

# Heavy Flavour Physics with ATLAS

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27.8.2013



# ATLAS detector

Inner Detector: tracking, momentum and vertex measurement

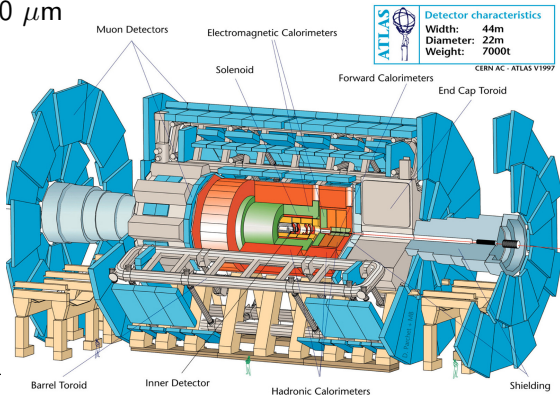
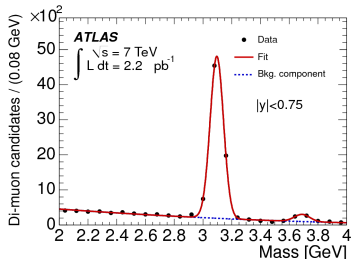
- $|\eta| < 2.5$ ,  $d_0$  resolution  $\sim 10 \mu\text{m}$

Muon Spectrometer: trigger and muon identification

- $|\eta| < 2.7$ , resolution  $\sim 40 \mu\text{m}$

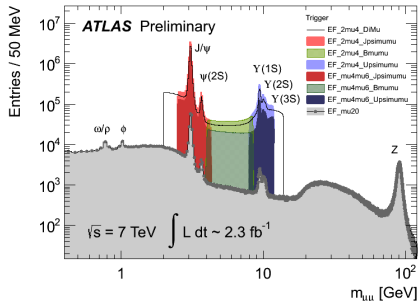
Mass resolution

- $\sigma(m_{J/\psi}) = 46 \pm 1 \text{ MeV}$



## B-physics trigger:

- muon and di-muon decays ( $J/\psi$ ,  $\Upsilon$ )
- L1: single and di-muon triggers (thresholds 4-40 GeV  $p_T$ )
- L2 and L3: muons from common vertex, opposite charge
- invariant mass window of  $J/\psi$ , B and  $\Upsilon$  un-prescaled



## Status of analyses:

- focusing on searches for BSM physics in rare and semi-rare decays
- first observation of  $\chi_b(3P)$ , W and prompt  $J/\psi$  production, W and charm production - M. Saleem
- all updated results on <http://twiki.cern.ch/twiki/bin/view/AtlasPublic>

$B^+$  cross-section measurement in  $B^+ \rightarrow J/\psi K^+$

# $B^+$ cross-section measurement in $B^+ \rightarrow J/\psi K^+$

## Analysis:

- find  $J/\psi$  candidates in 2.7-3.5 GeV
- fit to common vertex with another charged track
- select  $B^+$  candidates with  $p_T > 9$  GeV and in  $|\eta| < 2.3$
- 2.4 fb<sup>-1</sup> data at 7 TeV

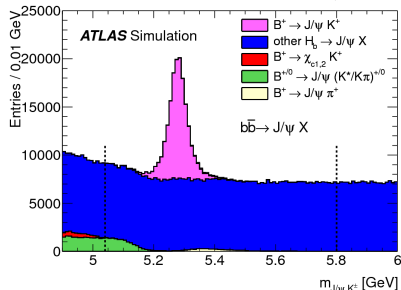
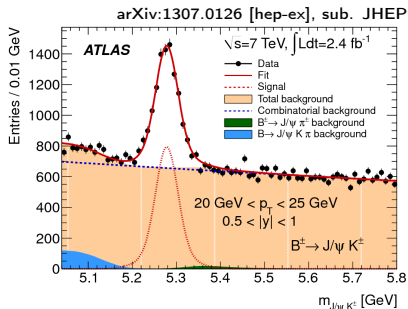
## Background:

- resonant  $J/\psi \pi$ ,  $J/\psi \pi K$
- combinatorial  $J/\psi X$

## Differential cross-section

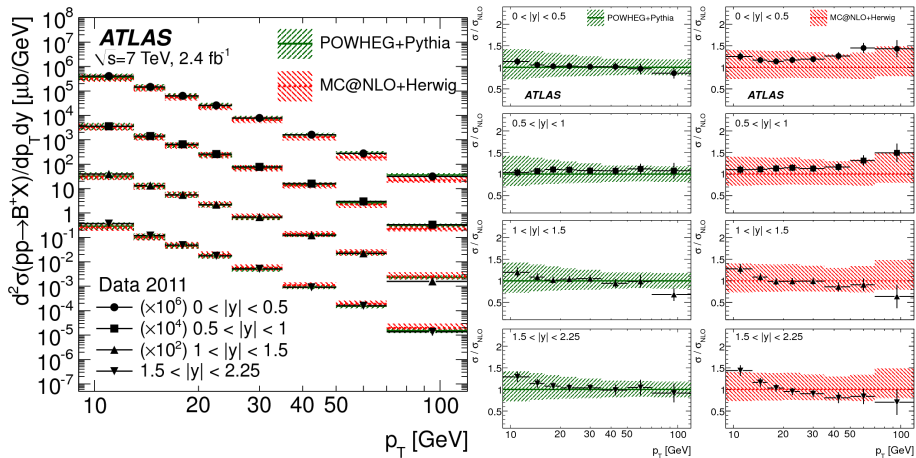
$$\frac{d^2\sigma(pp \rightarrow B^+ X)}{dp_T dy} \cdot \mathcal{B} = \frac{N^{B^+}}{\mathcal{L} \cdot \Delta p_T \cdot \Delta y}$$

$$N^{B^+} = \frac{1}{A} \frac{N_{\text{reco}}^{B^+}}{\epsilon^{B^+}} = \frac{1}{A} \frac{N_{\text{reco}}^{B^-}}{\epsilon^{B^-}} = \frac{1}{A} \frac{N_{\text{reco}}^{B^\pm}}{\epsilon^{B^+} + \epsilon^{B^-}}$$



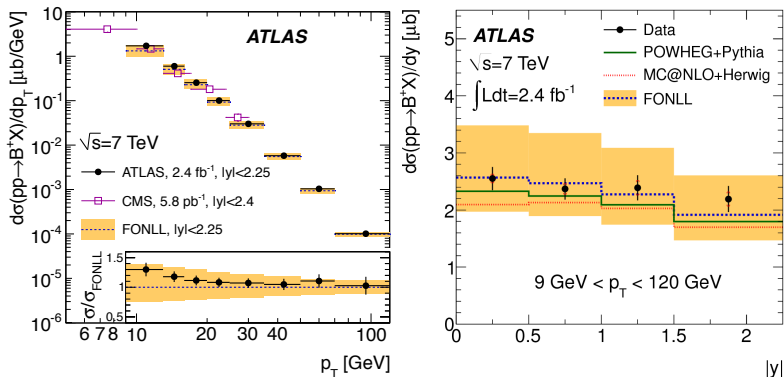
# $B^+$ cross-section measurement in $B^+ \rightarrow J/\psi K^+$

Double differential cross-section compared with NLO MC



- good agreement with POWHEG + Pythia
- slightly higher cross-section at low  $p_T$  than MC@NLO + Herwig

# $B^+$ cross-section measurement in $B^+ \rightarrow J/\psi K^+$



- compared to FONLL (Fixed-Order-Next-to-Leading-Logarithm)
- FONLL provides a good description for the data points
- integrated  $B^+$  production cross-section ( $9 \text{ GeV} < p_T < 120 \text{ GeV}$ )  
 $\sigma(pp \rightarrow B^+ X) = 10.6 \pm 0.3(\text{stat.}) \pm 0.7(\text{syst.}) \pm 0.2(\text{lumi.}) \pm 0.4(\mathcal{B}) \mu\text{b}$

# Angular analysis of $B_d^0 \rightarrow K^{*0} \mu^+ \mu^-$



# Angular analysis of $B_d^0 \rightarrow K^{*0} \mu^+ \mu^-$

ATLAS-CONF-2013-038

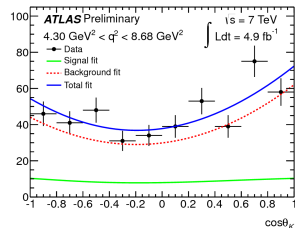
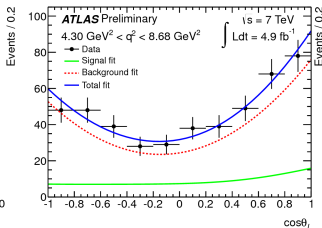
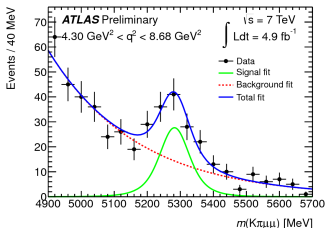
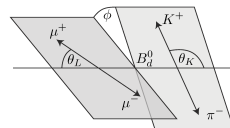
$b \rightarrow s$  transition allowed only at loop level in SM, search for new physics

Event selection: based on  $K\pi$  and  $K\pi\mu\mu$  invariant mass

- excluded resonant  $J/\psi$  and  $\psi(2s)$
- MC-optimized cuts for combinatorial and radiative charmonium decays background

Analysis:

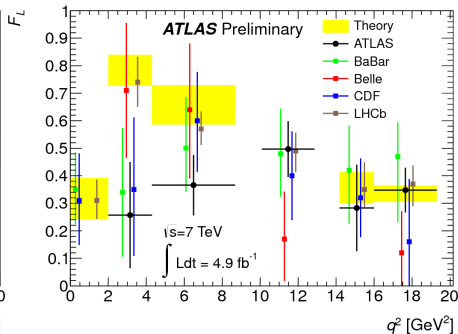
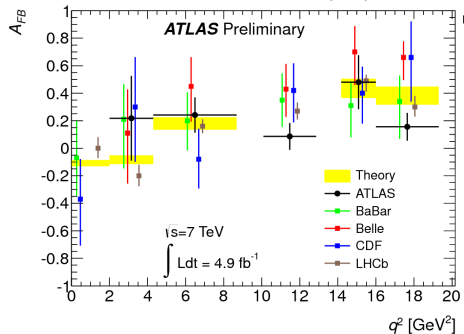
- use unbinned maximum likelihood fit
- fit mass to separate signal from background



# Angular analysis of $B_d^0 \rightarrow K^{*0} \mu^+ \mu^-$

Forward-backward asymmetry and longitudinal polarization fraction

$$\frac{1}{\Gamma} \frac{d^2\Gamma}{dq^2 d\cos\theta_L} = \frac{3}{4} F_L(q^2)(1 - \cos^2\theta_L) + \frac{3}{8}(1 - F_L(q^2))(1 + \cos^2\theta_L) + A_{FB}(q^2)\cos\theta_L$$



- measurement consistent with SM
- uncertainties statistically dominated (working on 2012 data)

$B_s^0 \rightarrow J/\psi \phi$ : measurement of  $\phi_s$  and  $\Delta\Gamma_s$

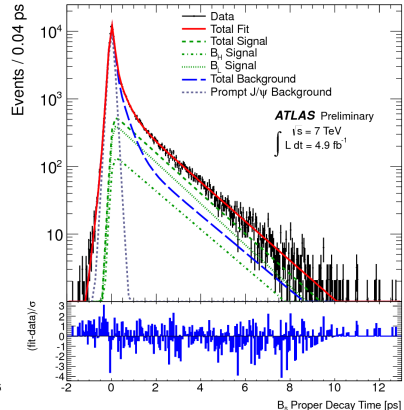
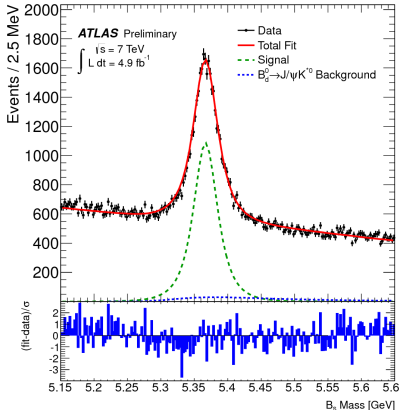
$$B_s^0 \rightarrow J/\psi \phi$$

Standard Model predicts very small value for  $B_s$  mixing phase

$$\phi_s = \arg(-M_{12}/\Gamma_{12}) \sim -0.04 \pm 0.002 \sim -2\beta_s$$

Event selection:  $J/\psi$  dimuon trigger, reconstruction of  $B_s \rightarrow \mu^+ \mu^- K^+ K^-$

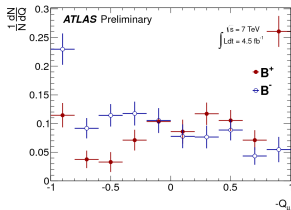
Measure mass and proper decay time  $\tau = \frac{L_{xy} M_{B_s}}{p_{tB}}$



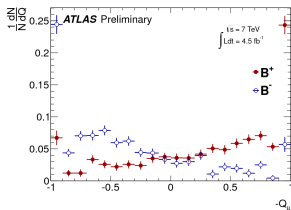
$$B_s^0 \rightarrow J/\psi \phi$$

Flavour tagging to determine initial flavour eigenstate of  $B_s$

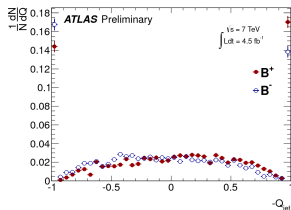
- using opposite side tagging, studied with  $B^\pm \rightarrow J/\psi K^\pm$
- muon tagger - muon from semileptonic decay, muon cone charge  $Q_\mu$
- jet charge tagger - jet from the same primary vertex, jet charge  $Q_{jet}$



segment muons



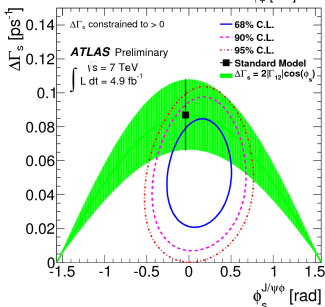
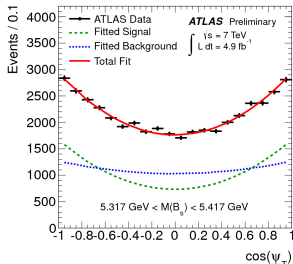
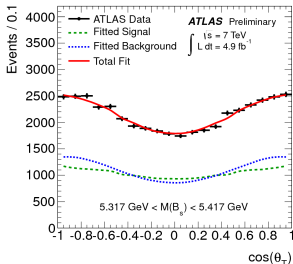
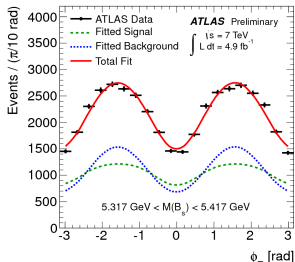
combined muons



jet charge

$$B_s^0 \rightarrow J/\psi \phi$$

## Transversity angles in signal region:



$$\phi_s = 0.12 \pm 0.25 \text{ (stat.)} \pm 0.11 \text{ (syst.) rad}$$

$$\Delta\Gamma_s = 0.053 \pm 0.021 \text{ (stat.)} \pm 0.009 \text{ (syst.) ps}^{-1}$$

- uncertainty of  $\phi_s$  improved by 40% w.r.t. untagged analysis, dominated by statistical error

$\Lambda_b \rightarrow J/\psi \Lambda^0 : \alpha_b$  and helicity

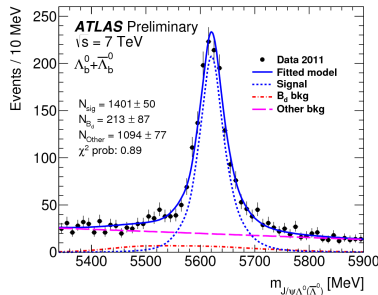
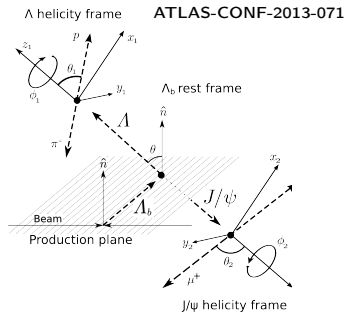
$$\Lambda_b \rightarrow J/\psi(\mu^+\mu^-) \Lambda^0(p\pi^-)$$

## Selection:

- $J/\psi$ :  $2.8 \text{ GeV} < m_{\mu\mu} < 3.4 \text{ GeV}$
- $\Lambda^0$ :  $1.08 \text{ GeV} < m_{hh} < 1.15 \text{ GeV}$
- $\Lambda_b^0$ :  $5.56 \text{ GeV} < m_{J/\psi\Lambda^0} < 5.68 \text{ GeV}$
- cascade topology:  $\chi^2/N_{dof} < 3$ ,  
 $L_{xy} > 10 \text{ mm}$ ,  $\tau_{\Lambda_b} > 0.35 \text{ ps}$
- 1400  $\Lambda_b^0$  and  $\bar{\Lambda}_b^0$

## Analysis:

- decay described by 4 helicity amplitudes
- parity violating asymmetry parameter  
 $\alpha_b = |a_+|^2 - |a_-|^2 + |b_+|^2 - |b_-|^2$
- full angular PDF
- used method of moments  $F_i$
- lifetime and mass measurement in  
Phys. Rev. D87 (2013) 032002





$$\Lambda_b \rightarrow J/\psi(\mu^+\mu^-) \Lambda^0(p\pi^-)$$

Check fit: compared  $F_i$  for data with weighted signal+background MC

Results:

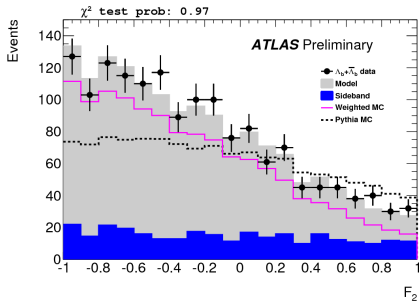
$$|a_+| = 0.17_{-0.17}^{+0.12}(\text{stat}) \pm 0.06(\text{syst})$$

$$|a_-| = 0.59_{-0.07}^{+0.06}(\text{stat}) \pm 0.04(\text{syst})$$

$$|b_+| = 0.78_{-0.05}^{+0.04}(\text{stat}) \pm 0.02(\text{syst})$$

$$|b_-| = 0.08_{-0.08}^{+0.13}(\text{stat}) \pm 0.05(\text{syst})$$

$$\alpha_b = 0.28 \pm 0.16(\text{stat}) \pm 0.06(\text{syst})$$



- $\Lambda^0$  and  $J/\psi$  are highly polarized in direction of their momenta
- $\alpha_b$  value consistent with LHCb:  $0.05 \pm 0.17(\text{stat}) \pm 0.07(\text{syst})$  (Phys. Lett.B724 (2013) 27)

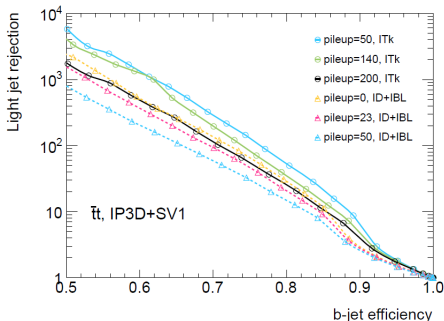
# Plans and upgrades

## Analysis plans:

- most of results are statistically limited
- more accurate measurements with 2012 data starting or ongoing ( $\chi_{cn}$  production and heavy flavour production nearly finished)
- $B_s \rightarrow \mu\mu$ : published analysis of 2011 data  
 $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) < 1.5 (1.2) \times 10^{-8}$  at 95% (90%) CL

## Detector upgrades:

- IBL - 4th layer of Pixel detector 3.3 cm from IP
- TDAQ and trigger upgrades
- Fast track trigger (2016/17)
- new all-silicon ID (2022/23)



# Backup

# $B_s^0 \rightarrow J/\psi \phi$ : tagging

Tagger	Efficiency [%]	Dilution [%]	Tagging Power [%]
Segment Tagged muon	$1.08 \pm 0.02$	$36.7 \pm 0.7$	$0.15 \pm 0.02$
Combined muon	$3.37 \pm 0.04$	$50.6 \pm 0.5$	$0.86 \pm 0.04$
Jet charge	$27.7 \pm 0.1$	$12.68 \pm 0.06$	$0.45 \pm 0.03$
Total	$32.1 \pm 0.1$	$21.3 \pm 0.08$	$1.45 \pm 0.05$

Complete results:

$$\phi_s = 0.12 \pm 0.25 \text{ (stat.)} \pm 0.11 \text{ (syst.) rad}$$

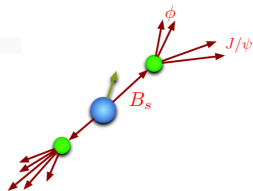
$$\Delta\Gamma_s = 0.053 \pm 0.021 \text{ (stat.)} \pm 0.009 \text{ (syst.) ps}^{-1}$$

$$\Gamma_s = 0.677 \pm 0.007 \text{ (stat.)} \pm 0.003 \text{ (syst.) ps}^{-1}$$

$$|A_0(0)|^2 = 0.529 \pm 0.006 \text{ (stat.)} \pm 0.011 \text{ (syst.)}$$

$$|A_{\parallel}(0)|^2 = 0.220 \pm 0.008 \text{ (stat.)} \pm 0.009 \text{ (syst.)}$$

$$\delta_{\perp} = 3.89 \pm 0.46 \text{ (stat.)} \pm 0.13 \text{ (syst.) rad}$$



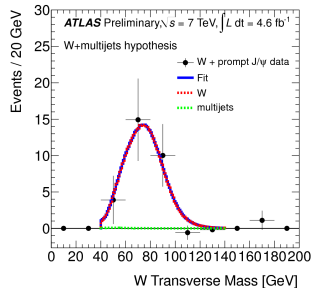
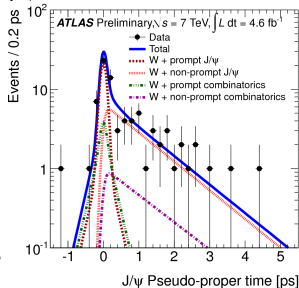
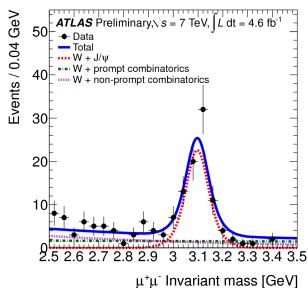
# Associated production of W and prompt J/ψ

ATLAS-CONF-2013-042

Probes quarkonium production mechanism, sensitive to multiple parton interactions.

Selection:

- prompt J/ψ via mass and pseudo-proper time
- $W^\pm$  muon trigger, identified by  $\mu$  and missing  $p_T$
- fit  $W^\pm$  transverse mass with multijet background
- 29 events with  $W^\pm$  J/ψ



# Associated production of W and prompt J/ψ

- double parton scattering estimate  $\sim 40\%$  from

$$d\sigma_{J/\psi|W} = \sigma_W \otimes \sigma_{J/\psi} / \sigma_{\text{eff}}$$

- extract inclusive (SPS+DPS) cross-section ratio
- comparison with theory: measured rate underestimated (but large uncertainties of data)

