LHCb Upgrade Plans

Franz Muheim
University of Edinburgh
on behalf of the LHCb collaboration

Standard Model and New Physics Sensitivity
LHCb Experiment
- Physics Programme the first 5 years
- Running LHCb at 10 times design luminosity

Physics Reach with a 100 fb\(^{-1}\) data sample
- CP violation in \(B_s\) decays
- Probe New Physics in hadronic
- and electroweak penguin decays
- CKM angle \(\gamma\)

LHCb Upgrade Detector and Trigger Plans
- LHCb Upgrade Detector
- Vertex detector studies
- Trigger and Read-out studies

Conclusions

Flavour in the LHC era
CERN Oct 9\(^{th}\) 2006
**Status of CKM Unitarity Triangles**

- **ICHEP2006 Status**
  - including CDF $\Delta m_s$ measurement

- **Tree diagrams**
  - Not sensitive to New Physics

- **Probe New Physics**
  - by comparing to SM predictions including loops
  - by measuring $\gamma$ in loop diagrams
  - same for $\alpha, \beta$ and $\chi$

- Standard Model is a very successful theory
- We are very likely beyond the era of «alternatives» to the CKM picture. NP would appear as «corrections» to the CKM picture

---

Flavour in the LHC era
CERN, 9 Oct 2006

F. Muheim
Probing New Physics in $B_s$ Mesons

- **Flavour Changing Neutral Currents**
  - NP appears as virtual particles in loop processes
  - leading to observable deviations from SM expectations in flavour physics and CP violation
  - New Physics parameterisation in $B_s$ Oscillations

\[
\Delta n_q = |1 + h_q e^{2i\sigma_q}| \Delta n_q^{SM}
\]

- $B_s \rightarrow \phi\phi$ penguin decay
- $B_s$-$B_s$ oscillations

- **If New Physics is found at LHC**
  - Probe NP flavour structure with FCNC

\[
\begin{align*}
B_s^0 \rightarrow B_s^0 \\
\bar{B}_s^0 \rightarrow \bar{B}_s^0
\end{align*}
\]
### LHCb Sensitivities with 2 fb⁻¹

<table>
<thead>
<tr>
<th>Channel</th>
<th>Yield</th>
<th>B/S</th>
<th>Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>γ</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B_s \to D_s^{+}K^-$</td>
<td>5.4k</td>
<td>&lt; 1.0</td>
<td>$\sigma(\gamma) \sim 14^\circ$</td>
</tr>
<tr>
<td>$B_d \to \pi^+\pi^-$</td>
<td>36k</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>$B_s \to K^+K^-$</td>
<td>36k</td>
<td>&lt; 0.06</td>
<td></td>
</tr>
<tr>
<td>$B_d \to D^0(K\pi,KK)K^{*0}$</td>
<td>3.4k, 0.5k, 0.6k</td>
<td>&lt; 0.3, &lt; 1.7, &lt; 1.4</td>
<td>$\sigma(\gamma) \sim 7^\circ - 10^\circ$</td>
</tr>
<tr>
<td>$B^- \to D^0(K^-\pi^+,K^+\pi^-)K^-$</td>
<td>28k, 0.5k</td>
<td>0.6, 1.5</td>
<td>$\sigma(\gamma) \sim 5^\circ - 15^\circ$</td>
</tr>
<tr>
<td>$B^- \to D^0(K^+K^-,\pi^+\pi^-)K^-$</td>
<td>4.3k</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>$B^- \to D^0(K_S\pi^+\pi^-)K^-$</td>
<td>1.5 - 5k</td>
<td>&lt; 0.7</td>
<td>$\sigma(\gamma) \sim 8^\circ - 16^\circ$</td>
</tr>
<tr>
<td><strong>β</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B_d \to J/\psi(\mu\mu)K_S$</td>
<td>216k</td>
<td>0.8</td>
<td>$\sigma(\sin2\beta) \sim 0.022$</td>
</tr>
<tr>
<td>$B_s \to D_s^-\pi^+$</td>
<td>120k</td>
<td>0.4</td>
<td>$\sigma(\Delta m_s) \sim 0.01$ ps⁻¹</td>
</tr>
<tr>
<td>$\phi_s$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B_s \to J/\psi(\mu\mu)\phi$</td>
<td>131k</td>
<td>0.12</td>
<td>$\sigma(\phi_s) \sim 0.023$</td>
</tr>
<tr>
<td><strong>Rare decays</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B_s \to \mu^+\mu^-$</td>
<td>17</td>
<td>&lt; 5.7</td>
<td></td>
</tr>
<tr>
<td>$B_d \to K^{*0}\mu^+\mu^-$</td>
<td>4.4k</td>
<td>&lt; 2.6</td>
<td>$\sigma(C_7^{eff}/C_9^{eff}) \sim 0.13$</td>
</tr>
<tr>
<td>$B_d \to K^{*0}\gamma$</td>
<td>35k</td>
<td>&lt; 0.7</td>
<td>$\sigma(A_{CP}) \sim 0.01$</td>
</tr>
<tr>
<td>$B_s \to \phi\gamma$</td>
<td>9.3k</td>
<td>&lt; 2.4</td>
<td></td>
</tr>
<tr>
<td><strong>charm</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$D^{**} \to D^0(K^-\pi^+)^+\pi^-$</td>
<td>100 M</td>
<td></td>
<td>$\sigma(\Delta m_s) \sim 0.01$ ps⁻¹</td>
</tr>
</tbody>
</table>
**LHCb Operations**
- Luminosity tuneable by adjusting beam focus
- Design is to run at \( \mathcal{L} \sim 2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1} \)
- Design is to run at \( \mathcal{L} \sim 5 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1} \)
- little pile-up \( n = 0.5 \)
- less radiation damage
- Luminosity will be achieved during 1st physics run

**LHCb Physics Goals**
- Run five (nominal) years at \( \mathcal{L} \sim 2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1} \) and collect 6 to 10 fb\(^{-1}\)
- Exploit the \( B_s \) system
- Observation of CP violation in \( B_s \) mesons
- Precision measurements of \( B_s \) mass and lifetime difference
- Reduce error on CKM angle \( \gamma \) by a factor 5
- Probe New Physics in rare B meson decays with electroweak, radiative and hadronic penguin modes
- First observation of very rare decay \( B_s \to \mu^+\mu^- \)
Physics Case for LHCb at High Luminosity

What’s next?
- Many LHCb results will be statistically limited
- New Physics effects are small → require better precision measurements
- LHCb is only B-physics experiment approved for running after 2010
- Can LHCb exploit the full potential of B physics at hadron colliders?

LHCb Luminosity
- Running at $\mathcal{L} \sim 2 \times 10^{32}$ cm$^{-2}$s$^{-1}$ is a LHCb design choice
- LHC design luminosity is 50 times higher $\mathcal{L} \sim 10^{34}$ cm$^{-2}$s$^{-1}$

LHCb Upgrade Plans
- Upgrade LHCb detector such that it can operate at 10 times design luminosity of $\mathcal{L} \sim 2 \times 10^{33}$ cm$^{-2}$s$^{-1}$
- Run ~5 yrs at $\mathcal{L} \sim 2 \times 10^{33}$ cm$^{-2}$s$^{-1}$
- Collect ~100 fb$^{-1}$ data sample
- Multiple interactions per beam crossing increases to $n \sim 4$
- Is compatible with possible LHC luminosity upgrade (SLHC)
- Does not require SLHC
- Could be implemented ~2013
CP Violation in $B_s$ mesons
- Interference in $B_s$ mixing and decay
- $B_s$ weak mixing phase $\phi_s$ is very small in SM
  $\phi_s = -\arg(V_{ts}^2) = -2\chi \approx -2\lambda^2 \eta \approx -0.035$
  - $\Rightarrow$ sensitive probe for New Physics
    e.g. stringent NMFV test
  - NP parameterisation
    \[ \Delta m_q = |1 + h_q e^{2i\phi_s}| \Delta m_q^{SM} \]
  - Angular analysis to separate $J/\psi\phi$
    2 CP-even and 1 CP-odd amplitudes

$\phi_s$ Sensitivity
- at $\Delta m_s = 20$ ps$^{-1}$
- Expect 131k $B_s \rightarrow J/\psi\phi$ signal events per 2 fb$^{-1}$ (1 year)
- Expected precision
  $\sigma(\sin \phi_s) \sim 0.023$
- Small improvement in $\phi_s$ precision by adding pure CP modes
\( \phi_s \) from \( B_s \rightarrow J/\psi \phi \)

- \( \phi_s \) will be the ultimate SM test
  - For CP in B mesons
  - Similar to \( \epsilon' \) in kaons for direct CP violation
- \( \phi_s \) Sensitivity
  - LHCb for 10 fb\(^{-1}\) (first 5 years)
  - \( \sim 3 \sigma \) SM evidence for \( \phi_s \approx -0.035 \)
  - \( \phi_s \) precision statistically limited
  - Theoretically clean
- Historical Aside
  - 1988 NA31 measures \( \sim 3 \sigma \) from zero \( \epsilon'/\epsilon = (3.3\pm1.1) \times 10^{-3} \)
  - Community approves NA48 & KTEV
- LHCb Upgrade Sensitivities
  - Based on 100 fb\(^{-1}\) data sample
  - Preliminary estimates by scaling with luminosity
  - Potential trigger efficiency improvements not included
- \( B_s \rightarrow J/\psi \phi \) - Key channel for LHCb Upgrade
  - \( \phi_s \) Sensitivity with 100 fb\(^{-1}\) data sample
  - \( \sim 10 \sigma \) SM measurement with 100 fb\(^{-1}\) \( \sigma(\sin \phi_s) \sim 0.003 \)
**Flavour in the LHC era**

**CERN, 9 Oct 2006**

- **Compare sin2β measurements**
  - in $B_d \rightarrow \phi K_S$ with $B_d \rightarrow J/\psi K_S$
  - Individually, each decay mode in reasonable agreement with SM
  - But all measurements lower than sin2β from Naïve $b \rightarrow s$ penguin average
    - $\sin^2 \beta_{\text{eff}} = 0.52 \pm 0.05$
    - $2.6 \sigma$ discrepancy from SM

- **Theory models**
  - Predict to increase sin2β eff in SM

---

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>World Average</th>
<th>BaBar</th>
<th>Belle</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^\pm \rightarrow \phi K^\pm$</td>
<td>$0.68 \pm 0.03$</td>
<td>$0.12 \pm 0.11 \pm 0.10$</td>
<td>$0.50 \pm 0.21 \pm 0.06$</td>
<td>$0.39 \pm 0.18$</td>
</tr>
<tr>
<td>$B^\pm \rightarrow \eta, \eta'$ $K^\pm$</td>
<td>$0.55 \pm 0.11 \pm 0.02$</td>
<td>$0.55 \pm 0.11 \pm 0.02$</td>
<td>$0.64 \pm 0.10 \pm 0.04$</td>
<td>$0.59 \pm 0.08$</td>
</tr>
<tr>
<td>$B^\pm \rightarrow \omega, \phi, \chi^\pm$ $K^\pm$</td>
<td>$0.66 \pm 0.28 \pm 0.08$</td>
<td>$0.66 \pm 0.28 \pm 0.08$</td>
<td>$0.30 \pm 0.32 \pm 0.08$</td>
<td>$0.51 \pm 0.21$</td>
</tr>
<tr>
<td>$B^\pm \rightarrow \pi, \rho, \omega$ $K^\pm$</td>
<td>$0.33 \pm 0.26 \pm 0.04$</td>
<td>$0.33 \pm 0.26 \pm 0.04$</td>
<td>$0.33 \pm 0.35 \pm 0.08$</td>
<td>$0.33 \pm 0.21$</td>
</tr>
<tr>
<td>$B^\pm \rightarrow \pi, \rho$ $K^\pm$</td>
<td>$0.17 \pm 0.52 \pm 0.26$</td>
<td>$0.17 \pm 0.52 \pm 0.26$</td>
<td>$0.17 \pm 0.58$</td>
<td>$0.17 \pm 0.58$</td>
</tr>
<tr>
<td>$B^\pm \rightarrow \omega K^\pm$</td>
<td>$0.62 \pm 0.39 \pm 0.02$</td>
<td>$0.62 \pm 0.39 \pm 0.02$</td>
<td>$0.11 \pm 0.46 \pm 0.07$</td>
<td>$0.48 \pm 0.24$</td>
</tr>
<tr>
<td>$B^\pm \rightarrow \phi K^\pm$</td>
<td>$0.62 \pm 0.23$</td>
<td>$0.62 \pm 0.23$</td>
<td>$0.18 \pm 0.23 \pm 0.11$</td>
<td>$0.42 \pm 0.17$</td>
</tr>
<tr>
<td>$B^\pm \rightarrow \omega K^\pm$</td>
<td>$0.84 \pm 0.71 \pm 0.08$</td>
<td>$0.84 \pm 0.71 \pm 0.08$</td>
<td>$-0.84 \pm 0.71$</td>
<td>$-0.84 \pm 0.71$</td>
</tr>
</tbody>
</table>

---

*Some of recent QCD estimates*  

$\sin^2 \beta_{\text{eff}} = \sin^2 \beta$

- $\phi K_S$  
- $\eta K_S$  
- $\pi K_S$  
- $\omega K_S$  
- $KK K_K$  

**PLB 620 (2005) 143**  
**hep-ph/0506268**

---

*Muheim*
- $b \rightarrow s$ Transitions in $B_s \rightarrow \phi\phi$

- $B_s \rightarrow \phi\phi$ hadronic penguin decay
  - In SM weak mixing phase $\phi_s$ is identical in $B_s \rightarrow \phi\phi$ and $B_s \rightarrow J/\psi\phi$
  - Define $\Delta S(\phi\phi) = \sin \phi_s (\phi\phi) - \sin \phi_s (J/\psi\phi)$
  - Measurement of $\Delta S(\phi\phi) \approx \sin \phi_s (\phi\phi) \neq 0$ is a clear signal for New Physics (NMFV)

- $\Delta S(\phi\phi)$ Sensitivity
  - Best $b \rightarrow s$ penguin mode for LHCb
  - Expect 1.2 k $B_s \rightarrow \phi\phi$ events per 2 fb$^{-1}$
  - Estimate sensitivity by scaling with $B_s \rightarrow J/\psi\phi$
    - $\sigma(\Delta S(\phi\phi)) \sim 0.14$ in 10 fb$^{-1}$

- Key channel for LHCb Upgrade
  - $\Delta S(\phi\phi)$ precision statistically limited
  - With 100 fb$^{-1}$ estimate precision $\sigma(\Delta S(\phi\phi)) \sim 0.04$ exciting NP probe
  - Requires 1st level detached vertex trigger for hadronic decay
  - Expect similar precision for $\Delta S(\phi K_s)$ in decay $B_d \rightarrow \phi K_s$

Flavour in the LHC era
CERN, 9 Oct 2006
F. Muheim 10
**LHCb goals for measuring CKM angle $\gamma$**
- $B^0 \to D^0 K^{*0}$, $B^\pm \to D^0 K^\pm$
  Two interfering tree processes in neutral or charged B decay
- Use decays common to $D^0$ and anti-$D^0$
  Cabbibo favoured self-conjugate $D$ decays
  e.g. $D^0 \to K_S \pi \pi$, $K_S K K$, $K K \pi \pi$ Dalitz analysis
  Cabbibo favoured, single & doubly Cabbibo suppressed $D$ decays
  e.g. $D^0 \to K \pi$, $K K$, $K \pi \pi \pi$ ADS (GLW) method
- $B_s \to D_s^{\mp} K^\pm$ - two tree decays ($b \to c$ and $b \to u$) of $O(\lambda^3)$
  Interference via $B_s$ mixing

**$\gamma$ Sensitivity**
- Expected precision for ADS and Dalitz $\sigma(\gamma) \sim 5^\circ$ - $15^\circ$ in 2 fb$^{-1}$

**Motivation for LHCb Upgrade**
- Theoretical error in SM is very small $< 1^\circ$
- Large statistics helps to reduce systematic error to similar level
- With 100 fb$^{-1}$ estimate precision $\sigma(\gamma) \sim 1^\circ$
- Requires 1st level detached vertex trigger for hadronic decays
Asymmetry $A_{FB}$ in $B_d \rightarrow K^*0 \mu^+ \mu^-$

- **Forward-backward asymmetry** $A_{FB}(s)$
  - Asymmetry angle - $B$ flight direction wrt $\mu^+$ direction in $\mu^+\mu^-$ rest-frame

- **Expected Signal Yield**
  - 4.4 k events per 2 fb$^{-1}$
  - Large statistics allows to measure additional transversity amplitudes
  - Sensitive to right-handed currents

- **$A_{FB}$ zero point sensitivity**
  - $s_0 = 4.0 \pm 0.5$ GeV$^2$ in 10 fb$^{-1}$

- **LHCb Upgrade Sensitivity**
  - $s_0 = 4.00 \pm 0.16$ GeV$^2$ in 100 fb$^{-1}$
  - 4% error on $C_7^{\text{eff}}/C_9^{\text{eff}}$

- **Sensitive probe of New Physics**
  - Deviations from SM by SUSY, graviton exchanges, extra dimensions
  - $A_{FB}(s_0) = 0$ - predicted at LO without hadronic uncertainties
  - Zero point $s_0$ and integral at high $s$ sensitive to Wilson coefficients

---

hep-ph/0003238
PRD61, 074024 (2000)
More Physics with 100 fb$^{-1}$

- What are key measurements?
  - Selection of four discussed above
  - Importance of different decays could change again with additional data from LHC, Tevatron and B-factories

- LHCb measurements
  - Many more are statistics limited
  - can be improved with LHCb Upgrade
  - many of these are very sensitive to New Physics

- Additional LHCb Upgrade measurements
  - Semileptonic charge asymmetry $A_{SL}$
  - Very rare decays
    - e.g. observation of $B_d \rightarrow \mu^+\mu^-$ and precision measurement of $B_s \rightarrow \mu^+\mu^-$
  - Electroweak and radiative penguin decays
    - e.g. $\Lambda_b \rightarrow \Lambda \mu^+\mu^-$
  - Other hadronic penguin decays
    - e.g. $B_d \rightarrow \phi K_S$, $B_d \rightarrow \eta' K_S$
  - CP violation and mixing in charm meson decays
  - Lepton flavour violation in B, charm and tau decays
    - e.g. $B^0 \rightarrow \mu^+\mu^-$, $D^0 \rightarrow \mu^+e^-$, $\tau^+ \rightarrow \mu^+\gamma$, $\tau^+ \rightarrow \mu^+\mu^+\mu^-$
Comparison with Super-B factory

Sensitivity Comparison ~2020
LHCb 100 fb\(^{-1}\) vs Super-B factory 50 ab\(^{-1}\)

SuperB numbers from M Hazumi - Flavour in LHC era workshop

Flavour in the LHC era
F. Muheim
CERN, 9 Oct 2006
LHCb Performance vs Luminosity

- **LHCb Luminosity**
  - Running at $\mathcal{L} \sim 2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$ is default
  - Make use of learning experience in running LHCb
  - Will operate at luminosity up to $\mathcal{L} \sim 5 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$

- **LHCb Detectors**
  - Detectors able to cope with $\mathcal{L} \sim 5 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$
  - Vertex detector sensors require replacing after 6 – 8 fb$^{-1}$ (~3 years)
  - Default replacement - same geometry, similar slightly improved sensors

- **Level-0 Trigger – L0**
  - High $p_T$ - $\mu$, $\mu\mu$, $e$, $\gamma$, hadron + pileup
  - Read-out at 40 MHz 4 $\mu$s latency
  - Existing Front-End electronics limits L0 Trigger output to 1.1 MHz
LHCb L0 Trigger

L0 efficiency

- **L0 muon trigger**
  - ~90% efficiency
  - scales with luminosity

- **L0 hadron trigger**
  - ~40% efficient
  - does not scale with luminosity
  - Required for $B_s \to \phi \phi$ and $B^\pm \to D^0 K^\pm$

Event Yield

- $B^0 \to \pi^+ \pi^-$
- $B_s \to \phi \gamma$
- $B_s \to J/\psi \phi$
- $B_s \to D_s K^-$

Luminosity

Event Yield vs. Luminosity

Flavour in the LHC era
CERN, 9 Oct 2006

F. Muheim
LHCb Upgrade Plans

- The Big Question
  - How do we upgrade LHCb detector such that it can operate at 10 times design luminosity of $\mathcal{L} \sim 2 \times 10^{33}$ cm$^{-2}$s$^{-1}$?
  - Physics, Detector and Trigger studies have started
  - Several approaches under investigation

- Vertex Detector
  - VELO sensors require replacing with radiation-hard sensors

- L0 Detached Vertex Trigger
  - Add Vertex Detector (VELO) and Trigger Tracker (TT) to L0 Trigger
  - Requires 40 MHz readout of VELO and TT
  - Implementation in FPGAs
  - Is Magnetic field in VELO region required?

- Other LHCb Detectors
  - need upgrade due to occupancy and/or irradiation
  - Replace inner most region of RICH photo detectors
  - Replace inner most region of ECAL with crystal calorimeter
  - Possibly add other sub-detectors to 40 MHz readout
Readout full detector at 40 MHz
- Requires new readout architecture
- All trigger decisions in CPU farm
- All Front-end electronics must be redesigned
- Increased radiation hardness required
- Electronics R&D can profit from common LHC development

Detectors for 40 MHz Readout
- VELO sensors require replacing with radiation-hard sensors
- Silicon tracker sensors (TT and IT) need to be replaced
- Outer tracker occupancy likely prohibitive
  Increase (decrease) area of Inner/Outer Tracker
- RICH photo detectors need to be replaced

Additional Considerations
- for running LHCb at $\mathcal{L} \sim 2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$
- Costs expected to compare favourably with existing infrastructure and complementary approaches
Vertex Detector Upgrade

- Critical for LHCb upgrade physics programme

Radiation Hard Vertex Detector
with
Displaced Vertex Trigger

VESPA
VElo Superior Performance Apparatus
Radiation Hard Vertex Detector

- Vertex Detector for LHCb Upgrade
  - requires high radiation tolerance device
    \( >10^{15} 1 \text{ MeV neutron}_{eq}/\text{cm}^2 \)
- Geometry - Strixels / Pixels
  - remove RF foil
    3% \( X_0 \) before 1\( \text{st} \) measurement
  - move closer to beam from 8 → 5mm

Strixels

Interaction region \( \sigma = 5.3 \text{ cm} \)

 VELO Module

Pixel Stations

Flavour in the LHC era
CERN, 9 Oct 2006

F. Muheim
Radiation Hard Technologies

- Active Technology R&D for LHC upgrades
- Applicable to strixels & pixels

Czochralski

3D

Extreme radiation hard
For $4.5 \times 10^{14}$ 24 GeV p/cm$^2$
Depletion voltage = 19V

F. Muheim
• **Method**
  - Combine L0 with detached vertex trigger
    L0 - hadron $E_T > 3$ GeV
    track with largest $p_T > 2$ GeV
    impact parameter $|IP| > 50$ um
  - Run L1 trigger algorithm at L0

• **Preliminary results**
  - $B_s \rightarrow D_s^{\mp} K^\pm$ at $L = 6 \times 10^{32}$
  - For L0+vxt Min. bias efficiency does not depend strongly on # of interactions $n_r$.
  - L0 - hadron rate: $r = 0.8$ MHz
    $B_s \rightarrow D_s^{\mp} K^\pm$ efficiency $\epsilon = 66$
  - Better efficiency than L0 trigger at $L = 2 \times 10^{32}$ (baseline)
    $r = 0.7$ MHz $\quad \epsilon = 39$
  - Yield $B_s \rightarrow D_s^{\mp} K^\pm$ is 5 times baseline
  - Yield scales linearly with luminosity
Conclusions

- **Standard Model is very successful**
  - Require precision measurements to probe/establish flavour structure of New Physics
- **Many LHCb results will be statistically limited**
  - LHCb plans to run initially for five years at $\mathcal{L} \sim 2 \times 10^{32}$ cm$^{-2}$s$^{-1}$
  - 6 - 10 fb$^{-1}$ data set will not reach full potential of B physics at hadron colliders
- **LHCb Upgrade Plans**
  - Replace VELO with radiation hard vertex detector
  - Add first level detached vertex trigger to LHCb experiment to trigger efficiently on hadronic modes at high luminosities
  - Readout of all LHCb detectors at 40 MHz
  - Requires new front-end electronics, silicon sensors, RICH photo detectors
  - Run five years at $\mathcal{L} \sim 2 \times 10^{33}$ cm$^{-2}$s$^{-1}$ and collect 100 fb$^{-1}$ data sample
- **LHCb Physics reach with 100 fb$^{-1}$**
  - Perform $\sim 10\sigma$ measurement of SM weak $B_s$ mixing phase $\phi_s = -0.035$ in $B_s \rightarrow J/\psi\phi$
  - Probe or establish New Physics by measuring $\phi_s$ in hadronic penguin decay $B_s \rightarrow \phi\phi$ with a precision of $\sigma(\Delta S(\phi\phi)) = 0.040$
  - Measure CKM angle $\gamma$ to a precision of $\sigma(\gamma) \sim 1^\circ$
  - Probe New Physics in rare B meson decays
    - Measure Wilson coefficient $C_7/C_9$ to 4% in electroweak decay $B \rightarrow K^0\mu^+\mu^-$
  - Measure $B_d \rightarrow \mu^+\mu^-$
LHCb Physics Programme

\( B^0_d \rightarrow \pi^0 \pi^+ \pi^- \)

\( \sim V_{ub}^* \sim V_{td} \)

\( \sim V_{cb} \)

\( B^0_d \rightarrow J/\Psi \ K^0 \)

\( B^0_s \rightarrow D^\pm K^\mp \gamma \rightarrow 2\chi \)

\( B^0_d \rightarrow \pi^+ \pi^- \) and \( B^0_s \rightarrow K^+ K^- \) \( \beta \) and \( \gamma \)

\( B^\pm_d \rightarrow D^0 K^\pm \)

\( B^0_d \rightarrow D^0 K^{*0} \)

\( B^0_s \rightarrow J/\Psi \ \Phi, J/\Psi \ \eta^{(')} \)

Rare decays - very sensitive to NP

- Radiative penguin \ e.g. \( B_d \rightarrow K^* \gamma, B_s \rightarrow \Phi \gamma \)
- Electroweak penguin \ e.g. \( B_d \rightarrow K^{*0} \mu^+ \mu^- \)
- Gluonic penguin \ e.g. \( B_s \rightarrow \Phi \Phi, B_d \rightarrow \Phi K_s \)
- Rare box diagram \ e.g. \( B_s \rightarrow \mu^+ \mu^- \)

B production, \( B_c \), b-baryon physics
Charm decays
Tau Lepton flavour violation

Flavour in the LHC era
CERN, 9 Oct 2006

F. Muheim 26