



# Heavy Flavour Measurements in ATLAS and CMS

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LMU Munich and Excellence Cluster Universe  
for the ATLAS and CMS Collaboration

Moriond Electroweak Interactions and Unified Theories

March 3<sup>rd</sup> – 10<sup>th</sup>, 2012



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# EXPERIMENTAL SETUP



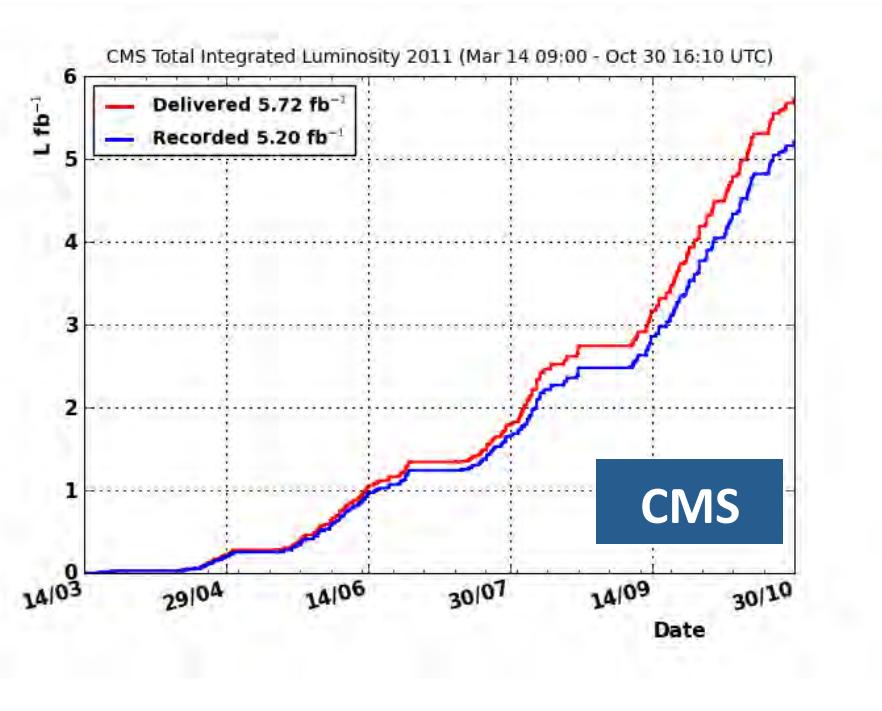
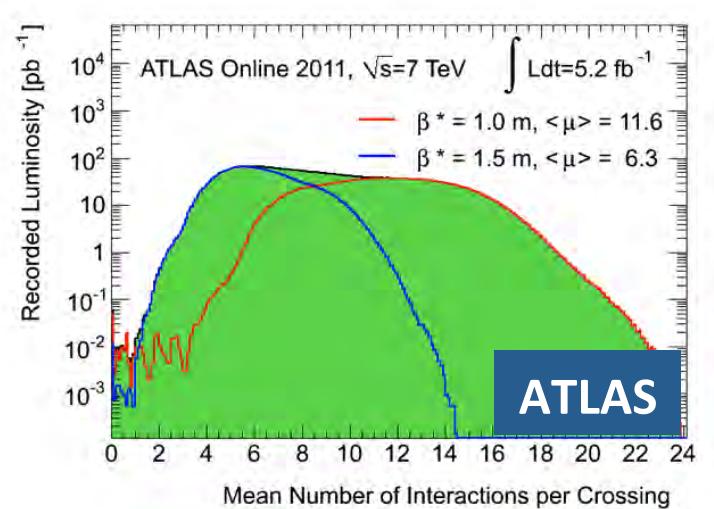
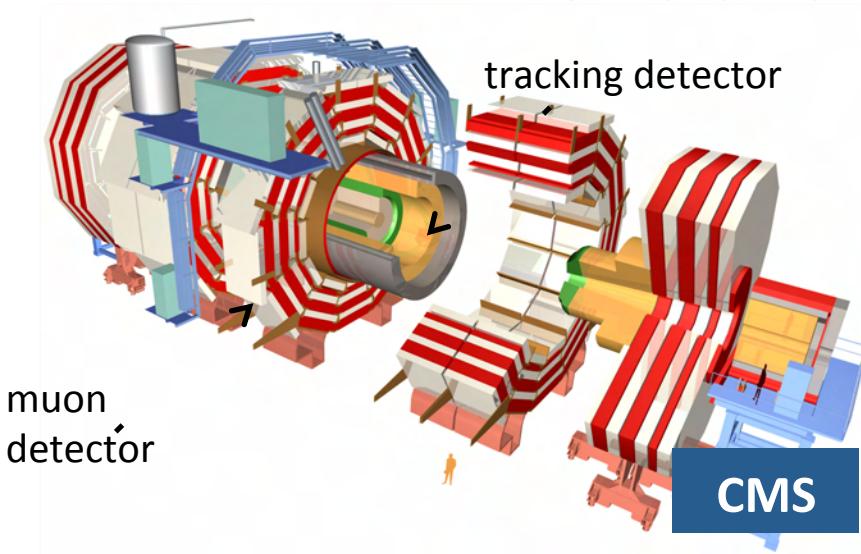
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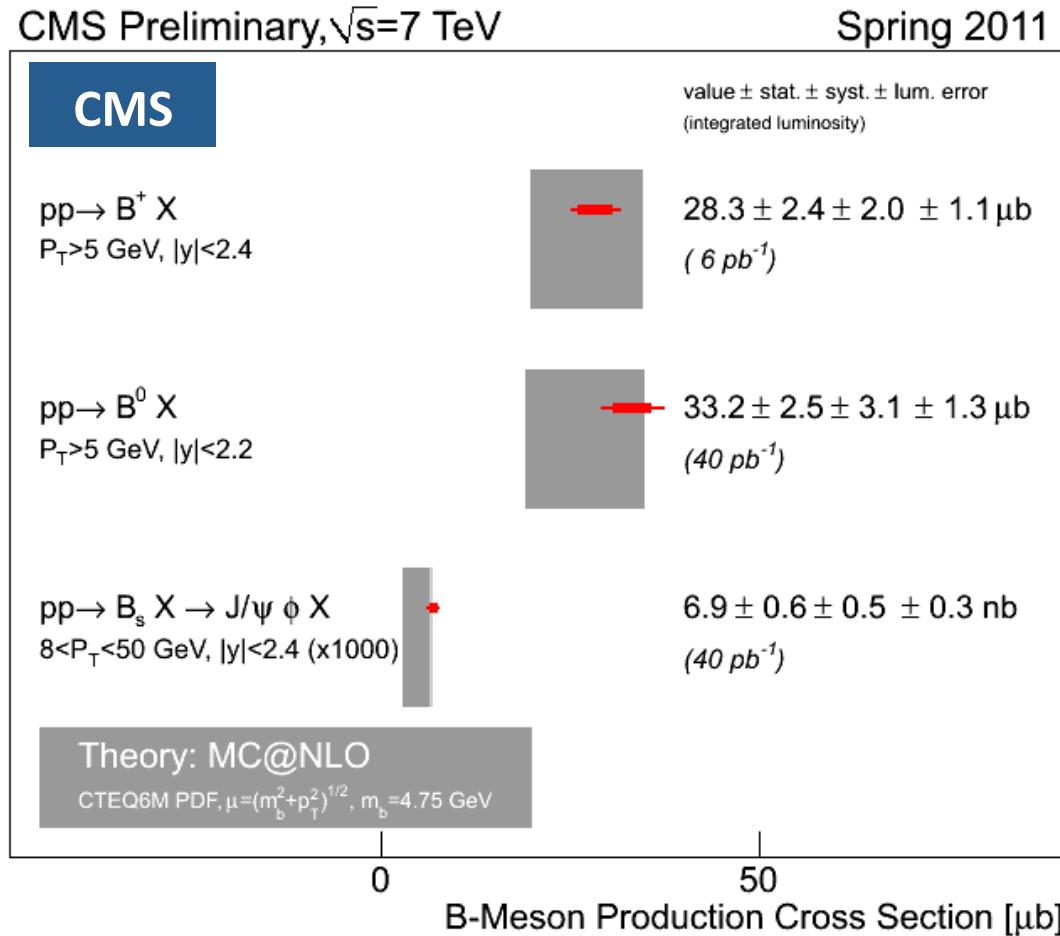


# Detector and Data



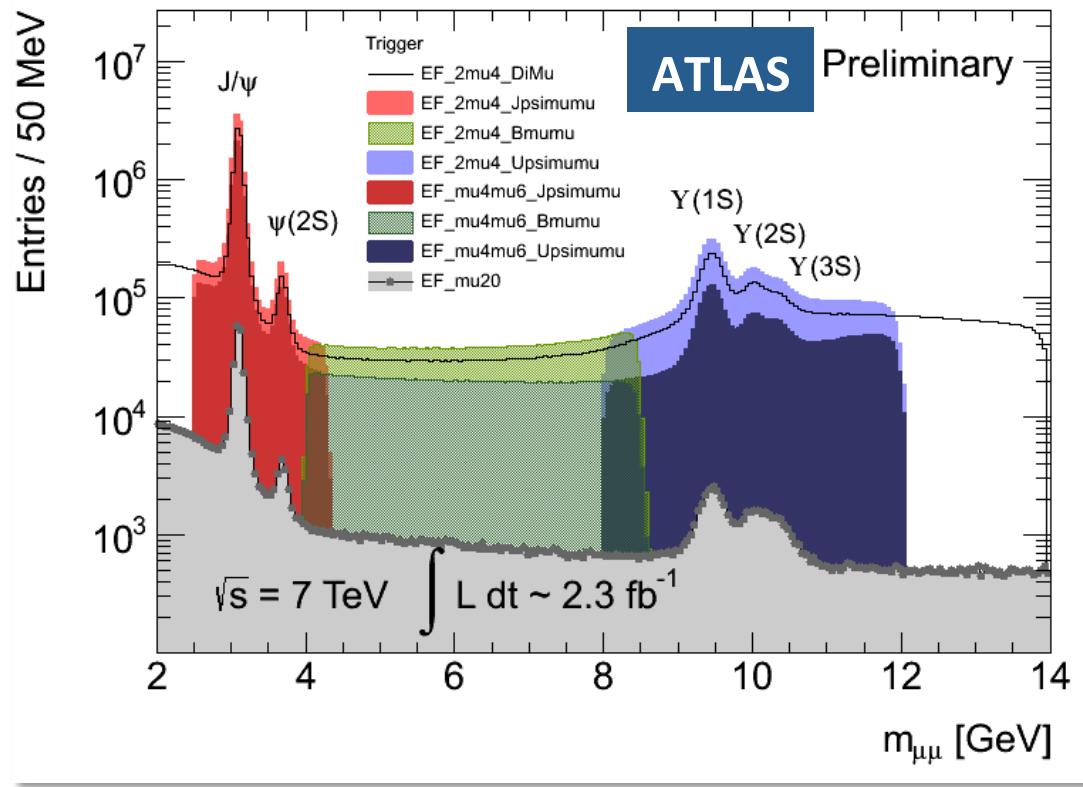
- max inst. luminosity  $\sim 3.5 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ 
  - up to 12 collisions / event on average
- integrated luminosity about  $5.2 \text{ fb}^{-1}$  per experiment

# B-Meson Production



- bb-production mostly at large  $\eta$
- CMS and ATLAS sensitive to low  $\eta$  region only
  - expect about  $\sim 150 \text{ G } B^0$ -pairs
  - $\sim 30 \text{ M } B_s \rightarrow J/\psi \phi$  events for  $5 \text{ fb}^{-1}$

# Di- $\mu$ Trigger for low $p_T$ di- $\mu$ Events



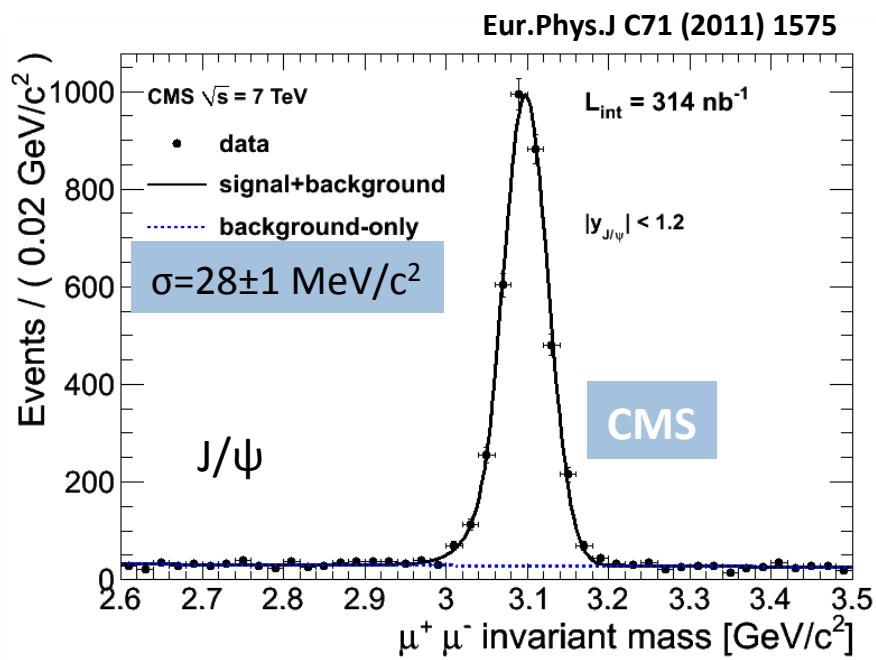
selection of events with  
b hadron using two  $\mu$  in  
the final state

- di- $\mu$ :  
 $\sim 1.5\text{-}14 \text{ GeV}$
- $J/\psi \rightarrow \mu\mu$ :  
 $\sim 2.5\text{-}4.3 \text{ GeV}$
- intermediate  $m_{\mu\mu}$   
 $\sim 4.0\text{-}8.5 \text{ GeV}$
- $Y \rightarrow \mu\mu$ :  $\sim 8\text{-}12 \text{ GeV}$

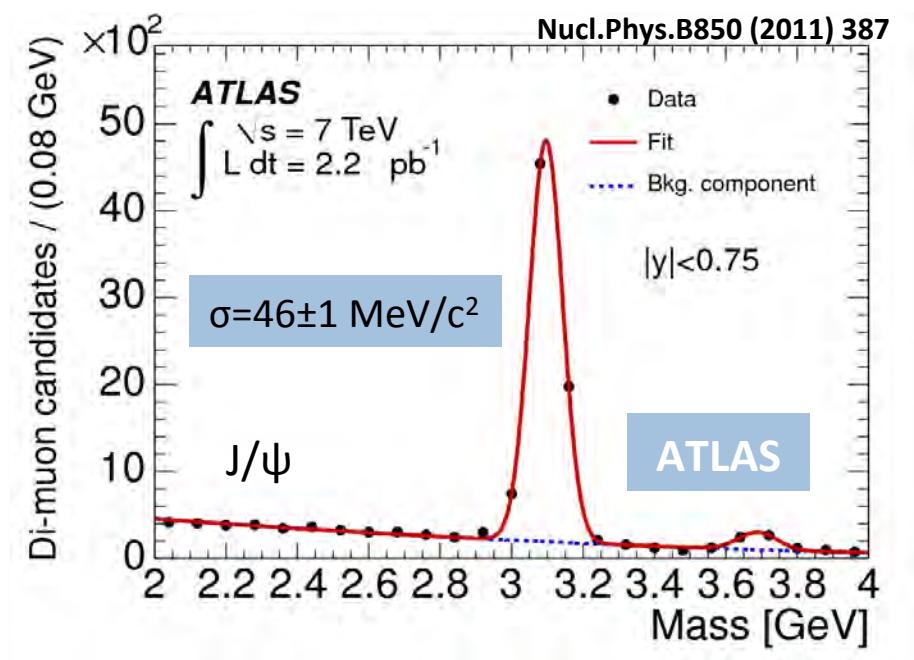
adjust trigger rates by increasing thresholds or prescale

# Detector Performance I:

## Mass Resolution



$$\sigma_{p_T}/p_T \sim 1-3\%$$

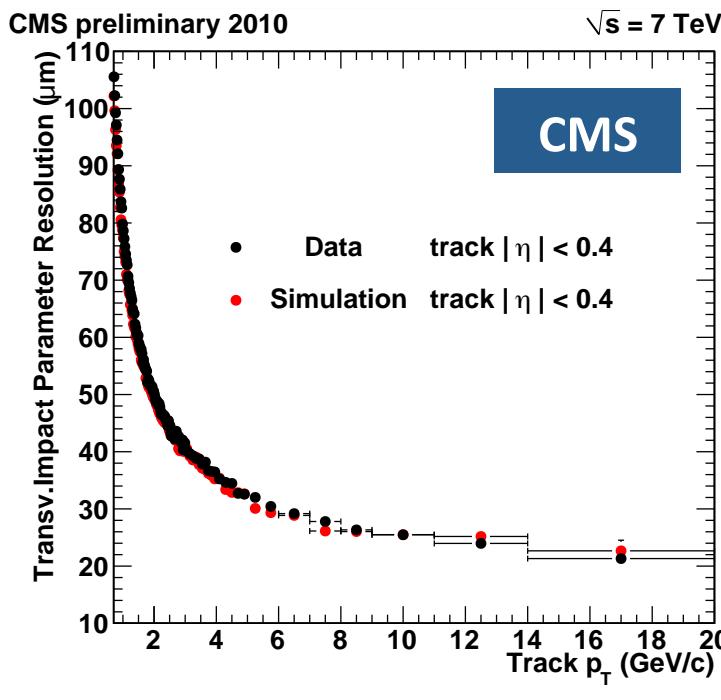


$$\sigma_{p_T}/p_T \sim 5-6\%$$

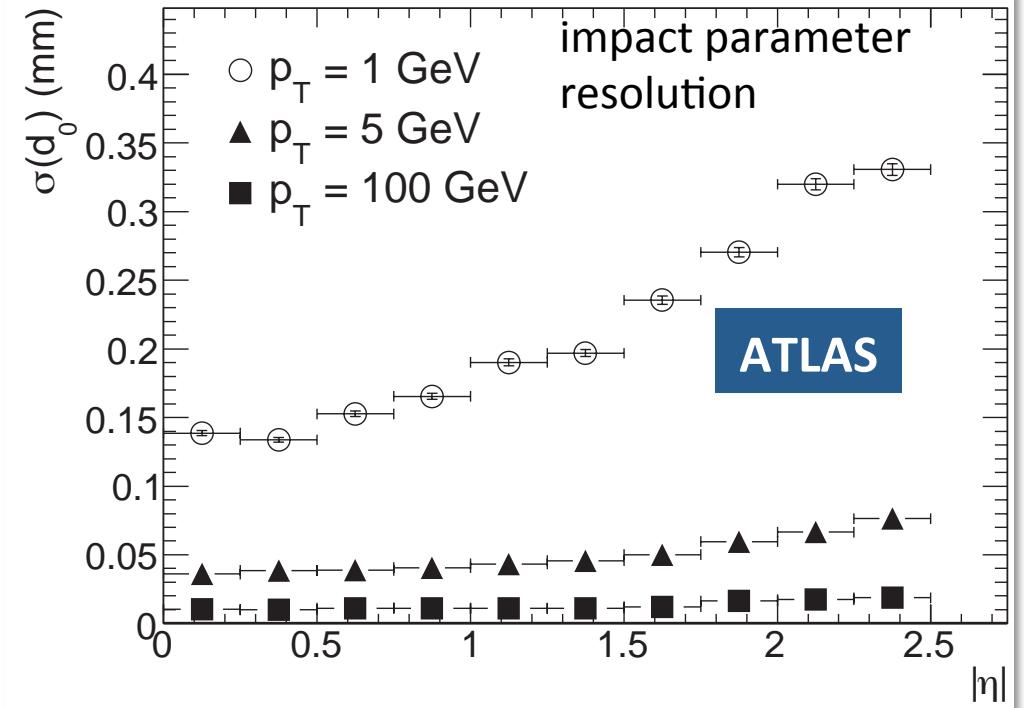
- excellent mass resolution required for good S/B performance
- limited particle ID (only for  $p_T < 1$  GeV/c K/ $\pi$  – separation possible)

# Detector Performance II : Impact Parameter Resolution

CMS-PAS-TRK-10-005



2008 JINST 3 S08003



- good impact parameter resolution required for lifetime based measurement

# B-HADRON PRODUCTION



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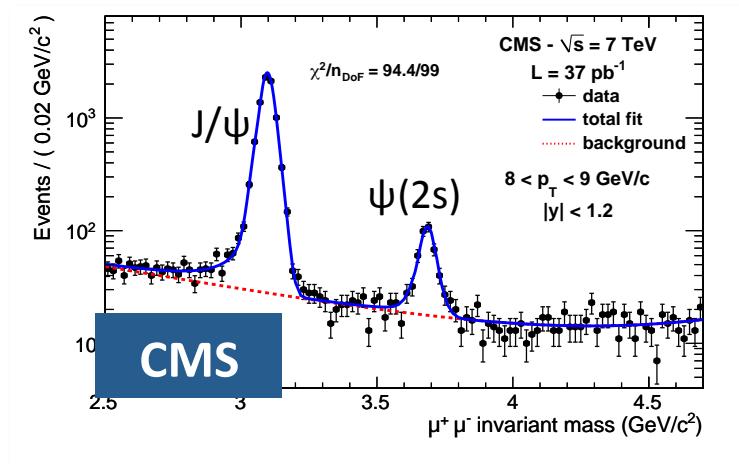
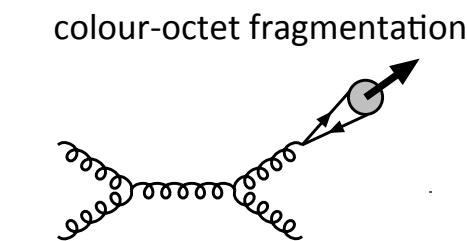
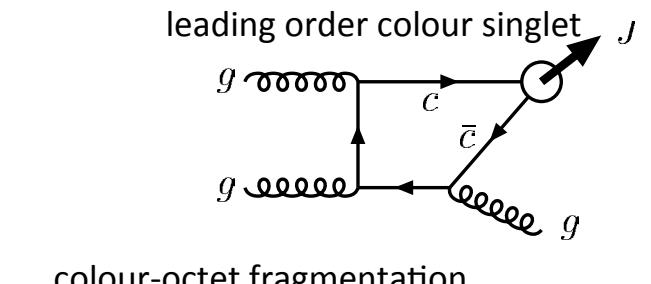
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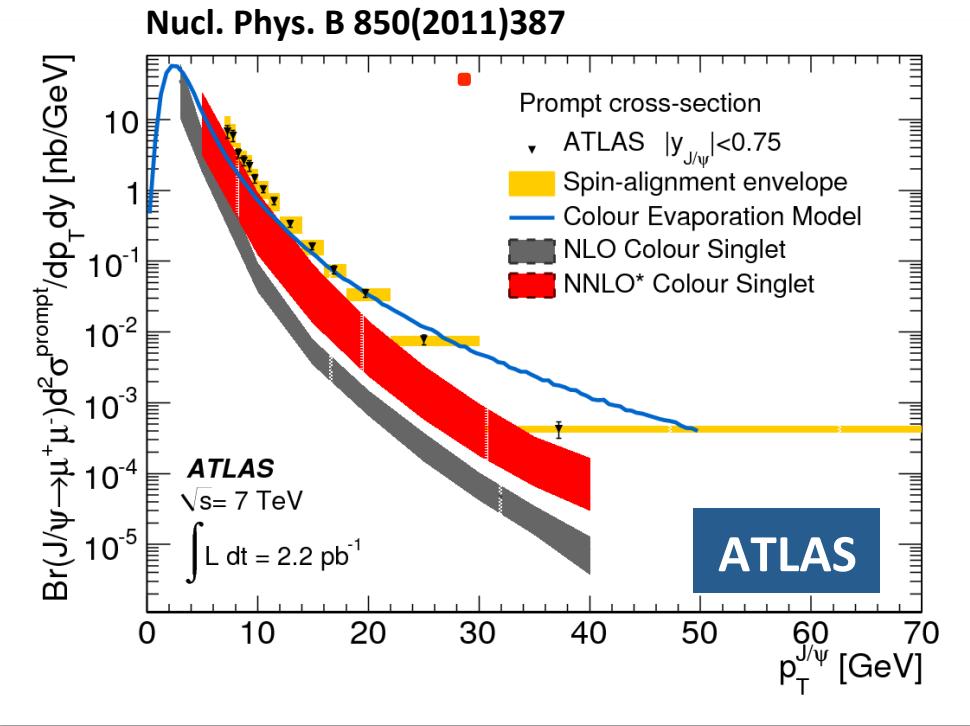
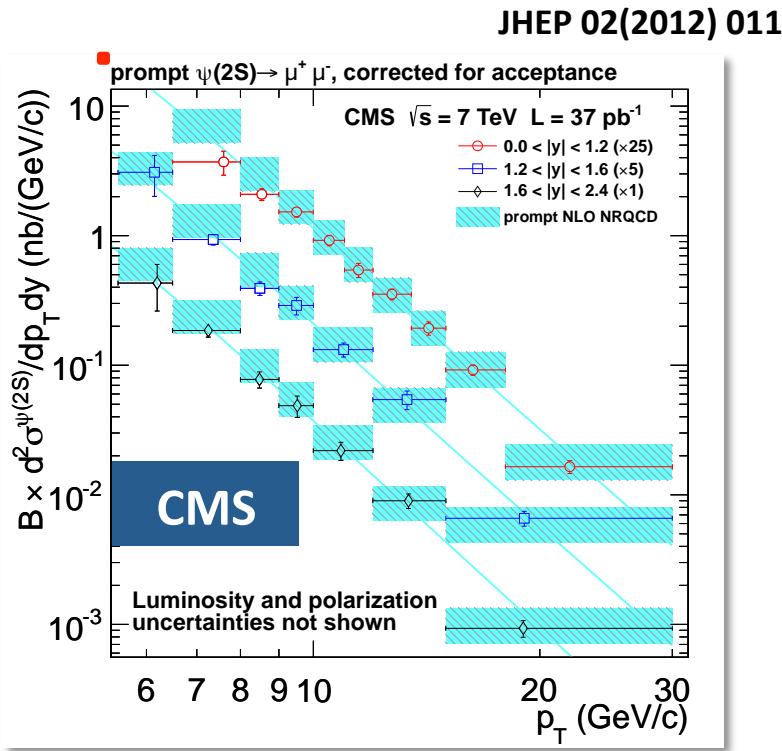


# Quarkonium Production

- production of heavy quarkonium at LHC offers possibility to test QCD
- measurement of
  - $J/\psi$  and  $\psi(2s)$  production
    - prompt and non-prompt contribution
  - $\Upsilon(1s)$  production



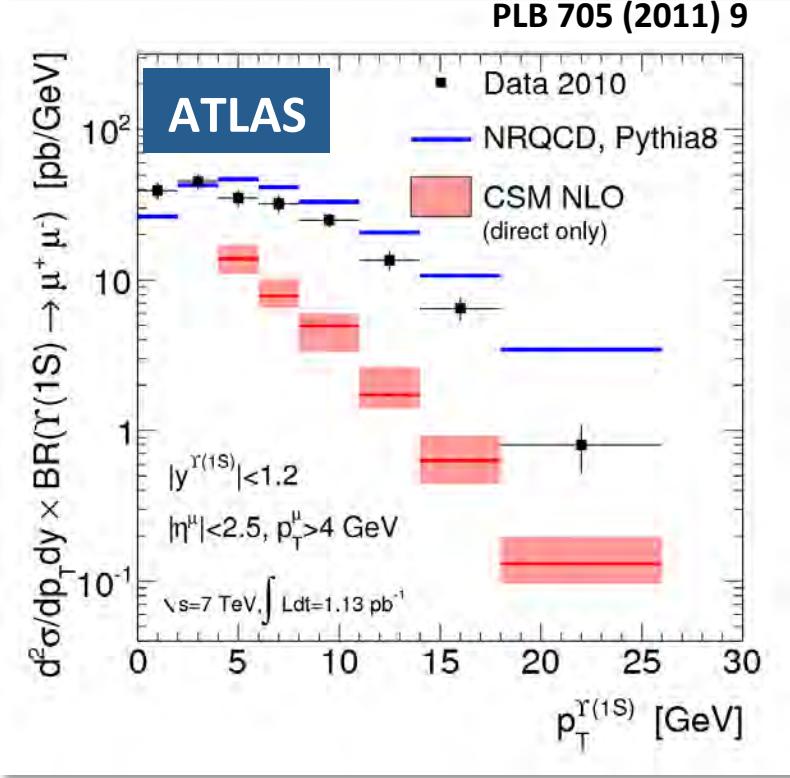
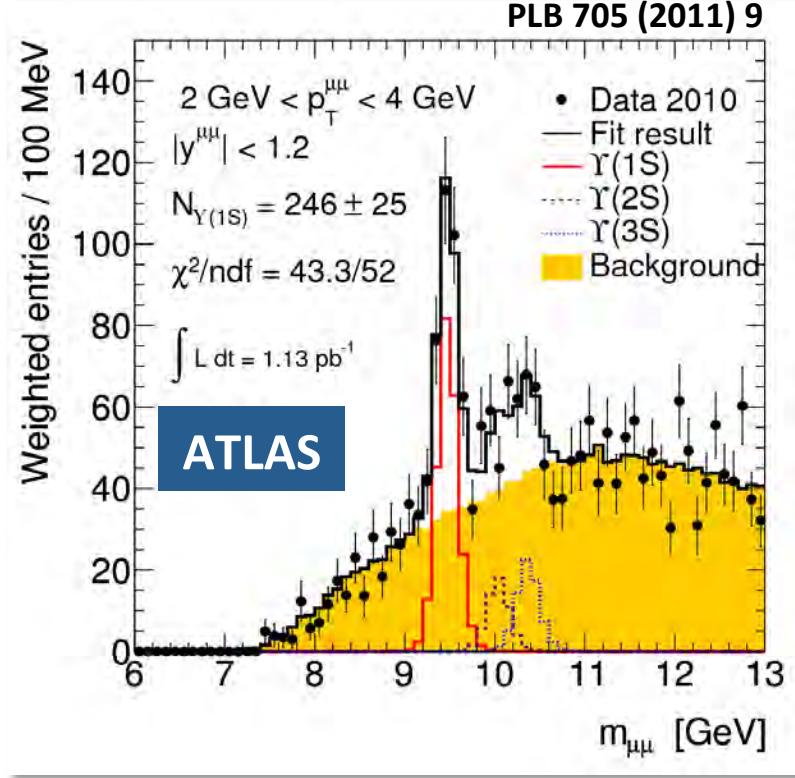
# J/ $\psi$ and $\Psi(2s)$ Production



- prompt  $\psi(2s)$  well reproduced by NLO NRQCD prediction

- improved CSM prediction of prompt  $J/\psi$  production by NNLO\*

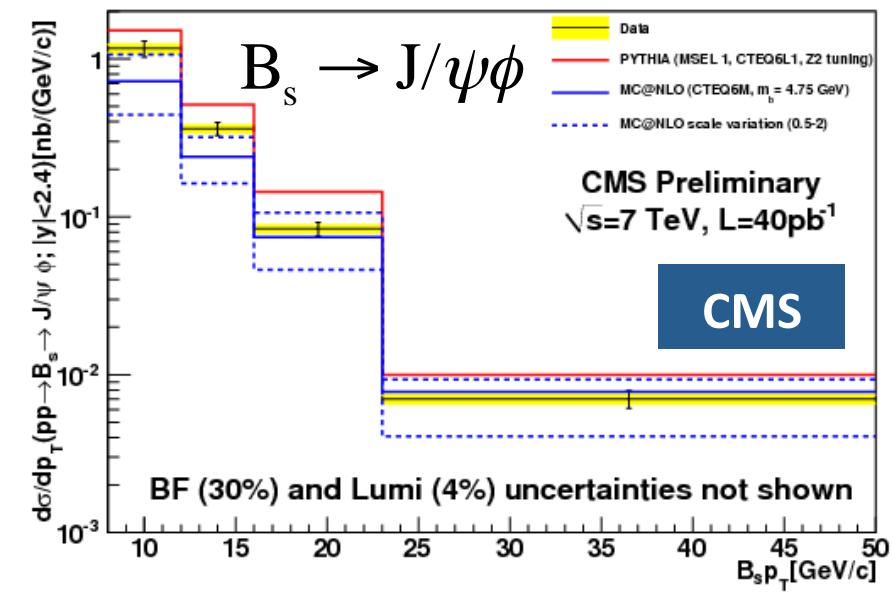
# $\Upsilon(1s)$ Production



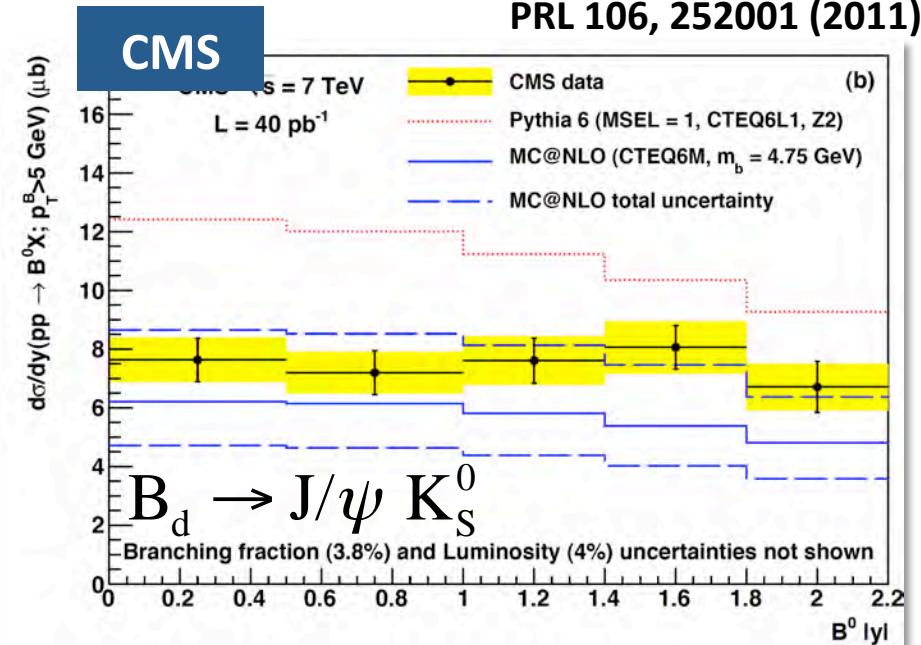
- only prompt contribution for  $\Upsilon(1s)$  production
- overall scale not well produced by theory prediction

# Measurement $B_x$ -Meson Production Cross Section

PRD D84 052008 (2011)



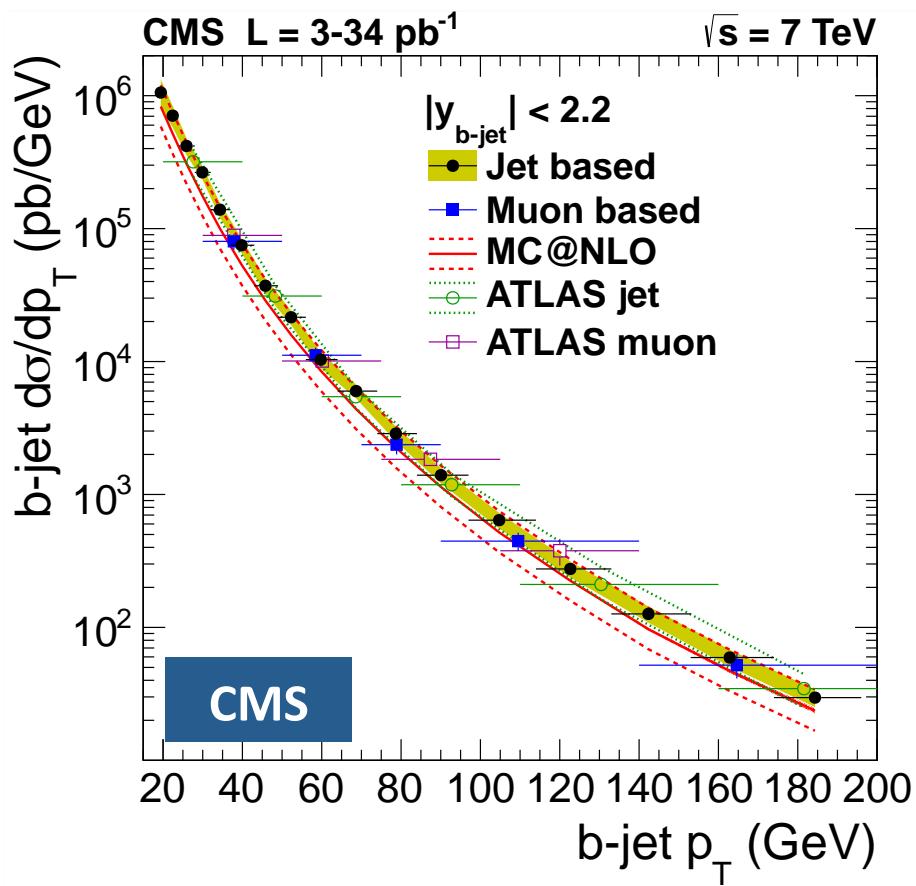
PRL 106, 252001 (2011)



- cross section between PYTHIA and MC@NLO prediction
- rapidity distribution flatter than PYTHIA prediction
- $B_d$  and  $B^+$  cross section in good agreement

# Inclusive b-jet Production

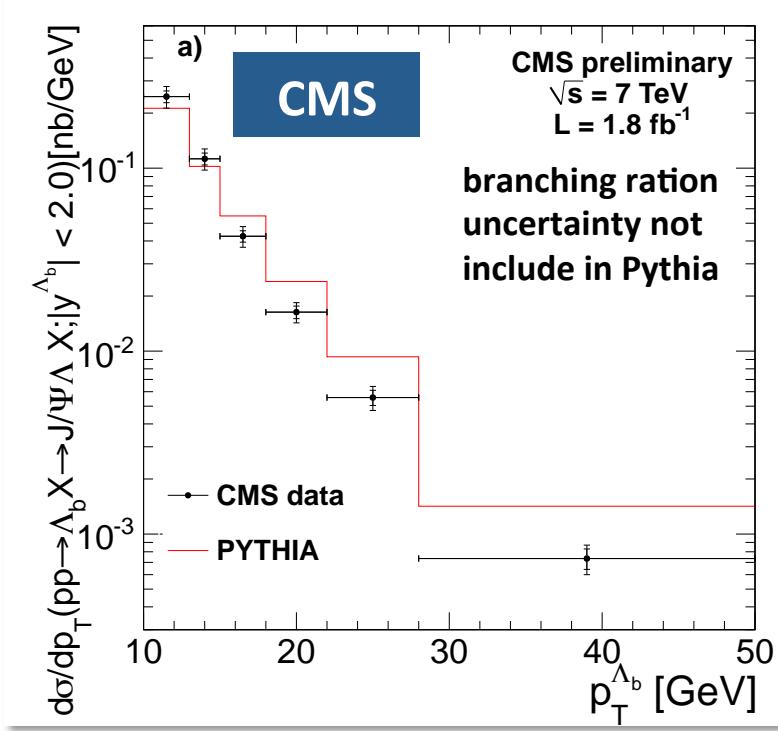
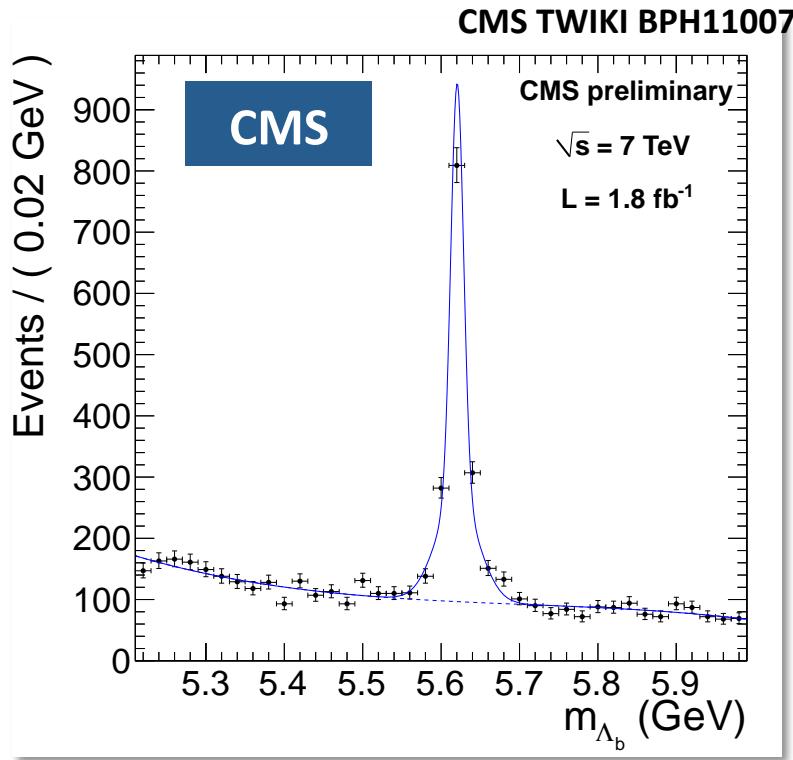
arXiv:1202:4617 (submitted to JHEP)



- two different analysis based on
  - b-jet identification
  - b-jet with a muon
- good agreement between
  - ATLAS and CMS
  - with MC@NLO prediction

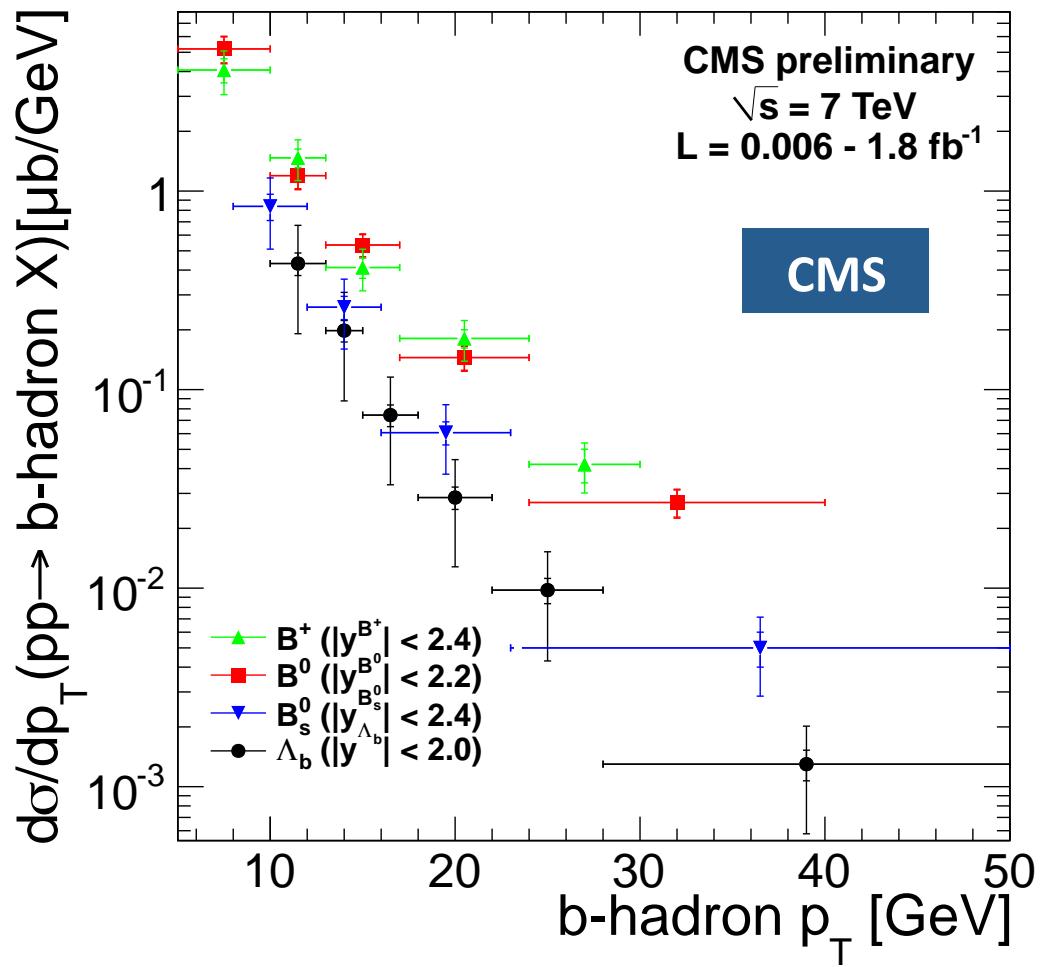


# Measurement of $\Lambda_b$ Production



- reconstruction of  $\Lambda_b$  via decay  $\Lambda_b \rightarrow J/\Psi \Lambda$
- data observed to fall faster in pt spectrum than Pythia
- production rate as a function of  $\eta$  and  $\Lambda_b/\Lambda_b$  ratio well reproduced by MC

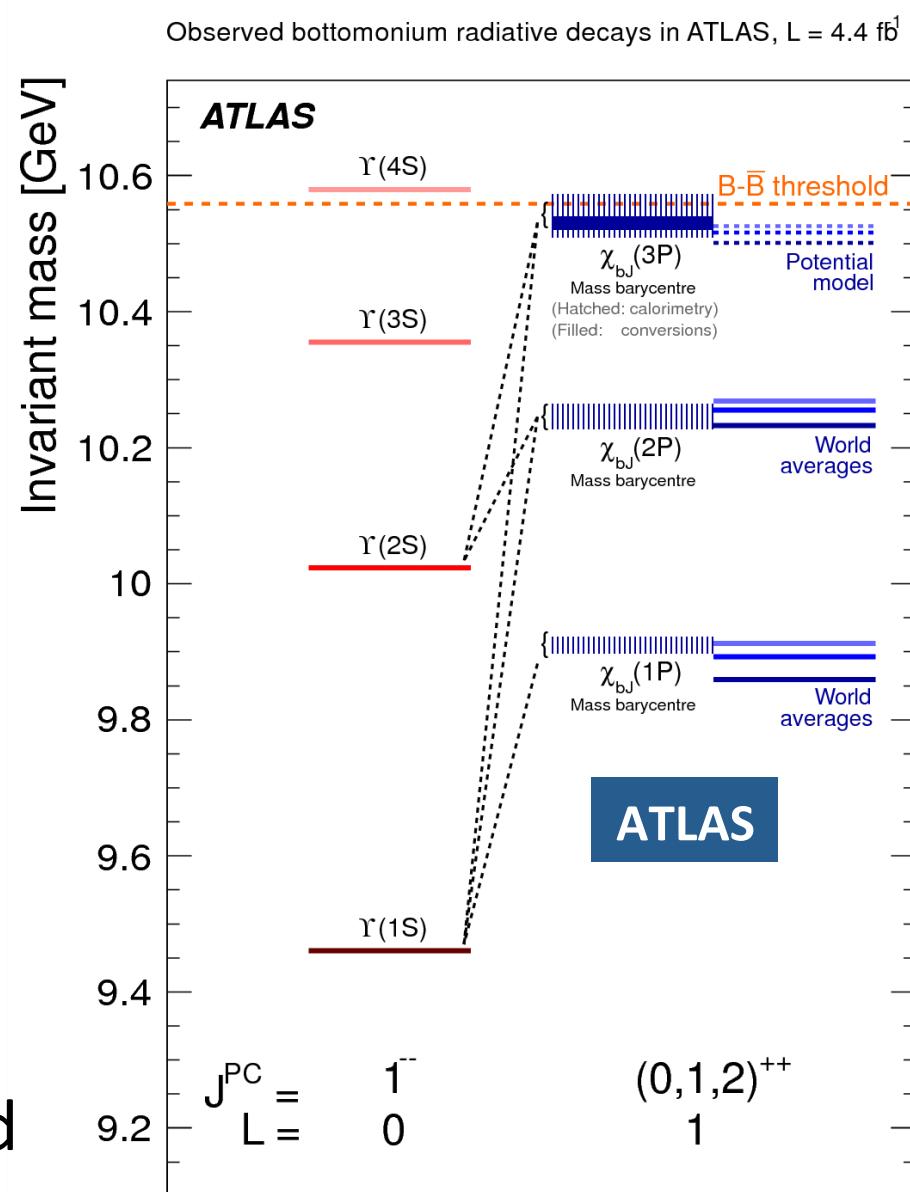
# Measurement of $\Lambda_b$ Production



- $p_T$  spectrum of  $\Lambda_b$  falls faster than observed B-meson spectrum
- $p_T$ -dependent hadronization ratio of baryon relative to mesons?

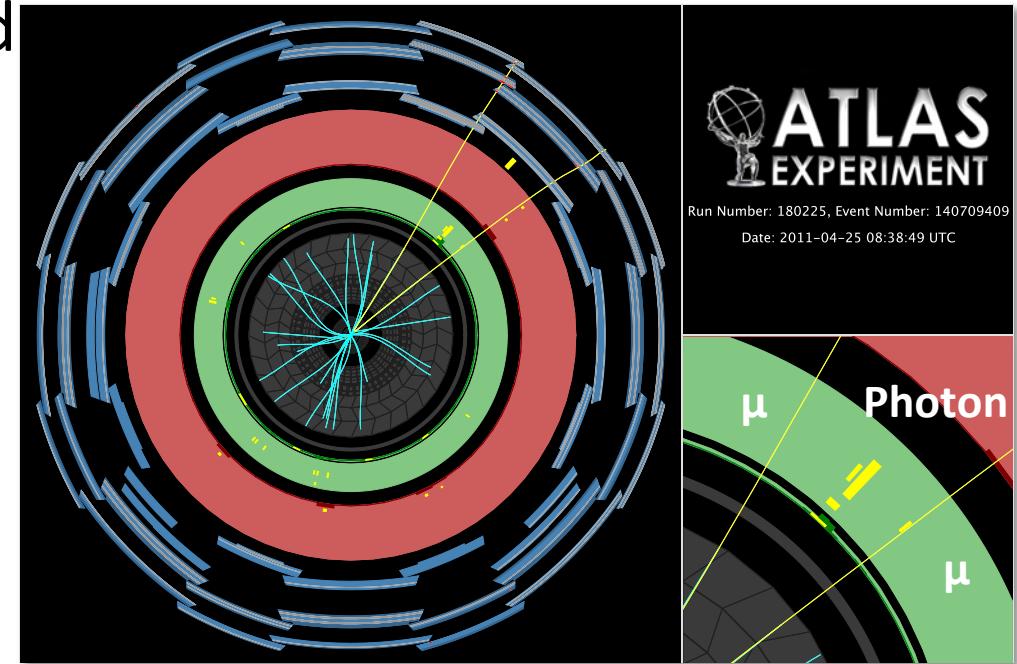
# Observation of a new $\chi_b$ state

- quarkonium bb-state with parallel spins
  - bb S-wave state:  $\Upsilon$
  - bb P-wave state:  $\chi_b$  with  $J=0,1,2$  triplet spin state
  - $\chi_b(1P)$  and  $\chi_b(2P)$  experimentally studied



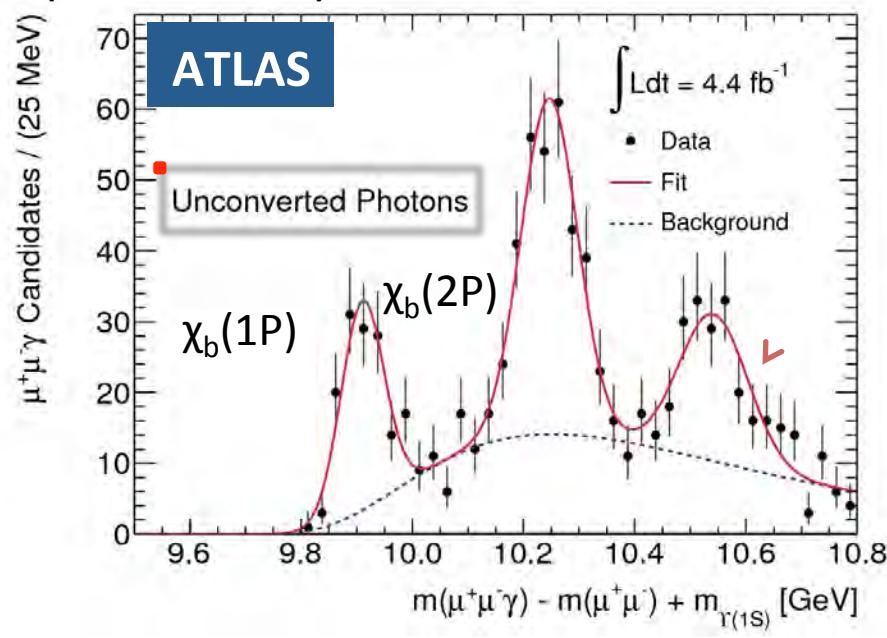
# Observation of a new $\chi_b$ state

- reconstruction of  $\chi_b$  through radiative decays
  - $\chi_b(nP) \rightarrow Y(1S) \gamma$  and  $\chi_b(nP) \rightarrow Y(2S) \gamma$
  - $\gamma$  well reconstructed with calorimeter measurement or via conversion to  $e^+e^-$ -pairs



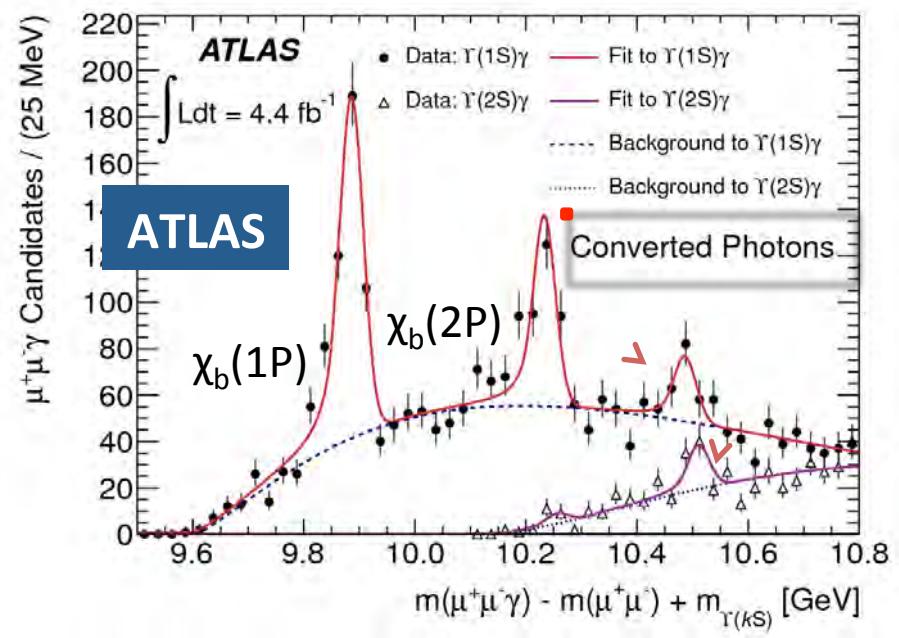
# Observation of a new $\chi_b$ state

accepted by Phys. Rev. Lett  
(arXiv: 1112:5154)



$\chi_b(3P) \rightarrow \gamma(1S)\gamma$

$\chi_b(3P) \rightarrow \gamma(2S)\gamma$



$$m_3 = 10.541 \pm 0.011(\text{stat.}) \pm 0.030(\text{syst.}) \text{ GeV}$$

$$m_3 = 10.530 \pm 0.005(\text{stat.}) \pm 0.009(\text{syst.}) \text{ GeV}$$

Theory (spin averaged): 10.525 GeV

# LIFETIME MEASUREMENTS



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# B Lifetime Measurements

- average B Lifetime using

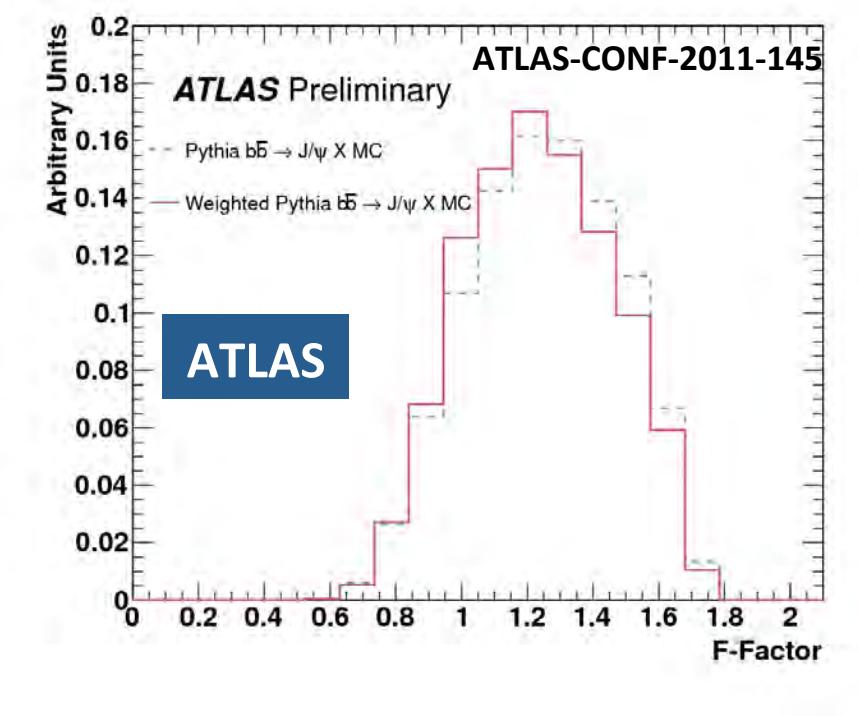
$$B_x \rightarrow J/\psi X \rightarrow \mu^+ \mu^- X$$

- use pseudo proper time:

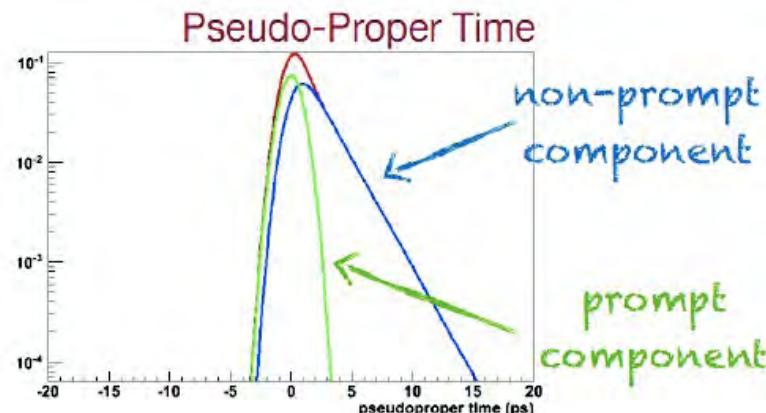
$$\tau_B = \frac{L_{XY} \cdot m_B^{\text{PDG}}}{p_T(B)} = \frac{L_{XY} \cdot m_{J/\psi}^{\text{PDG}}}{p_T(J/\psi)} \cdot F$$

- $J/\psi$  carries only part of the initial  $p_T$  of B-Meson

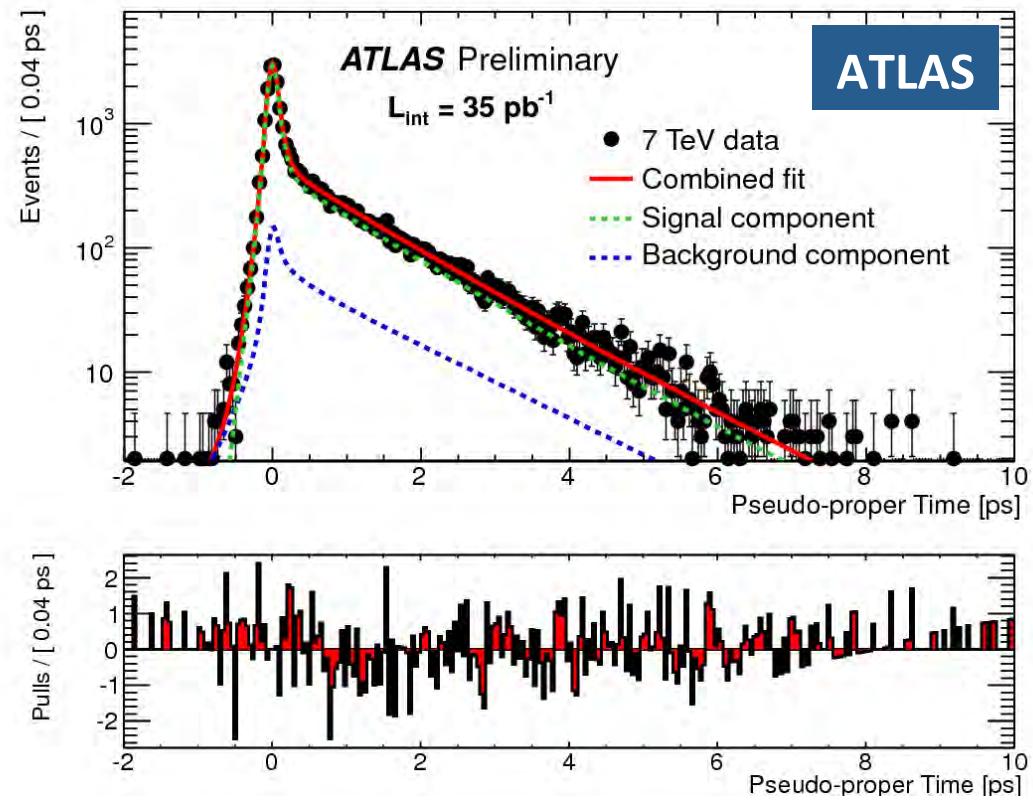
➤ correction factor  $F$  to take momentum difference between B and  $J/\psi$  into account  
determined from MC weighted according to BaBar



# B Lifetime Measurements



- main systematic uncertainty for preliminary measurement:
  - time background model
  - residual misalignment
- improved systematic uncertainty expected for final publication



- no lifetime bias in trigger selection

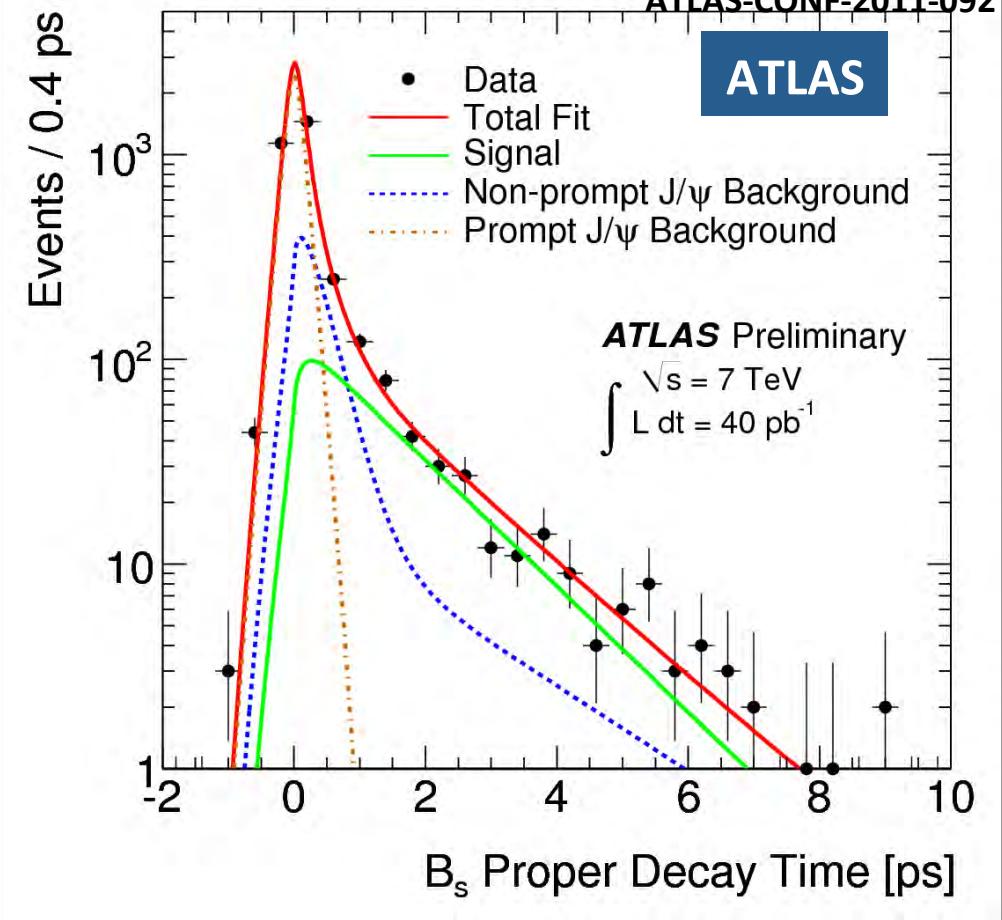
$$\langle \tau_B \rangle = 1.489 \pm 0.016(\text{stat.}) \pm 0.043(\text{syst}) \text{ ps}$$

(PDG:  $1.568 \pm 0.009$  ps dominated by LEP)

# Exclusive Lifetime Measurement

ATLAS-CONF-2011-092

- measure lifetime of exclusive reconstructed events:  $B_d \rightarrow J/\psi K^{*0}$  and  $B_s \rightarrow J/\psi \phi$
- detector performance well understood
  - important milestone for successful CP-violation measurement of  $\beta_s$



$$\tau_{B_s} = 1.41 \pm 0.08(\text{stat.}) \pm 0.05(\text{syst.})$$

# RARE DECAYS



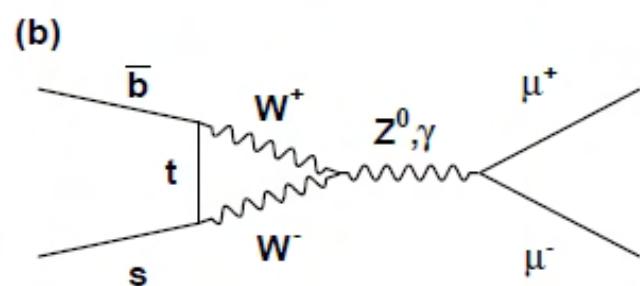
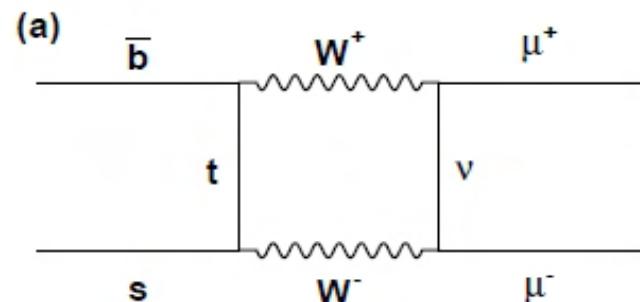
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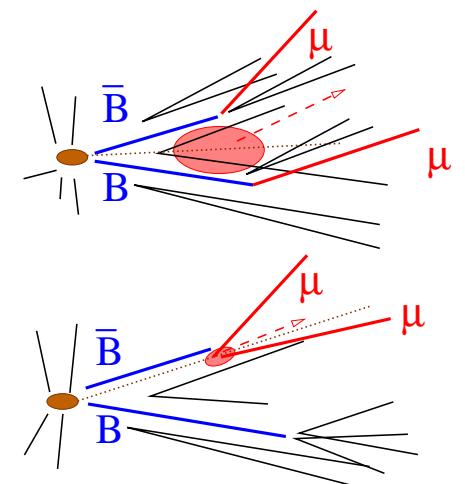
# Search for Rare B-Decays



- flavour changing neutral currents (FCNC) are highly suppressed in the Standard Model  
 $\text{Br}(B_s \rightarrow \mu^+ \mu^-) = (3.2 \pm 0.2) \times 10^{-9}$   
 $\text{Br}(B_d \rightarrow \mu^+ \mu^-) = (1.0 \pm 0.1) \times 10^{-10}$
- branching ratio might be substantially enhanced by coupling to non-SM particles
- orthogonal search for physics beyond the standard model

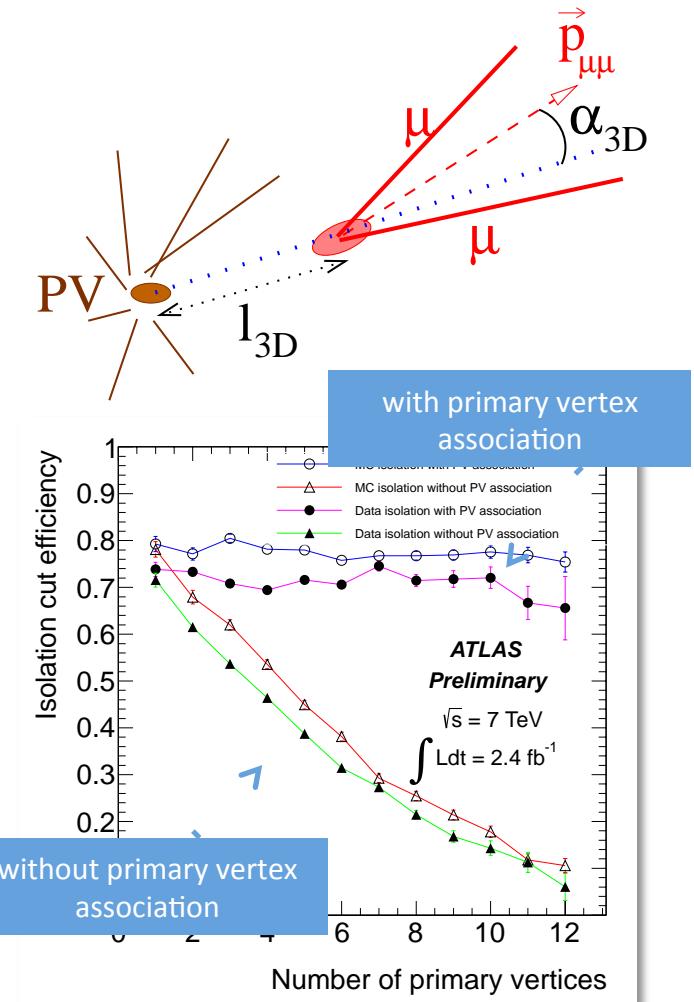
# Search for Rare Decays

- summarize only recent ATLAS results
  - see dedicated talk for latest CMS results by Luca Martini
- ATLAS profits from large luminosity
  - integrated luminosity  $2.4 \text{ fb}^{-1}$
  - expected mass resolution:
    - ATLAS:  $\sigma_{B \rightarrow \mu\mu} \sim 60$  (barrel) –  $110$  (forward) MeV
- main background sources:
  - continuum with smooth di-muon invariant mass
    - estimated from sidebands
    - dominant background contribution
  - resonant contribution from mis-reconstructed decays
    - irreducible background, estimated with MC



# Search for Rare Decays

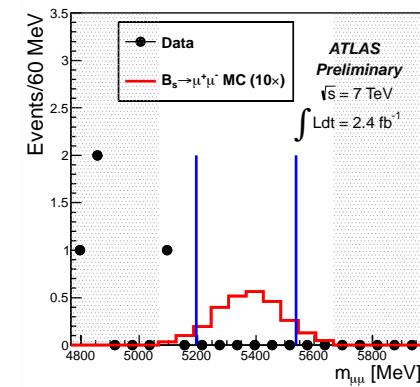
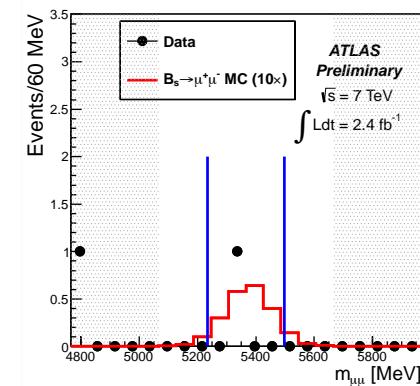
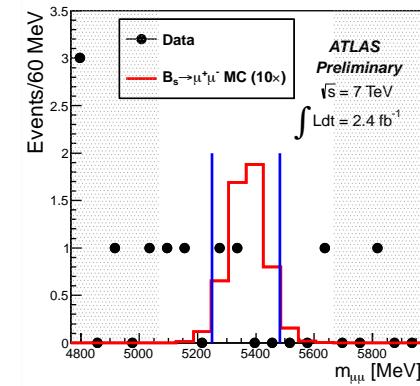
- select events based on their decay topology
  - use boosted decision tree (BDT) classifier calculated with 14 input variables
  - selection independent from number of primary vertices
- calculate branching ratio with respect to high statistic decay mode ( $B_d \rightarrow J/\psi K$ )



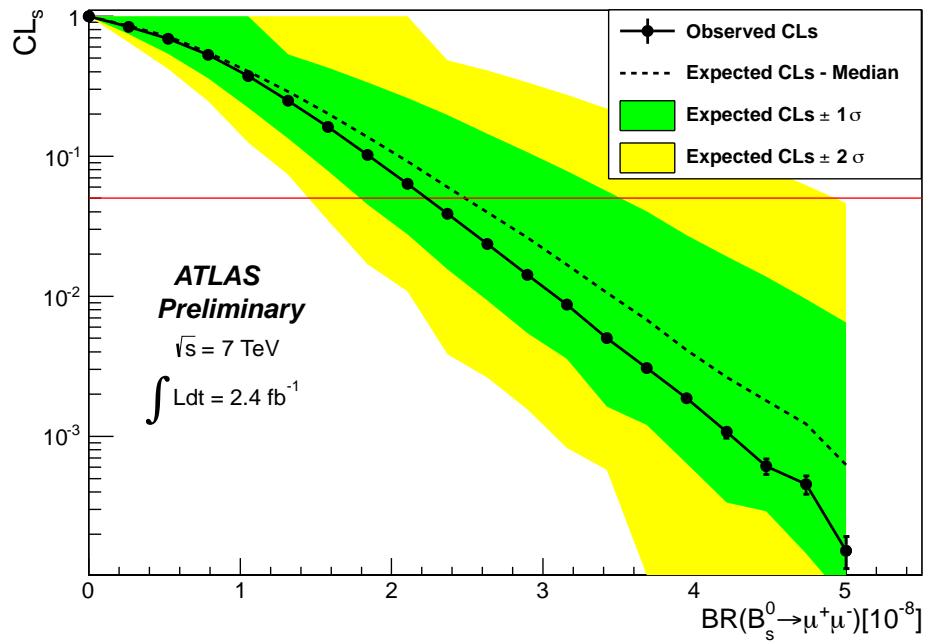
# Search for Rare Decays

- optimization and estimation of background events performed on different sideband event samples
  - avoid bias on expected limit**
- use different categories in mass resolution (in  $\eta$ )

$ \eta_{\max} $	0-1.0	1.0-1.5	1.5-2.5
side band count $N_{\text{bg}}$ (even numbered events)	5	0	2
bkg. scaling factor	1.29	1.14	0.88
expected resonant bg	0.1	0.06	0.08
search region count $N_{\text{sig}}$	2	1	0



# Search for Rare Decays



- no excess of signal events over expected background observed
  - limit on branching ratio
  - expected limit:  
 $Br_{exp}: (2.3+1.0-0.5) \times 10^{-8}$
- measurement consistent with expectation from SM  
( $Br_{SM}: (3.5 \pm 0.3) \times 10^{-9}$ )

ATLAS:  $Br(B_s \rightarrow \mu^+ \mu^-) < 2.2 \times 10^{-8}$  ( $2.4 \text{ fb}^{-1}$ )

CMS:  $Br(B_s \rightarrow \mu^+ \mu^-) < 7.7 \times 10^{-9}$  ( $4.9 \text{ fb}^{-1}$ )

LHCb:  $Br(B_s \rightarrow \mu^+ \mu^-) < 4.5 \times 10^{-9}$  ( $1 \text{ fb}^{-1}$ )

(at 95% CL)

# Conclusion

- large available statistics and excellent detector performance allow competitive heavy flavour measurements at ATLAS and CMS
  - measurements of heavy quark production cross sections allow precise studies of QCD
  - observation of new quarkonium state  $\chi_b(3P)$
  - lifetime measurements show excellent detector performance and open the possibility for time dependent CPV-measurements
  - no sign for enhanced branching ratio in rare decays

# BONUS MATERIAL



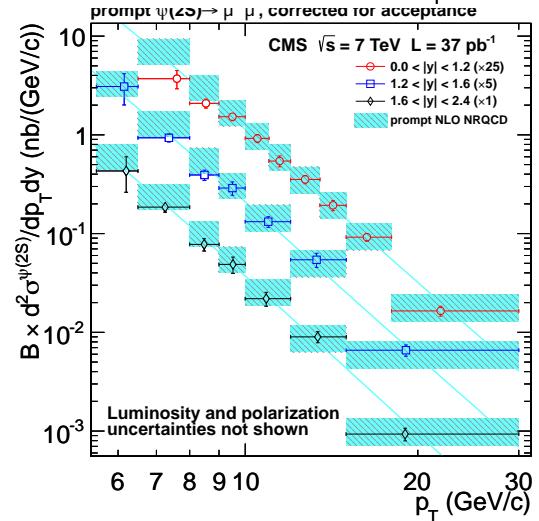
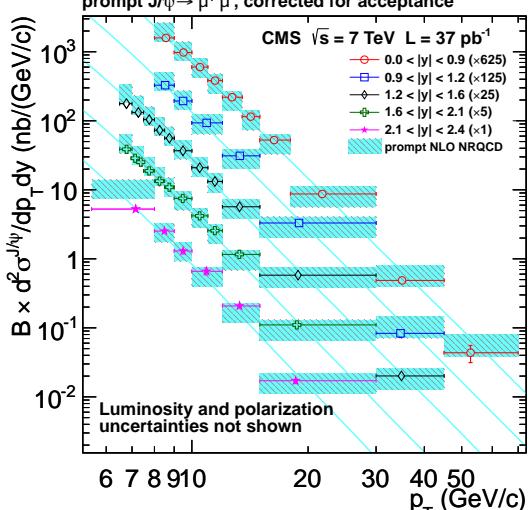
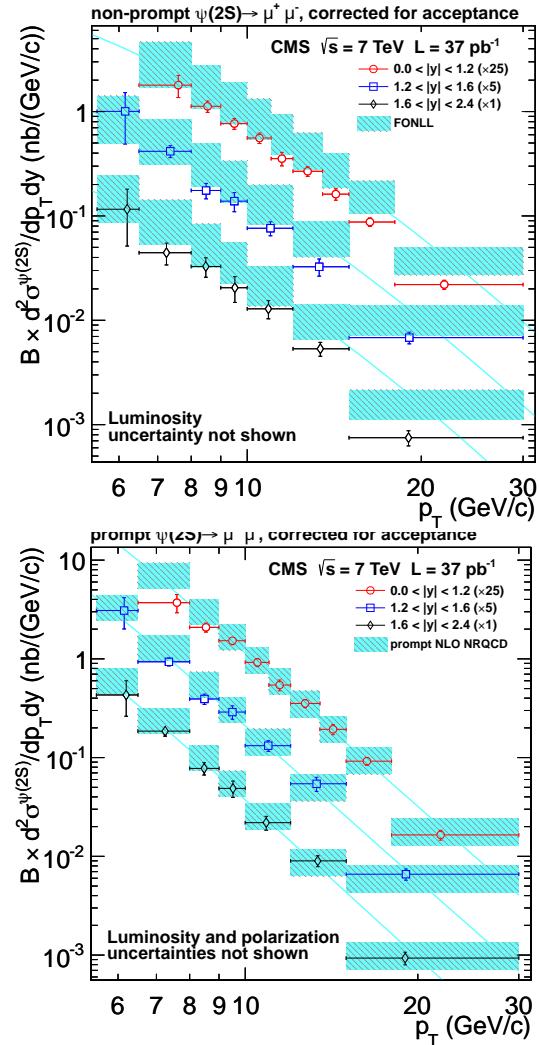
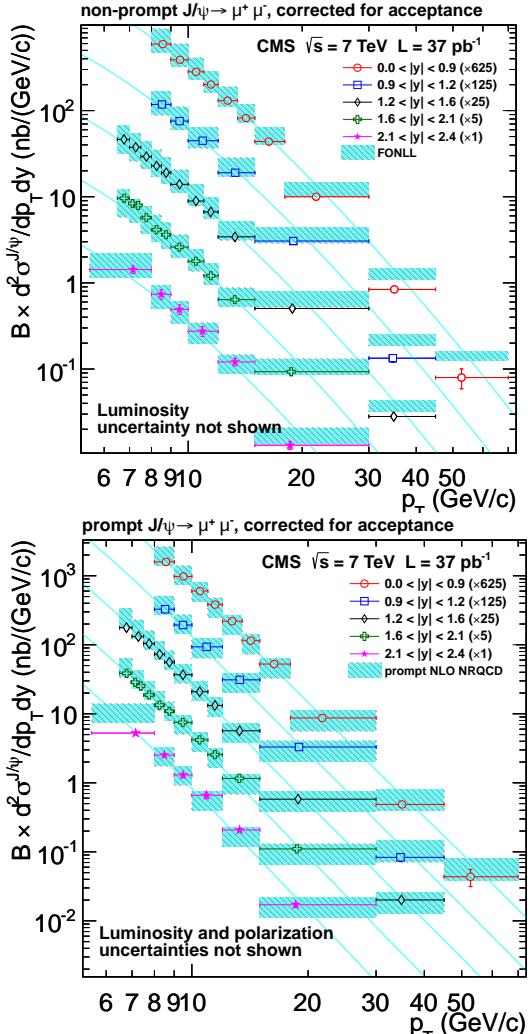
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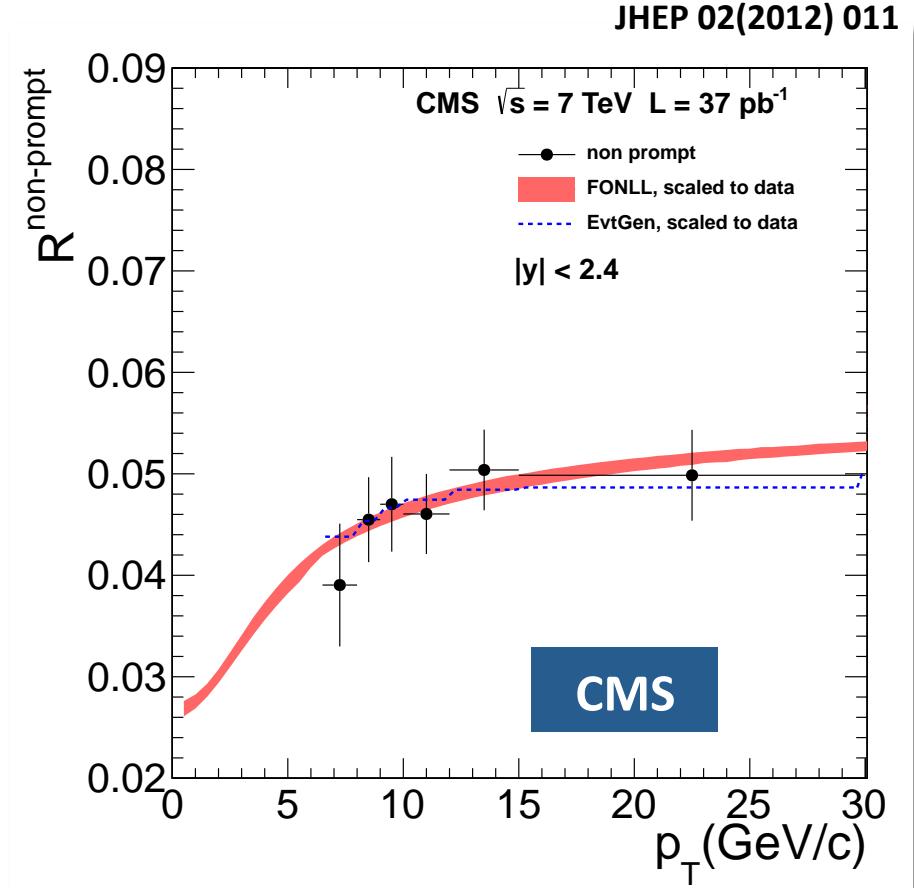
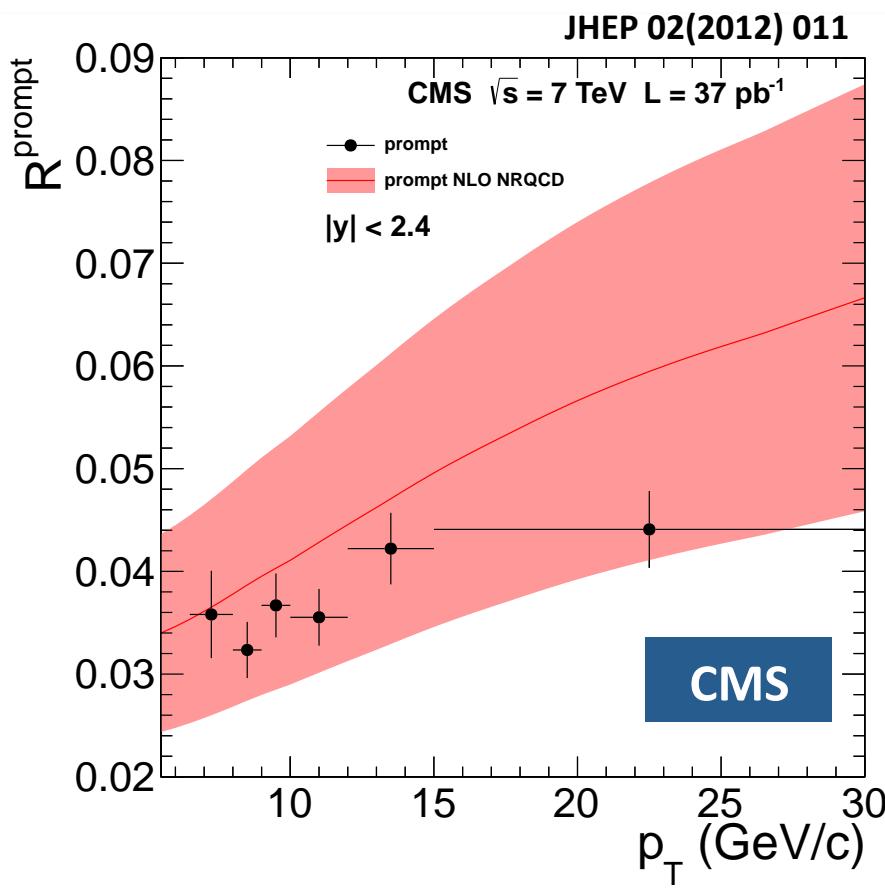
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# J/ $\psi$ and $\Psi(2s)$ Production



# J/ $\psi$ and $\Psi(2s)$ Production



- ratio  $J/\psi / \Psi(2S)$  well described by Theory

