24th Rencontres de Blois
Particle Physics and Cosmology

Results on heavy flavour production at ATLAS and CMS

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May 27th – Jun 1st 2012

Introduction and Outline

- Atlas and CMS can explore a different phase space with respect to previous experiments and LHCb

- Interesting tests of QCD can be performed, models tuned, generators refined

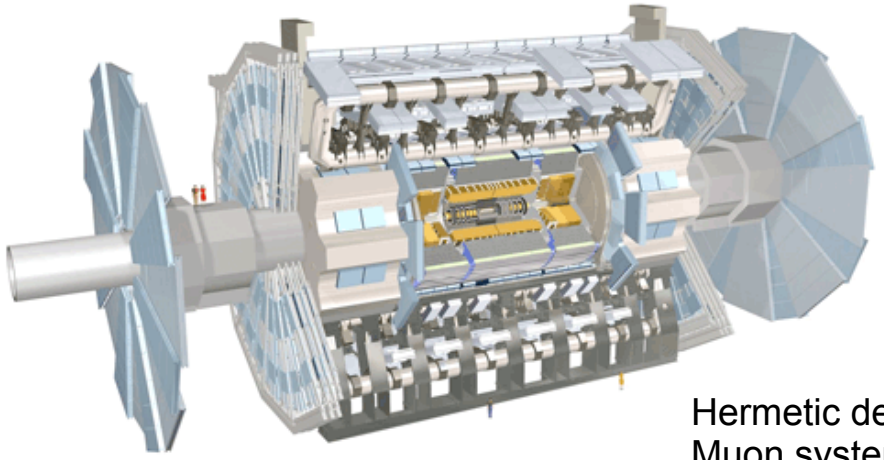
- Challenges detector performance and physics reconstruction

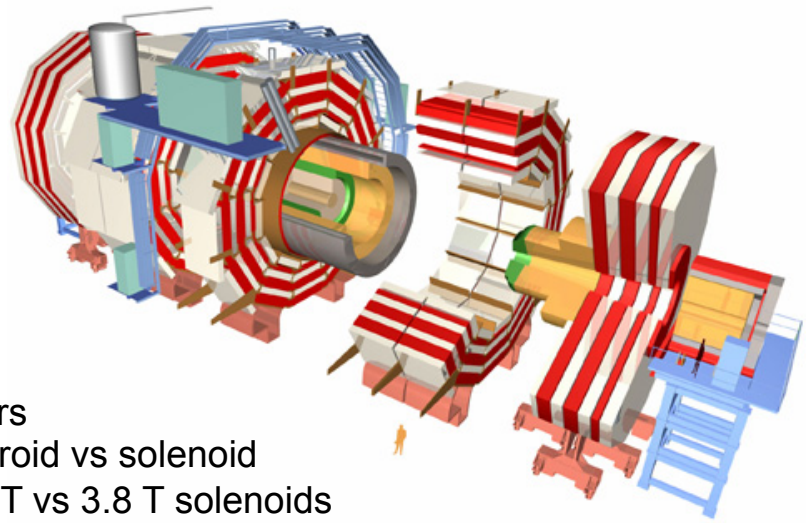
Structure of this talk

- Observation of new states
- Production Cross sections
  - Quarkonia
  - Exclusive
  - Inclusive
  - Summary
- Conclusions

- Note: b-physics results on CPV and search for new Physics from ATLAS and CMS from Louise Oakes yesterday's session

The ATLAS and CMS experiments at LHC





Hermetic detectors
Muon system : toroid vs solenoid
Silicon tracker : 2T vs 3.8 T solenoids
Different calorimeter system

LHC
7 TeV 2011, 8 TeV 2012
peak L = 6 10^{33} cm^{-2} s^{-1}
200 pb^{-1} /day peak

Observation of new states

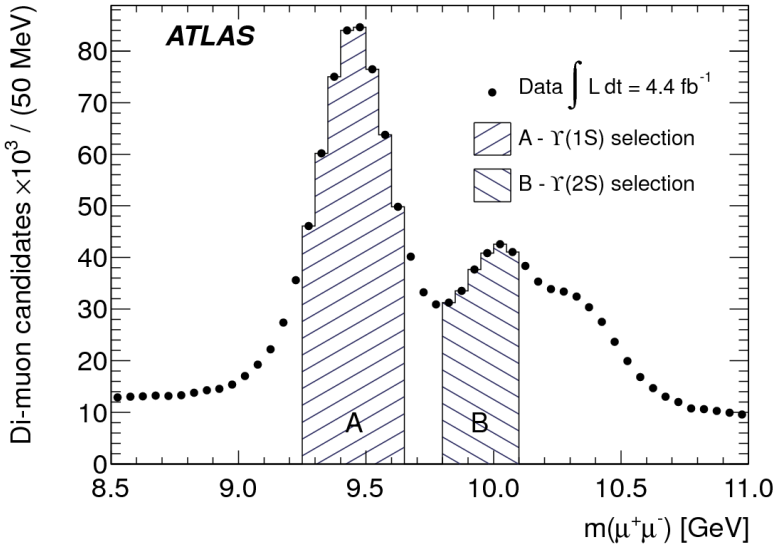
"Observation of a new χ_b state …" [$\chi_b(3P)$]

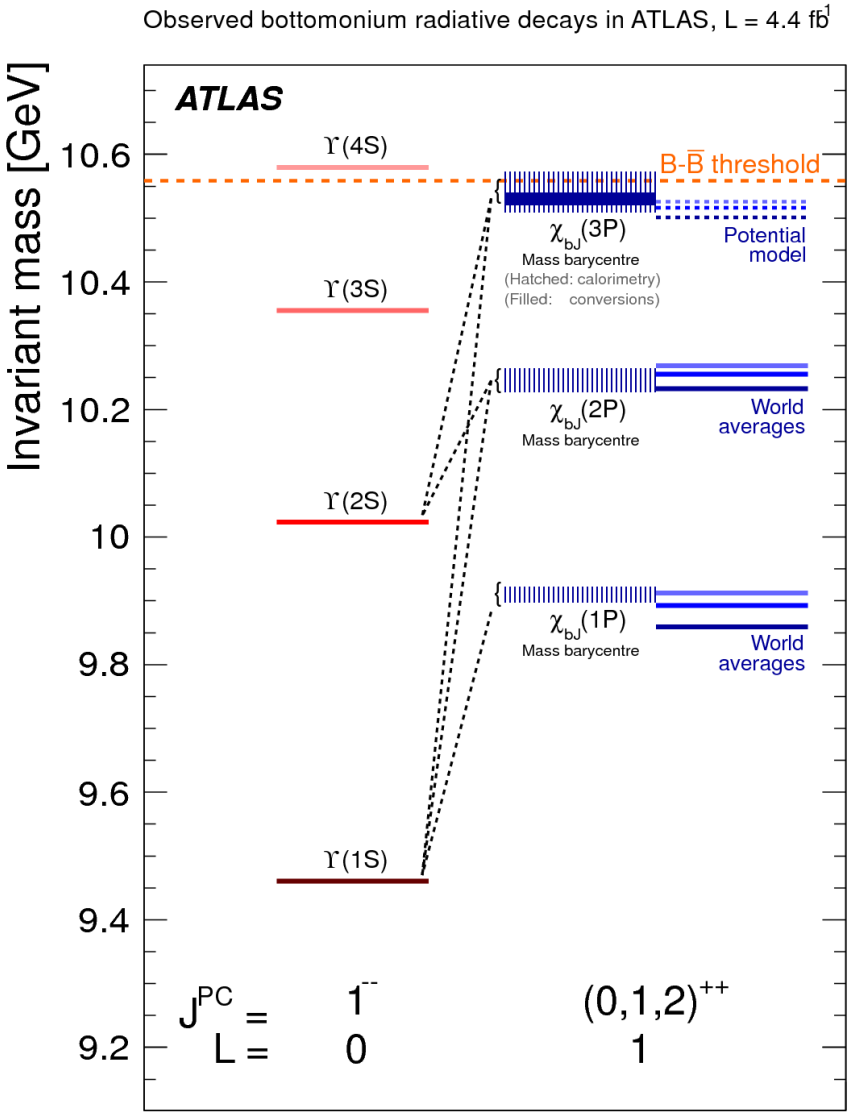
arXiv:1112.5154, PRL 108, 152001 (2012).

$$\chi_b(nP) \rightarrow \Upsilon(nS) + \gamma$$

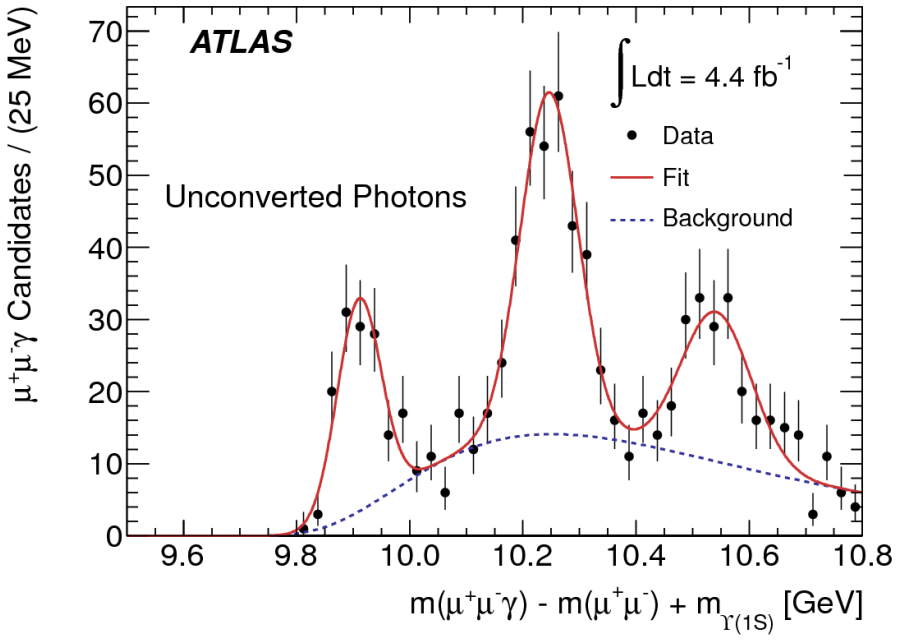
Photon measurement :

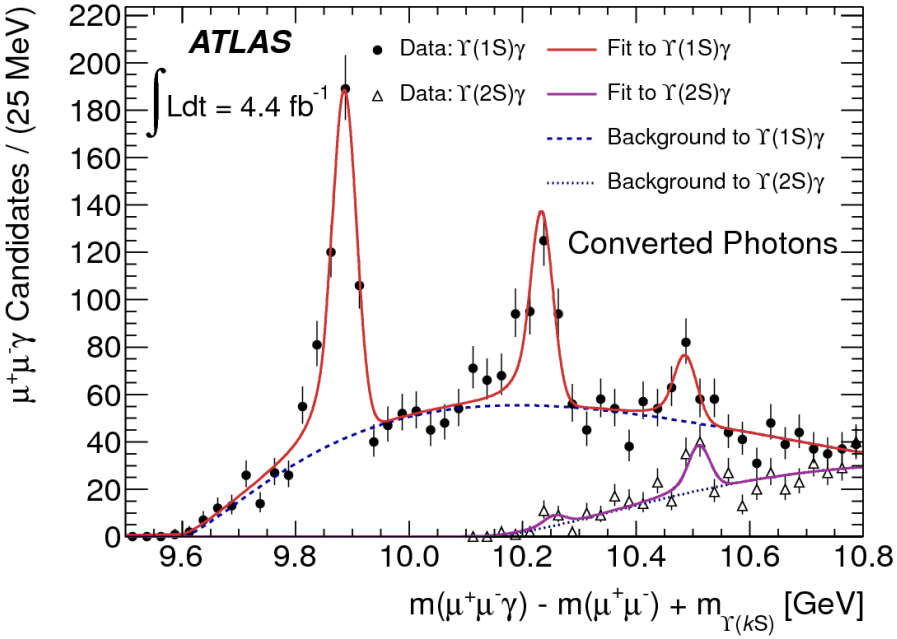
- **Calorimetric** :
  higher efficiency, modest resolution
- e^+e^- **conversion** in the tracker:
  small efficiency, better resolution





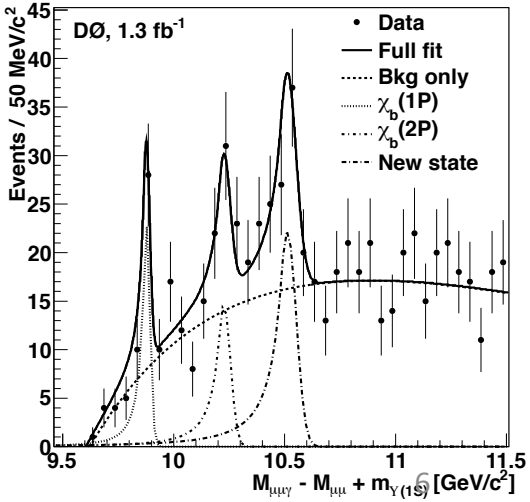
Observation of new states : $\chi_b(3P)$





Each peak represents a J=(0),1,2 triplet

State	Model predictions [3,4] [MeV]	Fitted masses [MeV] Unconverted photons	Converted photons
$\chi_b(1P)$	9900	9910 ± 6(stat) ± 11(syst)	Fixed to χ_{b1} = 9892.78 and χ_{b2} = 9912.21 [9]
$\chi_b(2P)$	10 260	10 246 ± 5(stat) ± 18(syst)	Fixed to χ_{b1} = 10 255.46 and χ_{b2} = 10 268.65 [9]
$\chi_b(3P)$	10 525	10 541 ± 11(stat) ± 30(syst)	10 530 ± 5(stat) ± 9(syst)

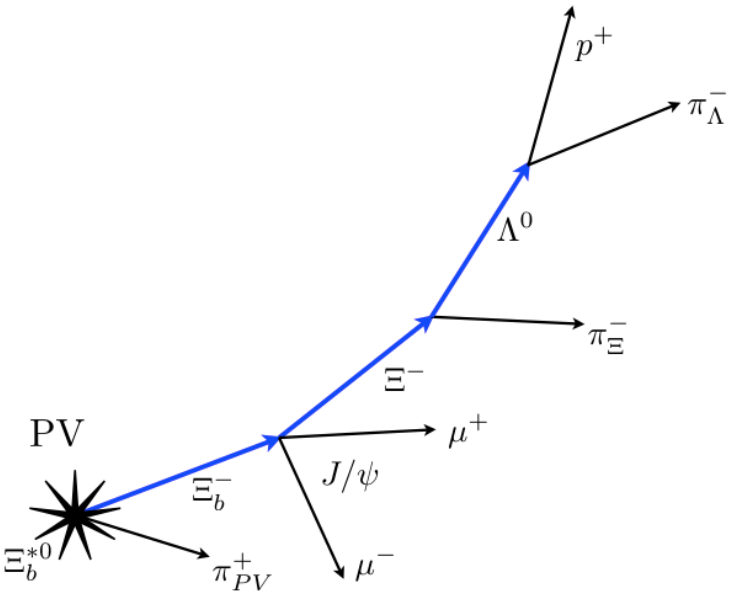


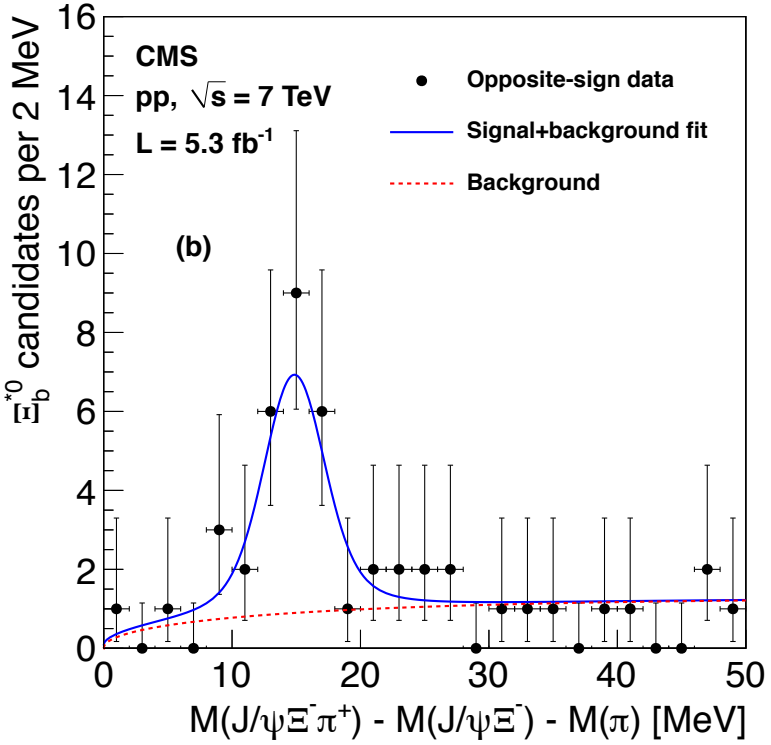
D0 confirms...

arXiv:1203.6034

"Observation of an excited Ξ_b baryon" [Ξ_b^*]

arXiv:1205.5955, submitted to PRL





Complicated cascade that challenges detector and reconstruction capabilities

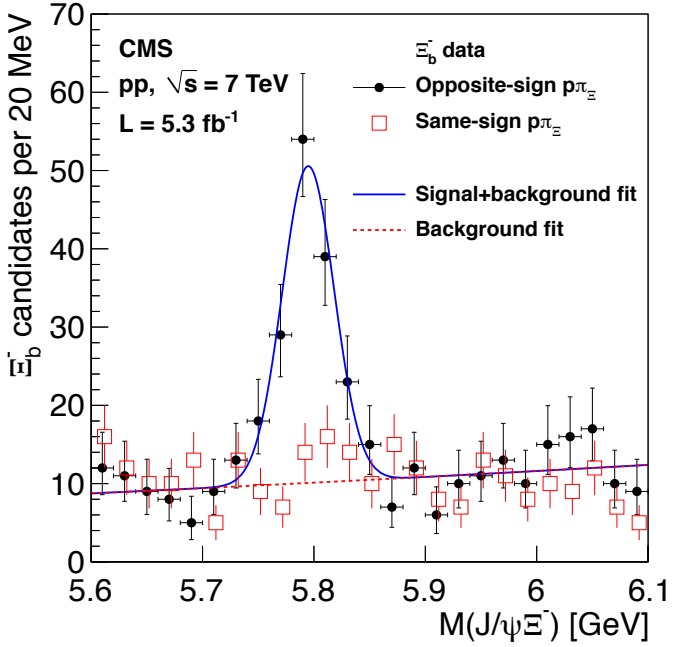
>5σ evidence

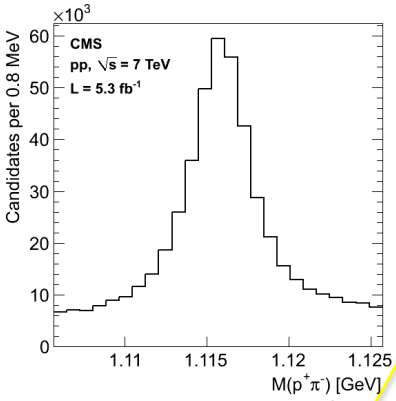
21 candidates observed, expected background : 3

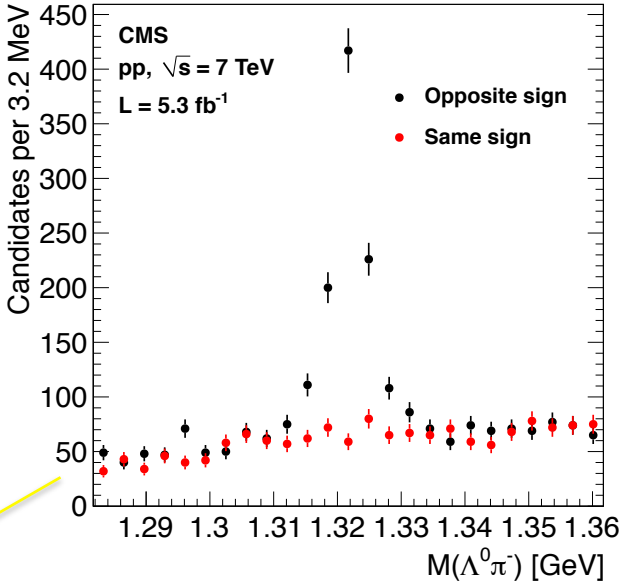
$$Q = M(\mathrm{J}/\psi\Xi^-\pi^+) - M(\mathrm{J}/\psi\Xi^-) - M(\pi) : 14.84 \pm 0.74\,(\mathrm{stat.}) \pm 0.28\,(\mathrm{syst.})\,\mathrm{MeV}$$

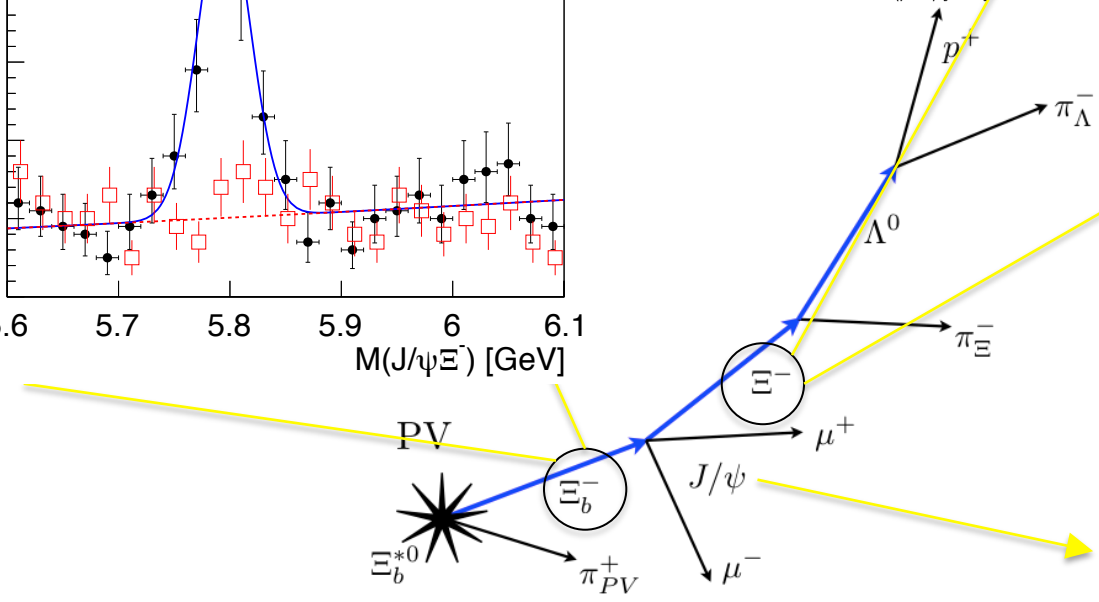
$m_{\Xi b^*}$ = 5945.0 ± 0.7(stat) ± 0.3(sys) ± 2.7(PDG) MeV

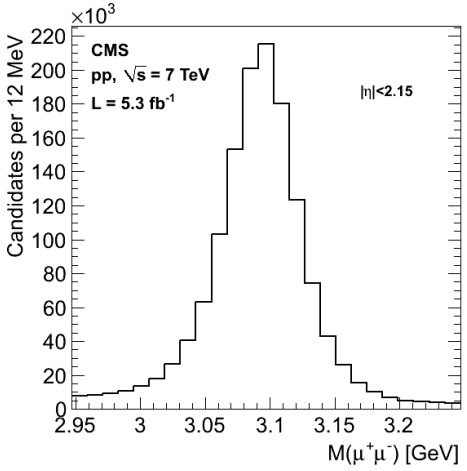
Observation of new states : Ξ_b^*



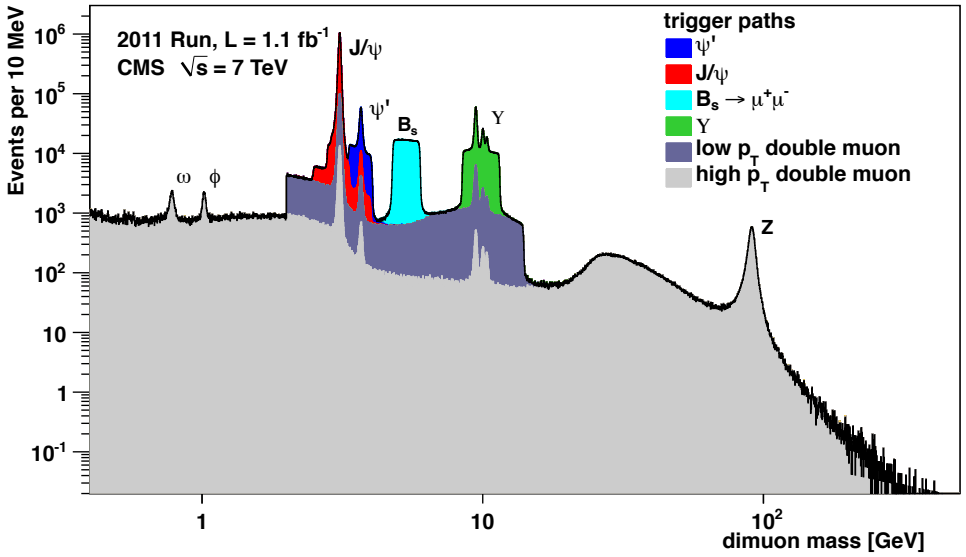




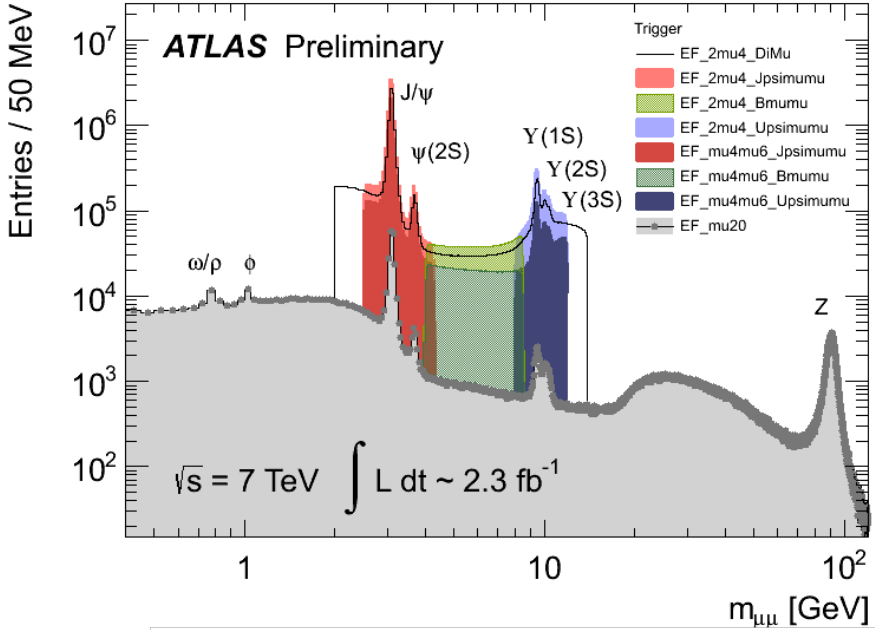




Reconstruction of intermediate states and purity



Production: Quarkonia



χ_{c2} / χ_{c1} production ratio

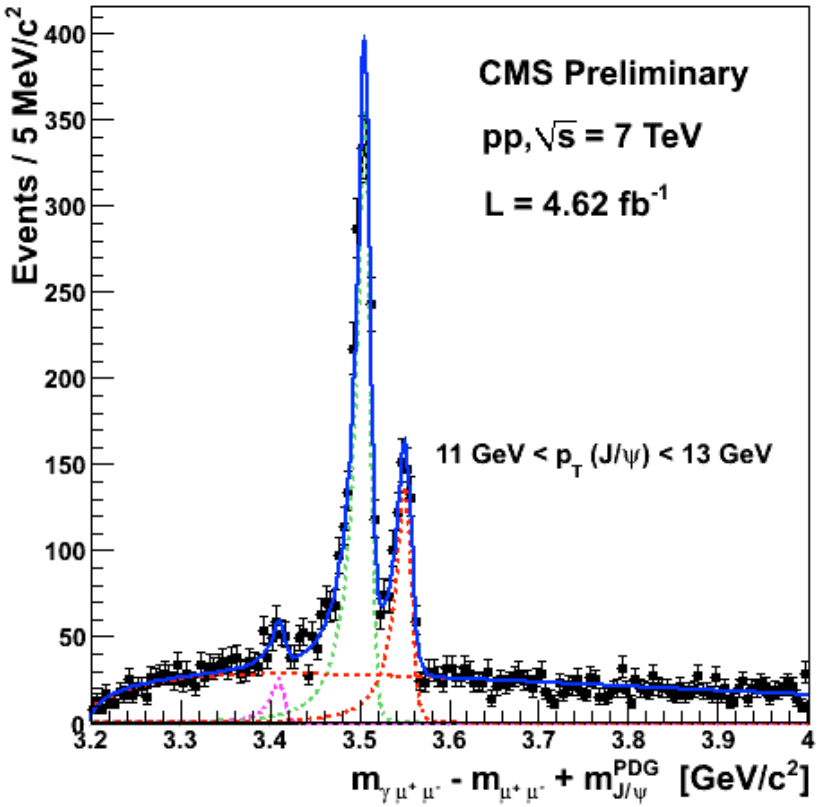
PAS-BPH-11-010

NEW PREMIERE

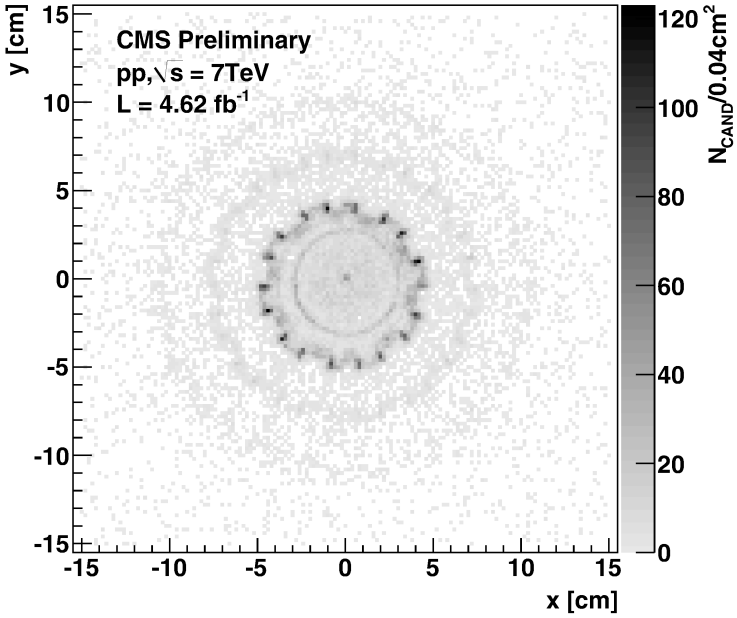
$$\frac{\sigma(pp \to \chi_{c2} + X)}{\sigma(pp \to \chi_{c1} + X)} \times \frac{BR(\chi_{c2} \to J/\psi + \gamma)}{BR(\chi_{c1} \to J/\psi + \gamma)}$$

Interesting test of QCD
Exp. and theo. uncertainties cancel
Puzzling results from previous measurements

$\chi_c \rightarrow J/\psi + \gamma$
$\hookrightarrow e^+e^-$

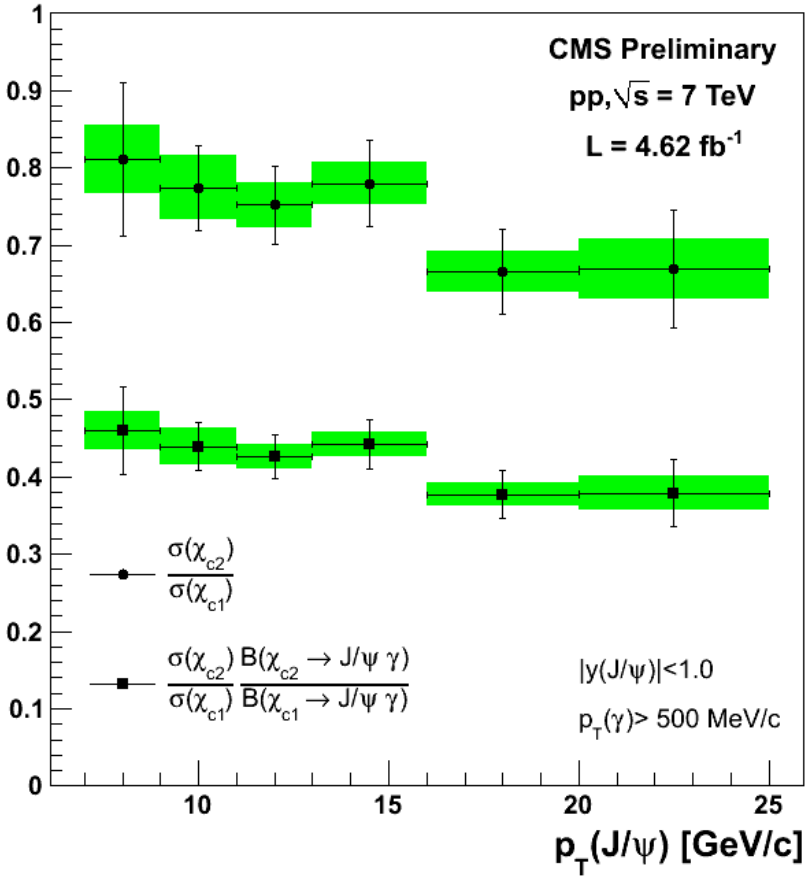


Q resolution ~6 MeV



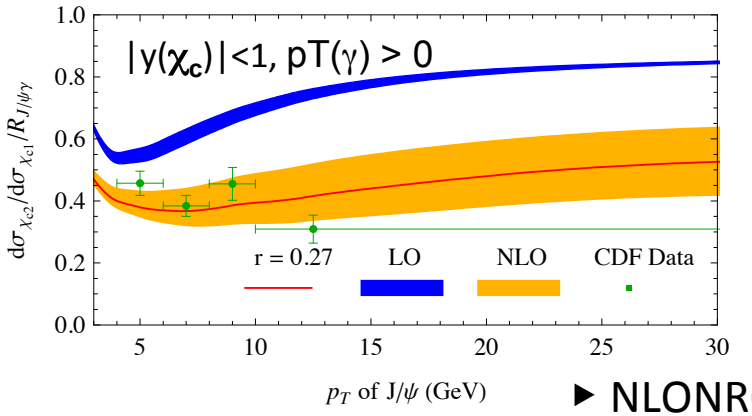
- Prompt J/ψ trigger
- Loose μ selection, 3.0< $m_{\mu\mu}$ < 3.2 GeV, prob(v)>0.01
- R_{conv}> 1.5 cm
- Prompt component selection: $l_{J/\psi}$> 30 μm
- |y(J/ψ)| > 1.0, pT(γ) > 500 MeV

χ_{c2} / χ_{c1} ratio

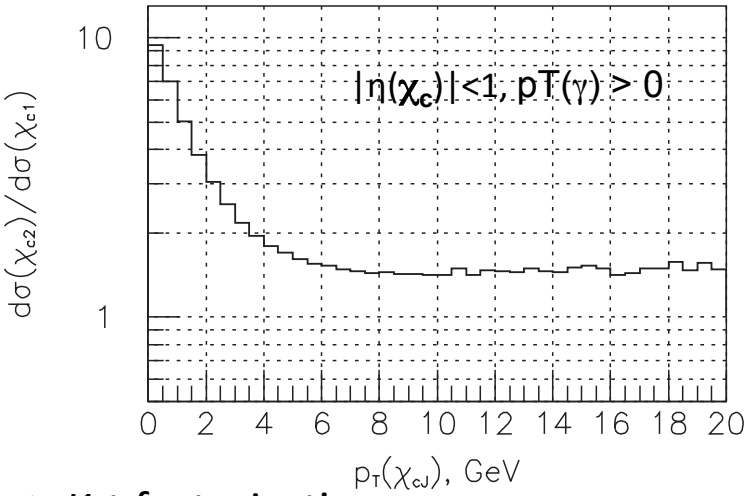


- Systematic errors from signal and bkg parameterization and efficiency corrections (calculated in the unpolarised case).
- Extreme polarisation scenarios can lead to variations up to 20%

Predictions for Tevatron



- NLONRQCD
  Phys. Rev. D 83, 111503(R) (2011)

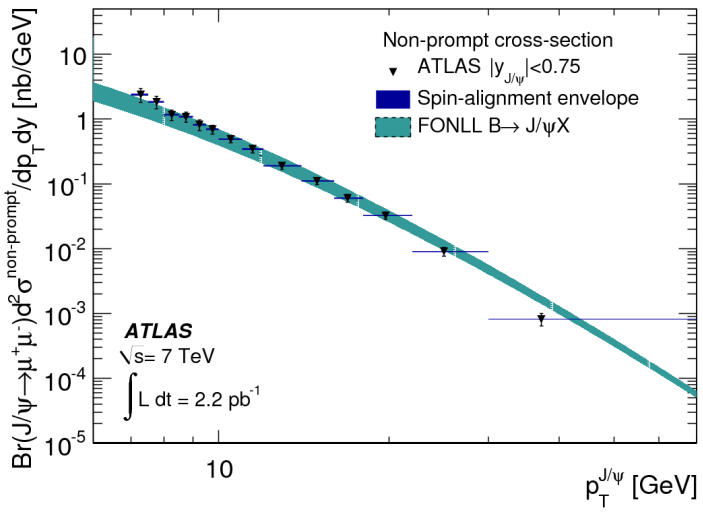


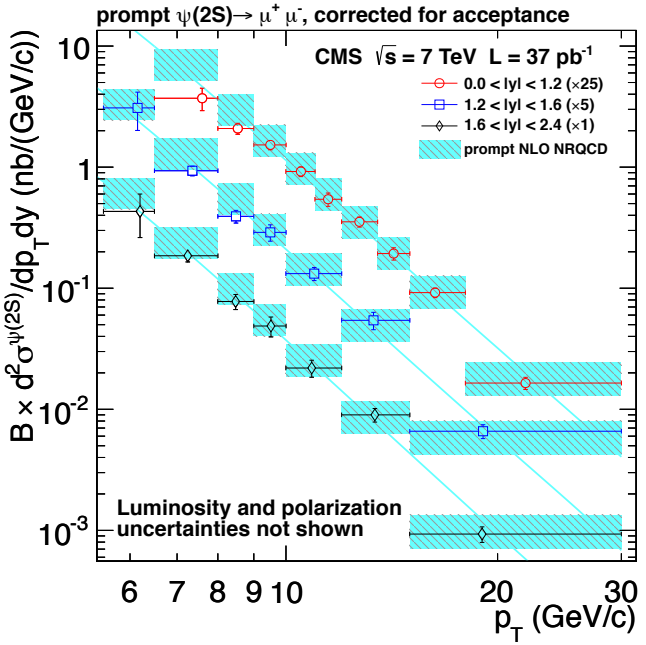
- K-t factorization
  Phys. Rev. D 83, 034035 (2011)

J/ψ , ψ'

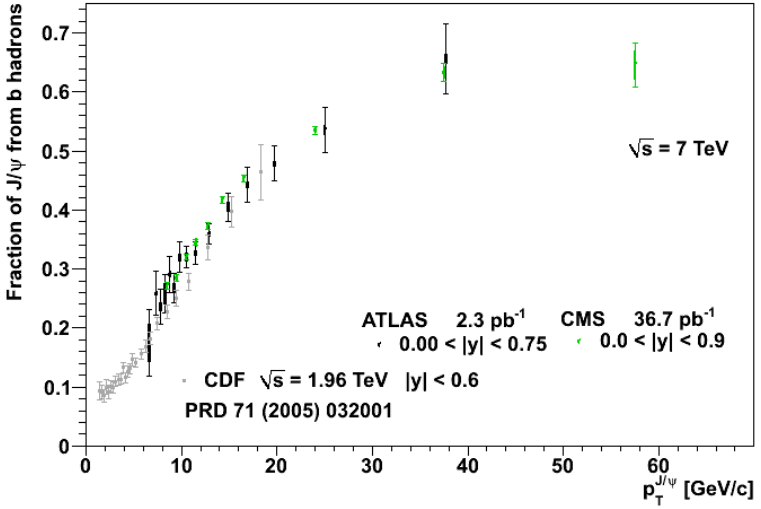
JHEP 02 (2012) 011

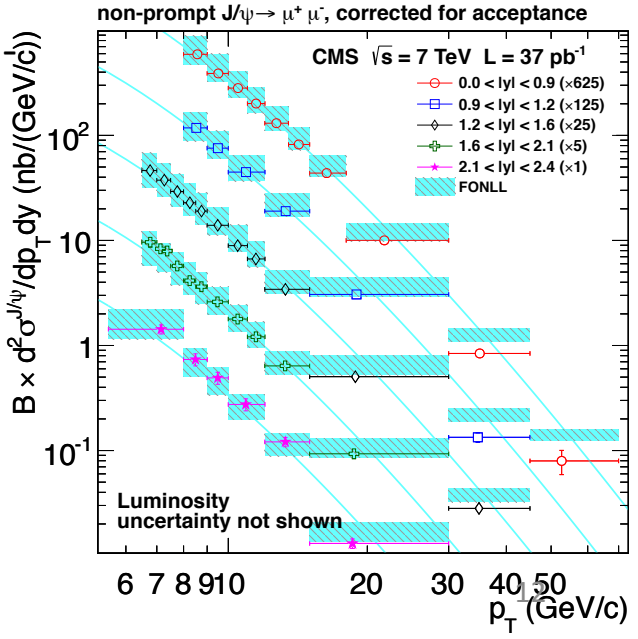
Nucl.Phys. **B850** (2011) 387-444





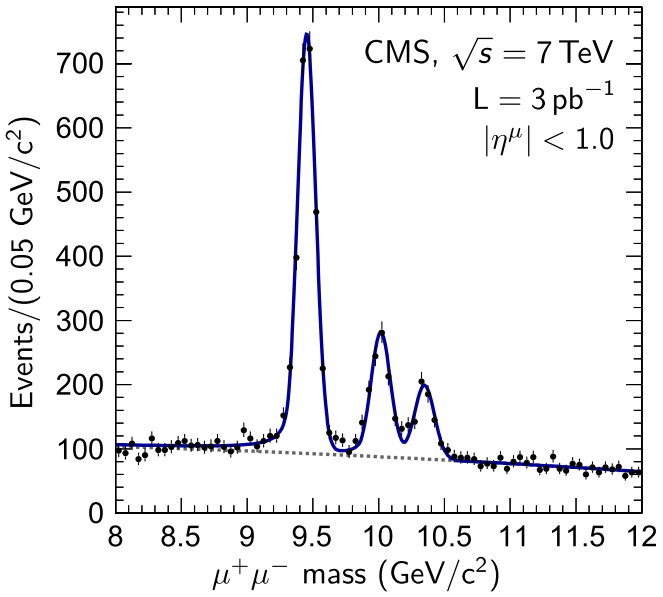
- Technique: 2D fits to mass and lifetime, per event ε corrections.
- Good agreement with NLO NRQCD (prompt) and FONLL (non-prompt)

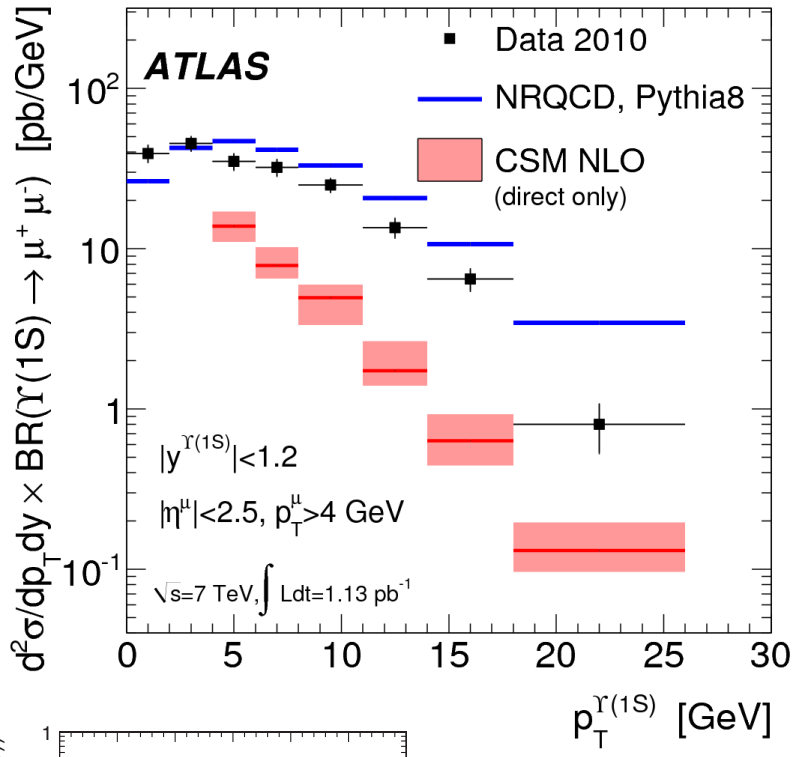


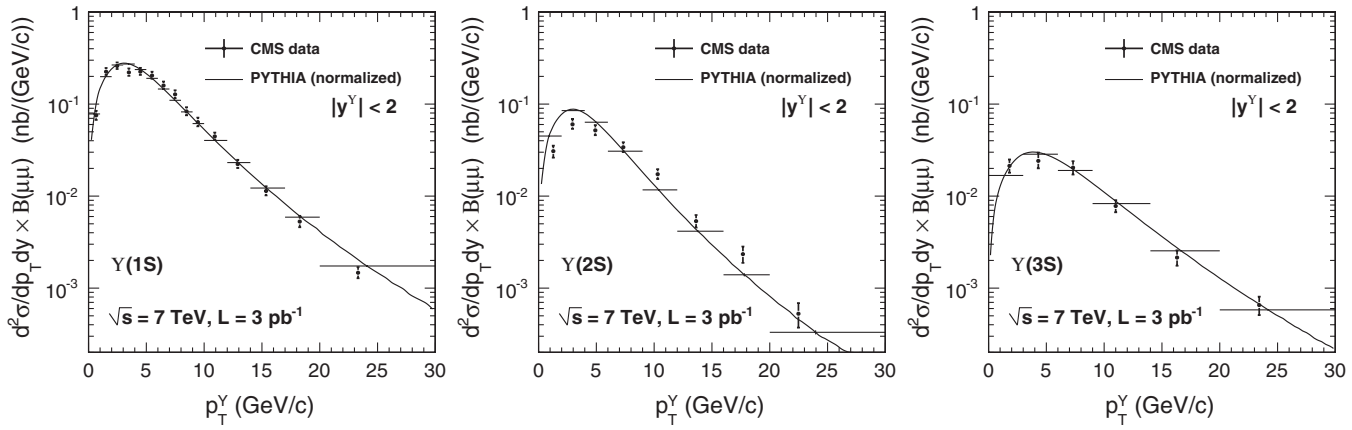


Υ

Phys. Rev. D 83, 112004 (2011)
Phys. Lett. B 705 (2011) 9-27







- The shape of $d\sigma/dp_T$ is well reproduced but absolute values overestimated by a factor 2 in NRQCD

Exclusive Production cross sections

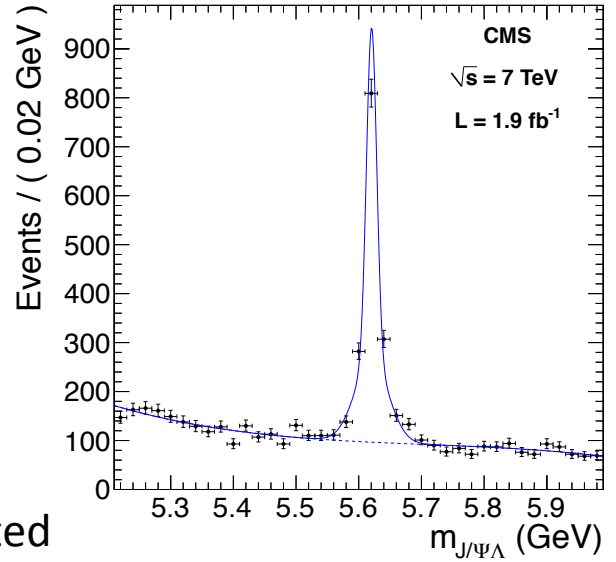
Measurement of the Λ_b differential cross section

arXiv:1205.5955, submitted to PLB

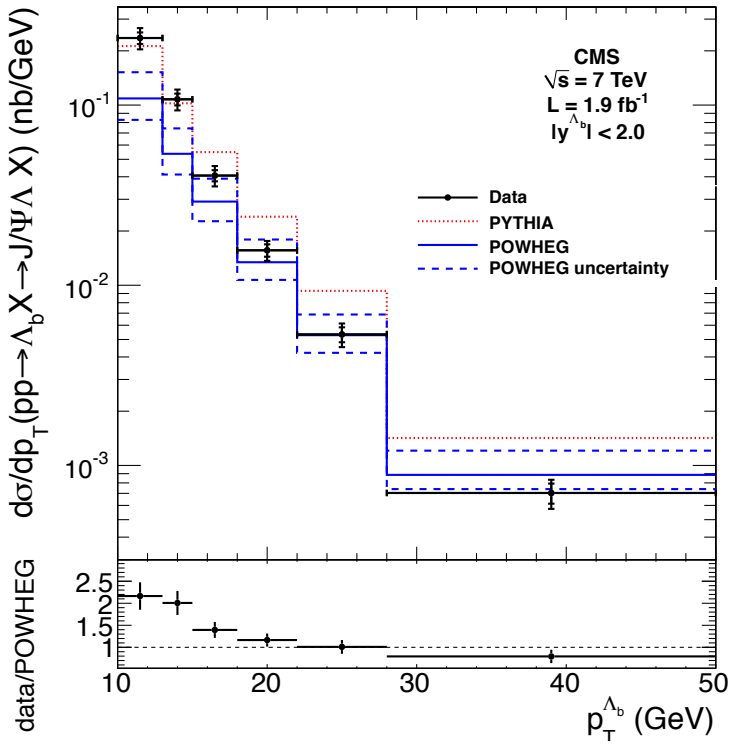
$$\Lambda_b \to J/\psi \Lambda^0 \to \mu\mu p\pi^-$$

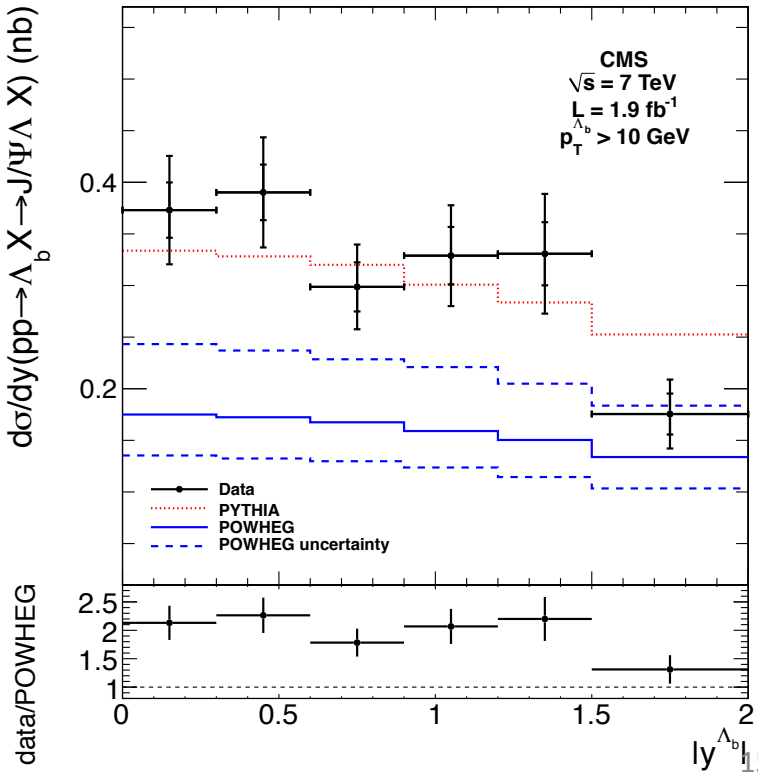
Displaced J/psi trigger

$$\frac{\mathrm{d}\sigma(\mathrm{pp} \to \Lambda_\mathrm{b} X)}{\mathrm{d}p_\mathrm{T}^{\Lambda_\mathrm{b}}} \times \mathcal{B}(\Lambda_\mathrm{b} \to \mathrm{J}/\psi\Lambda) = \frac{n_\mathrm{sig}}{2 \cdot \epsilon \cdot \mathcal{B} \cdot \mathcal{L} \cdot \Delta p_\mathrm{T}^{\Lambda_\mathrm{b}}},$$

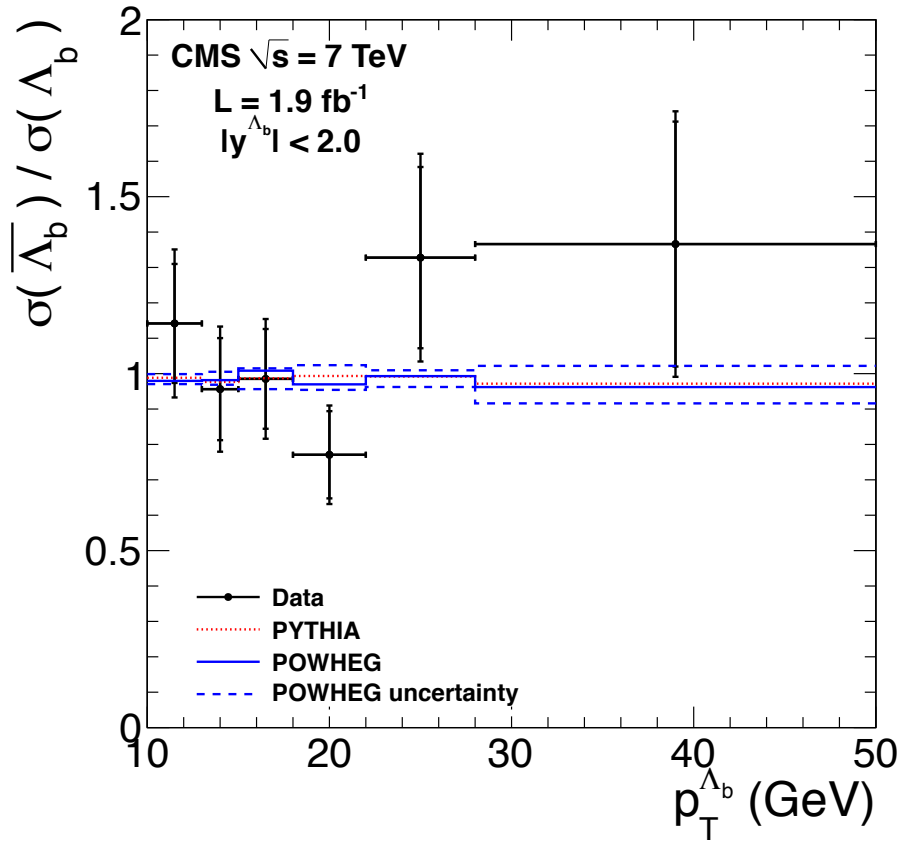


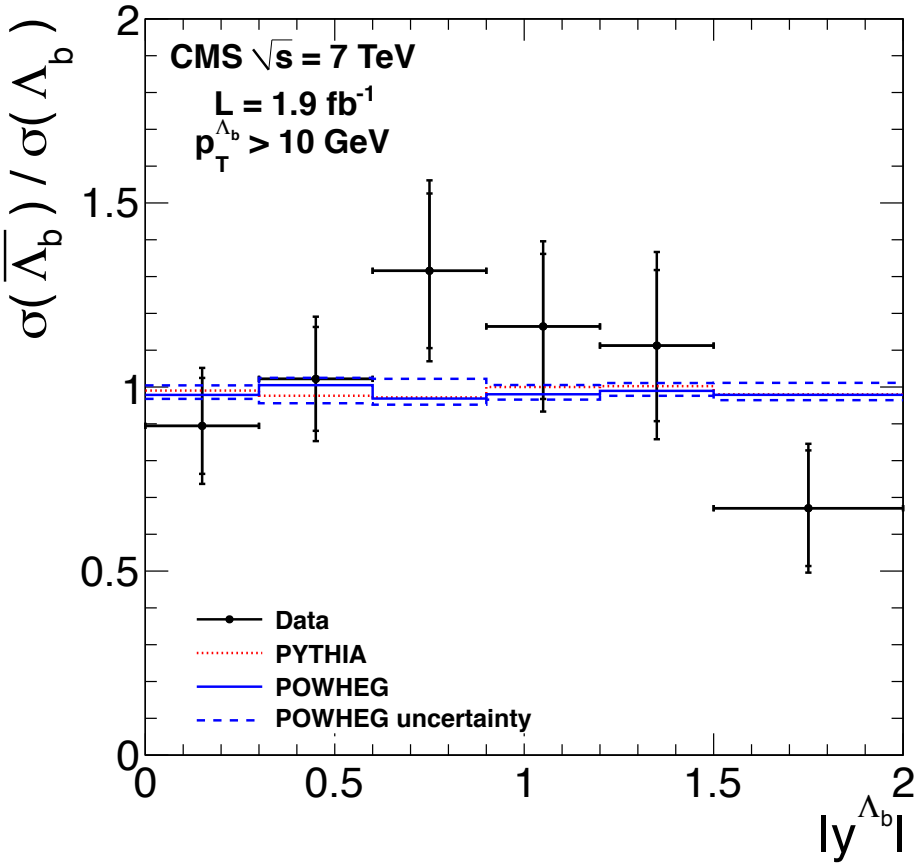
Measured p_T spectrum seems to fall more steeply than predicted





Λ_b - asymmetries





- The measured asymmetry is consistent with unity and constant with p_T and y

Measurement of $D^{*\pm}$ meson production in jets

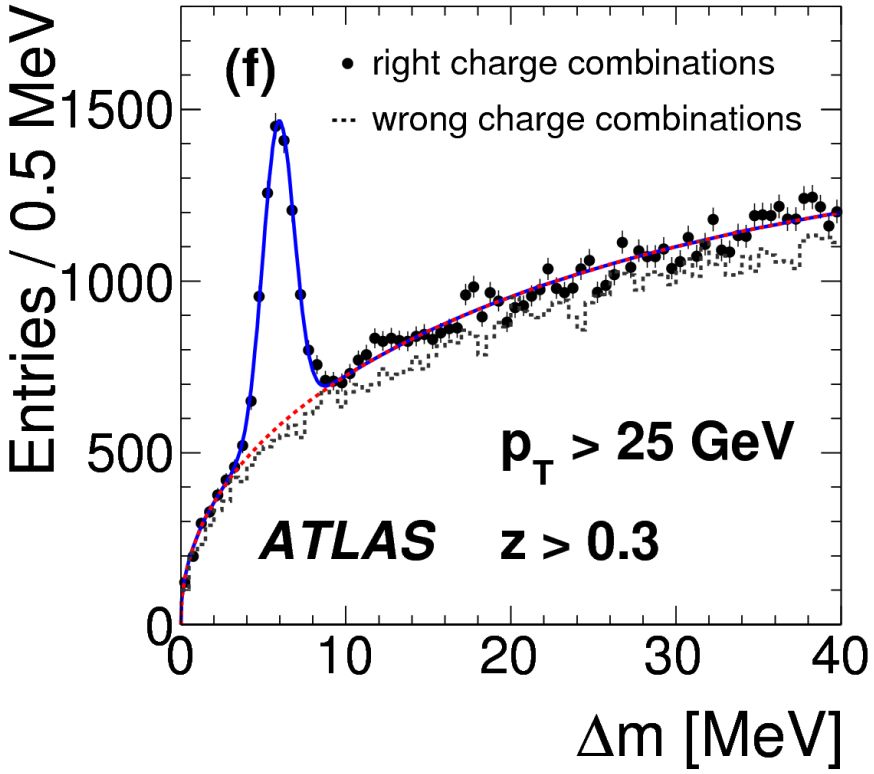
Phys. Rev. D 85, 052005 (2012)

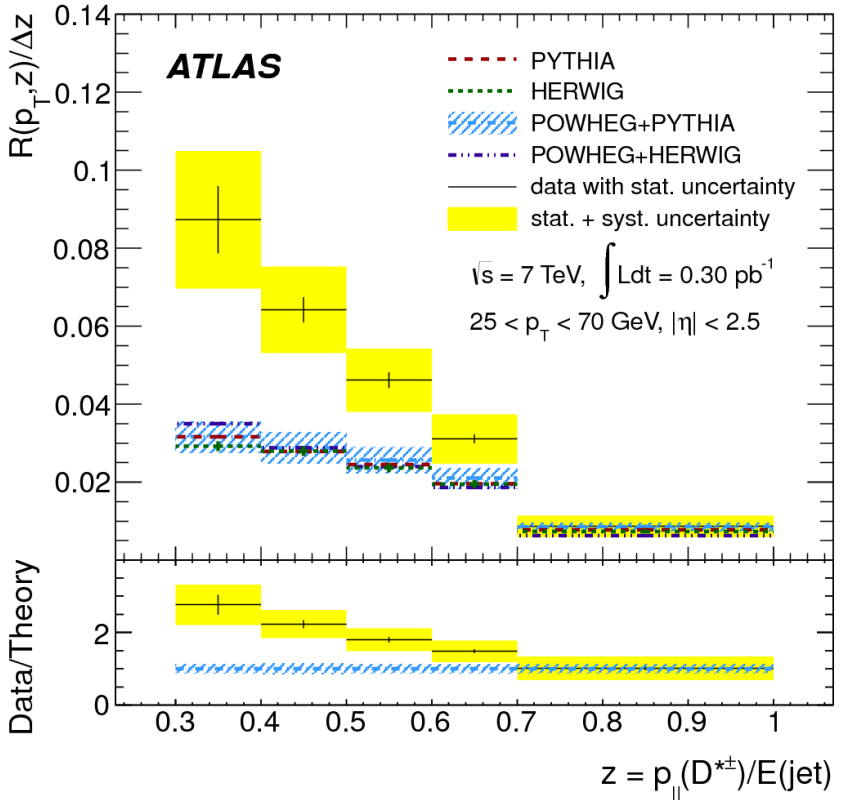
$D^{*+} \rightarrow D^0\pi^+, D^0 \rightarrow K^-\pi^+$

$$\mathcal{R}(p_T, z) = \frac{N_{D^{*\pm}}(p_T, z)}{N_{\text{jet}}(p_T)},$$

$$z = p_{\parallel}(D^{*\pm})/E(\text{jet})$$

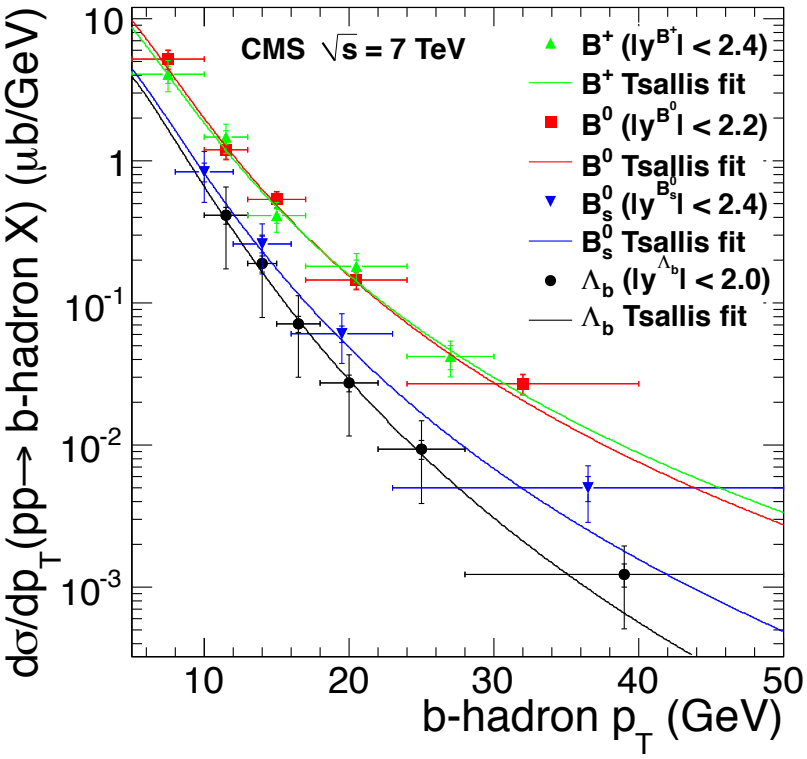
$$\mathcal{R} = 0.025 \pm 0.001(\text{stat.}) \pm 0.004(\text{syst.})$$

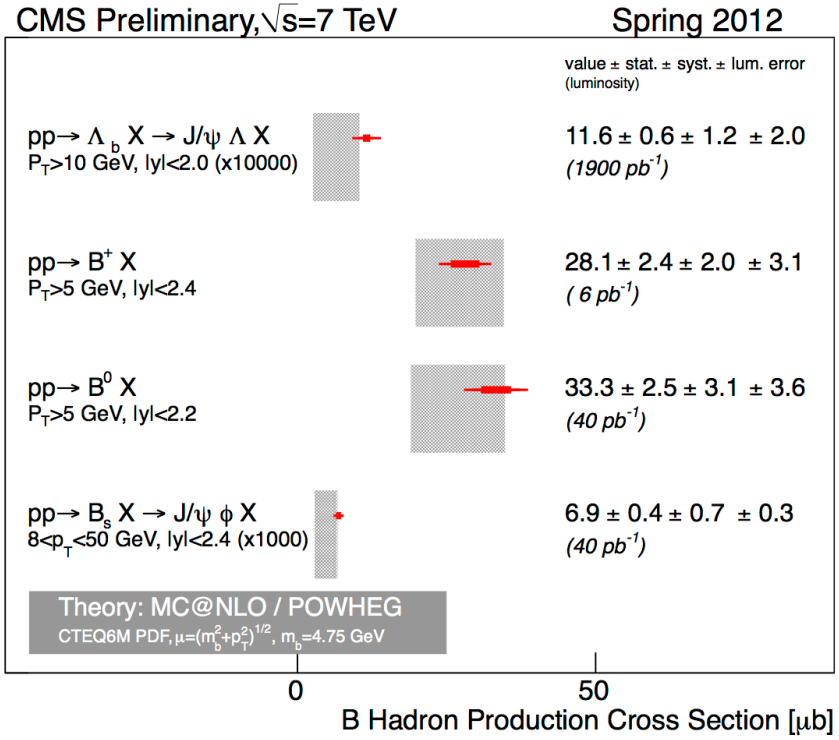




Sizeable discrepancies with all the models considered are found

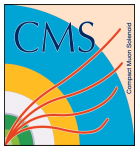
Summary of exclusive





- Recently measured Λ_b spectrum found to fall faster than B meson spectra and predictions

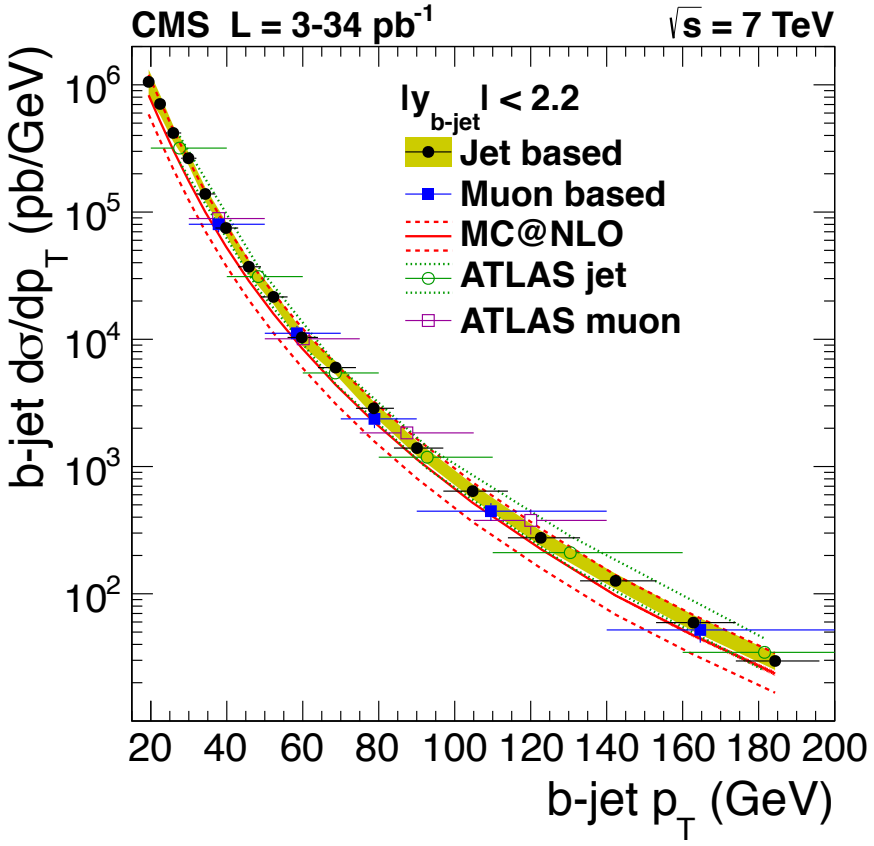
- D* predictions lower by a factor 2 or 3 at low z and p_T

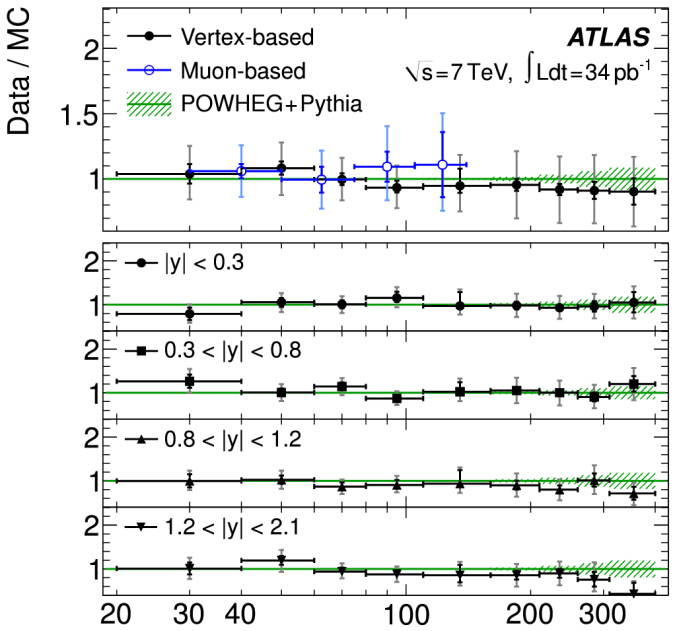


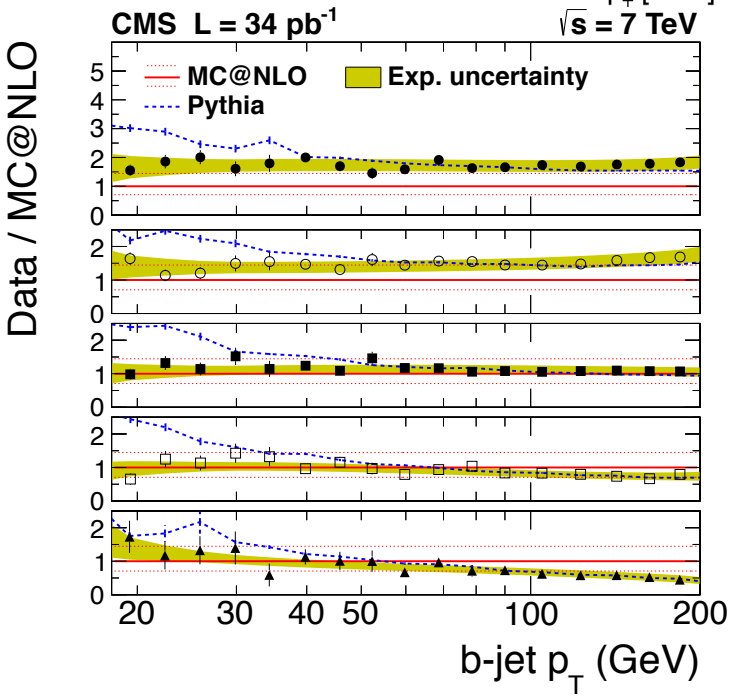

Inclusive b production

Inclusive b-jet production

Eur.Phys.J.C 71 (2011) 1846
arXiv: 1202.4617

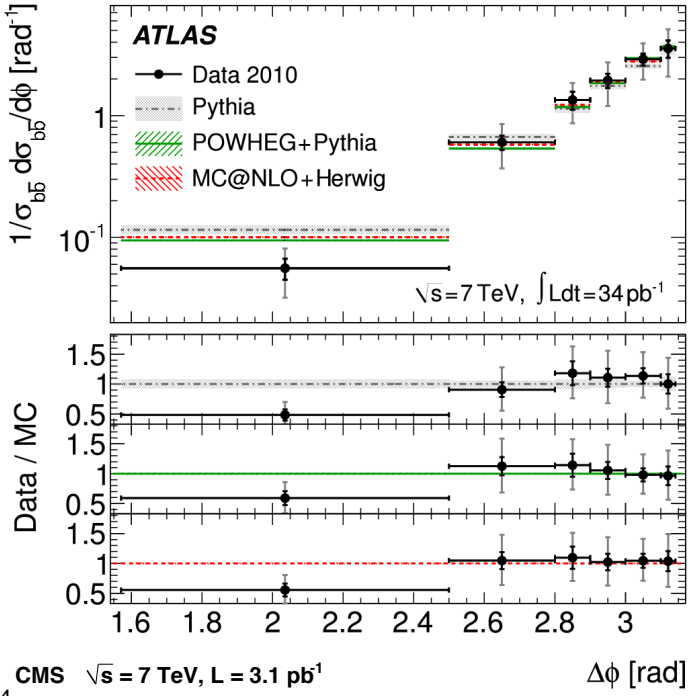


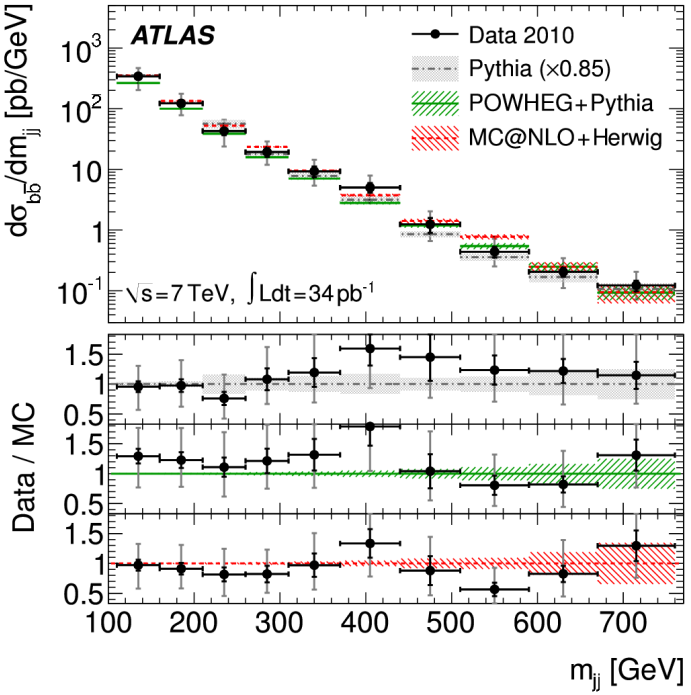


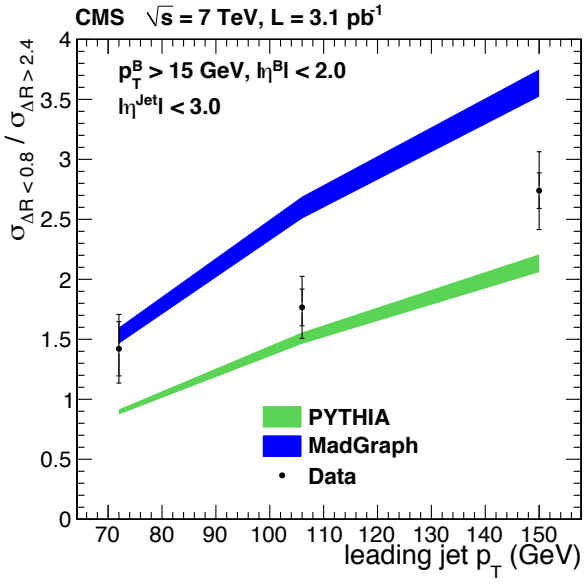


Atlas and CMS presented compatible dσ/dp$_T$ measurements in good agreement with models

Inclusive b-jet production







JHEP03(2011)136

Good agreement CMS/ATLAS
Good agreement with theory except for small ΔΦ .
Angular correlations not explained by models

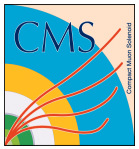
Conclusions

- ATLAS and CMS are providing high-quality heavy flavour results
- Several analyses on 2011 data in the works.
- Terse message from this talk:
  - New states : $\chi_b(3P)$ and Ξ_b^*
  - New measurements : Λ_b cross sections and χ_c ratio
  - Open Beauty measurements well described by theory except: angular correlations, small $\Delta\Phi$
  - Open Charm not so well understood

More Info:

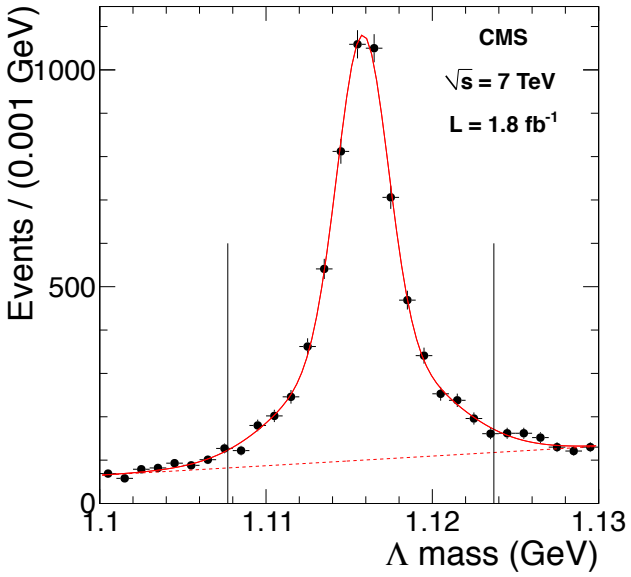
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/BPhysPublicResults

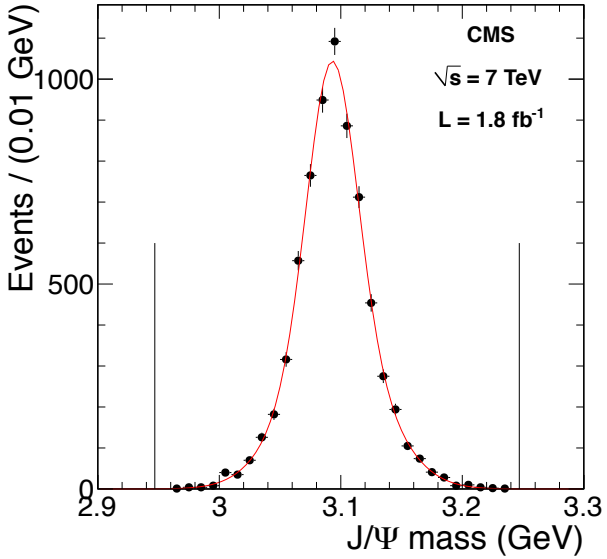
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH



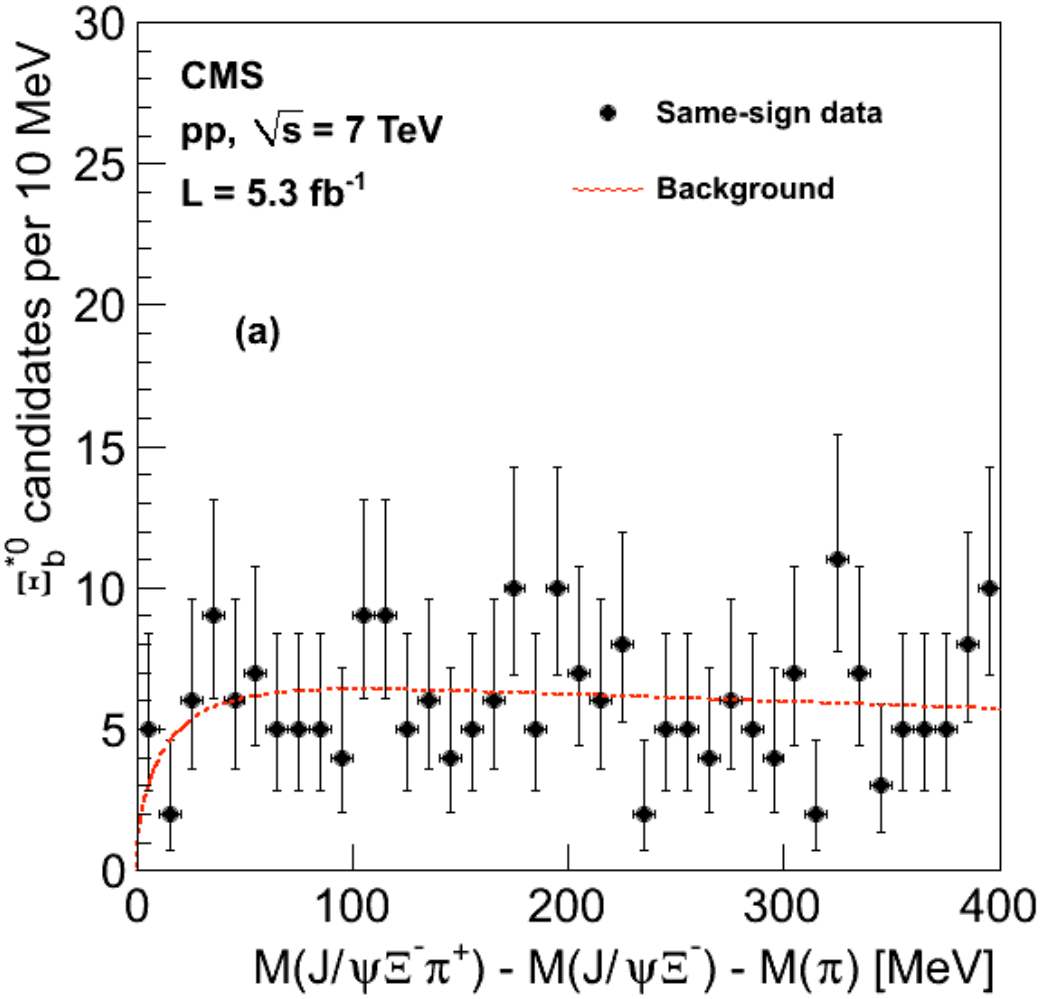

BACKUPS

Λ_b


CMS
√s = 7 TeV
L = 1.8 fb-1
Events / (0.001 GeV)
1000
500
0
1.1
1.11
1.12
1.13
Λ mass (GeV)

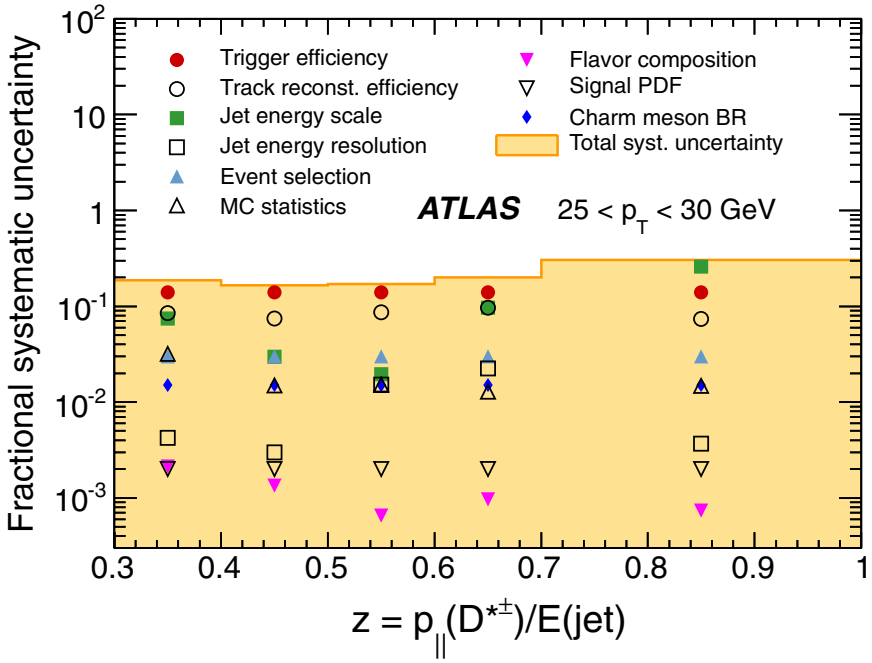

CMS
√s = 7 TeV
L = 1.8 fb-1
Events / (0.01 GeV)
1000
500
0
2.9
3
3.1
3.2
3.3
J/Ψ mass (GeV)

Ξ_b^*



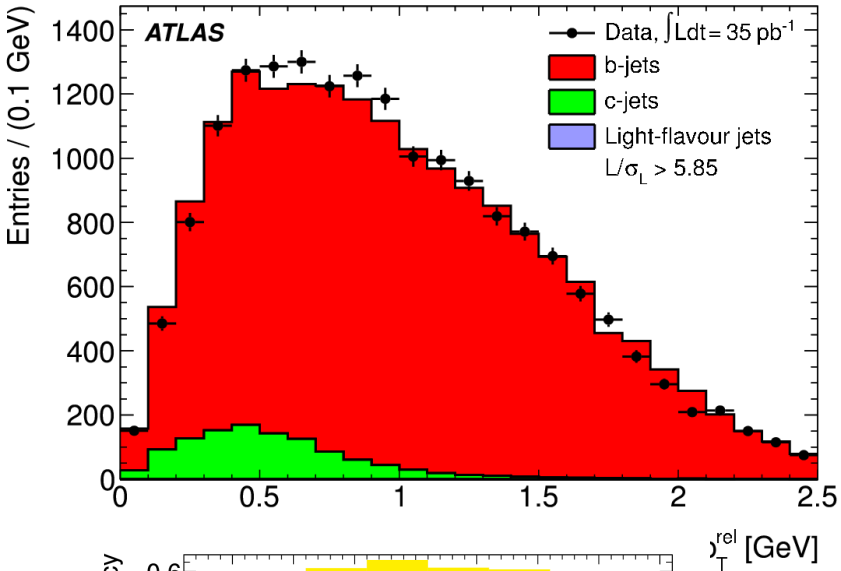
same sign xib* pi pv

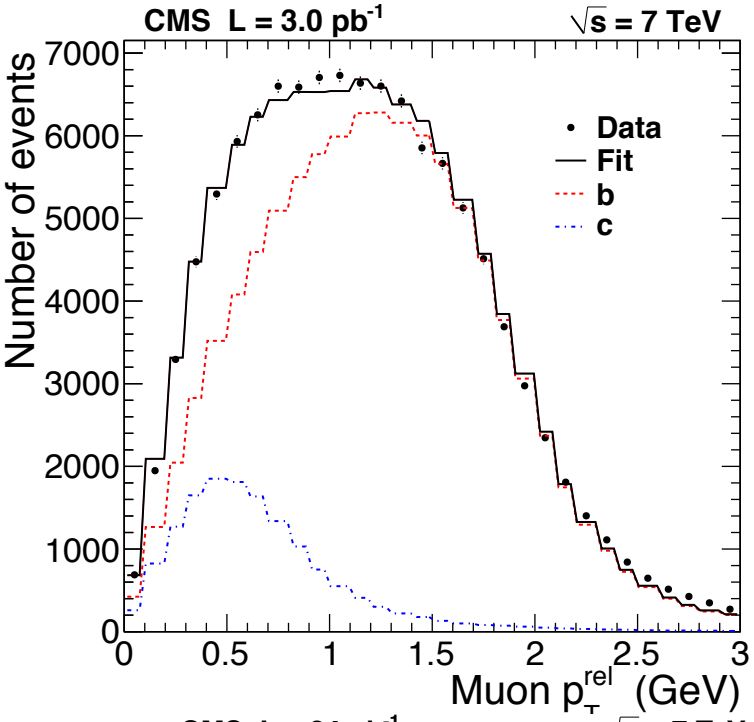
D^{0*}

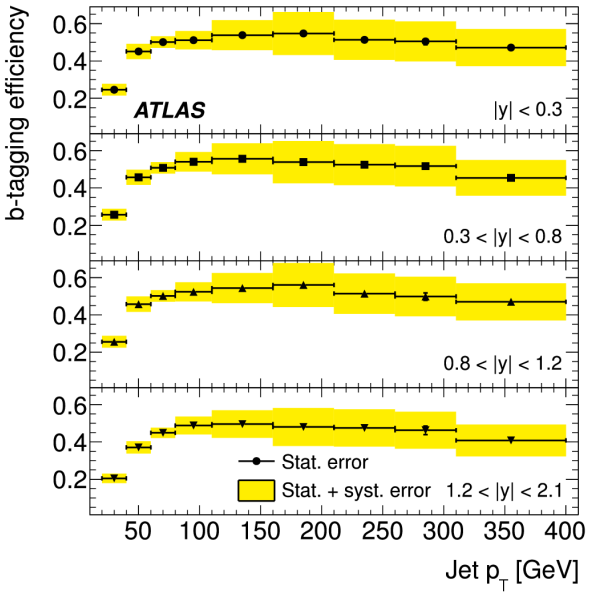


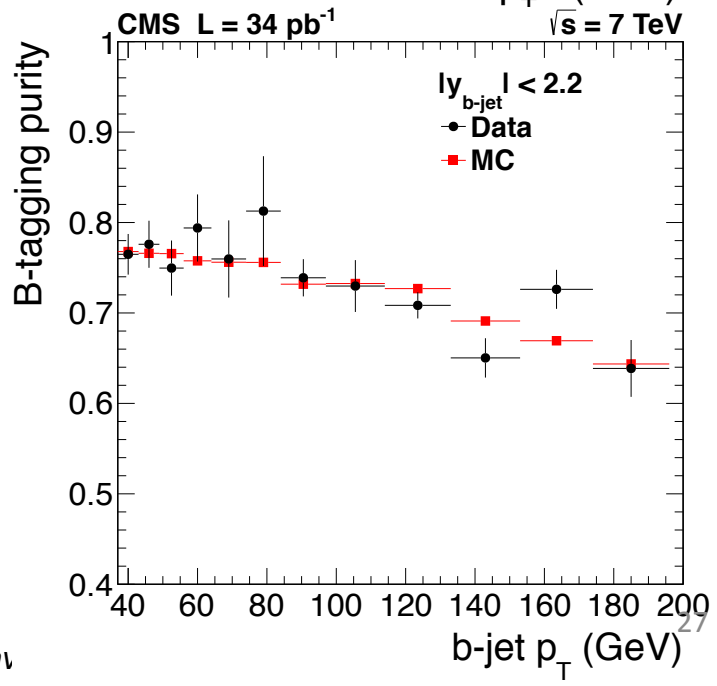
Systematic uncertainties

b-tag

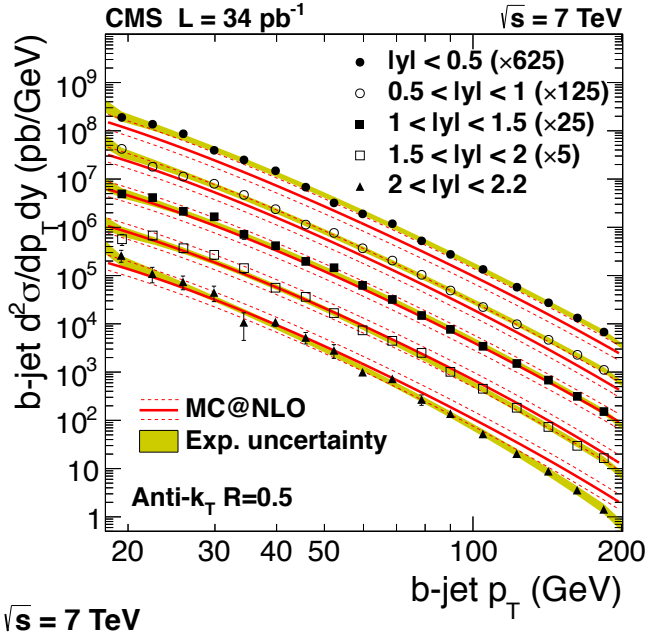

ATLAS
Data, ∫Ldt = 35 pb⁻¹
b-jets
c-jets
Light-flavour jets
L/σ_L > 5.85
Entries / (0.1 GeV)
p_T^rel [GeV]

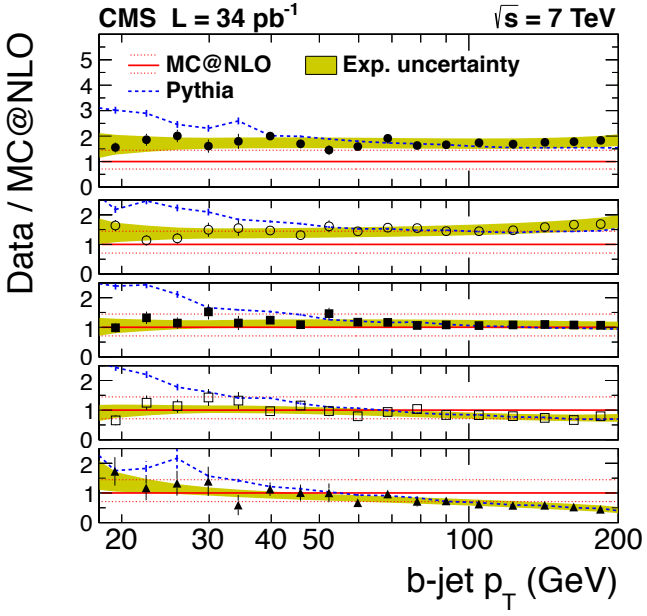

CMS L = 3.0 pb⁻¹
√s = 7 TeV
Data
Fit
b
c
Number of events
Muon p_T^rel (GeV)

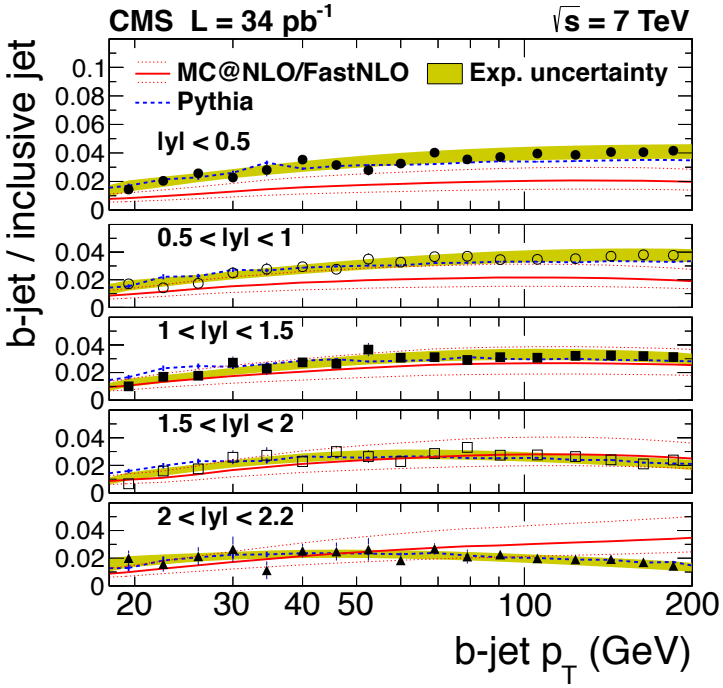

ATLAS
|y| < 0.3
0.3 < |y| < 0.8
0.8 < |y| < 1.2
1.2 < |y| < 2.1
Stat. error
Stat. + syst. error
b-tagging efficiency
Jet p_T [GeV]

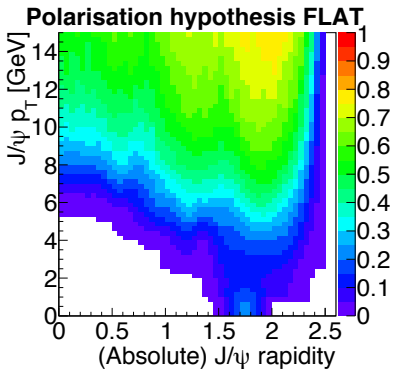

CMS L = 34 pb⁻¹
√s = 7 TeV
|y_b-jet| < 2.2
Data
MC
B-tagging purity
b-jet p_T (GeV)

Inclusive B

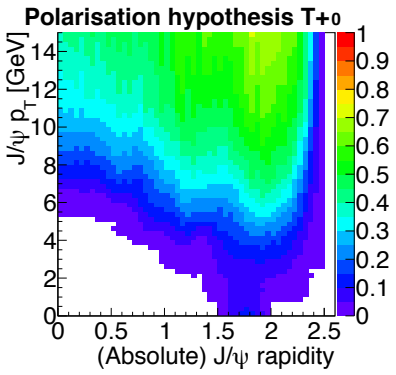

CMS L = 34 pb-1
√s = 7 TeV
|y| < 0.5 (×625)
0.5 < |y| < 1 (×125)
1 < |y| < 1.5 (×25)
1.5 < |y| < 2 (×5)
2 < |y| < 2.2
MC@NLO
Exp. uncertainty
Anti-kT R=0.5
b-jet d2σ/dpTdy (pb/GeV)
b-jet pT (GeV)


CMS L = 34 pb-1
√s = 7 TeV
MC@NLO
Exp. uncertainty
Pythia
Data / MC@NLO
b-jet pT (GeV)

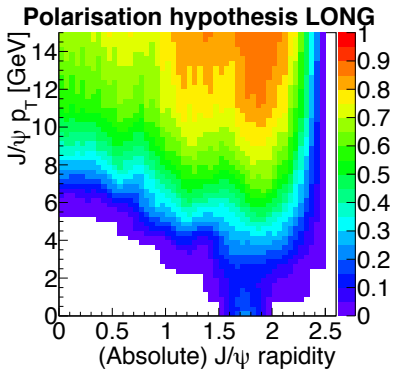

CMS L = 34 pb-1
√s = 7 TeV
MC@NLO/FastNLO
Exp. uncertainty
Pythia
|y| < 0.5
0.5 < |y| < 1
1 < |y| < 1.5
1.5 < |y| < 2
2 < |y| < 2.2
b-jet / inclusive jet
b-jet pT (GeV)



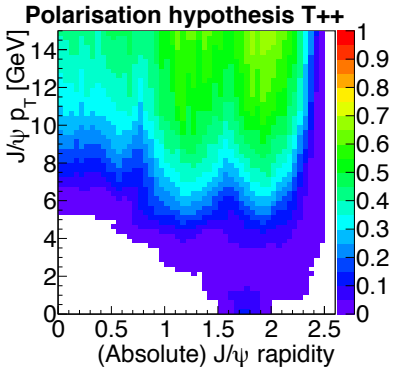
(a) $\lambda_\theta = \lambda_\phi = \lambda_{\theta\phi} = 0$



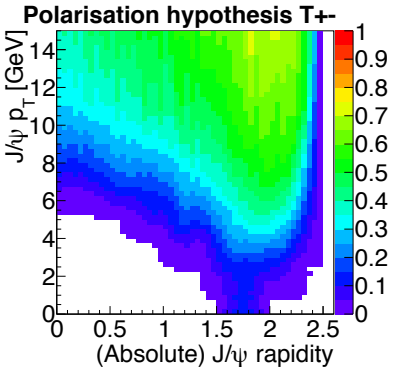
(b) $\lambda_\theta = +1, \lambda_\phi = \lambda_{\theta\phi} = 0$



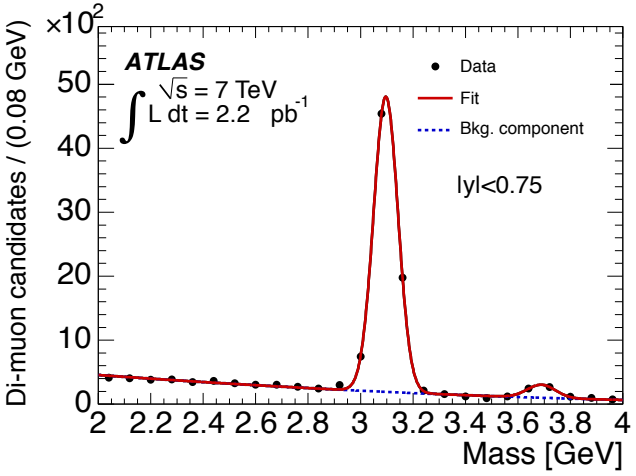
(c) $\lambda_\theta = -1, \lambda_\phi = \lambda_{\theta\phi} = 0$

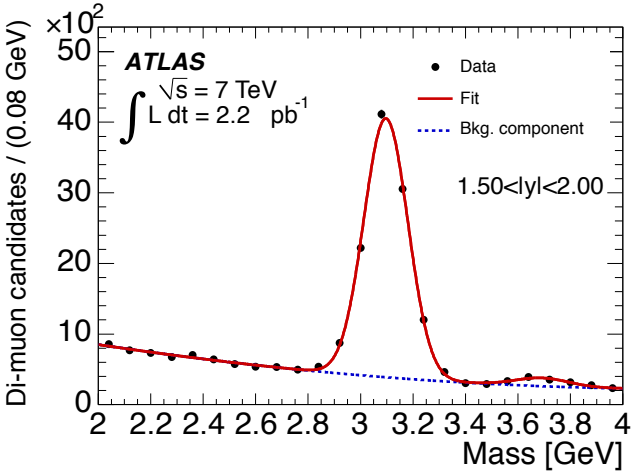


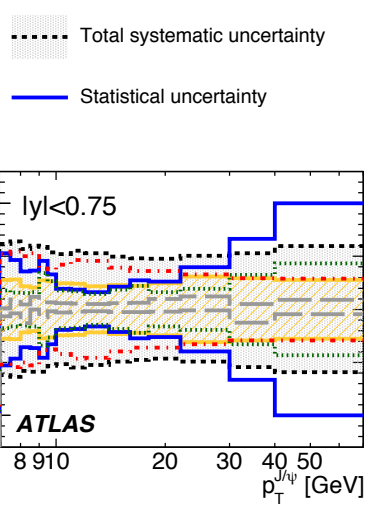
(d) $\lambda_\theta = +1, \lambda_\phi = +1, \lambda_{\theta\phi} = 0$

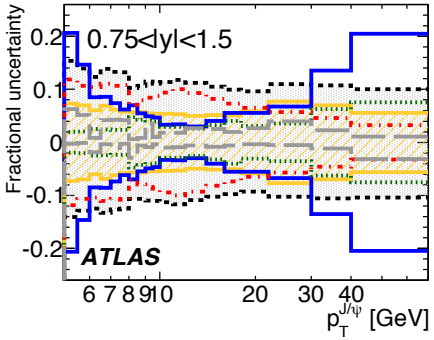


(e) $\lambda_\theta = +1, \lambda_\phi = -1, \lambda_{\theta\phi} = 0$



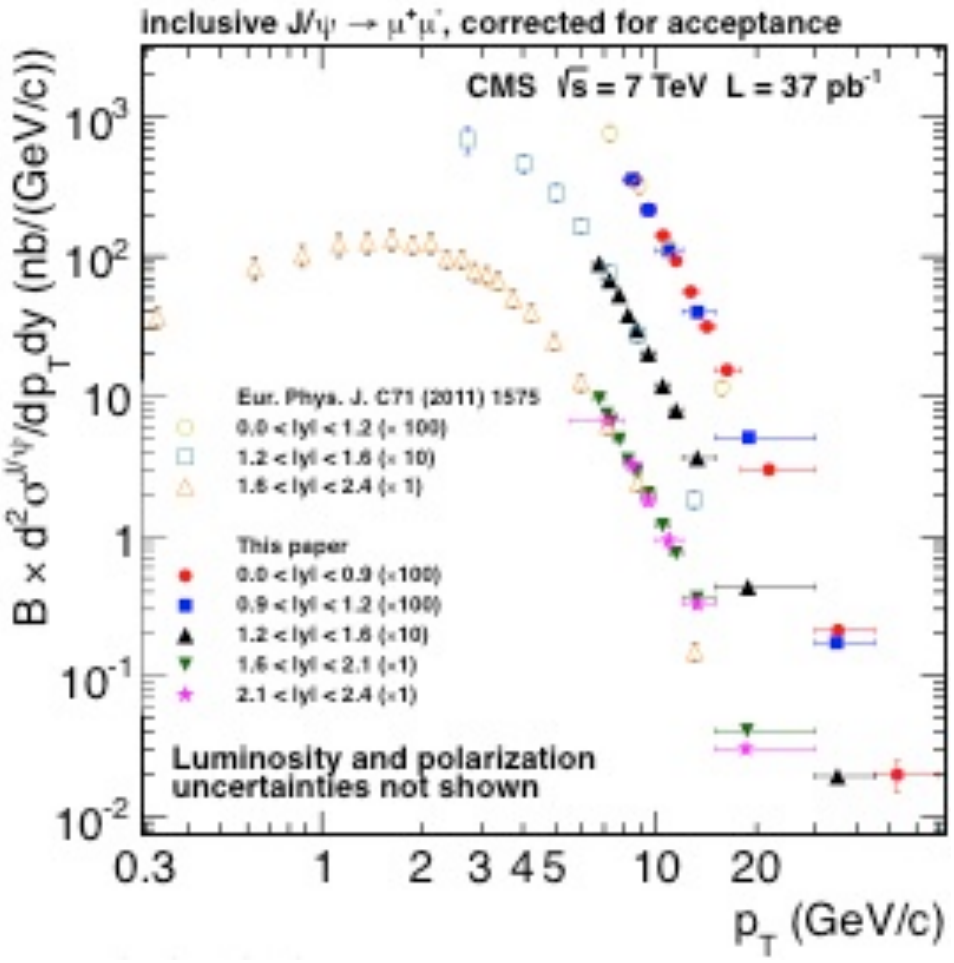


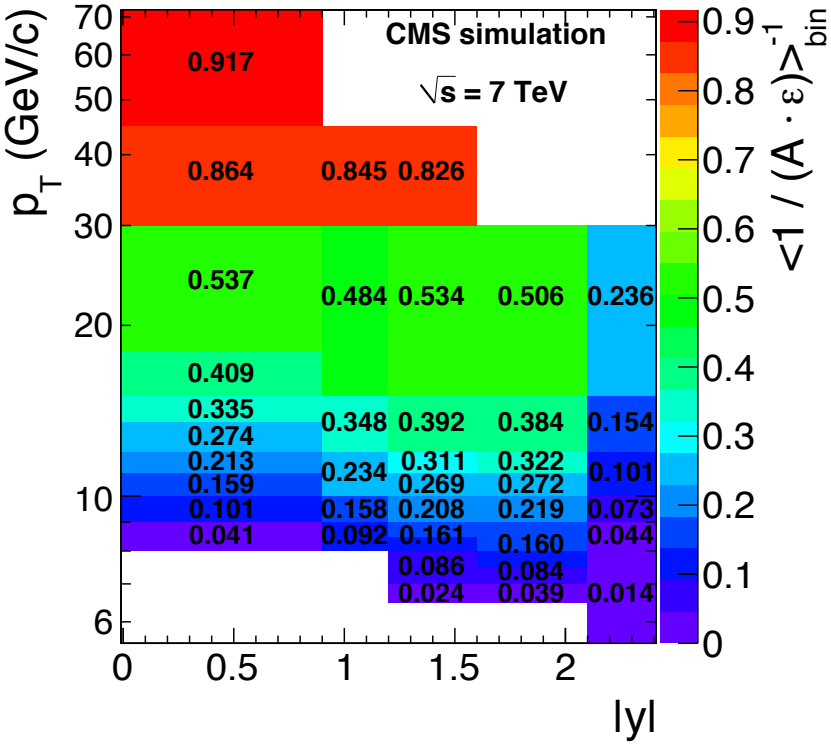




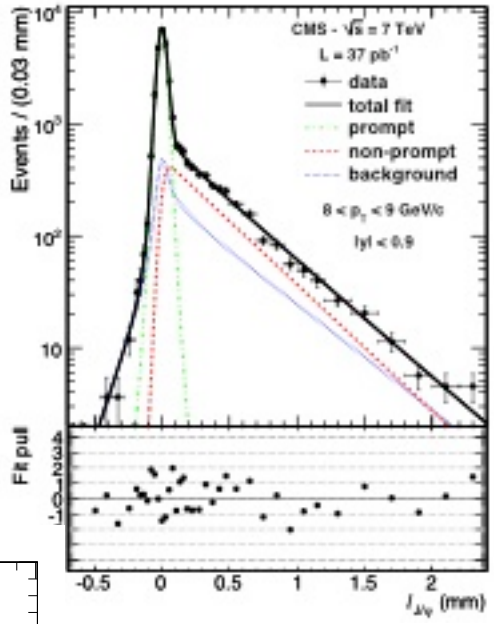
ATLAS J/ψ

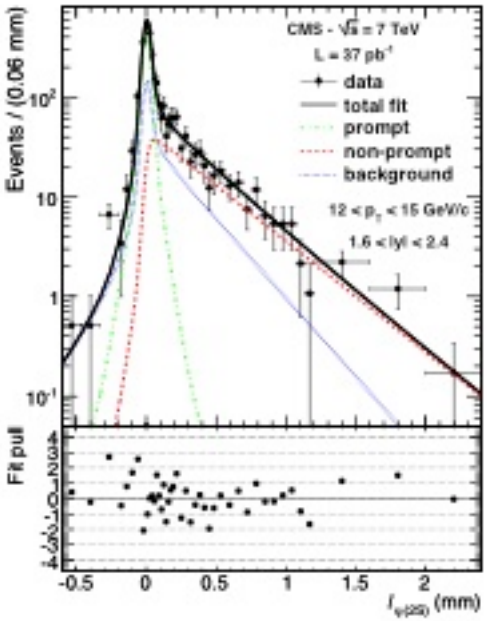
J/ψ , ψ'

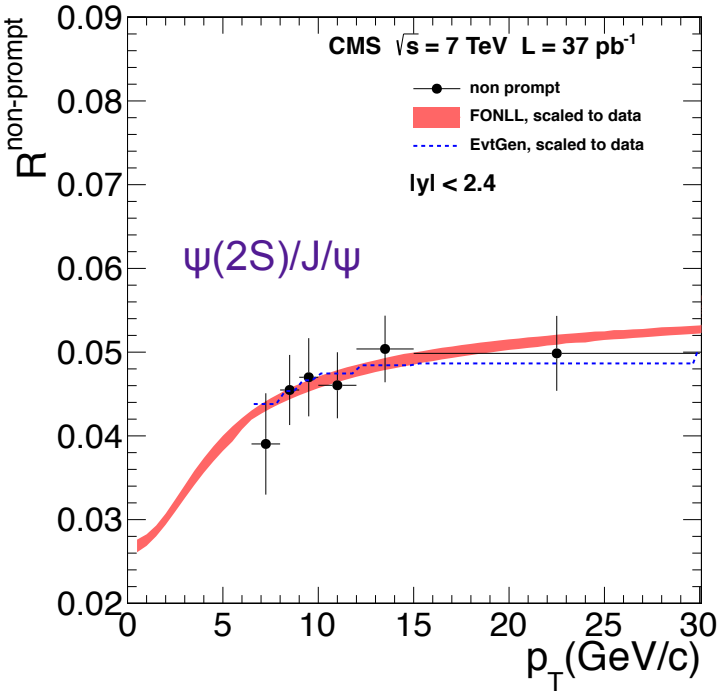

inclusive J/ψ → μ⁺μ⁻, corrected for acceptance
CMS √s = 7 TeV L = 37 pb⁻¹
Eur. Phys. J. C71 (2011) 1575
0.0 < |y| < 1.2 (×100)
1.2 < |y| < 1.6 (×10)
1.6 < |y| < 2.4 (×1)
This paper
0.0 < |y| < 0.9 (×100)
0.9 < |y| < 1.2 (×100)
1.2 < |y| < 1.6 (×10)
1.6 < |y| < 2.1 (×1)
2.1 < |y| < 2.4 (×1)
Luminosity and polarization uncertainties not shown
B × d²σ^J/ψ/dp_T dy (nb/(GeV/c))
p_T (GeV/c)

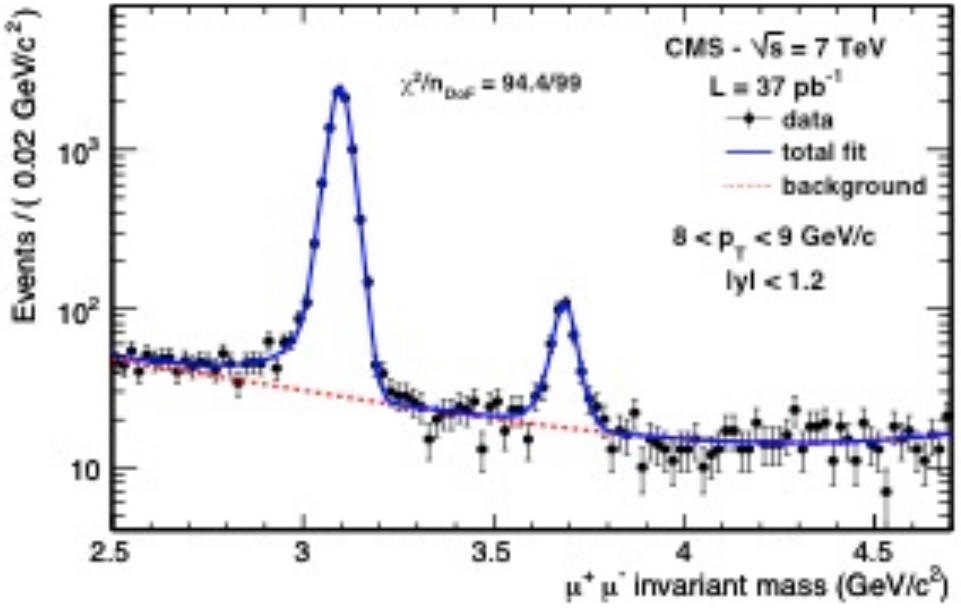

CMS simulation
√s = 7 TeV
p_T (GeV/c)
|y|
<1 / (A · ε)>^-1 bin
0.917
0.864 0.845 0.826
0.537 0.484 0.534 0.506 0.236
0.409
0.335 0.348 0.392 0.384 0.154
0.274
0.213 0.234 0.311 0.322 0.101
0.159 0.269 0.272
0.101 0.158 0.208 0.219 0.073
0.041 0.092 0.161 0.160 0.044
0.086 0.084
0.024 0.039 0.014

J/ψ , ψ'

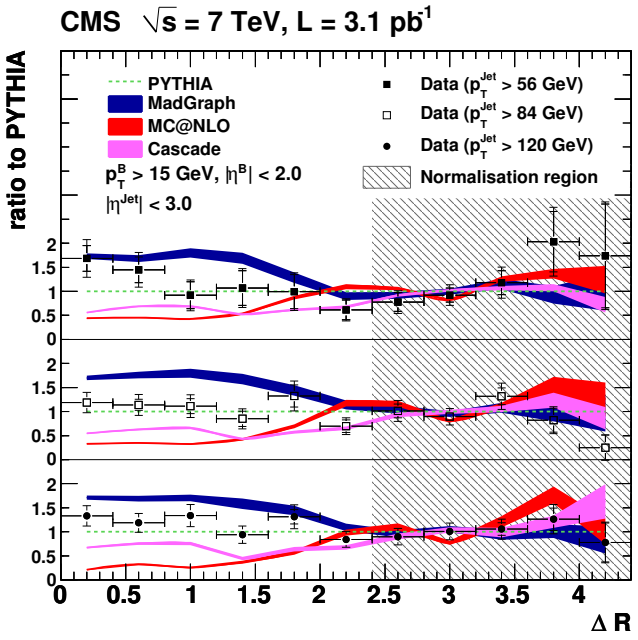

CMS - √s = 7 TeV
L = 37 pb⁻¹
data
total fit
prompt
non-prompt
background
8 < p_T < 9 GeV/c
|y| < 0.9
Events / (0.03 mm)
Fit pull
l_J/ψ (mm)

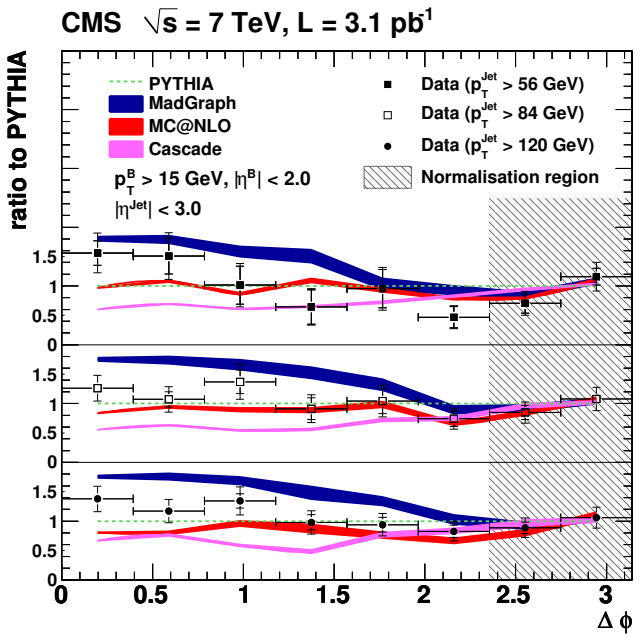

CMS - √s = 7 TeV
L = 37 pb⁻¹
data
total fit
prompt
non-prompt
background
12 < p_T < 15 GeV/c
1.6 < |y| < 2.4
Events / (0.06 mm)
Fit pull
l_ψ(2S) (mm)

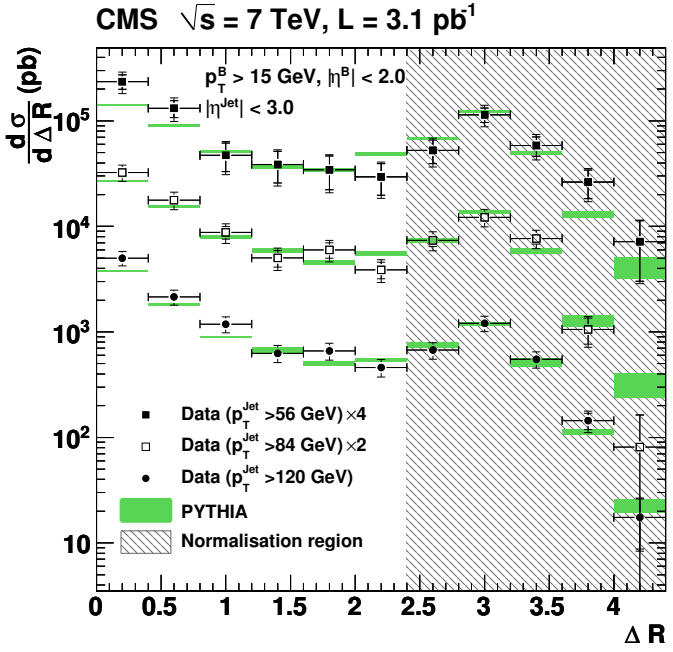

CMS √s = 7 TeV L = 37 pb⁻¹
non prompt
FONLL, scaled to data
EvtGen, scaled to data
|y| < 2.4
ψ(2S)/J/ψ
R non-prompt
p_T (GeV/c)

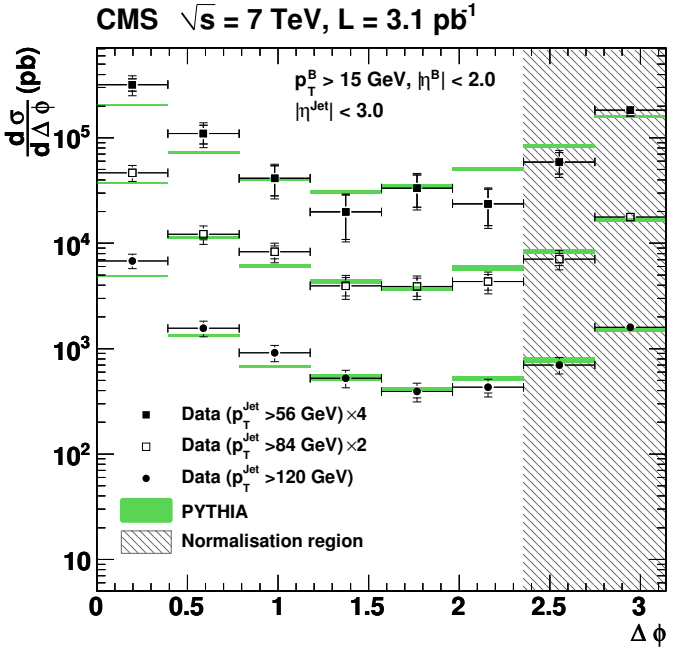

CMS - √s = 7 TeV
L = 37 pb⁻¹
χ²/n_DoF = 94.4/99
data
total fit
background
8 < p_T < 9 GeV/c
|y| < 1.2
Events / (0.02 GeV/c²)
μ⁺ μ⁻ invariant mass (GeV/c²)

BB angular correlations

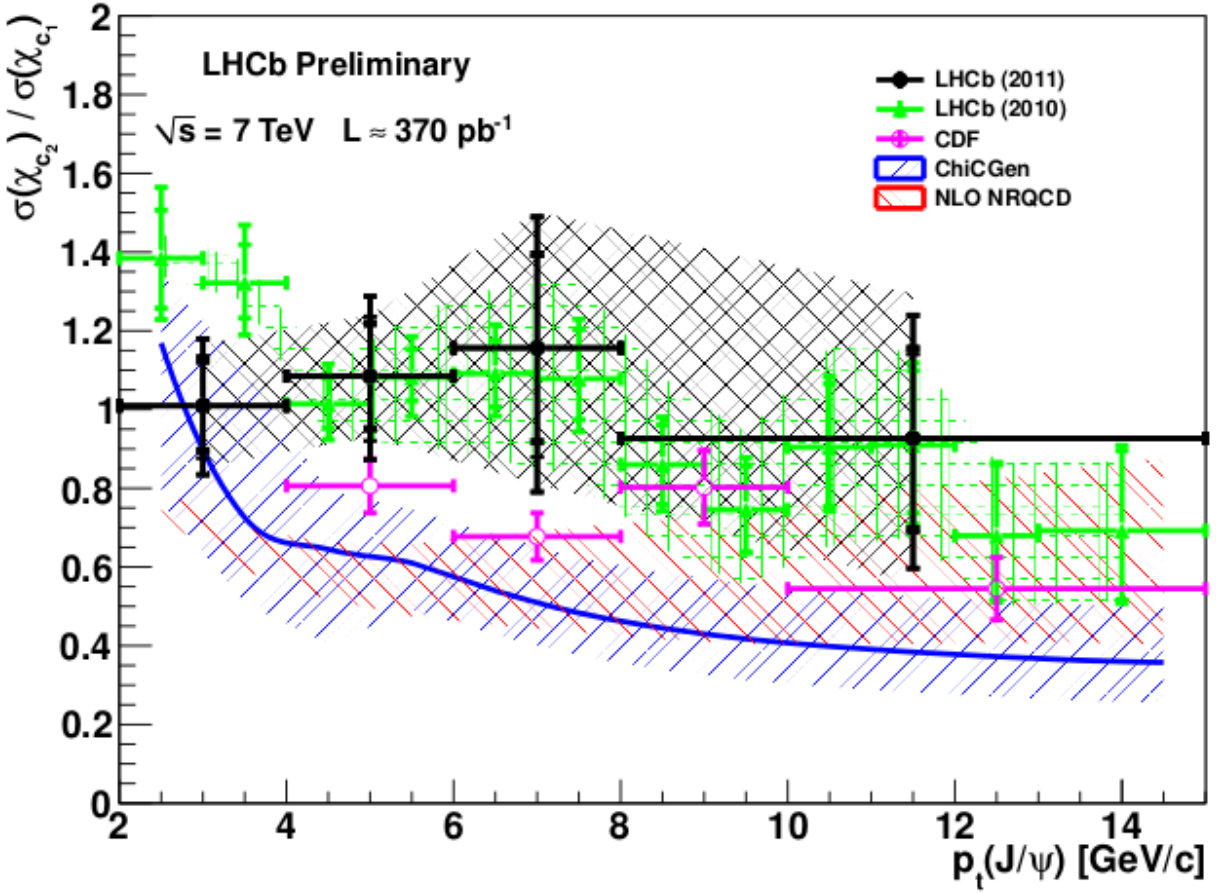








χ_{c2} / χ_{c1}



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