



SuperB a Super-Flavour-Factory

M. Biagini, INFN-LNF

on behalf of the SuperB Accelerator Team

II Annual EuCARD Meeting

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SuperB Accelerator Collaborators

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- ❑ S. Bettoni (PSI)
- ❑ Yuan Zhang (IHEP, Beijing)
- ❑ Hopefully soon: John Adams & Cockcroft Institute from UK

SuperB Accelerator

- SuperB is a 2 rings, asymmetric energies ($e^- @ 4.18$, $e^+ @ 6.7$ GeV) collider with:
 - large Piwinski angle and “crab waist” (LPA & CW) collision scheme
 - ultra low emittance lattices
 - longitudinally polarized electron beam
 - **target luminosity of $10^{36} \text{ cm}^{-2} \text{ s}^{-1}$ at the $Y(4S)$**
 - possibility to run at τ /charm threshold with $L = 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$
- Criterias used for the design:
 - Minimize building costs
 - Minimize running costs
 - Minimize wall-plug power and water consumption
 - Reuse of some PEP-II B-Factory hardware (magnets, RF)
- SuperB can be also a good “light source”: there will be some Synchrotron Radiation beamlines (collaboration with Italian Institute of Technology) → work in progress

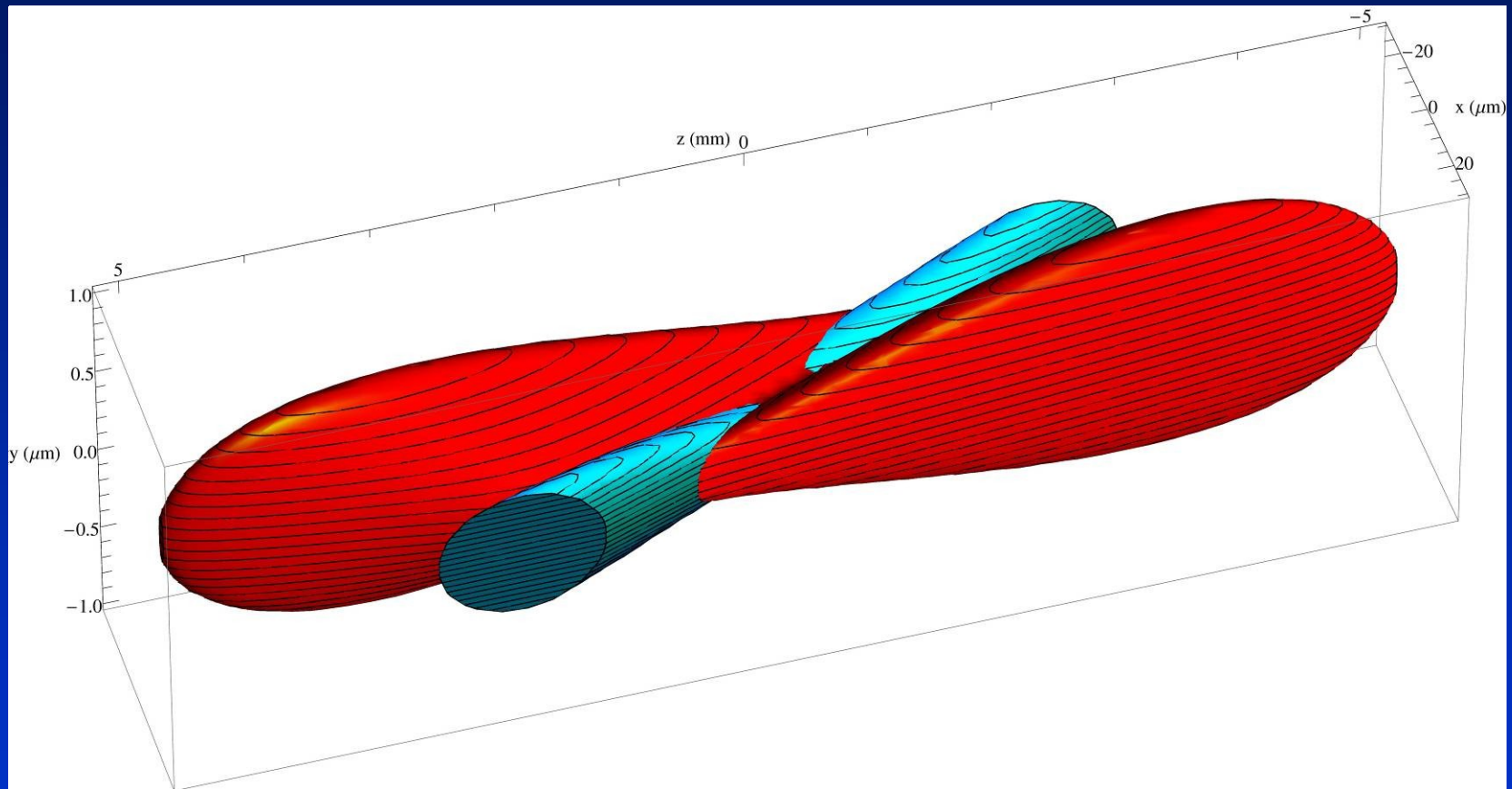
SuperB design

- The design requires state-of-the-art technology for emittance and coupling minimization, vibrations and misalignment control, e-cloud suppression, etc...
- SuperB has many similarities with the Damping Rings of ILC and CLIC, and with latest generation SL sources, and can profit from the collaboration among these communities
- For details see the new Conceptual Design Report (Dec. 2010) on:

<http://arxiv.org/abs/1009.6178>

Crab-waist scheme

Crab sextupoles OFF: Waist line is orthogonal to the axis of other beam



Crab sextupoles ON: Waist aligned with path of other beam

- particles at higher β do not see full field of other beam
- no excessive beam-beam parameter due to hourglass effect

LPA&CW Advantages

1. Large Piwinski angle

$$\Phi = (\text{tg } \theta) * \sigma_z / \sigma_x \cong \theta * \sigma_z / \sigma_x$$

Half crossing angle

- a) Luminosity gain with N
- b) Very low horizontal tune shift
- c) Less parasitic crossings

2. Vertical beta comparable with overlap area

$$\beta_y \approx \sigma_x / \theta$$

- a) Geometric luminosity gain
- b) Lower vertical tune shift
- c) Vertical tune shift decreases with oscillation amplitude
- d) Suppression of vertical synchro-betatron resonances

3. Crabbed waist transformation

$$y = xy' / (2\theta)$$

- a) Suppression of X-Y betatron and synchro-betatron resonances
- b) Geometric luminosity gain

Parameter Table

Parameter	Units	Base Line		Low Emittance		High Current		Tau/Charm (prelim.)	
		HER (e+)	LER (e-)	HER (e+)	LER (e-)	HER (e+)	LER (e-)	HER (e+)	LER (e-)
LUMINOSITY	cm ⁻² s ⁻¹	1.00E+36		1.00E+36		1.00E+36		1.00E+35	
Energy	GeV	6.7	4.18	6.7	4.18	6.7	4.18	2.58	1.61
Circumference	m	1258.4		1258.4		1258.4		1258.4	
X-Angle (full)	mrاد	66		66		66		66	
Piwinski angle	rad	22.88	18.60	32.36	26.30	14.43	11.74	8.80	7.15
β _x @ IP	cm	2.6	3.2	2.6	3.2	5.06	6.22	6.76	8.32
β _y @ IP	cm	0.0253	0.0205	0.0179	0.0145	0.0292	0.0237	0.0658	0.0533
Coupling (full current)	%	0.25	0.25	0.25	0.25	0.5	0.5	0.25	0.25
ε _x (without IBS)	nm	1.97	1.82	1.00	0.91	1.97	1.82	1.97	1.82
ε _x (with IBS)	nm	2.00	2.46	1.00	1.23	2.00	2.46	5.20	6.4
ε _y	pm	5	6.15	2.5	3.075	10	12.3	13	16
σ _x @ IP	μm	7.211	8.872	5.099	6.274	10.060	12.370	18.749	23.076
σ _y @ IP	μm	0.036	0.036	0.021	0.021	0.054	0.054	0.092	0.092
Σ _x	μm	11.433		8.085		15.944		29.732	
Σ _y	μm	0.050		0.030		0.076		0.131	
σ _L (0 current)	mm	4.69	4.29	4.73	4.34	4.03	3.65	4.75	4.36
σ _L (full current)	mm	5	5	5	5	4.4	4.4	5	5
Beam current	mA	1892	2447	1460	1888	3094	4000	1365	1766
Buckets distance	#	2		2		1		1	
Ion gap	%	2		2		2		2	
RF frequency	Hz	4.76E+08		4.76E+08		4.76E+08		4.76E+08	
Harmonic number		1998		1998		1998		1998	
Number of bunches		978		978		1956		1956	
N. Particle/bunch		5.08E+10	6.56E+10	3.92E+10	5.06E+10	4.15E+10	5.36E+10	1.83E+10	2.37E+10
Tune shift x		0.0021	0.0033	0.0017	0.0025	0.0044	0.0067	0.0052	0.0080
Tune shift y		0.0970	0.0971	0.0891	0.0892	0.0684	0.0687	0.0909	0.0910
Long. damping time	msec	13.4	20.3	13.4	20.3	13.4	20.3	26.8	40.6
Energy Loss/turn	MeV	2.11	0.865	2.11	0.865	2.11	0.865	0.4	0.166
σ _E (full current)	dE/E	6.43E-04	7.34E-04	6.43E-04	7.34E-04	6.43E-04	7.34E-04	6.94E-04	7.34E-04
CM σ _E	dE/E	5.00E-04		5.00E-04		5.00E-04		5.26E-04	
Total lifetime	min	4.23	4.48	3.05	3.00	7.08	7.73	11.41	6.79
Total RF Power	MW	17.08		12.72		30.48		3.11	

Tau/charm threshold running at 10³⁵

Baseline + other 2 options:
 • Lower y-emittance
 • Higher currents (twice bunches)

Baseline:
 • Higher emittance due to IBS
 • Asymmetric beam currents

RF power includes SR and HOM

Flexibility for parameters choice

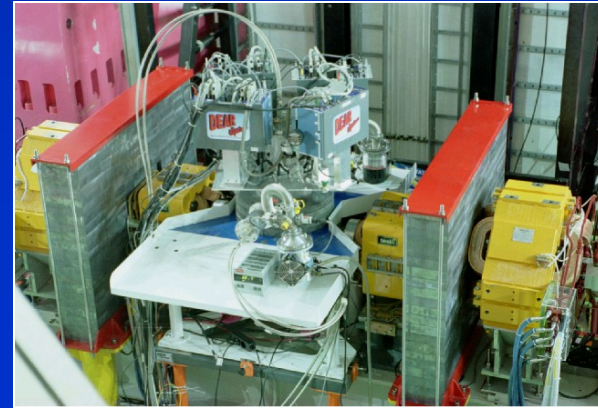
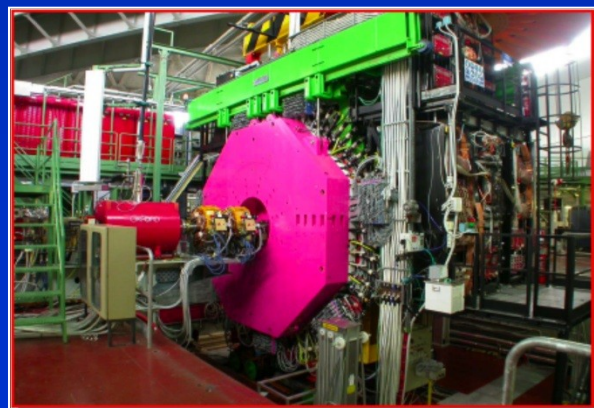
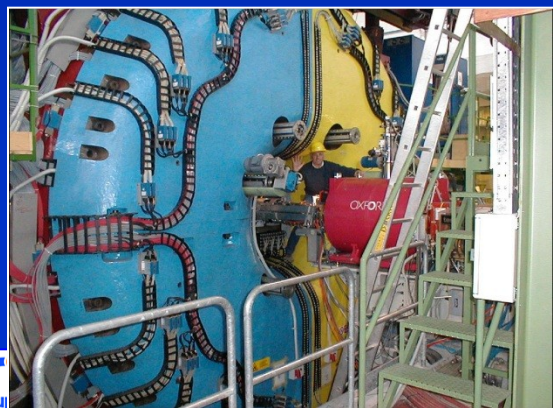
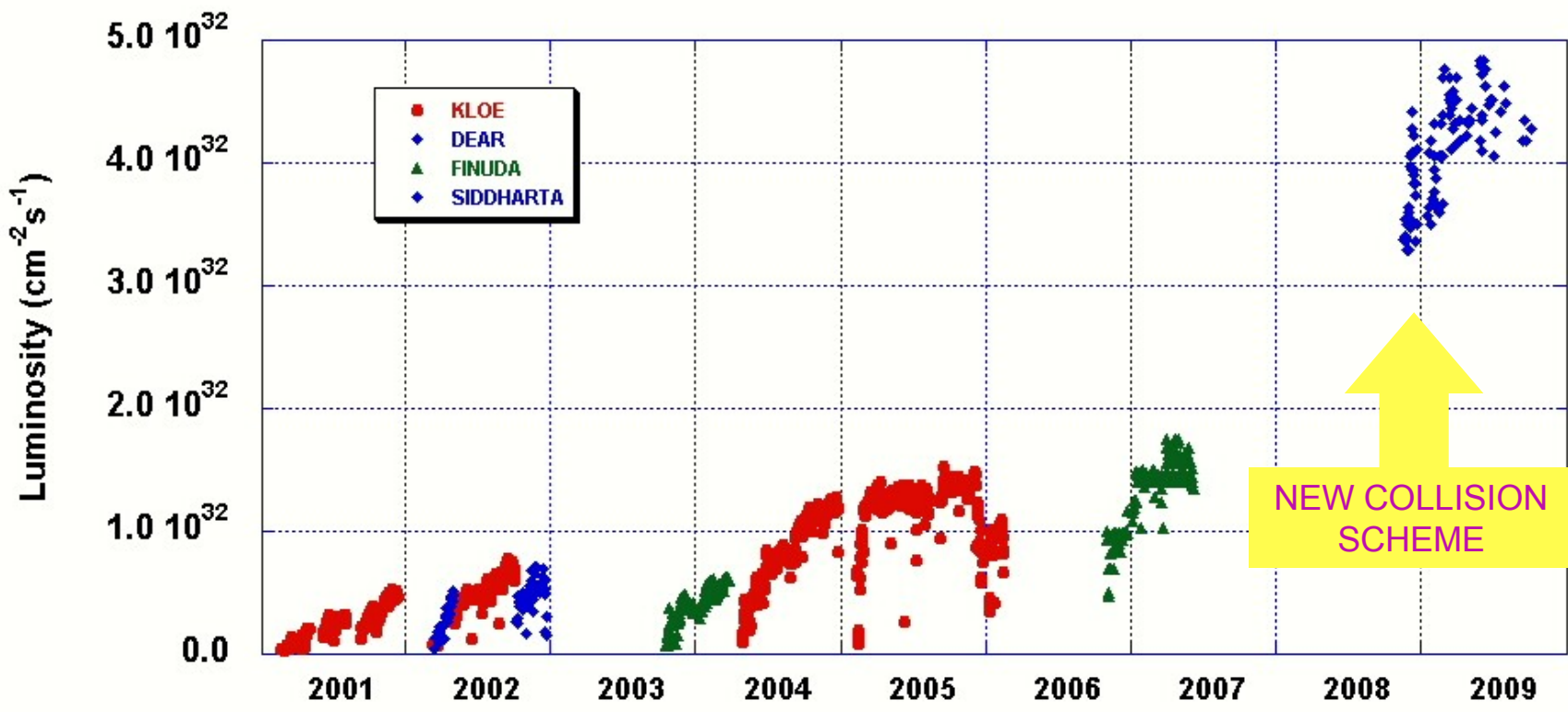
- The horizontal emittance can be decreased by about a factor 2 in both rings by changing the partition number (by changing the RF frequency [LER] or the orbit in the Arcs) and the natural ARC emittance by readjusting the lattice functions
- The Final Focus system as a built-in capability of about a factor 2 in decreasing the IP beta functions
- The RF system will be able to support higher beam currents (up to a factor $\times 1.6$) over the baseline, when all the available PEP-II RF units are installed

The crab waist @ DAΦNE

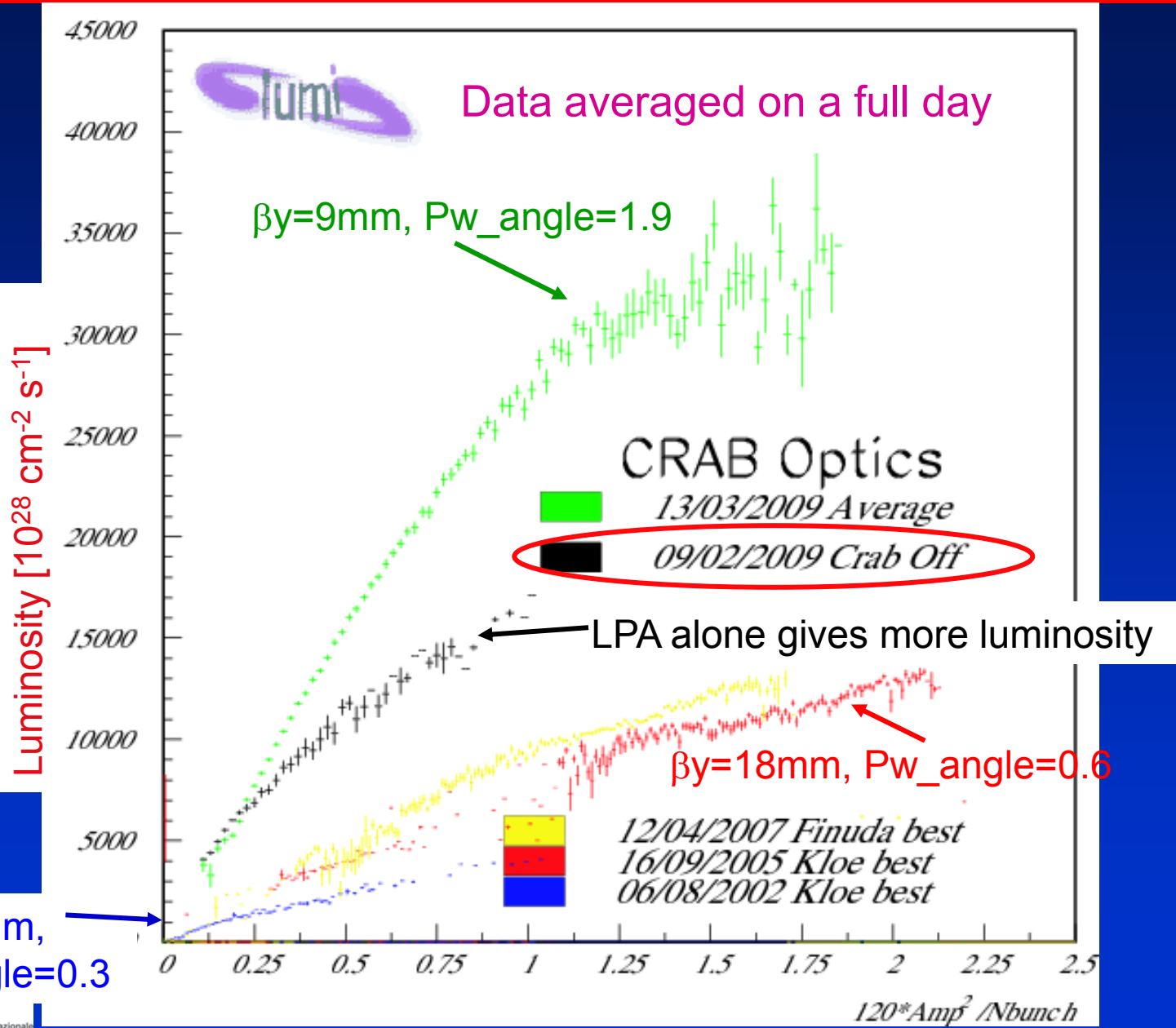
- In 2007-2008 DAΦNE was upgraded to include a crab-waist IR for testing the principle
- There were some additional (conventional) improvements as well
 - Improved injection
 - Improved impedance reduction
 - Improved feedback systems
- The predicted luminosity increase was about a factor of 3 (from 1.6×10^{32} to 4.5×10^{32})

DAΦNE Peak Luminosity

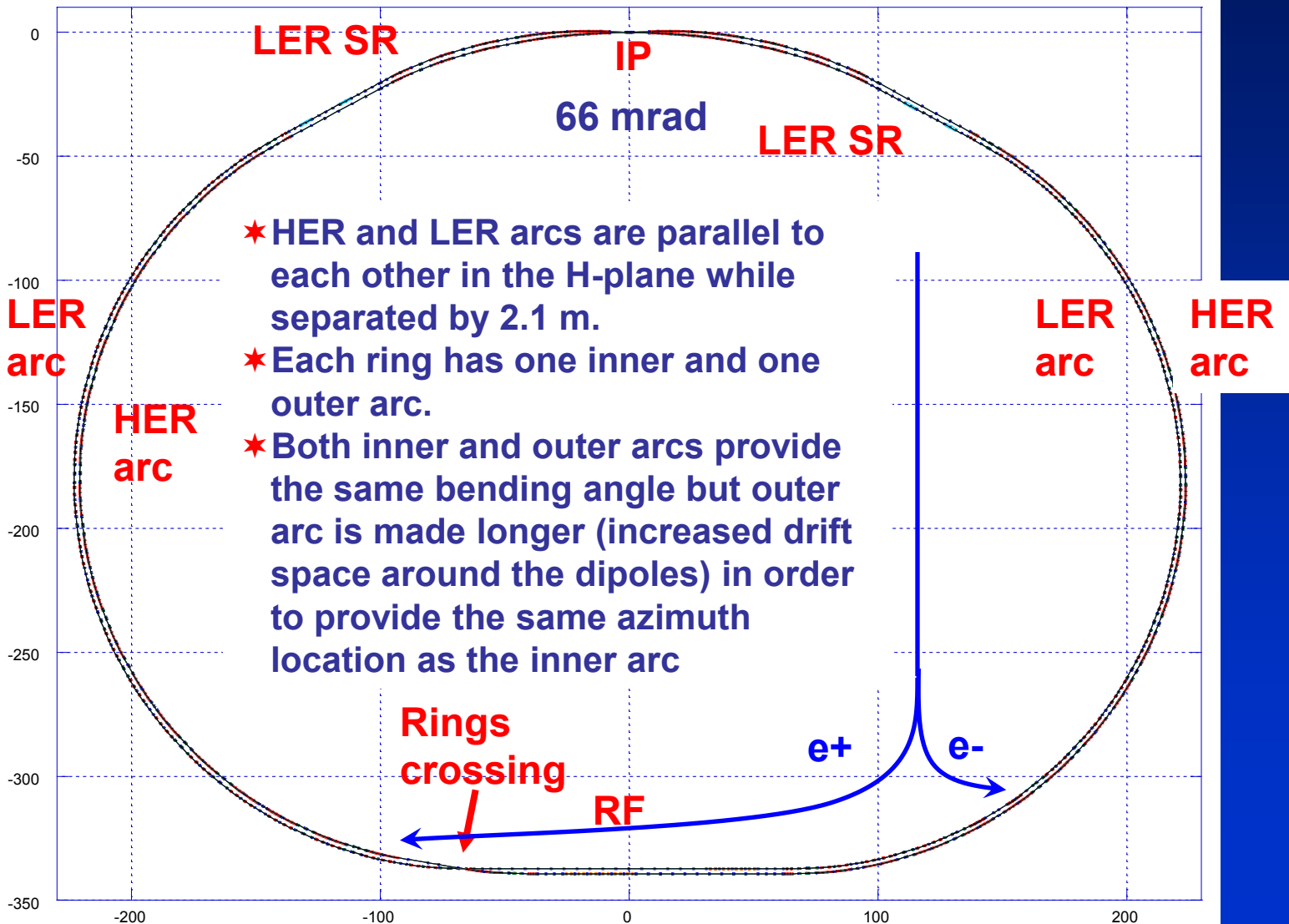
Design Goal



Peak luminosity vs currents



Layout



Beam-beam in LPA and CW regime

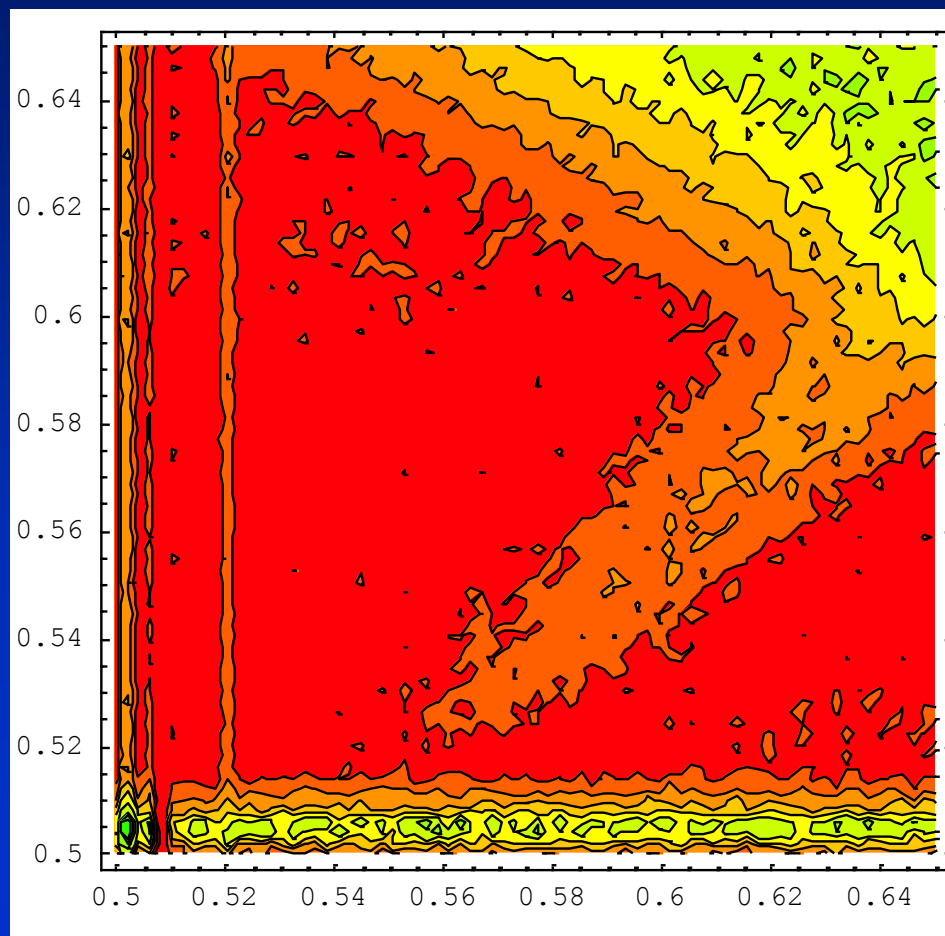
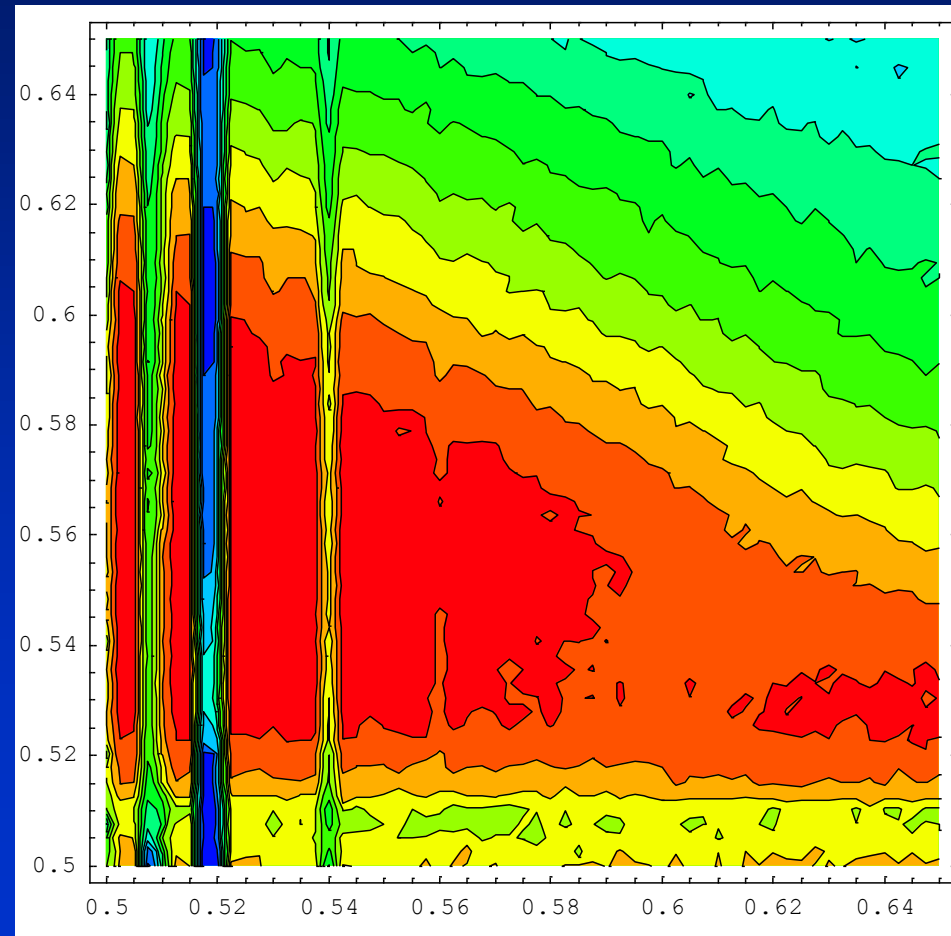
- Beam-beam tune scan performed with latest beam parameters and latest beam-beam code, improved to take into account crabbed beams (D.Shatilov, BINP)
- Comparison with previous parameters: lower bb tune shift increases tune operation area and achievable luminosity (10^{36} in the large red area)
- Needs to be run including lattice nonlinearities for beam beam tails and lifetime, as soon as the lattice is “reasonably” stable

Beam-beam tune scan

Shatilov

CDR, $\xi_y = 0.17$

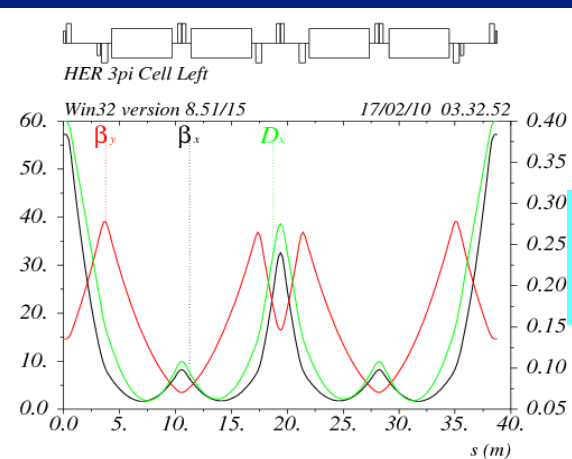
CDR2, $\xi_y = 0.097$



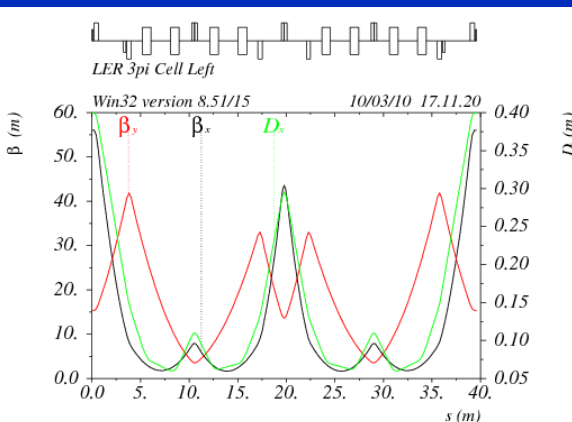
L (red) = $1 \cdot 10^{36}$

SuperB Arcs

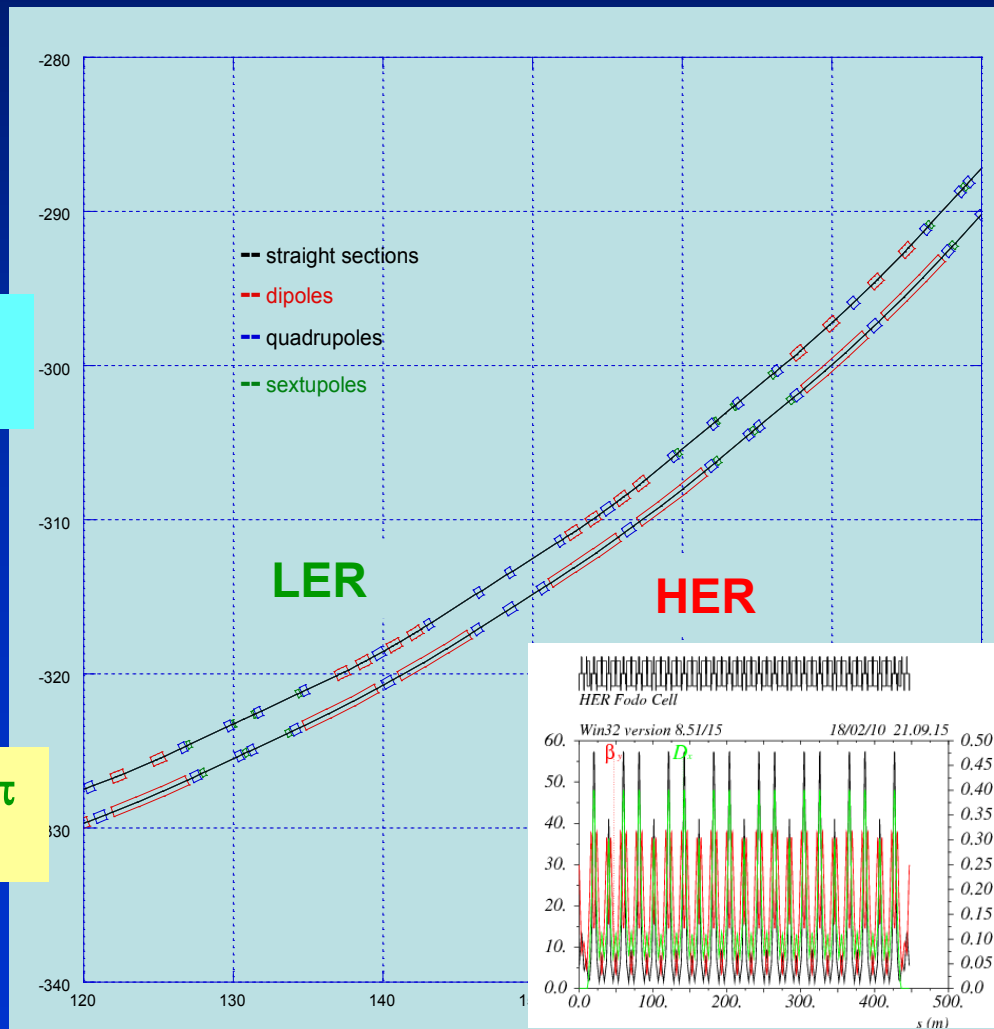
HER and LER arcs have conceptually the same lattice. LER arc dipoles are shorter (bend radius about 3 times smaller) than in the HER in order to match the ring emittances at the asymmetric beam energies



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

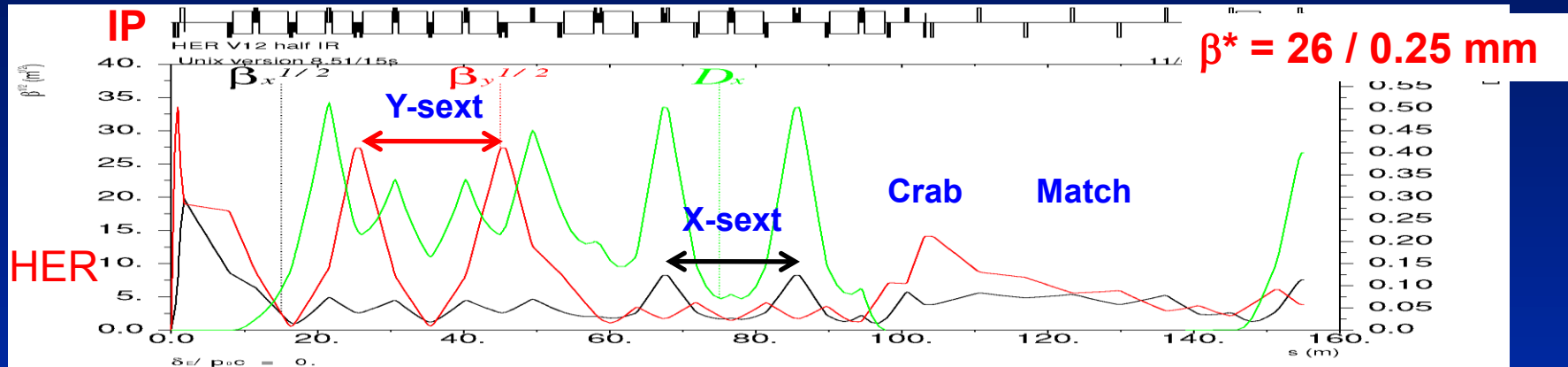


$\mu_x = 3\pi, \mu_y = \pi$
Cell in LER

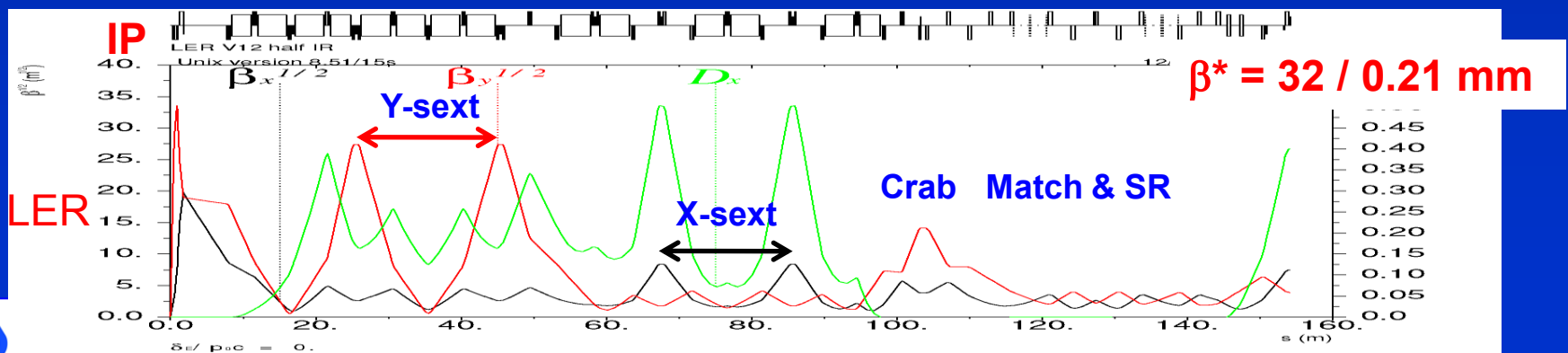


FF optics

- “Spin rotator” optics is replaced with a simpler matching section



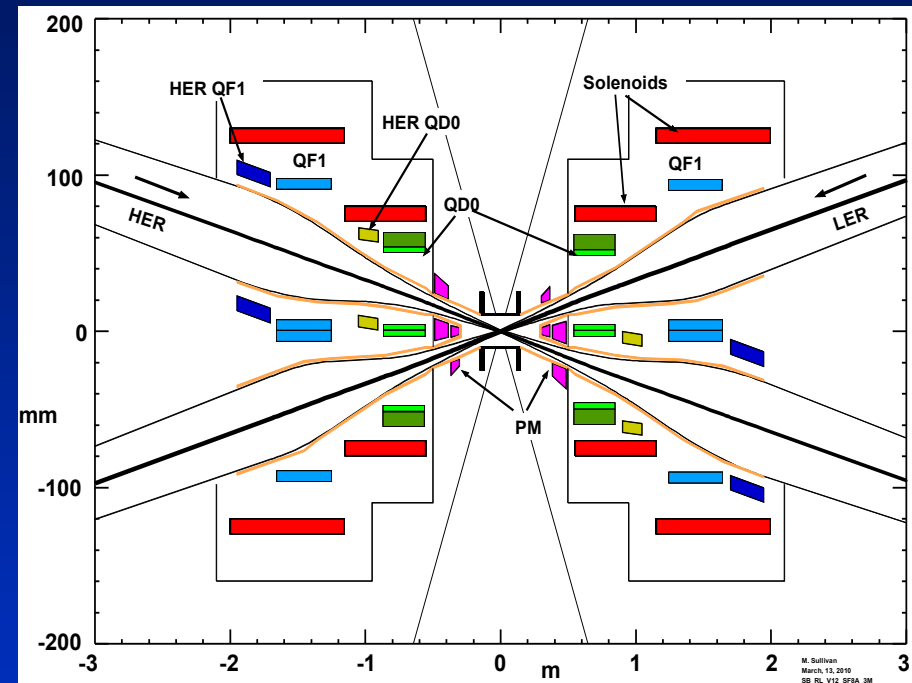
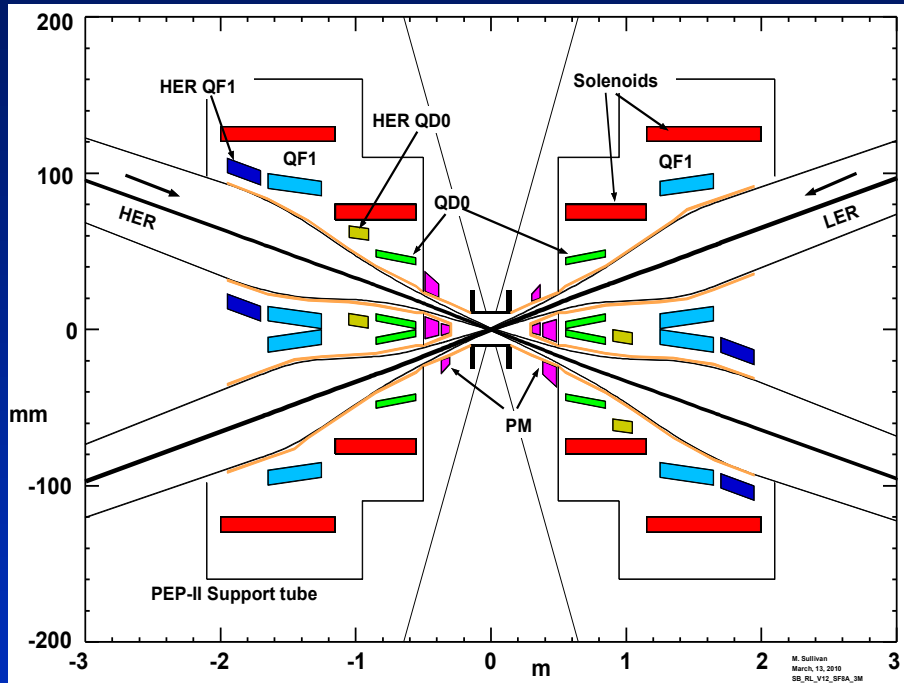
- Matching section is shorter than HER to provide space for spin rotator optics.
- $\pm 33 \text{ mrad}$ bending asymmetry with respect to IP causes a slight spin mismatch between SR and IP resulting in $\sim 5\%$ polarization reduction.



IR design

- We have two designs that are flexible and have good:
 - SR backgrounds
 - Lattice functions
 - Beam apertures
- The two designs are:
 - Vanadium Permendur for QD0 and QF1
 - Parallel air-core dual quads for QD0 and QF1 (prototype in progress)
 - Both designs include additional vanadium permendur Panofsky quads on the HER
- These IR design demonstrates initial robustness
 - Two separate QD0 designs work
 - The direction of the beams can be either way with a weak preference for the incoming beams to be from the outside rings due to the location of the SR power on the cryostat beam pipe

QD0 Design: 2 possible choices



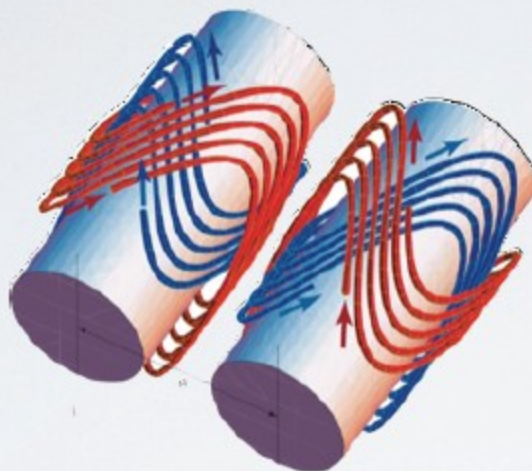
*Vanadium Permendur
"Russian" Design*

*Air core "Italian" QD0,
QF1 Design*

QD0 DESIGN OPTIONS

“Italian” Design

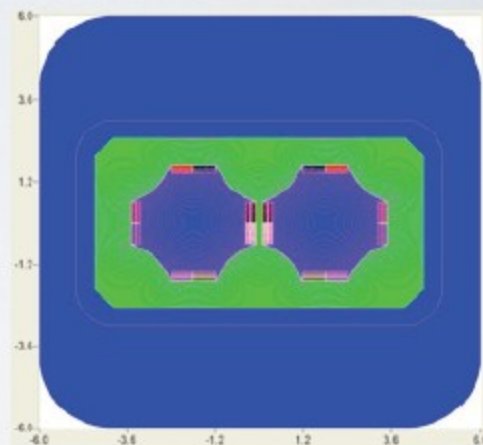
E. Paoloni ,
P. Fabricatore,
R. Musenich,
S. Farinon ,
S. Bettoni



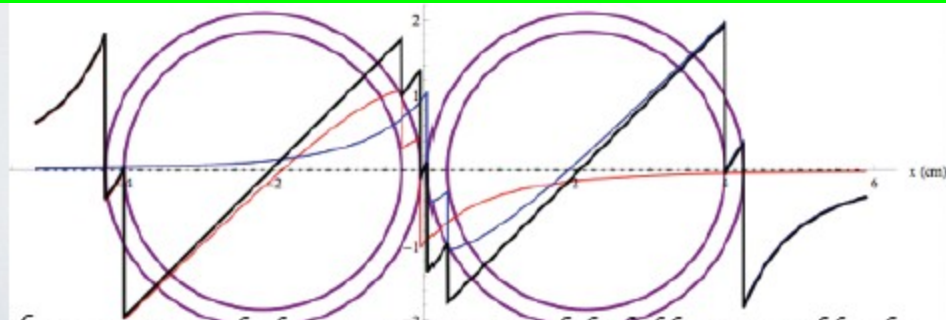
Conceptual sketch.

“Russian” Design

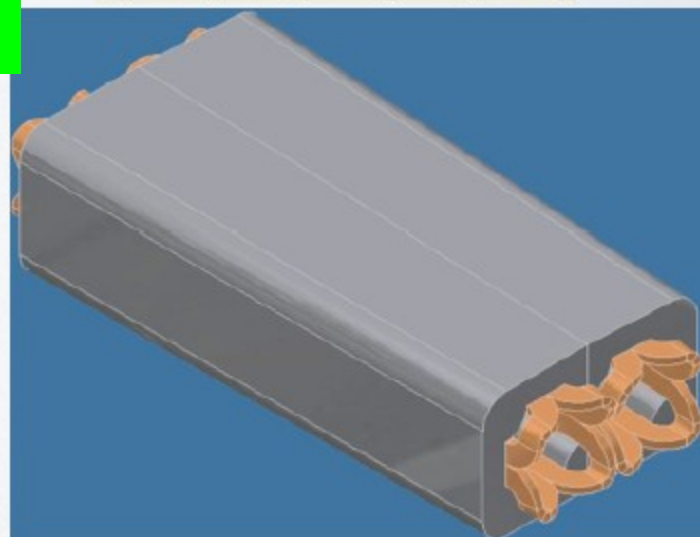
I. Okunev, V. Syrovatin, A. Bragin, P. Vobly



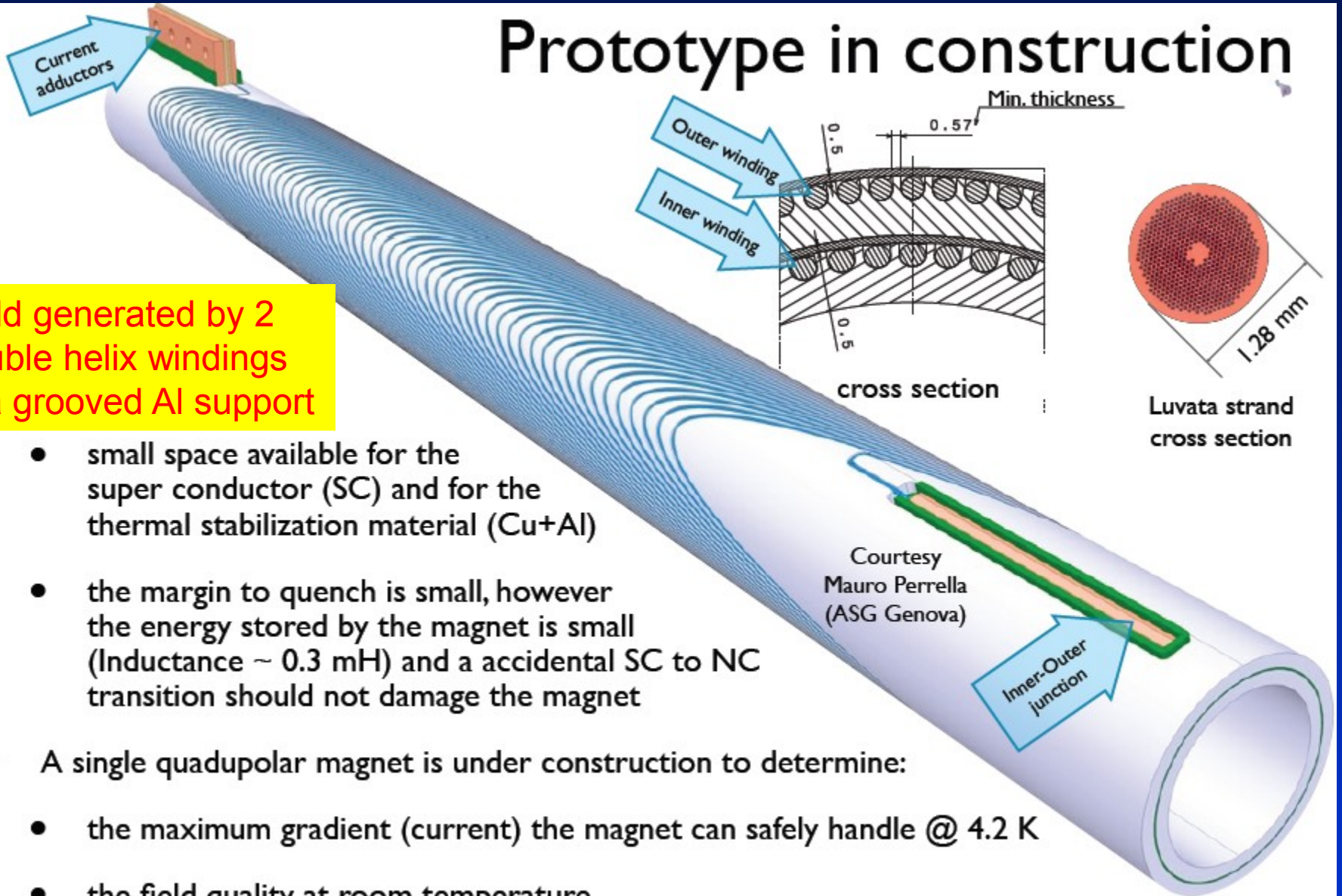
Air-core QD0 is a SC iron free septum double quad



Design concept: the linear superposition of the fields generated by the left coil (in red) and by the right one (in blue) produces the needed quadrupolar field (in black).



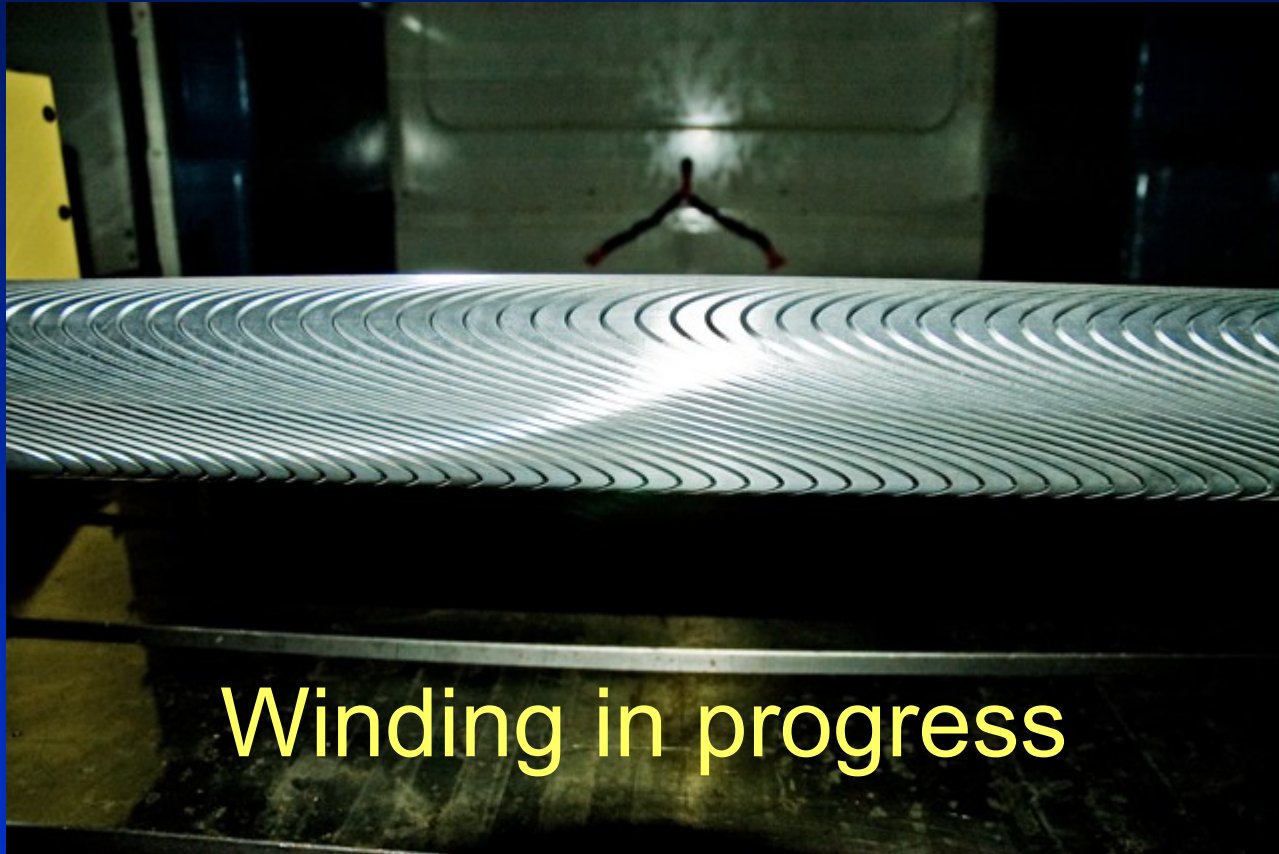
Prototype in construction



Field generated by 2 double helix windings in a grooved Al support

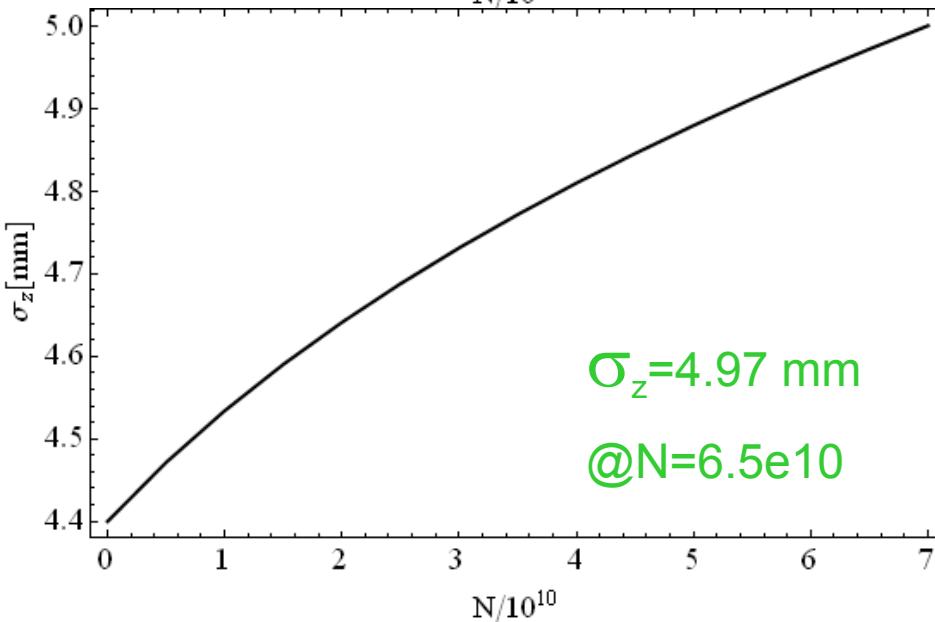
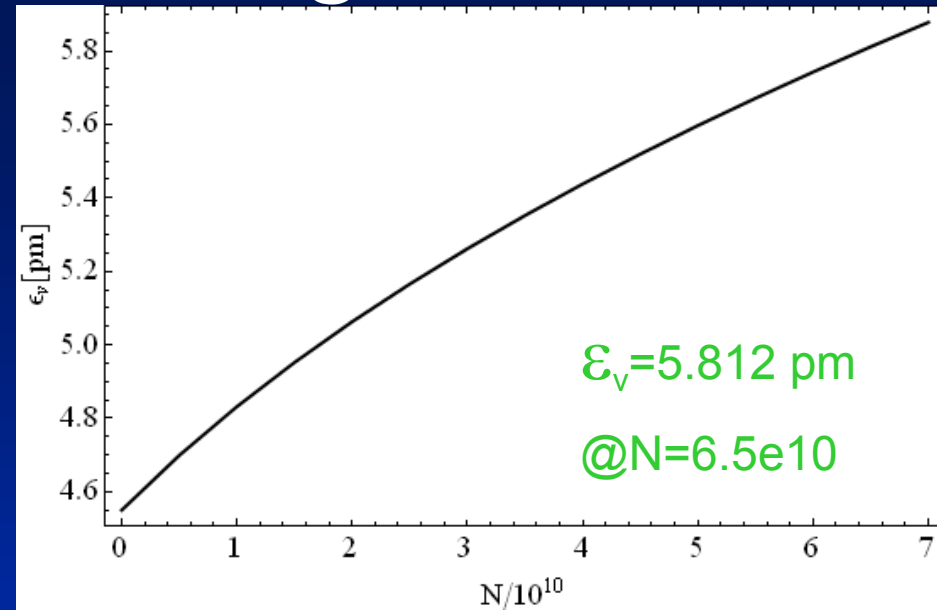
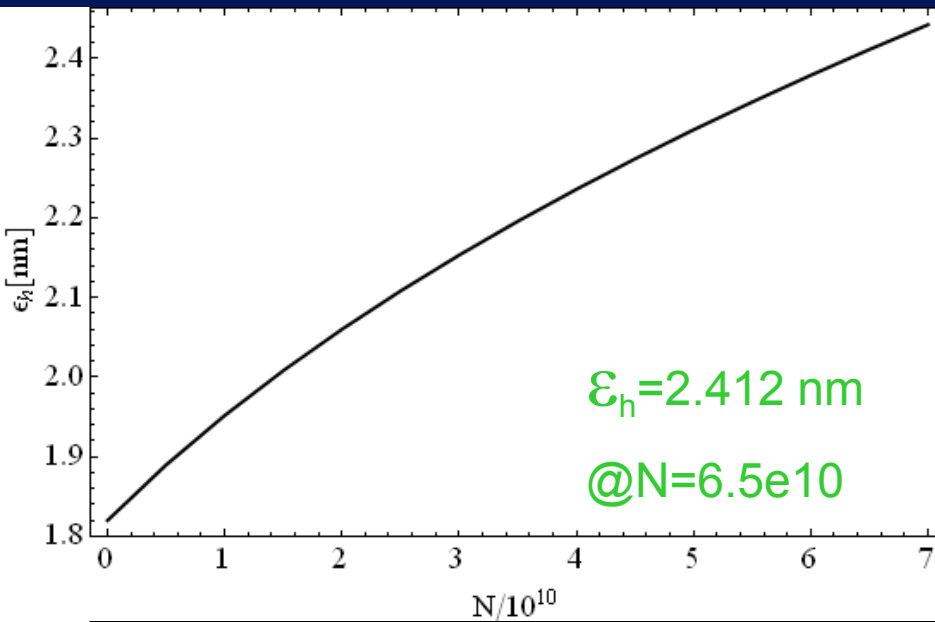
- small space available for the super conductor (SC) and for the thermal stabilization material (Cu+Al)
- the margin to quench is small, however the energy stored by the magnet is small (Inductance ~ 0.3 mH) and a accidental SC to NC transition should not damage the magnet
- A single quadupolar magnet is under construction to determine:
 - the maximum gradient (current) the magnet can safely handle @ 4.2 K
 - the field quality at room temperature
- 200 m of SC wire kindly gifted by Luvata: $\Phi=1.28$ mm, Cu/NbTi = 1.0, I_c 2450 A @ 4T, 4.2K

The actual grooved Al support



Ready before Summer for tests and field measurements at CERN

Intra Beam Scattering in LER

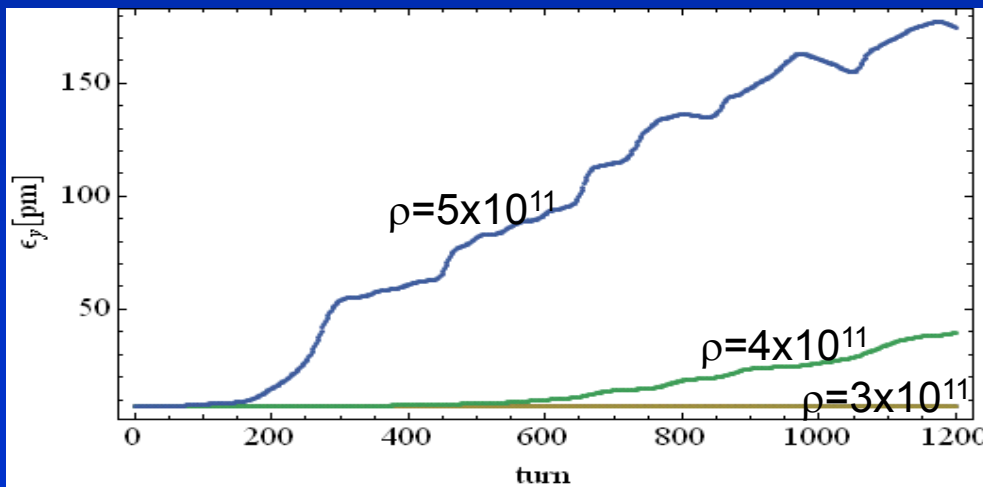


The effect of IBS on the transverse emittances is about 30% in the LER and less than 5% in HER.

Interesting aspects of the IBS such as its impact on damping process and on generation of non Gaussian tails are being investigated with a multiparticle algorithm \rightarrow 6D MC

e-cloud instability

- Single bunch instability simulations for SuperB HER taking into account the effect of solenoids have been performed using CMAD (Pivi, SLAC). They indicate a threshold density of $\sim 10^{12}$ e-/m³ (roughly 2 times previous estimates)
- The obtained thresholds have to be compared with build-up simulations using updated parameters to determine safe regions of the parameter space (SEY, PEY)
- Work is in progress to:
 - Estimate the effect of radiation damping on long term emittance growth
 - Estimate the fraction of synchrotron radiation absorbed by antechambers



Vertical emittance growth induced by e-cloud

Low Emittance Tuning: LER tolerances

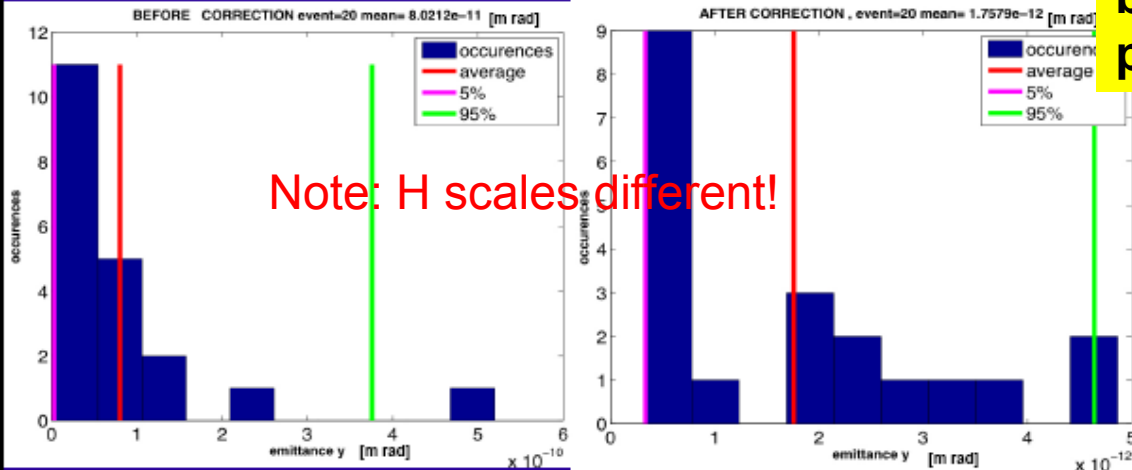
LER

Elements From QF1R to QF1L are considered as a single element.

109-ARCS+60-FF

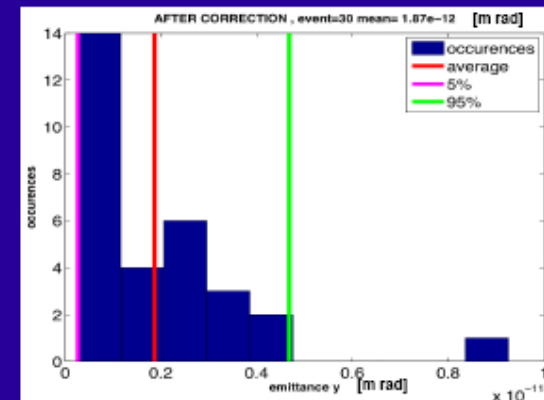
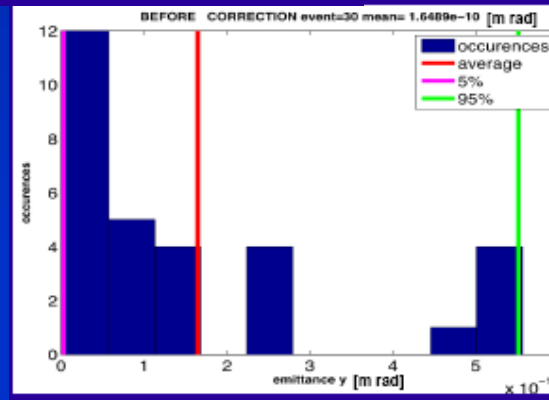
Misalignment	Tolerated value	
	ARC	FF
Quadrupole H and V	50 μm	20 μm
Quadrupole Tilt	50 μrad	20 μrad
Sextupole H and V	50 μm	20 μm
BPM resolution	1 μm	1 μm
BPM Offset	50 μm	20 μm

LER ARC's tolerances evaluated using a Response Matrix technique that optimizes orbit, in order to recover the design values for Dispersion, Coupling and Beta-beating, and obtain the lowest possible vertical emittance



Misalignment	Value	
	ARC	FF
Quadrupole H and V	50 μm	00 μm
Quadrupole Tilt	50 μrad	00 μrad
Sextupole H and V	50 μm	00 μm
BPM resolution	1 μm	0 μm
BPM Offset	50 μm	00 μm

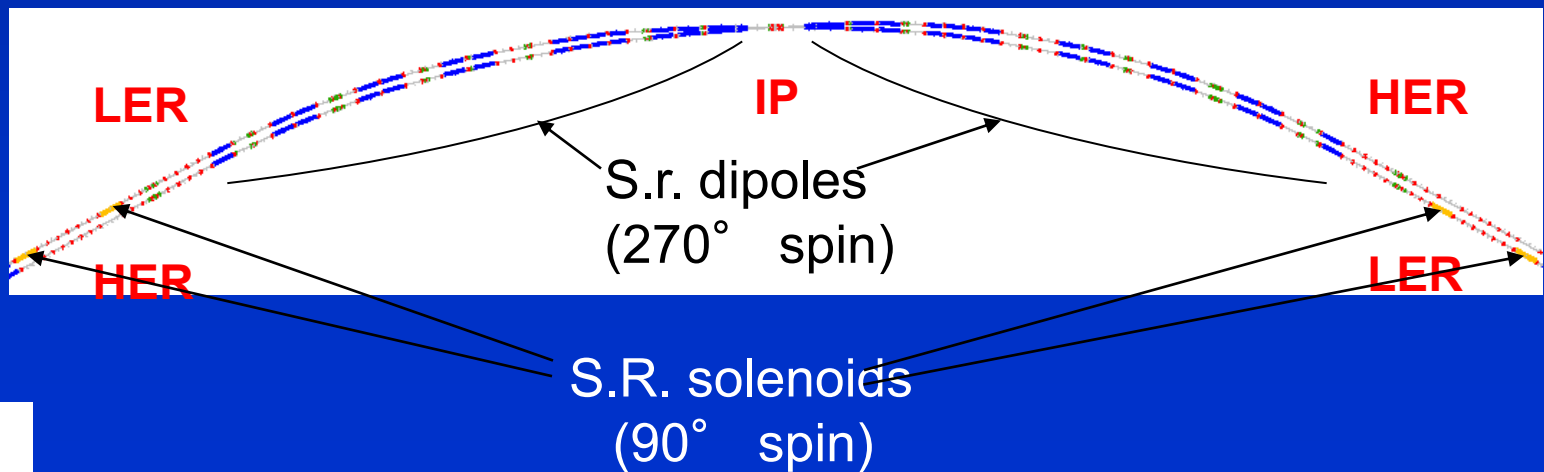
Final Focus introduces stringent restrictions on alignment of both FF and ARCS (even for no errors in FF)



The introduction of the Final Focus In the lattice defines more stringent tolerances also in the arcs

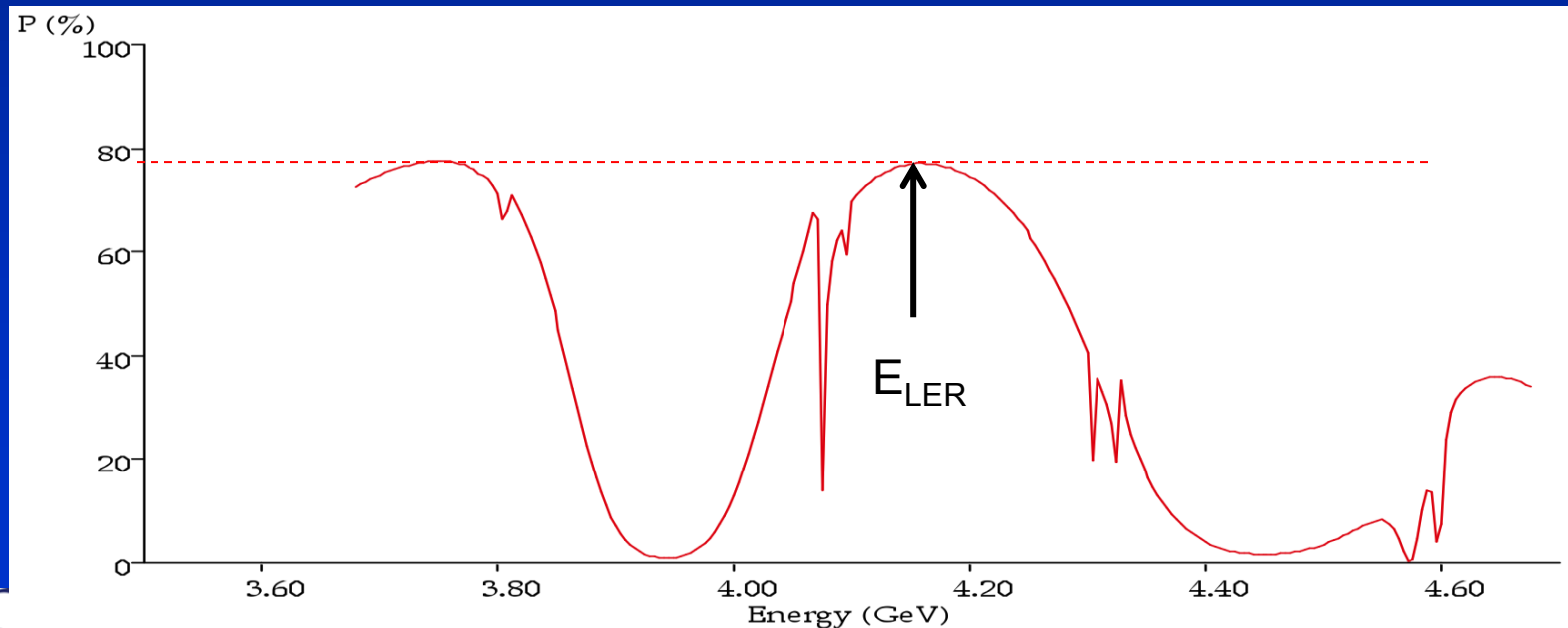
Polarization in SuperB

- 90° spin rotation about x axis
 - 90° about z followed by 90° about y
- “flat” geometry → no vertical emittance growth
- Solenoid scales with energy → LER more economical
- Solenoids are split & decoupling optics added
- The SR optics design has been matched to the Arcs and a similar (void) insertion added to HER
- This design poses severe constraints on the FF bending angles of LER and HER in order to achieve the “right” spin dynamics
- A polarimeter has been designed to measure polarization



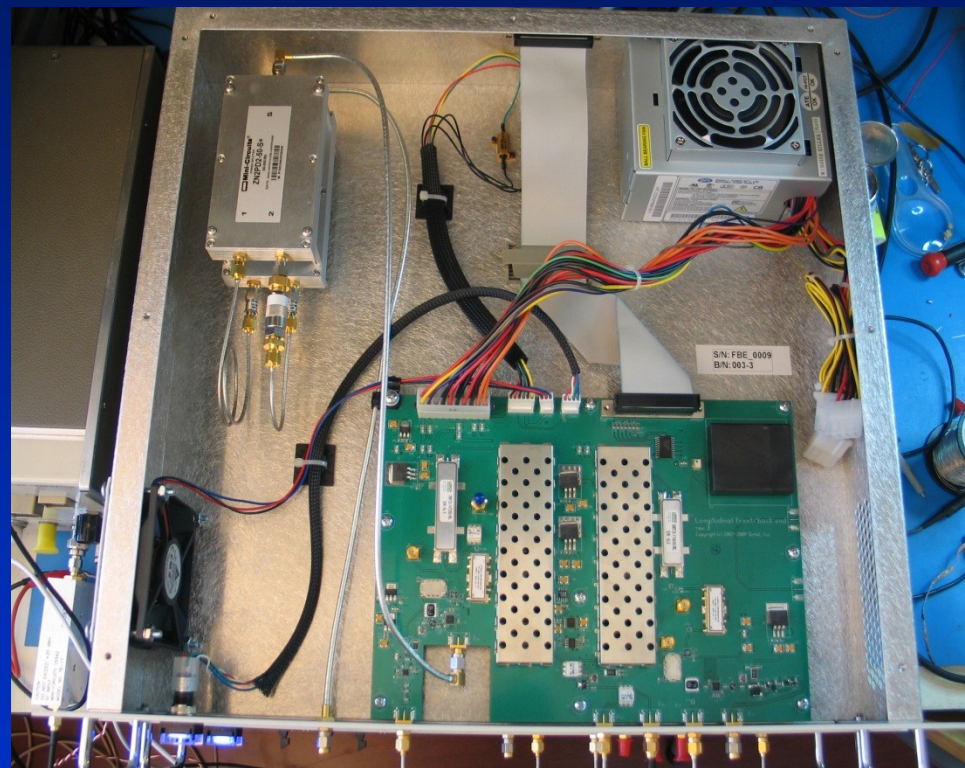
Polarization resonances

- ❑ Beam polarization resonances do constraint the beam Energy choice
- ❑ Plot shows the resonances in the energy range of LER
- ❑ Beam polarization computed assuming
 - 90% beam polarization at injection
 - 3.5 minutes of beam lifetime (bb limited)
- ❑ From this plot is clear that the best energy for LER should be 4.18 GeV → HER must be 6.7 GeV



Bunch-by-bunch feedback

- ❑ All 6 DAΦNE feedbacks have been upgraded with a new 12bit system
- ❑ VFB – new 12 bit iGp systems with larger dynamic range and software compatibility with the previous version
- ❑ LFB - **completely new systems** in place of the old systems designed in 1992-1996 in collaboration with SLAC/LBNL: fe/be analog unit connected to iGp-8 as processing unit
- ❑ HFB: upgrade hw/sw of the iGp-8bit system already used
- ❑ **This will be the baseline design for SuperB H-V-L feedbacks**

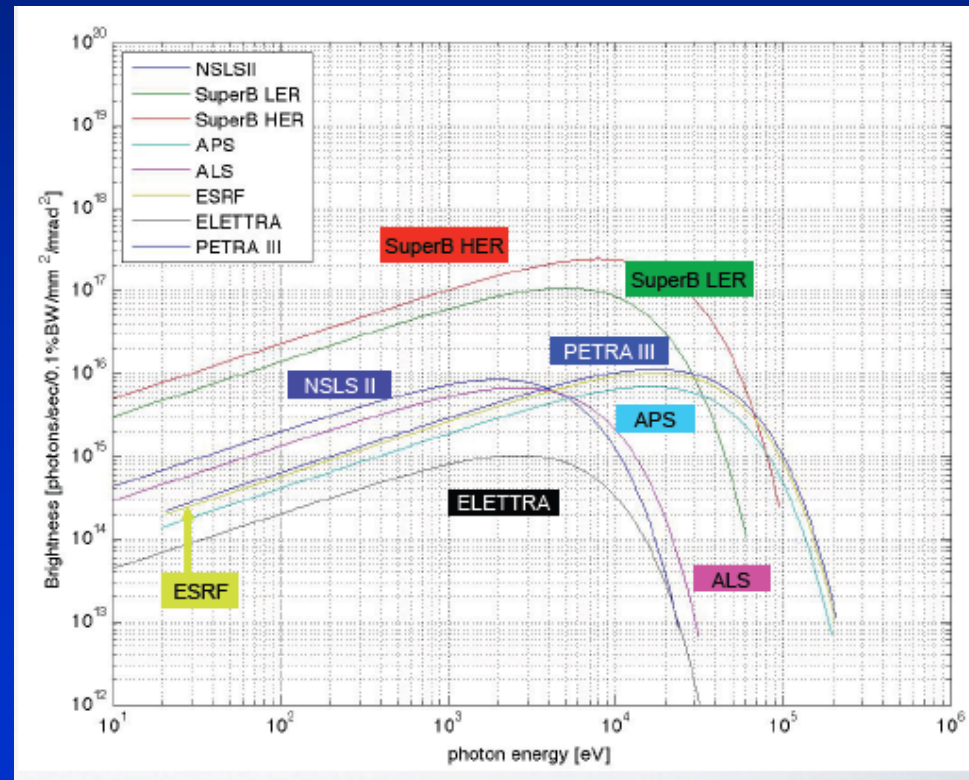


- ❑ New front-end/back-end analog unit used in the longitudinal feedback

Synchrotron light options @ SuperB

- Comparison of brightness and flux from bending magnets and undulators for different energies dedicated SL sources & SuperB HER and LER
- Synchrotron light properties from dipoles are competitive
- Assumed undulators characteristics as NSLS-II
- Light properties from undulators still better than most LS, slightly worst than PEP-X (last generation project)

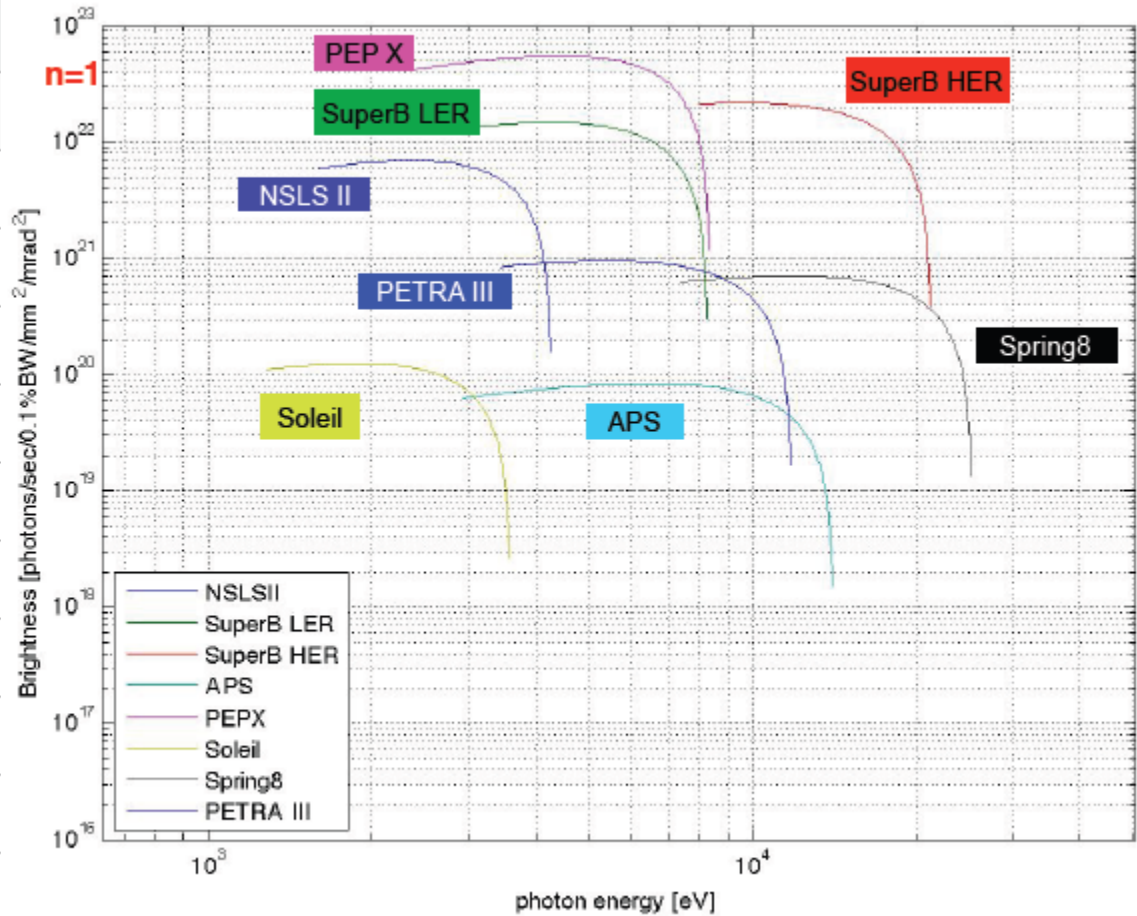
Parameters *	SuperB HER	SuperB LER	NSLS II
E [GeV]	6.7	4.18	3
I [mA]	1892	2447	500
ρ [m]	69.64	26.8	24.975
ϵ_x [m rad]	2.0 E-9	2.46 E-9	0.55 E-9
ϵ_y [m rad]	5.0 E-12	6.15 E-12	8.0 E-12
$\gamma\gamma$ [m ⁻¹]	0.334	0.537	0.05
σ_x [mm]	82.1 E-3	92.1 E-3	125.0 E-3
σ_y [mm]	8.66 E-3	9.11 E-3	13.4 E-3



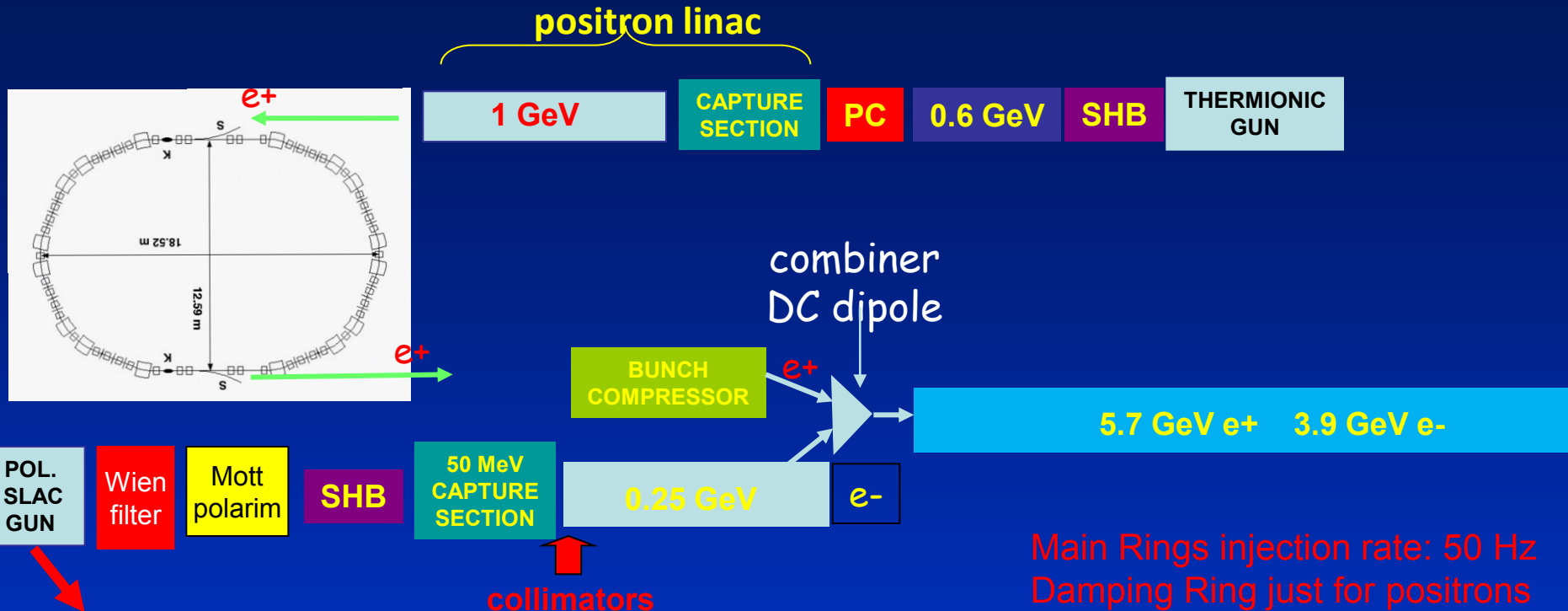
Brightness from bending magnets

Brightness from undulators

Parameters *	SuperB HER	SuperB LER	NSLS II
	IVU20	IVU20	IVU20
E [GeV]	6.7	4.18	3
I [mA]	1892	2447	500
σ_x [mm]	60.0 E-3	66.5 E-3	33.3 E-3
σ_y [mm]	2.4 E-3	2.6 E-3	2.9 E-3
σ_x' [mrad]	33.3 E-3	37.0 E-3	16.5 E-3
σ_y' [mrad]	2.1 E-3	2.7 E-3	2.7 E-3
N [1]	148	148	148
λ_u [mm]	20	20	20
Kmax [1]	1.83	1.83	1.83
Kmin [1]	0.1	0.1	0.1



Injection System



Main Rings injection rate: 50 Hz
Damping Ring just for positrons

Parameter	Units	SLC
Electron charge per bunch	nC	16
Bunches per pulse		2
Pulse rep rate	Hz	120
Cathode area	cm ²	3
Cathode bias	kV	-120
Bunch length	ns	2
Gun to SHB1 drift	cm	150
$e_{n,rms,gun}$ (fm EGUN)	10 ⁻⁶ m	15

from A. Brachmann - SuperB Workshop
SLAC, October 2009

Round beam
Emittance @ 4.16 GeV = 1.8 nm
Required bunch charge for e- ≈ 0.3 nC
... scrapers .. collimators needed

Layout, Site

- The rings footprint is at the moment the same as the baseline (2 rings in same tunnel, about 1250 m long)
- The insertion of synchrotron beamlines, with their impact on the layout and lattice is being studied
- We are looking for a green field site in order to exploit at best the facility (SuperB and SL)
- Several sites seem available, first pick at the moment is in Tor Vergata University campus and we are studying its compatibility with the requirements
- Preliminary ground measurements have been performed at Tor Vergata in mid-April, waiting for their elaboration
- The layout will be adjusted as soon as the site is chosen to further optimize the system performances

Tor Vergata University campus

Possible site

About 4.5 Km

LNf Lab

Via di Passolombardo

SP77b
© 2011 Tele Atlas

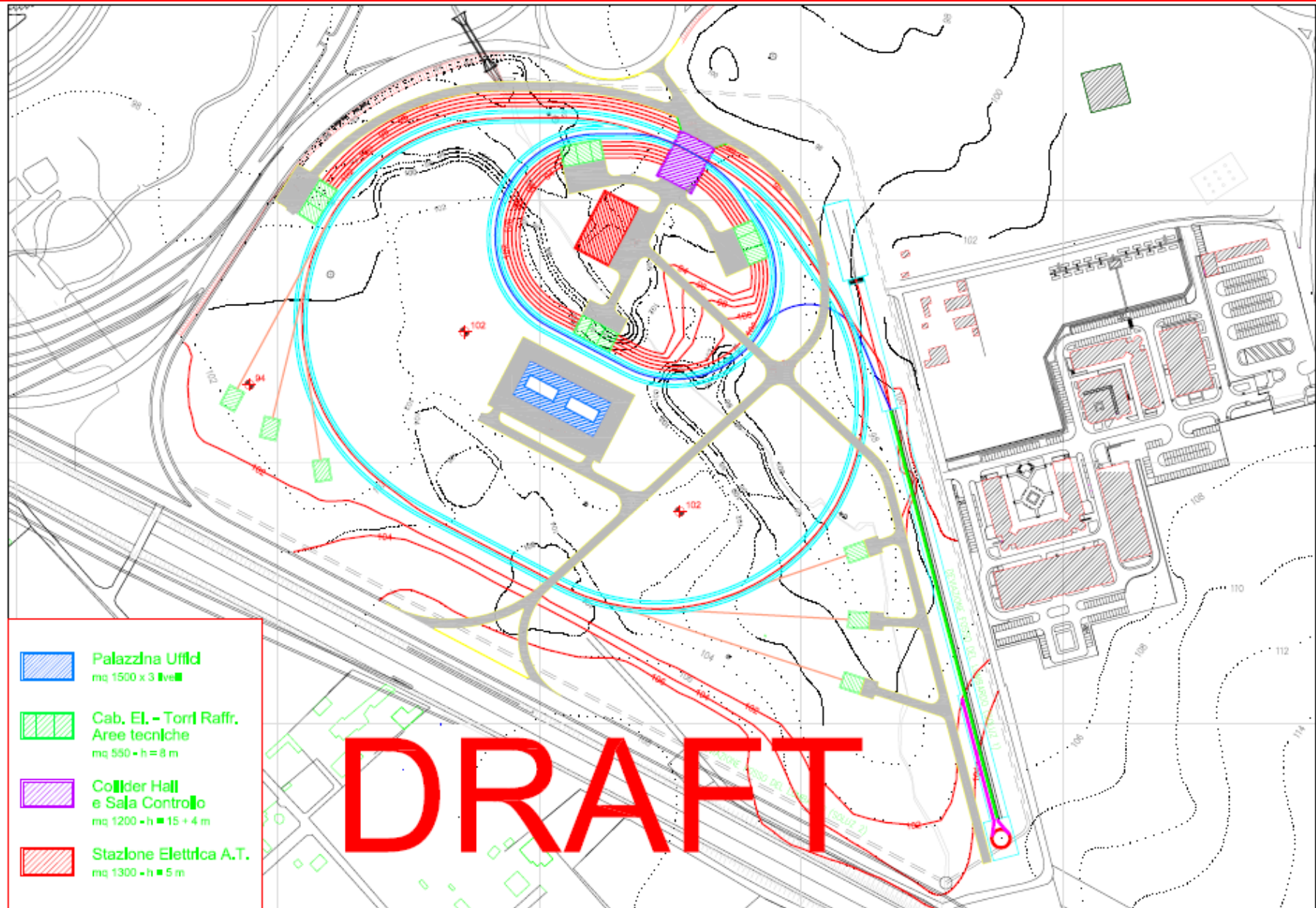
SS215
Image © 2011 DigitalGlobe
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Recent developments

- SL users need a lower emittance lattice, dedicated ID cells, long beamlines
- Difficult to achieve with 2 different E rings in the same tunnel
- A shorter (about $\frac{1}{2}$ HER) LER ring can be better optimized:
 - Same SR power (present LER arcs have many unused drifts just to match HER geometry)
 - Easier LER geometry for spin matching if not bound to HER FF
 - With $\varepsilon_x \approx \frac{1}{2} \rightarrow$ Luminosity $\approx \times 2$ ($L \propto 1/\varepsilon_x$)
 - Collective effects in a shorter ring are less severe

Possible new layout ?????

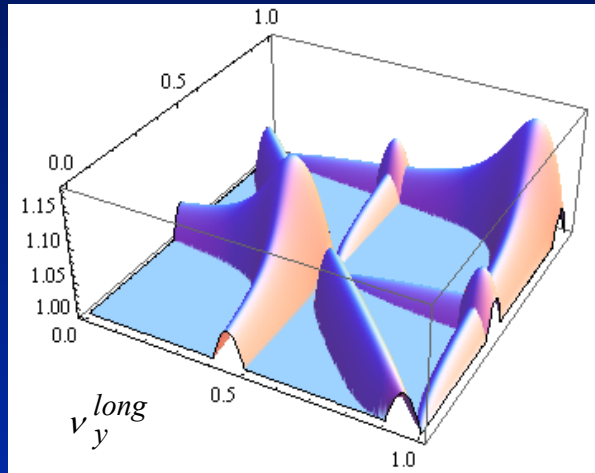


Beam-beam resonances for asymmetric rings

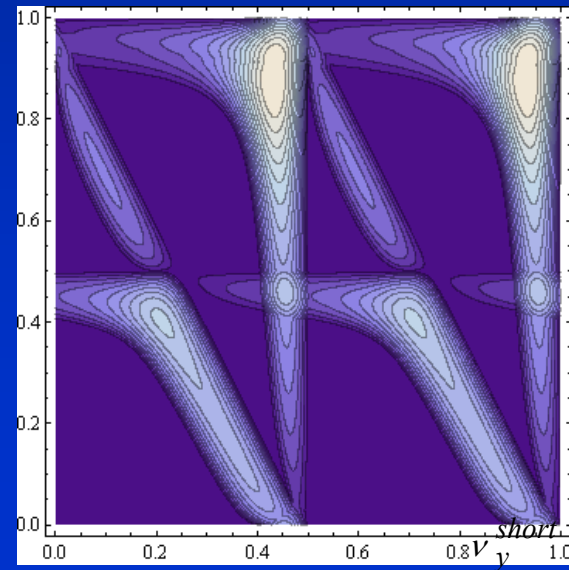
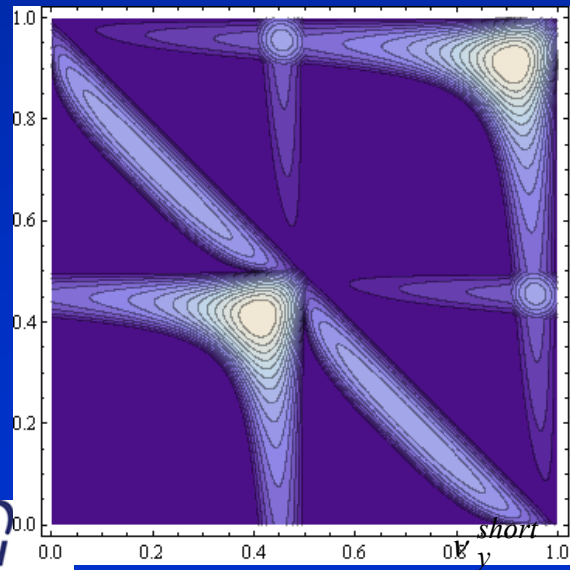
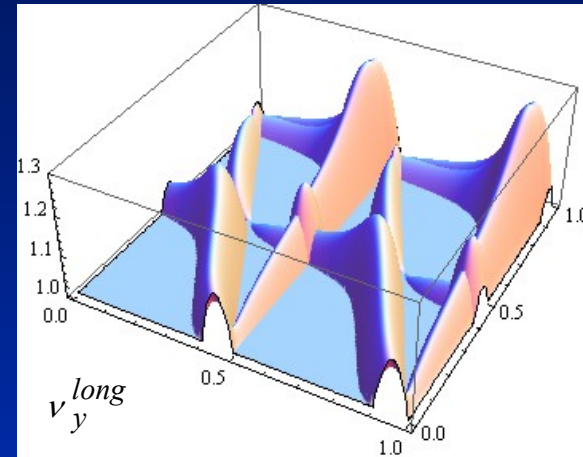
- The «short» against «long» rings collision has been theoretically studied in the early '90 by Hirata, Keil, Chao...
- They pointed out the rising of strong low order coherent resonances for asymmetric colliding rings
- Some analytical estimation have been done for the simple example of DAΦNE by M. Zobov
- Strong-strong bb simulations are needed, work in progress by Y. Zhang (BEPCII) on the same example
- For the moment results are that a suitable choice of the tunes (close to half-integer for «short» ring and to integer for «long» ring) can avoid the resonances and provide enough space for operation even with a high vertical tune shift

Tune space with coherent bb resonances

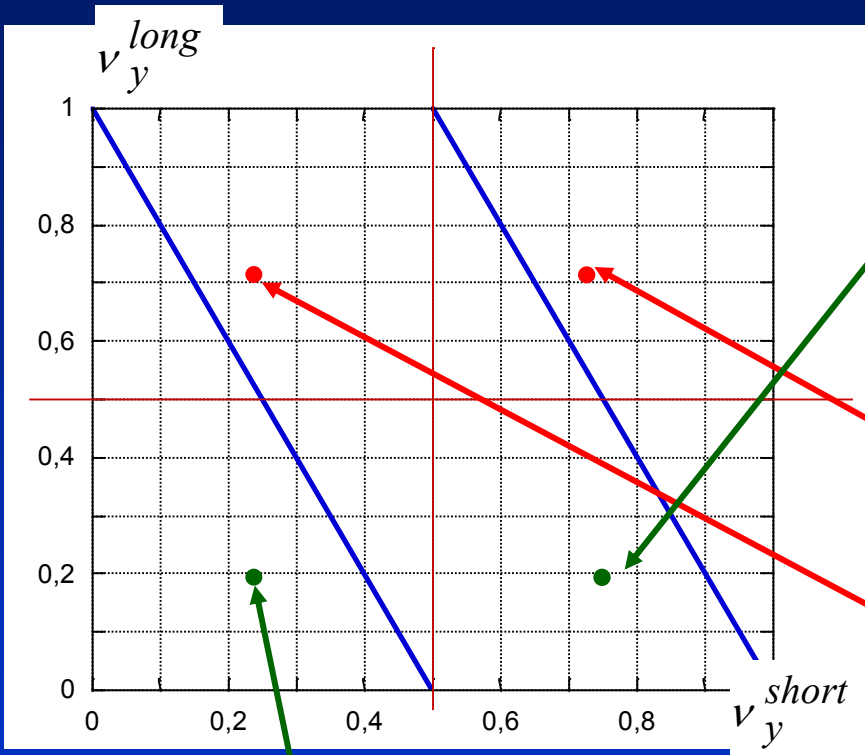
Symmetric Rings



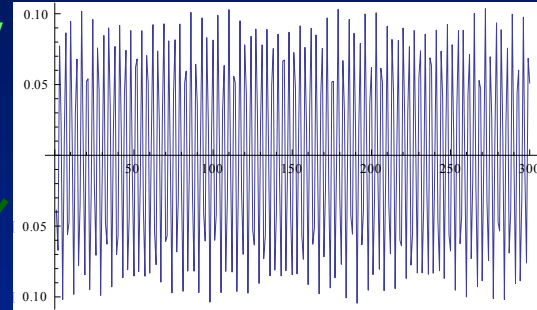
Asymmetric Rings (2:1)



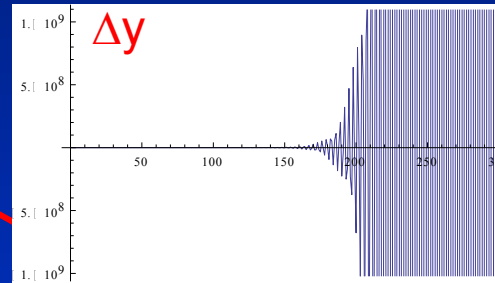
Working Point Choice to Avoid Coherent Beam-Beam Resonances



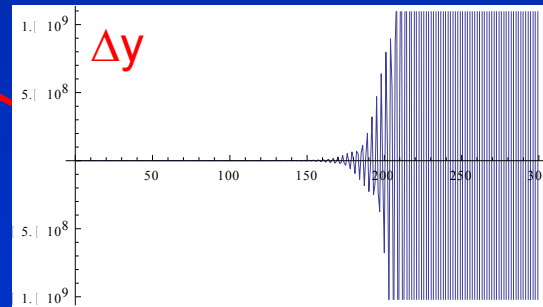
Δy



turns

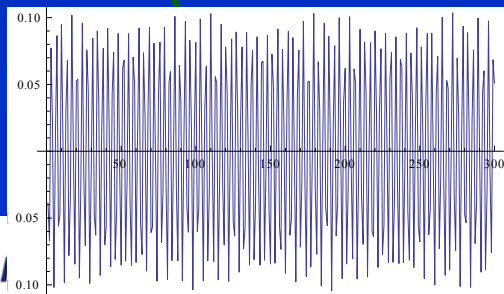


turns



turns

Δy

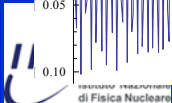


turns

Stable Motion

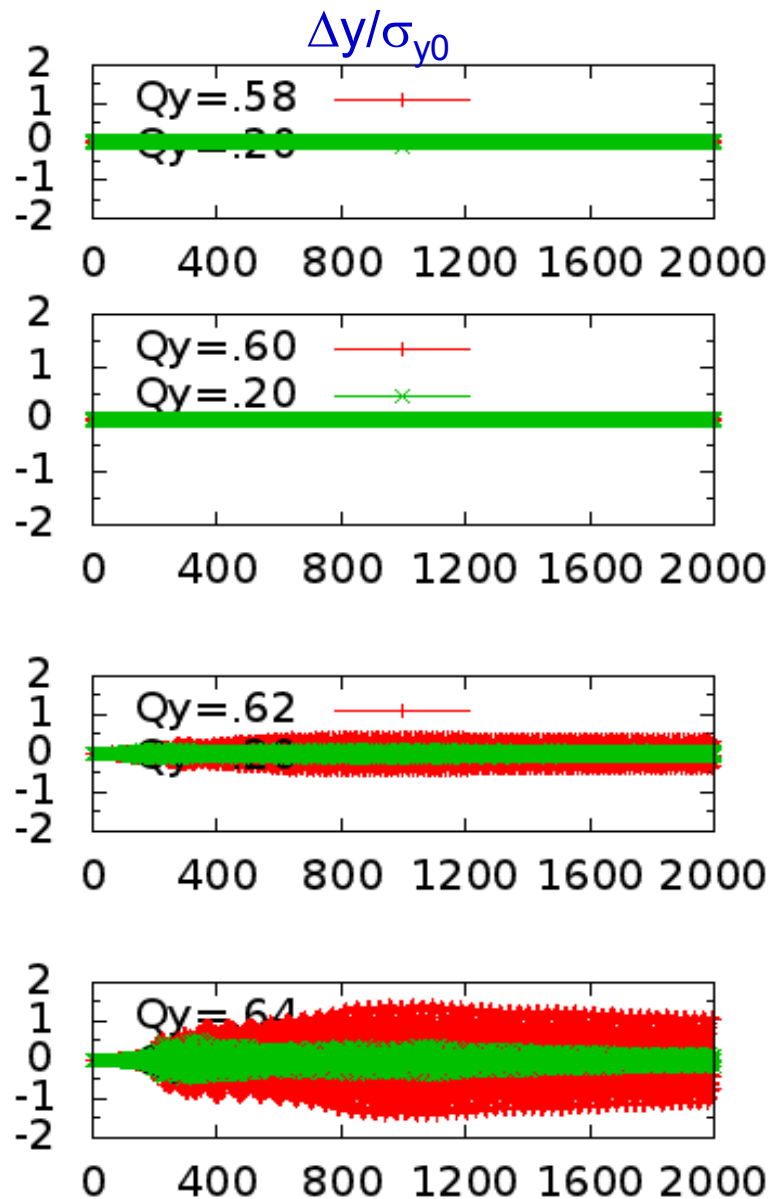
Unstable Motion

M. Zobov



Preliminary strong-strong bb simulations for different tune WPs

Vertical beam baricenter movement

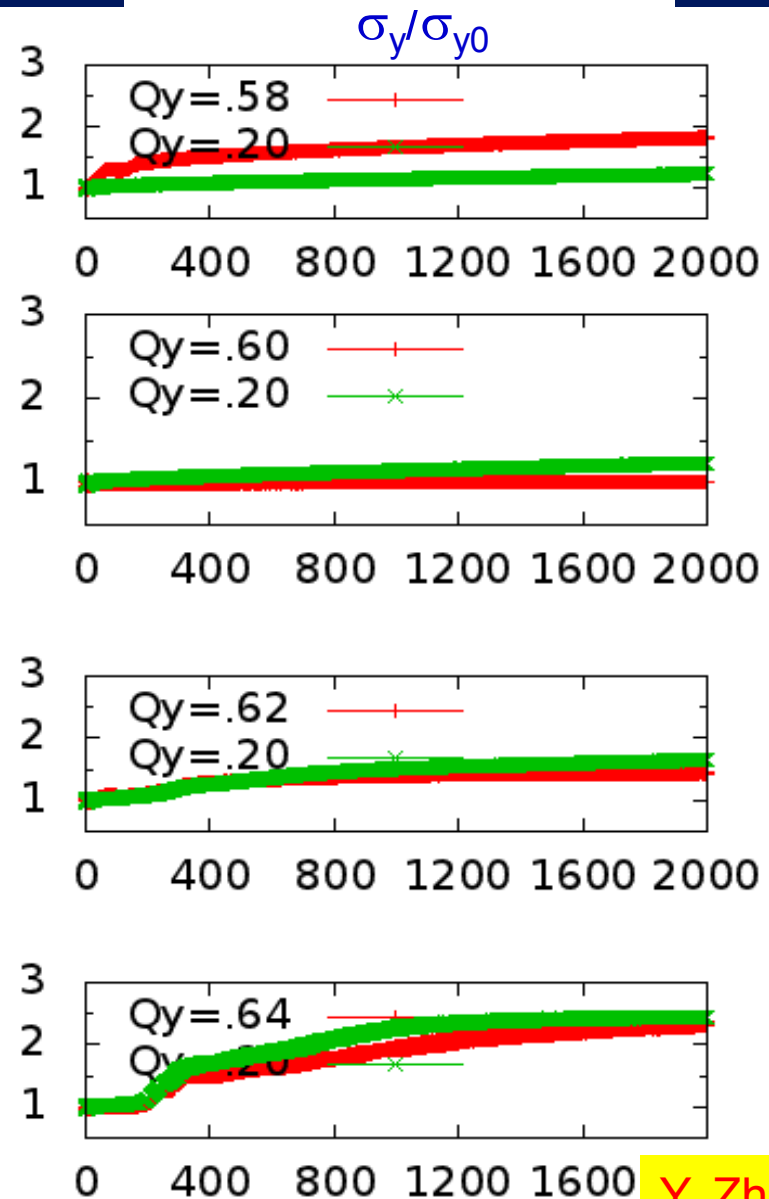


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Vertical beam blow-up



Synergies with state-of-the art international efforts

- SuperB design has many characteristics in common with state-of-the-art colliders (LC, CLIC) and SL sources, to cite just a few:
 - Alignment of magnets, and orbit and coupling correction with the precision needed to produce vertical emittances of just a few pico-meters on a routine basis
 - Optimization of lattice design and tuning to ensure sufficient dynamic aperture for good injection efficiency (for both) and lifetime (particularly for SuperB LER), as well as control of emittances
 - Feedbacks (IP and rings)
 - Control of beam instabilities, including electron cloud, ion effects and CSR
 - Reduction of magnet vibration to a minimum, to ensure beam orbit stability at the level of a few microns
- All these issues are presently active areas of research and development, the similarity of the proposed operating regimes presents an opportunity for a well-coordinated program of activities that could yield much greater benefits than would be achieved by separate, independent R&D programs

Conclusions

- Accelerator design is converging
- Lattice and parameters optimization is continuing, for better performances and more flexibility
- Synchrotron Light beamlines are being considered
- A possible new layout is being studied, with special IDs insertions
- Work is in progress on more subtle beam dynamics issues (IBS, FII, CSR, e-cloud, beam-beam, feedbacks,...)
- Components and lattice tolerances with corrections are being studied
- Polarization is progressing: beam-beam depolarization studies, trying to simplify the polarized gun, spin tracking, spin measurements set-up
- Italian Government has approved SuperB as Flagship Project and allocated 270 Meuro in 5 years
- We are collaborating with other Labs (SLAC, LAL, BINP, CERN, PSI, DIAMOND, IHEP, Cornell,...) to solve common issues