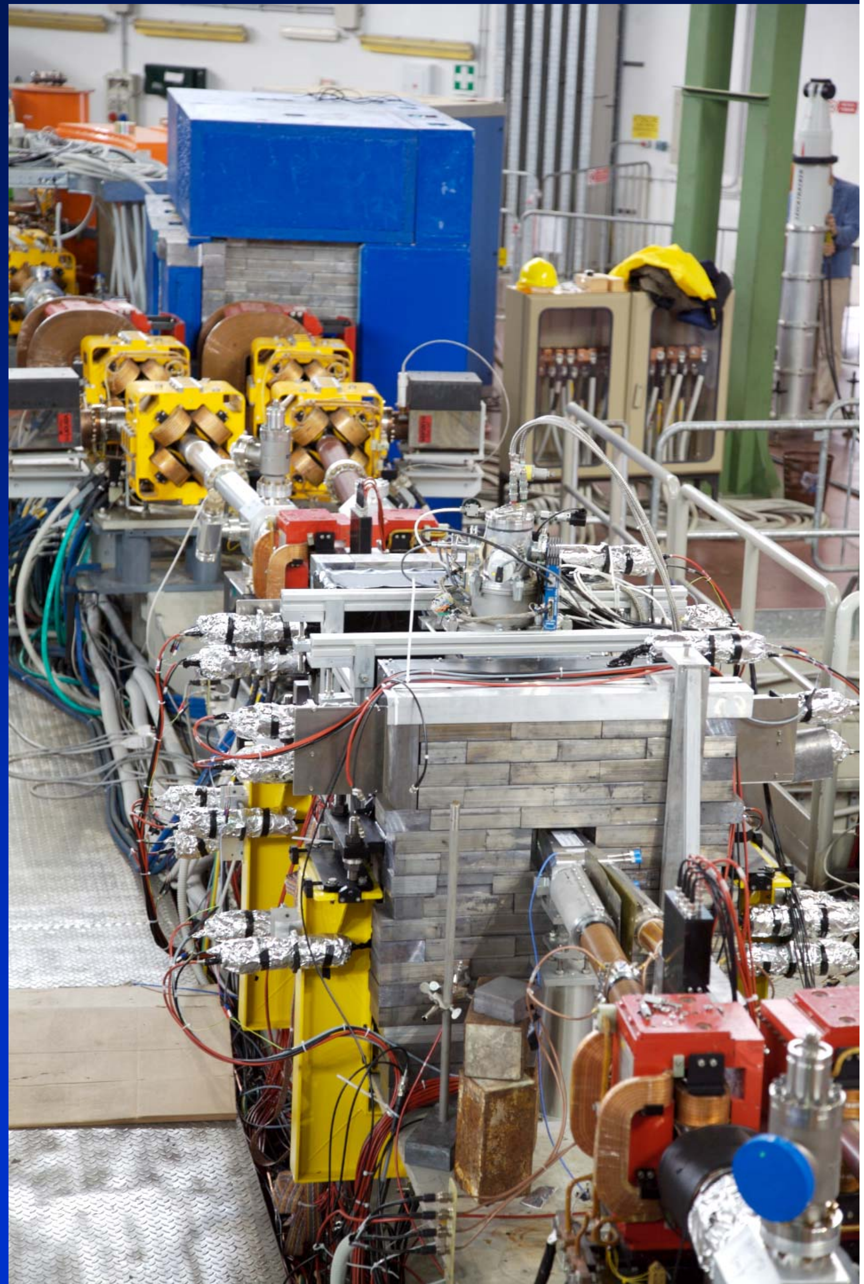
Results of the DAFNE Upgrade and Prospect for a SuperB

P. Raimondi for DAΦNE and SuperB Teams



La Thuile March-7,2009

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)),

Paolo Valente (INFN-Roma, Roma),

Kazuhito Ohmi (KEK, Ibaraki),

D. Teytelman, J. Fox (SLAC),

Nicolas Arnaud, Dominique Breton, Patrick Roudeau, Achille Stocchi, Alessandro Variola, Benoit Francis Viaud (LAL, Orsay),

Marco Esposito (Rome University La Sapienza, Roma),

Eugenio Paoloni (University of Pisa and INFN, Pisa),

Paolo Branchini (University Roma3, Rome)

SuperB Collaboration Team

M. E. Biagini, M. Boscolo, A. Drago, S. Guiducci, M. Preger, P. Raimondi, S. Tomassini, C. Vaccarezza, M. Zobov (INFN/LNF, Italy), K. Bertsche, Y. Cai, A. Fisher, S. Heifets, A. Novokhatski, M.T. Pivi, J. Seeman, M. Sullivan, U. Wienands, W. Wittmer (SLAC, US), T. Agoh, K. Ohmi, Y. Ohnishi (KEK, Japan), I. Koop, S. Nikitin, E. Levichev, P. Piminov, D. Shatilov (BINP, Russia), A. Wolski (Cockcroft, UK), M. Venturini (LBNL, US), S. Bettoni (CERN, Switzerland), A. Variola (LAL, France), E. Paoloni, G. Marchiori (Pisa Univ., Italy)

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. 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, Italy), I. Koop, E. Levichev, P. Piminov, D. Shatilov, V. Smaluk (BINP, Russia), S. Bettoni (CERN, Switzerland), K. Ohmi (KEK, Japan), N. Arnaud, D. Breton, P. Roudeau, A. Stocchi, A. Variola, B. F. Viaud (LAL, France), M. Esposito (Rome1 Univ., Italy), E. Paoloni (Pisa Univ., Italy), P. Branchini (Roma3 Univ., Italy), M. Schioppa (INFN-Cosenza, Italy) , P. Valente (INFN-Roma, Italy)

OUTLINE

- SuperB project
- Dafne Upgrade:
  - Hardware
  - Commissioning
  - Results and Perspectives
- Conclusions

SuperB: a 10^{36} cm^{-2} s^{-1} accelerator

- *SuperB* is an international enterprise aiming at the construction of a very high luminosity (10^{36} cm^{-2} s^{-1}) asymmetric e^+e^- Flavor Factory, with location at the campus of the University of Rome Tor Vergata, near the INFN Frascati National Laboratory
- A heavy flavor factory such as *SuperB* will be a complementary window to LHC and ILC
- The physics studies possible at such a machine will provide a uniquely important source of deeper understanding of the NP found at LHC, and if not found, will bring a sensitivity to seeing signs of NP at even higher energies than LHC to help set the scale of NP
- A Conceptual Design Report, signed by 85 Institutions was published in March 2007 (arXiv:0709.0451 [hep-ex])

Accelerator basic concepts (1)

- B-Factories (PEP-II and KEKB) have reached high luminosity (>10^{34} cm^{-2} s^{-1}) but, to increase L of ~ 2 orders of magnitude, bordeline parameters are needed such as:
  - Very high currents ⇒ HOM in beam pipe
    - *overheating, instabilities, power costs*
    - *detector backgrounds increase*
  - Very short bunches ⇒ RF voltage increases
    - *costs, instabilities*
  - Smaller damping times ⇒ Wiggler magnets
    - *costs, instabilities*
  - Crab cavities for head-on collision
    - KEKB experience

Difficult and costly operation

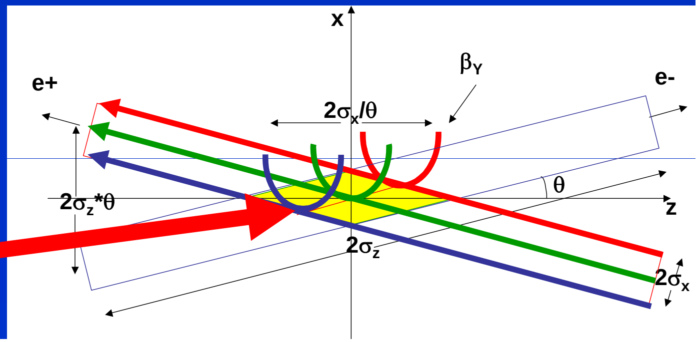
SuperB

Accelerator basic concepts (2)

- *SuperB* exploits an alternative approach, with a new IP scheme:
  - Small beams (ILC-DR like)
    - very low emittances, ILC-DR R&D
  - Large Piwinsky angle and "*crab waist*" with a pair of sextupoles/ring $(\Phi = tg(\theta)\sigma_z/\sigma_x)$
    - interaction region geometry
  - Currents comparable to present Factories
    - lower backgrounds, less HOM and instabilities

Requires a lot of fine machine tuning

Small collision area: σ_x/θ



A new idea for collisions

Thigher focus on beams at IP and a “large” crossing angle (large Piwinski angle) + use a couple of sextupoles/ring to “twist” the beam waist at the IP

- Ultra-low emittance
- Very small β^* at IP
- Large crossing angle
- “Crab Waist” transformation

- Small collision area
- Lower β^* is possible
- NO parasitic crossings
- NO x-y-betatron resonances

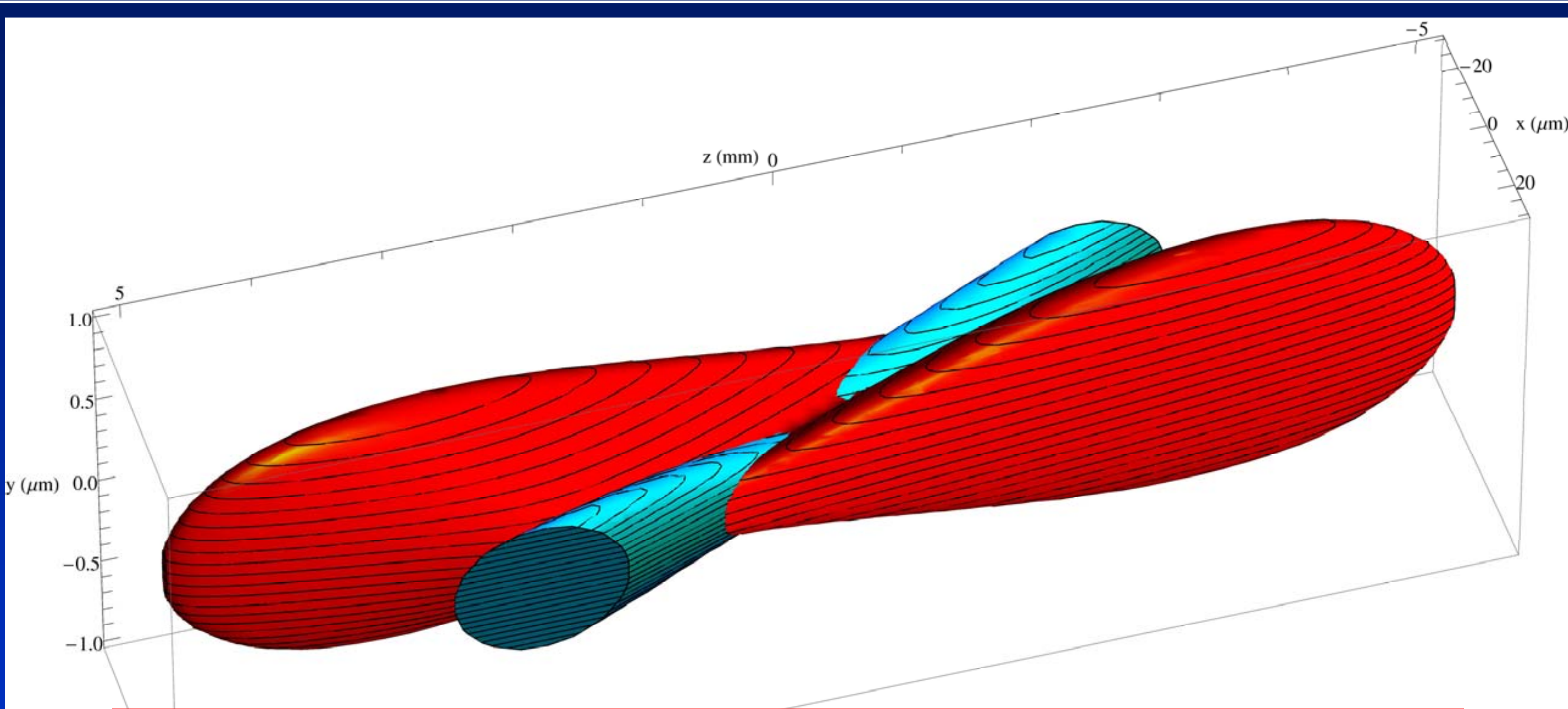
1. *P.Raimondi, 2° SuperB Workshop, March 2006*
2. *P.Raimondi, D.Shatilov, M.Zobov, physics/0702033*

and...

- Relatively easier to make *small* σ_x with respect to *short* σ_z
- Problem of parasitic collisions automatically solved due to higher crossing angle and smaller horizontal beam size
- There is no need to increase excessively beam current and to decrease the bunch length:
  - Beam instabilities are less severe
  - Manageable HOM heating
  - No coherent synchrotron radiation of short bunches
  - No excessive power consumption

How it works

Crab sextupoles OFF: Waist line is orthogonal to the axis of other beam



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

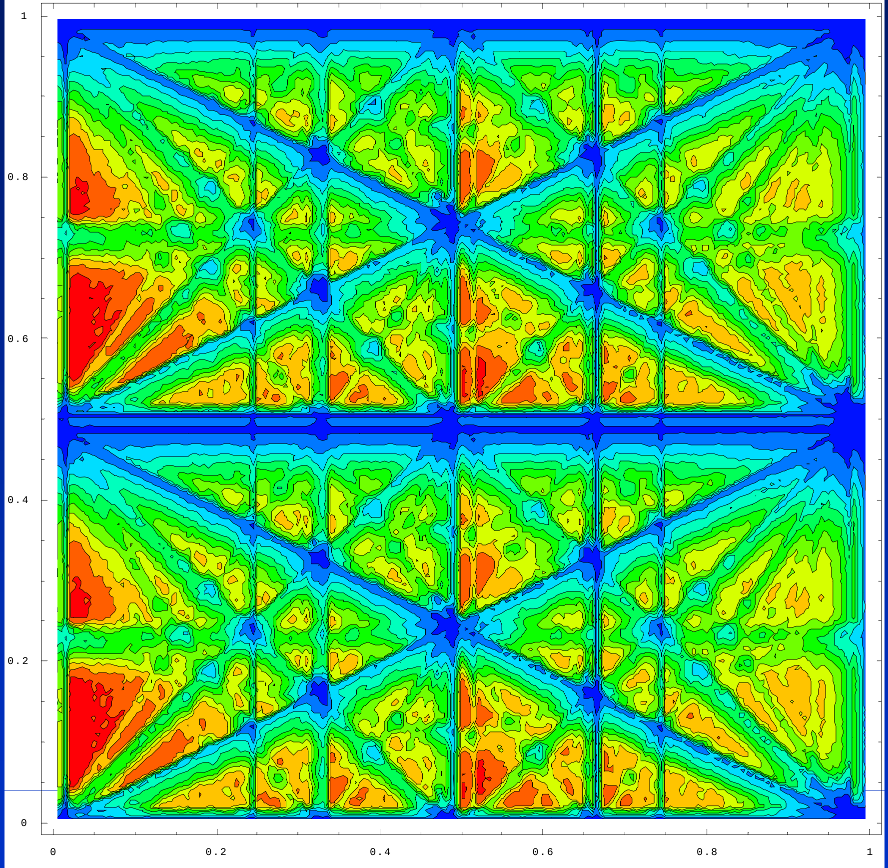
Crab sextupoles ON: Waist moves parallel to the axis of other beam: maximum particle density in the overlap between bunches

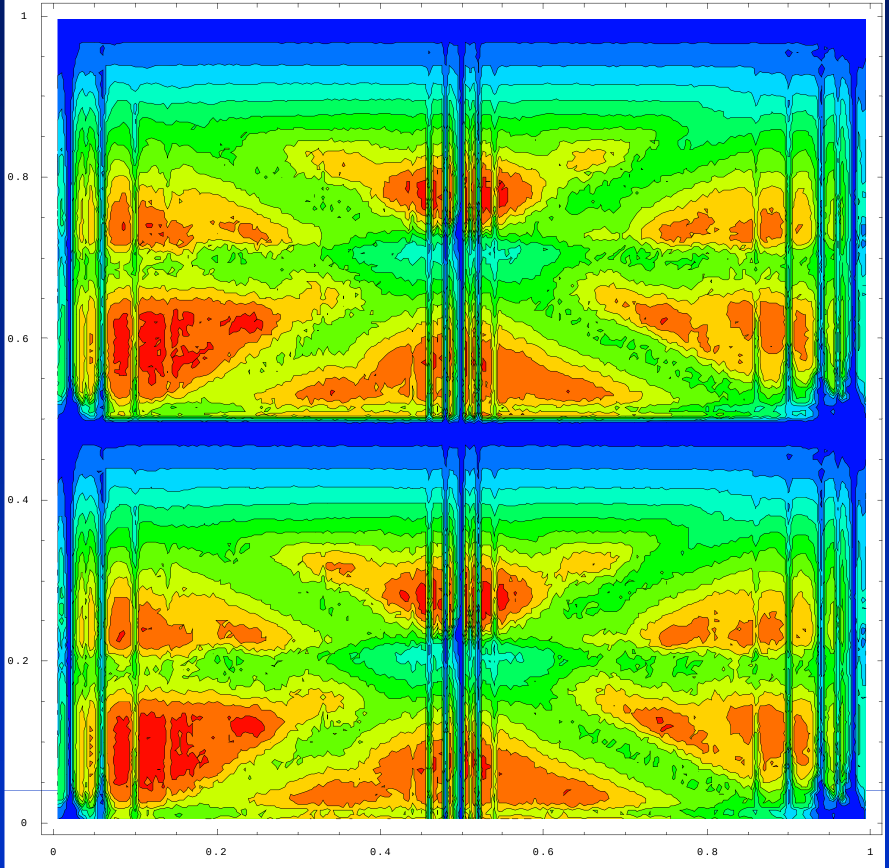
Plots by E. Paoloni

Example of x-y resonance suppression

D.Shatilov's (BINP), ICFA08 Workshop

Much higher luminosity!





Typical case (KEKB, DAΦNE):

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

Crab Waist On:

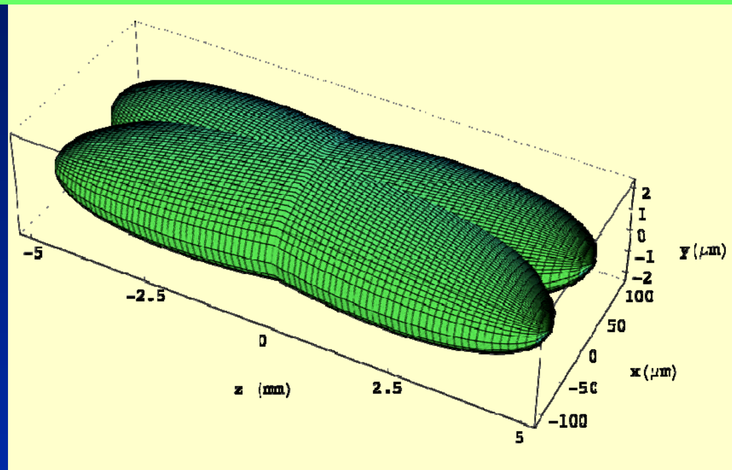
1. large Piwinski angle $\Phi >> 1$
2. β_y comparable with σ_x/θ

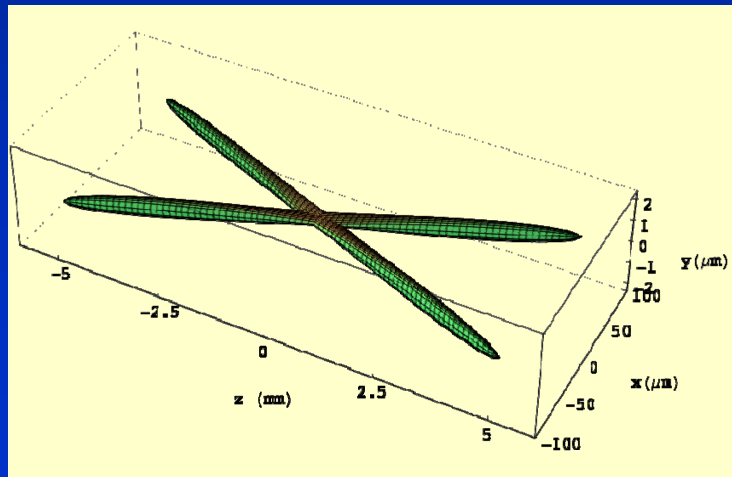
Comparison of SuperB to Super-KEKB

Parameter	Units	*SuperB*	Super-KEKB
Energy	GeV	4x7	3.5x8
Luminosity	10^{36}/ cm^2/s	1.0 to 2.0	0.5 to 0.8
Beam currents	A	1.9x1.9	9.4x4.1
β_y*	mm	0.22	3.
β_x*	cm	3.5x2.0	20.
Crossing angle (full)	mrad	48.	30. to 0.
RF power (AC line)	MW	20 to 25	80 to 90
Tune shifts	(x/y)	0.0004/0.2	0.27/0.3

100 times more luminosity obtained just with 100 times smaller vertical beam

IP beam distributions for KEKB





IP beam distributions for *SuperB*

SuperB main features

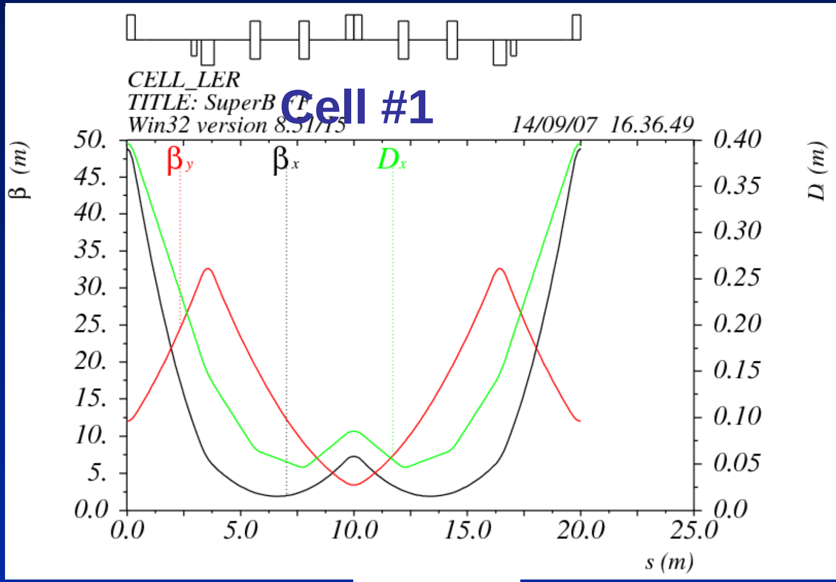
- Goal: maximize luminosity while keeping wall power low
- 2 rings (4x7 GeV) design: flexible but challenging
- Ultra low emittance optics: 7x4 pm vertical emittance
- Beam currents: comparable to present Factories
- Crossing angle and “crab waist” used to maximize luminosity and minimize beam size blow-up
  - Presently under test at DAΦNE
- No “emittance” wigglers used in Phase 1 (save in power)
- Design based on recycling PEP-II hardware (corresponds to a lot of money)
- Longitudinal polarization for e^- in the HER is included (unique feature)

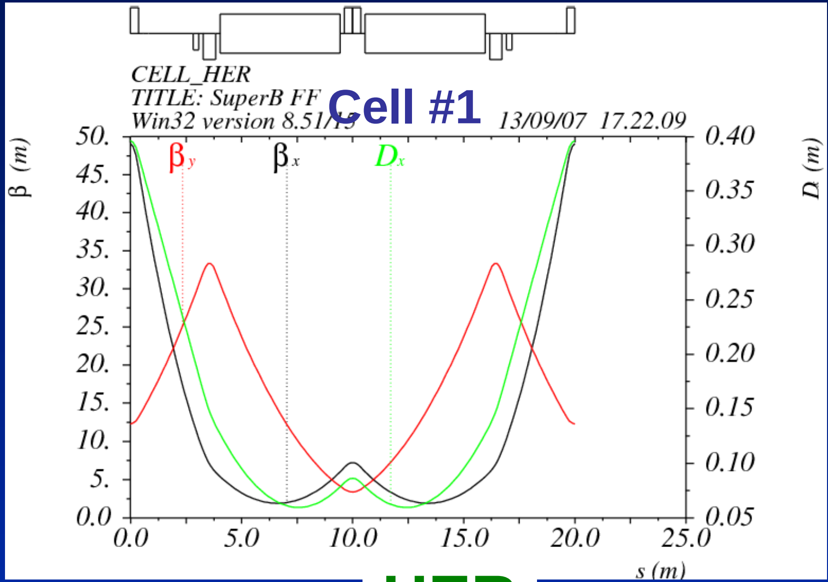
Lattice overview

- 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

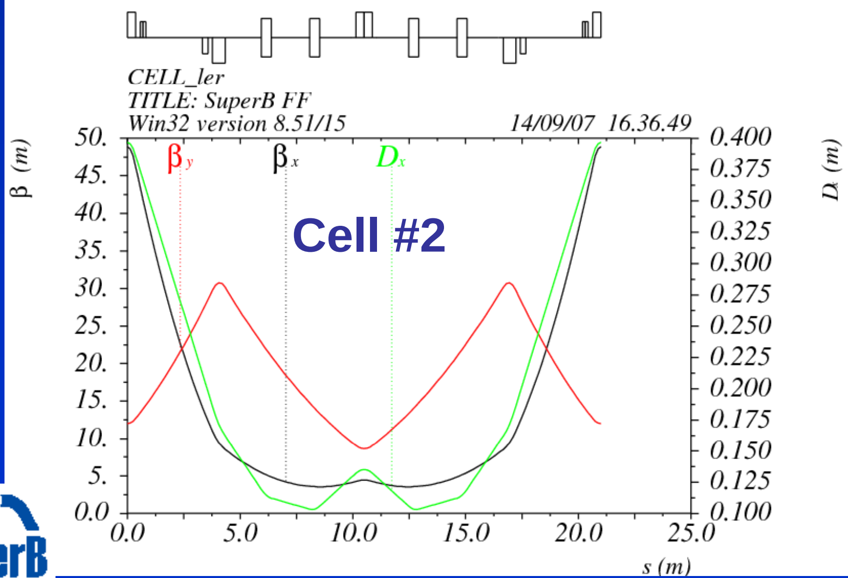
M. Biagini

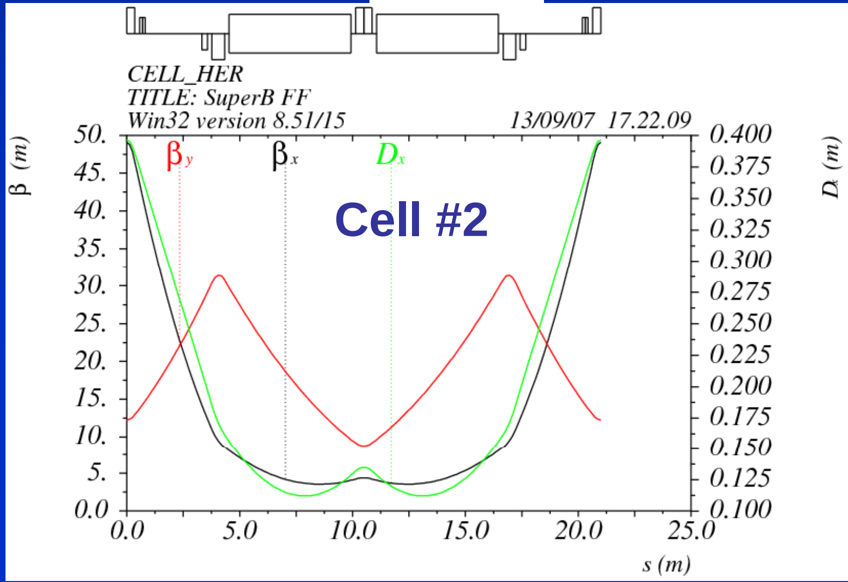




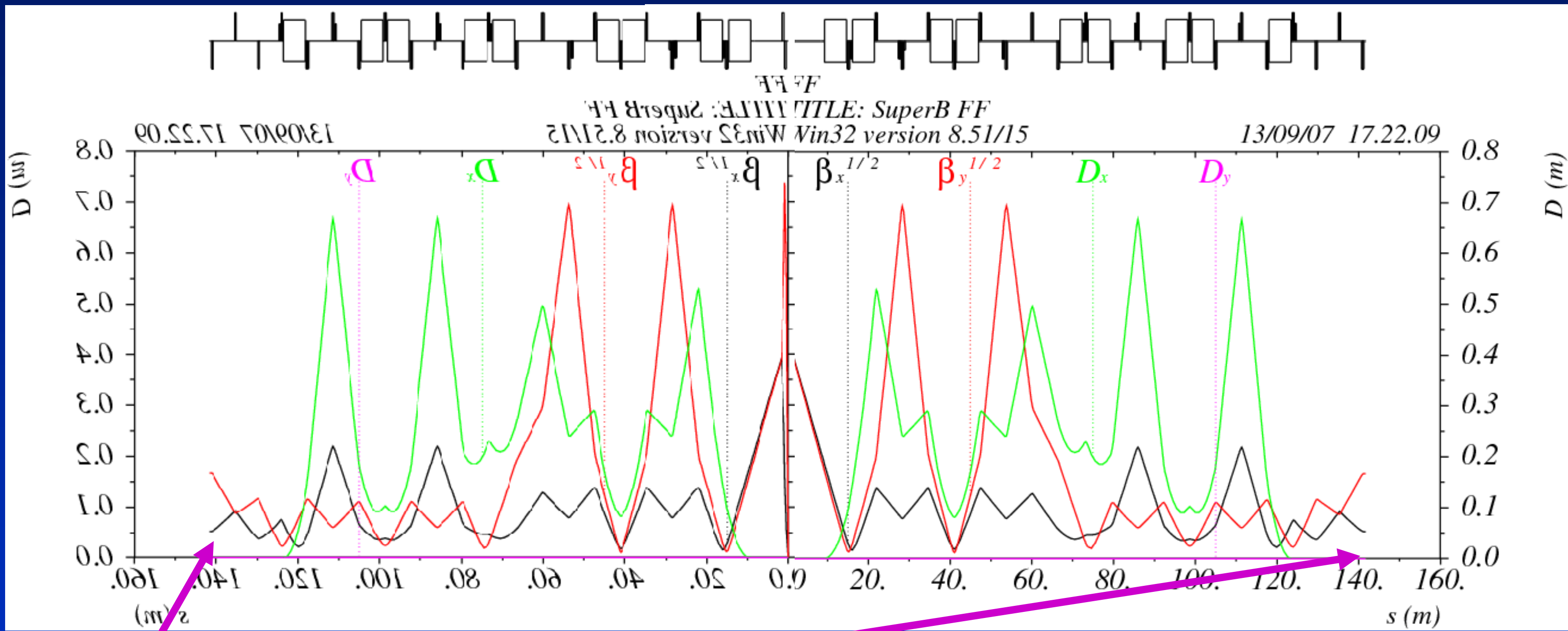
LER

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

Super-B builds on the Successes of Past Accelerators

- PEP-II LER stored beam current: 3.2 A in 1722 bunches (4 nsec) @ 3.1 GeV and 23 nm, with little ECI effect on luminosity
- Low emittance lattices designed for ILC damping rings, PETRA-3, NSLC-II, and PEP-X (few nm horizontal x few pm vertical)
- Very low emittance achieved in an ILC test ring: ATF
- Successful crab waist luminosity improvement at DAΦNE
- Successful crab cavity tests at KEKB at low currents
- Spin manipulation tests in Novosibirsk
- Efficient spin generation with a high current gun and spin transport to the final focus at the SLC
- Successful two beams, asymmetric, interaction regions built by KEKB and PEP-II
- Continuous injection works with the detector taking data (KEKB and PEP-II)

SuperB

SuperB design challenges

- Beam beam
  - high tune shift
  - strong-strong simulations for large crossing angle
  - effect of tolerances and component errors
- Low emittance
  - tolerances
  - achieving vertical emittance
  - tuning and preserving
  - vibrations
- IR design
  - 50 nm IP vertical beam size
  - QD0 design
  - luminosity backgrounds
- Polarization
  - impact on lattice
  - depolarization time
  - impact on beam-beam
  - continous injection
- Lattice
  - dynamic aperture with crab sextupoles and spin rotator
  - choice of good working point

All are being addressed in view of the TDR

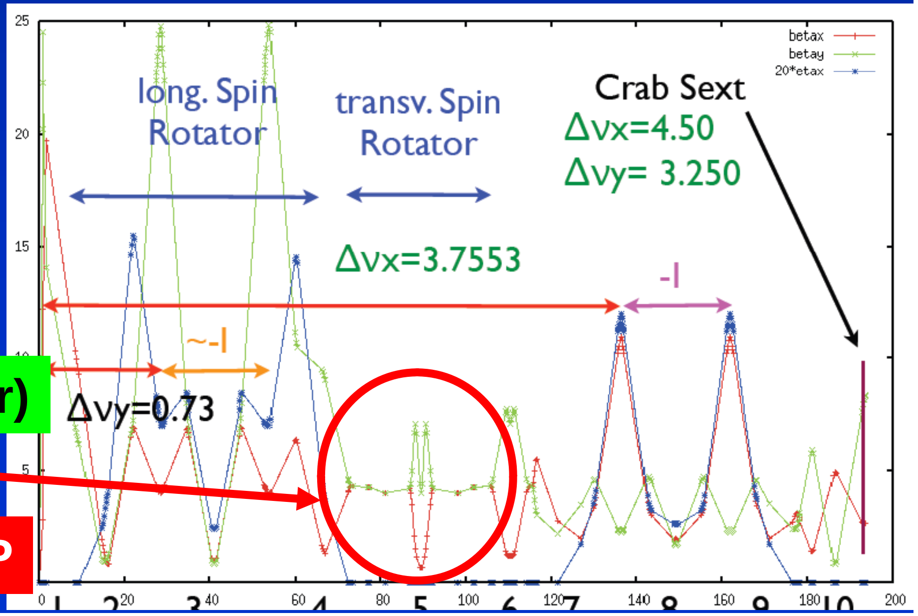
Polarization

- 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
- 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)

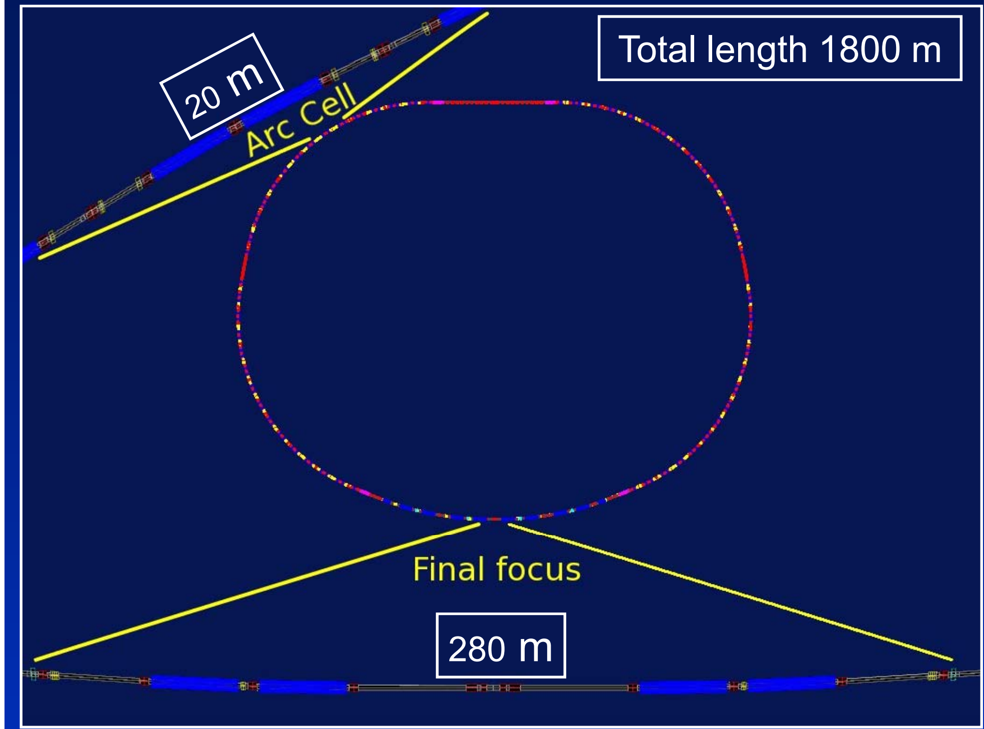
- Expected longitudinal polarization at IP ~ 87%(inj) x 97%(ring) = 85%(effective)
- Polarization section implementation in lattice is in progress

Half IR with spin rotator (Wienands, Wittmer)

IP



Lattice layout: PEP-II magnets reuse



Available

Needed

Dipoles

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

Quads

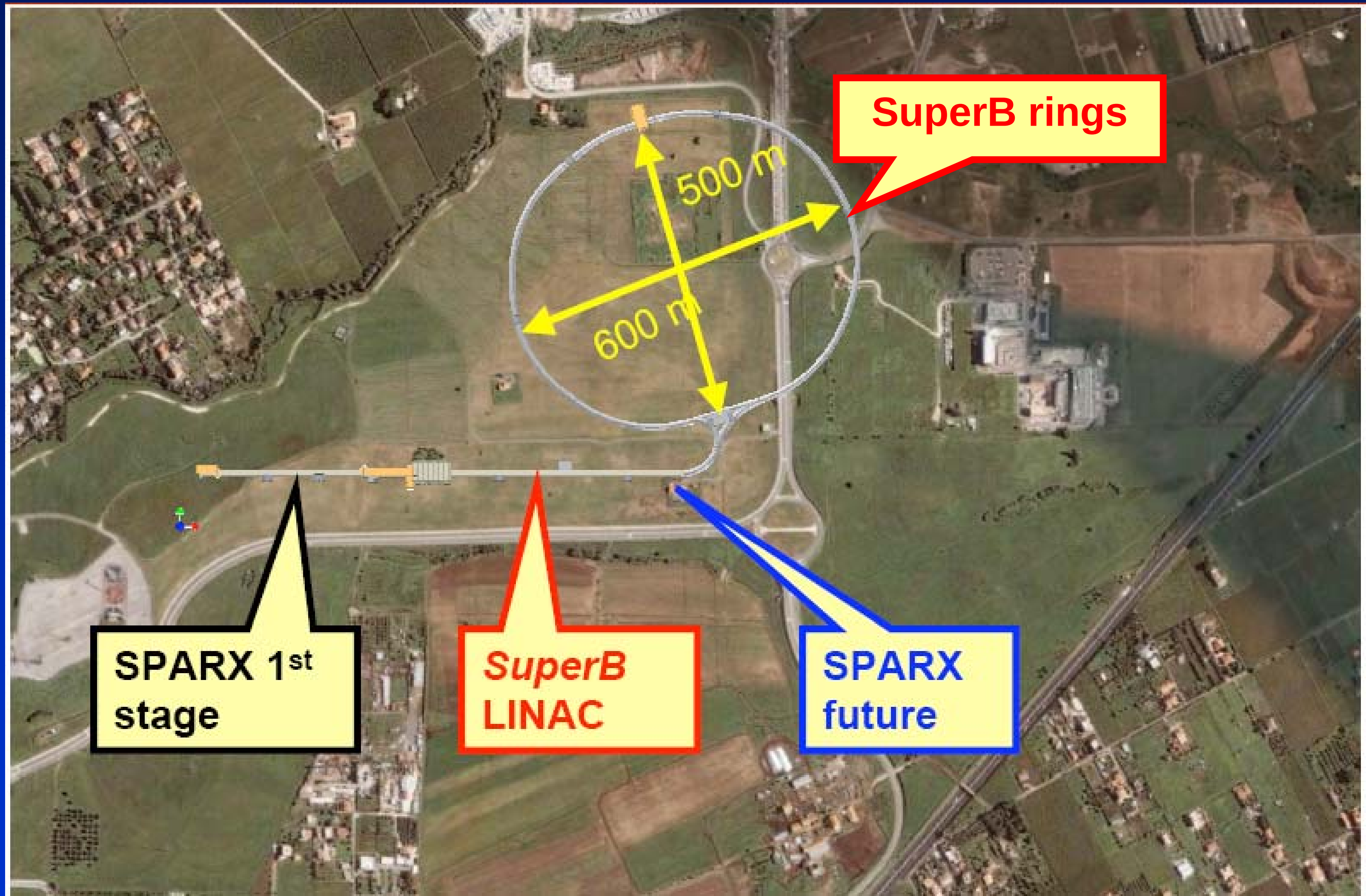
L_{mag} (m)	0.56	0.73	0.43	0.7	0.4
PEP HER	202	82	-	-	-
PEP LER	-	-	353	-	-
SBF HER	165	108	-	2	2
SBF LER	88	108	165	2	2
SBF Total	253	216	165	4	4
Needed	51*	134	0	4	4

Sexts

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

All PEP-II magnets can be used, dimensions and fields are in range
RF requirements are met by the present PEP-II RF system

SuperB footprint on Tor Vergata site



Good Opportunity to prove and use the LPA & CW in Dafne

for Physics Programs

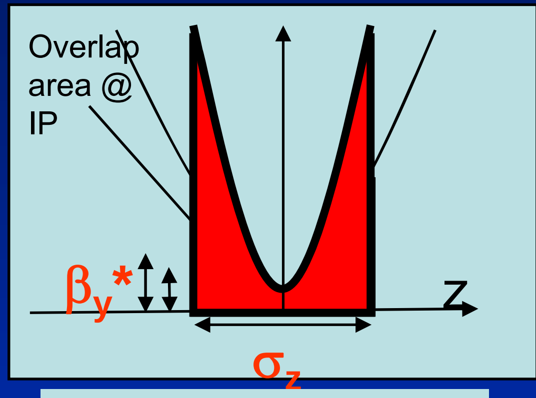
1. Fits DAΦNE schedule (shut down for SIDDHARTA installation in mid 2007)
2. Satisfies new physics programs (SIDDHARTA, KLOE2, FINUDA...)
3. Requires moderate modifications
4. Relatively low cost (1 mln Euro)

for Beam Dynamics

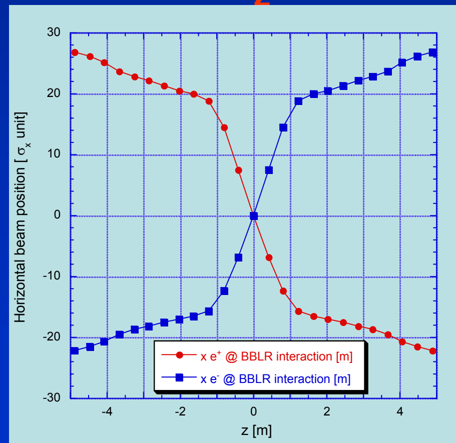
1. No detector solenoidal field
2. No splitter magnets
3. No compensating solenoids
4. No parasitic crossings
5. Lower beam impedance (simple IR, new bellows, new injection kickers)

Rationale for the Upgrade

$L_{peak} \sim 1.6\ 10^{32}\ cm^{-2}\ s^{-1}$ was the maximum luminosity achievable in the original DAΦNE configuration due to:



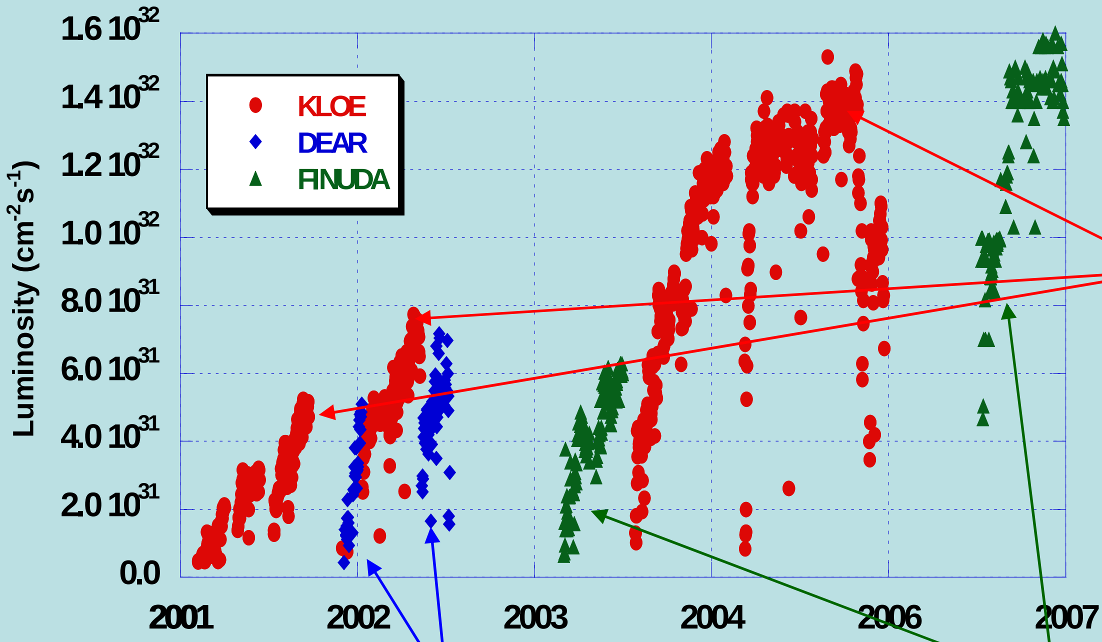
- $\beta^*_y \sim \sigma_z$ to avoid hourglass effect
- Long-range beam-beam interactions causing $\tau^+\ \tau^-$ reduction limiting $I^+_{MAX}\ I^-_{MAX}$ and consequently L_{peak} and $L_\int$
- Transverse size enlargements due to the beam-beam interaction

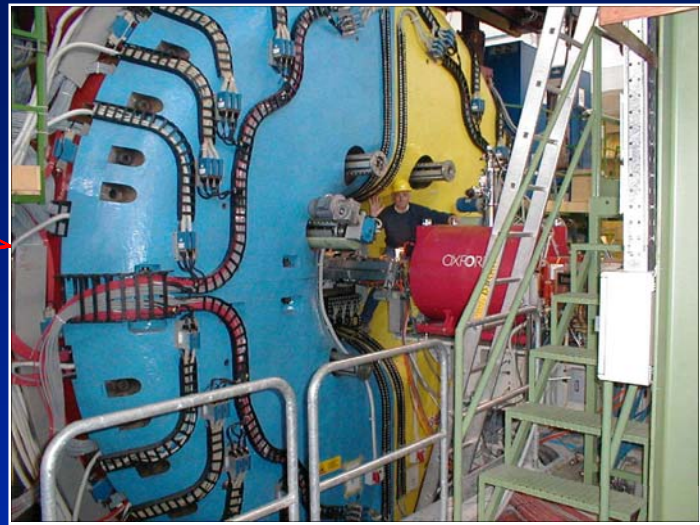


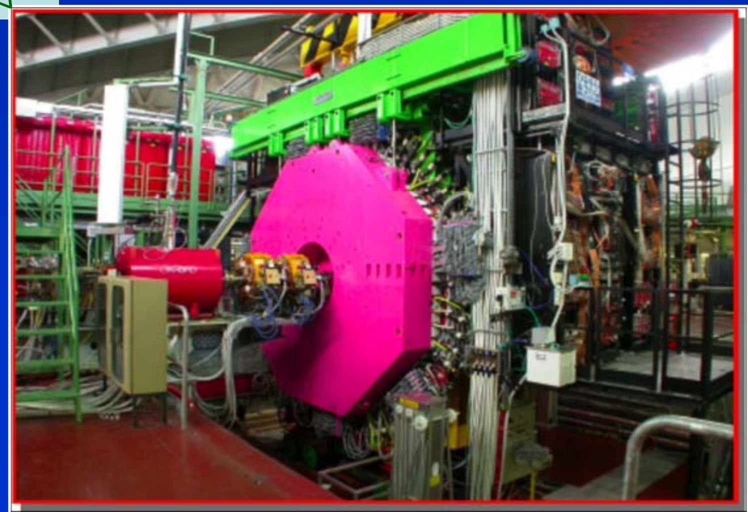
A new conceptual approach was necessary to reach L~10^{33}

Collision scheme based on **Large Piwinski** angle and **Crab-Waist**

DAΦNE Peak Luminosity

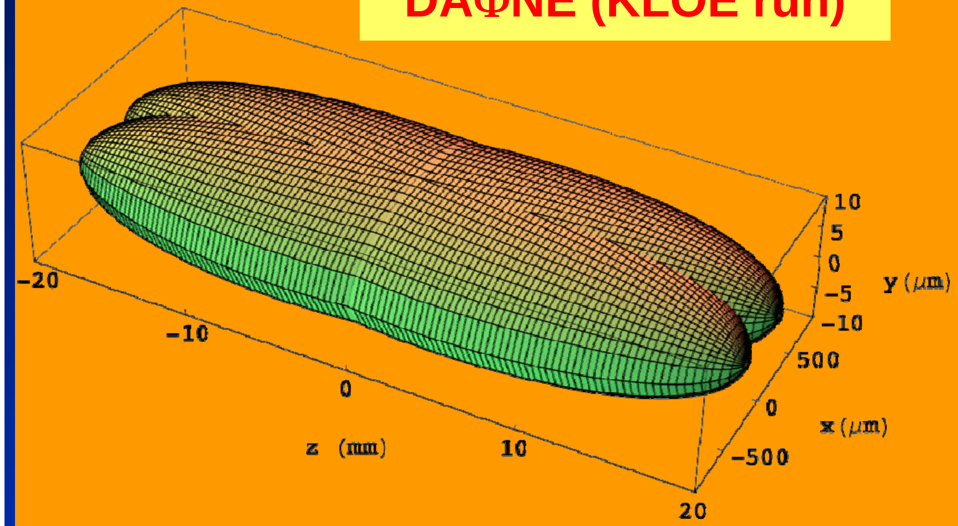




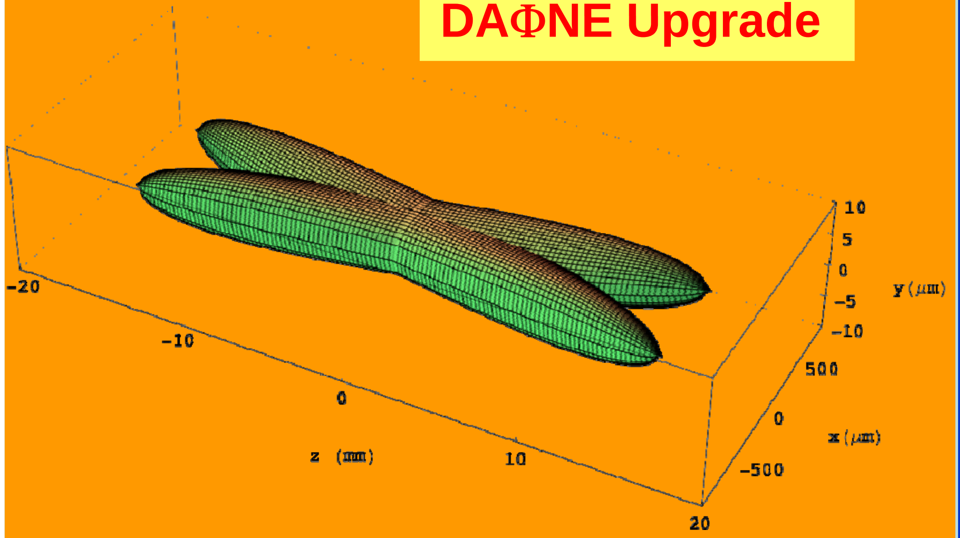


BEAM PROFILES @IP AND NEW PARAMETERS

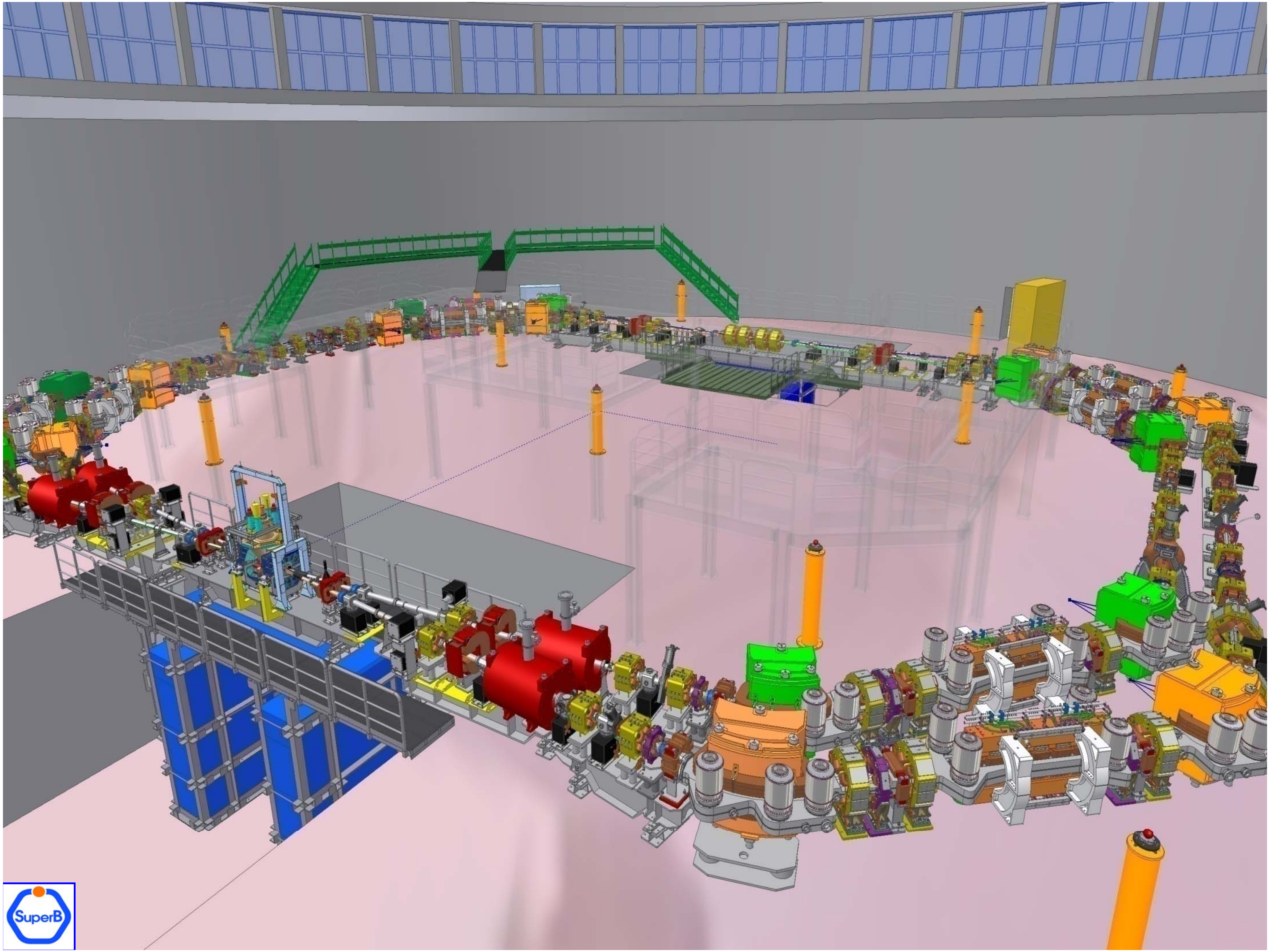
DAΦNE (KLOE run)



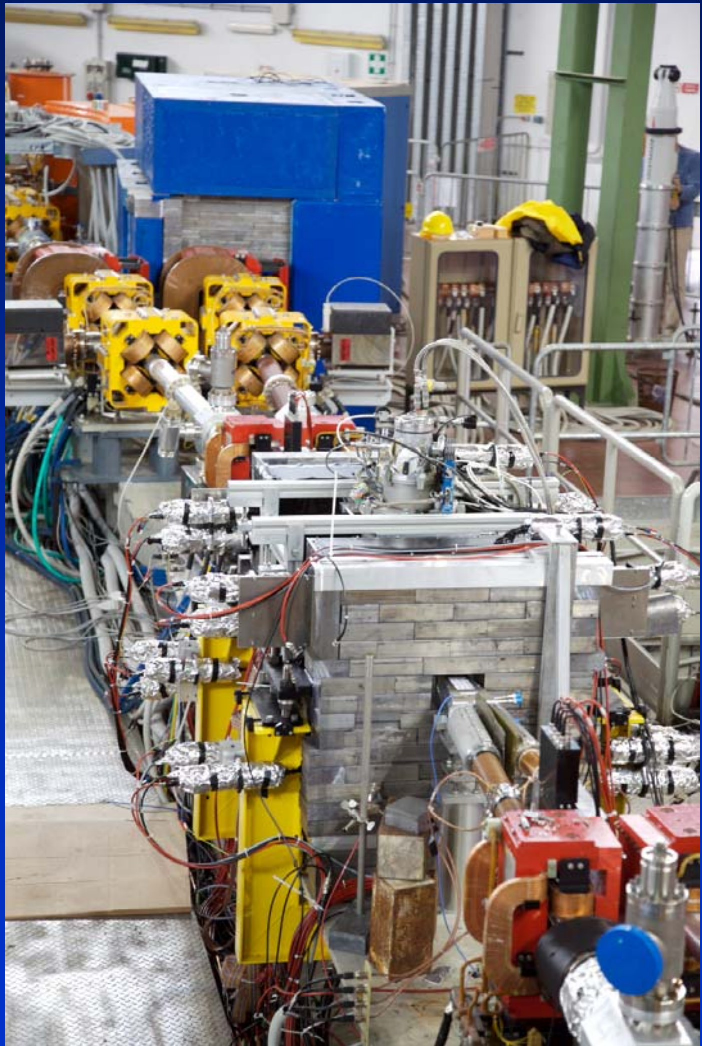
DAΦNE Upgrade

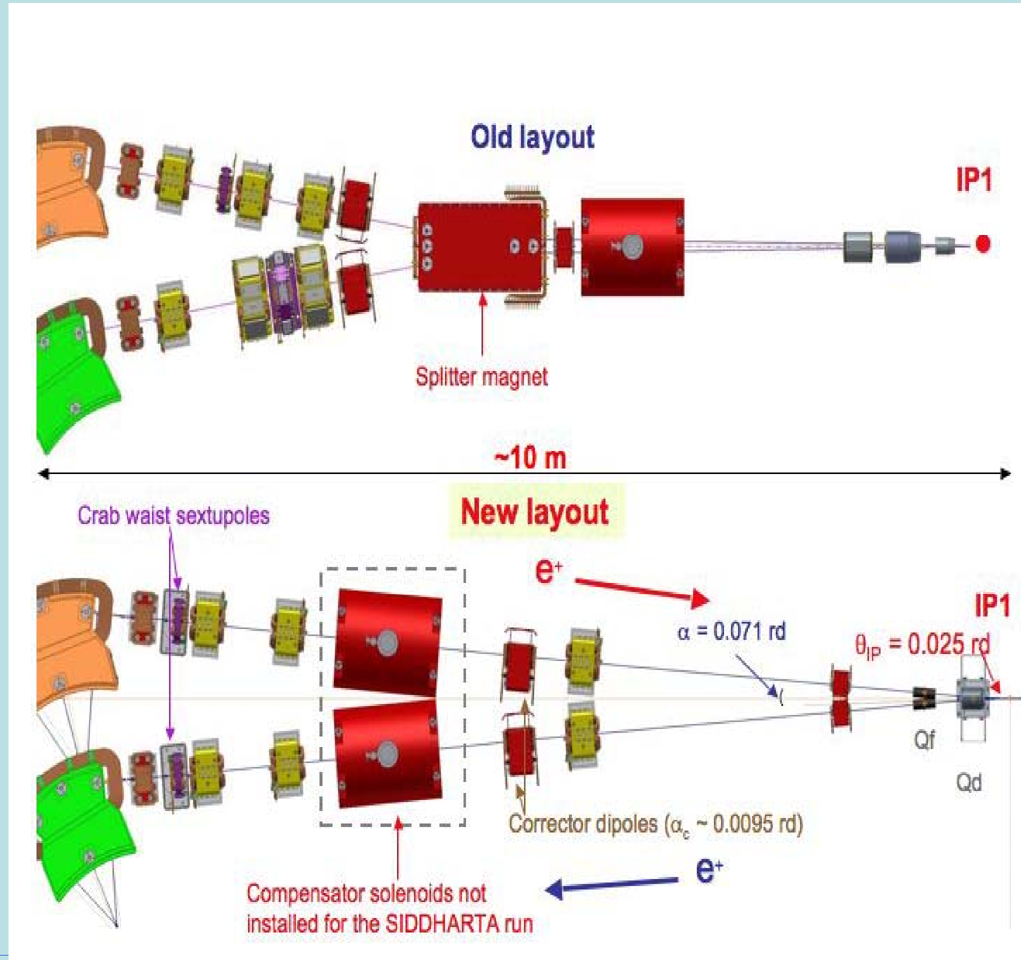


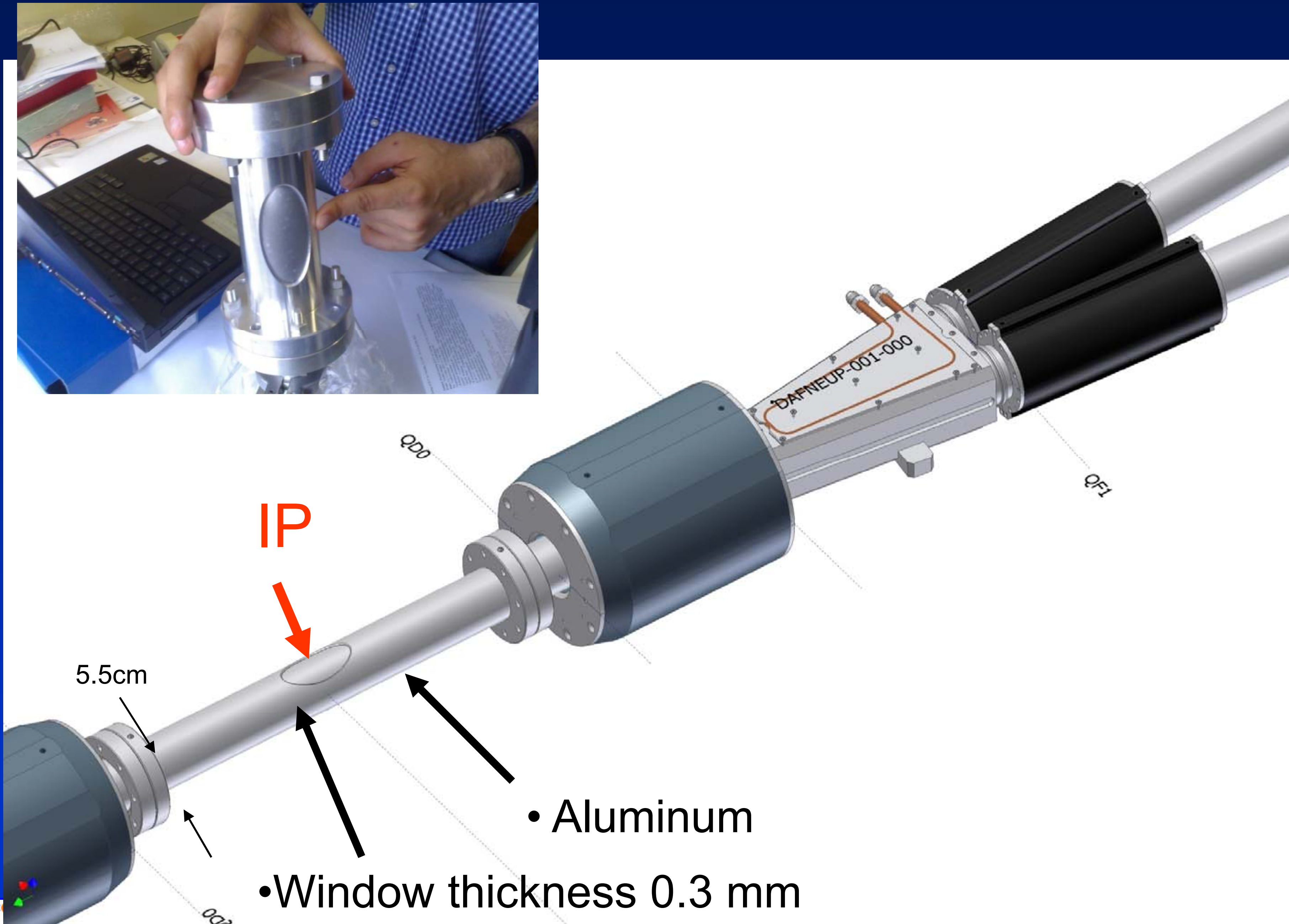
	DAΦNE (KLOE run)	DAΦNE Upgrade
I_{bunch} (mA)	13	13
N_{bunch}	110	110
β_y^* (cm)	1.8	0.85
β_x^* (cm)	160	26
σ_y^* (μm)	5.4 low curr	3.1
σ_x^* (μm)	700	260
σ_z (mm)	25	20
Horizontal tune shift	0.04	0.008
Vertical tune shift	0.04	0.055
θ_{cross} (mrad) (half)	12.5	25
$\Phi_{Piwinski}$	0.45	2.0
L ($cm^{-2}s^{-1}$)	1.5×10^{32}	$>5 \times 10^{32}$



New Experimental Interaction Region







- Aluminum
- Window thickness 0.3 mm

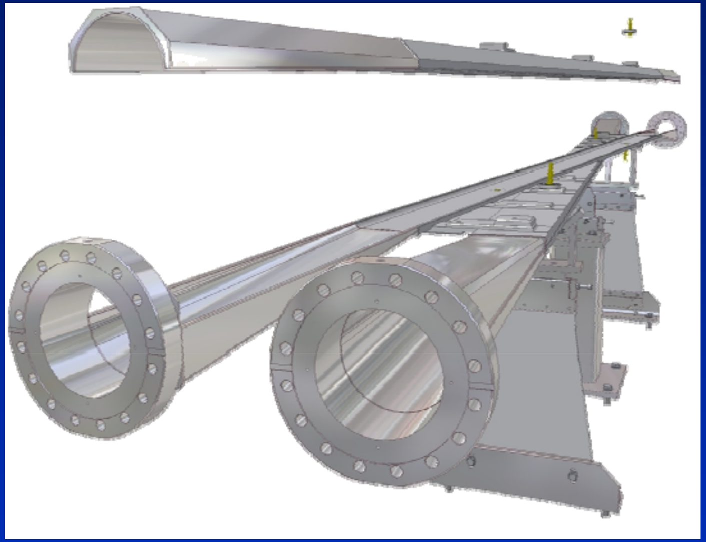
High current operation

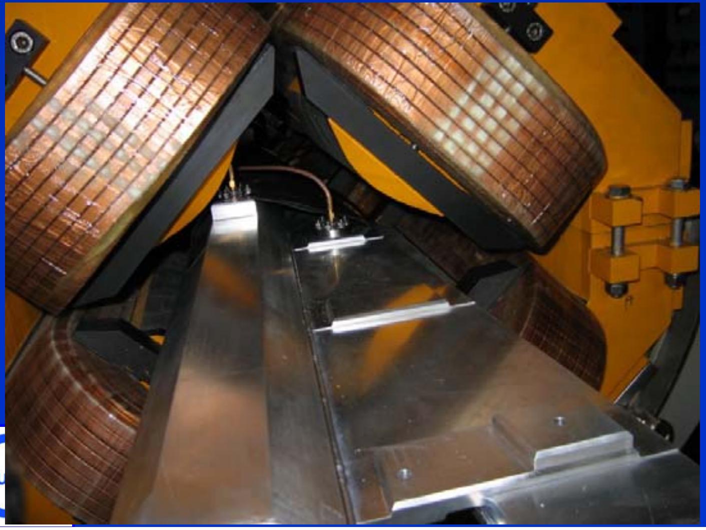
- Three main hardware upgrades have been implemented to improve the stored current:

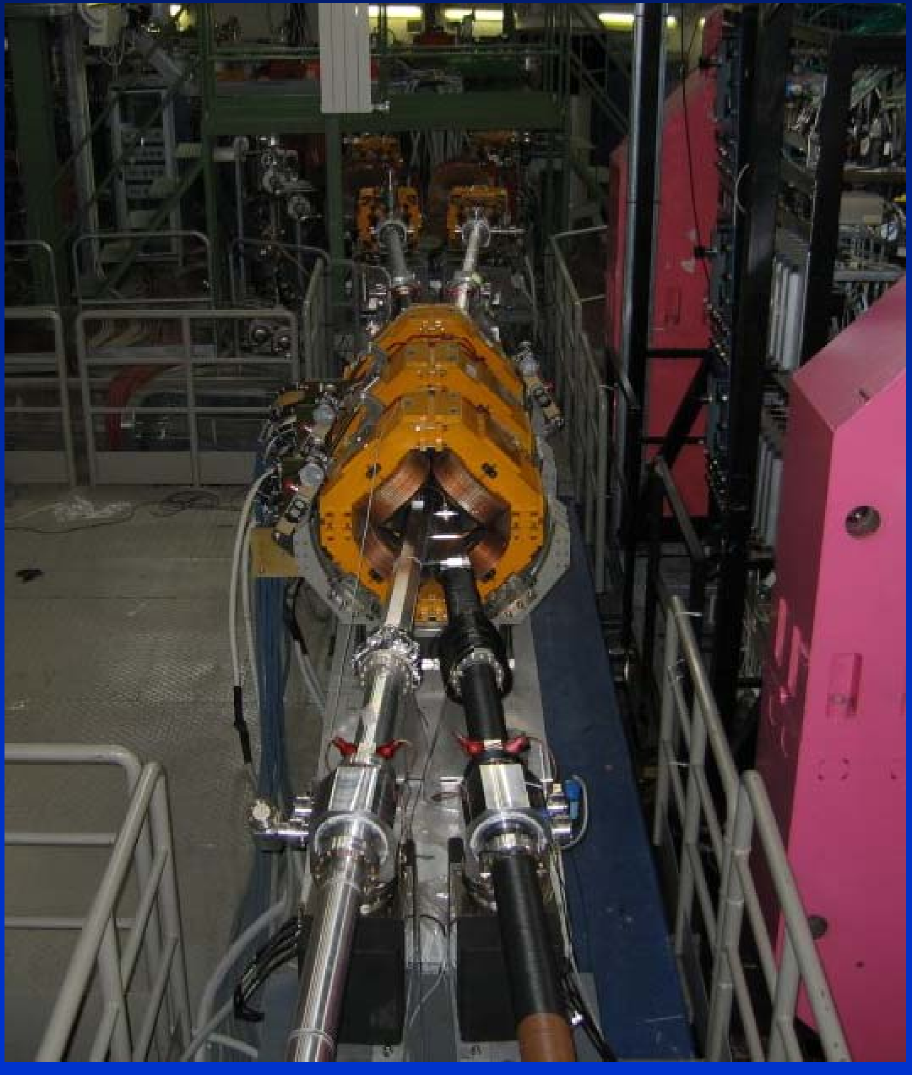
- Fast kickers
- Feedback upgrade
- Lower impedance vacuum chamber
- Solenoid Windings

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)

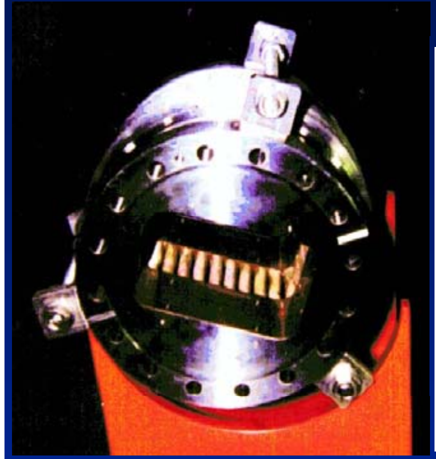


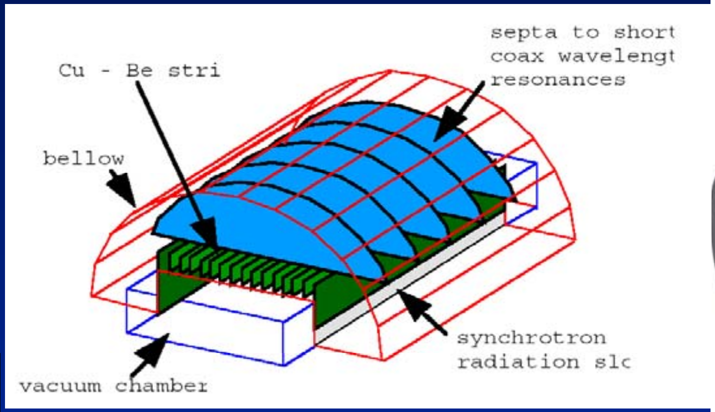


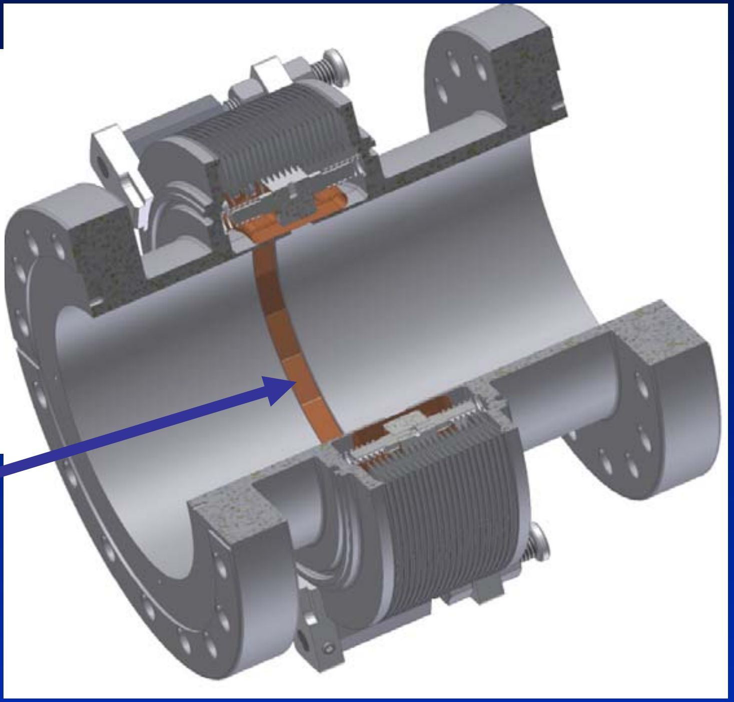


NEW BELLOWS

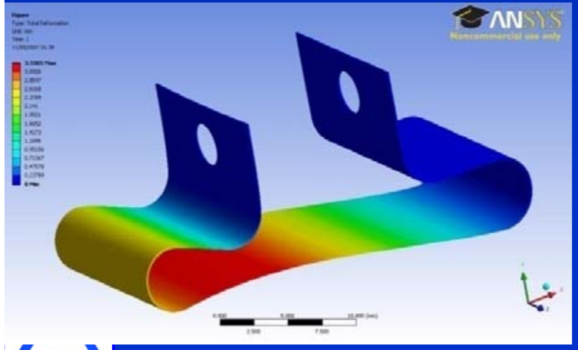
OLD BELLOW



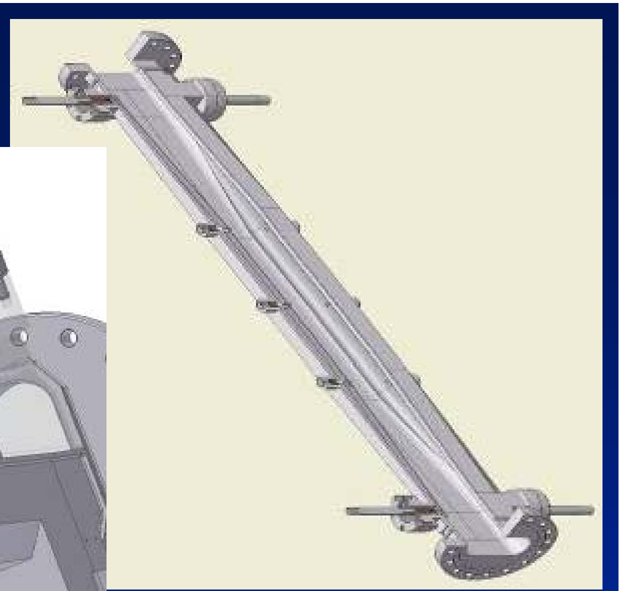


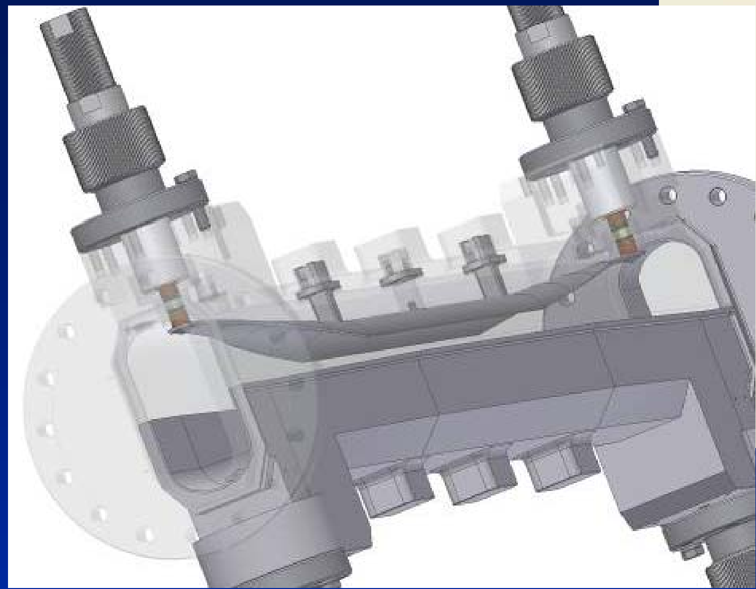


- 6 new bellows for each ring
- Shielding based on Be-Cu W strips 0.2 mm thick
- lower impedance and better mechanical performance

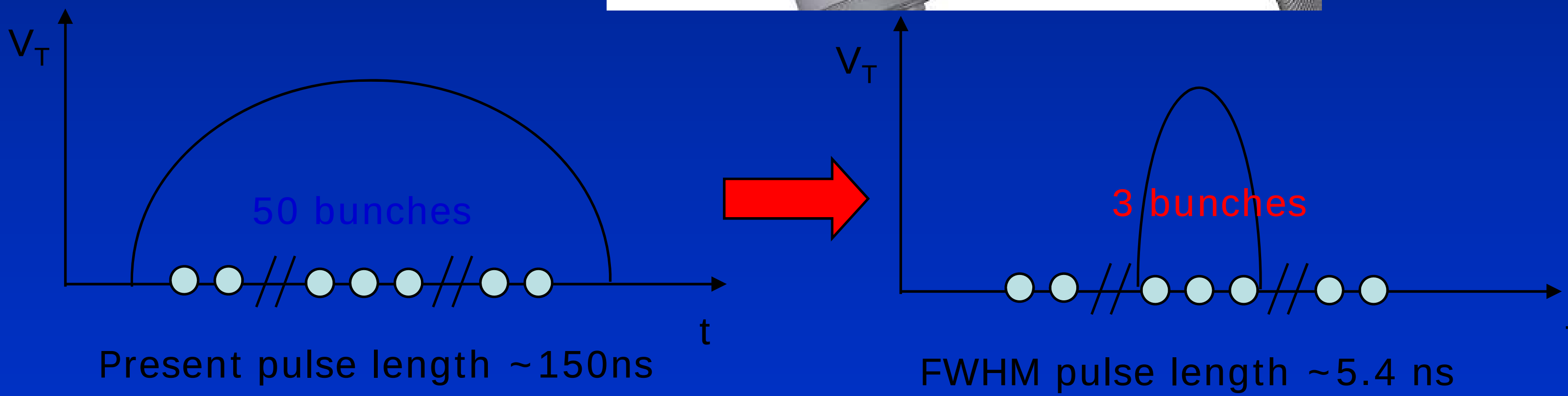


New Fast Injection Kickers





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

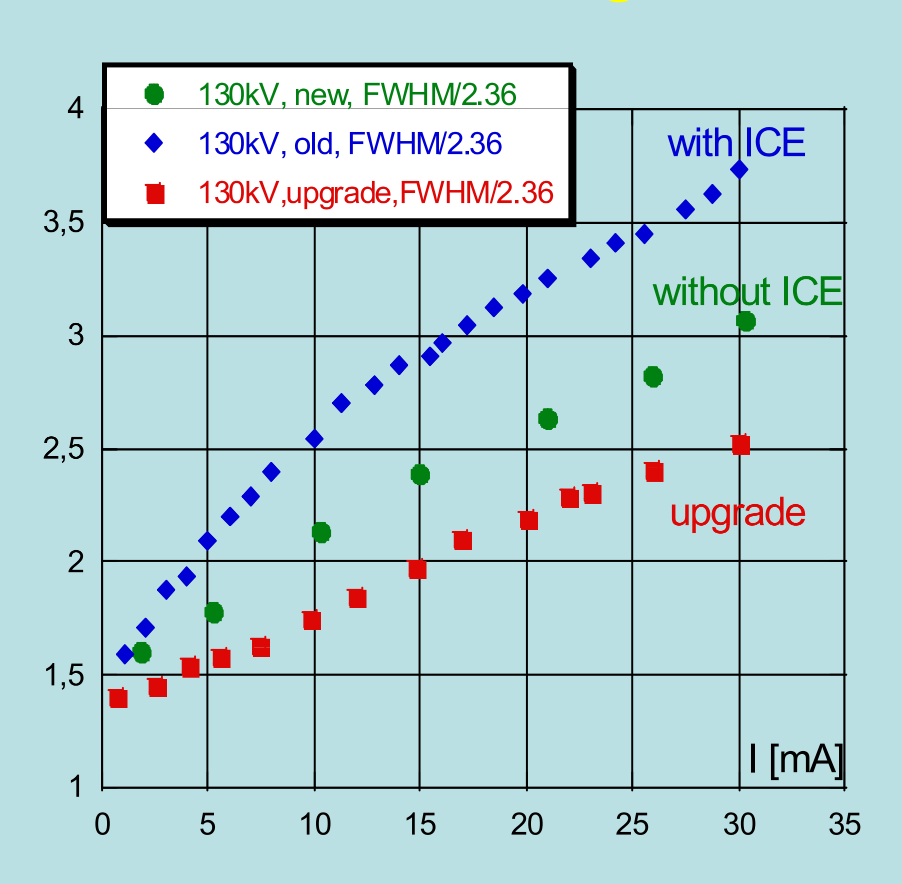


Expected benefits:

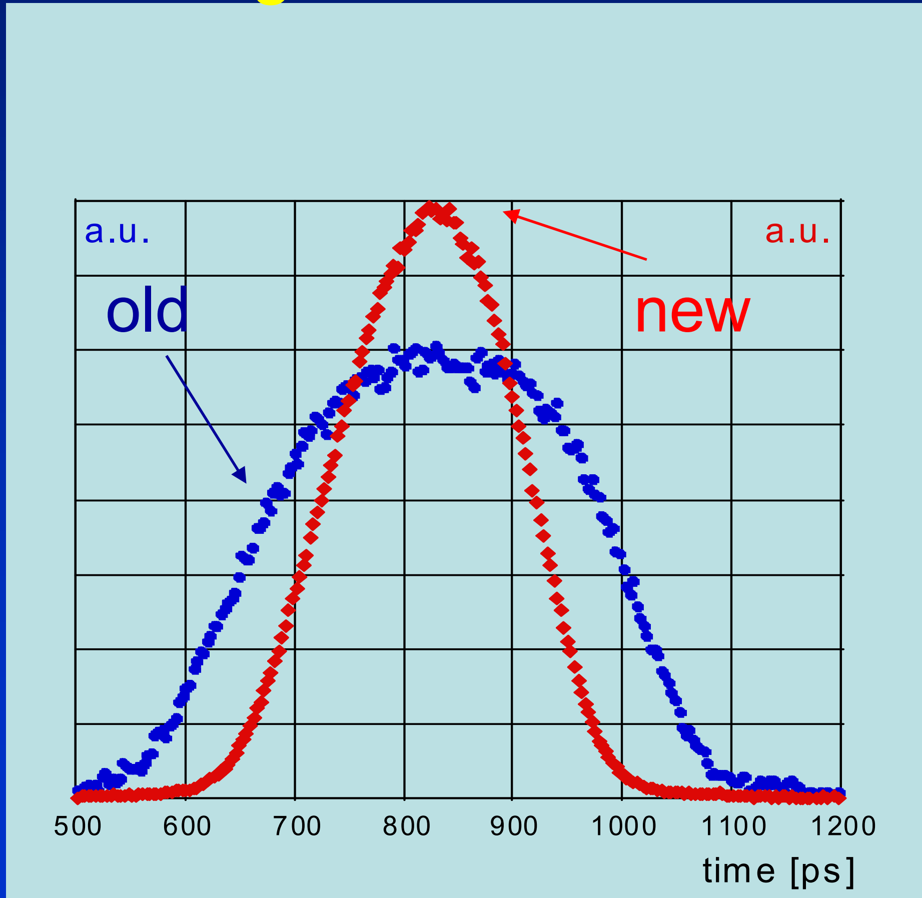
- **higher maximum stored currents**
- **Improved stability of colliding beams during injection**
- **less background allowing data acquisition during injection**

Bunch Lengthening in Upgraded Vacuum Chamber

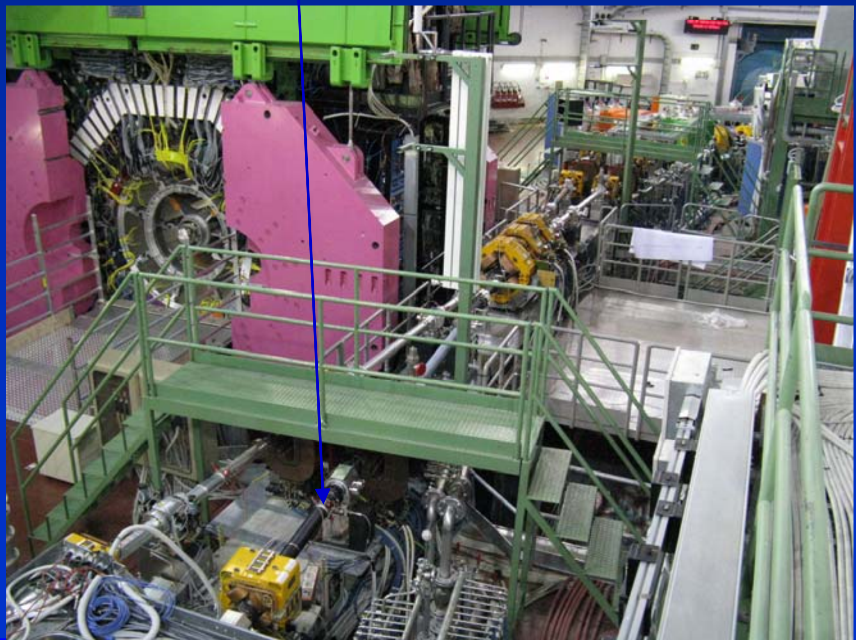
Bunch Length



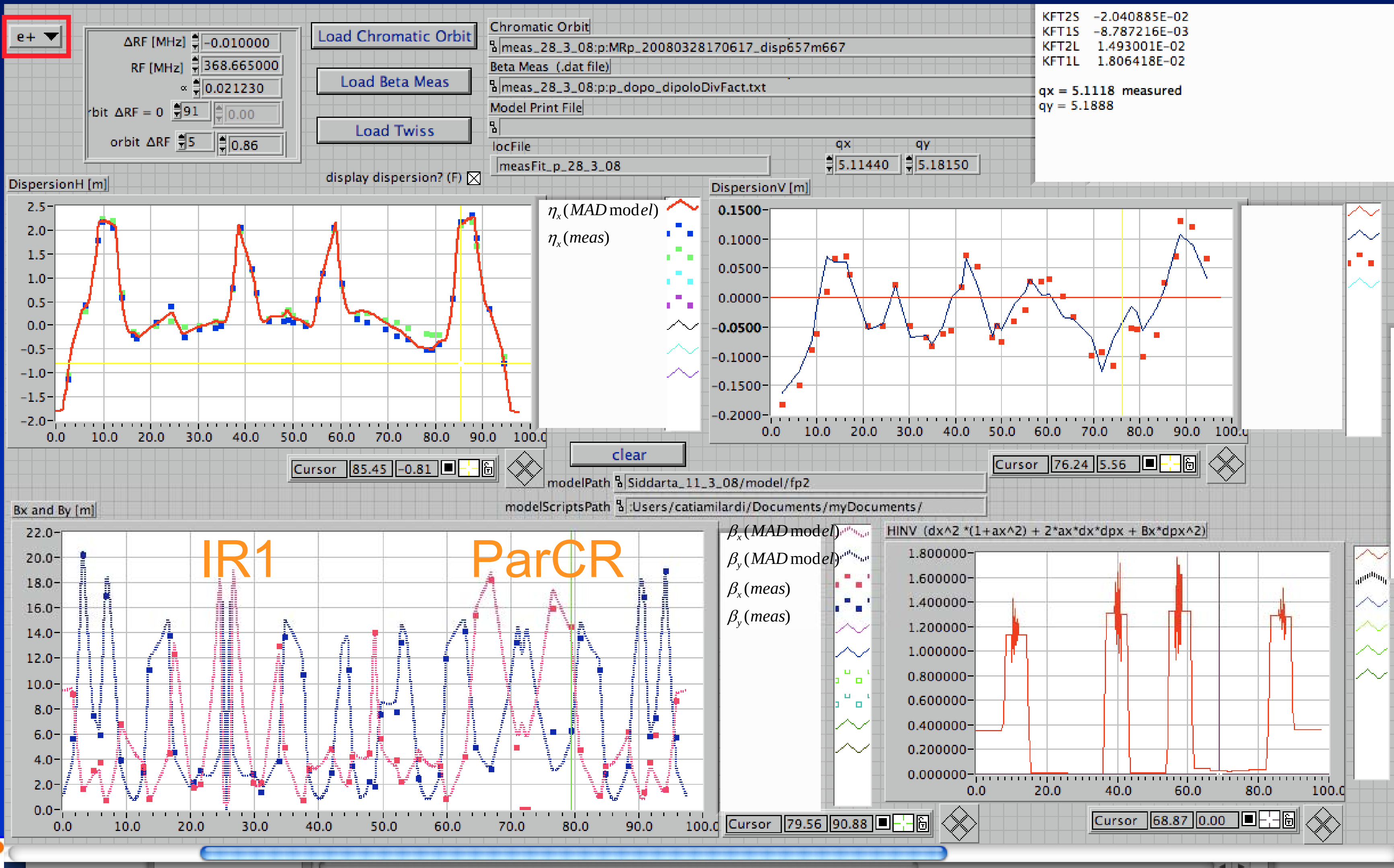
Charge Distribution



Solenoids



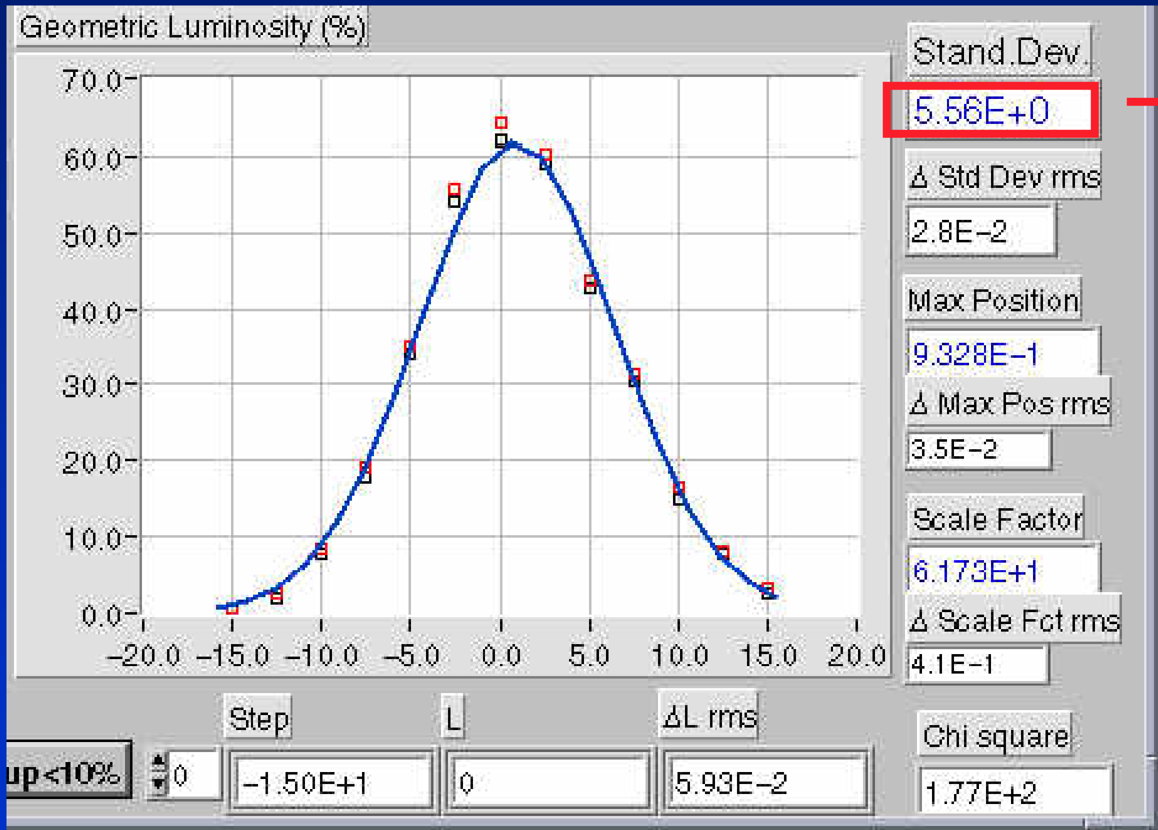
Present SIDDHARTA Optics



Vertical beam-beam Luminosity scan

$$\Sigma_y = \sqrt{\sigma_{yp}^2 + \sigma_{ye}^2}$$

$$\Sigma_y = \Sigma_y^{meas} * 0.88$$



$$\sigma_y \approx 3.5\mu m$$

Design is 3.1μm

July 2008

LPA & CW Optics Commissioning

- Lot of work done to match the optic (main problems from IP-Permanent Magnets out of specs w.r.t. gradient)
- Well established the proper CW optics requirements Sext=>IP=>AntiSext
- Well define sextupoles aligned procedure in single beam mode:

- turn on one sext at the time, measure the tune shift and move the orbit:

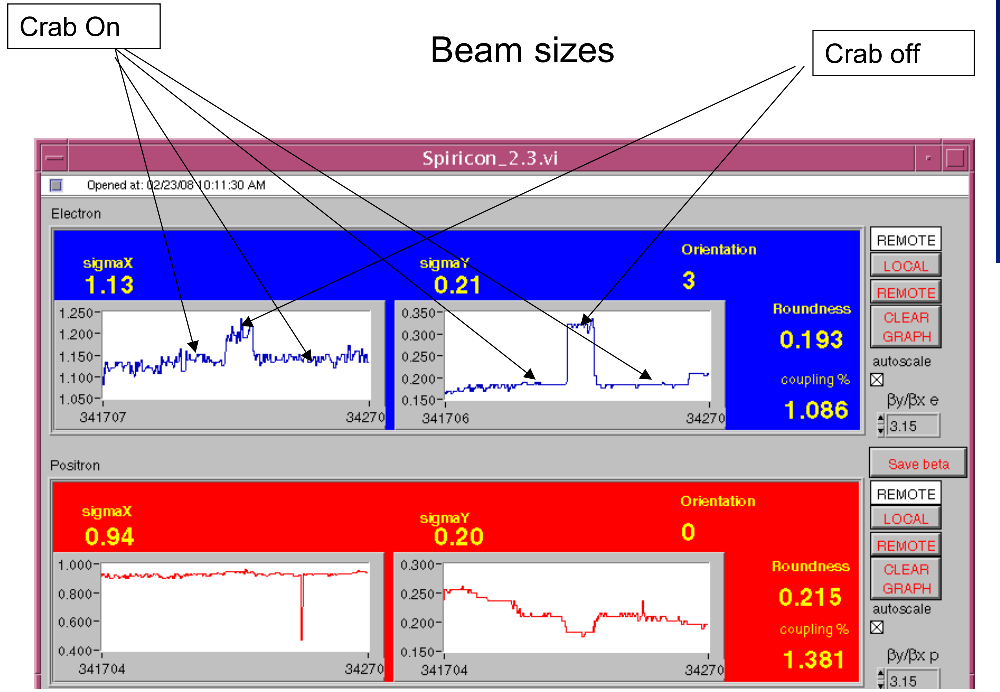
1) horizontally until no tune shift is observed

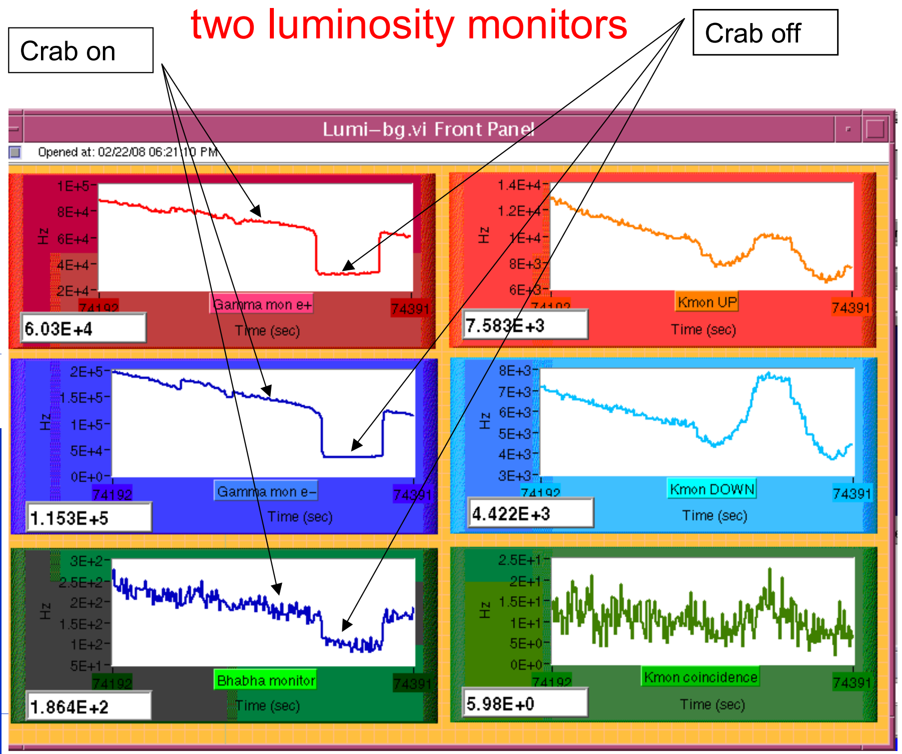
2) vertical until no coupling change is observed on our Synchrotron Light Monitor

- Verified that turning on both sextupoles there are no effects on:
  - Tunes
  - Coupling
  - Lifetime
  - Background

Finally we did turn on the sextupoles in collision for the first time…

Crab Waist Works: First Experimental Evidence





Crab Sextupoles on all the time since the first time we tested them

Present Performances

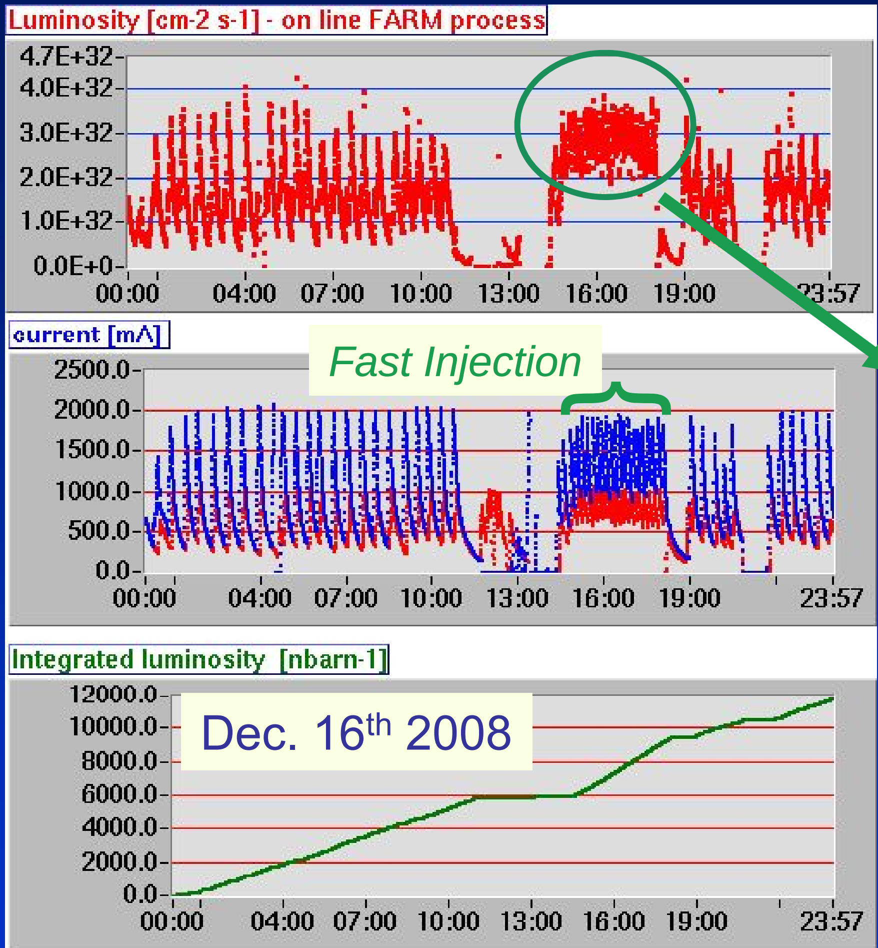
- Peak Luminosity: 4.1e32 (1.52e32) obtained with 1.50 (1.55) Amps e- vs 1.1 (1.25) Amps e+ 105 (110) Bunches
- Peak Hourly rate 1.023 (0.44) pb-1/hour
- Peak Daily rate 15.0 (9.83) pb-1 with long coasting (Long coasting needed for Siddharta, not for Kloe or Finuda)

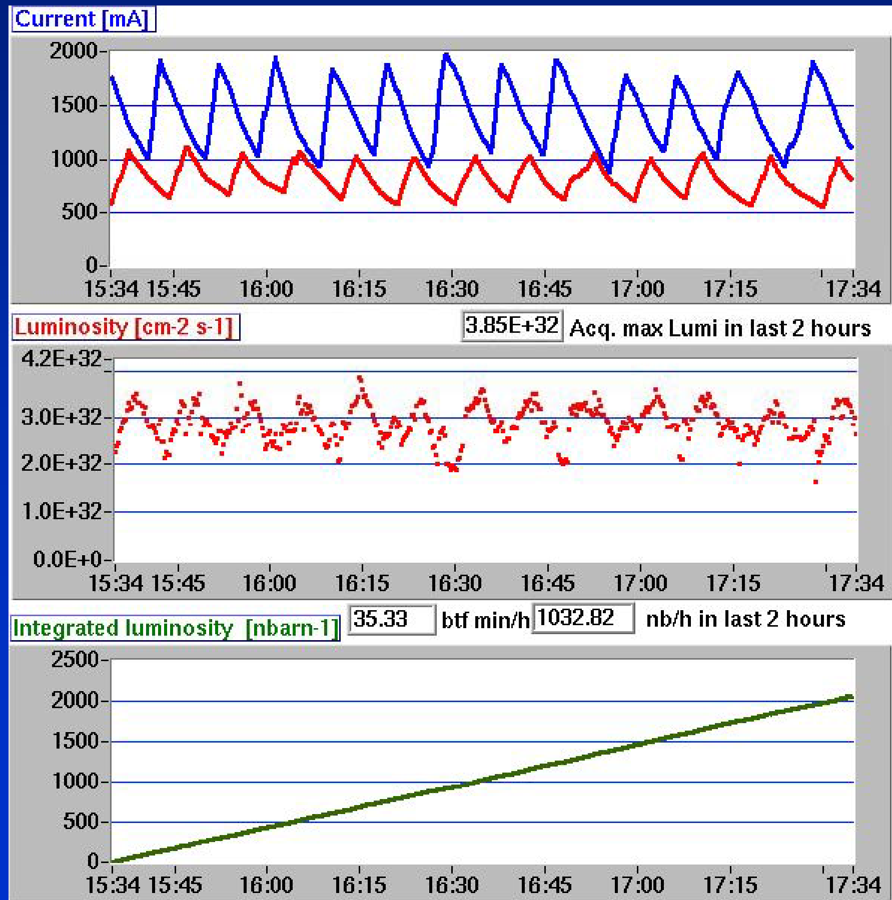
Red are the Kloe records before the upgrade

Best hourly integrated luminosity

$L_{\int 1\ hour} = 1.033\ pb^{-1}$

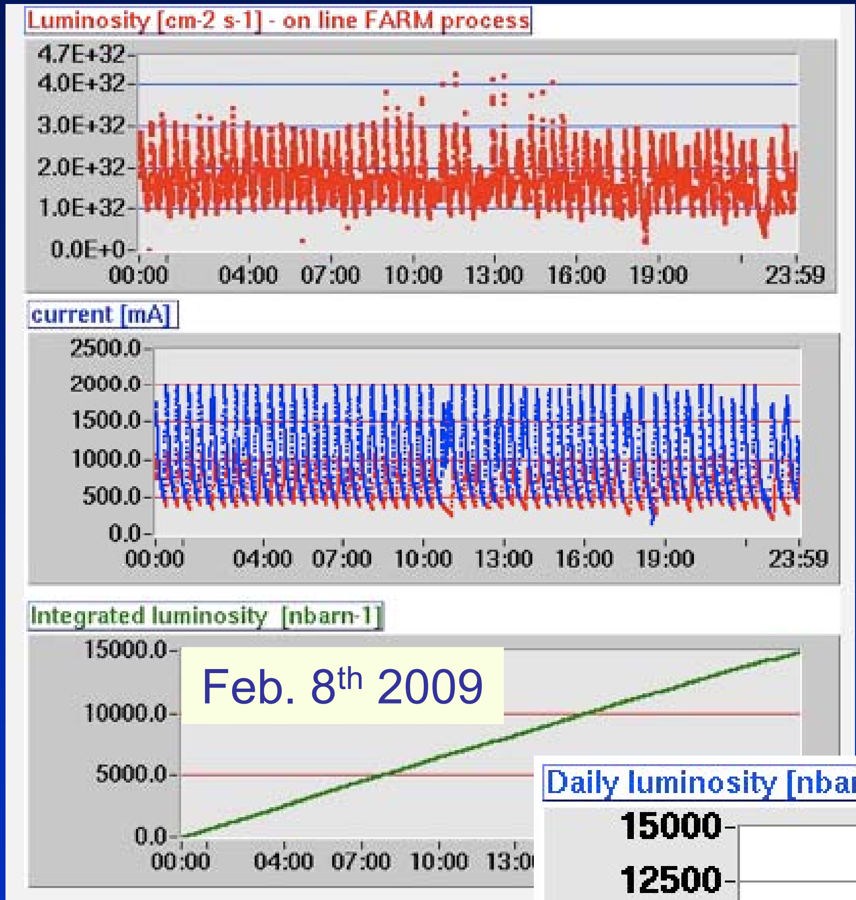
- *High rate injection regime*
- *105 colliding bunches*
- *Very **useful for a future KLOE run***





Fast injection is not compatible with the SIDDHARTA operations!

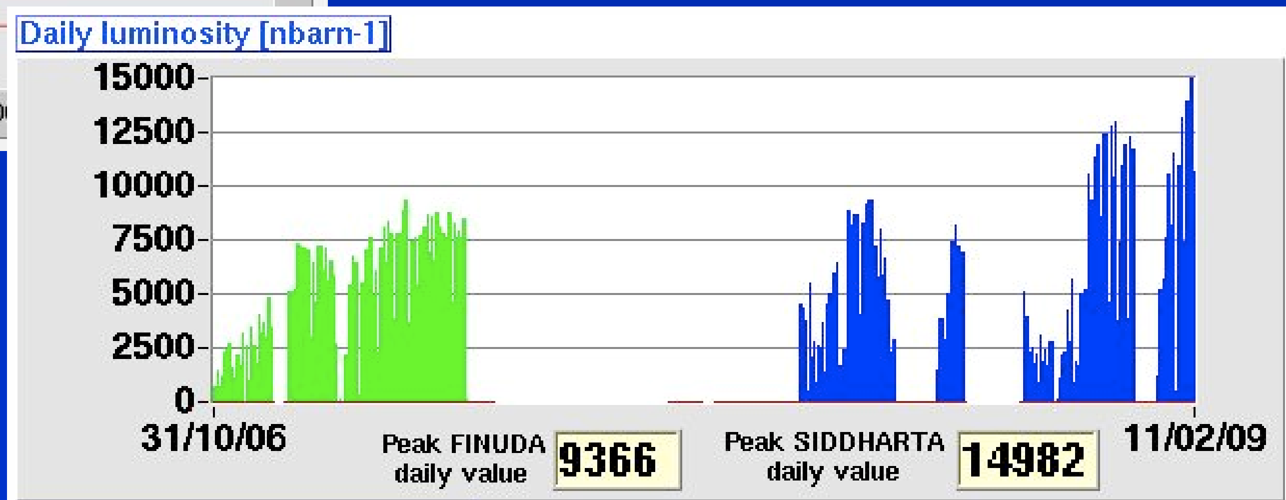
Best daily integrated luminosity

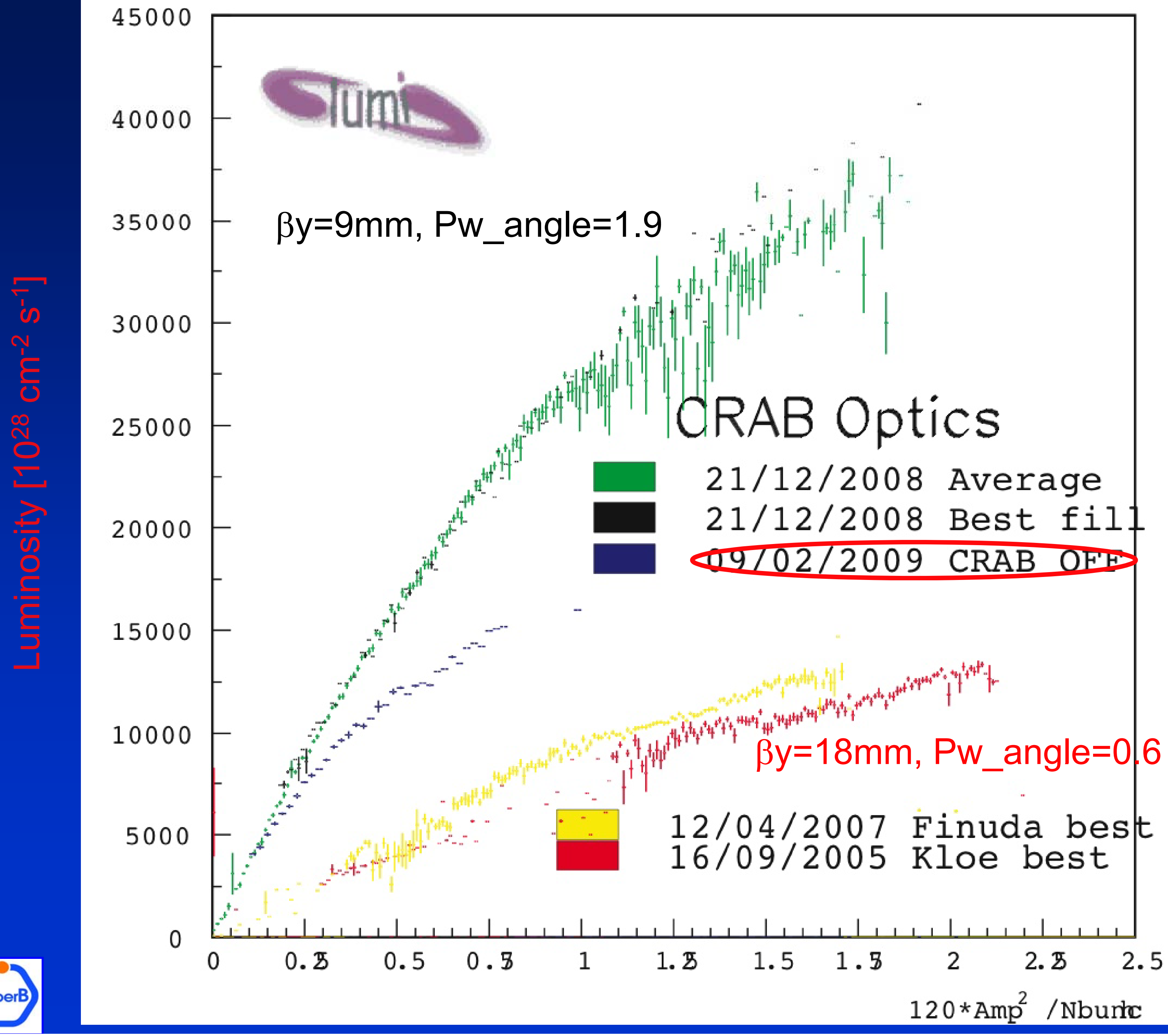


$L_{\int day} = 15.\ pb^{-1}$

- *moderate injection rate regime*
- *105 colliding bunches*
- $L_{\int hour} = 0.62\ pb^{-1}$

+ 60 % FINUDA 2007





Luminosity [10^{28} cm^{-2} s^{-1}]
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
lumi
βy=9mm, Pw_angle=1.9
CRAB Optics
21/12/2008 Average
21/12/2008 Best fill
09/02/2009 CRAB OFF
βy=18mm, Pw_angle=0.6
12/04/2007 Finuda best
16/09/2005 Kloe best
0
0.5
1
1.5
2
2.5
120*Amp^2 /Nbunc

- Results even more striking since we have also reduced the Dafne Wigglers Field (less damping needed since beam-beam is small) in order to save on running cost:

  - 6 MW Wall Plug power during the Kloe data taking

  - 4 MW now

- Performances are still limited because of "standard problems":

  - e-cloud
  - Ion trapping
  - RF stability

- We hope to further reduce their impact on the performances and gain more in Luminosity at a given current and in peak currents

36th MEETING OF THE LNF SCIENTIFIC COMMITTEE

FINDINGS AND RECOMMENDATIONS

1 THE DAΦNE PROGRAM: STATUS AND RECOMMENDATIONS

1.1 DAΦNE UPGRADE: PERFORMANCE AND OUTLOOK

… fact that the principle of crab-waist compensation has been shown to work; this must be recognised as a major advance in the long history of fighting the beam-beam effect in e^+e^- colliders. It is also an important step towards validation of the SuperB design concepts.

……..

Finally, the effect of the crab-waist compensation is striking. As we were able to observe directly in the control room, excitation of the sextupoles on either or both beams reduces the corresponding beam sizes in collision, as predicted.

Conclusions

LPA & CW is promising to push forward the high luminosity frontier for storage rings colliders

Tests on adapting an existing machine, Dafne, have been very succesfull, the Siddharta experiment is taking data very smoothly. The HEP program at Frascati has been extended and a new physics run for Kloe has been approved, aimed at >5fb^{-1}/year for at least 3 years

A B-factory based on such a scheme could give unprecedent and hard to beat luminosity

Other machines and projects might benefit as well (BEPc LHC SuperTau (Novosibirsk)), but its implementation on existing layouts is not trivial