Early ATLAS B physics with the first 10 – 100 pb^{-1}

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On behalf of ATLAS Collaboration

ATL-PHYS-SLIDE-2009-261
14 September 2009

BEAUTY 2009

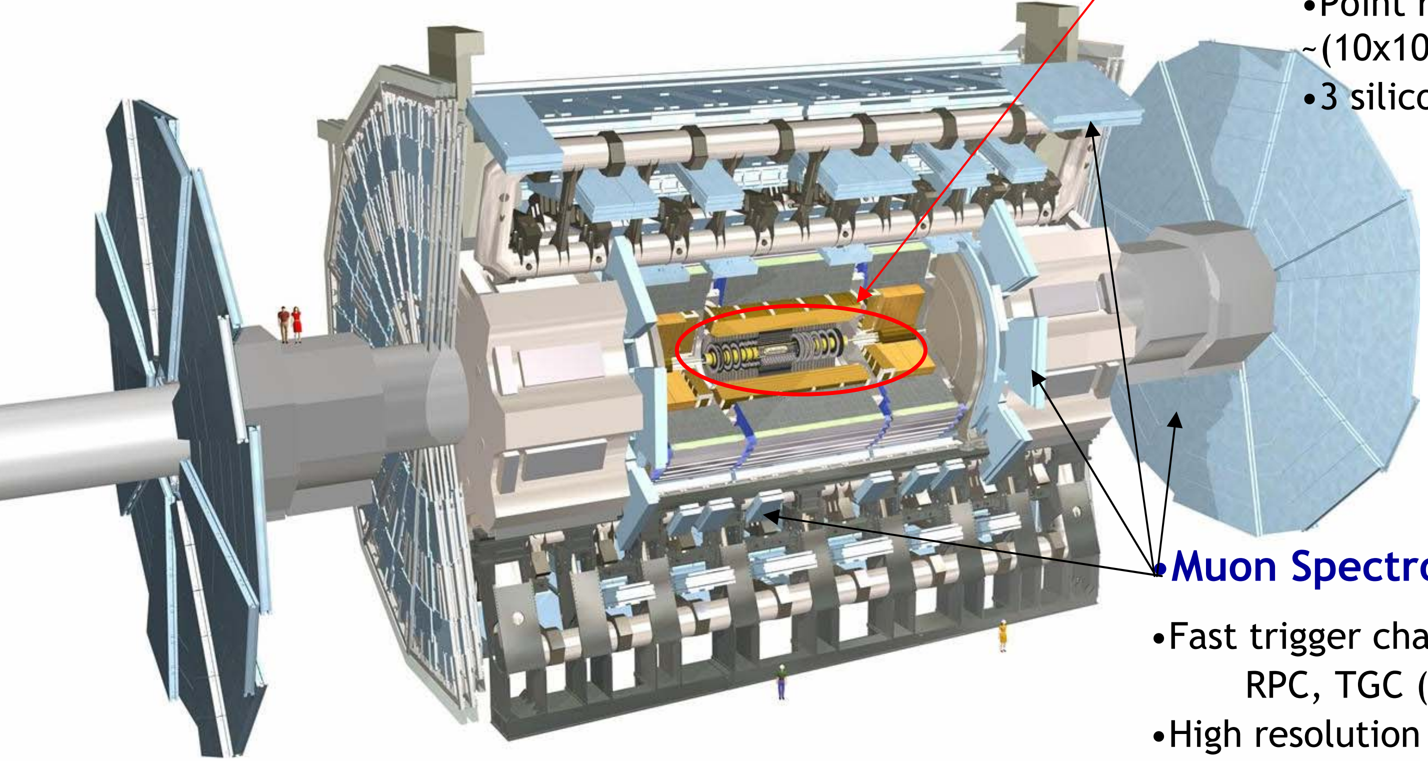
12TH INTERNATIONAL CONFERENCE ON B-PHYSICS AT HADRON MACHINES

SEPTEMBER 7TH - 11TH 2009, HEIDELBERG UNIVERSITY, GERMANY

Outline

- The ATLAS detector and the Trigger system
- B-physics program with early data
  - B-physics trigger
  - Total and differential cross sections of Exclusive channels
  - Heavy quarkonia physics.
  - Polarization measurements
  - B masses and lifetime measurements
- Summary

The ATLAS Detector

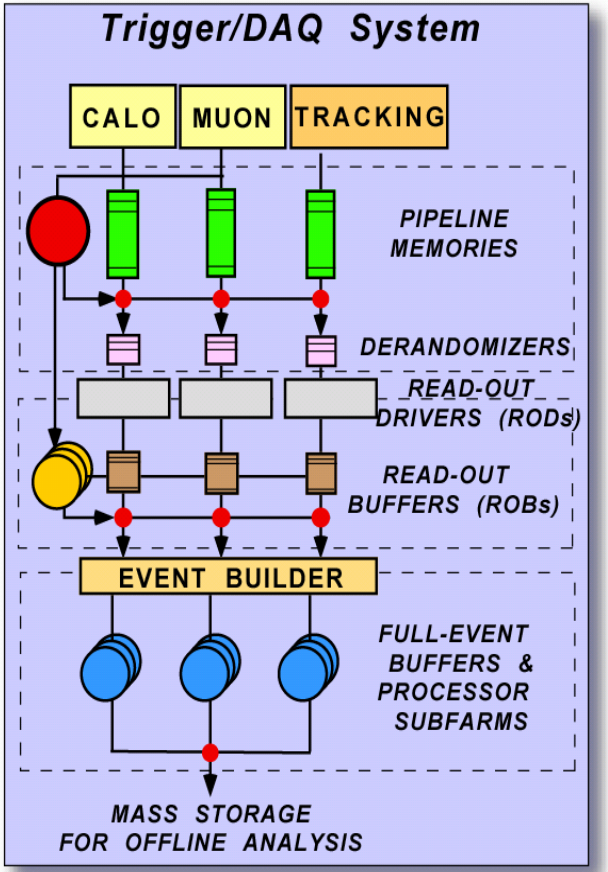


- **Inner Detector**
(High granularity, tracking coverage: $|\eta|<2.5$)
  - Si pixel detector
  - SCT (strip detector)
  - TRT (transition radiation)
- Point resolution of Pixel Detector ~(10x100)μm (φ-z)
- 3 silicon layers, innermost @ 5cm

See talk of Sofia Chouridou

- **Muon Spectrometer**
- Fast trigger chambers
RPC, TGC (<10 ns time resol)
- High resolution tracking detectors:
MDT, CSC (40 μm spatial resolution)

Three stage system
Level1: Hardware,
High Level Trigger: (LVL2+EF) Software



- LVL1
  - hardware-based, identifies Regions of Interest (RoI) for further processing, Total rate 75 kHz
- LVL2
  - Confirmation of LVL1 data using precition detectors
  - Muon tracks extrapolation to inner detector
  - Track reconstruction in ROIs
  - Total rate 2 kHz
- EF
  - refines LVL2 selection using offline-like algorithms
  - Vertexing, transverse decay length cut, angular distribution cut, full event, alignment and calibration data available

hardware

software

Total rate 200 Hz ➔ to tape
(5-10% dedicated to B-Physics)

B-physics program for early data

L_{int} = 10 - 100 pb^{-1}

- Detector & trigger understanding : calibration with J/ψ, Υ and exclusive B-channels as a tester, alignment, material, field, reconstruction.

- Physics
  - cross section measurements at new energy in order to test QCD predictions.
  - Prompt J/ψ →μμ and Υ →μμ differential production cross-sections
  - Polarisation of J/ψ and Υ as a function of quarkonium transverse momentum
  - χ_c(nP) → J/ψ(μμ)γ cross-section(s)
  - Mass and lifetime measurements.

- Large b cross section allows extraction of exclusive decays like $B^+ \to J/\Psi K^+$, $B_d \to J/\psi K^*_0$, $B_s \to J/\psi \varphi$, which serves as reference channels for the muonic rare decays.

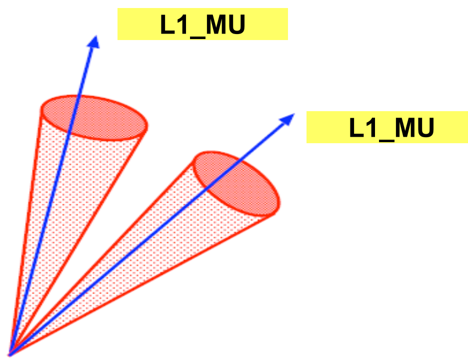
- Use measurement of well known B-physics quantities to test and monitor the detector performance, later with increasing integrated luminosity improve precisions of these.

The B physics Di-muon triggers

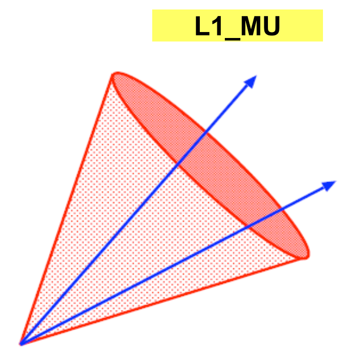
- B-physics has an efficient, fast and clean trigger based on muons
  Many B-physics channels involve a di-muon signature, (B→J/ψ(μμ)X, *b*→sμμ, B→μμ etc)

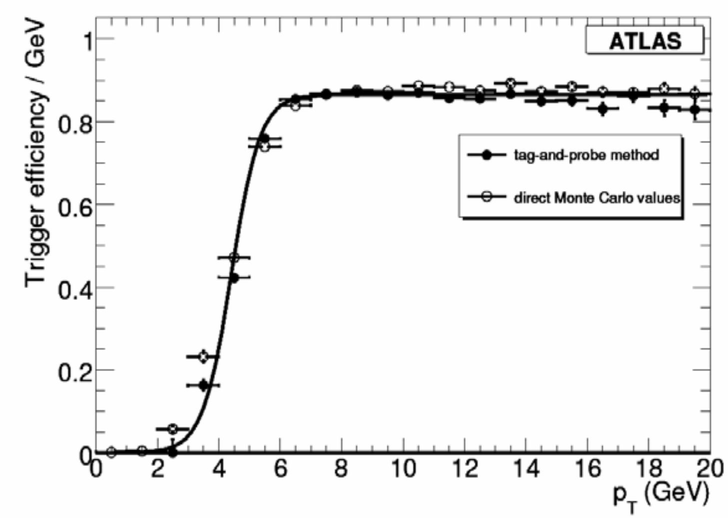
- The most effective trigger for such events uses the di-muon signature from the lowest trigger level.

Topological trigger
Two L1 muons
Perform tracking in small RoI
Confirm muons at L2
Two HLT muons → HLT Bphysics
(mass & vertex cuts)
(μ4μ4, μ6μ4)



TrigDiMuon
One L1 muon
(confirm muon at HLT)
→ HLT Bphysics
Perform tracking in extended RoI, search for second muon, (mass & vertex cuts)





Trigger Efficiency
Estimate Level1, Level2 and EF efficiencies using Tag & Probe method with reconstructed J/ψ's, using single muon trigger (μ+track)

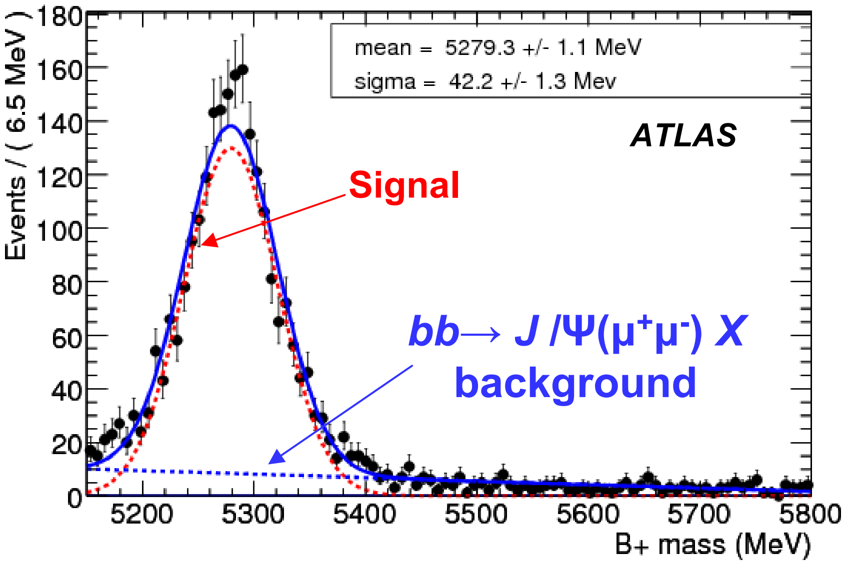
$B^+ \rightarrow J/\psi(\mu^+\mu^-)\, K^+$

- **Selection and reconstruction of events**

  Di-μ J/ψ trigger (μ6μ4)

  - First reconstruction of J/ψ by combining 2μ
  - p_T1(2)> 6(3) GeV, common vertex, ±120 MeV around $m_{J/\psi}$, Proper decay length λ > 0.1 mm, Fit a common vertex of K+ and J/ψ candidate ⇨ B+ candidate

  for $\mathcal{L}$=10 pb^{-1} efficiency: 29.8±0.8 %
  uncert. :M(B+)~0.02%, σ(B+)~3.5%



- Width σ and efficiency $\mathscr{A}$ for various p_T bins and for p_T>10 GeV for the total cross-section:

p_T range [GeV]	$p_T \in [10,18]$	$p_T \in [18,26]$	$p_T \in [26,34]$	$p_T \in [34,42]$
$\mathscr{A}$ [%]	20.1±1.0	37.3±1.7	45.0±3.1	51.6±4.7
$\sigma(B^+)$ [MeV]	38.5±2.0	42.3±2.1	46.1±3.2	46.6±4.0

total cross-section	
$\mathscr{A}$ [%]	29.8±0.8
$\sigma(B^+)$ [MeV]	42.2±1.3

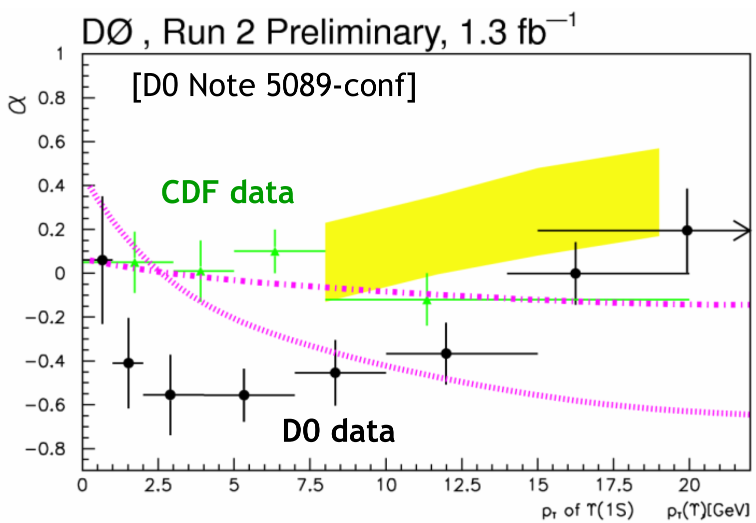
Statistical and systematic uncertainties (for $\mathcal{L}$=10 pb^{-1})

- Statistical uncertainty <5% for total and ~10% for differential cross-section measurement
- Systematic uncertainty includes the uncertainties from the luminosity (~10%) and the BR (~10%)

p_T range [GeV]	$p_T \in [10,18]$	$p_T \in [18,26]$	$p_T \in [26,34]$	$p_T \in [34,42]$	$p_T \in [10,\inf)$
stat. + $\mathscr{A}$ [%]	7.7	6.9	10.5	13.9	4.3
total [%]	16.1	15.8	17.6	19.8	14.8

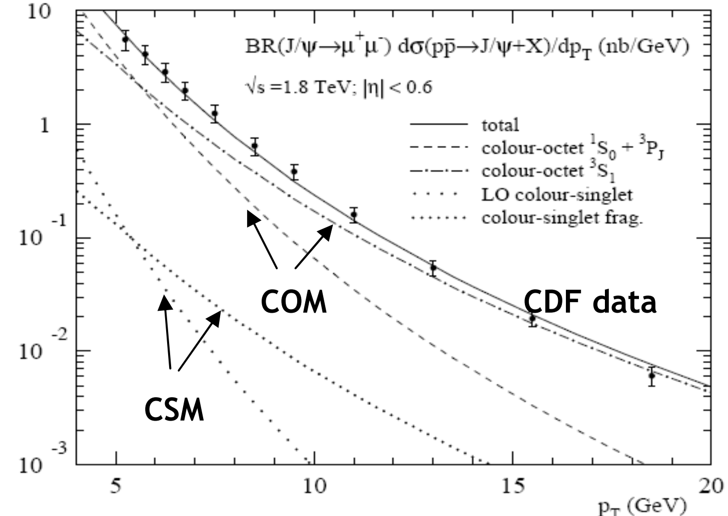
Heavy Prompt Quarkonia motivation

- Production was described via the Color Singlet Model (CSM).
- Inconsistency with the Tevatron Xsection =>Color Octet Model suggested (COM).
- COM failed to predict quarkonia polarization dependence on its P_T.
- Alternative suggestions k_T factorization.



COM prediction disagrees with polarization data in ϒ→μμ

[arXiv:hep-ph/0106120]

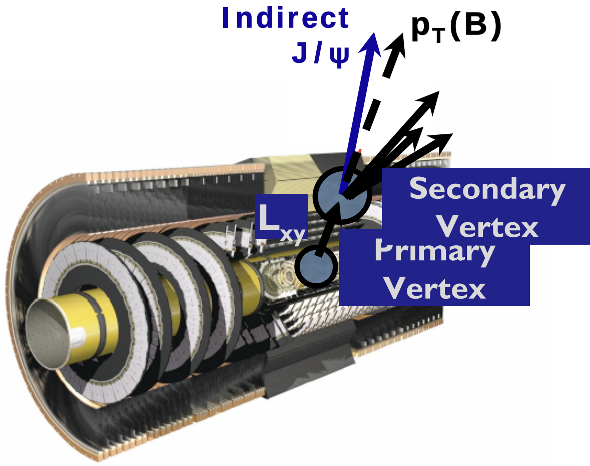


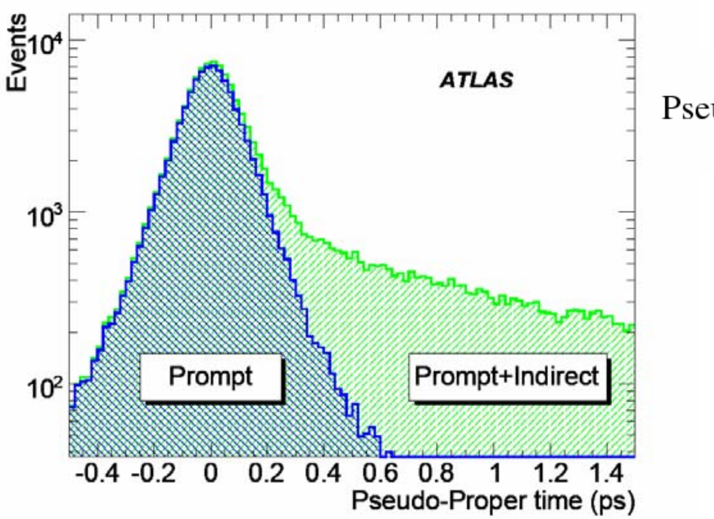
CDF data require Color Octet Model contributions to describe J/ψ cross section

ATLAS is capable of detail checks of the predictions of various models and the degree of polarisation of J/ψ and Y

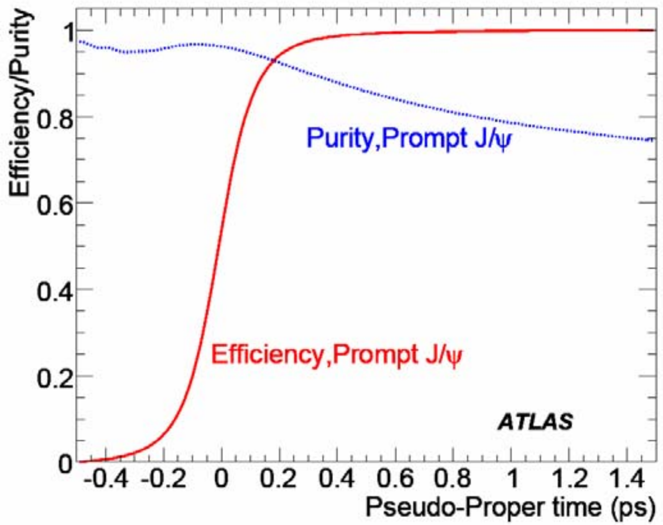
Heavy Prompt Quarkonia, background separation

- J/ψ from B-decays form significant background to prompt J/ψ, in addition to muons from b-quark decays
- Measurement of prompt J/ψ to indirect cross-section relies on separation (and understanding of separation) of these two processes
- Prompt J/ψ typically have zero proper time while Indirect J/ψ have positive proper time
  - Cut on pseudo-proper time to separate indirect/prompt
  - 'Pseudo-proper time' cut of <0.2 ps gives prompt J/ψ efficiency of 95% with 5% contamination

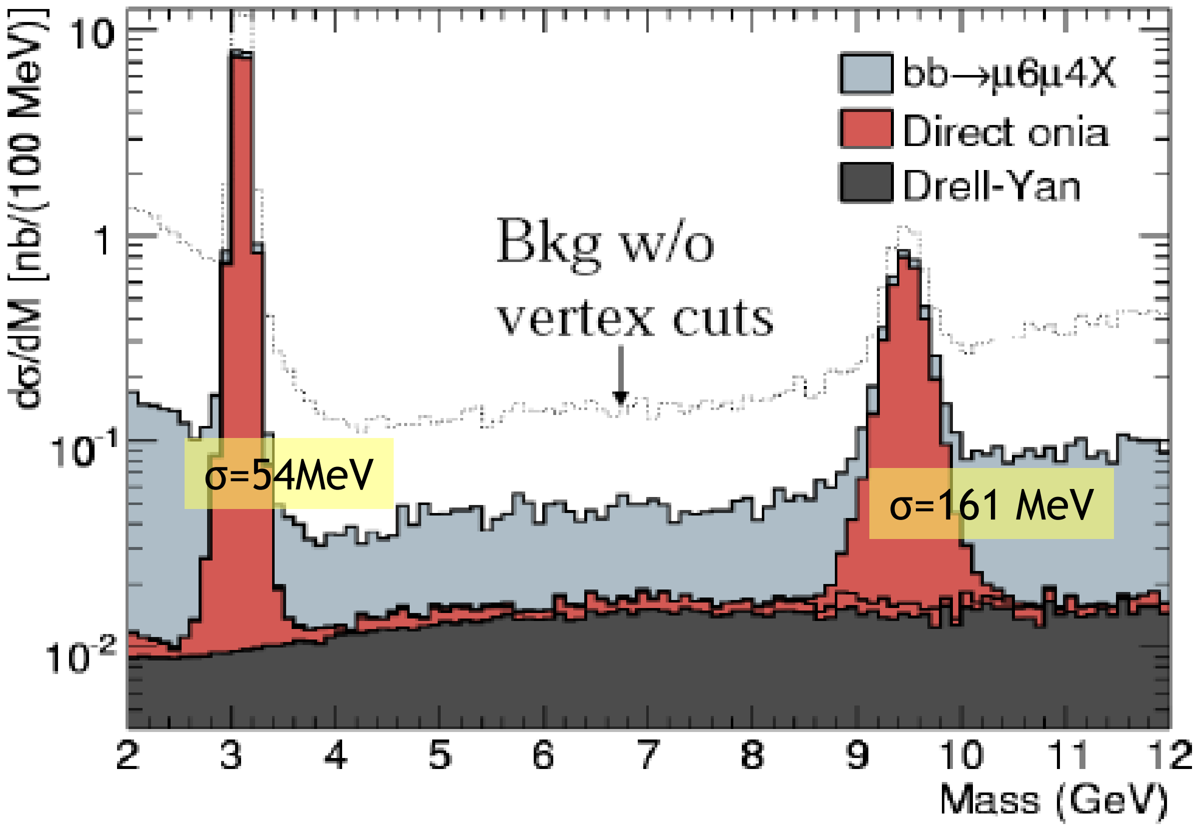




$$\text{Pseudo-proper time} = \frac{L_{xy} \cdot M_{J/\psi}}{p_T(J/\psi) \cdot c},$$



Heavy Prompt Quarkonia, Invariant mass



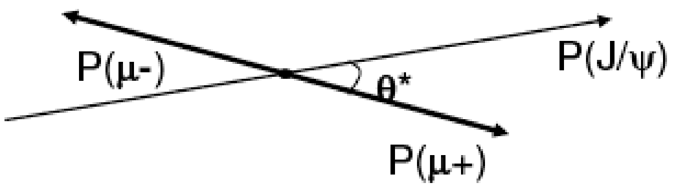
Dedicated J/ψ and Υ trigger signatures

- Seeded by Level1 Di-μ trigger (μ6μ4)
  - μ tracks from primary vertex,
  - pseudo-proper time < 0.2 ps (background suppression)

- 150 000 J/ψ and 25 000 Υ for 10 pb^{-1} using di-μ trigger (μ6μ4)
- S/B (at peak) = 60 (J/ψ), 10 (Υ)

Spin-alignment measurement

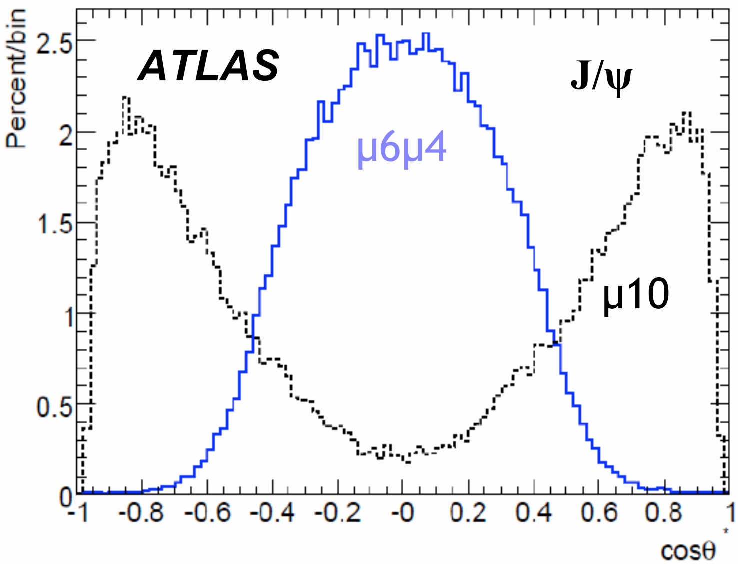
Angle defined between positive muon direction in quarkonium rest frame and quarkonium direction in lab frame.



- Dimuon triggers:
  little or no information for high cosθ*

Using di-muon trigger, both muons from J/Ψ must have relatively large p_T.
=> affects the polarization angle distribution.

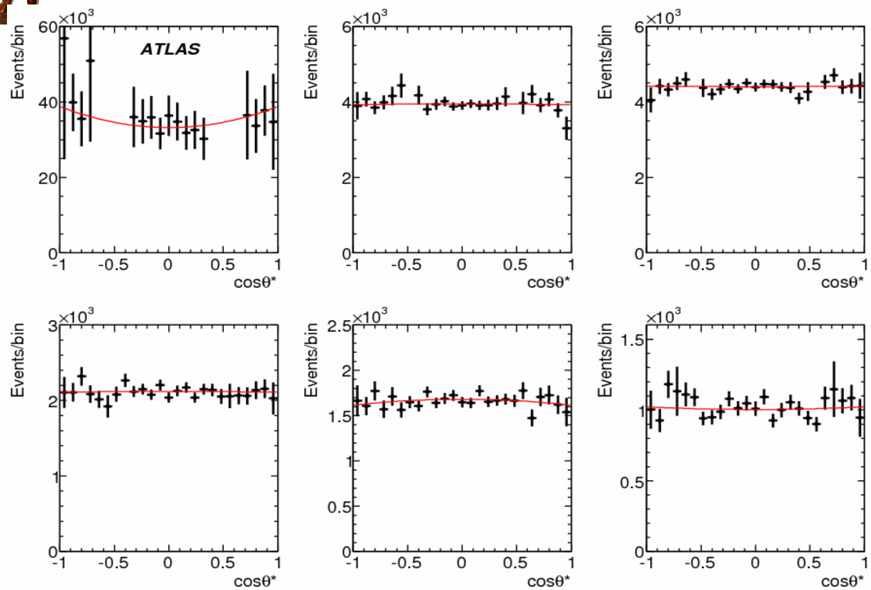
- Single μ10 trigger:
  - Second track can be reconstructed offline (>0.5 GeV p_T)
  - |cos θ*| ~ 1 corresponds to a configuration where one muon is fast, the other slow
  - Provides similar p_T range of onia to **μ6μ4** configuration and similar rates!



- Single-μ trigger => larger background
  Still: S/B = 1.2 (J/ψ) and 0.05 (Y)

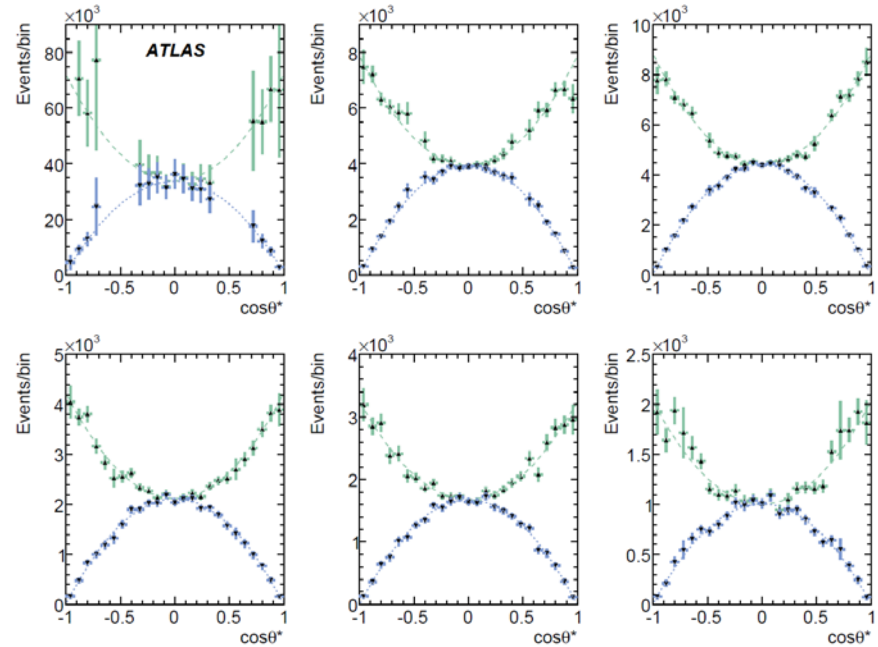
Measurements using μ6μ4 and μ10 trigger have to be combined to achieve full coverage in cosθ*

Spin-alignment measurement



Combined and corrected distributions in J/ψ polarisation angle cosθ*, for various p_T slices (unpolarised data)

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



Combined and corrected distributions in J/ψ polarisation angle cosθ*, for various p_T slices, for Longitudinal (α_{gen}=-1, dotted line) and Transversely (α_{gen}=1, dashed line) polarised

Spin-alignment measurement

J/ψ and Υ polarisation and cross sections measured in various p_T slices, for 10 pb^{-1}

Sample	p_T, GeV	$9-12$	$12-13$	$13-15$	$15-17$	$17-21$	>21
J/ψ, $\alpha_{gen}=0$	α	0.156 ±0.166	−0.006 ±0.032	0.004 ±0.029	−0.003 ±0.037	−0.039 ±0.038	0.019 ±0.057
	σ, nb	87.45 ±4.35	9.85 ±0.09	11.02 ±0.09	5.29 ±0.05	4.15 ±0.04	2.52 ±0.04
J/ψ, $\alpha_{gen}=+1$	α	1.268 ±0.290	0.998 ±0.049	1.008 ±0.044	0.9964 ±0.054	0.9320 ±0.056	1.0217 ±0.088
	σ, nb	117.96 ±6.51	13.14 ±0.12	14.71 ±0.12	7.06 ±0.07	5.52 ±0.05	3.36 ±0.05
J/ψ, $\alpha_{gen}=-1$	α	−0.978 ±0.027	−1.003 ±0.010	−1.000 ±0.010	−1.001 ±0.013	−1.007 ±0.014	−0.996 ±0.018
	σ, nb	56.74 ±2.58	6.58 ±0.06	7.34 ±0.06	3.53 ±0.04	2.78 ±0.03	1.68 ±0.02
Υ, $\alpha_{gen}=0$	α	−0.42 ±0.17	−0.38 ±0.22	−0.20 ±0.20	0.08 ±0.22	−0.15 ±0.18	0.47 ±0.22
	σ, nb	2.523 ±0.127	0.444 ±0.027	0.584 ±0.029	0.330 ±0.016	0.329 ±0.015	0.284 ±0.012

J/ψ polarisation

J/ψ cross-section

Results at extrema of polarisation states

ϒ polarisation

ϒ cross-section

We can expect cross-section measurement precision in bins of p_T of the order of 1% (dependent on the polarisation)

The precision of the J/ψ polarisation measurement can reach 0.02-0.06, while the expected error on Y polarisation is unlike to be better than 0.2.

χ decays $\chi_c \to J/\psi + \gamma$ events

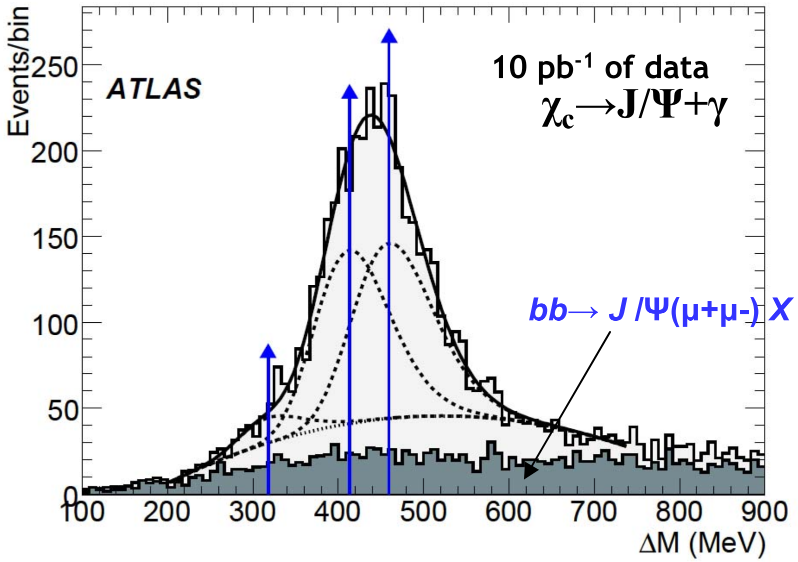
- For J/ψs, ~30% of total cross-section comes from $\chi_c \to J/\psi + \gamma$

Interested in χ_c decays to J/ψ or ϒ and a soft photon.

Low χ reconstruction efficiency due to the difficulty in retrieving this photon.

Preliminary studies suggest we can recover few % of those χ_c events from reconstructed J/ψ's

1. Have a J/ψ candidate
2. Look in narrow cone (cos θ>0.98) around quarkonium momentum direction for photon (reduces combinatorics)
3. μμγ-μμ invariant mass difference shows peaks where χ_{c0}, χ_{c1} or χ_{c2} was reconstructed
4. A simultaneous fit of three Gaussians and quadratic background, can find the three peaks with a typical resolution of 40 MeV



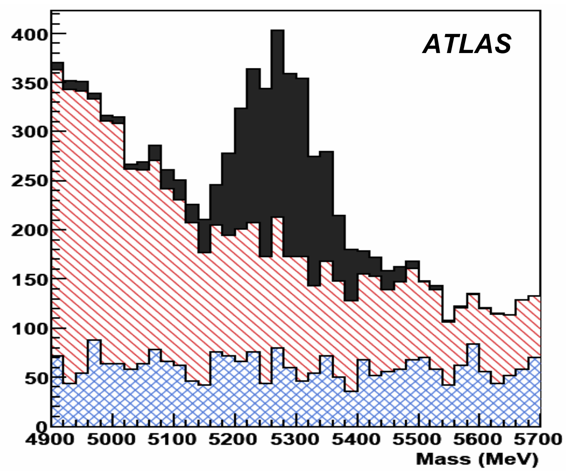
➢Only ~4% of χ_c decays into J/ψ γ have the right kinematics for photons to be reliably reconstructed and identified in ECAL

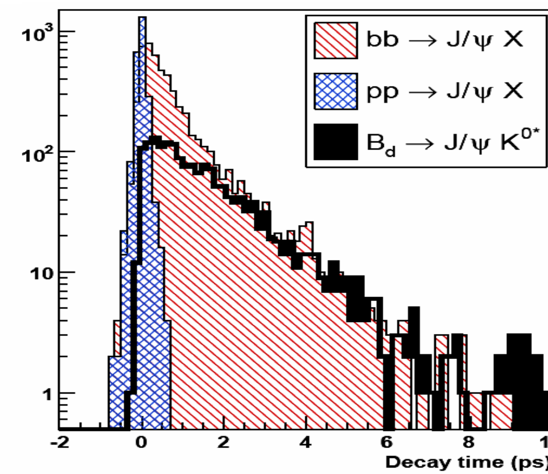
➢Studies on-going to include photon conversions using ID tracks, which should have better resolution, at the price of much reduced efficiency.

It will be possible to measure the masses and proper lifetimes for these decays with sufcient precision to allow them to be used for detector performance checks.

- $B_d \to J/\psi\ K_0^*$ vertex reconstructed from two muons, one kaon and one pion track: this channel allows sensitive performance tests from $10 pb^{-1}$

- In early data, loose cuts will be used (No vertex displacement cut)
- Simultaneous fit to mass and decay time used to extract signal mass and lifetime from data





Parameter	Simulated value	Fit result with statitical error
Γ, ps^{-1}	0.651	0.73 ± 0.07
$m(B)$, GeV	5.279	5.284 ± 0.006
σ, ps		0.132 ± 0.004
σ_m, GeV		0.054 ± 0.006

- Mass can be measured with a precision of $\sim 10^{-3}$
- B-Lifetime can be measured with a precision of ~10% with $10\ pb^{-1}$.
- Measurement of resolution possible with $10\ pb^{-1}$ allowing for ID tests stability.

See talk of Weina Ji

Summary

- The ATLAS B-physics program will run from the earliest days and will concentrate on:
  - total and differential cross sections of B-hadrons and onia
  - Polarization measurements
  - Mass and lifetime measurements

- An efficient, fast and clean di-muon trigger will allow to collect large samples of B-hadrons and Quarkonium throughout the lifetime of the experiment.

- Already with the first pb^{-1},
  - mass and lifetime measurements of exclusive channels will serve to validate and monitor ID performance and alignment
  - J/ψ and Upsilon resonances will provide calibration points

Waiting for the data …
its going to be interesting!

- Thank you!