Recent results of quarkonium and heavy flavour at ATLAS

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Outline

Introduction of heavy flavour physics program at ATLAS

1. Search for the X(5568) in $B_s^0\pi^\pm$ final states (Phys. Rev. Lett. 120 (2018) 202007)
2. Measurement of b-hadron pair production (JHEP 11 (2017) 62)
3. Quarkonium production in 5.02 TeV pp & pPb collisions (Eur. Phys. J. C 78 (2018) 171)
4. Angular analysis of the decay B_d^0->$K^*\mu^+\mu^-$ (1805.04000 submitted to JHEP)

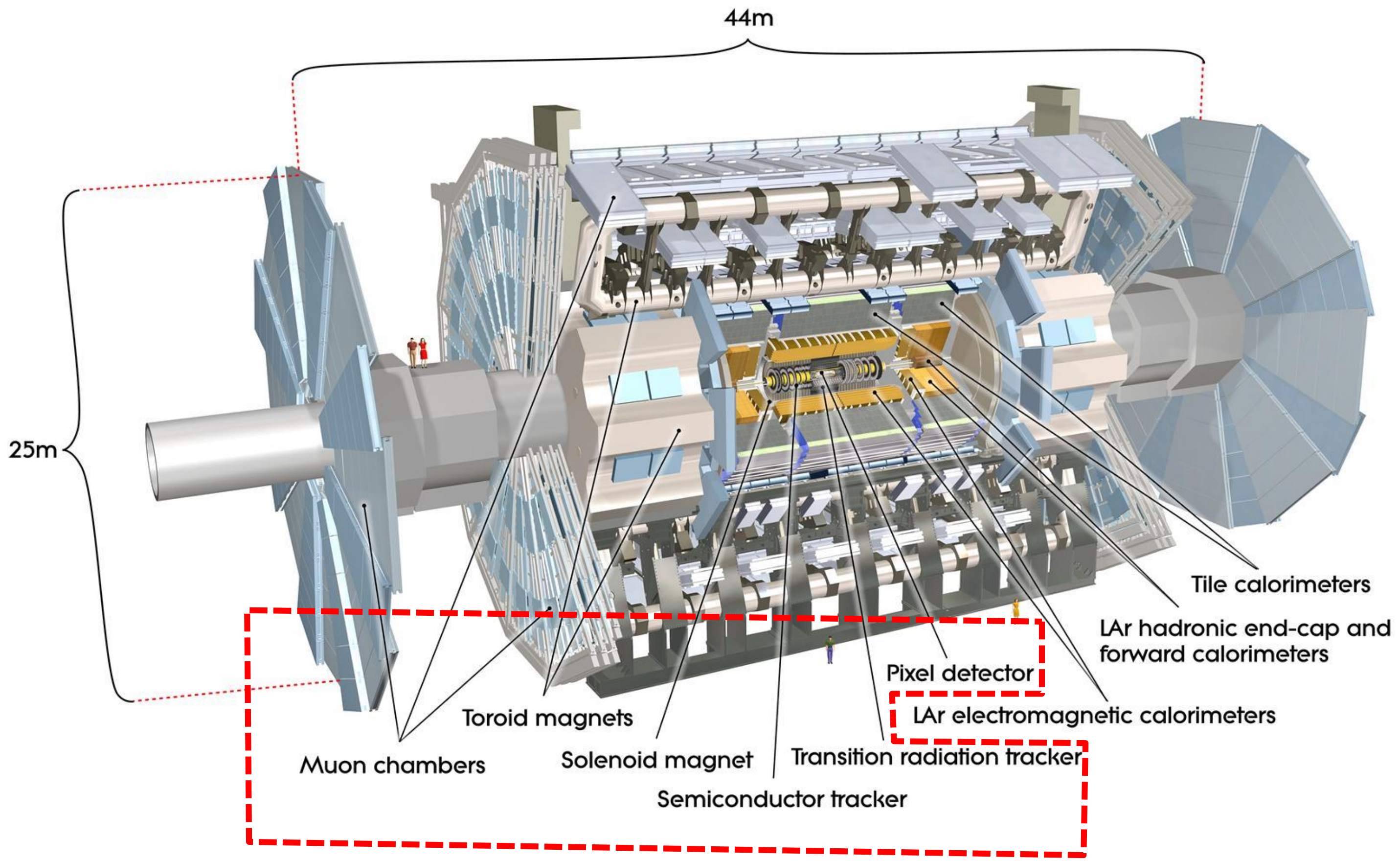
Summary

Heavy Flavour physics program at ATLAS

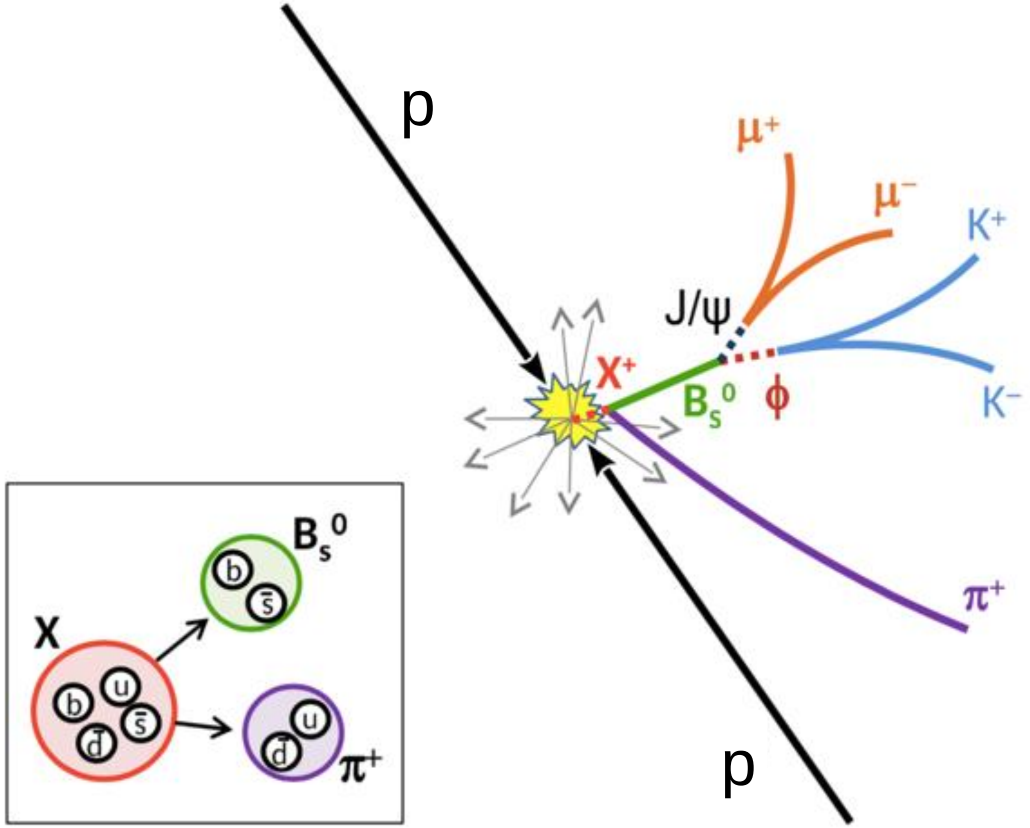
- Precision measurement to find hint of derivation from SM: rare decays, such $B_s^0 \to \mu^+\mu^-$ branching fraction measurement……

- Production and decay of heavy flavour hadrons to understand the strong interaction, such as the discovery of $B_c(2S)$……

- Usually, two muons with a common vertex with invariant mass near J/Ψ are required: the inner tracker and muon detector are used

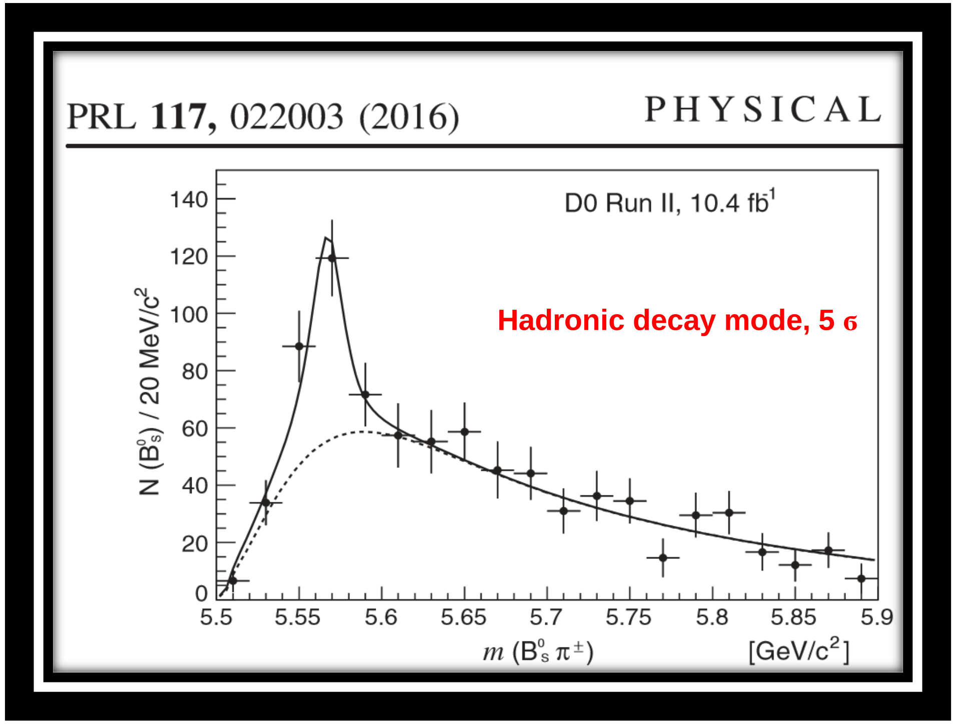


Search for the X(5568) in $B_s^0\pi^\pm$ final states

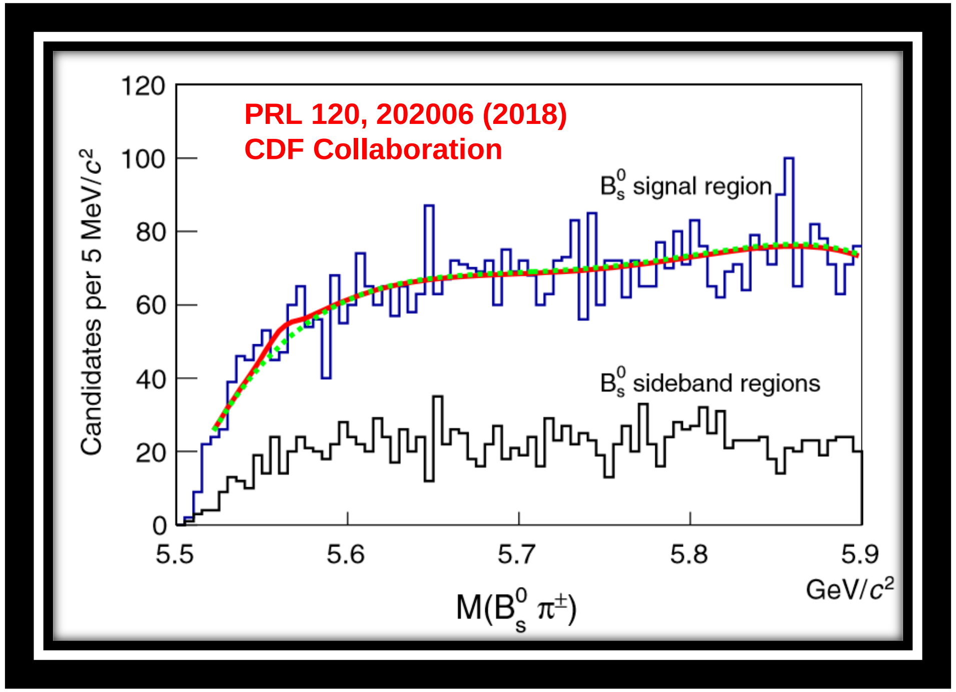


Plot from website

D0 Collaboration reported evidence of the X(5568) -> $B_s^0\pi^\pm$, B_s^0 ->J/Ψ ϕ, and reported consistent result in the semi-leptonic decay of B_s^0 :



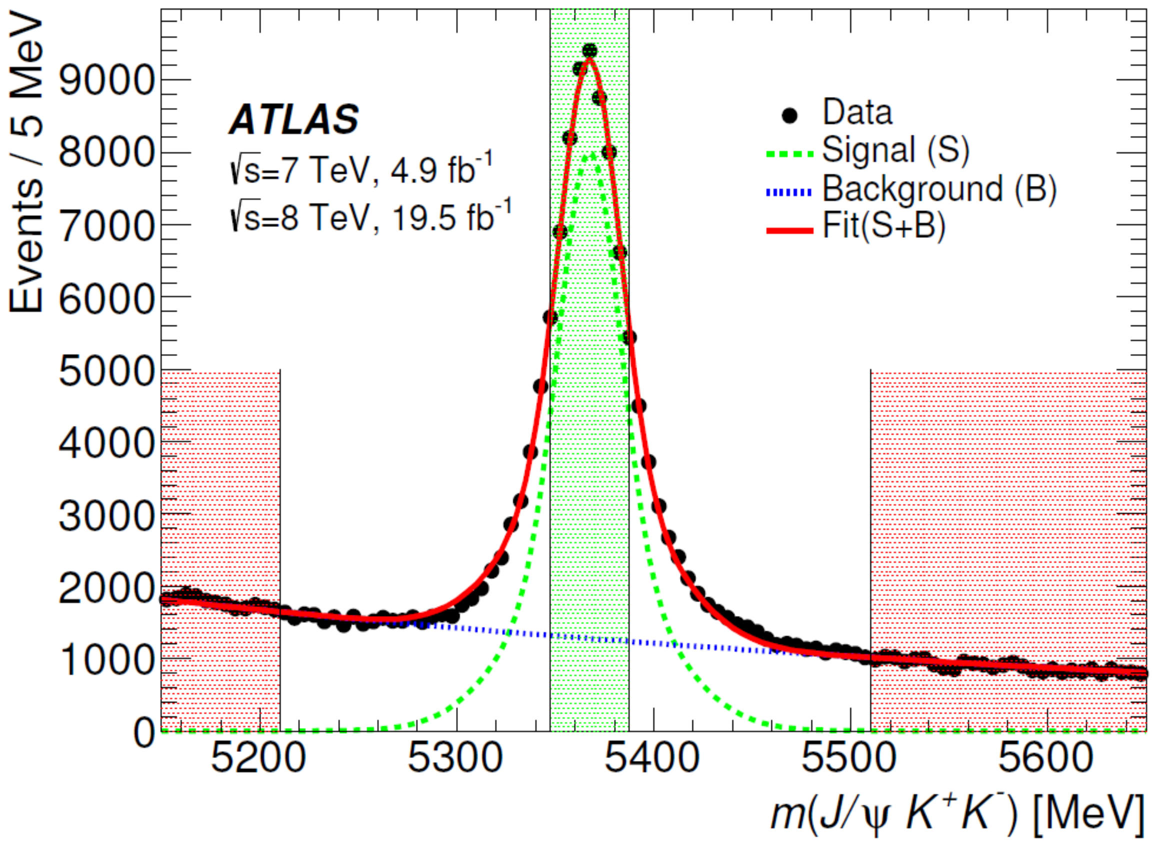
Mass ~ 5568 MeV; Width ~ 20 MeV
Good candidate for tetraquark state



LHCb, CMS at LHC and CDF at Tevatron reveald no signal with similar technic.

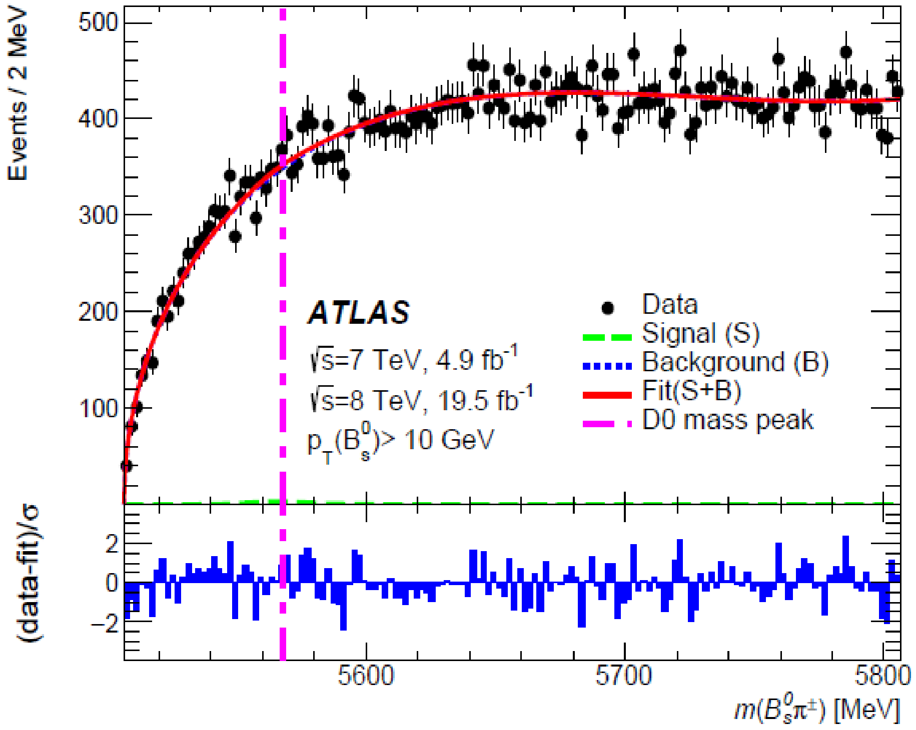
Search for the X(5568) in $B_s^0\pi^\pm$ final states

- Di-muon trigger is used
- Four final states from B_s^0 -> J/Ψ ϕ -> μμ KK are fitted to a common vertex
- Mass constrain of J/Ψ-> μμ; mass cut on 1008.5<m(KK)<1030.5 MeV
- Decay time of B_s^0 > 0.2 ps
- Primary vertex is chosen as the one with least d0, calculated based on the B_s^0 vertex and momentum direction
- One track assumed to be π from the primary vertex

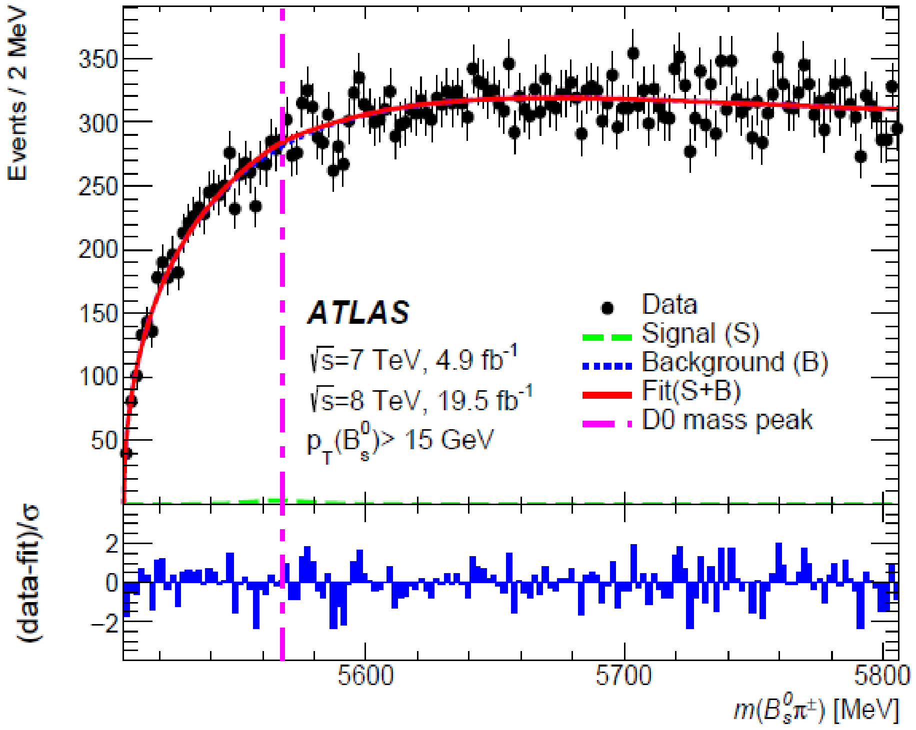


S: double Gaussian; B: Exponential

Search for the X(5568) in $B_s^0\pi^\pm$ final states



$p_T(B_s^0) > 10$ GeV



$p_T(B_s^0) > 15$ GeV

No obvious X(5568) is observed!

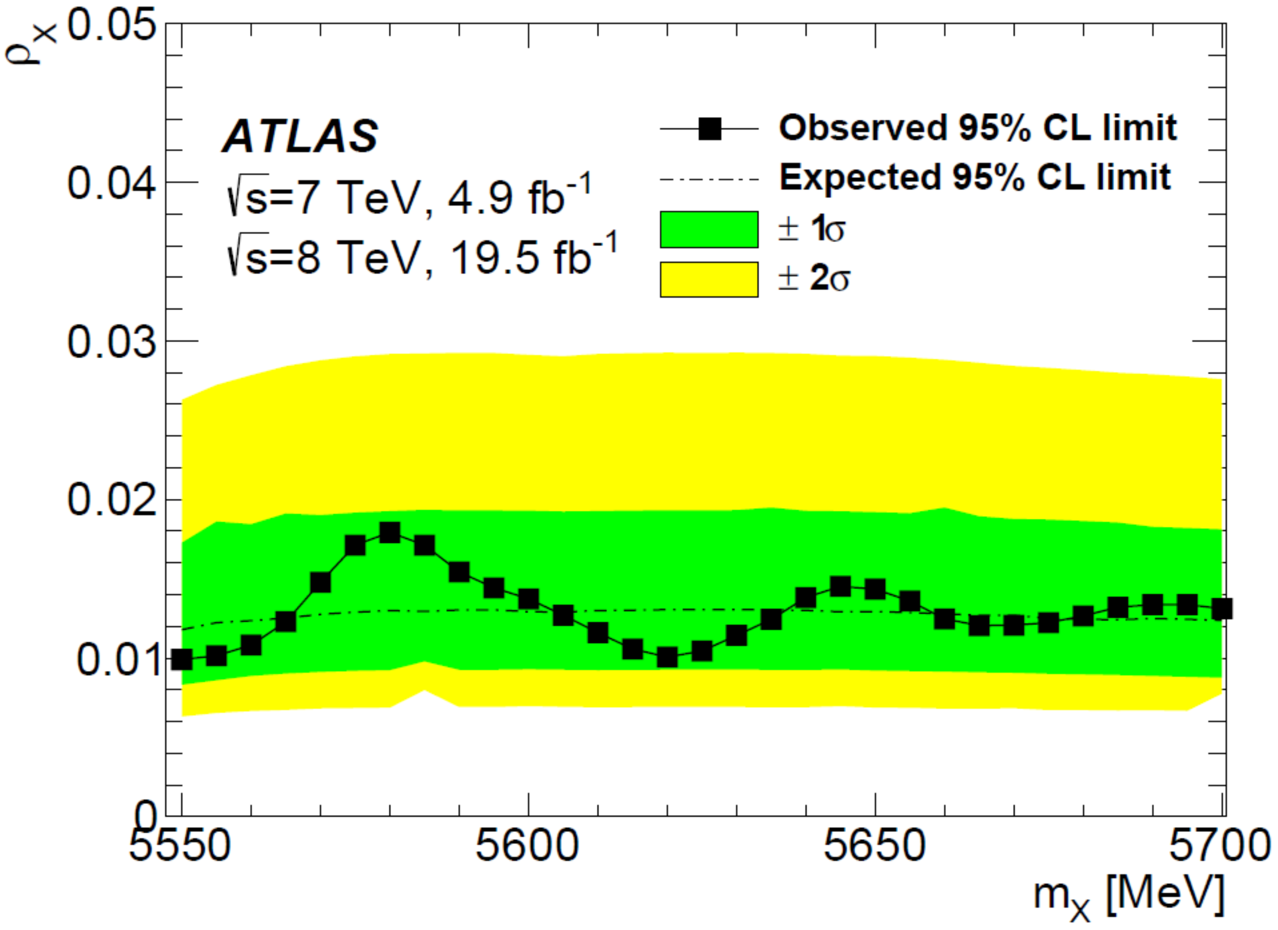
Search for the X(5568) in $B_s^0\pi^\pm$ final states

Mass range: 5550-5700 MeV

Width: 21.9 MeV

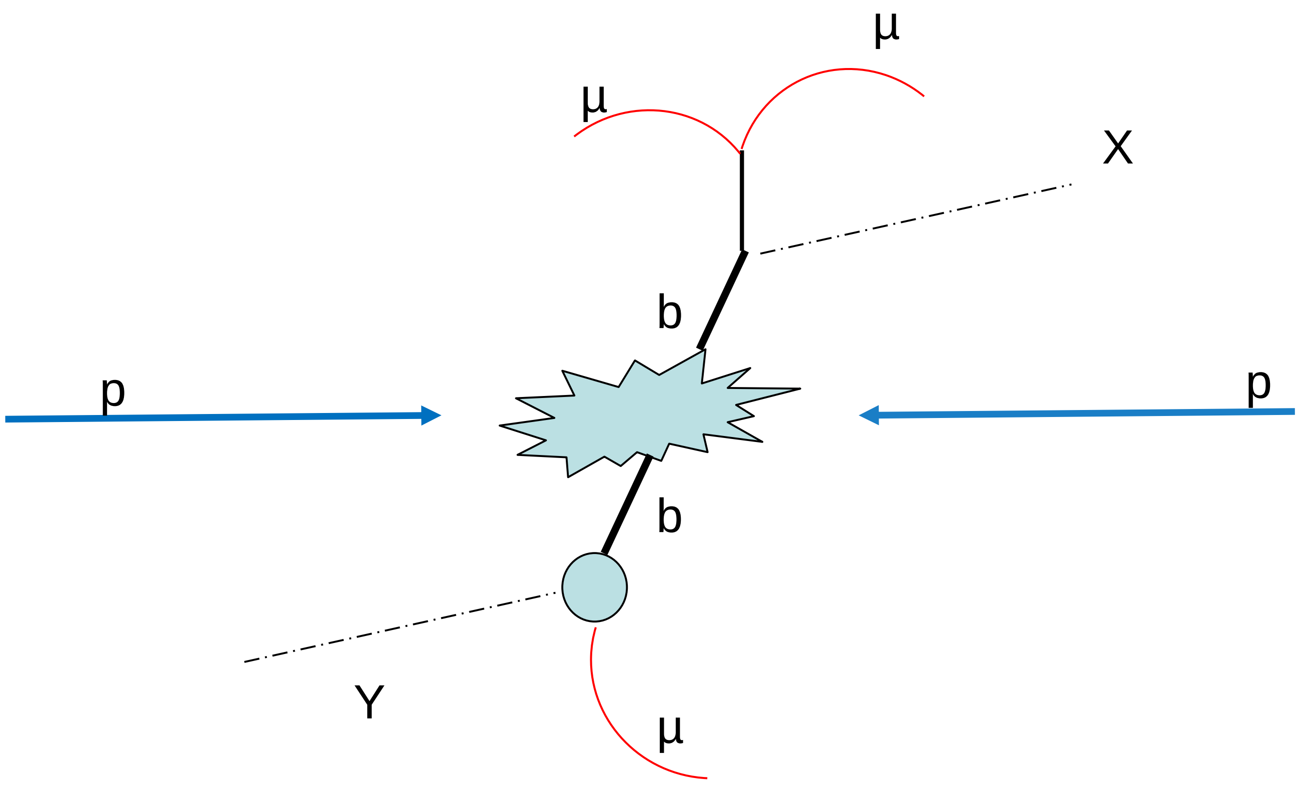
$P_T(B_s^0) > 10$ GeV

Upper limit on the production rate is set

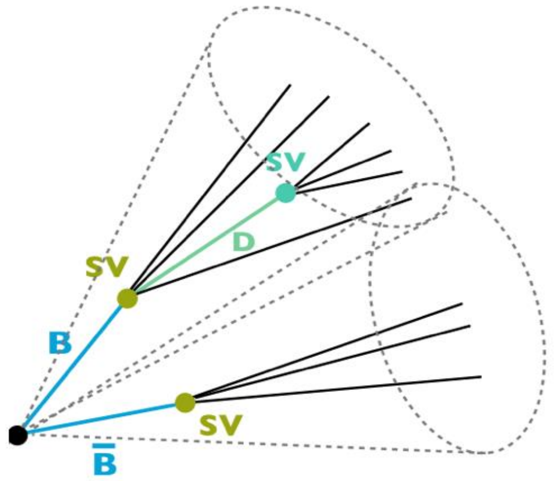


$$\rho_X \equiv \frac{\sigma(pp \to X + \text{anything}) \times \mathcal{B}(X \to B_s^0\pi^\pm)}{\sigma(pp \to B_s^0 + \text{anything})} = \frac{N(X)}{N(B_s^0)} \times \frac{1}{\epsilon^{\text{rel}}(X)}$$

Measurement of b-hadron pair production



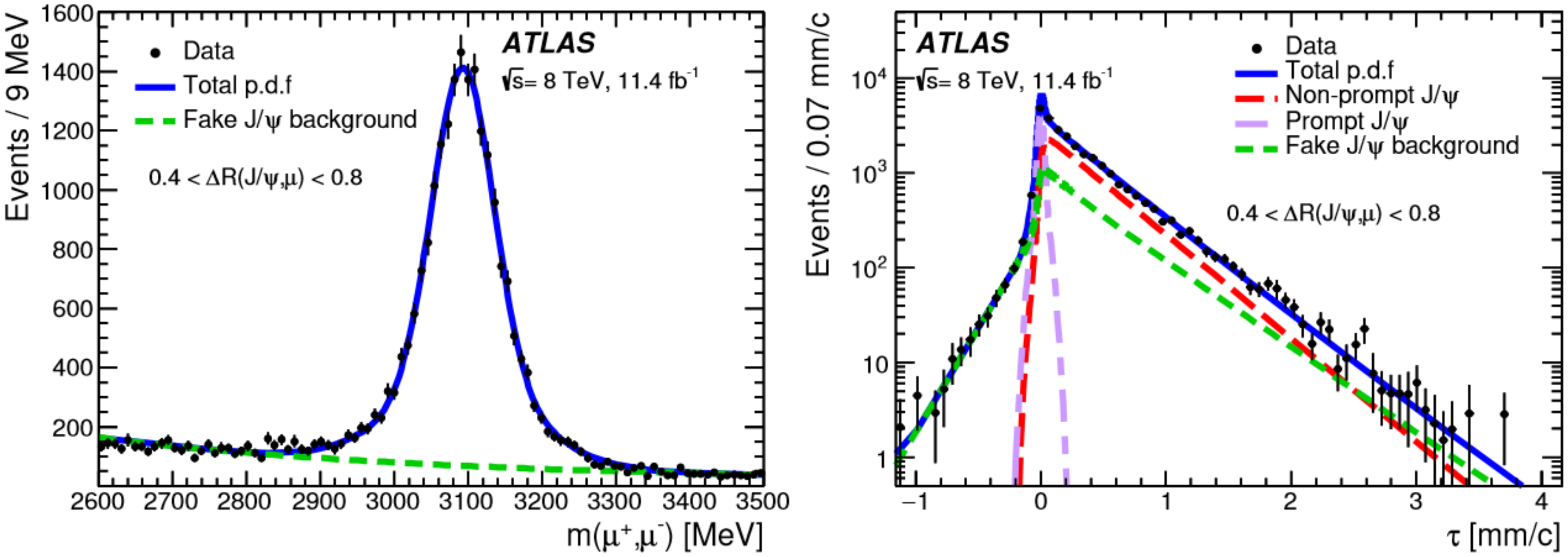
Measurement of b-hadron pair production



- The $b\bar{b}$ production cross section could be measured with different b hadron identifying techniques, such as b-jet tagging.
- Above method does not work well when the angle between two b-hadron is small.
- The information in this region is crucial for VH, H->$b\bar{b}$ analysis.
- The new method used here tags one b-hadron in the decay mode of J/Ψ(-> μμ) + X, and tag the other b-hadron in of μ +Y
- Several differential cross sections (for example $\Delta\phi$(J/Ψ, μ)) are measured and compared to generators

Measurement of b-hadron pair production

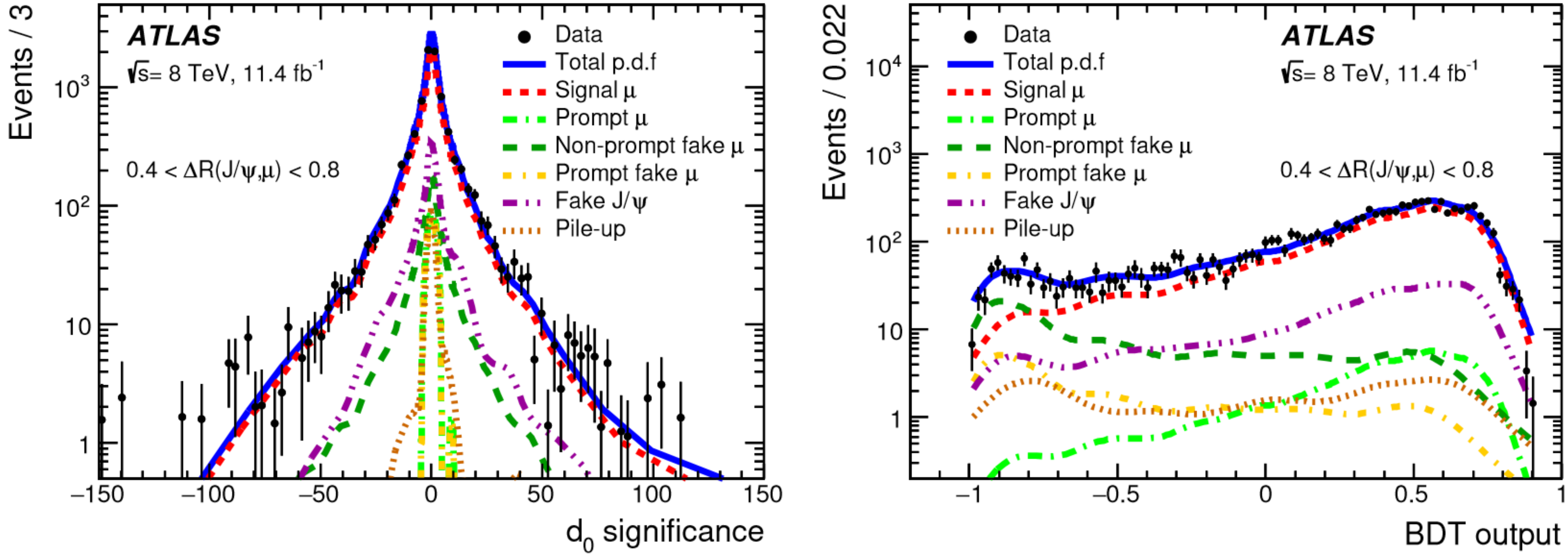
Get the non-prompt J/Ψ from 2D fit:



$$\tau = L_{xy} \times m(J/\psi_{\mathrm{PDG}})/p_{\mathrm{T}}(\mu^+\mu^-)$$

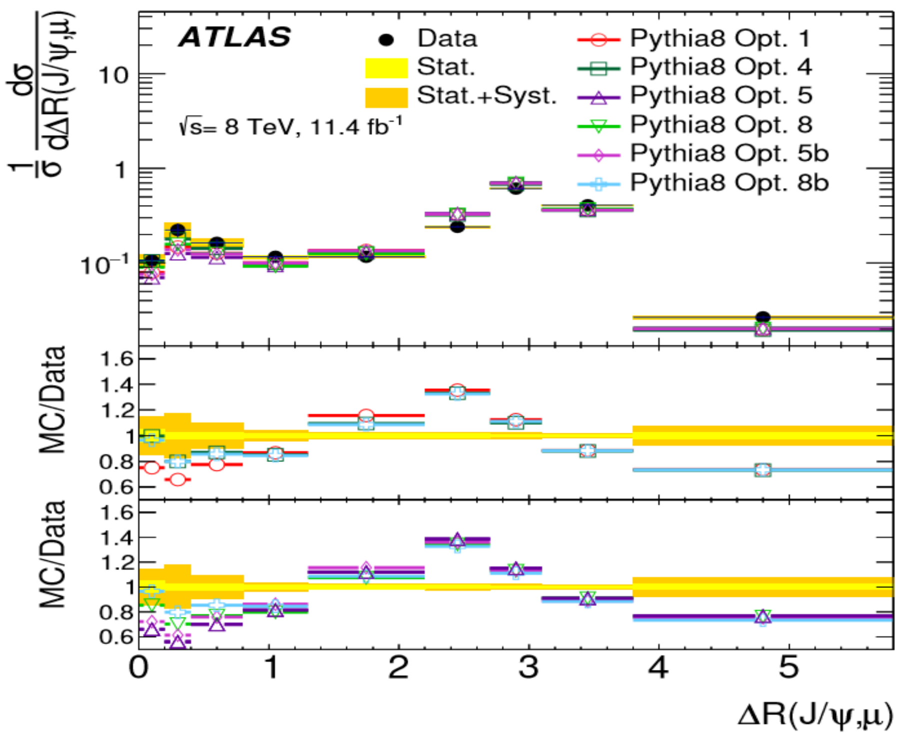
Measurement of b-hadron pair production

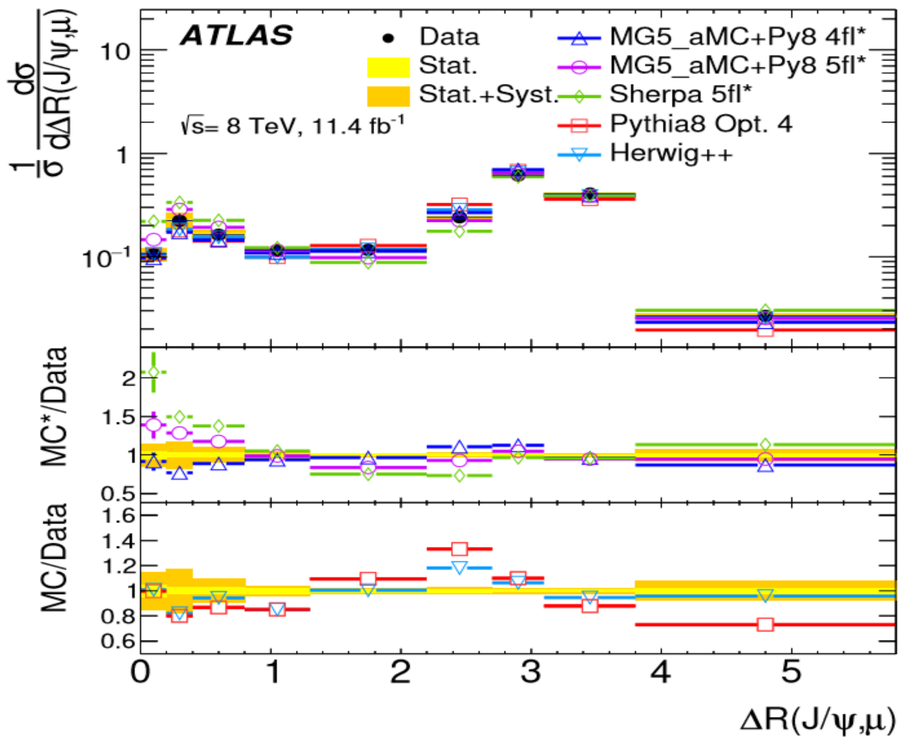
Get the third muon from an other 2D fit:



Measurement of b-hadron pair production

Unfolding the detector effect, and get the particle level cross sections:





Compare to PYTHIA8 with different options for the g-> $b\bar{b}$ splitting kernel: the p_T-based kernel gives the best agreement

Compare to different generators: MG5_aMC@NLO with 4-flavour gives best agreement

Quarkonium production in 5.02 TeV pp & pPb collisions

- p+A collision could be used to disentangle Cold-Nuclear-Matter effect for quark-gluon plasma study;

- Nuclear modification factor results for J/Ψ from LHCb and ALICE are different from ALTAS and CMS where J/Ψ is produced with small rapidities and high transverse momentum: rapidity and transverse momentum dependence

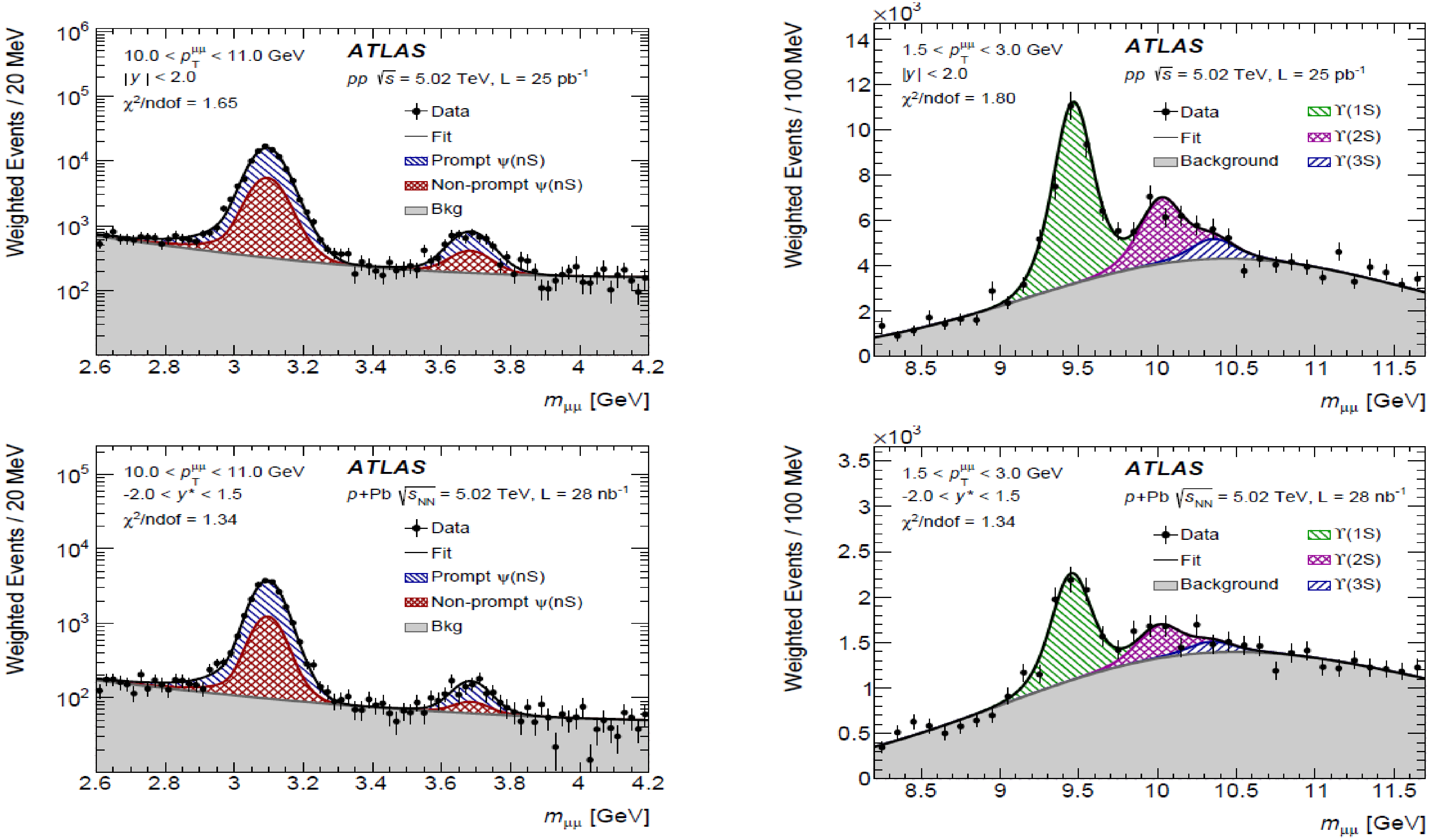
$$R_{p\mathrm{Pb}} = \frac{1}{208} \frac{\sigma^{\mathcal{O}(n\mathrm{S})}_{p+\mathrm{Pb}}}{\sigma^{\mathcal{O}(n\mathrm{S})}_{pp}}$$

- Double ratio is found to be less than unity by CMS: final state interactions

$$\rho^{\mathcal{O}(n\mathrm{S})/\mathcal{O}(1\mathrm{S})}_{p\mathrm{Pb}} = \frac{R_{p\mathrm{Pb}}(\mathcal{O}(n\mathrm{S}))}{R_{p\mathrm{Pb}}(\mathcal{O}(1\mathrm{S}))} = \frac{\sigma^{\mathcal{O}(n\mathrm{S})}_{p+\mathrm{Pb}}}{\sigma^{\mathcal{O}(1\mathrm{S})}_{p+\mathrm{Pb}}} \Big/ \frac{\sigma^{\mathcal{O}(n\mathrm{S})}_{pp}}{\sigma^{\mathcal{O}(1\mathrm{S})}_{pp}}$$

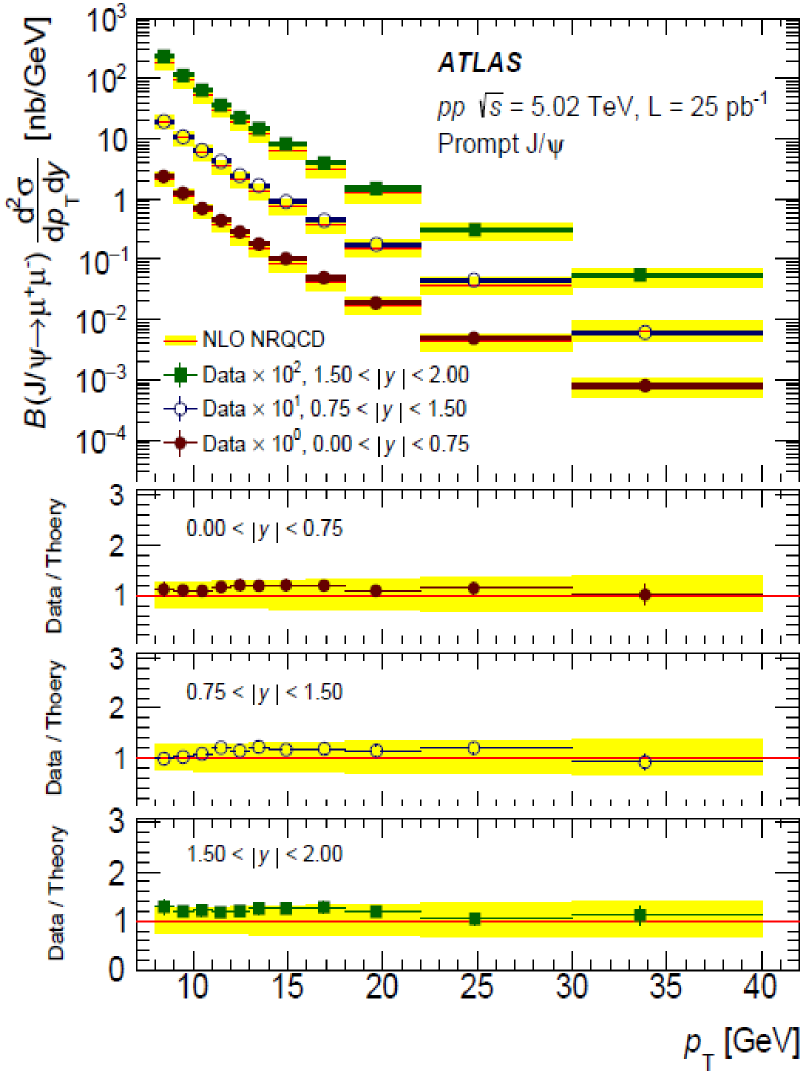
Quarkonium production in 5.02 TeV pp & pPb collisions

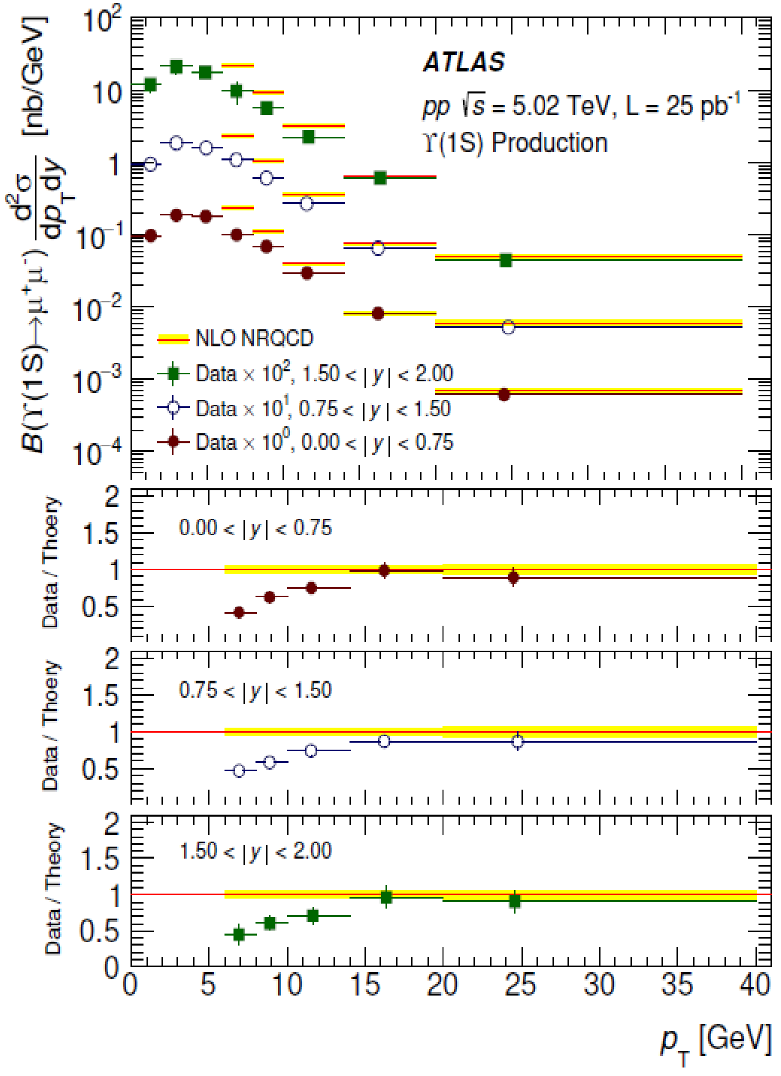
Di-muon is used to selected the signal events: J/Ψ on the left and ϒ(nS) on the right



Quarkonium production in 5.02 TeV pp & pPb collisions

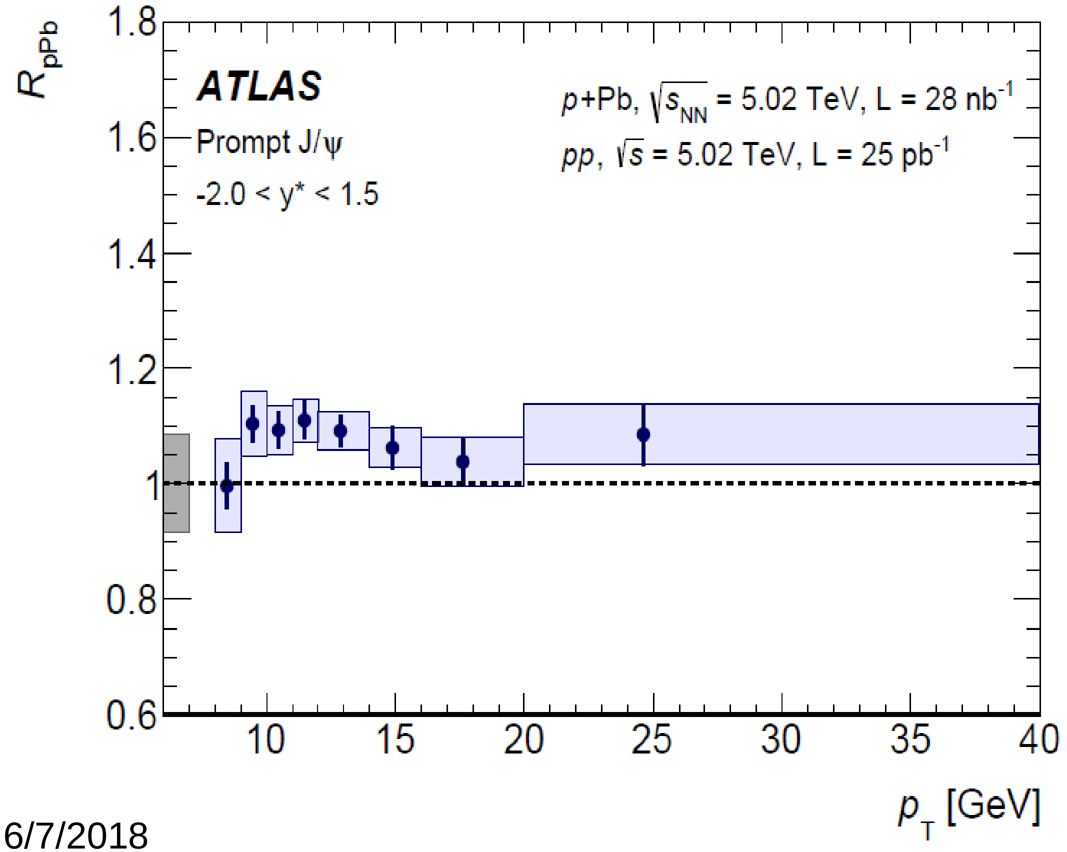
For charmonium, the cross section from NRQCD is compatible with data, and for bottomonium only pT>15 GeV data can be described by NRQCD



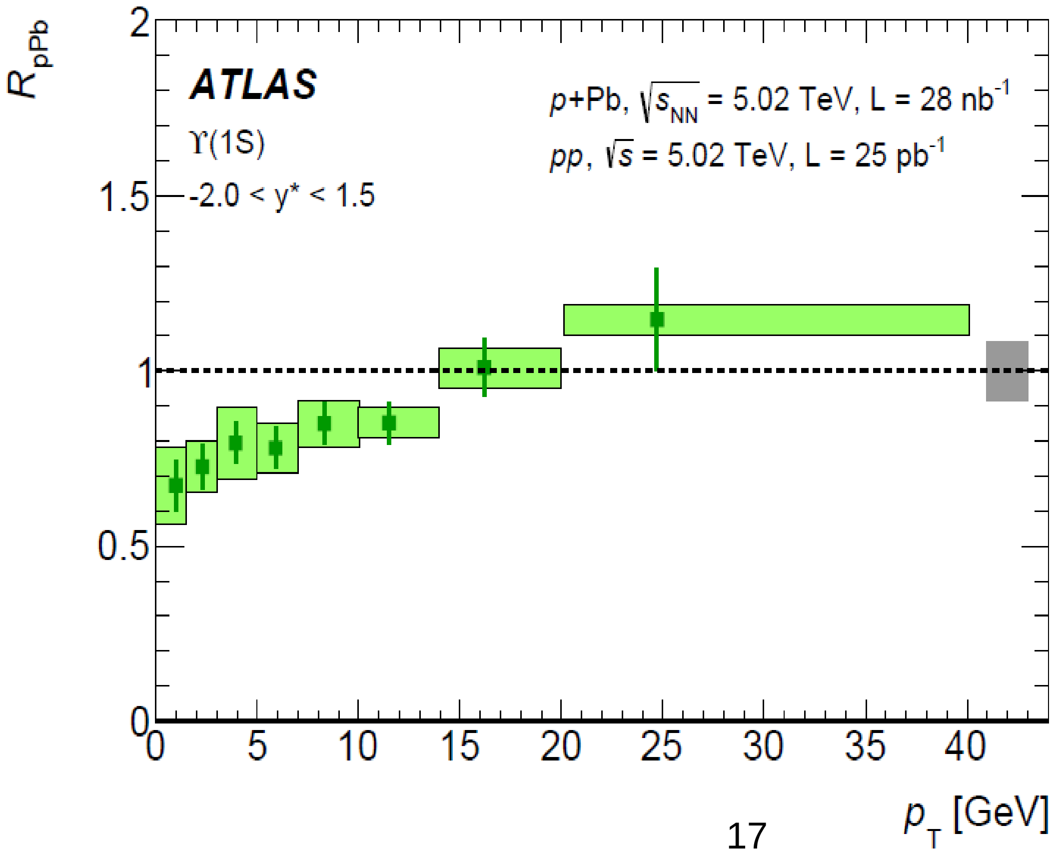


Quarkonium production in 5.02 TeV pp & pPb collisions

No obvious modification is observed for J/Ψ

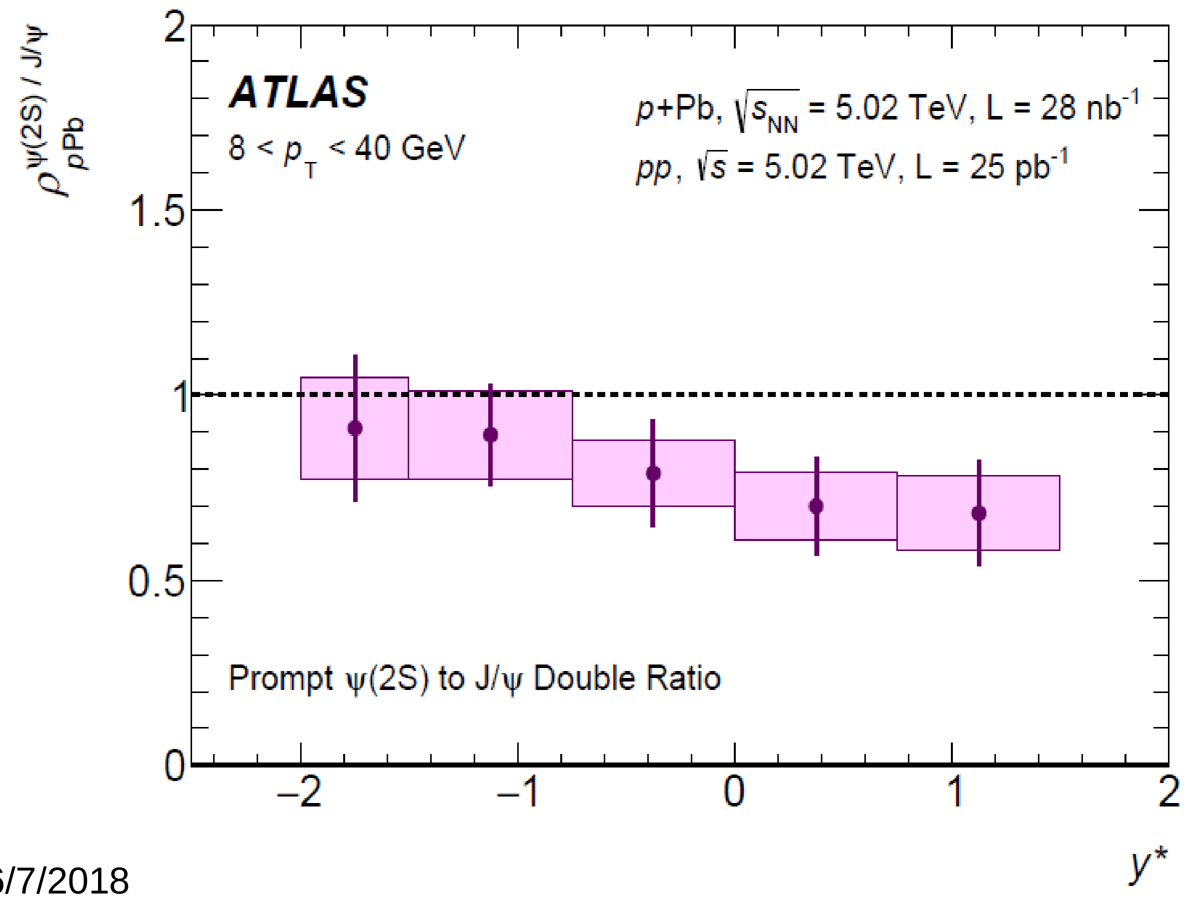


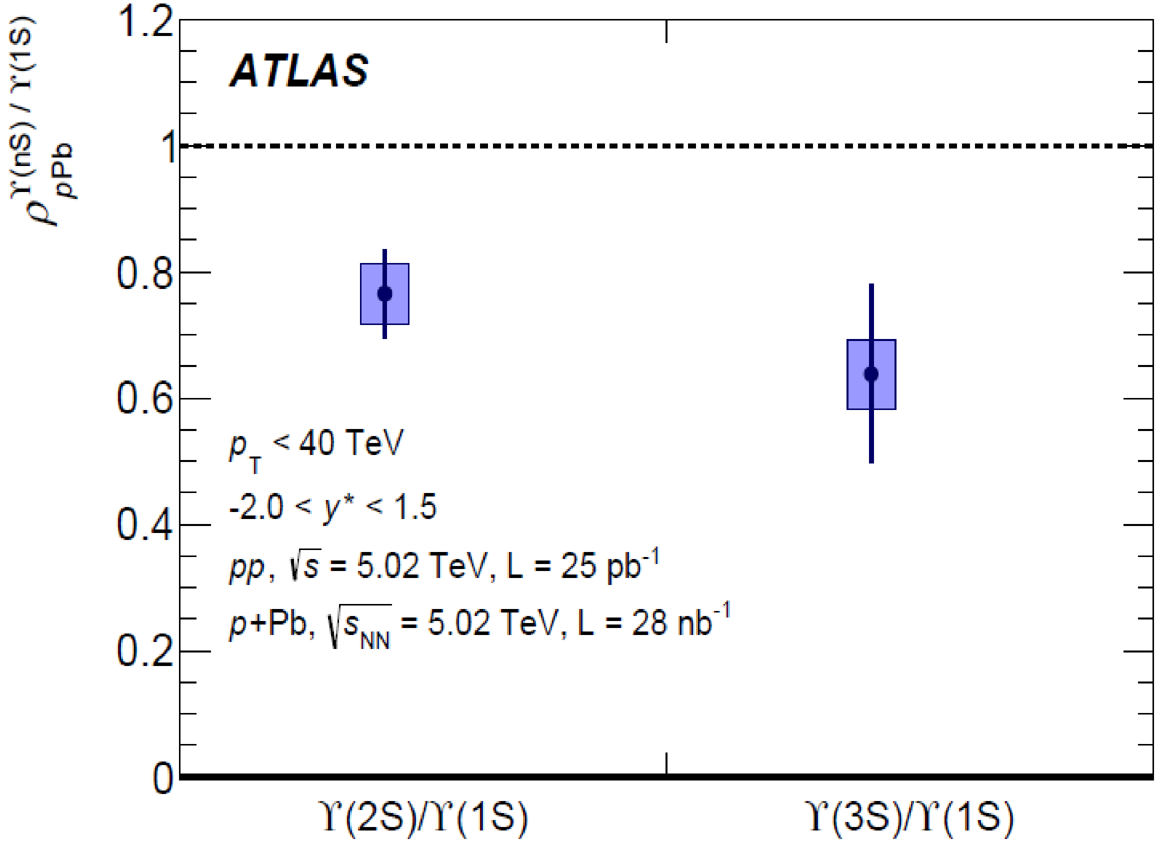
An obvious modification is observed for ϒ(1S)



Quarkonium production in 5.02 TeV pp & pPb collisions

Double ratios are away from unity in both charmonium and bottomonium sectors

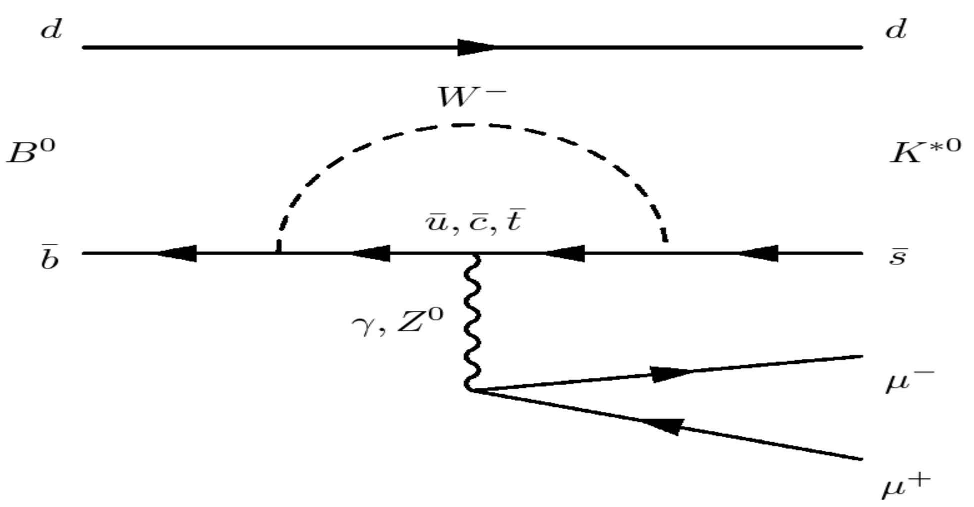




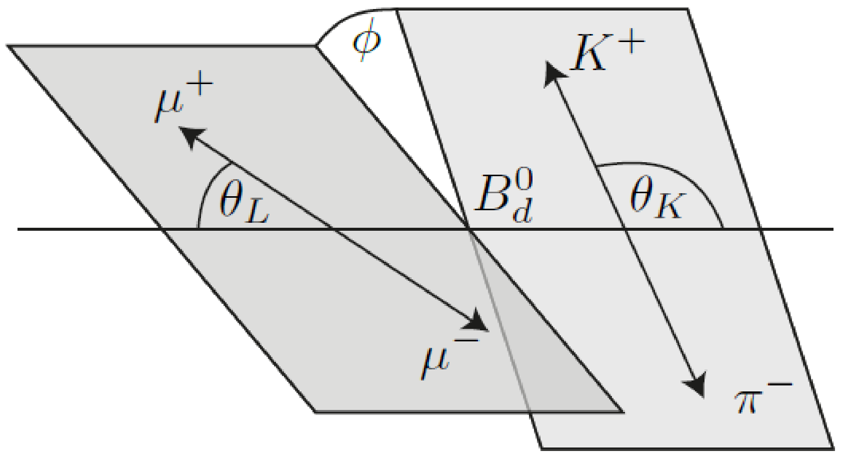
Angular analysis of the decay $B_d^0 \to K^*\mu^+\mu^-$

- FCNC process is sensitive to physics beyond SM; LHCb reported a hint of 3.4σ deviation.

- The differential decay rates is the function of the three angles, and the coefficients are to be measured in this analysis:

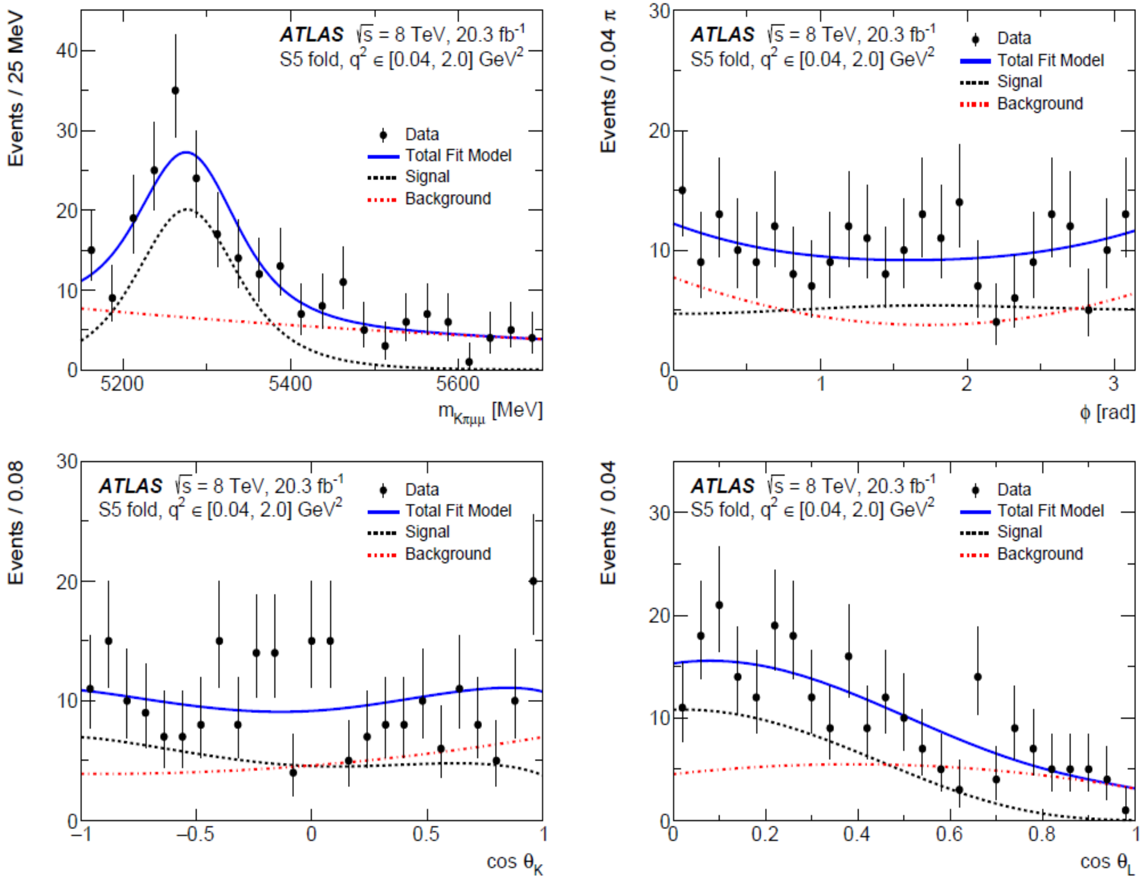


$$\frac{1}{d\Gamma/dq^2}\frac{d^4\Gamma}{d\cos\theta_L\, d\cos\theta_K\, d\phi\, dq^2} = \frac{9}{32\pi}\Bigg[\frac{3(1-F_L)}{4}\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1-F_L}{4}\sin^2\theta_K\cos 2\theta_L$$
$$-F_L\cos^2\theta_K\cos 2\theta_L + S_3\sin^2\theta_K\sin^2\theta_L\cos 2\phi$$
$$+S_4\sin 2\theta_K\sin 2\theta_L\cos\phi + S_5\sin 2\theta_K\sin\theta_L\cos\phi$$
$$+S_6\sin^2\theta_K\cos\theta_L + S_7\sin 2\theta_K\sin\theta_L\sin\phi$$
$$+S_8\sin 2\theta_K\sin 2\theta_L\sin\phi + S_9\sin^2\theta_K\sin^2\theta_L\sin 2\phi\Bigg]. \quad (1)$$



Angular analysis of the decay B_d^0->$K^*\mu^+\mu^-$

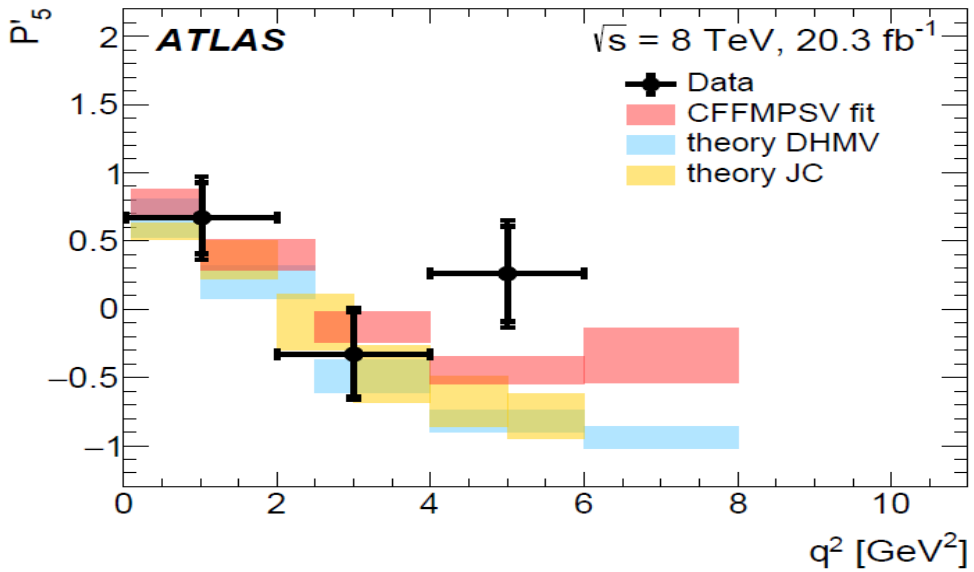
- Multiple muon triggers are used
- Di-muon from a common vertex
- K* are formed form two oppositely charged tracks, and the invariant mass near the K*(892)
- B_d^0 are from the K* and two oppositely charge muons, and the four tracks share the same vertex, with invariant mass between 5150 MeV and 5700 MeV
- The lifetime significance of B_d^0 > 12.5
- B_d^0 momentum shared the same direction as the vector from primary vertex to B_d^0 vertex
- q^2 in [0.04, 6.0] GeV and the ϕ(1020) is vetoed
- Control region for K*J/ Ψ and K* Ψ(2S) are defined

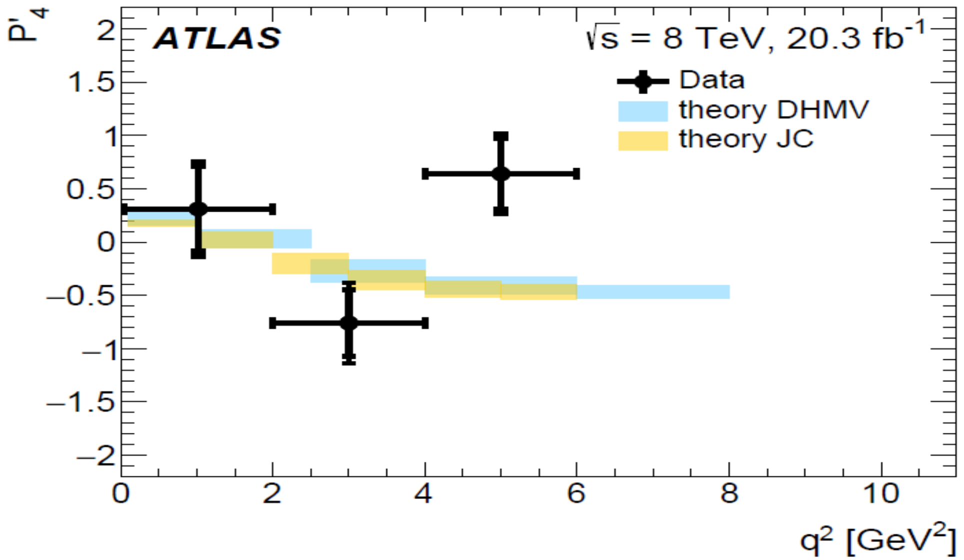


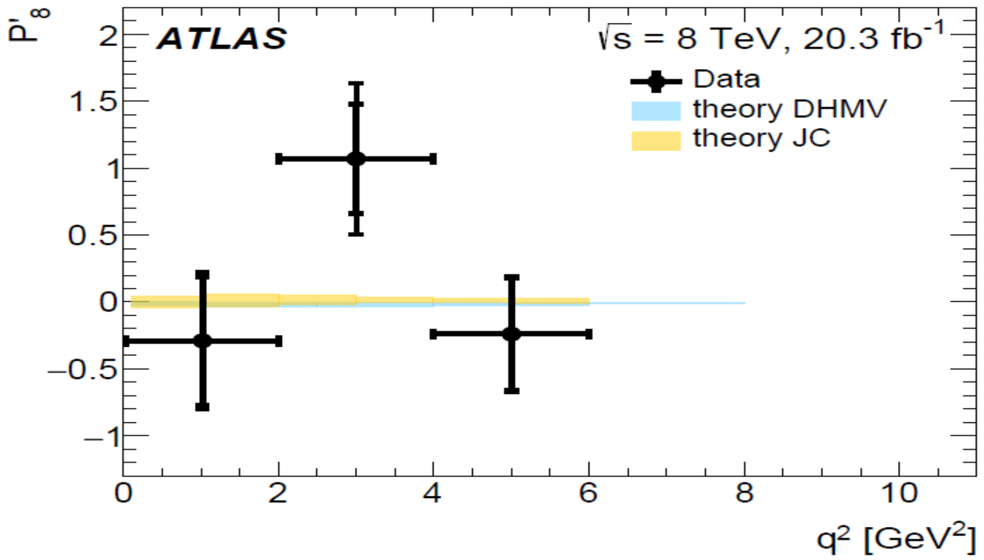
Fit result for S5 fold and for the first q^2 bin

Angular analysis of the decay $B_d^0 \to K^* \mu^+ \mu^-$

The measured angular parameters are consistent with SM predictions, except for P'$_4$, P'$_5$, P'$_8$, which are with less than 3σ deviation.







Summary

The following four analyses about heavy flavour and quarkonium from ATLAS are reviewed in this talk:

1. Search for the X(5568) in $B_s^0\pi^{\pm}$ final states (Phys. Rev. Lett. 120 (2018) 202007)
   No obvious signal is there!

2. Measurement of b-hadron pair production (JHEP 11 (2017) 62)
   The results could be used to tune the generators!

3. Quarkonium production in 5.02 TeV pp & pPb collisions (Eur. Phys. J. C 78 (2018) 171)
   An additional dataset for constraining models of cold-nuclear-mater effect!

4. Angular analysis of the decay $B_d^0 \to K^* \mu^+ \mu^-$ (1805.04000 submitted to JHEP)
   No evidence beyond SM is observed!

More results about heavy flavour and quarkonium from ATLAS are under tuning, and will come soon.

Science & Technology Facilities Council

Thank you very much!

BACK UP

Fit model in $B_d^0 \to K^*\mu^+\mu^-$

$$\mathcal{L} = \frac{e^{-n}}{N!} \prod_{k=1}^{N} \sum_{l} n_l P_{kl}(m_{K\pi\mu\mu}, \cos\theta_K, \cos\theta_L, \phi; \widehat{p}, \widehat{\theta})$$

$$F_L, S_3, S_5, P_5' : \begin{cases} \phi \to -\phi & \text{for } \phi < 0 \\ \theta_L \to \pi - \theta_L & \text{for } \theta_L > \frac{\pi}{2} \end{cases}$$

$$\begin{aligned} P_1 &= \frac{2S_3}{1-F_L} \\ P_2 &= \frac{2}{3}\frac{A_{\mathrm{FB}}}{1-F_L} \\ P_3 &= -\frac{S_9}{1-F_L} \\ P'_{j=4,5,6,8} &= \frac{S_{i=4,5,7,8}}{\sqrt{F_L(1-F_L)}}. \end{aligned}$$

BDT in b-hadron pair production

- *Track deflection significance*: This parameter is the maximum value of the significance of the difference in track curvature calculated upstream and downstream of a point somewhere along the track reconstructed in the inner detector. DIF muons originating from a point inside the inner detector typically have higher values of track deflection significance than the signal muons.
- *Track deflection neighbour significance*: Computed considering track segments, between adjacent hits, along the inner detector track. The largest value over the whole track of the significance of the angular difference between adjacent track segments is taken. This variable quantifies the significance of a deflection along a muon track; DIF muons originating from a point inside the inner detector populate larger values.
- *Momentum balance significance*: The significance of the difference between the track momenta reconstructed in the inner detector and in the muon spectrometer. If a pion or kaon decays outside the inner detector, the inner detector track may be matched to a lower-momentum muon spectrometer track produced by the resulting muon. The imbalance between the two track momenta is higher for these DIF muons than for inner detector and muon spectrometer tracks produced by a single muon. This variable also offers discrimination between signal and hadronic shower leakage muons.
- *Absolute pseudorapidity*, $|\eta|$: Muon candidates produced in the background processes are more likely to be produced at high absolute pseudorapidities.