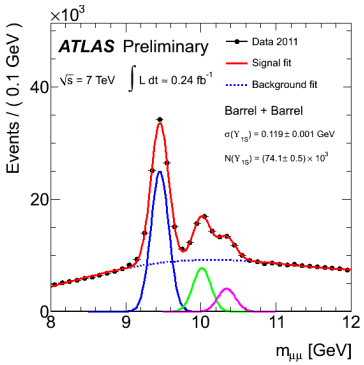
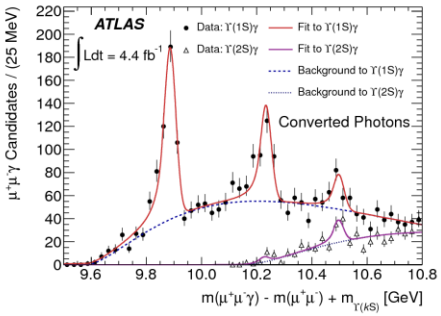
Latest B physics results from ATLAS

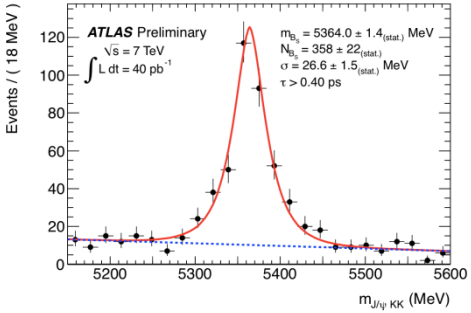
Julie Kirk
Rutherford Appleton Laboratory
on behalf of the ATLAS Collaboration

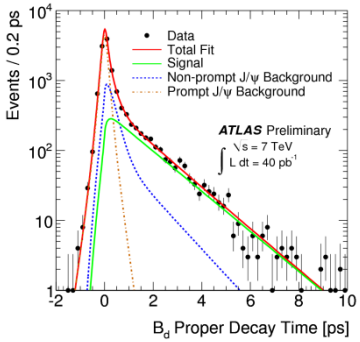
2010 data
- Quarkonia production (J/ψ and ϒ)
- B hadron production and properties (lifetime)

New result - 2011 data
- Observation of $\chi_b(3P)$
- Future prospects



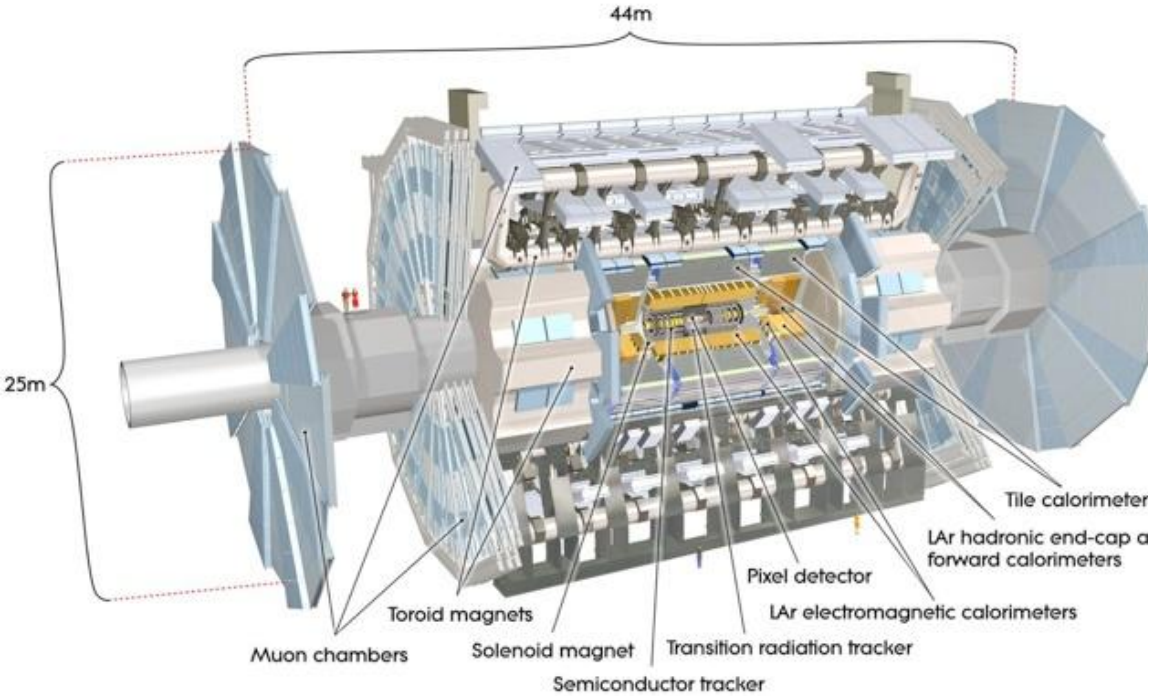


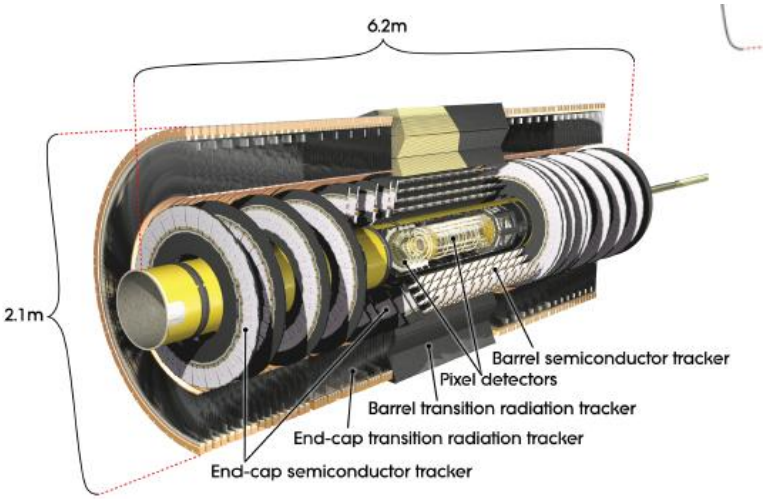




ATLAS experiment

For B physics measurements require excellent tracking capabilities and muon identification



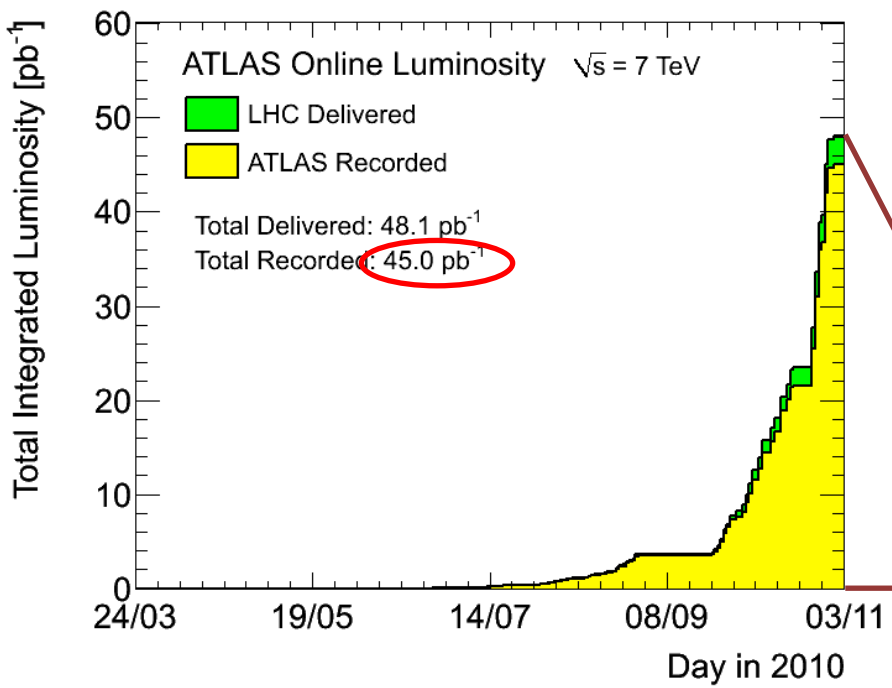


- **Muon Spectrometer**
  - $|\eta|<2.7$
  - Toroid B-Field, average ~0.5T
  - Muon Momentum resolution
    $\sigma/p<$ 10% up to ~ 1 TeV

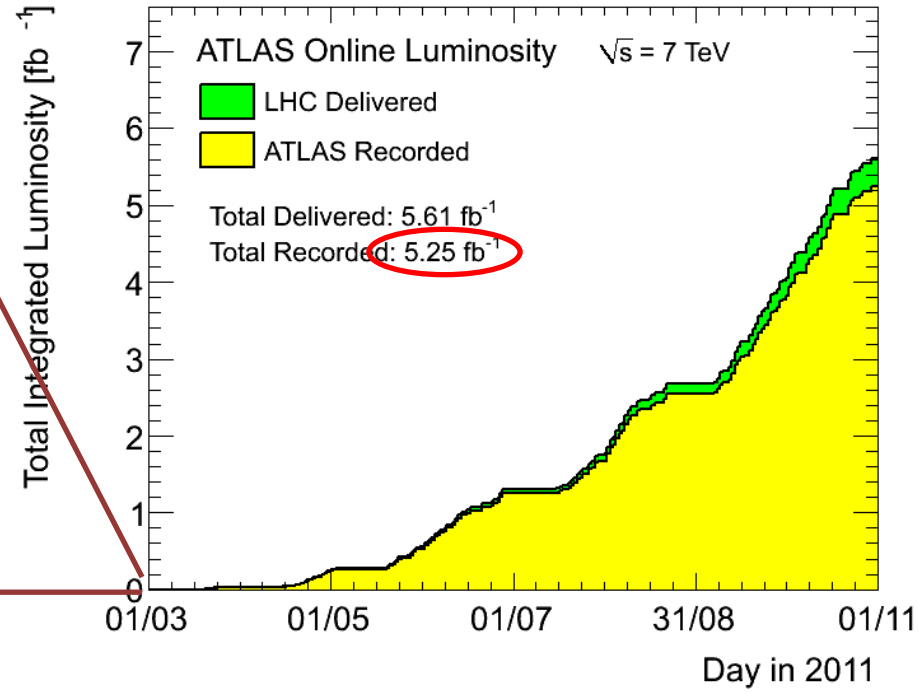
- **Inner Detector**
  - $|\eta|<2.5$,
  - Solenoid B=2T
  - Si Pixels,
  - Si strips,
  - Transition Radiation Tracker (TRT)
  - $\sigma/p_T \sim 3.4\times10\text{-}4\ p_T + 0.015$ for ($|\eta|<1.5$)
  - Used for Tracking and Vertexing:
  - Precision momentum and lifetime measurements

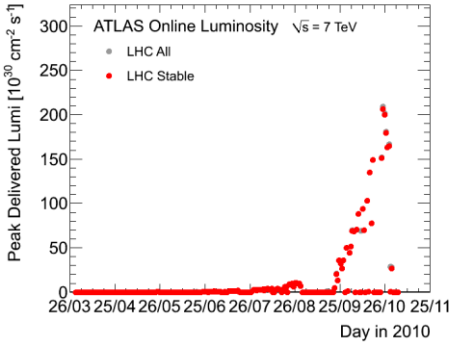
ATLAS data sample

2010

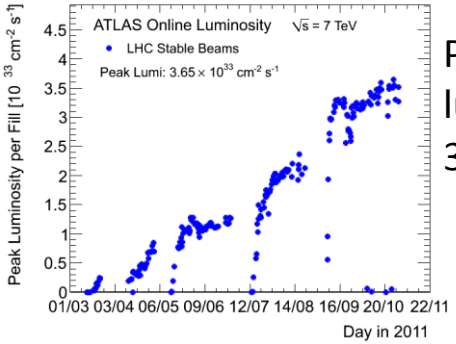


2011





Peak instantaneous luminosity:
2×10^{32} cm^{-2}s^{-1}



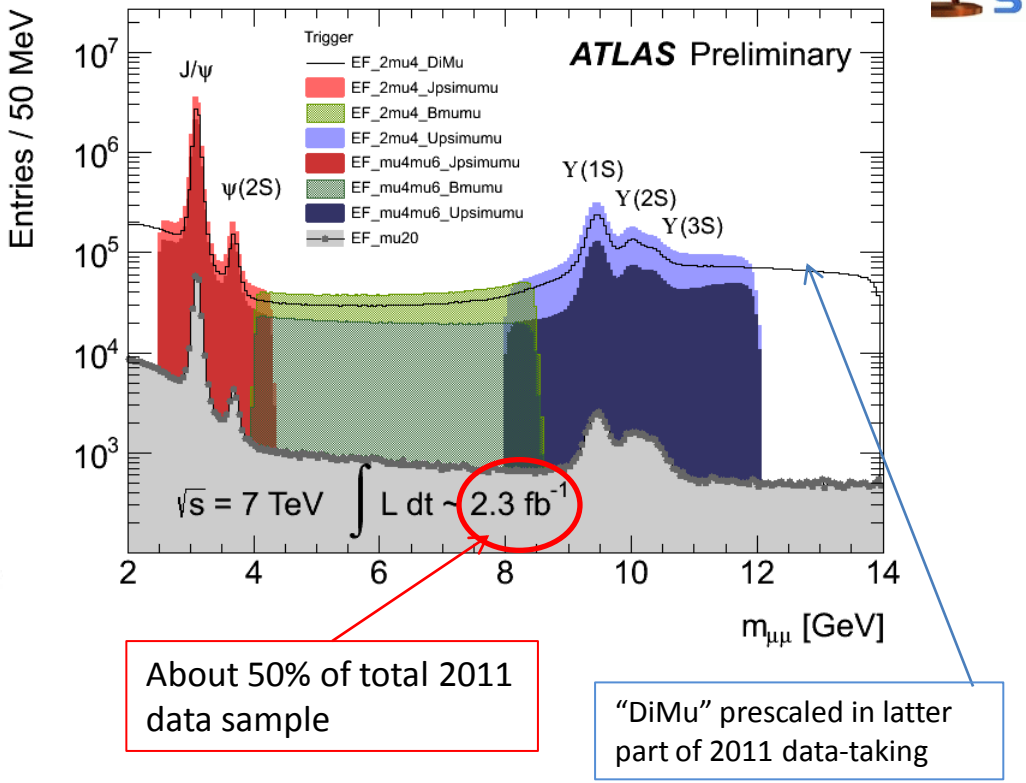
Peak instantaneous luminosity:
3.6×10^{33} cm^{-2}s^{-1}

ATLAS B-physics programme and trigger strategy

ATLAS is a general purpose detector – main focus is on high pT discovery physics but also has a dedicated B physics programme.

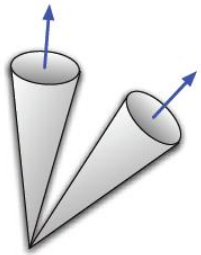
B-physics programme concentrates on low p_T di-muon signatures:

- Onia studies ($J/\psi \rightarrow \mu^+\mu^-$, $\Upsilon \rightarrow \mu^+\mu^-$)
- $B \rightarrow J/\psi(\mu\mu)X$, mixing and CP violation studies
- Rare and semi-rare B decays $B \rightarrow \mu\mu(X)$
- (Purely hadronic channels not discussed here)



Trigger on low p_T (4,6 GeV) di-muon

- 2 muons at Level1
- Confirmed in High Level Trigger
- Then require vertex fit and mass cuts



- Used unprescaled '2mu4' trigger for Jpsi, Upsilon and $B \rightarrow \mu^+\mu^-$ throughout 2011 data-taking
- Large samples of events recorded for the B-physics programme

Trigger	Mass window	No. of events (M)
2mu4_DiMu	1.4 – 14 GeV	27
2mu4_Jpsimumu	2.5 – 4.3 GeV	14
2mu4_Bmumu	4 – 8.5 GeV	3.7
2mu4_Upsimumu	8 – 12 GeV	9.1

Quarkonia production

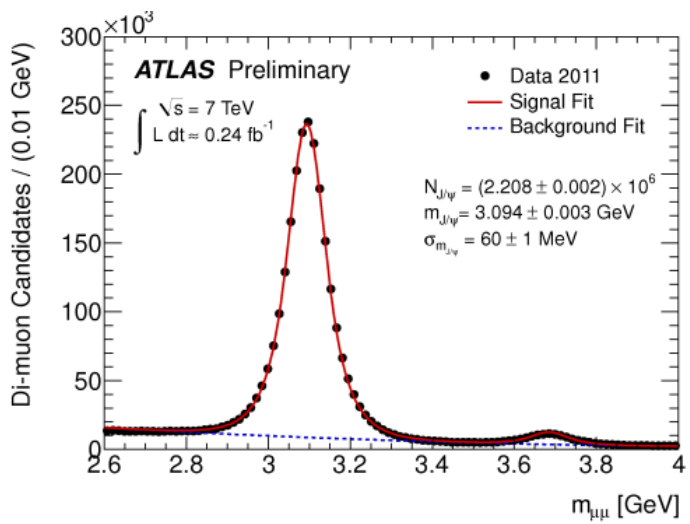
AIMS:

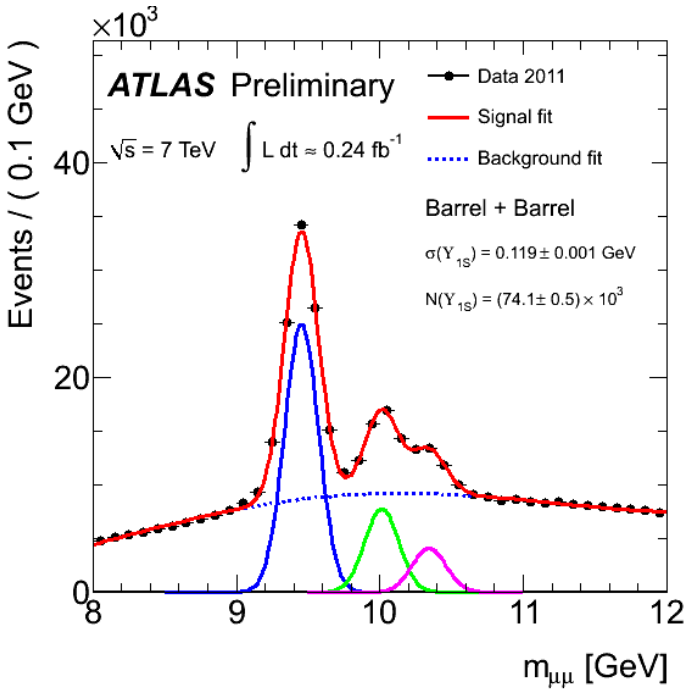
- Test perturbative QCD at new energy regime, higher transverse momentum and wider rapidity range than previously
- Production mechanism for quarkonium states (J/ψ and ϒ) not fully understood

J/ψ and ϒ candidates (2011)

- 2 oppositely charged muons
- $p_T(\mu_1) > 4$ GeV, $p_T(\mu_2) > 2.5$ GeV (4,4 for Upsilon)

- ~2.2 million J/ψ from 240 pb^{-1}
- Next slides show published data (2010 only).





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

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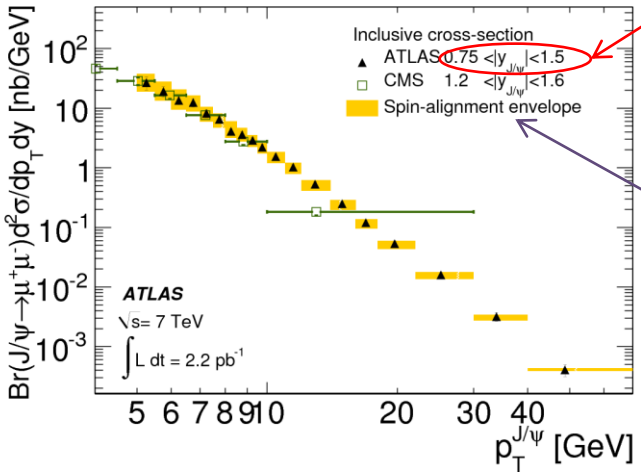
Inclusive J/ψ cross-section

Event weight:

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

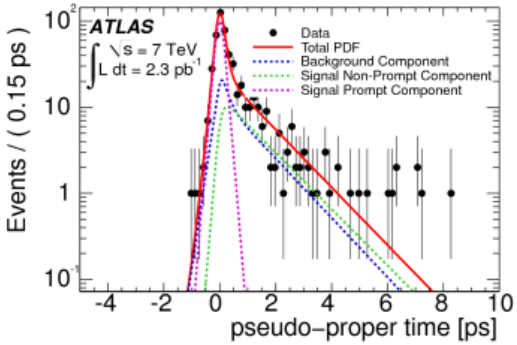
Detector Acceptance – from generator level MC
Bin migration correction – due to finite detector resolution
Reconstruction efficiency – from tag-and-probe method using data
Trigger efficiency – determined from MC and re-weighted to data



Example of one rapidity bin (4 in total)

5 extreme spin alignment scenarios used for acceptance maps – variation taken as systematic effect.

Fraction of J/ψ from B hadrons



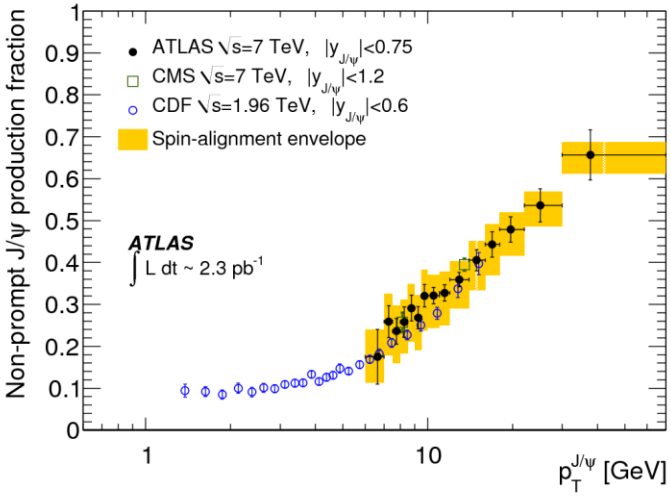
Perform simultaneous fit to mass and pseudo-proper decay time

xy displacement of candidate from PV

Invariant mass of candidate

$$\tau = \frac{L_{xy}\, m(J/\psi)}{p_T(J/\psi)}$$

p_T of candidate

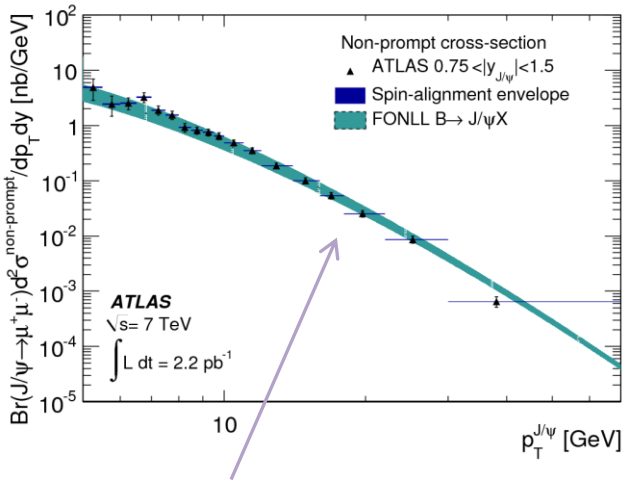


Good agreement with CDF – fraction is energy independent

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

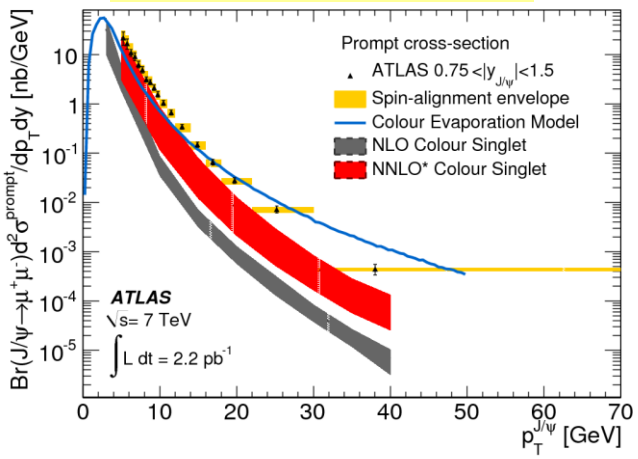
Derive non-prompt and prompt production cross-section separately

Non-prompt J/ψ cross-section



Good agreement with theory

Prompt J/ψ cross-section



Great theoretical interest:

- CEM is not describing shape
- Colour Singlet Model (CSM) is low for NLO but good shape
- CSM NNLO* is significant improvement

$\Upsilon \rightarrow \mu^+\mu^-$

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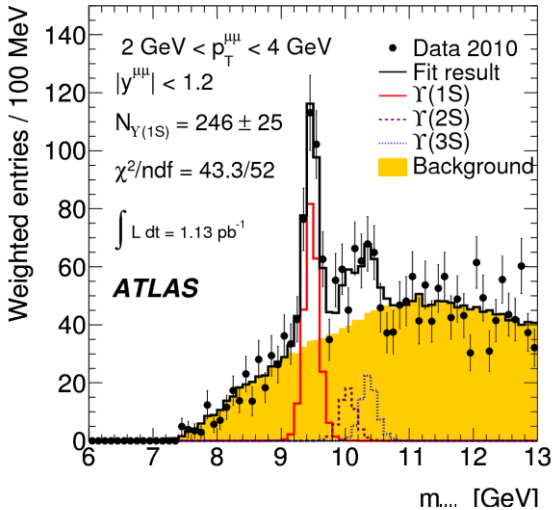
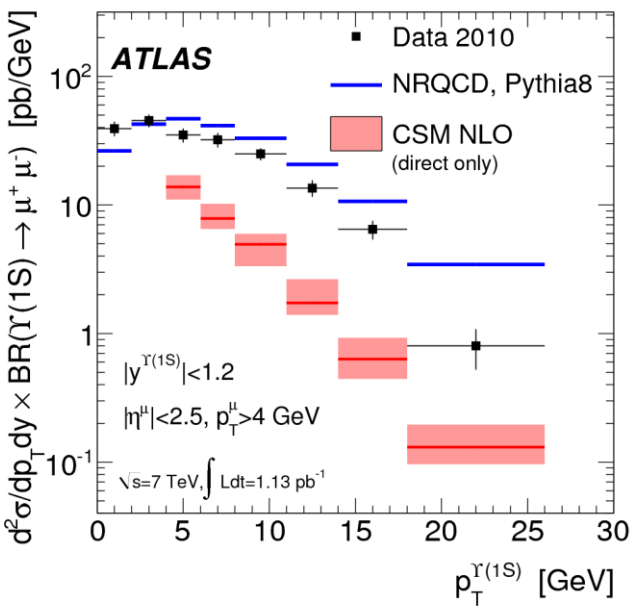
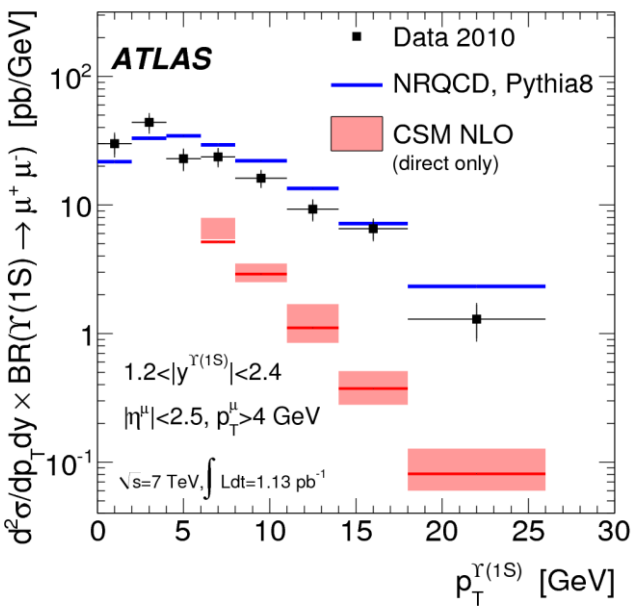


- Cross-section $\Upsilon \rightarrow \mu\mu$
- Restrict muon kinematics:
  - $|p_T| > 4$ GeV
  - $|\eta| < 2.5$
- Reduces uncertainty due to Υ spin alignment.
- Agree within factor 2 with NRQCD although shape not well described
- Colour Singlet Model prediction is low but contains no feed down from higher order states



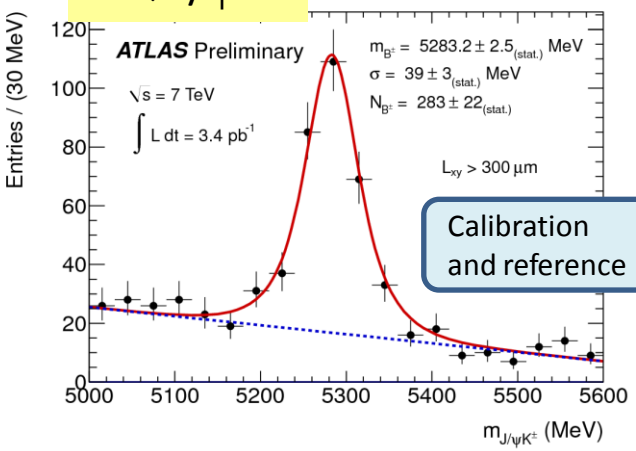


Observation of exclusive b-hadron decays using J/ψ

Masses all agree with PDG values

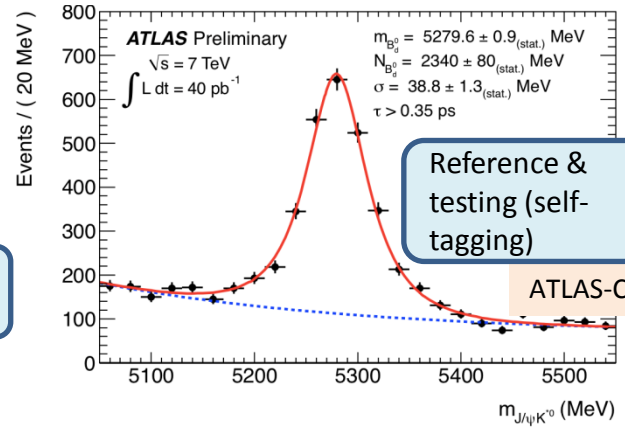
$B^{\pm} \rightarrow J/\psi K^{\pm}$

ATLAS-CONF-2010-098



Calibration and reference

$B^0_d \rightarrow J/\psi K^{0*}(K\pi)$



Reference & testing (self-tagging)

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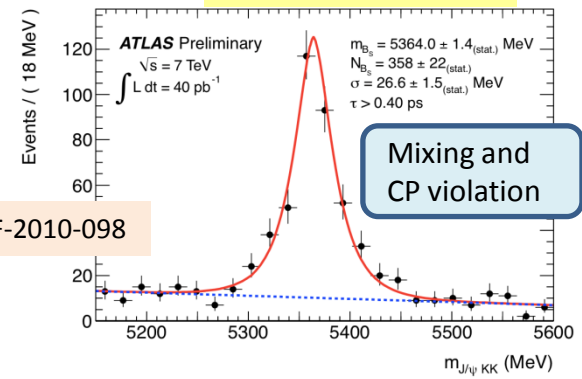
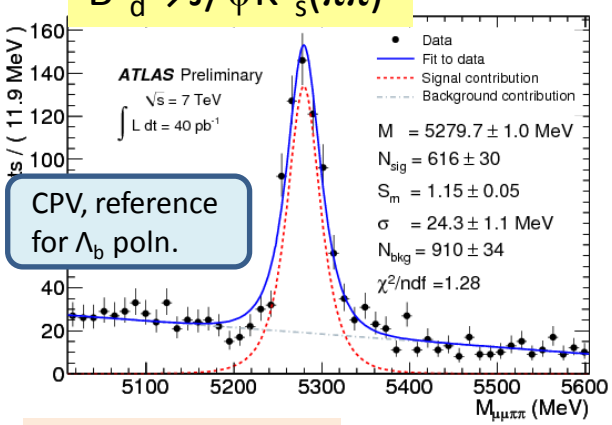
$B^0_s \rightarrow J/\psi\varphi(KK)$



Mixing and CP violation

$B^0_d \rightarrow J/\psi K^0_s(\pi\pi)$

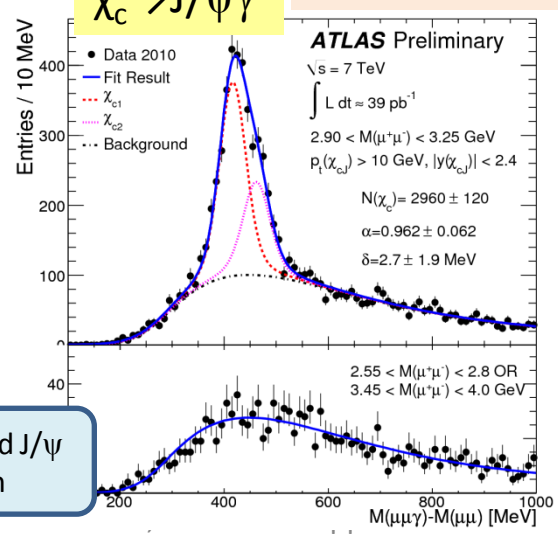


CPV, reference for Λ_b poln.

ATLAS-CONF-2010-105

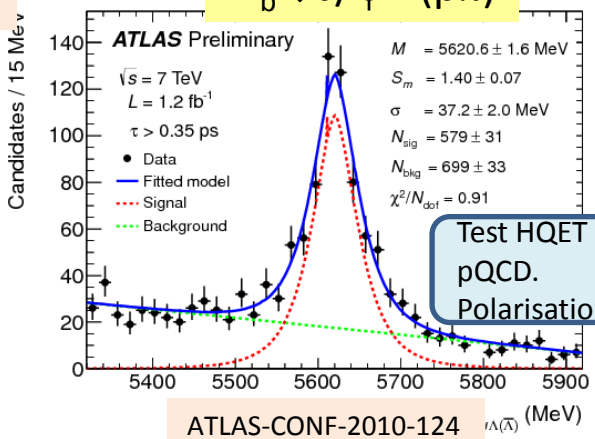
$\chi_c \rightarrow J/\psi\gamma$

ATLAS-CONF-2010-136



Understand J/ψ production

$\Lambda_b \rightarrow J/\psi\Lambda(p\pi)$



Test HQET & pQCD. Polarisation

ATLAS-CONF-2010-124

Lifetimes

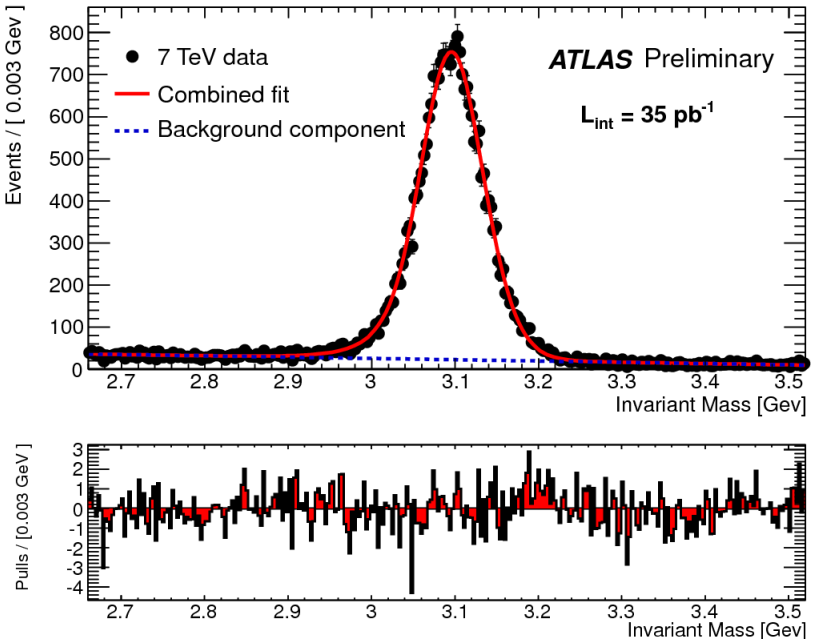
- Motivation:
  - Test of Heavy Quark Effective Theory - predicts lifetime ratios of different B-hadron species
  - Lifetime difference ($\Delta\Gamma_s$) in the B_s system – mass eigenstates have different lifetime. Commission lifetime measurement ready for CP violation studies
  - Validation of tracking and secondary vertex finding (resolution, calibration, alignment)

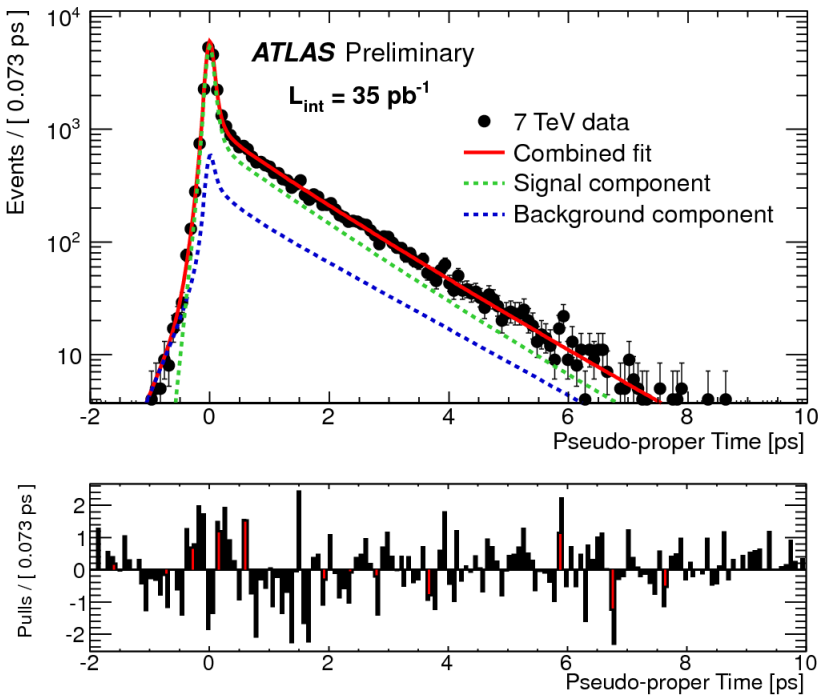
- Measure lifetime for:
  - Inclusive $B \rightarrow J/\psi X$ decays
  - Exclusive B hadron decays ($B^0 \rightarrow J/\psi K^*$, $B_s \rightarrow J/\psi \varphi$)

Average b hadron lifetime

Inclusive sample – extract average B-lifetime from B→J/ψX decays

ATLAS-CONF-2011-145





- $\langle\tau_B\rangle$=1.489 ± 0.016(stat) ± 0.043(syst) ps
- In agreement with CDF measurement and world average from different B-hadron species: $\langle\tau_B\rangle$=1.544 ±0.014 ps
- Dominant systematic from background modelling and detector alignment uncertainties.

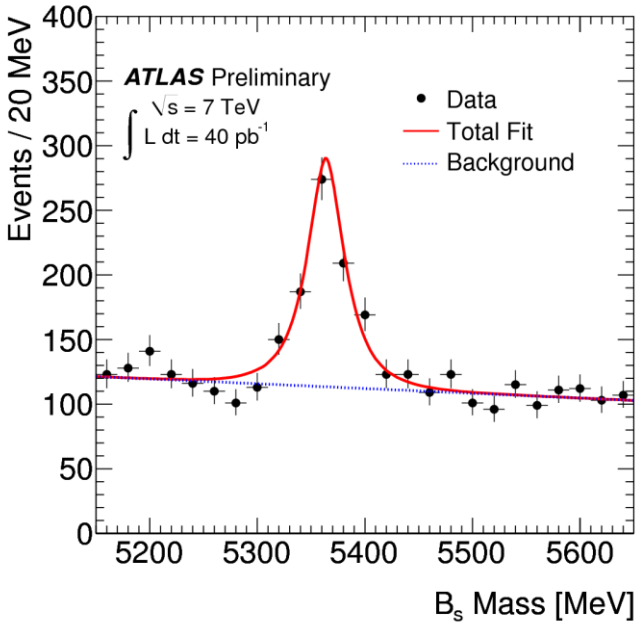
B^0, B_s lifetime

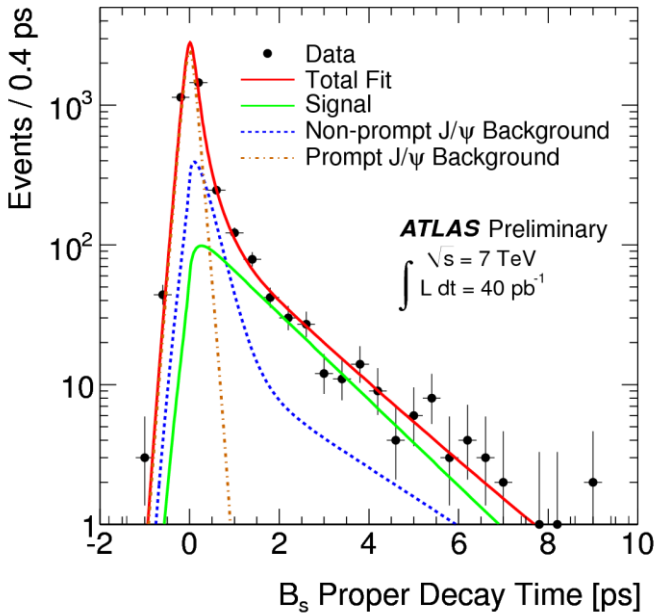
Simultaneous fit to invariant mass and proper decay time

$$\tau = \frac{L_{xy}\, m_B^{PDG}}{p_T^B}$$

- Extract signal, B-mass and lifetime

ATLAS-CONF-2011-092





- $B^0 \rightarrow J/\psi K^*$: τ_{Bd} = 1.51 ± 0.04 (stat) ± 0.04 (syst) ps (2750 events)
- $B_s \rightarrow J/\psi \varphi$: τ_{Bs} = 1.41 ± 0.08 (stat) ± 0.05 (syst) ps (463 events)

Agree with world average

Observation of $\chi_b(3P)$

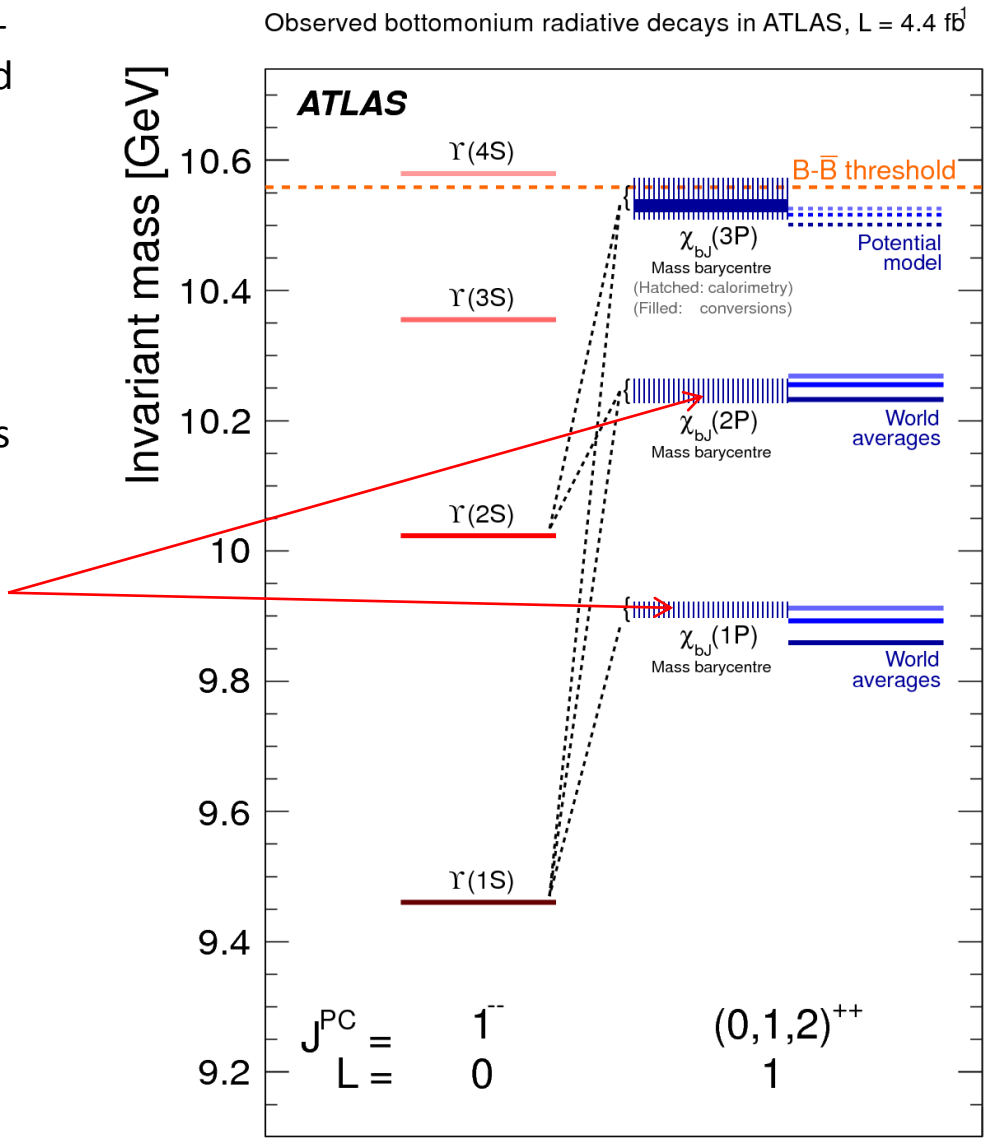
Accepted by Phys. Rev. Lett.

The χ_c and χ_b represent the spin triplet (S=1) P-wave (L=1) states of the charmonium $(c\bar{c})$ and bottomonium $(b\bar{b})$ spectra.

- The χ represent a triplet of states with J^{PC} = 0^{++}, 1^{++}, 2^{++}
- Hyperfine mass splitting of the 3 states is small $\mathcal{O}$(10 MeV)
- Branching fractions for the radiative decays $\chi_b \rightarrow \Upsilon\gamma$ are large $\mathcal{O}$(10%)

- $\chi_b(1P)$ and $\chi_b(2P)$ previously observed.
- $\chi_b(3P)$ also predicted below $B\overline{B}$ threshold.

Search for $\chi_b(3P)$ states in $\chi_b \rightarrow \Upsilon\gamma$ decays. Photon reconstructed either directly in the calorimeter or through conversion to e^+e^-

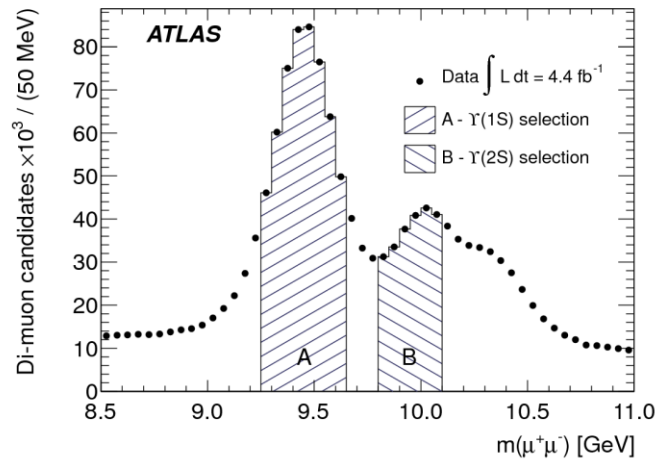


Event selection

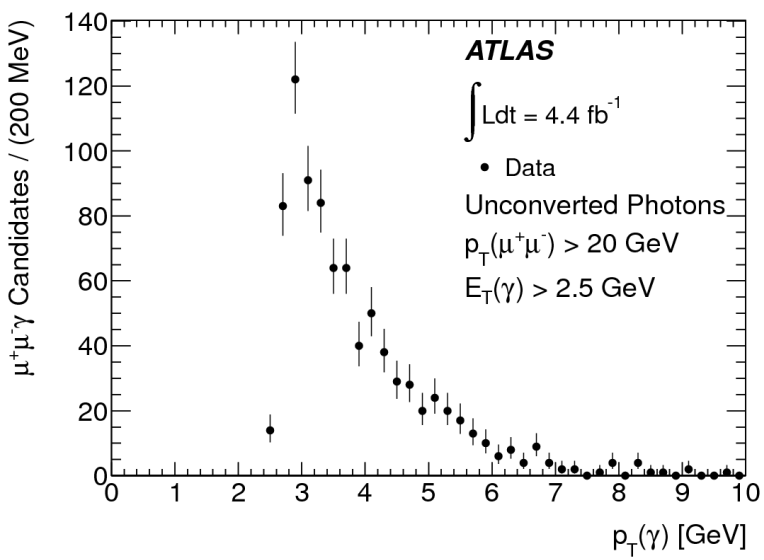
Selection of $\Upsilon \rightarrow \mu\mu$ is common to both analyses:

- Opposite charged di-muons ($p_T > 4$ GeV)
- Vertex fit $\chi^2 < 20$
- $p_T(\mu\mu) > 12$ GeV, $|y(\mu\mu)| < 2$.

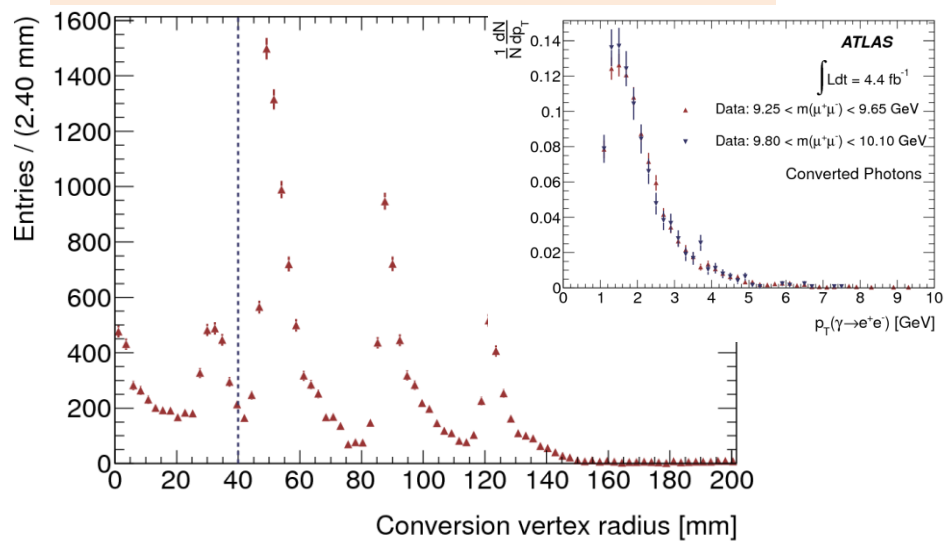
- $\Upsilon(1S) \rightarrow \mu\mu$: $9.25 < m(\mu\mu) < 9.65$ GeV
- $\Upsilon(2S) \rightarrow \mu\mu$: $9.80 < m(\mu\mu) < 10.10$ GeV



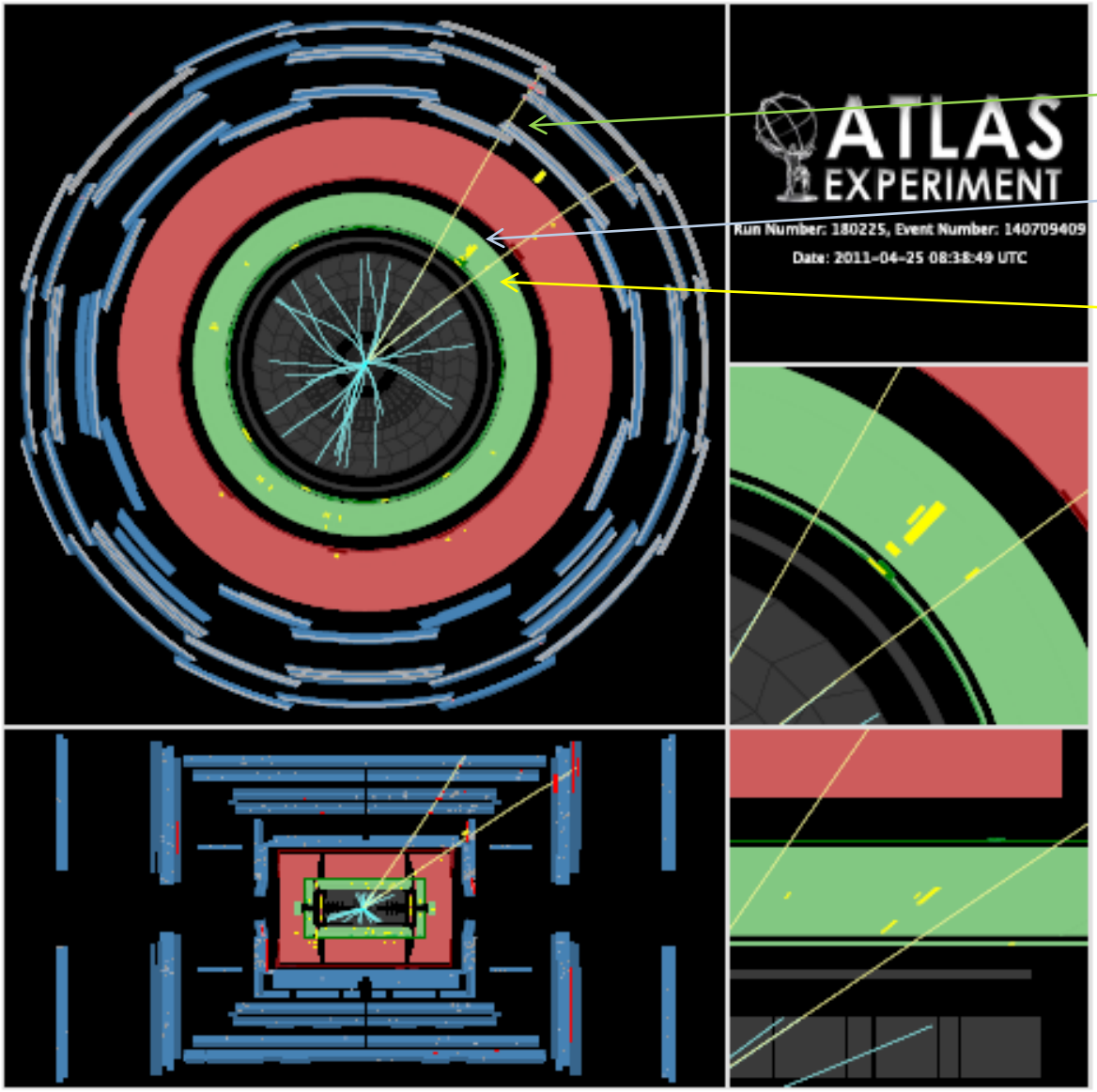
Unconverted photon selected using EM calorimeter



Converted photon selected using Inner Detector (better resolution, softer photons)



$\chi_b(3P)$ candidate reconstructed using an unconverted photon



Muon 1

Photon

Muon 2

$m(\mu\mu\gamma) - m(\mu\mu) + m(\Upsilon(1S)) = 10.54$ GeV

$p_T(\gamma)>2.5$ GeV

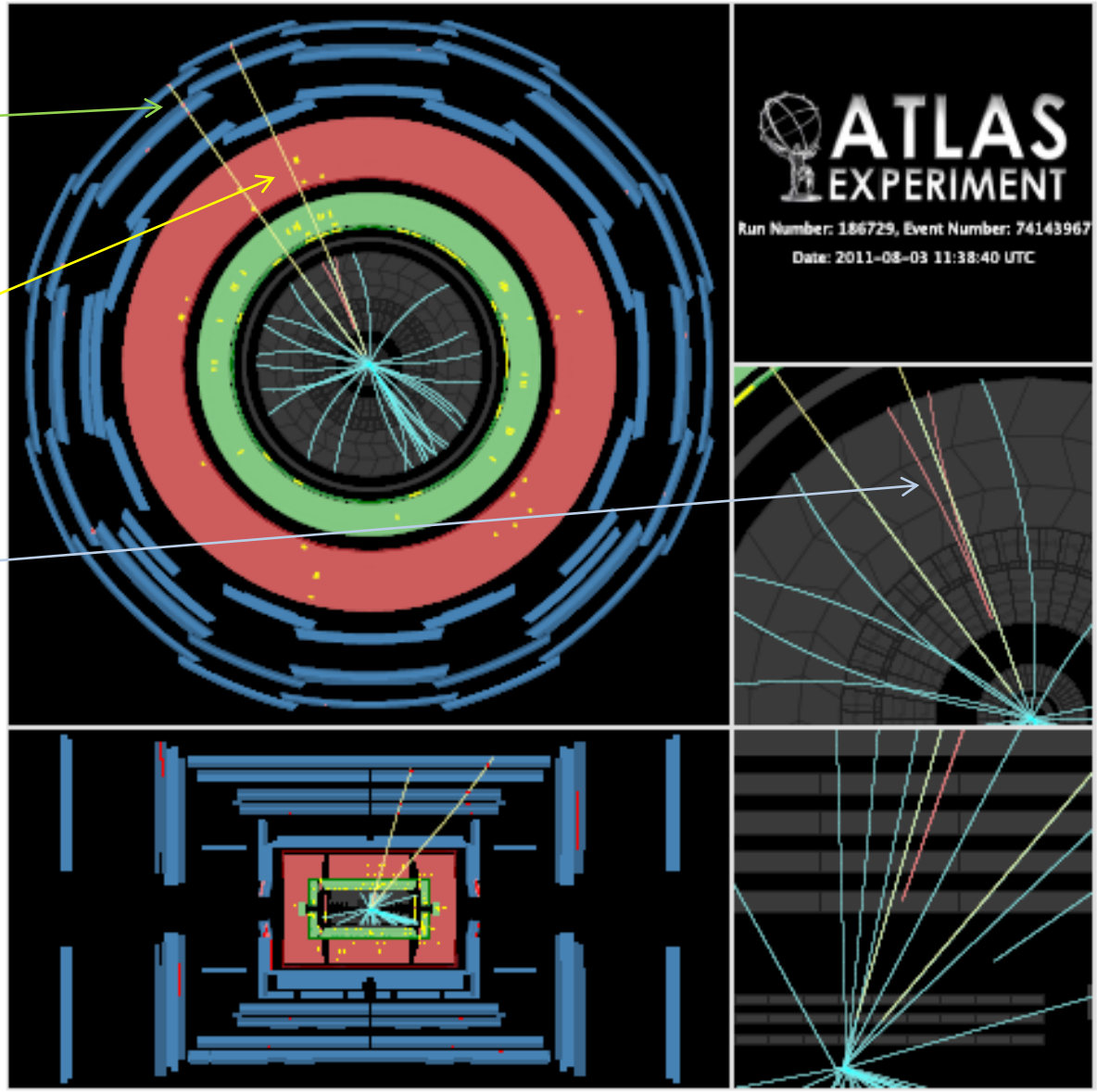
Can reconstruct $\chi_b \rightarrow \Upsilon(1S)\gamma$ only

$\chi_b(3P)$ candidate reconstructed using a converted photon

Muon 1

Muon 2

Photon

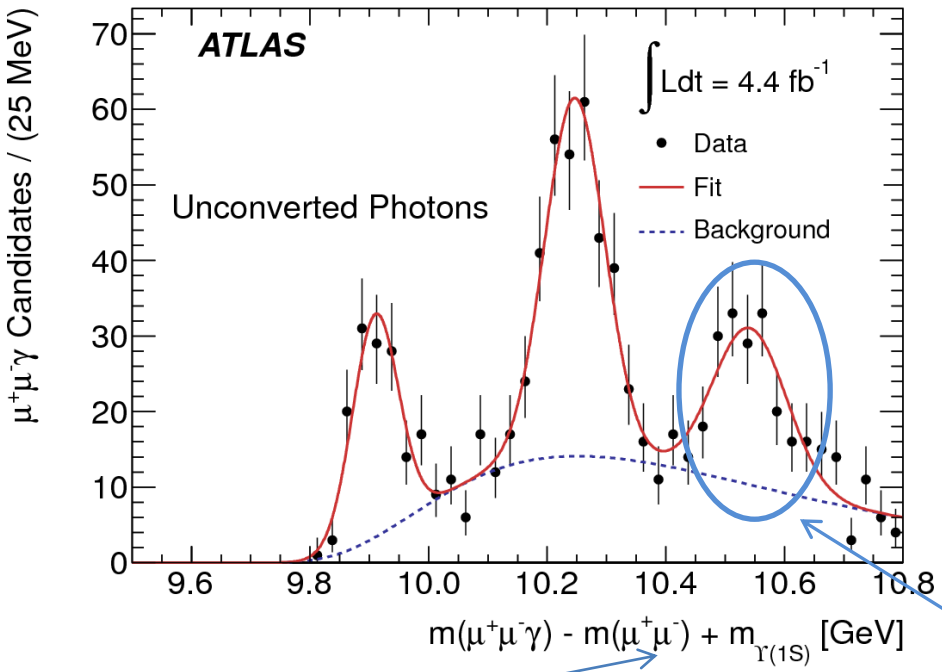


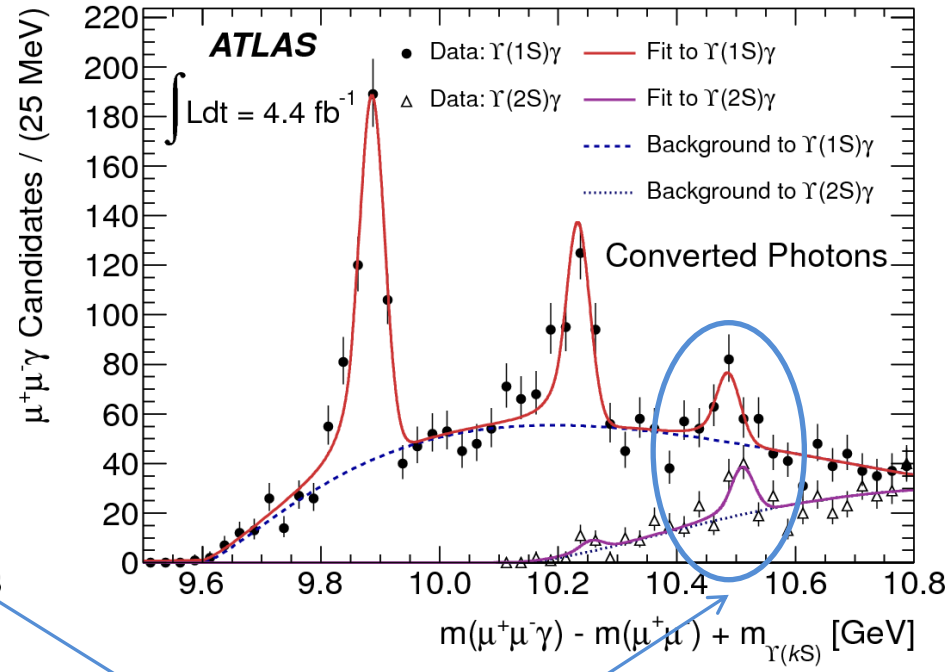
$m(\mu\mu\gamma) - m(\mu\mu) + m(\Upsilon(1S)) = 10.54\text{GeV}$

$p_T(\gamma) > 1.0$ GeV

Can reconstruct $\chi_b \rightarrow \Upsilon(1S,2S)\gamma$

$\chi_b(nP) \rightarrow \Upsilon(1S,2S)\gamma$





Reduce effect of mass resolution

- Observe mass peaks corresponding to $\chi_b(1P,2P)$
- Additional structure at higher mass, consistent with predictions for $\chi_b(3P)$

Mass ($\chi_b(3P)$) = 10.530 ± 0.005 (stat.) ± 0.009 (syst) GeV

Currently unable to resolve the hyperfine splitting – measure mass barycentre

On the horizon

ATLAS has collected a fantastic di-muon sample in 2011.

Already have many interesting measurements:

- J/ψ and Υ cross-sections published
- Observation of B-hadrons and lifetime measurements
- Observation of new state $\chi_b(3P)$

This is just "scratching the surface". Expect many new results soon:

- Quarkonia:
  - J/ψ spin alignment
  - Upsilon production cross-section
  - Plus many more (ψ cross-section, J/ψ: $\psi(2S)$ ratio, double Onia, J/ψ + W/Z .....)
- B-hadron:
  - CP violation and mixing measurements with $B_s \rightarrow J/\psi\varphi$
  - $\Lambda_b \rightarrow J/\psi\Lambda$ lifetime and polarisation
  - $B^+_c \rightarrow J/\psi\pi^+$
  - $J/\psi+\mu$ correlations
  - .....
- Rare Decays:
  - Limit on $BR(B_s \rightarrow \mu^+\mu^-)$
  - $B^0_s \rightarrow \mu^+\mu^-\varphi$, $B_d \rightarrow \mu^+\mu^-K^*$

Looking forward to much more data in 2012