DESIGN REPORT

SuperB Accelerator

Overview and Lattice

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for the *SuperB* Accelerator Team

ICFA08 Workshop

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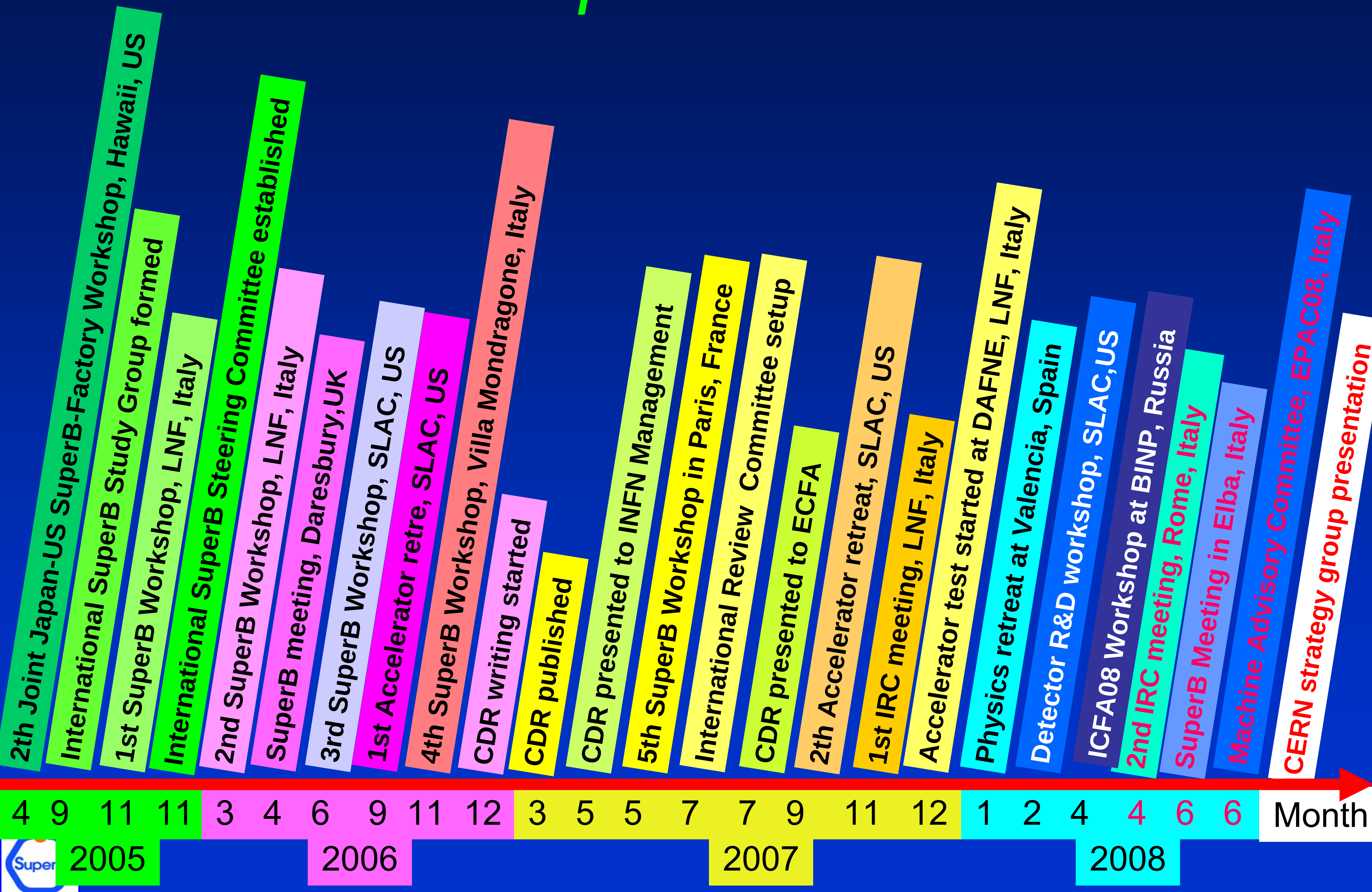
Outline

- The SuperB project
- Luminosity and new concepts
- Transparency conditions
- Beam-beam studies
- Beam dynamics studies
- Lattice
- Conclusions

SuperB project

- *SuperB* aims at the construction of a very high luminosity (10^{36} cm^{-2} s^{-1} at least) asymmetric e^+e^- Flavour Factory, with possible location at the campus of the University of Rome Tor Vergata, near the INFN Frascati National Laboratory.
- Attempts to design a Super B-Factory date to 2001. The initial approach at SLAC and KEK had much in common: they were extrapolations of the very successful B Factory designs, with increased bunch charge, more bunches, and crab cavities to correct for the crossing angle at the Interaction Point.
- These proposed designs reached luminosities of 5 to 7 x 10^{35} cm^{-2} s^{-1} but had wall plug power of the order of 100 MW. This daunting power consumption was a motivation to adapt linear collider concepts from SLC and ILC to the regime of high luminosity storage ring colliders.

The SuperB Process

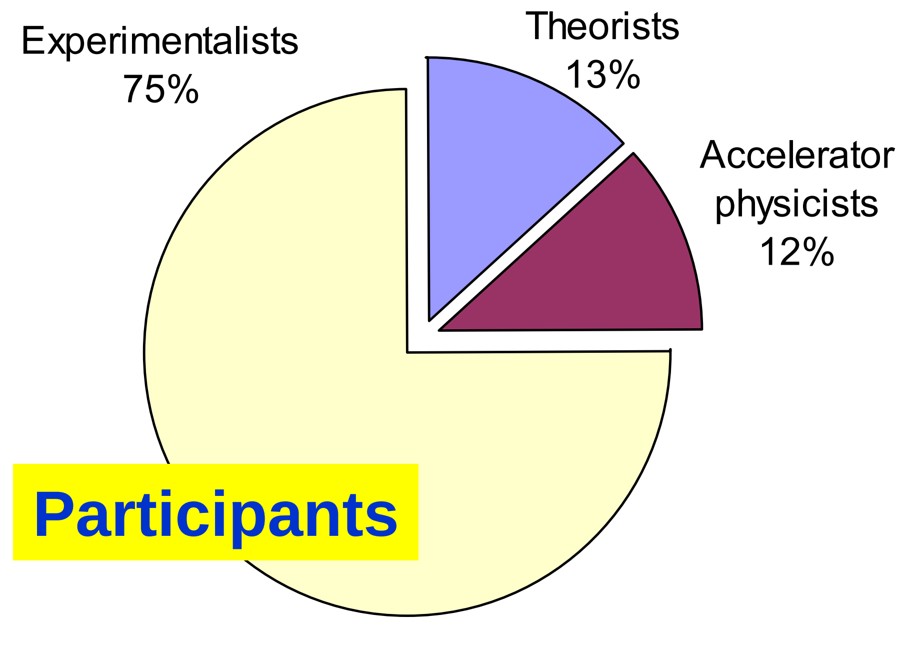


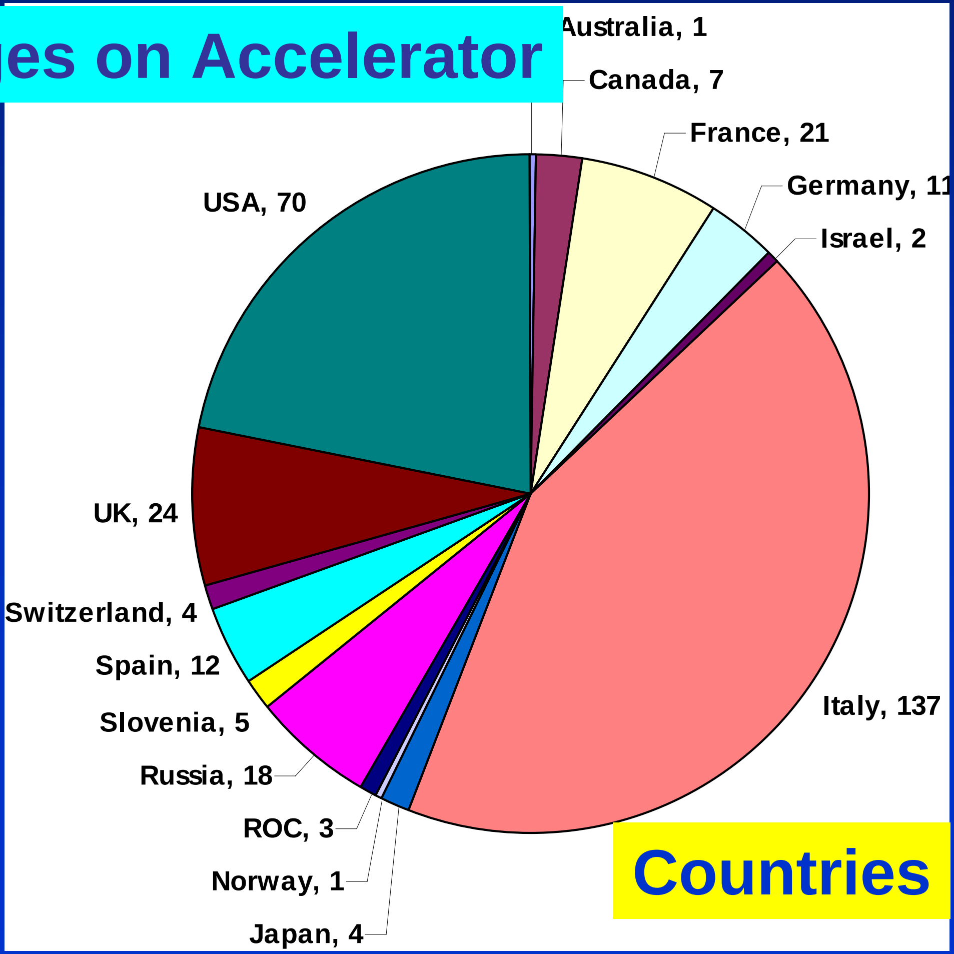
The SuperB CDR

"Conceptual Design Report" (450 pp), March 2007
INFN/AE-07/2,SLAC-R-856, LAL 07-15, arXiv:0709.0451 [hep-ex]
www.pi.infn.it/SuperB/?q=CDR

- 320 CDR signatures
- 85 Institutions
- 239 Experimentalists

200 pages on Accelerator





SuperB Accelerator CDR Contributors

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Basic concepts

- B-Factories (PEP-II and KEKB) reached very high luminosity (>10^{34} s^{-1} cm^{-2}), but to increase L of ~ two orders of magnitude bordeline parameters are needed, such as:
  - Very high currents
  - Smaller damping time
  - Shorter bunches
  - Crab cavities for head-on collision
  - Higher power

Difficult and costly operation

- *SuperB* exploits an alternative approach, with a new IP scheme:
  - Small beams (ILC-DR like)
  - Large Piwinsky angle and "*crab waist*"
  - Currents comparable to present Factories

How to increase L ?

“Brute force”

- Increase beam currents
- Decrease β_y^*
- Decrease bunch length

But...

- HOM in beam pipe
  - *overheating, instabilities, power costs*
- Detector backgrounds increase
- Chromaticity increases
  - *smaller dynamic aperture*
- RF voltage increases
  - *costs, instabilities*

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-DR like)
- Very small β^* at IP
- Large crossing angle
- "Crab Waist" scheme

- Small collision area
- Lower β is possible

- NO parasitic crossings
- NO synchro-betatron resonances due to crossing angle

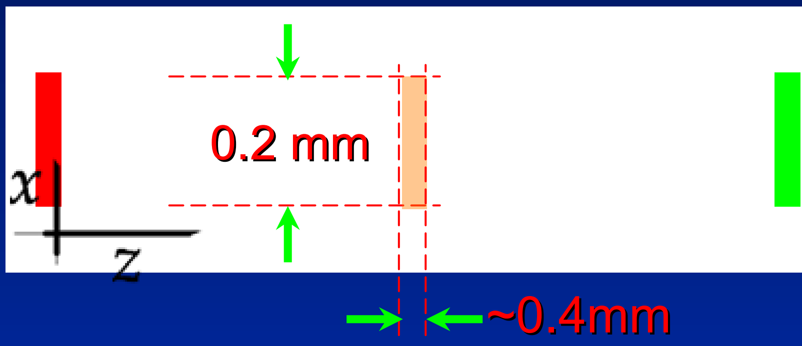
Test at DAΦNE now !!!

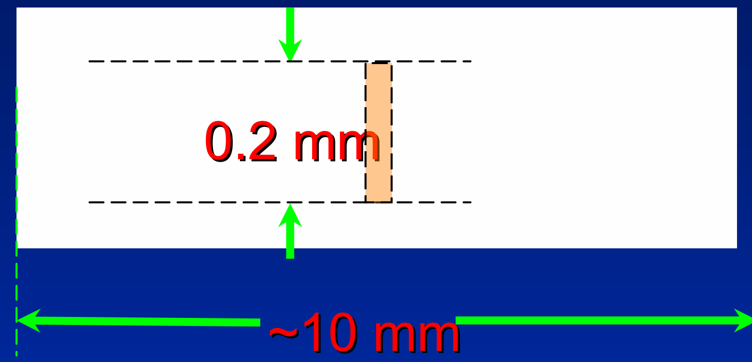
... and ...

- 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 with respect to short σ_z
- Parasitic collisions becomes negligible due to higher crossing angle and smaller σ_x

Large crossing angle, small x-size

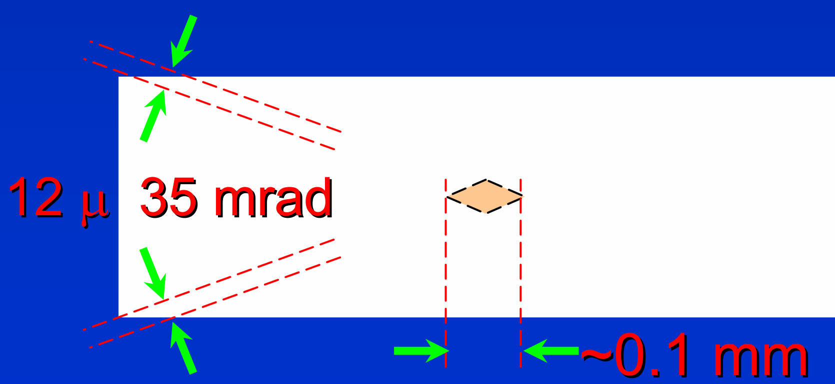




Short bunches
aspect ratio $\sigma_y/\sigma_x \sim 1/3000$

Long bunches
aspect ratio $\sigma_y \sigma_x \sim 1/300$

A large crossing angle "swaps" x with z



Large Piwinski angle:

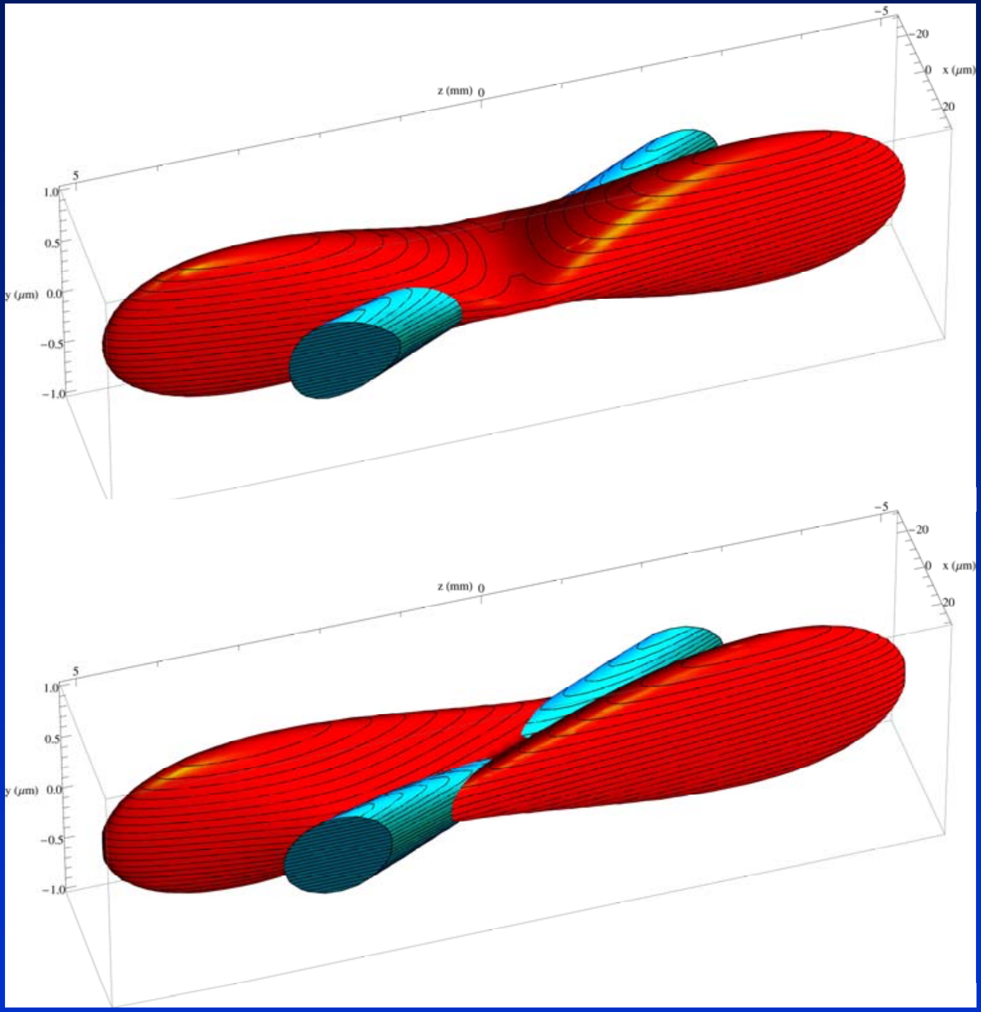
$\Phi = tg(\theta)\sigma_z/\sigma_x$

E. Paoloni

Beams distribution at IP

E. Paoloni

Crab sextupoles OFF



waist line is orthogonal to the axis of one bunch

Crab sextupoles ON

waist moves to the axis of other beam

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

SuperB transparency condition (1)

- To have equal tune shifts with asymmetric energies in PEP-II and KEKB the "design" beam currents ratio is:

$$I^+/I^- \sim E^-/E^+$$

- Due to *SuperB* large crossing angle, new conditions are possible: LER and HER beams can have different emittances and β* and equal currents

$$\xi^+ = \xi^- \Leftrightarrow \frac{N^+}{N^-} = \frac{E^-}{E^+} \quad \Leftrightarrow \quad \xi^+ = \xi^- \Leftrightarrow \frac{\beta_y^+}{\beta_y^-} = \frac{E^+}{E^-}$$

Present B-factories | ***SuperB***

Transparency condition (2)

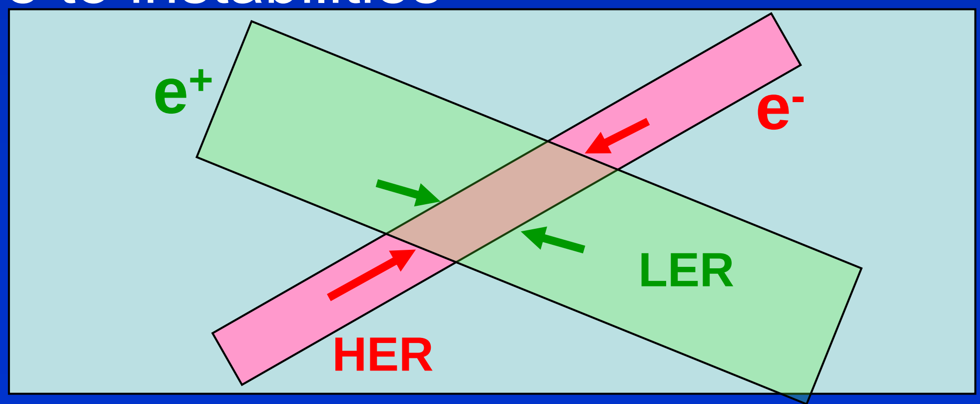
$$\xi^{+} = \xi^{-} \Leftrightarrow \frac{\beta_y^{+}}{\beta_y^{-}} = \frac{E^{+}}{E^{-}}$$

$$\boxed{\sigma_y^{+} = \sigma_y^{-}} \Leftrightarrow \beta_y^{+} = \frac{E^{+}}{E^{-}}\beta_y^{-}$$

$$\varepsilon_y^{+} = \frac{E^{-}}{E^{+}}\varepsilon_y^{-}, \quad \varepsilon_x^{+} = \frac{E^{-}}{E^{+}}\varepsilon_x^{-}$$

$$\sigma_x^{+} = \frac{E^{-}}{E^{+}}\sigma_x^{-}$$

- LER sees a shorter interaction region, (4/7 of the HER one)
- LER has a smaller β_y*, easier to acheive in the Final Focus
- LER has larger emittance, 2.8 nm, better for Tousheck effect and tolerance to instabilities



Transparency condition (3)

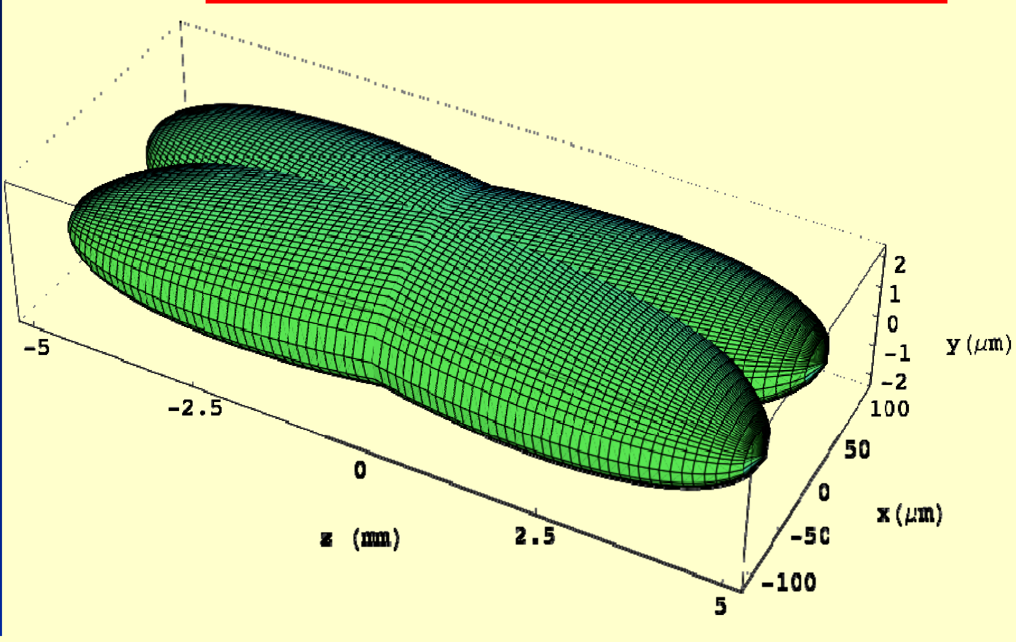
- Both beam lifetimes are increased (larger emittances), injection rates reduced
- Beam-eam simulations show good results, no blow up is seen for HER, 1-3% for LER, but some more optimization is possible: tunes, crabbing ($L=10^{36}$ is predicted)
- Upgrade parameters can be implemented in any order:
  - decrease the emittances first, or...
  - increase the bunch charge, or...
  - increase the number of bunches, or...
  - decrease the bunch length
- Less RF Voltage is needed

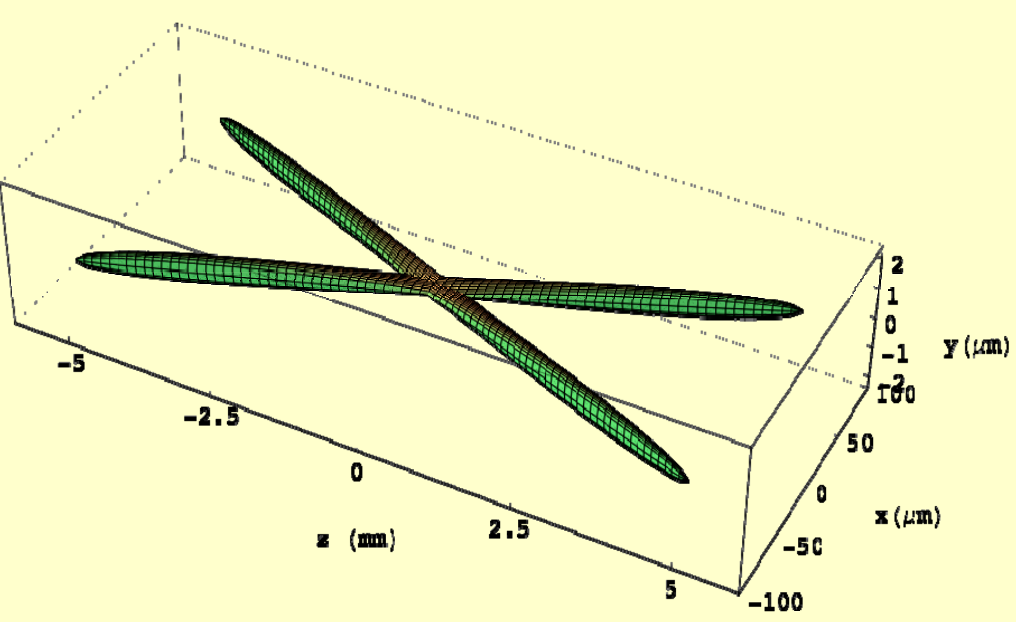
SuperB New Parameters

	Nominal		Upgrade	
PARAMETER	LER (e+)	HER (e-)	LER (e+)	HER (e-)
Energy (GeV)	4	7	4	7
Luminosity x 10^{36}	1.0		2.0	
Circumference (m)	1800	1800		
Revolution frequency (MHz)	0.167			
Eff. long. polarization (%)	0	80		
RF frequency (MHz)	476			
Momentum spread ($\times 10^{-4}$)	7.9	5.6	9.0	8.0
Momentum compaction ($\times 10^{-4}$)	3.2	3.8	3.2	3.8
Rf Voltage (MV)	5	8.3	8	11.8
Energy loss/turn (MeV)	1.16	1.94	1.78	2.81
Number of bunches	1251			
Particles per bunch ($\times 10^{10}$)	5.52			
Beam current (A)	1.85			
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)	13	20	6.9	10.3
Effective beam lifetime (min)	4.5	5.1	2.3	2.5
Injection rate pps ($\times 10^{11}$) (100%)	2.6	2.3	5.1	4.6
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	

Transparency conditions in red

IP beam distributions for KEKB





IP beam distributions for SuperB

SuperB beams are focused in the y-plane 100 times more than in the present factories, thanks to:

- small emittances
- small beta functions
- larger crossing angle

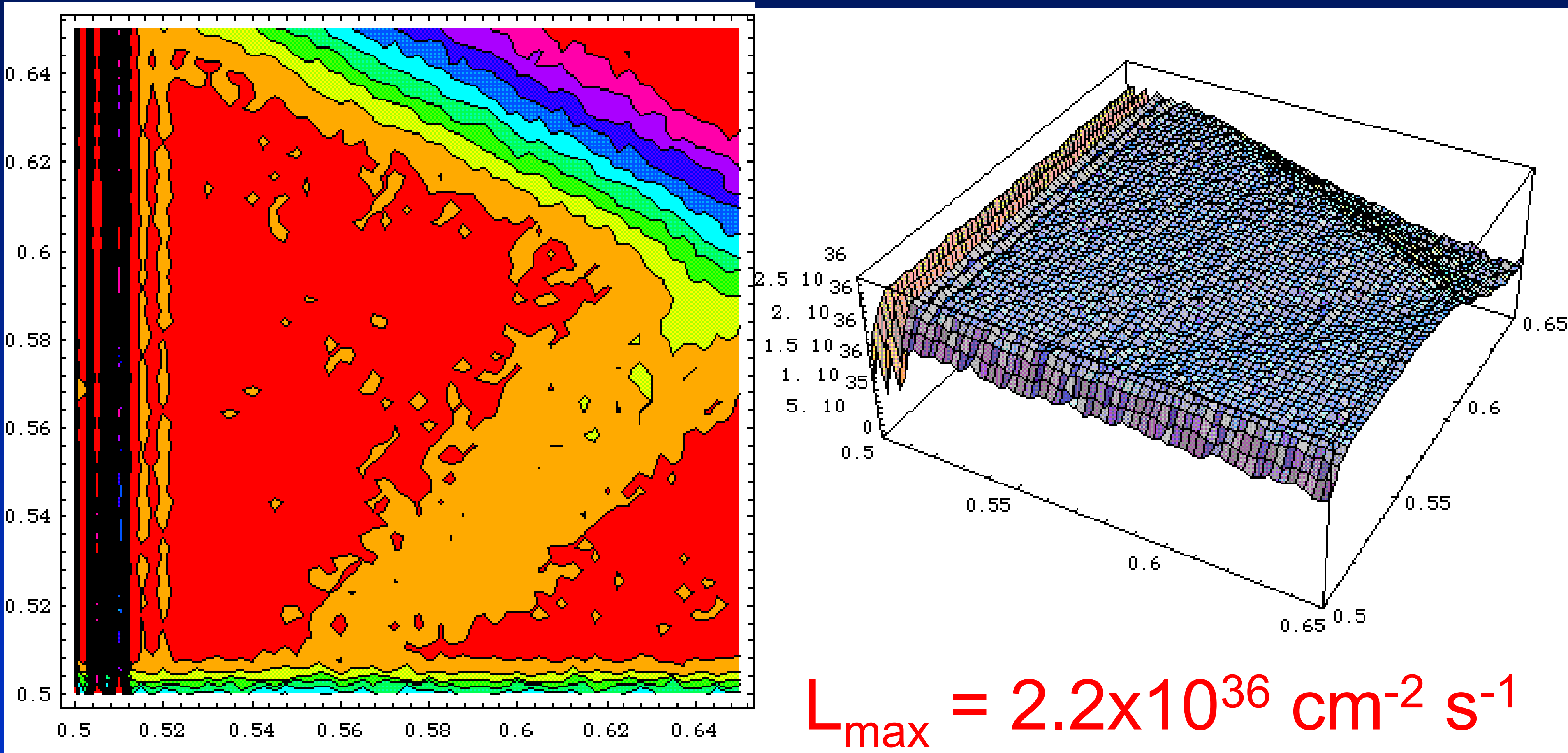
Tune shifts and longitudinal overlap are greatly reduced

	KEKB	SuperB
I (A)	1.7	2.
β_y^* (mm)	6	0.22/0.39
β_x^* (mm)	300	22/39
σ_y^* (µm)	3	0.039
σ_x^* (µm)	80	10/6
σ_z (mm)	6	5
L ($cm^{-2}s^{-1}$)	1.7×10^{34}	$1.\times10^{36}$

Here is Luminosity gain

Beam-beam Luminosity Tune Scan

(crab=0.8/θ, σ_z = 7 mm; $3x10^{10}$ particles)

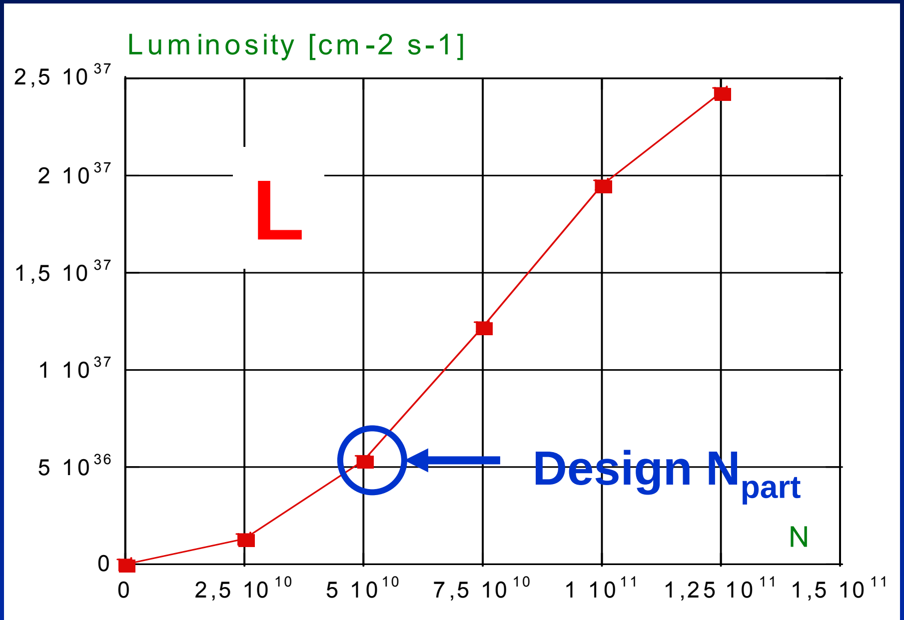


$L_{max} = 2.2x10^{36}\ cm^{-2}\ s^{-1}$

2D and 3D surface luminosity plots. The red color on the contour plot corresponds to the highest luminosity while the blue is the lowest. Each contour line corresponds to a 10% luminosity reduction.

D. Shatilov, M. Zobov, IV SuperB Workshop

Luminosity and emittances vs N_{part}



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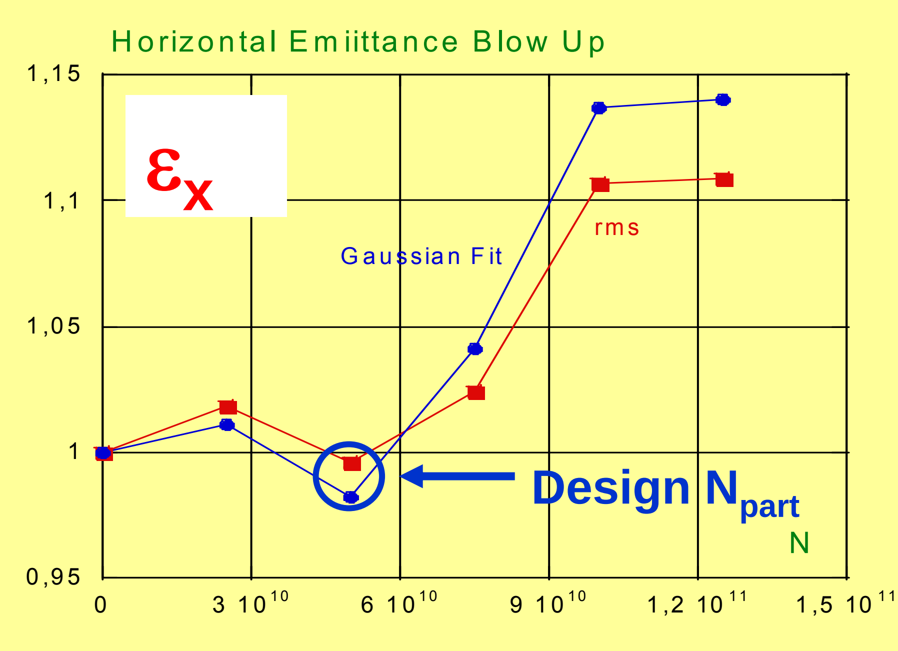
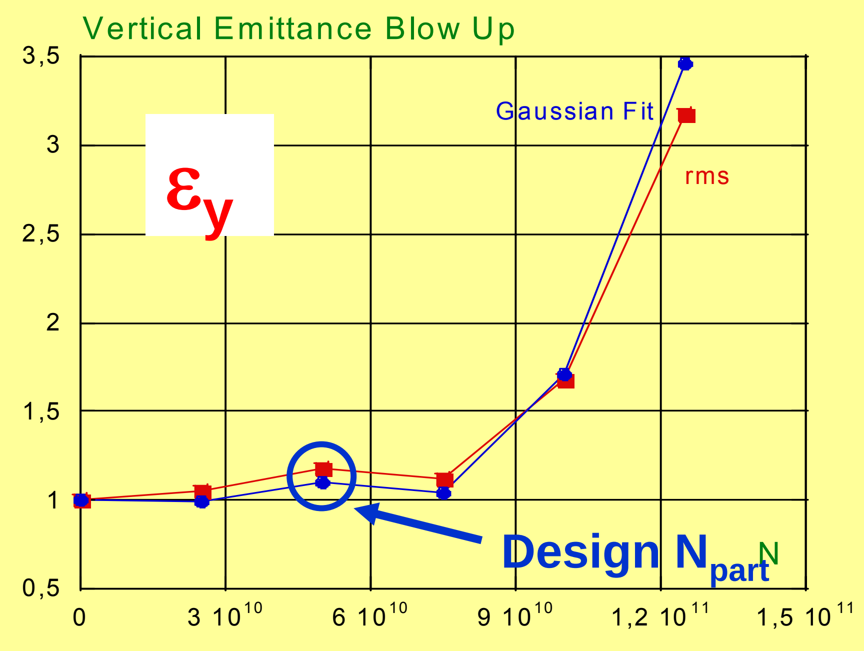
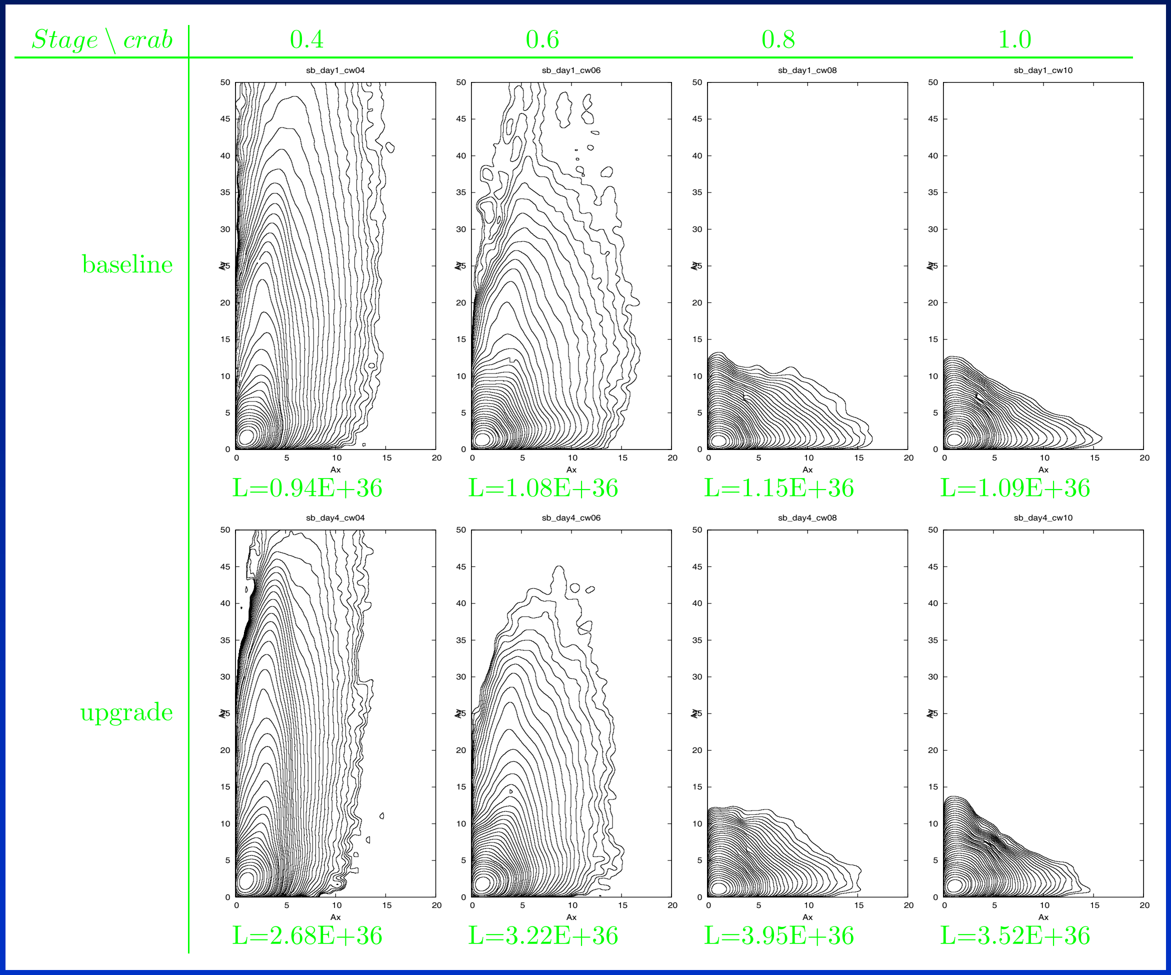
- Luminosity linear up to 2 x design N_{part}
- No blow-up in emittances up to 1.6 x N_{part}





Beam tails and Luminosity vs Crab sextupole strength



ξ_y = 0.183

τ_s = 16 msec

ξ_y = 0.212

τ_s = 12 msec

$$A_x = (0:20)\sigma_x \qquad A_y = (0:50)\sigma_y$$

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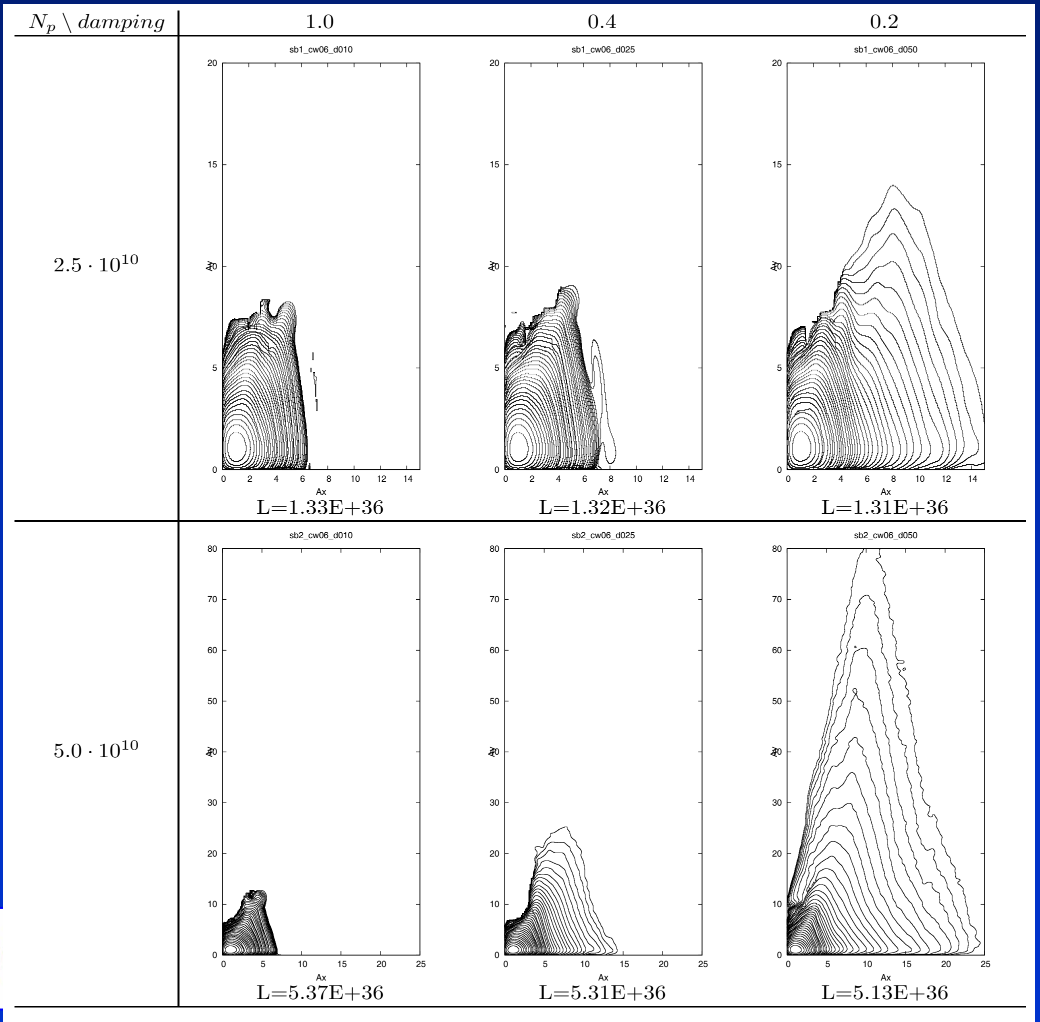
Luminosity and blow-up vs damping time and N_p

Nominal damping: 10msec/3Km rings

2.5 times longer

5 times longer



$N_p = 2.5 \times 10^{10}$

$A_x \times A_y = 15\ \sigma_x \times 20\ \sigma_y$

$N_p = 5.0 \times 10^{10}$

$A_x \times A_y = 25\ \sigma_x \times 80\ \sigma_y$

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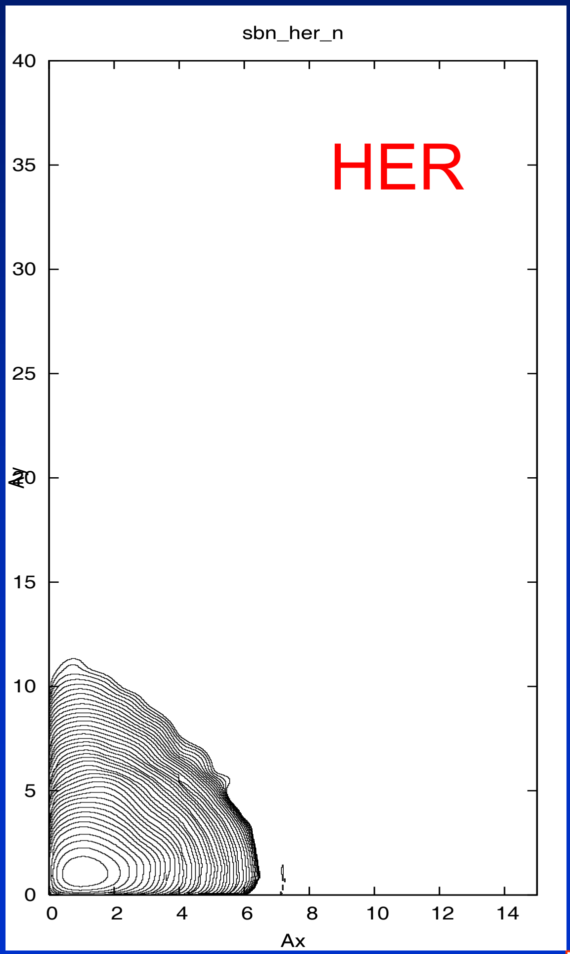
Beam-beam blow up with new transparency parameters

D. Shatilov

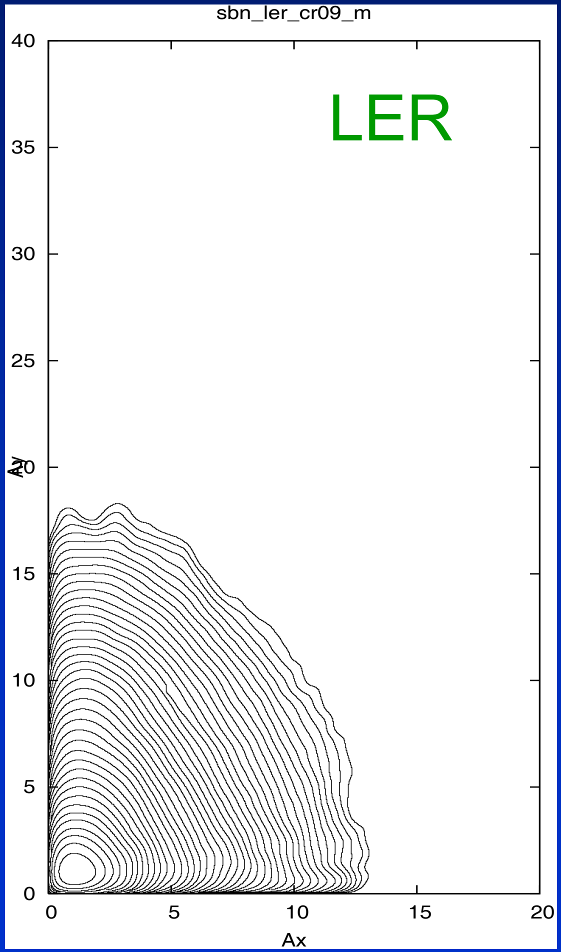
Crab=0.8Geom_Crab



No blow up is seen for HER,

1-3% for LER, but some more optimization is still possible: tunes, crabbing...

Crab=0.9Geom_Crab



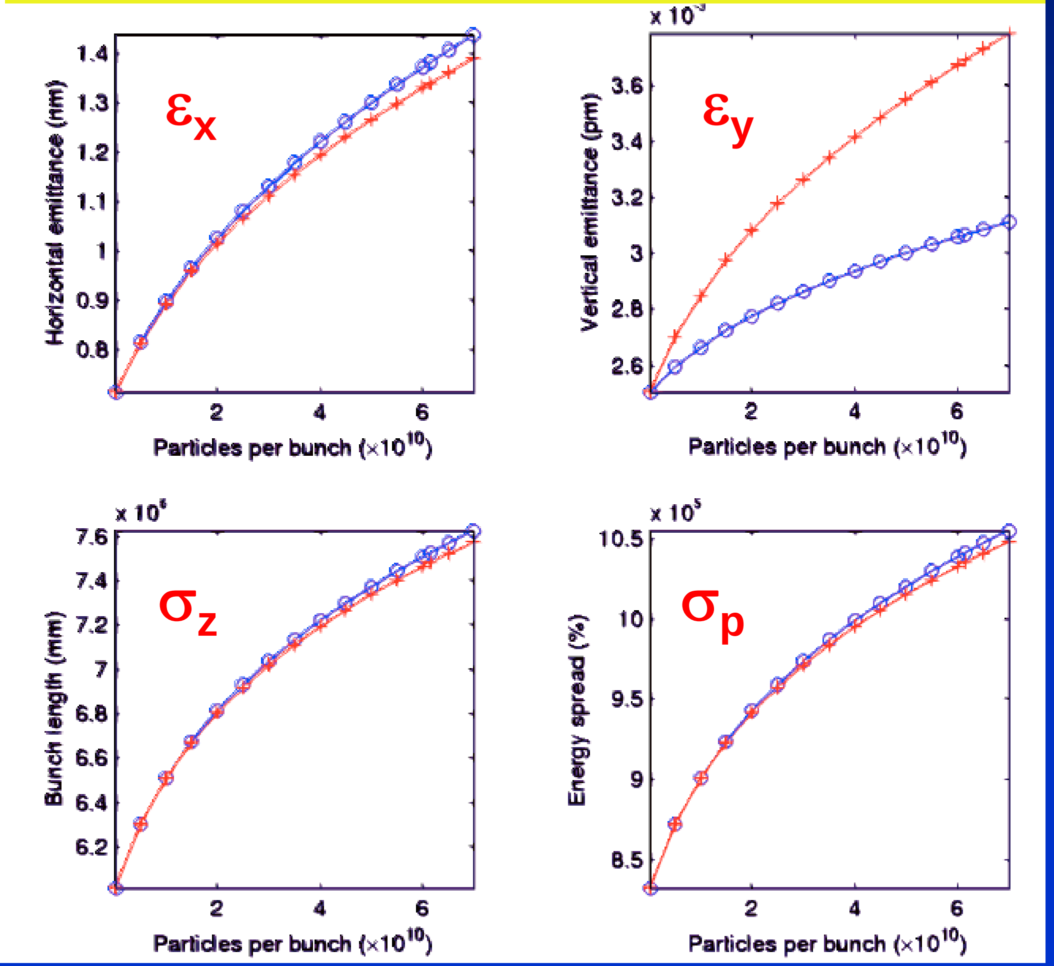
$L=10^{36}$ cm^{-2} s^{-1}

IntraBeam Scattering

- IBS is associated with Touschek effect: while single large-angle scattering between particles in a bunch leads to loss of particles (Touschek lifetime), multiple small-angle scattering leads to emittance growth.
- Usually IBS has long growth rates, but for machines that operate with high bunch charges and very low vertical emittance (ILC-DR), the IBS growth rates can be large enough that significant emittance increase can be observed.
- IBS growth rates decrease rapidly with increasing energy → LER problem only.
- Depend on ε and N_{part}, better with new LER parameters

SuperB LER (A. Wolski)

Blue: β-tron coupling makes a 10% contribution to ε_y, with η_y contributing 50%.
Red: β-tron coupling and η_y make equal contributions.



RF power estimate

Including synchrotron radiation, HOMs and RF power with 50% klystron efficiency

Total klystron power

A. Novokhatski

Total klystron power (LER+HER)		
	MW	
"Old"	22.84	CDR parameters
Nominal	16.96	
Upgrade	25.23	New parameters
Ultimate	58.22	

Lattice overview

- The SuperB lattice 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**
- This collaboration is very important for the completion of the Technical Design Report
- Simulations were performed in many labs and with different codes:
  - LNF, BINP, KEK, LAL, CERN
- 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
- Further studies after CDR completion led to new lattice

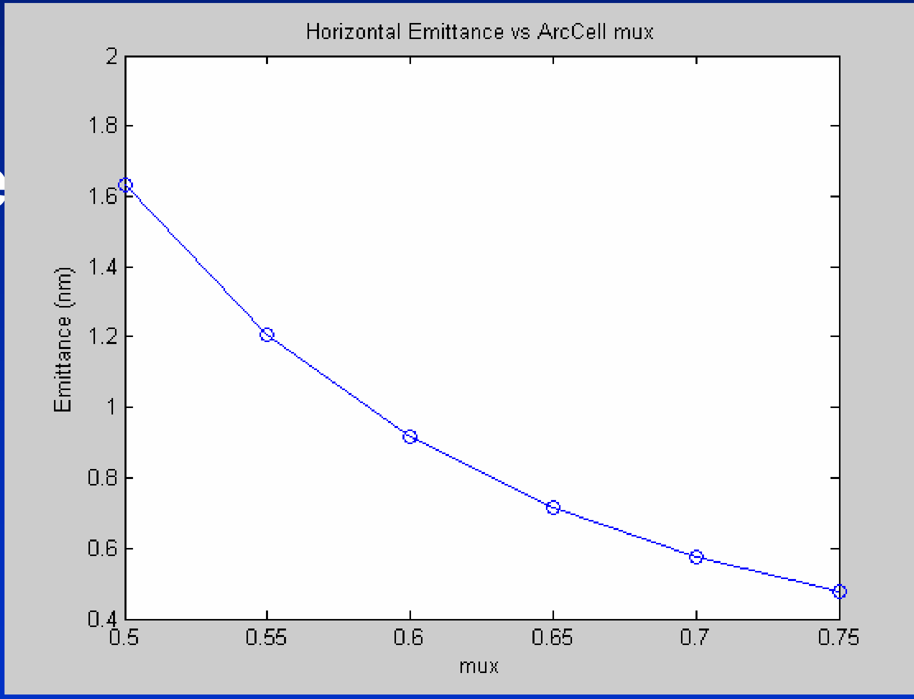
Evolution of lattice (1)

- Several accelerator issues have been addressed after completion of the CDR. In particular:
  - Power consumption
  - Costs
  - Site requirements
  - Crab waist compensation
  - Optimization of ring cell and Final Focus
  - QD0 quadrupole design (see Paoloni's talk)
  - Touschek backgrounds (see Paoloni's talk)
  - Polarization schemes (see Koop's talk)

- The evolution of the lattice design is a consequence of the effort in minimizing costs and power consumption.

Evolution of lattice (2)

- Natural emittance decreases further by increasing the arc cell μ_x, and nominal values can be obtained even without inserting wigglers
- Dynamic aperture shrinks with larger μ_x, but is still large enough (Final Focus is the dominant factor)



x-emittance vs x-phase advance/cell

New layout (1)

- Reduced length and symmetry to:
  - 4 “arcs”, 14 cells/arc
  - Only 2 wiggler straights, 40 m long, empty in Phase I
  - Final Focus
  - One long straight for RF, injection (beams will be vertically separated here)
  - 2 sections will be devoted to polarization scheme

- No “emittance” wigglers used in Phase 1

- Arcs further optimized in order to:

  - improve chromatic properties
  - increase dynamic aperture
  - decrease intrinsic emittance

New layout (2)

- Alternating sequence of two different arc cells: a $\mu_x = \pi$ cell, that provides the best dynamic aperture, and a $\mu_x = 0.72$ cell with much smaller intrinsic emittance which provides phase slippage for sextupoles pairs, so that one arc corrects all phases of chromaticity. Then:

  - chromatic function $W_x < 20$ everywhere

  - β and α variation with particle momentum are close to zero

  - larger dynamic aperture

•Cell #1: L=20 m, $\mu_x = 0.72$, $\mu_y = 0.27$

•Cell #2: L=21 m, $\mu_x = 0.5$, $\mu_y = 0.2$

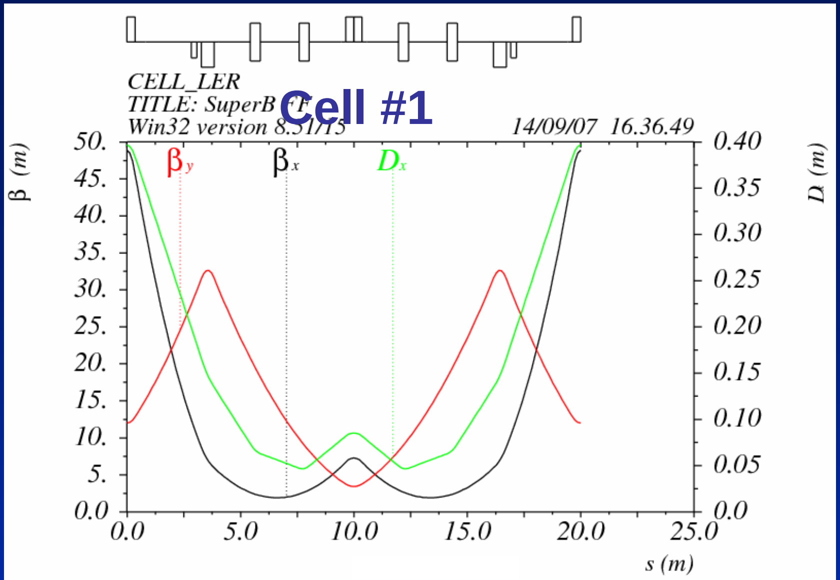
•New cell layout (double-cell wrt CDR lattice):

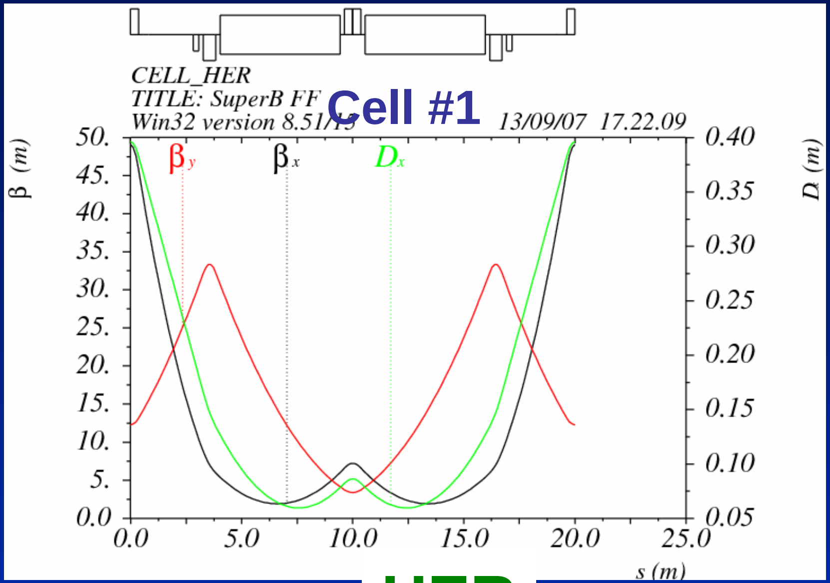
QF/2-QD-B-B-QF-B-B-QD-QF/2

New layout (3)

- HER: ε_x = 1.6 nm, τ_s = 19.8 msec
- LER: ε_x = 2.8 nm, τ_s = 19.5 msec
- HER cells host 2 x 5.4 m long PEP-II dipoles
- LER cells host 4 x 0.45 m long PEP-II dipoles
- Final Focus sections have 18 HER-type bends (16 in CDR)
- 2 straights between cells can host wigglers if needed
- 2 new sections, about 200 m long, will be added for the polarization scheme (not included in present lattice)
- Total length ~ 1800 m including spin rotator

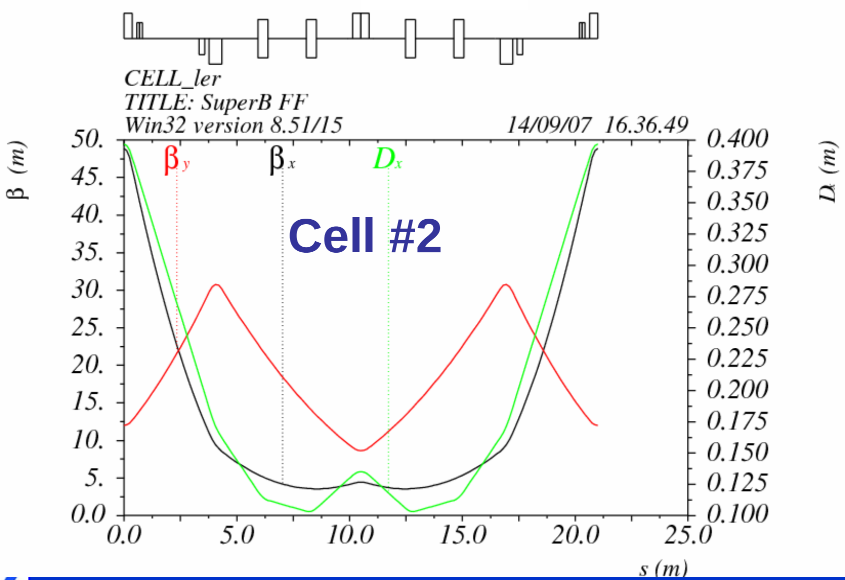
Arc cells layout

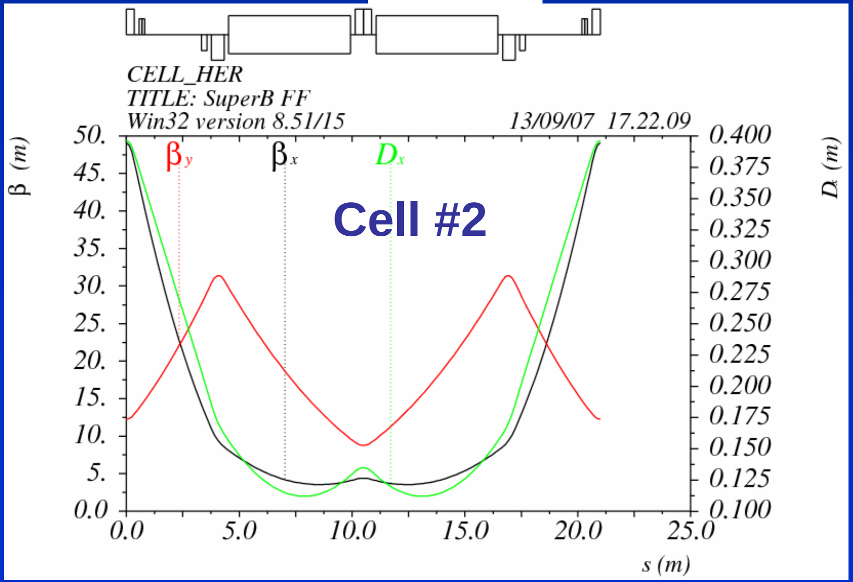




LER

HER





The Rings

- HER, 7 GeV
- LER, 4 GeV

same length and similar lattice

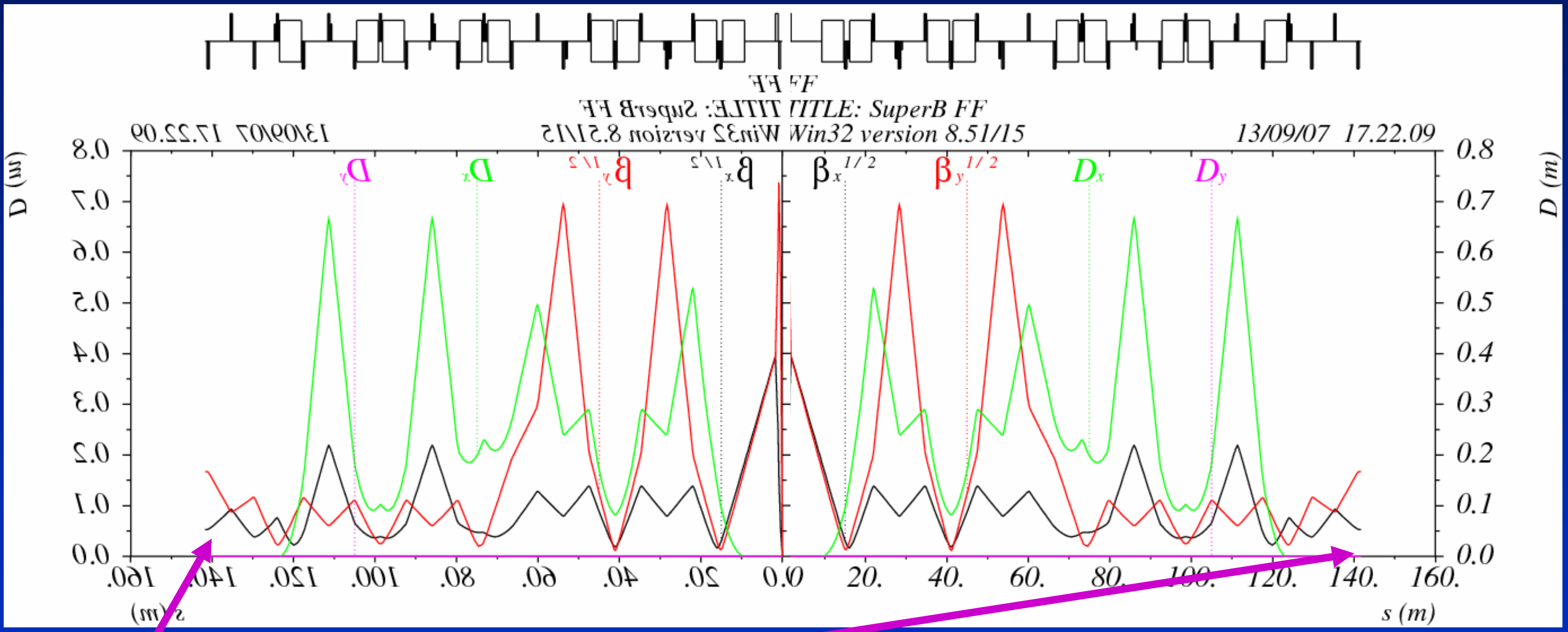
- Rings cross in one Interaction Point with a 48 mrad horizontal crossing angle
- Ultra low emittance lattice: inspired by ILC Damping Rings
- Circumference scaled down to shortest possible
- Rings lattice based on recycling PEP-II hardware (save a lot of money !)
- Maximize Luminosity keeping low wall power:
  - Total power: 17 MW, lower than PEP-II

Final Focus Optimization

- FF design complies all the requirements in terms of high order aberrations correction, needs to be slightly modified for LER to take care of energy asymmetry
- Chromaticity locally corrected
- Design based on ILC/FFTB-like Final Focus. Increased crossing angle to 2*24 mrad (was 2*17 mrad)
- Increased L*=0.4 m (was 0.3 m)
- Horizontal beam separation at QD0: 2 cm, about 180 σ_x
- Increased QF1 length to 0.7m in order to decrease its synchrotron radiation. If necessary it could be lenghtened further
- Radiative Bhabhas hitting the IR beam pipes are a lot
- Sychrotron radiation power is large
- A possible solution with a septum QD0 is being studied:

SC array of wires placed in the middle of QD0 to shift the magnetic center, opposite for the 2 beams, to get no net steering from QD0 (see Paoloni's talk). Overall thickness ~ 8mm, leaving about 60 σ_x of beam stay-clear

Final Focus optical functions ($\sqrt{\beta}$)

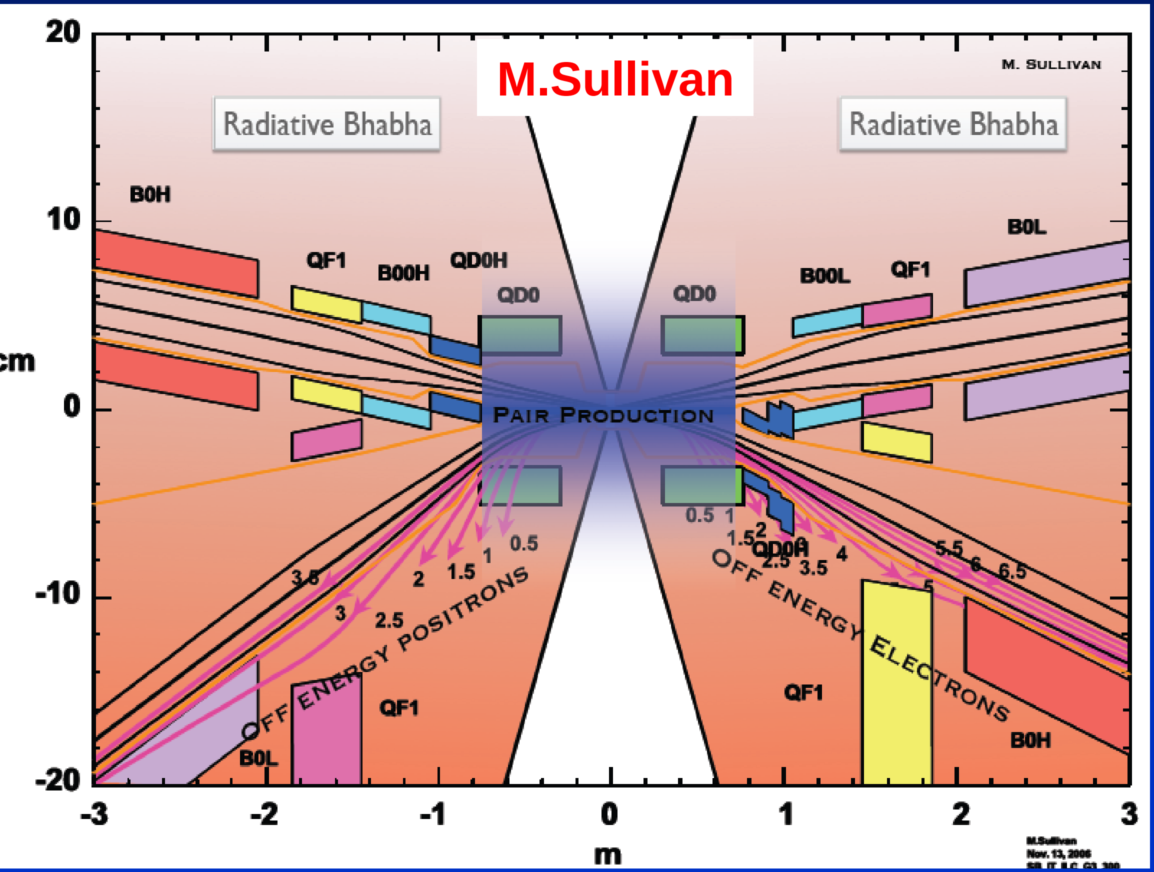


Crab sextupoles

LER: $\beta_x^* = 35$ **mm,** $\beta_y^* = 220\ \mu$

HER: $\beta_x^* = 20$ **mm,** $\beta_y^* = 390\ \mu$

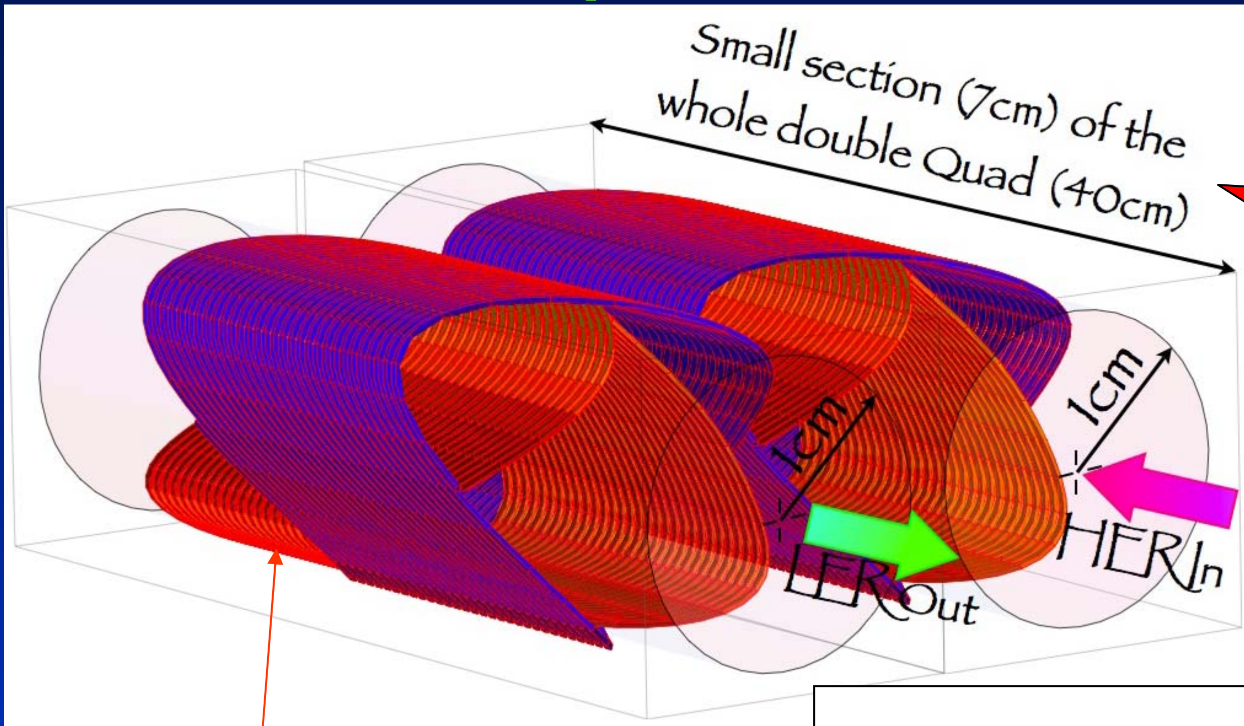
IP layout



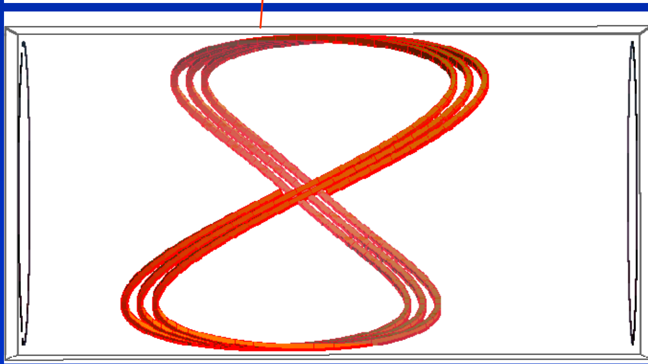
Avoid backgrounds in detector by over-bent off-energy particles in QD0: novel QD0 design based on SC "helical-type" windings.

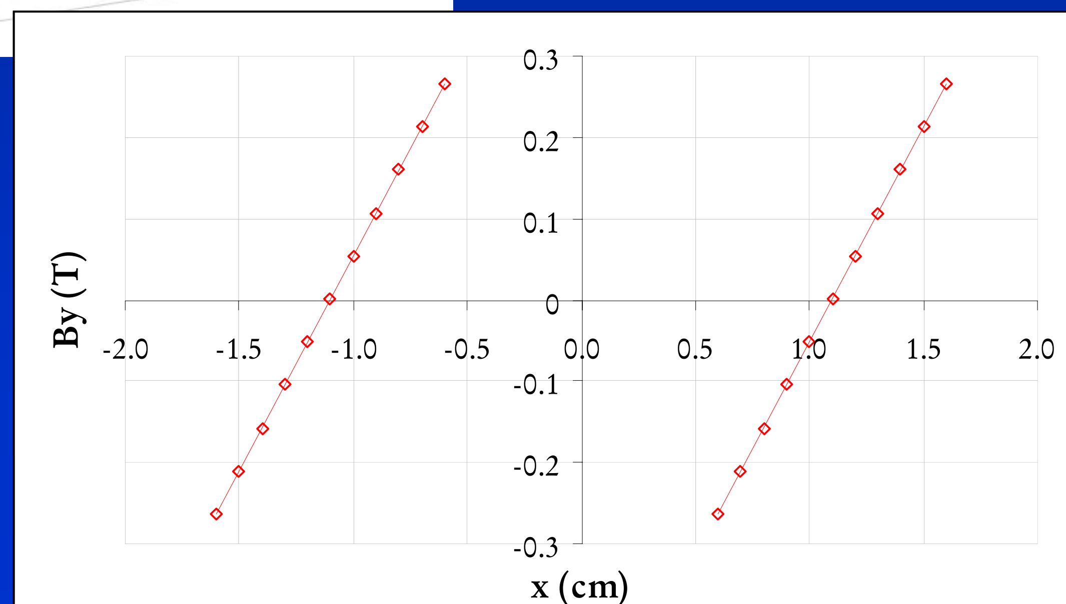
Overall thickness ~ 8mm

Example of QD0 design

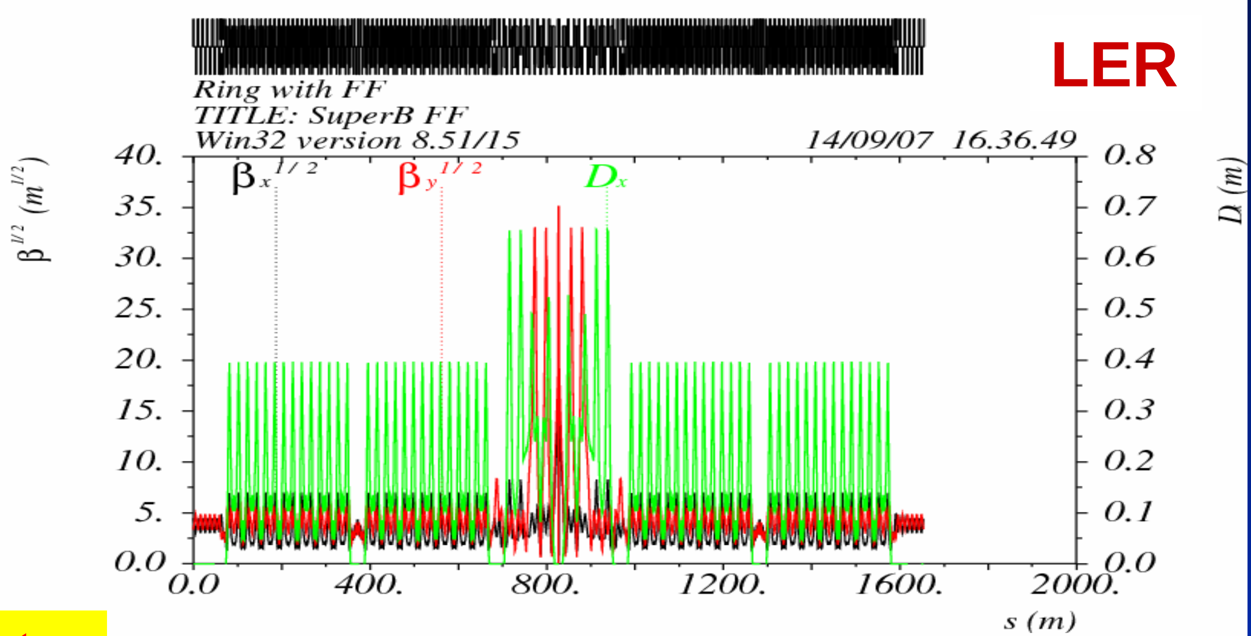


S. Bettoni, E. Paoloni
See Paoloni's talk

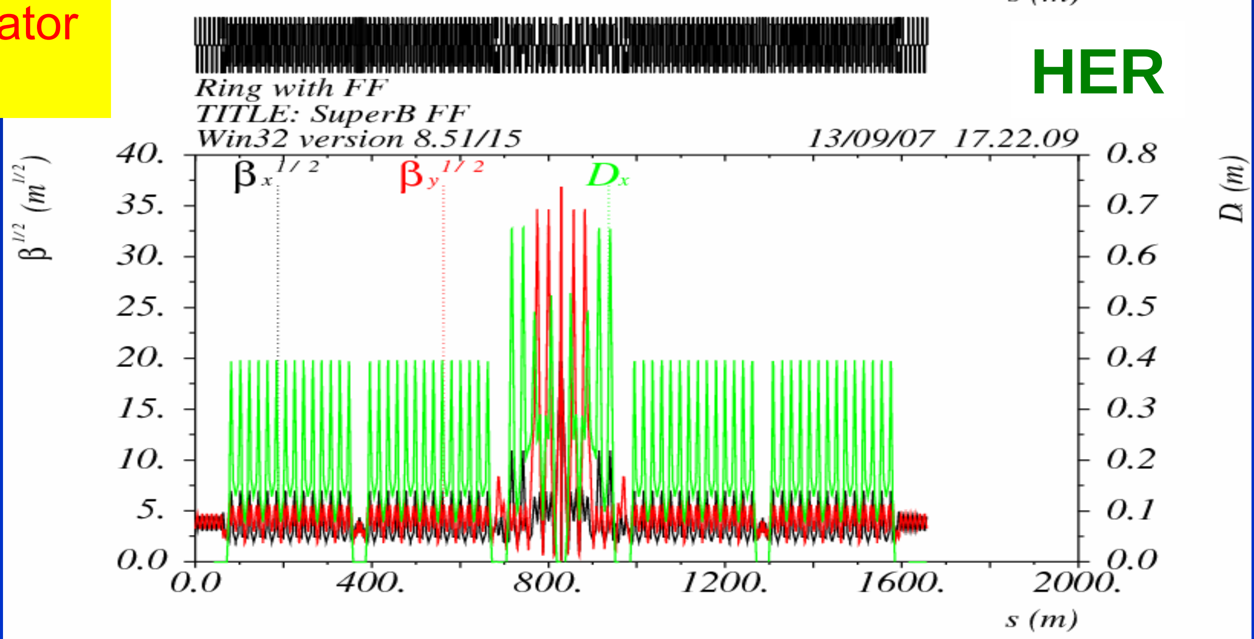




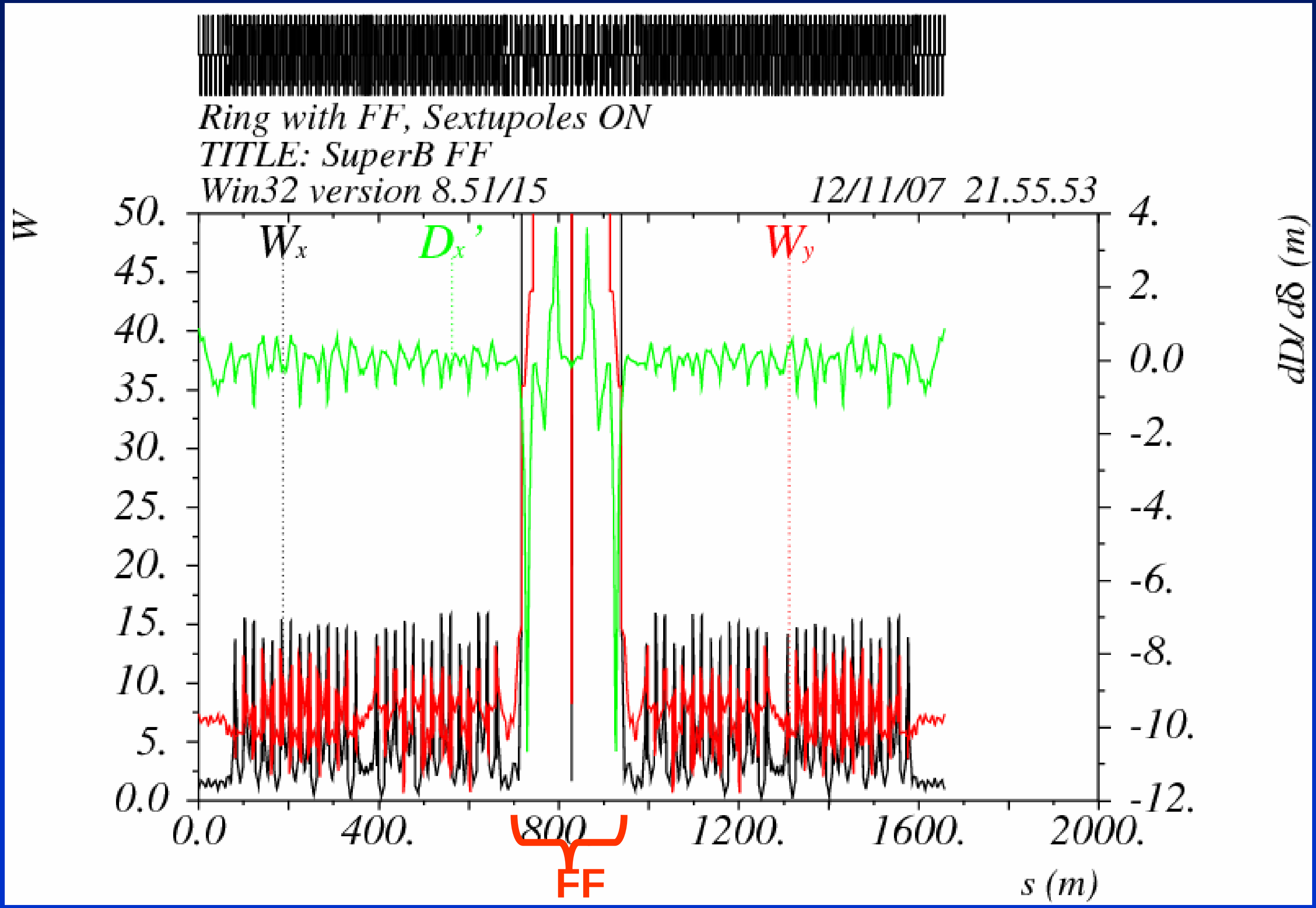
Rings optical functions



No spin rotator here

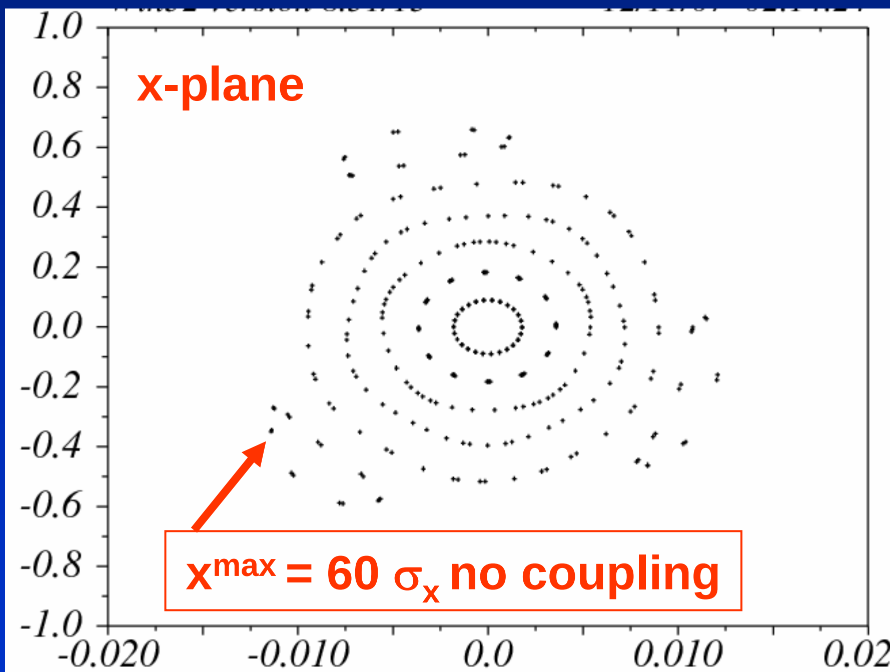


Chromatic functions (zoom)



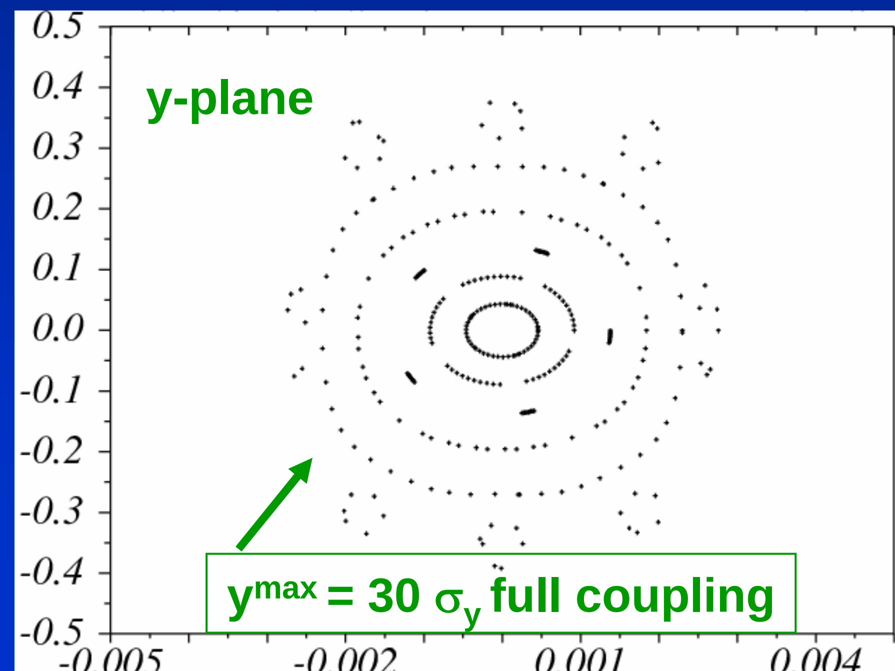
Dynamic Aperture (no optimization yet)

With crab sextupoles

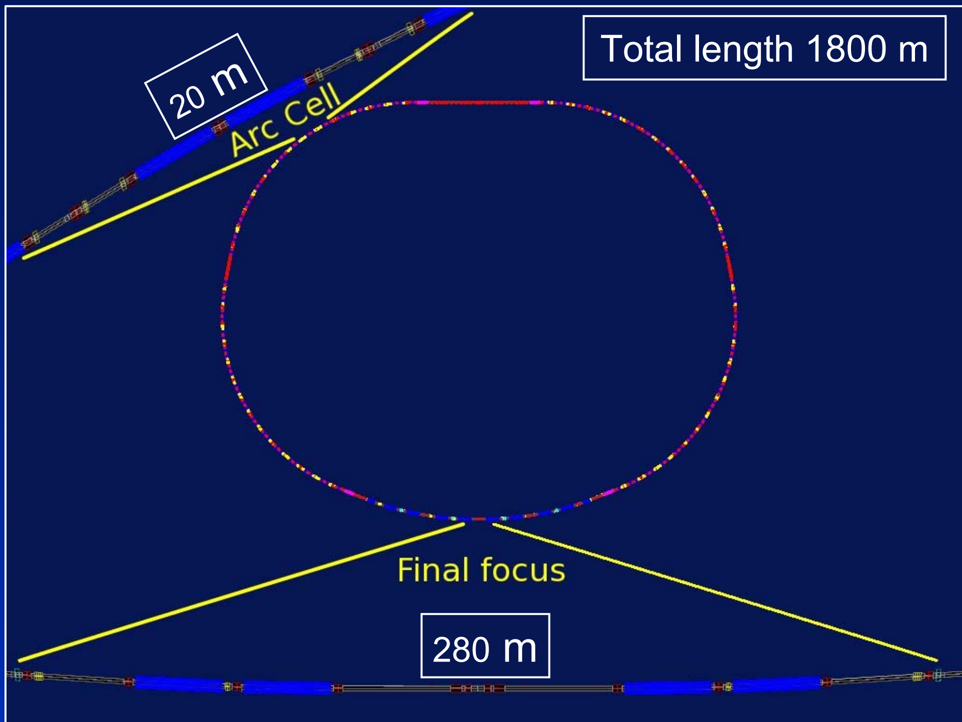


Crab sextupoles reduce DA by 30%

- **DA represents stability area of particles over many turns**
- **Lifetimes depend on it**



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

Lattice summary

- New cell layout more flexible in terms of emittance
- Rings are shorter and cheaper
- Longer Tousheck lifetime in LER (x2.3)
- Lower vertical tune shift (13%)
- More relaxed LER parameters
- Lower currents (20%)
- Longer damping times (20%)
- Possible to run Phase #1 without wigglers
- Upgrade parameters possible with wiggler installation

Polarization

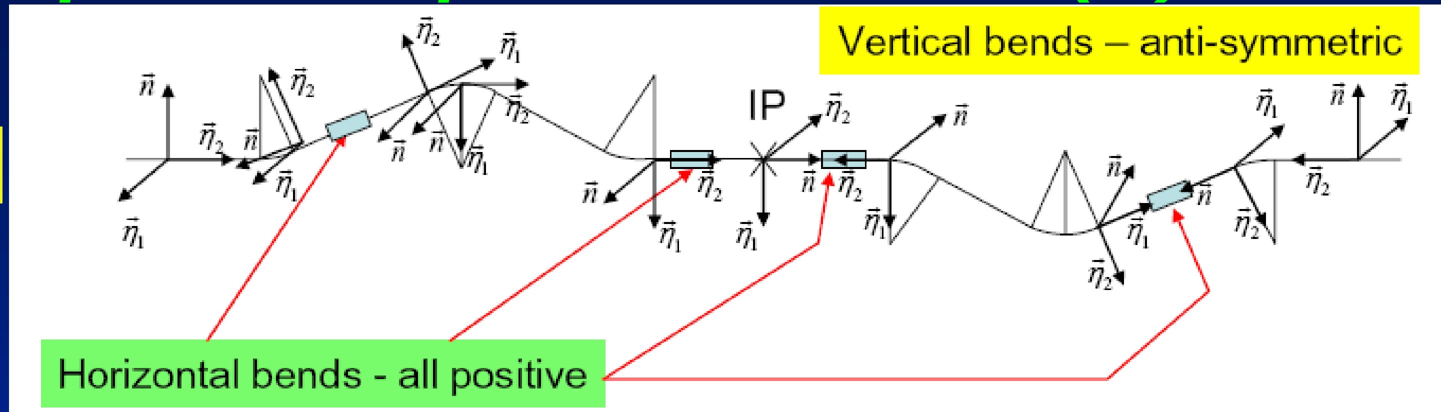
(see I. Koop's talk)

- Polarization of one beam is included in *SuperB*
  - Either energy beam could be the polarized one
  - The LER would be less expensive, the HER easier
- Longitudinal polarization times and short beam lifetimes indicate a need to inject vertically polarized electrons
- There are several possible IP spin rotators:
  - Solenoids look better at present (vertical bends give unwanted vertical emittance growth)
- Expected longitudinal polarization at the IP of about 87%(inj) x 97%(ring)=85%(effective)
- Polarization section implementation in lattice: in progress

Example of spin rotators (1)

I. Koop

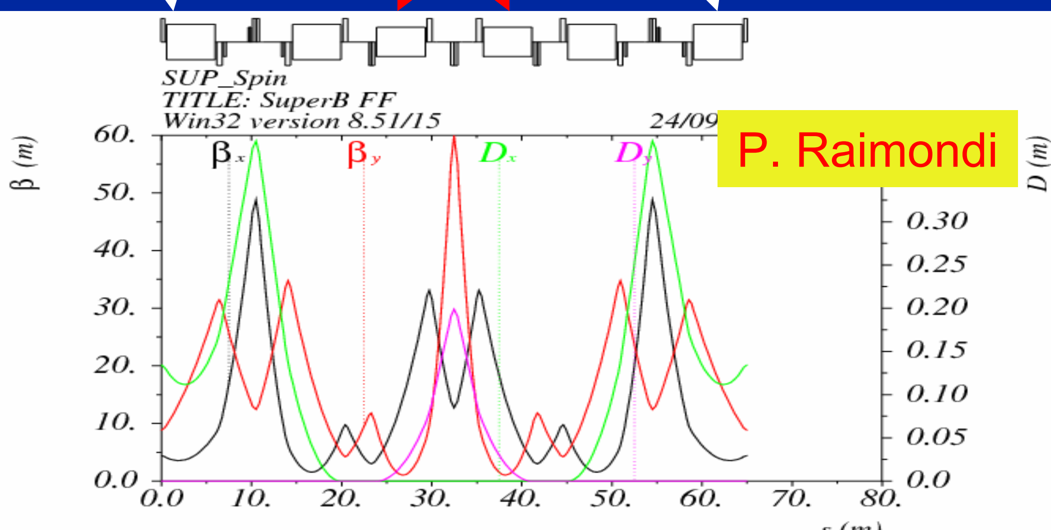
HER ~7GeV

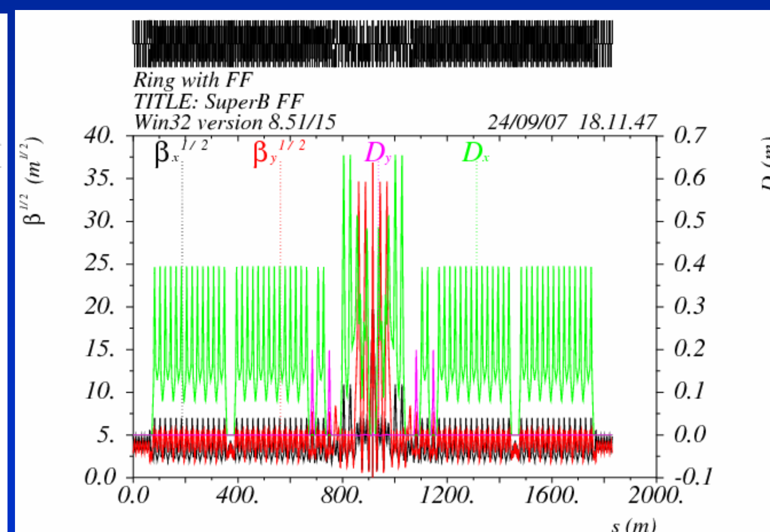


H-bends

V-bends

H-bends



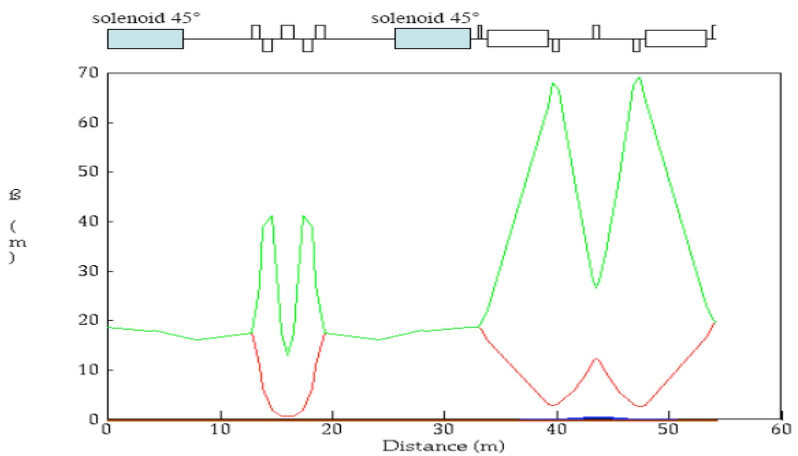


The solutions with vertical bends introduce unwanted vertical emittance

Example of spin rotators (2)

Solenoids (2.5 T) + dipoles (.21 T)

not a solution, but illustrates match to low-ε dipole cell



U. Wienands

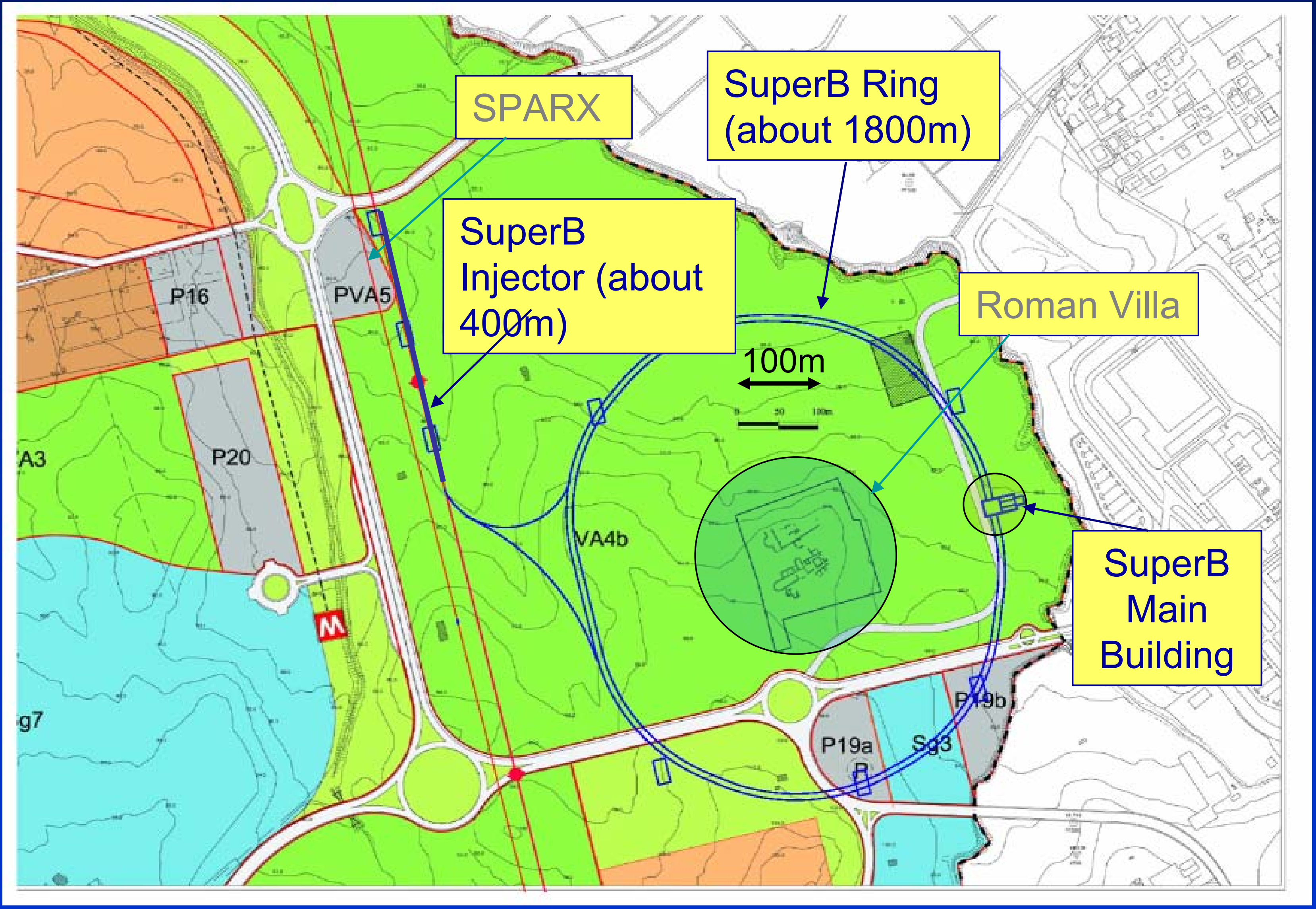
Proof-of-principle scheme

HER Spin Rotator

- Solenoid + Dipole scheme (90°+90°)
  - Zholents-Litvinov decoupling & spin match
- $G \approx 0.001$, 7 GeV=> $\gamma G = 15.89$, $B\rho = 23.35$ Tm
- Solenoid:
  - ϑ_{spin}=(1+G)*BL/($B\rho$) => 18.32 Tm for 45° spin rot.
  - 5 T field => 3.66 m length, 15E6 Amp turns
- Dipole
  - ϑ_{spin}=(1+γG)*BL/$B\rho$ => 2.3 Tm, 5.7° orbit for 90° spin
  - use 2 HER dipoles + 2 low-field dipoles
  - optics needed in between these to match dispersion

No V-emittance growth.
Maybe possible to incorporate into lattice using the Final Focus bends to provide the spin rotation.
Work in progress

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.

Schedule

- Overall schedule dominated by:
  - Site construction
  - PEP-II/Babar disassembly, transport, and reassembly
- We consider possible to reach the commissioning phase after 5 years from T_0.

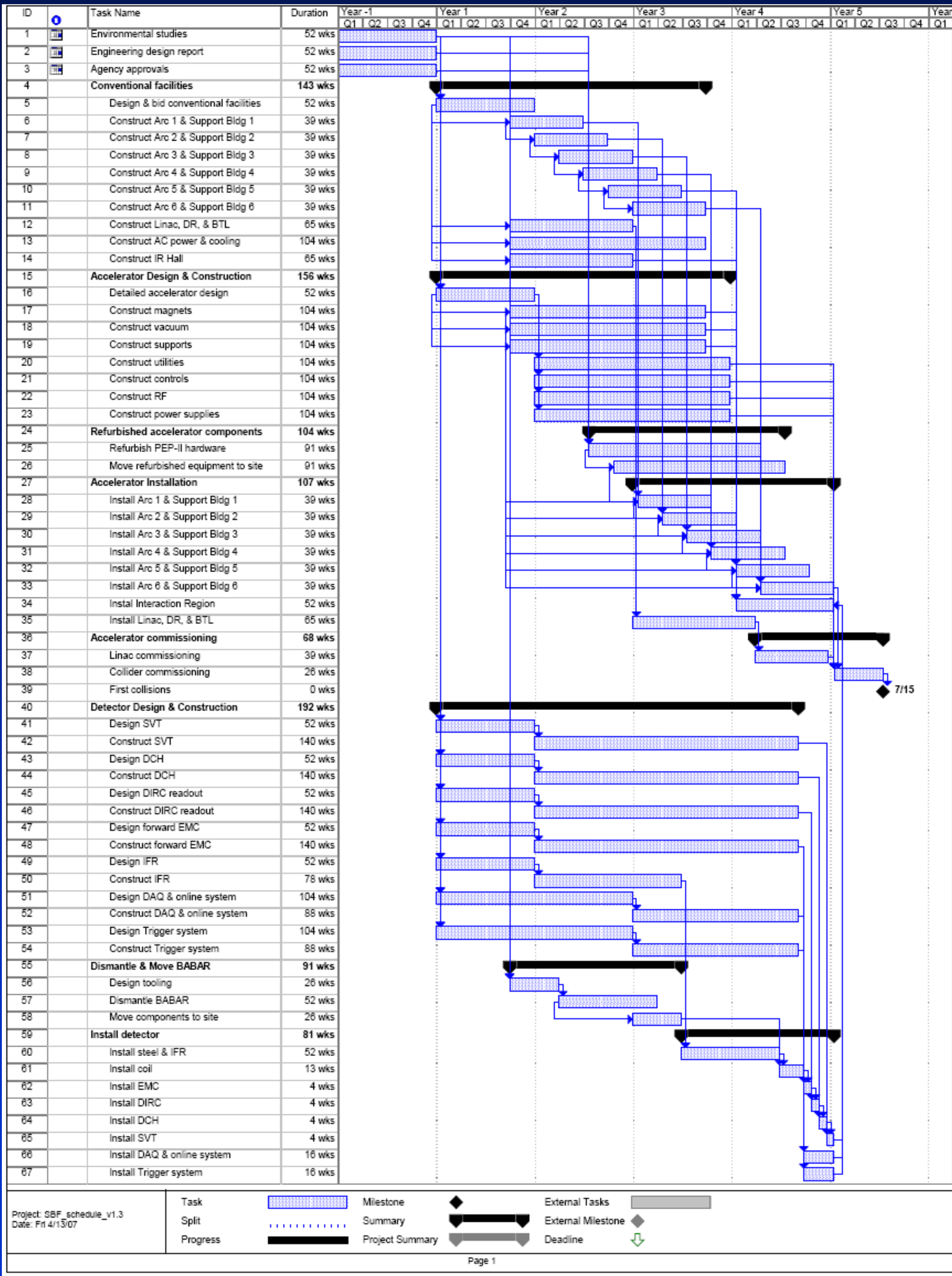


Figure 5-1. *Overall schedule for the construction of the SuperB project.*

Topics to study for the TDR (most were covered in CDR)

- Machine-Detector interface:
  - IR design
  - Background remediation

  in progress
- Tolerances and orbit correction for low emittance beams
- Magnet tolerances
- FF tuning for high luminosity operation
- Beam-beam with real lattice (ex. Shatilov’s code)
- Dynamic aperture optimization with errors (ex. Piminov’s code)
- Polarization scheme into lattice (in progress), and effect beam-beam performances (see Nikitin’s talk)
- IBS and Tousheck for new parameters (should be better with larger emittances, in progress)
- Instabilities with new parameters:
  - e-cloud (**in progress**)
  - Fast ion
  - HOMs
  - Wakefields
  - CSR (should be better with larger emittances)

Conclusions (1)

- SuperB is a new machine that can exploit novel very promising design approaches:
  - large Piwinski angle scheme allows for peak luminosity $\geq$ **10^{36} cm^{-2} s^{-1}** well beyond the current state-of-the-art, *without a significant increase in beam currents or shorter bunch lengths*
  - "*crab waist*" sextupoles used for suppression of dangerous resonances
  - low current design presents reduced detector and background problems, and affordable operating costs
  - a polarized electron beam can produce polarized τ leptons, opening an entirely new realm of exploration in lepton flavor physics

- The principle of operation is being tested at DAΦNE

Conclusions (2)

- A CDR is being reviewed by an International Review Committee, chaired by J. Dainton (UK)
- In case of positive answer a TDR will be ready by 2010
- *SuperB* studies are already proving useful to the accelerators and particle physics community
- The baseline lattice, based on the reuse of all PEP-II hardware, fits in the Tor Vergata University campus site, near Frascati
- We hope to gather in the enterprise as many labs and institutions as possible...

Please join us!