DAΦNE: the Italian Meson Factory

Catia Milardi
Scientific Responsible of the DAΦNE Accelerator Complex
on behalf of the DAΦNE Team

Strange and non-strange mesons induced processes studies at
DAFNE, J-PARC and RIKEN: present and future, Frascati July 2017.

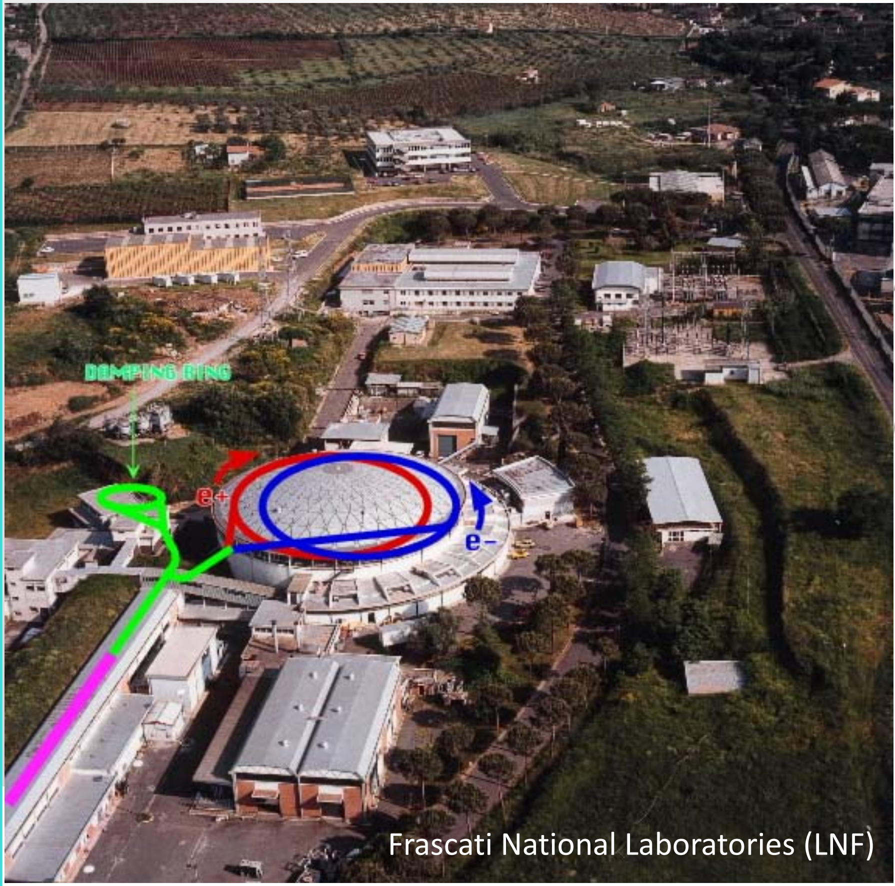
The DAΦNE Team

C. Milardi, D. Alesini, S. Bini, O. Blanco, M. Boscolo, B. Buonomo, S. Guiducci, S. Cantarella, S. Caschera, A. De Santis, G. Di Pirro, G. Delle Monache, A. Drago, L. Foggetta, A. Gallo, R. Gargana, A. Ghigo, C. Ligi, M. Maestri, A. Michelotti, L. Pellegrino, R. Ricci, U. Rotundo, A. Stella, A. Stecchi, M. Zobov, *LNF-INFN, Frascati, Italy*

Outlines

- *DAΦNE overview*
- *Crab-Waist Collision Scheme*
- *SIDDHARTA test run*
- *The new CW based IR for KLOE-2*
- *KLOE-2 run*
- *SIDDHARTA-2 studies and plans*
- *Conclusions*

The DAΦNE Accelerator Complex

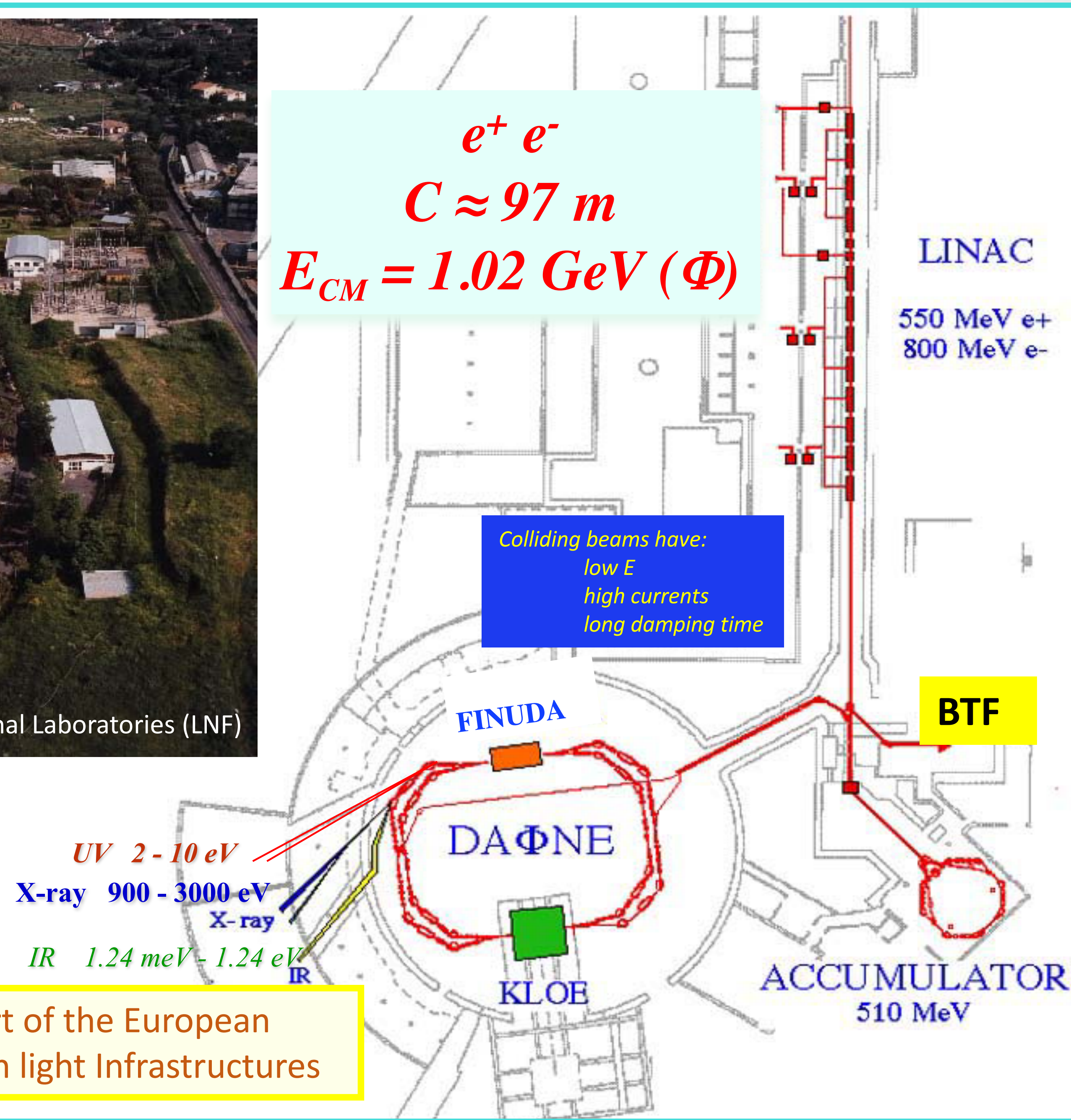


$e^{+}\ e^{-}$

$C \approx 97\ m$

$E_{CM} = 1.02\ GeV\ (\Phi)$

Colliding beams have:
- *low E*
- *high currents*
- *long damping time*

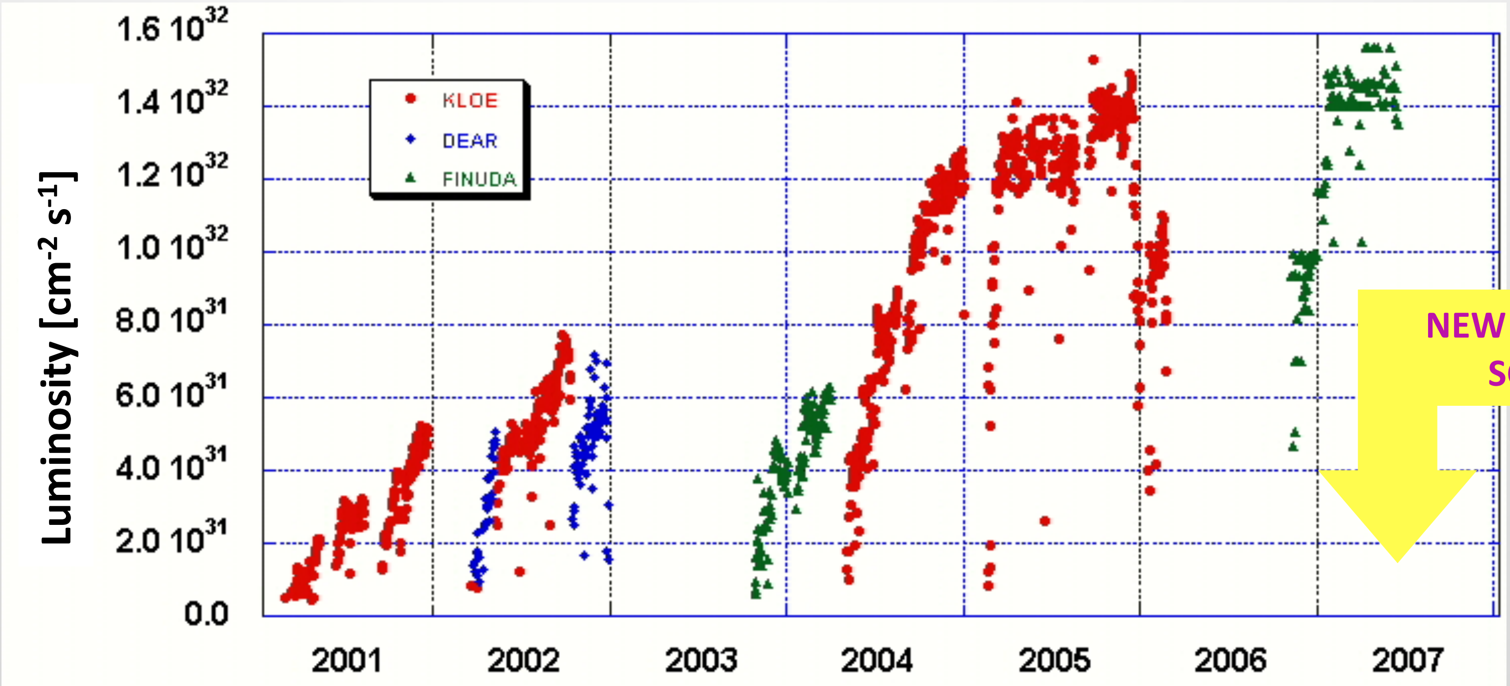


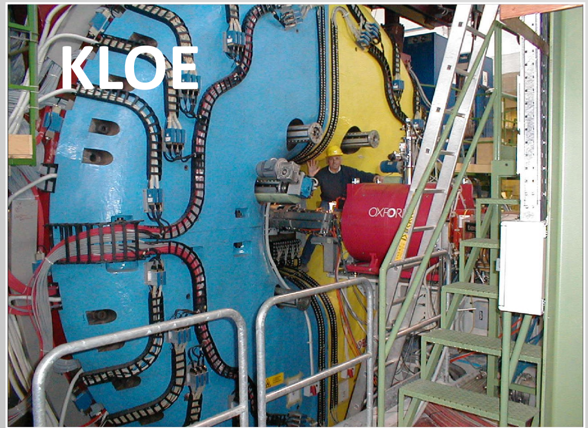
LNF are part of the European synchrotron light Infrastructures

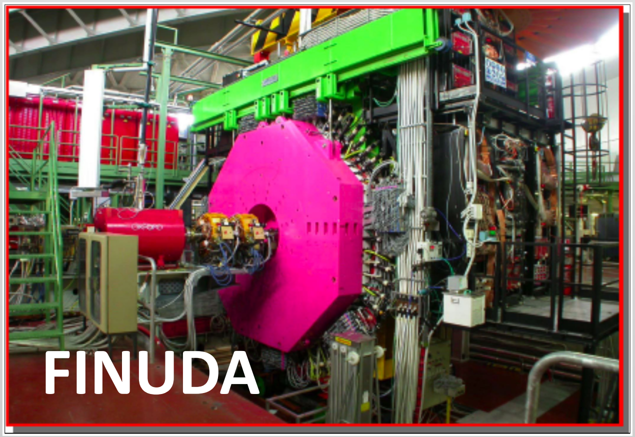
L_{peak} at DAΦNE 2001 ÷ 2007

L_{peak} had a remarkable evolution mainly due to several machine upgrades

Experiments took data one at the time, although DAΦNE had been originally conceived as collider with two IRs







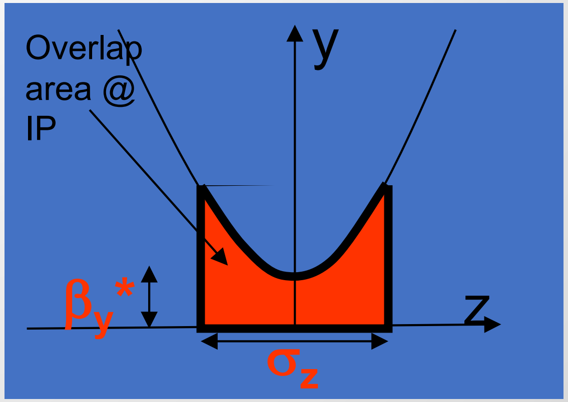
L_{logged} (fb^{-1}) 2001÷2007

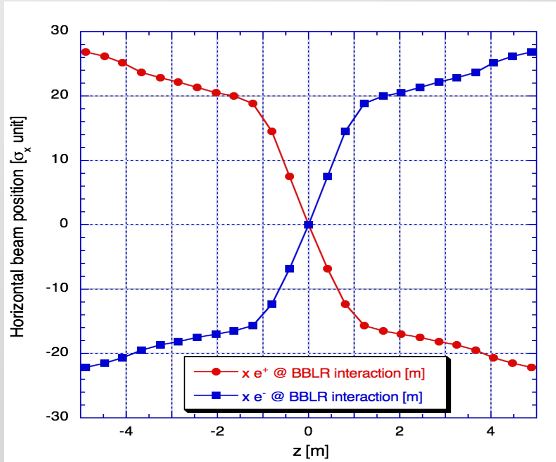
KLOE	3.0
FINUDA	1.2
DEAR	0.2

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:

- $\beta^*_y \sim \sigma_z$ 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





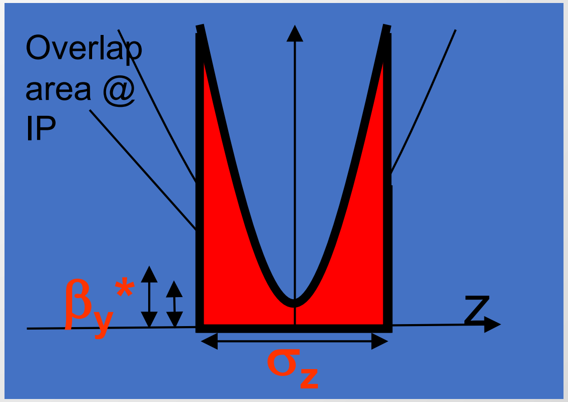
A new conceptual approach was necessary to reach L~10^{33}

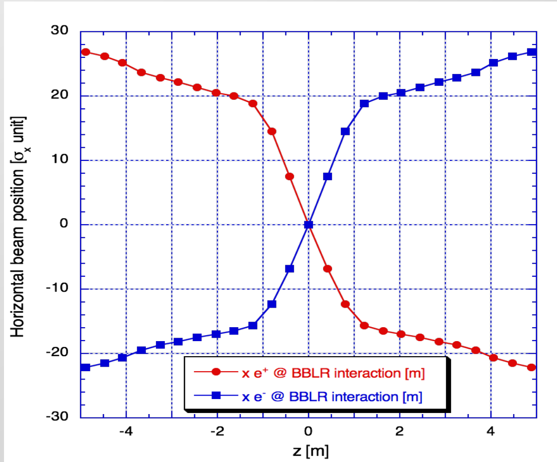
Collision scheme based on **Large Piwinski** angle and **Crab-Waist**

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:

- $\beta^*_y \sim \sigma_z$ 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

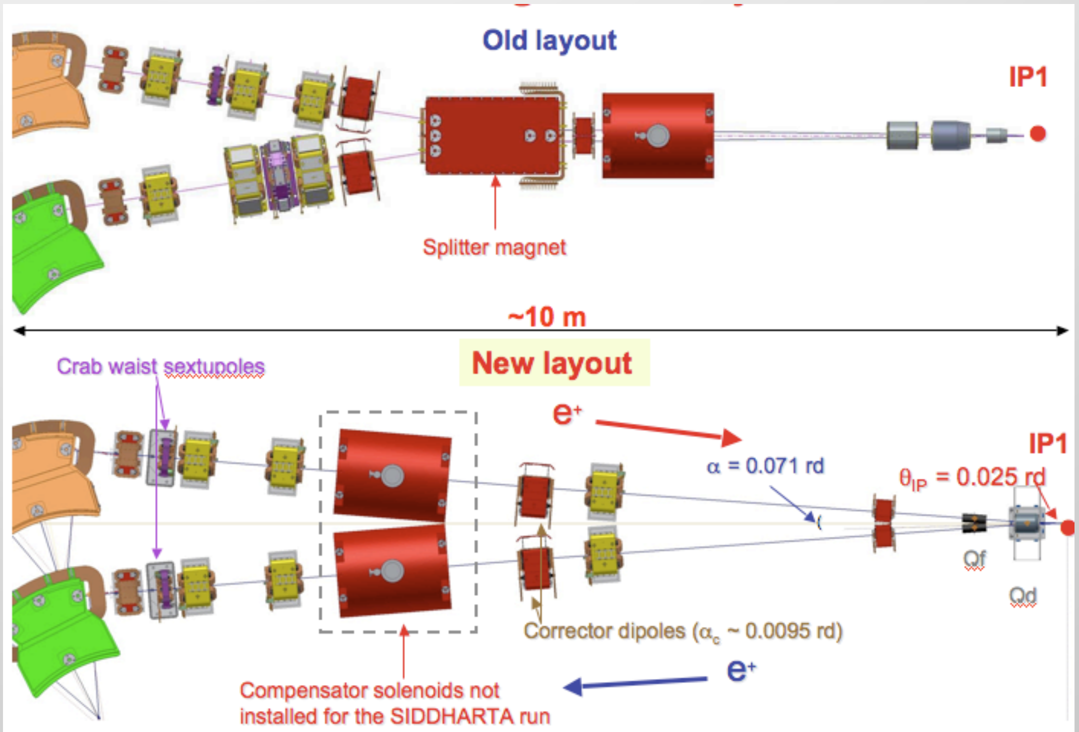
large θ

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

- 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

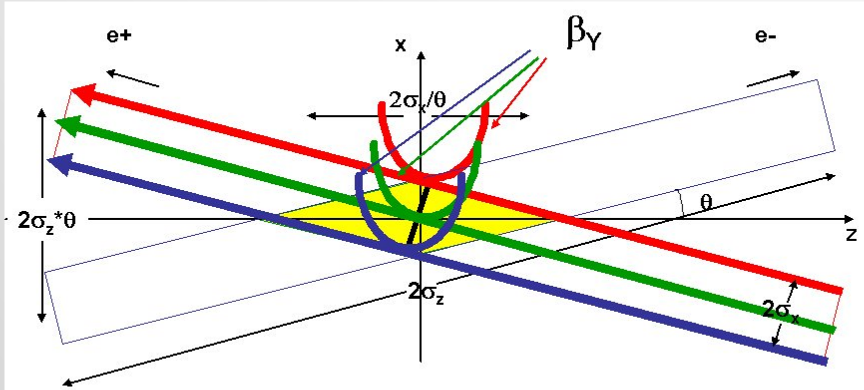


Lower β^*_y possible

Small β_y^* in fact the bunch overlap lenght 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

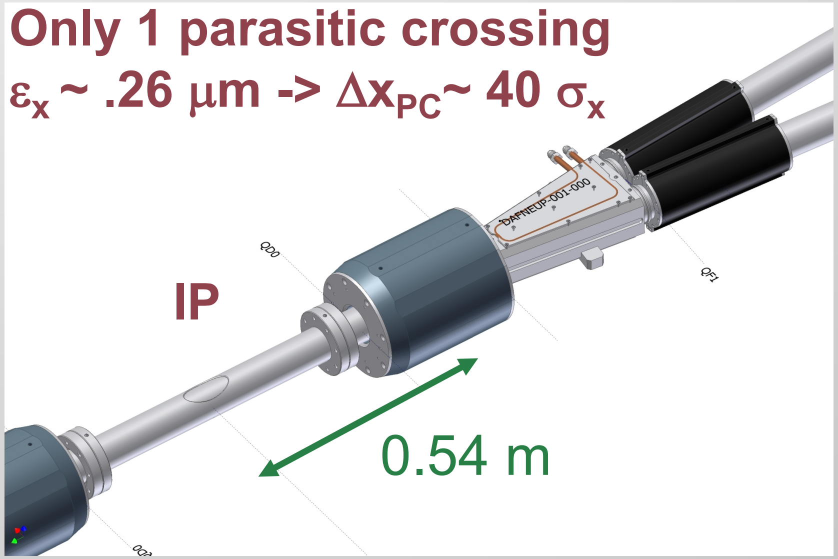


New low-β section

- *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



Crab-Waist compensation

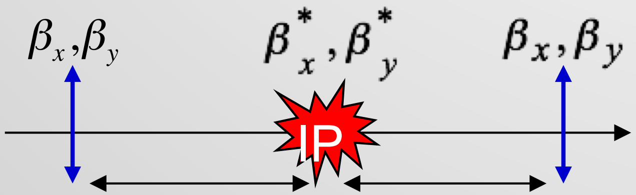
Collision with large Φ is not a new idea …..

Crab-Waist transformation is !

(P.Raimondi et al., 2006)

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

sextupole (anti)sextupole

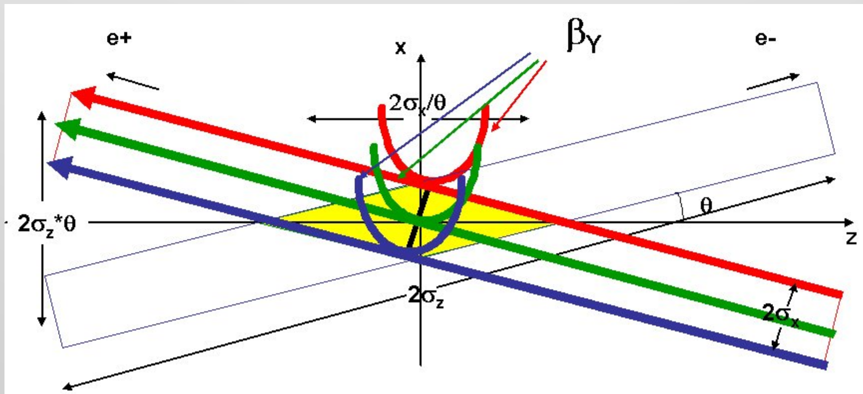


$$\Delta\nu_x = \pi$$

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

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

P. Raimondi et al., arXiV:physics/0702033
C. Milardi et al., Int.J.Mod.Phys.A24, 2009
M. Zobov et al., Phys. Rev. Lett. 104, 2010



Crab-Waist Compensation

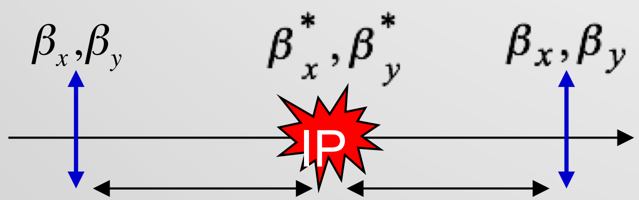
Collision with large Φ is not a new idea .....

Crab-Waist transformation is !

(P.Raimondi et al., 2006)

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

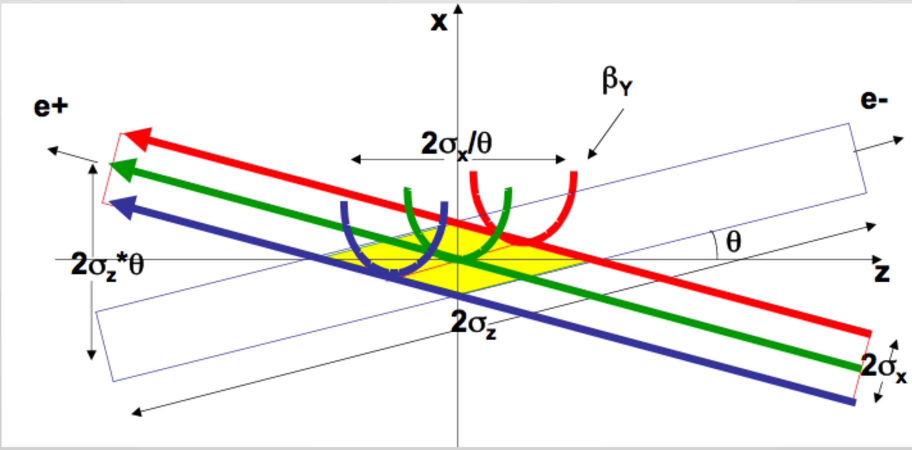
sextupole (anti)sextupole



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

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

P. Raimondi , *2° SuperB Workshop, March 2006*
P.Raimondi, D.Shatilov, M.Zobov, physics/0702033
C. Milardi et al., Int.J.Mod.Phys.A24, 2009
M. Zobov et al., Phys. Rev. Lett. 104, 2010

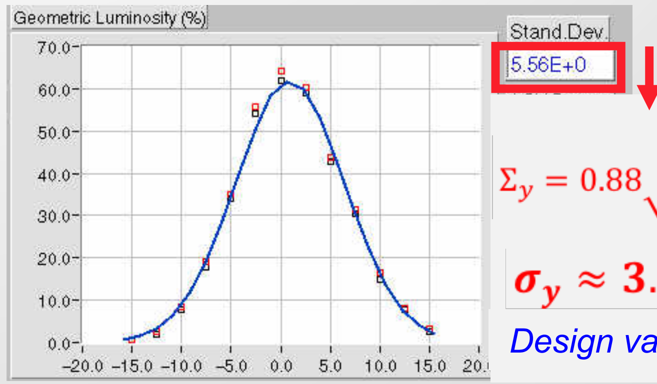


Crab-Waist collisions and SIDDHARTA

- Large crossing angle and *Crab-Waist* collisions proved to be effective in increasing luminosity by a factor 3

- The DAΦNE collider, based on the new collision scheme including Large Piwinski angle and *Crab-Waist*, has been successfully commissioned achieving record performances

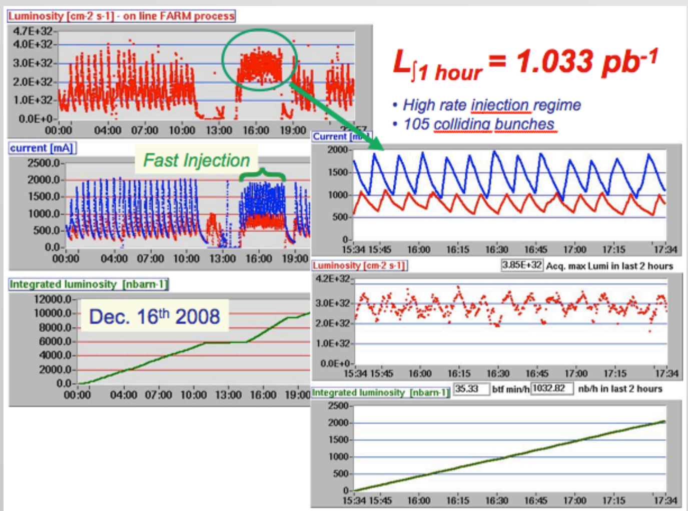
L_{peak}= 4.5*10^{32} cm^{-2} s^{-1}
$L_{\int 1\ day}$= 15.0 pb^{-1}
$L_{\int 1\ hour}$ = 1.033 pb^{-1}
$L_{\int run}$~ 2.8 fb^{-1} (delivered in 18 months)

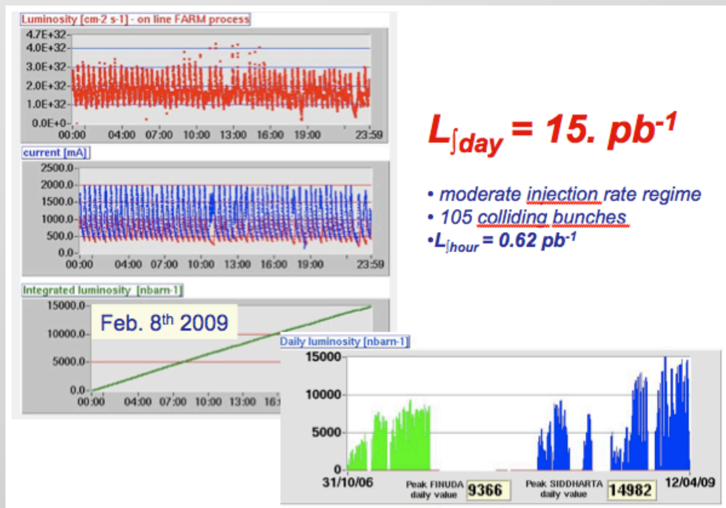


$$\Sigma_y = 0.88\sqrt{\sigma_{Ypos}^2 + \sigma_{Yele}^2}$$

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

Design value 3.1μm





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

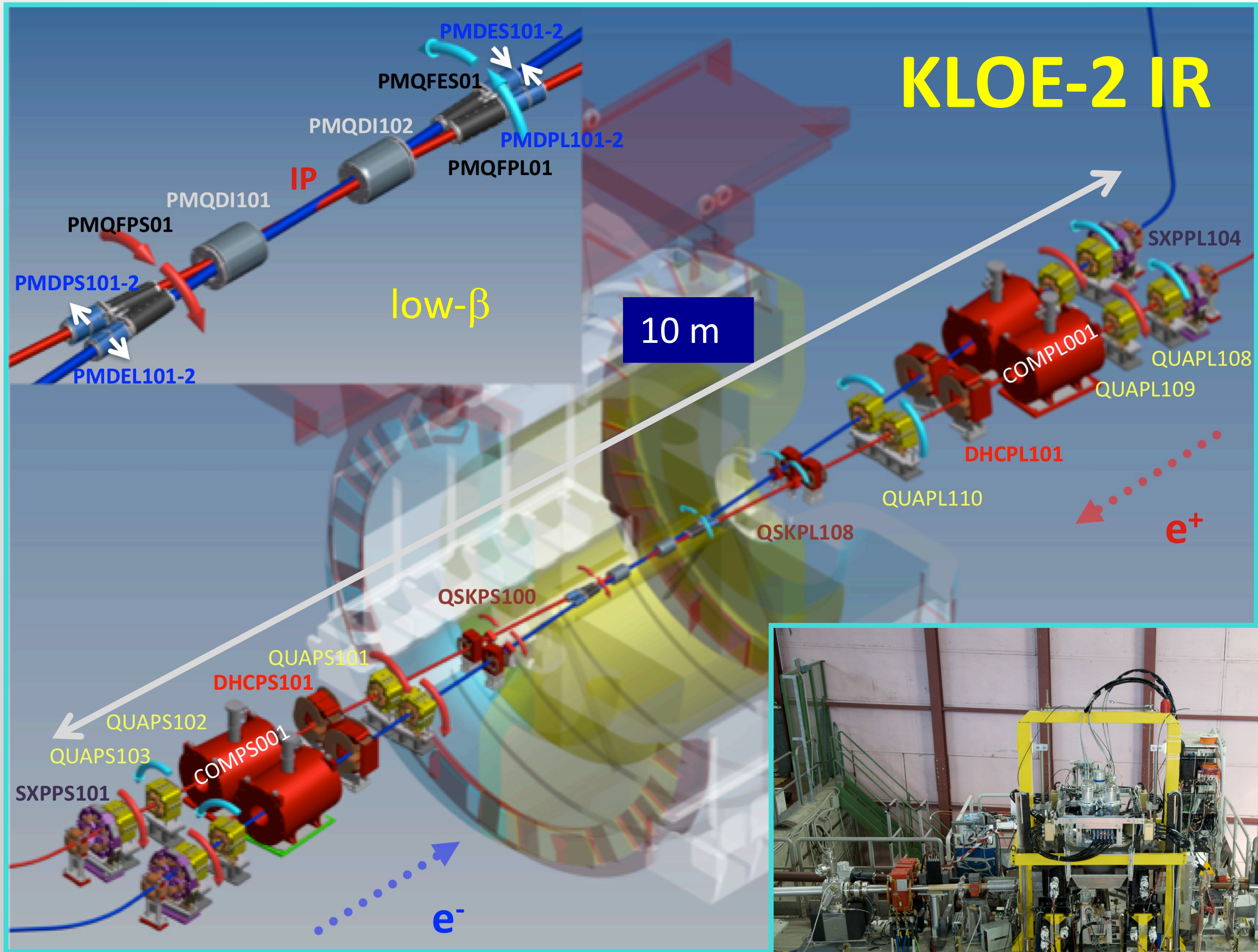
Crucial Points:

IR optics complying with:

- Low-β
- ***Crab-Waist*** collision scheme
- Coupling compensation
- Beam trajectory control

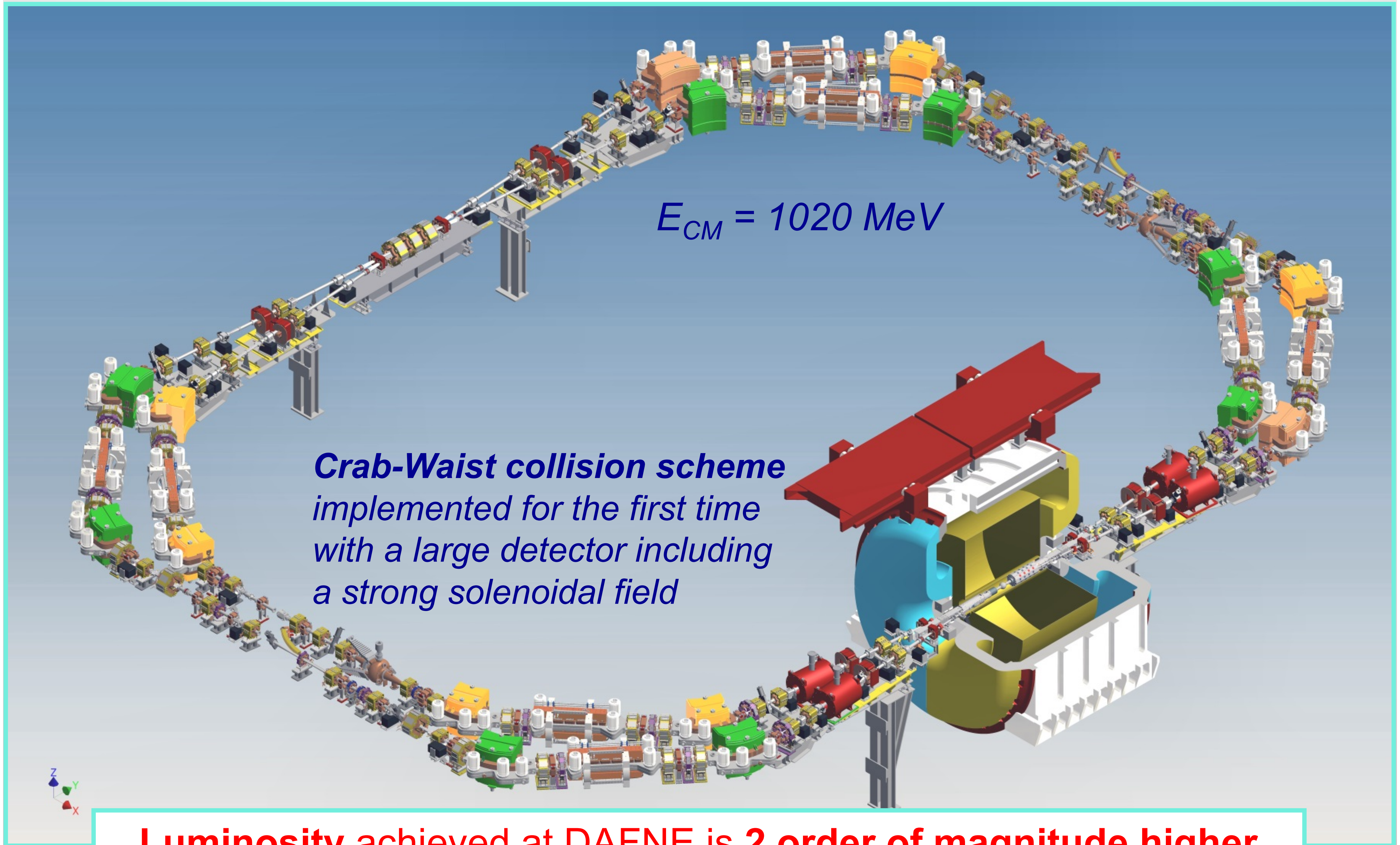
IR mechanical design allowing:

- Large crossing angle
- Early vacuum pipe separation after IP inside the detector



C. Milardi *et al 2012 JINST 7 T03002.*

DAΦNE and KLOE-2



Luminosity achieved at DAFNE is **2 order of magnitude higher** than the best measured in colliders working at the **same E**

KLOE-2 Data Taking Program

I Run Nov 16th 2014 ÷ Jul 3rd 2015

goal 1 fb^{-1}

II Run Spt 28th 2015 ÷ Jun 29th 2016

goal 1.5 fb^{-1}

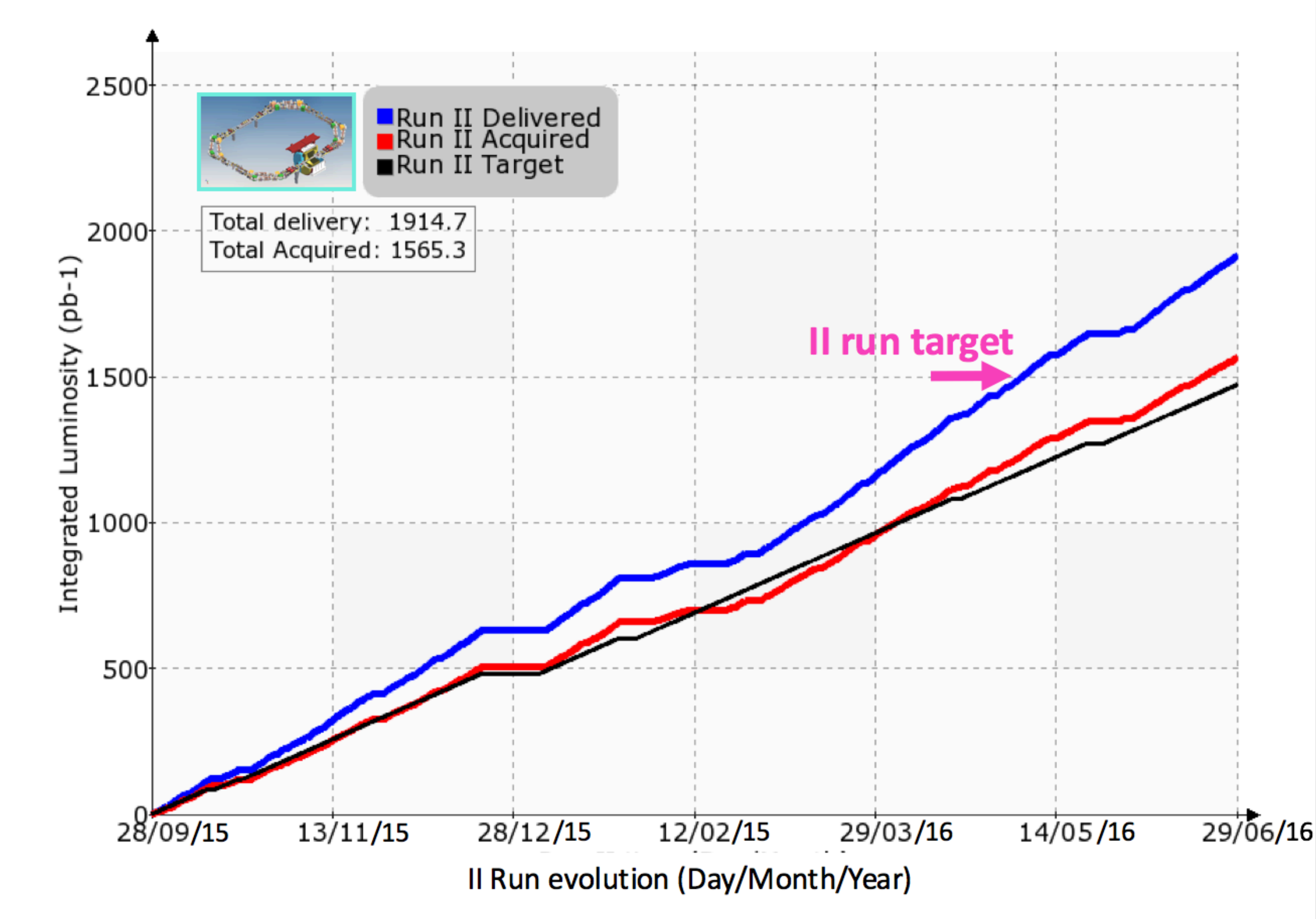
III Run Spt 12nd 2016 ÷ Aug 1st 2017

goal 2 fb^{-1}

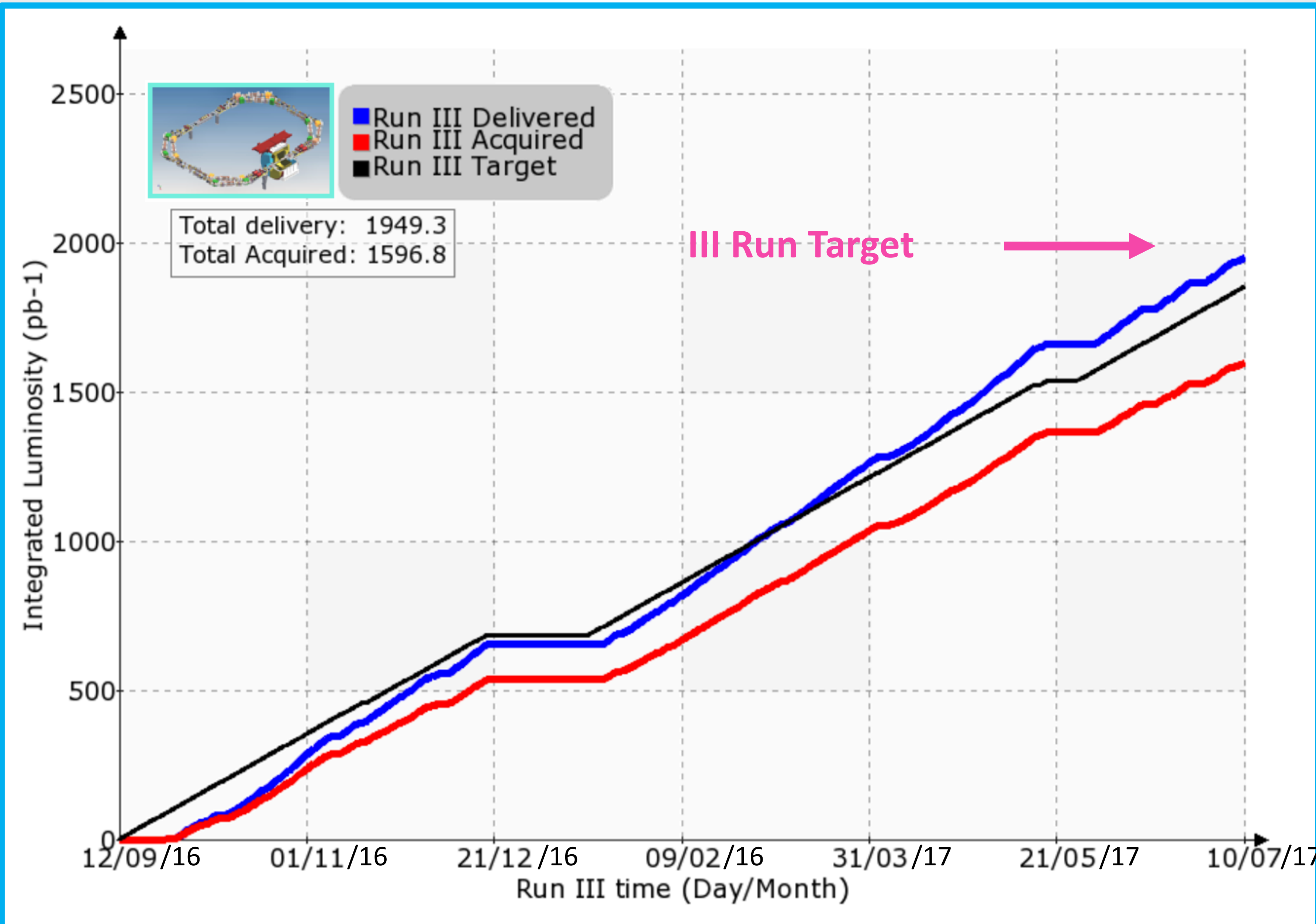
IV Run Spt 6th 2017 ÷ Mar 31st 2018

End of the DAΦNE activities for the KLOE-2 detector

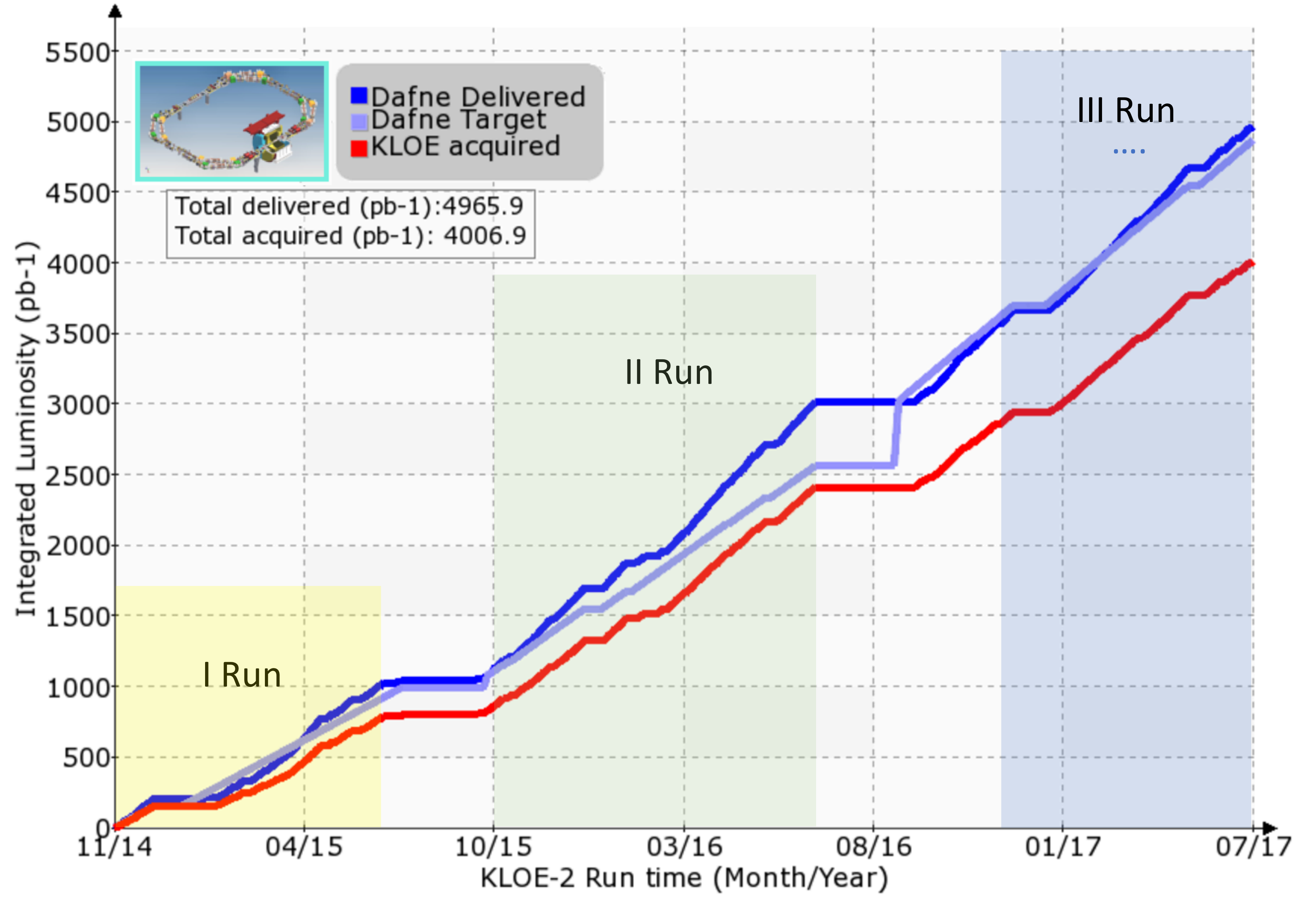
I and II Run Summary



III Run so far



KLOE-2 Data Taking overview



Machine studies and optimizations

Till now KLOE-2 data taking has been privileged w.r.t. machine studies and optimization

Very few activities have been undertaken to optimize the collider:

- Tle optics
- MRe working point
- Collisions on the Φ resonance peak
- Longitudinal FBKs in the MRs
  - QPSK features
  - 20% more power

Working Point Studies

Lifetrack is a fully symplectic 6D weak – strong simulation code allowing for simulations including:

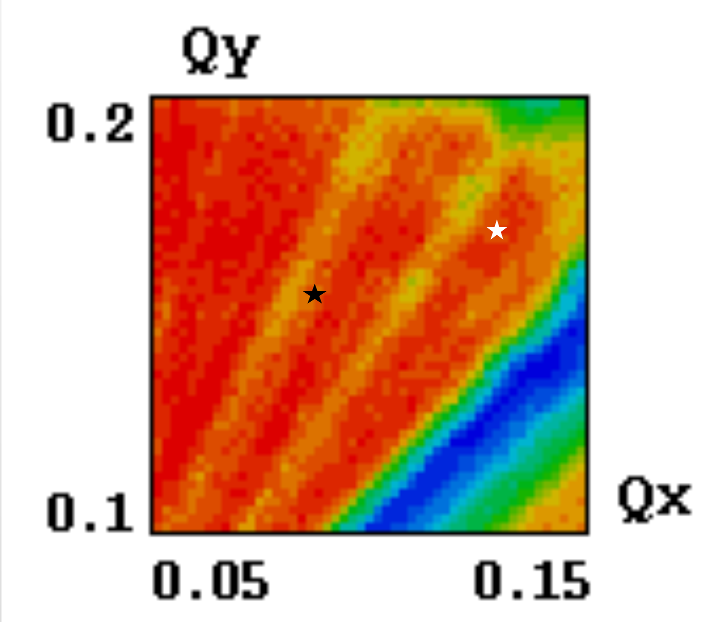
- non-linearities
- coupling
- chromaticity
- beam-beam
- large crossing angle
- beam crabbing

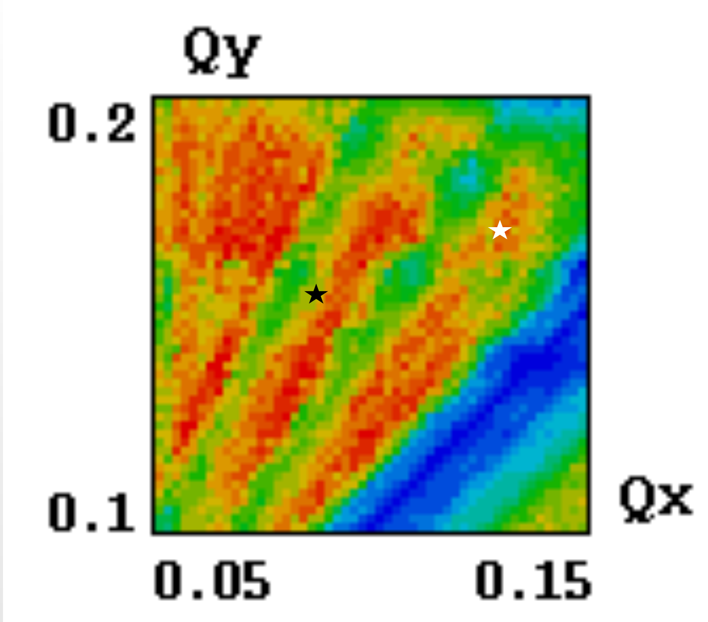
The code provides:

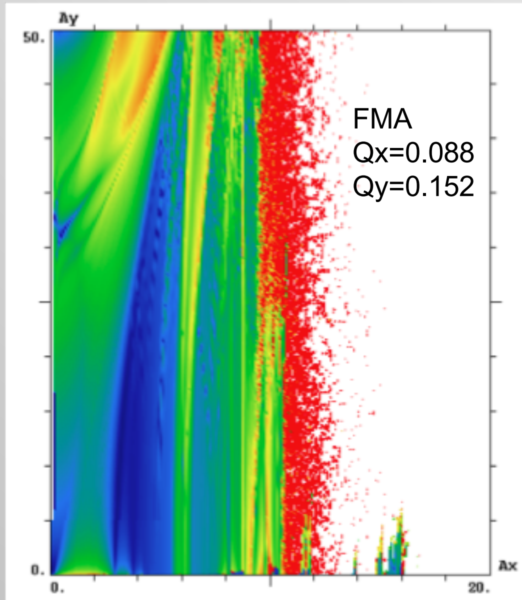
3D density of weak beam
specific luminosity and beam lifetime
DA and FMA

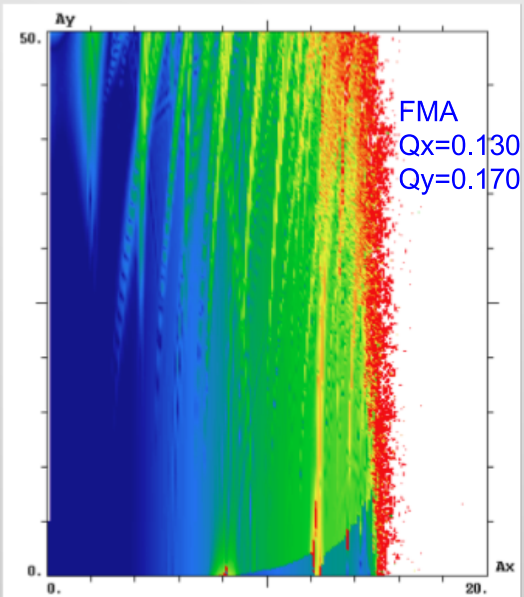
e^- Working Point Scan

Luminosity	Inverse beam sizes









MRe was moved to the optimal WP

Qx=0.135 Qy=0.17

obtaining:

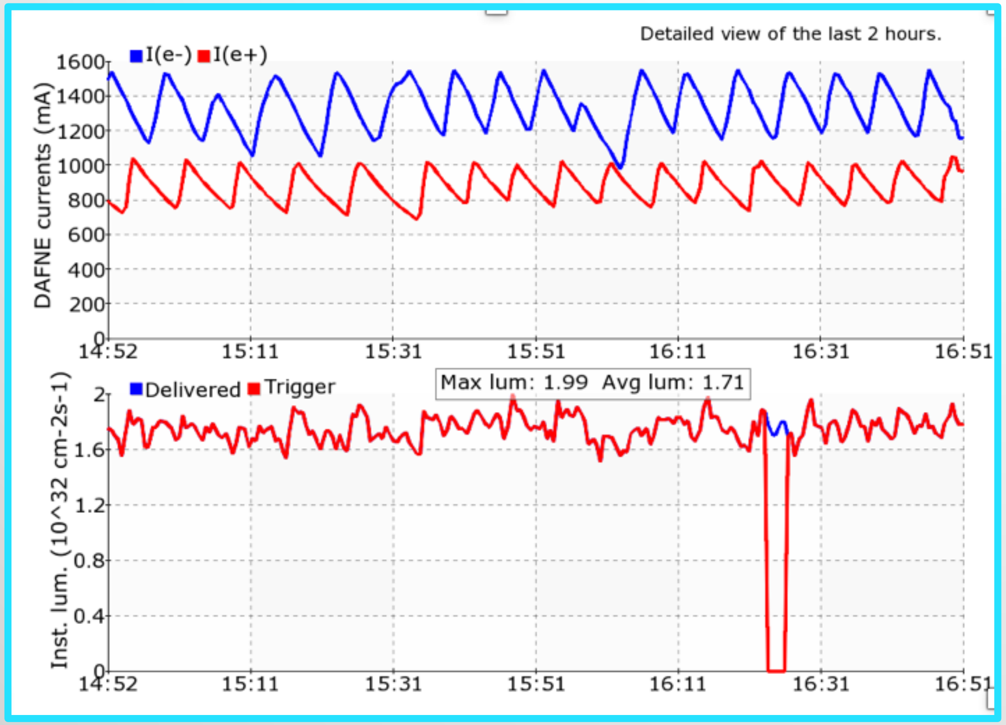
improved injection efficiency

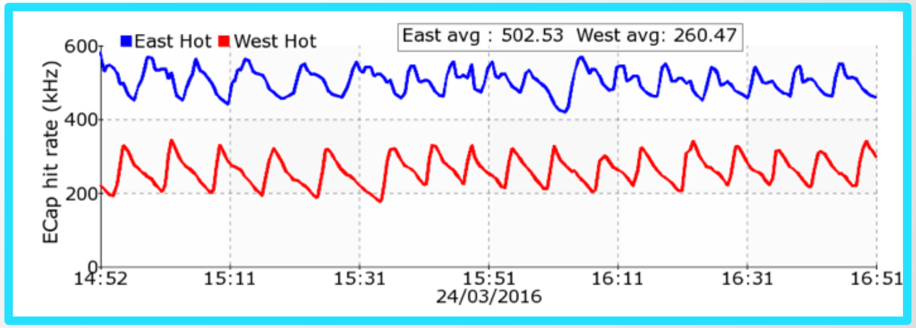
higher beam lifetime

Reduced background

higher luminosity

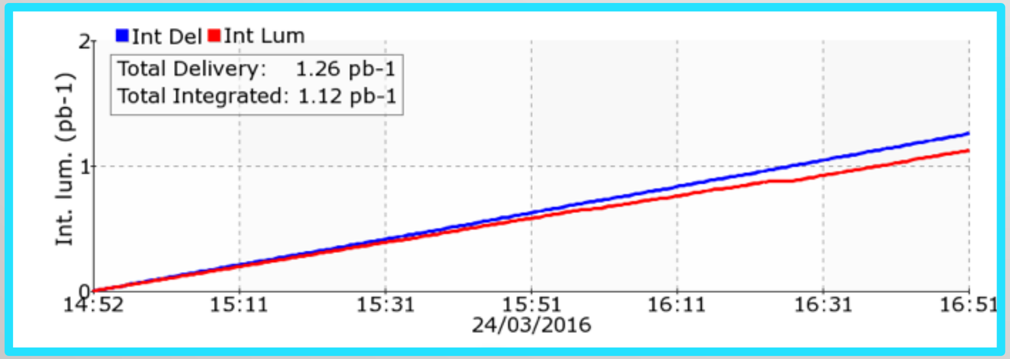
Best **Hourly** Integrated Luminosity





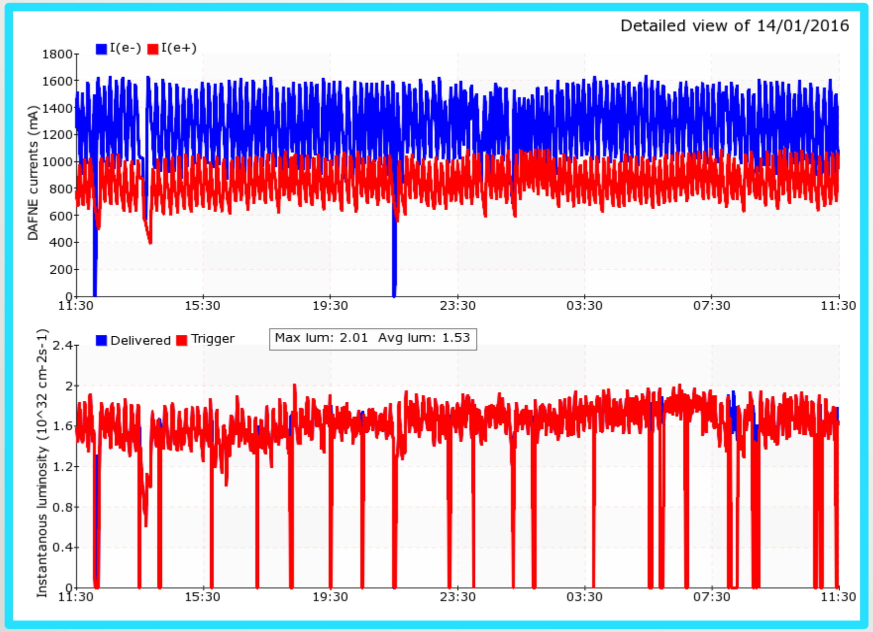
$$\int_{1h} L \sim 0.63\ pb^{-1}$$

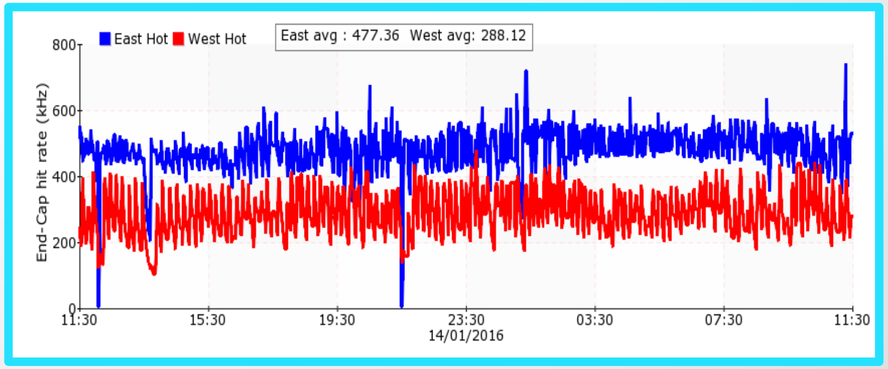
$$\int_{1\ day} L \sim 15.1\ pb^{-1}$$



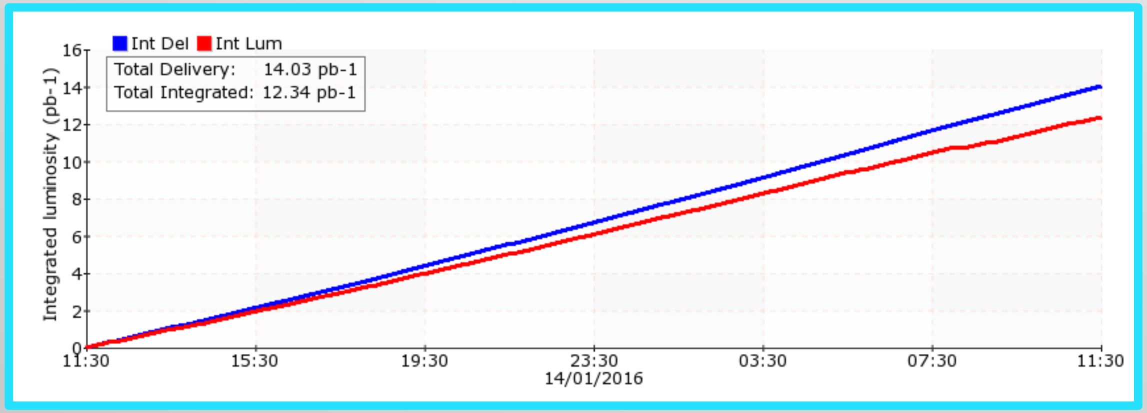
Each beam is injected at least 16 times in 2 hours. Any delay in the injection process produces a negative impact on instantaneous and integrated Luminosity.

Best 24 Hours Integrated Luminosity





- 2 beam losses due to PS faults
- 105 bunches
- $I^-_{MAX} = 1.5 \div 1.6$ A
- $I^+_{MAX} = 1.0 \div 1.16$ A
- Sustainable background



$\int_{del} L \sim 14.03\ pb^{-1}$

$\int_{acq} L \sim 12.34\ pb^{-1}$

Uptime ~98%

Crab-Waist Collision Scheme & DAΦNE Performances

	DAΦNE **No CW** KLOE (2005)	**DAΦNE CW upgrade SIDDHARTA (2009)**	**DAΦNE CW KLOE-2 (2017)**
L_{peak} [10^{32} $cm^{-2}s^{-1}$]	1.5	**4.53**	**2.2**
$\int_{day}L$ [pb^{-1}]	9.8 (rarely)	**14.98** (test run)	**14.03** (data taking)
$\int_{1\ hour}L$ [pb^{-1}]	0.4 (rarely)	**1.033**	**0.62**
I^-_{MAX} in collision [A]	1.38	**1.52**	**1.5**
I^+_{MAX} in collision [A]	1.18	**1.0**	**1.0**
$N_{bunches}$	111	**105**	**105**
ξ S-S (W-S)	0.024	**0.0443** (0.09)	(to be evaluated)

The new collision scheme including Large Piwinski angle and Crab-Waist compensation of the beam-beam interactions has proved to be a viable approach to increase the luminosity of the DAΦNE collider.

It has been succesfully tested and routinelly used during the SIDDHARTA run when a factor 3 higher instantaneous luminosity has been measured.

Still the potential of the Crab-Waist scheme with KLOE-2 has not yet been fully exploited

Crab-Waist Collision Scheme & KLOE-2 Run

*The **KLOE-2 run** has clearly assessed the **Crab-Waist*** **collision scheme effectiveness even in presence of a large detector including high intensity solenoidal field**.

Regardless the peak luminosity gain achieved so far is still a factor two lower wrt to the record value measured during the SIDDHARTA run, the impact of the new collisions scheme on the DAΦNE performances is quite evident.

Presently DAΦNE can provide to the detector:

- a 46% higher peak luminosity
- a daily integrated luminosity comparable with the best ever measured at LNF
- an 81% higher luminosity integration rate (see table)
- more stable and reproducible operations

Still the factor limiting the present peak luminosity have been studied identified and could be cured investing time a manpower for machine developments.

	DAΦNE – No CW KLOE 2004÷2005	DAΦNE-CW KLOE-2 2014÷2017
Operation Time [months]	18.0	24.3
$\int_{tot}$***L*** *(delivered)* [fb^{-1}]	2.0	4.88

Further Developments

Beam Physics

A considerably higher luminosity might be attained by:

- refining transverse betatron coupling correction
- improving CW-Sextupoles alignment on beam orbit and optimizing their strengths
- pushing the microwave instability threshold toward higher single bunch current value by means of new optics configuration having higher **α_c and higher chromaticity**
- exploring a new working point for the e+ beam
- further feedback noise reduction
- tuning the interplay between RF 0-mode feedback and longitudinal feedback

These activities are very much time consuming

The importance of DAΦNE

The design study of several new circular colliders includes the Crab-Waist collision scheme as a main design concept

Crab-Waist Colliders

Colliders	Location	Status
DAΦNE	Φ-Factory Frascati, Italy	In operation
SuperKEKB	B-Factory Tsukuba, Japan	Commissioning started in first months of 2016
SuperC-Tau	C-Tau-Factory Novosibirsk, Russia	Russian mega-science project
FCC-ee	Higgs-Factory CERN,Switzerland	100 km, CW baseline design option
CEPC	Higgs-Factory China	54 km, local double ring option with CW
LHC Upgrade	LHC CW Option CERN,Switzerland	LHC with very flat beams (low priority)

DAΦNE after KLOE-2

DAΦNE Timeline

March 31st 2018
end of the KLOE-2 Run

April 1st ÷ July 31st
KLOE-2 roll-out and SIDDHARTA-2 installation

September ÷ December 2018
DAΦNE commissioning and SIDDHARTA setup

January 2019
start the SIDDHARTA-2 data taking

Collisions for SIDDHARTA

Several well founded considerations recommend to install SIDDHARTA on the IR1

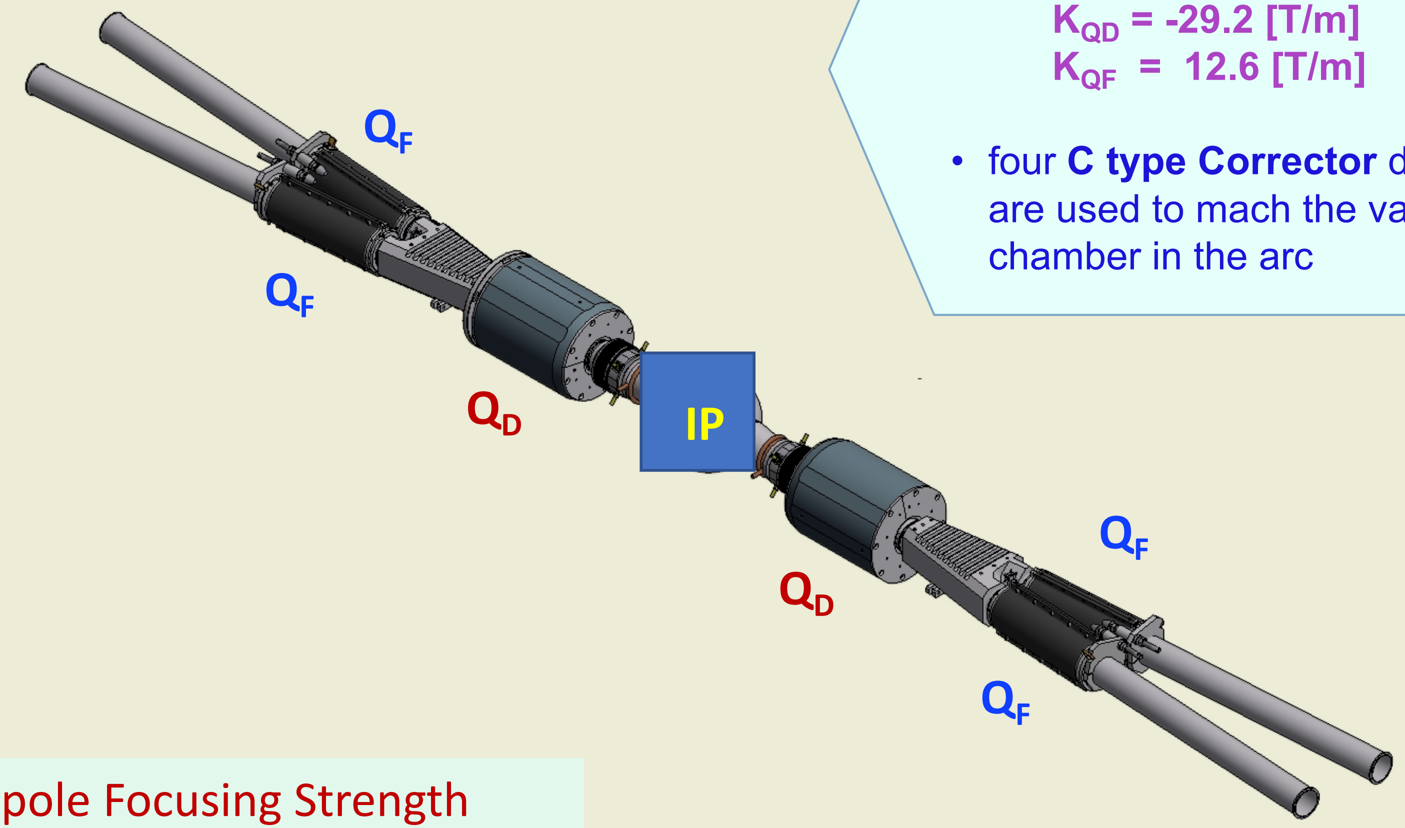
KLOE-2 detector must be removed

To respect the DAΦNE schedule it's necessary to rebuild the low-β section presently tightly packed among cables and detector layers deep inside KLOE-2

As a consequence a new low-β section has to be build

- quadrupoles
- vacuum chambers
- diagnostics

SIDDHARTA Low-β section

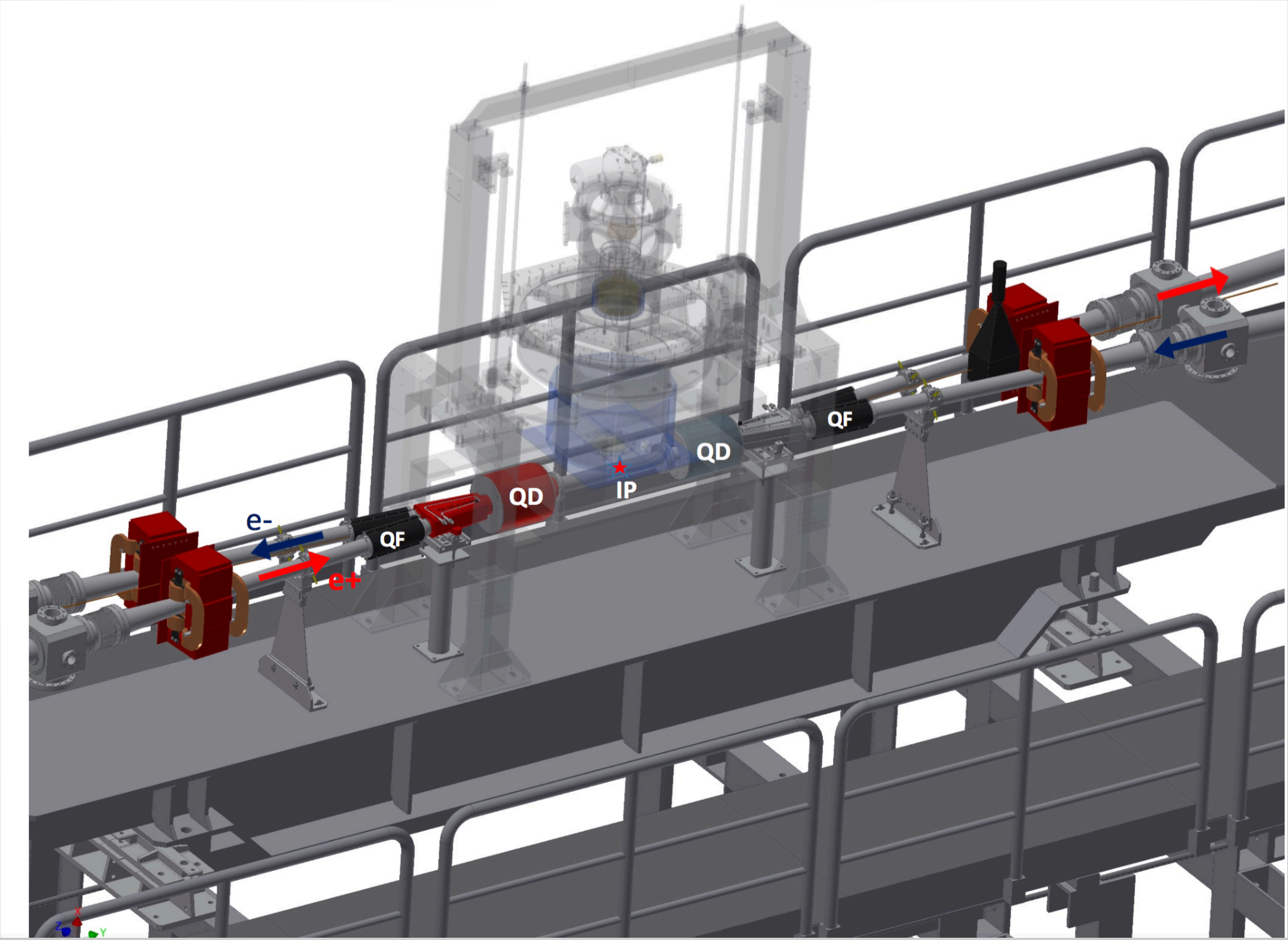


- **large collision angle ~ 50 mrd**
- *low-beta* section based on **Permanent Magnet QUADs**:
  - K_{QD} = -29.2 [T/m]
  - K_{QF} = 12.6 [T/m]
- four **C type Corrector** dipole are used to mach the vacuum chamber in the arc

Quadrupole Focusing Strength

$$\boldsymbol{k}[m^{-2}] = \frac{e}{pc}\frac{\boldsymbol{dB_y}}{\boldsymbol{dx}} = \frac{0.299\boldsymbol{g}[T/m]}{\beta E[GeV]}$$

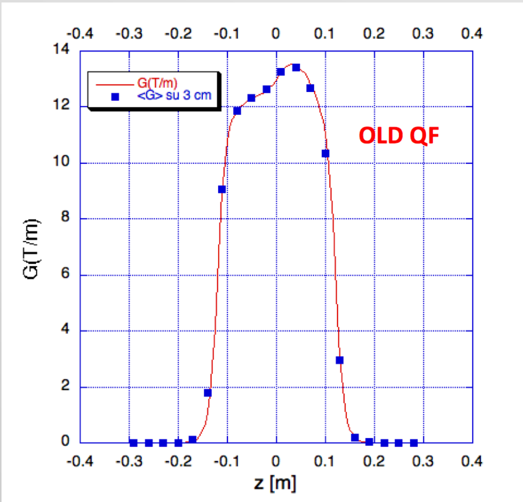
SIDDHARTA-2 & DAΦNE IR

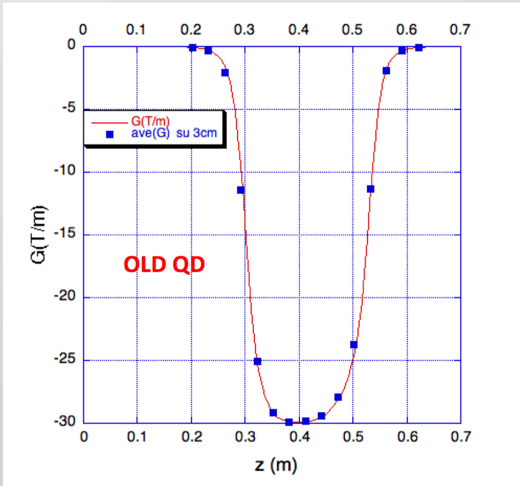


New Low-β QUADs

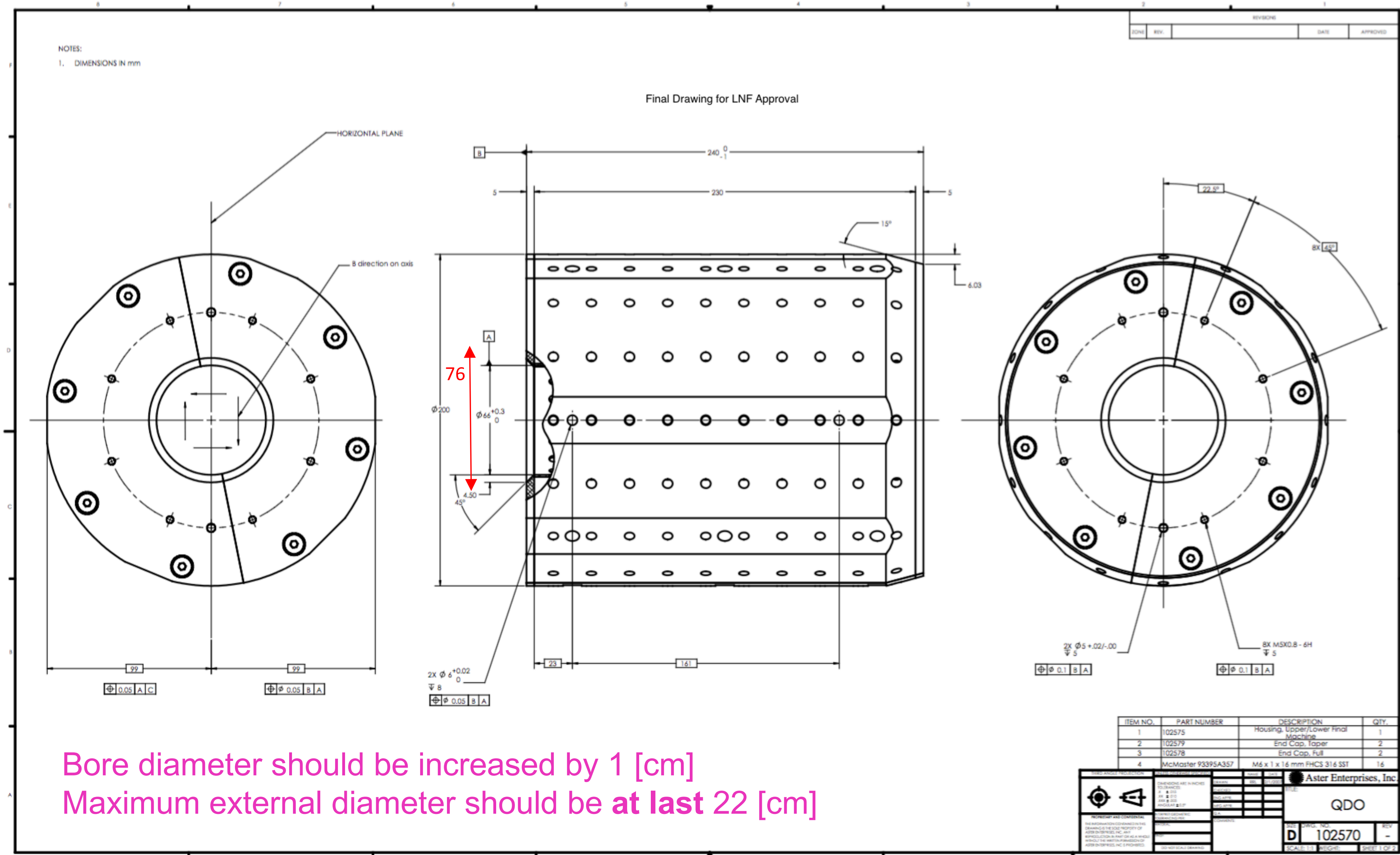
Aimed at improving several aspects:

- good field region
- uniformity of the gradient
- QD aperture thinking to:
    - stay clear aperture
    - background
    - luminosity monitor
- mechanical assembly especially for QF





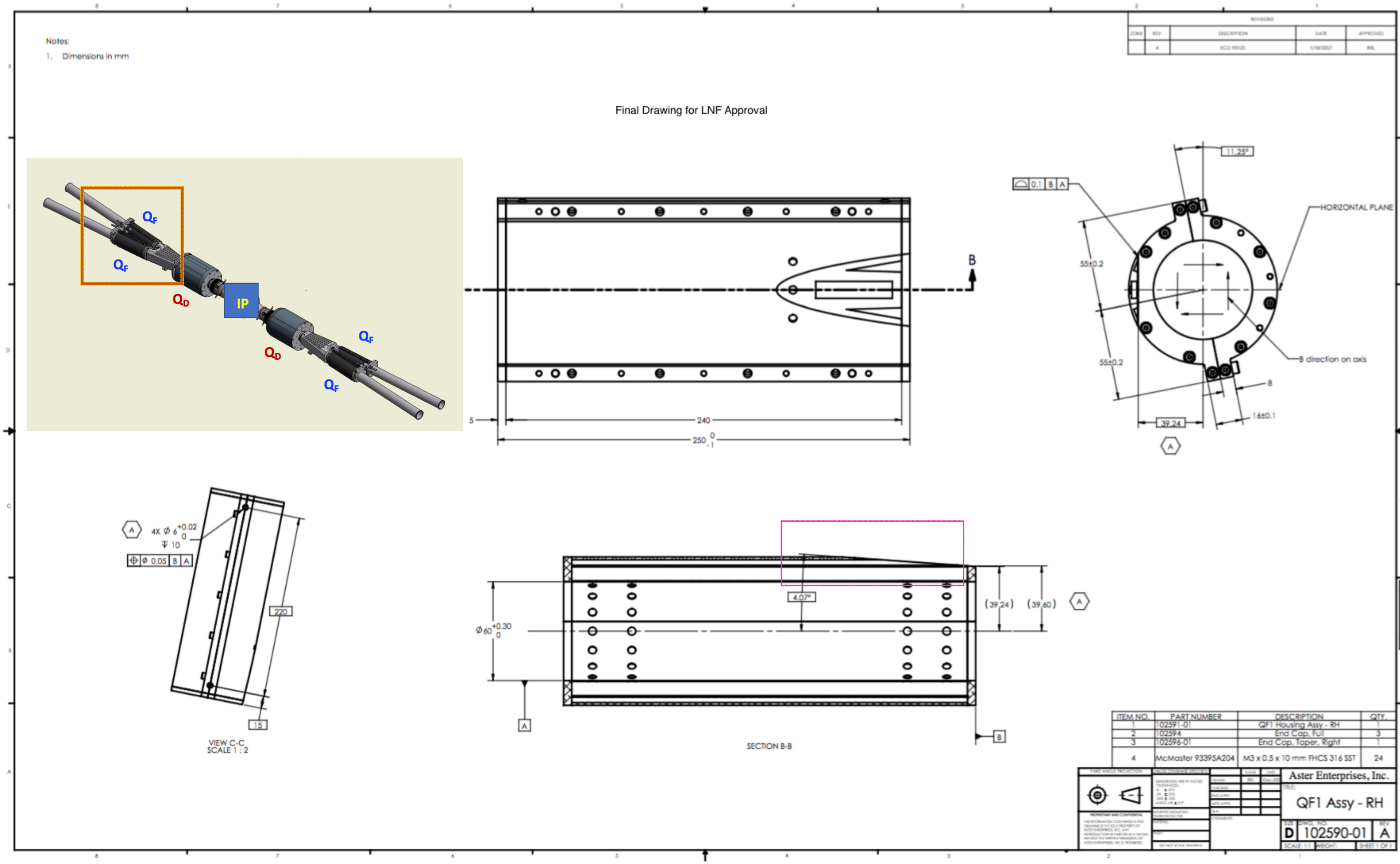
Larger Stay Clear Aperture for the PM QD



Bore diameter should be increased by 1 [cm]

Maximum external diameter should be **at last** 22 [cm]

Optimized Mechanical Assembly for the PM QF



PM QD design status

Magnet layout

Design: elliptical core + circular shimming
Aperture: 76 x 65 mm x mm
Length: 220 mm
Outer radius: 100 mm at nominal shim positions
Material: Sm_2Co_{17}, B_R = 1.1 T

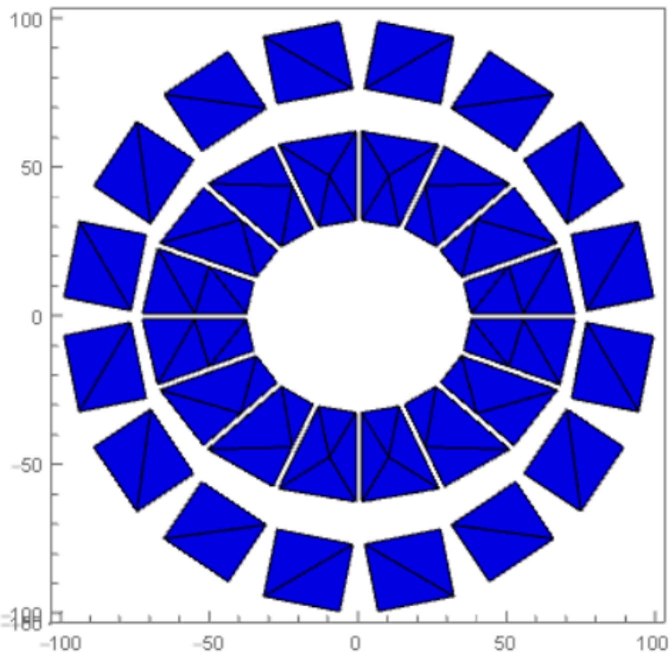


Fig. 1. Shape of the elliptical aperture QD0

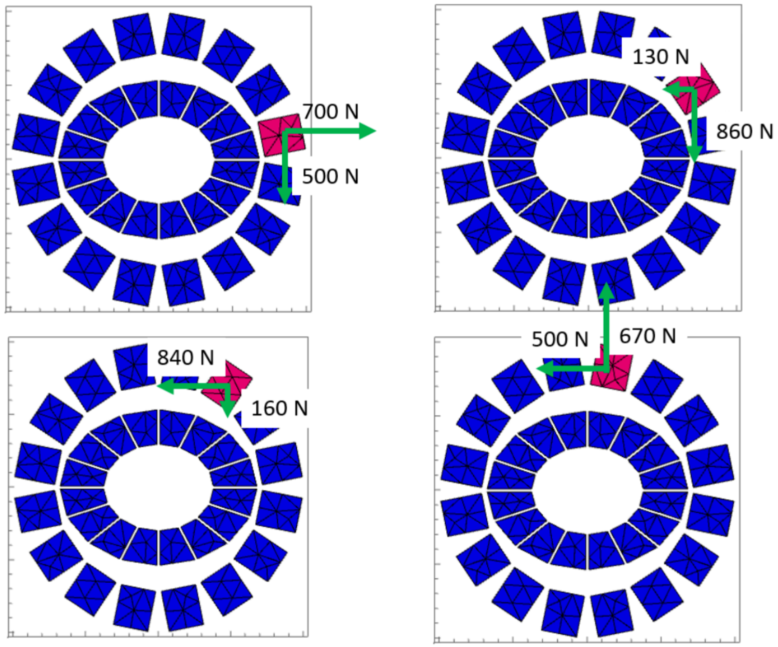


Fig. 3. Forces applied on the outer magnet blocks.

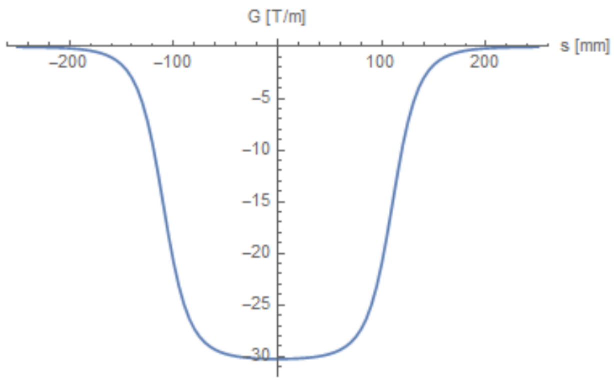


Fig. 3. Longitudinal profile of the field gradient.

PM QF design status

Magnet layout

PM aperture: 61 mm (circular)
Length of the inner ring: 240 mm
Length of the outer ring: 90 mm
Gap between magnets: 1.5 mm
Outer radius: 43 mm
Material: Sm_2Co_{17}, B_R = 1.1 T

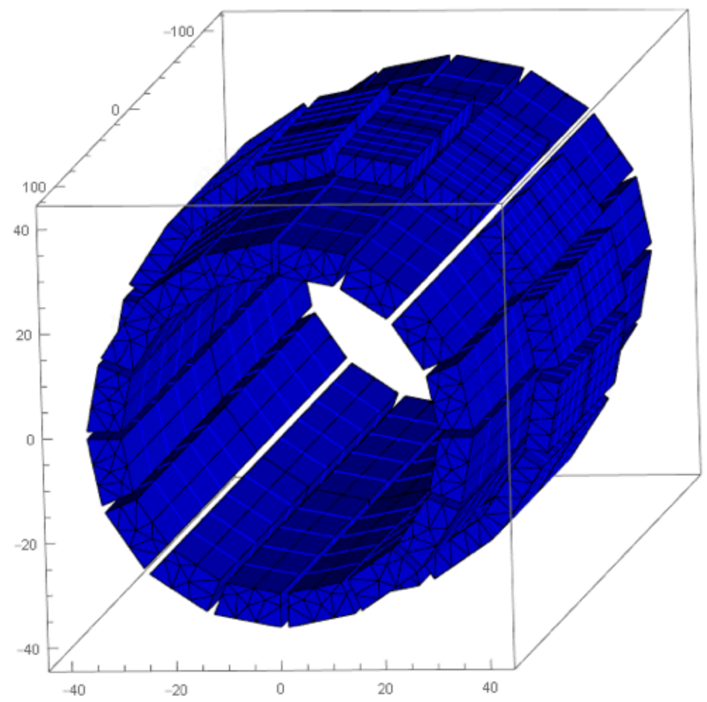


Fig. 1. Magnetic design view of the QF1.

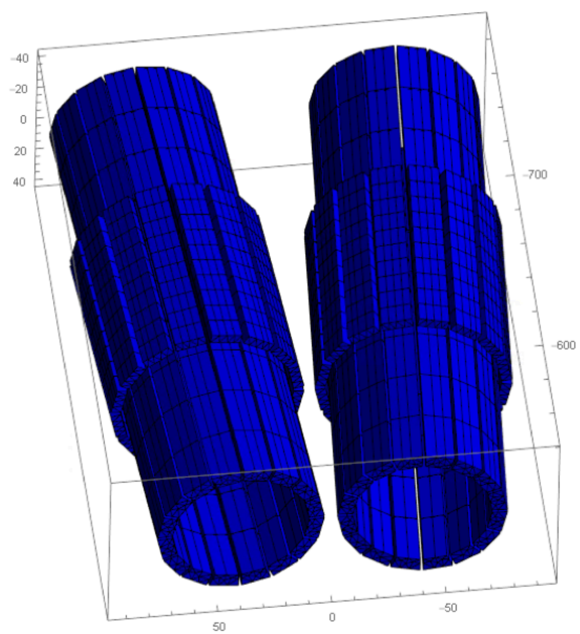


Fig. 2. View of the two QF1 magnets, assuming a 8.3° angle between the magnets (measured on the drawings)

Other R&D Activities

- Vacuum components
- General maintenance of the ~ 600 PSs of the DAΦNE magnets
- Installation of laser treated vacuum chamber and diagnostics for e-cloud mitigation
- Additional transverse horizontal FBK for the positron beam
- Fast luminometer for machine tune-up

PM QUADs construction plan

Activity	responsibility	Duration	start	End
Magnet performance specification	**CM**	**0 g**	**31/03/17**	**31/03/17**
Magnetic simulation and design optimization	ESRF	55 g	31/03/17	15/06/17
Preliminary magnetic design delivered		**0 g**	**15/06/17**	**15/06/17**
Mechanical design of casing and supports	GS	30 g	16/06/17	27/07/17
Thermal and mechanic simulation	LP	20 g	28/07/17	24/08/17
Mechanical design of tools for the assembly	GS	20 g	28/07/17	24/08/17
Validation of mech-mag design	LNF-ESRF	20 g	25/08/17	21/09/17
Mechanical design ready		**0 g**	**21/09/17**	**21/09/17**
REM Tender assignment	LNF	30 g	22/09/17	02/11/17
REM procurement	LNF	85 g	03/11/17	01/03/18
Casing, tools and supports procurement	LNF	85 g	22/09/17	18/01/18
Magnets assembly	ESRF-LNF	22 g	02/03/18	02/04/18
Magnetic and mechanical measurements and shimming	ESRF-LNF	15 g	03/04/18	23/04/18
END of Activity		**0 g**	**23/04/18**	**23/04/18**

Conclusions

DAΦNE performances:

- *operation are stable and reproducible*
- *background is compatible with an efficient data-taking*

The target of the 3rd KLOE-2 run has been almost reached

Instantaneous luminosity is a 45% higher than the best ever measured with the KLOE detector although:

- *the full potential of the Crab-Waist collision scheme has not yet been exploited*
- *beam currents are still lower than in 2005*

Maximum daily integrated luminosity is comparable with the best achieved during the Crab-Waist test run with SIDDHARTA and has been measured while KLOE-2 was taking data

Work is in progress to realize the run for the SIDDHARTA-2 detector

Aknowledgments

Many thanks to all the colleagues of the

AD and DT secretariats

Personnel Service

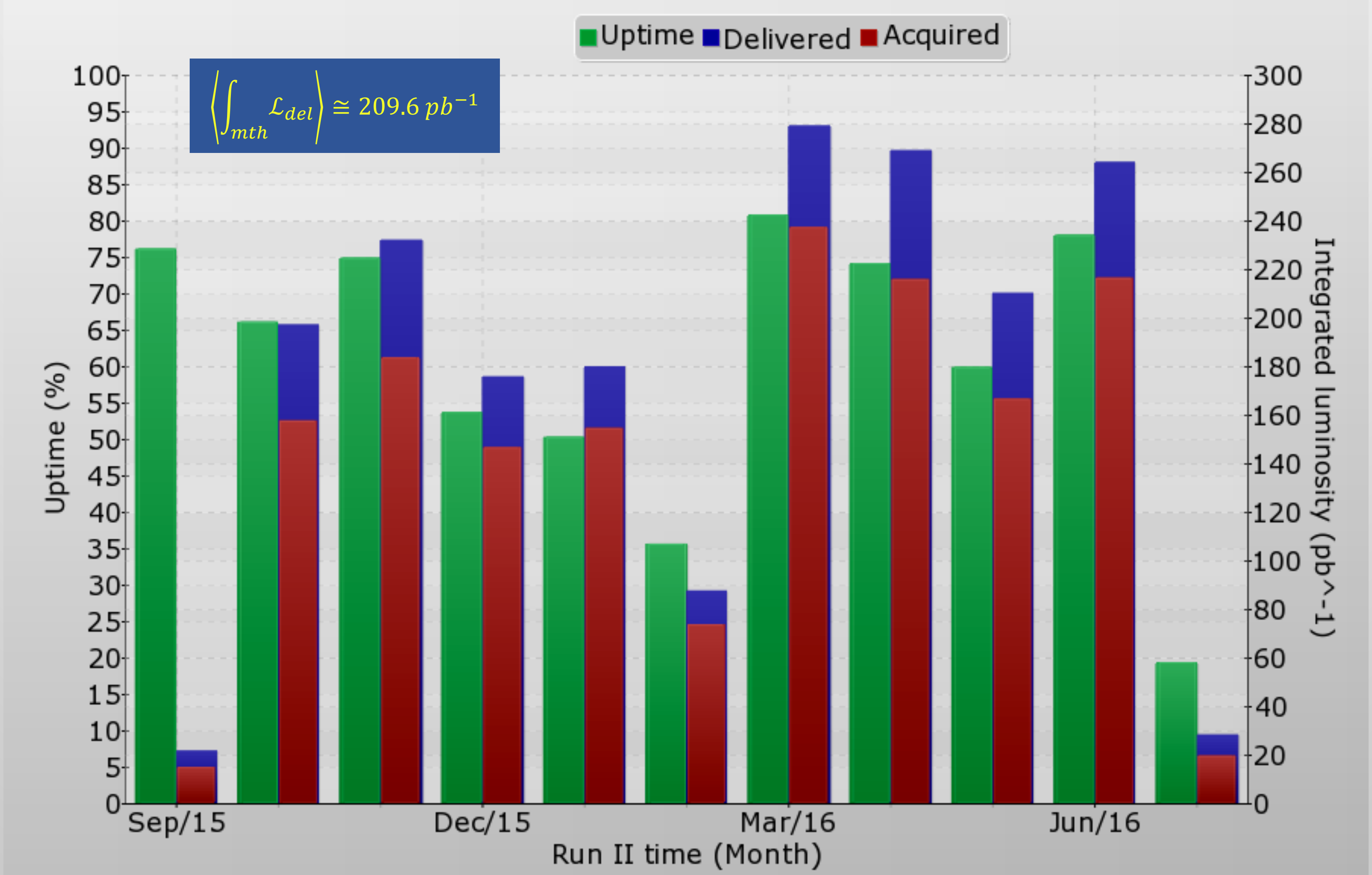
for contributing with their commitment to the huge administrative effort necessary to run DAFNE

Thank you for your attention

Spare Slides

II Run Monthly Performances

?

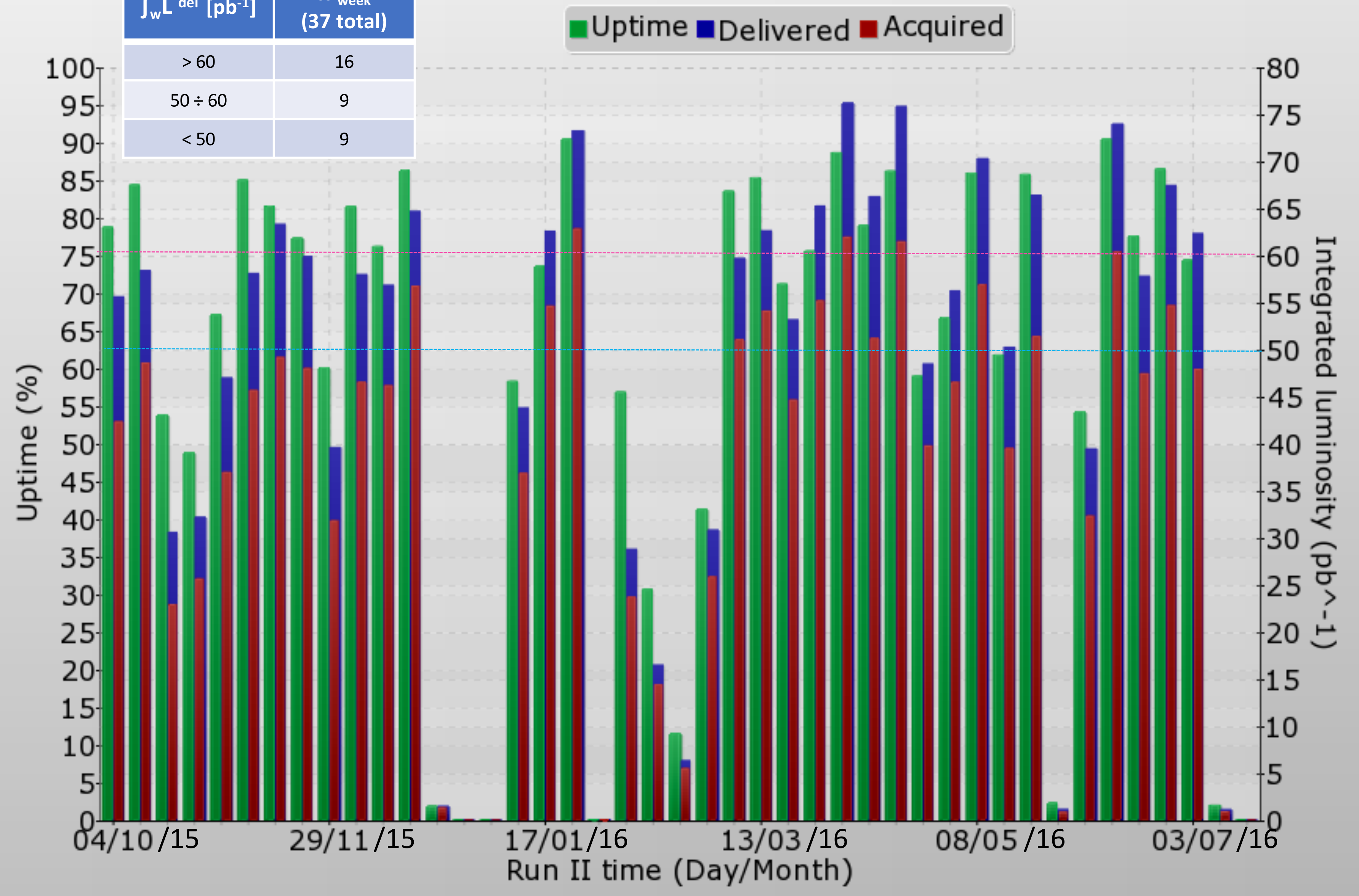


Uptime is defined as the percentage fraction of the day in which the collider has been delivering luminosity, suitable for acquisition

II Run Weekly Performances

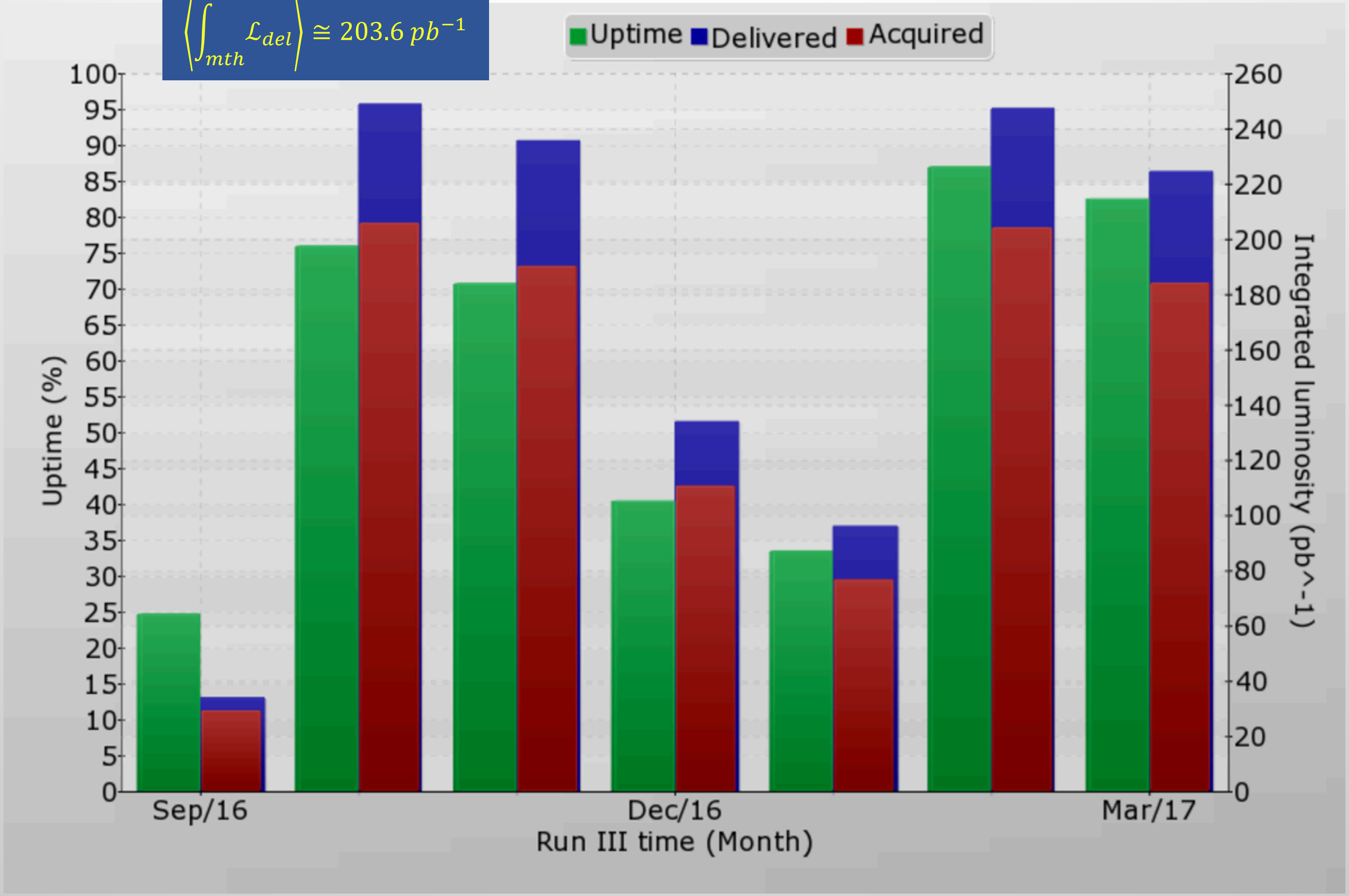
?

$\int_w L^{del}$ [pb^{-1}]	n_{week} (37 total)
> 60	16
50 ÷ 60	9
< 50	9



III Run Monthly Performances

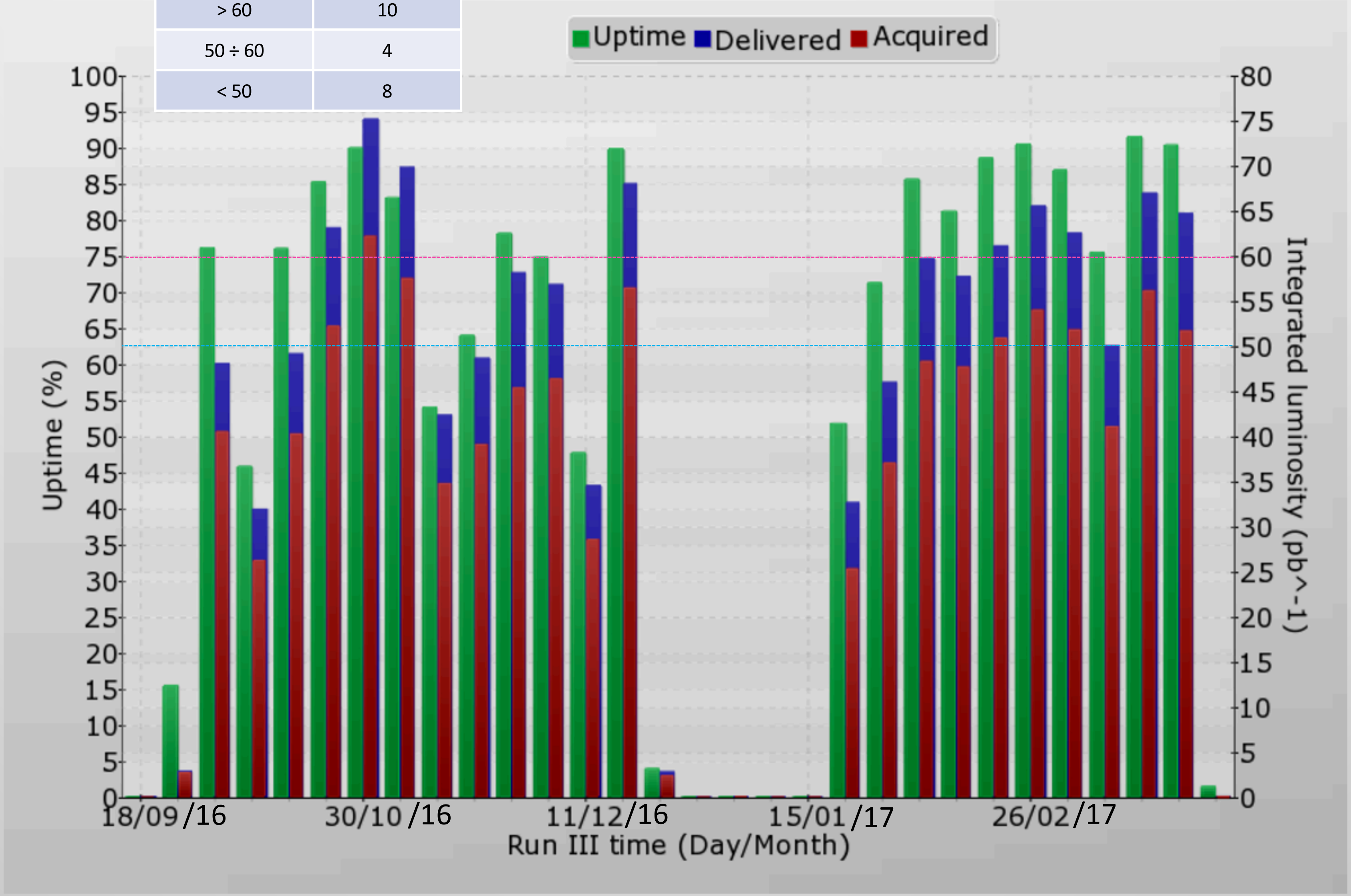
$$\left\langle \int_{mth} \mathcal{L}_{del} \right\rangle \cong 203.6\ pb^{-1}$$



Uptime is defined as the percentage fraction of the day in which the collider has been delivering luminosity, suitable for acquisition

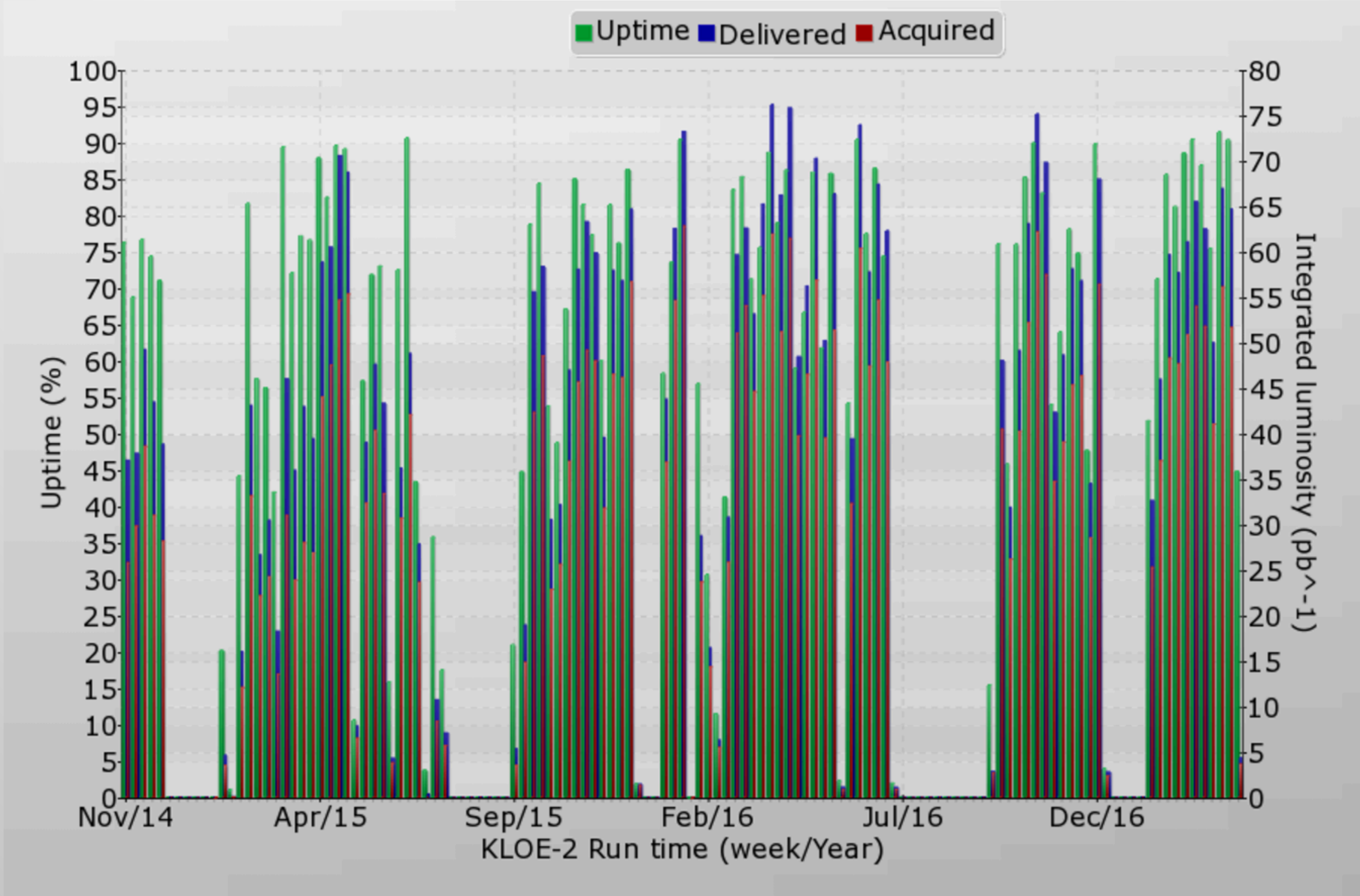
III Run Weekly Performances

$\int_w L^{del}$ [pb^{-1}]	n $_{week}$ (22 total)
> 60	10
50 ÷ 60	4
< 50	8



Uptime is defined as the percentage fraction of the day in which the collider has been delivering luminosity, suitable for acquisition

Weekly Performance Overview



Monthly Performance Overview