The LHCb upgrade

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on behalf of the LHCb collaboration

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et Aix-Marseille Université
Outline

- Introduction
- The LHCb experiment
- The LHCb upgrade
- Conclusions

Reference: Letter of Intent for the LHCb upgrade, LHCC-I-018, 2011
Introduction
Heavy flavour physics

- LHCb experiment is devoted to the study of flavour changing processes and CP violation in the $b$ and $c$-quark sectors.

- State-of-the-art:

  Flavour changing processes and CP violation are mostly driven by the CKM mechanism.

- Major evolution: moving from validation of the CKM mechanism to tool to probe NP

\[
\begin{align*}
\bar{\rho} & = 0.144^{+0.023}_{-0.026} \\
\bar{\eta} & = 0.343^{+0.015}_{-0.014} \\
\beta & = 21.84^{+0.80}_{-0.76}^\circ \\
\gamma & = 67.3^{+4.2}_{-3.5}^\circ
\end{align*}
\]
Indirect search for new physics

- Flavour changing processes are mediated by box and penguin amplitudes:

These processes are sensitive to the coupling and to the mass of the new particle entering in the loops.

- To probe new particles, measure observables:
  - Involving flavour changing processes suppressed or forbidden in SM
  - Well predicted in the SM
  and look for deviation with respect to the expectation.
The golden observables for LHCb

- Branching fraction $B_{d,s} \rightarrow \mu\mu$
- CP Violation phase $\phi_s$ in $B_s$ mixing
- $A_{FB}$ in $B \rightarrow K^*\mu\mu$
- Angle $\gamma$ in $B_{(s)} \rightarrow D_{(s)}K$ mediated by tree amplitude
- CP violation in charm ($\Delta A_{CP}$)
- Photon polarisation in $B_s \rightarrow \phi\gamma$
- ...

The LHCb experiment
The LHCb detector

- Forward spectrometer covering pseudo rapidity range $2 < \eta < 5$

Integrated luminosity and pileup

- In 2011:
  - Recorded luminosity 1.1 fb\(^{-1}\)
  - Constant luminosity of \(\sim 3.5 \times 10^{32}\) cm\(^{-2}\)s\(^{-1}\)
  - Interactions / beam crossing \(\sim 1.4\)
Highlight on hot measurements

\[ B | B_s \to \mu \mu | < 4.5 \times 10^{-9} \text{ at } 95\% \text{ CL} \]

\[ \phi_s = [-0.002 \pm 0.083 (\text{stat.}) \pm 0.027 (\text{syst.})] \]

- SM like but uncertainties are large
- Many more measurements. See other LHCb contributions to this workshop.
Expected sensitivity

- End 2017, LHCb will integrated an equivalent of 5 fb⁻¹ at 14 TeV

<table>
<thead>
<tr>
<th>Observable</th>
<th>Sensitivity</th>
<th>SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B(B_s \rightarrow \mu\mu)$</td>
<td>observed at 3σ (SM)</td>
<td>$(3.2\pm0.2) \times 10^9$</td>
</tr>
<tr>
<td>$\phi_s$</td>
<td>0.02 rad</td>
<td>0.036±0.002 rad</td>
</tr>
<tr>
<td>$\gamma$ (tree)</td>
<td>4°</td>
<td>$67.3^{+4.2}_{-3.5}$°</td>
</tr>
<tr>
<td>Zero of $A_{FB}(B_d \rightarrow K^*\mu\mu)$</td>
<td>4% of SM value</td>
<td>$4.36^{+0.36}_{-0.33}$ GeV²</td>
</tr>
</tbody>
</table>

More details: Letter of Intent for the LHCb upgrade, LHCC-I-018, 2011

- Currently, it is likely that all sources of flavour and CP violation have the same patterns as those of the SM (MFV)

Therefore, we must have to increase our sensibilities considerably → LHCb upgrade.
The LHCb upgrade
Targets

- Collect **50 fb⁻¹**
- Increase the annual yield by a factor 5 for leptonic channels and by a factor 10 for hadronic channels
- Reach experimental sensitivities comparable or better than theoretical uncertainties

Enlarged core physics program:
- Leptons flavour physics [Majorana neutrino, LV in $\tau^\pm$ decays]
- Electroweak physics [$\sin 2 \theta_{\text{eff}}^\text{lept}, M_W$]
- Exotic search [hidden valleys,...]
- QCD [central exclusive production]
Running conditions

- Constant luminosity $\mathcal{L} = 1 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1}$ with 25 ns bunch spacing.

  design upgraded sub-system to sustain a peak luminosity of $\mathcal{L}_{\text{peak}} = 2 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1}$

- Interactions / beam crossing $\sim 2.3$

Already gained expertise running LHCb in such conditions:
Current Triggers

The hadronic channel yields saturate increasing $\mathcal{L}$:

- **40 MHz**: Pileup, PS, SPD, ECAL, HCAL, Muon
- **1 MHz**: All detectors information
- **2 kHz**: HLT, tracking and vertexing $p_T$ and impact parameter cuts inclusive/exclusive selections

![Graph showing trigger yield vs luminosity](image)
Triggers upgraded

- Upgrade to a flexible **software** trigger processing all crossings:

  ![Diagram](image)

  - LLT efficiencies
    
    | LLT-rate (MHz) | 1    | 5    | 10   |
    |----------------|------|------|------|
    | $B_s \rightarrow \phi\phi$ | 0.12 | 0.51 | 0.82 |
    | $B^0 \rightarrow K^*\mu\mu$ | 0.36 | 0.89 | 0.97 |
    | $B_s \rightarrow \phi\gamma$ | 0.39 | 0.92 | 1.00 |

- A challenge to read out LHCb at **40 MHz**
Tracking

At $\mathcal{L} = 1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$, increase of:
- number of primary vertices
- Tracks multiplicity
- Bunch-to-bunch spillover $[0.86]$ (shown in the graph)
- Detectors occupancy
- Number of ghost tracks

Challenge to keep:
- High momentum resolution $[\sigma(p)/p \sim 4 \times 10^{-3}]$
- High track efficiency $[\sim 90\% \text{ when } p \geq 5 \text{ GeV}]$
- Low ghost rate $[\sim 10\%]$
- Low processing time in HLT $[\sim 25 \text{ ms}]$
- Low material budget
Detector modifications

**VELO**
New pixel system

**TRACKING**
New TT and IT

**RICH**
New photon detector

**CALO + MUON**
Remove M1, SPD, PS

Replace all the front-end electronics + DAQ network
VELO upgrade

- $(r, \varphi)$ strip detector with a pitch $35 - 100 \mu m$
  - replace by a pixel detector:
    - Very low occupancy for each channel
    - Reduce combinatorial for tracking
    - Very high data rate $\geq 12$ Gbit for the hottest pixel chip
    - High radiation level of $\sim 370$ MRad or $8 \times 10^{15} n_{\alpha}/cm^2$

VELOPix ASIC based on TimePix/Medipix chip
- $256 \times 256$ pixels
- Square pixel $55 \times 55 \mu m^2$

Alternative option based on strips
Current Trackers

- TT and IT are microstrips silicon detector. Pitch 200 µm, length 11, 22 and 33 cm.

- Outer tracker is a gaseous detector based on very thin (5 mm) and very long straw tube (2.4 – 5 m).

Occupancy limited to 20 – 25%
Trackers upgrade

- **TT:**
  - microstrips silicon detector
  - enlarge acceptance at high $\eta$
  - improved granularity in $\gamma$

- **T stations:**
  - Light and large-area IT
  - or
  - Scintillating Fibre + SiPM

- or
  - Central tracker
RICH upgrade

- Replace HPD by MaPMT readout by a 40 MHz chip (MAROC-3 or custom)
- Remove aerogel not exploitable at $10^{33}$ cm$^{-2}$s$^{-1}$
  Will be replaced by a time-of-flight detector TORCH.
**TORCH detector**

- **Novel detector:**
  - TOF of Cerenkov photon generated in 1 cm thick quartz plate
  - Photon detector Micro Channels Plate
  - Arrival time of particles 10 – 15 ps
  - improve hadron identification $1 < p < 10$ GeV
Rough draft LHC 10 years plan

More details: S. Meyer, LHC machine status and prospects including upgrades, EPS 2011, Grenoble, France
LHCb Time line

- Letter of Intend submitted in March 2011
  - Physics case fully endorsed by LHCC
  - 40 MHz readout reviewed, considered as challenging but feasible

- Framework TDR to be submitted in June 2012
  It defines cost, milestones and institutes scientific interest

- TDR(s) in 2013

- Production and quality control in 2014 – 2017

- Installation and commissioning in 2018
Heavy flavor prospects

- Expected sensitivity with 50 fb$^{-1}$

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<th>Sensitivity</th>
<th>SM</th>
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<tbody>
<tr>
<td>$B(B_s \rightarrow \mu\mu)$</td>
<td>8% of SM value</td>
<td>$(3.2\pm0.2)\times10^9$</td>
</tr>
<tr>
<td>$\phi_s$</td>
<td>17% of SM value</td>
<td>$0.036\pm0.002$ rad</td>
</tr>
<tr>
<td>$\gamma$ (tree)</td>
<td>1.3% of SM value</td>
<td>$\left</td>
</tr>
<tr>
<td>Zero of $A_{FB}(B_d \rightarrow K^*\mu\mu)$</td>
<td>1% of SM value</td>
<td>$4.36^{+0.36}_{-0.33}$ GeV$^2$</td>
</tr>
</tbody>
</table>

More details: Letter of Intent for the LHCb upgrade, LHCC-I-018, 2011
## A rich program

<table>
<thead>
<tr>
<th>Type</th>
<th>Observable</th>
<th>Current precision</th>
<th>LHCb (5 fb⁻¹)</th>
<th>Upgrade (50 fb⁻¹)</th>
<th>Theory uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gluonic penguin</td>
<td>$S(B_s \to \phi\phi)$</td>
<td>-</td>
<td>0.08</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>$S(B_s \to K^{*0}K^{*0})$</td>
<td>-</td>
<td>0.07</td>
<td>0.02</td>
<td>&lt; 0.02</td>
</tr>
<tr>
<td></td>
<td>$S(B^0 \to \phi K^0_S)$</td>
<td>0.17</td>
<td>0.15</td>
<td>0.03</td>
<td>0.02</td>
</tr>
<tr>
<td>$B_s$ mixing</td>
<td>$2\beta_s \ (B_s \to J/\psi\phi)$</td>
<td>0.35</td>
<td>0.019</td>
<td>0.006</td>
<td>$\sim 0.003$</td>
</tr>
<tr>
<td>Right-handed</td>
<td>$S(B_s \to \phi\gamma)$</td>
<td>-</td>
<td>0.07</td>
<td>0.02</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>currents</td>
<td>$A^{\Delta\Gamma}_s (B_s \to \phi\gamma)$</td>
<td>-</td>
<td>0.14</td>
<td>0.03</td>
<td>0.02</td>
</tr>
<tr>
<td>E/W penguin</td>
<td>$A_T^{(2)}(B^0 \to K^{*0}\mu^+\mu^-)$</td>
<td>-</td>
<td>0.14</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>$s_0 A_{FB}(B^0 \to K^{*0}\mu^+\mu^-)$</td>
<td>-</td>
<td>4%</td>
<td>1%</td>
<td>$\sim 7%$</td>
</tr>
<tr>
<td>Higgs penguin</td>
<td>$\mathcal{B}(B_s \to \mu^+\mu^-)$</td>
<td>-</td>
<td>30%</td>
<td>8%</td>
<td>&lt; 10%</td>
</tr>
<tr>
<td></td>
<td>$\frac{\mathcal{B}(B^0 \to \mu^+\mu^-)}{\mathcal{B}(B_s \to \mu^+\mu^-)}$</td>
<td>-</td>
<td>-</td>
<td>$\sim 35%$</td>
<td>$\sim 5%$</td>
</tr>
<tr>
<td>Unitarity triangle angles</td>
<td>$\gamma (B \to D^{(<em>)}\bar{D}^{(</em>)})$</td>
<td>$\sim 20^\circ$</td>
<td>$\sim 4^\circ$</td>
<td>0.9$^\circ$</td>
<td>negligible</td>
</tr>
<tr>
<td></td>
<td>$\gamma (B_s \to D_s K)$</td>
<td>-</td>
<td>$\sim 7^\circ$</td>
<td>1.5$^\circ$</td>
<td>negligible</td>
</tr>
<tr>
<td></td>
<td>$\beta (B^0 \to J/\psi K^0)$</td>
<td>1$^\circ$</td>
<td>0.5$^\circ$</td>
<td>0.2$^\circ$</td>
<td>negligible</td>
</tr>
<tr>
<td>Charm CPV</td>
<td>$A_T$</td>
<td>$2.5 \times 10^{-3}$</td>
<td>$2 \times 10^{-4}$</td>
<td>$4 \times 10^{-5}$</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>$A^{dir}<em>{CP}(K K) - A^{dir}</em>{CP}(\pi\pi)$</td>
<td>$4.3 \times 10^{-3}$</td>
<td>$4 \times 10^{-4}$</td>
<td>$8 \times 10^{-5}$</td>
<td>-</td>
</tr>
</tbody>
</table>

From: Letter of Intent for the LHCb upgrade, CERN-LHCC-2011-001
QCD prospects

- Central exclusive production: \( pp \rightarrow p + X + p \) with rapidity gap

Event display in the VELO region of candidate CEP \( J/\psi \rightarrow \mu^+\mu^- \) event

- Promising CEP measurements at LHCb
Conclusions

- Excellent performance of LHC and LHCb

- In 2012, LHCb will collect ~1.5 fb$^{-1}$ at $\sqrt{s} = 8$ TeV with a constant luminosity of $4 \times 10^{32}$ cm$^{-2}$ s$^{-1}$

- The performance of the current detector and the purity of the samples already accumulated gives confidence that measurements of very high sensitivity can be achieved.

- LHCb upgrade is a good opportunity to join the LHCb collaboration. New collaborators are very welcome.