A REVIEW OF DAΦNE PERFORMANCES DURING THE KLOE-2 RUN

Catia Milardi
on behalf of the DAFNE Team

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

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The DAΦNE Team

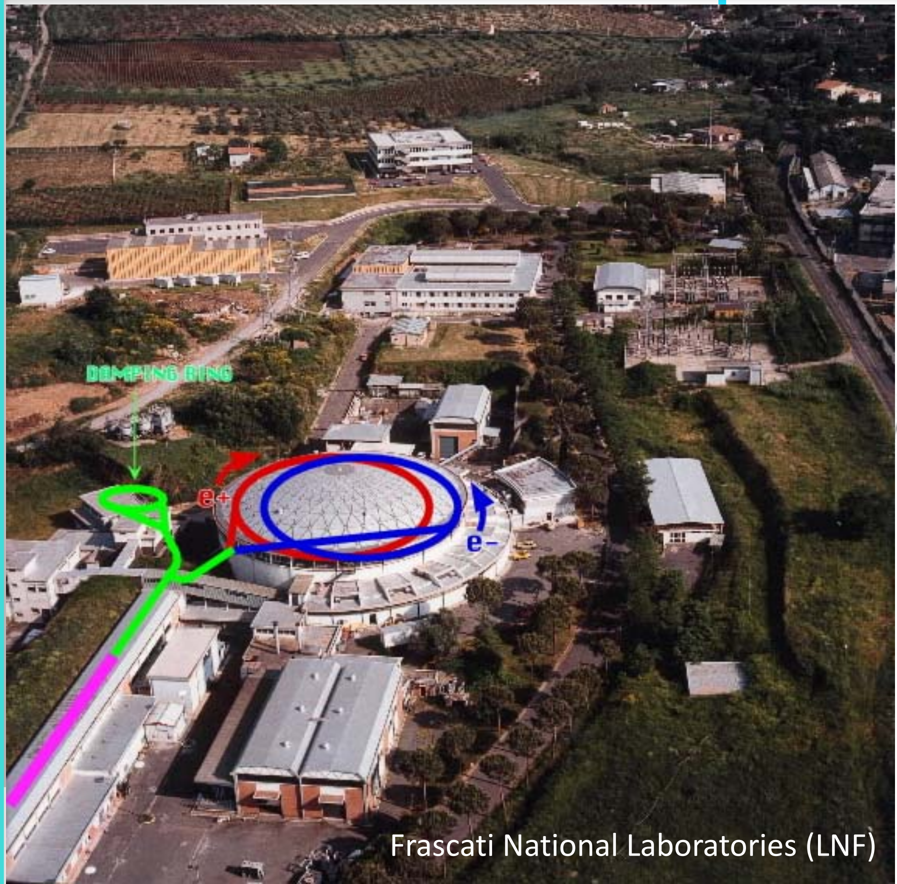
C. Milardi, D. Alesini, S. Bini, O. R. Blanco-Garcia, M. Boscolo, B. Buonomo, S. Cantarella, S. Caschera, A. De Santis, G. Delle Monache, C. Di Giulio, G. Di Pirro, A. Drago, A. D'Uffizzi, L. Foggetta, A. Gallo, R. Gargana, A. Ghigo, S. Guiducci, , C. Ligi, M. Maestri, A. Michelotti, L. Pellegrino, R.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

LNF-INFN, Frascati, Italy

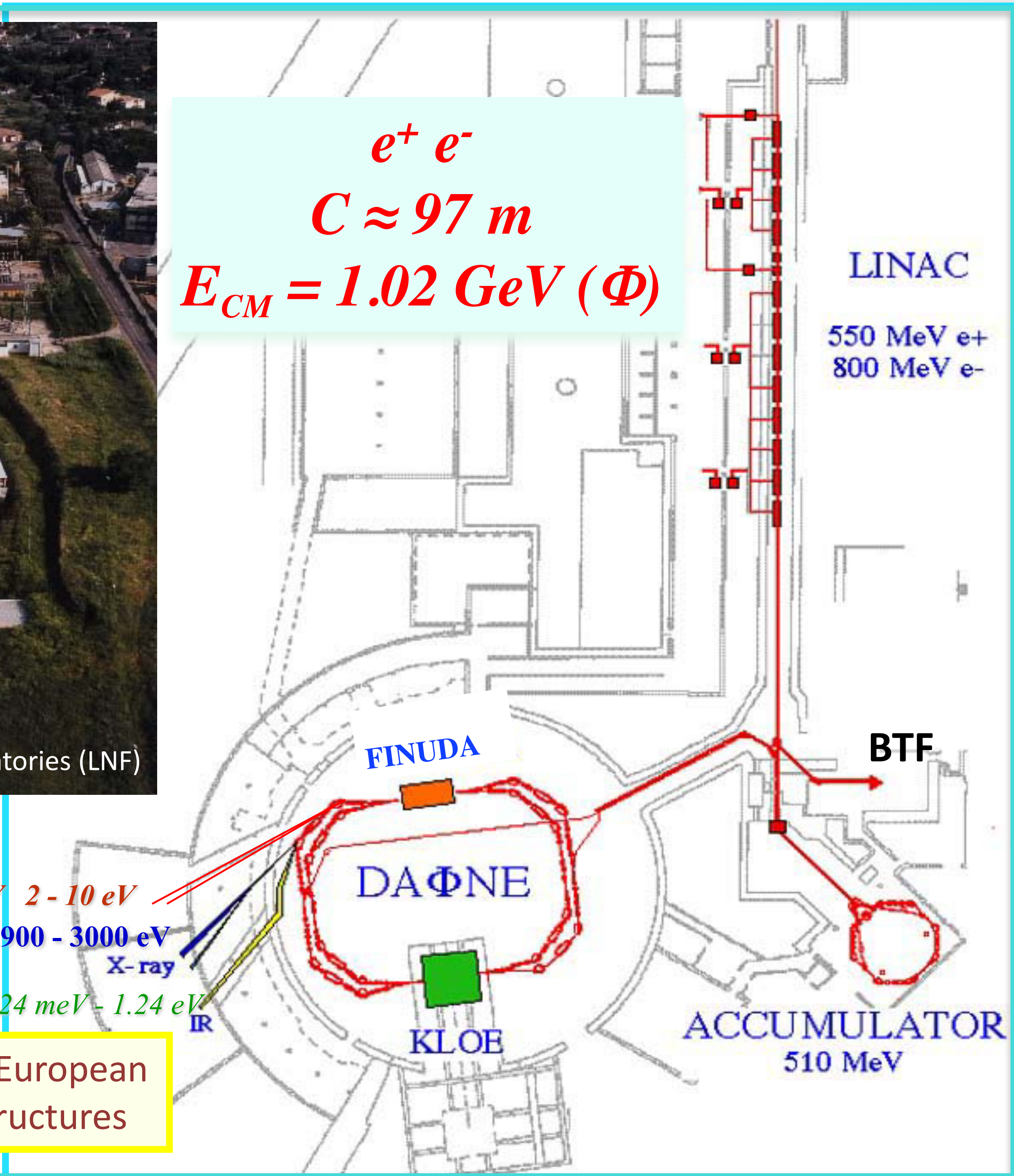
Outline

- *DAΦNE overview*
- *KLOE-2 operations*
- *Beam physics studies*
- *DAΦNE timeline*
- *Conclusions*

The DAΦNE Accelerator Complex

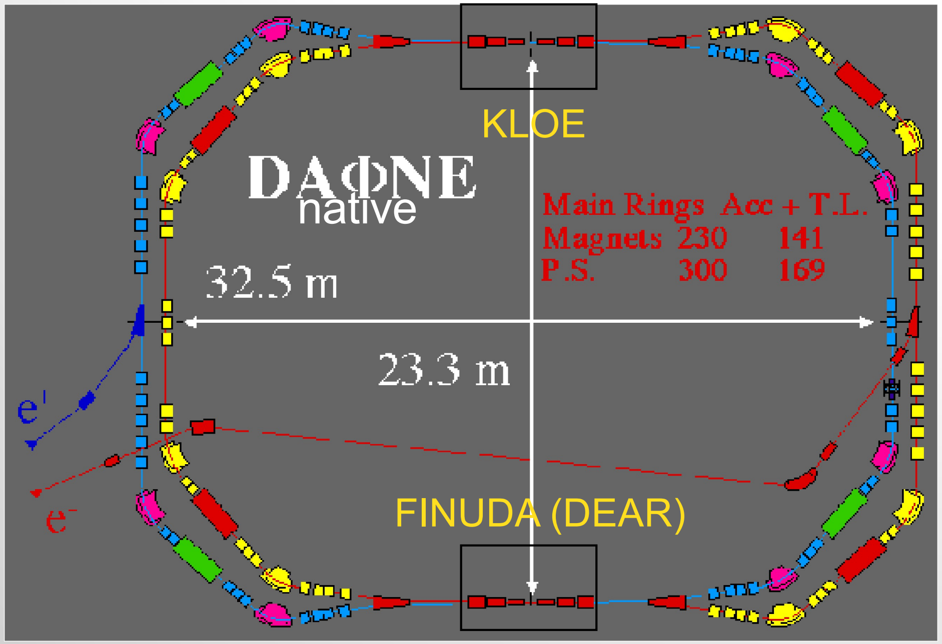


Frascati National Laboratories (LNF)



LNF are also part of the European synchrotron light Infrastructures

DAΦNE Layout and Parameters



"Proposal for a Φ-factory", LNF-90/031 (IR),1990.

	DAΦNE native	DAΦNE Crab-Waist
Energy (MeV)	510	510
$\theta_{cross}/2$ (mrad)	12.5	25
ε_x (mm•mrad)	0.34	0.28
β_x^* (cm)	160	23
σ_x^* (mm)	0.70	0.25
$\Phi_{Piwinski}$	0.6	1.5
β_y^* (cm)	1.80	0.85
σ_y^* (μm) low current	5.4	3.1
Coupling, %	0.5	0.5
Bunch spacing (ns)	2.7	2.7
I_{bunch} (mA)	13	13
σ_z (mm)	25	15
N_b	120	120

Colliding Beams have:
- *low E*
- *high currents*
- *short bunch spacing 2.7 nsec*
- *long damping time*

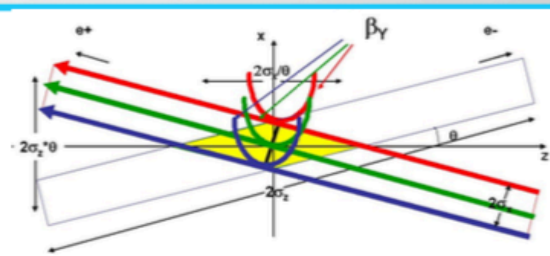
DAΦNE's Approach to *Beam-Beam* Interaction Optimization

A new collision scheme, the *Crab-Waist* collision scheme, has been devised and implemented on the DAΦNE collider in order to overcome all the limitations coming from:

- hourglass effect $\beta^*_y \sim \sigma_z$
- ***LRBB*** interactions
- beam transverse sizes enlargement due to ***BB* interaction**

and the synchro-betatron resonances due to the new configuration itself

Crab-Waist is based on:



Large Piwinski angle Φ — large θ, small σ^*_x

$$\Phi \approx \frac{\sigma_z}{\sigma^*_x} tg\left(\frac{\theta}{2}\right) >> 1$$

→ *L* gain with N
low ξ_x
ξ_y decrease with Y oscillation amplitude

β^*_y comparable with overlap area

$$\beta^*_y \approx 2\sigma^*_x/\theta$$

→ *L* geometrical gain
lower ξ_y
Y Synchro-betatron resonances suppression

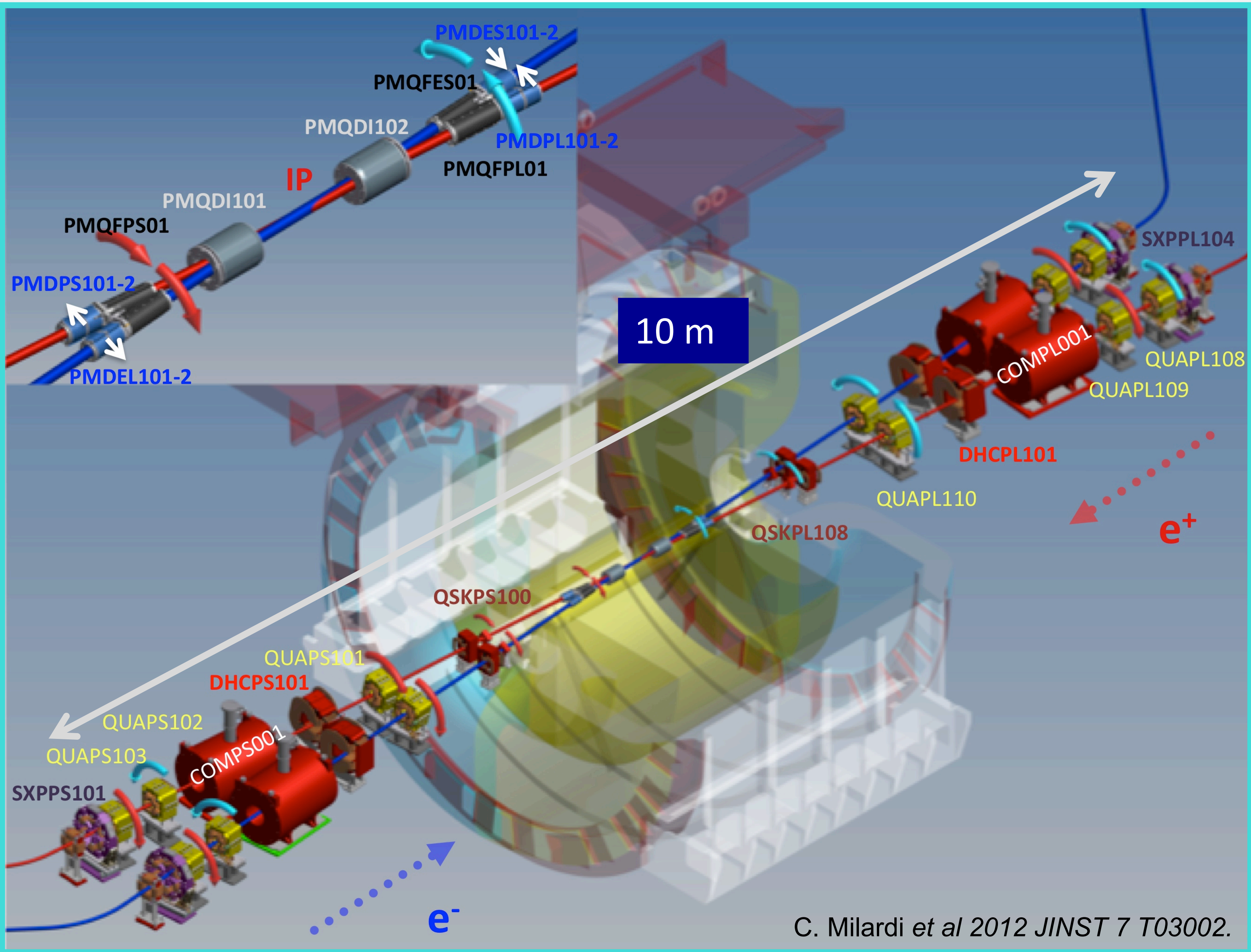
Crab-Waist transformation by two Sextupoles

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

→ *L* geometrical gain
lower ξ_y
X-Y Synchro-betatron resonances 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.

KLOE-2 IR



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

DAΦNE Activity Program for KLOE-2

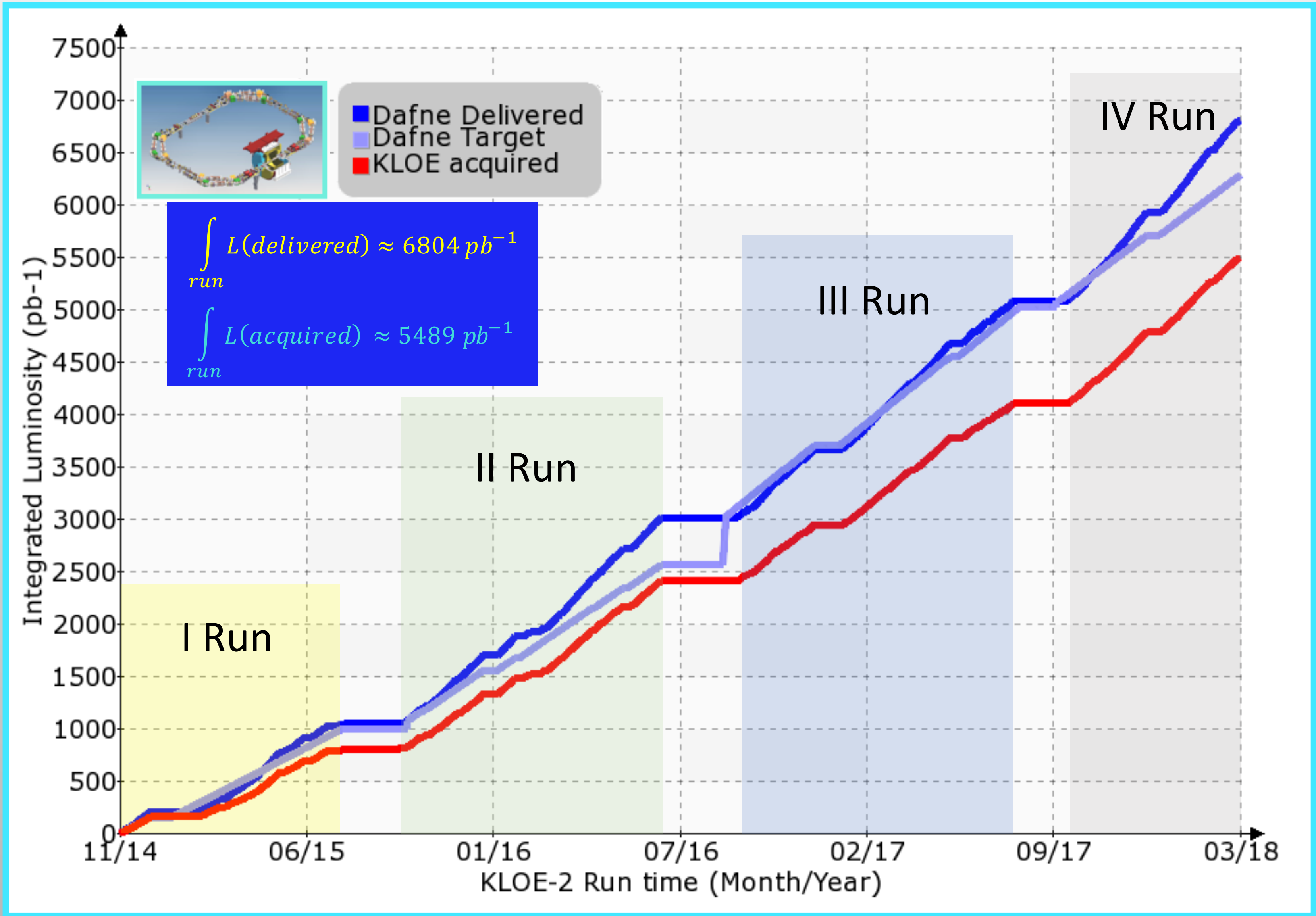
Preliminary Test Phase *fall 2010 ÷ Dec 2012*

Collider Consolidation
KLOE-2 detector layers installed *Dec 2012 ÷ Jun 2013*

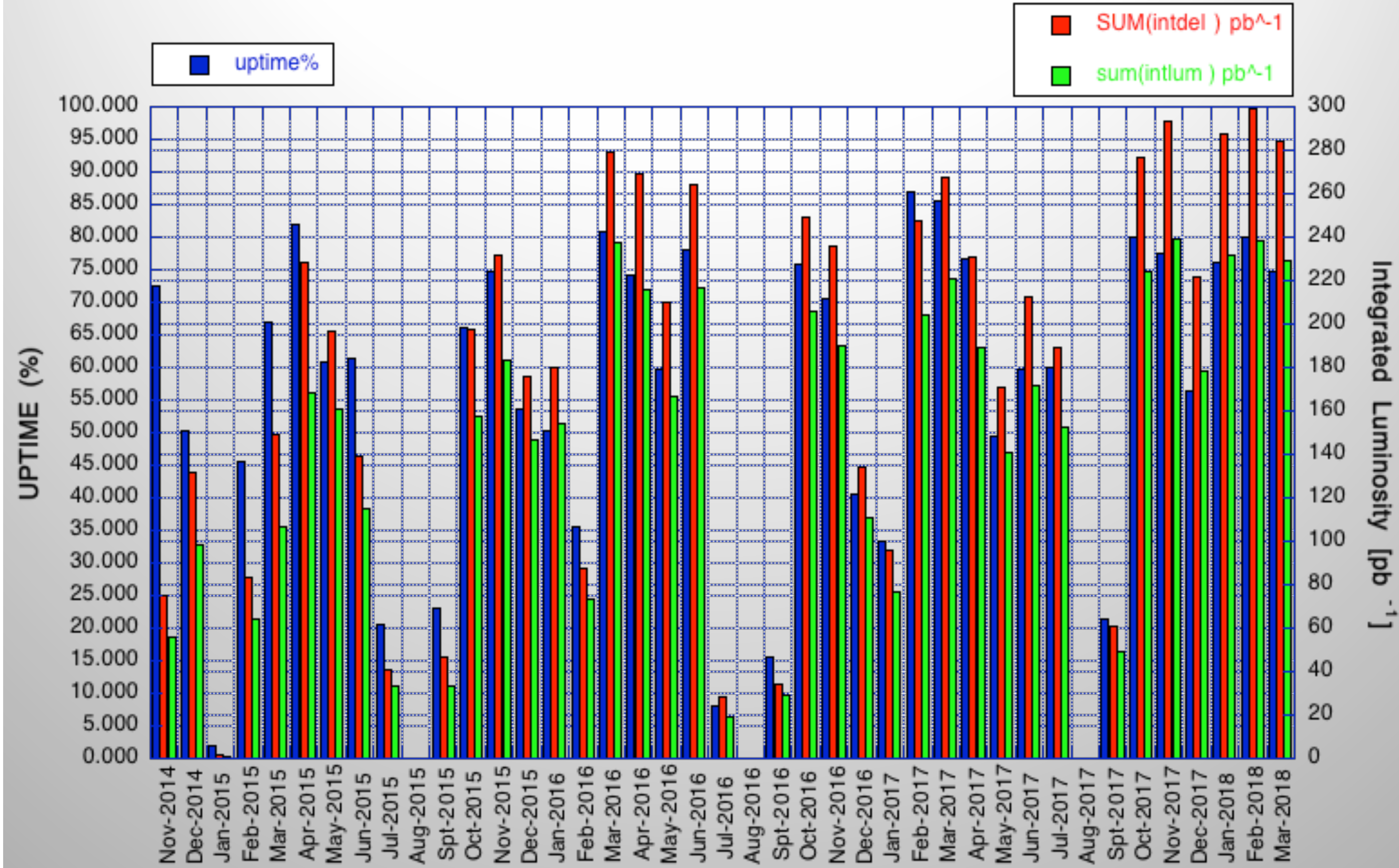
KLOE-2 data taking

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*
goal 1.5 fb^{-1}

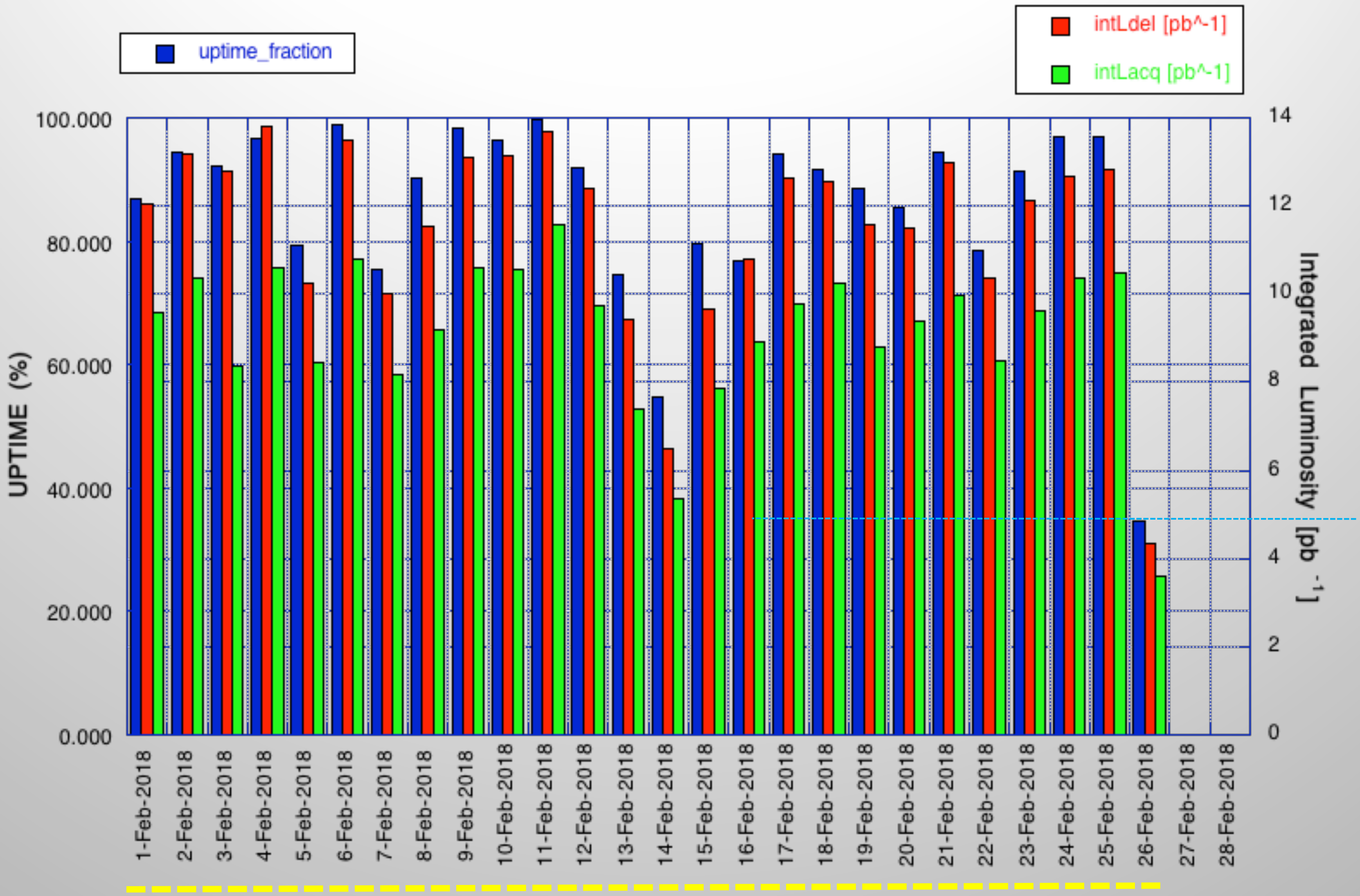
KLOE-2 Run Overview



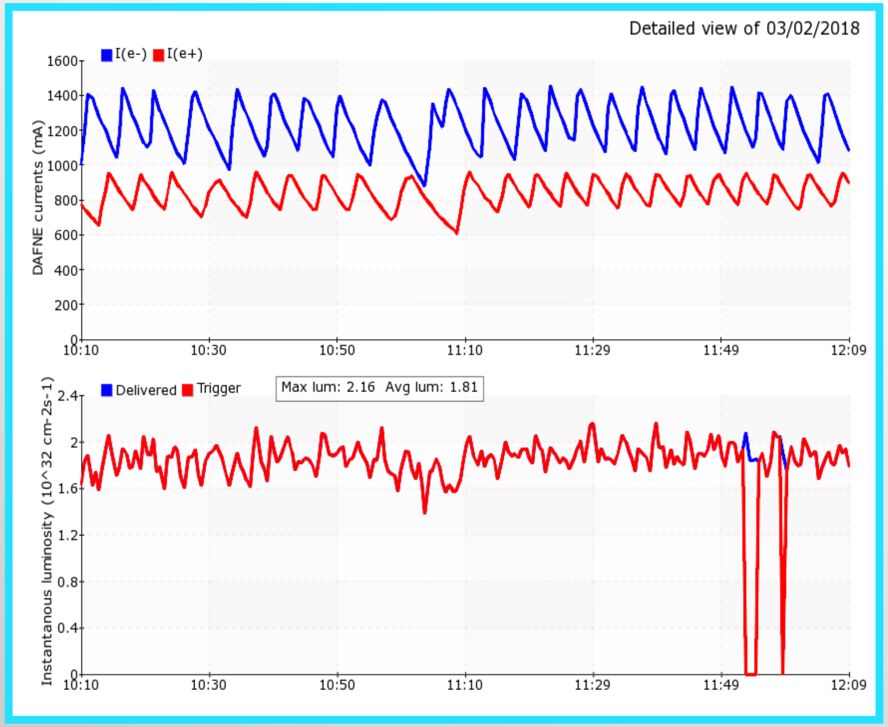
Month by Month Luminosity Trend

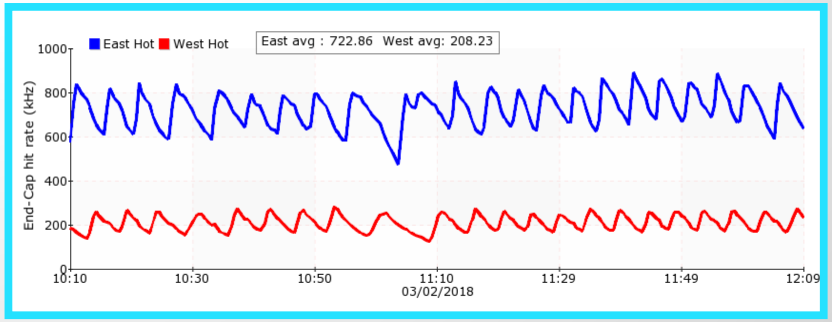


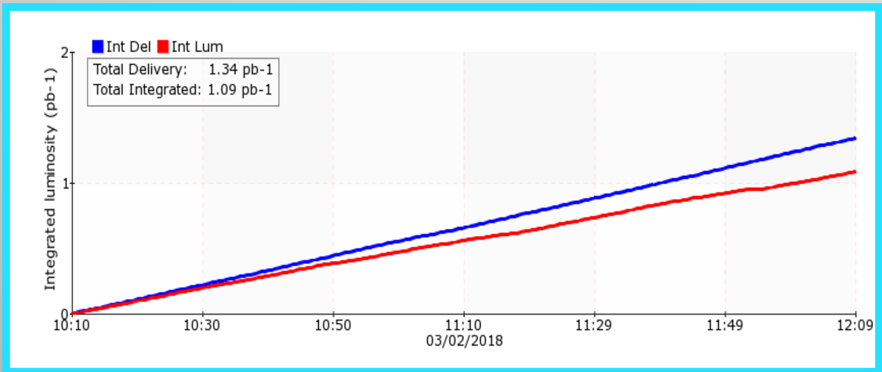
Best Operations Month



Highest Hourly Integrated Luminosity





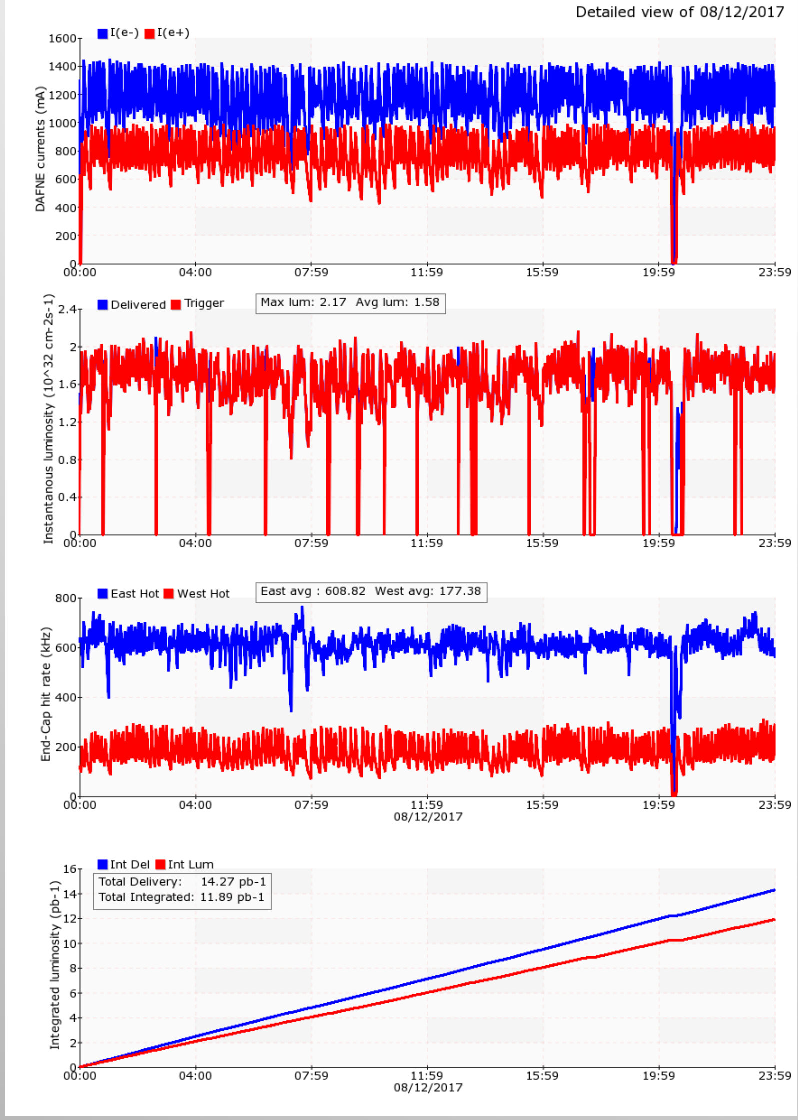


$$\int_{1h} L \sim 0.67\ pb^{-1}$$

$$N_b = 107$$

$$\int_{1\ day} L \sim 16\ pb^{-1}$$

Highest Daily Integrated Luminosity

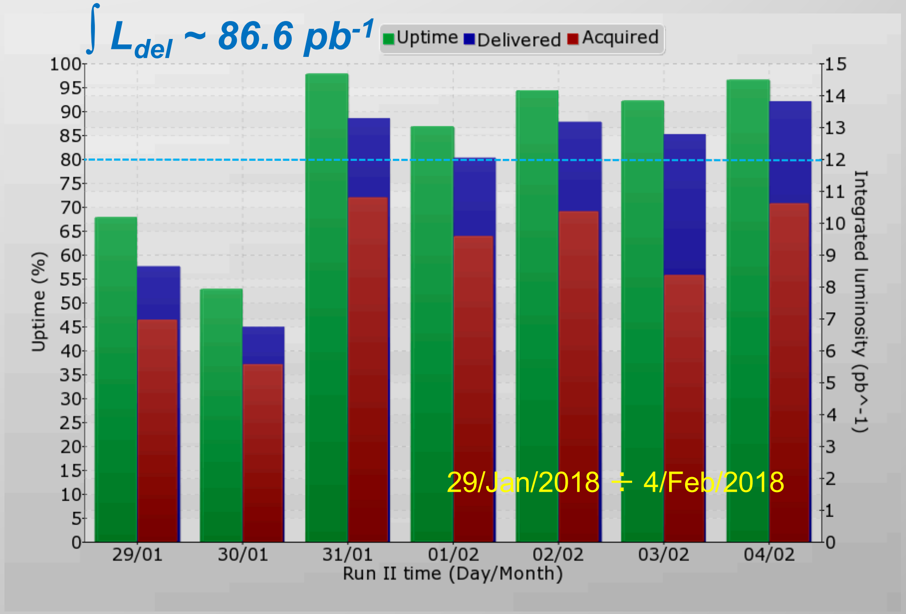


$\int L_{del} \sim 14.3\ pb^{-1}$

$\int L_{acq} \sim 11.9\ pb^{-1}$

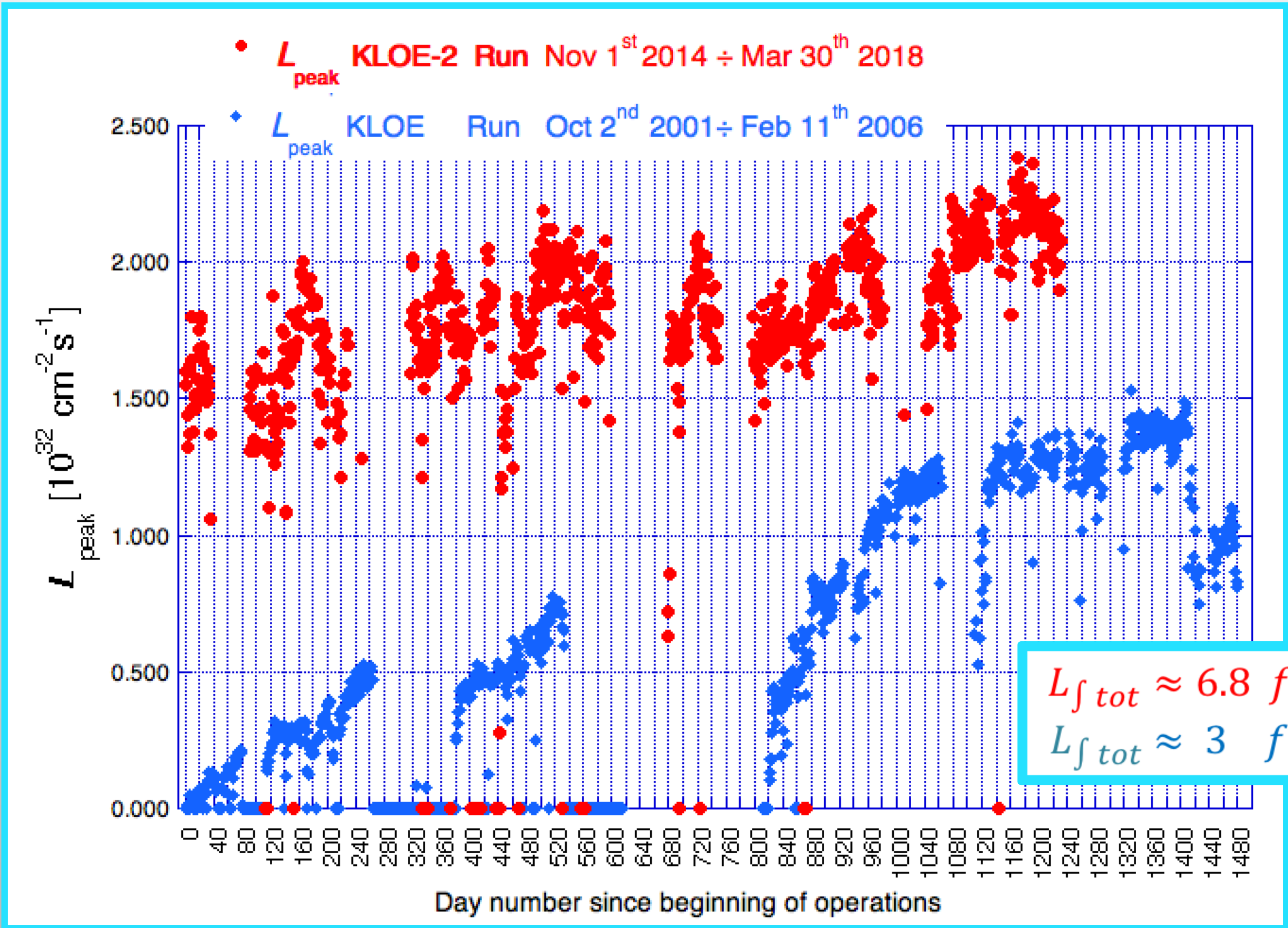
Uptime ~98%

- 106 bunches
- $I^{-}_{MAX} = 1.45 \div 1.6$ A
- $I^{+}_{MAX} = 0.99 \div 1.16$ A
- Sustainable background



Crab-Waist Luminosity Gain

Crab-Waist provides a 59% increase in terms of peak luminosity as evidenceded by data taken by the same detector with the same accuracy

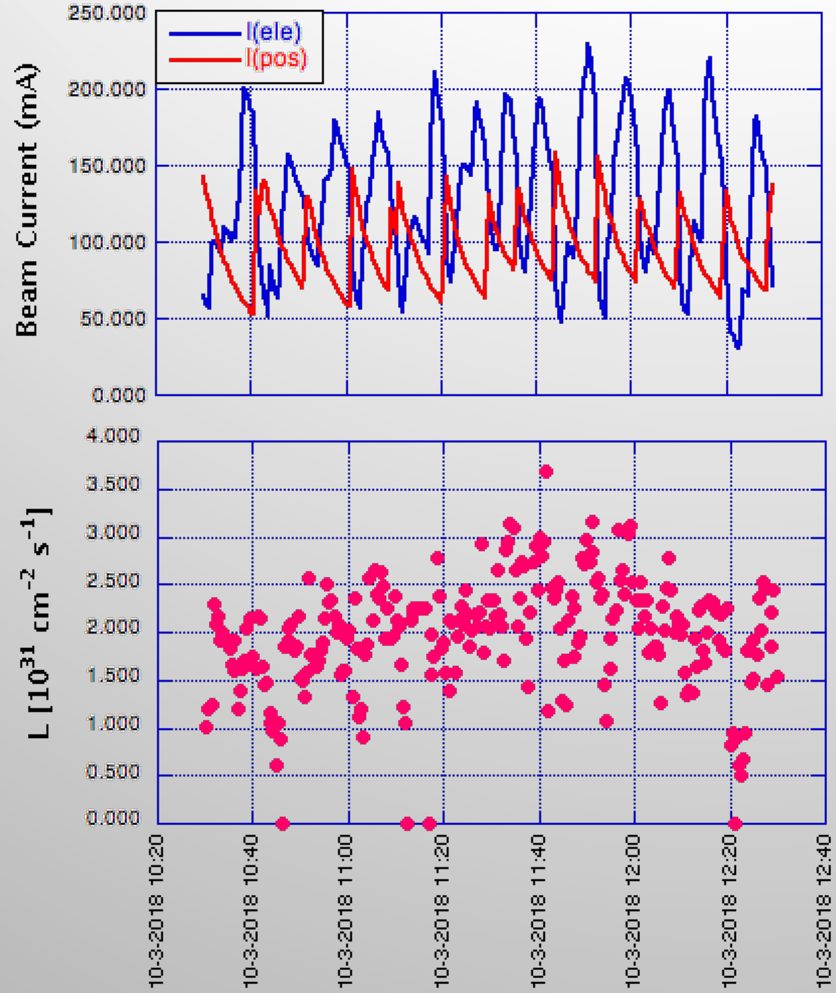


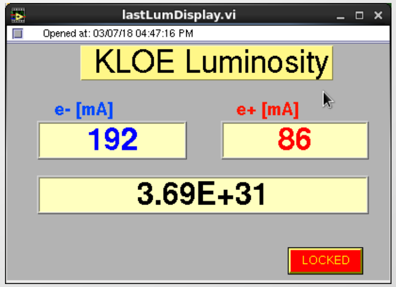
$L_{\int tot} \approx 6.8\ fb^{-1}$

$L_{\int tot} \approx 3\ \ fb^{-1}$

10 Bunches Collisions

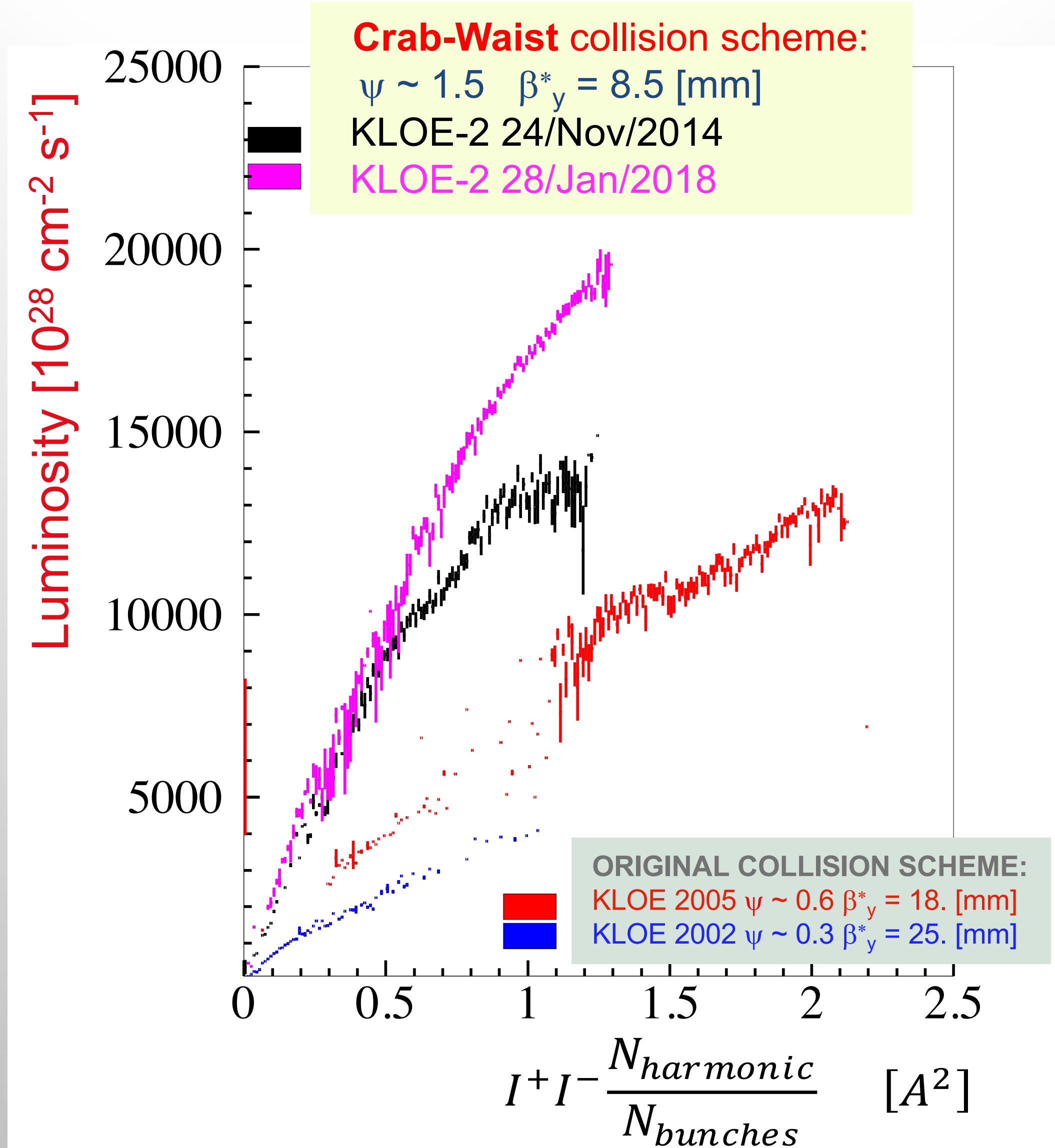
Aiming at minimizing the impact of multi-bunches effects and e-cloud instabilities on *Luminosity*





- *L_{peak} ~ 3 •10^{32} cm^{-2} s^{-1} might be achieved by colliding 100 bunches*
- *Beam-beam is not a limiting factor*
- *Crab-Waist Sextupoles work*

Crab-Waist Luminosity Gain



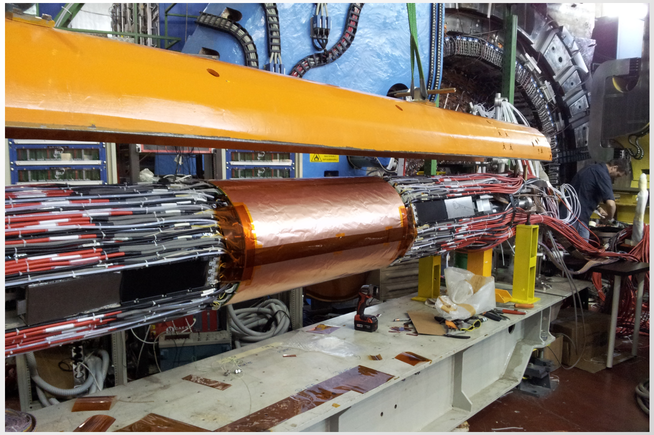
Peak Luminosity

	DAΦNE CW upgrade SIDDHARTA (2009)	DAΦNE KLOE (2005)	DAΦNE (CW) KLOE-2 (2014)
L_{peak} [$cm^{-2}s^{-1}$]	$4.53 \cdot 10^{32}$	$1.50 \cdot 10^{32}$	$2.38 \cdot 10^{32}$
I^- [A]	1.52	1.4	1.18
I^+ [A]	1.0	1.2	0.87
$N_{bunches}$	105	111	106
$\int_{day} L$ [pb^{-1}]	14.98	9.8 (seldom)	14.3

L_{peak} exceeds by a 59% the best luminosity ever achieved, at DAΦNE, during operations for an experimental apparatus including high field detector solenoid.

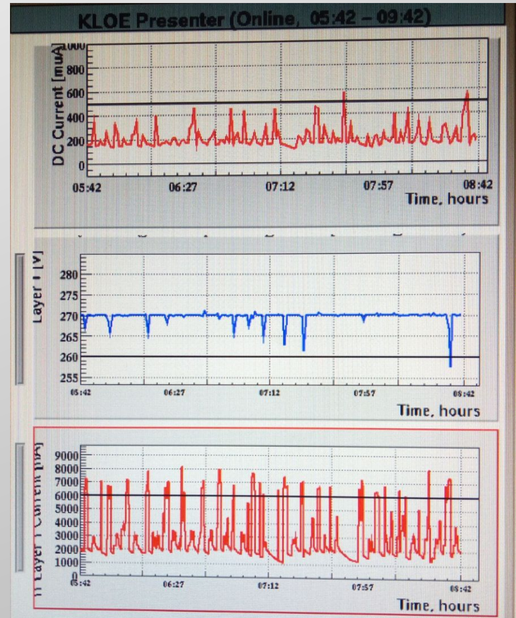
Background Control

The new detector layers installed around the beam pipe posed new tight requirements on background level and control.



Criteria for acceptable background became:

- counting rate on the detector endcaps
- current amplitude measured by the different drift chamber sectors
- discharge threshold on the innermost IT layer



Background on the IT was heavily dependent on the injection process which had to be accurately optimized and stabilized (THPAK020)

Even small drifts in the energy of the incoming beam, 0.01 ÷ 0.02 %, were causing unaffordable background level.

e^- Ring Working Point Scan

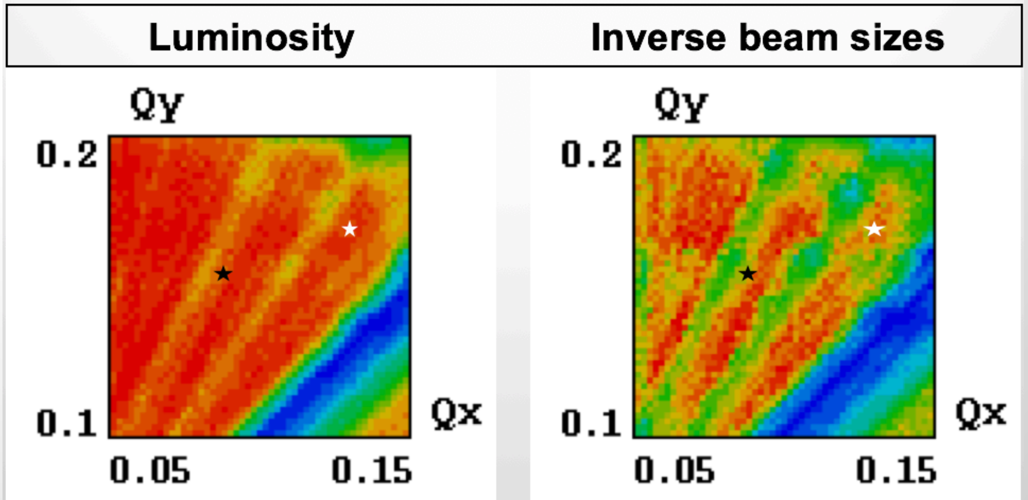
Numerical simulations aiming at improving:

dynamical aperture

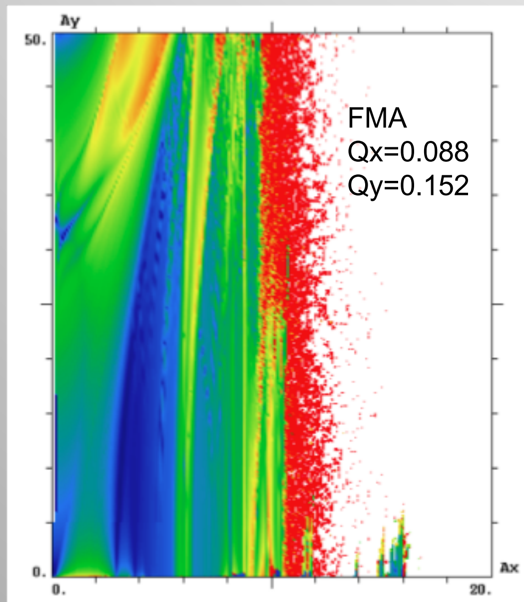
specific luminosity

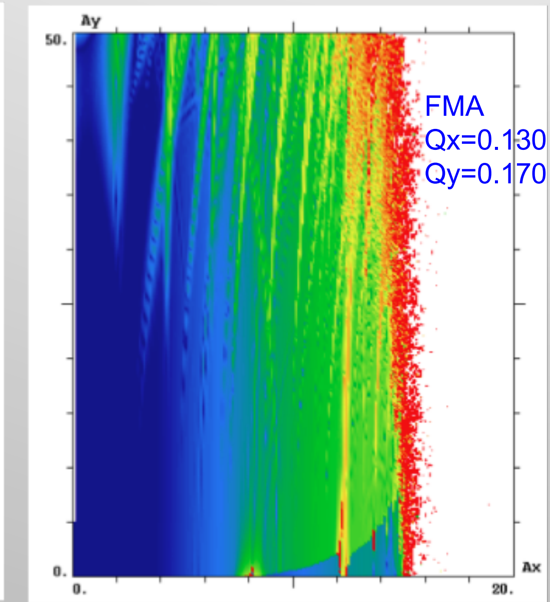
led to define a new working point for the e^- ring

Qx=0.135 Qy=0.17



M. Zobov *et al*., *IEEE Trans. Nucl. Sci.*, Vol. 63, no. 2, pp. 818-822,2016.





achieving:

larger DA 2 – 3 σ

Improved injection efficiency

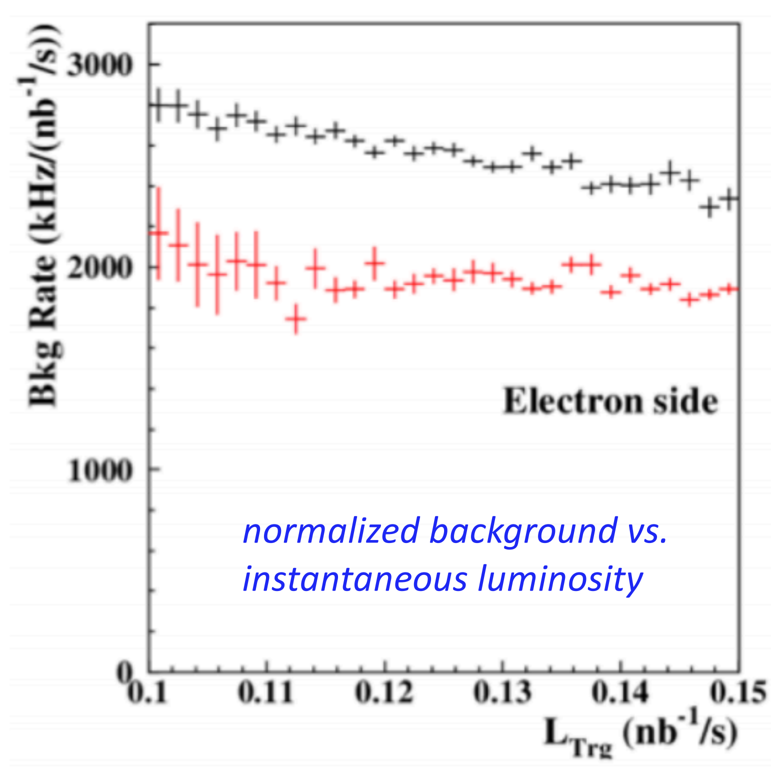
higher beam lifetime

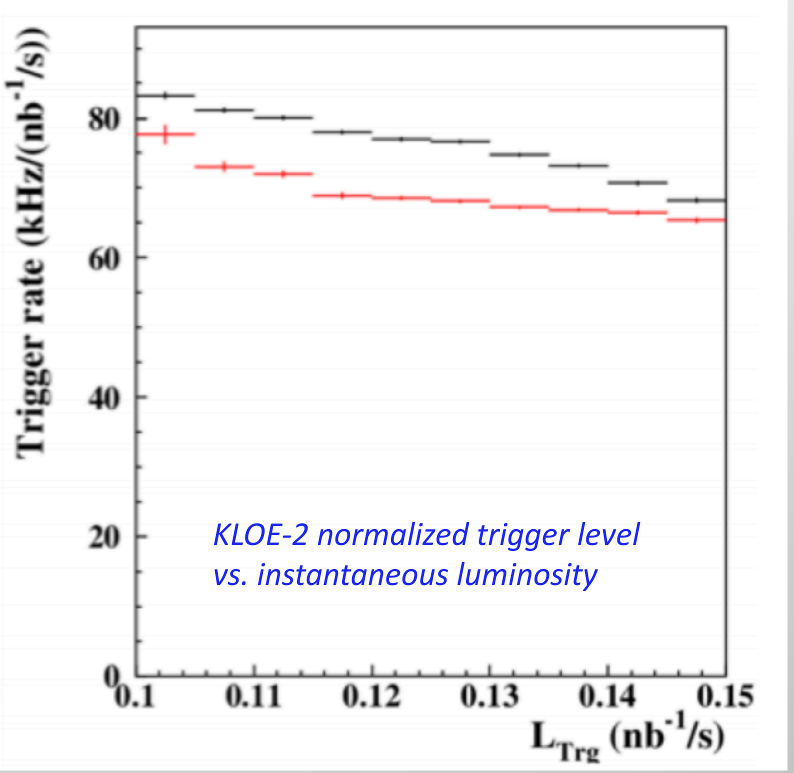
reduced background ~ 20%

higher luminosity ~ 7%

Impact of the New e^- Ring Configuration

- old WP
- new WP





Electron Beam Dynamics

During the KLOE-2 run the maximum e^- currents stored at regime in collision has been in the range

$$1.3 \div 1.5 \text{ A}$$

It was mainly limited by:

- ion in the residual gas
- impedance induced effects (TMCI)

Ions are neutralized introducing a suitable gap in the batch

As dynamical vacuum was improving filled bunches have been progressively increased the range of 93 $\div$ 108 with the same total current, thus reducing:

- Touschek contribution to the background
- the impact of the microwave instability threshold

Best machine performances have been achieved through collisions of 106 consecutive bunches.

Positron Beam Dynamics

During the KLOE-2 run the maximum current stored in the e^+ beam has been of the order of $I^+ \sim 1.2$ A.

Highest e^+ current stored routinely in collision rarely exceeded $I^+ > 0.95$ a value considerably lower than the one achieved during the past runs

Beam dynamics in the e^+ ring is clearly dominated by the e-cloud induced instabilities

At DAΦNE the e-cloud effects are controlled by:

- solenoid windings
- FBK systems
- electrodes ECE
- moving ξ_x ξ_y to higher positive values
- lengthening the bunch by reducing the RF cavity voltage

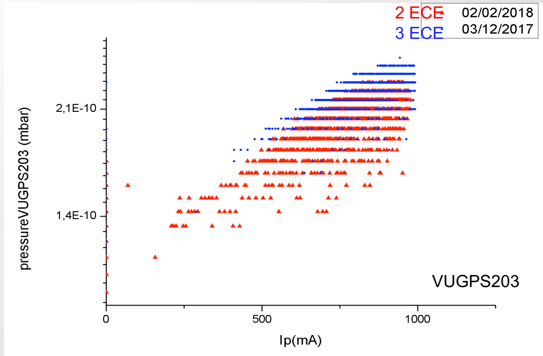
Experience with ECE at DAΦNE

ECE have been fundamental in order to achieve high e^+ currents mostly in the first stage of operations

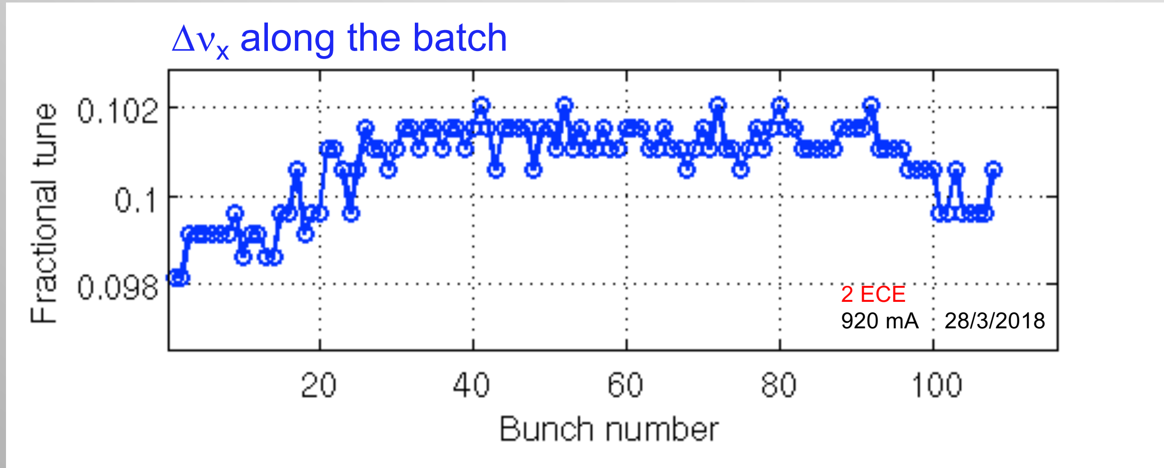
At the end of the run only 2 out of the 12 devices were working properly, none of them was in the wigglers

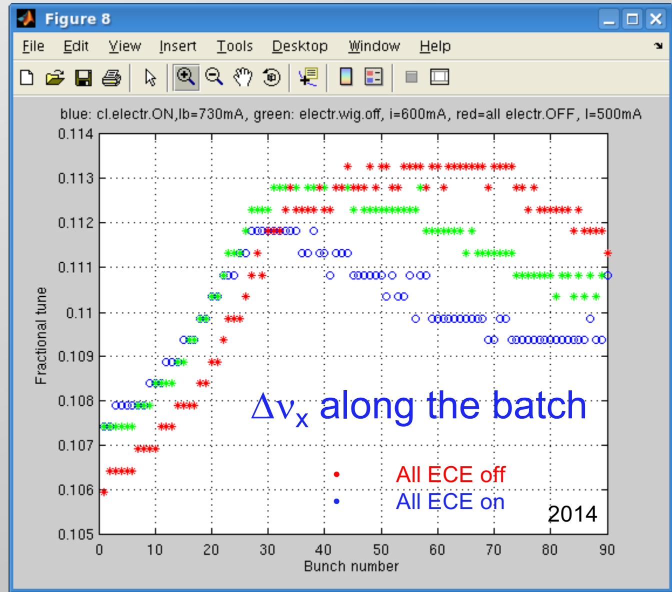
High current operations have still been possible thanks to the scrubbing process as confirmed by the data about

- vacuum pressure rise in the e+ ring arcs
- tune spread measurements



A posteriori analysis to explain the ECE behavioue is under way





DAΦNE Feedback Systems

In a low energy machine as DAΦNE high current performances depend greatly on bunch by bunch feedback systems.

DAΦNE works routinely thanks to the 3 bunch by bunch feedbacks installed in each ring

The total power available for each apparatus is of the order of 500 W and 750 W for transverse and longitudinal feedbacks respectively

Beam current limits observed

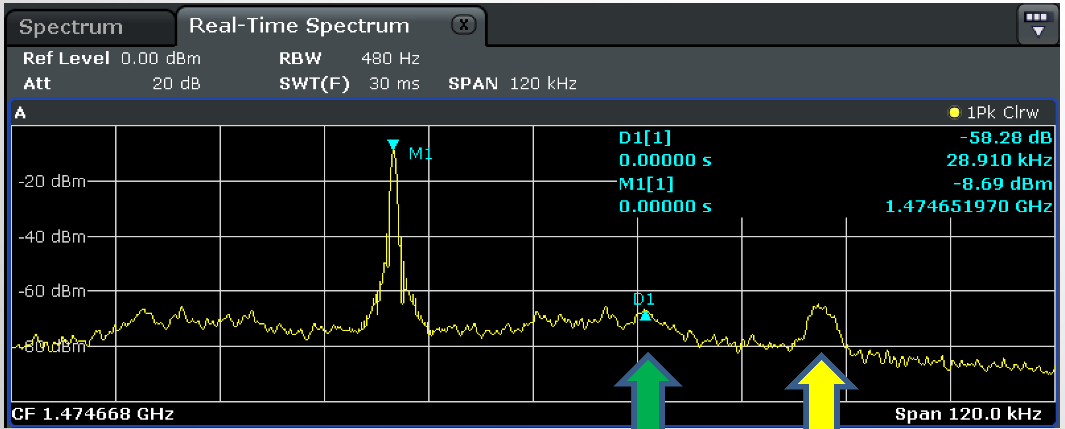
- longitudinal mode-0 & quadrupole oscillations
- noise coming from pickups (harmful for vertical sizes)
- e-cloud effects (in the e+ ring)

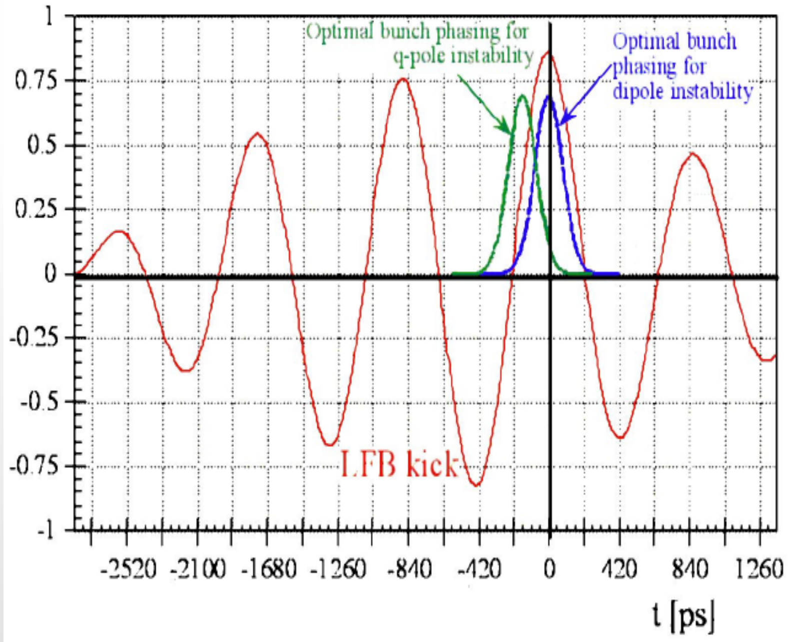
Solutions:

- Longitudinal quadrupole control by a special technique implemented at DAFNE in the dipole feedback system
- Transverse low noise front end (in collaboration with KEK)

Longitudinal Quadrupole Oscillations

@ $f \sim 2 \cdot f_{sync}$

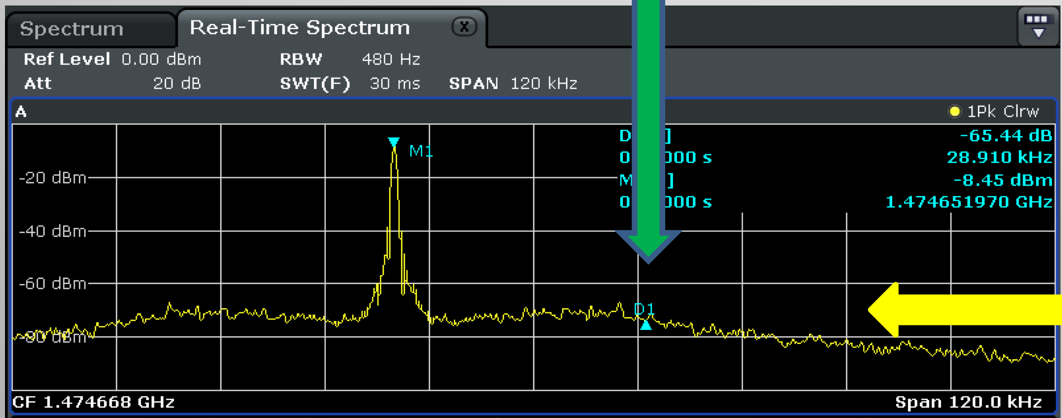




Revolution harmonic

Quadrupole oscillation

Synchrotron (dipole) oscillations damped by Long FBK



The present source of quadrupole instability is still under investigation
This instability, if not controlled, saturates the longitudinal feedback

(A.Drago, et al., PRST-AB, 6, 052801-1-11, 2003)

Time Managment

Achieving milestones for the KLOE-2 run required a careful scheduling of the time for:

maintanance
machine studies and measurements
facing unexpected faults even caused by external factors
data taking

looking at the machine uptime, at the integrated luminosity trend, and at the fault rate in every accelerator subsystems

Regardless the major upgraid planned before the start of the run, many relevant interventions had to be done during data taking as for instance:

replacemnet of the Cryo plant compressor
revision of the cooling system serving low-β section and detector electronic equipments
revision of the wiggler magnet cooling system

Time originally allocated for machine studies and measurements has been often spent for:

planning interventions suggested by anomalous fault rates in specific subsystems
outlining problems resulting in subtle effects affecting beam optics and beam dynamics.

As in the case of the electronic phase shifter in electron ring LLRF. which caused the cavity e^- RF phase, and consequently the beam, to shift slowly and randomly by about 10 deg

This approach and a considerable lack of manpower did not allow to exploit the DAΦNE's full potential as a collider, but assured data taking.

DAΦNE Timeline

March 31st 2018

end of the KLOE-2 Run

April ÷ September

KLOE-2 roll-out and SIDDHARTA-2 IR installation

September ÷ December 2018

DAΦNE commissioning and SIDDHARTA setup

(MOPFM088)

In year 2019

SIDDHARTA-2 data taking

Starting from 2020 DAΦNE might be transformed in a test facility:

DAΦNETF

Conclusion

DAΦNE has just concluded the run for the KLOE-2 experiment achieving unprecedented results in terms of luminosity.

This has been possible thanks to an effective integration of the Crab-Waist Collision Scheme with the high field detector solenoid.

The Crab-Waist Collision Scheme has proven to be a viable approach to increase luminosity in circular colliders even in presence of an experimental apparatus strongly perturbing beam dynamics.

Good news for all the new machines and projects around the world that have adopted Crab-Waist as their main design concept .

Thank you for your attention