Dafne Collaboration Team

Results of the DAFNE Upgrade

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OUTLINE

- Dafne Upgrade:
  - Hardware
  - Commissioning
  - Results and Perspectives

- Conclusions
A new idea for collisions

Thigher focus on beams at IP and a “large” crossing angle (large Piwinski angle) + use a couple of sextupoles/ring to “twist” the beam waist at the IP

- Ultra-low emittance
- Very small $\beta^*$ at IP
- Large crossing angle
- “Crab Waist” transformation
- Small collision area
- Lower $\beta^*$ is possible
- NO parasitic crossings
- NO x-y-betatron resonances

1. P.Raimondi, 2°SuperB Workshop, March 2006
2. P.Raimondi, D.Shatilov, M.Zobov, physics/0702033
Good Opportunity to prove and use the LPA & CW in Dafne

for Physics Programs

1. Fits DAΦNE schedule (shut down for SIDDHARTA installation in mid 2007)
2. Satisfies new physics programs (SIDDHARTA, KLOE2, FINUDA...)
3. Requires moderate modifications
4. Relatively low cost (1 mln Euro)

for Beam Dynamics

1. No detector solenoidal field
2. No splitter magnets
3. No compensating solenoids
4. No parasitic crossings
5. Lower beam impedance (simple IR, new bellows, new injection kickers)
Rationale for the Upgrade

$L_{\text{peak}} \sim 1.6 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ 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 $\tau^+ \tau^-$ reduction limiting $I^+_{\text{MAX}} I^-_{\text{MAX}}$ and consequently $L_{\text{peak}}$ and $L_j$
- Transverse size enlargements due to the beam-beam interaction

A new conceptual approach was necessary to reach $L \sim 10^{33}$ Collision scheme based on Large Piwinski angle and Crab-Waist
DAΦNE Peak Luminosity
BEAM PROFILES @IP AND NEW PARAMETERS

DAΦNE (KLOE run)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DAΦNE (KLOE run)</th>
<th>DAΦNE Upgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I_{\text{bunch}} ) (mA)</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>( N_{\text{bunch}} )</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>( \beta_y^* ) (cm)</td>
<td>1.8</td>
<td>0.85</td>
</tr>
<tr>
<td>( \beta_x^* ) (cm)</td>
<td>160</td>
<td>26</td>
</tr>
<tr>
<td>( \sigma_y^* ) ((\mu\text{m}))</td>
<td>5.4 low curr</td>
<td>3.1</td>
</tr>
<tr>
<td>( \sigma_x^* ) ((\mu\text{m}))</td>
<td>700</td>
<td>260</td>
</tr>
<tr>
<td>( \sigma_z ) (mm)</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Horizontal tune shift</td>
<td>0.04</td>
<td>0.008</td>
</tr>
<tr>
<td>Vertical tune shift</td>
<td>0.04</td>
<td>0.055</td>
</tr>
<tr>
<td>( \theta_{\text{cross}} ) (mrad) (half)</td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>( \Phi_{\text{Piwinski}} )</td>
<td>0.45</td>
<td>2.0</td>
</tr>
<tr>
<td>( L ) (cm(^{-2})s(^{-1}))</td>
<td>(1.5\times10^{32})</td>
<td>(&gt;5\times10^{32})</td>
</tr>
</tbody>
</table>

3 times more luminosity obtained just with 3 times smaller vertical beam
### Comparison of SuperB to Super-KEKB

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>SuperB</th>
<th>Super-KEKB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>GeV</td>
<td>4x7</td>
<td>3.5x8</td>
</tr>
<tr>
<td>Luminosity</td>
<td>$10^{36}$/cm²/s</td>
<td>1.0 to 2.0</td>
<td>0.5 to 0.8</td>
</tr>
<tr>
<td>Beam currents</td>
<td>A</td>
<td>1.9x1.9</td>
<td>9.4x4.1</td>
</tr>
<tr>
<td>$\beta_y^*$</td>
<td>mm</td>
<td>0.22</td>
<td>3.</td>
</tr>
<tr>
<td>$\beta_x^*$</td>
<td>cm</td>
<td>3.5x2.0</td>
<td>20.</td>
</tr>
<tr>
<td>Crossing angle (full)</td>
<td>mrad</td>
<td>48.</td>
<td>30. to 0.</td>
</tr>
<tr>
<td>RF power (AC line)</td>
<td>MW</td>
<td>20 to 25</td>
<td>80 to 90</td>
</tr>
<tr>
<td>Tune shifts (x/y)</td>
<td></td>
<td>0.0004/0.2</td>
<td>0.27/0.3</td>
</tr>
</tbody>
</table>

100 times more luminosity obtained just with 100 times smaller vertical beam.
New Experimental Interaction Region

Old layout

~10 m

New layout

Crab waist sextupoles

Compensator solenoids not installed for the SIDDHARTA run

\[ \alpha = 0.071 \text{ rd}, \quad \theta_\text{ip} = 0.025 \text{ rd}, \quad \alpha_\text{c} \sim 0.0095 \text{ rd} \]
- Aluminum
- Window thickness 0.3 mm
High current operation

Three main hardware upgrades have been implemented to improve the stored current:

- Fast kickers
- Feedback upgrade
- Lower impedance vacuum chamber
- Solenoid Windings
SECOND CROSSING REGION LAYOUT

- Second crossing region symmetric with respect to first one (Possibility to use it as an alternative interaction point)
- “Half Moon” chamber allows complete beam separation (no 2nd IP)
NEW BELLOWS

OLD BELLOW

• 6 new bellows for each ring
• Shielding based on Be-Cu W strips 0.2 mm thick
• lower impedance and better mechanical performance
New Fast Injection Kickers

New injection kickers with 5.4 ns pulse length to reduce perturbation on stored beam

Expected benefits:
• higher maximum stored currents
• Improved stability of colliding beams during injection
• less background allowing data acquisition during injection
Bunch Lengthening in Upgraded Vacuum Chamber

Bunch Length

Charge Distribution

- **130kV, new, FWHM/2.36**
- **130kV, old, FWHM/2.36**
- **130kV, upgrade, FWHM/2.36**

**Bunch Length Charge Distribution**

- *old*
- *new*
Solenoids
Vertical beam-beam Luminosity scan

\[ \Sigma_y = \sqrt{\sigma_{yp}^2 + \sigma_{ye}^2} \]

\[ \Sigma_y = \Sigma_y^{\text{meas}} \times 0.88 \]

\[ \sigma_y \approx 3.5 \mu m \]

Design is 3.1 \mu m
Lot of work done to match the optic (main problems from IP-Permanent Magnets out of specs w.r.t. gradient)
Well established the proper CW optics requirements Sext=>IP=>AntiSext
Well define sextupoles aligned procedure in single beam mode:
  - turn on one sext at the time, measure the tune shift and move the orbit:
    1) horizontally until no tune shift is observed
    2) vertical until no coupling change is observed on our Synchrotron Light Monitor
  - Verified that turning on both sextupoles there are no effects on:
    - Tunes
    - Coupling
    - Lifetime
    - Background

Finally we did turn on the sextupoles in collision for the first time…
Crab Waist Works: First Experimental Evidence

Crab Sextupoles on all the time since the first time we tested them
Present Performances

- Peak Luminosity: $4.53 \times 10^{32}$ ($1.52 \times 10^{32}$) obtained with 1.40 (1.55) Amps e- vs 1.1 (1.25) Amps e+ 105 (110) Bunches
- Peak Hourly rate 1.023 (0.44) pb-1/hour
- Peak Daily rate 15.0 (9.83) pb-1 with long coasting (Long coasting needed for Siddharta, not for Kloe or Finuda)

Red are the Kloe records before the upgrade
Fast injection is not compatible with the SIDDHARTA operations!

Best hourly integrated luminosity

$L_{f1 \text{ hour}} = 1.033 \text{ pb}^{-1}$

- High rate injection regime
- 105 colliding bunches
- Very useful for a future KLOE run

Dec. 16th 2008
Best daily integrated luminosity

\[ L_{\text{day}} = 15. \text{ pb}^{-1} \]

- Long Coasting Regime
- 105 colliding bunches
- \[ L_{\text{hour}} = 0.62 \text{ pb}^{-1} \]

Feb. 8th 2009
Luminosity \([10^{28} \text{ cm}^{-2} \text{ s}^{-1}]\)

Data averaged on a full day

- \(\beta y=9\text{mm}, \ P_w\_angle=1.9\)
- \(\beta y=18\text{mm}, \ P_w\_angle=0.6\)
- \(\beta y=25\text{mm}, \ P_w\_angle=0.3\)

LPA alone gives more luminosity
Same beam sizes and specific luminosity at low current with and without Crab Sextupoles

- $\beta_y = 9\text{mm}$, $Pw_{\text{angle}} = 1.9$
- $\beta_y = 18\text{mm}$, $Pw_{\text{angle}} = 0.6$
- $\beta_y = 25\text{mm}$, $Pw_{\text{angle}} = 0.3$
Best two fills Luminosity vs Current Product

Luminosity $[\text{cm}^{-2} \text{s}^{-1}]$

$I^+ \times I^- [\text{A}^2]$

Single Bunch Specific Luminosity $[\text{cm}^{-2} \text{s}^{-1} \text{mA}^{-2}]$

$\xi_y(\text{max}) = 0.042$

- $L_{\text{March 15}}^{\text{th}} \ 2009$
- $L_{\text{March 13}}^{\text{th}} \ 2009$
- $L_{\text{specific}}^{\text{March 15}}^{\text{th}} \ 2009$
- $L_{\text{specific}}^{\text{March 13}}^{\text{th}} \ 2009$
Crab on/off Specific Luminosity vs Current Product

Crab on/off Luminosity vs Current Product
Luminosity in weak-weak and strong-weak regime

Low currents
\[ \xi_y \sim 0.020 \]

Asymmetric currents
\[ \xi_y \sim 0.0626 \]
Results even more striking since we have also reduced the Dafne Wigglers Field (less damping needed since beam-beam is small) in order to save on running cost:
- 6 MW Wall Plug power during the Kloe data taking
- 4 MW now

Performances are still limited because of “standard problems”:
- e-cloud
- Ion trapping
- RF stability

We hope to further reduce their impact on the performances and gain more in Luminosity at a given current and in peak currents
fact that the principle of crab-waist compensation has been shown to work; this must be recognised as a major advance in the long history of fighting the beam-beam effect in e^+e^- colliders. It is also an important step towards validation of the SuperB design concepts.

Finally, the effect of the crab-waist compensation is striking. As we were able to observe directly in the control room, excitation of the sextupoles on either or both beams reduces the corresponding beam sizes in collision, as predicted.
Conclusions

LPA & CW is promising to push forward the high luminosity frontier for storage rings colliders

Tests on adapting an existing machine, Dafne, have been very successful, the Siddharta experiment is taking data very smoothly. The HEP program at Frascati has been extended and a new physics run for Kloe has been approved, aimed at >5fb⁻¹/year for at least 3 years