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 $B_\pm$ 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**

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Status of CKM Unitarity Triangles

ICHEP2006 Status
- including CDF $\Delta m_s$ measurement

Tree diagrams
- Not sensitive to New Physics

- 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

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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

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

$B_s \rightarrow \phi\phi$ penguin decay

$B_s - B_s$ oscillations

$\Delta m_q = |1 + h_q e^{2i\sigma_q}| \Delta m_q^{SM}$
### 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>$B_s \to D_s^{*-} K^-$</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>$\sigma(\gamma) \sim 4^\circ$</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>3.4 k, 0.5 k, 0.6 k</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>4.3 k</td>
<td>1.0</td>
<td>$\sigma(\gamma) \sim 8^\circ - 16^\circ$</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></td>
</tr>
<tr>
<td>$\gamma$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B_d \to \pi^+\pi^-\pi^0$</td>
<td>14k</td>
<td>&lt; 0.8</td>
<td>$\sigma(\alpha) \sim 10^\circ$</td>
</tr>
<tr>
<td>$B \to \rho^+\rho^0, \rho^+\rho^-, \rho^0\rho^0$</td>
<td>9k, 2k, 1k</td>
<td>1, &lt;5, &lt;4</td>
<td></td>
</tr>
<tr>
<td>$\beta$</td>
<td></td>
<td></td>
<td>$\sigma(\sin 2\beta) \sim 0.022$</td>
</tr>
<tr>
<td>$\Delta m_s$</td>
<td>$B_s \to D_s^-\pi^+$</td>
<td>120k</td>
<td>0.4</td>
</tr>
<tr>
<td>$\phi_s$</td>
<td>$B_s \to J/\psi(\mu\mu)\phi$</td>
<td>131k</td>
<td>0.12</td>
</tr>
<tr>
<td>Rare decays</td>
<td>$B_s \to \mu^+\mu^-$</td>
<td>17</td>
<td>&lt; 5.7</td>
</tr>
<tr>
<td>$B_d \to K^{*0}\mu^+\mu^-$</td>
<td>4.4 k</td>
<td>&lt; 2.6</td>
<td>$\sigma(C_7^{\text{eff}}/C_9^{\text{eff}}) \sim 0.13$</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>9.3 k</td>
<td>&lt; 2.4</td>
<td></td>
</tr>
<tr>
<td>charm</td>
<td>$D^{*-} \to D^0 (K^-\pi^+)\pi^+$</td>
<td>100 M</td>
<td></td>
</tr>
</tbody>
</table>
LHCb - The First Five Years

- **LHCb Operations**
  - Luminosity tuneable by adjusting beam focus
  - Design is to run at $\mathcal{L} \sim 2 \times 10^{32}$ cm$^{-2}$s$^{-1}$
  - Design is to run at $\mathcal{L} \sim 2 \times 10^{32}$ cm$^{-2}$s$^{-1}$
  - Detectors up to $5 \times 10^{32}$ cm$^{-2}$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 $\mathcal{L} \sim 2 \times 10^{32}$ cm$^{-2}$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 $B_s \rightarrow \mu^+\mu^-$
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 $\mathcal{L} \sim 2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$ is a LHCb design choice
  - LHC design luminosity is 50 times higher $\mathcal{L} \sim 10^{34} \text{ cm}^{-2}\text{s}^{-1}$

- **LHCb Upgrade Plans**
  - Upgrade LHCb detector such that it can operate at 10 times design luminosity of $\mathcal{L} \sim 2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$
  - Run ~5 yrs at $\mathcal{L} \sim 2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$
  - 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
**φ_s from B_s → J/ψφ**

- **CP Violation in B_s mesons**
  - Interference in B_s mixing and decay
  - B_s weak mixing phase φ_s is very small in SM
    \[
    φ_s = -\arg(V_{ts}) = -2χ ≈ -2λ^2η ≈ -0.035
    \]
  - ∋ sensitive probe for New Physics e.g. stringent NMFV test
  - NP parameterisation
    \[
    Δm_q = |1 + h_q e^{2iσ_q}|Δm_q^{SM}
    \]
  - Angular analysis to separate J/ψφ 2 CP-even and 1 CP-odd amplitudes

- **φ_s Sensitivity**
  - at Δm_s = 20 ps^{-1}
  - Expect 131k B_s → J/ψφ signal events per 2 fb^{-1} (1 year)
  - Expected precision
    \[
    σ(sin φ_s) \sim 0.023
    \]
  - Small improvement in φ_s precision by adding pure CP modes

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CDF 2006

LHCb 1 year

hep-ph/0604112
hep-ph/0509242
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**φs from B_s → J/ψφ**

- **φs** will be the ultimate SM test
  - For CP in B mesons
  - Similar to ε' in kaons for direct CP violation

- **φs Sensitivity**
  - LHCb for 10 fb⁻¹ (first 5 years)
  - ~3 σ SM evidence for φs ≈ -0.035
  - φs precision statistically limited
  - Theoretically clean

- **Historical Aside**
  - 1988 NA31 measures ~3 σ from zero
  - 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 → J/ψφ - Key channel for LHCb Upgrade**
  - φs Sensitivity with 100 fb⁻¹ data sample
  - ~10 σ SM measurement with 100 fb⁻¹

- $\sigma(\sin \phi_s) \approx 0.003$

- $\epsilon'/\epsilon = (3.3 \pm 1.1) \times 10^{-3}$
**b → s Transitions in B_d Mesons**

\[ \sin(2\beta^{\text{eff}}) = \sin(2\phi_1^{\text{eff}}) \]

- **Compare \(\sin 2\beta\) measurements**
  - in \(B_d \to \phi K_S\) with \(B_d \to J/\psi K_S\)
  - Individually, each decay mode in reasonable agreement with SM
  - But all measurements lower than \(\sin 2\beta\) from Naïve \(b \to s\) penguin average
    - \(\sin 2\beta^{\text{eff}} = 0.52 \pm 0.05\)
    - 2.6 \(\sigma\) discrepancy from SM
- **Theory models**
  - Predict to increase \(\sin 2\beta^{\text{eff}}\) in SM

<table>
<thead>
<tr>
<th>(b \to c\bar{c}s)</th>
<th>World Average</th>
<th>(0.69 \pm 0.03)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(b \to \phi K^0)</td>
<td>Belle</td>
<td>(0.50 \pm 0.06)</td>
</tr>
<tr>
<td>(b \to \eta' K^0)</td>
<td>Average</td>
<td>(0.39 \pm 0.18)</td>
</tr>
<tr>
<td>(b \to J/\psi K_S)</td>
<td>Average</td>
<td>(0.30 \pm 0.08)</td>
</tr>
<tr>
<td>(b \to \phi K_S)</td>
<td>Average</td>
<td>(0.33 \pm 0.08)</td>
</tr>
<tr>
<td>(b \to \omega K_S)</td>
<td>Average</td>
<td>(0.17 \pm 0.07)</td>
</tr>
<tr>
<td>(b \to f_0 K^0)</td>
<td>Average</td>
<td>(0.23 \pm 0.11)</td>
</tr>
<tr>
<td>(b \to \pi^0 K_S)</td>
<td>Average</td>
<td>(0.42 \pm 0.17)</td>
</tr>
<tr>
<td>(b \to K^0 K^0)</td>
<td>Average</td>
<td>(0.68 \pm 0.03)</td>
</tr>
<tr>
<td>(b \to 3K_S)</td>
<td>Average</td>
<td>(0.58 \pm 0.06)</td>
</tr>
</tbody>
</table>

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[Image of the graph]
**Flavour in the LHC era**

**CERN, 9 Oct 2006**

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<b -> s Transitions in B_s -> phi phi

- **B_s -> phi phi hadronic penguin decay**
  - In SM weak mixing phase φ_s is identical in B_s -> phi phi and B_s -> J/psi
  - Define ΔS(ϕ) = sinφ_s(ϕ) - sinφ_s(J/ψφ)
  - Measurement of ΔS(ϕ) ≈ sinφ_s(ϕ) ≠ 0 is clear signal for **New Physics (NMFV)**

- **ΔS(ϕ phi) Sensitivity**
  - Best b -> s penguin mode for LHCb
  - Expect 1.2 k B_s -> phi phi events per 2 fb^-1
  - Estimate sensitivity by scaling with B_s -> J/ψφ

  \[ \sigma(ΔS(\phi\phi)) \approx 0.14 \] in 10 fb^-1

- **Key channel for LHCb Upgrade**
  - ΔS(ϕ phi) precision statistically limited
  - With 100 fb^-1 estimate precision \[ \sigma(ΔS(\phi\phi)) \approx 0.04 \] exciting NP probe
  - Requires **1st level detached vertex trigger** for hadronic decay

  Expect similar precision for ΔS(ϕK_s) in decay B_d -> ϕK_s
**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
**Flavour in the LHC era**

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### 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

**Additional Notes**

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

- LHCb Upgrade Sensitivity:
  - $s_0 = 4.0 \pm 0.5$ GeV$^2$ in 10 fb$^{-1}$
  - $s_0 = 4.00 \pm 0.16$ GeV$^2$ in 100 fb$^{-1}$
  - 4% error on $C_7^{\text{eff}}/C_9^{\text{eff}}$

**Graphical Elements**

- Graph showing $A_{FB}(s)$ for $B^0 \rightarrow K^{*0} \mu^+ \mu^-$
  - SUSY plots with $C_7 > 0, C_9 > 0$

- Expected Signal Yield graph:
  - 4.4 k events per 2 fb$^{-1}$
  - Large statistics allows to measure additional transversity amplitudes

- 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

**References**

- 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
    - observation of $B_d \to \mu^+\mu^-$ and precision measurement of $B_s \to \mu^+\mu^-$
    - Electroweak and radiative penguin decays
      - $\Lambda_b \to \Lambda\mu^+\mu^-$
  - Other hadronic penguin decays
    - $B_d \to \phi K_S$, $B_d \to \eta' K_S$
  - CP violation and mixing in charm meson decays
  - Lepton flavour violation in B, charm and tau decays
    - $B^0 \to \mu^+\mu^-$, $D^0 \to \mu^+\mu^-$, $\tau^+ \to \mu^+\gamma$, $\tau^+ \to \mu^+\mu^+\mu^+$
Comparison with Super-B factory

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

- \(\Delta m_s\)
- \(\Delta \Gamma / \Gamma\)
- \(\sin(\phi_3)\)
- BR\((B \rightarrow \mu\mu)\)
- \(\gamma(B \rightarrow KK)\)
- \(\gamma(B_s \rightarrow D_sK)\)
- \(\Delta S(\phi\phi)\)
- \(\sin 2\beta\)
- \(\alpha(\rho \pi)\)
- \(\gamma(D_{K^{(*)}})_{GLW}\)
- \(\gamma(D_{K^{(*)}})_{ADS}\)
- \(\gamma(D_{K^{(*)}})_{Dalitz}\)
- \(A_{C_Y}(B \rightarrow (X/K^*)\gamma)\)
- \(C_Y A_{T_Y}(B \rightarrow K^{*}\gamma)\)
- \(C_{10} A_{T_{10}}(B \rightarrow K^{*}\gamma)\)
- \(\Delta S(\phi K^0)\)
- \(\Delta S(\eta^* K^0)\)
- \(S(K^{*+})\)
- \(\alpha(\rho \pi; \text{isospin})\)
- BR\((B \rightarrow K^{*}\nu\nu)\)
- BR\((B^0 \rightarrow D\nu\nu)\)
- BR\((B \rightarrow X_s\gamma)\)

B\(_s\) only accessible to LHCb

Common

Neutrals, \(\nu\)

No IP

Preliminary

SuperB numbers from M Hazumi - Flavour in LHC era workshop
LHCb Upgrade Detector and Trigger
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 $B_s \rightarrow \phi \phi$ and $B^\pm \rightarrow D^0 K^\pm$

Event Yield

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

Luminosity

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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
LHCb Upgrade Plans II

- **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
    \( >10^{15} \text{ 1 MeV neutron}_{eq}/\text{cm}^2 \)
- **Geometry - Strixels / Pixels**
  - remove RF foil
  - 3% \( X_0 \) before 1st measurement
  - move closer to beam from 8 → 5mm

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**Strixels**

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

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**VELO Module**

**Pixel Stations**
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

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LHCb Upgrade Trigger Studies

- **Method**
  - Combine LO with detached vertex trigger
    - LO - hadron $E_T > 3$ GeV
    - track with largest $p_T > 2$ GeV
    - impact parameter $|\text{IP}| > 50$ um
  - Run L1 trigger algorithm at LO

- **Preliminary results**
  - $B_s \rightarrow D_s^{\mp} K^\pm$ at $L = 6 \times 10^{32}$
  - For LO+vxt Min. bias efficiency does not depend strongly on # of interactions $n_r$
  - LO - hadron rate: $r = 0.8$ MHz
    - $B_s \rightarrow D_s^{\mp} K^\pm$ efficiency $\varepsilon = 66\%$
  - Better efficiency than LO trigger at $L = 2 \times 10^{32}$ (baseline)
    - $r = 0.7$ MHz
    - $\varepsilon = 39\%$
  - 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 $\mathcal{L} \sim 2 \ldots 5 \times 10^{32}$ 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 $B_s \to J/\psi\phi$
  - Probe or establish New Physics by measuring $\phi_s$ in hadronic penguin decay $B_s \to \phi\phi$ 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 $B \to K^{*0}\mu^+\mu^-$
  - Measure $B_d \to \mu^+\mu^-$
LHCb Physics Programme

\[ B^0_d \rightarrow \pi^0 \pi^+ \pi^- \]

\[ \sim V_{ub} \]

\[ \sim V_{td} \]

\[ \sim V_{cb} \]

\[ B^0_d \rightarrow J/\Psi K^0_s \]

\[ B^0_s \rightarrow D_{s}^{\pm} K_{s}^{\mp} \gamma - 2\chi \]

\[ B^0_d \rightarrow \pi^+ \pi^- \text{ and } B^0_s \rightarrow K^+ K^- \beta \text{ and } \gamma \]

\[ B^0_d \rightarrow D^0 K^\pm \]

\[ B^0_d \rightarrow D^0 K^*0 \}

\[ \gamma \]

\[ \Delta m_s \]

\[ B^0_s \rightarrow D_s \pi \]

\[ \sim V_{ub} \]

\[ \sim V_{td} \]

\[ \sim V_{ts} \]

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

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

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. \( B_s \rightarrow \mu^+ \mu^- \)