B-Physics at LHCb

XXXI International Meeting
On Fundamental Physics

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Outline

- **Introduction**
  CKM picture of CP violation.
  Measurements of the angles.
  How new physics modifies the picture.

- **LHC experimental conditions**
  LHC as a B-factory.
  Detector requirements.

- **LHCb detector**
  Vertex.
  Particle Identification.
  Trigger.

- **LHCb performance**
  Event reconstruction and event yields.
  Some examples of the LHCb potential.

- **Outlook and conclusions**

Many thanks to T. Nakada and O. Schneider for allowing me to recycle some of their transparencies.
LHCb Detector
The LHCb detector
The Vertex Locator (VELO)

Number of silicon sensors: 88
Area of silicon: 0.47m²
Number of channels: 180,000
Vacuum feed-throughs: 416
The Vertex Locator (VELO)

- Silicon sensors, 7mm close to the LHC beams, are placed in a secondary vacuum for minimizing material.
- The two detector halves are retracted during injection.
The Vertex Locator (VELO)

VELO has

- low occupancy
- high resolution
- radiation hard
Decay time resolution...

Dilution of CP asymmetry for $B_s$ due to $\sigma_\tau$ must be less than due to other sources: $< 0.5$

$\sigma_\tau < 50 \, \text{fs} \approx 0.03 \, \tau_B$

$<l_B> \approx 1 \, \text{cm}$

$\sigma_l < 300 \, \mu\text{m}$

$\sigma_{IP}(B\text{-decays}) < 50 \, \mu\text{m}$
The RICH detectors

Required momentum range and angular coverage.

(a) $B \rightarrow \pi\pi$ decay

(b) tagging kaons
The RICH detectors

Three Cherenkov radiators are used, to cover the full momentum range:

- \( \theta_{C_{\text{max}}}=242 \text{ mrad} \)
- Silica aerogel
  \( n=1.03 \)
- \( C_4F_{10} \) gas
  \( n=1.0014 \)
- \( CF_4 \) gas
  \( n=1.0005 \)

\[ \begin{array}{c}
\theta_{C} \text{ (mrad)} \\
\hline
0 & 50 & 100 & 150 & 200 & 250 \\
\hline
1 & 2 & 3 & 4 & 5 & 6 \\
\end{array} \]
The RICH detectors

**RICH-1 layout**

- Flat mirror to limit extent along z
- Photodetectors out of spectrometer acceptance, in magnetic shield
- Spherical mirror to focus Cherenkov light
- Tilted to bring image out of acceptance
- Aerogel and C₄F₁₀ combined in a single device.

**RICH-2 layout**

- Entry Window
- Exit Window
- Flat Mirror
- Spherical Mirror
- CF4 gas
- Beam line 245 cm

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The RICH detectors

**K–π separation**

- For all long tracks matched to a true $\pi$ calculate the $K–\pi$ separation from the difference in likelihood of their $K$ and $\pi$ hypotheses in the RICH

$$\Delta \sigma = \sqrt{2 |\Delta \ln L|}$$

signed according to $\Delta \ln L$
The RICH detectors

- Most relevant parameters for most physics analyses are
  K selection efficiency and π → K misid rate

- Current performance shown as a function of momentum for reconstructed tracks (in Bs → K−π+ events):

- Threshold behaviour noticeable at p ~ 2, 9 and 16 GeV/c

\[ \langle \varepsilon_{K \rightarrow K} \rangle = 88\% \ (2–100 \text{ GeV/c}) \]
\[ \langle \varepsilon_{\pi \rightarrow K} \rangle = 2.7\% \]
The LHCb Trigger
The LHCb Trigger

$p_T$ and $E_T$ triggers
(muon + calorimeters)

vertex triggers
(Si vertex detector
+ Si Tracker)

confirmation
and event filters

ATLAS CMS

LHCb

BTeV

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The LHCb Trigger

- LO Pileup veto reduces rate to 9 MHz. Hence, LO Pt cuts only need a factor 9 reduction with medium Pt cuts (\(E_t(h) \sim 3.5\) GeV, \(E_t(\gamma) \sim 3\) GeV, \(P_t(\mu) \sim 1.2\) GeV,...), with a fixed latency of 4 \(\mu s\).

- L1 reduces the output rate to <40 kHz using trackers information, with a maximum latency of 50 ms.

- HLT reduces rate to 200 Hz with access to full event data.
The LHCb Trigger

**L0 Trigger**

Bandwidth division:
- ~ 600 kHz (hadron's trigger)
- ~ 200 kHz ($\mu+\mu$ trigger)
- ~ 200 kHz ($e+\gamma+\pi^0$ trigger)

Pileup veto:
- Selects simple events, hence more robust system
- Improves correlation with offline selection (better efficiency).

Pt cuts:
- Relatively low reduction factor (~9), hence relatively low Pt cuts.
The LHCb Trigger

L1 Trigger

LHCb
Reconstructed event

trigger

primary vertex

$B^0 \rightarrow \pi^+ \pi^-$

$B^0 \rightarrow \mu^- D^+ n$

$L1$ Trigger
L1 triggers on tracks with significant impact parameter and high $Pt$

Minimum Bias after L0.

Track from $B$ decays

$B^0_d \rightarrow \pi^+ \pi^-$ after L0 and offline selected.

$L1$ triggers on tracks with significant impact parameter and high $Pt$
# The LHCb Trigger

**Work in progress**

<table>
<thead>
<tr>
<th>Process</th>
<th>L0(%)</th>
<th>L1(%)</th>
<th>HLT(%)</th>
<th>Total(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_s \rightarrow \pi^+ \pi^-$</td>
<td>μ 6 9 3</td>
<td>55</td>
<td>61</td>
<td>51</td>
</tr>
<tr>
<td>$B_s \rightarrow D_s K$</td>
<td>8 7 5 2</td>
<td>37</td>
<td>44</td>
<td>65</td>
</tr>
<tr>
<td>$B_s \rightarrow J/\psi(\text{ee})\phi$</td>
<td>7 7 36 4</td>
<td>24</td>
<td>52</td>
<td>43</td>
</tr>
<tr>
<td>$B_s \rightarrow J/\psi(\mu\mu)\phi$</td>
<td>90 89 5 3</td>
<td>30</td>
<td>93</td>
<td>73</td>
</tr>
<tr>
<td>$B_d \rightarrow K^*\gamma$</td>
<td>6 6 28 47 30</td>
<td>82</td>
<td>33</td>
<td>-</td>
</tr>
</tbody>
</table>

- Trigger efficiencies are ~30%, higher for dimuon channels.
- Hadron trigger is crucial for LHCb physics goals.

Evenly spread selectivity = robust and flexible

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LHCb Performance
Event Reconstruction and Event Yield

\[ \text{primary vertex} \]

\[ \text{B}_s^0 \text{ impact parameter} > 0 \]

\[ \text{B}_s^0 \text{ decay distance} > 0 \]

\[ \text{K}^+ \text{ impact parameter} > 0 \]

\[ \text{Ds}^- \text{ impact parameter} > 0 \]

\[ \text{Ds}^- \text{ decay distance} > 0 \]

\[ \sigma_l(B_s) = 170 \mu m \]

\[ \sigma_t(B_s) = 40 \text{ fs} \]
Event Reconstruction and Event Yield
Event Reconstruction and Event Yield

**Tracking Performance**

- Track reconstruction efficiency ~96%
- Momentum resolution ~0.4%
- Impact Parameter resolution <40μm
## Tracking efficiency for B decays

<table>
<thead>
<tr>
<th>Decay chain</th>
<th>Tracks to be reconstructed</th>
<th>( \varepsilon_{\text{reco all}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( B^0 \rightarrow \pi^+ \pi^- )</td>
<td>2 long hadrons</td>
<td>( (91.8 \pm 0.2)%</td>
</tr>
<tr>
<td>( B^0 \rightarrow K^+ \pi^- )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( B^0_s \rightarrow K^+ K^- )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( B^0_s \rightarrow D_s^- (K^+ K^- \pi^-) \pi^+ )</td>
<td>4 long hadrons</td>
<td>( (84.6 \pm 0.5)%</td>
</tr>
<tr>
<td>( B^0_s \rightarrow D_s^- (K^+ K^- \pi^-) K^+ )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( B^0_s \rightarrow J/\psi (\mu^+ \mu^-) \phi(K^+ K^-) )</td>
<td>4 long (incl. 2 muons)</td>
<td>( (84.6 \pm 0.6)%</td>
</tr>
<tr>
<td>( B^0_s \rightarrow J/\psi (e^+ e^-) \phi(K^+ K^-) )</td>
<td>4 long (incl. 2 electrons)</td>
<td>( (81.8 \pm 0.6)%</td>
</tr>
</tbody>
</table>

- Reconstruction efficiency for all final state tracks (before trigger), including minimal track quality requirement (loose \( \chi^2 \) cut), but no PID

- Consistent with \( \sim 96\% \) efficiency per single long track (\( \sim 94\% \) in case of electrons).
Event Reconstruction and Event Yield

Primary vertex reconstruction

\[ \sigma_x = \sigma_y = 8.5 \, \mu m, \quad \sigma_z = 47 \, \mu m \]

\[ \sigma_1 = 8.291 \pm 0.251 \, \mu m \]
\[ \sigma_2 = 19.60 \, \mu m \text{ (18.19\% at peak)} \]

\[ \sigma_1 = 47.33 \pm 1.584 \, \mu m \]
\[ \sigma_2 = 1.377 \, \mu m \text{ (11.84\% at peak)} \]
Event Reconstruction and Event Yield

Flavour tag with high $p_T$ leptons and large impact parameter ($d_0$) kaons

B-B oscillations: irreducible wrong tag

$\varepsilon_{\text{tag}} = 0.4$, $\omega_{\text{tag}} = 0.3$
Event Reconstruction and Event Yield

$B^0_{(s)} \rightarrow h^+h^-$

- **Charged tracks:**
  - Each leg identified as a K, or a particle lighter than K (using RICH)
  - Cuts on $p$, max. $p_T$, min. $p_T$, max. $IP/\sigma_{IP}$, min. $IP/\sigma_{IP}$, and $\chi^2$ of common vertex

- **B candidate:**
  - Cuts on $p_T$, $IP_B/\sigma_{IP}$, $L$, and mass

Single Gaussian fit: $\sigma=41\pm1$ fs
Event Reconstruction and Event Yield

Rejection of comb. back. ($B^0 \rightarrow \pi^+ \pi^-$)

- Assume combinatorial background dominated by bb events
- Can reject all generated bb background (also when relaxing B mass cut):

\[ S/B \geq 1 \]

- Contribution of ghost tracks to the combinatorial background is negligible
Event Reconstruction and Event Yield

Rejection of physics background

Relying on
- RICH PID
- mass resolution (~18 MeV/c^2)

<table>
<thead>
<tr>
<th>Channel</th>
<th>BR x 10^6</th>
</tr>
</thead>
<tbody>
<tr>
<td>B^0 → π^+ π^-</td>
<td>4.4</td>
</tr>
<tr>
<td>B^0 → K^+ π^-</td>
<td>17.4</td>
</tr>
<tr>
<td>B^0_s → π^+ K^-</td>
<td>4.4</td>
</tr>
<tr>
<td>B^0_s → K^+ K^-</td>
<td>17.4</td>
</tr>
<tr>
<td>Λ_b → π^- p</td>
<td>4.4</td>
</tr>
<tr>
<td>Λ_b → K^- p</td>
<td>17.4</td>
</tr>
</tbody>
</table>

B^0 → π^+ π^- mass spectrum
B^0 → K^+ π^- mass spectrum
B^0_s → K^+ K^- mass spectrum

92% purity
96% purity
98% purity

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**Event Reconstruction and Event Yield**

\[ B^0_s \rightarrow D_s^- \pi^+, D_s^- K^+ \]

- \( B^0_s \rightarrow D_s^\mp \pi^+ \) is a physics background for \( B^0_s \rightarrow D_s^+ K^- \) selection
  - \( \text{BR}(B^0_s \rightarrow D_s^+ K^-)/\text{BR}(B^0_s \rightarrow D_s^- \pi^+) \sim 1/12 \)
  - \( \varepsilon(B^0_s \rightarrow D_s^- K^+)/\varepsilon(B^0_s \rightarrow D_s^- \pi^+) \sim 70 \)
    with present selection cuts (RICH PID)

\[ \sigma_{\text{core}} = 42 \pm 5 \text{ fs} \]
Event Reconstruction and Event Yield

Vertex resolutions ($B^0_s \rightarrow D_s^- \pi^+$)

(dominate proper time measurement)

$\sigma_{\text{core}} = 418 \pm 31 \, \mu m$

$\sigma_{\text{core}} = 168 \pm 15 \, \mu m$
Event Reconstruction and Event Yield

Mass resolutions ($B^0_s \rightarrow D_s^- \pi^+$)

$\sigma_1 = 3.4 \pm 0.6$ MeV (34%)
$\sigma_2 = 8.1 \pm 0.5$ MeV (66%)

$\sigma_{\text{core}} = 12.7 \pm 0.6$ MeV
Event Reconstruction and Event Yield

\[ B^0_s \rightarrow J/\psi \, \phi \]

- Both \( J/\psi \rightarrow \mu^+\mu^- \) and \( e^+e^- \) decays

For \( e^+e^- \) channel, recover Bremsstrahlung in material before magnet

**J/\psi \rightarrow \mu^+\mu^- \text{ after Bs selection}**

**J/\psi \rightarrow e^+e^- \text{ after Bs selection}**

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Event Reconstruction and Event Yield

\[ B^0 \rightarrow K^{*0} \gamma \]

- Specific background from \( B^0 \rightarrow K^{*0} \pi^0 \) can be rejected (different \( K^{*0} \) helicity)
- Mass resolution \( \sim 80 \text{ MeV}/c^2 \)
# Event Reconstruction and Event Yield

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^0 \rightarrow \pi^+ \pi^-$</td>
<td>27 k</td>
</tr>
<tr>
<td>$B^0 \rightarrow K^+ \pi^-$</td>
<td>115 k</td>
</tr>
<tr>
<td>$B^0_s \rightarrow K^+ K^-$</td>
<td>35 k</td>
</tr>
<tr>
<td>$B^0_s \rightarrow D^- \pi^+$</td>
<td>72 k</td>
</tr>
<tr>
<td>$B^0_s \rightarrow D_{s}^{-} K^{+-}$</td>
<td>8 k</td>
</tr>
<tr>
<td>$B^0_s \rightarrow J/\psi(\mu^+ \mu^-) \phi$</td>
<td>109 k</td>
</tr>
<tr>
<td>$B^0_s \rightarrow J/\psi(e^+ e^-) \phi$</td>
<td>19 k</td>
</tr>
<tr>
<td>$B^0 \rightarrow J/\psi(\mu^+ \mu^-) K^0_s$</td>
<td>119 k</td>
</tr>
<tr>
<td>$B^0 \rightarrow K^{*0} \gamma$</td>
<td>20 k</td>
</tr>
</tbody>
</table>

NB: expect ~1k $B^0 \rightarrow \pi^+ \pi^-$ from 500 fb$^{-1}$ at a B factory.

Large event yields

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Some examples of the LHCb potential

$\beta$ from $B^0 \rightarrow J/\psi K_S$

- Huge statistics (especially ATLAS & CMS)
- Can also fit for $A_{\text{dir}}$ (expected $\approx 0$ in SM)
  \[ A_{\text{CP}}(t) = A_{\text{dir}} \cos(\Delta m_d t) - \sin(2\beta) \sin(\Delta m_d t) \]
- LHCb & BTeV: compare with Penguin decay $B^0 \rightarrow \phi K_S$

Reach in $10^7$ s

<table>
<thead>
<tr>
<th></th>
<th>$\sigma(\sin(2\beta))$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATLAS</td>
<td>0.017</td>
</tr>
<tr>
<td>CMS</td>
<td>0.015</td>
</tr>
<tr>
<td>LHCb</td>
<td>&lt;0.021</td>
</tr>
<tr>
<td>BTeV</td>
<td>0.025</td>
</tr>
</tbody>
</table>

BaBar/Belle(2007) 0.02
Some examples of the LHCb potential

B_s mixing phase from B_s \rightarrow J/\psi \phi, J/\psi \eta

- Strange counterpart of B^0 \rightarrow J/\psi K_S
- SM prediction of B_s mixing phase is small \( \phi_s = 2\delta\gamma = 2\lambda^2\eta = \mathcal{O}(10^{-2}) \)
- Sensitive probe for new physics
- \( J/\psi \phi \) is not pure CP final state
  - can reach \( \sigma(\phi_s) \approx 0.02 \) in 1 year, under assumptions on the strong phases
  - need angular analysis for clean extraction
- \( J/\psi \eta^{(')} \) is pure CP=-1
  - need photon detection
  - BTeV: \( \sigma(\phi_s) = 0.033 \) in 1 year

<table>
<thead>
<tr>
<th>Signal (untagged)</th>
<th>Backgr.</th>
<th>Break</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHCb (5 years)</td>
<td>420 k eVts</td>
<td>3 %</td>
</tr>
<tr>
<td>ATLAS (3 years)</td>
<td>300 k eVts</td>
<td>15 %</td>
</tr>
<tr>
<td>CMS (3 years)</td>
<td>600 k eVts</td>
<td>10 %</td>
</tr>
</tbody>
</table>

NP-LR: left-right symmetric model with spontaneous CP viol.
NP-DQ: iso-singlet down quark mixing model

SM (95% CL)

3σ discovery lines

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Some examples of the LHCb potential

\[ B^0 \rightarrow \pi^+ \pi^- \text{ asymmetry, etc ...} \]

\[ A_{CP}(t) = A_{dir} \cos(\Delta m_d t) + A_{mix} \sin(\Delta m_d t) \]

- \( A_{dir} \) and \( A_{mix} \) can be measured
  - e.g. \( \pm 0.05 \) with 1 year at LHCb
  but Penguin “pollution” hampers \( \alpha \) extraction

- Study of \( B^0 \rightarrow (\rho^+\pi^-, \rho^-\pi^+, \rho^0\pi^0) \rightarrow \pi^+ \pi^- \pi^0 \)
  (time-dependent analysis of Dalitz plot)
  to extract \( \alpha \), Penguin and tree terms
  - BTeV/LHCb claim \( 10.8 > 3.3k \) untagged per year
  - more study needed to quote \( \sigma(\alpha) \) (5–10° ?)

- Measure \( A_{dir} \) and \( A_{mix} \) for \( B_s \rightarrow K^+K^- \)
  e.g. \( \pm 0.07 \) with 1 year at LHCb (if \( \Delta m_s = 20 \text{ ps}^{-1} \))
  and combine with \( B^0 \rightarrow \pi^+\pi^- \) results
  to extract \( \gamma \) assuming U-spin symmetry
  - LHC claim \( \sigma(\gamma) \sim 5^\circ \) after 1 year

\begin{tabular}{|l|c|c|c|}
\hline
 & Tagged & Untagged & S/B \\
\hline
ATLAS & 2.3k & 0.17 & \\
CMS & 0.9k & 1.2 & \\
LHCb & 11k & 27k & >1 \\
BTeV & 23.8k & 3 & \\
\hline
\end{tabular}
Some examples of the LHCb potential

\[ \gamma \text{ from } B^0 \rightarrow D^*\pi^+ , D^*\pi^- \]

- Small interference between two tree decays, with and without prior \(B^0\) mixing
- Extract \(\gamma+2\beta\) and \(\Delta^{\text{strong}}\) simultaneously from the two time-dependent asymmetries
- Use \(2\beta\) from \(J/\psi\) \(K_S\) to obtain value of \(\gamma\) insensitive to possible new physics in mixing

- LHCb study:
  use both exclusive and inclusive reconstruction of neutral \(D\) from \(D^*\)

<table>
<thead>
<tr>
<th>Process</th>
<th>Annual yield (untagged)</th>
<th>#/B</th>
<th>(\sigma(m_B))</th>
<th>(\sigma(t_B))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(B' D^*(D(K\pi)\pi)\pi)</td>
<td>183 k</td>
<td>5.6</td>
<td>13.6</td>
<td>60</td>
</tr>
<tr>
<td>(B' D^*(D(\text{incl})\pi)\pi)</td>
<td>1150 k</td>
<td>4.4</td>
<td>220</td>
<td>170</td>
</tr>
</tbody>
</table>

\[ \sigma(\gamma) = O(10^\circ) \] (1 year)

depends on \(2\beta+\gamma\) and \(\Delta^{\text{strong}}\)

\[ V_{cb}V_{ud} \propto \lambda^2 \]

\[ V_{ub}V_{cd} \propto \lambda^4 e^{i\gamma} \]

assumed amplitude ratio \(|\eta| = 0.02\)

\[ \Delta^{\text{strong}} = 0 \]

\[ 10\% \text{ error on } |\eta| \]

\[ \text{no error on } |\eta| \]

\[ 1 \text{ year} \]

\[ 5 \text{ years} \]
Some examples of the LHCb potential

\[ \gamma \text{ from } B_s \rightarrow D_s^- K^+, D_s^+ K^- \]

- Strange counterpart of \( B^0 \rightarrow D^{*+} \pi^-, D^{*+} \pi^- \)
- Here measure \( \gamma - 2 \delta \gamma \), and take \( 2 \delta \gamma \) from \( J/\psi \phi \)
- Important differences:
  - Asymmetry larger because two tree amplitudes of similar order \( (\propto \lambda^3) \)
  - Proper time resolution more important
  - Background from Cabibbo-allowed \( D_s^- \pi^+ \)

<table>
<thead>
<tr>
<th>LHCb</th>
<th>8 k</th>
<th>&gt; 1</th>
<th>13</th>
<th>43</th>
</tr>
</thead>
<tbody>
<tr>
<td>B TeV</td>
<td>9.7 k</td>
<td>7</td>
<td>17</td>
<td>43</td>
</tr>
</tbody>
</table>

Sensitivity on \( \gamma \) depends on:
- amplitude ratio
- strong phase difference
- \( \gamma \)
- \( \Delta m_s \)

For \( \Delta m_s = 20 \text{ ps}^{-1} \):

\[ \sigma(\gamma) = O(10^\circ) \]

(1 year, each expt)
Some examples of the LHCb potential

\[ \frac{|V_{td}|}{|V_{ts}|} \text{ from } B \rightarrow \mu^+\mu^-X_{s,d} \]

- \( B \rightarrow \mu^+\mu^-X_{s,d} \) involve loop & box with \( V_{td}, V_{ts} \)
- Ratio of inclusive rates with “non-resonant” dimuon mass allows extraction of \( \frac{|V_{td}|}{|V_{ts}|} \) with small theoretical error of \( \mathcal{O}(1\%) \)

\[ \Rightarrow \text{Relative error on } \frac{|V_{td}|}{|V_{ts}|} \text{ of } \sim 11\% \]
\[ \Rightarrow \text{Error on } A_{fb} \sim 3\% \quad (B \rightarrow \mu^+\mu^-K^*)\]
Outlook and Conclusions

**CP asymmetries in**

\[ B_d \rightarrow J/\psi \ K_S \] (140k /10^7 sec)
\[ \sigma_{\sin 2\beta} = 0.02 /10^7 \text{ sec} \]

\[ B_s \rightarrow J/\psi \ \phi \] (130k /10^7 sec) + **excellent** \( \sigma_t \)
\[ \sigma_{2\delta\phi} = 0.04 - 0.06 /10^7 \text{ sec} \ (x_s = 20 - 40) \]

**B_s oscillations:** **hadron trigger, excellent** \( \sigma_t \)

\[ B_s \rightarrow D_s \ \pi \] measurable up to \( x_s \approx 80 \ (54 \text{ ps}^{-1}) \) with 5\( \sigma \)

**CP violation in radiative decays**

\[ B \rightarrow X_{s,d} \ \mu^+\mu^- \] relative error on \( |V_{td}|/|V_{ts}| \) of \( \sim 11\% \)

\[ B_d \rightarrow K^*0 \ \mu^+\mu^- \] \( s = 4.5k / 10^7 \text{ sec} \ (Br=1.5\times10^{-6}), \ s/b = 16 \)
error on forward-backward asymmetry \( \approx 0.03/10^7 \text{ sec} \)

\[ B_d \rightarrow K^*0 \gamma \] \( s = 20k / 10^7 \text{ sec} \ (Br=4.9\times10^{-5}), \ s/b = 1 \)
error on CP asymmetry \( \approx 0.01/10^7 \text{ sec} \)
## Outlook and Conclusions

### CP asymmetries in

<table>
<thead>
<tr>
<th>Process</th>
<th>Hadron Trigger</th>
<th>Time</th>
<th>Particle ID, Hadron Trigger, Excellent $\sigma_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_d \rightarrow D^{*\pm} \pi^\mp$</td>
<td>hadron trigger</td>
<td>650 k /10^7 sec</td>
<td>$\sigma_\gamma \approx 10^\circ$</td>
</tr>
<tr>
<td>$B_s \rightarrow D_s^{\mp} K^\pm$</td>
<td>particle ID, hadron trigger, excellent $\sigma_t$</td>
<td>8 k /10^7 sec</td>
<td>$\sigma_\gamma \approx 10^\circ$</td>
</tr>
</tbody>
</table>

### Time dependent Dalitz plot study: hadron trigger

<table>
<thead>
<tr>
<th>Process</th>
<th>Hadron Trigger</th>
<th>Time</th>
<th>Particle ID, Hadron Trigger, Excellent $\sigma_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_s \rightarrow \pi^+\pi^-\pi^0$</td>
<td>hadron trigger</td>
<td>$\sigma_{\beta+\gamma} \approx 5^\circ$ to $10^\circ$/10^7 sec</td>
<td></td>
</tr>
</tbody>
</table>

### CP asymmetries in

<table>
<thead>
<tr>
<th>Process</th>
<th>Hadron Trigger</th>
<th>Time</th>
<th>Particle ID, Hadron Trigger, Excellent $\sigma_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_d \rightarrow \pi^+\pi^-$</td>
<td>particle ID, hadron trigger</td>
<td>27 k /10^7 sec</td>
<td></td>
</tr>
<tr>
<td>and $B_s \rightarrow K^+ K^-$</td>
<td>particle ID, hadron trigger, excellent $\sigma_t$</td>
<td>35 k /10^7 sec</td>
<td>$\sigma_\gamma \approx 5^\circ$/10^7 sec for $\Delta m_s = 20$ ps$^{-1}$</td>
</tr>
</tbody>
</table>

### Rare decays

<table>
<thead>
<tr>
<th>Process</th>
<th>Time</th>
<th>Br = 3.5×10^{-9}, s/b = 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_s \rightarrow \mu^+\mu^-$</td>
<td>$s = 10$ /10^7 sec</td>
<td></td>
</tr>
</tbody>
</table>

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24-28 February 2003

Frederic Teubert
Outlook and Conclusions

Unique property of LHC
Large yield for different b hadrons \((10^{12}/10^7\) sec) +

Unique properties of LHCb

**Trigger:** high \(P_T\) lepton or hadron + large impact parameter
Sensitive to final states: lepton only & leptons+hadrons & hadrons only

**RICH system:** clean K/p separation over wide range of p
Kaon tag (enhancing the importance of the hadron trigger),
Clean reconstruction of hadronic final states

**Vertex detector:** excellent decay time resolution
High CP and B-meson oscillation sensitivities for the \(B_s\) system

= Unique opportunity to search for new physics
through CP violation and rare decays in B-meson decays!!