LHCb: Results and plans

Miami 2010
December 16th, 2010

Xabier Cid Vidal
University of Santiago de Compostela, on behalf of the LHCb collaboration
Outline

- Introduction to LHCb:
  - Our detector, trigger and reconstruction; and how they performed in 2010

- Early physics results
  - $K_s$, $b\bar{b}$ production cross sections
  - $J/\Psi$ studies
  - Preliminary DCPV and $B^0\bar{B}^0$ oscillation

- Prospects for next year
  - $\Phi_s$ from $B_s \to J/\Psi\Phi$
  - Rare decays
  - Charm

- Conclusions
Introduction to LHCb
The LHCb experiment at CERN
LHCB Overview (I)

- LHCB searches indirectly for New Physics in the $b$ (and $c$) sectors. This approach can access higher energy scales and see **NP effects earlier**. It has happened before in the history of physics...
- NP enters through contributions from virtual heavy particles in loop-mediated processes
- LHCB physics divided in two main categories:
  - **Study of FCNC**
    - Search for $\Phi_s$ angle ($B_s \rightarrow J/\Psi\Phi$)
    - Rare Decays: $BR(B_s \rightarrow \mu\mu)$, $A_{FB}(B \rightarrow K^*\mu\mu)$
    - CP violation phase in charm mixing
  - **CKM “precision” measurements**
    - Compare two measurements of the same quantity sensitive and not to the NP (tree vs loop)
    - $\gamma$: $B_s \rightarrow D_s K$, $B_s \rightarrow hh$
LHCb Overview (II)

- LHCb designed for b physics. Some of its **strongest points** are:
  - Vertexing and IP
  - PID
  - Momentum and mass resolution
  - Flexible trigger
  - **Forward spectrometer**! Angular coverage 10-250 mrad (V) and 10-300 mrad (H)

- LHCb is complementary to the other LHC experiments!
Introduction to LHCb

Our detector, trigger and reconstruction; and how they performed in 2010
LHCb detector

- Tracking: Vertex Locator, Silicon Tracker (TT and IT), Outer Tracker
- Particle Identification: RICHs, Calorimeters, Muon System
- Magnet: momentum measurement
Excellent performance of the detector, trigger and reconstruction!

First LHC collisions at 3.5 TeV
30 March 2010 – around 1pm

First $B^+ \rightarrow J/\Psi \ K^+$ Candidate
5 April 2010 – around 1am
Excellent performance of the detector, trigger and reconstruction!

Efficiency of the different channels (total number 544063)

LHCb integrated luminosity

(≈37 pb⁻¹ recorded out of ≈42 →90% eff.)

And this in spite of up to more than 2.5 interactions per crossing on average (nominal ≈0.4). Significantly harsher conditions than design:
- multiple primary vertices
- high occupancies, track multiplicities
LHCb trigger

- LHCb trigger has two levels:
  - LO (hardware)
  - HLT (software)

- The trigger has been changed continuously to cope with the different running conditions.

- Trigger efficiencies determined on data in good agreement with simulation.

<table>
<thead>
<tr>
<th>Muon trigger (J/ψ)</th>
<th>Hadron Trigger (D^0, p_T&gt;2.6 GeV/c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>(94.9 ± 0.2) %</td>
</tr>
<tr>
<td>Simulation</td>
<td>(93.3 ± 0.2) %</td>
</tr>
<tr>
<td></td>
<td>(60 ± 4) %</td>
</tr>
<tr>
<td></td>
<td>66 %</td>
</tr>
</tbody>
</table>
Vertexing, tracking and PID (I)

- **Vertexing:**
  - good vertex resolution crucial for high-level triggers and most physics analysis

- **Tracking:**
  - excellent momentum resolution for invariant mass resolution, rejection of combinatorial backgrounds

- **Calorimeters:**
  - trigger on hadronic decay channels
  - reconstruction of final states with $e$, $\gamma$, $\pi^0$
Muon identification: Extrapolate tracks to muon system and obtain associated hits

RICH: 
- K/π identification very important for separation of B decays with identical topology, as $B \rightarrow hh$

- No PID, π mass assumed for both decay particles

- Apply PID cuts

$Y(1s),(2s),(3s) \rightarrow \mu^+\mu^-$
Early physics results
First measurement for LHCb with 2009 run data ($\sqrt{s}=0.9$ TeV)
- $K_S \rightarrow \pi^+\pi^-$ selection based on tracking and impact parameters

bb production cross section

- Obtained with the decay $B^0 \rightarrow D^0 \mu^- \nu X^+$
  - reconstruct $D^0 \rightarrow K^- \pi^+$ decay mode
  - reconstruct $D^0 \mu^-$ pairs from a common vertex, and $D^0$ from $B$ by large impact parameter
  - use wrong-sign $D^0 \mu^+$ pairs to estimate background

- Measured $\sigma(pp \rightarrow b\bar{b}X)$

<table>
<thead>
<tr>
<th>Within LHCb acceptance (2&lt;\eta&lt;6)</th>
<th>Total (estimated with Pythia to full phase space)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma(\mu b)$</td>
<td>$75 \pm 5.4 \pm 13$</td>
</tr>
</tbody>
</table>

~in agreement with MC used in sensitivity studies (~250 \mu b).

- Second LHCb publication:
  
Prompt J/Ψ and b→J/ΨX

- Use distribution of “pseudo proper time”, $t_z$, to identify J/Ψ from b
  - Can measure prompt and “from b” production cross sections!

- For prompt production, measurement uncertainties dominated by unknown J/Ψ polarization, will eventually be measured.
  - Prompt J/Ψ differential cross section:
Prompt $J/\Psi$ and $b\rightarrow J/\Psi X$

- Use distribution of “pseudo proper time”, $t_z$, to identify $J/\Psi$ from $b$
  - Can measure prompt and “from $b$” production cross sections!
- For $J/\Psi$ from $b$, measurement can be use to obtain the $bb$ production cross section.
  - $\sigma(pp\rightarrow bbX)$:

<table>
<thead>
<tr>
<th>Within LHCb acceptance ($2&lt;\eta&lt;6$)</th>
<th>Total (estimated with Pythia to full phase space)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma (\mu b)$</td>
<td>$1.16 \pm 0.01 \pm 0.17$</td>
</tr>
<tr>
<td></td>
<td>$295 \pm 4 \pm 48$</td>
</tr>
</tbody>
</table>

- In agreement with measured in published result ($\sigma = 284 \pm 20 \pm 49 \mu b$)
Separate into $B^0$ and $\bar{B}^0$ using particle identification
- Raw asymmetry shows CP Violation at $3\sigma$
- Preliminary! Small corrections from production and detector asymmetry still to be corrected!

$B^0 \rightarrow K^+\pi^-$

$\bar{B}^0 \rightarrow K^-\pi^+$

\[
A_{CP} = \frac{\Gamma(\bar{B}^0 \rightarrow K^-\pi^+)-\Gamma(B^0 \rightarrow K^+\pi^-)}{\Gamma(\bar{B}^0 \rightarrow K^-\pi^+)+\Gamma(B^0 \rightarrow K^+\pi^-)}
\]

$A_{CP}$ Belle: $-0.094 \pm 0.020$

$A_{CP}$ Babar: $-0.107 \pm 0.019$
First oscillation signal seen in:

\[ B^0 \rightarrow D^{*-}(D^0\pi^-)\mu^+\nu_\mu \]

- Lepton tag and opposite-side Kaon tags used to tag initial flavour of B meson
- Performance currently at ~50% of expectation, calibration on data ongoing

b tagging is crucial for several LHCb analysis!
Prospects for next year
Φs from \( B_s \to J/\psi \Phi \)

- \( B_s - \bar{B}_s \) mixing phase \( \Phi_s \): small in the Standard Model, can be enhanced by New Physics. Some hints from CDF/D0 but not significant

- *Golden channel* for \( \Phi_s \): time-dependent CP asymmetry in \( B_s \to J/\psi \Phi \).
  - requires **large statistics** for angular analysis to separate CP even and CP odd final states. Fit to \( B_s \) differential decays rates with **9 physics and 15 detectors parameters**
  - requires **flavour tagging** to tag initial \( B_s \)
  - requires **excellent proper-time resolution** to resolve fast \( B_s - \bar{B}_s \) oscillation (\( \Delta m_s = 17.8 \) ps\(^{-1} \)). Currently \( \sim 60 \) fs where 38 fs expected (we are trying to understand why)

**35k selected events expected per fb\(^{-1} \)**
(CDF: 7k events with 5.2 fb\(^{-1} \))
FCNC very suppressed in the SM:
- $\text{BR}(B_s \rightarrow \mu \mu) = (3.35 \pm 0.32) \cdot 10^{-9}$

Current experimental upper limit (CDF) $\sim 10$ times higher!

NP can modify the BR from smaller SM up to current experimental upper limit $\rightarrow$ Any measured value will constraint NP searches!

Analysis with 3-dimensions binned likelihood:
- Invariant mass of muon pair
- Muon identification
- Geometrical Likelihood or GL (combines lifetime, IP, DOCA...)

Use control channels to calibrate likelihoods from data and normalize: $B^+ \rightarrow J/\Psi K^+$, $B \rightarrow hh$, $B_s \rightarrow J/\Psi \Phi$
The $\gamma/Z$ penguin diagram of $B^0 \to K^*\mu^+\mu^-$ introduces a forward-backward asymmetry in the $B$ rest frame. This asymmetry can be affected by NP!

- Study the forward-backward asymmetry vs the $q^2$ of the muons
- **Yields:**

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHCb (expected per $fb^{-1}$)</td>
<td>1.4 k</td>
</tr>
<tr>
<td>Belle (85% of data)</td>
<td>250</td>
</tr>
<tr>
<td>Babar (75% of data)</td>
<td>100</td>
</tr>
<tr>
<td>CDF (4.4 $fb^{-1}$)</td>
<td>100</td>
</tr>
</tbody>
</table>

Most critical part of the analysis: understand biases from acceptance, trigger, selection, PID.
Prospects in the charm sector

- The charm sector has **high sensitivity** to New Physics. LHCb is ideal for charm physics: we have already **overtaken B factories yields**!

- Physics example: **CP violation in D⁰-\bar{D}⁰ lifetime asymmetries**:

  \[
  A_\Gamma \equiv \frac{\tau(\bar{D}^0 \rightarrow K^+K^-) - \tau(D^0 \rightarrow K^+K^-)}{\tau(\bar{D}^0 \rightarrow K^+K^-) + \tau(D^0 \rightarrow K^+K^-)}
  \]

  - Use slow pion from D^{*+} → D⁰n⁺ to tag D⁰ flavour
  - **Competitive measurement** expected very soon!
and the best is yet to come...
Conclusions
Conclusions

☐ LHCb designed to search for **new physics through the loops** → access higher energy scales and do it earlier!

☐ **The experiment is working really fine.** Data approaching MC in tracking, vertexing and PID.

☐ **First physics results** obtained in 2010 showing the potential of LHCb (e.g. $b\bar{b}$ cross section measurement, observation of direct CP violation).

☐ 2011 will be (hopefully) our year. **We have a very nice chance of seeing new physics** (if it is there!)
  - $\Phi_s$ from $B_s \rightarrow J/\Psi\Phi$
  - $BR(B_s \rightarrow \mu^+\mu^-)$
Backup
Measure differential cross sections in bins of pseudo-rapidity up to $\eta = 4.5$ and transverse momentum down to $p_T = 0$
  - large uncertainties on theory predictions
  - use impact parameter to reject “D from B”
  - separate measurements for $D^0$, $D^{*+}$, $D^+$, $D_s^+$

Use published fragmentation fractions to calculate also open charm cross-section for each analysis and take least-squares fit, measured $\sigma(pp \to \bar{c}c)$

<table>
<thead>
<tr>
<th>Within LHCb acceptance (2&lt;\eta&lt;6)</th>
<th>Total (estimated with Pythia to full phase space)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma \text{ (mb)}$</td>
<td>$1.23 \pm 0.19$</td>
</tr>
<tr>
<td></td>
<td>$6.10 \pm 0.93$</td>
</tr>
</tbody>
</table>

~in agreement with expected $\sigma(pp \to \bar{c}c) \sim 20 \times \sigma(pp \to \bar{b}b)$
γ angle

- Direct measurement of γ has large errors $(70^{+21}_{-25})^\circ$ compared with indirect measurements.

- LHCb expected sensitivities:

<table>
<thead>
<tr>
<th>From trees</th>
<th>From loops</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma (\gamma) (1 \text{ fb}^{-1})$</td>
<td>$8^\circ$</td>
</tr>
<tr>
<td>$\sigma (\gamma) (2 \text{ fb}^{-1})$</td>
<td>-</td>
</tr>
<tr>
<td>$\sigma (\gamma) (~10 \text{ fb}^{-1})$</td>
<td>$1.2^\circ$ - $2.7^\circ$</td>
</tr>
</tbody>
</table>
a_{fs} in LHCb

- **Inclusive method** (similar to the one of D0) is difficult at LHCb due to the $\sim 10^{-2}$ production asymmetry in pp collisions and control of detector asymmetry.

- **Subtraction method** in semi-leptonic modes used instead:
  - $B^0 \rightarrow D^- \mu^+ \nu$ and $B^0_s \rightarrow D_s^- \mu^+ \nu$ (same final state $K^+ K^- \pi^- \mu^+$)
  - Measure the difference between $B^0_s$ and $B^0$, substract non time dependent part of $A_{fs}^d$ and $A_{fs}^s$:

\[
\Delta A_{fs}^{s,d} \sim \frac{a_{fs}^s - a_{fs}^d}{2}
\]

- difference suppresses production asymmetry
- same final state suppresses detector biases

**KKn, D_s^+ mass difference**

- LHCb Preliminary

- Measure the difference between $B^0_s$ and $B^0$, substract non time dependent part of $A_{fs}^d$ and $A_{fs}^s$:

- LHCb: MC stat. uncertainty only