SuperB Accelerator Status

M. Biagini
for the Super*B* Accelerator Team
SuperB Workshop LNF
LNF, Frascati, April 4-6, 2011

Present SuperB Accelerator Team

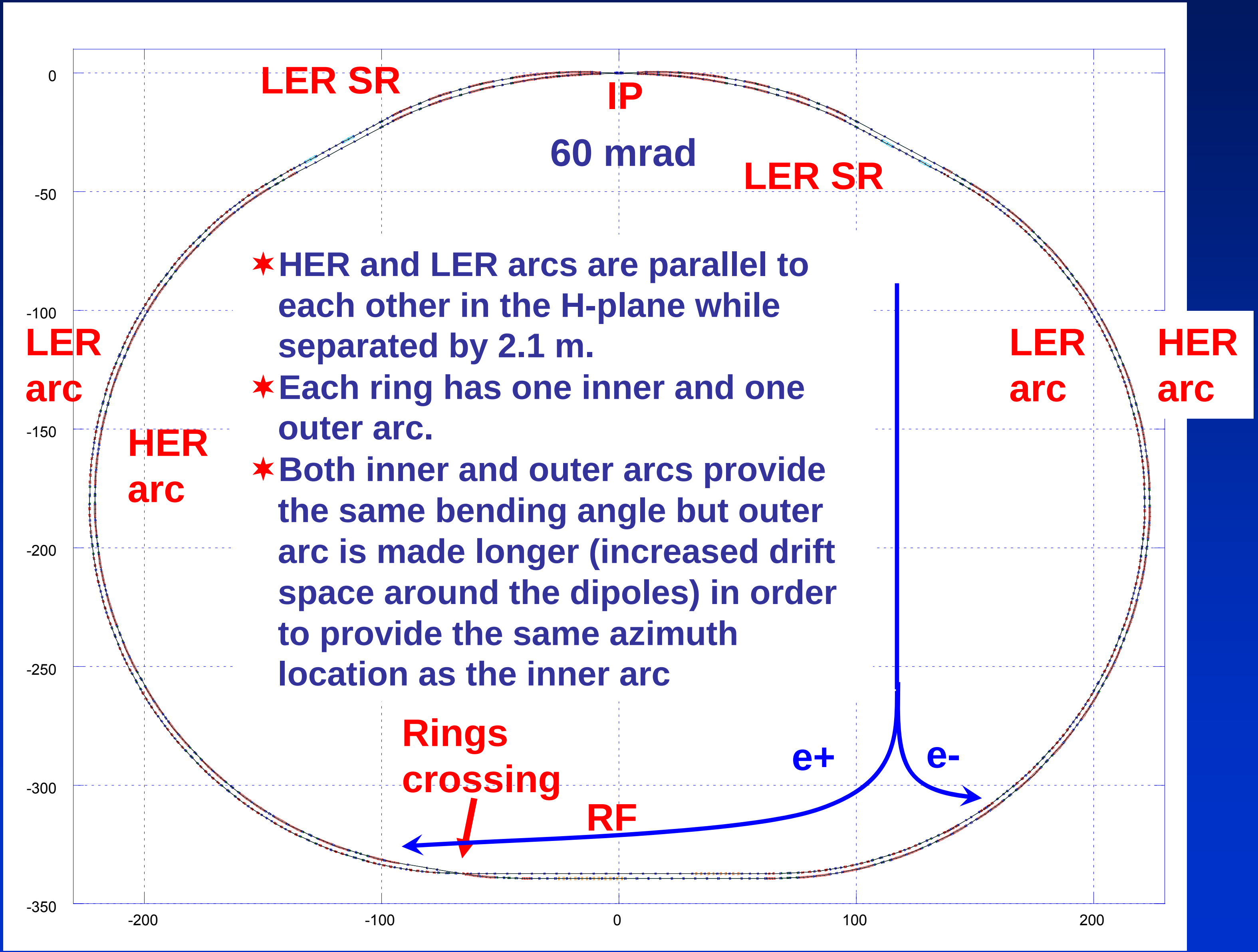
- M. E. Biagini, S. Bini, R. Boni, M. Boscolo, B. Buonomo, S. Calabro', T. Demma, E. Di Pasquale, A. Drago, M. Esposito, L. Foggetta, S. Guiducci, , S. Liuzzo, G. Mazzitelli, L. Pellegrino, M. A. Preger, P. Raimondi, R. Ricci, U. Rotundo, C. Sanelli, M. Serio, A. Stella, S. Tomassini, M. Zobov (LNF)
- K. Bertsche, A. Brachman, Y. Cai, A. Chao, R. Chestnut, M. H. Donald, C. Field, A. Fisher, D. Kharakh, A. Krasnykh, K. Moffeit, Y. Nosochkov, A. Novokhatski, M. Pivi, C. Rivetta, J. T. Seeman, M. K. Sullivan, S. Weathersby, A. Weidemann, J. Weisend, U. Wienands, W. Wittmer, M. Woods, G. Yocky (SLAC)
- A.Bogomiagkov, I. Koop, E. Levichev, S. Nikitin, I. Okunev, P. Piminov, S. Sinyatkin, D. Shatilov, P. Vobly(BINP)
- F. Bosi, E. Paoloni (INFN & University of Pisa)
- J. Bonis, R. Chehab, O. Dadoun, G. Le Meur, P. Lepercq, F. Letellier-Cohen, B. Mercier, F. Poirier, C. Prevost, C. Rimbault, F. Touze, A. Variola (LAL-Orsay)
- B. Bolzon, L. Brunetti, A. Jeremie (LAPP-Annecy)
- M. Baylac, O. Bourrion, J.M. De Conto, Y. Gomez, N. Monseu, D. Tourres, C. Vescovi (LPSC-Grenoble)
- A. Chancé (CEA-Saclay)
- D.P. Barber (DESY & Cockcroft Institute)
- S. Bettoni (PSI)
- P. Fabbricatore, R. Musenich, S. Farinon (INFN & University of Genova)
- Yuan Zhang (IHEP, Beijing) *NEW ENTRY*
- Hopefully soon: R.Bartolini, A. Seryi, A. Wolski et al… (John Adams & Cockcroft Institute)

SuperB Accelerator

- SuperB Progress Reports -- Accelerator updated in January:

  http://arxiv.org/abs/1009.6178v2
- Site still under study
- Layout will evolve following the site chosen & the new options (SR beamlines)
- Collaboration is growing but manpower recruitment is needed as soon as possible
- R&D on QD0 progressing very well
- More R&D starting (RF, beam-beam, SR beamlines layout…)

Layout V12, 1.25 Km



- HER and LER arcs are parallel to each other in the H-plane while separated by 2.1 m.
- Each ring has one inner and one outer arc.
- Both inner and outer arcs provide the same bending angle but outer arc is made longer (increased drift space around the dipoles) in order to provide the same azimuth location as the inner arc

Machine Parameters for 10^{36} cm^{-2} s^{-1}

- The IP and ring parameters have been optimized based on several constraints to maintaining wall plug power, beam currents, bunch lengths, and RF requirements comparable to present B-Factories

- Simplifying the IR design as much as possible. In particular, reduce the synchrotron radiation in the IR, reduce the HOM power and increase the beam stay-clear

- Relaxing as much as possible the requirements on the beam demagnification at the IP. Improved chromatic correction in arc cells

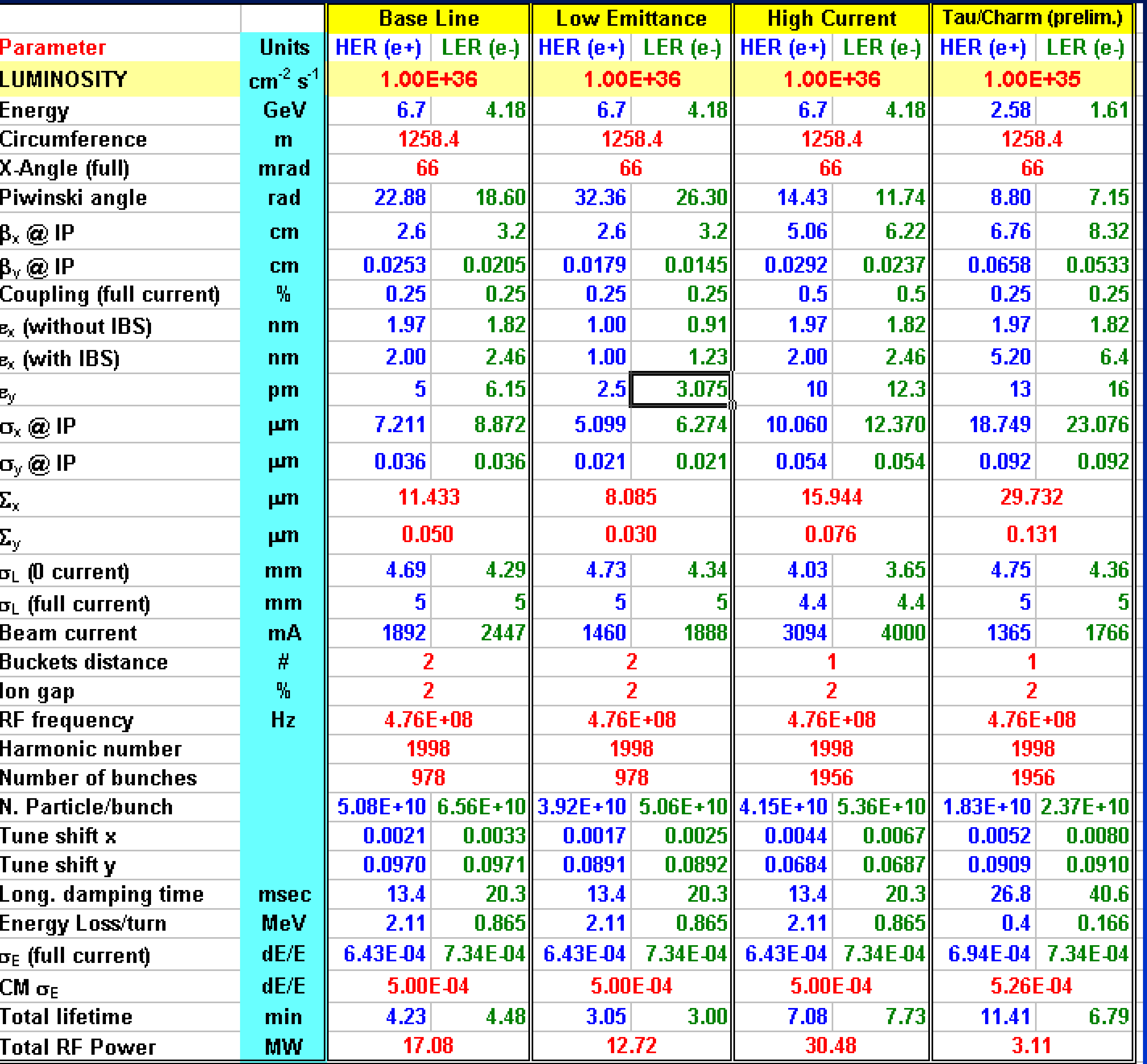
Flexibility for parameters choice

- 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 x1.6) over the baseline, when all the available PEP-II RF units are installed

Parameters list



		Base Line		Low Emittance		High Current		Tau/Charm (prelim.)	
Parameter	Units	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)	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)**

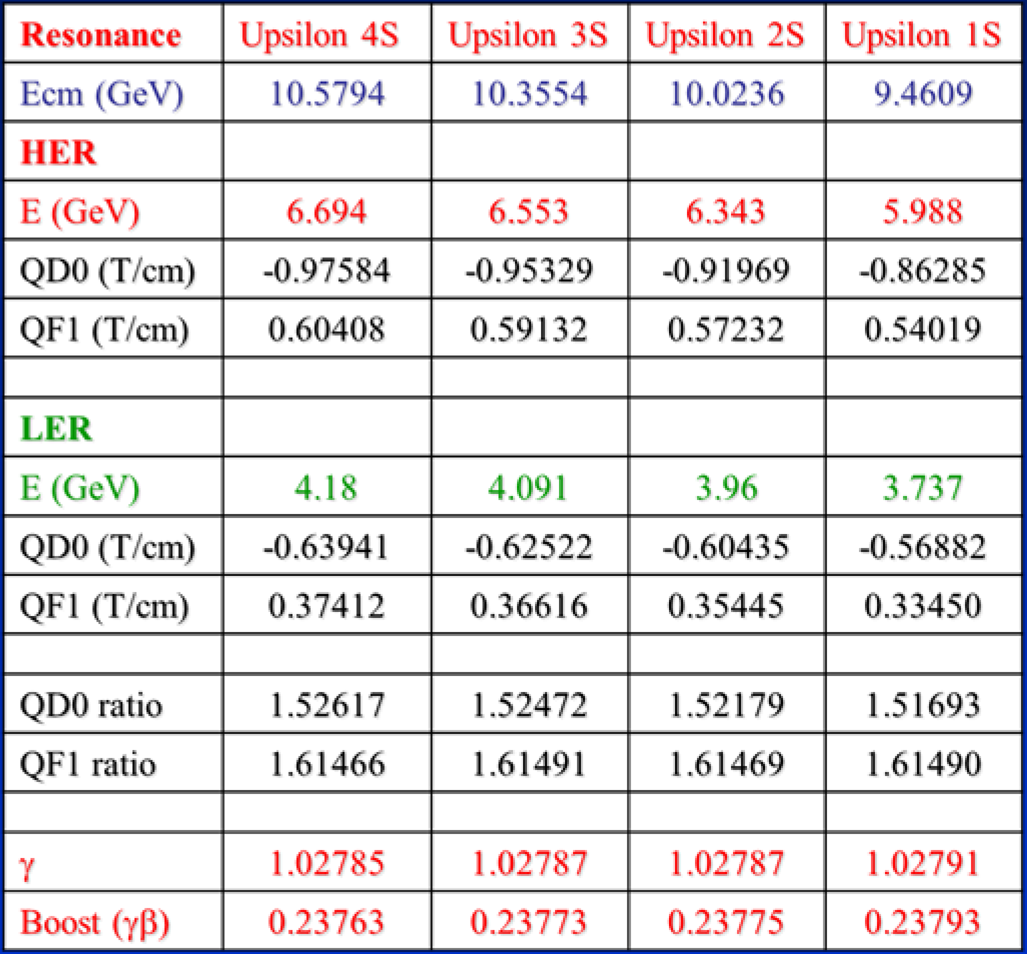
Baseline:
- **Higher emittance due to IBS**
- **Asymmetric beam currents**

RF power includes SR and HOM

Energy scan

Sullivan

- Change center of-mass energy while maintaining the same magnetic field strength ratio for QD0 and QF1
- Can get to all of the Upsilon resonances Υ(1S)…Υ (5S)
- Can scan the center-of-mass energy above the Υ(4S) without removing or changing any of the permanent magnets
- Have to remove most if not all of the permanent magnets for Tau-charm energy region



Resonance	Upsilon 4S	Upsilon 3S	Upsilon 2S	Upsilon 1S
Ecm (GeV)	10.5794	10.3554	10.0236	9.4609
HER				
E (GeV)	6.694	6.553	6.343	5.988
QD0 (T/cm)	-0.97584	-0.95329	-0.91969	-0.86285
QF1 (T/cm)	0.60408	0.59132	0.57232	0.54019
LER				
E (GeV)	4.18	4.091	3.96	3.737
QD0 (T/cm)	-0.63941	-0.62522	-0.60435	-0.56882
QF1 (T/cm)	0.37412	0.36616	0.35445	0.33450
QD0 ratio	1.52617	1.52472	1.52179	1.51693
QF1 ratio	1.61466	1.61491	1.61469	1.61490
γ	1.02785	1.02787	1.02787	1.02791
Boost (γβ)	0.23763	0.23773	0.23775	0.23793

Beam-beam

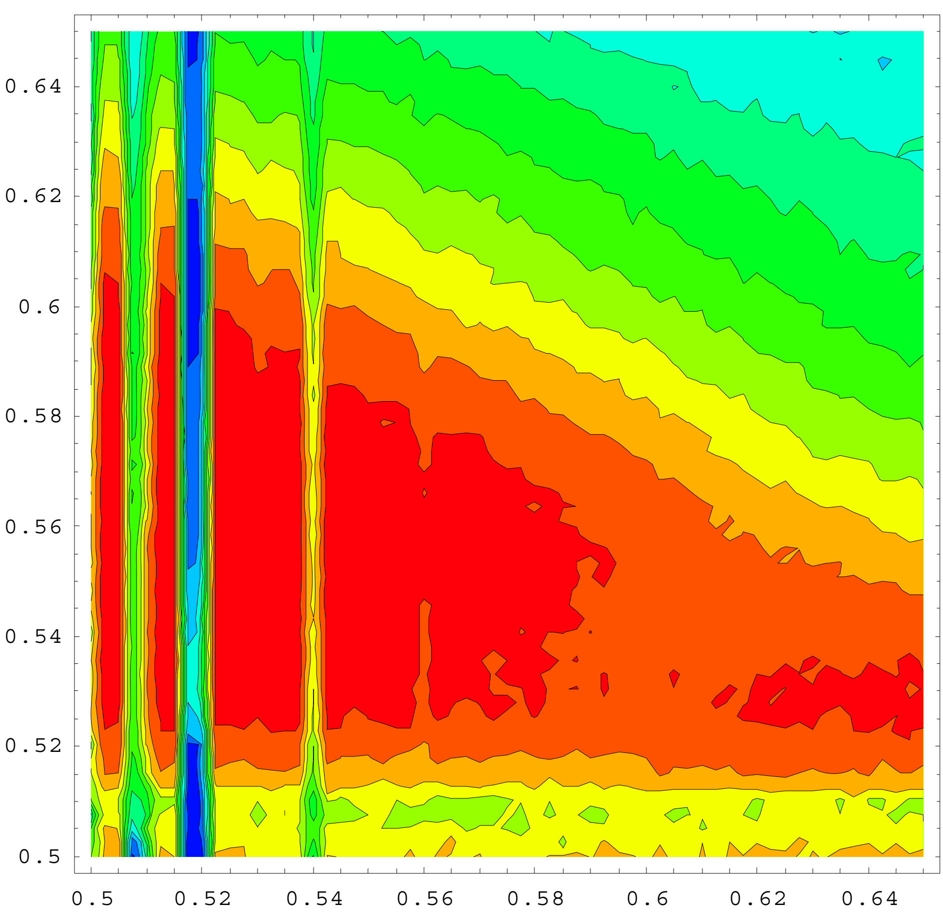
Shatilov

- Beam-beam tune scan performed with latest beam parameters (V12) and latest beam beam code, improved to take into account crabbed beams
- 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

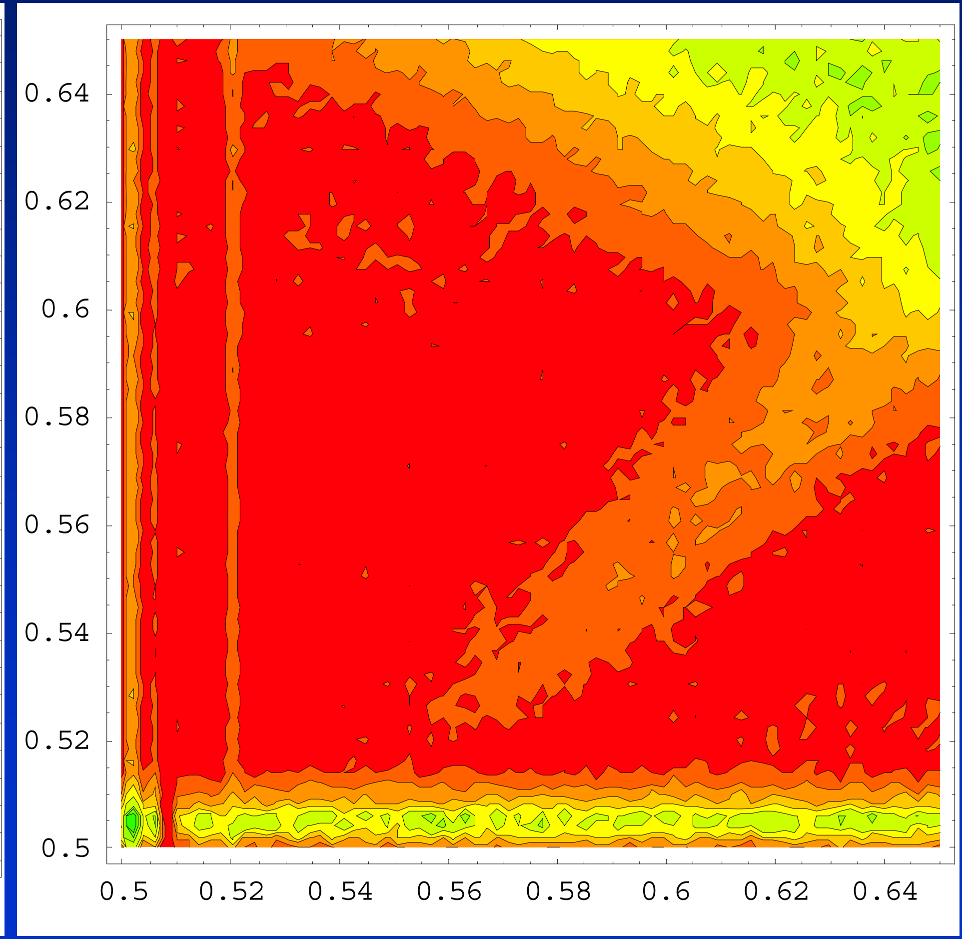
Beam-beam tune scan

Shatilov

CDR, $\xi_y = 0.17$



CDR2, $\xi_y = 0.097$

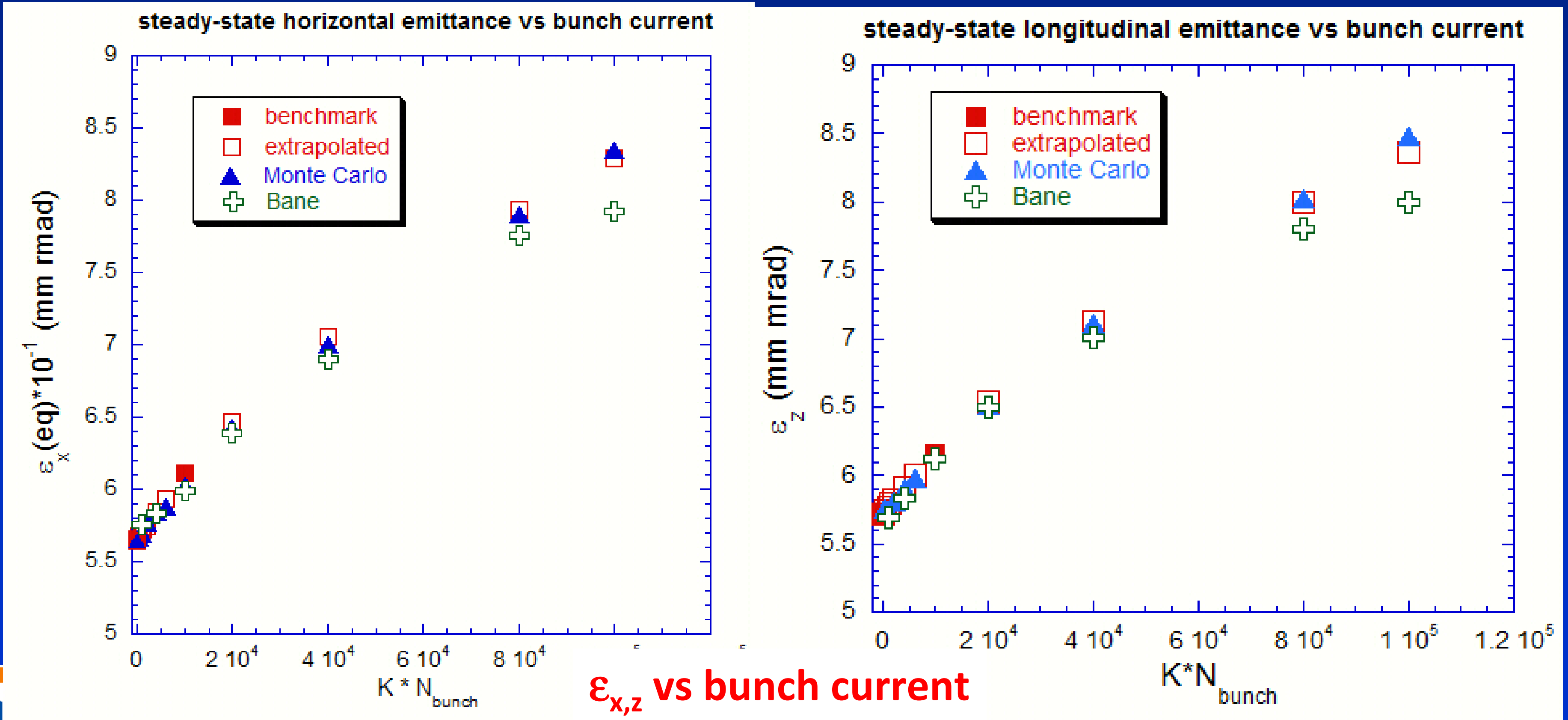


L (red) = 1. $\cdot 10^{36}$

Intra Beam Scattering

Boscolo, Chao, Demma

- 3 methods used, all in good agreement:
  - Bane (theoretical), allows for emittance growth rates estimate
  - Chao (theoretical), allows for emittance time evolution estimate
  - 6D MonteCarlo → more accurate, all of above, will include non-gaussian tails, soon to be translated from Mathematica to Fortran for speed and precision reasons (collaboration with M. Pivi, SLAC)



$\varepsilon_{x,z}$ vs bunch current

e-cloud instability

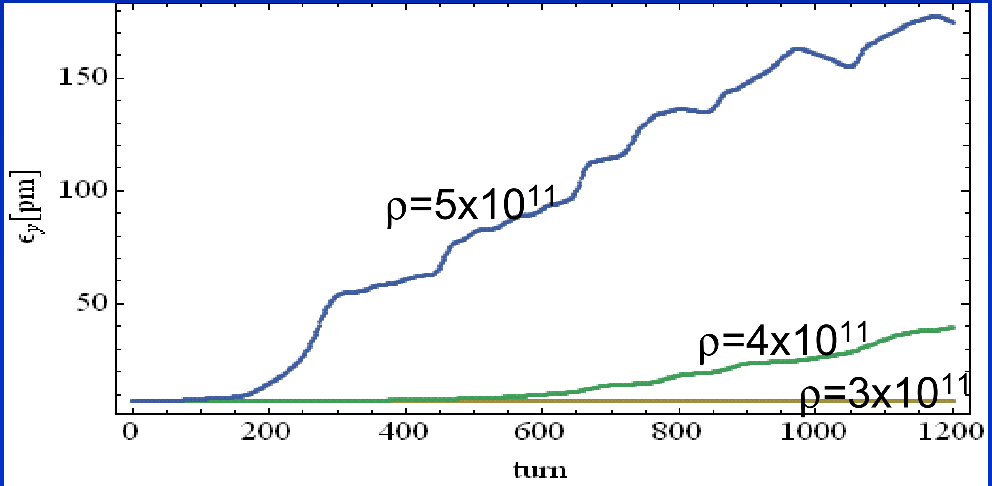
Demma, Pivi

- Single bunch instability simulations for SuperB HER (V12 and V13) taking into account the effect of solenoids have been performed using CMAD (M. Pivi). They indicate a threshold density of ~10^{12} e-/m^3 (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)

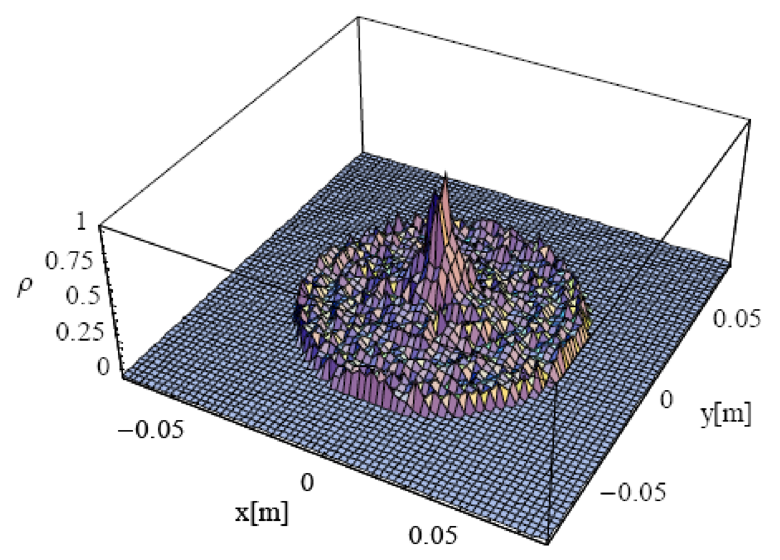
- Work is in progress to:
  - Estimate the effect of radiation damping on long term emittance growth
  - Estimate the fraction of synchrotron radiation absorbed by antechambers.

Vertical emittance growth induced by e-cloud



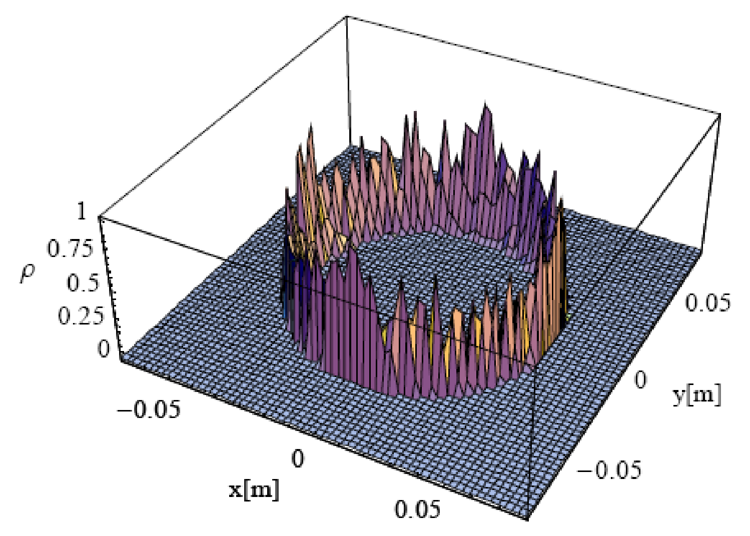
Build-up in Free Field Regions

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

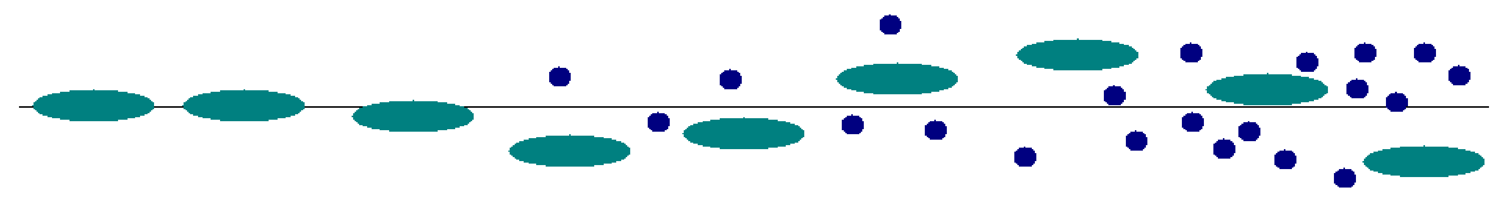


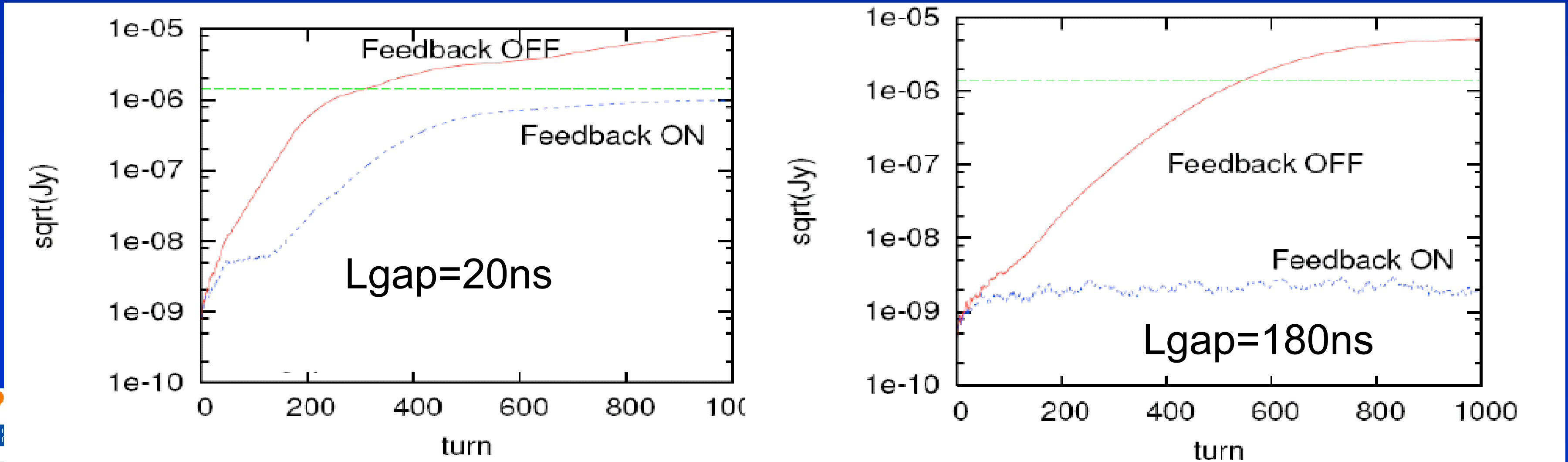
Solenoids reduce to 0 the e-cloud density at center of beam pipe

Fast Ion Instability

Demma

- Residual gas in the vacuum chamber can be ionized by the single passage of a bunch train
- The interaction of the electron beam with residual gas ions results in mutually driven transverse oscillations
- Ions can be trapped by the beam potential or can be cleared out after the passage of the beam
- Multi-train fill pattern with regular gaps is an efficient and simple way to cure FII
- Beam oscillations are suppressed by the feedback system for *Lgap ≥ 40 ns*, while considerable residual oscillation remains for *Lgap ≤ 20 ns*



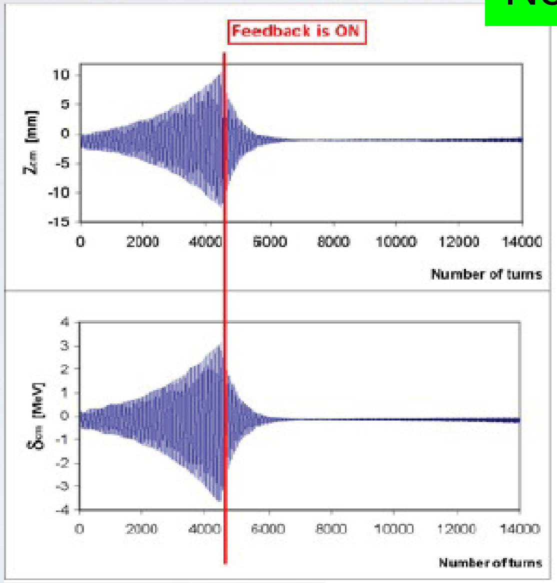


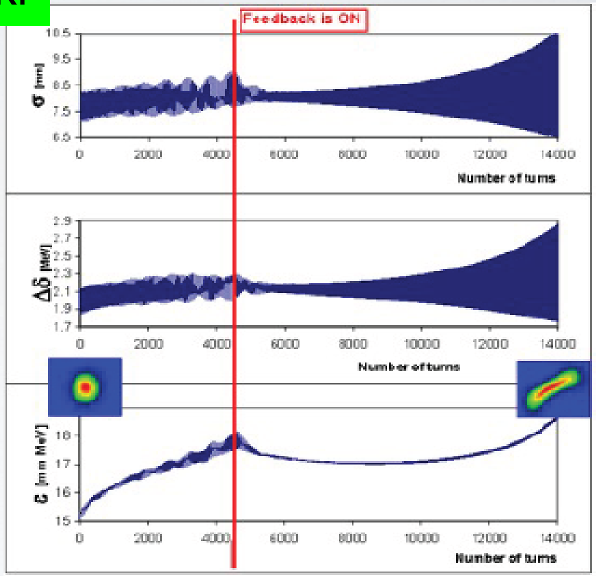
Second order momentum compaction studies

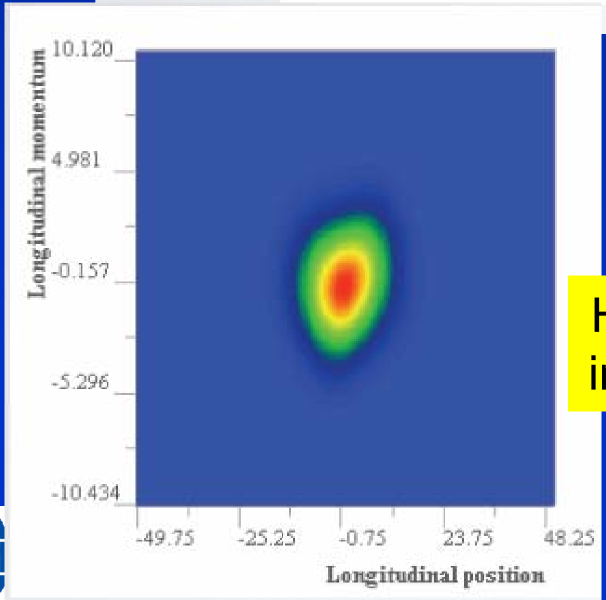
$$\alpha = \alpha_1 + \alpha_2\delta + \alpha_3\delta^2$$

If the energy loss decreases with bunch length we have an instability without any threshold for a positive sign of $\frac{\alpha_2}{\alpha_1}$

Novokhatski

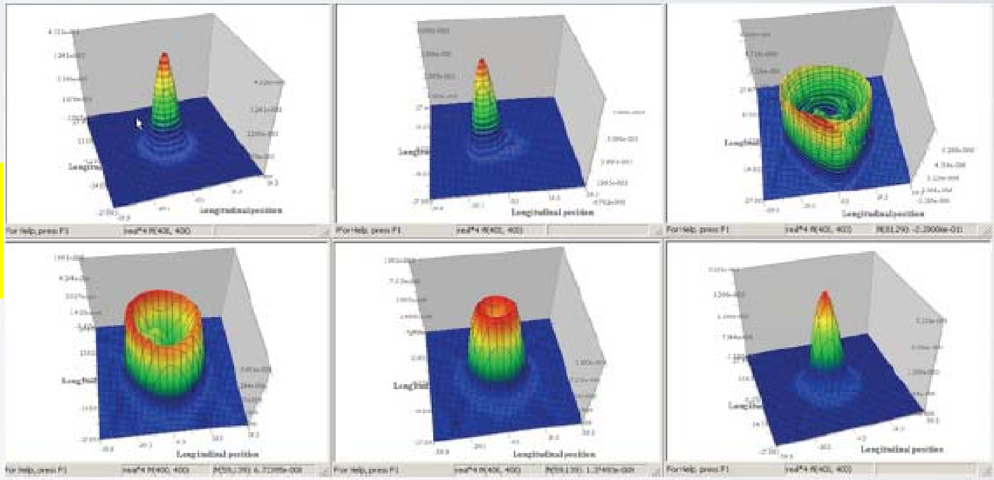






Head-tail instability

Saw tooth behavior



Low Emittance Tuning for LER

Liuzzo

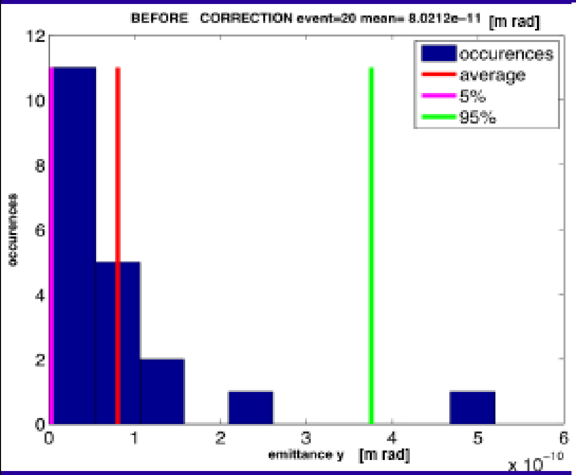
LER

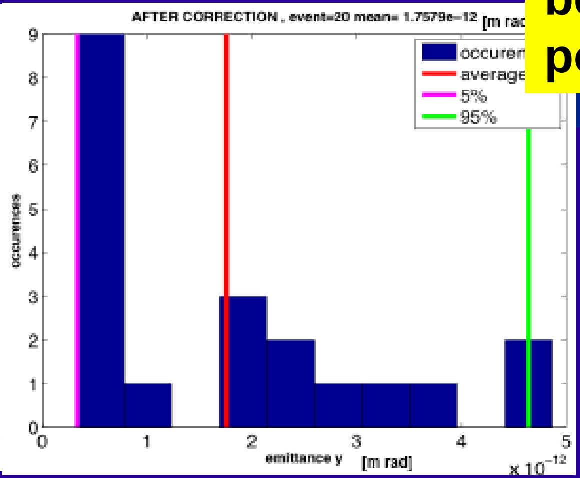
Elements From QF1R to QF1L are considered as a single element.

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**

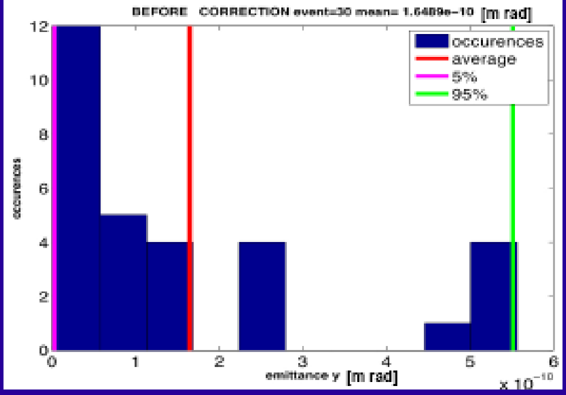
LER ARC's tolerances evaluated using a Response Matrix technique that optimizes orbit, in order to recover the design values for Dispersion, Coupling and Beta-beating, and obtain the lowest possible vertical emittance

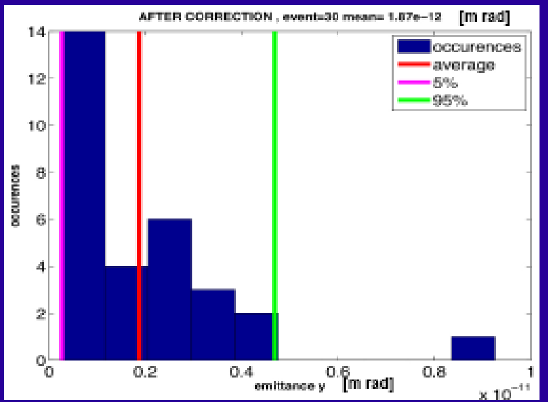




Misalignment	Value	
	ARC	FF
Quadrupole H and V	**50 µm**	**00 µm**
Quadrupole Tilt	**50 µrad**	**00 µrad**
Sextupole H and V	**50 µm**	**00 µm**
BPM resolution	**1 µm**	**0 µm**
BPM Offset	**50 µm**	**00 µm**

Different sets of correctors tested, may be reduced to 109. 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

HER tolerances

Liuzzo

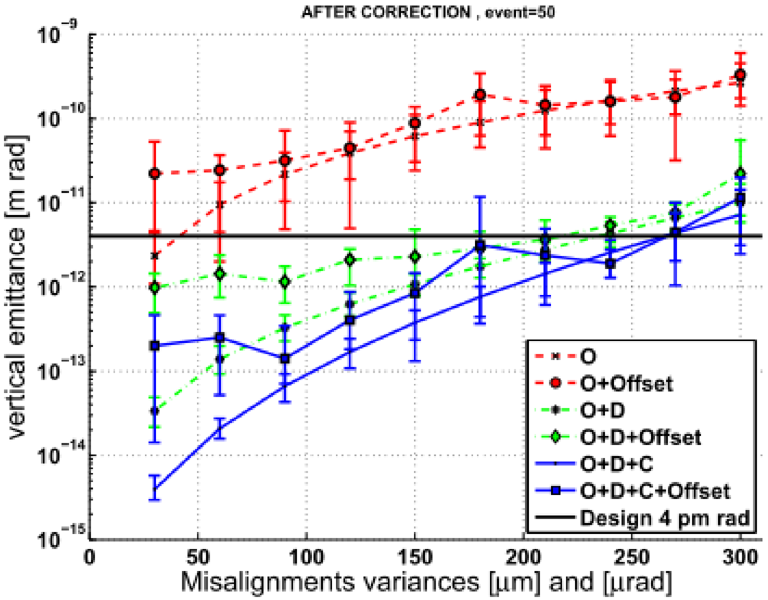


Figure 2: Vertical emittance (m) for machine misalignment from 30 to 300μm H and V for Sext and Quad and qudrupole Tilts of 30-300 μrad. Orbit (O), Dispersion (D) and Coupling and Beta-beating (C) Free Steering are compared

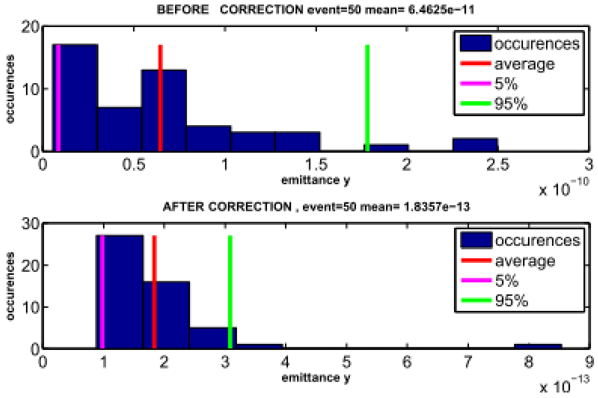


Figure 4: Vertical emittance for 50 simulation with misalignment and tilts from Table 1.

Table 1: Tolerances; values of the combined tolerated displacements, tilts and monitor offsets.

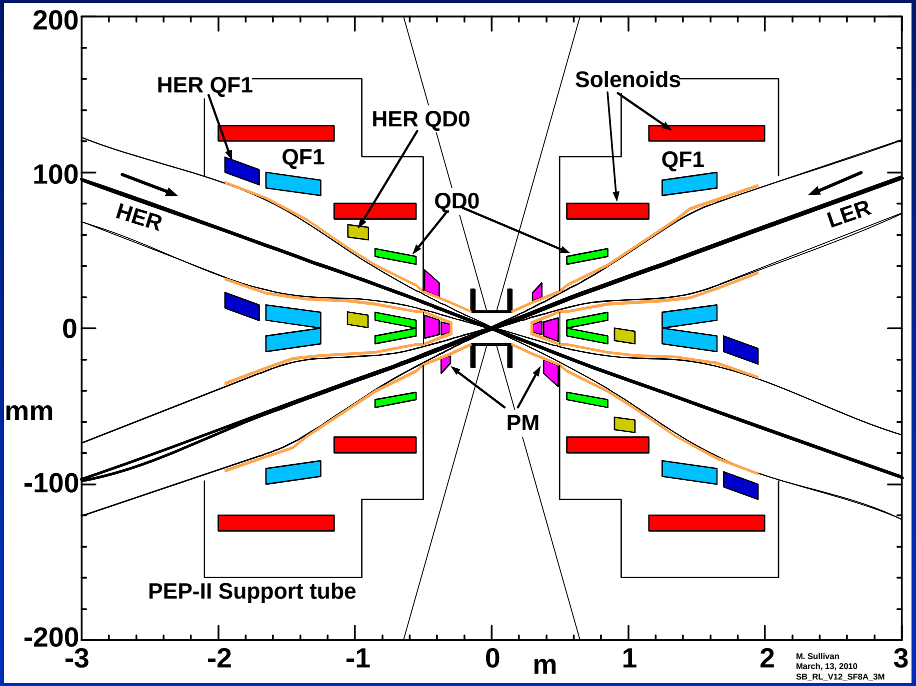
error	tolerance
quadrupole Y	300 μm
quadrupole X	300 μm
quadrupole tilt	300 μrad
sextupole Y	150 μm
sextupole X	150 μm
BPM OFFSET	400 μm
vertical emittance	< 1 pmrad

IR design

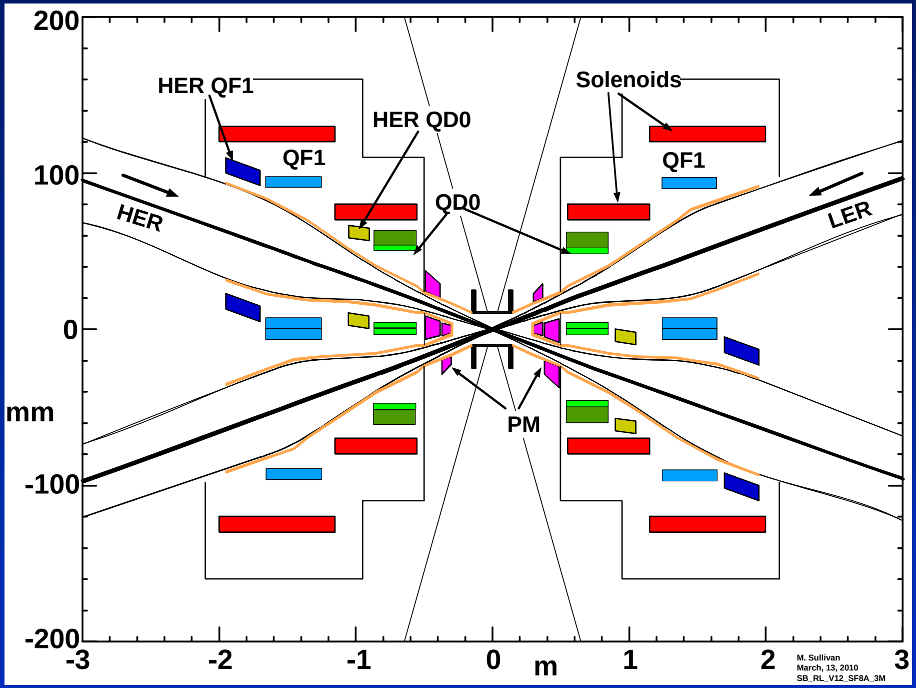
Sullivan

- 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

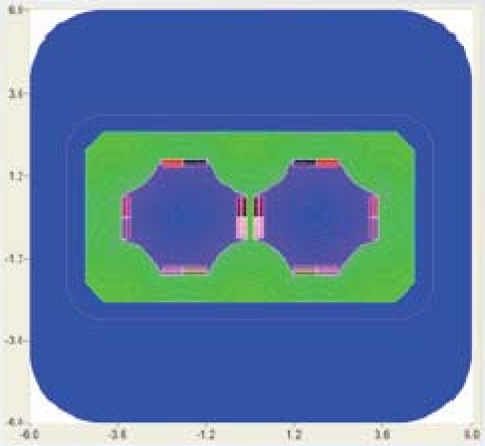
"Italian" Design

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

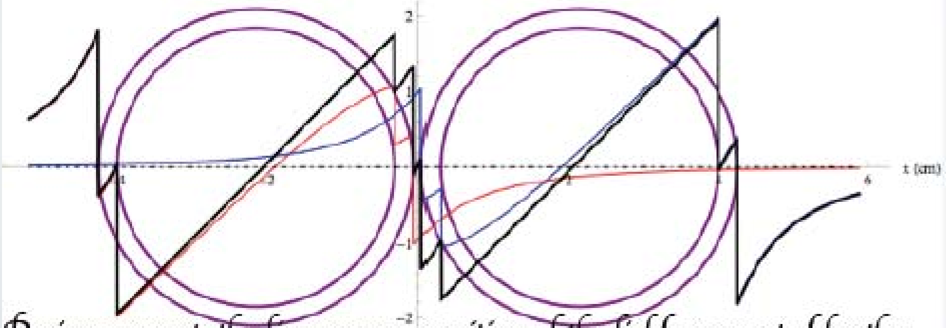
Conceptual sketch

"Russian" Design

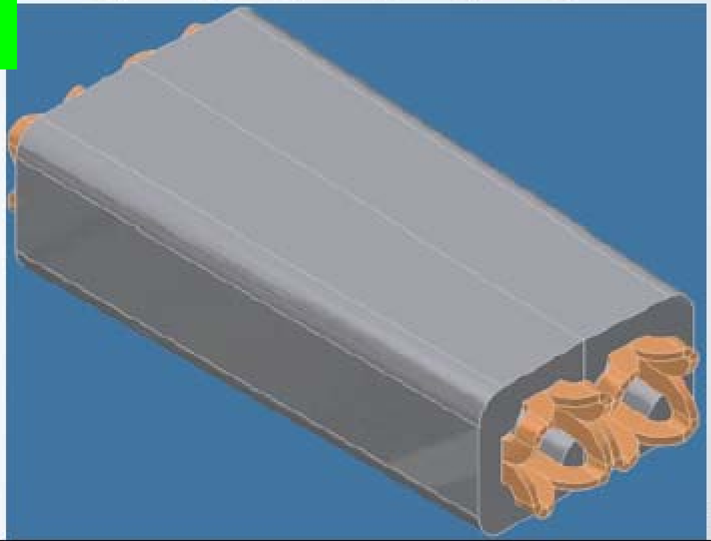
I. Okunev, V. Syrovatin, A. Bragin, P. Vobly



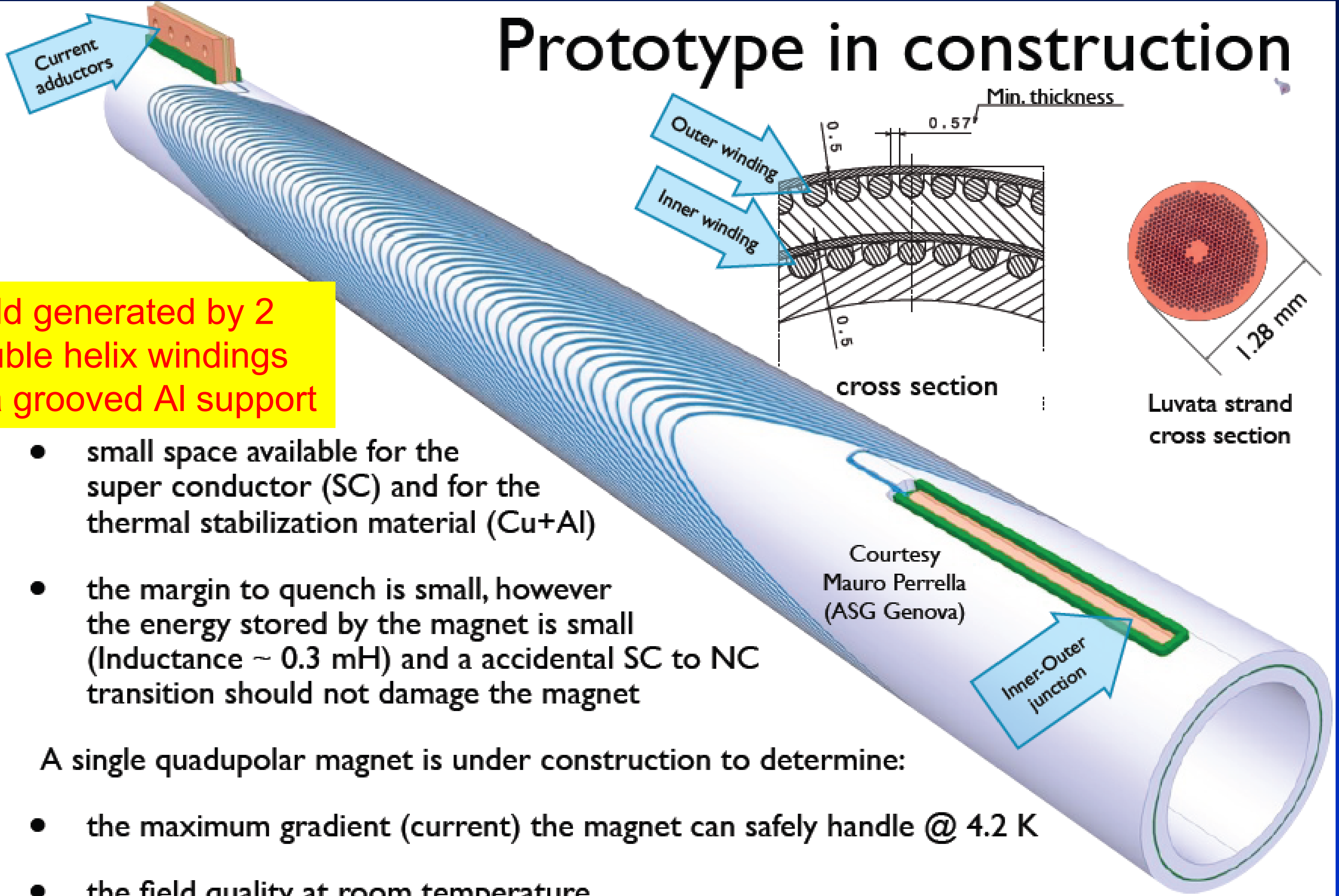
Air-core QD0 is a SC iron free septum double quad



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



Courtesy Mauro Perrella (ASG Genova)

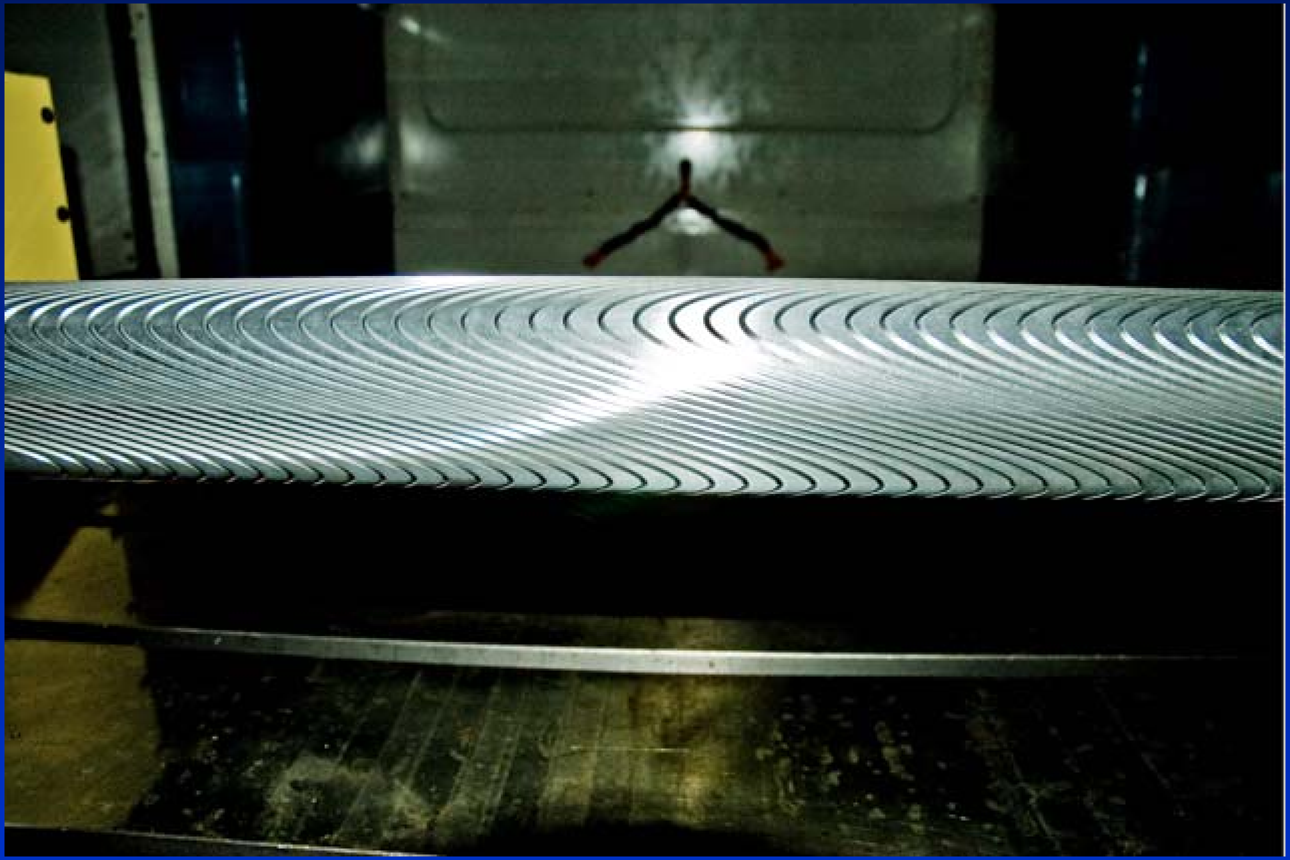
Field generated by 2 double helix windings in a grooved Al support

- 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, Paoloni

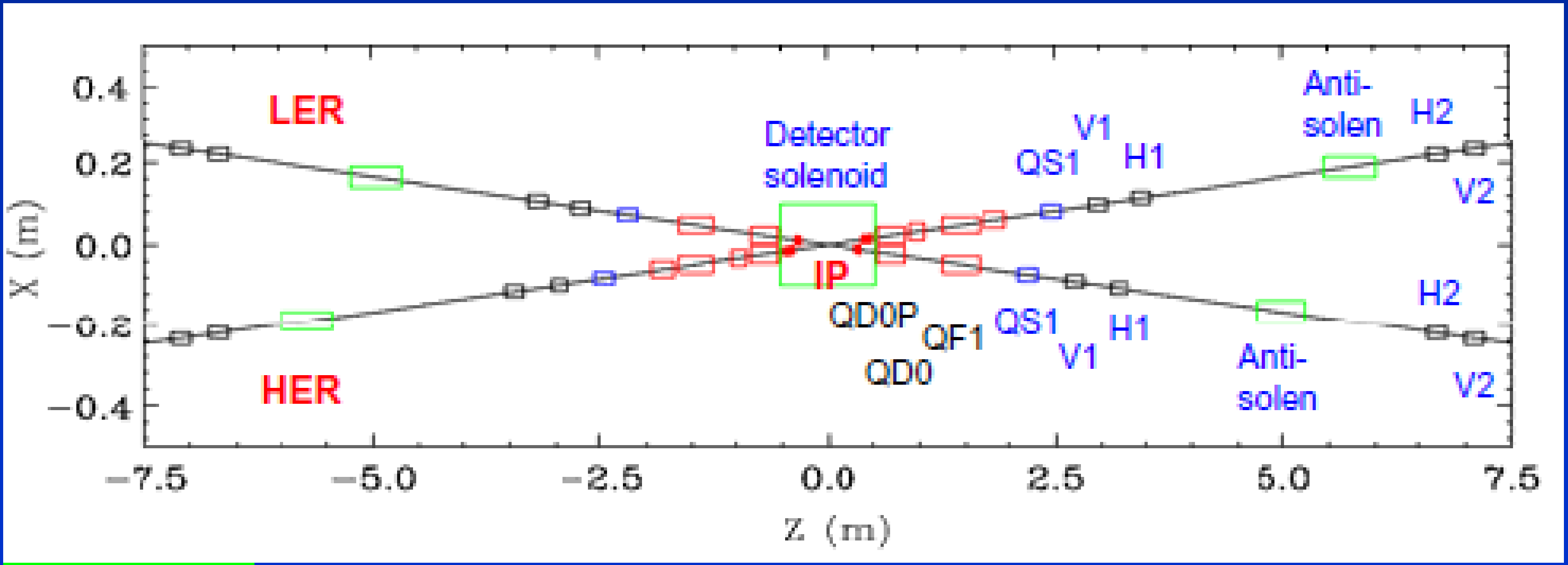
The actual grooved Al support



- Ready before Summer for tests and field measurements at CERN

Coupling correction with detector solenoid ON

- Scheme based on a hard edge solenoid field model. It includes bucking solenoids, an anti-solenoid, rotated IR permanent quadrupoles, skew quadrupole component in the SC quadrupoles, and a full set of skew quadrupoles and orbit correctors for complete compensation of linear coupling, orbit, dispersion and β function perturbation in each half-IR. Most of the correctors are rather weak
- The same system can be used to correct the coupling effect when the solenoid is off, but the SC quadrupole coupling components and QD0P rotation remain. The latter can be adjusted for most local correction
- Further studies are needed to evaluate the effect of solenoid on FF bandwidth and dynamic aperture. The non-linear solenoid effects need to be studied as well



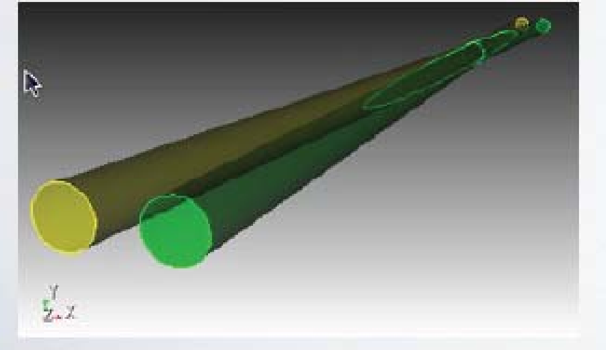
Nosochkov

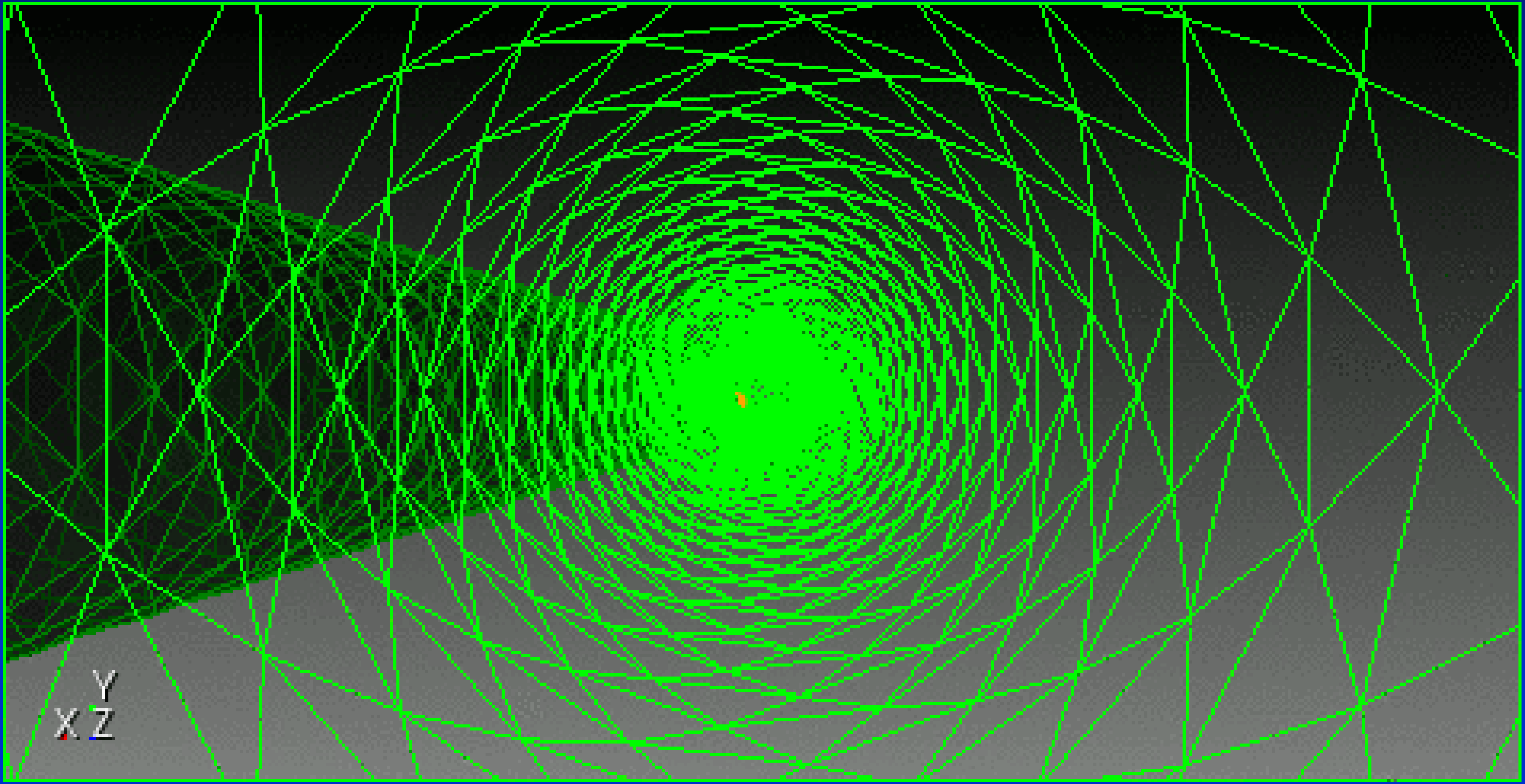
Other correctors are outside of this region

Beam’s eye view in a round chamber model

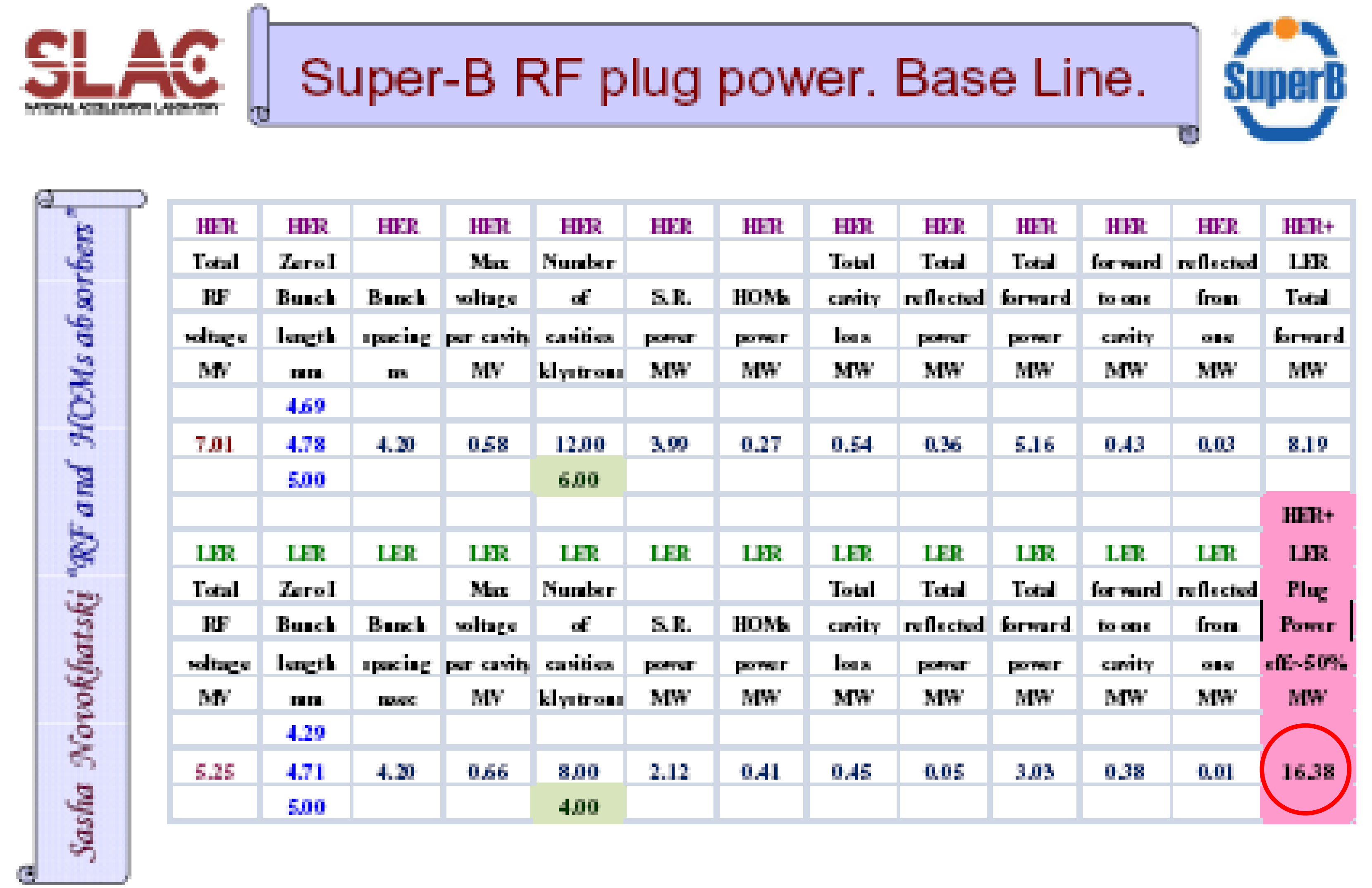
Weathersby

- SLAC Advanced Computing Department parallel Finite Element Method electromagnetic time domain solver (t3p) as a tool for IR wakefield computation





RF Power



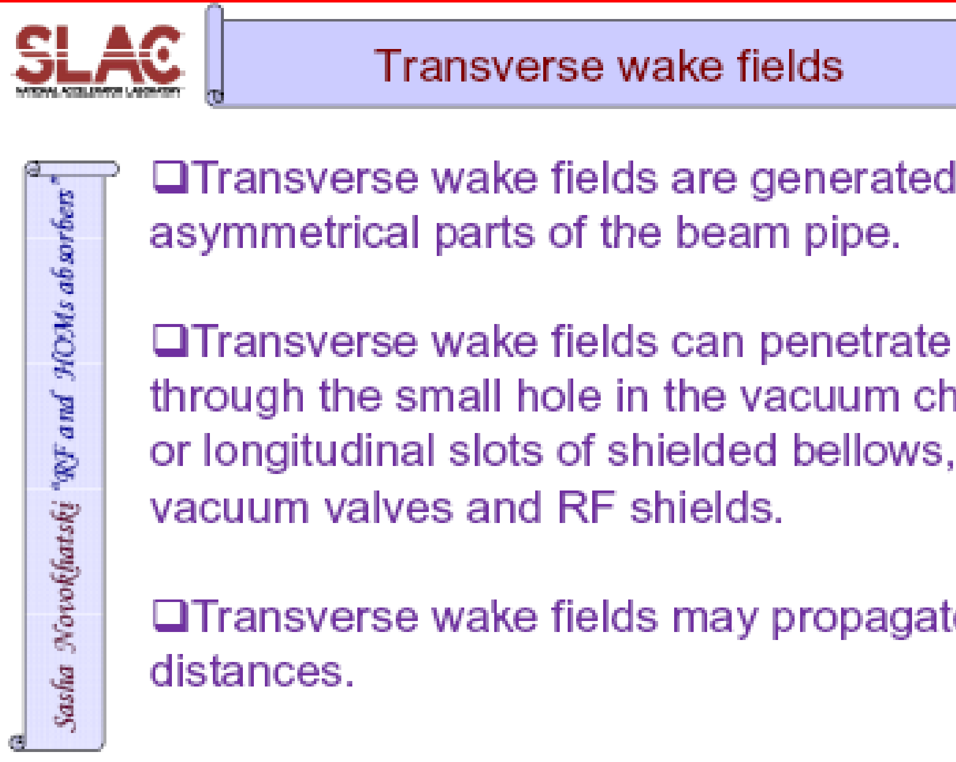
Super-B RF plug power. Base Line.

Sasha Novokhatski "RF and HOMs absorbers"

HER Total RF voltage MV	HER Zero I Bunch length mm	HER Bunch spacing ns	HER Max voltage per cavity MV	HER Number of cavities klystrons	HER S.R. power MW	HER HOMs power MW	HER Total cavity loss MW	HER Total reflected power MW	HER Total forward power MW	HER forward to one cavity MW	HER reflected from one MW	HER+ LER Total forward MW
	4.69											
7.01	4.78	4.20	0.58	12.00	3.99	0.27	0.54	0.36	5.16	0.43	0.03	8.19
	5.00			6.00								

LER Total RF voltage MV	LER Zero I Bunch length mm	LER Bunch spacing nsec	LER Max voltage per cavity MV	LER Number of cavities klystrons	LER S.R. power MW	LER HOMs power MW	LER Total cavity loss MW	LER Total reflected power MW	LER Total forward power MW	LER forward to one cavity MW	LER reflected from one MW	HER+ LER Plug Power eff.~50% MW
	4.29											
5.25	4.71	4.20	0.66	8.00	2.12	0.41	0.45	0.05	3.03	0.38	0.01	16.38
	5.00			4.00								

Wakefields

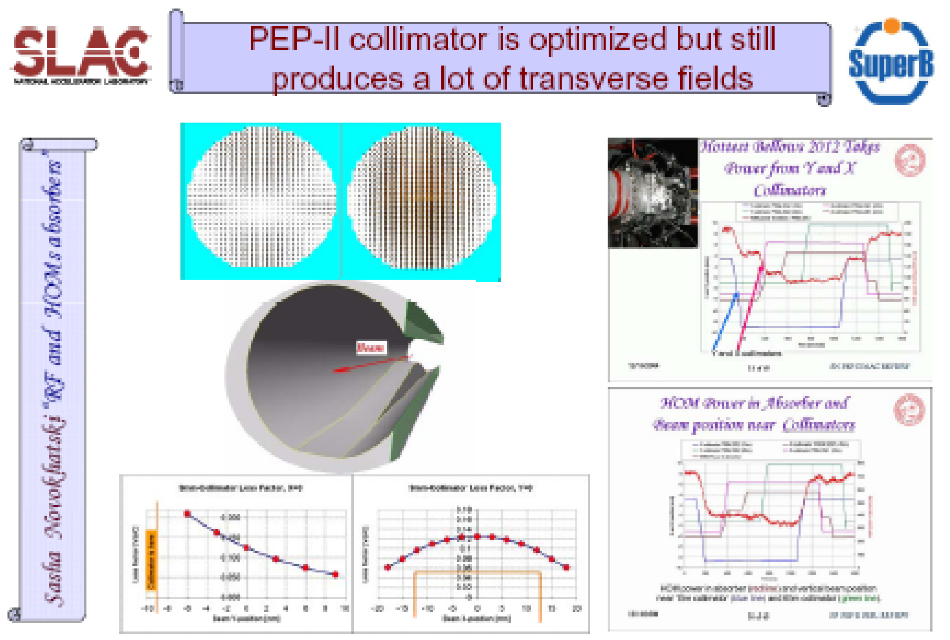


Transverse wake fields

- ❑Transverse wake fields are generated in the asymmetrical parts of the beam pipe.
- ❑Transverse wake fields can penetrate through the small hole in the vacuum chamber or longitudinal slots of shielded bellows, vacuum valves and RF shields.
- ❑Transverse wake fields may propagate long distances.

Sasha Novokhatski "RF and HOMs absorbers"

Need Collimators PEP-II ones are OK



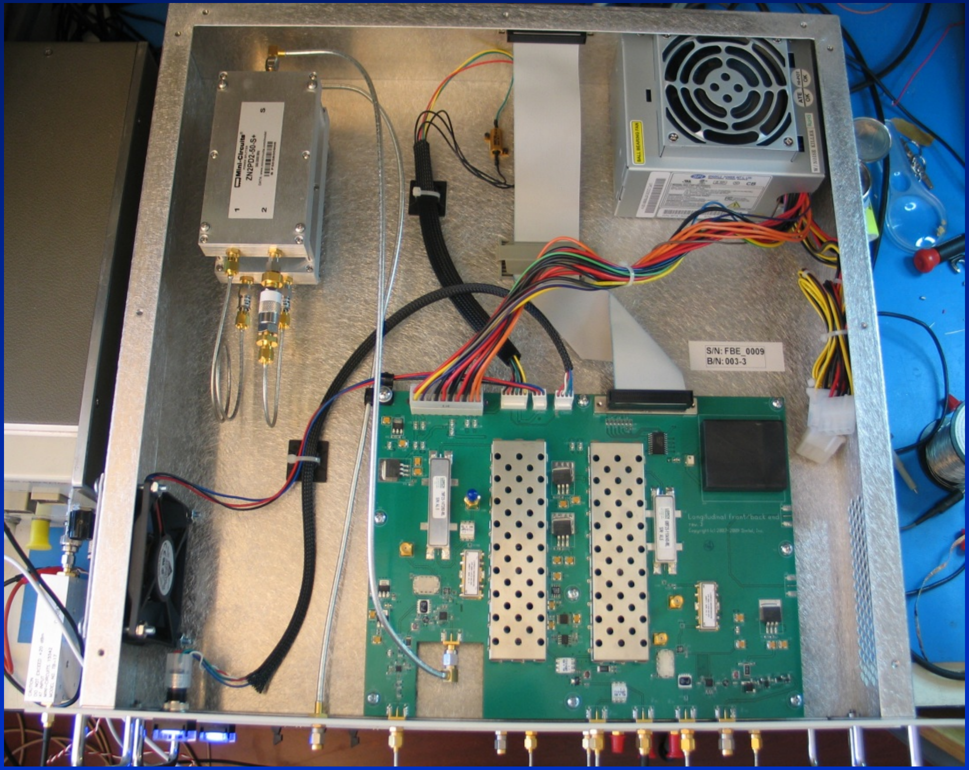
PEP-II collimator is optimized but still produces a lot of transverse fields

Sasha Novokhatski "RF and HOMs absorbers"

Bunch-by-bunch feedback upgrade

Drago

- During last month all the 6 DAΦNE feedback have been upgraded
- 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
- Epics server upgraded to the last version of LINUX

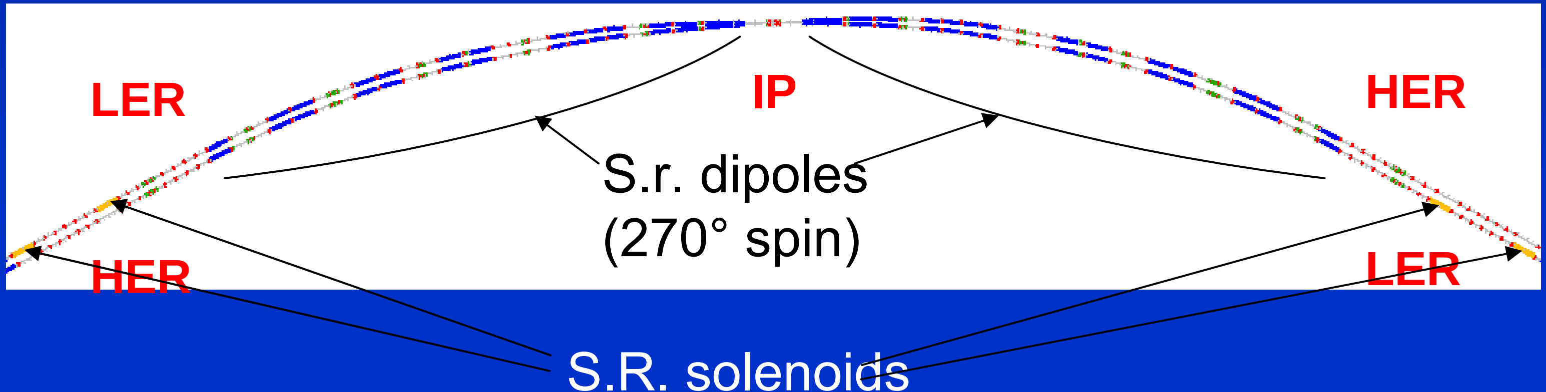


- New front-end/back-end analog unit used in the longitudinal feedbacks

Polarization in SuperB

Barber, Monseu, Wienands, Wittmer

- 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



LER

IP

HER

S.r. dipoles
(270° spin)

HER

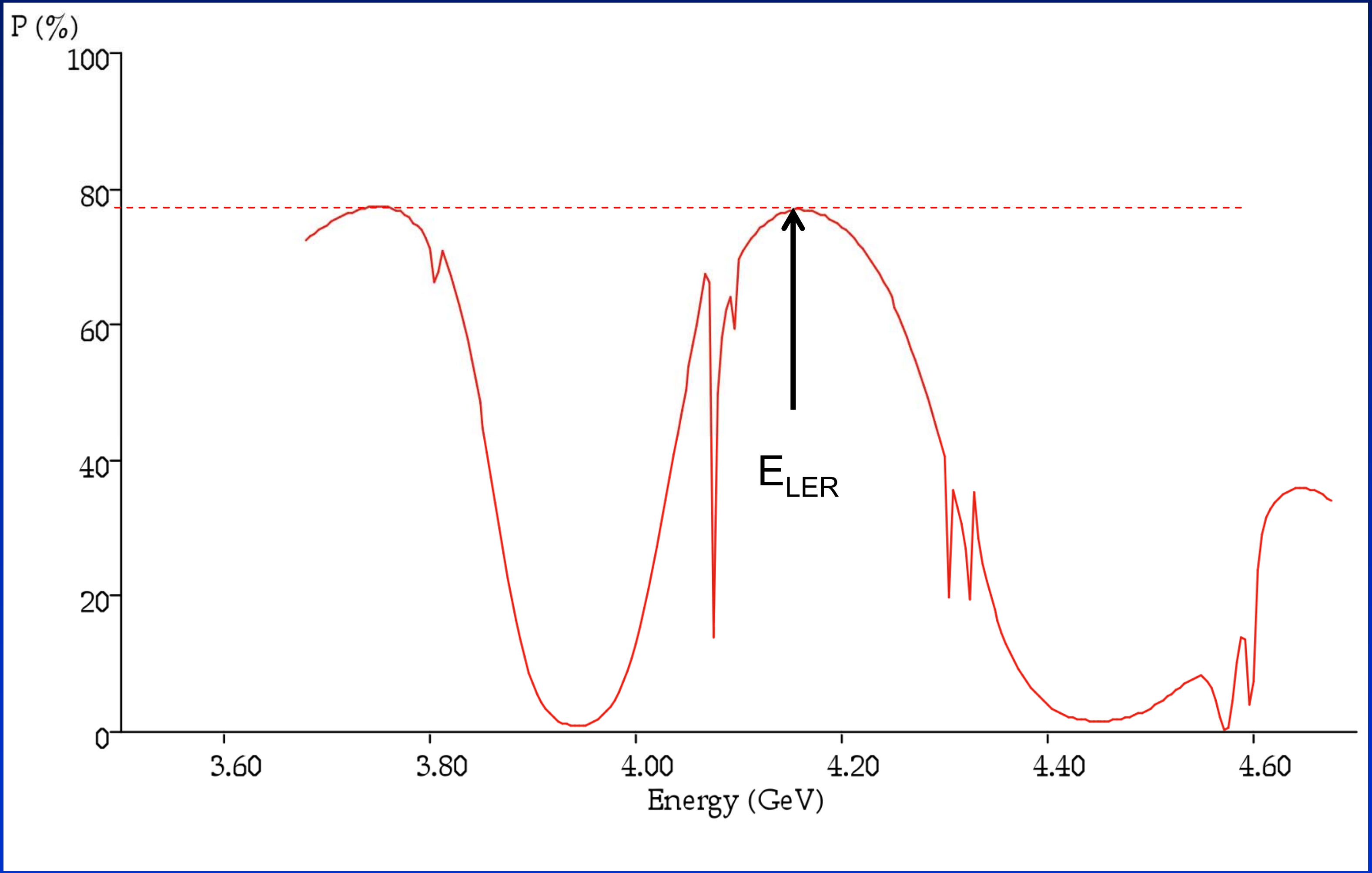
LER

S.R. solenoids
(90° spin)

Polarization ($P_{inj} = 90\%$)

Wienands

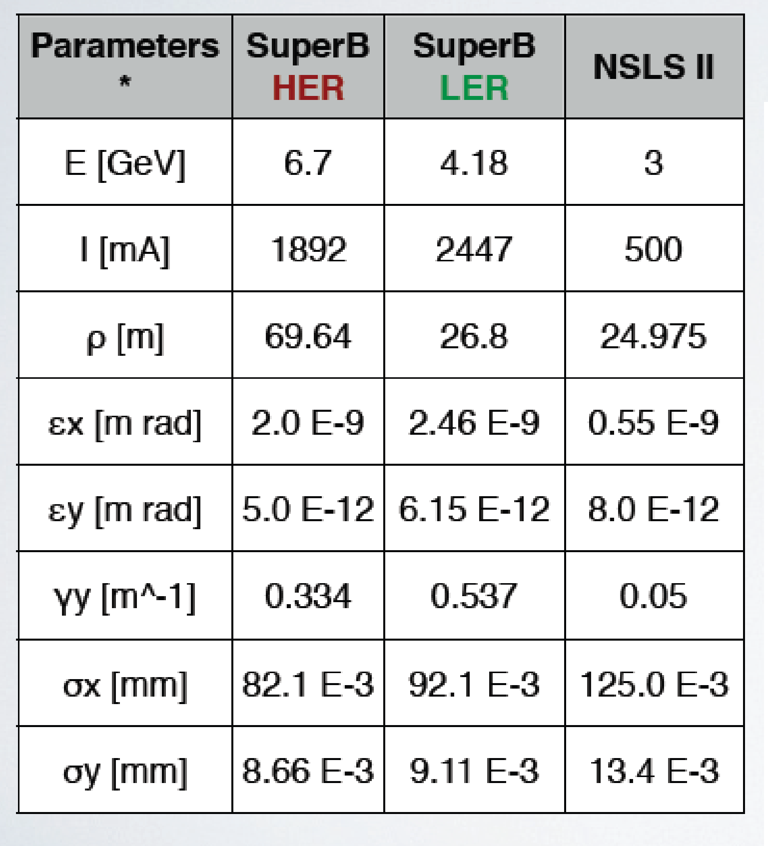
3.5 min beam lifetime



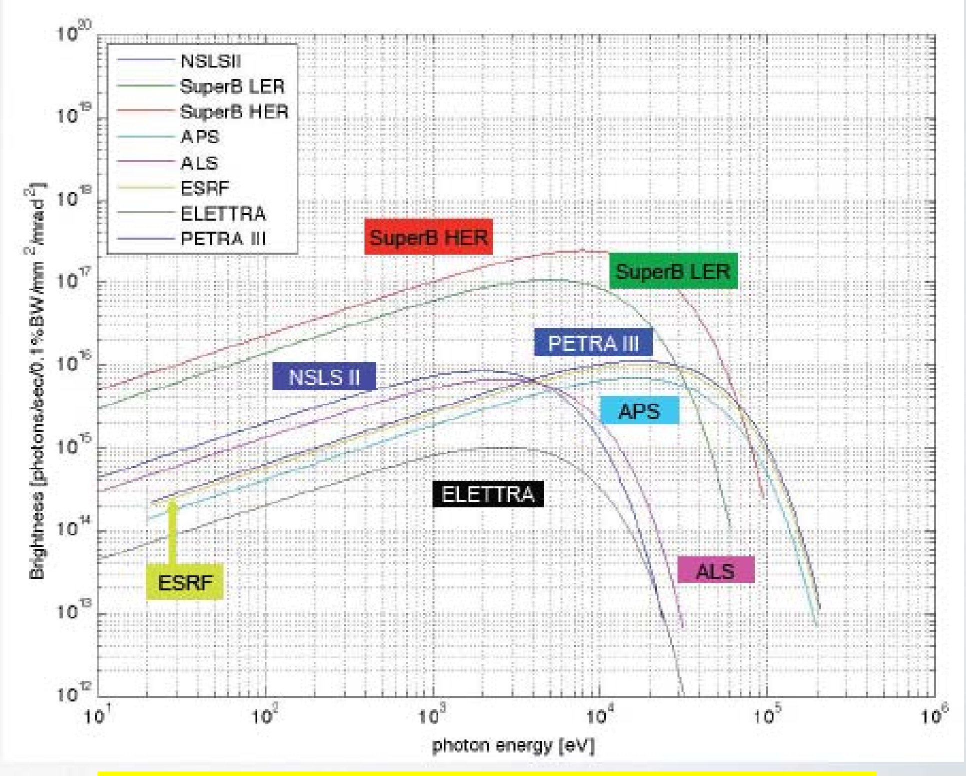
Synchrotron light options @ SuperB

Wittmer

- 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)



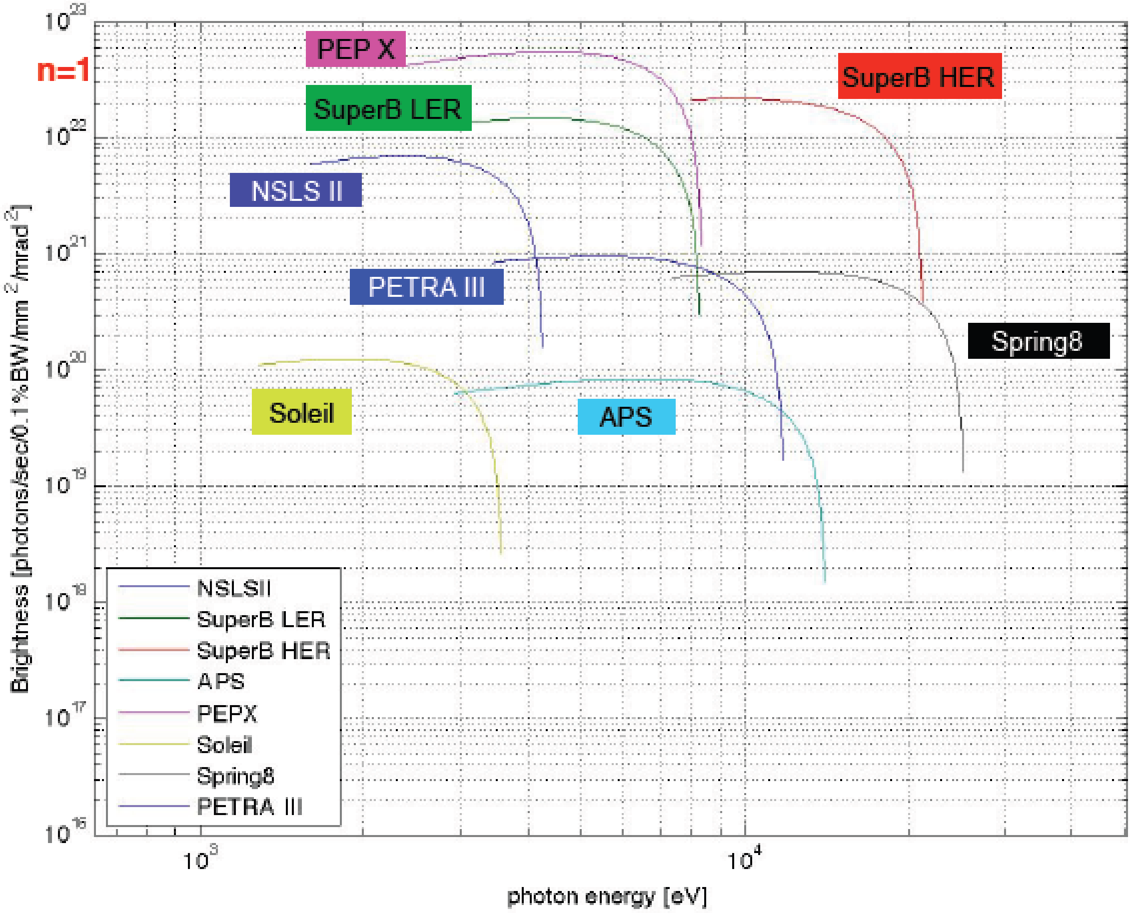
Parameters *	SuperB HER	SuperB LER	NSLS II
E [GeV]	6.7	4.18	3
I [mA]	1892	2447	500
ρ [m]	69.64	26.8	24.975
εx [m rad]	2.0 E-9	2.46 E-9	0.55 E-9
εy [m rad]	5.0 E-12	6.15 E-12	8.0 E-12
γy [m^-1]	0.334	0.537	0.05
σx [mm]	82.1 E-3	92.1 E-3	125.0 E-3
σy [mm]	8.66 E-3	9.11 E-3	13.4 E-3



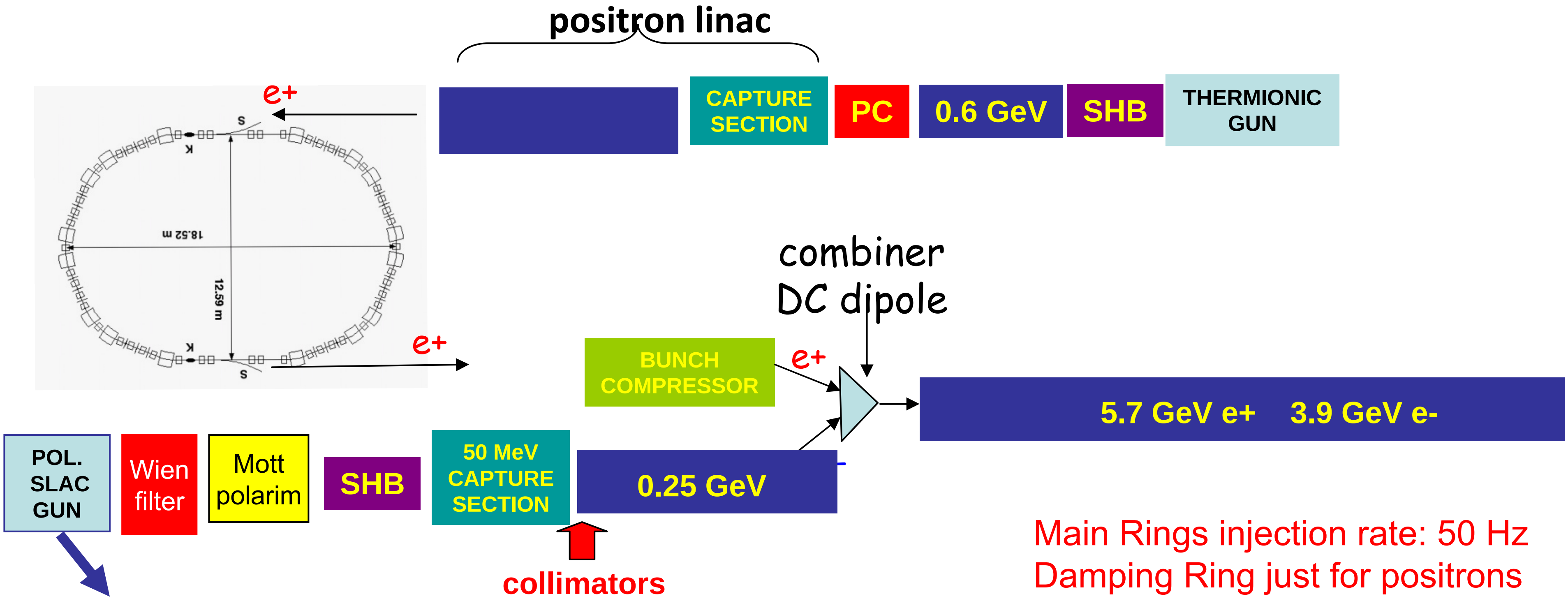
Brightness from bending magnets

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
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



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

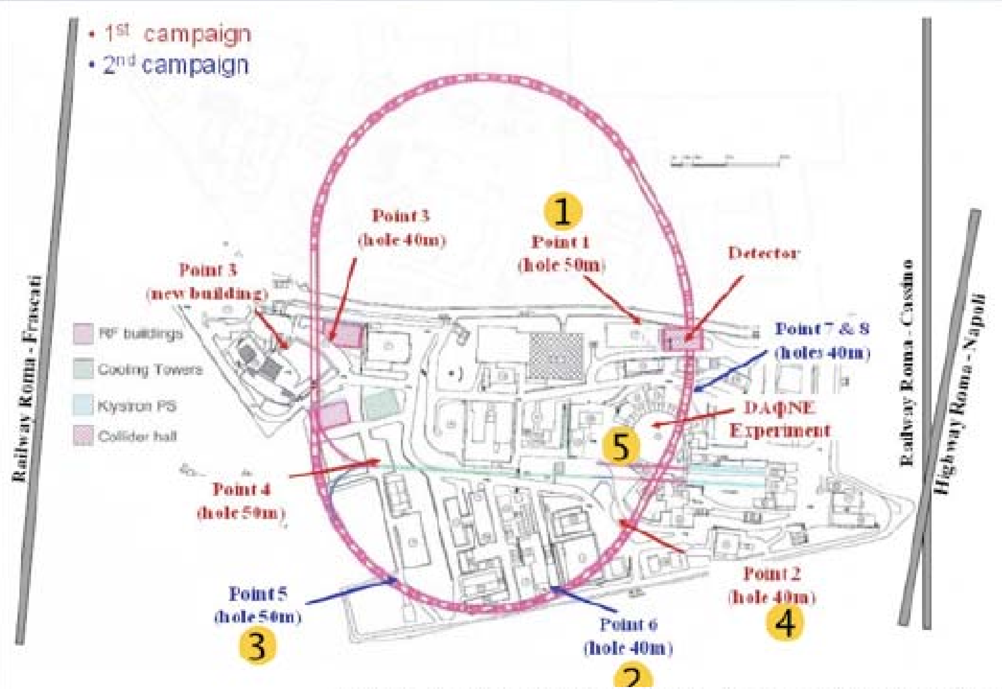
Round beam
Emittance @ 4.16 GeV = 1.8 nm
Required bunch charge for electrons ≈ 0.3 nC
… scrapers .. collimators needed

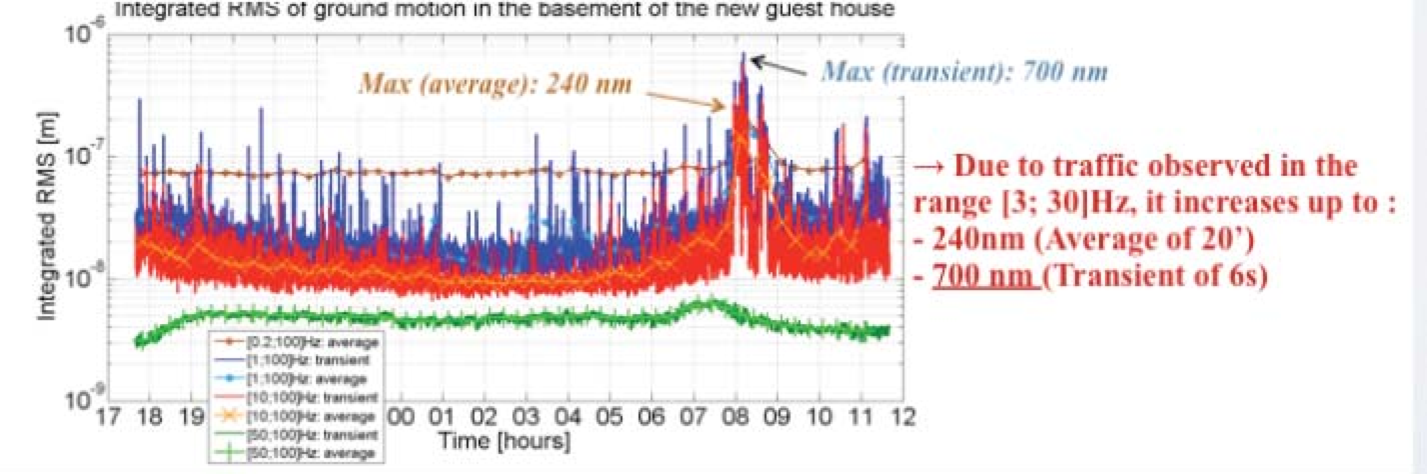
Boni, Chancé, Dadoun, Guiducci, Hermes, Poirier, Preger, Seeman, Variola

Ground motion at LNF

Bolzon, Brunetti, Jeremie,Tomassini

- A second campaign of geological prospections has been done @ LNF (four additional holes)
- A new campaign of ground motion measurements was carried out in October with the collaboration of the LAPP group





→ Due to traffic observed in the range [3; 30]Hz, it increases up to :
- 240nm (Average of 20')
- 700 nm (Transient of 6s)

Vibrations budget

Bertsche

- The small beam sizes at the IP pose stringent vibration requirements. Beam position at the IP is very sensitive to individual motion of IR components
- However, the present IR design with shared elements in a common cryostat will cause coherent motion of these elements, greatly reducing the vibration sensitivity of the IR.
- Cryostat vibration should be kept below 800 nm rms, and cryostat rotation less than 2 µm rms
- Vibration of the remaining FF and arc quadrupoles should be kept to less than 200 nm rms
- A fast luminosity feedback system should have a bandwidth of at least 100 Hz, achieving at least 10xvibration reduction at low frequencies
- With these requirements the vibration budget can be met even during the noisiest part of the day, limiting vibration-induced luminosity loss to less than 1%

Layout, Site

- The rings footprint is at the moment the same as presented at Elba. Injection and transfer lines are also unchanged
- 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 seems available, first pick at the moment is in Tor Vergata University campus and we are studying its compatibility with the requirements (Site Committee will visit April 18-19)
- The layout will be adjusted as soon as the site is chosen to further optimize the system performances

Accelerator Team Organization

- Frascati Lab will host the team in the initial phase (at least 2 years...)
- Need to assemble a team:
  - INFN Frascati
  - INFN other Labs
  - SLAC
  - France
  - BINP
  - Poland
  - UK
  - More welcome!
- Need to obtain (a lot of) engineering help

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 research and development program

Conclusions

- Accelerator design is converging with most aspects starting to look feasible
- Lattice and parameters optimization is continuing, for better performances and more flexibility
- More subtle beam dynamics issues are being studied (e.g. IBS, FII, emittance diffusion, beam-beam effects, feedbacks)
- Components and lattice tolerances with corrections are being studied
- Polarization is progressing: beam-beam depolarization, trying to simplify the polarized gun, spin measurements
- Synchrotron Light beamlines option is being studied
- CDR2 is ready
- We are already actively collaborating with other Labs (CERN, PSI, Rutherford, Cornell,…) to solve common issues
- We need to organize the effort for the project