Low emittance tuning experience and plans in \( \text{DAΦNE} \)

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Outline

- Few words about DAΦNE
- $\varepsilon_x$ tuning
- $\varepsilon_y$ tuning
- ring impedance impact on $\varepsilon_y$
DAΦNE

$e^+e^-$

$C = 97\ m$

$E = 0.51\ GeV\ (\Phi)$

Damping ring

Main rings

Test beam

Linac

DEAR & FINUDA

Run  Event  Date
6757  738533  Apr. 20, 99
Best DAΦNE performances

Obtained during the run for the KLOE experiment (May 2004 ÷ Nov 2005)

\[ \mathcal{L}_{\text{peak}} \approx 1.5 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1} \]

\[ \mathcal{L}_{\text{day}} \approx 10 \text{ pb}^{-1} \text{ (maximum value)} \]

\[ \mathcal{L}_{\text{KLOE run}} = 2 \text{ fb}^{-1} \text{ (May 2004 ÷ Nov 2005)} \]
## DAΦNE parameters

### KLOE configuration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy [GeV]</td>
<td>0.51</td>
</tr>
<tr>
<td>Circumference [m]</td>
<td>97.69</td>
</tr>
<tr>
<td>RF frequency [MHz]</td>
<td>368.26</td>
</tr>
<tr>
<td>Harmonic number</td>
<td>120</td>
</tr>
<tr>
<td>Damping time $\tau_E/\tau_x$ [ms]</td>
<td>17.8 / 36.0</td>
</tr>
<tr>
<td>Bunch length full $l_e/l_e^+$ [cm]</td>
<td>$2.7 \div 2.$</td>
</tr>
<tr>
<td>Emittance [m]</td>
<td>$3.4 \times 10^{-6}$</td>
</tr>
<tr>
<td>Betatron coupling at $l \sim 0$ [%]</td>
<td>0.2</td>
</tr>
<tr>
<td>$\beta_{x,y}$ at main IP [m]</td>
<td>1.7 / 0.017</td>
</tr>
<tr>
<td>Maximum $\xi_{x,y}$</td>
<td>$0.03 \div 0.04$</td>
</tr>
<tr>
<td>Colliding bunches</td>
<td>108</td>
</tr>
<tr>
<td>Max. coll. currents $l^-, l^+$ [A]</td>
<td>2.4 / 1.4</td>
</tr>
</tbody>
</table>
Main Rings magnetic layout

4 arcs based on 4 different bending magnets each including a wiggler

\[ C = 97 \text{ m} \]
\[ E = 0.51 \text{ GeV (} \Phi \text{)} \]
\( \varepsilon_x \) tuning

\( \varepsilon_x \) is tuned by a proper choice of the machine optics.

Dominant source of \( \Delta \varepsilon_x \) are:
- mismatch in the horizontal \( \eta \) and \( \beta \) functions due to:
  - large horizontal orbit
  - large steering magnet strengths
- large values of the \( W_x \ W_y \ \eta'' \) functions
$\eta$ matching by:
- Measuring dispersive orbit at the BPMs
- Fitting the measurement by the first order multipole in the wigglers end-poles
- Matching the dispersion function to the required value by using the 3 QUADs installed around each wiggler

In this way the required $\varepsilon_x$ and $\alpha_c$ are obtained
Non-linear optics matching

- Build a reliable machine model including non-linear terms
- Design the optics in order to minimize the second order optical functions: $\eta^\prime\prime$, $W_x$, $W_y$

Finuda run 2003 - 2004
Beam Steering by Measured Response Matrix

Response Matrix measurement

\[ A_{ij} = \frac{\partial z_j}{\partial I_i} \quad z = x,y \]

\[ A^H = \begin{bmatrix} A^{HH} & 0 \\ 0 & A^{HV} \end{bmatrix} \]

\[ A^V = \begin{bmatrix} 0 & A^{VV} \\ A^{VH} & 0 \end{bmatrix} \]

\[ i = 1..n_{\text{kick}} \quad n_{\text{kick}} = 31 \text{ for CHH} \quad n_{\text{kick}} = 31 \text{ for CVV} \]

\[ j = 1..n_{\text{mon}} \quad n_{\text{mon}} = 47 \]

MRS is also used to:

- understand & improve machine linear model
- dispersion function control
- coupling evaluation
- orbit correction
- closed bump calculation
- corrector strength reduction
- Orbit Correction
- Corrector strengths reduction
- Vertical Dispersion Correction

\[
\begin{align*}
\vec{z} &= A \Delta \vec{I} \\
(\vec{z} + A \vec{I}_0) &= A \vec{I} \\
\vec{u} &= D \Delta \vec{I}
\end{align*}
\]

Equations are least square solved by Singular Value Decomposition

\[
\begin{align*}
u &= \begin{pmatrix}
z_1 \\
\vdots \\
z_{n_{\text{mon}}} \\
\eta_1 \\
\vdots \\
\eta_{n_{\text{mon}}}
\end{pmatrix}, \\
D &= \begin{pmatrix}
p_{\text{kick}} \\
\frac{\partial z_i}{\partial I_j} \\
\frac{\partial \eta_i}{\partial I_j}
\end{pmatrix}
\end{align*}
\]

is not affected by:
- model imperfections
- corrector calibration constants
- offsets in BPMs alignment
Bare orbit minimization by element alignment

\[ z_{\text{bare}} = z_{\text{beam}} - z_{\sum \text{Steers}} \]

- Misalignment errors are identified by fitting the measured bare orbit with the machine model
- Bare orbit has been reduced in both rings by repositioning the outer electromagnetic QUADS in the FINUDA IR
- After alignment:
  - strengths of the steering magnets adjacent to the IR2 section are considerably reduced
  - bare orbit is significantly reduced and is comparable in the two rings

FINUDA run 2006 ÷ 2007
ε_y tuning

Dominant source of ε_y are:
• large vertical orbit
• vertical dispersion
• transverse betatron coupling due to:
  - experimental solenoid
  - roll errors in quadrupoles
  - vertical orbit distortion in sextupoles
• vacuum chamber impedance
e+ Ring Vertical Dispersion Correction

\[ \text{rms}(\eta_{yc}) = 0.0411 \text{ [m]} \]
\[ \text{rms}(\eta_y) = 0.0647 \text{ [m]} \]

\[ R^+ = 0.093 \text{ measured at SLM} \]
\[ R_{\eta_c}^+ = 0.081 \]
Compensation scheme for the coupling due to the experimental detector

- $\int B \, \delta I = 2.4 \text{Tm}$
- 2 superconductive compensator solenoids
- 4 permanent magnet QUADs
- 4 electromagnetic QUADs
- Independent QUADs rotation
FINUDA @ DAΦNE
Betatron coupling correction algorithm

- local correction
  - by minimizing the coupling term of the measured Response Matrix by the IRs QUAD rotations $\Delta \phi_j$
  
  $j=1..r$

$$M\Delta \phi = C^{meas}$$

- linear system solved by SVD
- after few iterations 40% reduction in rms ($C^{meas}$)
The main part of natural transverse coupling is corrected by rotating the QUADs in IR2.

Fine tuning is performed using skew QUADs.

\[ \beta \sim 0.2\% \]

\( \alpha \) is the amount of horizontal oscillation transferred to the vertical plane.

\( \alpha \rightarrow 0 \) means no betatron coupling.
• global correction by SKEW QUADs

\[ \Sigma_x = 1.1 \text{ mm} \]

\[ \sigma_x \approx 0.8 \text{ mm @IP} \]

\[ \Sigma_y = 6.7 \mu \]

\[ \sigma_y \approx 6.9 \mu \text{ @IP} \]

\[ \Sigma_{x,y} = \sqrt{\sigma_{x,y}^2 + \sigma_{x,y}^2} \]

\[ \kappa = 0.2\% \]

measured by
- beam - beam scan at low current
- beam aspect ratio @ SLM

It’s possible to reach a satisfactory \( \kappa \) correction even in presence of huge coupling sources and without sophisticated diagnostic tools.
Impedance Effects in the e⁻ Ring

\[ \alpha_c = 0.02 \]

Stronger Bunch Lengthening  Vertical Size Blow \( f(V_{RF}, I_b) \)

**Graphs:**
- **Bunch Length [mm] vs. I [mA]:**
  - e⁻ ring
  - e+ ring

- **\( \sigma_y [mm] \) vs. V [kV]:**
  - 1.5 mA
  - 9 mA
  - 19 mA

**Equation:**
\[ \alpha_c = 0.02 \]
e- Vertical Size Blow Up

- Single bunch (beam) effect
- It is correlated with the longitudinal microwave instability threshold:
  \[ \text{Threshold scales} = \sqrt{\frac{1}{V_{RF}}} \propto 1.27 \]
- the same threshold and the same dependence on RF voltage
- It is relevant for the e- ring having higher coupling impedance
- The threshold is higher for higher momentum compaction

Data from KLOE run Apr. 05
Experiment with $\alpha_c < 0$

- Bunch shortens as predicted by numerical simulations
- Good agreement with DAΦNE optics model
- $I_{\text{bunch}} > 40$ mA is stored with negative chromaticity
- No problems with RF and feedbacks: about 1 A of stable current in both beams
- Coupling and geometric luminosity as in usual operation conditions
- First collisions at low currents (200 mAmps) with $L_{\text{peak}} = 2.5 \times 10^{31}$
- Fast growth of electron vertical beam size with currents above the longitudinal microwave instability threshold => hardware changes are needed to overcome the effect
e- Vertical Size Blow Up has been neutralized halving the e- ring impedance by removing all broken Ion-Clearing-Electrodes (ICEs) and all ICEs in wigglers since they were, according simulations, responsible for the difference in coupling impedance between e+ and e- ring:

\[
\left( \frac{Z}{n} \right)_{e^+}^0 \approx 0.54 \, \Omega \\
\left( \frac{Z}{n} \right)_{e^-}^0 \approx 1 \, \Omega
\]

Presently no beam blow up is observed for the e- beam with RF voltage
Conclusions

Efficient tools have been developed to:
  correct closed orbit, vertical dispersion and coupling
tune horizontal dispersion

Betatron coupling can be made as low as .2% despite the huge
coupling source introduced by the experimental detector

Dependence of transverse vertical dimension on coupling
impedance, in the e⁻ ring, has been detected, studied and eventually
removed