Super(B)nuclei

Production and study of Baryons with beauty at the Italian heavy flavor factory (SuperB)

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The INFN SuperB project

The (nuclear) physics case

A possible experimental program
SuperB is a flagship INFN project

It was approved and funded in December 2010 by Italian Education and Research Minister

## SuperB beam parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Base Line</th>
<th>Low Emittance</th>
<th>High Current</th>
<th>Tau/Charm (prolim)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LUMINOSITY</strong></td>
<td>cm⁻² s⁻¹</td>
<td>1.00E+06</td>
<td>1.00E+06</td>
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<tr>
<td>Energy</td>
<td>GeV</td>
<td>6.7</td>
<td>4.18</td>
<td>6.7</td>
<td>4.18</td>
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<tr>
<td>Circumference</td>
<td>m</td>
<td>1258.4</td>
<td>1258.4</td>
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<tr>
<td>X Angle (full)</td>
<td>mrad</td>
<td>66</td>
<td>66</td>
<td></td>
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<tr>
<td>Piwinskie angle</td>
<td>rad</td>
<td>22.88</td>
<td>16.60</td>
<td>32.36</td>
<td>25.30</td>
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<tr>
<td>β₀ @ IP</td>
<td>cm</td>
<td>2.6</td>
<td>3.2</td>
<td>2.6</td>
<td>3.2</td>
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<tr>
<td>β₁ @ IP</td>
<td>cm</td>
<td>0.0253</td>
<td>0.0205</td>
<td>0.0179</td>
<td>0.0145</td>
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<tr>
<td>Coupling (full current)</td>
<td>%</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>εₓ (without IBS)</td>
<td>nm</td>
<td>1.97</td>
<td>1.02</td>
<td>1.00</td>
<td>0.91</td>
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<tr>
<td>εₓ (with IBS)</td>
<td>nm</td>
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<td>1.00</td>
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<tr>
<td>εᵧ</td>
<td>μm</td>
<td>5</td>
<td>6.15</td>
<td>2.5</td>
<td>3.075</td>
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<tr>
<td>Σₓ</td>
<td>μm</td>
<td>11.433</td>
<td>8.085</td>
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<tr>
<td>Σᵧ</td>
<td>μm</td>
<td>0.050</td>
<td>0.030</td>
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<td>σₓ (0 current)</td>
<td>mm</td>
<td>4.69</td>
<td>4.29</td>
<td>4.73</td>
<td>4.34</td>
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<tr>
<td>σₓ (full current)</td>
<td>mm</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
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<tr>
<td>Beam current</td>
<td>mA</td>
<td>1892</td>
<td>2447</td>
<td>1460</td>
<td>1888</td>
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<tr>
<td>Buckets distance</td>
<td>#</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
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<td>Ion gap</td>
<td>%</td>
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<td>2</td>
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<tr>
<td>RF frequency</td>
<td>Hz</td>
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<td>4.76E+08</td>
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<td>Harmonic number</td>
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<td></td>
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<tr>
<td>Number of bunches</td>
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<td>970</td>
<td>970</td>
<td></td>
<td></td>
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<tr>
<td>N. Particle/bunch</td>
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<td>5.08E+10</td>
<td>6.56E+10</td>
<td>3.92E+10</td>
<td>5.06E+10</td>
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<tr>
<td>Tune shift x</td>
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<td>0.0021</td>
<td>0.0033</td>
<td>0.0017</td>
<td>0.0025</td>
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<tr>
<td>Tune shift y</td>
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<td>0.0079</td>
<td>0.0074</td>
<td>0.0094</td>
<td>0.0092</td>
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<tr>
<td>Long. damping time</td>
<td>msec</td>
<td>13.4</td>
<td>20.3</td>
<td>13.4</td>
<td>20.3</td>
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<tr>
<td>Energy Loss/turn</td>
<td>MeV</td>
<td>2.11</td>
<td>0.865</td>
<td>2.11</td>
<td>0.865</td>
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<tr>
<td>σₑ (full current)</td>
<td>dE/E</td>
<td>6.43E-04</td>
<td>7.34E-04</td>
<td>6.43E-04</td>
<td>7.34E-04</td>
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<tr>
<td>CM σₑ</td>
<td>dE/E</td>
<td>5.00E-04</td>
<td>5.00E-04</td>
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<td></td>
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<tr>
<td>Total lifetime</td>
<td>min</td>
<td>4.23</td>
<td>4.40</td>
<td>3.05</td>
<td>3.00</td>
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<tr>
<td>Total RF Power</td>
<td>MW</td>
<td>17.08</td>
<td>12.72</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- LER arc: LER Energy: 4.2 GeV, Germany, Jülich
- HER arc: HER Energy: 6.7 GeV, München, e+ e− 2011
- Polarization 80% for e−, ~ 0.5m
Study of **fundamental symmetries** of Nature, as CP and CPT, through a **systematic observation** of B meson decay

**omissis**

Search for **deviations from** the Standard Model behavior as signal of **new physics**

SuperB apparatus (with option)

Detector modelling

Geant4 Model

Forward TOF

Backward EMC

DIRC (New Read out)

DCH R/O electronic material

IFR (New segmentation)

FWD EMC

new segmentation

A. Feraccioli / hadron.2011, München, Germany, June 13-17, 2011.

M.A. Giorgi @ XVII SuperB Workshop, La Biodola, May 28-June 2, 2011
Good ideas are like good wine...
Bottom baryons at SuperB?!?

Impossible!!!  \( E_{\text{c.m.}} \approx 10600 \text{ MeV} < m(\Lambda_b^0 \bar{\Lambda}_b^0) = 2 \times 5620.2 \text{ MeV} = 11240.4 \text{ MeV} \)

lightest bottom baryon

Strange baryons at DAΦNE?!?

Impossible!!!  \( E_{\text{c.m.}} \approx 1020 \text{ MeV} < m(\Lambda^0 \bar{\Lambda}^0) = 2 \times 1115.7 \text{ MeV} = 2231.4 \text{ MeV} \)

lightest strange baryon

\[ e^- + e^+ \rightarrow \phi \]

\[ K^- + K^+ \]

\[ K_{\text{stop}} + N_{\text{bound}} \rightarrow \Lambda^0 + \pi^- \]

\( KLOE: M_{\text{inv}} = 1115,723 \pm 0.003 \text{ stat (MeV/c}^2) \)

PDG:  \( M_{\Lambda} = 1115,683 \pm 0.006 \text{ stat} \pm 0.006 \text{ syst (MeV/c}^2) \)

\( \sigma = 0.289 \pm 0.003 \text{ MeV/c}^2 \)

O. Vazquez Doce, 40° Meet. LNF SC

vertex rec.: no \hspace{1cm} yes

experimental results
Event rate rough estimate (I)

\[ e^- + e^+ \rightarrow \gamma(4S') \]

\[ \sigma \approx 1.1 \text{ nb} \quad \mathcal{L} \approx 1 \times 10^{36} \text{ cm}^{-2} \text{s}^{-1} \quad \approx 1.1 \text{ kHz} \]

\[ B^- + B^+ \]

\[ 76.7 \text{ MeV} \lesssim T_{B^\pm} \lesssim 273.7 \text{ MeV} \quad \approx 550 \text{ Hz} \]

\[ B_{\text{stop}} + N_{\text{bound}} \rightarrow \Lambda_b^0 + \pi^{-0} \]
\[ B_{\text{stop}} + N_{\text{bound}} \rightarrow \Sigma_b^{\pm} + \pi^{-0+} \]
\[ B_{\text{stop}} + N_{\text{bound}} \rightarrow \Sigma_b^{\pm*} + \pi^{-0+} \]

\[ B_{\text{flight}} + N_{\text{bound}} \rightarrow \Xi_b^{-0} + K^{+0} \quad ? \]

\[ B_{\text{flight}} + N_{\text{bound}} \rightarrow \Omega_b^{-} + K^+ + K^0 \]

A. Feliciello / hadron 2011, München, Germany, June, 13-17, 2011.
Event rate rough estimate (II)

B⁻ surviving probability: \( \approx 0.7\% \)

\[ \approx 4 \text{ Hz} \]

target acceptance + stop efficiency: \( \approx 10\% \)

\[ \approx 0.4 \text{ Hz} \]

reconstruction efficiency: \( \approx 10\% \)

\[ \approx 0.04 \text{ Hz} \]

daily duty cycle: \( \approx 70\% \)

\[ \approx 2.3 \times 10^3 \text{ ev/d} \]

Few weeks of data taking could allow to collect a data sample larger than the statistics available today on bottom baryons.
Physics goals

- To provide a high statistics data sample to determine the bottom baryon properties
- To get information on non-perturbative QCD and potential models
- From hyper- to super-nuclear physics (?)
From hyper- to super-nuclear physics

\[ \Lambda(uds) \]
\[ m = 1115.7 \text{ MeV} \]
\[ \tau = 263.1 \text{ ps} \]

\[ \Lambda^+(udc) \]
\[ m = 2286.5 \text{ MeV} \]
\[ \tau = 200.0 \text{ fs} \]

\[ \Lambda^0_b(udb) \]
\[ m = 5620.2 \text{ MeV} \]
\[ \tau = 1391.0 \text{ fs} \]
Kinematics issue

$B_{\text{stop}} + \mathcal{N}_{\text{free}} \rightarrow \Lambda^0_b + \pi^{-0}$

$B_{\text{stop}} + \mathcal{N}_{\text{free}} \rightarrow \Sigma^+_b + \pi^{-0+}$

$\Sigma^+_b$ momentum [GeV/c]

$\Lambda^0_b$ momentum [GeV/c]
Physics goals

- To study of the interaction potential between $B_i$ and nucleus ($i = s, c, b, ...$)

- To get basic information about flavour baryons and nucleon interaction at low energies (absolutely inaccessible by other experimental methods)
SuperB fast simulation output

**reconstructed B vertex distribution in xy plane (front view)**

- Entries: 8282
- Mean x: 0.091222
- Mean y: -0.003155
- RMS x: 0.005411
- RMS y: 0.000159

- 200 μm

**reconstructed B momentum**

- Entries: 5269
- Mean: 1.303
- RMS: 0.11484

**reconstructed B vertex distribution in zx plane (top view)**

- Entries: 8282
- Mean x: 0.008961
- Mean y: -0.0012
- RMS x: 0.03422
- RMS y: 0.0005452

\[ p_y \quad \Upsilon(4S) \quad 0.359 \text{ GeV/c} \]

\[ p_z \quad 2.519 \text{ GeV/c} \]

- \( e^+ \) (6700 MeV)
- \( e^- \) (4200 MeV)

- 33 mrad

- 33 mrad
**Schematic target design**

- **Requirement:** to maximize the fraction of $B^-$ mesons entering the target (keeping in mind that $c\tau = 501 \, \mu m$) \(\Rightarrow\) to minimize $d = r \sin \theta$

- **Constraint:** to avoid any interference between target and circulating beams \(\Rightarrow\) to not introduce any (additional) background source

- **Material:** to maximize event counting rate
  - $Au$ vs. $Pt$: comparable, good physics, thermal and electrical properties
  - $Pt$: higher density and higher melting point

"twin" radius (frustum of) cone to cope with the beam divergence
Schematic target design
Outlook

- Despite the experimental hardness SuperB could offer a unique opportunity for:
  - an extensive study of the bottom baryon properties
  - a new and, hopefully, fruitful approach to the super-nuclear physics field

- Next steps:
  - to validate the initial calculations by means of SuperB full simulation program and to give more solid basis to the proposal
  - to carefully evaluate machine and physics backgrounds
  - to get feedback from the Community about the interest in the subject