DAΦNE lifetime optimization with octupoles and compensating wires

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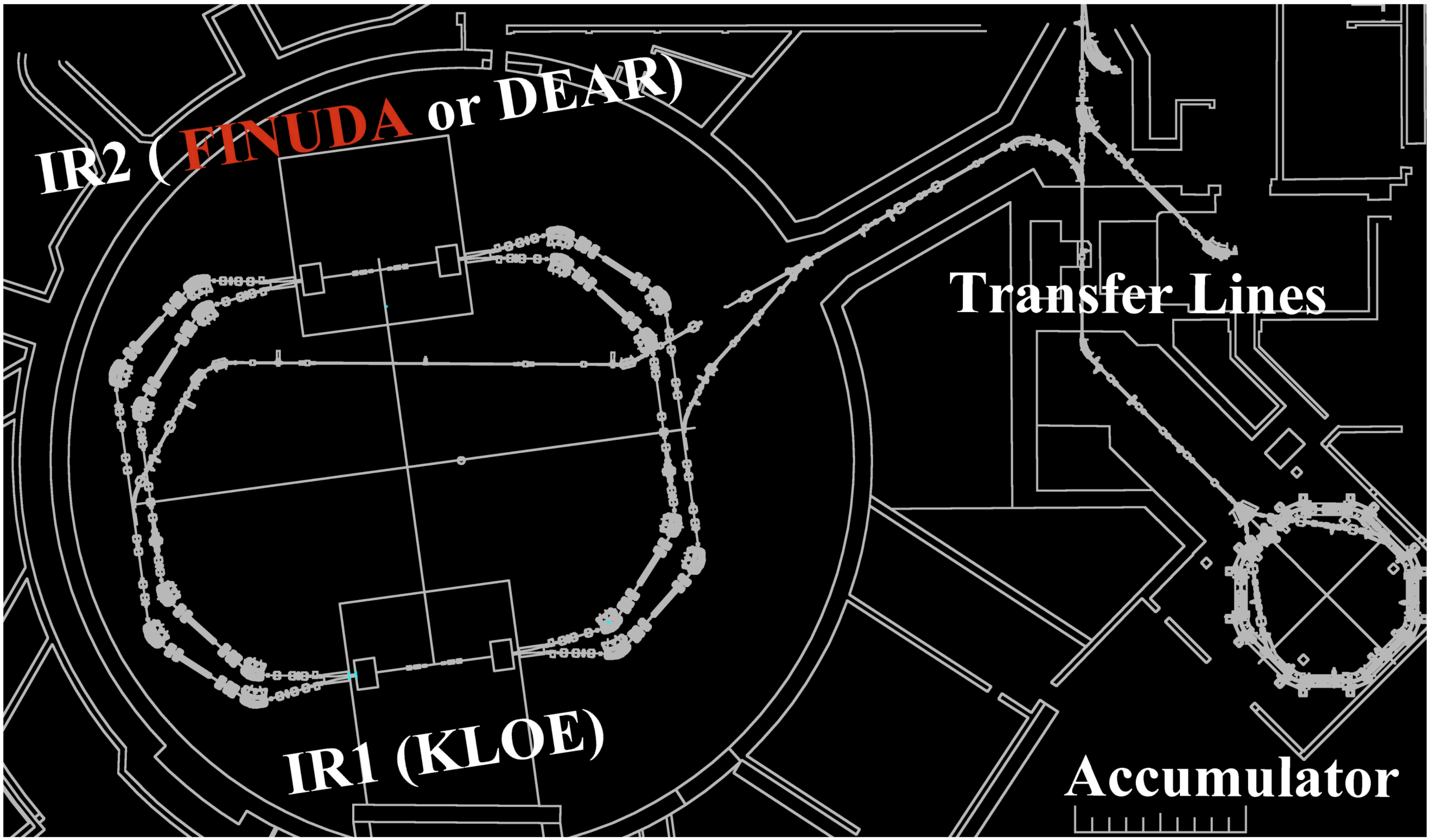
Outlines

- DAΦNE accelerator complex
- BBLR interaction
- parasitic crossing compensation by WIRES
- Operation with wires during the last two DAΦ
  NE runs
- Global nonlinearities compensation at DAΦNE
- LRBB interaction compensation for the next
  DAΦNE upgrade

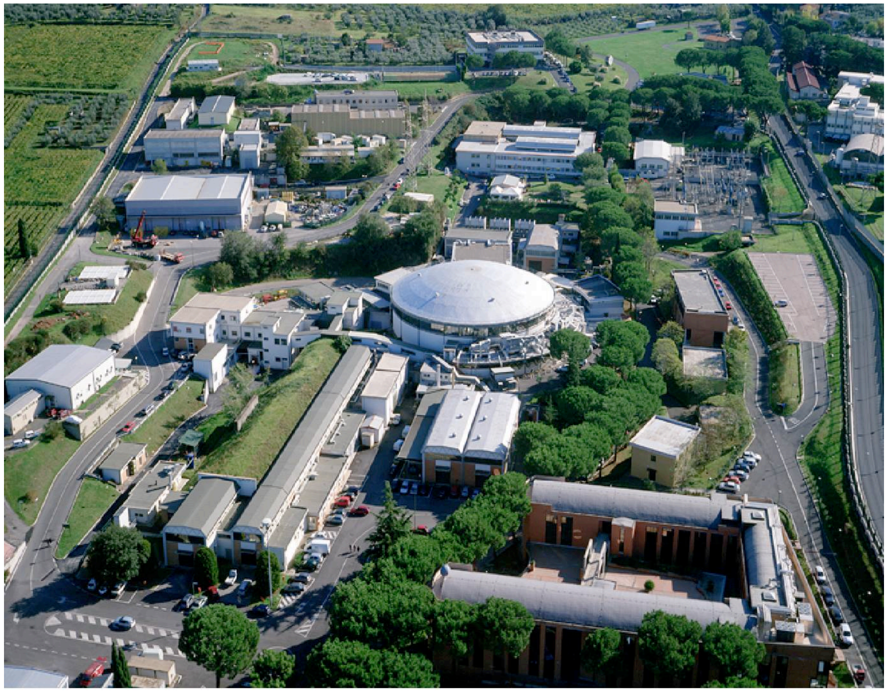
DAΦNE complex

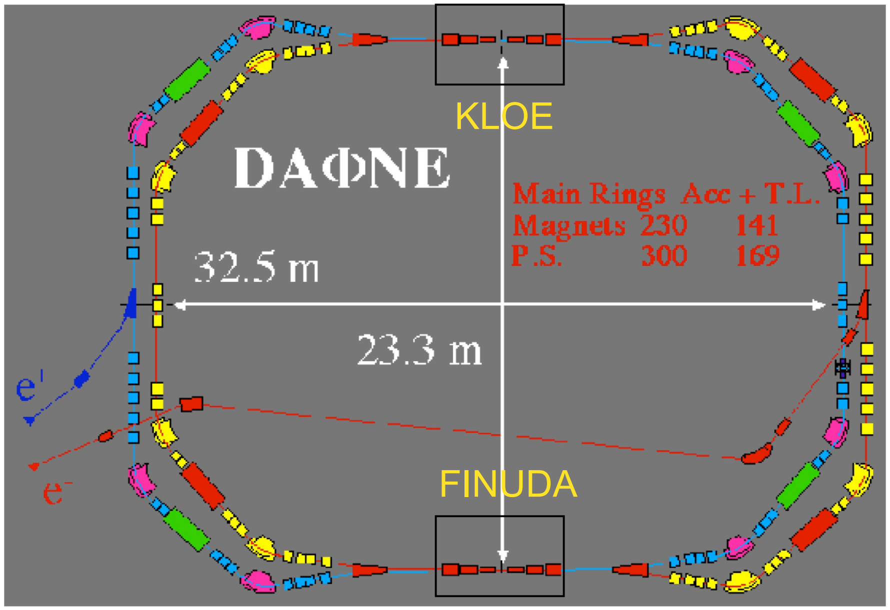
- ✓ DAΦNE is the e^+e^- collider operating at the energy of the Φ resonance (1.02 GeV c.m.)
- ✓ It consists of two independent rings 97 m long sharing two interaction regions: IR1 and IR2.



DAΦNE

- Lepton collider
- Wiggler dominated rings
- Experimental solenoid field is integral part of the lattice
- All magnetic elements are independently powered
- Flat beams ($\sigma_x^* \sim 1$ mm $\sigma_y^* \sim 10\mu$ $\sigma_z^* = 20 \div 25$ mm) colliding with horizontal crossing angle
- Bunch separation 2.7 ns, shortest among the existing factories and colliders
- Colliding bunches 109 ÷ 111 Working point close to the integer
- Beam lifetime dominated by the Toushek effect

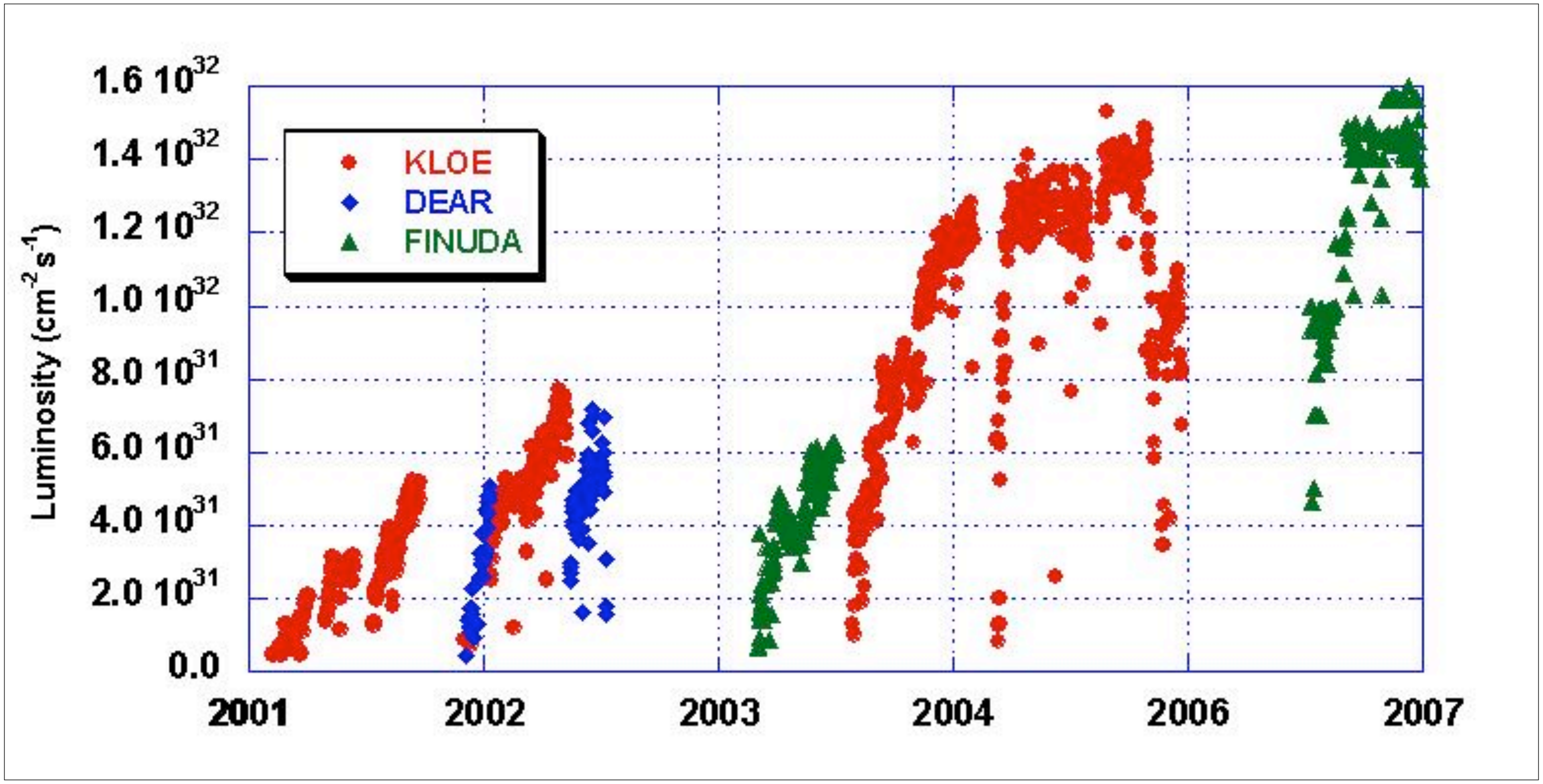




DAΦNE performances

Neutral kaon are used by the **KLOE** experiment to study
CP, CPT, rare decays

Charged kaons are used by:
FINUDA to produce Hypernuclei
DEAR (next **SIDDHARTA**) for exotic atom research



- ✓ Despite the horizontal crossing angle the bunches experience 24 Long Range Beam Beam (LRBB) interactions or Parasitic Crossings (PCs) in the main IR until they are separated by splitter magnets into two different rings.

- ✓ LRBB in unused IR are negligible if a large separation is applied

- ✓ Effects of the PCs on the beam dynamics:

  - orbit distortion, that can be reproduced by simulation codes including PCs
  - beam lifetime reduction during and soon after injection with a consequent limitation in the maximum storable current and in the integrated luminosity.

Looking for LRBB interaction compensation scheme wire have been installed both ends of the IRs revising an idea proposed for LHC

DAΦNE parameters during KLOE runs

(Nov 2005 ÷ Feb 2006)

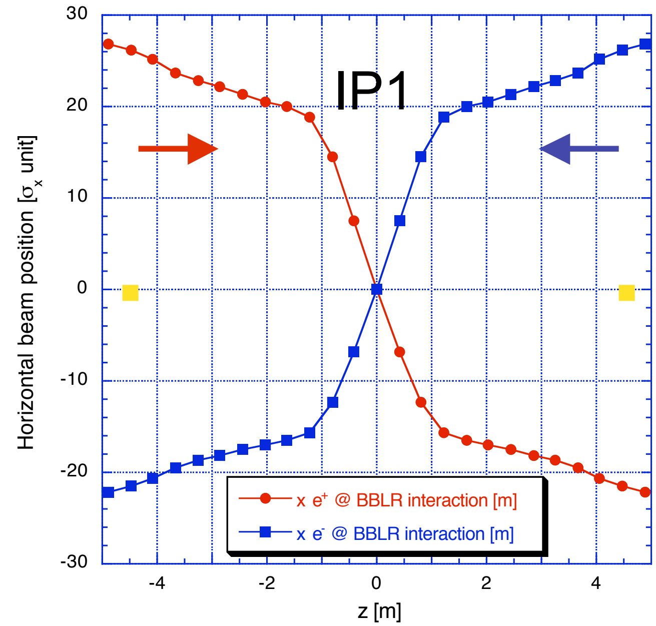
Number of colliding bunches	$\mathbf{n_{bunches}}$	**= 105 ÷ 111 (maximum 120)**
Bunch separation	$\mathbf{\Delta z}$	**= 2.7 ns**
Total average e^- current in collision	I^-_{total}	= 1.8 ÷ 2.2 A
Total average e^+ current in collision	I^+_{total}	= 1.3 ÷ 1.4 A
Horizontal crossing angle in IR1	$\boldsymbol{\theta}$	**= 14.5 mrd**
Vertical separation in IR2	$\mathbf{\Delta y}$	**= 200 σ_y**
Peak luminosity	L_{peak}	~ $1.5 \times 10^{32}\ cm^{-2}\ s^{-1}$
Maximum daily integrated luminosity	$L_{\int day}$	~ $10\ pb^{-1}$
Total delivered luminosity	$L_{\int KLOE\ run}$	= $2\ fb^{-1}$ (May 2004 ÷ Nov 2005)

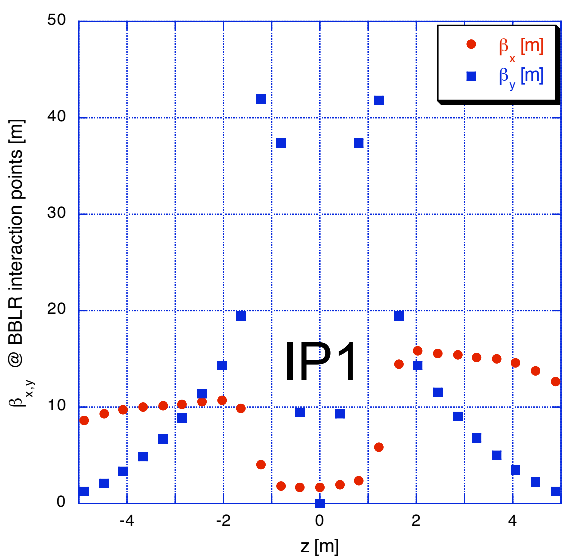
Parasitic Crossings in the DAΦNE IR1

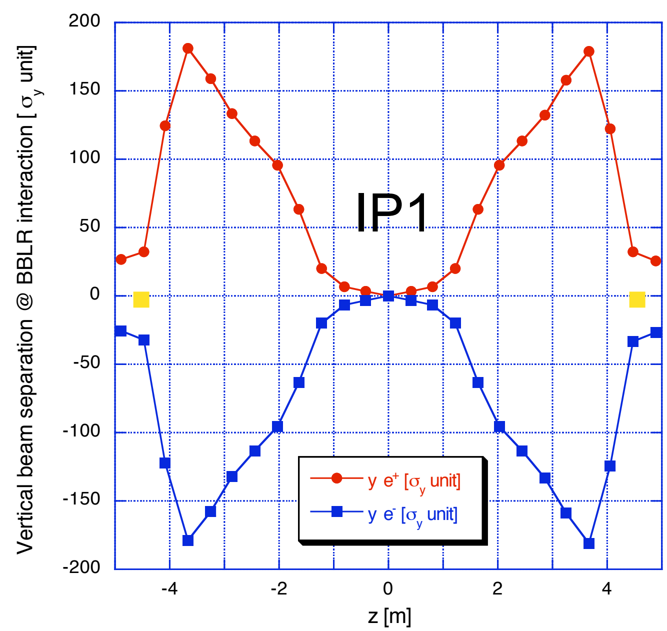
In the DAΦNE IRs the beams experience 24 Long Range Beam Beam interactions

Parameters for the Pcs, one every four, in IR1.

PC order	$Z-Z_{IP}$ [m]	β_x [m]	β_y [m]	$\mu_x-\mu_{IP}$	X [σ_x]	Y [σ_y]
BB12L	-4.884	8.599	1.210	0.167230	26.9050	26.238
BB8L	-3.256	10.177	6.710	0.140340	22.8540	159.05
BB4L	-1.628	9.819	19.416	0.115570	19.9720	63.176
BB1L	-0.407	1.639	9.426	0.038993	7.5209	3.5649
IP1	0.000	1.709	0.018	0.000000	0.0000	0.0000
BB1S	0.407	1.966	9.381	0.035538	-6.8666	3.5734
BB4S	1.628	14.447	19.404	0.092140	-16.4650	63.196
BB8S	3.256	15.194	6.823	0.108810	-18.7050	157.74
BB12S	4.884	12.647	1.281	0.126920	-22.1880	25.505

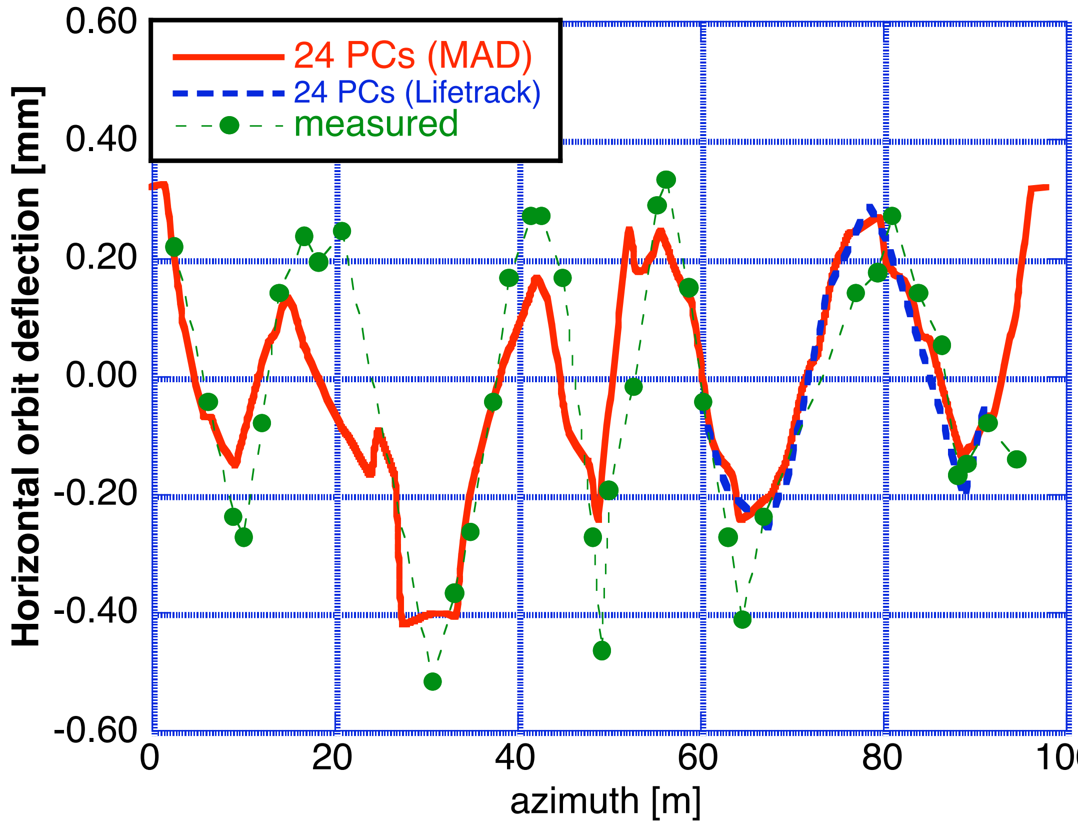




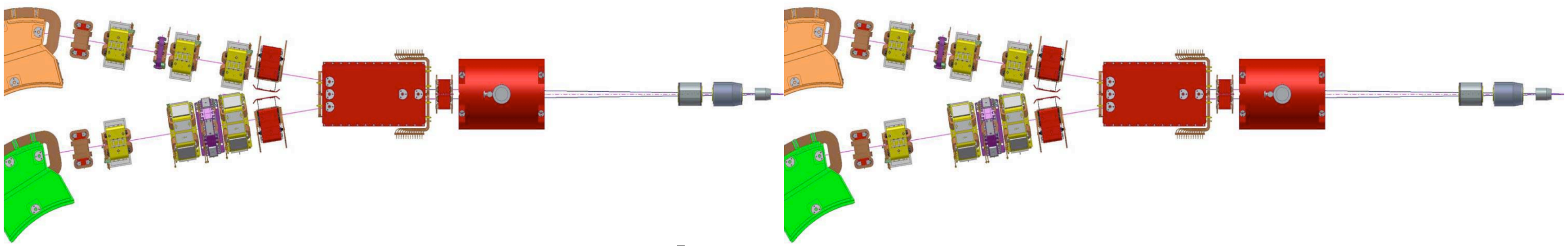


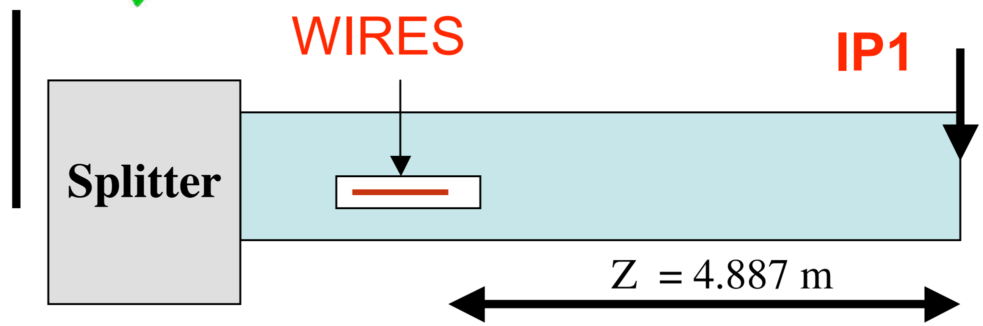
Orbit distortion due to LRBB interaction in IR1

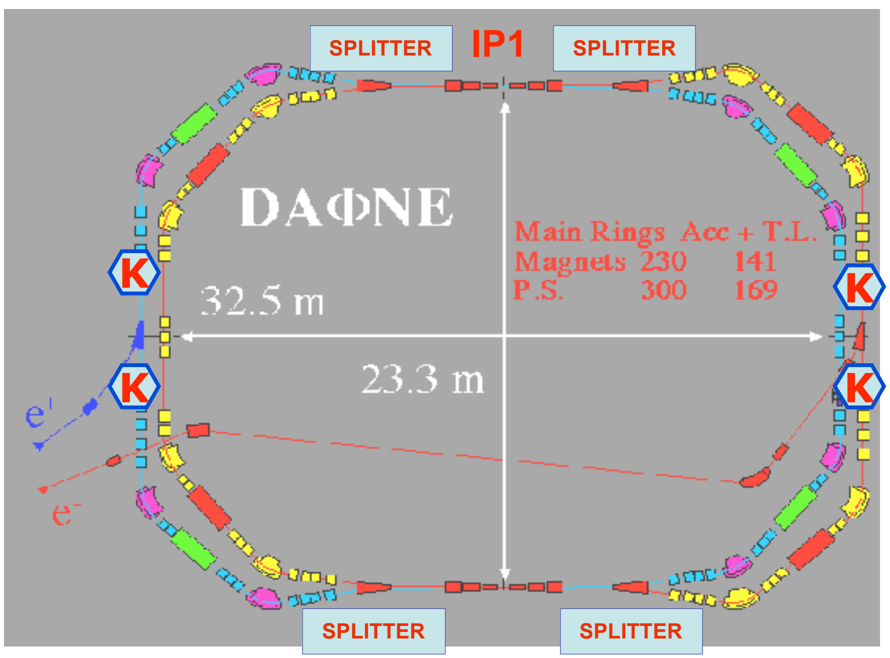
computed orbit deflection due to 24 LRBB interactions for the positron bunch colliding against 10 mA electron bunches.



KLOE IR1

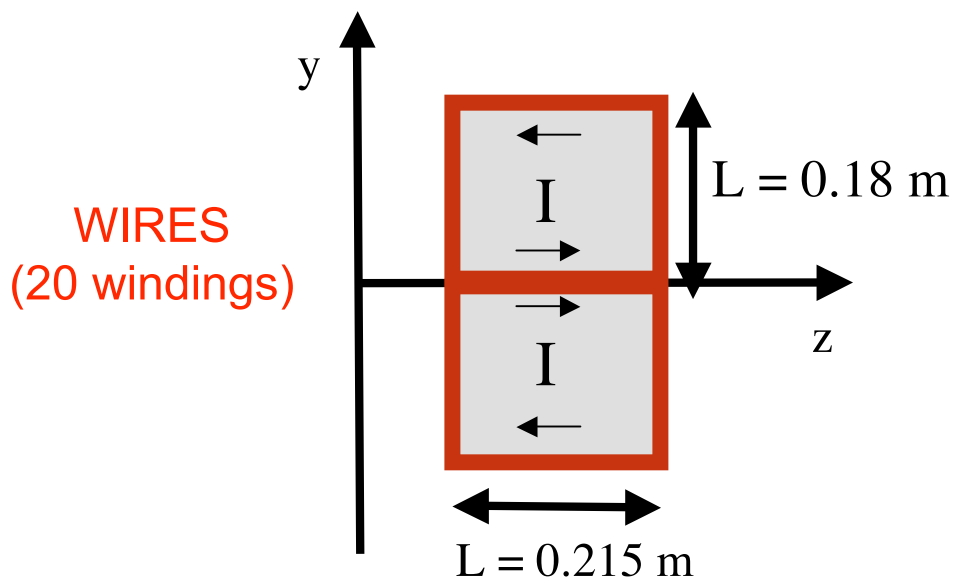




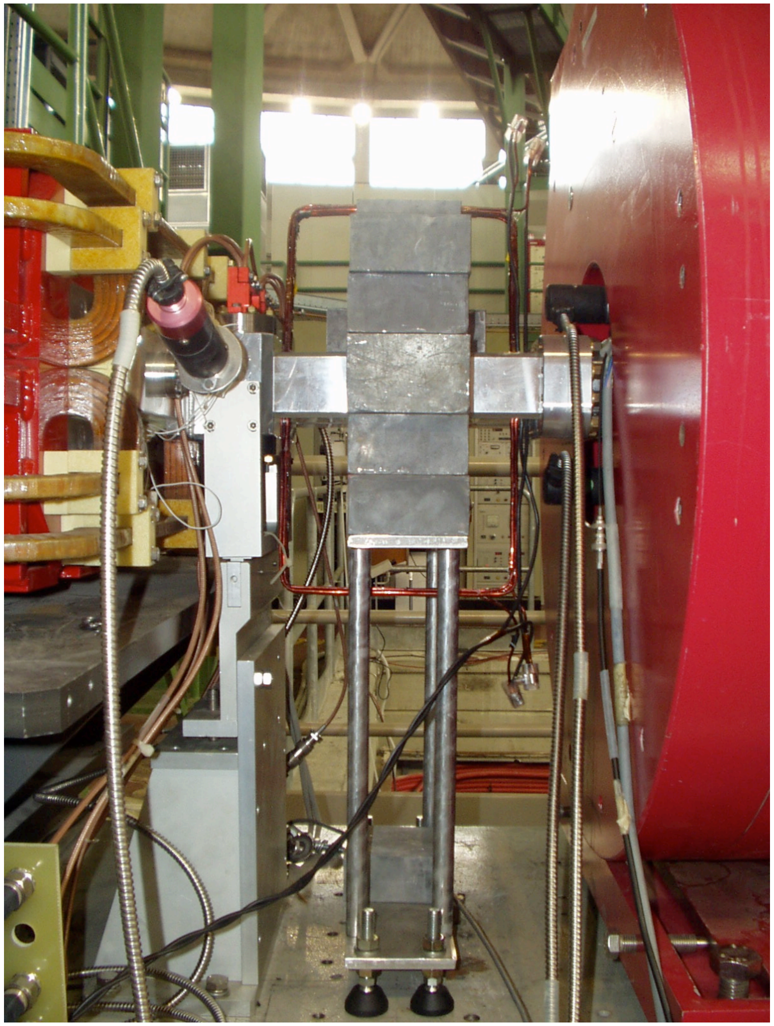


- ✓ The wires are installed outside the vacuum chamber using of a short section in IR1, just before the splitters, where the vacuum pipes are separated.
- ✓ The wires carry a tunable DC current, and produce a stationary magnetic field (1/r) with a shape similar to the one created by the opposite beam

The wires have been built and installed in IR1 in November 2005.
Each device is made of two rectangular coils, 20 windings each, installed symmetrically with respect to the horizontal plane.



The wires installed on one side of the IR1 between the splitter magnet (left) and the compensator solenoid (right)



Numerical simulations show that BBLR interactions can be compensated by current windings (WIRES)

The weak-strong Lifetrack code was used to simulate the equilibrium distribution of the positron (weak) beam

The wires were simulated as additional PCs ('wire-PC') because the $\beta_{x,y}$ functions at the wire locations (β_x=16.5 m, β_y = 4 m) are:

- much larger than both the bunch and wire lengths
- rather small to have a large separation in units of the transverse beam size (≈20), so the actual 'shape of wire' does not matter and it works like a simple 1/r lens.

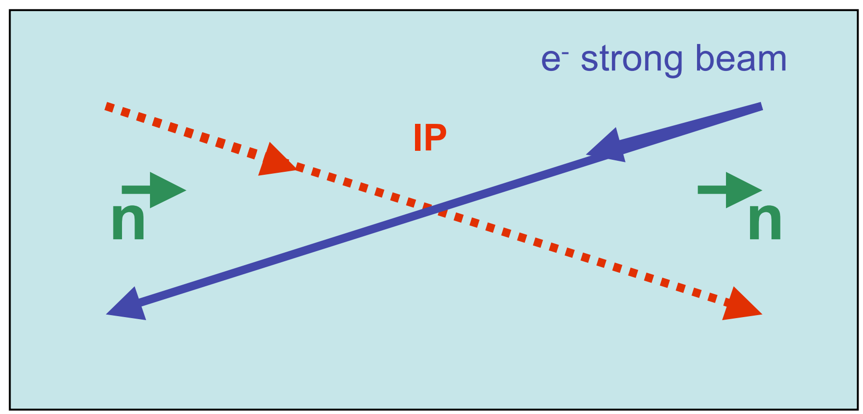
Simulation results have shown:

- the computed tails growth due to PCs for a 'weak' e^+ beam colliding against a 'strong' e^- beam (I^-_{bunch} = 10 mA) is quite relevant
- switching on the wires with the proper polarity the tails shrink
- powering the wires with the wrong polarity, the tails blow-up becomes even stronger.

The PCs compensation with a single wire on each side of the IR is not perfect since distances between the beams at PC locations are different in terms of the horizontal sigma and phase advances between PCs and wires are not completely compensated.

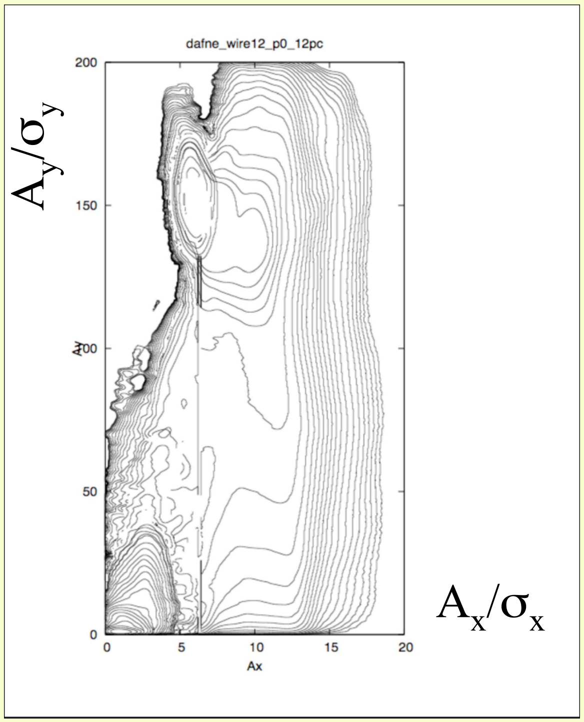
Numerical simulations did not show improvements in luminosity the only positive effect is the tails reduction leading to a longer lifetime and to a larger integrated luminosity.

1. Simulations take into account 1 IP and 24 PCs
2. Tails are much shorter for the compesating “nn” wires polarity
3. The wires seem to compensate each other when they have opposite polarities “pn” or “np”
4. The tails explode with the wrong wires polarity “pp”
5. The best wire intensity correspond to the “6 equivalent PC” compensation
(1 equivalent PC compensation = intensity necessary to compensate the only first PC)

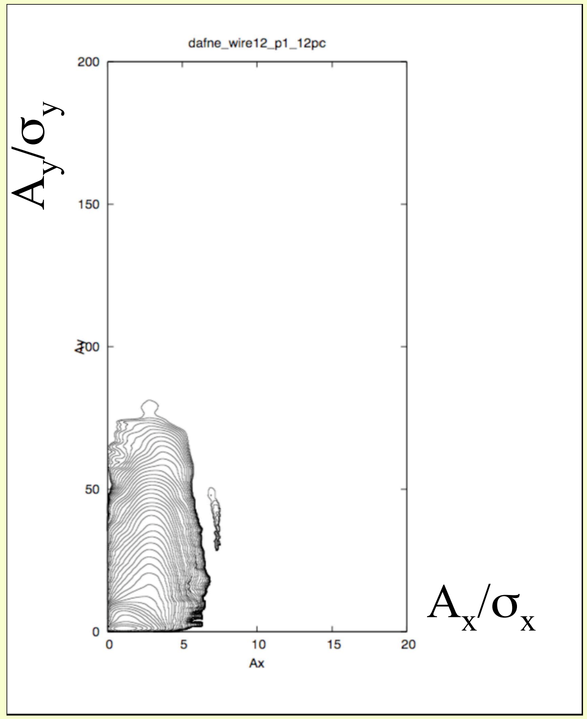


RESULTS from LIFETRACK

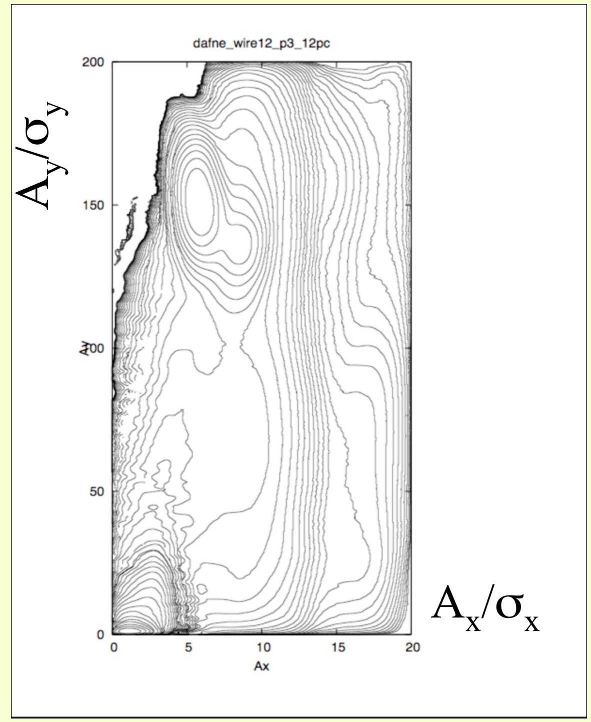
$A_{x,y}$ are the particle equilibrium density in the transverse space of normalized betatron amplitude



Wires OFF

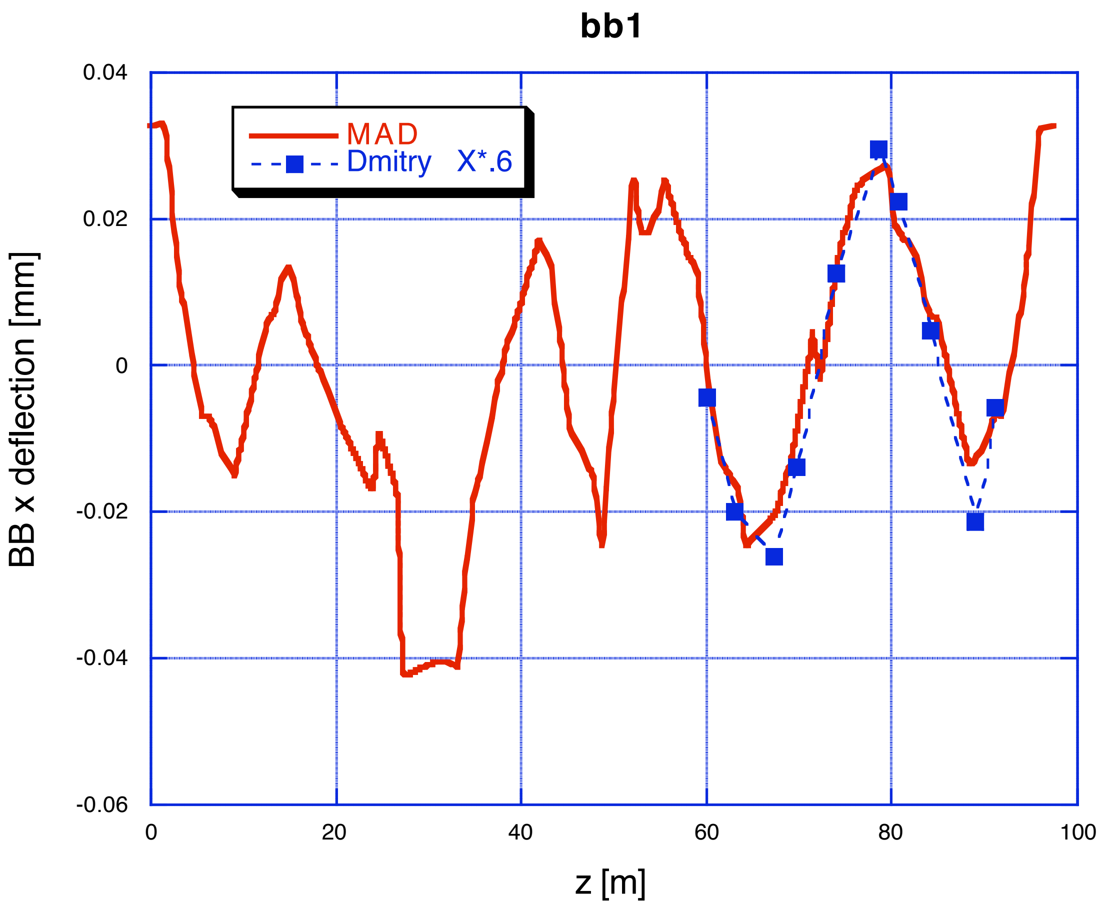


Wires ON



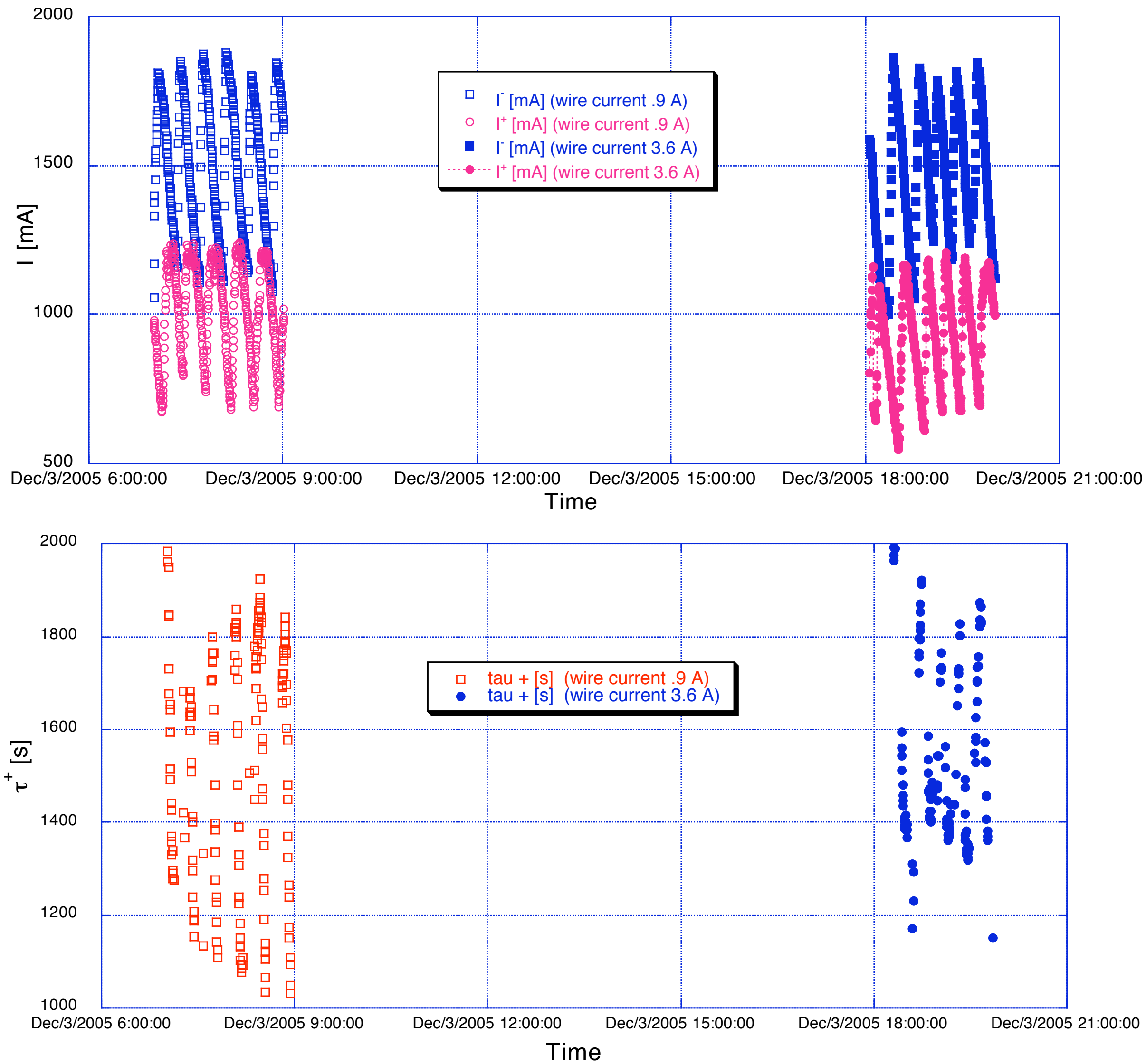
Wires ON (wrong polarity)

Comparison between orbit deflections due to 24 BBLR interactions computed by MAD and by Lifetrack.



Wires have been used to reduce the impact of BBLR interactions

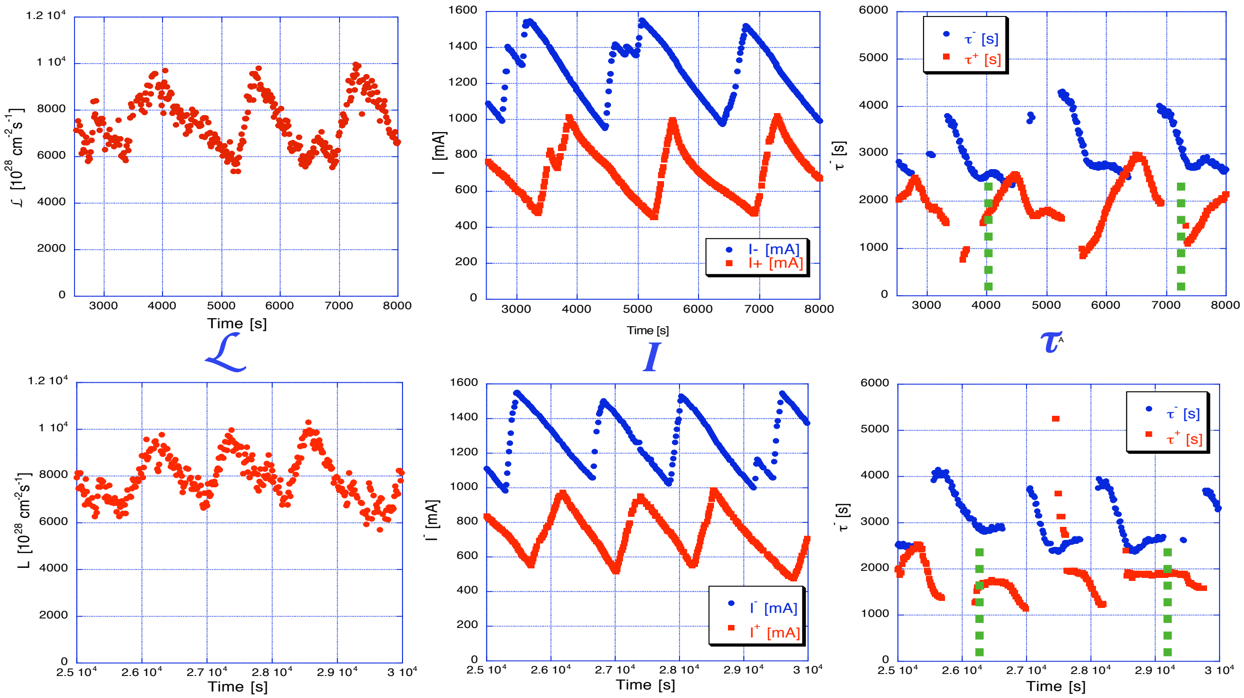
First test (December 2005)



Systematic study (March 2006)

WIRES ON

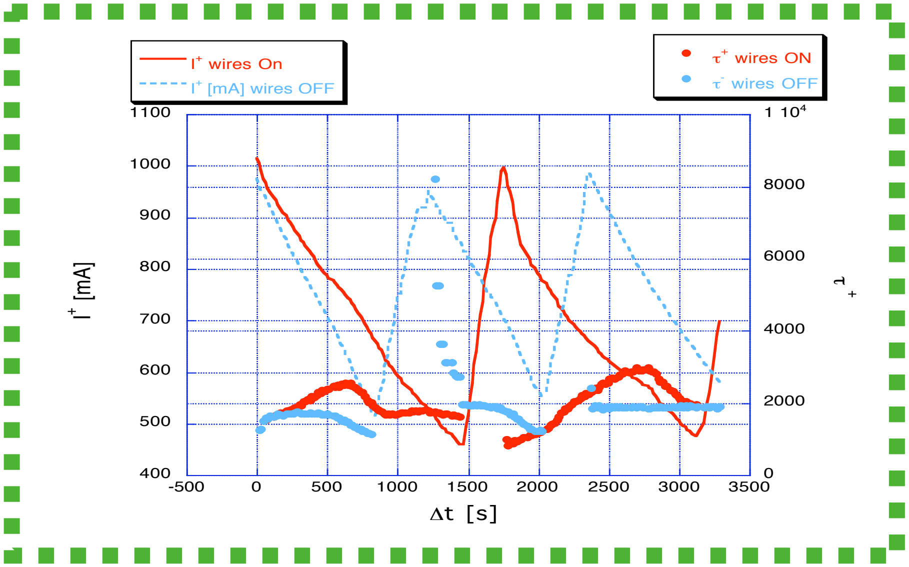
WIRES OFF



Have shown that is possible to improve the lifetime τ^+ of the 'weak' positron beam in collision.

- ✓ Switching on and off the wires we obtain the same luminosity while colliding the same beam currents.
- ✓ The positron lifetime is on average higher when wires are on, while the electron one is almost unaffected.
- ✓ The beam blow-up occurring from time to time at the end of beam injection, corresponding to a sharp increase in the beam lifetime, almost disappear.

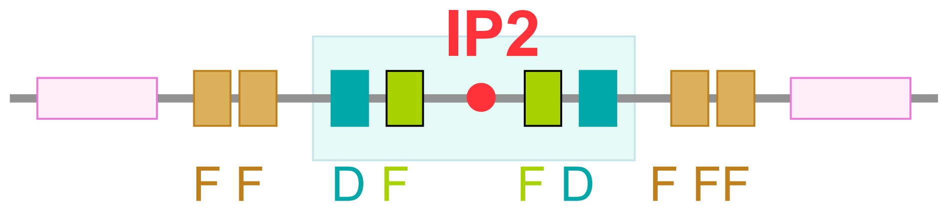
Experimental results (KLOE run)

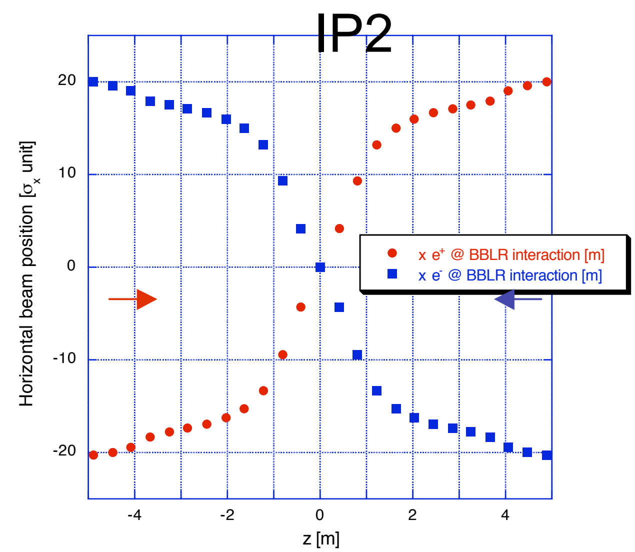


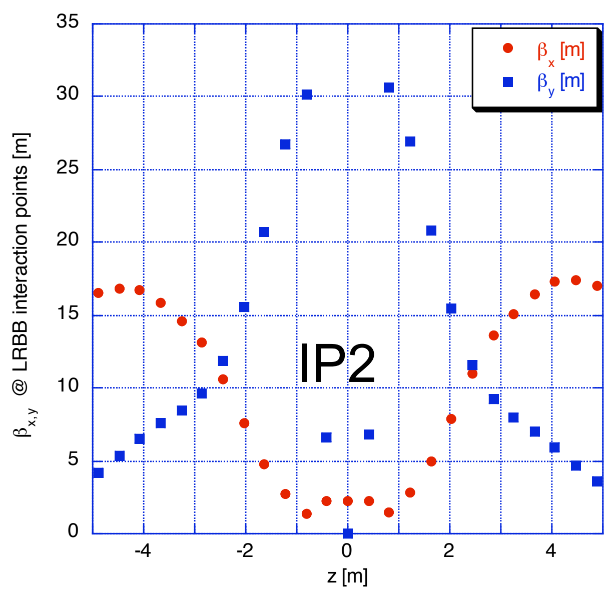
- ✓ It is possible to deliver the same integrated luminosity injecting the beam two times only instead of three in the same time integral, or to increase the integrated luminosity by the same factor keeping the same injection rate.
- ✓ A higher τ means less background on the experimental detector.
- ✓ It is possible to optimize the collision at maximum current

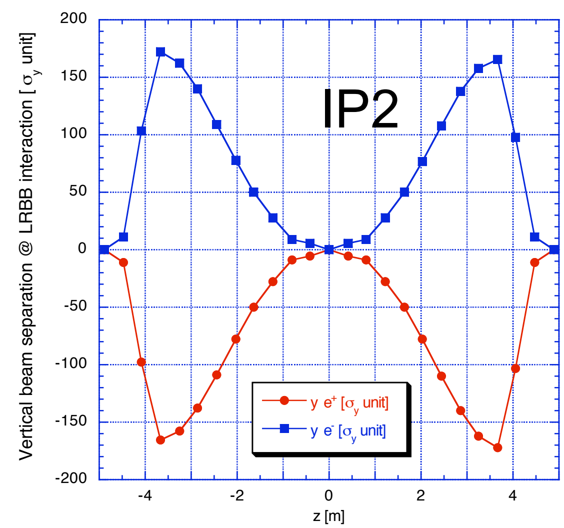
FINUDA run

Energy [GeV]	0.51
Circumference [m]	97.69
RF Frequency [MHz]	368.26
Harmonic Number	120
Damping Time, z/x [ms]	17.8/36.0
Bunch Length [cm]	1÷3
Emittance [mm × mrad]	0.34
Coupling [%]	0.3
β x/y at IP2 [m]	2./0.019
Max. Tune Shifts	.03-.04
Number of Bunches	106
I e-/e+ (MAX) [A]	1.7/1.1









Vertical separation in the detuned IP1 ~ 240 σ_y

Using the wires at IR2 produced few % increase in the τ^+, however the closed orbit distortion due to LRBB interaction, larger than during the KLOE run, remained mainly uncompensated.

A more satisfactory compensation has been obtained by tuning parameters at IP1:

- Halving β_y
- Increasing the vertical separation
- Using the wires installed in IR1

Blow up due to Beam-Beam Parasitic Interaction in IR1

IP2 parameters:

- ε_x = .34 mm mrad
- β^*_x = 2 m
- β^*_y = .019 m
- θ_c = .029 rad (H crossing angle)

β^{IP1}_y

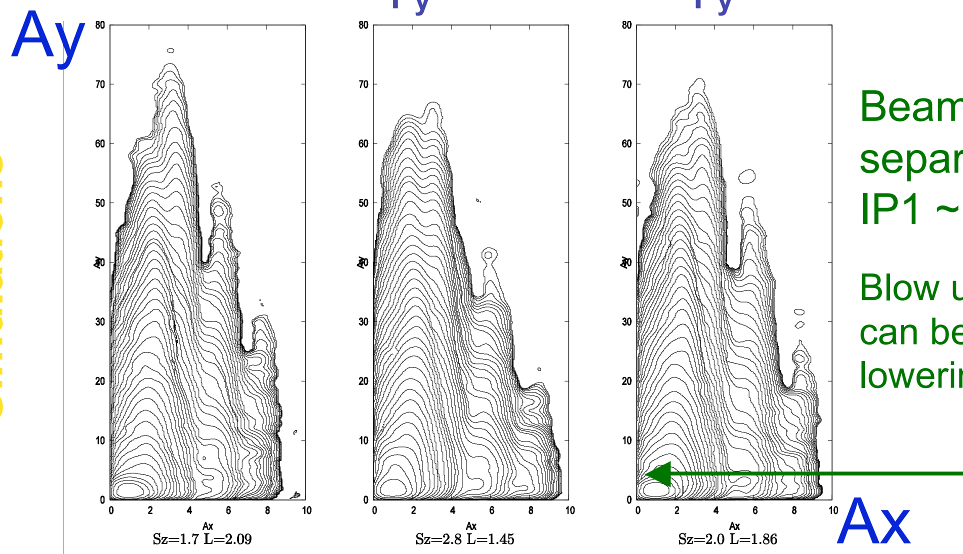
- β^{IP1}_y = 24 m -> 11 m

•tuned in order to trade off between an efficient beam-beam separation and the need to keep under control the blow-up due to LRBB interaction

•Vertical separation in the unused IP ~ 420 σ_y

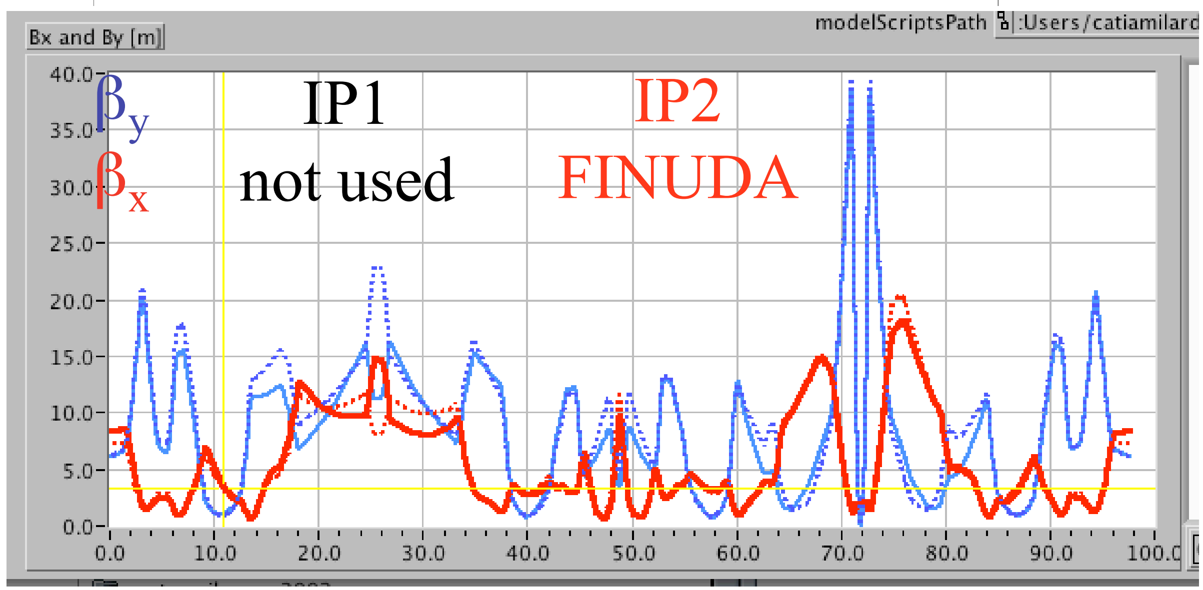
Interaction at | IP2 | IP2 and IP1 β_y^{IP1}= 25 m | IP2 and IP1 β_y^{IP1}= 5 m

Simulations



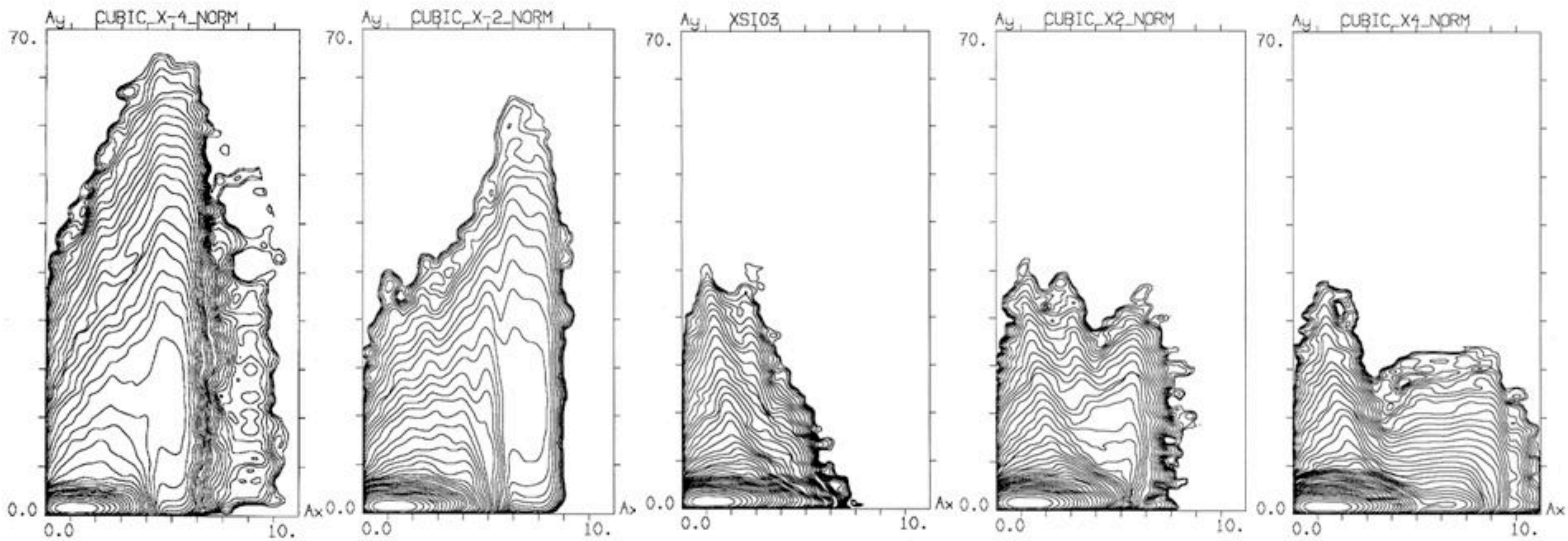
Beam separation at IP1 ~ 2 cm

Blow up reduction can be achieved by lowering β_y at IP1



Crosstalk between beam-beam effects and lattice nonlinearities

Only 1 IP + C_{11}.....

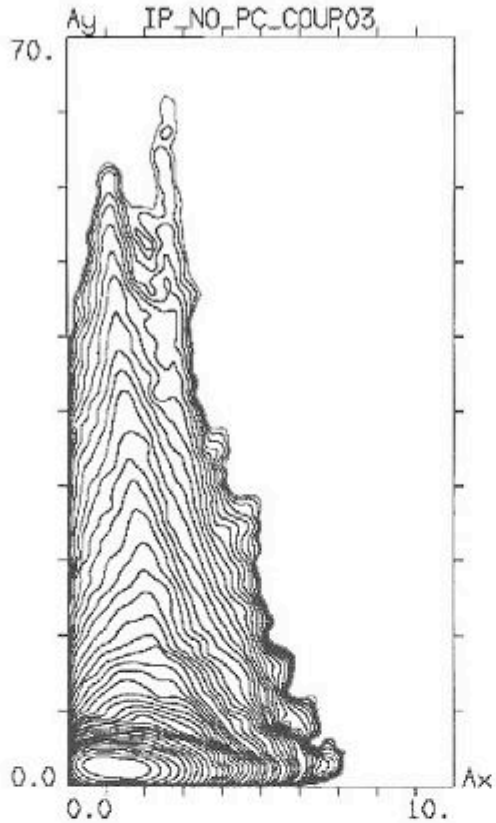


$C_{11} = -400$	$C_{11} = -200$	$C_{11} = 0$	$C_{11} = +200$	$C_{11} = +400$
$\sigma_x/\sigma_{x0} = 1.053$	$\sigma_x/\sigma_{x0} = 1.075$	$\sigma_x/\sigma_{x0} = 1.067$	$\sigma_x/\sigma_{x0} = 1.110$	$\sigma_x/\sigma_{x0} = 1.160$
$\sigma_y/\sigma_{y0} = 1.30$	$\sigma_y/\sigma_{y0} = 1.038$	$\sigma_y/\sigma_{y0} = 1.047$	$\sigma_y/\sigma_{y0} = 1.055$	$\sigma_y/\sigma_{y0} = 1.044$

$|C_{11}| < 200$

1 IP + 2 nearest PC + C_{11}...

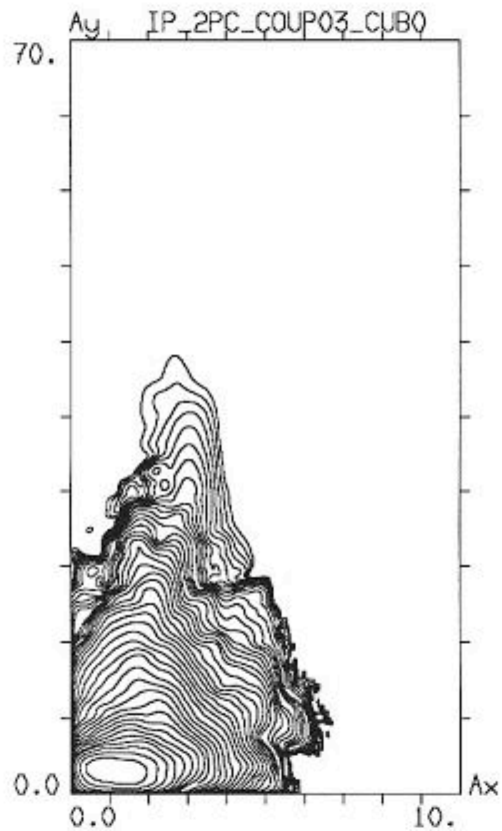
1 IP



a)

$\sigma_x/\sigma_y = 1.076$
$\sigma_y/\sigma_{y0} = 1.449$
$\tau = \infty$

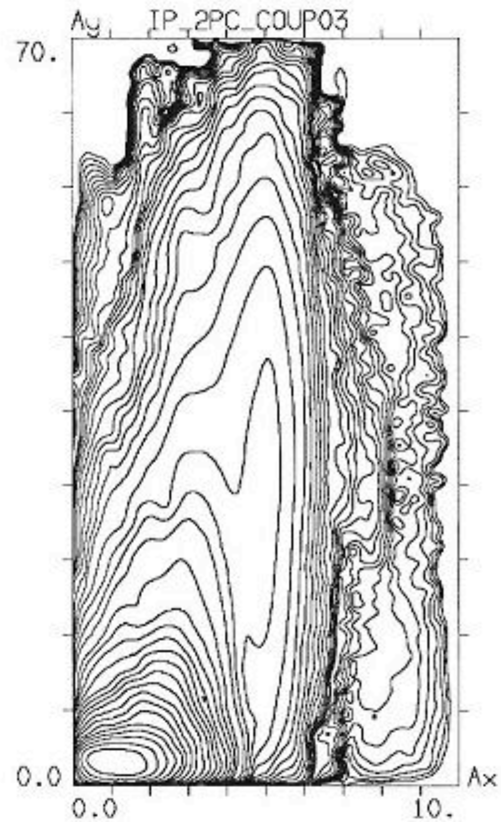
1 IP+ 2 PC



b)

$\sigma_x/\sigma_{x0} = 1.097$
$\sigma_y/\sigma_{y0} = 1.954$
$\tau = \infty$

1 IP + 2 PC + C_{11}



c)

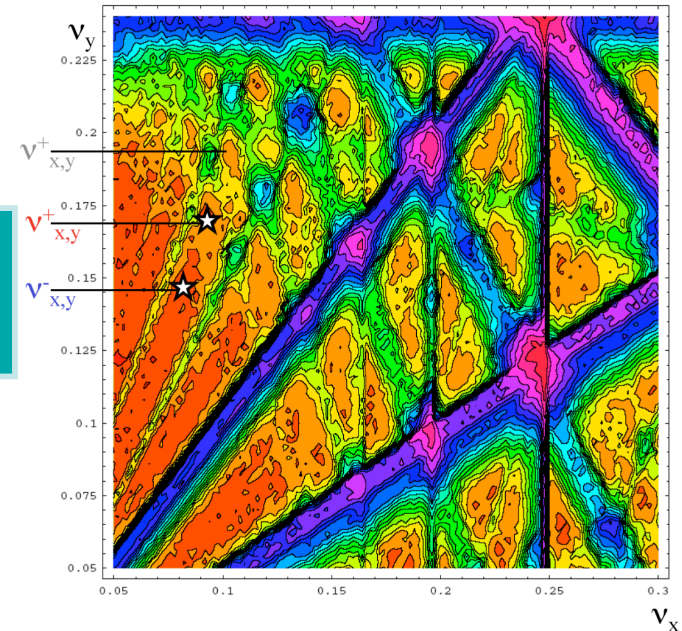
$\sigma_x/\sigma_{x0} = 1.099$
$\sigma_y/\sigma_{y0} = 2.498$
$\tau = 36$ sec

Working point & nonlinearities compensation tuning during FINUDA run (Nov 06 ÷ May 07)

New tunes:
- Improve peak luminosity
- limit beam-beam blow-up at high currents

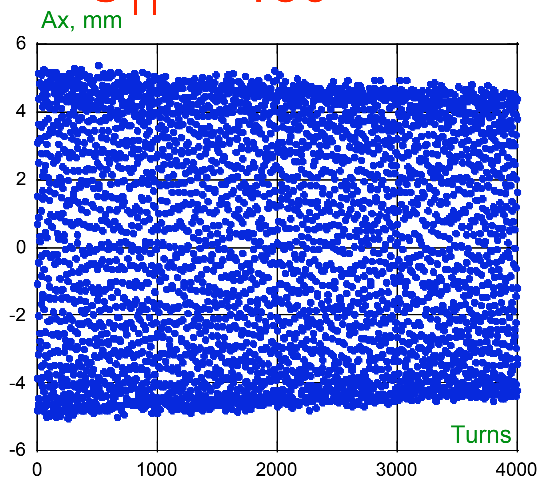
$\nu^-_x = .086 \quad \nu^+_x = .1090$
$\nu^-_y = .1560 \quad \nu^+_y = .1910$

$\nu^-_x = .076 \quad \nu^+_x = .096$
$\nu^-_y = .14 \quad \nu^+_y = .168$



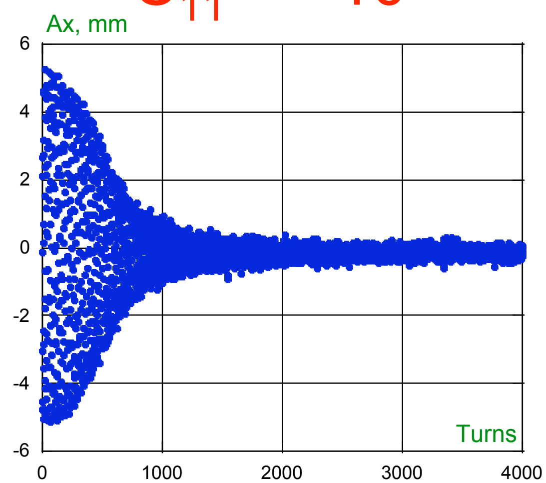
During e^- beam injection
$\Delta\nu^+_{x,y} = 0.0005 \div 0.0015$
$\Delta\kappa^+_3 = 5. \div 15$ A
double the e+ beam llifetime

$C_{11} = -180$



Octupole ON (I =43 A)

$C_{11} = +10$



Octupole OFF

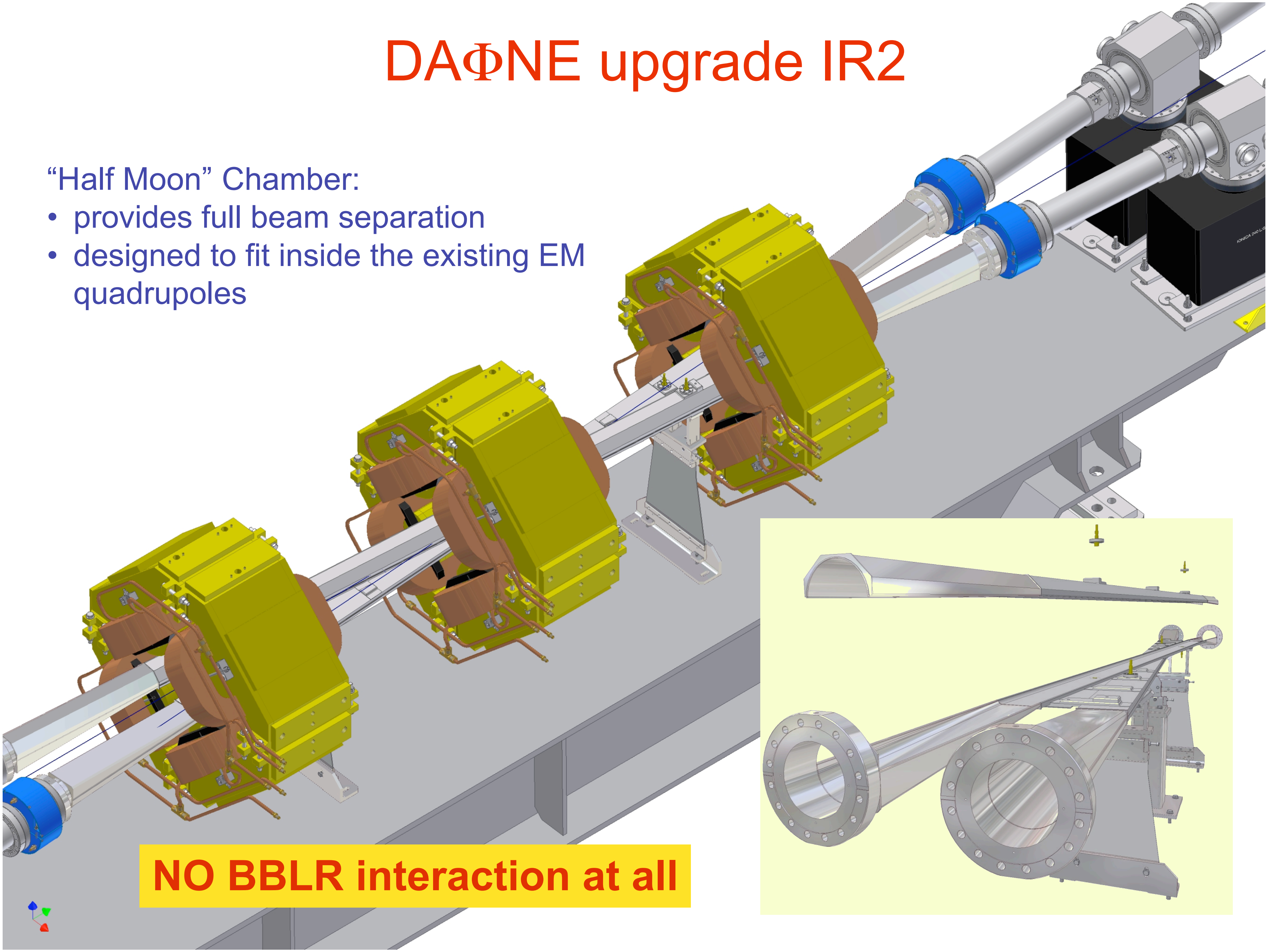
Octupole variation affects:
- c_{11}
- dynamic aperture
- ξ''

26÷28 Feb 07 II FINUDA run

DAΦNE upgrade IR2

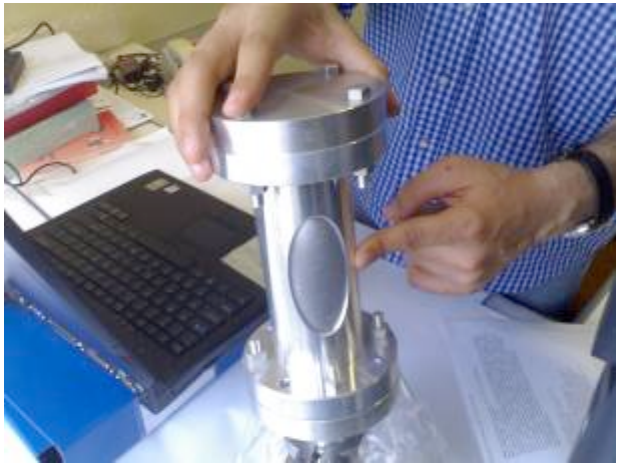
"Half Moon" Chamber:

- provides full beam separation
- designed to fit inside the existing EM quadrupoles

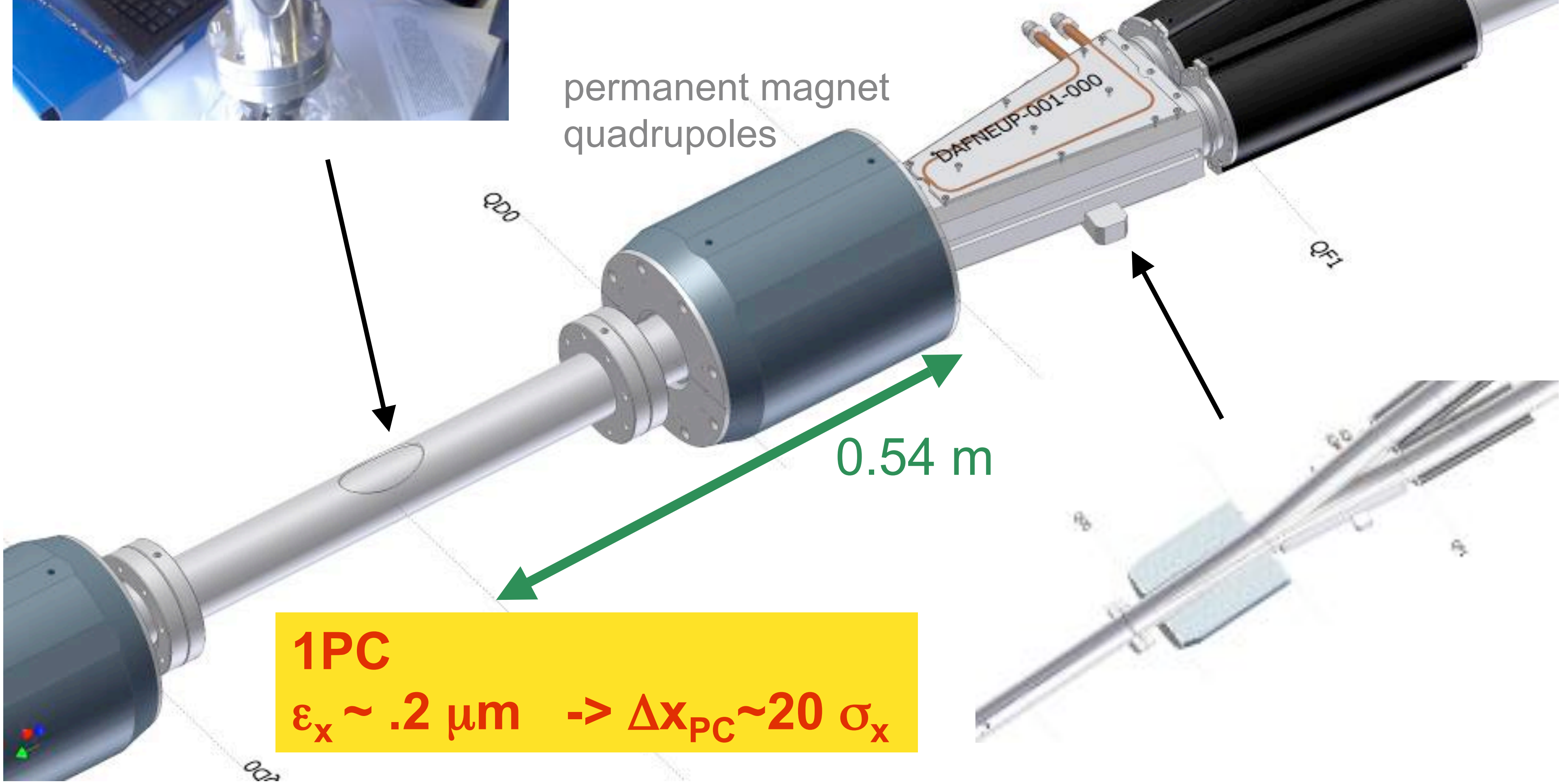


NO BBLR interaction at all

DAΦNE upgrade IR



- Aluminum vacuum chamber
- Thin window thickness= 0.3 mm
- Installation done



1PC

$\varepsilon_x \sim .2\ \mu m$ -> $\Delta x_{PC} \sim 20\ \sigma_x$

Conclusions

Current-carrying wires and octupoles have been used in order to compensate LRBB interactions and the crosstalk between beam-beam effects and lattice nonlinearities.

The PCs effect is expected to be almost negligible after the DAΦNE upgrade, due to application of the crabbed waist scheme with larger crossing angle and smaller horizontal beam sizes at the PCs. Moreover a special vacuum chamber has been designed to eliminate almost all PCs, but the first one, in the main IR.

Weak strong simulation proved to be reliable and very helpful in finding the proper approach to the compensation of nonlinearities coming from LRBB interaction and from the ring lattice