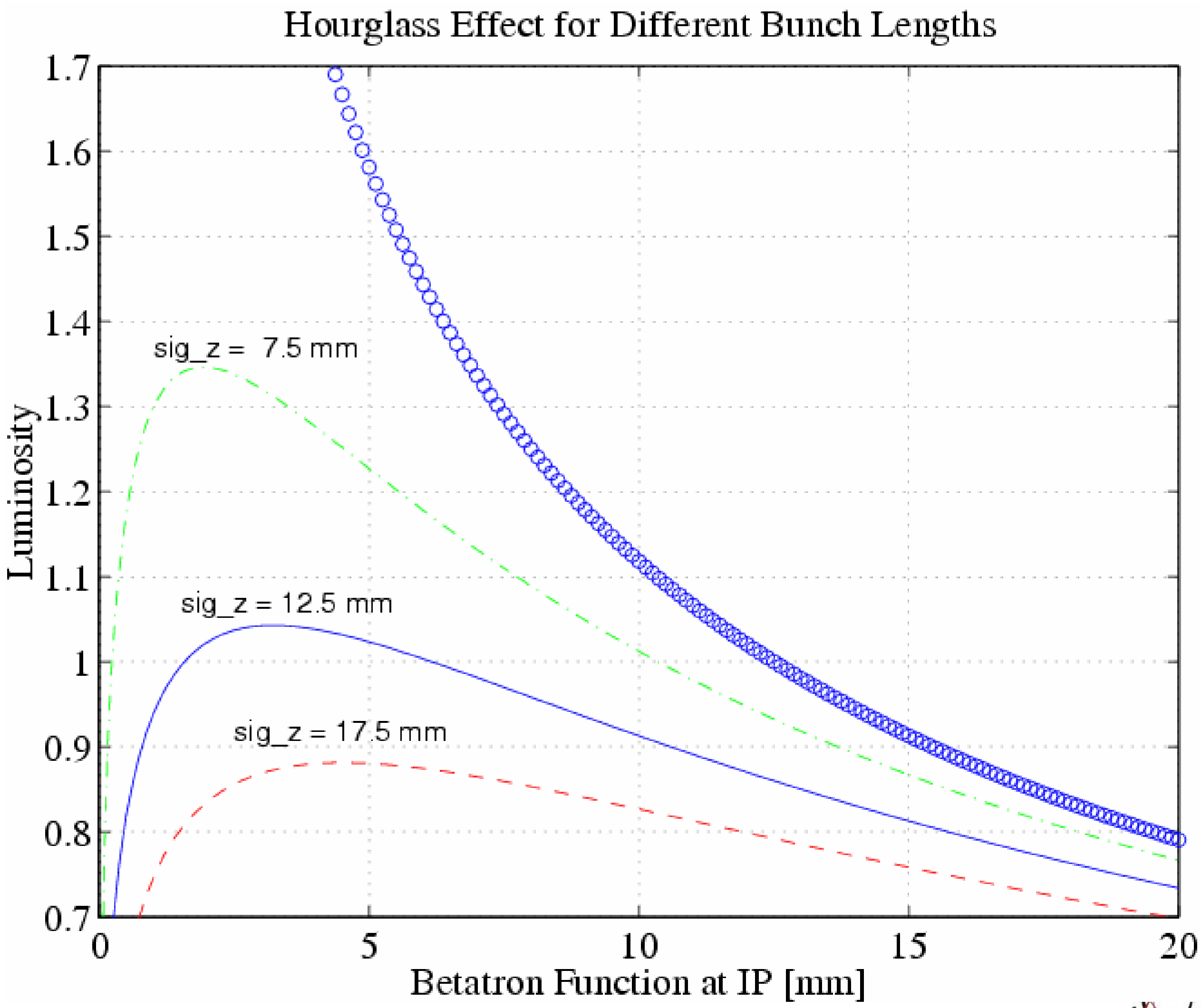
Collider	Bunch length	βy*	βx*
	(mm)	(mm)	(mm)
DORIS-II	36	40	630
VEPP-4M	50	50	750
CESR	18	18	1000
PEP-II	11	9	26-50
KEKB	7	6	900
Super-KEKB	3/5	3	200
Super-B	6	0.25/0.35	20/35

Lower β_y* to increase luminosity



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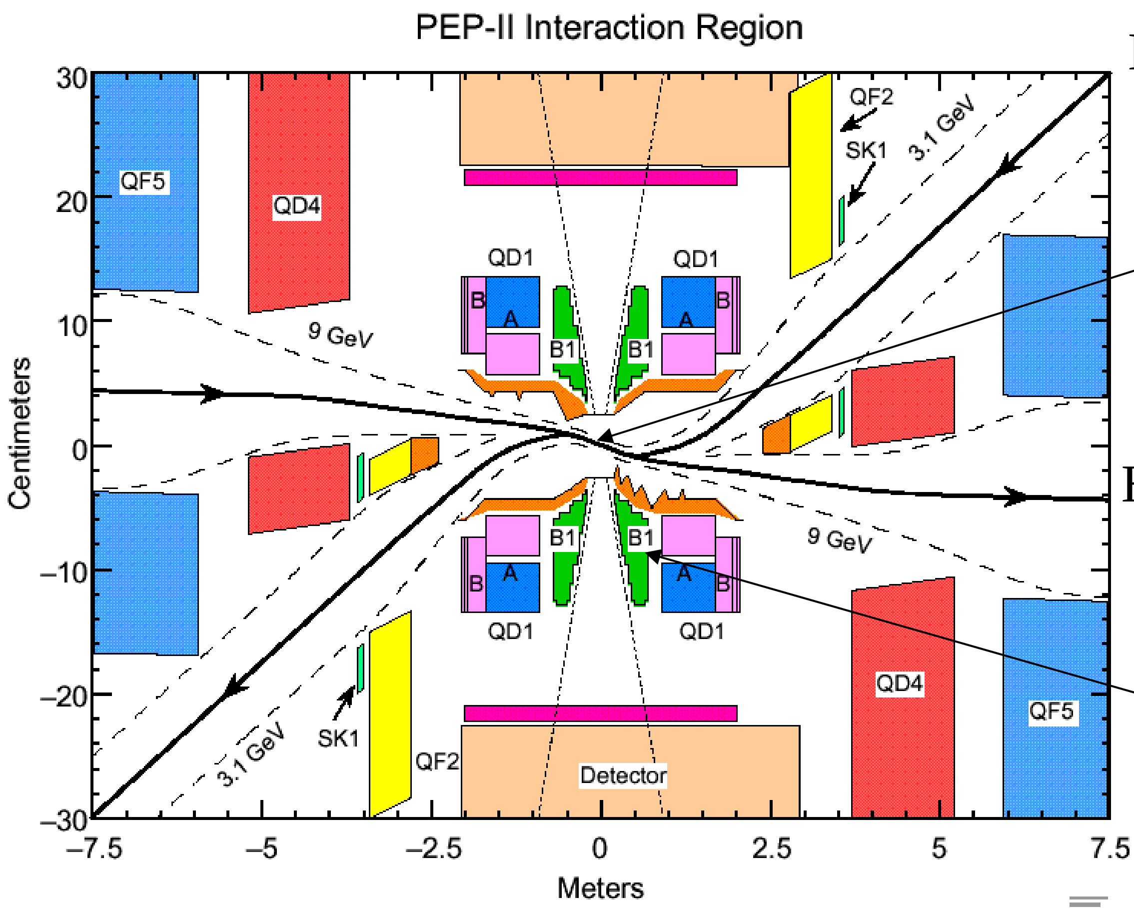
PEP-II Near Interaction Region



Low Energy Ring LER beam

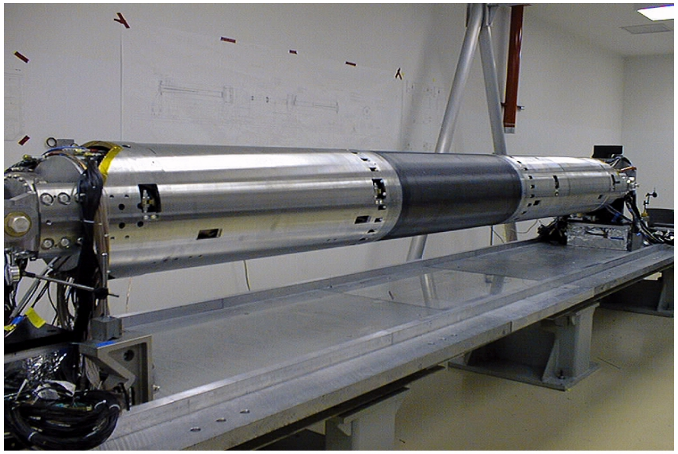
Head-on collisions

High Energy Ring HER beam

Permanent magnet dipoles and quadrupoles inside BaBar's 1.5 T solenoid

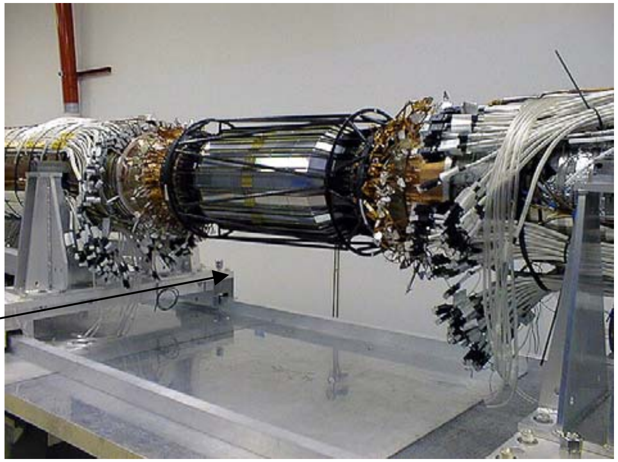
Interaction Region Support Tube

MS_108 05/27/98

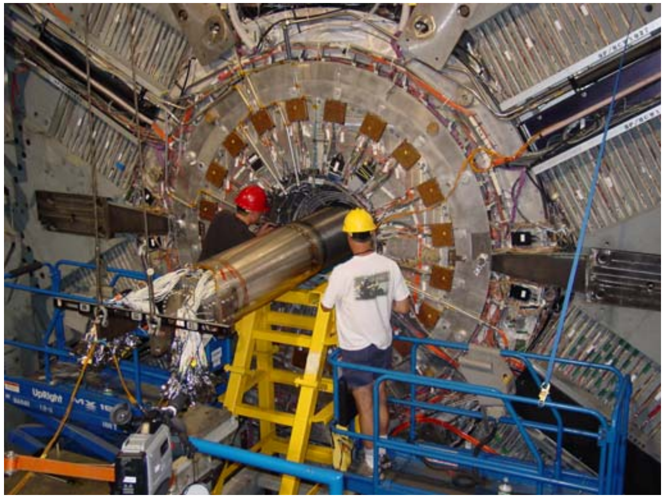


MS_140 Support Tube ready for Installation 06/08/98

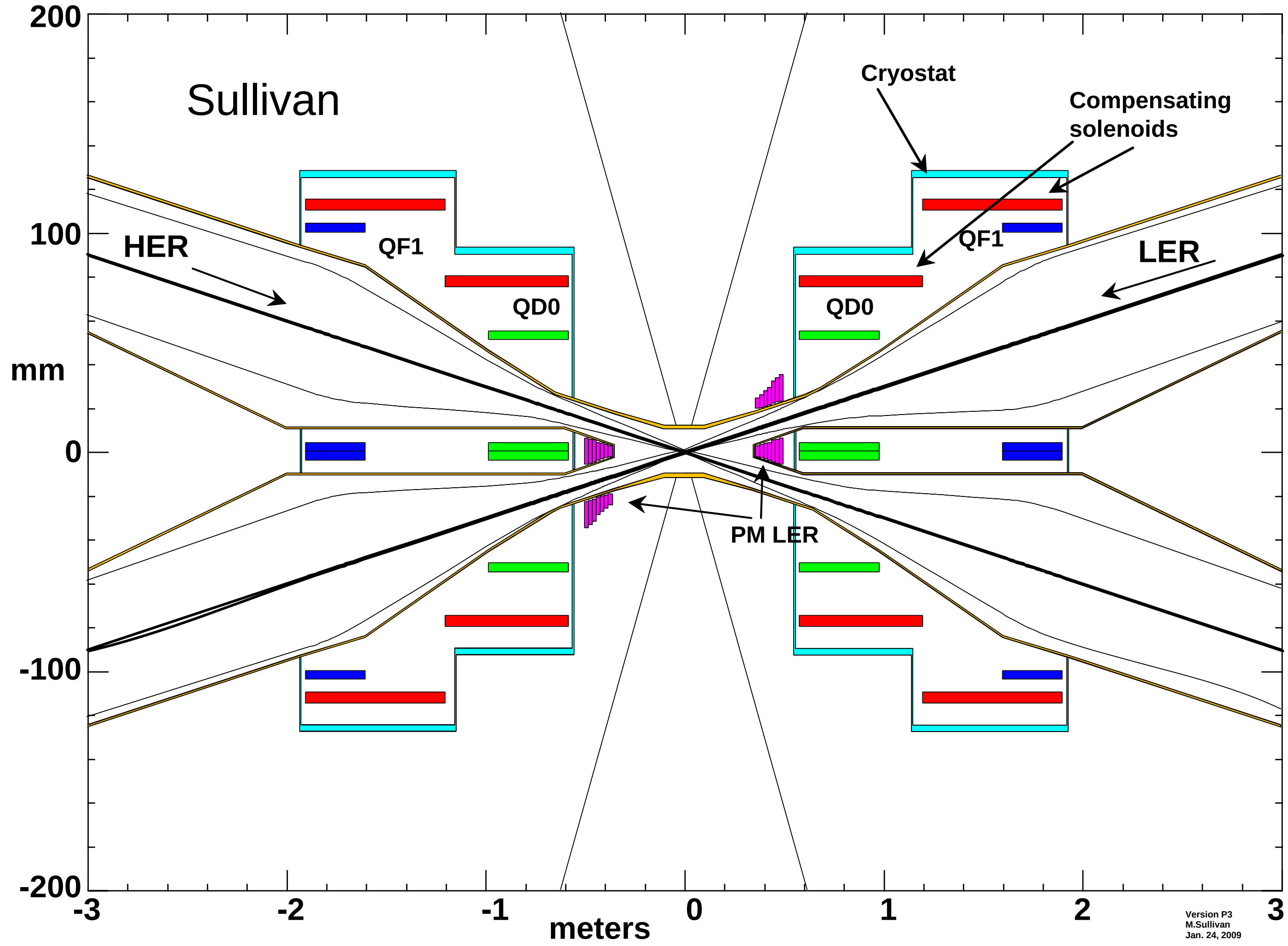
Be chamber



Silicon
Vertex
Tracker
SVT



SuperB Interaction Region Layout View (Jan 2009)



M. Sullivan

IP Free Space, Crossing Angles, Horizontal Emittance

*

Collider	L* to 1st IR Quadrupole	Crossing Angle	ε_x
	(m)	(mrad)	(nm)
DORIS-II	~2	0	571
VEPP-4M	2	0	1333
CESR	0.6	0	211
PEP-II	0.9	0	23-48
KEKB	1.35/1.68	22	20-23
Super-KEKB	~1	30	18-24
Super-B	0.36/0.58	60	2-3

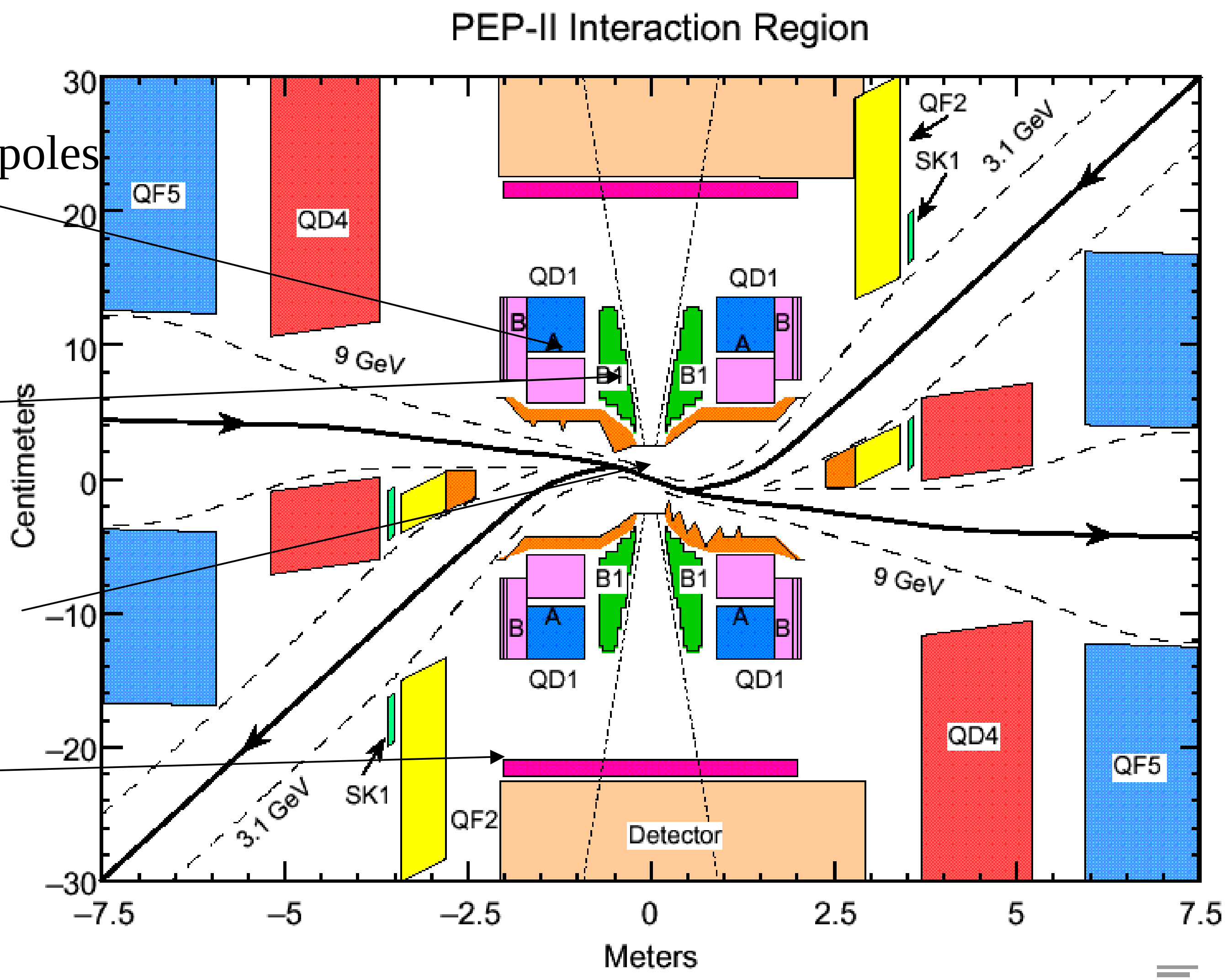
PEP-II IR

Permanent magnet
Quadrupoles and dipoles

Permanent magnet
dipoles

Head-on collisions

BaBar Solenoid



Super-B Lattice cells (P. Raimondi)

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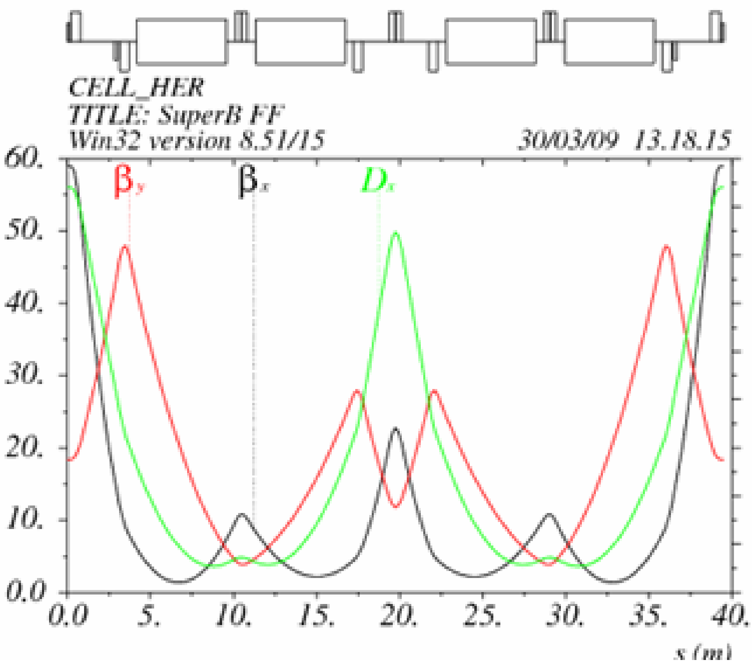
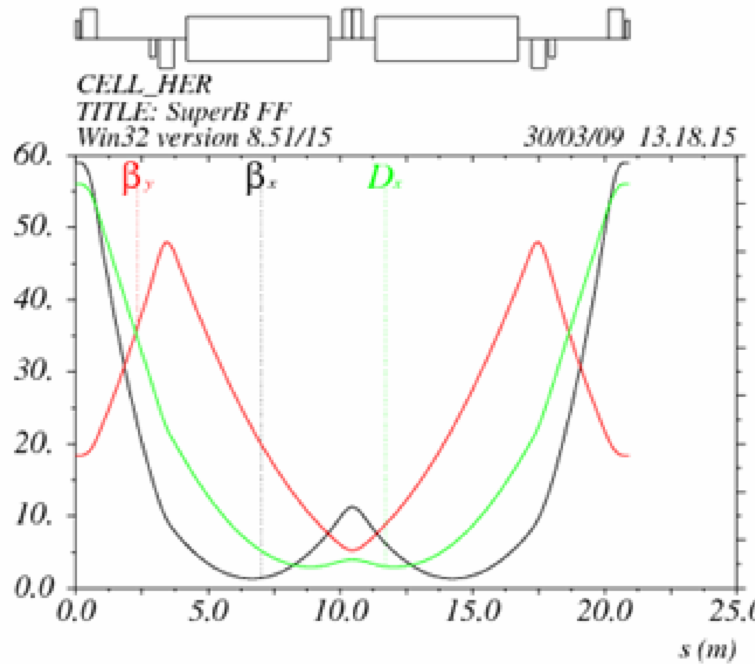
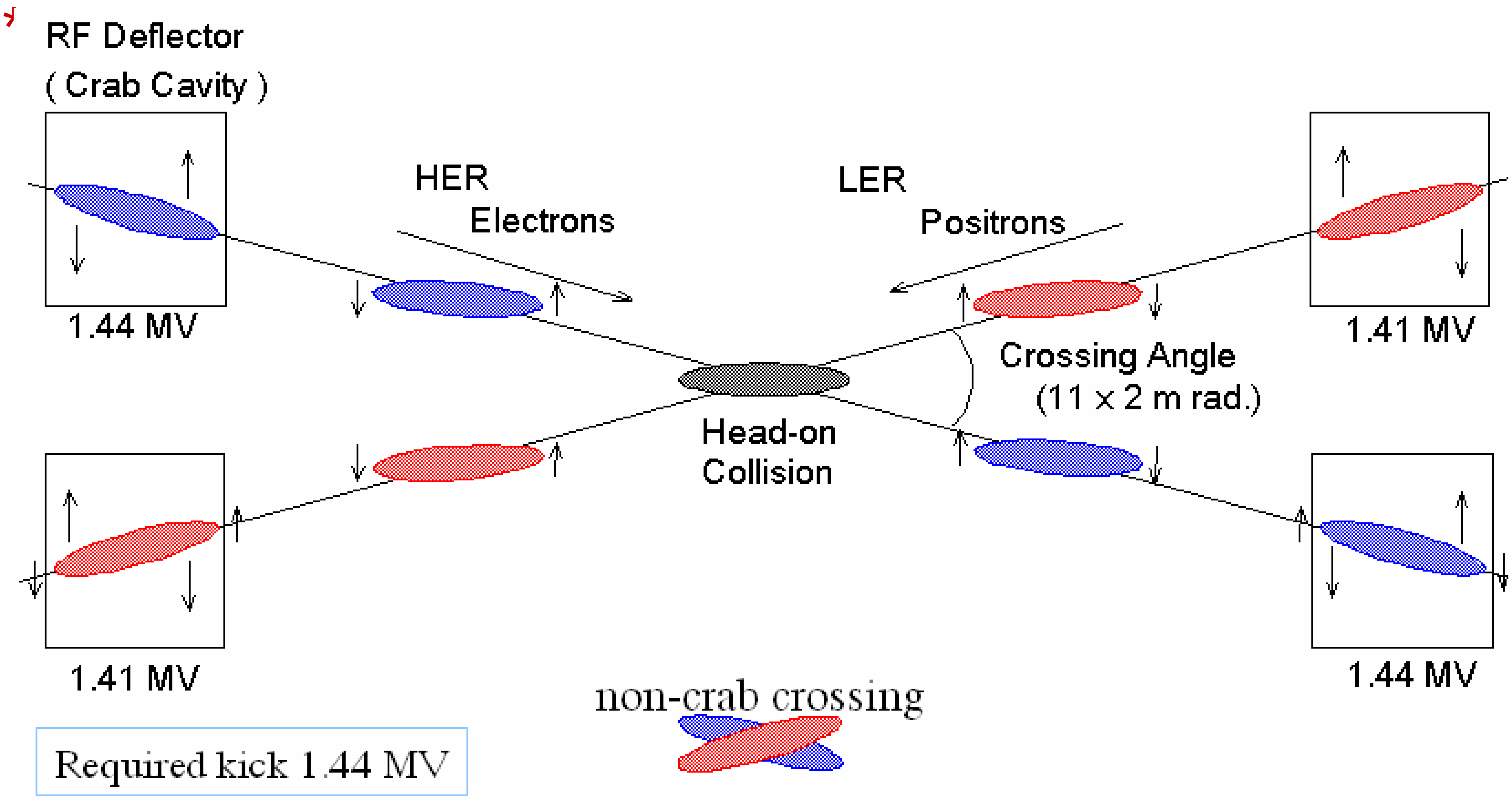
Distances between magnets
compatible with PEP hardware
All K-values are in range

Arc Cells





KEKB Crab Crossing



KEKB Crab Cavities

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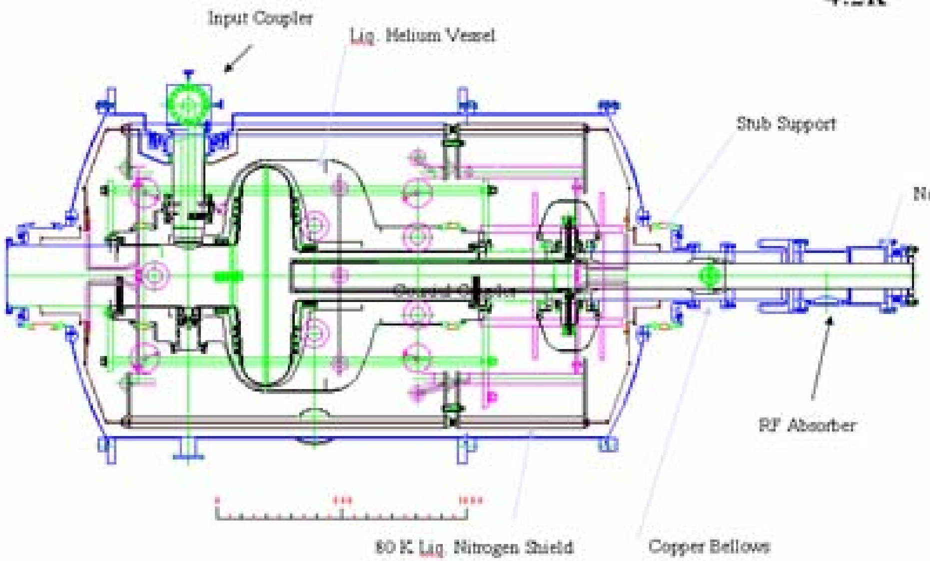
Heat Loss
80K 11
4.2K 1



Crab Waist Scheme (Raimondi)

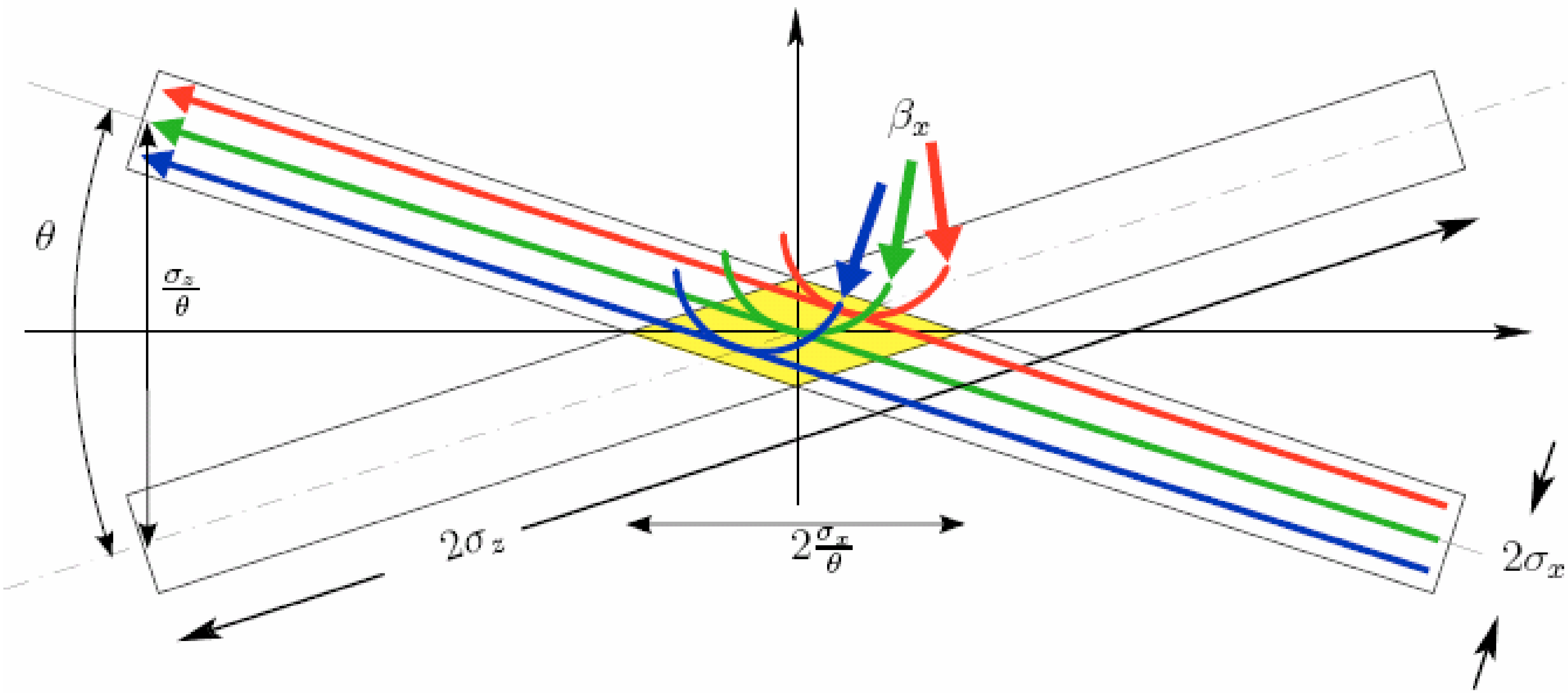
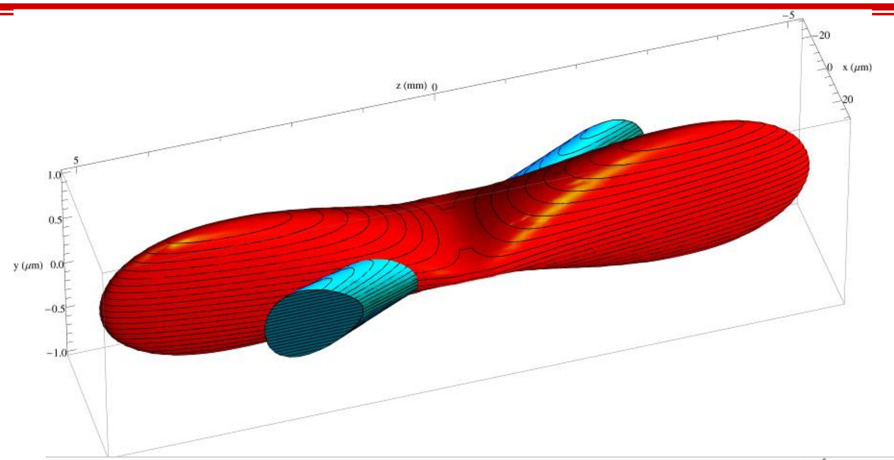


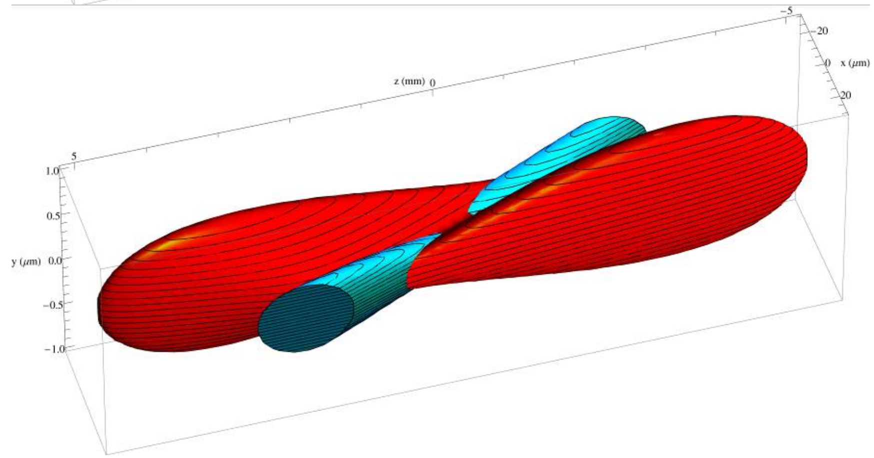
Figure 3-1. *Large Piwinski angle and crabbed waist scheme. The collision area is shown in yellow.*

Beams distribution at IP

E. Paoloni



Without
Crab-sextupoles



With
Crab-sextupoles

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

Super-B IR Lattice with Polarization (W. Wittmer)

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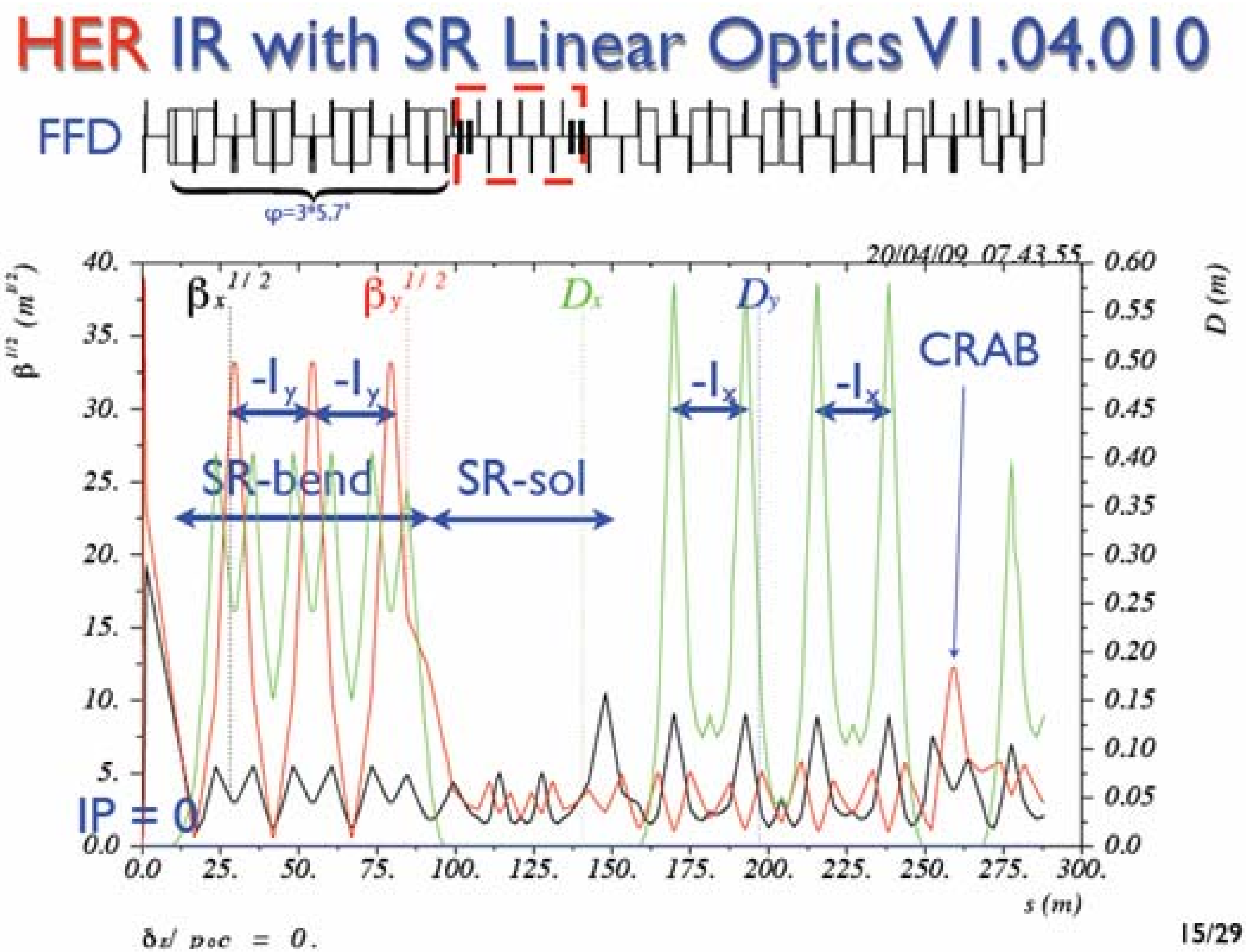


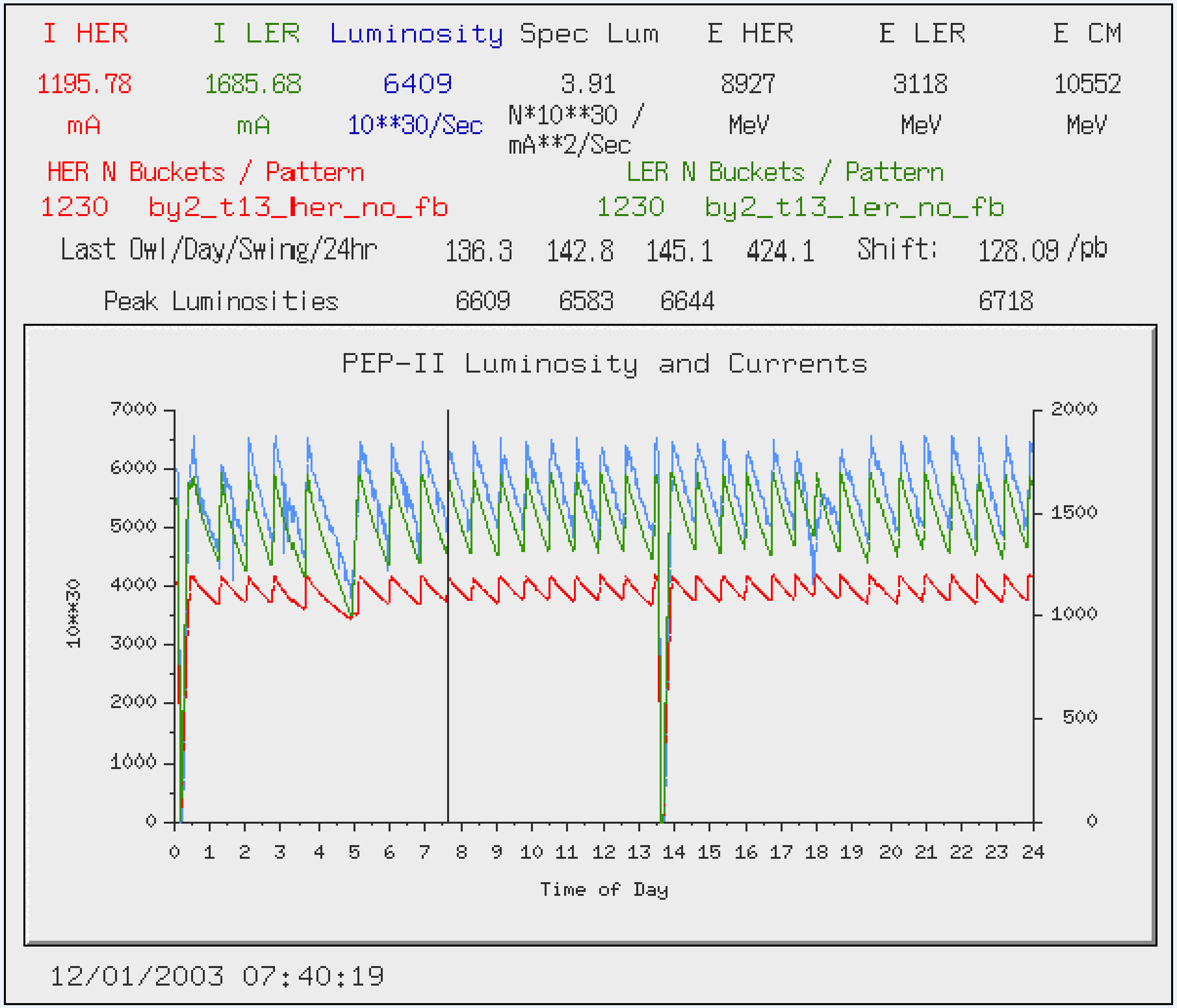
Injection

*

Collider		Injector	Top-off (continuous)
			Detector on
DORIS-II		Linac/Synch	No
VEPP-4M		Synchrotron	No
CESR		Linac/Synch	Possible
PEP-II		Linac/DR	Yes
KEKB		Linac	Yes
Super-KEKB		Linac/DR	Planned
Super-B		Linac/DR	Planned

Running before Trickle (Continuous) Injection (PEP-II)

*



Continuous Injection for PEP-II

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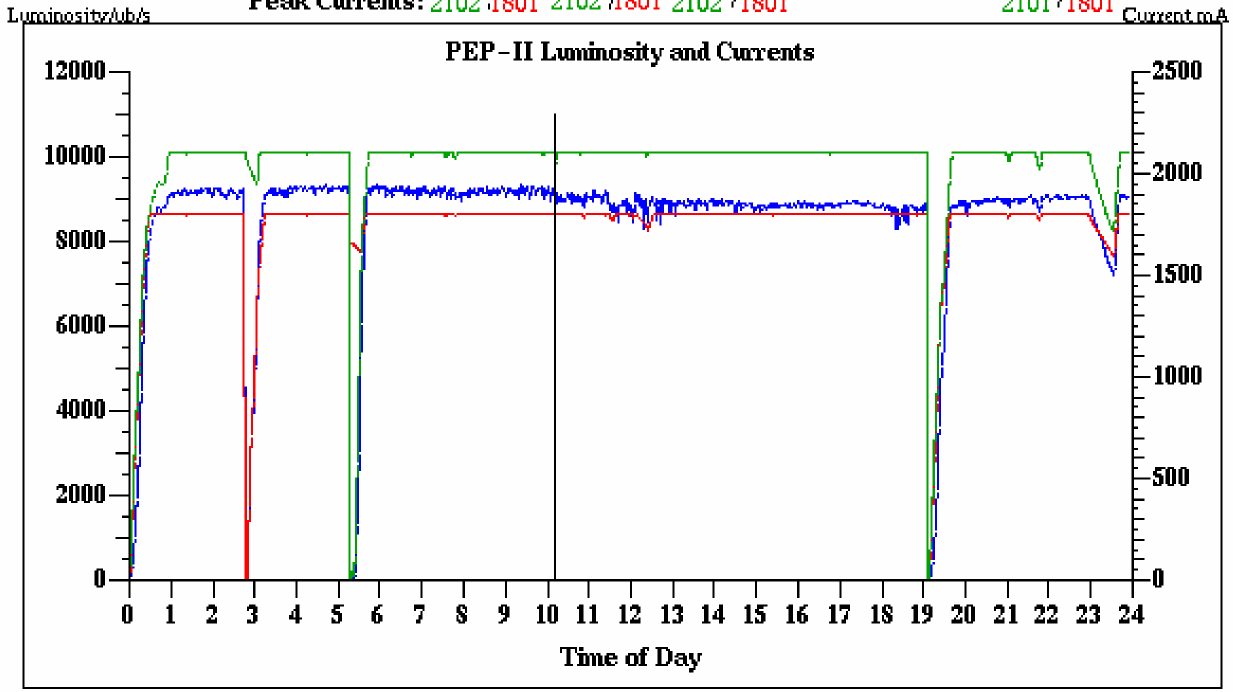
I HER	I LER	Luminosity	Spec Lum	E HER	E LER	E CM
1800.38 mA	2099.04 mA	9237 /ub/sec	4.21 /ub/s/mA^2	8597 MeV	3120 MeV	10359 MeV

N Bunches/HER Pattern		N Bunches/LER Pattern	
1722	0:3442:2	1722	0:3442:2

Last Owl/Day/Swing/24 Hr:	230.0	256.8	238.2	725.0	Shift: 72.10	/pb
Peak Luminosities:	9376	9271	9137		9386	
Stable Beams in Hours:	7.12	8.00	7.53		2.17	
Peak Currents:	2102 /1801	2102 /1801	2102 /1801		2101 /1801	



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KEKB Currents and Luminosity April 2009

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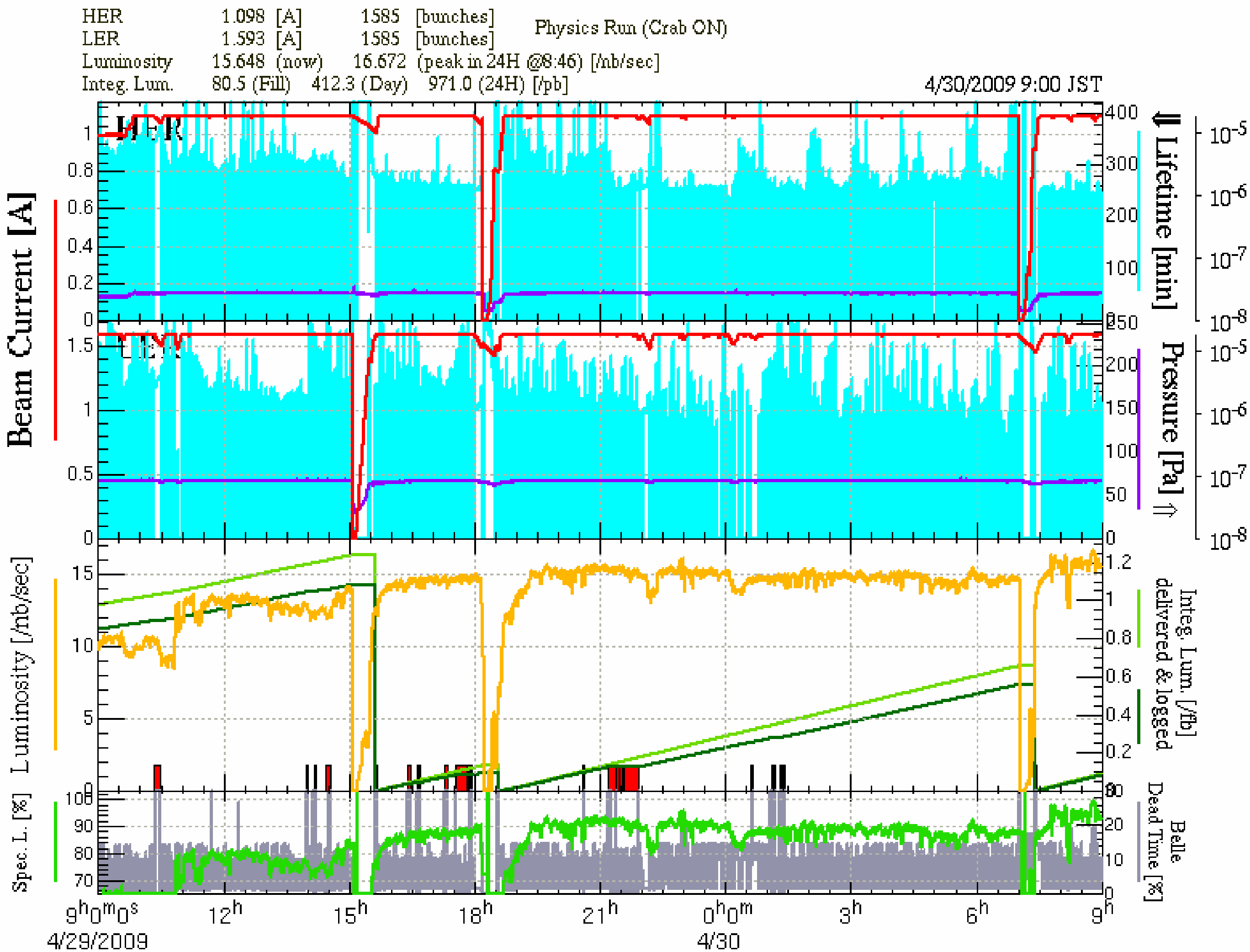

Beam-Beam Parameter and Luminosity

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Collider		ξ_y*	Luminosity
		(mm)	X $10^{32}/cm^2/s$
DORIS-II		0.026	0.33
VEPP-4M		0.059	0.2
CESR		0.068	12.8
PEP-II		0.065	121.
KEKB		0.09	176.
Super-KEKB		0.3-0.5 (plan)	5300 (projected)
Super-B		0.09 (plan)	10000 (projected)

CESR Luminosity and Tune Shift

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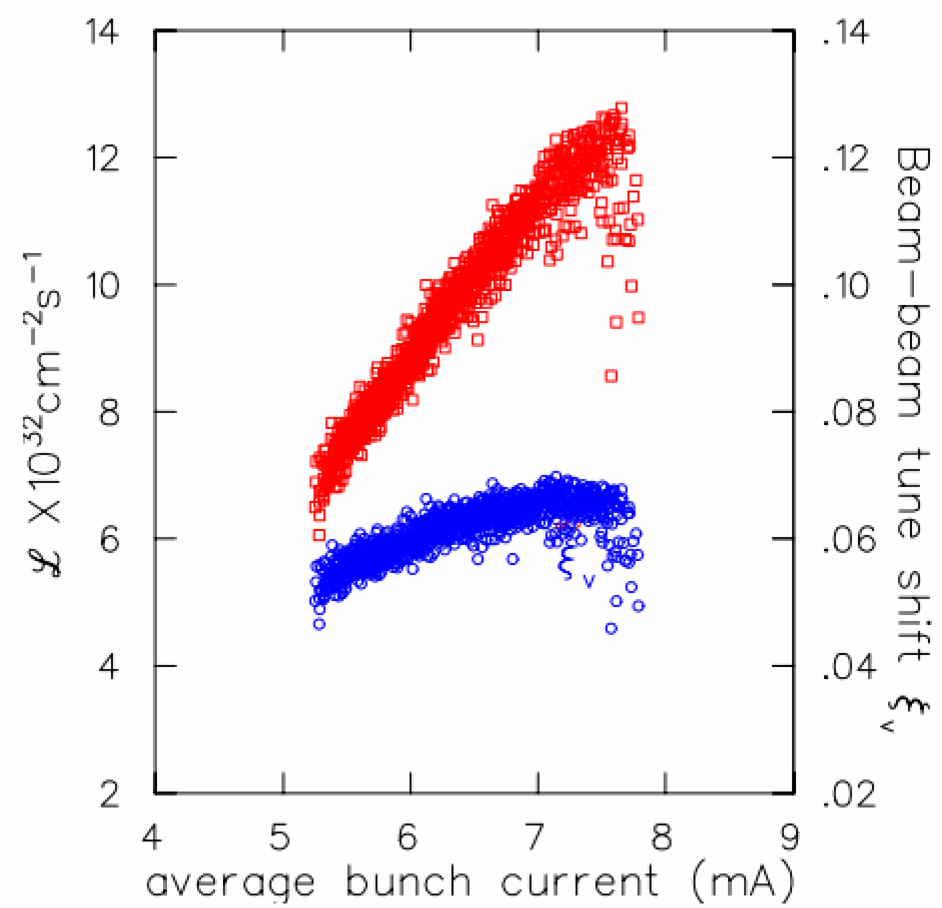
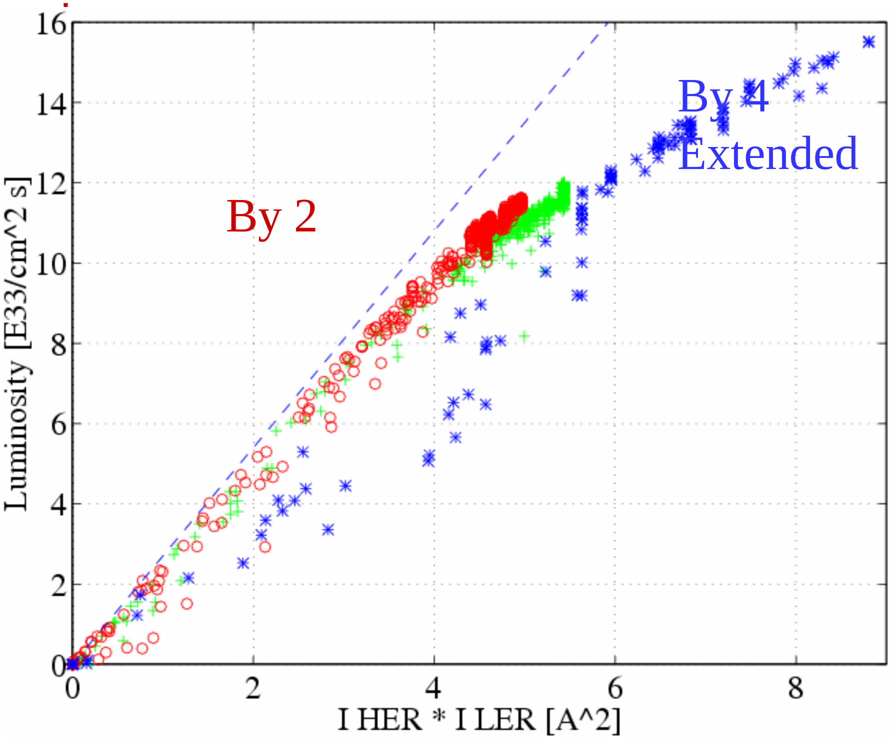


Beam-beam parameters



$\sigma_y^* = \sim 3.5\text{-}4.3\ \mu m.$

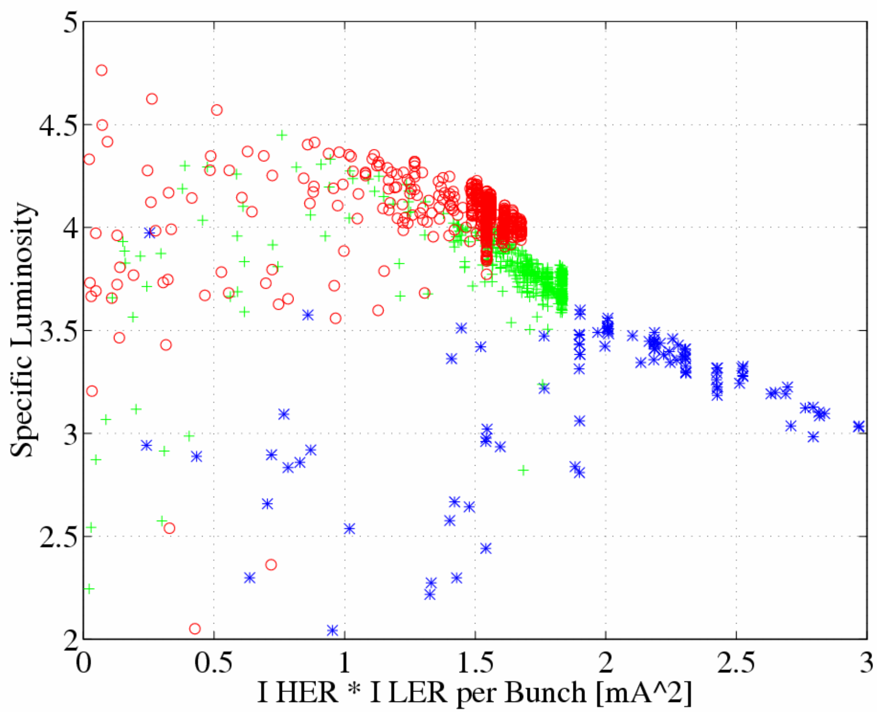
$\xi_y = 0.05\text{-}0.06$

$\xi_x = 0.03\text{-}0.09$

I^- increases LER y size.

I^+ increases LER x size.

I^+ increases HER y size.



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KEKB Specific Luminosity

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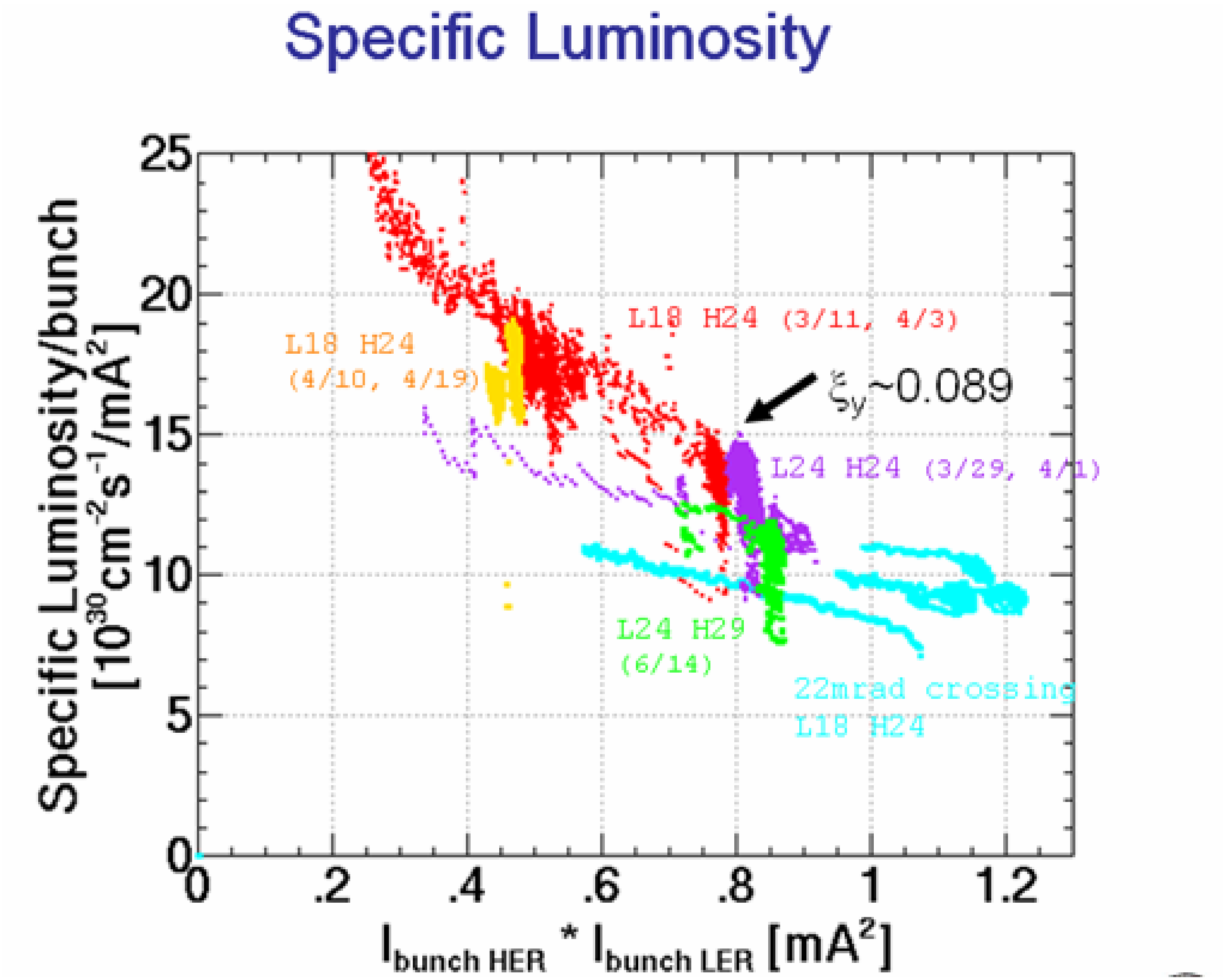

Peak Luminosities of Various Colliders

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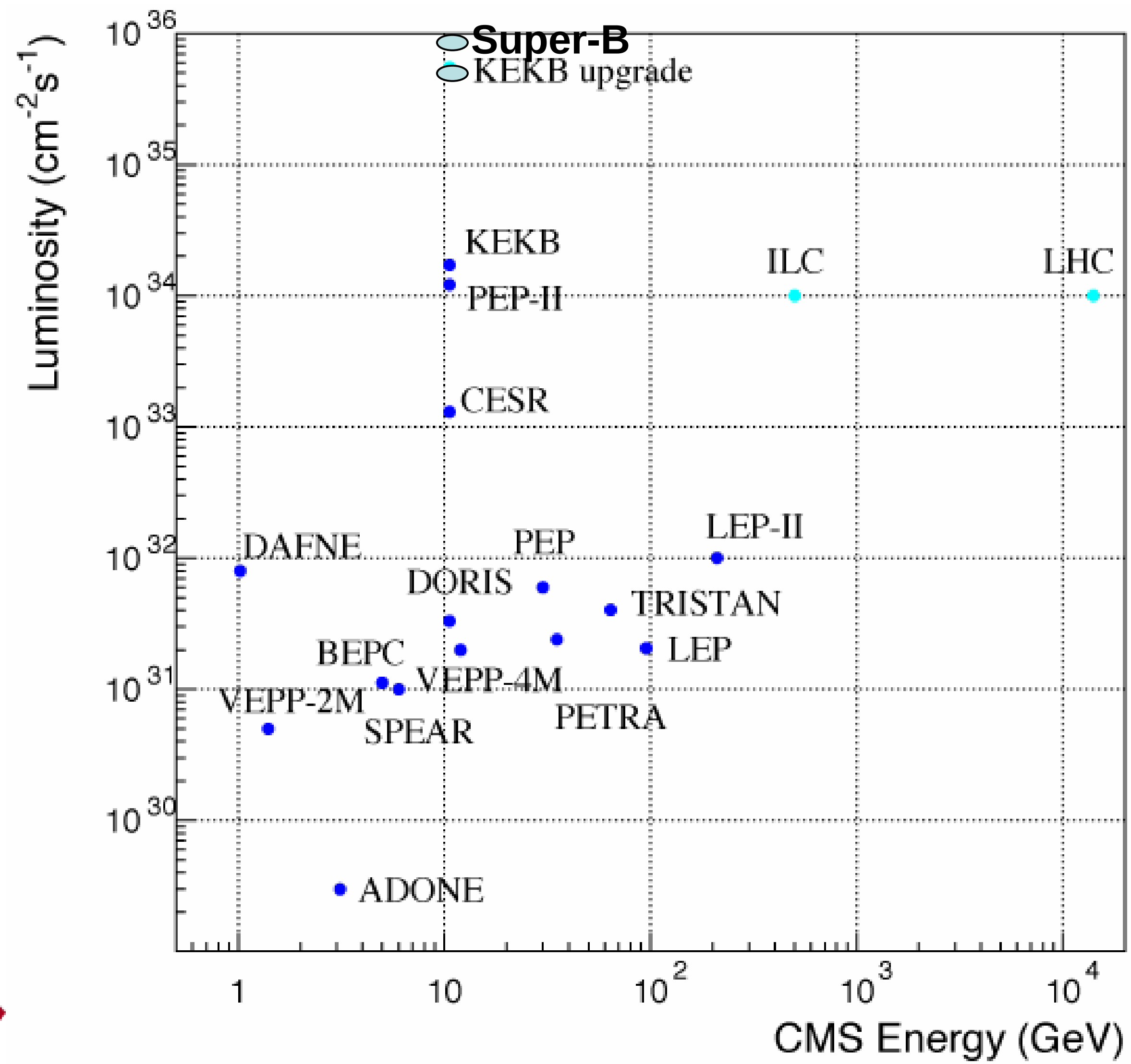

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Collider Luminosity Trends

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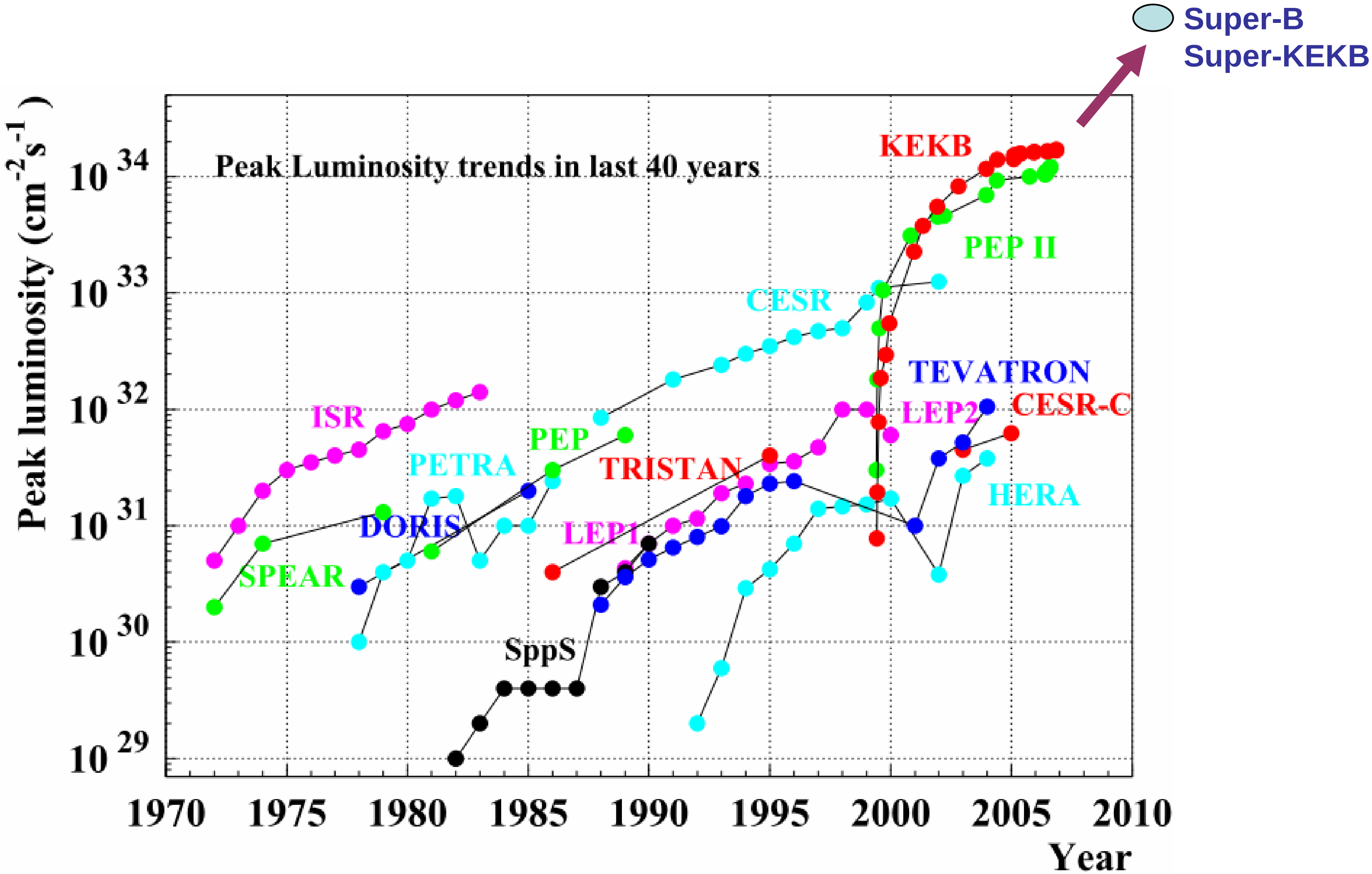

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Conclusions

* There has been a lot of progress in collider design since the first colliders at the Upsilon resonance 30 years ago.
* The recent KEKB and PEP-II B-Factories have been very successful (Nobel prizes this year!)
* Innovations are still being made to significantly enhance the luminosity of a future collider.
* The field is (nearly) technically ready to build the next very high luminosity collider (perhaps Super-B or Super-KEKB).