Heavy flavor production at ATLAS

Daniel Scheirich on behalf of ATLAS

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Data collection in 2011 and 2012

- ATLAS triggers for $b$-physics
- $B$-hadron masses
- $B$-hadron lifetimes
- Measurement of $\Lambda^0_b$ lifetime and mass (new result)
- Search for the rare decay $B_s^0 \rightarrow \mu^+\mu^-$
LHC and ATLAS are performing very well

ATLAS recorded luminosity: $5.25 \, fb^{-1}$ in 2011; already $>3 \, fb^{-1}$ in 2012

$B$-physics data selected by muon triggers

2011 integrated luminosity after trigger and DQ selection: $4.9 \, fb^{-1}$
ATLAS triggers for $b$-physics

- Trigger: $b$ decays with di-muon or $J/\psi$ in the final state, e.g. $B_s^0 \rightarrow \mu^+\mu^-$, $\Lambda_b \rightarrow J/\psi(\mu^+\mu^-)\Lambda^0(p^+\pi^-)$, etc.
- No explicit displaced vertex selection requirements → advantage for lifetime measurements
  - $2.5 < m_{\mu\mu} < 4.3$ GeV ($J/\psi$) and $4 < m_{\mu\mu} < 8.5$ GeV ($B$)
- Single-muon trigger with threshold of 18 GeV: wide range of di-$\mu$ mass
- Exclusive decays with $J/\psi$ in the final state
- Mass extracted using unbinned maximum likelihood fit
- Consistency with the world average values $\rightarrow$ good $p_T$ scale determination

**$B$-hadron masses**

- $B^0_d \rightarrow J/\psi (\mu^+ \mu^-) K^0_S (\pi^+ \pi^-)$
- $B^0_s \rightarrow J/\psi (\mu^+ \mu^-) \phi (K^+ K^-)$
- $B^\pm_c \rightarrow J/\psi (\mu^+ \mu^-) \pi^\pm$

ATLAS

ATLAS-CONF-2012-055

5279.6 ± 0.2 ± 1.0 MeV

ATLAS-CONF-2011-092

5363.7 ± 1.2(stat) MeV

ATLAS-CONF-2012-028

6282 ± 7(stat) MeV

ATLAS

5279.50 ± 0.30 MeV

PDG

5366.3 ± 0.6 MeV

6277 ± 6 MeV
**B-hadron lifetimes**

- Good lifetime measurements important for study of CPV
- Results consistent with the world average values
- The $B_0^d$ measurement serves as a cross-check for $\Lambda_b^0$ lifetime and mass measurement (next slides)

**Results**

- $B \rightarrow J/\psi(\mu^+\mu^-)X$
  - ATLAS: $1.489 \pm 0.016 \pm 0.043$ ps
  - PDG: $1.544 \pm 0.014$ ps

- $B_0^d \rightarrow J/\psi(\mu^+\mu^-)K_S^0(\pi^+\pi^-)$
  - ATLAS: $1.509 \pm 0.012$ ps
  - PDG: $1.519 \pm 0.007$ ps

- $B_0^s \rightarrow J/\psi(\mu^+\mu^-)\phi(K^+K^-)$
  - ATLAS: $1.41 \pm 0.04 \pm 0.04$ ps
  - PDG: $1.472 \pm 0.026$ ps

**ATLAS-CONF-2011-145**
**ATLAS-CONF-2012-055**
**ATLAS-CONF-2011-092**

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PLHC 2012
Measurement motivation

- $\Lambda^0_b$ reconstructed in $\Lambda^0_b \to J/\psi(\mu^+\mu^-)\Lambda^0(p^+\pi^-)$ decay mode
- $\Lambda^0_b$ lifetime measured by LEP, Tevatron, and LHC
- Discrepancies between CDF and DØ results: more than 2-$\sigma$ difference
- $\Lambda^0_b$ and $B^0_d$ lifetime ratio is of theoretical interest as it can be predicted by HQET and pQCD:
  - Eur.Phys.J. C33 (2004) S895–S899: $\tau_{\Lambda_b}/\tau_{B_d} = 0.88 \pm 0.05$
  - Phys.Rev. D70 (2004) 094031: $\tau_{\Lambda_b}/\tau_{B_d} = 0.86 \pm 0.05$
- We can improve precision of the world average value of $\Lambda^0_b$ mass:
  $$m_{\Lambda_b}^{PDG} = 5620.2 \pm 1.6 \text{ MeV}$$

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Signal reconstruction and selection

- Cascade topology: secondary ($J/\psi$) and tertiary ($\Lambda^0$) vertices
- $\Lambda^0$ reconstruction efficiency decreases with distance from the centre of the detector → careful study of selection biases is needed
- Selected 4075 $\Lambda_b^0$ and 4081 $\bar{\Lambda}_b^0$ candidates in 4.9 fb$^{-1}$ of 2011 data
Proper decay time

- The proper decay time is calculated for each candidate

\[ \tau = \frac{L_{xy} m_{PDG}^P}{pT} \]

- where \( L_{xy} \) is the measured decay length
- \( m_{PDG}^P \) is the world average value of the \( \Lambda_b^0 \) mass
- Lifetime and mass extracted using the unbinned maximum likelihood fit simultaneously in mass and decay time
Results of the ML fit

Reported in ATLAS-CONF-2012-055, paper in preparation

\[ \tau_{\Lambda_b} = 1.449 \pm 0.036(\text{stat}) \pm 0.017(\text{syst}) \text{ ps} \]

\[ m_{\Lambda_b} = 5619.7 \pm 0.7(\text{stat}) \pm 1.1(\text{syst}) \text{ MeV} \]
Comparison to other measurements\(^2\)

- Lifetime result consistent with the PDG, CDF\(^3\), and LHCb\(^4\) values
- Mass measurement is more precise than the PDG average

\(^4\)LHCb-CONF-2011-001
Theoretical predictions: $0.88 \pm 0.05$ (NLO$^1$) and $0.86 \pm 0.05$ (NLO$^1$)

ATLAS ratio: $R = \frac{\tau_{\Lambda_b}}{\tau_{B_d}^{PDG}} = 0.960 \pm 0.025 \pm 0.016$

Consistent with PDG, compatible with the latest DØ and CDF measurements and theoretical predictions
- Rare decay $B_s^0 \rightarrow \mu^+ \mu^-$ highly suppressed in SM
- Predicted BR: $3.5 \pm 0.3 \times 10^{-9}$
- Process can be highly enhanced by coupling to non-SM heavy particles (e.g. MSSM) → probe of new physics
- ATLAS analysis (arXiv:1204.0735) with 2.4 fb$^{-1}$: limit to BR of $B_s^0 \rightarrow \mu^+ \mu^-$
Search for rare decays $B^0_s \rightarrow \mu^+\mu^-$

Method

- Using reference channel $B^\pm \rightarrow J/\psi(\mu^+\mu^-)K^\pm$ channel
- Branching ratio:
  \[ BR(B^0_s \rightarrow \mu^+\mu^-) = BR(B^\pm \rightarrow J/\psi K^\pm) \times \frac{f_u}{f_s} \times \frac{N_{\mu\mu}}{N_{J/\psi K}} \times \frac{\varepsilon_{J/\psi K} A_{J/\psi K}}{\varepsilon_{\mu\mu} A_{\mu\mu}} \]
- $BR(B^\pm \rightarrow J/\psi K^\pm)$ and relative production probability $\frac{f_u}{f_s}$ from previous measurements (PDG and LHCb)
- Efficiency and acceptance form MC calibrated on data
- Reference channel selected with as-close-as possible selection
- Selection based on 14 variables using BDT
- Half of events in sidebands used to model background, other half to optimize BDT
- CL limit set using frequentist method
Search for rare decays $B_s^0 \rightarrow \mu^+\mu^-$

Unblinded invariant mass distribution

- 3 mass resolution categories: 3 mass windows
- Comparison to MC assuming $BR(B_s^0 \rightarrow \mu^+\mu^-) = 3.5 \times 10^{-8}$ (10-times larger than the SM prediction)
Branching fraction limits

- Circles: observed CL as a function of BR
- Dashed line: expected CL determined by pseudo-experiments setting the counts in the signal region by interpolating sidebands+resonant background before unblinding
- 95% CL limit: $\text{BR}(B^0_s \rightarrow \mu^+\mu^-) < 2.2 \times 10^{-8}$ (red line)
Conclusions

- Good quality data collected in 2011 (∼5 fb$^{-1}$)
- LHC is performing very well in 2012, ATLAS already collected >3 fb$^{-1}$
- $B$-hadron masses consistent with PDG → excellent $p_T$ scale calibration, vertexing and alignment
- $\Lambda^0_b$ mass and lifetime measured with good precision, improving our knowledge of $\Lambda^0_b$ baryon
  \[
  \tau_{\Lambda_b} = 1.449 \pm 0.036(\text{stat}) \pm 0.017(\text{syst}) \text{ ps} \\
  m_{\Lambda_b} = 5619.7 \pm 0.7(\text{stat}) \pm 1.1(\text{syst}) \text{ MeV}
  \]
- Measured lifetime consistent with PDG, CDF, and LHCb result
- Set limit on rare decay $B^0_s \rightarrow \mu^+\mu^-$
Backup slide
Bias due to $V^0$ reconstruction determined from MC
- Trigger bias measured from data using tag-and-probe method ($J/\psi$)
- Selection bias is small, estimated $-19$ fs
- The result correction: the efficiency function part of the fitted PDF