Early Physics in LHCb

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Representing LHCb collaboration
LHCb Detector

- Looks at pp collisions at LHC in a unique way

- **Forward acceptance:**
  - Optimal for $b\bar{b}$ physics, affordable
  - Will complement the central detectors in studies of hadronic physics in early stages of LHC
Design luminosity

- LHCb design luminosity is much smaller than the LHC design luminosity of $10^{34}$ cm$^{-2}$s$^{-1}$:
  - Smaller occupancies, less confusion
  - Little pile-up ($n=0.5$)
  - Less radiation damage
  - Nominal design luminosity is $2\times10^{32}$ cm$^{-2}$s$^{-1}$
  - Detector can withstand up to $5\times10^{32}$ cm$^{-2}$s$^{-1}$ (beams will be defocused to prevent further increase in instantaneous luminosity) but only channels with muons benefit from the increase

- LHC 2010 run will approach optimal running conditions for LHCb

- After a few years of running LHCb physics reach will saturate
- LHCb detector upgrade plan for 2015:
  - Rebuilt the detector to operate at luminosities up to $2\times10^{33}$ cm$^{-2}$s$^{-1}$
Vertex detector (VELO)

- **Long vertex detector, very close to the beam:**
  - Forward particle momenta minimize multiple scattering effects
  - Excellent impact parameter (~30 μm) and decay time resolutions (~40 fs)
  - Designed for beauty and charm detection:
    - triggering, background suppression and measurement of time dependent CP-asymmetries
  - In very early LHC phases it will aid production studies of strange V0s ($K^0_s \to \pi\pi$, $\Lambda \to p\pi$)
  - Unique sensitivity to NP particles decaying to bb with long lifetime
Tracking system

- Good momentum (0.35-0.5%) and mass resolution (~15 MeV for B)
Hadron identification

- **Good $\pi/K/p$ separation is a unique feature compared to central detectors:**
  - Important for background suppression in B and D reconstruction and for **flavor tagging**: $\varepsilon D^2 \sim 6\% (4\%)$ for $B_s (B_d)$
  - Inclusive charged hadron spectra from early data

![Diagram of RICH1 and RICH2](image)

![Plot of Kaon identification performance](image)

- $K \rightarrow K$, $Pr: 97.29 \pm 0.06 \%$
- $\pi \rightarrow K$, $Pr: 5.15 \pm 0.02 \%$
Muon detector, calorimeters and L0 trigger

L0 hardware trigger (customs boards) with 4 μs latency (40MHz→1MHz):

- Extrapolation through the magnet to the interaction region gives μ momentum in L0

- Muon detector:
  - Low reconstruction thresholds in offline and trigger: p>3 GeV, p_t>0.5 GeV
  - Single- and di-muon triggers: p_{t1} + (p_{t2}) >~1.3 GeV

- HCAL:
  - triggering on purely hadronic B decays: E_t > ~3.6 GeV

- ECAL:
  - triggering on electrons and photons: E_t > ~2.7 GeV
  - Offline electron ID, photon and π⁰ reconstruction ( \( \sigma(E)/E \sim 8.2% /\sqrt{E} + 0.9% \) )

- Minimum bias trigger in early running based on total energy in calorimeters
HLT trigger

Online computer farm.

- **Early running:**
  - Write data out at nominal frequency:
    - Offline data processing assumes ~2kHz but we can actually log data at higher rates (event size ~35 kB)
  - Tighten trigger criteria with increasing luminosity
  - Muon triggers provide safe fall back strategy

- **HLT1:** 1MHz → 30kHz
  - Confirm L0 seeds with tracking detector hits/tracks
  - Improve \( p_t \) determination.
  - Reconstruct primary vertices.
  - Optionally add Impact Parameter cuts
  - Add companion tracks for secondary vertex cuts

- **HLT2:** 30MHz → 2kHz
  - Full event reconstruction.
  - Inclusive and exclusive physics selections.
Commissioning

Muons reconstructed in VELO from beam stop during injection tests on August 24, 2008

• Detector is installed and ready for data
First Measurements

- Late 2009/early 2010
- Inelastic collision rate reaches our event logging rate (~2kHz) already at luminosity of ~4x10^{28} cm^{-2}s^{-1}
- Use minimum bias trigger \( \frac{\sigma}{\sigma_{mb}} \)
- ~10^8 events in a day
- Detector calibration and alignment
- Physics of minimum bias interactions, tuning of MC generators

Physics reach vs accumulated minimum bias statistics
Example: Strange baryon production

- **Strangeness is a good probe for fragmentation processes:**
  - Created in fragmentation
  - Heavier, but not too heavy s-quark mass
- **Existing minimum bias/underlying event models tuned to CDF/D0 data (central region, higher $p_t$):**
  - Need also measurements in forward region and lower $p_t$ to distinguish different models at LHC – LHCb is well suited for this!
- **Transport of beam baryon number can distinguish different models of color flow:**
  - Strange baryon / anti-baryon asymmetries
  - Effects are larger closer to the beam: larger $\eta$ smaller $p_t$ – LHCb!
$\Lambda/\Lambda$ ratio vs $\eta$

### LHC 10 TeV

**Inelastic, Non-Diffractive**

$\Lambda^0$bar / $\Lambda^0$ $\eta$ Distribution (generator-level)

- Perugia 0
- Pro-pT0
- DW-Pro
- A

**Pythia 6.420**

- **ATLAS/CMS ~1% effect**
- **LHCb ~5% effect**

**Older models:**
- Baryon number locked in the beam remnant

**Newer models:**
- Baryon number “liberated” via different multi-parton dynamics

- From Peter Skands:
$\Lambda / \bar{\Lambda}$ ratio with LHCb

Cuts: DoCA $\leq 0.3$ mm, $ct \geq 4$ mm, $IP \leq 0.1$ mm, $p_{t,\text{wrt mother}} \geq 10$ MeV (no PID cuts)

- MC: $\sim 10^7$ minimum bias events
\( \frac{\Lambda}{\Lambda} \) ratio with LHCb

- With \(10^8\) minimum bias events expect statistical errors of \(~1.3\%\) per bin
- We will be able to distinguish between the old and new MPI models

MC: \(~10^7\) min.bias events

See talk by Markward Britsch at DIS 2009, 26-30 April 2009, Madrid
D/D ratios with LHCb

- Geometric and kinematic cuts only (no PID used)
- For $1.8<\eta<3.5$ with $10^8$ minimum bias events expect:
  - ~5% error on $\overline{D^0}/D^0$
  - ~6% error on $D^-/D^+$

MC: ~$10^7$ min. bias events
Early running with loose muon trigger

- **Spring 2010, ~5 pb\(^{-1}\)**
- **Use lifetime unbiased single muon trigger with \(p_t > 1\) GeV**
- **Clean J/\(\psi\)\(\rightarrow\)\(\mu\mu\) signal without biasing the 2\(^{nd}\) muon:**
  - Can study trigger and muon identification efficiencies
- **Physics with J/\(\psi\):**
  - **Prompt** production studies, including polarization:
    \(\sigma_{\text{prompt}} \approx 3100\) nb with both muons in \(2.5<\eta<5.5\)
  - \(b\bar{b}\) cross-section via \(b\rightarrow J/\psi\ X\): \(\sigma_{b \rightarrow J/\psi} \approx 240\) nb (7%)
  - Other charmonium states via decays to J/\(\psi\)

*(Wenbin Qian who was supposed to report on J/\(\psi\) studies at this workshop did not receive US visa on time)*
J/ψ production studies

MC: ~2x10^7 minimum bias events

- **Selection:**
  - 1 primary vertex
  - 2 identified muons, forming a common vertex
  - 1 muon with p_t > 1.5 GeV

- **Expect ~2.1x10^6 events in 5 pb^-1 at 8 TeV**
- **Mass resolution ~11 MeV**
- **S/B~4** (background dominated by decays in flight)

- **Use fit to proper time distribution to disentangle prompt and b components**
J/ψ production studies

- We will measure prompt J/ψ and b̅b cross section in a region not accessible to other collider experiments.
**χc production studies**

- At Tevatron \(\sim 30\%\) of J/ψ come from \(\chi_{c1,2} \rightarrow \gamma J/ψ\).
- Model builders interested in measurements of \(\sigma(\chi_{c2})/\sigma(\chi_{c1})\).

Mass resolution is \(\sim 27\) MeV

\(M(\chi_{c2}) - M(\chi_{c1}) = 55\) MeV

Some sensitivity to \(\sigma(\chi_{c2})/\sigma(\chi_{c1})\)
Other charmonium/bottomonium studies

- \( \psi(2S) \rightarrow \pi\pi J/\psi \) production
  - measure \( \sigma(\psi(2S))/\sigma(J/\psi) \)
  - polarization

- \( X(3872) \rightarrow \pi\pi J/\psi \)
  - CDF has the world largest sample
  - About \( \sim 20\% \) from \( B \rightarrow X(3872) \) \( K \)
    - Especially useful for \( J^{PC} \) determination (1\( ^{++} \) or 2\( ^{-+} \)?) because of known polarization
    - Advantages of LHCb:
      - Higher cross-section. Kaon ID.

- \( B \rightarrow Z(4430)^+ K, Z(4430)^+ \rightarrow \psi(2S) \pi^+ \)

- Production and polarization of \( \Upsilon \rightarrow \mu\mu \)
  (~37 MeV mass resolution)

- \( \Upsilon(nS) \rightarrow \pi\pi \Upsilon \), including possible \( Y_b(10890) \) hybrid state
Drell-Yan at low-x

- LHCb has unique coverage in $\eta$ reaching towards low-x
- LHCb muon reconstruction and trigger thresholds are low:
  - Reconstruction:
    - $p > 3\text{GeV}$, $p_t > 0.5 \text{GeV}$
  - Prompt di-muon trigger:
    - $p_{t1} + p_{t2} > 1.5 \text{GeV}$,
    - $M_{\mu\mu} > 2.5 \text{GeV}$
    - no IP cuts
- LHCb will provide unique constraints on PDFs

$x_{1,2} = M_{\mu\mu} \exp(\pm \eta) / \sqrt{s}$
Drell-Yan at low-x

After all cuts

- Signal
- HQ decays
- Mis-id

<table>
<thead>
<tr>
<th>Mass range (GeV)</th>
<th>Events/pb-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$2.5 &lt; M_{\mu\mu} &lt; 5$</td>
<td>119.1 ± 1.0</td>
</tr>
<tr>
<td>$5 &lt; M_{\mu\mu} &lt; 10$</td>
<td>287.3 ± 1.6</td>
</tr>
<tr>
<td>$10 &lt; M_{\mu\mu} &lt; 20$</td>
<td>147.6 ± 0.9</td>
</tr>
<tr>
<td>$20 &lt; M_{\mu\mu} &lt; 40$</td>
<td>42.3 ± 0.4</td>
</tr>
</tbody>
</table>

- See Jonathan Anderson talk at DIS 2009, 26-30 April 2009, Madrid
Drell-Yan at low-x

- Substantial constraints at low-x (down to $\sim 1.5 \times 10^{-6}$)
Early B physics results

• Early analyses, even though interesting in their own right, are stepping stones for B physics program

• Best world measurements in many important B decay channels can be obtained even with as little as 200 pb$^{-1}$

• **Late 2010**: as luminosity increases, muon triggers will be tightened while continuing to commission hadronic and e,$\gamma$ triggers

• Show two examples for $B_s$ results relying on muon triggers only (see next)

• First measurements of angle $\gamma$ relying on hadronic triggers are also likely
Measurement of $\phi_s$

- Phase of $B_s^{-}$-$\bar{B}_s$ oscillations
- Very small in SM. Sensitive to NP contributions.
- $B_s \rightarrow J/\psi \phi$
  - Simultaneous fit of CP asymmetry to time and angular distributions (to disentangle CP-odd and -even amplitudes)
- At present CDF+D0 results $\sim 2.2\sigma$ away from SM prediction
- LHCb has much better sensitivity:
  - Large signal yield ($13k/200 \text{ pb}^{-1}$), excellent time resolution ($\sim 40 \text{ fs}$) and flavor tagging ($\sim 6\%$)

200 pb$^{-1}$
**BR(B_s → μμ)**

- Very small in SM. Sensitive to NP contributions.
- LHCb exploits high cross-section, high trigger efficiency, good mass resolution (~18 MeV) and vertexing, and good muon ID.
- Background from two semileptonic b decays

![Graph showing BR(B_s^0 → μ^+μ^-) vs. L (fb^{-1})](image)

**Standard Model:**

![Standard Model Feynman diagram](image)

**SUSY (MSSM):**

![SUSY (MSSM) Feynman diagram](image)

90% C.L. exclusion limits at 8 TeV CM

\[ \sim \tan^6 \beta \]

Could be strongly enhanced.
Hidden Valley NP

- Hidden Valley models:
  - Predict light new particles, hidden from us at existing accelerators, since their production goes via heavy intermediate particles
  - LHCb has unique capabilities for detection of anything decaying to $b\bar{b}$, even with a substantial lifetime (hundreds of ps).

For favorable model parameters LHCb could observe a few hundred events in $200\text{pb}^{-1}$ with small background if $m_h \sim 120$ GeV
Conclusions

• With $10^8$ minimum bias events (1 day of running with minimum bias trigger at low luminosity) LHCb will do interesting measurements testing theoretical models:
  – Complementary to ATLAS/CMS since at larger $\eta$ and lower $p_t$
  – Strange particles ratios in forward region will distinguish old and new fragmentation models

• With 5-10 pb$^{-1}$ and muon triggers
  – $J/\psi$ production studies in forward region:
    • Prompt and $b$- production
    • Measurements of $b\bar{b}$ cross-section
    • Heavier charmonium states including exotics
  – Meaningful constraints on PDFs at low-$x$ from Drell-Yan at low $Q^2$

• With 200 pb$^{-1}$ first results from rare B decays. LHCb will take over Tevatron in $B_s$ physics:
  – Will the disagreement with SM in $\phi_s$ deepen or ease up?
  – Any hints of NP in $\text{BR}(B_s \to \mu\mu)$?