Status of the SuperB Collider Project

T. Demma, INFN-LNF

on behalf of the SuperB Accelerator Team

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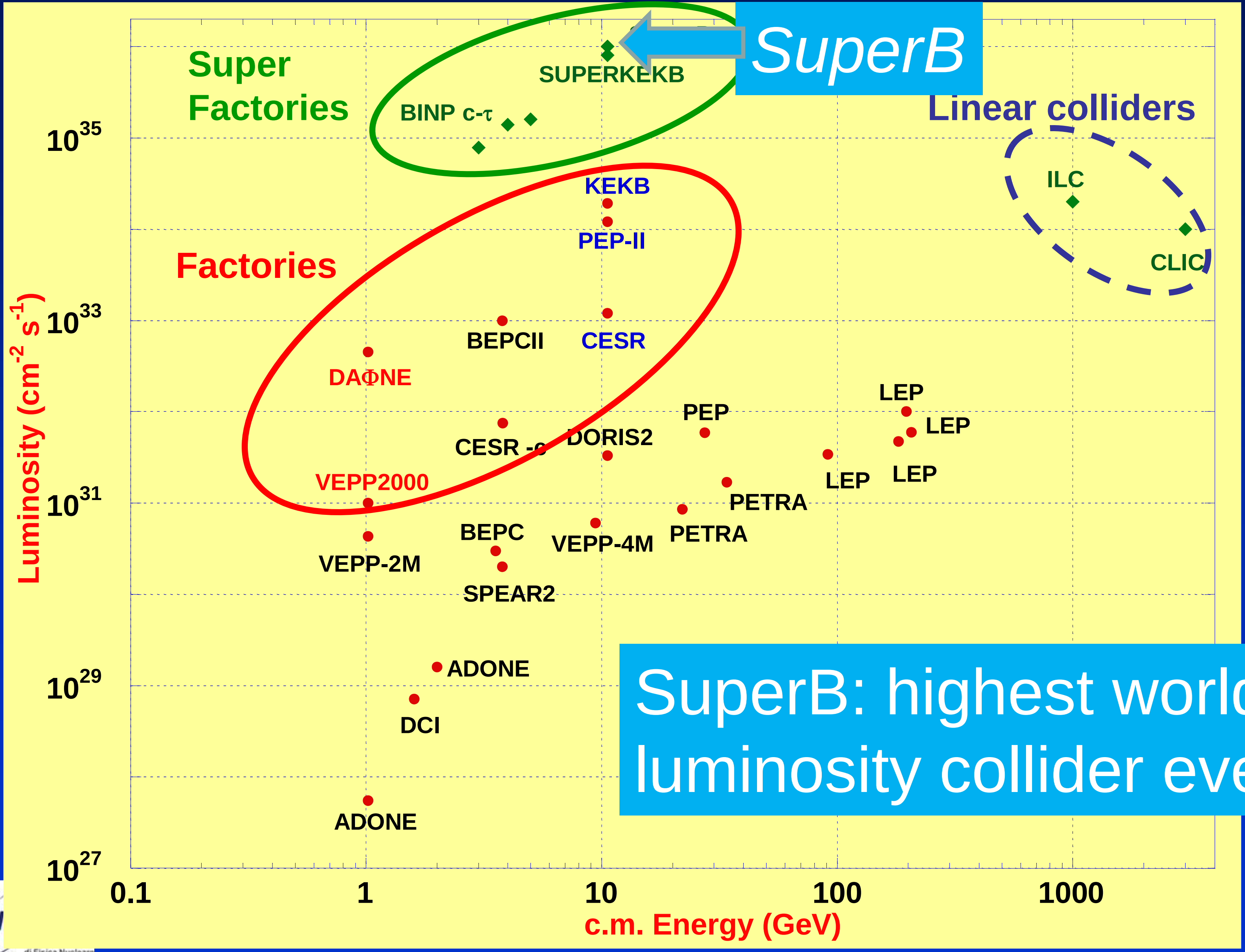
Budker Institute of Nuclear Physics

SuperB Accelerator

- SuperB is a 2 rings, asymmetric energies (e^- @ 4.18, e^+ @ 6.7 GeV) collider with:
  - longitudinally polarized electron beam
  - target luminosity of 10^{36} cm^{-2} 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 Sinchrotron Radiation beamlines (collaboration with Italian Institute of Technology)

World e^+e^- colliders luminosity



SuperB: highest world luminosity collider ever

How to increase L to 10^{36} ?

- B-Factories (PEP-II and KEKB) have reached high luminosity ($>10^{34}$ cm^{-2} s^{-1}) but, to increase L of ~ 2 orders of magnitude, parameters need to be pushed to uncomfortable limits:

  - Very high currents
    - *overheating, instabilities*
    - *power costs*
    - *detector backgrounds increase*
  - Very short bunches (low β_y*)
    - *RF voltage increases*
    - *costs, instabilities*
  - Crab cavities for head-on collision
    - *KEKB experience not very positive*

Difficult and costly operation

A new idea for L increase (LPA & CW)

P.Raimondi, 2° SuperB Workshop, March 2006

P.Raimondi, D.Shatilov, M.Zobov, physics/0702033

Principle: beams more focused at IP + "large" crossing angle (LPA) + 2 sextupoles/ring to "twist" the beam waist at the IP (CW)

- Ultra-low emittance
- Very small β^* at IP
- Large crossing angle
- "Crab Waist" transformation
- Small collision area
- NO parasitic crossings
- NO x-y-betatron resonances

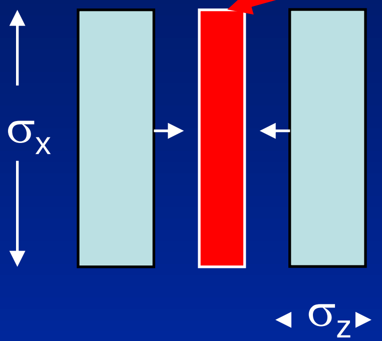
Proved to work at upgraded DAΦNE Φ-Factory 2008-2009

Large crossing angle, small x-size

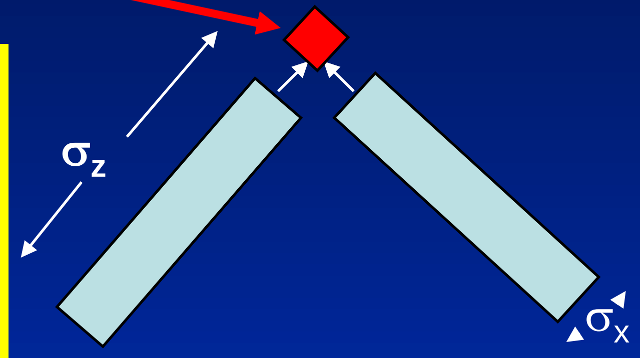
1) Head-on, Short bunches

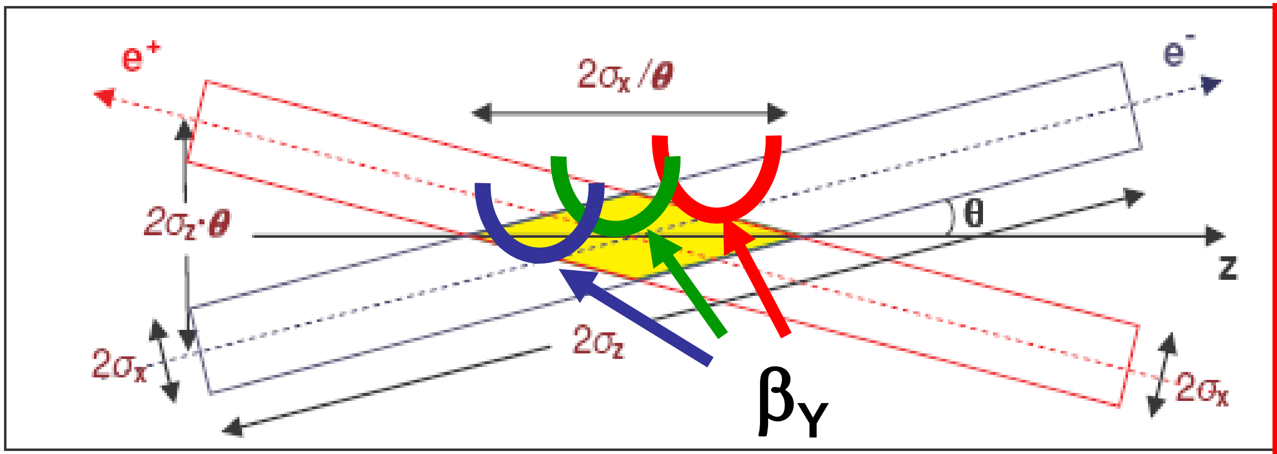
Overlap region

2) Large crossing angle, long bunches



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





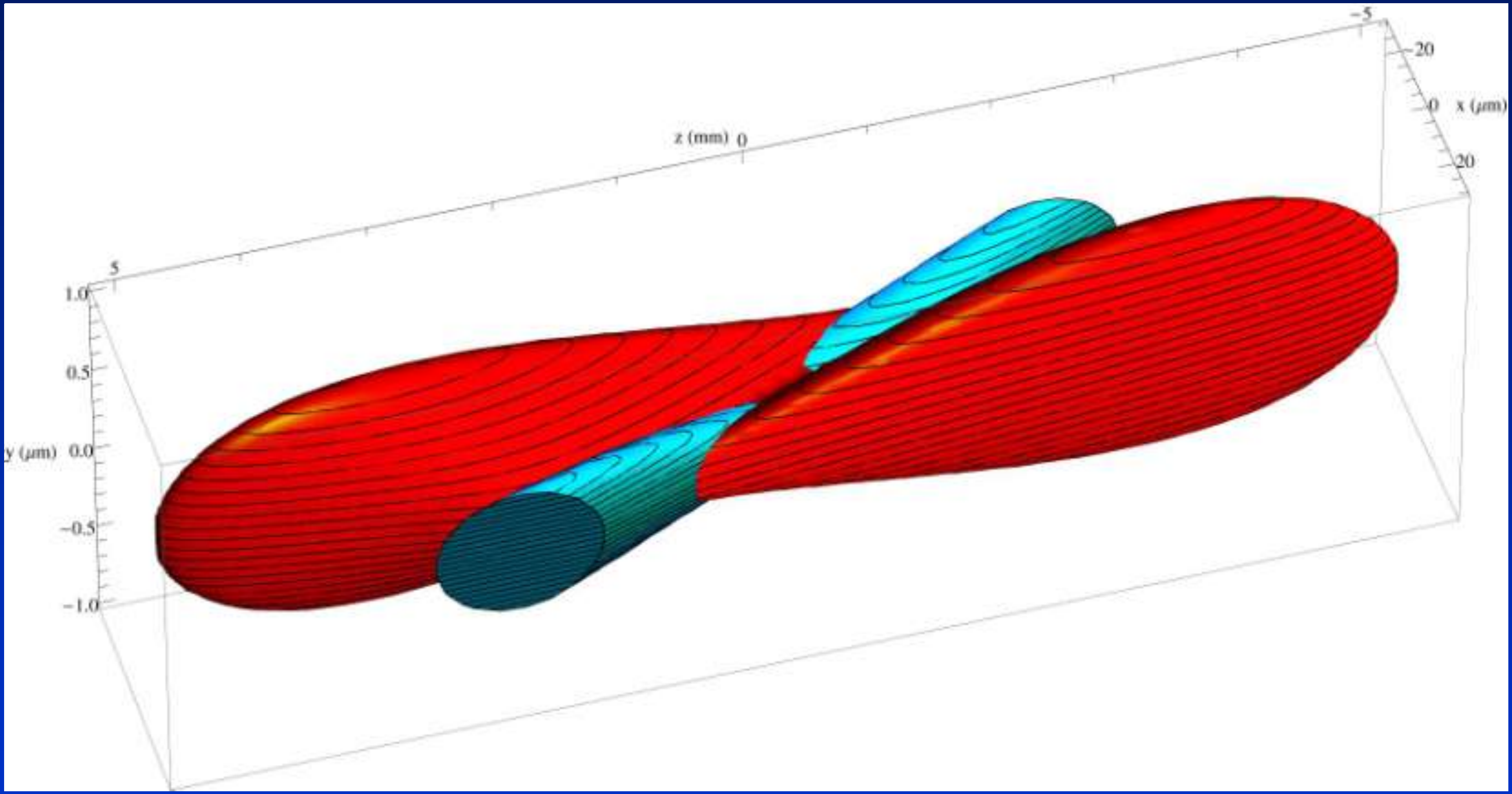
y waist can be moved along z with a sextupole on both sides of IP at proper phase

"Crab Waist"

Crab-waist scheme

Raimondi, Shatilov, Zobov
http://arxiv.org/abs/physics/0702033

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 ß do not see full field of other beam**
- **no excessive beam-beam parameter due to hourglass effect**

Advantages

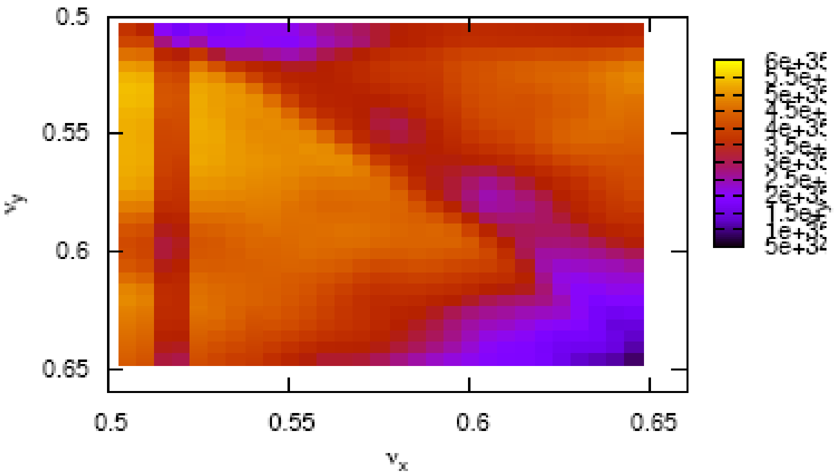
- Larger operational space in tunes plane
- Higher luminosity with about substantially lower currents and shorter bunch lengths:
  - Beam instabilities are less severe
  - No excessive power consumption
- Lower beam-beam tune shifts
- Parasitic collisions becomes negligible due to higher crossing angle and smaller σ_x

Strong-strong bb simulations

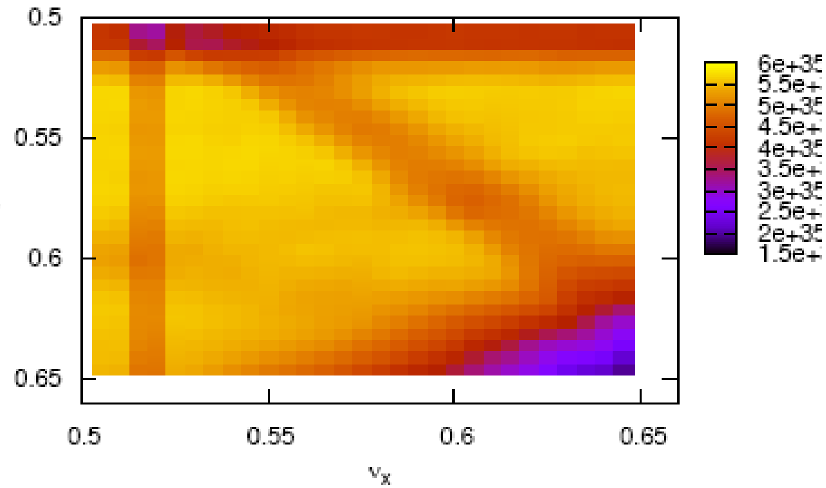
K. Ohmi

Tune scan with/without crab waist

No crab waist



crab waist

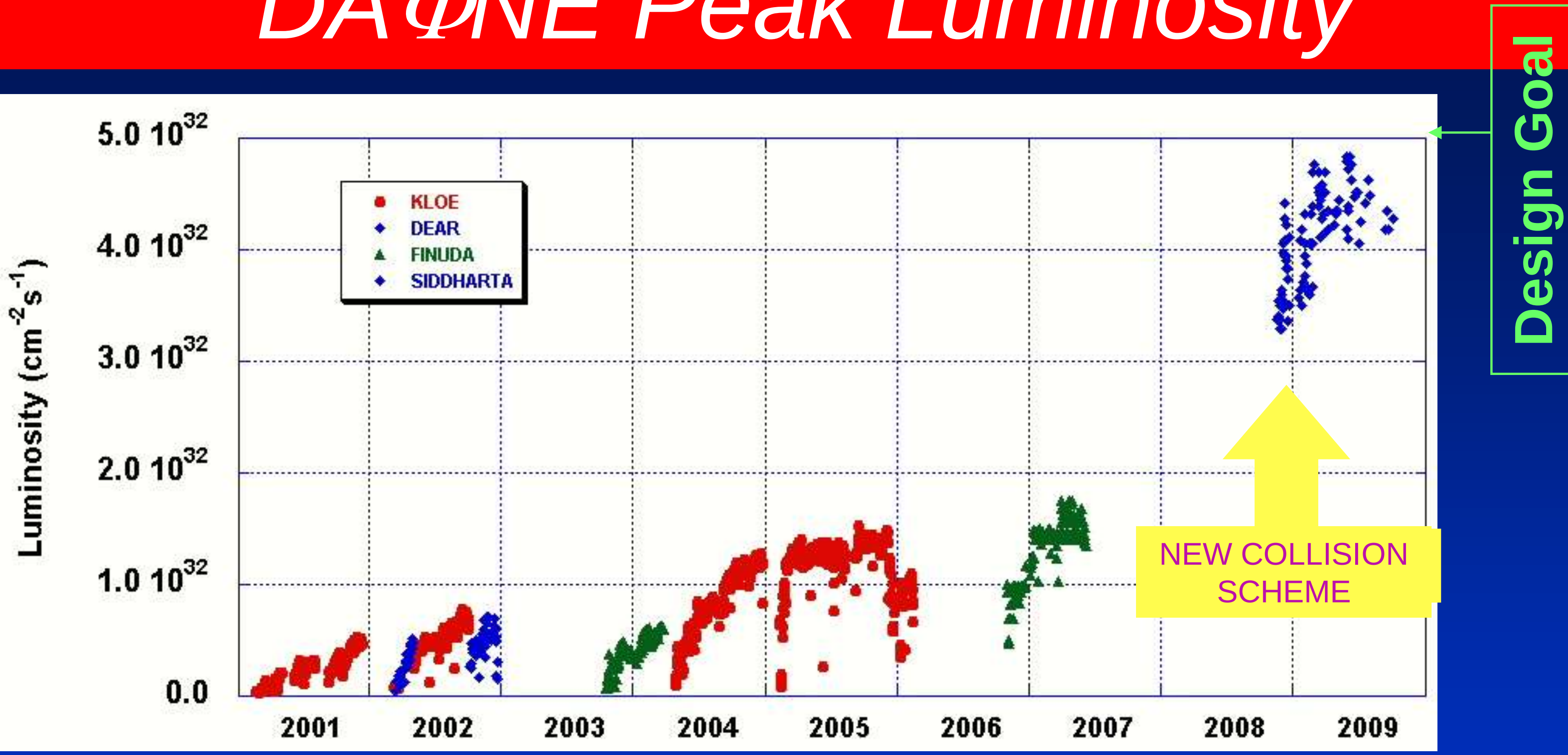


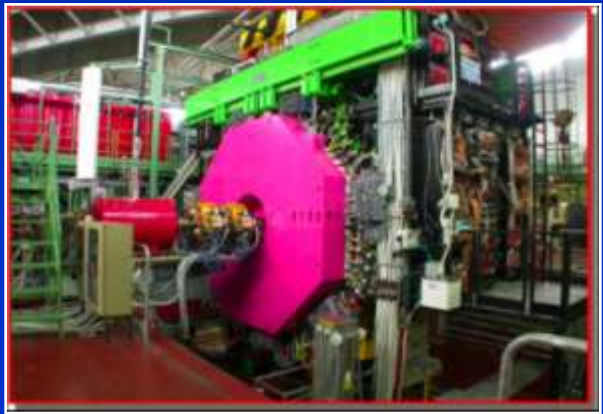
- Crab waist gives better performance.
- Synchro-beta resonance is seen in both cases.

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 impedence 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





SuperB design

- The design requires state-of-the-art technology for emittance and coupling minimization, vibrations and misalignment control, instabilities control, 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/1009.6178v3

Parameter Table

Parameter	Units	Base Line HER (e+)	Base Line LER (e-)	Low Emittance HER (e+)	Low Emittance LER (e-)	High Current HER (e+)	High Current LER (e-)	Tau/Charm (prelim.) HER (e+)	Tau/Charm (prelim.) 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)	mrad	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 10^{35}

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

Baseline:
- **Higher emittance due to IBS**
- **Asymmetric beam currents**

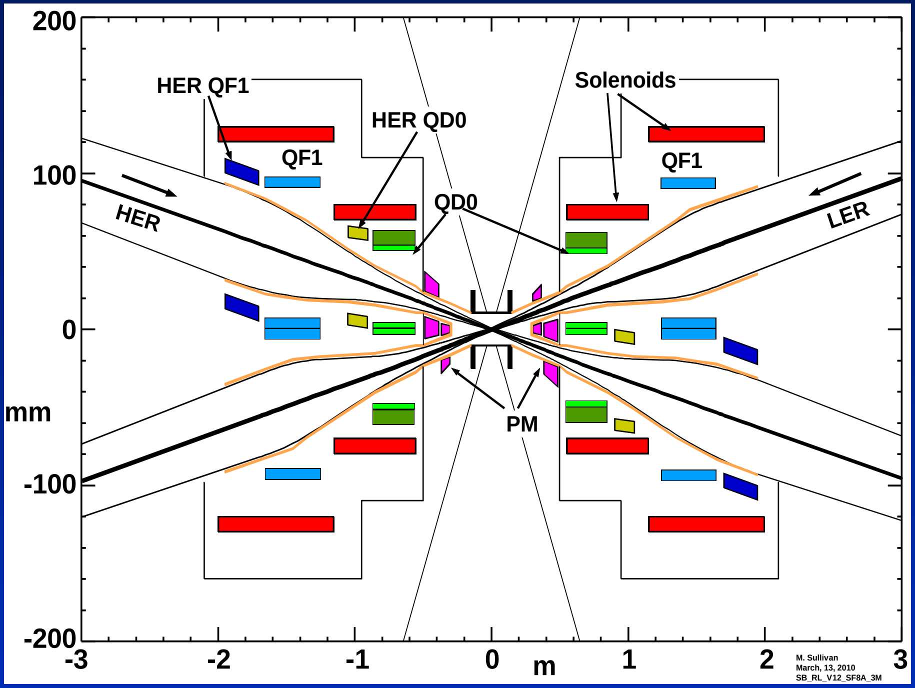
RF power includes SR and HOM

Interaction Region

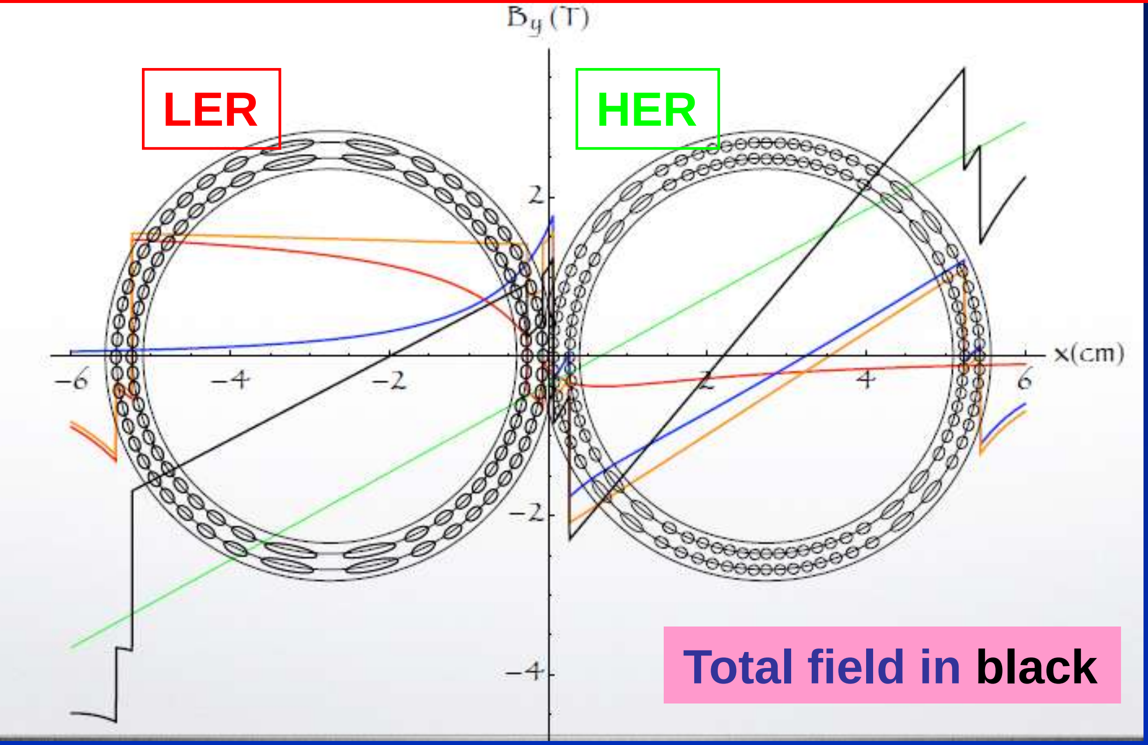
- The Interaction Region must satisfy both machine and detector requirements:
  - Final Focus elements as close as possible to the IP
  - Small detector beam pipe
  - Enough beam stay clear → small emittance helps
  - Control Synchrotron Radiation backgrounds
  - Magnet vibrations need to be damped (at the level of 10nm)
  - A state-of-the-art luminosity feedback is needed

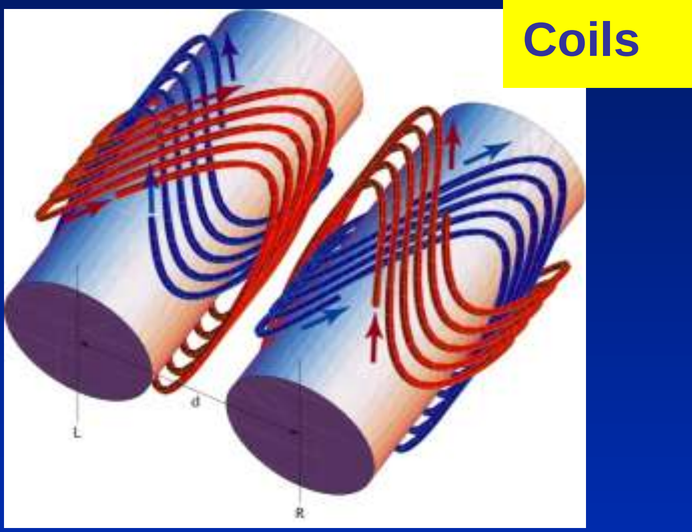
IR Magnets

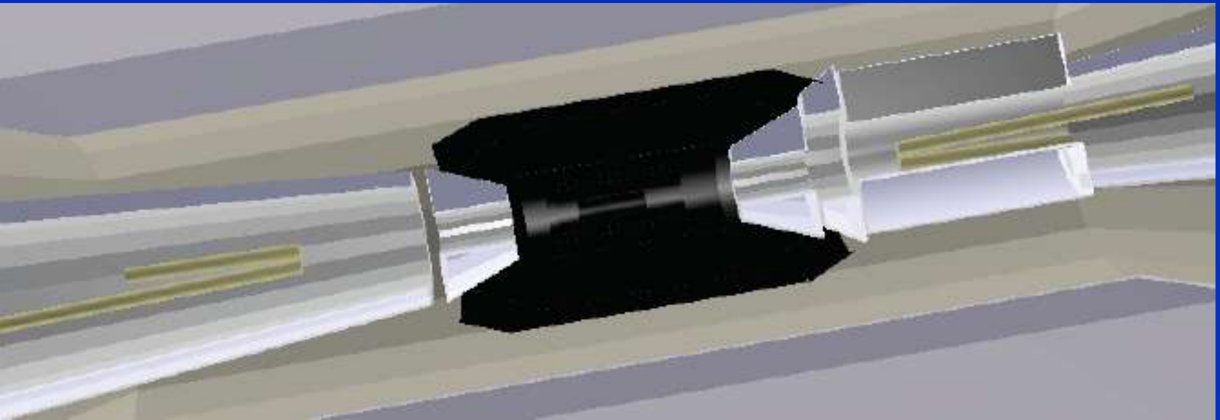
- Up to now at least one IP quadrupoles was shared by the two beams
- With the large crossing angle the beam is off-axis in the quadrupole
- This beam is not only focused but also bent, so producing unwanted SR backgrounds and emittance growth
- For SuperB we are developing a new design of the first doublet with «twins» quadrupoles



R&D on SC Quadrupoles at the IP

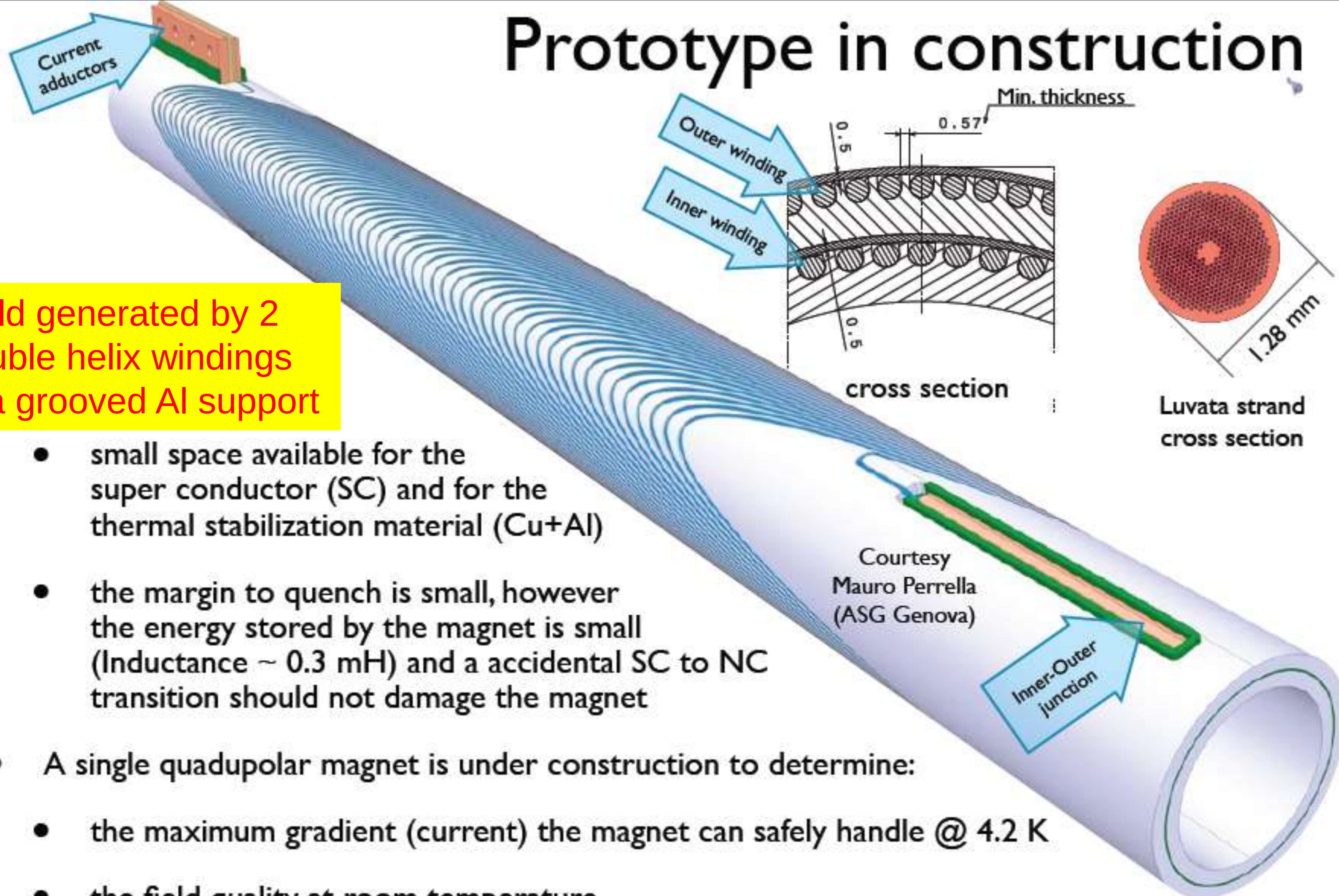






E. Paoloni (Pisa),
S. Bettoni (CERN)

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: Φ=1.28 mm, Cu/NbTi = 1.0, Ic 2450 A @ 4T, 4.2K

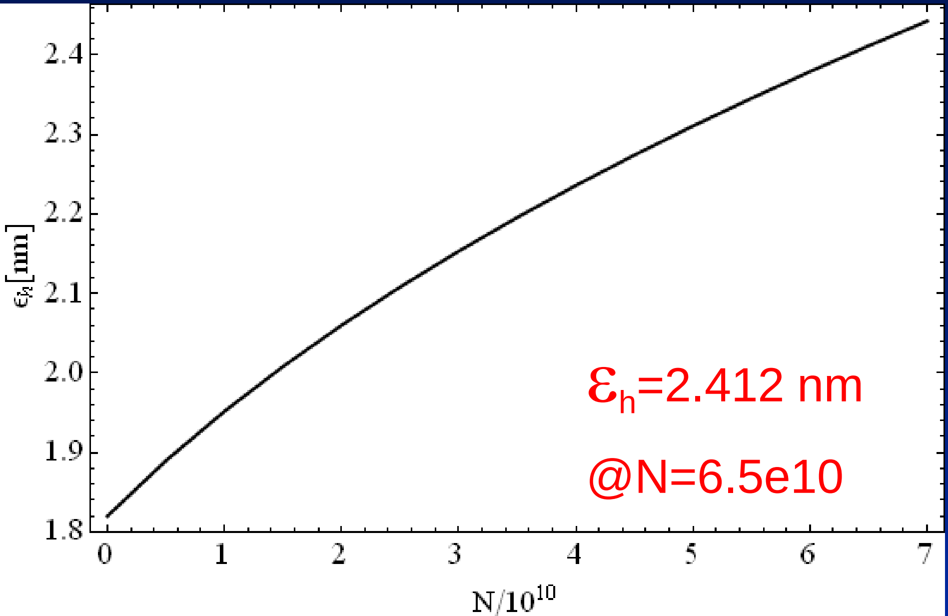
Fabbricatore, Farinon, Musenich (Genova) Paoloni (Pisa)

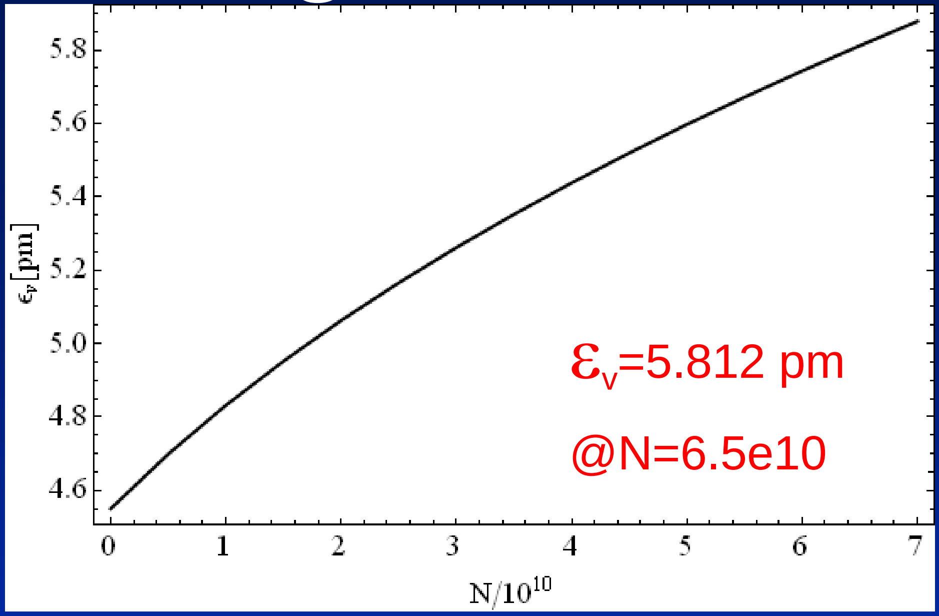
Collettive effects

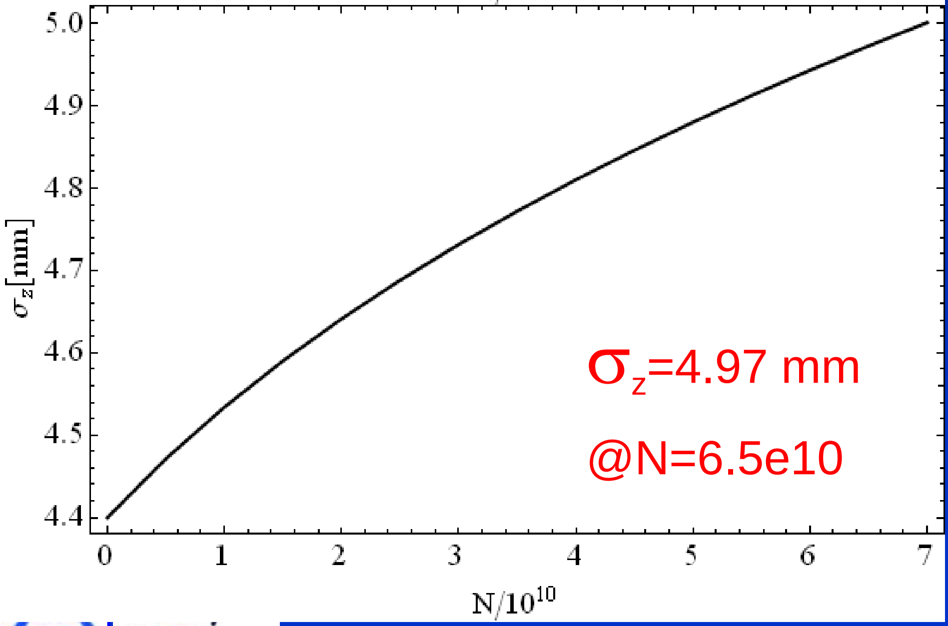
- Stored beams are subject to effects that can produce instabilities or degrade the beam quality, such as:
  - Intra-Beam-Scattering (IBS) inside the bunch produces emittance and energy spread growth
  - Electron-cloud instability limits the current threshold of the positron beam → needs mitigation methods (ex. solenoids, beam pipe coating, clearing electrodes...)
  - Fast Ions Instability is critical for the electron beam

- These effects need to be studied in detail

Intra Beam Scattering in LER







The effect of IBS on the transverse emittances is about 30% in the LER and less then 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 →6D MC

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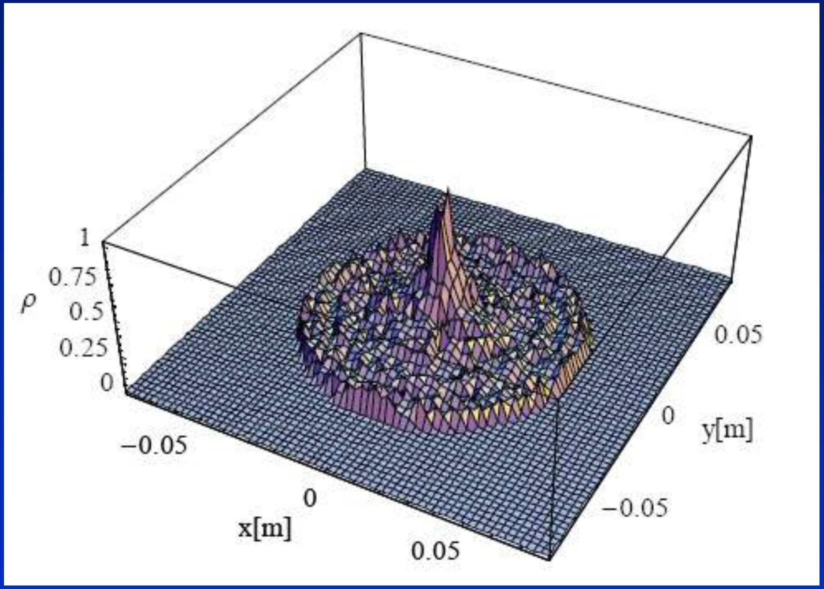
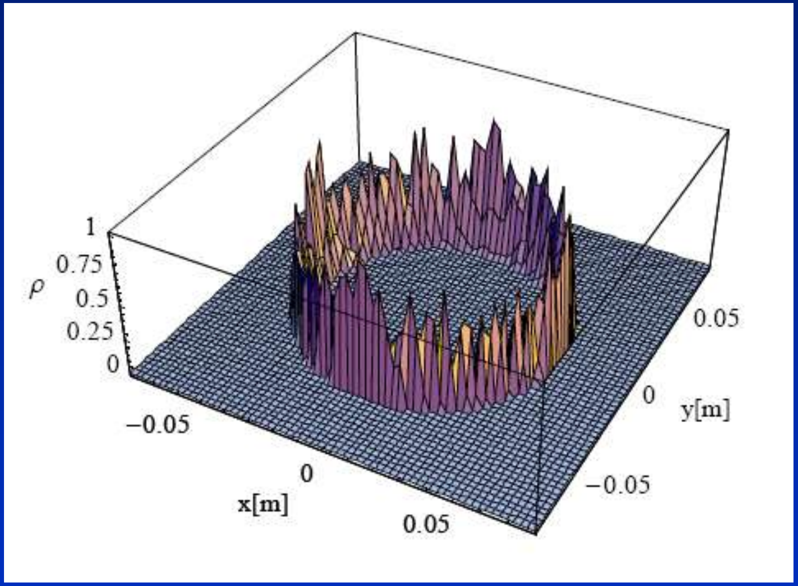
E-cloud build-up in Free Field Regions

Snapshot of the electron (x,y) distribution



Density at center of the beam pipe is larger then the average value.

Snapshot of the electron (x,y) distribution
50G solenoids on



Solenoids reduce to 0 the e-cloud density at center of beam pipe

Low emittance tuning

- The extremely low design beam emittance needs to be tuned and minimized → careful correction of the magnet alignment and field errors
- These errors produce emittance coupling with transfer of some horizontal emittance to the vertical plane → this needs to be minimized
- Beta-beating (ring β-functions are not as in the model machine, but are perturbed by the magnet errors) also needs minimization
- Vertical dispersion at IP needs to be corrected to the lowest possible value not to compromise luminosity

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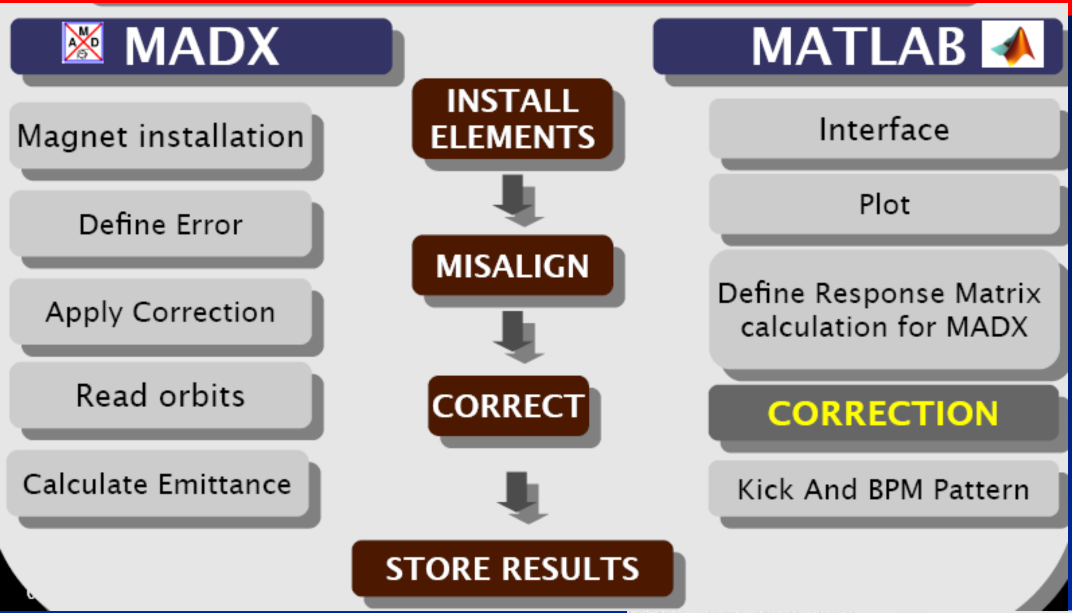
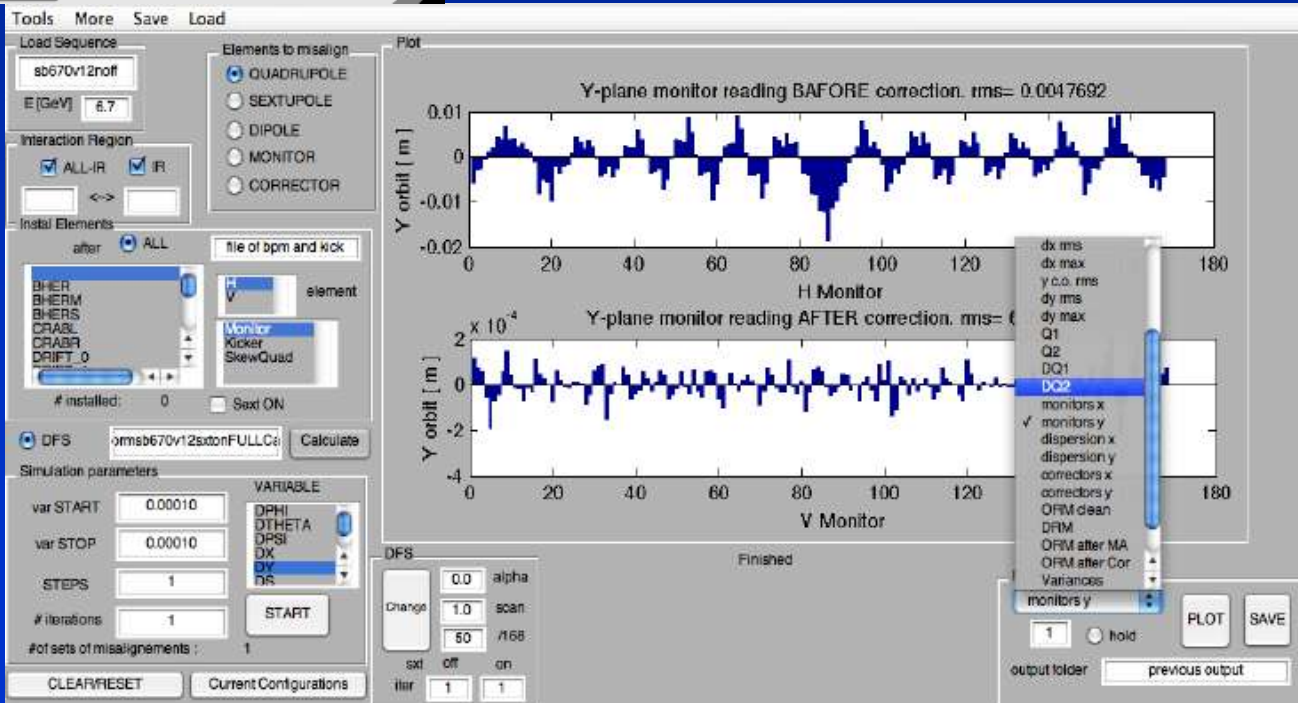
LET Tool



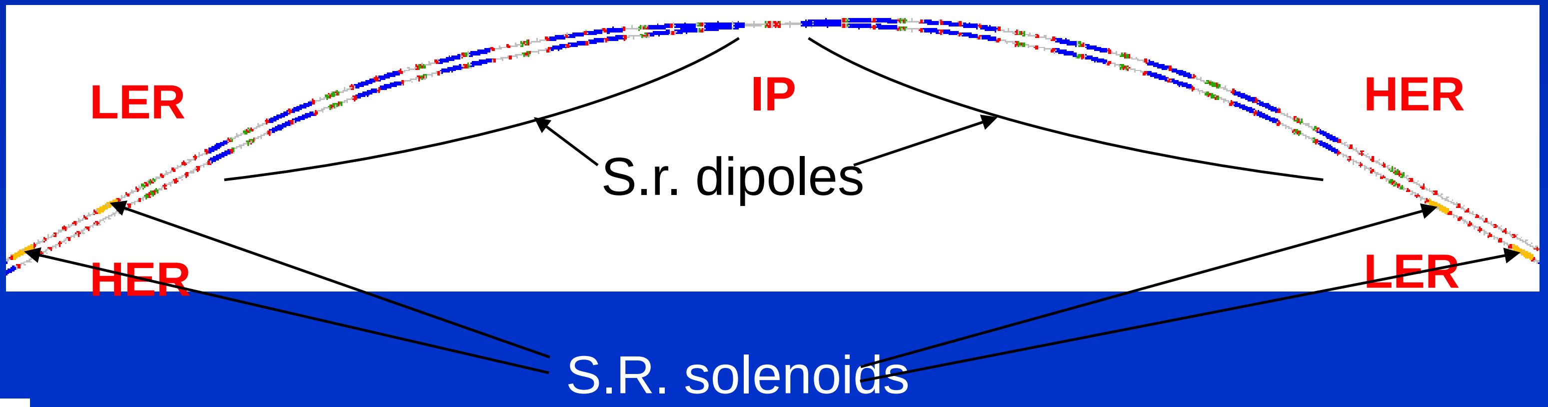
This tool has been successfully tested at Diamond (RAL) and SLS (PSI) synchrotron light sources,
which have similar emittances as SuperB.

This work allows to set tolerances on magnet alignment and once the machine is running is able to detect such errors for correction



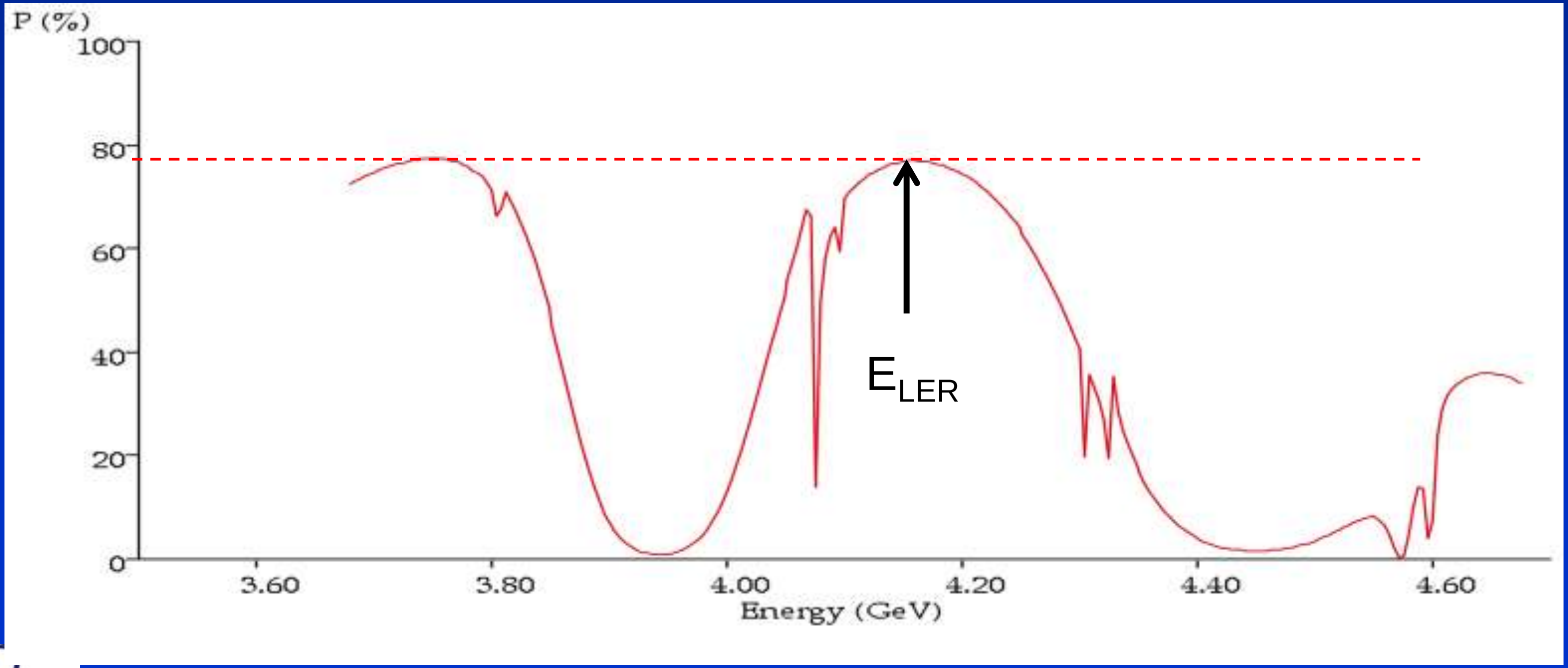
Polarization in SuperB

- 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

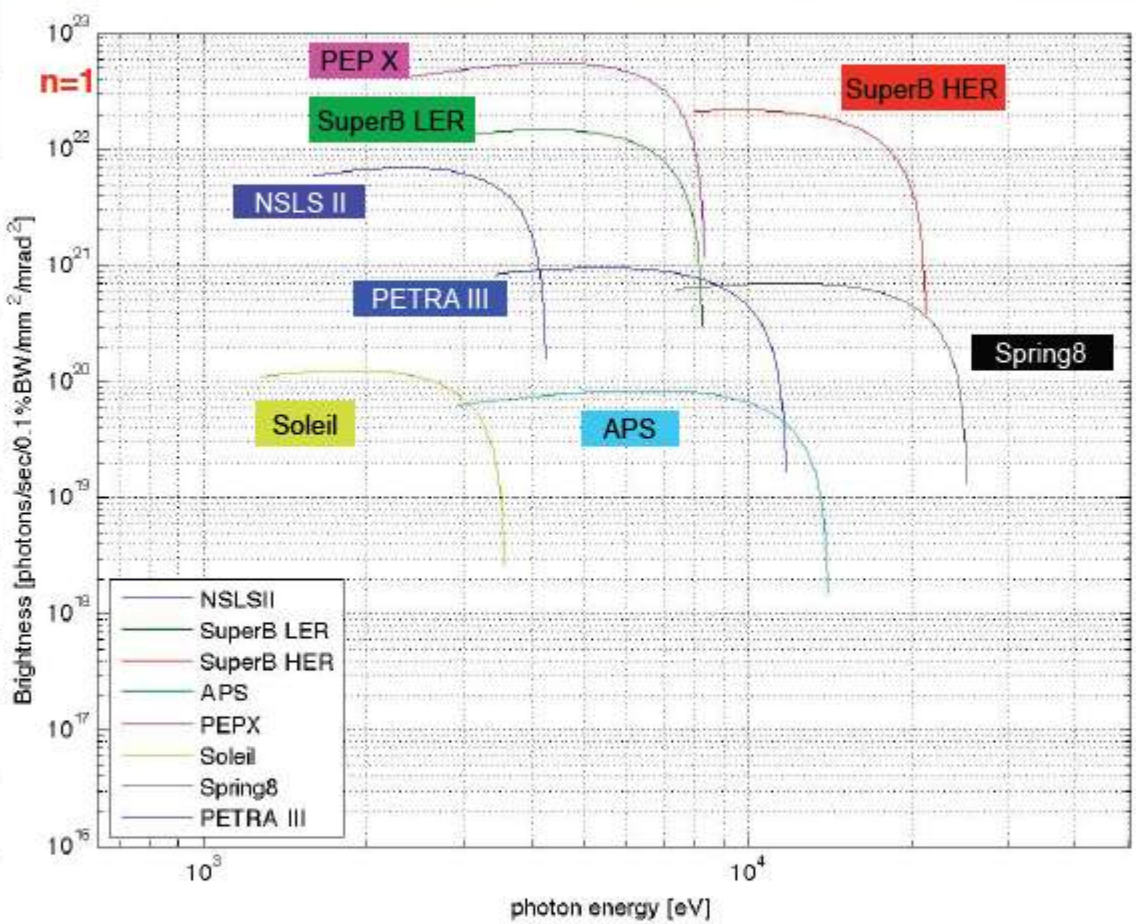
- Beam polarization resonances do constraint the beam Energy choice
- Plot shows the resonances in the energy range of LER
- Beam polarization computed assuming
  - 90% beam polarization at injection
  - 3.5 minutes of beam lifetime (bb limited)
- From this plot is clear that the best energy for LER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



Synchrotron light options @ SuperB

- Comparison of brightness and flux from undulators for different energies dedicated SL sources & SuperB HER and LER
- Light properties from undulators better than most SL

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

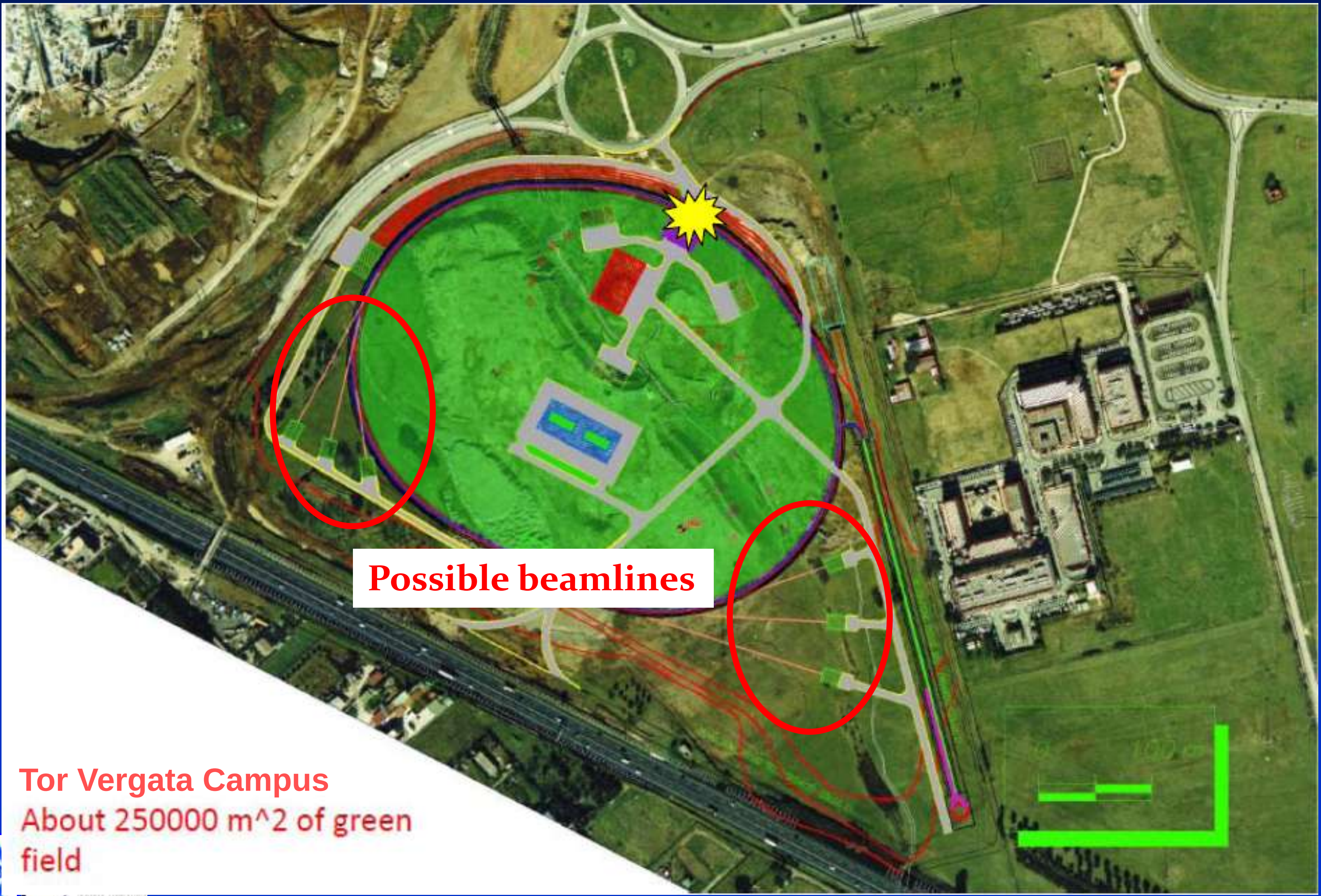


Brightness from undulators

SuperB layout

- Site chosen @ Tor Vergata University (Rome II) campus
- Sinchrotron Light (SL) beamlines are becoming part of the layout (HER preferred at the moment)
- One tunnel will host both rings, which will probably have a tilt one respect to the other, to allow for easier crossing and SL beamlines from both HER and LER (if needed)
- The position of the Linac complex has still to be finalized, depending on the injection requirements
- The rings layout has been recently improved to accomodate Insertion Devices (ID) needed for SL users

SuperB site @ Tor Vergata



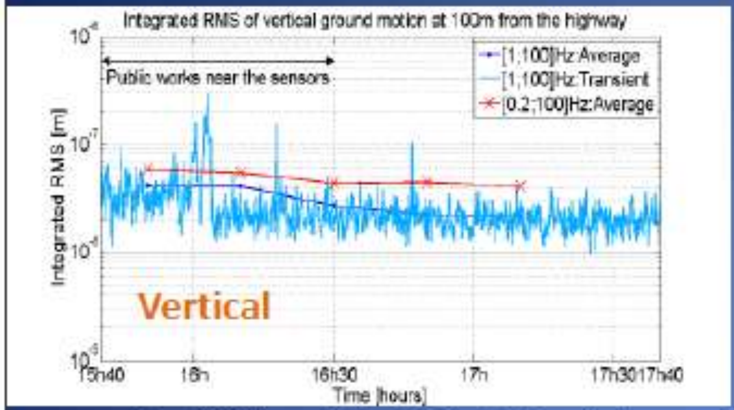
Tor Vergata Campus

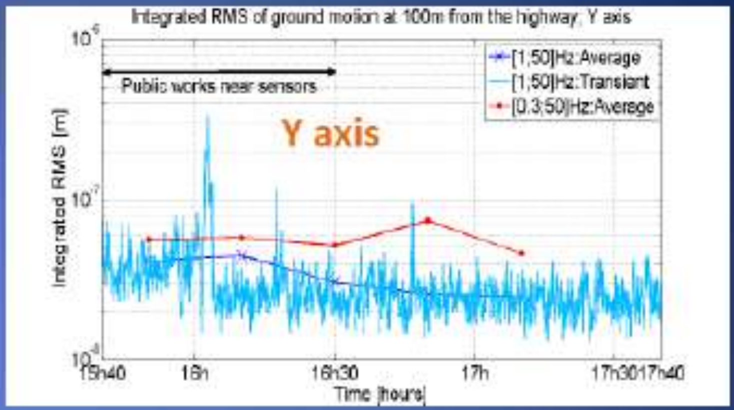
About 250000 m^2 of green field

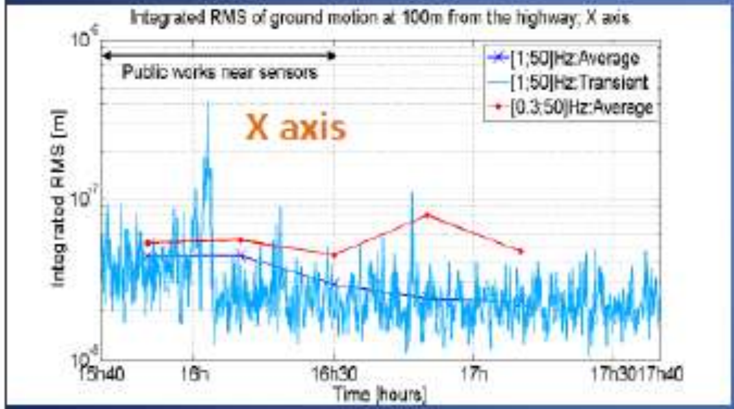
Vibrations measurements 100 m from highway

(B. Bolzon et al)

Integrated RMS of ground motion







- ✓ N.B: Public works near the measurement point from 15h40 to 16h30

- ✓ Except during the public works, ground motion very low: between 20nm and 30nm in the three directions!!
  - ➢ Vibrations of the highway well attenuated with the distance (100m)!!

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Conclusions

- LPA & CW scheme is promising to push forward the high luminosity frontier for storage rings colliders (tests on adapting an existing machine, DAΦNE, have been very successfull)
- *SuperB* parameters are being optimized around $1x10^{36}$ cm^{-2} s^{-1}
- R&D activities are ongoing in cooperation with many laboratories/Institutions, taking into account their expertise in the field.
- A first contact with IIT has been established to explore the needs for the SL users

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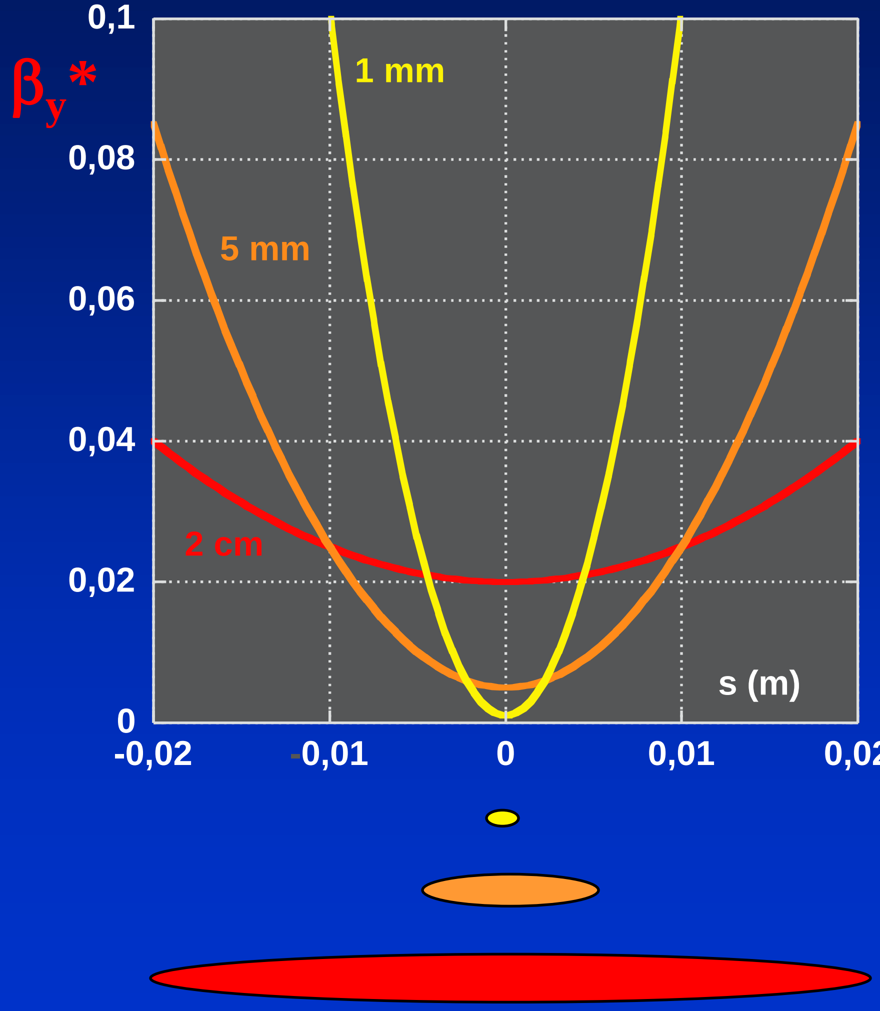
SPARE SLIDES

Hourglass effect

- To squeeze the vertical beam dimensions, 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, otherwise particles in the head and tail of the bunch will collide at a larger β_y.



Bunch length

Fast IP feedback

- IP feedback is essential to control beams at IP in order not to degrade luminosity and stabilize source beam at beamlines

- Two different approaches being considered:
  - extension of the fast Luminosity feedback at PEP-II using fast dither coils to induce a fairly high dither rate for the x position, the y position and the y angle at the IP. The luminosity signal is read out with three independent lock-in amplifiers. An overall correction is computed, based on the lock-in signal strengths, and beam corrections for x and y position and y angle at the IP are simultaneously applied to the beam
  - FONT5 intra-train feedback system developed for the ATF facility at KEK (P. Burrows et al), aiming at stabilizing the beam orbit by correcting both the position and angle jitter in the vertical plane on a bunch-to-bunch timescale, providing micron-level stability at the entrance to FF system

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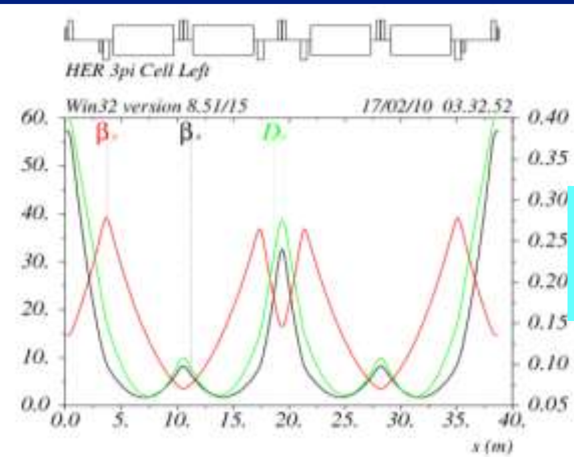
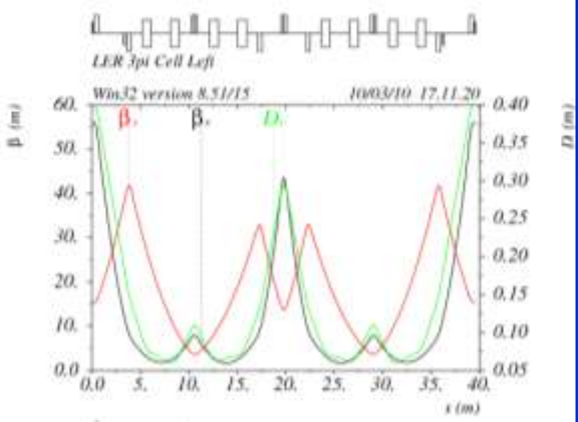
SuperB Arcs lattice

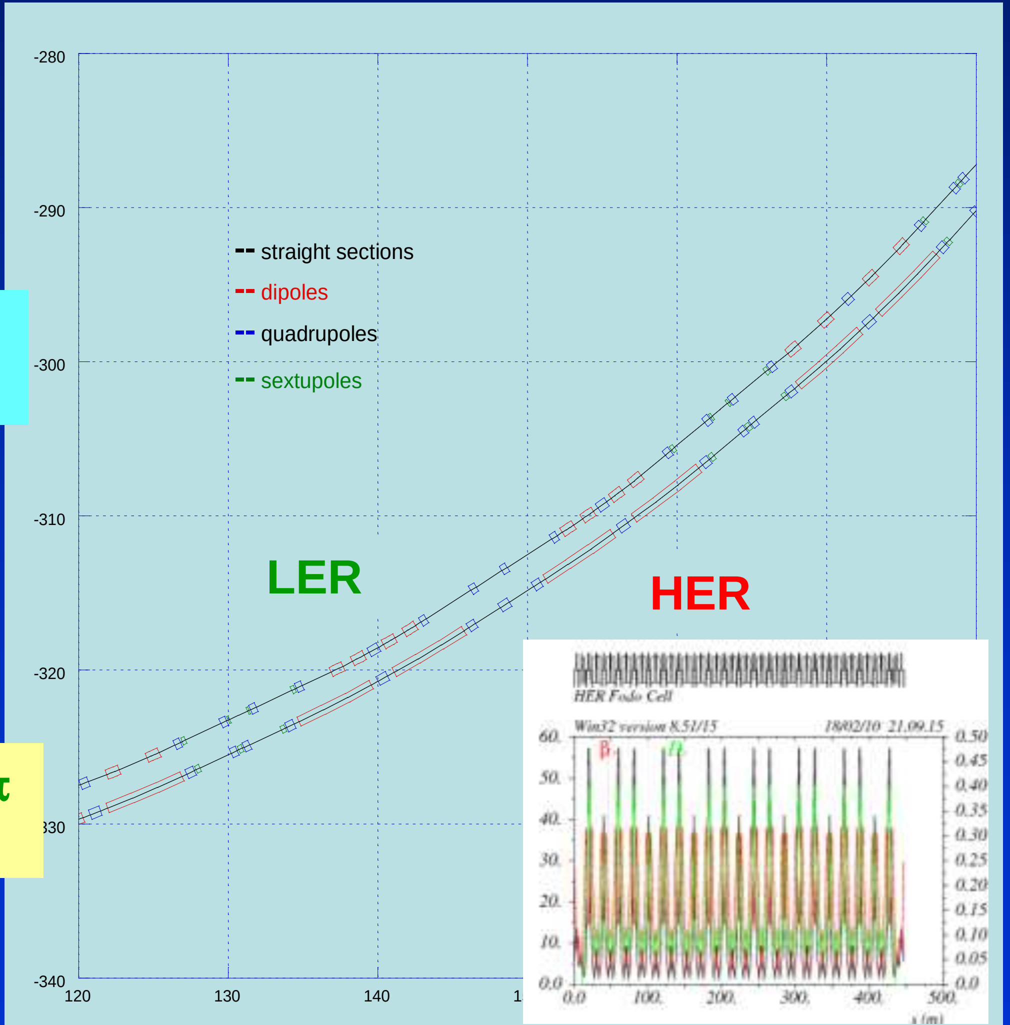
- HER and LER arcs have conceptually the same lattice. LER arc dipoles are shorter (bend radius about 3 times smaller) than in the HER in order to match the ring emittances at the asymmetric beam energies



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

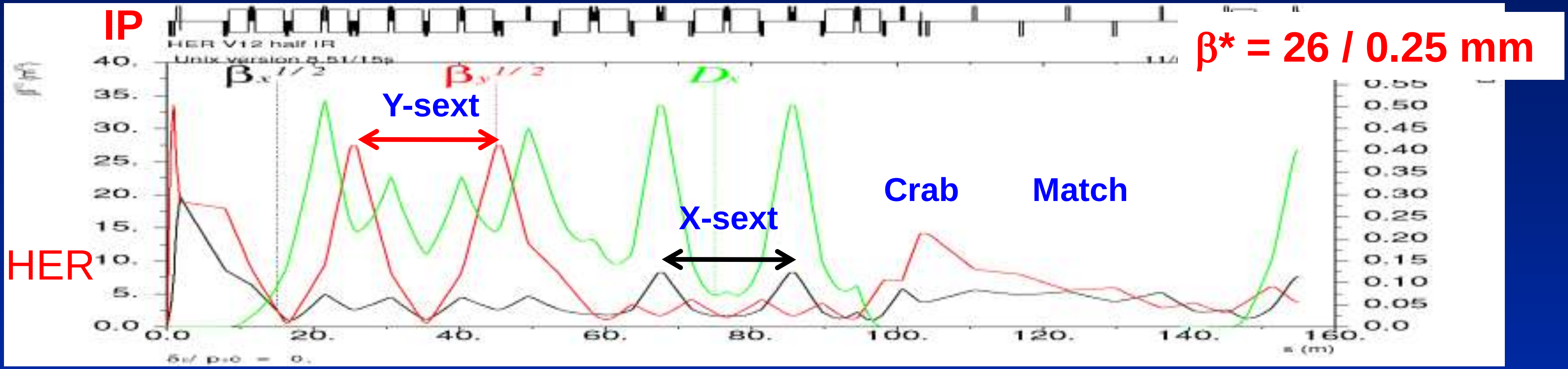


$\mu_x = 3\pi$, $\mu_y = \pi$
Cell in LER

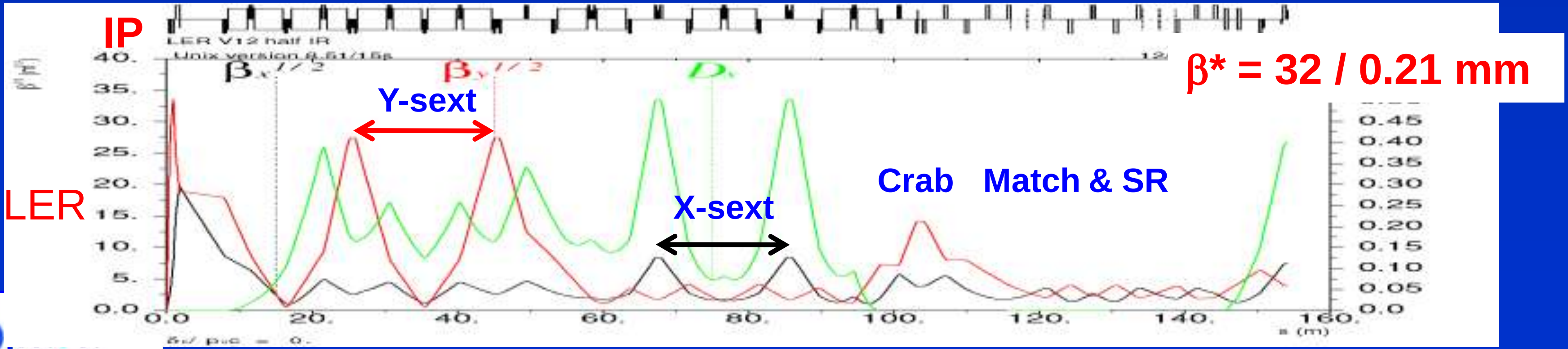


FF optics

- "Spin rotator" optics is replaced with a simpler matching section



- Matching section is shorter than HER to provide space for spin rotator optics.
- ±33 mrad bending asymmetry with respect to IP causes a slight spin mismatch between SR and IP resulting in ~5% polarization reduction.



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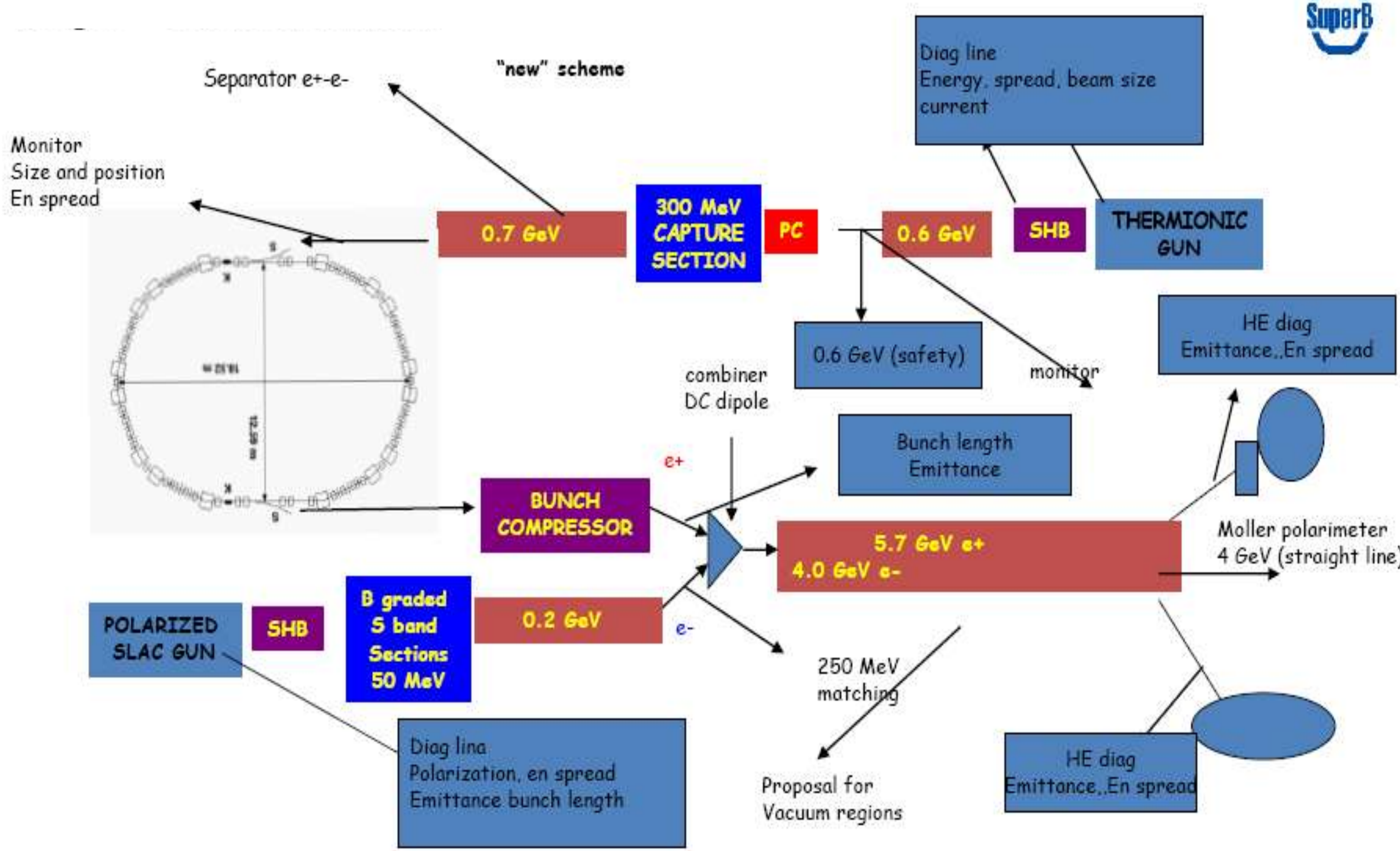
Injection complex scheme



Peak luminosity vs currents