Towards Higher Luminosities in B and PHI factories

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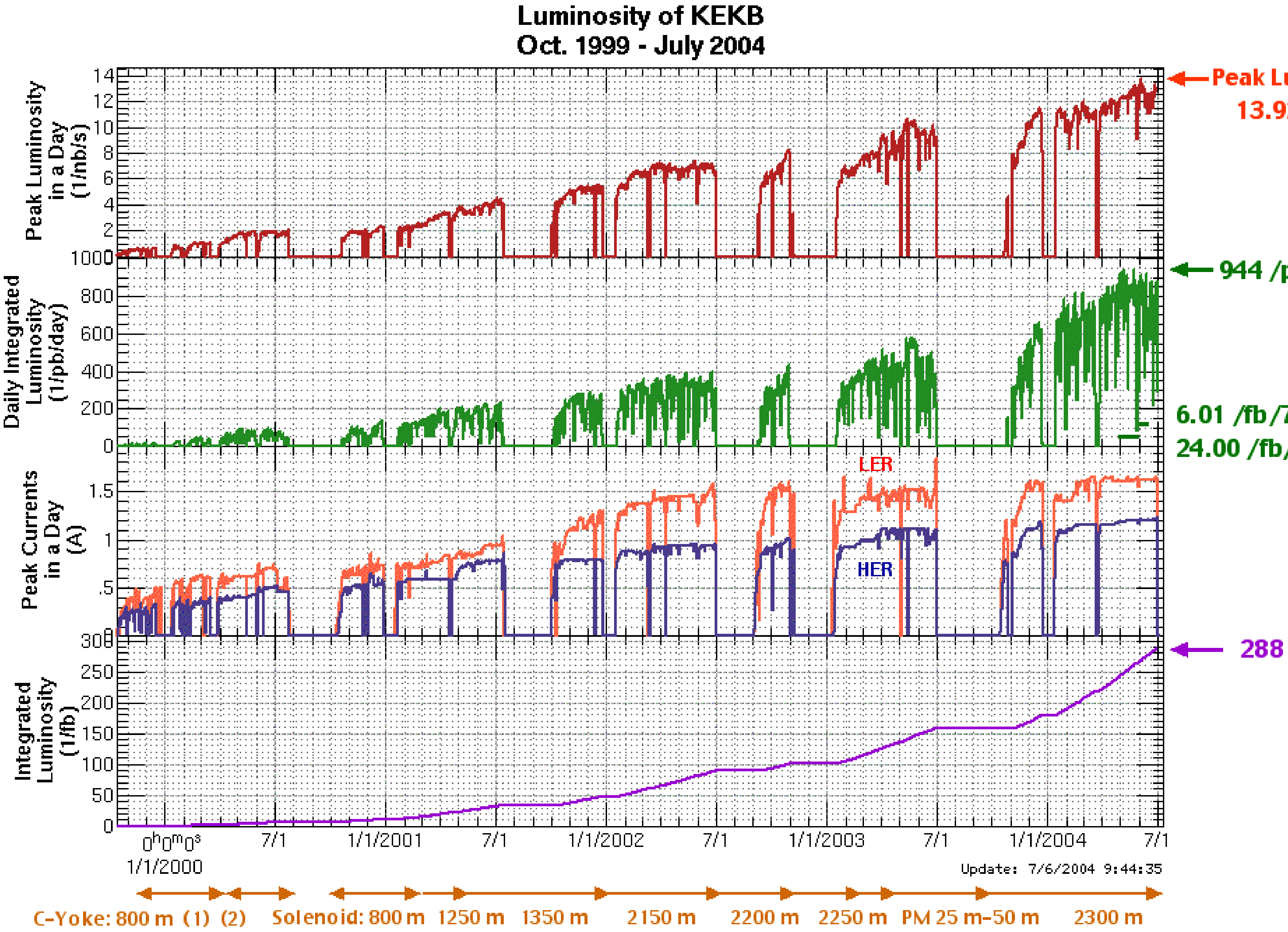
EPAC04, July 2004, Lucerne

OUTLINE

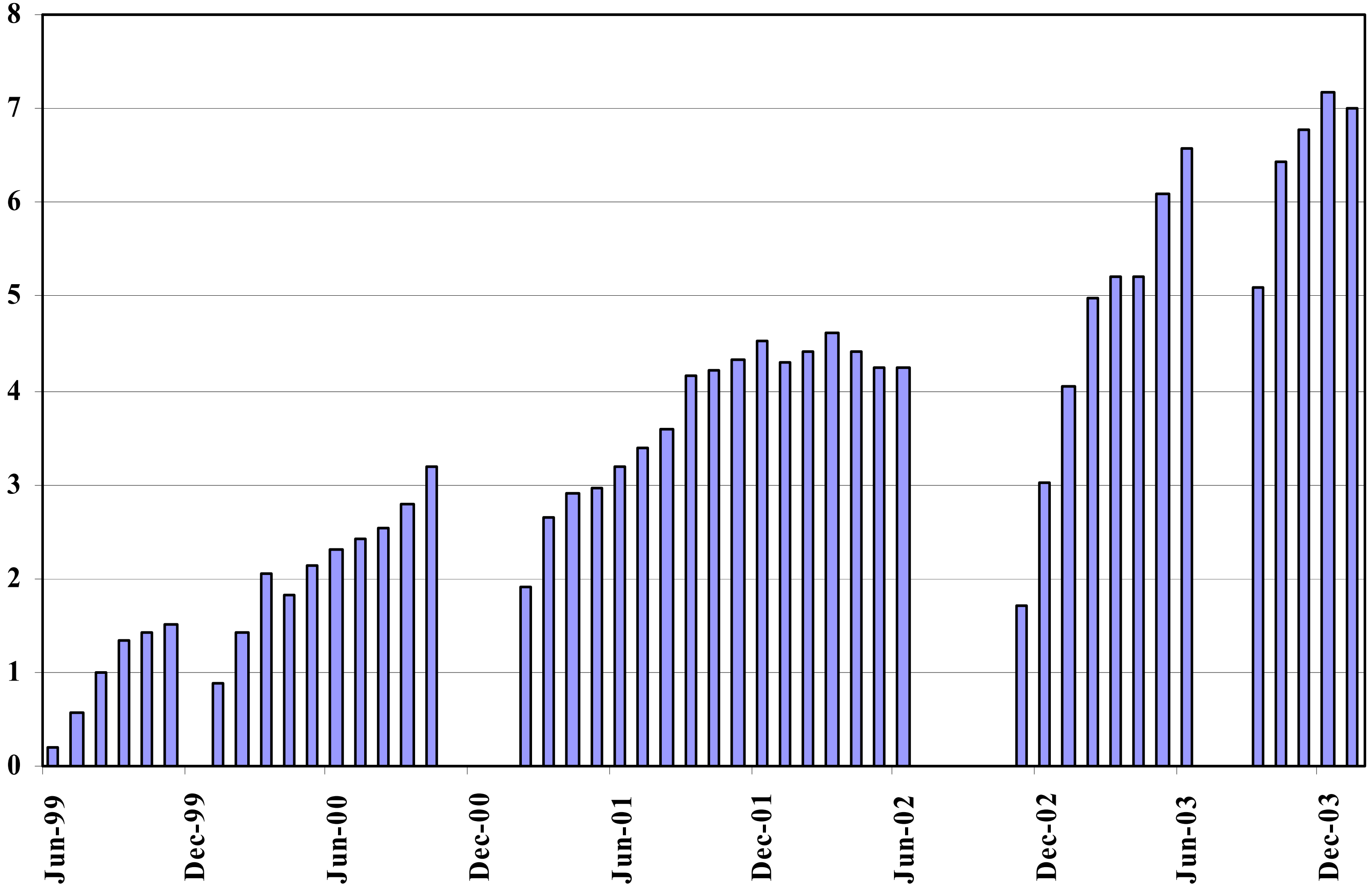
- Performances of the B and PHI factories
- Mid term upgrades and goals
- Challenges for the next generation factories
- Conclusions

- The B and Phi factories began operations around 1999. Since then, the B factories (PEPII and KEK-B) have exceeded their design peak luminosity and greatly exceeded the expected integrated luminosity, The DAFNE phi factory is still about a factor 5 below the design peak and total integrated luminosity
- DAFNE is the only factory with two possible interaction regions, and already 3 different experiments have taken data. In particular the integrated luminosity requirement for DEAR and FINUDA have been met and these experiments have successfully completed their data taking.

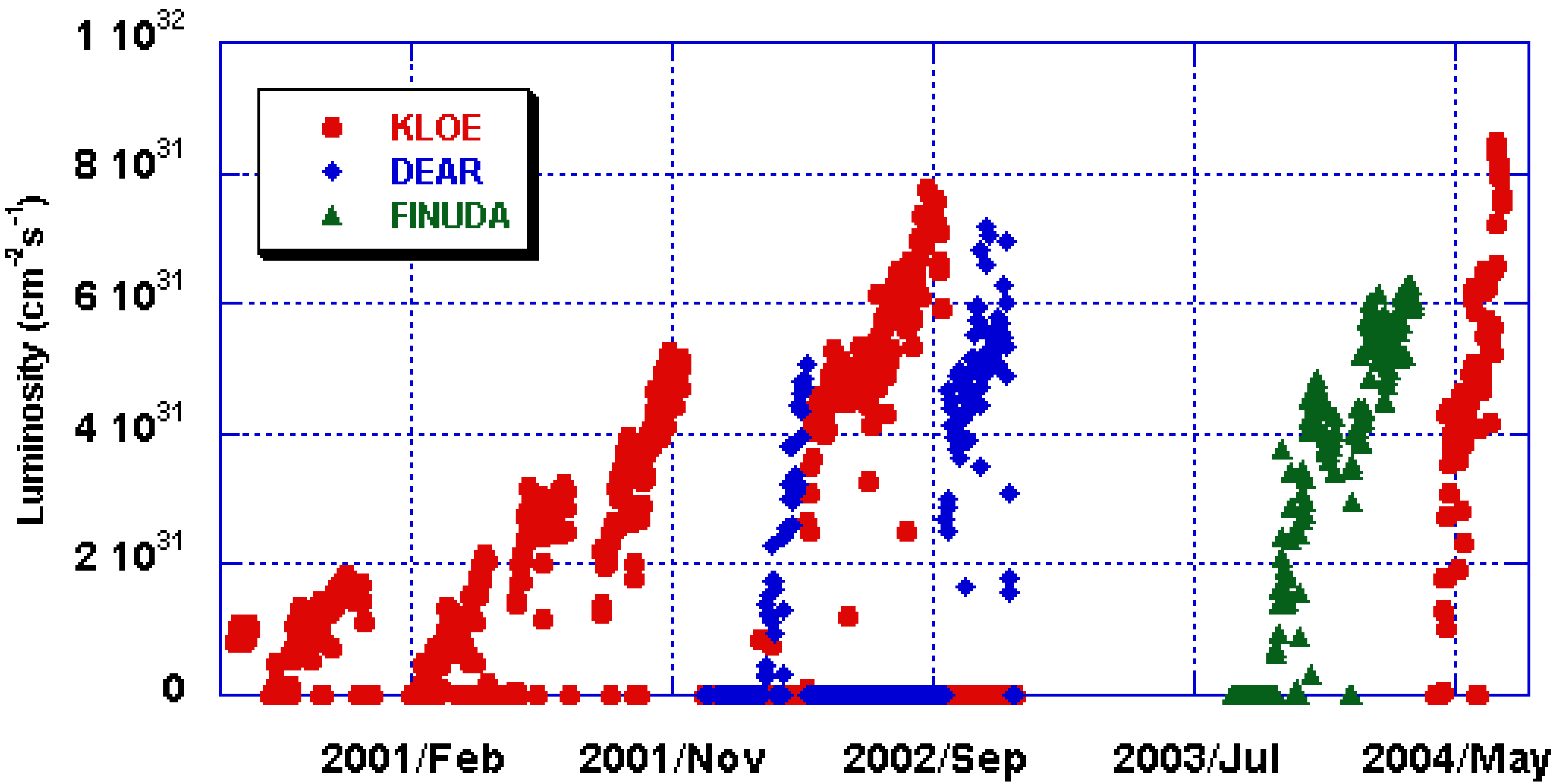


Luminosity of KEKB
Oct. 1999 - July 2004
Peak Luminosity in a Day (1/nb/s)
Daily Integrated Luminosity (1/pb/day)
Peak Currents in a Day (A)
Integrated Luminosity (1/fb)
LER
HER
Peak Lu
13.9
944 /p
6.01 /fb/7
24.00 /fb/
288
0h0m0s 1/1/2000
7/1
1/1/2001
7/1
1/1/2002
7/1
1/1/2003
7/1
1/1/2004
7/1
Update: 7/6/2004 9:44:35
C-Yoke: 800 m (1) (2)
Solenoid: 800 m
1250 m
1350 m
2150 m
2200 m
2250 m
PM 25 m-50 m
2300 m

Peak PEP-II Luminosity (x1E33) per Month



Peak DAFNE Luminosity, red:KLOE, blue:DEAR, green:FINUDA



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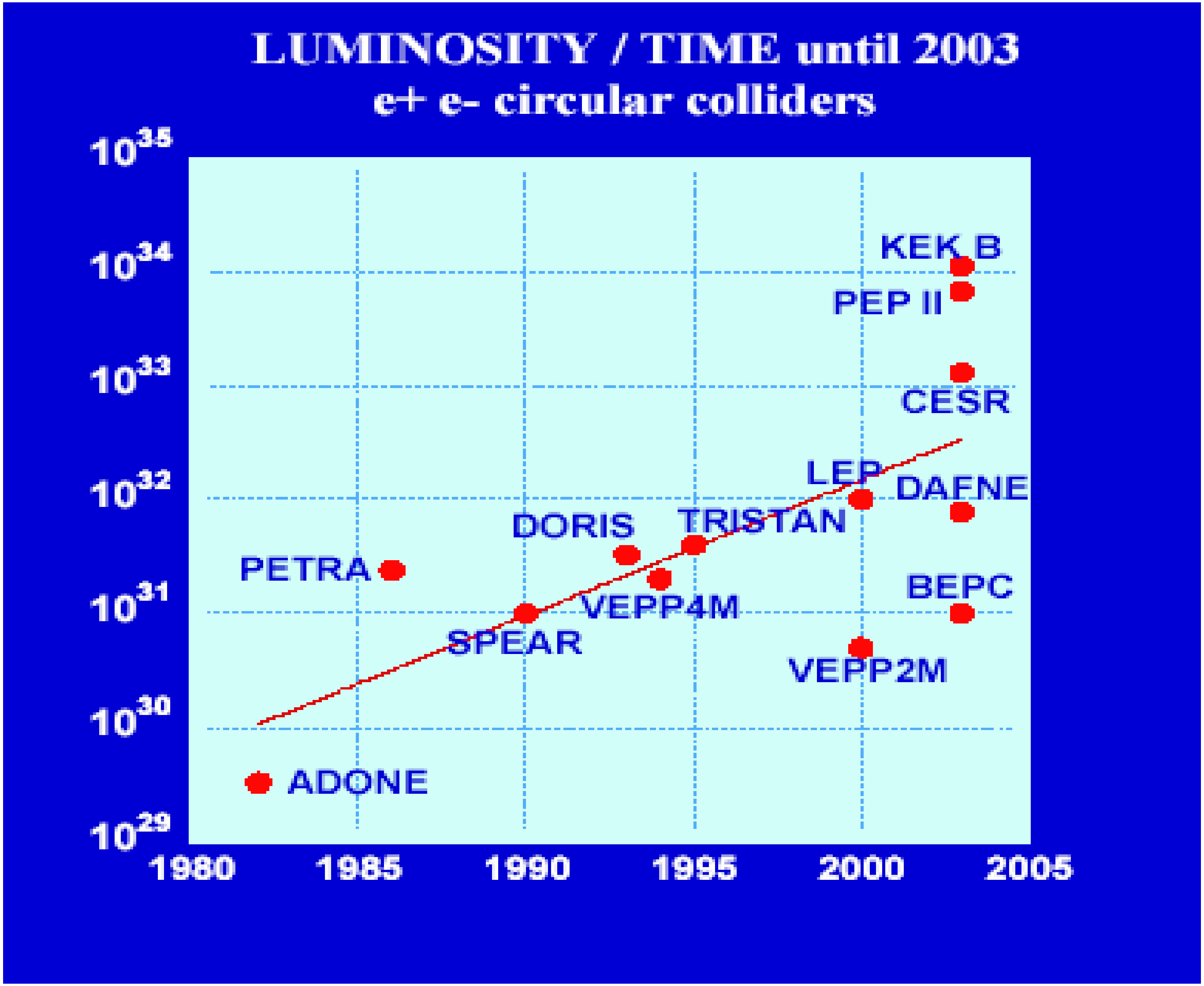
LUMINOSITY / TIME until 2003
e+ e- circular colliders
10^35
10^34
10^33
10^32
10^31
10^30
10^29
1980
1985
1990
1995
2000
2005
KEK B
PEP II
CESR
LEP
DAFNE
TRISTAN
DORIS
PETRA
VEPP4M
BEPC
SPEAR
VEPP2M
ADONE

	PEP-II	KEK	DAFNE	
LER energy	3.	3.5	0.51	GeV
HER energy	9.0	8.0	0.51	GeV
LER current	2.4	1.6	1.1	A
HER current	1.6	1.2	1.1	A
β_y^*	10.0	6.5	27	mm
β_x^*	25	60	250	cm
X emittance	50	20	600	nm-rad
Estimated σ_y^*	5.0	2.2	6.0	μm
Bunch spacing	1.26	2.4	1.6	m
Number of bunches	1317	1284	50	
Collision angle	0	22	24	mrads
Beam pipe radius	2.5	1.5	4.0	cm
Luminosity	9.2×10^{33}	13.9×10^{33}	$7.5*10^{31}$	$cm^{-2}\ sec^{-1}$

Factories Parameters list

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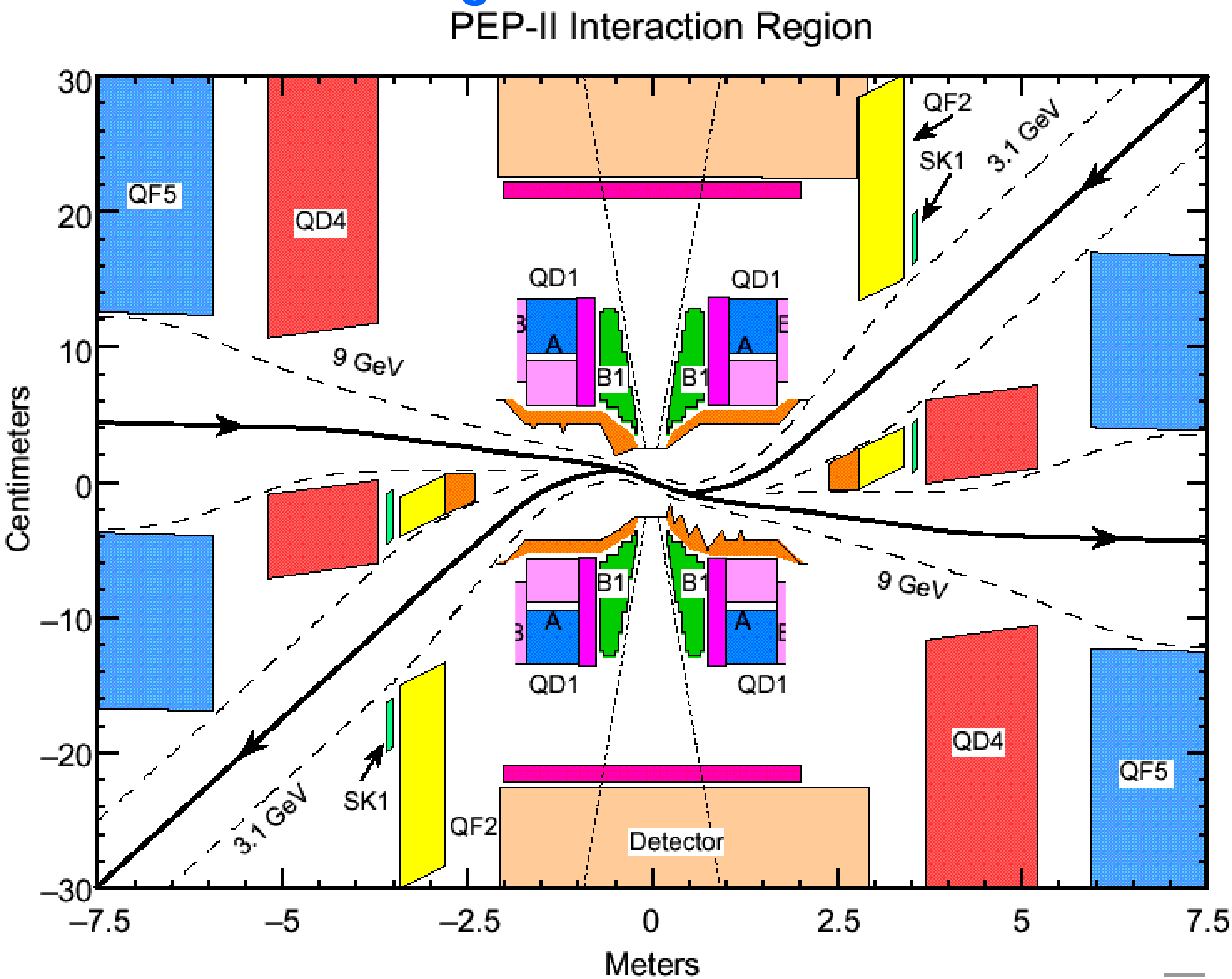
Beam sizes optimization

- KEK has reached an higher luminosity with less beam current, mainly thanks to a smaller β_y at the IP and a better coupling correction..
- During the years, all the machines have constantly improved the specific luminosity with an “adiabatic” reduction of β_y and vertical emittance
- The need to further decrease the vertical beam size and the effect of the parasitic crossings has driven a redesign of the interaction regions for PEPII and DAFNE

Fall –Winter PEPII 2003-2004 Improvements

- Number of bunches:
  - June 2003: 1030 bunches in the by-3 pattern.
  - January 2004: 1317 bunches in the by-2.
- HER and LER RF stations added to beam.
  - I^- to 1376 mA peak.
  - I^+ to 2430 mA peak.
- Trickle charging
  - All data now taken in trickle charge mode (LER only).
- HER beta-y*
  - Beta-y* lowered from 12 to 10 mm in January.

Modified Head-on design



PEPII Beam Parameters Goals

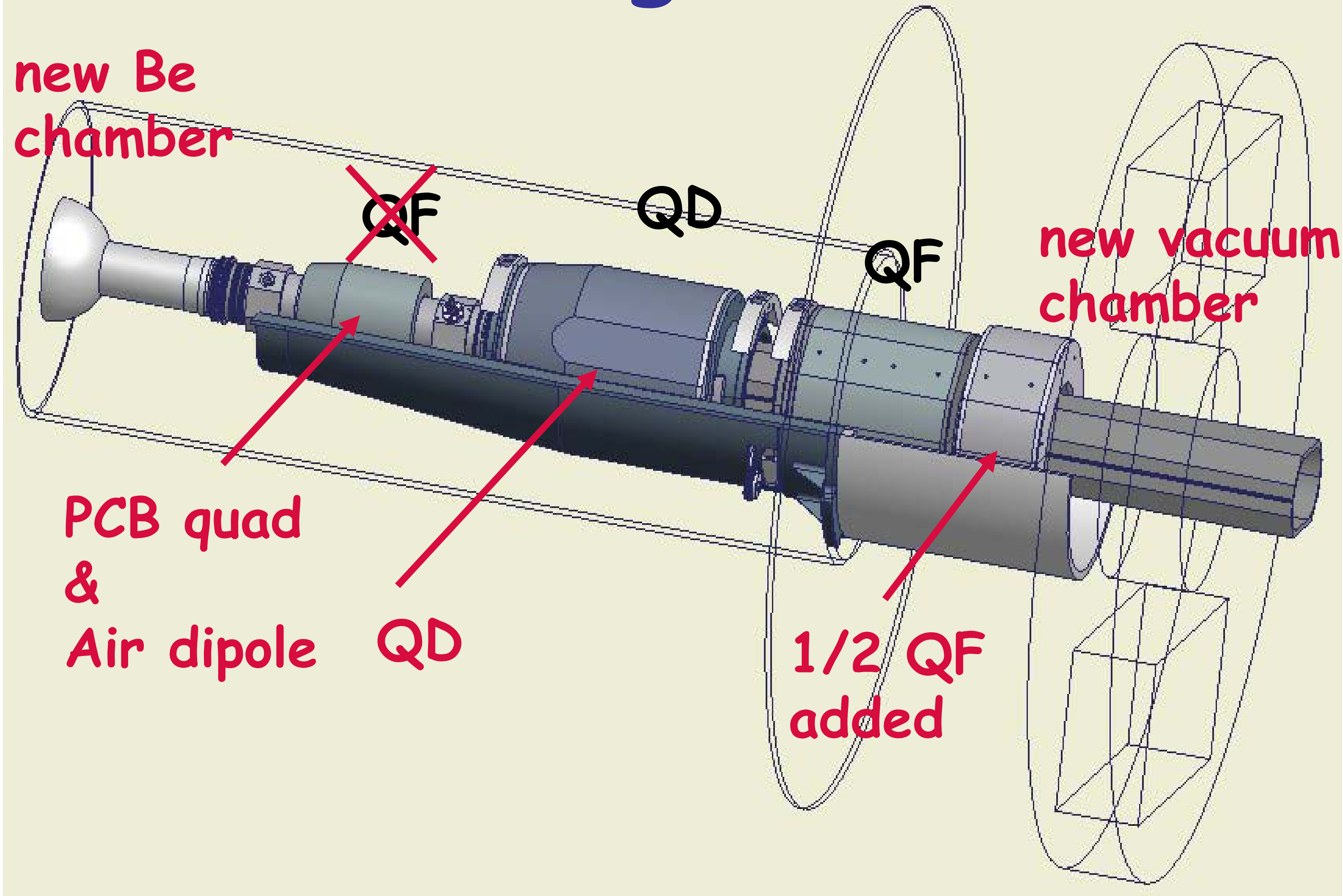
- June 2003: 1.45A x 1.1 A β_y*=12 mm 1034 bunches L=6.6E33
- July 2004: 2.7A x 1.6 A β_y*=9 mm 1450 bunches L=12.1E33
- June 2005: 3.6A x 1.8 A β_y*=8.5 mm 1500 bunches L=18.2E33
- July 2006: 3.6A x 2.0 A β_y*=6.5 mm 1700 bunches L=23.0E33
- July 2007: 4.5A x 2.2 A β_y*=6 mm 1700 bunches L=33.E33

- With good integration reliability:
- 100 fb^{-1} more integrated by Summer 2004.
- 500 fb^{-1} total integrated by Fall 2006.
- About 1 to 1.4 ab^{-1} integrated by Fall 2009.

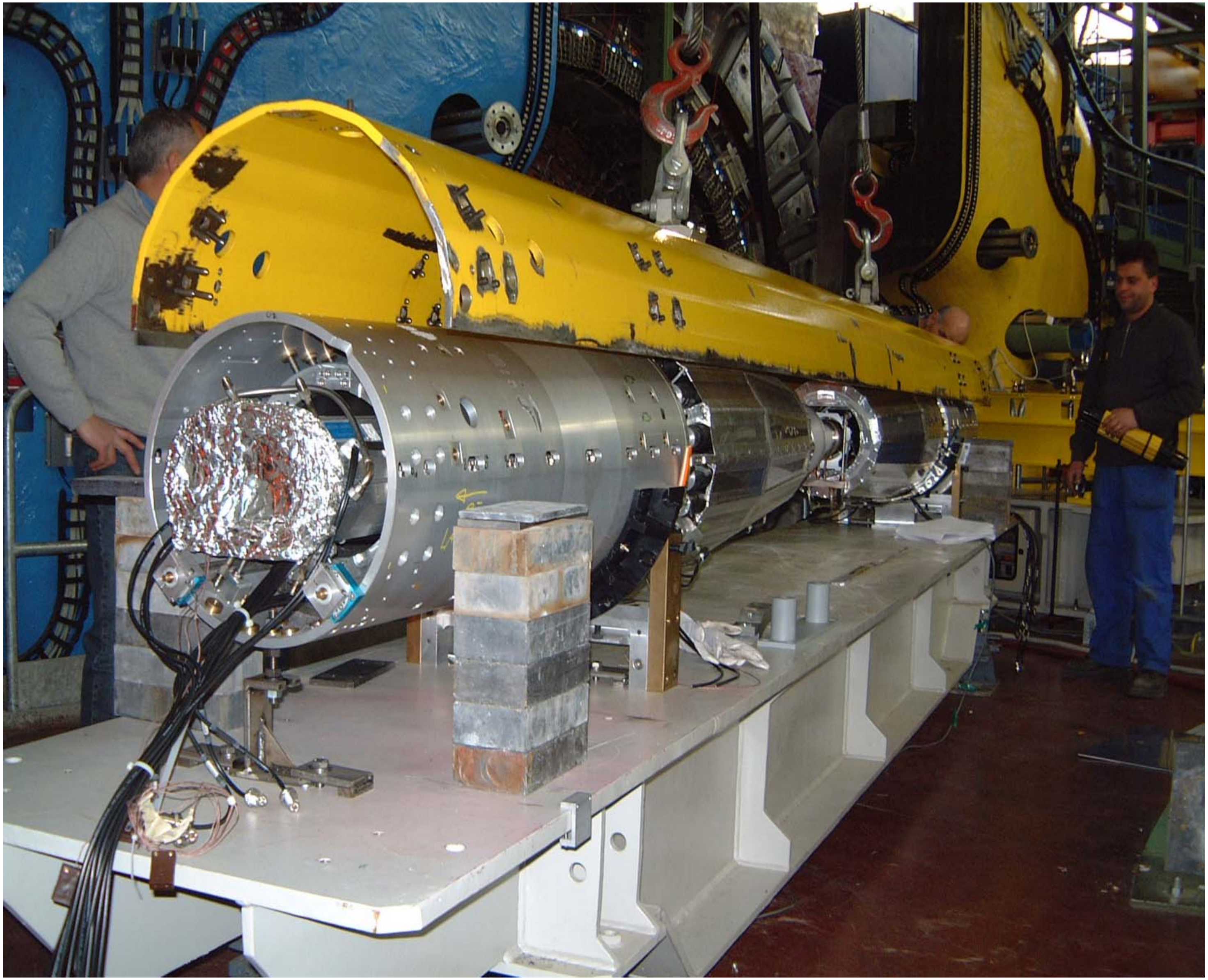
DAFNE 2003 MAIN HARDWARE ACTIVITIES

- Finuda Installation
- Kloe new I.R. installation
- Straight long sections and kickers mods
- Scrapers upgrades
- Bellows upgrades
- New Ion clearing electrodes
- Wigglers poles modification

KLOE New Interaction Region



Kloe Old I.R. removal



BARE Kloe I.R.

	PEP-II	DAFNE	
LER energy	3.0	0.51	GeV
HER energy	9.0	0.51	GeV
LER current >	3.6	1.5	A
HER current >	2.0	1.5	A
$\beta_y^* <$	7.0	19	mm
β_x^*	25	130	cm
X emittance	40	380	nm-rad
$\sigma_y^* <$	2.6	5.0	µm
Bunch spacing	1.26	0.8	m
Number of bunches	1700	100	
Collision angle	0	32	mrads
Luminosity>	30×10^{33}	$2.0*10^{32}$	$cm^{-2}\ sec^{-1}$

PEPII and DAFNE TARGET PARAMETERS WITH

UPGRADES (to become effective in the 2004-2006)

Beam currents growth

- Beam currents have constantly increased while preserving as much as possible the “low current” beam parameters and acceptable background level in the detectors
- RF systems constantly upgraded
- Longitudinal and transverse feedbacks have to work harder to cope with stronger instabilities and shorter bunch spacing. In particular this is true for DAFNE that now has the smaller bunch spacing and little beam stiffness due to the lower operating energy
- Elctron cloud instabilities succesfully reduced with solenoids
- New collimators constantly added
- Vacuum chamber and bellows upgraded to minimize wakefields effect.

Luminosity Equation

- When vertical beam-beam parameter limited.
- $\xi_y \sim 0.06$ in PEP-II and KEKB.
- To raise luminosity: lower β_y^*, raise I & ξ_y.

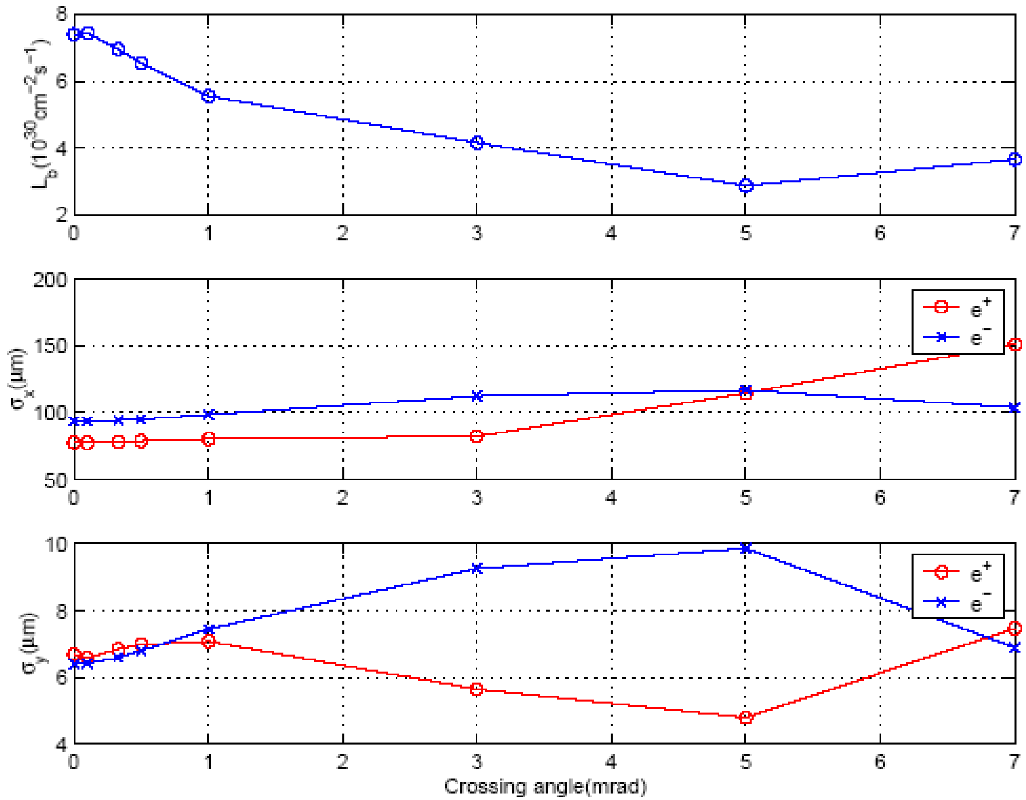
$$\xi_y^+ = \frac{r_0 N_b^- \beta_y^{*+}}{2\pi\gamma^+ \sigma_y^{*-} \sigma_x^{*-}} (flatbeams)$$

$$L = 2.17 x 10^{34} \frac{n \xi_y E I_b}{\beta_y^*}$$

Bunch lenght shortening

- The bunch length does not appear naturally in the luminosity equation, however since the machines do mostly operate in a vertical beam-beam limited regime, the luminosity is inversely proportional to the β_y and the minimum value for β_y is equal to the bunch length, for smaller values the hourglass effect causes a big loss in luminosity.
- Additional luminosity reduction comes from the crossing angle, that introduces synchro-betatron coupling and an additional increase of the horizontal size, since the projected beam size along the interaction region will be larger (Piwinski angle > 0). Finally the beam-beam effects in the vertical plane are enlarged by the crossing angle together with a finite bunch length. All these combined effects make the luminosity decrease faster then $1/\sigma_z$.

PEP-II with a Crossing Angle

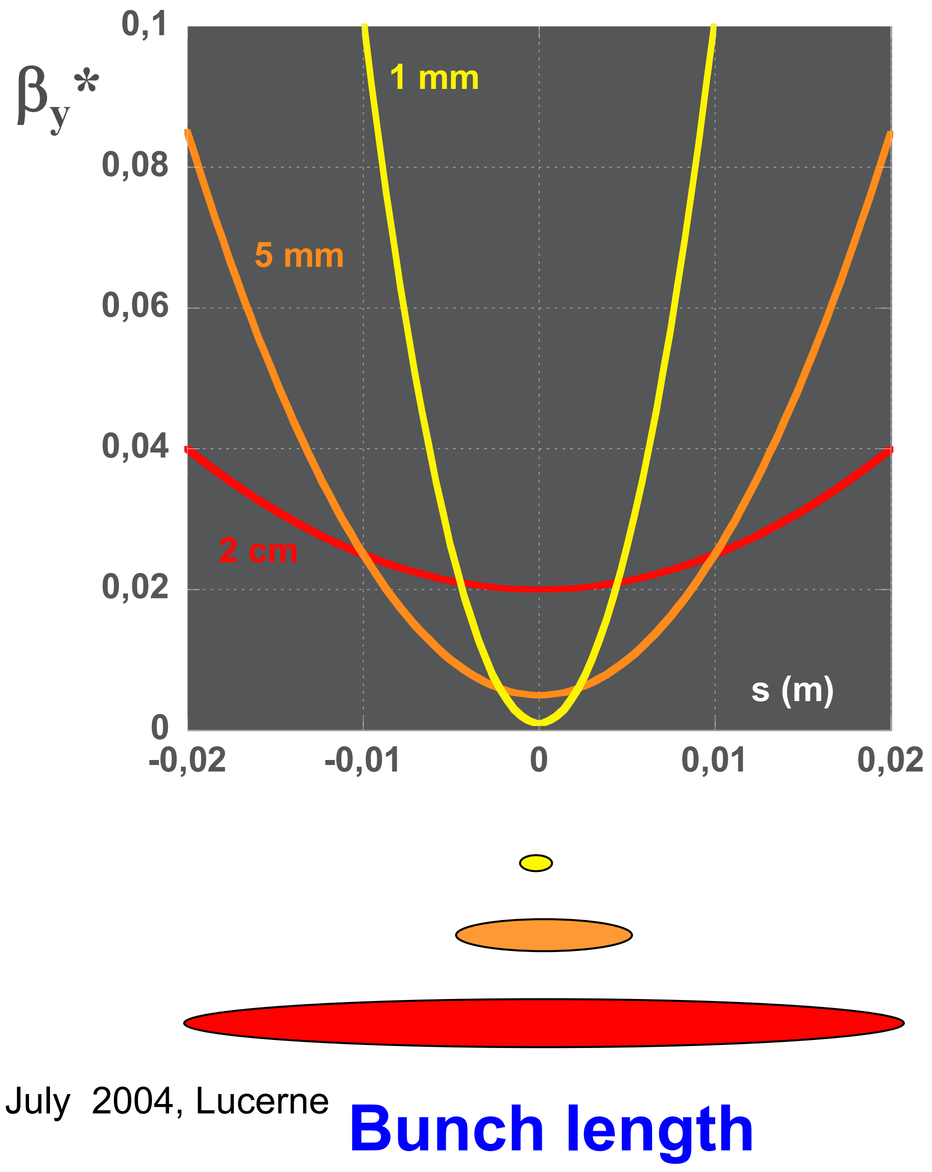


Plot of luminosity degradation as a function of increasing crossing angle
(courtesy of Yunhai Cai)

For $\phi = \pm 3mrad$, we see a degradation of luminosity by 43%. Similar results have been obtained by Ohmi and Tawada.

“Hourglass” effect

Gain in luminosity by squeezing the bunch vertical dimensions through the β-function is only possible if the bunch length is also decreased



Bunch lenghts shortening

- The current β_y for PEPII and KEKB are getting closer and closer to the bunch lengths, although the hourglass limit will not be exceeded in the mid-term upgrades
- In DAFNE the limit has been already reached, since the microwave instability appears at very low bunch charge. At the operating currents the bunch is about 27mm long, causing a severe limit in the attainable luminosity. RF voltage is a very weak parameter to squeeze to bunch.
- Possible solution is to change sign to the momentum compaction α_c. If α_c <0 the longitudinal wake field becomes focusing reducing the bunch length a low current. At higher currents it becomes overfocusing and the bunch starts to grow again

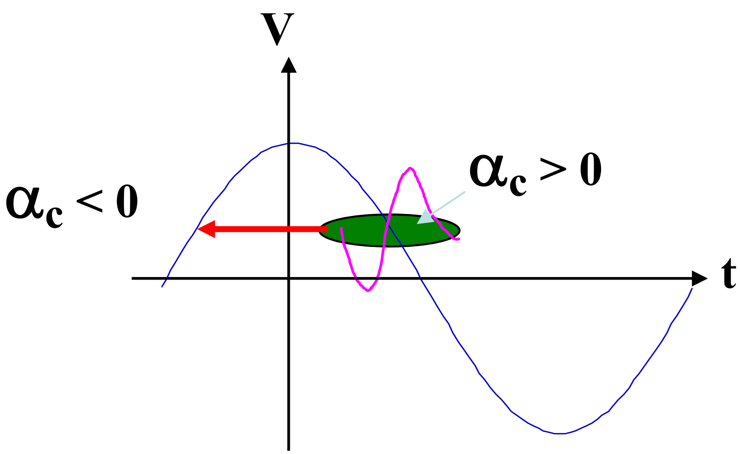
Negative momentum compaction α_c

$$\frac{\Delta L}{L} = \alpha_C \frac{\Delta p}{p}$$

relates normalized one-turn path elongation and energy deviation

$\alpha_c>0$ (usual): particles with higher energy run a longer closed orbit

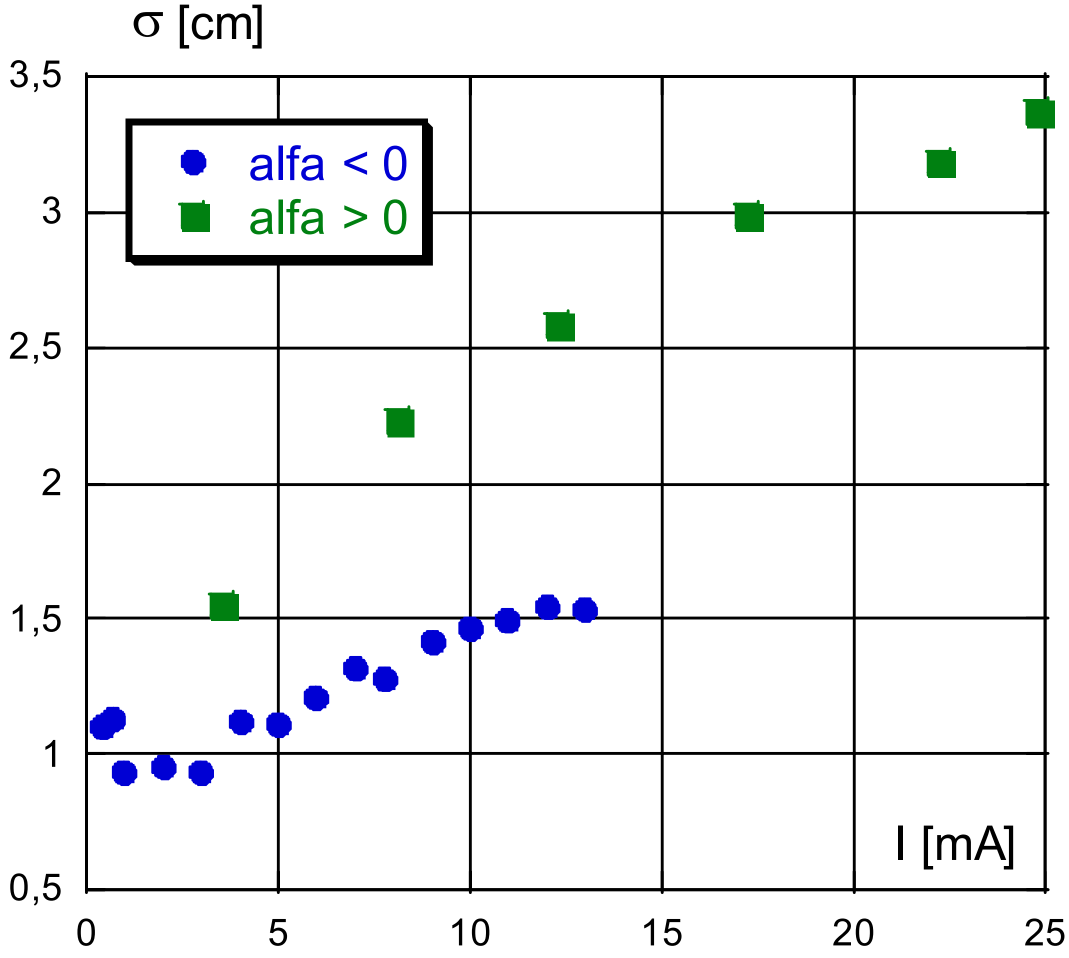
$\alpha_c<0$ (possible): particles with higher energy run a shorter closed orbit



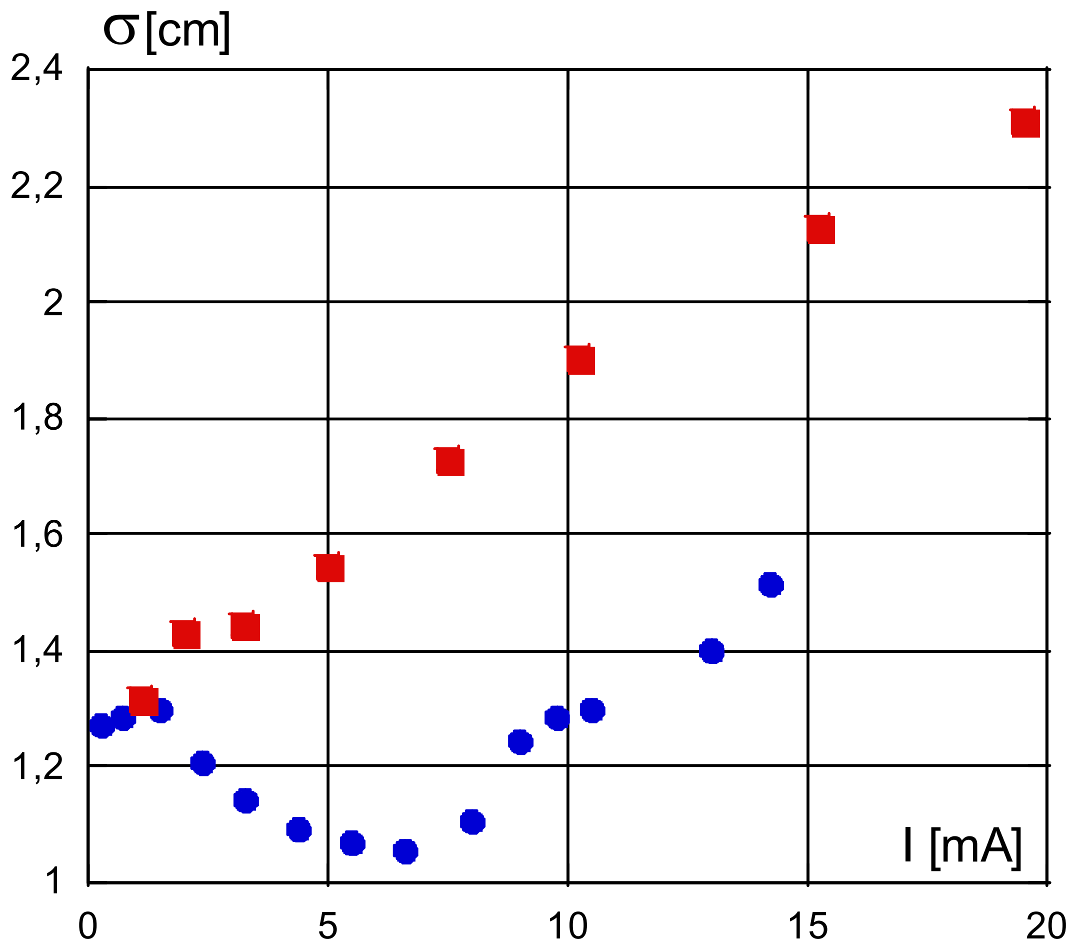
The bunch wake has always a positive slope on the bunch core.
For positive (negative) momentum compaction the stable phase is on the RF negative (positive) slope.
The wake is defocusing for $\alpha_c>0$ (bunch lengthens), while it is focusing for $\alpha_c<0$.

- **Bunch is shorter with a more regular shape**
- **Longitudinal beam-beam effects are less dangerous**
- **Microwave instability threshold is higher**
- **Sextupoles can be relaxed since head-tail disappears**

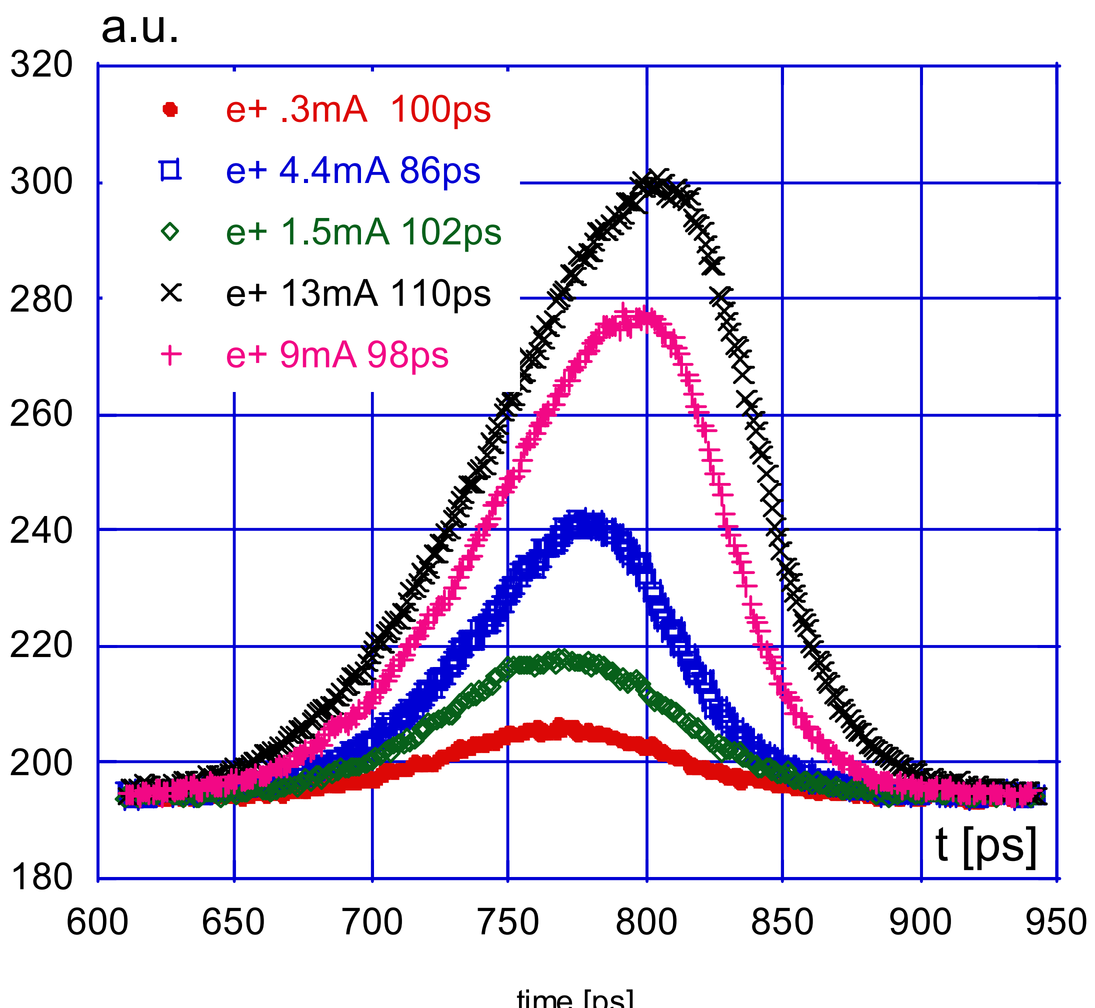
Bunch Length Comparison for e- DAFNE Ring, measured on 15/6/2004



Bunch Length Comparison for e+ DAFNE Ring, measured on 16/6/2004



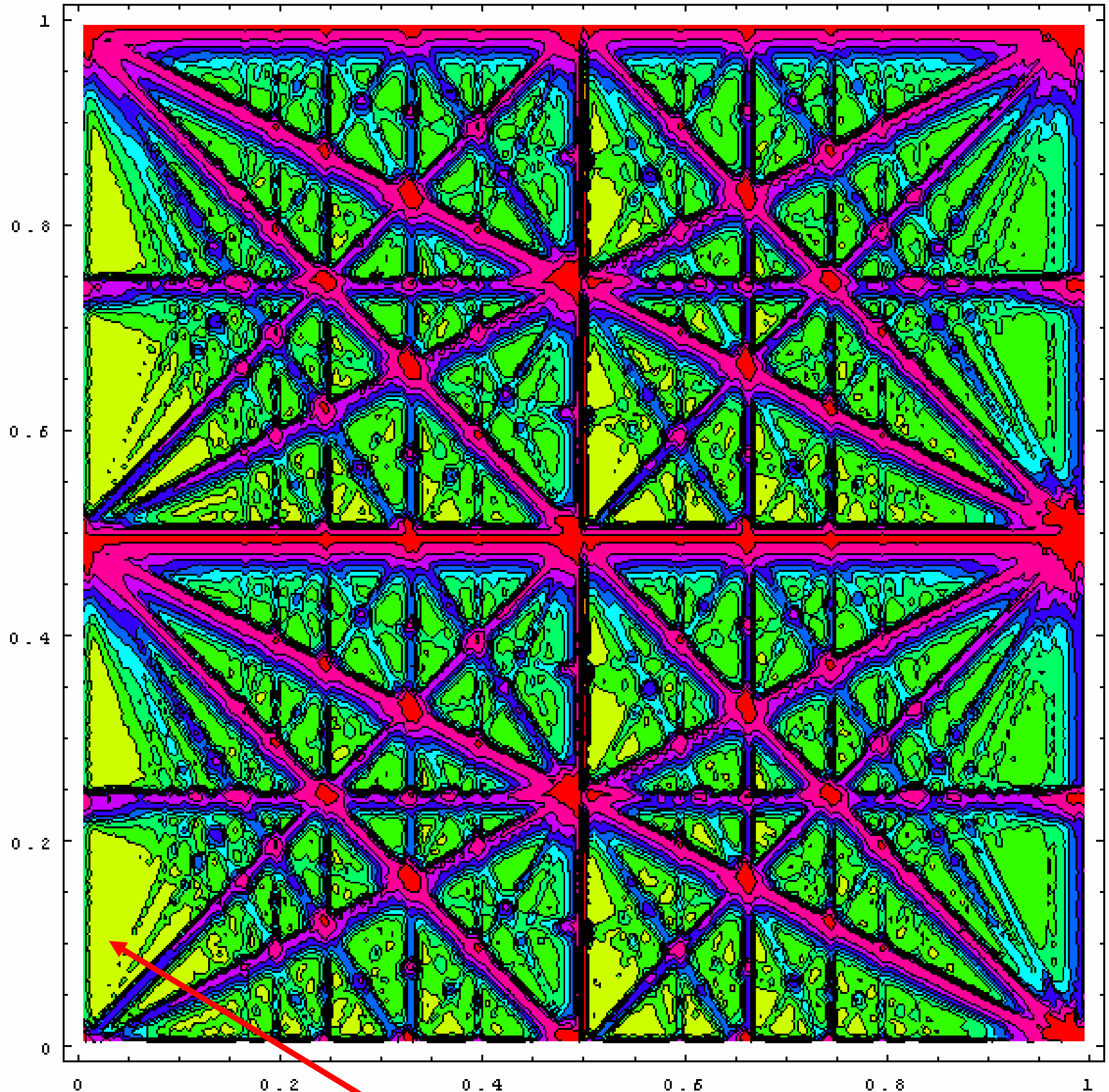
Bunch Lengthening at Negative Momentum Compaction (DAFNE positron ring, 16/06/2004)



The Road to L > 10^{32} for DAFNE

- **Negative momentum compaction: shorter bunch**
- **Lower β_y**
- **Lower Tunes**
- **Reaching 2 A per beam**

DAFNE: Change of the Working Point: toward lower tunes



- Enlarging the Dynamic Aperture
- Possibility to shift the working point closer to integers

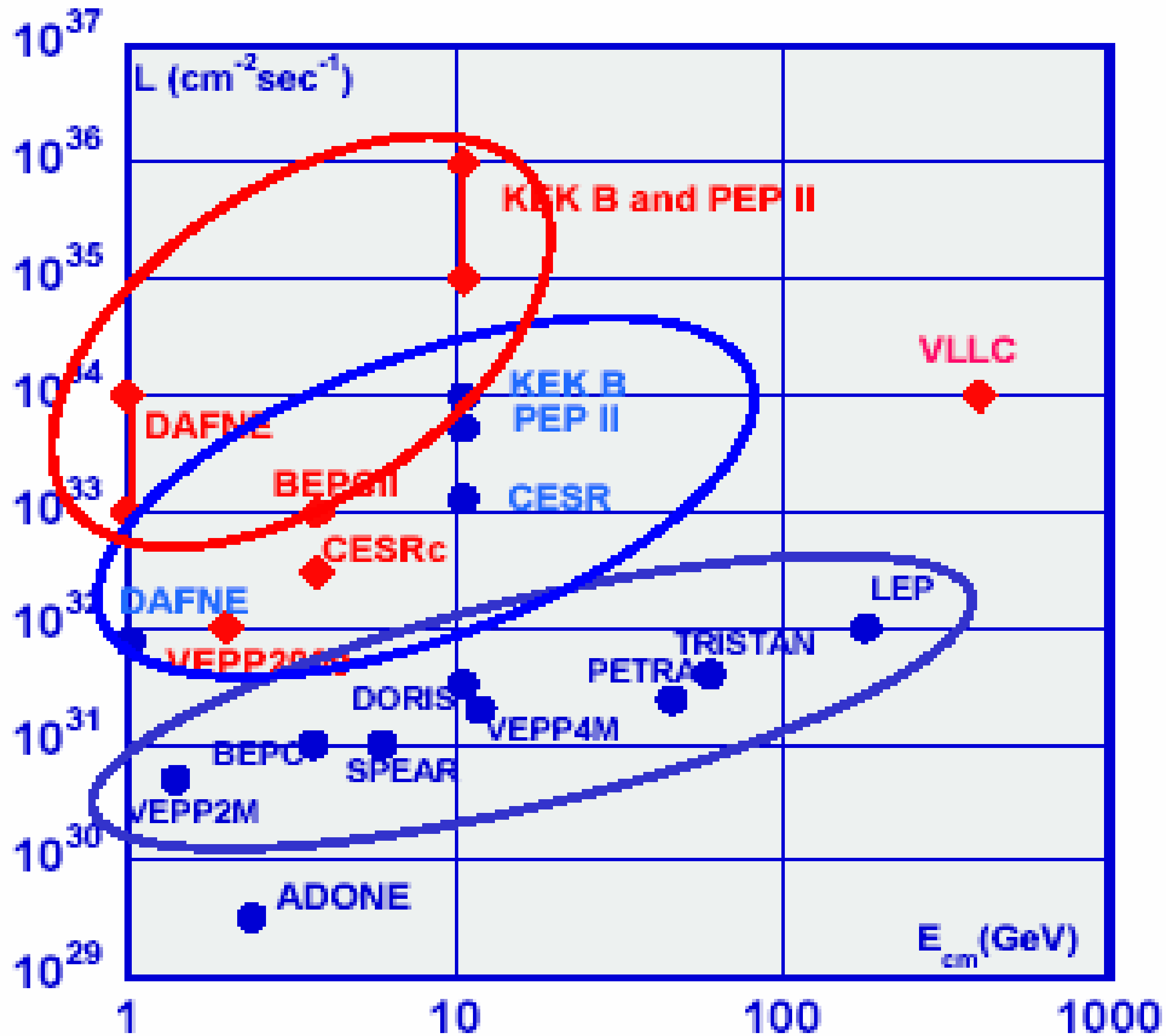
(B-Factories w.p. around Qx=0.53 Qy=0.59)

e

NEXT GENERATION FACTORIES

- The next generation factories designs aim to a luminosity of the order of 10^{36} for the B factories and 10^{34} for the phi
- These projects are targeted to begin operations around beginning of next decade

	PEP-II	KEK	DAFNE	
LER energy	3.	3.5	0.51	GeV
HER energy	9.7	8.0	0.51	GeV
LER current	22.0	9.0	3.5	A
HER current	10.1	4.1	3.5	A
β_y^*	1.5	3.0	2.5	mm
β_x^*	15	20	30	cm
X emittance	79	18	260	nm-rad
Estimated σ_y^*	1.1	0.7	1.6	μm
Bunch spacing	0.5	0.6	0.5	m
Number of bunches	6900	5000	150	
Collision angle	30	30	30	mrads
Luminosity >	1.0×10^{36}	0.5×10^{36}	1.0^{34}	$cm^{-2}\ sec^{-1}$



Luminosity vs energy for "standard" rings, factories and super-factories

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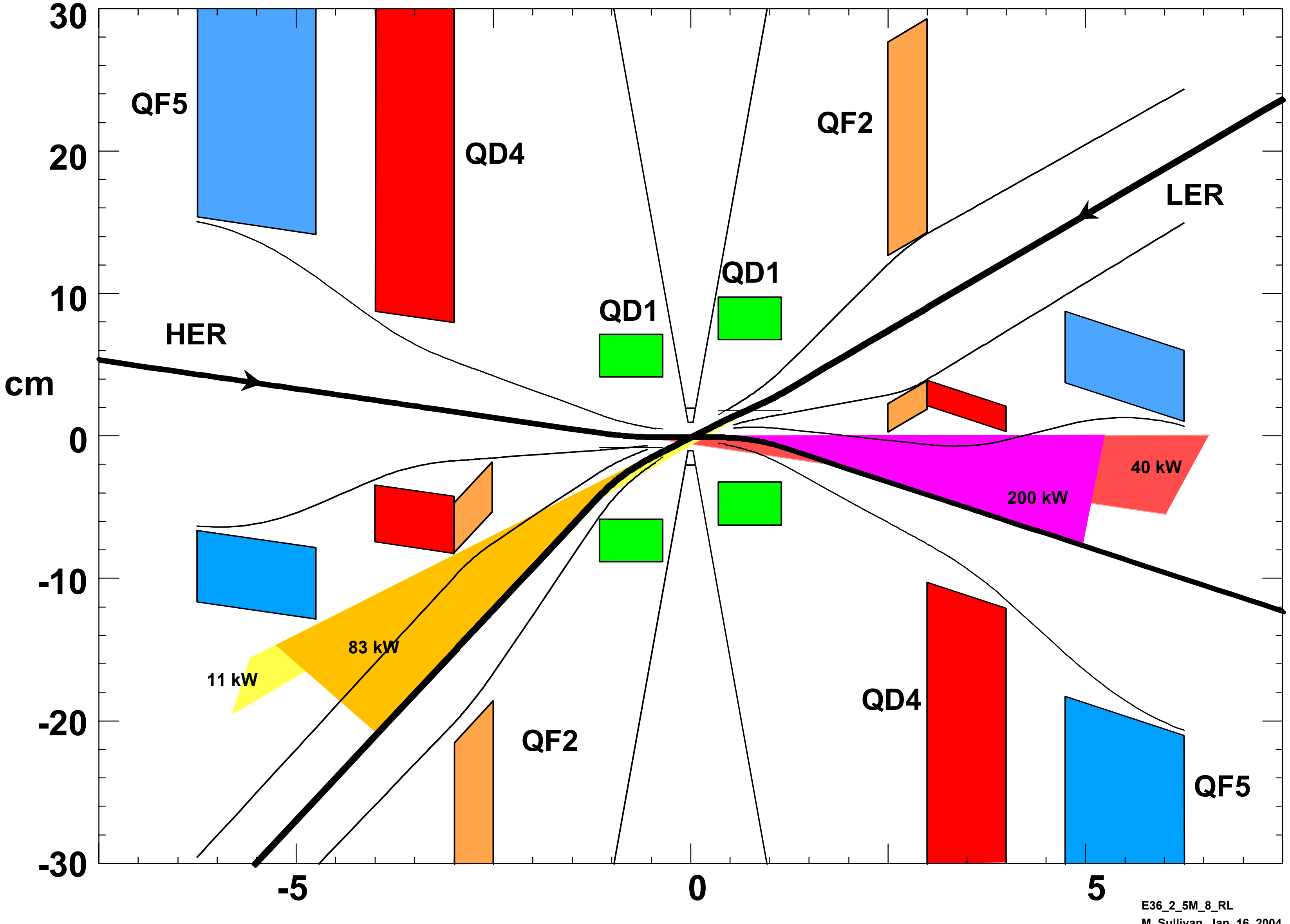
New techniques of the Next Generation B-Factory

- Beam lifetimes will be low → continuous injection. (Seeman)
- Very low β_y^* (6 to 10 mm→2 to 3 mm). (Sullivan)
- Higher tune shift (trade beam-beam lifetimes for tune shifts) (Seeman)
- Higher beam currents (x 10 or so). (Novokhatski, Teytelman)
- Higher frequency RF (more bunches). (Novokhatski)
- Bunch-by-bunch feedbacks at the 1 nsec scale. (Teytelman)
- Very short bunch lengths (2 mm). (Novokhatski)
- High power vacuum chambers with antechambers and improved or no bellows. (Soon to start)
- Reduce energy asymmetry to save wall power.
- **All designs based on maintaning the current layout to save cost and time**

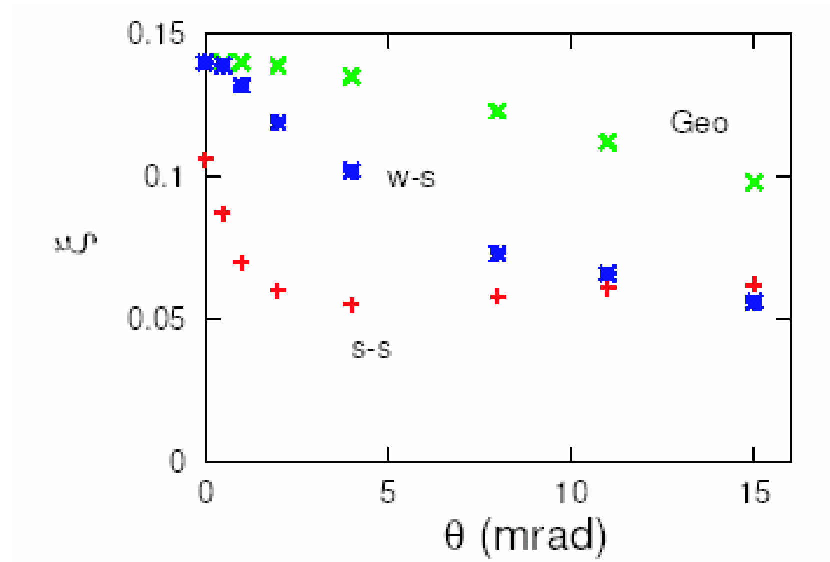
Super B-factory IR

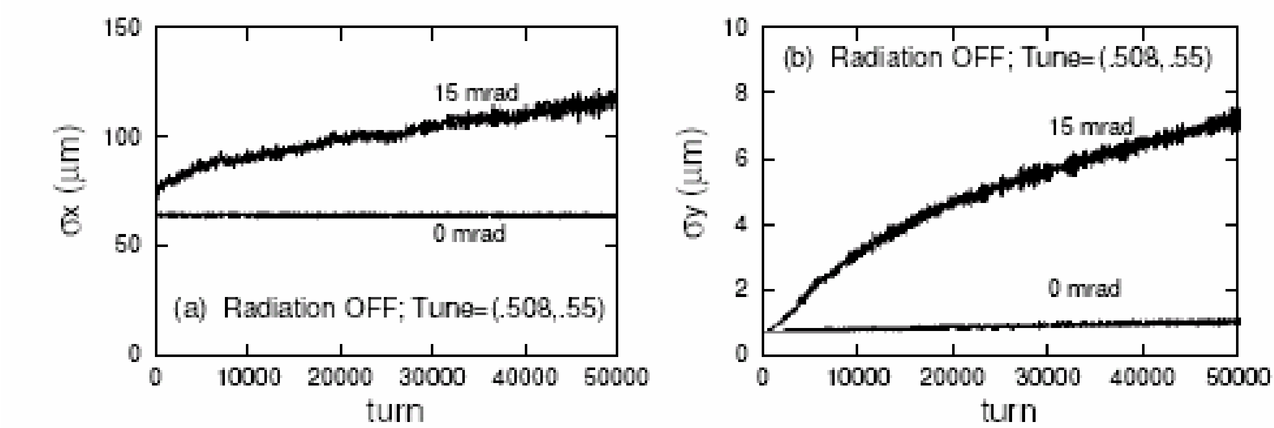


Simulation: Crossing Angle Dependence

- Luminosity reduced with a crossing angle
  - Geometric effects
  - Nonlinear diffusion -> beam size growth =>

CRAB CAVITY NEEDED





Lattice for SUPER KEKB

Non-interleaved 2.5-Pi Cell

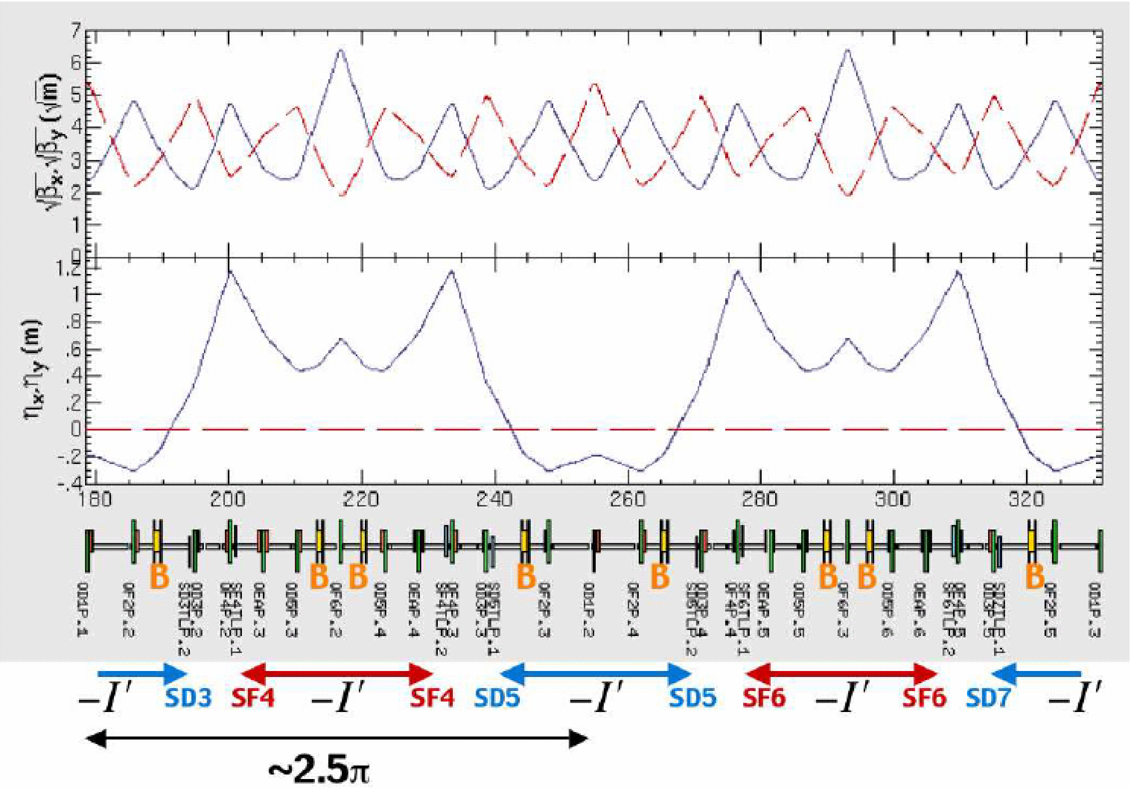


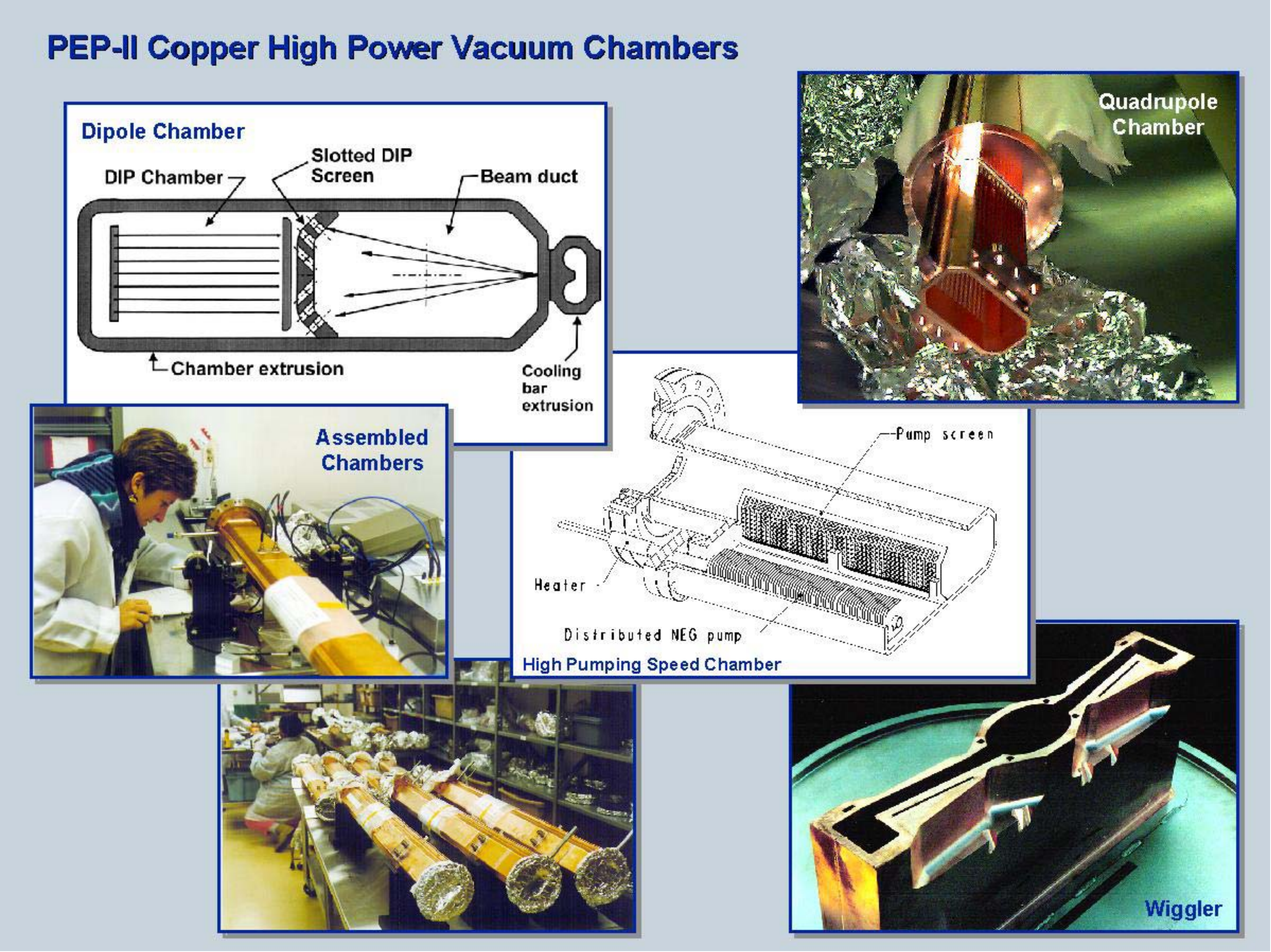
Figure 4.1: Noninterleaved 2.5π cell structure in LER.

erne

Wide tunability of horizontal emittance, momentum compaction factor.

Principle nonlinearities in sextupole pairs cancelled out to give large dynamic aperture

PEP-II Copper Vacuum System: 3 A at 9 GeV



Cu chambers absorbing 100 W/cm of synchrotron radiation

Total SR power = 5 MW in the HER

LER Magnets and Aluminum Vacuum System: 3 A at 3.5 GeV

Magnets made by our Chinese IHEP collaborators

Antechambers Reduce Electron-Cloud-Instability

High power photon stops

LER SR power = 2 MW.

Vacuum System

- Prototype ante-chamber tested at KEKB
- Combined with solenoid field is very effective at reducing photoelectron build-up.

Figure 9.24: Prototype ante-chamber (1st trial model).

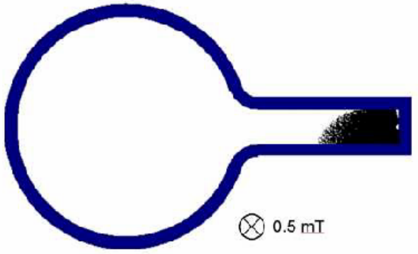


Figure 9.19: Photoelectron distribution in LER ante-chamber with solenoid magnetic field of 0.5 mT.

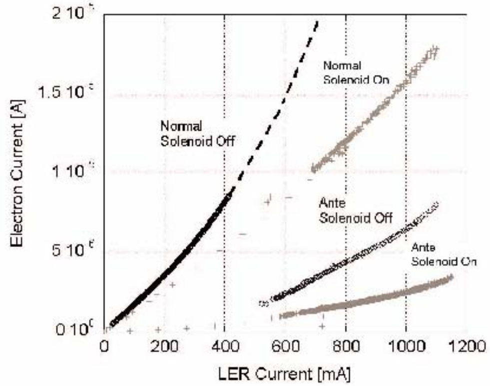


Figure 9.25: Measurement of photoelectron yield as a function of LER beam current.

Power Scaling Equations

- Synch rad ~ I E^4/ρ
- Resistive wall ~ $I^2_{total}/r_1/f_{rf}/\sigma_z^{3/2}$
- Cavity HOM ~ $I^2_{total}/f_{rf}/\sigma_z^{1/2}$
- Cavity wall power = 50 kW
- Klystron gives 0.5 MW to each cavity (PEP)
- Magnet power ~ gap~r_1

Many more RF stations needed

RF System for SuperKEKB

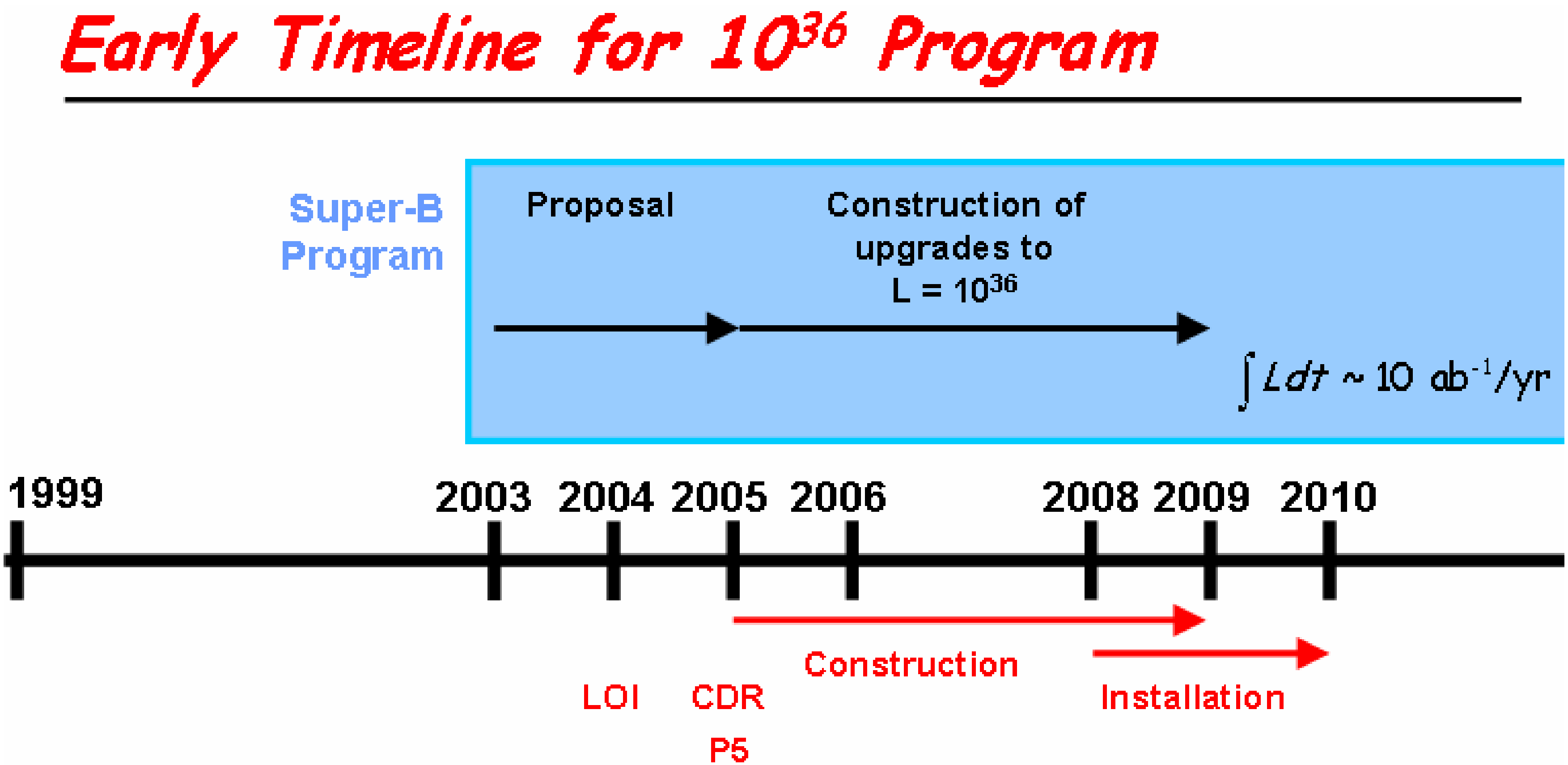
- ARES Cavity System
  - Normal-conducting cavities with energy-storage cavities attached.
  - LER & HER
- Superconducting Cavity (SCC) System
  - High cavity voltage
  - HER only

		KEKB		SuperKEKB		
		LER	HER	LER	HER	
Oho	D4		3		14	ARES
	D5		3	8	2	ARES
Fuji	D7	5		10		ARES
	D8	5		10		ARES
Nikko	D10		4		6	SCC
	D11		4		6	SCC
Total		24		56		

Total number of RF units at KEKB and SuperKEKB.

One unit = one klystron + 1 SCC or 1(2) ARES at SuperKEKB (KEKB)

Possible Super-PEP-II Timeline



Construction Scenario for SuperKEKB

- The upgrade of KEKB to SuperKEKB is proposed for around 2007.
- R&D and production of various components will be done in the first four years in parallel with the physics experiment at KEKB.
- The installation will be done during a one year shutdown in 2007, and then the commissioning of SuperKEKB will begin.

DAFNE additional challenge
Damping time at low energy

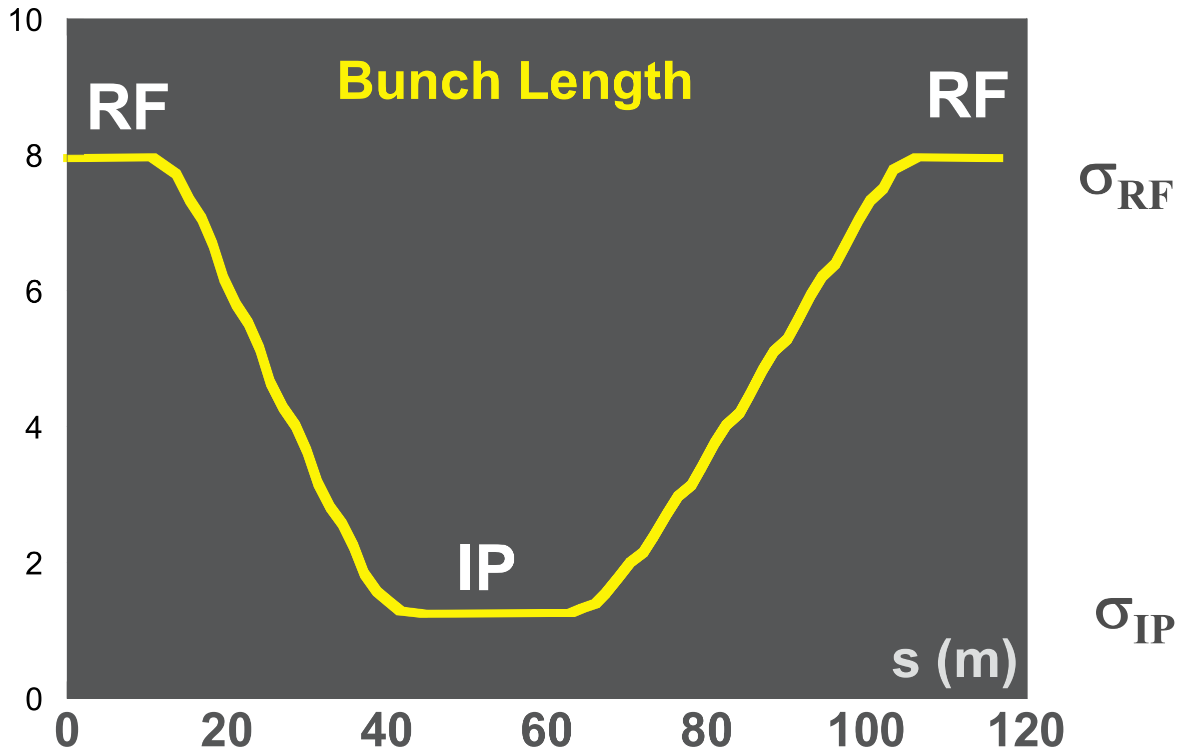
$$\alpha_x \approx \frac{C_\alpha}{C} E^3 I_2$$

$$U_o = C_\gamma \frac{E^4}{2\pi} I_2$$

$$I_2 = \int_{dipoles} \frac{ds}{\rho^2}$$

Optimization of luminosity at low energy by **increasing I_2**

DAFNE additional challenge
Short bunches at low energy



Strong RF Focusing (SRFF)

Modulation of bunch length along the ring with a minimum at the IP

Allows very small vertical β^* (few mm)

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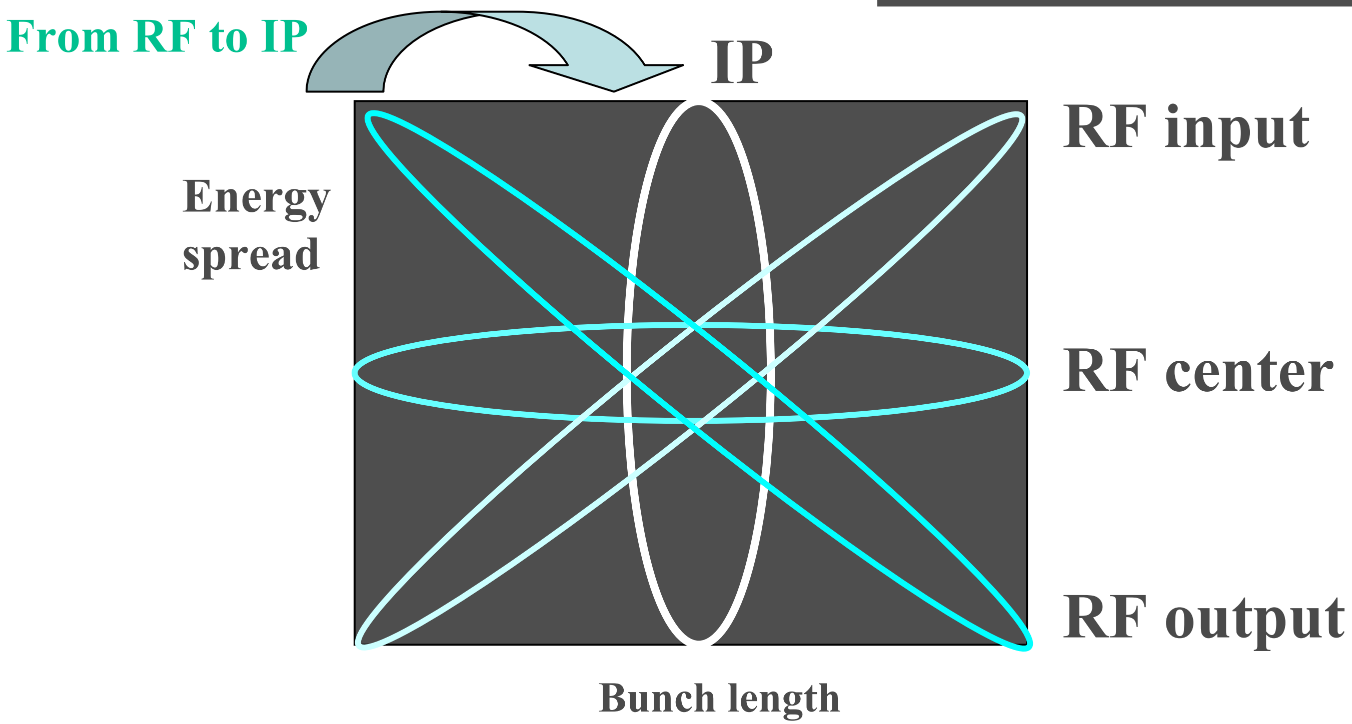
High RF voltage + **Magnetic lattice which correlates longitudinal position with energy deviation (high α_c)**

Longitudinal phase space



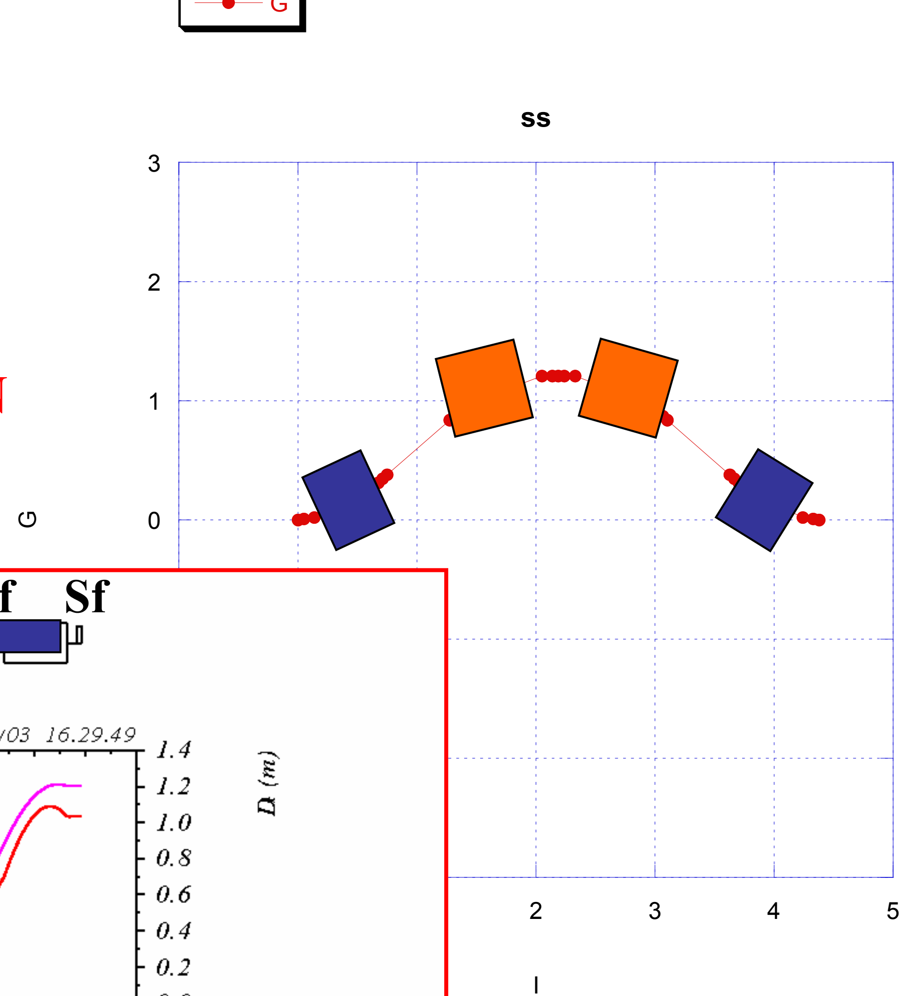
$$\frac{\sigma_{z_{\min}}}{\sigma_{z_{\max}}} = \sqrt{\frac{1+\cos\mu}{2}}$$

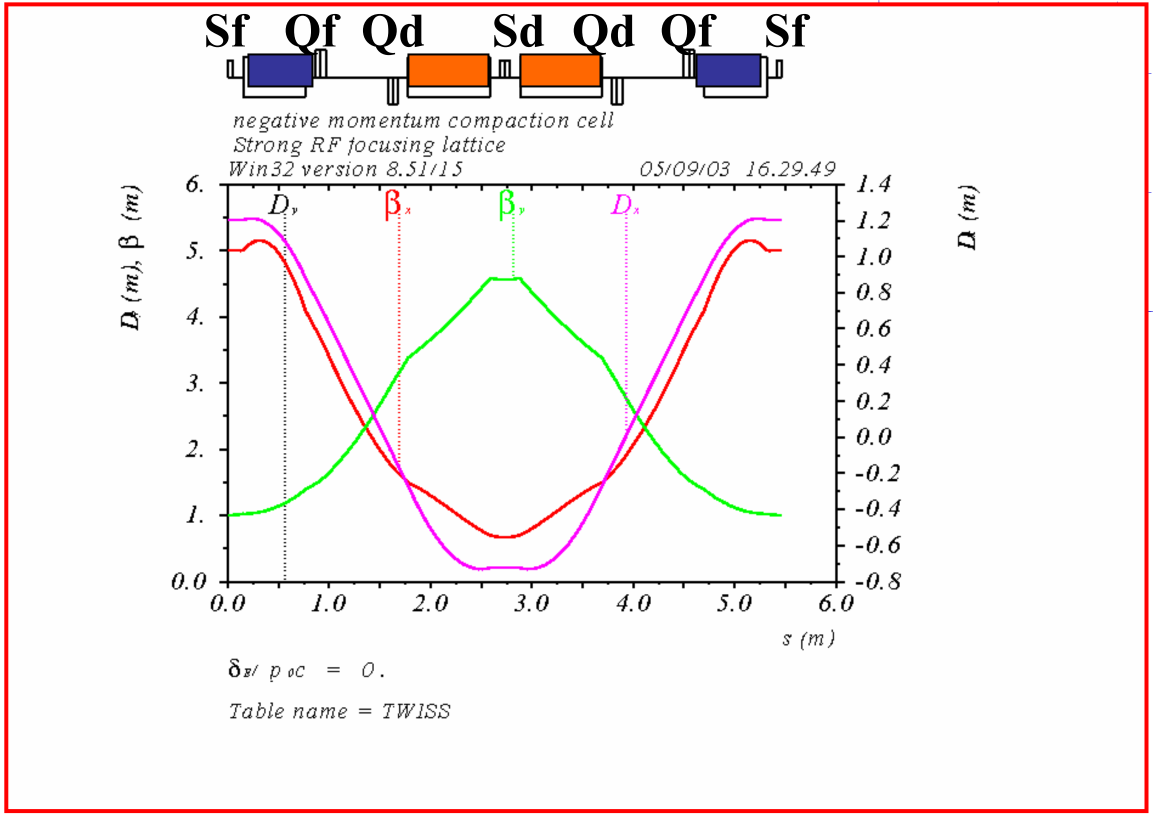
$$\cos\mu = 1 - \pi \frac{\alpha_c L}{\lambda_{rf}} \frac{V_{rf}}{E/e}$$

μ = one-turn longitudinal phase advance

Super-DAFNE LATTICE:

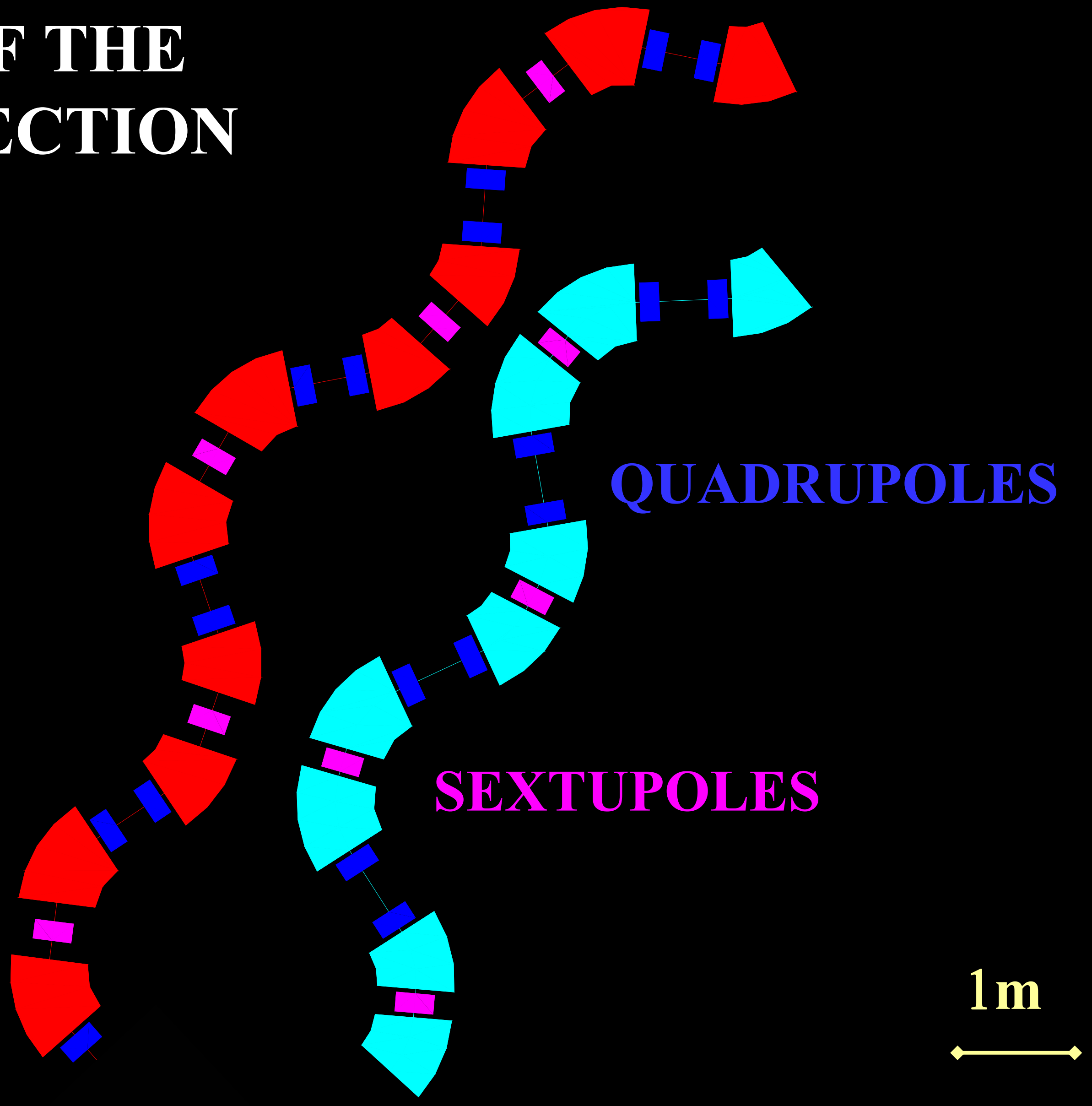
HIGH and NEGATIVE MOMENTUM COMPACTION strong RADIATION emission





Alternating positive and negative bending dipoles

ZOOM OF THE RINGS SECTION



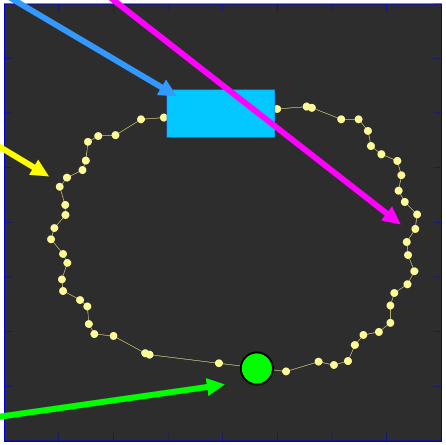
Layout similar to present DAΦNE rings:

One IR

Second crossing for injection, RF, diagnostics

Short inner arc and long outer arc with the condition of equal longitudinal phase advance between cavity and IP in both directions

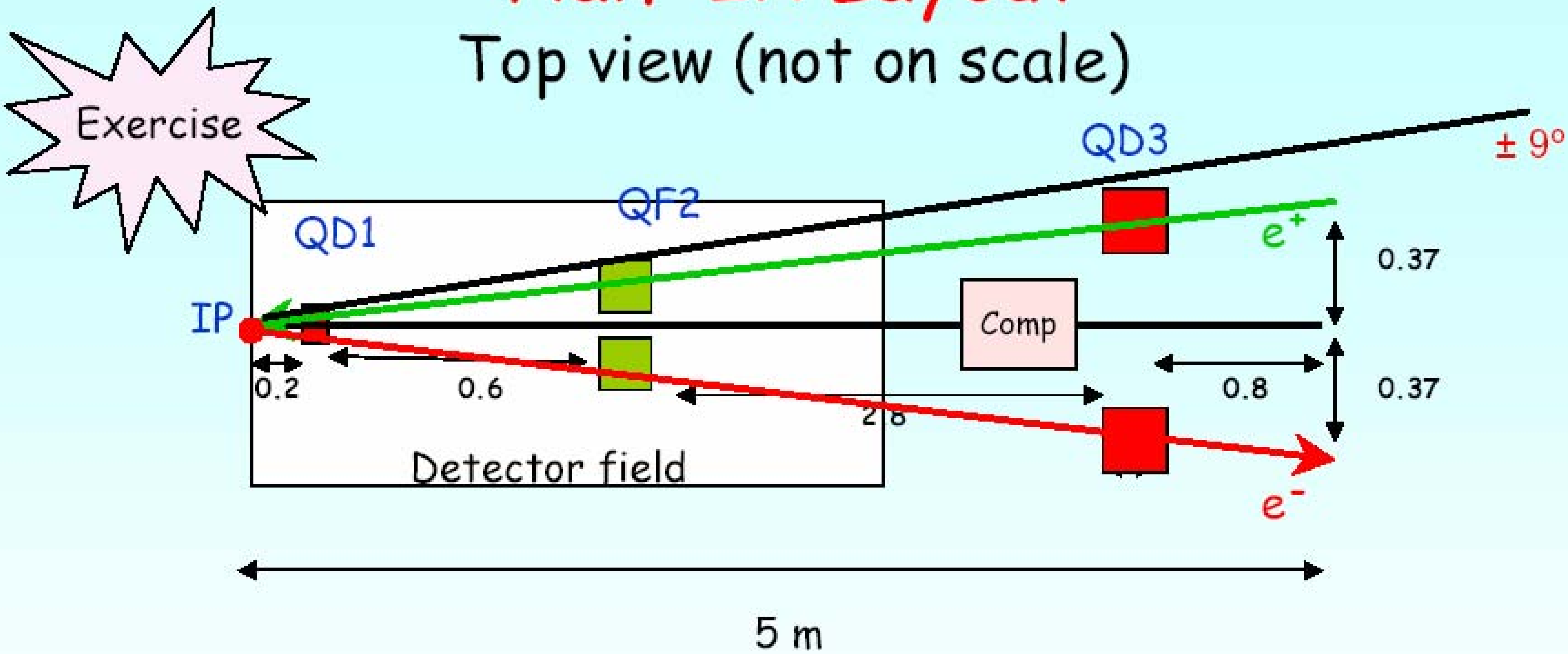
$$R_{56}(rf \rightarrow IP) = R_{56}(IP \rightarrow rf)$$



rf

Half-IR Layout

Top view (not on scale)



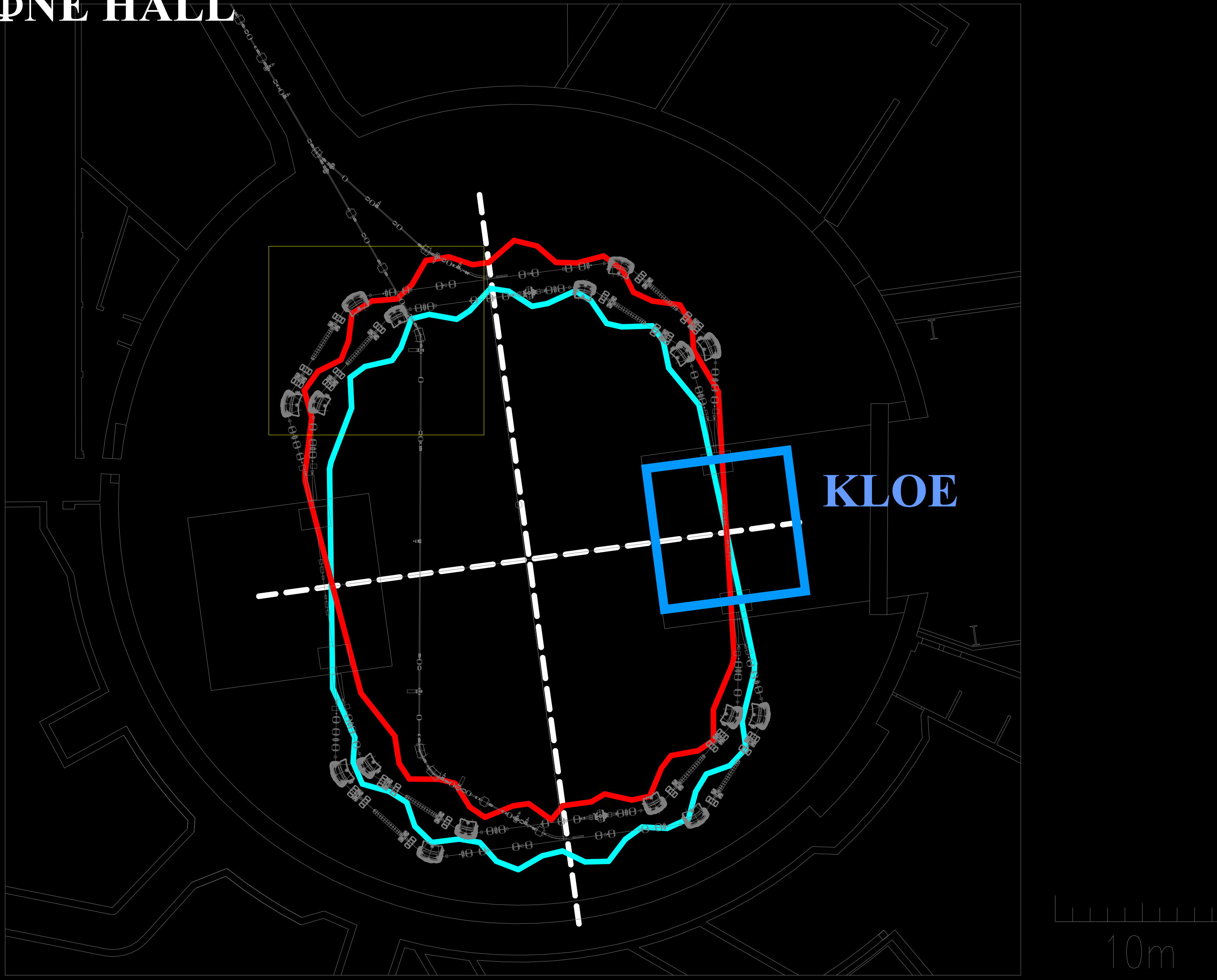
With ± $10\sigma_x$ clearance, ± 9° cone, ±30 mrad angle:

QD1: L= 20 cm, pole radius = 1.5 cm, R_{ext} = 3 cm, pm thickness= 1.5 cm

QF2: L= 20 cm, pole radius = 11 cm, R_{ext} = 16 cm, pm thickness= 1.5 cm, 4 cm space between 2 quads

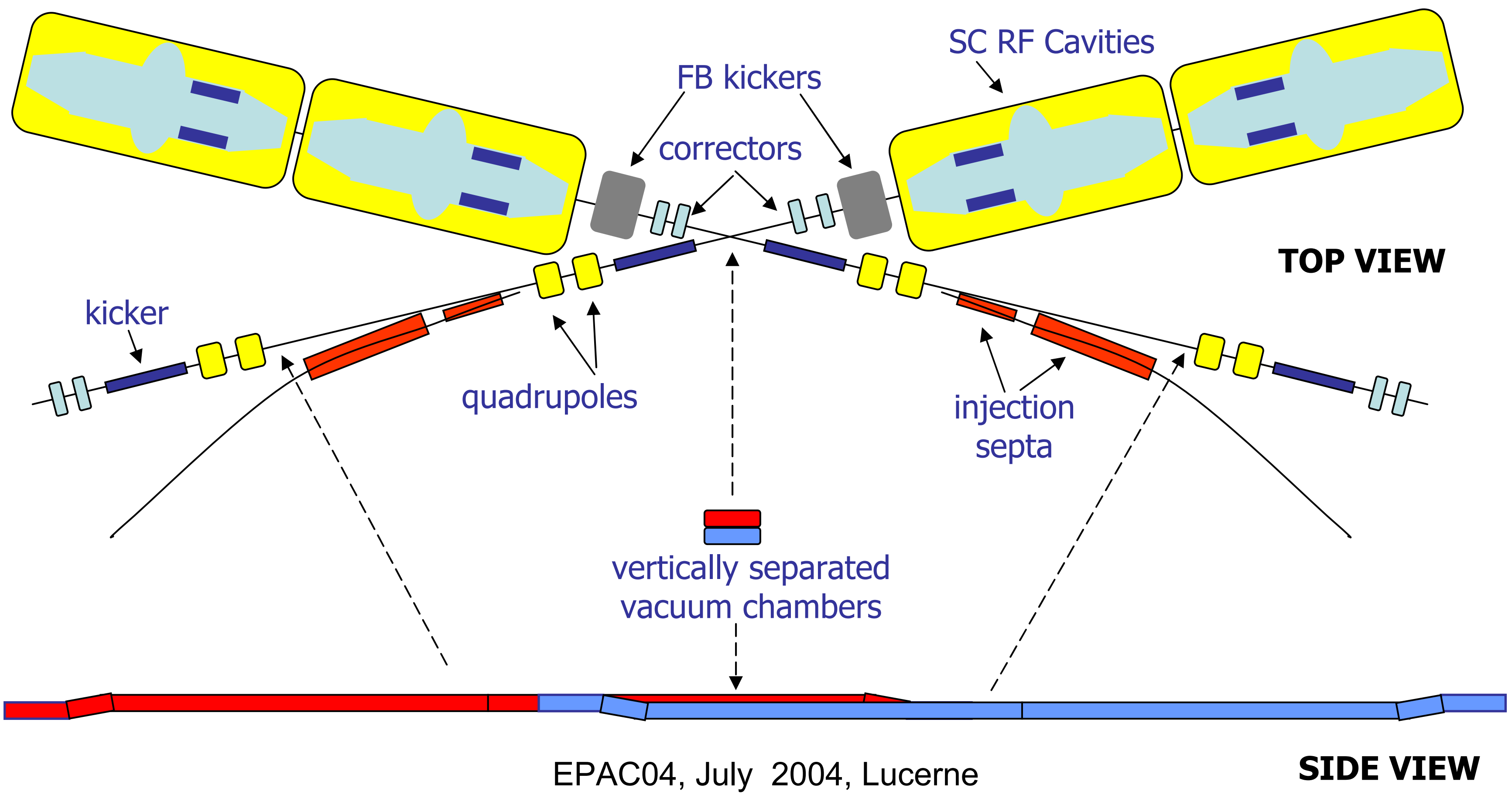
QD3: L= 20 cm, pole radius = 15 cm , R_{ext} = 63 cm, 25 cm space between 2 quads

DAΦNE HALL



F. Sgamma

Crossing point section schematic layout



Luminosity Upgrade @ Φ

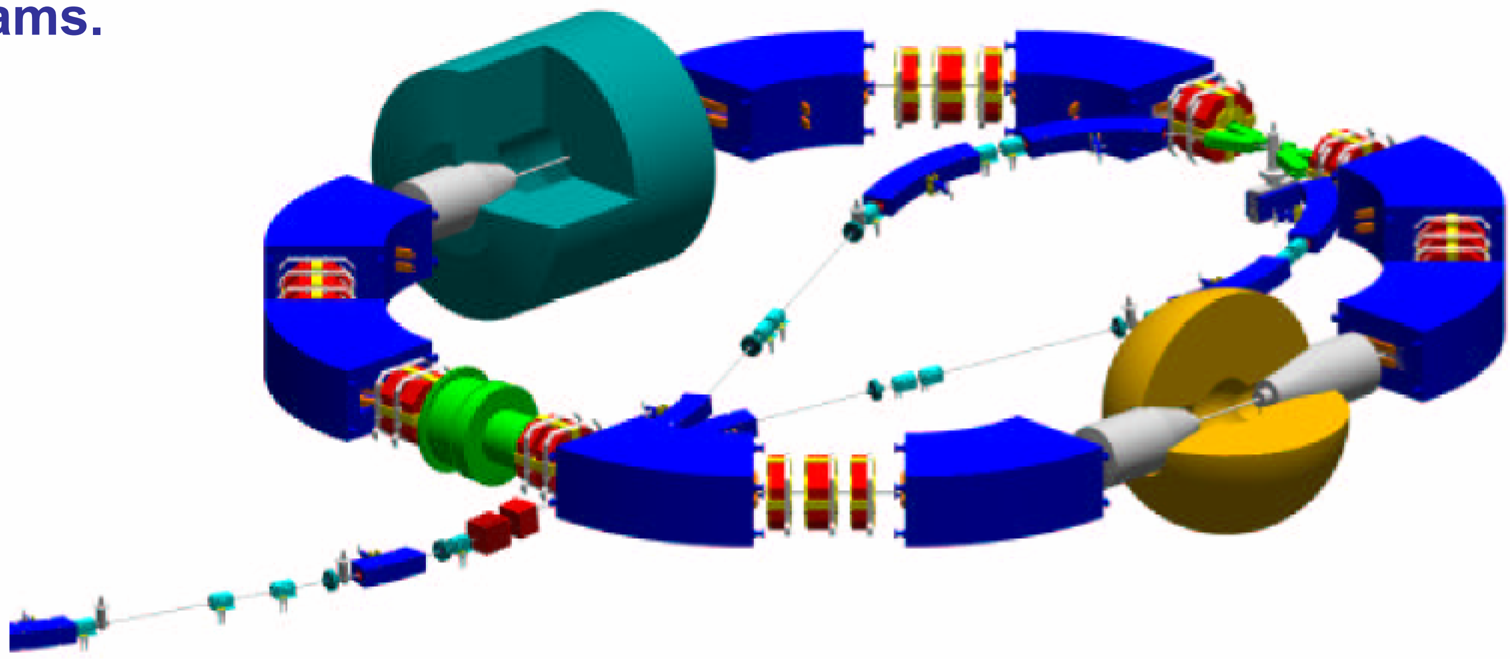
	K Physics	Hyper-nuclei	Exotic atoms		
2004 2006	$2\ 10^{32}$ >2 fb^{-1}	10^{32} 0.5 fb^{-1}	10^{32} 0.5 fb^{-1}		
2007	**SHUTDOWN**				
2008 2014	10^{33} to 10^{34} 100 fb^{-1}	10^{33} >1 fb^{-1}			
2015	???	???	???		
	KLOE	FINUDA	SIDDHARTA		
Cost (M€)	60 Accelerator				

ALTERNATIVE PROPOSALS FOR ACHIEVING ULTRA-HIGH LUMINOSITY AT LOW ENERGIES:

Round Beams to increase the linear beam-beam tune shift parameter ξ

View of the VEPP-2000 collider

Experimental testing of RCB should verify predictions on extremely high attainable space charge parameters for the round beams.



Conclusions

- The factories have so far met and exceeded the design luminosity with exception of DAFNE that had an even more ambitious target, considering the lower energy and smaller ring
- Almost 5 years of experience proved that was much easier, although not without hard work, to bring the IP sizes way below the original design values than to bring the ring currents up to the specs. This has been very challenging and a lot of different problems have been met and solved to reach the present very high currents
- Therefore the increase of about a factor 5-10 in the operating currents will be the crucial point for the super-factories, with a lot of foreseen and unknown problems to be faced