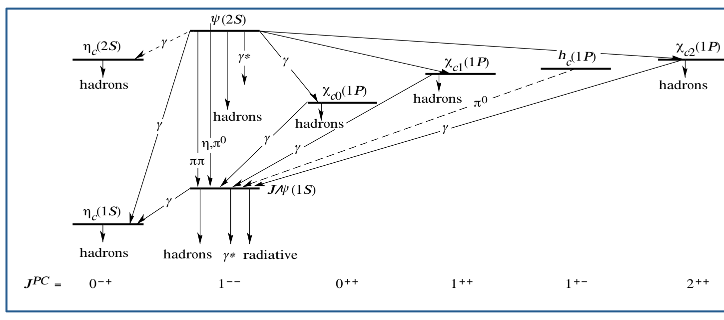
LHCC Poster Session - CERN, 21 March 2012

Radiative χ_c and χ_b decays in ATLAS

Introduction

The χ_c and χ_b states represent the spin triplet ^3P_J states of the charmonium and bottomonium systems. Each triplet of states, denoted $\chi_{c(b)J}$, have the quantum numbers $J^{PC} = 0^{++}, 1^{++}, 2^{++}$. The production of the χ_c and χ_b states in proton-proton collisions at the LHC is a topic of significant theoretical interest and the experimental study of χ_c production at the LHC can provide useful constraints on theoretical models of charmonium hadro-production. The χ_b system is experimentally much less well-studied than the χ_c system. The known χ_c and χ_b states have been observed in ATLAS data. Recently, the ATLAS experiment observed new structure in radiative decays to $\Upsilon(1S)$ and $\Upsilon(2S)$ consistent with a χ_b (3P) signal [1].

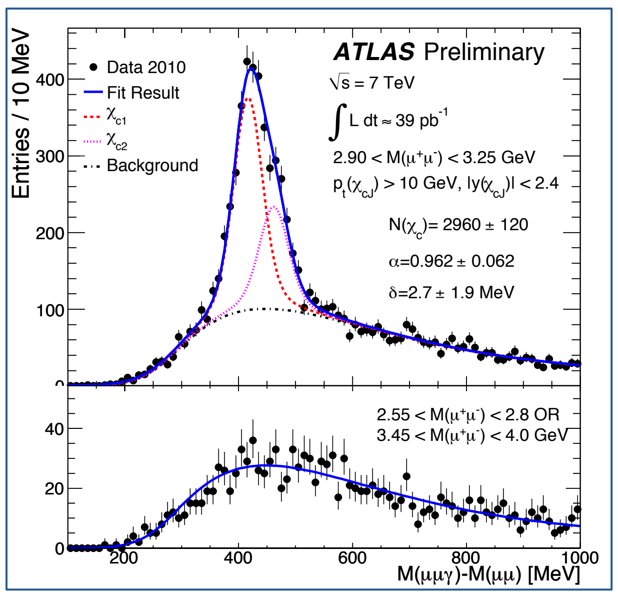


	Mass [MeV]	$M(\chi_c) - M(J/\psi)$ [MeV]	$Br(\chi_c \to J/\psi\,\gamma)$
χ_{c0}	3414.75 ± 0.31	317.83	(1.16 ± 0.08) %
χ_{c1}	3510.66 ± 0.07	413.74	(34.5 ± 1.5) %
χ_{c2}	3556.20 ± 0.09	459.28	(19.5 ± 0.8) %

The currently accepted model of the charmonium system below the open charm threshold. Diagram and world average quantities from the PDG [3].

1. The χ_c system

The χ_c system consists of a single triplet of narrow states below the open charm threshold with hyperfine splittings of a few tens of MeV. The charmonium production cross section at the LHC is large and the radiative branching fractions are substantial, allowing large candidates samples to be collected. The observation of the χ_c states in ATLAS data is described in [2].



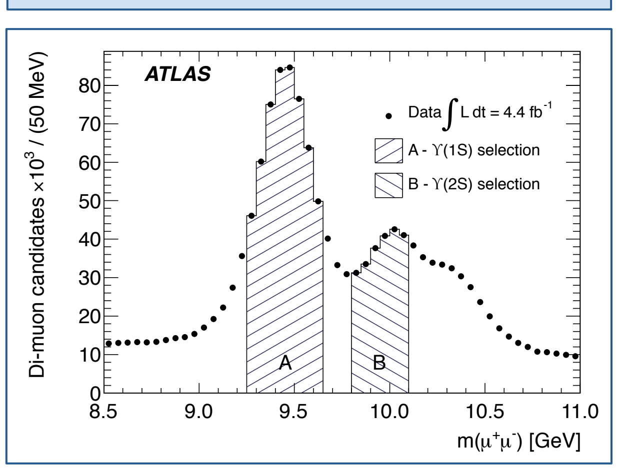
The $m(\mu^+\mu^-\gamma) - m(\mu^+\mu^-)$ distribution for selected χ_c candidates with photons reconstructed from direct calorimetric measurements alone.

2. Reconstruction of radiative $\chi_{c(b)}$ decays with ATLAS

The radiative decays of the $\chi_{c(b)}$ states to $J/\Psi(\Upsilon)(\mu^+\mu^-)\,\gamma$ represent the cleanest channels to study the $\chi_{c(b)}$ states at a hadron collider. Photons from these decays can be reconstructed in two ways:

Unconverted Photons: Photons reconstructed with a direct calorimetric measurement typically have poorer energy and momentum resolution when compared to converted photons but tend to provide higher yields.

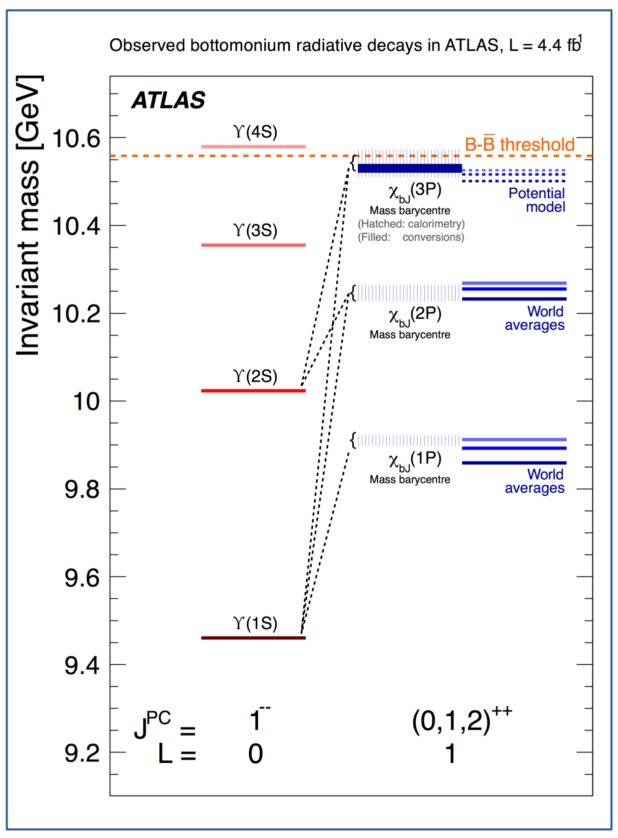
Converted Photons: Photons that convert into an e^+e^- pairs due to interaction with material in the ATLAS Inner Detector (ID) can be reconstructed from these e^+e^- tracks. This approach offers improved momentum resolution at the expense of reconstruction yields.



The invariant mass of selected di-muon candidates. The shaded regions A and B show the selections for $\Upsilon(1S)$ and $\Upsilon(2S)$ candidates.

3. The χ_b system

In contrast to the χ_c system, the χ_b system consists of two confirmed χ_b triplets below the open beauty threshold, the $\chi_b(1P)$ and $\chi_b(2P)$. The hyperfine splitting between the individual χ_b states is smaller (at around 10-20 MeV) than for the χ_c. The branching fractions for the radiative decays into the vector bottomonium states, the $\Upsilon(nS)$, are also large.

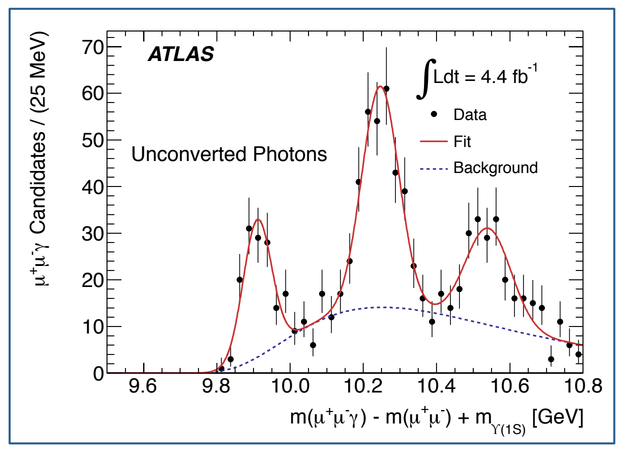


Masses and radiative transitions of the χ_b states as observed in ATLAS. The first column shows the world-average masses of the Υ states. The second column shows the ATLAS mass barycentre determination for each χ_b triplet.

4. Observation of radiative χ_b decays in ATLAS

ATLAS has observed the $\chi_b(1P)$ and $\chi_b(2P)$ triplets in radiative decays to $\Upsilon(1S)$. Additionally, a further structure at higher mass is observed in radiative decays to both $\Upsilon(1S)$ and $\Upsilon(2S)$, interpreted as the $\chi_b(3P)$ system [1].

$\Upsilon \to \mu^+\mu^-$ candidates are formed from a pair of oppositely charged muons reconstructed from tracks in both the ID and Muon Spectrometer. Radiative χ_b decays are reconstructed with both converted and unconverted photons.



The $m(\mu^+\mu^-\gamma) - m(\mu^+\mu^-) + m(\Upsilon(1S))$ distribution of $\chi_b \to \Upsilon(1S)\,\gamma$ candidates reconstructed from unconverted photons.

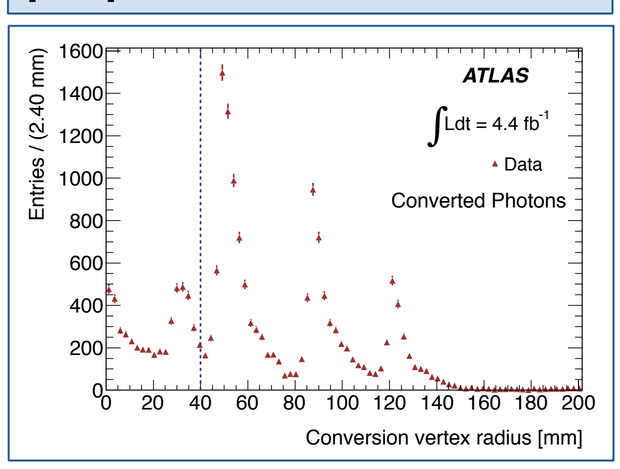
6. Converted Photons

Converted photons are reconstructed from two oppositely charged ID tracks, both with transverse momentum greater than 500 MeV, that intersect at a common vertex. The ability of ATLAS to reconstruct converted photons with transverse momentum as low as 1 GeV allows radiative decays into both $\Upsilon(1S)$ and $\Upsilon(2S)$ to be reconstructed.

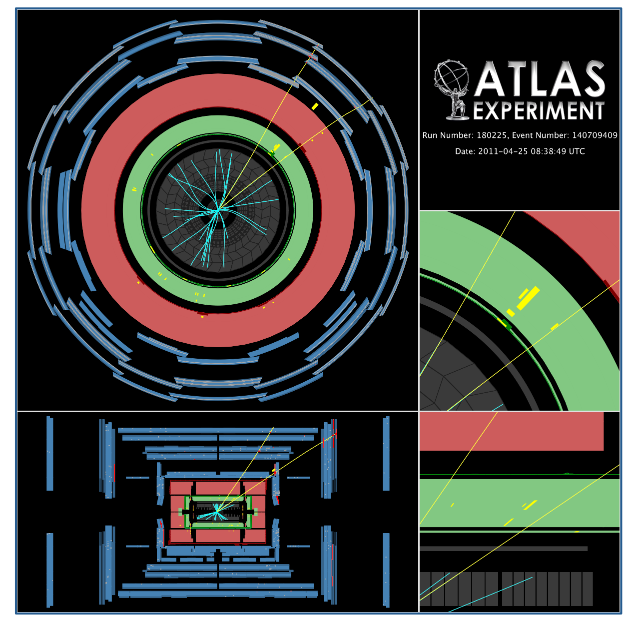
The mass barycentre of the third structure is determined from a simultaneous fit to the two mass distributions $m(\mu^+\mu^-\gamma) - m(\mu^+\mu^-) + m(\Upsilon(kS))$ (k=1,2). Using converted photon candidates alone, this is measured to be:

10.530 ± 0.005 (stat.) ± 0.009 (syst.) GeV

This value is consistent with theoretical predictions for the $\chi_b(3P)$ system [4,5,6].



The distribution of conversion vertex radius from the beam axis. The four peaks correspond to the beam pipe and the inner three silicon detector layers. To reduce combinatorial background, conversion candidates are required to be reconstructed with R > 40 mm.

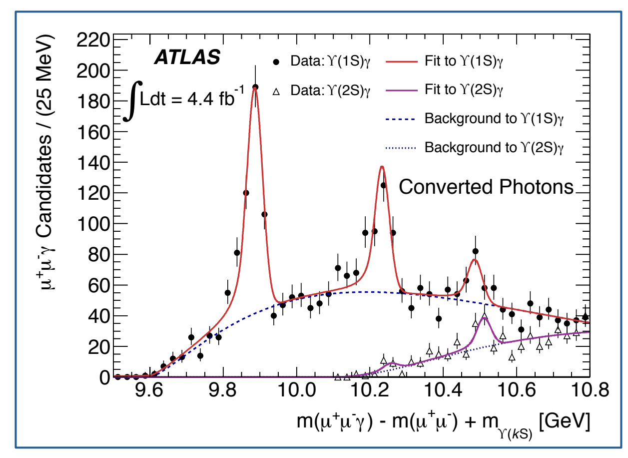


An event containing a candidate χ_b (3P) $\to \Upsilon$ (1S) γ decay. The photon is reconstructed with a direct calorimetric measurement. For this candidate, $m(\mu^+\mu^-\gamma) - m(\mu^+\mu^-) + m(\Upsilon(1S)) = 10.54$ GeV.

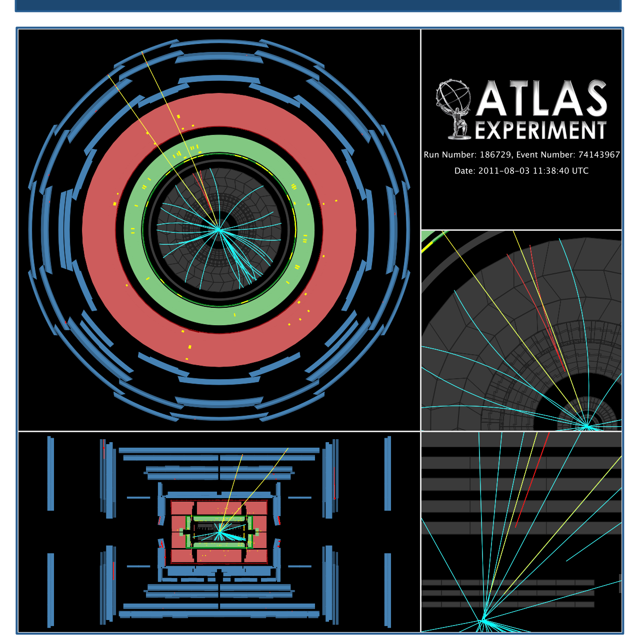
5. Unconverted Photons

Unconverted photons are reconstructed from energy deposits in the ATLAS electromagnetic calorimeter that are consistent with a photon hypothesis. Photons with transverse energy greater than 2.5 GeV and pseudorapidity $|\eta| < 2.37$ are considered.

The resolution of unconverted photons to be improved by correcting the polar angle of the photon to point back to the reconstructed di-muon vertex. Photons not compatible with having originated from this vertex are rejected.



The $m(\mu^+\mu^-\gamma) - m(\mu^+\mu^-) + m(\Upsilon(kS))$ distribution (k=1,2) for $\chi_b \to \Upsilon(kS)\,\gamma$ candidates reconstructed from e^+e^- conversions.



An event containing a candidate χ_b (3P) $\to \Upsilon$ (1S) γ decay. For this candidate, $m(\mu^+\mu^-\gamma) - m(\mu^+\mu^-) + m(\Upsilon(1S)) = 10.54$ GeV. The photon is reconstructed from an e^+e^- conversion.

References

[1] The ATLAS Collaboration, arXiv:1112.5154 [hep-ex]
[2] The ATLAS Collaboration, ATLAS-CONF-2011-136
[3] K. Nakamura et al. [PDG], J. Phys. G 37 (2010) 075021
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Andrew Chisholm, for the ATLAS Collaboration