Heavy Flavour Production and Spectroscopy in ATLAS

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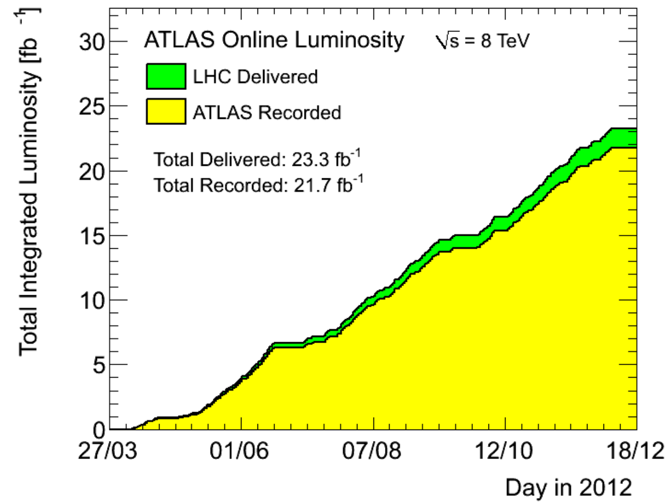
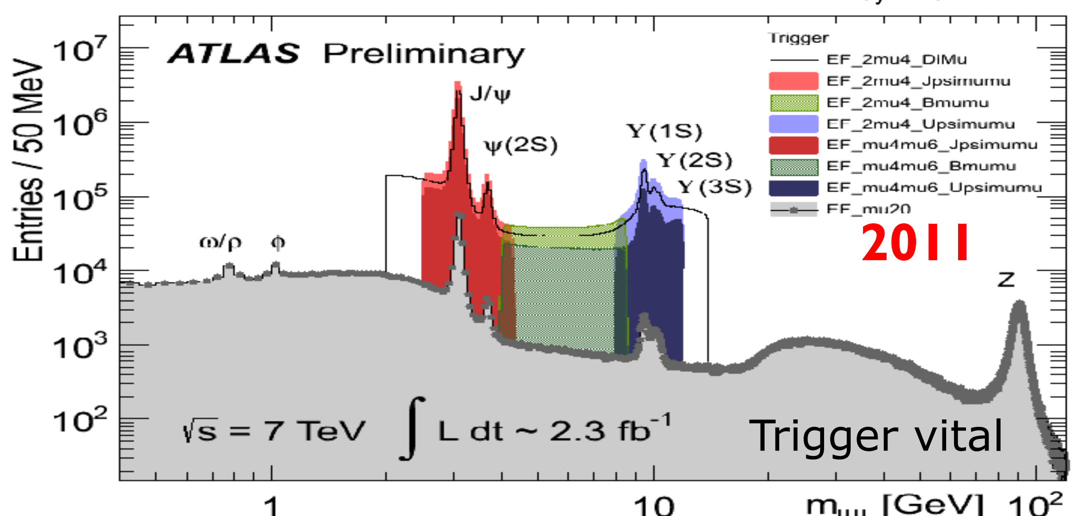
On behalf of the ATLAS Collaboration

La Thuile 2013, 24 Feb-2 March 2013

ATLAS Heavy Flavours overview

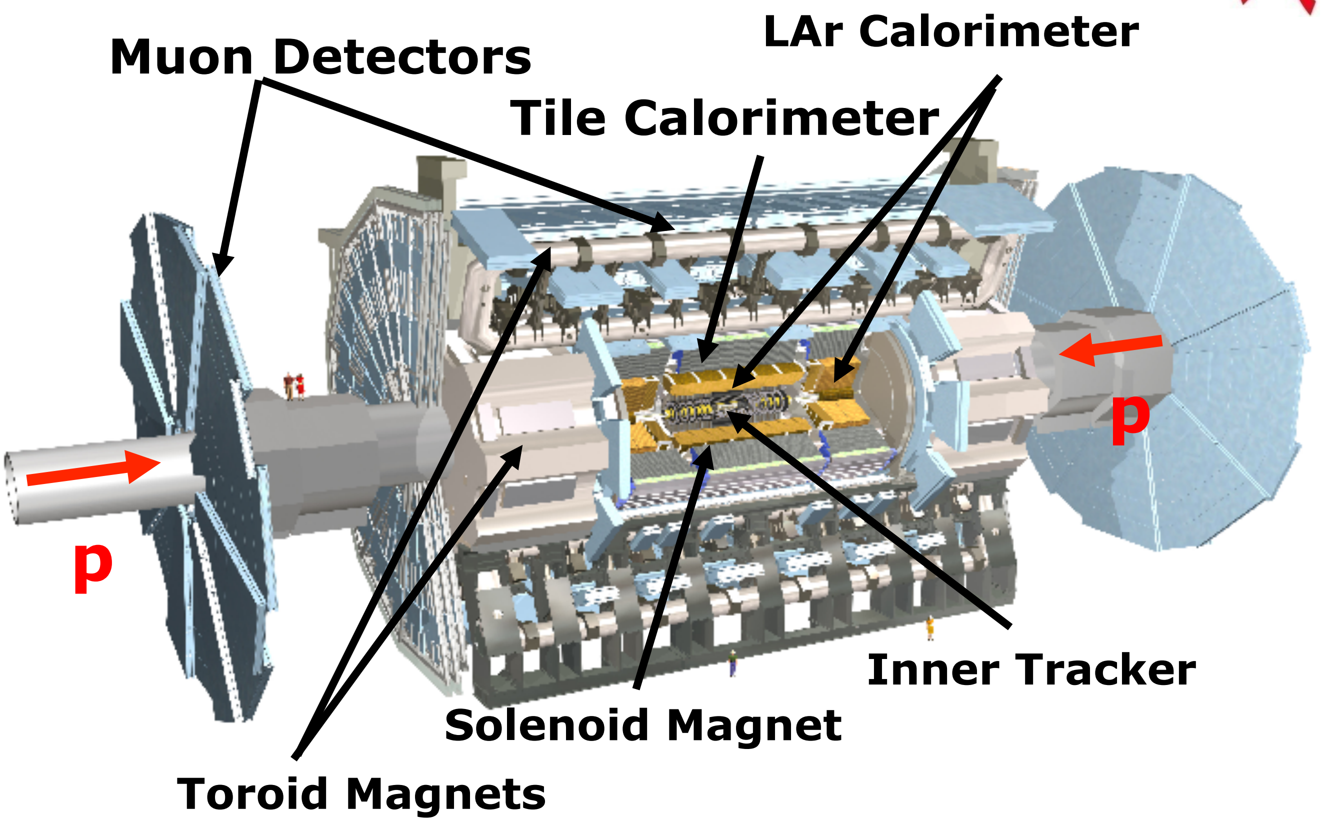
- HF sensitive to new physics
- ATLAS advantage: high luminosity
- Largely relies on dimuon trigger
- Wide program
  - Inclusive b, c production (+A. Buckley)
  - Production with jets
  - Charm production
  - Onia production
  - B-hadron production
  - CP violation
  - Rare decays





ATLAS

- Inner Tracker
  - 2T solenoid
  - |η|<2.5
  - Silicon pixel
  - Silicon strips
  - straw tracker
- Muon System
  - 0.5-2T toroid
  - |η|<2.7
  - Precision & Trigger chambers

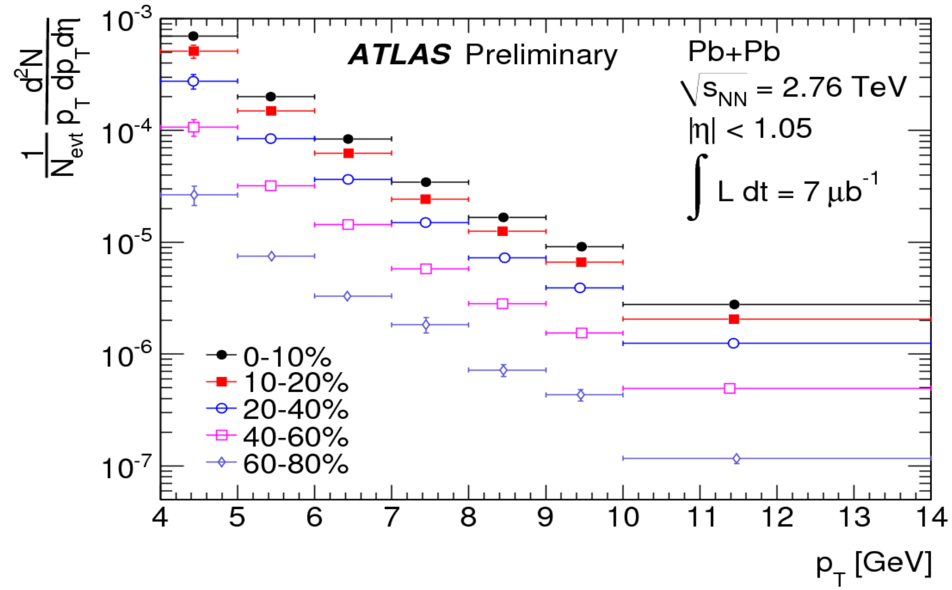


- $\sigma_{Pt}/Pt \sim 0.05\% Pt[GeV] \oplus 1.5\%$
- ~ 10 μm impact parameter resolution

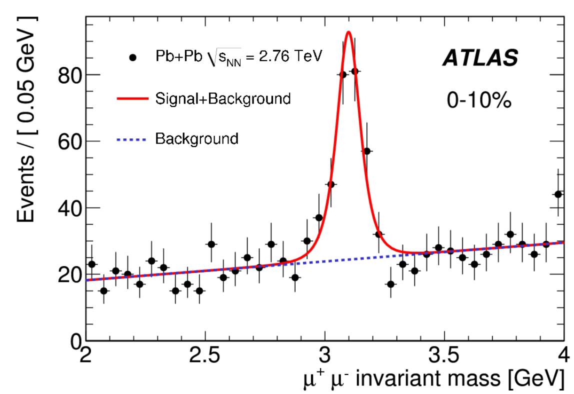
Heavy Flavours in Heavy Ions

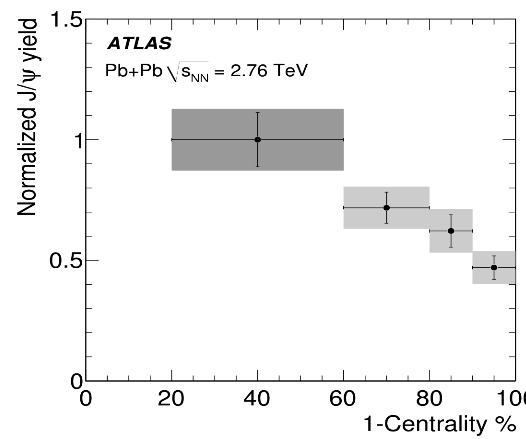
Different physics to pp, but HF an important tools

ATLAS-CONF-2012-050
Inclusive muons:
ATLAS PbPb: 2.76TeV, $|\eta| < 1.05$
4 Gev $< p_{T(\mu)} <$ 14 GeV
Dominated by HF decays
Yield falls with increasing p_T and centrality



PRB 697 (2011) 294-312
J/ψ production @ 2.76TeV
Normalized J/ψ yield falls with increasing centrality





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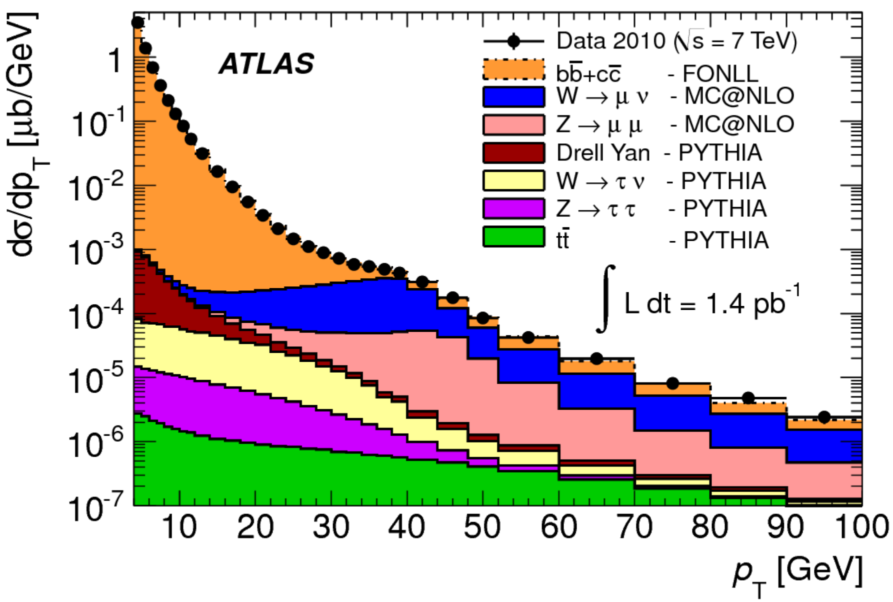
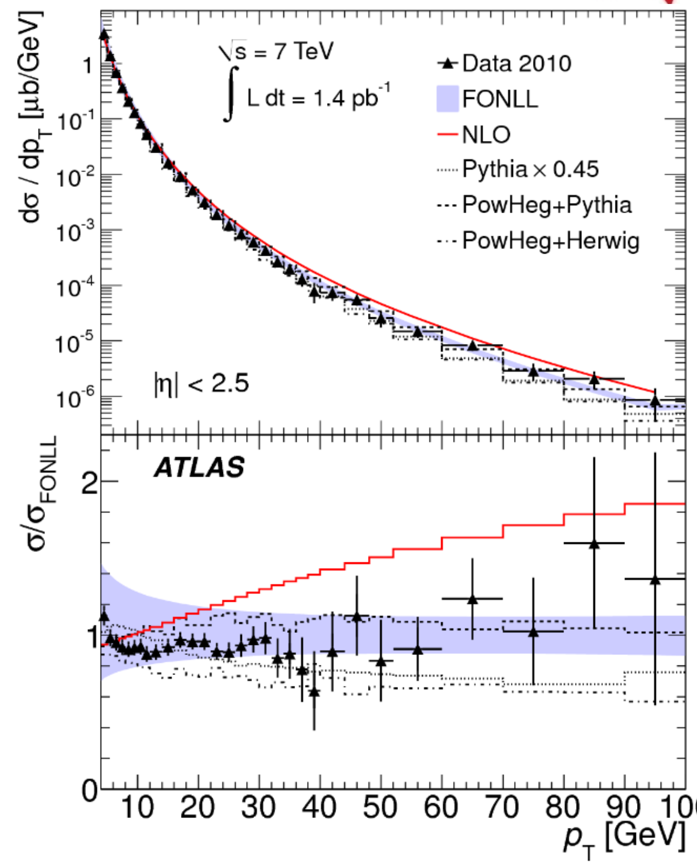
ATLAS: PLB 707 (2012) 438

ATLAS pp: $|\eta| < 2.5$, $4 < p_T(\mu) < 100$ GeV

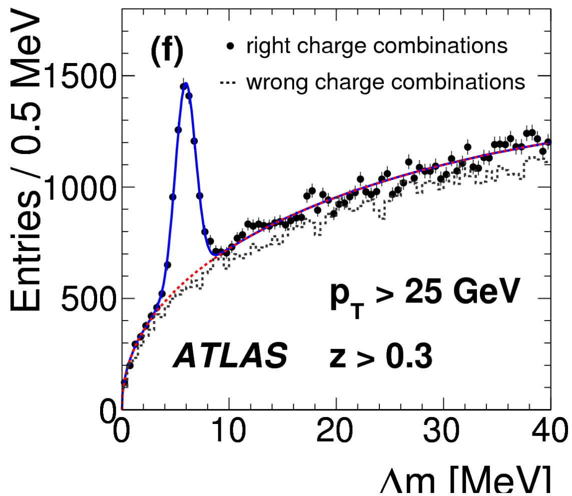
Perturbative calculations doing a good job at low p_T but deviate at higher p_T

FONLL doing well in the full range covered





See also inclusive production results in Andy Buckley's talk this morning
W+b
Flavour composition of di-jets



PRD 85 (2011) 052005

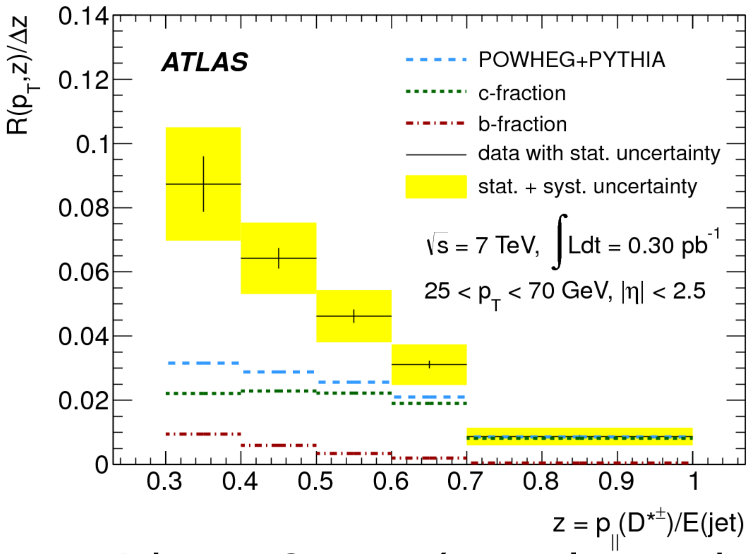
$D^{*\pm} \rightarrow D^0\pi^+$, $D^0 \rightarrow K^-\pi^+$

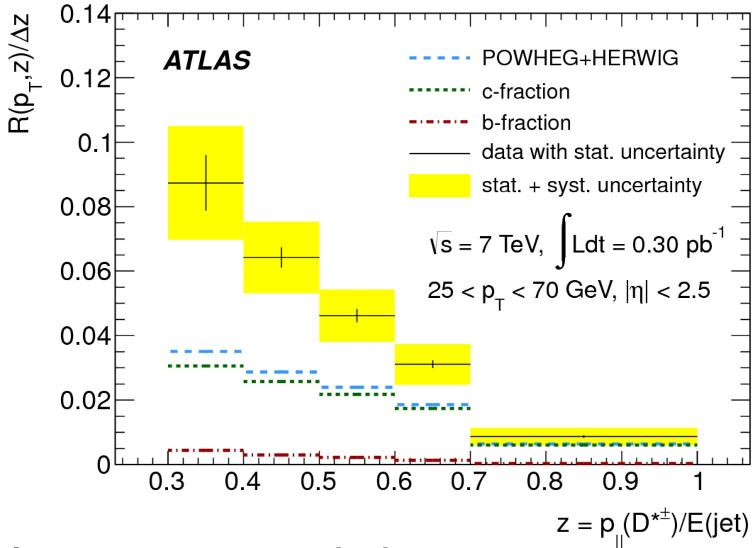
Anti-kT ΔR<0.6 topological cluster

$|\eta_{jet}|<2.5$

$25<p_{Tjet}<70$GeV

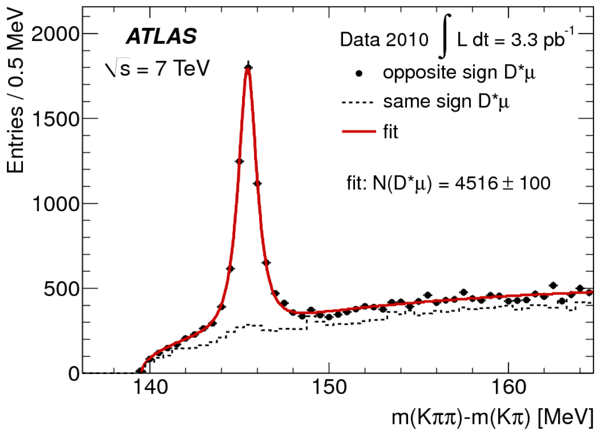
$Z = p_{||}(D^*)/E_{jet}$

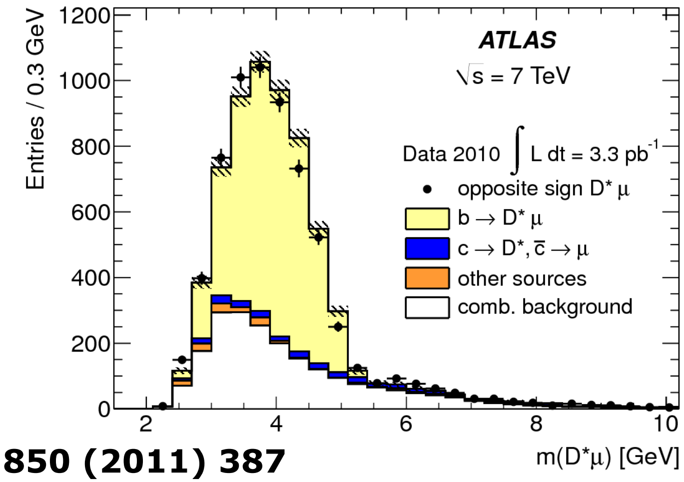




Neither LO+ pT/angular ordered model gives a good description esp. at low z

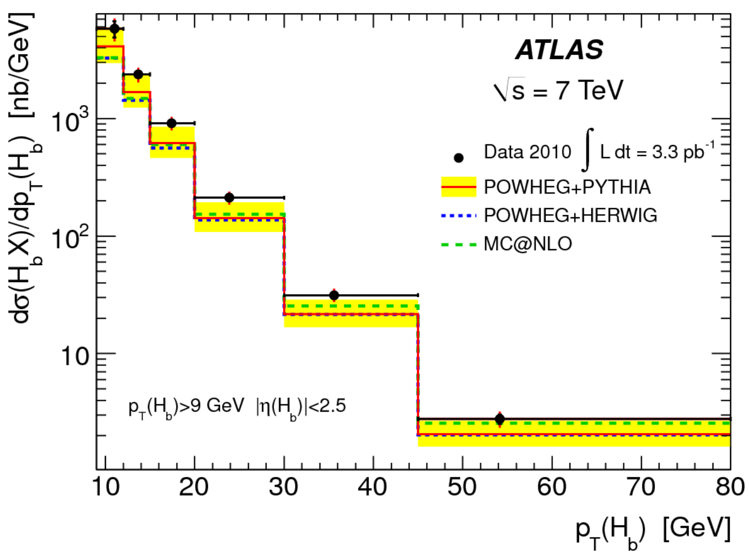
Beauty hadrons – D*μX in jets

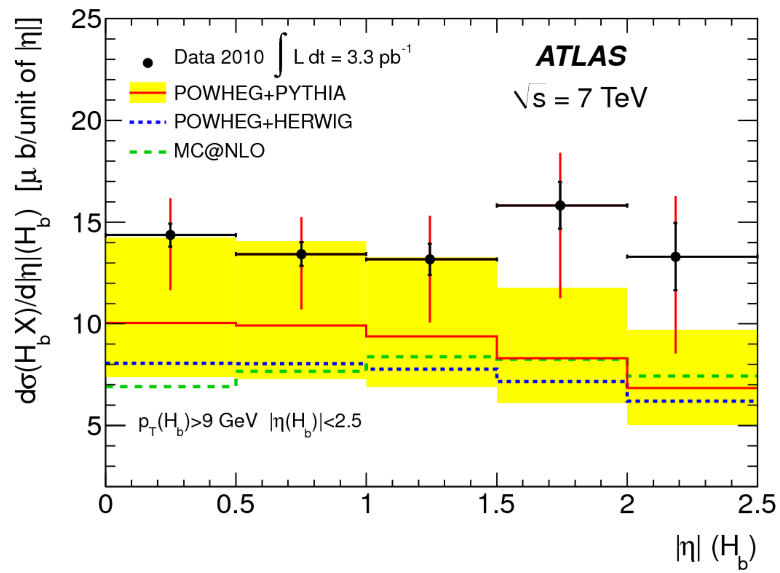




Fiducial cuts
$\sqrt{s}$=7 TeV,
$|y| < 2.5$
$10 < p_T < 80$GeV

NPB 850 (2011) 387





NLO models slightly underestimate the observed rates

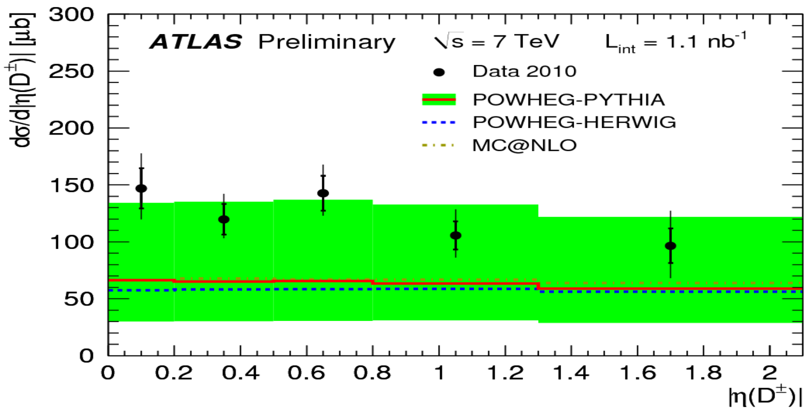
Shapes of both pT and eta distributions reasonably reproduced by several MC models

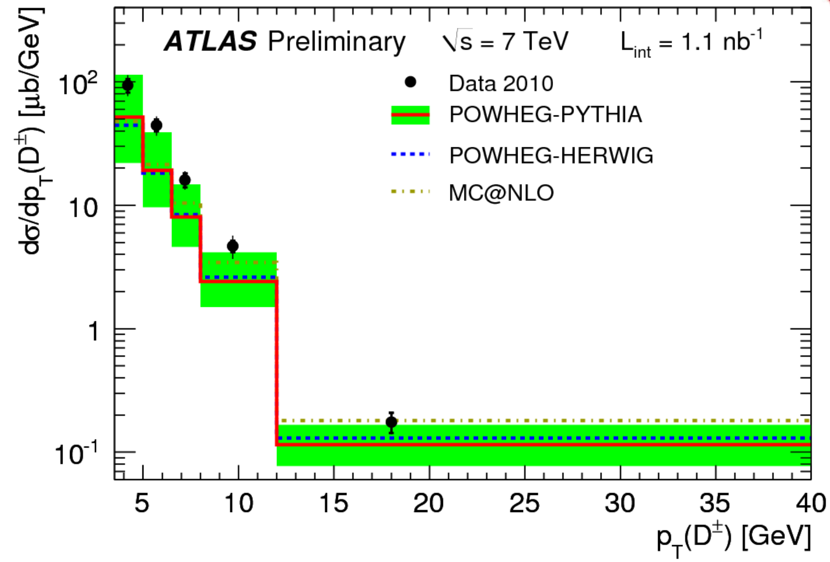
Open charm production

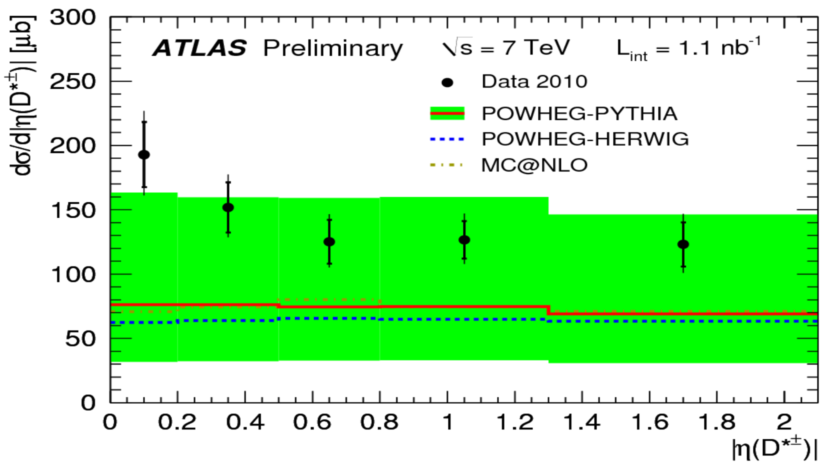
ATLAS-CONF-2011-017

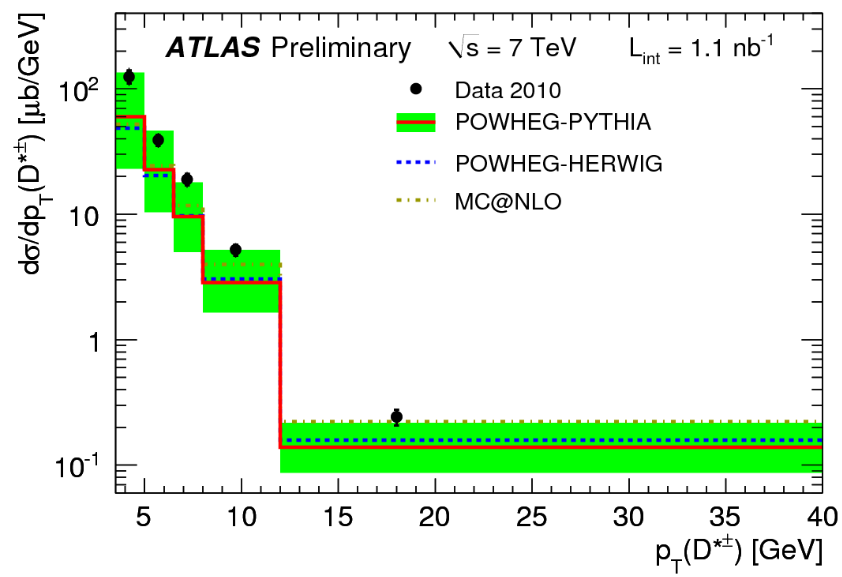
$s^{1/2}$ = 7 TeV, L_{int} = 1.1 nb^{-1}, $|y_D|<2.1$

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









All described within uncertainties by models based on perturbative QCD, although the data is higher

Fraction & non-prompt cross-section of J/ψ from B decays

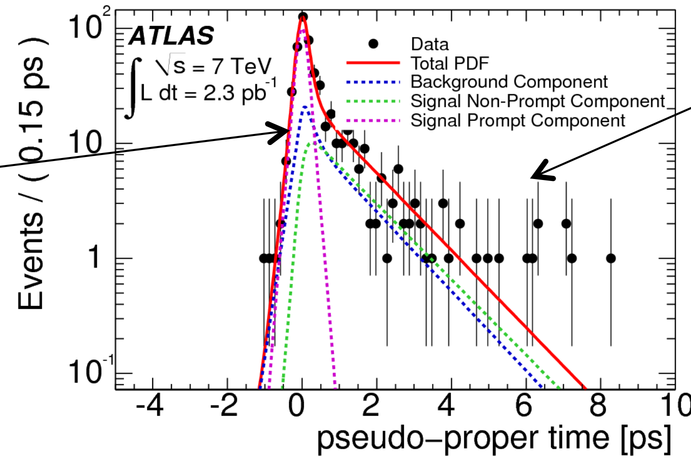
J/ψ: now measured by CDF and all four LHC experiments

ATLAS: NPB 850 (2011) 387

Use (pseudo) proper time to separate prompt and non-prompt charmonium

Prompt from QCD production

Non-prompt J/ψ and ψ(2S) are produced in B hadron decays



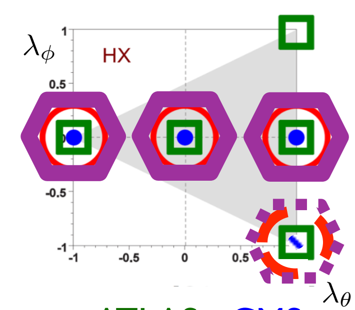
Must consider all possibilities until spin alignment measured directly
Must not integrate over decay angles in polarization measurements

A vector state $|\psi\rangle = a_{-1}\,|1,-1\rangle + a_0\,|1,0\rangle + a_{+1}\,|1,+1\rangle$

produced in a single exclusive process, and decaying into a pair of fermions, has the general angular distribution:

$$\frac{dN}{d\Omega} = 1 + \lambda_{\theta^\star}\cos^2\theta^\star + \lambda_{\phi^\star}\sin^2\theta^\star\cos 2\phi^\star + \lambda_{\theta^\star\phi^\star}\sin 2\theta^\star\cos\phi^\star$$

$$\lambda_{\theta^\star} = \frac{1-3|a_0|^2}{1+|a_0|^2} \qquad \lambda_{\phi^\star} = \frac{2Re\,a^*_{+1}a_{-1}}{1+|a_0|^2} \qquad \lambda_{\theta^\star\phi^\star} = \frac{\sqrt{2}Re\,[a^*_0(a_{+1}-a_{-1})]}{1+|a_0|^2}$$



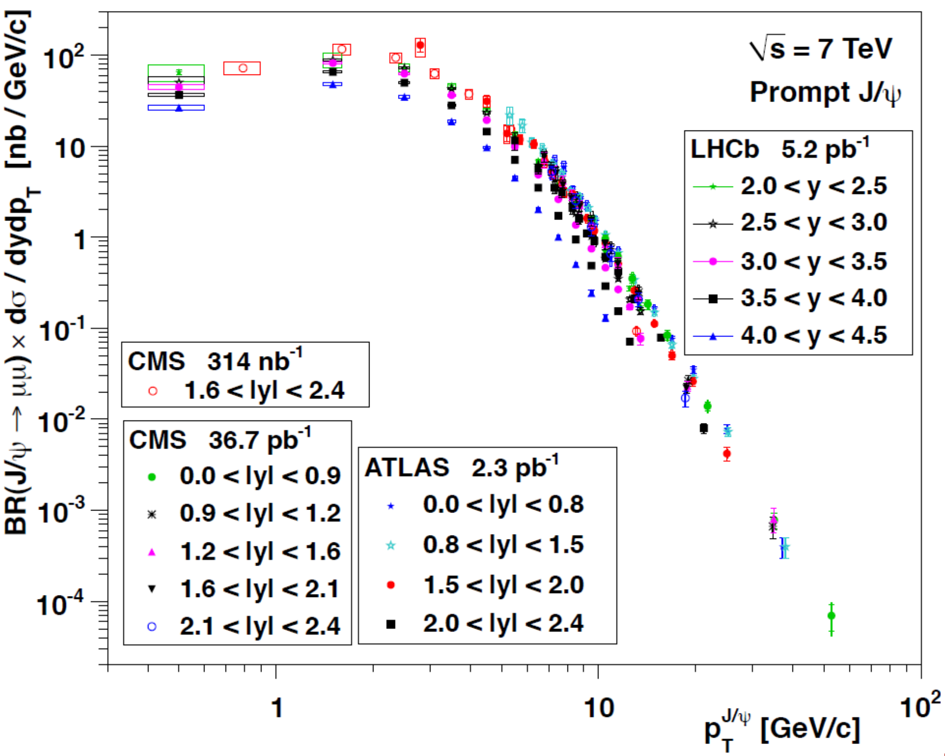
ATLAS CMS
LHCb ALICE

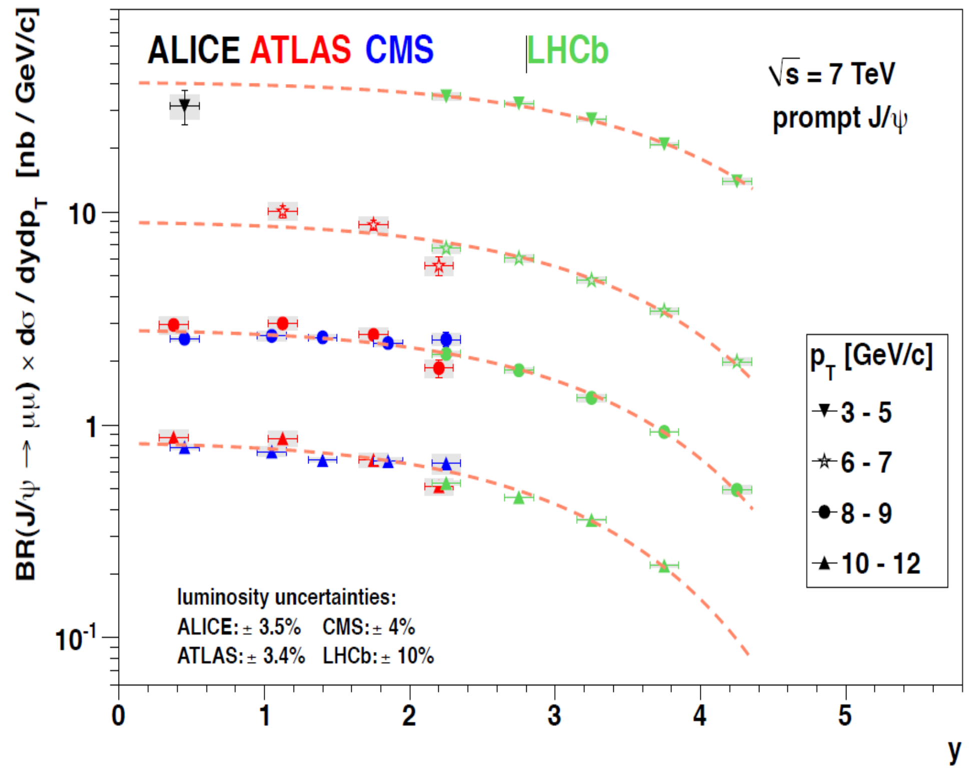
Hidden charm - Prompt J/ψ

ATLAS with the other experiments cover a huge kinematic range |y| < 4.5, 0<p_T<70 GeV

Over 6 orders of magnitude in p_T

Measurements mostly consistent when overlap, some differences in rapidity shapes





Compiled by Hermine K. Woehri

ALICE: arXiv:1205.5880
ATLAS: NPB850 (2011) 387
CMS: JHEP02 (2012) 011
LHCb: EPJC71 (2011) 1645

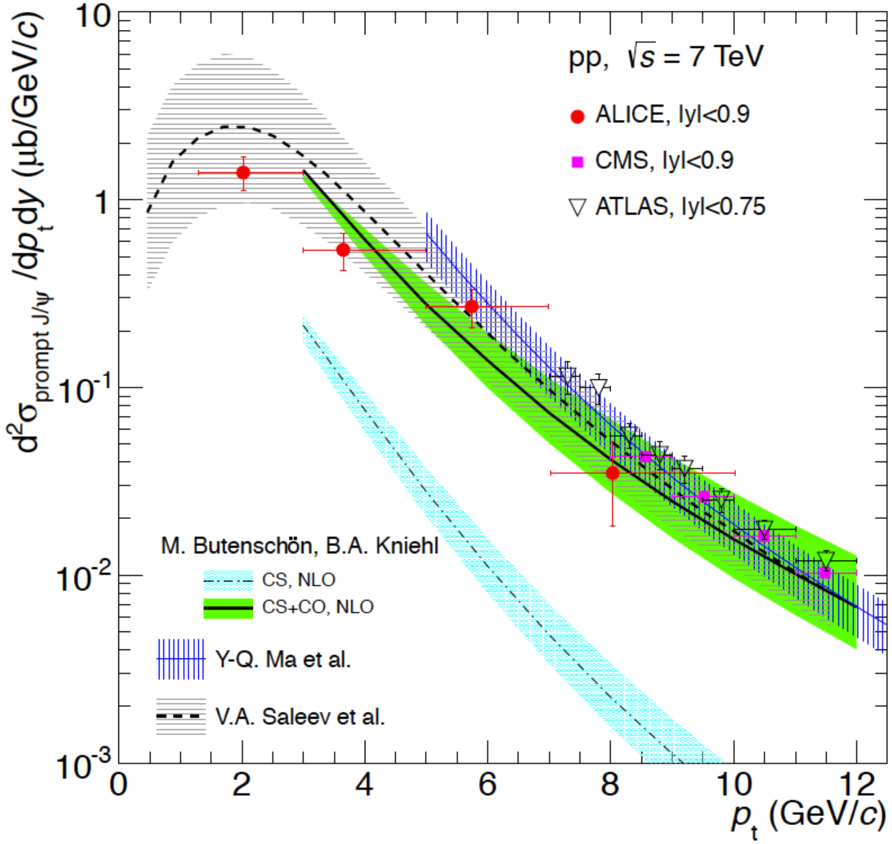
Prompt J/ψ vs theory

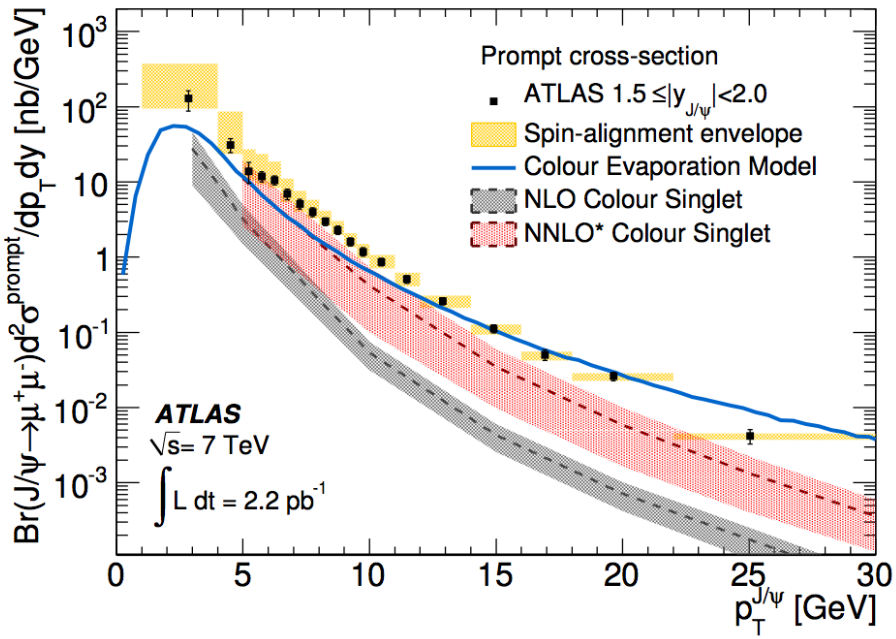
Multitude of models (CSM, CEM, COM) in various incarnations all do a reasonable job, but none is perfect

Some have virtually no parameters (CSM, CEM)

Others (NRQCD-based) have have quite a few

p_T spectra alone not enough to distinguish between models



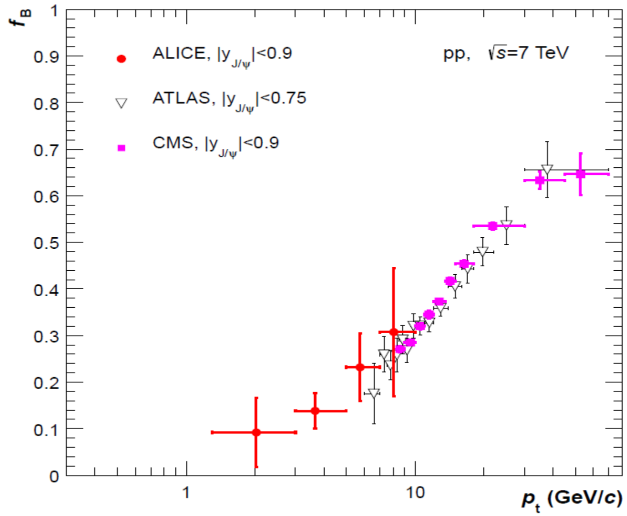


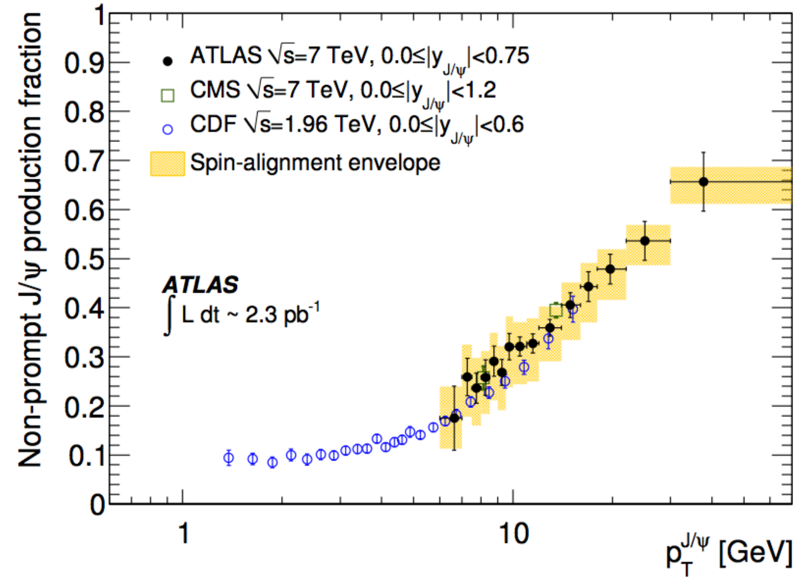
Alice: arXiv:1205.5880
ATLAS: NPB850 (2011) 387
CMS: JHEP (2012) 011
Also LHCb: EPJC71 (2011) 1645

Fraction & non-prompt cross-section of J/ψ from B decays

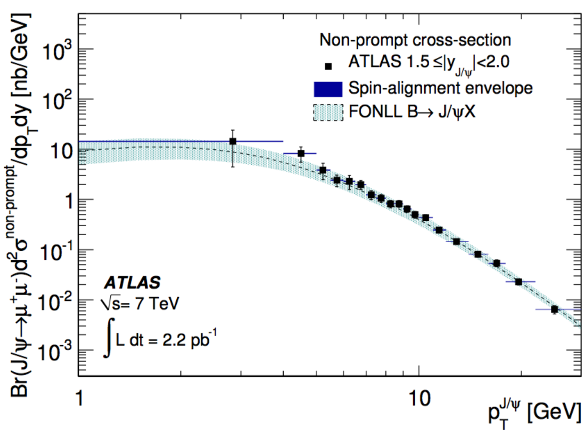
J/ψ: now measured by CDF and all four LHC experiments
Below 10% at low p_T, central rapidity, increasing with p_T to ~70%
This increase slows down at forward rapidities
Weak energy dependence at best

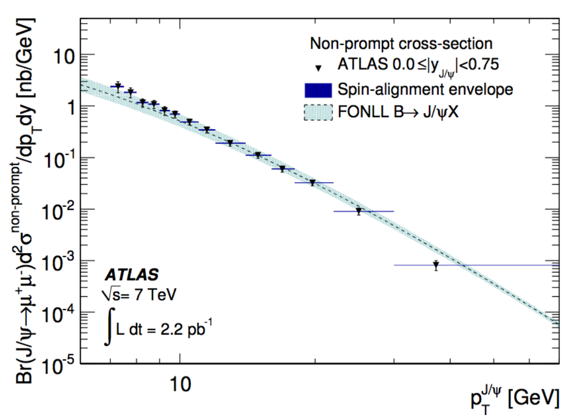
ATLAS: NPB 850 (2011) 387



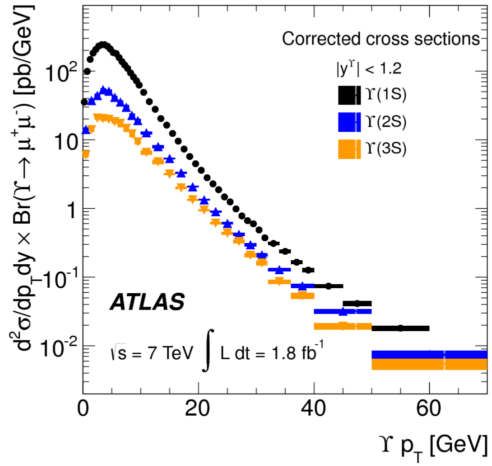


ATLAS: NPB 850 (2012) 387
CMS: JHEP 02 (2012) 011
CDF: PRD 71 (2005) 032001
CDF: PRD 80 (2009) 031103
LHCb: EPJ C71 (2011) 1645
LHCb: arXiv:1204.1258





Perturbative QCD calculations describe non-prompt contributions reasonably well, with no free parameters

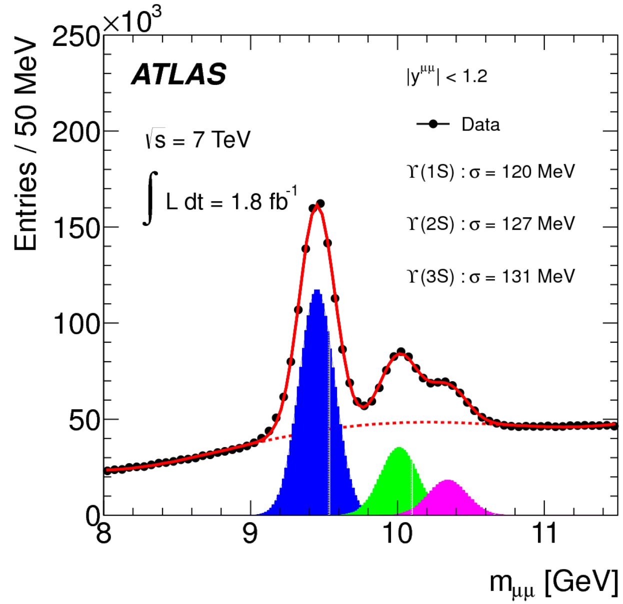


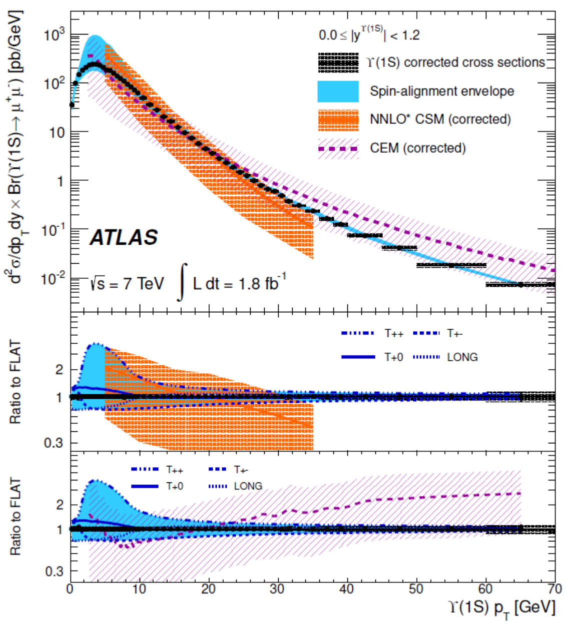
ATLAS: arXiv:1211.7255
accepted PRD

Double- differential cross section of Y(1,2,3S) from 1.8 fb^{-1}

Extended p_T range,
finer binning

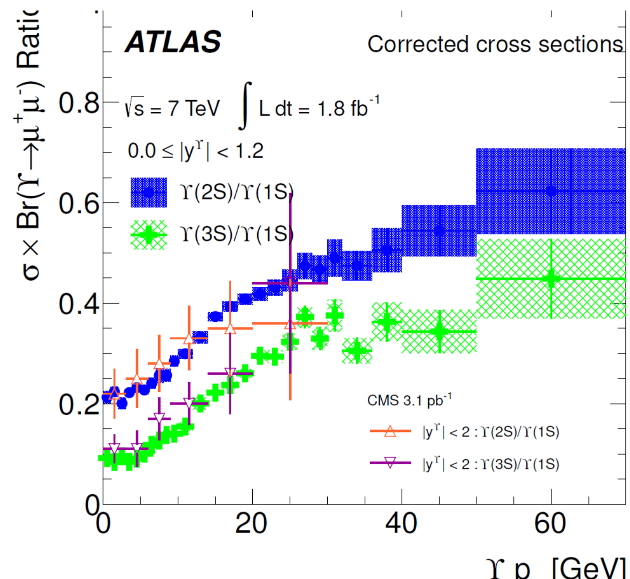
Agrees well with data from CMS (and LHCb), wide coverage
p_T: 0 to 70 GeV, |y| : < 4.5



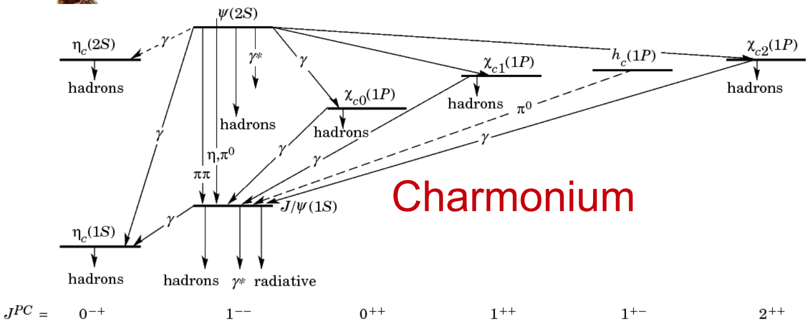


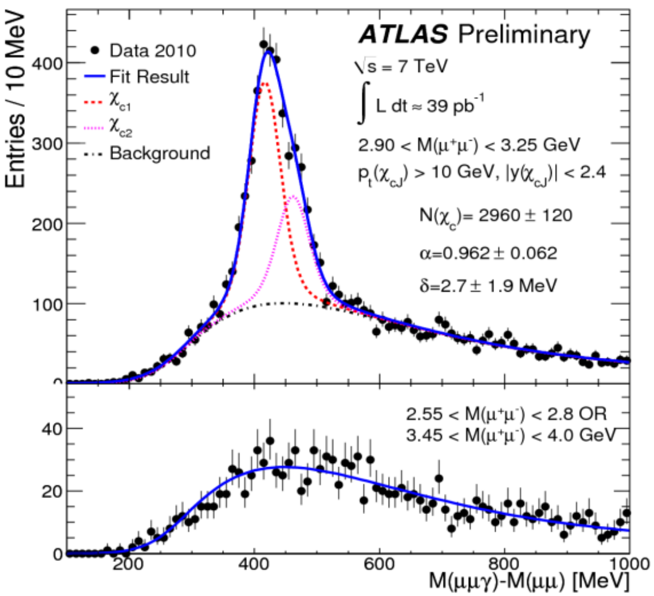
CSM, COM, CEM, etc - doing a reasonable job but none perfect

Intriguing: p_T dependence of ratios Y(2S)/Y(1S), Y(3S)/Y(1S) confirms existence of multiple mechanisms,
hints on their
p_T evolution



Quarkonium spectroscopy and χ feeddown

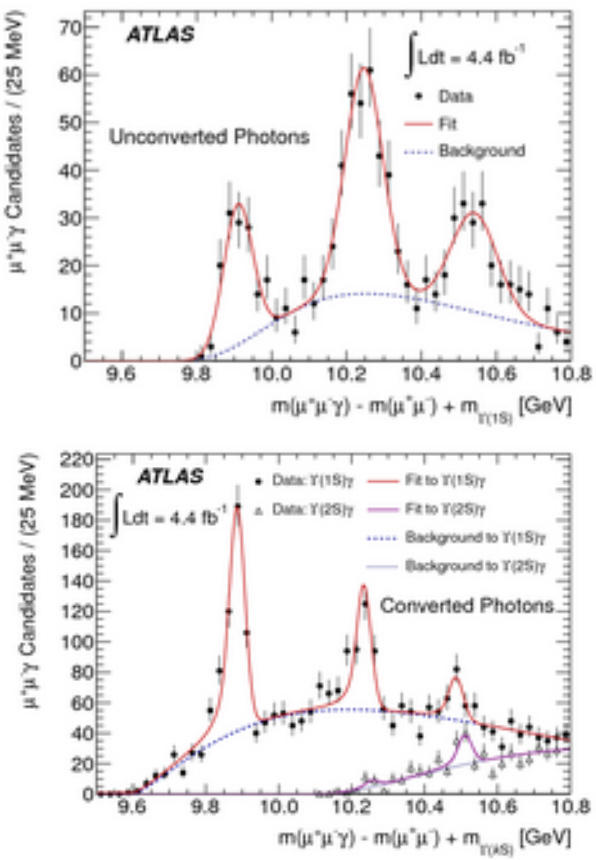


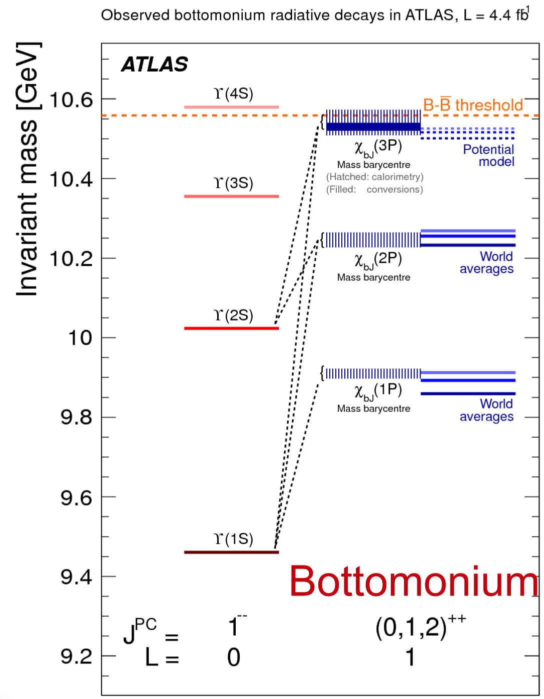


ATLAS-CONF-2011136

Unconverted photons

ATLAS: $\chi_b(3P)$ – ATLAS discovery at LHC, now confirmed by D0, LHCb with lower significance

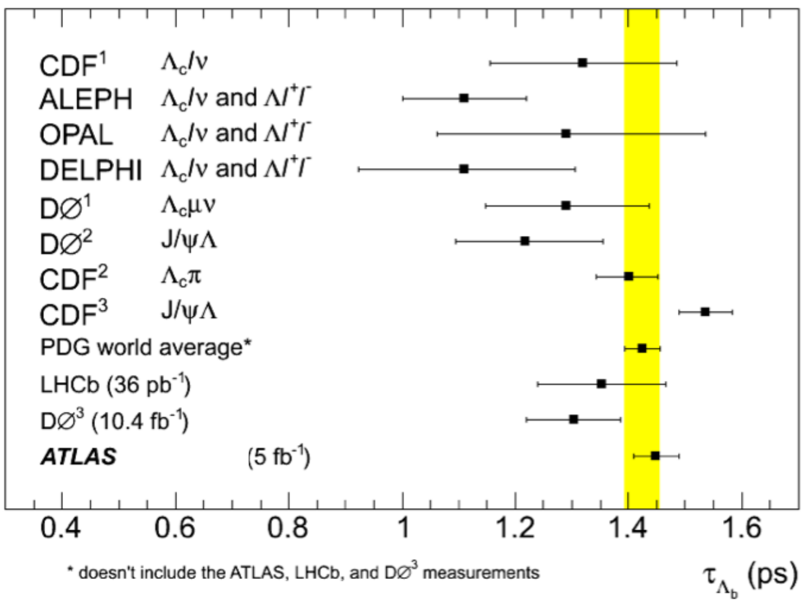




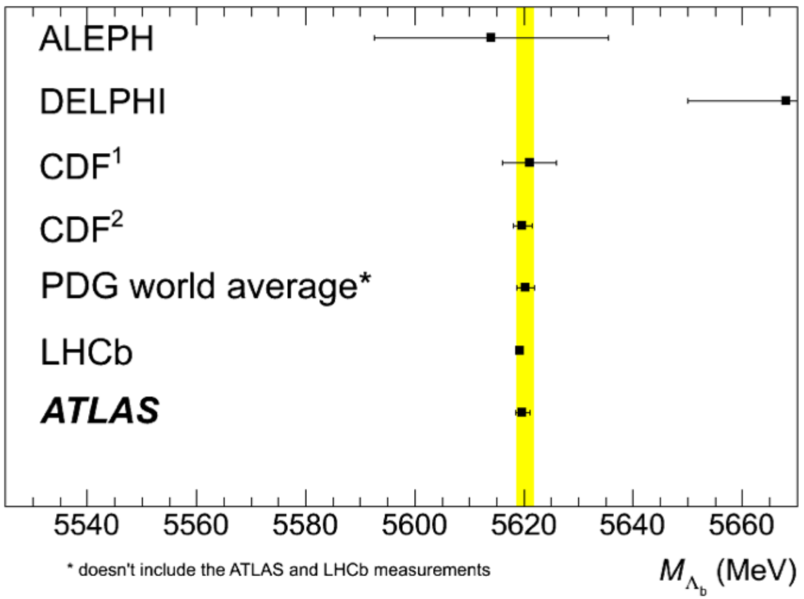
ATLAS: PRL 108 (2012) 152001
LHCb: CONF-2012-020
PRD 86 (2012) 031103(R)

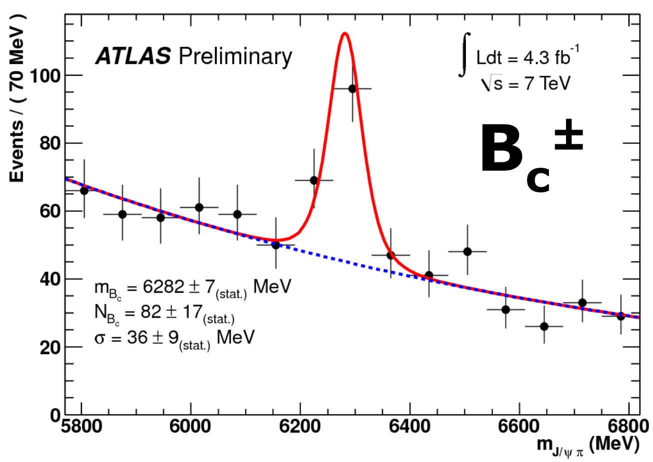
ATLAS B Spectroscopy Highlights

arXiv:1207.2284 [hep-ex]

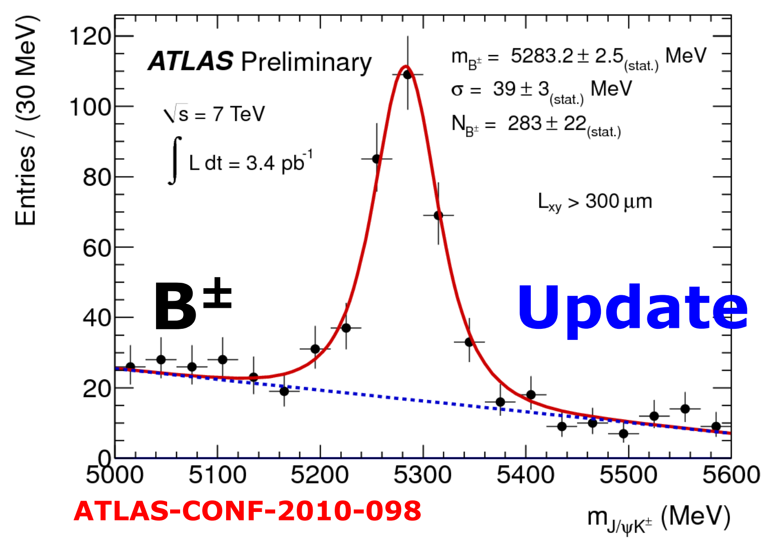


Λ_b





ATLAS-CONF-2012-028



Update soon

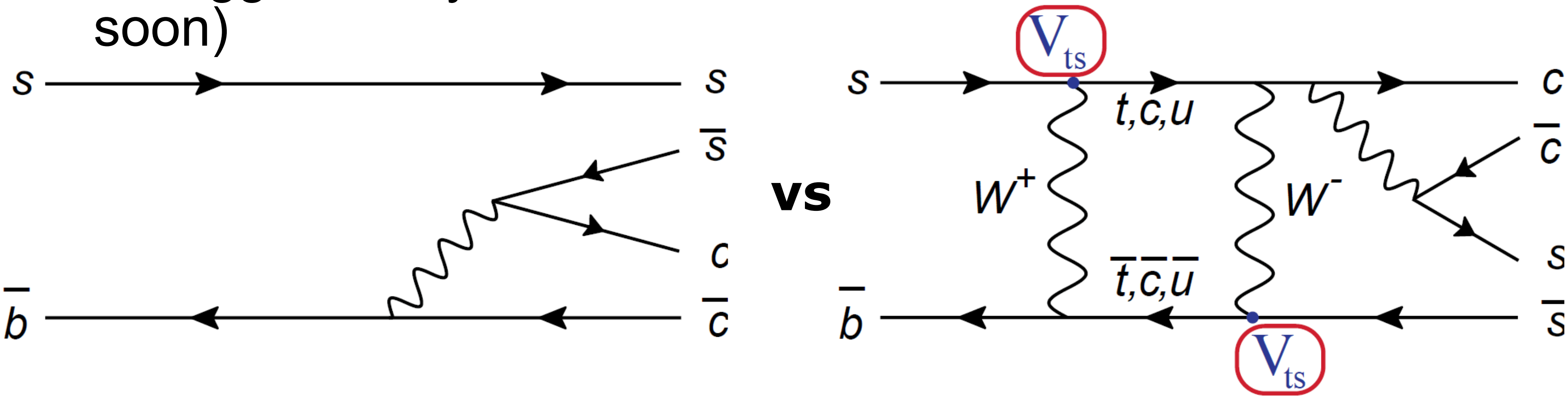
ATLAS-CONF-2010-098

$B_s \to J/\psi\varphi$

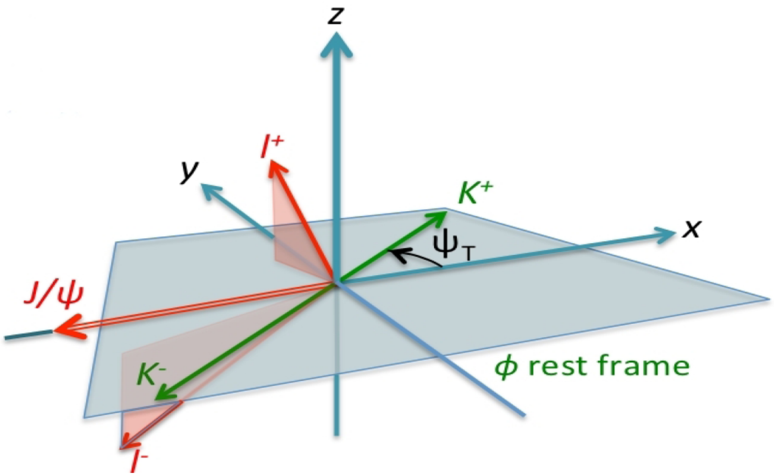
- Interference between mixing and unmixed decays
- $B_s \to$Vector-Vector decay, three spin states

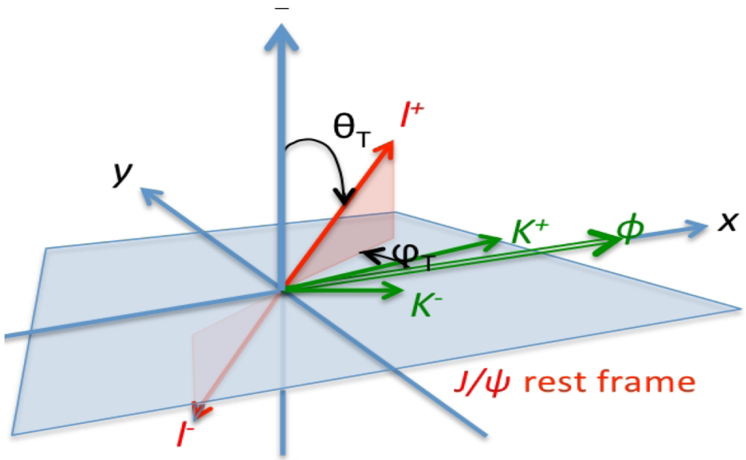
L=0,2 (A_0, $A_\parallel$) CP-even L=1 ($A_\perp$) CP-odd

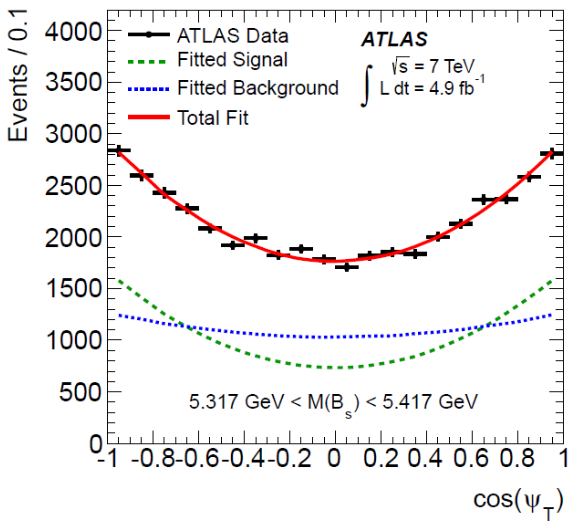
- Use angular analysis to disentangle contributions
- Untagged analysis: oscillation terms drop out (tagged update soon)

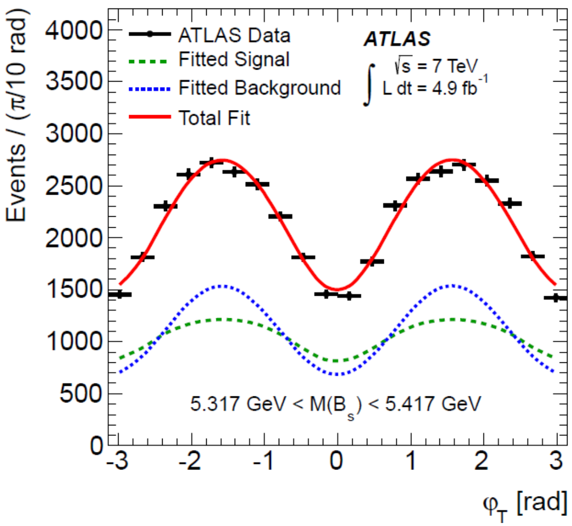


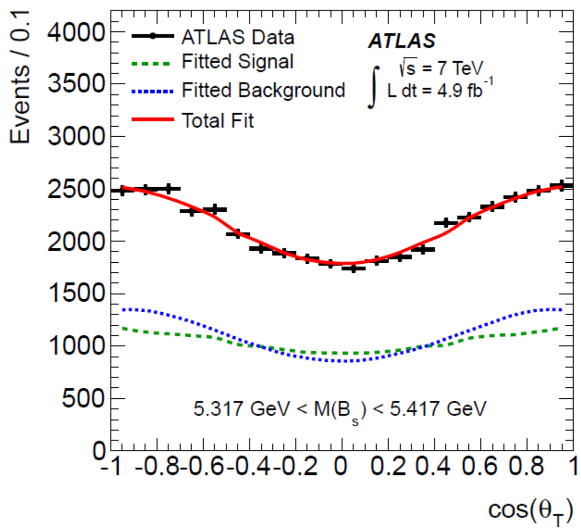
$B_s \to J/\psi\phi$ Angular Analysis











$B_s \to J/\psi\varphi$ Likelihood

- Unbinned likelihood fit

$$\mathcal{L} = \prod f_s \cdot \mathcal{F}_{sig}(m_i, t_i, \Omega_i, \sigma_m, \sigma_t) + f_s \cdot f_{B0} \cdot \mathcal{F}_{B0}(m_i, t_i, \Omega_i, \sigma_m, \sigma_t) + (1 - f_s \cdot (1 + f_{B0})) \cdot \mathcal{F}_{bkg}(m_i, t_i, \Omega_i, \sigma_m, \sigma_t) + \mathrm{Gauss}(\delta_\perp)$$

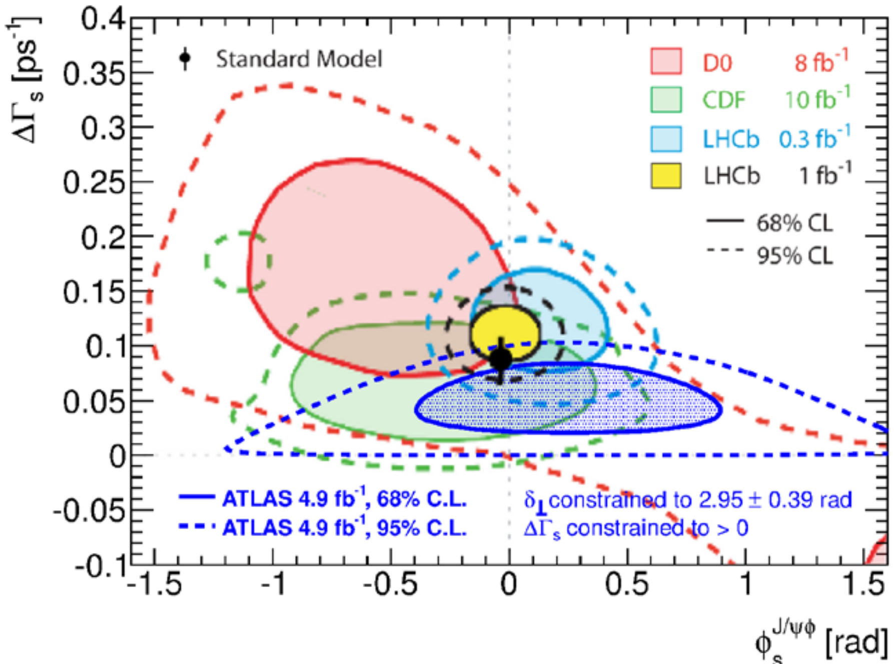
- $\Omega = (\psi_T, \theta_T, \phi_T)$
- B^0 background
- Background
- Phase constraint

$\frac{1}{2}\lvert A_0(0)\rvert^2 \left[(1+\cos\phi_s)\,e^{-\Gamma_L^{(s)}t} + (1-\cos\phi_s)\,e^{-\Gamma_H^{(s)}t}\right]$	$2\cos^2\psi_T(1-\sin^2\theta_T\cos^2\varphi_T)$
$\frac{1}{2}\lvert A_\parallel(0)\rvert^2 \left[(1+\cos\phi_s)\,e^{-\Gamma_L^{(s)}t} + (1-\cos\phi_s)\,e^{-\Gamma_H^{(s)}t}\right]$	$\sin^2\psi_T(1-\sin^2\theta_T\sin^2\varphi_T)$
$\frac{1}{2}\lvert A_\perp(0)\rvert^2 \left[(1-\cos\phi_s)\,e^{-\Gamma_L^{(s)}t} + (1+\cos\phi_s)\,e^{-\Gamma_H^{(s)}t}\right]$	$\sin^2\psi_T\sin^2\theta_T$
$\frac{1}{2}\lvert A_0(0)\rvert\lvert A_\parallel(0)\rvert\cos\delta_\parallel \left[(1+\cos\phi_s)\,e^{-\Gamma_L^{(s)}t} + (1-\cos\phi_s)\,e^{-\Gamma_H^{(s)}t}\right]$	$\frac{1}{\sqrt{2}}\sin 2\psi_T\sin^2\theta_T\sin 2\varphi_T$
$\frac{1}{2}\lvert A_\parallel(0)\rvert\lvert A_\perp(0)\rvert\left(e^{-\Gamma_H^{(s)}t} - e^{-\Gamma_L^{(s)}t}\right)\cos(\delta_\perp-\delta_\parallel)\sin\phi_s$	$\sin^2\psi_T\sin 2\theta_T\sin\varphi_T$
$-\frac{1}{2}\lvert A_0(0)\rvert\lvert A_\perp(0)\rvert\left(e^{-\Gamma_H^{(s)}t} - e^{-\Gamma_L^{(s)}t}\right)\cos\delta_\perp\sin\phi_s$	$\frac{1}{\sqrt{2}}\sin 2\psi_T\sin 2\theta_T\cos\varphi_T$
$\frac{1}{2}\lvert A_S(0)\rvert^2 \left[(1-\cos\phi_s)\,e^{-\Gamma_L^{(s)}t} + (1+\cos\phi_s)\,e^{-\Gamma_H^{(s)}t}\right]$	$\frac{2}{3}\left(1-\sin^2\theta_T\cos^2\varphi_T\right)$
$-\frac{1}{2}\lvert A_S(0)\rvert\lvert A_\parallel(0)\rvert\left(e^{-\Gamma_H^{(s)}t} - e^{-\Gamma_L^{(s)}t}\right)\sin(\delta_\parallel-\delta_S)\sin\phi_s$	$\frac{1}{3}\sqrt{6}\sin\psi_T\sin^2\theta_T\sin 2\varphi_T$
$\frac{1}{2}\lvert A_S(0)\rvert\lvert A_\perp(0)\rvert \left[(1-\cos\phi_s)\,e^{-\Gamma_L^{(s)}t} + (1+\cos\phi_s)\,e^{-\Gamma_H^{(s)}t}\right]\sin(\delta_\perp-\delta_S)$	$\frac{1}{3}\sqrt{6}\sin\psi_T\sin 2\theta_T\cos\varphi_T$
$-\frac{1}{2}\lvert A_0(0)\rvert\lvert A_S(0)\rvert\sin(-\delta_S)\left(e^{-\Gamma_H^{(s)}t} - e^{-\Gamma_L^{(s)}t}\right)\sin\phi_s$	$\frac{4}{3}\sqrt{3}\cos\psi_T\left(1-\sin^2\theta_T\cos^2\varphi_T\right)$

$B_s \to J/\psi\phi$ 2011 untagged results

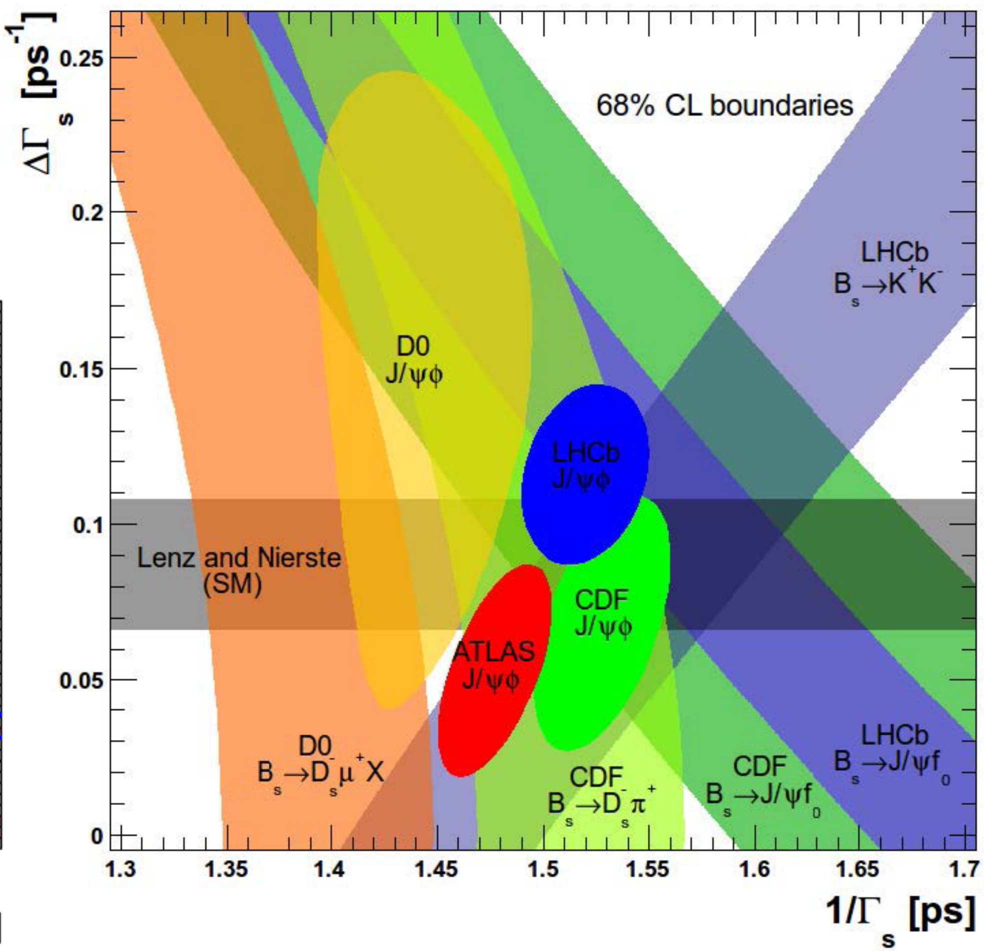
JHEP 12 (2012) 072

$$\phi_s = 0.22 \pm 0.41 \text{ (stat.)} \pm 0.10 \text{ (syst.) rad}$$
$$\Delta\Gamma_s = 0.053 \pm 0.021 \text{ (stat.)} \pm 0.010 \text{ (syst.) ps}^{-1}$$
$$\Gamma_s = 0.677 \pm 0.007 \text{ (stat.)} \pm 0.004 \text{ (syst.) ps}^{-1}$$
$$|A_0(0)|^2 = 0.528 \pm 0.006 \text{ (stat.)} \pm 0.009 \text{ (syst.)}$$
$$|A_\parallel(0)|^2 = 0.220 \pm 0.008 \text{ (stat.)} \pm 0.007 \text{ (syst.)}$$



No tagging yet

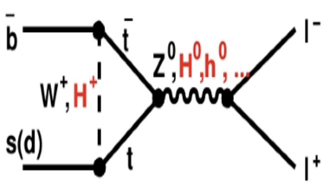
Much larger sample with 2012 data

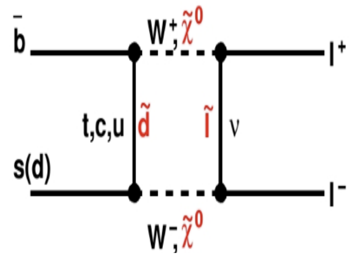


Rare Decays: $B_s \to \mu\mu$

PRB 713 (2012) 180

- Rare decays sensitive to new physics through loops
  - **In SM Br($B_s \to \mu\mu$)~(3.2 ± 0.2)x10^{-9}**
  - **NP enhancement or suppression**





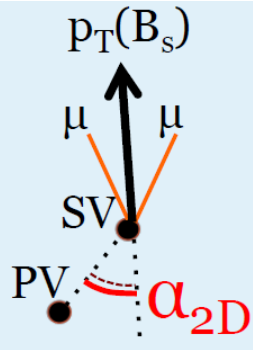
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \boxed{\mathcal{B}(B^\pm \to J/\psi K^\pm \to \mu^+\mu^- K^\pm) \times \frac{f_u}{f_s}} \times \boxed{\frac{N_{\mu^+\mu^-}}{N_{J/\psi K^\pm}}} \times \boxed{\frac{A_{J/\psi K^\pm}}{A_{\mu^+\mu^-}} \times \frac{\varepsilon_{J/\psi K^\pm}}{\varepsilon_{\mu^+\mu^-}}}$$

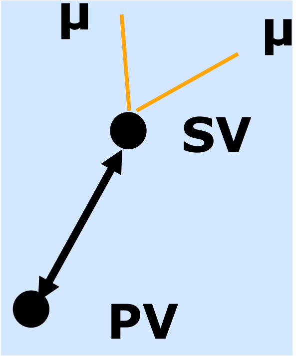
$$= N_{\mu^+\mu^-} \times \boxed{\mathrm{SES}}$$

- Signal yield normalized to reference decay $B^\pm \to J/\psi K^\pm$
- Signal yield: count in window, subtract non-resonant background estimate from sidebands and resonant background from MC
- Relative production rate: Br from PDG, f_s from LHCb
- Relative efficiency & acceptance: from Simulation
- SES: Single Event Sensitivity

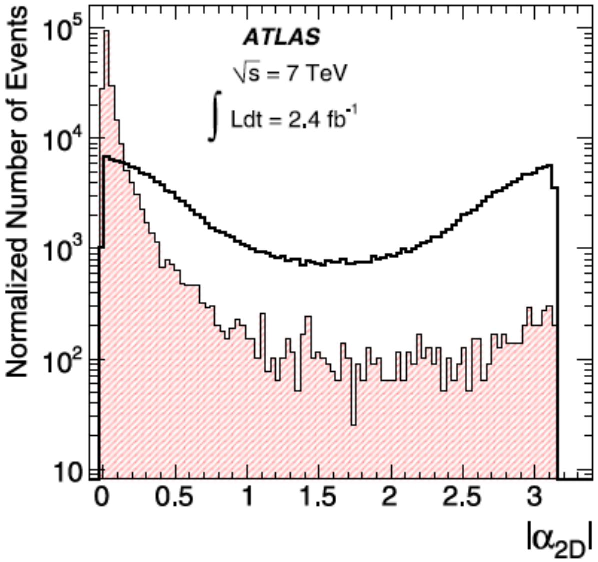
Discriminating variables: $B_s \to \mu\mu$

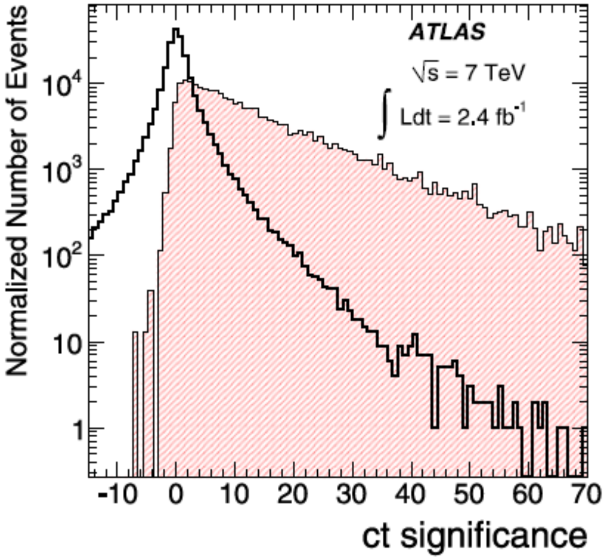
- Discriminate against non-resonant background

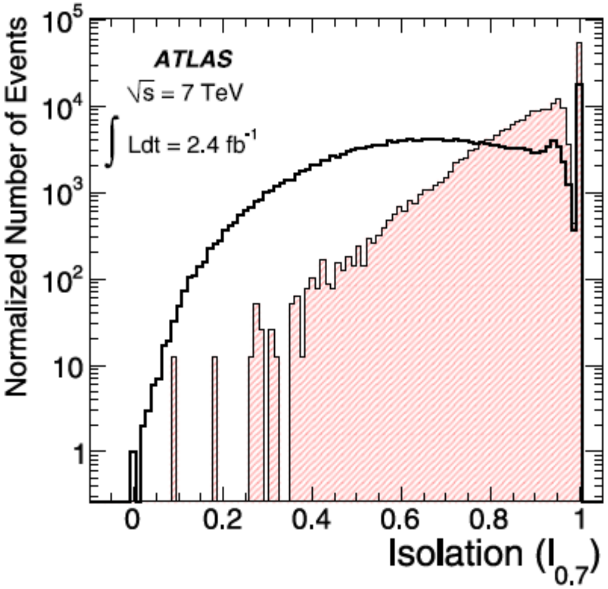




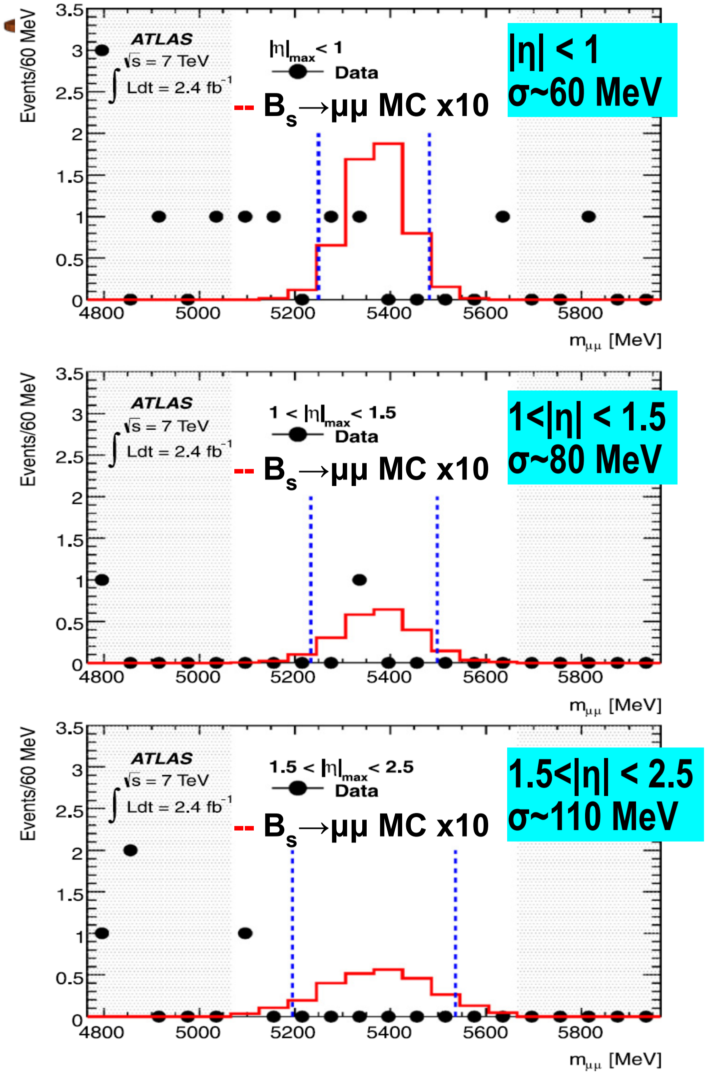
$$I_{0.7} = \frac{\left|\vec{p}_T^{\,B}\right|}{\left|\vec{p}_T^{\,B}\right| + \sum_{\Delta R<0.7} \left|\vec{p}_T^{\,track}\right|}$$



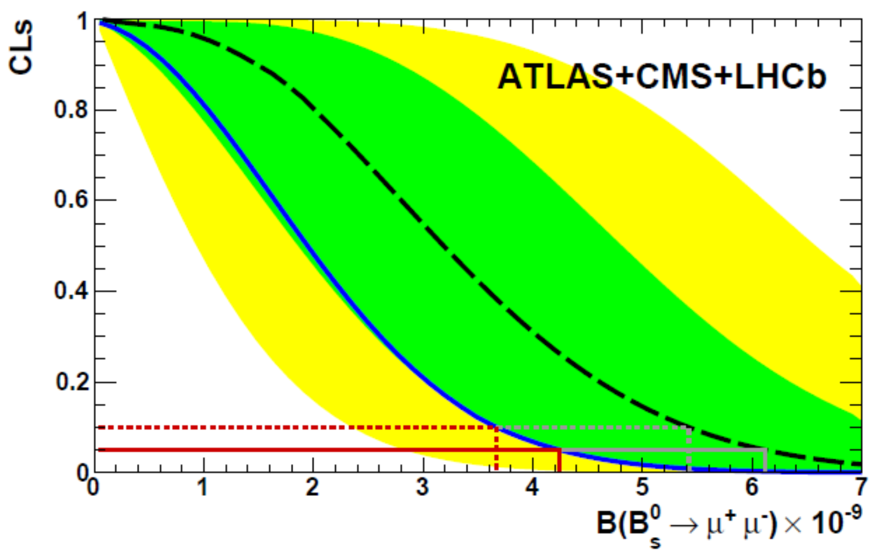




Results $B_s \to \mu\mu$



Combined ATLAS+CMS+LHCb Limit:
$Br(B_s \to \mu\mu) < 4.2 \times 10^{-9}$ at 95%



Recent Observation by LHCb:

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.2\,^{+1.4}_{-1.2}(\text{stat})\,^{+0.5}_{-0.3}(\text{syst})) \times 10^{-9}$$

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Conclusion

- ATLAS has an active heavy flavour programme
- Benefits from higher luminosity (and sometimes increased pT thresholds) but also more difficult environment due to pileup
- Interesting Results on
  - QCD production
  - rare decays: $Br(B_s \rightarrow \mu\mu) < 4.2 \times 10^{-9}$ at 95%
  - CP Violation: $\varphi_s = 0.22 \pm 0.41_{stat.} \pm 0.1_{syst.}$ rad
- Further results and updates in progress
- New Physics is still elusive

$B_s \rightarrow J/\psi\phi$ Likelihood

- T

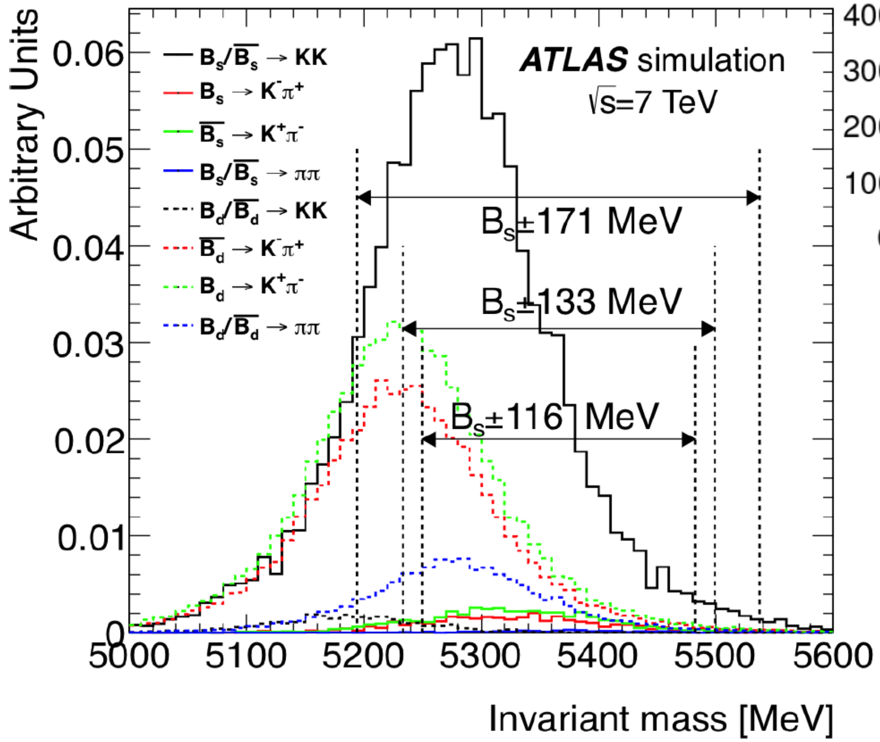
1	$\vert A_0\vert^2(t)$	$=$	$\vert A_0\vert^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) \pm \sin\phi_s \sin(\Delta m t)\right],$
2	$\vert A_{\parallel}(t)\vert^2$	$=$	$\vert A_{\parallel}\vert^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) \pm \sin\phi_s \sin(\Delta m t)\right],$
3	$\vert A_{\perp}(t)\vert^2$	$=$	$\vert A_{\perp}\vert^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) \mp \sin\phi_s \sin(\Delta m t)\right],$
4	$\Im(A_{\parallel}(t)\, A_{\perp}(t))$	$=$	$\vert A_{\parallel}\vert\vert A_{\perp}\vert e^{-\Gamma_s t}\left[-\cos(\delta_{\perp} - \delta_{\parallel}) \sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right.$ $\left.\mp \cos(\delta_{\perp} - \delta_{\parallel}) \cos\phi_s \sin(\Delta m t) \pm \sin(\delta_{\perp} - \delta_{\parallel}) \cos(\Delta m t)\right],$
5	$\Re(A_0(t)\, A_{\parallel}(t))$	$=$	$\vert A_0\vert\vert A_{\parallel}\vert e^{-\Gamma_s t} \cos(\delta_{\parallel} - \delta_0)\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right.$ $\left.\pm \sin\phi_s \sin(\Delta m t)\right],$
6	$\Im(A_0(t)\, A_{\perp}(t))$	$=$	$\vert A_0\vert\vert A_{\perp}\vert e^{-\Gamma_s t}\left[-\cos(\delta_{\perp} - \delta_0) \sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right.$ $\left.\mp \cos(\delta_{\perp} - \delta_0) \cos\phi_s \sin(\Delta m t) \pm \sin(\delta_{\perp} - \delta_0) \cos(\Delta m t)\right],$
7	$\vert A_s(t)\vert^2$	$=$	$\vert A_s\vert^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) \mp \sin\phi_s \sin(\Delta m t\right],$
8	$\Re(A_s^*(t) A_{\parallel}(t))$	$=$	$\vert A_s\vert\vert A_{\parallel}\vert e^{-\Gamma_s t}\left[-\sin(\delta_{\parallel} - \delta_s) \sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) \mp \sin(\delta_{\parallel} - \delta_s)\ \cos\phi_s \sin(\Delta m t)\right.$ $\left.\pm \cos(\delta_{\parallel} - \delta_s) \cos(\Delta m t)\right],$
9	$\Im(A_s^*(t) A_{\perp}(t))$	$=$	$\vert A_s\vert\vert A_{\perp}\vert e^{-\Gamma_s t} \sin(\delta_{\perp} - \delta_s)\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right.$ $\left.\mp \sin\phi_s \sin(\Delta m t)\right],$
10	$\Re(A_s^*(t) A_0(t))$	$=$	$\vert A_s\vert\vert A_0\vert e^{-\Gamma_s t}\left[-\sin(\delta_0 - \delta_s) \sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right.$ $\left.\mp \sin(\delta_0 - \delta_s) \cos\phi_s \sin(\Delta m t) \pm \cos(\delta_0 - \delta_s) \cos(\Delta m t)\right].$

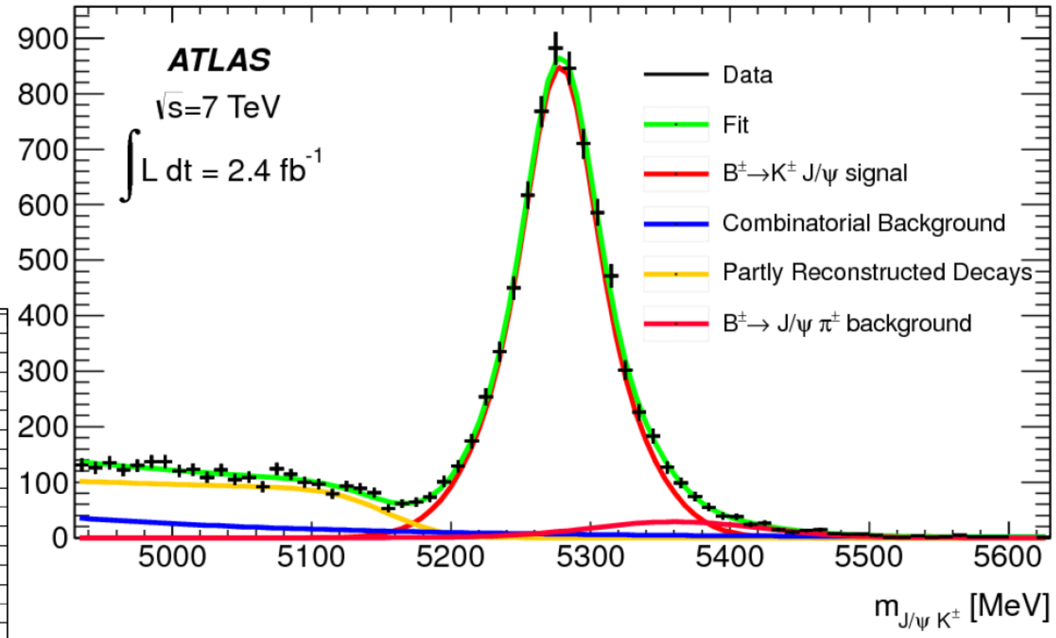
$B_s \to J/\psi\varphi$ Likelihood

$$
\begin{aligned}
\mathscr{L} = & \prod_{1}^{N}\Big[f_s \cdot P_s(m|\sigma_m)\cdot P_s(\sigma_m)\cdot P_s(\Omega,t|\sigma_t)\cdot P_s(\sigma_t)\cdot A(\Omega_i,p_{Ti})\cdot P_s(p_{Ti}) \\
& + f_s\cdot f_{Bd}\cdot P_{Bd}(m)\cdot P_s(\sigma_m)\cdot P_{Bd}(t|\sigma_t)\cdot P_{Bd}(\theta)\cdot P_{Bd}(\varphi)\cdot P_{Bd}(\psi)\cdot P_s(\sigma_t)\cdot P_s(p_{Ti}) \\
& + (1-f_s-f_s\cdot f_{Bd})\cdot P_b(m)\cdot P_b(\sigma_m)\cdot P_b(t|\sigma_t)\cdot P_b(\theta)\cdot P_b(\varphi)\cdot P_b(\psi)\cdot P_b(\sigma_t)\cdot P_b(p_{Ti})\Big]
\end{aligned}
$$

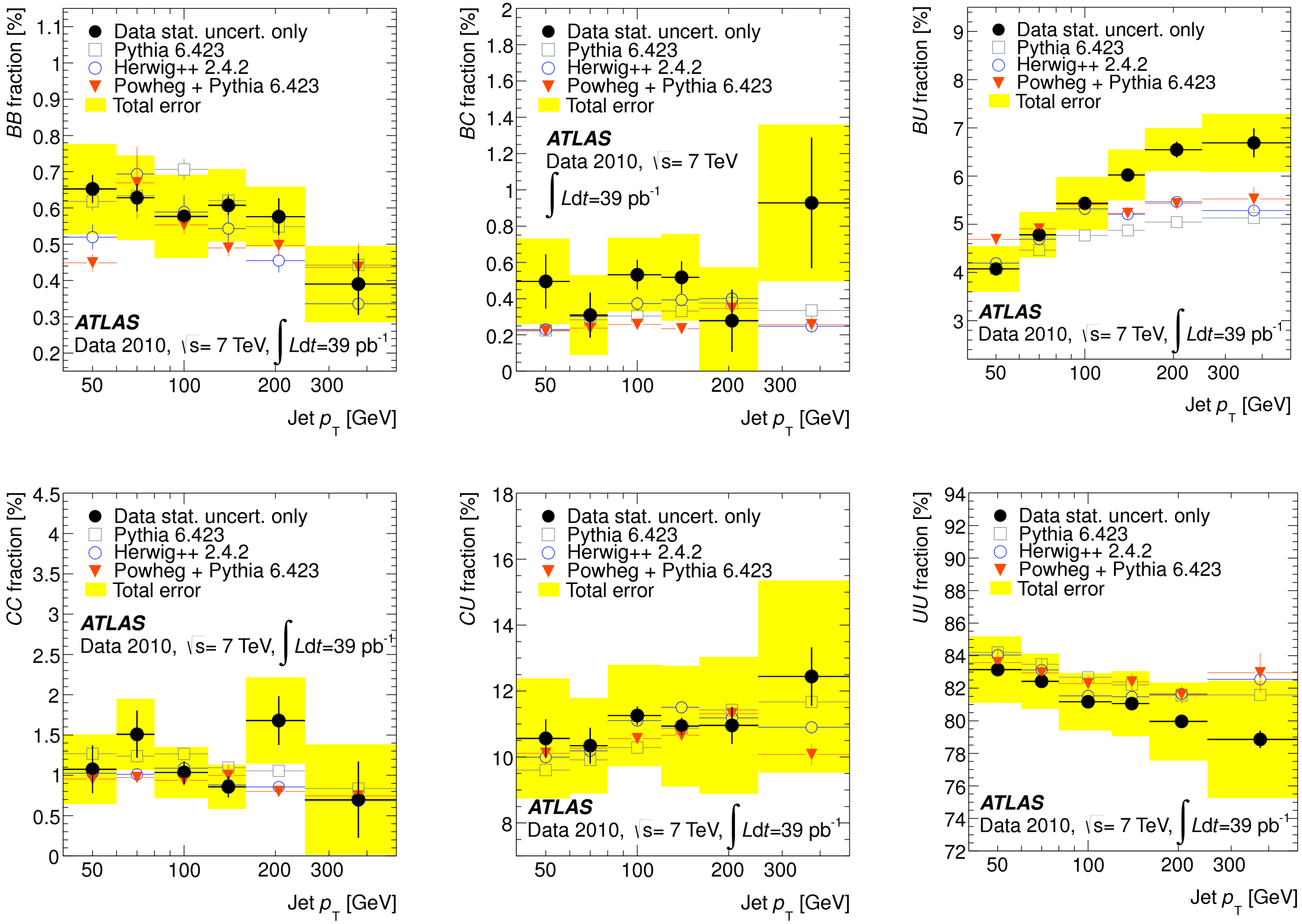
$\frac{1}{2}\lvert A_0(0)\rvert^2 \left[(1+\cos\phi_s)\,e^{-\Gamma_{\rm L}^{(s)}t}+(1-\cos\phi_s)\,e^{-\Gamma_{\rm H}^{(s)}t}\right]$	$2\cos^2\psi_T(1-\sin^2\theta_T\cos^2\varphi_T)$
$\frac{1}{2}\lvert A_\parallel(0)\rvert^2 \left[(1+\cos\phi_s)\,e^{-\Gamma_{\rm L}^{(s)}t}+(1-\cos\phi_s)\,e^{-\Gamma_{\rm H}^{(s)}t}\right]$	$\sin^2\psi_T(1-\sin^2\theta_T\sin^2\varphi_T)$
$\frac{1}{2}\lvert A_\perp(0)\rvert^2 \left[(1-\cos\phi_s)\,e^{-\Gamma_{\rm L}^{(s)}t}+(1+\cos\phi_s)\,e^{-\Gamma_{\rm H}^{(s)}t}\right]$	$\sin^2\psi_T\sin^2\theta_T$
$\frac{1}{2}\lvert A_0(0)\rvert\lvert A_\parallel(0)\rvert\cos\delta_{\parallel}$ $\left[(1+\cos\phi_s)\,e^{-\Gamma_{\rm L}^{(s)}t}+(1-\cos\phi_s)\,e^{-\Gamma_{\rm H}^{(s)}t}\right]$	$\frac{1}{\sqrt{2}}\sin 2\psi_T\sin^2\theta_T\sin 2\varphi_T$
$\frac{1}{2}\lvert A_\parallel(0)\rvert\lvert A_\perp(0)\rvert\left(e^{-\Gamma_{\rm H}^{(s)}t}-e^{-\Gamma_{\rm L}^{(s)}t}\right)\cos(\delta_\perp-\delta_{\parallel})\sin\phi_s$	$\sin^2\psi_T\sin 2\theta_T\sin\varphi_T$
$-\frac{1}{2}\lvert A_0(0)\rvert\lvert A_\perp(0)\rvert\left(e^{-\Gamma_{\rm H}^{(s)}t}-e^{-\Gamma_{\rm L}^{(s)}t}\right)\cos\delta_\perp\sin\phi_s$	$\frac{1}{\sqrt{2}}\sin 2\psi_T\sin 2\theta_T\cos\varphi_T$
$\frac{1}{2}\lvert A_S(0)\rvert^2\left[(1-\cos\phi_s)\,e^{-\Gamma_{\rm L}^{(s)}t}+(1+\cos\phi_s)\,e^{-\Gamma_{\rm H}^{(s)}t}\right]$	$\frac{2}{3}\left(1-\sin^2\theta_T\cos^2\varphi_T\right)$
$-\frac{1}{2}\lvert A_S(0)\rvert\lvert A_\parallel(0)\rvert\left(e^{-\Gamma_{\rm H}^{(s)}t}-e^{-\Gamma_{\rm L}^{(s)}t}\right)\sin(\delta_\parallel-\delta_S)\sin\phi_s$	$\frac{1}{3}\sqrt{6}\sin\psi_T\sin^2\theta_T\sin 2\varphi_T$
$\frac{1}{2}\lvert A_S(0)\rvert\lvert A_\perp(0)\rvert$ $\left[(1-\cos\phi_s)\,e^{-\Gamma_{\rm L}^{(s)}t}+(1+\cos\phi_s)\,e^{-\Gamma_{\rm H}^{(s)}t}\right]\sin(\delta_\perp-\delta_S)$	$\frac{1}{3}\sqrt{6}\sin\psi_T\sin 2\theta_T\cos\varphi_T$
$-\frac{1}{2}\lvert A_0(0)\rvert\lvert A_S(0)\rvert\sin(-\delta_S)\left(e^{-\Gamma_{\rm H}^{(s)}t}-e^{-\Gamma_{\rm L}^{(s)}t}\right)\sin\phi_s$	$\frac{4}{3}\sqrt{3}\cos\psi_T\left(1-\sin^2\theta_T\cos^2\varphi_T\right)$

Introduction, Rare Decays: $B_s \to \mu\mu$





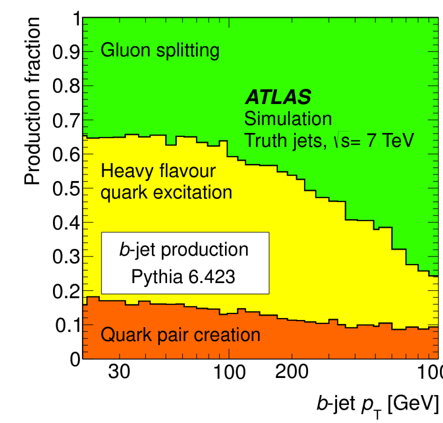
Dijet flavour composition at 7TeV



$|Y_{jet}|<2.1$

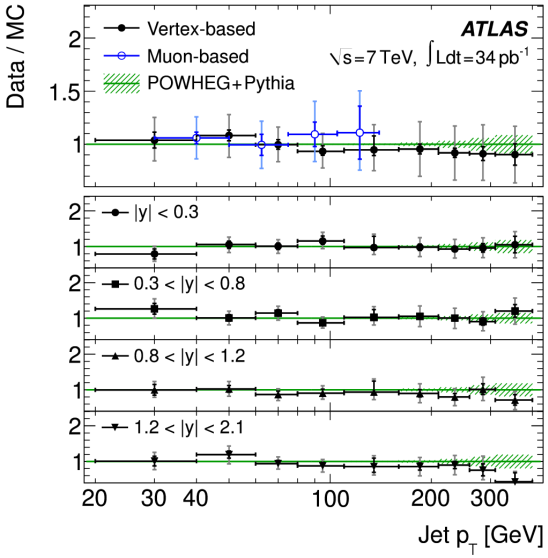
Good agreement with LO and NLO except here

Quark pair sources



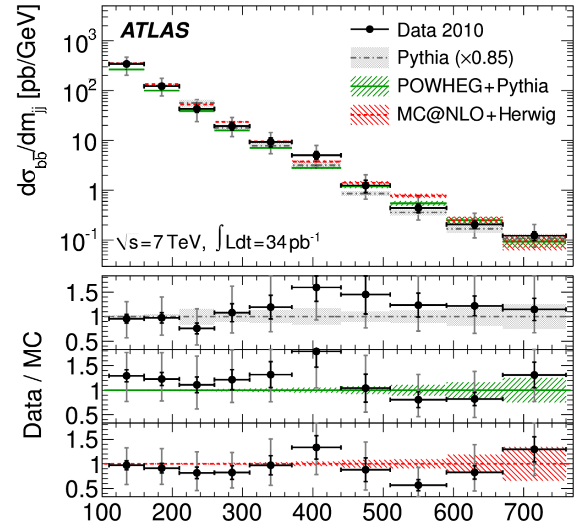
Use of excellent b-tagging plus kinematics
Template fits, unfolding
Gluon splitting to 2 b-jets observed

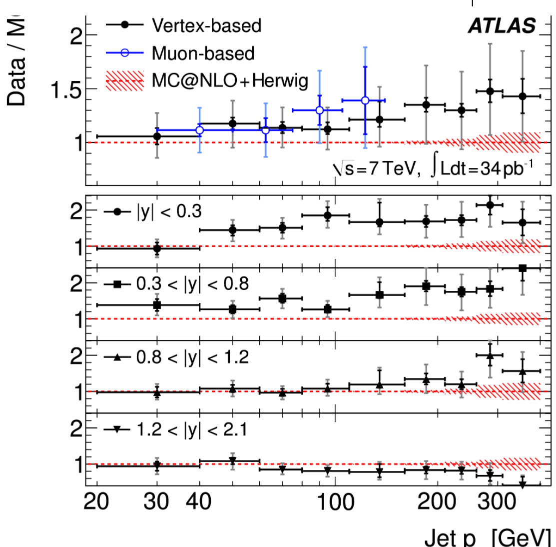
Beauty single- and Dijets at 7TeV

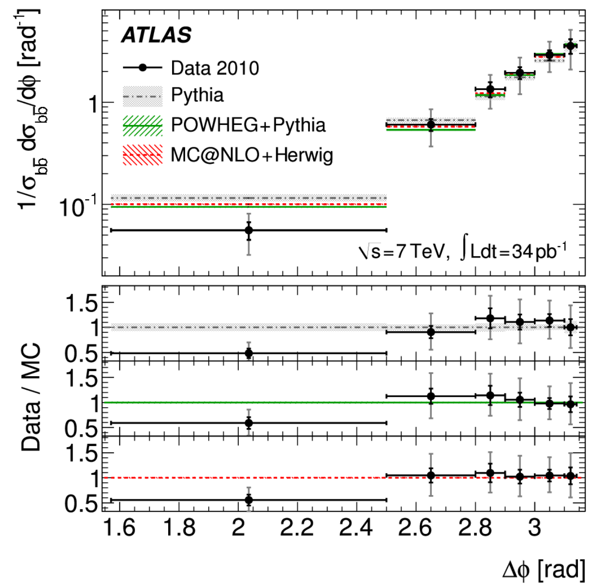


$|Y_{jet}|<2.1$
Anti-kT4

PYTHIA+POWHEG general good agreement







MC@LO+HERWIG – less successful for inclusive, esp. for central and high-pT

W+ b-jet production

An important test of QCD

Contributes to H bb and new physics backgrounds

Overlap with single top and tt production

Semileptonic W (track & cluster- isolated e/μ with MET) plus 1 or 2 jets

Lifetime + topology for b-tags

$|Y_{jet}|<2.1$, $pT_{jet}>25GeV$
Single top included