



the **ATLAS Experiment**



B and onia production in ATLAS

Else Lytken (CERN)

On behalf of the ATLAS collaboration

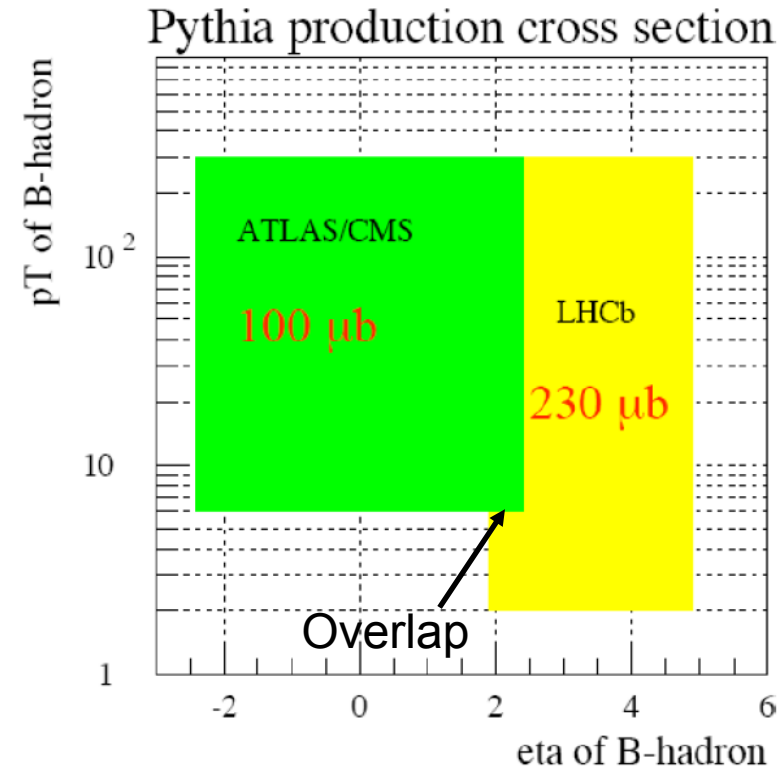
HERA-LHC workshop May 2008



B and onia production in ATLAS

Take advantage of copious $b\bar{b}$ production at 14 TeV:
 $\sigma(b\bar{b}) \sim 500 \mu\text{b}$

- Measure cross sections at new energy
 - σ , $d\sigma/dp_T$, $d\sigma/d(\Delta\phi)$, $d\sigma/d\eta$
- B physics a window for new discoveries
 - Observe rare decays, measure CP violation parameters
- Detailed understanding of the $b\bar{b}$ spectrum as background to other processes.
- Commissioning/early physics: calibration, alignment, trigger efficiencies etc.



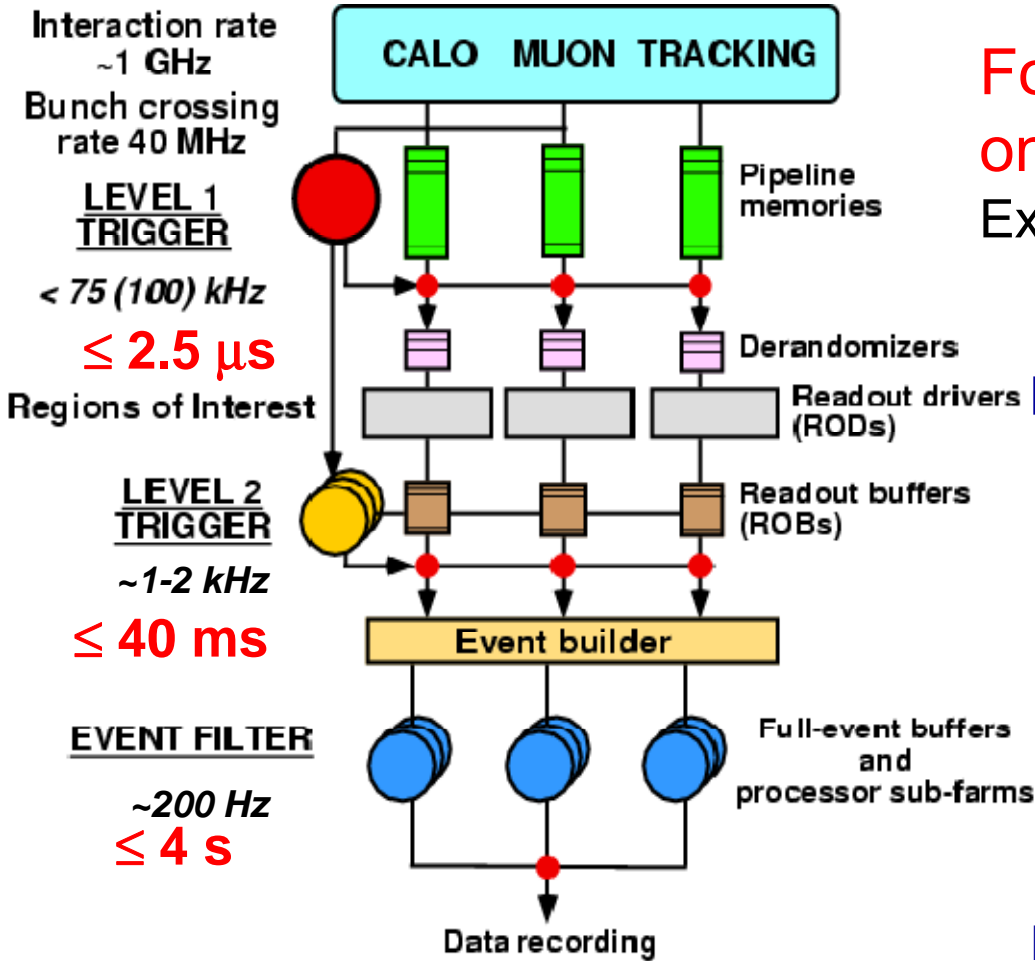
Early physics with b's and onia

- Focus of this talk is on the measurements during commissioning phase/early physics: $\mathcal{L}_{inst} = 10^{31} - 10^{32} \text{ cm}^{-2}\text{s}^{-1}$

Production of B's and the quarkonia narrow resonances gives us a handle for first performance measurements complementary to and extending other SM “standard candles” such as W's and Z's.

- For instance crucial for Higgs and SUSY searches to understand our performance with lower p_T leptons
- Lower luminosities means lower p_T trigger thresholds possible, both for electrons and muons
- Given the high rates our trigger menus have the **flexibility** to account for different luminosity scenarios

Initial triggers: relevant examples



For initial low luminosities can trigger on both low p_T electrons and muons.

Expected L1 rates and prescale factors:

	PS	Rate (kHz)	PS	Rate (kHz)
		$L=10^{31}$		$L=10^{32}$
Electrons				
EM3	60	~ 0.7	600	~ 0.7
2EM3	1	~ 6.5	10	~ 6.5
Muons				
MU6	1	~ 0.6	1	~ 6.4
MU10	1	~ 0.3	1	~ 3.6
2MU4	1	~ 0.1	1	~ 0.7
MU6JET10	10	~ 1	100	~ 1

L2: confirm L1 signal + additional search in regions of interest

EF: offline algorithms for final selection

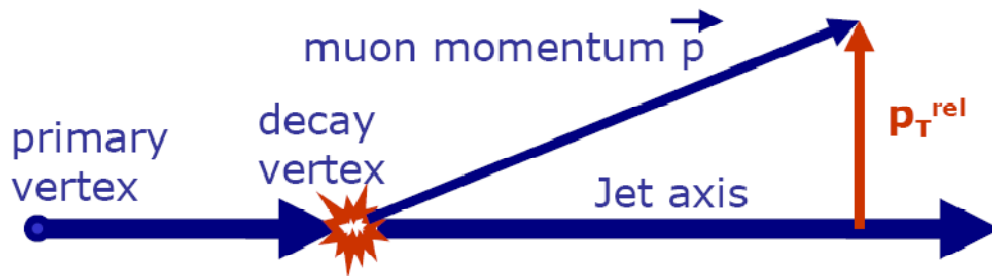
Inclusive b production cross section: $\mu + b\text{-jet}$

$$\sigma(b\bar{b} \rightarrow \mu(p_T^\mu > 6 \text{ GeV})X) = \frac{N_b^{\text{sel}}}{\int \mathcal{L} dt} \cdot \frac{f_b}{\epsilon_b^{\text{trig}} \cdot \epsilon_b^{\text{rec}}}$$

$$\epsilon_b^{\text{trig}} = 13.5\%$$

$$\epsilon_b^{\text{rec}} = 85\%$$

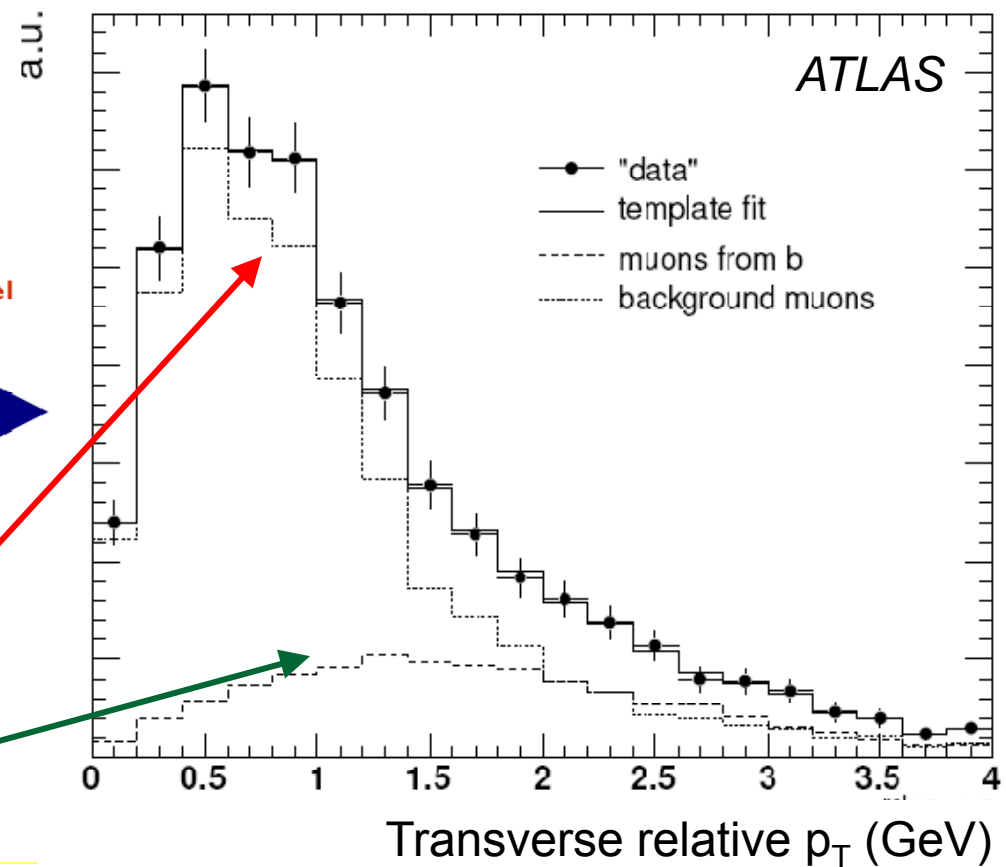
f_b found from fitting transverse relative p_T to templates:



With 15 pb^{-1} such a fit gives us:

$$f_{\text{backgr}} = 77 \pm 4 \% \quad (c \rightarrow \mu; \pi, K \rightarrow \mu)$$

$$f_b = 23 \pm 2 \% \quad (b \rightarrow \mu; b \rightarrow c \rightarrow \mu)$$



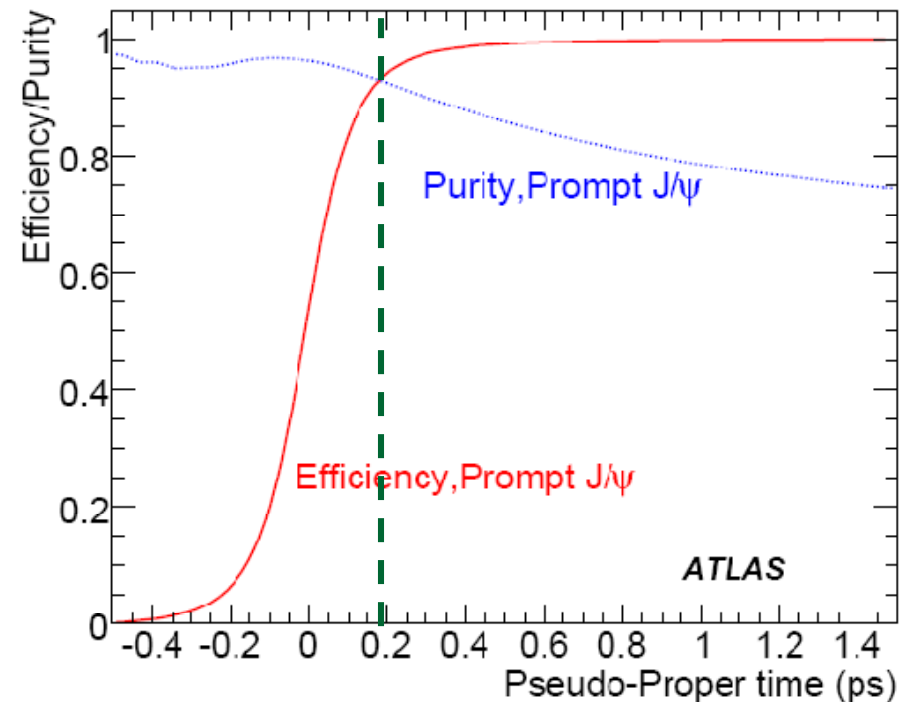
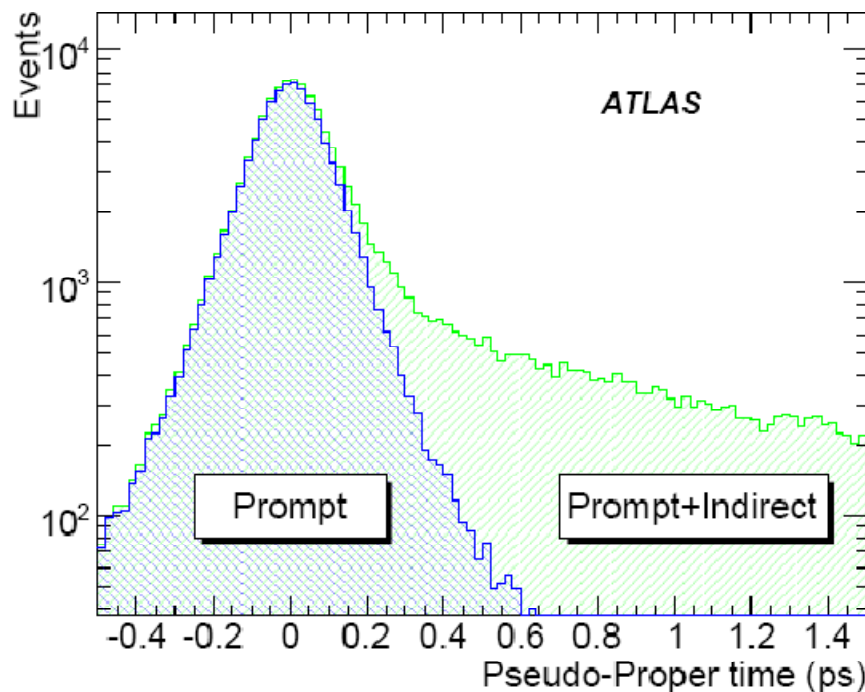
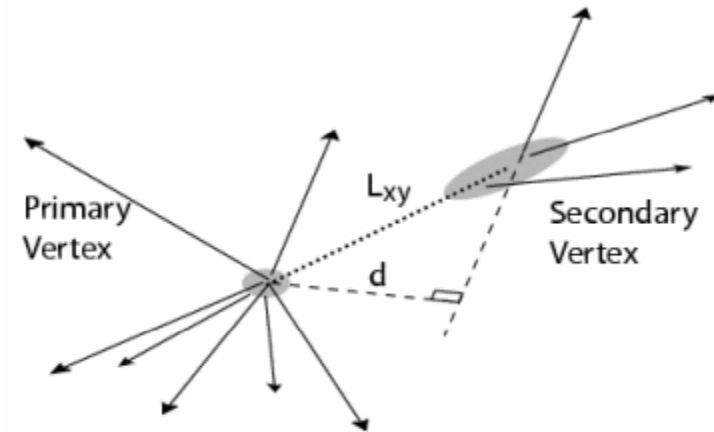
Inclusive cross section: dimuons

To distinguish $b\bar{b} \rightarrow J/\psi X$ (indirect J/ψ)
 from $pp \rightarrow J/\psi$ (prompt J/ψ 's, $\sim \sigma \times 2$)

Useful variable: the (pseudo-) proper time:

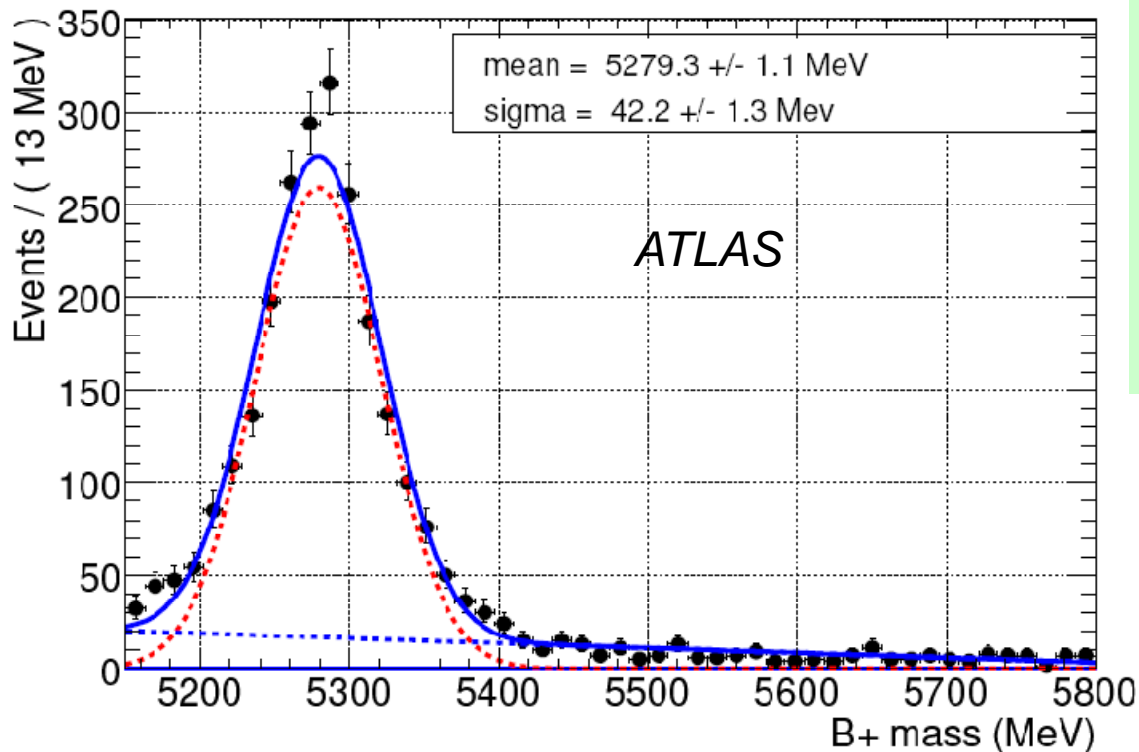
$$t = \frac{L_{xy} \cdot M_{J/\psi}}{p_T(J/\psi) \cdot c}$$

L_{xy} = transverse
 decay length



B σ measurements using excl. channels

- ✓ Due to high cross sections and dedicated triggers we can reconstruct exclusive channels in early data
- ✓ Reconstruction of the mass and lifetime of the B^\pm meson from $B^\pm \rightarrow J/\psi K^\pm$ decay very useful for calibration and alignment performance.



Requirements:

- dimuon trigger
- displaced vertex ($\lambda \geq 100 \mu\text{m}$) $\lambda = \frac{L_{xy} m}{p_T}$
- add. track with $p_T \geq 1.5 \text{ GeV}$
- track and $\mu\mu$ fit to same vertex
- $m(\mu\mu, \text{track})$ within 120 MeV of B^+ mass.

Results with 10 pb⁻¹:

$$\sigma(m_{B^+}) = 42.2 \pm 1.3 \text{ MeV}$$
$$\varepsilon(\text{total}) = 29.8 \pm 0.84 \%$$

B cross section with excl. channels

Measurement of $d\sigma_B/p_T$ using $B^+ \rightarrow J/\psi K^+$ after 10 pb^{-1} :

(GeV)	$10 < p_T < 18$	$18 < p_T < 26$	$26 < p_T < 34$	$34 < p_T < 42$	$10 < p_T < 42$
Acceptance + stat. (%)	7.7	6.9	10.5	13.9	4.3
Total uncertainty (%)	16.1	15.8	17.6	19.8	14.8

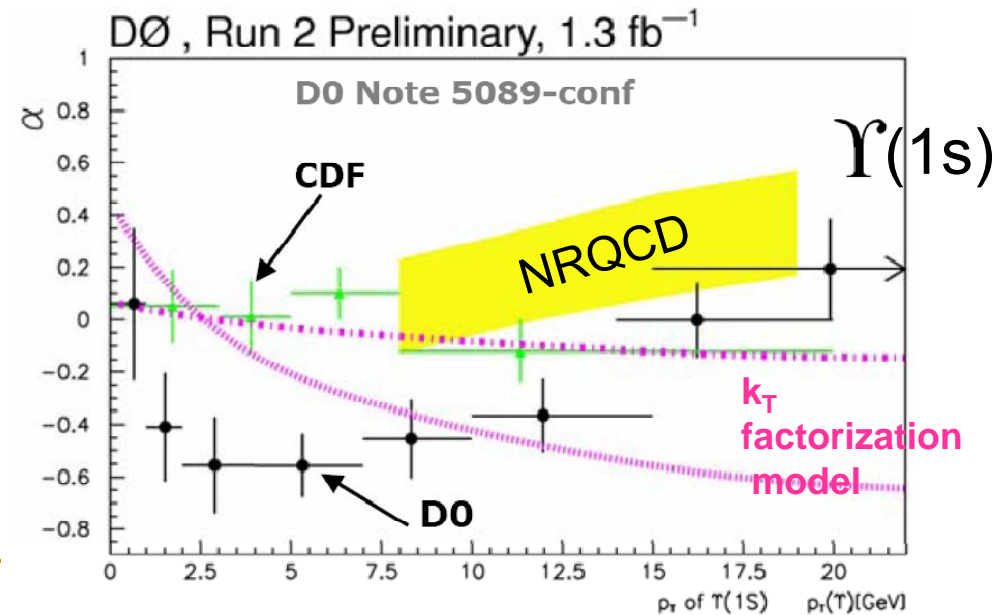
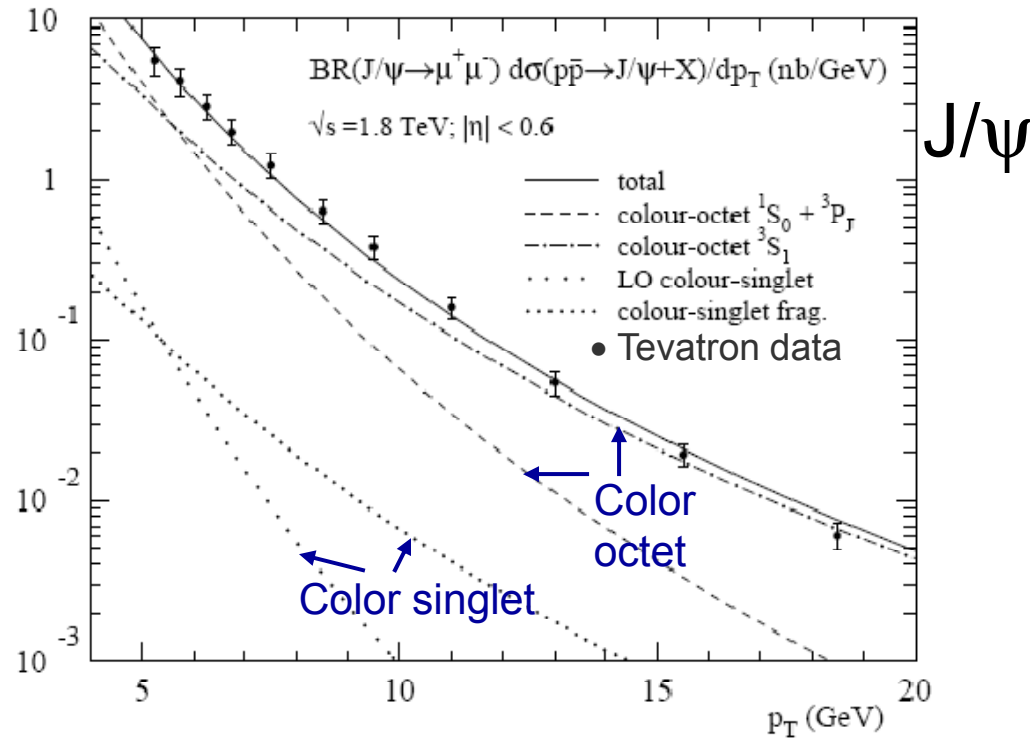
Available statistics
with 100 pb^{-1} :

Channel	N (100 pb^{-1})
$B^+ \rightarrow J/\psi K^+$	17000
$B^0 \rightarrow J/\psi K^{0*}$	8700
$B_s \rightarrow J/\psi \phi$	900
$\Lambda_b \rightarrow J/\psi \Lambda$	260

Quarkonia

- Among first measurements + theoretical interest:
What is the production mechanism?
- The Color Octet Mechanism agrees well with measured σ shape from Tevatron
- Polarization measurements:
CDF sees no sign of pol. for J/ψ and $D\bar{O}$ $\Upsilon(1S)$ measurements not consistent with predictions.

More data with high- p_T needed!



Quarkonia in ATLAS: $J/\psi \rightarrow e^+e^-$

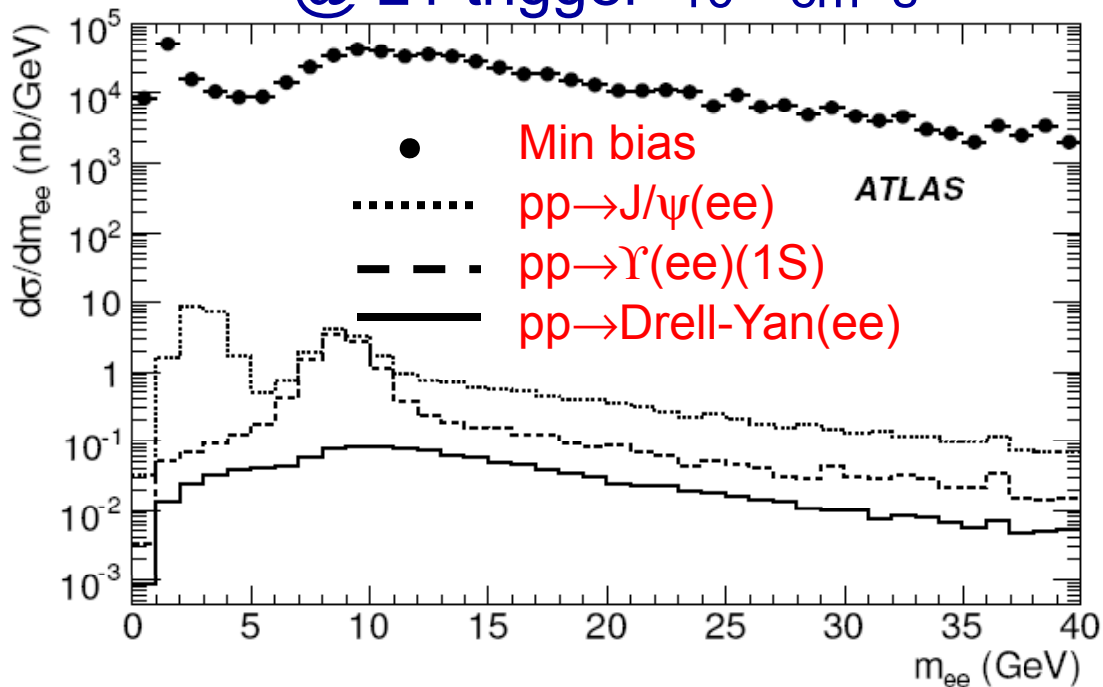
Initial data: take advantage of electron trigger paths as well

Current studies using **2EM3**

Single-e triggers under investigation

Later data (“low luminosity”, $L=10^{33}\text{cm}^{-2}\text{s}^{-1}$) has to rely on single- μ b trigger also for $J/\psi(ee)X$, $\Upsilon(ee)X$

@ L1 trigger $10^{31}\text{cm}^{-2}\text{s}^{-1}$



L1 $\epsilon(\text{trig}) \sim 27\%$

L2, EF under optimization

$N(J/\psi)$ after L1: 4.2 M events

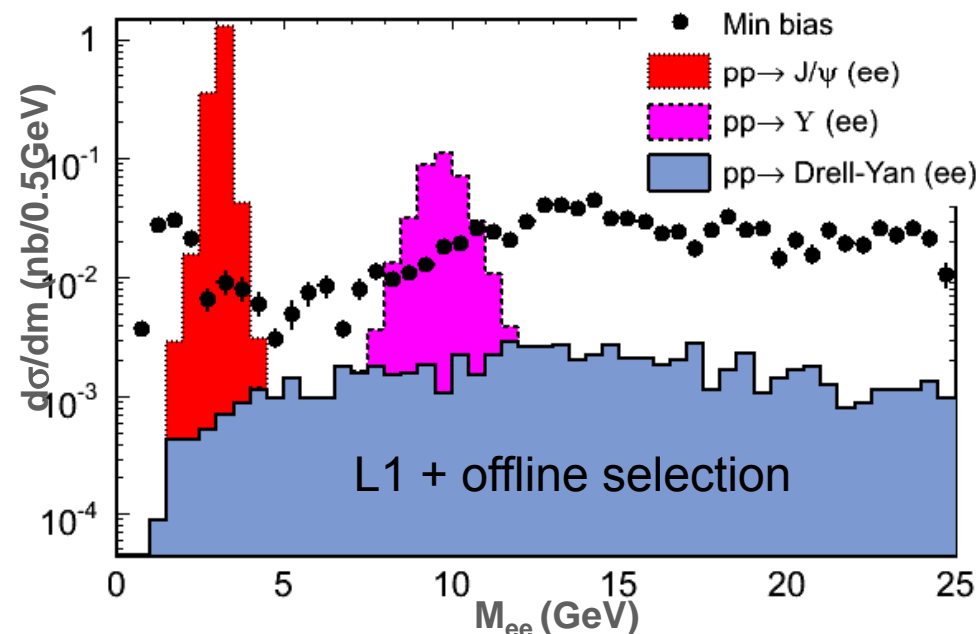
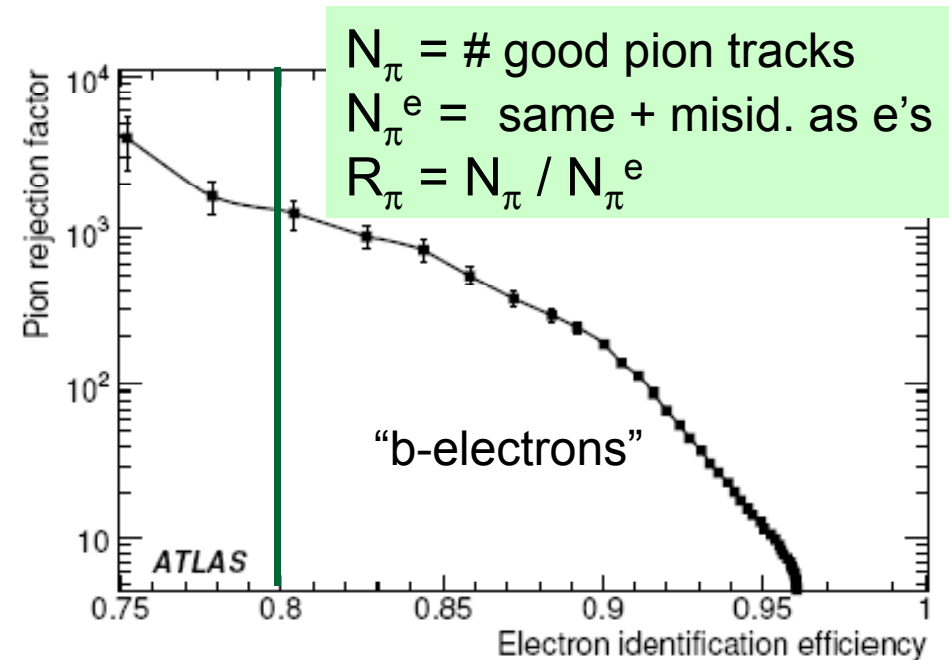
$N(\Upsilon)$ after L1: 1.2 M events

$J/\psi \rightarrow e^+e^-$

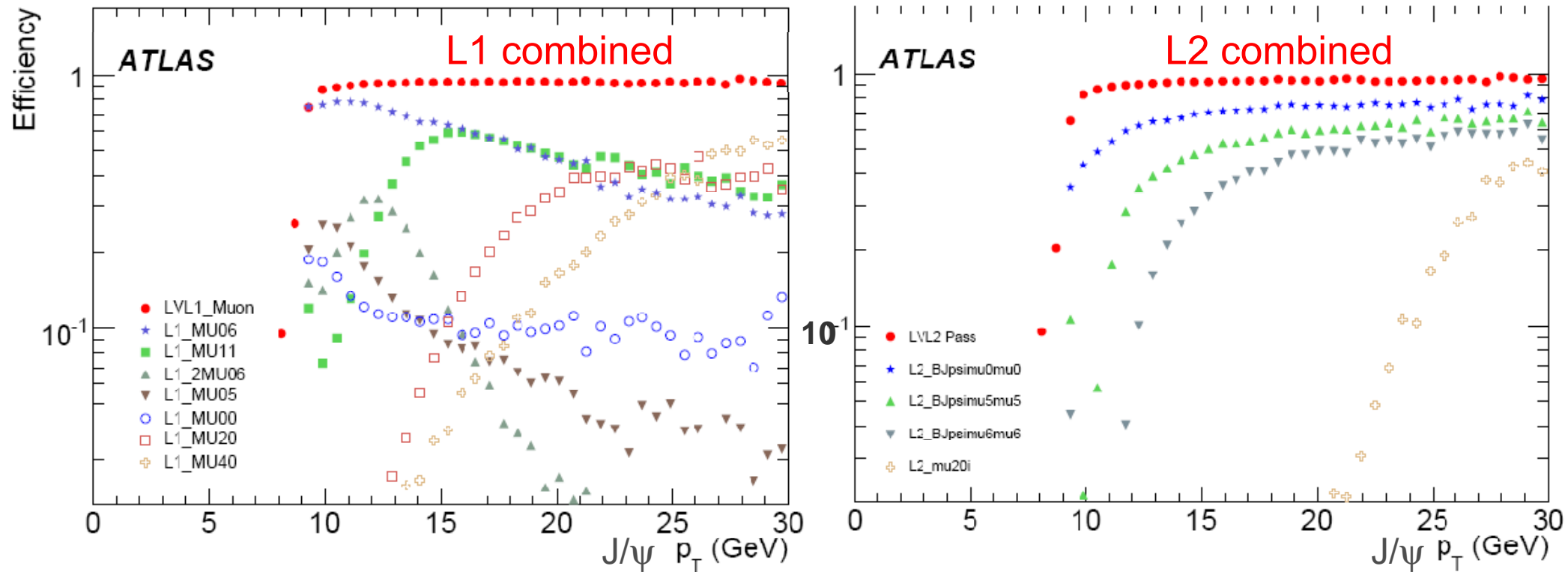
Two electron id methods explored:

- Low p_T version of standard ATLAS isolated electron cut based on shower shapes, associated to high quality tracks with $E/p > 0.7$, conversion veto, and transition radiation hits
- Less efficient for electrons from b's \Rightarrow 2nd method ($p_T \geq 2$ GeV/c) extrapolates in narrow window to calorimeter and uses likelihood ratio (similar variables)

After offline selection 100 pb^{-1} :
 $\sim 230\text{k}$ J/ψ 's and $\sim 43\text{k}$ Υ 's
 Expect to measure $m(J/\psi)$ to $\sim 0.6\%$



$$J/\psi \rightarrow \mu^+ \mu^-$$



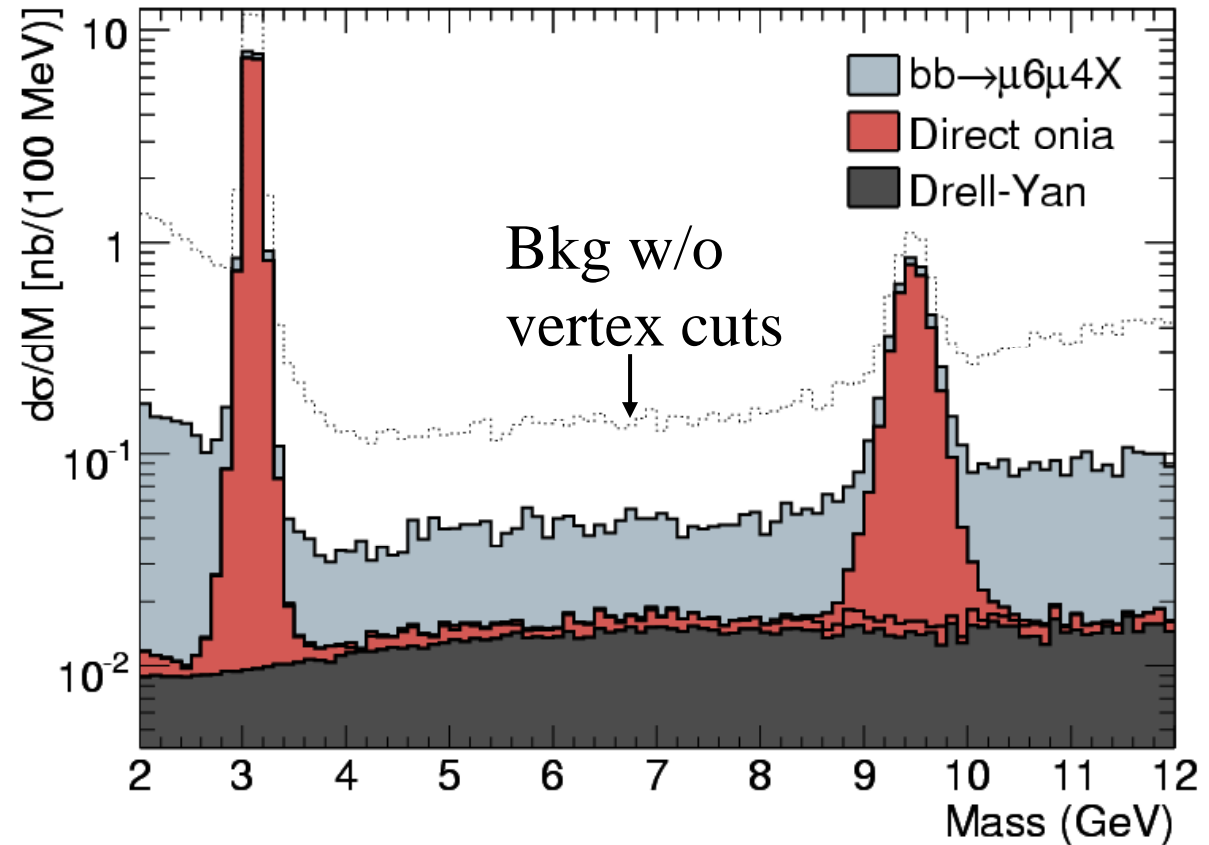
- Current studies use a combination dimuon trigger, $\epsilon(\text{trig}) = 87\% \text{ L1}, 97\% \text{ L2}$, with analysis cuts of 6 and 4 GeV
- Rate $\leq 1 \text{ Hz}$ expected at EF for all quarkonium $\rightarrow \mu\mu$ (incl $\psi', \Upsilon(2,3S)$)

Dimuons: Results

Require: muons from same vertex and proper time < 0.2 ps

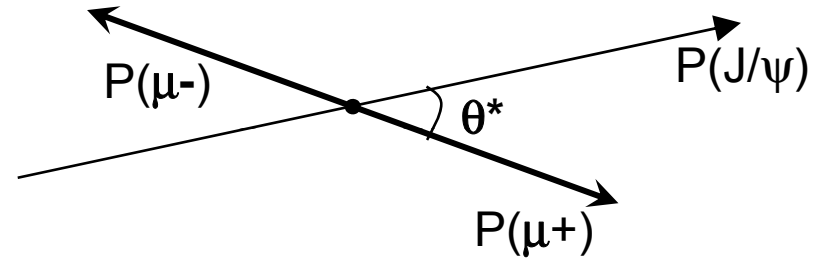
With $p_{T1} \geq 6$ GeV,
 $p_{T2} \geq 4$ GeV:
15k J/ψ 's per 1 pb^{-1}
2.5k Υ 's (1S)
1-2 days with
 $\mathcal{L} = 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$

With 10 pb^{-1} :
S/B = 60 for J/ψ and 10 for Υ
 $d\sigma/dp_T \sim 1\%$ for J/ψ , $\sim 5\%$ for Υ

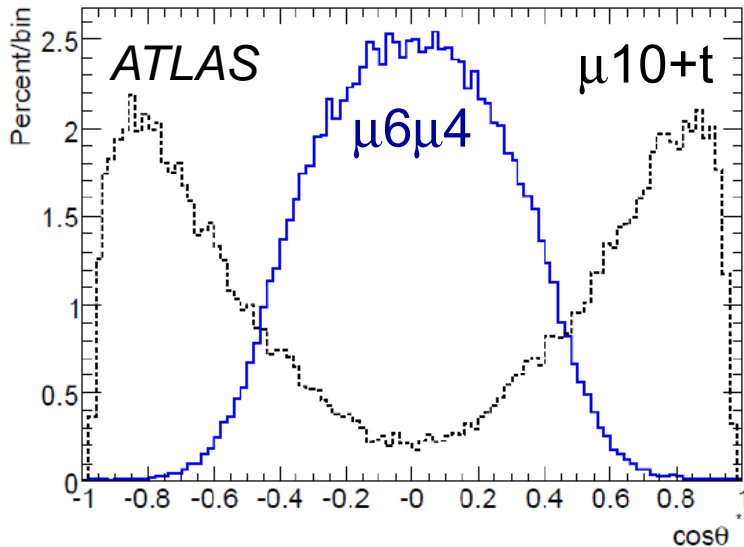


10 pb^{-1} : also measurement of
 $\chi_c \rightarrow J/\psi(\mu\mu) \gamma$
 $\sim 1 \text{ fb}^{-1}$: $\chi_b \rightarrow \Upsilon(\mu\mu) \gamma$

Polarization



Measure high- p_T polarization to distinguish production models

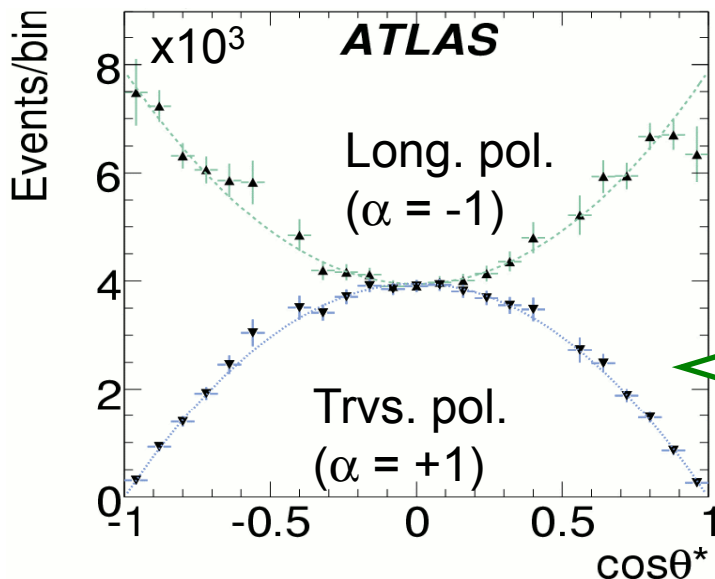


$$\frac{dN}{d \cos \theta^*} \propto 1 + \alpha \cos^2 \theta^*$$

Dimuon triggers: little or no information for high $\cos\theta^*$

Single- μ : combined with ≥ 0.5 GeV track gives access to these values ($\sim p_T$ range but larger $\Delta p_T(\mu^+, \mu^-)$)

Single- u trigger \Rightarrow larger background
Still: S/B = 1.2 (J/ ψ) and 0.05 (Upsilon)

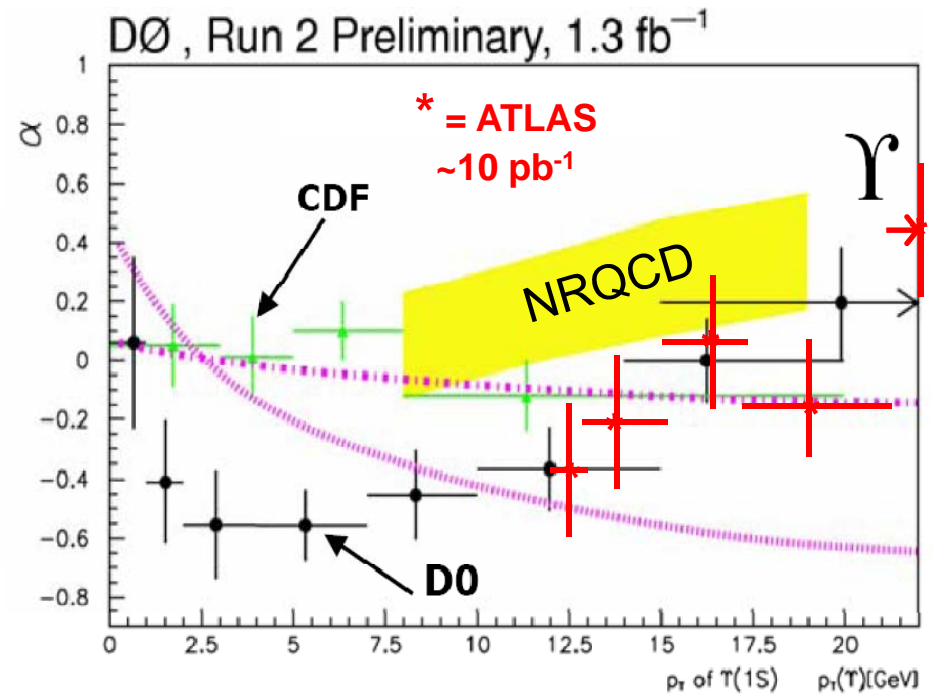
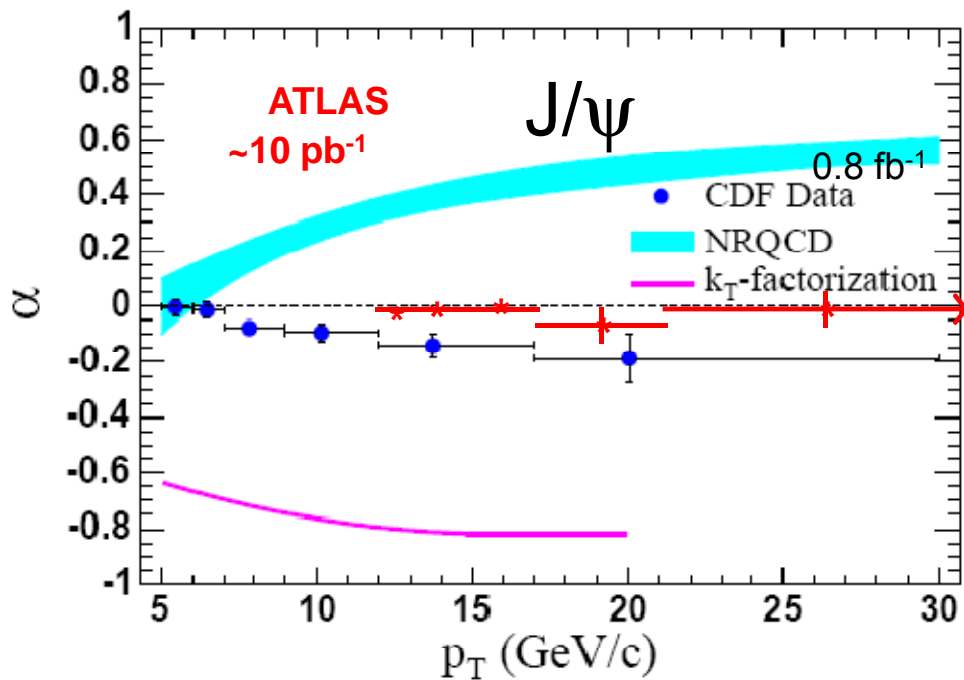


Combine and fit to measured distribution in slices of p_T
Shown: $12 \leq p_T \leq 13$ GeV

Polarization results

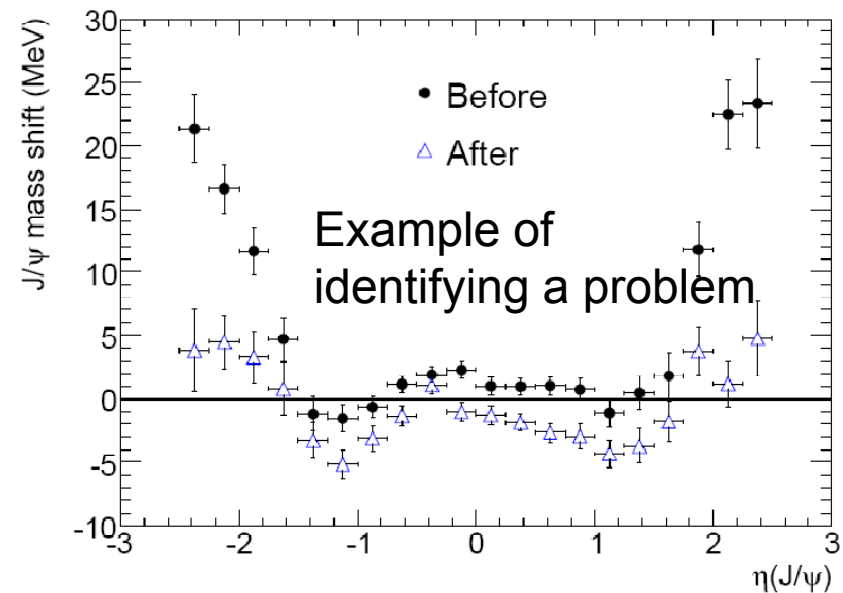
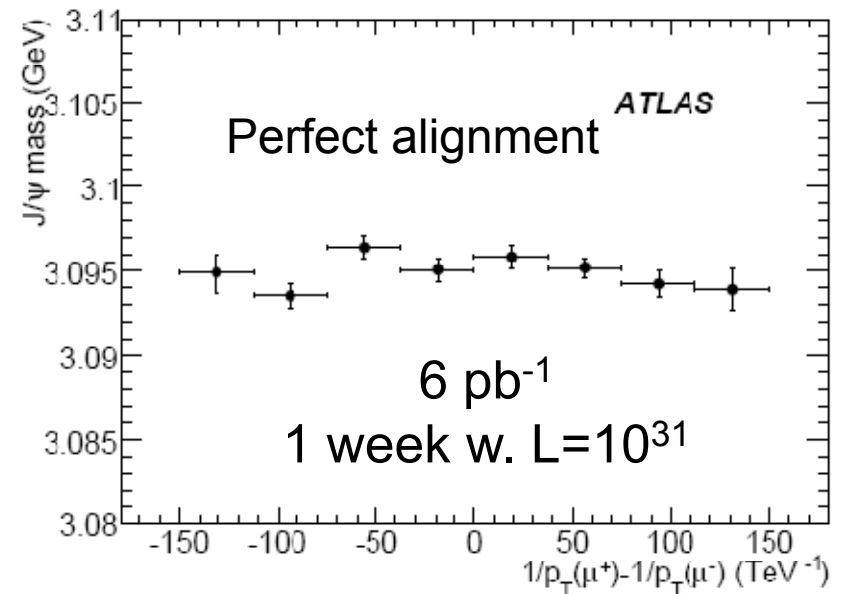
Already with 10 pb^{-1} : measure J/ψ pol. to same precision as TeV with 1.3 fb^{-1} - but with interesting high p_T data!
 Same precision for Υ polarization studies can be reached after $\sim 100 \text{ pb}^{-1}$

Crude superimpose of ATLAS stat uncertainties with 10 pb^{-1} assuming $\alpha=0$:



Quarkonia as a monitoring tool

- **Offline** and **online** monitoring with J/ψ 's and Υ 's important to have a low p_T data point in addition to Z 's
- Given the large statistics expected should be able to use this already in the beginning
- Check mass shift as a function of
 - **p_T :**
momentum scale, energy loss
 - **curvature diff:**
detector misalignments
 - **η and ϕ :**
magnetic field, material effects



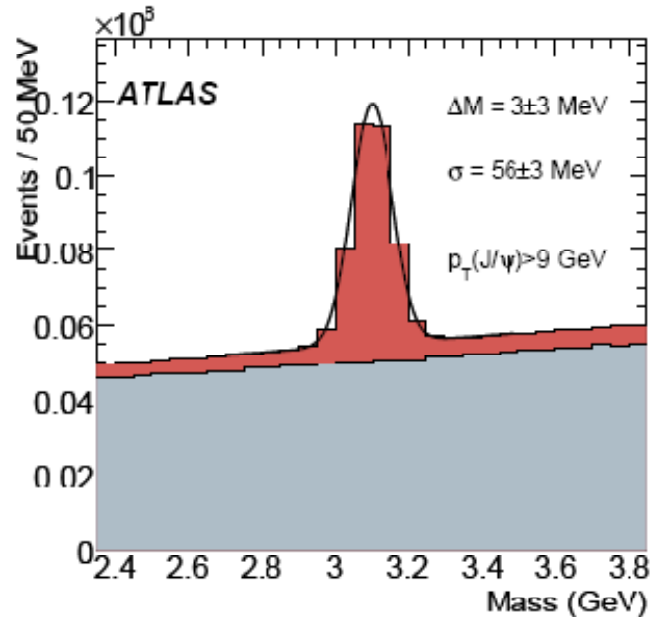
Summary and outlook

- ATLAS well prepared for B and quarkonia cross section measurements in initial low luminosity period
- Early data studies will also help us during commissioning
- For cross section measurements already enough statistics with the early data! (10 pb^{-1} or less)
- Key measurements based on muon triggers but in initial period will also have electron channels for comparison
- Stay tuned for the next chapter in J/ψ and Upsilon high- p_T polarization measurements!

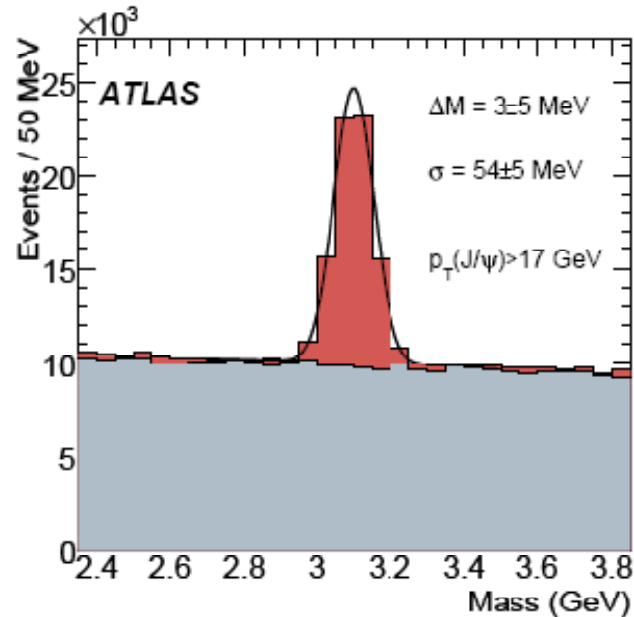
Backup

Single-muon trigger: S/B

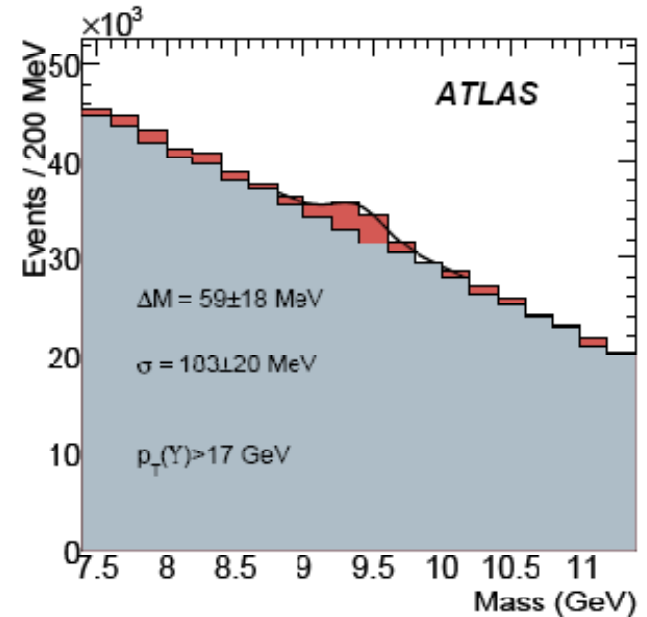
Most relevant for J/ψ studies ...



(a) $J/\psi \geq 9$ GeV



(b) $J/\psi \geq 17$ GeV



(c) $\Upsilon \geq 17$ GeV

Polarization measurement

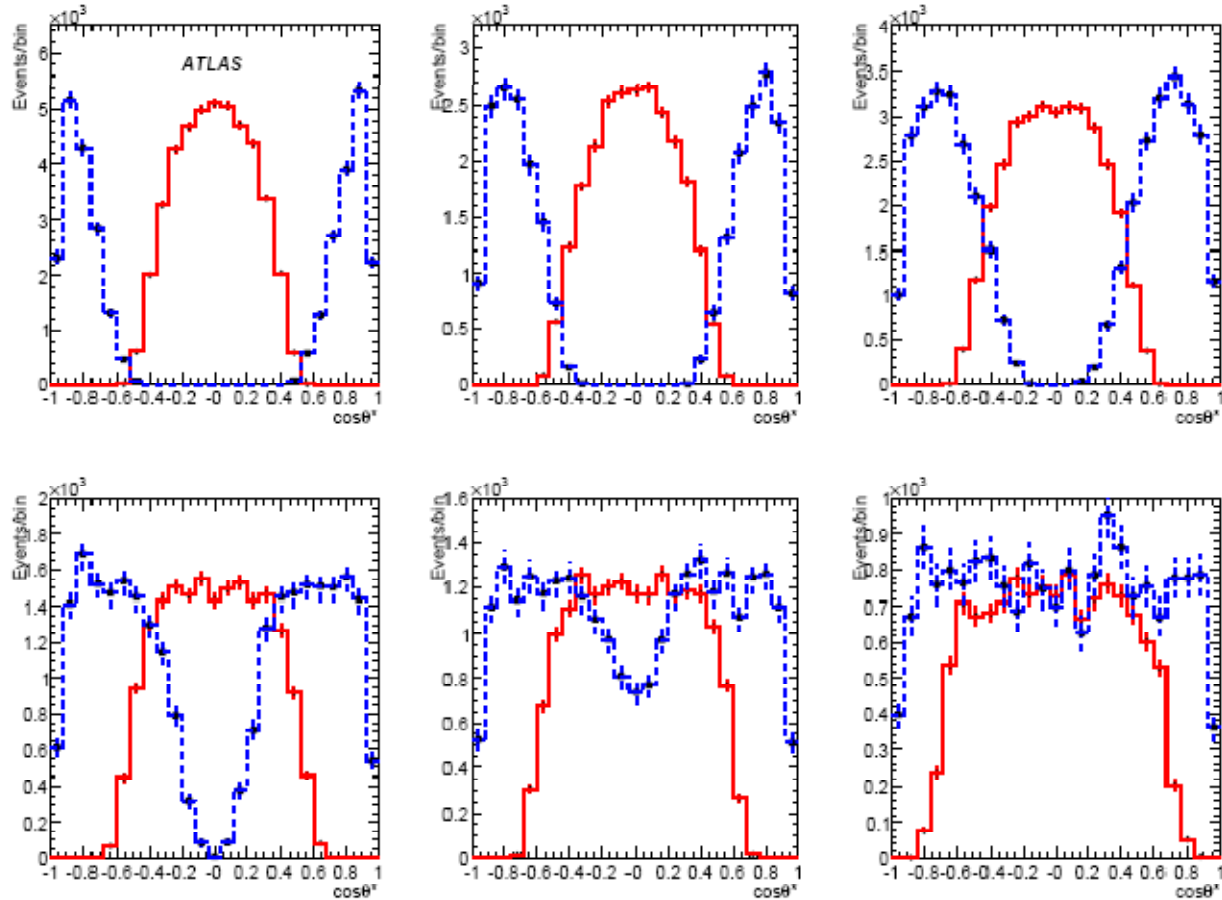
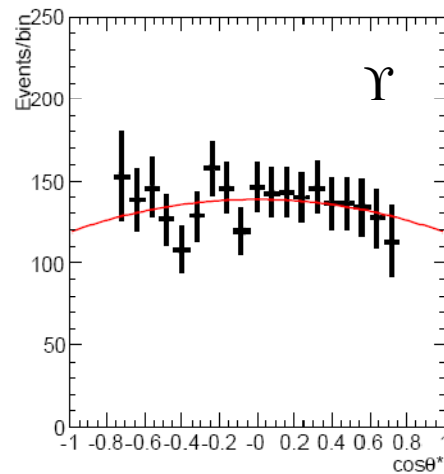
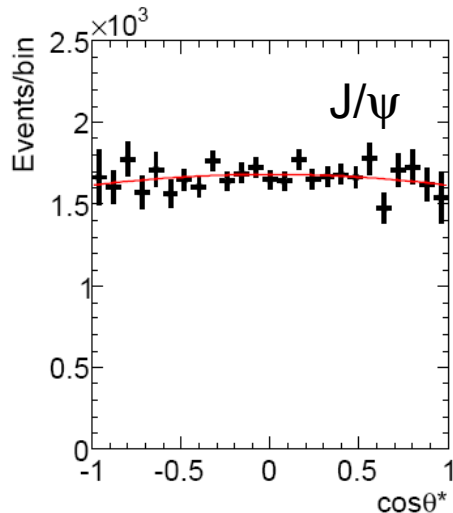
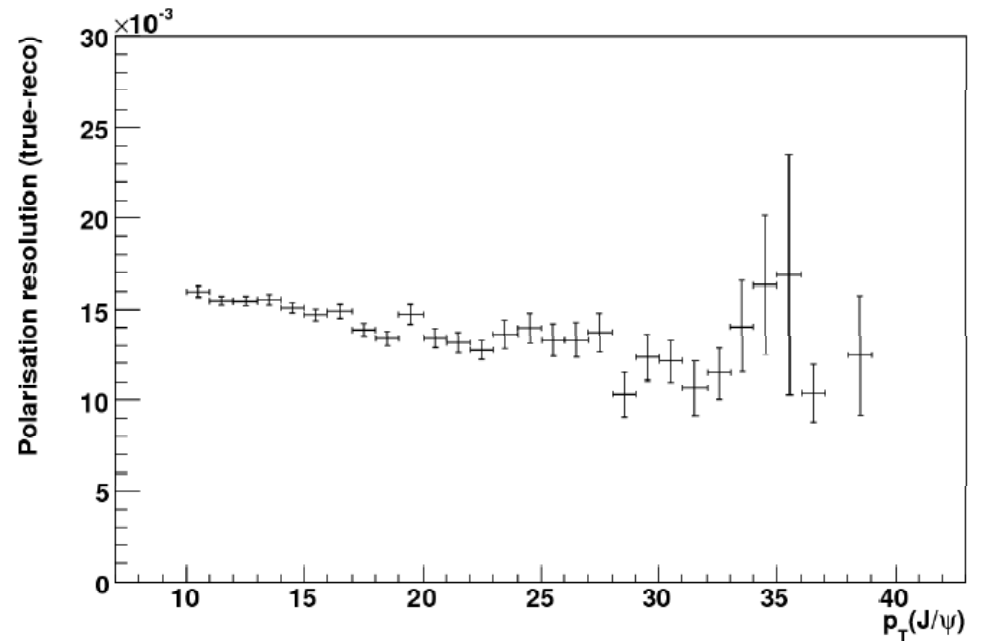


Figure 19: Measured distributions for $\mu 6\mu 4^-$ (solid red lines) and $\mu 10^-$ (dashed blue lines) triggered events, in the same p_T slices of the J/ψ candidate as in Figure 18. The simulated data sample is unpolarised. Statistics correspond to 10 pb^{-1} .

More on polarization

Resolution of reconstructed $\cos\theta^*$ is ~ 0.0015



← Combined measurement
Unpolarized
 $17 < p_T < 21$ GeV

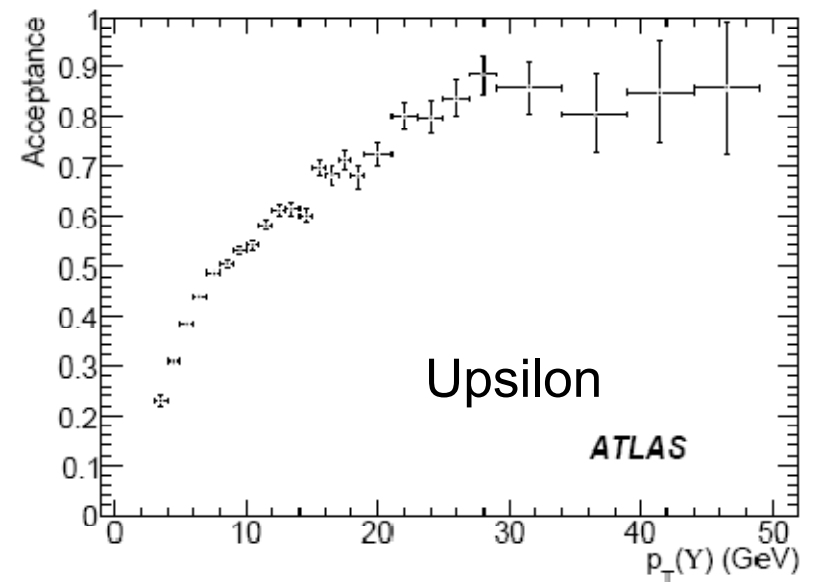
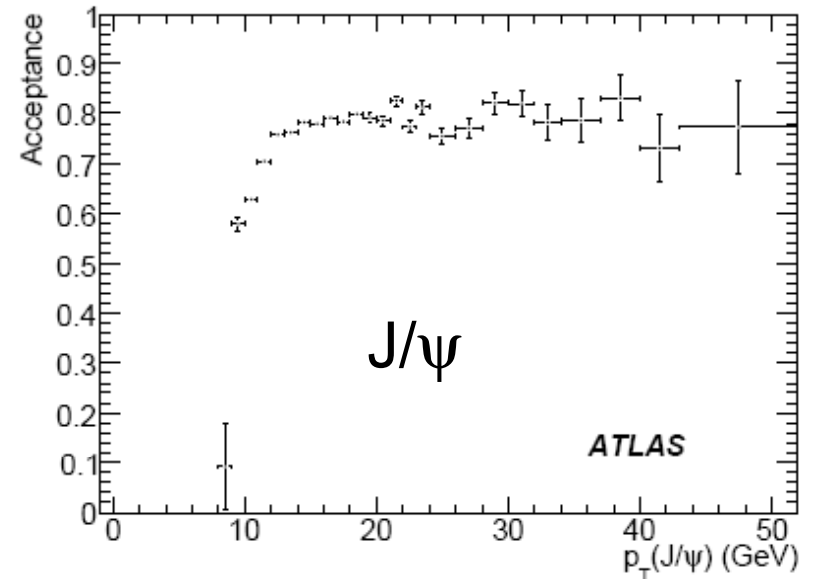
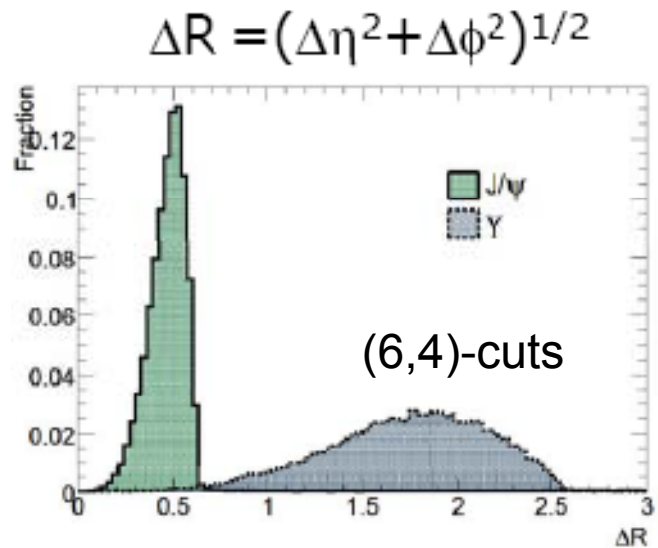
Acceptance

p_T cuts (trigger and offline) means
 $p_T(J/\psi) \geq 10$ GeV, whereas non-zero
 \cancel{A} for Upsilon also at ~ 0

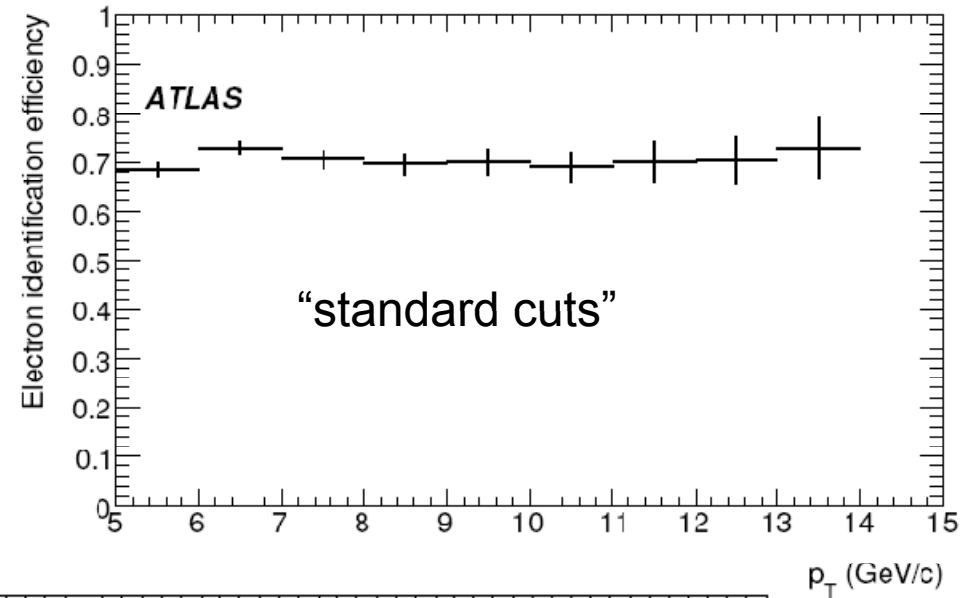
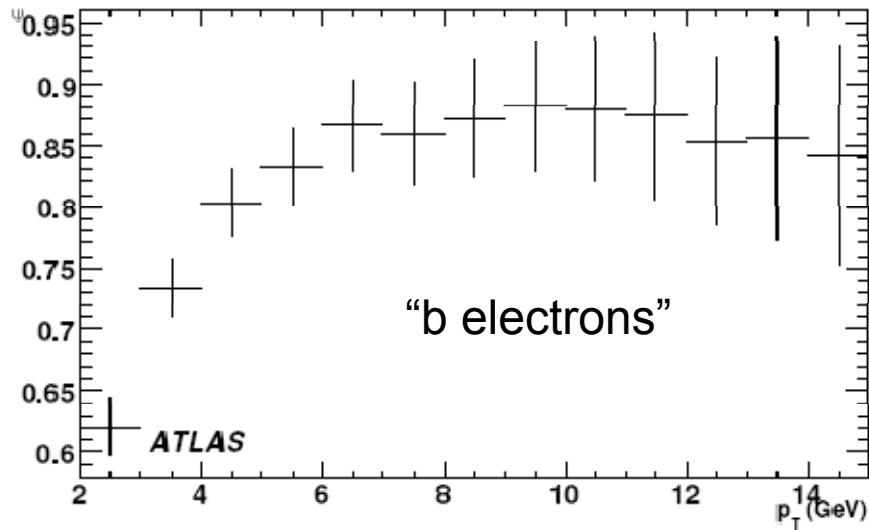
RoI's based on trigger towers of

$$\Delta\eta \times \Delta\phi \sim 0.1 \times 0.1$$

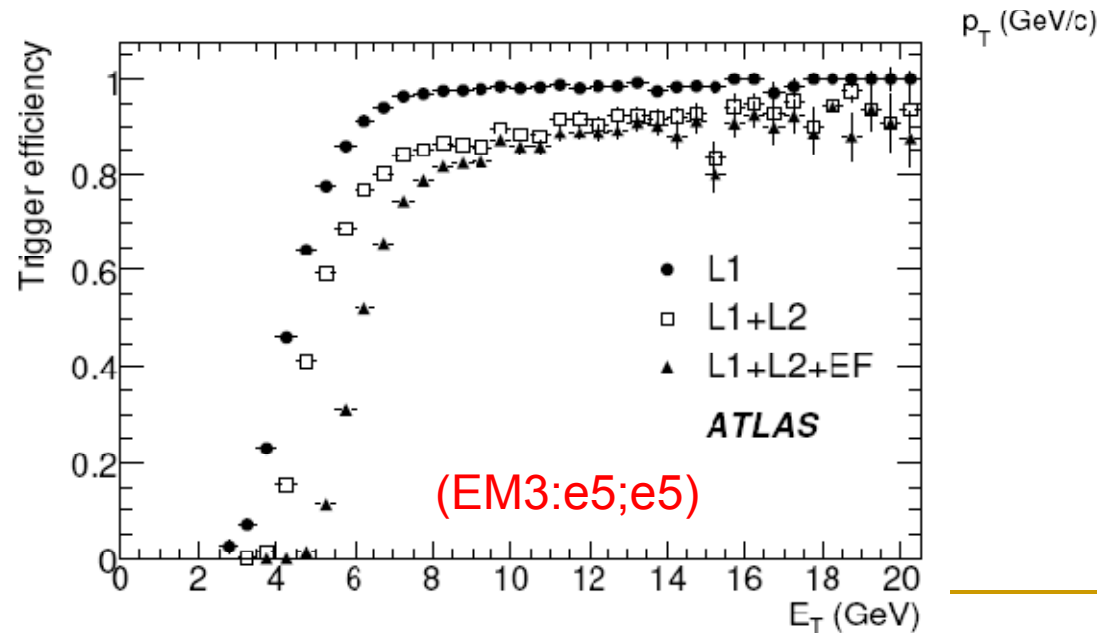
ΔR separation between leptons also
affects sensitivity to material effects



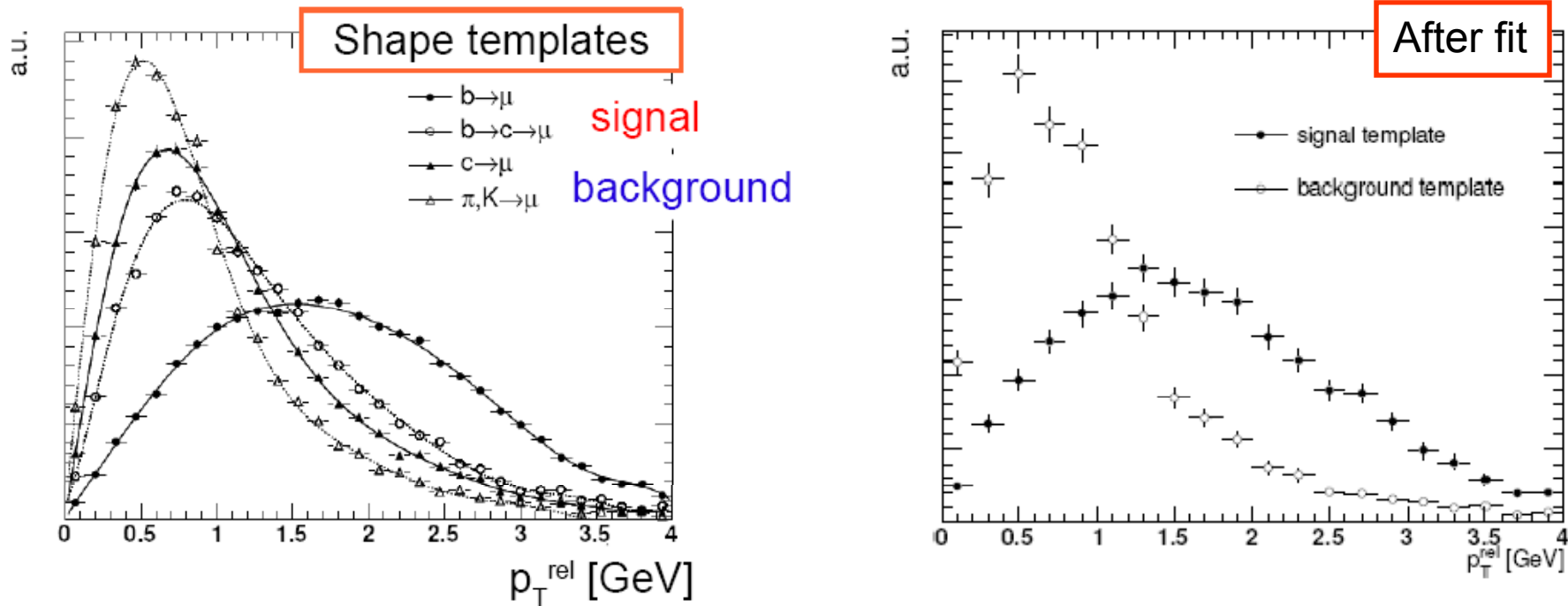
Electron efficiencies



Efficiency of single electrons
based on MC truth



Inclusive b production

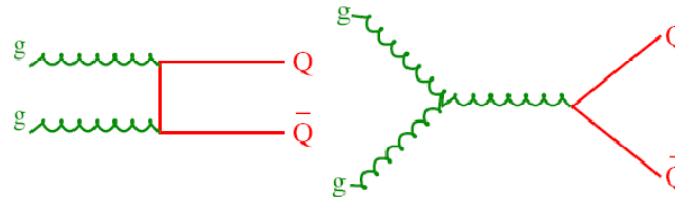


channel	specific luminosity [$\text{cm}^{-2}\text{s}^{-1}$]		
	$\mathcal{L} = 10^{31}$	$\mathcal{L} = 10^{32}$	$\mathcal{L} = 10^{33}$
$b\bar{b} \rightarrow J/\psi(\mu 6 \mu 4) + X$ with 2 μ LVL1	1 year (PS 1)	1 month (PS 1)	1 month (PS 10)
$b\bar{b} \rightarrow \mu(6) + b - \text{jet} + X$	1 month (PS 10)	1 month (PS 100)	1 month (PS 1000)

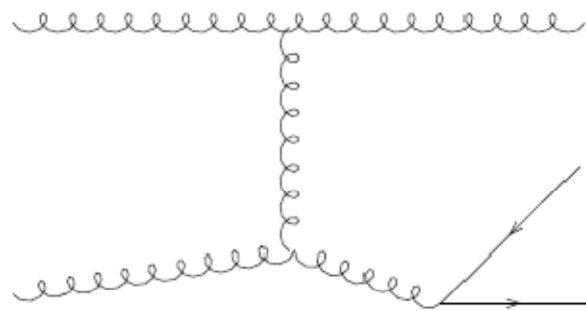
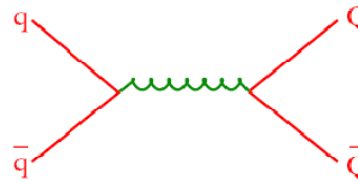
Table 12: *Estimated time to obtain a statistical precision of the inclusive cross section measurement of $\mathcal{O}(1\%)$. To keep the rate acceptable, prescale factors (PS) for the corresponding trigger have to be applied which can be lowered at lower specific luminosities.*

The 3 production mechanisms

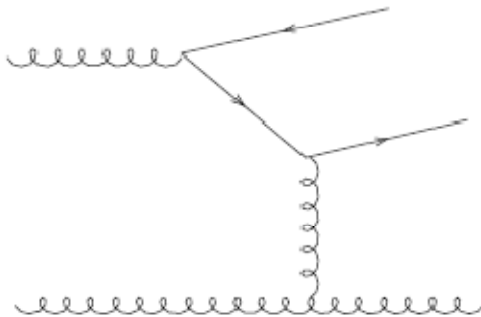
LO: Flavour creation



NLO: Gluon splitting



NLO: Flavour excitation, sensitive to PDF's



Standard PDFs are functions of x , the fraction of the momentum carried by the parton longitudinal to the hadron direction. Partons also have a small transverse momentum component:

— k_T factorization : $f(x) \rightarrow f(x, k_T)$, $\sigma(x, s) \rightarrow \sigma(k_T, x, s)$