Crab Waist collisions in Dafne and SuperB design

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for the Dafne and SuperB teams
EPAC08

DAFNE upgrade team

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Outline

- Short summary on the upgrade
- Commissioning history
- Collider optical parameters
- Low current results
- High current operation
- Present performance
- Conclusions

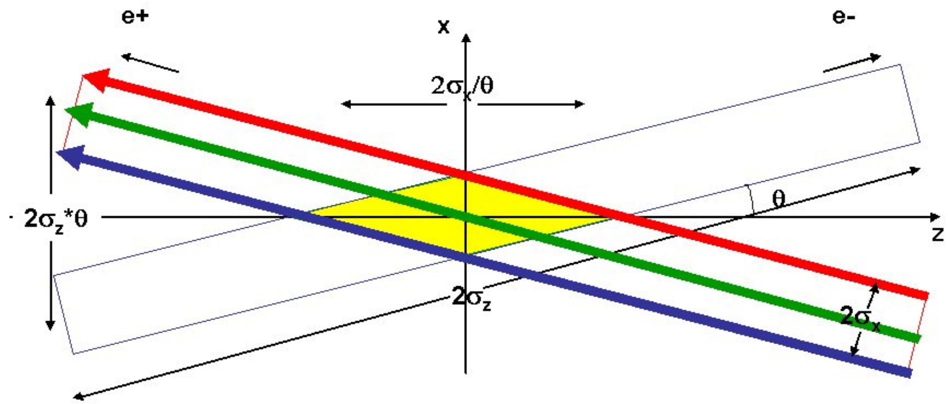
Large Piwinski angle $\Phi_{P=}\theta\sigma_z / \sigma_x$

Geometric luminosity gain

Very low horizontal tune shift

No parasitic collisions

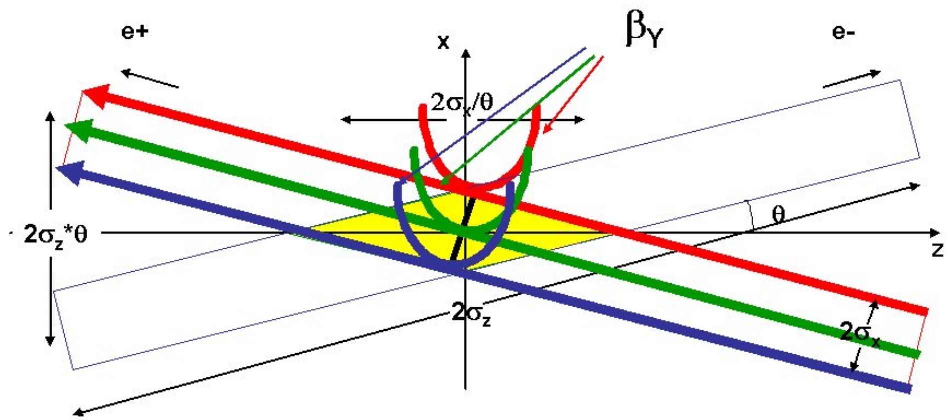
short overlap region



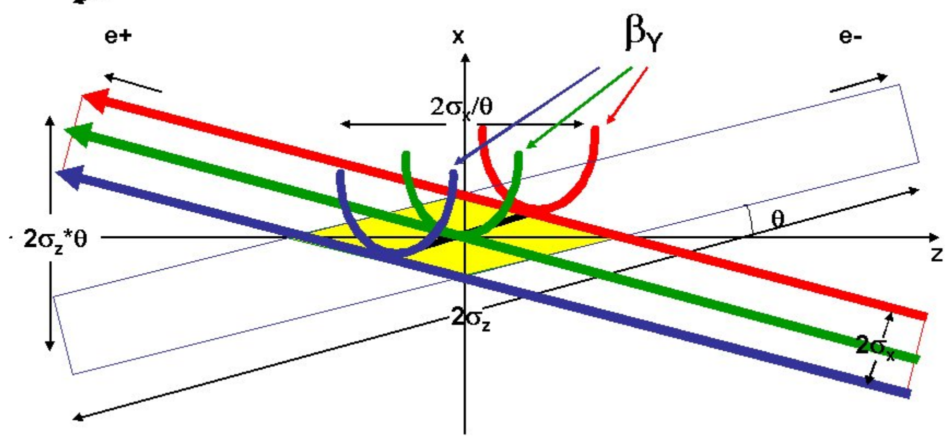
small β_y* (β_y* ~σ_x /θ)

Geometric luminosity gain

low vertical tune shift



Crab waist transformation (realized with two sextupoles @π in x and 1.5π in y from IP)

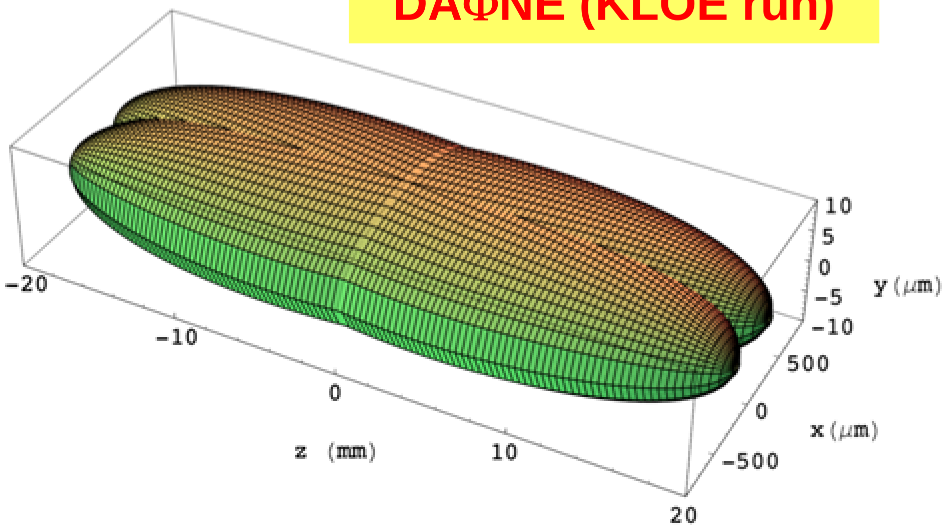


Geometric luminosity gain

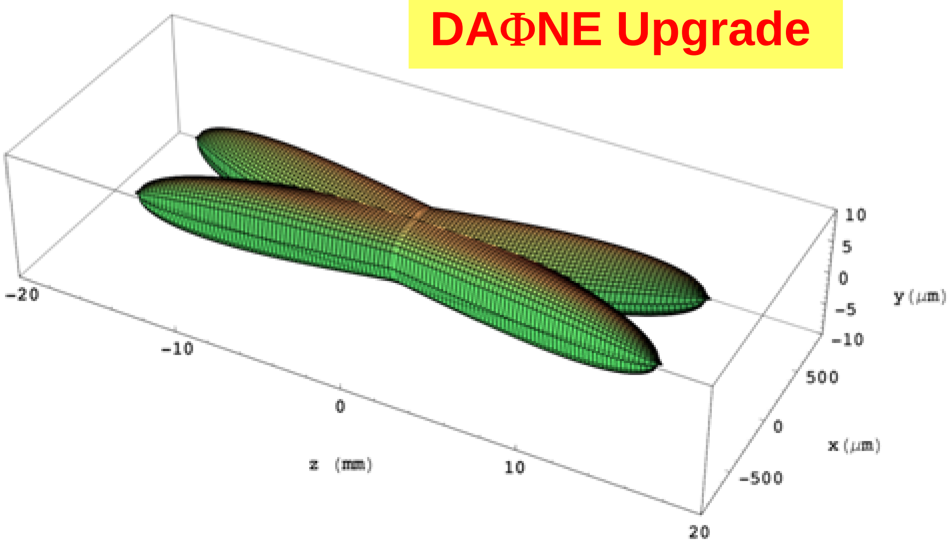
Suppression of X-Y betatron and synchrobetatron resonances

BEAM PROFILES @IP AND NEW PARAMETERS

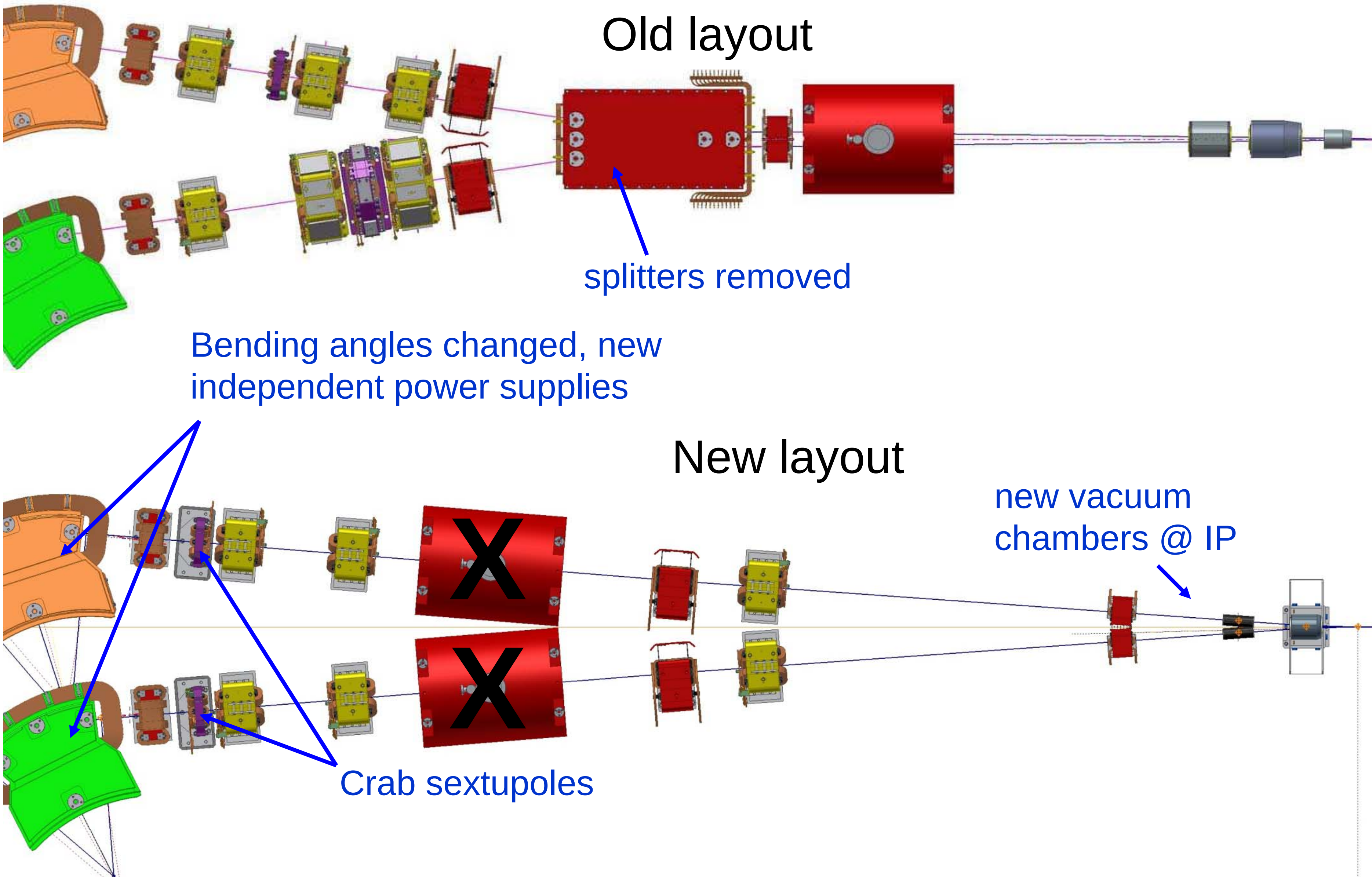
DAΦNE (KLOE run)

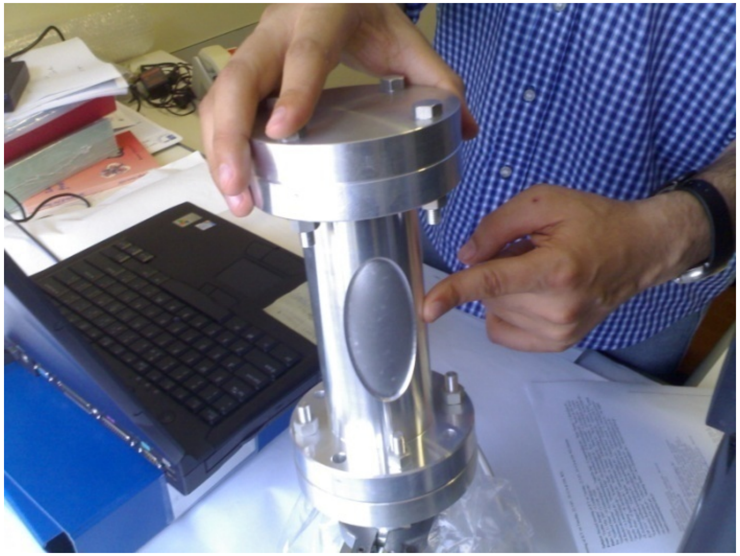


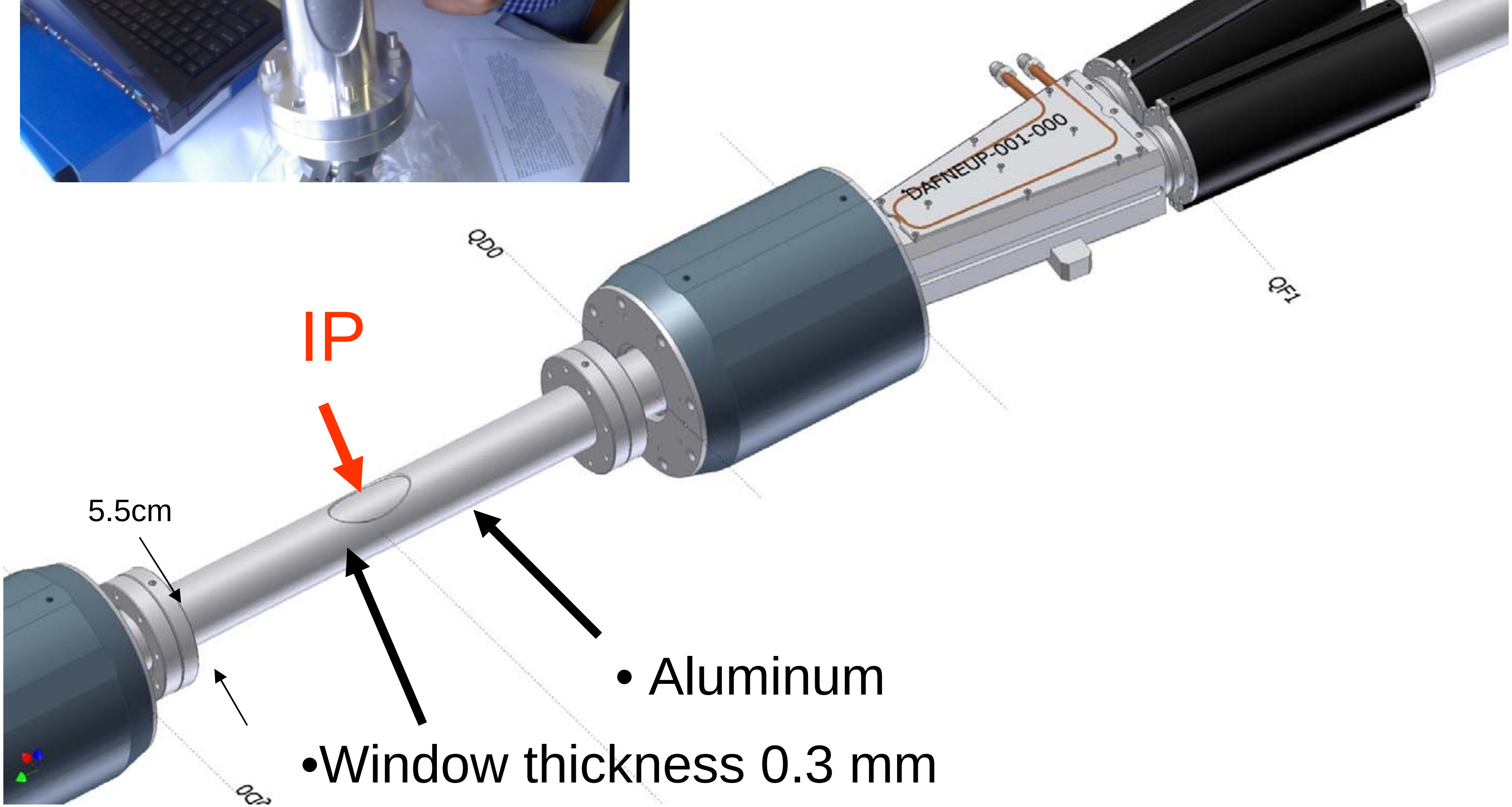
DAΦNE Upgrade



	DAΦNE (KLOE run)	DAΦNE Upgrade
I_{bunch} (mA)	13	13
N_{bunch}	110	110
β_y^* (cm)	1.7	0.65
β_x^* (cm)	170	20
σ_y^* (μm)	7	2.6
σ_x^* (μm)	700	200
σ_z (mm)	25	20
Horizontal tune shift	0.04	0.008
Vertical tune shift	0.04	0.055
θ_{cross} (mrad) (half)	12.5	25
$\Phi_{Piwinski}$	0.45	2.5
L ($cm^{-2}s^{-1}$)	1.5×10^{32}	$>5\times10^{32}$

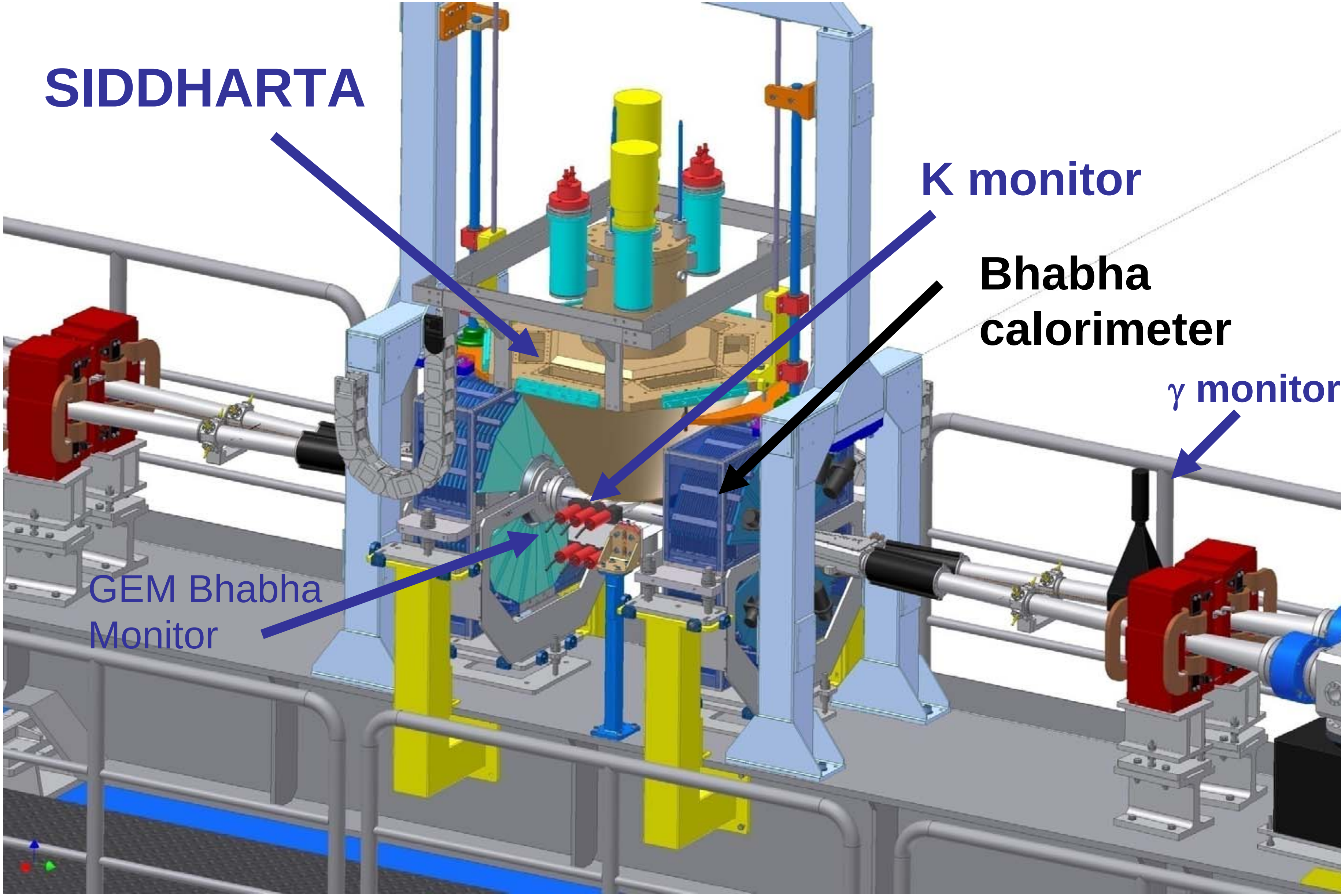

Old layout
splitters removed
Bending angles changed, new
independent power supplies
New layout
new vacuum
chambers @ IP
X
X
Crab sextupoles



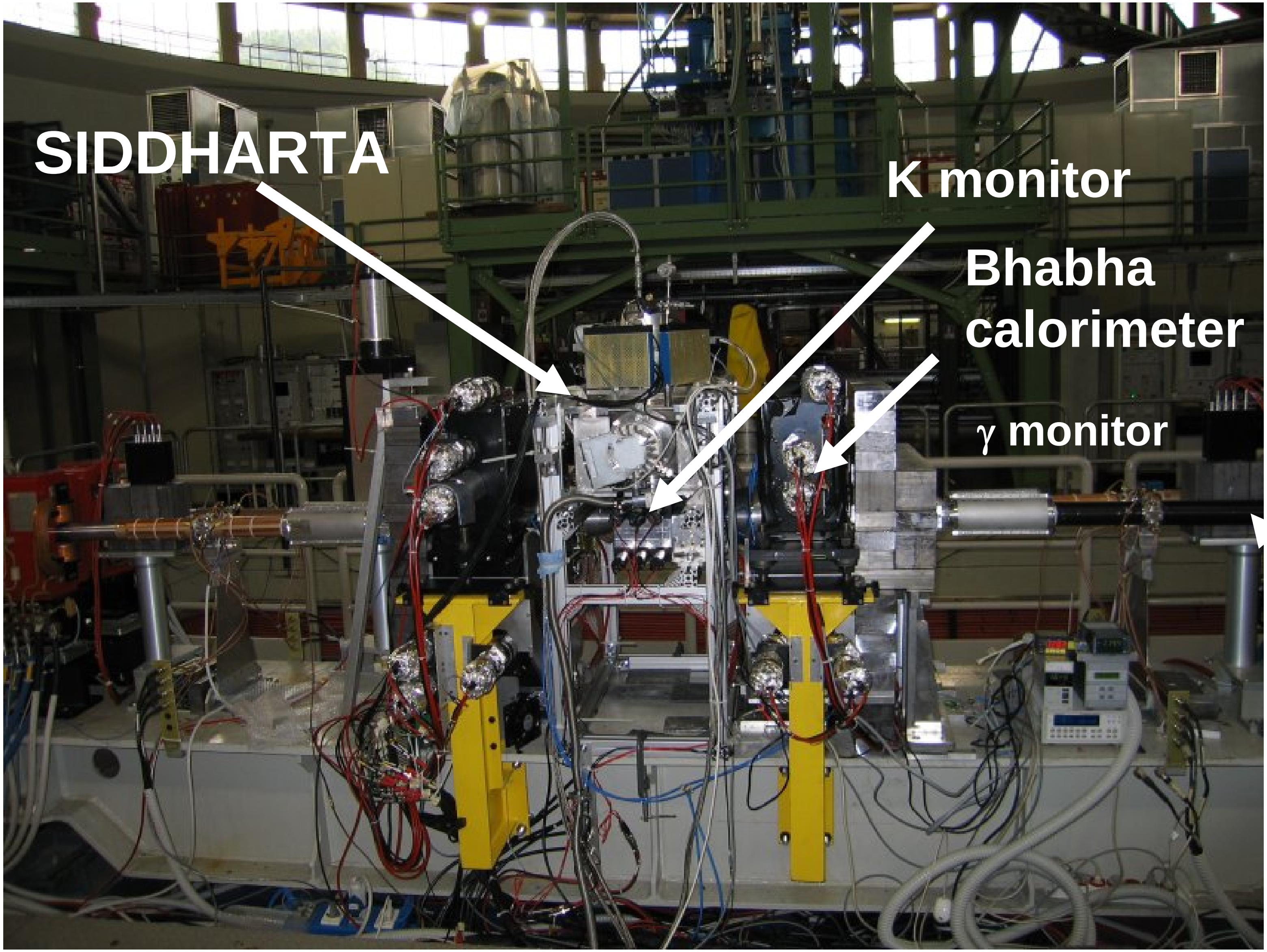


- Aluminum
- Window thickness 0.3 mm

IP LAYOUT AND LUMINOSITY MONITORS

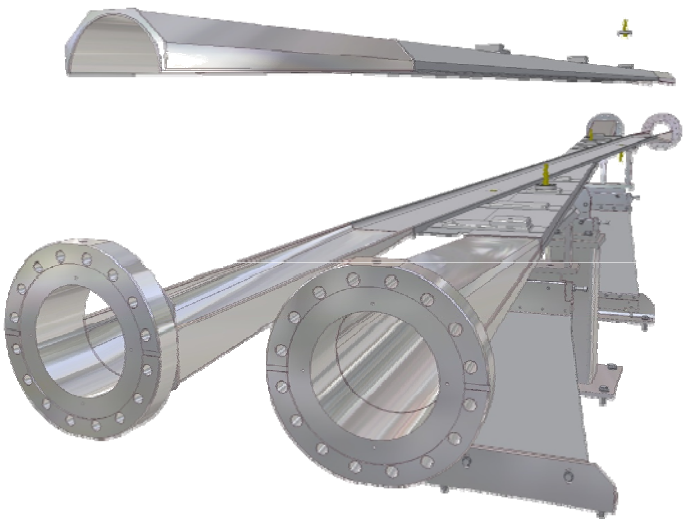


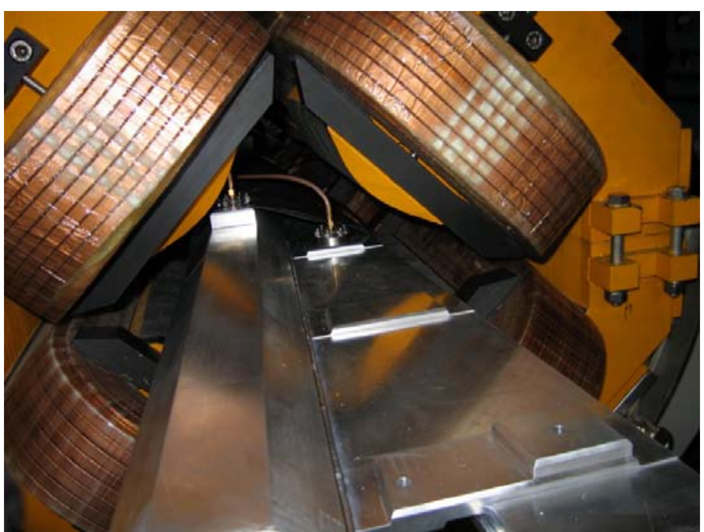
IP LAYOUT AND LUMINOSITY MONITORS

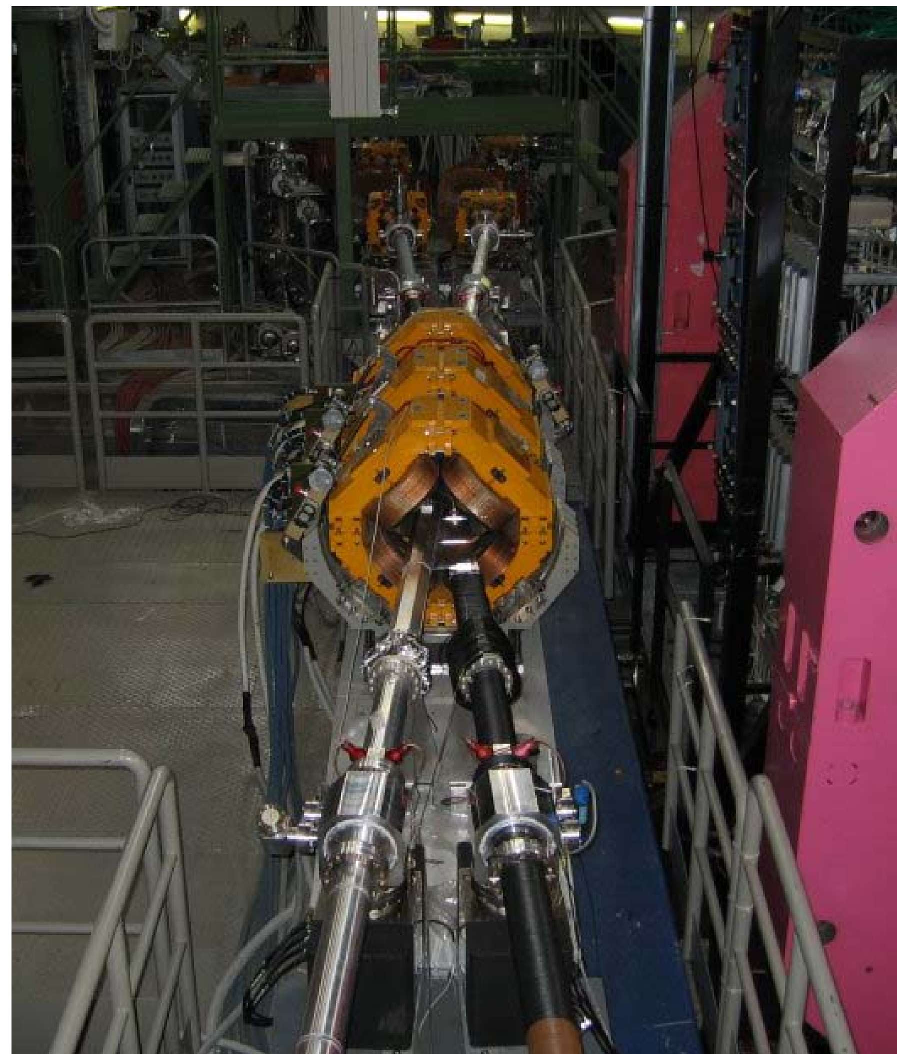


SECOND CROSSING REGION LAYOUT

- Second crossing region ***symmetric*** with respect to first one (Possibility to use it as an alternative interaction point)
- "Half Moon" chamber allows complete beam separation (no 2nd IP)







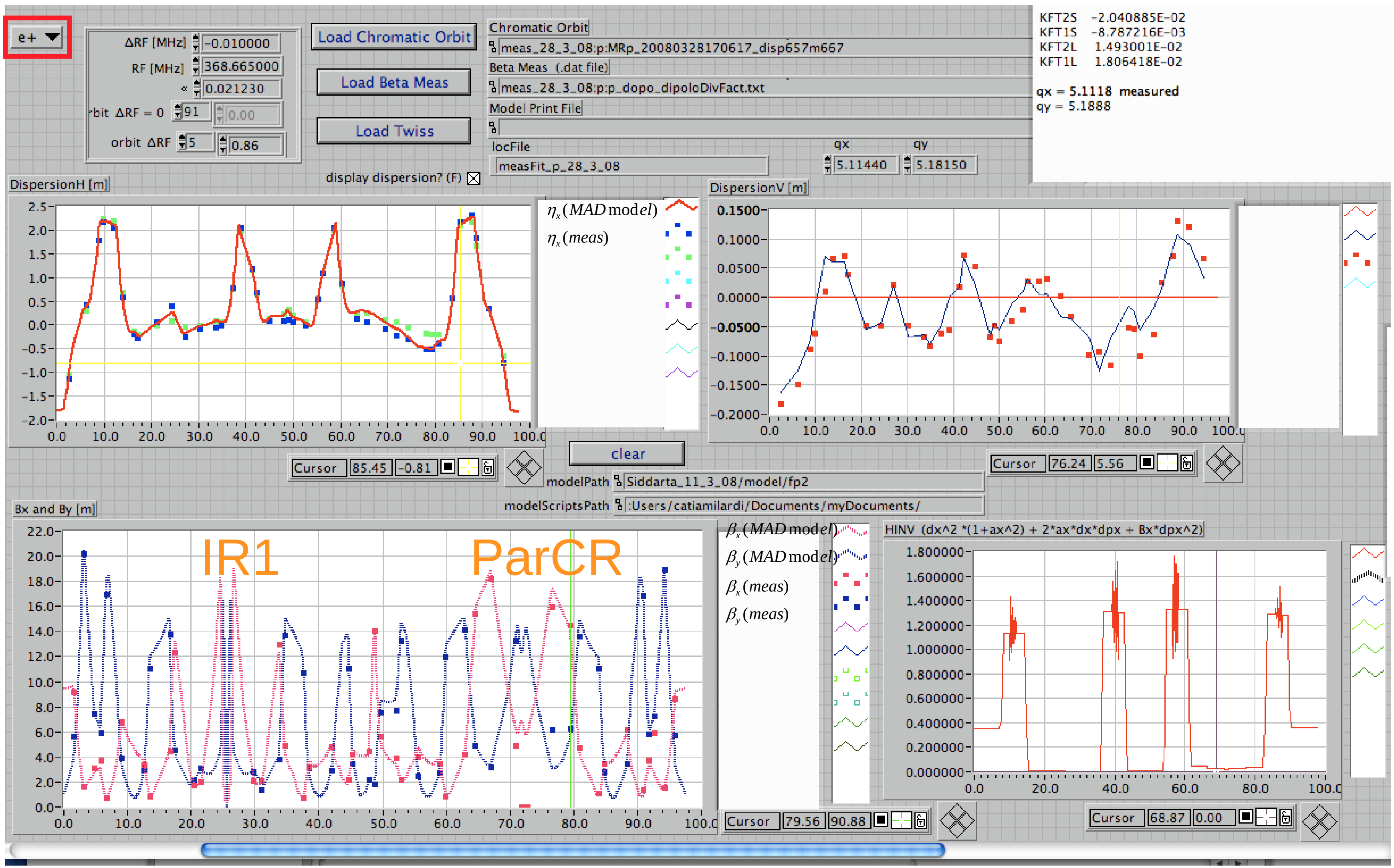
Commissioning history

- **Machine start-up** end of November
- **Both beams stored** first days of December with detuned lattice
- **Low-β optics** applied in January
- **Solenoid windings** installed in positron ring and 800 mA e+ current stored with pattern not suitable for collisions in first week of February
- **Crab-Waist** sextupoles in operation in February
- **Bhabha Luminosity** monitor installed on February 11th
- **First L ~ 10^{32}cm^{-2}s^{-1}** measured beginning of March
- **SIDDHARTA prototype** installation March 10th
- **New horizontal feedback** installed in the electron ring first half of March
- **Background in the kaon trigger** optimization end of March
- **Transverse and longitudinal feedbacks** tuning end of April

Optical parameters

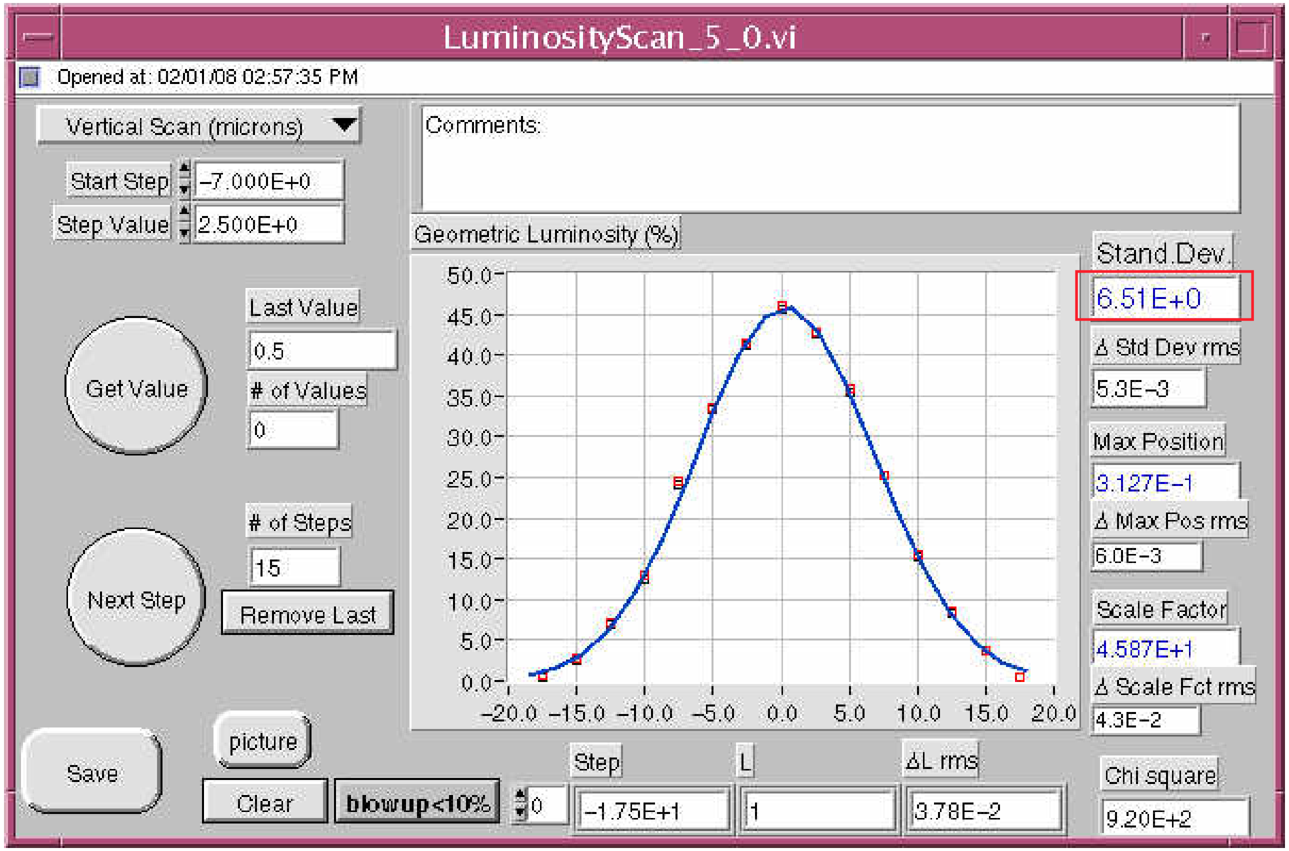
	electrons design	electrons achieved	positrons design	positrons achieved
emittance (mm.mrad)	0.20	0.25	0.20	0.25
β_x @IP (m)	0.20	0.27	0.20	0.24
β_y @IP (m)	0.0065	0.0106	0.0065	0.0096
coupling (%)	0.5	≈0.7	0.5	≈0.7
σ_x @ IP (mm)	0.20	0.26	0.20	0.25
σ_y @ IP (μm)	2.6	4.0	2.6	4.0
Piwinski angle (10mA)	2.5	1.6	2.5	1.7

Present SIDDHARTA Optics



Vertical beam-beam scan

$$\Sigma_y = \sqrt{\sigma_{yp}^2 + \sigma_{ye}^2} \qquad \Sigma_y = \Sigma_y^{meas} * 0.88$$ Hourglass factor



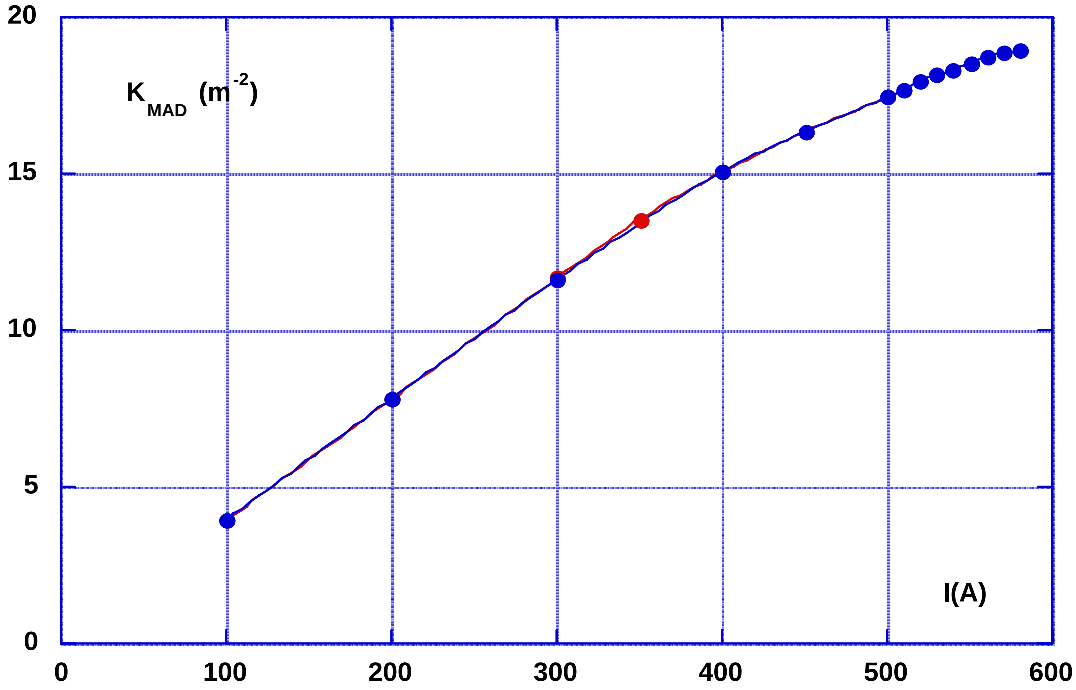
$$\Sigma_y = 5.63\mu m$$

$$\sigma_{ye}^2 \cong \sigma_{yp}^2 \cong \sigma_y^2$$

$$\sigma_y \approx 4\mu m$$

Crab sextupoles parameters

$$k_s = \frac{1}{2\theta}\frac{1}{\beta_y^*\beta_y^{sext}}\sqrt{\frac{\beta_x^*}{\beta_x^{sext}}}$$



θ (mrad)	25
β_y*(mm)	10
β_x*(mm)	250
β_y^{sext}(m)	13.5
β_x^{sext}(m)	4.2
K_s (m^{-2})	36

We plan to install 4 "large" sextupoles of the arcs with K_{max} ≈ 25 m^{-2} during final Siddharta installation

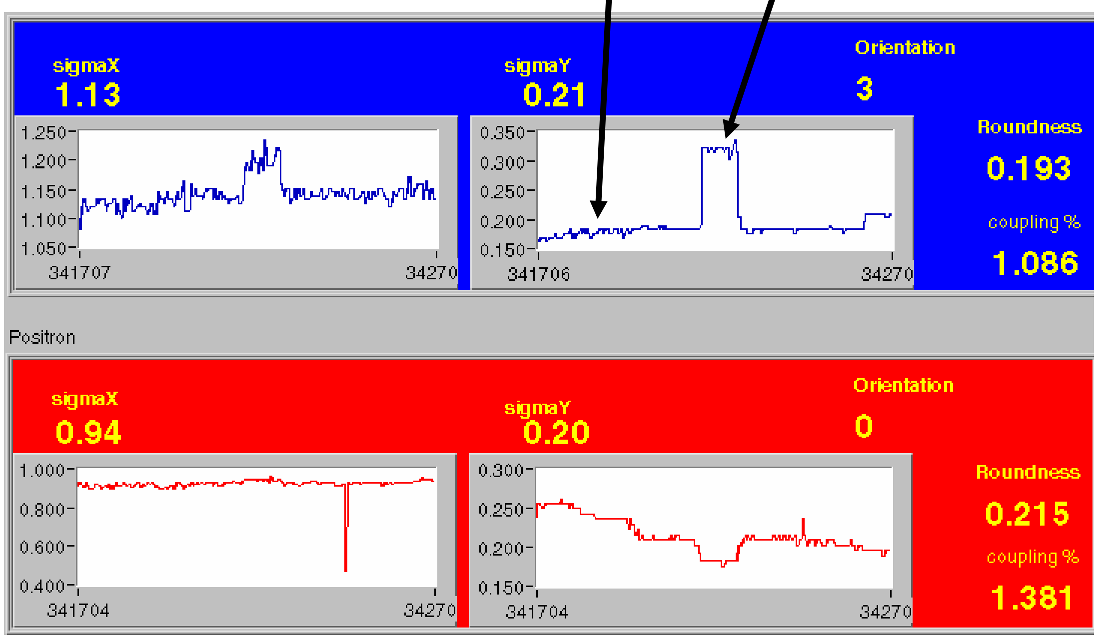
CRAB SEXTUPOLES WORK !!

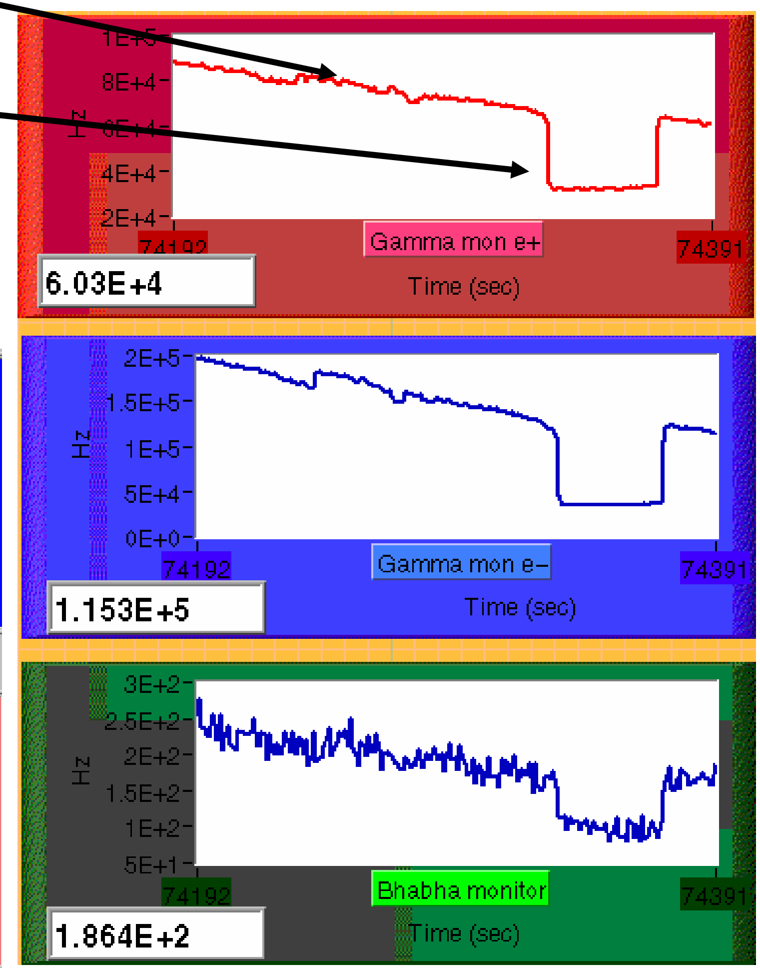
e^- sextupoles on

LUMINOMETERS

e^- sextupoles off

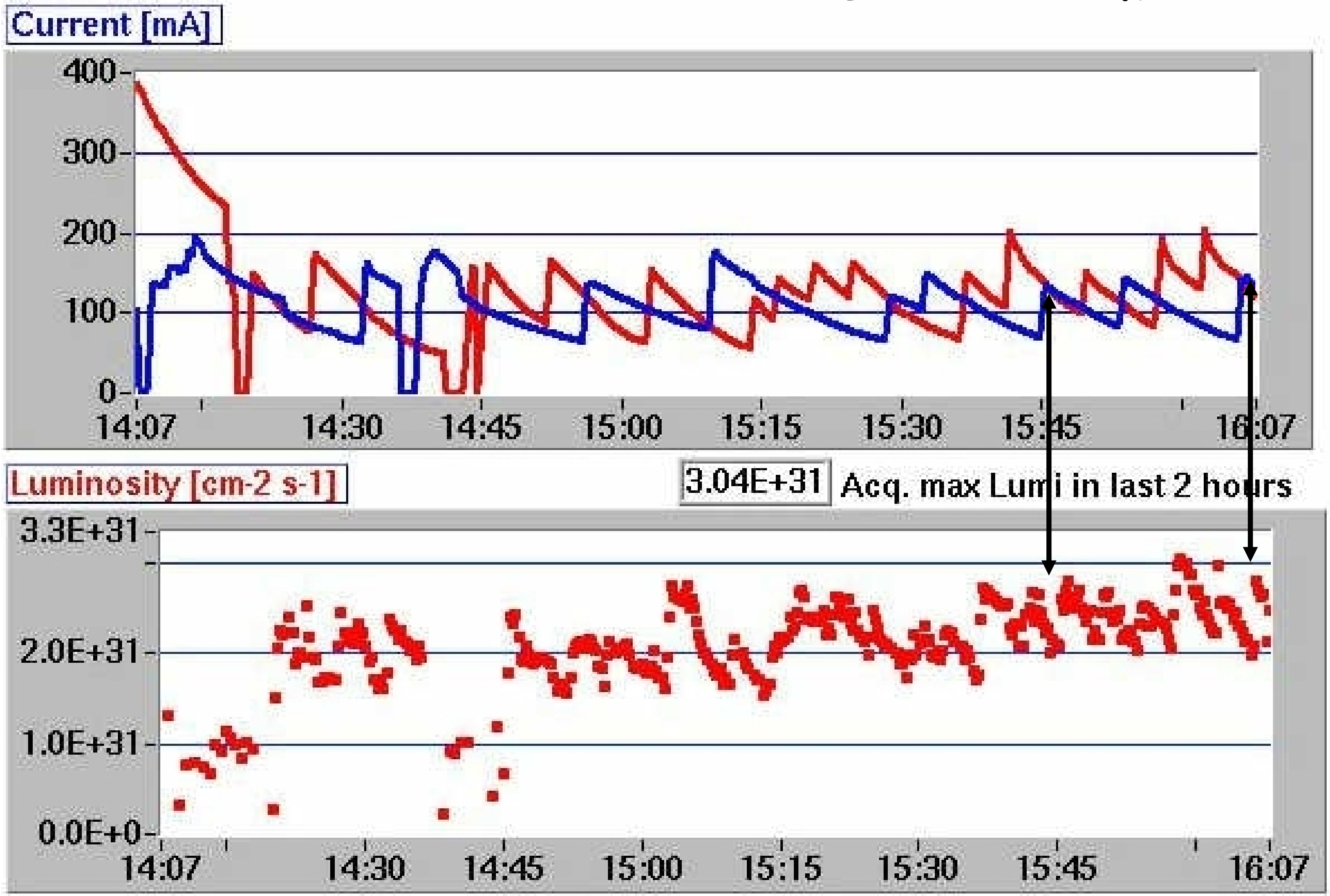
Transverse beam sizes at Synchrotron Light Monitors

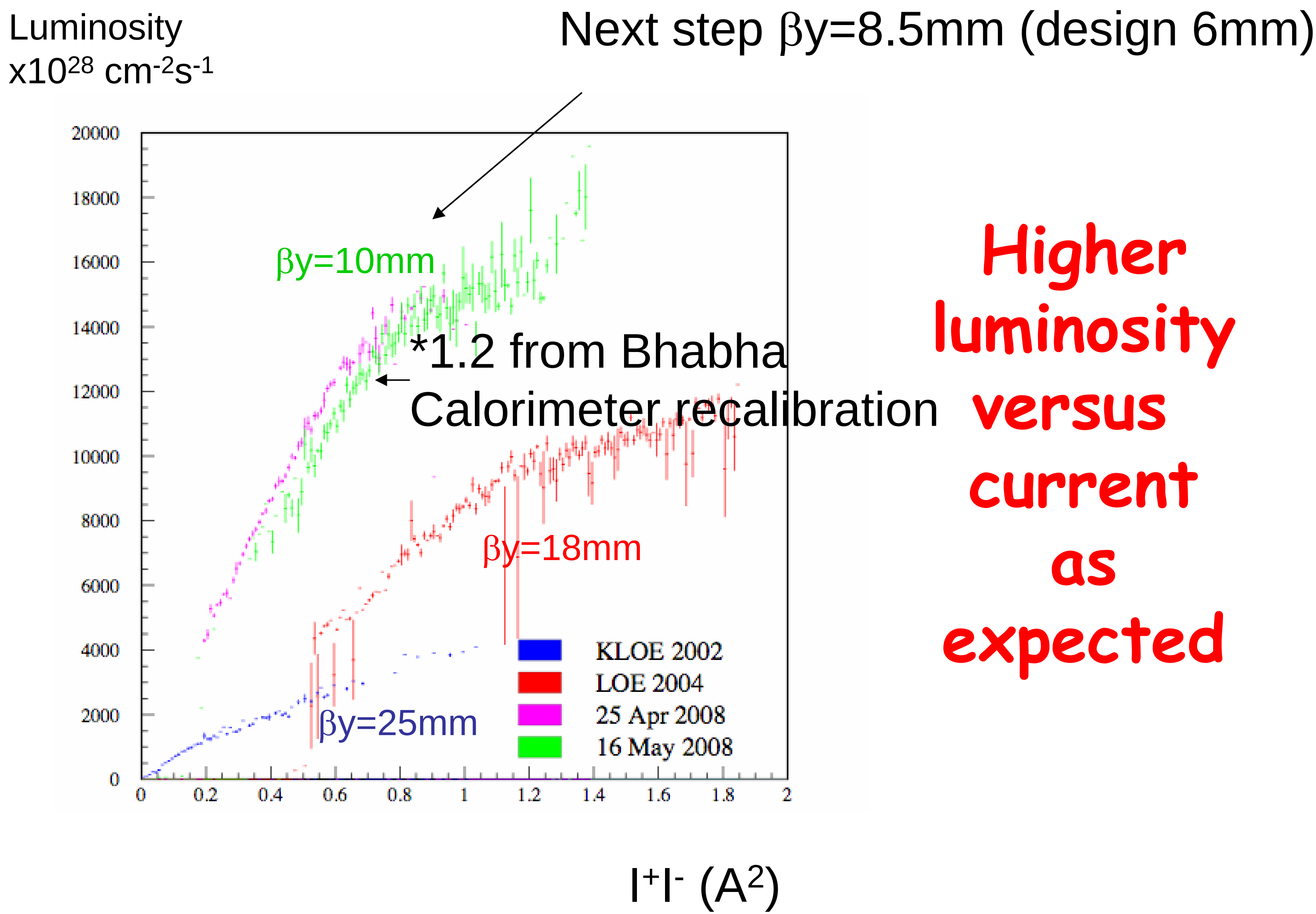




Low current results

10 bunches 2/5/2008
$I_b \approx 13$ mA/bunch
$L \approx 3 \times 10^{31} cm^{-2} s^{-1}$





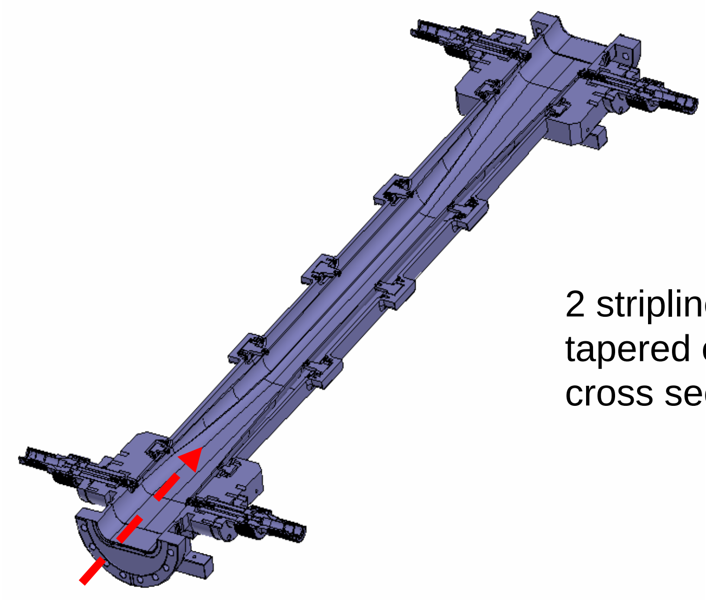
Higher luminosity versus current as expected

High current operation

- Three main hardware upgrades have been implemented to improve the stored current:

- Fast kickers
- Feedback upgrade
- Low impedance bellows

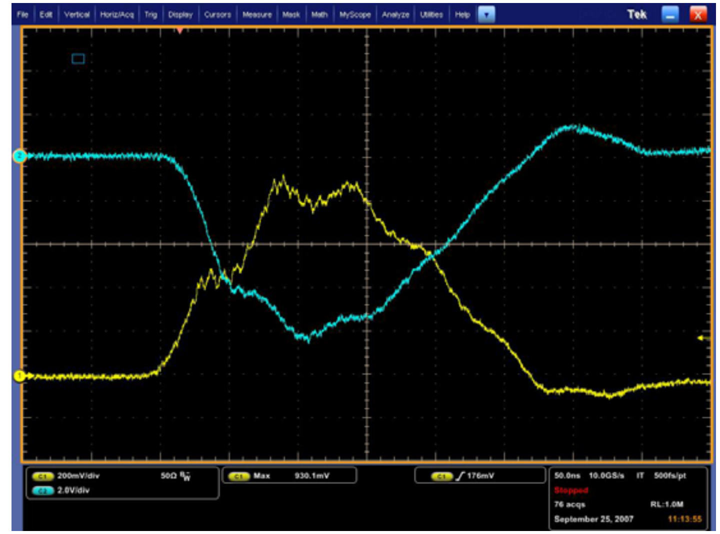
TEST OF FAST PULSERS WITH NEW KICKERS



BEAM

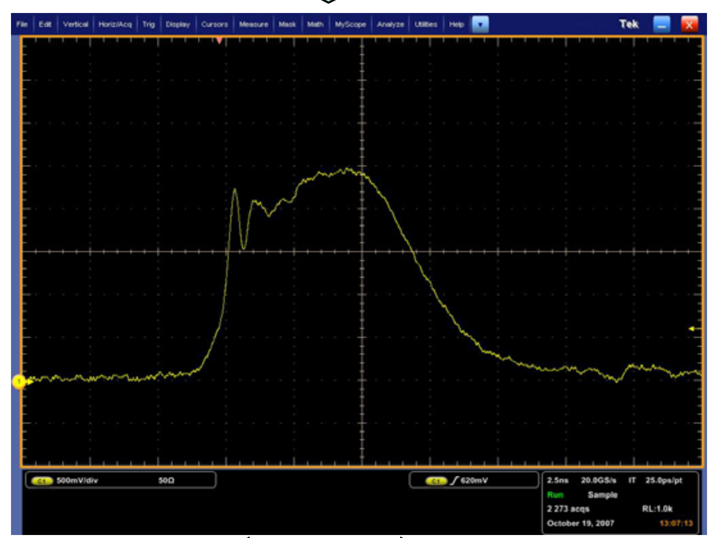
2 striplines with
tapered elliptical
cross section

25 kV



200 ns

45 kV



5 ns

⇒ The new kickers can be fed by the old pulsers (200 ns) or by the ***new pulsers (6 ns).***

⇒ ***First beam injection test on e+ ring with fast pulsers successfully done.***

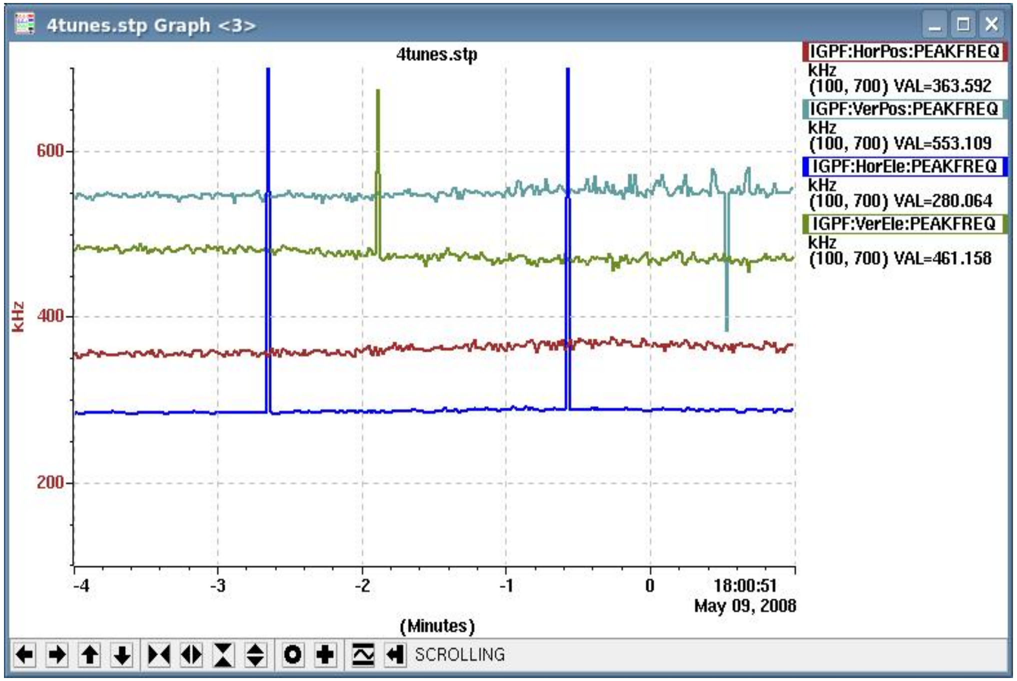
⇒ Unfortunately we had ***problems with the new fast FID pulsers*** after few hours of operation. They are now recovered and ready to be re-installed.

Feedback: hardware upgrade and bugs fixing

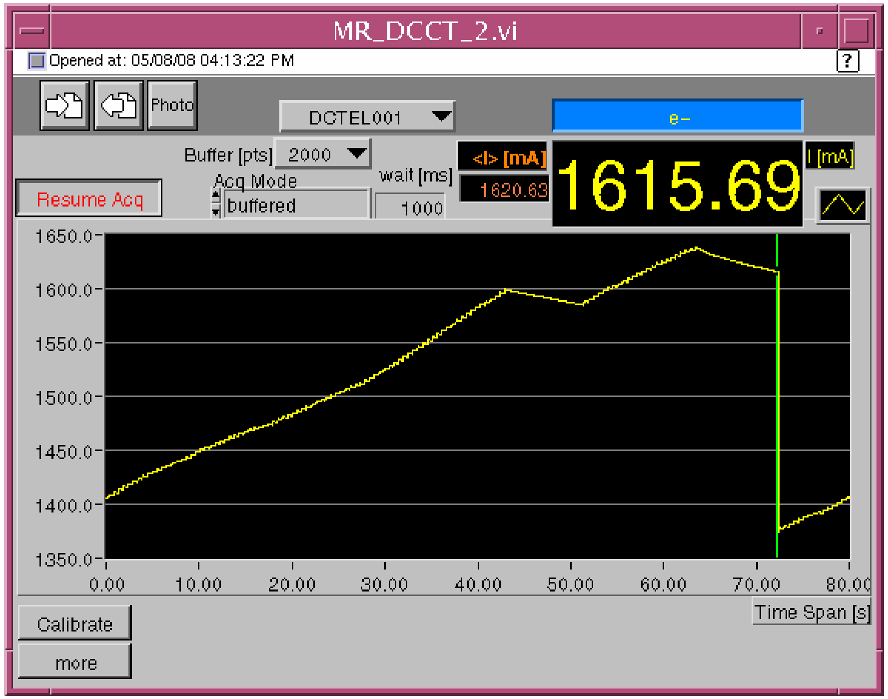
- **Transverse feedbacks**
  - 2 new “iGp” system (developed by a collaboration LNF/KEK/SLAC) installed. Now 4 identical setups are in operation
  - Simplified analog front end reducing crosstalk between adjacent bunches
  - Front end delay lines (no more necessary) eliminated
  - Back end delay lines (no more necessary) limiting the feedback response bandwidth eliminated
- **Longitudinal positron feedback**
  - Front end phase shifter remote control introducing spurious signal at 26 kHz eliminated.
  - Back to manual control.

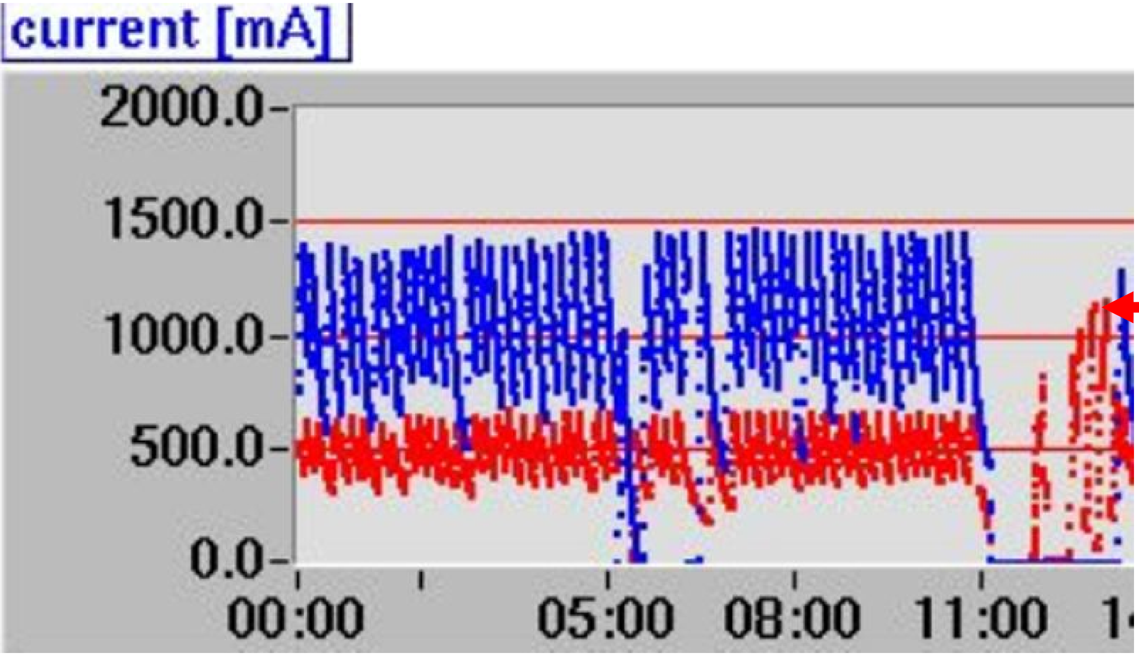
Feedback: transverse system software & gateware upgrade

- New software and gateware release
- All 4 systems run now the same code release
- Only one powerful server (PC) also used as operator interface
- New features in the operator interface
- Non-invasive 4 betatron tunes monitors



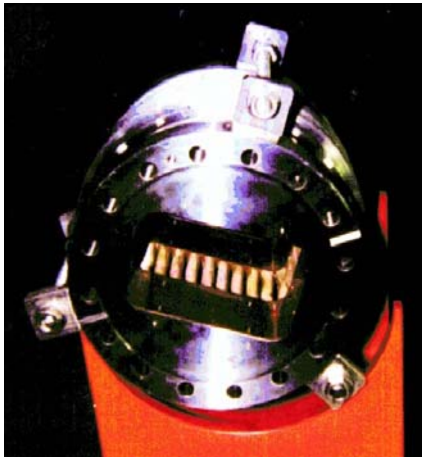
09/May/08: e- beam in collision, stable with 100 bunches, 1640 mA



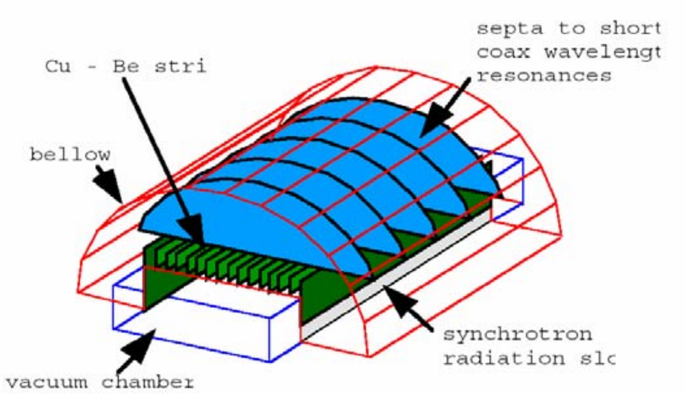


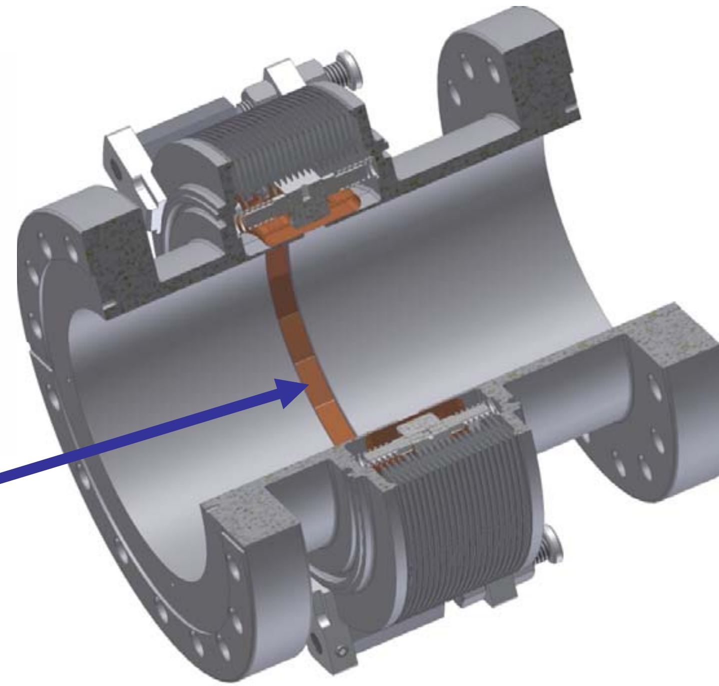
08/May/08: e+ > 1150mA in 120 bunches, (best result ever for single beam e+)

NEW BELLOWS

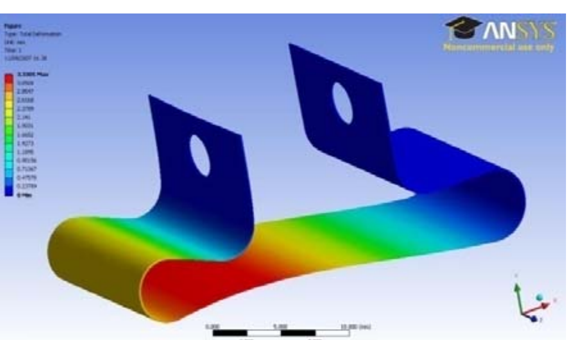


OLD BELLOW

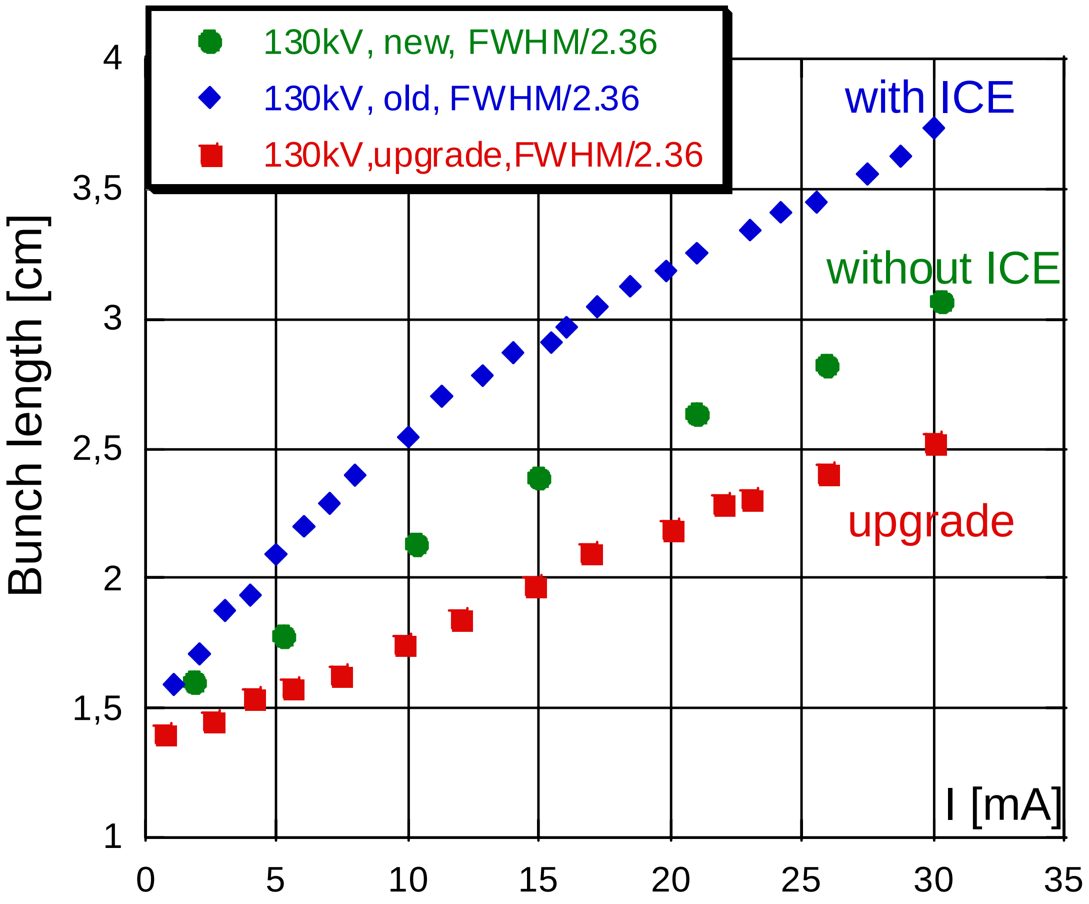




- 6 new bellows for each ring
- Shielding based on Be-Cu W strips 0.2 mm thick
- lower impedance and better mechanical performance



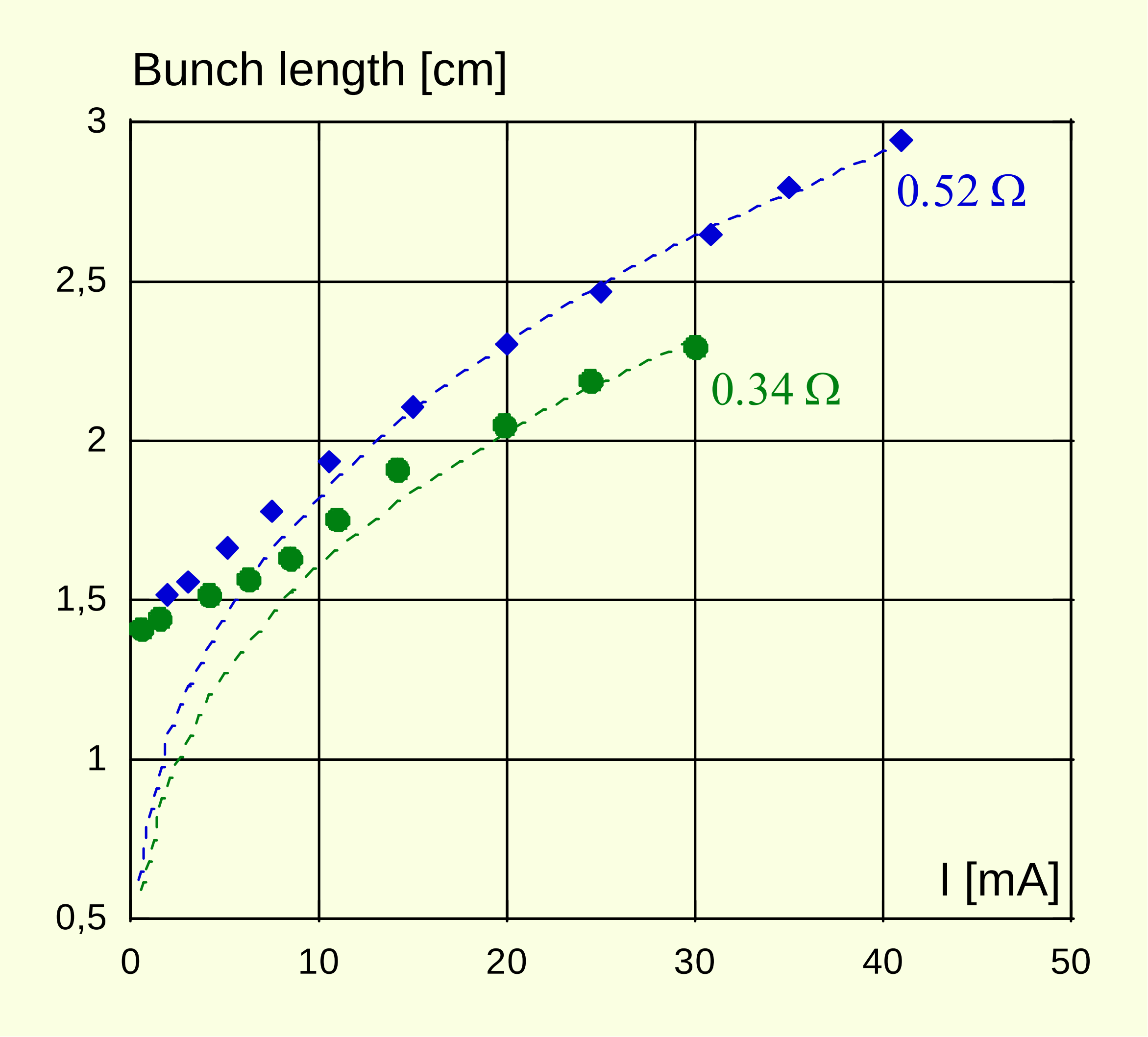
e⁻ bunch length measurement



20% bunch length reduction @ 10 mA due to:

- **ICE removal**
- **New injection kickers**
- **New bellows**

e⁺ bunch length measurement

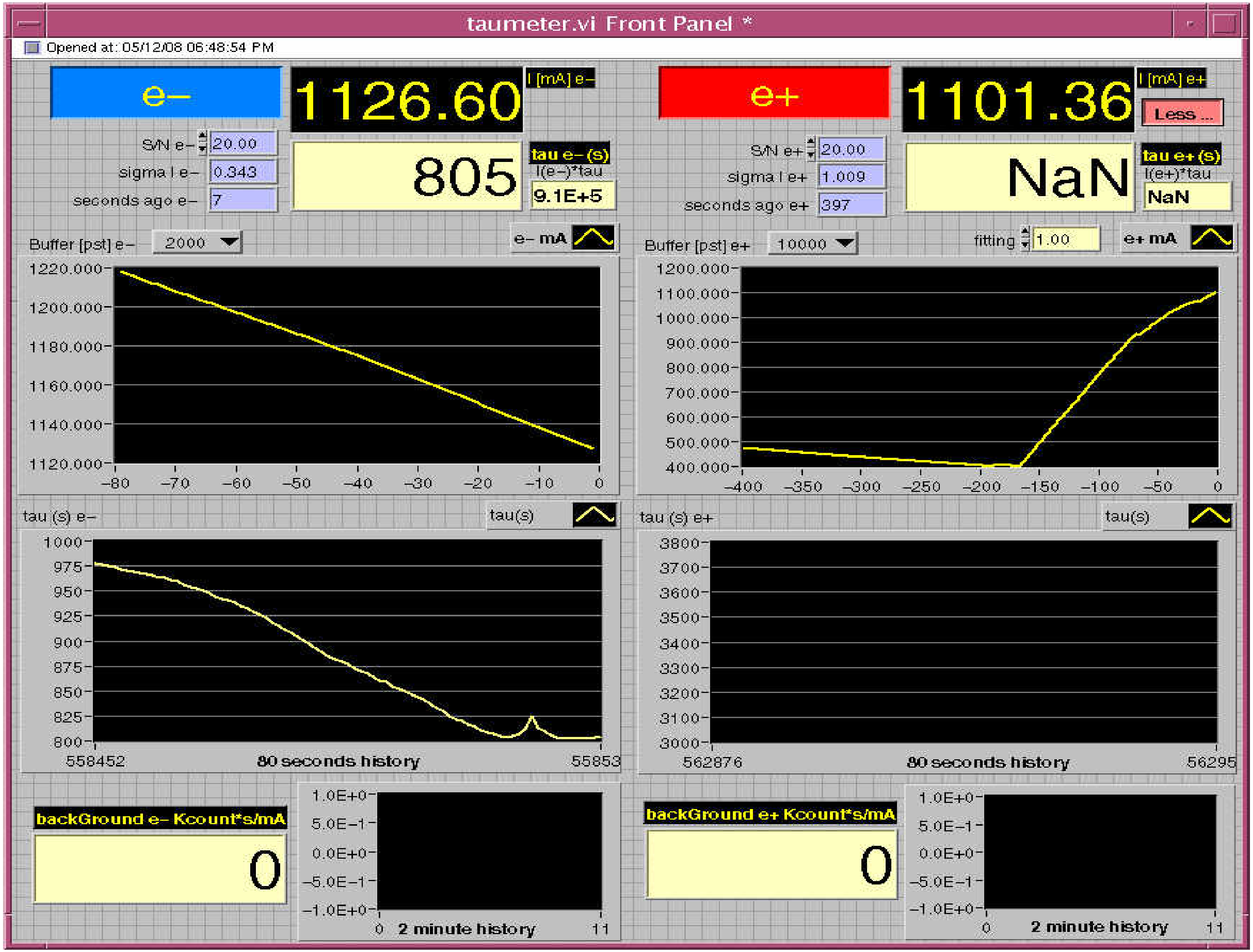


≈10% reduction in bunch length @ 10 mA due to:

- New injection kickers
- New bellows

Present performance

- Stored current in electron beam = 1.79A in 95 bunches (weak positron beam ≈0.45 A)
- Stored current in positron beam = 1.15A in 120 bunches (no electron beam)
- Stored current of interacting beams at the same time = ≈($1.2e^{-}$+$1.1e^{+}$) A in 95 bunches
- Peak luminosity ≈$2.2\times10^{32}cm^{-2}s^{-1}$ (measured by Bhabha monitor; value from Kaon monitor larger by 10÷20%) (old KLOE record 1.5e32)
- Integrated luminosity per day ≈9.6 pb^{-1} (measured by Bhabha monitor during operation for Siddharta)
- Integrated luminosity per hour (measured by Bhabha monitor on 2 hours) = 0.55 pb^{-1} (old KLOE record 0.44pb-1)


taumeter.vi Front Panel *
Opened at: 05/12/08 06:48:54 PM
e−
1126.60
I [mA] e−
S/N e− 20.00
sigma I e− 0.343
seconds ago e− 7
805
tau e− (s)
I(e−)*tau
9.1E+5
e+
1101.36
I [mA] e+
Less ...
S/N e+ 20.00
sigma I e+ 1.009
seconds ago e+ 397
NaN
tau e+ (s)
I(e+)*tau
NaN
Buffer [pst] e− 2000
e− mA
Buffer [pst] e+ 10000
fitting 1.00
e+ mA
tau (s) e−
tau(s)
80 seconds history
tau (s) e+
tau(s)
80 seconds history
backGround e− Kcount*s/mA
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2 minute history
backGround e+ Kcount*s/mA
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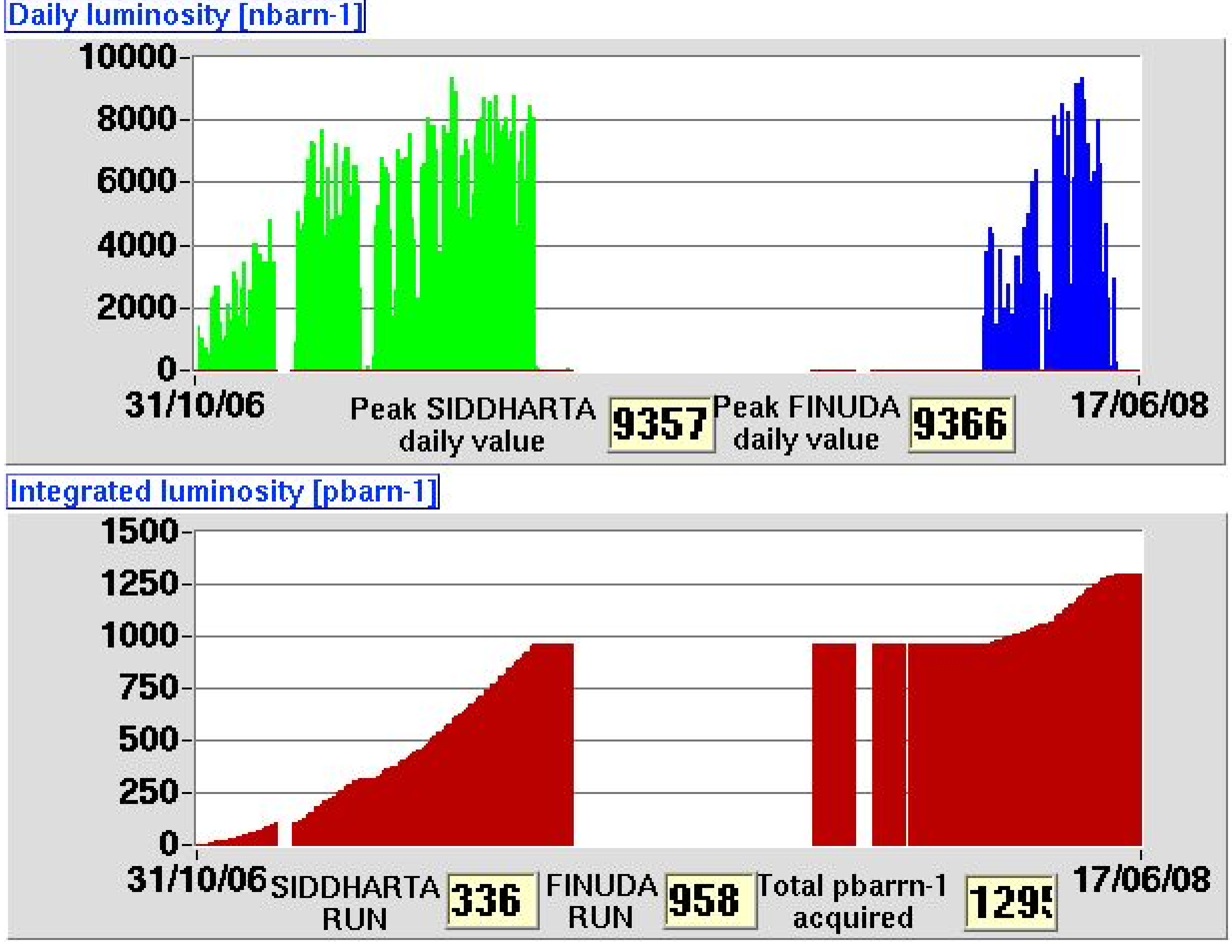
2 minute history



SIDDHARTA run luminosity estimeted by DAFNE luminosity Bhabha monitor, data logging starts 14/03/2008

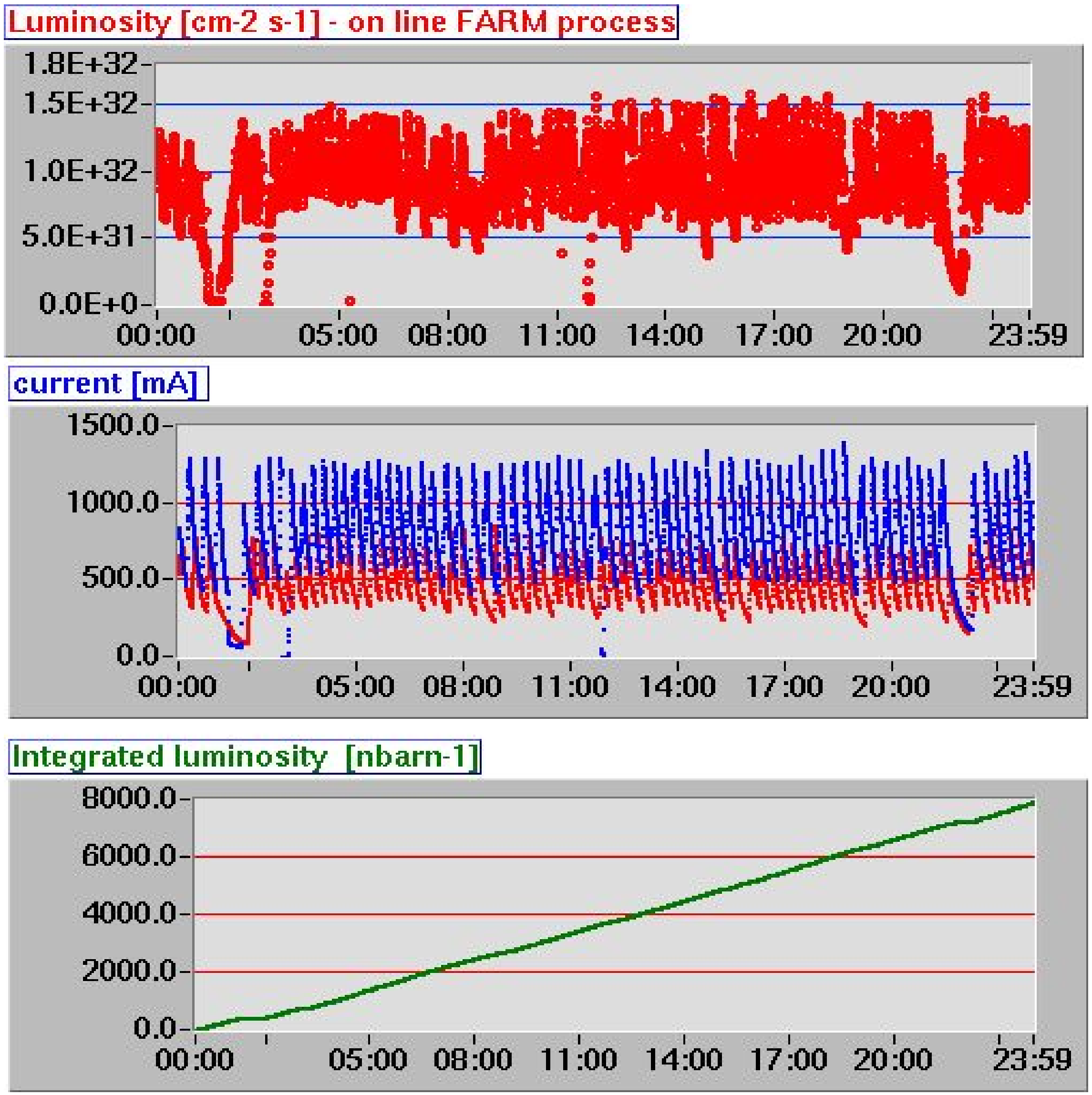
Integrated and peak luminosity equaled the previous runs performances in mid April

Effective Rates might be different upon fine calibrations of the Luminosity detectors

(demonstrated a steady run condition for a week)

50% improvement by May 15 achieved in peak and average

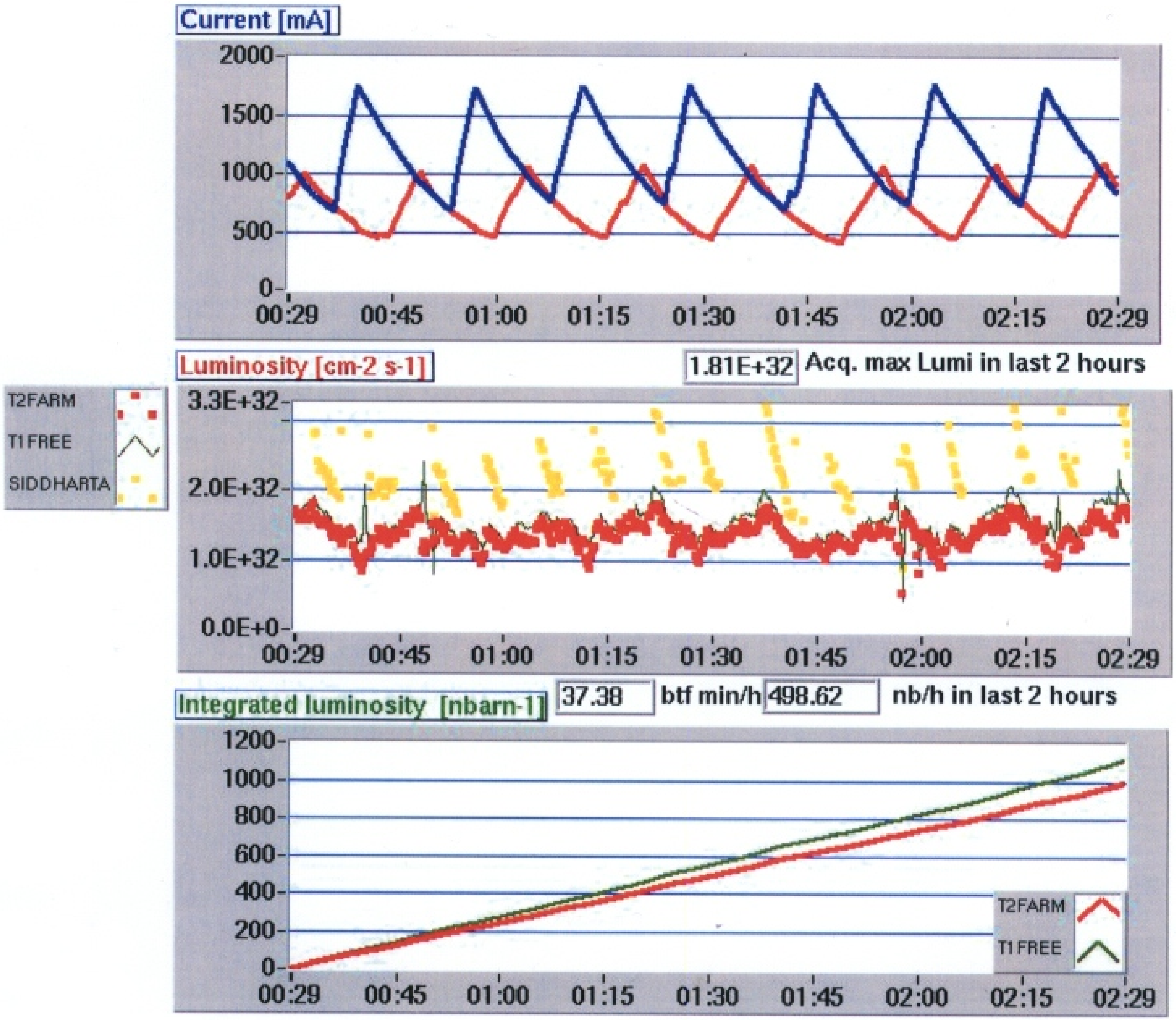
"BEST" INTEGRATED LUMINOSITY on APRIL 25th



Maximum interacting currents ≈800+800 mA

measured by Bhabha monitor with background subtraction

2 hours luminosity

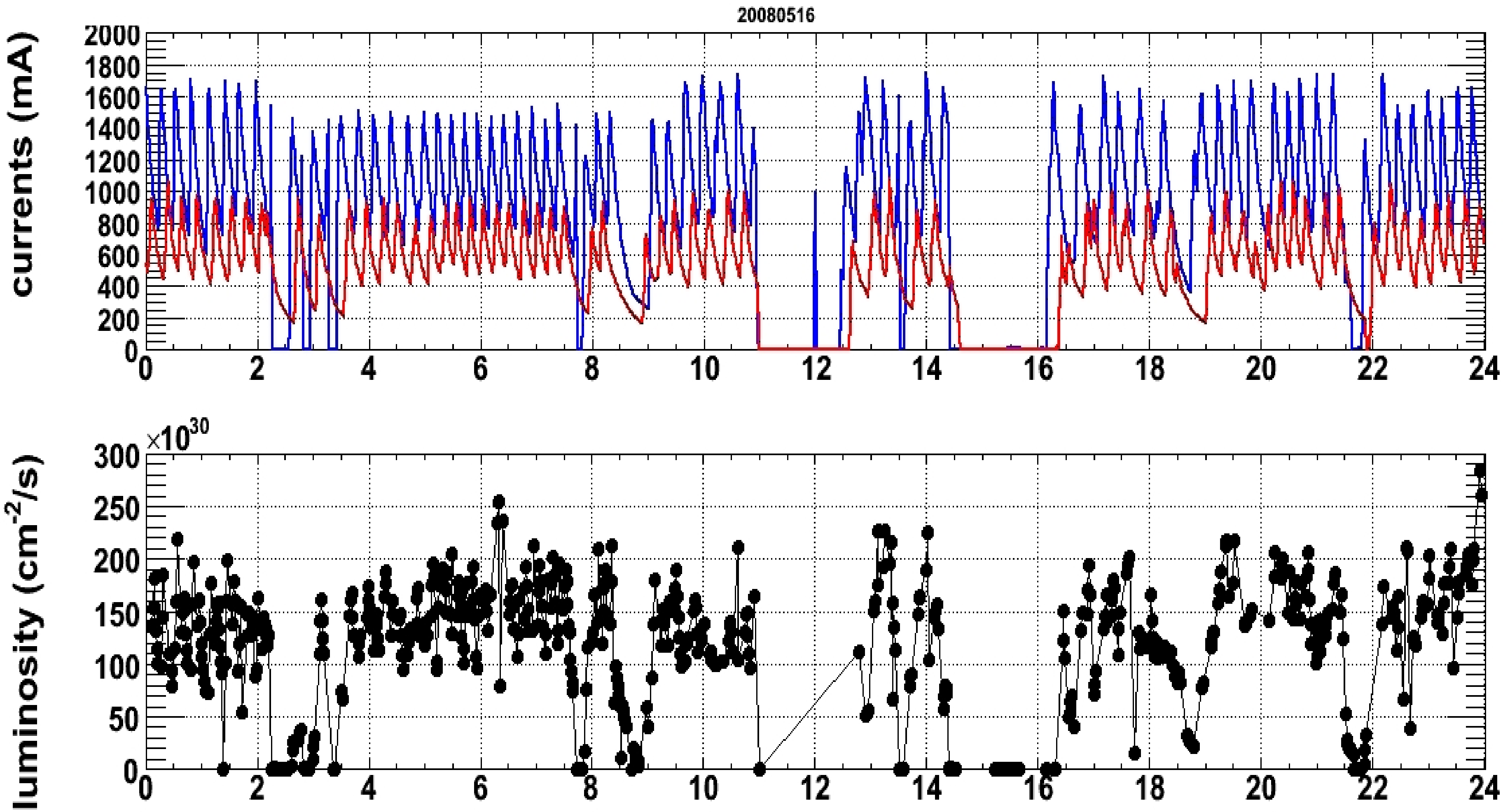


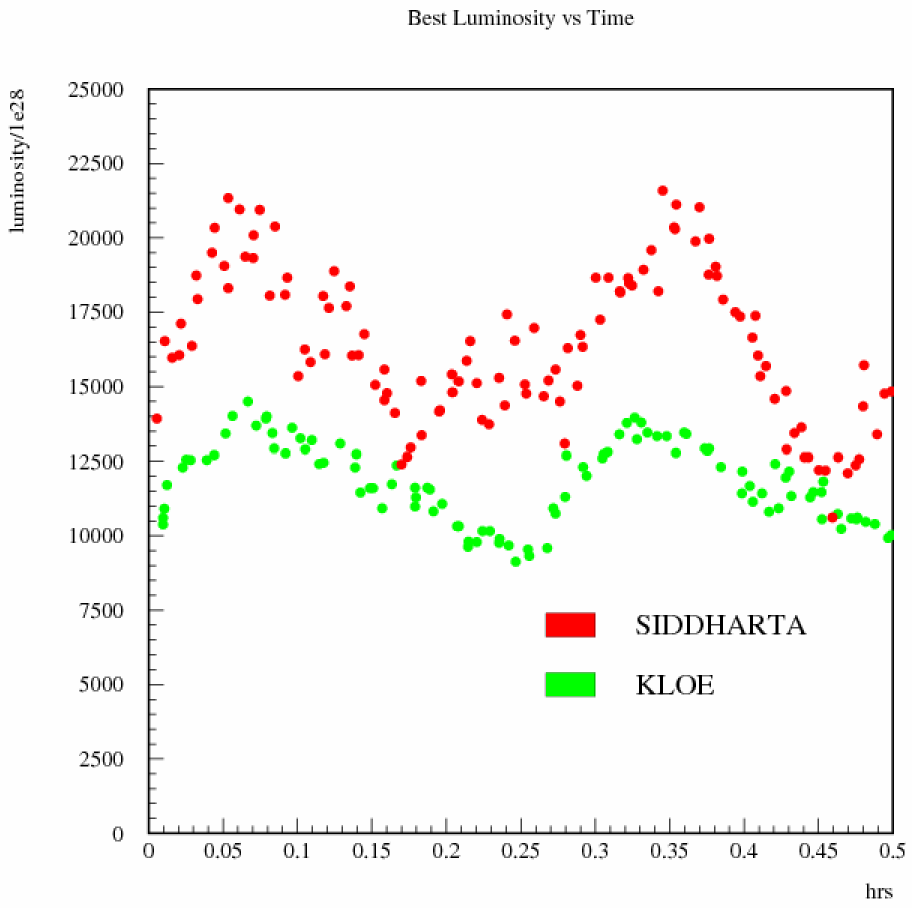
- kaon monitor without background subtraction

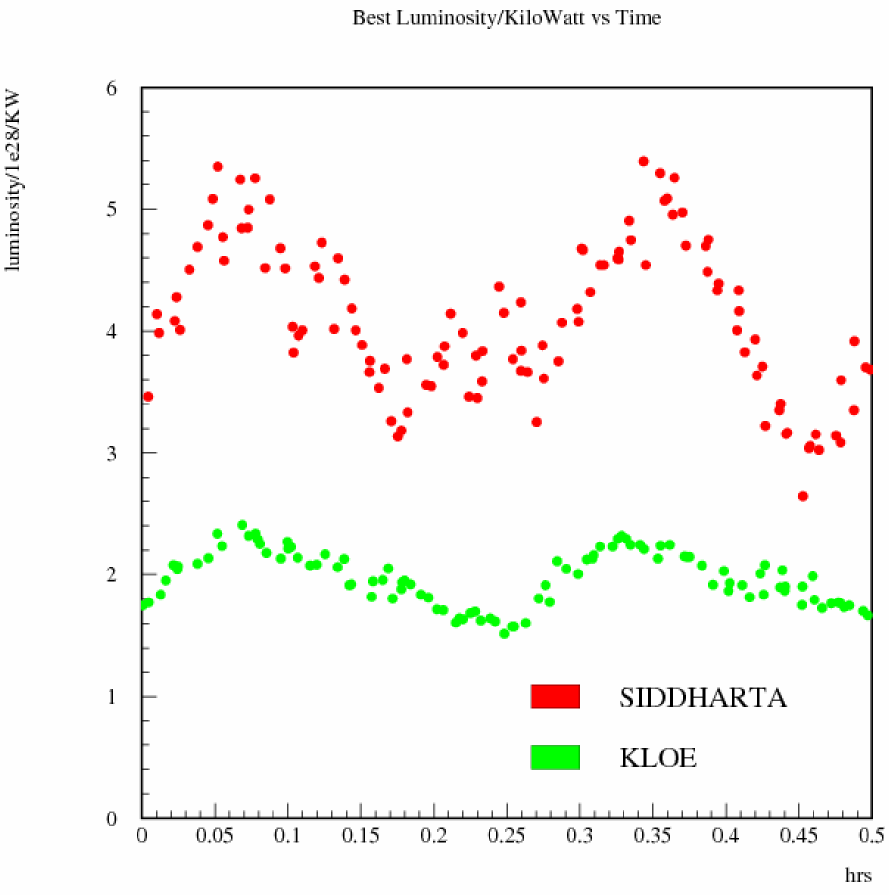
-- Bhabha monitor without background subtraction

- Bhabha monitor with background subtraction

Kaon monitor luminosity (average on a single run scaled by the product of stored currents)







Absolute rates estimated with Bhabha 50% higher with 30% less current

Absolute rates estimated with Kaons are 10-20%higher (L>2.5e32)

Absolute power consumption decreased from 6MW to 4MW

To do list

- Equalization and availability on line of all kinds of luminosity measurements (direct and estimated, Bhabha and Kaon monitor with background subtraction, γ monitor, "geometric" luminosity from currents and beam sizes)
- Increase number of stored bunches from 95 to 110
- Decrease β and dispersion beating from 20% to 5% (β_y* from 10 to 8.5 mm)
- Faster switch between electron and positron injection and faster positron injection rate
- From June 3rd to June 18th:
- Installl stronger (by 50%) Crab sextupoles
- Add solenoid windings on positron injection straight section
- Reduce injection kickers pulse duration
- Install final Siddharta detector
- Overall luminosity increase by ≈50% expected
- Lower βy* down to 6mm is hard because we have to lower βx and εx too, and might affect the Siddharta background

Conclusions

- Upgraded completed with 1 month delay wrt schedule
- The collider has been successfully commissioned in the new “crab waist” mode by the beginning of March (1e32 achieved), with about 2months delay wrt schedule.
- First Siddharta measurement completed (Kaonic Nitrogen) with about 3 months delay wrt schedule.
- Machine luminosity and background conditions suitable for the second measurement (Kaonic Hydrogen) in 2months+1/2 for commissioning the second detector.
- Background has to be reduced by another factor 10 for the Kaonic Deuterium measurement. Tight collaboration with the Siddharta team is under way to reach this goal (needed after the Kaonic Hydrogen measurement (3 months from now).
- Further quasi-adiabatic improvements of machine operation are likely to fulfill the requirements for a future roll-in of KLOE at the beginning of 2009 (needed about L=4e32, Lint/day=20pb-1), instead of in the second half of 2008 as initially planned.

SuperB Accelerator

Overview and Status

SuperB Accelerator

Overview and Status

Outline

- SuperB project
- Luminosity and beam-beam
- Beam dynamics studies
- Conclusions

SuperB Project

- *SuperB* aims at the construction of a very high luminosity (1-4 x 10^{36} cm^{-2} s^{-1}) asymmetric e^+e^- Flavour Factory, with possible location at the campus of the University of Rome Tor Vergata, near the INFN Frascati National Laboratory.

SuperB Accelerator Contributors

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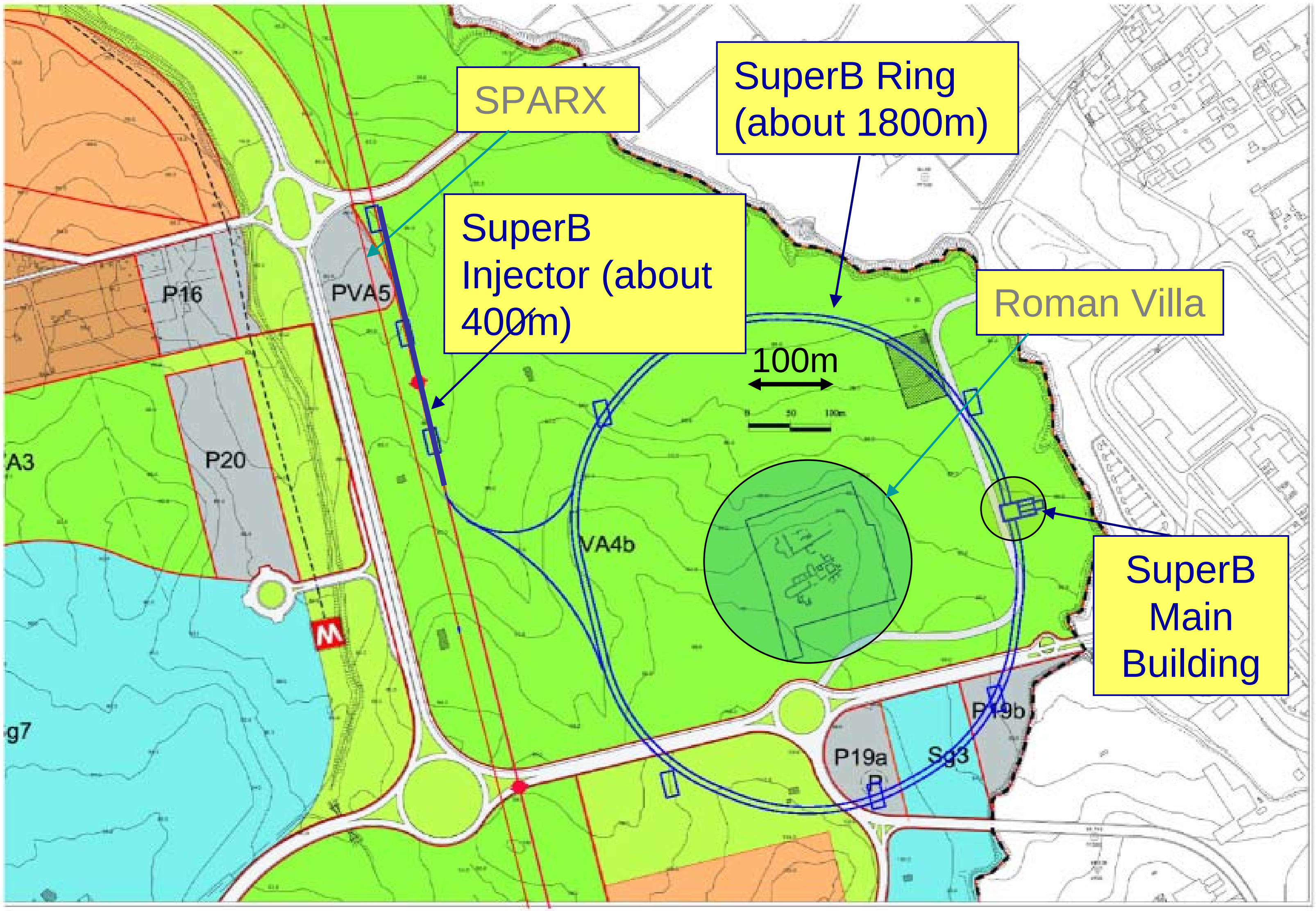
- Wolski (Liverpool University, UK)
- M. Venturini (LBNL, US)
- S. Bettoni (CERN, Switzerland)
- A. Variola (LAL/Orsay, France)
- E. Paoloni, G. Marchiori (Pisa University, Italy)

SuperB footprint on Tor Vergata site



Super-B New Parameters

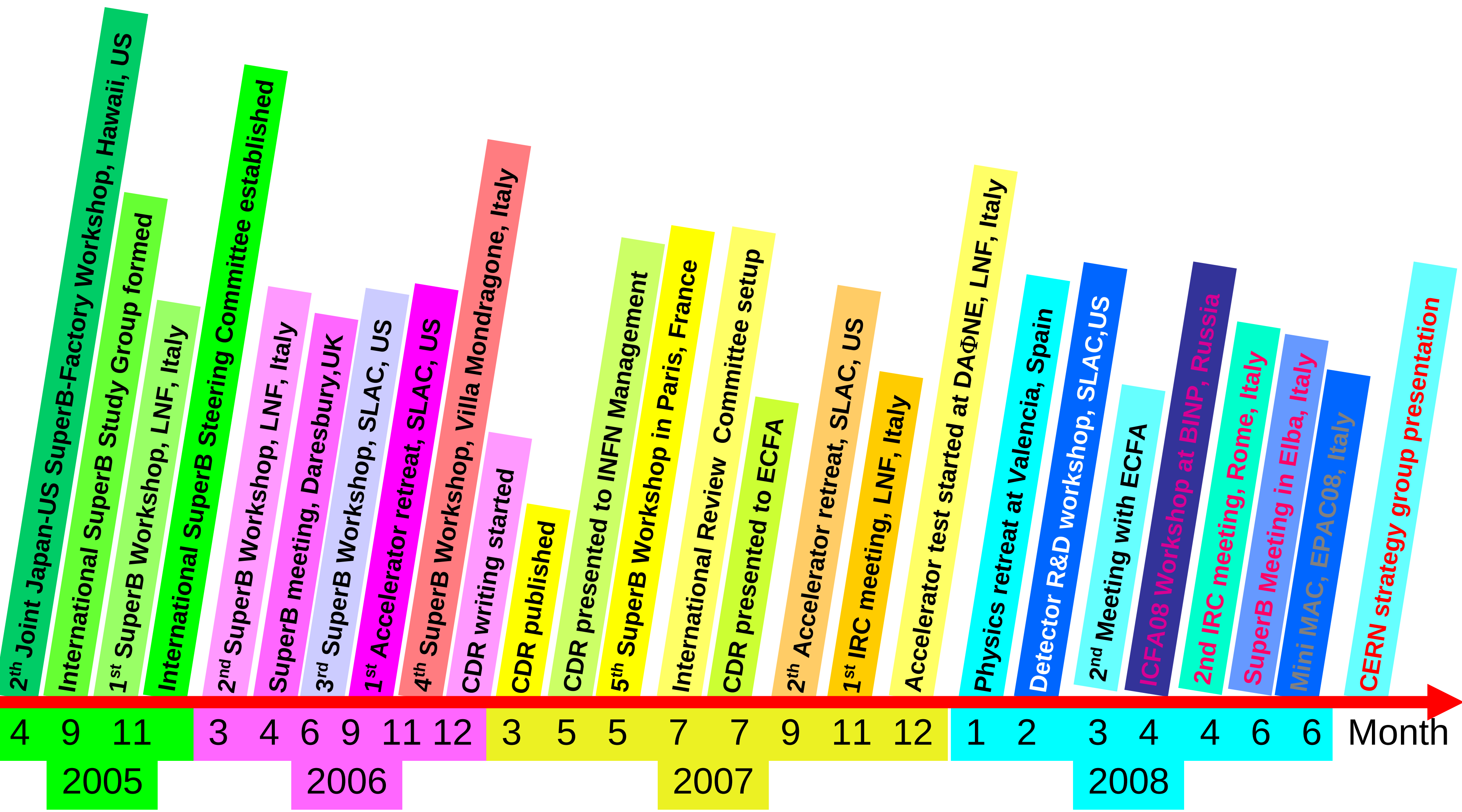
	Nominal		Upgrade		Ultimate	
PARAMETER	LER (e+)	HER (e-)	LER (e+)	HER (e-)	LER (e+)	HER (e-)
Energy (GeV)	4	7	4	7	4	7
Luminosity x 10^{36}	1.0		2.0		4.0	
Circumference (m)	1800	1800				
Revolution frequency (MHz)	0.167					
Eff. long. polarization (%)	0	80				
RF frequency (MHz)	476					
Momentum spread ($\times 10^{-4}$)	7.9	5.6	9.0	8.0		
Momentum compaction ($\times 10^{-4}$)	3.2	3.8	3.2	3.8		
Rf Voltage (MV)	5	8.3	8	11.8	17.5	27
Energy loss/turn (MeV)	1.16	1.94	1.78	2.81		
Number of bunches	1251				2502	
Particles per bunch ($\times 10^{10}$)	5.52				6.78	
Beam current (A)	1.85				3.69	
Beta y* (mm)	0.22	0.39	0.16	0.27		
Beta x* (mm)	35	20				
Emit y (pm-rad)	7	4	3.5	2		
Emit x (nm-rad)	2.8	1.6	1.4	0.8		
Sigma y* (microns)	0.039	0.039	0.0233	0.0233		
Sigma x* (microns)	9.9	5.66	7	4		
Bunch length (mm)	5		4.3			
Full Crossing angle (mrad)	48					
Wigglers (#) 20 meters each	0	0	2	2		
Damping time (trans/long)(ms)	40/20	40/20	28/14	28/14		
Luminosity lifetime (min)	6.7		3.35			
Touschek lifetime (min)	20	40	38	20		
Effective beam lifetime (min)	5.0	5.7	3.1	2.9		
Injection rate pps ($\times 10^{11}$) (100%)	2.6	2.3	5.1	4.6	10	9.1
Tune shift y (from formula)	0.15		0.20			
Tune shift x (from formula)	0.0043	0.0025	0.0059	0.0034		
RF Power (MW)	17		25		58.2	

Beam-beam transparency conditions in red

Comparison of SuperB to SuperKEKB

Parameter		SuperB	Super-KEKB
Energy	GeV	4x7	3.5x8
Luminosity	10^{36} /cm^2/s	1.0 to 2.0	0.4 to 0.8
Beam Currents	Amps	1.9x1.9	10.0x4.0
βy^*	mm	0.22	3.0
βx^*	cm	3.5x2.0	20.
Crossing angle (full)	mrad	48	30
RF power (AC line)	MW	17 to 25	80 to 90
Tune shifts	(x/y)	0.0004/0.2	0.4/0.8

The SuperB Process (M. Biagini)



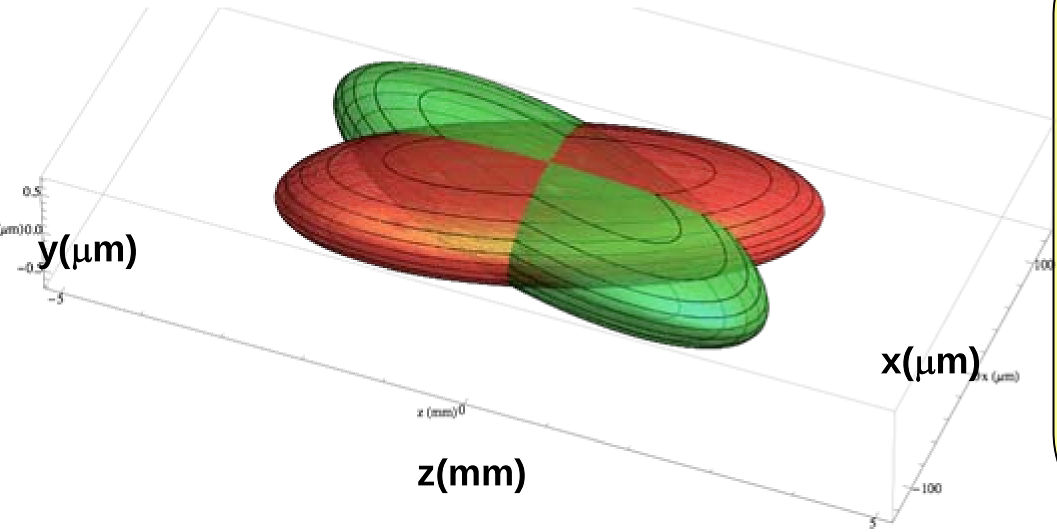
Basic concepts

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

Difficult and costly operation

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

IP beam distributions for KEKB

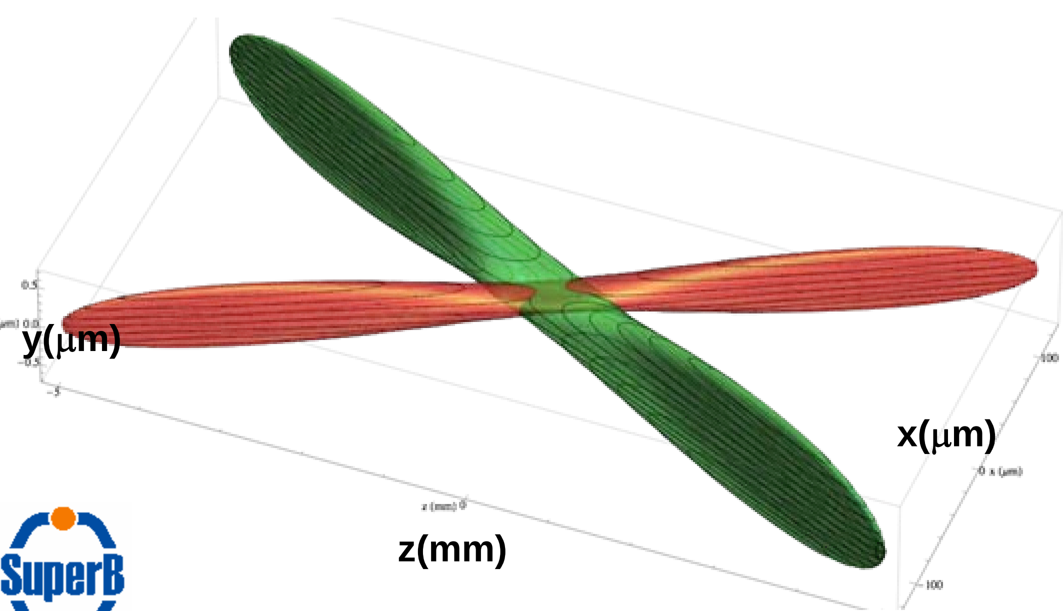


SuperB beams are focused in the y-plane 100 times more than in the present factories, thanks to:

- small emittances
- small beta functions
- larger crossing angle

Tune shifts and longitudinal overlap are greatly reduced

IP beam distributions for SuperB

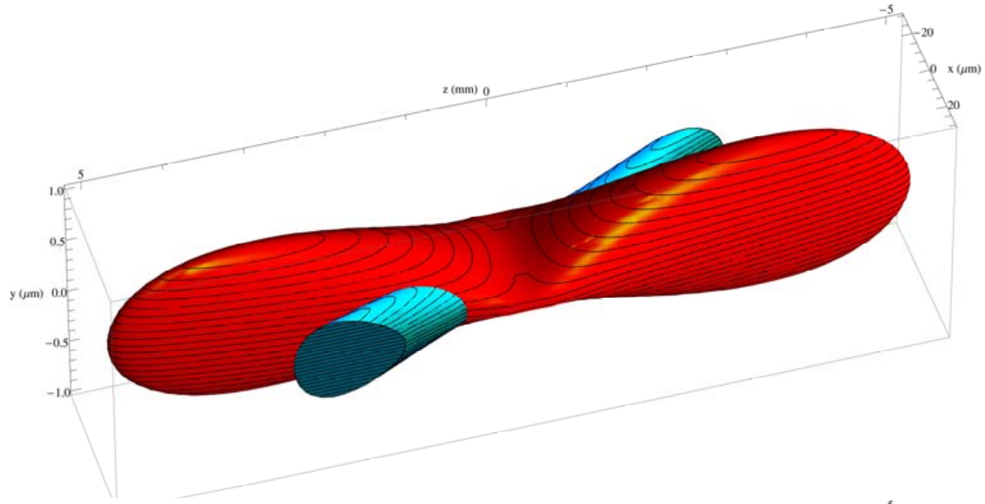


	KEKB	SuperB
I (A)	1.7	2.
β_y^* (mm)	6	0.22/0.39
β_x^* (mm)	300	22/39
σ_y^* (μm)	3	0.039
σ_x^* (μm)	80	10/6
σ_z (mm)	6	5
L ($cm^{-2}s^{-1}$)	1.7×10^{34}	$1. \times 10^{36}$

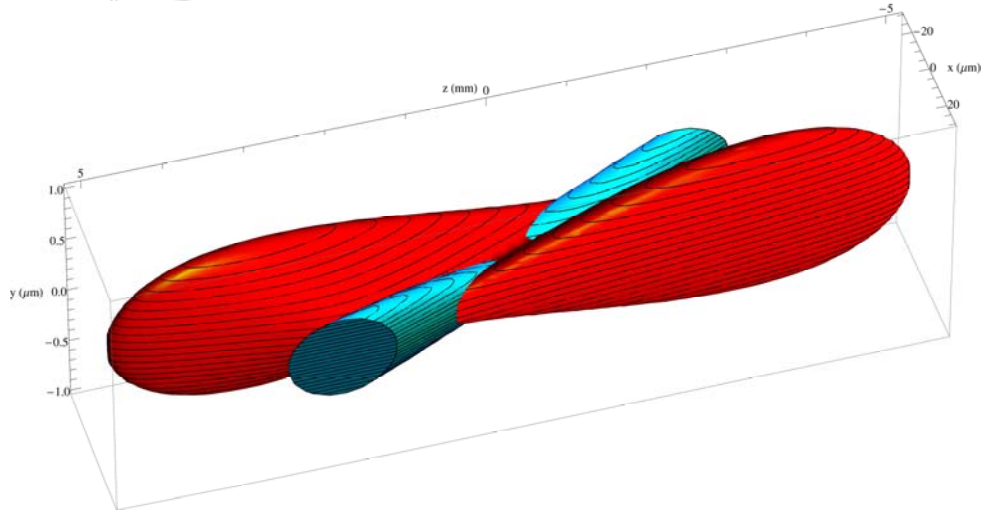
SuperB

Beams distribution at IP

E. Paoloni



Without
Crab-sextupoles



With
Crab-sextupoles

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

SuperB transparency condition

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

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

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

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

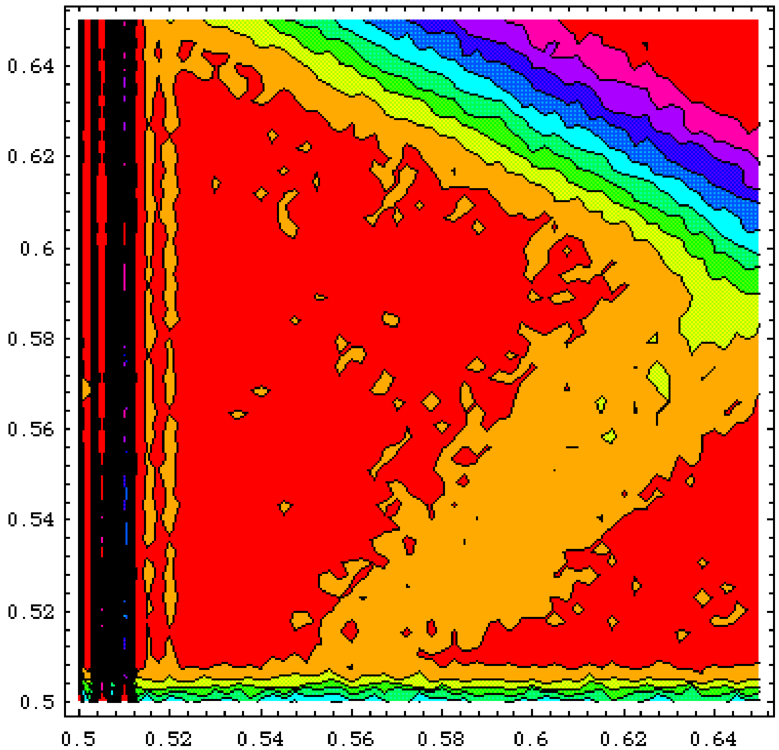
$$\xi^+ = \xi^- \Leftrightarrow \frac{\beta_y^+}{\beta_y^-} = \frac{E^+}{E^-}$$

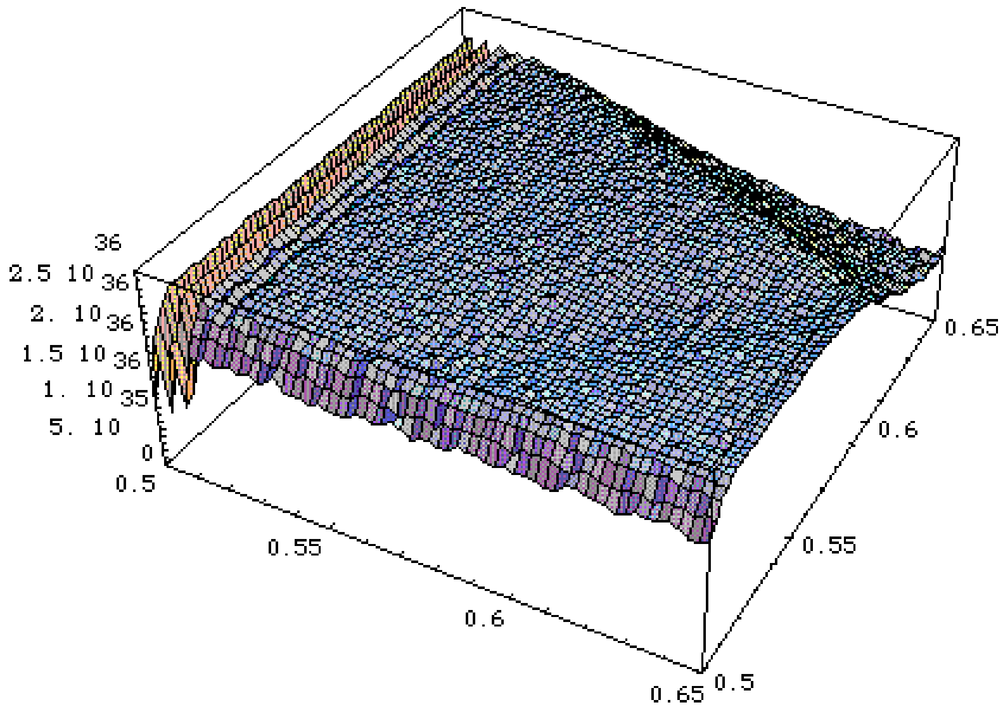
Present B-factories

SuperB

Beam-beam Luminosity Tune Plane Scan

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





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

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

D. Shatilov, M. Zobov, IV SuperB Workshop

RF power estimate

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

Total klystron power

A. Novokhatski

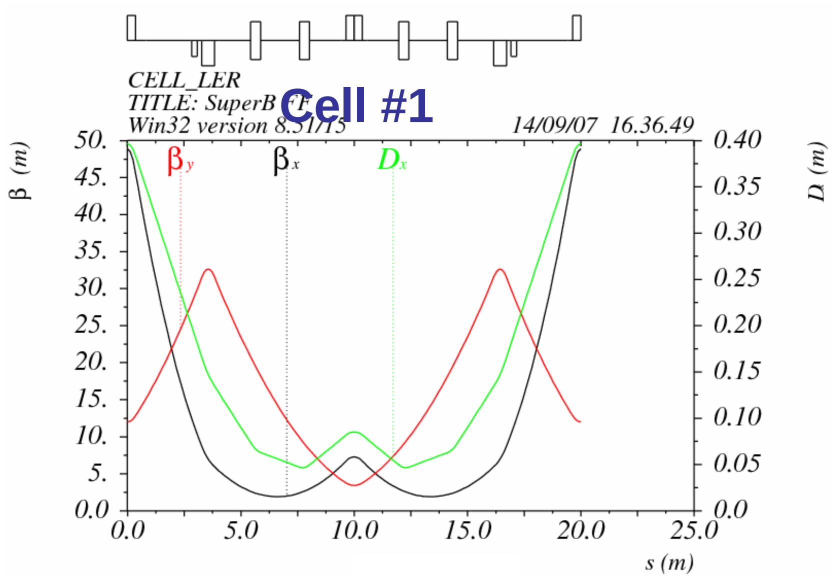
Total klystron power (LER+HER)		
	MW	
"Old"	22.84	CDR parameters
Nominal	16.96	
Upgrade	25.23	New parameters
Ultimate	58.22	

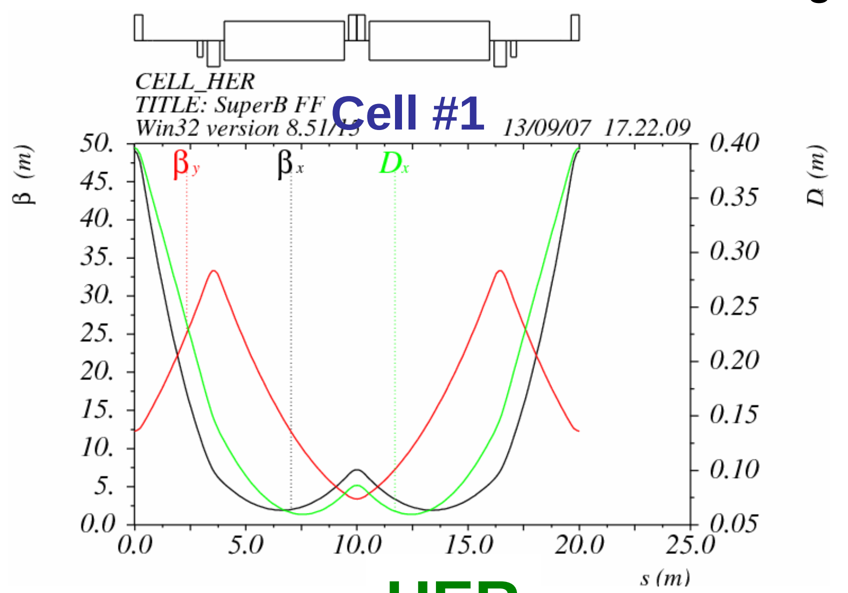
Lattice overview

- The SuperB lattice as described in the Conceptual Design Report is the result of an international collaboration between experts from **BINP, Cockcroft Institute, INFN, KEKB, LAL/Orsay, SLAC**
- Simulations were performed in many labs and with different codes:
  - LNF, BINP, KEK, LAL, CERN
- The design is flexible but challenging and the synergy with the ILC Damping Rings which helped in focusing key issues, will be important for addressing some of the topics
- Further studies after the CDR completion led to an evolution of the lattice to fit the Tor Vergata Site and to include polarization manipulation hardware.

Arc cells layout

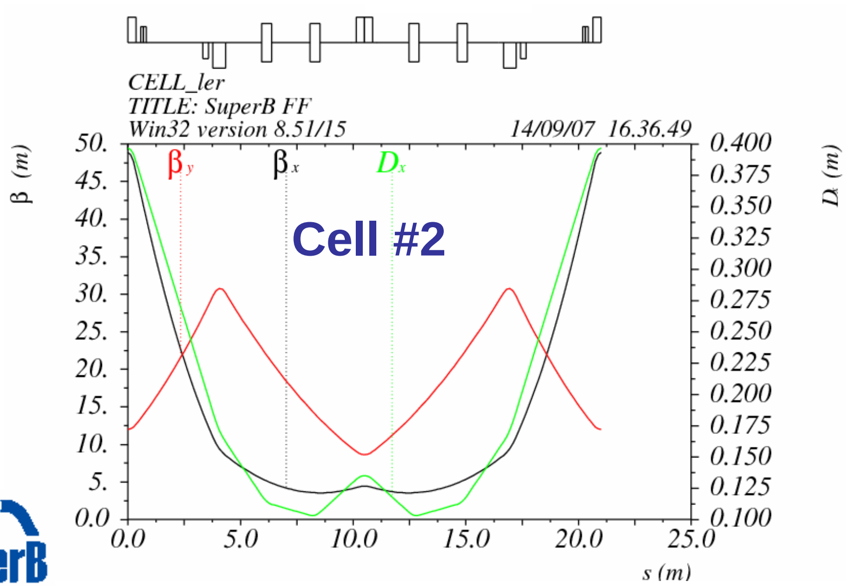
M. Biagini

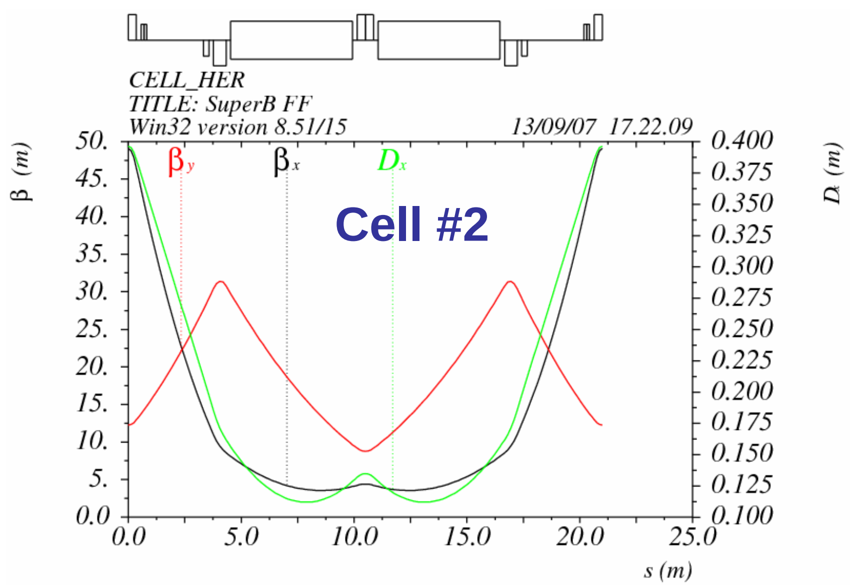




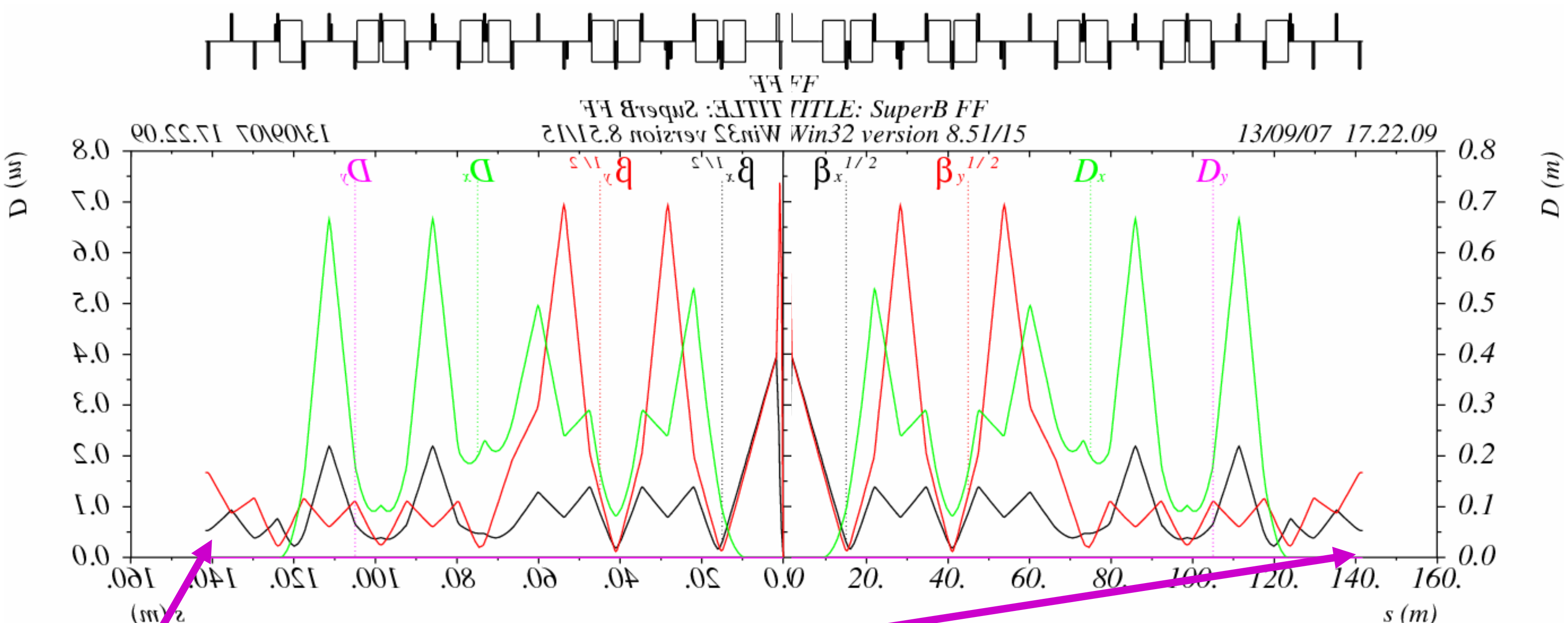
LER

HER





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



Crab sextupoles

LER: β_x^* = 35 mm, β_y^* = 220 μ

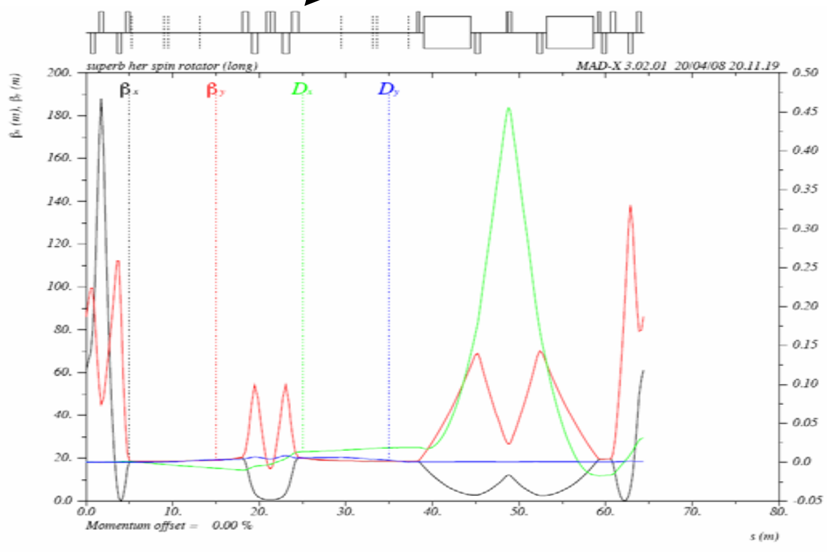
HER: β_x^* = 20 mm, β_y^* = 390 μ

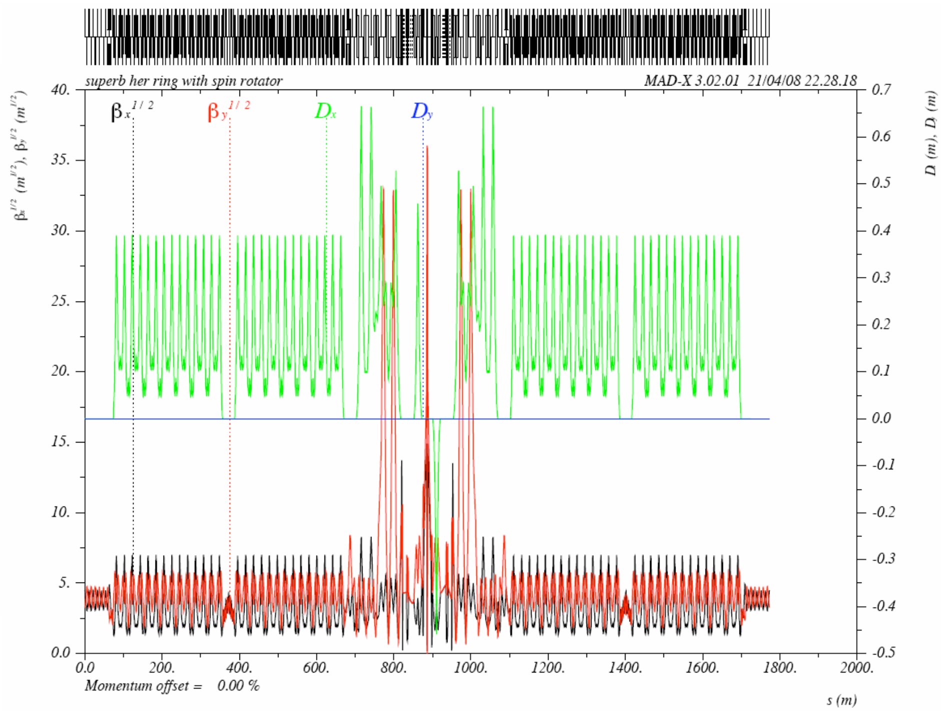
M. Biagini

HER spin manipulation hardware

Spin rotators in the HER

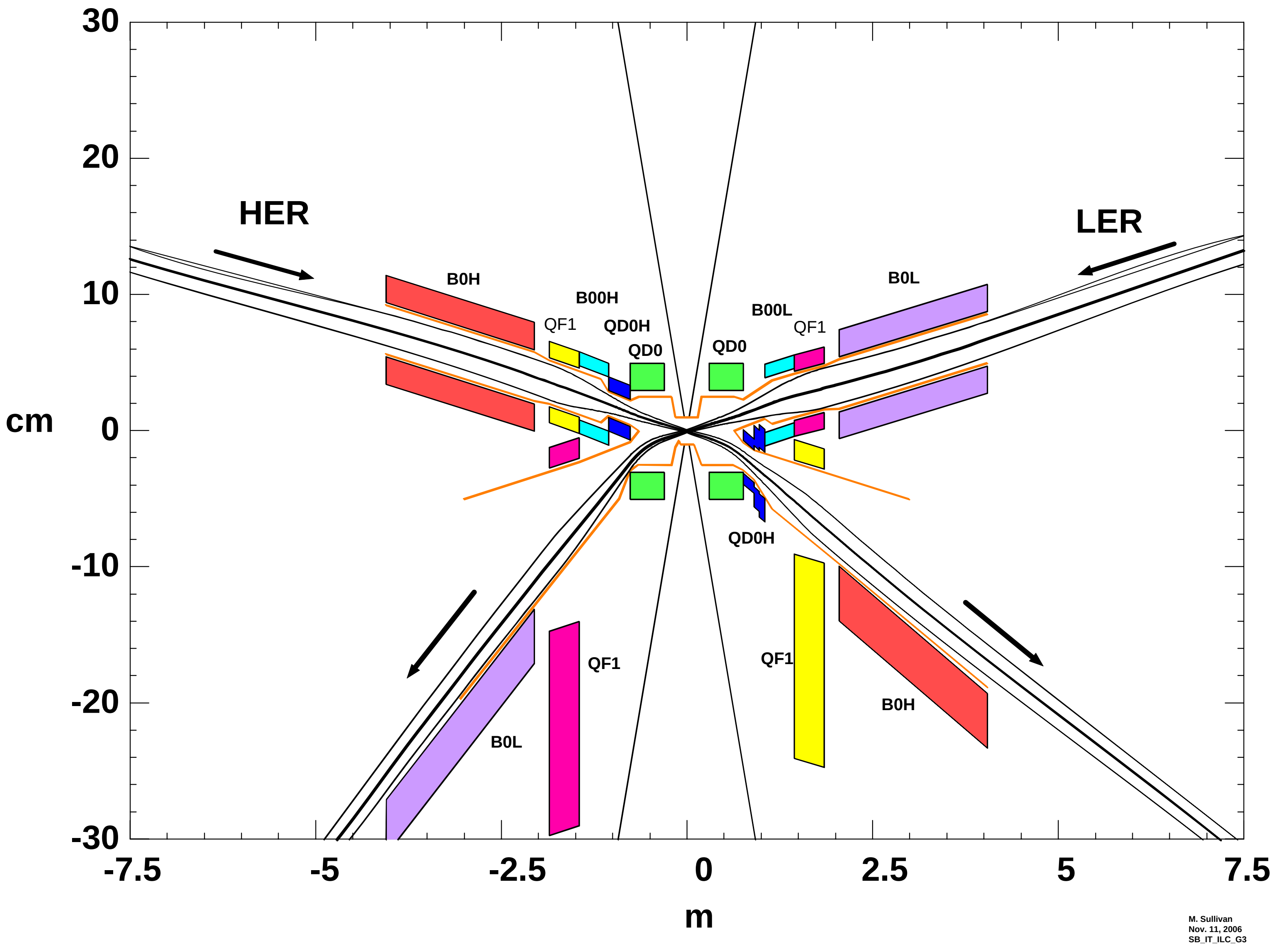
Full HER lattice





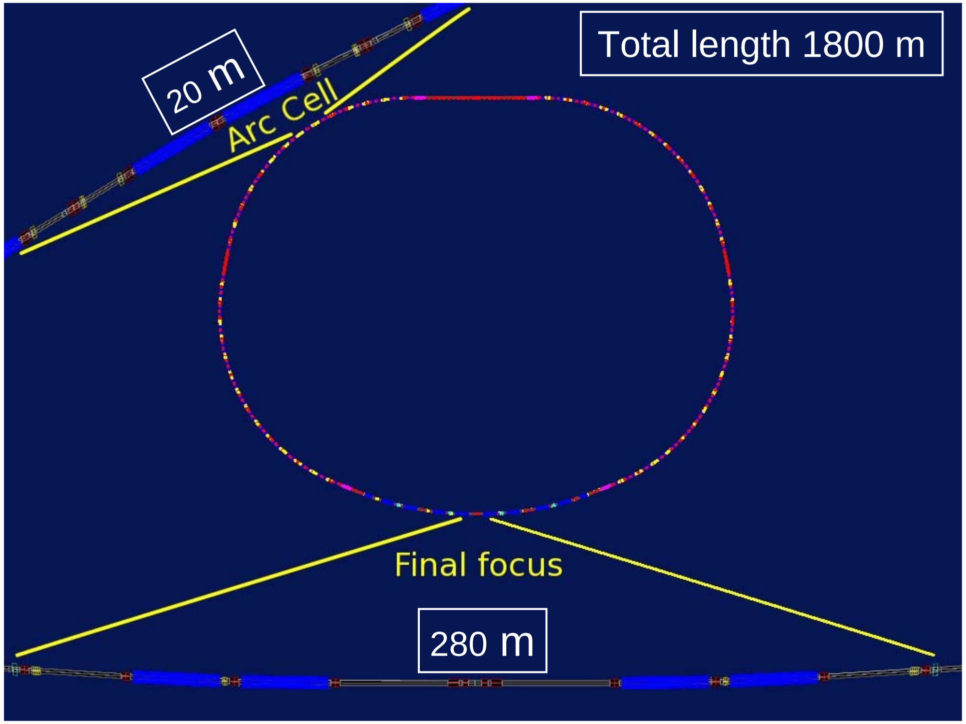
Wittmer, Wienands, Biagini

SuperB Interaction Region



(M. Sullivan)

Lattice layout, PEP-II magnets reuse



Available

Needed

Quads

L_{mag} (m)	0.45	5.4
PEP HER	-	194
PEP LER	194	-
SBF HER	-	130
SBF LER	224	18
SBF Total	224	148
Needed	30	0

L_{mag} (m)	0.56	0.73	0.43	0.7	0.4
PEP HER	202	82	-	-	-
PEP LER	-	-	353	-	-
SBF HER	165	108	-	2	2
SBF LER	88	108	165	2	2
SBF Total	253	216	165	4	4
Needed	51*	134	0	4	4

Sexts

L_{mag} (m)	0.25	0.5
PEP HER/LER	188	-
SBF Total	372	4
Needed	184	4

All PEP-II magnets are reused.

Dimensions and fields are properly sized.

Polarization

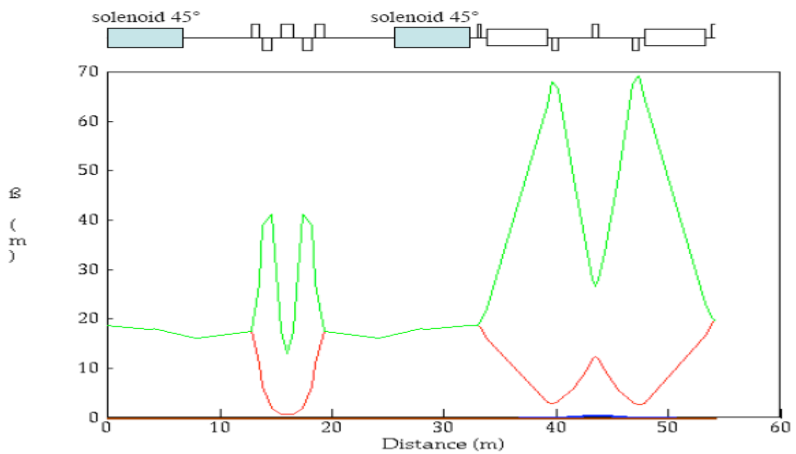
- Polarization of one beam is included in *SuperB*
  - Either energy beam could be the polarized one
  - The LER would be less expensive, the HER easier
  - HER was chosen for now.
- Longitudinal polarization times and short beam lifetimes indicate a need to inject vertically polarized electrons.
  -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

Example of spin rotators

U. Wienands

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

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



Proof-of-principle scheme

HER Spin Rotator

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

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

Accelerator & site cost estimate

WBS	Item	EDIA mm	Labor mm	M\&S kEuro	Rep.Val. kEuro
1	**Accelerator**	**5429**	**3497**	**191166**	**126330**
1.1	Project management	2112	96	1800	0
1.2	Magnet and support system	666	1199	28965	25380
1.3	Vacuum system	620	520	27600	14200
1.4	RF system	272	304	22300	60000
1.5	Interaction region	370	478	10950	0
1.6	Controls, Diagnostics, Feedback	963	648	12951	8750
1.7	Injection and transport systems	426	252	86600	18000

WBS	Item	EDIA mm	Labor mm	M\&S kEuro	Rep.Val. kEuro
2.0	**Site**	**1424**	**1660**	**105700**	**0**
2.1	Site Utilities	820	1040	31700	0
2.2	Tunnel and Support Buildings	604	620	74000	0

Schedule

- Overall schedule dominated by:
  - Site construction
  - PEP-II/BaBar disassembly, transport, and reassembly
- The goal is to reach the commissioning phase after about 5 years from the start of the project.

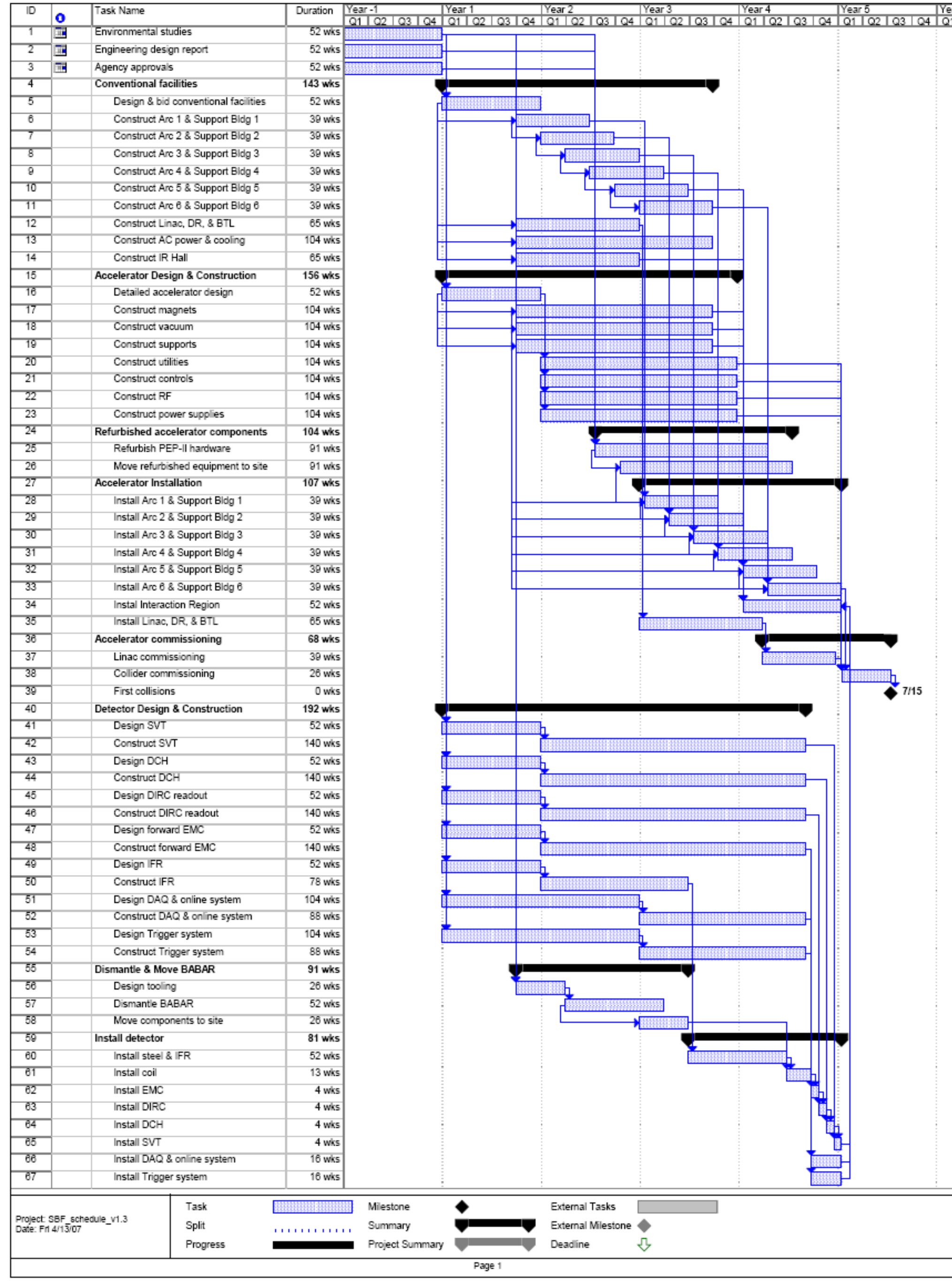


Figure 5-1. *Overall schedule for the construction of the SuperB project.*

Conclusions

- The initial SuperB design meets the goals requested by the experimenters.
- IR polarization rotators have now been added to the lattice.
- Beam dynamics issues are receiving a fresh look.
- The next phase for the accelerator group is to form a team to complete the Technical Design Report.