Studies of suppressed processes in B-meson decays and of mixing/CP violation in the $B_s$ system with the ATLAS detector

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The 2013 European Physical Society Conference on High Energy Physics
July 18th-24th, 2013

Jochen Schieck - Flavour Physics at ATLAS
Overview

• Flavour tagged time dependent angular analysis of the decay $B_s \rightarrow J/\Psi \Phi$ and extraction of $\Delta \Gamma_s$ and the weak phase $\Phi_s$

• Angular Analysis of the decay $B^0 \rightarrow K^{0*}\mu^+\mu^-$

ATLAS-CONF-2013-039

ATLAS-CONF-2013-038
EXPERIMENTAL SETUP
The ATLAS Experiment and Data Sample

- Analyses based on 4.9 fb\(^{-1}\) collected in 2011
- Max inst. luminosity \(\sim 3.5 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}\)
  - up to 12 collisions / event on average
- Expect about \(\sim 0.5 \times 10^9 \ B^0\)–pairs and \(\sim 10^7 \ B_s \rightarrow J/\psi \phi\) events
  and \(\sim 10^5 \ B \rightarrow K^* \mu^+ \mu^-\) events for 5 fb\(^{-1}\)

Muon Detector trigger and muon identification

Inner Detector momentum and vertex measurement
**Detector Performance**

**Impact Parameter Resolution**

- Good impact parameter resolution required for lifetime based measurements
- Excellent mass resolution required for good S/B performance
- Limited particle ID (only for $p_T < 1$ GeV $K/\pi$ – separation possible)
MEASUREMENT OF $\Delta \Gamma_s$ AND $\Phi_s$ IN THE DECAY $B_s \rightarrow J/\Psi \Phi$
Introduction

• Motivation:
  – Standard Model predicts very small value for $B_s$ mixing phase $\Phi_s = \arg(-M_{12}/\Gamma_{12}) \approx -0.04 \pm 0.002 \approx 2\beta_s$
  – Any significant deviation would be a signal for physics beyond the Standard Model

• Experimental Challenge:
  – Good vertex resolution for time information
  – Significant background (no PID)
  – $J/\psi \Phi$ not a pure CP eigenstate
    $\rightarrow$ statistical decomposition of CP-states
Measurement of $\Delta \Gamma$ and $\Phi_S$ in the decay $B_s \to J/\Psi \Phi$

**Event Selection**

- $J/\Psi$ trigger
- Reconstruction of $B_s \to \mu^+ \mu^- K^+ K^-$ candidate

- Determine mass and proper decay time
- Measure transversity angles of the event
  \[ \tau = \frac{L_{xy} M_{B_s}}{p_{t_B}} \]
  transv. angles: $\theta_T$, $\psi_T$ and $\phi_T$
Charge Flavour Tagging

Task: determine flavour eigenstate of $B_s$-meson at production time

- Opposite side flavour tagging used
- Two different methods applied in hierarchy of performance

**Muon Tagger**
- Identify the muon from semileptonic decay
- Calculate muon cone charge $Q_\mu$

**Jet Charge Tagger**
- Identify jet originating from same primary vertex
- Calculate jet charge $Q_{\text{jet}}$
Charge Flavour Tagging

- Determine probability that signal decay contains $\bar{b}$ as function of $Q_\mu$ and $Q_{\text{jet}}$ using calibration sample $B^+ \rightarrow J/\psi K^+$

<table>
<thead>
<tr>
<th>Tagger</th>
<th>Efficiency [%]</th>
<th>Dilution [%]</th>
<th>Tagging Power [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segment Tagged muon</td>
<td>1.08 ± 0.02</td>
<td>36.7 ± 0.7</td>
<td>0.15 ± 0.02</td>
</tr>
<tr>
<td>Combined muon</td>
<td>3.37 ± 0.04</td>
<td>50.6 ± 0.5</td>
<td>0.86 ± 0.04</td>
</tr>
<tr>
<td>Jet charge</td>
<td>27.7 ± 0.1</td>
<td>12.68 ± 0.06</td>
<td>0.45 ± 0.03</td>
</tr>
<tr>
<td>Total</td>
<td>32.1 ± 0.1</td>
<td>21.3 ± 0.08</td>
<td>1.45 ± 0.05</td>
</tr>
</tbody>
</table>

Summary of Tagging Performance
Measurement of $\Delta \Gamma_S$ and $\phi_S$

- Unbinned maximum likelihood fit taking event-by-event errors into account
- Non resonant $B_s \to J/\psi K^+K^-$ decays included by additional amplitude $A_S$
- Dedicated function to describe background from $B \to J/\psi K^*$ and $B \to J/\psi K\pi$ decays (6.5% and 4.5%)
Measurement of $\Delta \Gamma$ and $\Phi_S$ in the decay $B_s \to J/\Psi \Phi$

$\phi_s = 0.12 \pm 0.25$ (stat.) $\pm 0.11$ (syst.) rad
$\Delta \Gamma_s = 0.053 \pm 0.021$ (stat.) $\pm 0.009$ (syst.) ps$^{-1}$
$\Gamma_s = 0.677 \pm 0.007$ (stat.) $\pm 0.003$ (syst.) ps$^{-1}$
$|A_0(0)|^2 = 0.529 \pm 0.006$ (stat.) $\pm 0.011$ (syst.)
$|A_\parallel(0)|^2 = 0.220 \pm 0.008$ (stat.) $\pm 0.009$ (syst.)
$\delta_\perp = 3.89 \pm 0.46$ (stat.) $\pm 0.13$ (syst.) rad

- Uncertainty on $\Phi_S$ improved by 40% compared to untagged analysis
- Uncertainty statistically dominated
  - 2012 data currently analysed
- Uncorrelated description of background angle dominant systematic uncertainty
ANGULAR ANALYSIS OF $B \rightarrow K^* \mu^+ \mu^-$
Introduction

• FCNC transitions only allowed at loop level and GIM suppressed
• Significant contribution from physics beyond SM possible
• $b \rightarrow s$ transitions offers such possibility with $B \rightarrow K^* \mu^+ \mu^-$ being one exclusive decay mode
Event Reconstruction

- Events triggered on single and di-muon trigger
- Cut based selection optimized for whole $q^2$ region ($q^2$: invariant mass of $\mu$-pair)
- Measure forward-backward asymmetry $A_{FB}$ and longitudinal polarization fraction $F_L$ with unbinned maximum likelihood fit

\[
\frac{1}{\Gamma} \frac{d^2\Gamma}{dq^2d\cos\theta_L} = \frac{3}{4} F_L(q^2) \left( 1 - \cos^2 \theta_L \right) + \frac{3}{8} \left( 1 - F_L(q^2) \right) \left( 1 + \cos^2 \theta_L \right) + A_{FB}(q^2) \cos \theta_L
\]
Signal Observation

• Mass-fit with Gauss function using per-candidate error and exponential background
• $B \rightarrow K^* \mu^+ \mu^-$ signal decay clearly visible
• reconstruct 446±34 signal and 1132±43 background events

Full range of di-muon mass with $J/\psi$ and $\psi(2s)$ region excluded
Measurement of $A_{FB}$ and $F_L$

- Measure $A_{FB}$ and $F_L$ in different regions of $q^2$
- Use unbinned maximum likelihood fit
- Sequential fit approach applied
  - Use mass to separate signal and background contribution
  - Angular fit with result from fit to mass fixed
Result

- Uncertainty statistically limited
- Measurement consistent with SM prediction

<table>
<thead>
<tr>
<th>$q^2$ range (GeV$^2$)</th>
<th>$N_{\text{sig}}$</th>
<th>$A_{\text{FB}}$</th>
<th>$F_L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.00 &lt; $q^2$ &lt; 4.30</td>
<td>19 ± 8</td>
<td>0.22 ± 0.28 ± 0.14</td>
<td>0.26 ± 0.18 ± 0.06</td>
</tr>
<tr>
<td>4.30 &lt; $q^2$ &lt; 8.68</td>
<td>88 ± 17</td>
<td>0.24 ± 0.13 ± 0.01</td>
<td>0.37 ± 0.11 ± 0.02</td>
</tr>
<tr>
<td>10.09 &lt; $q^2$ &lt; 12.86</td>
<td>138 ± 31</td>
<td>0.09 ± 0.09 ± 0.03</td>
<td>0.50 ± 0.09 ± 0.04</td>
</tr>
<tr>
<td>14.18 &lt; $q^2$ &lt; 16.00</td>
<td>32 ± 14</td>
<td>0.48 ± 0.19 ± 0.05</td>
<td>0.28 ± 0.16 ± 0.03</td>
</tr>
<tr>
<td>16.00 &lt; $q^2$ &lt; 19.00</td>
<td>149 ± 24</td>
<td>0.16 ± 0.10 ± 0.03</td>
<td>0.35 ± 0.08 ± 0.02</td>
</tr>
<tr>
<td>1.00 &lt; $q^2$ &lt; 6.00</td>
<td>42 ± 11</td>
<td>0.07 ± 0.20 ± 0.07</td>
<td>0.18 ± 0.15 ± 0.03</td>
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Measurement of $A_{FB}$ and $F_L$

Very competitive measurement in low recoil region
SUMMARY
Summary

• ATLAS able to provide high quality B-physics measurements:
  – measurement of CP violating phase $\Phi_S$ and the decay width difference $\Delta \Gamma_S$ in the decay $B_S \rightarrow J/\Psi \Phi$
  – angular analysis of the decay $B^0 \rightarrow K^{0*} \mu^+ \mu^-$
• Both measurements are consistent with prediction from the Standard Model
  – no sign for physics beyond the Standard Model
• Both measurements are statistically limited
  – analysis including 2012 data ($\sim 20$ fb$^{-1}$) ongoing
Low $p_T \mu^+\mu^-$-Events

Selection of events with b hadron using two muons in the final state

- $\mu^+\mu^-$: ~1.5-14 GeV
- $J/\psi \rightarrow \mu^+\mu^+$: ~2.5-4.3 GeV
- Intermediate $m_{\mu\mu}$: ~4.0-8.5 GeV
- $Y \rightarrow \mu^+\mu^-$: ~8-12 GeV

Adjust trigger rates by increasing thresholds or prescaling