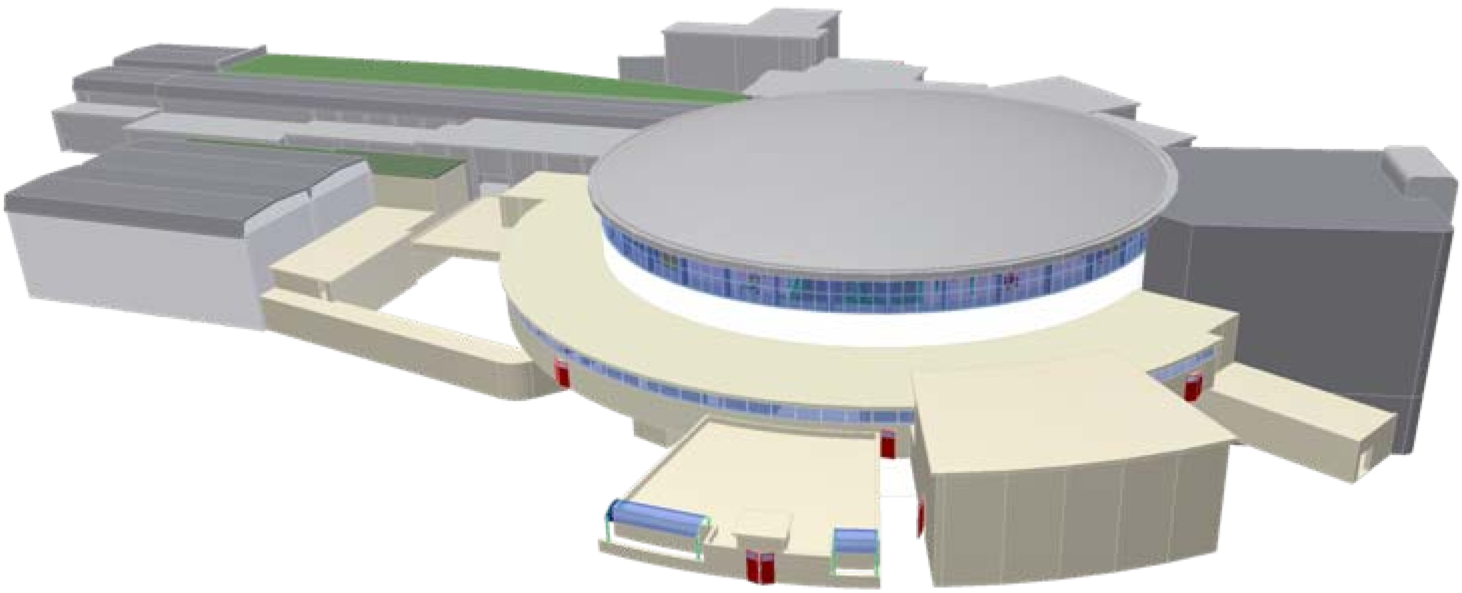
DAΦNE Operating Experience with Crab Waist Collisions

M. Zobov for DAΦNE Collaboration



XXI Russian Particle Accelerator Conference

28 September-03 October 2008, Zvenigorod, Russia

DAΦNE Collaboration Team

D.Alesini, M.E. Biagini, C.Biscari, R.Boni, M.Boscolo, F.Bossi, B. Buonomo, A.Clozza, G.Delle Monache, T. Demma, E.Di Pasquale, G.Di Pirro, A.Drago, A.Gallo, A.Ghigo, S.Guiducci, C.Ligi, F.Marcellini, G.Mazzitelli, C.Milardi, F.Murtas, L.Pellegrino, M.A.Preger, L.Quintieri, P.Raimondi, R.Ricci, U. Rotundo, C.Sanelli, M.Serio, F.Sgamma, B.Spataro, A.Stecchi, A.Stella, S.Tomassini, C.Vaccarezza, M.Zobov

(INFN/LNF, Frascati (Roma)),

I.Koop, E.Levichev, S.Nikitin, P.Piminov, D.Shatilov, V.Smaluk

(BINP SB RAS, Novosibirsk),

S.Bettoni (CERN, Geneva),

M.Schioppa (INFN Gruppo di Cosenza, Arcavacata di Rende (Cosenza)),

P.Valente (INFN-Roma, Roma),

K.Ohmi (KEK, Ibaraki),

D.Teytelman, J. Fox (SLAC),

N.Arnaud, D.Breton, P.Roudeau, A.Stocchi, A.Variola, B.F.Viaud (LAL, Orsay),

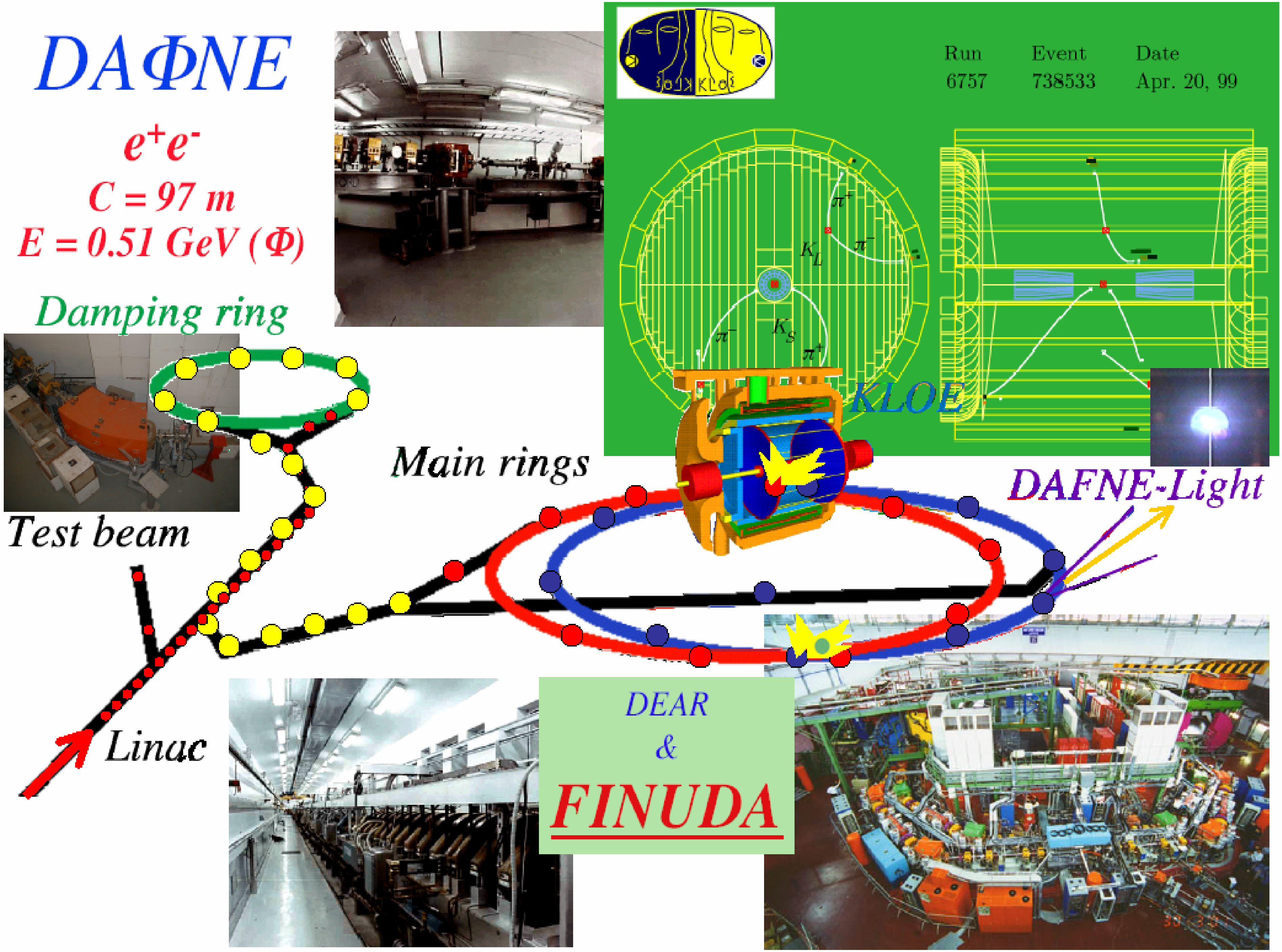
M.Esposito (Rome University La Sapienza, Roma),

E.Paoloni (University of Pisa and INFN, Pisa),

P.Branchini (University Roma3, Rome)

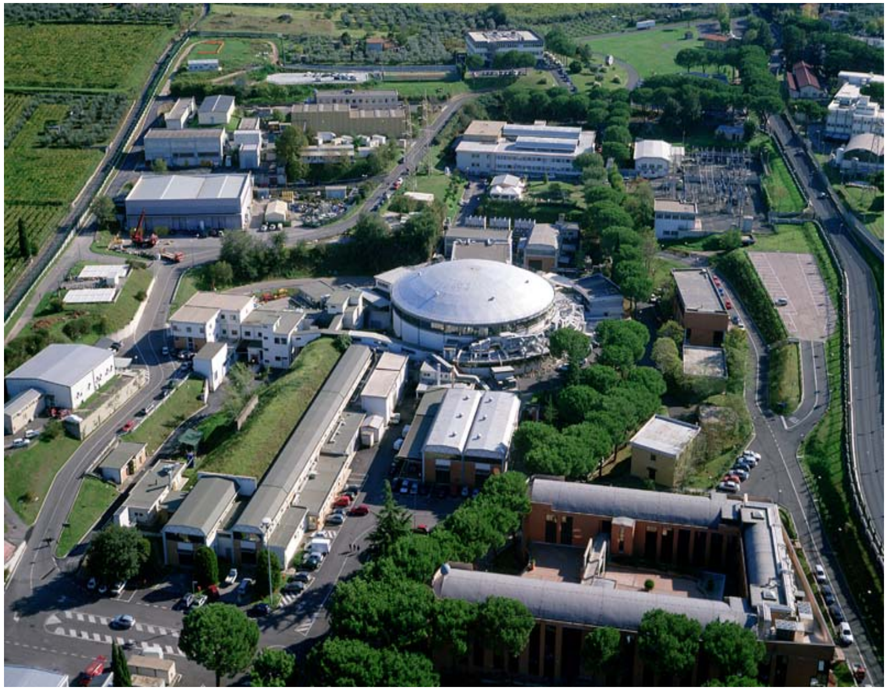
OUTLINE

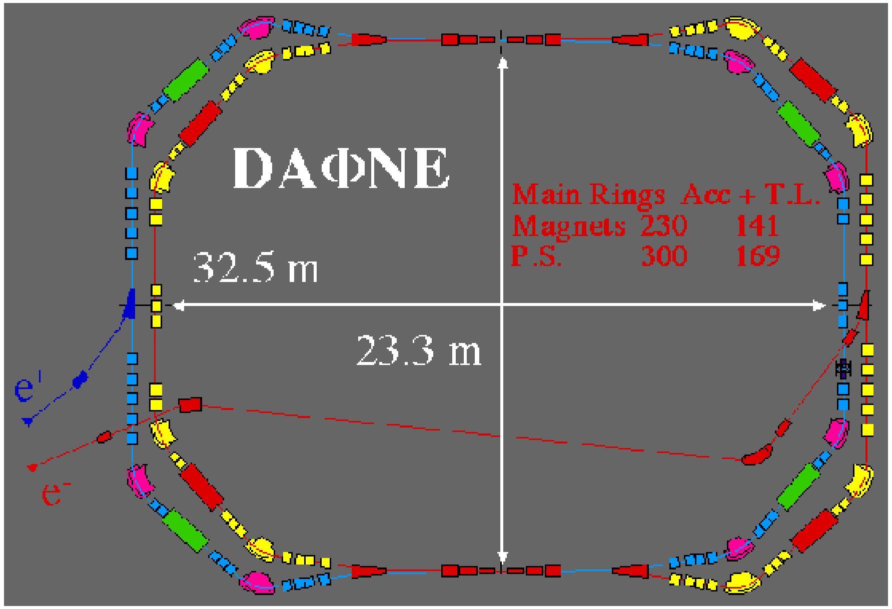
- DAΦNE brief description
- Crab Waist Concept
- Hardware Upgrade
- New Configuration Comissioning
- Crab Wait Collision Test Results


DAΦNE
e^+e^-
C = 97 m
E = 0.51 GeV (Φ)
Damping ring
Test beam
Linac
Main rings
Run 6757
Event 738533
Date Apr. 20, 99
π^+
π^-
K_L
K_S
KLOE
DAFNE-Light
DEAR
&
FINUDA

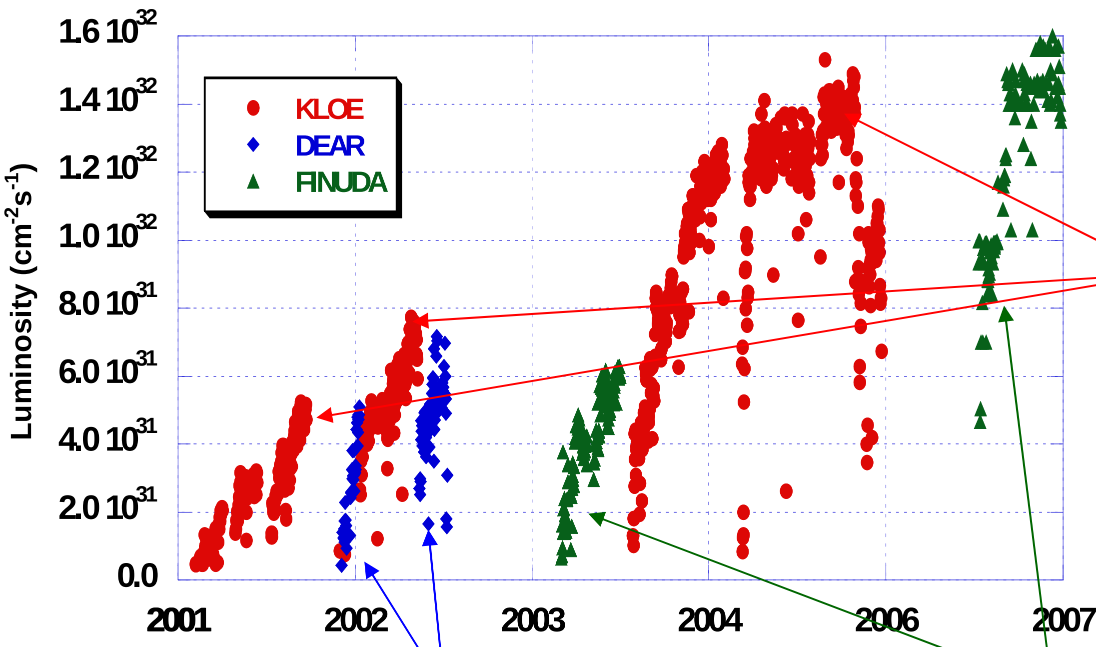
DAΦNE Parameters
(KLOE configuration)

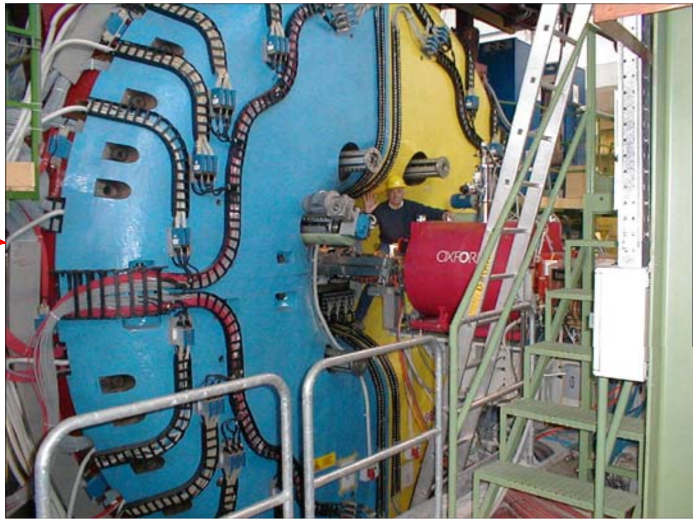
Energy, GeV	0.51
Circumference, m	97.69
RF Frequency, MHz	368.26
Harmonic Number	120
Damping Time, ms	17.8/36.0
Bunch Length, cm	1-3
Emittance, mmxmrad	0.34
Coupling, %	0.2-0.3
Beta Function at IP, m	1.7/0.017
Max. Tune Shifts	.03-.04
Number of Bunches	111
Max.Beam Currents, A	2.4/1.4

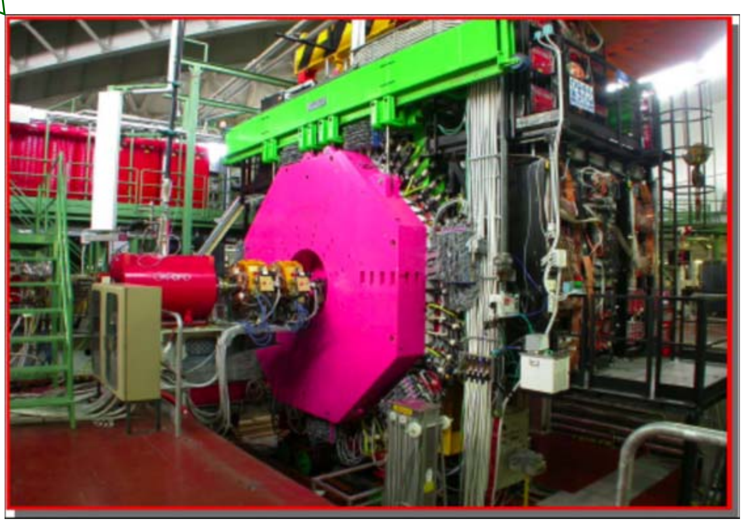




DAΦNE Peak Luminosity



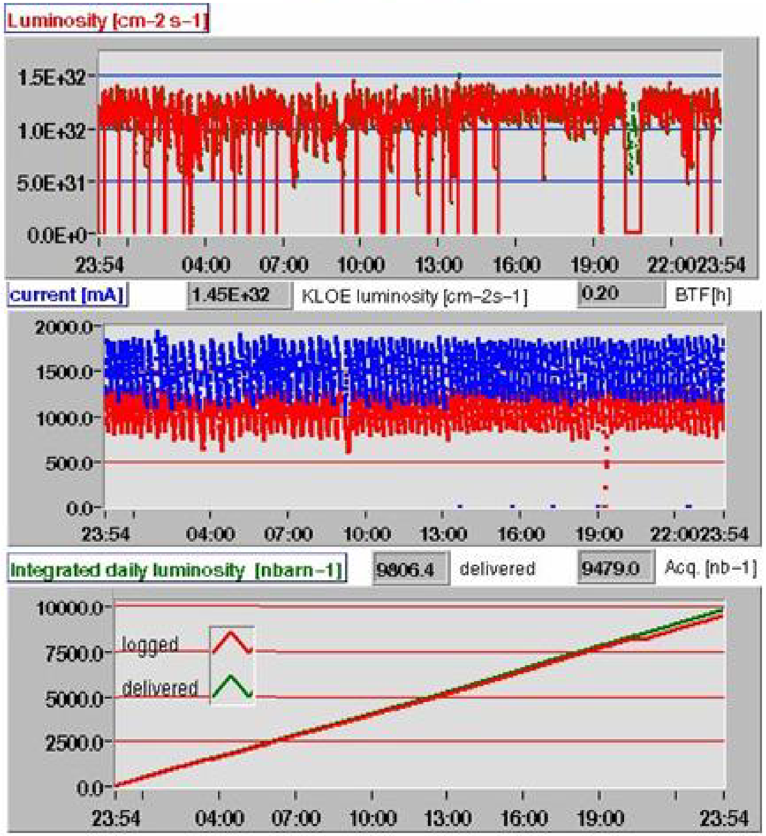




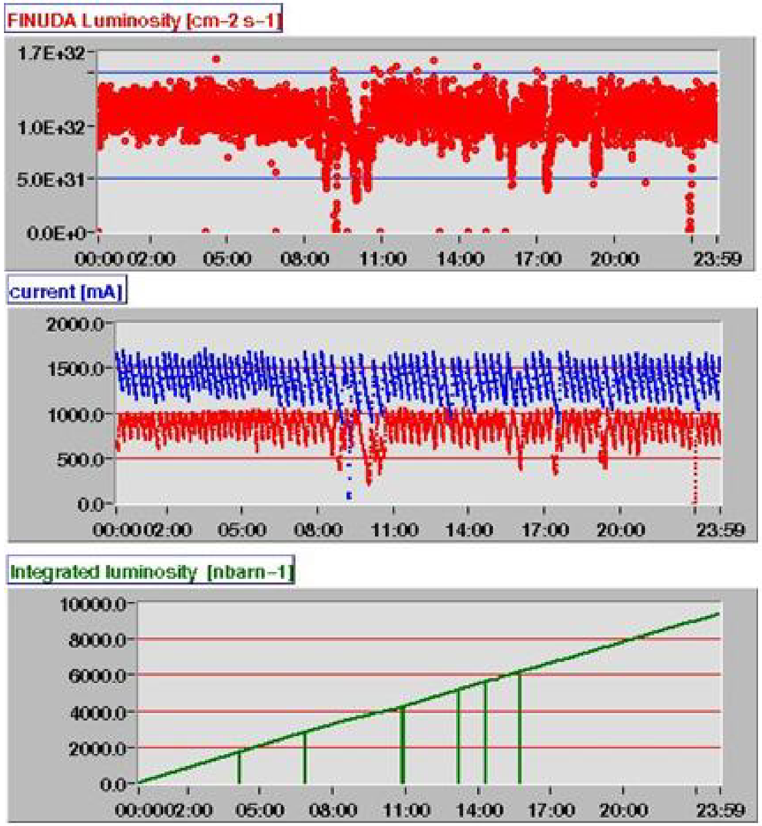
The nature of a Φ-factory in itself indictates a minimum target luminosity of 10^{32} cm^{-2} s^{-1}….

"Proposal for a Φ-factory", LNF-90/031 (IR),1990.

KLOE



FINUDA

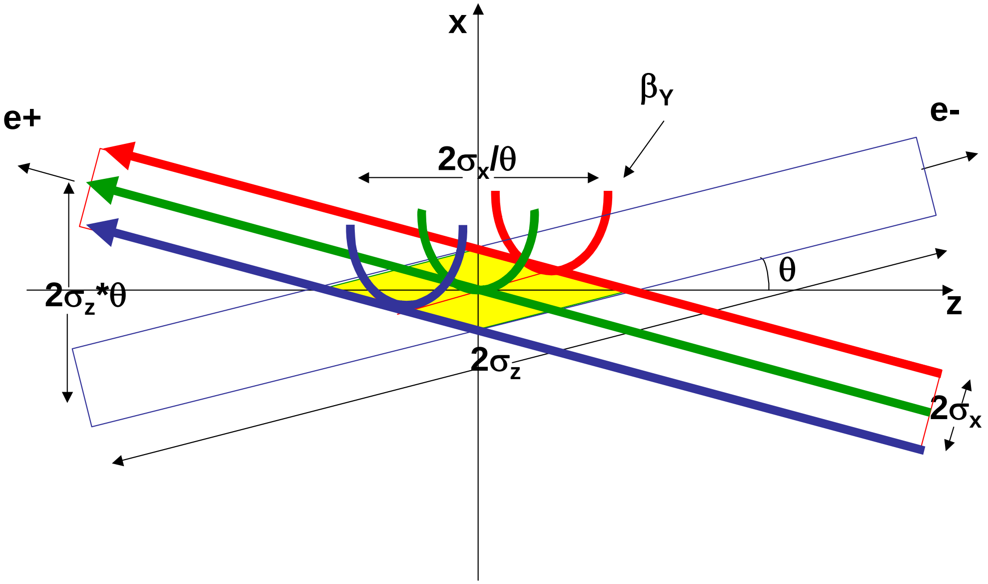


111 bunches, $\beta_y^* = 1.8$ cm, $\beta_x^* = 1.5$ m

106 bunches, $\beta_y^* = 1.9$ cm, $\beta_x^* = 2.0$ m

Crab Waist in 3 Steps

1. Large Piwinski's angle $\Phi = tg(\theta)\sigma_z/\sigma_x$
2. Vertical beta comparable with overlap area $\beta_y \approx \sigma_x/\theta$
3. Crab waist transformation $y = xy'/(2\theta)$

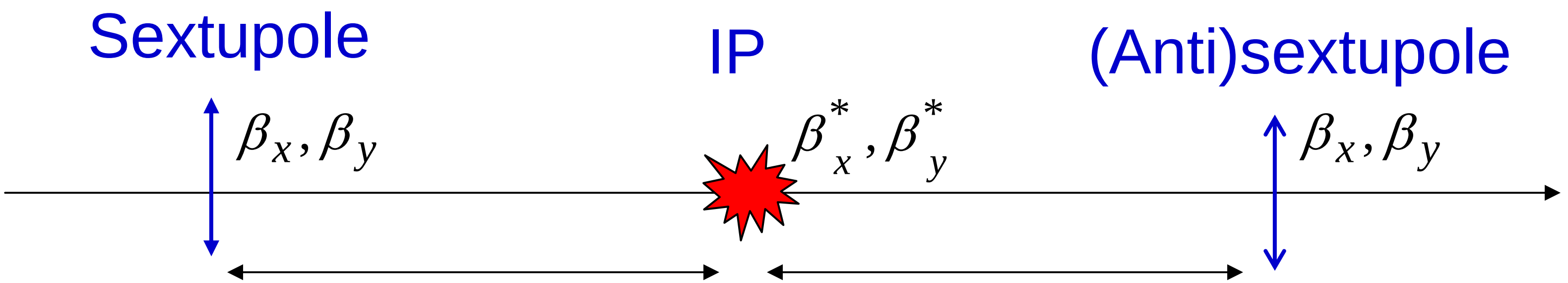


Crabbed waist is realized with a sextupole in phase with the IP in X and at $\pi/2$ in Y

1. *P.Raimondi, 2° SuperB Workshop, March 2006*

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

Crabbed Waist Scheme



$$\Delta\mu_y = \frac{\pi}{2} \qquad \Delta\mu_y = \frac{\pi}{2}$$

$$\Delta\mu_x = \pi \qquad \Delta\mu_x = \pi$$

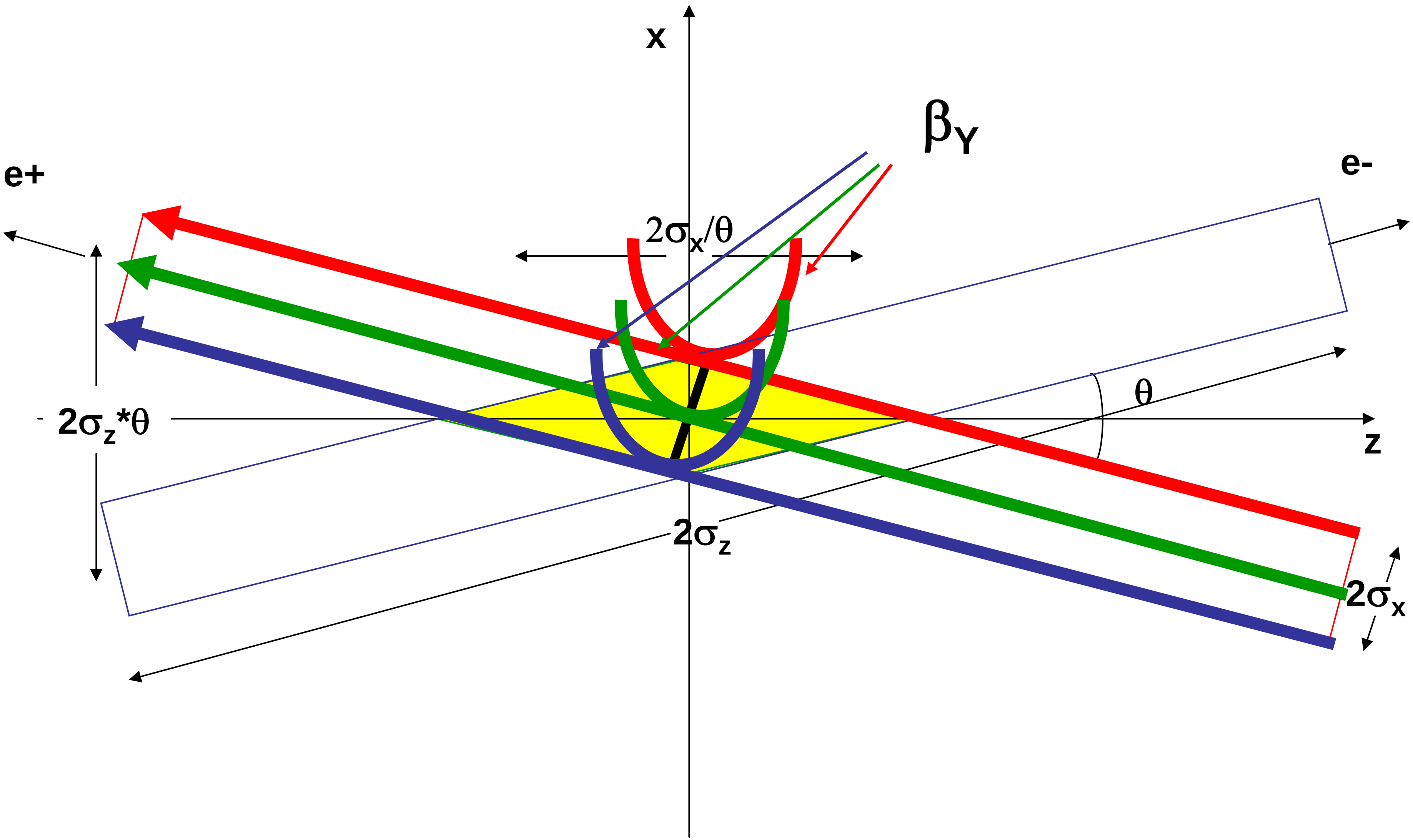
Sextupole strength

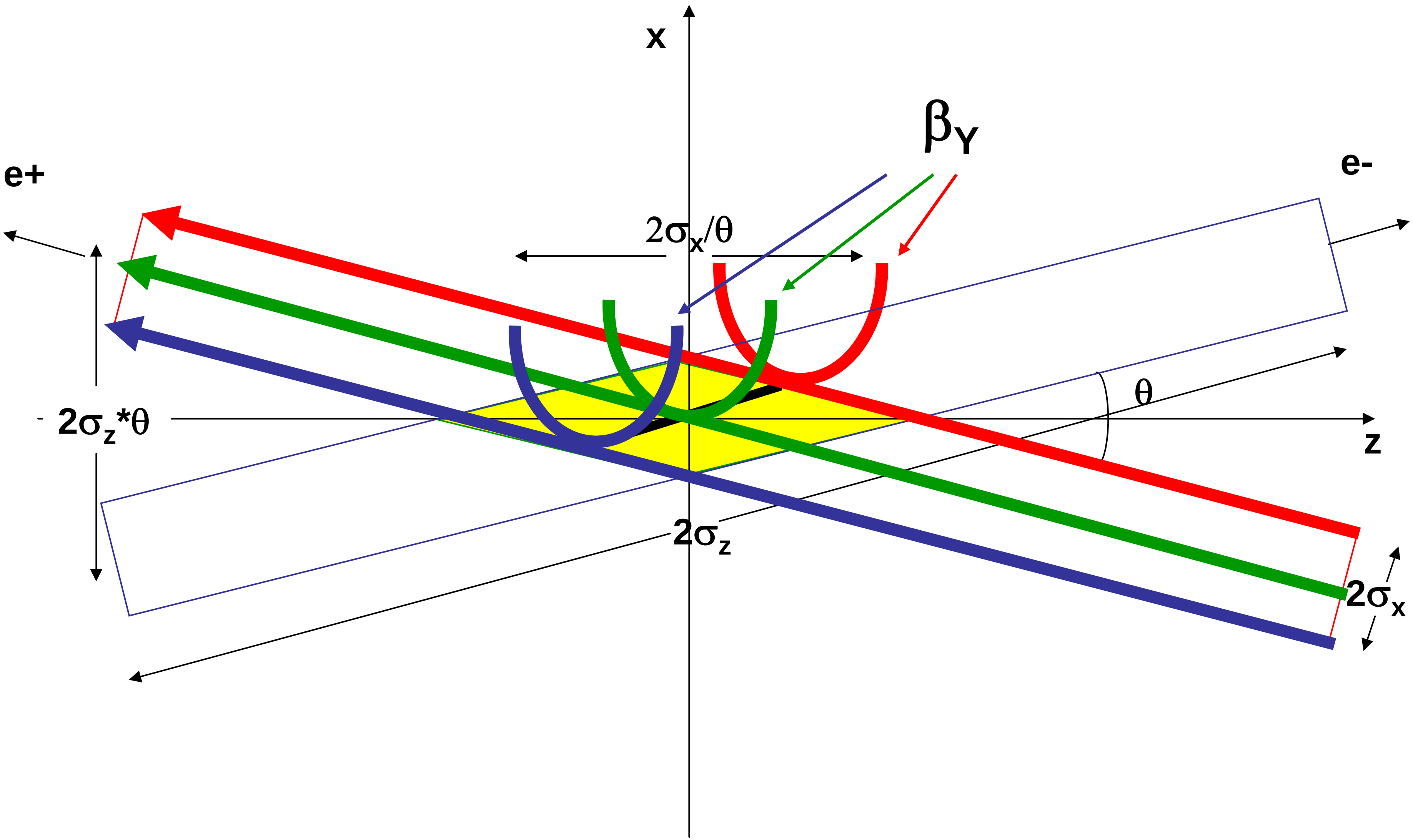
$$K = \frac{1}{2\theta}\frac{1}{\beta_y^*\beta_y}\sqrt{\frac{\beta_x^*}{\beta_x}}$$

Equivalent Hamiltonian

$$H = H_0 + \frac{1}{2\theta}xp_y^2$$

$$\beta_y = \beta_y^* + \frac{(s - x/\theta)^2}{\beta_y^*}$$


x
βY
e+
e-
2σx/θ
θ
2σz*θ
z
2σz
2σx


x
βY
e+
e-
2σx/θ
2σz*θ
θ
z
2σz
2σx

Crabbed Waist Advantages

1. Large Piwinski's angle

$$\Phi = tg(\theta)\sigma_z/\sigma_x$$

→

a) Geometric luminosity gain

b) Very low horizontal tune shift

2. Vertical beta comparable with overlap area

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

→

a) Geometric luminosity gain

b) Lower vertical tune shift

c) Vertical tune shift decreases with oscillation amplitude

d) Suppression of vertical synchro-betatron resonances

3. Crabbed waist transformation

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

→

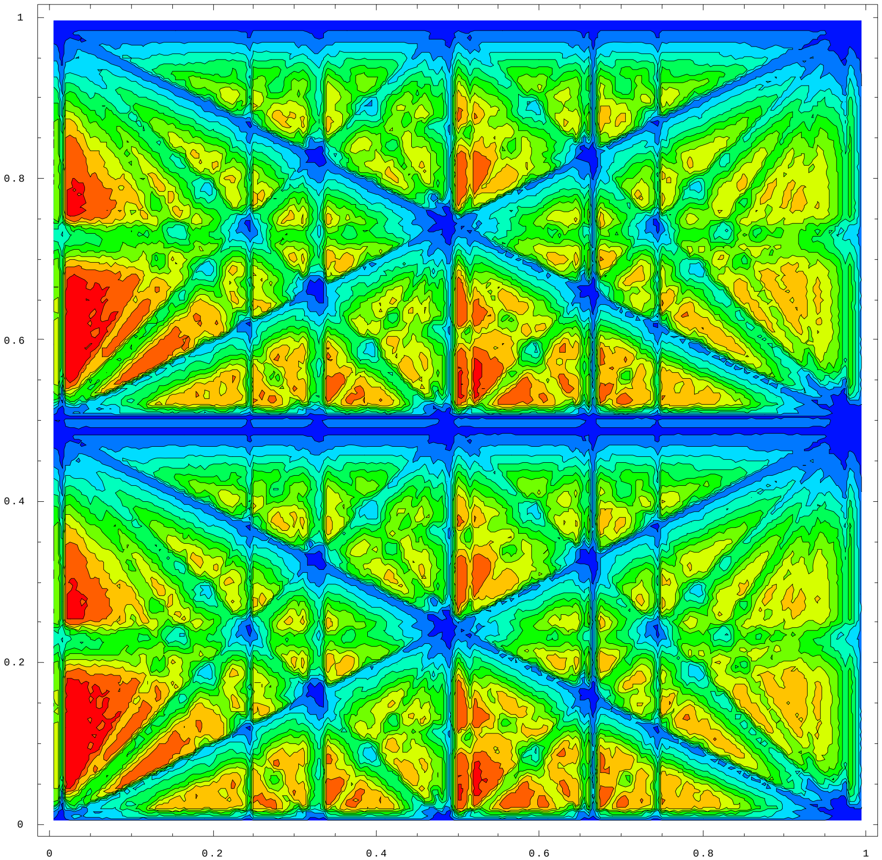
a) Geometric luminosity gain

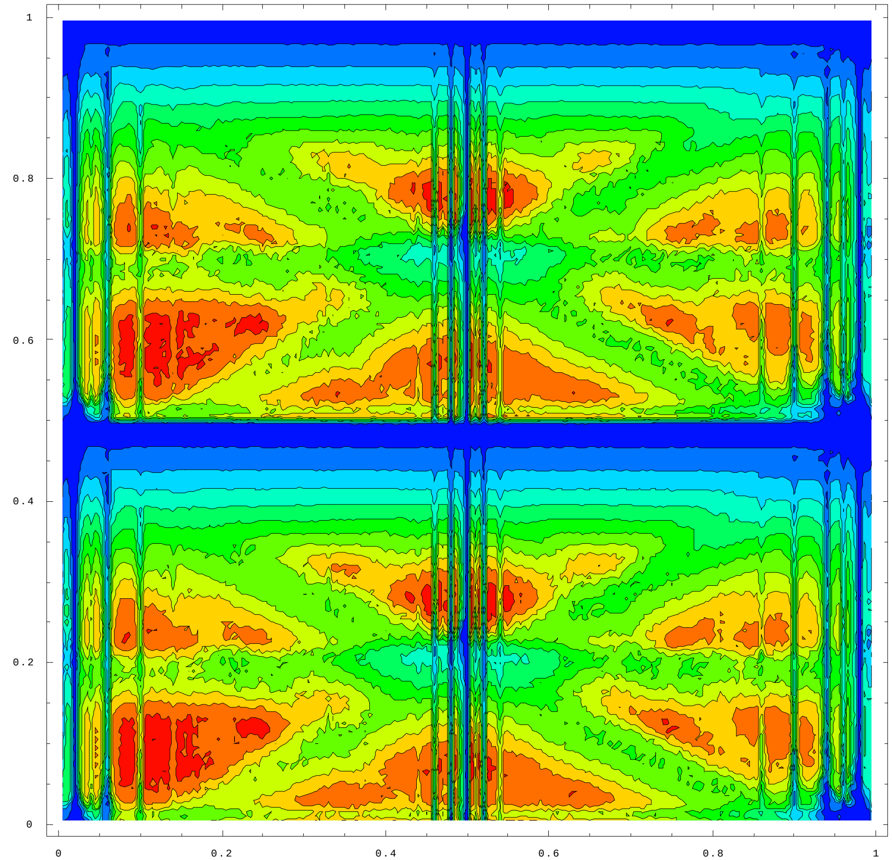
b) Suppression of X-Y betatron and synchro-betatron resonances

X-Y Resonance Suppression

D.N.Shatilov

Much higher luminosity!





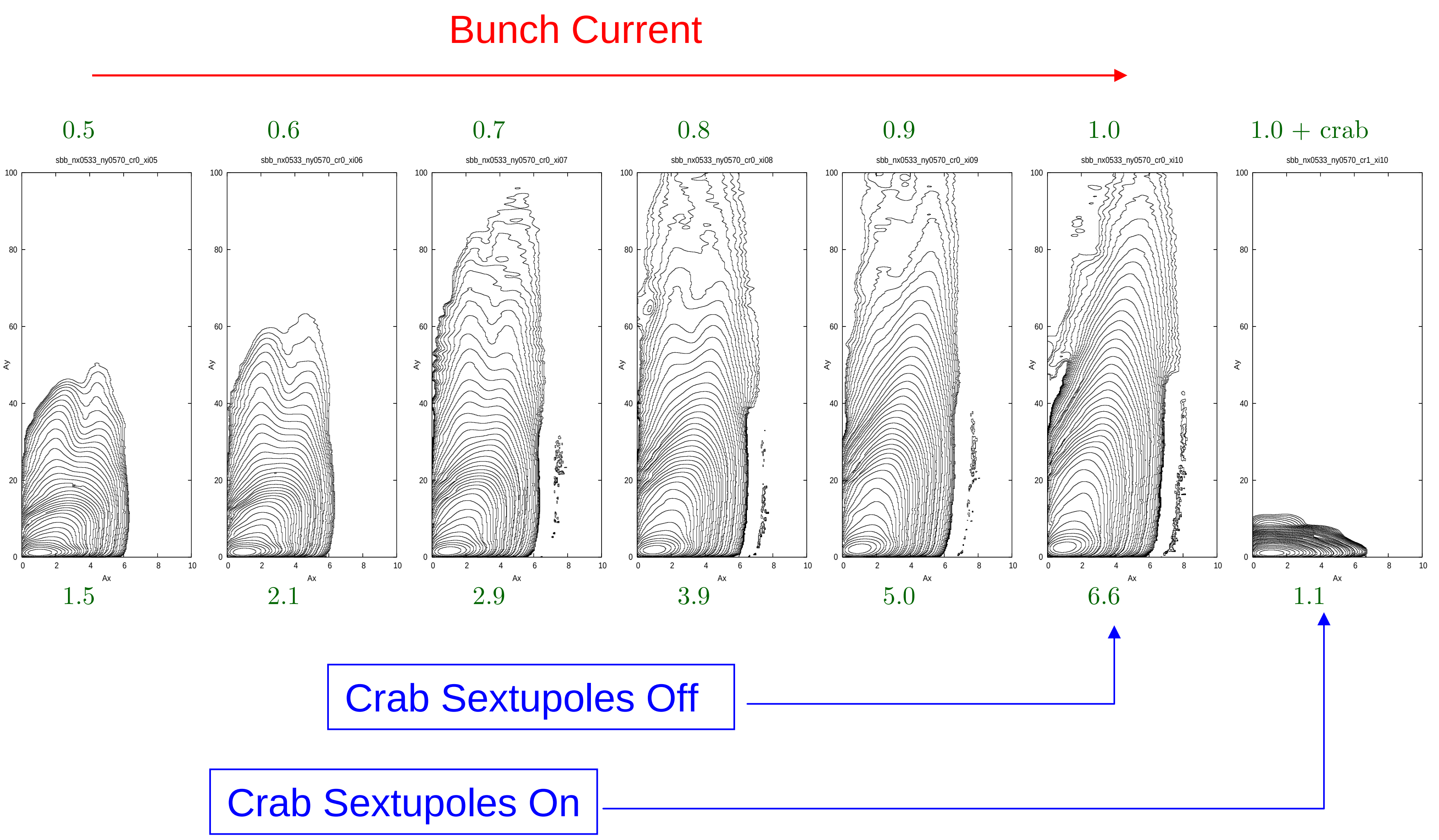
Typical case (KEKB, DAΦNE etc.):

1. low Piwinski angle $\Phi < 1$
2. β_y comparable with σ_z

Crab Waist On:

1. large Piwinski angle $\Phi >> 1$
2. β_y comparable with σ_x/θ

Tails in SuperB



..and besides,

a) There is no need to increase excessively beam current and to decrease the bunch length:

1) Beam instabilities are less severe
2) Manageable HOM heating
3) No coherent synchrotron radiation of short bunches
4) No excessive power consumption

b) The problem of parasitic collisions is automatically solved due to higher crossing angle and smaller horizontal beam size

The project of τ–charm factory with crab waist in Novosibirsk

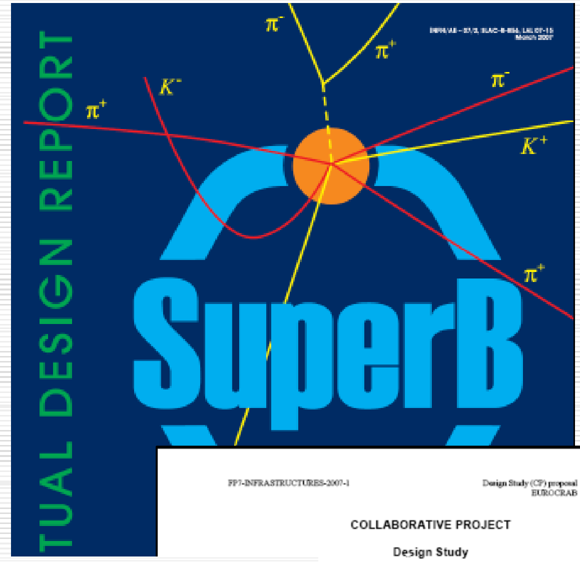
Crab Waist Studies for SuperB and KEKB

Y. Ohnishi/KEK
SuperB Workshop V

Paris
10/May/2007

Unlimited Muon Collider
Luminosity with Fixed Beam Power

D. J. Summers
Univ. of Mississippi - Oxford



FP7-INFRASTRUCTURES-2007-1

Design Study (CP) proposal
EUROCRAB

COLLABORATIVE PROJECT

Design Study

FP7-INFRASTRUCTURES-2007-1

rab Waist Study for High Luminosity Colliders

EUROCRAB

18/04/2007
onal):2

List of participants in the Design Study

icipant organisation name	Part. short name	Country
Nazionale di Fisica Nucleare	INFN	Italy
aboratori Nazionali di Frascati	INFN-LNF	Italy
sa	INFN-Pisa	Italy
oma1	INFN-Ro1	Italy
an Organization for Nuclear ch	CERN	Switzerland
National de la Recherche ique	CNRS/IN2P3	France
aboratoire de l'Accélérateur , Orsay	LAL	France
de Physique Nucléaire de Lyon	INPL	France
iversity of Liverpool	Liverpool	UK
Institute of Nuclear Physics	BINP	Russia
an Synchrotron Radiation	ESRF	France
rone Trieste	ELETTRA	Italy

List of Contributors in the Design Study

tributor organisation name	Part. short name	Country
rd Linear Accelerator Center	SLAC	US
Energy Accelerator Research ization	KEK	Japan

pics addressed
ms at studying key questions regarding high luminosity colliders. The topics ucial for the upgrade in luminosity of existing facilities as the DAΦNE Φ- ("emerging" proposal in the ESFRI list), the Large Hadron Collider at CERN, gn of a new European Super B-Factory with unprecedented luminosity.

LHC Upgrade

Crabbed Waist Scheme at DAΦNE

M. Zobov for DAΦNE Upgrade Team

SuperB IV, 13-15 November 2006
Monte Porzio Catone - Italy

SuperB at Fermilab

David Hitlin
Fermilab Steering Group
May 7, 2007

SuperB

1

Good Opportunity

for Physics Programs

1. Fits DAΦNE schedule (shut down for SIDDHARTA installation in mid 2007)
2. Satisfies new physics programs (SIDDHARTA, KLOE2, FINUDA...)
3. Requires moderate modifications
4. Relatively low cost (1 mln Euro)

for Beam Dynamics

1. No detector solenoidal field
2. No splitter magnets
3. No compensating solenoids
4. No parasitic crossings
5. Lower beam impedance (simple IR, new bellows, new injection kickers)

DAΦNE Upgrade Parameters

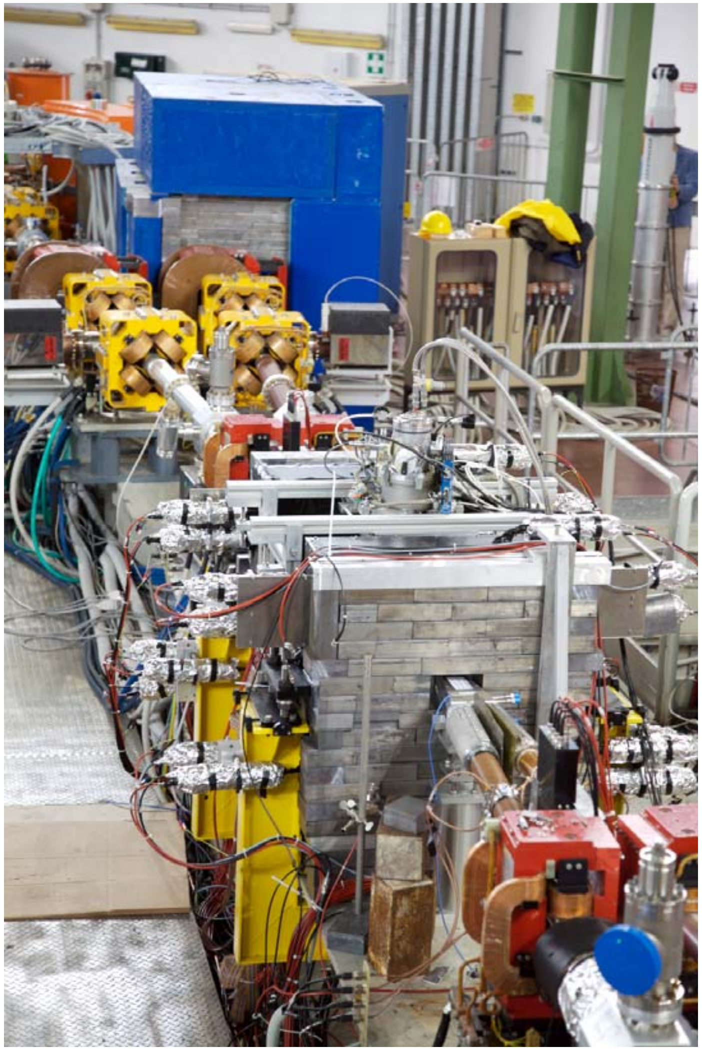
	DAΦNE FINUDA	DAΦNE Upgrade
$\theta_{cross}/2$ (mrad)	12.5	25
ε_x (mm x mrad)	0.34	0.20
β_x^* (cm)	170	20
σ_x^* (mm)	0.76	0.20
$\Phi_{Piwinski}$	0.36	2.5
β_y^* (cm)	1.70	0.65
σ_y^* (μm)	5.4 (low current)	2.6
Coupling, %	0.5	0.5
I_{bunch} (mA)	13	13
N_{bunch}	110	110
σ_z (mm)	22	20
L ($cm^{-2}s^{-1}$) x10^{32}	1.6	5

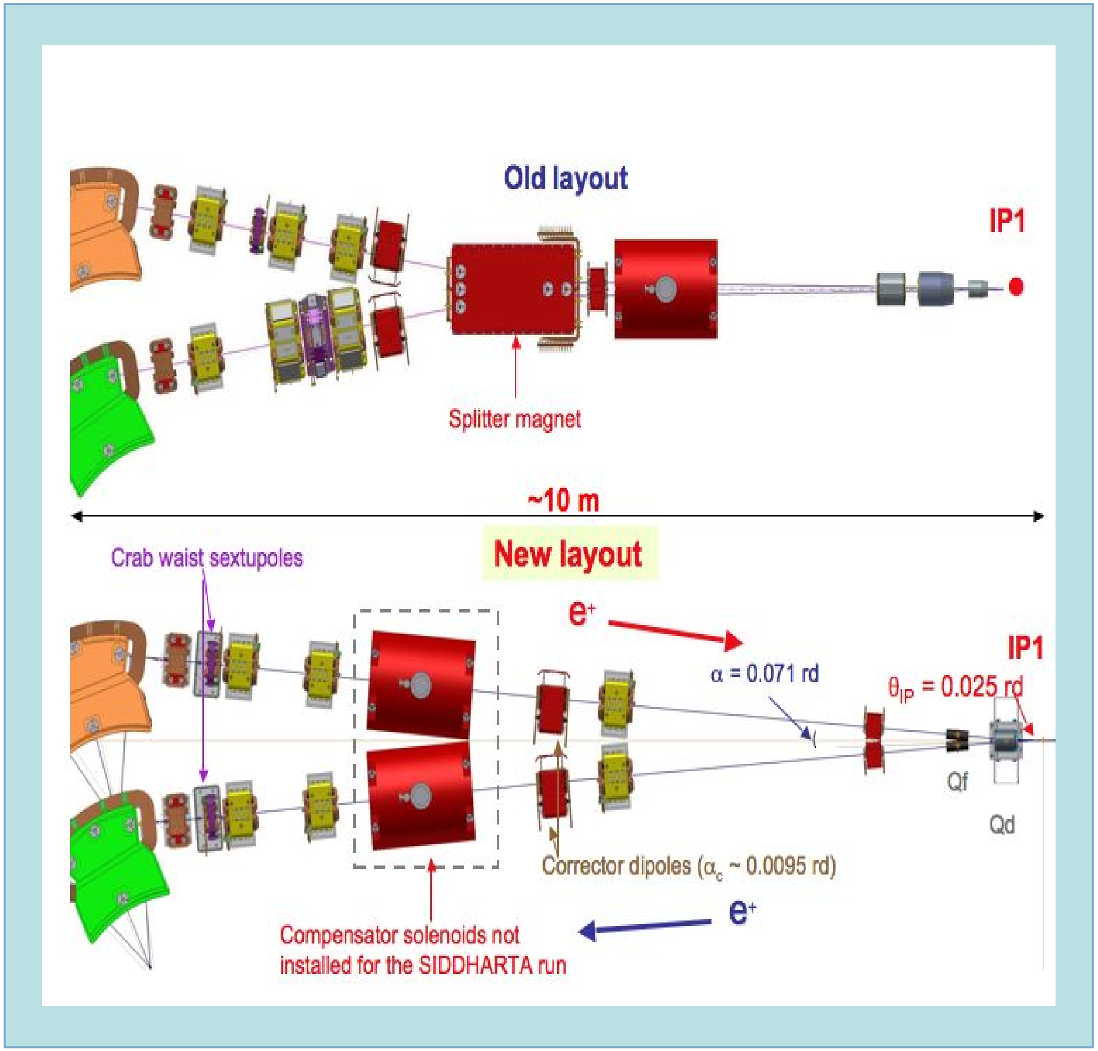
Larger Piwinski angle ($\theta_{cross}/2$, ε_x, β_x^*, σ_x^*, $\Phi_{Piwinski}$)

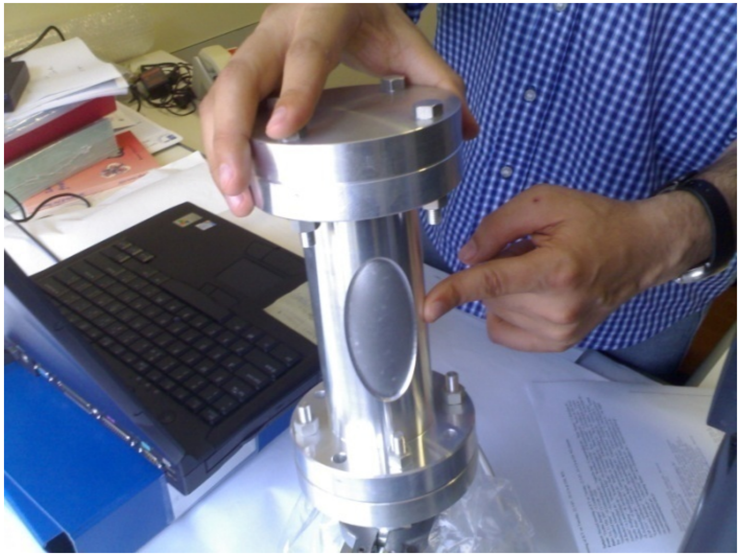
Lower vertical beta (β_y^*, σ_y^*)

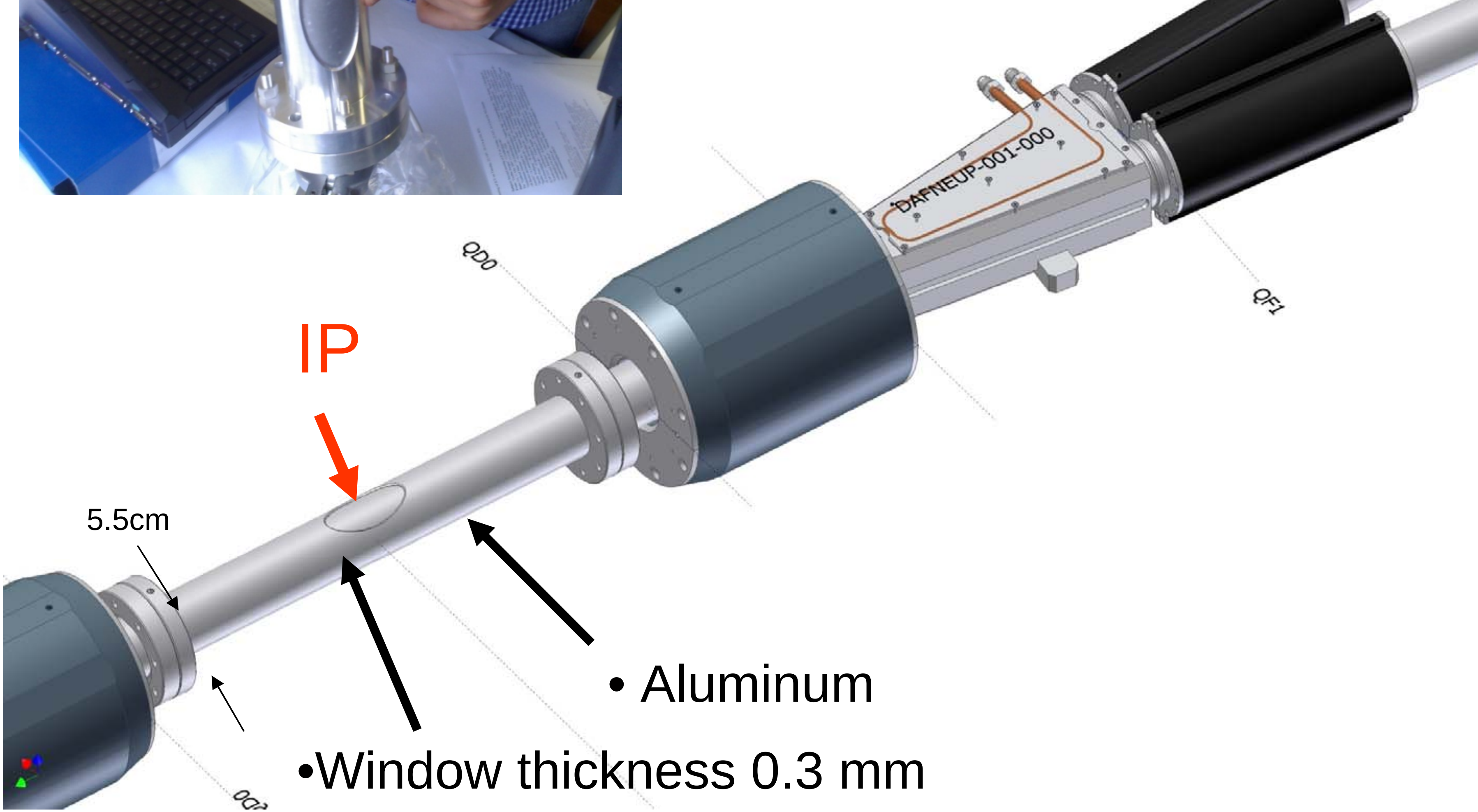
Already achieved (Coupling, I_{bunch}, N_{bunch}, σ_z)

New Experimental Interaction Region



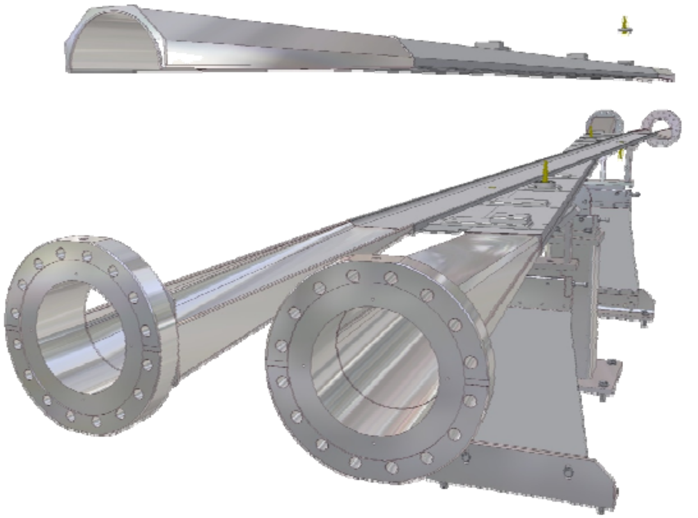


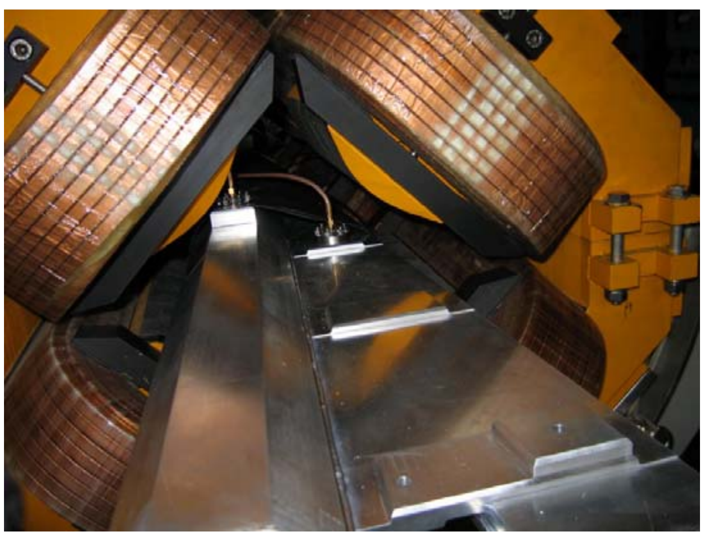



DAFNEUP-001-000
QD0
QF1
IP
5.5cm
• Aluminum
•Window thickness 0.3 mm

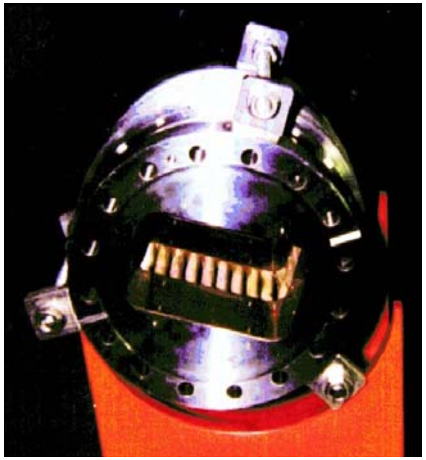
SECOND CROSSING REGION LAYOUT

- 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)

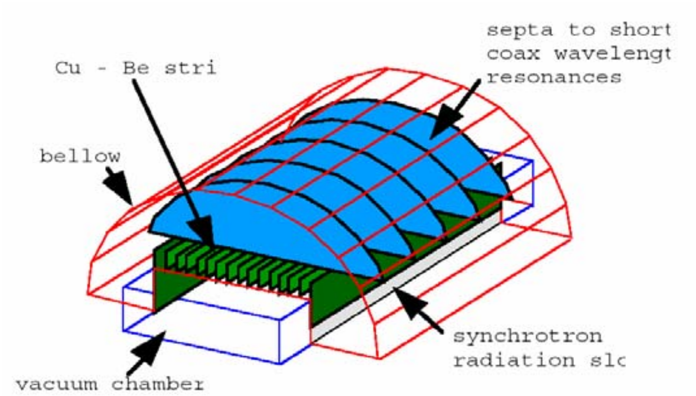


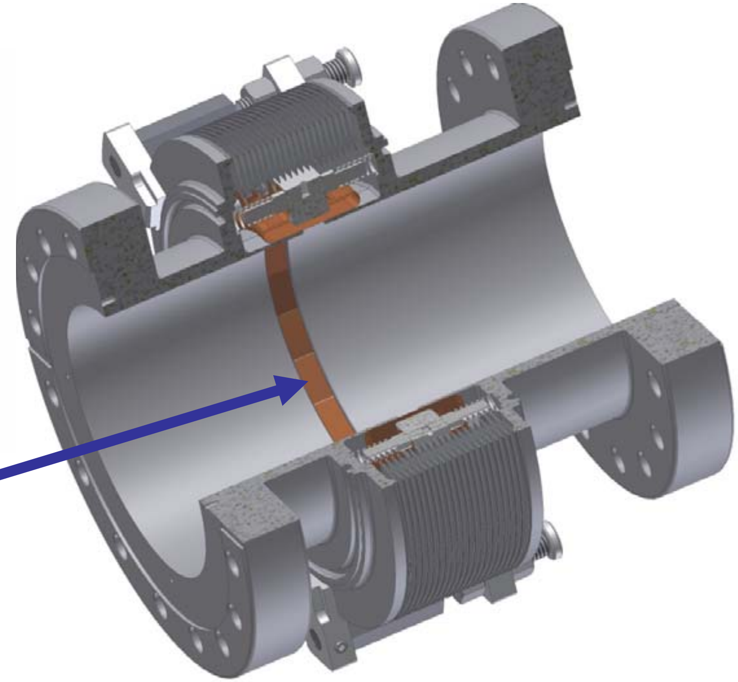


NEW BELLOWS

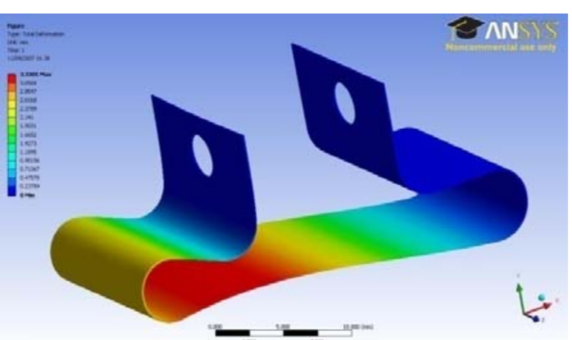


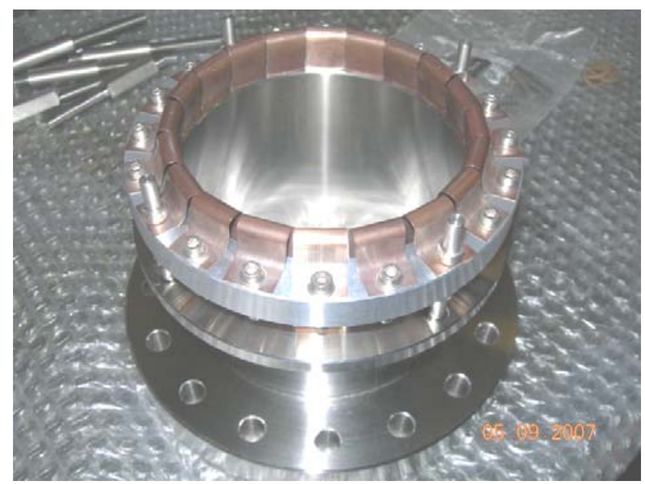
OLD BELLOW



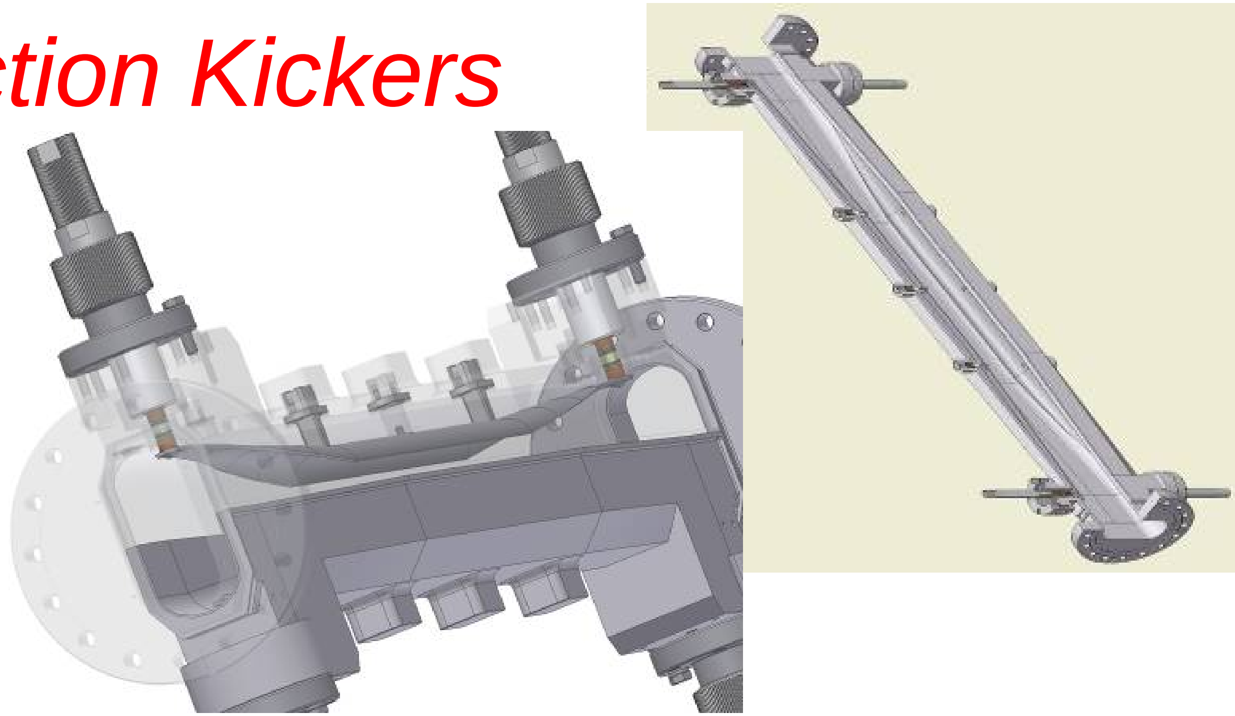


- 6 new bellows for each ring
- Shielding based on Be-Cu W strips 0.2 mm thick
- lower impedance and better mechanical performance

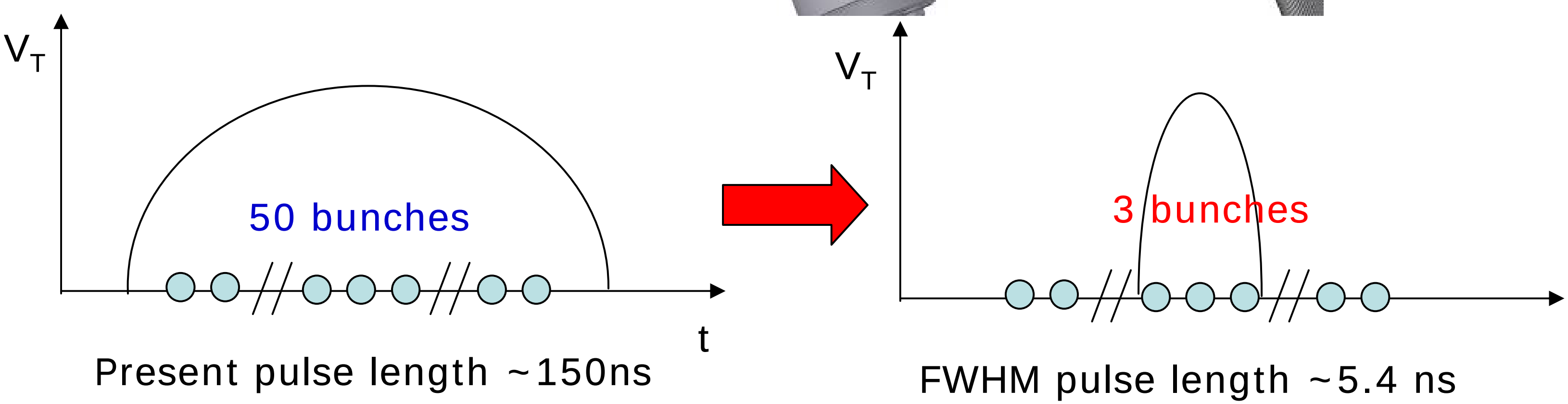




New Fast Injection Kickers



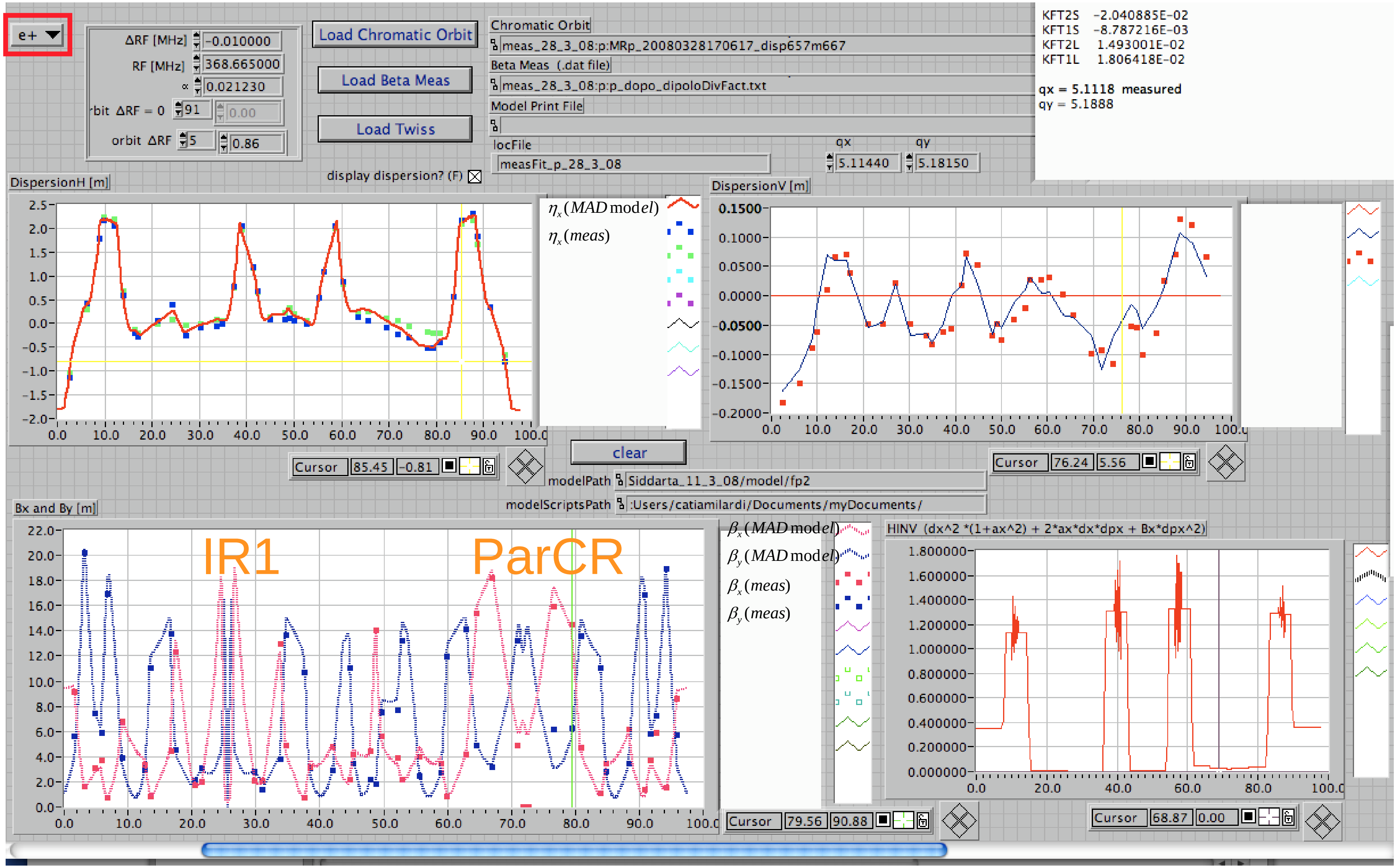
New injection kickers with
5.4 ns pulse length
to reduce perturbation on stored beam



Expected benefits:

- **higher maximum stored currents**
- **Improved stability of colliding beams during injection**
- **less background allowing data acquisition during injection**

Present SIDDHARTA Optics

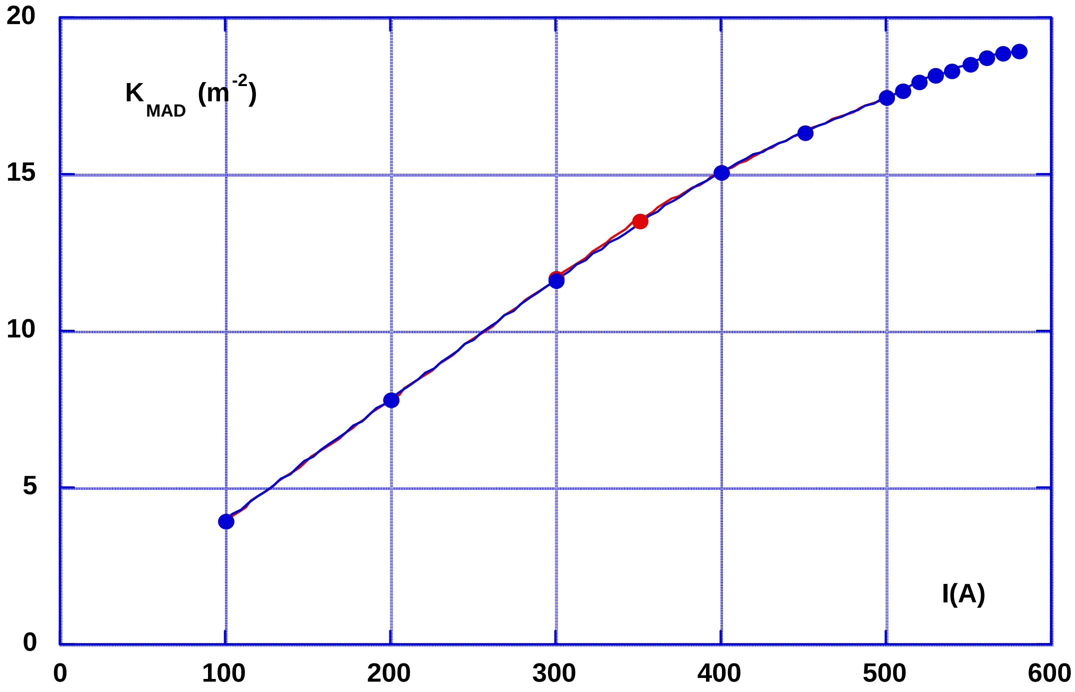


Optical parameters (July 2008)

	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	0.0085	0.0065	0.0085
coupling (%)	0.5	0.2	0.5	0.2
σ_x @ IP (mm)	0.20	0.26	0.20	0.25
σ_y @ IP (μm)	2.6	3.2	2.6	3.2
Piwinski angle (10mA)	2.5	1.6	2.5	1.7

Crab sextupoles parameters

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

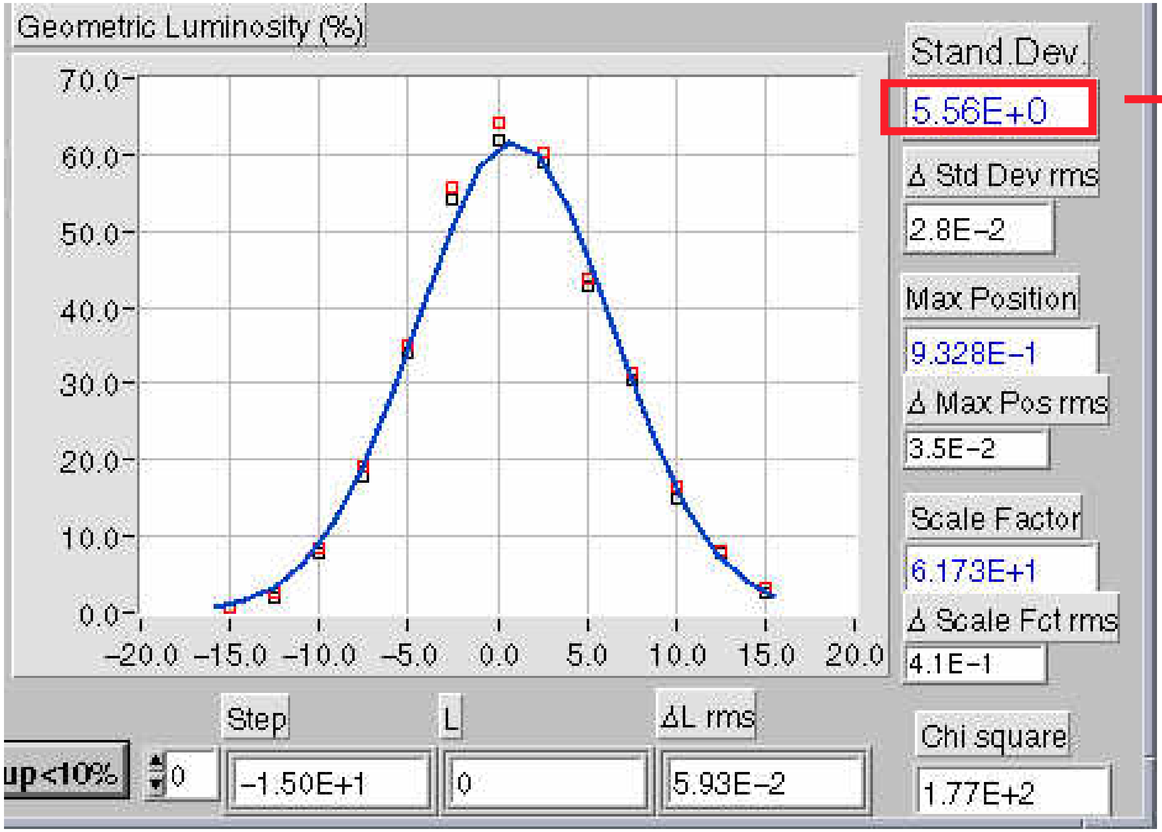


θ (mrad)	25
β_y*(mm)	10
β_x*(mm)	250
β_y^{sext}(m)	13.5
β_x^{sext}(m)	4.2
K_s (m^{-2})	36

On June 2008 Installed 4 "large" sextupoles of the arcs with $K_{max} \approx 25\ m^{-2}$

Vertical beam-beam Luminosity scan

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



$\sigma_y \approx 3.5\mu m$

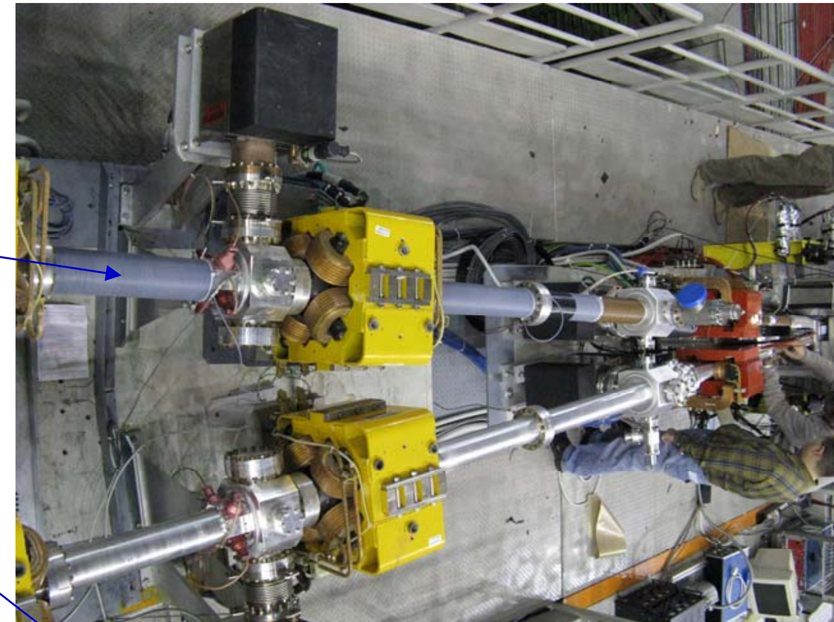
July 2008

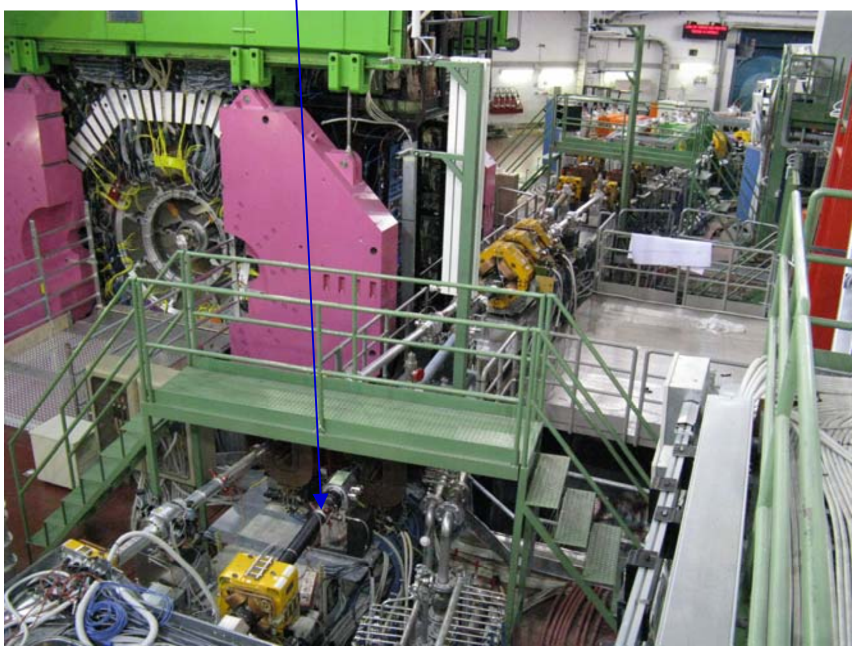
High current operation

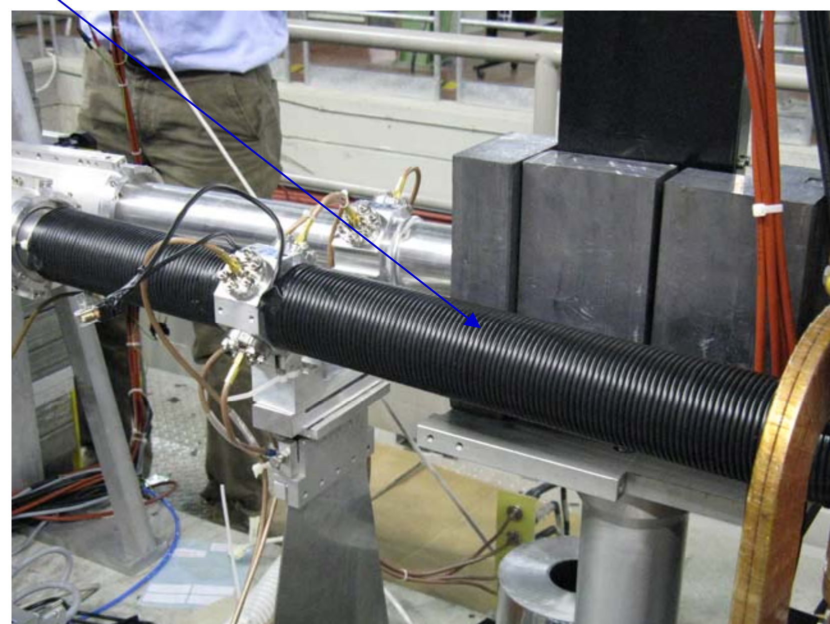
- Three main hardware upgrades have been implemented to improve the stored current:

- Fast kickers
- Feedback upgrade
- Lower impedance vacuum chamber
- Solenoid Windings

Solenoids

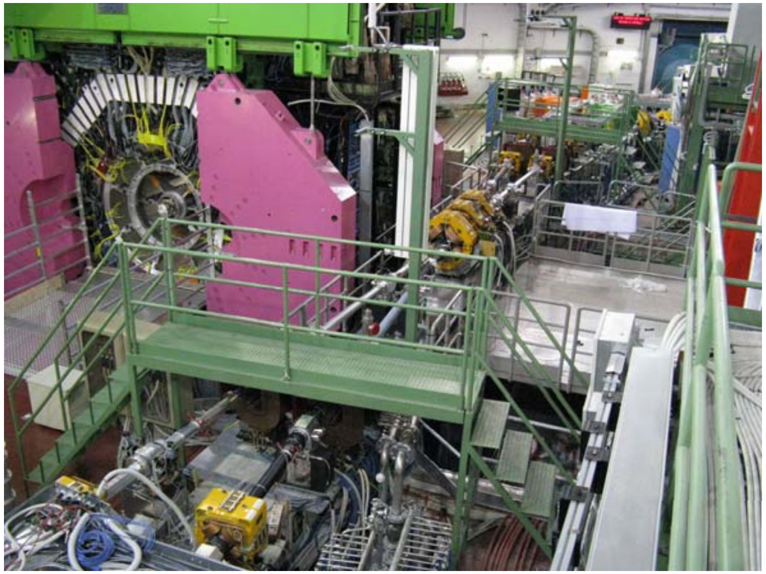






Modified Vacuum Chamber

Interaction Region 1



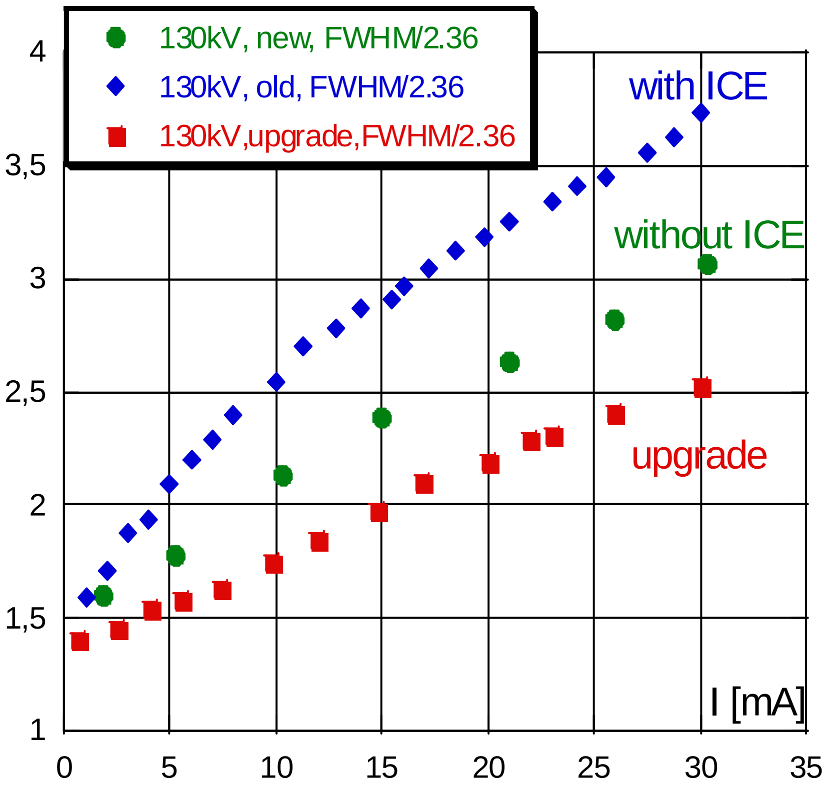
Interaction Region 2

New Injection Kickers

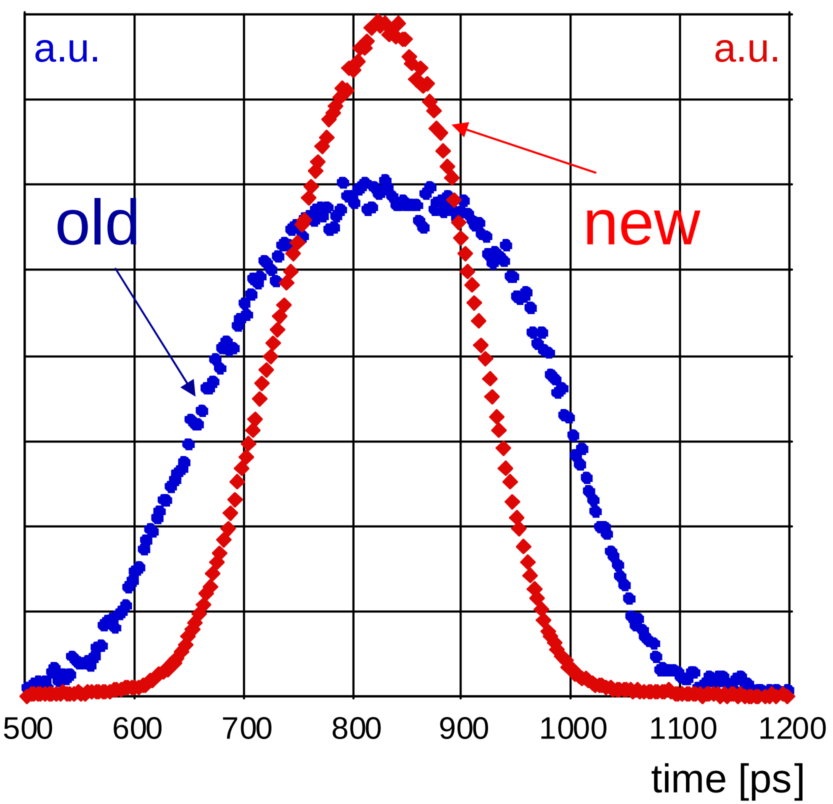
New Bellows

Bunch Lengthening in Upgraded Vacuum Chamber

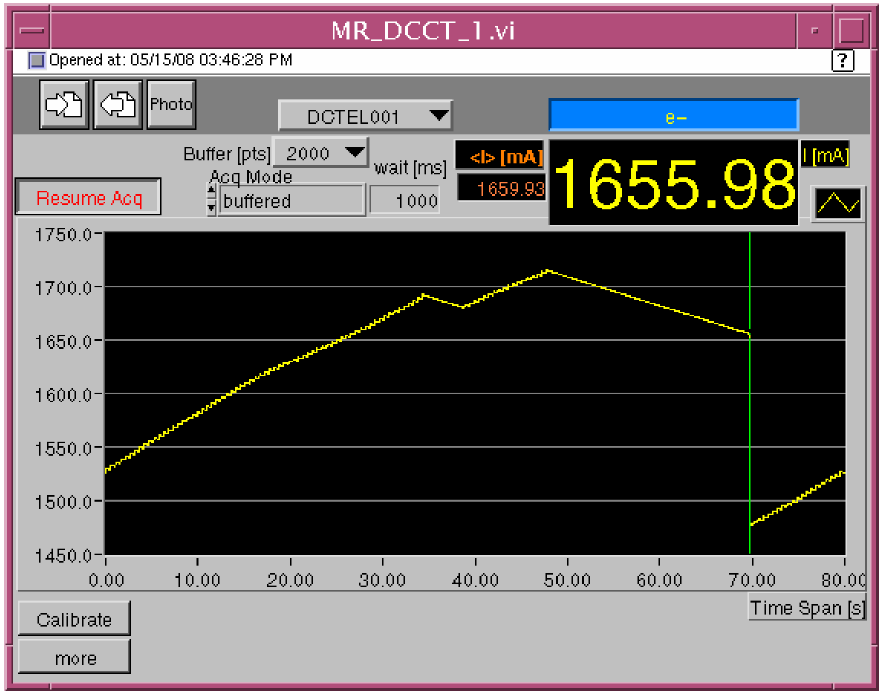
Bunch Length

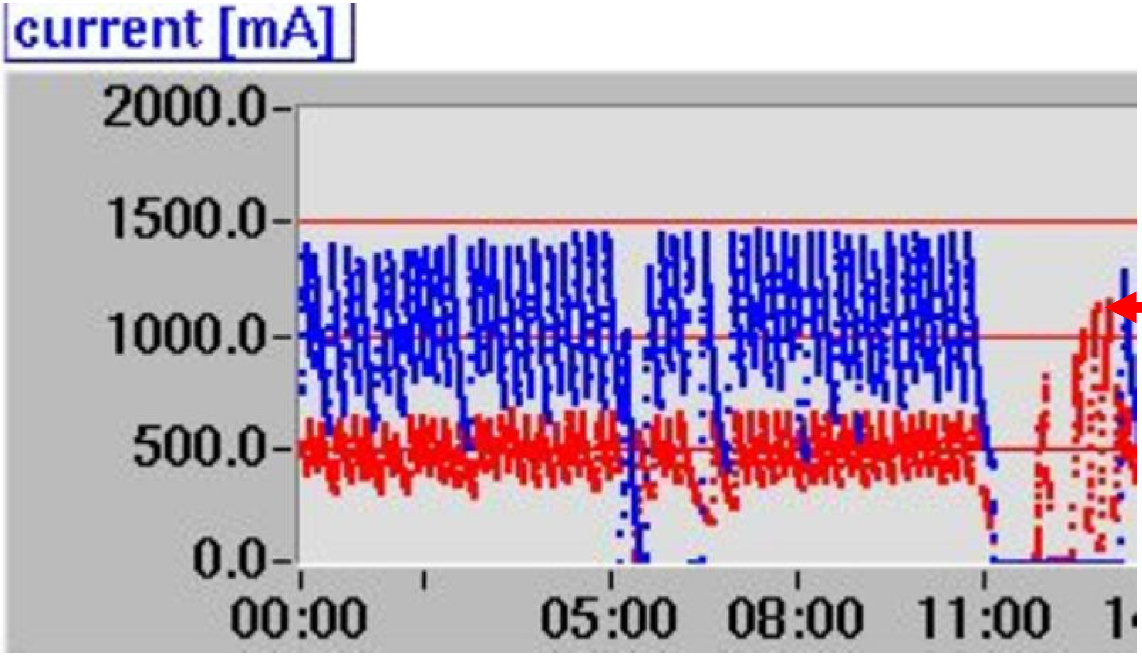


Charge Distribution



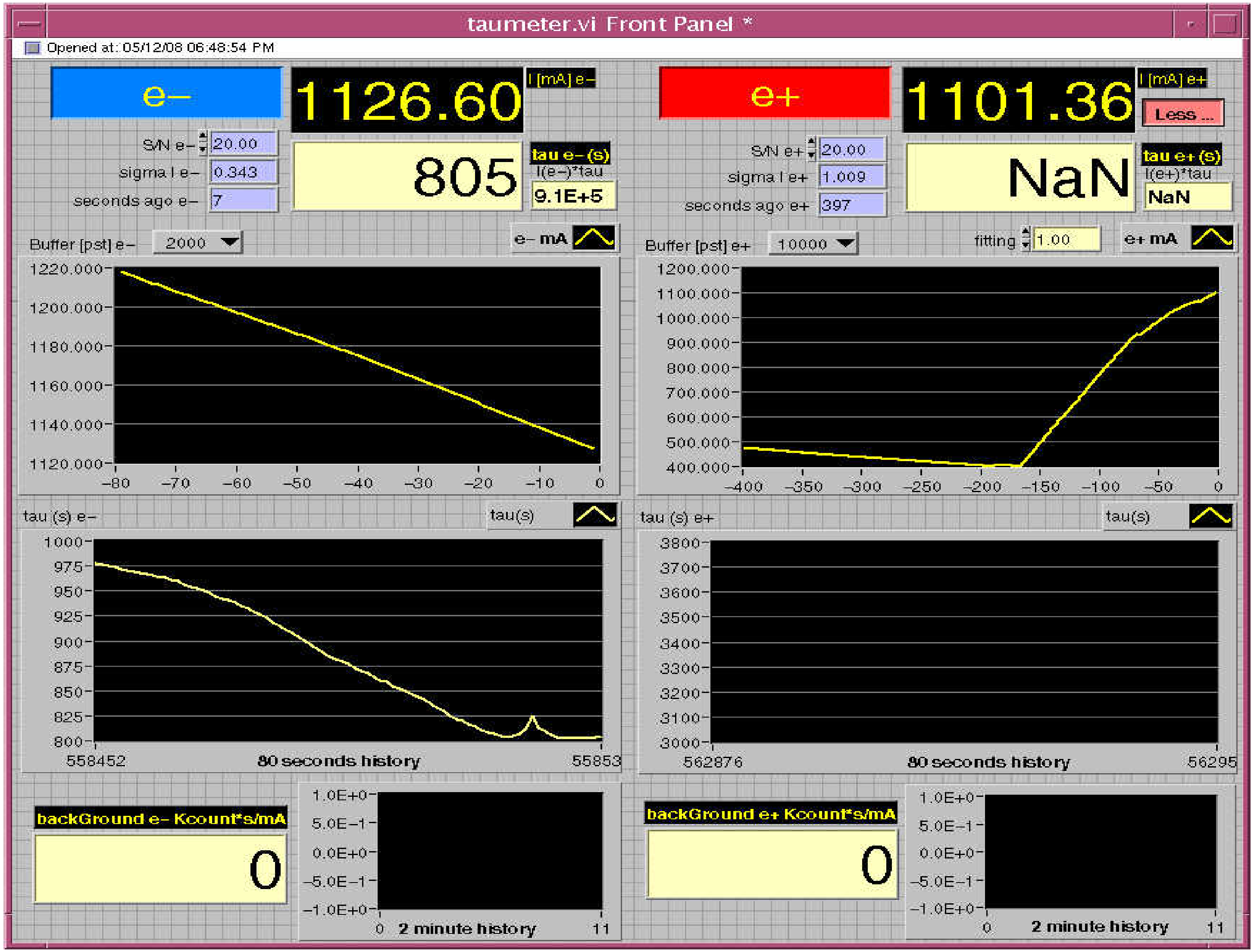
16/May/08: e- beam in collision, stable with 100 bunches, >1700 mA





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

Maximum Currents in Collision

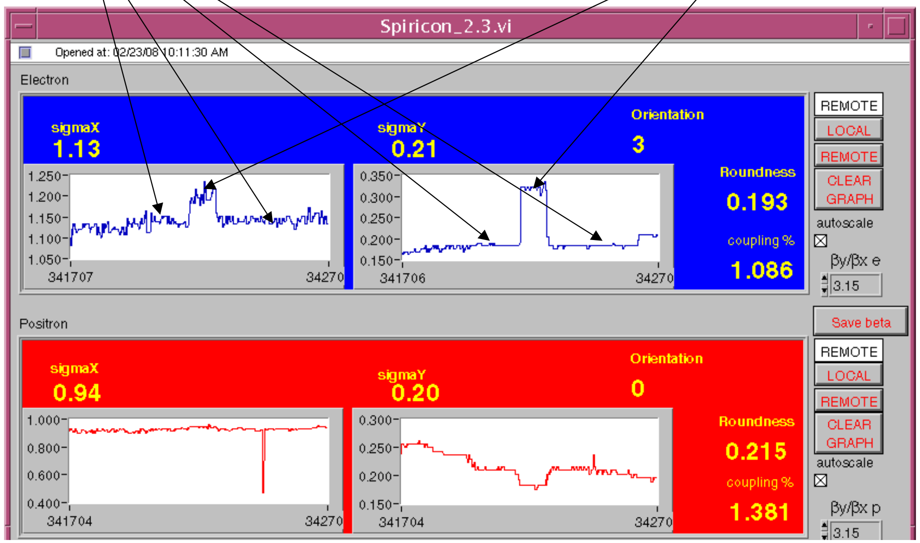


Crab Waist Works: Experimental Evidence

Crab On

Beam sizes

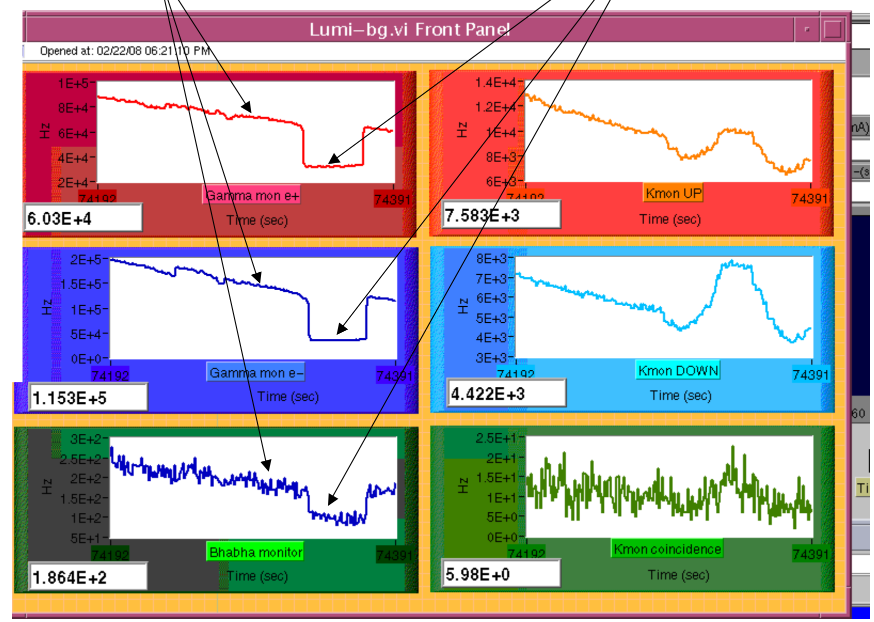
Crab off



Crab on

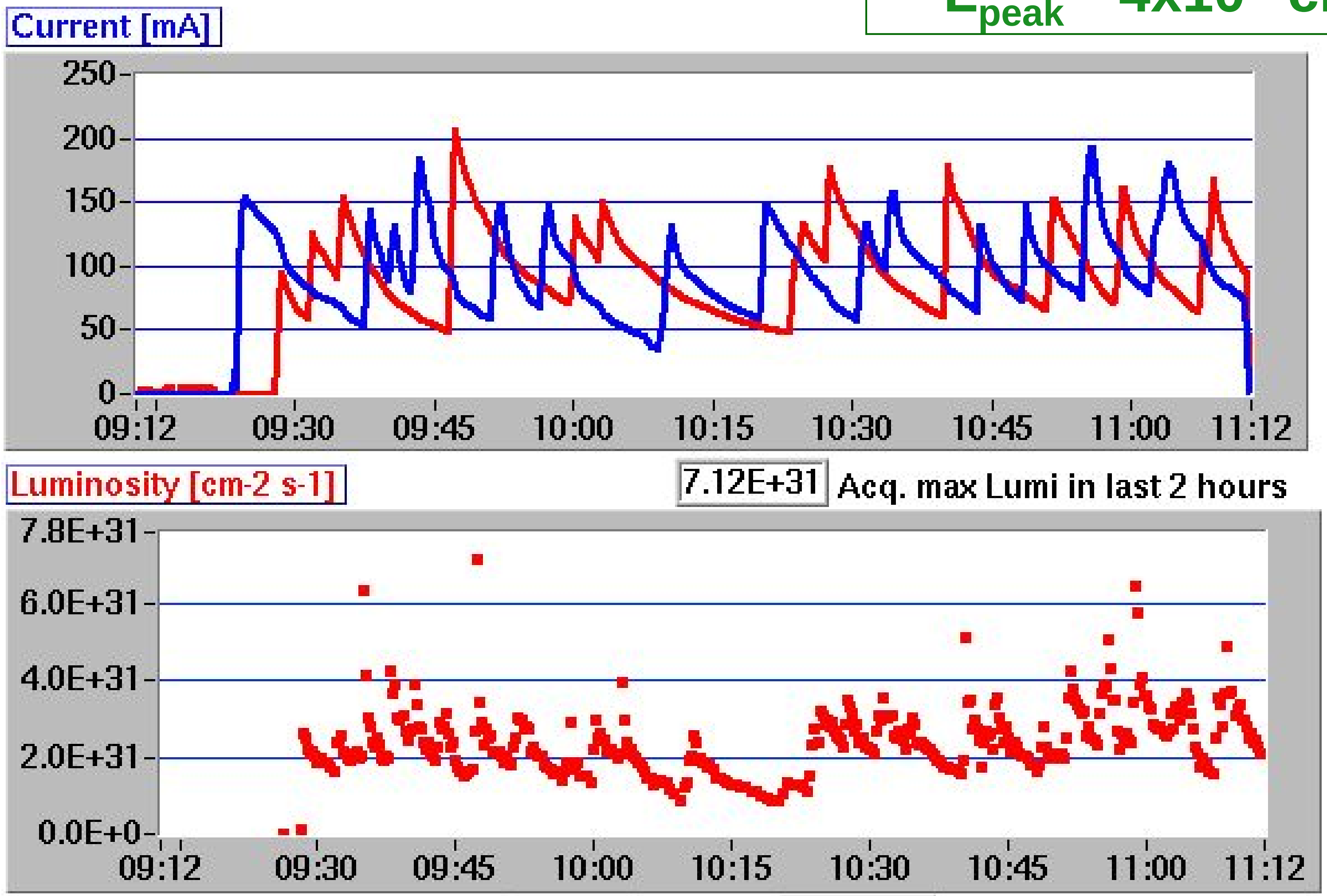
two luminosity monitors

Crab off



Luminosity with 10 Bunches

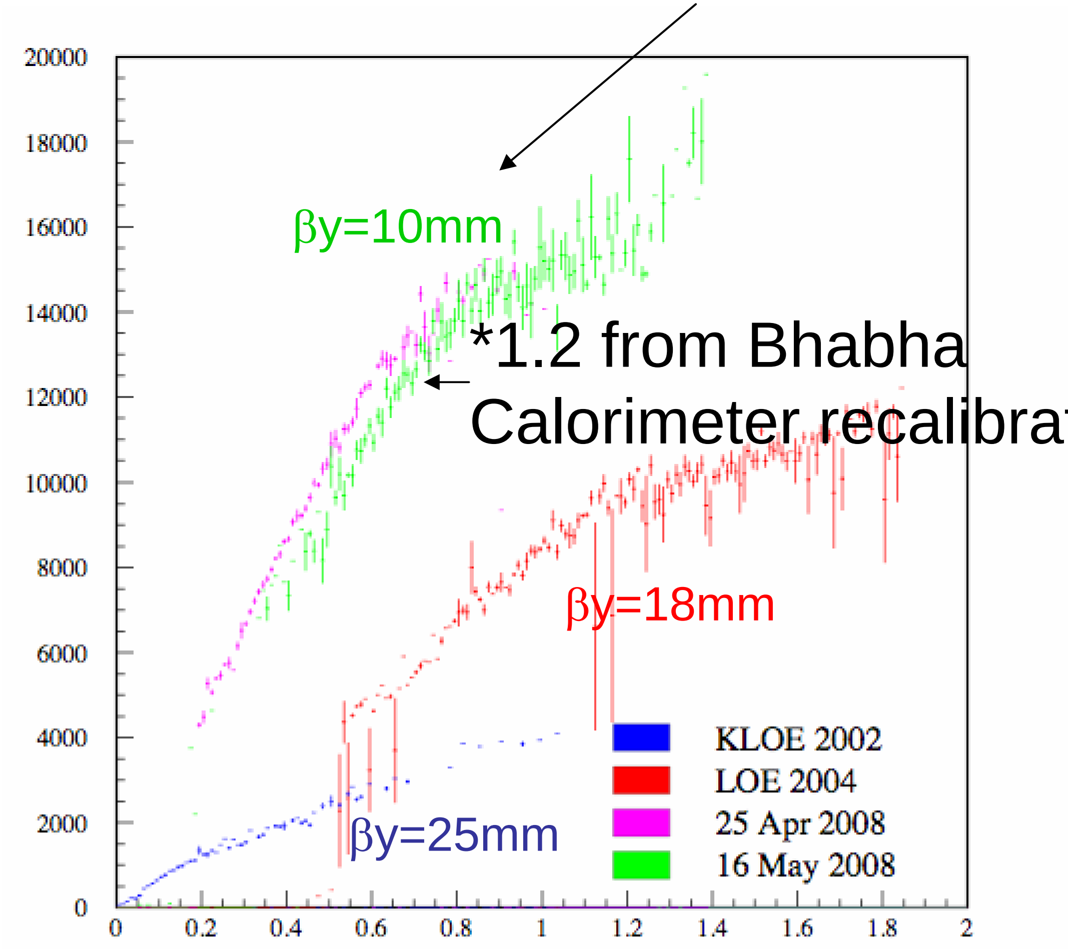
$\langle I_b \rangle \approx$ 13 mA/bunch
$L_{peak} \approx 4 \times 10^{31} cm^{-2} s^{-1}$



July 2008

Luminosity
x10^{28} $cm^{-2}s^{-1}$

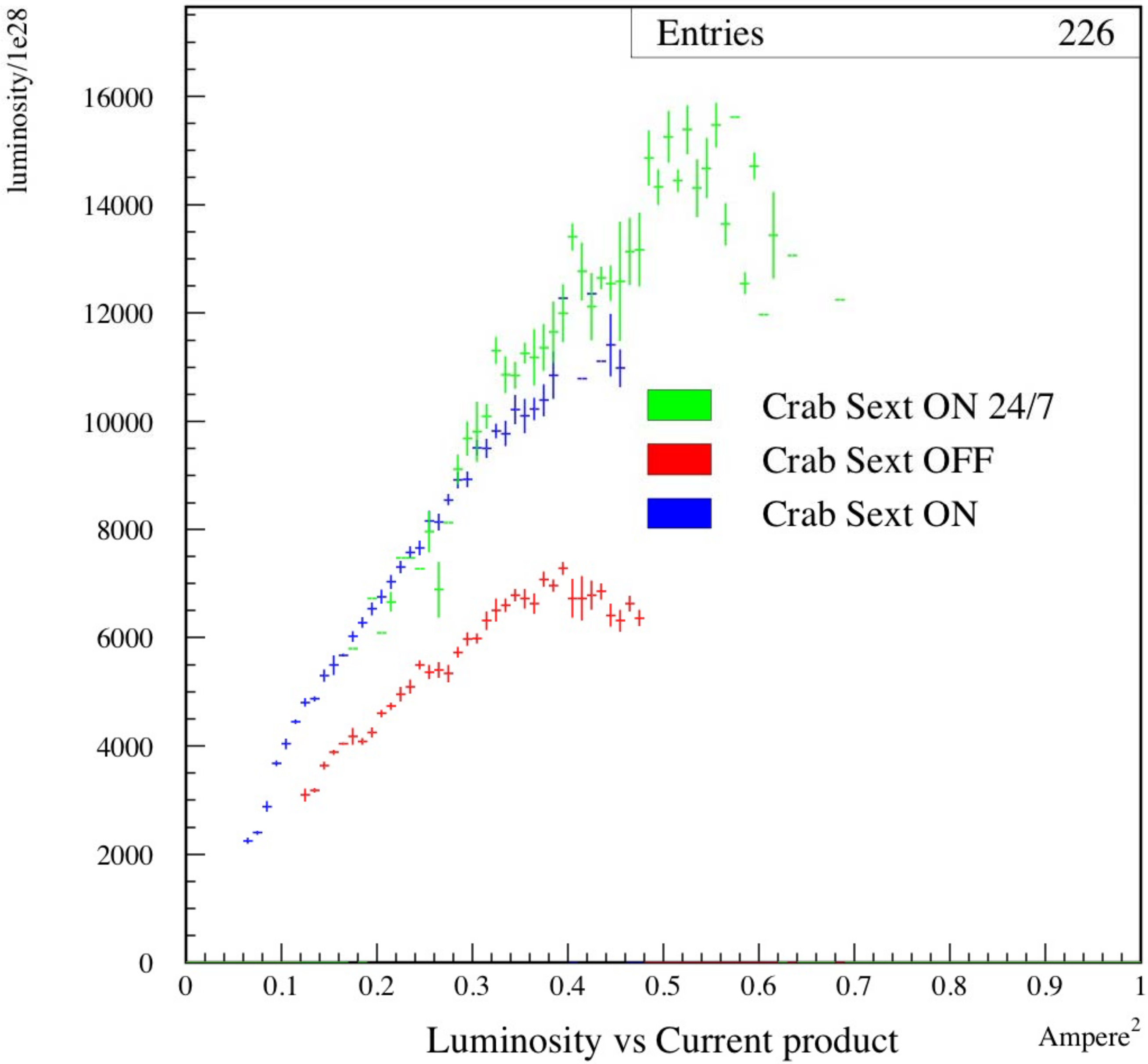
Next step βy=8.5mm (design 6mm)



Higher luminosity versus current as expected

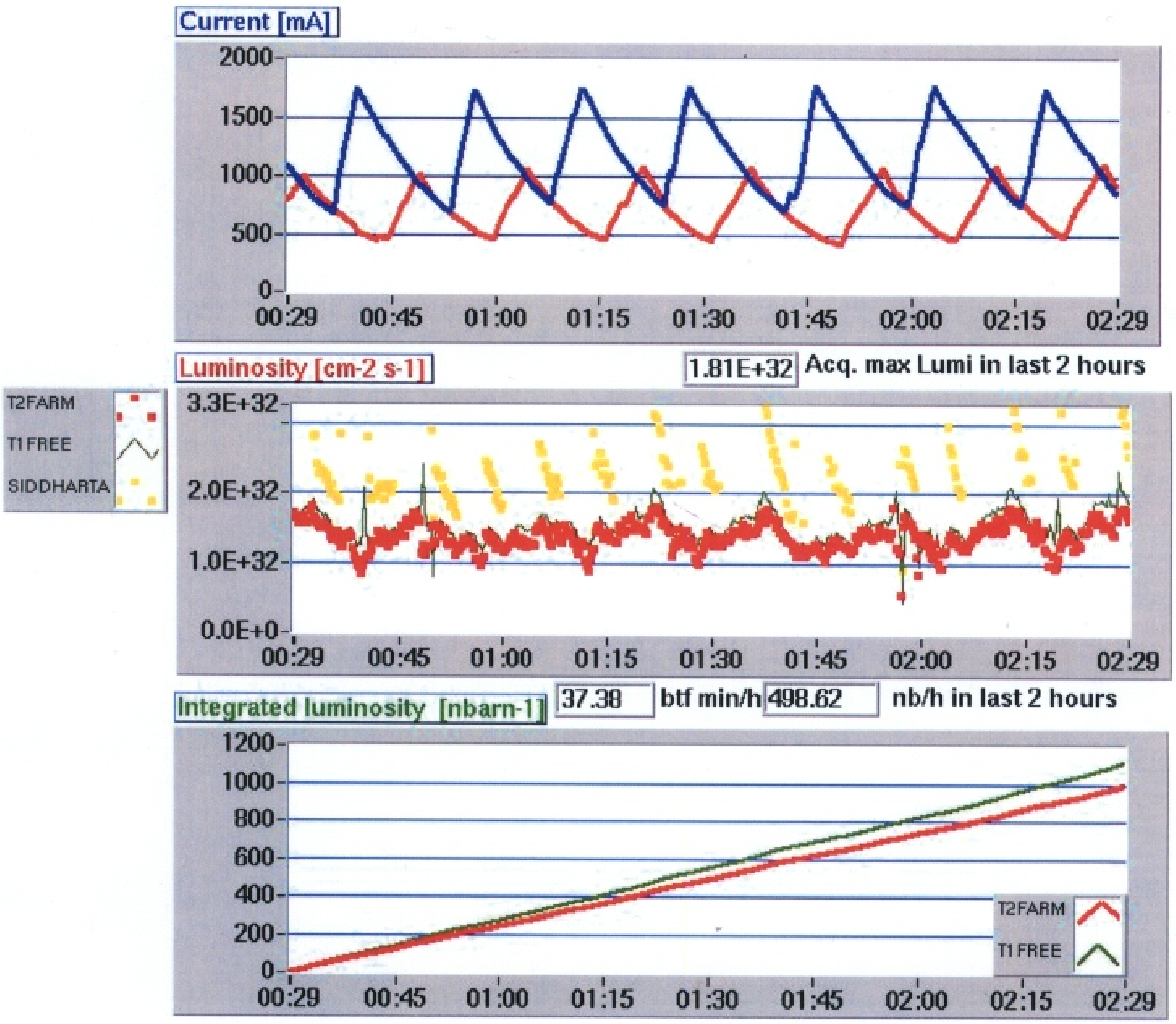
I^+I^- (A^2)

CRAB Sextupoles & Luminosity



July 2008

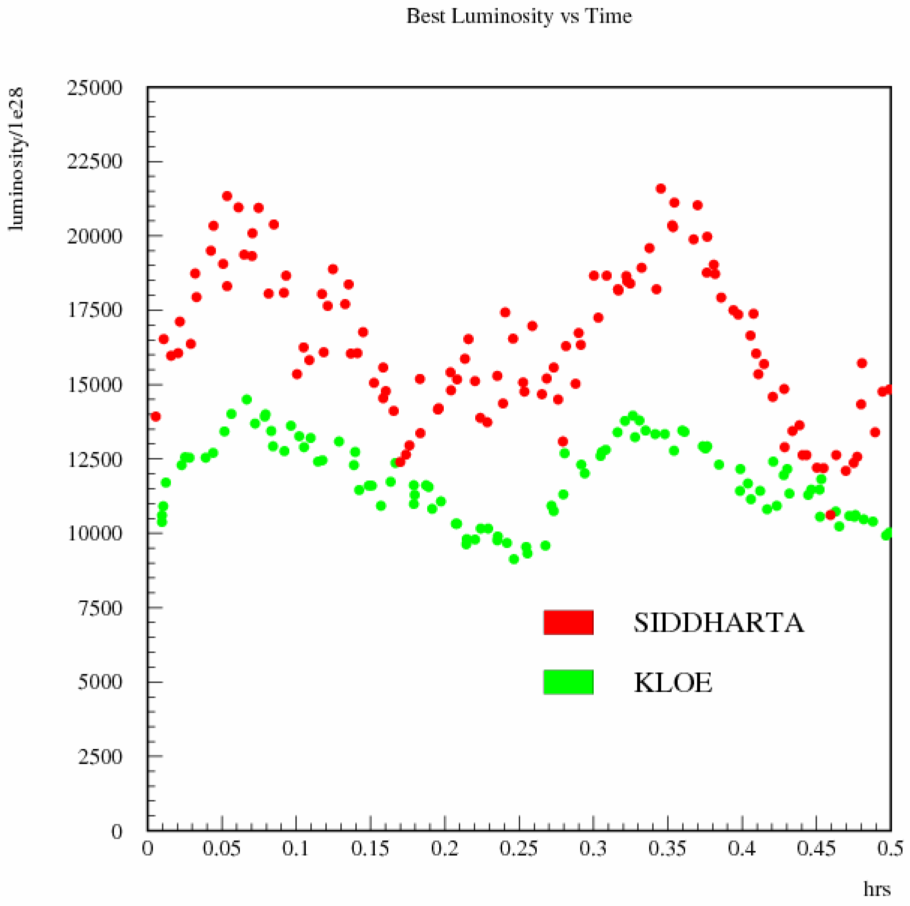
2 hours luminosity

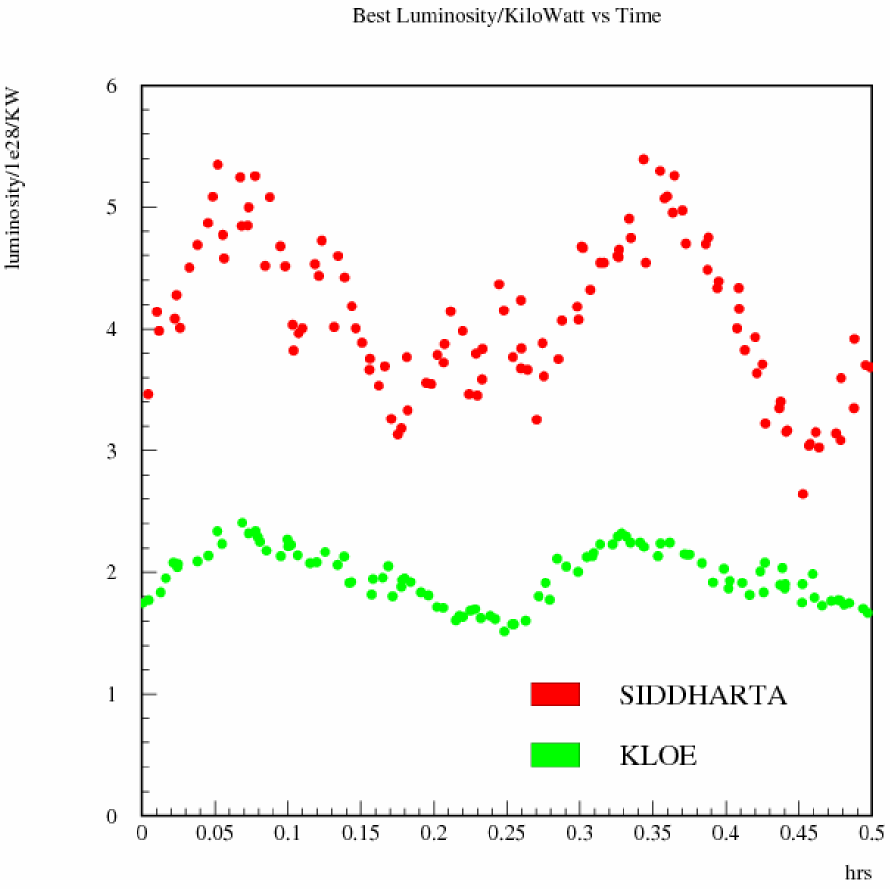


- kaon monitor without background subtraction

-- Bhabha monitor without background subtraction

- Bhabha monitor with background subtraction



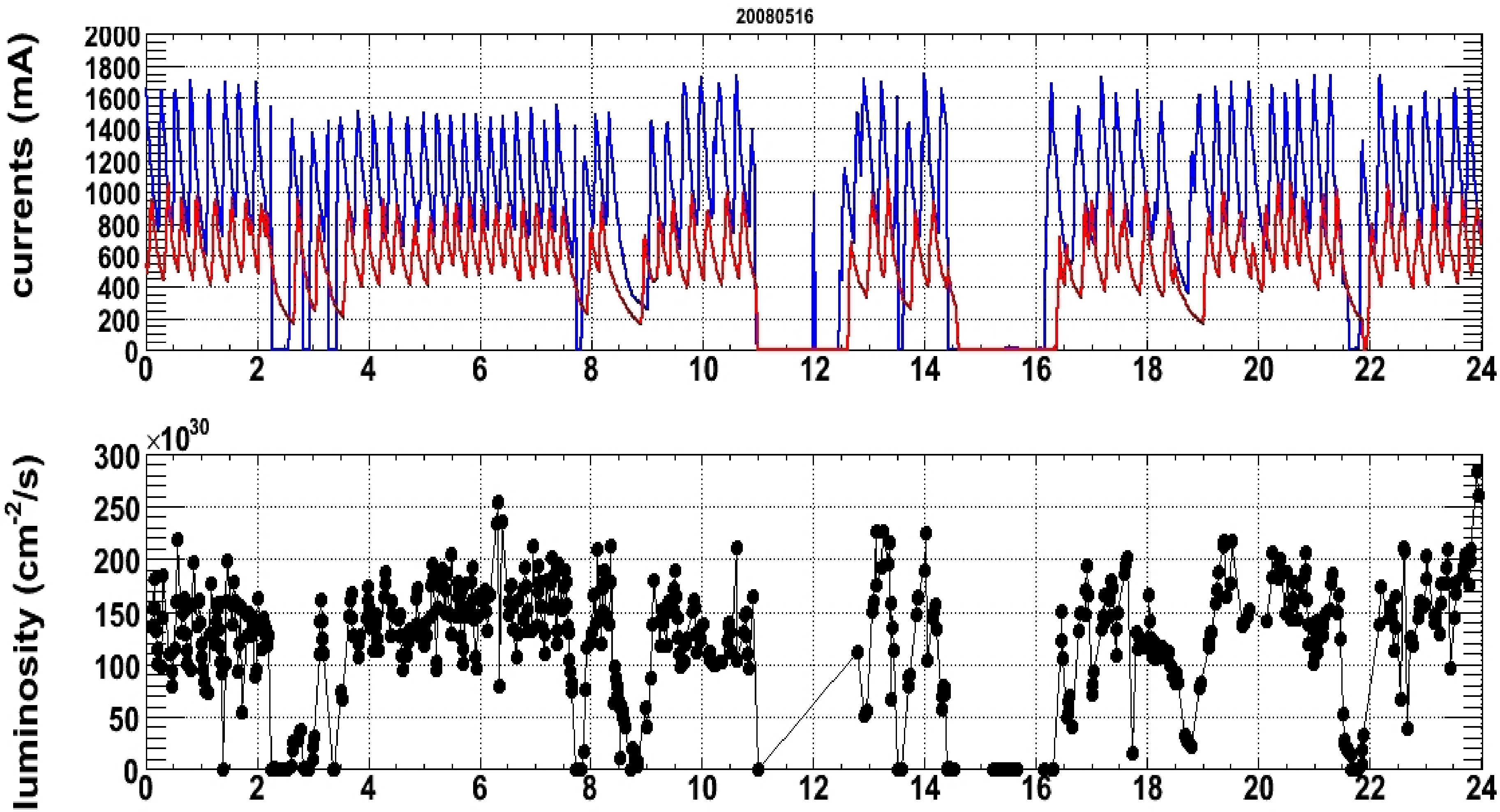


Absolute rates estimated with Bhabha 50% higher with 30% less current

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

Absolute power consumption decreased from 6MW to 4MW

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



To Do List

1. Increase the positron beam current
   a) Transverse and longitudinal feedback optimization
   b) New injection kicker pulsers with shorter pulse length
   c) New solenoids for e-cloud mitigation
2. Fully exploit recently installed stronger crab waist sextupoles
3. Fine collider tuning with lower beta function at the IP, β_y = 8.5 mm

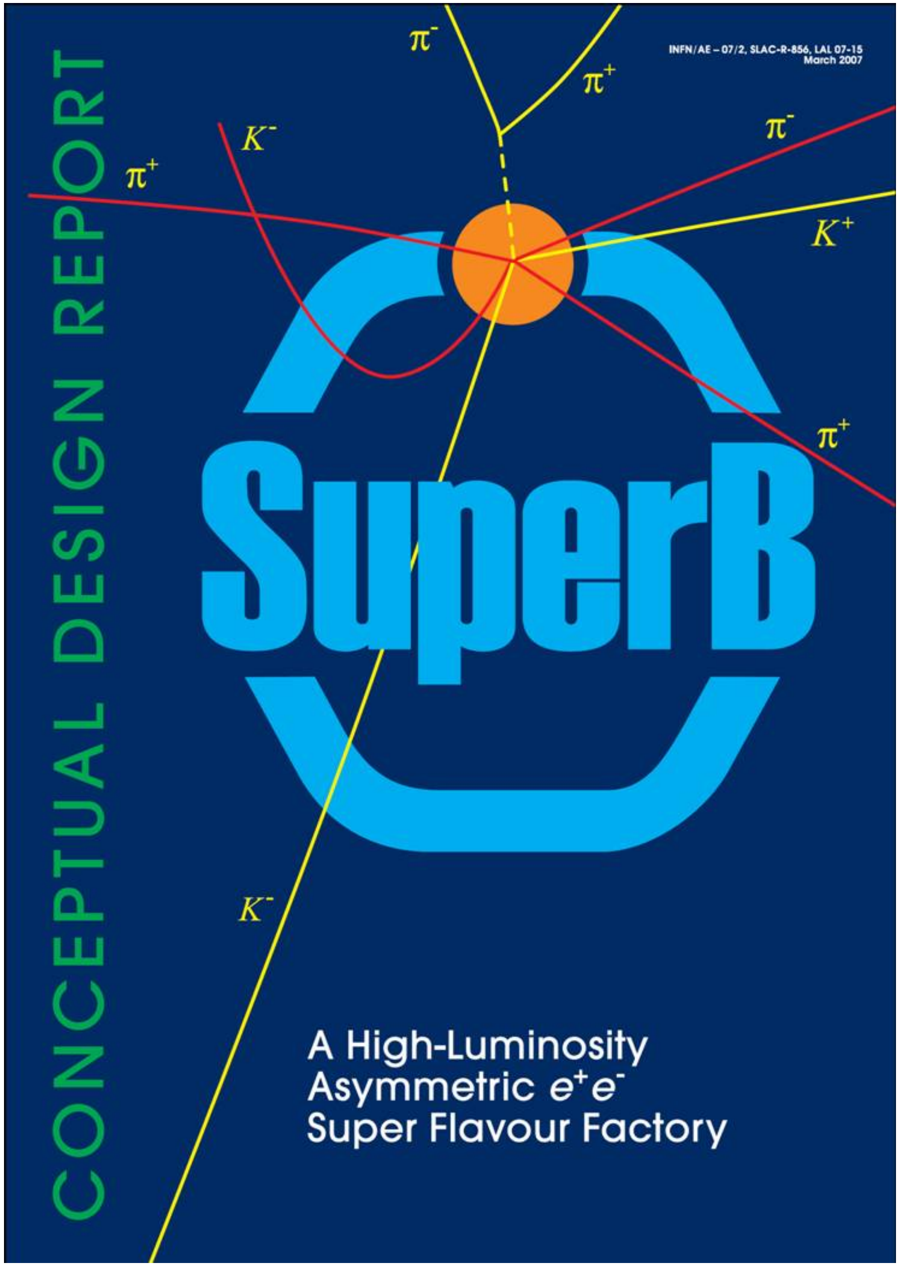
CONCLUSIONS

1. DAΦNE collider has been successfully commissioned in the new “Crab Waist” mode and is presently delivering luminosity to the SIDDHARTA detector

2. Crab waist concept is proved to work effectively. The peak luminosity has been already improved by about 50% with respect to the previous best DAΦNE runs

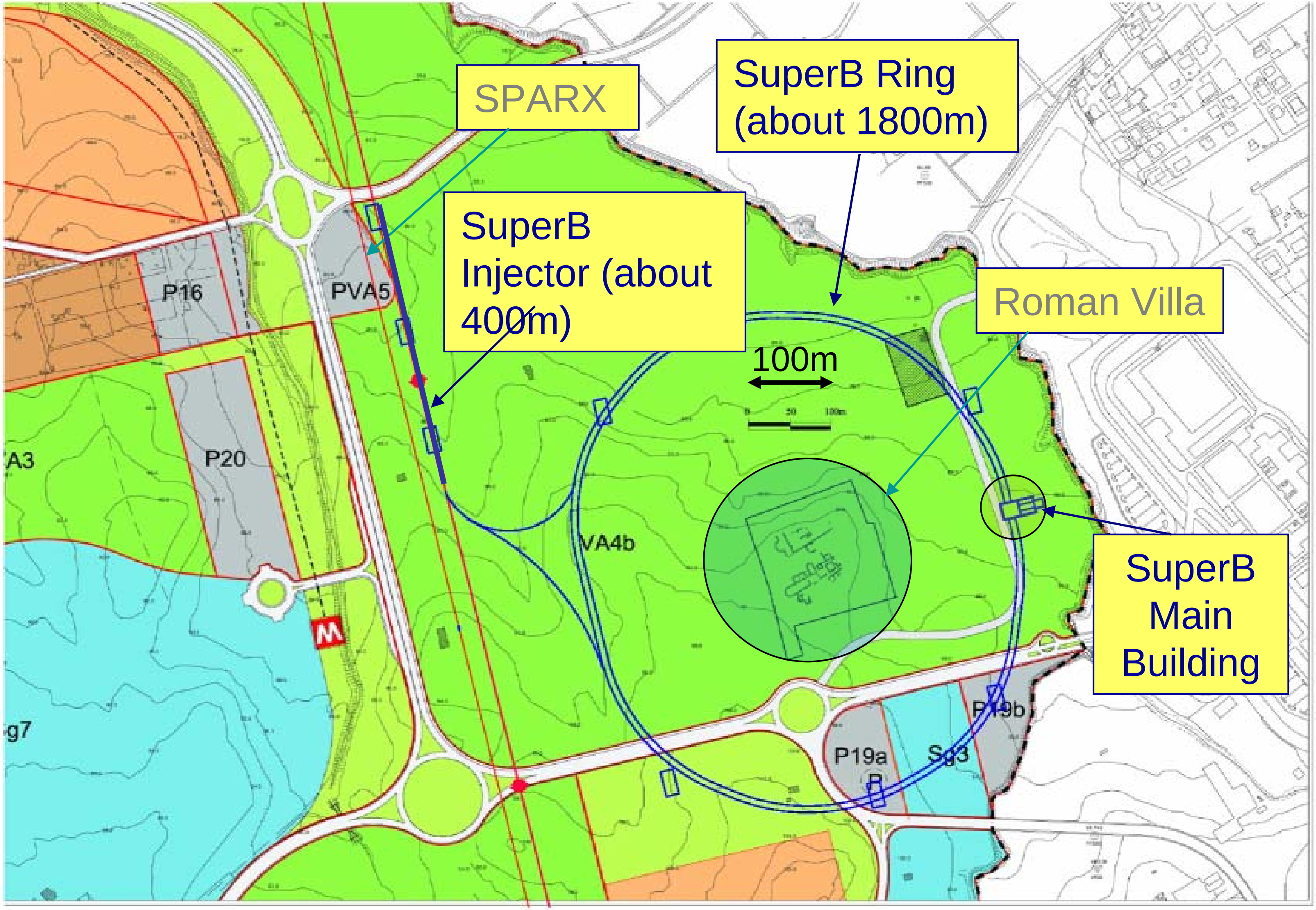
3. The work is in progress to obtain the ultimate design luminsity goal

Thank you!


CONCEPTUAL DESIGN REPORT
INFN/AE – 07/2, SLAC-R-856, LAL 07-15
March 2007
SuperB
A High-Luminosity
Asymmetric e^+e^-
Super Flavour Factory

-Factory

SuperB footprint on Tor Vergata site



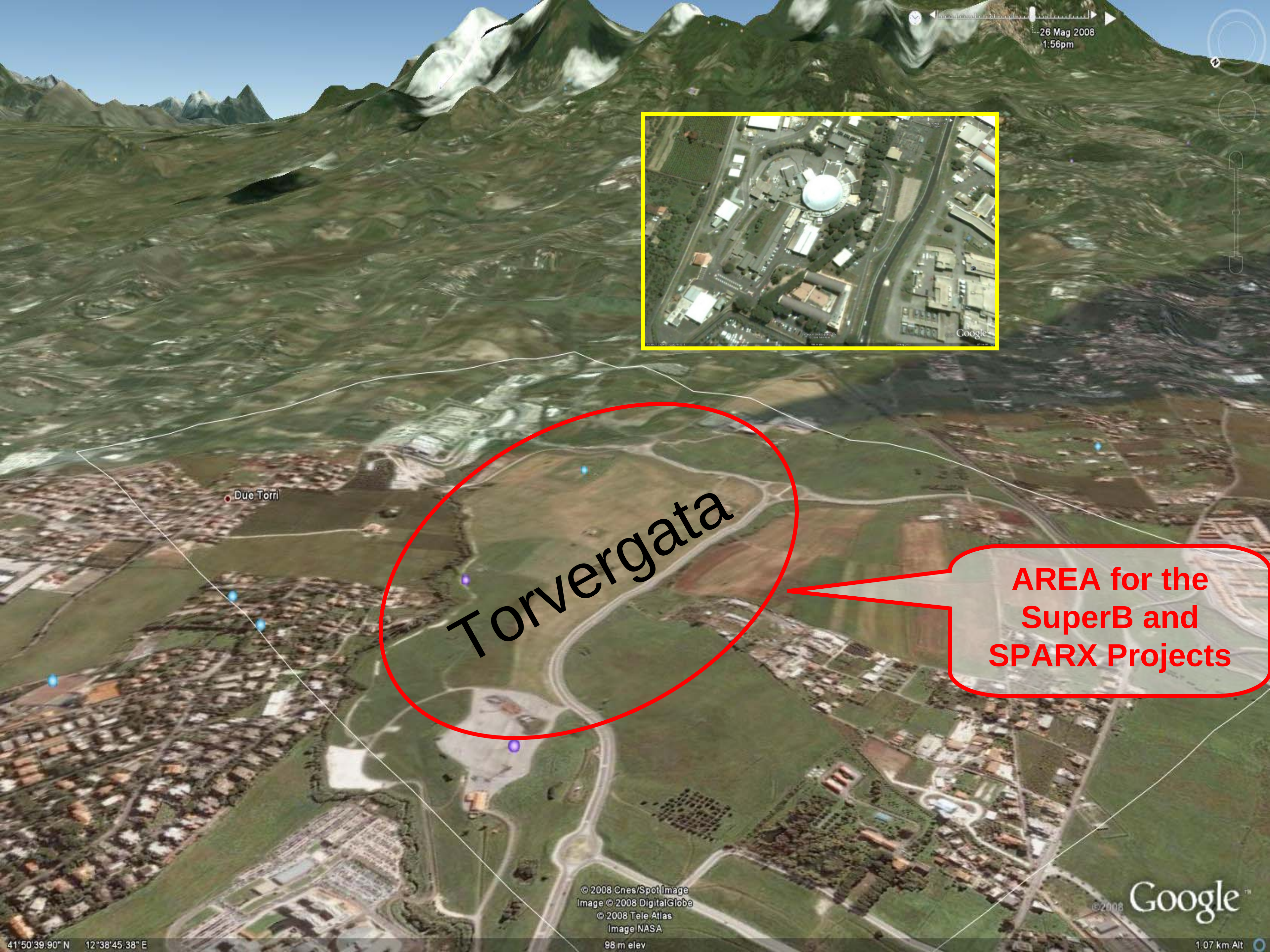

26 Mag 2008
1:56pm
Due Torri
Torvergata
AREA for the SuperB and SPARX Projects
© 2008 Cnes/Spot Image
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Image NASA
Google
41°50'39.90" N 12°38'45.38" E
98 m elev
1.07 km Alt

Super-B New Parameters

PARAMETER	Nominal LER (e+)	Nominal HER (e-)	Upgrade LER (e+)	Upgrade HER (e-)	Ultimate LER (e+)	Ultimate 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 ($x10^{-4}$)	7.9	5.6	9.0	8.0		
Momentum compaction ($x10^{-4}$)	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 ($x10^{10}$)	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 ($x10^{11}$) (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