Design study for a Super $\Phi$ Factory at LNF

C. Biscari

for the DA$\Phi$NE team

LNF, INFN
PAST, PRESENT AND FUTURE

SUPER FACTORIES

FACTORIES

COLLIDERS

L (cm$^{-2}$ sec$^{-1}$)

$E_{cm}$ (GeV)

KEK B and PEP II

DAFNE

BEPC II

CESRc

VEPP2000

PETRA

TRISTAN

LEP

VLLC
“No first generation machine has ever improved by more than a factor 10 a crucial parameter”

J.P. Delahaye, CLIC Project Leader, October 2003
<table>
<thead>
<tr>
<th></th>
<th>$E_{cm}$ GeV</th>
<th>logged $\int L$</th>
<th>requested $\int L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B$</td>
<td>10.6</td>
<td>$\sim 300$ fb$^{-1}$</td>
<td>10 ab$^{-1}$</td>
</tr>
<tr>
<td>$\tau$</td>
<td>3.9</td>
<td>$&lt; 1$ fb$^{-1}$</td>
<td>$&gt; 100$ fb$^{-1}$</td>
</tr>
<tr>
<td>light quarks</td>
<td>2</td>
<td>$&lt; 10$ pb$^{-1}$</td>
<td>500 pb$^{-1}$</td>
</tr>
<tr>
<td>$\Phi$</td>
<td>1</td>
<td>$&lt; 1$ fb$^{-1}$</td>
<td>$&gt; 100$ fb$^{-1}$</td>
</tr>
</tbody>
</table>

requested $\int L$ for next collider generations
# Frascati colliders

<table>
<thead>
<tr>
<th></th>
<th>$E_{cm}$ (GeV)</th>
<th>$L \ (10^{32})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADA</td>
<td>1960</td>
<td>0.4</td>
</tr>
<tr>
<td>ADONE</td>
<td>1969/78</td>
<td>0.6/3.1</td>
</tr>
<tr>
<td></td>
<td>.. 2003/2006</td>
<td>x 2</td>
</tr>
</tbody>
</table>

**FUTURE**
Workshop on e+ e- in the 1-2 GeV range: Physics and Accelerator Prospects
ICFA Mini-workshop - Working Group on High Luminosity e+e- Colliders

10-13 September 2003, Alghero (SS), Italy

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http://www.lnf.infn.it/conference/d2/
**PEAK Luminosity**
- increase bunch density
- increase collision frequency

**AVERAGE Luminosity**
- continuos injection

\[
L = \frac{f_{\text{coll}} N^+ N^-}{4\pi \sigma_x \sigma_y}
\]
**high currents**

- Singlebunch instabilities
- Multibunch instabilities
- Feedbacks
- Impedance
- ECI
- CSR
- Power: vacuum, rf, cooling

**beam-beam**

- Crossing angle
- Low $\beta_y$ - short bunch length
- Resonances
- Dynamic aperture
- Blowup

**Background**

- Masks
- Collimators
- Cooling
- Touschek scattering
- Lattice phase advances
- IR designs

**lifetime - injection**

- Beam-gas scattering
- Touschek effect
- Beam-beam loss rate

\[ \tau \sim \text{hours} \rightarrow \tau \sim \text{few minutes} \]

\[ L \sim 10^{34} \rightarrow L \sim 10^{36} \]

**Continuous injection**
Basic concepts:

Luminosity is generally higher for high energy rings for several reasons, some of the more beneficial are:

1) Tune shifts scales with 1/Energy (E) leading to a fundamental linear increase of the luminosity vs Energy

2) Radiation damping-time decrease with 1/E^3 leading to higher limits for tune-shifts

3) Touschek effect decrease with 1/E^3

4) Natural bunch length shorter

5) Beam stiffer, single and multi bunch instabilities decrease with 1/E

P. RAIMONDI
DAFNE2

Energy x 2
Specifications

Upgrade of DAΦNE from the present energy of 1.02 GeV c.m. up to and above the neutron-antineutron threshold, 2-2.4 GeV c.m., using the existing systems and structures.

Luminosity $\sim 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$

Compatibility with present operation at $\Phi$
WHAT CAN BE USED FROM DAΦNE

• DAFNE2 can exploit DAΦNE hardware:
  – vacuum chamber
  – all quads and sexts
  – RF cavity
  – Feedback, vacuum system...

• But needs new:
  – stronger bending dipoles
  – 4 SC quads in IR2
DAΦNE DIPOLES

C. Ligi, R. Ricci     INFN – LNF

$e^+ e^-$ in the 1–2 GeV range – Alghero 12/9/2003
IR2 BETA FUNCTIONS

• $\beta_x = 2.5\ m$ and $\beta_y = 2.5\ cm$, already achieved at DAΦNE

• FF DFFD FF quad sequence
Superconducting IR Quadrupoles

Requirements

Tunable

510MeV -> 1.2GeV

Solenoid compensation

Superimposed skew quad windings
Alghero workshop
HE working group Conclusions

Energy upgrade to 1.1 GeV/beam straight forward and at moderate cost

Exploit most of existing hardware

Preliminary design for dipoles with some questions about
- current dependence of field quality
- current dependence

Parameters of superconducting IR quadrupoles are well within the range of existing designs
Super ДАΦΝΕ

Luminosity x 100
Some will be tested in near future:

- Crab cavities (KEK-B)
- Collisions with round beams (VEPP2000)
- Negative $\alpha_C$ (KEK-B, DAΦNE)

Others ...

- Collisions with neutralized beams (four beams) + feedback system
- Ring against linac
- Monochromators
- Collisions with large crossing angle:
  \[ E_{cm} = 2E_{beam}\cos(\theta_c/2), \]
  e.g. $\theta_c/2 = 60^\circ$, $E_{beam} = 1$ GeV
Main guidelines for the design
$L > 10^{34}$ at $\Phi$ energy

- Powerful damping
- Short bunch at IP
- Negative momentum compaction

Which kind of collider is possible at Frascati using present infrastructures?
Damping time on magnetic field

$$\alpha_x \approx \frac{C \alpha}{C} E^3 I_2$$

For $C = 100$ m
$E = 510$ MeV

$$\tau_x (\text{sec}) \approx \frac{\rho^2}{2.8 L_{\text{dip}}}$$

Factor 2 on tuneshift
by factor 10 on damping time
Beam Dynamics with $\alpha_c < 0$

- Bunch is shorter with a more regular shape
- Longitudinal beam-beam effects are less dangerous
- Microwave instability threshold is higher (?)
- Sextupoles are not necessary
- It is worthwhile to try a collider operation with a negative momentum compaction factor since this can provide several advantages in beam dynamics.

- Simulations indicate that by shifting the working point close to the integers and applying a lattice with the negative momentum compaction we have a possibility to push DAΦNE luminosity to $10^{33}$ cm$^{-2}$s$^{-1}$ level.

M. ZOBOV
Hour-glass effect

Squeezing vertical dimensions is effective only if bunch length is also decreased to the same dimension.
Strong RF Focusing for Luminosity Increase

A. Gallo, P. Raimondi, M. Zobov
Longitudinal Lattice Model

Longitudinal conjugate variables $\Rightarrow \begin{bmatrix} z \\ \epsilon_E \end{bmatrix}$

$z = c \cdot \tau \quad (\tau = \text{particle delay respect to synch. phase})$

$\epsilon_E = \Delta E/E = \text{relative energy error}$

$R_{56}(s) = \int_{0}^{s} \frac{\eta(\tilde{s})}{\rho(\tilde{s})} \, d\tilde{s}$

$M(s_0, s) = \begin{bmatrix} 1 & R_{56}(s) - R_{56}(s_0) \\ 0 & 1 \end{bmatrix}$

$M(s_c^-, s_c^+) = \begin{bmatrix} 1 & 0 \\ -\frac{V_{RF}}{E/e \lambda_{RF}} & 1 \end{bmatrix}$

$\text{RF Cavity} = \text{long. thin lens}$
Varying bunch length along the ring

**Comparison with Numerical Results:**

These analytical results have been compared with multi-particle tracking simulations of the bunch longitudinal dynamics in a strong RF focusing configuration. Uniform $R_{56}$ growth and emission rate in the arcs have been assumed in the tracking. The agreement is evident.
HIGH and NEGATIVE MOMENTUM COMPACTION

strong RADIATION emission

Alternating positive and negative bending dipoles
(proposed by Raimondi)
ZOOM OF THE RINGS SECTION

QUADRUPOLES

SEXTUPOLES

1m
The Working Point of a strongly RF focused ring consists in a set of values for the following fundamental parameters:

1. $\mu$ - One-turn synchrotron phase advance
2. $\frac{\sigma_E}{E}$ - Energy spread of the equilibrium distribution in the strong RF focusing regime
3. $R_{56}(L) = \alpha_c L$ - One-turn normalized path elongation (total $R_{56}$)
4. $\left| \frac{\sigma_E}{E} \right|_0$ - Energy spread of the equilibrium distribution in the “weak” focusing regime ($\mu << 1$)
5. $V_{RF}$ - RF Voltage
6. $\lambda_{RF}$ - RF wavelength

To obtain the required bunch length $\sigma_z$ at the IP.
2. Bunch energy spread in the strong RF focusing regime

The bunch energy spread rapidly grows with the phase advance and its maximum acceptable value is limited by:
- The $\Phi$-resonance width;
- The machine energy acceptance (quantum lifetime)

To avoid $\Phi$ production degradation:

$$\sigma_E/E \leq 1.4 \%$$

The beam quantum lifetime requires a ring energy acceptance of $\approx 1\%$ at least.

<table>
<thead>
<tr>
<th>$\sigma_z(IP)$</th>
<th>$\sigma_E/E$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 mm</td>
<td>1.2 %</td>
</tr>
<tr>
<td>2 mm</td>
<td>1.4 %</td>
</tr>
<tr>
<td>1 mm</td>
<td>1.4 %</td>
</tr>
</tbody>
</table>
Half-IR Layout
Top view (not on scale)

Exercise

With $\pm 10\sigma_x$ clearance, $\pm 9^\circ$ cone, $\pm 30$ mrad angle:

**QD1**: $L = 20$ cm, pole radius = 1.5 cm, $R_{\text{ext}} = 3$ cm, pm thickness = 1.5 cm

**QF2**: $L = 20$ cm, pole radius = 11 cm, $R_{\text{ext}} = 16$ cm, pm thickness = 1.5 cm, 
4 cm space between 2 quads

**QD3**: $L = 20$ cm, pole radius = 15 cm, $R_{\text{ext}} = 63$ cm, 25 cm space between 2 quads

10-13 September 2003

Alghero

BIAGINI
Dynamic aperture

First evaluation by
E. Levichev, P. Piminov*)
BINP, Lavrentiev 13, Novosibirsk 630090, Russia

ACCELERATICUM computer code [*]
Symplectic 6-D tracking for transversely and longitudinally coupled magnetic lattice

Choice of the working point

Adding the longitudinal phase plane:

3D – resonances

Tune footprint in 2D - transverse
Strong dependence on $V$ but specially on $Q_s$ => Resonances in 3D

$V = 300$ kV
$Q_s = 0.059$

$V = 3$ MV
$Q_s = 0.2$

$V = 5$ MV
$Q_s = 0.3$

----- no synchr oscill
----- $Dp/p = 0$
----- $Dp/p = 0.1\%$
----- $Dp/p = 0.5\%$
Feedback systems
First analysis
by J. Fox, D. Teitelmann
SLAC
GBoard 1.5 GS/sec. processing channel

- Next-generation instability control technology
- SLAC, KEK, LNF-INFN collaboration - useful at PEP-II, KEKB, DAFNE and several light sources.
- Transverse instability control
- Longitudinal instability control
- High-speed beam diagnostics (1.5 GS/sec. sampling/throughput rate)
- Builds on existing program in instability control and beam diagnostics.
- Significant advance in the processing speed and density previously achieved.
DAΦNE with strong RF focusing

As an example we will consider the effect of proposed RF configuration on longitudinal feedback. The proposed design has a much higher gap voltage which results in significantly shorter bunches at the IP and higher synchrotron frequency.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Current</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF frequency ($f_{\text{rf}}$)</td>
<td>368.25 MHz</td>
<td>500 MHz</td>
</tr>
<tr>
<td>Momentum compaction ($\alpha_c$)</td>
<td>0.029</td>
<td>-0.171</td>
</tr>
<tr>
<td>Circumference ($L$)</td>
<td>97.69 m</td>
<td>105 m</td>
</tr>
<tr>
<td>Revolution frequency ($f_{\text{rev}}$)</td>
<td>3.069 MHz</td>
<td>2.857 MHz</td>
</tr>
<tr>
<td>Harmonic number</td>
<td>120</td>
<td>175</td>
</tr>
<tr>
<td>RF voltage ($V_{\text{rf}}$)</td>
<td>120 kV</td>
<td>10.677 MV</td>
</tr>
<tr>
<td>Synchrotron frequency ($f_s$)</td>
<td>30 kHz</td>
<td>1.31 MHz</td>
</tr>
<tr>
<td>Revolutions per synchrotron period</td>
<td>~102</td>
<td>2.18</td>
</tr>
<tr>
<td>Bunch length ($\sigma_z$)</td>
<td>19 - 38 mm</td>
<td>2.6 - 20.4 mm</td>
</tr>
</tbody>
</table>
Beam lifetime (S. Guiducci)

Touschek lifetime has been calculated with a preliminary set of longitudinal parameters. A further optimization is possible.

Anyway

At \( L = 10^{34} \)

lifetimes are of the order of 10 minutes

• continuous injection is needed
Background

High current
Short beam lifetime
Continuos injection

\{ \}

High rate of particle losses

Dominated by Touschek lost particles
IR design together with detector design
# Dipole parameters

<table>
<thead>
<tr>
<th>Type</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>22</td>
<td>22</td>
<td>4</td>
</tr>
<tr>
<td>Alpha [rad]</td>
<td>0.6545</td>
<td>0.8528</td>
<td>0.5236</td>
</tr>
<tr>
<td>Chord [m]</td>
<td>0.607</td>
<td>0.781</td>
<td>0.489</td>
</tr>
<tr>
<td>Sagitta [m]</td>
<td>0.050</td>
<td>0.085</td>
<td>0.032</td>
</tr>
<tr>
<td>Magnet length</td>
<td>0.618</td>
<td>0.805</td>
<td>0.494</td>
</tr>
<tr>
<td>VolFe [m c]</td>
<td>0.282</td>
<td>0.362</td>
<td>0.227</td>
</tr>
<tr>
<td>VolCu [m c]</td>
<td>0.041</td>
<td>0.047</td>
<td>0.037</td>
</tr>
<tr>
<td>WeightFe [kg]</td>
<td>2222</td>
<td>2859</td>
<td>1789</td>
</tr>
<tr>
<td>WeightCu [kg]</td>
<td>359</td>
<td>410</td>
<td>324</td>
</tr>
<tr>
<td>Total Weight [kg]</td>
<td>2581</td>
<td>3269</td>
<td>2113</td>
</tr>
<tr>
<td>Power [W]</td>
<td>7234</td>
<td>8260</td>
<td>6537</td>
</tr>
</tbody>
</table>

Cost evaluated: 1600 k€
Poisson FEM simulation

Dipolo SuperDafne. Bnom=1.8 T I=26350 A
Injection system upgrade

• The proposed transfer lines pass in existing controlled area

• Additional shielding needed in the area between the accumulator and DAFNE buildings
Crossing point section schematic layout

- SC RF Cavities
- injection septa
- kicker
- quadrupoles
- vertically separated vacuum chambers
- FB kickers
- correctors
- TOP VIEW
- SIDE VIEW
Transfer Lines Layout in the DAFNE Hall
Luminosity $10^{34}$

set of consistent parameters

- $\alpha_C = -0.17$
- $N^{+,-} = 5 \times 10^{10}$
- $\beta_x = 0.5 \text{ m}$
- $\beta_y = 2 \text{ mm}$
- $\epsilon_x = 0.26 \mu\text{rad}$
- $\kappa = 0.6\%$
- $n_b = 150$
- $I_b = 22 \text{ mA}$
- $I_{tot} = 3.3 \text{ A}$

new

challenges
<table>
<thead>
<tr>
<th>MAIN PARAMETERS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C (m)</td>
<td>105</td>
</tr>
<tr>
<td>E (MeV)</td>
<td>510</td>
</tr>
<tr>
<td>$f_{rf}$ (MHz)</td>
<td>497</td>
</tr>
<tr>
<td>V (MV)</td>
<td>10</td>
</tr>
<tr>
<td>$\varepsilon_x$ (µ rad)</td>
<td>0.26</td>
</tr>
<tr>
<td>$\varepsilon_y$ (µ rad)</td>
<td>0.002</td>
</tr>
<tr>
<td>$\alpha_c$</td>
<td>-0.165</td>
</tr>
<tr>
<td>$\beta_x^*$ (m)</td>
<td>0.5</td>
</tr>
<tr>
<td>$\beta_y^*$ (mm)</td>
<td>2.0</td>
</tr>
<tr>
<td>N / bunch</td>
<td>5 e10</td>
</tr>
<tr>
<td>h</td>
<td>180</td>
</tr>
<tr>
<td>L /bunch (cm$^{-2}$ sec$^{-1}$)</td>
<td>$9 \times 10^{31}$</td>
</tr>
<tr>
<td>L tot (cm$^{-2}$ sec$^{-1}$)</td>
<td>$1.4 \times (1. @ \Phi) \times 10^{34}$</td>
</tr>
</tbody>
</table>
Tests foreseen in collaboration with other machines
Negative alfa tests at KEKB

Ikeda, KEKb
We are considering the possibility of testing the strong RF focusing in PEP2, KEK-B, CESR, ALS, …
10^{33}
Optimistic extrapolation of present knowledge and technologies

10^{34}
Very challenging design based on new ideas
Proofs of principle and validation needed

10^{35}

.................
DAFNE status and outlook

- Adiabatic changes on DAFNE approaching to an end.
- DAFNE performances expected to reach the original design goals (L= 5 * 10^{32}), within the next 2 years.
- 3-4 years of physics program fully booked with current (or slightly upgraded) detectors.
- After that, only radical changes possible.

S. Bertolucci, closing Alghero workshop
Conclusions

Energy X 2
Feasible, reasonable cost and time
AND / OR
L X 100
Challenging
Interesting
Worth preliminary design report
in collaboration with other Institutes (already begun)

Depends strongly on physics community interest