Latest results on b-physics from the ATLAS and CMS experiments

E. Pasqualucci (INFN Roma)
On behalf of the
ATLAS and CMS Collaborations

Latest ATLAS and CMS results

- Rare and semi-rare $B^0_{(s)}$ decays
  - ATLAS and CMS
  - $B^0_{(s)} \to \mu^+\mu^-$ and $B^0 \to K^*\mu^+\mu^-$
- Simmetry violation
  - New measurements from ATLAS:
    - Parity violation in $\Lambda_b \to \Lambda^0 J/\psi$ decay
    - CP violating parameters in $B_s \to J/\psi\ \phi$ (tagged)
- Quarkonia
  - Y(nS) cross section
    - ATLAS and CMS
  - Y and ψ polarization
    - CMS
  - *Search for exotic quarkonium states (in the Appendix)*
    - CMS
  - *Associated $W^\pm$ + prompt J/ψ production (in the Appendix)*
    - ATLAS

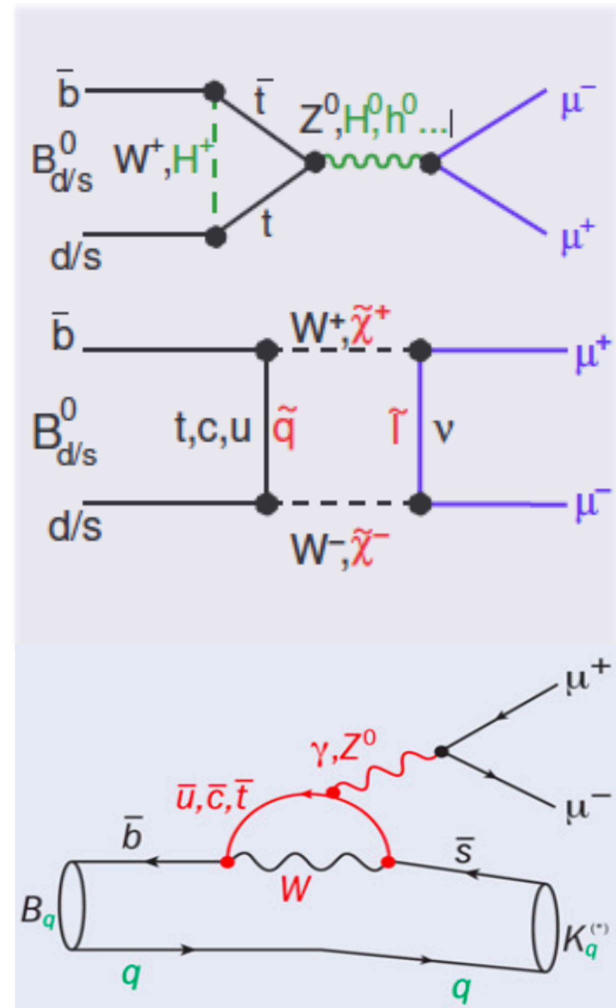
Rare decays: $B^0_{(s)} \to \mu^+\mu^-$ and $B^0 \to K^*\mu^+\mu^-$

- Motivation
  - Flavor changing neutral current
    - Forbidden at tree level
  - Sensitive to new physics
  - Precise SM predictions

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.57 \pm 0.30) \times 10^{-9}$$

$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.07 \pm 0.10) \times 10^{-10}$$

  - Exclusive processes
  - Experimentally accessible
- Measurements:
  - $B^0_{(s)} \to \mu^+\mu^-$
    - Branching ratio
  - $B^0 \to K^*\mu^+\mu^-$ (B.R. = $(1.06 \pm 0.1) \times 10^{-6}$)
    - Forward-backward asymmetry of muons
    - Longitudinal polarization of K*(892)



$B^0_{(s)} \to \mu^+\mu^-$

- Data set
  - 2011 data, 4.9 fb^{-1} @ 7 TeV (ATLAS)
    - Upper limit to $B^0_s \to \mu^+\mu^-$
  - 2011 and 2012 data (CMS, 2011 data re-blinded)
    - 5 fb^{-1} @ 7 TeV + 20 fb^{-1} @ 8 TeV
      - Average pileup ≈ 9 and ≈ 21
    - Measurement of $B^0_s \to \mu^+\mu^-$ and limit to $B^0 \to \mu^+\mu^-$
- Methodology
  - Measurement relative to normalization channel
    - $B^\pm \to J/\psi K^\pm \to \mu^+\mu^- K^\pm$
    - (Nearly) identical data selection
    - Reduce systematic uncertainties

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = \frac{n^{\rm obs}_{B^0_s}}{\varepsilon_{B^0_s} N_{B^0_s}} = \frac{n^{\rm obs}_{B^0_s}}{\varepsilon_{B^0_s} \mathcal{L}\, \sigma(pp \to B^0_s)}$$

$$= \frac{n^{\rm obs}_{B^0_s}}{N(B^\pm \to J/\psi K^\pm)} \frac{A_{B+}}{A_{B^0_s}} \frac{\varepsilon^{ana}_{B+}}{\varepsilon^{ana}_{B^0_s}} \frac{\varepsilon^{\mu}_{B+}}{\varepsilon^{\mu}_{B^0_s}} \frac{\varepsilon^{trig}_{B+}}{\varepsilon^{trig}_{B^0_s}} \frac{f_u}{f_s} \mathcal{B}(B^+ \to J/\psi\,[\mu^+\mu^-]K)$$

LHCb

Phys. Rev. Lett. 110 (2013)

$R_{A\varepsilon}$ (from MC)

$B^0_{(s)} \to \mu^+\mu^-$ results

- Analysis via BDT
- ATLAS
  - 6 events after un-blinding

$\mathcal{B}(B^0_s \to \mu^+\mu^-)$ **$< 1.5 \times 10^{-8}$ (95% C.L.)**

- CMS
  - From the BDT categorized analysis

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.0^{+1.0}_{-0.9}) \times 10^{-9}$$

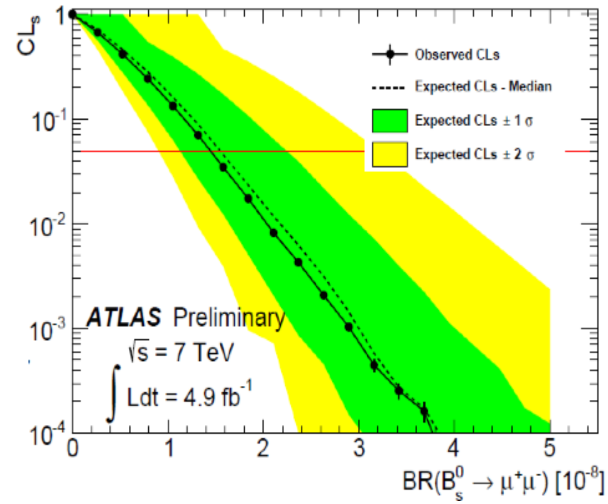
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (3.5^{+2.1}_{-1.8}) \times 10^{-10}$$

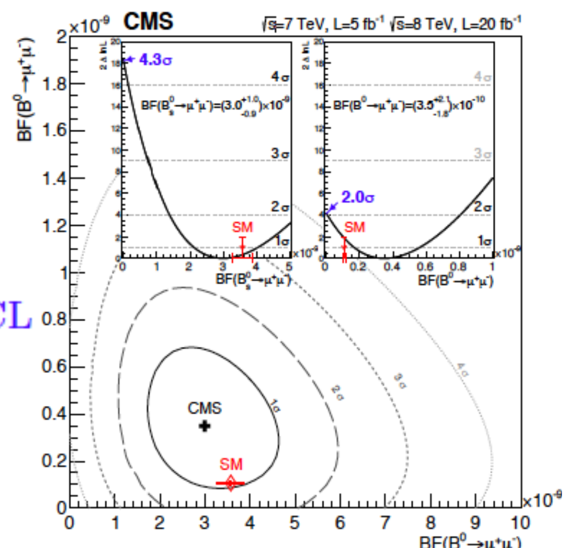
  - Significance
    - $B^0_s \to \mu^+\mu^-$: 4.3 σ
    - $B^0 \to \mu^+\mu^-$: 2.0 σ
  - Upper limit on $B^0 \to \mu^+\mu^-$

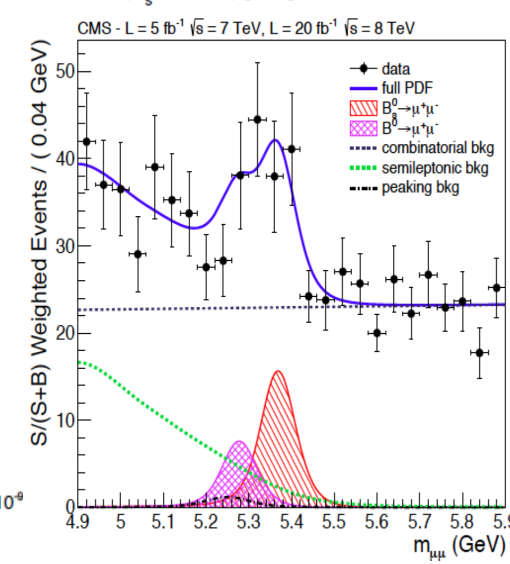
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.1 \times 10^{-9} \quad 95\%\text{CL}$$

  - Comparable to LHCb results

ArXiv:1307.5024v1

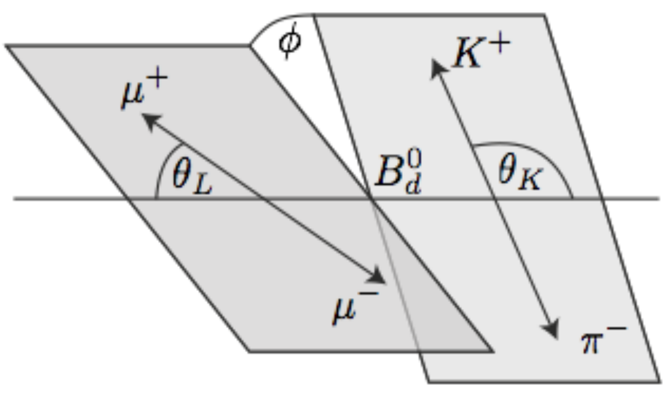


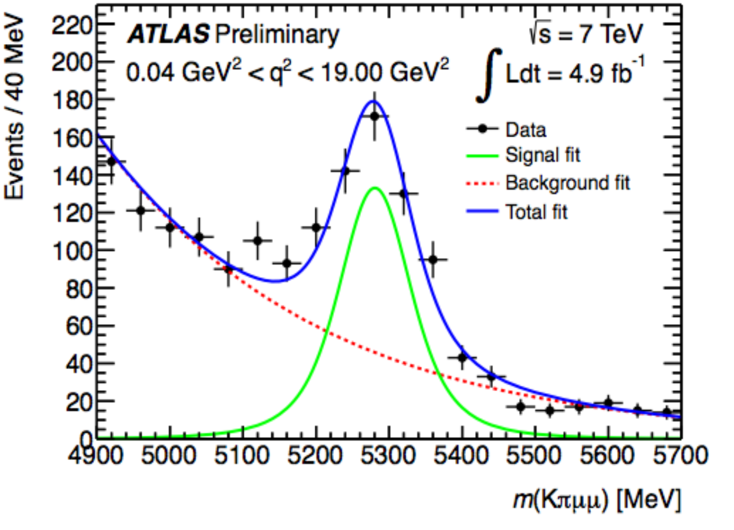




$B^0 \rightarrow K^{*0}\mu^+\mu^-$

- Full 2011 data set
  - Both experiments
- Process described by 4 kinematic variables
  - q^2
  - 3 angles (ϕ, θ_K, θ_L)
- A_{FB} and F_L studied in bins of q^2 ($M_{\mu\mu}$)





$B^0 \to K^{*0}\mu^+\mu^-$

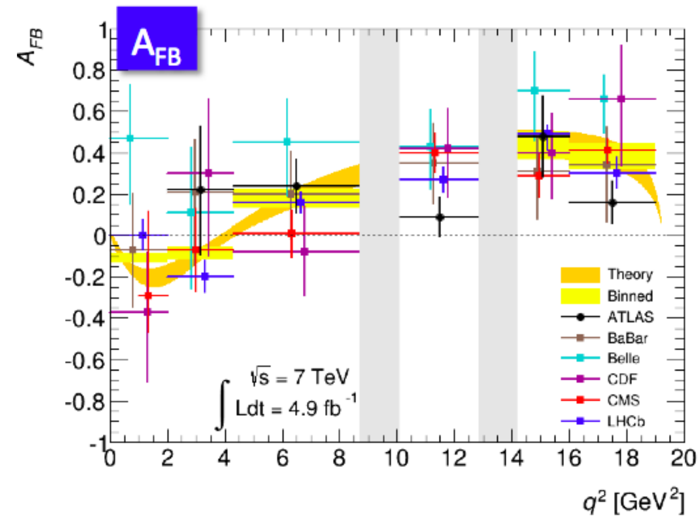
- Differential decay rate

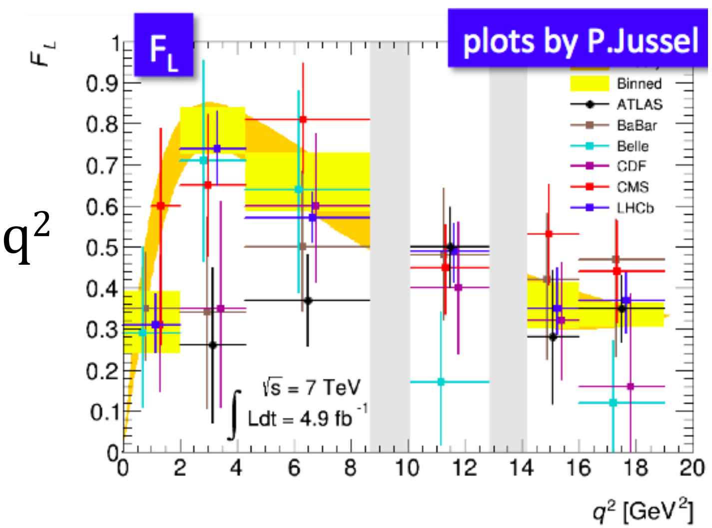
$$\frac{1}{\Gamma}\frac{d^2\Gamma}{dq^2 d\cos\theta_L} = \frac{3}{4}F_L(q^2)\left(1-\cos^2\theta_L\right) + \frac{3}{8}\left(1-F_L(q^2)\right)\left(1+\cos^2\theta_L\right) + A_{FB}(q^2)\cos\theta_L$$

$$\frac{1}{\Gamma}\frac{d^2\Gamma}{dq^2 d\cos\theta_K} = \frac{3}{2}F_L(q^2)\cos^2\theta_K + \frac{3}{4}\left(1-F_L(q^2)\right)\left(1-\cos^2\theta_K\right).$$

$$\begin{aligned}\text{p.d.f.}(m,\cos\theta_K,\cos\theta_l) = {} & Y_S\, S(m)\cdot S(\cos\theta_K,\cos\theta_l)\cdot\epsilon(\cos\theta_K,\cos\theta_l) \\ & + Y_B^c\, B^c(m)\cdot B^c(\cos\theta_K)\cdot B^c(\cos\theta_l) \\ & + Y_B^p\, B^p(m)\cdot B^p(\cos\theta_K)\cdot B^p(\cos\theta_l).\end{aligned}$$

- Uncertainties
  - Statistically dominated
  - Larger uncertainties in ATLAS at low q^2
    - Due to HLT cuts
- Measurements consistent with SM
  - Analysis ongoing on 2012 data set



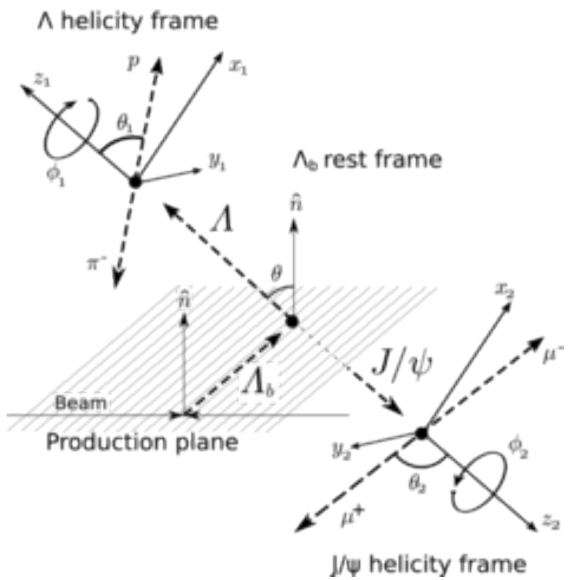


Λ_b properties

Amplitude	λ_Λ	$\lambda_{J/\psi}$
a_+	+½	0
a_-	-½	0
b_+	-½	-1
b_-	+½	+1

- Use decay $\Lambda_b \to J/\psi(\mu^+\mu^-)\Lambda^0(p\pi^-)$ to measure:
  - Λ_b mass and lifetime Phys. Rev. D87 (2013) (ATLAS) arXiv:1304.7495 (CMS)
  - Parity violating asymmetry parameter α_b (ATLAS)
  - CMS measured Phys. Lett. B714 (2012)
    - Differential Λ_b production cross section and $\sigma(\overline{\Lambda}_b)$ / $\sigma(\Lambda_b)$ (1.9 fb-1)
- 2011 data set (7 TeV, 4.6 fb^{-1}) used
- Decay described by 4 helicity amplitudes
  - $|a_+|^2 + |a_-|^2 + |b_+|^2 + |b_-|^2 = 1$
  - $\alpha_b = |a_+|^2 - |a_-|^2 + |b_+|^2 - |b_-|^2$
- Full angular PDF

$$W(\vec{\Omega},\vec{A},P) = \frac{1}{(4\pi)^3}\sum_{i=0}^{19} f_{1i}(\vec{A}) f_{2i}(P\alpha_\Lambda) F_i(\vec{\Omega})$$



α_b measurement

- Fit result

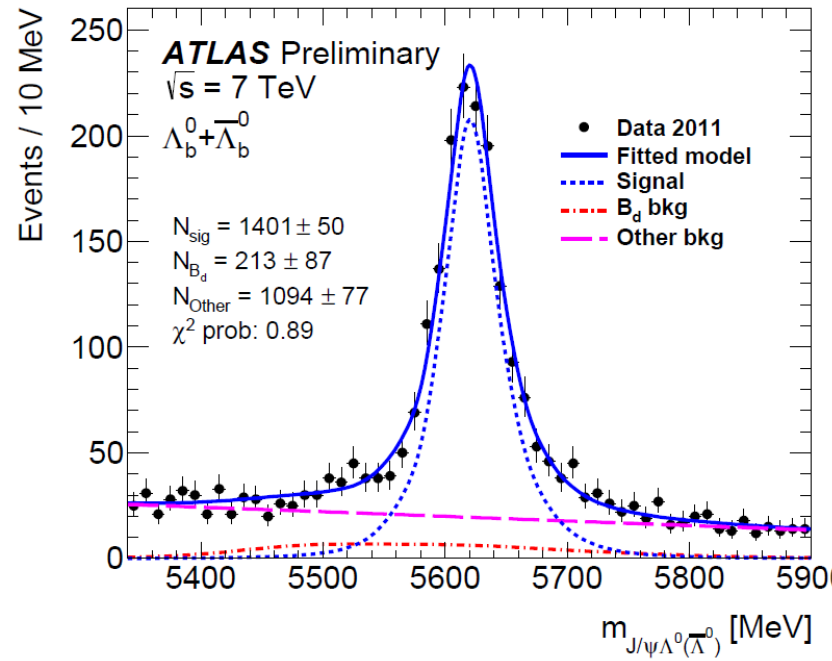
$\alpha_b = 0.28 \pm 0.16 \pm 0.06$

$|a_+| = 0.17^{+0.12}_{-0.17}$ (stat.) $\pm$ 0.06 (syst.)

$||a_-| = 0.59^{+0.06}_{-0.07}$ (stat.) $\pm$ 0.04(syst.)

$|b_+| = 0.78^{+0.04}_{-0.05}$ (stat.) $\pm$ 0.02 (syst),

$|b_-| = 0.08^{+0.13}_{-0.08}$ (stat.) $\pm$ 0.05 (syst.)



- Main results:
  - Λ^0 and J/ψ highly polarized in the direction of their momenta
  - Large $|a_-|$ and $|b_+| \rightarrow$ negative-helicity states for Λ^0 preferred
  - α_b value consistent with LHCb: 0.05 ± 0.17 (stat.) ± 0.07 (syst.)
  - Intermediate between pQCD and HQET predictions: Phys. Lett. B724 (2013)
    - ~2.5 σ w.r.t. pQCD –(0.14 ~ 0.18) Chou et al., Phys. Rev. D65 (2002)
    - ~2.9 σ w.r.t. HQET (0.78) Leitner et al., Nucl. Phys. A755 (2005) Ajaltouni et al., Phys. Lett. B614 (2005)

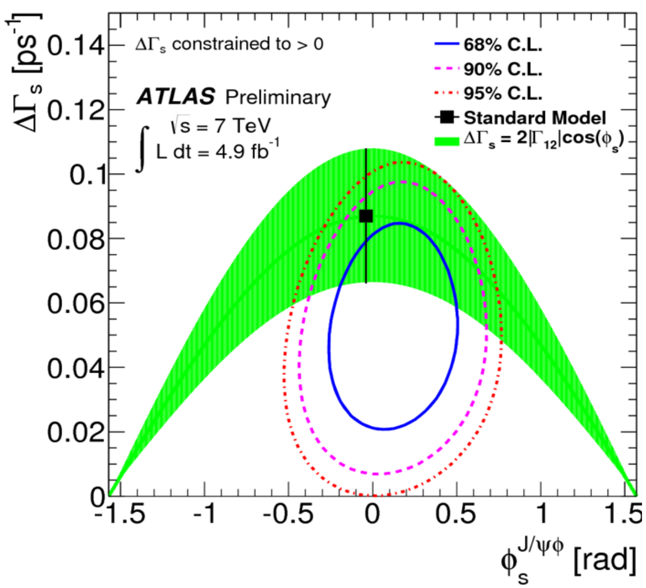
$B_s \to J/\psi\ \phi$

- New ATLAS measurement Updates JHEP 1212 (2012)
  - Full 2011 data set
- CP violation parameter
  - ϕ_s
    - Phase difference between B_s-$\bar{B}_s$ mixing amplitude and $b \to c\bar{c}s$ decay amplitude
    - Directly connected to CKM matrix elements
      - $\phi_s \simeq -2\ \beta_s$; $\beta_s = \arg\left[-(V_{ts}V_{tb}^*)/(V_{cs}V_{cb}^*)\right]$
      - $\phi_s \simeq -2\ \beta_s = -0.0368 \pm 0.0018$ (SM)
  - $\Delta\Gamma_s$
    - $(\Gamma_L - \Gamma_H)$ of B_L and B_H
- Flavor tagging used to distinguish initial B_s and $\bar{B}_s$ states
- CP states separated statistically through
  - Decay time-dependence $\tau = \frac{L_{xy}\, M_{B_s}}{p_{t_B}}$
- Angular correlations amongst final state particles

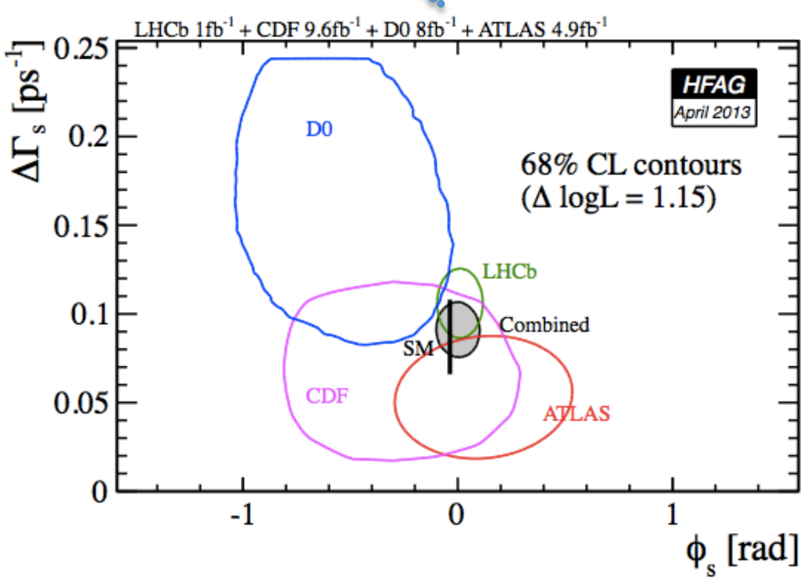
$B_s \to J/\psi\ \phi$

- ~22000 candidate B_s selected
- Uncertainty improved by 40%
  - with respect to untagged analysis
- Uncertainty statistically dominated
  - 2012 data analysis ongoing

$$\phi_s = 0.12 \pm 0.25\ \text{(stat.)} \pm 0.11\ \text{(syst.) rad}$$
$$\Delta\Gamma_s = 0.053 \pm 0.021\ \text{(stat.)} \pm 0.009\ \text{(syst.) ps}^{-1}$$
$$\Gamma_s = 0.677 \pm 0.007\ \text{(stat.)} \pm 0.003\ \text{(syst.) ps}^{-1}$$
$$|A_0(0)|^2 = 0.529 \pm 0.006 \text{(stat.)} \pm 0.011\ \text{(syst.)}$$
$$|A_\parallel(0)|^2 = 0.220 \pm 0.008 \text{(stat.)} \pm 0.009\ \text{(syst.)}$$
$$\delta_\perp = 3.89 \pm 0.46\ \text{(stat.)} \pm\ 0.13\ \text{(syst.) rad}$$



Preliminary and unofficial



Quarkonia

- Motivations
  - Production mechanism not well understood
    - Inconsistencies between data and predictions on production and polarization
    - Input by production and polarization measurements, double quarkonia associated production
    - Theory and measurements made complex by feed-down
      - Indirect measurement : ratios as function of kinematic variables
- Recent measurements
  - ATLAS measurements
    - $d\sigma/dp_T$ for Υ(nS) up to 70 GeV (1.8 fb^{-1} @ 7 TeV) Phys. Rev. D87, 052004 (2013)
    - *Associated $W^{\pm}$ and J/ψ production (2011 data set)*
  - CMS measurements (full 2011 data set)
    - $d\sigma/dp_T$ for Υ(nS) up to 100 GeV
    - Prompt quarkonium polarization
    - *Search for new exotic bottomonium states*

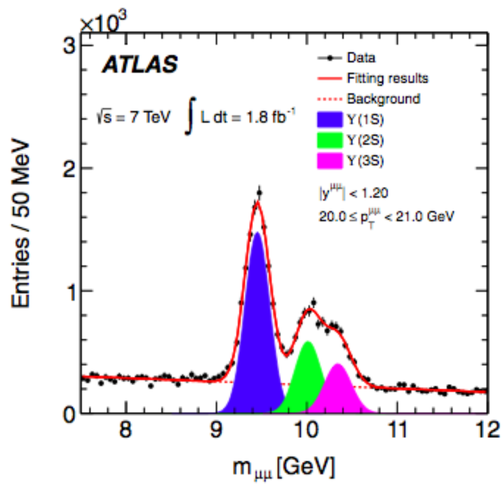
Y(nS) production

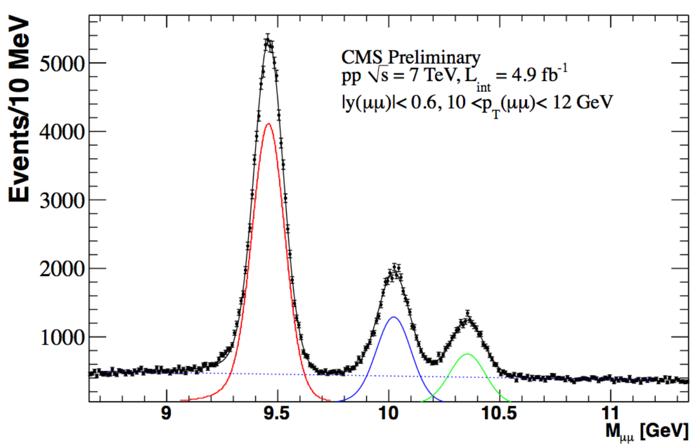
- Differential cross section for a given |y| interval

$$\frac{d\sigma(pp \to \Upsilon(nS))}{dp_T} \times \mathcal{B}(\Upsilon(nS) \to \mu^+\mu^-) = \frac{N^{fit}_{\Upsilon(nS)}(p_T)}{L_{int} \cdot \Delta p_T \cdot \varepsilon(p_T) \cdot \mathcal{A}(p_T)}$$

Depends on spin alignment,
i.e. angular distribution of muons.
Averaged in the measurement

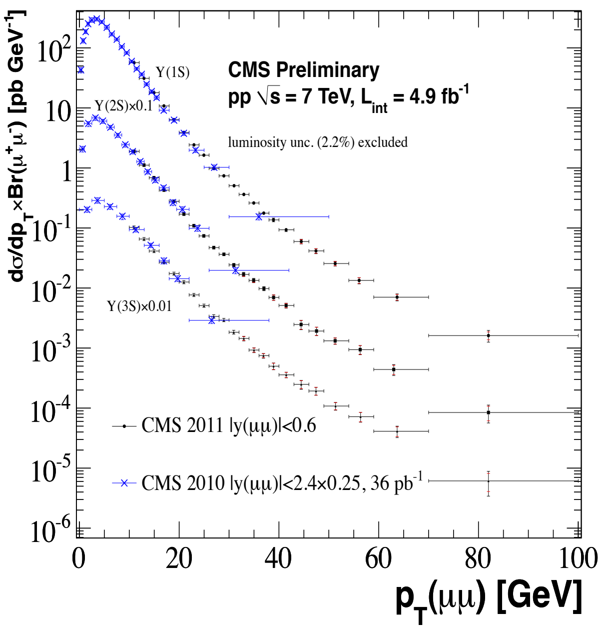
- Yield
  - Obtained by re-fit of the $M_{\mu\mu}$ plot in a given (|y|, p_T) bin

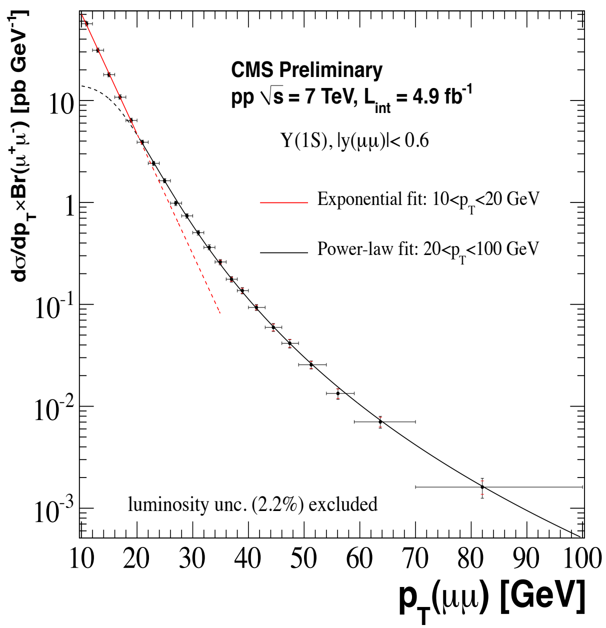


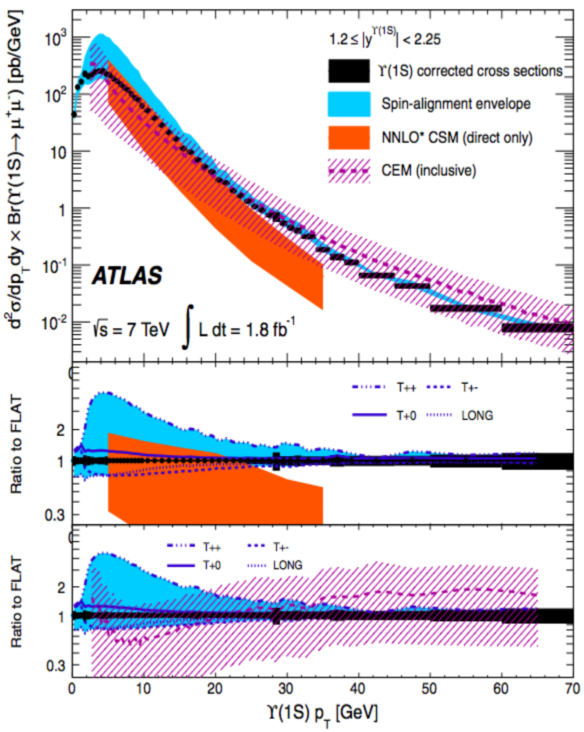


Υ(nS) production

- Similar behavior for all three states
  - Change of slope for $p_T > 20$ GeV

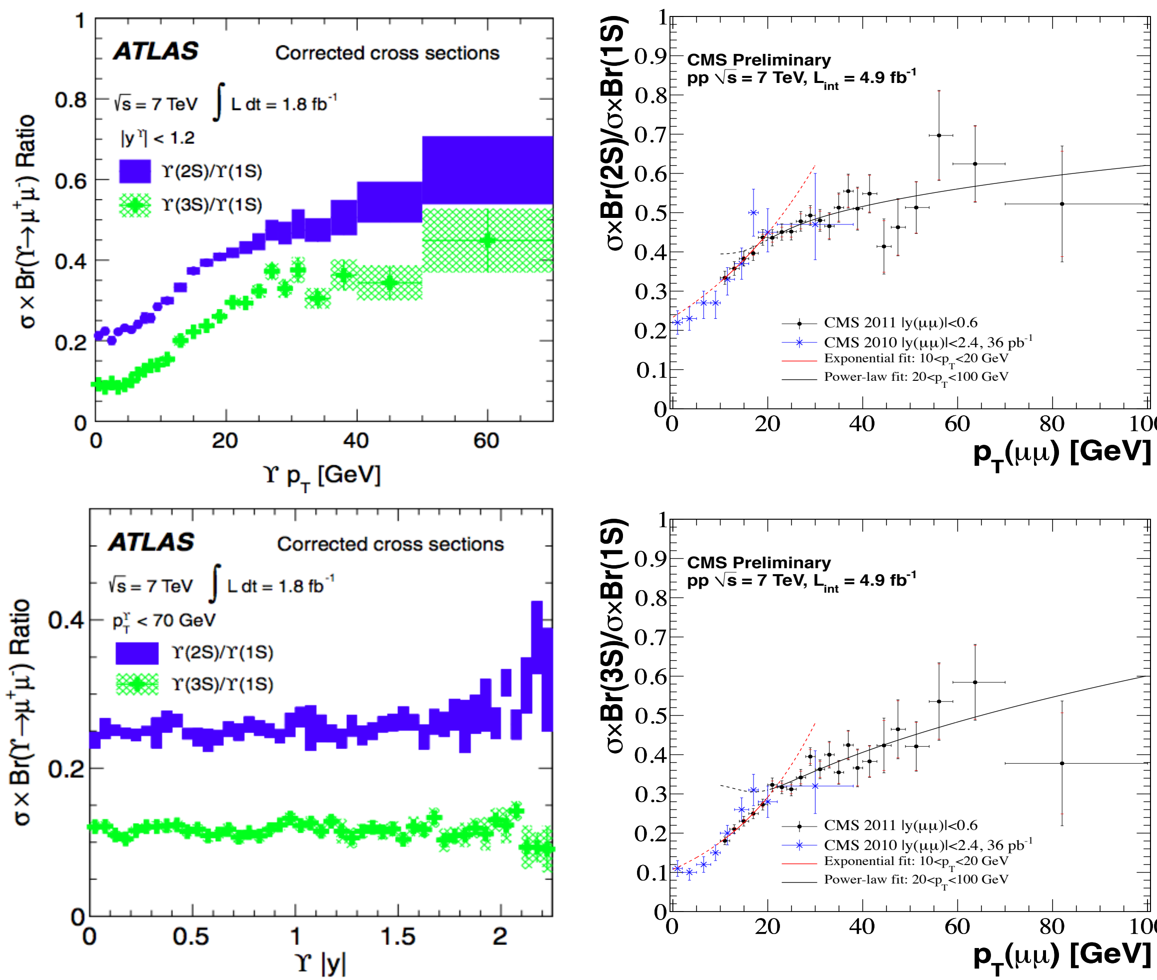






Υ(nS) production ratios

- Common features
  - Almost flat on |y|
  - Change of slope
    - p_T > 20-24 GeV
    - Change in production mechanism?



Quarkonium polarization (CMS)

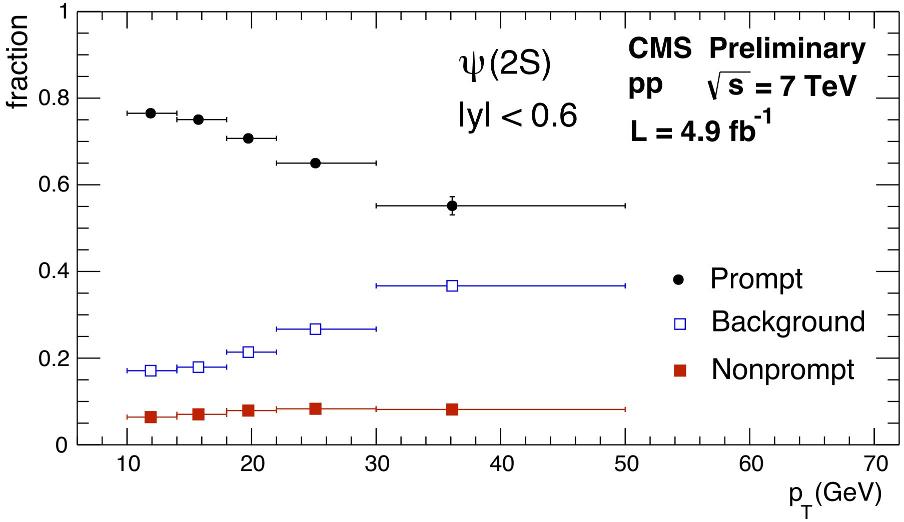
- S-wave quarkonia @ high p_T
  - Predicted transversely polarized
- Studied through the angular distribution of μ from decay
  - In 3 polarization frames

$$W(\cos\vartheta, \varphi|\vec{\lambda}) = \frac{3/(4\pi)}{(3+\lambda_\vartheta)}(1+\lambda_\vartheta\cos^2\vartheta + \lambda_\varphi\sin^2\vartheta\cos 2\varphi + \lambda_{\vartheta\varphi}\sin 2\vartheta\cos\varphi)$$

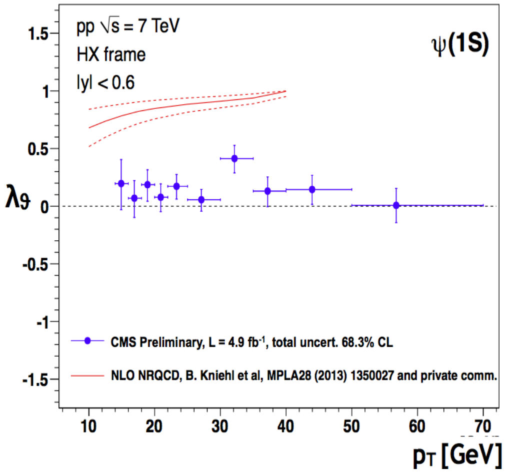
$\tilde{\lambda} = (\lambda_\vartheta + 3\lambda_\varphi)/(1-\lambda_\varphi)$ Frame invariant, characterizes the shape of the distribution

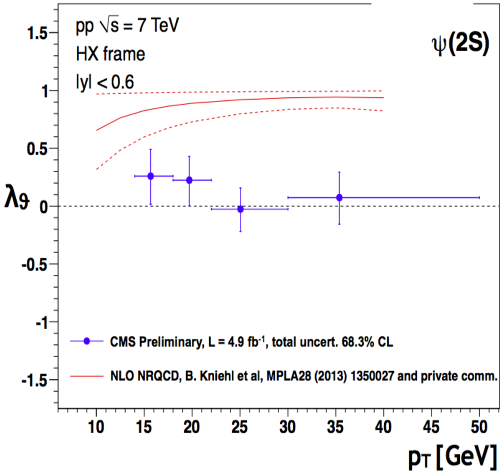
- Measurement as a function of p_T and |y|
  - Υ(nS): 10 GeV < p_T < 50 GeV (5 bins), |y| < 1.2 (2 bins) PLR 110, 081802 (2013)
  - J/ψ: 14 GeV < p_T < 70 GeV (10 bins), |y| < 1.2 (2 bins)
  - ψ(2S): 14 GeV < p_T < 50 GeV (4 bins), |y| < 1.5 (3 bins)

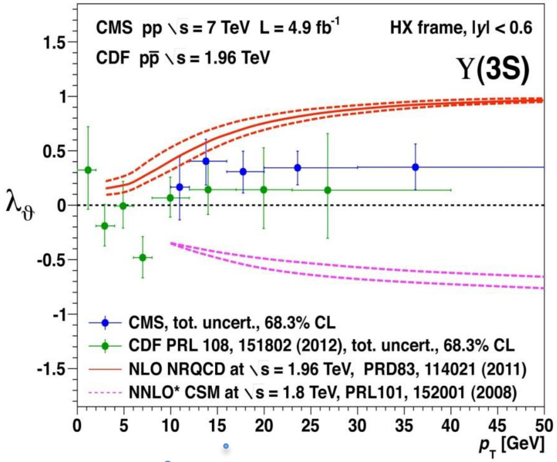
ψ(nS) comparison to NRQCD



- ψ(2S) not affected by feed-down
- Non-prompt component to be taken into account
- No sign of strong polarization
  - Color octet calculation shown in the plots
  - NNLO* Color singlet model
    - < -0.5 @ pt > 10 GeV







Compiled by V. Kartvelishvili (HCP2012)

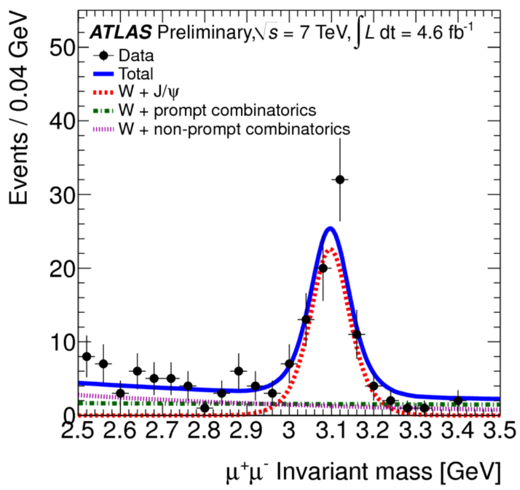
Summary

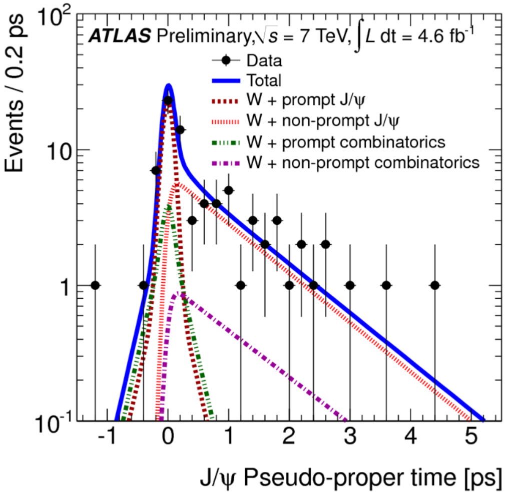
- New interesting results from ATLAS and CMS on
  - Rare B decays
    - $B_s \to \mu^+\mu^-$ measurement
      - ATLAS analyzed 2011 data → new upper limit
      - CMS used the full 2011 and 2012 data set → measurement
    - New results on $B^0 \to K^*\mu^+\mu^-$ from ATLAS (2011 data set)
    - Results are consistent with SM
  - Parity violation in Λ_b decay
    - Results are intermediate between model predictions (ATLAS)
  - CP parity violation parameters in $B_s \to J/\psi\ \phi$
    - Results in agreement with the standard model
  - Quarkonia
    - Differential cross section for Y(nS) production
    - Prompt quarkonium polarization
      - ψ(2s) exhibits no sign of strong polarization (CMS)
    - *Associated $W^\pm$ and J/ψ production*
      - *First ATLAS measurement, shows discrepancies with predictions*
    - *Search for new exotic X_b bottomonium state*
      - *No evidence for a new X_b state up to now (CMS, 2012 data set)*
- Further measurements expected with 2012 full data set

Appendix

$W^{\pm}$ + prompt J/ψ measurement

- Search for associated production of
  - W (→μν) and prompt J/ψ (μμ)
- Probes quarkonium production mechanism
- Sensitive to multiple parton interactions
- ATLAS, 4.6 fb^{-1} @ 7 TeV (first observation)
- Event selection
  - Events triggered on W muon
  - W identified via μ + missing transverse energy
  - Prompt J/ψ via mass and pseudo-proper time
- ~29 $W^{\pm}$ + prompt J/ψ events observed
  - Background-only hypothesis rejected at 5.3 σ level





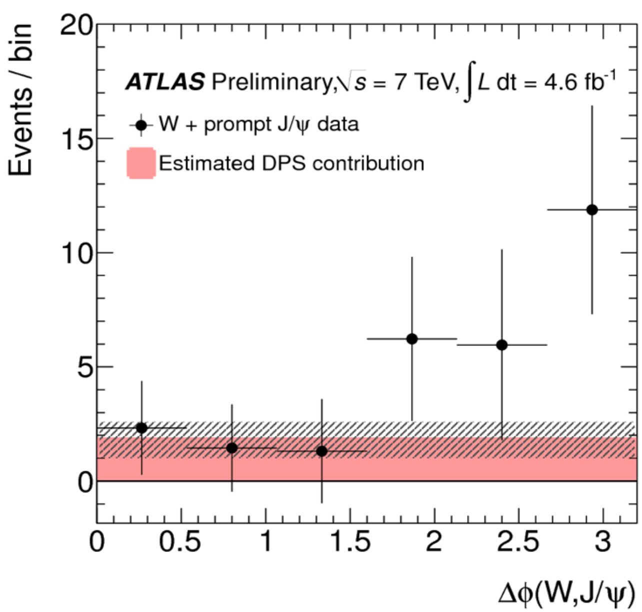
$W^{\pm}$ + prompt J/ψ measurement

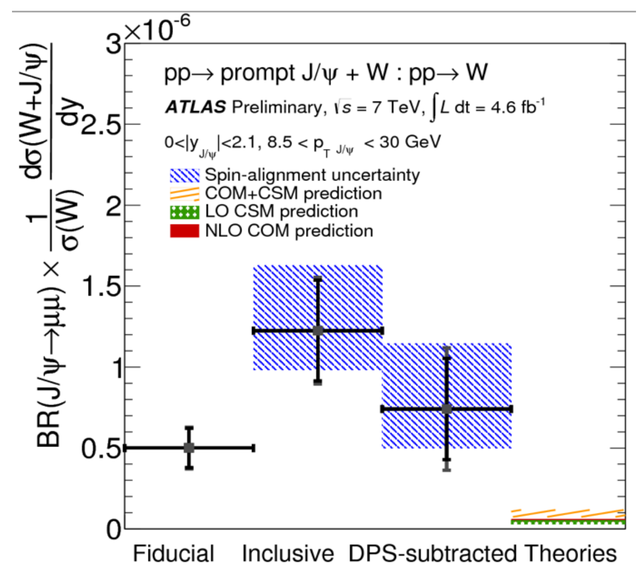
- Double parton scattering contribution
  - Probability parametrized as $P_{J/\psi|W} = \sigma_{J/\psi}/\sigma_{eff}$

From ATLAS W + 2 jets

From ATLAS prompt J/ψ

  - Total yield estimated 10.8 ± 4.2 events (~40%)
  - DPS contribution expected flat in Δϕ between W and J/ψ
    - Under the assumption of independent interactions



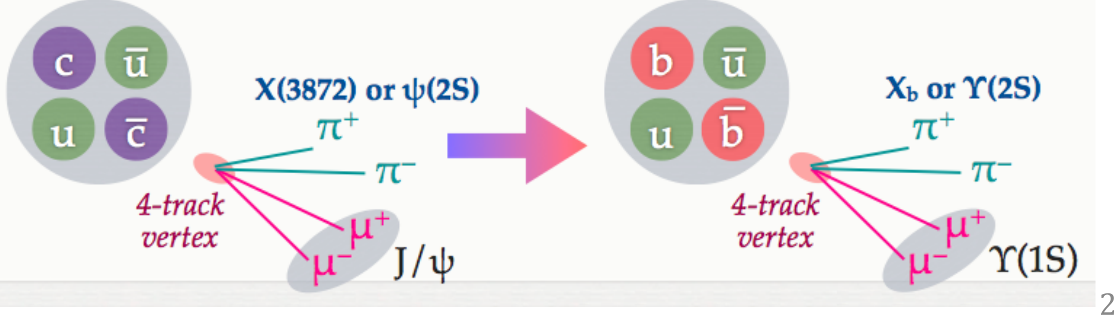


Exotic quarkonium states

- The discovery of the first exotic charmonium state X(3872) in 2003 has renewed the interests in the hadron spectroscopy
- Several new states found, however:
  - Unconventional states are mostly seen in charmonium system
  - Few candidates in bottom/strange sector
  - Theoretical picture unclear
    - What is the nature of these states?
  - More experimental inputs needed
    - Property measurements
    - Extended searches
- Large statistics provided by LHC
  - > 12000 X(3872) candidates seen by CMS

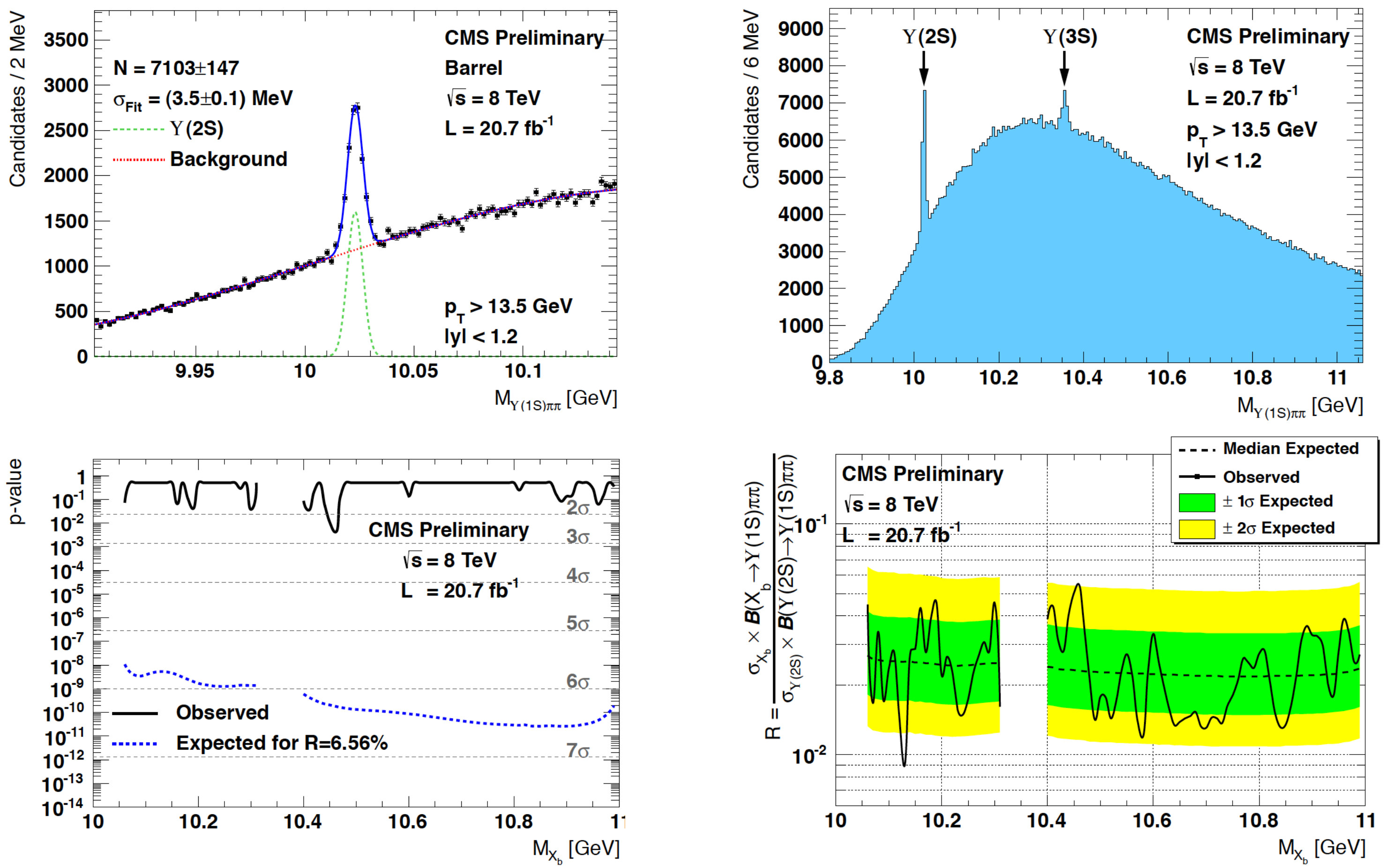
Search for X_b

- Search for X_b based on full CMS 2012 data
  - 20.7 fb^{-1} @ 8 TeV
  - Look for narrow resonance in $Y(1S)\pi^+\pi^-$ final state
    - Presumably between 10 to 11 GeV
    - Around B*B threshold
  - Candidates from Belle
    - Y_b (1086) → $Y\pi^+\pi^-$
    - Z_b (10610), Z_b (10650) → $Y\pi^\pm$



Search for X_b

- $\Upsilon(2s) \rightarrow \Upsilon(1s)\pi\pi$ as reference channel
- No evidence for a X_b state
  - B.R. upper limit set as a function of mass



Backup

$B^0_{(s)} \to \mu^+\mu^-$

- Data set
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    - Upper limit to $B^0_s \to \mu^+\mu^-$
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- Methodology
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    - (Nearly) identical data selection
    - Reduce systematic uncertainties

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = \frac{n^{\rm obs}_{B^0_s}}{\varepsilon_{B^0_s} N_{B^0_s}} = \frac{n^{\rm obs}_{B^0_s}}{\varepsilon_{B^0_s} \mathcal{L}\, \sigma(pp \to B^0_s)}$$

$$= \frac{n^{\rm obs}_{B^0_s}}{N(B^\pm \to J/\psi\, K^\pm)} \frac{A_{B+}}{A_{B^0_s}} \frac{\varepsilon^{ana}_{B+}}{\varepsilon^{ana}_{B^0_s}} \frac{\varepsilon^{\mu}_{B+}}{\varepsilon^{\mu}_{B^0_s}} \frac{\varepsilon^{trig}_{B+}}{\varepsilon^{trig}_{B^0_s}} \frac{f_u}{f_s} \mathcal{B}(B^+ \to J/\psi\,[\mu^+\mu^-]K)$$

LHCb (→ f_u/f_s)

Phys. Rev. Lett. 110 (2013)

$R_{A\varepsilon}$ (from MC)

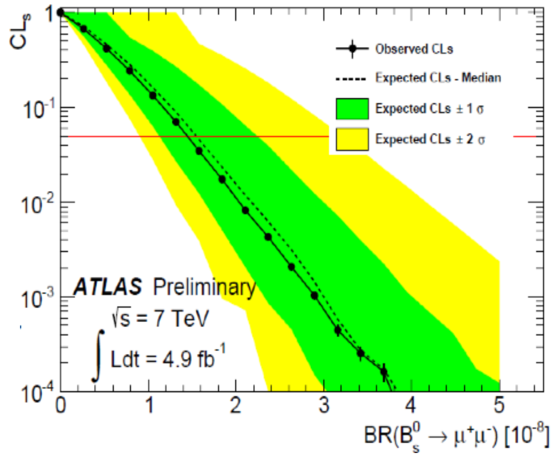
$B^0_{(s)} \rightarrow \mu^+\mu^-$

- Data selection
  - Trigger
    - 2 muons used for level 1 trigger
    - HLT slightly different
      - Two muons from common vertex with opposite charge
      - Loose cut on invariant mass for B and J/ψ
  - Data analysis
    - Blind analysis after simple pre-selection
    - Control sample used to validate MC simulation
      - $B^0_s \rightarrow J/\psi\ \phi \rightarrow \mu^+\mu^- K^+K^-$
    - Use of Multi-Variate Analysis (BDT) to
      - Refine muon identification (CMS)
        - » Muon misidentification probability $\sim 10^{-3}$ for p, π and K
      - Distinguish signal from combinatorial background
        - » Trained on MC simulated signal and sidebands events for the background

$B^0_{(s)} \to \mu^+\mu^-$ results

- Analysis via BDT
  - Independent from pileup
- ATLAS
  - 6 events after un-blinding
  - 6.75 estimated background

    $\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 1.5 \times 10^{-8}$ (95% C.L.)



- CMS
  - From the BDT categorized approach

    $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.0^{+1.0}_{-0.9}) \times 10^{-9}$

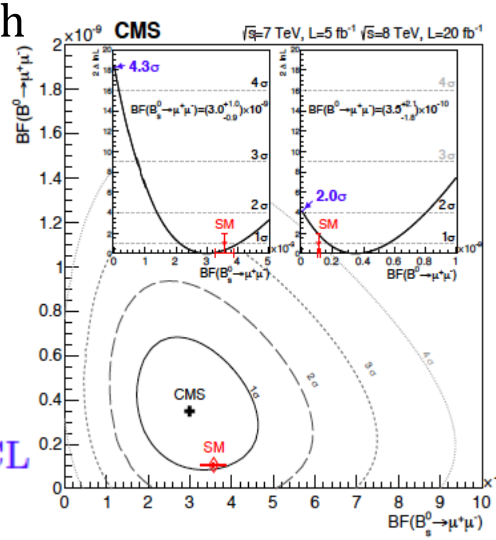
    $\mathcal{B}(B^0 \to \mu^+\mu^-) = (3.5^{+2.1}_{-1.8}) \times 10^{-10}$

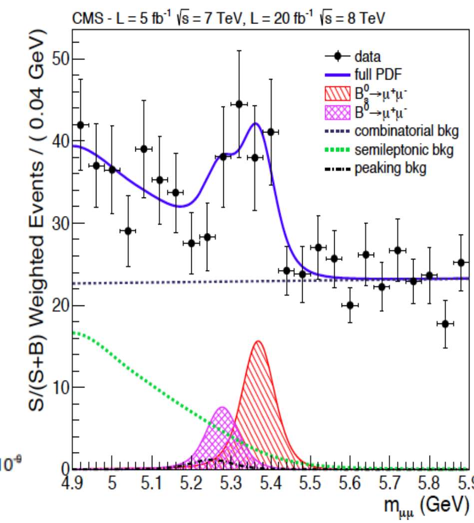
  - Significance
    - $B^0_s \to \mu^+\mu^-$: 4.3 σ
    - $B^0 \to \mu^+\mu^-$: 2.0 σ
  - Upper limit on $B^0 \to \mu^+\mu^-$

    $\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.1 \times 10^{-9}$ 95%CL

  - Comparable to LHCb results

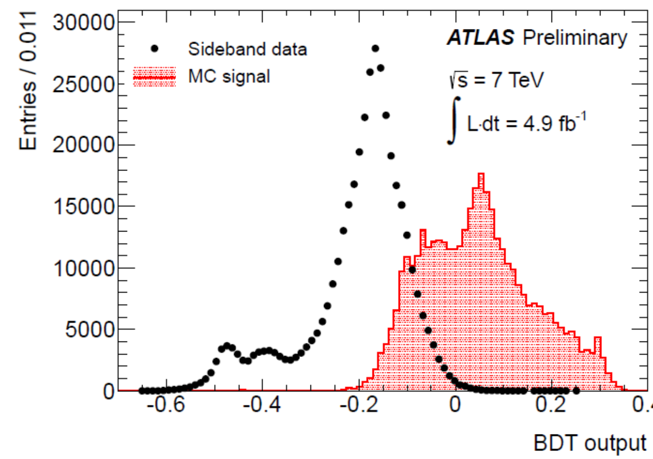
ArXiv:1307.5024v1

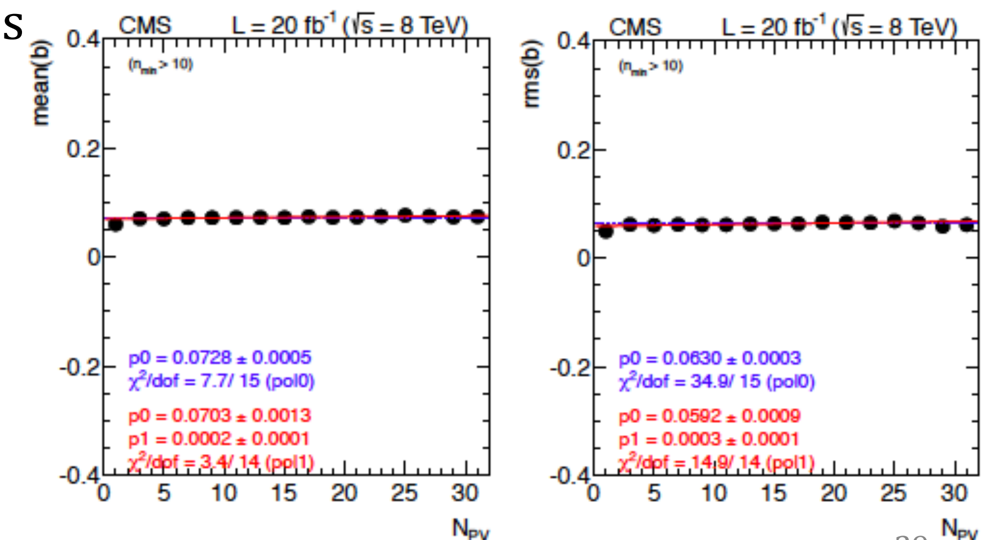




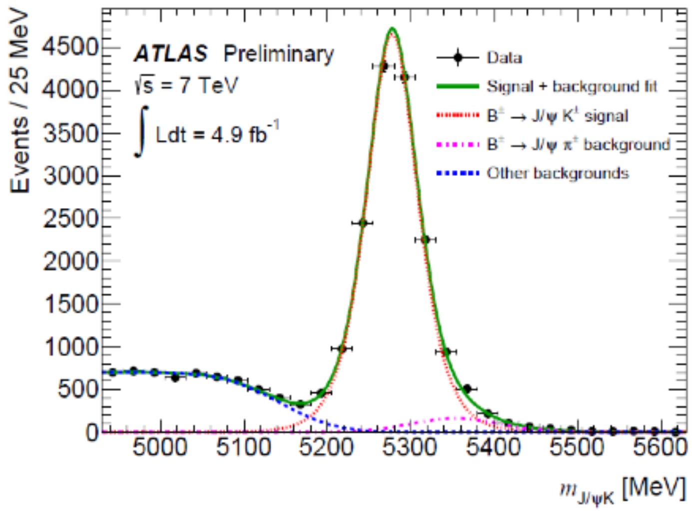
$B^0_{(s)} \rightarrow \mu^+\mu^-$

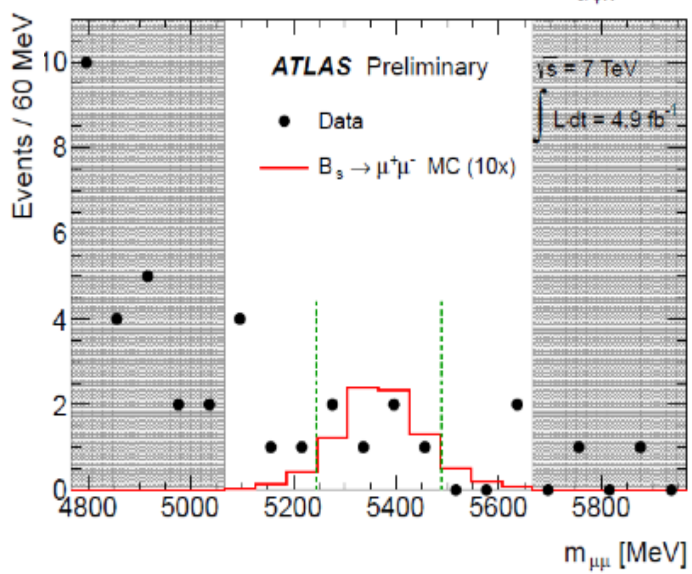
- Background sources
  - Combinatorial
  - Semi-leptonic B decays
  - Peaking background
- BDT method
  - Optimized cut on discriminant for upper limits
  - Categorized analysis for measurement
  - Pileup independence checked
- Likelihood fit to extract the yields
- Main uncertainties from:
  - $R_{A\varepsilon}$
  - f_s/f_u
  - BR of reference channel
  - μ misidentification
  - PDF shapes





$B^0_{(s)} \rightarrow \mu^+\mu^-$ (ATLAS)





- $R_{A\varepsilon}$
  - Evaluated from MC

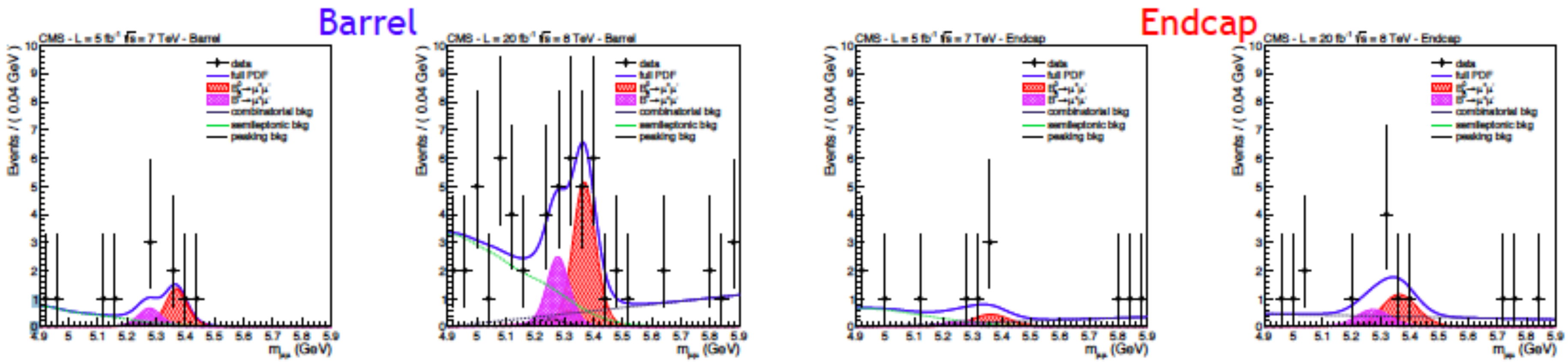
$$R_{A\epsilon} = 0.267 \pm 1.8\%(\text{stat.}) \pm 6.9\%(\text{syst.})$$

- Yield for reference channel
  - Even-# events

$$N_{J/\psi K^{\pm}} = 15\,214 \text{ even-no. events } \pm 1.1\%(\text{stat.}) \pm 2.4\%(\text{syst.})$$

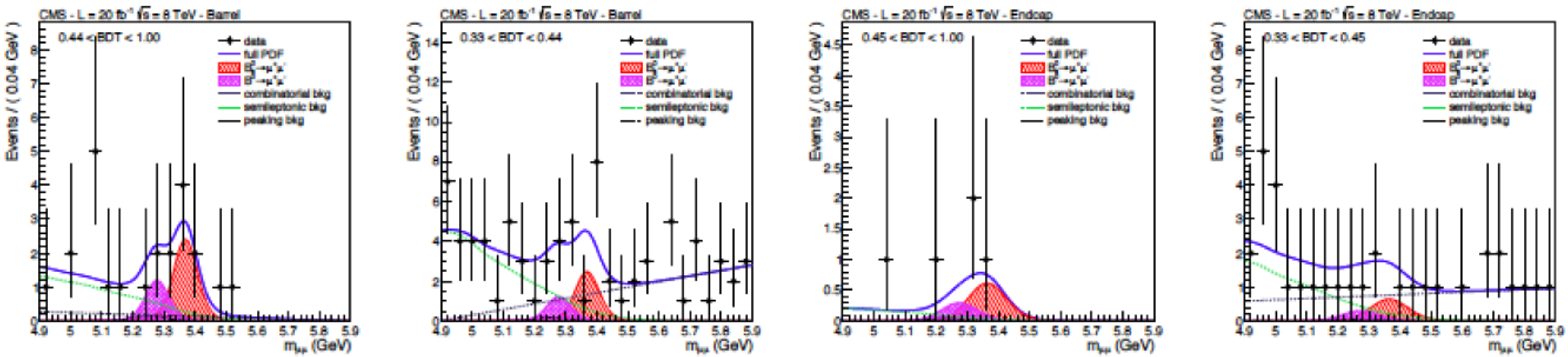
- Un-blinded mass region
  - 6 event observed after un-blinding
  - Estimate background from SB: 6.75

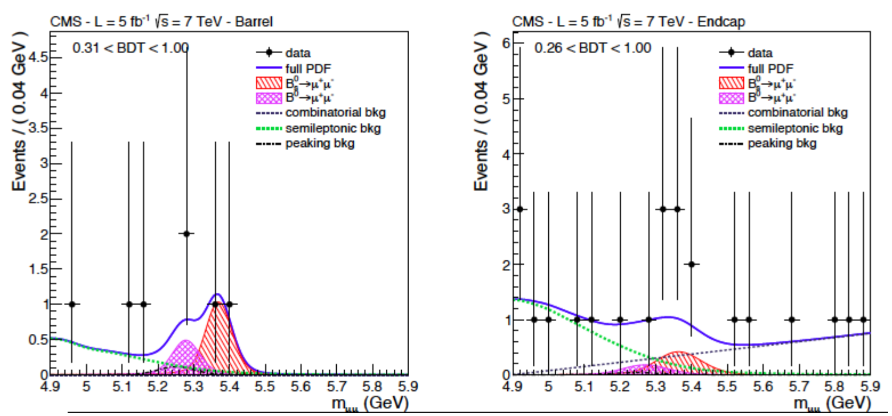
CMS 1D approach



CMS categorized approach

Highest and 2nd highest S/B categories for (barrel, endcap) x (2011, 2012)





- Signal candidate distributions
  - Consistent with expectations
    - Kinematic variables
    - Vertexing variables

$B^0 \to K^{*0}\mu^+\mu^-$

- Dependence of decay rates from kinematical variables
  - Keeps into account possible contribution from spin-less $K^+\pi^-$

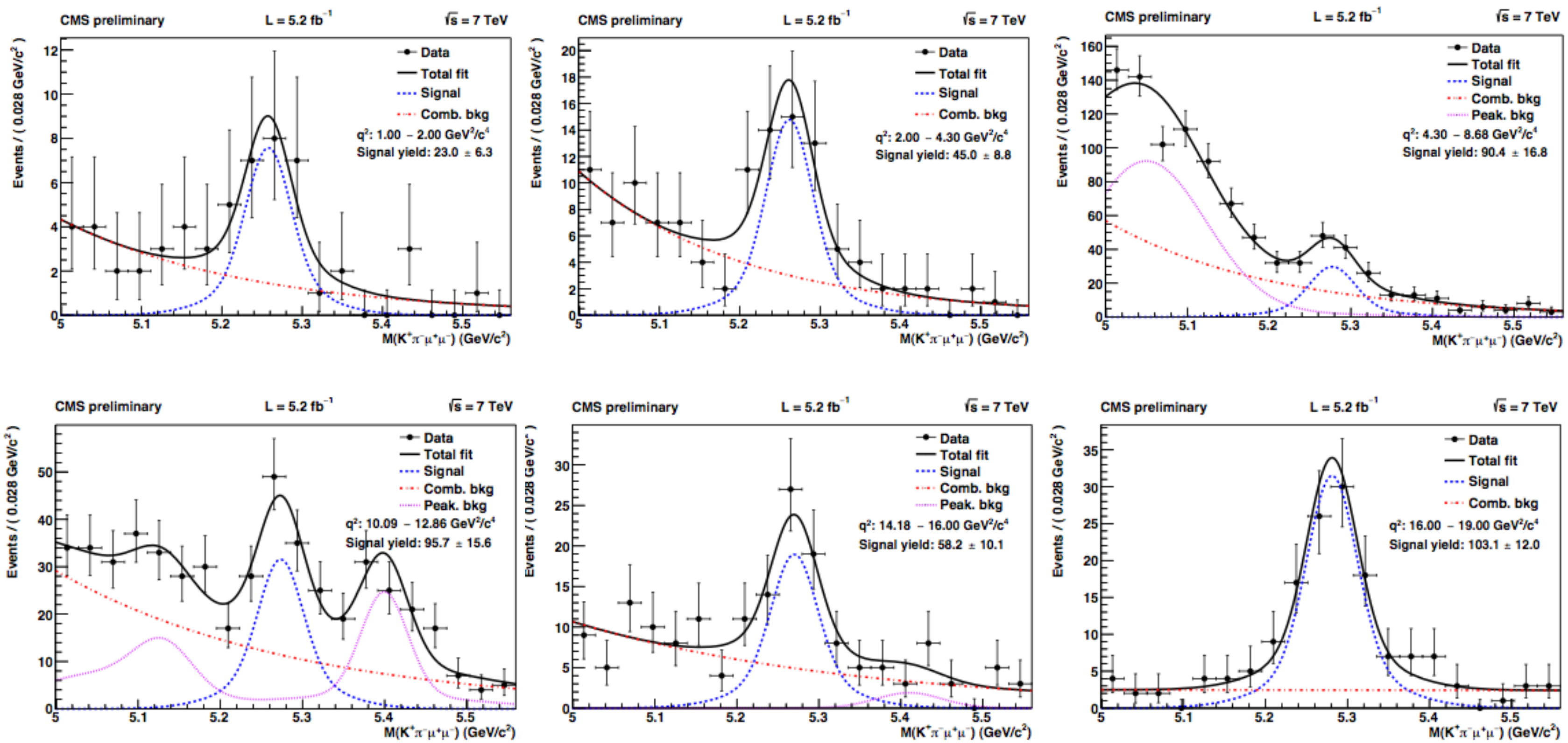
$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_K \mathrm{d}\cos\theta_l \mathrm{d}q^2} = \frac{9}{16}\left\{\left[\frac{2}{3}F_S + \frac{4}{3}A_S\cos\theta_K\right]\left(1-\cos^2\theta_l\right)\right.$$
$$+ \left(1-F_S\right)\left[2F_L\cos^2\theta_K\left(1-\cos^2\theta_l\right)\right.$$
$$+ \frac{1}{2}\left(1-F_L\right)\left(1-\cos^2\theta_K\right)\left(1+\cos^2\theta_l\right)$$
$$\left.\left. + \frac{4}{3}A_{FB}\left(1-\cos^2\theta_K\right)\cos\theta_l\right]\right\}.$$

- PDF for each q^2 bin

$$\text{p.d.f.}(m,\cos\theta_K,\cos\theta_l) = Y_S\, S(m)\cdot S(\cos\theta_K,\cos\theta_l)\cdot\epsilon(\cos\theta_K,\cos\theta_l)$$
$$+ Y_B^c\, B^c(m)\cdot B^c(\cos\theta_K)\cdot B^c(\cos\theta_l)$$
$$+ Y_B^p\, B^p(m)\cdot B^p(\cos\theta_K)\cdot B^p(\cos\theta_l).$$

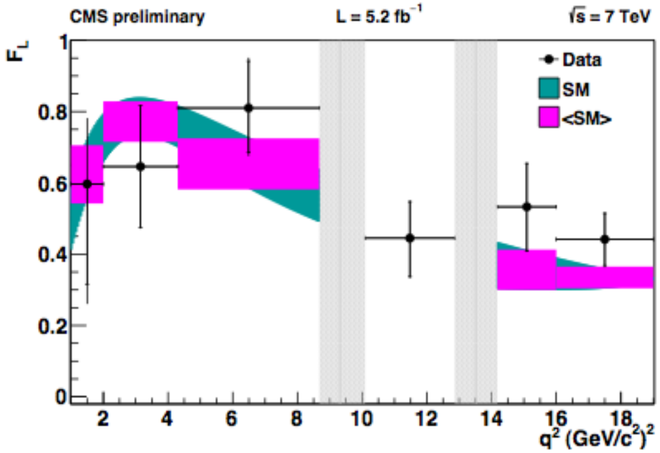
$B^0 \rightarrow K^{*0}\mu^+\mu^-$

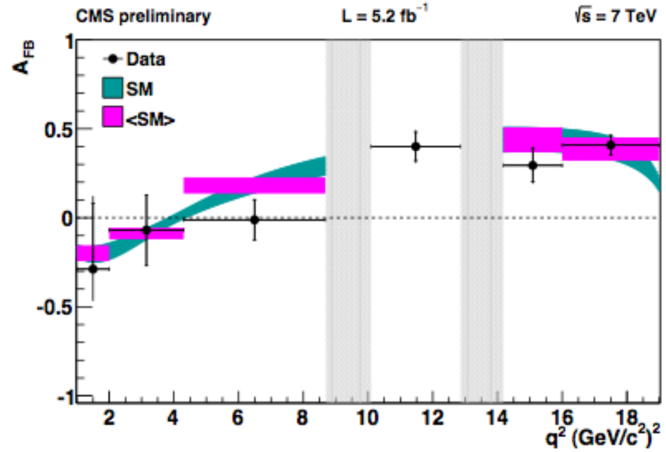
- Invariant mass distributions for each q^2 bin (CMS)



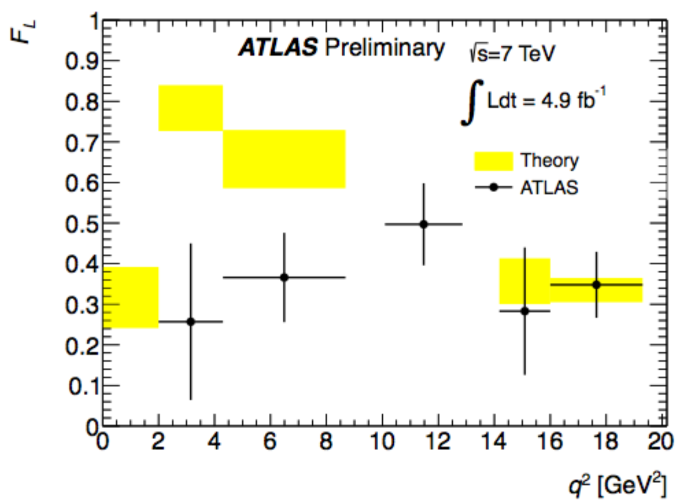
$B^0 \rightarrow K^{*0}\mu^+\mu^-$

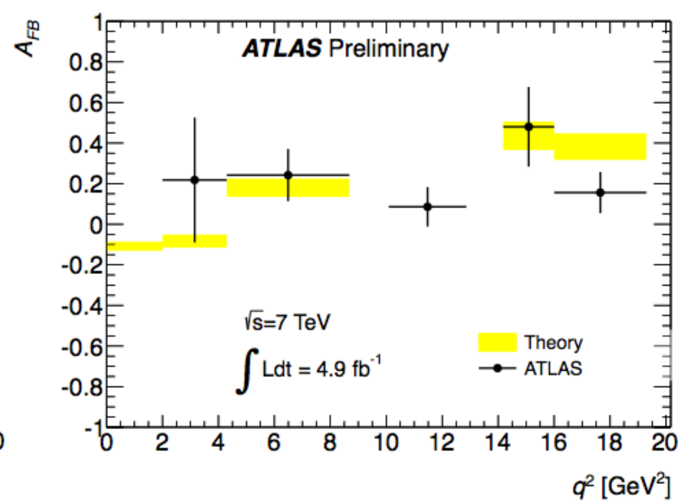
- F_L and A_{FB} (CMS)





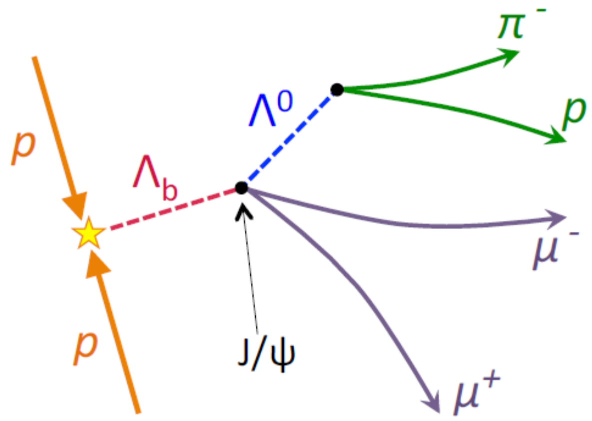
- F_L and A_{FB} (ATLAS)





Λ_b data selection (ATLAS)

- J/ψ di-muon trigger
  - Di-muon trigger
    - Threshold on each μ is $p_T = 4$ GeV
      - Minimum p_T in the sample is 2.5 GeV
  - Opposite charge and 2.5 GeV < $M_{\mu\mu}$ < 4.3 GeV
- Signal selection
  - MS used for trigger, ID used for p_T
  - 2.8 GeV < $M_{\mu\mu}$ < 3.4 GeV
  - 1.08 GeV < $M_{p\pi}$ < 1.15 GeV
    - Both Λ and $\bar{\Lambda}$ considered
- Reconstruction
  - Global re-fit of tracks
    - Mass constraints for decay products
    - Λ^0 decay length > 10 mm, p_T > 3.5 GeV
    - Λ_b τ > 0.35 ps (average 1.4 ps)
    - Re-fit as a B_d and (if compatible) compare χ^2 probability
    - Mass of Λ_b between 5560 and 5680 MeV



Λ_b mass and lifetime

- Control signal

τ_{Bd} = 1.509±0.012(stat)±0.018(syst) ps
m_{Bd} = 5279.6 ± 0.2(stat) ± 1.0(syst) MeV

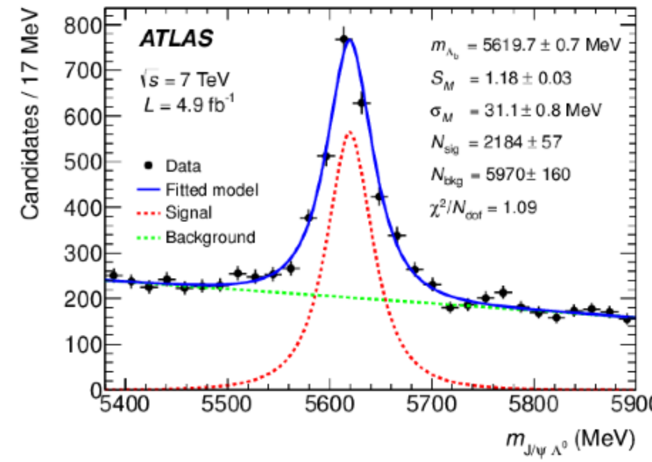
  – Consistent with PDG:

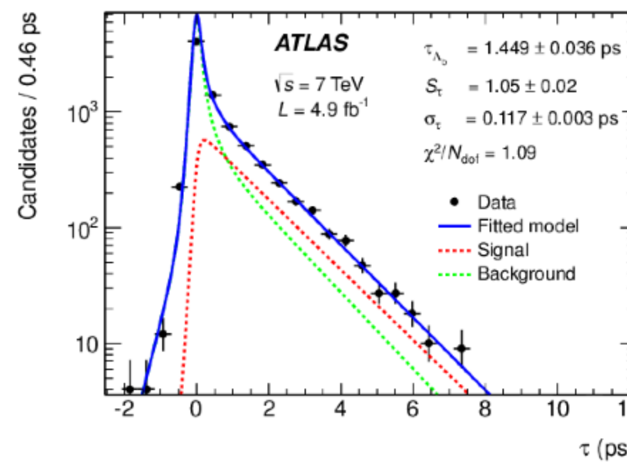
τ^{PDG} = 1.519 ± 0.007 ps
m^{PDG} = 5279.50 ± 0.30 MeV

- Results on Λ_b

$\tau_{\Lambda b}$ = 1.449 ± 0.036(stat) ± 0.017(syst) ps
$m_{\Lambda b}$ = 5619.7 ± 0.7(stat) ± 1.1(syst) MeV

R = $\tau_{\Lambda b} / \tau_{Bd}$ = 0.960 ± 0.025(stat) ± 0.016(syst)





α_b measurement

- Decay described by 4 helicity amplitudes
  - $|a_+|^2 + |a_-|^2 + |b_+|^2 + |b_-|^2 = 1$
  - $\alpha_b = |a_+|^2 - |a_-|^2 + |b_+|^2 - |b_-|^2$
- Full angular PDF

$$W(\vec{\Omega},\vec{A},P) = \frac{1}{(4\pi)^3}\sum_{i=0}^{19} f_{1i}(\vec{A})f_{2i}(P\alpha_\Lambda)F_i(\vec{\Omega})$$

  - $F_{1i}(\vec{A})$: bilinear combination of helicity amplitudes

$$\vec{A} \equiv (a_+, a_-, b_+, b_-) \quad a_+ = |a_+| e^{i\rho_+},\ a_- = |a_-| e^{i\rho_-},\quad b_+ = |b_+| e^{i\omega_+},\ b_- = |b_-| e^{i\omega_-}$$

  - $F_{2i}(P,\alpha_\Lambda)$ has values $P\alpha_\Lambda$, P, α_Λ or 1
    - $\alpha_\Lambda = 0.642 \pm 0.013$ for $\Lambda^0 \to p\pi^-$
    - Exploit ATLAS symmetry in $\eta \to$ Polarization = 0
  - $F_i(\vec{\Omega})$: orthogonal functions of decay angles
  - Only 5 independent parameters
- χ^2 fit to measured $\langle F_i \rangle$

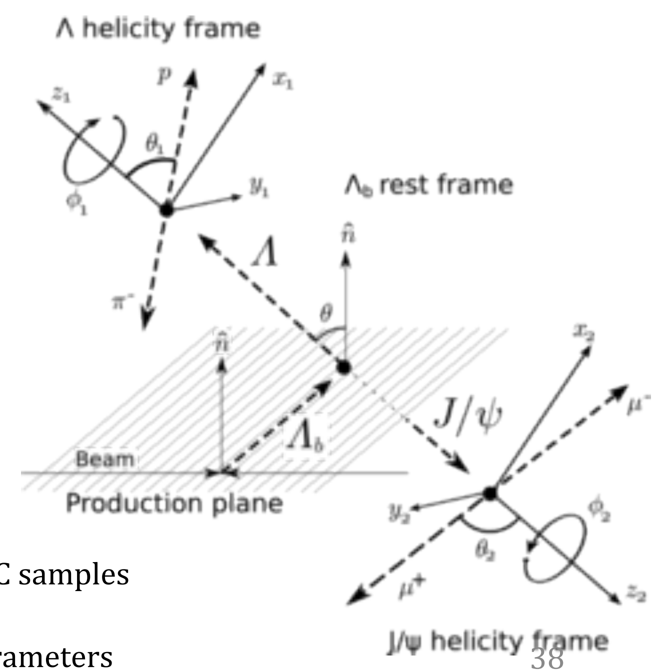
$$\chi^2 = \sum_{i=1}^{5}\sum_{j=1}^{5}(\langle F_i\rangle^{\text{expected}} - \langle F_i\rangle)V_{ij}^{-1}(\langle F_j\rangle^{\text{expected}} - \langle F_j\rangle)$$

$$\langle F_i\rangle^{\text{expected}} = \sum f_j(\vec{A})C_{ij}$$

Detector effects, determined by MC samples (C_{ij})

Model, defined in terms of free parameters ($f_j(\vec{A})$)

Amplitude	λ_Λ	$\lambda_{J/\psi}$
a_+	+½	0
a_-	-½	0
b_+	-½	-1
b_-	+½	+1



Λ_b asimmetry measurement

- Full angular PDF $\quad W(\vec{\Omega},\vec{A},P) = \frac{1}{(4\pi)^3}\sum_{i=0}^{19} f_{1i}(\vec{A}) f_{2i}(P\alpha_\Lambda) F_i(\vec{\Omega})$

i	f_{1i}	f_{2i}	F_i
0	$a_+a_+^* + a_-a_-^* + b_+b_+^* + b_-b_-^*$	1	1
1	$a_+a_+^* - a_-a_-^* + b_+b_+^* - b_-b_-^*$	P	$\cos\theta$
2	$a_+a_+^* - a_-a_-^* - b_+b_+^* + b_-b_-^*$	α_Λ	$\cos\theta_1$
3	$a_+a_+^* + a_-a_-^* - b_+b_+^* - b_-b_-^*$	$P\,\alpha_\Lambda$	$\cos\theta\,\cos\theta_1$
4	$-a_+a_+^* - a_-a_-^* + \frac{1}{2}b_+b_+^* + \frac{1}{2}b_-b_-^*$	1	$\frac{1}{2}(3\cos^2\theta_2 - 1)$
5	$-a_+a_+^* + a_-a_-^* + \frac{1}{2}b_+b_+^* - \frac{1}{2}b_-b_-^*$	P	$\frac{1}{2}(3\cos^2\theta_2 - 1)\cos\theta$
6	$-a_+a_+^* + a_-a_-^* - \frac{1}{2}b_+b_+^* + \frac{1}{2}b_-b_-^*$	α_Λ	$\frac{1}{2}(3\cos^2\theta_2 - 1)\cos\theta_1$
7	$-a_+a_+^* - a_-a_-^* - \frac{1}{2}b_+b_+^* - \frac{1}{2}b_-b_-^*$	$P\,\alpha_\Lambda$	$\frac{1}{2}(3\cos^2\theta_2 - 1)\cos\theta\cos\theta_1$
8	$-3Re(a_+a_-^*)$	$P\,\alpha_\Lambda$	$\sin\theta\,\sin\theta_1\,\sin^2\theta_2\,\cos\varphi_1$
9	$3Im(a_+a_-^*)$	$P\,\alpha_\Lambda$	$\sin\theta\,\sin\theta_1\,\sin^2\theta_2\,\sin\varphi_1$
10	$-\frac{3}{2}Re(b_-b_+^*)$	$P\,\alpha_\Lambda$	$\sin\theta\,\sin\theta_1\,\sin^2\theta_2\,\cos(\varphi_1 + 2\varphi_2)$
11	$\frac{3}{2}Im(b_-b_+^*)$	$P\,\alpha_\Lambda$	$\sin\theta\,\sin\theta_1\,\sin^2\theta_2\,\sin(\varphi_1 + 2\varphi_2)$
12	$-\frac{3}{\sqrt{2}}Re(b_-a_+^* + a_-b_+^*)$	$P\,\alpha_\Lambda$	$\sin\theta\,\cos\theta_1\,\sin\theta_2\,\cos\theta_2\,\cos\varphi_2$
13	$\frac{3}{\sqrt{2}}Im(b_-a_+^* + a_-b_+^*)$	$P\,\alpha_\Lambda$	$\sin\theta\,\cos\theta_1\,\sin\theta_2\,\cos\theta_2\,\sin\varphi_2$
14	$-\frac{3}{\sqrt{2}}Re(b_-a_-^* + a_+b_+^*)$	$P\,\alpha_\Lambda$	$\cos\theta\,\sin\theta_1\,\sin\theta_2\,\cos\theta_2\,\cos(\varphi_1 + \varphi_2)$
15	$\frac{3}{\sqrt{2}}Im(b_-a_-^* + a_+b_+^*)$	$P\,\alpha_\Lambda$	$\cos\theta\,\sin\theta_1\,\sin\theta_2\,\cos\theta_2\,\sin(\varphi_1 + \varphi_2)$
16	$\frac{3}{\sqrt{2}}Re(a_-b_+^* - b_-a_+^*)$	P	$\sin\theta\,\sin\theta_2\,\cos\theta_2\,\cos\varphi_2$
17	$-\frac{3}{\sqrt{2}}Im(a_-b_+^* - b_-a_+^*)$	P	$\sin\theta\,\sin\theta_2\,\cos\theta_2\,\sin\varphi_2$
18	$\frac{3}{\sqrt{2}}Re(b_-a_-^* - a_+b_+^*)$	α_Λ	$\sin\theta_1\,\sin\theta_2\,\cos\theta_2\,\cos(\varphi_1 + \varphi_2)$
19	$-\frac{3}{\sqrt{2}}Im(b_-a_-^* - a_+b_+^*)$	α_Λ	$\sin\theta_1\,\sin\theta_2\,\cos\theta_2\,\sin(\varphi_1 + \varphi_2)$

α_b measurement

- Polarization P=0 due to:
  - Symmetry of initial state
  - ATLAS symmetry in η
  - Coefficients reduced to 6

i	f_{1i}	f_{2i}	F_i
0	1	1	1
2	$(k_0^2 + k_1^2 - 1) + \alpha_b(k_0^2 - k_1^2)$	α_Λ	$\cos\theta_1$
4	$\frac{1}{4}[(3k_1^2 - 3k_0^2 - 1) + 3\alpha_b(1 - k_1^2 - k_0^2)]$	1	$\frac{1}{2}(3\cos^2\theta_2 - 1)$
6	$-\frac{1}{4}[(k_0^2 + k_1^2 - 1) + \alpha_b(3 + k_0^2 - k_1^2)]$	α_Λ	$\frac{1}{2}(3\cos^2\theta_2 - 1)\cos\theta_1$
18	$\frac{3}{\sqrt{2}}[\frac{1-\alpha_b}{2}\sqrt{k_1^2(1-k_1^2)}\cos(-\Delta_-) - \frac{1+\alpha_b}{2}\sqrt{k_0^2(1-k_0^2)}\cos(\Delta_+)]$	α_Λ	$\sin\theta_1\ \sin\theta_2\ \cos\theta_2\ \cos(\varphi_1 + \varphi_2)$
19	$-\frac{3}{\sqrt{2}}[\frac{1-\alpha_b}{2}\sqrt{k_1^2(1-k_1^2)}\sin(-\Delta_-) - \frac{1+\alpha_b}{2}\sqrt{k_0^2(1-k_0^2)}\sin(\Delta_+)]$	α_Λ	$\sin\theta_1\ \sin\theta_2\ \cos\theta_2\ \sin(\varphi_1 + \varphi_2)$

- Use of the following 5 parameters to define the model:

$$\alpha_b = |a_+|^2 - |a_-|^2 + |b_+|^2 - |b_-|^2$$

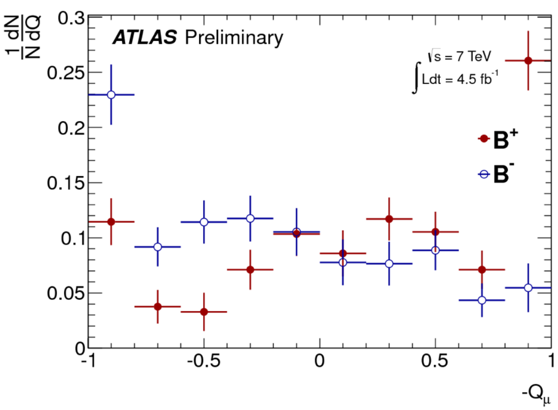
$$k_0 = \frac{|a_+|}{\sqrt{|a_-|2+|b_+|^2}}, \quad k_1 = \frac{|b_-|}{\sqrt{|a_-|^2+|b_-|^2}}$$

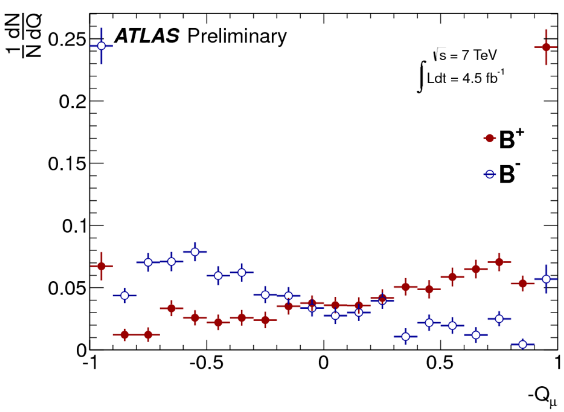
$$\Delta_+ = \rho_+ - \omega_+, \qquad \Delta_- = \rho_- - \omega_-$$

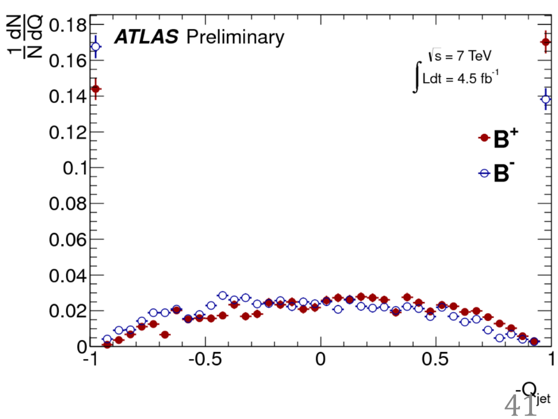
$B_s \to J/\psi\ \phi$

Tagging methods, calibrated using $B^{\pm} \to J/\psi\ K^{\pm}$ decays
Determine probability that signal contains $\bar{b}$

- Muon tagging
  - From semi-leptonic decays
  - Diluted by
    - B_s oscillations
    - $b \to c \to u$ cascade decay
- Jet tagging
  - B-tagged jet required







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

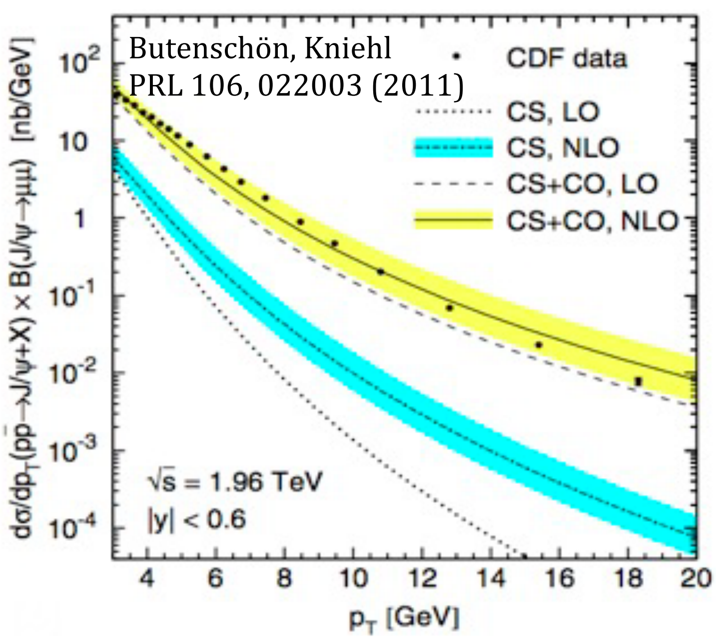
- Differential decay rate

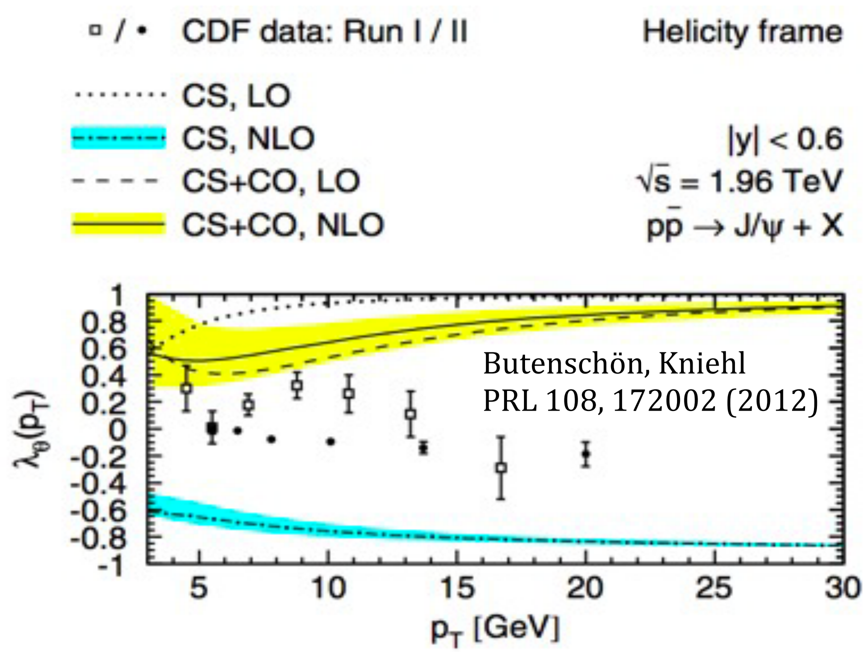
$$\frac{d^4\Gamma}{dt\ d\Omega} = \sum_{k=1}^{10} \mathscr{O}^{(k)}(t) g^{(k)}(\theta_T, \psi_T, \phi_T)$$

- Tag information used
  - Extra PDF terms to account for the background
  - Background tag probability modeled on the sidebands
  - 25 parameters, 9 of them physical

Quarkonium production

- No theory explains at the same time
  - Production ($d\sigma/dp_T$)
  - Polarization
    - Previous measurements: only one polarization parameter (out of three)





Uncertainties on Υ(nS) production

- ATLAS

Source	Relative uncertainty [$\Upsilon(1S)/\Upsilon(2S)/\Upsilon(3S)$] [%] $\lvert y^{\mu\mu}\rvert < 1.2$	$1.2 \leq \lvert y^{\mu\mu}\rvert < 2.25$
Statistical uncertainty	1.5–10/2–10/3–10	2–15/2.5–12/4–18
Fit model	0.3–2/0.3–10/0.3–15	0.4–10/0.3–5.0/0.2–12
Luminosity	3.9	3.9
Trigger efficiency	2.0–3.0/1.0–2.0/1.0–2.0	2.0–3.0/2.0–4.0/2.0–7.0
Muon reconstruction efficiency	0.7–2.0/0.4–1.2/0.4–1.2	0.5–5.0/0.4–3.0/0.4–3.0
Acceptance corrections	0.7–1.5	0.7–1.5
Track reconstruction efficiency	1.0	1.0

Quarkonia polarization

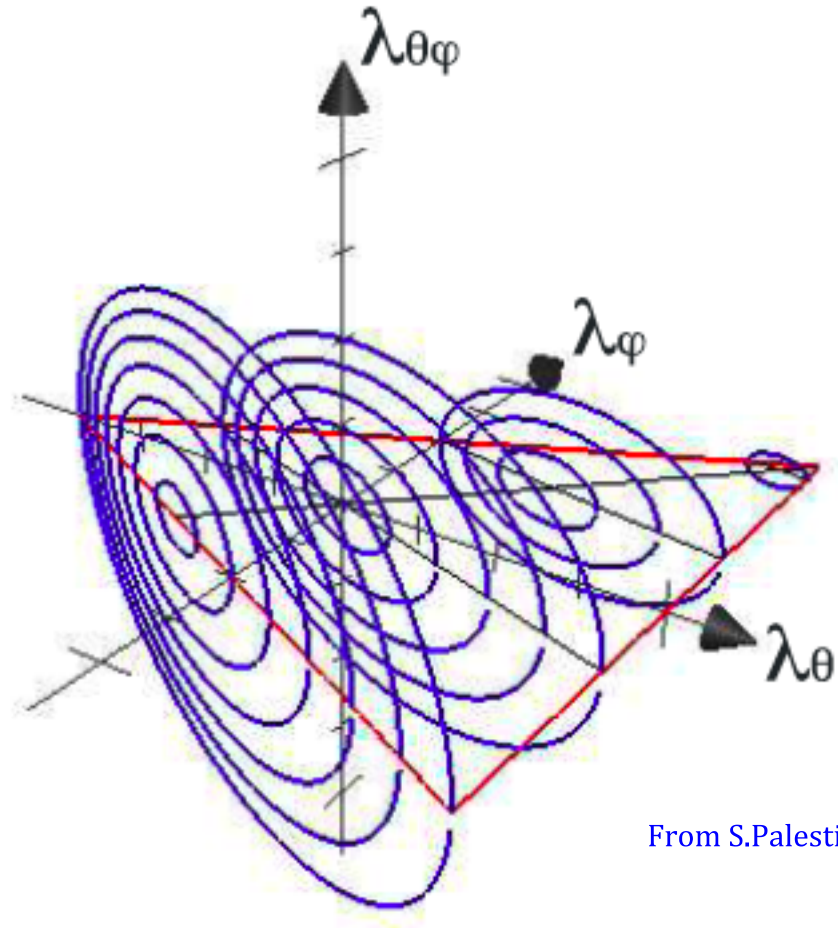
- Polarization measured through the average angular decay distribution – for vector particles:

$$W(\cos\vartheta, \varphi|\vec{\lambda}) = \frac{3/(4\pi)}{(3+\lambda_\vartheta)}(1 + \lambda_\vartheta \cos^2\vartheta + \lambda_\varphi \sin^2\vartheta \cos 2\varphi + \lambda_{\vartheta\varphi} \sin 2\vartheta \cos\varphi)$$

$\tilde{\lambda} = (\lambda_\vartheta + 3\lambda_\varphi)/(1 - \lambda_\varphi)$ (frame-invariant)

- Angular decay distribution measure with respect to 3 reference frames:
  - Center-of mass helicity frame HX (polar axis ≈ direction of quarkonium momentum)
  - Collins-Soper CS (z_{CS} ≈ direction of relative velocity of colliding particles)
  - Perpendicular helicity PX ($z_{PX} \perp z_{CS}$)
- Distribution shape is characterized by the frame invariant parameter $\tilde{\lambda}$

Polarization parameters



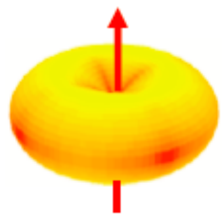
From S.Palestini, Phys. Rev. **D83** (2011)

Quarkonia polarization

- Two extreme angular decay distributions

Longitudinal polarization
$J_z = 0$

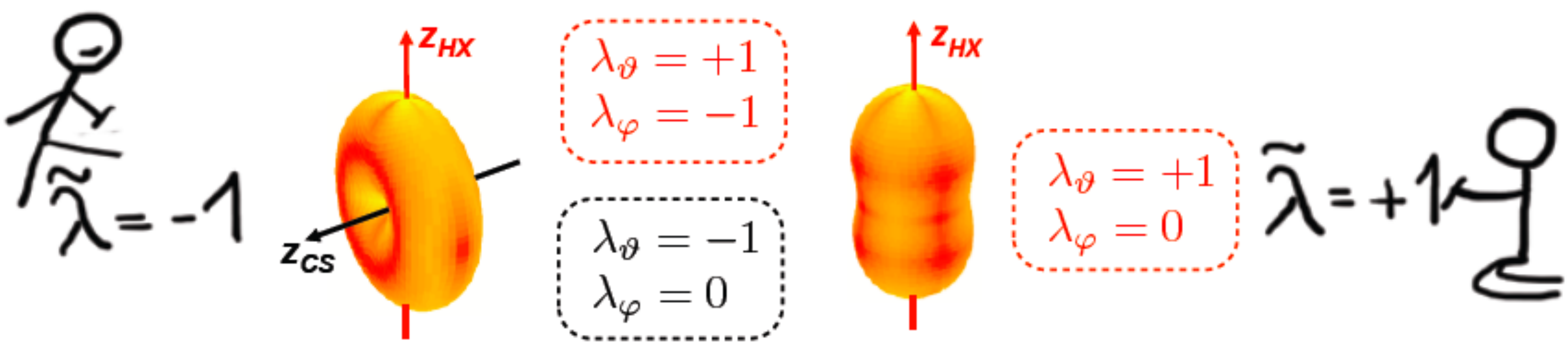
$\lambda_\vartheta = -1$
$\lambda_\varphi = 0$
$\lambda_{\vartheta\varphi} = 0$



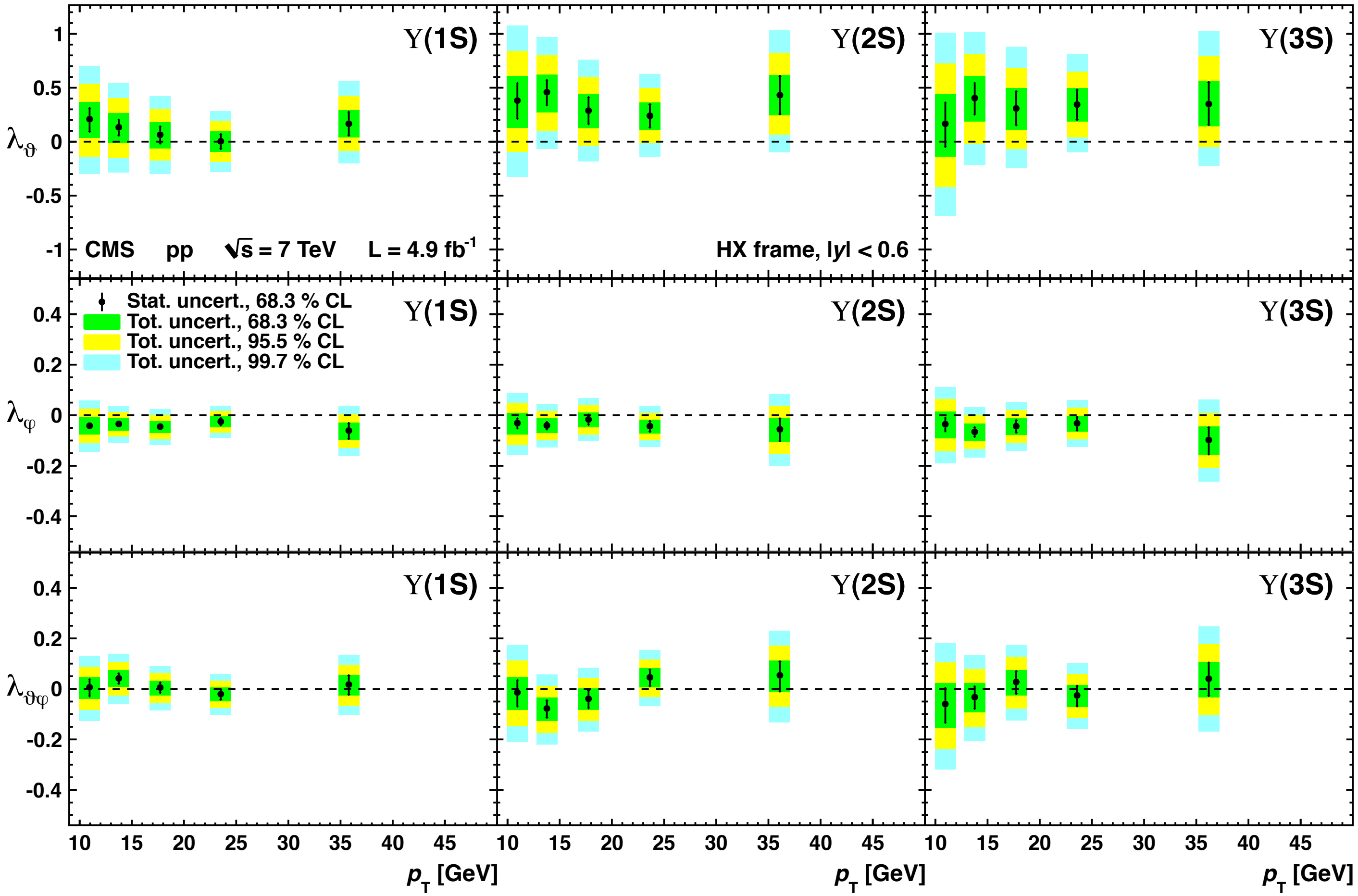
Transverse polarization
$J_z = \pm 1$

$\lambda_\vartheta = +1$
$\lambda_\varphi = 0$
$\lambda_{\vartheta\varphi} = 0$

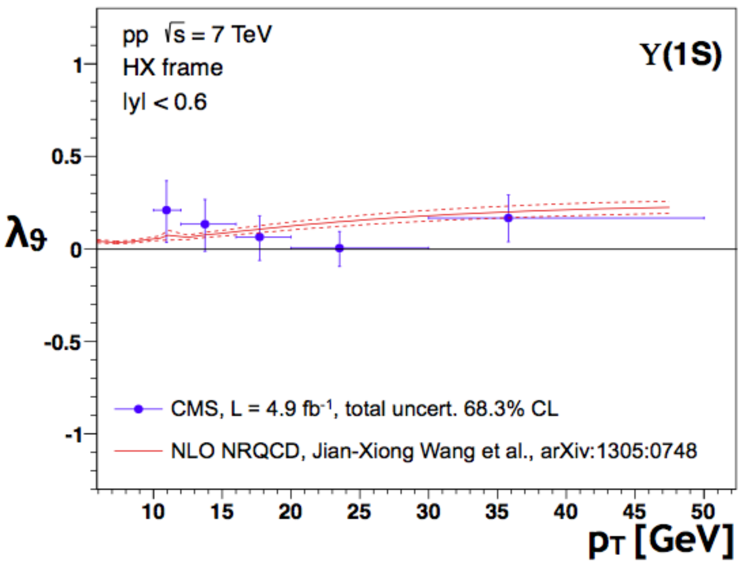
- The full angular distribution has to be measured. Otherwise two very different physical cases cannot be distinguished.
- The shape of the distribution is invariant and can be characterized by the frame invariant parameter $\tilde{\lambda} = (\lambda_\vartheta + 3\lambda_\varphi)/(1 - \lambda_\varphi)$

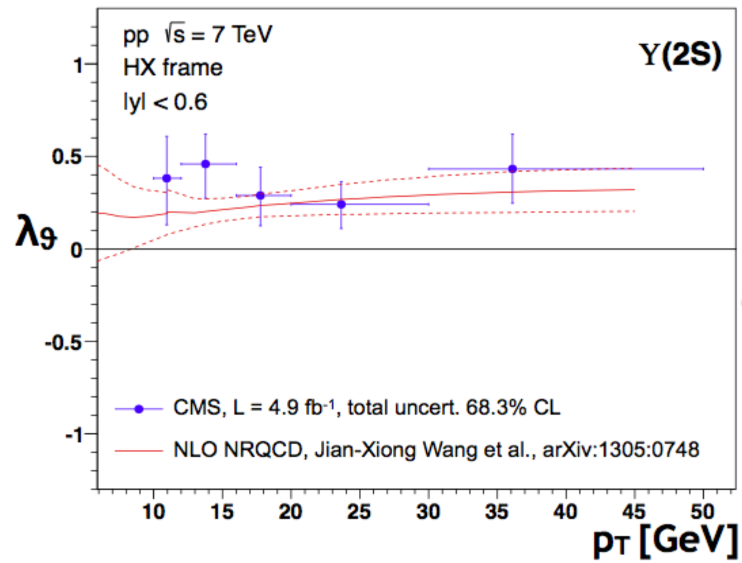


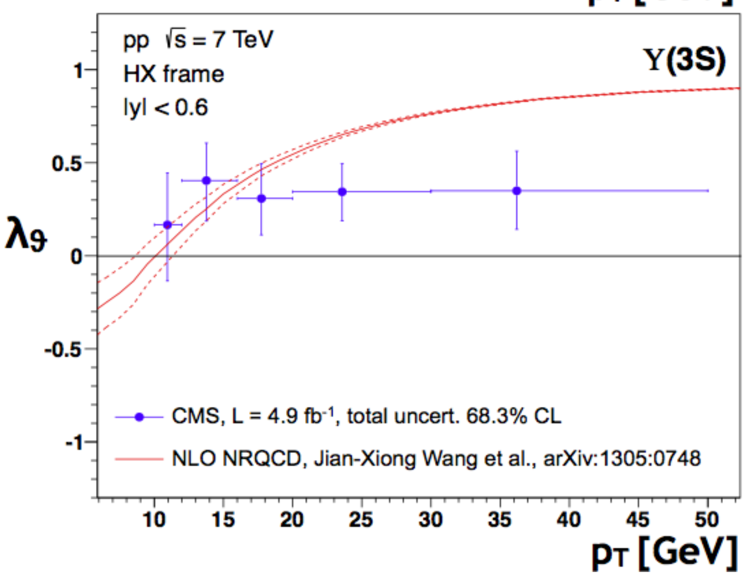
Υ(nS) polarization in the HX Frame, |y| < 0.6



Υ(nS) comparison with NRQCD

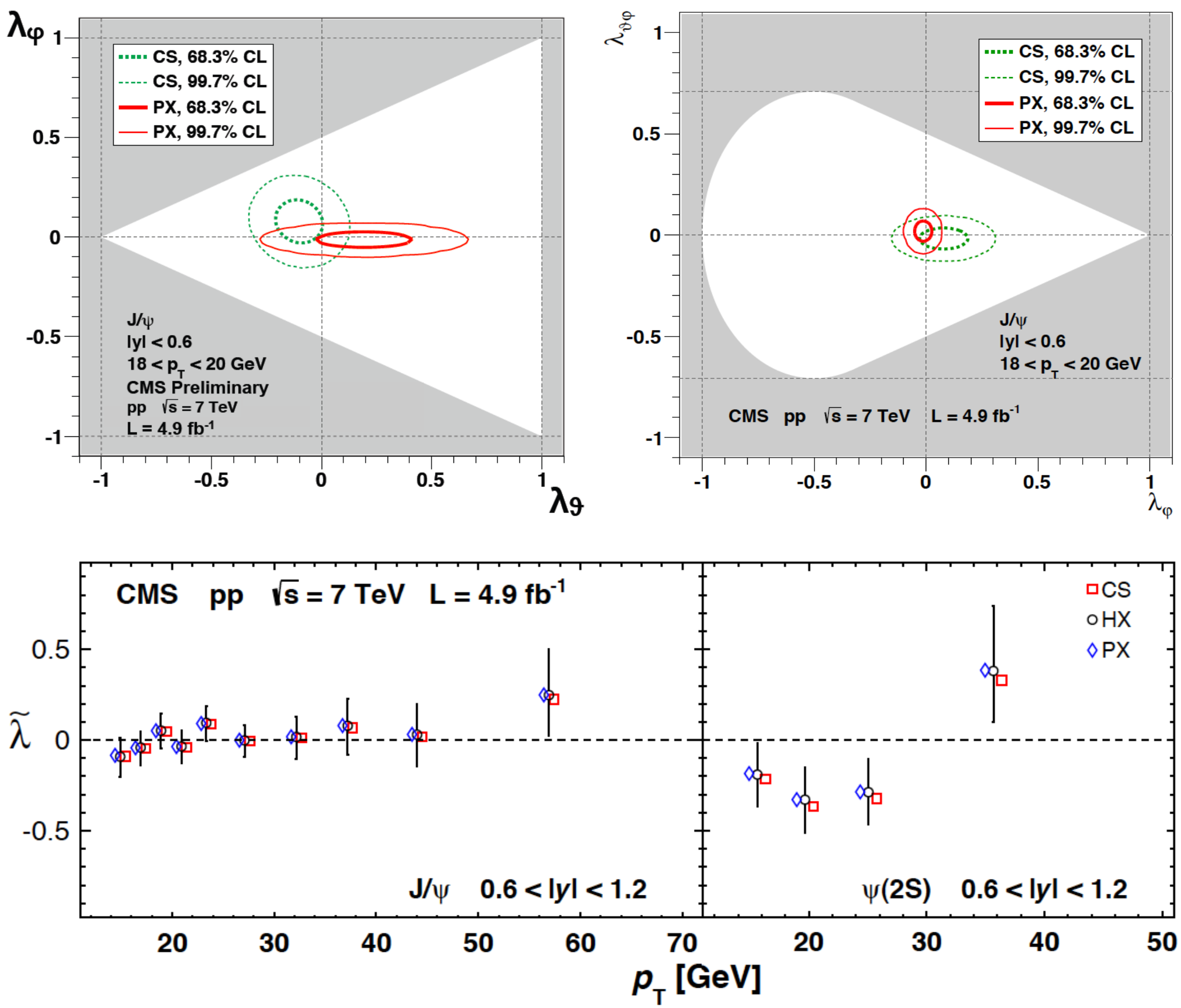






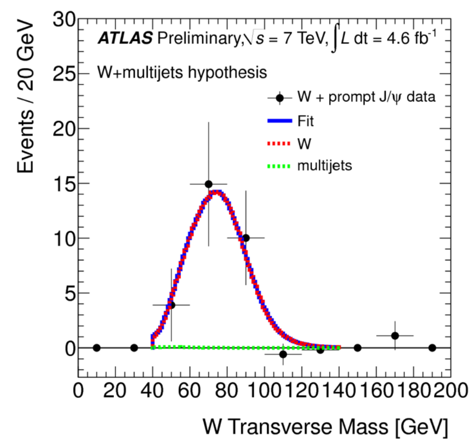
- Calculation accounts for feed-down contributions to Υ(1S) and Υ(2S)
- Prediction for Υ(3S) may change
  - Feed-down from $\chi_b(3P)$ to be included

J/ψ polarization and shape invariance



$W^{\pm}$ + prompt J/ψ measurement

- Background sources
  - $t \to W^{\pm}b$, where $b \to J/\psi\ X$
    - Expected yield < 0.28 @ 95% CL
  - $W^{\pm}b$ others than t decay
    - Ratio to W± production is consistent with ratio W± + non-prompt J/ψ to W±
  - $Z \to \mu^+\mu^-$ vetoed by removing $m_{\mu\mu} = m_Z \pm 10$ GeV
  - Multi-jet production
    - Shape evaluated looking at non-isolated muons
    - Fit on W transverse mass
- Pileup
  - Estimated yield 1.8 ± 0.2
- Double-parton scattering
  - Evaluated via $P_{J/\psi|W} = \sigma_{J/\psi}/\sigma_{\mathrm{eff}}$

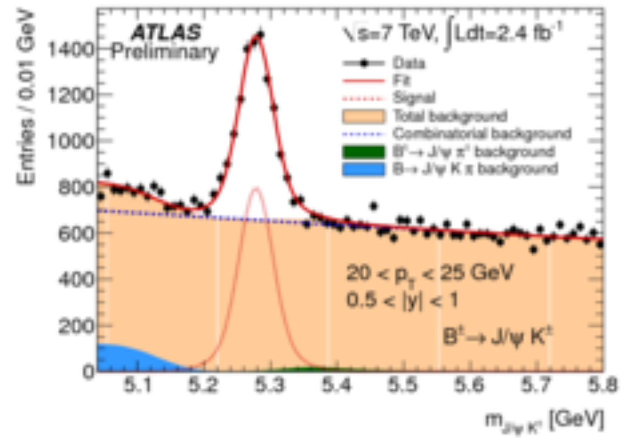


$W^{\pm}$ + prompt J/ψ measurement

Yields from two-dimensional fit			
Process	Barrel	Endcap	Total
Prompt J/ψ	$10.0^{+4.7}_{-4.0}$	$19.2^{+5.8}_{-5.1}$	$29.2^{+7.5}_{-6.5}$
Non-prompt J/ψ	$27.9^{+6.5}_{-5.8}$	$13.9^{+5.3}_{-4.5}$	$41.8^{+8.4}_{-7.3}$
Prompt background	$20.4^{+5.9}_{-5.1}$	$18.8^{+6.3}_{-5.3}$	$39.2^{+8.6}_{-7.3}$
Non-prompt background	$19.8^{+5.8}_{-4.9}$	$19.2^{+6.1}_{-5.1}$	$39.0^{+8.4}_{-7.1}$
p-value	1.5×10^{-3}	1.4×10^{-6}	4.4×10^{-8}
Significance	3.0	4.7	5.3

Source	Barrel	Endcap
J/ψ muon efficiency	$\approx 5\%$	$\approx 5\%$
$W^{\pm}$ boson kinematics	2%	5%
Fit procedure	$^{+3}_{-2}\%$	$^{+2}_{-1}\%$
Choice of fit nuisance parameters	1%	1%
Choice of fit functional forms	4%	4%
Muon momentum scale	negligible	
J/ψ spin-alignment	$^{+36}_{-25}\%$	$^{+27}_{-13}\%$
Statistical	$^{+47}_{-40}\%$	$^{+30}_{-27}\%$

B^+ production (ATLAS)



- 2.4 fb^{-1}, 7 TeV, 2011
- $d^2\sigma(pp \rightarrow B^+X)/dp_T dy$
  - Up to $p_T \sim 100$ GeV
  - 4 rapidity regions, $|y| < 2.25$
  - via $B^+ \rightarrow J/\psi\ K^+ \rightarrow \mu^+\mu^- K^+$
    - (B.R. = (6.03 +- 0.21) x 10^{-5})
- Event selection
  - Di-muon trigger
  - At least 2 μ with matching MS and ID tracks
    - $2.5 < m_{\mu\mu} < 4.3$ GeV (ID kinematics)
    - Reconstructed muons must match the trigger ones
- Background
  - $B^{\pm} \rightarrow J/\psi\ \pi^{\pm}$
  - $B^{\pm/0} \rightarrow J/\psi\ K^{*\pm/0}$ and $B^{\pm/0} \rightarrow J/\psi\ K^{\pm}\pi^{\pm/0}$
  - Combinatorial background from J/ψ plus a track

B+ production (ATLAS)

- Comparison with theory
  - NLO and FONLL