SuperB
The INFN Super Flavor Factory
and
What’s in it for SLAC?

David Hitlin
SLUO Meeting
February 7, 2008
A Super Flavor Factory

• Why do you want to do this? Isn’t this more of the same old BABAR physics? So twentieth century!

• No, it’s not. Not any more than the measurement of $B(K_L^0 \rightarrow \pi^0 \nu \bar{\nu})$ has the same physics objective as the measurement of $\varepsilon'/\varepsilon$ or the measurement of $B(K_L^0 \rightarrow \mu^+ \mu^-)$
But isn’t it “Precision Physics”

- Yes. Until the EPP2010 report, making measurements of physical quantities was generally regarded as a worthwhile endeavor.

- One way to frame the issue:
  - Should all (or most) HEP papers be titled “Search for ………..”? or is there still room for some titled “Measurement of ………..”? 
  - Both approaches can yield papers titled “ Evidence for ………”, which is the name of the game.
Are priorities immutable?

- What is the organizing principle of EPP2010 priorities?
  - Energy frontier
  - Astrophysics
  - Neutrinos
  - Flavor
  Facilities based

- It is possible to imagine a different principle
  - Find and understand physics beyond the Standard Model
  - Astrophysics
  - Neutrinos
  Physics based
The physics objectives of SuperB

- To study rare $\tau$, $b$ and $c$ decays with sufficient sensitivity to isolate evidence for physics beyond the Standard Model
  - Find charged lepton flavor violation in $\tau$ decays and study it
  - Search for $CP$ violation in $\tau$ production and decay and measure the $\tau$ anomalous magnetic moment
  - Precisely measure $CP$-violating asymmetries in penguin-dominated $B$ decays search for new physics effects
  - Measure $x$ and $y$ in $D^0\bar{D}^0$ mixing
  - Search for new physics effects on branching fractions and kinematic distributions in rare decay processes

- Requires a polarized electron beam

There are, of course, a very large number of other measurements in weak decay flavor physics and in QCD that can be made for the first time or greatly improved
A conversation between SuperB, LHC and ILC

• When evidence is found for New Physics at the LHC, attention will turn to understanding the details
  – Is it SUSY? What type of symmetry breaking?
  – Is it extra dimensions? Are they warped?

• The ILC will eventually sharpen the picture by, for example, measuring slepton masses

• SuperB will be crucial to an understanding of the flavor sector of any type of new physics
  – Are there new $CP$ phases?
  – Is there a charged Higgs?
  – Is there minimal flavor violation in the (s)quark sector?
  – Is there charged lepton flavor violation?
Lepton flavor violation (LFV)

- Lepton flavor violation is unobservably small in the Standard Model
- Neutrino mixing proves that there is neutral LFV
- The next natural question is whether there is charged LFV?
- Will the neutrino pattern be repeated?
  - If so, then LFV will be largest in $3\mu 2$ transitions

- Best bets: $\tau \mu \gamma$, $\tau \tau \ell$
Charged lepton flavor violation in $\tau$ decays

<table>
<thead>
<tr>
<th>LFV is expected in many Standard Model extensions</th>
<th>$\tau \rightarrow \mu \gamma$</th>
<th>$\tau \rightarrow \ell \ell \ell$</th>
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<tbody>
<tr>
<td><strong>SM + $\nu$ mixing</strong></td>
<td>$10^{-54}$ –</td>
<td>$10^{-14}$</td>
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<tr>
<td>Lee, Shrock, PRD 16 (1977) 1444</td>
<td>$10^{-40}$</td>
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<tr>
<td>Cheng, Li, PRD 45 (1980) 1908</td>
<td>$10^{-10}$</td>
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<tr>
<td>Pham EPJ C8 (1999) 513</td>
<td>$10^{-7}$</td>
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<tr>
<td><strong>SUSY Higgs</strong></td>
<td></td>
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<tr>
<td>Dedes, Ellis, Raidal, PLB 549 (2002) 45</td>
<td>$10^{-10}$</td>
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<tr>
<td>Brignole, Rossi, PLB 566 (2003)</td>
<td>$10^{-7}$</td>
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<tr>
<td><strong>SM + heavy Majorana $\nu_R$</strong></td>
<td></td>
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<tr>
<td>Cvetic, Dib, Kim, Kim, PRD66 (1982)</td>
<td>$10^{-9}$</td>
<td>$10^{-10}$</td>
</tr>
<tr>
<td><strong>Non-universal $Z'$</strong></td>
<td></td>
<td></td>
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<tr>
<td>Yue, Zhang, Liu, PLB 547 (2002)</td>
<td>$10^{-9}$</td>
<td>$10^{-8}$</td>
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<tr>
<td><strong>SUSY SO(10)</strong></td>
<td></td>
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<tr>
<td>Masiero, Vempati, Vives, NPB 626 (1999)</td>
<td>$10^{-8}$</td>
<td>$10^{-10}$</td>
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<tr>
<td>Fukuyama, Kikuchi, Okada, PRD 73 (1998)</td>
<td>$10^{-7}$</td>
<td></td>
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<tr>
<td><strong>mSUGRA + Seesaw</strong></td>
<td></td>
<td></td>
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<tr>
<td>Ellis, Gomez, Leontaris, Lola, NPB 626 (1999)</td>
<td>$10^{-7}$</td>
<td></td>
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<tr>
<td>Ellis, Hisano, Raidal, Shimizu, PRD 68 (1999)</td>
<td></td>
<td>$10^{-9}$</td>
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</tbody>
</table>

SuperB sensitivity
For 75 ab$^{-1}$

<table>
<thead>
<tr>
<th>Process</th>
<th>Sensitivity</th>
</tr>
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<tbody>
<tr>
<td>$B(\tau \rightarrow \mu \gamma)$</td>
<td>$2 \times 10^{-9}$</td>
</tr>
<tr>
<td>$B(\tau \rightarrow e \gamma)$</td>
<td>$2 \times 10^{-9}$</td>
</tr>
<tr>
<td>$B(\tau \rightarrow \mu \mu \mu)$</td>
<td>$2 \times 10^{-10}$</td>
</tr>
<tr>
<td>$B(\tau \rightarrow e e e)$</td>
<td>$2 \times 10^{-10}$</td>
</tr>
<tr>
<td>$B(\tau \rightarrow \mu \eta)$</td>
<td>$4 \times 10^{-10}$</td>
</tr>
<tr>
<td>$B(\tau \rightarrow e \eta)$</td>
<td>$6 \times 10^{-10}$</td>
</tr>
<tr>
<td>$B(\tau \rightarrow \ell K_S^0)$</td>
<td>$2 \times 10^{-10}$</td>
</tr>
</tbody>
</table>
Flipping the helicity of the polarized electron beam allows us to determine the chiral structure of dimension 6 four fermion lepton flavor-violating interactions.

Dassinger, Feldmann, Mannel, and Turczyk
JHEP 0710:039, 2007;

[See also Matsuzaki and Sanda
arXiv:0711.0792 [hep-ph]]
Polarization at Super$B$

- The Super$B$ design includes a polarized electron beam
  - SuperKEKB does not, and cannot, have a polarized beam
- Spins must be vertical in the ring $\uparrow\downarrow$ spin rotators at the IP
  - Solenoid spin rotators appear best
  - 36.6 Tesla-meters for 90° spin rotation in the LER
    - e.g. 2.5 Tesla x 14.66 meters with 30x$10^6$ ampere-turns
- Expected longitudinal polarization at the IP:
  - 87\%(injection) x 97\%(ring)=85\%(effective)
In the Standard Model we expect the same value for “sin2β” in $b\bar{c}c\bar{s}$, $b\bar{c}c\bar{d}$, $b\bar{s}s\bar{s}$, $b\bar{d}d\bar{s}$ modes, but different SUSY models can produce different asymmetries.

Since the penguin modes have branching fractions one or two orders of magnitude less than tree modes, a great deal of luminosity is required to make these measurements to meaningful precision.

\[
\lambda_{\text{tree}} > \frac{q}{p} \frac{A}{A} > \frac{\eta}{\bar{W}} \frac{V_{tb}^{*} V_{td}}{V_{cb}^{*} V_{cs}} > (1)e^{-2i\beta} \\
\lambda_{\text{penguin}} > \frac{q}{p} \frac{A}{A} > \frac{\eta}{\bar{H}} \frac{V_{tb}^{*} V_{td}}{V_{cb}^{*} V_{cs}} > (1)e^{-2i\beta}
\]

\[
\lambda > e^{i(2\beta, \phi_{\text{SUSY}})} \frac{A}{\bar{A}} \\
S_{\phi_K} > \sin(2\beta, \phi_{\text{SUSY}})
\]
Squark mass matrix ($d$ sector)

\[
\begin{pmatrix}
    m_{\tilde{d}_L}^2 & m_{\tilde{d}_L} (A_d - \mu \tan \beta) & (\Delta_{12}^d)_{LL} & (\Delta_{12}^d)_{LR} \\
    (\Delta_{12}^d)_{RL} & m_{\tilde{d}_R}^2 & (\Delta_{12}^d)_{RR} & \\
    m_{\tilde{s}_L}^2 & m_{\tilde{s}_R}^2 & m_s (A_s - \mu \tan \beta) & (\Delta_{23}^d)_{LL} \\
    (\Delta_{23}^d)_{RL} & (\Delta_{23}^d)_{RR} & m_{\tilde{b}_L}^2 & m_b (A_b - \mu \tan \beta)
\end{pmatrix}
\]

Assuming all $\Delta$'s small and squarks nearly degenerate approximation (MIA):

\[
(\delta_{ij}^d)_{AB} = \frac{(\Delta_{ij}^d)_{A}}{m^2}
\]

with new Feynman rule:

\[
(\tilde{d}_i^A)_A \times (\tilde{d}_j^B)_B \rightarrow (\Delta_{ij}^d)_{AB} = m^2 (\delta_{ij}^d)_{AB}
\]
Statistical errors on $CP$ asymmetries

$BABAR$ measurement errors

10 to 50 ab$^{-1}$ are required for a meaningful comparison

$10^{36}$ yields 15 ab$^{-1}$/year

Five year total: 75 ab$^{-1}$
$B \rightarrow \phi K^0$ at 50/ab with present WA value

\[ \lambda > e^{i(2\beta, \phi_{\text{SUSY}})} \left| \frac{\bar{A}}{A} \right| \ddot{y} \quad S_{\phi K} > \sin(2\beta, \phi_{\text{SUSY}}) \]
The pattern of deviation from the SM values is diagnostic

<table>
<thead>
<tr>
<th>Model</th>
<th>$B_d$ Unitarity</th>
<th>Time-dep. CPV</th>
<th>Rare $B$ decay</th>
<th>Other signals</th>
</tr>
</thead>
<tbody>
<tr>
<td>mSUGRA (moderate tan $\beta$)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>mSUGRA (large tan $\beta$)</td>
<td>$B_d$ mixing</td>
<td>-</td>
<td>$B \rightarrow (D)^* \tau \nu$ $b \rightarrow s \ell^+ \ell^-$</td>
<td>$B_s \rightarrow \mu \mu$ $B_s$ mixing</td>
</tr>
<tr>
<td>SUSY GUT with $\nu^R$</td>
<td>-</td>
<td>$B \rightarrow \phi K_S$ $B \rightarrow K^* \gamma$</td>
<td>-</td>
<td>$B_s$ mixing $\tau$ LFV, $n$ EDM</td>
</tr>
<tr>
<td>Effective SUSY</td>
<td>$B_d$ mixing</td>
<td>$B \rightarrow \phi K_S$</td>
<td>$A_{CP} (b \rightarrow s \gamma)$ $b \rightarrow s \ell^+ \ell^-$</td>
<td>$B_s$ mixing</td>
</tr>
<tr>
<td>KK graviton exchange</td>
<td>-</td>
<td>-</td>
<td>$b \rightarrow s \ell^+ \ell^-$</td>
<td>-</td>
</tr>
<tr>
<td>Split fermions in large extra dimensions</td>
<td>$B_d$ mixing</td>
<td>-</td>
<td>$b \rightarrow s \ell^+ \ell^-$</td>
<td>$K^0 \bar{K}^0$ mixing $D^0 \bar{D}^0$ mixing</td>
</tr>
<tr>
<td>Bulk fermions in warped extra dimensions</td>
<td>$B_d$ mixing</td>
<td>$B \rightarrow \phi K_S$</td>
<td>$b \rightarrow s \ell^+ \ell^-$</td>
<td>$B_s$ mixing $D^0 \bar{D}^0$ mixing</td>
</tr>
<tr>
<td>Universal extra dimensions</td>
<td>-</td>
<td>-</td>
<td>$b \rightarrow s \ell^+ \ell^-$</td>
<td>$K \rightarrow \pi \nu \nu$</td>
</tr>
</tbody>
</table>
A Super $B$ Factory is a DNA chip for New Physics

- mSUGRA (moderate tan $\beta$)
- mSUGRA (large tan $\beta$)
- SU(5) SUSY GUT with $\Omega_R$
- Effective SUSY
- KK graviton exchange
- Split fermions in large extra dimensions
- Universal extra dimensions

- $B_d$ unitarity
- Time-dependent CP violation
- Rare $B$ decays
- Other signals

David Hitlin  SLUO Meeting  February 7, 2008
Project X flavor physics

$B(K^0_L \rightarrow \pi^0 \nu \bar{\nu})$ and $B(K^+ \rightarrow \pi^+ \nu \bar{\nu})$

$\mu \to e$ conversion

$R_{\mu e} < 2 \times 10^{-17}$

in a generation

1 family 2 transition

MECO/Mu2e are large, expensive experiments

Sensitivity with respect to $\mu \to e \gamma$?

Is this more or less interesting than $2 \to 3$?
How do you gather the data sample?

- Access to new physics effects in the flavor sector requires a data sample 100x the total existing BABAR + Belle sample and therefore an asymmetric $e^+e^-$ collider with ~100x current luminosity.
- There are different approaches:
  - Increase the current and number of bunches: SuperPEP-II, SuperKEKB
    - High bunch charge, small $\beta$, CSR, heating, background and total power issues
  - Decrease the emittance and beam size at the IP: SuperB
    - PEP-II currents, and power, ILC Damping Ring emittance and alignment regime
How do you gather the data sample?

- An expert opinion: from Katsunobu Oide’s summary talk at the 2005 2nd Hawaii Joint Super B Factory Workshop:
  (quoted verbatim)
  - Present design of SuperKEKB hits fundamental limits in the beam-beam effect and the bunch length (HOM & CSR).
  - Higher current is the only way to increase the luminosity.
  - Many technical and cost issues are expected with a new RF system.

We need a completely different collider scheme...
How to increase luminosity

SuperKEKB approach

• Increase beam currents
• Decrease $\beta_y^*$
• Decrease bunch length

But...

• HOM in beam pipe
  – heating, instabilities, power costs
• Increased detector backgrounds
• Increased chromaticity
  – smaller dynamic aperture
• Increase RF voltage
  – Capital and operating costs, instabilities
A new idea...

Build low emittance rings, à la ILC, focus the beams strongly at the interaction point with a large crossing angle → large Piwinski angle.

- Ultra-low emittance
- Very small $\beta$ at the IP
- Large crossing angle
- “Crab Waist” scheme
  - Small collision area
  - Lower $\beta$ is possible
  - No parasitic crossings
  - Reduce effect of synchrobetatron resonances

David Hitlin  
SLUO Meeting  
February 7, 2008
Comparison with the brute force approach

<table>
<thead>
<tr>
<th>KEKB</th>
<th>SuperB</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{LER}$ (GeV)</td>
<td>3.5</td>
</tr>
<tr>
<td>$E_{HER}$ (GeV)</td>
<td>8</td>
</tr>
<tr>
<td>$N_{part}$ ($\times 10^{10}$)</td>
<td>5.8</td>
</tr>
<tr>
<td>$I_{LER}$ (A)</td>
<td>1.68</td>
</tr>
<tr>
<td>$I_{HER}$ (A)</td>
<td>1.29</td>
</tr>
<tr>
<td>Wallplug power (MW)</td>
<td>45</td>
</tr>
<tr>
<td>Crossing angle (mrad)</td>
<td>±15</td>
</tr>
<tr>
<td>Bunch length $\sigma_z$ (mm)</td>
<td>6</td>
</tr>
<tr>
<td>$\sigma_y^*$ (nm)</td>
<td>2000</td>
</tr>
<tr>
<td>$\sigma_x^*$ ($\mu$m)</td>
<td>110</td>
</tr>
<tr>
<td>$\beta_y^*$ (mm)</td>
<td>6</td>
</tr>
<tr>
<td>Vertical beam-beam tune shift $\xi_y$</td>
<td>0.055</td>
</tr>
<tr>
<td>Luminosity (cm$^{-2}$s$^{-1}$) ($\times 10^{34}$)</td>
<td>...</td>
</tr>
</tbody>
</table>

IP beam distributions for KEKB

IP beam distributions for SuperB
Ring Layout

Length 20 m

Total length ~1800 m

Length 280 m

Arc Cell

Final focus

HER

nb: polarization Insertion not modeled in this version
## Comparison of SuperB and SuperKEKB

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SuperB</th>
<th>SuperKEKB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumference (m)</td>
<td>1800</td>
<td>3016</td>
</tr>
<tr>
<td>Energy (GeV) (LER/HER)</td>
<td>4/7</td>
<td>3.5/8</td>
</tr>
<tr>
<td>Current (A)/beam</td>
<td>2.</td>
<td>9.4/4.1</td>
</tr>
<tr>
<td>No. bunches</td>
<td>1342</td>
<td>5018</td>
</tr>
<tr>
<td>No. part/bunches</td>
<td>5.5x10^{10}</td>
<td>12/5x10^{10}</td>
</tr>
<tr>
<td>$\theta$ (rad)</td>
<td>2x24</td>
<td>2x15</td>
</tr>
<tr>
<td>$\epsilon_x$ (nm-rad) (LER/HER)</td>
<td>2.8/1.6</td>
<td>24</td>
</tr>
<tr>
<td>$\epsilon_y$ (pm-rad) (LER/HER)</td>
<td>7/4</td>
<td>180</td>
</tr>
<tr>
<td>$\beta_y^*$ (mm) (LER/HER)</td>
<td>0.22/0.39</td>
<td>3</td>
</tr>
<tr>
<td>$\beta_x^*$ (mm) (LER/HER)</td>
<td>35/20</td>
<td>200</td>
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<tr>
<td>$\sigma_y^*$ ($\mu$m) (LER/HER)</td>
<td>0.039</td>
<td>1</td>
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<tr>
<td>$\sigma_x^*$ ($\mu$m) (LER/HER)</td>
<td>10/6</td>
<td>50</td>
</tr>
<tr>
<td>$\sigma_z$ (mm)</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Power (MW)</td>
<td>17</td>
<td>60 (RF only)</td>
</tr>
<tr>
<td>$L$ (cm$^{-2}$s$^{-1}$)</td>
<td>1x10^{36}</td>
<td>4x10^{35}</td>
</tr>
</tbody>
</table>

Includes 2x for crab crossing
Masa Yamauchi, SuperKEKB leader, said in a visit to SLAC in January that power costs and need to accumulate funds for additional RF would limit running to 4-5 months/year.
SuperB luminosity profile

Peak luminosity can be upgraded to $2.5 \times 10^{36}$ (conservatively)

160 ab$^{-1}$ in ten years
~100 x combined $BABAR+Belle$ data sample
An upgrade of \textit{BABAR} works well at \textit{SuperB}

Straightforward R&D on \textit{SuperB} upgrade components is underway.

R&D for a detector that can function in the SuperKEKB environment, a much more difficult problem, is also underway.
The SuperB location on the Tor Vergata campus
SuperB footprint at Tor Vergata

- SPARX
- SuperB Ring (circumference 1800m)
- SuperB Injector (about 400m)
- Roman Villa
- SuperB Main Building
What’s in it for SLAC?

- This is an interesting (in the Chinese proverb sense) time of transition for HEP at SLAC
- With no onsite HEP accelerator, the future will clearly be distinct from the past
  - Does one attempt to salvage something from the glorious past or just move on? Physics should decide
  - With no forefront accelerators in the US contemplated in the next few decades, how does the HEP component of a multipurpose lab, or an entire lab, for that matter, justify the premium for support of laboratory experimental groups over university groups?
  - How is the extraordinary capability of SLAC in electron accelerator physics best extrapolated into the future?
What’s in it for SLAC?

• Fermilab and BNL have made strides in confronting the question by becoming the US centers for CMS and ATLAS, respectively
  – This was done not only to provide opportunities for inmates, but also to make these labs important centers for the LHC efforts of the broader community

• SLAC, building on its leadership in $e^+e^-$ colliders and the physics derived therefrom, can position itself in a similar way, with SuperB as the vehicle
  – By becoming the center for US involvement in the INFN SuperB project, both SLAC and the user community benefit
What does SuperB involvement entail?

• The SuperB design uses many PEP-II components
  – Recognizing that there is internal competition for some of these items, a DOE HEP contribution of PEP-II magnets, RF and vacuum components, as well as of BABAR, as the basis for a detector upgrade, to SuperB would give the US a central position in a new high quality, high visibility project, for very little additional capital investment

• SLAC would then be the natural center for US SuperB activities, in a role that only a national lab can play
  – Accelerator design and possible component construction
  – Detector design and system construction
  – Physics

• There are different possible levels of participation
SuperB uses many PEP-II components

### Quadrupoles

<table>
<thead>
<tr>
<th>$L_{\text{mag}}$ (m)</th>
<th>PEP HER</th>
<th>PEP LER</th>
<th>SuperB HER</th>
<th>SuperB LER</th>
<th>SuperB Total</th>
</tr>
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<tbody>
<tr>
<td>0.56</td>
<td>202</td>
<td>-</td>
<td>165</td>
<td>193</td>
<td>253</td>
</tr>
<tr>
<td>0.73</td>
<td>82</td>
<td>-</td>
<td>103</td>
<td>18</td>
<td>121</td>
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<tr>
<td>0.43</td>
<td>-</td>
<td>-</td>
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<tr>
<td>0.7</td>
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<td>0.4</td>
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### Dipoles

<table>
<thead>
<tr>
<th>$L_{\text{mag}}$ (m)</th>
<th>PEP HER</th>
<th>PEP LER</th>
<th>SuperB HER</th>
<th>SuperB LER</th>
<th>SuperB Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.45</td>
<td>-</td>
<td>194</td>
<td>-</td>
<td>130</td>
<td>224</td>
</tr>
<tr>
<td>5.4</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Needed

- + RF (cavities, klystrons, .....)
- + vacuum components
- + accelerator expertise
- + BABAR

Why not do this at SLAC as an upgrade of PEP-II?

This is sufficiently logical that it must be happening in another part of the multiverse, But, apparently, not in our sector.
How much will SuperB cost?

From the SuperB CDR

<table>
<thead>
<tr>
<th></th>
<th>EDIA [my]</th>
<th>Labor [my]</th>
<th>M&amp;S [k€]</th>
<th>Net replacement value [k€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerator</td>
<td>452</td>
<td>291</td>
<td>191,166</td>
<td>126,330</td>
</tr>
<tr>
<td>Site (Lazio region)</td>
<td>119</td>
<td>138</td>
<td>105,700</td>
<td>0</td>
</tr>
<tr>
<td>Detector</td>
<td>283</td>
<td>156</td>
<td>40,747</td>
<td>46,471</td>
</tr>
</tbody>
</table>

Costs are presented “ILC-style”, with replacement value for reusable PEP-II/\textit{BABAR} components.

Value of reusable items from PEP-II and \textit{BABAR}.

Disassembly, crating, refurbishment and shipping costs are included in columns to the left.
Four year construction, preceded by 2-3 years of design and prototyping, which overlaps organizational and funding activities.
Conclusions

- **SuperB** is an opportunity for SLAC and the US program
  - **Great physics**: results will be crucial to understand new physics uncovered at the LHC
    - Physics in our lifetime
  - **Leverage**: a major role in a European project for a small investment
  - **Timing**: upswing of work on SuperB meshes with decreasing effort on **BABAR** and will retain a substantial fraction of the **BABAR** community as SLAC “users”
    - Retains an important aspect of the lab’s core expertise in $e^+e^-$ colliders: a responsibility to the community
Backup slides
Footprint
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lol (updated)</th>
<th>Upgrade (LER/HER)</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emittance</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>$\varepsilon_x$</td>
<td>24</td>
<td>12/13</td>
<td>nm</td>
</tr>
<tr>
<td>$\varepsilon_y$</td>
<td>0.18</td>
<td>0.060/0.066</td>
<td>nm</td>
</tr>
<tr>
<td>Beta at IP</td>
<td></td>
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</tr>
<tr>
<td>$\beta_x^*$</td>
<td>200</td>
<td>200</td>
<td>mm</td>
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<tr>
<td>$\beta_y^*$</td>
<td>3</td>
<td>3</td>
<td>mm</td>
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<tr>
<td>Beam size at IP (includes beam-beam)</td>
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</tr>
<tr>
<td>$\sigma_x^*$</td>
<td>50.0</td>
<td>37.5/39.8</td>
<td>$\mu$m</td>
</tr>
<tr>
<td>$\sigma_y^*$</td>
<td>1.0</td>
<td>2.11/2.28</td>
<td>$\mu$m</td>
</tr>
<tr>
<td>Bunch length</td>
<td>3</td>
<td>3</td>
<td>mm</td>
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<tr>
<td>Transverse damping time</td>
<td>t_x</td>
<td>47</td>
<td>msec</td>
</tr>
<tr>
<td>Betatron/synchrotron tune</td>
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</tr>
<tr>
<td>$\nu_x/\nu_y/\nu_s$</td>
<td>M+0.506/N+0.545/-0.031</td>
<td>M+0.505/N+0.550/-0.025</td>
<td>M,N:integer</td>
</tr>
<tr>
<td>Beam Energy</td>
<td>$E_x/E_y$</td>
<td>3.5/8.0</td>
<td></td>
</tr>
<tr>
<td>Beam current</td>
<td>$I_x/I_y$</td>
<td>9.4/4.1</td>
<td>A</td>
</tr>
<tr>
<td>#bunches</td>
<td>$N_b$</td>
<td>5018</td>
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</tr>
<tr>
<td>Crossing angle</td>
<td>$2\phi_x$</td>
<td>30 → 0 (crab crossing)</td>
<td>30 → 0 (crab crossing)</td>
</tr>
<tr>
<td>Beam-beam extrapolated from lumi</td>
<td>$\xi_x$</td>
<td>0.135</td>
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<tr>
<td></td>
<td>$\xi_y$</td>
<td>0.215</td>
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<tr>
<td>Beam-beam reduction</td>
<td>$R_{\xi_x}$</td>
<td>0.99</td>
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<tr>
<td></td>
<td>$R_{\xi_y}$</td>
<td>1.11</td>
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<tr>
<td>Luminosity reduction</td>
<td>$R_L$</td>
<td>0.86</td>
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<tr>
<td>Luminosity</td>
<td>L</td>
<td>4.0x10^{35}</td>
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</tbody>
</table>
Crab crossing experience at KEKB

- Lower bunch current product makes luminosity twice of the crossing-angle collision.
- However, slope of the specific luminosity is NOT understood well.
- If the reason is an electron cloud, no problem after upgrade.
- If luminosity is limited by something else, we must investigate it.
  - Synchro-beta resonance?
  - Other nonlinear effects?

\[ L_{sp} = \frac{L}{I+I} \quad I \text{ is bunch current} \]

Onishi at Atami Workshop