# Review of DAΦNE Performances During the KLOE-2 Run and a Quick Look to the Future

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on behalf of the DAFNE Team

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# The DAΦNE Team

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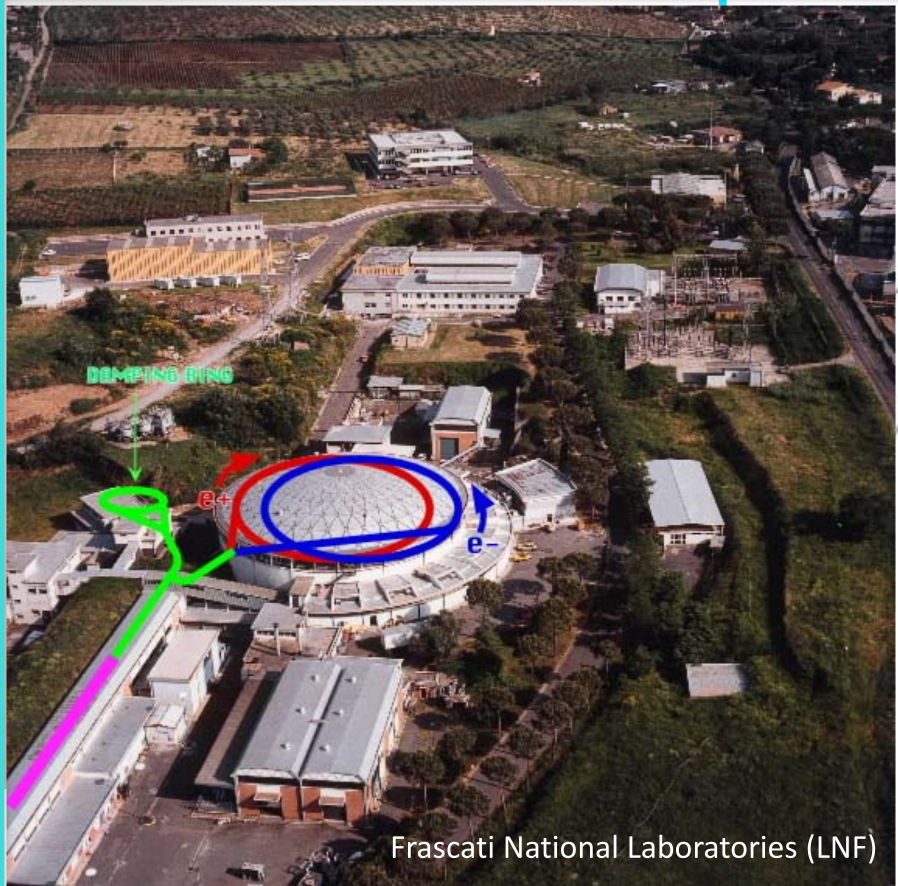
*LNF-INFN, Frascati, Italy*

# Outline

- *DAΦNE overview*
- *KLOE-2 operations*
- *DAΦNE timeline*
- *Preparation for the SIDDHARTA-2 run*
- *Conclusions*

# The DAΦNE Accelerator Complex

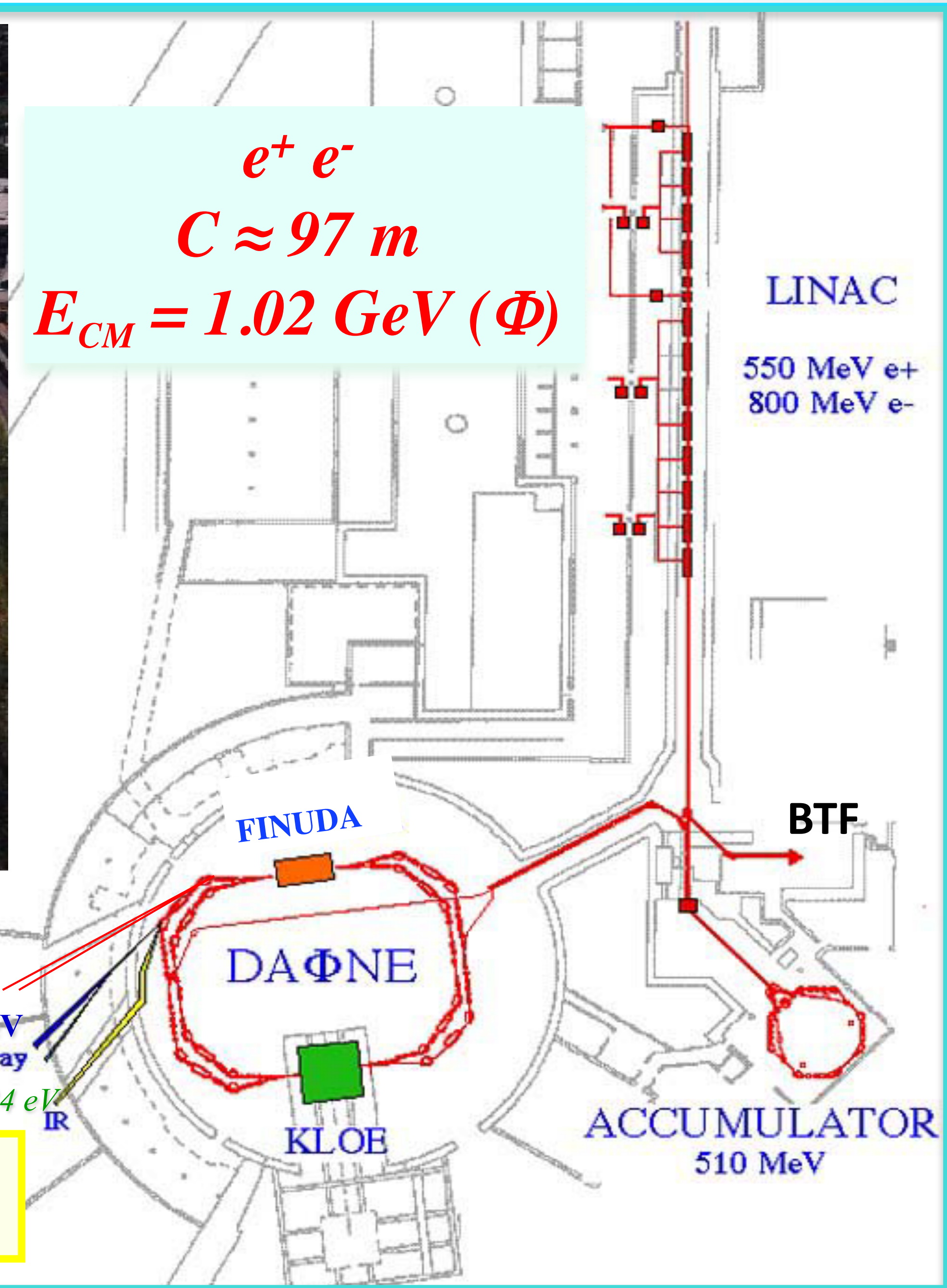



Frascati National Laboratories (LNF)

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

$C \approx 97\ m$

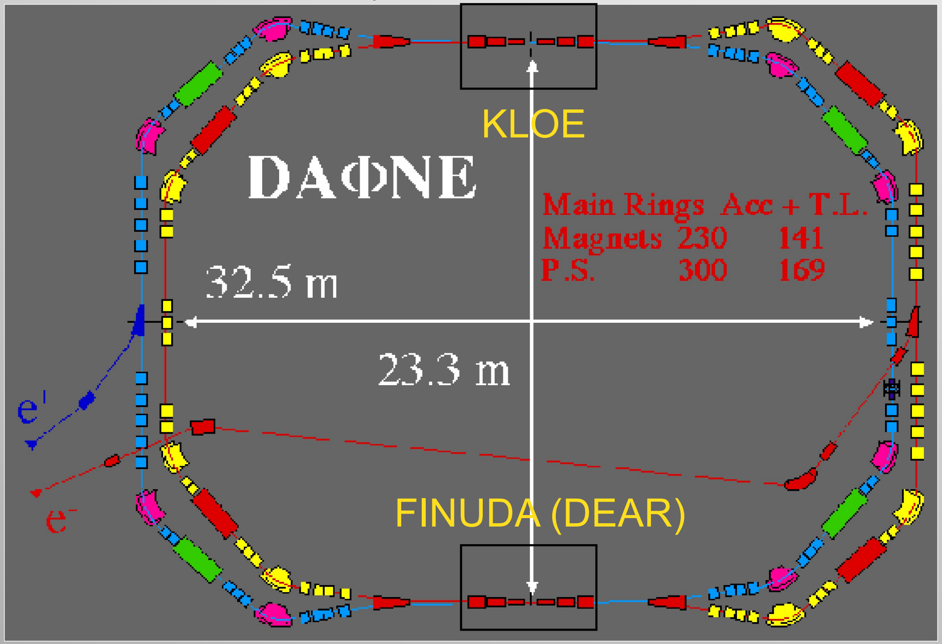
$E_{CM} = 1.02\ GeV\ (\Phi)$




LNF are also part of the European synchrotron light Infrastructures

# DAΦNE Layout and Parameters


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.




"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 |
| $\varepsilon_x$ (mm•mrad) | 0.34 | 0.28 |
| $\beta_x^*$ (cm) | 160 | 23 |
| $\sigma_x^*$ (mm) | 0.70 | 0.25 |
| $\Phi_{Piwinski}$ | 0.6 | 1.5 |
| $\beta_y^*$ (cm) | 1.80 | 0.85 |
| $\sigma_y^*$ (μm) low current | 5.4 | 3.1 |
| Coupling, % | 0.5 | 0.5 |
| Bunch spacing (ns) | 2.7 | 2.7 |
| $I_{bunch}$ (mA) | 13 | 13 |
| $\sigma_z$ (mm) | 25 | 15 |
| $N_b$ | 120 | 120 |

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

# DAΦNE 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**

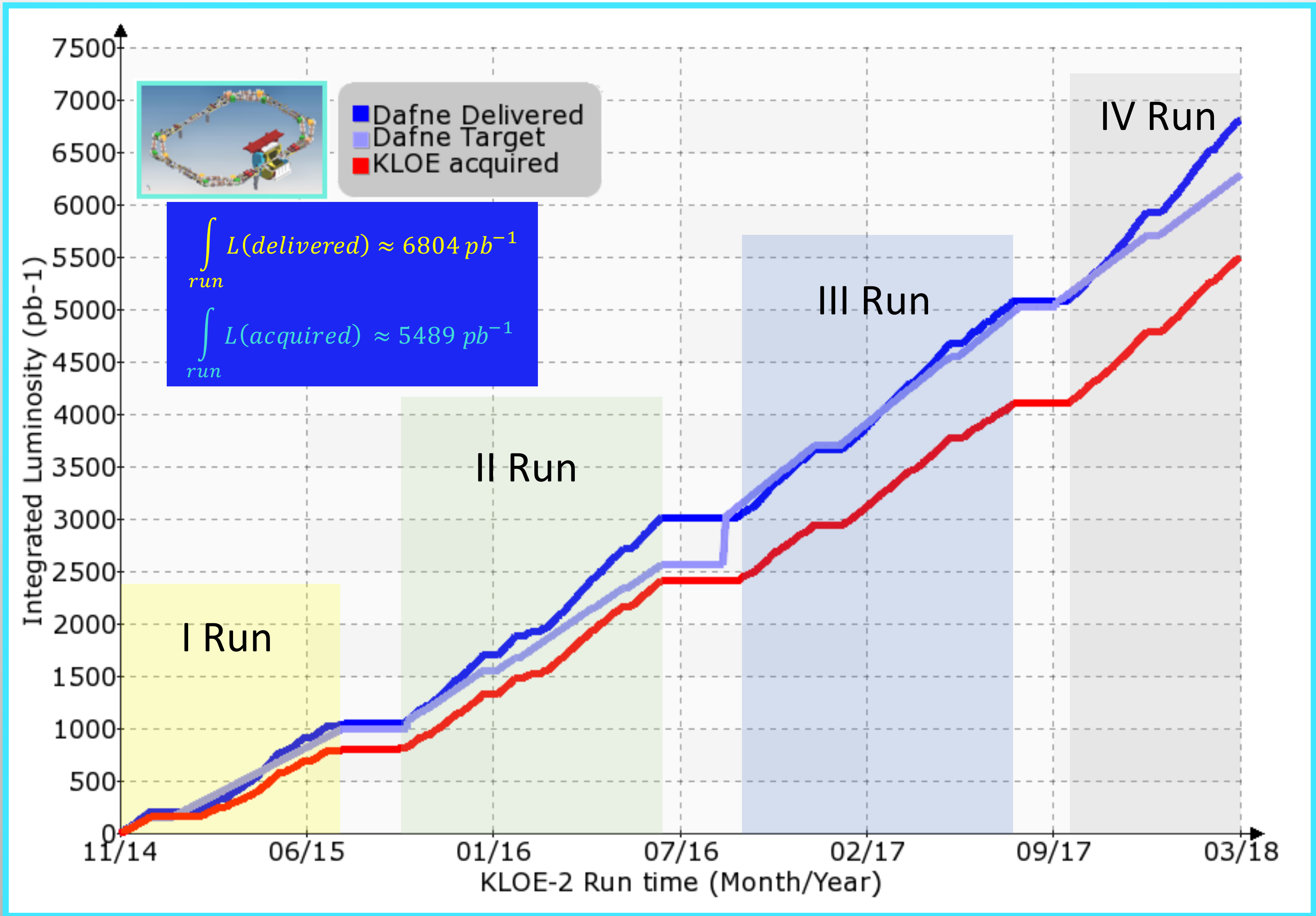
I Run *Nov 16th 2014 ÷ Jul 3rd 2015*
goal 1 $fb^{-1}$

II Run *Spt 28th 2015 ÷ Jun 29th 2016*
goal 1.5 $fb^{-1}$

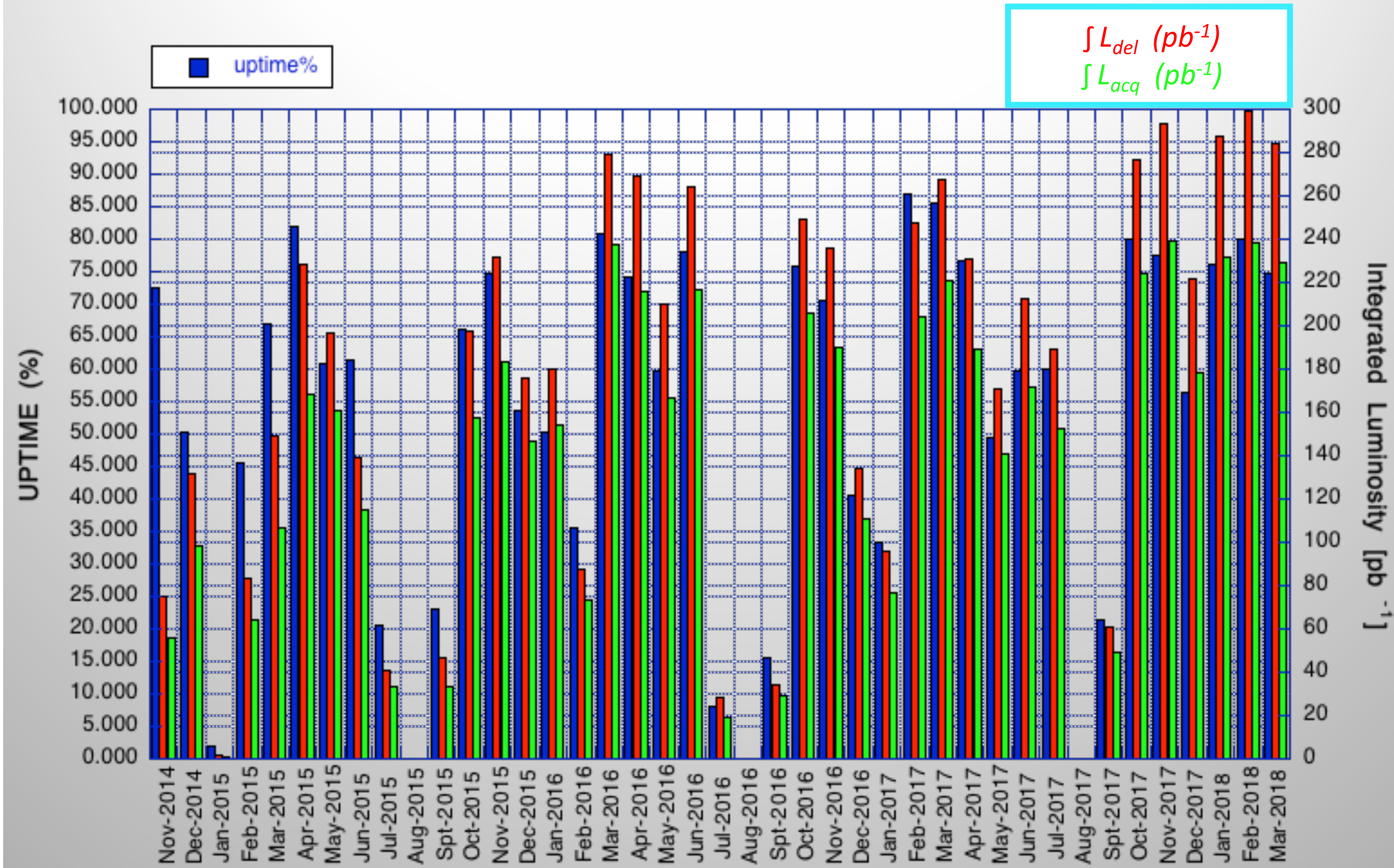
III Run Spt 12nd 2016 ÷ Aug 1st 2017
goal 2 $fb^{-1}$

IV Run *Spt 6th 2017 ÷ Mar 31st 2018*
goal 1.5 $fb^{-1}$

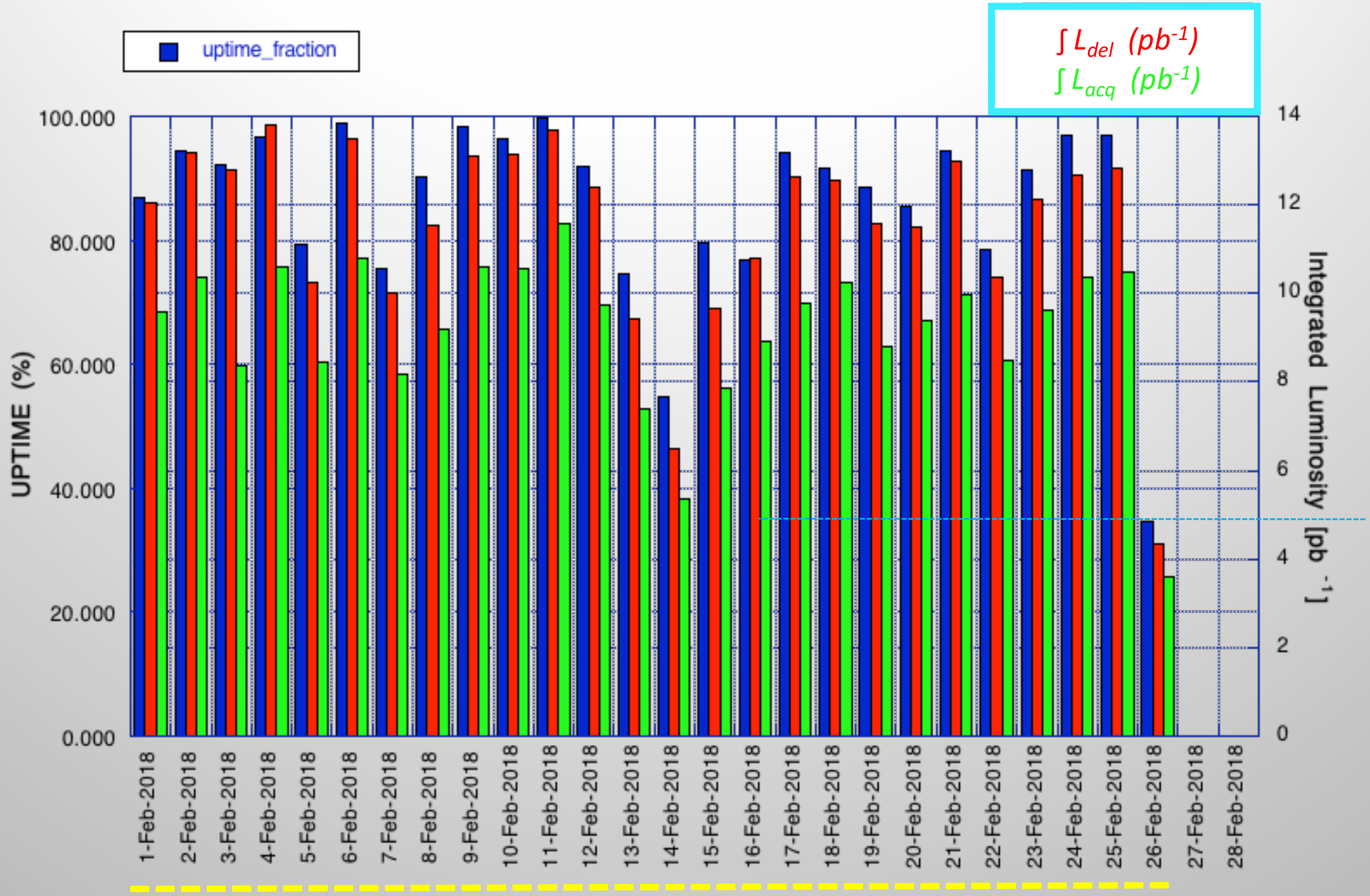
# KLOE-2 Run Overview



# Month by Month Luminosity Trend

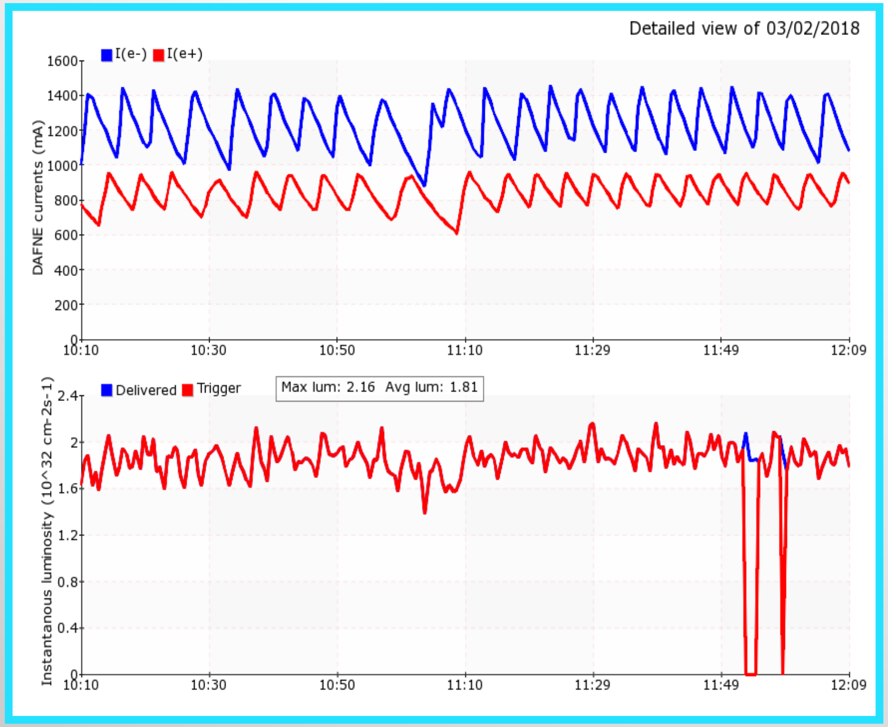


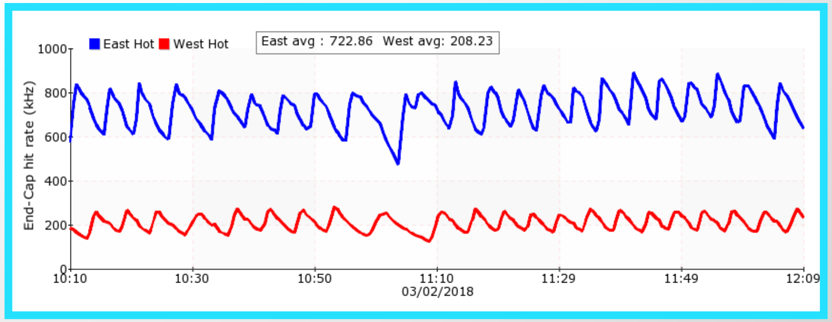
# Best Operation Month

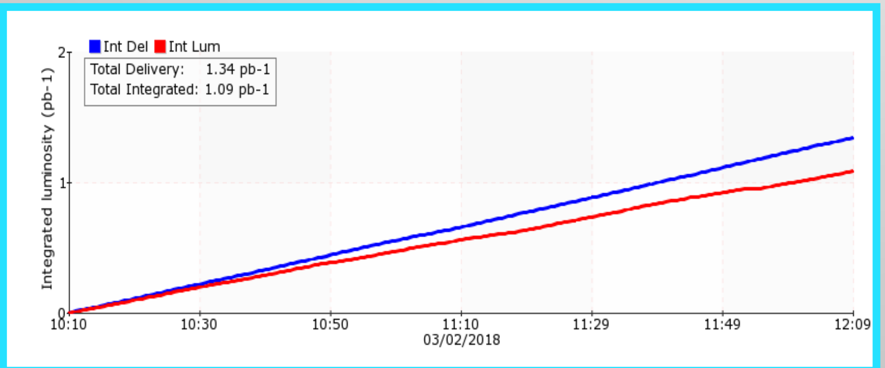



$\int L_{del} \sim 300\ (pb^{-1})$ *in 26 days*

# Highest Hourly Integrated Luminosity



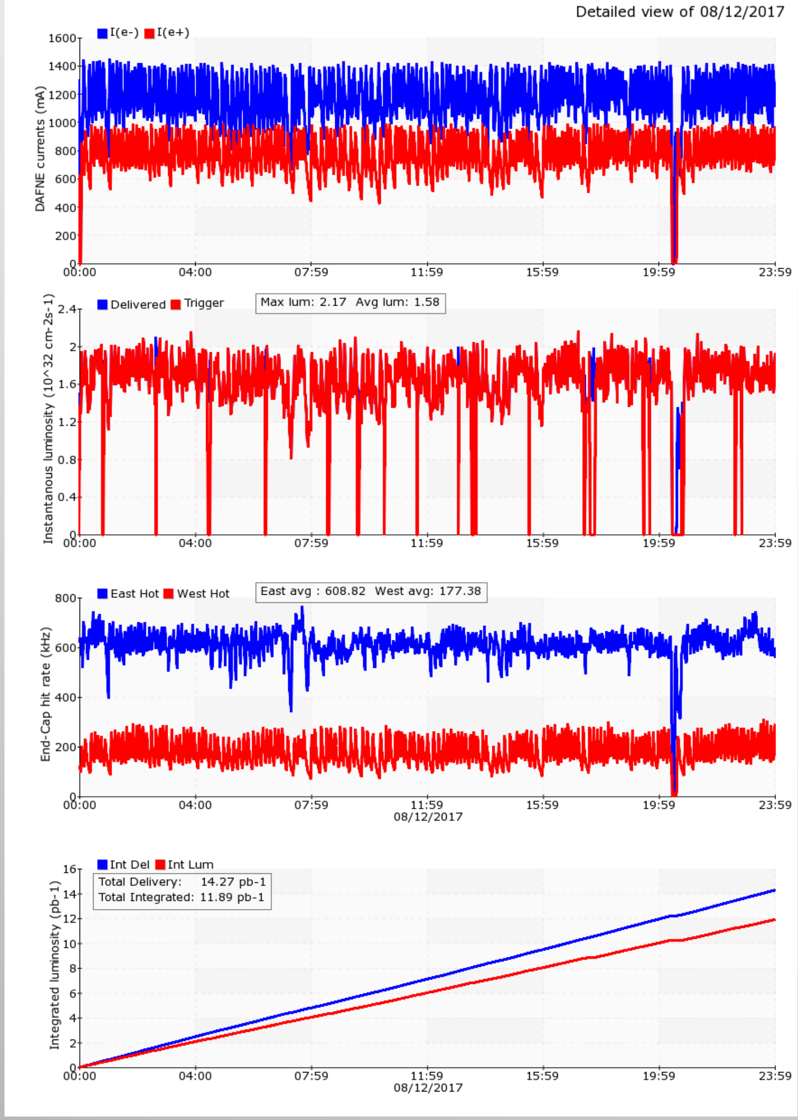




$\int_{1h} L \sim 0.67\ pb^{-1}$

$N_b = 107$

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

# Highest Daily Integrated Luminosity

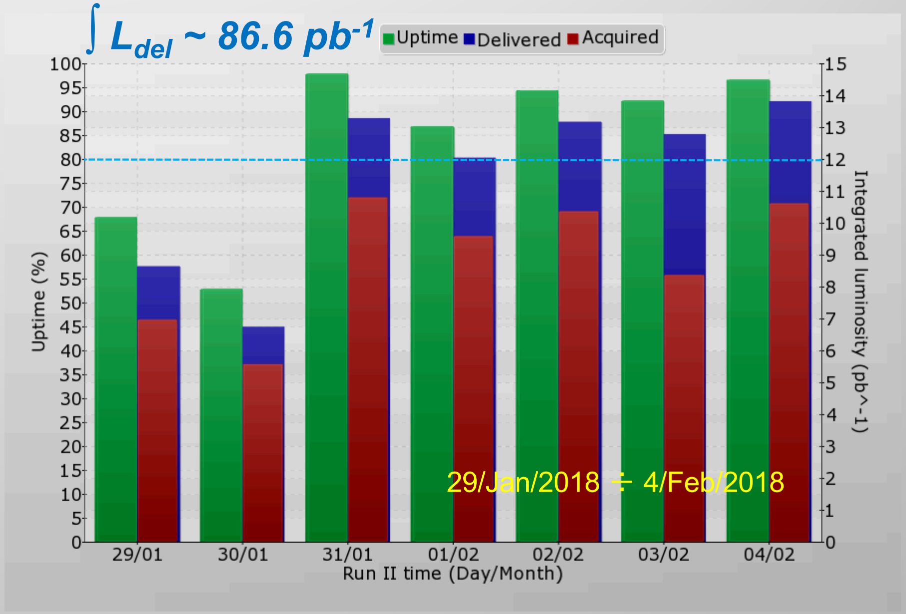



$\int L_{del} \sim 14.3\ pb^{-1}$

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

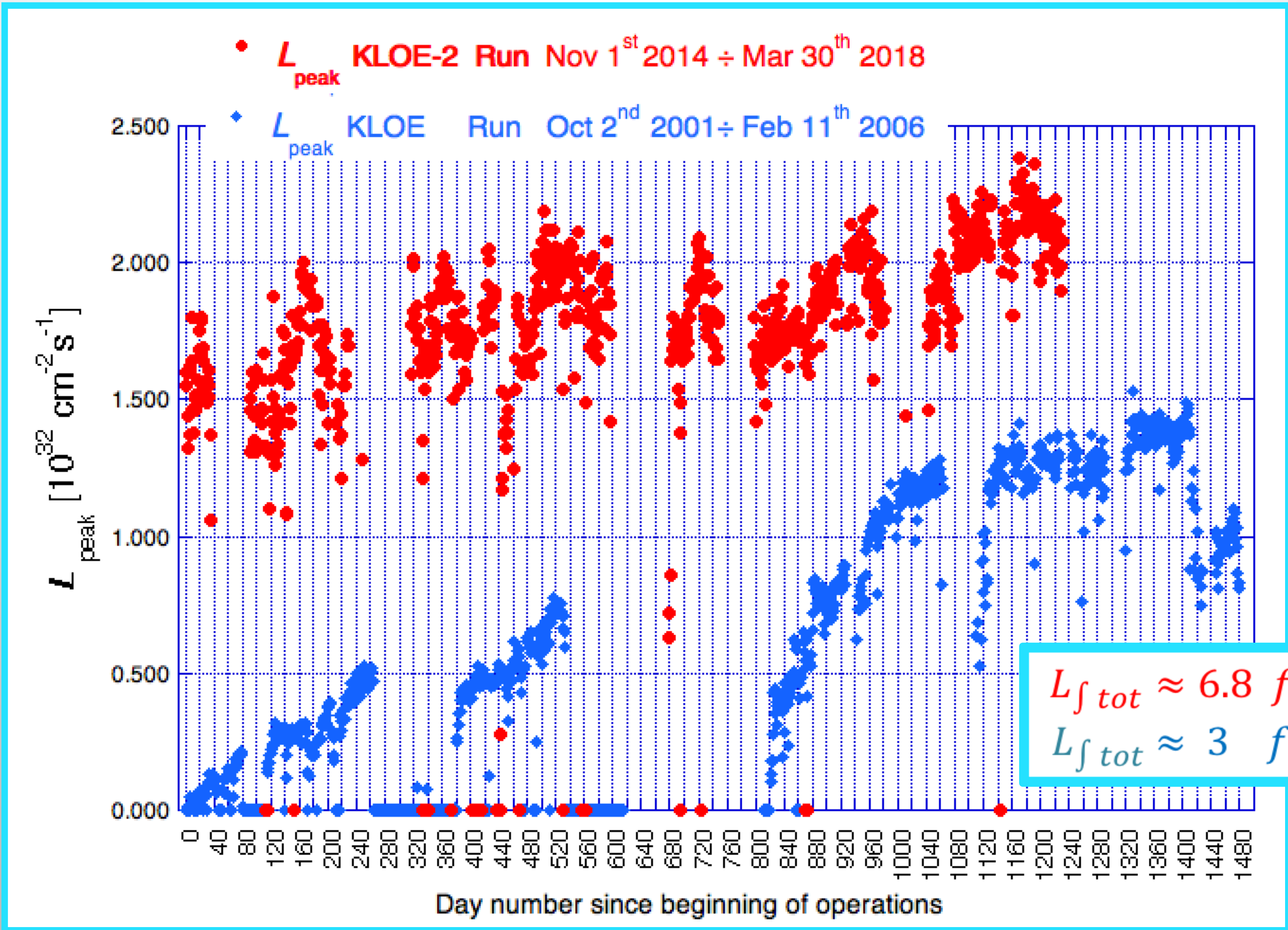
*Uptime ~98%*

- 106 bunches
- 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

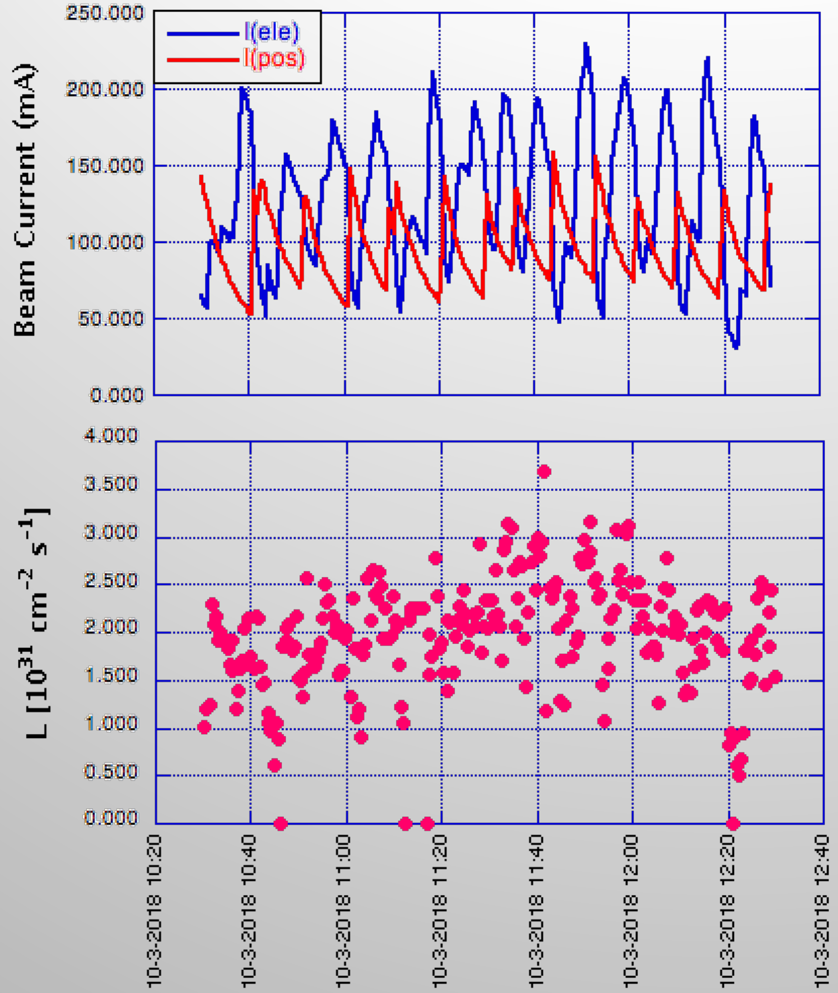


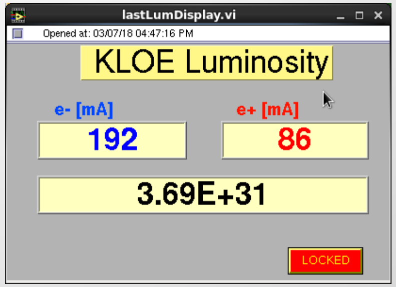

$L_{\int tot} \approx 6.8\ fb^{-1}$

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

# 10 Bunches Collisions

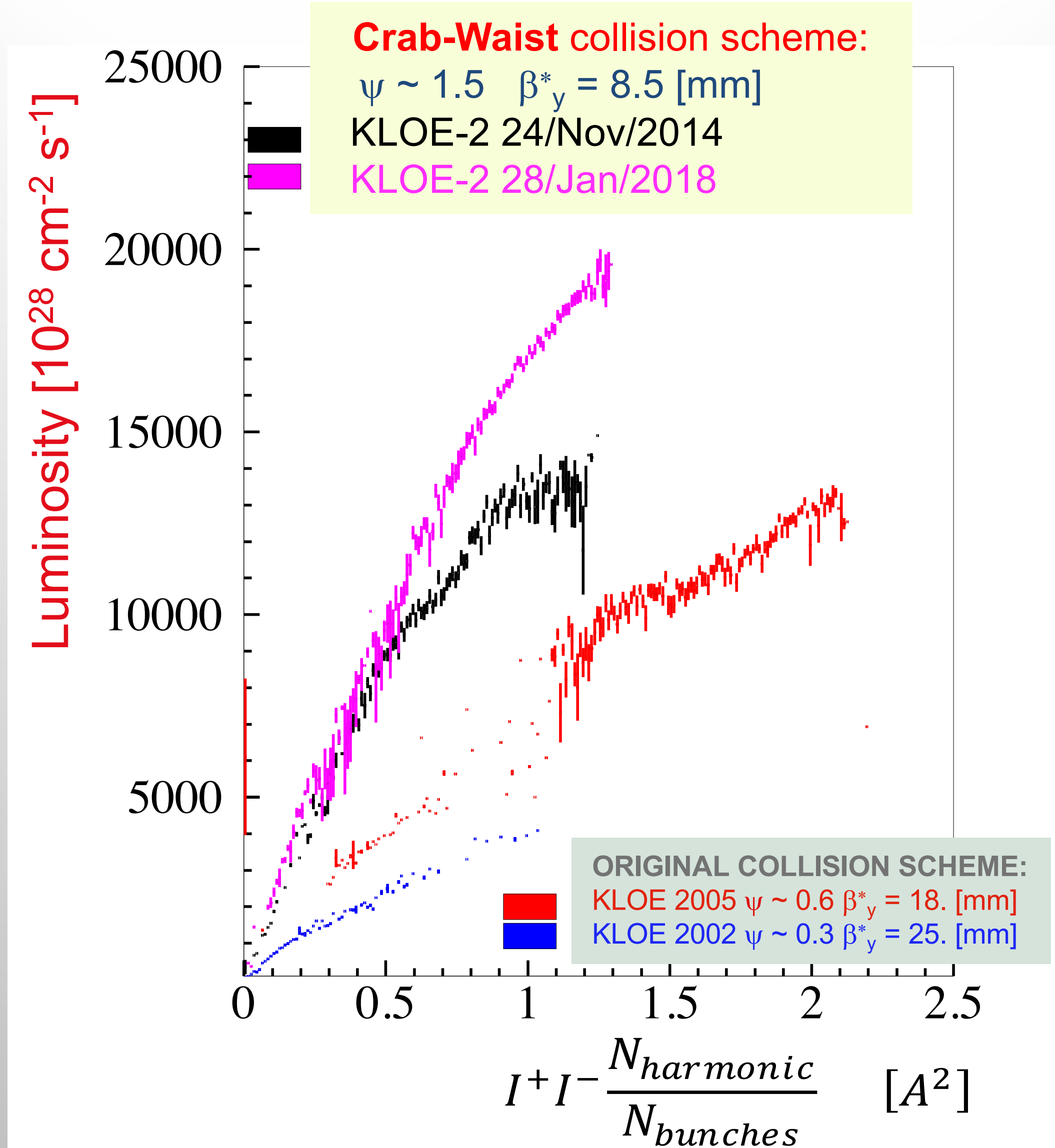
Aiming at minimizing the impact of multi-bunches effects and e-cloud instabilities on *Luminosity*



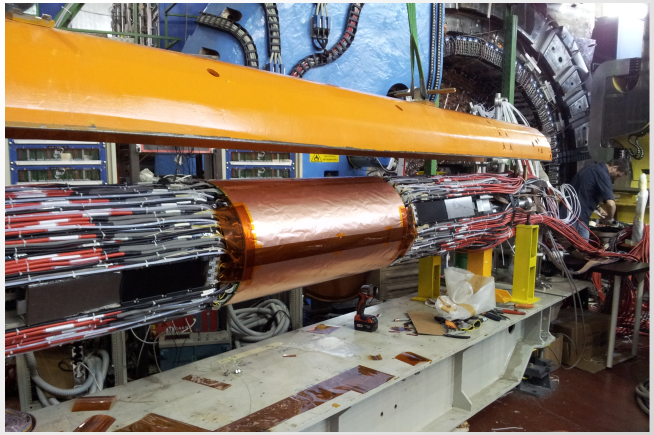

- ***$L_{peak}$ ~ 3 •$10^{32}$ $cm^{-2}$ $s^{-1}$*** *might be achieved by colliding 100 bunches*
- *Beam-beam is not a limiting factor*
- *Crab-Waist Sextupoles work*

# Crab-Waist Luminosity Gain



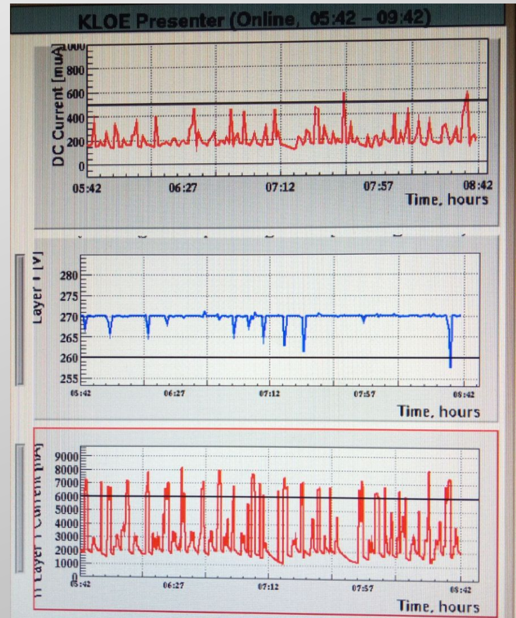
# Background Control

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

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

# 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 $\xi_x$ $\xi_y$ 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

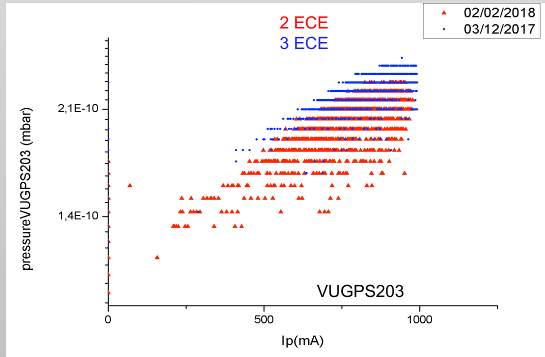
At the end of the run only 2 out of the 12 devices were working properly, none of them was in the wigglers

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

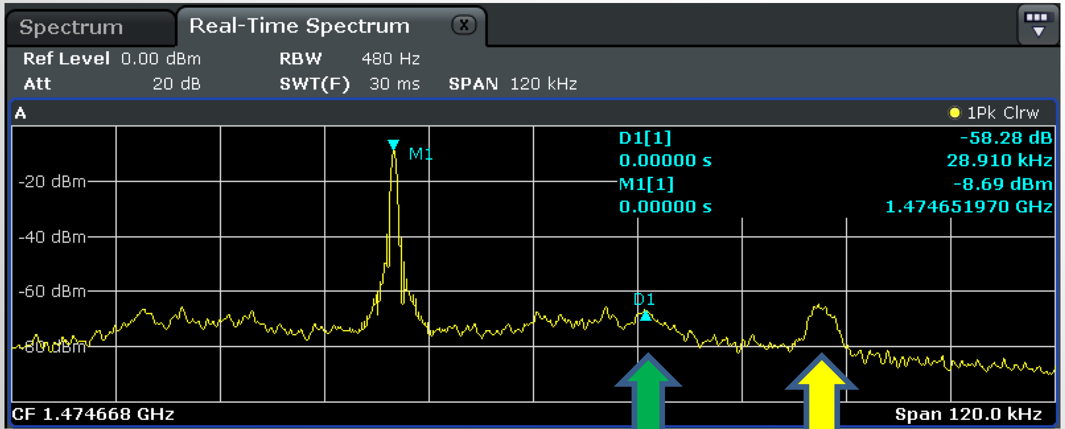
- longitudinal mode-0 & quadrupole oscillations
- noise coming from pickups (harmful for vertical sizes)
- e-cloud effects (in the e+ ring)

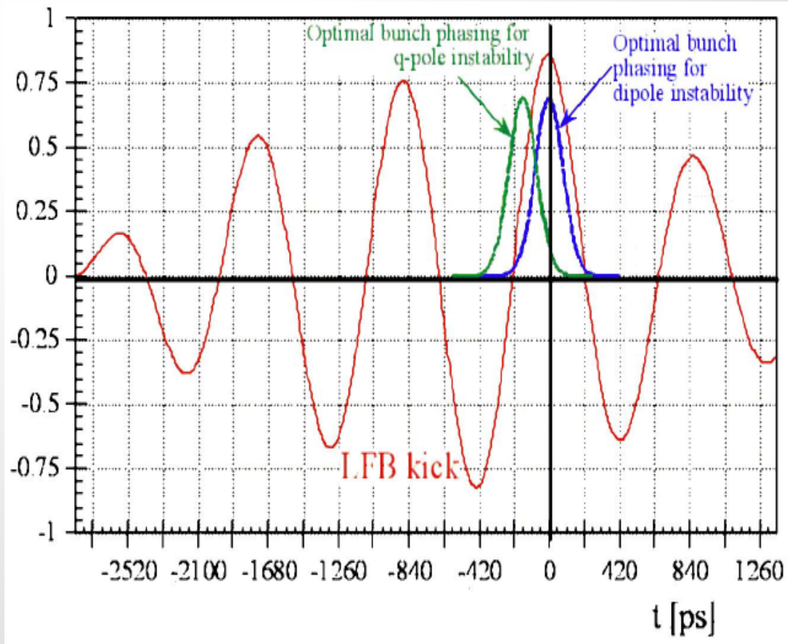
Solutions:

- 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

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

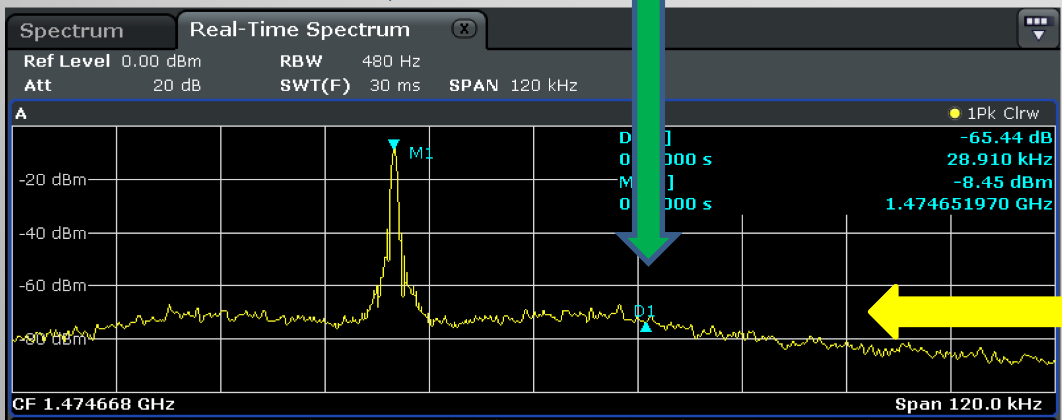



Revolution harmonic

Quadrupole oscillation

Synchrotron (dipole) oscillations damped by Long FBK

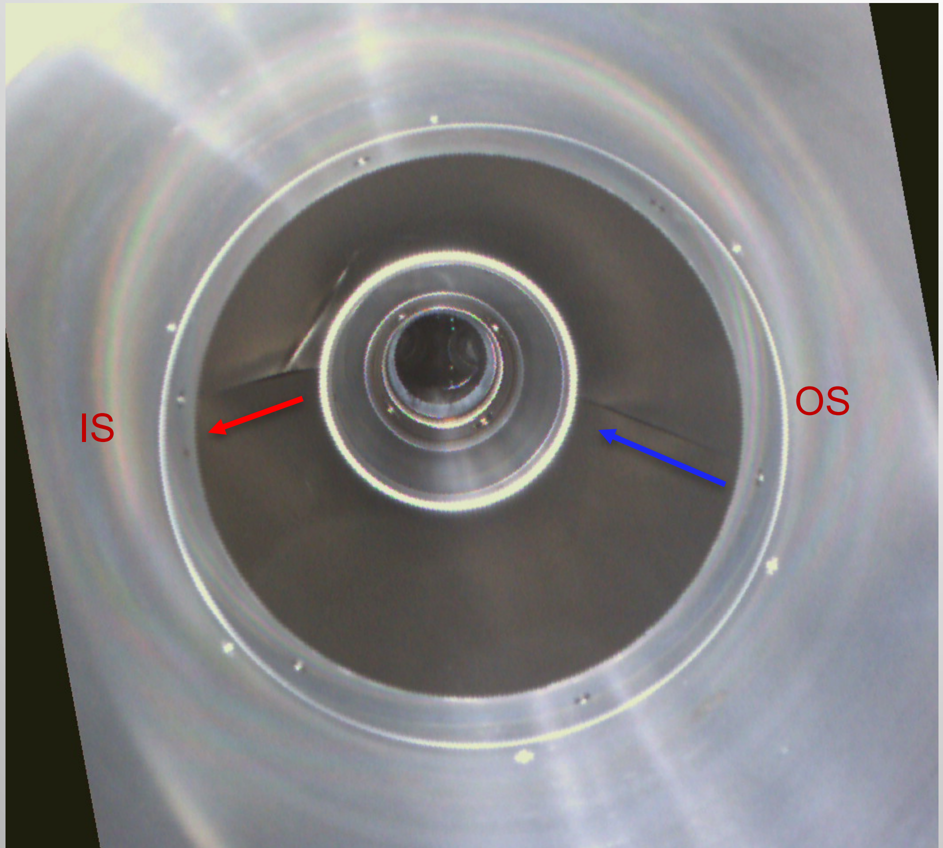



The present source of quadrupole instability is still under investigation
This instability, if not controlled, saturates the longitudinal feedback

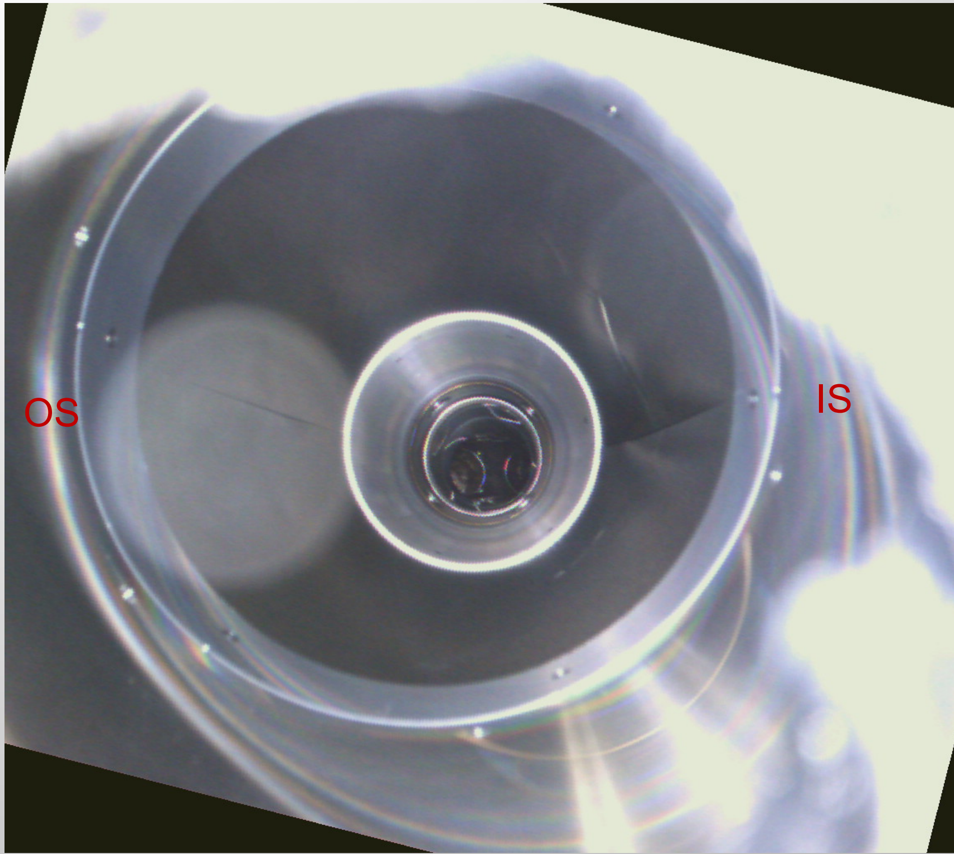
(A.Drago, et al., PRST-AB, 6, 052801-1-11, 2003)

# Post Hoc Analysis of the IP Vacuum Chamber

View from the IR branch side downstream the positron beam




View from the IR branch side downstream the electron beam



# Time Managment

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

*maintenance*
*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 of every collider subsystems

# Time Managment

Regardless the major upgrade done before starting the run, many relevant measures had to be done during data taking as for instance:

*replacement of the Cryo plant compressor*

*revision of the cooling system serving low-$\beta$ section and detector electronic equipment*

*revision of the wiggler magnet cooling system*

*Linac gun pulser replaced + several mendings*

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

*planning interventions suggested by anomalous fault rates in specific subsystems*

*outlining failures resulting in subtle effects on beam optics and beam dynamics.*

As in the case of the failure affecting the electronic phase shifter in the $e^-$ ring LLRF, which caused the 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 DAFNE's full potential as a collider, but assured:

*successful data taking*

*collision uptime of the order of 75%*

# DAΦNE Timeline

**March 31st 2018**

end of the KLOE-2 Run

**April ÷ November**

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

**December 2018**

beginning of the DAΦNE commissioning and SIDDHARTA setup

**In year 2019**

operations for the SIDDHARTA-2 experiment

powering parasitically the SR beam lines

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

*DAΦNETF*

# SIDDHARTA-2 Preparatory Phase

**Power Supplies**

All the ~500 PS maintained

pulsed magnet PSs upgraded by replacing capacitor banks

steering magnet PS hopefully replaced in both rings

**Dump Kickers**

The one in the $e^-$ ring will be replaced by a straight section

In the $e^+$ ring it will be replaced by a new horizontal feedback kicker

**Feedback Systems**

A second horizontal feedback system will be implemented in the $e^+$ ring

**Vacuum**

exhausted vacuum pumps replaced

NEG in the IR replaced

**Cooling System**

Variable Speed Drive will be installed upstream:

- the cooling tower serving A and TLs
- the circuit serving the main rings magnets

# SIDDHARTA-2 Preparatory Phase

**Control System**

Consoles running the GUI will be replaced with upgraded devices

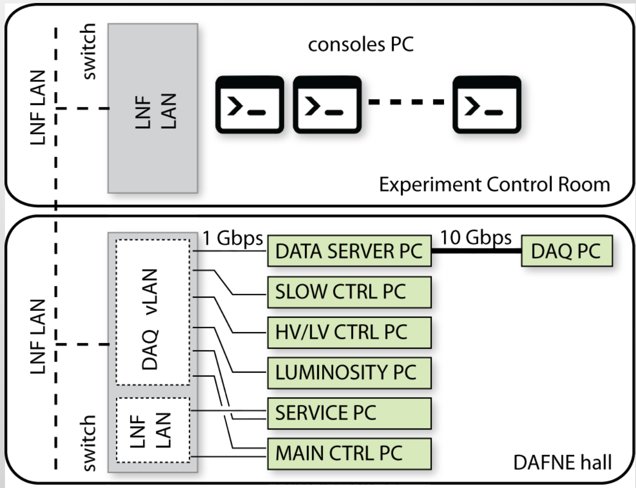
**Machine – Experiment Data Exchange**

design of the network dedicated to:

- acquisition and management of the experiment front-end;
- data exchange between the collider Control System and the experiment data acquisition.

definition of :

- variable set and related format;
- data exchange protocols (JSON streaming through http REST and NFS).



# 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.*

*The preparatory phase for the SIDDHARTA-2 run is well established*

# Many thanks to the Operation Group

Their expertise, competence, and enthusiasm made the difference

***On Duty***

*G.Baldini, Battisti, Beatrici, Belli, Bolli, G.Ceccarelli, R.Ceccarelli, Cecchinelli, Clementi, Coiro, De Biase, Ermini, Fontana, Gaspari, Giacinti, Iungo, Marini, Martelli, Mencarelli, Monteduro, Pellegrini, Piermarini, Quaglia, Rossi, Sardone, Scampati, Sensolini, Sorgi, Sperati, Sprecacenere, Strabioli, Zarlenga, Zolla.*

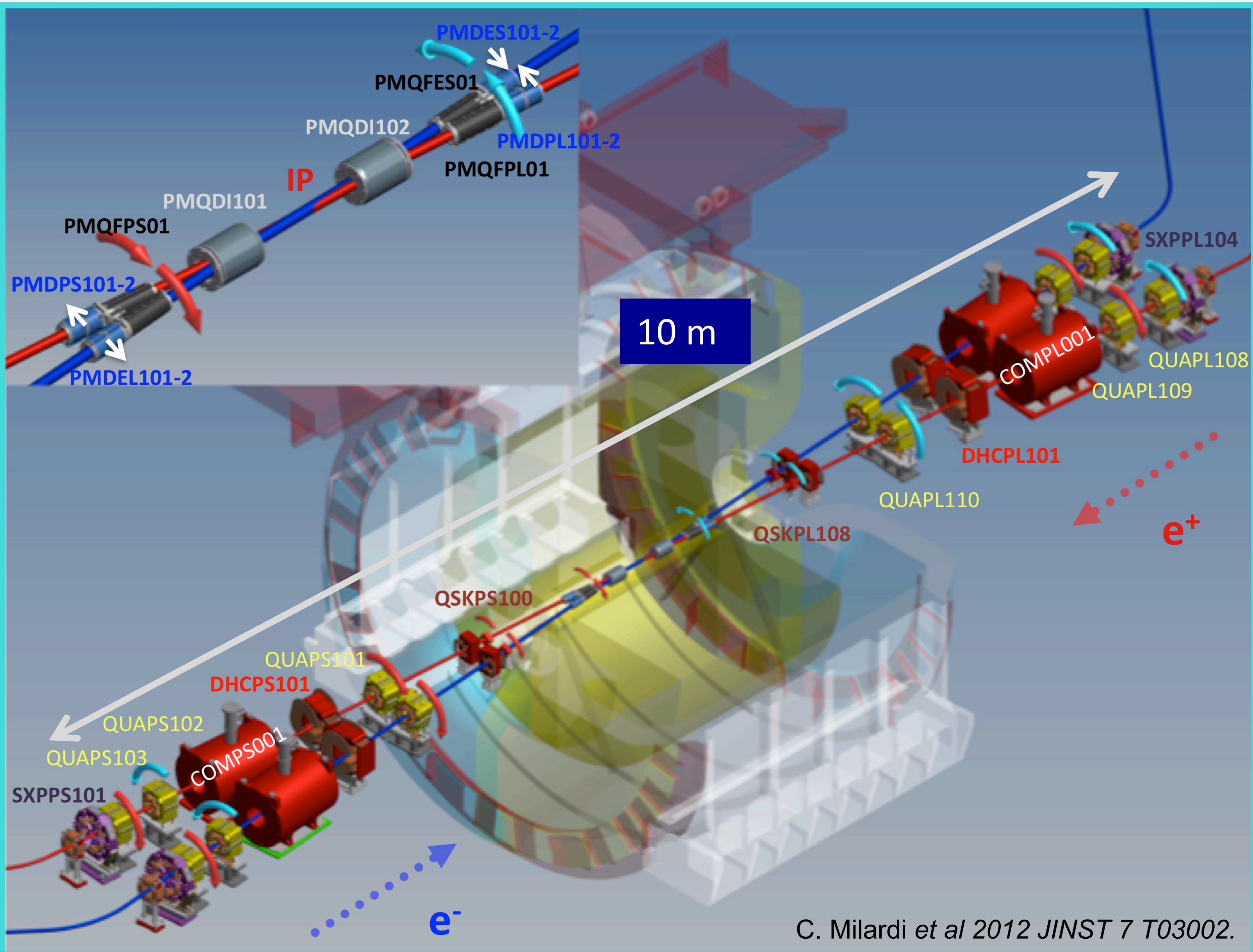
*Thank you for your attention*

# Peak Luminosity

| | DAΦNE CW upgrade<br>SIDDHARTA (2009) | DAΦNE<br>KLOE (2005) | DAΦNE (CW)<br>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.

# KLOE-2 IR




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