The LHCb Upgrade
Silvia Borghi on behalf of the LHCb Collaboration

**Motivation**

- The flavour sector offers a very rich programme to search for physics beyond the Standard Model, a complementary way to the direct particle searches carried out at ATLAS and CMS.
- Recent LHCb results have shown the potential of flavour Physics at LHC and the excellent performance of the detector.
- LHCb can exploit the full range of B hadrons, including unique NP prospects in B decays.
- A broad charm physics programme is carried out at LHCb.
- LHCb thanks to its forward coverage geometry complies a complementary pseudo-rapidity range to the one of ATLAS and CMS.
- LHCb upgrade would allow to fully exploit flavour physics potential and extend the programme to be a general purpose detector for the forward region.

**Data taking prospect**

- Collect 50 fb⁻¹
- Increase annual yield
- Leptonic channels: >10
- Hadronic channels: >20
- Reach experimental sensitivities for many observables comparable or better than theoretical uncertainties
- Physics programme beyond beauty and charm: 
  - Lepton flavour violation (Majorana neutrino, LFV in B decays)
  - Electroweak physics (sin2θW, Mw)
  - Exotic searches (chiral valleys, ..)
  - QCD (central exclusive production, ..)

**Tracking**

- Reduce straw coverage
  - a) fiber tracker
  - b) larger silicon tracker
- 40 MHz
  - Full detector readout
- 4.5 kHz to storage

**Upgrade**

- Timepix
- 20kHz

**Physics Prospects at LHCb Upgrade**

- Measurement of the CP-violating phase \( \phi_s \) in \( B \) decays
  - Phase I: observe NP if \( \phi_s \) is larger than 3\( \sigma \)
  - Upgrade: beyond SM precision measurement
- Rare penguin decay topologies sensitive to NP: charmless hadronic B decays
  - Phase I: direct CP violation in \( B \) and \( \Delta m \), time dependent CPV in \( B \to K \bar{K} \)
  - Upgrade: precision time dependent CP violation in penguin dominated \( B \to K \bar{K} \), \( B \to \phi \phi \)
- Measurement of CKM angle \( \gamma \) using different ways
  - Phase I: precision to few degrees
  - Upgrade: precision better than 1 degree

**Rare decays**

- \( B_s^0 \to \mu^+\mu^- \)
  - Phase I: search for new physics in \( B_s \to \mu^+\mu^- \)
  - Upgrade: evaluation of BR(\( B_s \to \mu^+\mu^- \)) and the correlation between \( B_s \to \mu^+\mu^- \) and \( B \to \mu^+\mu^- \) to distinguish the theory predictions
- \( B_s^0 \to \mu^+\mu^- \)
  - Phase I: measure \( \Delta m \) and other observables
  - Upgrade: precise full angular analysis to study further observables (transverse asymmetries) sensitive to NP
- \( D^0 \to \mu^+\mu^- \)
  - Current limit 10\(^{10} \) larger than SM prediction
- Radiative decays: \( B \to \ell
\nu \ell' \to \ell
\nu \ell' \)
- Study of the photon polarisation

**Sensitivity to various flavour observables**

<table>
<thead>
<tr>
<th>Type</th>
<th>Observable</th>
<th>Current precision</th>
<th>LHCb</th>
<th>Upgrade</th>
<th>Theory</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>B ( \ell )-mixing</td>
<td>( \bar{B}_s \to \ell \bar{\mu} \to \ell \bar{\nu} )</td>
<td>10(^{10} )</td>
<td>10(^{10} )</td>
<td>10(^{10} )</td>
<td>10(^{10} )</td>
<td>10(^{10} )</td>
</tr>
<tr>
<td>G-parity</td>
<td>( \bar{B}_s \to \ell \bar{\mu} \to \ell \bar{\nu} )</td>
<td>10(^{10} )</td>
<td>10(^{10} )</td>
<td>10(^{10} )</td>
<td>10(^{10} )</td>
<td>10(^{10} )</td>
</tr>
<tr>
<td>Right-handed currents</td>
<td>( \mu^+ \mu^- \to \ell \tilde{\nu} )</td>
<td>10(^{10} )</td>
<td>10(^{10} )</td>
<td>10(^{10} )</td>
<td>10(^{10} )</td>
<td>10(^{10} )</td>
</tr>
<tr>
<td>Electron pseudoproduction</td>
<td>( \bar{B}_s \to \ell \bar{\mu} \to \ell \bar{\nu} )</td>
<td>10(^{10} )</td>
<td>10(^{10} )</td>
<td>10(^{10} )</td>
<td>10(^{10} )</td>
<td>10(^{10} )</td>
</tr>
<tr>
<td>Right-handed currents</td>
<td>( \mu^+ \mu^- \to \ell \tilde{\nu} )</td>
<td>10(^{10} )</td>
<td>10(^{10} )</td>
<td>10(^{10} )</td>
<td>10(^{10} )</td>
<td>10(^{10} )</td>
</tr>
</tbody>
</table>

**Mixing and CPV search in the charm sector**

- Measurements of mixing parameters with several decays (WS, CP eigenstates, 3-body decays)
  - Phase I: measurement of mixing at \( c > 5 \sigma \)
  - Upgrade: precision better than \( 10^5 \) \( \sigma \)
- Search of direct and indirect CP violation
  - Phase I: precision of \( 0.5 \times 10^{-6} \)
  - Upgrade: precision of \( 0.1 \times 10^{-6} \)

**LHC schedule**

- LHC startup, \( \sqrt{s} = 900 \) GeV
  - \( \sqrt{s} \) = 7 TeV, \( L = 5 \times 10^{33} \) cm\(^{-2}\)\(\text{s}^{-1}\), bunch spacing 50 ns
  - Go to design energy, nominal luminosity
  - \( \sqrt{s} \) = 13-14 TeV, \( L = 4 \times 10^{33} \) cm\(^{-2}\)\(\text{s}^{-1}\), bunch spacing 25 ns
- Injector and LHC Phase-1 upgrade to full design luminosity
  - \( \sqrt{s} \) = 14 TeV, \( L = 1.2 \times 10^{34} \) cm\(^{-2}\)\(\text{s}^{-1}\), bunch spacing 25 ns
- HL-LHC Phase-2 upgrade, IR, crab cavities
  - \( \sqrt{s} \) = 14 TeV, \( L = 5 \times 10^{34} \) cm\(^{-2}\)\(\text{s}^{-1}\), luminosity levelling

**VEO upgrade**

- Requirements
  - To deal with high data rates \( \geq 12 \) Gbps/asic
  - High radiation level of \( \sim 370 \) Mrad or \( 8 \times 10^{20} \) m\(^2\)\(\text{sr}\)\(\text{cm}^{-2}\)
- Pixel detector
  - VELOPIX based on Tinsel chip
  - 55 \( \mu \)m \( \times \) 55 \( \mu \)m pixel size, 256 \( \times \) 256 matrix
- Alternative option based on strips
  - Similar to existing detector: R\&D geometry
  - Increased number of strips, smaller pitch and strip length
  - R\&D programme
  - Module structure (X\( \mu \))
  - Sensor options: Planar Si, Diamond, 3D
  - RF-foil of vacuum box

**RICH**

- New photon detector
- Replace all the front-end electronics and DAQ network

**Calorimeter-Muon**

- Remove ML, M0L, F0 (new photomultiplier FE electronics)

**Upgrades**

- Requirements
  - To deal with high data rates \( \geq 12 \) Gbps/asic
  - High radiation level of \( \sim 370 \) Mrad or \( 8 \times 10^{20} \) m\(^2\)\(\text{sr}\)\(\text{cm}^{-2}\)
- Pixel detector
  - VELOPIX based on Tinsel chip
  - 55 \( \mu \)m \( \times \) 55 \( \mu \)m pixel size, 256 \( \times \) 256 matrix
- Alternative option based on strips
  - Similar to existing detector: R\&D geometry
  - Increased number of strips, smaller pitch and strip length
  - R\&D programme
  - Module structure (X\( \mu \))
  - Sensor options: Planar Si, Diamond, 3D
  - RF-foil of vacuum box