PRODUCTION OF EXOTIC AND CONVENTIONAL QUARKONIA AND OPEN BEAUTY/OPEN CHARM AT ATLAS

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Outline

- Introduction: Heavy Flavour production in pp collisions
- The ATLAS experiment
- Quarkonia production
  - J/ψ , $\psi(2S)$ and X(3872) prompt and non-prompt production
  - χ_{c1} and χ_{c2} prompt and non-prompt production
  - Search for "exotic" X_b states in the 10 ÷ 11 GeV mass range
- Open charm/beauty production
  - D, D* and D_s production
  - B^+ production
  - B-fragmentation fraction measurement
- Summary

Introduction - I: Heavy Flavour production in pp collisions

- Large HF cross-sections at LHC: $\sigma(c) \approx 5$ mb and $\sigma(b) \approx 250$ μb
- Challenge for theory predictions: many ingredients needed:
  - Open HF: $$d\sigma_{H+X} = \sum_{i,j} f_i^A \otimes f_j^B \otimes d\hat{\sigma}_{ij\to q+X} \otimes D_q^H(z)$$
  - Quarkonia: $$d\sigma_{Q+X} = \sum_{i,j} f_i^A \otimes f_j^B \otimes d\hat{\sigma}_{ij\to q\bar{q}+X} \otimes \langle O_Q^n \rangle$$

→ ***Proton PDFs***
Hard Scattering XS
Hadronization

- Several approaches considered → MC generators available
  - Quarkonia production:
    - CEM (Color Evaporation Model)
    - CSM (Color Singlet Model)
    - NRQCD (Non-Relativistic QCD including CS and CO, up to NLO)
  - Open HF
    - GM-VFNS (General Mass Variable Flavour Number Scheme)
    - FONLL (Fixed Order + Next to Leading Logs)
    - MC@NLO + Pythia/Herwig
    - POWHEG + Pythia/Herwig
- In the following mostly comparisons between data and predictions

Introduction – II: prompt vs. non prompt charmonium production

- Specific issue in the case of charmonium production:
- Two distinct mechanisms at the LHC:
  - Prompt: Produced directly in the primary pp interaction or through feed-down from decays of a heavier (directly produced) states
  - Non-prompt: Produced in the decays of b-hadrons, can be separated experimentally (exploiting the “long” b-hadron lifetime)
- Around 35% of prompt J/ψ come from feed-down, ψ(2S) are almost all direct!
- Discrimination based on the “pseudo-proper time” τ

$$\tau = \frac{L_{xy} m(\mu\mu)}{\left|\vec{p}_T(\mu\mu)\right|}$$

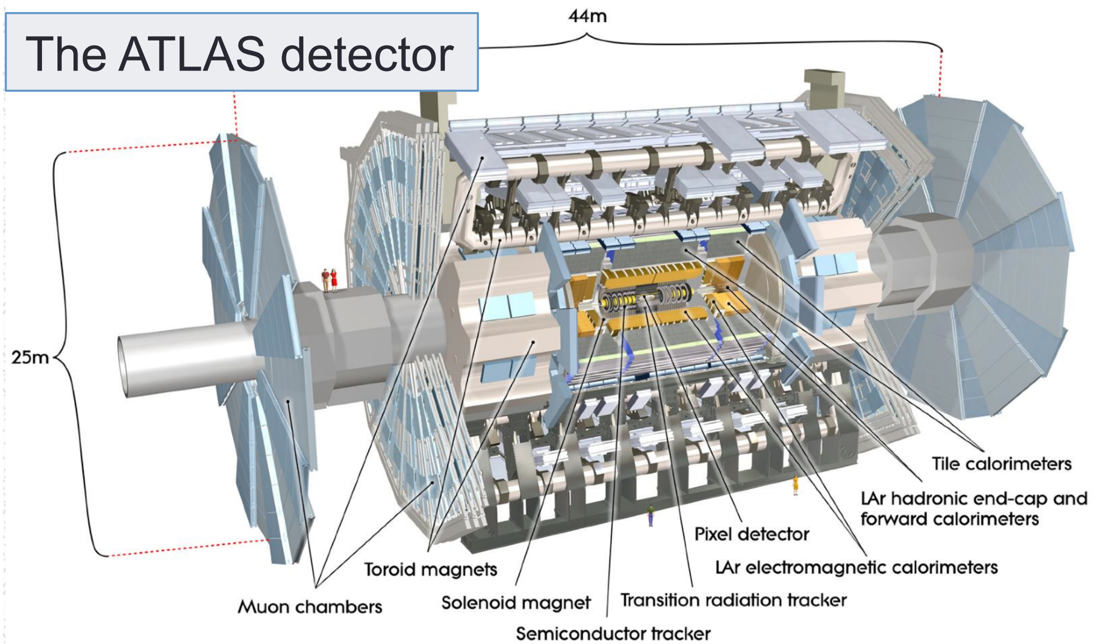
with L_{xy} the travel distance of the quarkonium in the transverse plane

$$L_{xy} = \frac{L \bullet \vec{p}_T(\mu\mu)}{\left|\vec{p}_T(\mu\mu)\right|}$$

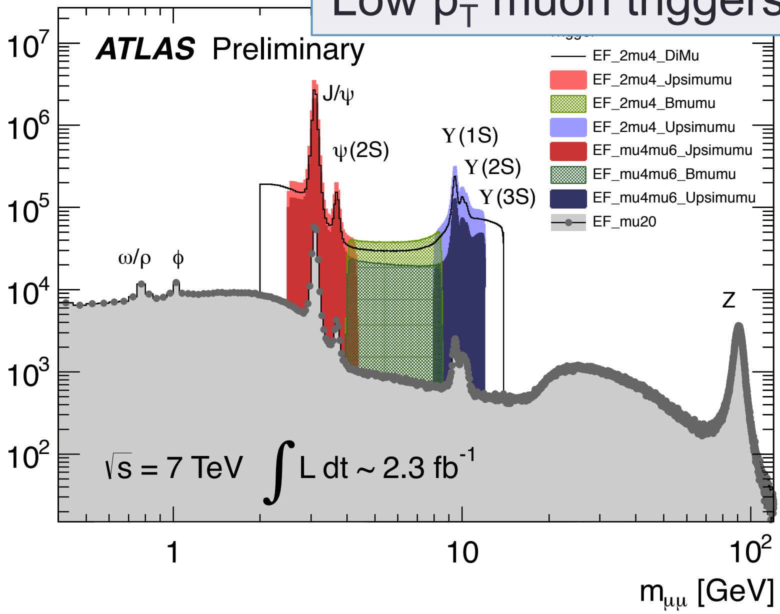
The ATLAS experiment

Heavy Flavour physics in ATLAS is mostly based on **low p_T muon triggers** (*) and **track reconstruction in the Inner Detector**

The ATLAS detector



Low p_T muon triggers



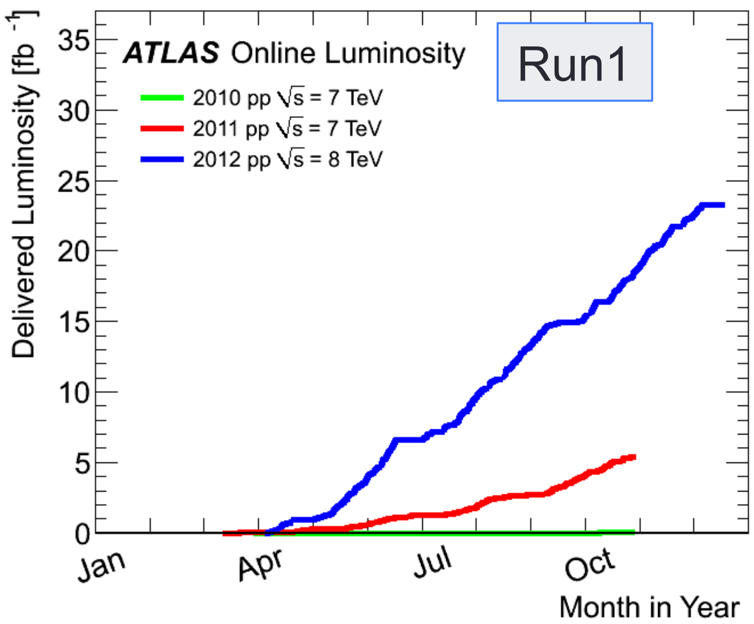
Muon Spectrometer: Triggering $|\eta| < 2.4$ and Precision Tracking $|\eta| < 2.7$
Inner Detector: Silicon Pixels, Strips, Transition Radiation Tracker $|\eta| < 2.5$
New for Run 2! "Insertable B-Layer" - additional inner-most pixel layer (r = 33 mm)
Resolution in $m(\mu^+\mu^-)$: ≈ 50 MeV at J/ψ and ≈ 150 MeV at ϒ(nS)

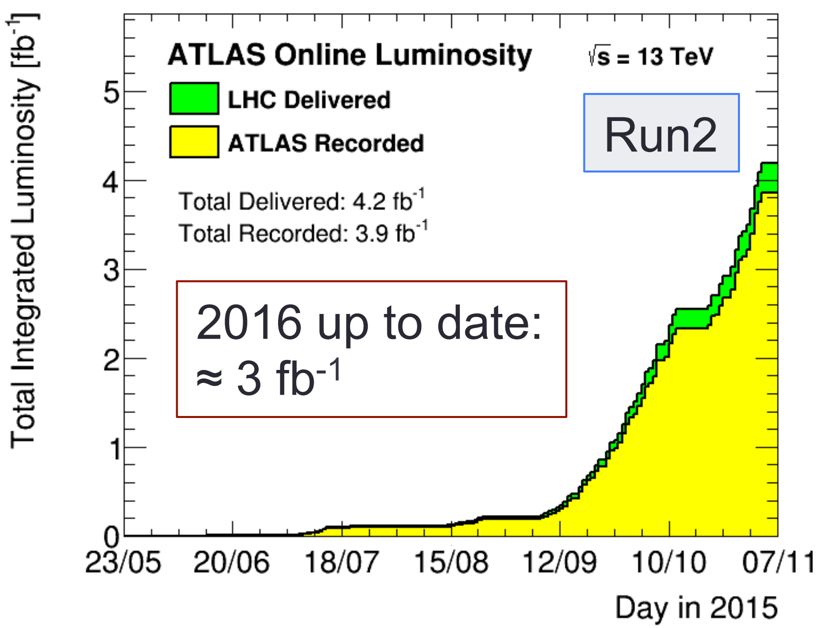
(*) exception: high p_T muon triggers are employed for J/ψ + W/Z analyses

Data samples

HF analyses are based on different data samples

Run	Year	$\sqrt{s}$ (TeV)	L_{int} (fb^{-1})	L_{peak} ($10^{33}cm^{-2}s^{-1}$)	<μ>
Run1	2011	2.76	0.004		<1
	2011	7	5.1	3.6	9.1
	2012	8	21.3	7.7	20.7
Run2	2015	13	3.9	5.0	13.7



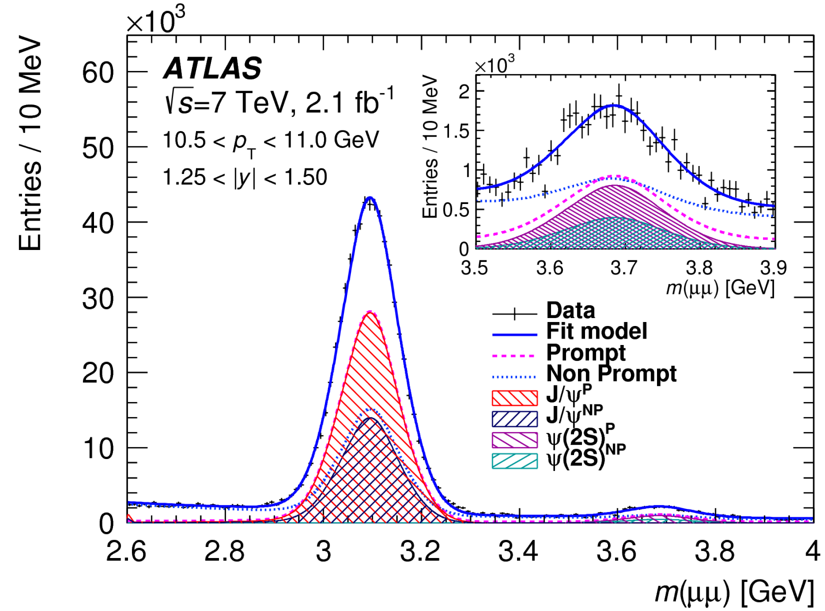


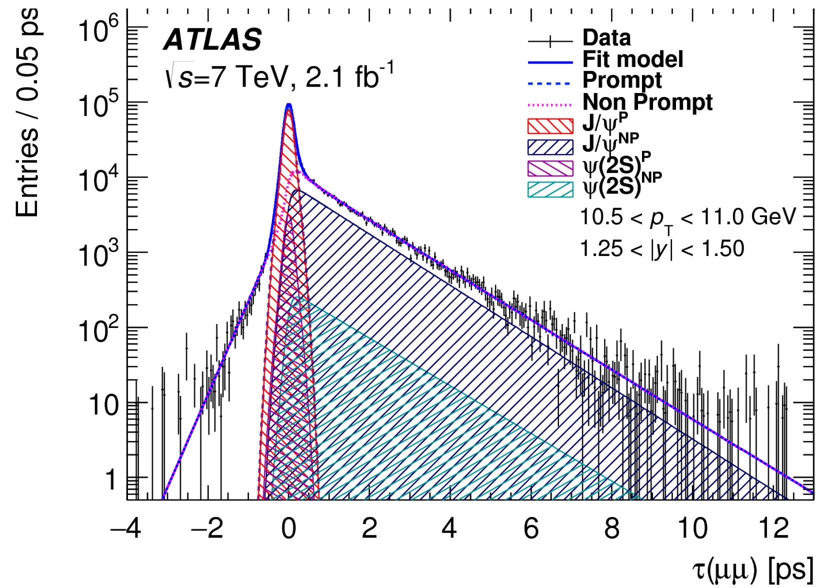
Differential cross-sections of prompt and non-prompt production of J/ψ and $\psi(2S)$

- Data sample:
  - 2.1 fb^{-1} @ 7 TeV
  - 11.4 fb^{-1} @ 8 TeV
- Search in the $\mu\mu$ channel
  - Dimuon trigger (p_T>4 GeV)
  - Measurement of proper decay time ➔ prompt/non-prompt discrimination
  - Combined $m(\mu\mu) - \tau(\mu\mu)$ fit to extract the yields

$N^{p}_{J/\psi}$ $N^{np}_{J/\psi}$ $N^{p}_{\psi(2S)}$ $N^{np}_{\psi(2S)}$

- Analysis vs. p_T $(\mu\mu)$and $y(\mu\mu)$
  - Isotropic spin-alignment is assumed
  - Kinematic coverage up to p_T=100 GeV and |y|=2

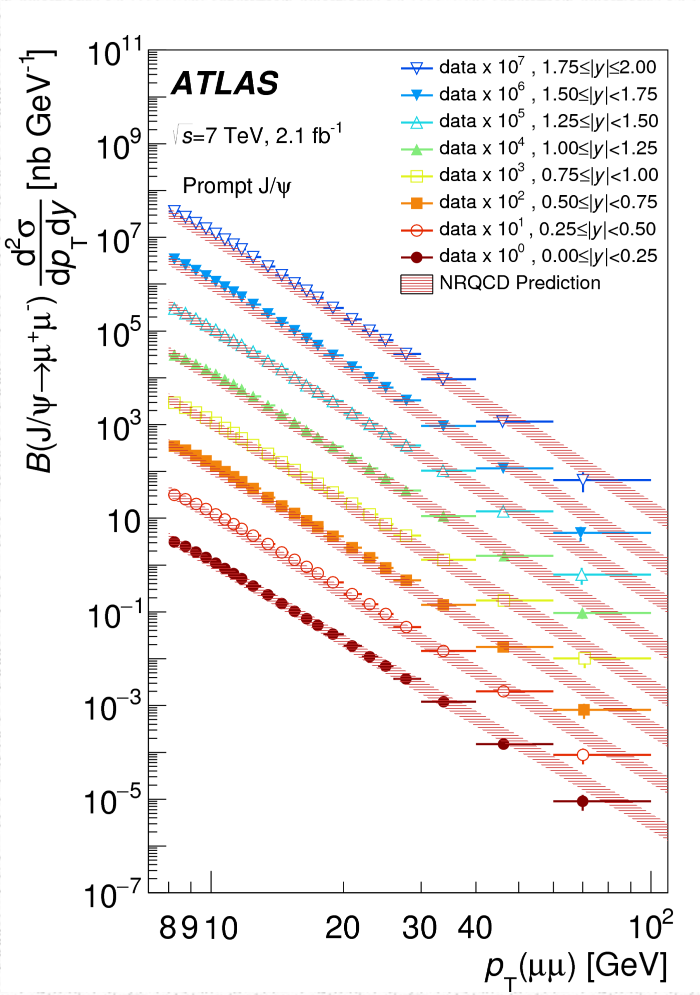


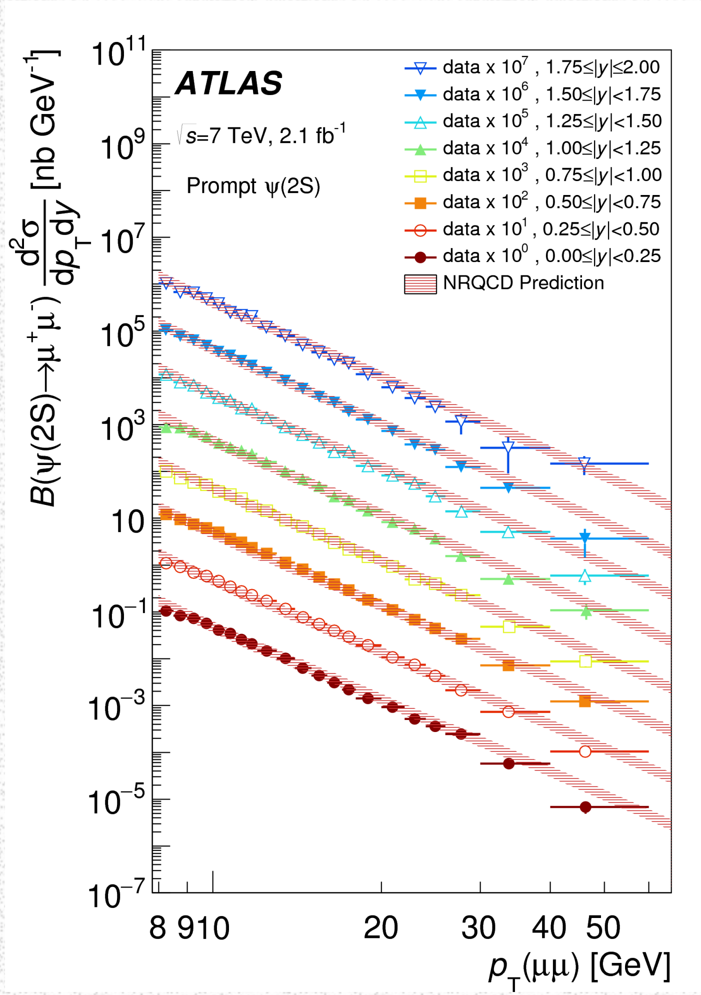


In the next slides: selection of results at 7 TeV

See ***Eur.Phys.J. C76 (2016) 5, 283***

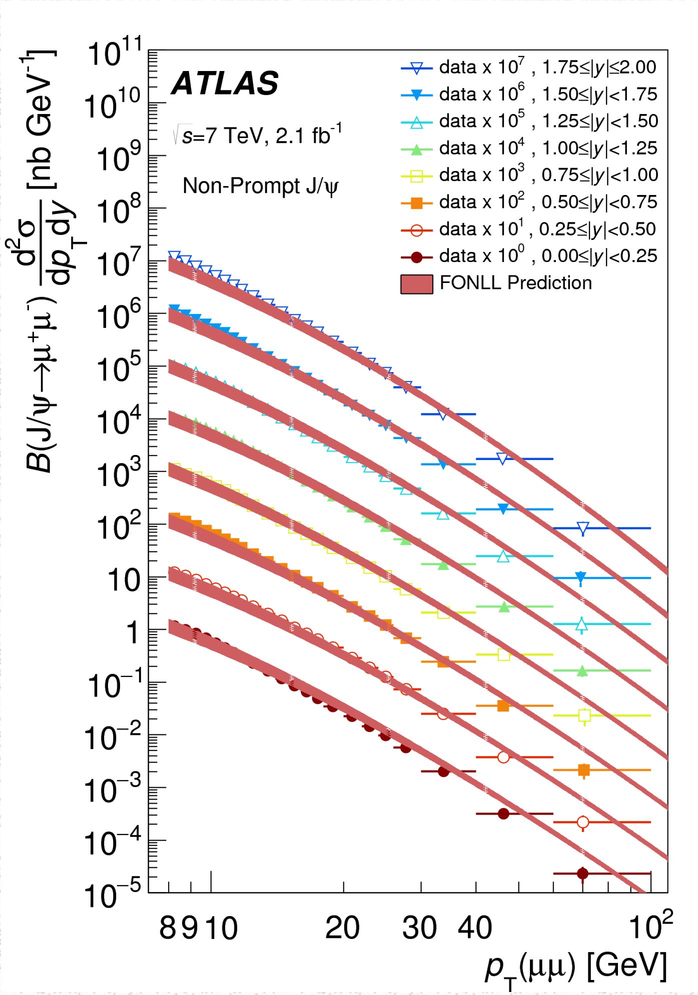
Results – I: prompt production cross-sections vs. $p_T(\mu\mu)$ and |y|. Comparison with NRQCD predictions

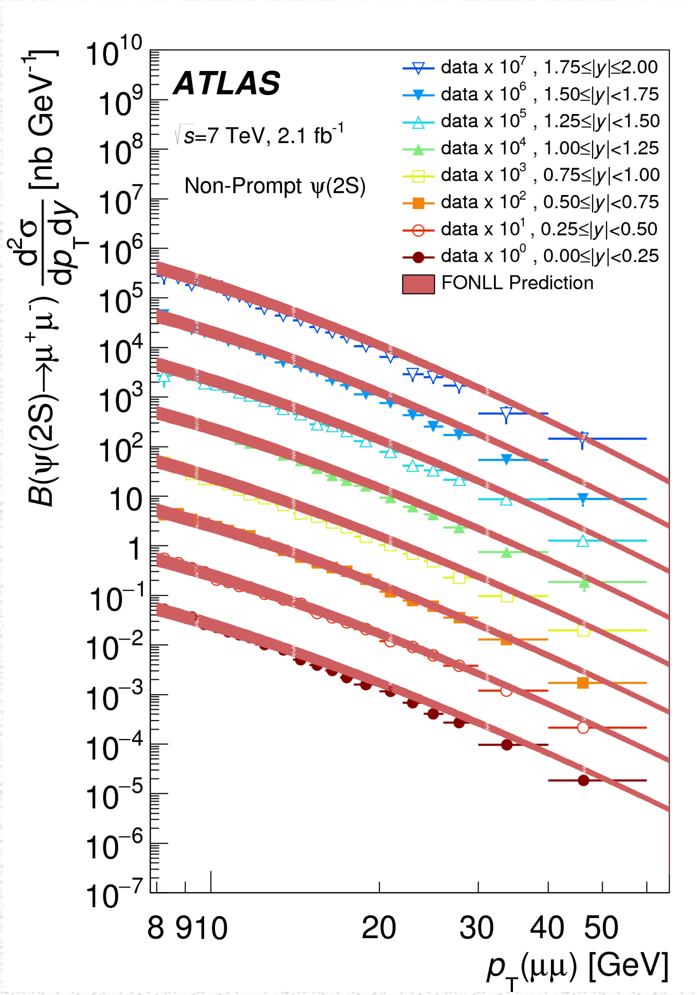




Fair agreement with NRQCD (based on LDMEs) in the whole p_T - |y| range.

Results – II: non-prompt production cross-section vs. $p_T(\mu\mu)$ and |y|. Comparison with FONLL predictions

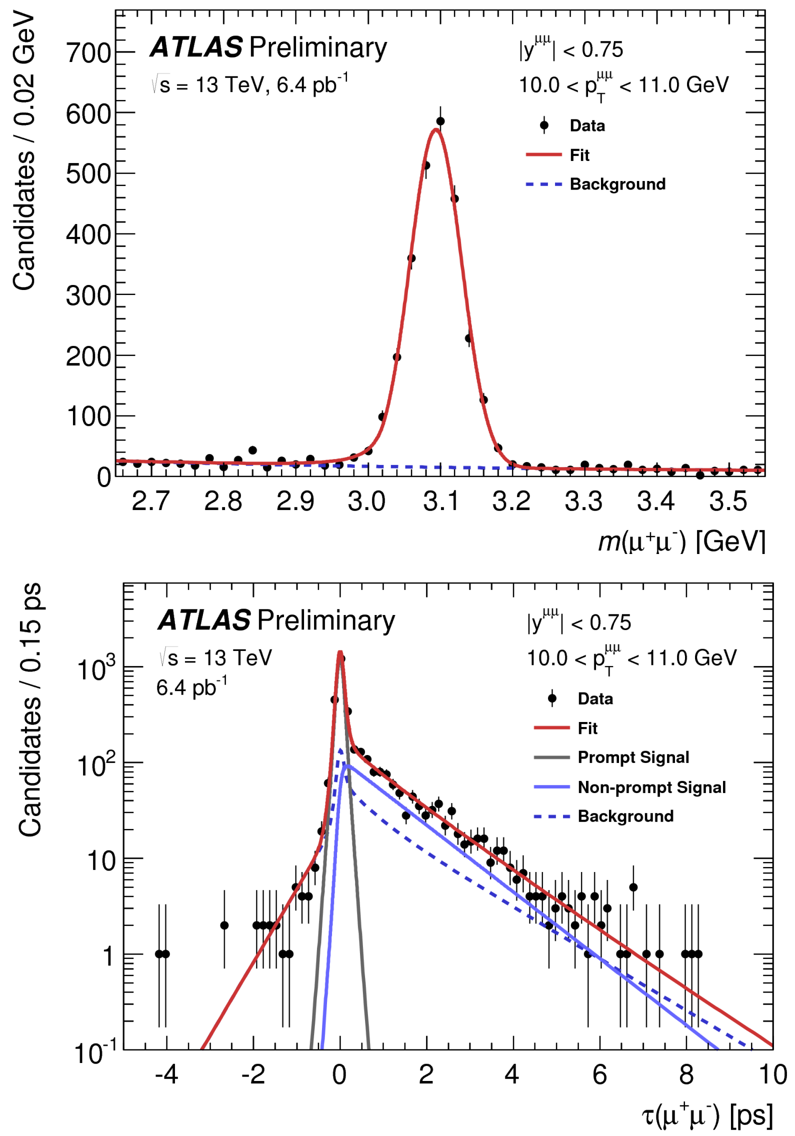




Theory predicts: for J/ψ a slightly harder p_T spectrum; for ψ(2S) higher yields wrt data

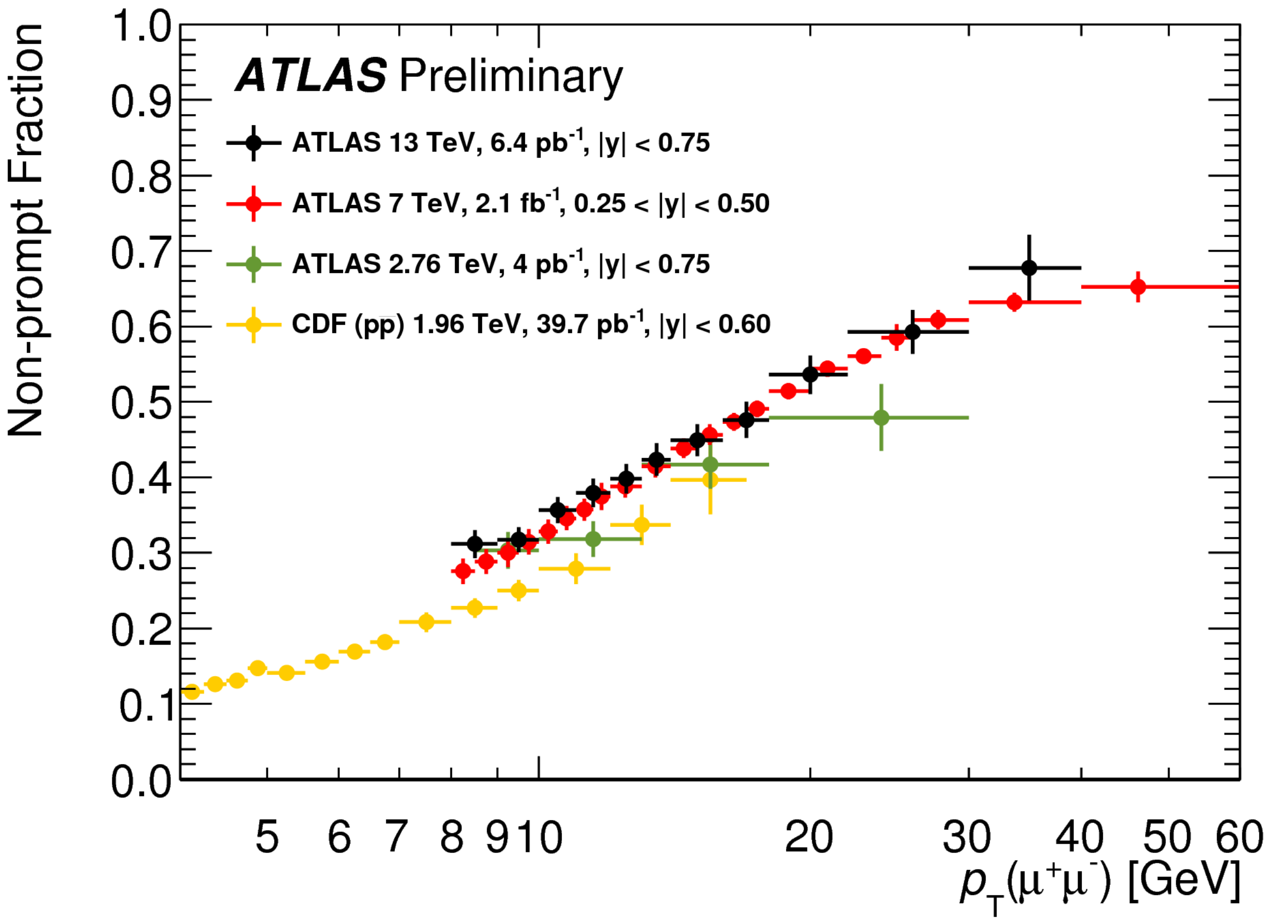
Measurement of the differential non-prompt J/ψ production fraction at √ s = 13 TeV

- Data sample:
  - 6.4 pb^{-1} @ 13 TeV
- Search in the μμ channel
  - Dimuon trigger (p_T>4GeV)
  - Measurement of proper decay time ➔ prompt/non-prompt discrimination
  - Same analysis procedure but lower statistics
- Comparison with data at different c.o.M. energies



See ***ATLAS-CONF-2015-030***

Results: non-prompt J/ψ fraction vs. $p_T(\mu\mu)$ from √s = 2.76 to 13 TeV compared with CDF at √s=1.96 TeV

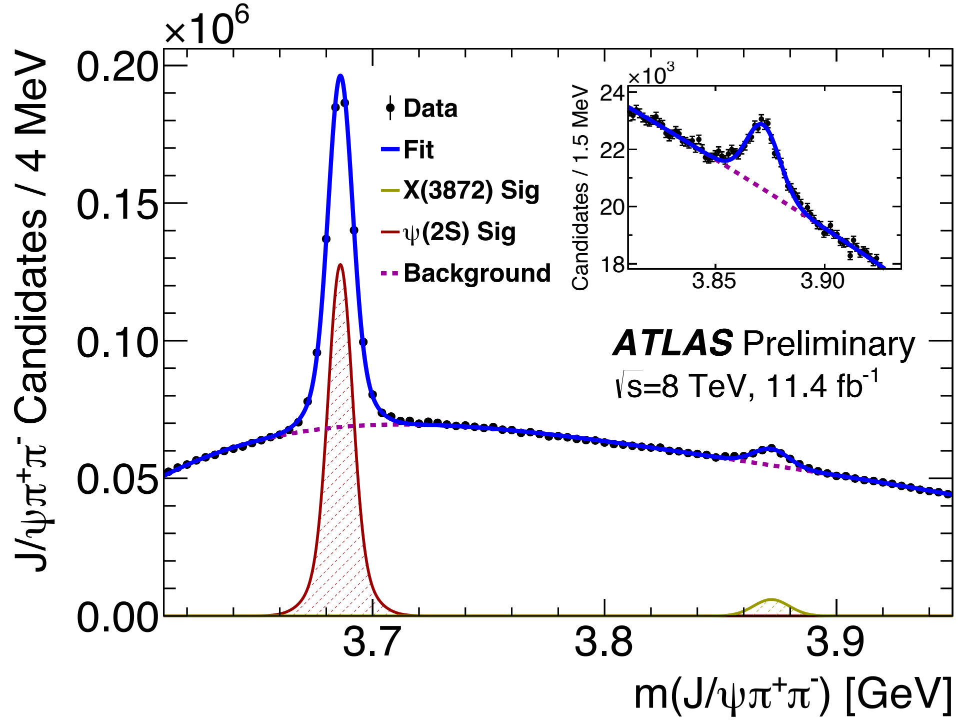


No significant difference btw √s = 7 TeV and √s = 13 TeV data.
Significant difference btw the √s = 7 TeV data and lower √s data.

Production measurements of $\psi(2S)$ and X(3872) decaying to $J/\psi\ \pi^+\pi^-$ at $\sqrt{s}$ = 8 TeV

- Data sample
  - 11.4 fb^{-1} @ 8 TeV
- Search in the $J/\psi\ \pi^+\pi^-$ with $J/\psi \rightarrow \mu\mu$ channel:
  - Dimuon trigger (p_T>4GeV)
  - Measurement of proper decay time ➔ prompt/non-prompt discrimination
  - Attempt to discriminate short and long lifetime components for X(3872)
  - Analysis of $m(\pi\pi)$ spectra
- Analysis vs. p_T and y in the range |y|<0.75 and $10<p_T<70$ GeV

See **ATLAS-CONF-2016-028**.

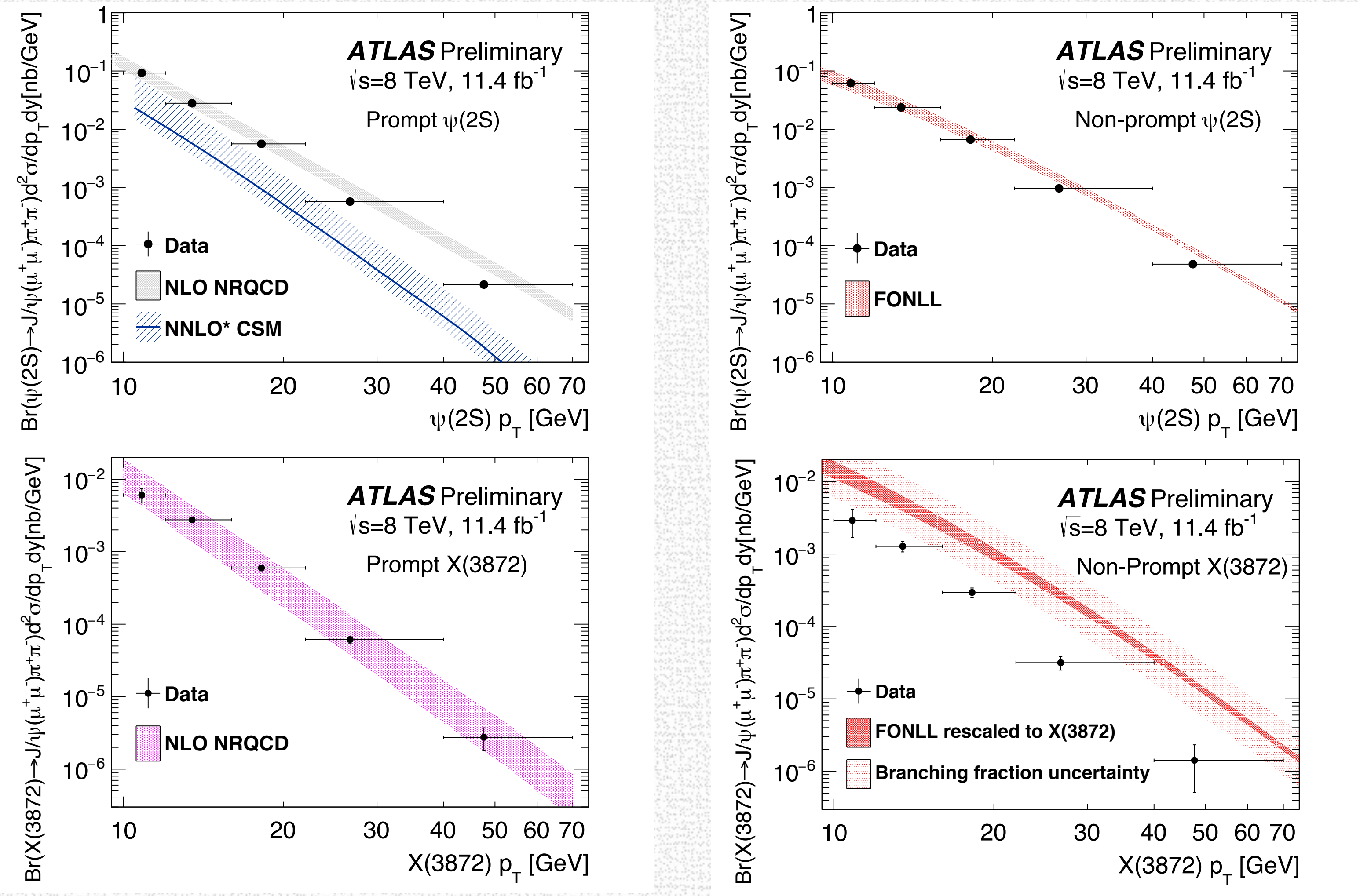


X(3872) "exotic" candidate:
CMS data disagrees with D^0D^{0*} molecule hypothesys

$X(3872) = D^0D^{0*} + \chi_{c1}(2P)$

NRQCD incorporates this recipe CMS ok

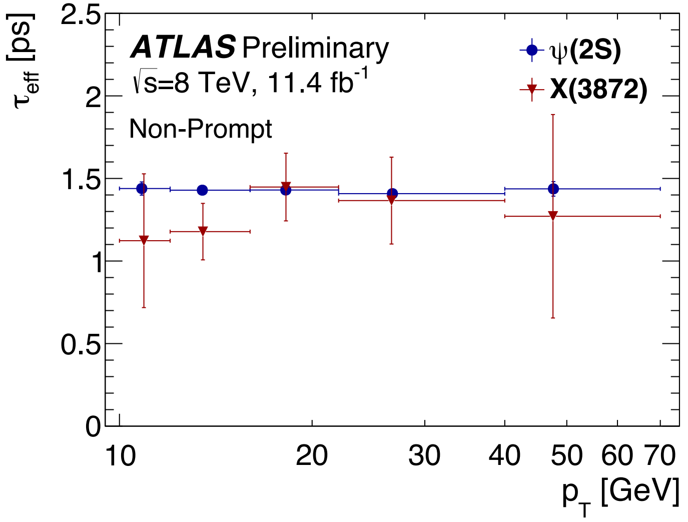
Results – I: prompt and non-prompt ψ(2S) and X(3872) production vs. p_T: comparison with theory



ψ(2S): well described by NLO NRQCD (prompt) and FONLL (non-prompt)
X(3872): well described by CMS-like mixing (prompt) not by FONLL (non-prompt)

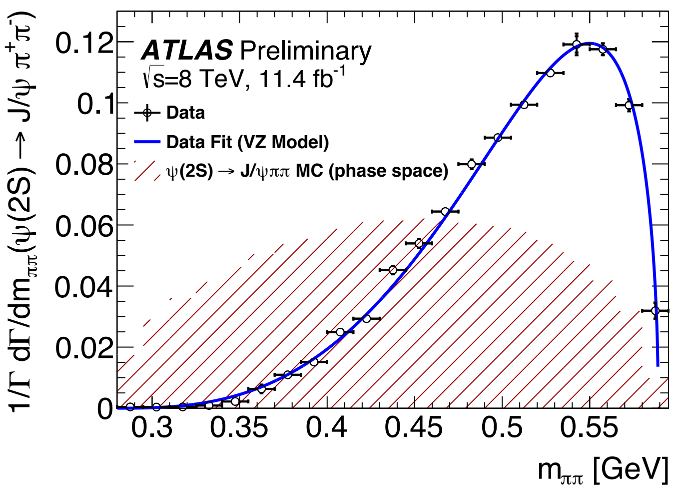
Results – II: short vs. long-lived X(3872) non-prompt production; m(ππ) spectra

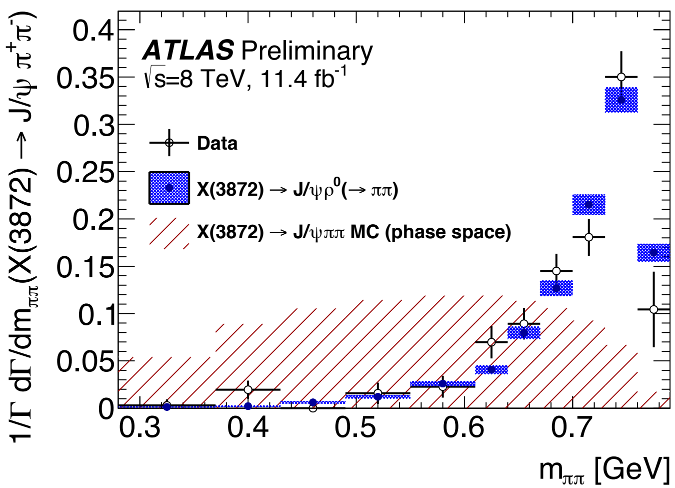
Double-exponential non-prompt time distributions tried for X non-prompt:
→ **ψ(2S)**: a single-exponential is ok
→ **X(3872)**: short-lived (due to B_c) and long-lived (due to B, B*, Bs)
R = (SL)/(LL) = (25±10(stat)±2(syst)±5(spin))%



Analysis of m(ππ) spectra:

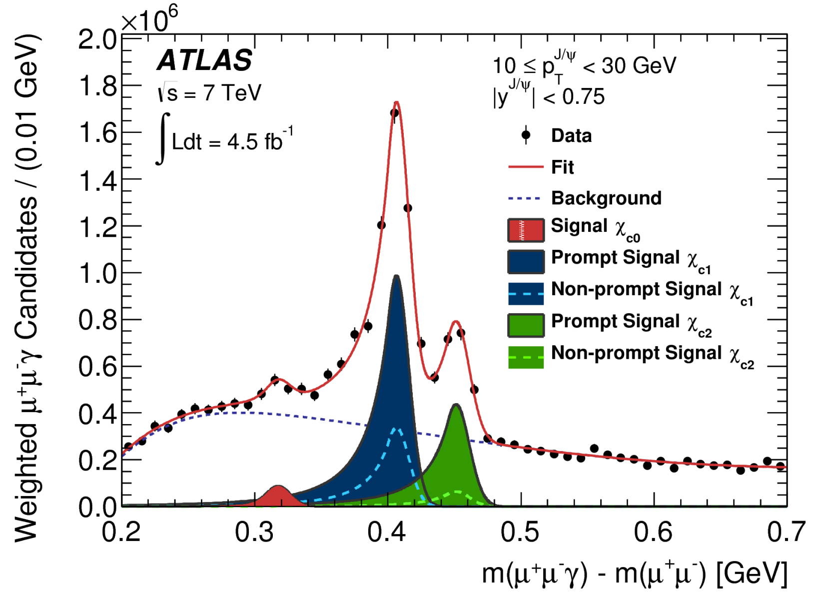
→ **ψ(2S)**: good agreement with Voloshin-Zakharov formula **λ=4.16±0.08**
→ **X(3872)** evidence of ***ρ-dominance*** in the decay

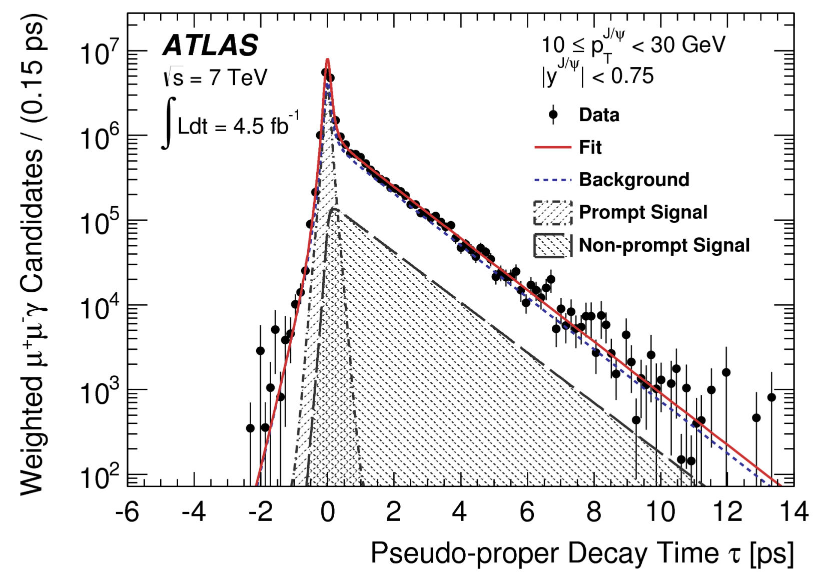




Measurement of χ_{c1} and χ_{c2} production with $\sqrt{s}$ = 7 TeV pp collisions

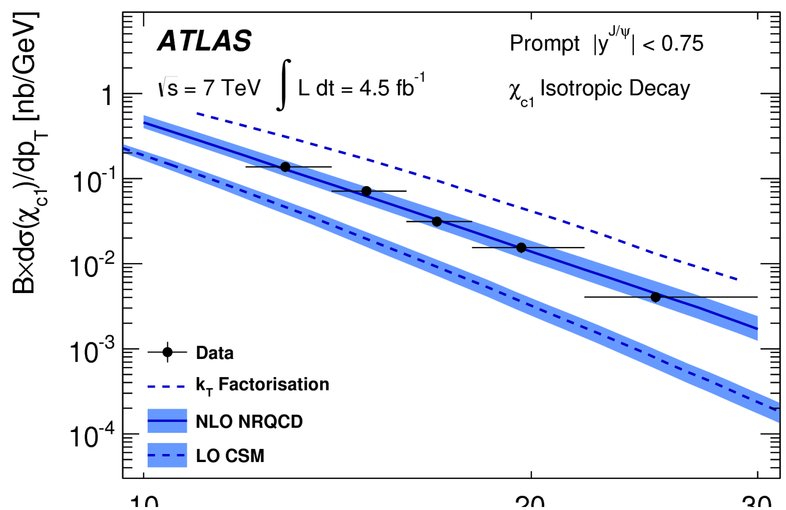
- Data sample
  - 4.5 fb^{-1} @ 7 TeV
- Search in the $J/\psi\ \gamma$ with $J/\psi \rightarrow \mu\mu$ channel
  - Dimuon trigger (p_T>4 GeV)
  - γ detection through $\gamma \rightarrow e^+e^-$ conversion
  - Measurement of proper decay time ➔ prompt/non-prompt discrimination
- Differential distributions in $p_T(\chi_{cJ})$ and $p_T(J/\psi)$

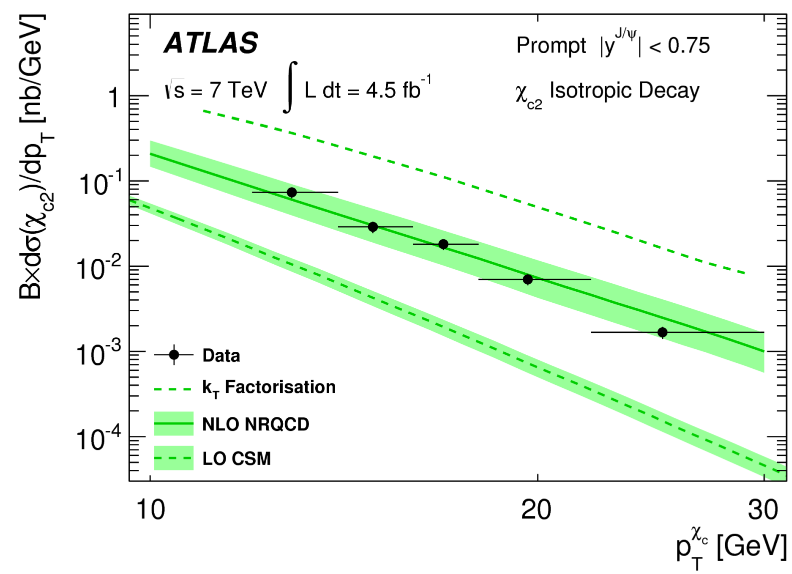


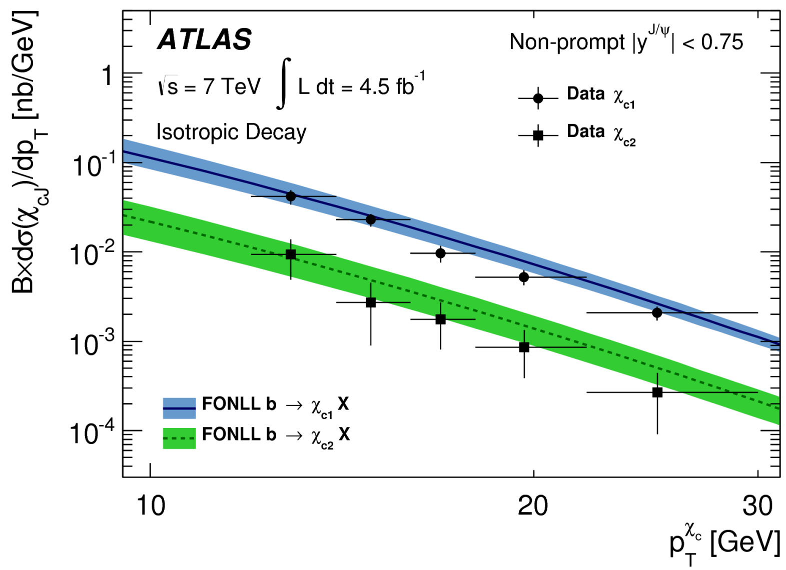


See *JHEP 07 (2014) 154*

Results: prompt and non-prompt χ_{c1} and χ_{c2} production vs. $p_T(\chi_c)$ compared to theory







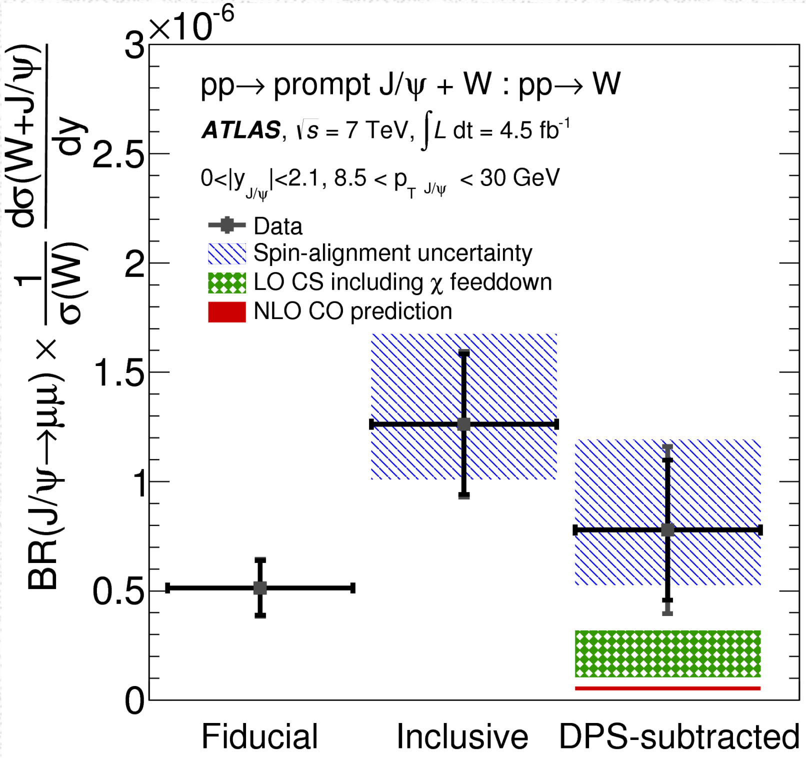
→ Good description of prompt data with NLO NRQCD model

→ LO CSM significantly below the data

→ Good description of non-prompt data with FONLL model

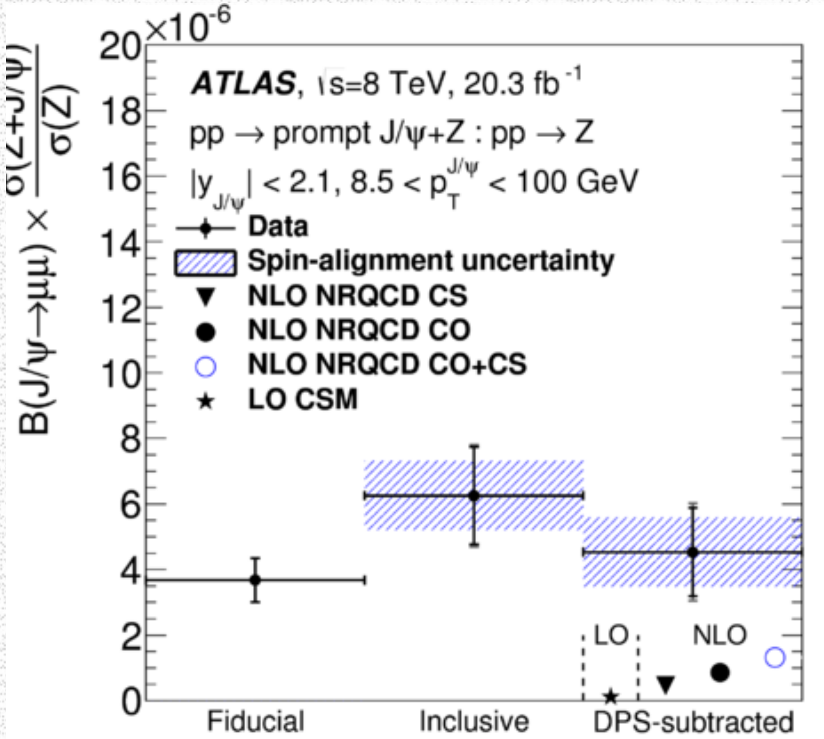
Measurement of associated production of the J/ψ with vector bosons W and Z

J/ψ +W: DPS-subtracted cross-section compared to CS and CO production models



See *JHEP 04 (2014) 172*

J/ψ +Z: DPS-subtracted cross-section compared to NLO NRQCD and LO CSM production models



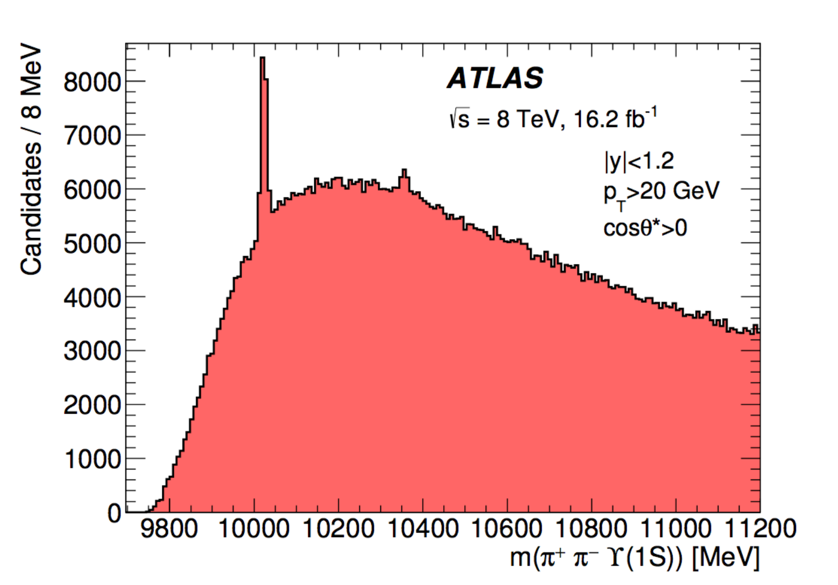
See *Eur. Phys. J. C75 (2015) 229*

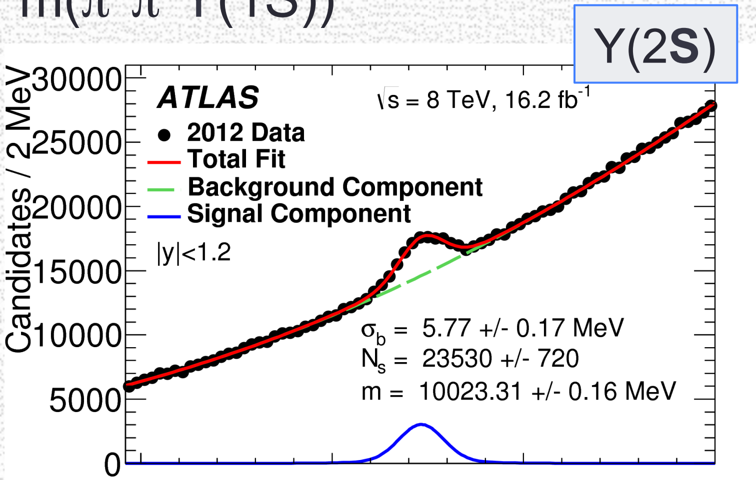
No model describes the large values of the associated production

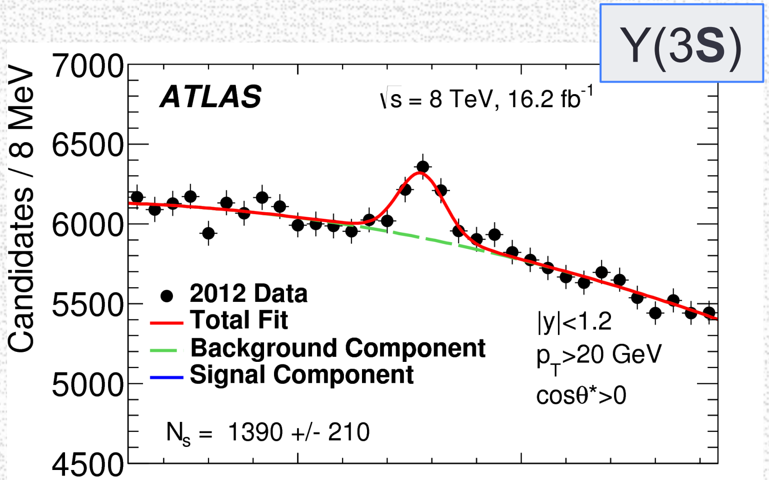
Search for the X_b and other hidden-beauty states in the $\pi^+\pi^-\Upsilon(1S)$ channel

- Search for possible "exotic" X_b states (predicted mass=10.5÷10.7 GeV), decaying to $\pi^+\pi^-\Upsilon(1S)$ with similar properties of X(3872)
- Data sample: 16.2 fb^{-1} @ 8 TeV - dimuon trigger (p_T>4 GeV) + four-track common vertex fit

→ $m(\pi^+\pi^-\Upsilon(1S))$

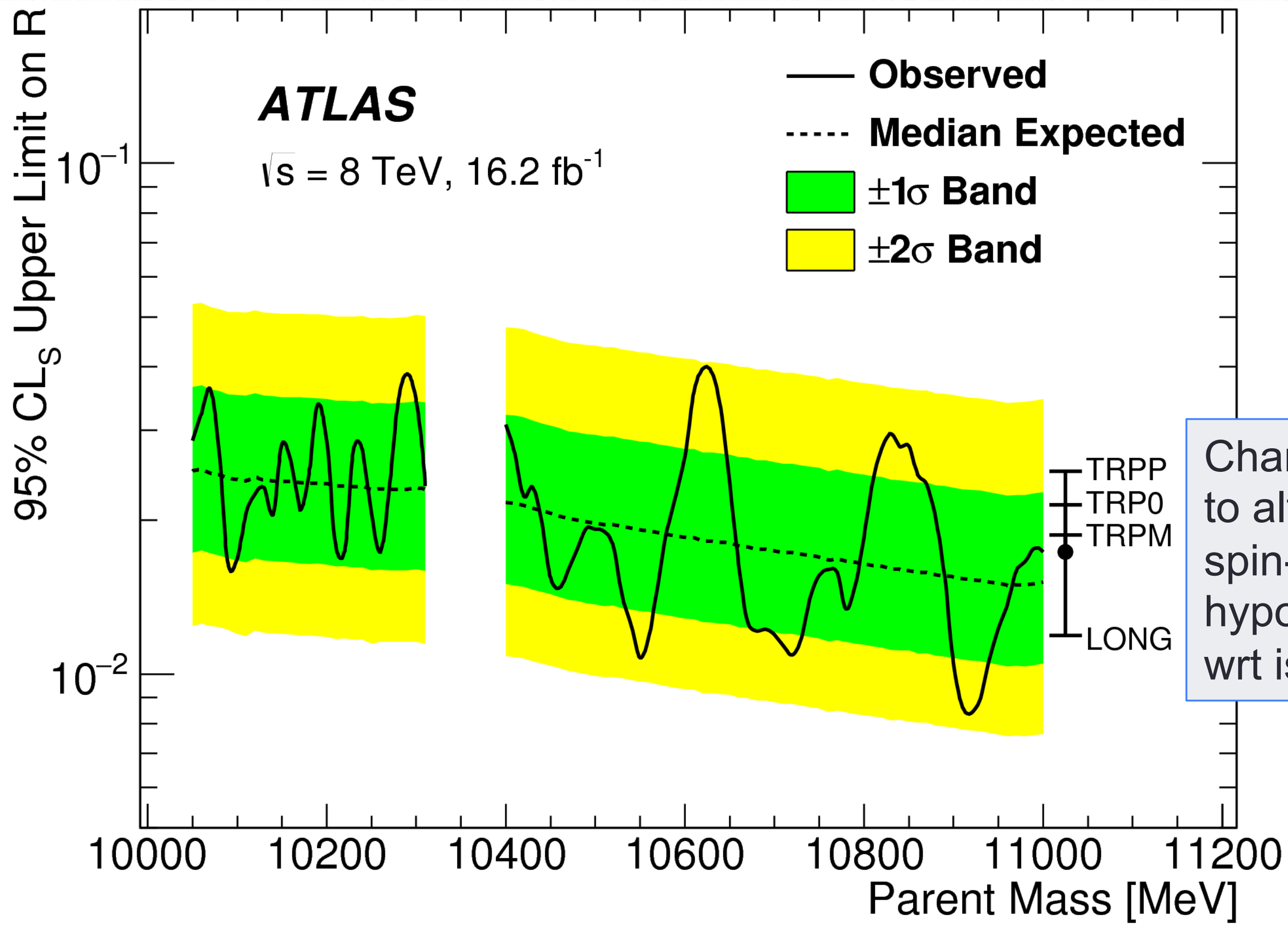






See *Phys. Lett. B740 (2015) 199-217*

Results: upper limits on the product of the X_b cross section and branching fraction, relative to those of the Υ(2S)



Changes due to alternative spin-alignment hypotheses wrt isotropy

Quarkonia - summary

- Prompt charmonium production well described by NLO NRQCD. Predictions from NNLO* colour-singlet model calculations underestimate the data, especially at higher transverse momenta.
- Non-prompt charmonium production reasonably well described by FONLL (with the exception of X(3872)).
- No good description yet of J/ψ + W, Z data
- X(3872) prompt data are in agreement with "mixed interpretation"
- No X_b states found in the 10 ÷ 11 GeV mass range.
- Other ATLAS results on quarkonia:
  - Cross-section measurement of $\psi(2S) \rightarrow J/\psi\ (\rightarrow \mu^+\mu^-)\ \pi^+\pi^-$ at $\sqrt{s}$ = 7TeV (***JHEP 09 (2014) 079***)
  - Inclusive Υ(nS) differential cross sections and ratios (***Phys. Rev. D 87 (2013) 052004***)
  - Observation of a new χ_b state in radiative transitions to Υ(1S) and Υ(2S) (***Phys. Rev. Lett. 108 (2012) 152001***)

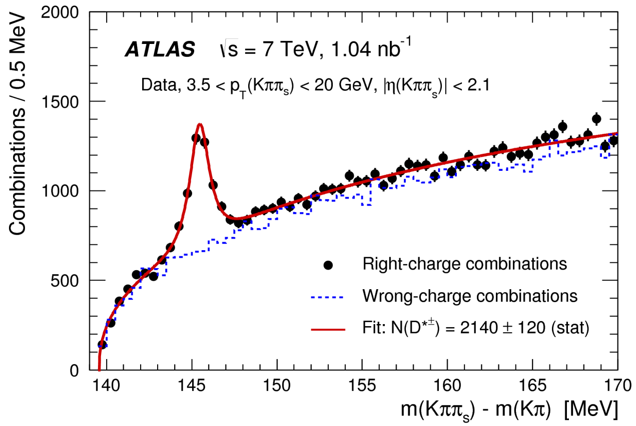
Measurement of $D^{*\pm}$, $D^{\pm}$ and $D_s^{\pm}$ meson production cross sections in pp collisions at $\sqrt{s}$=7 TeV

- Data sample: 280 nb^{-1} @ 7 TeV, search in the $K\pi\pi$ ($KK\pi$) final state
- MBTS trigger + jet trigger (p_T>5,10,15 GeV)
- D mesons reconstructed in 3.5 < $p_T(D)$ < 100 GeV, $|\eta(D)|$ < 2.1
- From the observed peaks ➔ production cross-sections vs.

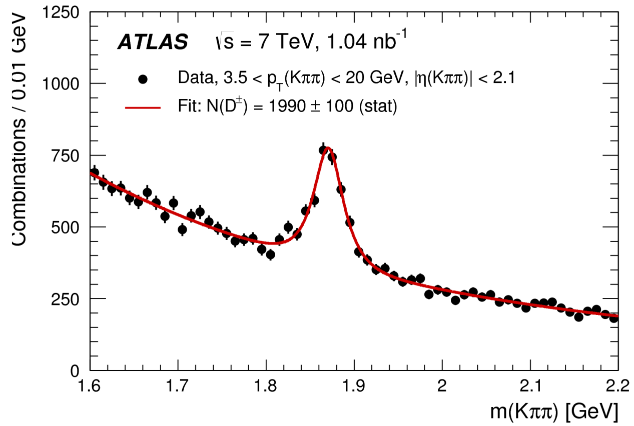
p_T and η (for D_s the statistics is too small)

- Comparison with GM-VFNS, FONLL, MC@NLO, POWHEG

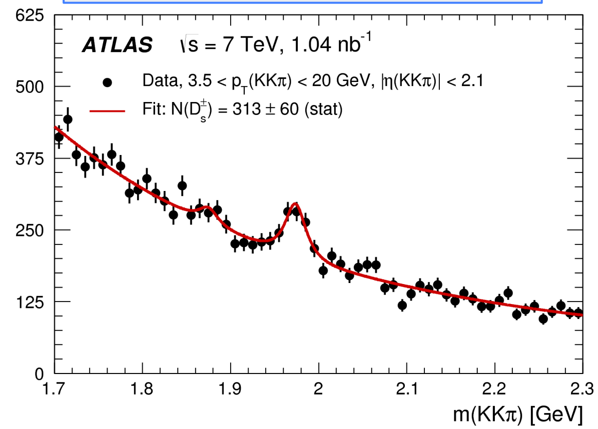
$D^{*\pm}$ 3.5<p_T<20 GeV



$D^{\pm}$ 3.5<p_T<20 GeV

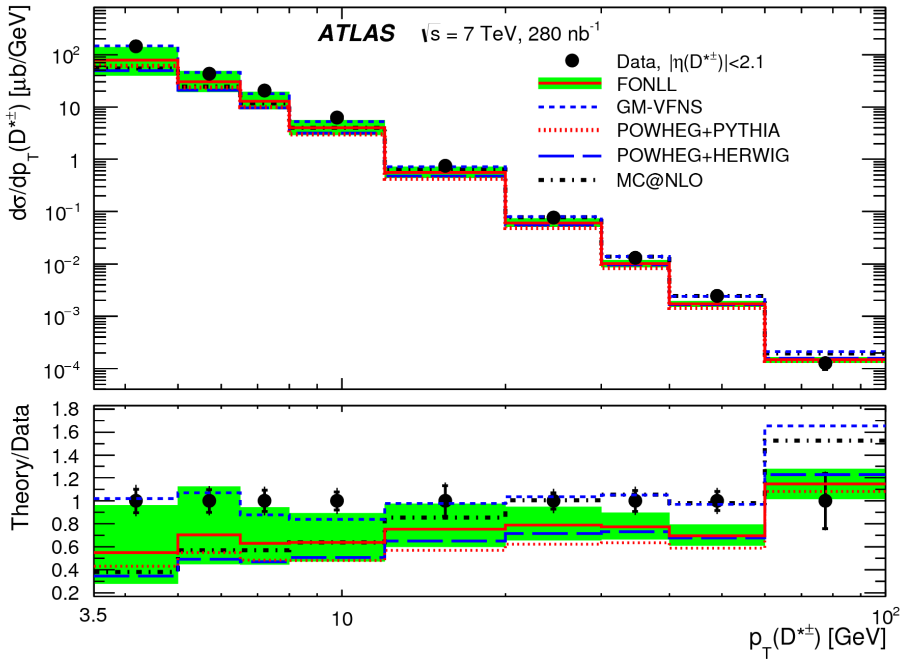


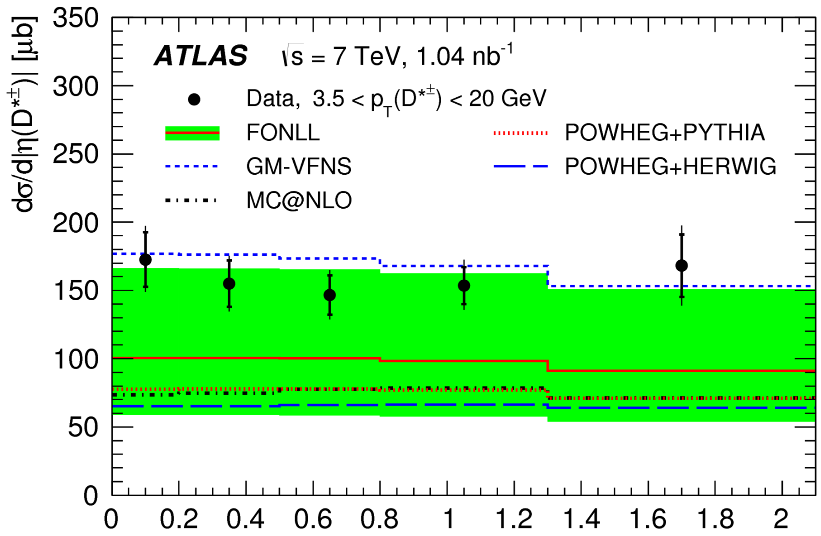
$D_s^{\pm}$ 3.5<p_T<20 GeV

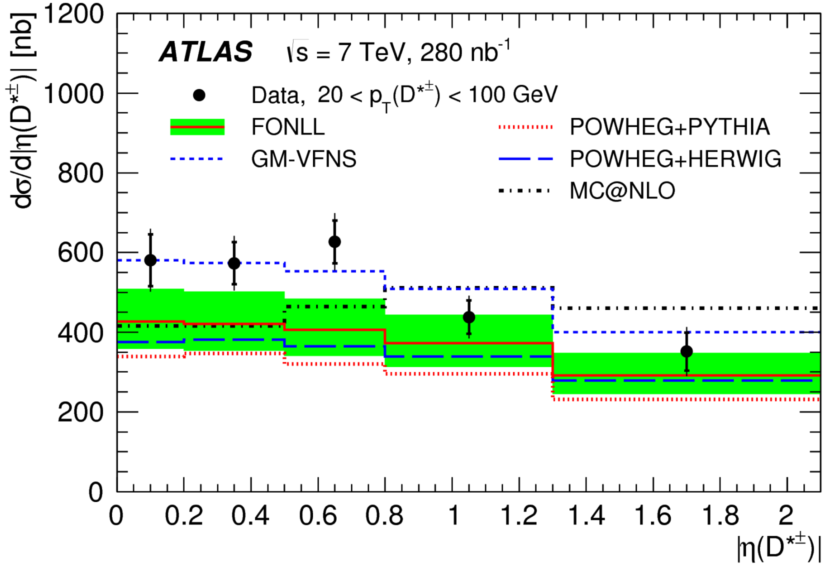


See ***Nucl.Phys. B907 (2016) 717***

Results-I: $D^{*\pm}$ cross-sections vs. p_T and η

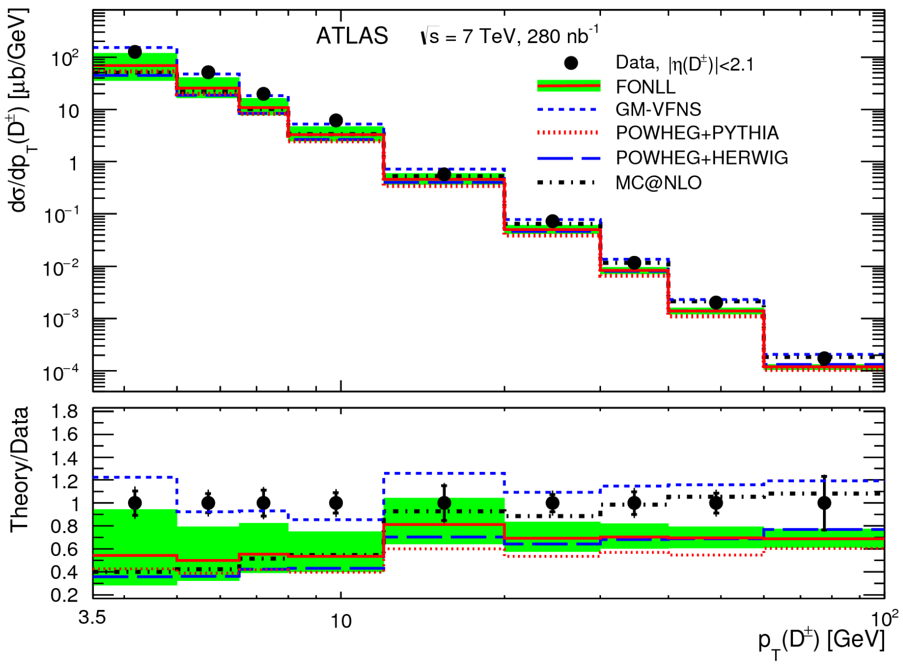


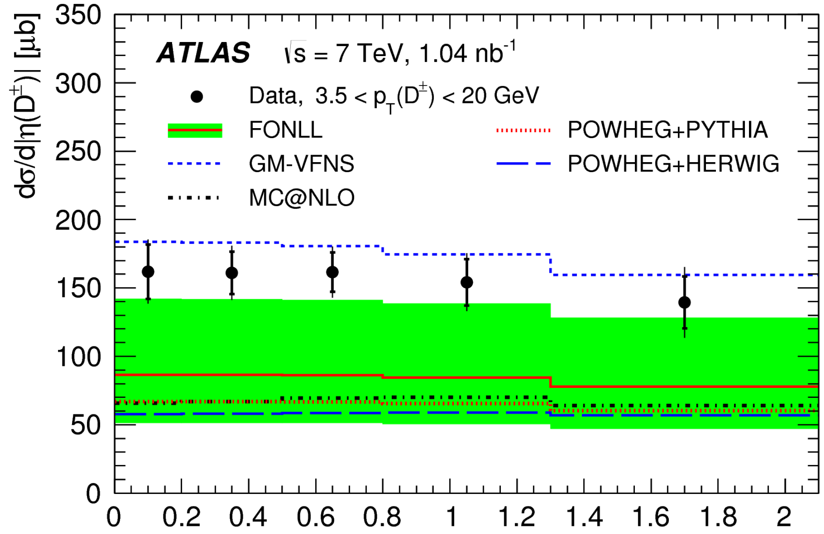


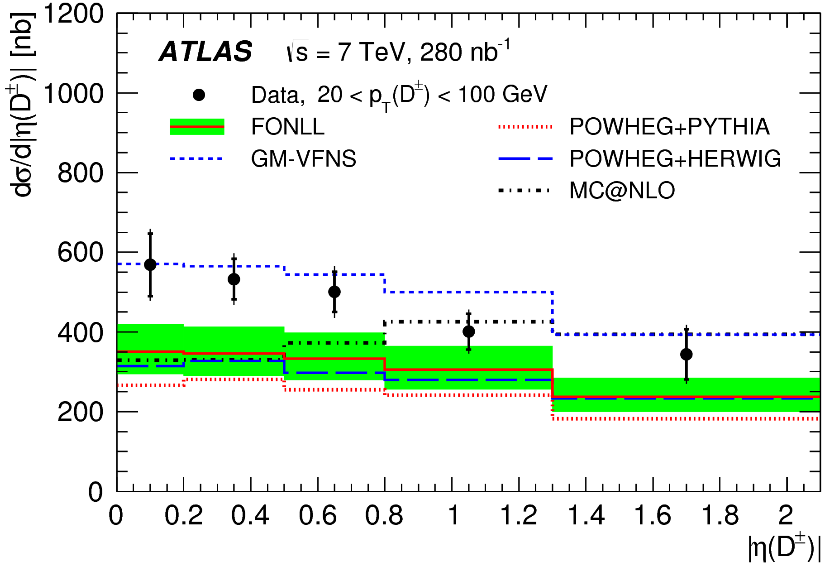


- FONLL, MC@NLO and POWHEG generally below the data.
- MC@NLO show also shape discrepancies.
- GM-VFNS agree with data in both shape and normalisation.

Results-II: $D^{\pm}$ cross-sections vs. p_T and η







Same considerations as for the D*.

Results – III: total cross-section and fragmentation ratios

→ From D*, D visible cross-sections extrapolate to total cross-sections
→ From D*, D total cross-sections to charm cross-section (applying fragm.fractions)

$$\sigma_{c\bar{c}}^{\text{tot}} = 8.6 \pm 0.3\,(\text{stat}) \pm 0.7\,(\text{syst}) \pm 0.3\,(\text{lum}) \pm 0.2\,(\text{ff})^{+3.8}_{-3.4}\,(\text{extr})\,\text{mb}$$

From D*, D D_s total cross-sections
→Charm fragmentation ratios

$$\gamma_{s/d} = 0.26 \pm 0.05\,(\text{stat}) \pm 0.02\,(\text{syst}) \pm 0.02\,(\text{br}) \pm 0.01\,(\text{extr})\,,$$

$$P_{\text{v}}^{d} = 0.56 \pm 0.03\,(\text{stat}) \pm 0.01\,(\text{syst}) \pm 0.01\,(\text{br}) \pm 0.02\,(\text{extr})\,.$$

Determination of the ratio of *b*-quark fragmentation fractions f_s/f_d in *pp* collisions

Fragmentation fraction $f_{s,d}$ = P(g→ss,dd) × (b-quark s(d)-quark overlap)

$f_u + f_d + f_s + f_c + f_{baryon} = 1$ ➔ f_s important to interpret rare B decays

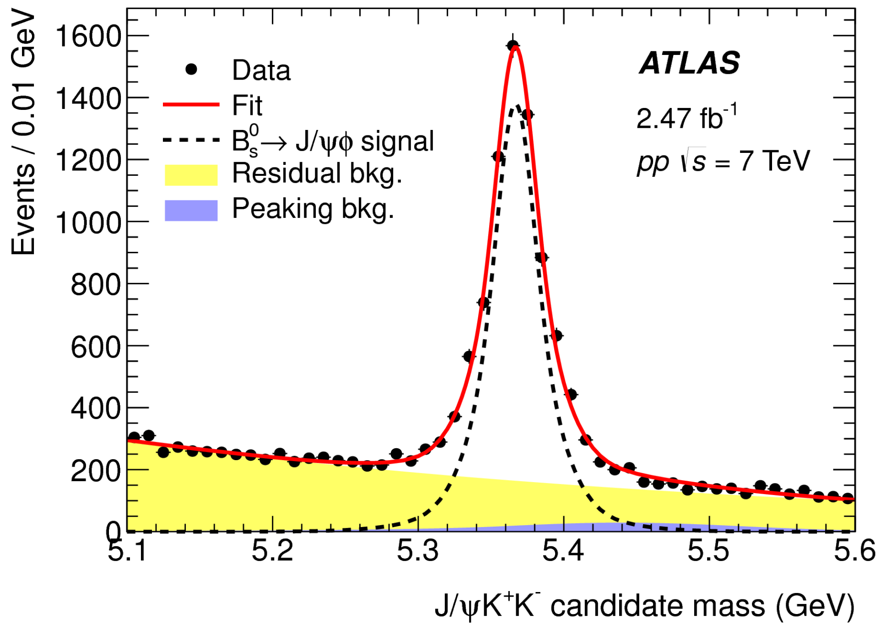
Data sample: 2.47 fb^{-1} @7 TeV: dimuon trigger + 4-tracks vertex fit

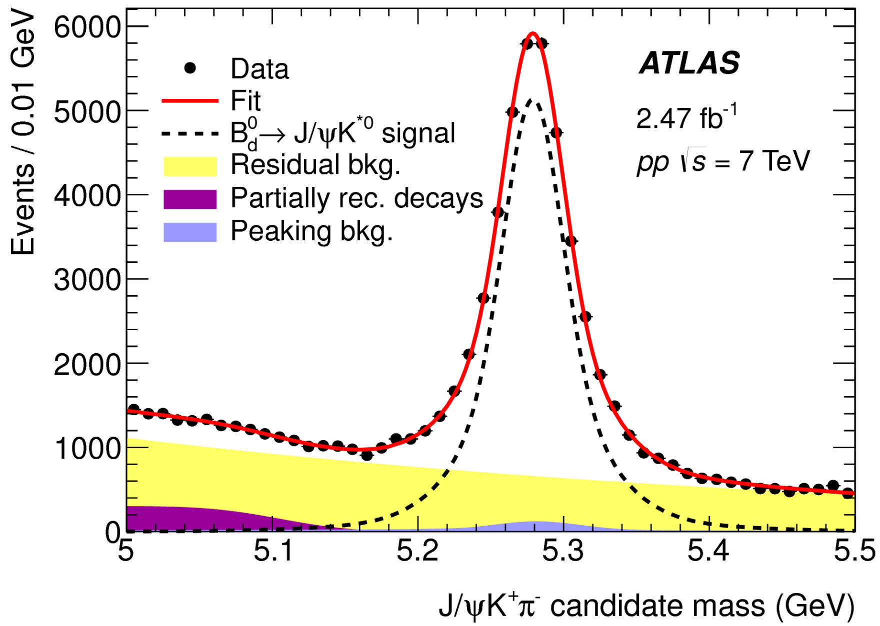
Count the number of:

$B_s^0 \to J/\psi\, \phi \to \mu^+\mu^- K^+K^-$

$B_d^0 \to J/\psi\, K^{*0} \to \mu^+\mu^- K^+\pi^-$

$$\frac{f_s}{f_d} = \frac{N_{B_s^0}}{N_{B_d^0}} \frac{\mathcal{B}(B_d^0 \to J/\psi K^{*0})}{\mathcal{B}(B_s^0 \to J/\psi \phi)} \frac{\mathcal{B}(K^{*0} \to K^+\pi^-)}{\mathcal{B}(\phi \to K^+K^-)} \mathcal{R}_{\rm eff}$$





See ***Phys. Rev. Lett. 115, 262001 (2015)***

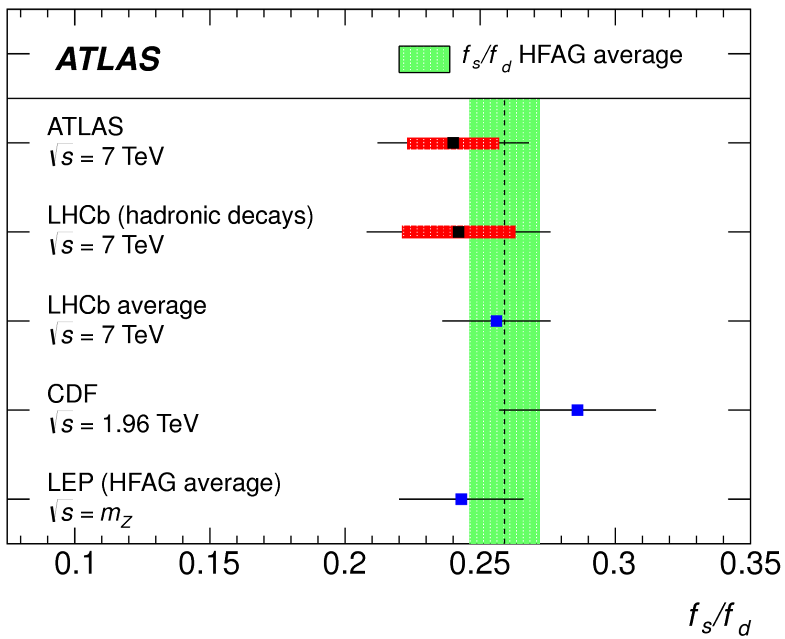
Results: comparison with previous measurements

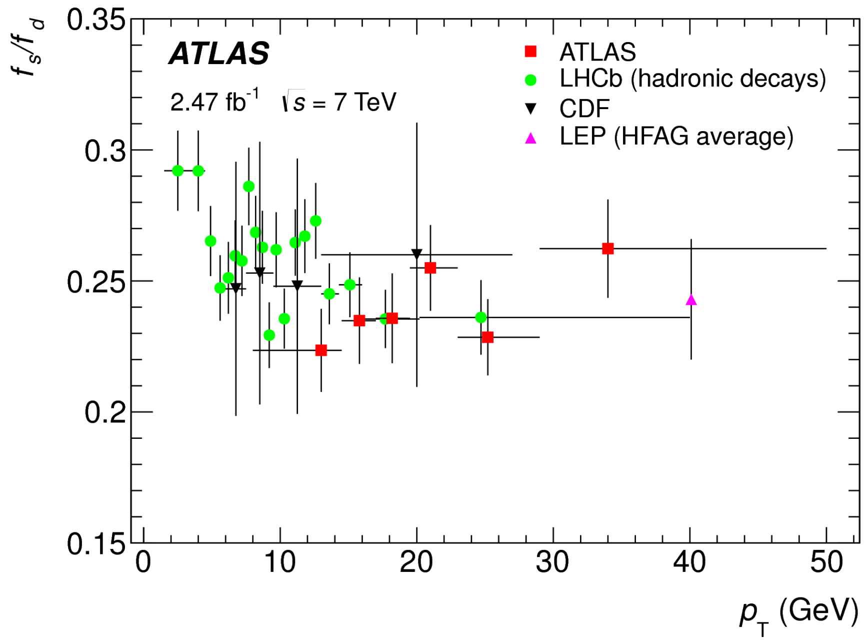
Observable	Value	σ	Ref.
$N_{B_s^0}$	$6640 \pm 100 \pm 220$	3.3%	
$N_{B_d^0}$	$36290 \pm 320 \pm 650$	1.8%	
$\mathcal{R}_{\text{eff}}$	$0.799 \pm 0.001 \pm 0.010$	1.3%	
$\mathcal{B}(\phi \to K^+K^-)$	0.489 ± 0.005	1.0%	[15]
$\mathcal{B}(K^{*0} \to K^+\pi^-)$	0.66503 ± 0.00014	0.02%	[15]
Total		4.1%	

$$\frac{f_s}{f_d} = 0.240 \pm 0.004(stat) \pm 0.010(syst) \pm 0.017(th)$$

Systematics: mainly from fit procedure and acceptance

Theory: due to the theoretical predictions on $BR(B_s^0 \to J/\psi\ \phi) / BR(B_d^0 \to J/\psi\ K^{*0})$





Open HF summary

- GM-VFNS gives the best description of open charm data
- FONLL and POWHEG describes well the open beauty data
- A new measurement of f_s/f_d extending the pT range
- Many other ATLAS results on open charm/beauty:
  - Measurement of *b*-quark fragmentation fractions f_s/f_d
  (***Phys. Rev. Lett. 115, 262001 (2015)***)
  - Observation and branching fraction of $\Lambda^0_b \to \psi(2S)\Lambda^0$ decay
  (***Phys. Lett. B 751 (2015) 63-80***)
  - Branching fractions of $B_c^+ \to J/\psi D_s^+$ and $B_c^+ \to J/\psi D_s^{*+}$ and transverse polarization fraction in the latter decay
  (***Eur. Phys. J. C, 76(1), 1 (2016)***)
  - Observation of an excited $B^{\pm}_c$ meson state with the ATLAS detector
  (***Phys. Rev. Lett. 113 (2014) 212004***)
  - Parity violating asymmetry parameter α_b and the helicity amplitudes for the decay $\Lambda_b^0 \to J/\psi\ \Lambda^0$
  (***Phys. Rev. D 89 (2014) 092009***)
  - b-hadron production cross-section from D*μX final states
  (***Nucl. Phys. B 864 (2012) 341-381***)

Conclusion and outlook

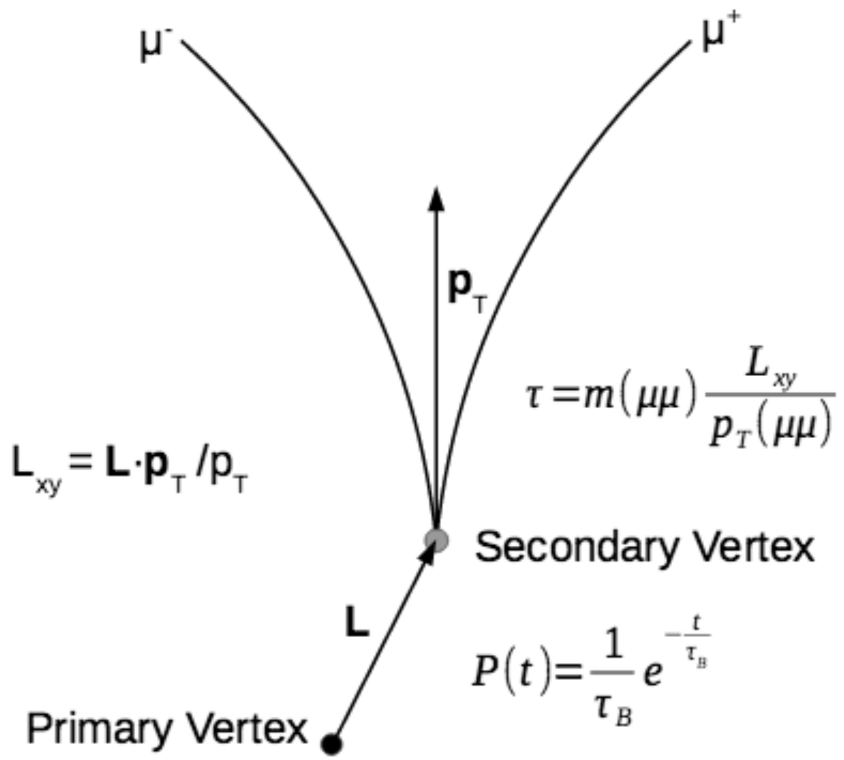
- ATLAS is carrying on a systematic study of Heavy Flavour production in pp collisions from 2.76 to 13 TeV c.o.M. energies.
- The excellent performance of the muon trigger and of the inner detector tracking allows to cover a large kinematic range thus challenging the theoretical predictions.
- Many analyses in progress:
  - Extension of the present analyses to wider kinematical ranges;
  - New exotic searches.

BACKUP

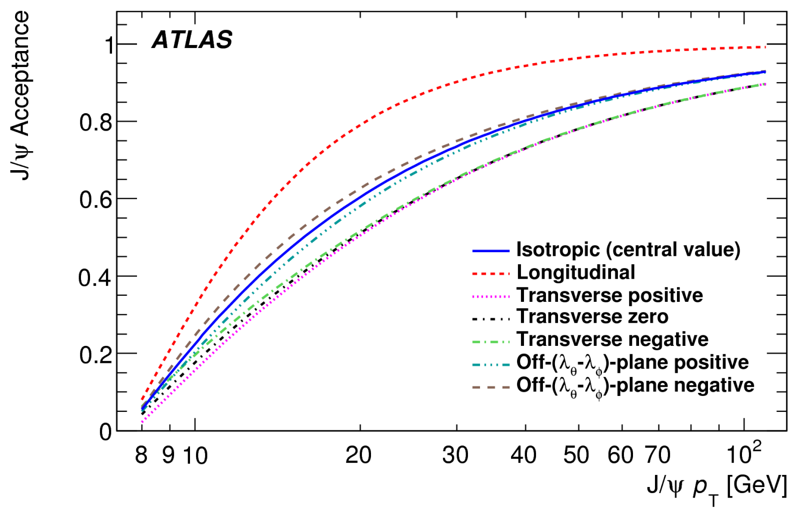
Measuring the Pseudo-proper Decay Time

Pseudo-proper Decay Time

- Distinguishes non-prompt and prompt sources
- **L**: distance from the primary vertex to the secondary vertex
- Use signed L_{xy} as a proxy for b-hadron decay length
- Good approximation when ψ momentum and b-hadron momentum are aligned



Trigger acceptance and efficiencies
Fit parametrization



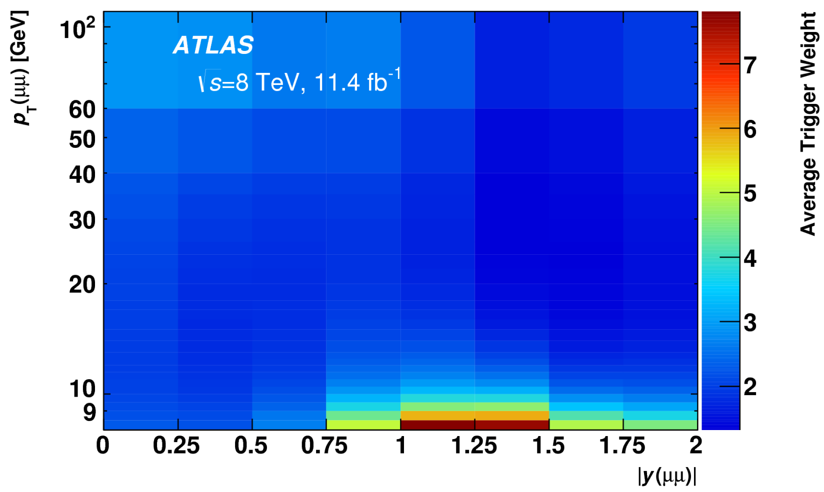
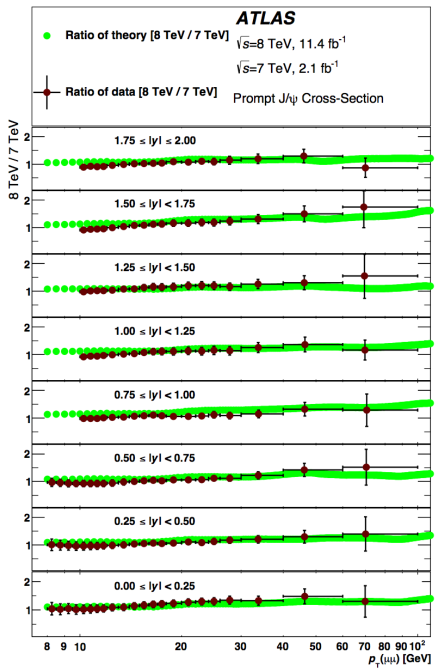
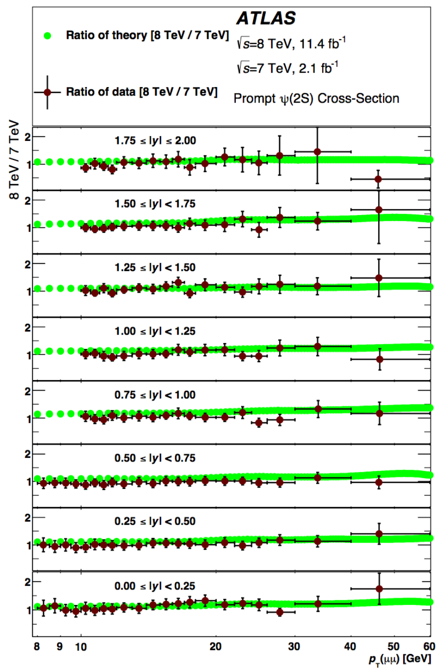


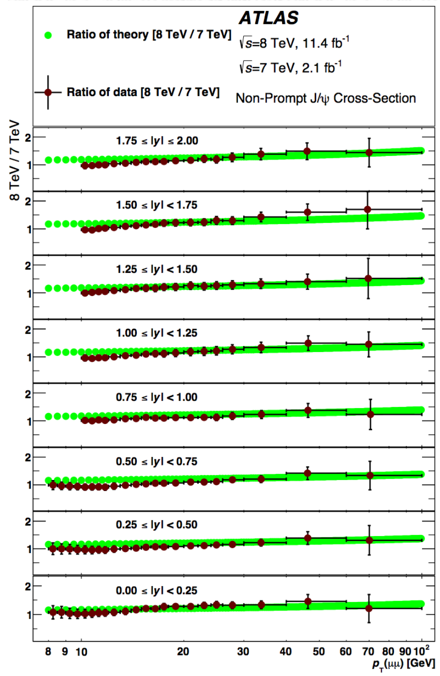
Table 2: Description of the fit model PDF in Eq. 3. Components of the probability density function used to extract the prompt (P) and non-prompt (NP) contributions for J/ψ and $\psi(2S)$ signal and the P, NP, and incoherent or mis-reconstructed background (Bkg) contributions.

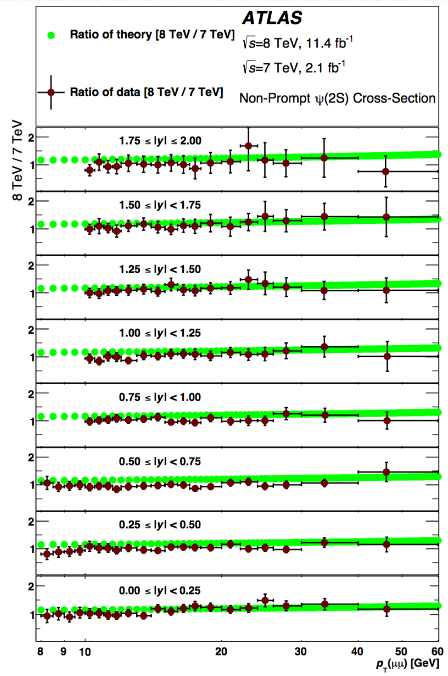
i	Type	Source	$f_i(m)$	$h_i(\tau)$
1	J/ψ	P	$\omega B_1(m) + (1-\omega)G_1(m)$	$\delta(\tau)$
2	J/ψ	NP	$\omega B_1(m) + (1-\omega)G_1(m)$	$E_1(\tau)$
3	$\psi(2S)$	P	$\omega B_2(m) + (1-\omega)G_2(m)$	$\delta(\tau)$
4	$\psi(2S)$	NP	$\omega B_2(m) + (1-\omega)G_2(m)$	$E_2(\tau)$
5	Bkg	P	F	$\delta(\tau)$
6	Bkg	NP	$C_1(m)$	$E_3(\tau)$
7	Bkg	NP	$E_4(m)$	$E_5(\|\tau\|)$

Results: scaling 7-8 TeV









J/ψ, ψ(2S): error budget

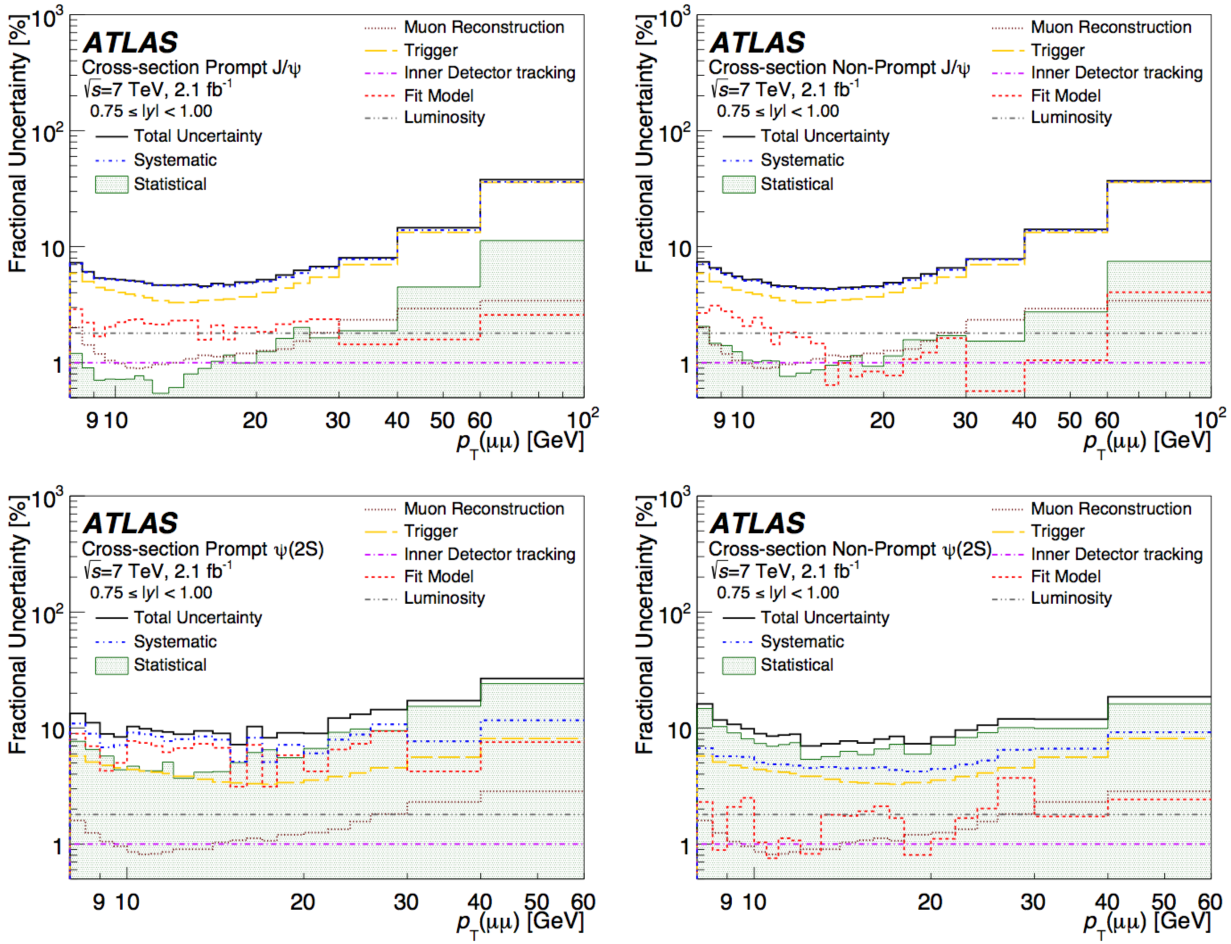
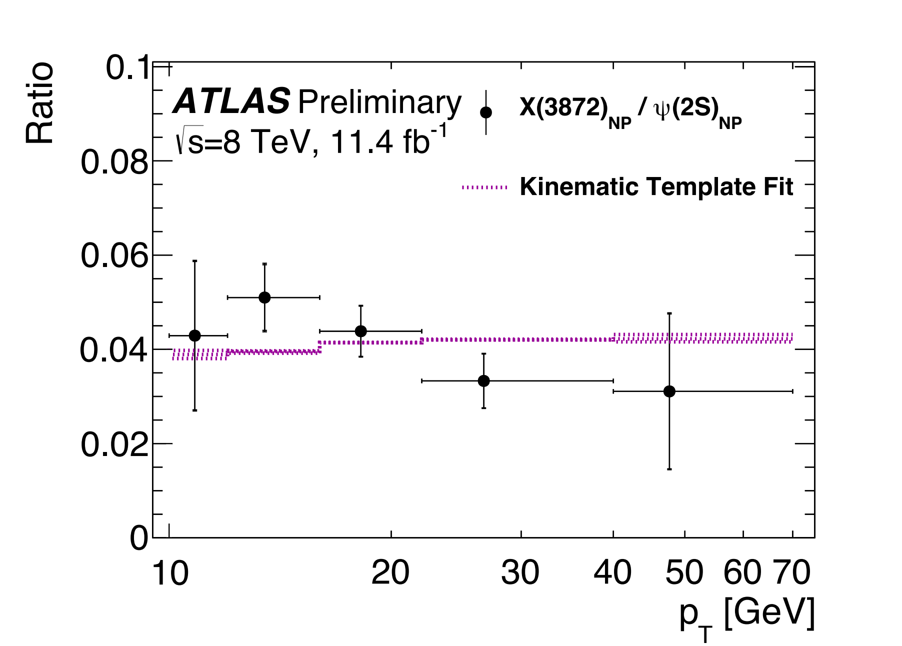
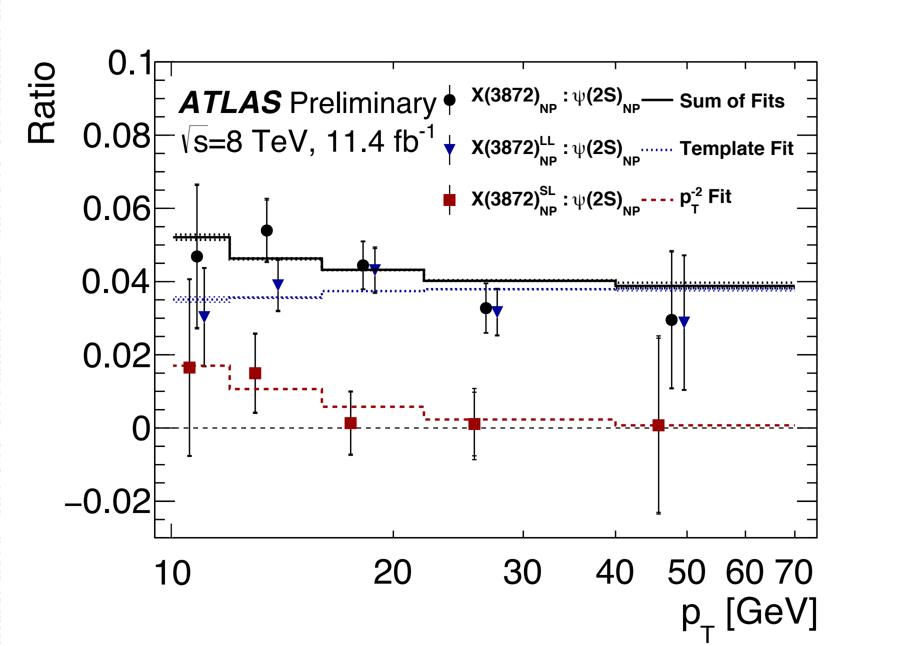
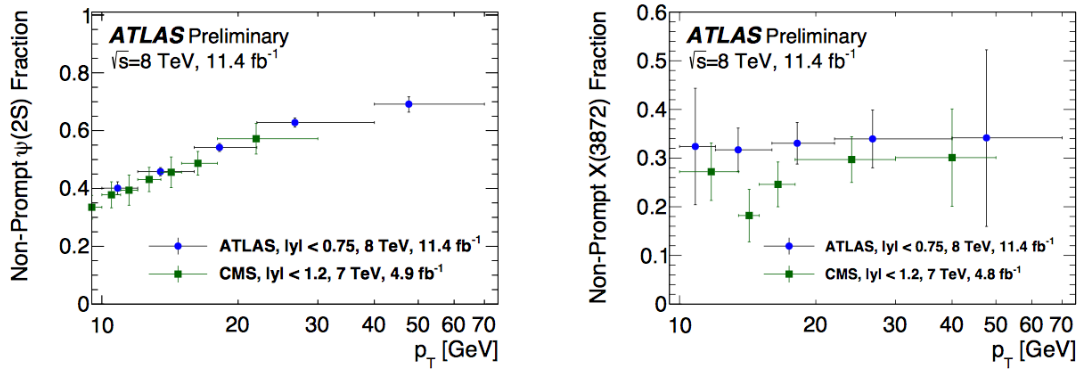


Figure 5: Statistical and systematic contributions to the fractional uncertainty on the prompt (left column) and non-prompt (right column) J/ψ (top row) and $\psi(2S)$ (bottom row) cross-sections for 7 TeV, shown for the region $0.75 < |y| < 1.00$.



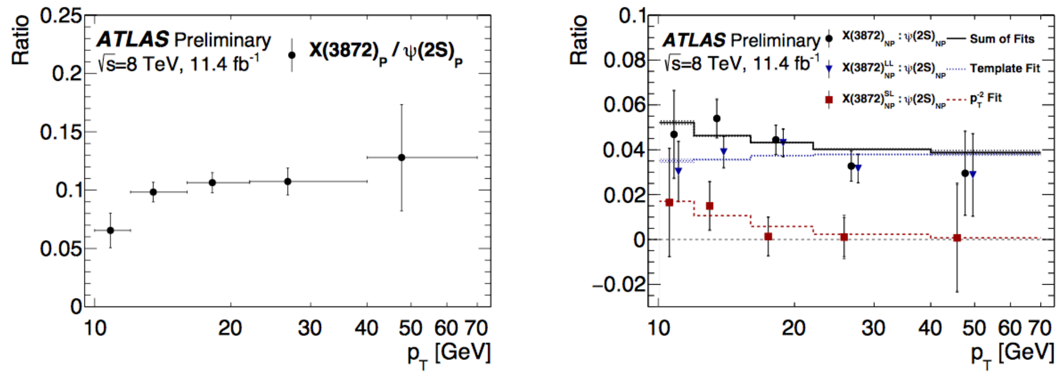


$$R_B^{1L} = \frac{Br(B \to X(3872))Br(X(3872) \to J/\psi\pi^+\pi^-)}{Br(B \to \psi(2S))Br(\psi(2S) \to J/\psi\pi^+\pi^-)} = (3.95 \pm 0.32(\text{stat}) \pm 0.08(\text{sys}))\%.$$



(a) (b)

Figure 6: Measured non-prompt fractions for (a) $\psi(2S)$ and (b) $X(3872)$ production, compared to CMS results at $\sqrt{s} = 7$ TeV. The blue circles are the results shown in this paper, while the green squares show CMS results [10, 30].



(a) (b)

Figure 7: Ratio of cross section times branching fraction between $X(3872)$ and $\psi(2S)$ for (a) prompt and (b) production. In (b), the total non-prompt ratio (black circles) is separated into short-lived (red squares) and long-lived (blue triangles) components for the $X(3872)$, shown with respective fits described in the text. The quality of all three fits is good, with $\chi^2/\mathrm{dof} = 0.43/4$, $2.3/4$ and $2.2/4$ for SL, LL and total NP components, respectively. The data points are slightly shifted horizontally for visibility.

m(ππ) spectrum in ψ(2S) and X(3872) decays to J/ψππ

Voloshin-Zacharov distribution

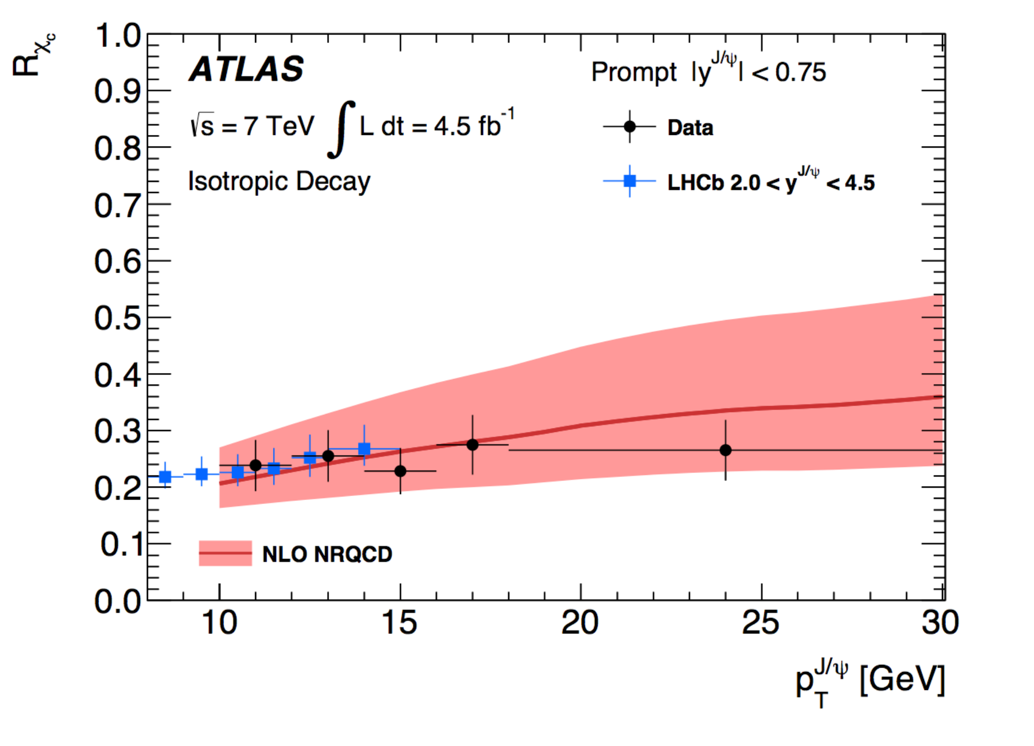
$$\frac{1}{\Gamma}\frac{d\Gamma}{dm_{\pi\pi}} \propto \left(m_{\pi\pi}^2 - \lambda m_\pi^2\right)^2 \times \mathrm{PS},$$

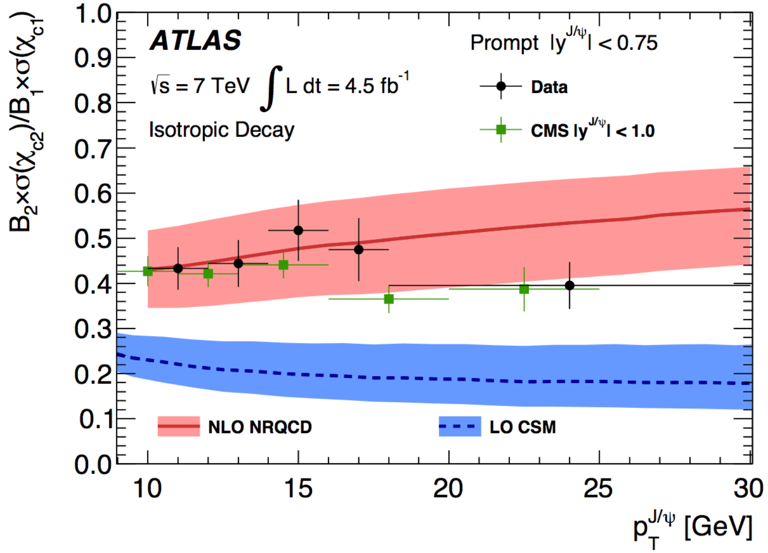
We get: λ = 4.16±0.06(stat)±0.03(sys),
to be compared with:

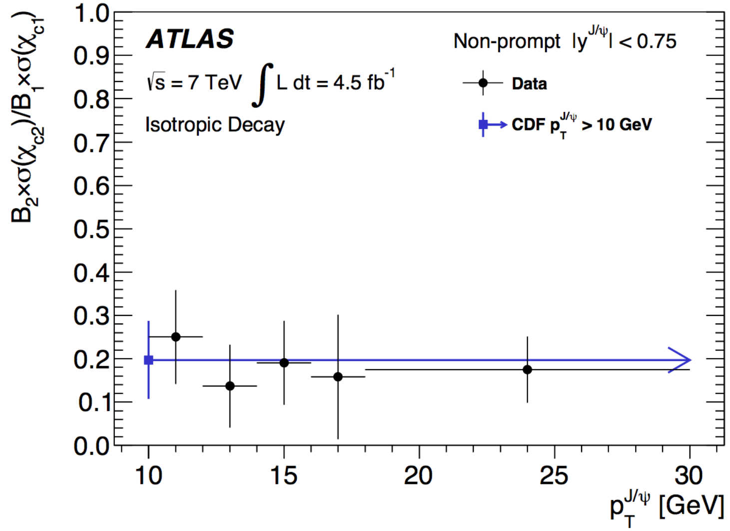
λ = 4.35±0.18 (BES)

λ = 4.46±0.25 (LHCb)

χ_c analysis: Additional results

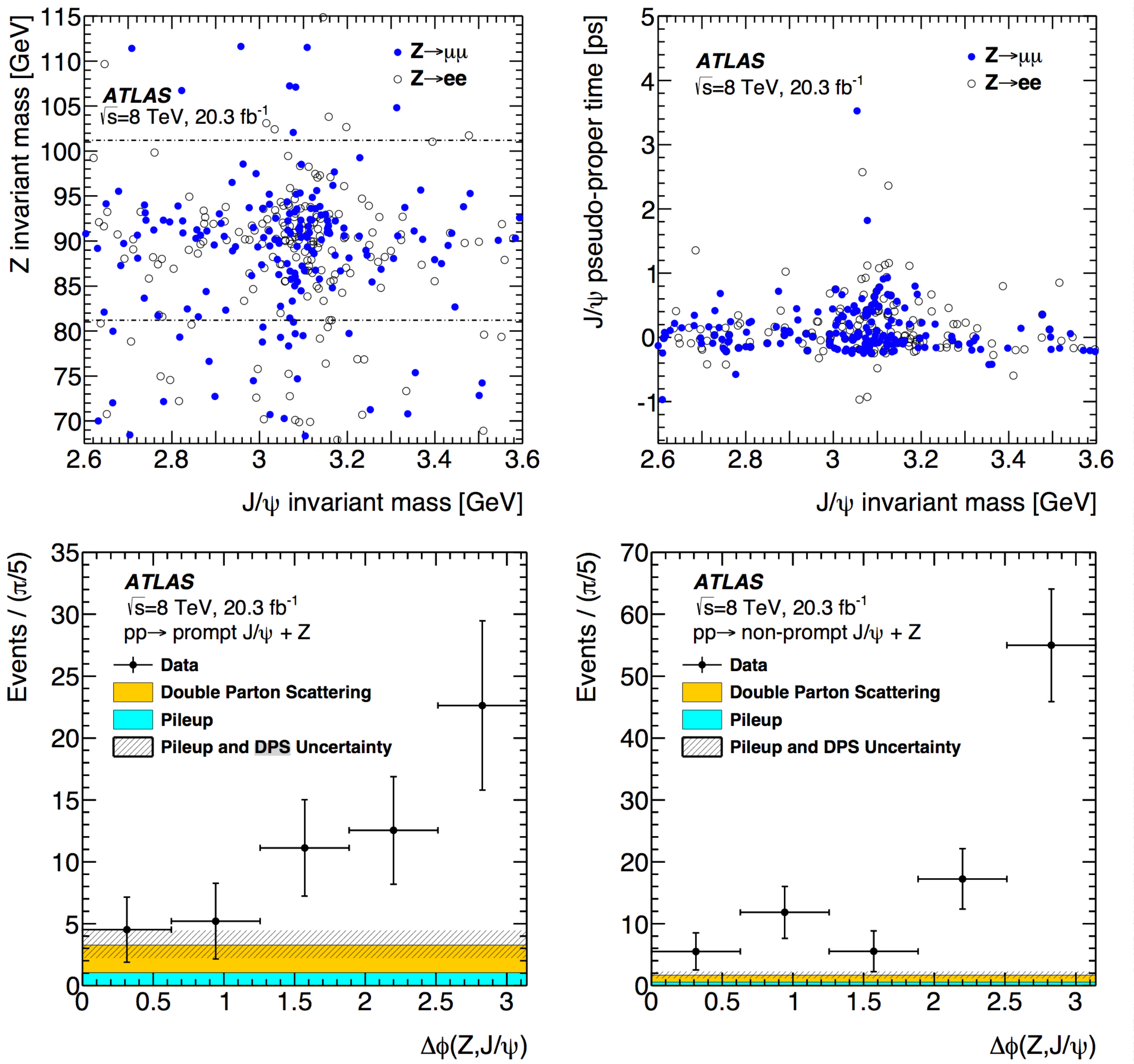




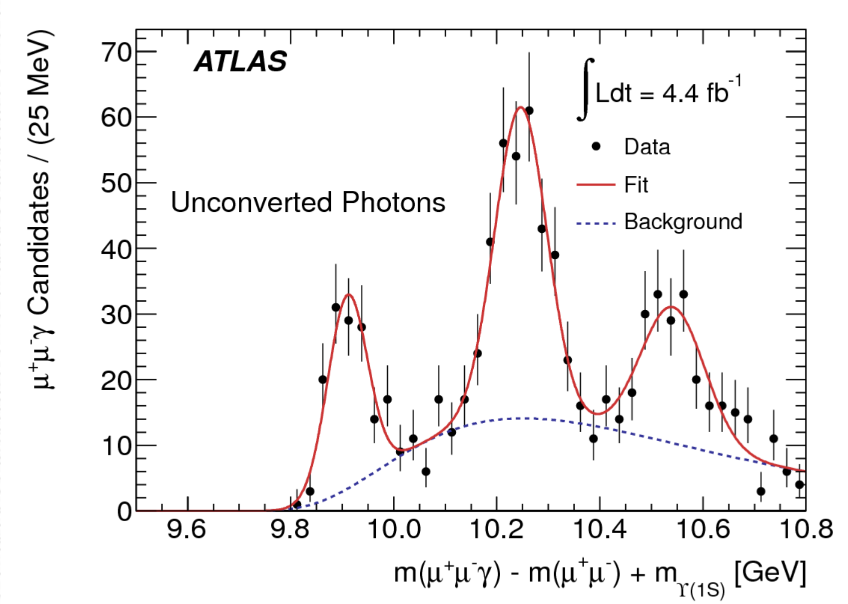


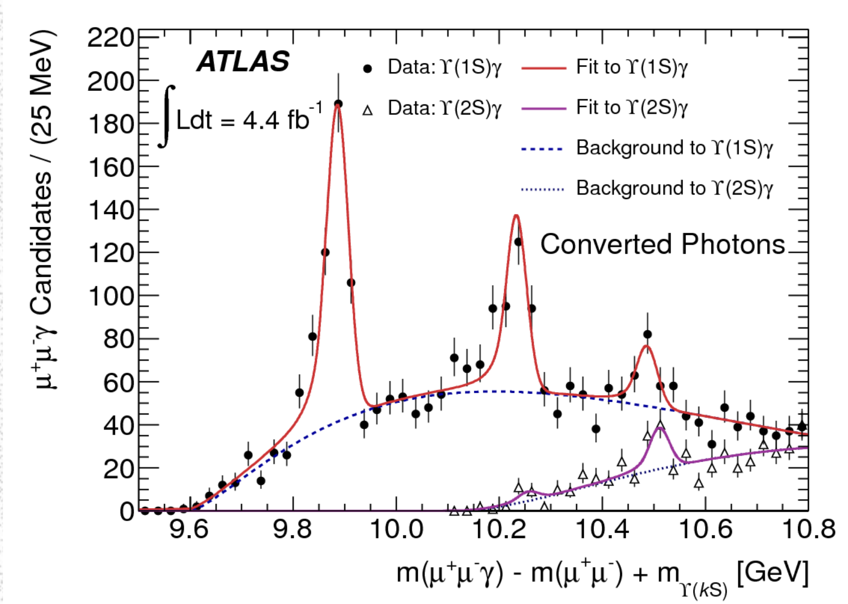
$B(B^{\pm} \to \chi_{c1} K^{\pm}) = (4.9 \pm 0.9\ (\text{stat.}) \pm 0.6\ (\text{syst.})) \times 10^{-4}$

Z+J/ψ: selection and DPS estimate



Observation of new $\chi_b(3P)$ state





D*, D, D_s total cross-section results - I

	$\sigma^{vis}(D^{*\pm})$		$\sigma^{vis}(D^{\pm})$		$\sigma^{vis}(D_s^{*\pm})$	
Range [units]	low-p_T [μb]	high-p_T [nb]	low-p_T [μb]	high-p_T [nb]	low-p_T [μb]	high-p_T [nb]
ATLAS	331 ± 36	988 ± 100	328 ± 34	888 ± 97	160 ± 37	512 ± 104
GM-VFNS	340^{+130}_{-150}	1000^{+120}_{-150}	350^{+150}_{-160}	980^{+120}_{-150}	147^{+54}_{-66}	470^{+56}_{-69}
FONLL	202^{+125}_{-79}	753^{+123}_{-104}	174^{+105}_{-66}	617^{+103}_{-86}	-	-
POWHEG+PYTHIA	158^{+179}_{-85}	600^{+300}_{-180}	134^{+148}_{-70}	480^{+240}_{-130}	62^{+64}_{-31}	225^{+114}_{-69}
POWHEG+HERWIG	137^{+147}_{-72}	690^{+380}_{-160}	121^{+129}_{-64}	580^{+280}_{-140}	51^{+50}_{-25}	268^{+107}_{-62}
MC@NLO	157^{+125}_{-72}	980^{+460}_{-290}	140^{+112}_{-65}	810^{+390}_{-260}	58^{+42}_{-25}	345^{+175}_{-87}

→ From D*, D visible cross-sections extrapolate to total cross-sections
→ From D*, D total cross-sections to charm cross-section (applying fragm.fractions)

$$\sigma_{c\bar{c}}^{tot} = 8.6 \pm 0.3\,(\text{stat}) \pm 0.7\,(\text{syst}) \pm 0.3\,(\text{lum}) \pm 0.2\,(\text{ff})^{+3.8}_{-3.4}\,(\text{extr})\,\text{mb}$$

D*, D, D_s total cross-section results - II

From D*, D D_s total cross-sections
→Fragmentation ratios

$$\gamma_{s/d} = \frac{\sigma_{c\bar{c}}^{\rm tot}(D_s^+)}{\sigma_{c\bar{c}}^{\rm tot}(D^{*+}) + \sigma_{c\bar{c}}^{\rm tot}(D^+) - \sigma_{c\bar{c}}^{\rm tot}(D^{*+})\cdot(1-\mathcal{B}_{D^{*+}\to D^0\pi^+})} = \frac{\sigma_{c\bar{c}}^{\rm tot}(D_s^+)}{\sigma_{c\bar{c}}^{\rm tot}(D^+) + \sigma_{c\bar{c}}^{\rm tot}(D^{*+})\cdot\mathcal{B}_{D^{*+}\to D^0\pi^+}},$$

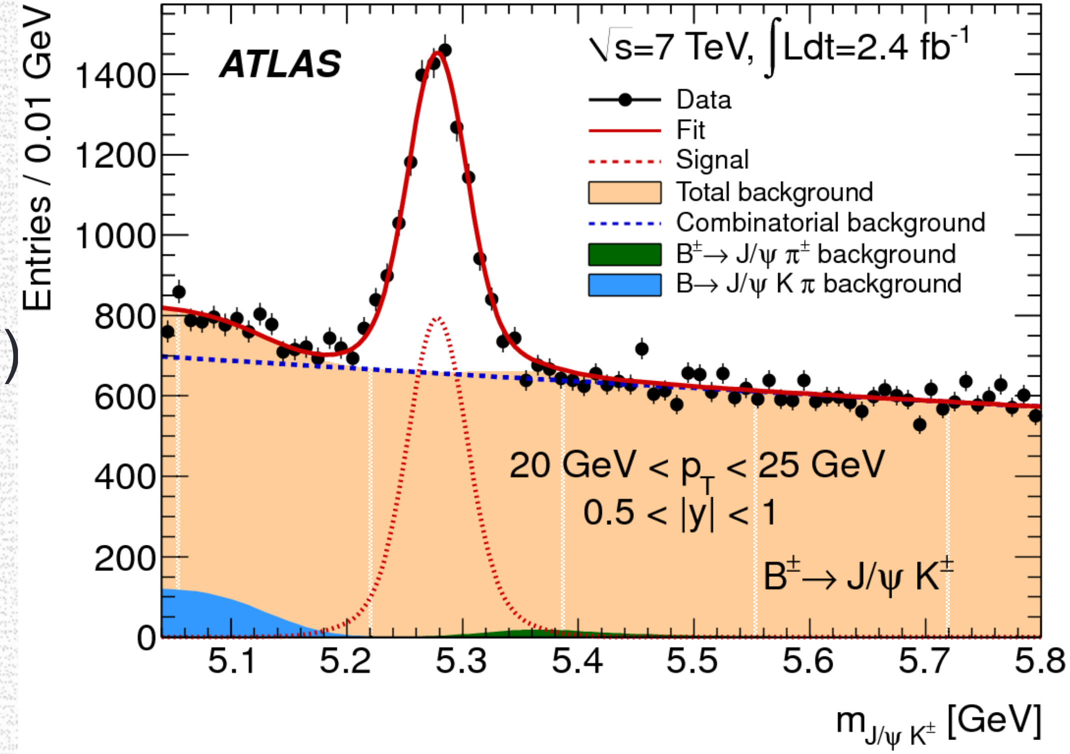
$$P_{\rm v}^d = \frac{\sigma_{c\bar{c}}^{\rm tot}(D^{*+})}{\sigma_{c\bar{c}}^{\rm tot}(D^{*+}) + \sigma_{c\bar{c}}^{\rm tot}(D^+) - \sigma_{c\bar{c}}^{\rm tot}(D^{*+})\cdot(1-\mathcal{B}_{D^{*+}\to D^0\pi^+})} = \frac{\sigma_{c\bar{c}}^{\rm tot}(D^{*+})}{\sigma_{c\bar{c}}^{\rm tot}(D^+) + \sigma_{c\bar{c}}^{\rm tot}(D^{*+})\cdot\mathcal{B}_{D^{*+}\to D^0\pi^+}}.$$

$$\gamma_{s/d} = 0.26 \pm 0.05\,({\rm stat}) \pm 0.02\,({\rm syst}) \pm 0.02\,({\rm br}) \pm 0.01\,({\rm extr}),$$

$$P_{\rm v}^d = 0.56 \pm 0.03\,({\rm stat}) \pm 0.01\,({\rm syst}) \pm 0.01\,({\rm br}) \pm 0.02\,({\rm extr}).$$

Measurement of the differential cross-section of B^+ meson production in pp collisions at $\sqrt{s}$ = 7 TeV

- Data sample
  - $2.4\ fb^{-1}$ @ 7 TeV
- Search in the J/ψ K with $J/\psi \rightarrow \mu\mu$ channel
  - Dimuon trigger (pT>4 GeV)
  - Vertex fit
  - 3-component mass fit to get B^+ yield
- Analysis vs. p_T and |y| up to p_T=100 GeV and |y|<2.25

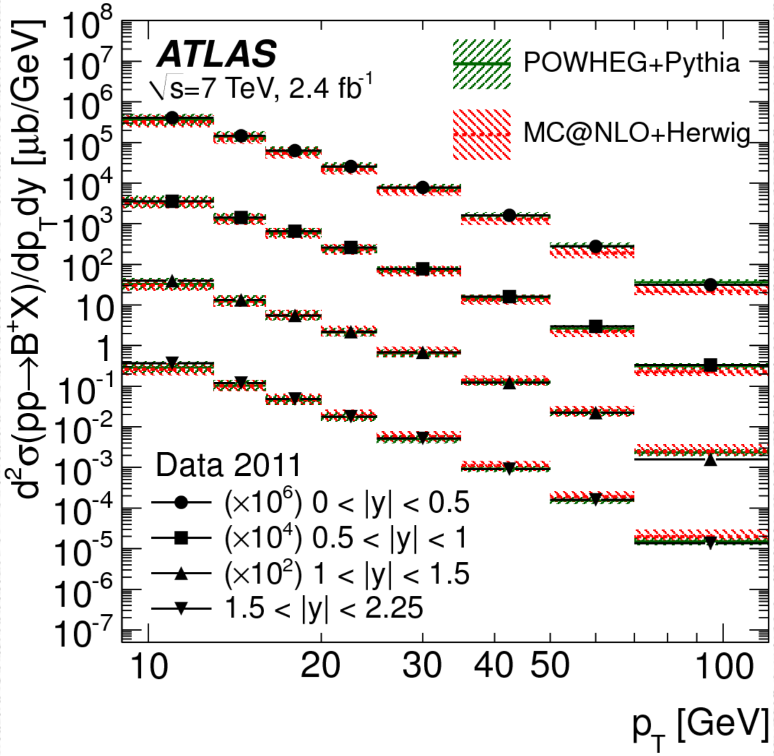


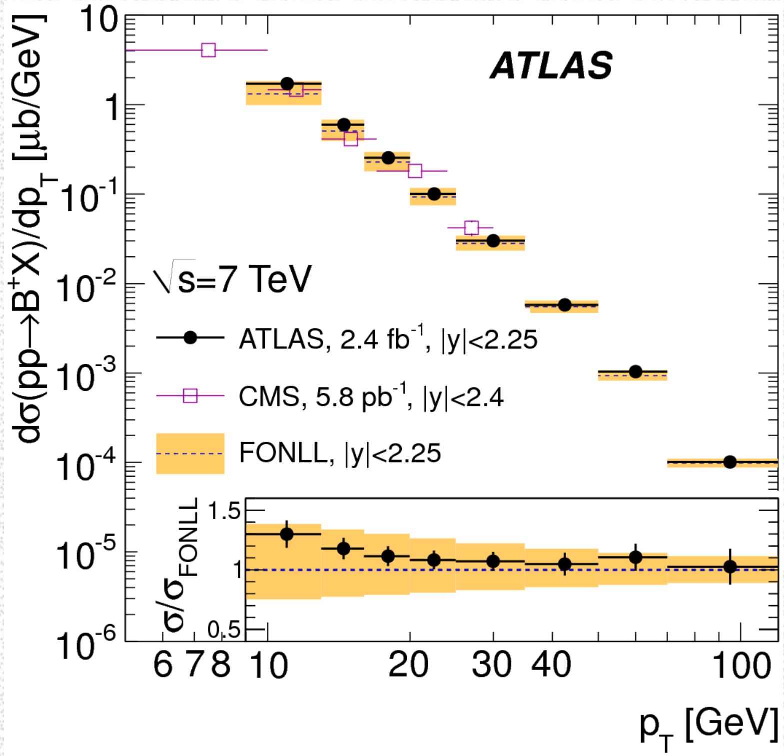
See *JHEP 10 (2013) 042*

Results: B^+ production cross-section vs. p_T and η compared to predictions

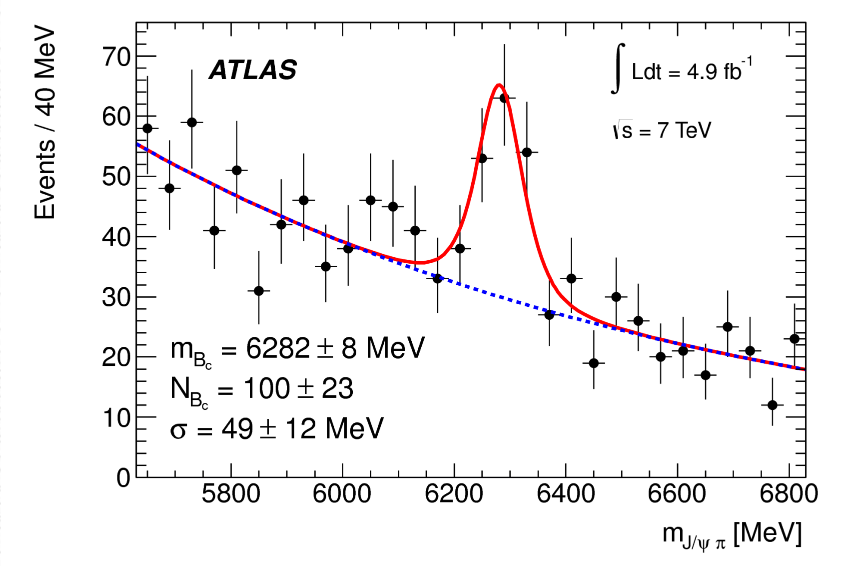
Comparison with theory predictions:

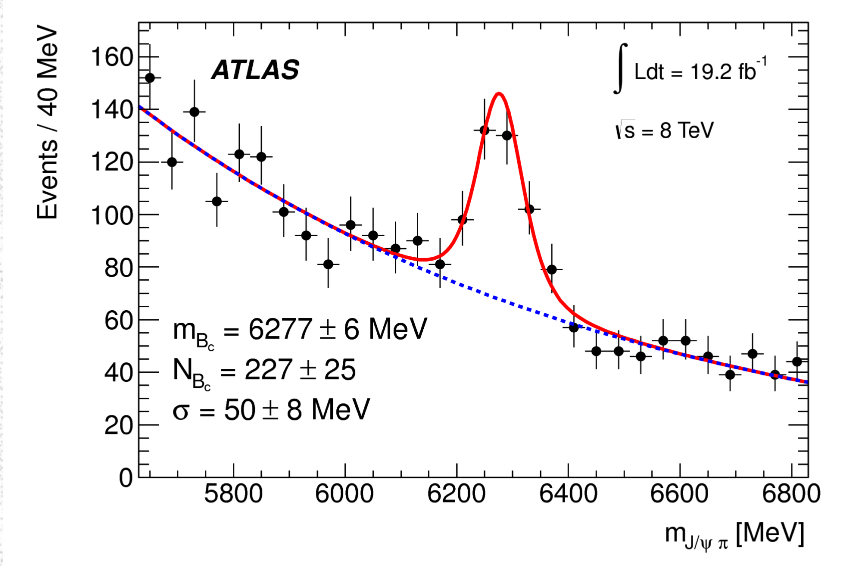
- POWHEG+PYTHIA gives a good description of the data
- MC@NLO+HERWIG has problems at large p_T
- FONLL gives a good description within large uncertainties



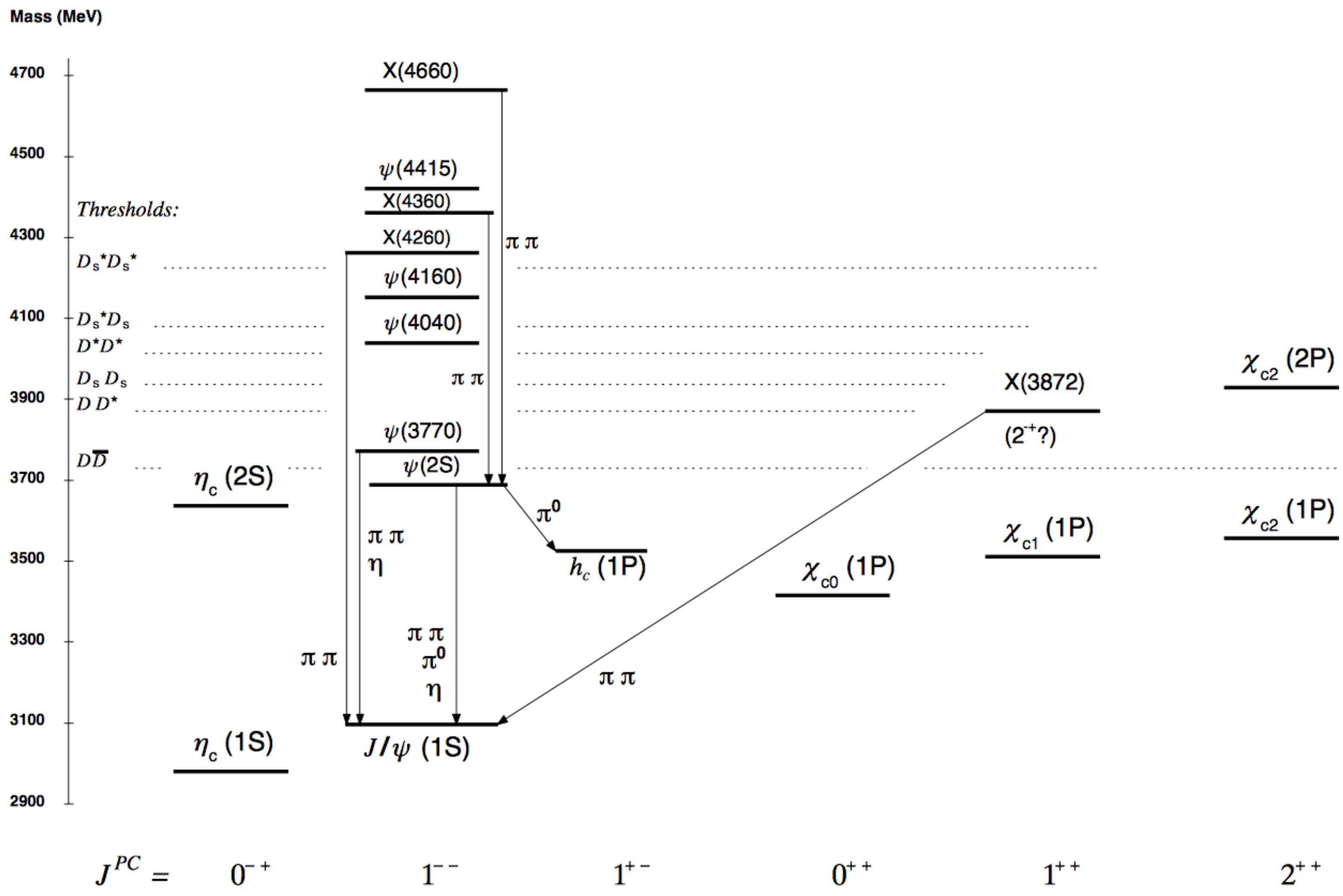


Observation of an excited $B_c^{\pm}(2S)$





THE CHARMONIUM SYSTEM



THE BOTTOMONIUM SYSTEM