Overview of B-Factories

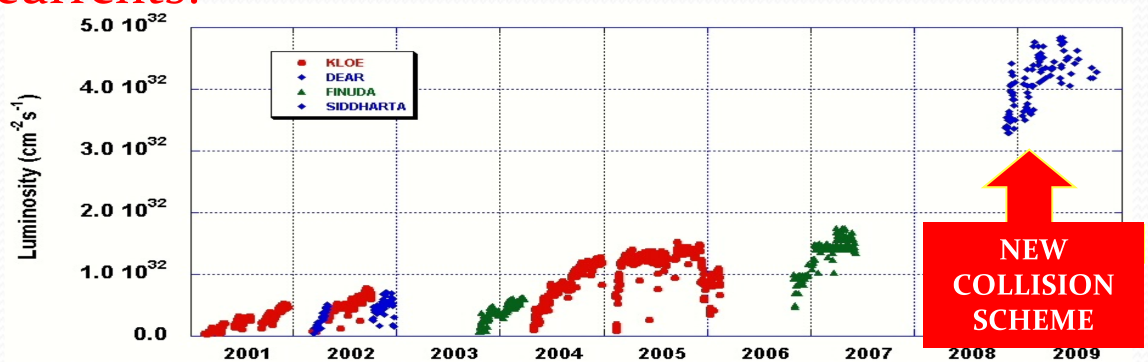
M. Biagini, INFN-LNF
on behalf of SuperKEKB and SuperB Teams
IPAC12, New Orleans, 21-25 May 2012

SuperB-Factories design in a nutshell

- To break B-Factories record in peak luminosity new collision scheme is needed
- The «Large Piwinski Angle» and «crab-waist sextupoles» option was first developed by P. Raimondi and tested at DAΦNE (LNF)
- Large crossing angle and very small beam sizes:
  - collision area is shorter, bunch length longer
  - lower vertical beta, beam size, hourglass and tune shift
  - small horizontal tune shift (1D beam-beam)
  - less parasitic crossings

$$\Phi_{Piwinski} = tg(\theta)\sigma_z/\sigma_x$$

- «Crab-waist» sextupoles at a proper phase wrt the IP:
  - suppress most of XY resonances
  - tunes area for operation is larger
- Same Luminosity with lower currents:
  - lower HOM heating
  - less power consumption



Design requirements & challenges (some!)

- Extremely small emittances, both H and V, comparable to those achieved in the last generation SR sources or planned for linear colliders Damping Rings
- Strong IP doublets:
  - SC quads in a restricted space
  - separated beams
  - control of background rates
  - physical aperture
- Coupling & chromaticity correction in the IR
- Dynamic aperture with crab sextupoles
- Control of vibrations at IP
- Sensitivity to magnets alignment errors → Low Emittance Tuning
- Touschek lifetime and IBS emittance growth

Super B-Factories main parameters

Parameter	SuperB		SuperKEKB	
	HER (e^+)	LER (e^-)	HER (e^-)	LER (e^+)
Luminosity ($cm^{-2}s^{-1}$)	10^{36}		$8x10^{35}$	
C (m)	1200		3016	
E (GeV)	6.7	4.18	7.007	4
Crossing angle (mrad)	60		83	
Piwinski angle	20.8	16.9	19.3	24.6
I (mA)	1900	2440	2600	3600
$\varepsilon_{x/y}$ (nm/pm) (with IBS)	2/5	2.5/6.2	4.6/11.5	3.2/8.6
IP $s_{x/y}$ (mm/nm)	7.2/36	8.9/36	10.7/62	10.1/48
σ_l (mm)	5	5	5	6
N. bunches	978		2500	
Part/bunch ($x10^{10}$)	5.1	6.6	6.5	9.04
σ_E/E ($x10^{-4}$)	6.4	7.3	6.5	8.14
bb tune shift (x/y)	0.0026/0.107	0.004/0.107	0.0012/0.081	0.0028/0.088
Beam losses (MeV)	2.1	0.86	2.4	1.9
Total beam lifetime (s)	254	269	332	346
Polarization (%)	0	80	0	0
RF (MHz)	476		508.9	

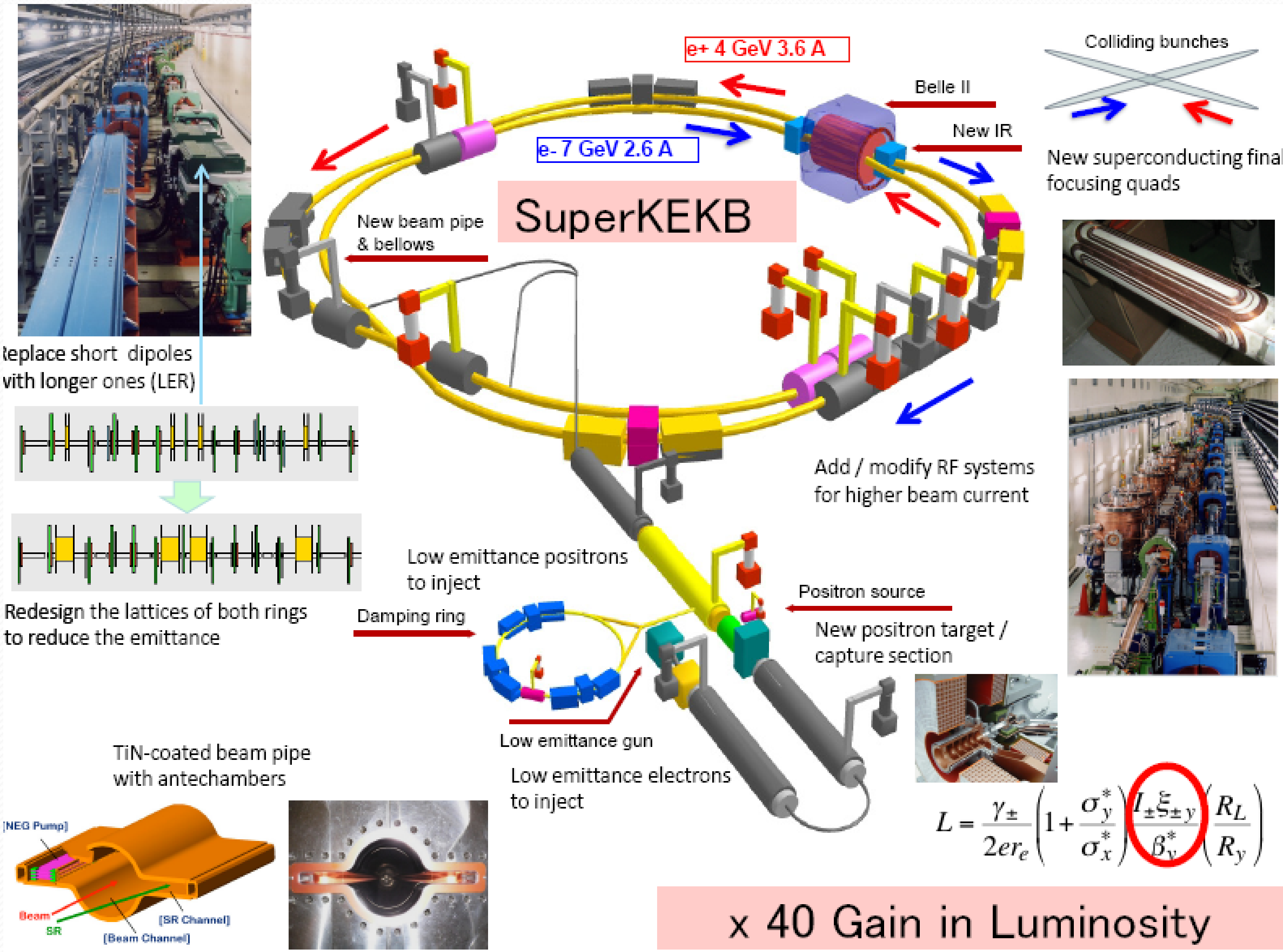
SuperKEKB Status

SuperKEKB design & progresses

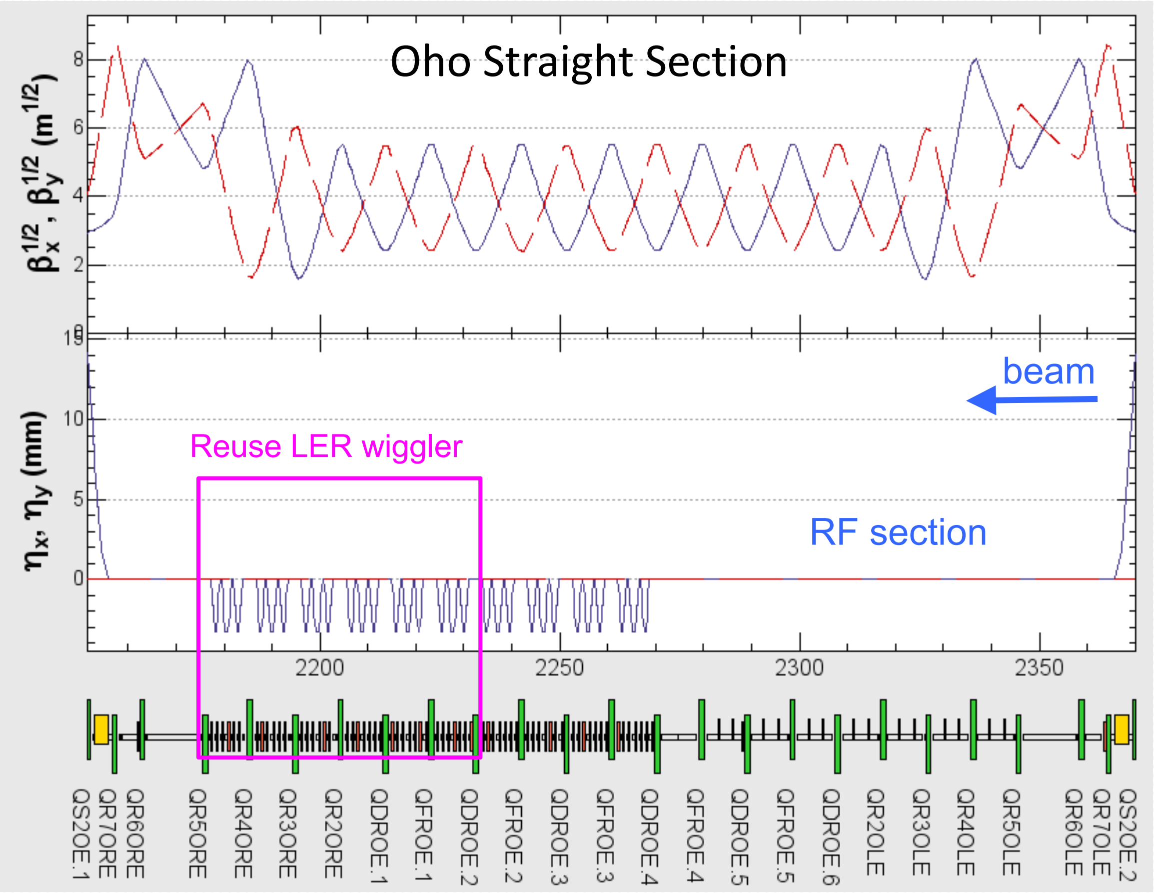
- Design based on «nano-beams» scheme inspired to SuperB
- Large crossing angle, small emittances and IP beam sizes
- No crab waist sextupoles foreseen at the moment
- Same tunnel as KEKB
- Double beam currents, different beam energies wrt KEKB
- Different rings lattices wrt KEKB
- Brand new Final Focus
- Upgrade of most sub-systems wrt KEKB
- New Damping Ring in the injection chain
- The recovery from March 2011 earthquake damages has slowed down the construction, now going on at full speed

K. Oide, «Design progresses and construction status of SuperKEKB», TUPPR006

SuperKEKB layout



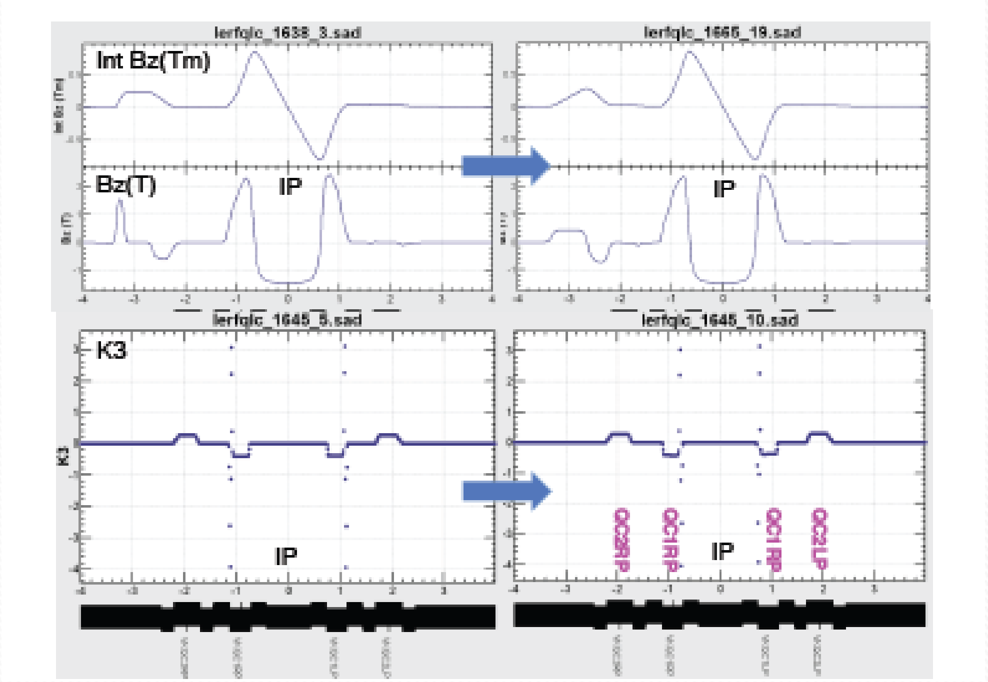
Lattice - HER wiggler section



- 60% wigglers with reuse LER wiggler magnets will be installed by T=0 to reduce horizontal emittance.
- Install more wigglers after T=0, if necessary (+40%)

Optimization of solenoid and higher multipole fields

- Dynamic aperture is very sensitive to nonlinear magnetic fields in FF → precise modeling of IR beam optics is indispensable



- Touschek lifetime is improved by decreasing B_z peak field on the arc side of QC2RP (upper) and by swapping the lead end and the return end of QC1Ps (lower)

H. Yamaoka, "Solenoid field calculation of the SuperKEKB IR", THPPD023

LER beam pipe fabrication @ BINP

Basic design of the vacuum system is near completion, and mass production of main components is going on:

- Al beam pipes with an antechamber for LER arc sections of 2 km length
- Cu beam pipes for the wiggler sections and the straight sections

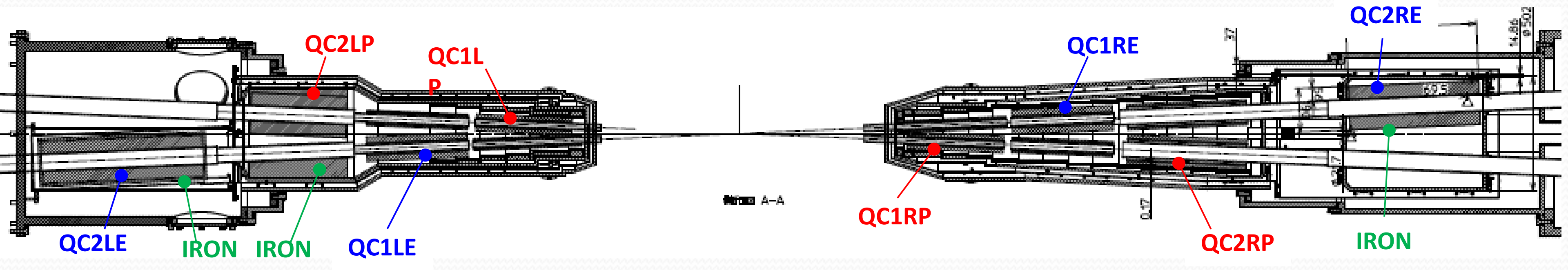
IR design

- Design of IR (magnets, vacuum chamber, beam background estimation, collimation system, collision feedback system, etc) has been improved
  - Iron yokes for 3 more SC quadrupoles (QC1LE, QC1RE, QC2RP)
  - More precise correction of higher multipoles
  - Optimization of solenoid field distribution
  - Optimization of physical aperture
- Modeling of IR optics has also been improved by using 3D magnetic field calculation
  - Touschek lifetime is marginally kept to be ~600 sec
- Many critical issues:
  - Optics design (Tsukuba straight section + a part of arc)
  - QCS design and fabrication
  - Other IR hardware design and assembly
  - Backgrounds
  - Error tolerance at local chromaticity correction and correction method
  - Ripple of power supply
  - Collision feedback

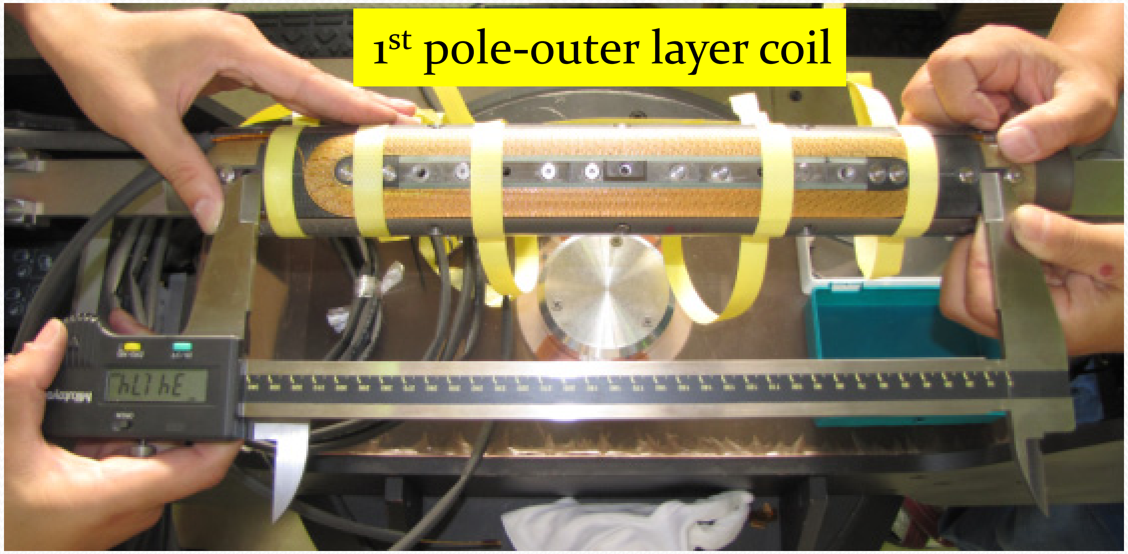
H. Nakayama, «Small β collimation of Beam-gas», TUOBC02

Status of R&D on IP magnet

Design changes in the magnets: introducing iron yokes to the quadrupoles and magnetic shields on the beam pipes. Construction of QC1RP R&D magnet started end of August 2011



New winding machine



1st pole-outer layer coil

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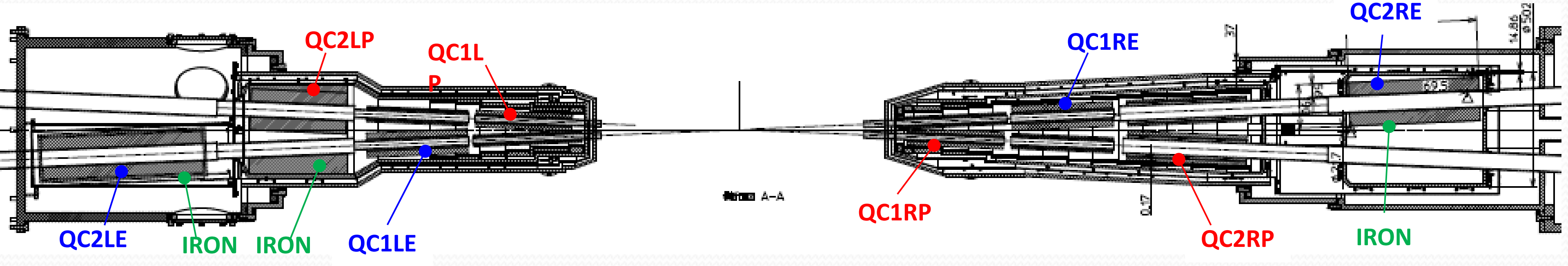

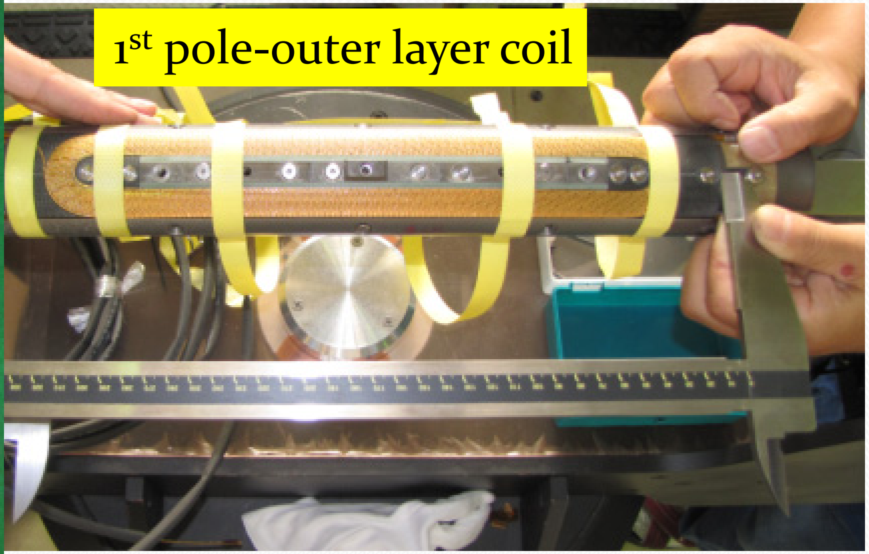

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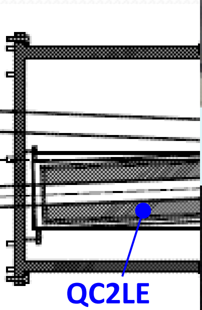
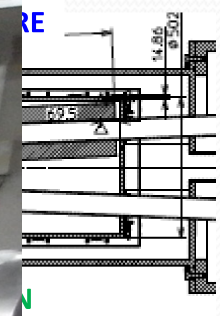
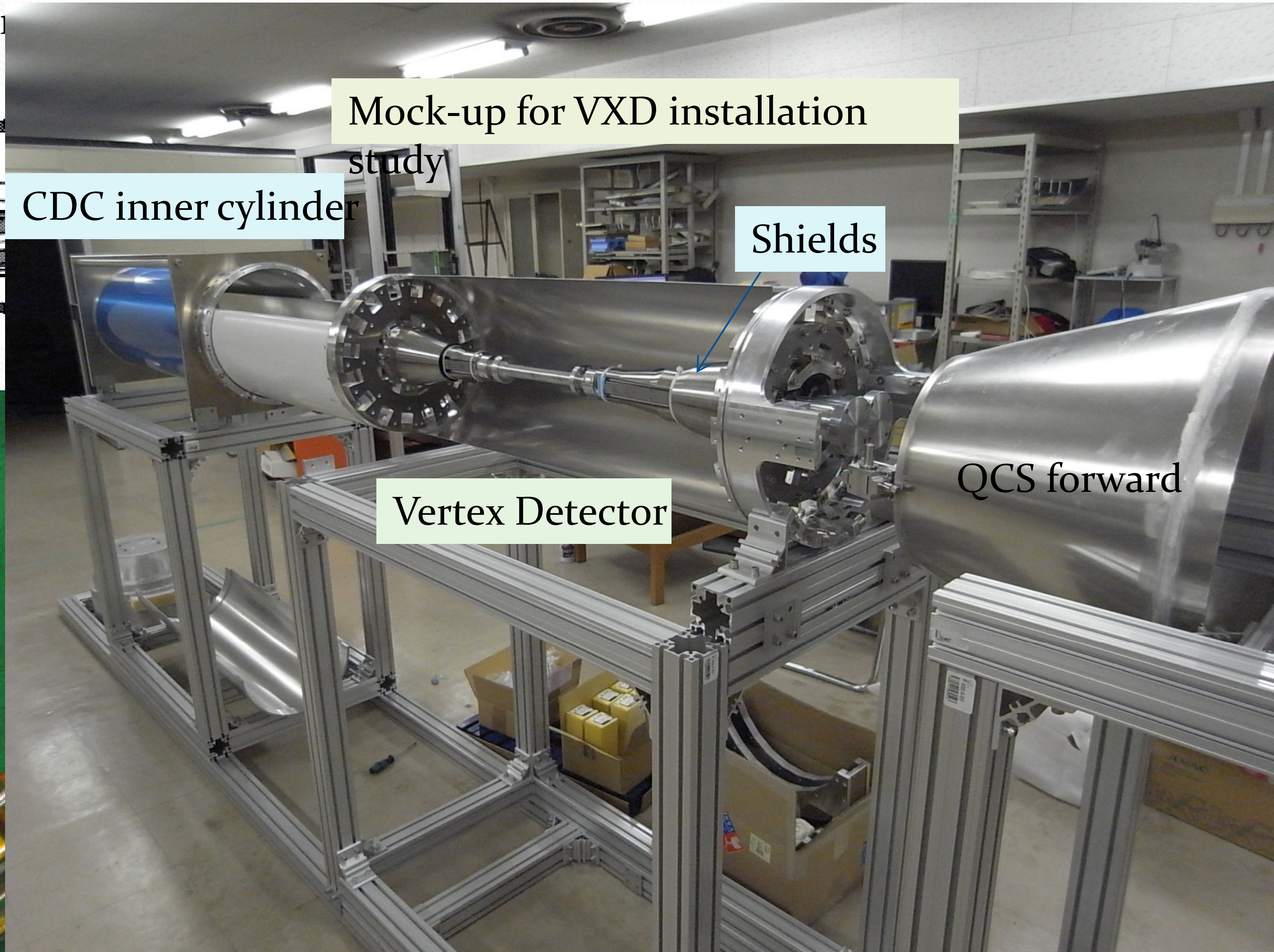






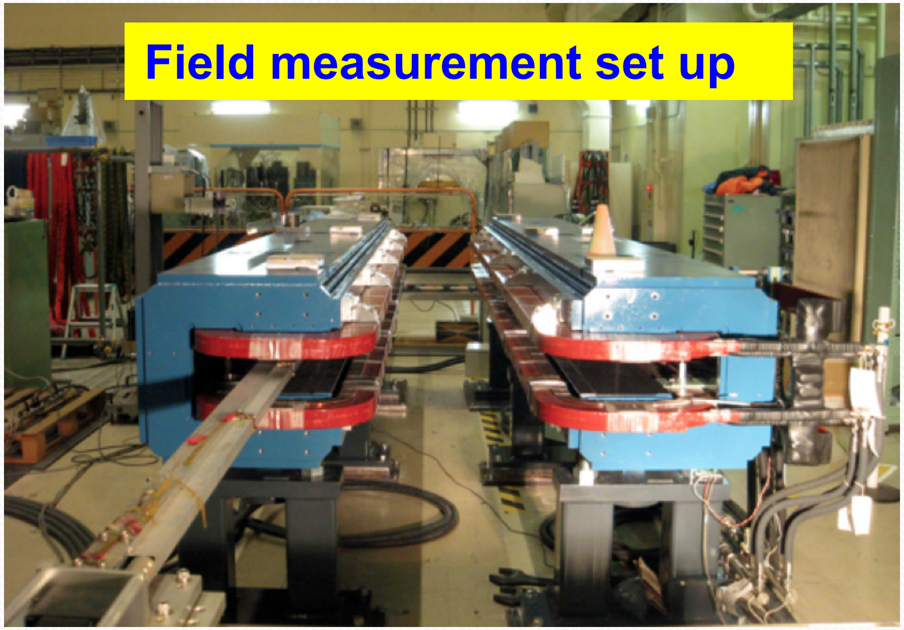
Background estimation status

- Touschek: expected to be severe in nano-beam scheme, but can be reduced by horizontal and vertical collimators.
- Beam-gas Coulomb: Also severe with thinner IR beam pipe and larger maximum by(~4000m), but can be reduced by narrow (few mm) vertical collimator, without losing beam stability if placed at small βy.
- Radiative Bhabha: $e^{+/-}$ with large ΔE after RBB process can be lost inside the detector and become considerable BG
- Synchrotron Radiation: tolerable (negligible SR hit rate on Be pipe thanks to the collimation on incoming beam pipe)
- 2-photon: tolerable (discrepancy between SuperB's estimation disappeared during the discussion at Joint BG workshop)
- Beam-gas brems, beam-beam kick, etc…

H. Nakayama, «Beam backgrounds and MDI for SuperKEKB», TUPPR007

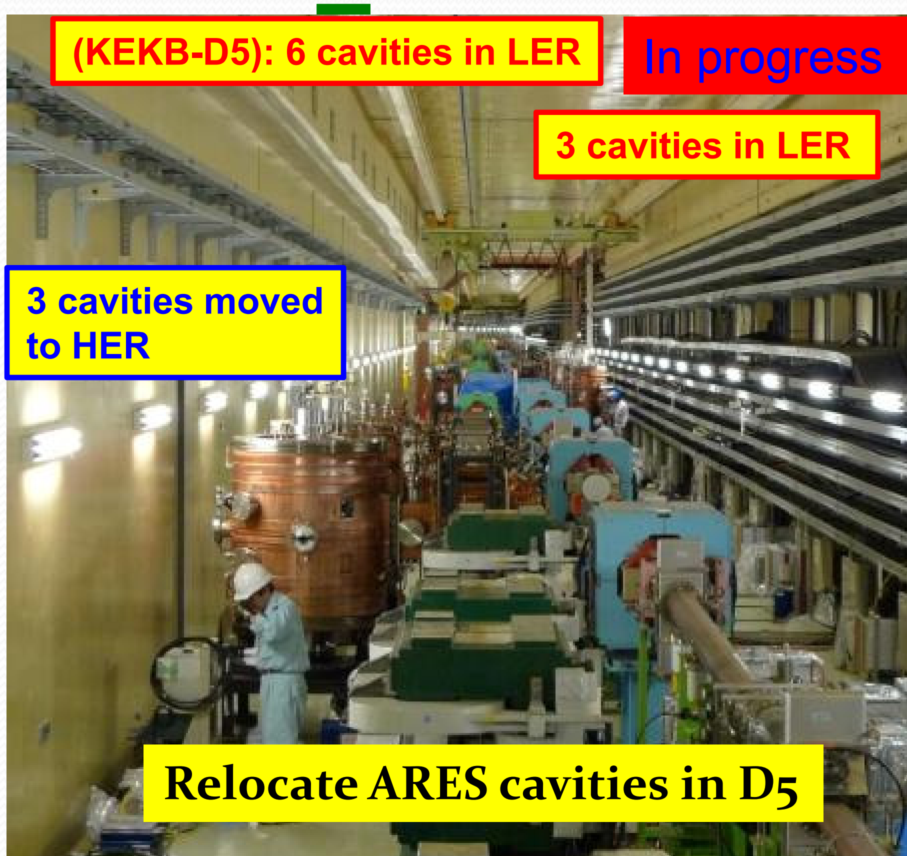
Magnet system

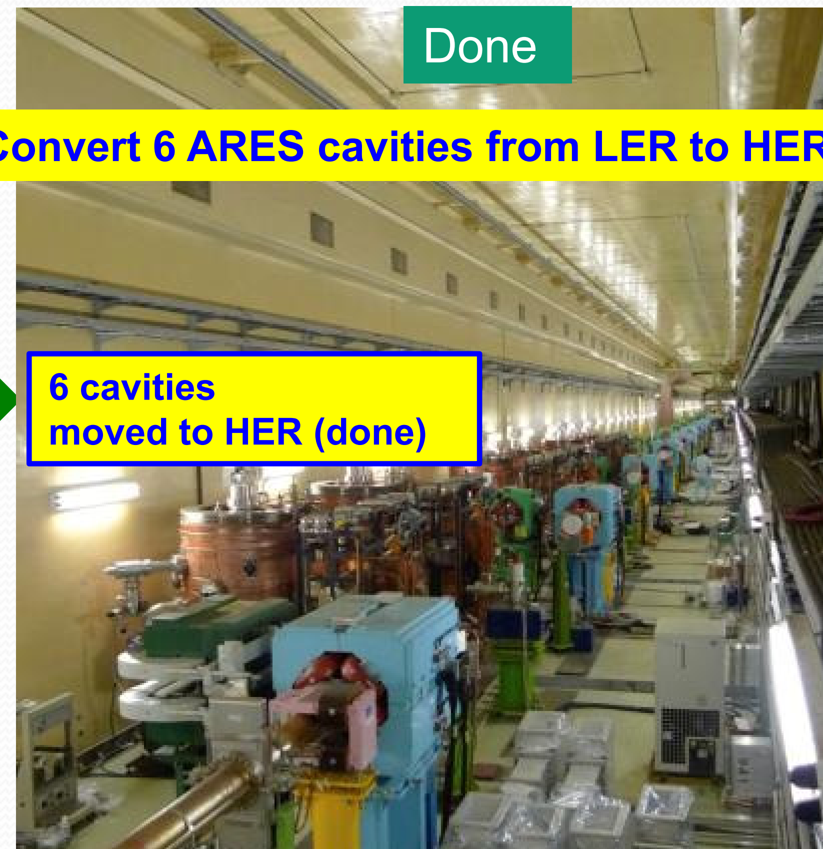
- One of the major upgrade for the magnet system is to replace the short arc dipoles in the LER with longer ones (4 m)
- The new dipoles for the LER arc sections and those for the LER and HER straight sections have been manufactured, already delivered to KEK, and magnetic measurements have been performed



RF system upgrade

- 1 klystron to 1 ARES cavity scheme to increase beam power (was 1 to 2)
- Rearrange ARES cavities
- Change input coupler of the ARES to increase coupling β from 3 to 6
- Cure for increasing HOM power
- Develop new LLRF and Damping Ring Cavity





Injector Linac

- Higher injection beam current
  - to meet the larger stored beam current and shorter beam lifetime in the rings
  - 4~8-times larger bunch current for electron and positron
  - reconstruction of positron generator, etc…
- Lower-emittance injection beam
  - to meet nano-beam scheme in the rings
  - positron with a Damping Ring
  - electron with a photo-cathode RF Gun
  - Emittance preservation by alignment and beam instrumentation
- Quasi-simultaneous injections to SuperKEKB electron and positron rings, and two Light Sources
  - Improvements to beam instrumentation, LLRF, Controls, etc…

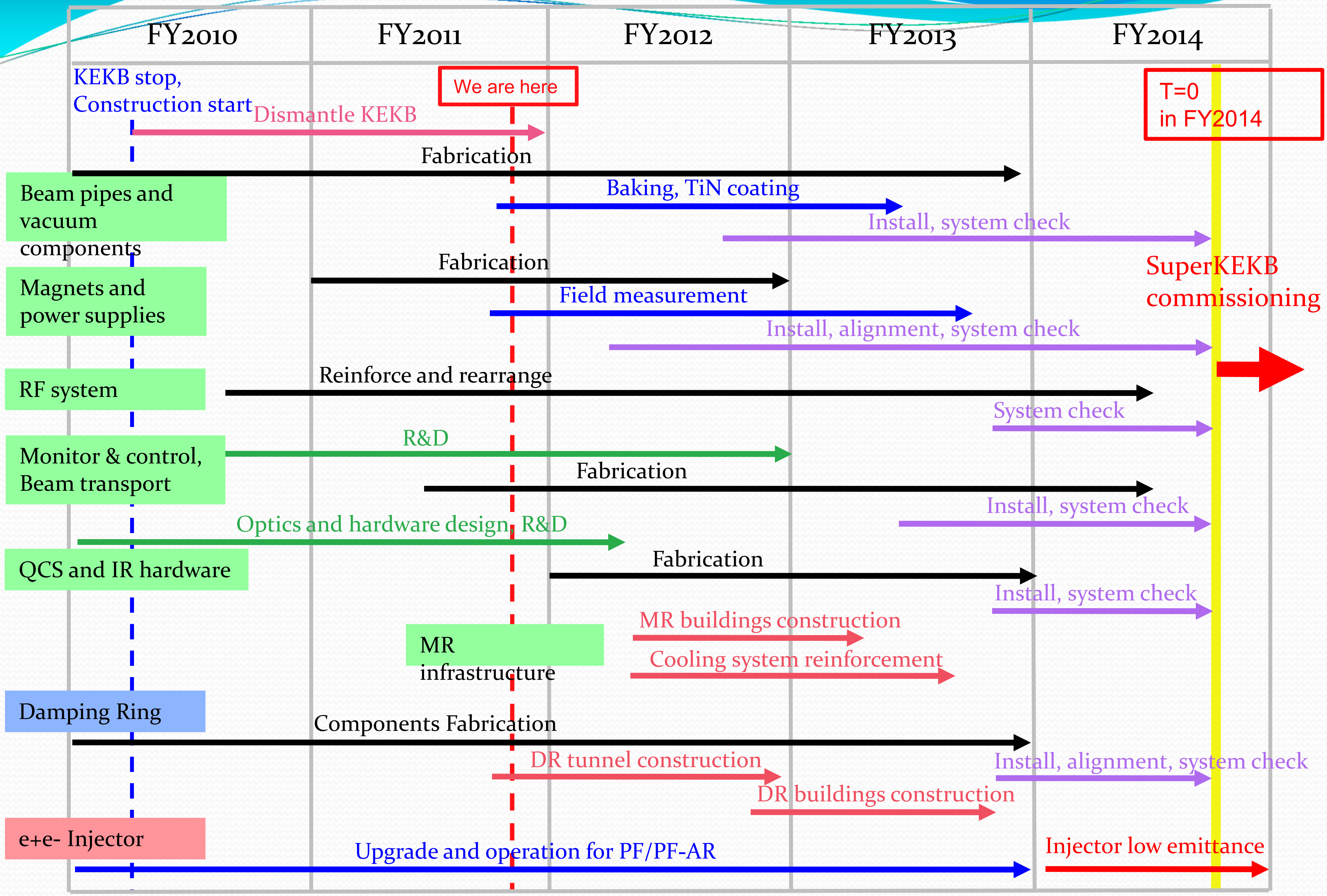
T. Higo, «Linac upgrade in intensity and emittance for SuperKEKB», TUPPR005

Damping Ring

- Design
  - Optics design is almost fixed
  - Beam pipe cross section has been decided from the view point of CSR and beam acceptance
- Components
  - Fabricating magnets and power supplies are ongoing as scheduled
  - Test beam pipes (aluminum, ante-chamber) is being made. Mass production will be conducted in 2012
  - R&D of DR cavity is going on. A prototype cavity has been completed in 2011, and will be high-power tested soon
- Tunnel and buildings
  - Tunnel construction has started. Buildings will be built in 2012 and 2013
- Issue
  - Since tunnel construction was delayed for six months due to the earthquake, installation of components will start only one year before T=0. Schedule in 2014 will be very tight with installation, cabling and piping, system check, etc…

SuperKEKB construction schedule

Revised on Feb. 10, 2012



SuperB Status

SuperB design & progresses

- Large Piwinski angle and crab-waist sextupoles
- Relatively low currents → lower power consumption
- Re-use of some PEP-II components
- Longitudinal polarization of e^- beam (70-80% @ 4.18 GeV)
- Possibility to run at lower energy (τ/charm threshold)
- Twin SC IP doublets of «new» design
- «Green field» accelerator, 5 Km from Frascati Labs
- «Nicola Cabibbo Laboratory» newly constituted will be in charge of construction and operation
- Accelerator management has been appointed and recruitment of the first personnel is in progress
- Design of principal systems is close to be frozen
- A review of the cost estimate is in progress based on the present baseline lattice

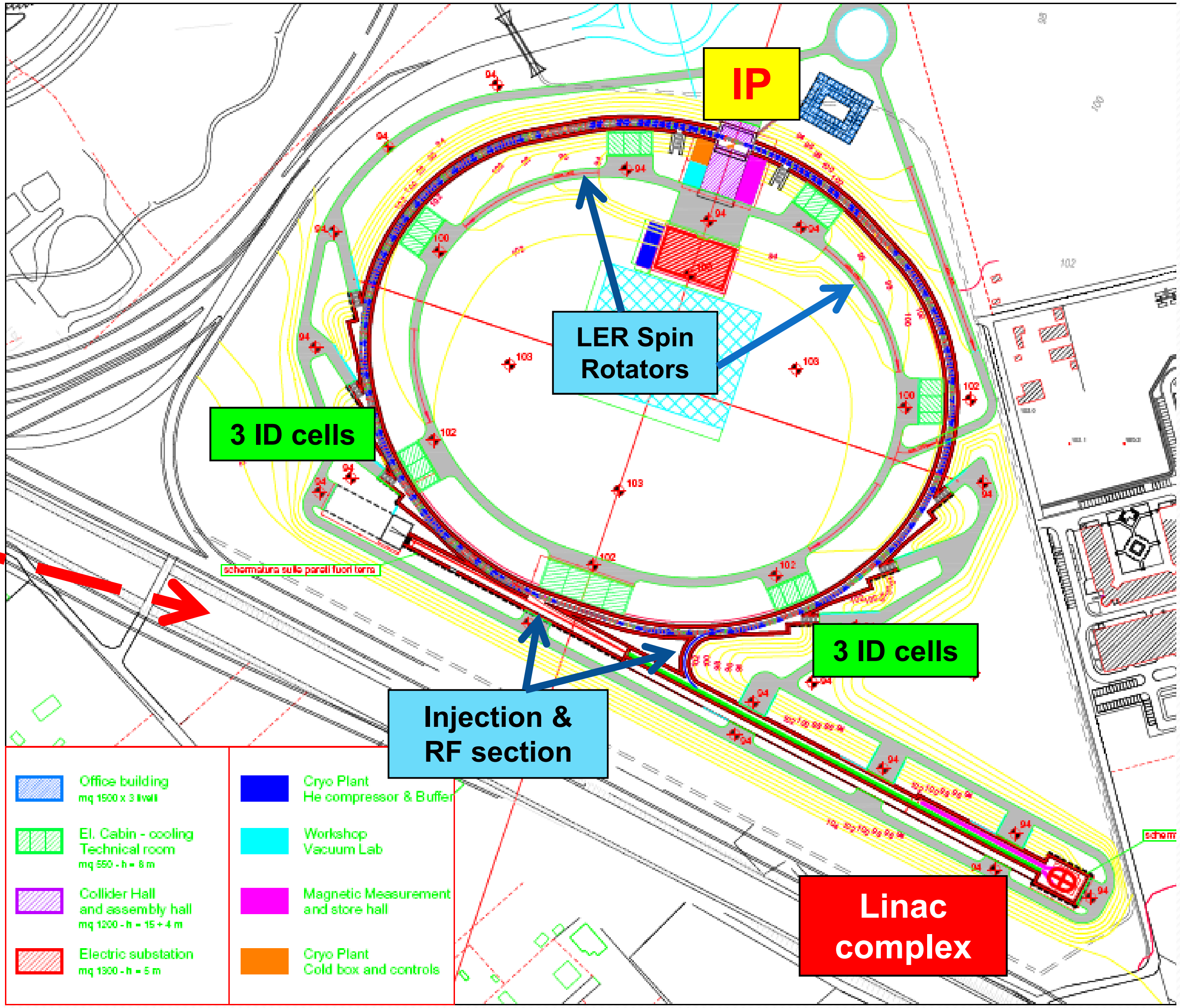
Main Rings

- The two rings have similar geometry and layout, except for the length of dipoles
- The arcs cells have a design similar to that of Synchrotron Light Sources and Damping Rings in order to achieve the very low emittances needed
- Rings are hosted in the same tunnel, separated about 2 m in horizontal and 1 m in vertical (opposite to IP)
- In the latest version of the lattice some cells suitable for SR Insertion Devices have been inserted. This is an open option to be exploited probably after the collider lifetime (tunnel will have possibility to extend SR beamlines from both rings)

Layout @ Tor Vergata University campus

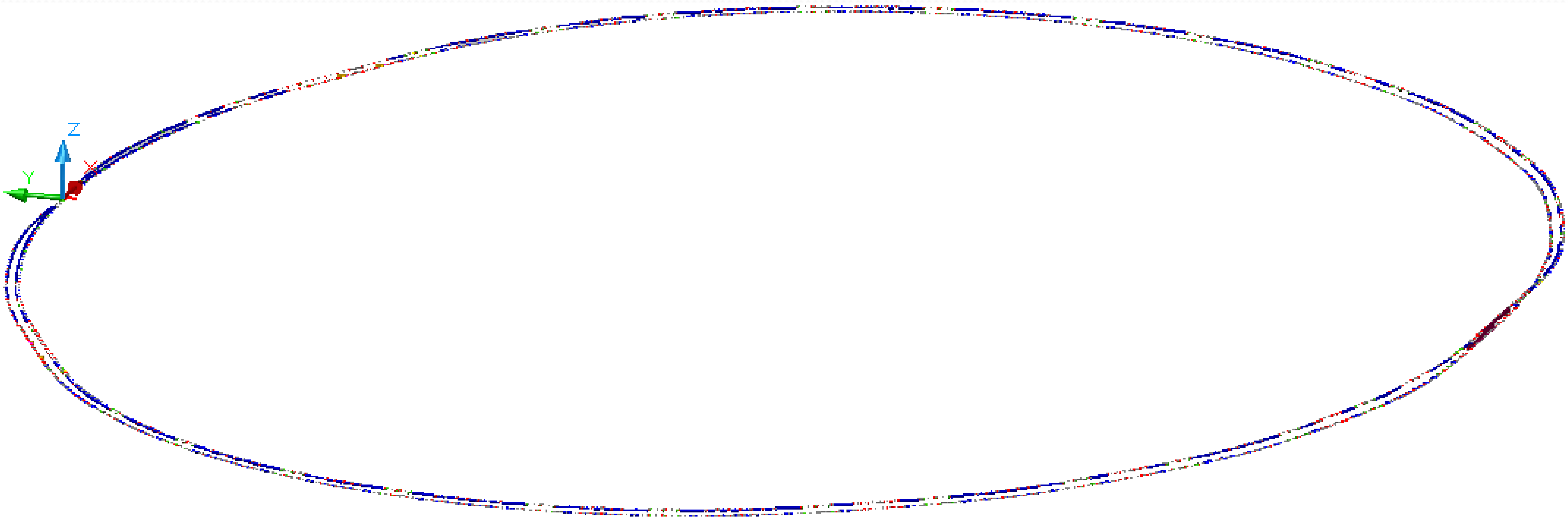
Ground motion measurements performed on site showed very «solid» grounds in spite of the vicinity of the highway, just 100 m away

The highway is at higher level with respect to the site, and the traffic vibrations («cultural noise») are very well damped



Rings layout

- Circumference 1200 m
- Horizontal separation of arc ~2 m
- Vertical separation of RF section 0.9 m



Small tilt at IP (by small solenoids not vertical bends) provides ~1 m vertical separation at the opposite point: (a) e+e- rings separation, (b) better equipment adjustment, (c) SR beamlines from both rings is possible

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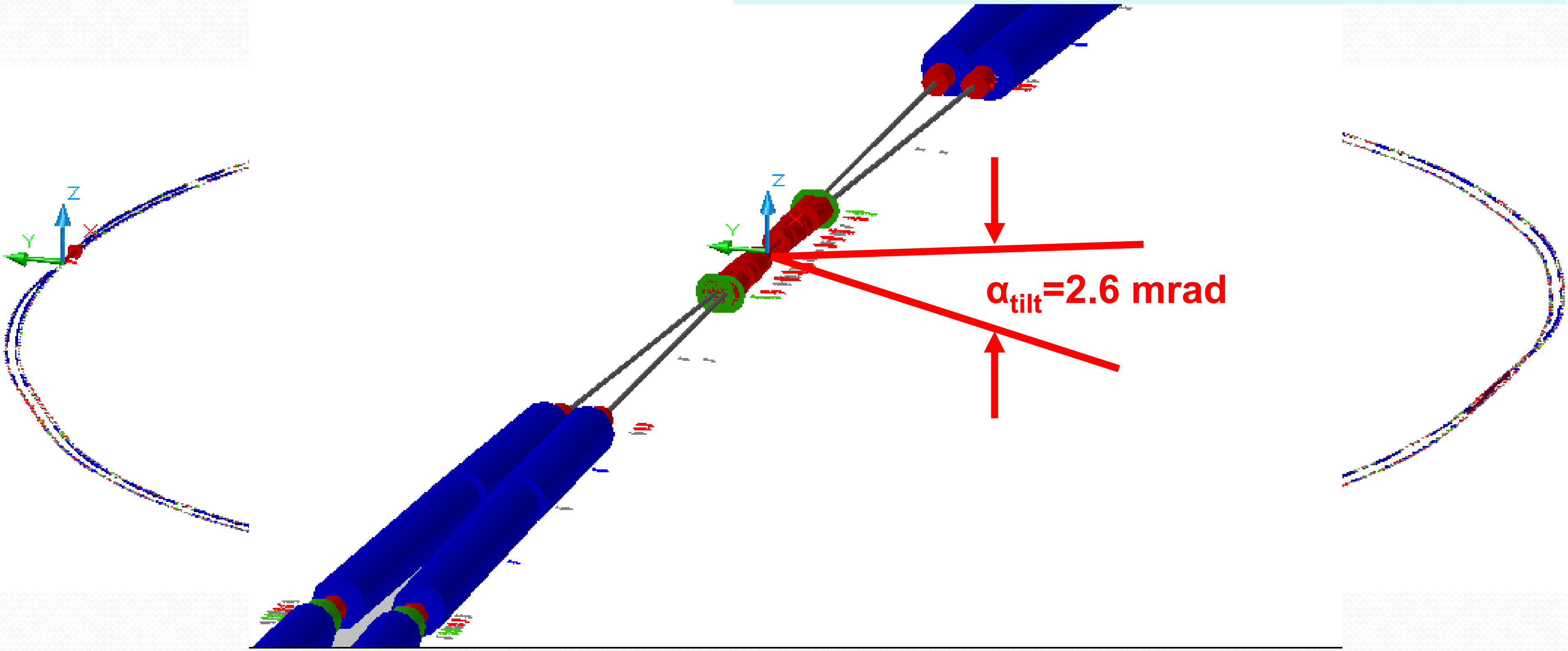

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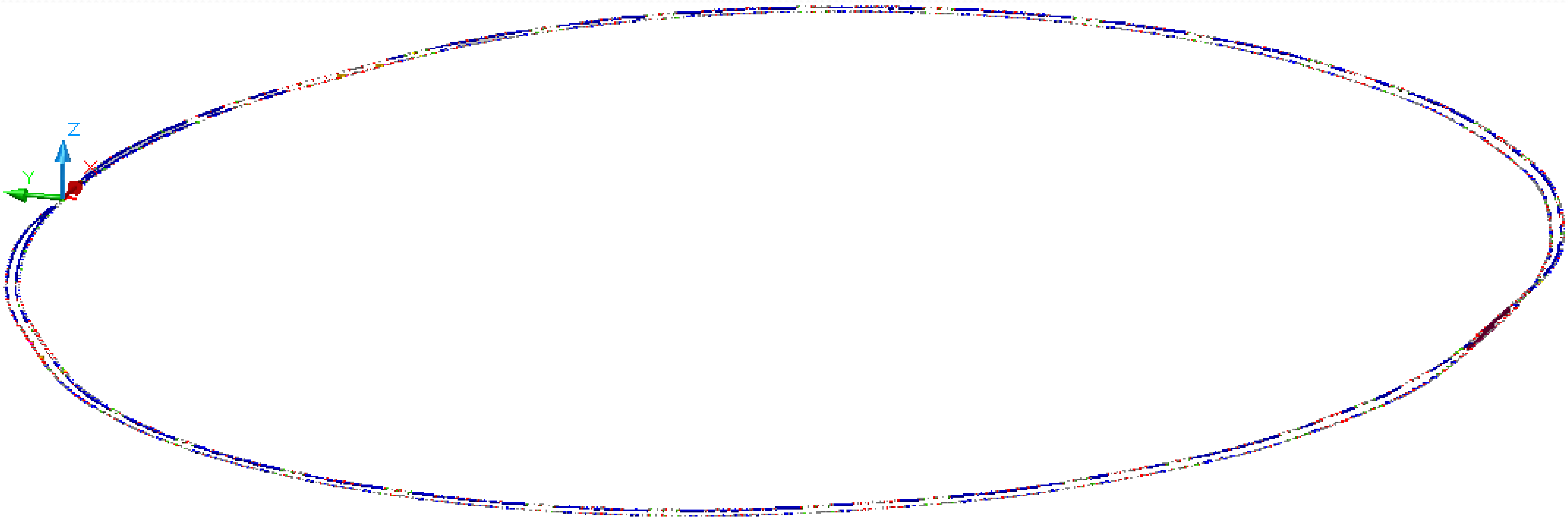

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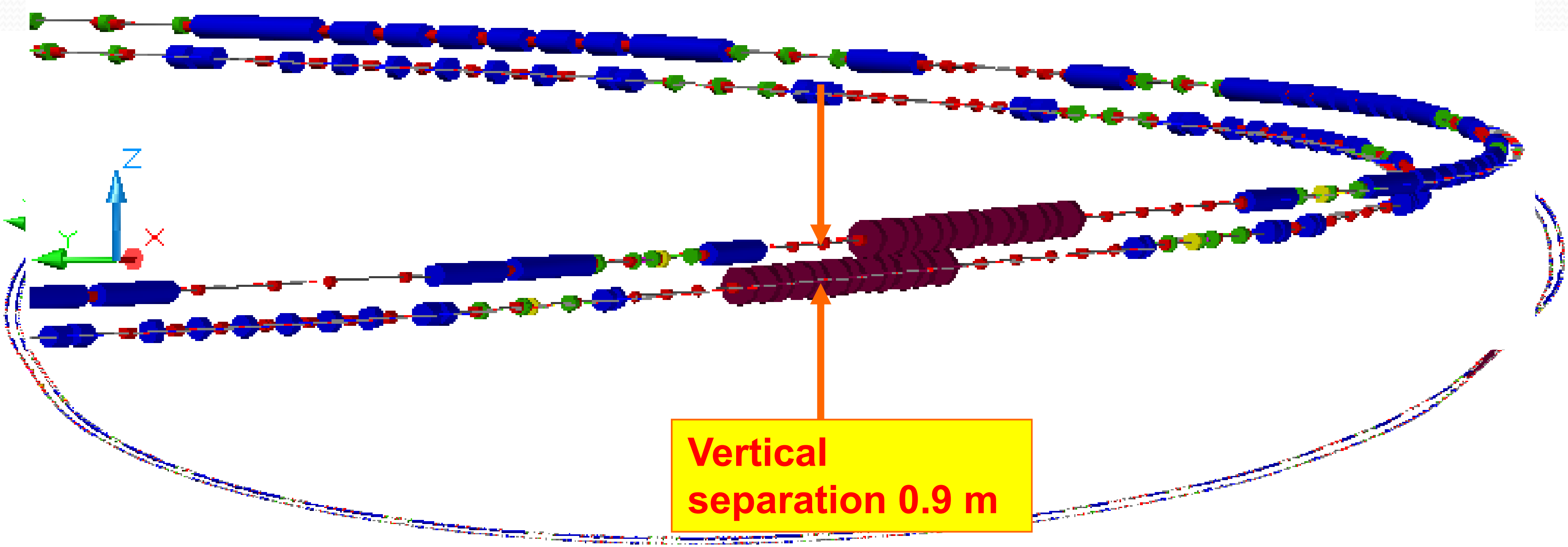

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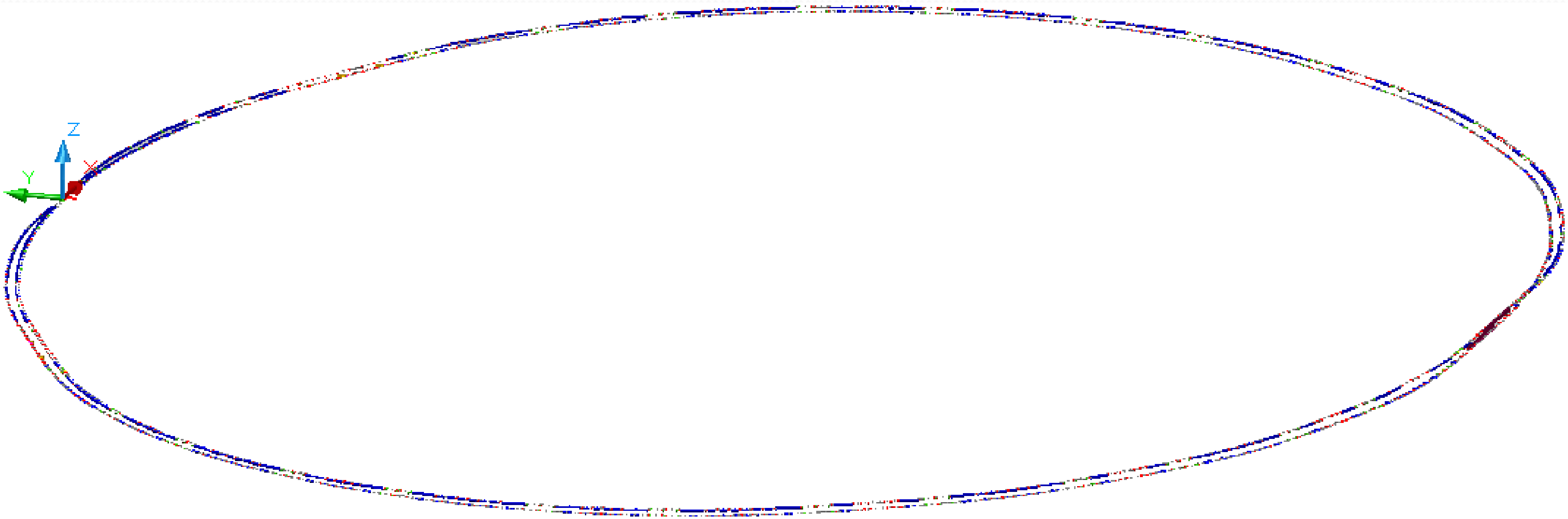

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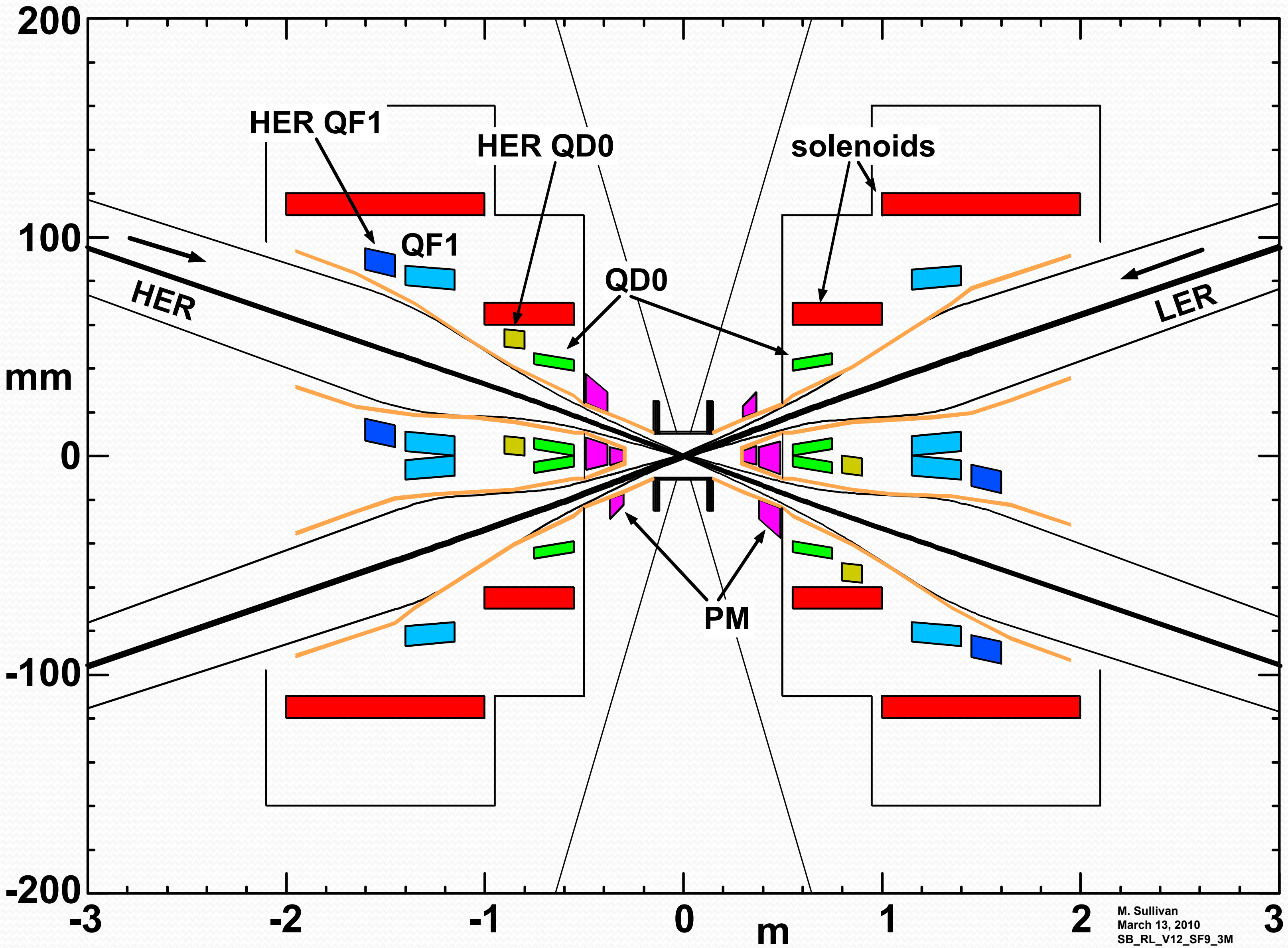
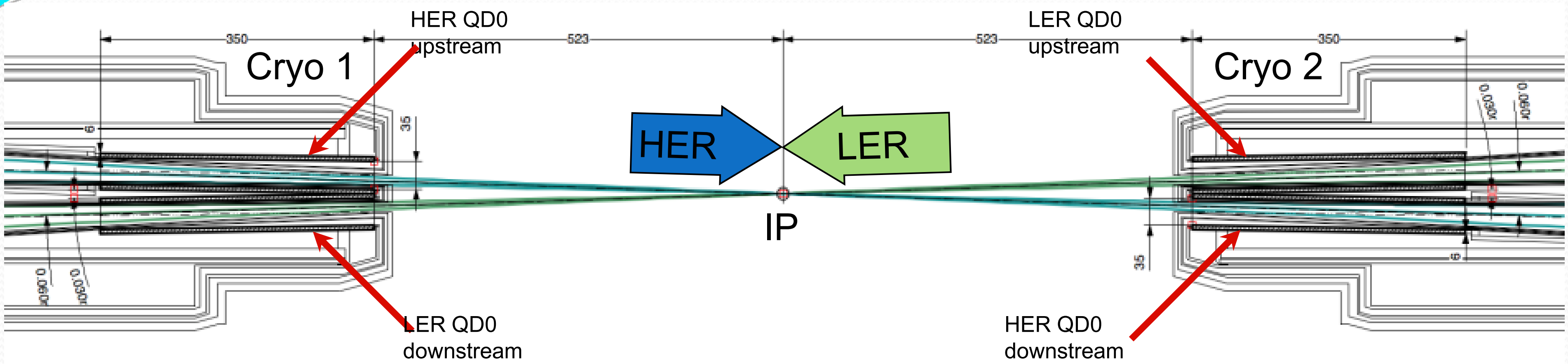
IR design - Cryostat Magnets and PMs

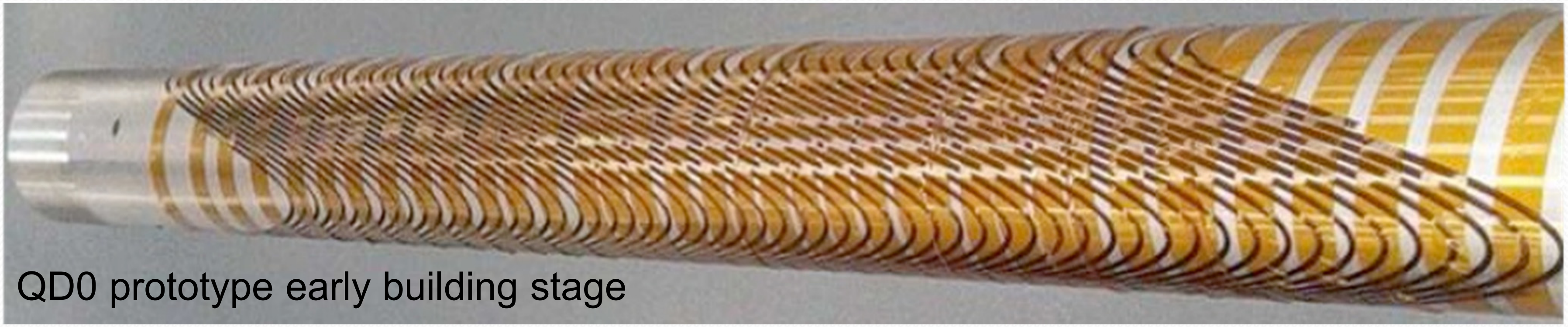


IP doublets design



- With the large crossing angle a shared quadrupole layout is not viable, since the displacement of the magnetic axis with respect to the nominal trajectories will generate unmanageable backgrounds by steering off-energy particles in the detector
- A new design of the first doublet with «twin» quadrupoles was then developed
- They must generate a large field gradient (100 T/m) to obtain β_y~0.2 mm at IP
- The thermal load on the QD0 beam pipe section must be evacuated at room temperature hence a cold pipe design is not feasible

QD0 prototype

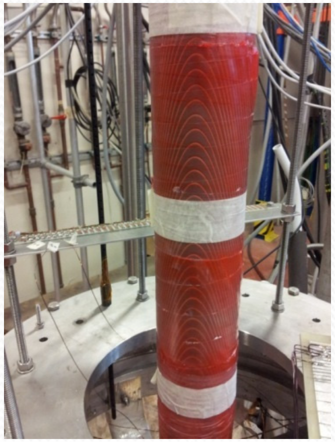


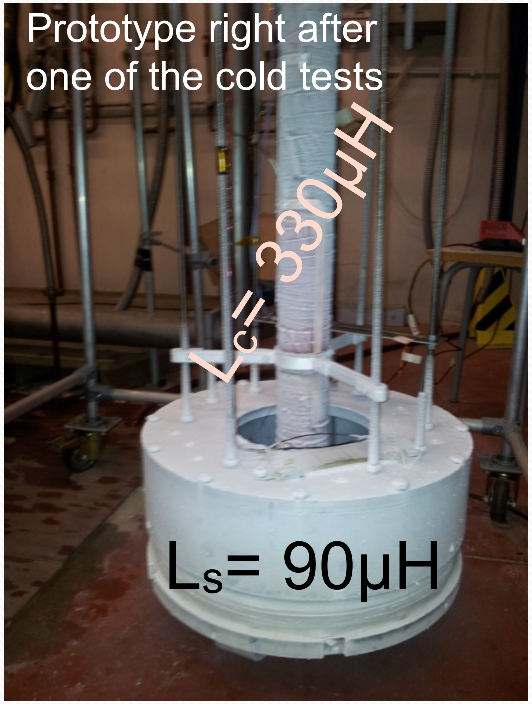
QD0 prototype early building stage

- Main goal of the prototype is to study its behavior during a quench
- Magnetic design is based on the double helical concept
  - Excellent field quality on almost the whole mechanical aperture
  - Possibility to produce arbitrary combinations of multipolar fields by a clever design of the winding shape
- NbTi SC wire for a nominal current of 2650 A
- Inner bore diameter is 50 mm to accommodate for a rotating coil device to measure the generated field quality

Cold test of the QD0 prototype

- An SC current transformer was built to feed the prototype
- The model was successfully tested. IT WORKS!
- Training process started at ~ 2300 A with the first quench. The magnet quickly improved its maximum current handling capability operating in steady state at its design current
- The subsequent quenches occurred at current exceeding 2750 A. The limitation seemed to be of mechanical nature. Further test are under way for better investigate this aspect





Backgrounds studies

- SuperB developed a fairly good set of tools to understand and predict the backgrounds features
- Background rates at IR are under control with an efficient H & V collimation system in the FF
- More beam-gas simulation studies under variable pressure along ring are in progress
- Technical Design of realistic collimators is planned

Touschek	HER	LER
No collimators, ε_x with IBS	2.5 GHz	17 GHz
With Collimators, ε_x with IBS	**7 MHz**	**100 MHz**

IR (<2m) Loss Rates

Coulomb No collimators, ε_x with IBS	11 GHz	25 GHz
Coulomb with collimators, ε_x with IBS	**11MHz**	**36 MHz**
Bremsstrahlung with coll	130KHz	450KHz

M. Boscolo, December 14th 2011

Primary Loss Rate	HER	LER
Touschek lifetime	τ_{TOU} (min)	τ_{TOU} (min)
No collimators, nominal ε_x (no IBS)	26.3	7.4
No collimators, ε_x with IBS	26	10.2
With Collimators, ε_x with IBS	22	7.9
Coulomb	76min	39 min
Bremsstrahlung	72 hrs	77 hrs

M. Boscolo, December 14th 2011

Touschek vs Rad. Bhabha

- LER Touschek IR loss rate 100 MHz vs Rad Bhabha 10 GHz
- But: the Touschek losses are fairly energetic ~ 4 GeV while the radiative Bhabha are quite soft
- The energy spectrum and the angular distributions of the secondaries are quite different.
- The total rate of the secondaries from Touschek is smaller
- The energy spectrum of the secondaries

Rad-Bhabha Losses at the Beam-pipe

Total rates around the IP (-3 to 3 mts)

HER positron rates

E range (GeV)	Rate (GHz)
0.0 – 1.0	4.735
1.0 – 2.0	2.789
2.0 – 3.0	0.025
3.0 – 4.0	0.003
4.0 – 5.0	0.003
5.0 – 6.0	0.003
6.0 – 7.0	0.005
0.0 – 7.0	7.563

LER electron rates

E range (GeV)	Rate (GHz)
0.0 – 1.0	7.863
1.0 – 1.5	2.289
1.5 – 2.0	0.031
2.0 – 2.5	0.007
2.5 – 3.0	0.004
3.0 – 3.5	0.005
3.5 – 4.2	0.003
0.0 – 4.2	10.202

Touschek	HER	LER
No collimators, ε_x with IBS	2.5 GHz	17 GHz
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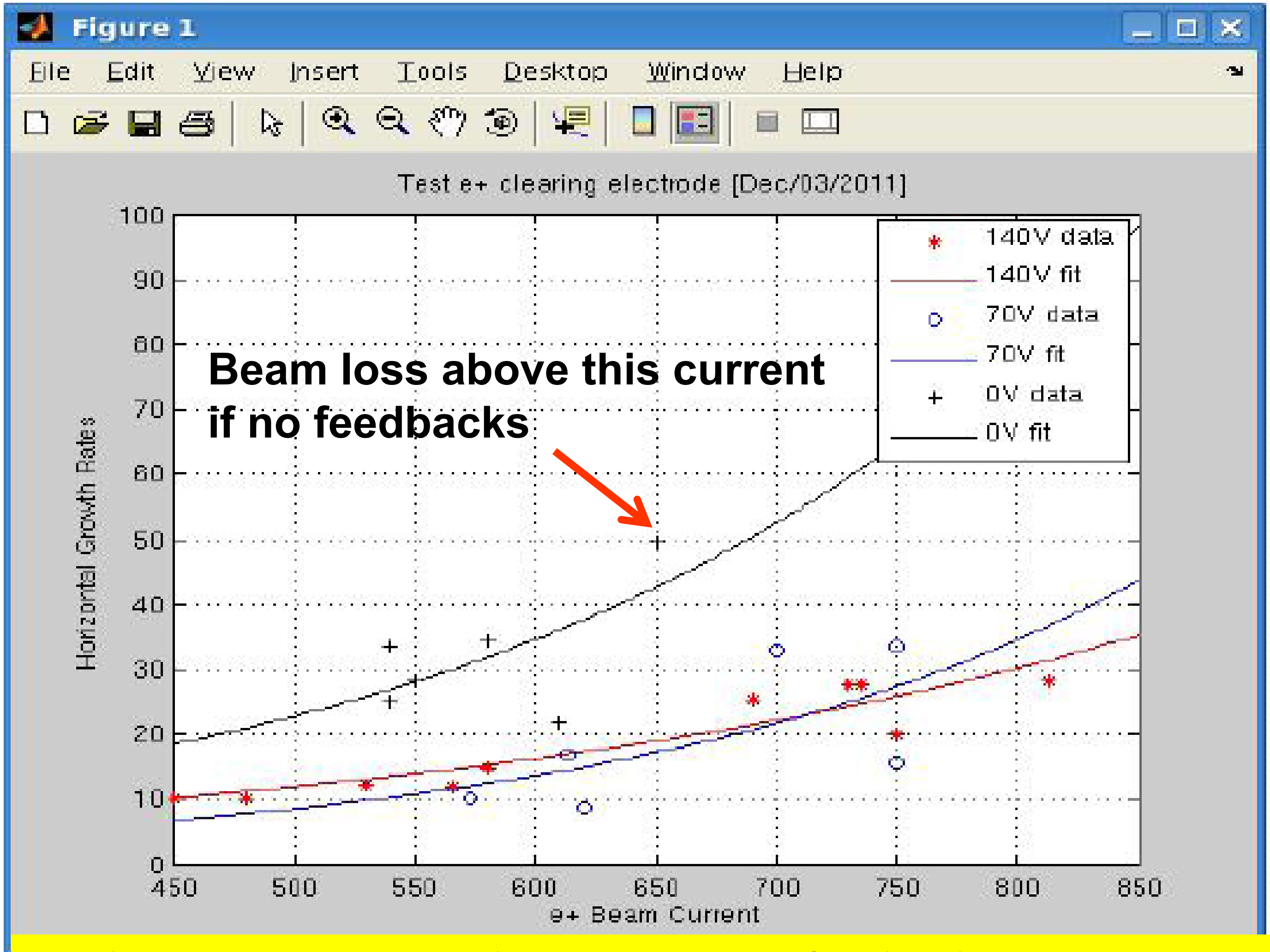
Test of e-cloud clearing electrodes at DAΦNE

Horizontal growth rate measurements



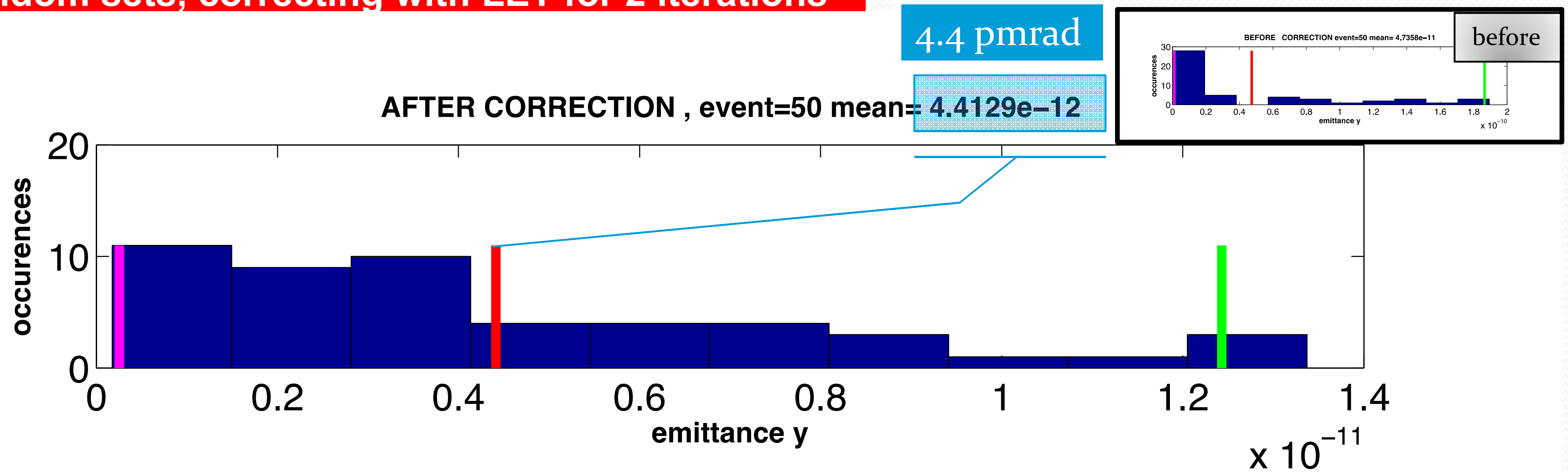
Very positive results: vertical beam dimension, tune shift and growth rates clearly indicate the good behaviour of these devices, which are complementary to solenoidal windings in field free regions

D. Alesini, «Experimental measurement of e-cloud mitigation at DAΦNE»,TUOBC03

Low Emittance Tuning

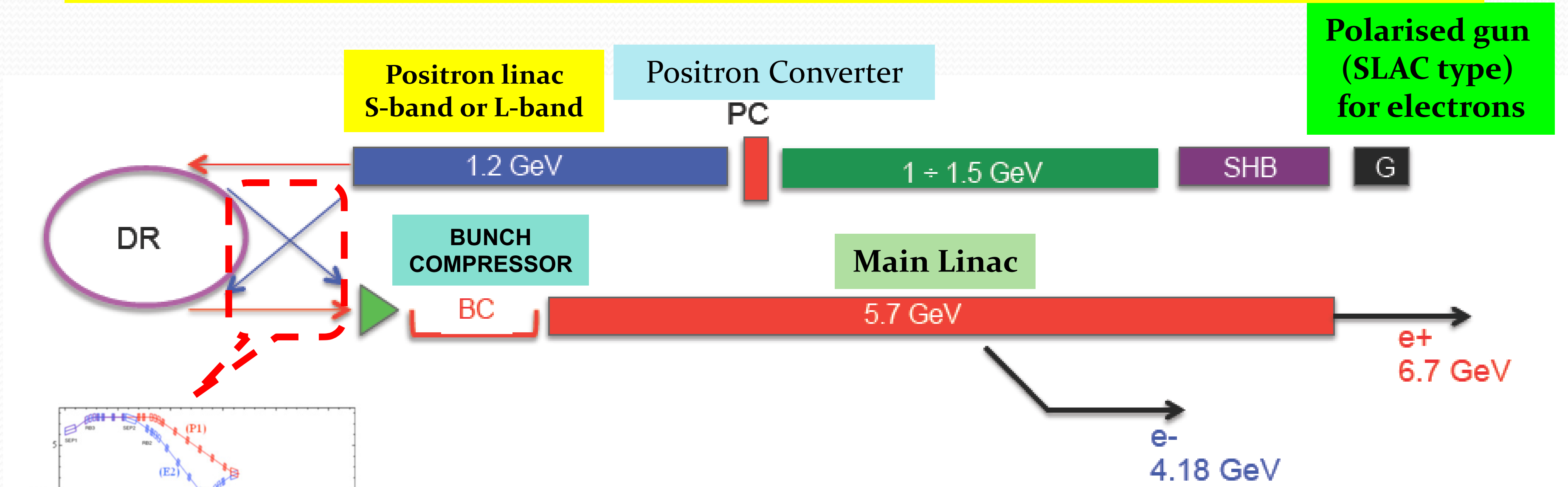
- Extremely low beam emittances → careful correction of all magnets and BPM alignment and field errors
- An efficient and fast tool has been implemented (talk by S. Liuzzo TUOAA03) and tested at DIAMOND and SLS, to correct orbit-dispersion-coupling and to detect the source of magnet and BPM errors
- Tables of error tolerances are being produced for SuperB

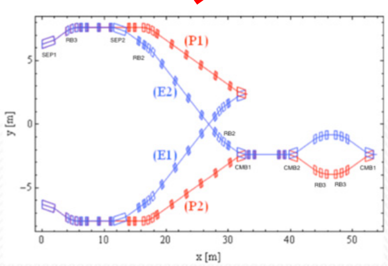
50 random sets, correcting with LET for 2 iterations



New injection system layout

S. Guiducci, "Baseline design of the SuperB Factory Injection System", THPPR088





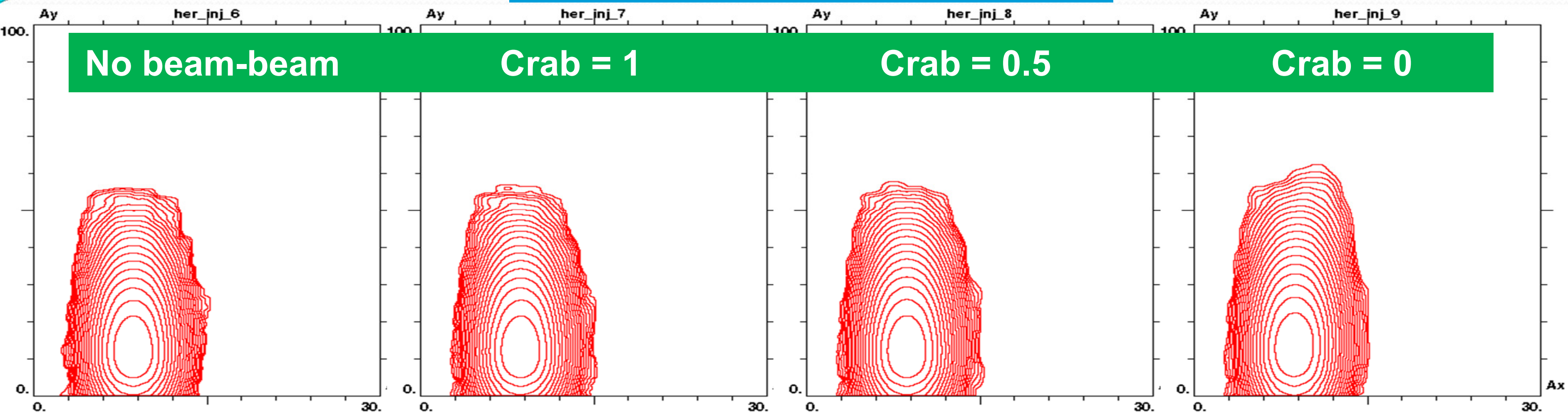
Transfer lines
Positron Source to Damping Ring (PSDR)
Damping Ring to Main Linac (PDRL)
Electron Source to Damping Ring (ESDR)
Damping Ring to Main Linac (EDRL)
Main Linac to HER (PLMR)
Main Linac to LER (ELMR)

Recent progresses:

- **Final design with DR for electrons too**
- **Start-to-end simulation**
- **Design of PSDR, ESDR and bunch compressor**
- **Options for e+ Linac still open (S-band or L-band)**
- **Design of Main Linac**
- **PLMR and ELMR to be modified**

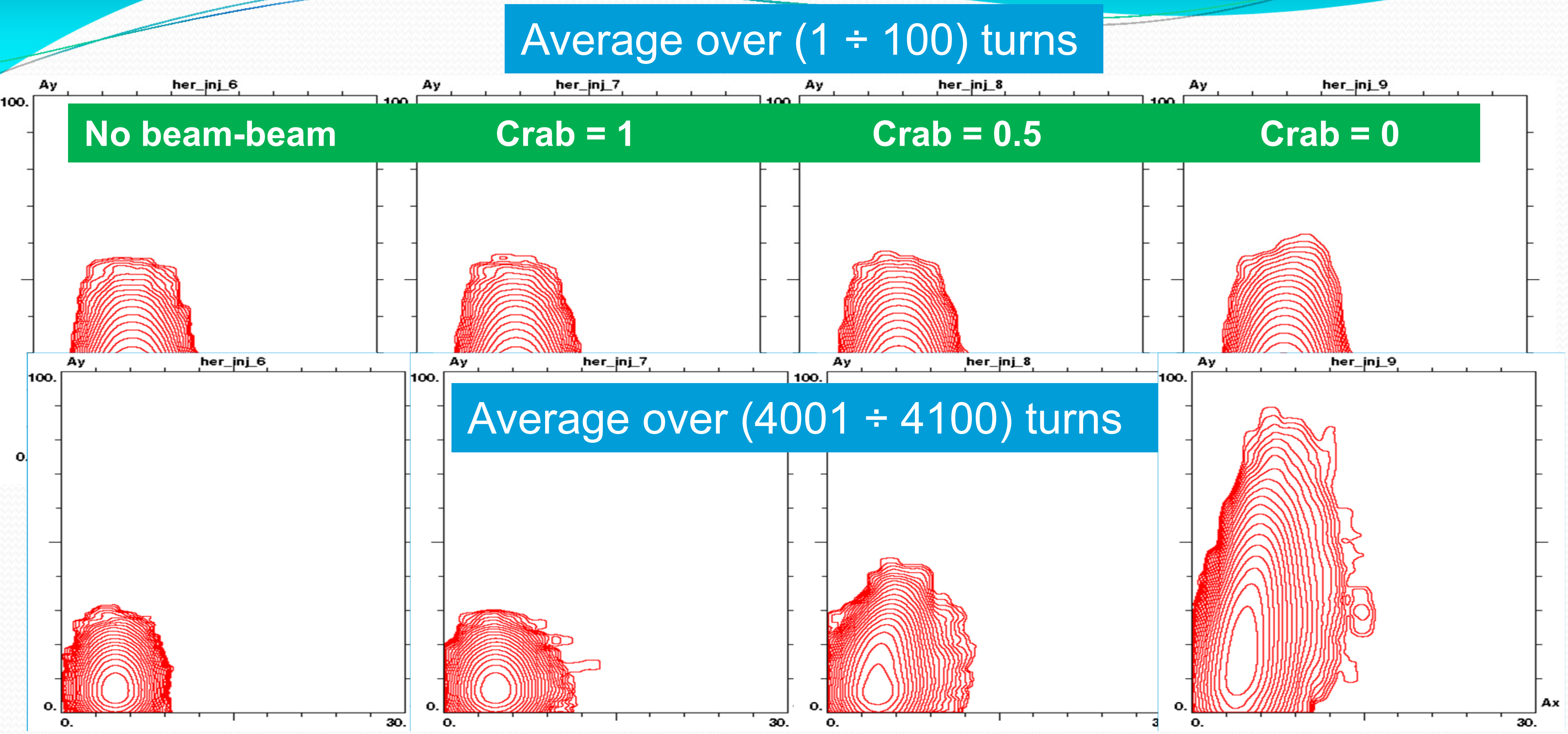
Injection tracking with beam-beam

Average over (1 ÷ 100) turns



Contour plots of the injected beam distribution in the plane of normalized betatron amplitudes. 10^5 particles were tracked, and their coordinates over 100 consecutive turns were collected to build the distribution.

Injection tracking with beam-beam

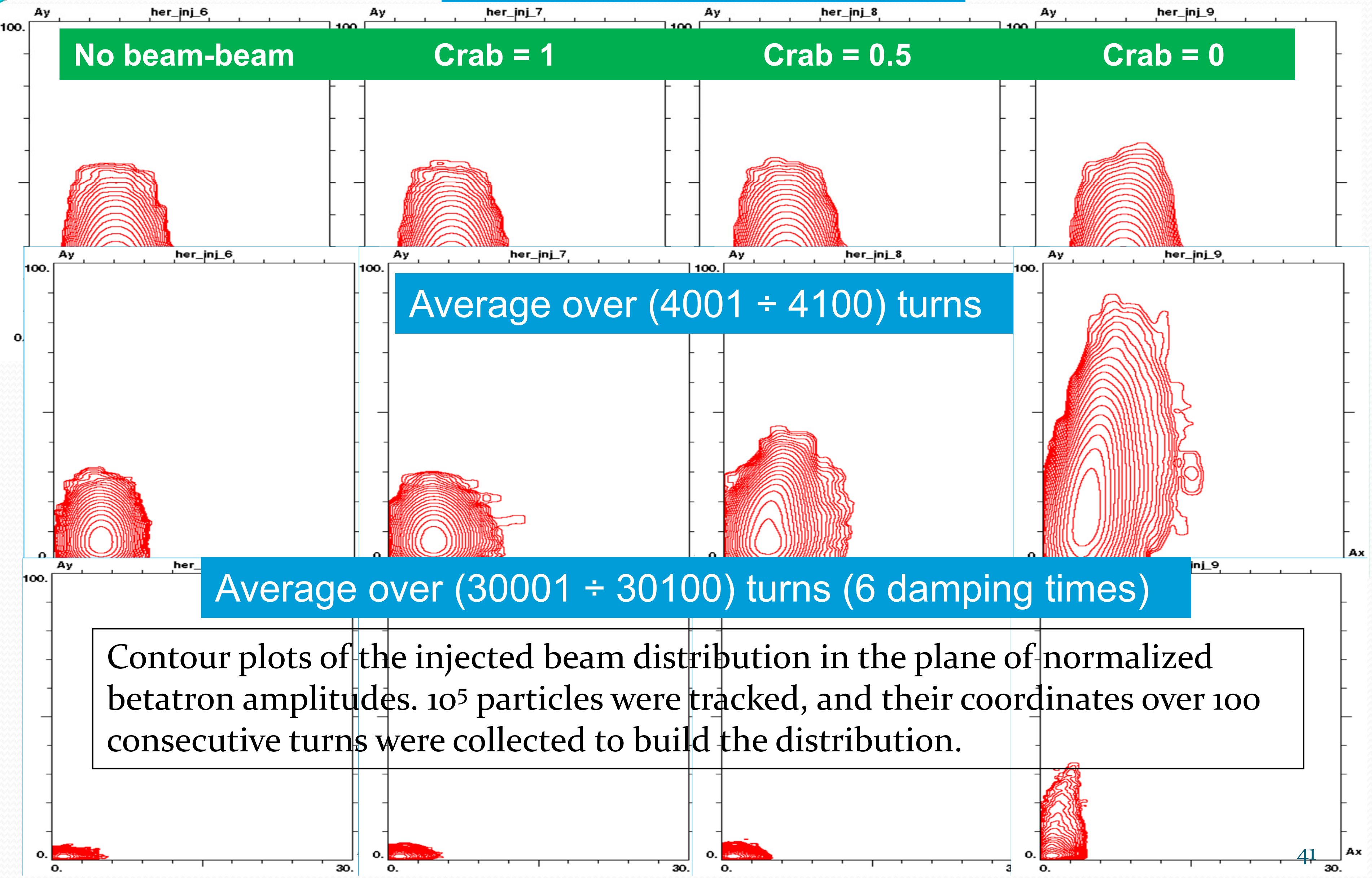


Contour plots of the injected beam distribution in the plane of normalized betatron amplitudes. 10^5 particles were tracked, and their coordinates over 100 consecutive turns were collected to build the distribution.

Injection tracking with beam-beam

Average over (1 ÷ 100) turns

No beam-beam	Crab = 1	Crab = 0.5	Crab = 0



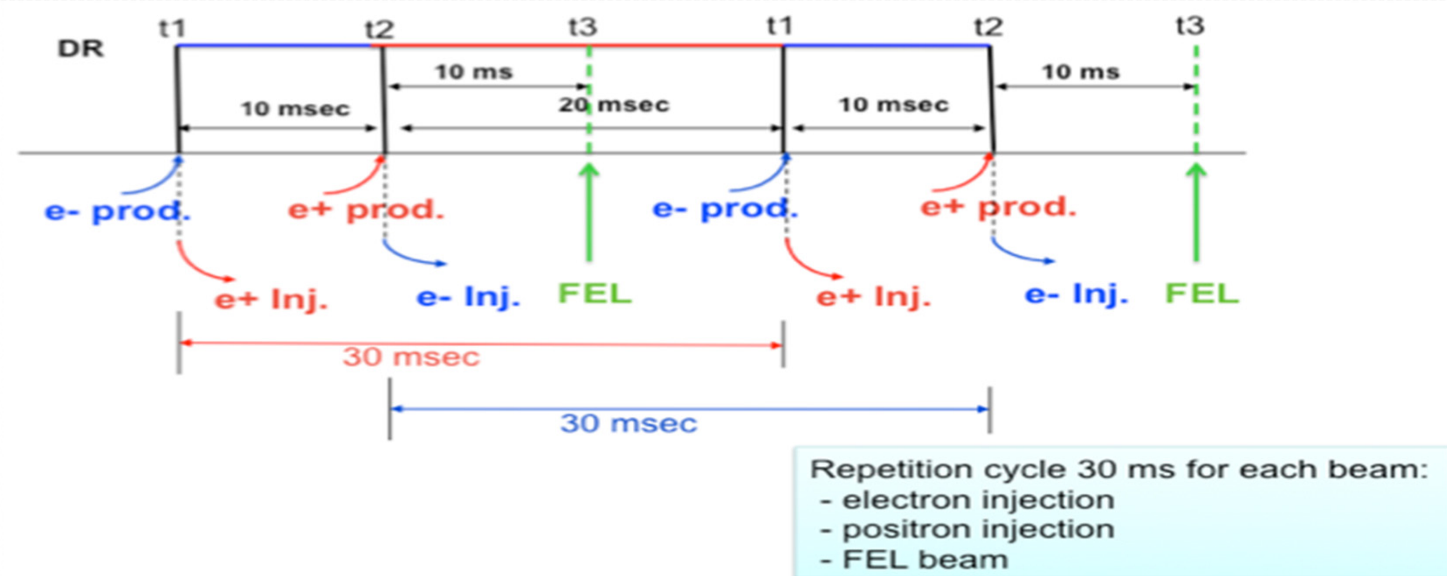
Average over (4001 ÷ 4100) turns

Average over (30001 ÷ 30100) turns (6 damping times)

Contour plots of the injected beam distribution in the plane of normalized betatron amplitudes. 10^5 particles were tracked, and their coordinates over 100 consecutive turns were collected to build the distribution.

SuperB as a SASE X-FEL

- The possibility to drive a SASE Hard-X FEL using the 6 GeV e^- linac has been recently considered
- A preliminary design study, based on FEL scaling laws supported by HOMDYN and GENESIS simulations, shows that a FEL source in the range of 1-3 Ang can be implemented still preserving the compatibility with the collider operation
- Linac repetition frequency is 100 Hz → accelerate a pulse for the X-FEL during the store time of e^+ in the DR, without affecting injection rate into MR → repetition cycle of 30 ms for each beam is possible: e^+ injection, e^- injection and a dedicated linac pulse for X-FEL



Conclusions

- SuperKEKB:
  - Construction work is going on in full swing, in parallel with recovery work from the 2011 earthquake
  - Design work still remains, in particular for very difficult parts like the IR
  - Beam commissioning is scheduled in 2014

- SuperB:
  - Design almost finalized in all sub-systems
  - Cabibbo Lab in charge of construction and operation
  - Management of Accelerator in place, hiring of some personnel in progress
  - New full cost analysis in progress
  - R&D on some specific topics still in progress
  - MOU with several international laboratories in preparation

Thank you for your attention