HIGH LUMINOSITY INTERACTION REGION DESIGN FOR COLLISIONS WITH DETECTOR SOLENOID*

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*Work supported by the EuCARD research programme, within the "Assessment of Novel Accelerator Concepts" work package (ANAC-WP11).

Outline

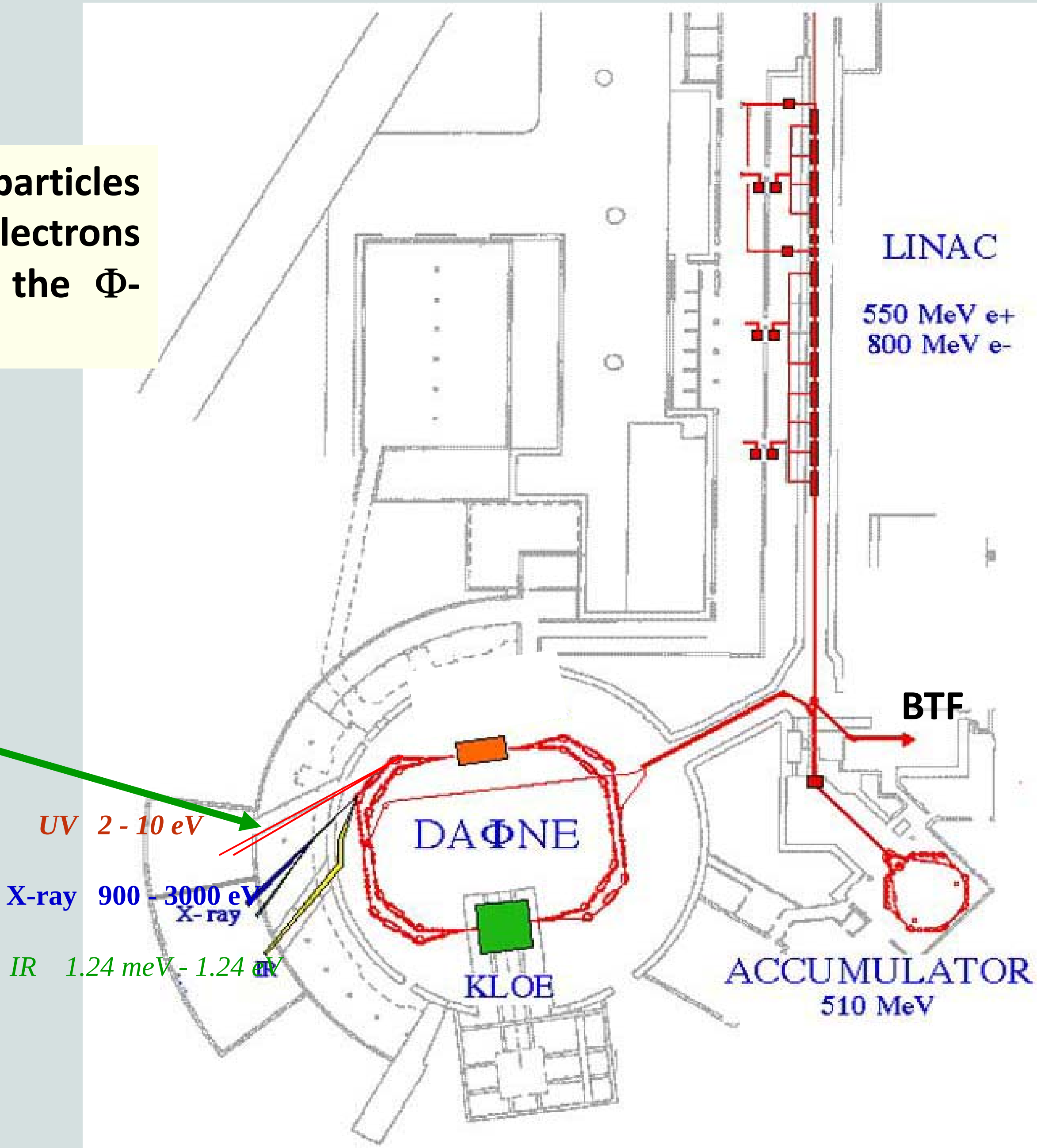
- *DAΦNE*
- *IR design for the the KLOE-2 experiment including Crab-Waist*
- *tests with the beam*
- *Operational experience*
- *Conclusions*

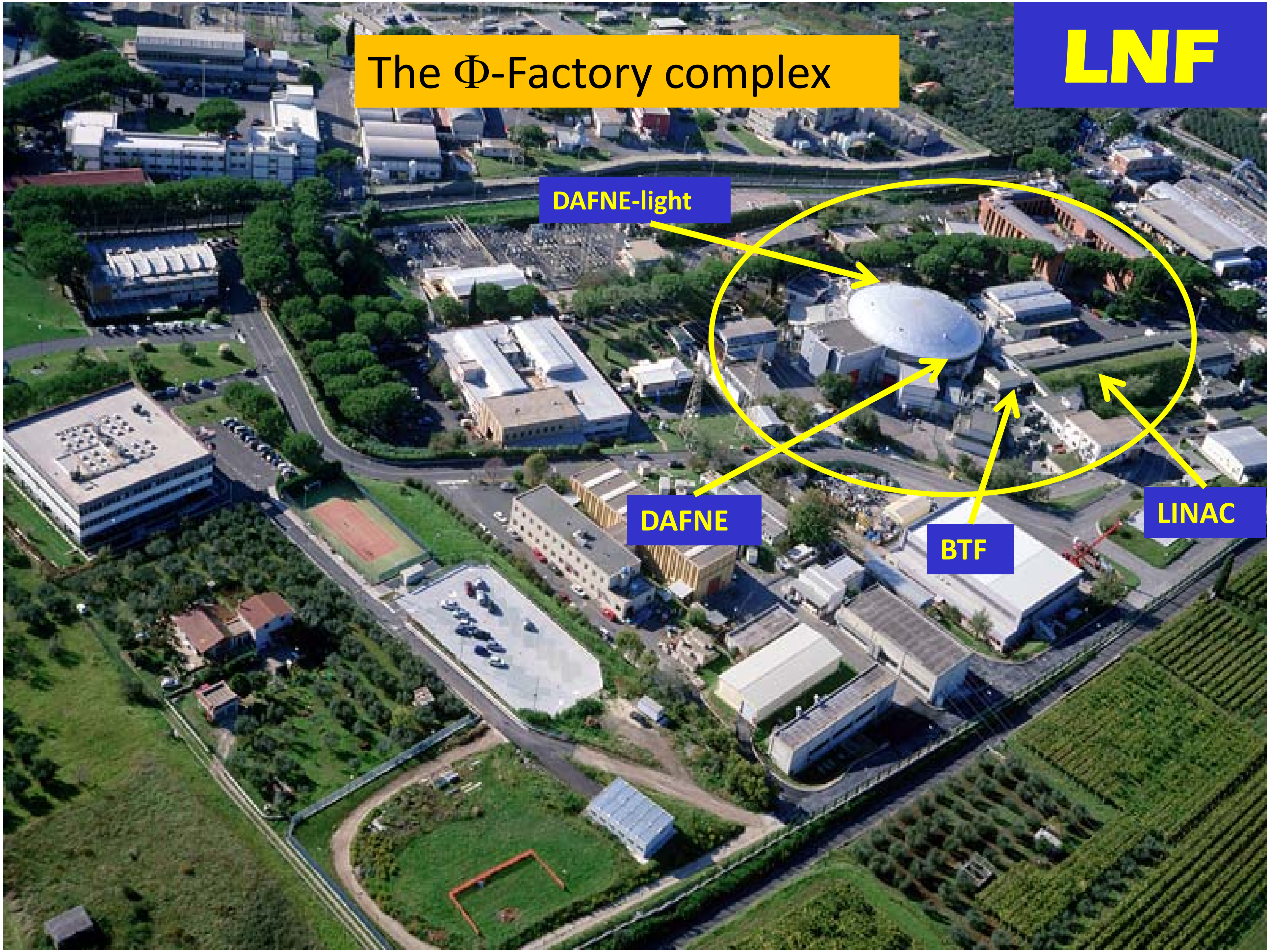
The Φ-Factory complex

Abundant production of Φ particles coming from the annihilation of electrons and positrons at the energy of the Φ-resonance.

Syncrotron ligth from DAFNE

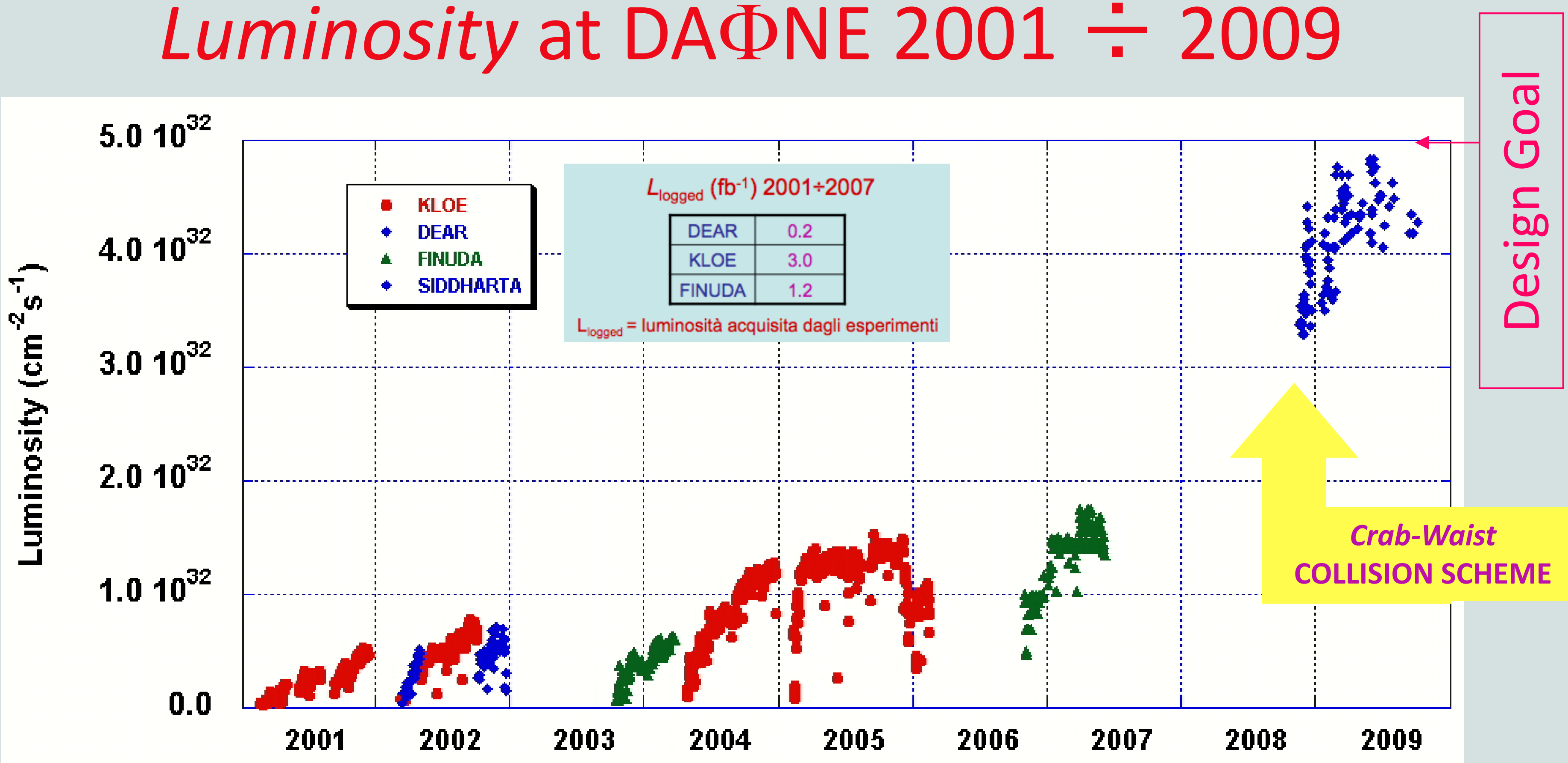
LNF are part of the European Infrastructure for syncrotron light

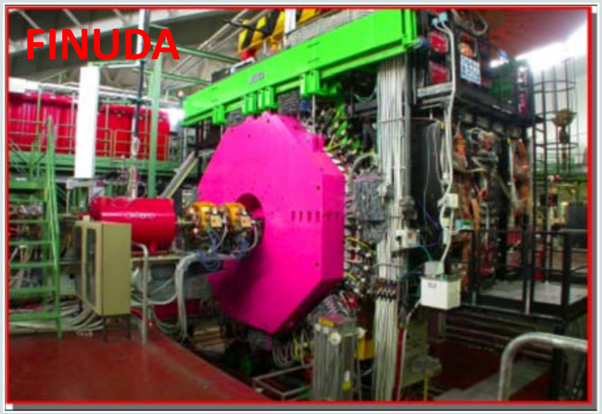




The Φ-Factory complex
LNF
DAFNE-light
DAFNE
BTF
LINAC

Luminosity at DAΦNE 2001 ÷ 2009





Crab-Waist collision scheme and KLOE-2

- Large crossing angle and Crab-Waist scheme proved to be effective in increasing luminosity, a factor 3 higher than in the past

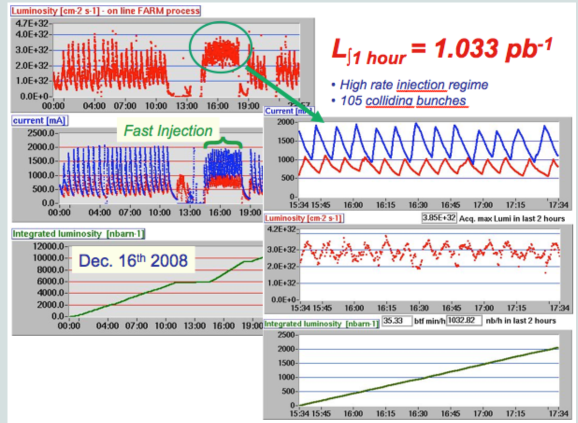
- The DAΦNE collider, based on a new collision scheme including Large Piwinski angle and Crab-Waist, has been successfully commissioned and has delivered:

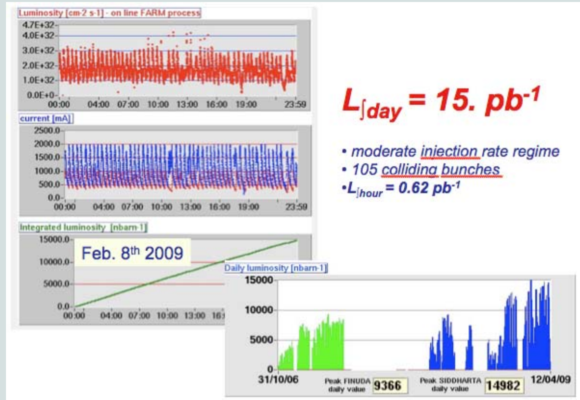
  $L_{peak} = 4.5 * 10^{32}\ cm^{-2}\ s^{-1}$

  $L_{\int 1\ day} = 15.0\ pb^{-1}$

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

  $L_{\int run} \sim 2.8\ fb^{-1}$ (SIDDHARTA detector)

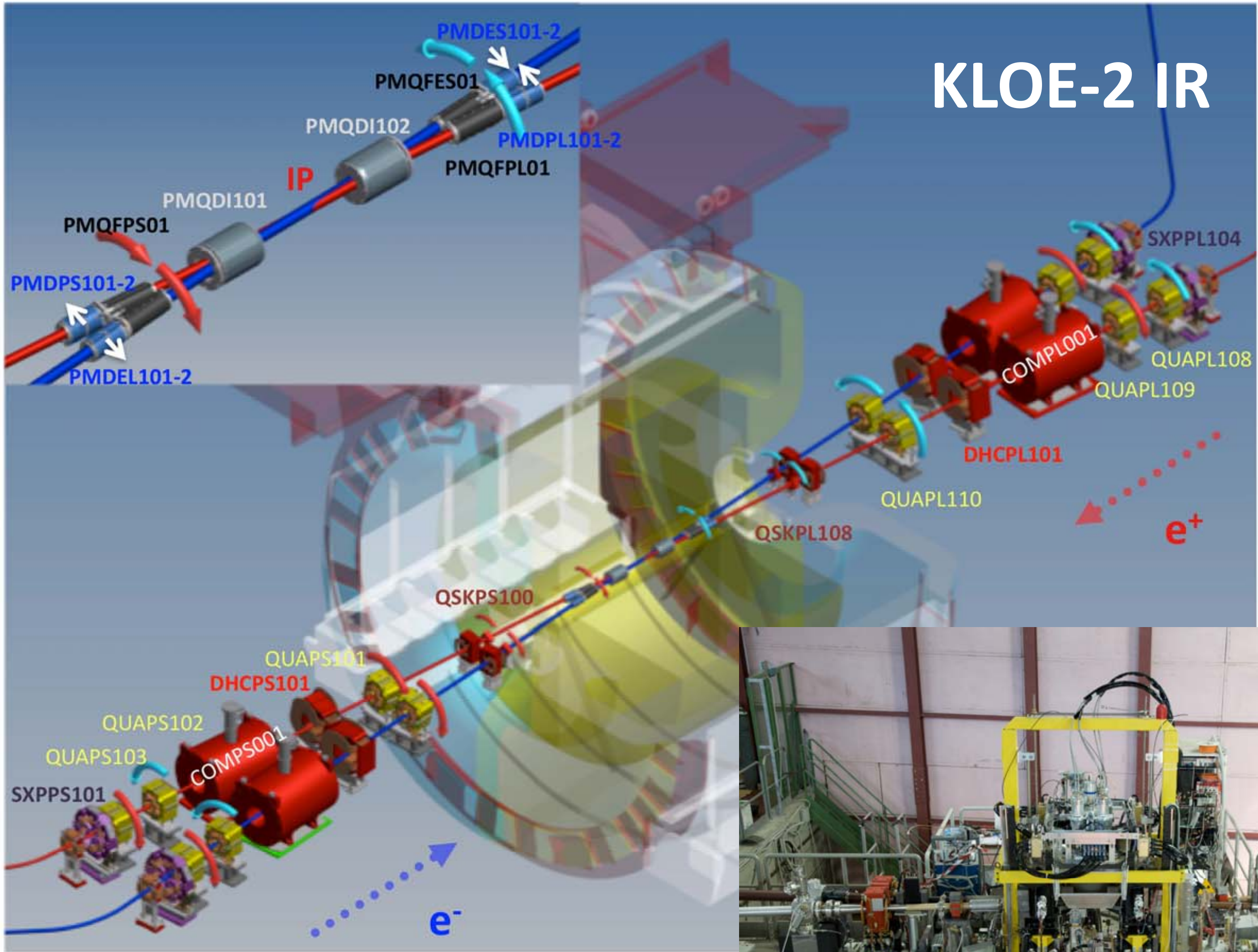




KLOE-2 run

Integrating the high luminosity collision scheme with a large experimental detector introduces new challenges in terms of:

- IR layout
- optics
- beam acceptance
- coupling correction

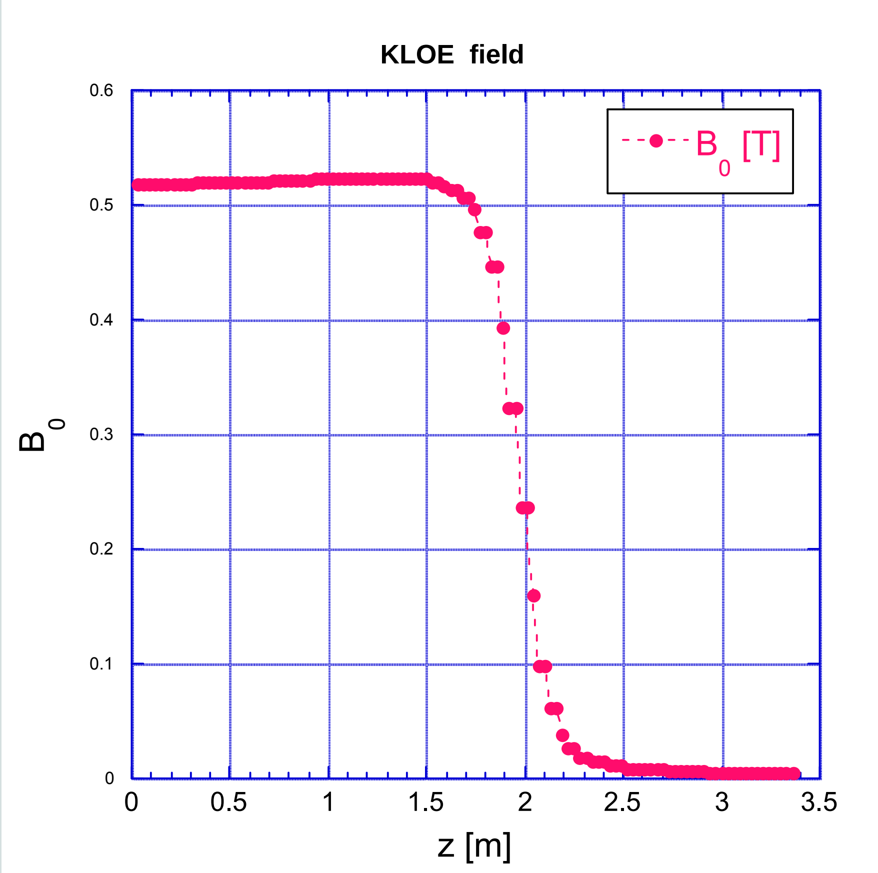

KLOE-2 IR
PMDES101-2
PMQFES01
PMQDI102
PMDPL101-2
PMQFPL01
IP
PMQDI101
PMQFPS01
PMDPS101-2
PMDEL101-2
SXPPL104
QUAPL108
COMPL001
QUAPL109
DHCPL101
QUAPL110
QSKPL108
e+
QSKPS100
QUAPS101
DHCPS101
QUAPS102
COMPS001
QUAPS103
SXPPS101
e-


SIDDHARTA IR

KLOE detector

KLOE detector is equipped with a superconductive solenoid providing an intense magnetic field

$$\int B\, dl = 2.3 \text{ Tm}$$



Solenoid

- perturbs beam trajectory
- affects transverse beam dynamics
- adds focusing effects and beam coupling

$$\theta_{KLOE} = 39^0$$

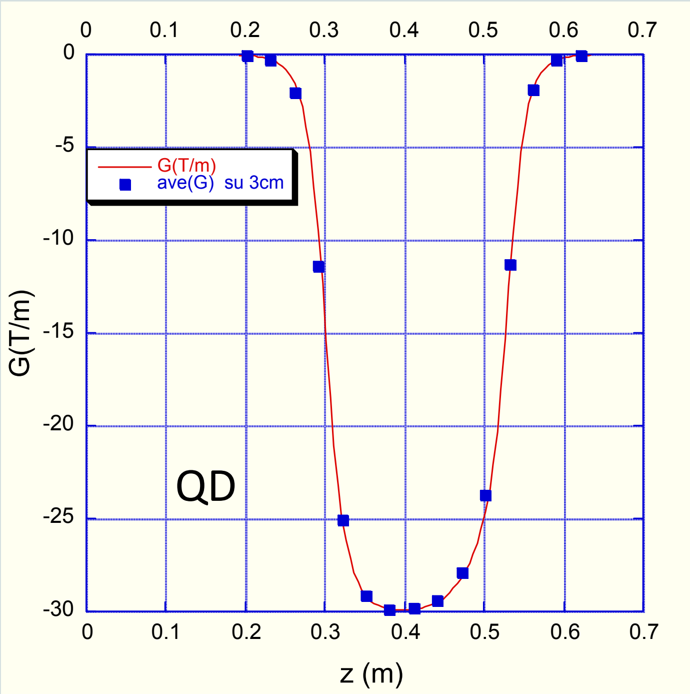
Low-β

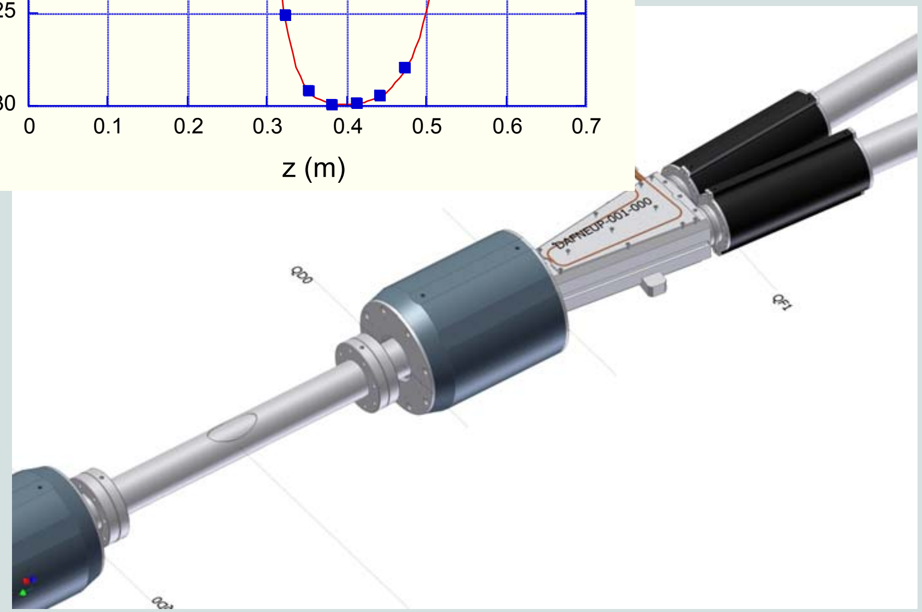
Low-β is based on permanent magnet (SmCo alloy) quadrupole doublets

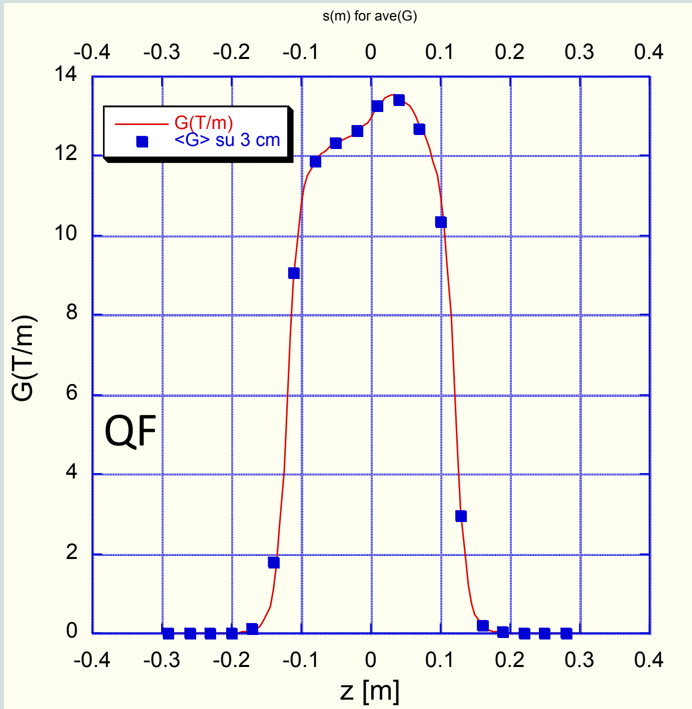
G_{QD} = 29.2 T/m

G_{QF} = 12.6 T/m

permanent magnet elements instead of superconducting tunable ones to provide the largest possible free solid angle for the detector







Low-β matching with the rings

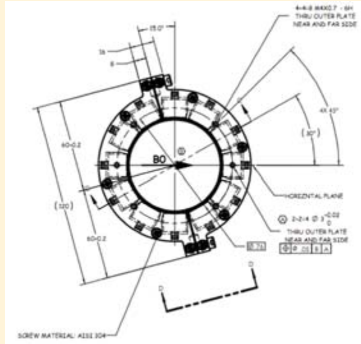
The first (PMQD) is horizontally defocusing and is shared by the two beams it is installed at 0.415 m from the IP

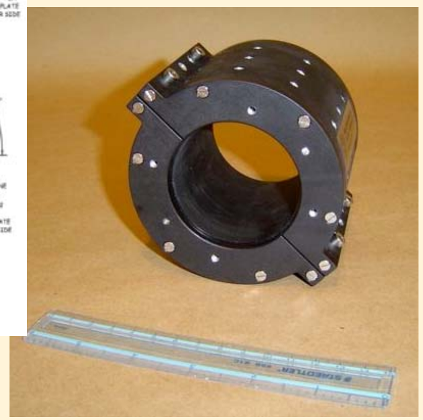
The second quadrupole (PMQF), horizontally focusing, is installed just after the point where the beam pipes of the two rings are separated and is therefore on axis

Being PMQD much stronger than in the original low-b setup and having doubled the horizontal half crossing angle, now ~25 mrad, a very efficient beam separation, ~ $40\sigma_x$, is achieved in the ~1.6 m long section of the IR common to the two rings

Beam Trajectory in the new IR

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

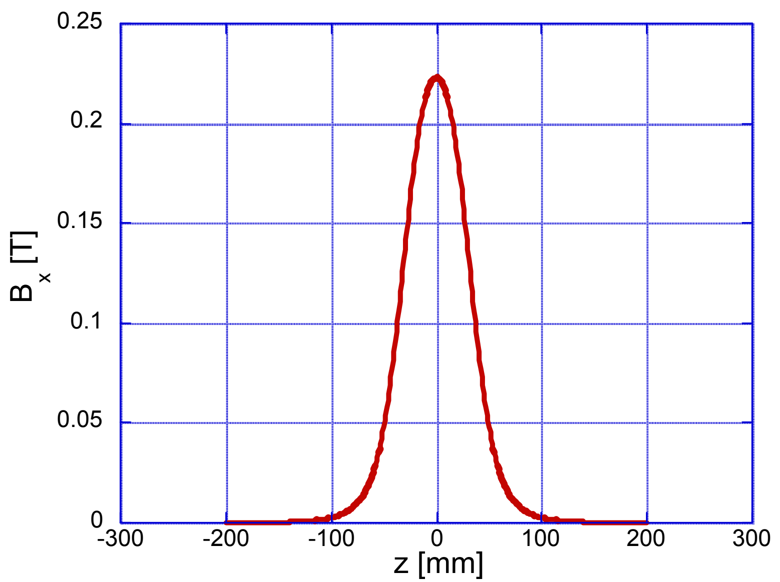




Magnetic length (mm) 75
field (T) 0,22933
Good field region radius (mm) 15
Magnet material type SmCo

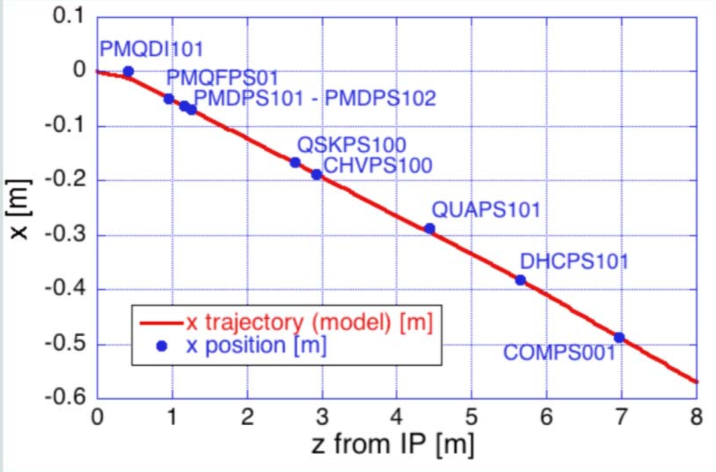
PMD consists of two halves each of them:

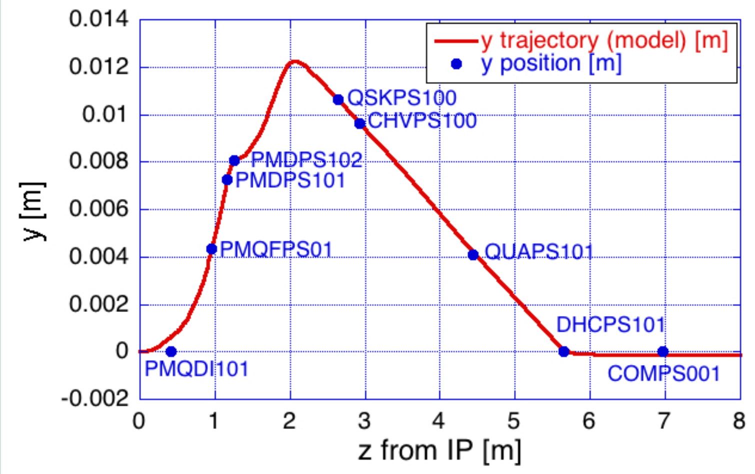
- Magnetic length 75.0 mm
- BL = 0.0168 Tm
- Bx is directed inward and outward in the e+ and e- rings respectively
- α_y ~ 10.0 mrad



Beam Trajectory in the IR

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





Trajectories and element position for the IR branch of the positron ring pointing to the short arc the corresponding branch for the electron ring being symmetric

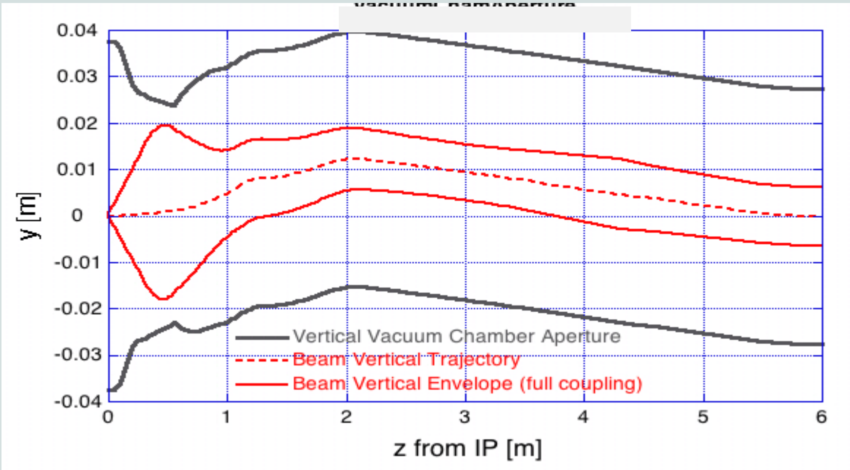
Beam Stay Clear

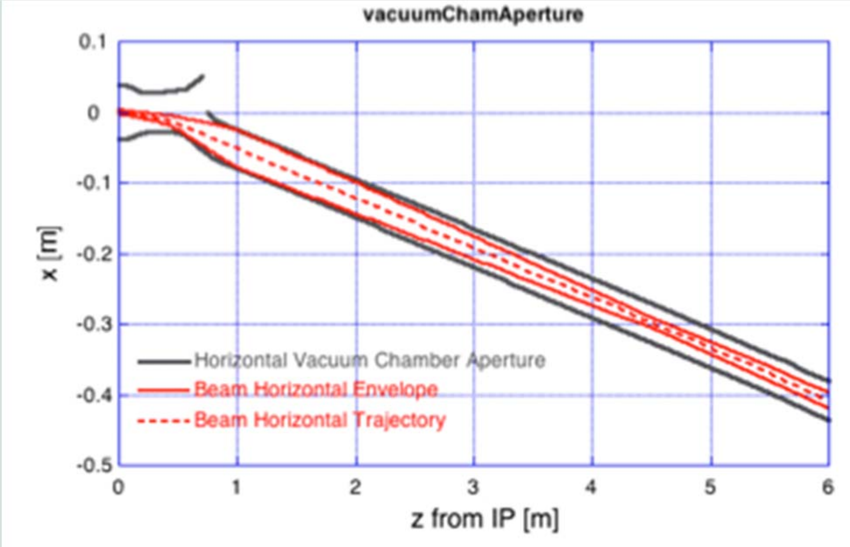
The horizontal and vertical beam stay-clear requirements have been defined as:

$$X_{SC} = x_{trj} \pm 10\sigma_x$$

$$Y_{SC} = y_{trj} \pm 10\sigma_y$$

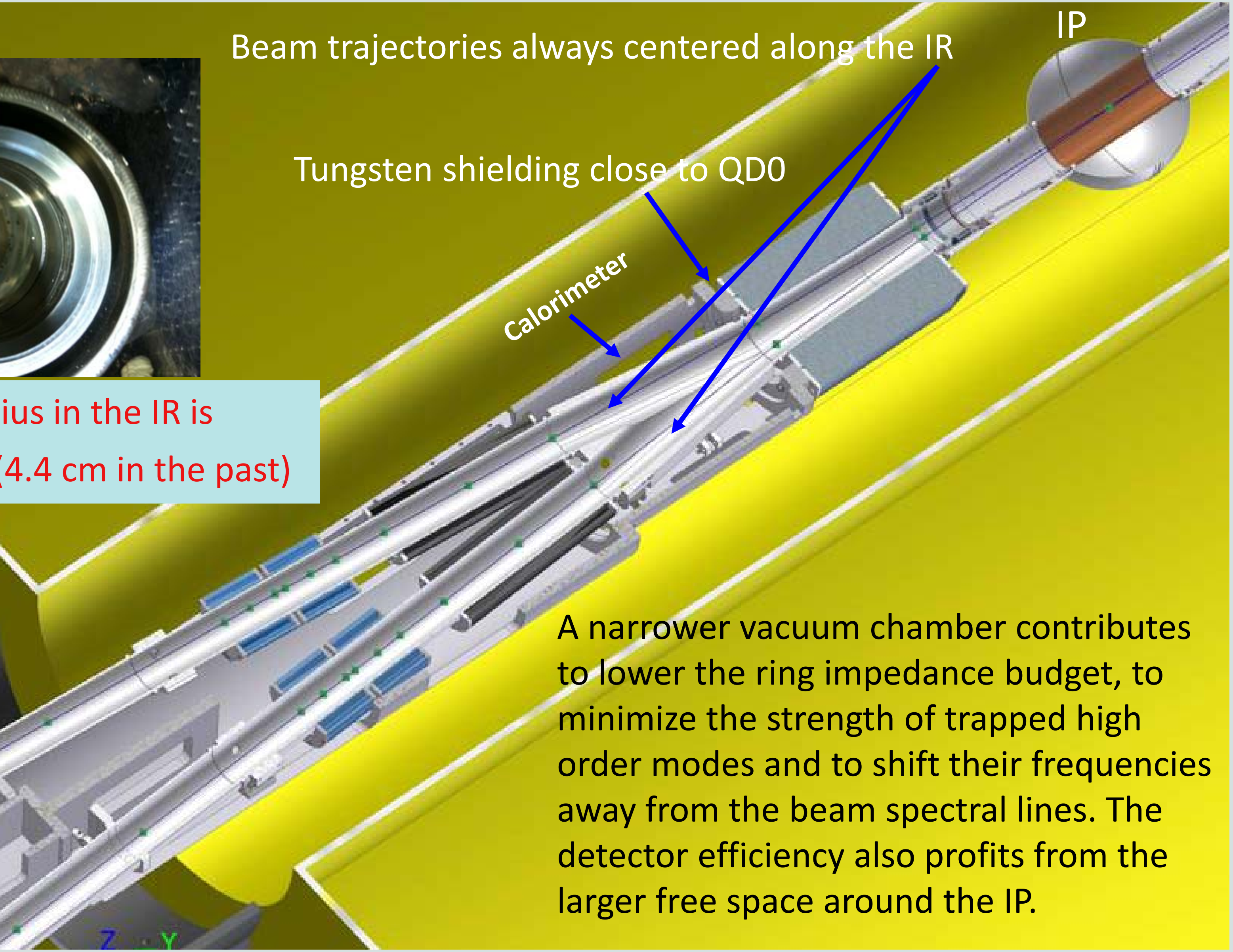
where σ_x and σ_y are the horizontal and vertical rms beam sizes respectively. Their values, computed with the collider emittance $\varepsilon = 0.4\ 10^{-6}$ m for the horizontal plane and full coupling for the vertical one.





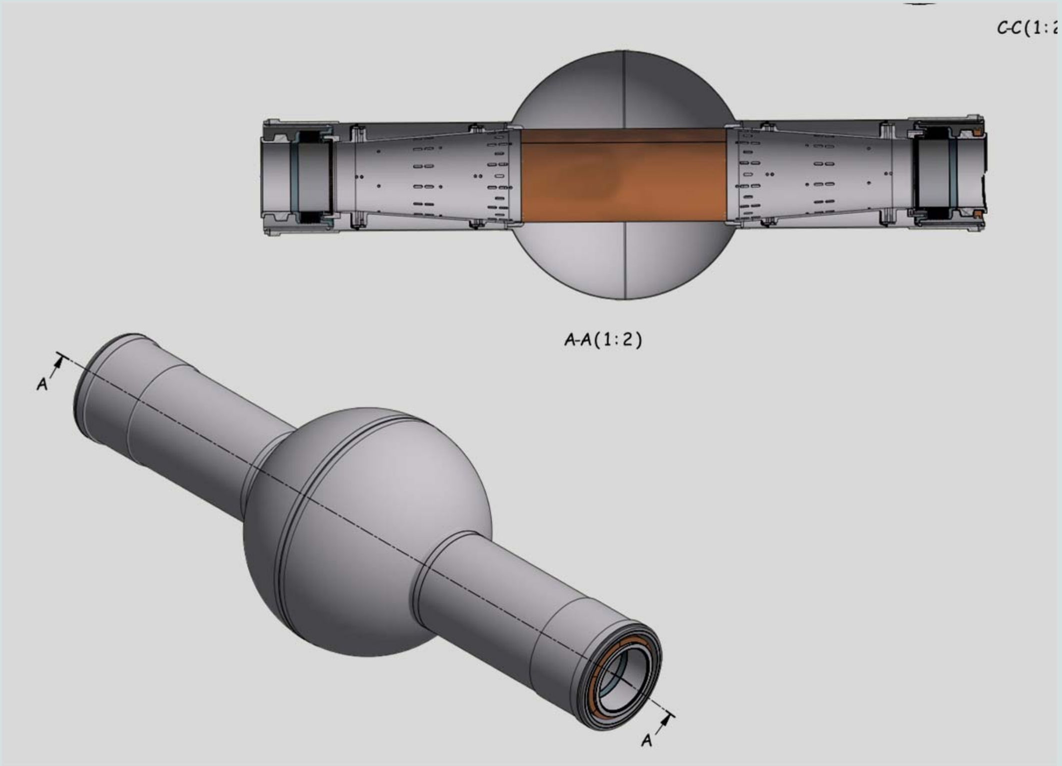
Radial section of the KLOE IP pipe

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



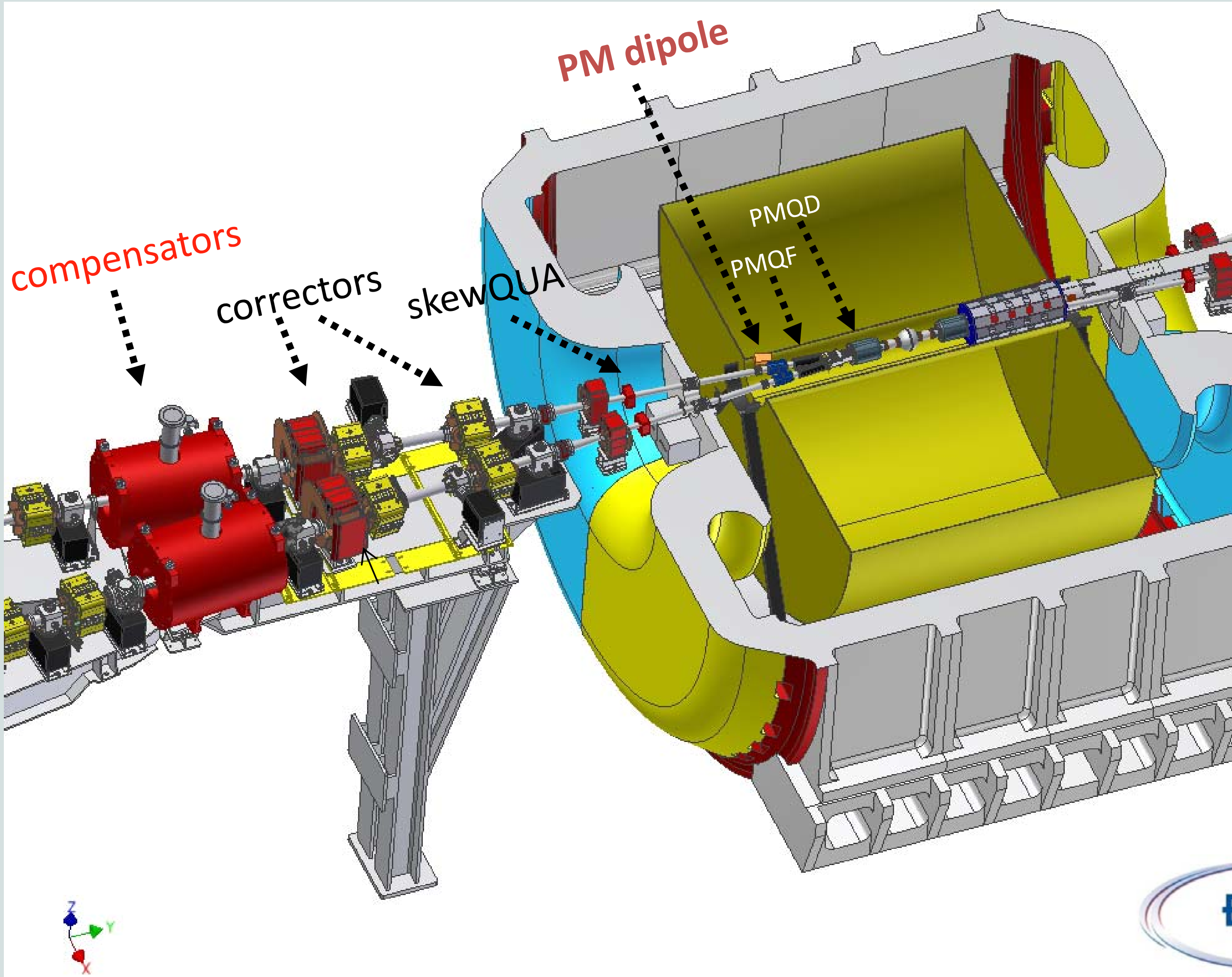
A narrower vacuum chamber contributes to lower the ring impedance budget, to minimize the strength of trapped high order modes and to shift their frequencies away from the beam spectral lines. The detector efficiency also profits from the larger free space around the IP.

IP beam pipe



The IR pipe is aluminum (AL6082) made with the exception of the sphere surrounding the IP, which is built in ALBEMET. Such a structure could trap HOMs and for this reason it is shielded from to the beam by means of a Be cylinder. To minimise K meson regeneration the shield thickness has been almost halved (35 mm instead of the 65 mm of the past KLOE run)

The new KLOE-2 IR



IR optics for the new KLOE run

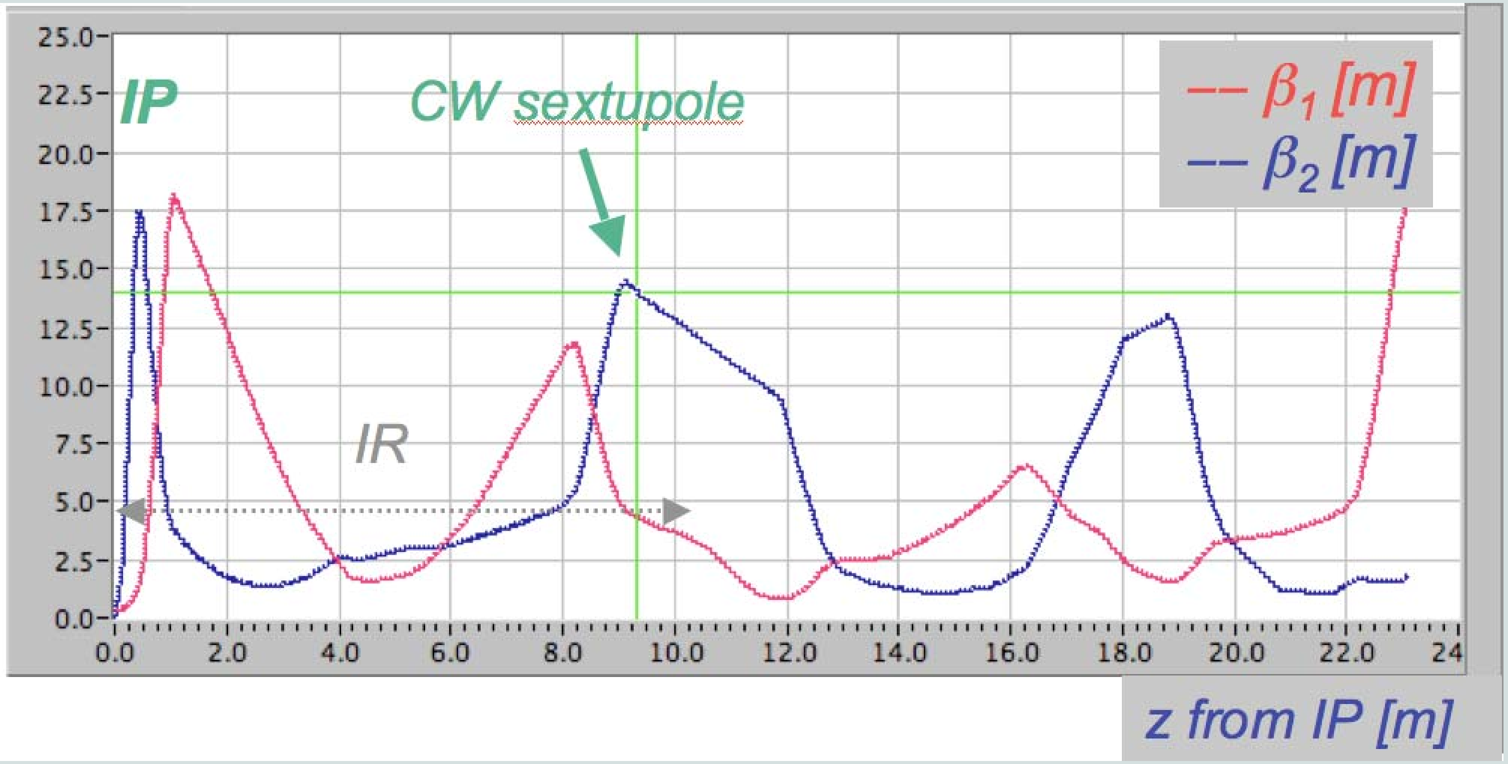
IR design criteria:

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

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

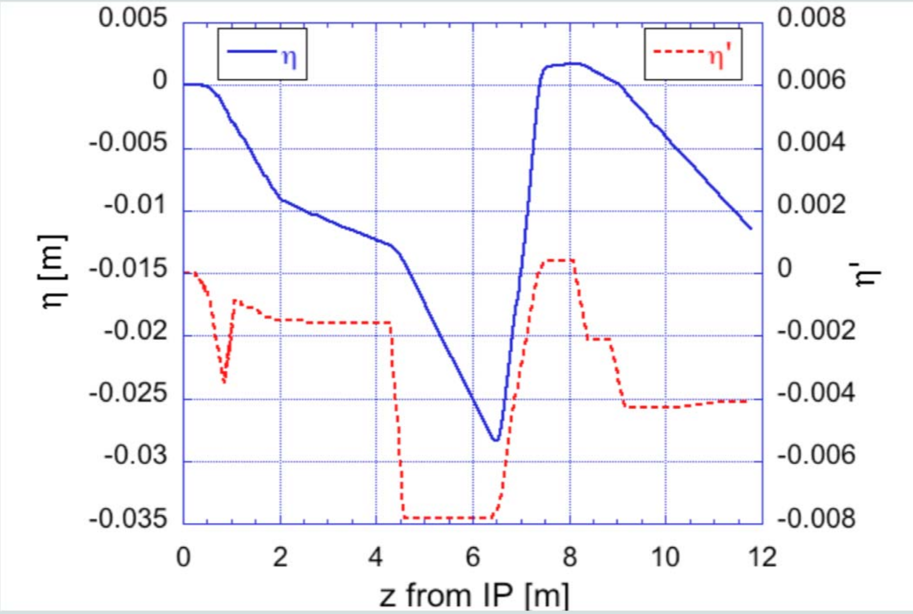
Low-β parameters:

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



Vertical dispersion in the IR

The presence of a strong solenoidal field superimposed to high gradient quadrupoles and to vertical bending magnets a not negligible vertical dispersion is generated in the IR. It has been matched to zero before the CW sextupole (9.3 m from the IP) and its derivative has been minimized in order to avoid any contribution to the vertical beam size.



Coupling correction

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

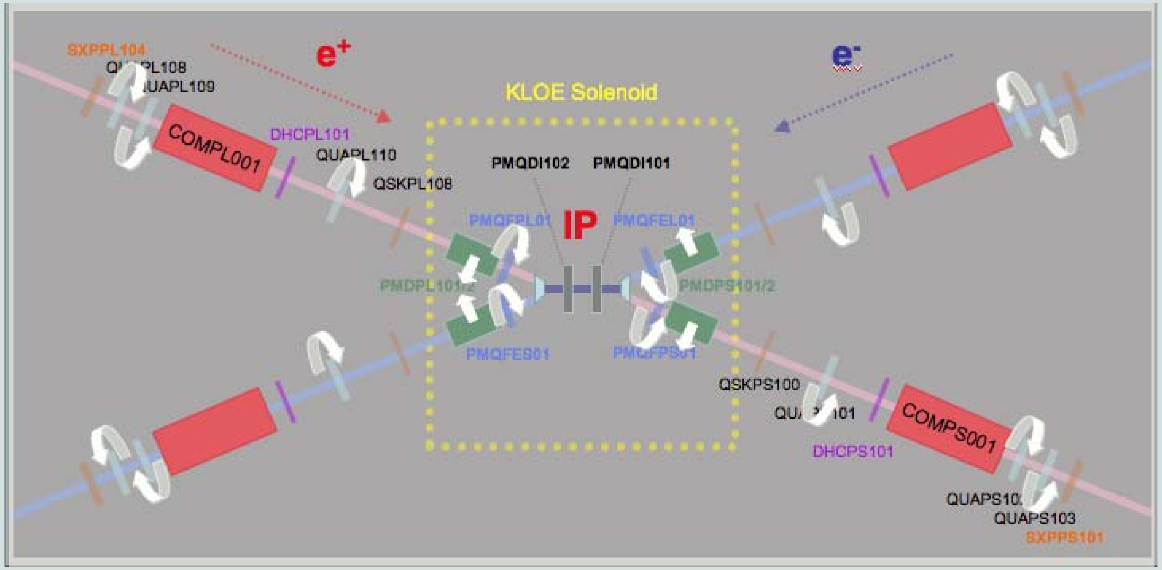
$$\int_{KLOE} B \cdot dl = 2.048 \quad [Tm] \quad \rightarrow \quad I_{KLOE} = 2300.[A]$$

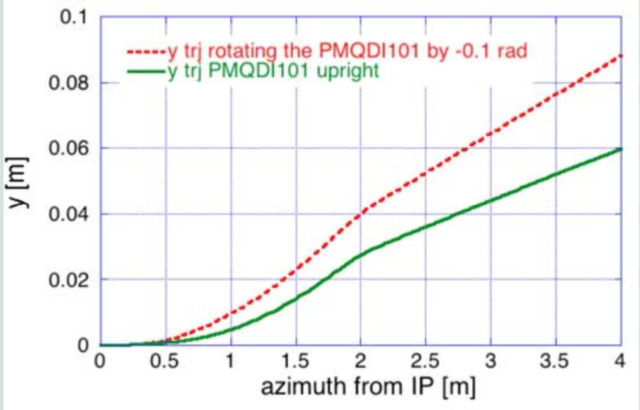
$$\int_{comp} B \cdot dl = \pm 1.024 \quad [Tm] \quad \rightarrow \quad I_{comp} = 86.7[A]$$

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)*

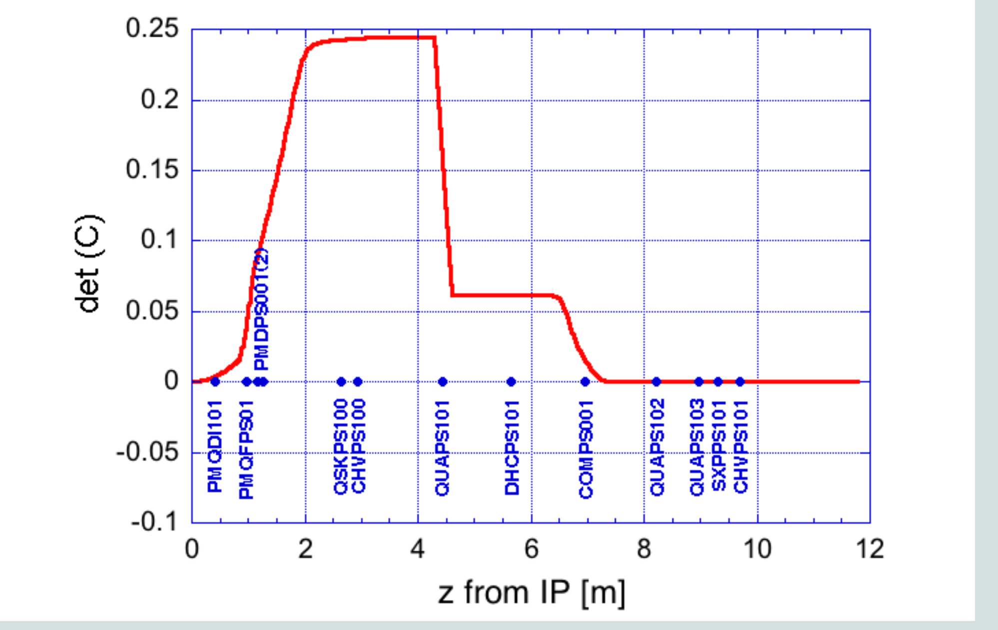
Fixed QUAD rotations
K is expected to be lower than for KLOE past
$K_{KLOE1} = 0.2 \div 0.3$ %



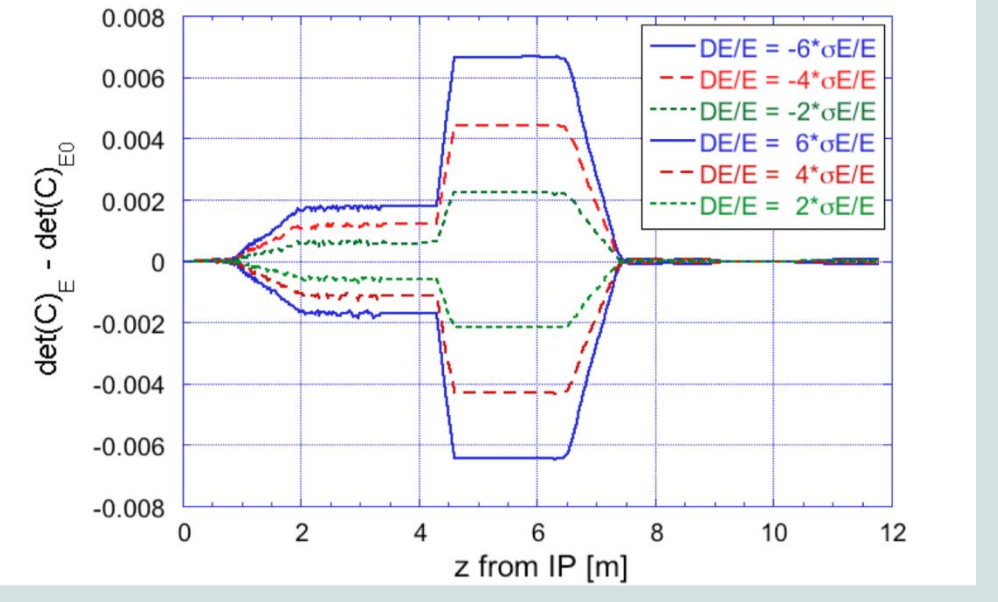


Coupling correction

Betatron coupling is carefully compensated before the CW sextupoles making the terms of the coupling matrix vanish at QUAPS103 in order to avoid any interference between the CW sextupoles and the coupling compensation scheme.



The relative deviation of the C determinant with respect to the nominal energy is within ±0.7% for energy deviations of $\pm 6 \cdot \sigma_E/E$ with $\sigma_E/E = 3.4 \times 10^{-4}$ and does not give any significant contribution neither at the IP nor at the CW sestupole



Permanent Magnet Dipole Assembly

ST

High luminosity interaction region design for collisions inside high field detector solenoid[1]

… and fundamental contribution of G. Sensolini

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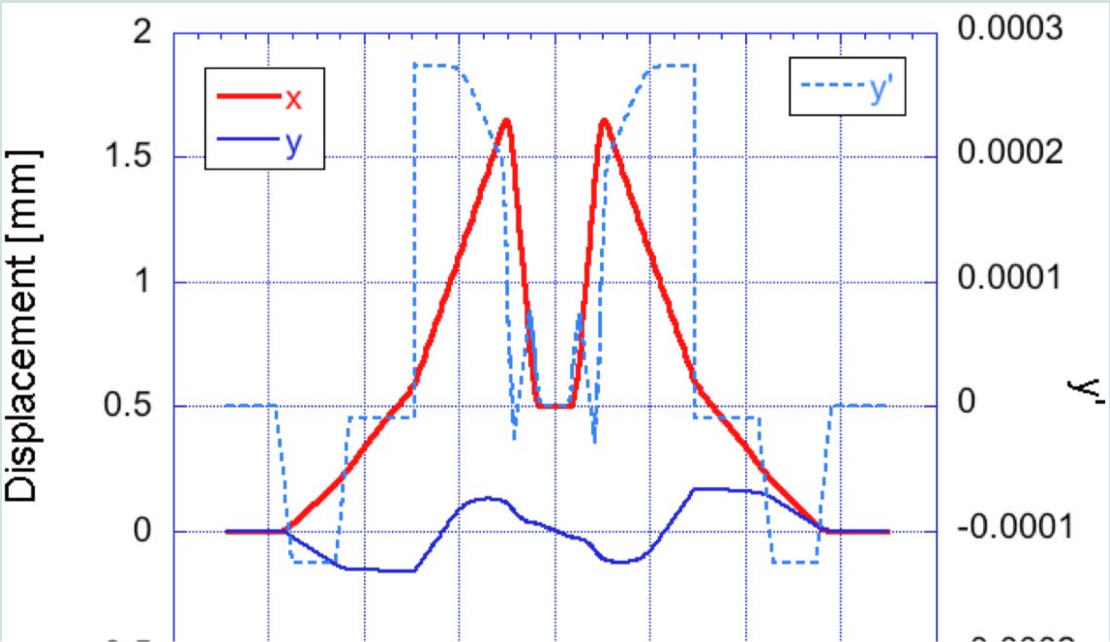
ABSTRACT: An innovative interaction region has been recently conceived and realized on the Frascati DAΦNE lepton collider. The concept of tight focusing and small crossing angle adopted to achieve high luminosity in multibunch collisions has evolved towards enhanced beam focusing at the interaction point with large horizontal crossing angle, thanks to a new compensation mechanism for the beam-beam resonances. The novel configuration has been tested with a small detector without solenoidal field yielding a remarkable improvement in terms of peak as well as integrated luminosity. The high luminosity interaction region has now been modified to host a large detector with a strong solenoidal field which significantly perturbs the beam optics introducing new design challenges in terms of interaction region optics design, beam transverse coupling control and beam stay clear requirements. Interaction region design criteria as well as the first luminosity results obtained with the beams in collision are presented and discussed.

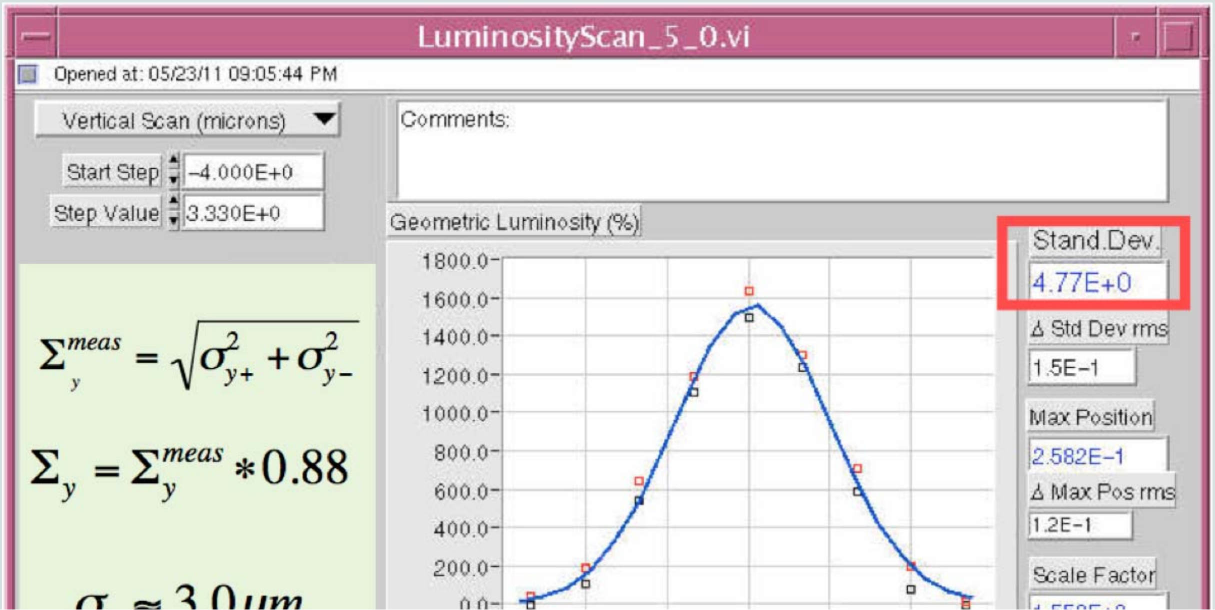
IP orbit bumps

Horizontal displacement bump at the IP must preserve the corresponding vertical oscillation in the IR, vertical displacement and its derivative at the IP must be equal to zero. The last issue is necessary to preserve the vertical overlap, which is quite demanding since DAΦNE works with flat beams

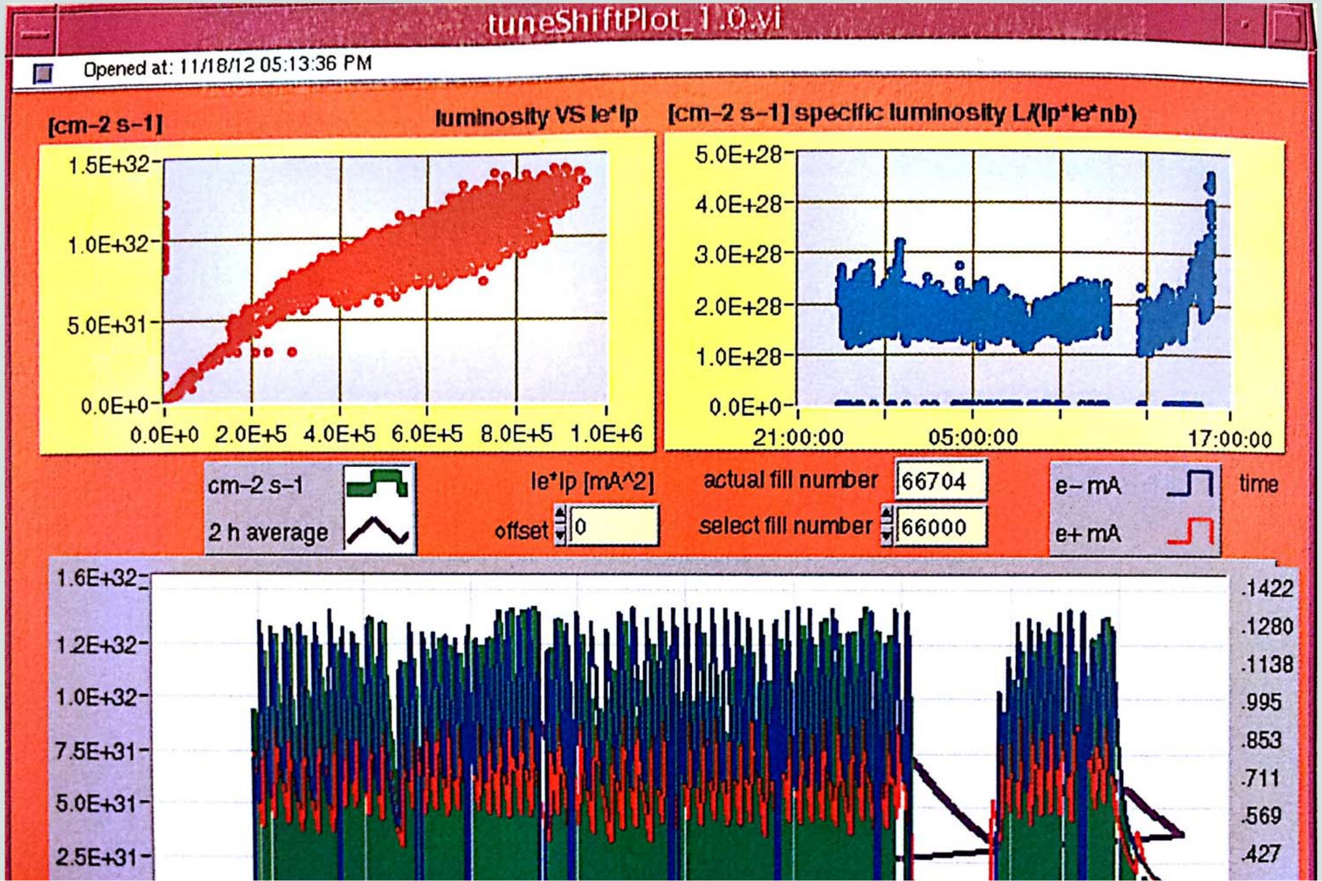


Vertical beam-beam scan

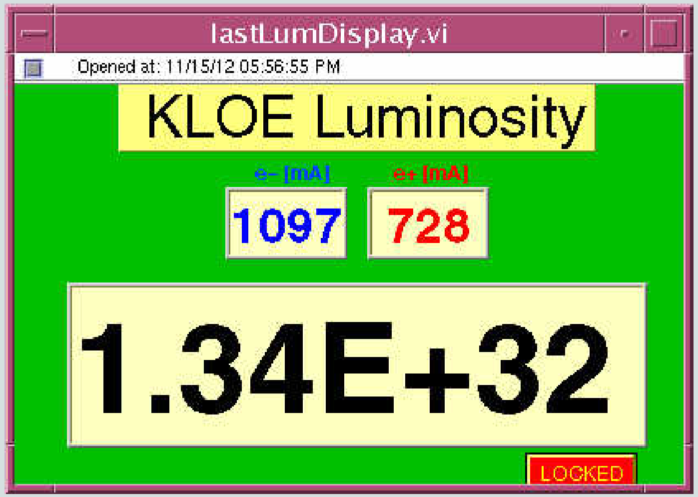
The convoluted vertical size of the colliding bunches at the IP measured by vertical beam-beam scan is σ_y = 3.0 mm (see Fig. 13), ~15% lower than the best measured in the past after a long optimization period and with a beam optics with the same β^*_y and natural emittance



Specific Luminosity at low current



Peak Luminosity



Nov. 21st 2012

Intermediate luminosity at the end of the electron injection

very imited σ_y blowup

$\tau^- > 1000$ sec

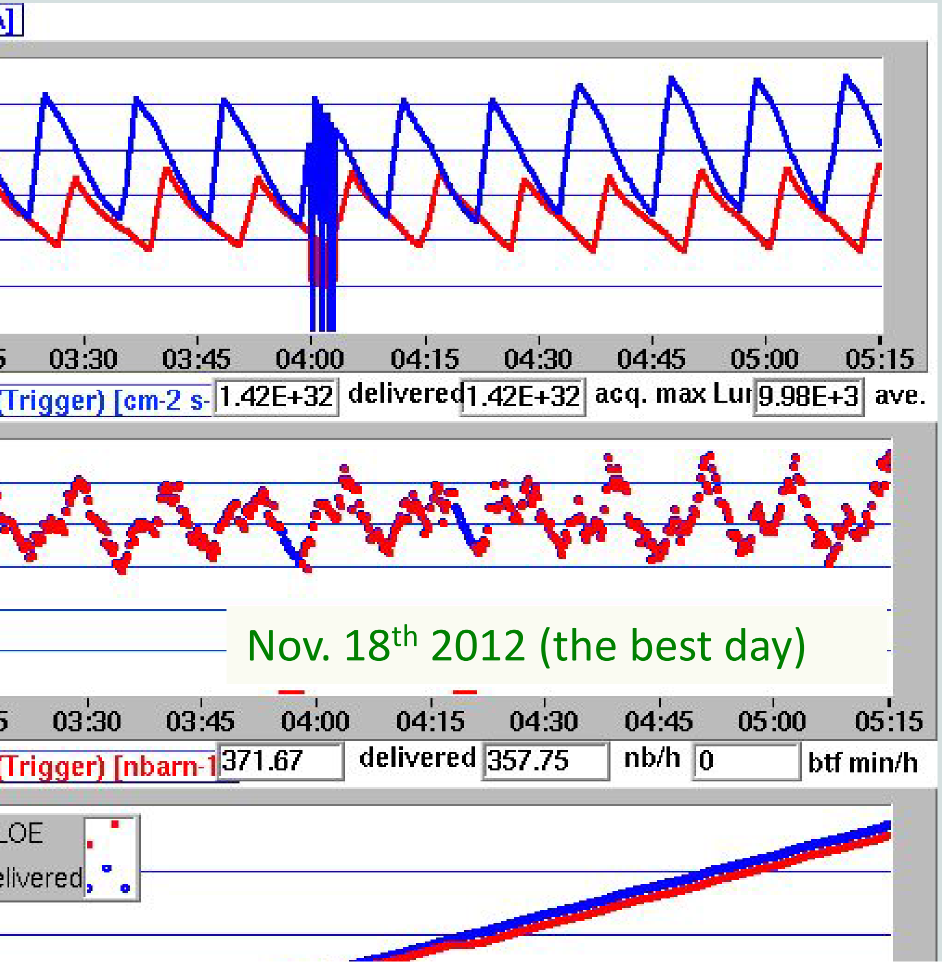
1.44E+32

$\boldsymbol{L}_{peak}$

102 bunches in collision

CW-Sextupoles set at half strength

Hourly integrated luminosity



$L_{\int 1\ hour} = 0.372\ pb^{-1}$

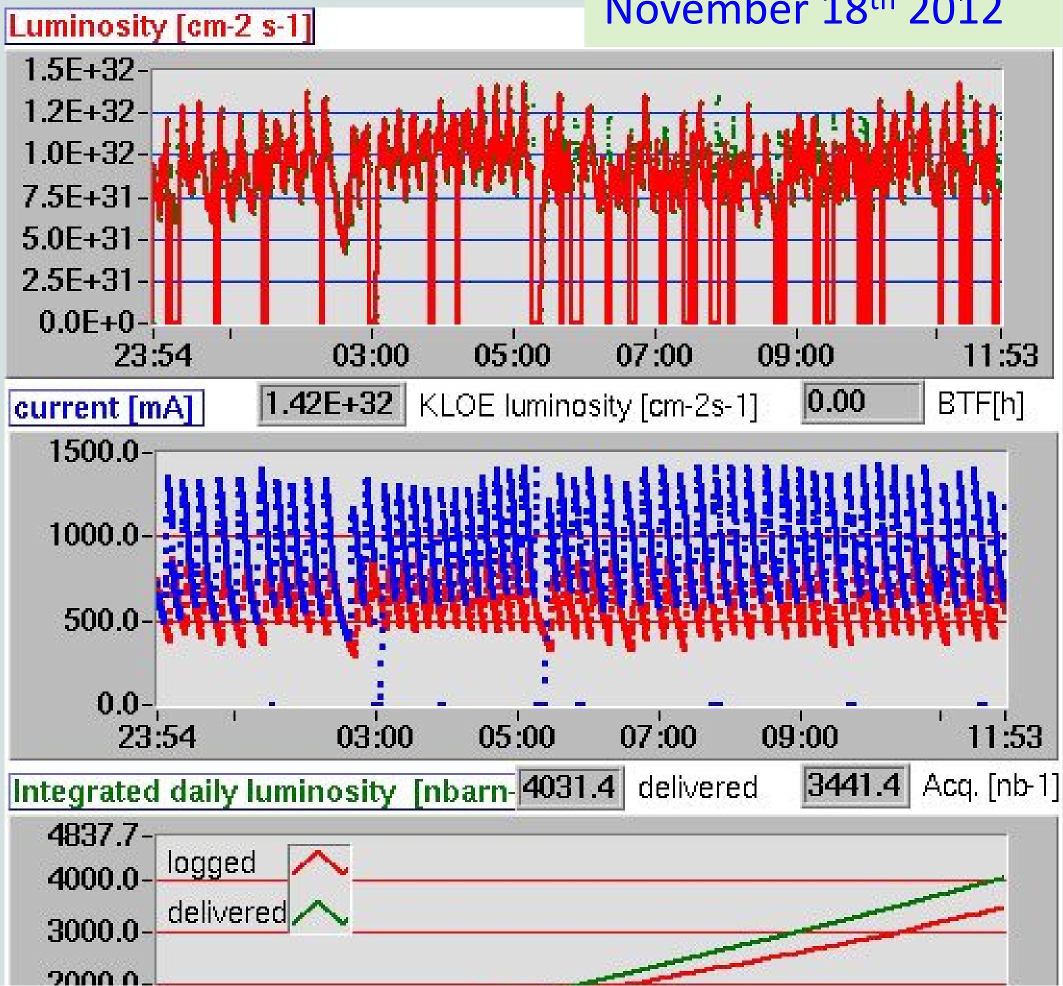
↓

$L_{\int day} = 8.9\ pb^{-1}$

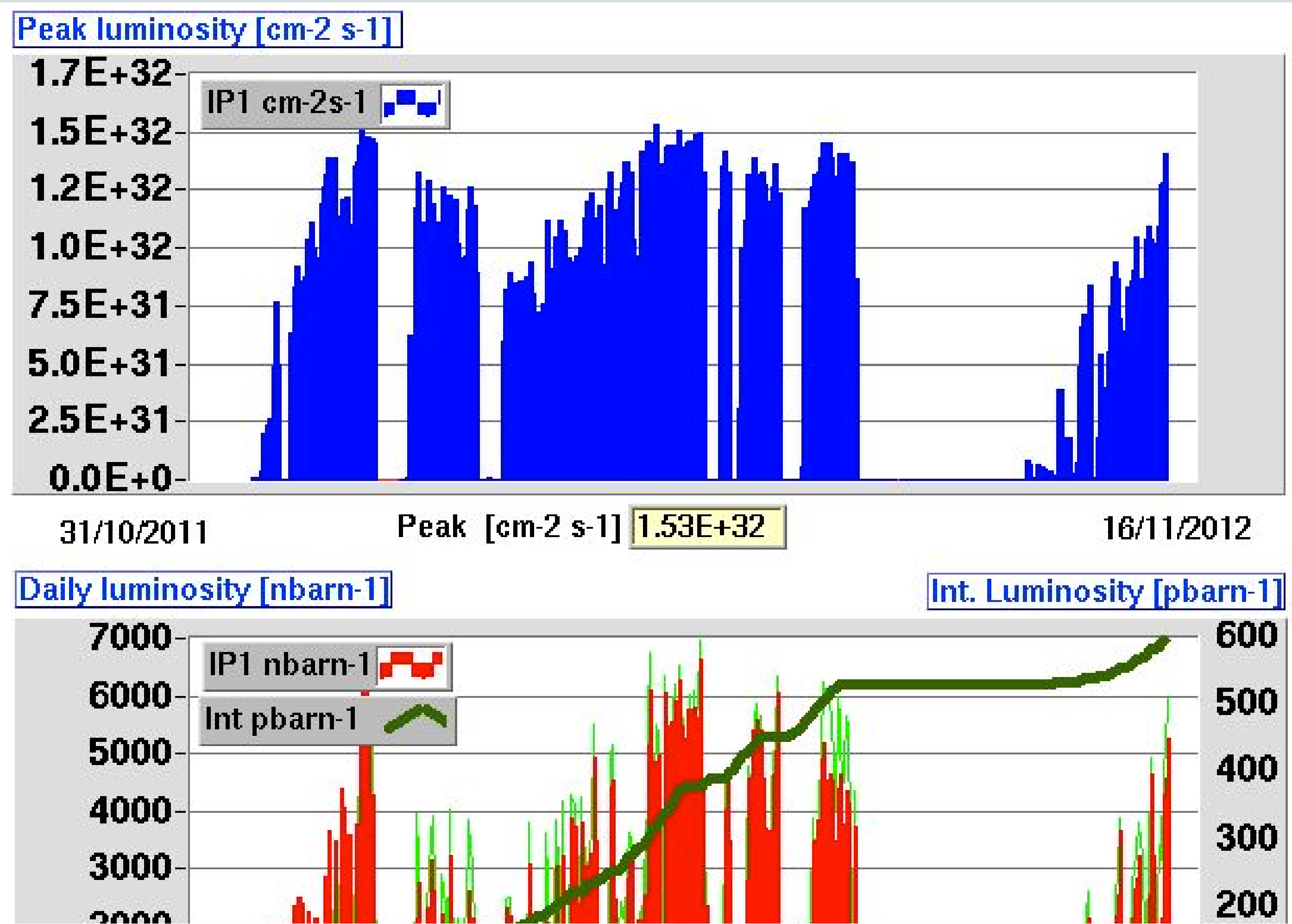
- *KLOE is taking data*
- *Aquired and delivered L are comparable*
- *L ... is the highest measured*

12 hours integrated luminosity

November 18th 2012



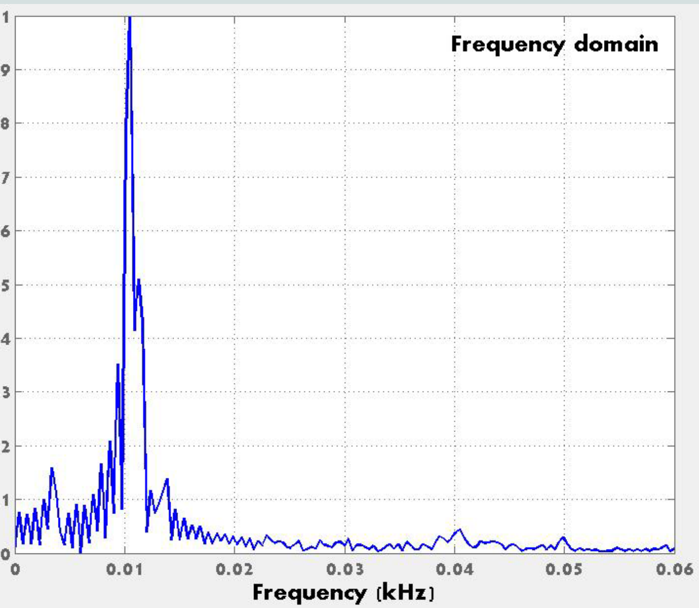
Luminosity History

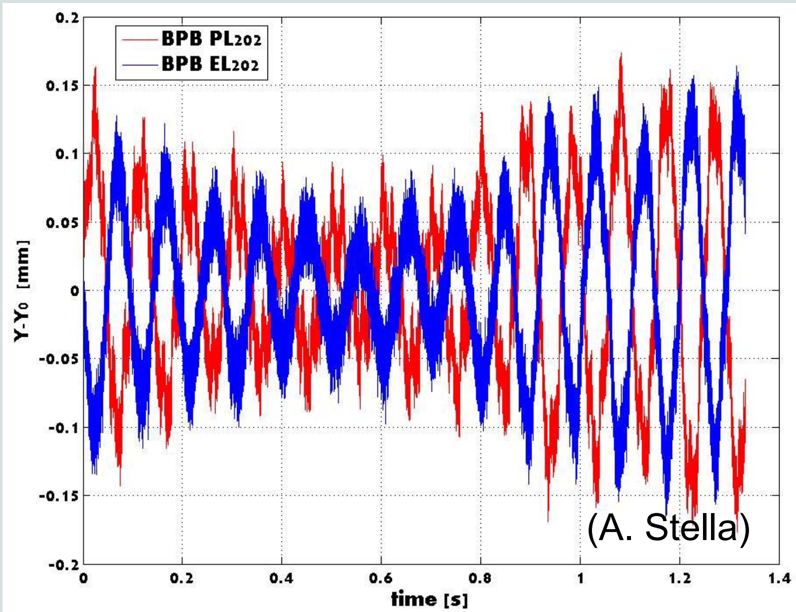


VERTICAL ORBIT OSCILLATION

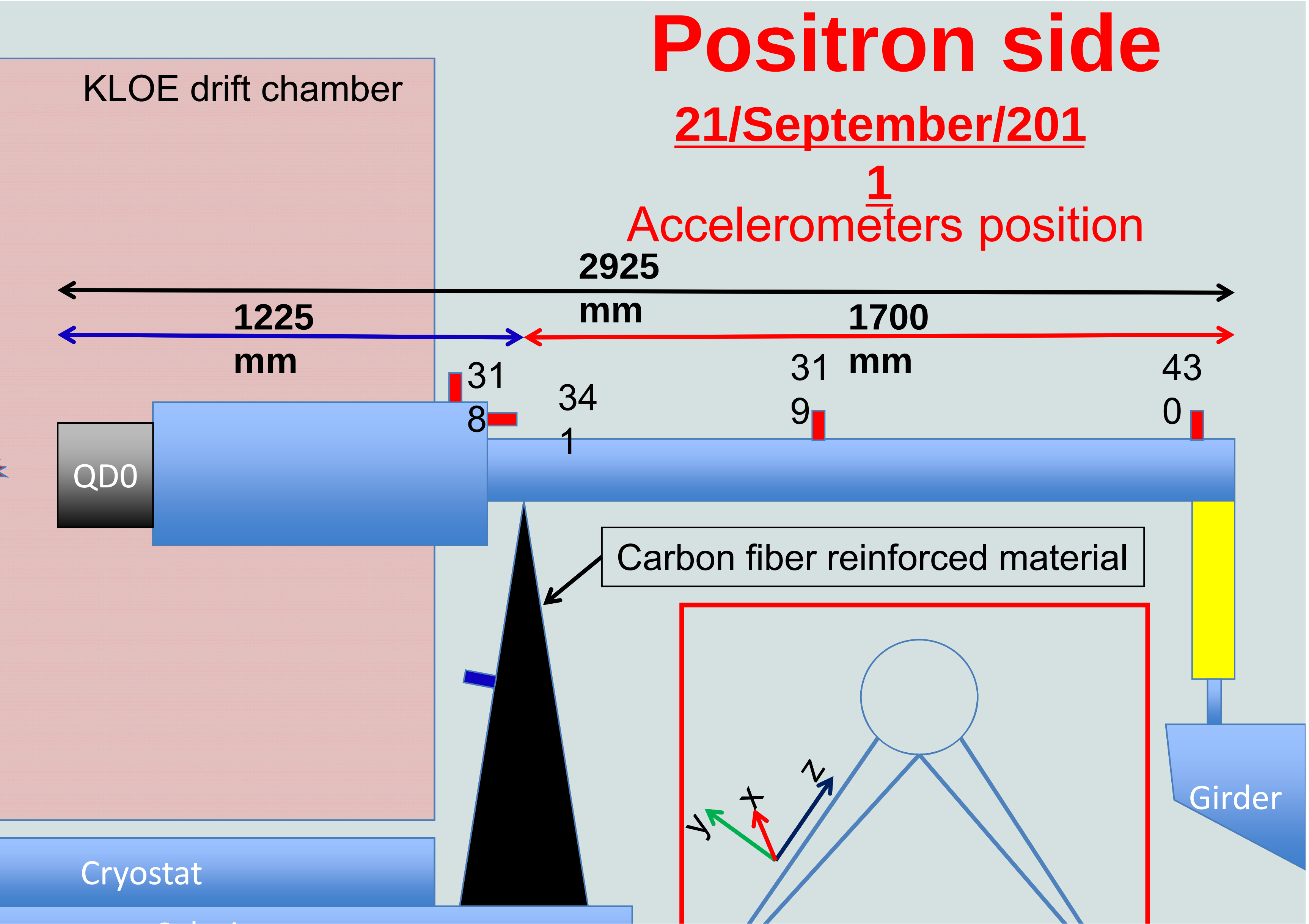
A random amplitude 10 Hz vibration has been observed on both beams which is compatible with a vibration in the defocusing low-beta quadrupoles. In fact when comparing the orbit variation for the two beams:

- ✓ it has the same amplitude
- ✓ The beam oscillations (red e+ blue e-) recorded in symmetric locations wrt the IP are opposite in phase indicating that the vibration source is $\pi/2$ in phase advance from the IP



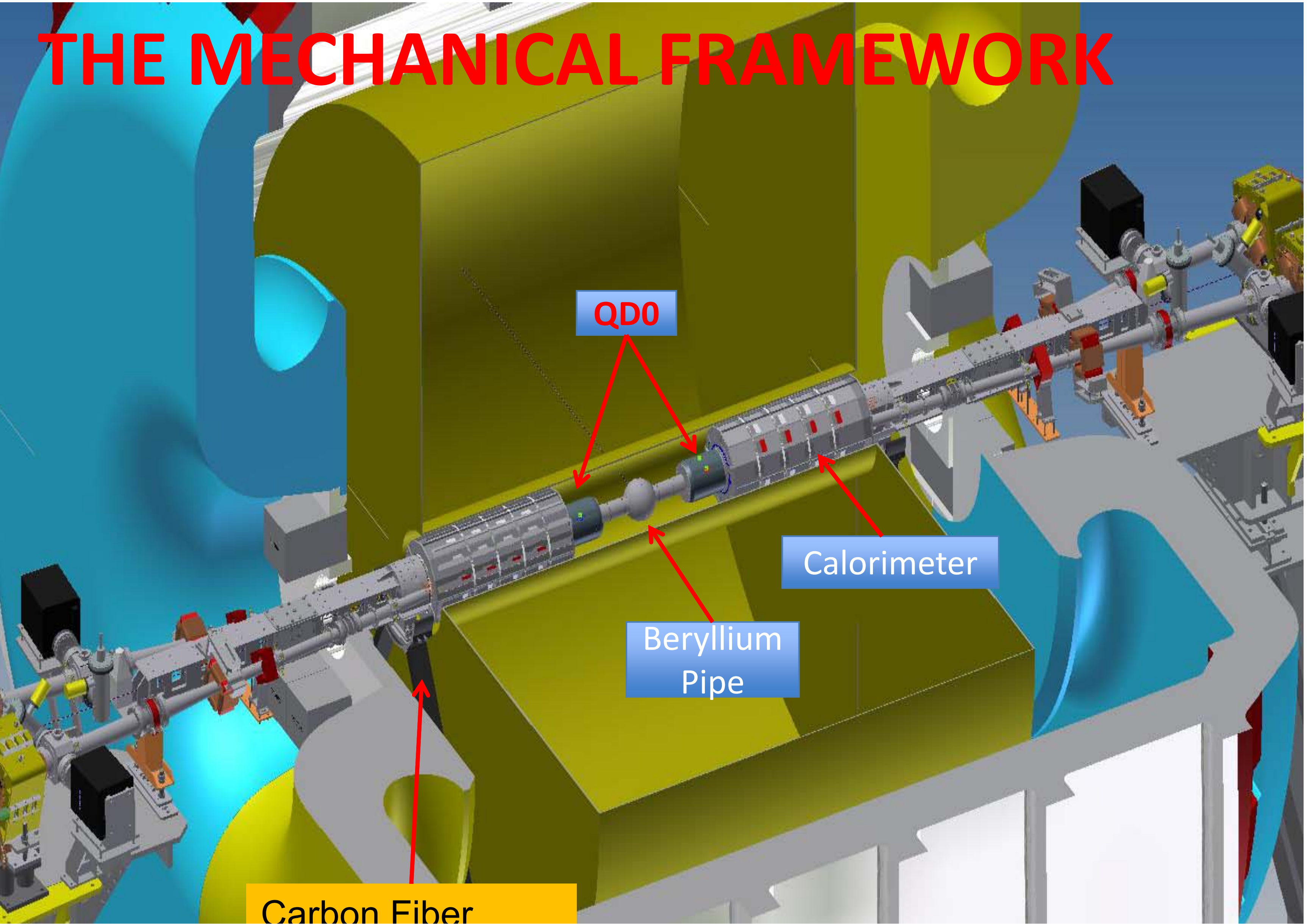


The vibration induces a vertical orbit displacement of the order of $1\sigma_y$

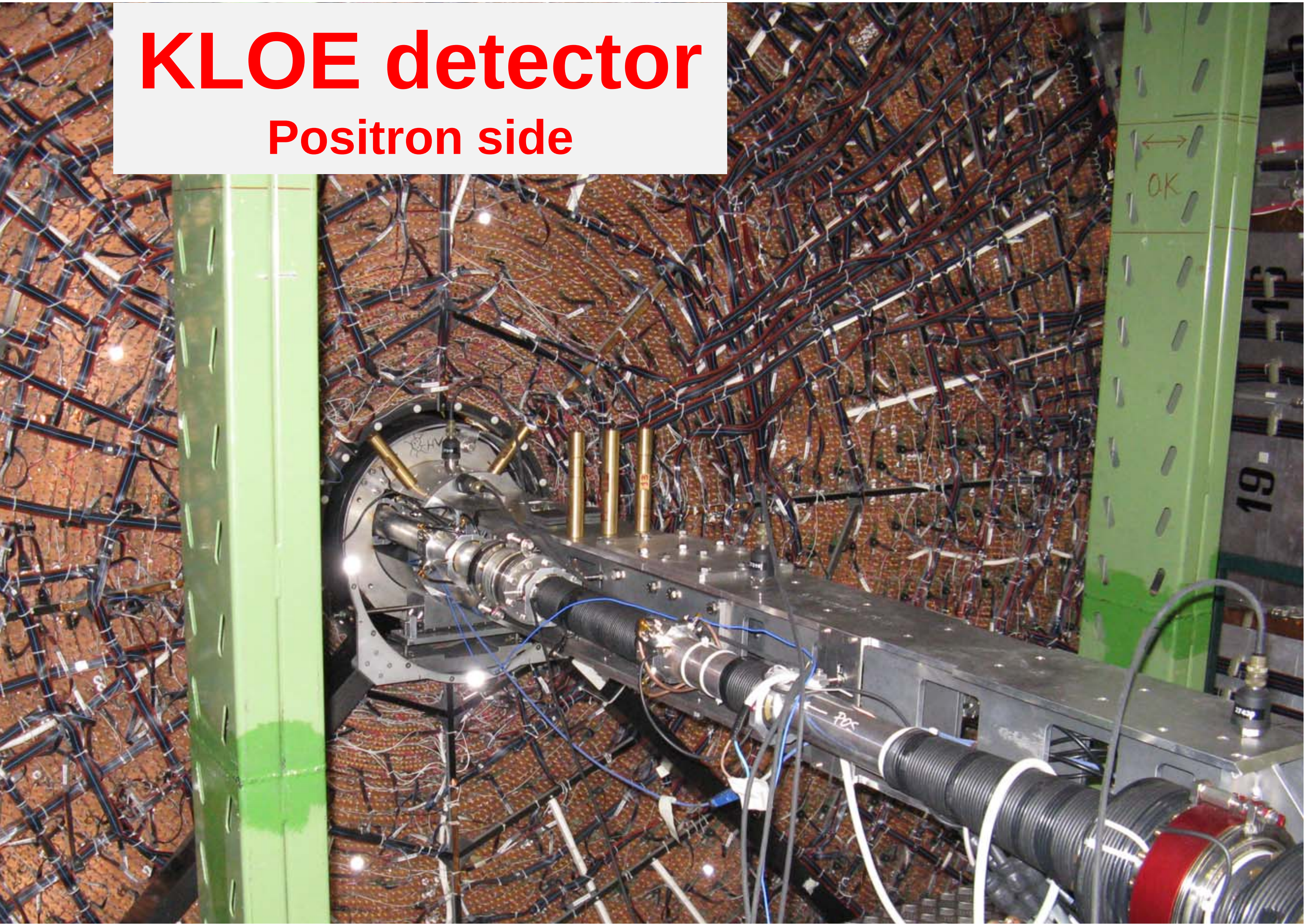


Positron side
21/September/2011
Accelerometers position
KLOE drift chamber
2925 mm
1225 mm
1700 mm
318
341
319
430
QD0
Carbon fiber reinforced material
y
x
z
Girder
Cryostat

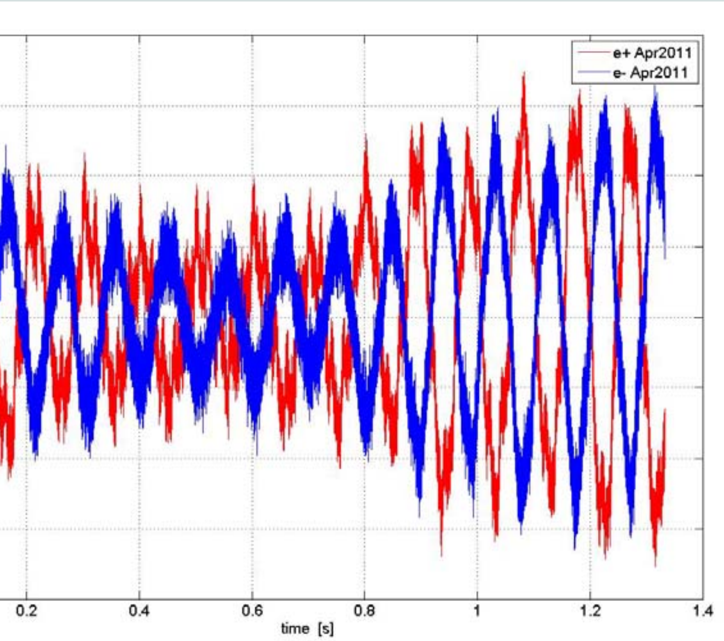
THE MECHANICAL FRAMEWORK

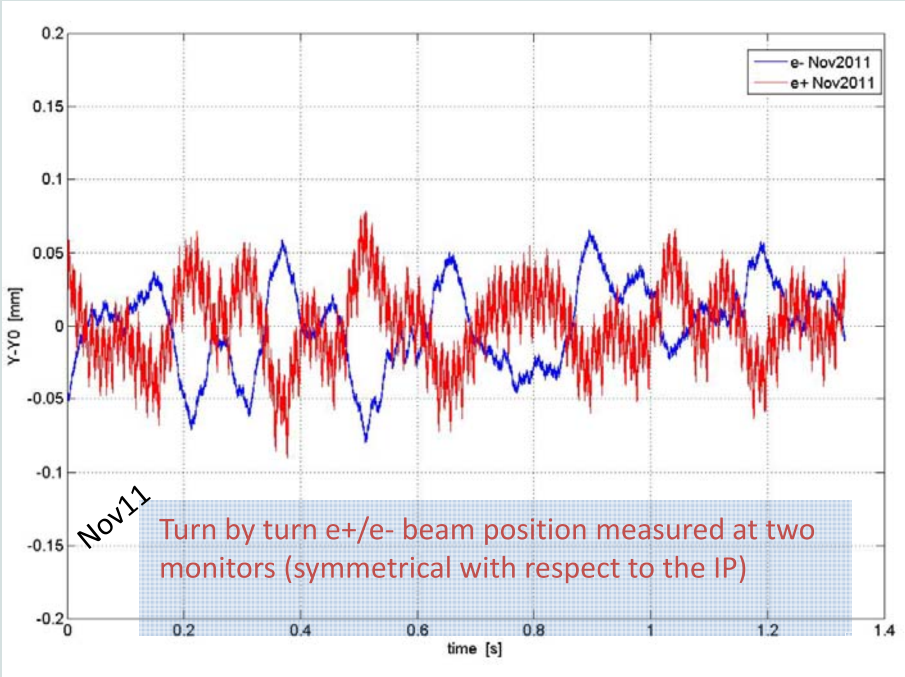


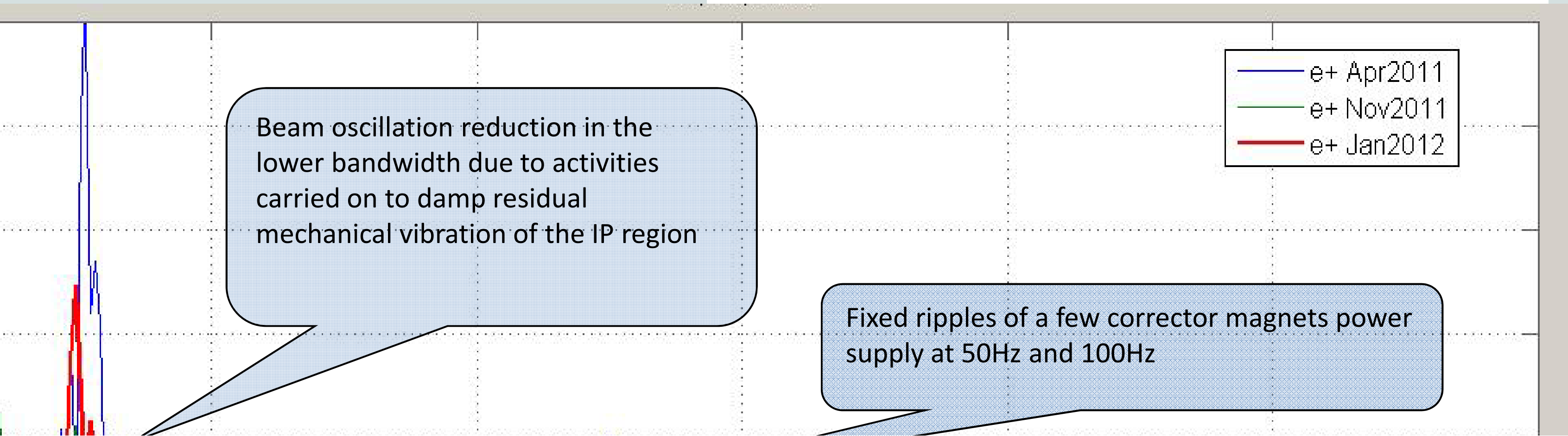
KLOE detector
Positron side



cal orbit oscillation

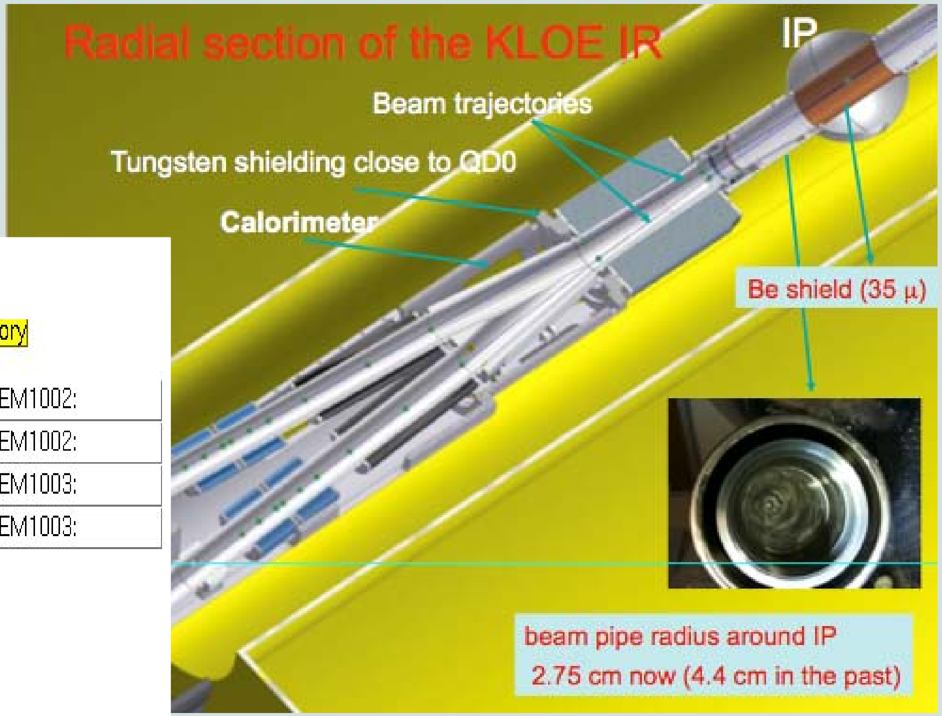




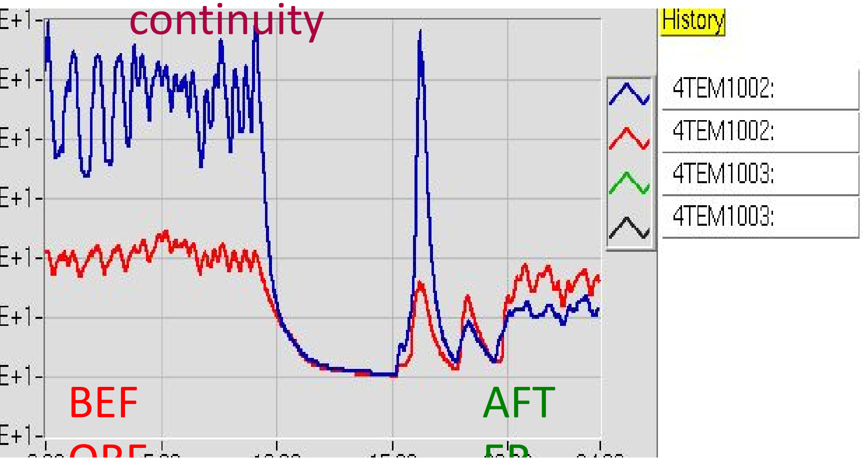


Electrical continuity in the IR

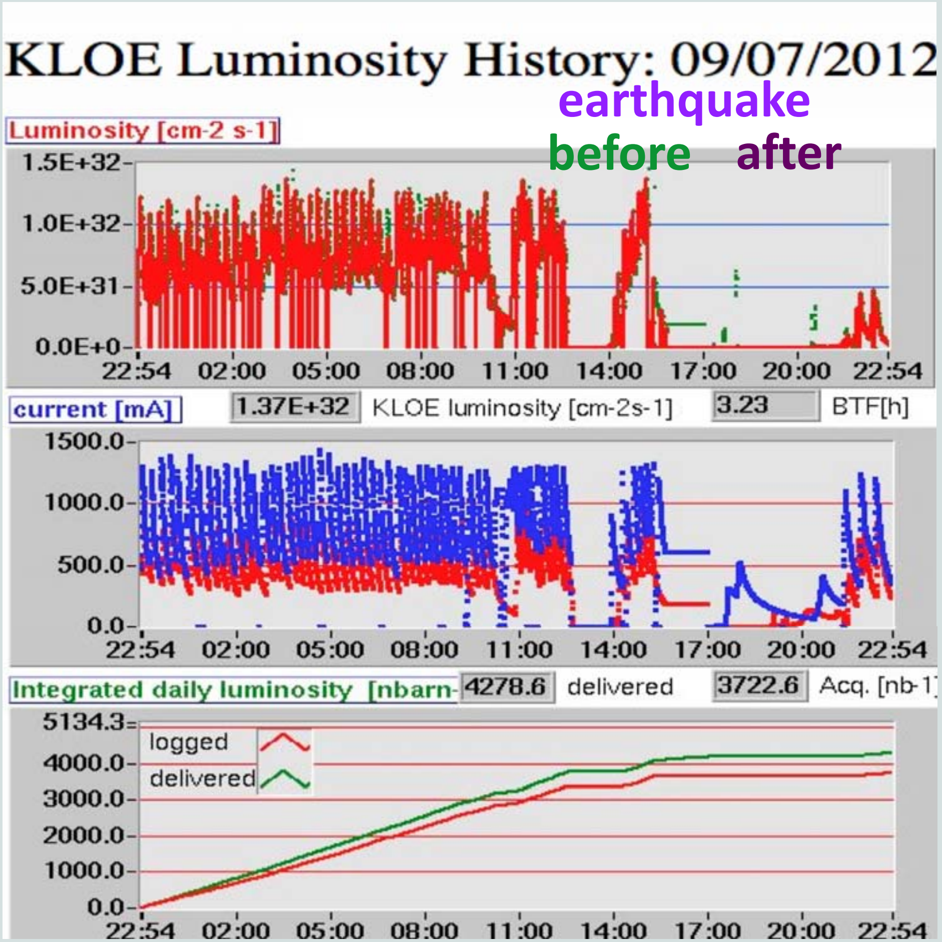
On mid January a sudden rise occurred in the temperature of the beam pipes inside the KLOE detector due to the leak of electrical continuity in the bellows at both ends of the section common to the two beams.



Restoring electrical continuity



Alignment



KLOE Luminosity History: 09/07/2012
earthquake
before
after
Luminosity [cm-2 s-1]
1.5E+32
1.0E+32
5.0E+31
0.0E+0
22:54 02:00 05:00 08:00 11:00 14:00 17:00 20:00 22:54
current [mA]
1.37E+32
KLOE luminosity [cm-2s-1]
3.23
BTF[h]
1500.0
1000.0
500.0
0.0
22:54 02:00 05:00 08:00 11:00 14:00 17:00 20:00 22:54
Integrated daily luminosity [nbarn-
4278.6
delivered
3722.6
Acq. [nb-1]
5134.3
4000.0
3000.0
2000.0
1000.0
0.0
logged
delivered
22:54 02:00 05:00 08:00 11:00 14:00 17:00 20:00 22:54

Summer shutdown (July 15th ÷ September 3rd 2012)

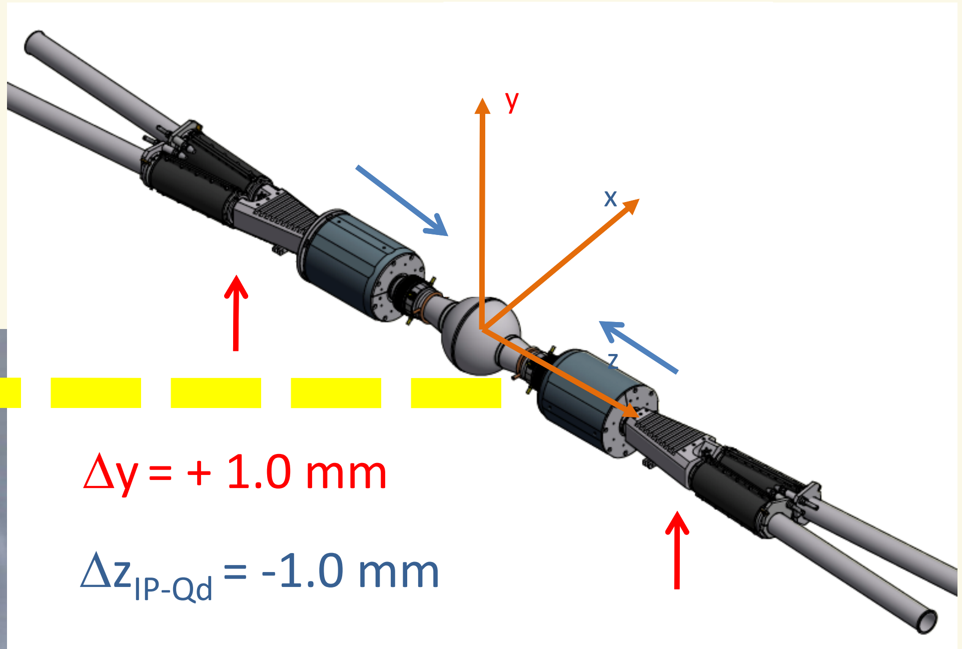
Summer shutdown has been anticipated to:

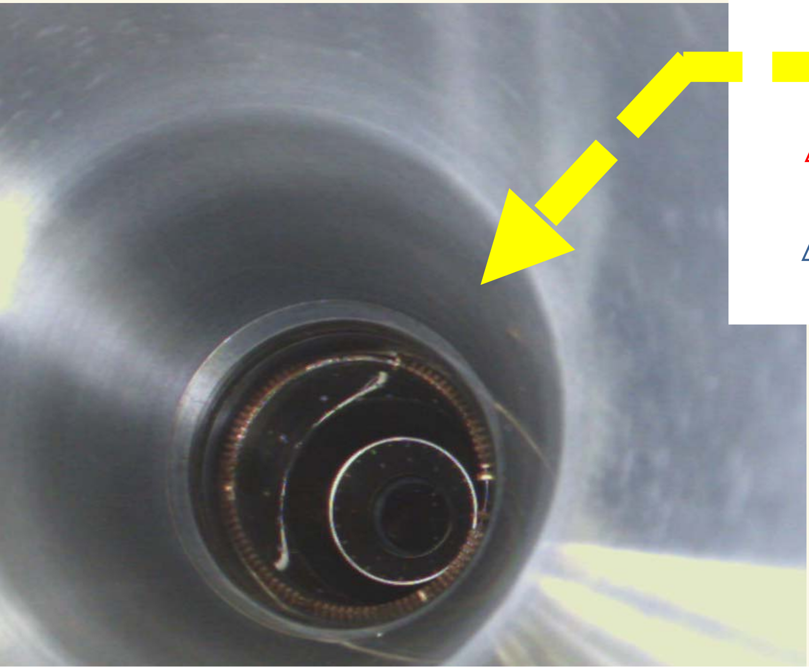
- perform an accurate position measurement of the low-β and of the electromagnetic quadrupoles in the IR
- Investigate the problem related to the eating in the IP vacuum chamber
- recover the proper vacuum condition
- align the low-β

Functionality of the low level system supervisor has been restored by using part from another broken equipment

Summer shutdown

neasurement and alignment





Endoscopic inspection of the low-β vacuum chamber

- 1 bellow is broken

IR mechanical update

Special component modification

Spherical vacuum chamber transitions

- Drawing to be finalized
- Welding tests by using the electron beam techniques are under way
- New beryllium shields already ordered

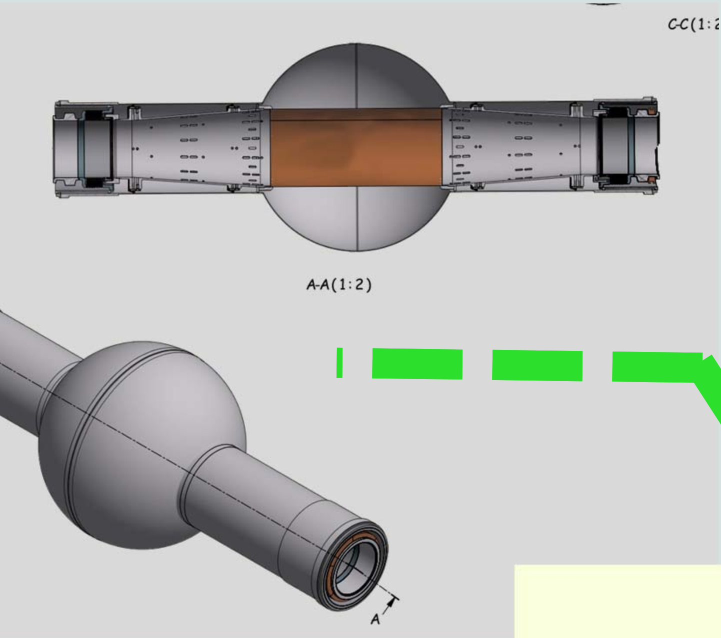
IR support modification

- Drawing to be finalized
- Compatibility between the new cylinders supporting the inner-tracker and the collider services has been studied and defined
- TT beam modification to improve stiffness

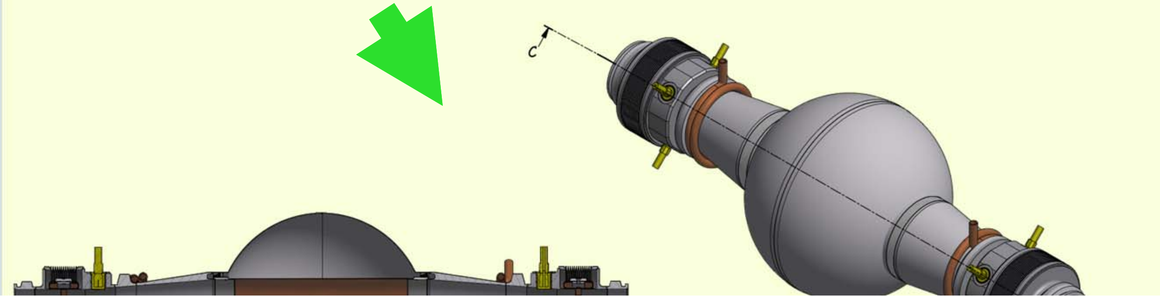
New mechanical controls for the rotation of the low-β Q_F

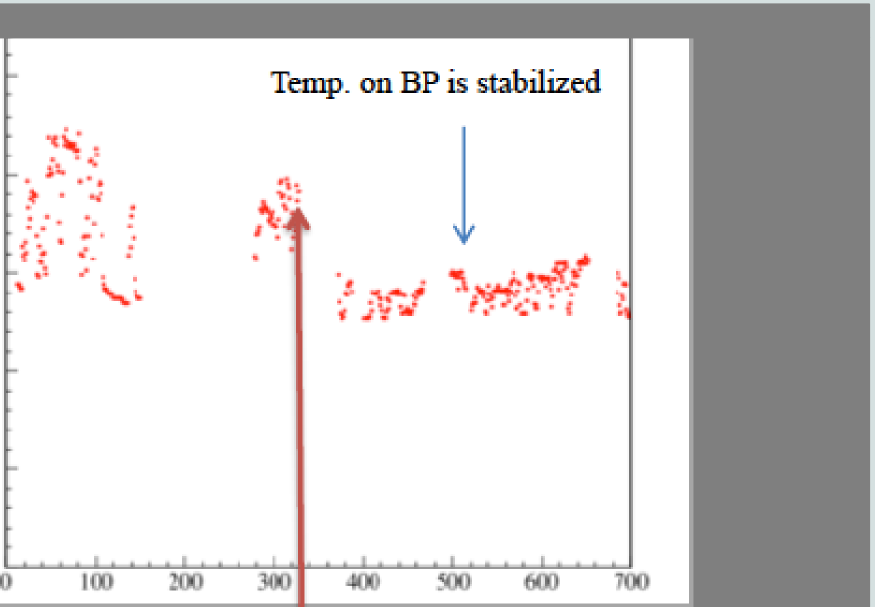
Integration between the KLOE and the DAFNE activities has been

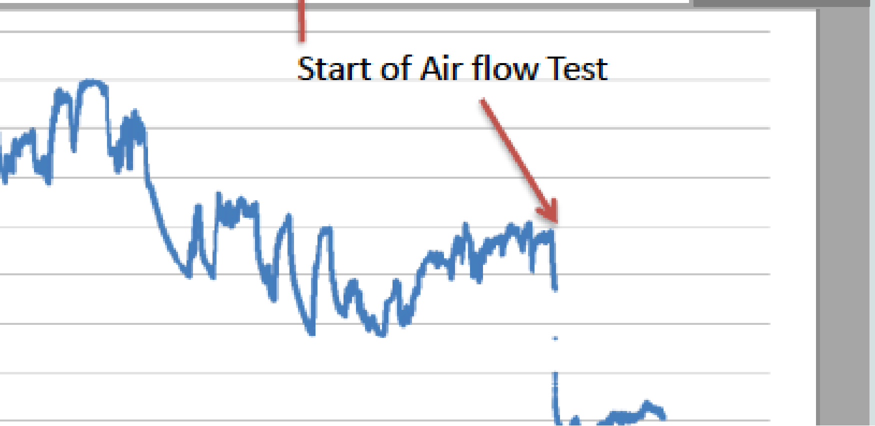
Spherical vacuum chamber evolution

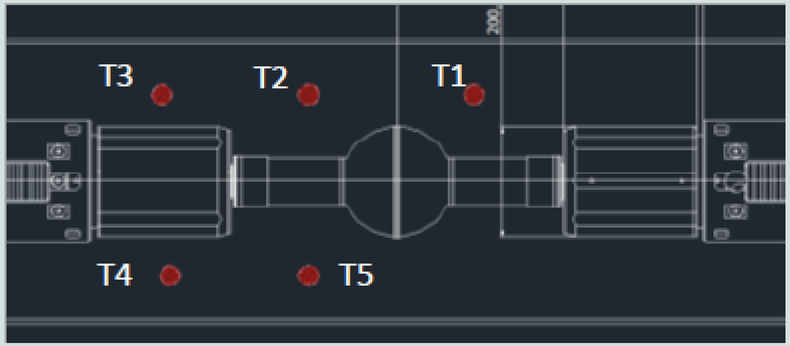


- Single vacuum chamber tapered
- New bellows with improved design
- 2 BPMS around the IP
- water cooling added
- New beryllium screens




Temp. on BP is stabilized
0
100
200
300
400
500
600
700


Start of Air flow Test


200
T3
T2
T1
T4
T5

- **SmCo magnets** experience a modification of Br with the temperature of the order of $4*10^{-4}/^{0}C$
- 30^{0} variation in the temperature of the low-β Q_D produces a 1% change in the gradient
- Before summer shutdown excursion in the range 50 ÷ 60 ^{0}C were observed with the beam current!!
- This effect caused optics non reproducibility and the relevant vertical tune variations (Δq_2 ~ 0.04) observed before summer

Standard Characteristics

Items			Materials	R26HS	
				C//	C⊥
Magnetic Properties	Remanence B_r		[T]	1.02 ~ 1.12	
			[G]	10200 ~ 11200	
	Coercivity	H_{cB}	[kA / m]	716 ~ 844	
			[Oe]	9000 ~ 10600	
		H_{cJ}	[kA / m]	1432 ~	
			[Oe]	18000 ~	
	Maximum Energy Product $(BH)_{max}$		[kJ / m^3]	191 ~ 239	
			[MGOe]	24 ~ 30	
	Recoil Permeability μ_r		[-]	1.02	
Temperature Properties	Thermal Coefficient of B_r		[% / K]	- 0.04 *1	
	Thermal Coefficient of H_{cJ}		[% / K]	- 0.20 *2	

IR mechanical update

Special component modification

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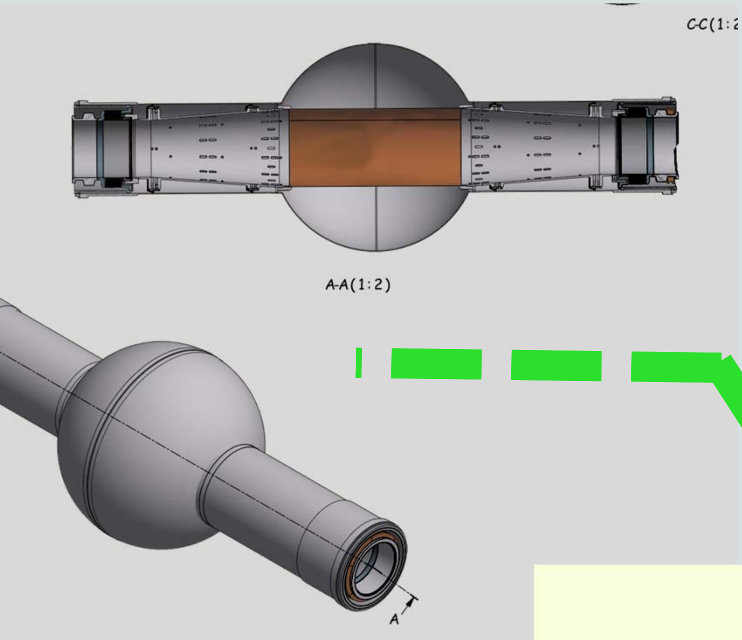

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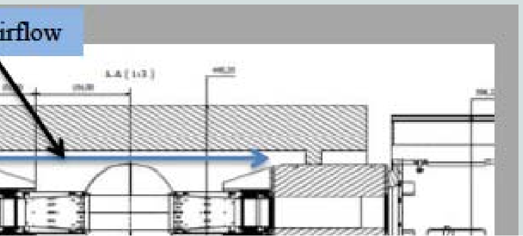
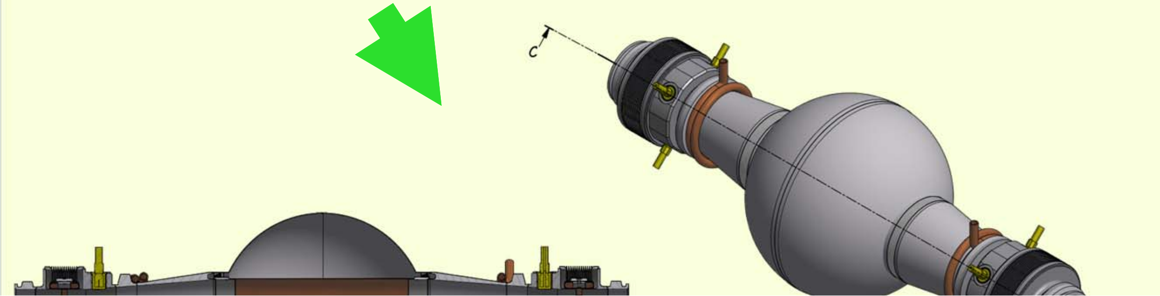
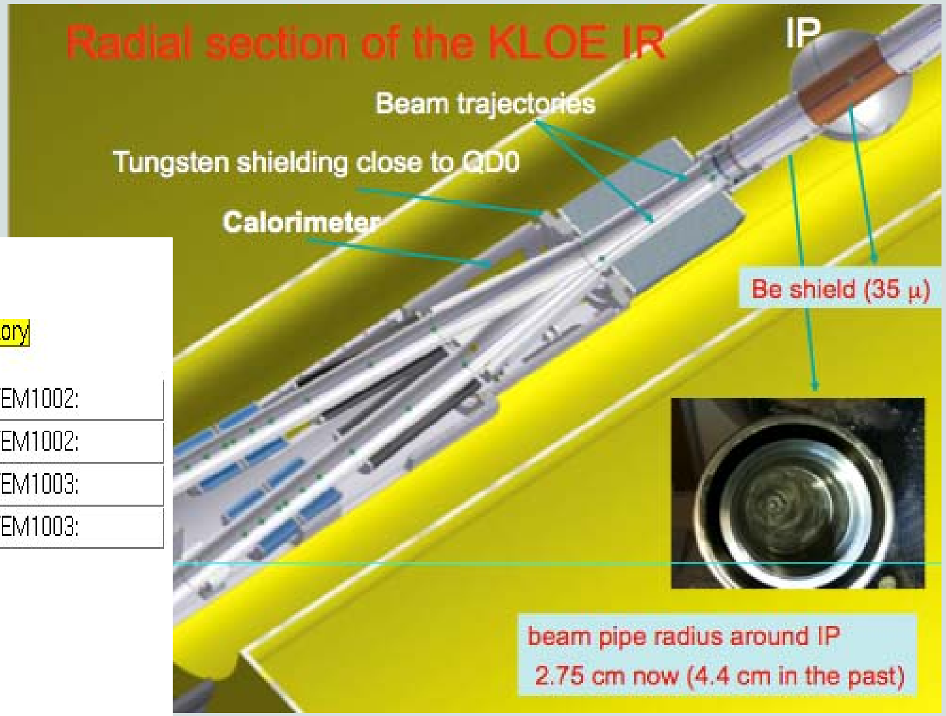


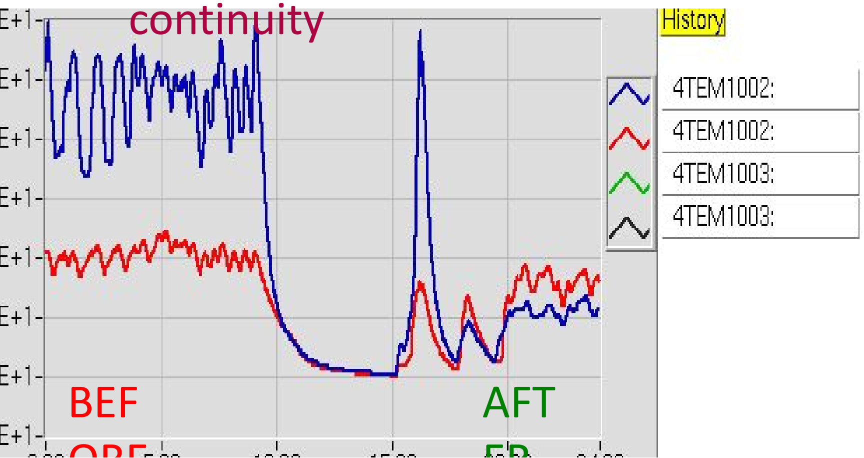


Electrical continuity in the IR

On mid January a sudden rise occurred in the temperature of the beam pipes inside the KLOE detector due to the leak of electrical continuity in the bellows at both ends of the section common to the two beams.



Restoring electrical continuity



Conclusions

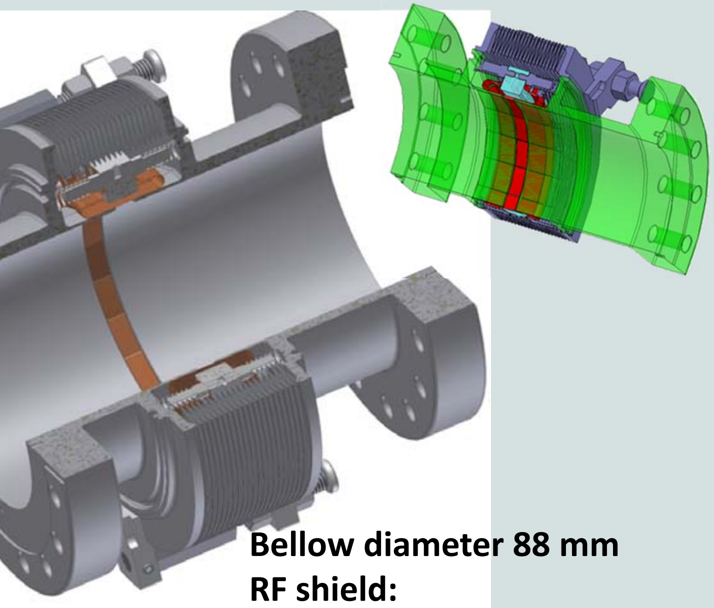
sed on large crossing angle and Crab-Waist compensation of the beam-
n interaction is operative on DAΦNE

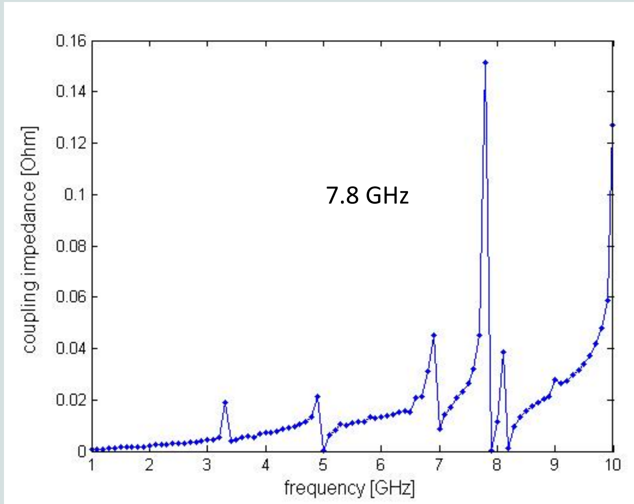
isfies the design requirement in terms of optics and betatron coupling
pensation

ational experience has pointed out same limitations concerning mainly the
hanical design. These aspects will be fixed and/or improved during the next
down necessary to install the inner tracker of the KLOE-2 detector

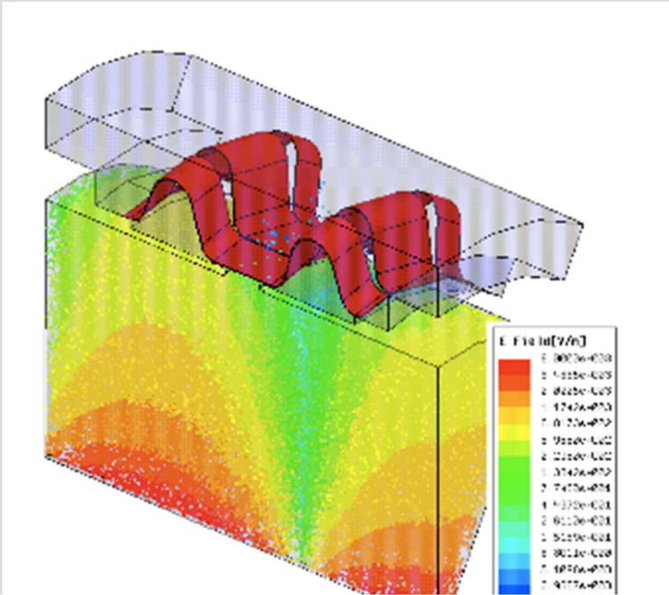
Thank you for your attention

Ω Shielded Bellows





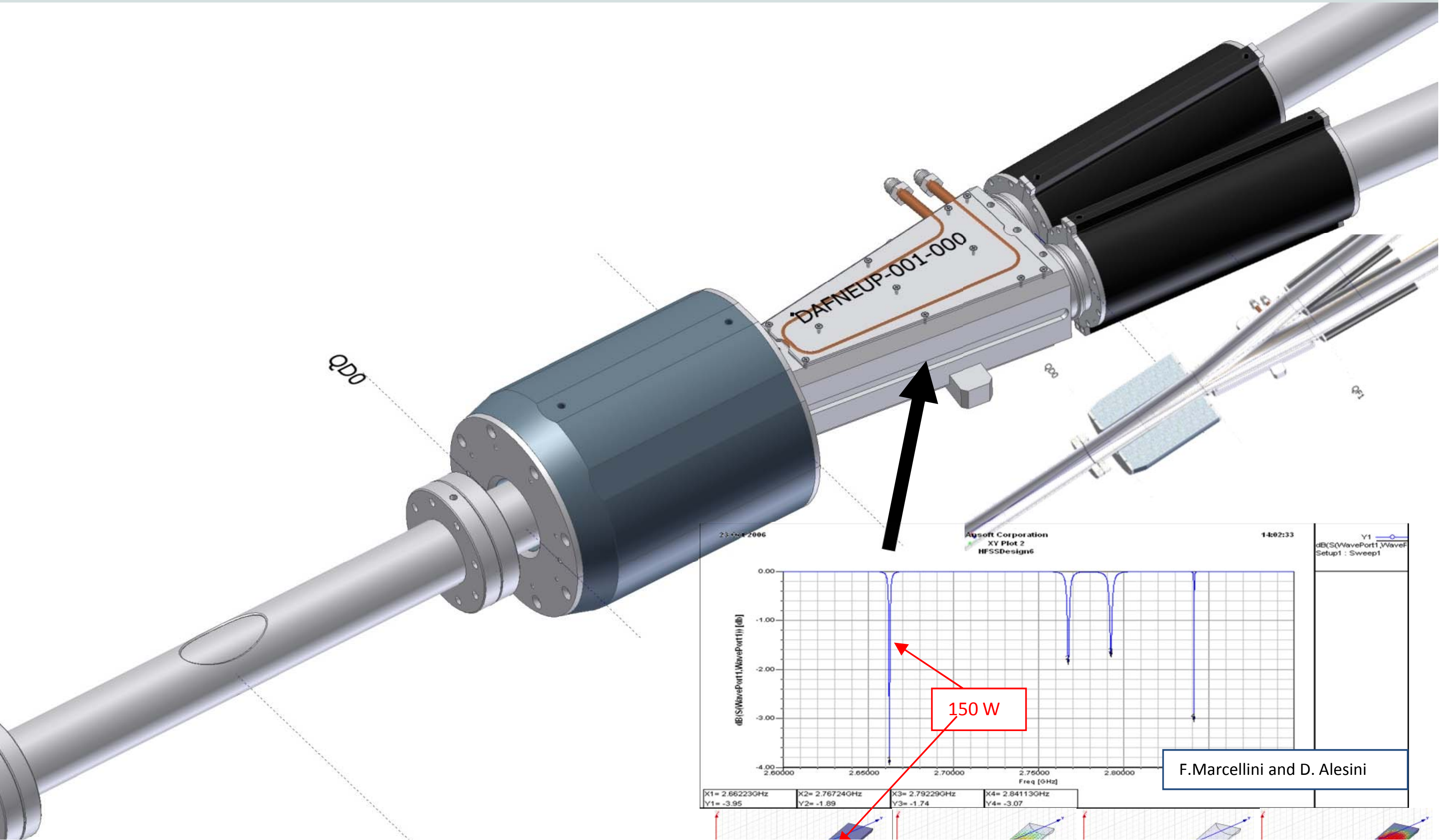
Bellow diameter 88 mm
RF shield:
Axial working stroke = ±7 mm
Radial offset = ±3 mm



ng based on Be-Cu Ω strips 0.2 mm thick
impedance and improved mechanical
cations

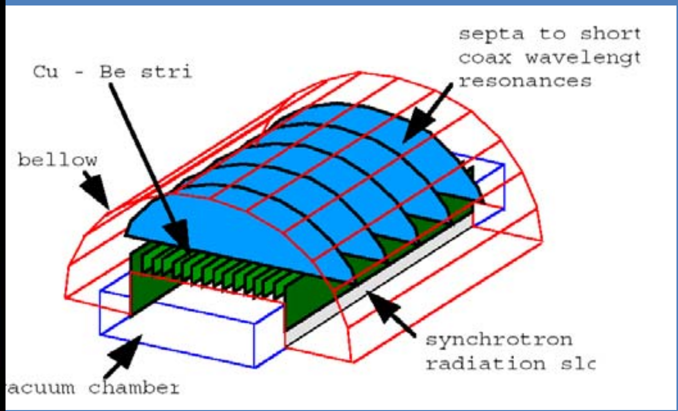
imulation

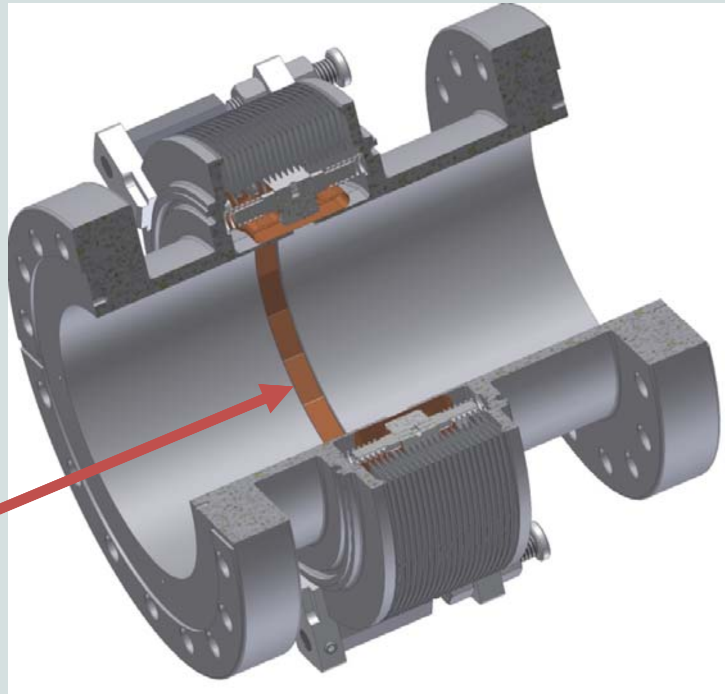
Y shaped vacuum chamber



NEW BELLOWS

OLD BELLOW





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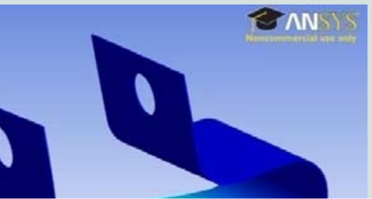
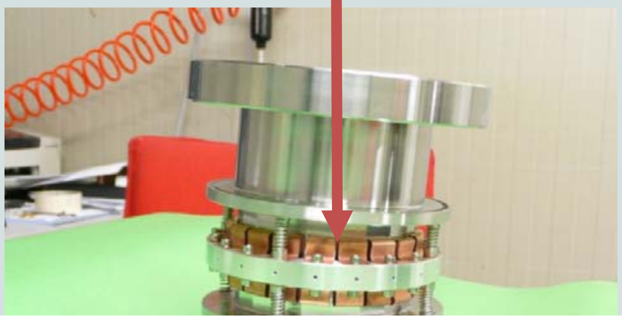
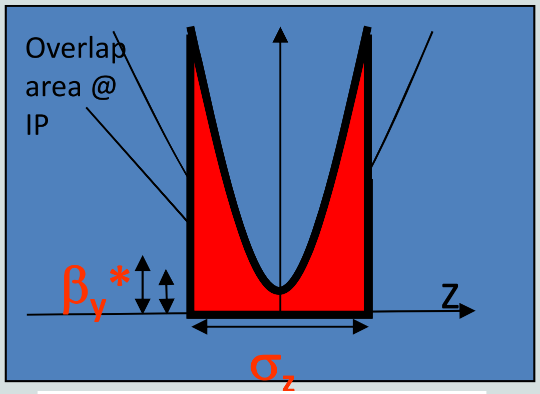


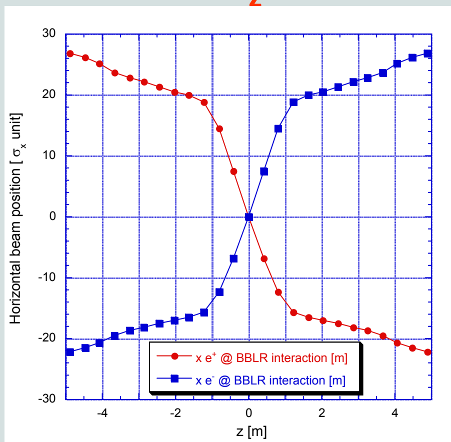


Rationale for the Upgrade

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



- β^*_y ~ σ_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

Large Piwinski angle

ge Piwinski angle Φ obtained by:

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

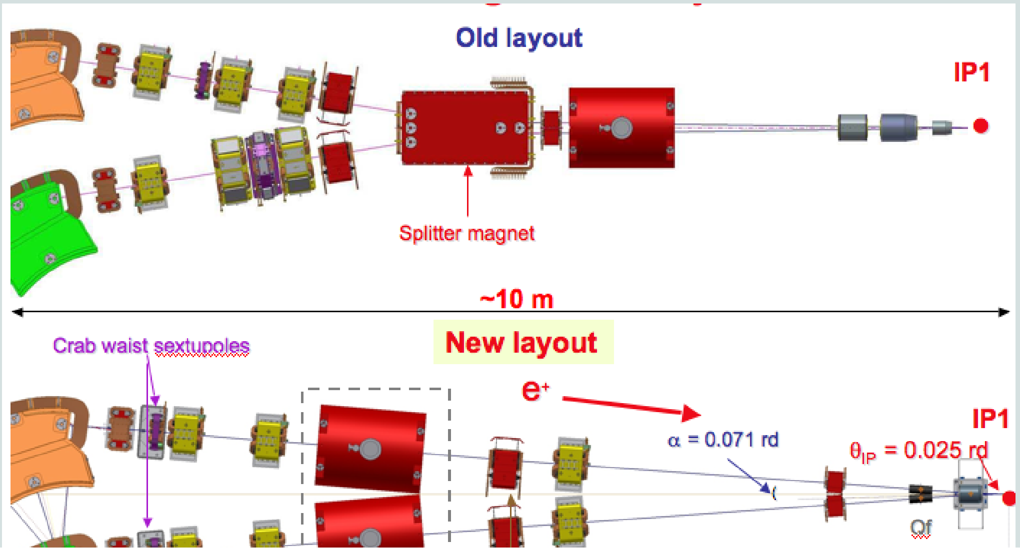
small σ_x
large θ

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

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

R magnetic layout

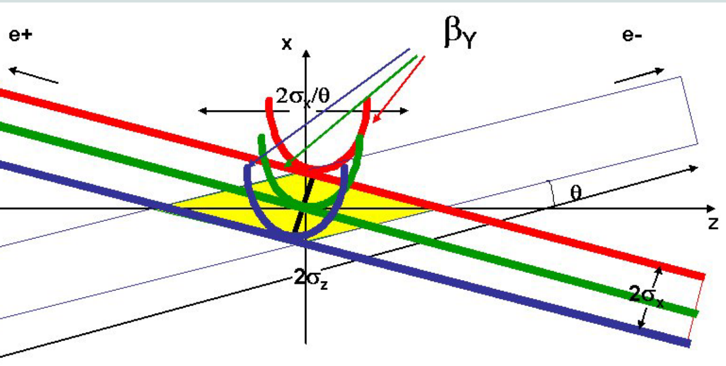
magnets and compensator
ds removed
w-β
dipols around IP rotated
ollision angle ~ 50 mrd
type corrector dipoles used to
he vacuum chamber in the arc



Lower β^*_y possible

β_y^* in fact the bunch overlap lenght Σ is:

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



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

v low-β section

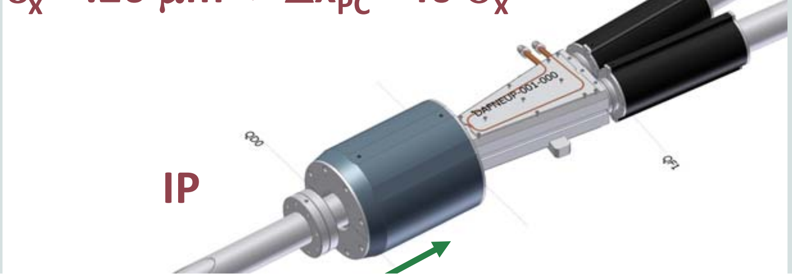
v-beta section based on PM QUADs:

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

K_{QF} = 12.6 [T/m]

Only 1 parasitic crossing

ε_x ~ .26 μm -> Δx_{PC}~ 40 σ_x



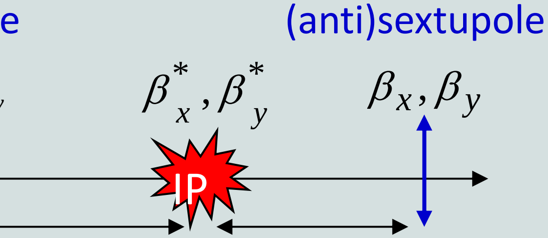
Crab-Waist compensation

llision with large Φ is not a new idea .....

ab-Waist transformation is !

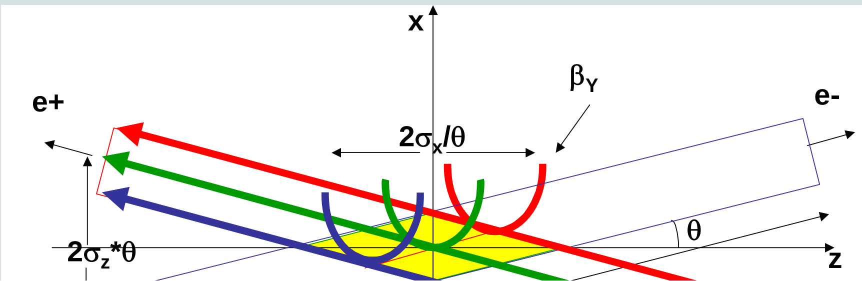
'aimondi et al., 2006)

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

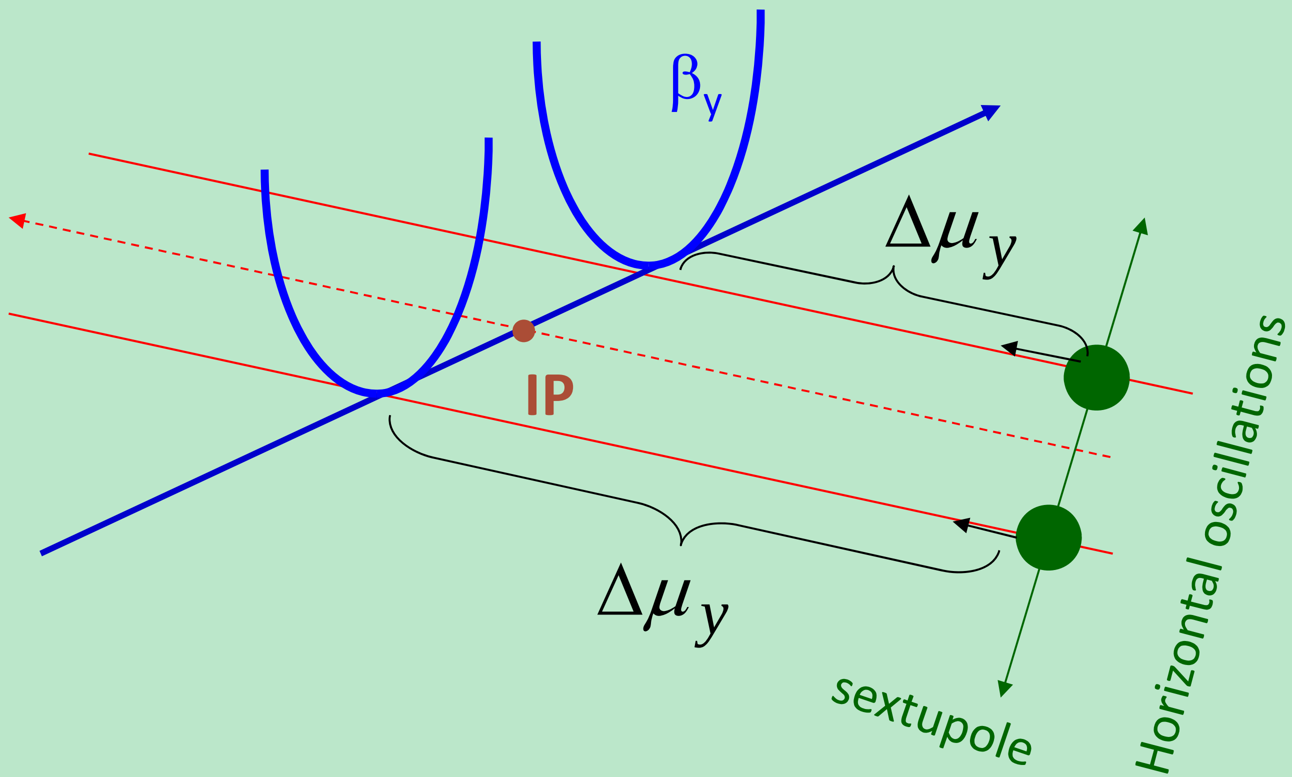


$$\Delta\nu_x = \pi$$
$$\Delta\nu_y = \frac{\pi}{2}$$

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



Suppression of X-Y Resonances

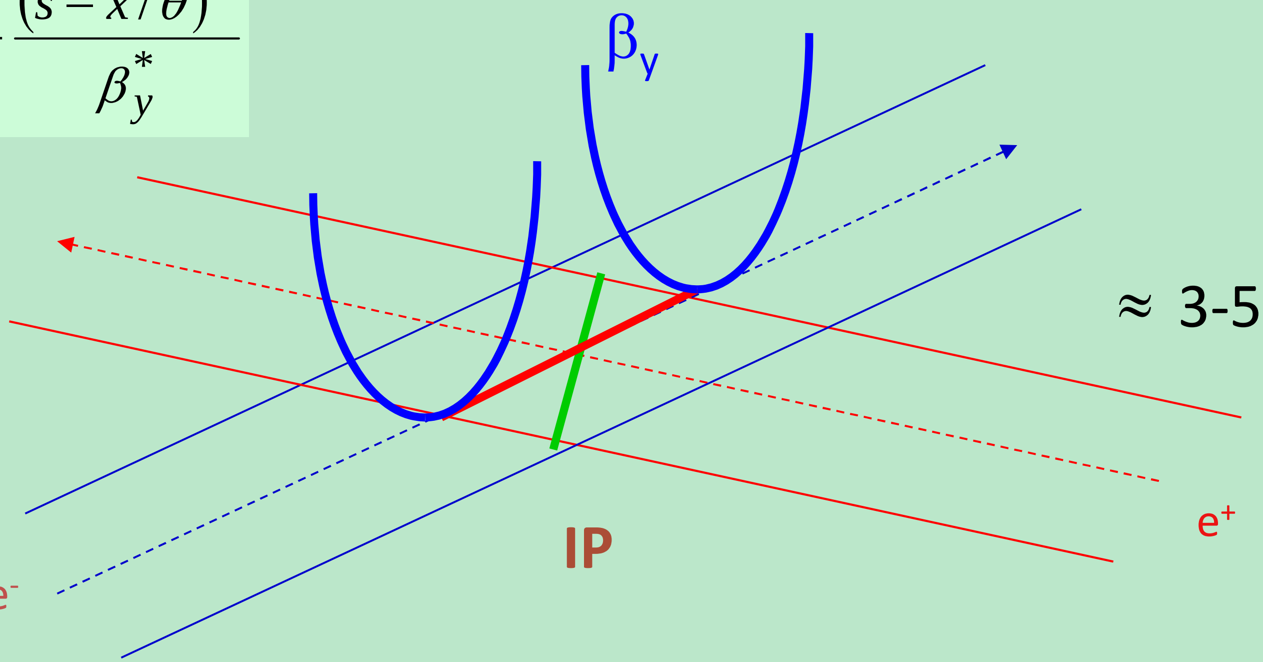


Performing horizontal oscillations:

- Particles see the same density and the same (minimum) vertical

Geometric Factor

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

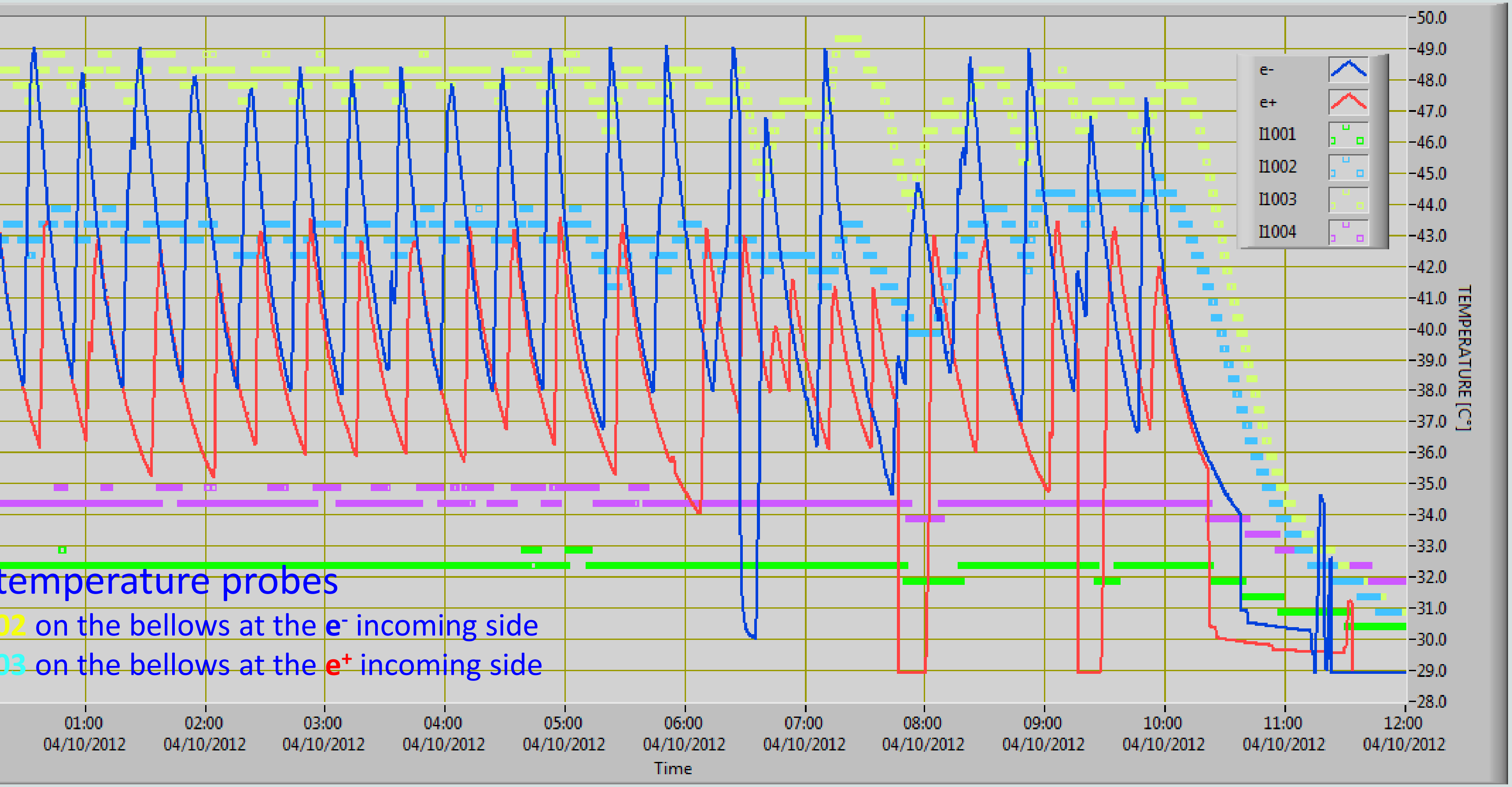


≈ 3-5%

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

Beam current & IP temperature



temperature probes

02 on the bellows at the e^- incoming side

03 on the bellows at the e^+ incoming side

Beam current & IP temperature

After airflow activation