A REVIEW OF DAFNE PERFORMANCES DURING THE KLOE-2 RUN

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on behalf of the DAFNE Team
The DAΦNE Team


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Outline

• DAΦNE overview
• KLOE-2 operations
• Beam physics studies
• DAΦNE timeline
• Conclusions
The DAΦNE Accelerator Complex

$e^+ e^-$

$C \approx 97 \, m$

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

LNF are also part of the European synchrotron light Infrastructures
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IPAC’18 – May 2018 - Vancouver

DAΦNE Layout and Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DAΦNE native</th>
<th>DAΦNE Crab-Waist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (MeV)</td>
<td>510</td>
<td>510</td>
</tr>
<tr>
<td>θ_{cross}/2 (mrad)</td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>ε_{x} (mm•mrad)</td>
<td>0.34</td>
<td>0.28</td>
</tr>
<tr>
<td>β_{x}* (cm)</td>
<td>160</td>
<td>23</td>
</tr>
<tr>
<td>σ_{x}* (mm)</td>
<td>0.70</td>
<td>0.25</td>
</tr>
<tr>
<td>Φ_{Piwinski}</td>
<td>0.6</td>
<td>1.5</td>
</tr>
<tr>
<td>β_{y}* (cm)</td>
<td>1.80</td>
<td>0.85</td>
</tr>
<tr>
<td>σ_{y}* (µm) low current</td>
<td>5.4</td>
<td>3.1</td>
</tr>
<tr>
<td>Coupling, %</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Bunch spacing (ns)</td>
<td>2.7</td>
<td>2.7</td>
</tr>
<tr>
<td>I_{bunch} (mA)</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>σ_{z} (mm)</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td>N_h</td>
<td>120</td>
<td>120</td>
</tr>
</tbody>
</table>

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


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 \( \Phi \)
  \[
  \Phi \approx \frac{\sigma_z}{\sigma_x} \tan \left( \frac{\theta}{2} \right) \gg 1
  \]
- Large \( \theta \)
- Small \( \sigma_x^* \)

- \( \beta_y^* \) comparable with overlap area
  \[
  \beta_y^* = 2\sigma_x^* / \theta
  \]

**Crab-Waist** transformation by two Sextupoles

- \( y = \frac{xy}{\theta} \)

\[ L \] gain with N
- Low \( \xi_x \)
- \( \xi_y \) decrease with Y oscillation amplitude

\[ L \] geometrical gain
- Lower \( \xi_y \)
- Y Synchro-betatron resonances suppression

\[ L \] geometrical gain
- Lower \( \xi_y \)
- X-Y Synchro-betatron resonances suppression

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P. Raimondi, 2° *SuperB Workshop*, March 2006,
P. Raimondi, D. Shatilov, M. Zobov, physics/0702033,
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KLOE-2 IR

C. Milardi et al 2012 JINST 7 T03002.
DAΦNE Activity Program for KLOE-2

Preliminary Test Phase  \textit{fall 2010 ÷ Dec 2012}

Collider Consolidation
KLOE-2 detector layers installed  \textit{Dec 2012 ÷ Jun 2013}

KLOE-2 data taking

I Run  \textit{Nov 16^{th} 2014 ÷ Jul 3^{rd} 2015}
\hspace{1cm} goal 1 fb^{-1}

II Run  \textit{Spt 28^{th} 2015 ÷ Jun 29^{th} 2016}
\hspace{1cm} goal 1.5 fb^{-1}

III Run  \textit{Spt 12^{nd} 2016 ÷ Aug 1^{st} 2017}
\hspace{1cm} goal 2 fb^{-1}

IV Run  \textit{Spt 6^{th} 2017 ÷ Mar 31^{st} 2018}
\hspace{1cm} goal 1.5 fb^{-1}
KLOE-2 Run Overview

\[
\int_{\text{run}} L(\text{delivered}) \approx 6804 \text{ pb}^{-1}
\]

\[
\int_{\text{run}} L(\text{acquired}) \approx 5489 \text{ pb}^{-1}
\]
Month by Month Luminosity Trend
Best Operations Month

The graph shows the uptime fraction and integrated luminosity for different dates in February 2018. The bars represent the uptime fraction, while the vertical lines indicate the integrated luminosity. The dates range from 1st to 28th of February 2018.
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Highest Hourly Integrated Luminosity

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

$$N_b = 107$$

$$\int_{1\text{ day}} L \sim 16 \, \text{pb}^{-1}$$
Highest Daily Integrated Luminosity

\[ \int L_{\text{del}} \sim 14.3 \text{ pb}^{-1} \]
\[ \int L_{\text{acq}} \sim 11.9 \text{ pb}^{-1} \]

**Uptime \sim 98\%**

- 106 bunches
- \( I_{\text{MAX}} = 1.45 \div 1.6 \text{ A} \)
- \( I_{\text{MAX}}^* = 0.99 \div 1.16 \text{ A} \)
- Sustainable background

29/Jan/2018 ÷ 4/Feb/2018

\[ \int L_{\text{del}} \sim 86.6 \text{ pb}^{-1} \]
Crab-Waist Luminosity Gain

Crab-Waist provides a 59% increase in terms of peak luminosity as evidenced by data taken by the same detector with the same accuracy.
10 Bunches Collisions

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

- $L_{\text{peak}} \sim 3 \times 10^{32} \text{ cm}^{-2} \text{s}^{-1}$ might be achieved by colliding 100 bunches
- Beam-beam is not a limiting factor
- Crab-Waist Sextupoles work
Crab-Waist Luminosity Gain

Crab-Waist collision scheme:
- $\psi \sim 1.5$  $\beta_y^* = 8.5$ [mm]
- KLOE-2 24/Nov/2014
- KLOE-2 28/Jan/2018

ORIGINAL COLLISION SCHEME:
- KLOE 2005 $\psi \sim 0.6$  $\beta_y^* = 18.$ [mm]
- KLOE 2002 $\psi \sim 0.3$  $\beta_y^* = 25.$ [mm]
# Peak Luminosity

<table>
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<tr>
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</thead>
<tbody>
<tr>
<td>$L_{\text{peak}}$ [cm$^{-2}$s$^{-1}$]</td>
<td>$4.53 \times 10^{32}$</td>
<td>$1.50 \times 10^{32}$</td>
<td>$2.38 \times 10^{32}$</td>
</tr>
<tr>
<td>$I^- [A]$</td>
<td>1.52</td>
<td>1.4</td>
<td>1.18</td>
</tr>
<tr>
<td>$I^+ [A]$</td>
<td>1.0</td>
<td>1.2</td>
<td>0.87</td>
</tr>
<tr>
<td>$N_{\text{bunches}}$</td>
<td>105</td>
<td>111</td>
<td>106</td>
</tr>
<tr>
<td>$\int_{\text{day}} L$ [pb$^{-1}$]</td>
<td>14.98</td>
<td>9.8 (seldom)</td>
<td>14.3</td>
</tr>
</tbody>
</table>

$L_{\text{peak}}$ 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.
Numerical simulations aiming at improving:
  dynamical aperture
  specific luminosity
led to define a new working point
for the e⁻ ring
\[ Qx = 0.135 \quad Qy = 0.17 \]

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

normalized background vs. instantaneous luminosity

KLOE-2 normalized trigger level vs. instantaneous luminosity
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 ÷ 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.
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 behaviour 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

\[ f \sim 2 \cdot f_{\text{sync}} \]

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 Management

Achieving milestones 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 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:

- replacement 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