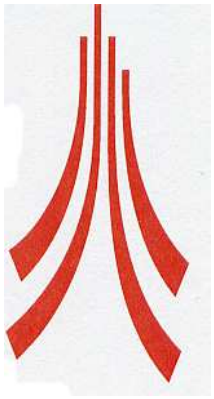
Perspectives for heavy flavour production in ATLAS

Evelina Bouhova-Thacker



Lancaster University, UK

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The ATLAS Detector

Multipurpose experiment designed to search for new particles at mass scales $\mathcal{O}(1\ TeV)$ and new phenomena based on high-p_T objects

- Lepton reconstruction and identification over a wide range of p_T
  - Electrons: from $p_T > 0.5\,\mathrm{GeV}$ in the outer part of the Inner Detector (ID) - the Transition Radiation Tracker, for $p_T > 4\,\mathrm{GeV}$ additional identification from the Electromagnetic Calorimeter (EM)
  - Muons: for $p_T > 6(4)\,\mathrm{GeV}$ combined information from the Muon Spectrometer (MS) and the Inner Detector
- Jet reconstruction in the Electromagnetic and Hadronic Calorimeters
- Charged tracks ($p_T > 0.5\,\mathrm{GeV}$, $|\eta| < 2.5$) and vertex information provided by the Inner Detector

Design luminosity $\mathcal{L} = 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, early data at $\mathcal{L} = 10^{31}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Heavy flavour studies presented here were done with early data and/or at low luminosity $\mathcal{L} = 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

B-Physics And Heavy Quarkonia Programme

- At $14\,\mathrm{TeV}$ $\sigma_{b\bar{b}} \sim 500\,\mu b$, 40 MHz rate, 1 $b\bar{b}$ in 100 pp collisions
- With $10\,\mathrm{pb}^{-1}$, i.e. one month of running expect about 2×10^8 beauty and 3×10^5 J/ψ events selected by the first level trigger (LVL1)
- $10 - 100\,\mathrm{pb}^{-1}$ B-Physics and quarkonia signatures used to
  - understand detector properties and trigger system
  - measure total and differential production cross-sections ($\sigma_{b\bar{b}}$, $\sigma_{J/\psi}$, σ_Υ and $B^+ \to J/\psi K^+$), polarisation of J/ψ and Υ, observe χ_c and χ_b decays, inclusive and exclusive B-hadron decay measurements
- $200\,\mathrm{pb}^{-1} - 1\,\mathrm{fb}^{-1}$ ($\sim$ currently at the Tevatron) - improve measurements of B-hadron properties, set new limits for discovery channels
- $10 - 30\,\mathrm{fb}^{-1}$ full B-physics potential reached

Trigger Strategies

LVL1: 40 kHz, 2.5 μ s

- Muon triggers
  - single-muon trigger: $\mathcal{L} = 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ $p_T >$ 6 - 8 GeV (1MU6, 1MU8)
    $\mathcal{L} = 10^{31}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ $p_T >$ 4 GeV (1MU4)
  - di-muon trigger: $p_T^{\mu_1} >$ 6 GeV, $p_T^{\mu_2} >$ 4 GeV (2MU6)
- $J/\psi/\Upsilon \to e^+e^-$ triggered by 2 EM clusters with $E_T >$ 3 (5) GeV, 2EM3 (2EM5) at $\mathcal{L} = 10^{31}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and by 1MU6 at $\mathcal{L} = 10^{31} - 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

LVL2: 1-2 kHz, $40\,\mathrm{ms}$ - confirm and refine LVL1 objects, search for additional signatures in LVL1 Regions of Interest (RoI)

- Single-muon: search in wider LVL1 RoI
- Di-muon: search in two LVL1 RoI

cross sections usually orders of magnitude smaller than for single-muons of the same p_T

Event Filter (EF): 200 Hz, $4\,\mathrm{s}$ - uses complete event data, "offline-like" algorithms to define complex signatures for final selection

Inclusive b Cross Section Strategy I

Based on "Quarkonium trigger": $b\bar{b} \rightarrow J/\psi(\mu^+\mu^-)X$ $\mathcal{L} = 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

invariant mass within a 3σ window

$\sigma_{J/\psi} = 56\,\mathrm{MeV}$, $\sigma_{\Upsilon} = 180\,\mathrm{MeV}$

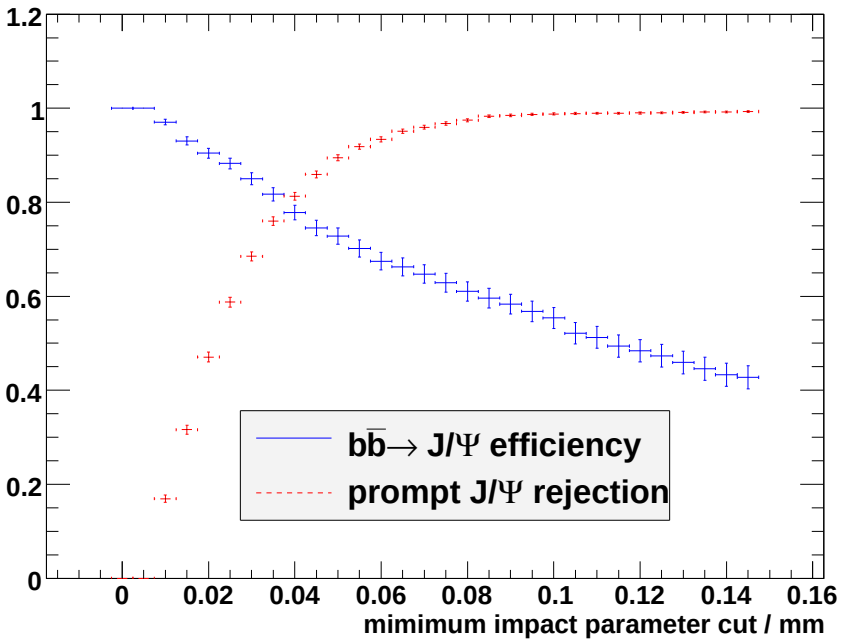
Background rates: J/ψ 6 Hz, Υ 13 Hz

Signal rates:

LVL1 1MU6 J/ψ 20 Hz, Υ 3 Hz

LVL1 2MU6 J/ψ 7 Hz, Υ 1 Hz

Fraction of J/ψ from B-decays: 33.7%



Offline selection: detached J/ψ vertex

- ΔR cut - combinatorial background
- Impact parameter cut - prompt background

  $\epsilon_{J/\psi} \sim 60\%$ background rejection $r_{\mathrm{prompt}} \sim 100\%$

$$N^{sel,sig}_{J/\psi} = N^{trig}_{J/\psi} \times 0.1005 \qquad \text{S/B} \approx 1.53 \;\; (J/\psi)$$

$$N^{sel,sig}_{\Upsilon} = N^{trig}_{\Upsilon} \times 0.4329 \qquad \text{S/B} \approx 0.33 \;\; (\Upsilon)$$

Inclusive b Cross Section Strategy II

Based on "b-Jet trigger"

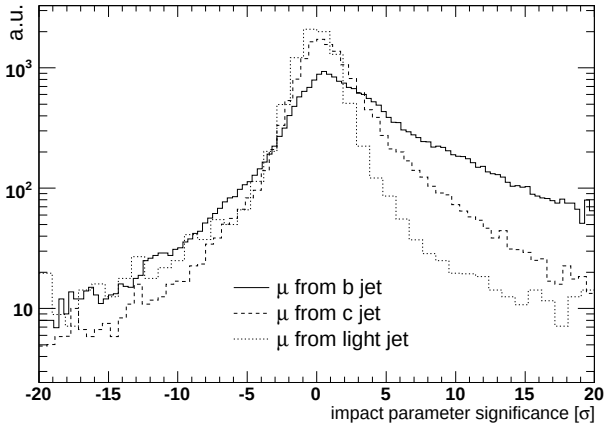
LVL1: 1MU6 + 1J17 (jet with $E_T > 17\,\mathrm{GeV}$)

LVL2: $E_T^{jet} > 30\,\mathrm{GeV}$, cut on b-jet weight

$\epsilon^{trig} = 13.5\%$, b-purity $p_b = 23\%$

with b-jet weight cut

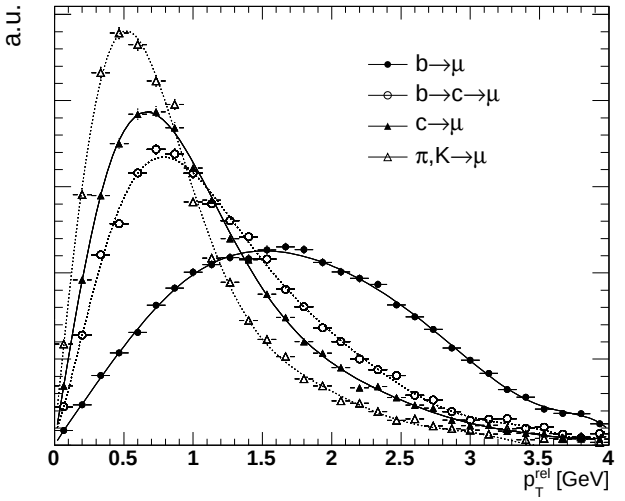
$\epsilon^{trig} = 7.5\%$, b-purity $p_b = 36\%$



Offline selection: jet selection based on

- life-time tag (impact parameter)
- μ-tag (p_T^{rel}: p_T^{μ} relative to jet axis)

$\epsilon^{rec} = 85\%$



Fractions of b-jets and background jets determined by fitting the simulated p_T^{rel} distributions to the data sample

b-fraction: $(23 \pm 2)\%$ background: $(77 \pm 4)\%$

$$N_{b\to\mu}^{sel} = N_{\mu-(b)jet} \times 0.0264(0.0147)$$

b-Production Cross Section

- Expected number of signal events ($\mathcal{L} = 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$)

	prescale	$0.01\,\mathrm{fb}^{-1}$	$0.1\,\mathrm{fb}^{-1}$	$1\,\mathrm{fb}^{-1}$
$b\bar{b} \to J/\psi(\mu 6 \mu 4)$ with 1 μ LVL1	10	2 200	22 000	220 100
$b\bar{b} \to J/\psi(\mu 6 \mu 4)X$ with 2 μ LVL1	10	700	7 300	72 900
$b\bar{b} \to \Upsilon(\mu 6 \mu 4)X$ with 2 μ LVL1	10	400	4 300	43 300
$b\bar{b} \to \mu(6) + b$-jet	1000	900	9 000	90 300

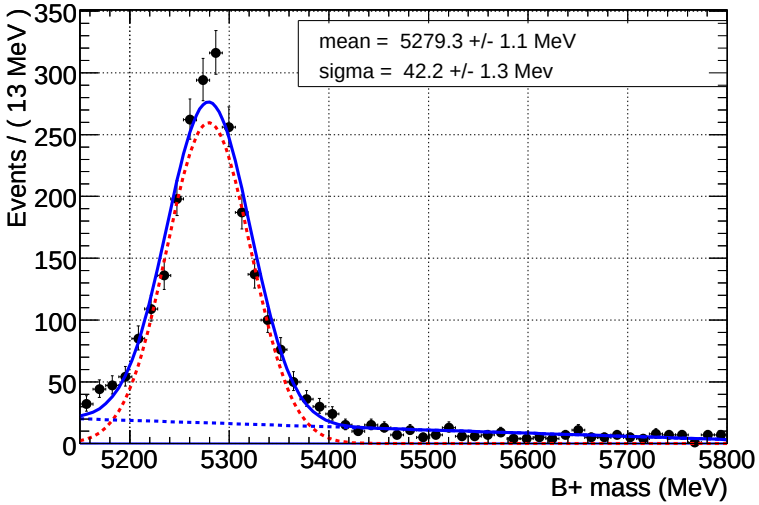
- Estimated time for $\mathcal{O}(1\%)$ measurement (statistical error only)

channel	specific luminosity $[\mathrm{cm}^{-2}\mathrm{s}^{-1}]$ $\mathcal{L} = 10^{31}$	$\mathcal{L} = 10^{32}$	$\mathcal{L} = 10^{33}$
$b\bar{b} \to J/\psi(\mu 6 \mu 4)X$	1 year (PS 1)	1 month (PS 1)	1 month (PS 10)
$b\bar{b} \to \mu(6) + b$-jet	1 month (PS 10)	1 month (PS 100)	1 month (PS 1000)

- Systematical error $\sim 9\%$ with $300\,\mathrm{pb}^{-1}$

$B^+ \to J/\psi K^+$ Cross Section

- Reference channel
- Di-muon J/ψ trigger, $\epsilon^{trig} = 82\%$
- J/ψ reconstruction: $\epsilon^{rec}_{J/\psi} = 55.8\%$
  $p_T^{\mu 1} > 6\,\mathrm{GeV}$, $p_T^{\mu 2} > 3\,\mathrm{GeV}$
  displaced vertex ($> 100\,\mu\mathrm{m}$ in xy)

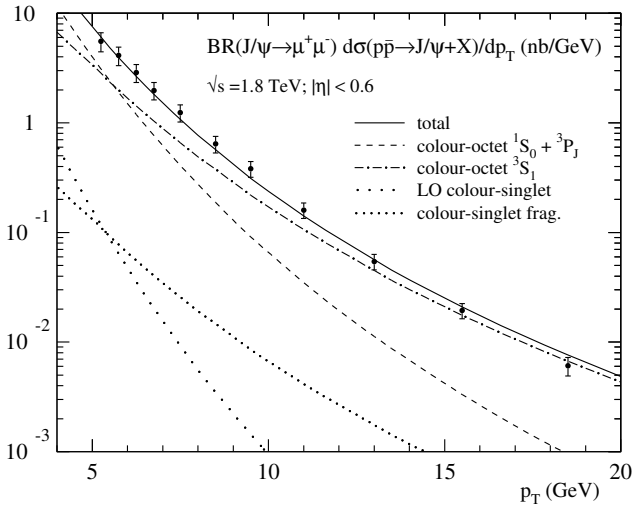


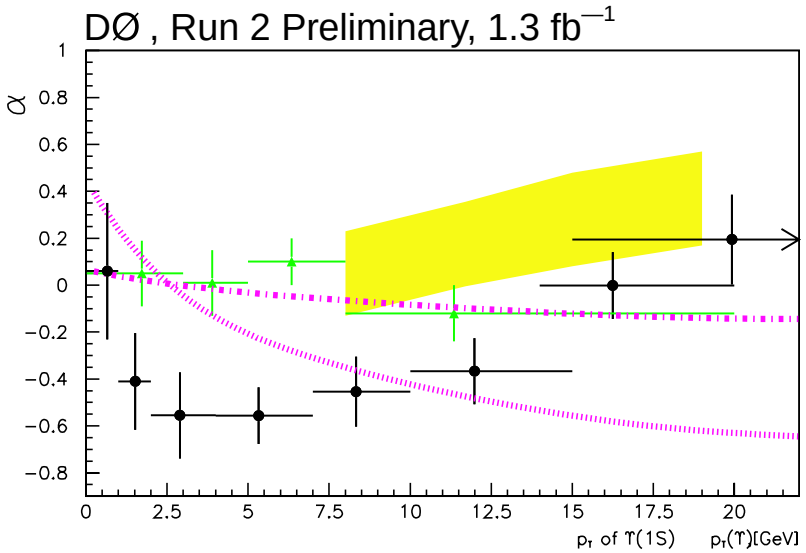
- B^+ reconstruction: $J/\psi + 1$ track ($p_T > 1.5\,\mathrm{GeV}$, $|d_0|/\sigma_{d_0} > 1$)
  displaced vertex ($> 100\,\mu\mathrm{m}$ in xy), mass in $\pm 120\,\mathrm{GeV}$ around m_{B^+}
- $\epsilon^{total} = (29.8 \pm 0.84)\%$ $\sigma(m_{B^+}) = (42.2 \pm 1.3)\,\mathrm{MeV}$
- with $13.2\,\mathrm{pb}^{-1}$ ($\sim$ 2100 signal events):

cross section to $\sim 3\%$ mass resolution $\sim 3\%$ signal lifetime to $\sim 2\%$

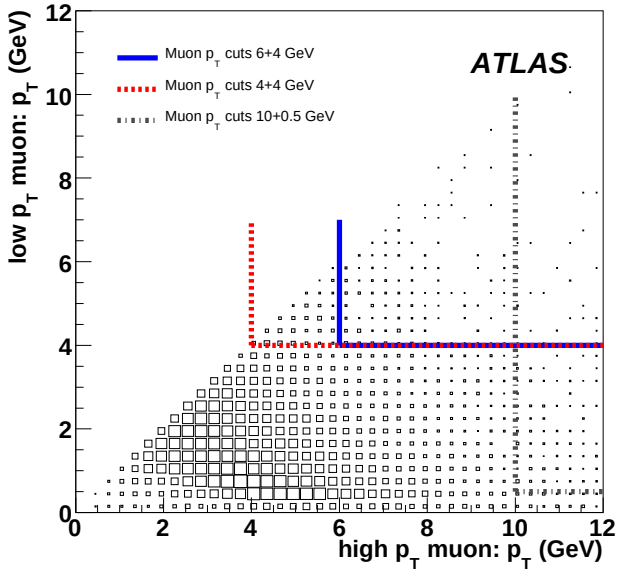
Heavy Quarkonia - Motivation

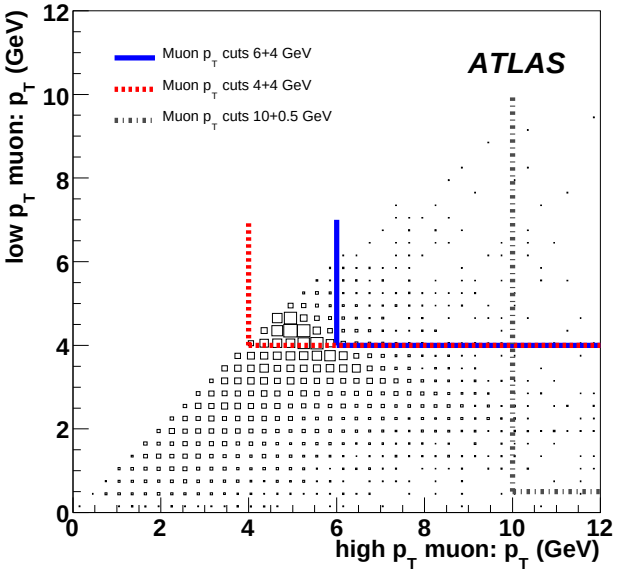
- Narrow resonances useful for detector studies (trigger and detector calibration and alignment) and on-line monitoring
- Background for many other processes at LHC
- Theoretical interest: production mechanism still not understood, testbed for QCD in perturbative and non-perturbative regimes





Quarkonia Cross Sections



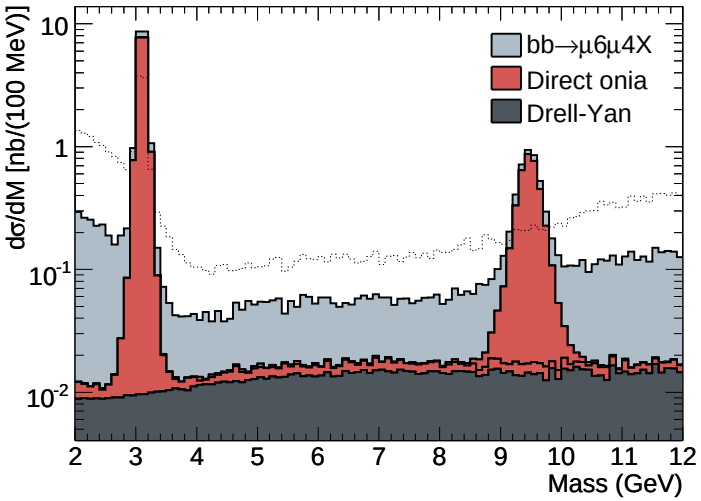


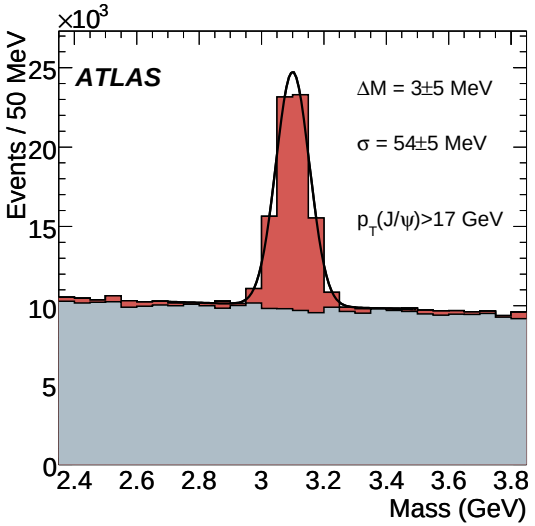
- Di-muon triggers: LVL1 2MU6 and 1MU4
- Single-muon trigger with $p_T > 10\,\mathrm{GeV}$

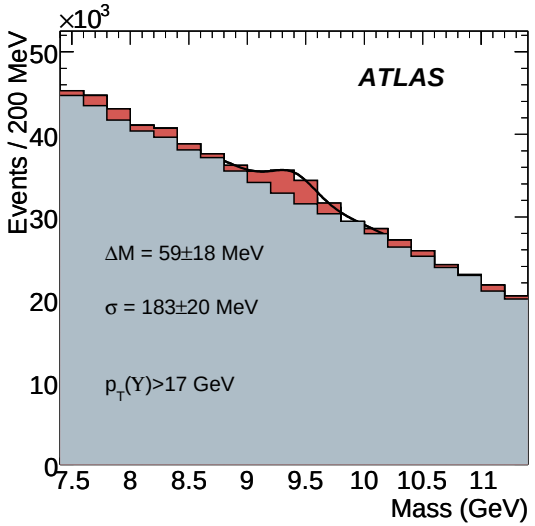
MC cuts	6 + 4 GeV	4 + 4 GeV	10 + 0.5 GeV
$\sigma(J/\psi)$	23 nb	28 nb	23 nb
$\sigma(\Upsilon)$	5.2 nb	48 nb	2.8 nb

Reconstruction of Prompt Quarkonia

- μ tracks from primary vertex $\mathcal{L} = 10^{31}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Pseudo-proper time $< 0.2\,\mathrm{ps}$
- Mass windows: $m^{PDG}_{J/\psi} \pm 300\,\mathrm{MeV}$ $m^{PDG}_{\Upsilon} \pm 1\,\mathrm{GeV}$







with 10 pb^{-1}	Number of events		S/B	
	J/ψ	Υ	J/ψ	Υ
Di-muon trigger	150 000	25 000	60	10
Single-muon trigger	160 000	20 000	1.2	0.05

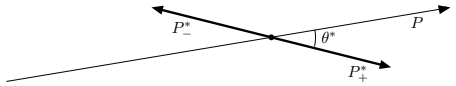
Quarkonium Spin Alignment

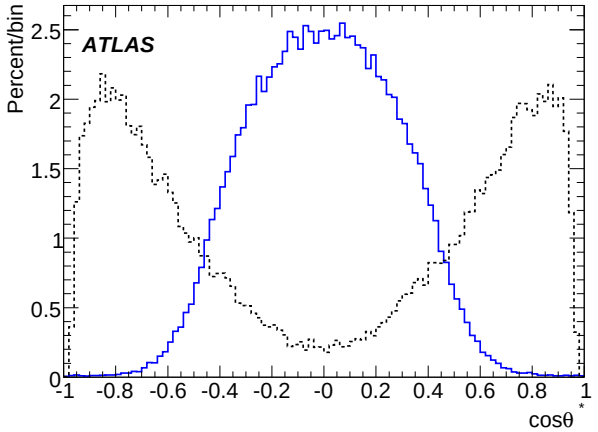
Can be determined by measuring the polarisation parameter α

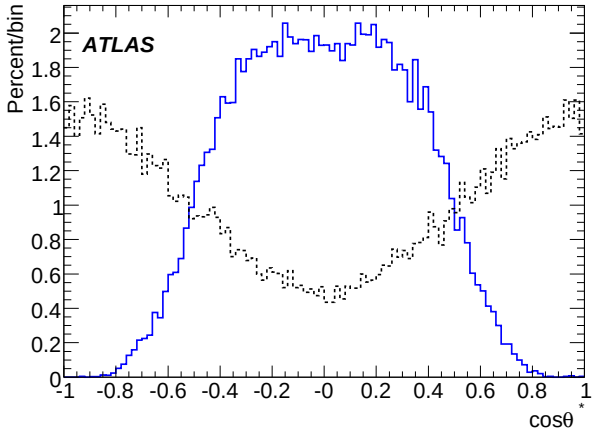
$\alpha = 0$ unpolarised, $= +1$ transverse, $=$ -1 longitudinal

- Different models predict different p_T dependencies
- Different acceptances for di-muon and single-muon samples

$$\frac{dN}{dcos\theta^*} = C\frac{3}{2\alpha+6}(1+\alpha cos^2\theta^*)$$



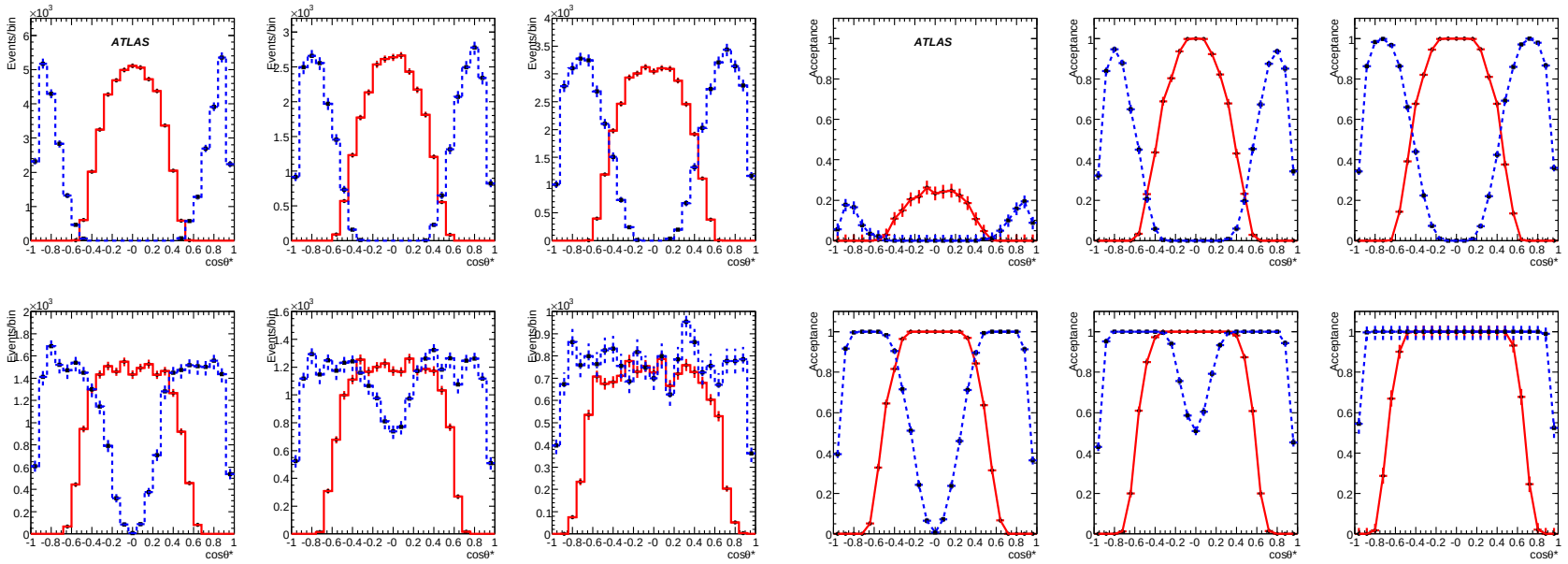




Spin-alignment Measurement

Unpolarised J/ψ sample ($10\,\mathrm{pb}^{-1}$)

- Split into 6 bins of p_T
- Measure reconstructed distributions
- Correct for acceptances and efficiencies



"Measured" distributions Acceptance and efficiency

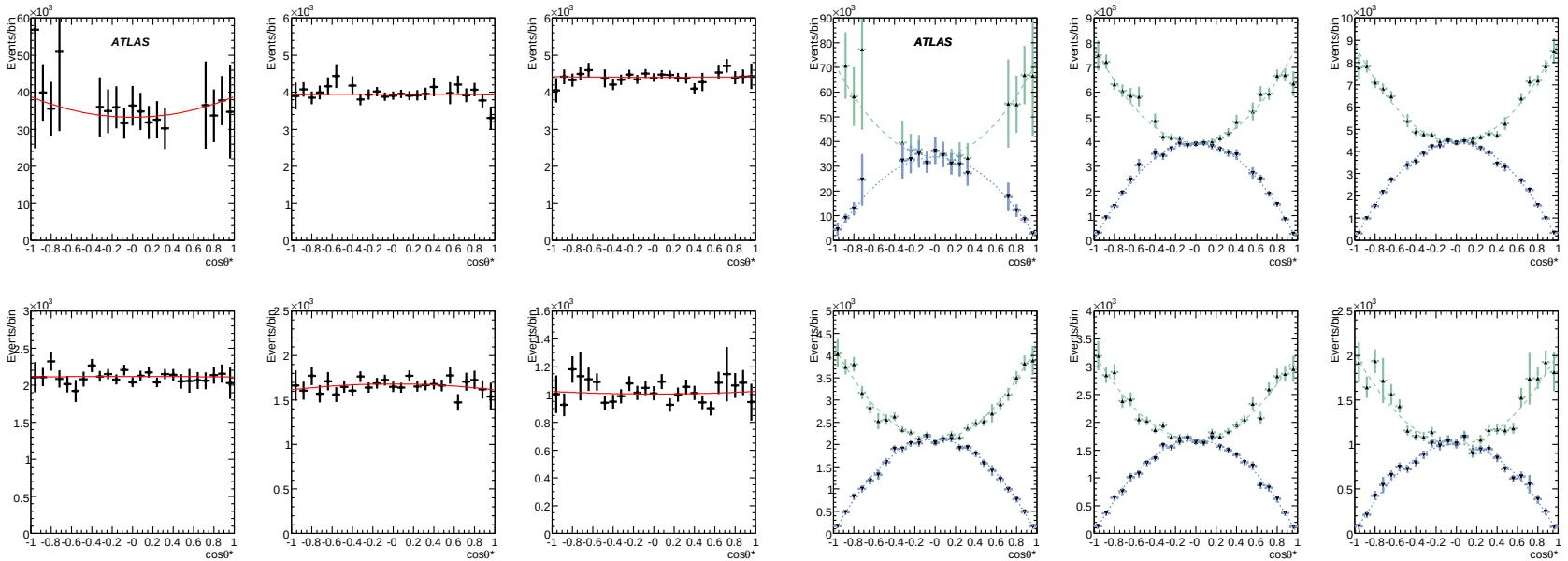
p_T bins: 9-12 GeV, 12-13 GeV, 13-15 GeV, 15-17 GeV, 17-21 GeV, $>$ 21 GeV

Spin-alignment Measurement

Both samples normalised to each other using overlapping high p_T events

Use pre-defined acceptance mask to combine the two datasets

Fit to the corrected distributions

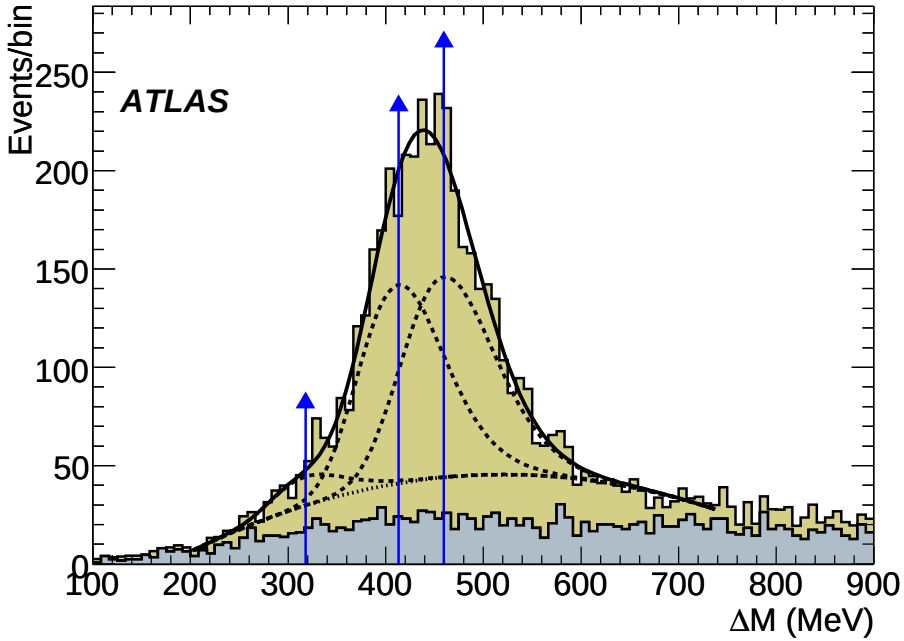


Precision in α with $10\,\mathrm{pb}^{-1}$: 0.02 - 0.06 for J/ψ and 0.2 for Υ

Decays of χ_c And χ_b

$\chi_c \to J/\psi(\mu^+\mu^-)\gamma$

- combine J/ψ with a soft γ
  - $\cos\alpha(J/\psi,\gamma) > 0.97$
  - $m_{\mu\mu\gamma} - m_{\mu\mu}$ in $(200, 700)\,\mathrm{MeV}$
- simultaneous fit to 3 Gaussians and a quadratic background
- $\epsilon^{rec} = 4\%$, resolution $\sim 40\,\mathrm{MeV}$
- observable with $10\,\mathrm{pb}^{-1}$



$\chi_b \to \Upsilon(\mu^+\mu^-)\gamma$

γ much softer, $\epsilon^{rec} = 0.03\% \to$ need $\sim 1\,\mathrm{fb}^{-1}$ to observe

$\chi_b \to J/\psi(\mu^+\mu^-)J/\psi(\mu^+\mu^-)$

$\epsilon^{total} \sim 0.8\% \to$ expect ~ 100 events with $10\,\mathrm{fb}^{-1}$

$J/\psi \to e^+e^-$ And $\Upsilon \to e^+e^-$ Decays

J/ψ and Υ one of the main sources of isolated electrons in early data

- Ideal for studies of the trigger and offline performance
- Calibration of the EM calorimeter
- EM trigger: LVL1 2EM3 ($\mathcal{L} = 10^{31}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$) $\epsilon = 27\%$
  ID tracks reconstructed in LVL1 RoI
- b-trigger: LVL1 1MU4 ($\mathcal{L} = 10^{31}$), 1MU6 ($\mathcal{L} = 10^{31} - 10^{33}$) $\epsilon = 88\%$
  ID tracks reconstructed in whole ID ($\mathcal{L} = 10^{31}$), in LVL1 RoI ($\mathcal{L} = 10^{33}$)

Electron reconstruction:

- strict quality cuts on ID tracks
- bremsstrahlung recovery
- veto conversions
- tracks extrapolated to EM calorimeter, $E/p > 0.7$

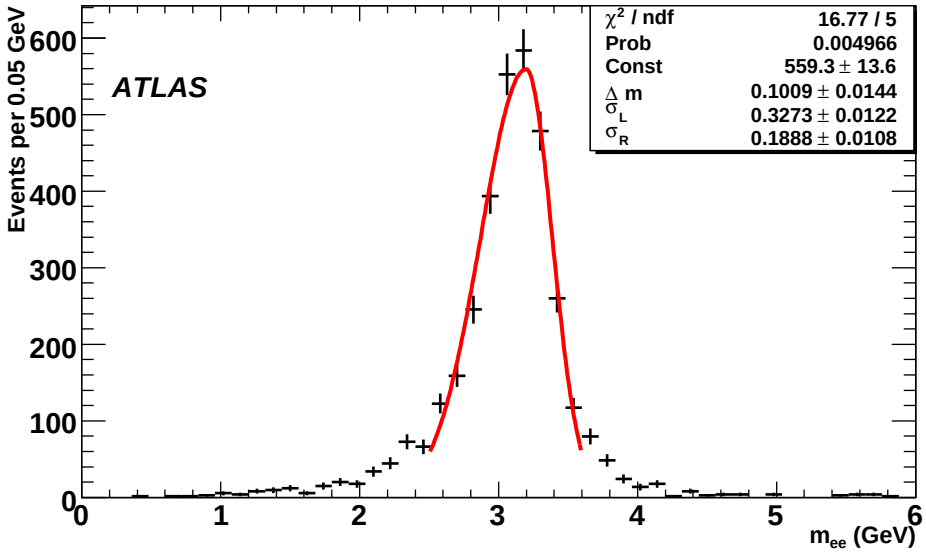
Electron identification:

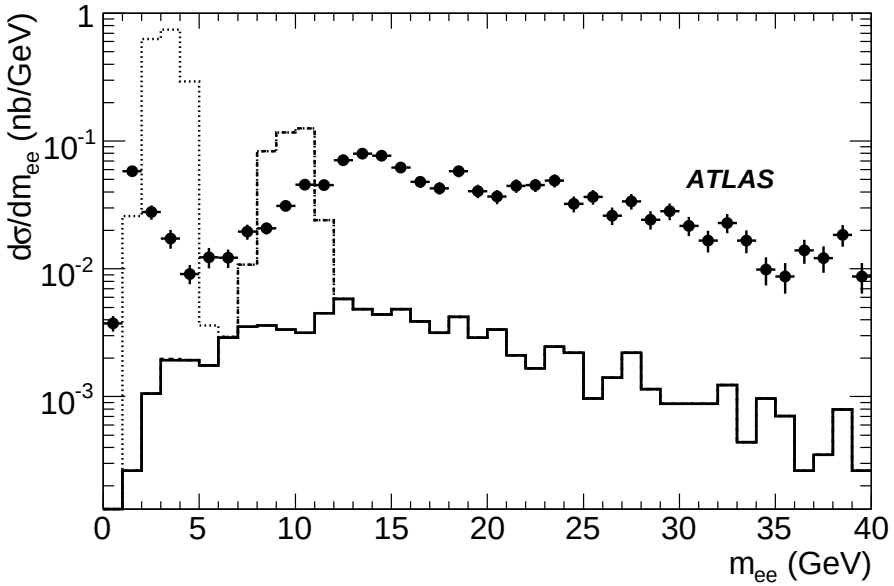
- isolated electrons: based on shower shapes, $\epsilon \sim 65\%$, pion rejection ~ 900 (740) for J/ψ (Υ)
- electrons from b: core of the EM shower used, $\epsilon \sim 80\%$, pion rejection ~ 1300

$J/\psi \to e^+e^-$ And $\Upsilon \to e^+e^-$ Decays

$J/\psi \to e^+e^-$ and $\Upsilon \to e^+e^-$ reconstruction:

- Momentum measurement from ID, energy from EM calorimeter
- displaced vertex ($> 250\,\mu\mathrm{m}$ in xy)
- 55% reconstructed within $\pm 200\,\mathrm{MeV}$ of $m_{J/\psi}$ (47% w/o brem recovery)





Expected events with $100\,\mathrm{pb}^{-1}$ ($\mathcal{L} = 10^{31}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$):

200 000 J/ψ, 43 000 Υ (2EM3 trigger) and 19 000 J/ψ (1MU6 trigger)

Conclusions

ATLAS will measure beauty and onia production cross sections via μX and $J/\psi X$ decays

- σ, $d\sigma/dp_T$, $d\sigma/d\eta$, $\sigma_{B^+ \to J/\psi K^+}$
- both $J/\psi \to \mu^+\mu^-$ and $J/\psi \to e^+e^-$ studied
- early data should provide sufficient statistics

Perform J/ψ and Υ polarisation studies

Many more tests of QCD expected

ATLAS has a rich B-physics programme (not covered here)

First data later this year!

ATLAS CSC Notes

Beauty Production Cross Section Measurements with Early LHC Data: B-Physics Reference Channel $B^+ \to J/\psi K^+$ and Inclusive Methods

M. zur Nedden, C. Petridou, C. Anasopoulos, S. Jetter, O. M. Kind, M. Volkmann

Heavy quarkonium physics with early ATLAS data

T. Alexopoulos, F. Antoniou, E. Etzion, E. N. Gazis, J. Ginzburg, V. Kartvelishvili, D. Price

Reconstruction of $J/\psi \to e^+e^-$ and $J/\psi \to e^+e^-$ decays

T. Berger-Hryn'ova, E. Bouhova-Thacker, J. Cochran, F. Derue, A. Kaczmarska, V. Kartvelishvili, J. Kirk, E. Lytken, A. Nelson