LHCb at the Large Hadron Collider

ATLAS/CMS
- Central: $-2.5 < \eta < 2.5$
- General purpose
- Full luminosity

Alice
- Central: $-2 < \eta < 2$
- Focus on heavy ions

LHCb
- Forward: $1.9 < \eta < 5$
- Focus on flavor physics
  - GP in forward region

Manuel Franco Sevilla

Recent results from LHCb
~ Focus on **flavor physics**

- 25% of $b\bar{b}$ production with 4% of solid angle ($2 \leq \eta \leq 5$)
- 100k $b$-hadrons produced every second

~ **Excellent secondary vertex reconstruction**

~ **PID**: $\pi$, $K$, $p$, $\mu$
LHCb sweet spot for many flavor measurements

$\mathcal{O} \left(10^9\right) B^{0/+}$ mesons
Low uncertainty on absolute rates, 100% $\varepsilon$(trigger), PID, low e-brem, knowledge of collision momentum

$\mathcal{O} \left(10^{11}\right) B_{(s)}^{0/+}$ mesons
Triggers primarily for flavor, PID, VELO, all b-hadron species

$\mathcal{O} \left(10^{12}\right) B_{(s)}^{0/+}$ mesons
All b-hadron species

Manuel Franco Sevilla
Recent results from LHCb
**LHC environment busier than B-factories**

**LHC**

$pp \rightarrow X_b B^0_s X$

$B^0_s \rightarrow \mu^+ \mu^-$

**B-factories**

Clean $e^+e^-$ collisions only produce two B mesons (for the most part)

$e^+e^- \rightarrow B^+_{\text{tag}} B^-_{\text{sig}}$

$B^- \rightarrow \rho^0 \mu^- \nu_\mu$

$B^0_s \rightarrow \mu^+ \mu^-$

$\nu (1.2 \text{ GeV})$

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

$\mu^- (3 \text{ GeV})$
Vertexing is key

- Superb vertexing by VELO in LHCb
  - Only 8.2 mm from IP
  - B mesons can fly ~cm thanks to large boost

\[ pp \rightarrow X_b B_s^0 X \]
\[ B_s^0 \rightarrow \mu^+ \mu^- \]
Outline

CP violation

CPv in charmless three-body decays

CKM angle $\gamma$ with

$B^{\pm} \to D[K^{\mp} \pi^{\pm} \pi^{\pm} \pi^{\mp}]h^{\pm}$

Beyond flavor

W boson mass

Hadron spectroscopy and $T_{cc}$

Antiproton production in pHe collisions (SMOG)

Lepton Universality violation

$\mathcal{R}(\Lambda_c)$ from $\Lambda_b^0 \to \Lambda_c^+ \tau^- \bar{\nu}_\tau$

BF and angular distribution of $B_s^0 \to \phi \mu^+ \mu^-$

$\mathcal{R}_{K_S^0}$, $\mathcal{R}_{K^{*+}}$ from $B \to K^{(*)} \ell^+ \ell^-$

LHCb upgrades

Upgrade I (2019-21)

Upgrade II (2033-34)
CP violation

CPv in charmless three-body decays
LHCb-PAPER-2021-049 in preparation

CKM angle $\gamma$ with $B^\pm \to D[K^{\mp}\pi^\pm\pi^\mp\pi^\mp]h^\pm$
LHCb-PAPER-2022-017 in preparation
Why is matter \(\gg\) anti-matter?

\[\begin{align*}
\text{QED} & \quad e^+ + e^- \rightarrow \gamma \\
\text{QCD} & \quad q^+ + q^- \rightarrow \gamma \\
\end{align*}\]

\(\sim\) QED and QCD treat matter exactly the same as anti-matter.

How did we end up in a matter universe?
Weak interaction violates P and C

- While W/Z bosons couple to \( q_L \), they don't couple to \( q_R \)
- Violates Parity (P)

- While W/Z bosons couple to \( q_L \), they don't couple to \( \bar{q}_L \)
- Violates Charge conjugation (C)

- However, W/Z bosons couple the same to \( q_L \) and to \( \bar{q}_R \)
- CP is conserved!
  * Mostly, different phase

\[
V_{\text{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1 - \lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \lambda^2/2 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix}
\]
\[ V_{CKM}^\dagger V_{CKM} = 1 \rightarrow V_{ud} V_{ub}^* + V_{td} V_{tb}^* + V_{cd} V_{cb}^* = 0 \]

\( \sim \) CP violation arises when both CP-odd (weak) and CP-even (strong) phases impact decay

**Strong phases** coming from short- and long-distance (eg, rescattering) contributions are difficult to estimate.
Charless 3-body decays

Measure number of $B^+$ and $B^-$
- $\pi\pi\pi$, $K\pi\pi$, $\pi KK$, $KKK$ channels

Correct $\varepsilon$ with MC
- $R = \langle e^- \rangle / \langle e^+ \rangle$

Correct production asym. with $B^{\pm} \to J/\psi K^{\pm}$

$A_{CP} = \frac{A_{raw} - A_{P}}{1 - A_{raw}A_{P}}$

LHCb-PAPER-2021-049 in preparation

<table>
<thead>
<tr>
<th>Decay mode</th>
<th>Total yield</th>
<th>$\varepsilon$</th>
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<tbody>
<tr>
<td>$B^{\pm} \to \pi^\pm \pi^\mp \pi^\mp$</td>
<td>+0.080 ± 0.004 ± 0.003 ± 0.003 (14.1$\sigma$)</td>
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<tr>
<td>$B^{\pm} \to K^\pm \pi^\pm K^\mp$</td>
<td>+0.011 ± 0.002 ± 0.003 ± 0.003 (2.4$\sigma$)</td>
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<tr>
<td>$B^{\pm} \to \pi^\pm K^\pm K^\mp$</td>
<td>-0.114 ± 0.007 ± 0.003 ± 0.003 (13.6$\sigma$)</td>
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<tr>
<td>$B^{\pm} \to K^\pm K^\pm K^\mp$</td>
<td>-0.037 ± 0.002 ± 0.002 ± 0.003 (8.5$\sigma$)</td>
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</table>

Recent results from LHCb

1st obs.
Local $A_{CP}$ in $B \rightarrow \pi\pi\pi$

Significant $A_{CP}$ in $\pi\pi \leftrightarrow KK$ rescattering region

For $m^2(\pi\pi)_{low} > 4$ GeV$^2$

largest $A_{CP}$ ever measured (75%)
CKM angle $\gamma$

$\sim$ Only CKM angle accessible at tree level
- Recent combination from LHCb
  \[ \gamma_{LHCb} = (65.4^{+3.8}_{-4.2}) \]  
  JHEP 12 (2021) 141

$\sim$ New measurement with $B^{\pm} \to D(\to K\pi\pi\pi) K^{\pm}$
- OS/LS ratio of (Opposite-sign to Like-sign)
  \[ \frac{\Gamma(B^{\pm} \to D [K^{\pm}\pi^{+}\pi^{+}\pi^{+}] K^{\pm})}{\Gamma(B^{\pm} \to D [K^{\pm}\pi^{+}\pi^{+}\pi^{+}] K^{\pm})} = \frac{r^{2}_{K3\pi} + (r^{K}_{B})^{2} + 2r^{K}_{K3\pi}r^{K}_{B}R_{K3\pi}\cos(\delta^{K}_{B} + \delta_{K3\pi} \pm \gamma)}{1 + (r^{2}_{K3\pi}r^{K}_{B})^{2} + 2r^{K}_{K3\pi}r^{K}_{B}R_{K3\pi}\cos(\delta^{K}_{B} - \delta_{K3\pi} \pm \gamma)} \]
- D decay parameters from CLEO-c/BESIII
- Sensitivity optimized via measurement in 4 bins

$\sim$ Second most precise result
\[ \gamma = [54.8^{+6.0}_{-5.8}(stat) \pm 0.6(syst) +^{6.7}_{-4.3}(ext)]^{\circ} \]

LHCb-PAPER-2022-017 in preparation
Lepton Universality violation

\( R(\Lambda_c) \) from \( \Lambda_b^0 \to \Lambda_c^+\tau^-\bar{\nu}_\tau \)

\( R_{K^0}, R_{K^*+} \) from \( B \to K^{(*)}\ell^+\ell^- \)

BF and angular distribution of \( B^0_s \to \phi\mu^+\mu^- \)
PRL 127, 151801 (2021), JHEP 11, 043 (2021)
It is assumed that electroweak gauge couplings to 3 fermion generations are identical.

Lepton Flavor Universality (LFU)
LFU tested to be conserved

**LFU tests with e/µ (1st/2nd gen.)**

- **To 0.28% in Z decays**
  \[
  \frac{\Gamma_{Z\to\mu\mu}}{\Gamma_{Z\to\mu\mu}} = 1.0009 \pm 0.0028 
  \]

- **To 0.8% in W decays**
  \[
  \frac{\mathcal{B}(W\to e\nu)}{\mathcal{B}(W\to \mu\nu)} = 1.004 \pm 0.008 
  \]
  CDF + LHC, JINST NPP, 46, 2 (2019)

- **To 0.31% in meson decays**
  \[
  \frac{\Gamma_{J/\psi\to\mu\mu}}{\Gamma_{J/\psi\to\mu\mu}} = 1.0016 \pm 0.0031 
  \]
  PDG (BESIII), RPP, Chin. Phys. C40 (2016) 100001

\[
\frac{\Gamma_{K\to e\nu}}{\Gamma_{K\to \mu\nu}} = (2.488 \pm 0.009) \times 10^{-5} 
\]

- **To 0.14% in \(\tau\to\ell\nu\nu\)**
  \[
  \frac{g_\mu}{g_\ell} = 1.0018 \pm 0.0014 
  \]
  PDG, A. Pich, Prog. Part. Nucl. Phys. 75 (2014) 41

**LFU tests with \(\tau\) (3rd gen.)**

- **To 0.32% in Z decays**
  \[
  \frac{\Gamma_{Z\to\tau\tau}}{\Gamma_{Z\to\mu\mu}} = 1.0019 \pm 0.0032 
  \]

- **2.6\(\sigma\) tension in W decays**
  \[
  \frac{\Gamma_{W\to\tau\nu}}{\Gamma_{W\to\mu\nu}} = 1.070 \pm 0.026 
  \]
  LEP, Phys. Rept. 532 (2013) 119

- **To 1.3% in W decays**
  \[
  \frac{\Gamma_{W\to\tau\nu}}{\Gamma_{W\to\mu\nu}} = 0.992 \pm 0.013 
  \]
  ATLAS, Nature 17, 813 (2021)

- **To 6.1% in \(D_s\) decays**
  \[
  \frac{\Gamma_{D_s\to\tau\nu}}{\Gamma_{D_s\to\mu\nu}} = 9.95 \pm 0.61 
  \]

- **To 0.15% in \(\tau\to\ell\nu\nu\)(with \(\tau_\tau\))**
  \[
  \frac{g_\tau}{g_\mu} = 1.0030 \pm 0.0015 
  \]
  PDG, S. Pich, Prog. Part. Nucl. Phys. 75 (2014) 41
Since 2012, hints of LFU

- Intriguing pattern
- Both in $b \rightarrow c\tau\nu$ and $b \rightarrow s\ell\ell$ transitions

2012: 3.4σ in $\mathcal{R}(D) / \mathcal{R}(D^*)$

2021: 3.1σ in $\mathcal{R}_{K^+}$
Possible LFU in $b \to c\tau\nu$ transitions

~ Powerful LFU tests with ratios

- Numerous uncertainties cancel

$\mathcal{R}(D) = \frac{\mathcal{B}(\bar{B} \to D^{(*)}\tau\nu_{\tau})}{\mathcal{B}(\bar{B} \to D^{(*)}\ell\nu_{\ell})}$

with $\ell = \mu, e$

$\mathcal{R}(D^{(*)}) \equiv \mathcal{R}(D)$ or $\mathcal{R}(D^*)$

Even $5\sigma$ on $\mathcal{R}(D)/\mathcal{R}(D^*)$ would not be sufficient to convince ourselves of NP

Important to test other observables, and LHCb has unique ability to study $b \to c\tau\nu$ transitions

LHCb published in 2018 first non-$\mathcal{R}(D^{(*)})$ measurement

$\mathcal{R}(J/\Psi) = 0.71 \pm 0.17 \pm 0.18$, 1.8$\sigma$ above SM

**First measurement of** $b \rightarrow c\tau\nu$ **in baryons**

- Complementary spin and backgrounds

**Measure this ratio**

$$\mathcal{R}(\Lambda_c^+) = \frac{\mathcal{B}(\Lambda_b^0 \rightarrow \Lambda_c^+\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\Lambda_b^0 \rightarrow \Lambda_c^+\pi\pi\pi)} \times \frac{\mathcal{B}(\Lambda_b^0 \rightarrow \Lambda_c^+\mu\nu_\mu)}{\mathcal{B}(\Lambda_b^0 \rightarrow \Lambda_c^+\pi\pi\pi)}$$

**$\tau \rightarrow \pi\pi\pi$ vertex provides powerful bkg rejection**

- $\pi\pi\pi$ kinematics used to reduce and measure background

**External branching fractions**

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**Recent results from LHCb**

**LHCb simulation**

- $\Lambda_c^0 \rightarrow$ Prompt $\Lambda_c^0\pi^+\pi^0\pi^+$
- $\Lambda_c^0 \rightarrow \Lambda_c^0\pi^0\pi^0\pi^0$
- $\Lambda_c^0 \rightarrow \Lambda_c^0\pi^0\pi^0\pi^+$

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**LHCb**

3 fb$^{-1}$

\( \mathcal{R}(\Lambda_c^+) \) results

\[\sim \text{First observation of } \Lambda_b^0 \rightarrow \Lambda_c^+\tau^-\bar{\nu}_\tau\]

- \( \sim 6.1\sigma \) significance
- Only Run 1 data, \( \sim20\% \) of current LHCb dataset

\( \sim \mathcal{R}(\Lambda_c^+) \) compatible with SM

- \( \mathcal{R}(\Lambda_c^+)_{SM} = 0.340 \pm 0.004 \)

\[\mathcal{R}(\Lambda_c^+) = 0.242 \pm 0.026(\text{stat}) \pm 0.040(\text{syst}) \pm 0.059(\text{ext})\]
Loop suppresses SM contribution
- Rare $B < 10^{-7}$

Easier to detect possible BSM physics
\[ B_s^0 \rightarrow \mu^+ \mu^- \]

Combination of ATLAS/CMS/LHCb is

\[ \mathcal{B} (B_s^0 \rightarrow \mu^+ \mu^-)_{WA} = (2.84 \pm 0.33) \times 10^{-9} \]

\[ \sim 22\% \text{ below SM prediction} \]

\[ \sim 2.3\sigma \text{ tension with SM} \]
Possible discrepancies in $b \to s \mu \mu$

**BFs involving muons consistently below SM expectations**

- **B** $\to K^+ \mu^+ \mu^-$
- **B** $\to K^0 \mu^+ \mu^-$
- **B** $\to K^{*0} \mu^+ \mu^-$

**Angular distributions involving muons show some discrepancies**

- **LHCb Run 1 + 2016**
- **LHCb Run 1 + 2016**

SM predictions subject to long-distance charm contributions, difficult to estimate robustly

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**Manuel Franco Sevilla**

Recent results from LHCb
**Electrons** have **worse mass resolution** and are more **difficult** to trigger on

![Diagram of electron and photon interaction](image)

Algorithm to recover **upstream bremsstrahlung** when $E_\gamma > 75$ MeV

**Downstream bremsstrahlung** follows the track: easy to find

**Use double ratio** with $B \to K^{(*)} J/\psi(\to \ell\ell)$

$$R_K = \frac{\mathcal{B}(B^+ \to K^+ \mu^+ \mu^-)}{\mathcal{B}(B^+ \to K^+ J/\psi(\mu^+ \mu^-))} \bigg/ \frac{\mathcal{B}(B^+ \to K^+ e^+ e^-)}{\mathcal{B}(B^+ \to K^+ J/\psi(e^+ e^-))}$$

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**Recent results from LHCb**

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**LFU ratios: electrons biggest challenge**
\( R_{K^*0} \) and \( R_{K^+} \)

\( R_{K^*0} \) with 25% of Run 1+2

\[ R_{K^*0}^{[0.045, 1.1]} = 0.66^{+0.11}_{-0.07} \pm 0.03 \]

2.1\( \sigma \) below SM

JHEP 08, 055 (2017)

\( R_{K^*0}^{[1.1, 6]} = 0.69^{+0.11}_{-0.07} \pm 0.05 \)

2.4\( \sigma \) below SM

\( R_{K^+} \) with 100% of Run 1+2

\[ R_{K^+}^{[1.1, 6]} = 0.846^{+0.042+0.013}_{-0.039-0.012} \]

3.1\( \sigma \) below SM

Nature Phys. 18, 3 (2022)
$R_{K^{*+}}$ and $R_{K_S^0}$

$B \to K^{(*)}\mu^+\mu^-$

$K^{*+}$  
LHCb  
Data 9 fb$^{-1}$

$N_{tot}^{\mu\mu} = 221 \pm 17$

$m(K^0\pi^+\mu^+\mu^-) [\text{MeV}/c^2]$

$B \to K^{(*)}e^+e^-$

$K^{*+}$  
LHCb  
Data 9 fb$^{-1}$

$N_{tot}^{ee} = 67 \pm 13$

$m(K^0\pi^+e^+e^-) [\text{MeV}/c^2]$

$B \to K^0\mu^+\mu^-$

$K^0$  
LHCb  
Data 9 fb$^{-1}$

$N_{tot}^{\mu\mu} = 155 \pm 15$

$m(K^0\mu^+\mu^-) [\text{MeV}/c^2]$

$B \to K^0e^+e^-$

$K_S^0$  
LHCb  
Data 9 fb$^{-1}$

$N_{tot}^{ee} = 45 \pm 10$

$m(K_S^0e^+e^-) [\text{MeV}/c^2]$

$R_{K^{*+}}$ with 100% of Run 1+2

$R_{K^{*+}}^{[0.045, 6.0]} = 0.70^{+0.18+0.03}_{-0.13-0.04}$

1.4$\sigma$ below SM

$R_{K_S^0}$ with 100% of Run 1+2

$R_{K_S^0}^{[1.1, 6]} = 0.66^{+0.20+0.02}_{-0.14-0.04}$

1.5$\sigma$ below SM

PRL 128, 191802 (2022)
Beyond flavor

W boson mass
JHEP 01, 036 (2022)

Hadron spectroscopy and $T_{cc}$
arXiv:2109.01038

Antiproton production in pHe collisions (SMOG)
arXiv:2205.09009

$\sqrt{s_{NN}} = 110$ GeV

$p \rightarrow \text{Gas (He,Ne, Ar...)}$
W mass is a key SM parameter

SM value constrained by $m_Z$, $\alpha$, $G_F$

$\sim m_W^{SM} = 80,357 \pm 4_{\text{inputs}} \pm 4_{\text{theor}}$ MeV

$\frac{m_W^2}{m_Z^2} \left( 1 - \frac{m_W^2}{m_Z^2} \right) = \frac{\pi \alpha}{\sqrt{2} G_F} (1 + \Delta)$

Loop corrections, and NP?

Science 376, 6589 (2022)

New CDF measurement 7\(\sigma\) away from SM
LHCb $m_W$ result

$\sim$ Fit $m_W$ and key EW production parameters from

- $W \to \mu\nu$ events: Muon $p_T$
  \[ \frac{\tan((\pi - \Delta \phi)/2)}{\cosh(\Delta \eta/2)} \sim \frac{p_T^2}{M^2} \]

- $Z \to \mu\mu$ events: $\phi^* = \frac{\Delta \phi}{\Delta \eta} \sim \frac{p_T^2}{M^2}$

$\sim$ Extensive calibration with $Z$, $\Upsilon$, $J/\Psi$ data

$\sim$ Proof-of-concept analysis with 25% of current LHCb data
  - Aim to $\sigma < 20$ MeV with full LHCb data

$m_W = 80,364 \pm 23_{\text{stat}}^{+11}_{-17} \text{exp} \pm 9_{\text{PDF}} \text{ MeV}$

Powerful combination with ATLAS/CMS due to anticorrelation on PDFs
Hadron spectroscopy and $T_{cc}$

~ Hadron spectroscopy key to understand non-perturbative QCD 
~ Many exotic tetra/pentaquarks 
~ All decay strongly, could be molecules

~ $T_{cc}^+ (cc\bar{u}\bar{d}) \rightarrow D^0\bar{D}^0\pi^+$ first open-charm tetraquark
~ Longest lived, $\Gamma = 410 \pm 165$ MeV
~ Paves the way for search of $b\bar{b}u\bar{d}$
~ Predicted below $BB$ threshold $\rightarrow$ weak decay

Manuel Franco Sevilla

Recent results from LHCb

Figure 1: The $D^0\bar{D}^0\pi^+$ mass distribution. The $D^0\bar{D}^0\pi^+$ mass distribution where the contribution of the non-$D^0$ background has been statistically subtracted. The result of the fit described in the text is overlaid.

Table 1: Signal yield, $N$, Breit–Wigner mass relative to $D^+D^0$ mass threshold, $m_{BW}$, and width, $\Gamma_{BW}$, obtained from the fit to the $D^0\bar{D}^0\pi^+$ mass spectrum. The uncertainties are statistical only.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N$</td>
<td>117 $\pm$ 16</td>
</tr>
<tr>
<td>$m_{BW}$</td>
<td>273 $\pm$ 61 keV/$c^2$</td>
</tr>
<tr>
<td>$\Gamma_{BW}$</td>
<td>410 $\pm$ 165 keV</td>
</tr>
</tbody>
</table>

The results are found to be consistent among all samples and analysis techniques. Furthermore, dedicated studies are performed to ensure that the observed signal is not caused by kaon or pion misidentification, doubly Cabibbo-suppressed $D^0K^+\pi^+$ decays and $D^0D^0$ oscillations, decays of charm hadrons originating from beauty hadrons, or artefacts.

arXiv:2109.01038
Dark matter and SMOG

The Cosmic-Ray Antiproton Excess

- Many of us in the cosmic-ray community have been somewhat skeptical of the anti-proton excess, driven by concerns pertaining to the systematic uncertainties associated with the antiproton production cross section.
- To convince us that this excess is real, it is imperative that laboratory measurements of this cross section be improved – if you have ideas of how to do this, please talk to me!

~ LHCb has unique capability to inject gas into interaction point (SMOG)
  - Provided most precise measurement of LHC luminosity
    - JINST 9 P12005 (2014)

~ Can also be used as fixed-target experiment
  - Highest energy in the world, $\sqrt{s_{NN}} = 110$ MeV
  - First measurement of prompt $\bar{p}$ production in $p$ He collisions
    - PRL 121, 222001 (2018)
Measure production of $\bar{p}$ in hyperon decays

- Hyperon lifetime results in detached vertex

$\sqrt{s_{NN}} = 110$ GeV

\[ R_{\bar{p}} \equiv \frac{\sigma(pHe \rightarrow HX \rightarrow \bar{p}X)}{\sigma(pHe \rightarrow \bar{p}_{\text{prompt}}X)} \]

Models largely underestimate hyperon contributions to $\bar{p}$ total yield

- Valuable input to improve predictions for secondary $\bar{p}$ cosmic flux

Recent results from LHCb
LHCb upgrades

Upgrade I (2019-21)
CERN-LHCC-2012-007

Upgrade II (2033-34)
CERN-LHCC-2017-003,
CERN-LHCC-2018-027,
CERN-LHCC-2021-012

The LHCb upgrades, LHCP 2022

LHCb Upgrade II

20/05/22

Upgrade I will not saturate precision in many key observables, so a further upgrade is necessary to fully realise the flavour-physics potential of the HL-LHC. There is steady progress towards plans for an Upgrade II, that will operate in Runs 5 and 6. Now part of the CERN baseline plan. Framework TDR recently approved by LHCC.

Tracking in LHCb and stand-alone track reconstruction for the Scintillating Fibre Tracker at the LHCb upgrade

• Read-Out system: the SiPM are connected to the Front-End electronics where dedicated algorithms (implemented in FPGA) are used to process the SiPM output producing clusters. Clusters are sent to the online into a packed form matching the bandwidth requirements and are used to perform track reconstruction.

The fibers mats in the first and fourth \(x\)-layer (within the same station) are vertically oriented, i.e. the fiber mats are parallel to the \(y\) axis of the laboratory frame. Therefore, the read-out of a \(x\)-layer provides the direct measurement of the \(x\) track (\(z\) layer) position. The second (\(u\)) and the third (\(v\)) layers are identical to the \(x\)-layer, but their fiber mats are tilted with respect to the \(x\)-layer by \(+5\) and \(-5\) respectively. The read-out of the \(u/v\)-layers provides the \(u\) and \(v\) stereo coordinates, which are used to extract the information on the \(y-z\) plane motion of the particles. The main geometrical information used in pattern recognition algorithms when dealing with \(u/v\)-layers are sketched in Fig. 4.10. In the following a description of the SciFi elementary components is provided as well as the flow of information to produce an actual hit, the elementary object used for pattern recognition.
Recent results from LHCb

Upgrade I

<table>
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<tr>
<th>Run 1</th>
<th>LS1</th>
<th>Run 2</th>
<th>LS2</th>
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Upgrade I

<table>
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<th>Upgrade I (being installed)</th>
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<tbody>
<tr>
<td><strong>40 MHz</strong> pp collisions</td>
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</tr>
<tr>
<td>LO Hardware 1.1 MHz Detector readout</td>
<td>Detector readout</td>
</tr>
<tr>
<td>HLT Software 12.5 kHz (0.6 GB/s) Events on disk</td>
<td>HLT Software 100 kHz (2-5 GB/s) Events on disk</td>
</tr>
</tbody>
</table>

All electronics upgraded to send every hit to flexible software trigger (GPUs + CPUs)

Increase granularity and longevity of 3 new trackers

5x higher inst. lumi. to $2 \times 10^{33}$ cm$^{-2}$s$^{-1}$, 5 visible interactions/crossing

CERN-LHCC-2012-007
Upgrade I status

173 servers with PCIe40 cards housing GPUs & FPGAs

SMOG2 installed, gas density ~100x larger

New RICH optics commissioned, taking data

SciFi installed in February

Pixel VELO just installed!

UT installation later in the year, not essential for early physics

1417 new RICH optics commissioned, taking data

173 servers with PCIe40 cards housing GPUs & FPGAs

SMOG2 installed, gas density ~100x larger

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SciFi installed in February

Pixel VELO just installed!

UT installation later in the year, not essential for early physics

CERN-LHCC-2019-005

UT installation later in the year, not essential for early physics

1417 new RICH optics commissioned, taking data
Preparation for Upgrade II

~ Targeting Run 3 detector performance at $1.5 \times 10^{34}$ cm$^{-2}$s$^{-1}$, pile-up of ~40!

~ Excellent radiation tolerance, higher granularity, precise timing information (~15 ps)

~ Framework TDR approved by LHCC CERN-LHCC-2021-012

~ Fantastic physics reach

CERN-LHCC-2018-027

Recent results from LHCb

Manuel Franco Sevilla

Slide 37
~ **Vey broad physics program** at LHCb
  - CP violation
  - Tests of Lepton Flavor Universality violation
  - Electroweak measurements
  - Hadron spectroscopy
  - Nuclear cross sections from fixed target mode

~ **Detector upgrades** to fully exploit the LHC potential for flavor physics and beyond
  - **Upgrade I** near completion, basically a new detector!
  - **Upgrade II** aims to record 300 fb⁻¹