# B and onia prodution in ATLAS

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On behalf of the ATLAS collaboration

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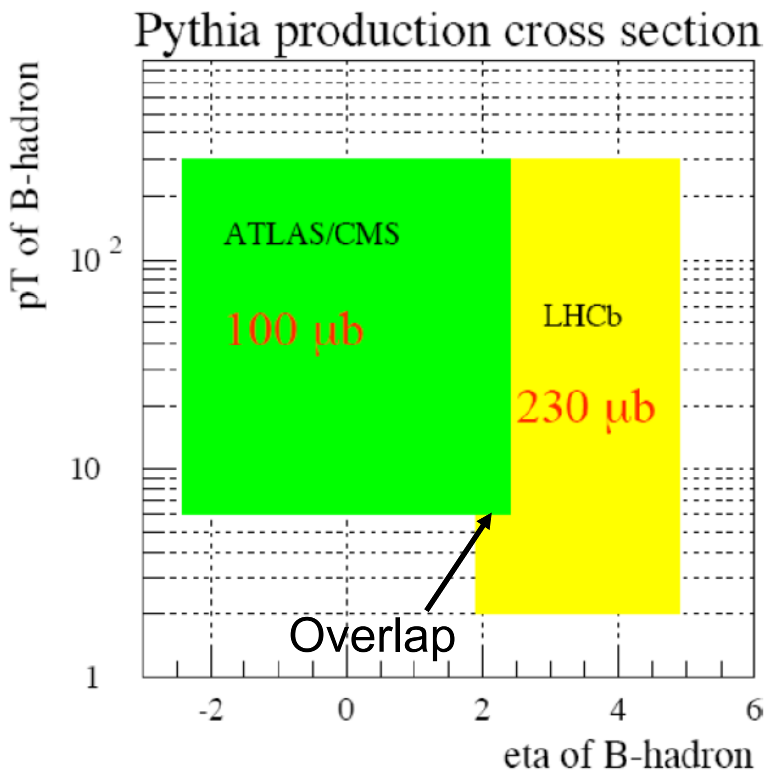
# B and onia production in ATLAS

Take advantage of copious $b\bar{b}$ production at 14 TeV:
$\sigma(b\bar{b})$ ~500 μb

- Measure cross sections at new energy
  - $\sigma$, $d\sigma/dp_T$, $d\sigma/d(\Delta\phi)$, $d\sigma/d\eta$
- 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.

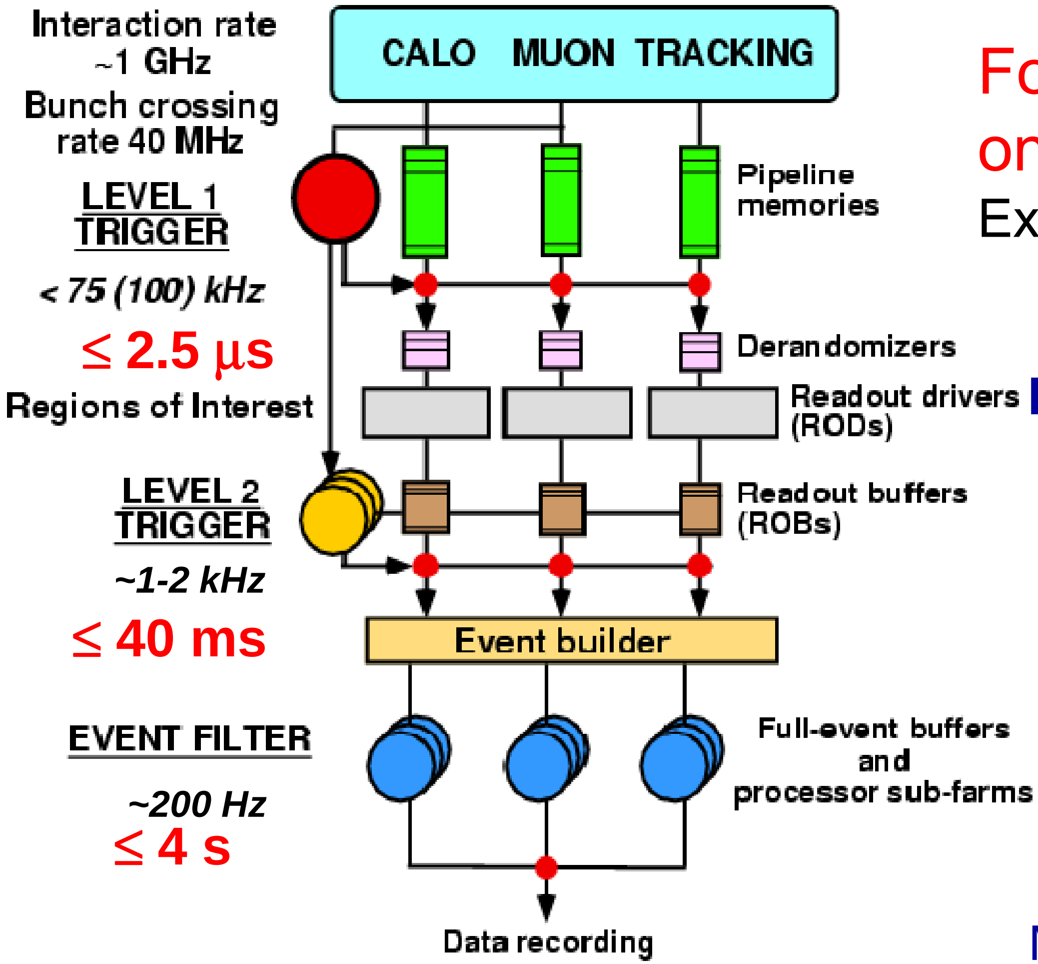


# Early physics with b's and onia

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

  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) L=$10^{31}$ | PS | Rate (kHz) 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

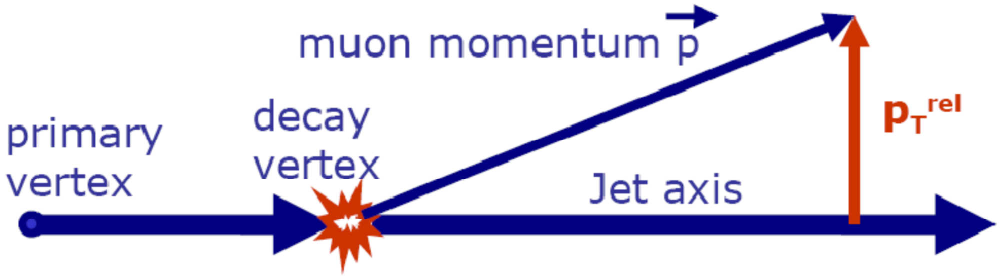
EF: offline algorithms for final selection

# Inclusive b production cross section: μ+b-jet

$$\sigma(b\bar{b} \to \mu(p_T^{\mu} > 6 \ \text{GeV})X) = \frac{N_b^{\text{sel}}}{\int \mathscr{L}\, \text{d}t} \cdot \frac{f_b}{\varepsilon_b^{\text{trig}} \cdot \varepsilon_b^{\text{rec}}}$$

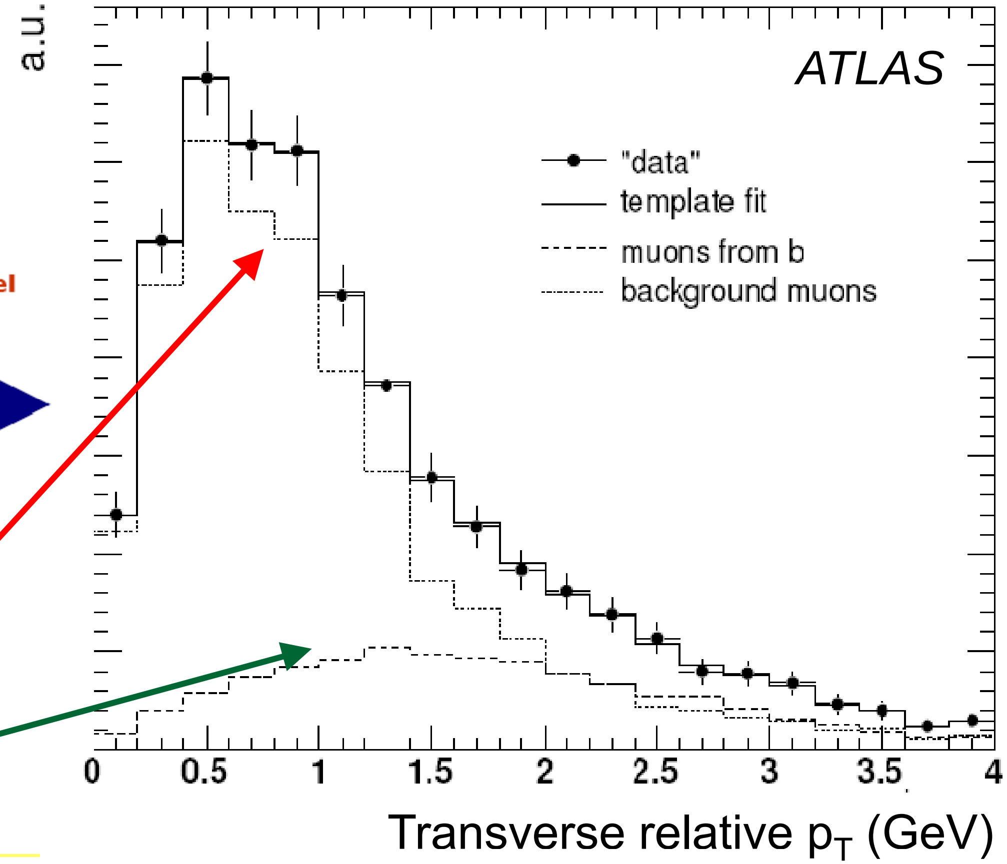
$\varepsilon_b^{\text{trig}} = 13.5\%$
$\varepsilon_b^{\text{rec}} = 85\%$

$f_b$ found from fitting transverse relative $p_T$ to templates:



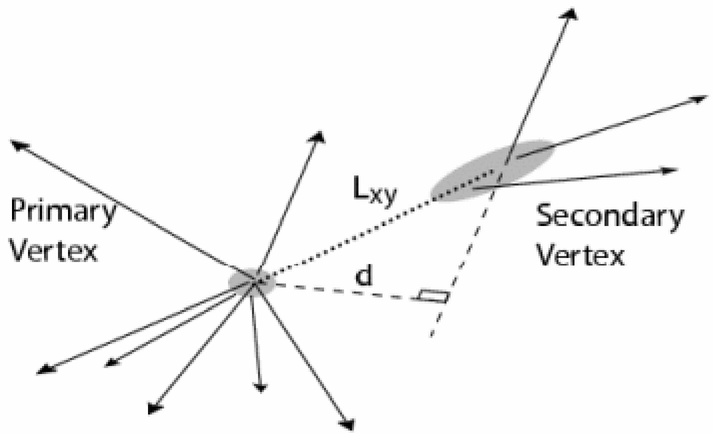

With 15 $pb^{-1}$ such a fit gives us:

$f_{backgr}$ = 77 ± 4 % (c→μ; π,K →μ)
$f_b$ = 23 ± 2 % (b →μ; b→c →μ)



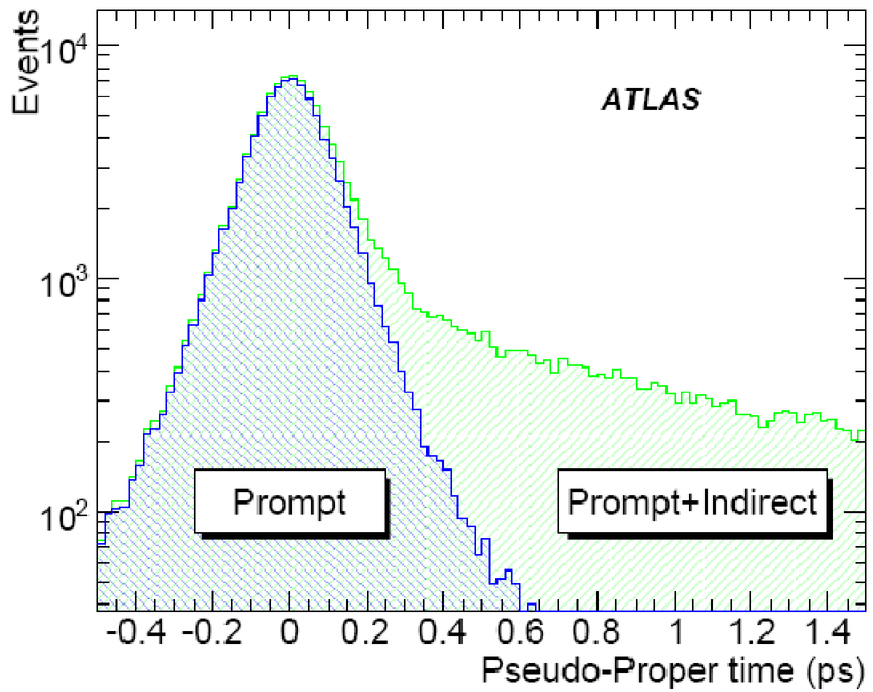
# Inclusive cross section: dimuons

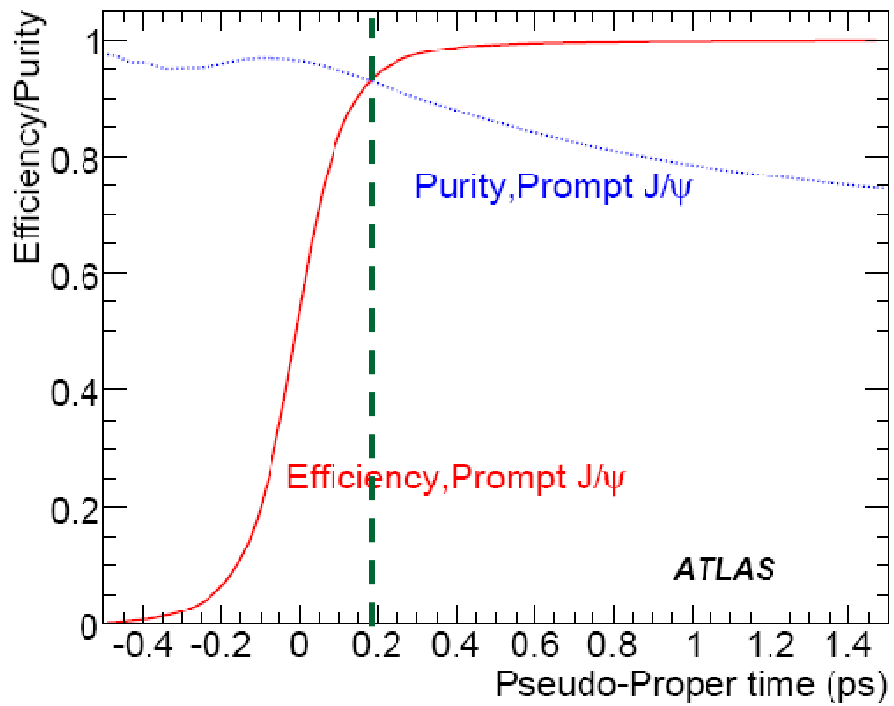
To distinguish $b\bar{b} \rightarrow J/\psi\ X$ (indirect $J/\psi$)
from $pp \rightarrow J/\psi$ (prompt $J/\psi$'s, $\sim \sigma \times 2$ )
Useful variable: the (pseudo-) proper time:




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

$L_{xy}$ = transverse decay length

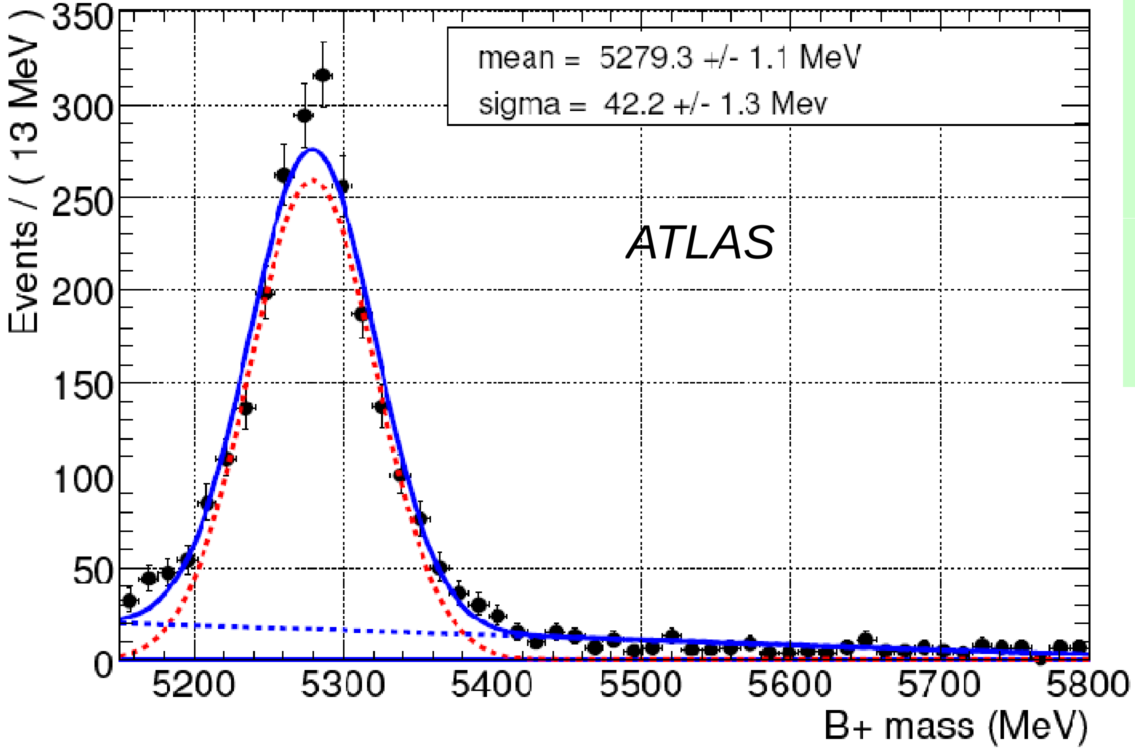


# B σ measurements using excl. channels

✓ 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 $B^{\pm} \to J/\psi K^{\pm}$ decay very useful for calibration and alignment performance.




**Requirements:**

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

Results with 10 $pb^{-1}$:

$\sigma(m_{B+}) = 42.2 \pm 1.3$ 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 statisitics with 100 $pb^{-1}$:

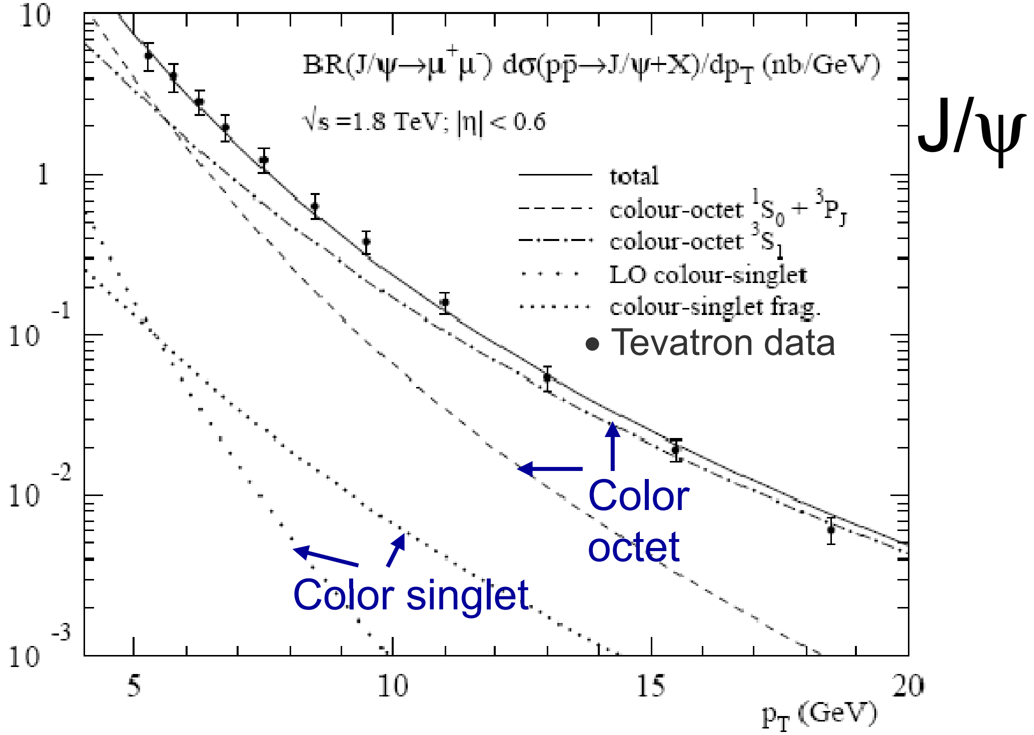
| Channel | N (100 $pb^{-1}$) |
|---|---|
| $B^+ \rightarrow J/\psi\ K^+$ | 17000 |
| $B^0 \rightarrow J/\psi\ K^{0*}$ | 8700 |
| $B_s \rightarrow J/\psi\ \phi$ | 900 |
| $\Lambda_b \rightarrow J/\psi\ \Lambda$ | 260 |

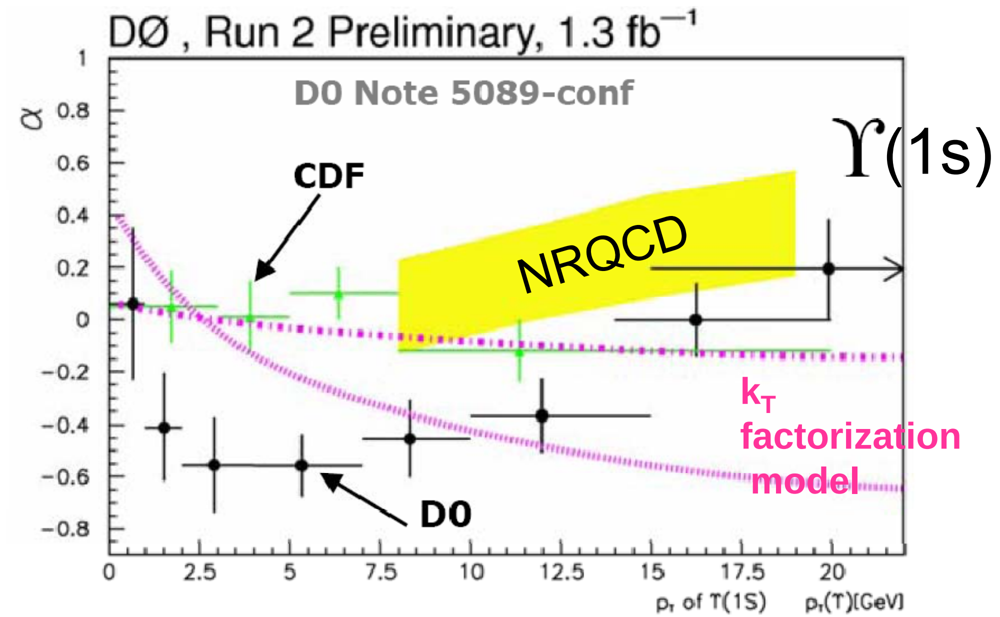
# Quarkonia

- 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 DØ ϒ(1S) measurements not consistent with predictions.

More data with high-$p_T$ needed!

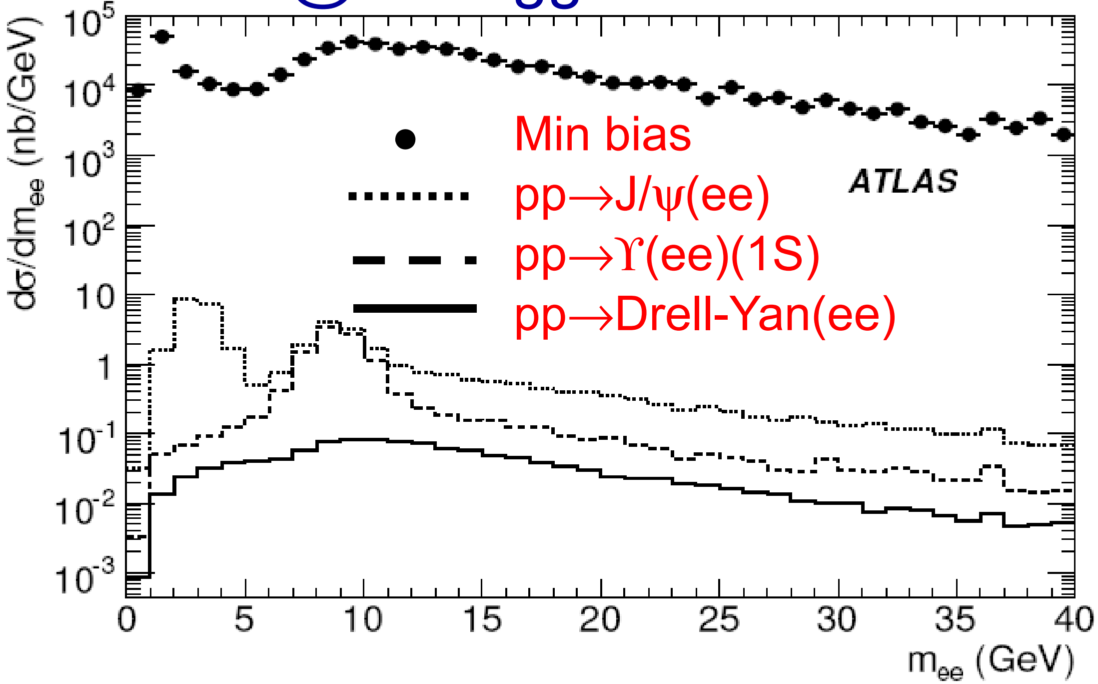


# Quarkonia in ATLAS: $J/\psi \to e^+e^-$

Initial data: take advantage of electron trigger paths as well
Current studies using **2EM3**
Single-e triggers under investigation
Later data ("low luminosity", $L=10^{33}cm^{-2}s^{-1}$) has to rely on single-μ b trigger also for $J/\psi(ee)X$, $\Upsilon(ee)X$

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




L1 ε(trig) ~ 27%
L2, EF under optimization

N(J/ψ) after L1: 4.2 M events
N(ϒ) after L1: 1.2 M events

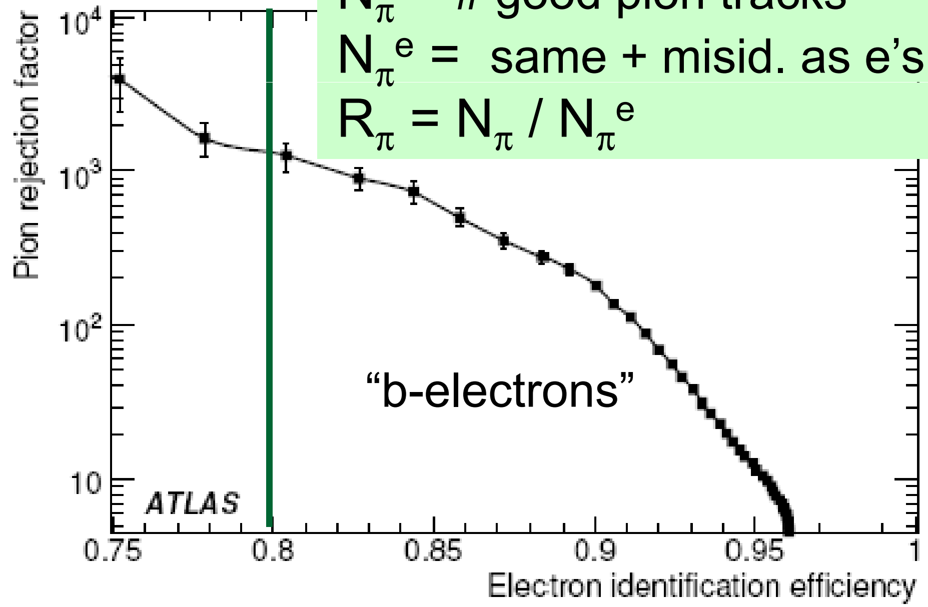
# $J/\psi \rightarrow e^+e^-$

Two electron id methods explored:

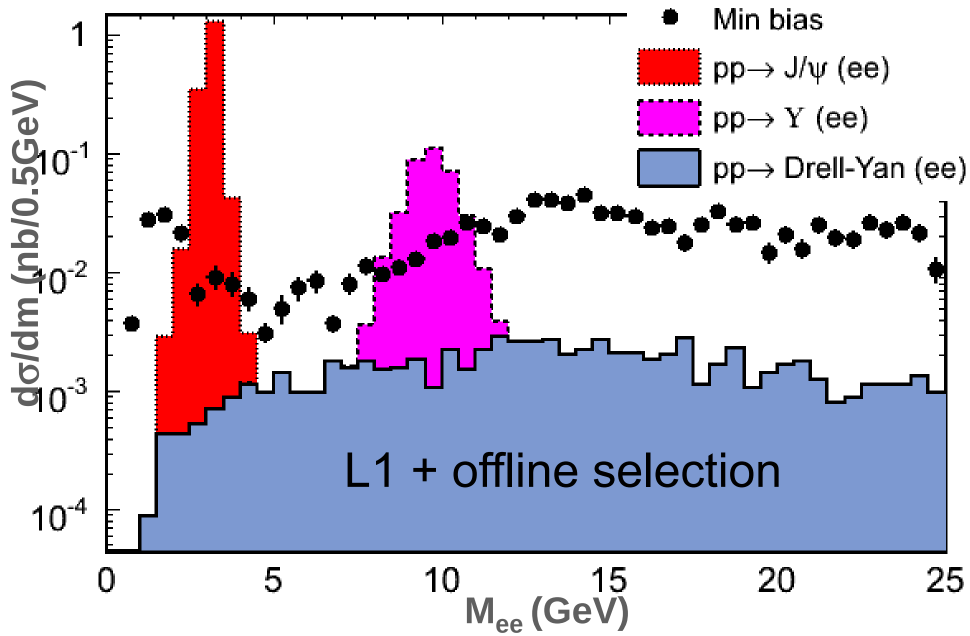
- Low $p_T$ version of standard ATLAS isolated electron cut based on shower shapes, associated to high quality tracks with E/p >0.7, conversion veto, and transition radiation hits
- Less efficient for electrons from b's

  $\Rightarrow$ 2nd method ($p_T \geq 2$ GeV/c) extrapolates in narrow window to calorimeter and uses likelihood ratio (similar variables)

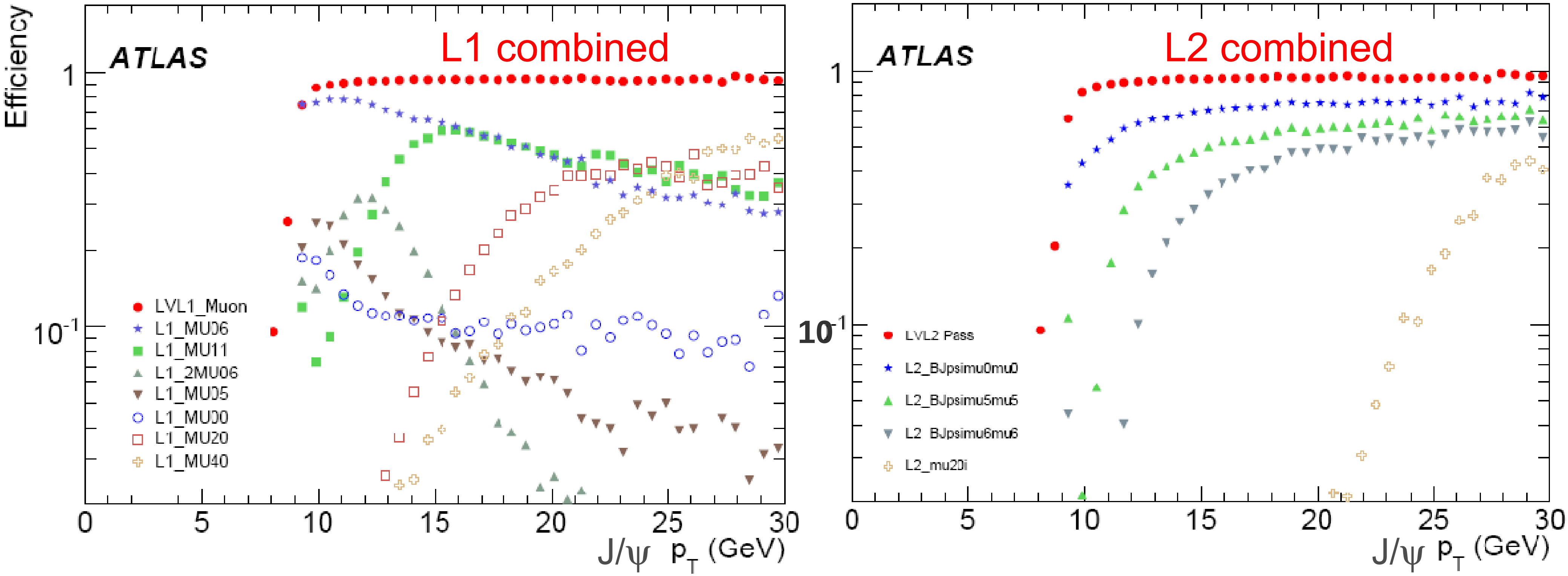
$N_\pi$ = # good pion tracks
$N_\pi^e$ = same + misid. as e's
$R_\pi = N_\pi / N_\pi^e$




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



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

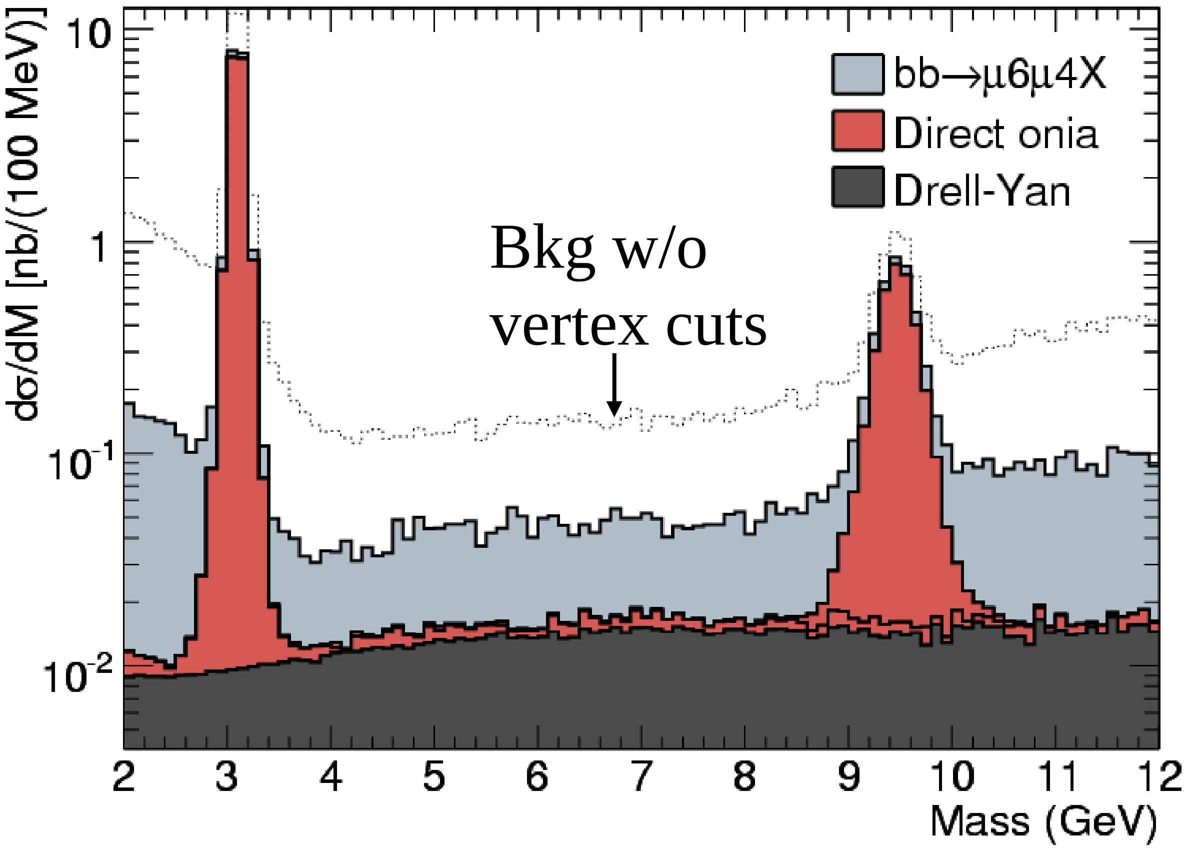



- Current studies use a combination dimuon trigger, ε(trig) = 87% L1, 97% L2, with analysis cuts of 6 and 4 GeV
- Rate ≤ 1 Hz expected at EF for all quarkonium → μμ (incl ψ', ϒ(2,3S) )

# Dimuons: Results

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

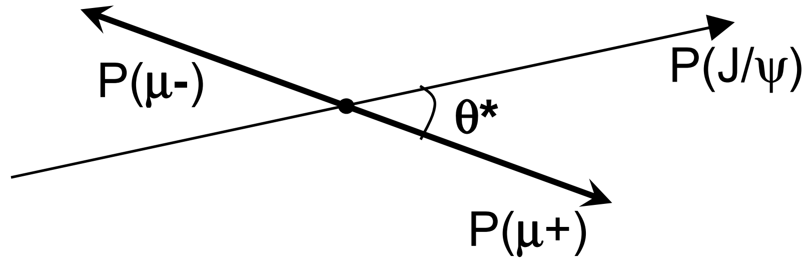
With $p_{T1} \geq 6$ GeV,
$p_{T2} \geq 4$ GeV:
15k J/ψ's per 1 $pb^{-1}$
2.5k ϒ's (1S)
1-2 days with
$\mathcal{L} = 10^{31} cm^{-2}s^{-1}$



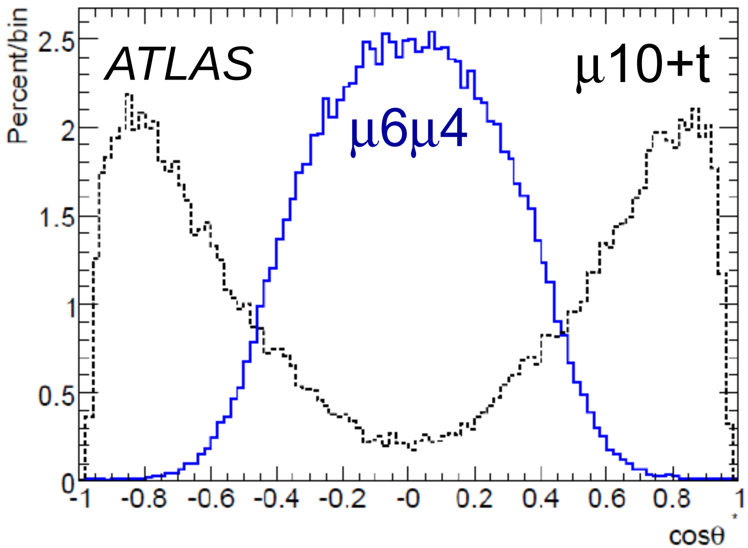

With 10 $pb^{-1}$:
S/B = 60 for J/ψ and 10 for ϒ
$d\sigma/dp_T$ ~ 1 % for J/ψ , ~5 % for ϒ

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

# Polarization




Measure high-$p_T$ polarization to distinguish production models



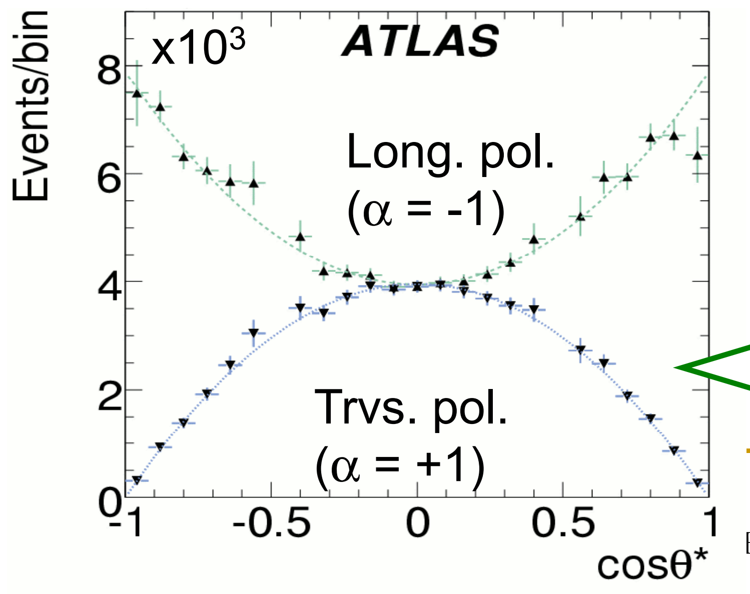

$$\frac{dN}{d\cos\theta^*} \propto 1 + \alpha \cos^2 \theta^*$$

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

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

Single-u trigger => larger background

Still: S/B = 1.2 (J/ψ) and 0.05 (Upsilon)



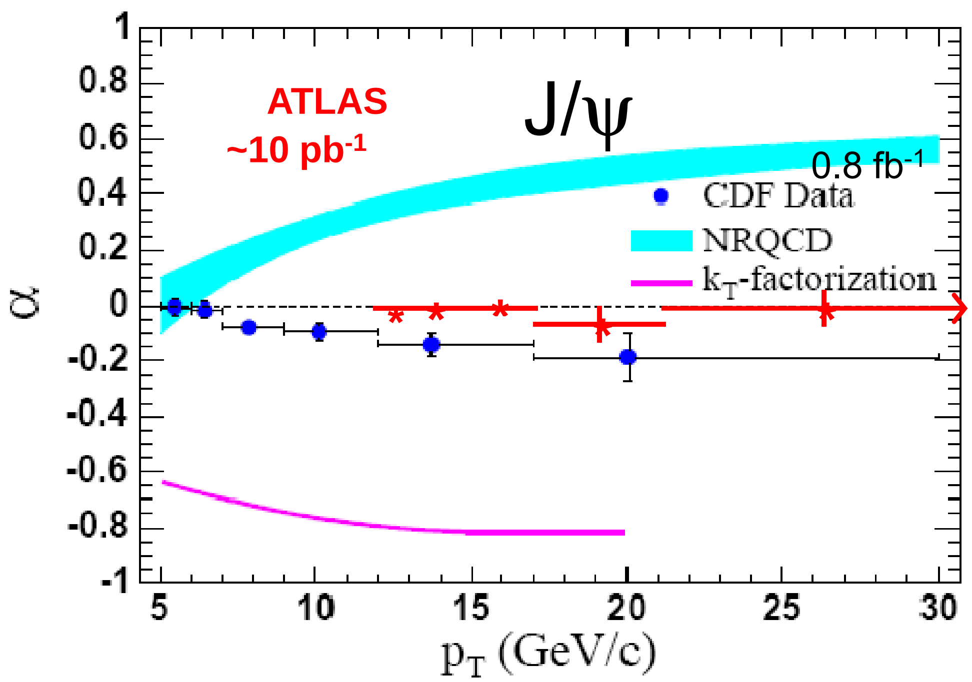

***Combine*** and fit to measured distribution in slices of $p_T$

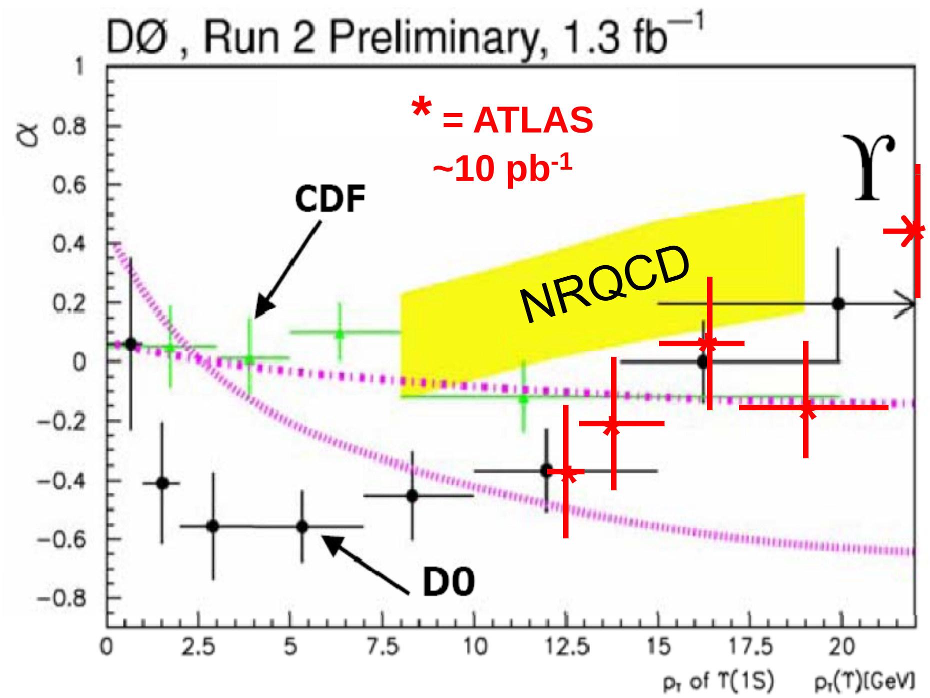
Shown: $12 \leq p_T \leq 13$ GeV

# 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 ~100 $pb^{-1}$

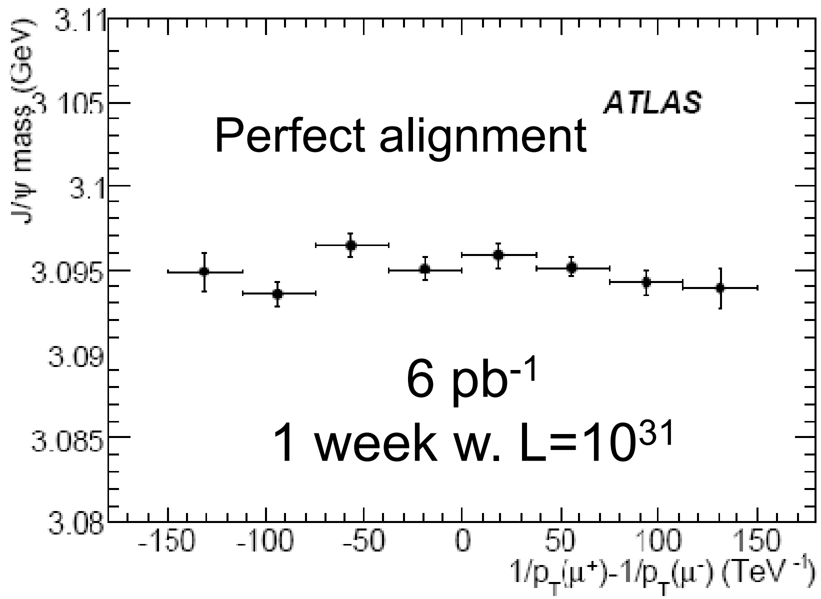
Crude superimpose of ATLAS stat uncertainties with 10 $pb^{-1}$ assuming $\alpha$=0 :

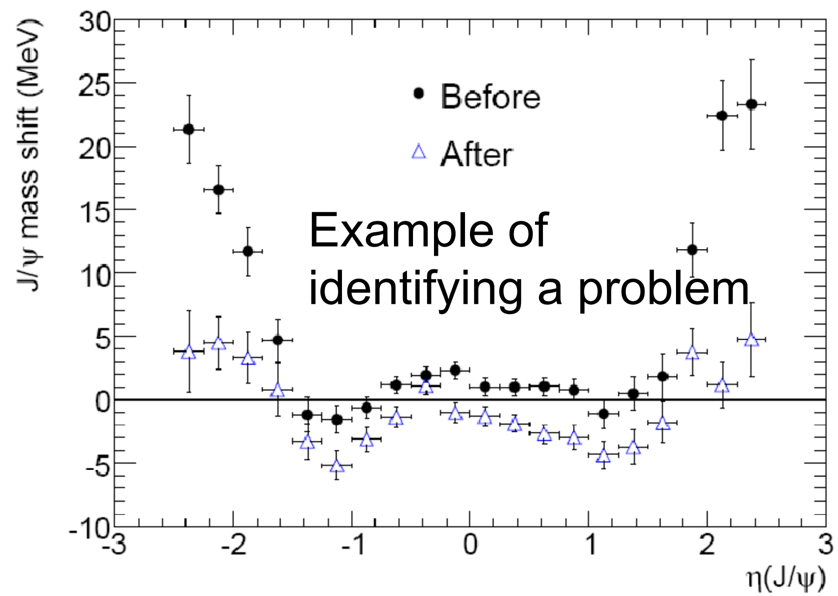


# Quarkonia as a monitoring tool

- ***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



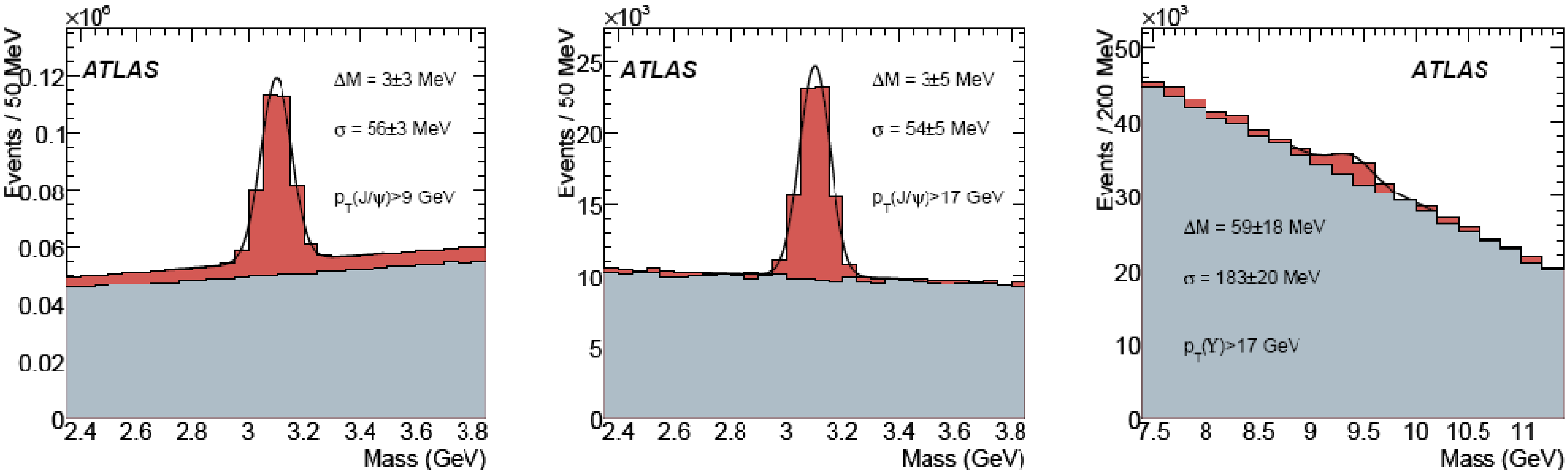
# Summary and outlook

- 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 $J/\psi$ 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) Υ ( ≥ .7 GeV

# Polarization measurement

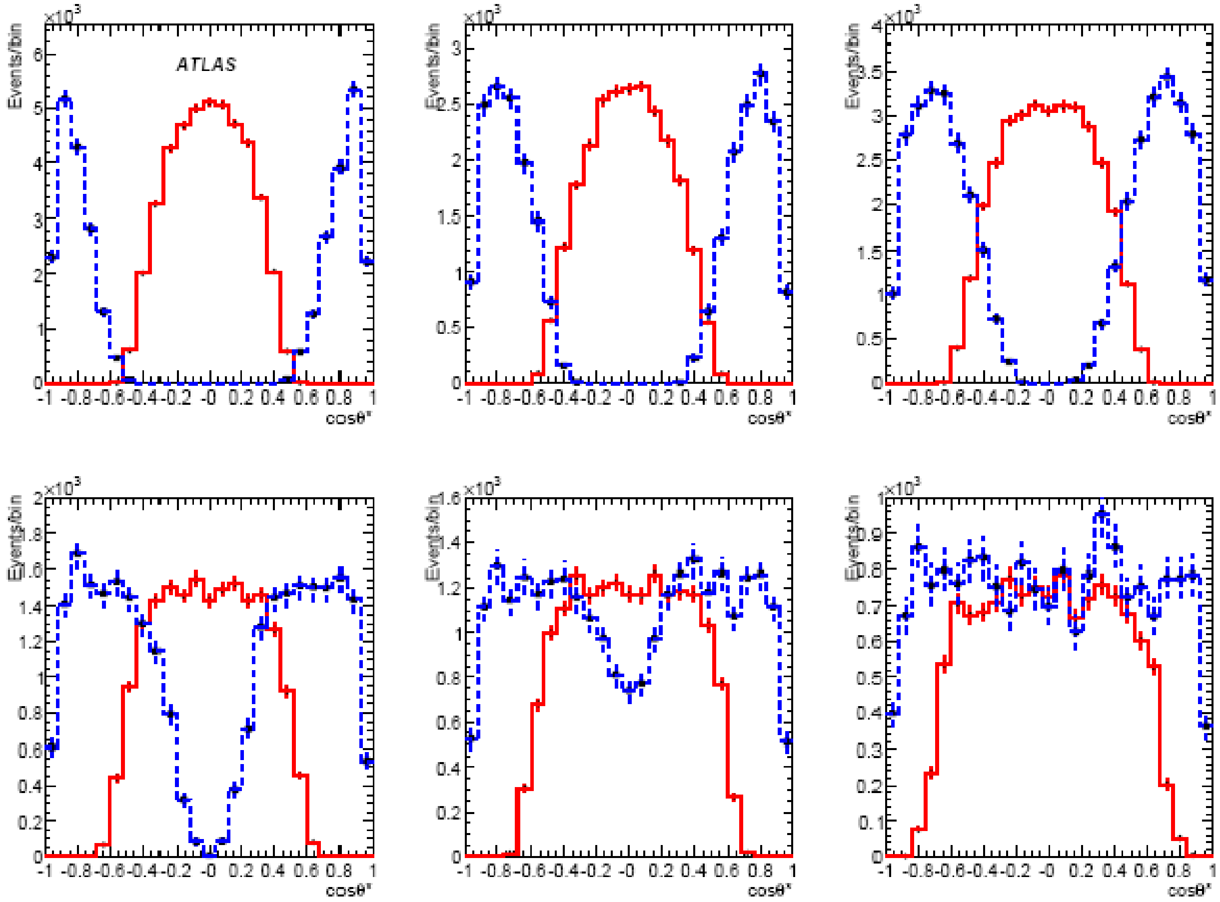
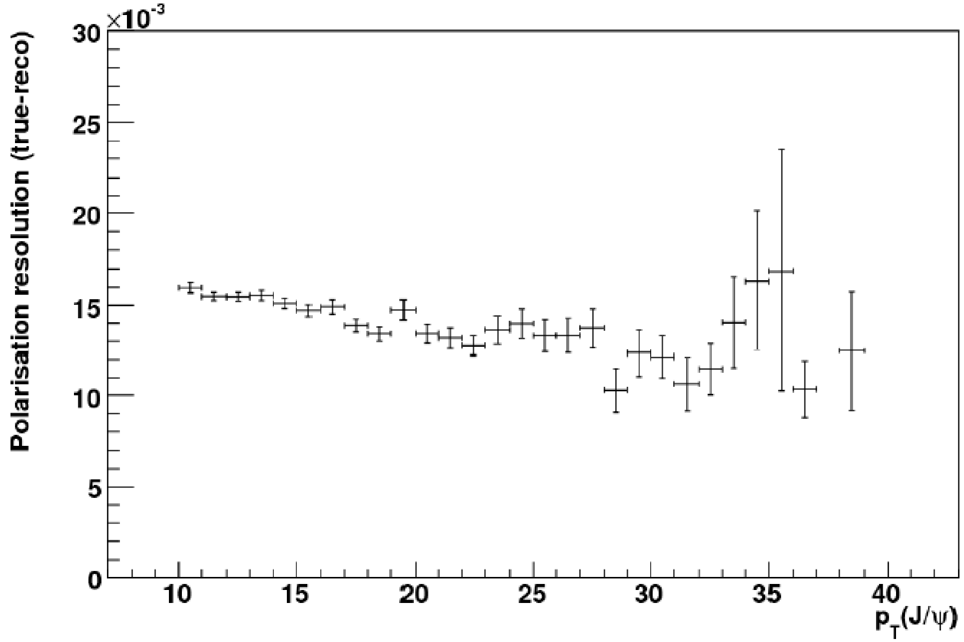
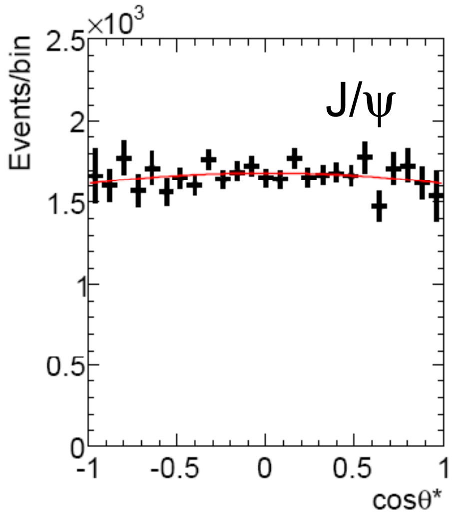


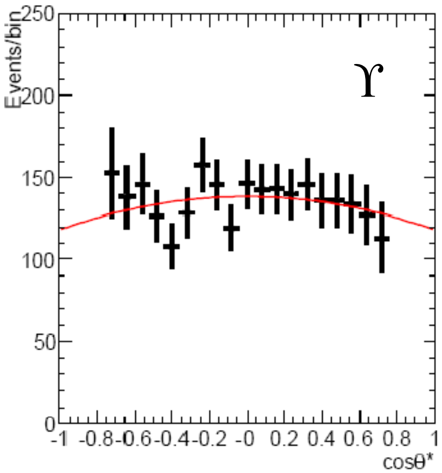

Figure 19: *Measured distributions for μ6μ4- (solid red lines) and μ10- (dashed blue lines) triggered events, in the same $p_T$ slices of the $J/\psi$ candidate as in Figure 18. The simulated data sample is unpolarised. Statistics correspond to 10 $pb^{-1}$.*

# More on polarization

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



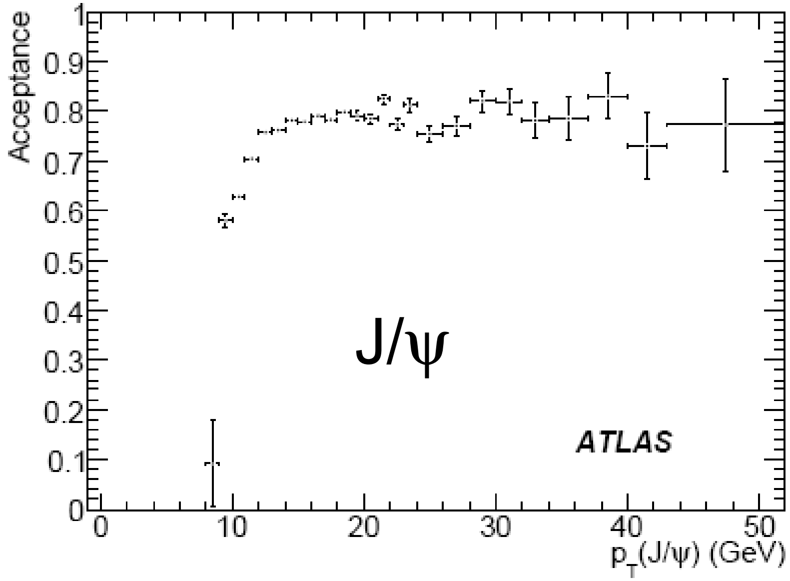

Combined measurement
Unpolarized
$17 < p_T < 21$ GeV

# Acceptance

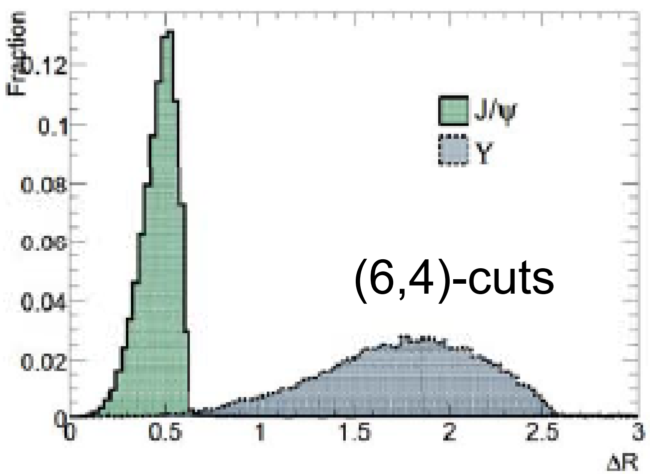
$p_T$ cuts (trigger and offline) means $p_T(J/\psi) \geq$ 10 GeV, whereas non-zero $\mathcal{A}$ for Upsilons also at ~0

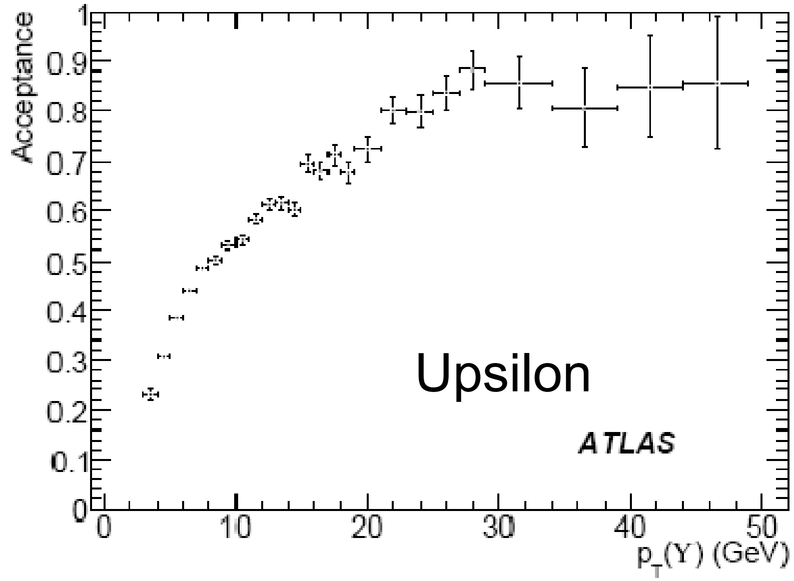
RoI's based on trigger towers of
$\Delta\eta \times \Delta\phi \sim 0.1 \times 0.1$

$\Delta R$ separation between leptons also affects sensitivity to material effects

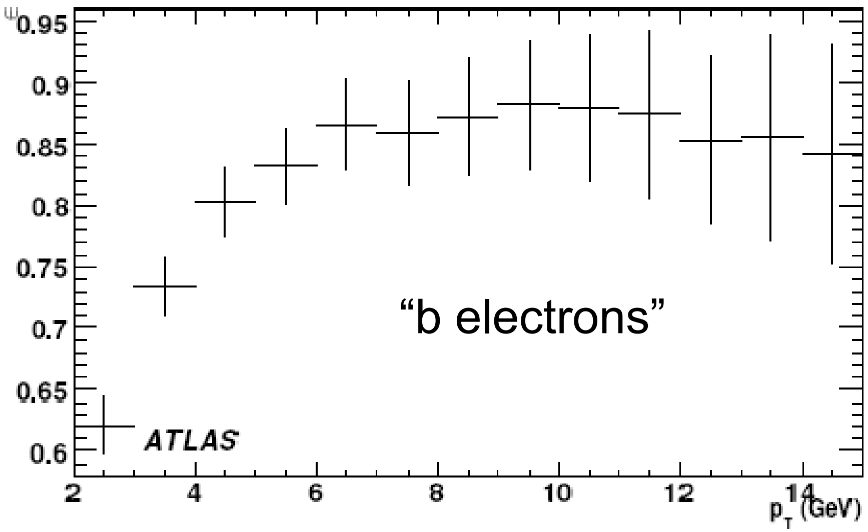


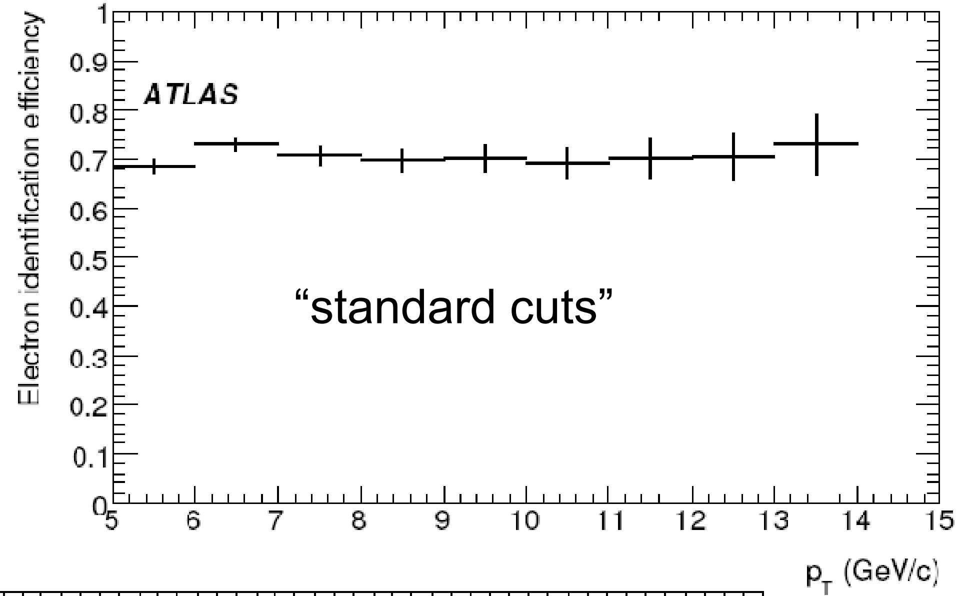

$$\Delta R = (\Delta\eta^2 + \Delta\phi^2)^{1/2}$$



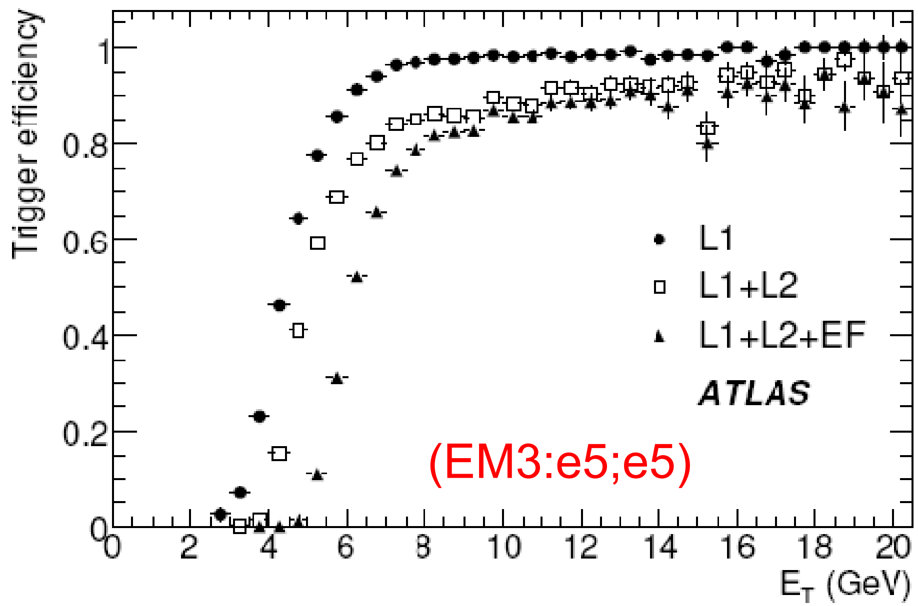



# Electron efficiencies

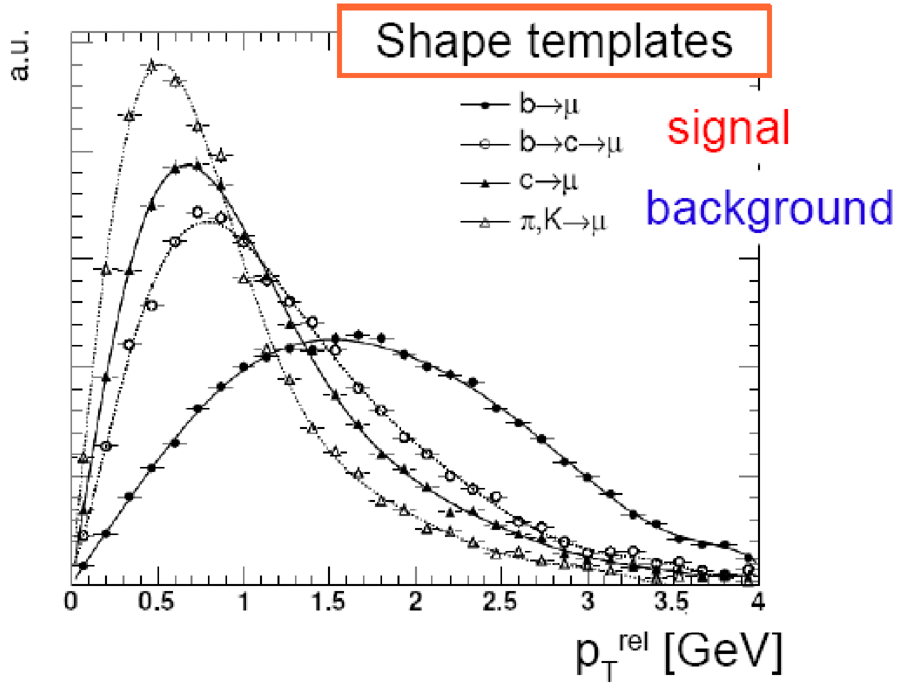


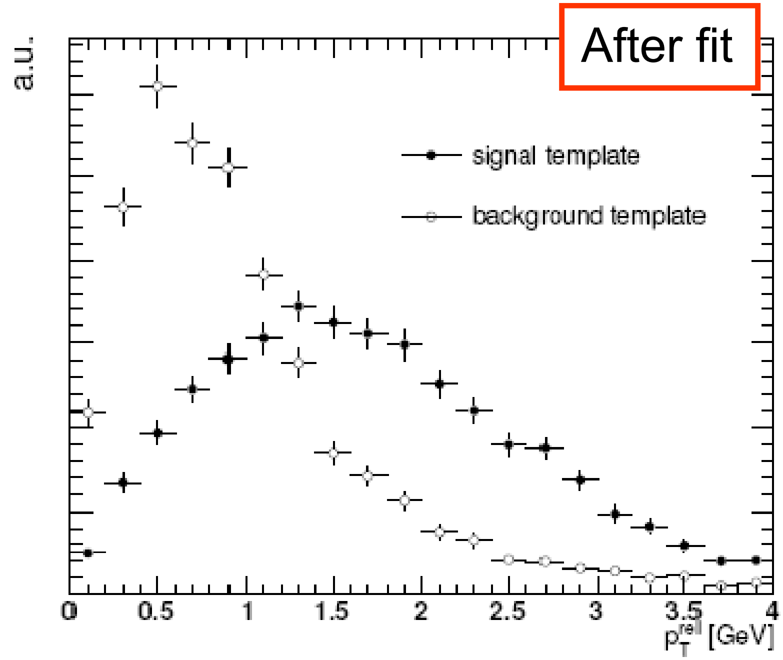




Efficiency of single electrons based on MC truth



# Inclusive b production



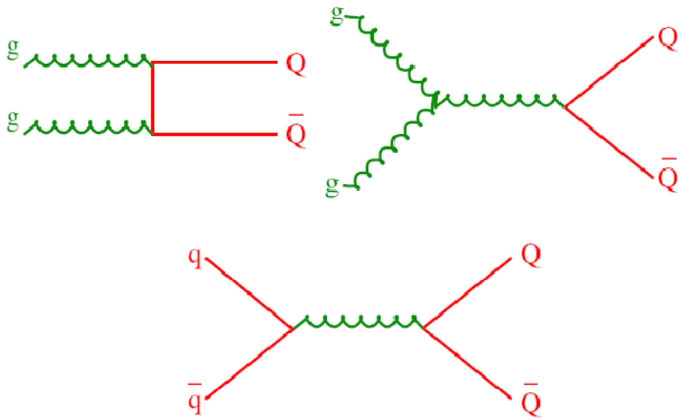




| channel | specific luminosity $[cm^{-2}s^{-1}]$ $\mathscr{L} = 10^{31}$ | $\mathscr{L} = 10^{32}$ | $\mathscr{L} = 10^{33}$ |
|---|---|---|---|
| $b\bar{b} \to J/\psi(\mu 6 \mu 4) + X$ with 2 $\mu$ LVL1 | 1 year (PS 1) | 1 month (PS 1) | 1 month (PS 10) |
| $b\bar{b} \to \mu(6) + b - \text{jet} + X$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

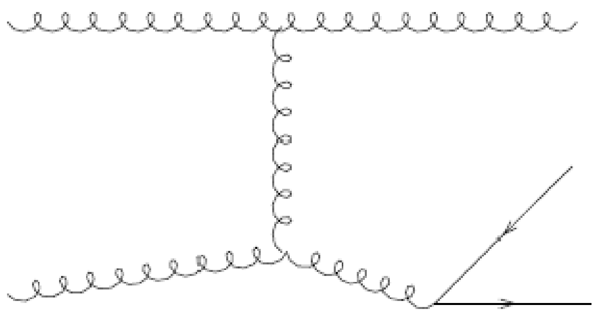
Table 12: *Estimated time to obtain a statistical precision of the inclusive cross section measurement of $\mathscr{O}(1\ \%)$. To keep the rate acceptable, prescale factors (PS) for the corresponding trigger have to be applied which can be lowered at lower specific luminosities.*

# The 3 production mechanisms

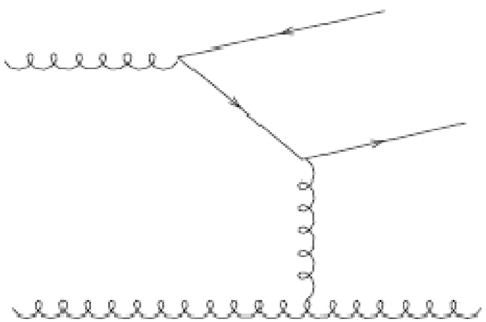
LO: Flavour creation




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