Heavy Flavour Production in ATLAS

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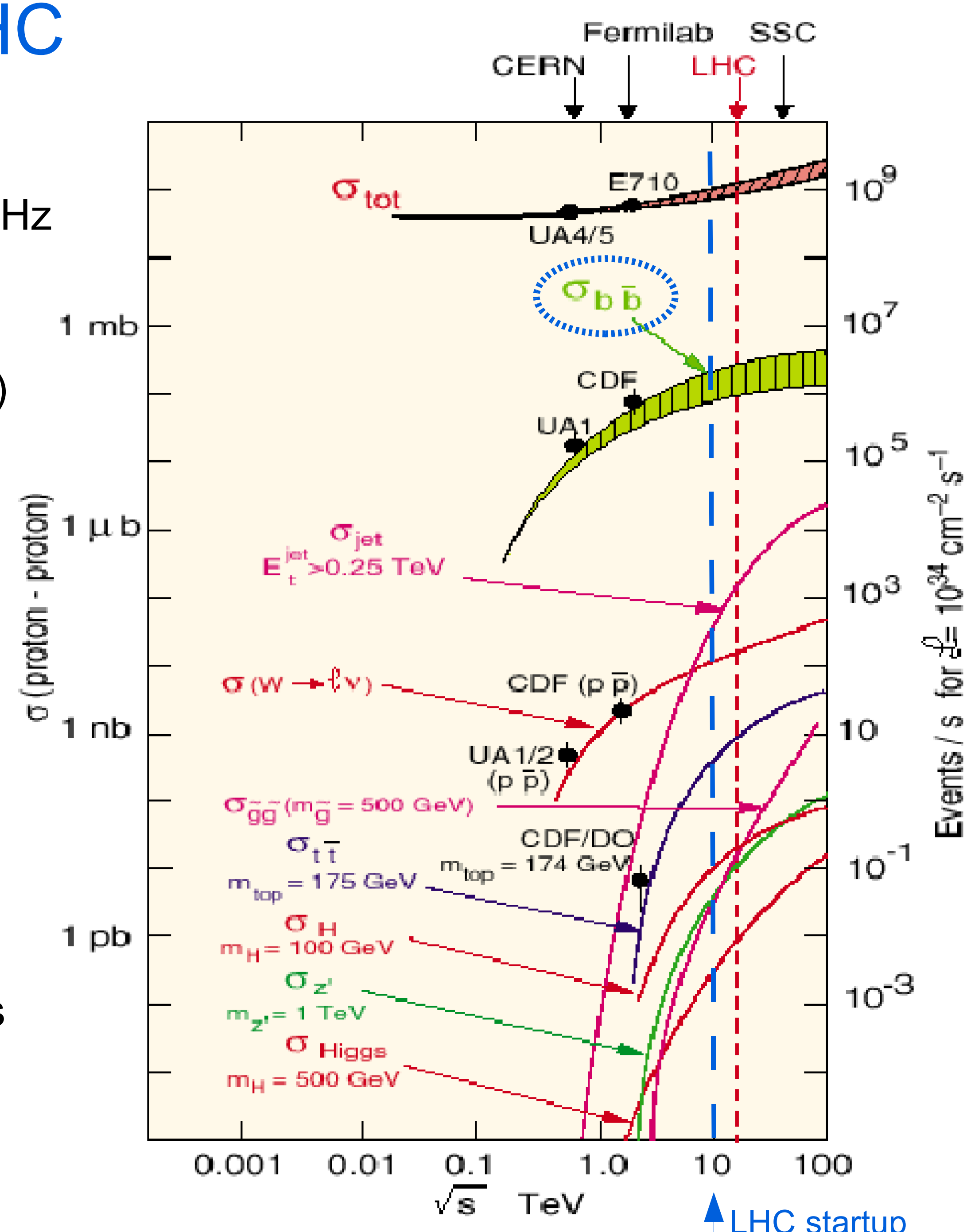
FSP 101 ATLAS

Outline

- Introduction
- Heavy flavour cross section measurements
  - Open b-flavour production with $B^+ \rightarrow J/\psi(\mu^+\mu^-) K^+$
  - Heavy quarkonia
- Polarization measurements
  - Heavy quarkonia
  - $\Lambda_b \rightarrow J/\psi(\mu^+\mu^-) \Lambda(p\pi^-)$
- Summary and conclusions

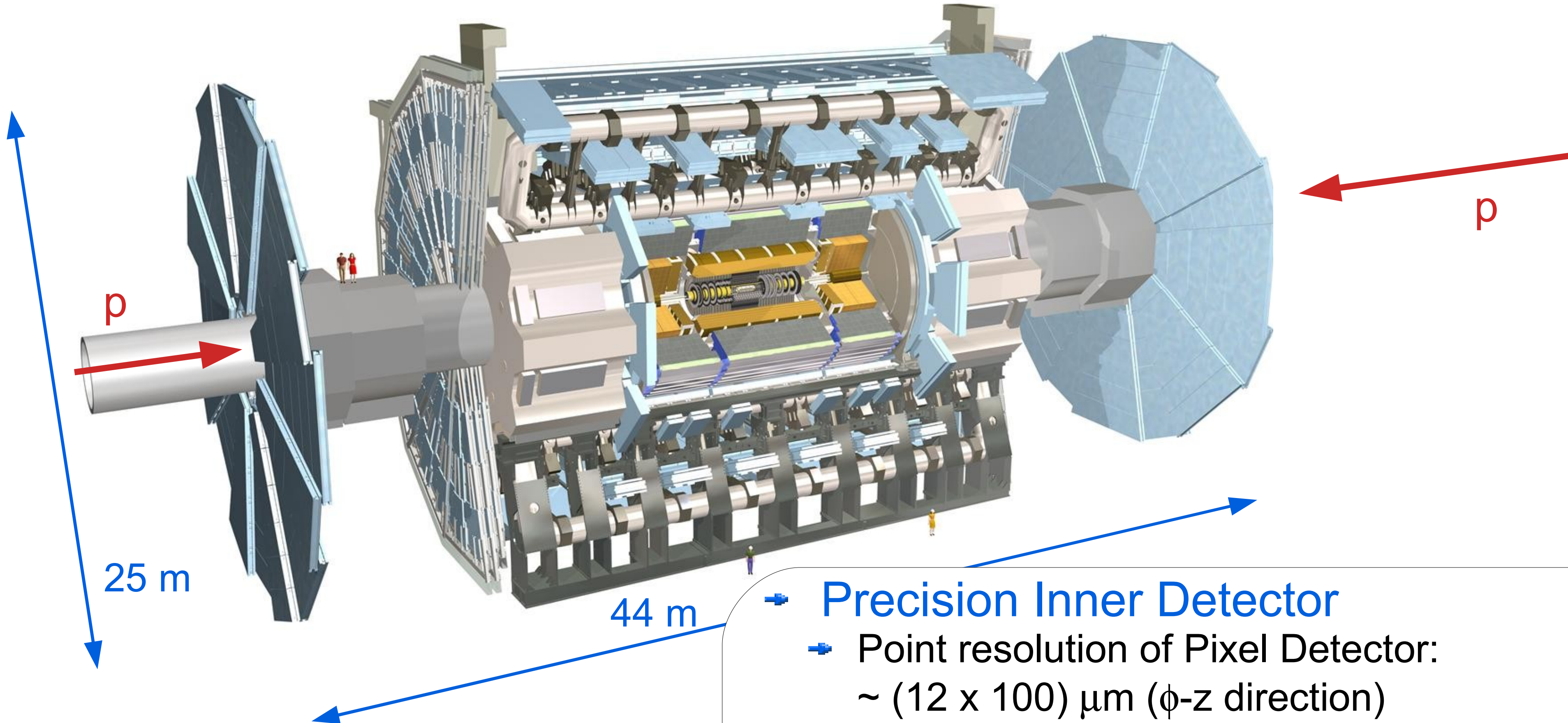
Beauty Production at LHC

- LHC
  - p-p collisions at E_{cm} = 14 TeV @ 40 MHz
  - Design luminosity of 10^{34} $cm^{-2}s^{-1}$
    ~100 fb^{-1} / year
    ('Early running': L = 10^{31}–10^{32} $cm^{-2}s^{-1}$)
  - First collisions expected this autumn
    (E_{cm} = 10 TeV)



- Large b-production cross section
  - $\sigma(b\bar{b})$ ~ 500 µbarn @ 14 TeV
  - 10^5 $b\bar{b}$-pairs/s @ 10^{33} $cm^{-2}s^{-1}$
  - Huge statistics allows precision measurements of B hadron species

The ATLAS Detector at the LHC



- **Precision Inner Detector**
  - Point resolution of Pixel Detector: ~ (12 x 100) μm (ϕ-z direction)
    - 3 silicon layers, innermost (b-layer) @ 5 cm
- **Muon Spectrometer**
  - Fast trigger chambers: TGC, RPC (<10 ns time resolution)
  - High resolution tracking detectors: CSC, MDT (40 μm spatial resolution)

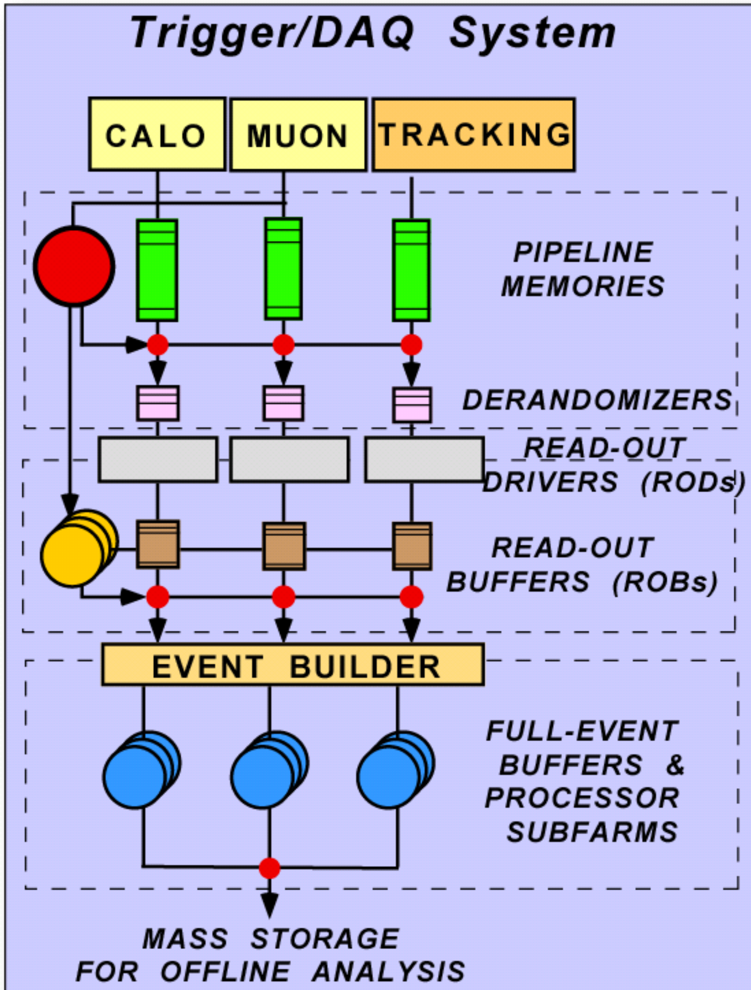
Trigger System of ATLAS

40 MHz
2.5 μsec

75 kHz
~20 msec

2 kHz
~2 sec

~100 – 200 Hz



- Three stage system
  - Level 1: Hardware
  - High Level Trigger (Level 2 + EF): Software

- Level 1
  - Single- and di-muon (di-μ) trigger
  - Identifies Regions of Interest (RoI) for further processing
- Level 2
  - Confirmation of Level 1 decision with higher precision
  - Fast reconstruction using precision muon chambers and Inner Detector (ID) measurements, RoI based
- Event Filter (EF)
  - Refine Level 2 selection using offline-like algorithms
  - Full event, alignment and calibration data available
- Dedicated B-trigger developed
  - Based on single- and di-μ signatures
  - Rejection of muons from decays in flight, di-μ invariant mass cuts and vertex fit available

b Cross Section - Motivation

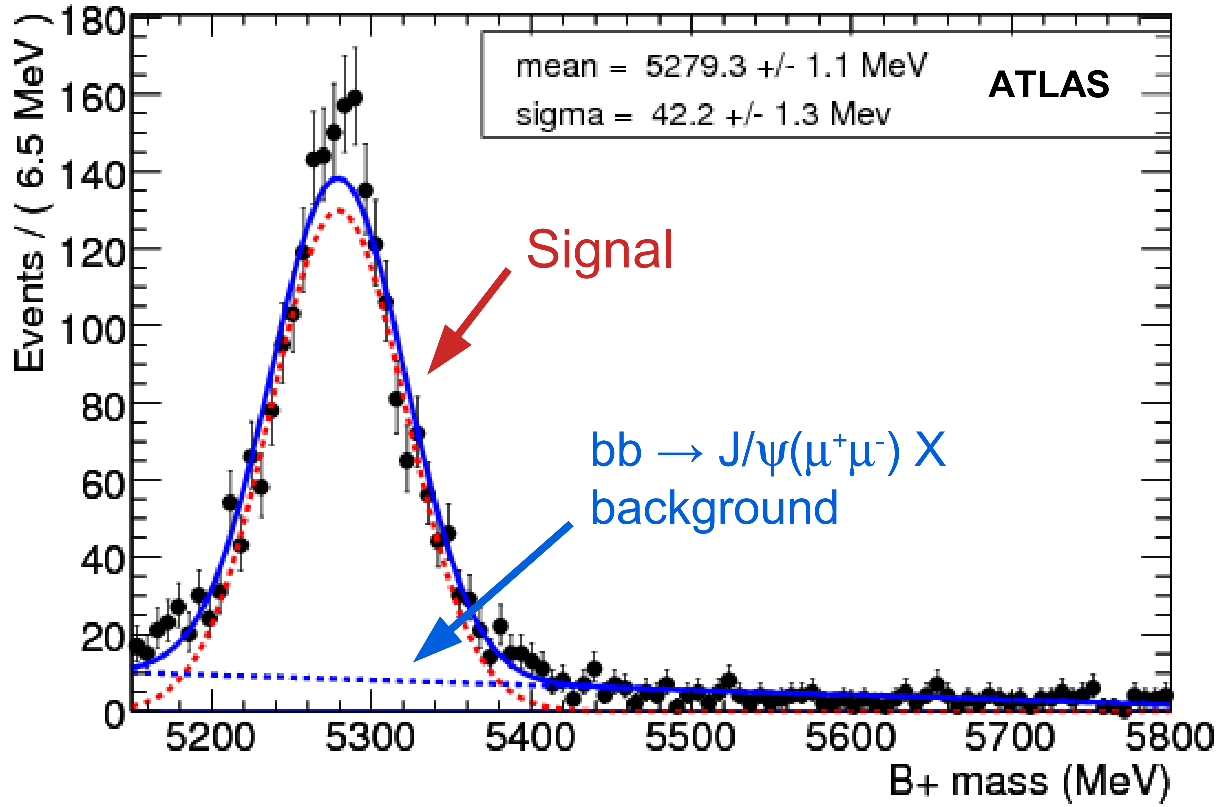
- Extrapolation of $\sigma(b\bar{b})$ to 14 TeV with large uncertainties
  - Test of QCD calculations of heavy flavour production in pp-collisions at new energy
  - Large b-production rates allow sufficient statistics to cover wider p_T range, as well as improve precision of $b\bar{b}$-correlations
    - Needed to constrain uncertainties in NLO QCD calculations
  - Needs to be measured early, since $b\bar{b}$-events are largest physics background in many studies
- Inclusive measurements planned for early running period using quarkonia
  - Probe different production models
- Exclusive channel $B^+ \rightarrow J/\psi(\mu^+\mu^-) K^+$
  - Reference channel for e.g. rare B-decays, flavor tagging algorithms
  - Detector performance studies like Inner Detector calibration and alignment

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

- Di-μ J/ψ trigger
  ($p_T(\mu_{1,2})$ > 6 GeV, 4 GeV)

- Offline:
  - J/ψ: $p_T(\mu_{1,2})$ > 6 GeV, 3 GeV, mass in ±120 MeV around $m_{J/\psi}$
  - B^+: J/ψ + 1 track
    (p_T > 1.5 GeV, $|\eta| < 2.5$, impact parameter significance $|d_0|/\sigma(d_0) > 1$), $p_T(B^+)$ > 10 GeV

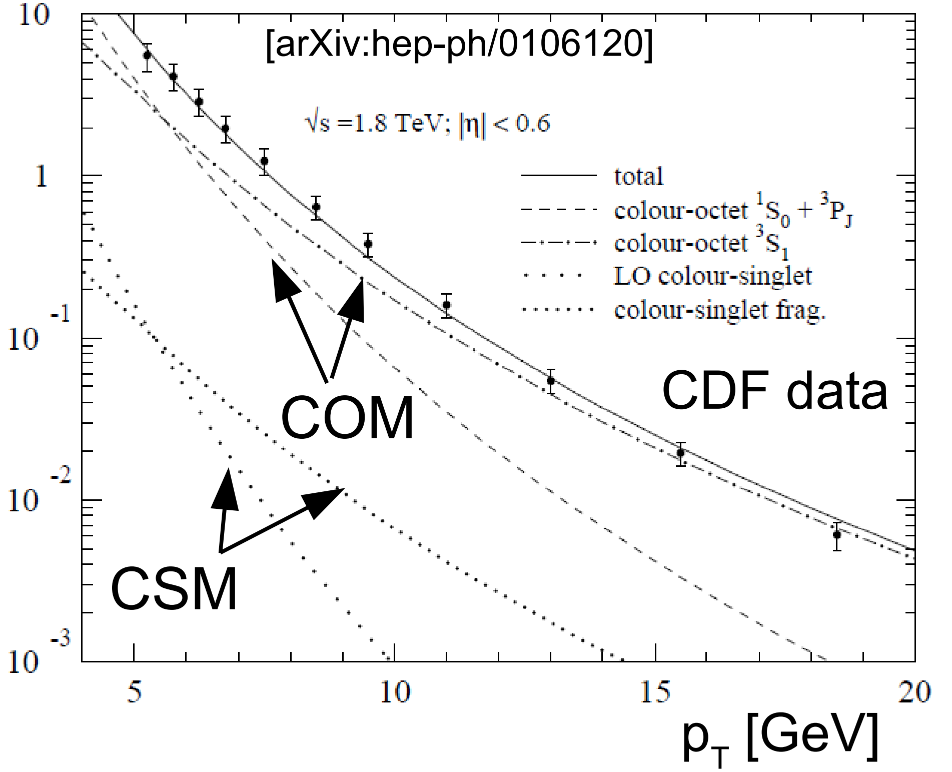
- Online and offline efficiency
  $\varepsilon^{total} = 29.8 \pm 0.8$ %
  $\sigma(m_{B^+}) = 42.2 \pm 1.3$ MeV



- With 10 pb^{-1}:
  - ~ 1600 signal events
  - Cross section (stat) (total)
    - Total to ~3 % ~15 %
    - $d\sigma/dp_T$ to ~10 % ~16-20 %
  - Signal lifetime to ~ 2.5 % (stat only)
- Statistical precision ~1 % with 100 pb^{-1}

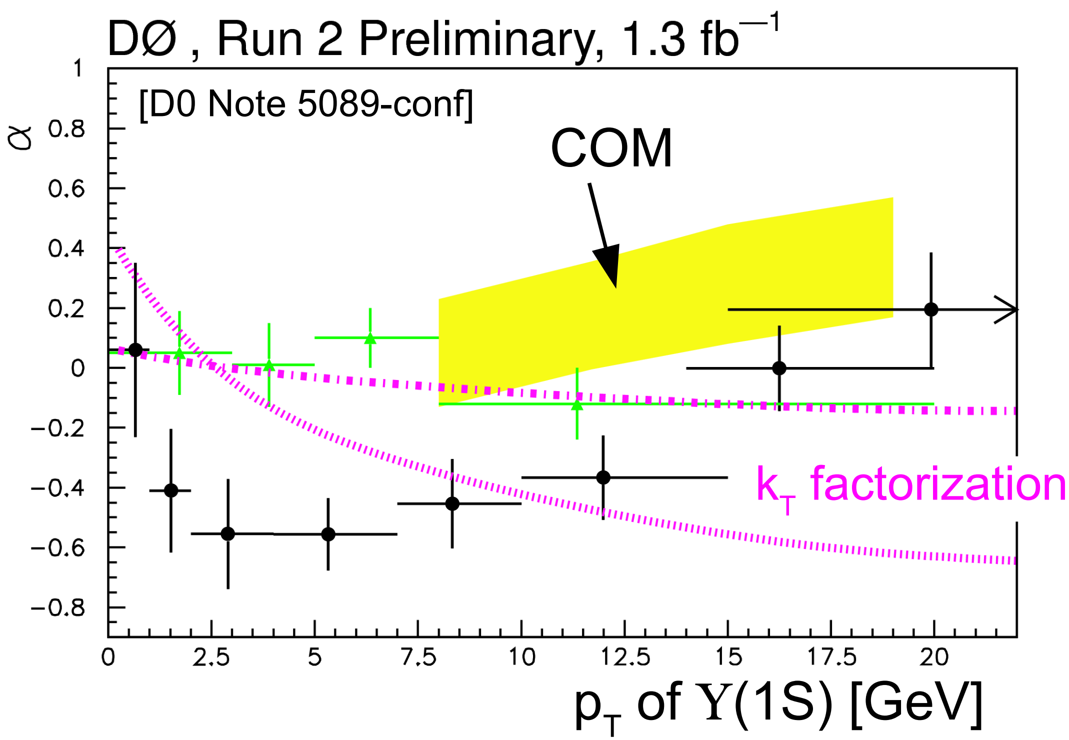
Heavy Prompt Quarkonia – Motivation

BR($J/\psi \to \mu^+\mu^-$)$d\sigma(pp \to J/\psi+X)/dp_T$ [nb/GeV]



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

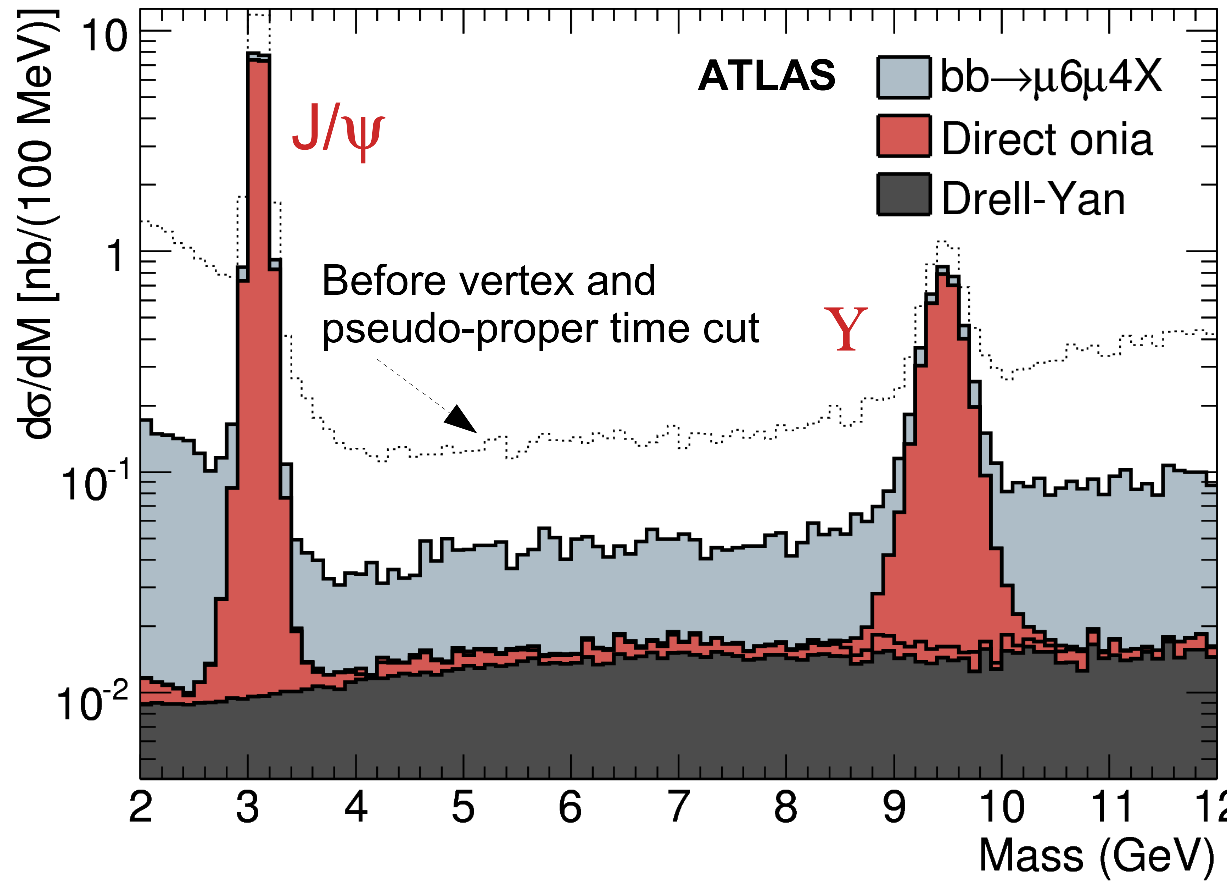
- Color Singlet (CSM) and Color Octet Model (COM) predictions from M. Kramer, Prog. Part. Nucl. Phys 47 (2001) 141.



- COM prediction disagrees with polarization data in $\Upsilon \to \mu\mu$

Heavy Prompt Quarkonia

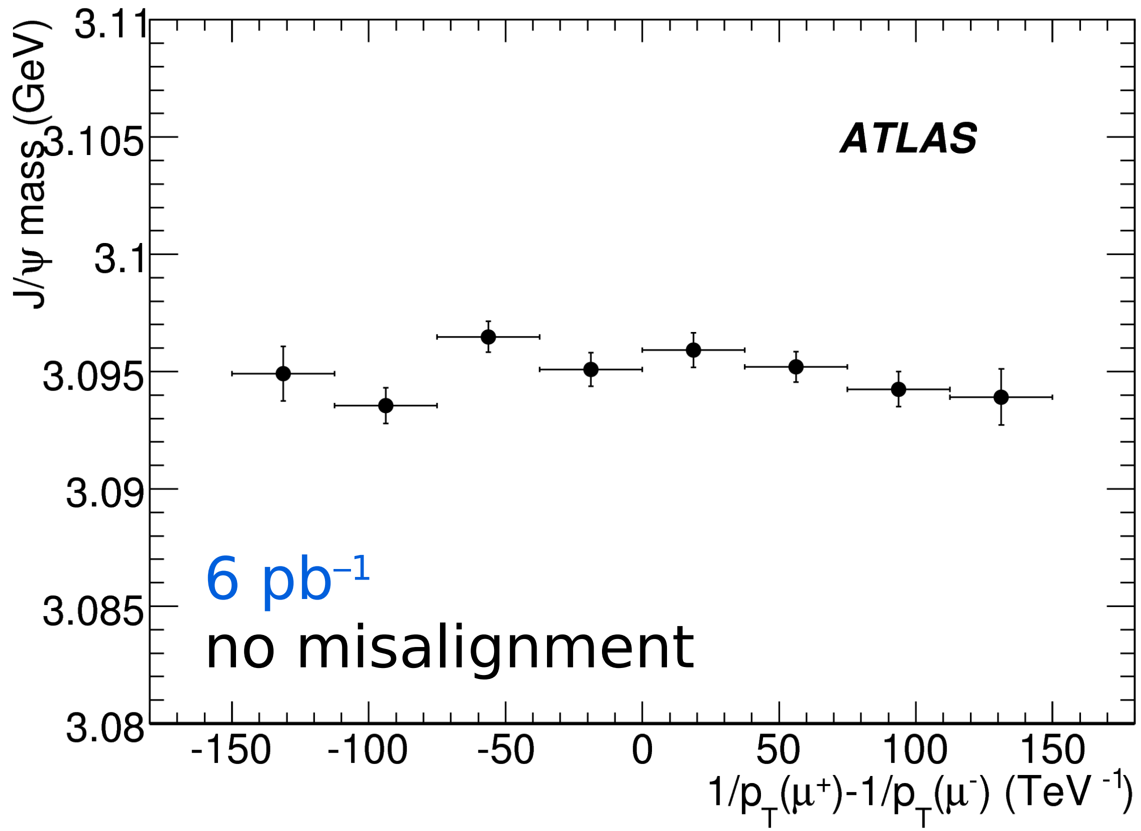
- Already with first data enough statistics to probe different production models
- Dedicated J/ψ and Υ trigger signatures
- Seeded by Level1 Di-μ trigger
  - μ tracks from primary vertex, pseudo-proper time < 0.2 ps (background suppression)
  - Mass windows:
    $m_{J/\psi}^{PDG}$ ± 300 MeV
    m_{Υ}^{PDG} ± 1 GeV
  - 17 000 J/ψ and 20 000 Υ per 1 pb^{-1} using di-μ trigger ($p_T(\mu_{1,2})$ > 4 GeV)
  - S/B = 60 (J/ψ), 10 (Υ)



- Expectation for 10 pb^{-1}
  $d\sigma/dp_T$ ~ 1 % level (J/ψ)
  5 % level (Υ)

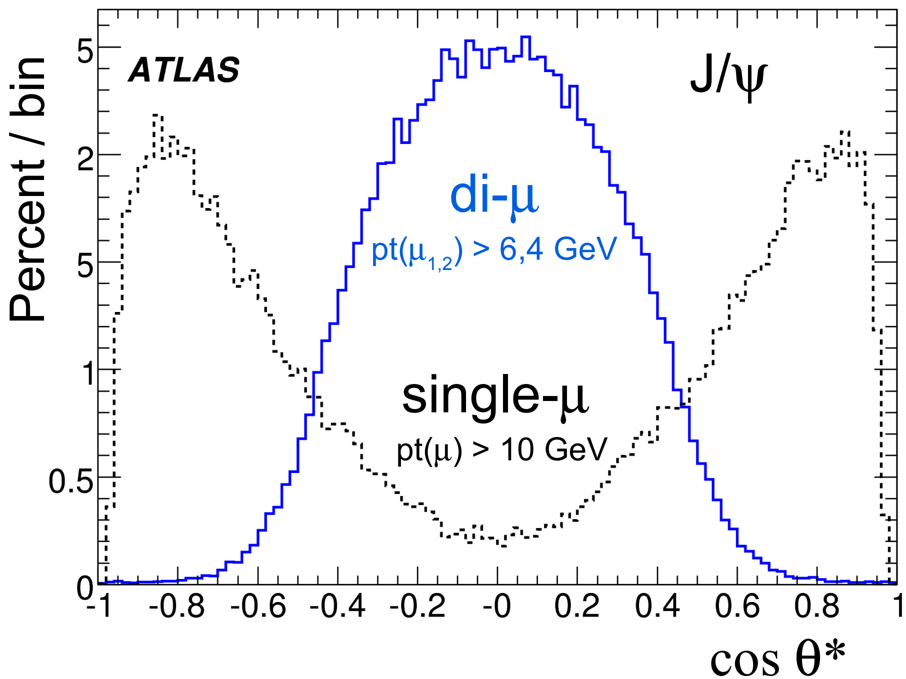
Online and Offline Monitoring

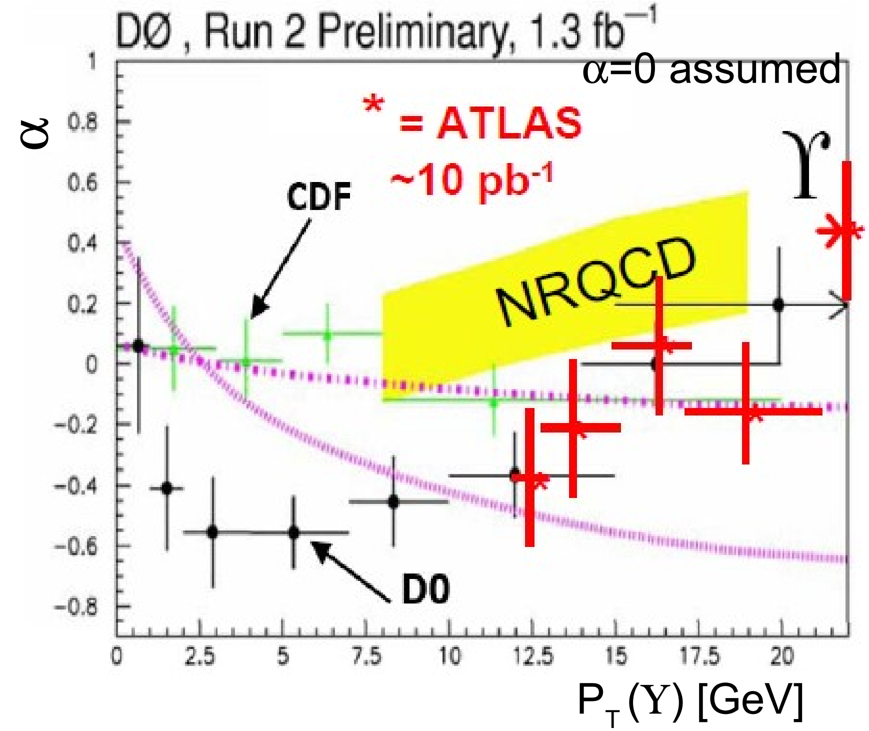
- Search for mass shifts in $m_{\mu\mu}$ (J/ψ or Υ)
  - vs. p_T:
    check muon momentum scale, energy loss corrections
  - vs. η and ϕ:
    check correct implementation of material effects, magnetic field uniformity and stability
  - vs. $1/p_T(\mu^+) - 1/p_T(\mu^-)$:
    check detector misalignment



- Data in low p_T region, complementary to Z boson sample
- Quarkonia decays will also be used for online monitoring (e.g. trigger efficiencies, detector calibration)

Polarization Measurements

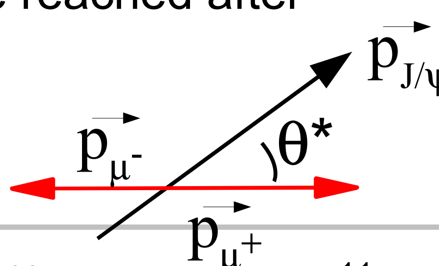




- Complementary acceptances in cos θ* for single and di-muon trigger
  - Seeded by Level1 single-μ trigger
    - Single-μ trigger ($p_T(\mu)$ > 10 GeV)
    - Track in cone $\Delta R_{\mu\text{-track}} < 3$
    - μ and track from primary vertex
- Fit polarization α in bins of p_T $\alpha = (\sigma_T - 2\sigma_L)/(\sigma_T + 2\sigma_L)$

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

- Precision in α of 0.02 – 0.06 (J/ψ) and 0.2 (Υ) with 10 pb^{-1} in p_T of 10 – 50 GeV
  - J/ψ polarization to same precision as Tevatron 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}



Λ_b Polarization with $\Lambda_b \rightarrow J/\psi(\mu^+\mu^-)\,\Lambda(p\pi^-)$

- Large polarizations have been observed in the inclusive Λ-Hyperons production at energies of several hundred GeV
  - Not known if due to unexplained effects of existing physics or pointing to New Physics
  - Possibility to clarify production mechanism of polarized b-quarks with Λ_b polarization measurements

- Parity violating parameter α_{λ_b} tests various heavy quark factorization models and pertubative QCD

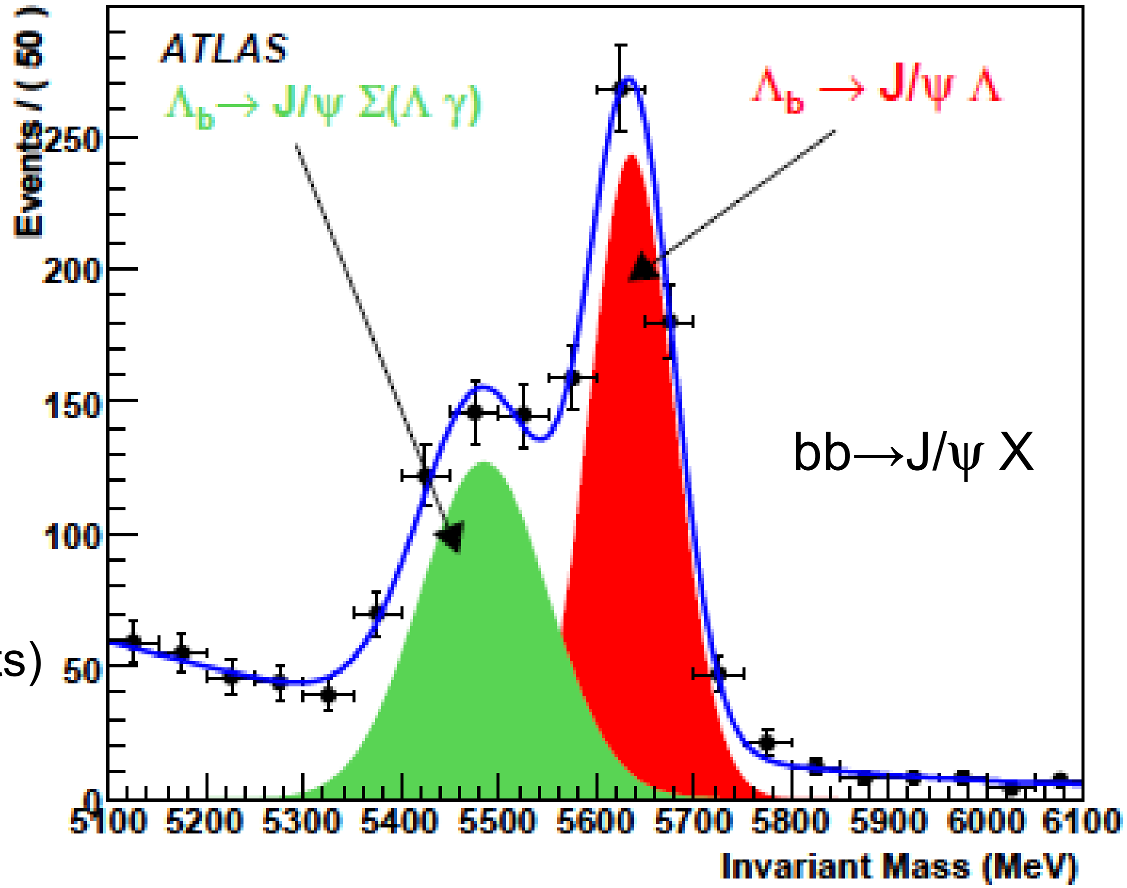
$$\alpha_{\Lambda_b} = \frac{|a_+|^2 - |a_-|^2 + |b_+|^2 - |b_-|^2}{|a_+|^2 + |a_-|^2 + |b_+|^2 + |b_-|^2}$$

$$a_+ = H_{1/2,0},\ a_- = H_{-1/2,0},\quad b_+ = H_{-1/2,1},\ b_- = H_{1/2,-1}$$

where $H_{\lambda_\Lambda,\lambda_{J/\psi}}$ are helicity amplitudes of the decay $\Lambda_b \rightarrow \Lambda\, J/\psi$

Λ_b Polarization with $\Lambda_b \rightarrow J/\psi(\mu^+\mu^-)\,\Lambda(p\pi^-)$

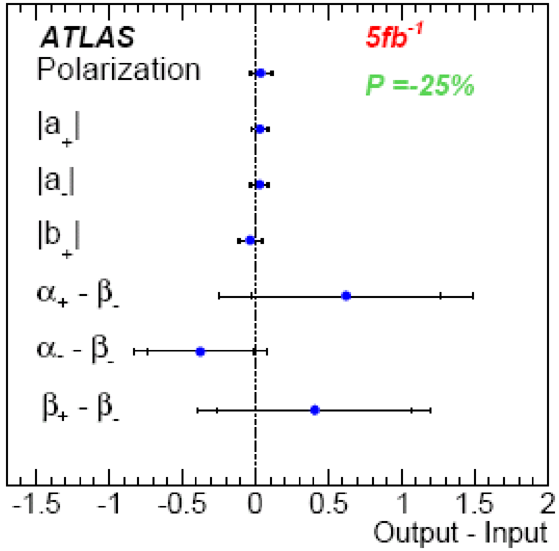
- Seeded by LVL1 di-μ trigger:
  ($p_T(\mu_{1,2})$ > 4 GeV)
  - J/ψ: muon tracks from same vertex, mass within 2.8 – 3.4 GeV
  - Λ: two tracks from same vertex ($p_T(p) > p_T(\pi)$), mass within 1.105 – 1.128 GeV,
    60 % decay @ r < 40 cm
    (for r > 40cm efficiency vanishes – insufficient number of silicon layer hits)
  - Λ_b: common vertex, proper decay length d_T > 200 μm, mass within 5.1 – 6.1 GeV
- Combined trigger and selection efficiency
  ε^{total} = 5.4 %

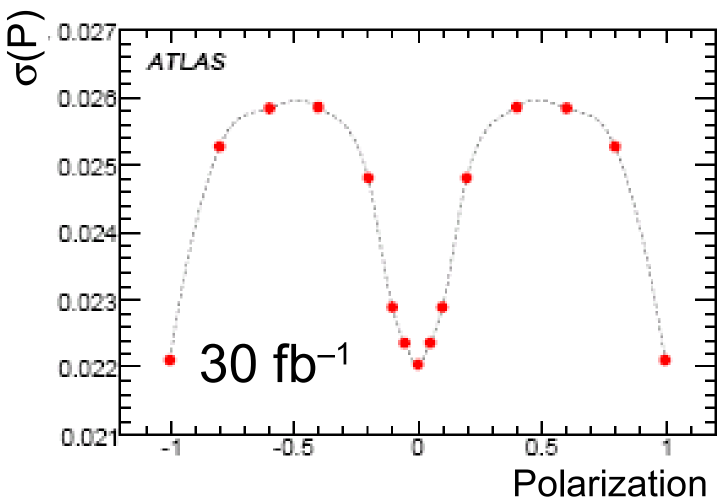


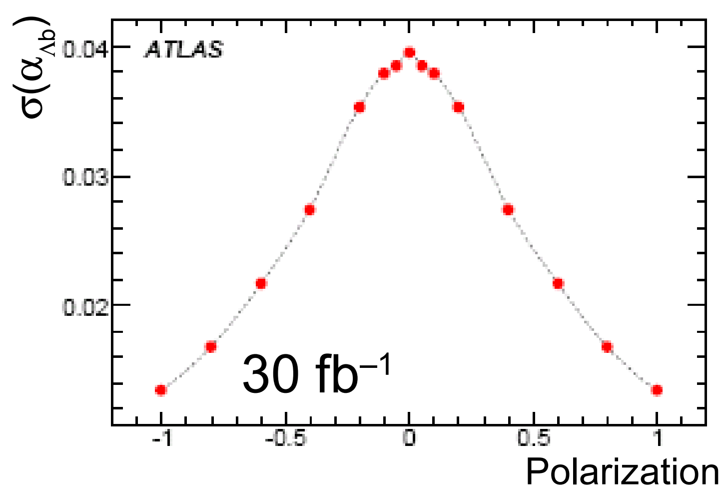
- ~13 500 Λ_b events for 30 fb^{-1}

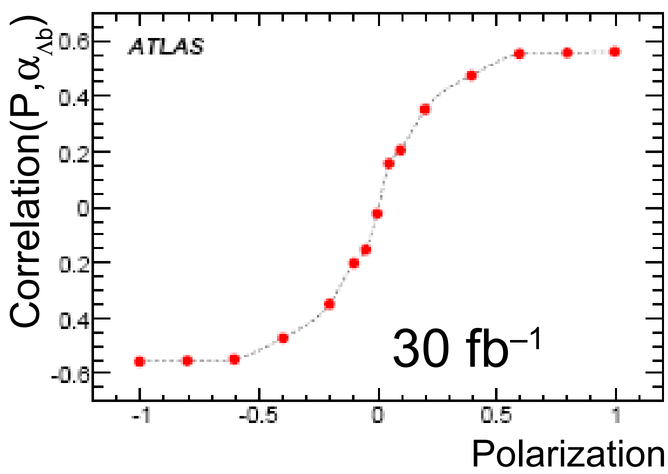
Λ_b Polarization with $\Lambda_b \rightarrow J/\psi(\mu^+\mu^-)\,\Lambda(p\pi^-)$

- Λ_b polarization (P) determined simultaneously with 6 parameters of helicity amplitudes $H_{\lambda_\Lambda,\lambda_{J/\psi}}$









- Polarization and asymmetry parameter α_{Λ_b} can be determined with precision of a few percent, with correlation varying (0 – 60%) depending on the value of P

Summary and Conclusions

- ATLAS will measure beauty and quarkonia production cross sections
  - Utilizing $B^+ \rightarrow J/\psi(\mu^+\mu^-) K^+$ and with 10 pb^{-1}, the total cross section can be measured to an accuracy of ~ 15 % and $d\sigma/dp_T$ to 16 – 20 %
  - J/ψ and Υ properties may be used for online- and offline-monitoring of detector performance
- J/ψ and Υ polarization
  - Precision in α of 0.02 – 0.06 (J/ψ) and 0.2 (Υ) with 10 pb^{-1}
  - Tevatron precision (@ 1.3 fb^{-1}) reached with 10 pb^{-1} (J/ψ) and 100 pb^{-1} (Υ)
  - Extending polarization measurements to interesting high p_T region
- Λ_b polarization as well as asymmetry parameter α_{Λ_b} determination to a few percent accuracy possible with 30 fb^{-1}
  - Correlation varying (0 – 60%) depending on the value of polarization
- Looking forward to first LHC data