Physics at SuperB

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University of Warwick

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SuperB is a very high luminosity asymmetric $e^+e^-$ flavour factory

Conceptual design report
INFN/AE-07/02, SLAC-R-856, LAL 07-15
http://www.pi.infn.it/SuperB

See also
- SuperKEKB Letter of Intent, KEK Report 04-4
- Flavour in LHC Era workshops, yellow book in preparation
Exploration of Two Frontiers

**THE ENERGY FRONTIER**
- Hadron Colliders: Tevatron, LEP II, SppS, TRISTAN, PETRA, PEP, SLC, LEP (N_v=3), ISR, CESR, SPEAR II, ADONE, SPEAR (charm quark, τ lepton)
- e^+e^- Colliders: ISR, SPEAR, PEP, TRISTAN, LEP, CESR-C, HERA

**THE LUMINOSITY FRONTIER**
- Peak Luminosity trends in last 30 years: KEKB, PEP II, TEVATRON, LEP2, CESR, TEVATRON, CESR-C, ISR, PETRA, PEP, TRISTAN, LEPI, HERA

- SuperB

- Constituent Center-of-Mass Energy (GeV): 10^36
Motivation

- Major challenge for particle physics in the next decade is to go beyond the Standard Model

“relativistic”

New heavy particles produced on mass shell
Sensitivity depends on:
- available centre-of-mass energy
- knowledge of Standard Model backgrounds

“quantum”

New heavy particles produced off mass shell (“virtual”)
Sensitivity depends on:
- luminosity
- knowledge of Standard Model backgrounds
Flavour Observables Sensitive to New Physics

\[ \Delta m_K \quad \epsilon_K \quad \epsilon'/\epsilon_K \quad B(K_L \to \pi^0 \nu \bar{\nu}) \quad B(K^+ \to \pi^+ \nu \bar{\nu}) \quad B(K^+ \to l^+ \nu) \]
\[ \Delta m_d \quad A_{SL}(B_d) \quad S(B_d \to J/\psi K_S) \quad S(B_d \to \phi K_S) \]
\[ \alpha(B \to \pi \pi, \rho \pi, \rho \rho) \quad \gamma(B \to DK) \quad \text{CKM fits} \]
\[ \Delta m_s \quad A_{SL}(B_s) \quad S(B_s \to J/\psi \phi) \quad S(B_s \to \phi \phi) \]
\[ B(b \to s \gamma) \quad A_{CP}(b \to s \gamma) \quad S(B^0 \to K_S \pi^0 \gamma) \quad S(B_s \to \phi \gamma) \]
\[ B(b \to d \gamma) \quad A_{CP}(b \to d \gamma) \quad A_{CP}(b \to (d+s) \gamma) \quad S(B^0 \to \rho^0 \gamma) \]
\[ B(b \to s l^+ l^-) \quad B(b \to d l^+ l^-) \quad A_{FB}(b \to s l^+ l^-) \quad B(b \to s \nu \bar{\nu}) \]
\[ B(B_s \to l^+ l^-) \quad B(B_d \to l^+ l^-) \quad B(B^+ \to l^+ \nu) \]
\[ B(\mu \to e \gamma) \quad B(\mu \to e^+ e^- e^+) \quad (g-2)_\mu \quad \mu \text{ EDM} \]
\[ B(\tau \to \mu \gamma) \quad B(\tau \to e \gamma) \quad B(\tau^+ \to l^+ l^- l^+) \quad \tau \text{ CPV} \quad \tau \text{ EDM} \]
\[ B(D_{(s)}^+ \to l^+ \nu) \quad \chi_D \quad \gamma_D \quad \text{charm CPV} \]

... add your favourite here ...
Good News and Bad News

• Bad news
  - no single “golden mode”
  - (of course, some channels preferred in certain models)

• Good news
  - very many observables sensitive to new physics
  - maximize sensitivity by combining information
  - correlations between results distinguish models

Super Flavour Factory
“treasure chest” of new physics observables
Will be Studied at SuperB

\[ \Delta m_K \; \bar{\epsilon}_K \; \epsilon' / \epsilon_K \; B(K_L \to \pi^0 \nu \bar{\nu}) \; B(K^+ \to \pi^+ \nu \bar{\nu}) \; B(K^+ \to l^+ \nu) \]

\[ \Delta m_d \; A_{SL}(B_d) \; S(B_d \to J/\psi K_S) \; S(B_d \to \phi K_S) \]

\[ \alpha(B \to \pi \pi, \rho \pi, \rho \rho) \; \gamma(B \to DK) \; \text{CKM fits} \]

\[ \Delta m_s \; A_{SL}(B_s) \; S(B_s \to J/\psi \phi) \; S(B_s \to \phi \phi) \]

\[ B(b \to s \gamma) \; A_{CP}(b \to s \gamma) \; S(B^0 \to K_S \pi^0 \gamma) \; S(B_s \to \phi \gamma) \]

\[ B(b \to d \gamma) \; A_{CP}(b \to d \gamma) \; A_{CP}(b \to (d + s) \gamma) \; S(B^0 \to \rho^0 \gamma) \]

\[ B(b \to s l^+ l^-) \; B(b \to d l^+ l^-) \; A_{FB}(b \to s l^+ l^-) \; B(b \to s \nu \bar{\nu}) \]

\[ B(B_s \to l^+ l^-) \; B(B_d \to l^+ l^-) \; B(B^+ \to l^+ \nu) \]

\[ \frac{B(\mu \to e \gamma)}{B(\mu \to e^+ e^- e^+)} \; (g-2)_\mu \; \mu \; \text{EDM} \]

\[ B(\tau \to \mu \gamma) \; B(\tau \to e \gamma) \; B(\tau^+ \to l^+ l^- l^+) \; \tau \; \text{CPV} \; \tau \; \text{EDM} \]

\[ B(D_{(s)}^+ \to l^+ \nu) \; \chi_D \; \gamma_D \; \text{charm CPV} \]
Super Flavour Factory

• Data taken at Y(4S) allows studies of B, tau, charm, charmonia, ISR, γγ physics (and more)

• SuperB is designed with flexible running energy
  – charm-tau threshold region
  – other Upsilon resonances – including Y(5S)
    ⇒ can study $B_s$ sector, including $\Delta \Gamma_s$ and $\phi_s$ (but not $\Delta m_s$)

• Considering beam polarization option
  – provides luminosity enhancement
  – significant improvement in sensitivity for $\tau$ EDM

Lepton Flavour Violation

- Observable LFV signals predicted in a wide range of models, including those inspired by Majorana neutrinos

\[ B(\tau \to \mu \gamma) \times 10^7 \]

<table>
<thead>
<tr>
<th>Process</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>( B(\tau \to \mu \gamma) )</td>
<td>( 2 \times 10^{-9} )</td>
</tr>
<tr>
<td>( B(\tau \to e \gamma) )</td>
<td>( 2 \times 10^{-9} )</td>
</tr>
<tr>
<td>( B(\tau \to \mu \mu \mu) )</td>
<td>( 2 \times 10^{-10} )</td>
</tr>
<tr>
<td>( B(\tau \to e e e) )</td>
<td>( 2 \times 10^{-10} )</td>
</tr>
<tr>
<td>( B(\tau \to \mu \eta) )</td>
<td>( 4 \times 10^{-10} )</td>
</tr>
<tr>
<td>( B(\tau \to e \eta) )</td>
<td>( 6 \times 10^{-10} )</td>
</tr>
<tr>
<td>( B(\tau \to \ell K_S^0) )</td>
<td>( 2 \times 10^{-10} )</td>
</tr>
</tbody>
</table>

Monte Carlo simulation of 5\( \sigma \) observation of \( \tau \to \mu \gamma \) at SuperB

\[ M_{\mu\gamma} \text{ (GeV/c}^2\text{)} \]

SuperB is much more sensitive to LFV than LHC experiments, even for \( \tau \to \mu \mu \mu \)
Charm at SuperB

- SuperB *uniquely* can study the full range of charm phenomena

Recent evidence for charm mixing opens the door for CP violation studies at SuperB

<table>
<thead>
<tr>
<th>Mode</th>
<th>Observable</th>
<th>$B$ Factories (2 ab$^{-1}$)</th>
<th>SuperB (75 ab$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^0 \rightarrow K^+K^-$</td>
<td>$y_{CP}$</td>
<td>$2.3 \times 10^{-3}$</td>
<td>$5 \times 10^{-4}$</td>
</tr>
<tr>
<td>$D^0 \rightarrow K^+\pi^-$</td>
<td>$y_D'$</td>
<td>$2.3 \times 10^{-3}$</td>
<td>$7 \times 10^{-4}$</td>
</tr>
<tr>
<td></td>
<td>$x_D^2$</td>
<td>$1.2 \times 10^{-4}$</td>
<td>$3 \times 10^{-5}$</td>
</tr>
<tr>
<td>$D^0 \rightarrow K_{s0}^0\pi^+\pi^-$</td>
<td>$y_D$</td>
<td>$2.3 \times 10^{-3}$</td>
<td>$5 \times 10^{-4}$</td>
</tr>
<tr>
<td></td>
<td>$x_D$</td>
<td>$2.3 \times 10^{-3}$</td>
<td>$5 \times 10^{-4}$</td>
</tr>
<tr>
<td>Average</td>
<td>$y_D$</td>
<td>$1.2 \times 10^{-3}$</td>
<td>$3 \times 10^{-4}$</td>
</tr>
<tr>
<td></td>
<td>$x_D$</td>
<td>$2.3 \times 10^{-3}$</td>
<td>$5 \times 10^{-4}$</td>
</tr>
</tbody>
</table>
Two Scenarios

1) LHC discovers new physics
   - Can it be flavour blind? (ie. no signals in flavour)
     • No, it must couple to SM, which violates flavour
     • Any TeV scale NP model includes new flavoured particles
   - What is the minimal flavour violation? (ie. worst case)
     • NP follows SM pattern of flavour and CP violation
     • SFF detects NP effects for particle masses up to >600 GeV
   - What if NP flavour couplings are not suppressed?
     • SFF measures NP flavour couplings and distinguishes models

2) LHC does not discover new physics
   - Problem for naturalness?
     • Not really – just an order of magnitude argument
   - How to probe higher mass scales?
     • NP models with unsuppressed flavour couplings can reach scales of 10s, 100s or even 1000s of TeV
Interplay of Energy and Luminosity Frontiers

- Important to note that flavour observables are complementary to those at the energy frontier
  - measure different new physics parameters
  - powerful to distinguish models

LHC new physics discovery?

YES

- Need to measure flavour parameters that cannot be studied at LHC

NO

- Need alternative way to search for new physics beyond the LHC scale

SuperB
Estimated Sensitivities

<table>
<thead>
<tr>
<th>Observable</th>
<th>B Factories (2 ab⁻¹)</th>
<th>SuperB (75 ab⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sin(2\beta)$ ($J/\psi K^0$)</td>
<td>0.018</td>
<td>0.005 (†)</td>
</tr>
<tr>
<td>$\cos(2\beta)$ ($J/\psi K^{*0}$)</td>
<td>0.30</td>
<td>0.05</td>
</tr>
<tr>
<td>$\sin(2\beta)$ ($Dh^0$)</td>
<td>0.10</td>
<td>0.02</td>
</tr>
<tr>
<td>$\cos(2\beta)$ ($Dh^0$)</td>
<td>0.20</td>
<td>0.04</td>
</tr>
<tr>
<td>$S(J/\psi \pi^0)$</td>
<td>0.10</td>
<td>0.02</td>
</tr>
<tr>
<td>$S(D^+D^-)$</td>
<td>0.20</td>
<td>0.03</td>
</tr>
<tr>
<td>$S(\phi K^0)$</td>
<td>0.13</td>
<td>0.02 (*)</td>
</tr>
<tr>
<td>$S(\eta' K^0)$</td>
<td>0.05</td>
<td>0.01 (*)</td>
</tr>
<tr>
<td>$S(K^0_sK^0_sK^0_s)$</td>
<td>0.15</td>
<td>0.02 (*)</td>
</tr>
<tr>
<td>$S(K^0_s\pi^0)$</td>
<td>0.15</td>
<td>0.02 (*)</td>
</tr>
<tr>
<td>$S(\omega K^0_s)$</td>
<td>0.17</td>
<td>0.03 (*)</td>
</tr>
<tr>
<td>$S(f_0K^0_s)$</td>
<td>0.12</td>
<td>0.02 (*)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Observable</th>
<th>B Factories (2 ab⁻¹)</th>
<th>SuperB (75 ab⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$</td>
<td>V_{cb}</td>
<td>$ (exclusive)</td>
</tr>
<tr>
<td>$</td>
<td>V_{cb}</td>
<td>$ (inclusive)</td>
</tr>
<tr>
<td>$</td>
<td>V_{ub}</td>
<td>$ (exclusive)</td>
</tr>
<tr>
<td>$</td>
<td>V_{ub}</td>
<td>$ (inclusive)</td>
</tr>
<tr>
<td>$\mathcal{B}(B \to \tau\nu)$</td>
<td>20%</td>
<td>4% (†)</td>
</tr>
<tr>
<td>$\mathcal{B}(B \to \mu\nu)$</td>
<td>visible</td>
<td>5%</td>
</tr>
<tr>
<td>$\mathcal{B}(B \to D\tau\nu)$</td>
<td>10%</td>
<td>2%</td>
</tr>
<tr>
<td>$\mathcal{B}(B \to \rho\gamma)$</td>
<td>15%</td>
<td>3% (†)</td>
</tr>
<tr>
<td>$\mathcal{B}(B \to \omega\gamma)$</td>
<td>30%</td>
<td>5%</td>
</tr>
<tr>
<td>$A_{CP}(B \to K^*\gamma)$</td>
<td>0.007 (†)</td>
<td>0.004 (†)</td>
</tr>
<tr>
<td>$A_{CP}(B \to \rho\gamma)$</td>
<td>~ 0.20</td>
<td>0.05</td>
</tr>
<tr>
<td>$A_{CP}(b \to s\gamma)$</td>
<td>0.012 (†)</td>
<td>0.004 (†)</td>
</tr>
<tr>
<td>$A_{CP}(b \to (s+d)\gamma)$</td>
<td>0.03</td>
<td>0.006 (†)</td>
</tr>
<tr>
<td>$S(K^0_s\pi^0\gamma)$</td>
<td>0.15</td>
<td>0.02 (*)</td>
</tr>
<tr>
<td>$S(\rho^0\gamma)$</td>
<td>possible</td>
<td>0.10</td>
</tr>
<tr>
<td>$\alpha (B \to \pi\pi)$</td>
<td>~ 16°</td>
<td>3°</td>
</tr>
<tr>
<td>$\alpha (B \to \rho\rho)$</td>
<td>~ 7°</td>
<td>1−2° (*)</td>
</tr>
<tr>
<td>$\alpha (B \to \rho\pi)$</td>
<td>~ 12°</td>
<td>2°</td>
</tr>
<tr>
<td>$\alpha$ (combined)</td>
<td>~ 6°</td>
<td>1−2° (*)</td>
</tr>
<tr>
<td>$2\beta + \gamma$ ($D^{(*)}\pm \pi\mp, D^\pm K^0_s\pi\mp$)</td>
<td>20°</td>
<td>5°</td>
</tr>
</tbody>
</table>

Still only a few measurements systematics (†) or theoretically (*) limited
Leptonic B Decays
Crucial for MFV models with large tan \( \beta \) (and MSSM)


Today's first observation will become a precise measurement at SuperB

\( B(B^+ \to \tau^+ \nu) \)

17.2 \(^{+5.3}_{-4.7} \) events

<table>
<thead>
<tr>
<th>Observable</th>
<th>( B ) Factories (2 ab(^{-1}))</th>
<th>SuperB (75 ab)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \mathcal{B}(B \to \tau \nu) )</td>
<td>20%</td>
<td>4% (\dagger)</td>
</tr>
<tr>
<td>( \mathcal{B}(B \to \mu \nu) )</td>
<td>visible</td>
<td>5%</td>
</tr>
<tr>
<td>( \mathcal{B}(B \to D \tau \nu) )</td>
<td>10%</td>
<td>2%</td>
</tr>
</tbody>
</table>

\( B = B_{SM}(1 - \tan^2 \beta \frac{M_B^2}{M_H^2})^{14} \)

See talks in this session
MSSM + Generic Squark Mass Matrices

Today's central values with SuperB precision

Real vs. imaginary parts of mass-insertion parameters: left ($\delta_{13}^{LL}$); right ($\delta_{23}^{LR}$)

$\Delta m_d$  
$A_{\text{SL}}$  
$\beta$  
All

$A_{\text{CP}}(B \to X\gamma)$  
$B(B \to X\gamma)$  
$B(B \to Xl^+l^-)$  
All

Red areas show $\delta > 3\sigma$ from zero with SuperB precision
Hadronic $b\to s$ Penguins

Current B factory hot topic

$$\sin(2\beta^{\text{eff}}) \equiv \sin(2\phi_1^{\text{eff}})$$

Many channels can be measured with $\Delta S \sim (0.01-0.04)$

<table>
<thead>
<tr>
<th>Observable</th>
<th>$B$ Factories (2 ab$^{-1}$)</th>
<th>SuperB</th>
</tr>
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<tbody>
<tr>
<td>$S(\phi K^0)$</td>
<td>0.13</td>
<td>0.02 (*)</td>
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<td>0.05</td>
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<tr>
<td>$S(K_s^0 K_s^0 K_s^0)$</td>
<td>0.15</td>
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<tr>
<td>$S(K_s^0 \pi^0)$</td>
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<td>$S(f_0 K_s^0)$</td>
<td>0.12</td>
<td>0.02 (*)</td>
</tr>
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(*) theoretical limited
Summary

• The case for flavour physics in the LHC era is compelling

• SuperB – a high-luminosity asymmetric e^+e^- Super Flavour Factory is the ideal tool
  – significant breakthrough in collider design

• Conceptual Design Report exists
  – clear road ahead to explore the flavour treasure chest by mid-2010s

• See talk by M.Giorgi in EPS-ECFA session for more details of the project
Back Up
## Estimated Sensitivities

<table>
<thead>
<tr>
<th>Observable</th>
<th>Super Flavour Factory sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sin(2\beta) (J/\psi K^0)$</td>
<td>0.005–0.012</td>
</tr>
<tr>
<td>$\gamma (B \to D^{(<em>)} K^{(</em>)})$</td>
<td>1–2°</td>
</tr>
<tr>
<td>$\alpha (B \to \pi\pi, \rho\rho, \rho\pi)$</td>
<td>1–2°</td>
</tr>
<tr>
<td>$</td>
<td>V_{ub}</td>
</tr>
<tr>
<td>$</td>
<td>V_{ub}</td>
</tr>
<tr>
<td>$\bar{\rho}$</td>
<td>1.7–3.4%</td>
</tr>
<tr>
<td>$\bar{\eta}$</td>
<td>0.7–1.7%</td>
</tr>
<tr>
<td>$S(\phi K^0)$</td>
<td>0.02–0.03</td>
</tr>
<tr>
<td>$S(\eta' K^0)$</td>
<td>0.01–0.02</td>
</tr>
<tr>
<td>$S(K^0_s K^0_s K^0_s)$</td>
<td>0.02–0.04</td>
</tr>
<tr>
<td>$B(B \to \tau\nu)$</td>
<td>3–4%</td>
</tr>
<tr>
<td>$B(B \to \mu\nu)$</td>
<td>5–6%</td>
</tr>
<tr>
<td>$B(B \to D\tau\nu)$</td>
<td>2–2.5%</td>
</tr>
<tr>
<td>$B(B \to \rho\gamma)/B(B \to K^*\gamma)$</td>
<td>3–4%</td>
</tr>
<tr>
<td>$A_{CP}(b \to s\gamma)$</td>
<td>0.004–0.005</td>
</tr>
<tr>
<td>$A_{CP}(b \to (s+d)\gamma)$</td>
<td>0.01</td>
</tr>
<tr>
<td>$S(K^0_s \pi^0\gamma)$</td>
<td>0.02–0.03</td>
</tr>
<tr>
<td>$S(\rho^0\gamma)$</td>
<td>0.08–0.12</td>
</tr>
<tr>
<td>$A_{FB}^S (B \to X_s \ell^+\ell^-) s_0$</td>
<td>4–6%</td>
</tr>
<tr>
<td>$B(B \to K\nu\bar{\nu})$</td>
<td>16–20%</td>
</tr>
<tr>
<td>$B(\tau \to \mu\gamma)$</td>
<td>$2\times 10^{-9}$</td>
</tr>
<tr>
<td>$B(\tau \to \mu\mu\mu)$</td>
<td>$0.2\times 10^{-9}$</td>
</tr>
<tr>
<td>$B(\tau \to \mu\eta)$</td>
<td>$0.4\times 10^{-9}$</td>
</tr>
</tbody>
</table>

Range of estimated sensitivities from SuperB CDR and SuperKEKB LoI
A Completely New Accelerator Design

Attempts to upgrade PEP-II and KEKB with high current hit limitations due to beam instabilities, backgrounds and power

⇒ Approach with small emittance bunches (SuperB)
  - initially inspired by ILC damping rings
  - large Piwinski angle ($\varphi = \theta \sigma_z / \sigma_x$)
  - “crab waist”

⇒ High luminosity
⇒ Low currents
⇒ Small backgrounds
⇒ Stable dynamic aperture
⇒ Wall plug power $\sim 30$ MW

Maximize beam overlap with finite crossing angle
Backgrounds and Detectors

- Backgrounds depend on various factors
  - luminosity
    - radiative BhaBha scattering
    - $e^+e^-$ pair production
  - currents
    - synchrotron radiation
    - beam-gas interaction
  - beam size
    - Touschek scattering
    - beam-beam interactions

- For either SuperKEKB or SuperB:
  - interaction point design & shielding requires care
  - detector can be based on existing BaBar / Belle

main problem for SuperKEKB: beam backgrounds ~ 20 x today
possible problem for SuperB: motivates smaller beam asymmetry (7 GeV on 4 GeV)
Detector R&D

- Detector R&D required for the several subsystems
  - vertex detector
    - first layer close (~1cm) to beam spot
    - use pixels or striplets to cope with occupancy
  - particle identification
    - improved readout for barrel (DIRC)
    - forward PID device (focussing RICH?)
  - calorimeter
    - CsI(Tl) too slow for endcaps → pure CsI? LSO?
  - electronics, trigger, DAQ & offline computing
    - need to deal with high physics trigger rate
SuperB Detector
Potential SuperB site on the University of Rome Tor Vergata campus

Synergy with approved and funded FEL project (SPARX)

NB. Baseline 2250m circumference (similar to PEP-II)
Comparison between SuperB and SuperKEKB

<table>
<thead>
<tr>
<th></th>
<th>SuperB (Upgrade)</th>
<th>SuperKEKB (Low Emittance)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Emittance</strong></td>
<td>$\varepsilon_x$</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Horizontal beta</strong></td>
<td>$\beta_x^*$</td>
<td>20</td>
</tr>
<tr>
<td><strong>Vertical beta</strong></td>
<td>$\beta_y^*$</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Horizontal beam size</strong></td>
<td>$\sigma_x^*$</td>
<td>4</td>
</tr>
<tr>
<td><strong>Vertical beam size</strong></td>
<td>$\sigma_y^*$</td>
<td>20</td>
</tr>
<tr>
<td><strong>Bunch length</strong></td>
<td>$\sigma_z$</td>
<td>6</td>
</tr>
<tr>
<td><strong>Half crossing angle</strong></td>
<td>$\phi_x$</td>
<td>17</td>
</tr>
<tr>
<td><strong>Piwinski angle</strong></td>
<td>$\phi$</td>
<td>25.5</td>
</tr>
<tr>
<td><strong>Current(LER/HER)</strong></td>
<td>$I_b$</td>
<td>3.95/2.17</td>
</tr>
<tr>
<td><strong>Luminosity (x10^{35})</strong></td>
<td>$L$</td>
<td>24</td>
</tr>
<tr>
<td><strong>AC Plug Power</strong></td>
<td>$P$</td>
<td>35</td>
</tr>
</tbody>
</table>

One order magnitude smaller than SuperKEKB
Backgrounds

- Dominated by QED cross section
  - Low currents / high luminosity
  - Beam-gas are not a problem
  - SR fan can be shielded

<table>
<thead>
<tr>
<th></th>
<th>Cross section</th>
<th>Evt/bunch xing</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiative Bhabha</td>
<td>~340 mbarn</td>
<td>~680</td>
<td>0.3THz</td>
</tr>
<tr>
<td>(E_γ/Ebeam &gt; 1%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e^+e^- pair production</td>
<td>~7.3 mbarn</td>
<td>~15</td>
<td>7GHz</td>
</tr>
<tr>
<td>Elastic Bhabha</td>
<td>O(10^-5) mbarn</td>
<td>~20/Million</td>
<td>10KHz</td>
</tr>
<tr>
<td>(Det. acceptance)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>γ (4S)</td>
<td>O(10^-6) mbarn</td>
<td>~2/million</td>
<td>1 KHz</td>
</tr>
</tbody>
</table>
Need serious amount of shielding to prevent the produced shower from reaching the detector.
Some Key Measurements

CP Violation in Hadronic $b \to s$

$$\sin(2\beta^{\text{eff}}) \equiv \sin(2\phi_1^{\text{eff}})$$

<table>
<thead>
<tr>
<th>Process</th>
<th>World Average</th>
<th>BaBar</th>
<th>Belle</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b \to c\bar{c}s$</td>
<td>$0.58 \pm 0.03$</td>
<td>$0.12 \pm 0.31 \pm 0.10$</td>
<td>$0.50 \pm 0.21 \pm 0.06$</td>
<td>$0.30 \pm 0.18$</td>
</tr>
</tbody>
</table>

$\phi_1^{K^0_L}$

<table>
<thead>
<tr>
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<th>Belle</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b \to c\bar{c}s$</td>
<td>$0.55 \pm 0.10 \pm 0.03$</td>
<td>$0.64 \pm 0.10 \pm 0.04$</td>
<td>$0.61 \pm 0.07$</td>
<td>$0.61 \pm 0.07$</td>
</tr>
</tbody>
</table>

$\tau^0_K$ $K^0_L$

<table>
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<tr>
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<th>World Average</th>
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<th>Belle</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b \to c\bar{c}s$</td>
<td>$0.66 \pm 0.26 \pm 0.08$</td>
<td>$0.30 \pm 0.32 \pm 0.08$</td>
<td>$0.51 \pm 0.21$</td>
<td>$0.51 \pm 0.21$</td>
</tr>
</tbody>
</table>

$\omega_K$ $K^0_L$

<table>
<thead>
<tr>
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<th>World Average</th>
<th>BaBar</th>
<th>Belle</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b \to c\bar{c}s$</td>
<td>$0.33 \pm 0.26 \pm 0.04$</td>
<td>$0.33 \pm 0.36 \pm 0.08$</td>
<td>$0.33 \pm 0.21$</td>
<td>$0.33 \pm 0.21$</td>
</tr>
</tbody>
</table>

$\tau^0_K$ $K^*$ $X^0$

<table>
<thead>
<tr>
<th>Process</th>
<th>World Average</th>
<th>BaBar</th>
<th>Belle</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b \to c\bar{c}s$</td>
<td>$0.62 \pm 0.36 \pm 0.02$</td>
<td>$0.11 \pm 0.46 \pm 0.07$</td>
<td>$0.46 \pm 0.24$</td>
<td>$0.62 \pm 0.23$</td>
</tr>
</tbody>
</table>

Rates & Asymmetries in $b \to s\gamma$

Lepton Flavour Violation in $\tau$ Decay

$SFF$ sensitivity @ $10 ab^{-1}$

$B \to \tau \nu$

$M(H^+)$ vs $\tan \beta$
Couplings and Scales

\[ L = L_{SM} + \sum_{k=1}^{\infty} \left( \sum_i c_i^k Q_i^{(k+4)} \right) / \Lambda^k \]

- New physics effects are governed by:
  - new physics scale \( \Lambda \)
  - effective flavour-violating couplings \( c_i \)
    - couplings may have a particular pattern (symmetries)
    - coupling strengths can vary (different interactions)

- If \( \Lambda \) known from LHC, measure \( c_i \)
- If \( \Lambda \) not known, measure \( c_i / \Lambda \)
MFV Confronts the Data

• Current experimental situation
  – some new physics flavour couplings are small

• Minimal flavour violation
  – all new physics flavour couplings are zero

MFV is a long way from being verified!

Need to establish correlations between different flavour sectors ($B_d, B_s, K$)
New Physics Sensitivity in MFV

\[ H_{\text{eff}}^{\Delta F=2} = H_{\text{SM}} + H_{\text{NP}} = \left( V_{tq} V_{tq'}^* \right)^2 \left( \frac{S_0(x_t)}{\Lambda_0^2} + \frac{a_{\text{NP}}}{\Lambda^2} \right) (q'q)_{(V-A)} \]

\[ S_0(x_t) \rightarrow S_0(x_t) + \delta S_0, \quad |\delta S_0| = O \left( 4 \frac{\Lambda_0^2}{\Lambda^2} \right), \quad \Lambda_0 = \frac{\pi Y_t}{\sqrt{2} G_F M_W} \approx 2.4 \text{ TeV} \]

Today
\[ \Lambda(\text{MFV}) > 2.3\Lambda_0 \text{ @95C.L.} \]
NP masses > 200 GeV

SuperB
\[ \Lambda(\text{MFV}) > \sim 6\Lambda_0 \text{ @95C.L.} \]
NP masses > 600 GeV

- analysis relies on CKM fits and improvements in lattice calculations
- only \( \Delta F=2 \) (mixing) operators considered
- further improvements possible including also \( \Delta F=1 \) (especially \( b \rightarrow s \gamma \))
Correlations Distinguish Models


\[ A_{CP}(b \rightarrow s \gamma) \]

SFF can reach \( \sim 0.4\% \) precision

\[ S(B^0 \rightarrow K_S \pi^0 \gamma) \]

SFF can reach 2\% precision

Plots show parameter scans in four different SUSY breaking schemes:

- mSUGRA
- \( SU(5) + \nu_R \) degenerate
- \( SU(5) + \nu_R \) non-degenerate
- U(2) flavour symmetry

Being updated for SuperKEKB physics report
Running at the Y(5S)

- Belle & CLEO have demonstrated potential for $e^+e^- \rightarrow Y(5S) \rightarrow B_s^* B_s^*$

- Some important channels, such as $B_s \rightarrow \gamma\gamma$, $A_{SL}(B_s)$ are unique to SuperB

- Problem: cannot resolve fast $\Delta m_s$ oscillations
  - retain some sensitivity to $\varphi_s$, since $\Delta \Gamma_s \neq 0$

$$\Gamma_{B_s \rightarrow f}(\Delta t) + \Gamma_{B_s \rightarrow f}(\Delta t) = \mathcal{N} e^{-|\Delta t|/\tau(B_s)} \left[ \cosh\left(\frac{\Delta \Gamma_s \Delta t}{2}\right) - \frac{2 \text{Re}(\lambda_f)}{1 + |\lambda_f|^2} \sinh\left(\frac{\Delta \Gamma_s \Delta t}{2}\right) \right].$$

cf. D0 untagged measurement of $\varphi_s$
Large New Physics Contributions Excluded

\[ \Delta m_K \quad \epsilon_K \quad \epsilon' / \epsilon_K \quad B(K_L \rightarrow \pi^0 \nu \bar{\nu}) \quad B(K^+ \rightarrow \pi^+ \nu \bar{\nu}) \quad B(K^+ \rightarrow l^+ \nu) \]
\[ \Delta m_d \quad A_{SL}(B_d) \quad S(B_d \rightarrow J/\psi K_S) \quad S(B_d \rightarrow \phi K_S) \]
\[ \alpha(B \rightarrow \pi \pi, \rho \pi, \rho \rho) \quad \gamma(B \rightarrow DK) \quad \text{CKM fits} \]
\[ \Delta m_s \quad A_{SL}(B_s) \quad S(B_s \rightarrow J/\psi \phi) \quad S(B_s \rightarrow \phi \phi) \]
\[ B(b \rightarrow s \gamma) \quad A_{CP}(b \rightarrow s \gamma) \quad S(B^0 \rightarrow K_S \pi^0 \gamma) \quad S(B_s \rightarrow \phi \gamma) \]
\[ B(b \rightarrow d \gamma) \quad A_{CP}(b \rightarrow d \gamma) \quad A_{CP}(b \rightarrow (d+s) \gamma) \]
\[ B(b \rightarrow s l^+ l^-) \quad B(b \rightarrow d l^+ l^-) \quad A_{FB}(b \rightarrow s l^+ l^-) \quad B(b \rightarrow s \nu \bar{\nu}) \]
\[ B(B_s \rightarrow l^+ l^-) \quad B(B_d \rightarrow l^+ l^-) \quad B(B^+ \rightarrow l^+ \nu) \]
\[ B(\mu \rightarrow e \gamma) \quad B(\mu \rightarrow e^+ e^- e^+) \quad (g-2)_\mu \quad \mu \text{ EDM} \]
\[ B(\tau \rightarrow \mu \gamma) \quad B(\tau \rightarrow e \gamma) \quad B(\tau^+ \rightarrow l^+ l^- l^+) \quad \tau \text{ CPV} \quad \tau \text{ EDM} \]
\[ B(D_{s}^+ \rightarrow l^+ \nu) \quad x_D \quad y_D \quad \text{charm CPV} \]
Will be Studied at SuperB

\[ \Delta m_K, \epsilon_K, \epsilon'/\epsilon_K, B(K_L \to \pi^0 \nu \bar{\nu}), B(K^+ \to \pi^+ \nu \bar{\nu}), B(K^+ \to l^+ \nu) \]

\[ \Delta m_d, A_{SL}(B_d), S(B_d \to J/\psi K_S), S(B_d \to \phi K_S) \]

\[ \alpha(B \to \pi \pi, \rho \pi, \rho \rho), \gamma(B \to DK), \text{CKM fits} \]

\[ \Delta m_s, A_{SL}(B_s), S(B_s \to J/\psi \phi), S(B_s \to \phi \phi) \]

\[ B(b \to s \gamma), A_{CP}(b \to s \gamma), S(B^0 \to K_S \pi^0 \gamma), S(B_s \to \phi \gamma) \]

\[ B(b \to d \gamma), A_{CP}(b \to d \gamma), A_{CP}(b \to (d+s) \gamma), S(B^0 \to \rho^0 \gamma) \]

\[ B(b \to s l^+ l^-), B(b \to d l^+ l^-), A_{FB}(b \to s l^+ l^-), B(b \to s \nu \bar{\nu}) \]

\[ B(B_s \to l^+ l^-), B(B_d \to l^+ l^-), B(B^+ \to l^+ \nu) \]

\[ B(\mu \to e \gamma), B(\mu \to e^+ e^- e^+) (g-2)_\mu, \mu \text{ EDM} \]

\[ B(\tau \to \mu \gamma), B(\tau \to e \gamma), B(\tau^+ \to l^+ l^- l^+) \]

\[ B(D^{+}_s \to l^+ \nu) \]

\[ X_D, Y_D, \text{charm CPV} \]
Will be studied at LHCb (+ upgrade)

\[
\Delta m_K, \epsilon_K, \epsilon'/\epsilon_K, B(K_L \to \pi^0 \nu \bar{\nu}), B(K^+ \to \pi^+ \nu \bar{\nu}), B(K^+ \to l^+ \nu)
\]

\[
\Delta m_d, A_{SL}(B_d), S(B_d \to J/\psi K_S), S(B_d \to \phi K_S)
\]

\[
\alpha(B \to \pi \pi, \rho \pi, \rho \rho), \gamma(B \to DK)
\]

CKM fits

\[
\Delta m_s, A_{SL}(B_s), S(B_s \to J/\psi \phi), S(B_s \to \phi \phi)
\]

\[
B(b \to s \gamma), A_{CP}(b \to s \gamma), S(B^0 \to K_S \pi^0 \gamma)
\]

\[
B(b \to d \gamma), A_{CP}(b \to d \gamma), A_{CP}(b \to (d+s) \gamma)
\]

\[
B(b \to s l^+ l^-), B(b \to d l^+ l^-), A_{FB}(b \to s l^+ l^-), B(b \to s \nu \bar{\nu})
\]

\[
B(B_s \to l^+ l^-), B(B_d \to l^+ l^-), B(B^+ \to l^+ \nu)
\]

\[
B(\mu \to e \gamma), B(\mu \to e^+ e^- e^+) \quad (g-2)_\mu \quad \mu \ EDM
\]

\[
B(\tau \to \mu \gamma), B(\tau \to e \gamma), B(\tau^+ \to l^+ l^- l^+) \quad \tau \ CPV \quad \tau \ EDM
\]

\[
B(D_{(s)}^+ \to l^+ \nu)
\]

\[
\chi_D, Y_D, \quad \text{charm CPV}
\]

dashed box = exclusive modes only