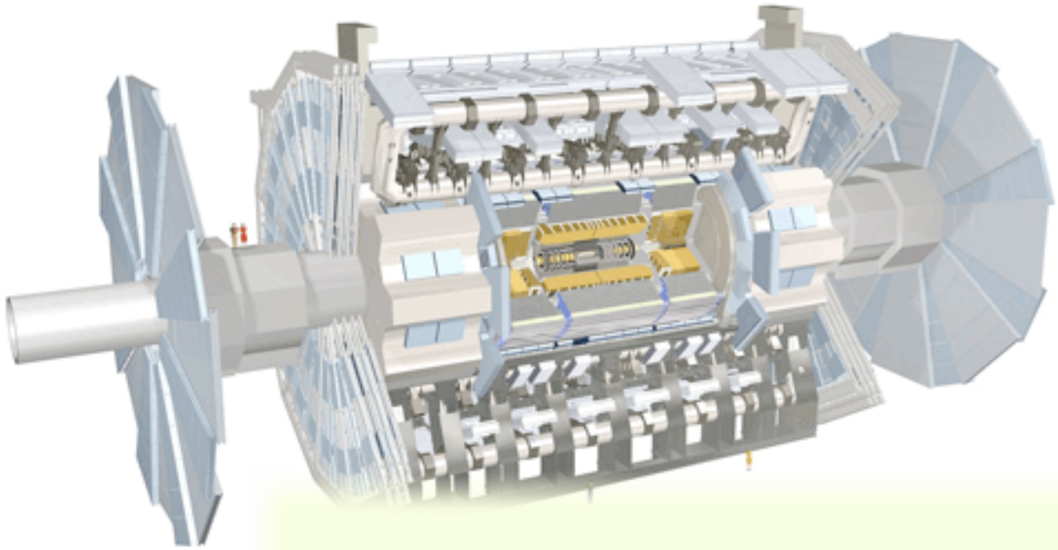
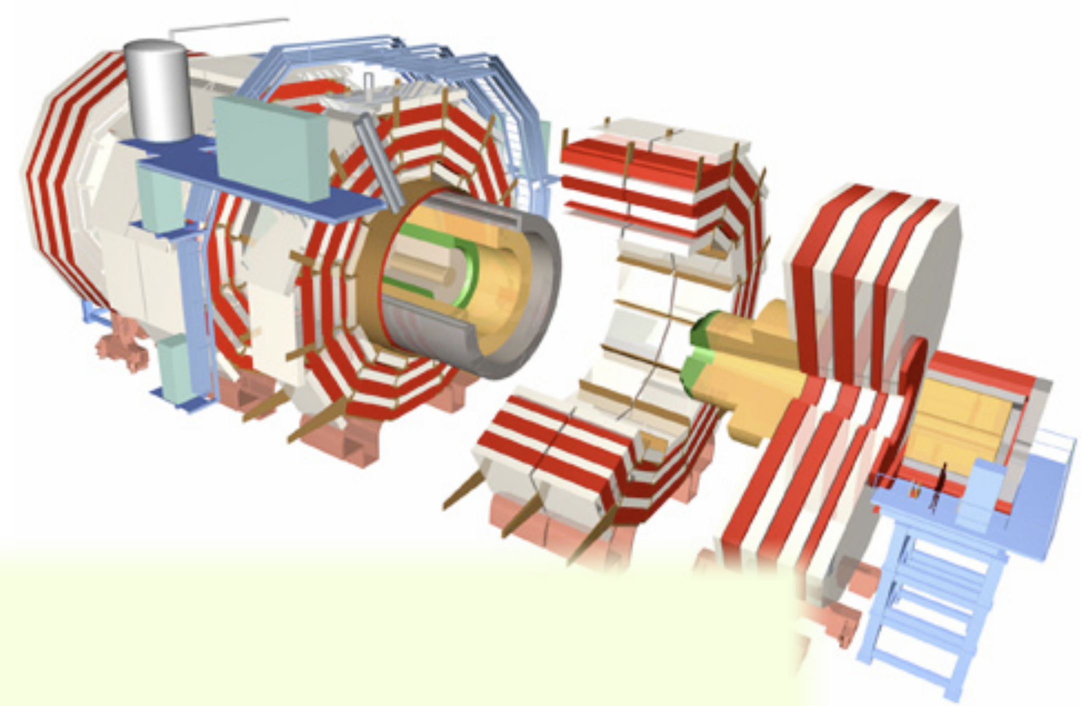




Heavy Flavor Measurements at LHC

Stefania Spagnolo
INFN Lecce and Dipartimento di Matematica e Fisica “Ennio De Giorgi”, Unisalento
ATLAS Experiment

on behalf of the **ATLAS** and **CMS** Collaborations

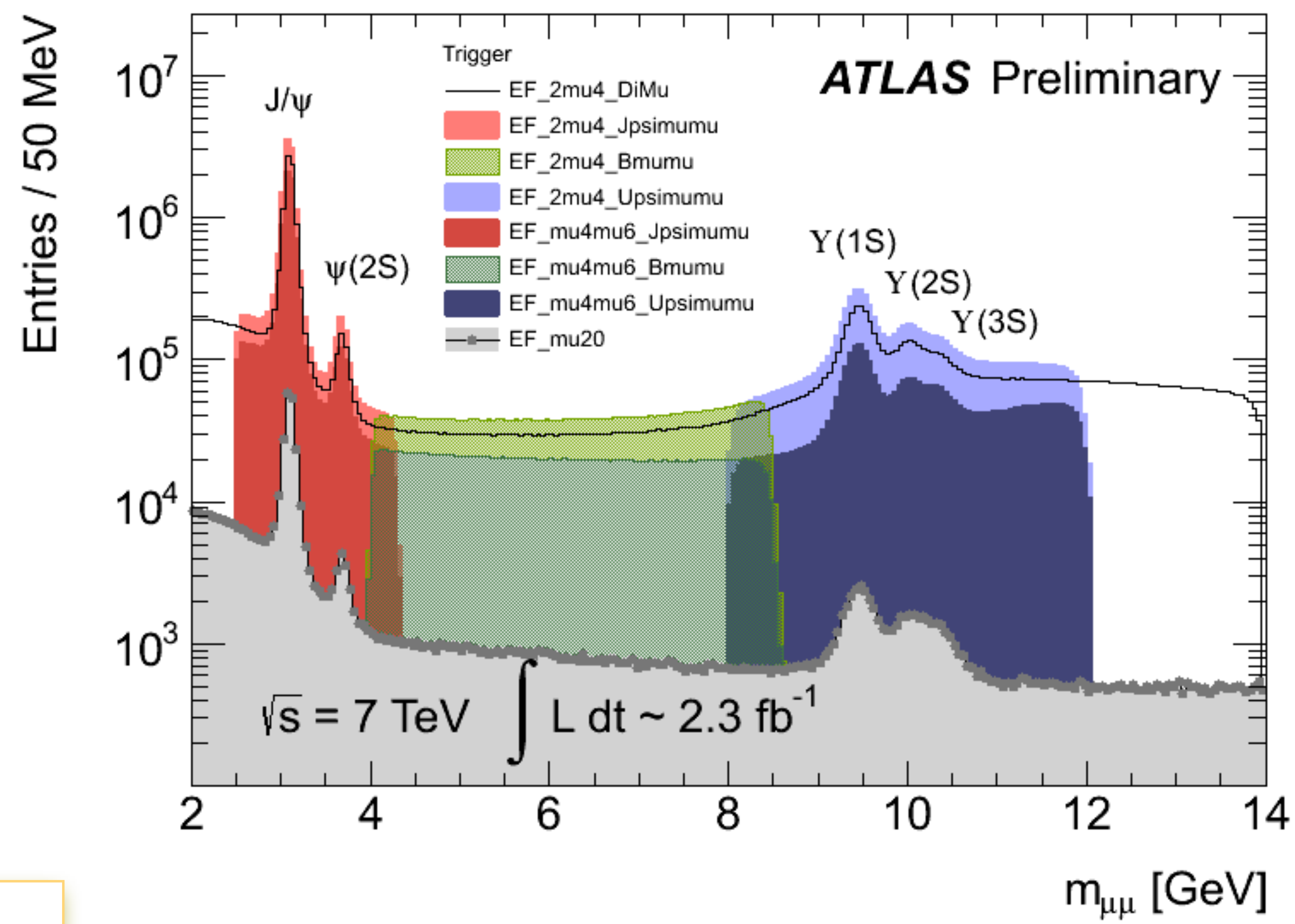
Les Rencontre de Moriond - EW Interactions and Unified Theories - 2-9 March 2013

Outline

- Most of the results shown here have already been presented in past conferences
  - review and focus on most recent (< 1 year old)
- Topics:
  - Inclusive Heavy Flavor production: b-jet and b-hadron measurements
  - Exclusive b-hadron measurements (cross sections, lifetimes, masses)
    - Λb and observations of rare and new b-hadrons
  - Onia
    - Υ cross section and polarization, χ_c production ratio, states with unclear interpretation
  - Bs system: lifetime difference and CP violation parameters
  - Search for New Physics in rare decays

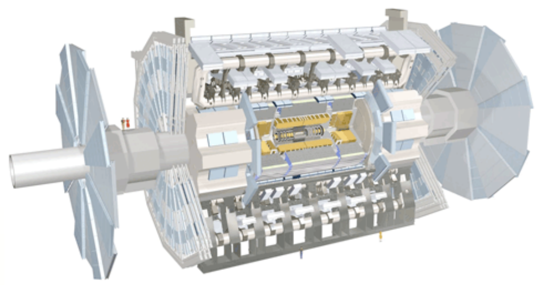
Triggers & detector performance for Heavy Flavor physics

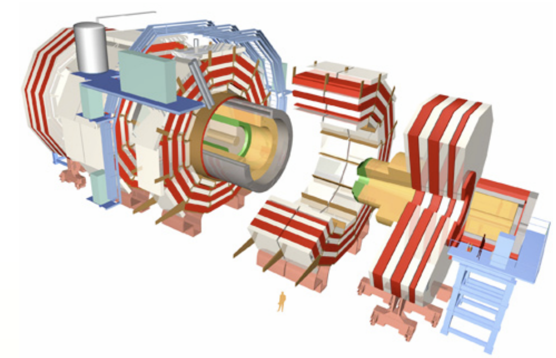
- Triggers:
  - single (low p_T thresholds in 2010 data) and di-μ triggers
    - semi-leptonic decays, decays to J/ψ➛μμ
  - di-μ generic triggers
  - J/ψ, ϒ dedicated triggers, Bs(μμ) [2011 data set]
    - using invariant mass selected regions (and common vertex fit constraint)



2010 data sets (40 pb^{-1} per experiment) widely exploited due to ideal conditions: low p_T trigger thresholds and limited pileup (1-3 events/beam crossing);
2011 data (5 fb^{-1} per exp.) ***partially used*** (<μ>=6-12)
No results yet on heavy flavor physics based ***on 2012 data*** (>20fb^{-1}/experiment) (<μ>=21)

	ATLAS	CMS
σ(Mμμ) J/ψ	60 MeV	30-50 MeV
σ(Mμμ) Bs	80 MeV	45 MeV
σ(τ) Bs➛J/ψ φ	100 fs	70 fs



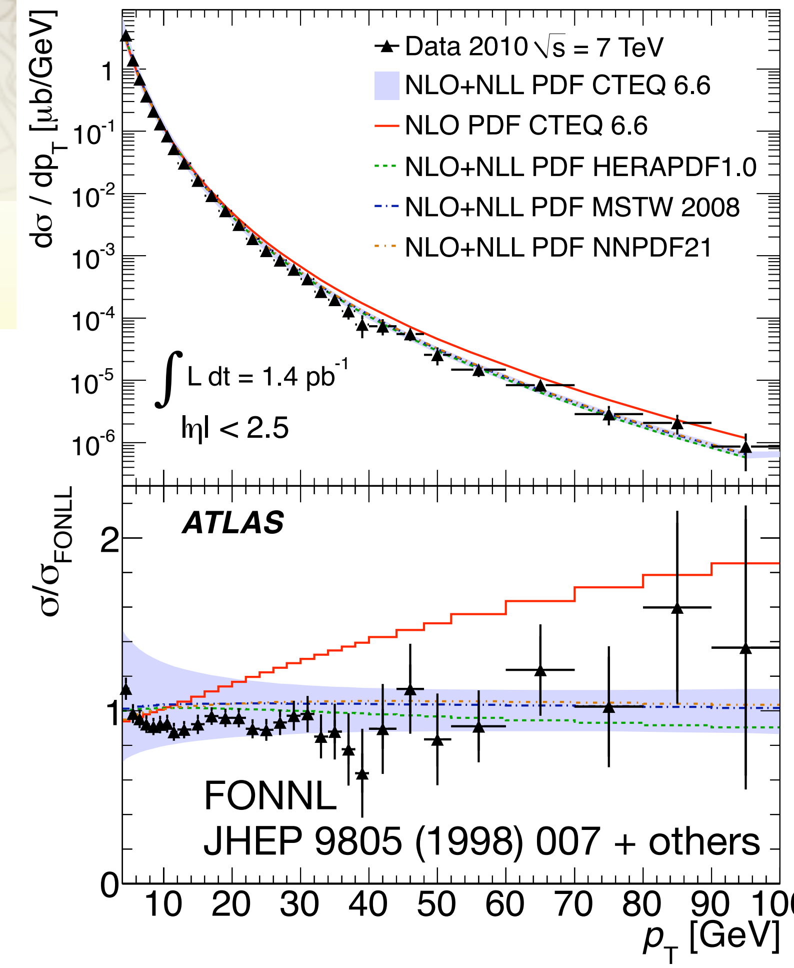


Inclusive Heavy Flavor production

in ATLAS and CMS

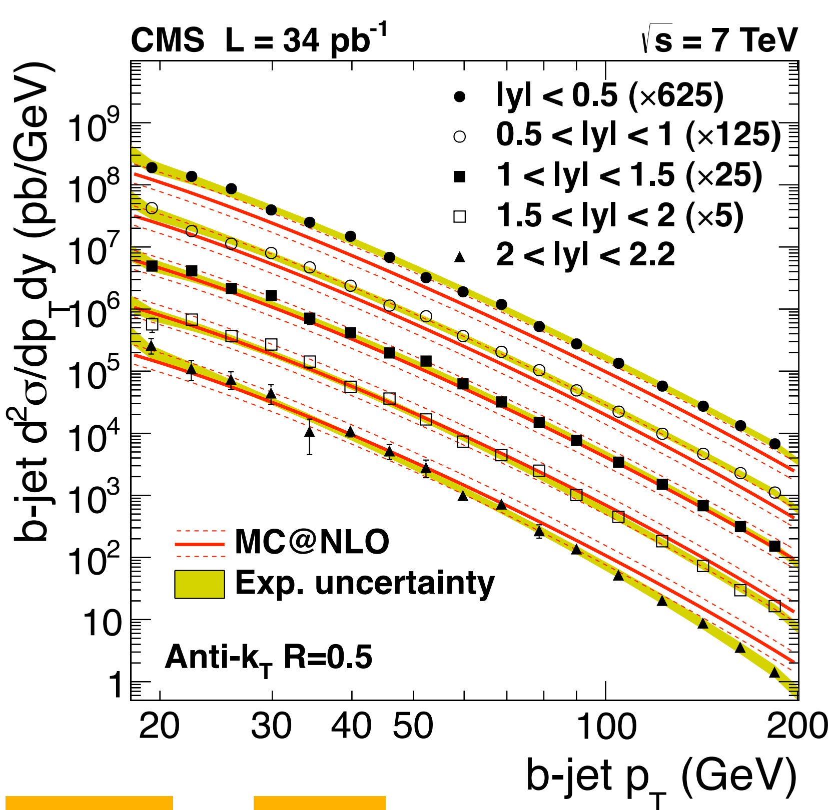
Inclusive heavy flavor production measurements

ATLAS



- ATLAS: b/c inclusive production from inclusive e/μ $d\sigma/dp_T$ at 7 TeV in 2010 data (~1.4 pb-1) Phys.Lett. B707 (2012) 438-458
  - good agreement with predictions from ***Fixed Order NLO*** calculations ***with NLL high-p_T resummation*** (first clear evidence at hadron colliders of the importance of these corrections); theory uncertainty (from 40%, at low p_T, to 20%) dominated by resum. and fact. scales

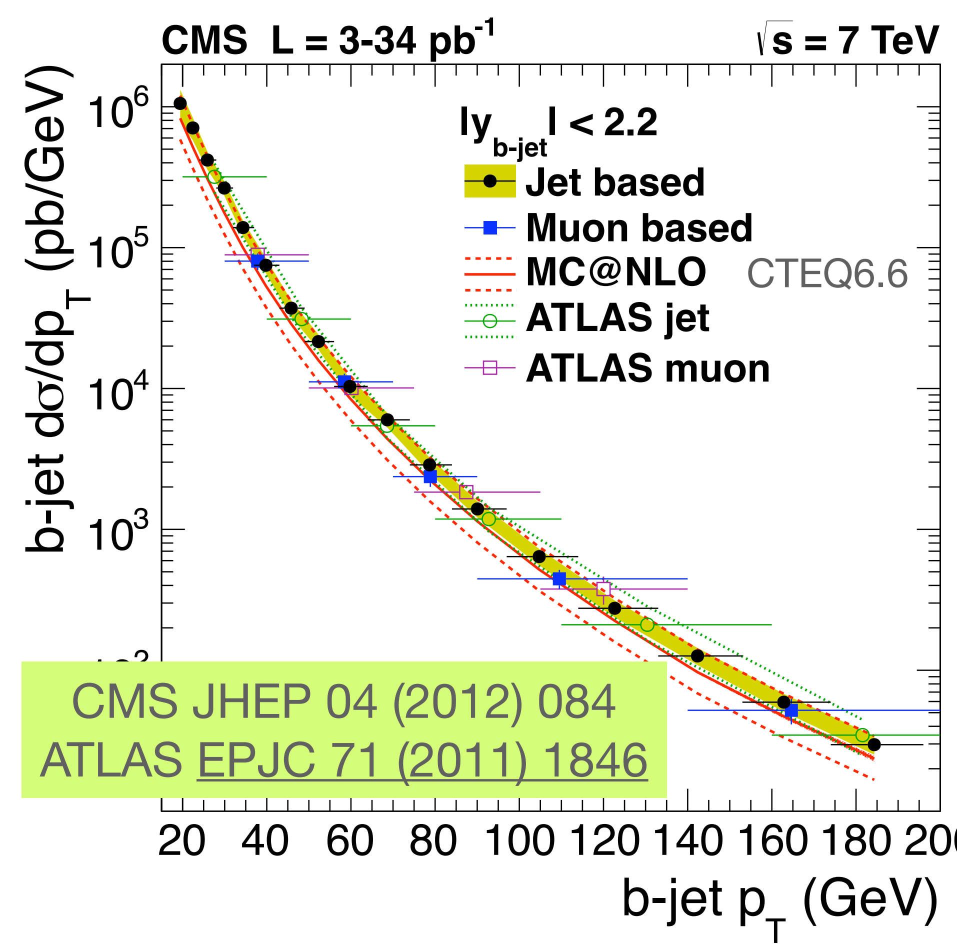
CMS JHEP 04 (2012) 084



ATLAS and CMS inclusive b-jet production cross section

- b-jet identification via secondary vertices (34pb-1) or μ from b decays (3 pb-1 CMS, 34 pb-1 ATLAS)
- measurements consistently higher (at high pT) than MC@NLO+Herwig prediction; largest discrepancies at high p_T for central jets

- ***POWHEG+Pythia in good agreement with data***

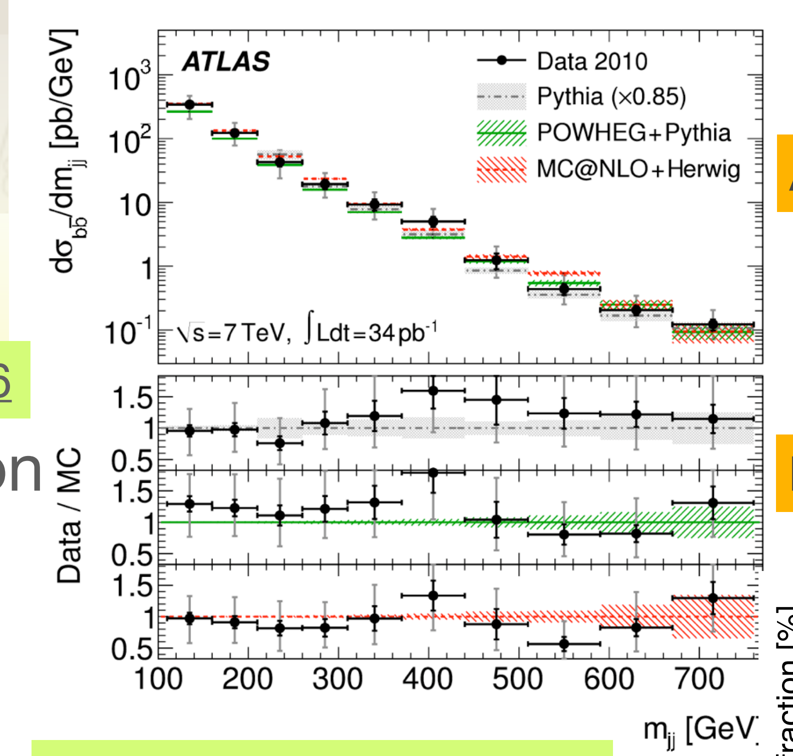


CMS JHEP 04 (2012) 084
ATLAS EPJC 71 (2011) 1846

ATLAS CMS

Inclusive b-jet pair production at 7 TeV

ATLAS EPJC 71 (2011) 1846



ATLAS

Mjj [GeV]

- ATLAS: b-bbar inclusive cross section in agreement with NLO predictions
- CMS $\sigma(pp \to bbX \to \mu\mu+X)$ in ~28 pb^{-1}

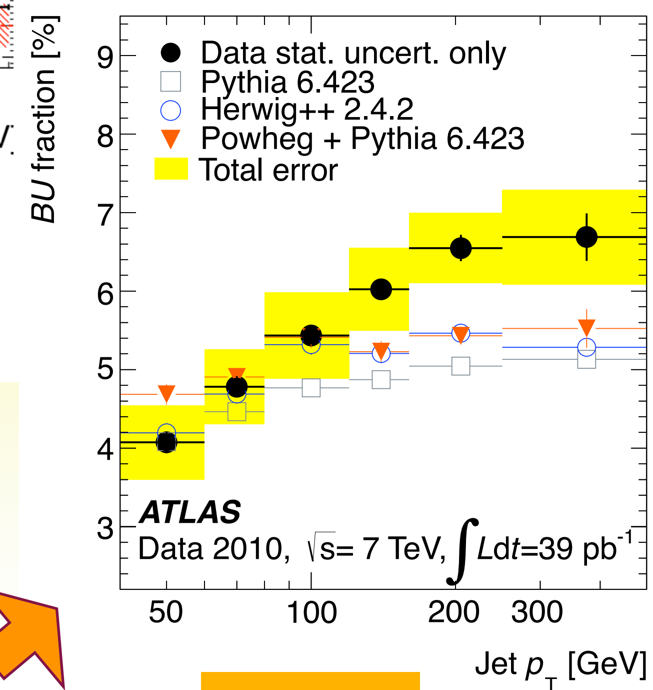
CMS JHEP06(2012)110

CMS

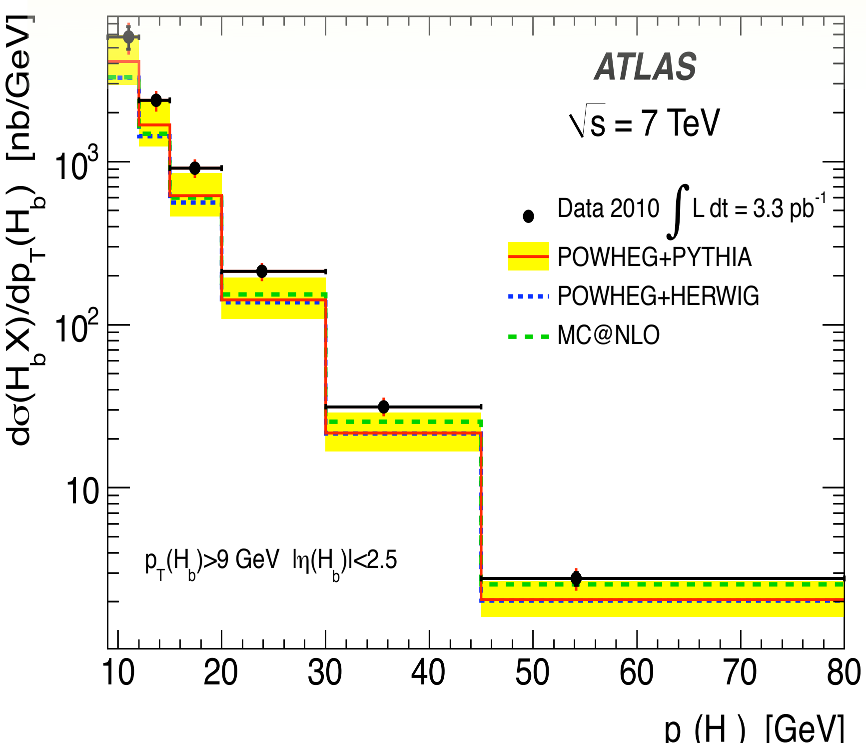
$$\sigma(pp \to b\bar{b}X \to \mu\mu X', p_T > 4\,\mathrm{GeV}, |\eta| < 2.1) = 26.4 \pm 0.1\,(\mathrm{stat.}) \pm 2.4\,(\mathrm{syst.}) \pm 1.1\,(\mathrm{lumi.})\ \mathrm{nb}$$

$$19.7 \pm 0.3\,(\mathrm{stat.})\ ^{+6.5}_{-4.1}\,(\mathrm{syst.})\ \mathrm{nb}$$

MC@NLO prediction



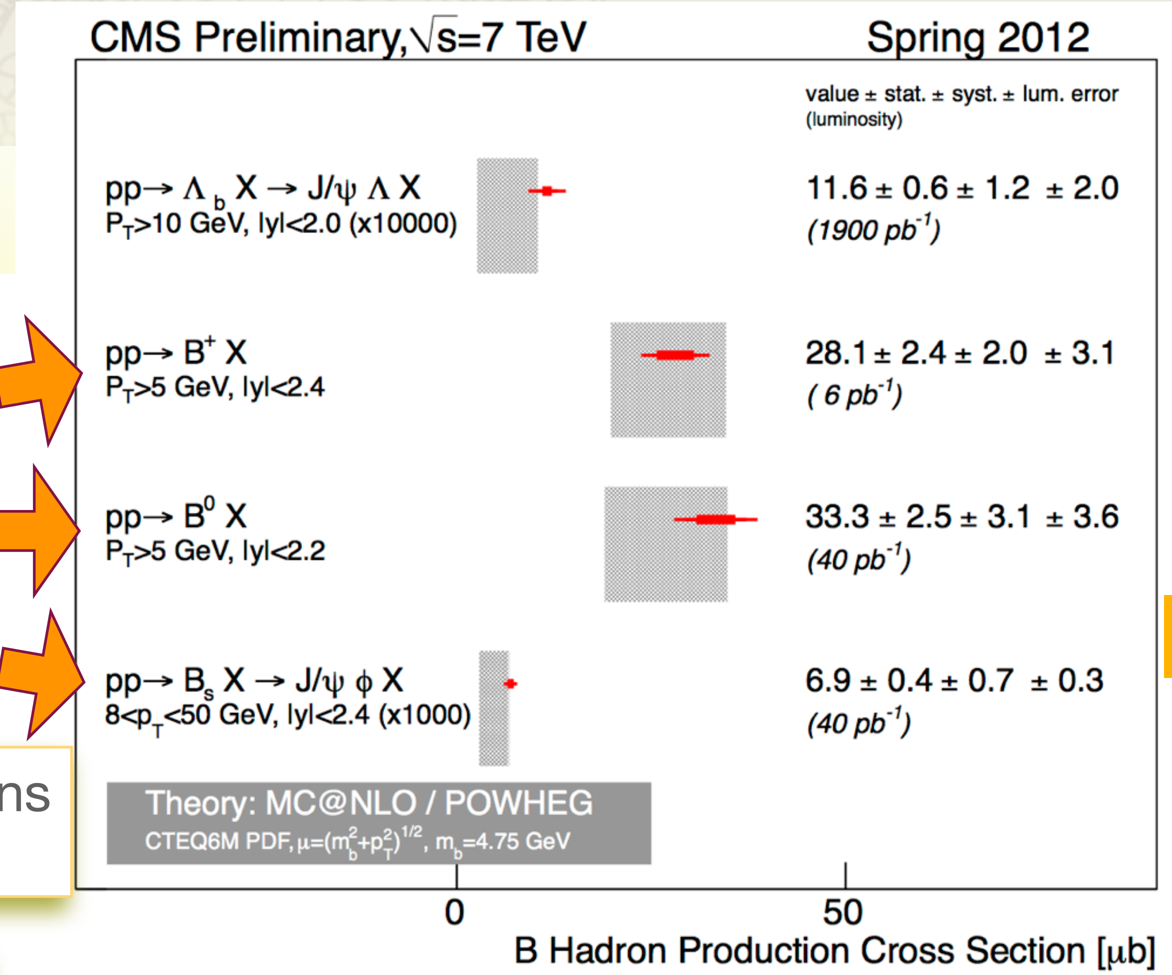
Other results



- ATLAS: flavor composition of di-jet events at 7 TeV — Fall 2012 — arXiv:1210.0441, submitted to EJP
- ATLAS: b-hadron (Hb) production at 7 TeV from D*+μ-X — Summer 2012 — Nucl. Phys. B864 (2012) 341-381
- ATLAS: Measurement of D*± in jets — PRD 85 (2012) 052005 — Fall 2011
- CMS: b-bbar angular correlation — JHEP (2011)1103:136 — Winter 2011

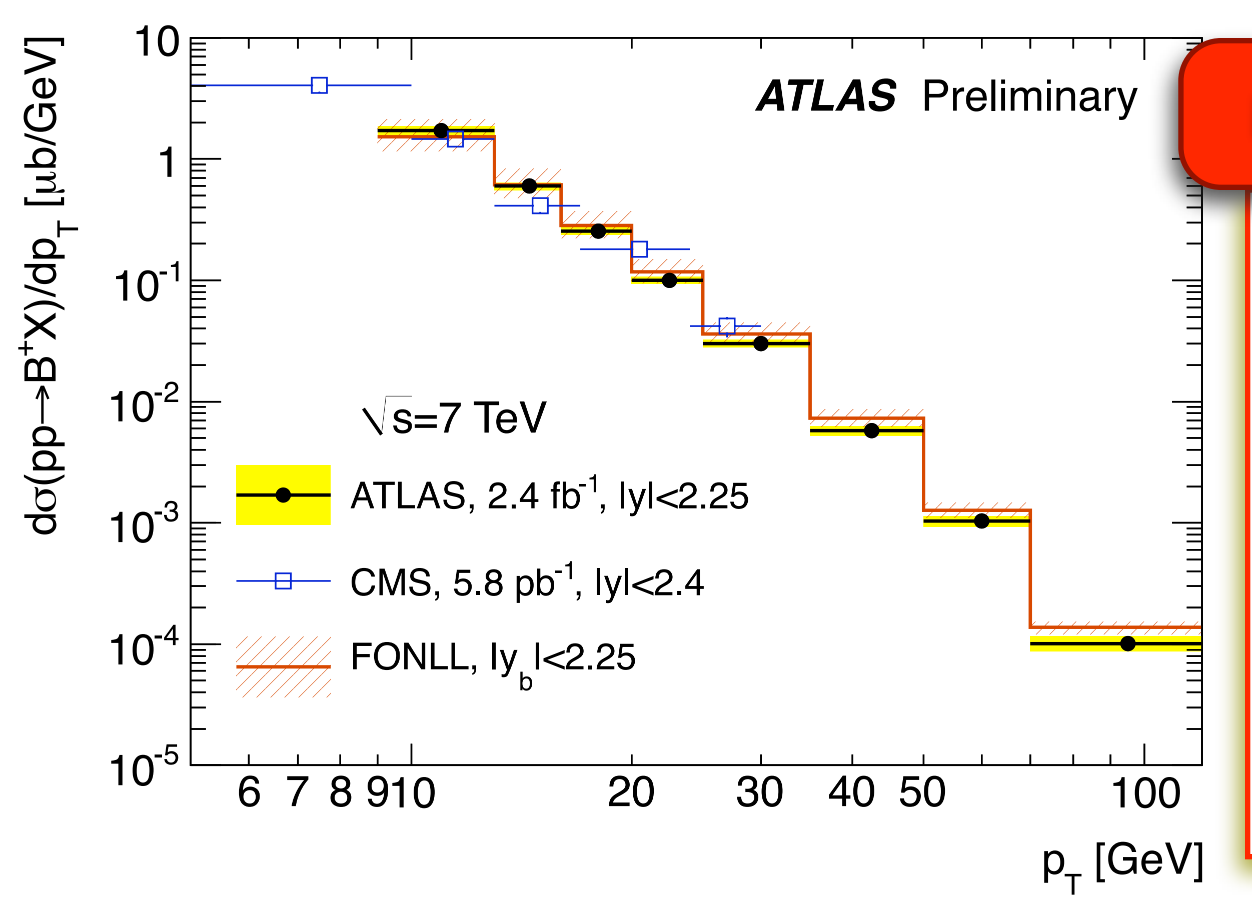
Exclusive B hadron production

- B^+ prod. σ (5.8 pb^{-1}) PRL106(2011)112001
- B^0_d prod. σ (40 pb^{-1}) PRL106 (2011)252001
- B^0_s prod. σ (40 pb^{-1}) PRD84(2011)052008



CMS

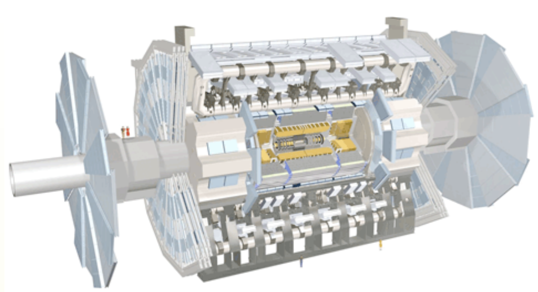
General trend of data to be higher than NLO predictions
Measurement error lower than theory uncertainty

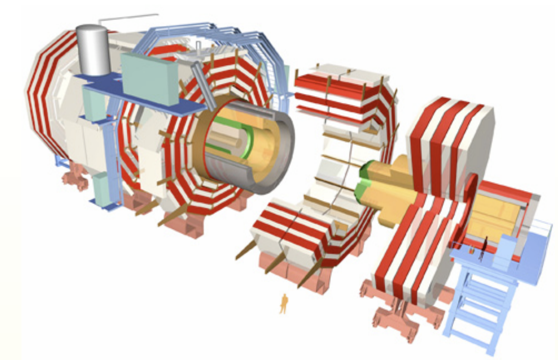


NEW

ATLAS-CONF-2013-008

- based on part of the 2011 ATLAS data set
  - high statistics meas. of $d\sigma/dp_T$ and $d\sigma/d|y|$ from a selection of $B^{\pm} \to J/\psi(\mu\mu)K^{\pm}$
  - good agreement with POWHEG+PYTHIA in rate and shape, while MC@NLO+HERWIG predicts lower rate and doesn't reproduce the p_T and y dependence
  - FONNL in agreement with measurements





Properties of hadrons with beauty: Λ_b

in ATLAS and CMS

Λ_b differential cross section and $\bar{\Lambda}_b/\Lambda_b$ ratio

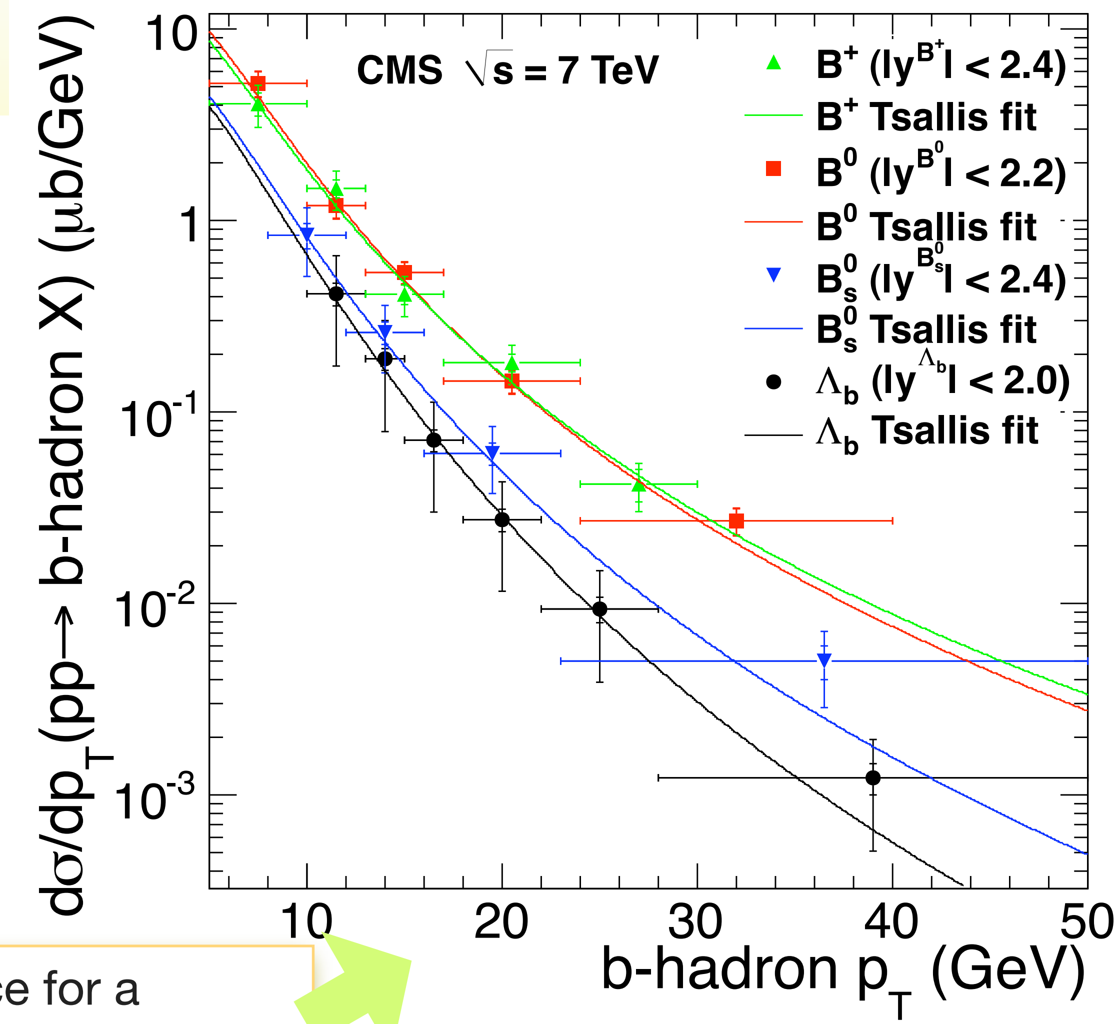
Spring 2012 CMS PLB714(2012)136

An exclusive B-baryon prod. cross section at 7TeV

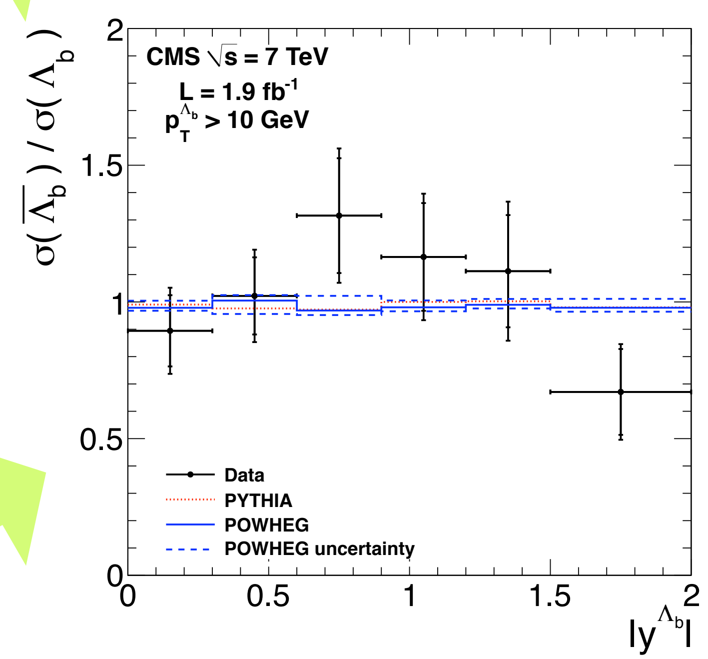
Shed light on b-quark fragmentation function (historical disagreement between Z➛bb [LEP] and Tevatron data)

y-dependent baryon/anti-baryon asymmetry predicted in baryon transport models

- using 1250 fully reconstructed ***Λ_b➛Λ J/ψ➛(pπ) (μμ)*** in 1.9 fb^{-1} exploiting J/ψ triggers
  - selection efficiency from 0.3% to 4%(at high pT) [limited di-μ acceptance, low Λ rec. eff.]; yield from unbinned ext. max. Likelihood fit to Λ_b and anti-Λ_b cand. inv. mass -main background J/ψ from B-decays
- measurements BR(Λ_b➛Λ J/ψ)×dσ(Λ)/dp_T and BR×dσ(Λb)/dy for p_T>10GeV and |y|<2;
  - inclusive ***σ×BR = 1.16±0.06^{stat}±0.12^{syst} nb*** agrees with PYTHIA and NLO POWHEG within large error on BR(Λb➛Λ J/ψ) ***known with ~54% error***
  - p_T spectrum steeper in data; y shape well modeled

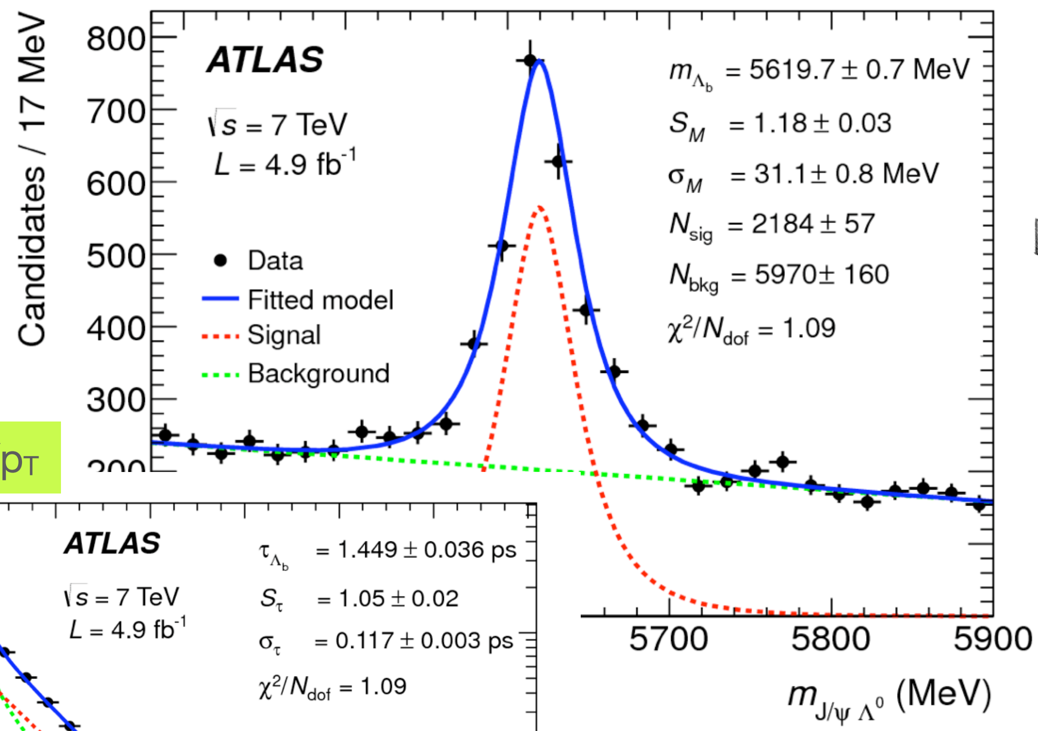


Evidence for a decrease with p_T of the fraction of b-quarks fragmenting to Λb (confirming LHCb)

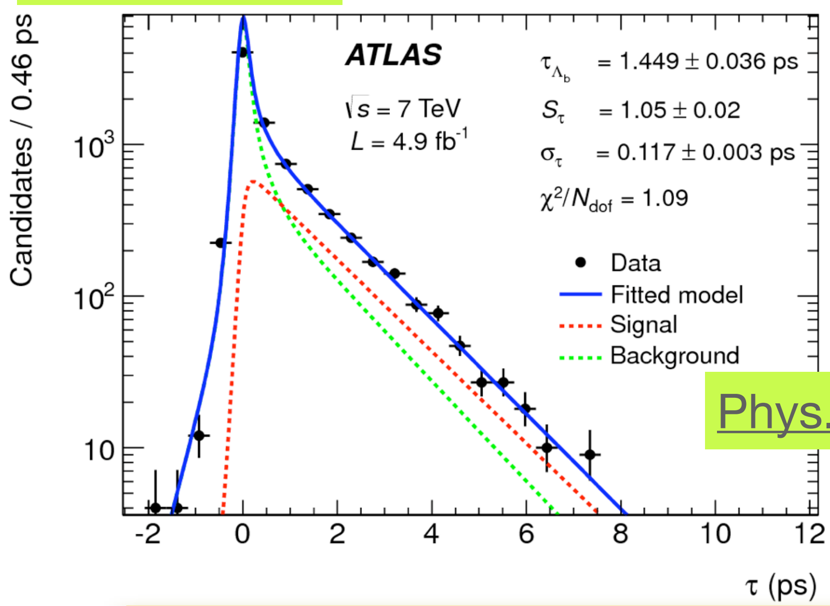


No evidence of y dep. baryon/anti-baryon asymmetry

Λ_b mass and lifetime

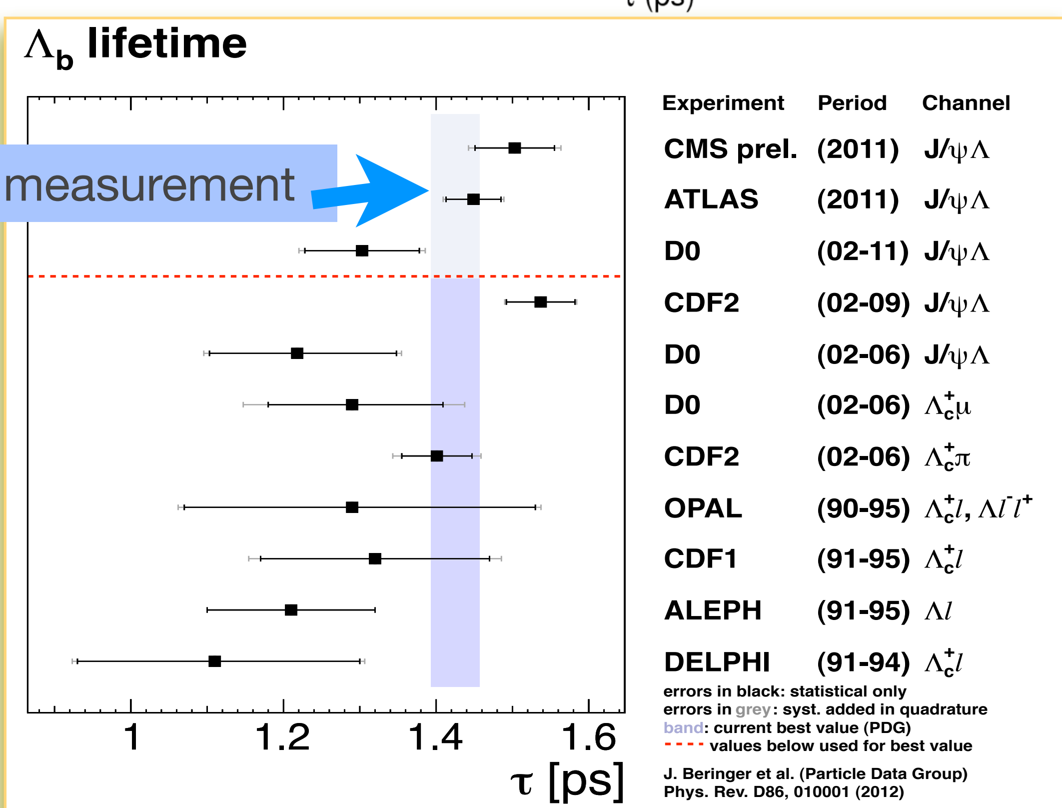


τ = Lxy M^{PDG}/p_T



Summer 2012 ATLAS

Phys. Rev. D 87, 032002 (2013)



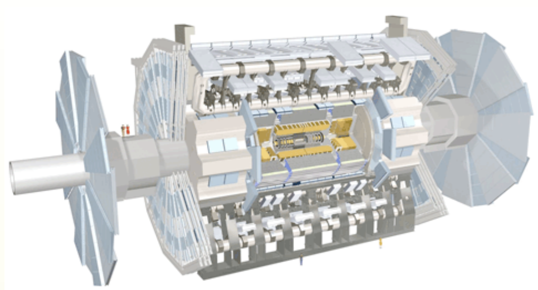
best measurement

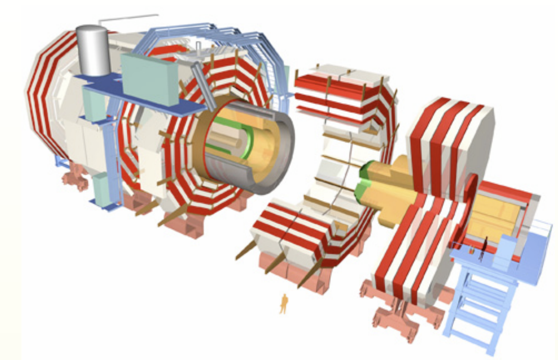
- ATLAS 2011 full data set (4.9fb^{-1})
  - using ***fully reconstructed $\Lambda_b \to \Lambda\, J/\psi \to (p\pi)(\mu\mu)$ decay***
    - kinematic fit of the 4-part. final state with constraints: 2 vertices, J/ψ and Λ world ave, mass, Λ cand flight direction intersecting μμ vertex; selection by transv. distance between Λ^0 cand decay and Λb cand decay vertex >10mm; M(4-part) in the range 5.38-5.90 GeV; $P_{\chi 2}(\Lambda b)$-$P_{\chi 2}(Bd)$>0.05
      - same topology for $B^0_d \to J/\psi(\mu\mu)Ks(\pi+\pi-)$
  - yield extracted from unbinned max Likelihood fit to 2d space of $M_{\Lambda b}$ and $\tau_{\Lambda b}$

m(Λ_b) = 5619.7 ± 0.7(stat) ± 1.1(syst) MeV
τ(Λ_b) = 1.449 ± 0.036(stat) ± 0.017(syst) ps

Fall 2012 CMS CMS BPH-11-013

τ(Λ_b) = 1.503 ± 0.052(stat) ± 0.031(syst) ps





Observations of rare B-hadron states

in ATLAS and CMS

Observation of a new Ξ_b baryon

Spring 2012 CMS

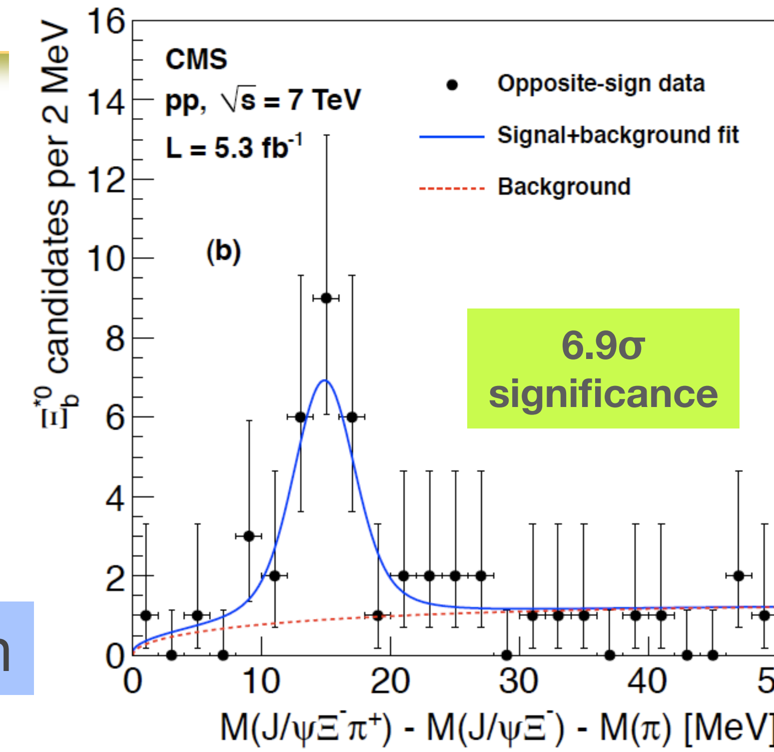
PRL108(2012)252002

Neutral and neg. charged **baryons with s and b** among the valence quarks are predicted in the standard quark model: Ξ_b(J^P=1/2+, ground state), Ξ_b' (J^P=1/2+) and **Ξ_b* (J^P=3/2+)** + 2 states with negative parity)

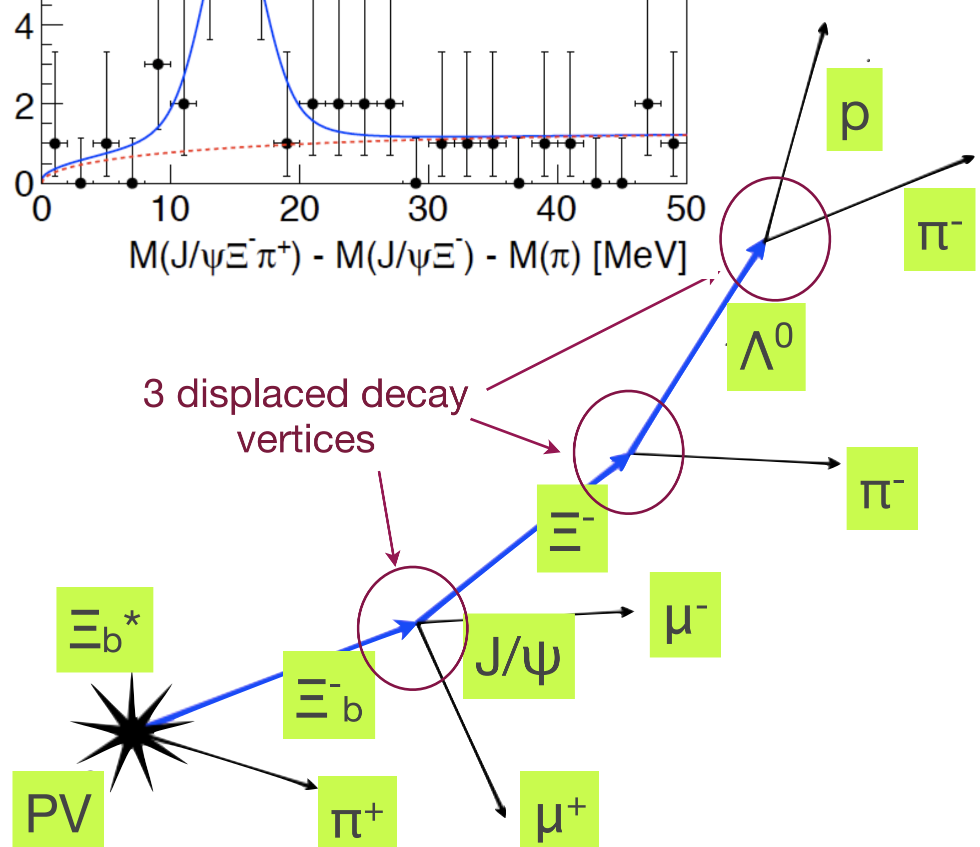
At Tevatron (2007) baryons (with charge 0 and -1) consistent with ground state Ξ_b were observed and confirmed earlier observations by DELPHI and ALEPH

- At CMS (2011 data , 5.3 fb^{-1}) search for Ξ_b^* in the strong decay to $\Xi_b^- \pi^+$ via a decay chain with 3 displaced vertices
  - Tracks from Λ, Ξ, Ξb must have transverse impact par. with high significance; Λ, Ξ, Ξb high quality vertex fit, high significance of the transverse decay length, 3d distance between flight direction and production vertex below optimized thresholds
  - ***$Q = M(J/\psi\, \Xi\, \pi^+) - M(J/\psi\, \Xi) - M(\pi^+)$***

first observation



- Q distribution fit with Breit-Wigner ⊗Gaus(1.9MeV, from MC)+bkg (from same-sign $\Xi_b\pi$)
  - **$Q=14.84\pm0.74^{stat}\pm0.28^{syst}$ MeV; $\Gamma=2.1\pm1.7^{stat}$ MeV**
    - syst. on Q from residual mismatch between fit and world ave. for Λ^0 and Ξ- masses
  - consistent with Lattice QCD (0<Q<50 MeV; Γ~0.5 MeV) for $J^P=3/2^+$



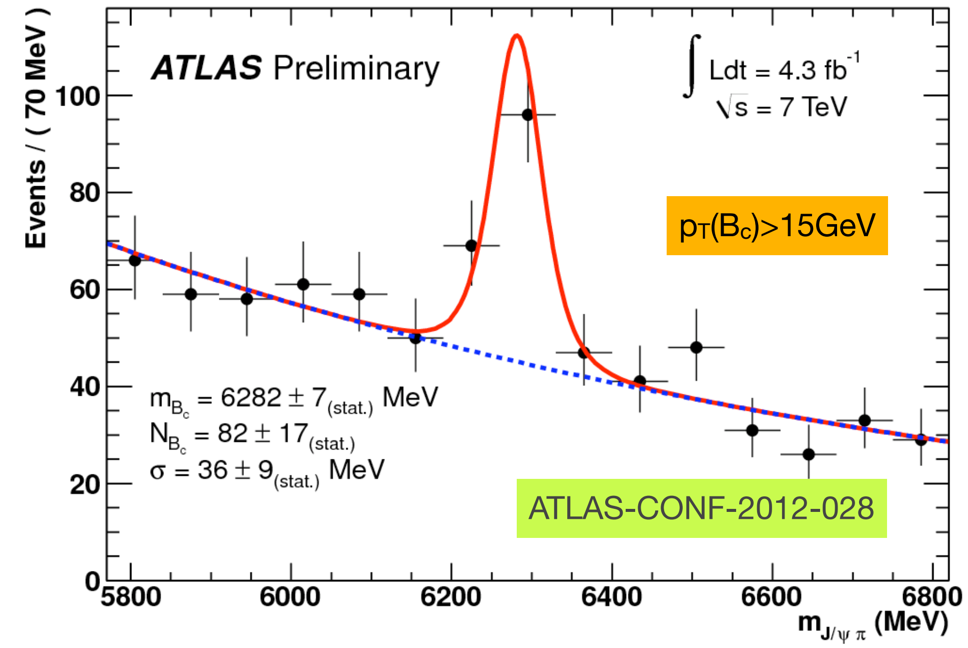
Observation of $B_c^{\pm}$

Spring (ATLAS) Summer (CMS) 2012

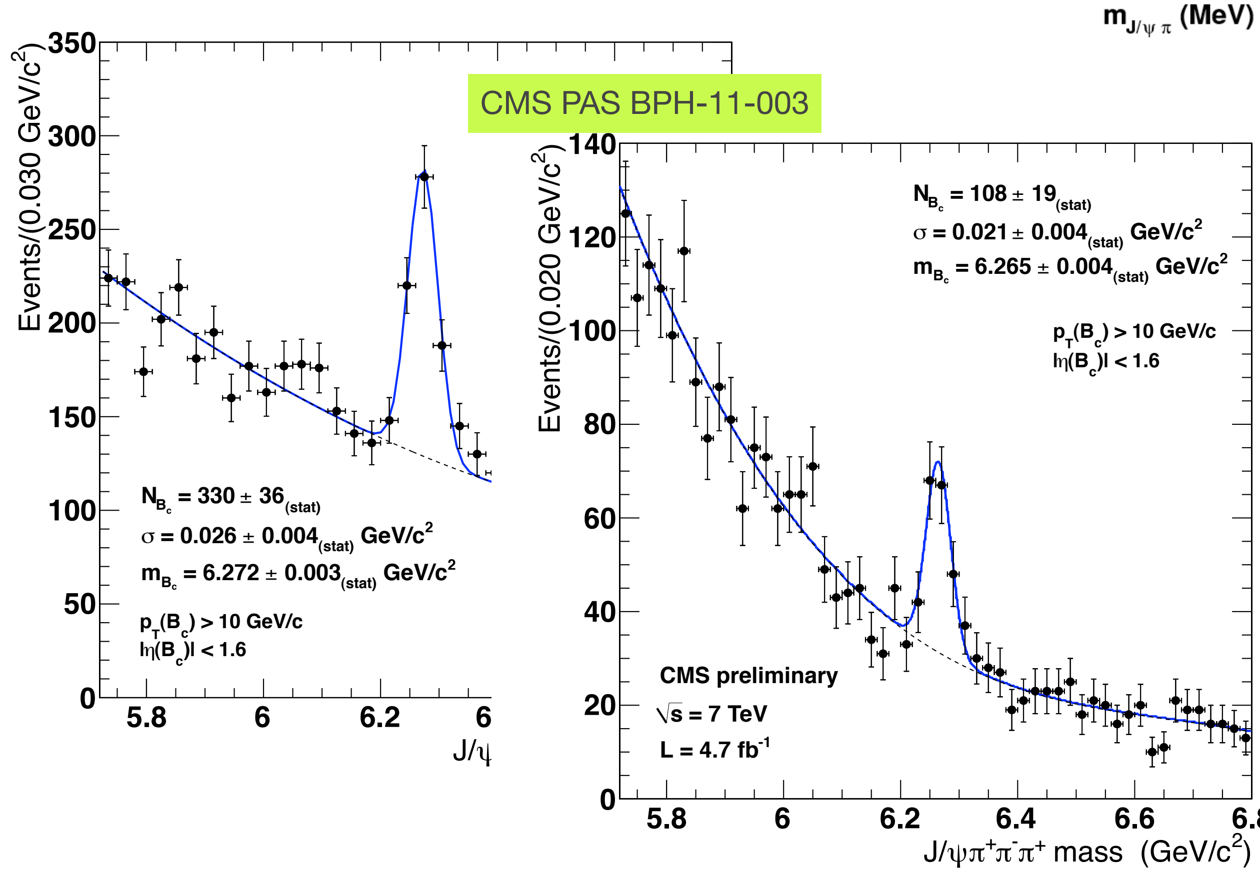
B_c very interesting particle with b- and c-quark content

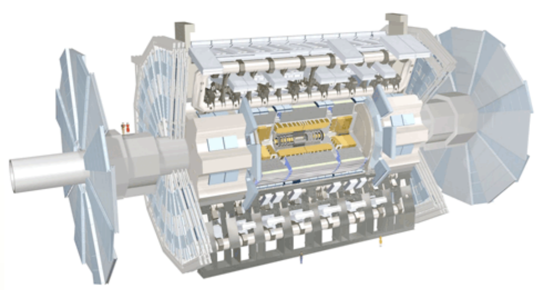
First observation in 1998 at CDF; mass and lifetime measured at CDF/D0; ratio of production rate to B at 7 TeV measured by LHCb

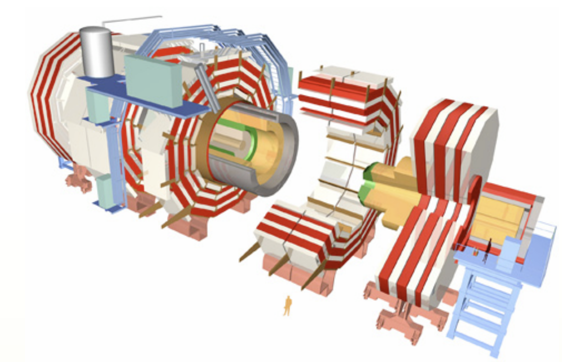
- Observed in **J/ψ π+** (ATLAS, CMS) and **J/ψ π+π-π+** (CMS) with 2011 data set with signal significance (s/sqrt(s+b)) of ~5 (ATLAS) and ~10 (CMS) in the 1st channel, of ~6 (CMS) in the 2nd channel
  - trigger: 2μ (ATLAS), J/ψ with displaced vertex (CMS);
  - analysis: J/ψ selection; per event mass from re-fit of 1(3)π and 2μ tracks (mass constrained to J/ψ) to a common vertex; combinatorial background suppression with $d^0_{xy}(\pi)/\sigma>5$ (ATLAS), $\lambda_{xyz}/\sigma>3$ and small angle between Bc line of flight and momentum $\cos\alpha_{xyz}>0.85$ [tighter cuts for J/ψ π+π-π+, due to higher comb. bkg]
- ***Mass consistent with world average***



CMS PAS BPH-11-003







Onia production and properties

in ATLAS and CMS

Charmonium measurements

Eur.Phys.J. C71 (2011) 1575 — J/ψ prompt and indirect production by - CMS (~300 nb^{-1})

JHEP 02 (2012) 011 — J/ψ and ψ(2S) production by - CMS (37 pb^{-1})

Nucl. Phys. B 850 (2011) 387-344 — Inclusive J/ψ production and non prompt to prompt ratio - ATLAS (2.3 pb^{-1})

Measurement of Υ(1S), Υ(2S), Υ(3S) polarizations $\sqrt{s}$ = 7 TeV

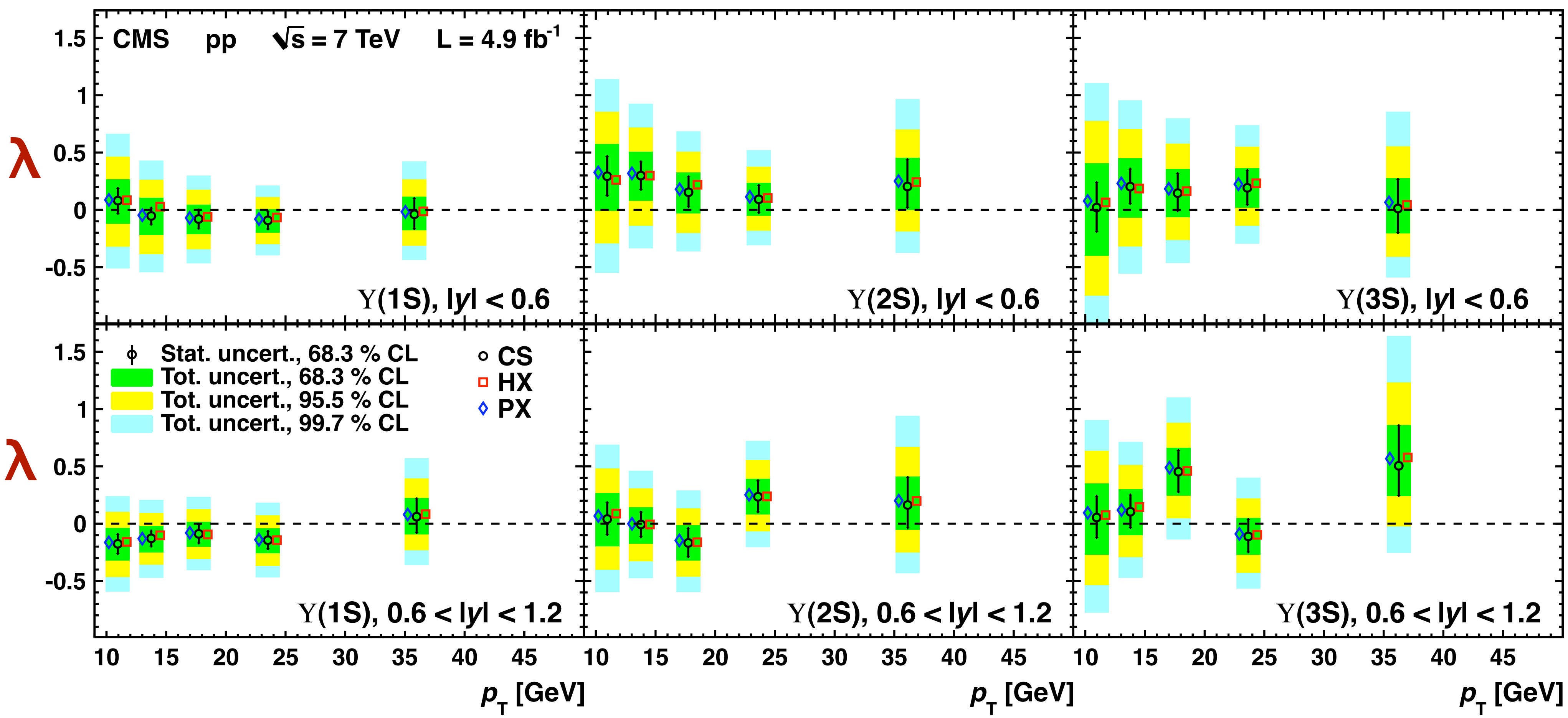
Fall 2012 CMS

accepted by PRL
arXiv:1209.2922

- Υ(1S), Υ(2S), Υ(3S) states in the μ+μ- final state in CMS 2011 full data set (4.9 fb^{-1})
  - high quality prompt 2μ candidates with a common vertex with 8.5<M<11.5GeV
  - data binned in 2 |y| intervals [0-0.6][0.6-1.2] and 5 p_T bins [10-12-16-20-30-50] GeV
  - λ_θ, λ_φ, $\lambda_{\theta\varphi}$ and frame-invariant **$\lambda=(\lambda_\theta+3\ \lambda_\varphi)/(1-\lambda_\varphi)$** measured in 3 frames
    - center-of-mass Helicity frame HX, Collins-Soper frame CS, perpendicular Helicity frame PX

Unbinned Max Likelihood (in a Bayesian appr.) using 2**μ** angles; per event efficiencies.

Background subtracted event by event based on $L_B/L_{(S+B)}$



Most comprehensive measurement so far (especially for Υ(3S))

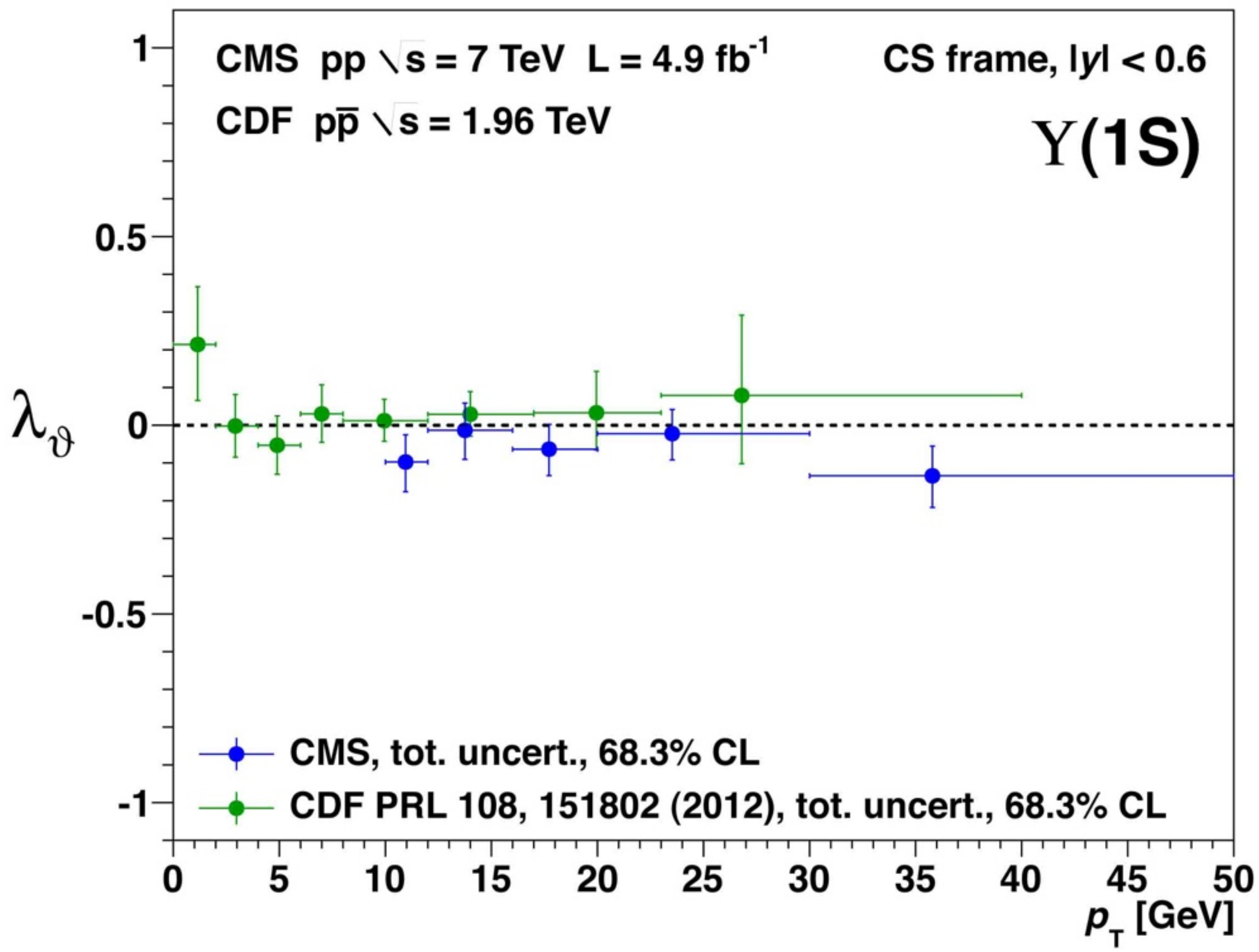
[earlier measurements from CDF and D0 runII]

No evidence of sizable transverse or longitudinal polarization

Measurement of Υ(1S), Υ(2S), Υ(3S) polarization $\sqrt{s}$ = 7 TeV

Fall 2012 CMS

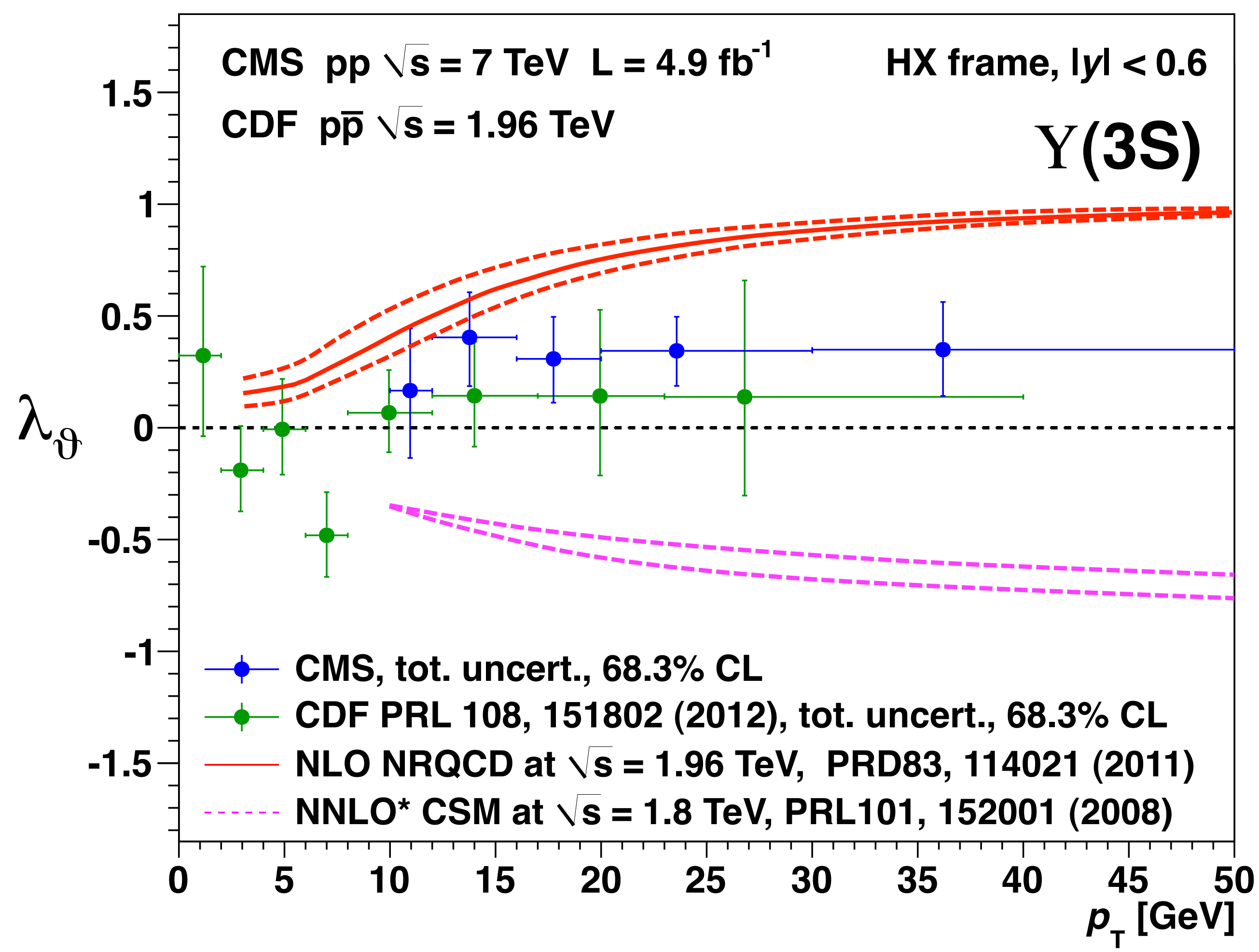
accepted by PRL
arXiv:1209.2922



No evidence of sizable transverse or longitudinal polarization

confirming CDF PRL108 (2012) 151802

contradicting D0 PRL101 (2008) 182004



General disagreement with theory predictions which, however, reproduce the main features of heavy quarkonia differential production cross sections

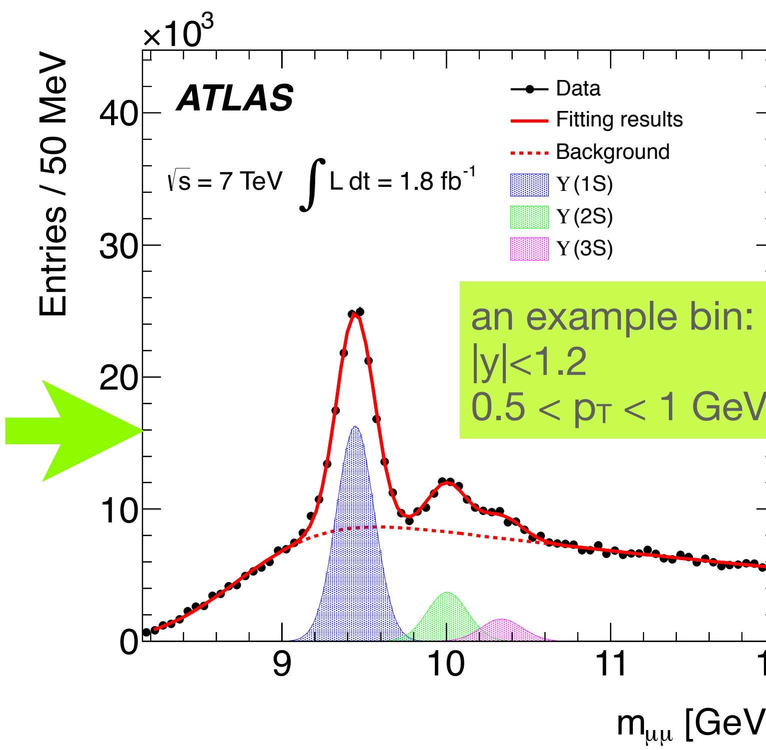
Υ(nS) differential production cross sections

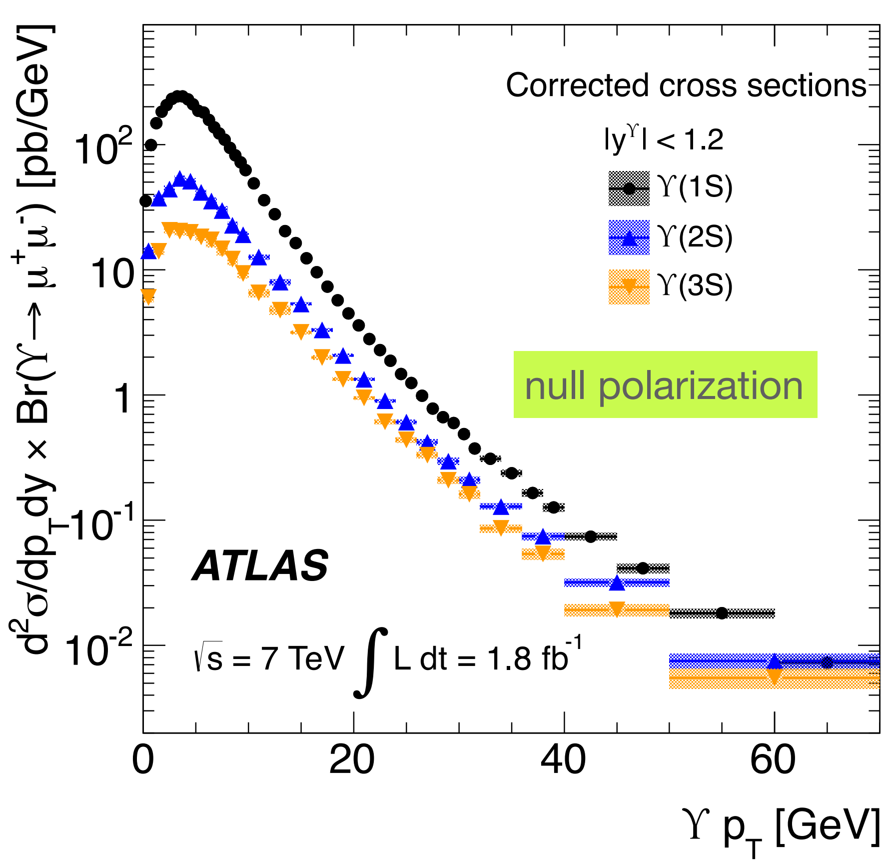
Fall 2012 ATLAS

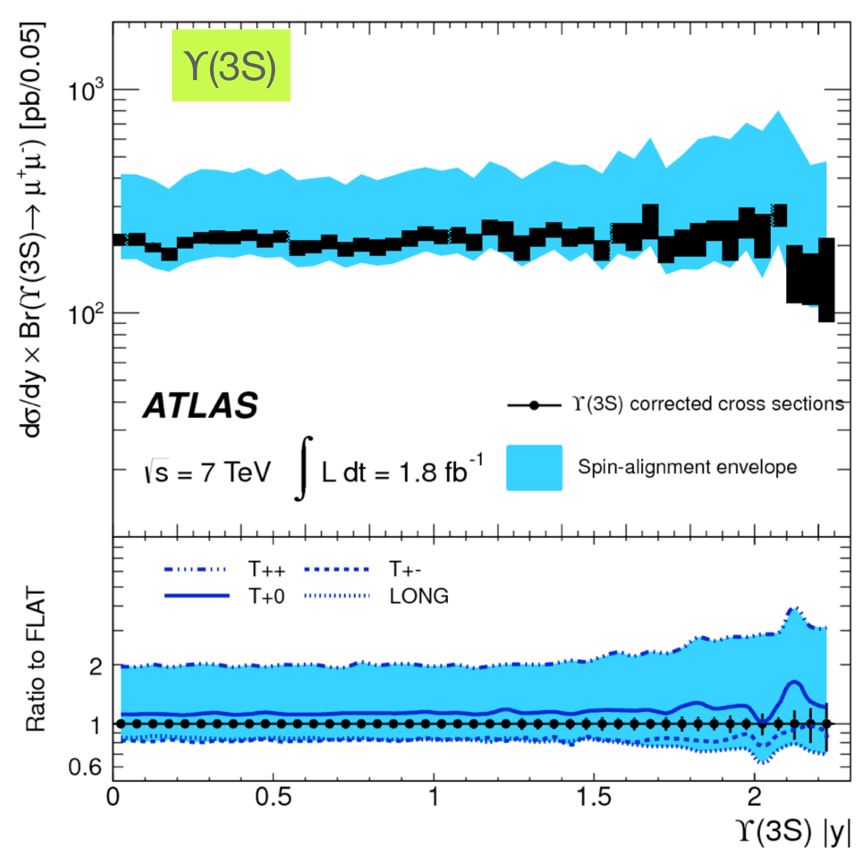
to appear in PRD arXiv:1211.7255

Υ(1S), Υ(2S), Υ(3S) states reconstructed in the μ+μ- final state in ATLAS 2011 data using 1.8 fb^{-1}

- high quality prompt 2μ candidates with a common vertex with 8<M<11.5GeV matching a 2μ trigger (with loose requirements on vertex fit quality); Acceptance (A) defined by single muon reconstruction fiducial region p_T^{μ}>4GeV $|\eta^{\mu}|$<2.3
- data binned in 2 |y| intervals [0-1.2][1.2-2.25] (with comparable statistics ~3×10^6) and 15 p_T bins up to p_T<70GeV
  - per event weight = (total efficiency)-1 (not)including A for (fiducial)corrected σ measurements - efficiency corrected Mμμ distributions fit to model for Υ(1S)+Υ(2S)+Υ(3S)+bkg to derive yield
- null polarization hypothesis: spin alignment envelop by far dominating systematic uncertainty







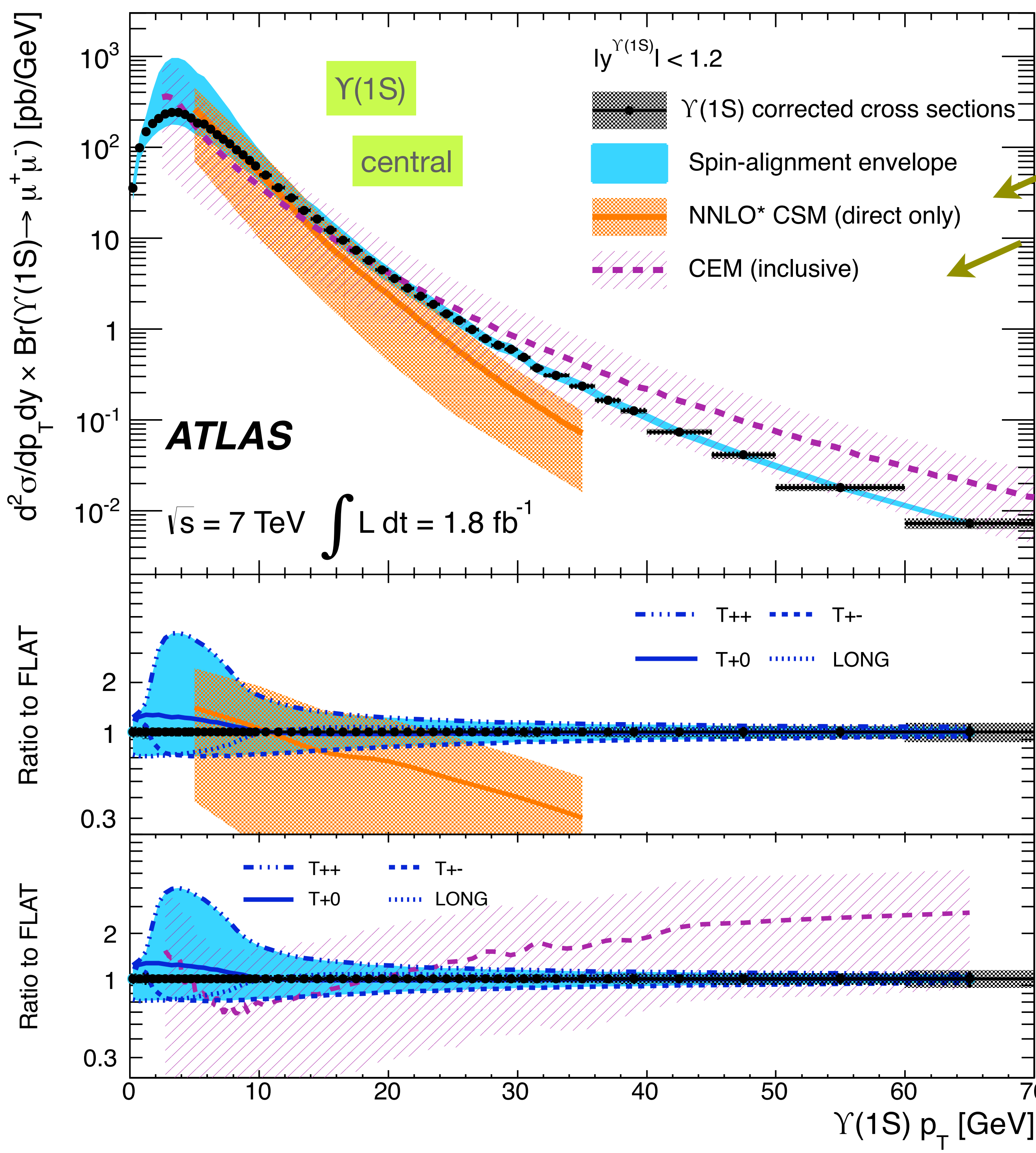
Measurement with largest p_T reach so far

High p_T domain is clean from spin alignment uncertainties and sensitive to new production channels

ϒ(nS) differential production cross sections

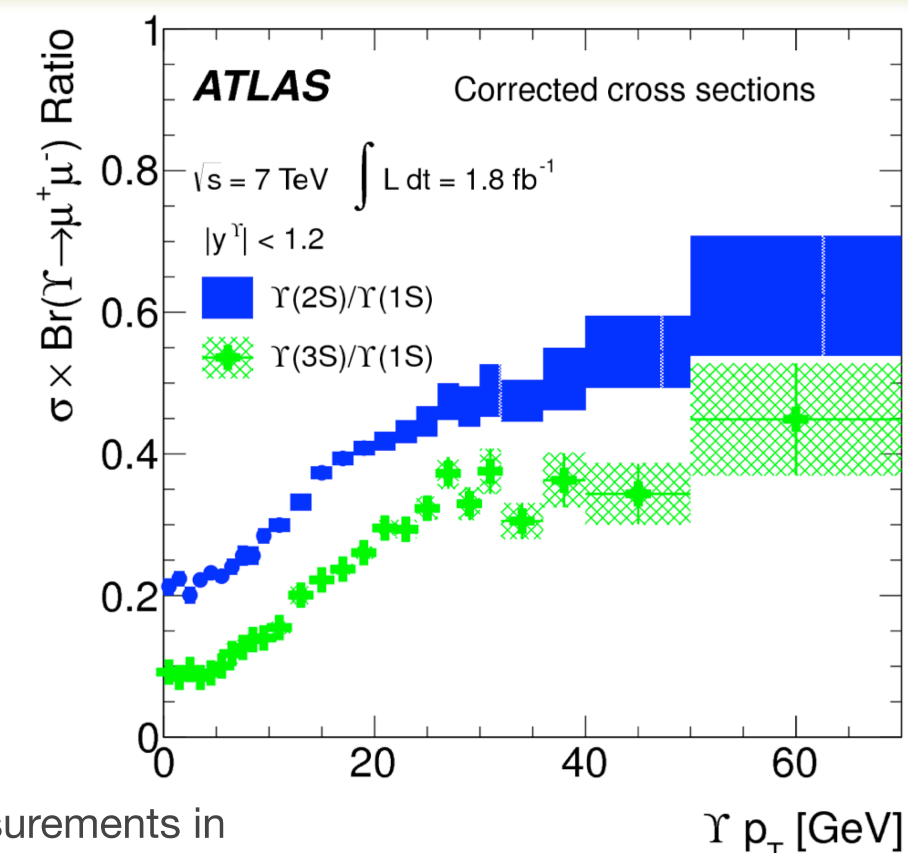
Fall 2012 ATLAS

to appear in PRD arXiv:1211.7255



PRL101(2008)152001, EPJC61(2009)693 + others
Feed-down from radiative decays of higher mass states, ***not accounted in the model,*** increases the direct production rate of ϒ(1S) by ~100%
➽ large long. pol. not seen in data

phenomenological Color Evaporation Model;
PLB390(1997)323, Phys.Rept.462(2008)125 + others;
naturally including feed down processes ➽ no sizable polarization predicted



All measurements in agreement with
CMS PRD83(2011)112004

Relative prompt production rate of χ_{c2} and χ_{c1}

Winter 2013 CMS

to appear in EPJC arXiv:1210.0875

Earlier measurements at CDF and LHCb - both suggesting no easy theoretical modeling

- CMS 2011 data 4.6 fb^{-1} - ***$\chi_c \to J/\psi(\mu^+\mu^-)+\gamma$(converted to e^+e^-)*** [in $|y(J/\psi)| < 1$ and $p_{T\gamma} > 0.5$GeV], $\chi_{c1,2}$ from primary *pp* vertex; ***E_γ =390(430) MeV, in the $\chi_{c1(2)}$ rest frame***
  - J/ψ trigger; pseudo-proper decay length ($L_{xy}\, M_{J/\psi}/p_T(J/\psi)$) <30µm [negligible 0.7% contamination from B decays];
  - γ reconstruction via tracker-based conversion reconstruction algorithm (iterative tracking for low p tracks from displaced vertices);

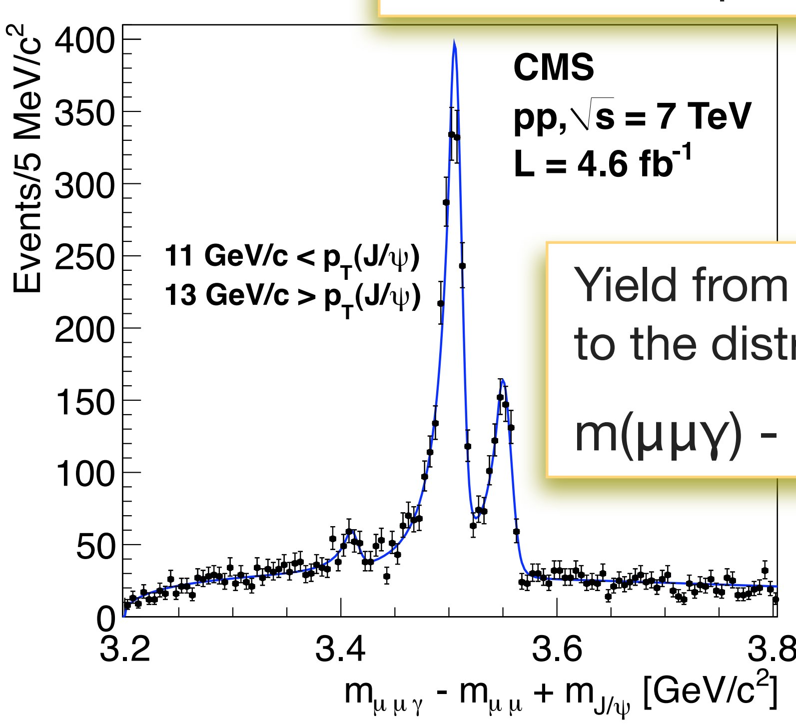
e+e- parallel at conversion point; Mee consistent with 0; various requirements reducing background from mis-reconstructed prompt tracks; π^0 veto

$$R_p \equiv \frac{\sigma(pp \to \chi_{c2}+X)\mathcal{B}(\chi_{c2} \to J/\psi+\gamma)}{\sigma(pp \to \chi_{c1}+X)\mathcal{B}(\chi_{c1} \to J/\psi+\gamma)} = \frac{N_{\chi_{c2}}}{N_{\chi_{c1}}} \cdot \frac{\varepsilon_1}{\varepsilon_2}$$

Difference in acceptance for γ from the two states - single particle MC with p_T as from ψ(2S) CMS measurement [very close in mass]

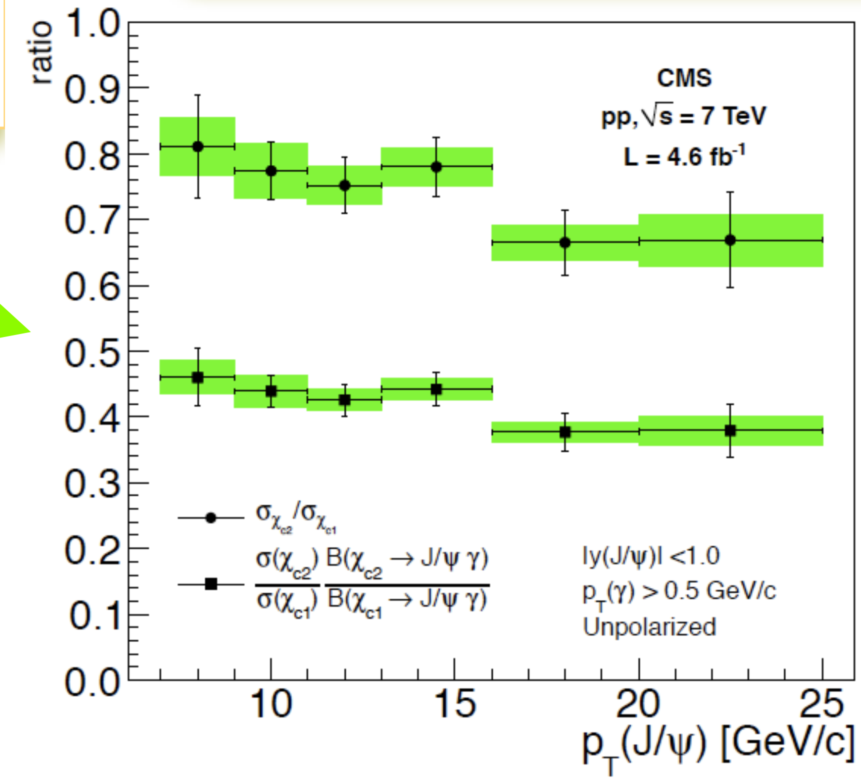
No polarization assumed for both χ_c states

Eff. ratio from MC approaching 1 at increasing p_T



Yield from unbinned max. lik. fit to the distribution of Q=

$m(\mu\mu\gamma) - m(\mu\mu) + M^{PDG}(J/\psi)$



Consistent with NRQCD (NNLO* and CSM) PRD 83 (2011) 111503

In disagreement with kT factorization PRD 83 (2011) 034035

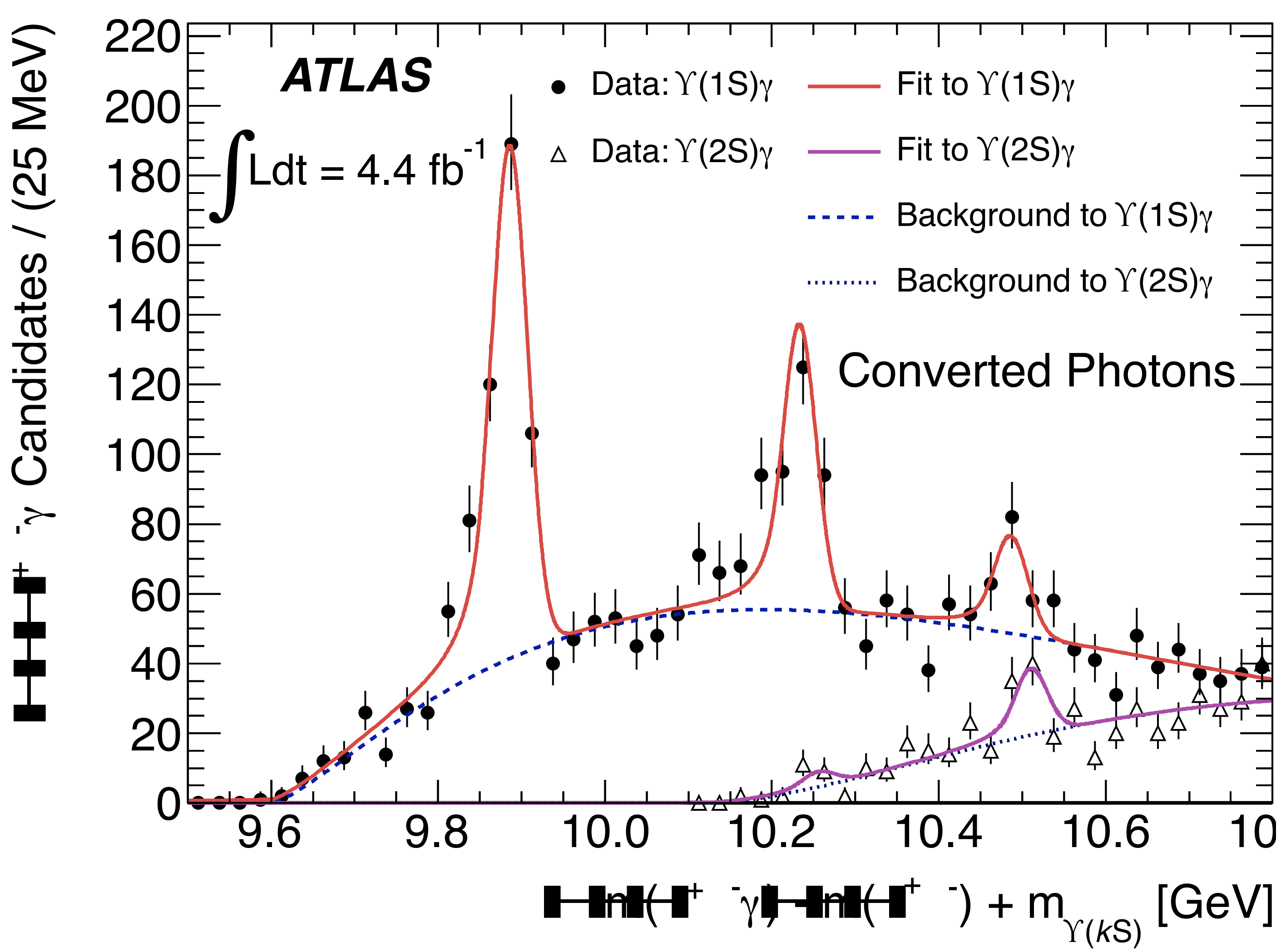
Reminder of $\chi_b(3P)$ first observation in ATLAS

Winter 2012 ATLAS

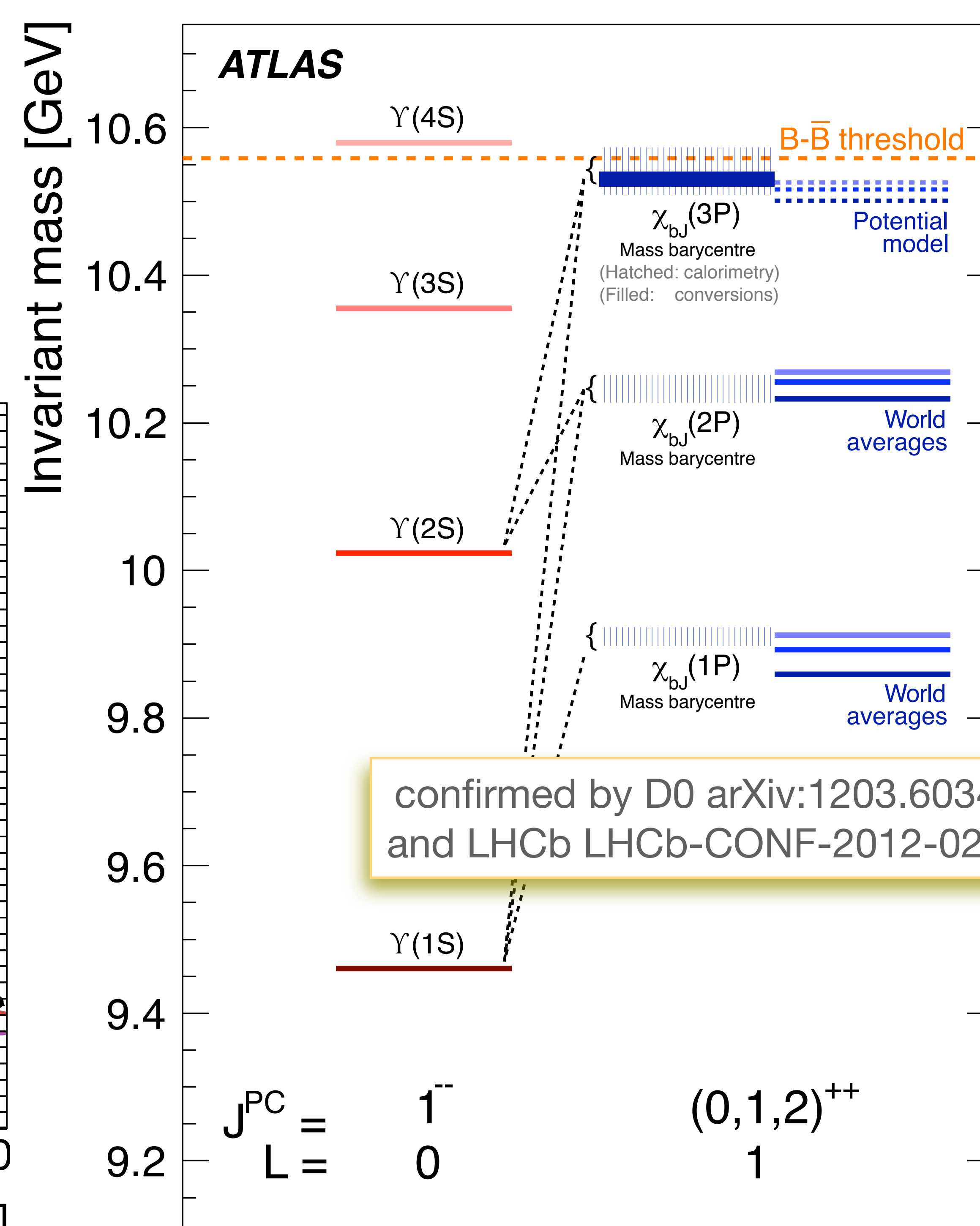
PRL108 (2012) 152001

ATLAS 2011 data, 4.4 fb^{-1}

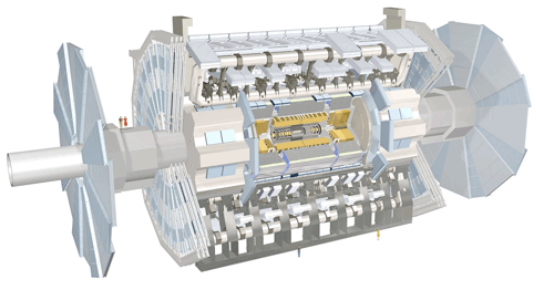
New state, interpreted as ***$\chi_b(3P)$***, at
$M = 10.530 \pm 0.005$ (stat.) ± 0.009 (syst.) GeV
seen in radiative transitions to $\Upsilon(1S)$ and $\Upsilon(2S)$

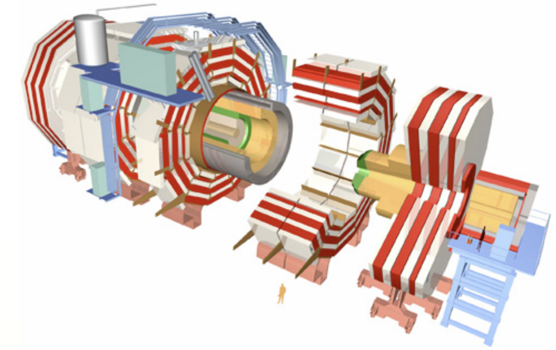


Observed bottomonium radiative decays in ATLAS, L = 4.4 fb^{-1}



confirmed by D0 arXiv:1203.6034 and LHCb LHCb-CONF-2012-020





States with Heavy Flavor content and unclear interpretation

in ATLAS and CMS

Measurement of X(3872) production cross section at √s=7 TeV

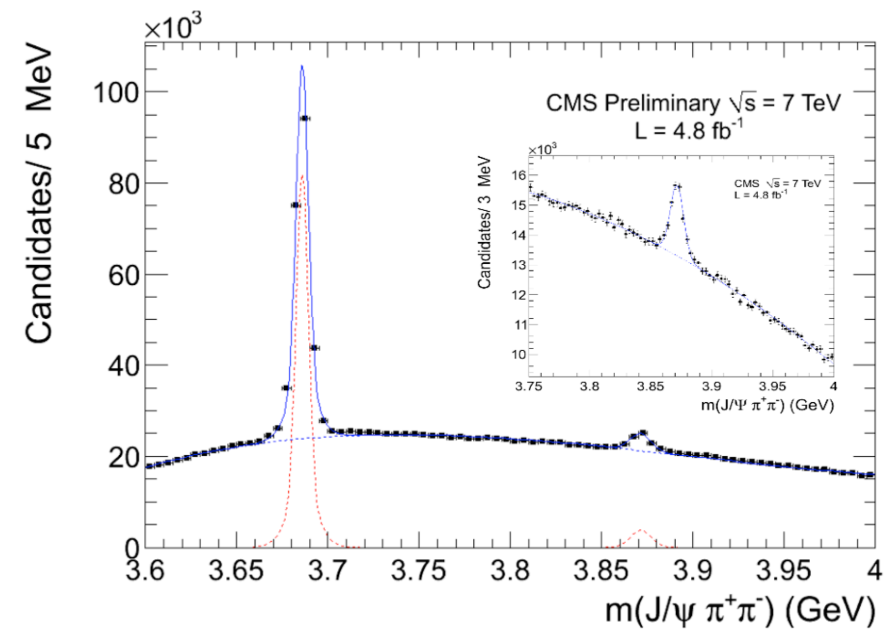
Fall 2012 CMS

CMS BPH-11-011

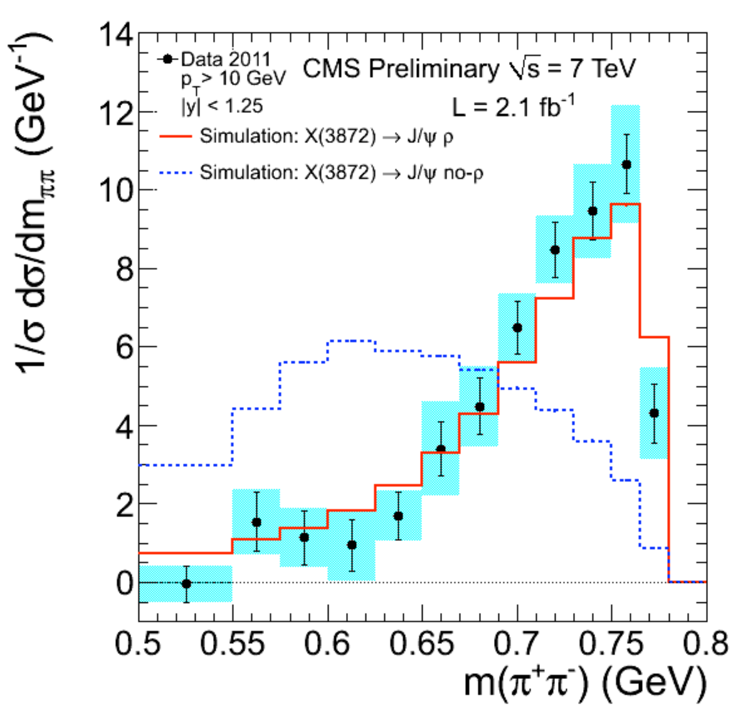
X(3872) well established state, since first observation in Belle in $B^{\pm} \to K^{\pm}(J/\psi\pi+\pi)$ decays - confirmed in CDF, D0, BaBar

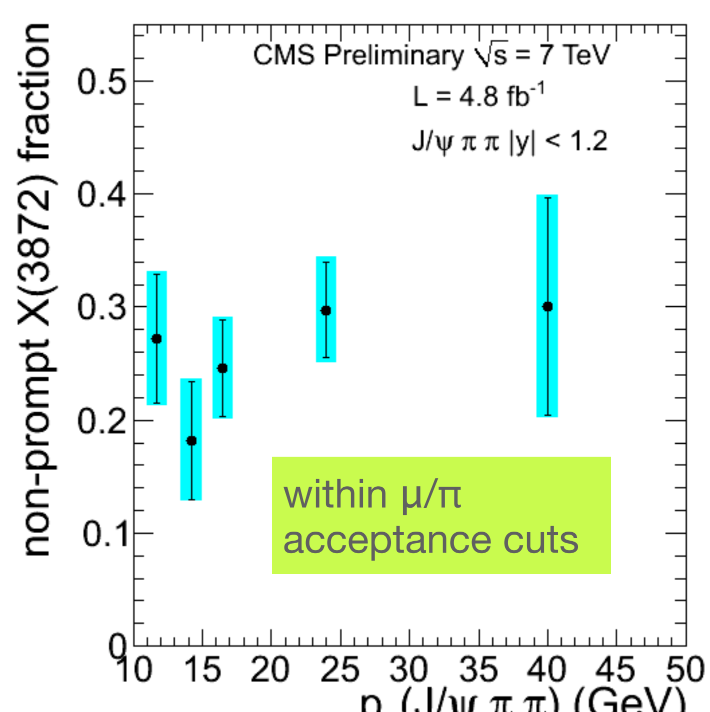
X(3872) doesn't easily fit in the quark model: candidate D^{*0}-anti-D^0 molecule; candidate tetra-quark; candidate charmonium state but $X \to J/\psi\gamma$ seen by Belle and Babar, $X \to \psi(2S)\gamma$ controversial [(not)seen by (Belle)BaBar]

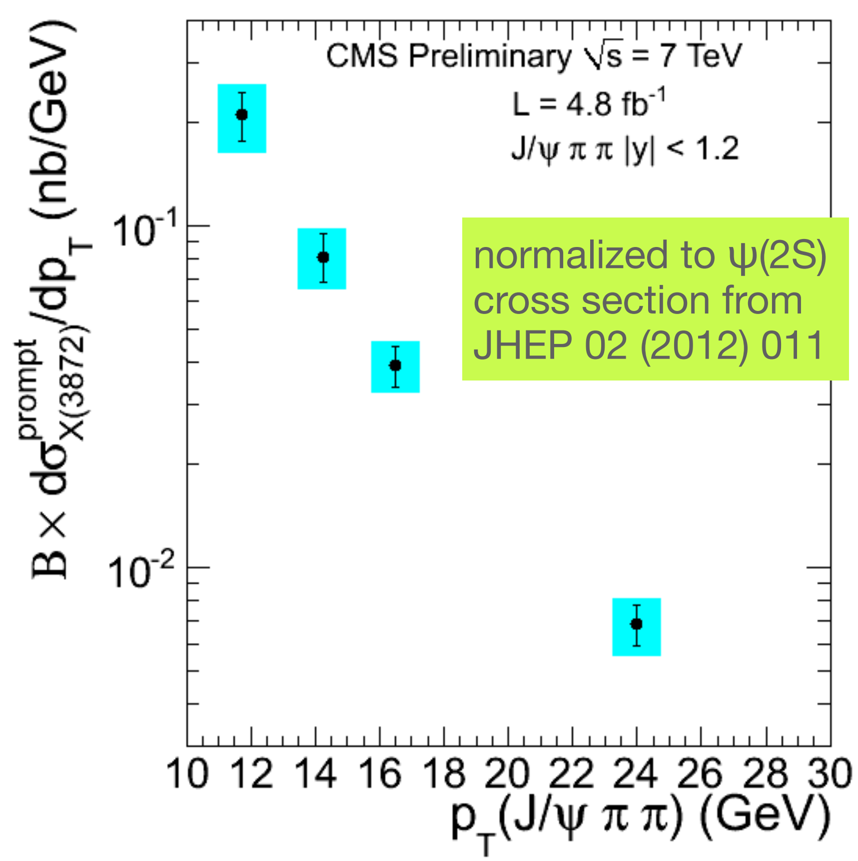
LHCb has very recently established the quantum numbers: $J^{PC} = 1^{++}$



- Study of ***X(3872)→J/ψ π+π-*** in CMS 2011 data (4.8 fb-1)
  - measurements: ratio of (prompt) production σ×BR(J/ψππ) to ψ(2S) as a function of p_T and fraction of X from B decays



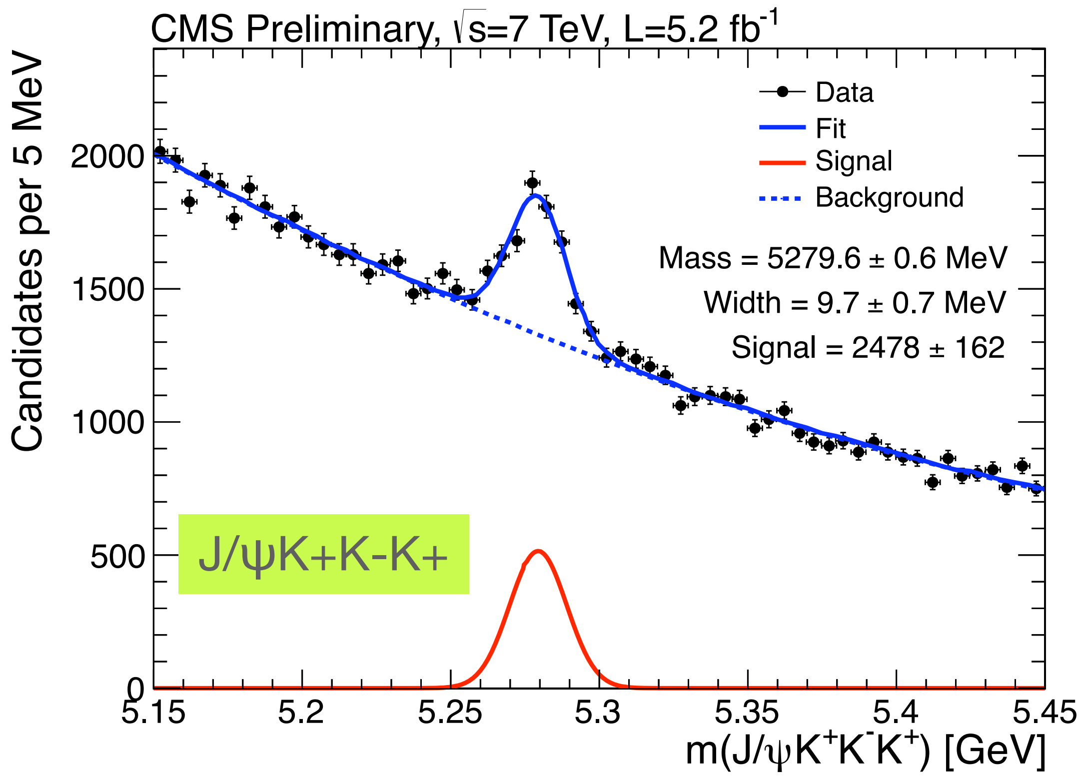




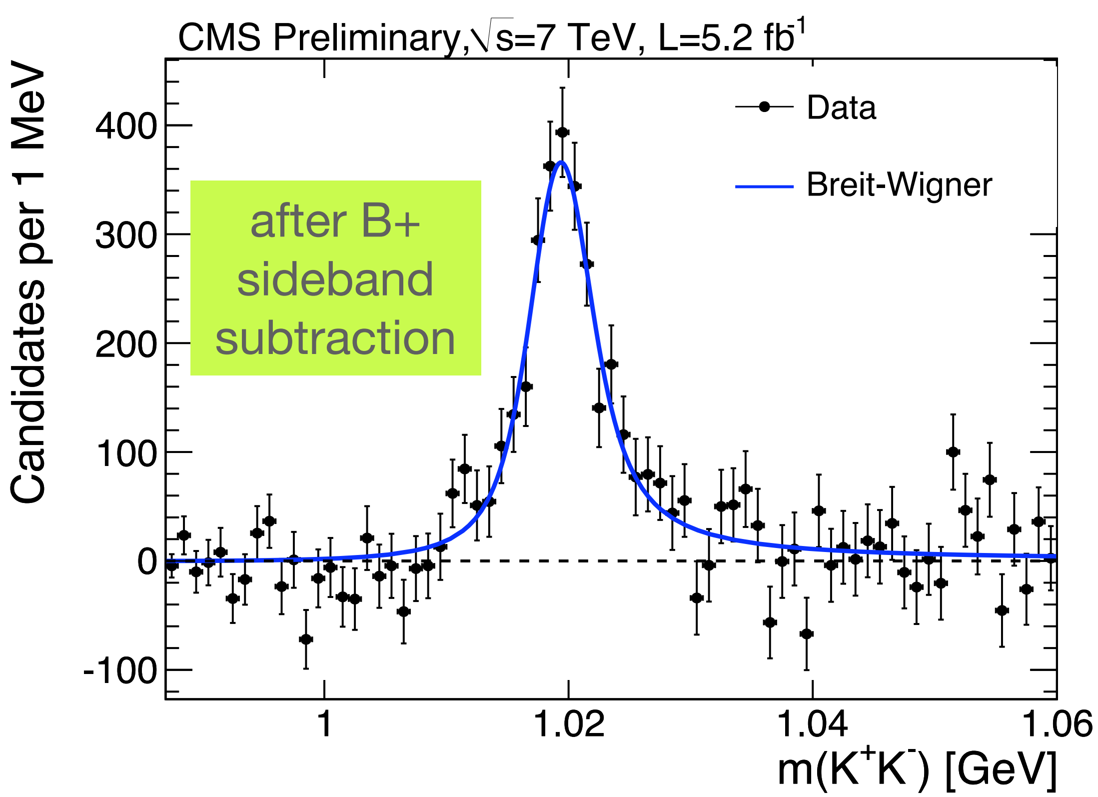
Observation of structures in the J/ψ φ spectrum in $B^+ \rightarrow K^+ J/\psi \varphi$

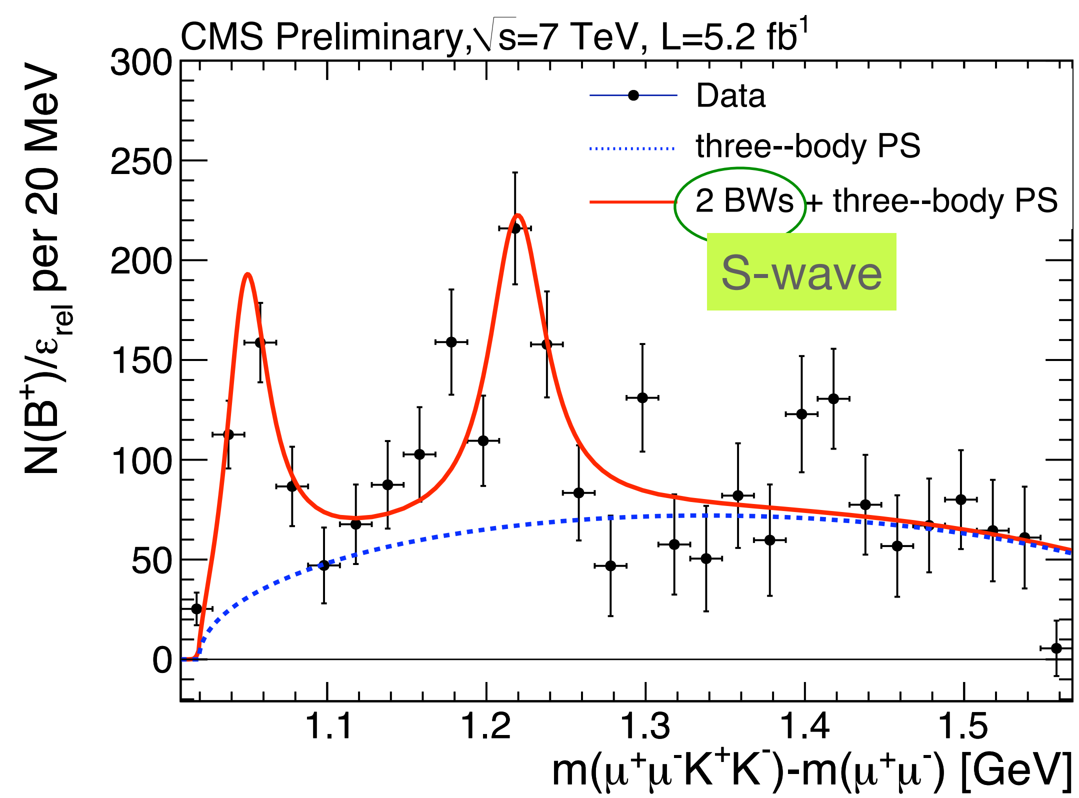
Fall 2012 CMS

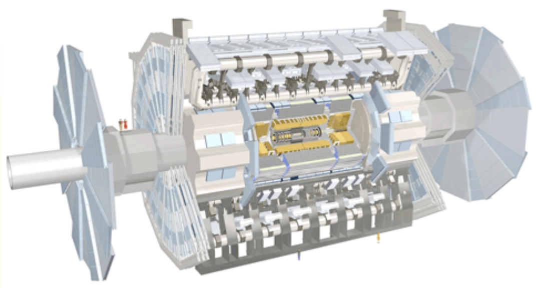
CMS BPH-11-026

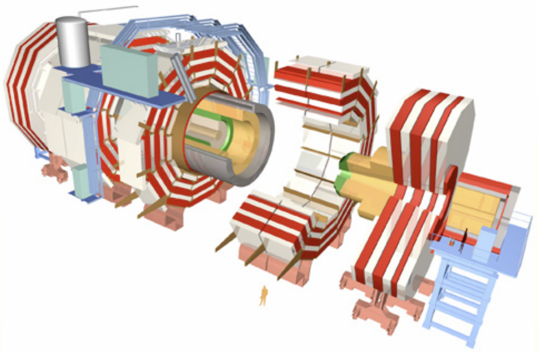


- CMS 2011 data (5.2 fb-1) at √s=7TeV
  - ***M(1st peak)= 4148.2 ± 2.0(stat) ± 4.6(syst) MeV***
    - significance exceeding 5-sigma
      - confirming some earlier (but controversial) claim by CDF; LHCb looked for this structure but didn't confirm it
  - ***M(2nd peak)=4316.7 ± 3.0(stat) ± 7.3(syst) MeV***









B^0_s lifetime and CP violation parameters

in ATLAS and CMS

CP-violating φ_s phase and $\Delta\Gamma_s$ from $B_s \to J/\psi\ \varphi$

$B_s \to J/\psi\ \varphi$, with $J/\psi \to \mu^+\mu^-$ and $\varphi \to K^+K^-$

Summer 2012 ATLAS

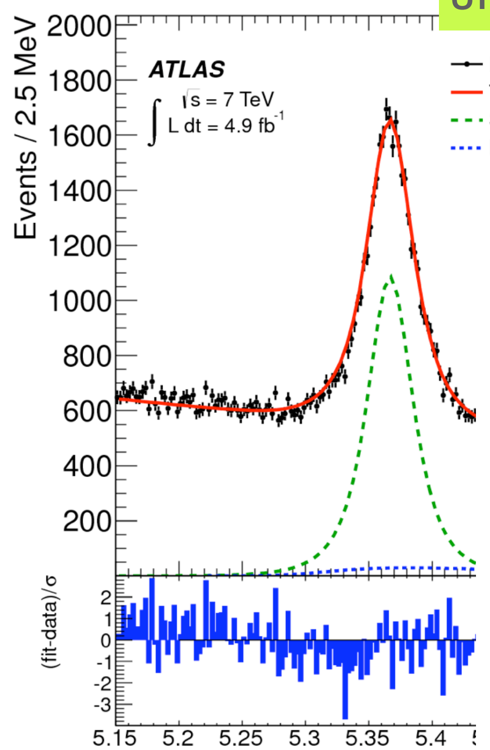
JHEP 12 (2012) 072

Interference between decay and oscillation give rise to CP violation with a phase $\varphi_s = \varphi_M - 2\varphi_D$ ($\varphi_s \approx -2\beta_s$)

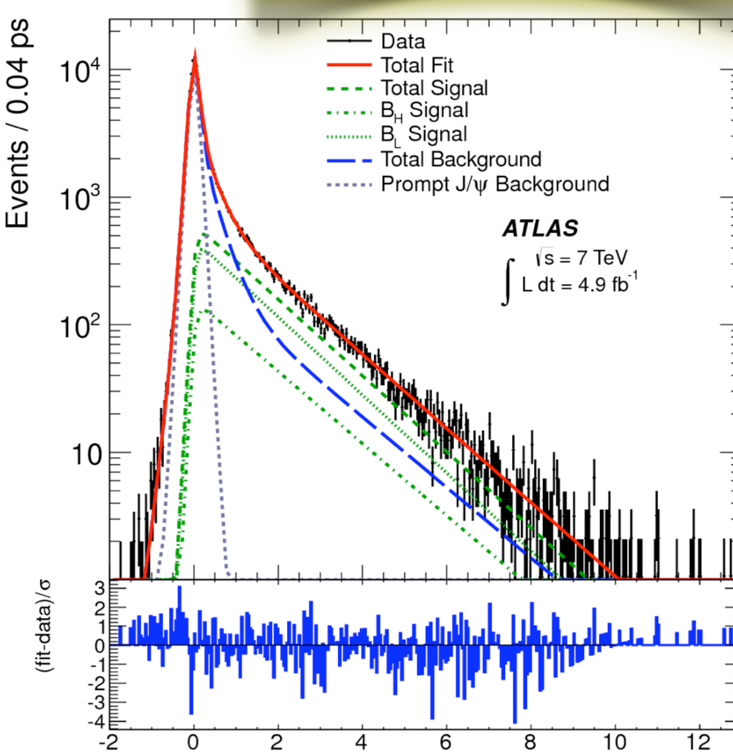
Flavor untagged analysis of the $B_s \to J/\psi\ \varphi$ decay in 2011 full data set

Final state in a mixture of CP-even and CP-odd eigenstates (3 amplitudes in the ***transversity frame***); the angular analysis ($\Omega \equiv (\theta,\varphi,\psi)$) allows to extract φ_s, Γ_s, $\Delta\Gamma_s = \Gamma_L - \Gamma_H$

large contributions to φ_s expected in various New Physics scenarios



Mass /GeV



Proper decay time /ps

- Event selection:
  - J/ψ trigger; reconstruction: good quality J/ψ candidates + KK high quality tracks, with M close to M_φ, forming a 4 track vertex with the μ pair
- Signal event extraction:
  - unbinned max. likelihood fit to ***M, τ and Ω***
    - background from $B^0 \to J/\psi K^+\pi^-$ or $J/\psi\ K^*$, combinatorial background from prompt J/ψ
  - ***22690±160 signal B^0s from the fit***

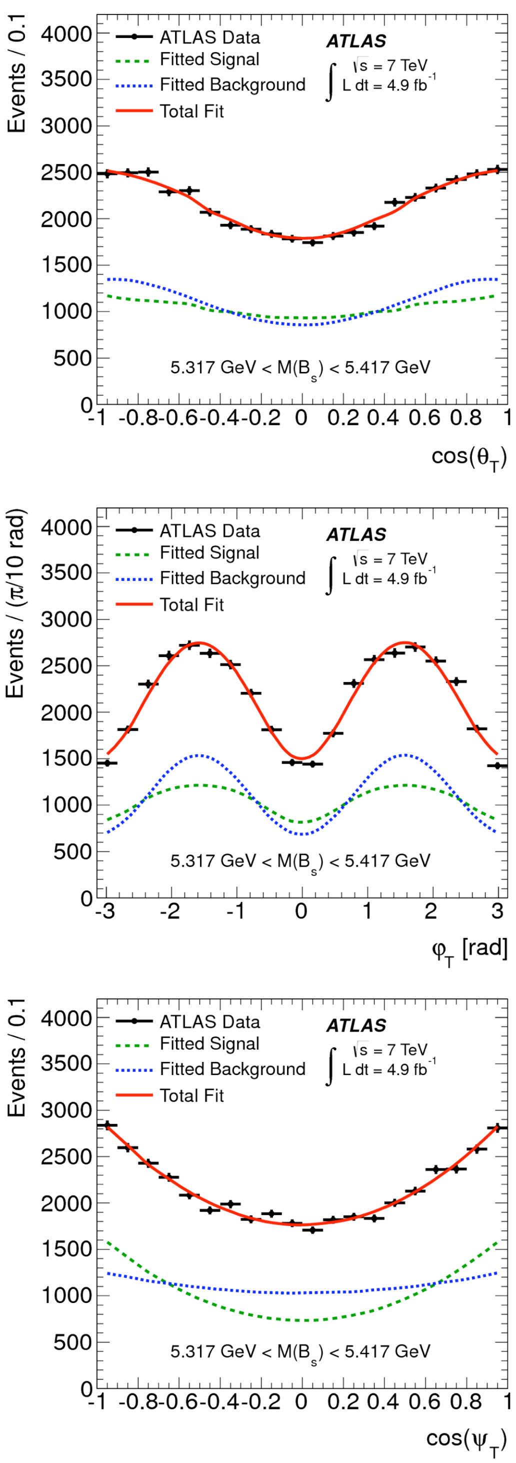
Main systematic uncertainties:

B^0 contribution (from error on the decay fractions), background modeling (angles [affecting all measurements], lifetime and mass [φ_s and $\Delta\Gamma_s$]) signal modeling (mass [φ_s and $\Delta\Gamma_s$]), ID alignment [φ_s]

CP-violating φ_s phase and $\Delta\Gamma_s$ from $B_s \to J/\psi\ \varphi$

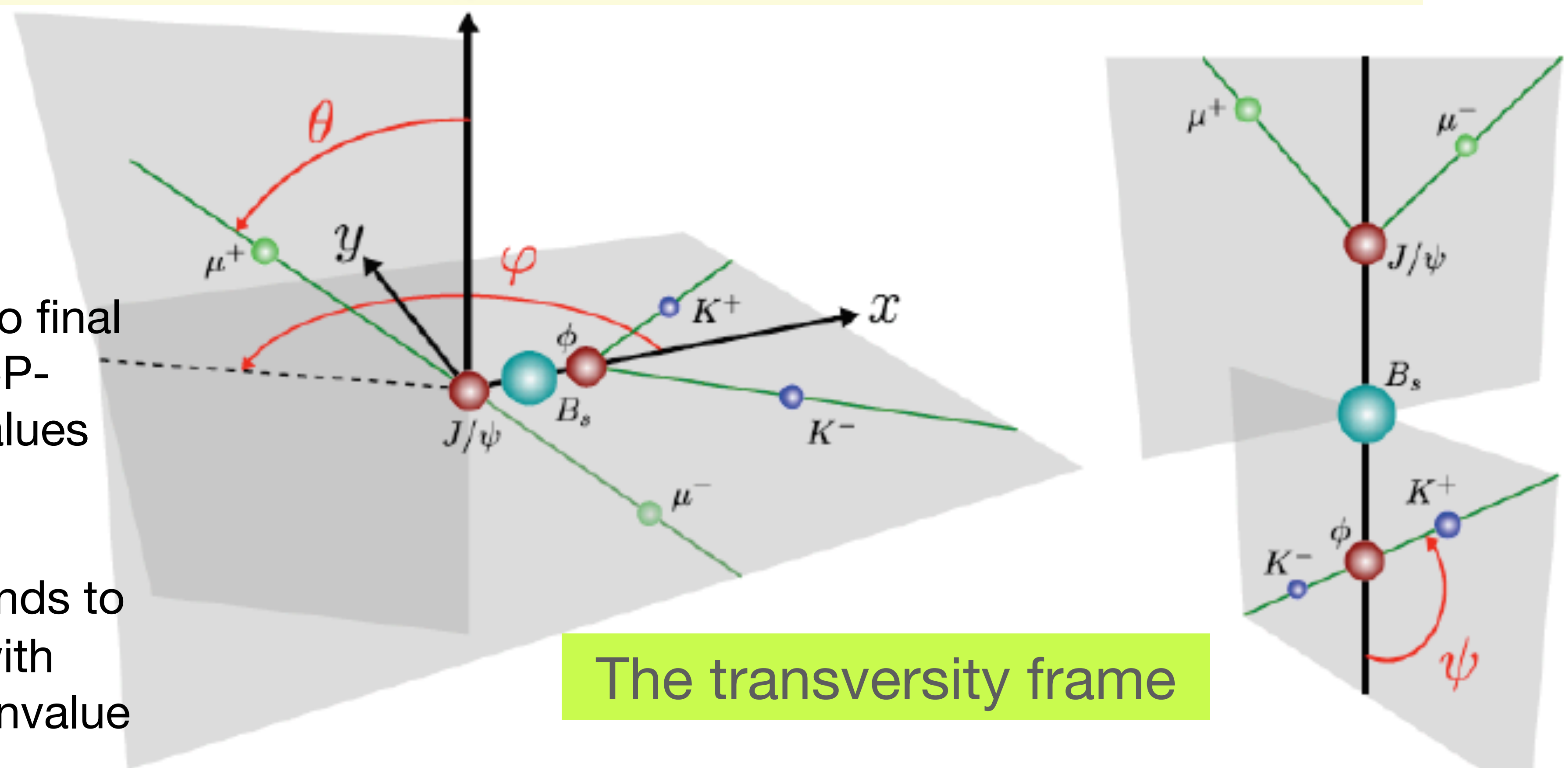
Summer 2012 ATLAS

JHEP 12 (2012) 072



A0 and A|| correspond to final states with CP-even eigenvalues (L=0,2)

A⊥ corresponds to final states with CP-odd eigenvalue (L=1)



The transversity frame

- **x axis**: defined by the direction of the φ in the J/ψ rest frame;
- **y axis**: in the plane defined by K+K-, with $p_y(K^+)>0$; **z axis** follows
- **θ, φ** = polar and azimuthal angles of the μ+ in the J/ψ rest frame;
- **ψ** angle between the x axis and K+ in the φ rest frame

SM prediction [hep-ph/0605213]
φ_s =-0.0368±0.0018

Results

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

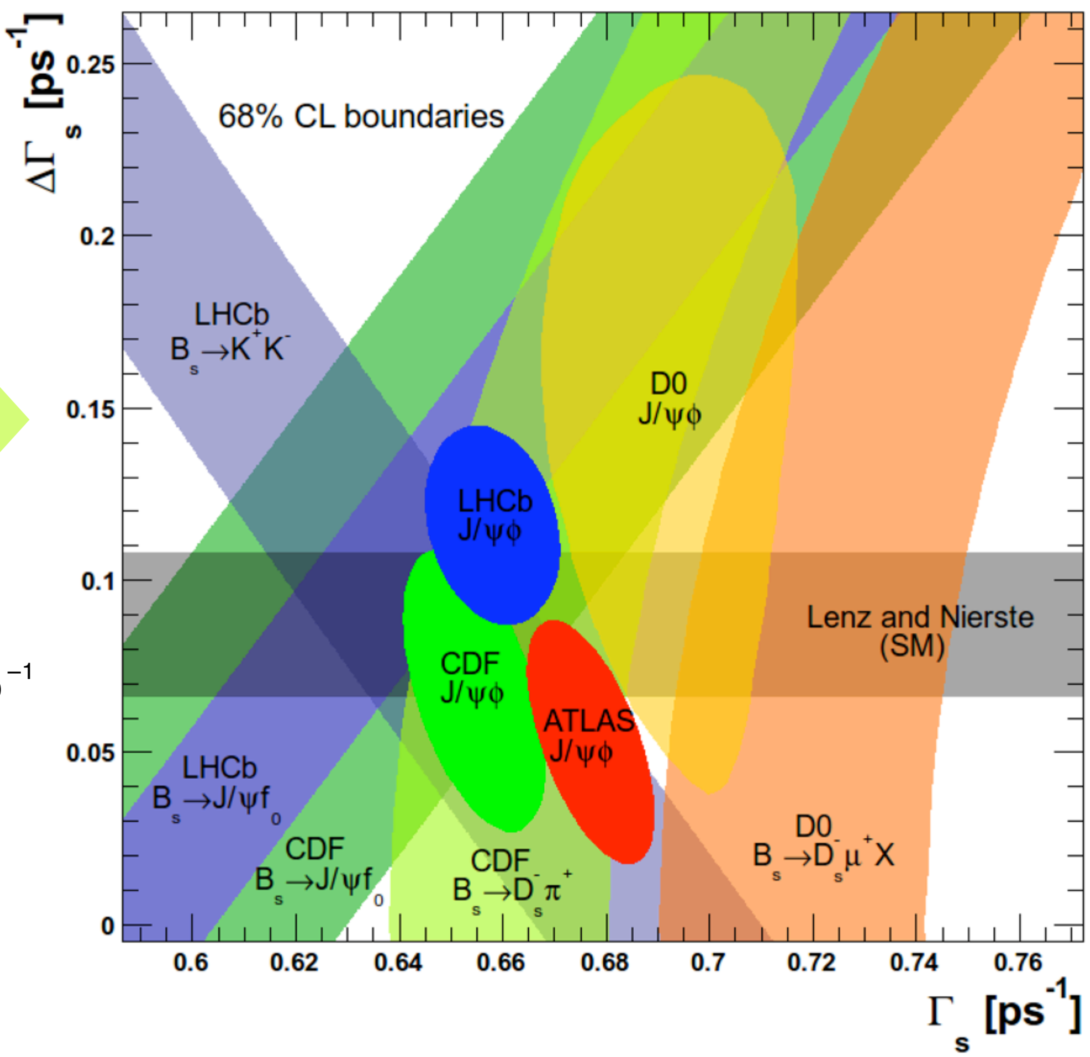
CP-violating φ_s phase and $\Delta\Gamma_s$ from $B_s \to J/\psi\ \varphi$

Summer 2012 ATLAS

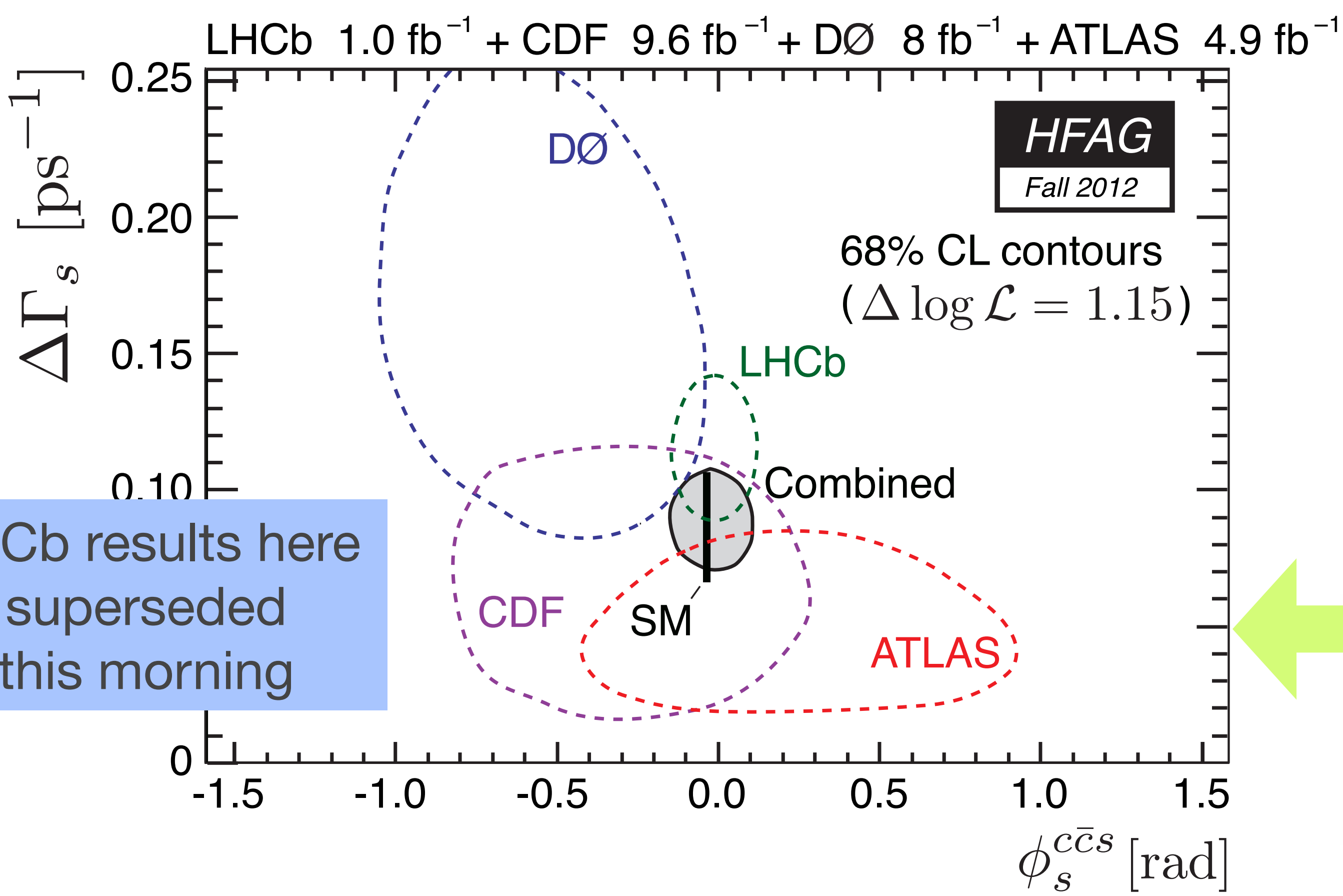
JHEP 12 (2012) 072

- ATLAS B^0s measurements compared with other measurements and SM prediction arXiv:1102.4274 [hep-ph]

	Signal Events	Resolution	Tagging
ATLAS	22.5k	$\sim$ 100 fs	No
LHCb	21k	$\sim$ 50 fs	Yes
CDF	11.5k	$\sim$ 100 fs	Yes
DØ	6.5k	$\sim$ 100 fs	Yes



- in ATLAS 4-fold ambiguity solved using LHCb constraints



LHCb results here superseded this morning

This ATLAS measurement enters the HFAG combination of $B^0s \to J/\psi\ \varphi$ in Fall 2012

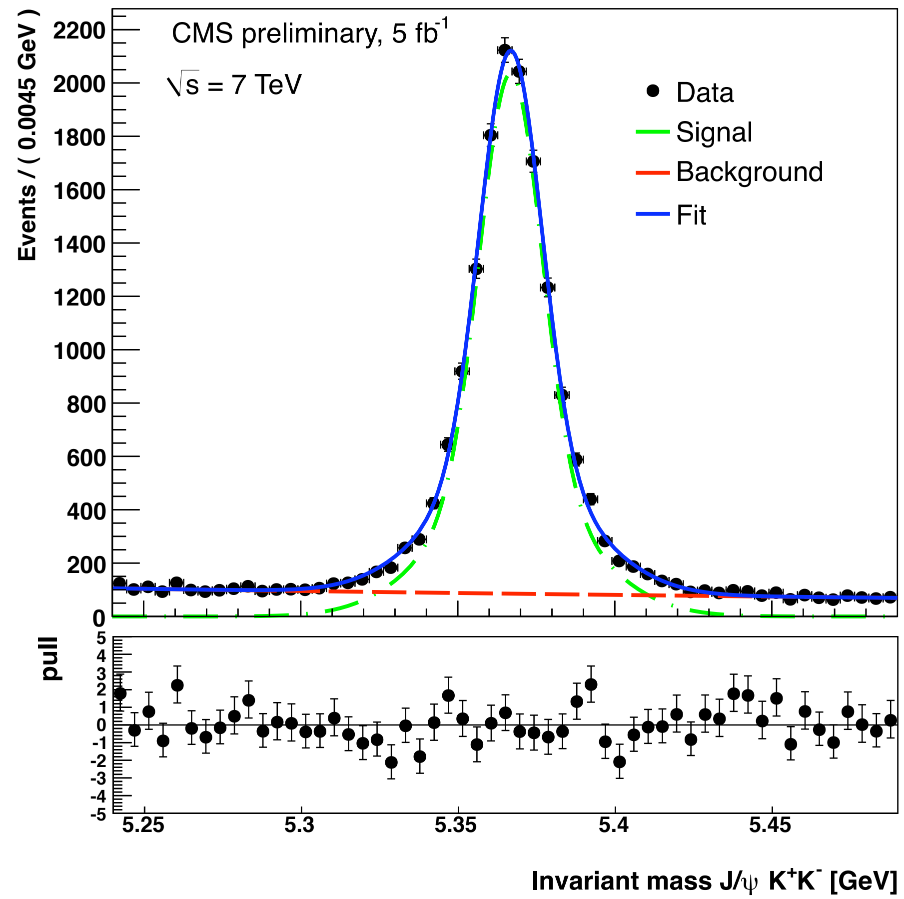
arxiv:1207.1158 and online update

B_s lifetime difference

Bs➛J/ψ φ
↘ μ+μ- ↘ K+K-

Fall 2012 CMS

CMS PAS BPH-11-006



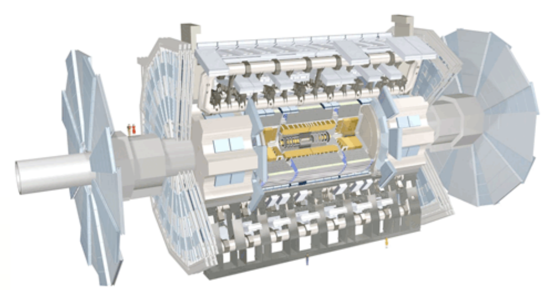
- Flavor untagged analysis of the lifetime difference between Bs mass eigenstates
  - 5fb^{-1}, 14.5k Bs➛J/ψ φ decays, ***null CP violating phase φ_s hypothesis***
- Similar signal selection and analysis strategy to ATLAS analysis but
  - more stringent selection requirements, higher purity but lower statics of B^0_s (~15k)
  - different choice of parameters to be determined from the more constrained (φ_s=0) fit

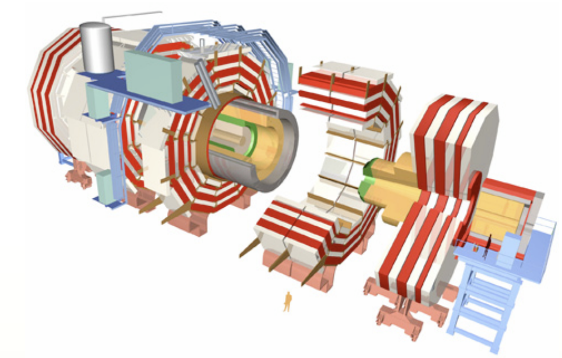
$$\begin{aligned}
\Delta\Gamma_s &= 0.048 \pm 0.024\,(\text{stat.}) \pm 0.003\,(\text{syst.})\,\text{ps}^{-1}\,,\\
\tau_{B_s} &= 0.04580 \pm 0.00059\,(\text{stat.}) \pm 0.00022\,(\text{syst.})\,\text{cm}\,,\\
|A_0|^2 &= 0.528 \pm 0.010\,(\text{stat.}) \pm 0.015\,(\text{syst.})\,,\\
|A_\perp|^2 &= 0.251 \pm 0.013\,(\text{stat.}) \pm 0.014\,(\text{syst.})\,,\\
\delta_{||} &= 2.79 \pm 0.14\,(\text{stat.}) \pm 0.19\,(\text{syst.})\,\text{rad}\,.
\end{aligned}$$

CMS

$$\Delta\Gamma_s = 0.053 \pm 0.021\,(\text{stat.}) \pm\; 0.010\,(\text{syst.})\,\text{ps}^{-1}$$

ATLAS for comparison





Search for new phenomena in B decays

in ATLAS and CMS

Search for $B^0_s \to \mu\mu$ measurement strategy in ATLAS and CMS

Winter 2012 CMS | JHEP 04(2012), 033

Spring 2012 ATLAS | PLB713(2012)387

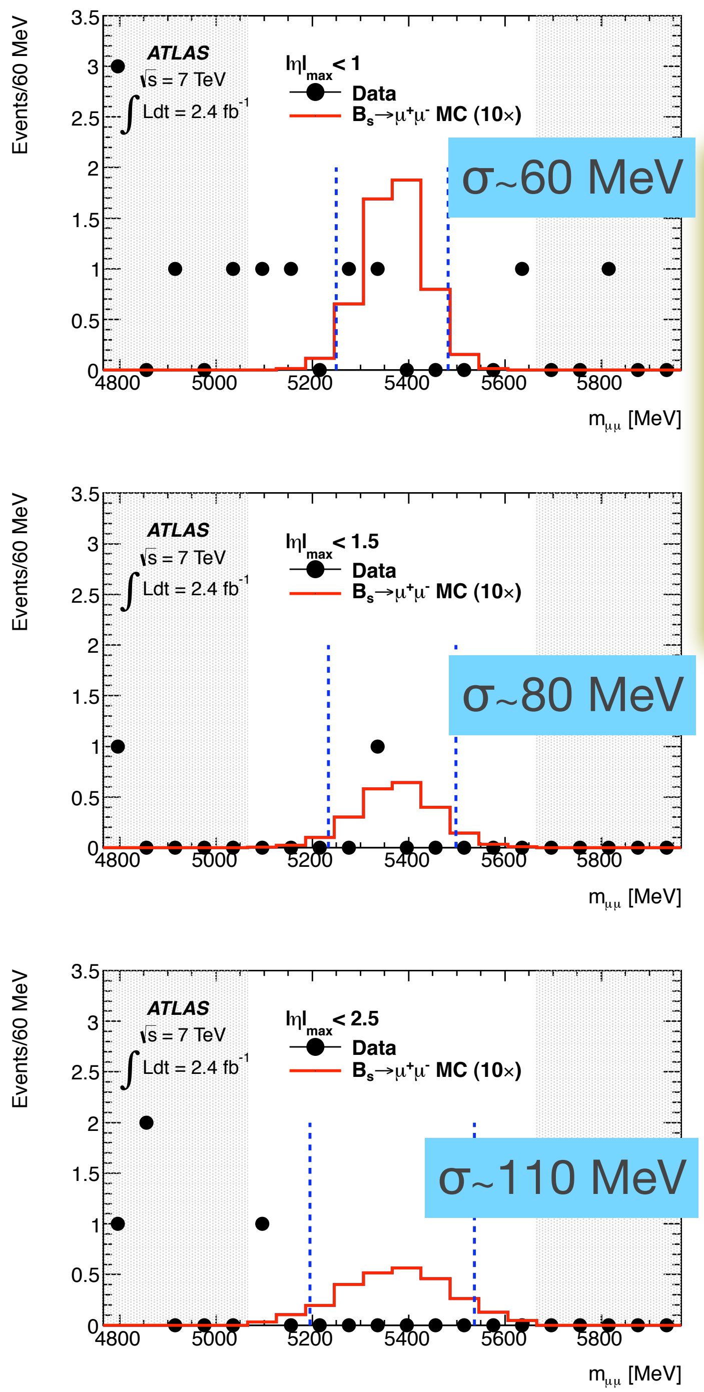
- CMS: 2011 data 5 fb-1; ATLAS: 2011 data 2.4 fb-1;

PDG

MC

$$BR(B^0_s \to \mu^+\mu^-) = BR(B^\pm \to J/\psi K^\pm \to \mu^+\mu^- K^\pm) \times \frac{f_u}{f_s} \times \frac{N_{\mu^+\mu^-}}{N_{J/\psi K^\pm}} \times \frac{A_{J/\psi K^\pm}}{A_{\mu^+\mu^-}} \frac{\epsilon_{J/\psi K^\pm}}{\epsilon_{\mu^+\mu^-}}$$

LHCb



ATLAS

3 |η| regions corresponding to different mass resolution

Sensitivity optimization based on 1/2 of the events in the sidebands

Non resonant background from the interpolation of the second half of the events in the sidebands

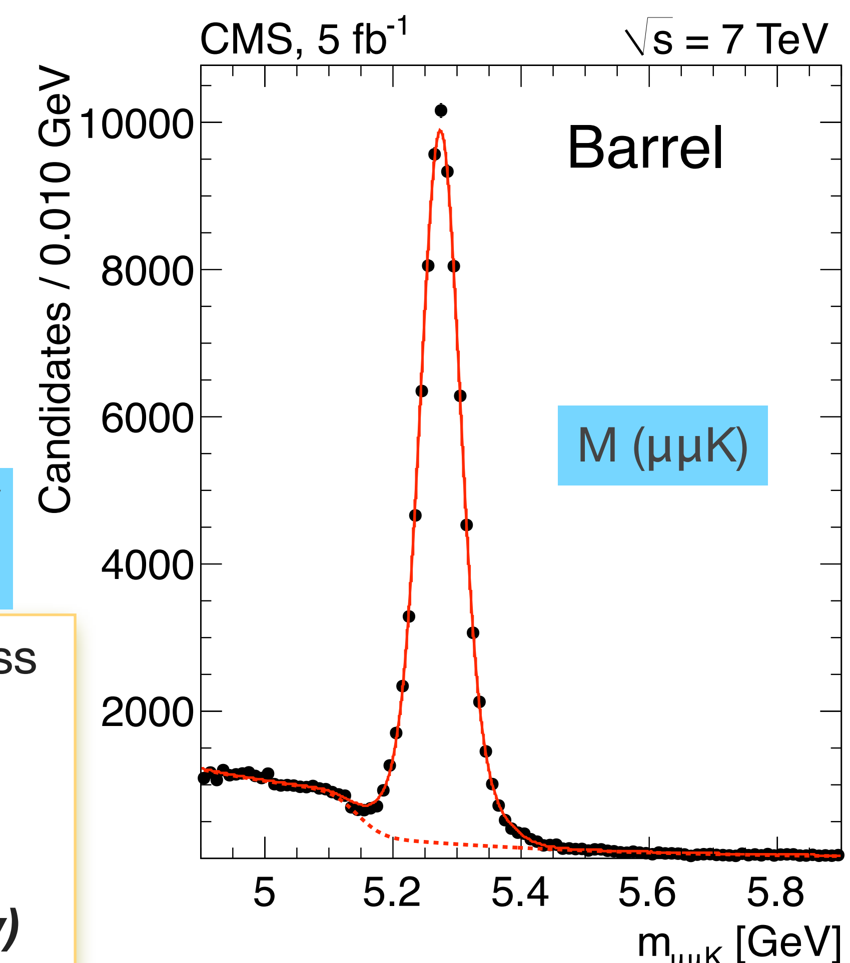
Resonant background from $B \to h^+h^-$ from MC

CMS

$\sigma(M_B)$~37-77 MeV depending on η

2 |η| regions corresponding to different mass resolution.

Combinatorial background in the search window extracted from a fit to the invariant mass sidebands (extremely low)



Search for $B^0, B^0_s \to \mu\mu$

Winter 2012 CMS — JHEP 04(2012), 033

Spring 2012 ATLAS — PLB713(2012)387

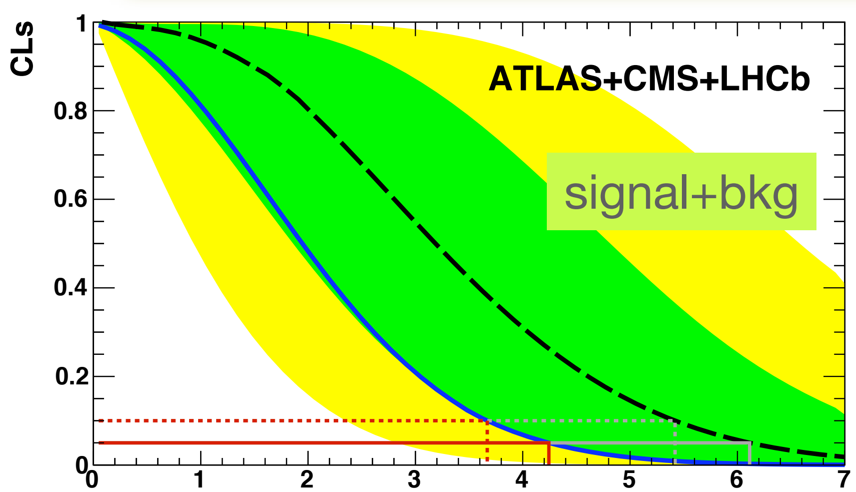
- CMS: 2011 data 5 fb-1; ATLAS: 2011 data 2.4 fb-1; LHCb: 2011 1 fb-1

95% CL

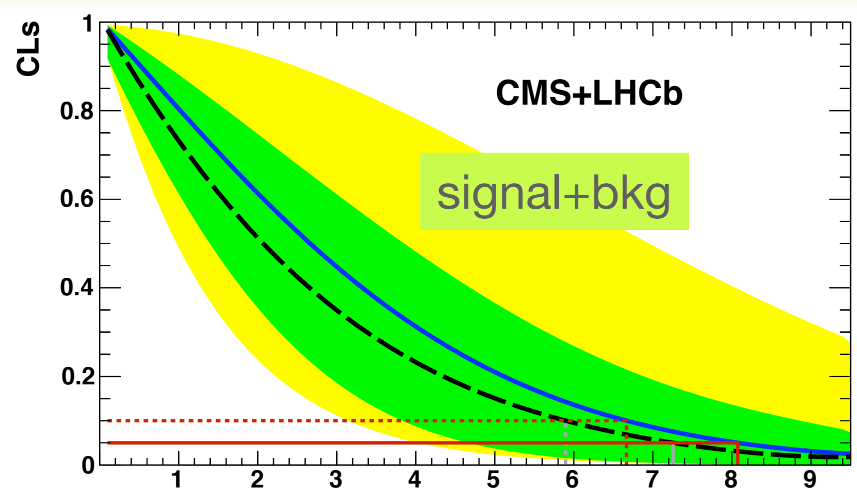
Mode	Limit	ATLAS	CMS	LHCb 2010	LHCb 2011	Combined
$B^0_s \to \mu^+\mu^-$ (10^{-9})	Bkg Only	23	(3.6)	65	3.4	2.3
	Bkg+SM		8.4		7.2	6.1
	Obs	22	7.7 (7.2)	56	4.5	4.2
$B^0 \to \mu^+\mu^-$ (10^{-10})	Bkg Only	–	(13)	180	11	7.3
	Bkg+SM	–	16			
	Obs	–	18 (16)	150	10	8.1

LHC combination: summer 2012
LHCb-CONF-2012-017,
CMS-PAS-BPH-12-009,
ATLAS-CONF-2012-061

New LHCb results supersede this combination - see LHCb report



$BR(B^0s \to \mu\mu) \times 10^{-9}$



$BR(B^0 \to \mu\mu) \times 10^{-10}$

$$\mathcal{B}(B^0_s \to \mu^+\mu^-)_{\rm SM} = (3.2 \pm 0.2) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-)_{\rm SM} = (1.0 \pm 0.1) \times 10^{-10}$$

JHEP 1010 (2010) 009 ***SM prediction*** includes time evolution of the initial state

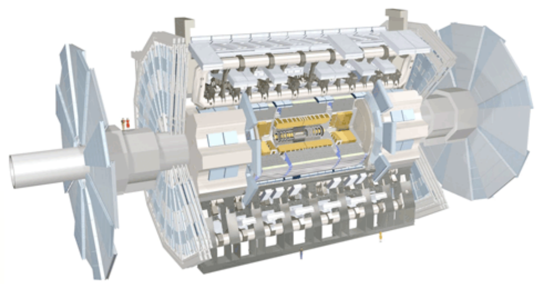
Data are consistent with SM within 1σ
NP effects are constrained to be not larger than the SM contribution

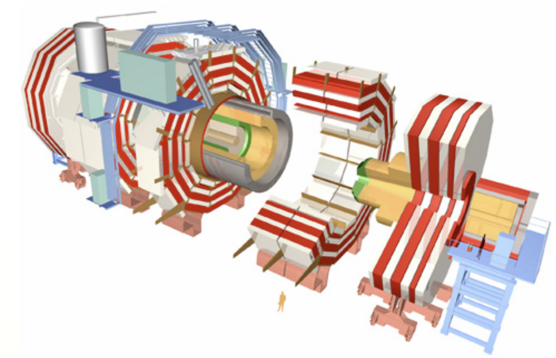
Feasibility of the ***search for $D^0 \to \mu\mu$*** demonstrated by **CMS** [although result, on 90 pb^{-1}, is not competitive with LHCb] BR < 5.4×10^{-7} at 90% CL

CMS PAS BPH-11-017

Conclusions

- Many interesting results on heavy flavor physics from ATLAS and CMS, general purpose experiments
- Inclusive measurements suggest that further tuning of the theory predictions are needed, particularly in some phase space regions
- Extensive measurements in the Onia sector challenge the theoretical models; none satisfactory from all perspectives (rate, polarization)
- Some puzzling states looking for interpretation
- Precision study of the Bs mesons allows measurements of CP violation sensitive parameters
- No sign of New Physics contributions in SM highly suppressed decays
- Still a lot of ATLAS and CMS data to be analyzed (delayed 2012 stream designed mainly for heavy flavor physics measurements)





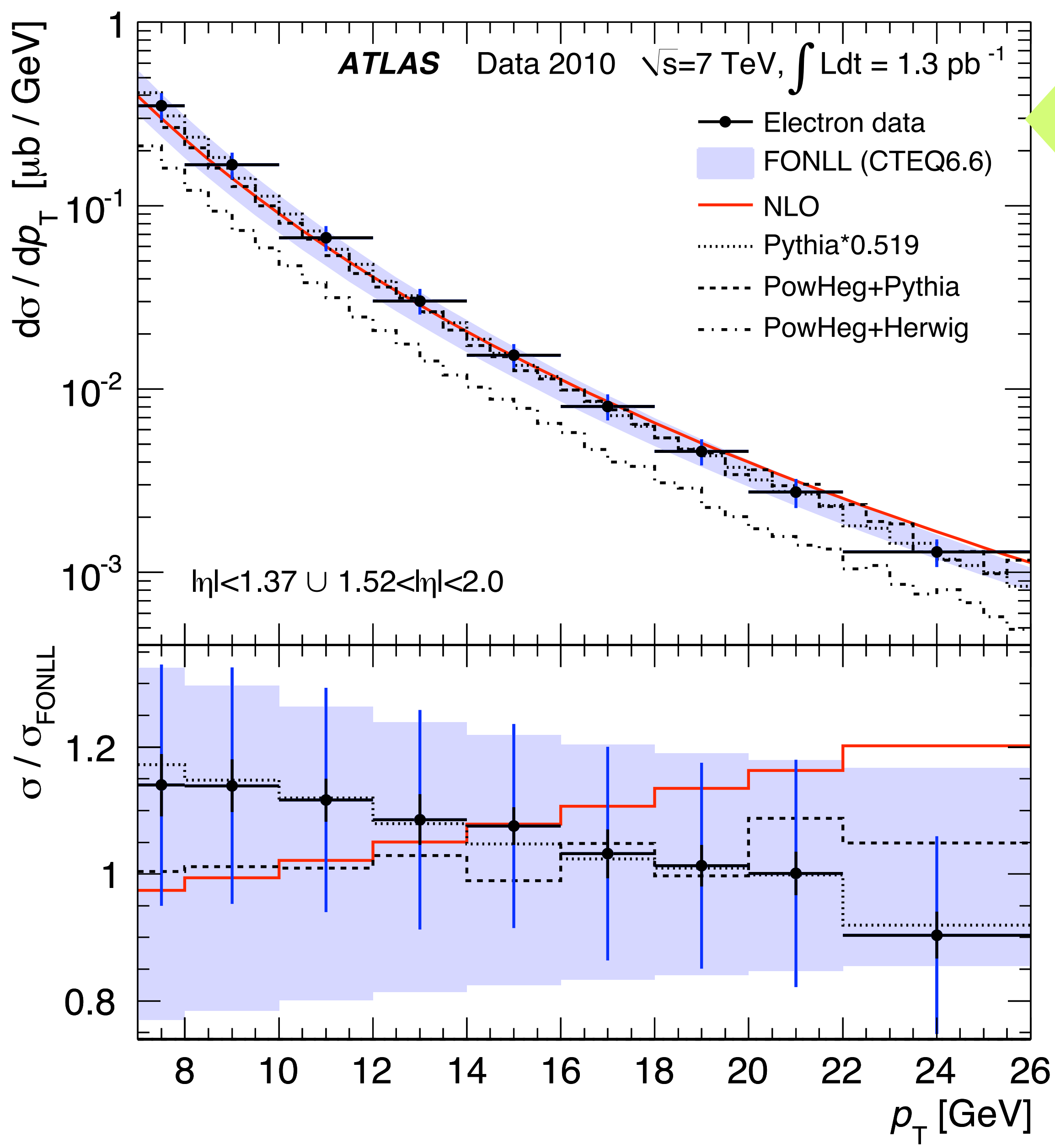
Extra Material

ATLAS: b/c inclusive production from inclusive e/μ dσ/dpT at 7 TeV

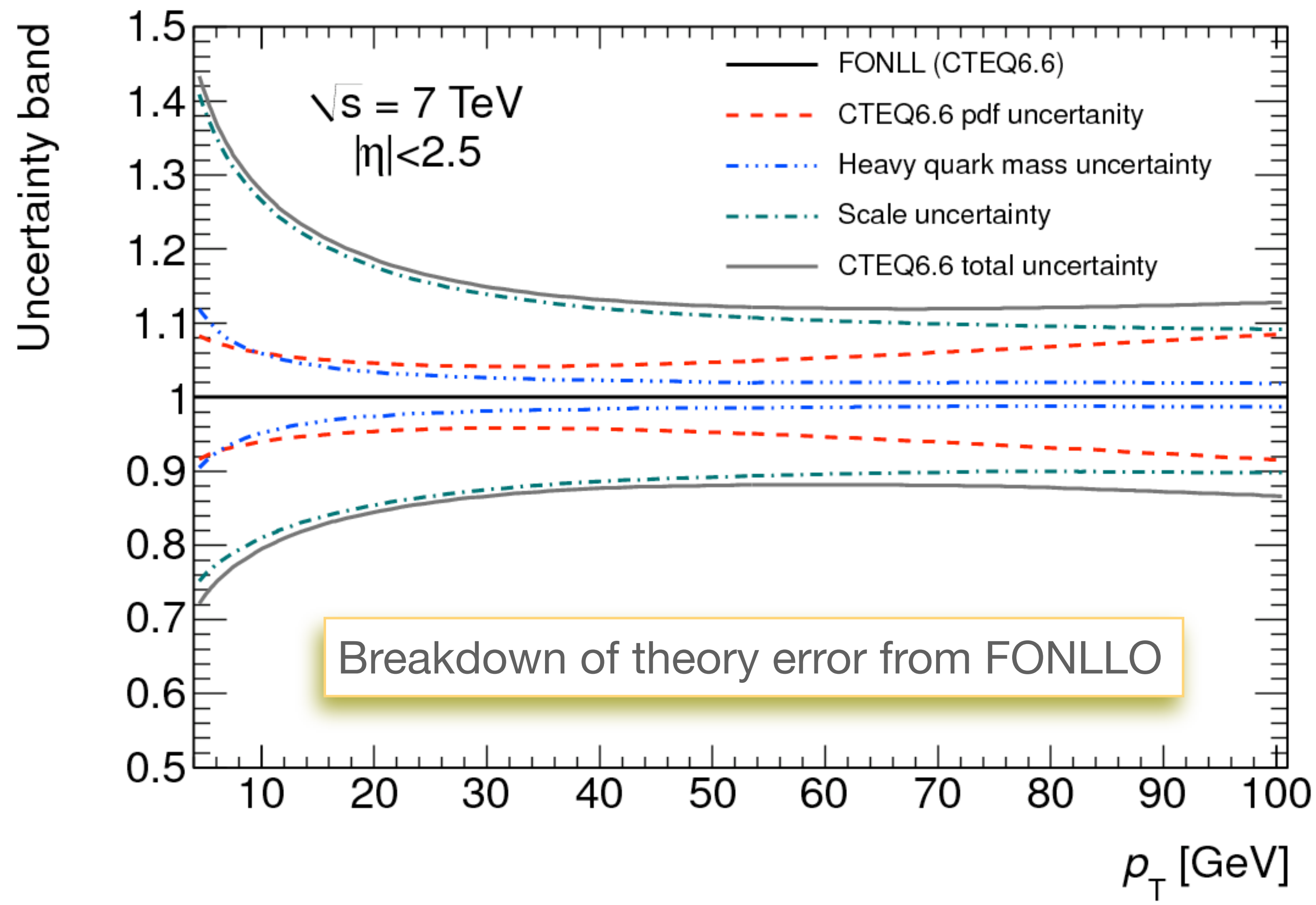
ATLAS

- ATLAS: b/c inclusive production from inclusive e/μ dσ/dp$_T$ at 7 TeV in 2010 data (~1.4 pb-1)

Phys.Lett. B707 (2012) 438-458



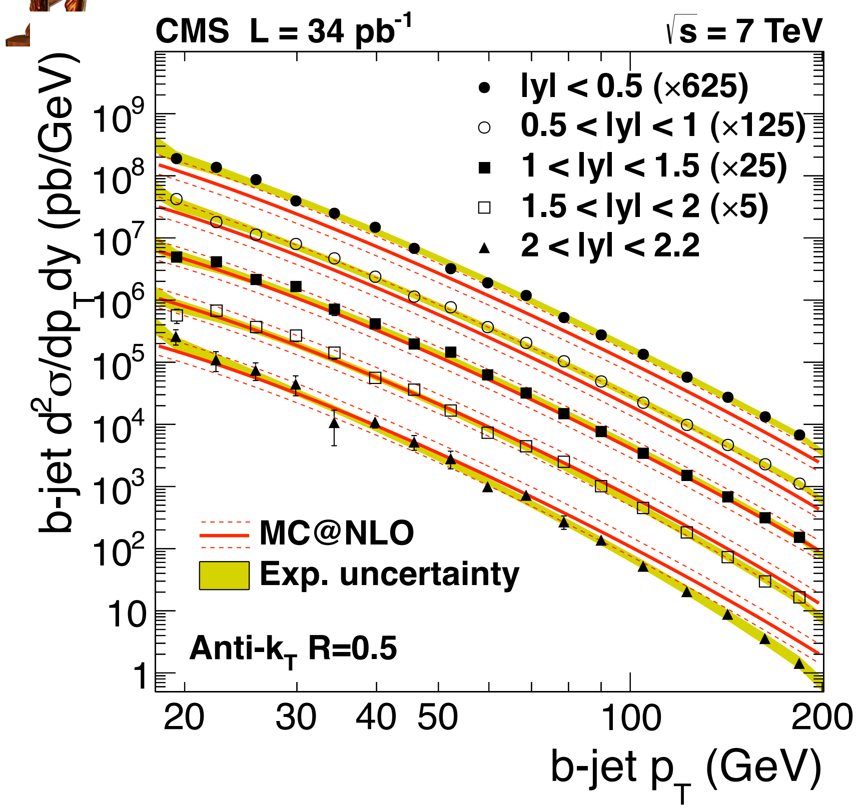
Comparison with MC show
- good agreement with POWHEG+Pythia,
- low predicted rate by POWHEG+HERWIG (not entirely explained by different decay tables used)
- a factor 0.5 off in PYTHIA LO rate prediction

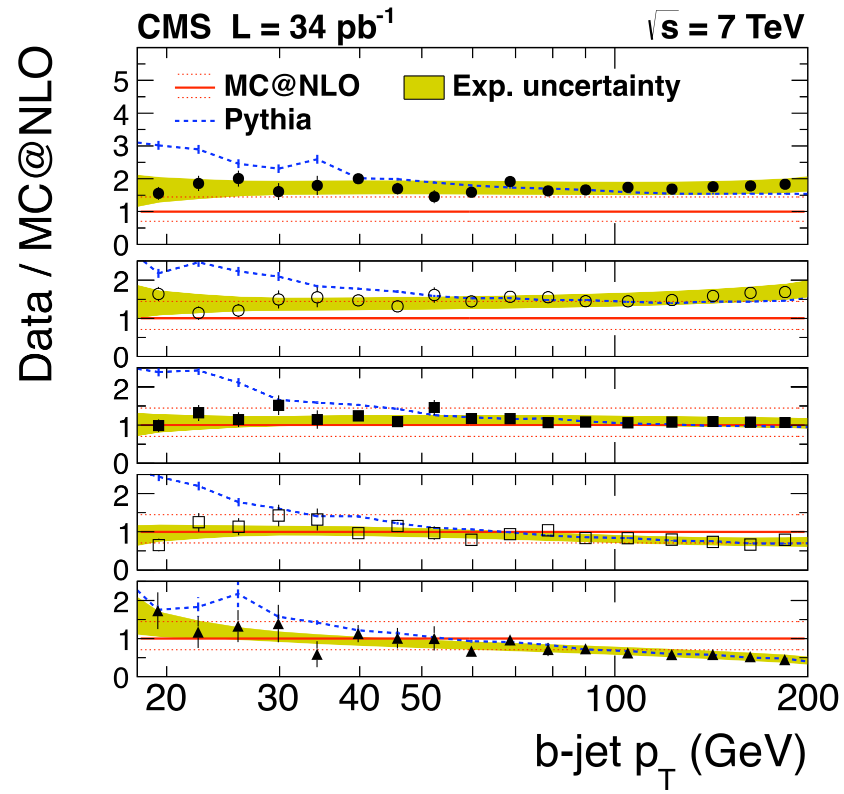


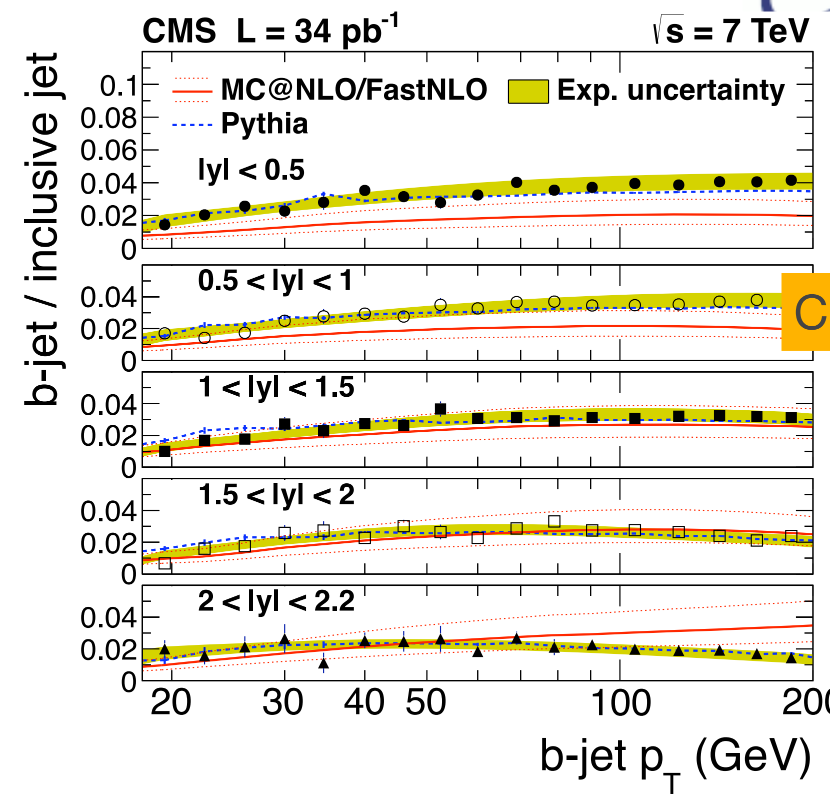
Breakdown of theory error from FONLLO

ATLAS / CMS b-jet inclusive production at 7 TeV in 2010 data

CMS JHEP 04 (2012) 084
ATLAS EPJC 71 (2011) 1846

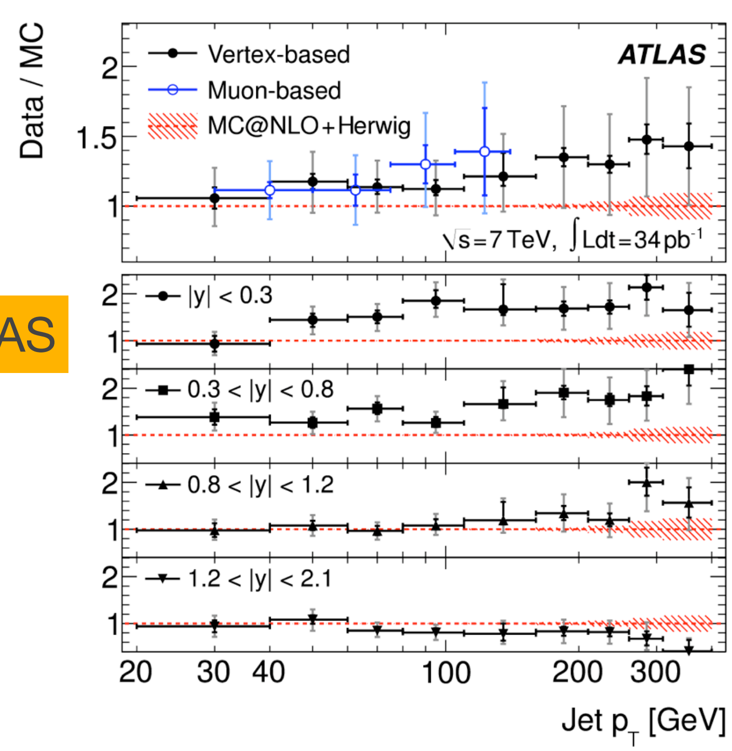


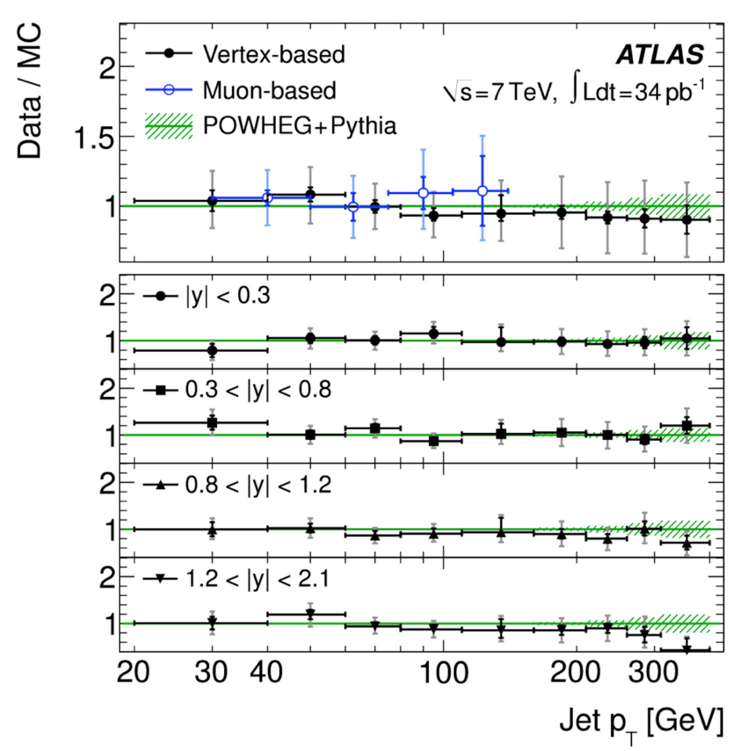


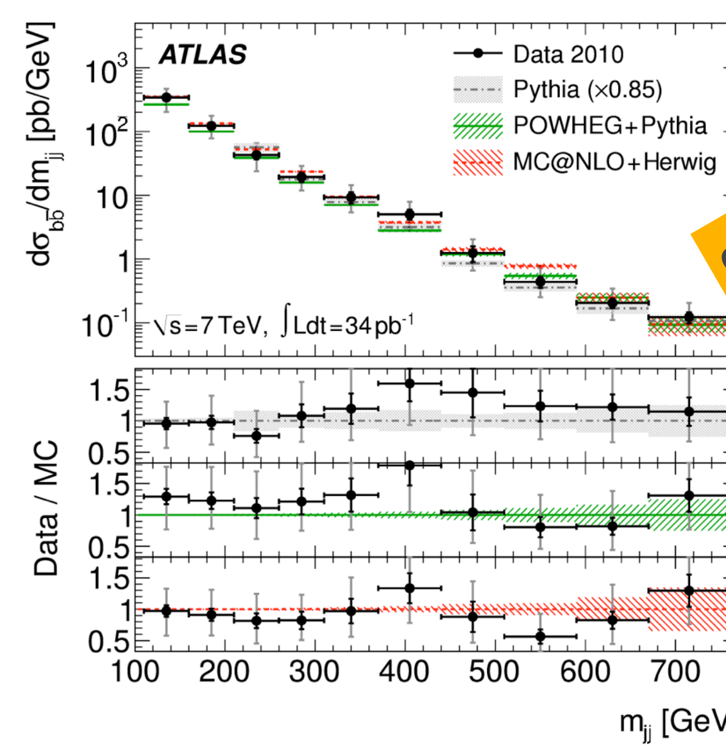


CMS

ATLAS





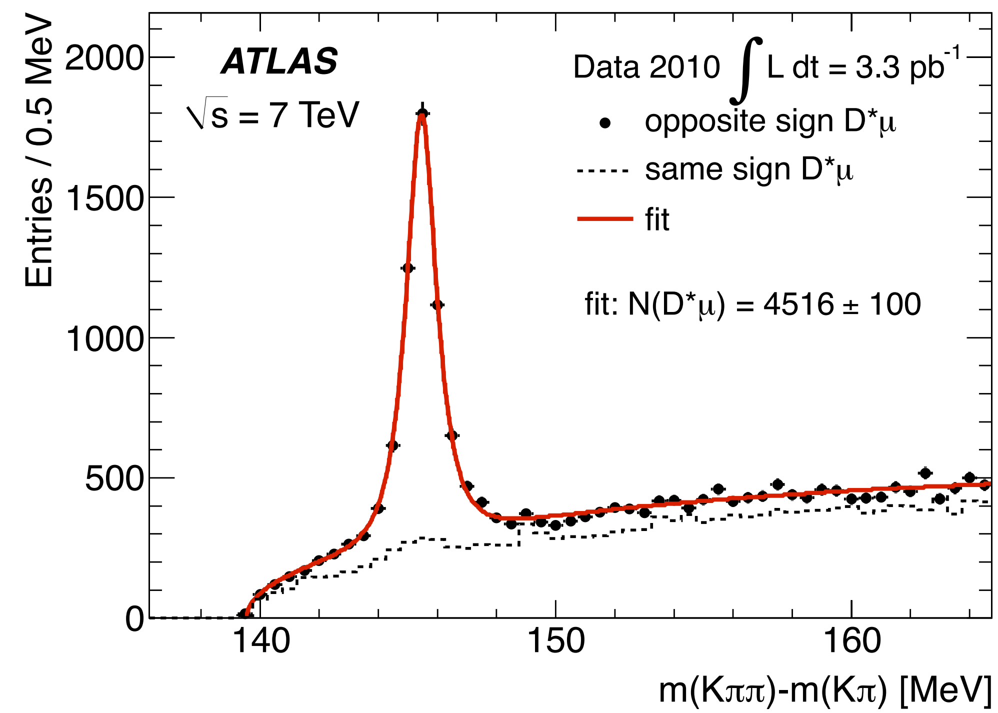


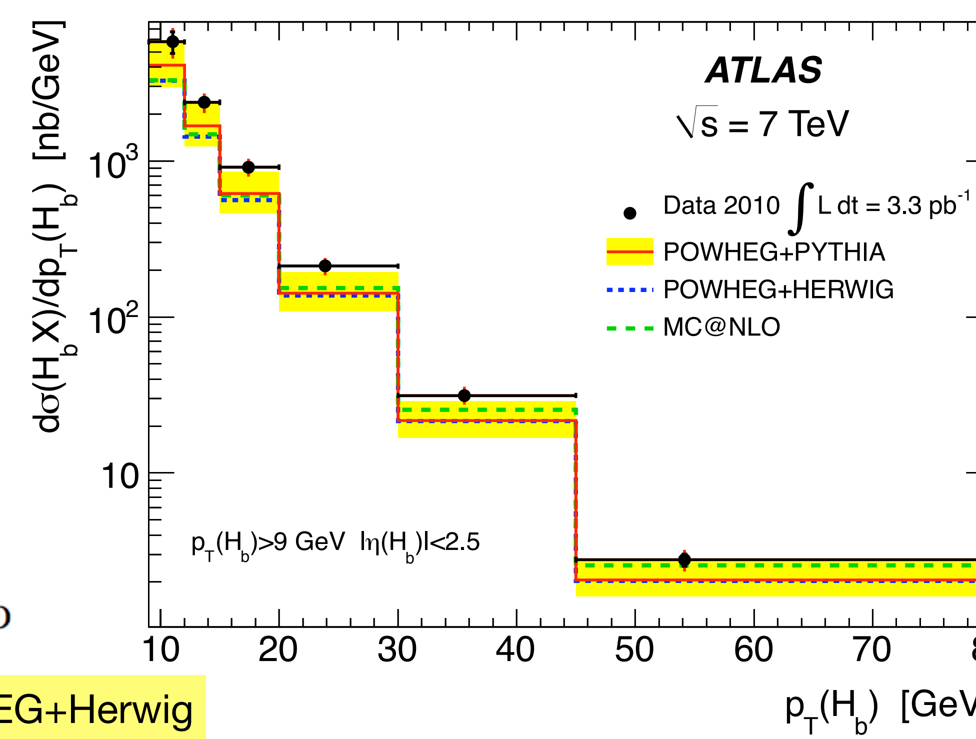
di-jet

b-hadron (H_b) production cross section at 7 TeV from the reconstruction of $D^{*+}\mu^-X$

Nucl. Phys. B864 (2012) 341-381 ATLAS Summer 2012

- ATLAS 2010 partial data set (3 pb-1)
- using $H_b \to D^{*+}\mu^- X$ with $D^{*+} \to \pi^+ D^0$ and $D^0 \to K^-\pi^+$ triggered by single muon triggers
- production cross section measured for H_b p_T>9GeV and $|\eta|$<2.5
  - syst. errors dominated by reco. eff., fraction of D^{*+} from H_b decays, model for yield extraction, correction from $D^{*+}\mu^-$ kin. to H_b kinematics
- results are compared with MC@NLO4.0+Herwig and POWHEG-HVQ(1.01)+HERWIG or PYTHIA; CTEQ6.6, b-q mass=4.75GeV
  - data above predictions
  - extrapolation to the full phase space agrees with inclusive measurements of b-bbar production





$$\sigma(pp \to H_b X) = 32.7 \pm 0.8\ (\text{stat.}) \pm 3.1\ (\text{syst.})^{+2.1}_{-5.6}(\alpha) \pm 2.3(\mathscr{B}) \pm 1.1(\mathscr{L})\ \mu\text{b}$$

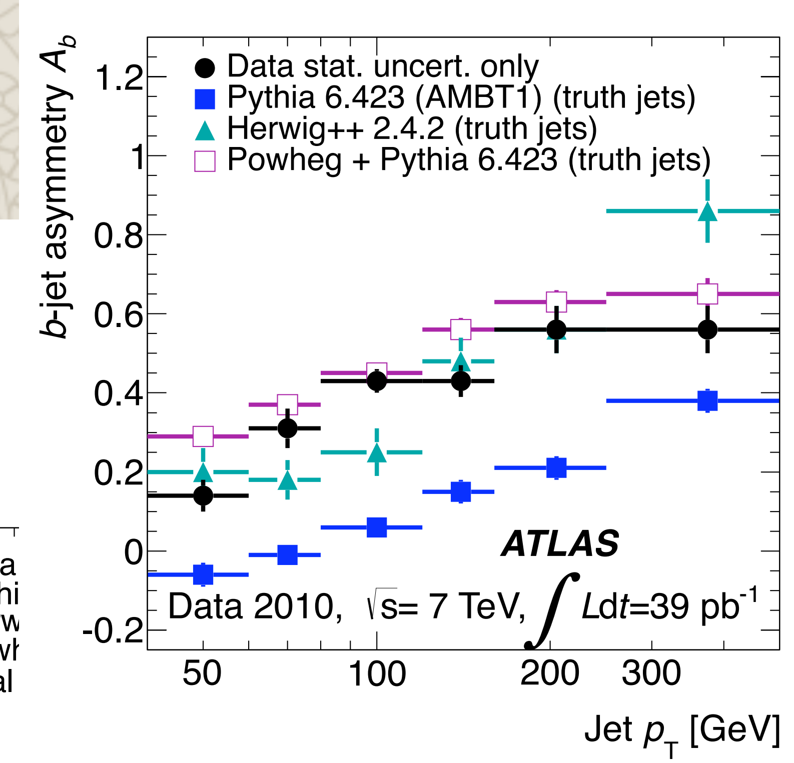
$$\sigma(pp \to H_b X) = 22.2\ ^{+8.9}_{-5.4}(\text{scale})\ ^{+2.1}_{-1.9}(m_b)\ ^{+2.2}_{-2.1}(\text{PDF})\ ^{+1.6}_{-1.5}(\text{hadr.})\ \mu\text{b}$$

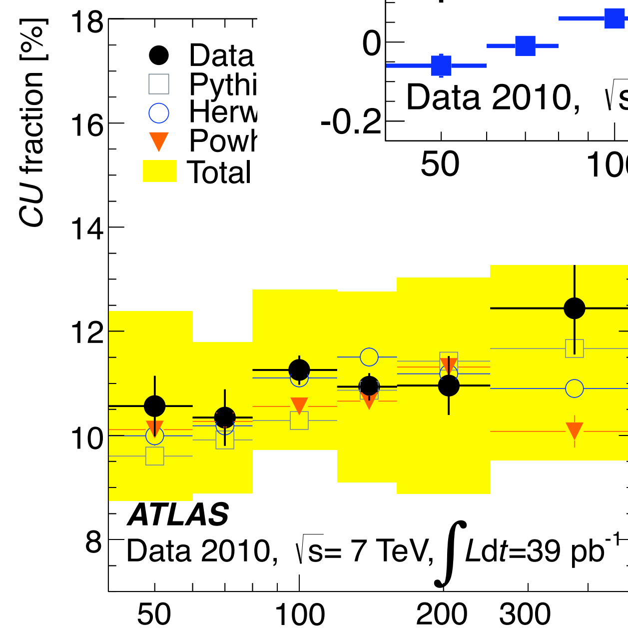
POWHEG+Herwig

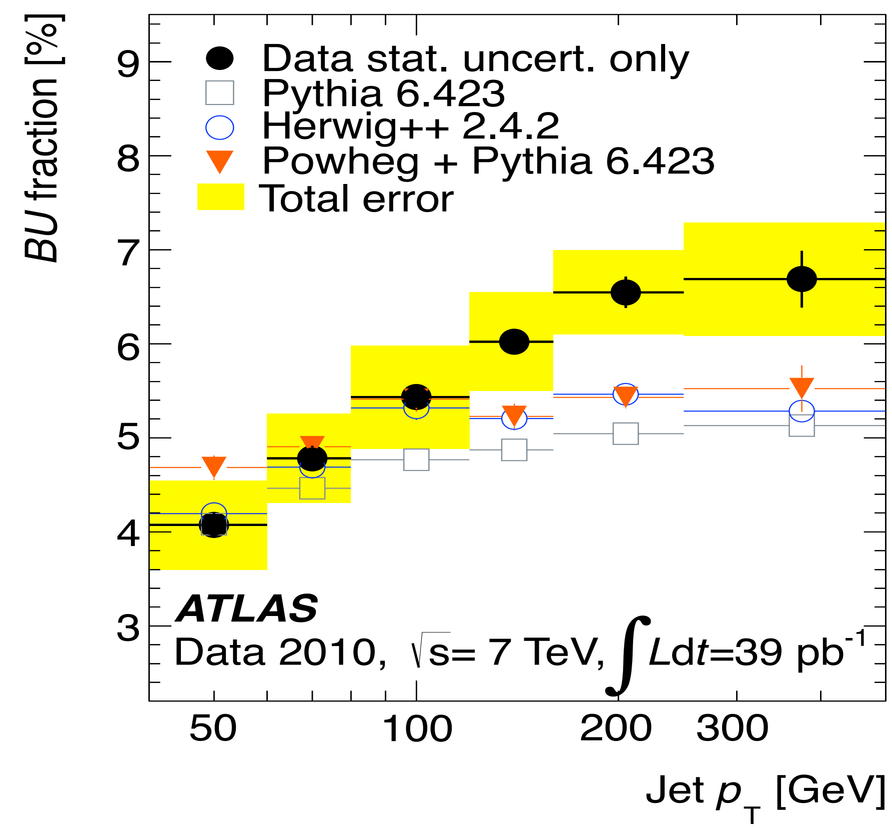
Flavor composition of di-jet events

arXiv:1210.0441, submitted to EJP | ATLAS Fall 2012

- ATLAS: flavor composition of di-jet events at 7 TeV (full 2010 data set 39 pb-1) as a function of leading jet p_T (6 categories: ll,lc,lb, cc, cb, bb)
  - anti-kT(R=0.4) jets with pT>30GeV and |y|<2.1; 2 highest pT jets must have $\Delta\varphi$>2.1rad
  - no explicit flavor tagging but flavor separation based on kinematic properties of the tracks associated to secondary vertices in the 2 jets
- for heavy flavor production: study balance between quark pair production (gg➛qqbar, qqbar➛qqbar) [pQCD], quark excitation (qg➛qX) [proton content] and gluon splitting (g➛qqbar)
- fraction of lb-dijet underestimated by NLO predictions at high p_T
- different b-jet fraction for leading and sub-leading jet, predicted by theory, is confirmed by data: $A_b = N_b^{SL}/N_b^{L} - 1$





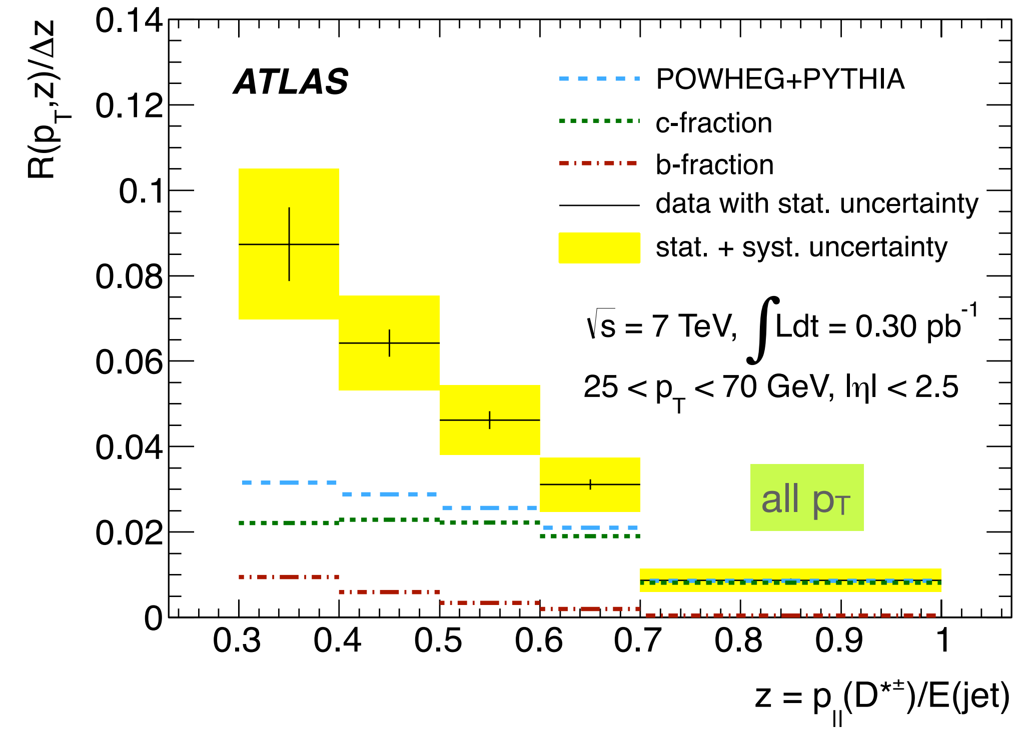


Measurement of $D^{*\pm}$ in jets at 7 TeV

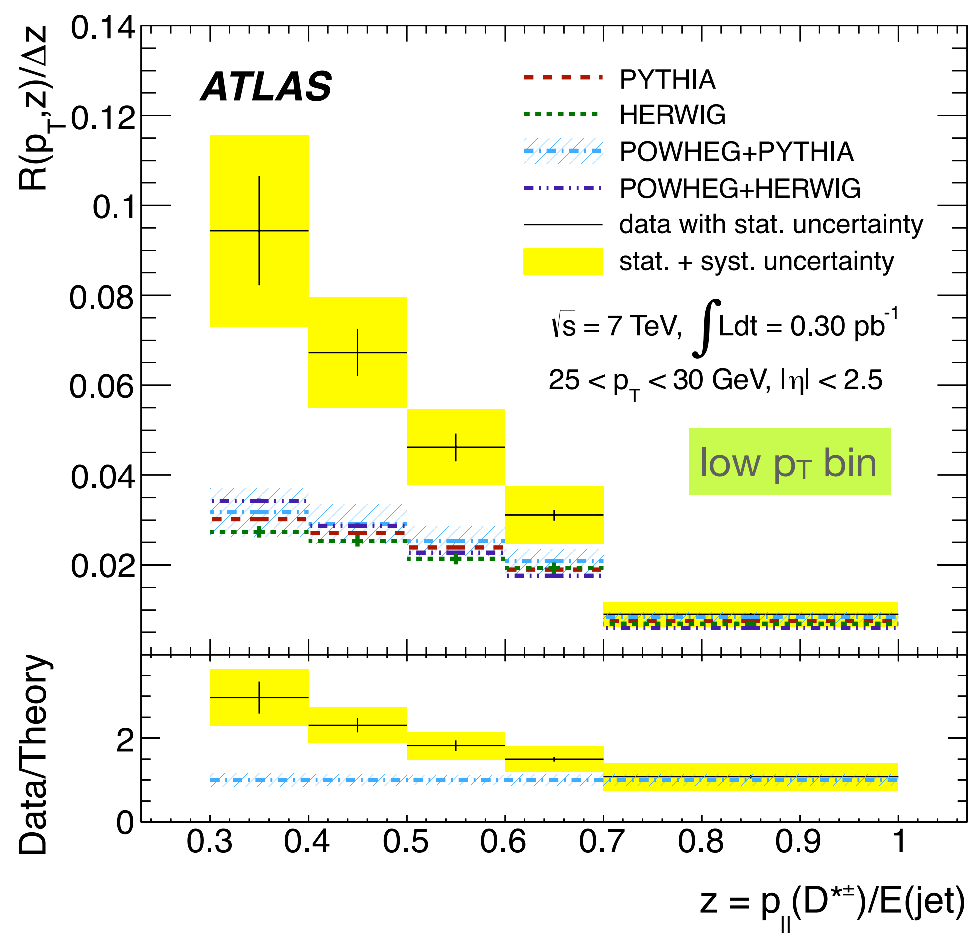
PRD 85 (2012) 052005

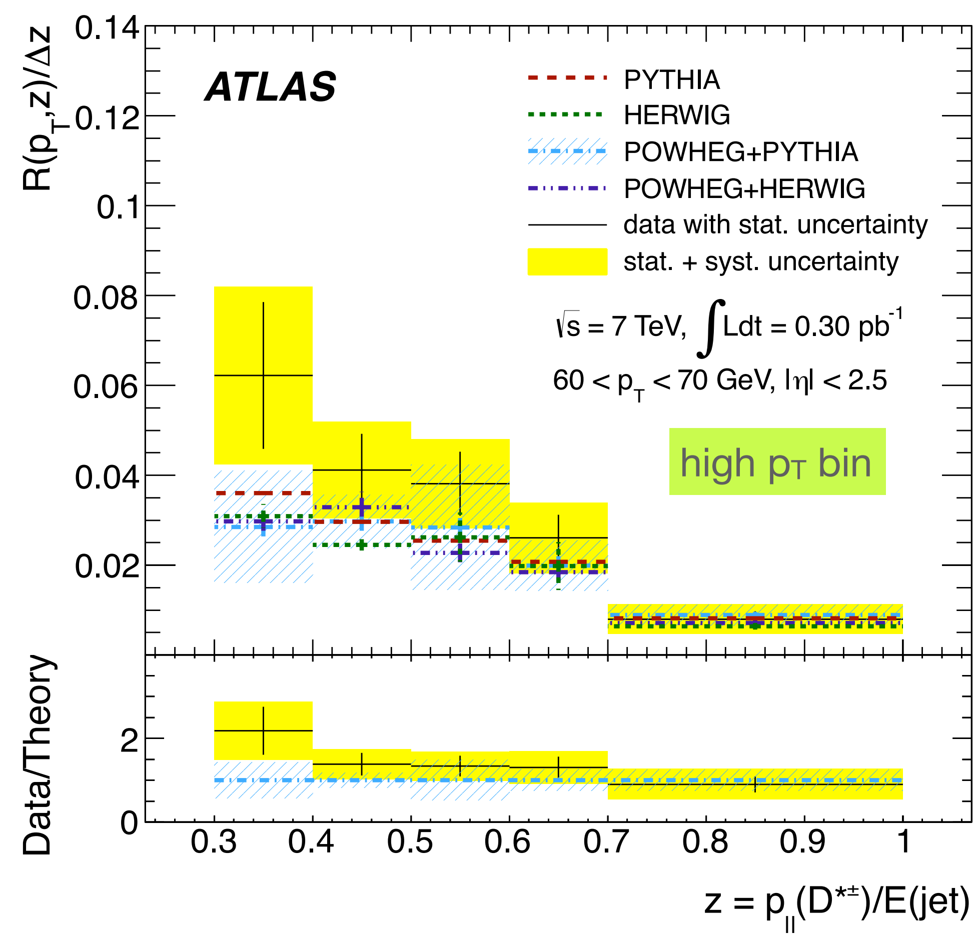
ATLAS Fall 2011

- ATLAS, small fraction of 2010 data ($0.3 pb^{-1}$)
- D^{*+} fully reconstructed in the channel $\pi^+ D^0$ and $D^0 \to K^- \pi^+$
- The measurement: $R = N_{D^*}(p_T, z)/Njet(p_T)$
  - p_T = jet p_T, $z = p_{//}(D^*)/E_{jet}$



The production of c jets (b jets) or their fragmentation into $D^{*\pm}$ mesons is not well modeled in current MC generators





Λ_b mass and lifetime

Summer 2012 ATLAS

Phys. Rev. D 87, 032002 (2013)

Parameter	Value
m_{Λ_b}	5619.7 ± 0.7 MeV
τ_{Λ_b}	1.449 ± 0.036 ps
f_{sig}	0.268 ± 0.007
S_m	1.18 ± 0.03
S_τ	1.05 ± 0.02

± 1.1 MeV

± 0.017 ps

Par.	Value
χ^2/N_{dof}	1.09
N_{sig}	2184 ± 57
N_{bkg}	5970 ± 160
σ_m	31.1 ± 0.8 MeV
σ_τ	0.117 ± 0.003 ps

Systematic uncertainty	$\sigma_\tau^{\text{syst}}$ (fs)	σ_m^{syst} (MeV)
Selection/reco. bias	12	0.9
Background fit models	9	0.2
B_d^0 contamination	7	0.2
Residual misalignment	1	...
Extra material	3	0.2
Tracking p_T scale	...	0.5
Total systematic error	17	1.1

$R = \tau_{\Lambda b}/\tau_{Bd} = 0.960 \pm 0.025^{\text{stat}} \pm 0.016^{\text{syst}}$

Λb properties currently accessible only at hadron colliders

Mass in good agreement with world average and recent LHCb measurement

Lifetime in agreement with world average (similar error)

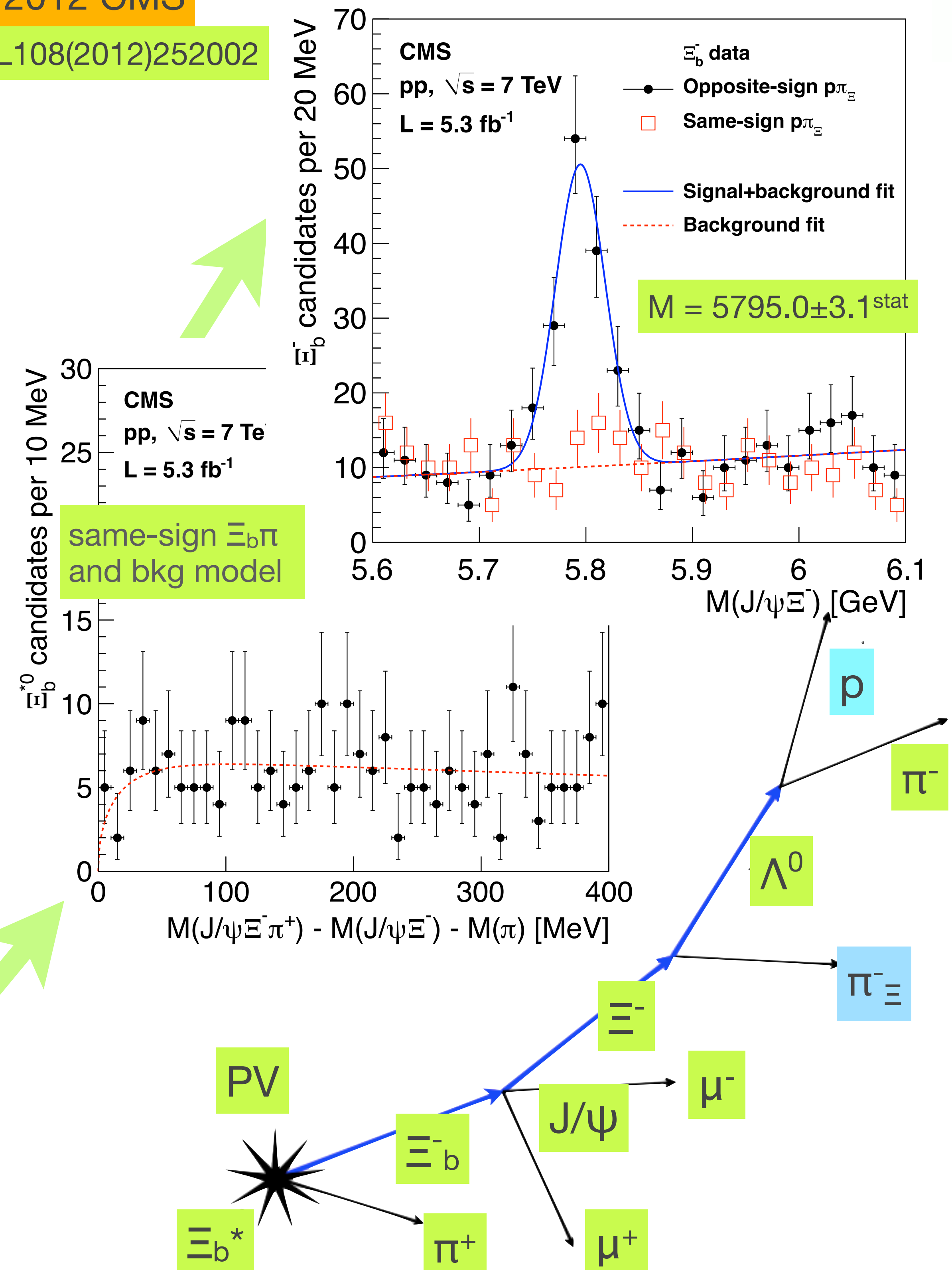
$R = \tau_{\Lambda b}/\tau_{Bd}$ more precise that earlier CDF and D0 determinations agrees with HQET [0.88,0.97] and NLO QCD [0.86-0.88]

Observation of a new Ξ_b baryon

Spring 2012 CMS

PRL108(2012)252002

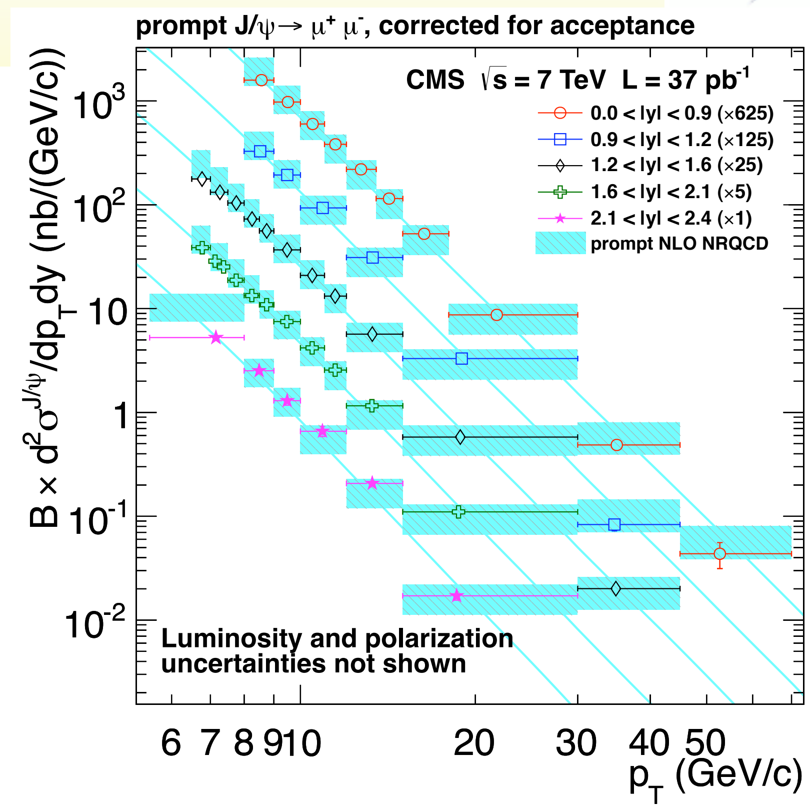
- trigger: 2μ at LVL1 and consistency with J/ψ mass and + common vertex at HLT
- analysis steps: ....
  - 1) J/ψ selection;
  - 2) Λ^0 reconstruction
  - 3) Ξ reconstruction by combining $\Lambda^0(p\pi^-)\pi^-$ 4) Ξ_b reconstruction with J/ψ Ξ combination (mass compatible with world average)
    - combinatorial background controlled with same-sign $p\pi_\Xi$
  - 5) combine Ξ_b candidates, within 2.5σ from the fitted value of the mass, with a π+ track and compute
- Q distribution fit with Breit-Wigner⊗Gaussian +bkg (from same-sign $\Xi_b\pi$)

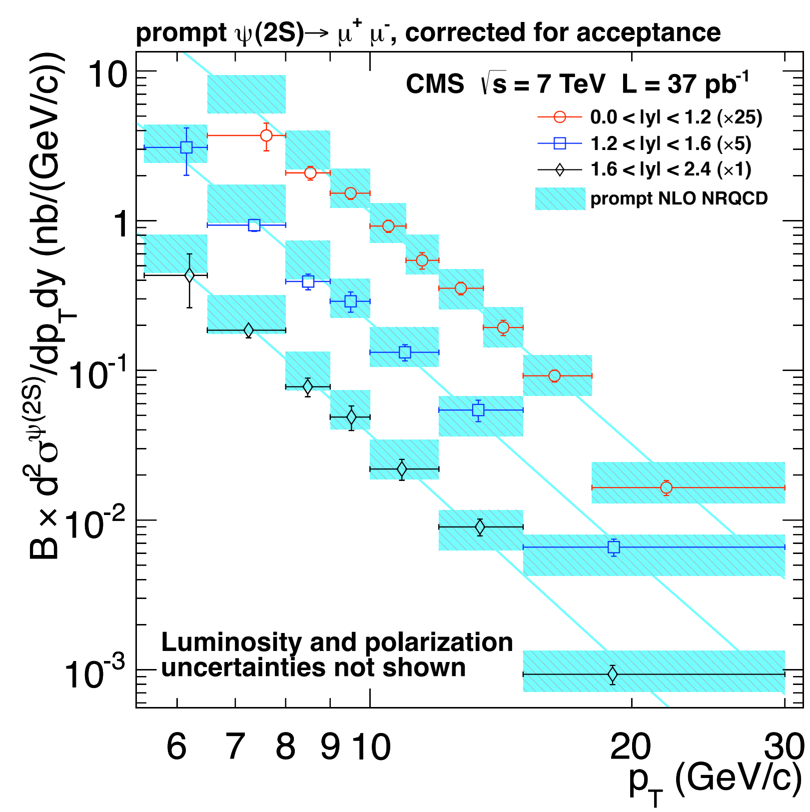


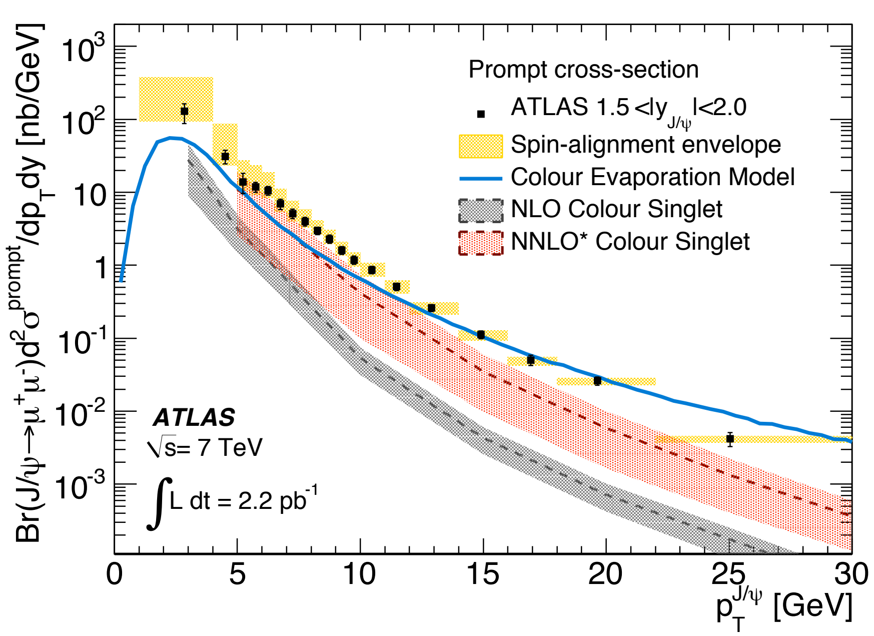
Charmonium results

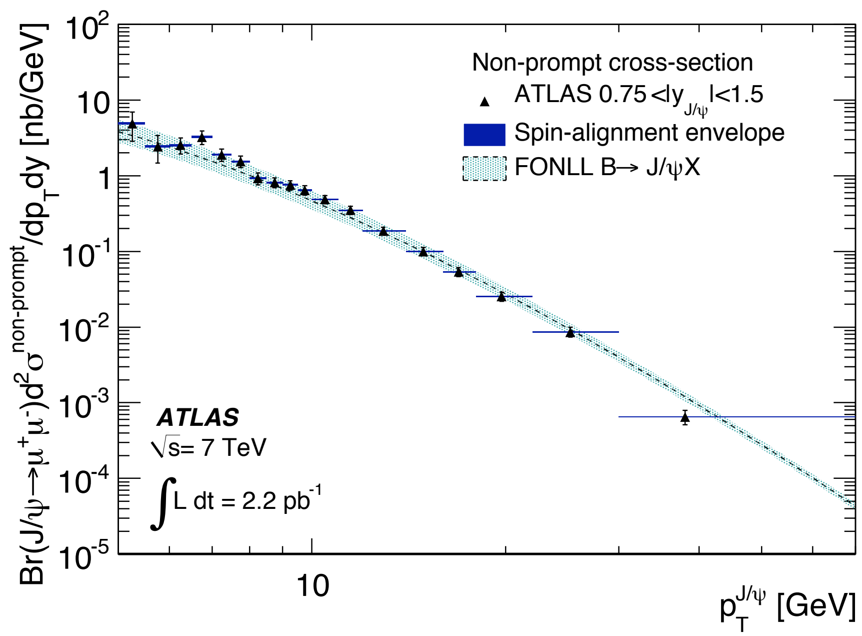
JHEP 02 (2012) 011

- J/ψ $d^2\sigma/dp_T dy$ from both ATLAS and CMS and ration of prompt to non-prompt production
- Same measurements on ψ(2S) from CMS only
- in CMS prompt production compared with NRQCD Phys. Rev. Lett. 106 (2011) 042002: NLO NRQCD with color octet contributions - in good agreement with data
- in ATLAS comparison with NNLO* NRQCD color single model Phys. Rev. Lett. 101 (2008) 152001 - in not too good agreement with data
- non-prompt component compared with FONNL- good agreement









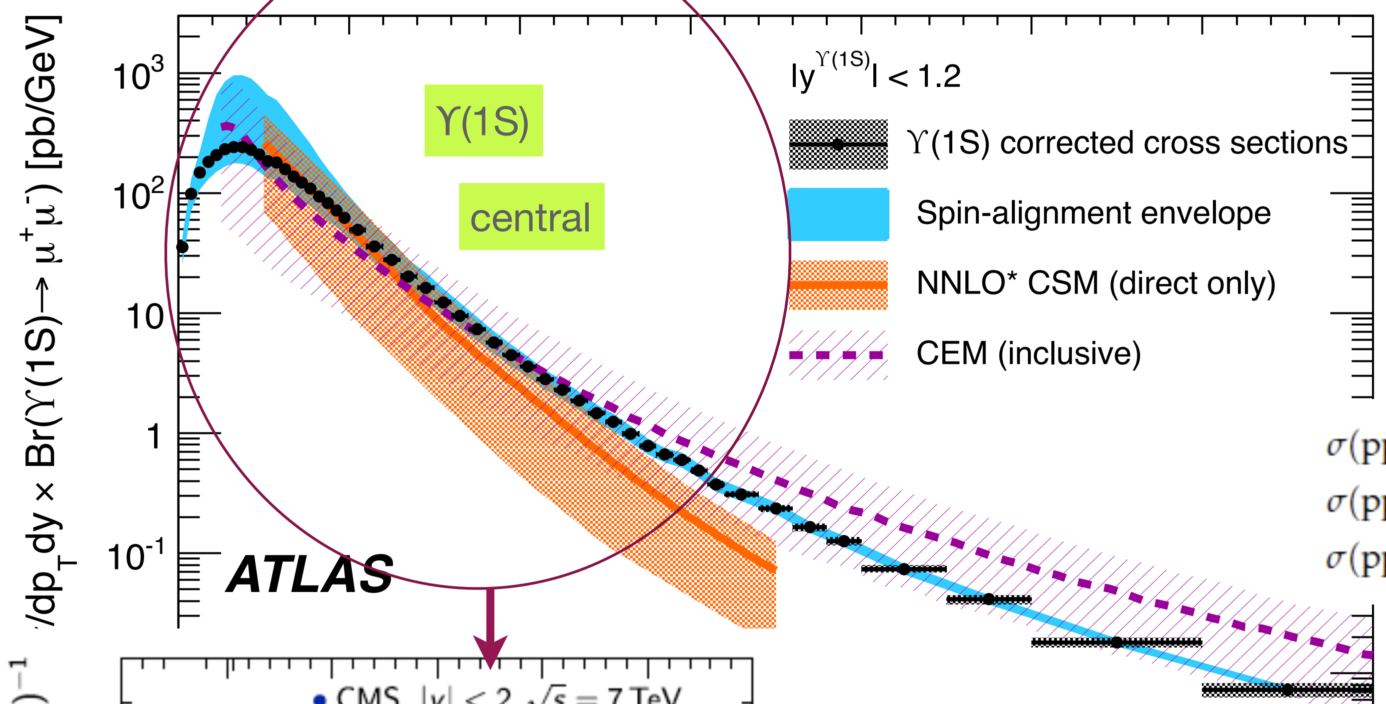
Nucl. Phys. B 850 (2011) 387-444

Υ(nS) differential production cross sections

Fall 2012 ATLAS

to appear in PRD arXiv:1211.7255

ATLAS arXiv:1211.7255

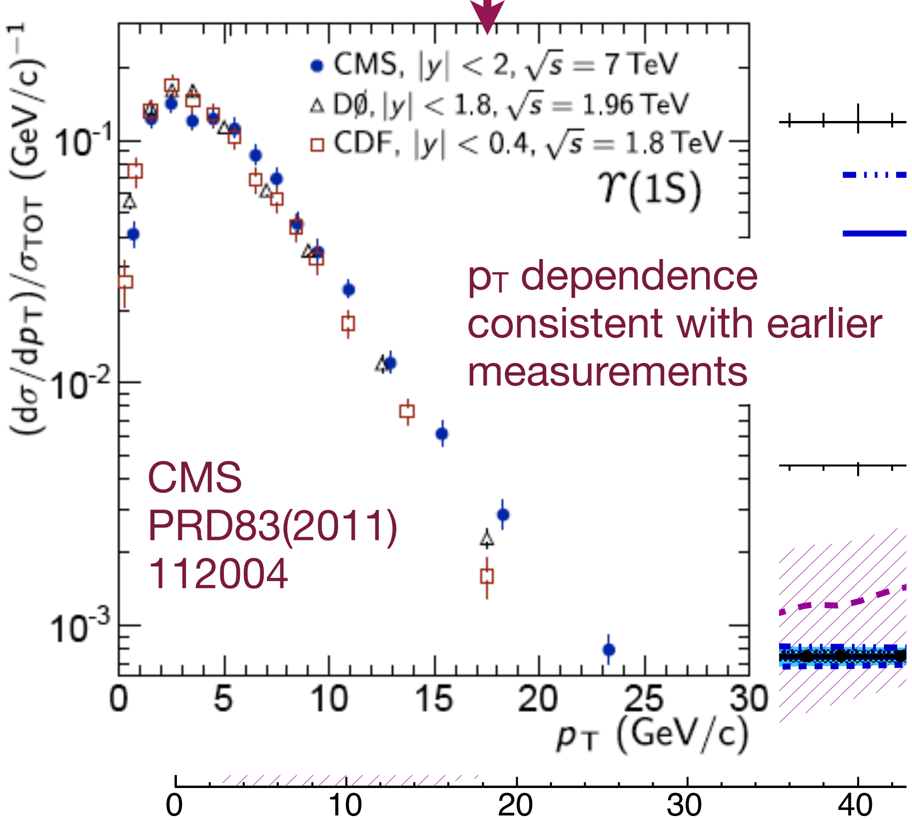


Integrated corrected cross sections	
State	$\sigma(pp \to \Upsilon) \times \mathrm{Br}(\Upsilon \to \mu^+\mu^-)$ Range: $p_T^{\Upsilon} < 70$ GeV, $\lvert y^{\Upsilon}\rvert < 2.25$
$\Upsilon(1S)$	$8.01 \pm 0.02 \pm 0.36 \pm 0.31$ nb
$\Upsilon(2S)$	$2.05 \pm 0.01 \pm 0.12 \pm 0.08$ nb
$\Upsilon(3S)$	$0.92 \pm 0.01 \pm 0.07 \pm 0.04$ nb

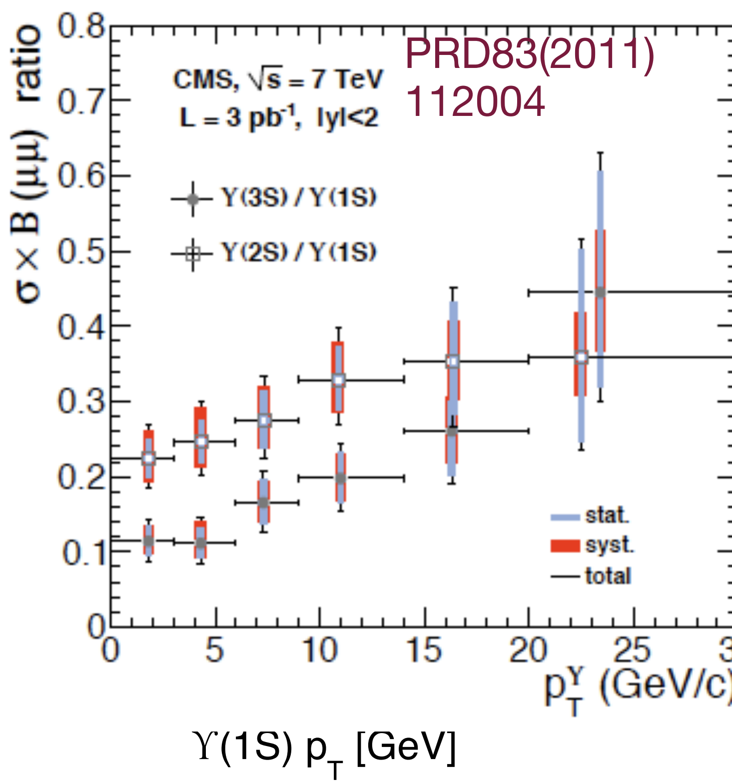
p_T total cross section in agreement with CMS

CMS PRD83(2011)112004

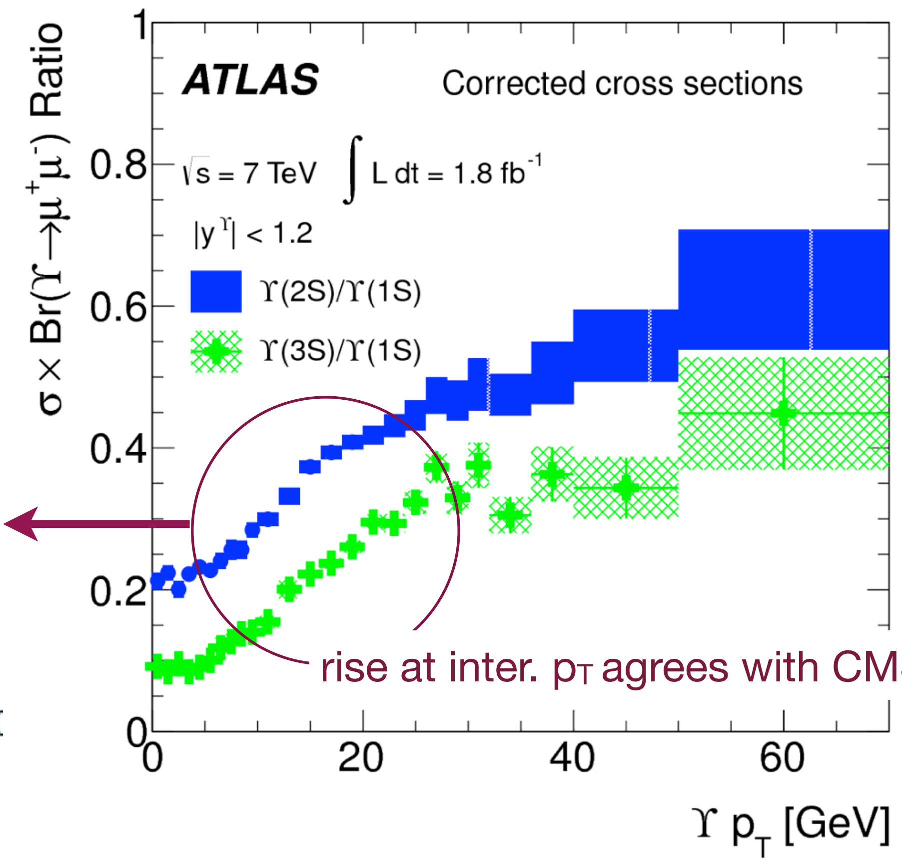
$$\sigma(pp \to \Upsilon(1S)X) \cdot \mathcal{B}(\Upsilon(1S) \to \mu^+\mu^-) = 7.37 \pm 0.13(\text{stat.})^{+0.61}_{-0.42}(\text{syst.}) \pm 0.81(\text{lumi.})\,\text{nb},$$
$$\sigma(pp \to \Upsilon(2S)X) \cdot \mathcal{B}(\Upsilon(2S) \to \mu^+\mu^-) = 1.90 \pm 0.09(\text{stat.})^{+0.20}_{-0.14}(\text{syst.}) \pm 0.24(\text{lumi.})\,\text{nb},$$
$$\sigma(pp \to \Upsilon(3S)X) \cdot \mathcal{B}(\Upsilon(3S) \to \mu^+\mu^-) = 1.02 \pm 0.07(\text{stat.})^{+0.11}_{-0.08}(\text{syst.}) \pm 0.11(\text{lumi.})\,\text{nb}.$$



p_T dependence consistent with earlier measurements



PRD83(2011) 112004



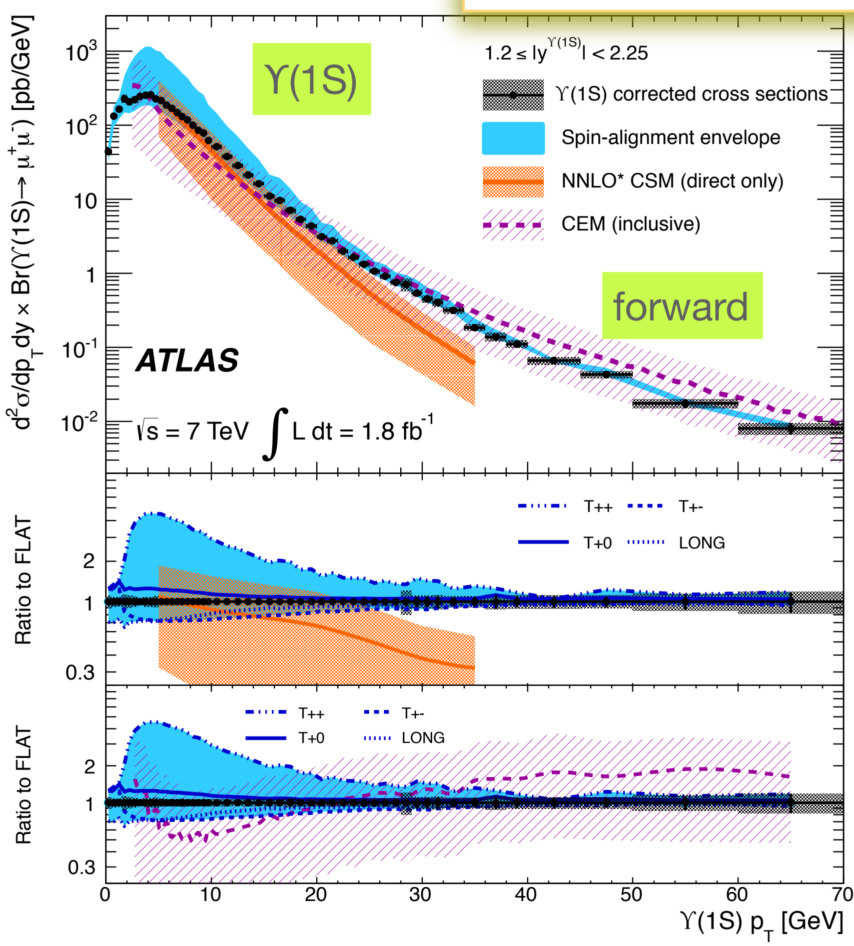
rise at inter. p_T agrees with CMS

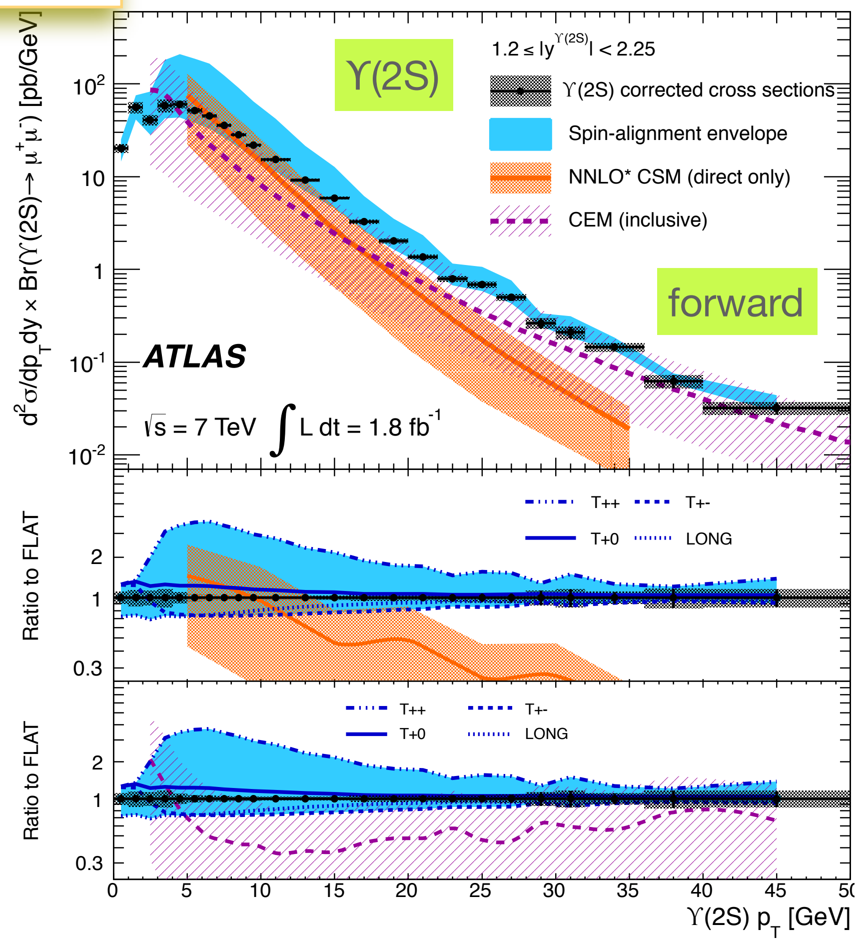
Υ(nS) differential production cross sections

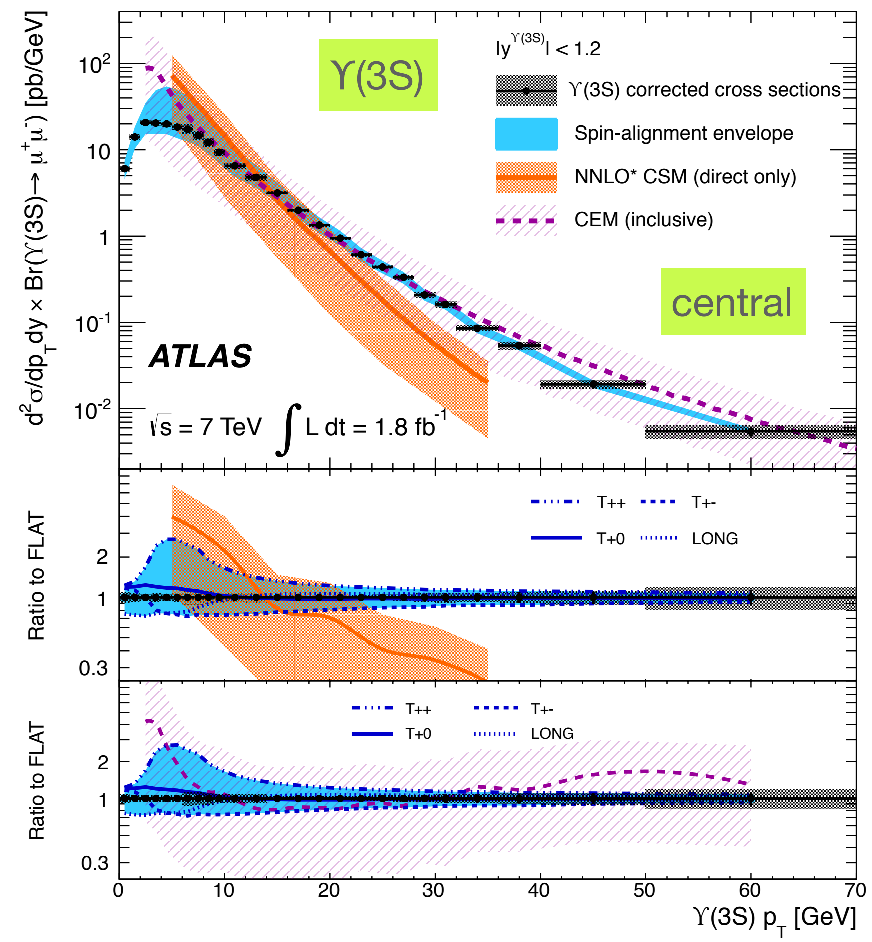
extra plots

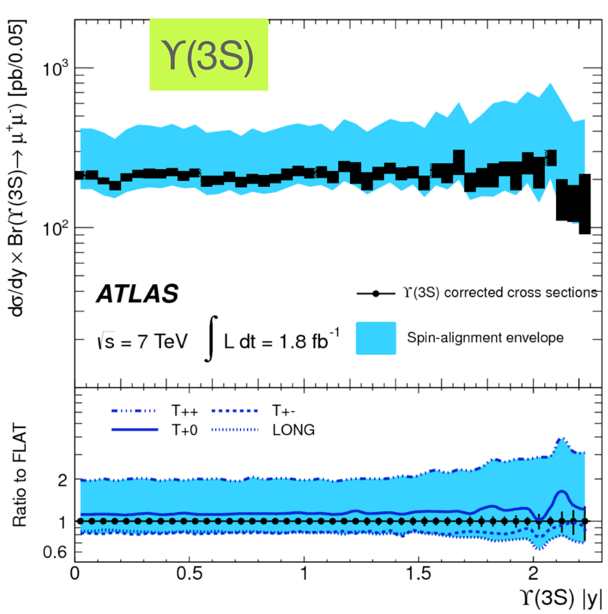
Fall 2012 ATLAS

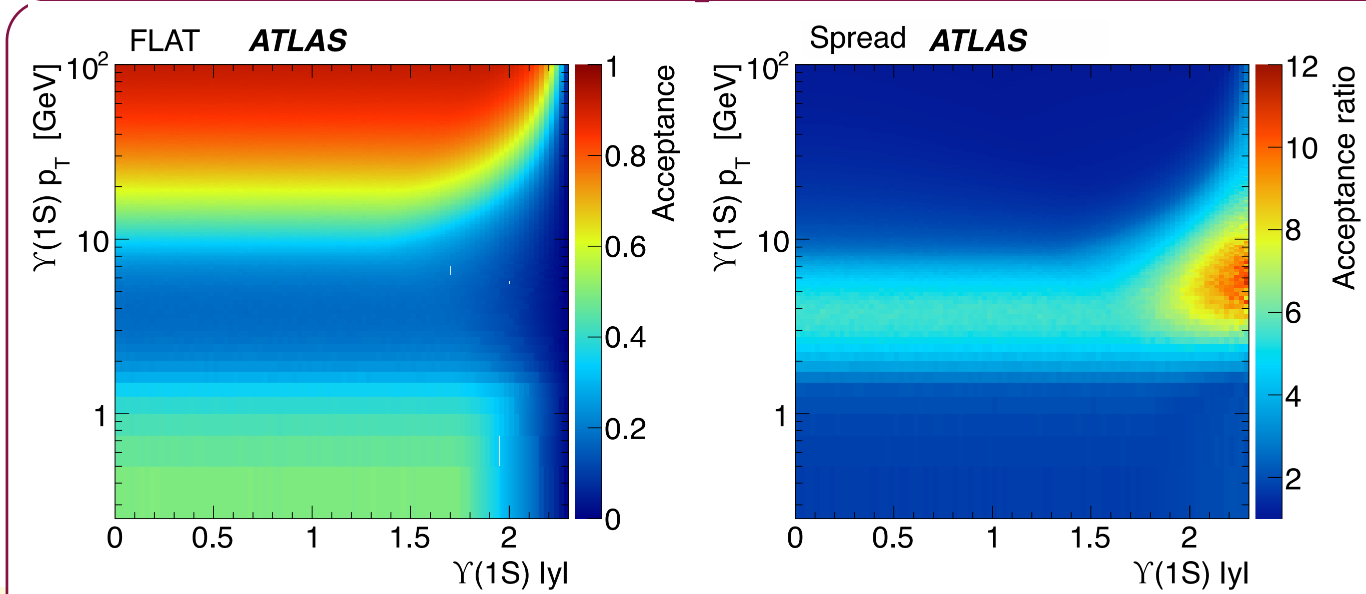
to appear in PRD arXiv:1211.7255









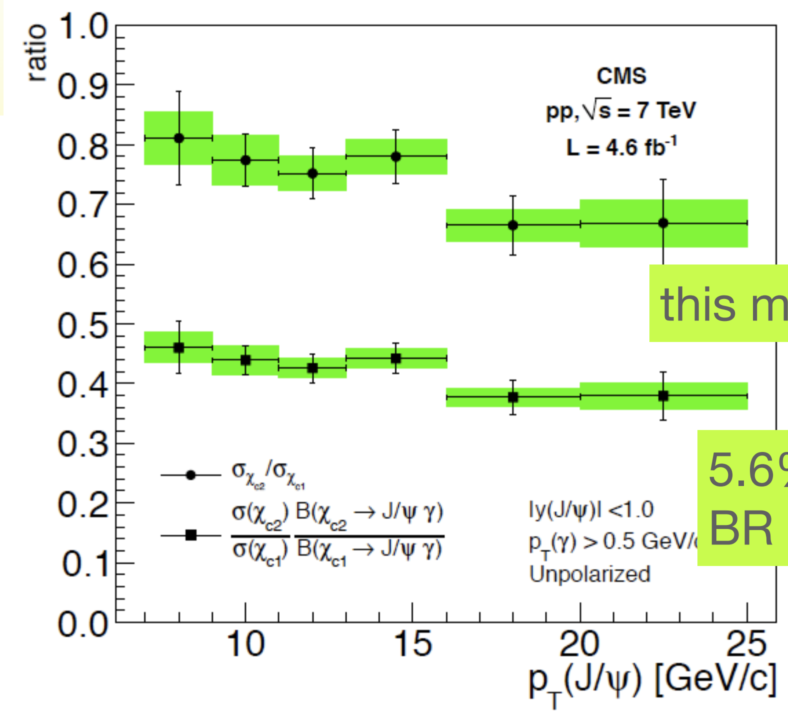


default acceptance map and ratio of max pol. variation to default

Relative prompt production rate of χ_{c2} and χ_{c1}

Winter 2013 CMS

to appear in EPJC arXiv:1210.0875



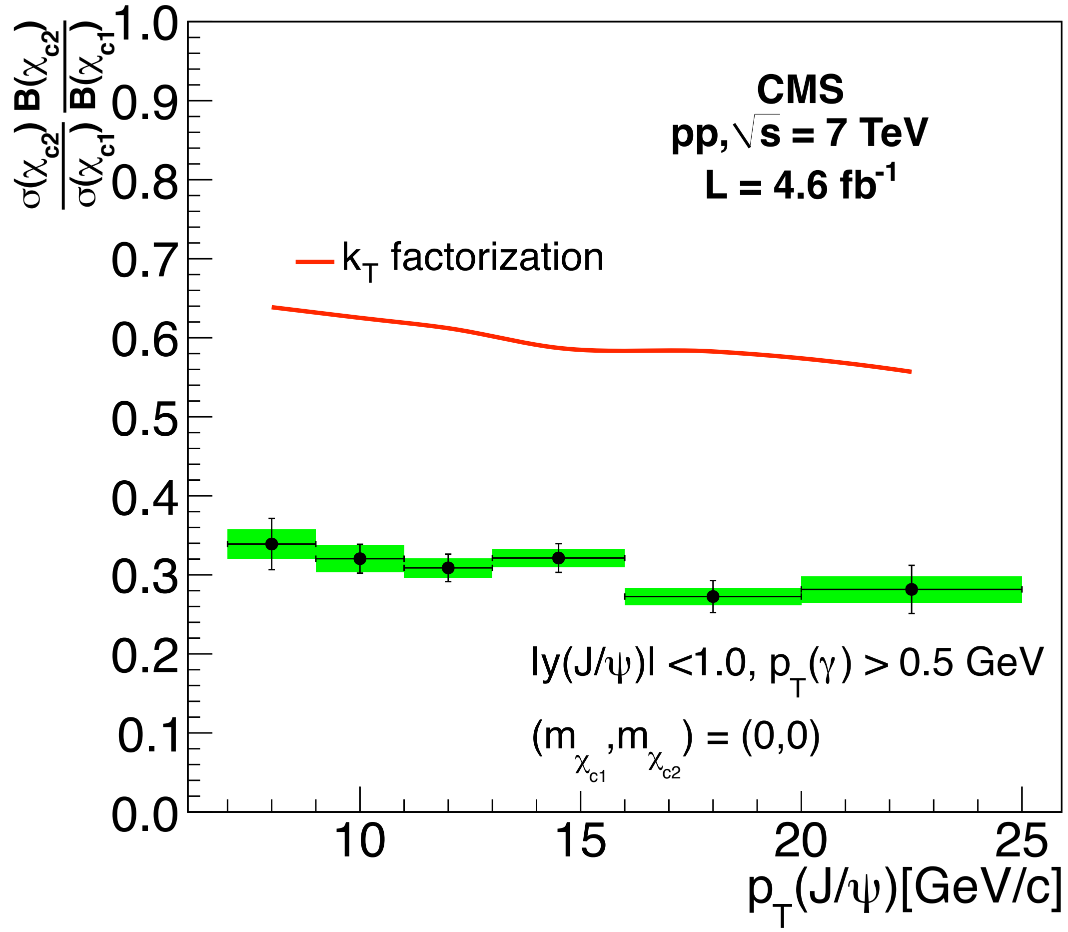
this measurement

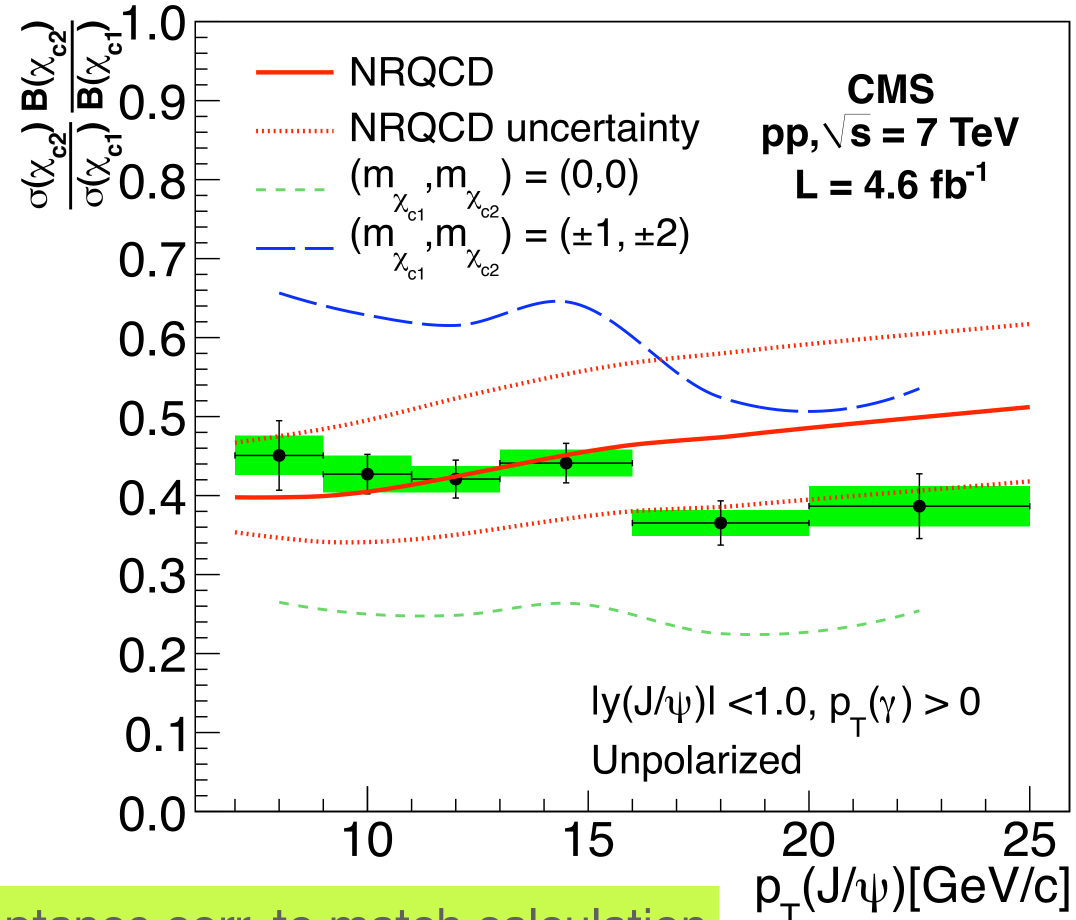
5.6% error from BR not included

k_T factorization
Phys. Rev. D 83 (2011) 034035

NRQCD
Phys. Rev. D 83 (2011) 111503

acceptance corr. applied for 0 helicity hyp. in kT fact.



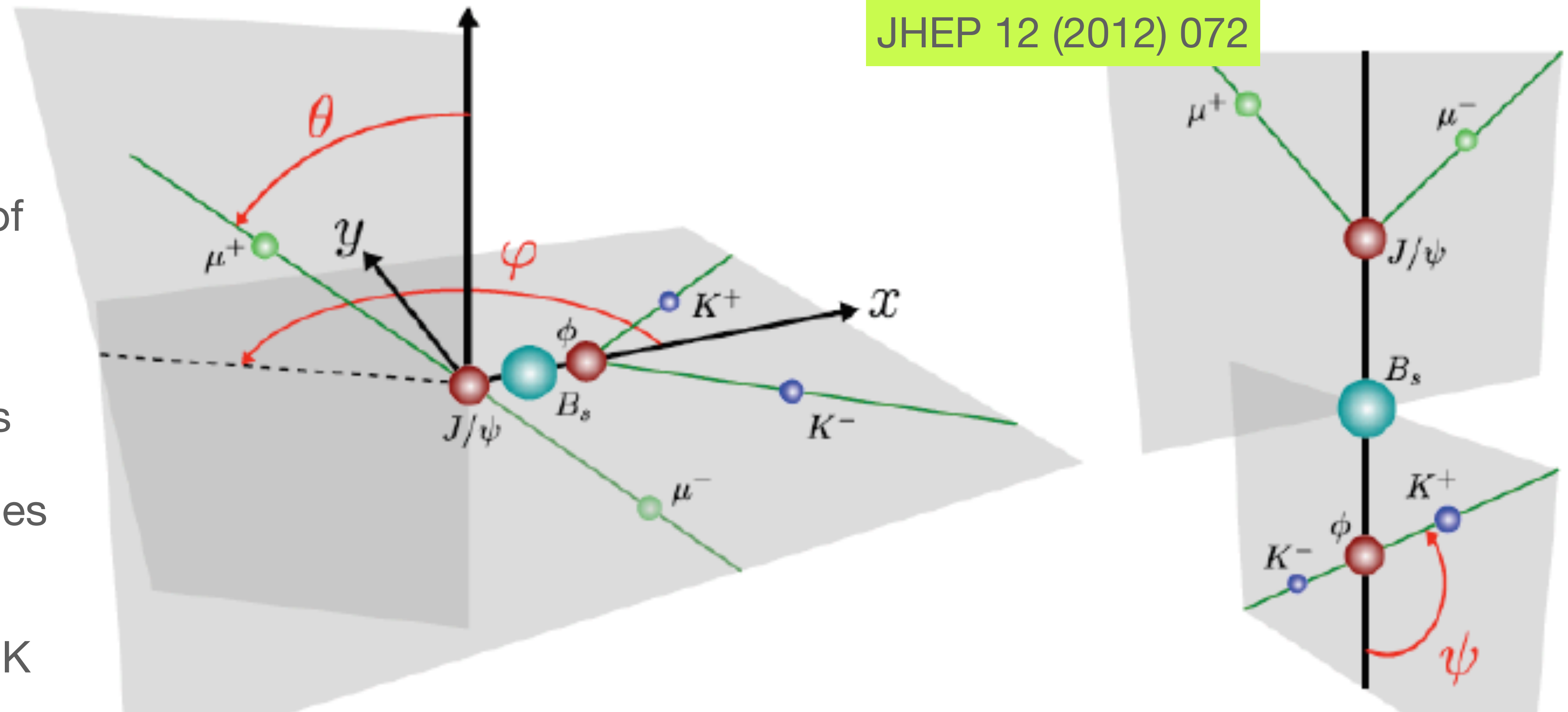


acceptance corr. to match calculation

CP-violating φ_s phase and $\Delta\Gamma_s$ from $B_s \to J/\psi\ \varphi$

Summer 2012 ATLAS

JHEP 12 (2012) 072



The transversity frame

- ***x axis***: defined by the direction of the φ in the J/ψ rest frame;
- ***y axis***: in the plane defined by K+K-, with $p_y(K^+)>0$; ***z axis*** follows
- **θ, φ** = polar and azimuthal angles of the μ+ in the J/ψ rest frame;
- **ψ** angle between the x axis and K+ in the φ rest frame

A0 and A|| correspond to final states with CP-even eigenvalues (L=0,2).
A⊥ corresponds to final states with CP-odd eigenvalue (L=1)

$$\mathcal{F}_s(m_i,t_i,\Omega_i) = P_s(m_i|\sigma_{m_i})\cdot P_s(\sigma_{m_i})\cdot P_s(\Omega_i,t_i|\sigma_{t_i})\cdot P_s(\sigma_{t_i})\cdot A(\Omega_i,p_{Ti})\cdot P_s(p_{Ti})$$

angular dependency

$$\frac{d^4\Gamma}{dt\,d\Omega} = \sum_{k=1}^{10} \mathcal{O}^{(k)}(t)\, g^{(k)}(\theta_T,\psi_T,\varphi_T)$$

signal PDF contains:
resolution terms,
acceptance term A,
PDF for the B0s pT
PDF for the angles and time dep. amplitudes

time-dep. amplitudes functions of $A_{||}$, A_0 and $A_\perp$ (**ignored** slightly diff. for B^0_s and anti-B^0_s);

CP-odd terms for Bs → J/ψK+K–(f0) included

Search for $D^0 \to \mu^+\mu^-$ in CMS

Summer 2012 CMS

CMS PAS BPH-11-017

- CMS preliminary result based on 90 pb^{-1} of data at $\sqrt{s}$=7TeV
- Search is restricted to D^0 from D^*+ decays; normalization channel: $D^0 \to K^- \mu^+ \nu$ (challenging reconstruction and triggering)

$$\frac{D^{*+} \to D^0(\mu^-\mu^+)\pi^+}{D^{*+} \to D^0(K^-\mu^+\nu)\pi^+}$$

  - SM predictions range 10^{-18} to 10^{-13}

Experiment	Upper Limit at 90% CL
BABAR	$< 1.3 \times 10^{-6}$
CDF	$< 2.1 \times 10^{-7}$
BELLE	$< 1.4 \times 10^{-7}$
CMS PAS BPH-11-017	$< 5.4 \times 10^{-7}$
LHCb	$<1.3 \times 10^{-8}$ (95% CL)