Crab-Waist Performance

Catia Milardi

(on behalf of the DAΦNE Commissioning Team)

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DAΦNE Commissioning Team

D.Alesini, M.E. Biagini, C.Biscari, A. Bocci, 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, Novosibirsk),

S.Bettoni (CERN, Geneva),

Paolo Valente (INFN-Roma, Roma),

Kazuhito Ohmi (KEK, Ibaraki),

D. Teytelman, (SLAC),

Nicolas Arnaud, Dominique Breton, Leonid Burmistrov, Achille Stocchi, Alessandro Variola, Benoit Viaud(LAL, Orsay),

Marco Esposito (Rome University La Sapienza, Roma),

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

Paolo Branchini (University Roma3, Rome)

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- *The new run with the KLOE detector*
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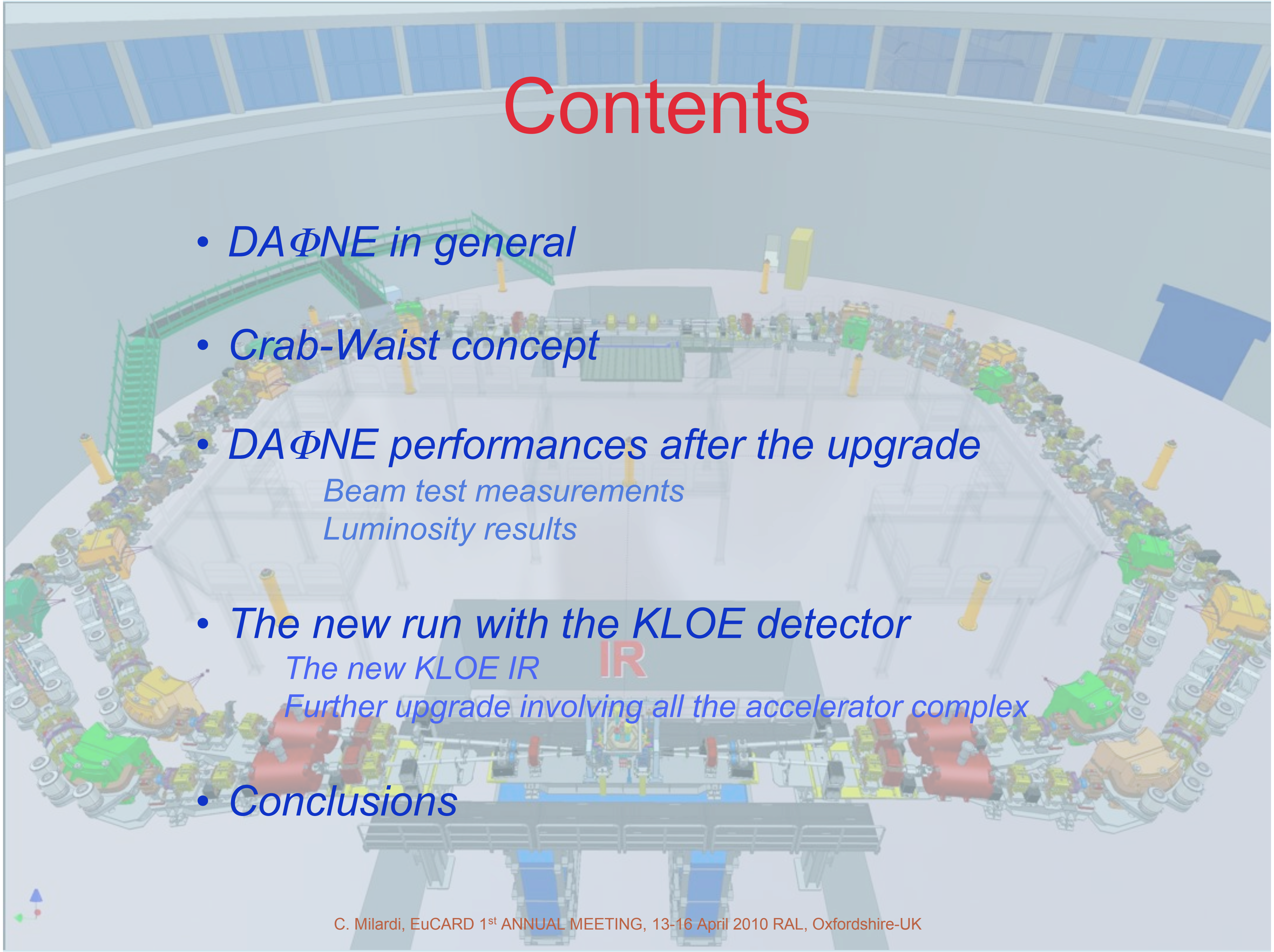
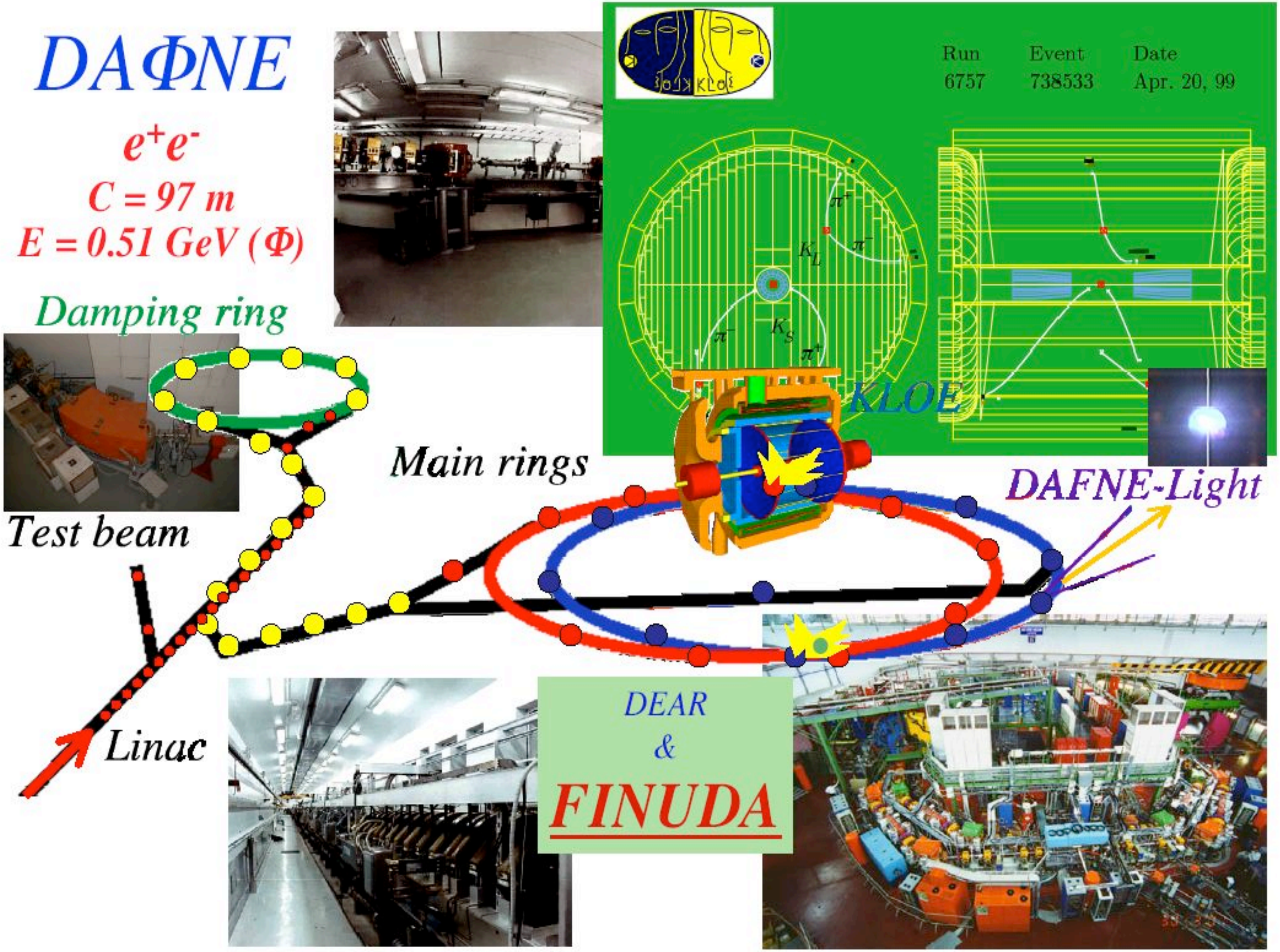
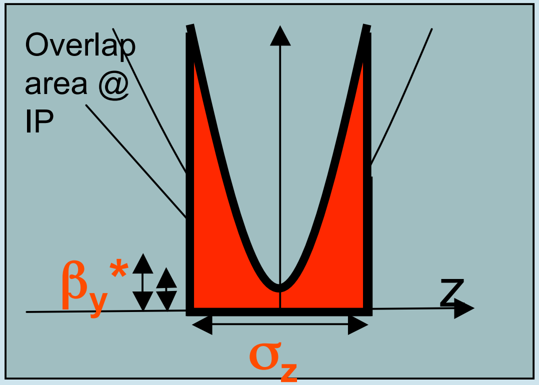
- *Conclusions*



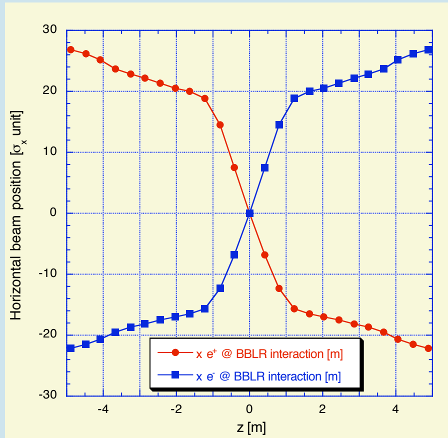

DAΦNE
e+e-
C = 97 m
E = 0.51 GeV (Φ)
Damping ring
Test beam
Main rings
Linac
Run Event Date
6757 738533 Apr. 20, 99
KLOE
DAFNE-Light
DEAR
&
FINUDA

Upgrade Motivations

L_{peak} ~ 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 τ^+ τ^- 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**

Large Piwinski angle

Large Piwinski angle Φ obtained by:

$$\Phi \approx \frac{\sigma_z}{\sigma^*_x}\frac{\theta}{2}$$

small σ_x

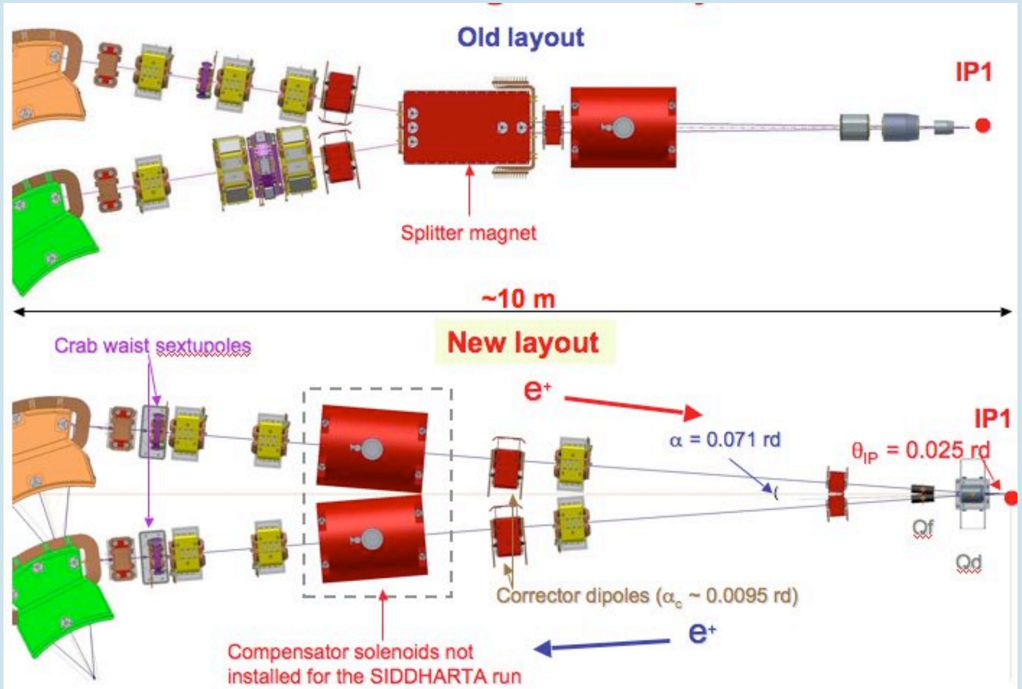
large θ

$$\xi_y \propto \frac{N\sqrt{\beta_y^*}}{\sigma_z\theta} \qquad \xi_x \propto \frac{N}{(\sigma_z\theta)^2} \qquad L \propto \frac{N\xi_y}{\beta_y^*}$$

- low ξ_x
- $L_{geometric}$ gain
- no parasitic crossing

New IR magnetic layout

- splitter magnets and compensator solenoids removed
- New low-β
- Sector dipols around IP rotated
- large collision angle ~ 50 mrd
- four C type corrector dipoles used to mach the vacuum chamber in the arc

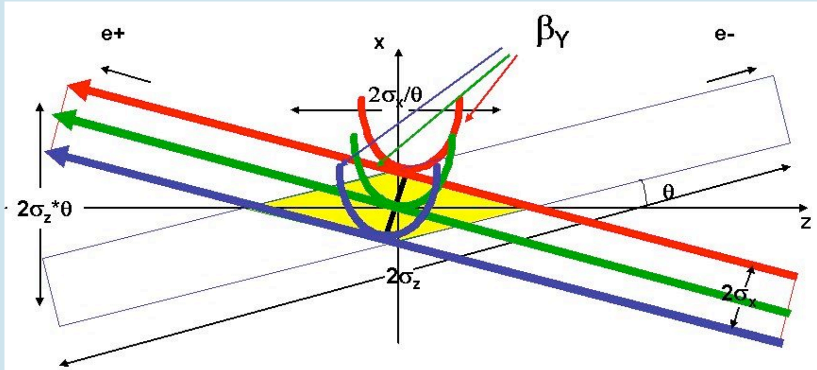


Lower β^*_y possible

Small β_y^* in fact the bunch overlap area Σ is:

$$\Sigma \propto \frac{\sigma_x}{\theta} \qquad \beta_y \propto \frac{\sigma_x}{\theta} << \sigma_z$$

- $L_{geometric}$ gain
- low ζ_y
- Vertical synchro-betatron resonances suppression



New low-β section

•*low-beta* section based on PM QUADs:

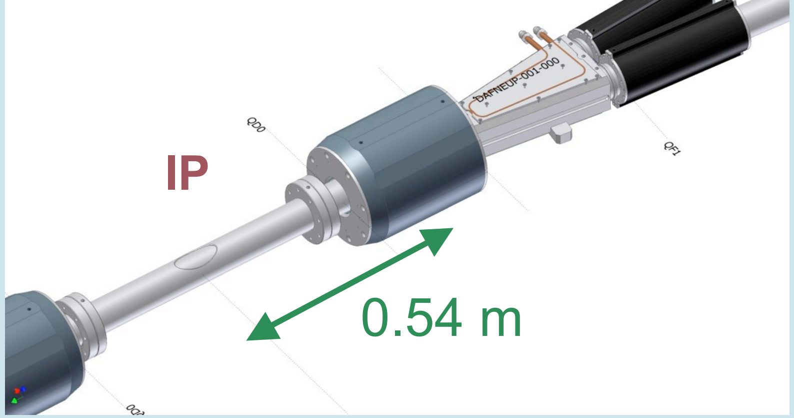
K_{QD} = -29.2 [T/m]

K_{QF} = 12.6 [T/m]

•$e^+ e^-$ vacuum chambers separate after Q_D

Only 1 parasitic crossing

$\varepsilon_x \sim .26\ \mu m \rightarrow \Delta x_{PC} \sim 40\ \sigma_x$



Crab-Waist compensation

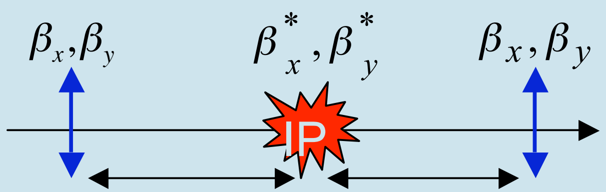
Collision with large θ had already been considered in the past .....

Large θ + Crab-Waist transformation is a new idea *(P.Raimondi et al., 2006)*

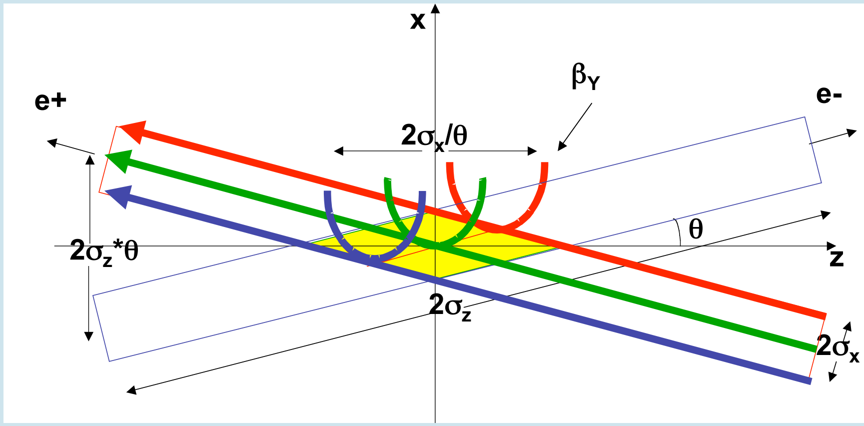
$$y = \frac{xy'}{2\theta}$$

- $L_{geometric}$ gain
- x-y synchro-betatron and betatron resonance suppression

sextupole   anti-sextupole

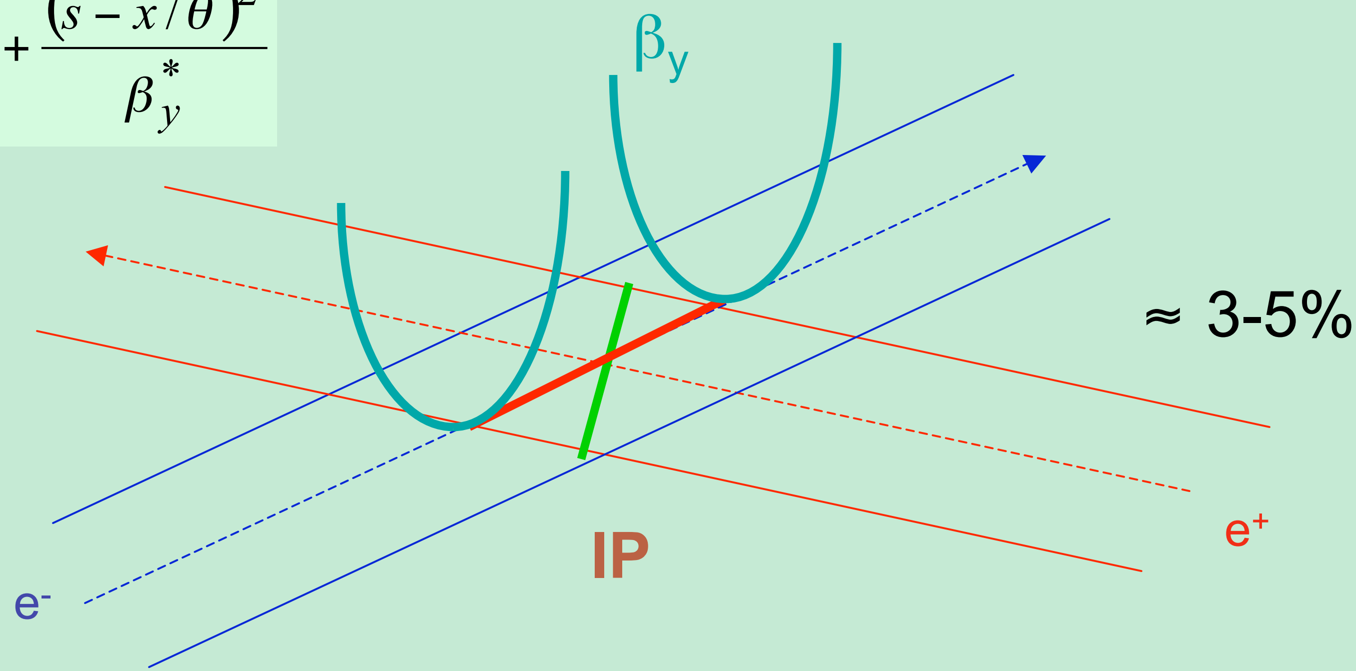


$$\Delta\nu_x = \pi$$
$$\Delta\nu_y = \frac{\pi}{2}$$



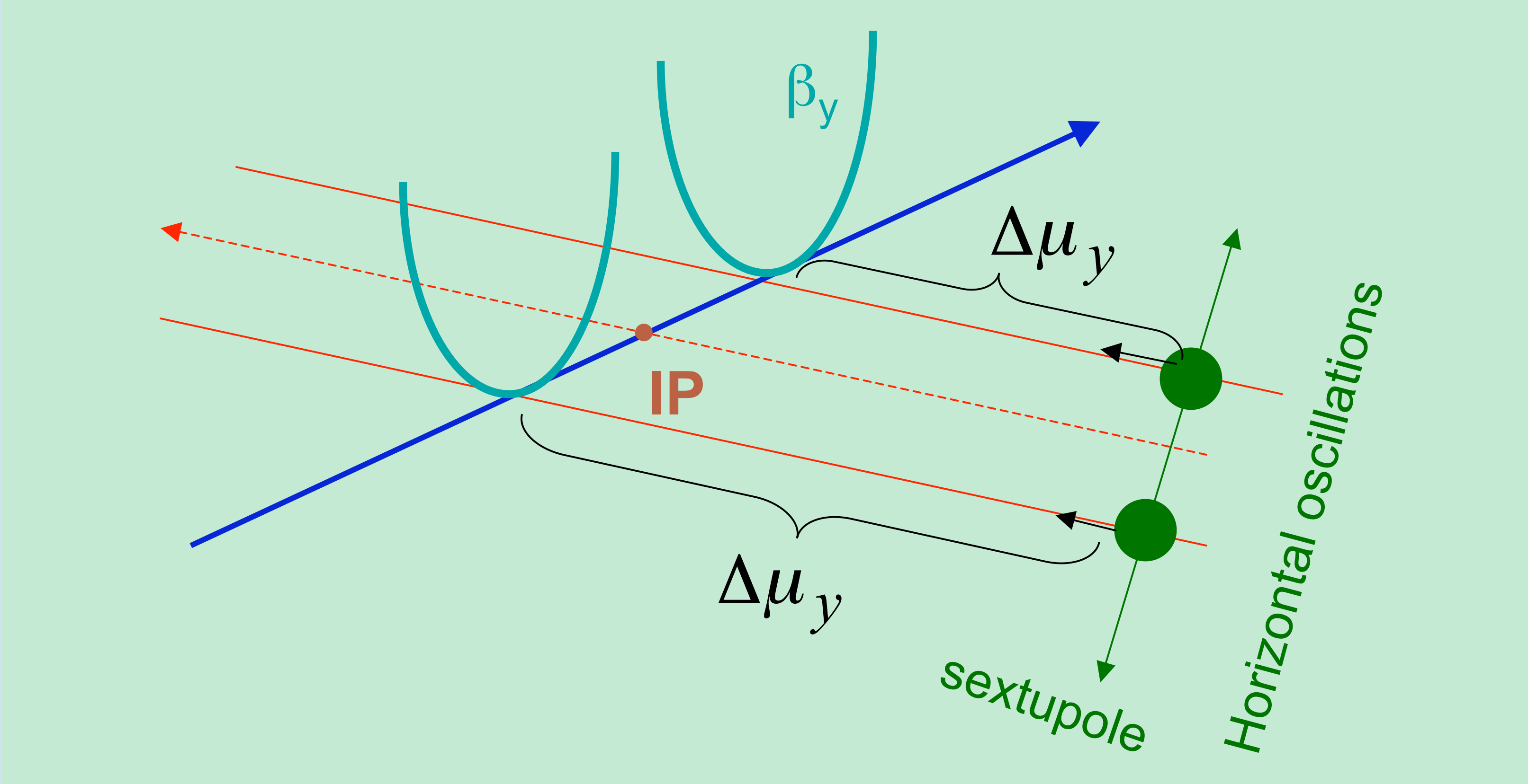
Geometric Factor

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



- Minimum of β_y for e- beam is along the maximum density of the opposite e+ beam;
- The waist length is oriented along the overlap area. The line of the minimum beta with the *Crab-Waist* (red line) is longer than without it (green line).

Suppression of X-Y Resonances



Performing horizontal oscillations:

- Particles see the same density and the same (minimum) vertical beta function
- The vertical phase advance between the sextupole and the collision point remains the same ($\pi/2$)

DAΦNE upgrade

- *In 2007 the DAΦNE accelerator complex has been upgraded in order to implement a new collision scheme based on **large Piwinski angle**, **low–β** and **Crab-Waist compensation** of the synchrobetatron resonances*

- *The upgrade took ~ **five months***

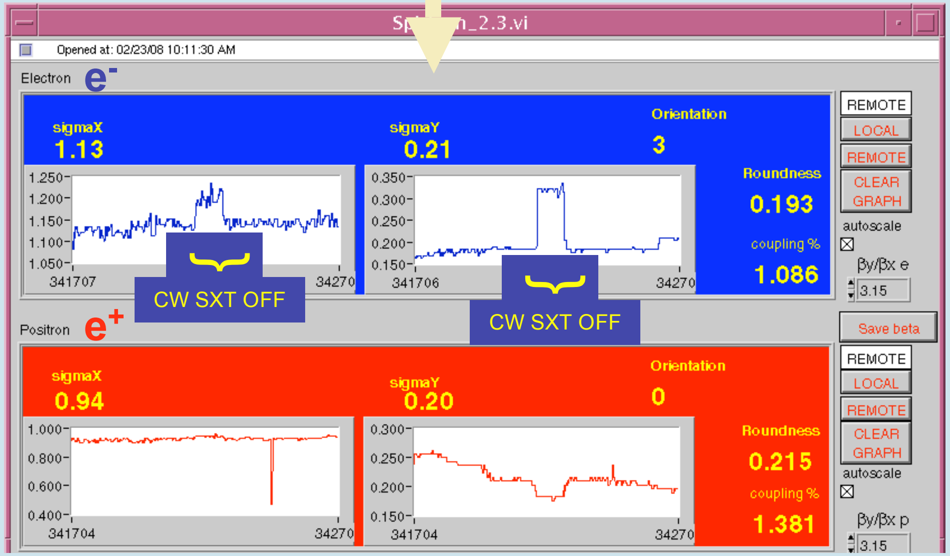
- ***Since May 2008** DAΦNE is delivering luminosity to the SIDDHARTA experiment.*

Beam optics parameters

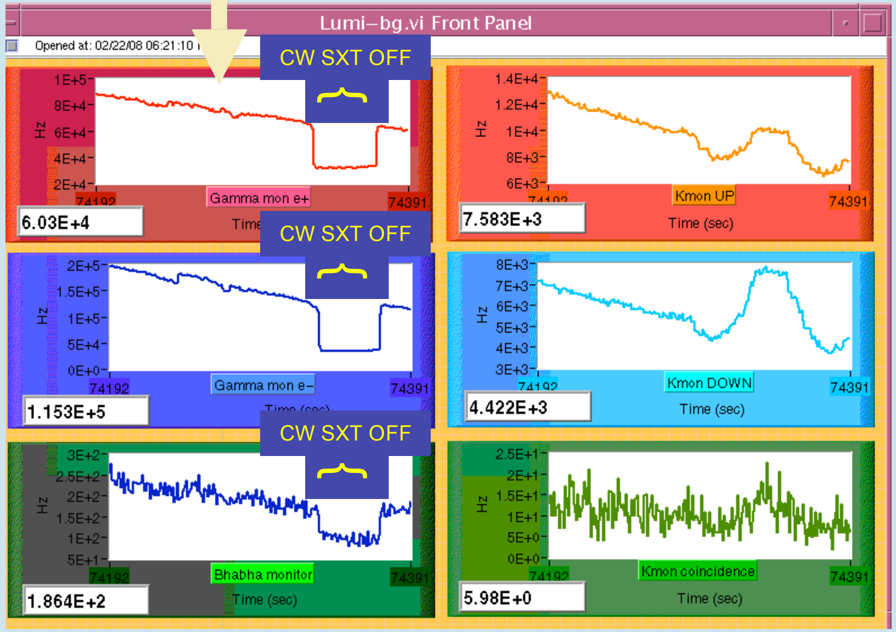
	DAΦNE KOE	DAΦNE Upgrade
$\theta_{cross}/2$ (mrad)	12.5	25
ε_x (mm mrad)	0.34	0.26
β_x^* (cm)	150	26
σ_x^* (mm)	0.70	0.26
$\Phi_{Piwinski}$	0.6	1.9
β_y^* (cm)	1.80	0.9
σ_y^* (μm) low-current	5.4	3.1
Coupling %	0.2÷0.3	0.3
I_{bunch} (mA)	13	>10
σ_z (mm)	25	20
N_{bunch}	111	105
L ($cm^{-2}s^{-1}$) $x10^{32}$	1.6	4.53 (5.)

Crab-Waist compensation first experimental evidence

Beam transverse size measured at the synchrotron light monitor



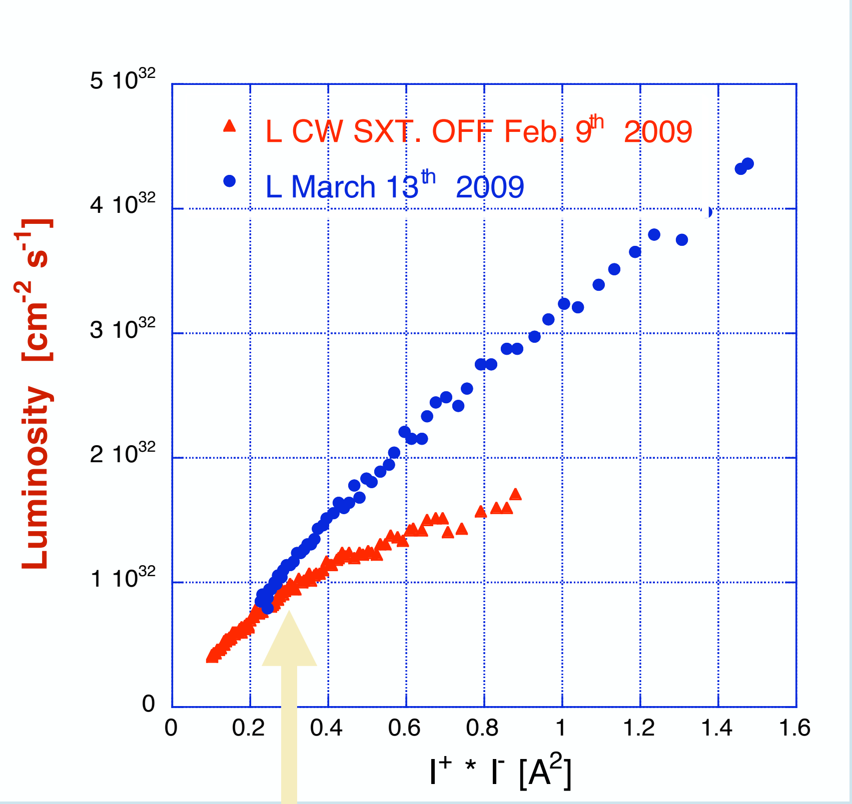
Luminosity measured by 2 different monitors

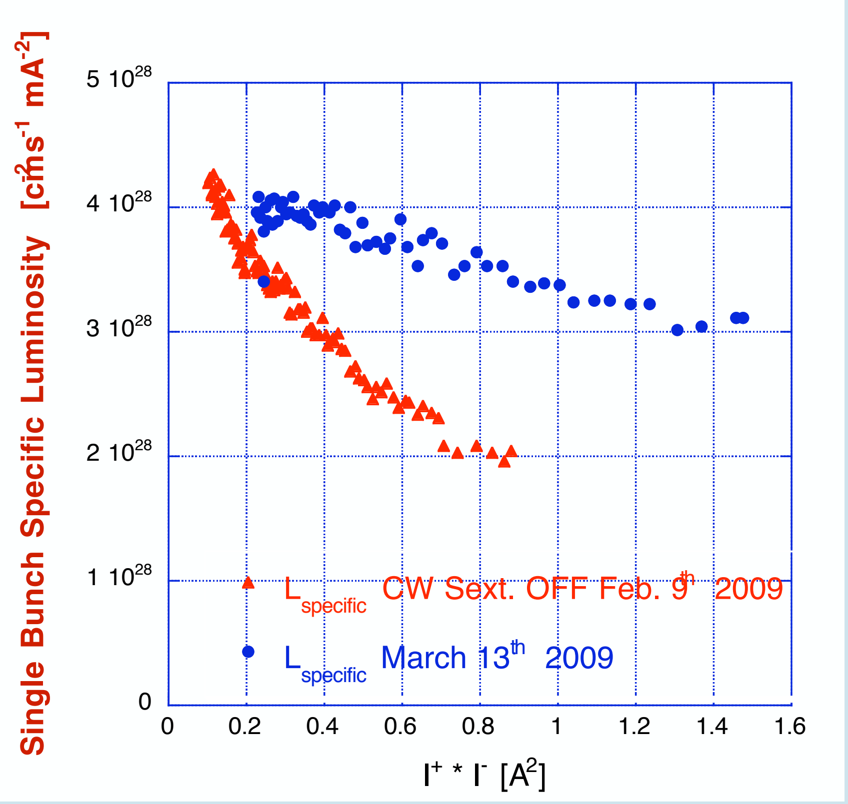


Transverse size (left) and luminosity dependence (right) on the *Crab-Waist* sextupole excitation in the e^- ring

Crab Sextupoles are working since the first time they have been tested

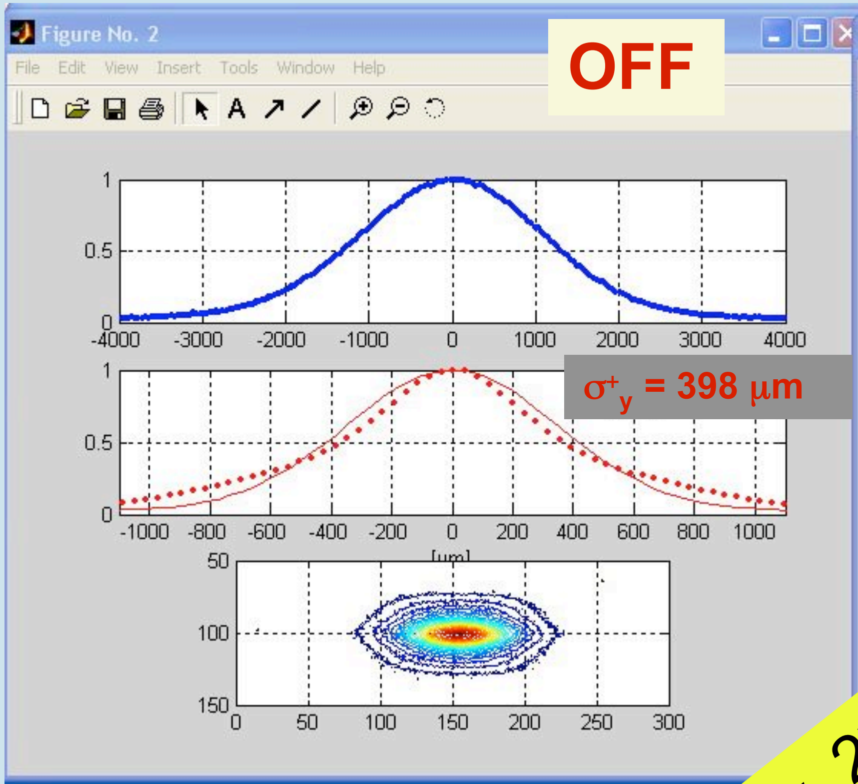
Crab-Waist compensation and luminosity

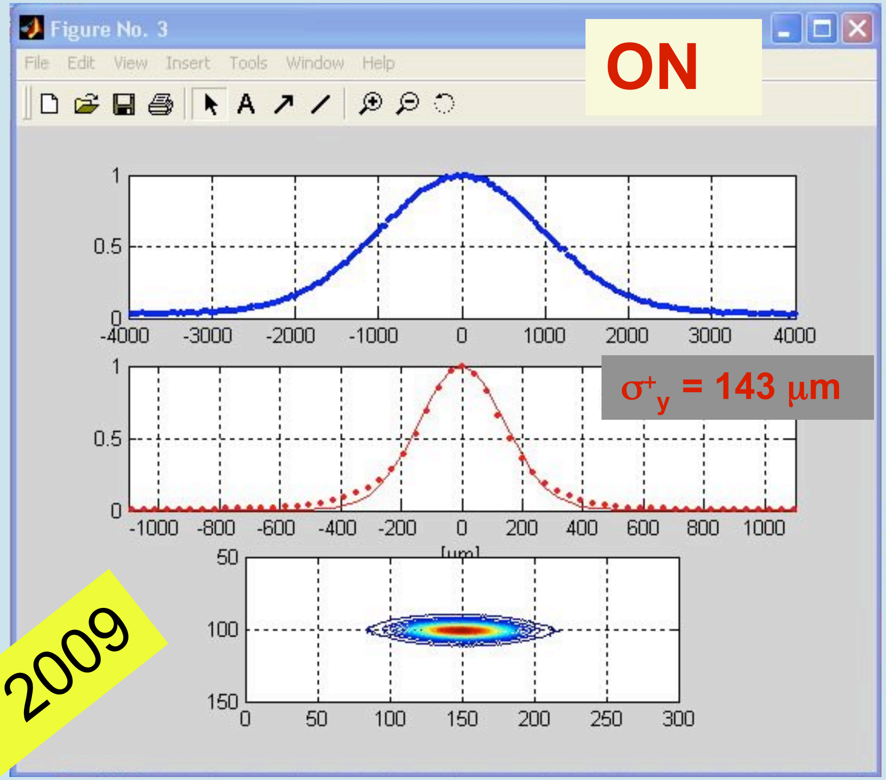




- Transverse beam blow-up
- Lifetime reduction

Transverse Beam profile measurements versus *Crab-Waist SEXTUPOLES*





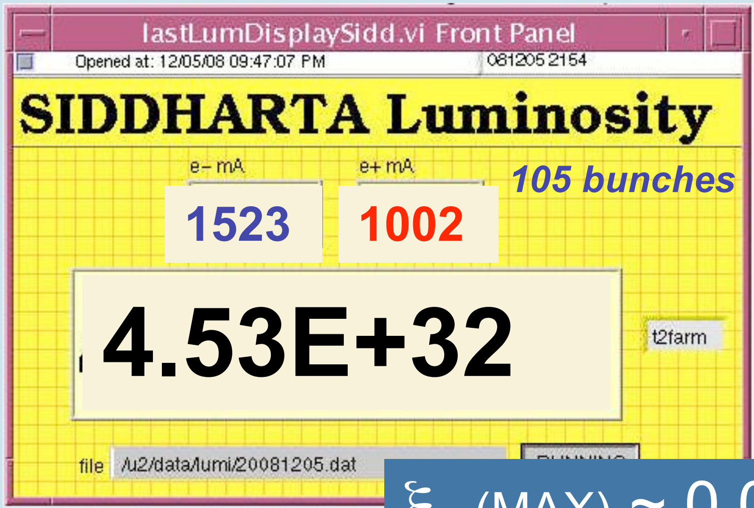
Nov. 2nd 2009

$I^- = 1$ A
$I^+ = 0.09$ A

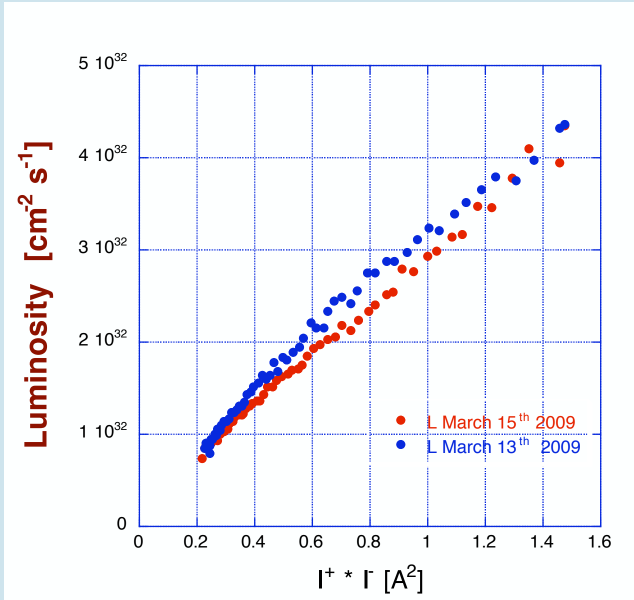
105 colliding bunches

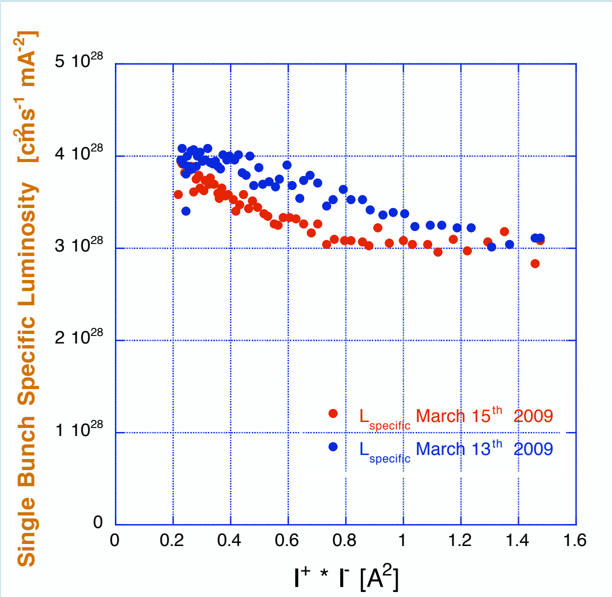
$I^- = 0.8$ A
$I^+ = 0.15$ A

Peak Luminosity



ξ_y (MAX) ~ 0.0443



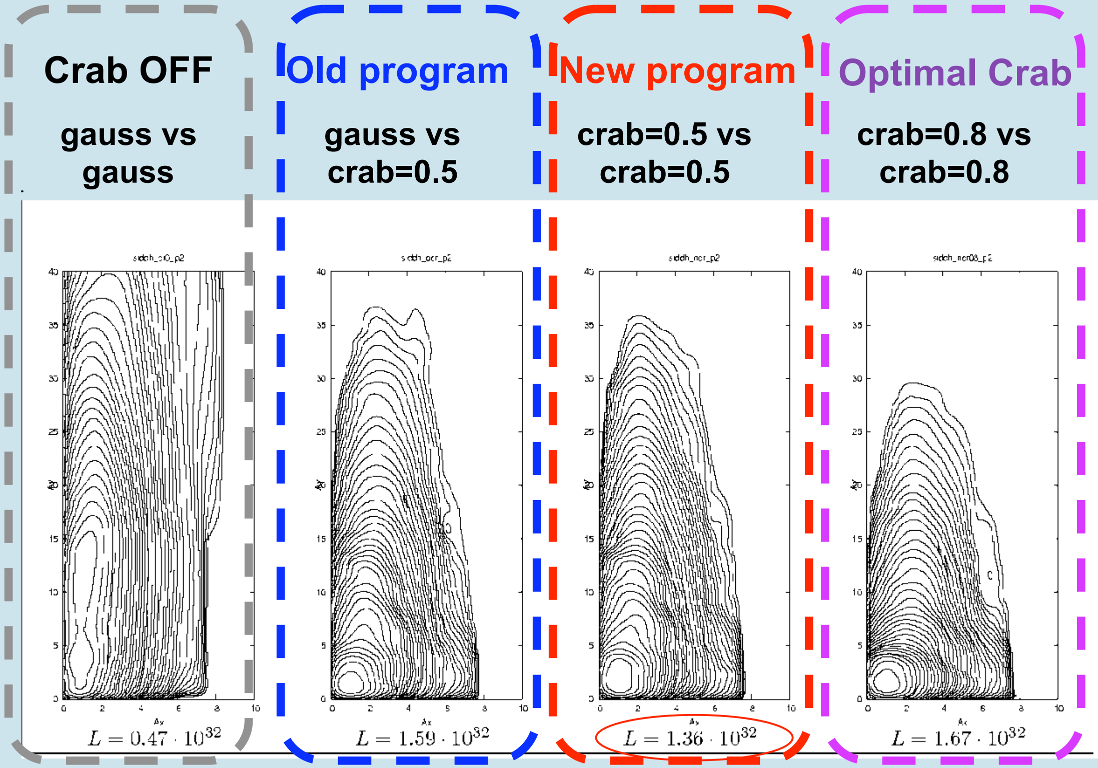


Specific Luminosity:

- Drops with the product of the colliding currents due to:
  - residual beam-beam blow up
  - bunch lengthening
- At low currents is four times higher than without *Crab-Waist*
- The reduction is underestimated since collisions are optimized mainly at high ***I***,
  it has been considerably reduced during the collider commissioning

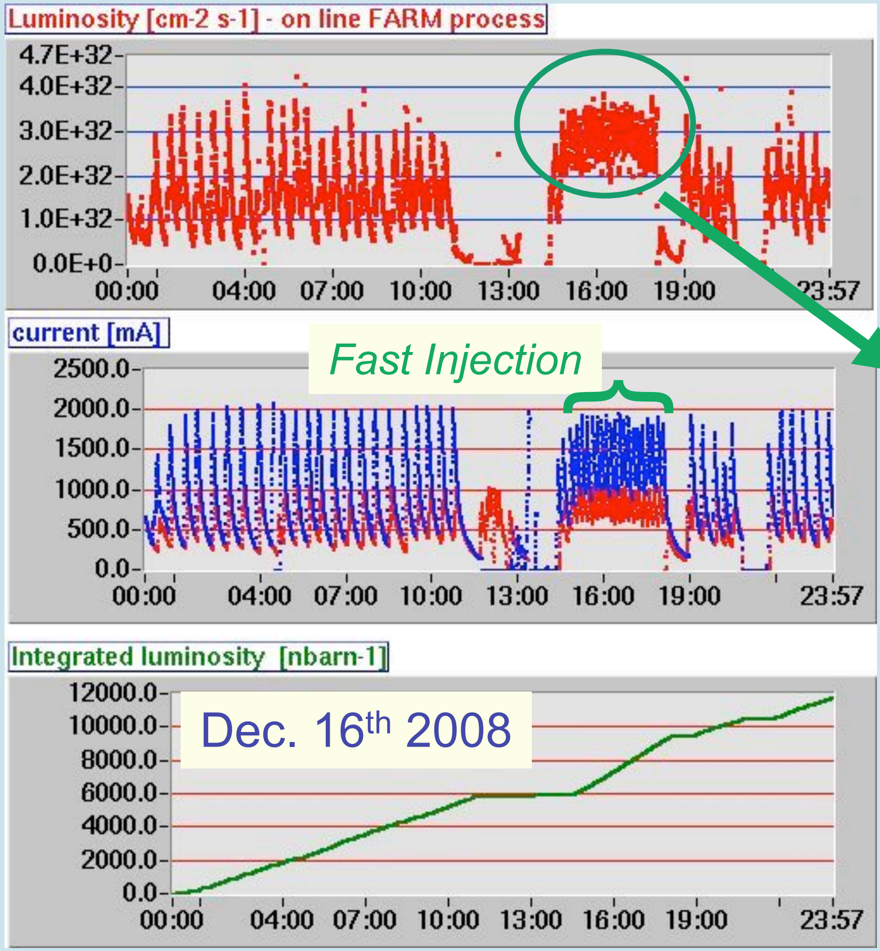
Weak-Strong Simulations

Crab-Waist compensation works in weak-strong regime also, and measured luminosity is in good agreement with theoretical simulation (lifetrack code)



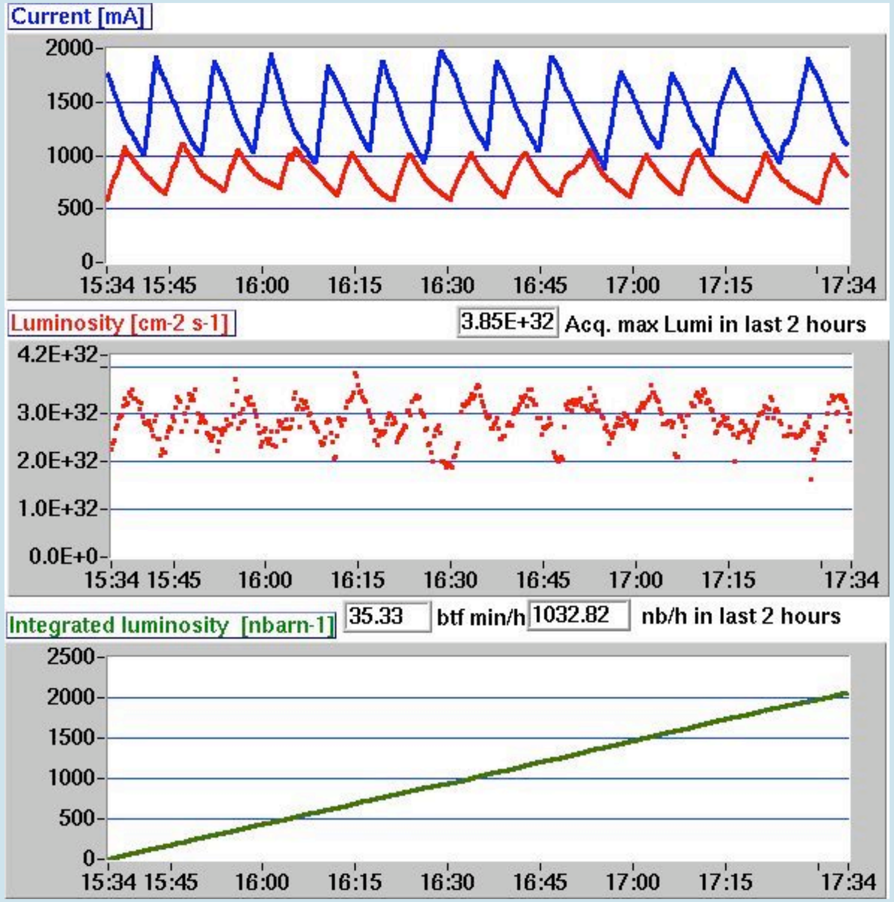
ξ_y(MAX) = **0.074**

Best hourly integrated luminosity



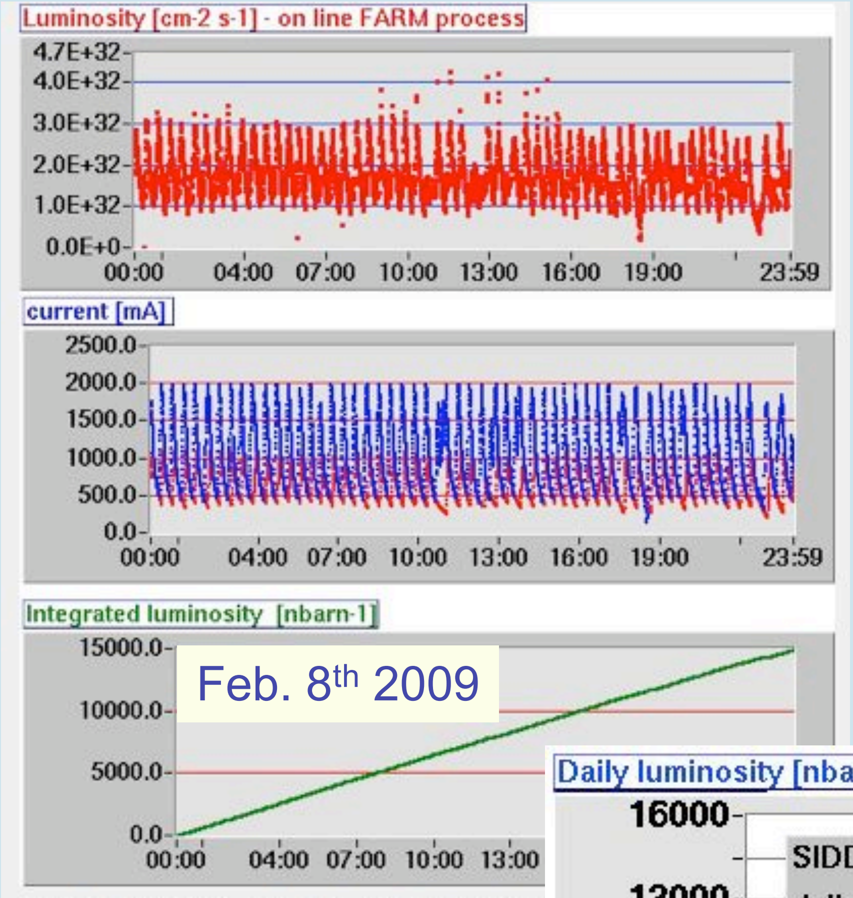
$L_{\int 1\ hour} = 1.033\ pb^{-1}$

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



Fast injection is not compatible with the SIDDHARTA operations!

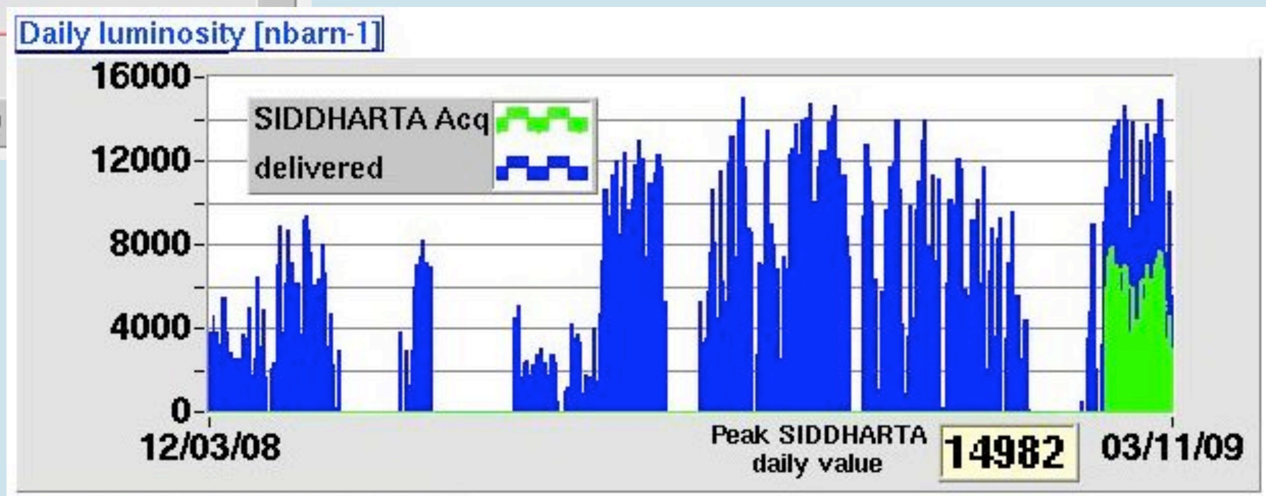
Best daily integrated luminosity



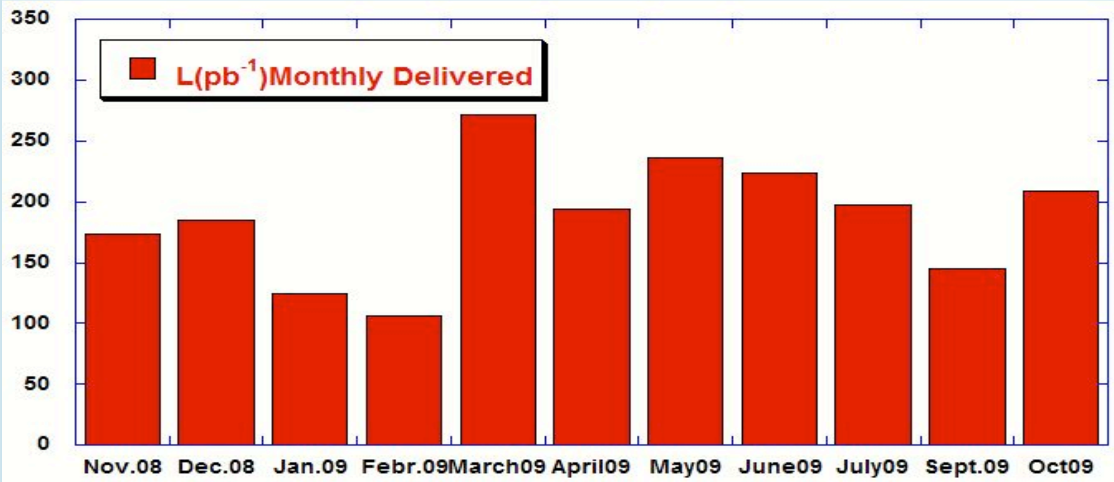
$L_{\int day} = 15.\ pb^{-1}$

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

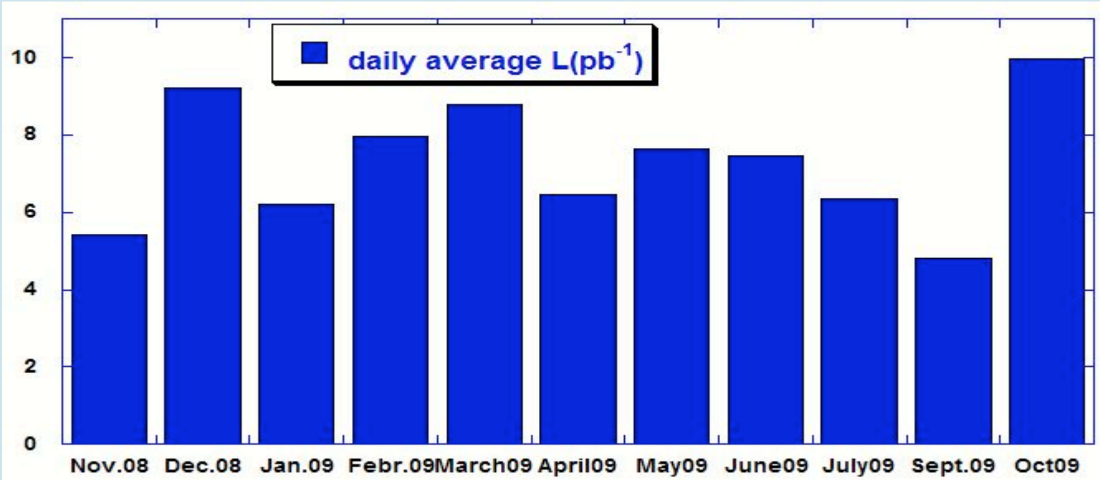
+ 60 % FINUDA 2007



Monthly performances (Nov. 1st 2008 – Oct. 23th 2009)



(Days of run) (20) (20) (24) (23)



tot. # running days 297

2.7 fbn^{-1} delivered in 18 months (Mar 2008 ÷ Nov 2009)

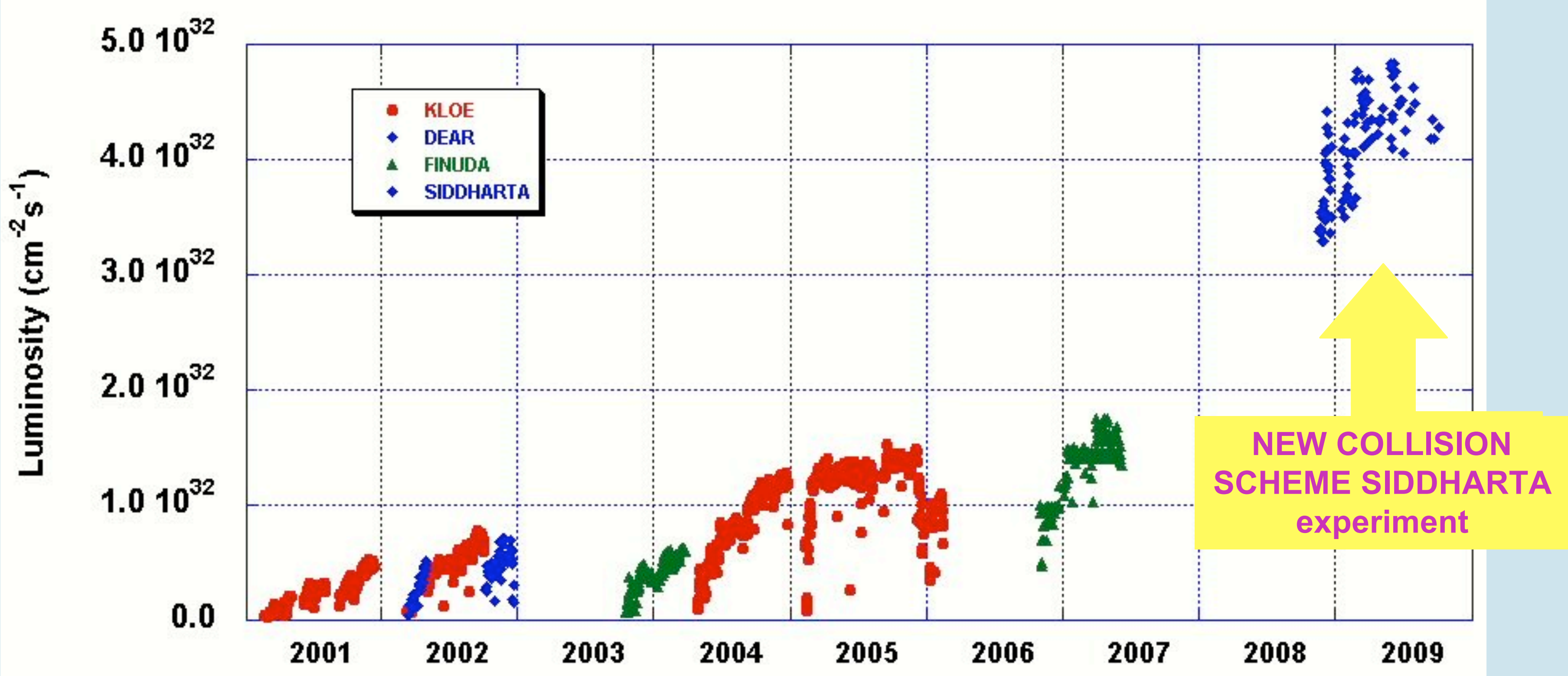
Summary about DAΦNE achievements

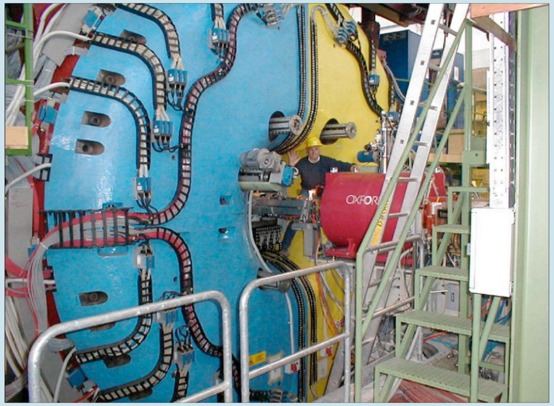
	DAΦNE upgrade SIDDHARTA	DAΦNE KLOE	DAΦNE FINUDA
L_{peak} [$cm^{-2}s^{-1}$]	**$4.53 \cdot 10^{32}$** **($5.0 \cdot 10^{32}$)**	$1.5 \cdot 10^{32}$	$1.6 \cdot 10^{32}$
$L_{\int day}$ [pb^{-1}]	**14.98**	9.8	9.4
$L_{\int 1\,hour}$ [pb^{-1}]	**1.033**	0.44	0.5
I^{-}_{MAX} in collision [A]	**1.52**	1.4	1.5
I^{+}_{MAX} in collision [A]	**1.0**	1.2	1.1
$N_{bunches}$	**105**	111	106
ξ_y	**0.0443** (0.074)	0.025	0.029

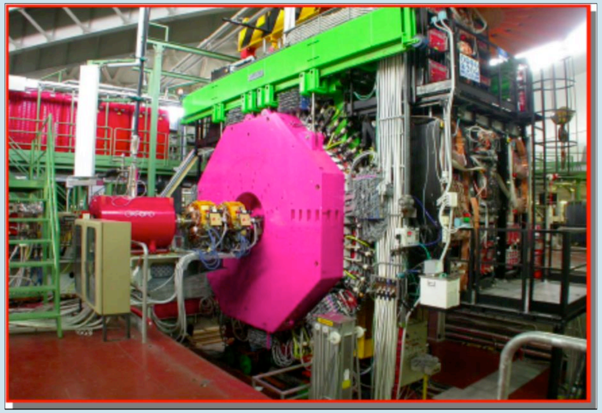
However collider performances are still limited by:

- *maximum positron current e-cloud*
- *beam lifetime*
- *hardware reliability*

L_{peak} at DAΦNE 2001 ÷ 2009







L_{logged} (fb^{-1}) 2001÷2007

KLOE	3.0
FINUDA	1.2
DEAR	0.2

…. Where from here?

Scaling the present data from the luminosity monitor:

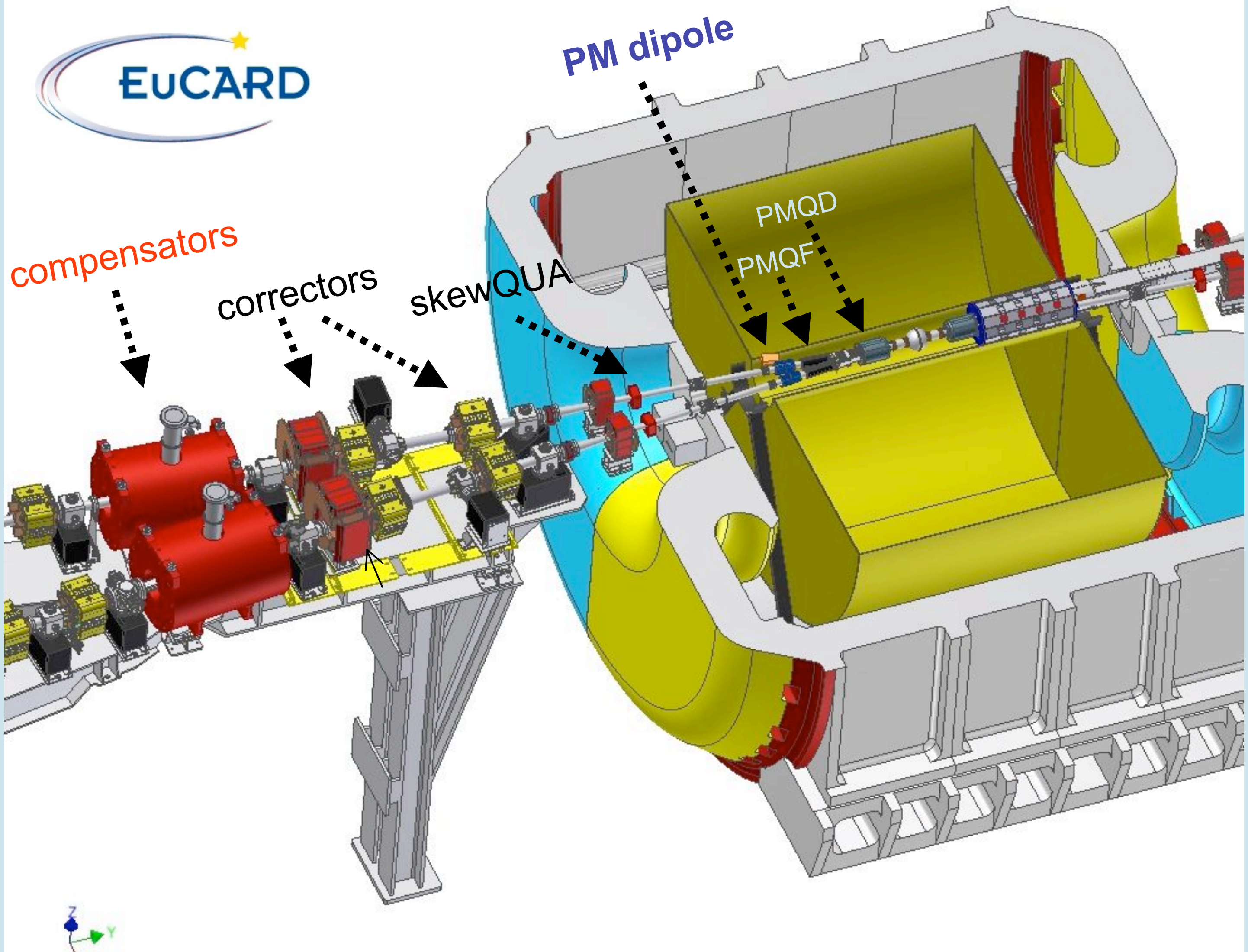
$L_{\int 1\ hour} = 1.033\ pb^{-1}$

$L_{\int day} \geq 20.\ pb^{-1}$ seems possible!

Assuming 80% collider uptime $\Rightarrow$ ***$L_{\int month} \sim .5\ fb^{-1}$***

….. in fact a new KLOE run has been approved …..

The new KLOE-2 IR



IR optics for the new KLOE run

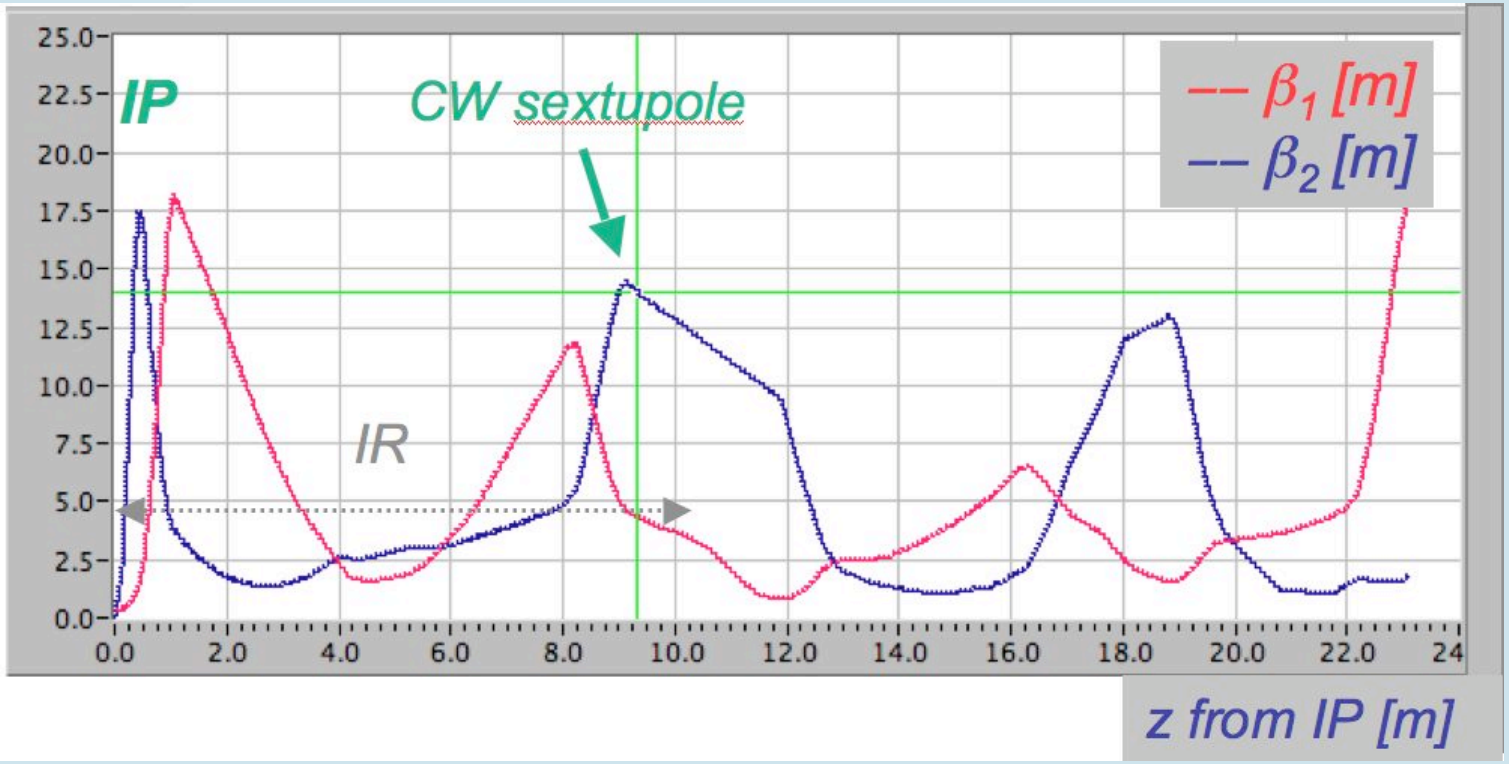
IR design criteria:

- *Coupling matrix = 0   before CW SXT*
- $\Delta\nu_x = \pi$
- $\Delta\nu_y = 3\pi/2$
- *highest* β_y *at the CW sextupole*

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

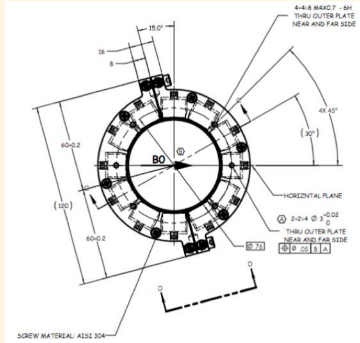
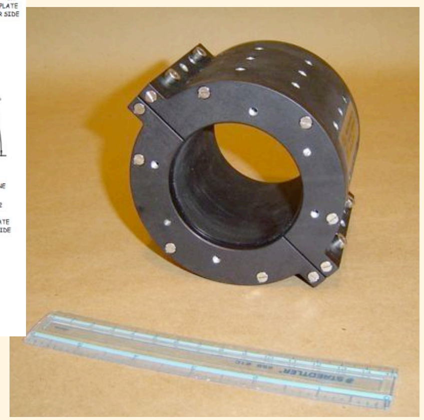
Low-β parameters:

- β^*_x = 26.5 cm
- β^*_y = 8.5 mm
- θ_{cross} = 26 mrad

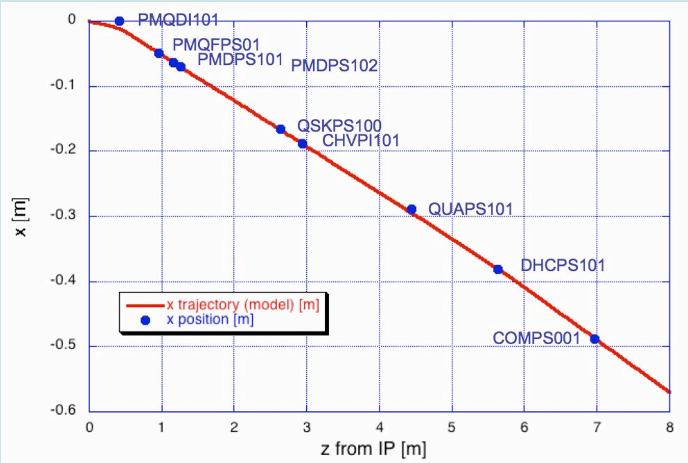


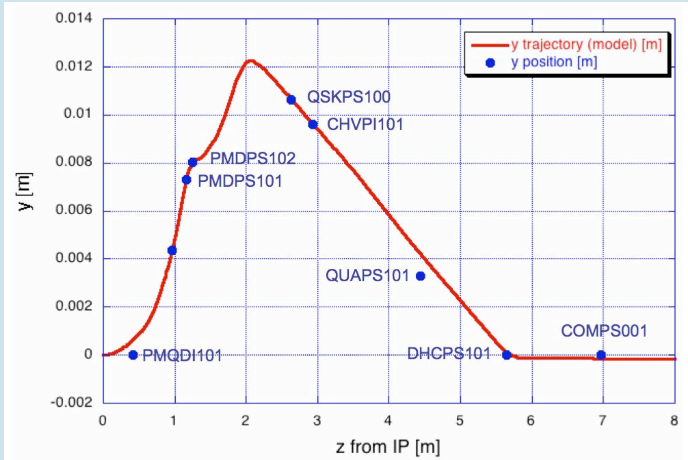
Beam Trajectory in the new IR

- *The beam in the IR is an order of magnitude larger than in the past KLOE run due to:*
  - *experimental solenoidal field*
  - *larger crossing angle*
  - *stronger first low-β quadrupole (PMQD)*
- *A **permanent magnet dipole** is used to keep under control the vertical beam trajectory.*

Magnetic length (mm) 75
field (T) 0,22933
Good field region radius (mm) 15
Magnet material type SmCo

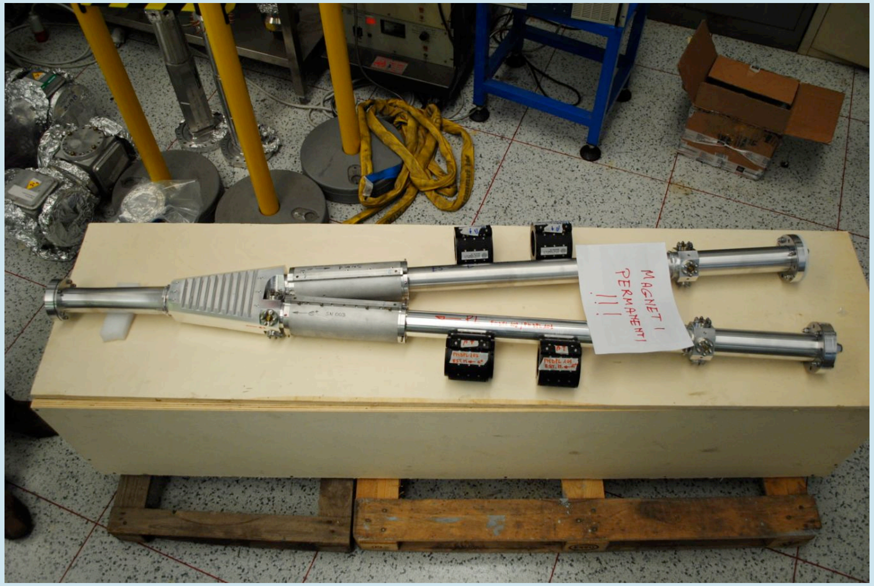




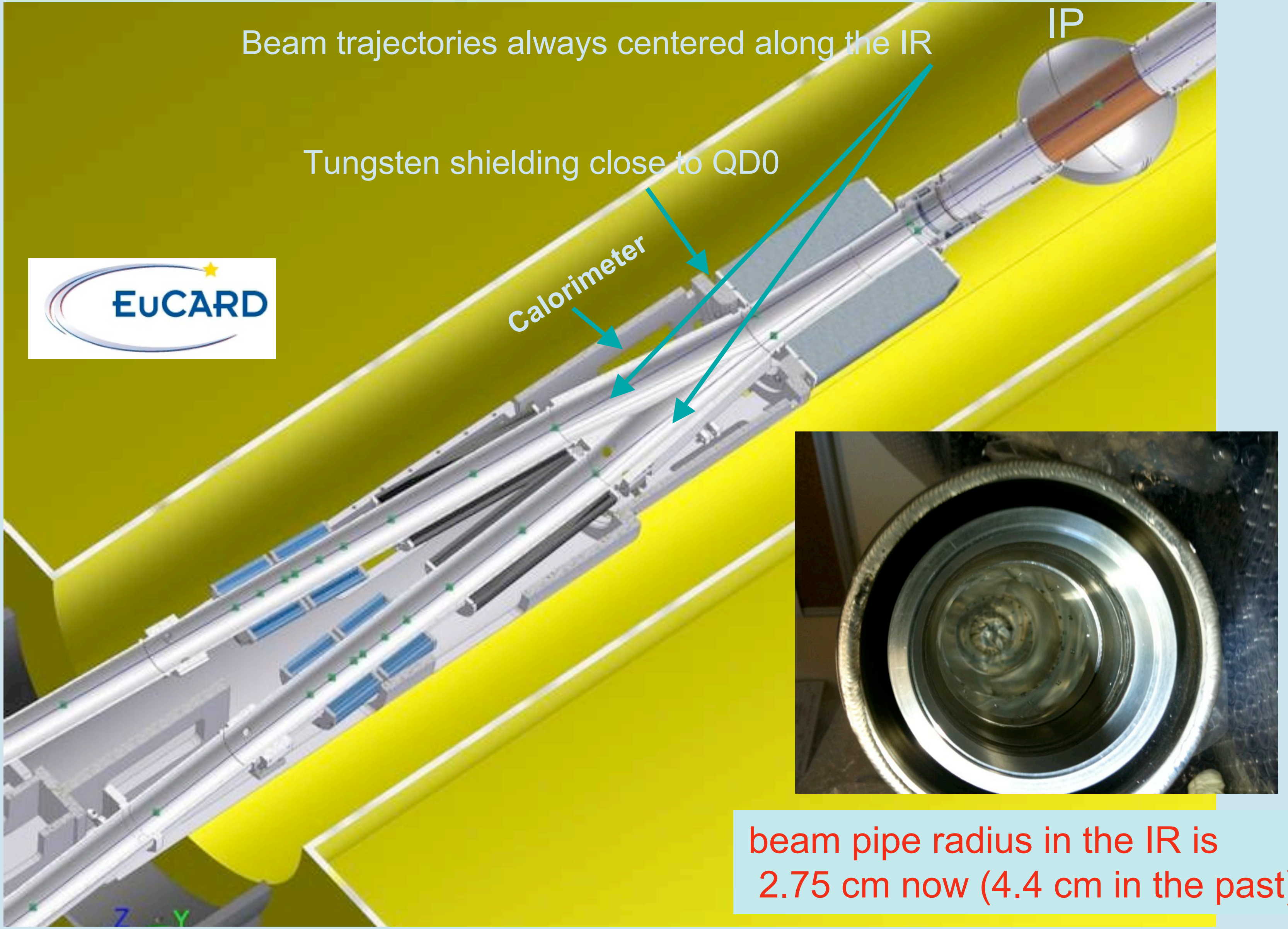
QUADs are centered as much as possible on the beam trajectory to improve beam acceptance.

Vacuum chamber design is very much simplified: straight sections and few bellows

Permanent Magnet Dipole Assembly



Radial section of the KLOE IR pipe



beam pipe radius in the IR is
2.75 cm now (4.4 cm in the past)

Coupling correction

- $\int_{KLOE} B \cdot dl$ canceled by 2 anti-solenoids for each beam

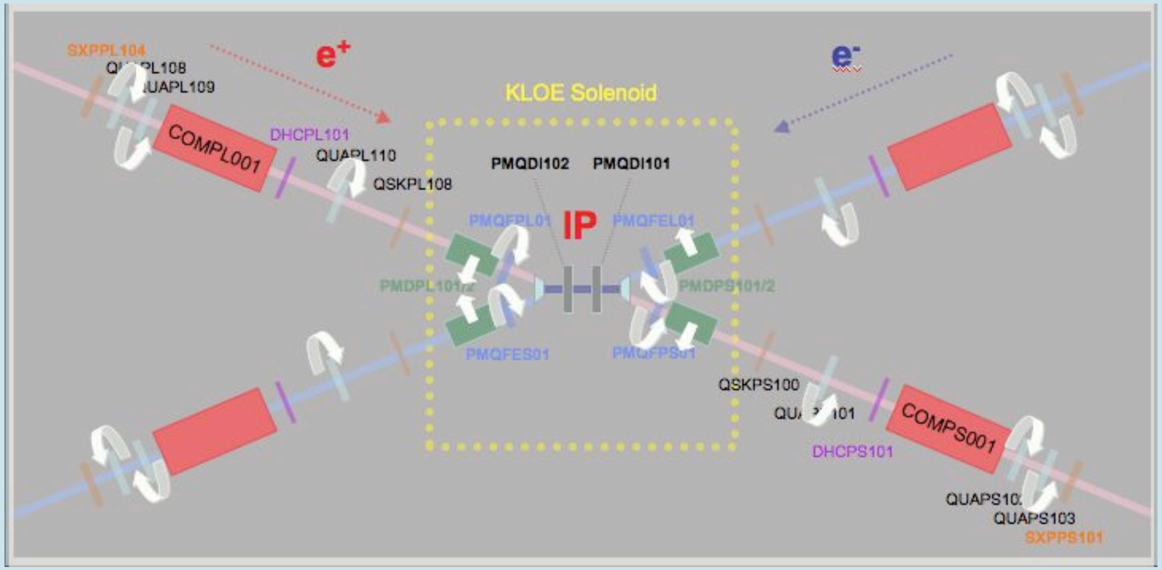
$$\int_{KLOE} B \cdot dl = 2.048 \quad [Tm] \quad \rightarrow \quad I_{KLOE} = 2300.[A]$$

$$\int_{comp} B \cdot dl = \pm 1.024 \quad [Tm] \quad \rightarrow \quad I_{comp} = 86.7[A]$$

In order to have coupling compensation also for off-energy particles

	Z from the IP [m]	Quadrupole rotation angles [deg] *Anti-solenoid current [A]*
PMQDI101	0.415	0.0
PMQFPS01	0.963	-4.48
QSKPS100	2.634	used for fine tuning
QUAPS101	4.438	-13.73
QUAPS102	8.219	0.906
QUAPS103	8.981	-0.906
COMPS001	*6.963*	*72.48 (optimal value 86.7)*

Fixed QUAD rotations
K is expected to be lower than for KLOE past
$K_{KLOE1} = 0.2 \div 0.3$ %



New kicker for horizontal feedback

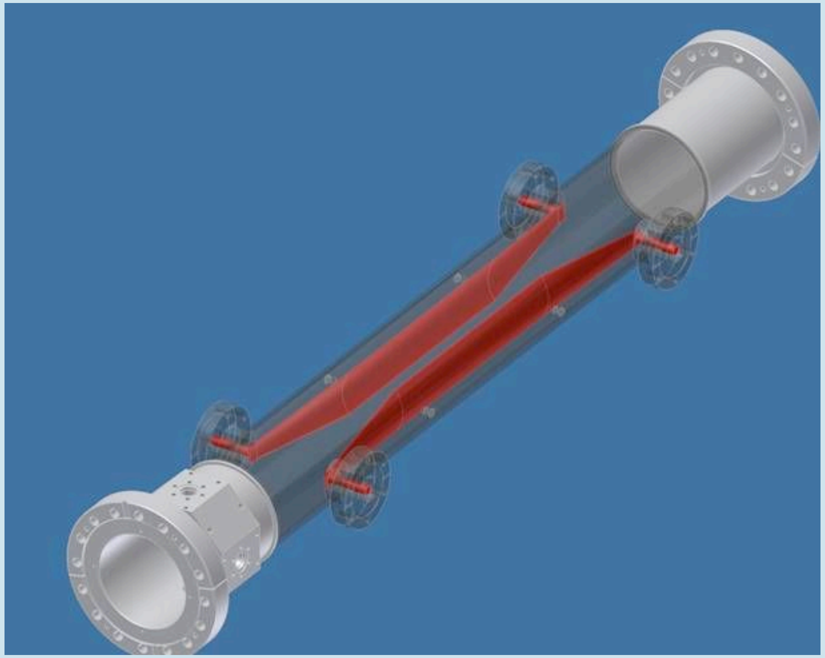
A new kicker has been designed to be used

- for transverse horizontal feedback in the e+ ring
- as beam dumper (less detector trips and radiation level)

The new kicker differs from the old one having:

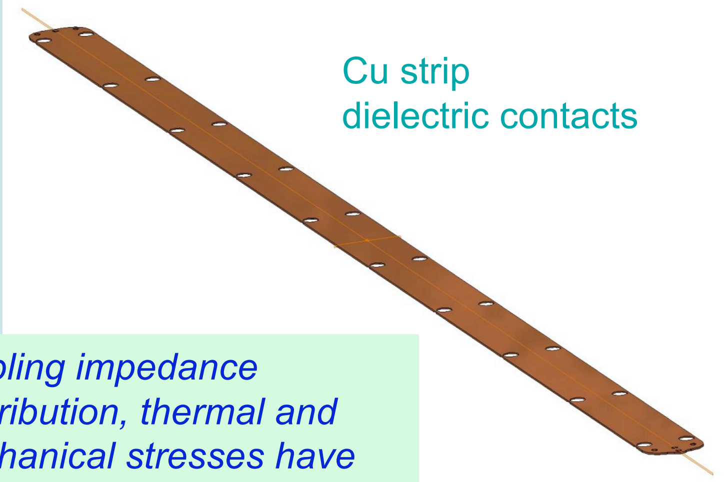
- *double Stripline length*
- *reduced stripline separation in the horizontal plane:*
  88 mm -> 60 mm
- *new position with higher β*

These features are expected to improve ***the kick strength by a factor ≈3*** *(with the same amplifier power).*

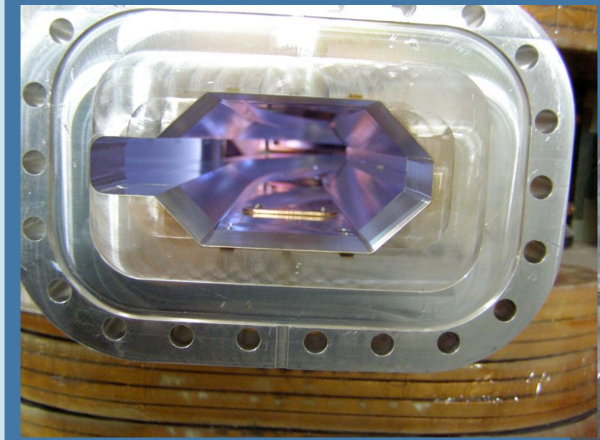


Stripline electrodes for e-cloud clearing
(in the positron Ring)

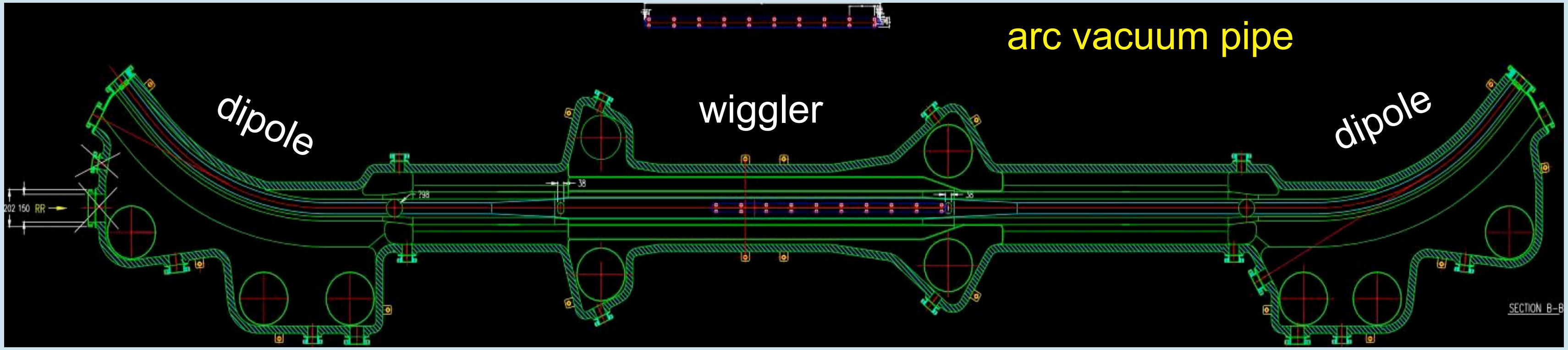
***e-cloud** formation in the wiggler and dipole vacuum chambers can be avoided by means of stripline electrodes kept at a moderate voltage.*



coupling impedance contribution, thermal and mechanical stresses have been carefully evaluated



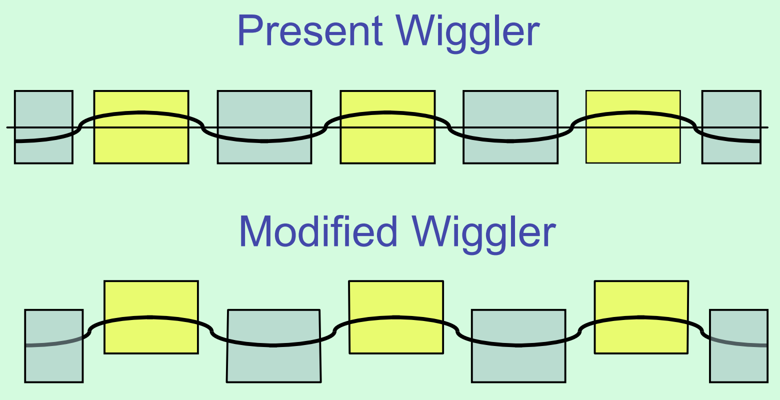
Already in place



Wigglers modification

The 8 Wigglers have been modified in order to:

- *Improve by more than a factor 2 the good field region*
- *Reduce the higher order components in the B*
- *Increase the B_{max} for a given current*
- *Decrease the wall plug power*
- *Eliminate 8 additional power supplies used for the terminal poles*



The pole axis is displaced in such a way that it leaves the beam trajectory approximately half on the right and half on the left: in this way ***even terms still cancel from pole to pole****, while* ***odd terms cancel inside each pole****.*

- Improved beam dynamics
- longer beam lifetimes
- 500KW power reduction with same B_{max} (0.5ME/Year)
- Less histeresys better reproducibility

Further Hardware Developments

- ***LINAC**: gun cathode replaced, diagnostics improved and a new accelerating section added*
- ***Cryogenic plant** upgraded (4 compensator solenoids in the IR)*
- *Low level RF feedback added to the cavity control*
- *Collimators modified*
- *Imperfect welding in the Ring Crossing Region have been retouched and quadrupole disposition optimized*
- *All the old style bellows will be replaced with the new ones having lower impedance and better mechanical behaviour*
- *The Ion Clearing Electrodes still present in the e- ring will be removed*
- ***Horizontal feedback power** will be doubled providing 500 W*
- *Control system*

Aimed at

Improving beam dynamics

Increasing collider uptime and operation reliability

Conclusions

- *The DAΦNE collider, based on a new collision scheme including Large Piwinski angle and Crab-Waist, has successfully delivered luminosity to the SIDDHARTA detector.*

- *Large crossing angle and Crab-Waist compensation proved to be effective in:*
  - *increasing luminosity, by a factor 3 controlling*
  - *keeping under control beam-beam instabilities*

- *DAΦNE operations with the large KLOE-2 detector are scheduled to start by the end of May 2010*