Quarkonium production at ATLAS

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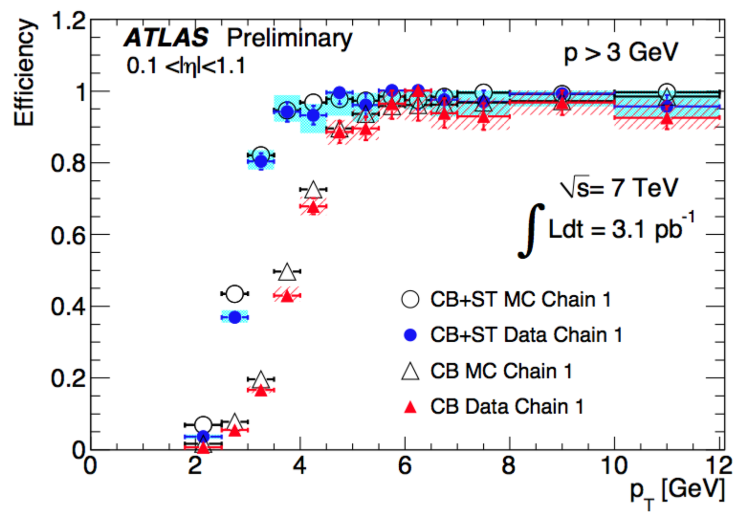
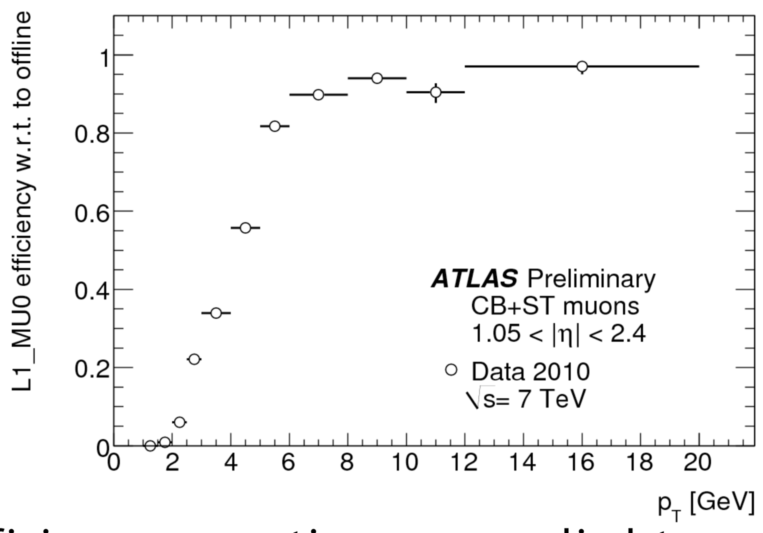
INTRODUCTION

Quarkonia are formed from a quark pair of same flavour and should represent one of the simplest systems described by QCD theory. Heavy quarkonium is a multiscale system, allowing for rigorous tests of the interplay between perturbative and non-perturbative QCD and a rich spectrum of radial and orbital excitations allow studies of spectroscopy and decay dynamics. In addition, quarkonia is an ideal probe of cold and hot nuclear matter effects. Many open questions exist in this area, and it has proven difficult to describe universally describe the kinematics and production properties of quarkonia. ATLAS plans to investigate quarkonium production through measurements of production, spin-alignment and associated hadronic activity of these various states. The first production measurements toward this goal are outlined below.

EFFICIENCY & ACCEPTANCE CORRECTIONS

Cross-section measurements presented here make use of data collected via a single muon trigger, first with no threshold on p_T then later with a threshold at 4 GeV. Trigger and reconstruction efficiencies (shown below, left & right) are measured in data and validated with Monte Carlo simulations.



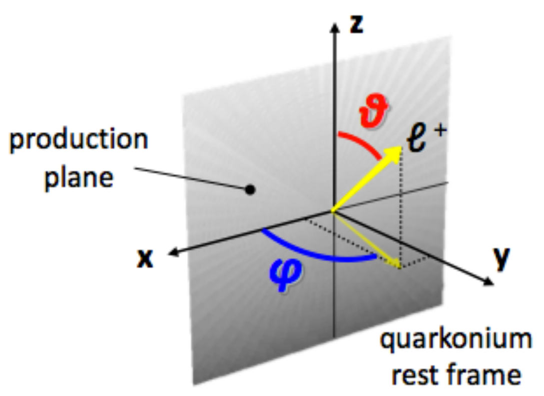


Weights incorporating acceptance & efficiency corrections are applied to quarkonia candidates on an event-by-event basis before fits are used to extract a cross-section.

$$w^{-1} = \mathcal{A} \cdot \mathcal{M} \cdot \mathcal{E}^2_{\text{trk}} \cdot \mathcal{E}^+_{\mu}(p^+_T, \eta^+) \cdot \mathcal{E}^-_{\mu}(p^-_T, \eta^-) \cdot \mathcal{E}_{\text{trig}}$$

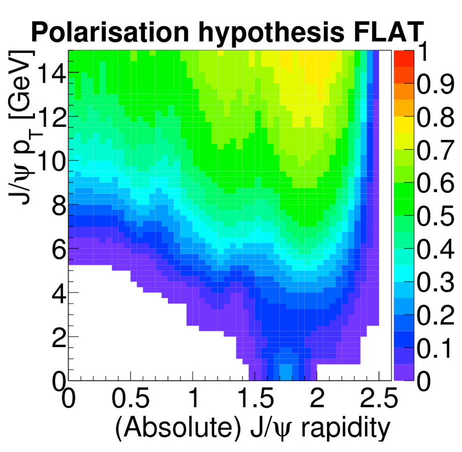
Detector acceptance ($\mathcal{A}$); Bin migrations ($\mathcal{M}$); ID reco efficiency (99.0%±0.5% per muon track) ($\mathcal{E}^2_{\text{trk}}$); Muon reconstruction efficiency ($\mathcal{E}_{\mu}$); Muon trigger efficiency ($\mathcal{E}_{\text{trig}}$)

SPIN ALIGNMENT UNCERTAINTY



Geometric acceptance represents the probability for quarkonium with given kinematics passing basic selection cuts. Dependent on nature of spin alignment of quarkonium, as yet unmeasured (need more data).

$$\frac{dN}{d\Omega} = 1 + \lambda_{\theta^\star}\cos^2\theta^\star + \lambda_{\phi^\star}\sin^2\theta^\star\cos 2\phi^\star + \lambda_{\theta^\star\phi^\star}\sin 2\theta^\star\cos\phi^\star$$

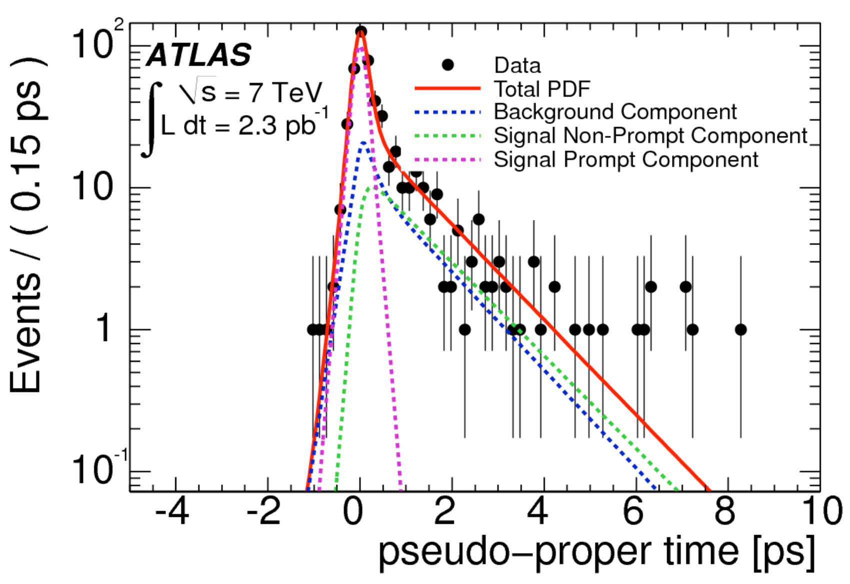


Five extreme spin-alignment scenarios have been calculated that represent the largest envelope of possible variation on visible cross-sections. Measurements are repeated under application of different acceptance maps reflecting different polarisation states as a systematic effect on measured production observables.

MEASUREMENT OF B-PRODUCTION FRACTION

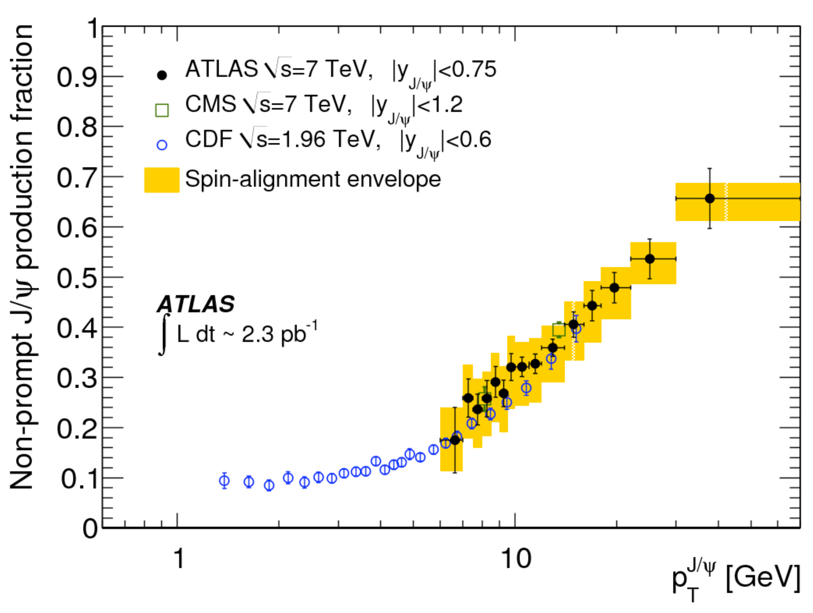
Production of J/ψ occurs promptly from the hard interaction, or may be produced non-promptly via decay of a B-hadron.

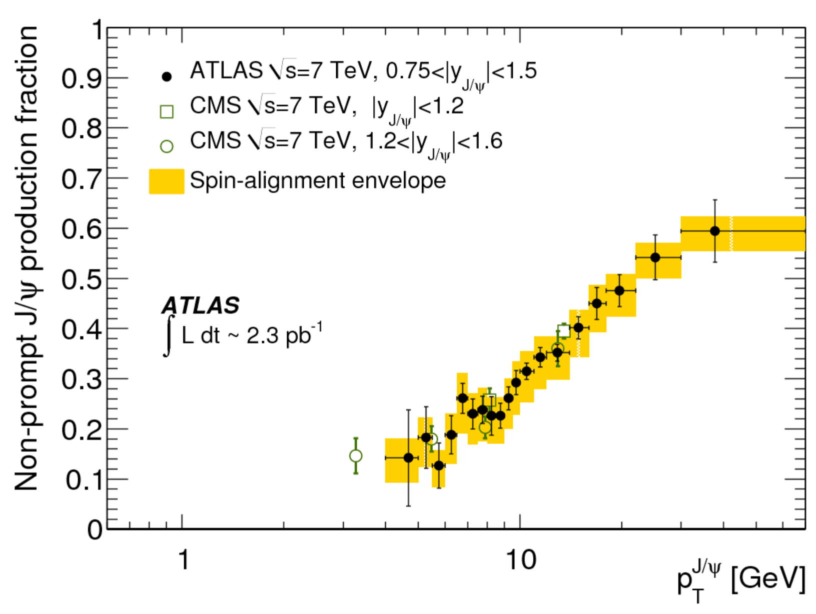
J/ψ from b-decays have positive displaced di-muon vertices and can be distinguished from prompt production via the pseudo-proper time discriminant τ related to the transverse decay length of the J/ψ vertex:



$$\tau = \frac{L_{xy}\, m^{J/\psi}_{\text{PDG}}}{p^{J/\psi}_T}$$

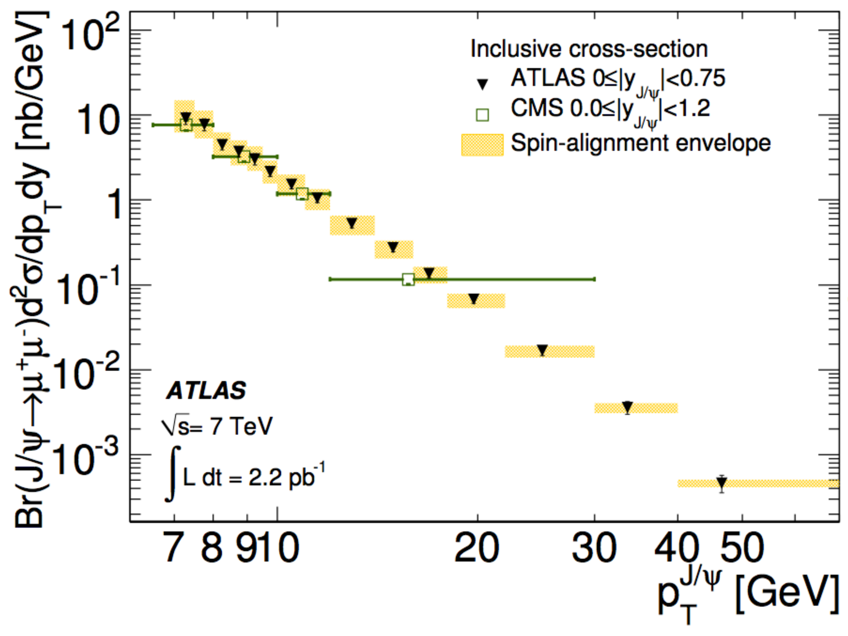
A simultaneous unbinned invariant mass & lifetime fit allows determination of the B-production fraction of J/ψ. Measured strong dependence as a function of p_T, slow dependence on rapidity and good agreement with CDF data (1.96 TeV, $p\bar{p}$).

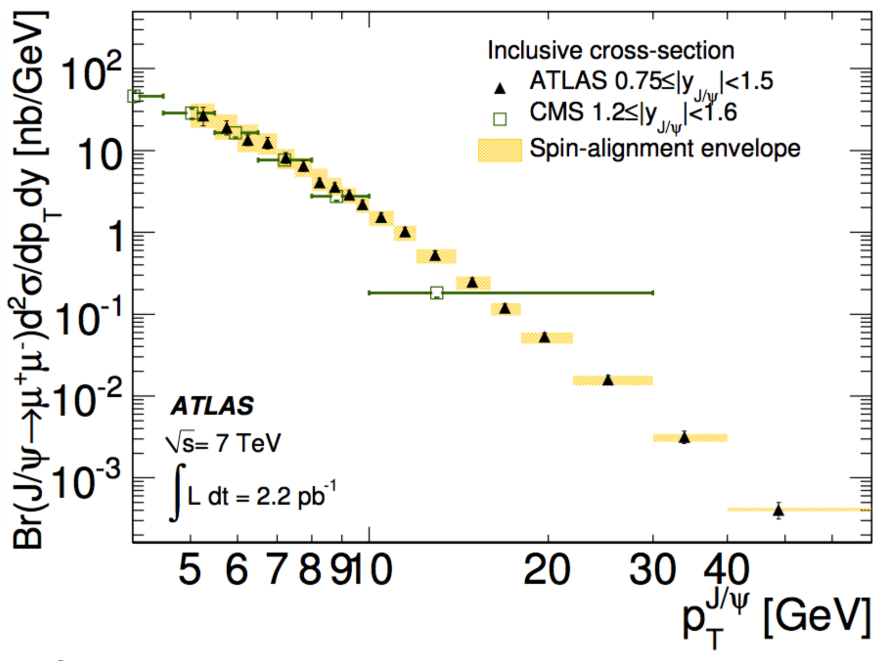




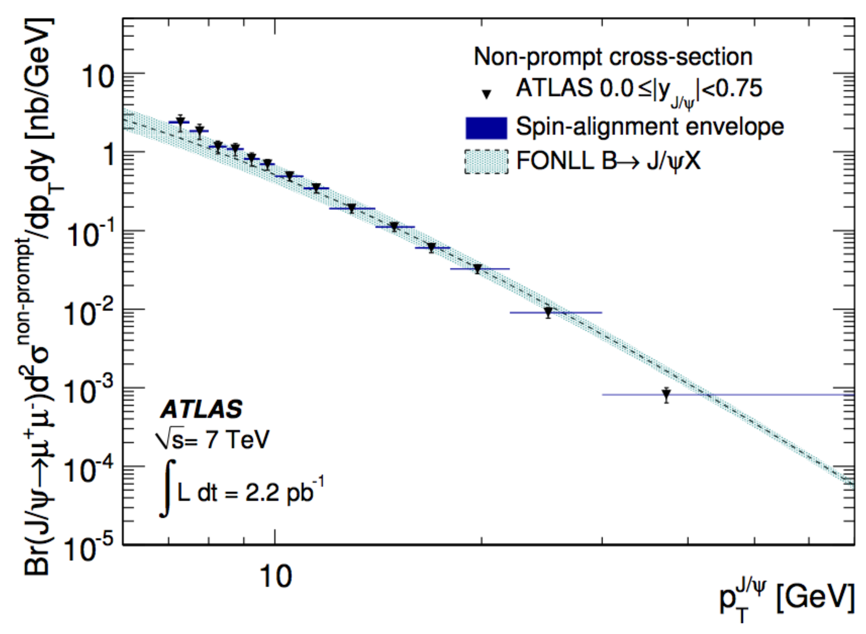
J/ψ CROSS-SECTION MEASUREMENTS

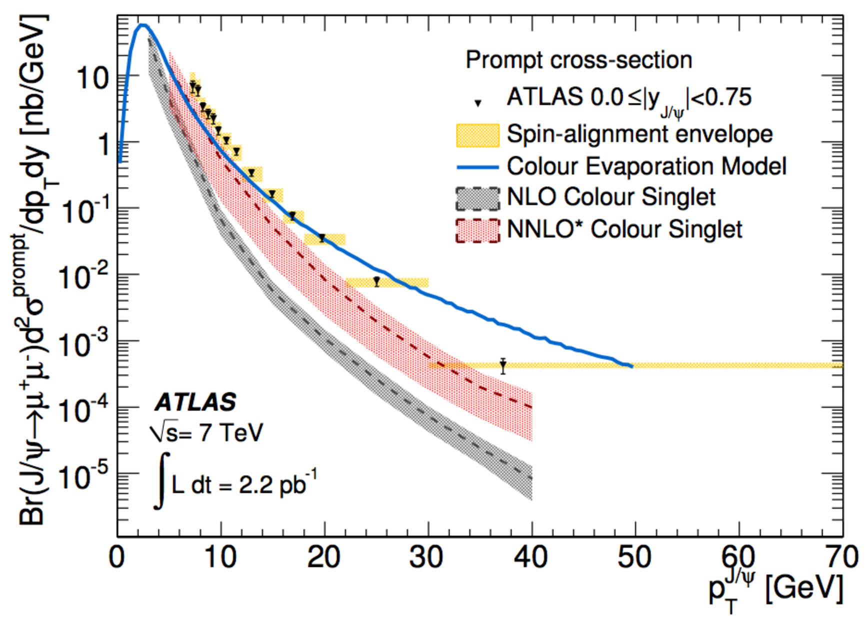
Applying candidate-by-candidate weights to di-muon pairs in p_T-y bins, extract signal yield from unbinned maximum likelihood fit to J/ψ peak. Plots below show inclusive cross-sections extracted in two rapidity bins (four in total), as a function of J/ψ p_T.





Combining the inclusive cross-section and B-fraction measurements, one can extract a non-prompt (J/ψ from b-decays) and prompt J/ψ cross-section versus p_T and rapidity.



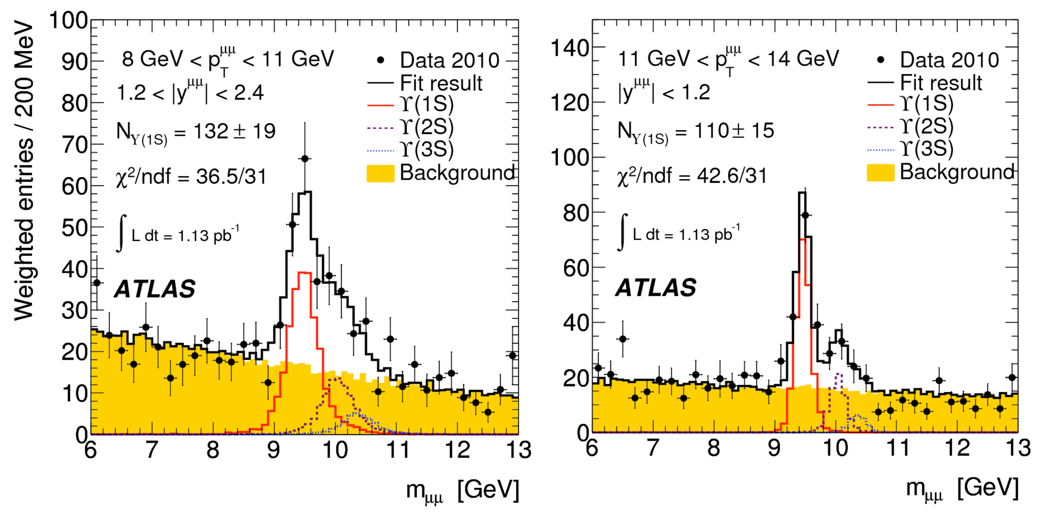


Measurements of J/ψ from b-decays agree well with Fixed-Order Next-to-Leading-Log theoretical predictions. Comparisons to colour singlet NNLO* pQCD predictions and the phenomenological Colour Evaporation Model show significant discrepancies in shape and normalisation, highlighting the uncertain nature of prompt J/ψ production.

UPSILON(1S) CROSS-SECTION MEASUREMENT

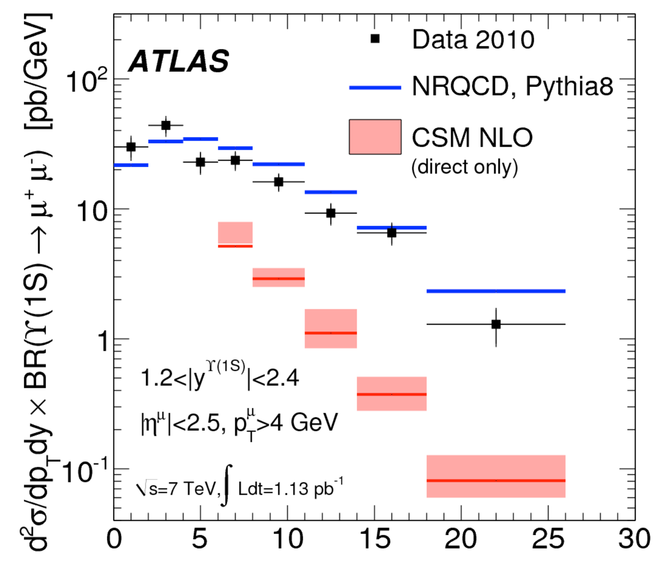
Measurement of the Υ(1S) cross-section has been performed in a similar manner.

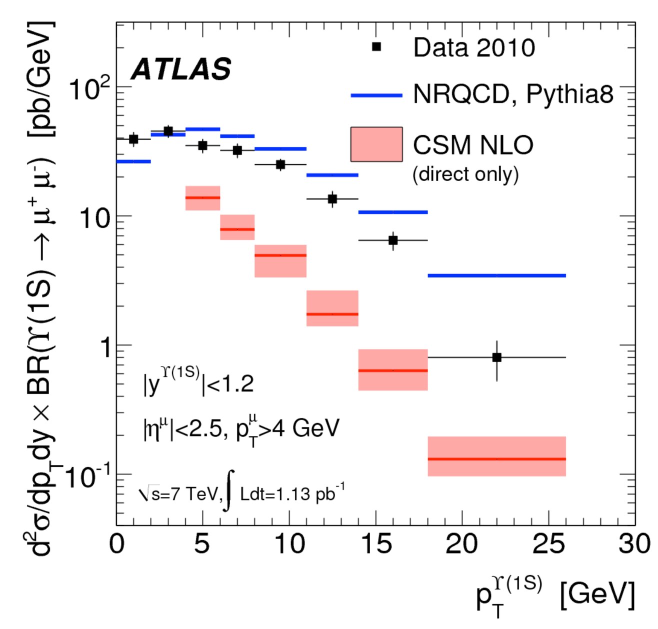
This measurement is presented in a fiducial region: p^{μ}_T>4 GeV, $|\eta^{\mu}|$<2.5 to remove the uncertainty due to spin alignment



Examples of di-muon invariant mass fits in the Υ region. Continuum backgrounds are modelled with opposite sign μ+track data templates, validated with same-sign & heavy flavour Monte Carlo.

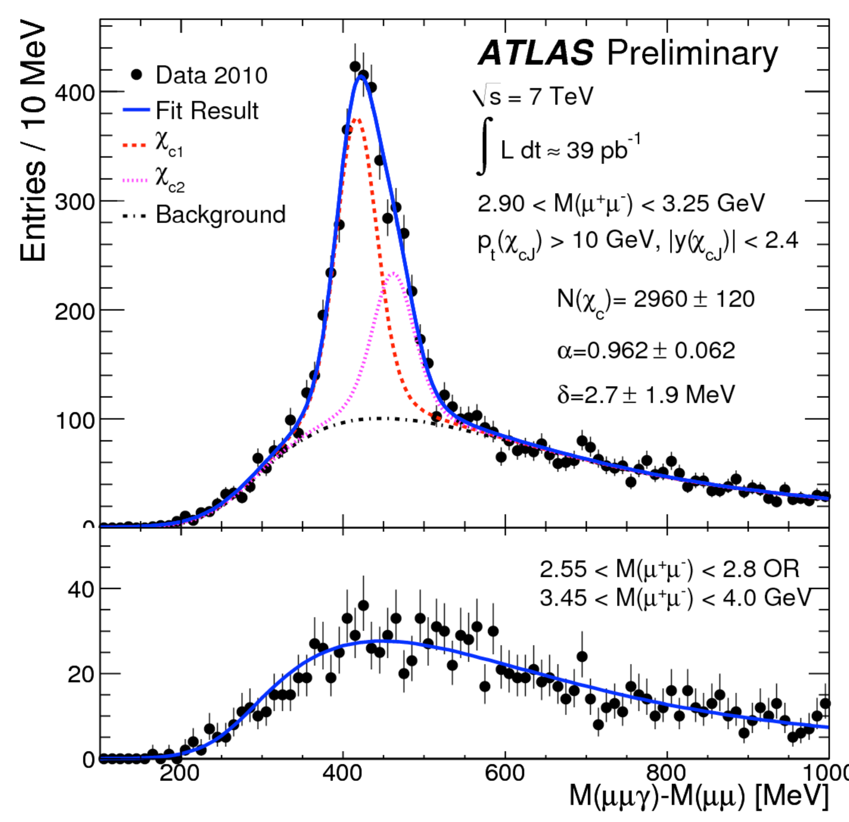
Unfolded differential cross-sections are compared to NLO pQCD. Significant disagreement is noted.

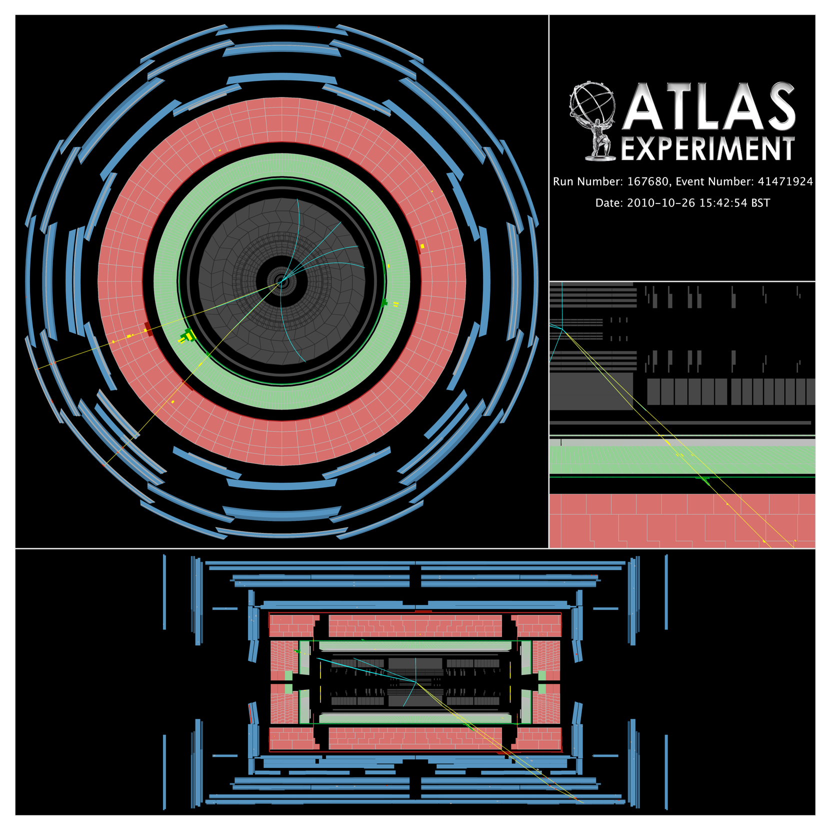




RECONSTRUCTION OF χ_C MESONS

The X_{c1} and X_{c2} mesons in radiative decays to a J/ψ and a photon have been observed via calorimetry. Measuring the production cross-section of X_c is crucial for precise understanding of J/ψ production and acts as a test of pQCD in its own right.





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