FLAVOR PHYSICS & CP VIOLATION
May 5-9, 2008, National Taiwan University, Taipei, Taiwan

Future e^+e^- flavour factories: accelerator challenges

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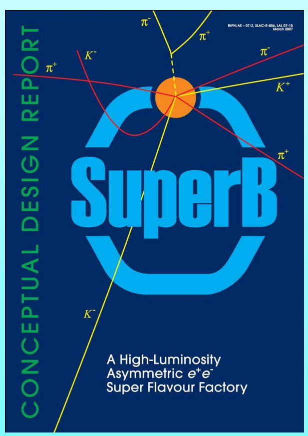
for the SuperB Team



KEKB
uest for CPV
kekb.jp

Super
KEKB
uest for BSM

The challenge

- PEP-II and KEKB have collected a huge aumount of data at the Υ(4S) resonance
- They have reached unprecedented peak luminosities larger than 10^{34} cm^{-2} s^{-1}, a borderline number just 10 years ago
- For detailed studies of heavy flavour physics a larger number of events is required
- A luminosity of the order of 10^{36} cm^{-2} s^{-1} or higher is then desirable

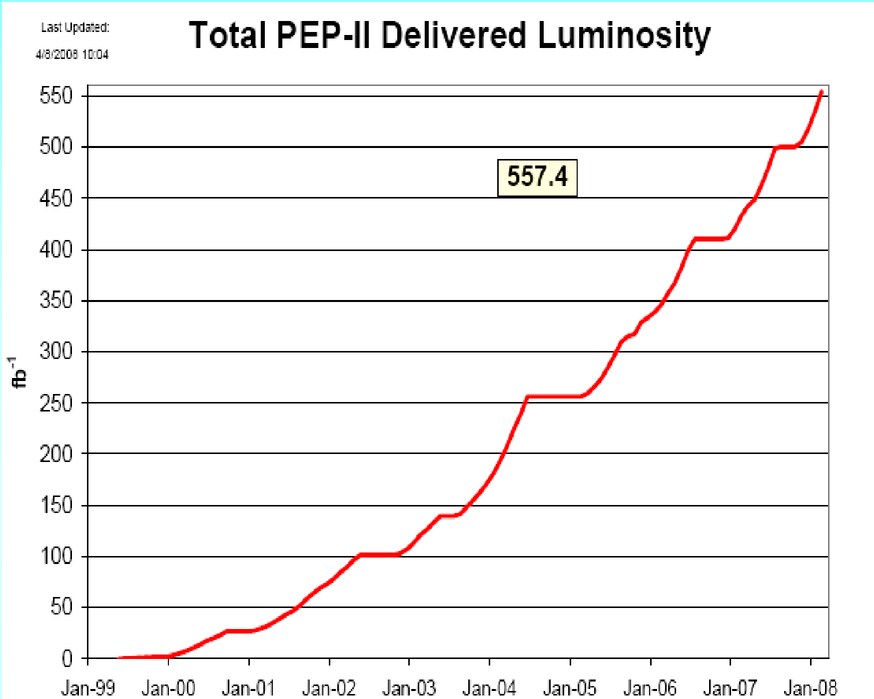
Super B-Factories come into the game

Lessons learned from B-Factories

- Asymmetric beam energies work well
- Understanding beam optics is crucial
- Transparency condition ($I^+/I^-=E^-/E^+$) is a weak condition ?
- Crossing angle is not a major limitation, but crab crossing (KEKB) or other collision schemes (*SuperB*) help
- IR backgrounds can be handled (but not easy)
- High currents can be stored (up to 3A for now) → RF ok
- Continuous injection works and is essential
- Bunch-by-bunch feedback work well (4 ns spacing)
- High beam-beam tune shifts can be reached (0.08 → 0.1)
- Both B-Factories had a smaller number of bunches than designed (more bunch current is sustainable)
- Both exceeded by far the design luminosity goals

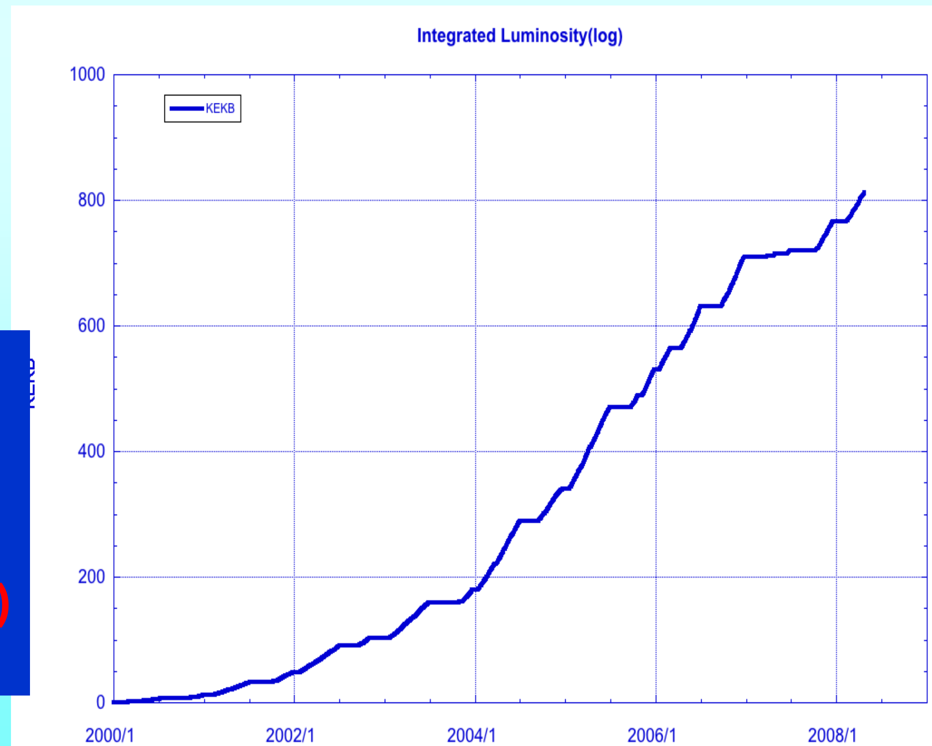
But… is this enough?

B-Factories performances

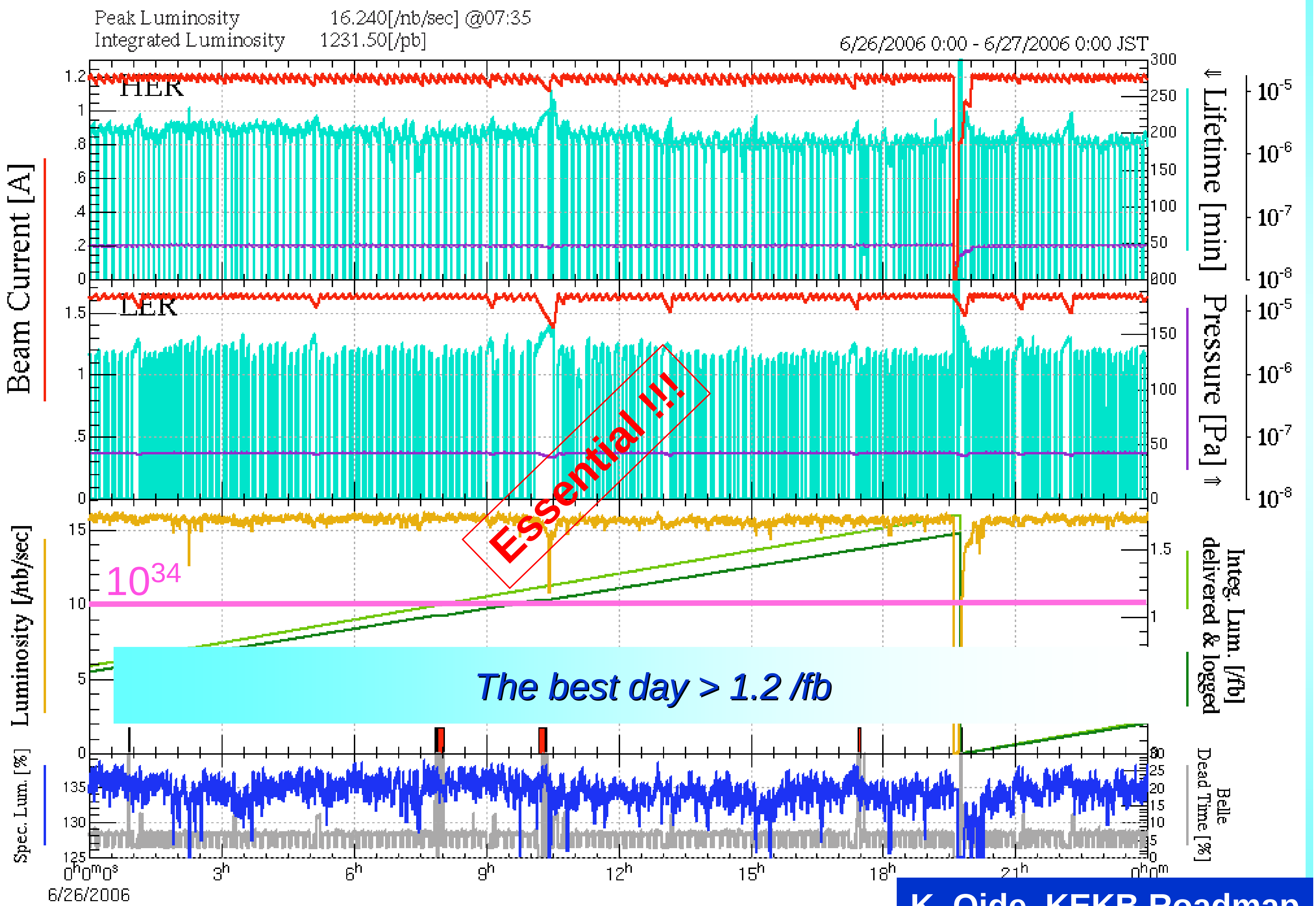


PEP-II, 1999-2008, 3.1x9 GeV
Design Peak L = 3×10^{33} cm^{-2} s^{-1}
Achieved Peak L = 1.2×10^{34} cm^{-2} s^{-1} (x4)
Design integrated L/day = 130 pb^{-1}
Achieved integrated L/day = 911 pb^{-1} (x7)
Total integrated L = 557.4 fb^{-1}

KEKB, 1999-present, 3.5x8 GeV
Design Peak L = 1×10^{34} cm^{-2} s^{-1}
Achieved Peak L = 1.7×10^{34} cm^{-2} s^{-1} (x1.7)
Design integrated L/day = 600 pb^{-1}
Achieved integrated L/day = 1231 pb^{-1} (x2)
Total integrated L > 824 fb^{-1}



The power of Continuous Injection Mode



Two approaches

- To increase Luminosity of ~ two orders of magnitude bordeline parameters are needed, such as (KEKB):
  - Very high currents
  - Smaller damping times
  - Shorter bunches (hourglass)
  - Crab cavities for head-on collision
  - Higher power

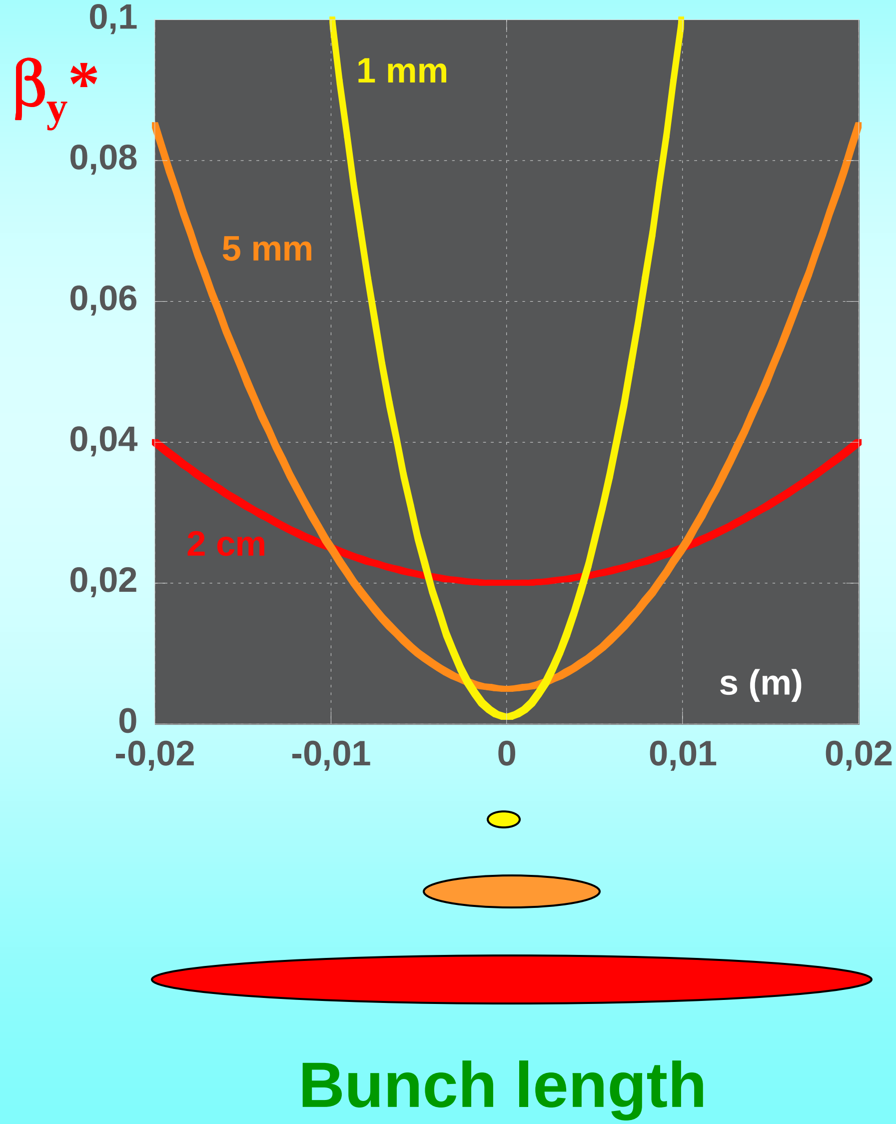
  } Difficult and costly operation (HOM, RF power, backgrounds)

- *SuperB* exploits an alternative approach, with a new IP scheme (P.Raimondi, LNF):
  - Small beams (ILC-DR like) — Tough to get
  - Large Piwinski angle and "*crab waist*"
  - Currents comparable to present Factories

- Both require status-of-the-art technology

Hourglass effect

- To squeeze vertical beam size, and increase Luminosity, β_y at IP must be decreased.
- This is efficient only if at the same time the bunch length is shortened to $\approx \beta_y$ value, or particles in the head and tail of the bunch will see a larger β_y.
- Shorter bunch requires an increase of RF voltage ($s_l \propto \mathrm{sqrt}(V_{rf})$).



KEKB & Super-KEKB

Factors to determine the luminosity

Stored current:

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

→ 9.4 /4.1 A (SuperKEKB)

Beam-beam parameter:

0.059 (KEKB)

→ >0.24 (SuperKEKB)

x5.5/x4.1

x4

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 electron radius

Beam size ratio

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

x47

x2/x2

Luminosity:

0.17×10^{35} $cm^{-2}s^{-1}$ (KEKB)

8×10^{35} $cm^{-2}s^{-1}$ (SuperKEKB)

Vertical β_y at the IP:

6.5/5.9 mm (KEKB)

→ 3.0/3.0 mm (SuperKEKB)

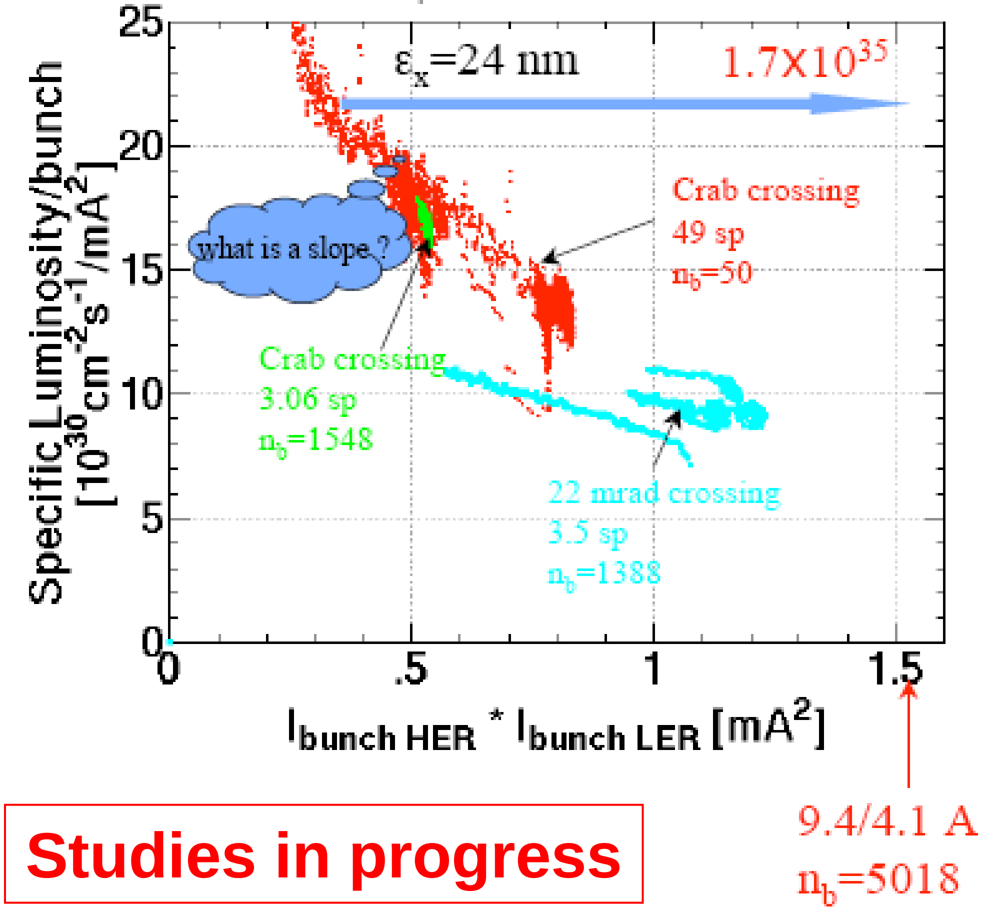
K. Oide, KEKB Roadmap

Crab cavity operation

Y. Ohnishi / KEK

Experiences at KEKB

$$L_{sp} = \frac{L}{I_+ I_-}$$ I is bunch current.



Studies in progress

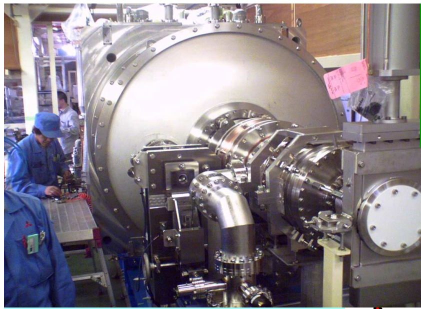
- Lower bunch current product makes luminosity twice of the crossing-angle collision.
- However, slope of the specific luminosity is NOT understood well.
- If the reason is an electron cloud, no problem after upgrade.
- If luminosity is limited by something else, we must investigate it.
  - Synchro-beta resonance ?
  - Other nonlinear effects ?

Luminosity upgrade

- Assumptions:
  - Specific luminosity/#bunches > 22×10^{30} $cm^{-2}s^{-1}mA^{-2}$ with crab cavities (factor of 2 at least) achieved at KEKB
  - High specific luminosity at high currents(9.4 A at LER) can be kept.
  - 5000 bunches can be stored.
  - No electron cloud and bunch-by-bunch feedback system working completely
  - Believe a beam-beam simulation

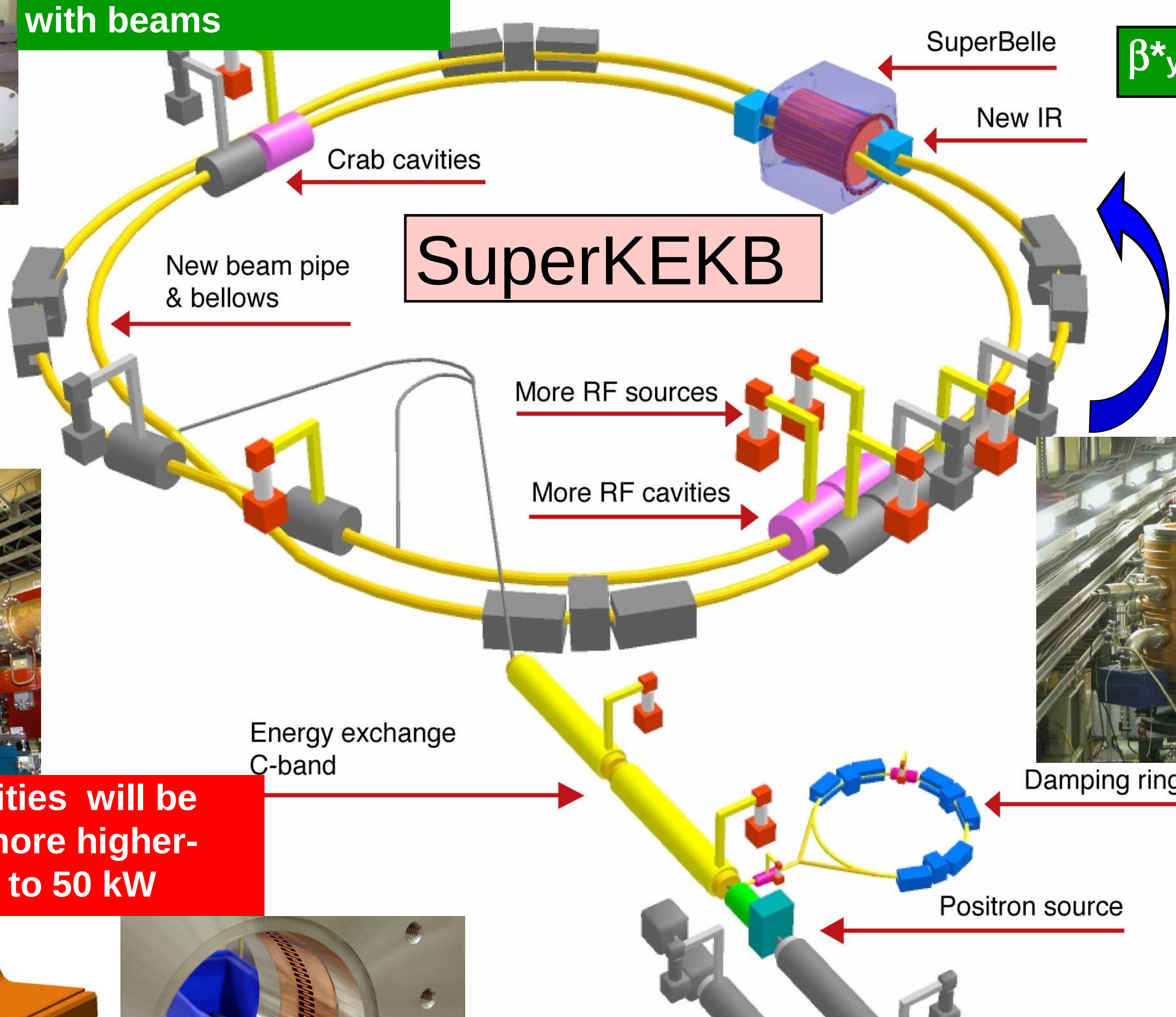
Y. Ohnishi, BNM 08, Atami, Jan. 2008

K. Oide, KEKB Roadmap



Crab cavities have been installed and tested with beams

$\beta^*_y = \sigma_z = 3$ mm

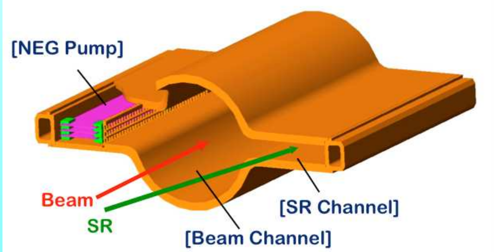


e^+ 4.1 A

e^- 9.4 A

Superconducting cavities will be upgraded to absorb more higher-order mode power up to 50 kW

ARES copper cavities will be upgraded with higher energy storage ratio to support higher currents



The beam pipes and all vacuum components will be replaced with higher-current-proof design

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

$$L = 8 \times 10^{35}\ \mathrm{cm^{-2}s^{-1}}$$

Costs & Effects

Preliminary

Item	Object	Oku-yen = 1.0 M$	Luminosity
New beam pipes	Enable high current Reduce e-cloud	178 (incl. BPM, magnets, etc.)	x1.5
New IR	Small β^*	31	x2
e+ Damping Ring	Allow injection with small increase e+ capture	40 incl. linac upgrade	if not, x0.75
More RF and cooling systems	High current	179 (incl. facilities)	x3
Crab Cavities	Higher beam-beam param.	15	x2 - x4

Items are interrelated.

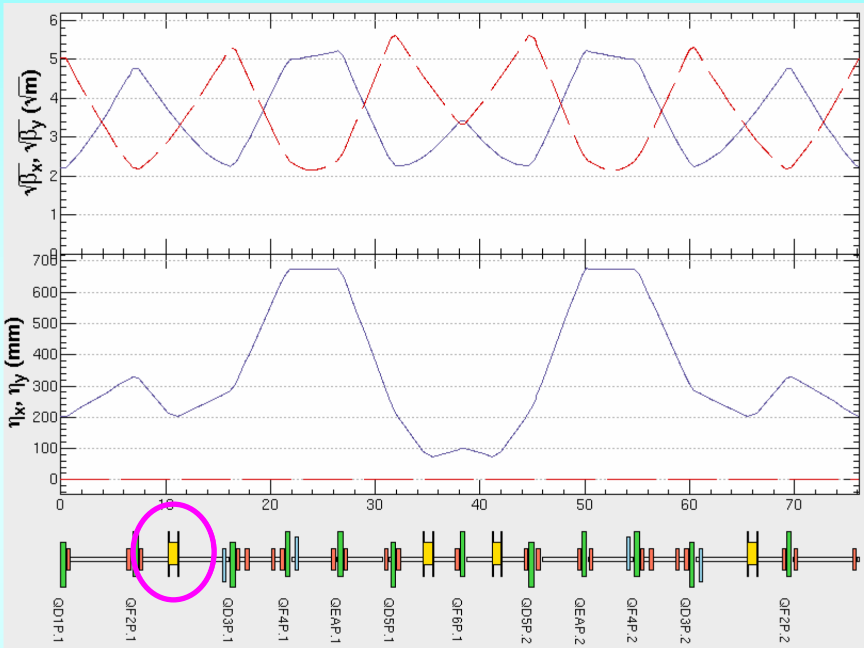
K. Oide, KEKB Roadmap

Compatibility with Italian option

LER arc cell

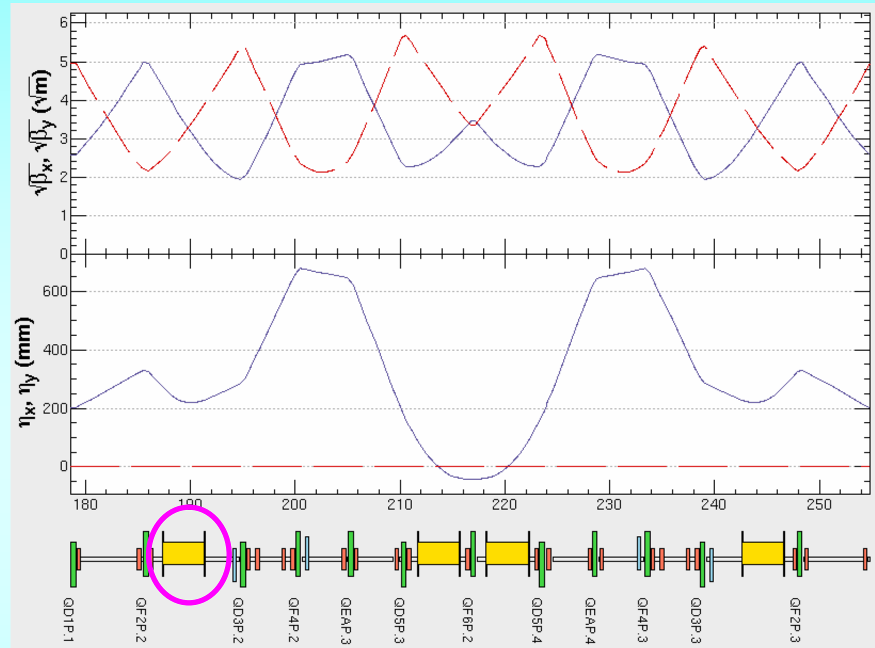
H. Koiso

Preliminary



L bend = 0.9 m

ε_x = 6.8 nm



L bend = 4.0 m

ε_x = 2.2 nm

- The arc cell lattice of the KEKB LER (left) can be modified to the low-emittance version (right), by weakening the magnetic field of the dipoles.
- No need for changing other components, beam pipes, geometry.
- The interaction region must be rebuilt.
- The HER's emittance is not reduced, but unequal emittance may be OK.

Super-KEKB summary

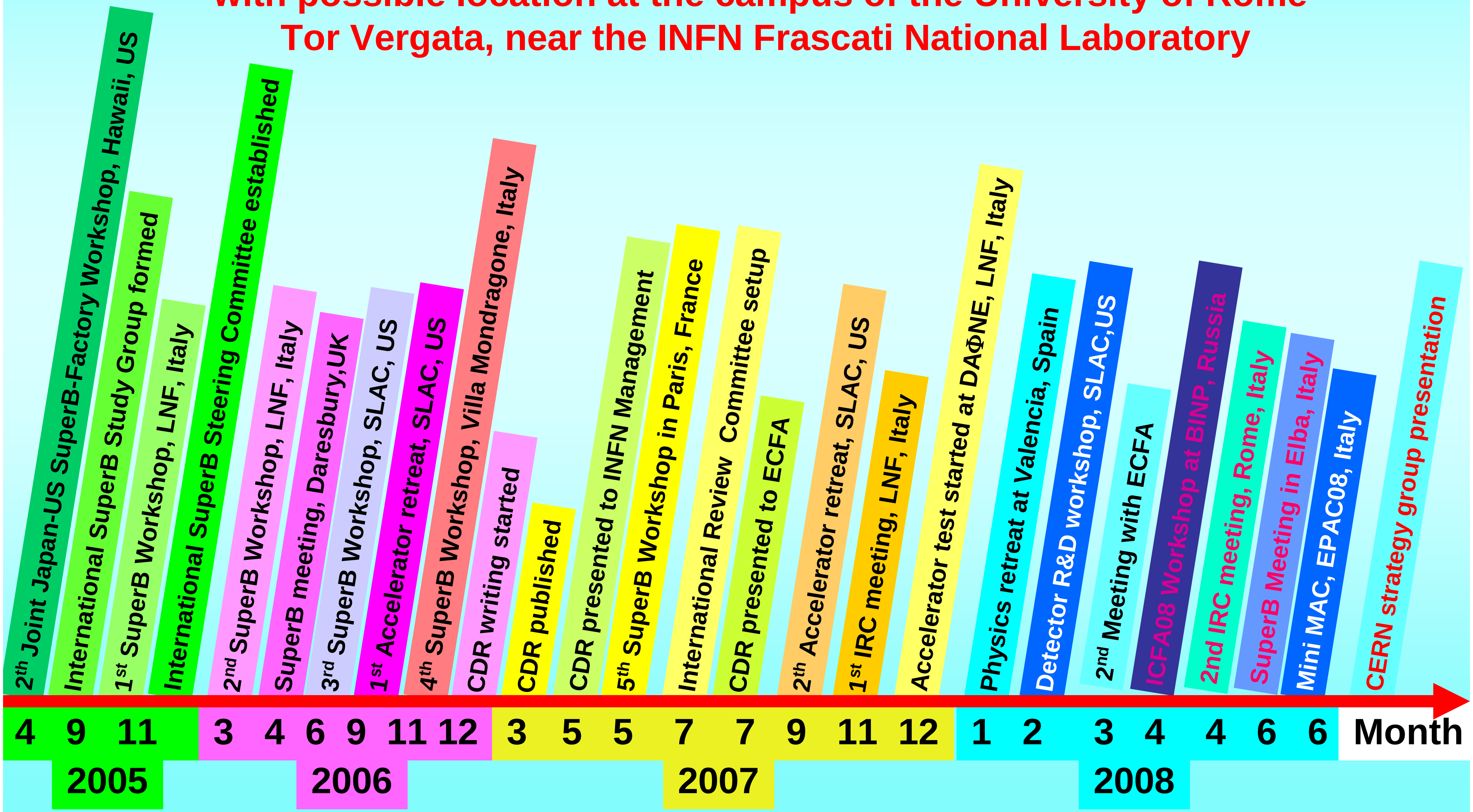
- High current scheme approach will allow to get a luminosity for KEKB upgrade of 5 to $8x10^{35}$ cm^{-2} s^{-1}
- ε_x=12 nm optics can be feasible (ε_x~2 nm if bends are replaced)
- Design of the vacuum system is almost completed except for the IR chamber. CSR evaluation not done yet
- In IR design, there are still things to be fixed, especially cure of SR fan, beam pipes

Y. Ohnishi, ICFA 08, BINP, Apr. 2008

SuperB

The SuperB Process

SuperB **aims at the construction of an asymmetric e^+e^- Flavour Factory with very high peak (1 to 4 x 10^{36} cm^{-2} s^{-1}) and integrated (>75ab^{-1}) luminosity, with possible location at the campus of the University of Rome Tor Vergata, near the INFN Frascati National Laboratory**



A new idea for L increase

P. Raimondi's: to focus more the beams at IP and have a "large" crossing angle → **large Piwinski angle**

- Ultra-low emittance (ILC-Damping Rings like)
- Very small β^* at IP
- Large crossing angle
- "Crab Waist" scheme (no RF cavity but sextupoles)

- Small collision area
- Lower β is possible (comparable to collision area, not to σ_l !)
- NO parasitic crossings
- NO synchro-betatron resonances due to crossing angle

Test at DAΦNE now !!!

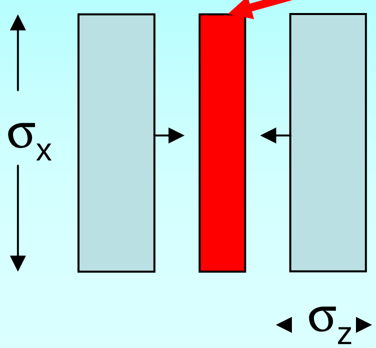
… and …

- Higher luminosity with same currents and bunch length:
  - Beam instabilities are less severe
  - Manageable HOM heating
  - No coherent synchrotron radiation of short bunches
  - No excessive power consumption

- Lower beam-beam tune shifts
- Relatively easier to make small σ_x w.r.t. short σ_l
- Parasitic collisions becomes negligible due to higher crossing angle and smaller σ_x
- Lower background rates (low currents)

Large crossing angle, small x-size

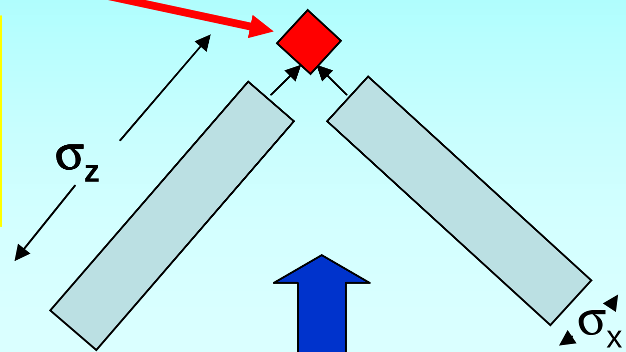
1) Head-on,
Short bunches



Overlap region

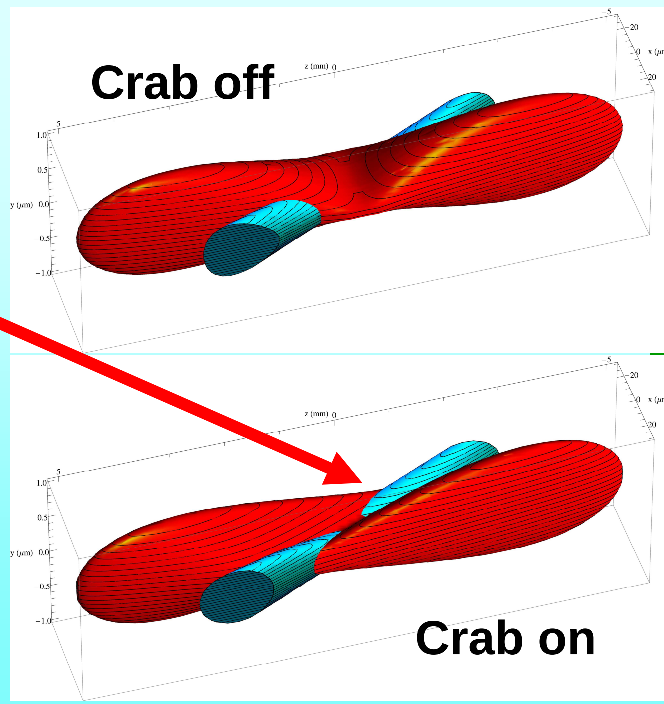
(1) and (2) have same Luminosity, but (2) has longer bunches and smaller σ_x

2) Large crossing angle,
long bunches



Large Piwinski angle:

$$\Phi = tg(\theta)\sigma_z/\sigma_x$$



y waist can be moved along z with a sextupole on both sides of IP at proper phase

⇓

"Crab Waist"

All particles in both beams collide at the minimum β_y region (waist) with a net luminosity gain

SuperB parameters

- The *SuperB,* as described in the Conceptual Design Report, is the result of an international collaboration between experts from BINP, Cockcroft Institute, INFN, KEKB, LAL/Orsay, SLAC
- The design is flexible but challenging and the synergy with the ILC Damping Rings, which helped in focusing key issues, will be important for addressing some of the topics (low ε, e-cloud, etc...)
- Beam currents are below 2 A for a luminosity up to $2x10^{36}$ $cm^{-2}s^{-1}$
- Crossing angle and “crab waist” are used to maximize luminosity and minimize beamsize blowup
    - Presently under test at DAΦNE
- No “emittance” wigglers used in Phase 1 (save in power)
- Design based on recycling all PEP-II hardware: dipoles, quadrupoles, sextupoles, RF system, and possibly vacuum system
    - Save a lot of money
- Longitudinal polarization for e^- is included
- Possibility to run at lower (τ) energy with a loss of a factor of 10 in Lumi
- Maximize Luminosity keeping low wall power:
    - Total power: 17 MW, lower than PEP-II

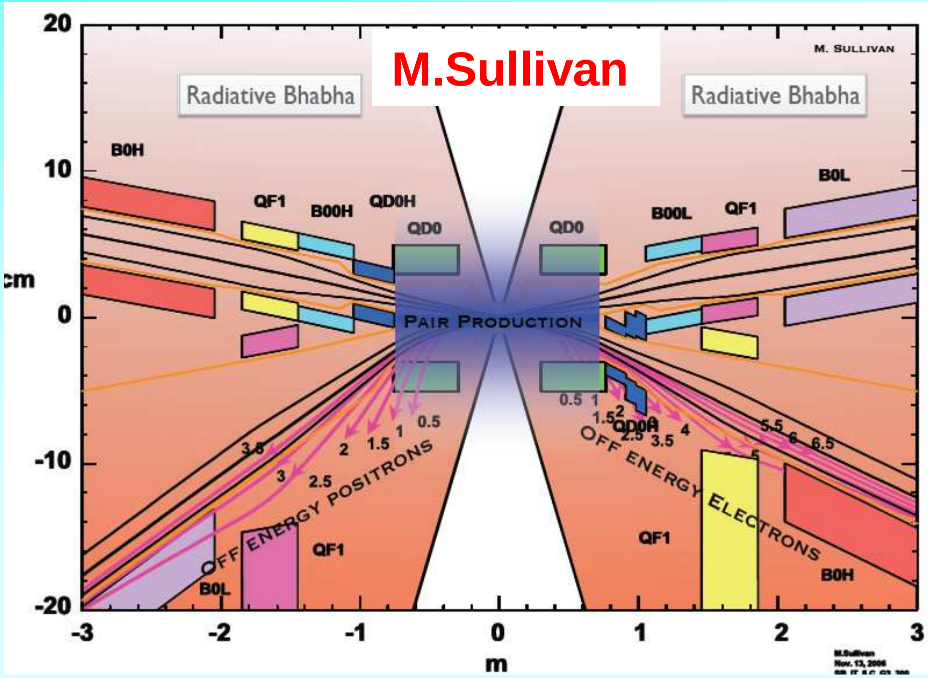
Super-B Parameters

	Nominal		Upgrade		Ultimate	
PARAMETER	LER (e+)	HER (e-)	LER (e+)	HER (e-)	LER (e+)	HER (e-)
Energy (GeV)	4	7	4	7	4	7
Luminosity x 10^{36}	1.0		2.0		4.0	
Circumference (m)	1800	1800				
Revolution frequency (MHz)	0.167					
Eff. long. polarization (%)	0	80				
RF frequency (MHz)	476					
Momentum spread ($x10^{-4}$)	7.9	5.6	9.0	8.0		
Momentum compaction ($x10^{-4}$)	3.2	3.8	3.2	3.8		
Rf Voltage (MV)	5	8.3	8	11.8	17.5	27
Energy loss/turn (MeV)	1.16	1.94	1.78	2.81		
Number of bunches	1251				2502	
Particles per bunch ($x10^{10}$)	5.52				6.78	
Beam current (A)	1.85				3.69	
Beta y* (mm)	0.22	0.39	0.16	0.27		
Beta x* (mm)	35	20				
Emit y (pm-rad)	7	4	3.5	2		
Emit x (nm-rad)	2.8	1.6	1.4	0.8		
Sigma y* (microns)	0.039	0.039	0.0233	0.0233		
Sigma x* (microns)	9.9	5.66	7	4		
Bunch length (mm)	5		4.3			
Full Crossing angle (mrad)	48					
Wigglers (#) 20 meters each	0	0	2	2		
Damping time (trans/long)(ms)	40/20	40/20	28/14	28/14		
Luminosity lifetime (min)	6.7		3.35			
Touschek lifetime (min)	20	40	38	20		
Effective beam lifetime (min)	5.0	5.7	3.1	2.9		
Injection rate pps ($x10^{11}$) (100%)	2.6	2.3	5.1	4.6	10	9.1
Tune shift y (from formula)	0.15		0.20			
Tune shift x (from formula)	0.0043	0.0025	0.0059	0.0034		
RF Power (MW)	17		25		58.2	

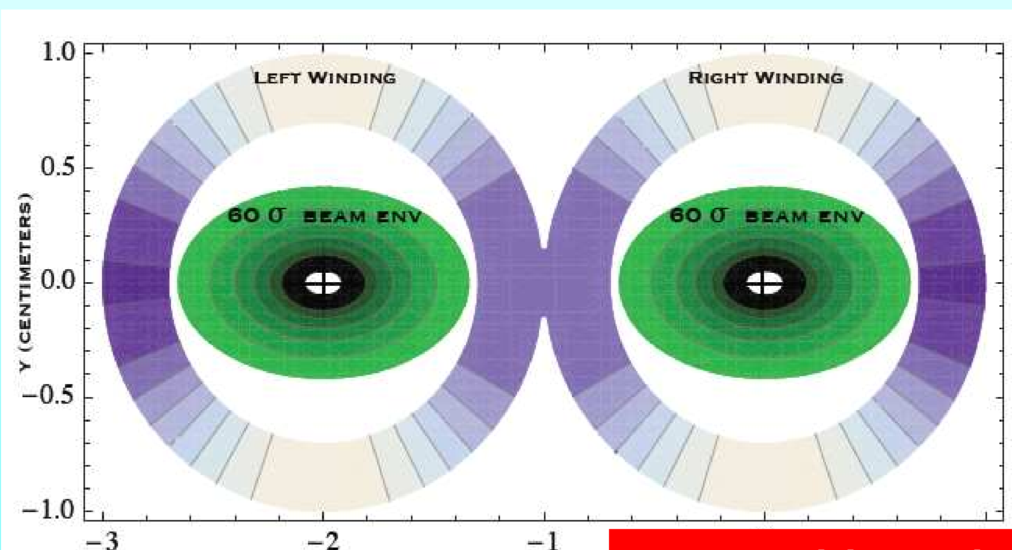
Comparison of SuperB to Super-KEKB

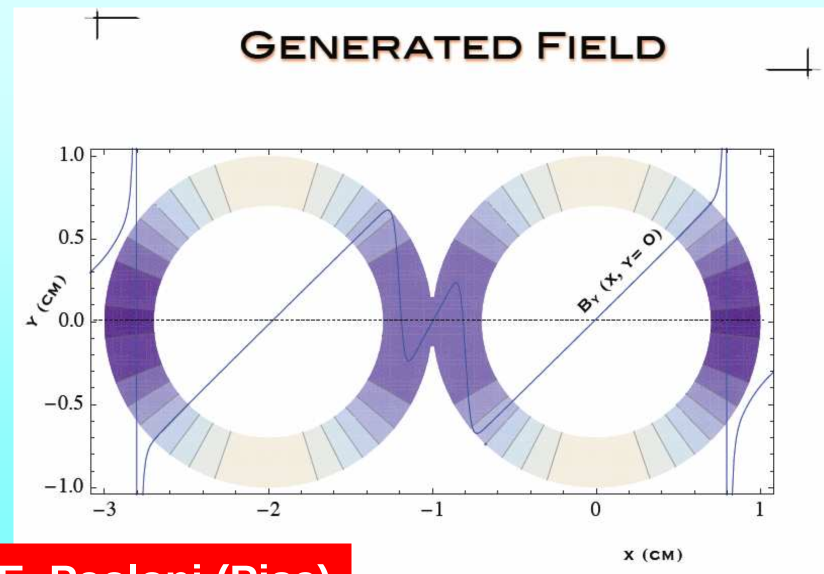
Parameter	Units	*SuperB*	Super-KEKB
Energy	GeV	4x7	3.5x8
Luminosity	$10^{36}/cm^2/s$	1.0 to 2.0	0.5 to 0.8
Beam currents	A	1.9x1.9	9.4x4.1
β_y*	mm	0.22	3.
β_x*	cm	3.5x2.0	20.
Crossing angle (full)	mrad	48.	30. to 0.
RF power (AC line)	MW	17 to 25	80 to 90
Tune shifts	(x/y)	0.0004/0.2	0.27/0.3

IP layout, “Siam twins QD0”



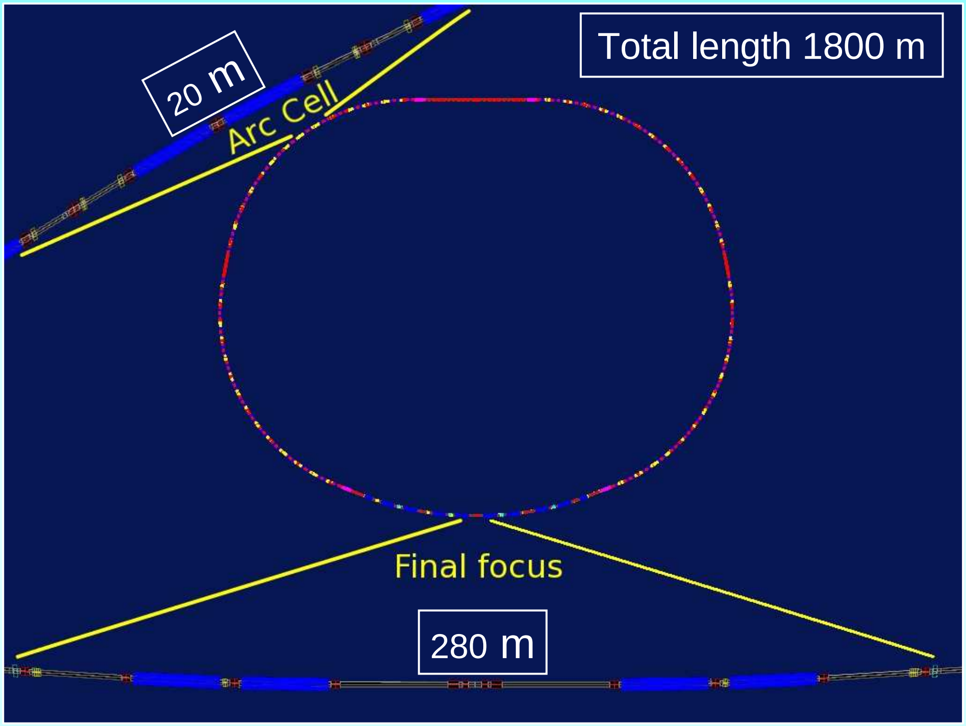
- **QD0 is common to HER and LER, with axis displaced toward incoming beams to reduce synchrotron radiation fan on SVT**
- **Dipolar component due to off-axis QD0 induces, as in all crossing angle geometries, an over-bending of low energy out coming particles eventually hitting the pipe or detector**
- **New QD0 design based on SC “helical-type” windings**





S. Bettoni (CERN), E. Paoloni (Pisa)

Lattice layout, PEP-II magnets reuse



Available

Needed

Dipoles

L_{mag} (m)	0.45	5.4
PEP HER	-	194
PEP LER	194	-
SBF HER	-	130
SBF LER	224	18
SBF Total	224	148
Needed	30	0

Quads

L_{mag} (m)	0.56	0.73	0.43	0.7	0.4
PEP HER	202	82	-	-	-
PEP LER	-	-	353	-	-
SBF HER	165	108	-	2	2
SBF LER	88	108	165	2	2
SBF Total	253	216	165	4	4
Needed	51*	134	0	4	4

Sexts

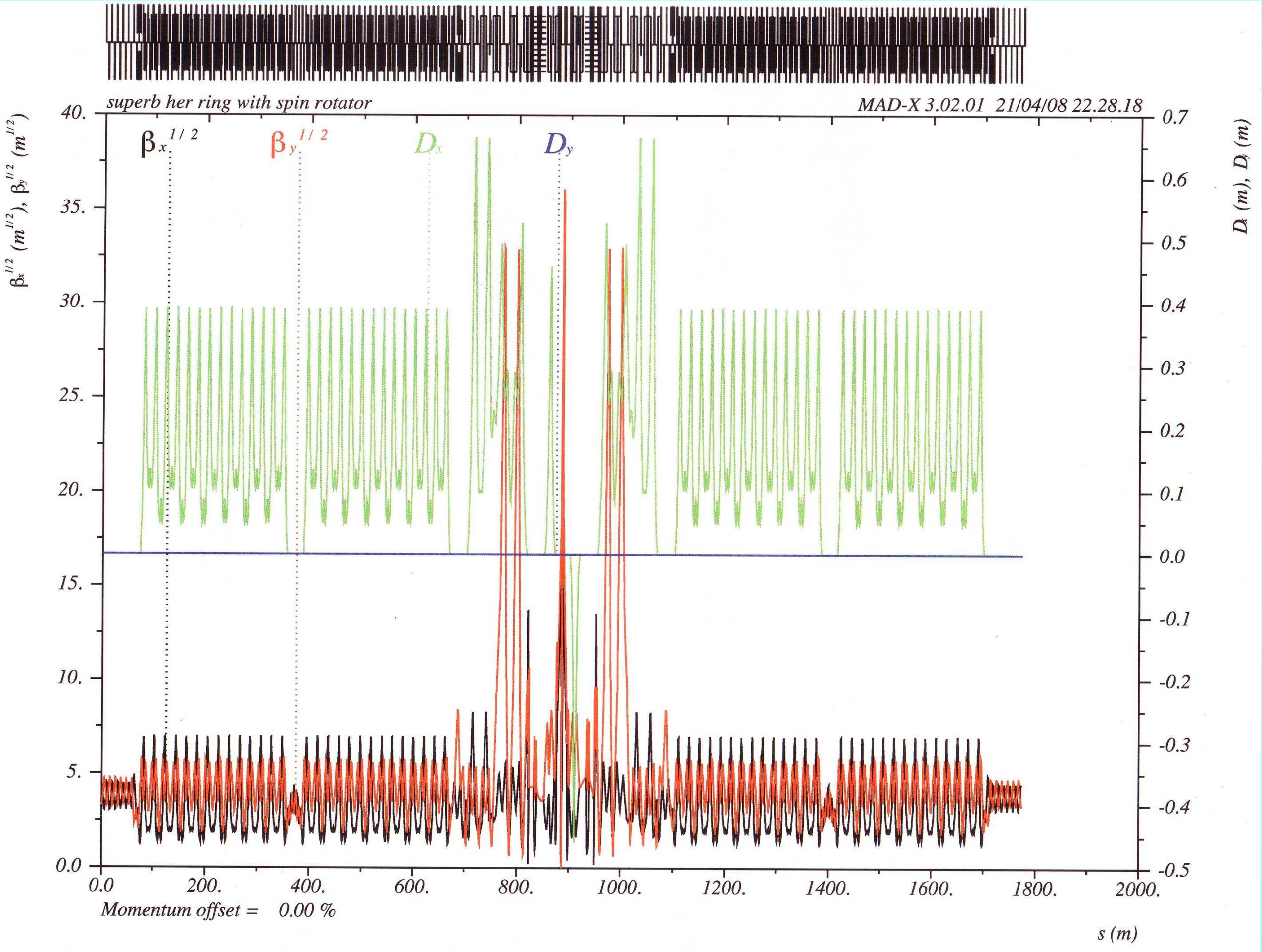
L_{mag} (m)	0.25	0.5
PEP HER/LER	188	-
SBF Total	372	4
Needed	184	4

All PEP-II magnets are used, dimensions and fields are in range

RF requirements are met by the present PEP-II RF system

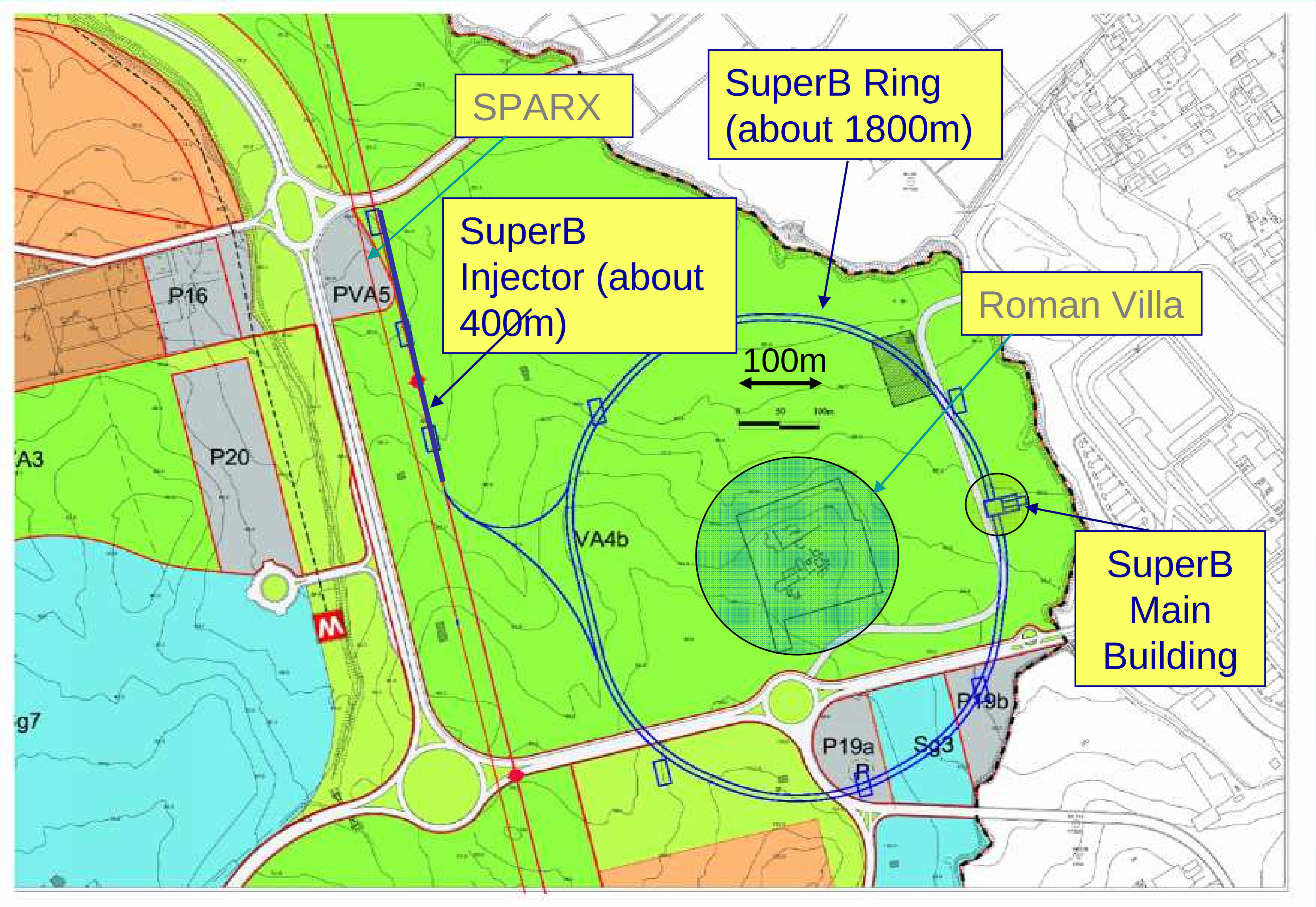
Super-B Lattice with spin rotator

Preliminary



Wittmer
Wienands
Biagini

SuperB footprint on Tor Vergata site



Accelerator & site cost estimate

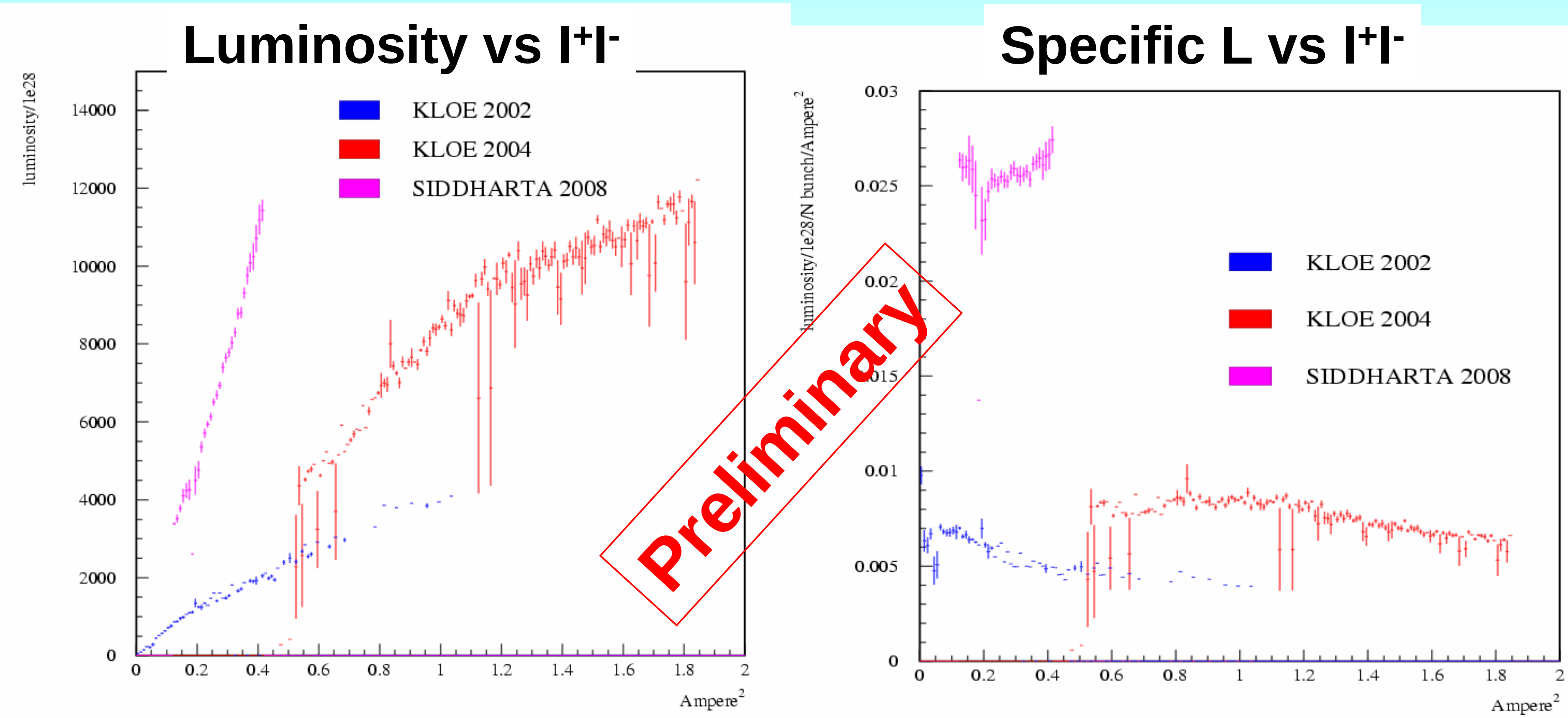
WBS	Item	EDIA mm	Labor mm	M\&S kEuro	Rep.Val. kEuro
1	**Accelerator**	**5429**	**3497**	**191166**	**126330**
1.1	Project management	2112	96	1800	0
1.2	Magnet and support system	666	1199	28965	25380
1.3	Vacuum system	620	520	27600	14200
1.4	RF system	272	304	22300	60000
1.5	Interaction region	370	478	10950	0
1.6	Controls, Diagnostics, Feedback	963	648	12951	8750
1.7	Injection and transport systems	426	252	86600	18000

WBS	Item	EDIA mm	Labor mm	M\&S kEuro	Rep.Val. kEuro
2.0	**Site**	**1424**	**1660**	**105700**	**0**
2.1	Site Utilities	820	1040	31700	0
2.2	Tunnel and Support Buildings	604	620	74000	0

Note: site cost estimate not as detailed as other estimates

First results of DAΦNE test

DAΦNE upgrade with improved interaction region to focus tighter beams at IP and have a "large" crossing angle → large Piwinski angle



Peak and specific luminosity vs product of beam currents for different colliding parameters in 2002, 2004, 2008

Summary for SuperB

- The initial *SuperB* design meets the goals requested by the experimenters
- SuperB has very ambitious goals in terms of peak and integrated luminosity, supported by a new collision scheme and confirmed by beam-beam simulations
- The test on this scheme is in progress and encouraging results have been achieved
- Work is continuing to focus on possible issues
- The next steps for the accelerator will be to form a team to complete a Technical Design Report by 2010, and…
- ...be included in the CERN Strategy Plan for European infrastructures

Conclusions

- KEKB and PEP-II experience was highly positive and instructive
- Upgrade of Flavour Factories is desirable and feasible
- Two different approaches are being considered for Super-KEKB and *SuperB*, with different challenges
- Super-KEKB is the natural continuation of KEKB, studies are advanced and is waiting for funding
- *SuperB* exploits new concepts in colliding beams physics, allowing for the collection of a larger data sample
- A *SuperB* Conceptual Design Report was issued in 2007 and is being reviewed by an International Review Committee, a TDR will be ready by 2010
- First results of upgraded DAΦNE with “Crab Waist” scheme are very encouraging and important for the very high luminosity regime required by future Flavour Physics studies

Stay tuned !