Production of quarkonium states at the ATLAS experiment

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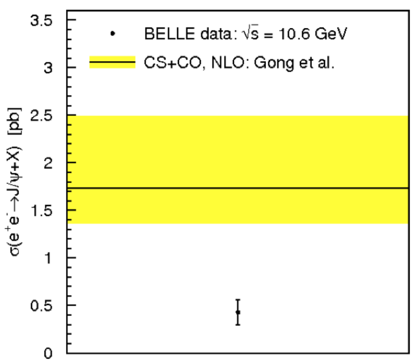
Quarkonium production

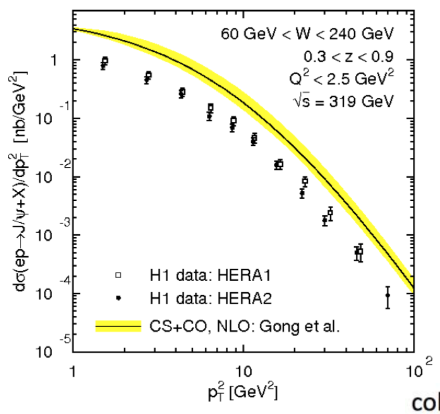
Ever since the November Revolution – discovery of J/ψ in 1974 – quarkonium provides valuable insights into QCD dynamics, as well as endless new puzzles

Taken from slides by Mathias Butenschön, CHARM2013

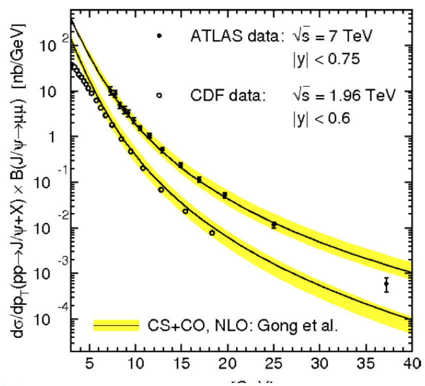
e+e- yields



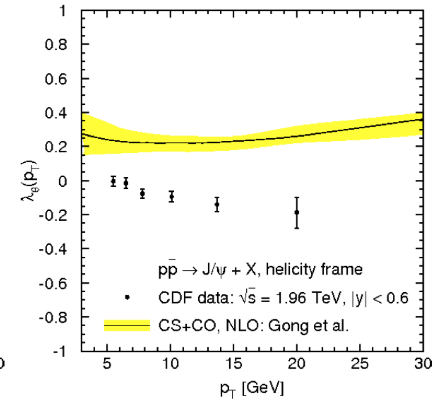
γ-p yields



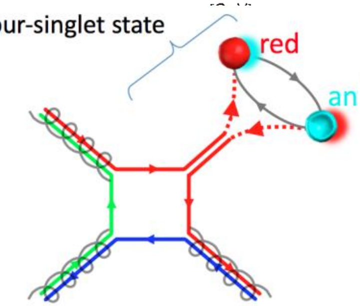
pp yields

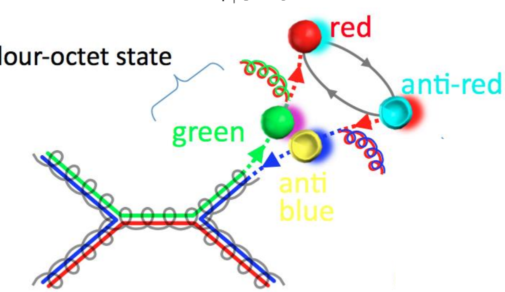


Polarisation



ATLAS measurements of quarkonium production provide additional precision data and new observables for:





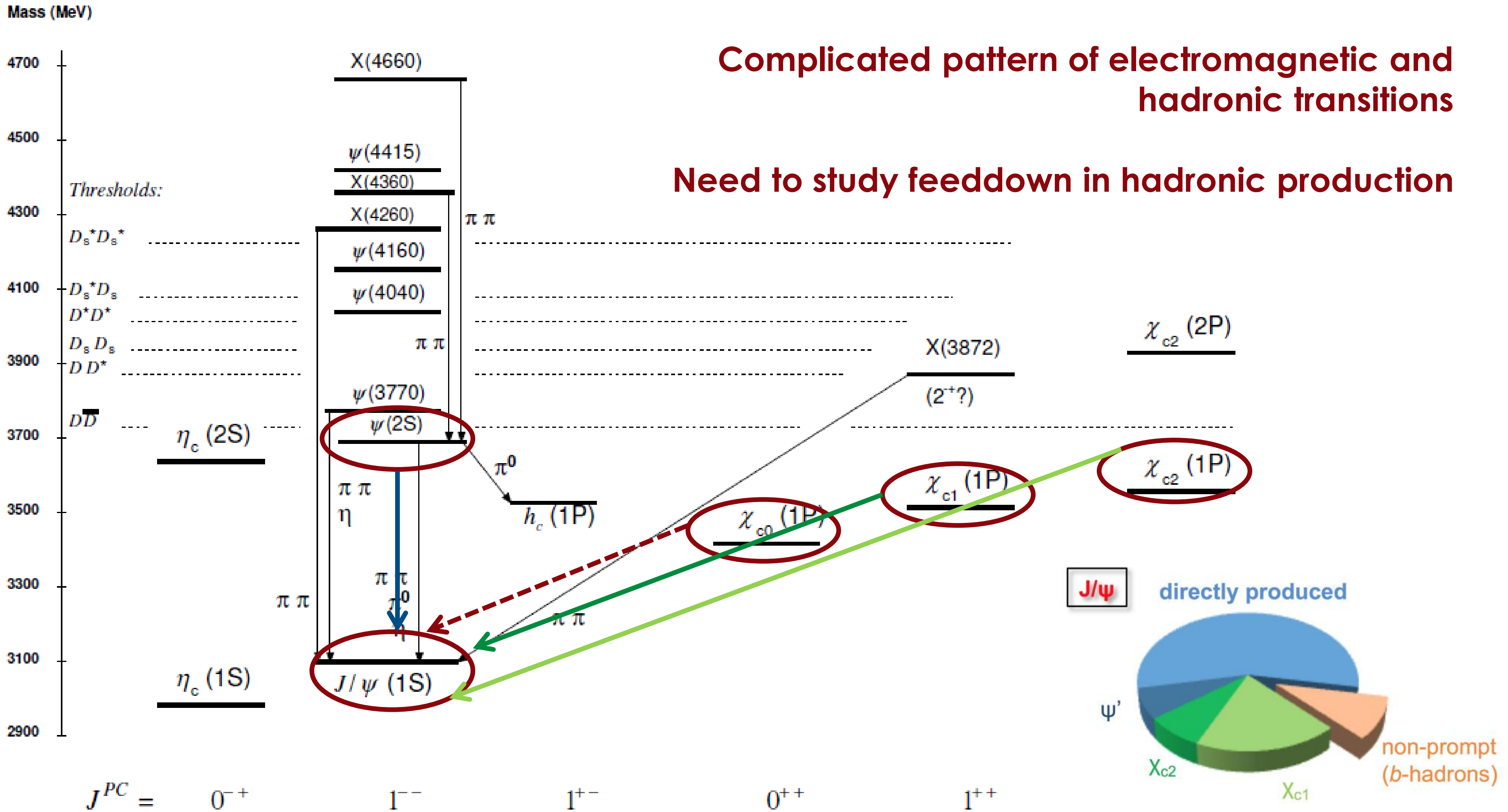
- Tests of **QCD calculations** at the perturbative / non-perturbative boundary
- **Standard candles** for Heavy Ions, B production, **backgrounds** to SM/BSM processes
- Test **multiple parton scattering** effects, **parton density functions**
- Search for **rare decays** and probes of **new physics**

Quarkonium spectroscopy and feeddown

Rich spectrum of states with a variety of quantum numbers

Complicated pattern of electromagnetic and hadronic transitions

Need to study feeddown in hadronic production



Latest results from ATLAS

ATLAS has a long-standing and evolving programme of studies on various aspects of quarkonium production

The most recent results from ATLAS covered in this talk:

- Measurement of the production cross-section of $\psi(2S) \rightarrow J/\psi(\rightarrow \mu^+\mu^-)\pi^+\pi^-$ in pp collisions at $\sqrt{s}$ = 7 TeV at ATLAS

  arXiv: 1407.5532
  Submitted to JHEP

- Measurement of χ_{c1} and χ_{c2} production with $\sqrt{s}$=7 TeV pp collisions at ATLAS

  Accepted by JHEP
  arXiv:1404.7035

See other ATLAS talks at BEACH 2014 for more related ATLAS results

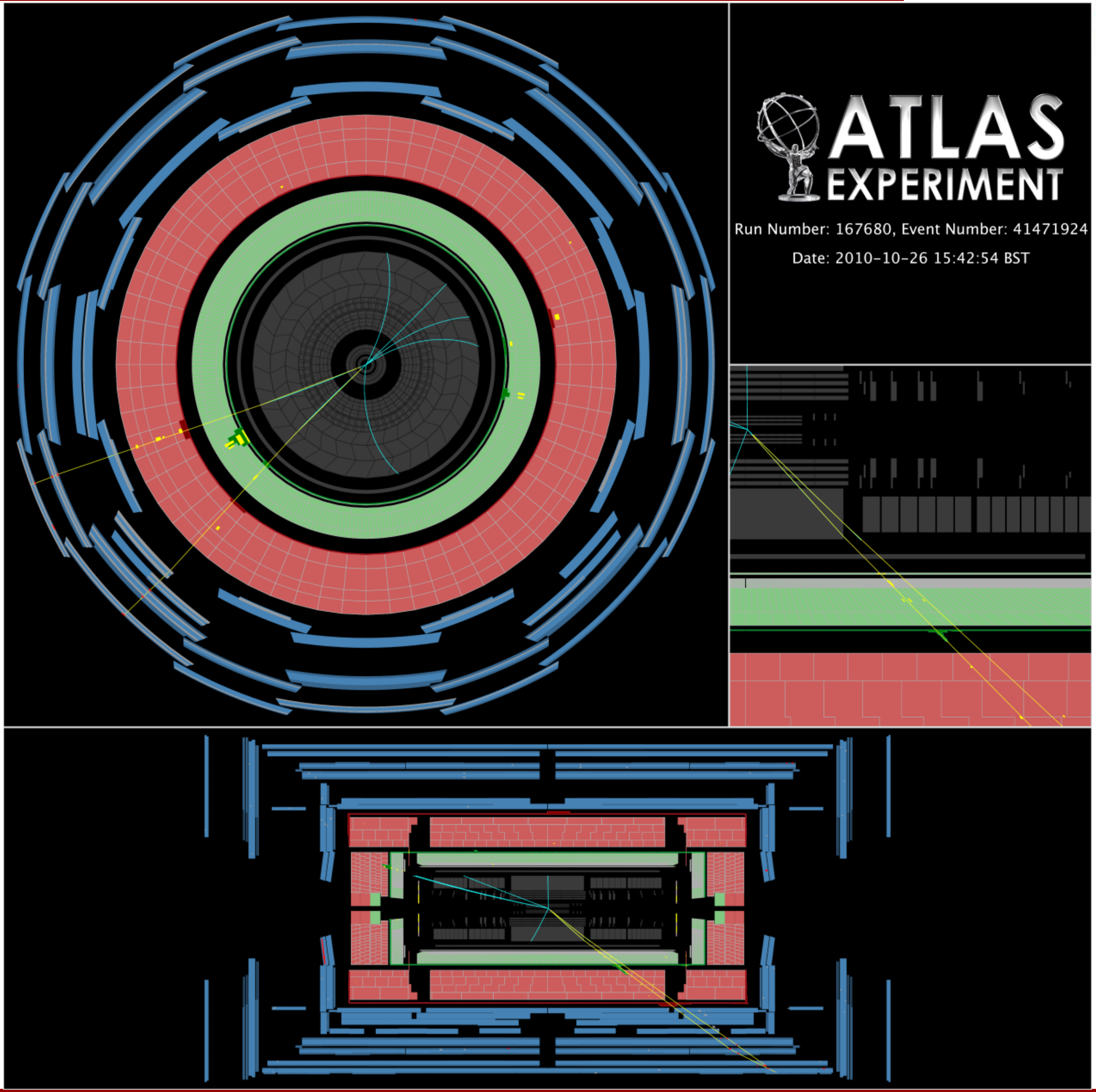
ATLAS event display: $\chi_c \to J/\psi(\mu^+\mu^-)\,\gamma$ candidate

Cross section views perpendicular and parallel to the beam line

Two muon tracks spanning the Inner Detector and the Muon System

A photon tower in Eclectromagnetic Calorimeter

Invariant mass in the χ_c region



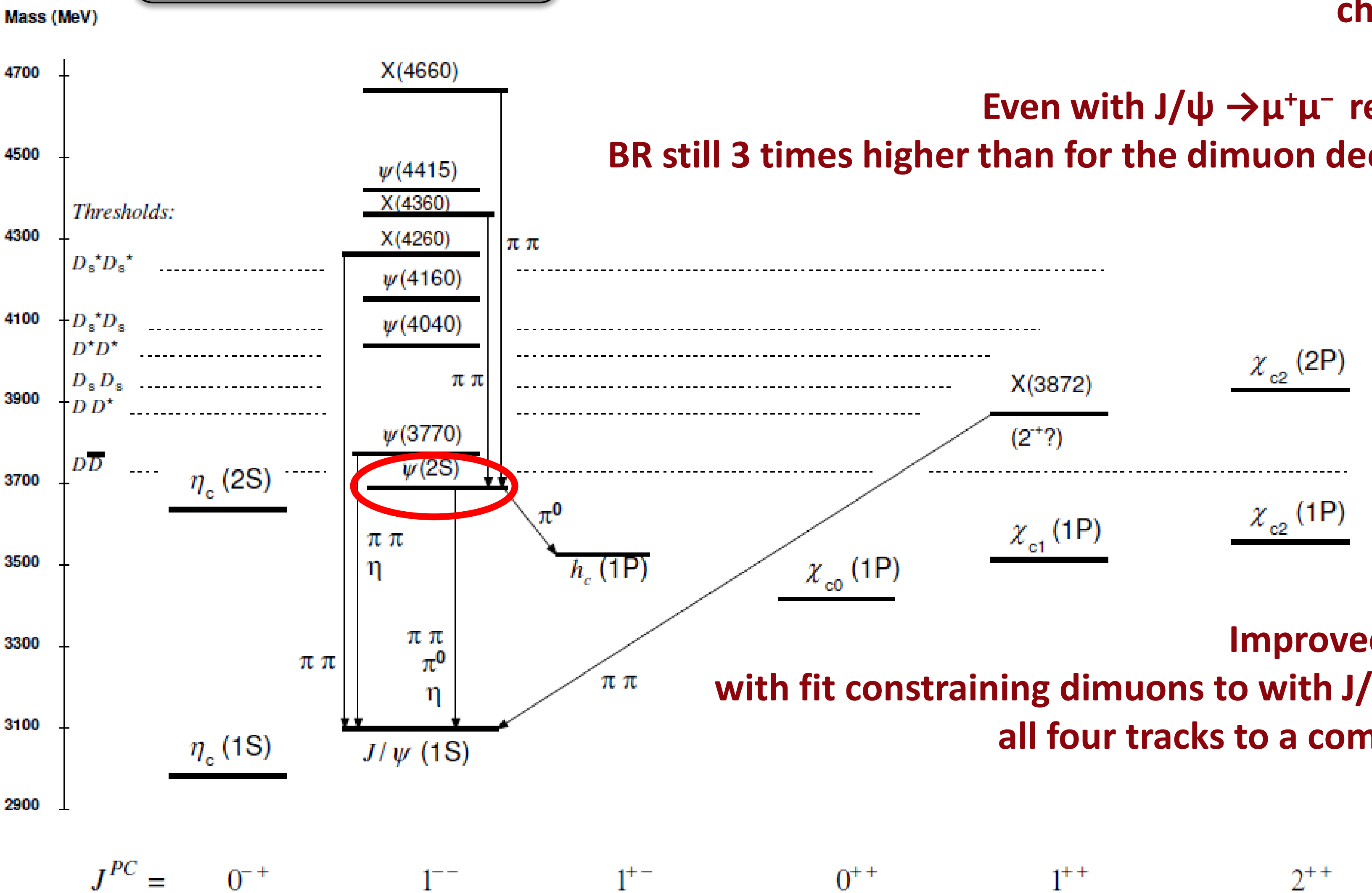
Production of ψ(2S) → J/ψ π⁺π⁻

arXiv: 1407.5532
Submitted to JHEP

About a third of all ψ(2S) decays into J/ψ and a pair of charged pions

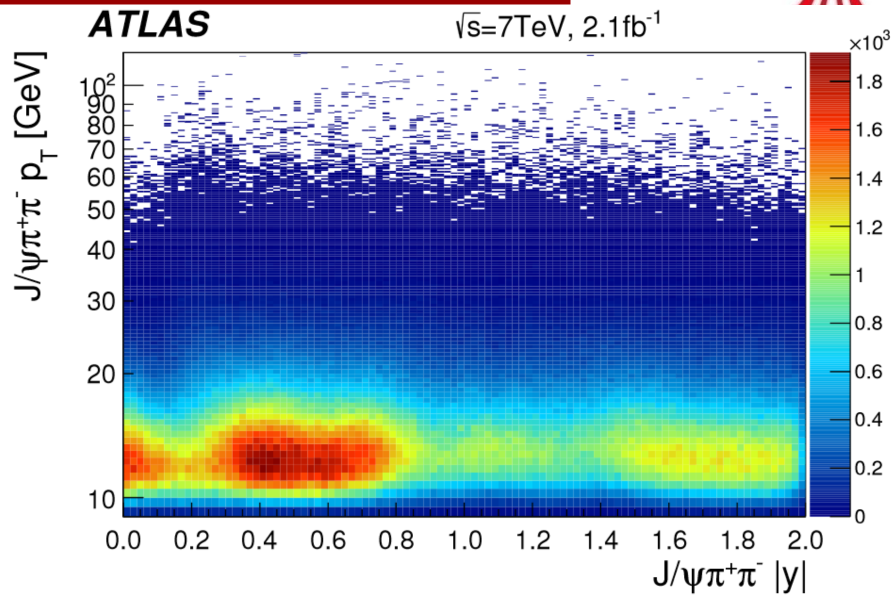
Even with J/ψ →μ⁺μ⁻ requirement,
BR still 3 times higher than for the dimuon decay of ψ(2S)

Improved resolution
with fit constraining dimuons to with J/ψ mass and all four tracks to a common vertex

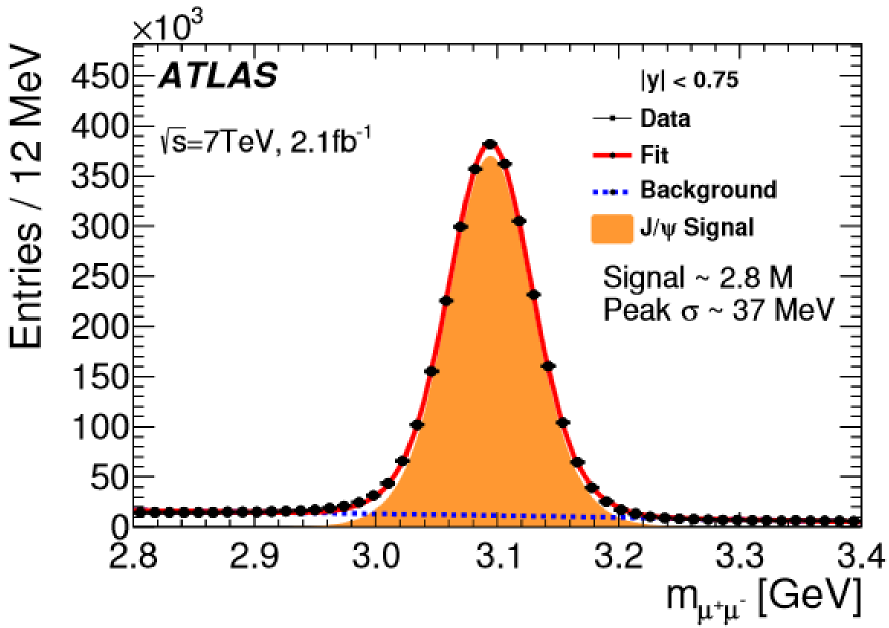


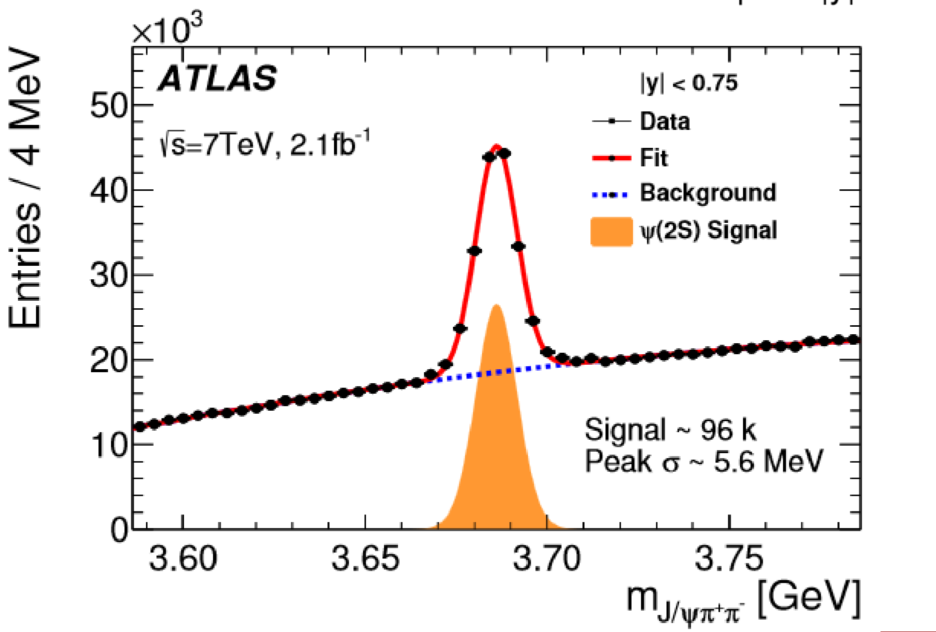
$J/\psi(\rightarrow\mu^+\mu^-)\pi^+\pi^-$ candidates

Scatter plot in p_T – rapidity space of $J/\psi(\rightarrow\mu^+\mu^-)\pi^+\pi^-$ candidates in the vicinity of $\psi(2S)$ mass



Resolution in $\mu^+\mu^-\pi^+\pi^-$ mass is greatly improved by a kinematic fit constraining $\mu^+\mu^-$ to J/ψ mass and all four tracks to the same vertex



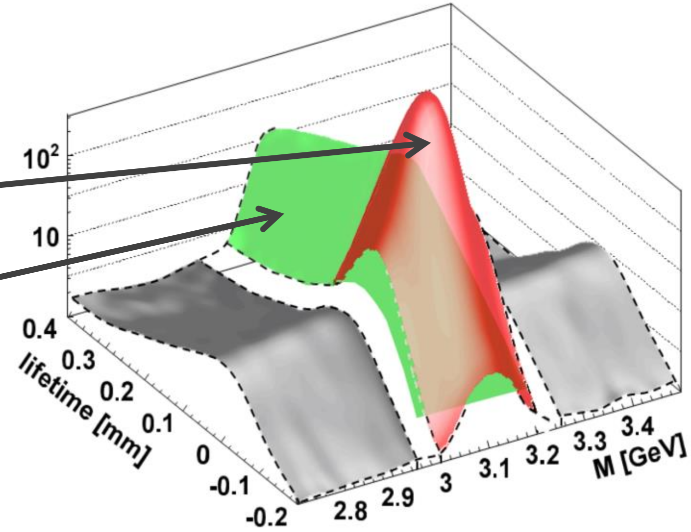


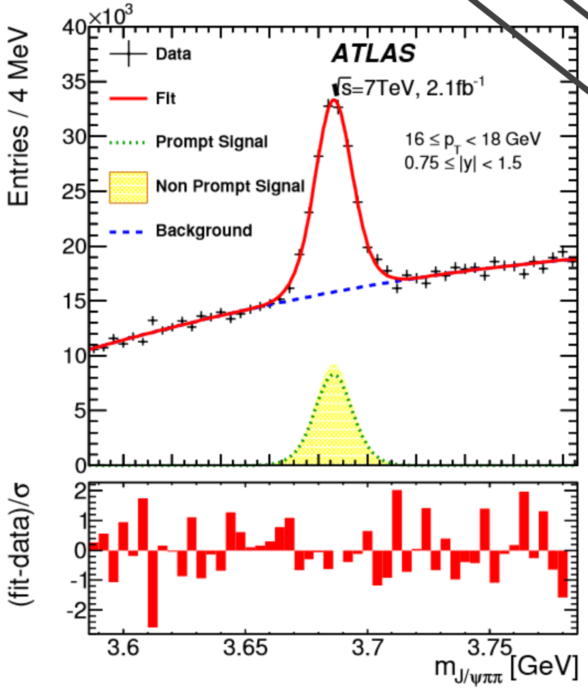
Prompt and Non-Prompt contributions

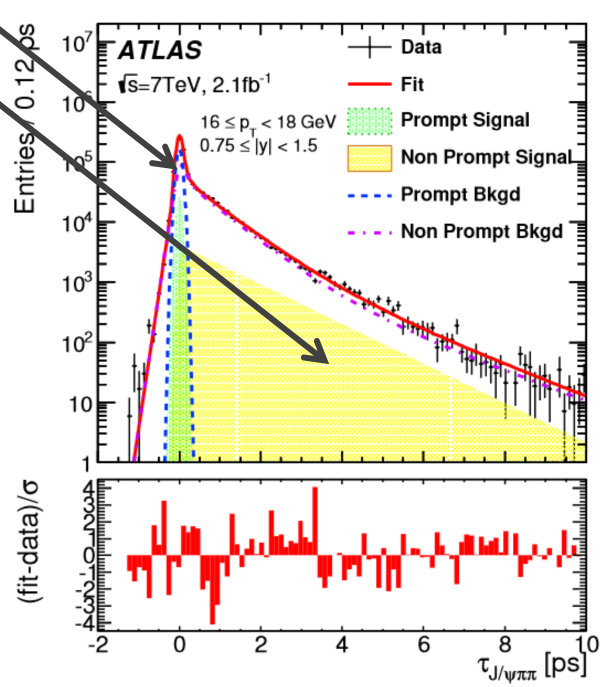
Use transverse pseudo-proper decay distance (or lifetime) of the J/ψ vertex to separate:

$$l_{J/\psi} = L_{xy} \cdot \frac{m_{J/\psi}}{p_T}$$

1. ***Prompt*** production -- from QCD (or short-lived) sources, with lifetimes consistent with resolution
2. ***Non-prompt*** production -- from long-lived sources such as b-hadron decays







2D mass vs lifetime unbinned maximum-likelihood fit

Candidates weighted to correct for acceptance and efficiency

Prompt and ***Non-prompt*** yields extracted in each p_T and rapidity bin

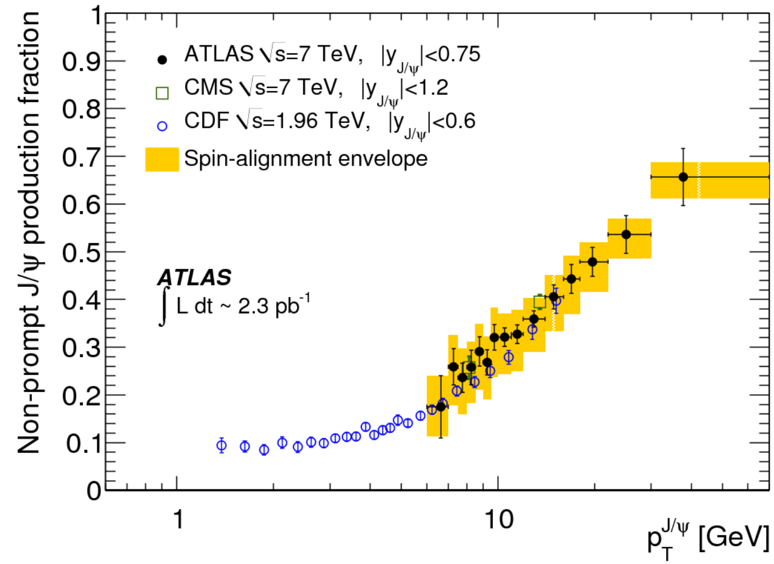
Two projections shown for a sample bin, with pull distributions

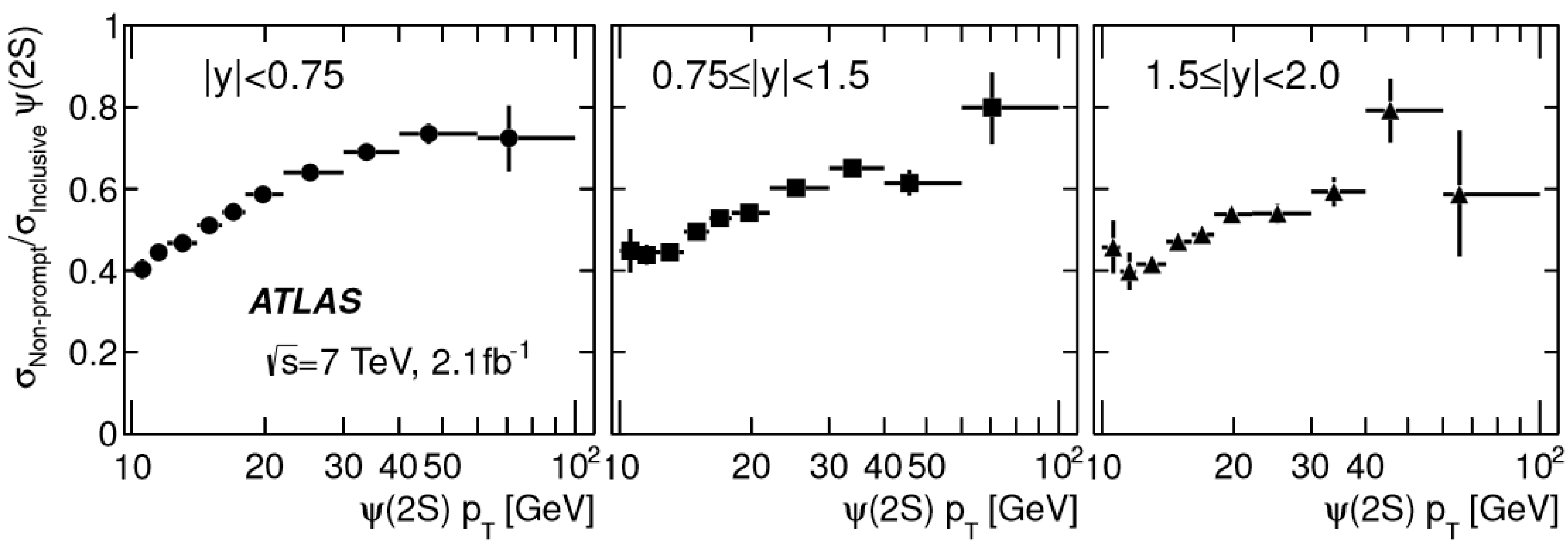
Non-prompt fraction of ψ(2S)

The fraction of ψ(2S) produced from b-hadron decays

Can be measured with better precision as many systematic effects largely cancel out

Increases with transverse momentum, but to a lesser extent than J/ψ

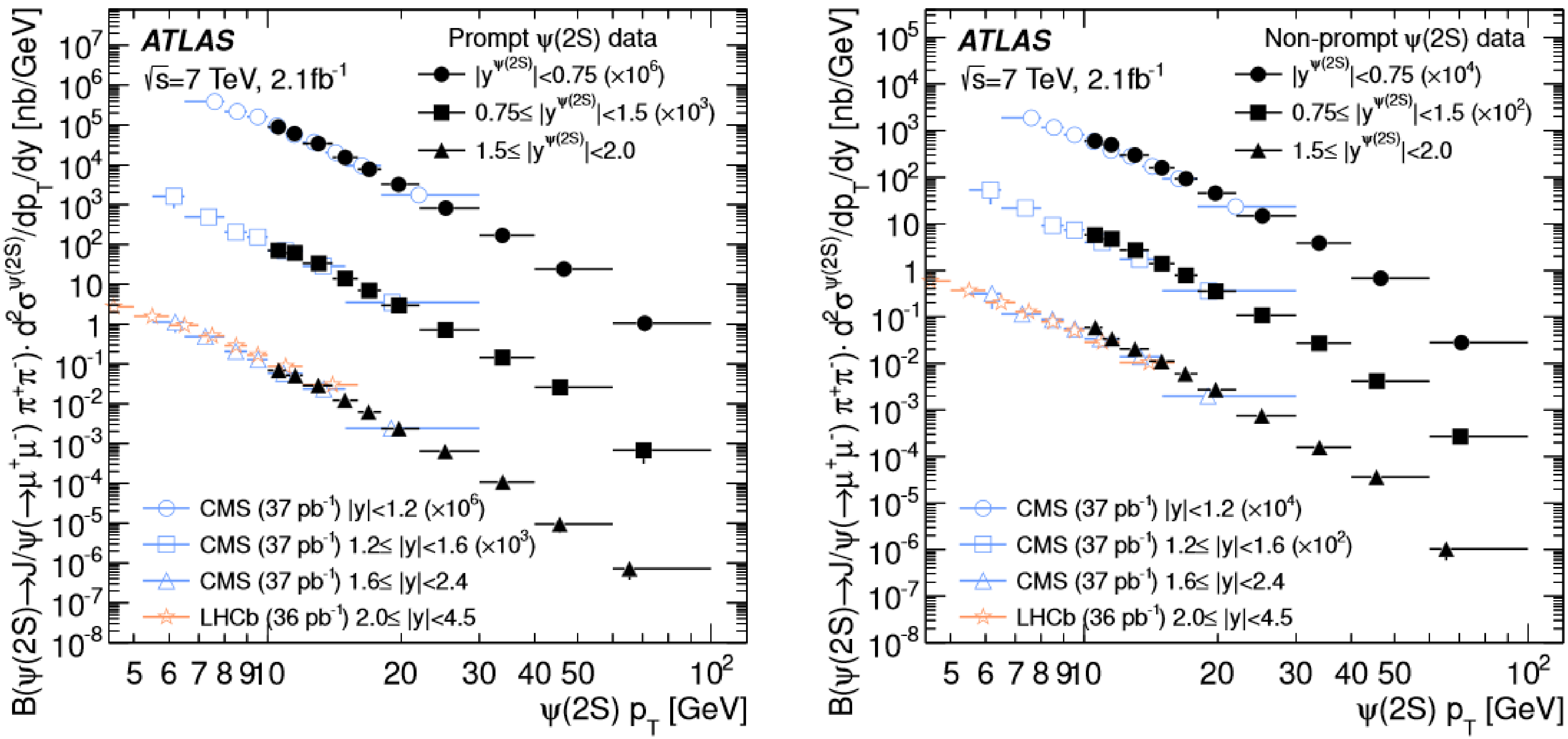




ψ(2S) production cross section

Measurement with 2.1 fb^{-1} pp data at 7 TeV

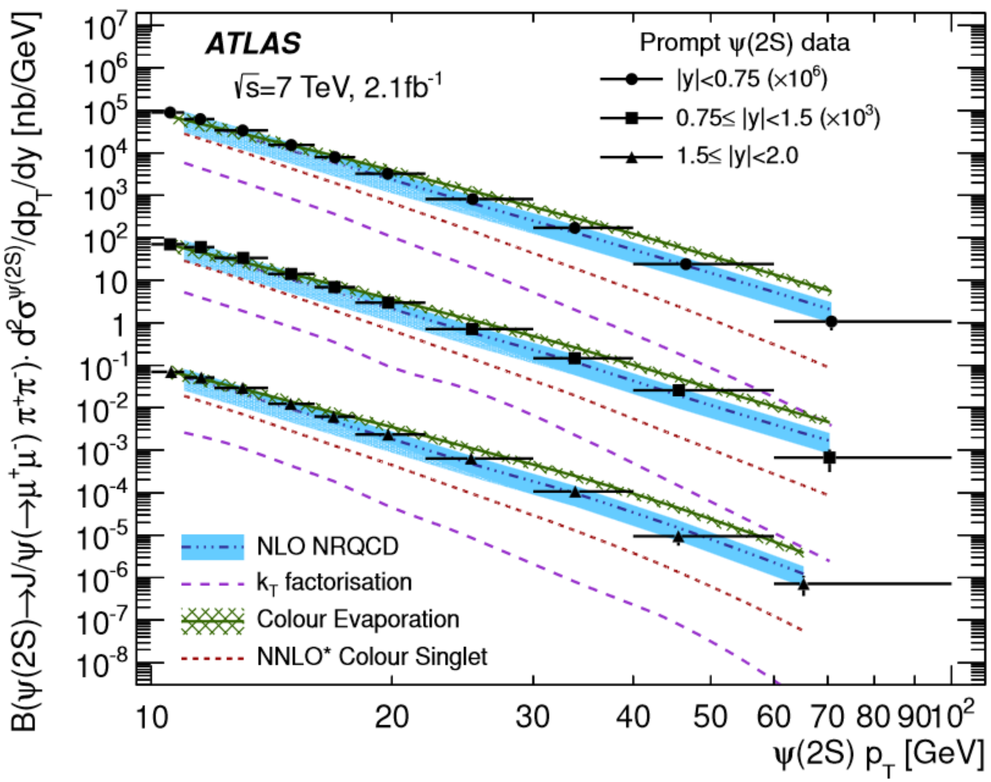
- Muon p_T > 4 GeV, pion candidate tracks p_T> 0.5 GeV
- p_T range extended to 100 GeV

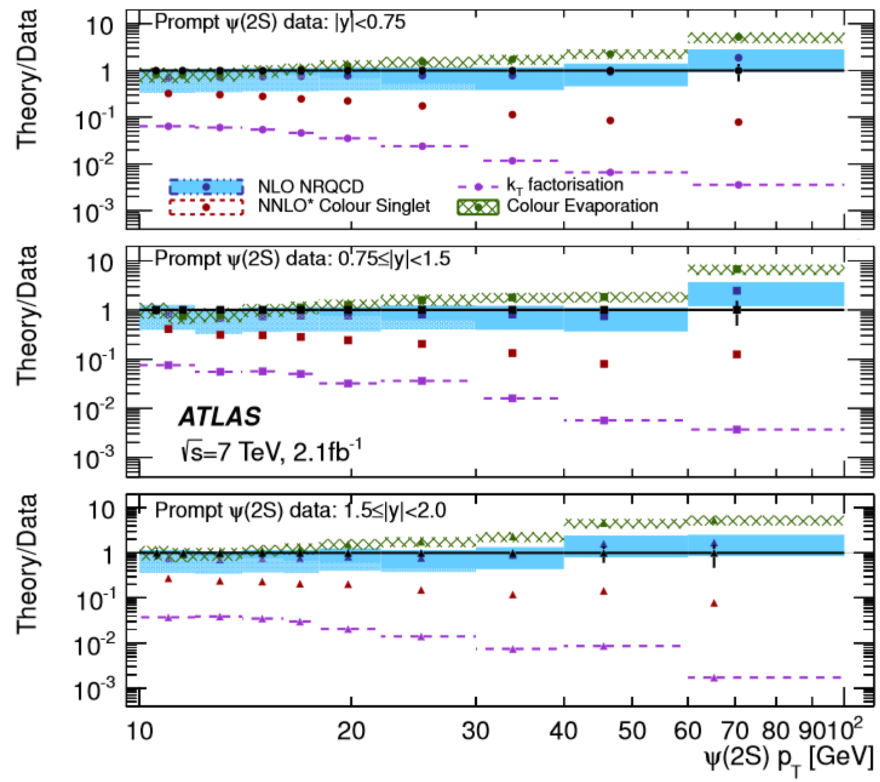


Prompt ψ(2S) → J/ψ π π production

High precision, wide reach prompt production cross-section in ψ(2S)→J/ψππ.

- **Agreement with NRQCD, hint of overestimate at highest p_T never before explored**
- **k_T-factorisation model goes well below the data**
- **Colour Singlet NNLO* predictions undershoot, especially at higher scales**
- **Colour Evaporation Model tends to overshoot at high transverse momenta**



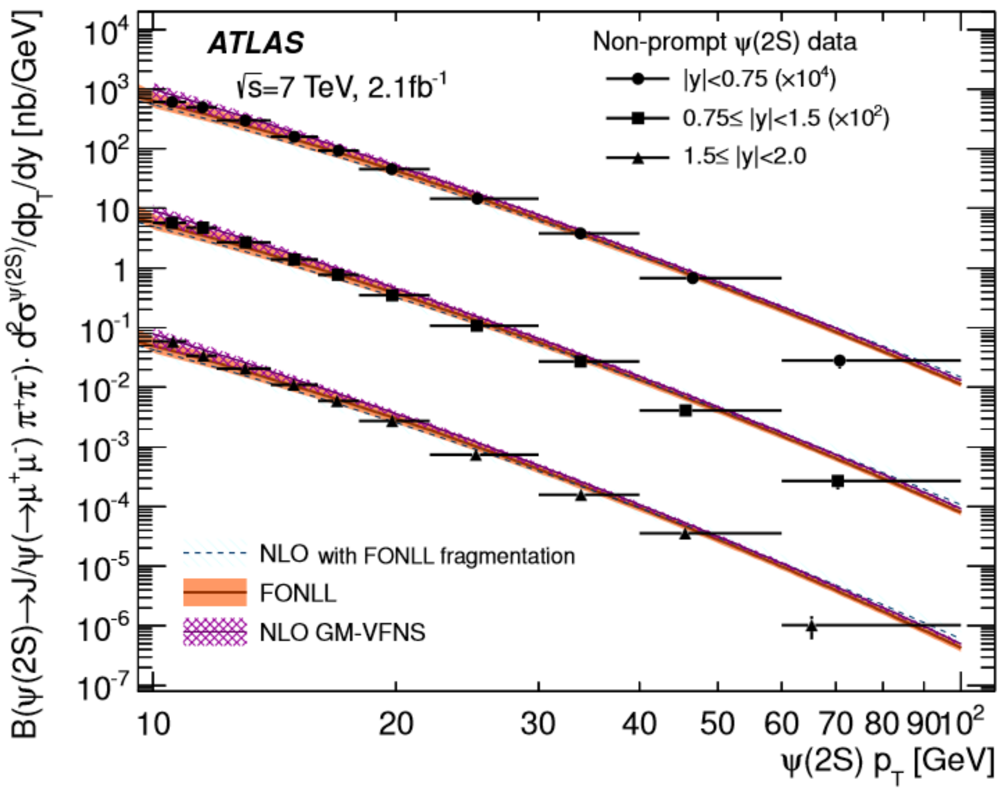


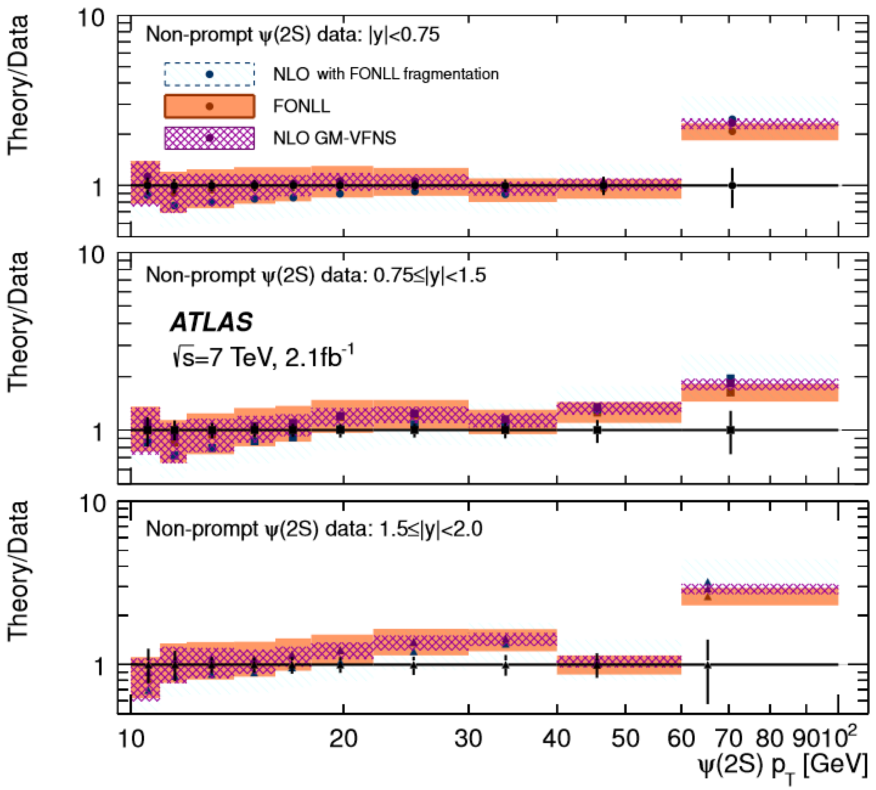
Non-prompt ψ(2S) → J/ψ π π production

Good agreement with NLO and FONLL predictions at low p_T, but some discrepancies observed with both models at larger p_T (more prevalent for NLO, without resummation)

High p_T B-hadron production and/or decay modelling issues?

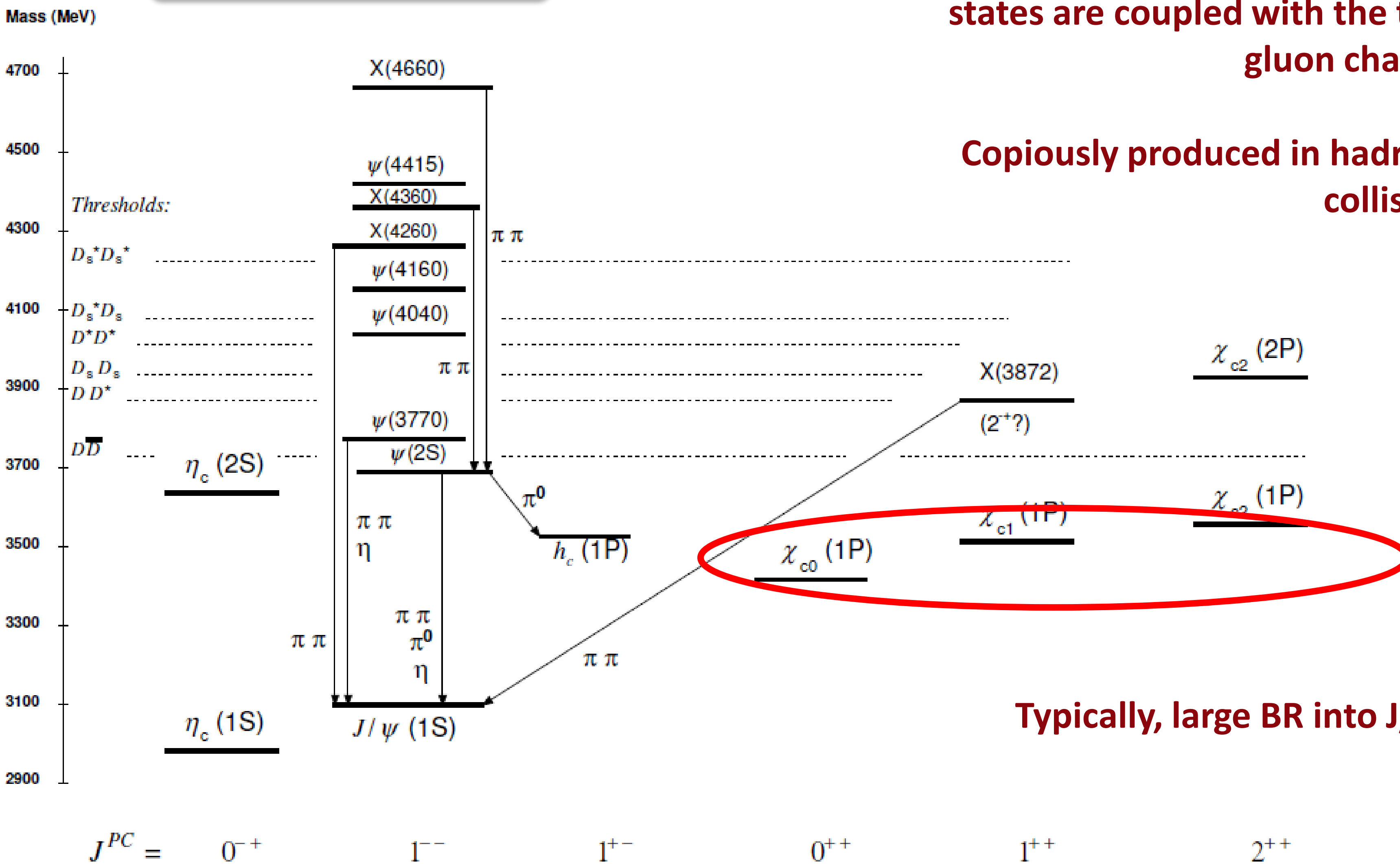
Had been hinted at by other measurements. Now able to probe with high precision.





Production of P-wave charmonium states

To be published in JHEP
arXiv:1404.7035



C-even, P-wave charmonium states are coupled with the two-gluon channel

Copiously produced in hadronic collisions

Typically, large BR into J/ψ γ

$\chi_c \rightarrow J/\psi(\rightarrow\mu\mu)\gamma$

P-wave charmonium production tricky to deal with, both theoretically and experimentally

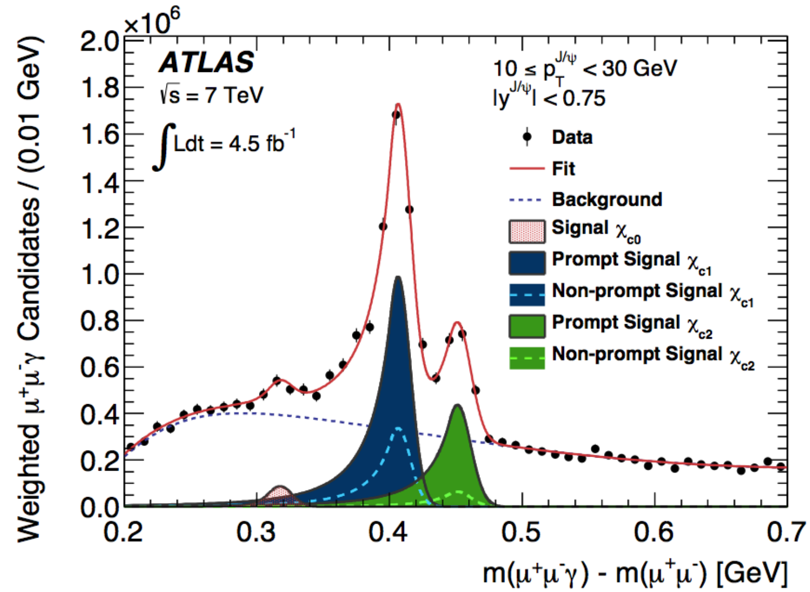
Important to understand this production channel to get a complete picture for J/ψ production

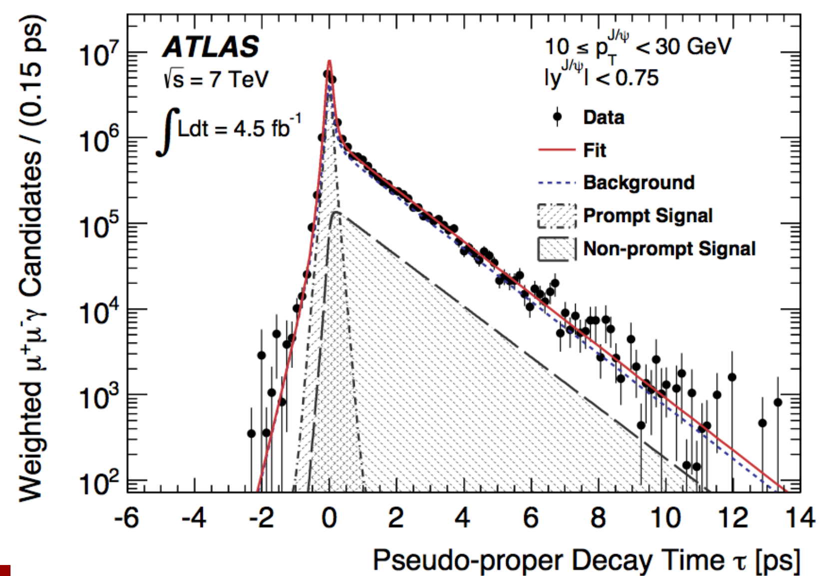
Experimentally challenging:

- low p_T muons
- precise reconstruction of soft (p_T>1 GeV) photons through conversions
  – low efficiencies

Perform a 2D (mass and lifetime) unbinned maximum likelihood fit on candidates corrected for acceptance and efficiency

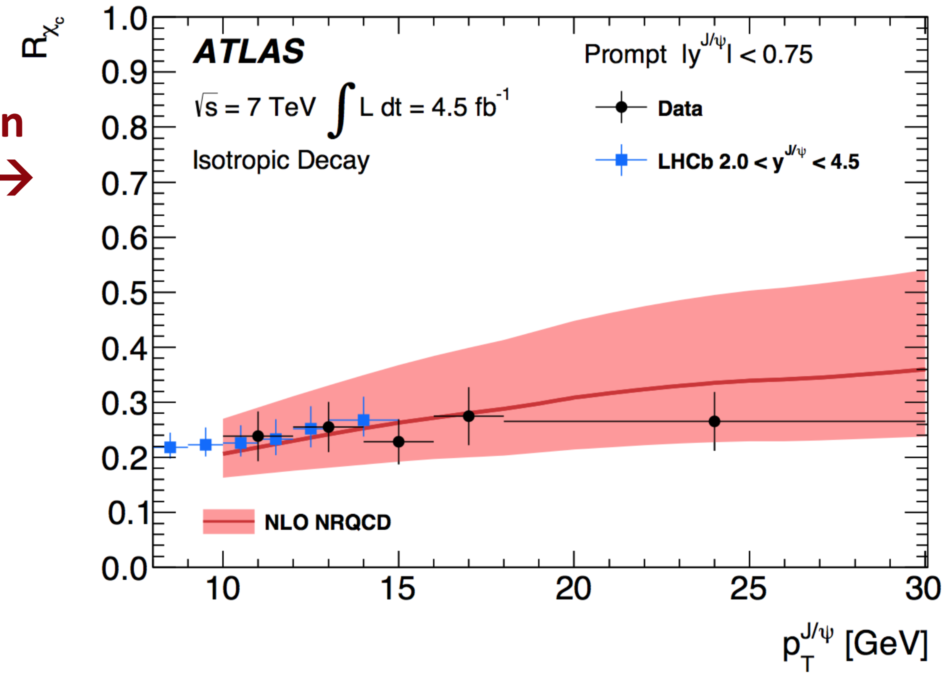
Extract ***prompt*** and ***non-prompt*** yields of the individual χ_c states in several p_T intervals



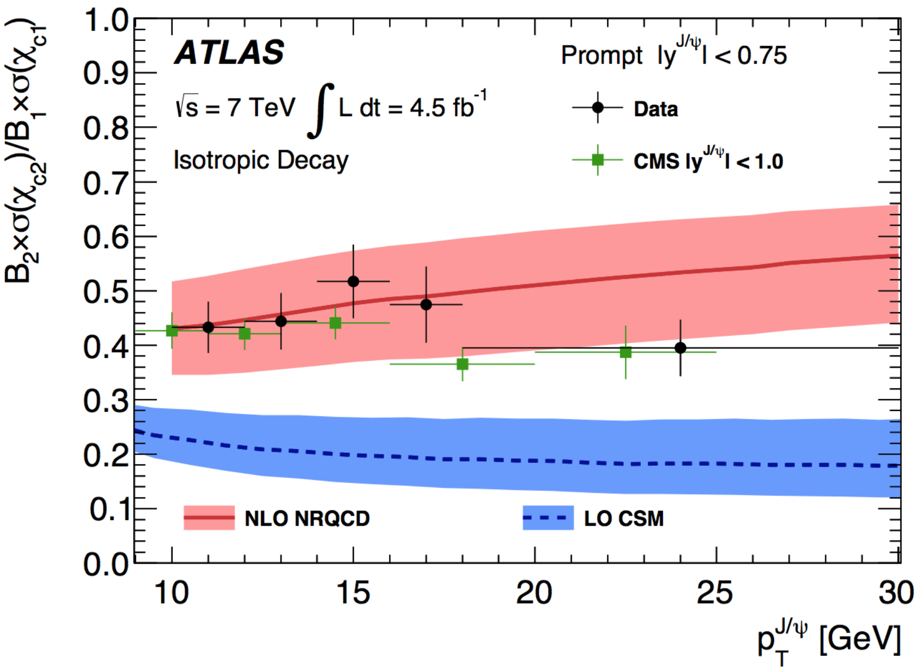


Prompt $\chi_c \rightarrow J/\psi\,\gamma$ and $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ ratios

Fraction of prompt J/ψ produced in χ_c feed-down (right)→



Data show that between 20–30% of prompt J/ψ are produced in χ_c decays



Prompt χ_c cross-section ratio ← (left)

Data show more χ_{c1} than χ_{c2}

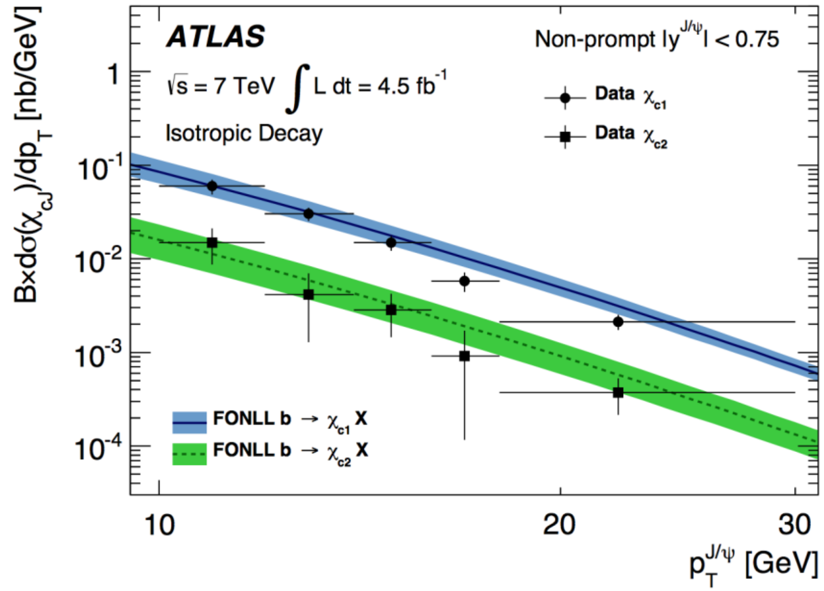
Ratio sensitive to presence of possible colour-octet contributions in NRQCD

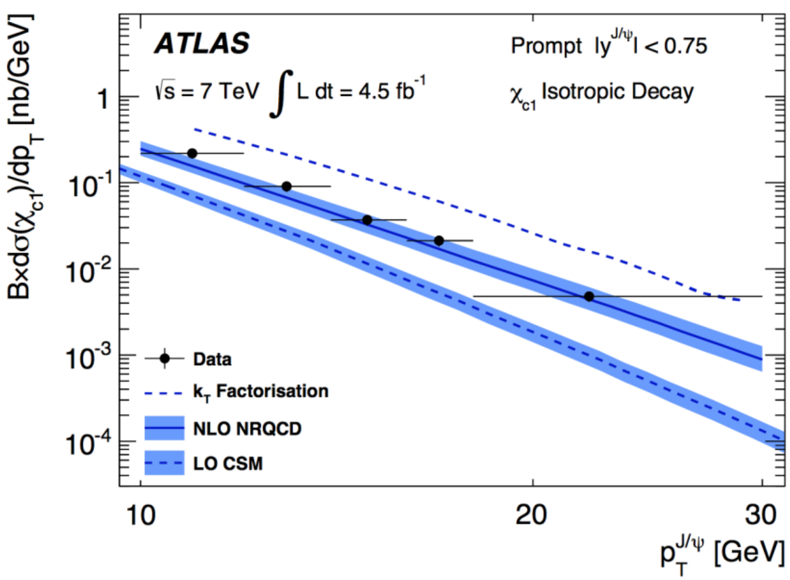
χ_c production cross sections

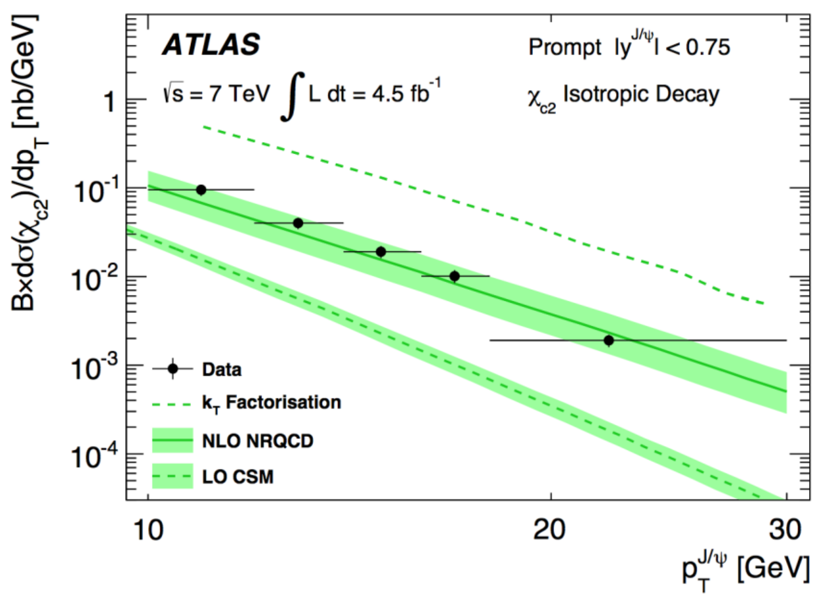
First measurement of absolute differential cross sections for non-prompt (right) and prompt (below) χ_{c1} and χ_{c2} at LHC

Compared to predictions

NRQCD / FONLL able to describe the data, but possible hints at high-p_T excess in latter?







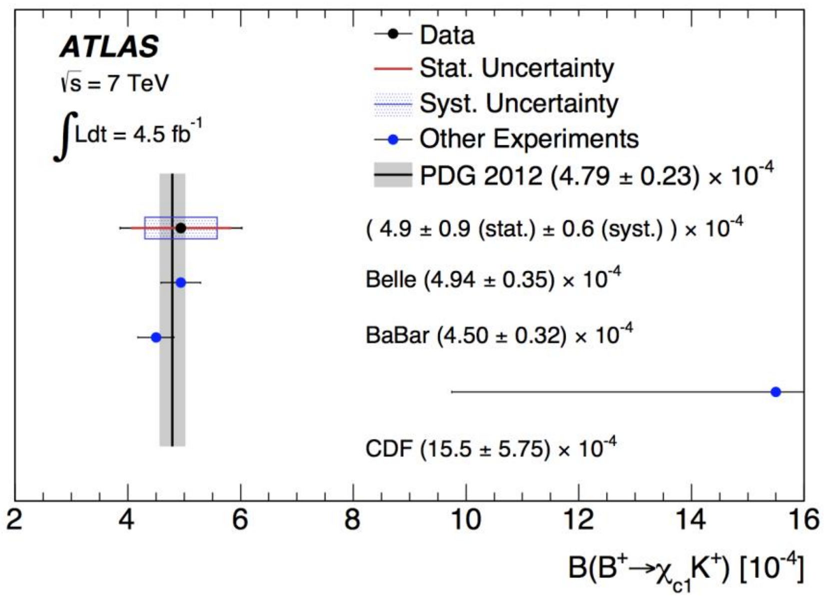
Measurement of Br($B^{\pm} \rightarrow \chi_{c1}K^{\pm}$)

Branching fraction measurement using same χ_c data sample and selections, can extract measurement of Br($B^{\pm} \rightarrow \chi_{c1}K^{\pm}$)

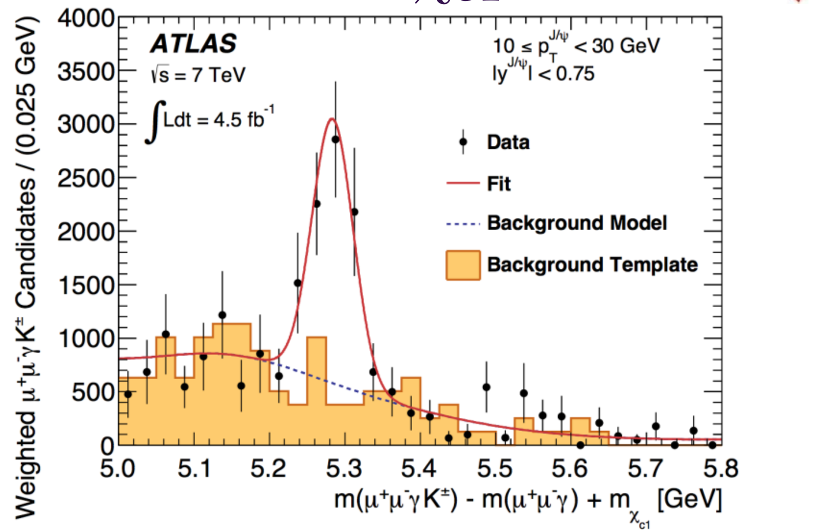
Use precisely-known $B^{\pm} \rightarrow J/\psi K^{\pm}$ decay as control.

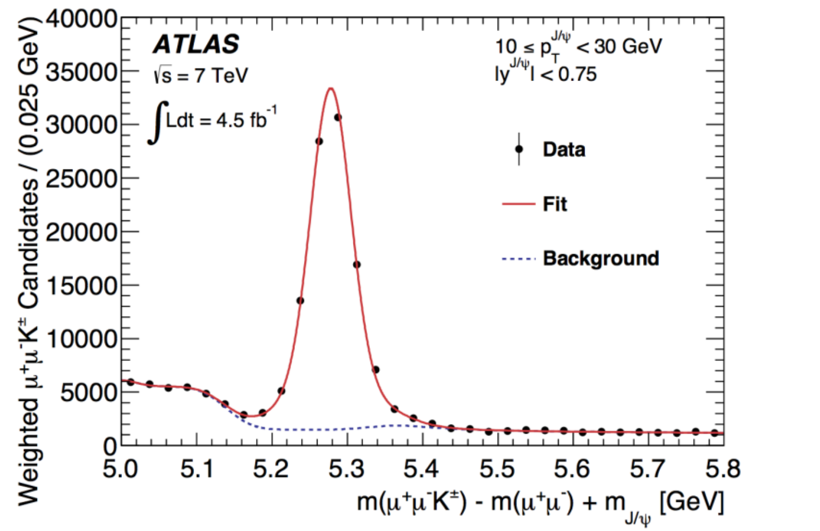
$$\mathcal{B}\left(B^{\pm} \to \chi_{c1}K^{\pm}\right) = \mathcal{A}_B \cdot \frac{N^B_{\chi_{c1}}}{N^B_{J/\psi}} \cdot \frac{\mathcal{B}\left(B^{\pm} \to J/\psi K^{\pm}\right)}{\mathcal{B}\left(\chi_{c1} \to J/\psi\,\gamma\right)}$$

ATLAS measurement not far from best B-factory results; prospects for improvements!



$B^{\pm} \rightarrow \chi_{c1}K^{\pm}$





$B^{\pm} \rightarrow J/\psi K^{\pm}$

Summary

With the excellent performance of the LHC and ATLAS in Run 1, and the large data samples available as a result, we are able to make precision measurements which were not possible in the past, at ever higher energies

Ever wider range of kinematic variables are being explored, providing new areas where the experimental measurements confront theoretical predictions

More quarkonium-related results from ATLAS are presented here at BEACH 2014 in :

- Heavy quark spectroscopy – E.Bouhova-Thacker (Lancaster)
- Quarkonium in associated production -- M.Watson (Birmingham)

Even more results are in the pipeline, so "watch this space"…

…and thanks for your attention today!