Recent results of heavy flavour physics at ATLAS

Weimin Song (宋维民)

Jilin University

weiminsong@jlu.edu.cn

6th workshops on the XYZ particles

Outline

Introduction of heavy flavour physics program at ATLAS

Five topics:

1. Search for the X(5568) in $B_s^0\pi^\pm$ final states (PRL 120, 202007 (2018))

2. Observation of an Excited $B_c^\pm$ Meson State (PRL 113, 212004 (2014))

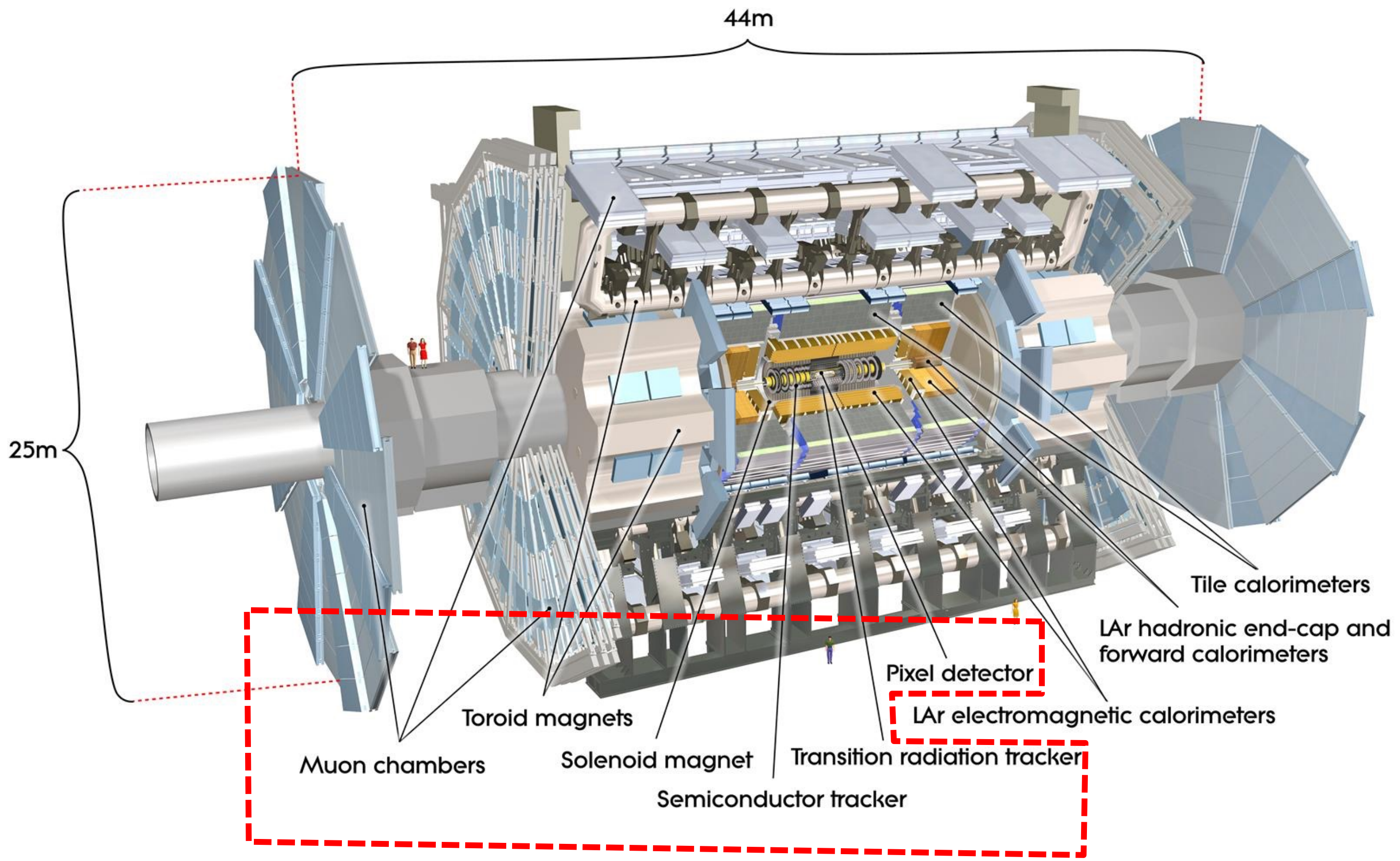
3. ϕs and $\Delta\Gamma s$ measurement in the $Bs^0 \to J/\Psi\ \phi$ channel (JHEP 08 (2016) 147, ATLAS-CONF-2019-009)

4. Bs^0 (and B^0) $\to \mu\mu$ measurement (JHEP 04 (2019) 098)

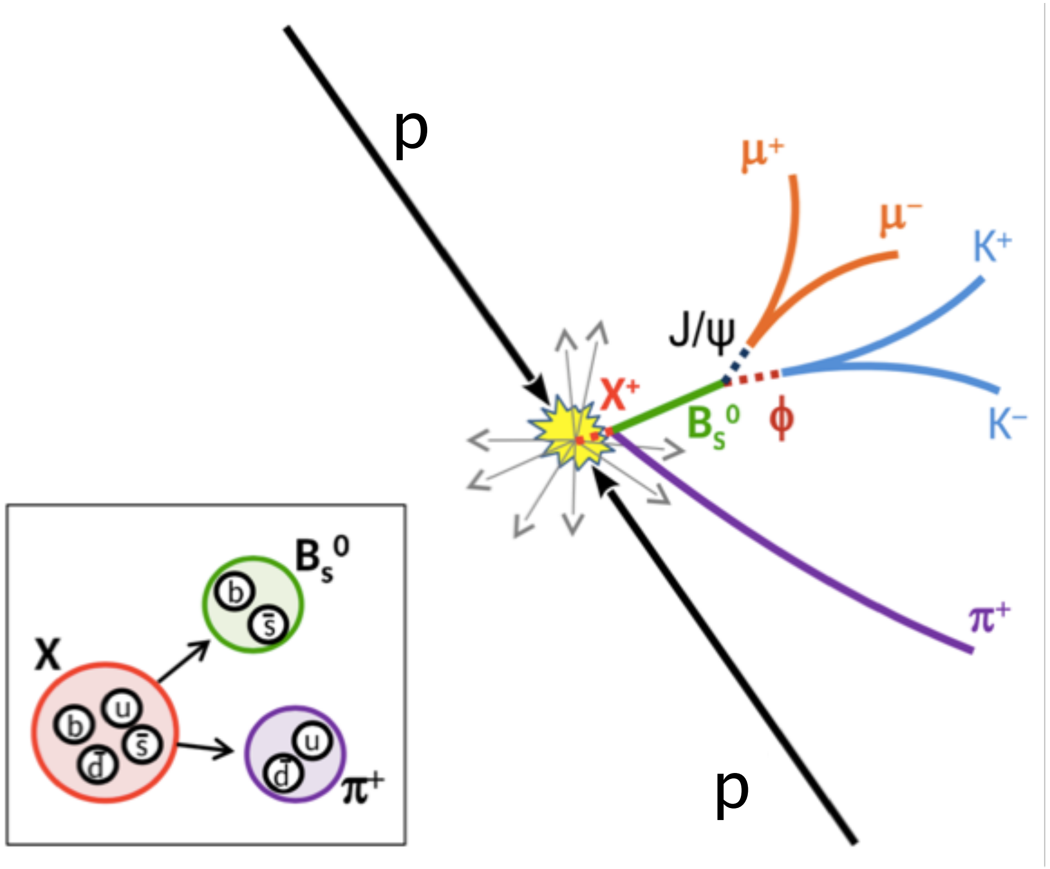
5. Ψ(2S) and X(3872) production (JHEP 01 (2017) 117)

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



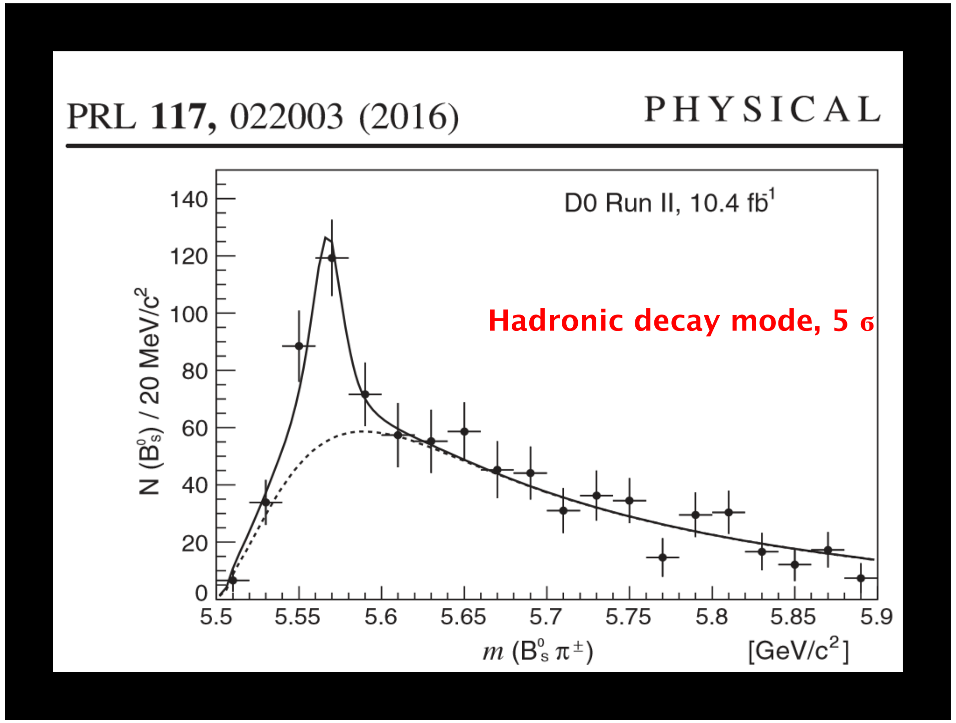
Search for the X(5568) in $B_s^0\pi^\pm$ final states

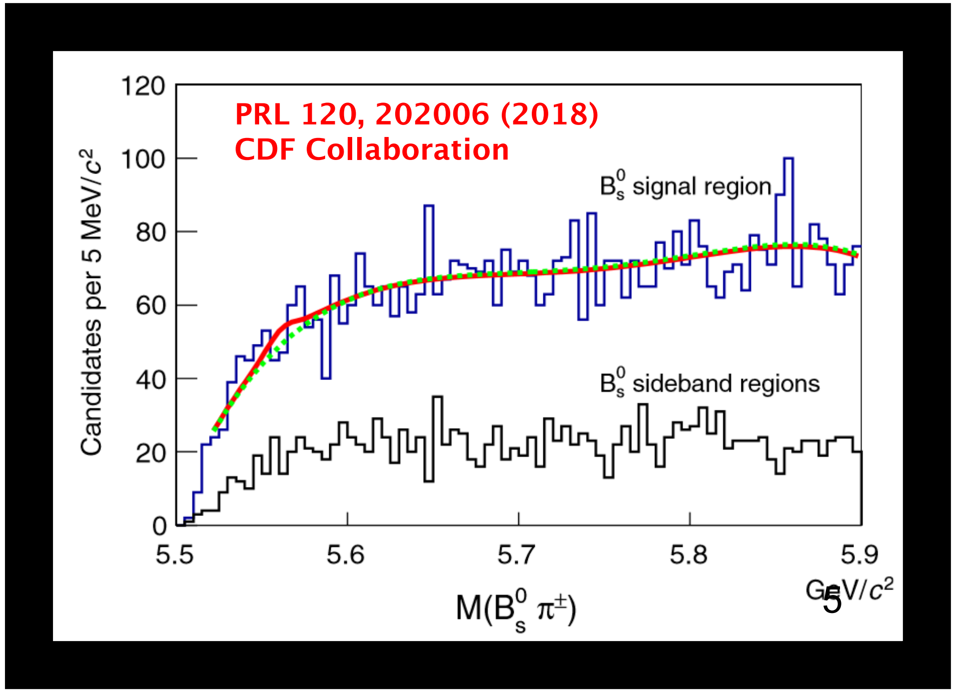


D0 Collaboration reported evidence of the $X(5568) \to B_s^0\pi^\pm$, $B_s^0 \to J/\Psi\ \phi$, and reported consistent result in the semi-leptonic decay of B_s^0 :

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

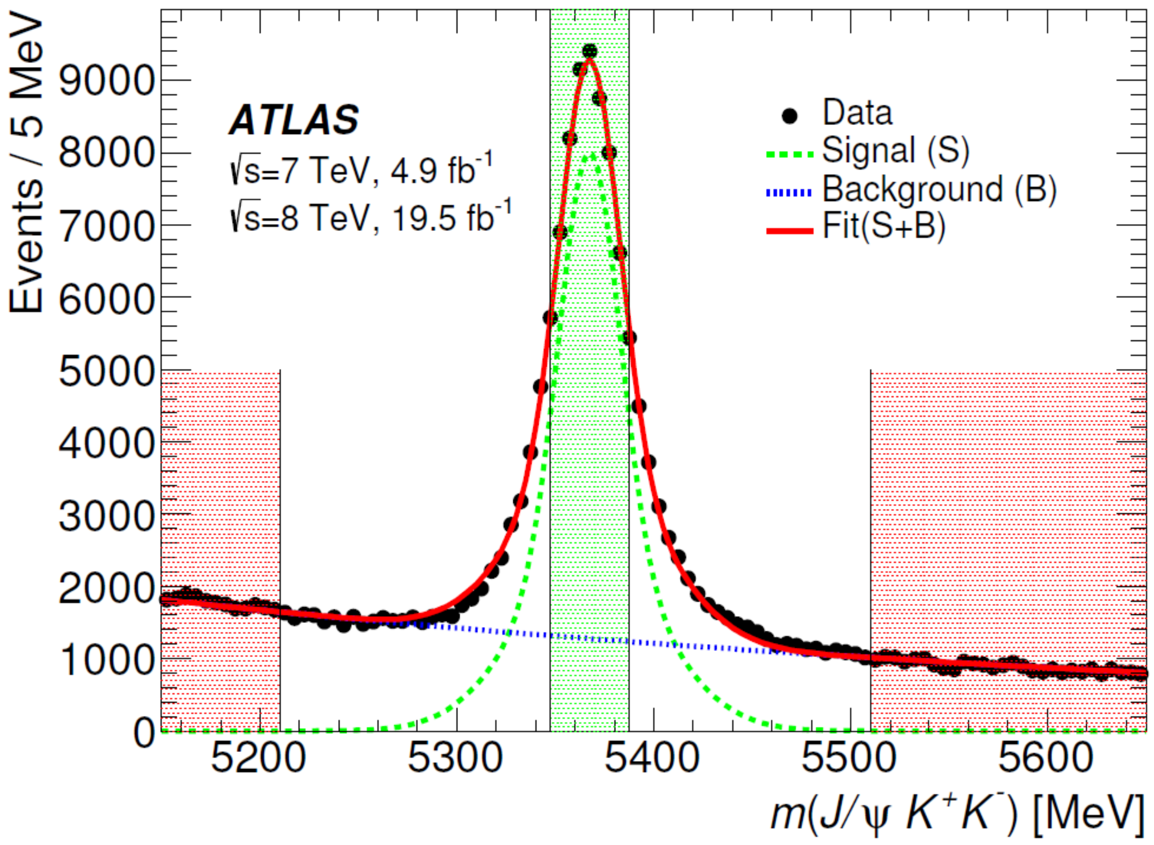
LHCb, CMS at LHC and CDF at Tevatron revealed no signal with similar techniques.





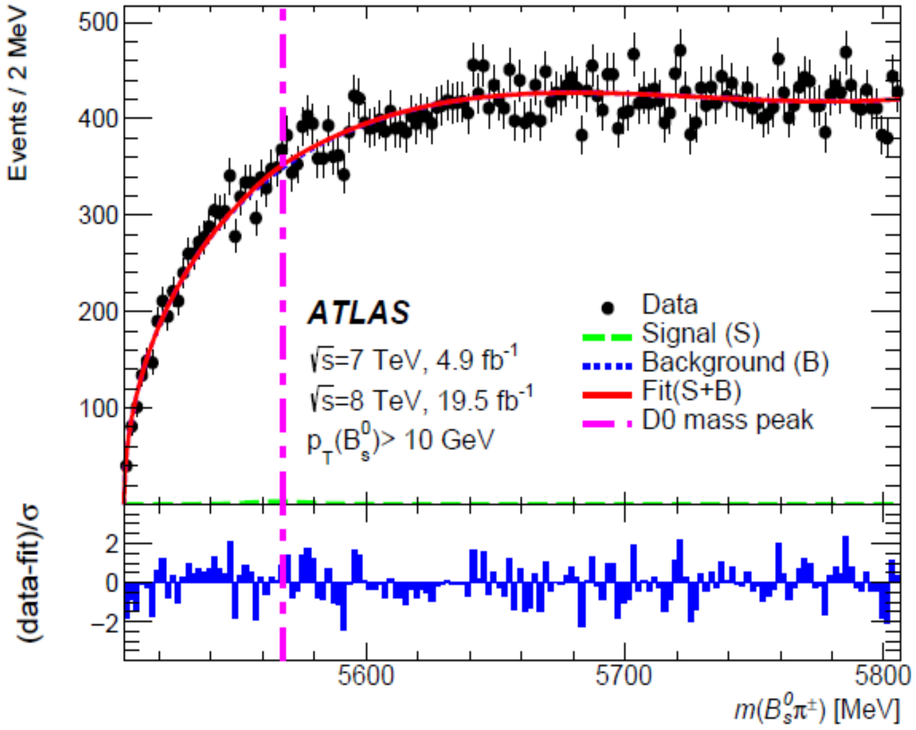
Search for the X(5568) in $B_s^0\pi^\pm$ final states

- 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 a0, calculated based on the B_s^0 vertex and momentum direction
- One track assumed to be π from the primary vertex

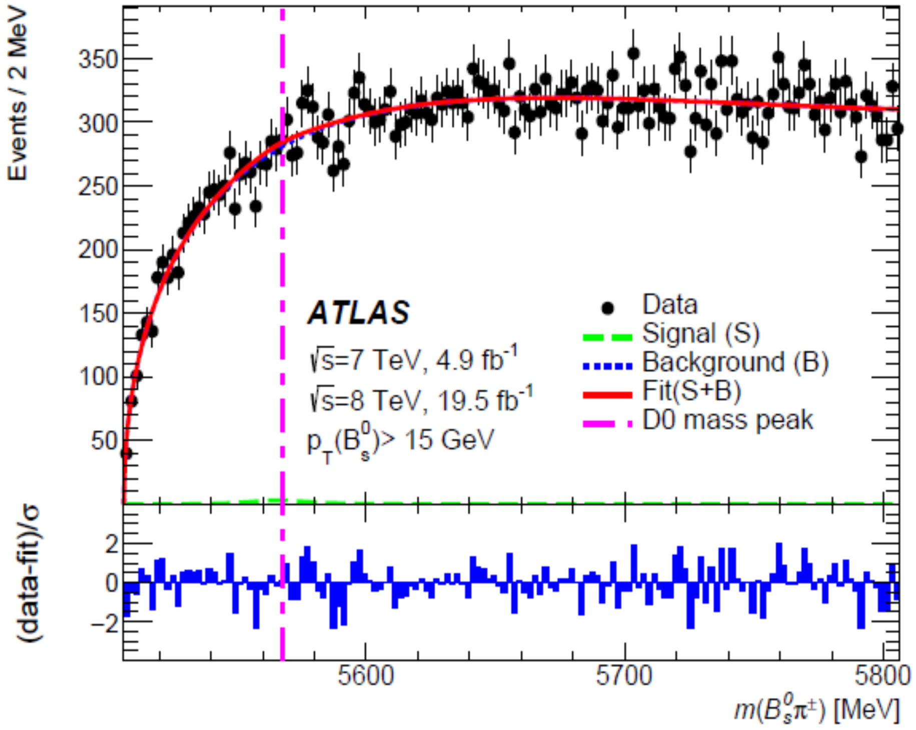


S: double Gaussian; B: Exponential

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!

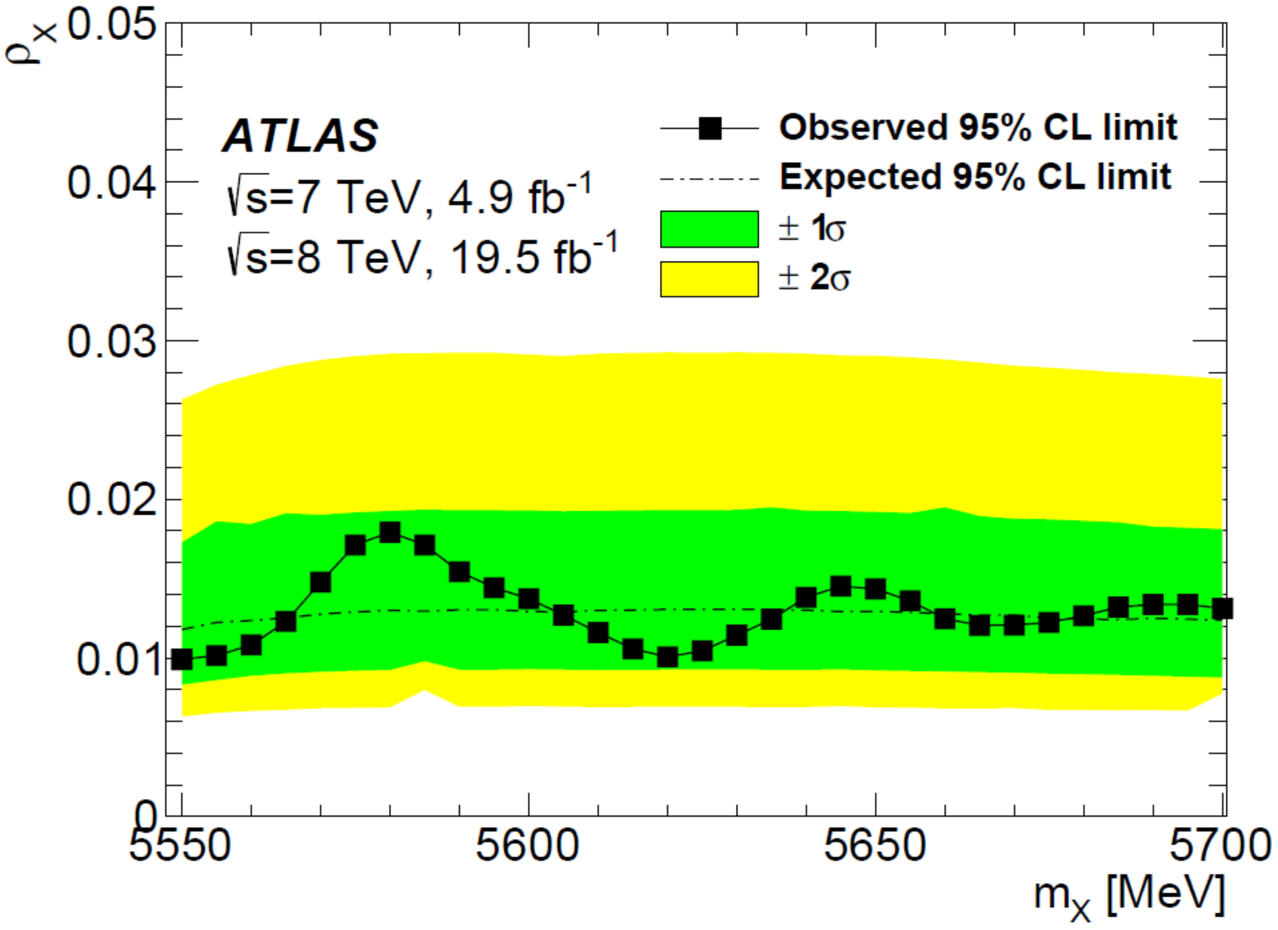
Search for the X(5568) in $B_s^0\pi^{\pm}$ final states

Mass range: 5550–5700 MeV

Width: 21.9 MeV

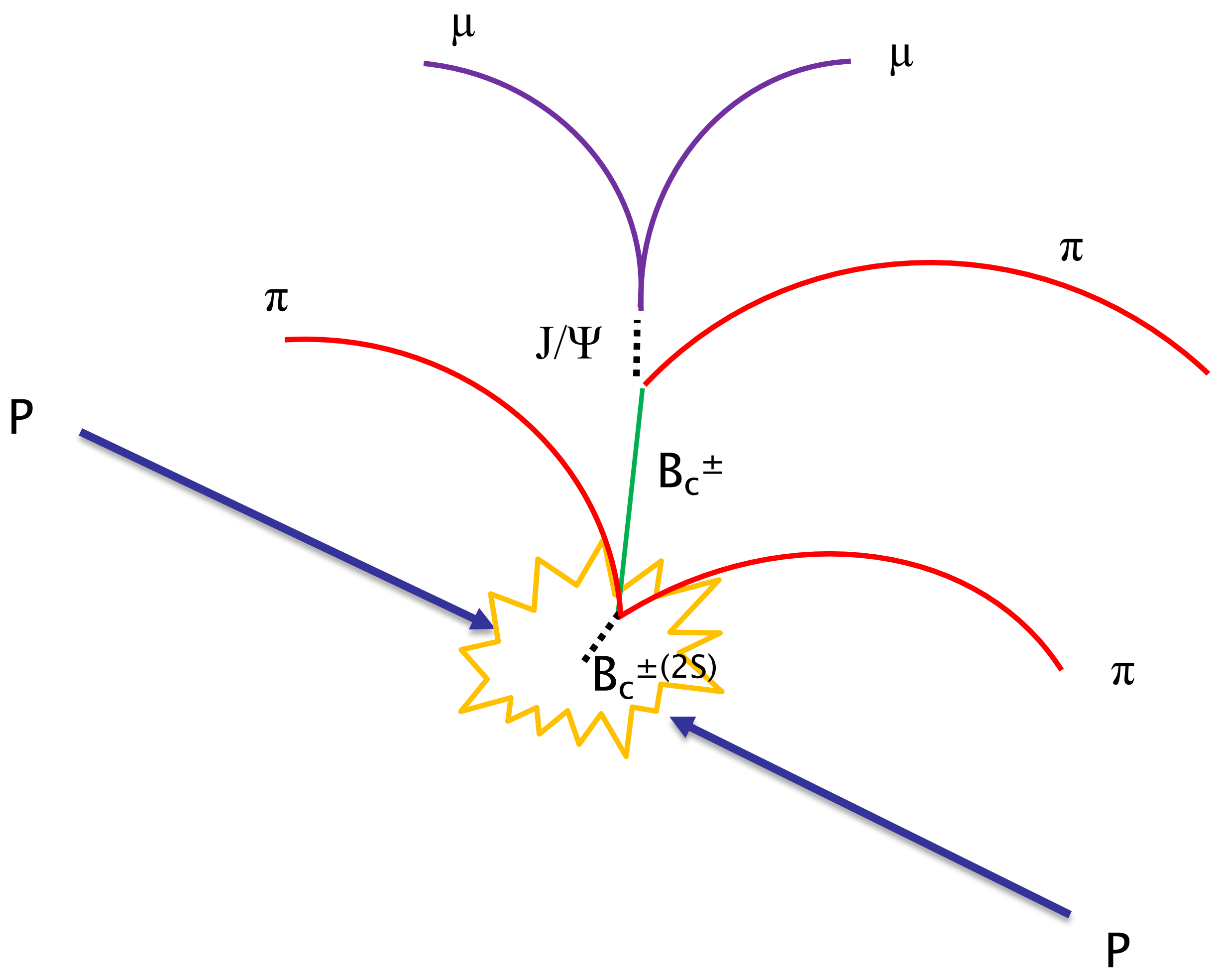
$P_T(B_s^0)$ > 10 GeV

Upper limit on the production rate is set



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

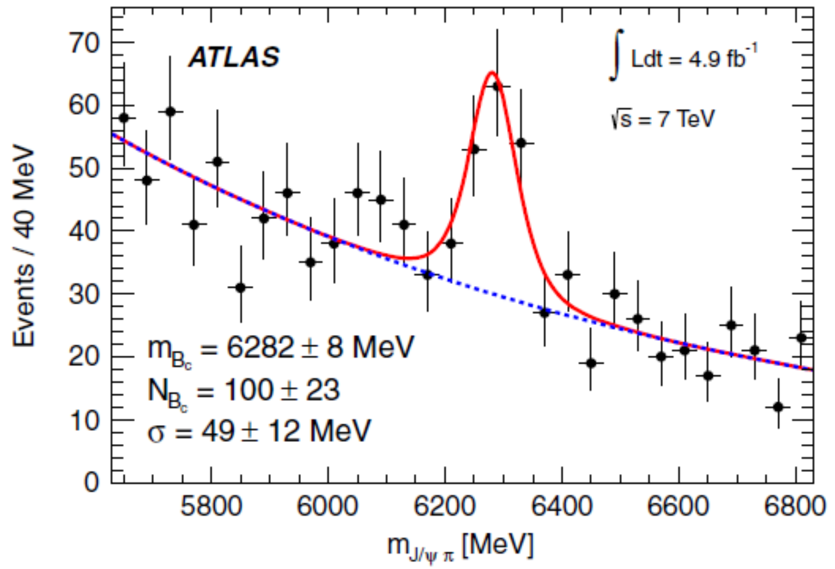
Observation of an Excited $B_c^{\pm}$ Meson State



Observation of an Excited $B_c^{\pm}$ Meson State

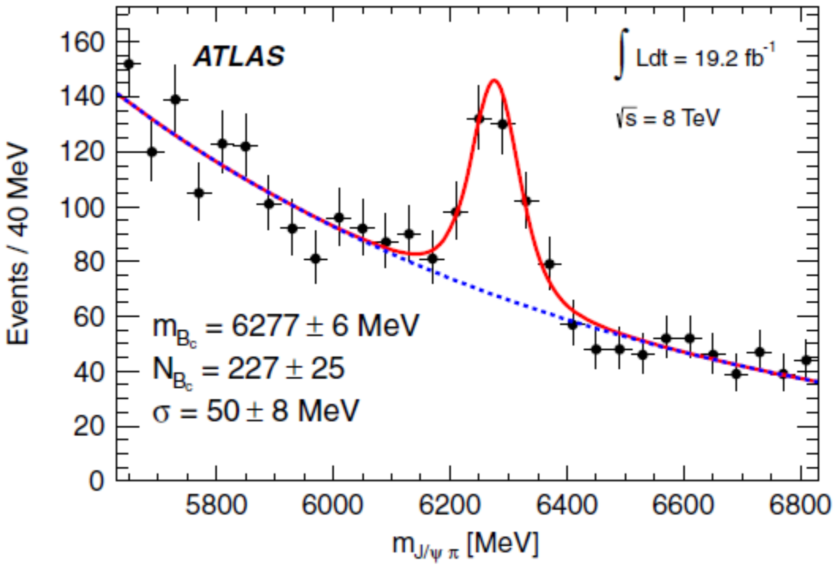
1. Select the J/Ψ into two opposite charged muons:

   pT(high) > 6 GeV; pT(low) > 4 GeV; vertex fit;
   mass constrain to PDG;



2. Select $B_c^{\pm}$ by adding a pion:

   pT > 4 GeV; common vertex to J/Ψ;
   cut on the impact parameter of the pion;
   pT ($Bc\pm$) > 15 GeV (18 GeV) for 7 TeV (8 TeV)



Observation of an Excited $B_c^{\pm}$ Meson State

3. Select two pions from the primary vertex:

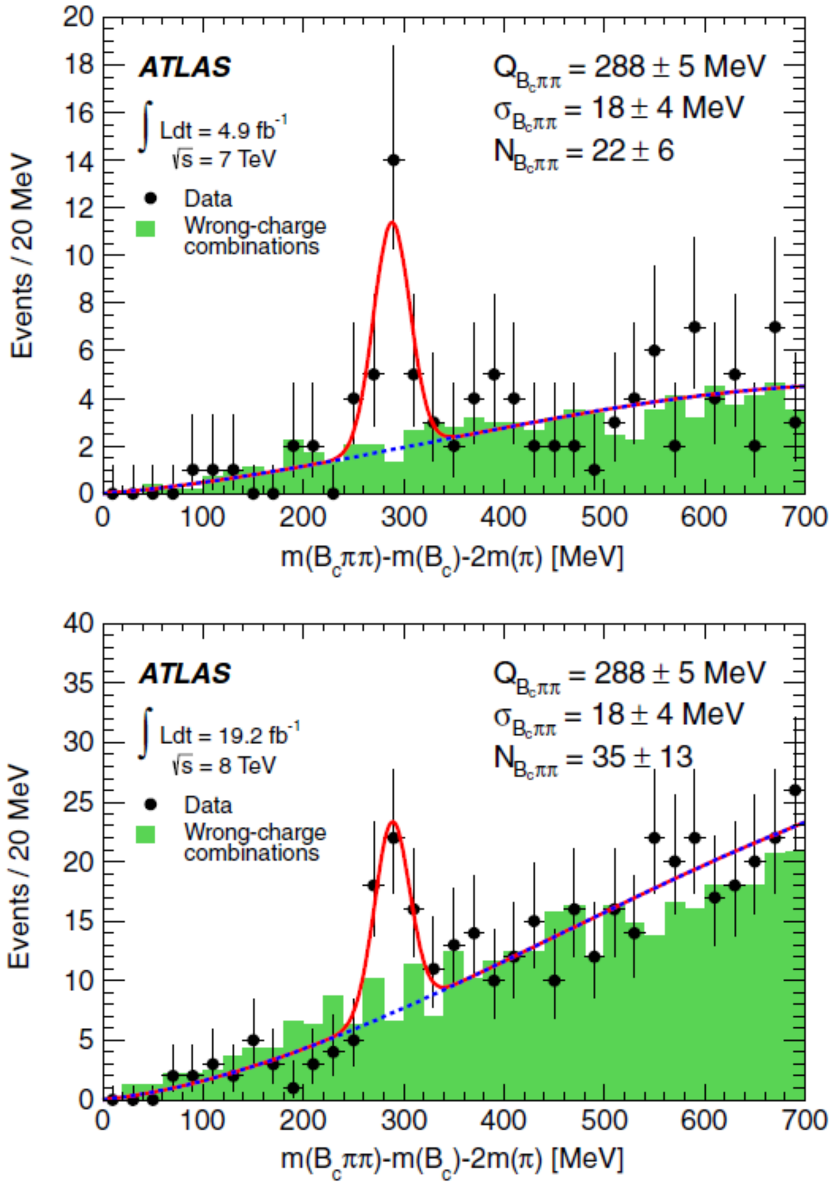
pT > 400 MeV

4. Fit the mass difference distribution:

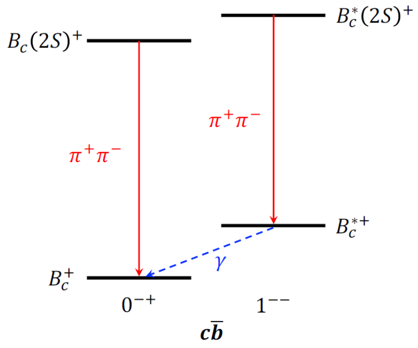
Gaussian for signal, third-order polynomial for background

Significance of the new structure

> 5 σ

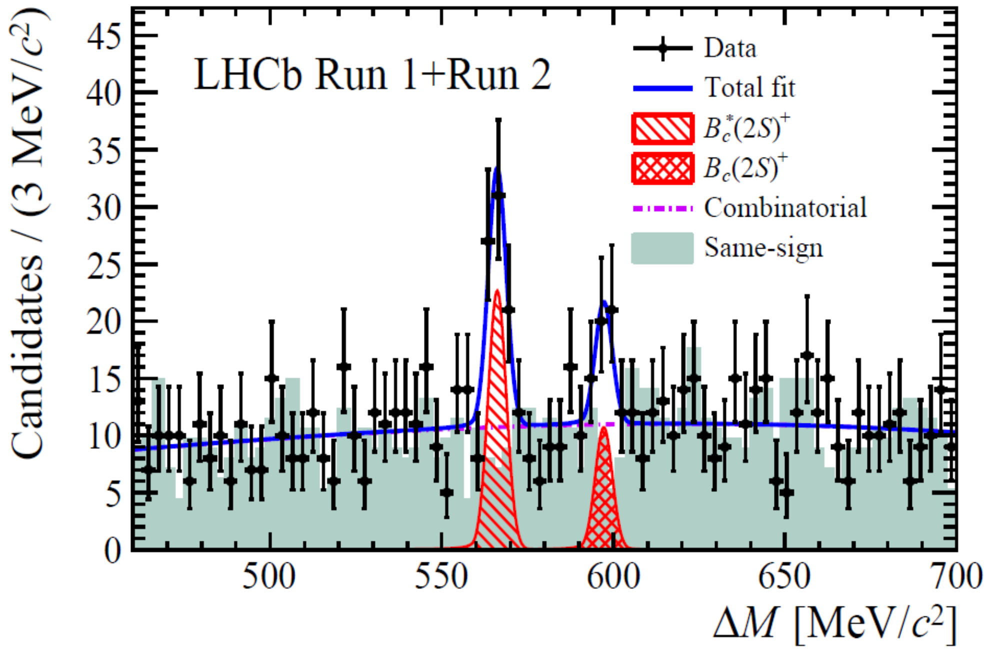


Fine structure?

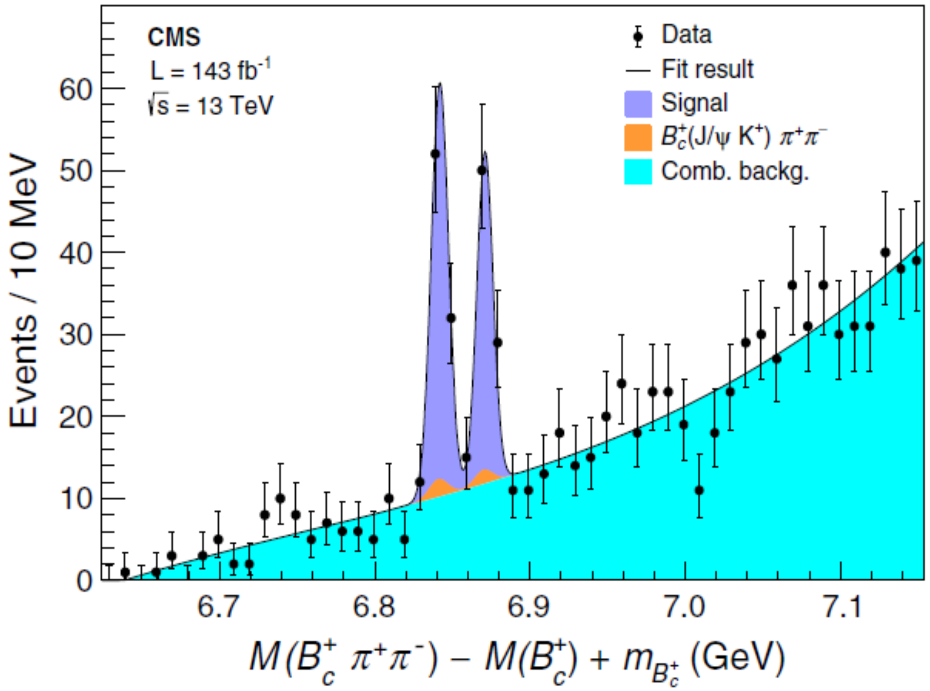


With the similar technique but larger sample, both CMS and LHCb observed two structures, and updated results on ATLAS to be expected

.



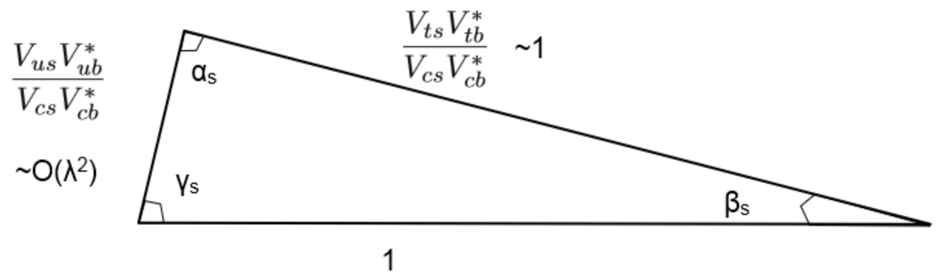
arXiv:1904.0008



PHYSICAL REVIEW LETTERS 122, 132001

ϕs and $\Delta\Gamma$s measurement in the Bs$^0 \rightarrow$ J/Ψ ϕ

$$V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0$$

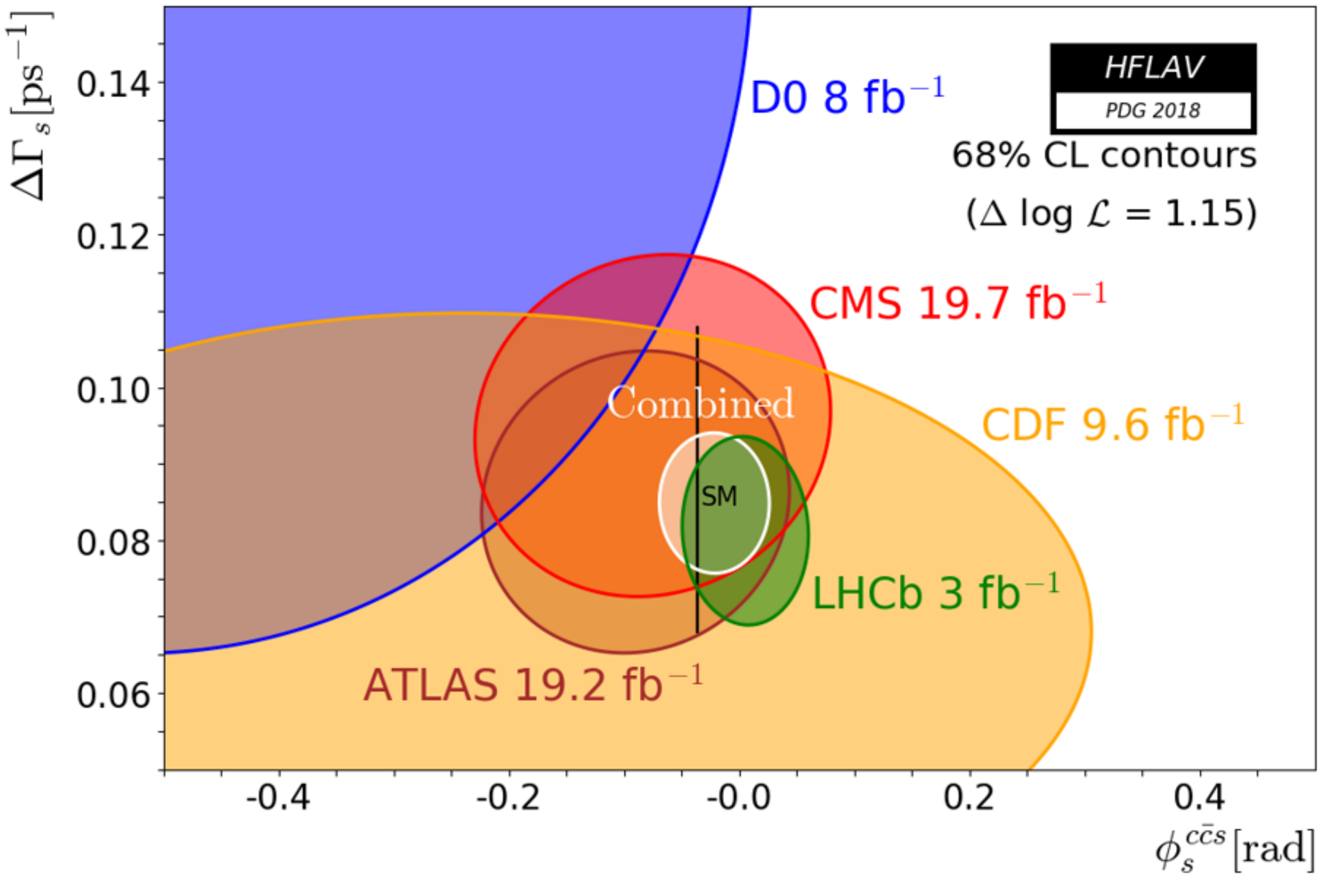


$\varphi_s = -2\,\beta_s = -\,0.0363 \pm 0.016$ rad

Charles et al, PRD84,033005

ϕs, the CP violating phase is defined as the phase difference between mixing amplitude and decay amplitude; In SM, it is small, and related to CKM matrix.

World averaged results before Moriond 2019

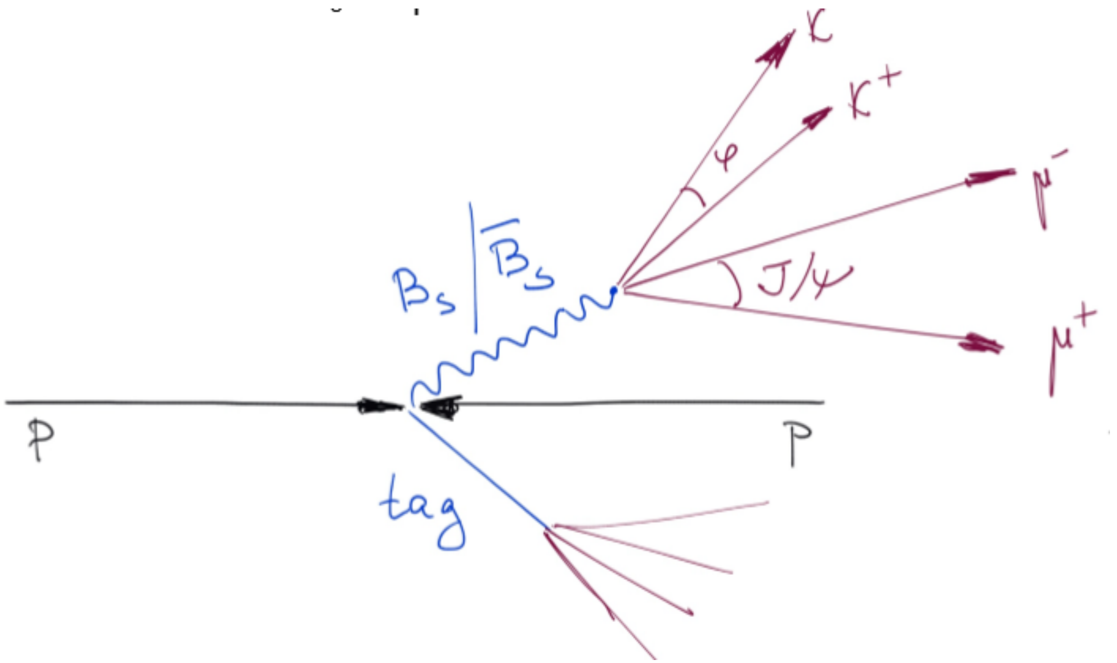


From HFLAV

New result based on 80 fb^{-1} at 13 TeV will be discussed here

Methodology

Flavour tagger: OST (opposite-side-tagging); lepton charge in semi-leptonic decay of B meson provides strong discrimination.

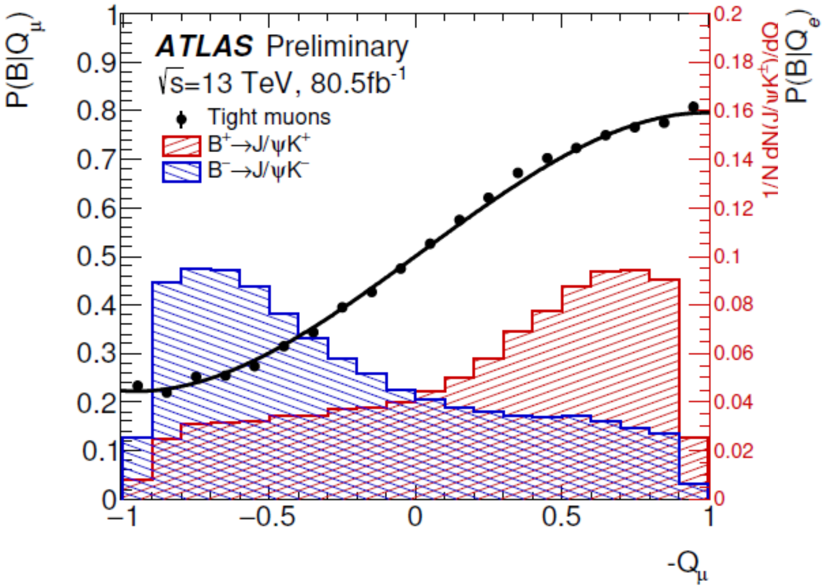


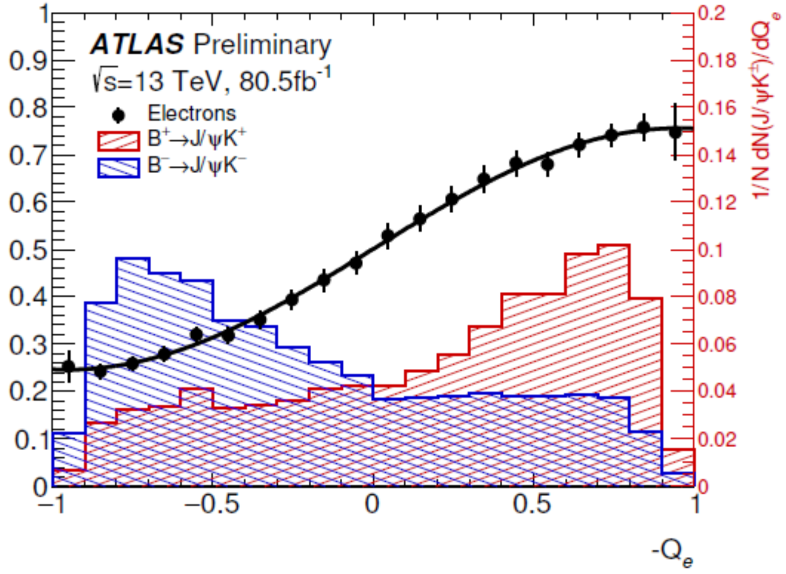
CP State tagger: CP even if L = 0 or 2; CP odd if L =1. L is the orbital angular momentum.

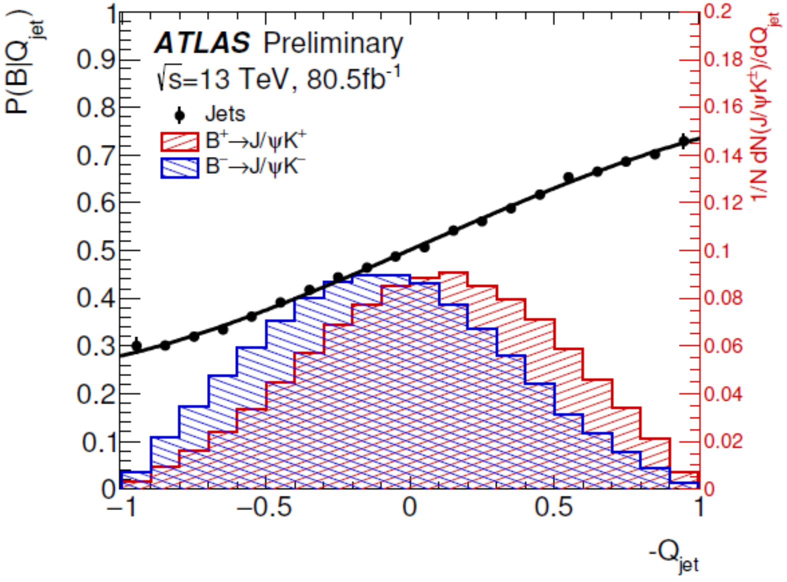
Tagger: weighted sum of charge in a cone

$$Q_x = \frac{\sum_i^{N\ \text{tracks}} q_i \cdot (p_{\mathrm{T}i})^{\kappa}}{\sum_i^{N\ \text{tracks}} (p_{\mathrm{T}i})^{\kappa}},$$

Tag method	Efficiency [%]	Effective Dilution [%]	Tagging Power [%]
Tight muon	4.50 ± 0.01	43.8 ± 0.2	0.862 ± 0.009
Electron	1.57 ± 0.01	41.8 ± 0.2	0.274 ± 0.004
Low-p_{T} muon	3.12 ± 0.01	29.9 ± 0.2	0.278 ± 0.006
Jet	5.54 ± 0.01	20.4 ± 0.1	0.231 ± 0.005
Total	14.74 ± 0.02	33.4 ± 0.1	1.65 ± 0.01







Fit results with RUN 2 data

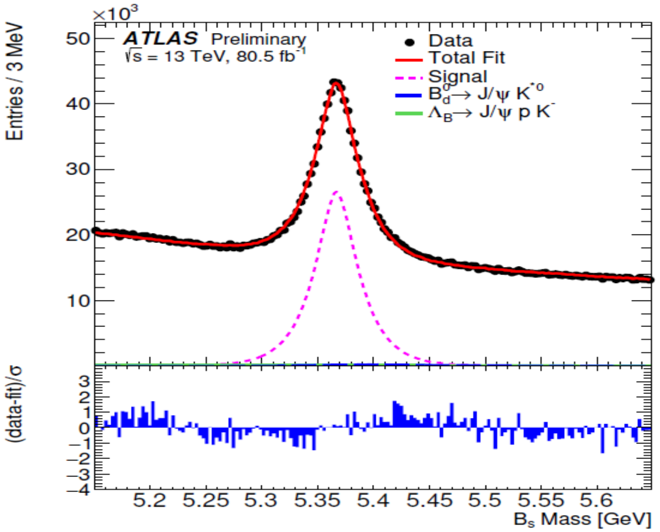
Simultaneous un-binned maximum-likelihood fit contains nine parameters:

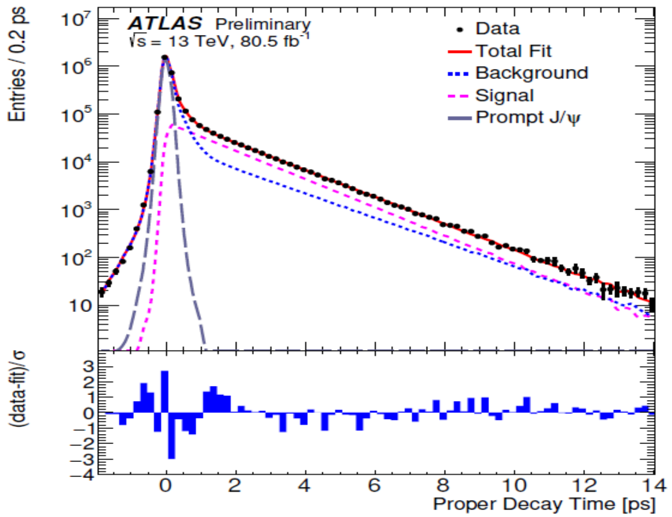
$$\Delta\Gamma_s,\ \phi_s,\ \Gamma_s,\ |A_0(0)|^2,\ |A_{\parallel}(0)|^2,\ \delta_{\parallel},\ \delta_{\perp},\ |A_S(0)|^2 \text{ and } \delta_S.$$

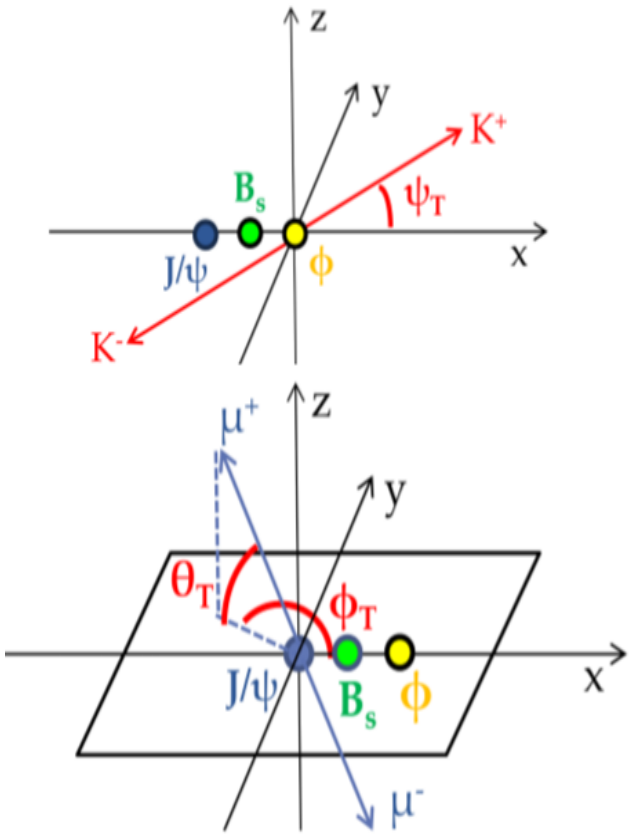
Information used in the fit: mass of Bs^0; proper decay time and its uncertainty; tagging probability; the transversity angles (defined in the next page)

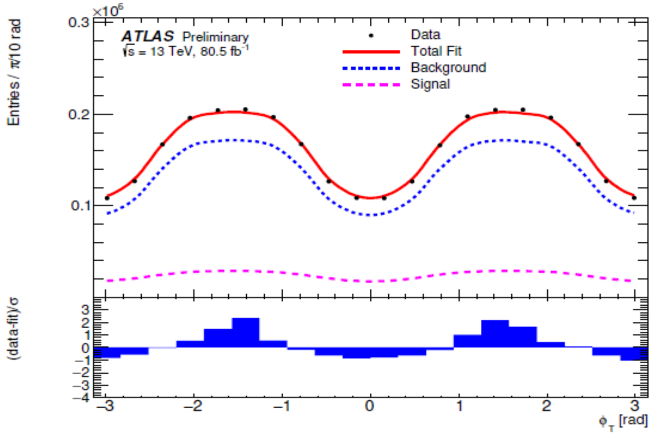
Parameter	Value	Statistical uncertainty	Systematic uncertainty
ϕ_s[rad]	−0.068	0.038	0.018
$\Delta\Gamma_s$[ps^{-1}]	0.067	0.005	0.002
Γ_s[ps^{-1}]	0.669	0.001	0.001
$\|A_{\parallel}(0)\|^2$	0.219	0.002	0.002
$\|A_0(0)\|^2$	0.517	0.001	0.004
$\|A_S(0)\|^2$	0.046	0.003	0.004
$\delta_{\perp}$ [rad]	2.946	0.101	0.097
$\delta_{\parallel}$ [rad]	3.267	0.082	0.201
$\delta_{\perp} - \delta_S$ [rad]	−0.220	0.037	0.010

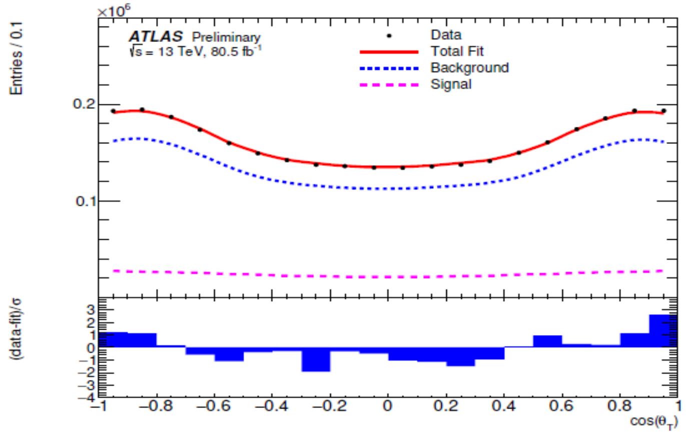
Fit projection

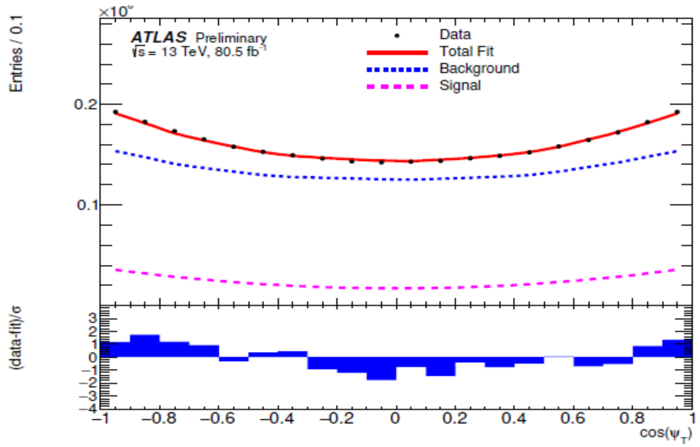




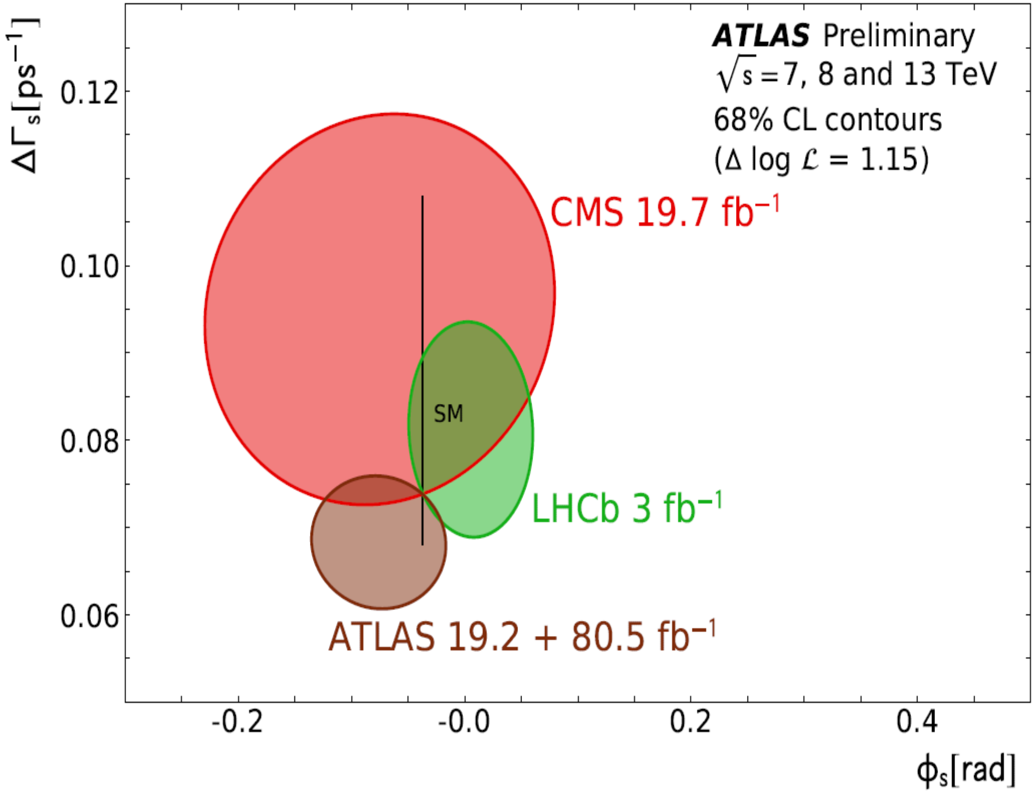






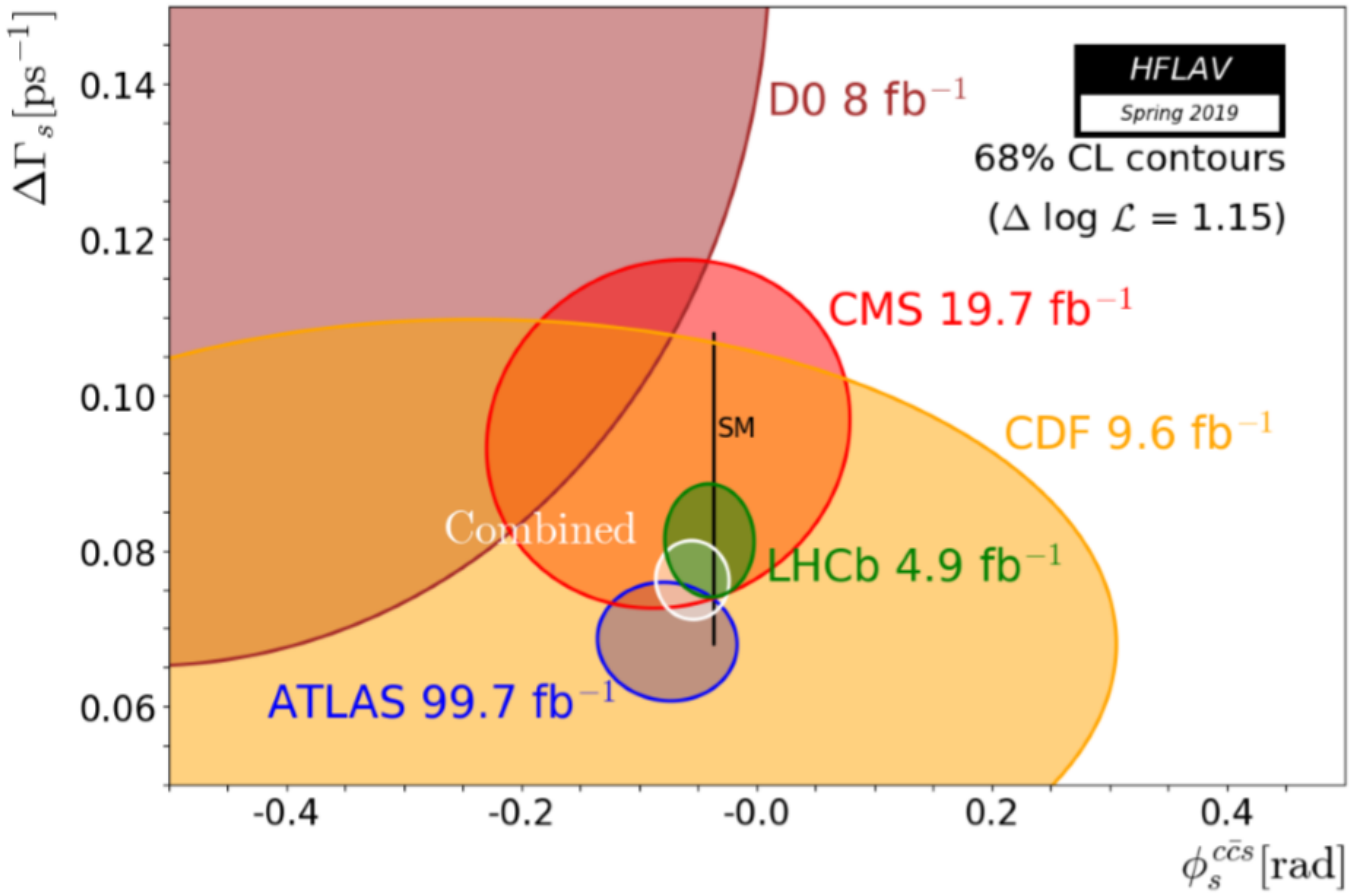


Result: combined with RUN1 result



Parameter	Value	Statistical uncertainty	Systematic uncertainty
ϕ_s[rad]	−0.076	0.034	0.019
$\Delta\Gamma_s$[ps^{-1}]	0.068	0.004	0.003
Γ_s[ps^{-1}]	0.669	0.001	0.001
$\lvert A_\parallel(0)\rvert^2$	0.220	0.002	0.002
$\lvert A_0(0)\rvert^2$	0.517	0.001	0.004
$\lvert A_S\rvert^2$	0.043	0.004	0.004
$\delta_\perp$ [rad]	3.075	0.096	0.091
$\delta_\parallel$ [rad]	3.295	0.079	0.202
$\delta_\perp - \delta_S$ [rad]	−0.216	0.037	0.010

Result: combined with LHCb new result



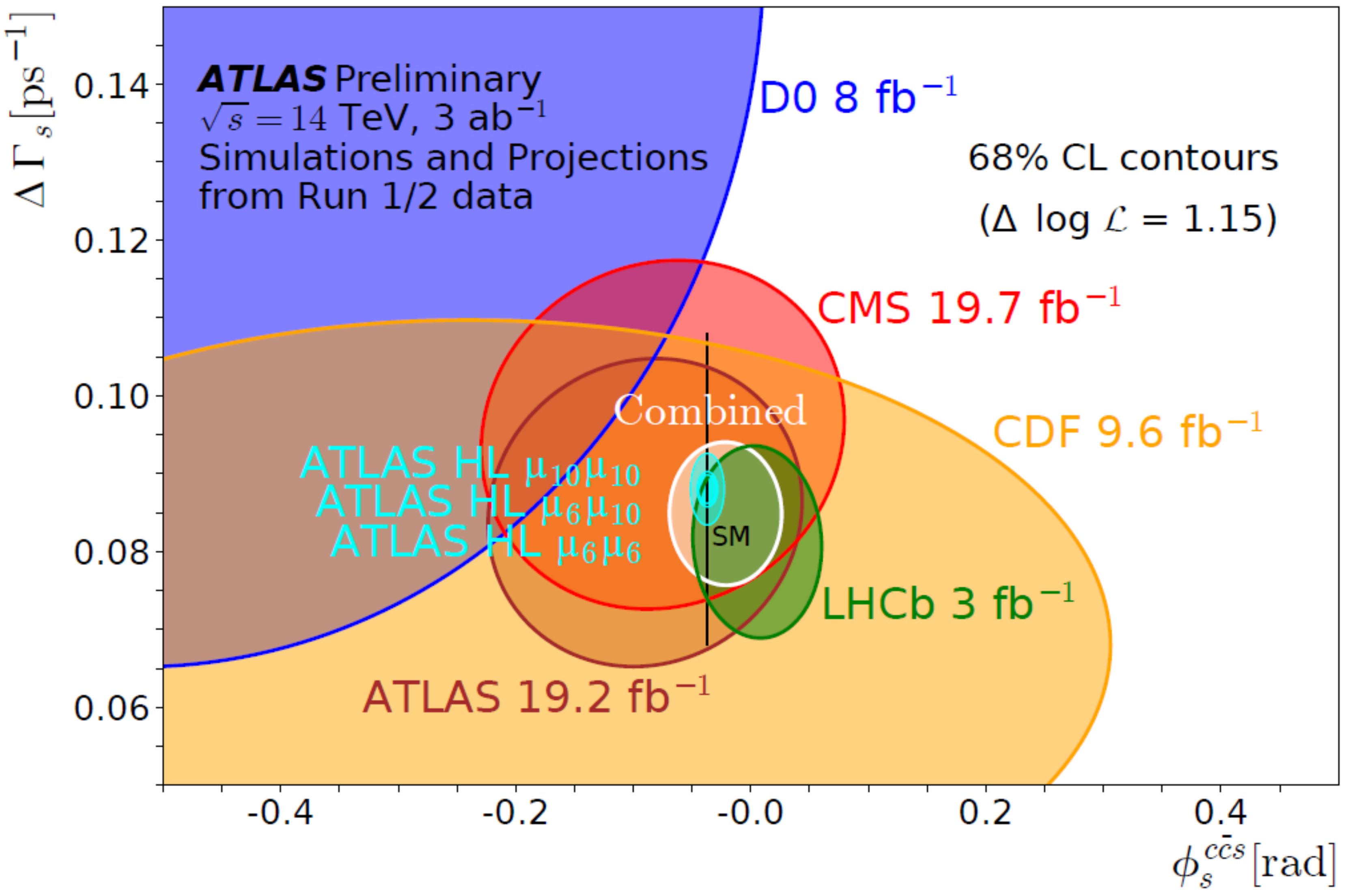
New HFLAV average

$$\phi_s = -0.0544 \pm 0.0205$$

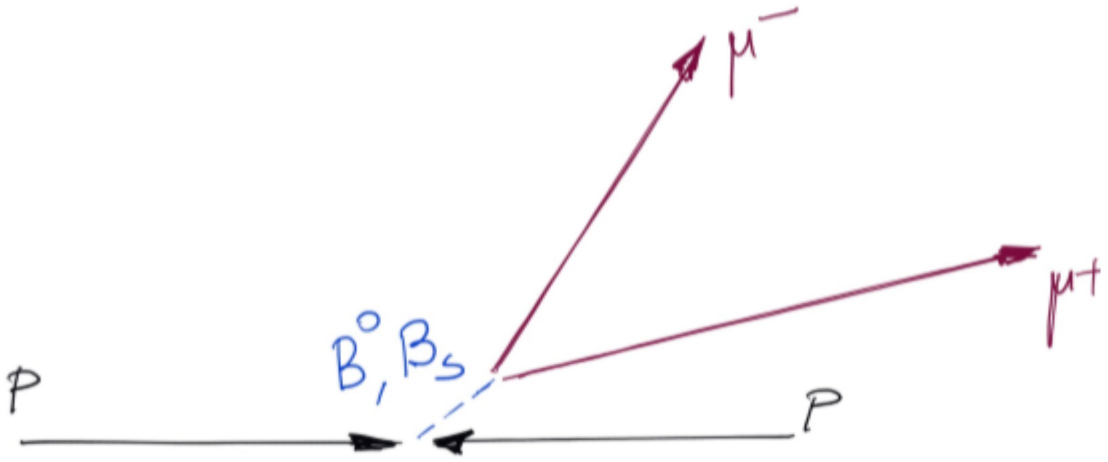
$$\Delta\Gamma_s = 0.0762 \pm 0.0033\,\mathrm{ps}^{-1}$$

ATL-PHYS-PUB-2018-041

ATLAS HL–LHC projection



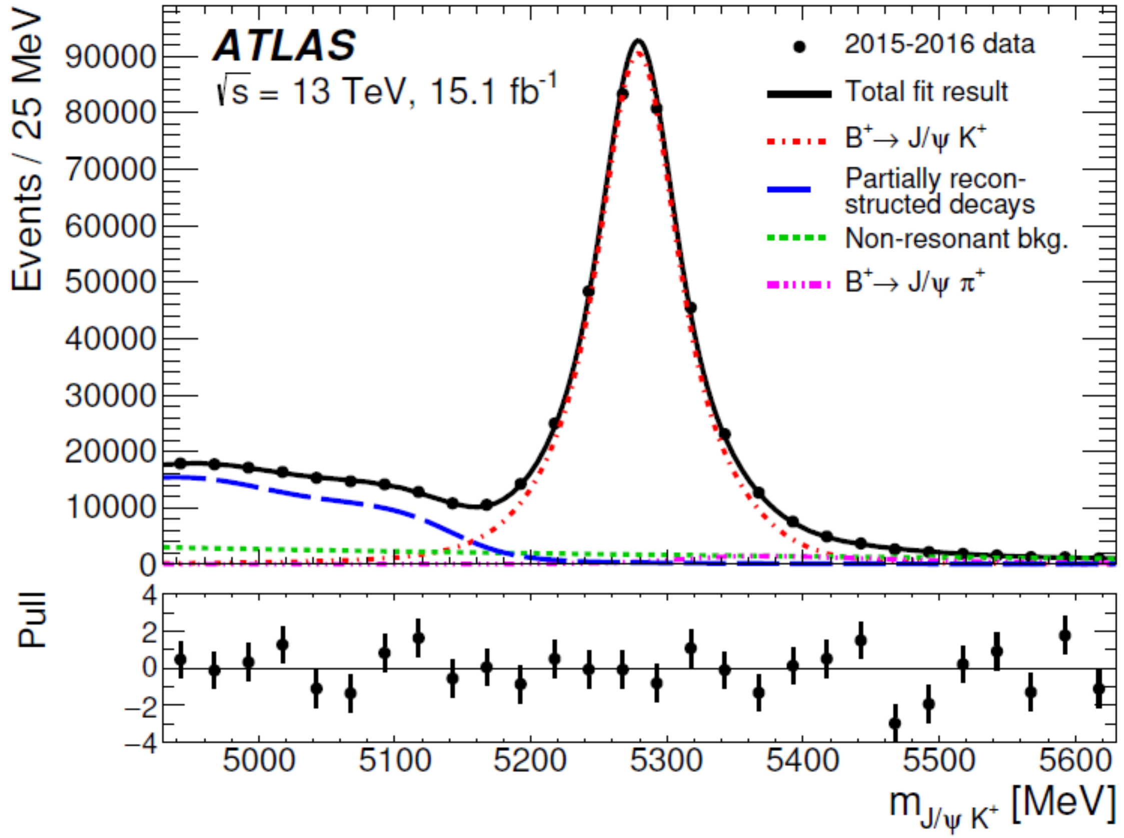
B_s^0 (and B^0) → μμ measurement



New result based on 26 fb^{-1} at 13 TeV
2015+2016

Methodology: take $B^+ \to J/\Psi K^+$ as reference

$$\mathcal{B}(B^0_{(s)} \to \mu^+\mu^-) = \frac{N_{d(s)}}{\varepsilon_{\mu^+\mu^-}} \times [\mathcal{B}(B^+ \to J/\psi\, K^+) \times \mathcal{B}(J/\psi \to \mu^+\mu^-)] \frac{\varepsilon_{J/\psi K^+}}{N_{J/\psi K^+}} \times \frac{f_u}{f_{d(s)}}$$



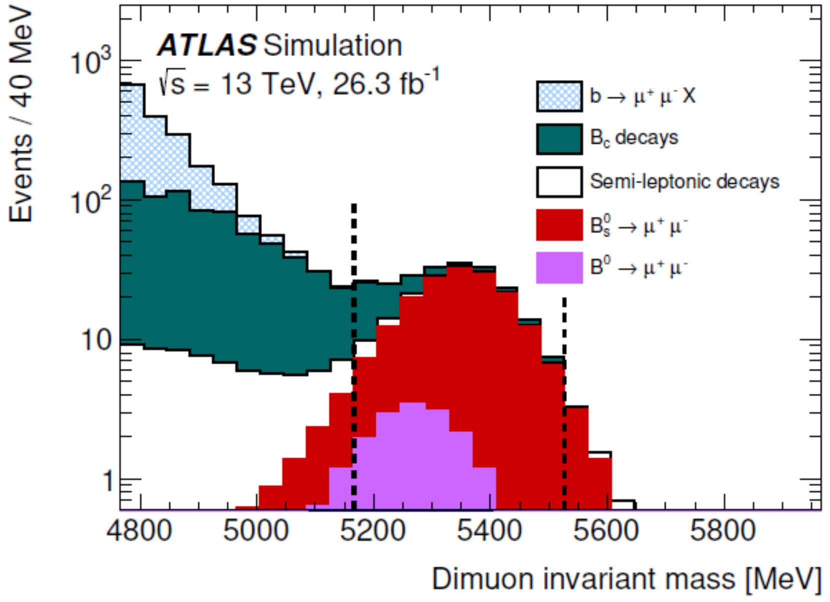
Abundant and well measured branching fraction!

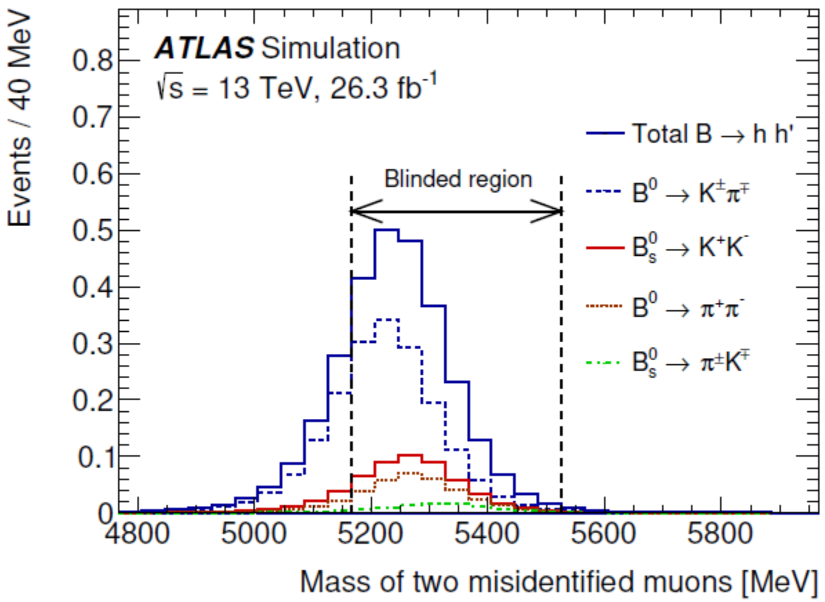
Background

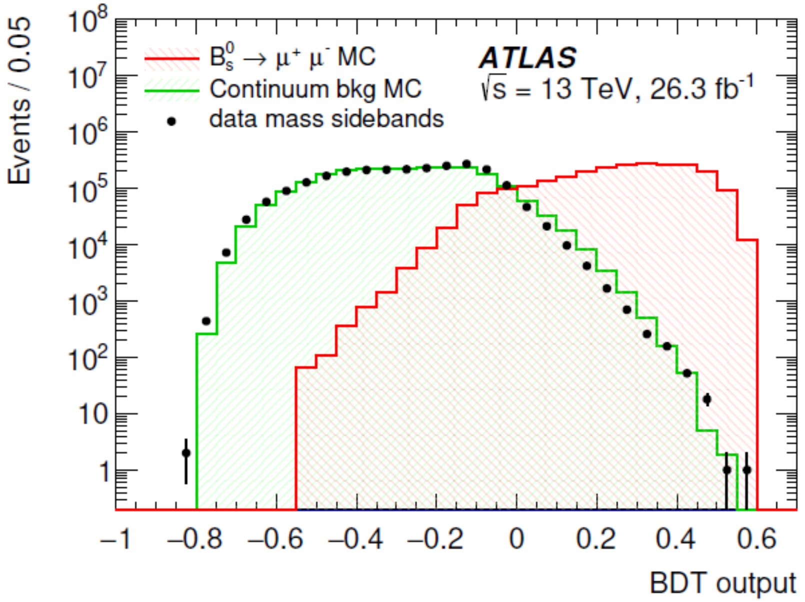
(Left) Particle reconstructed decays: lower dimuon invariant mass

(Middle) Peaking background: from muon misidentification

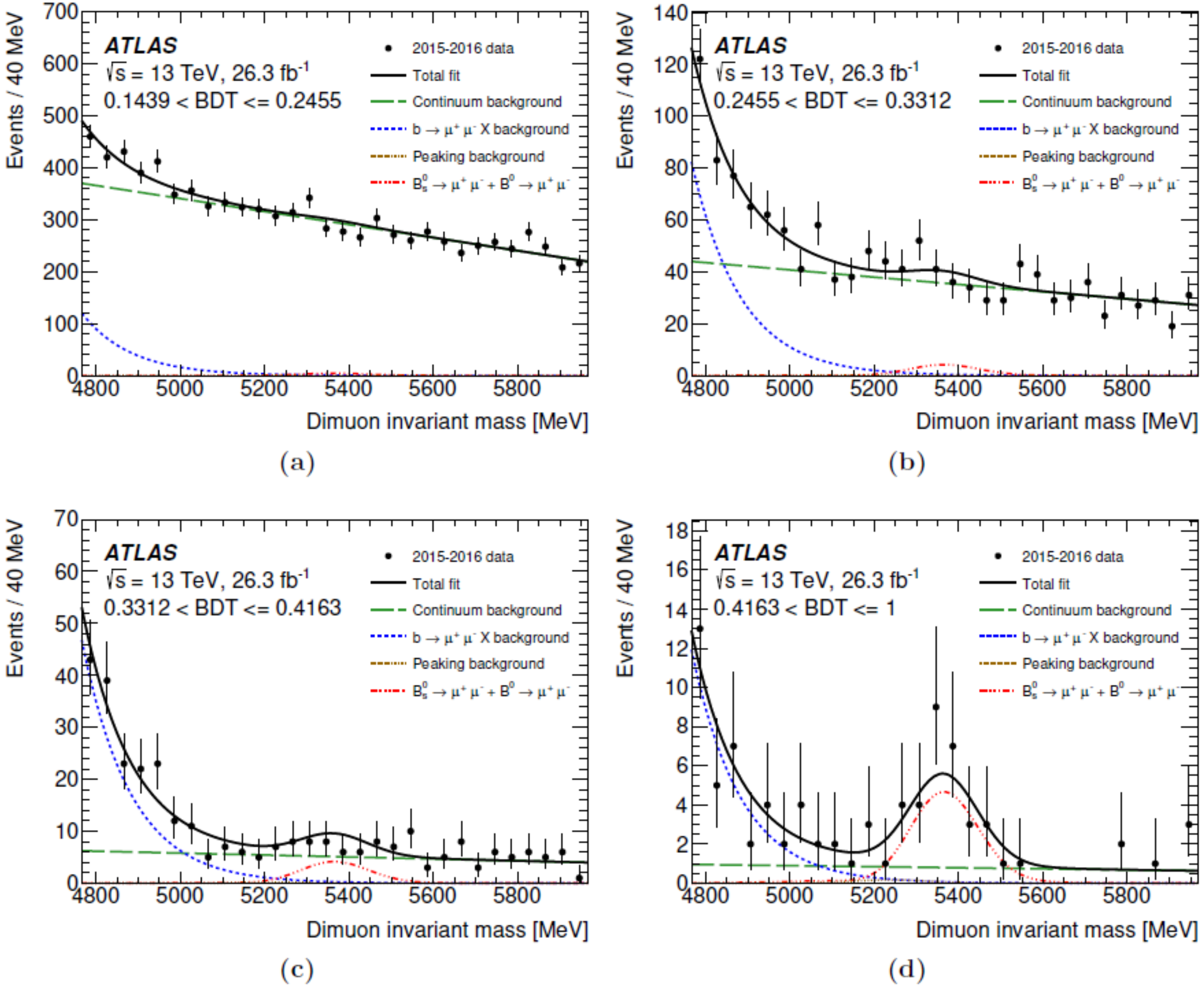
(Right) Continuum background: dominant, flat distribution; reduced with BDT.





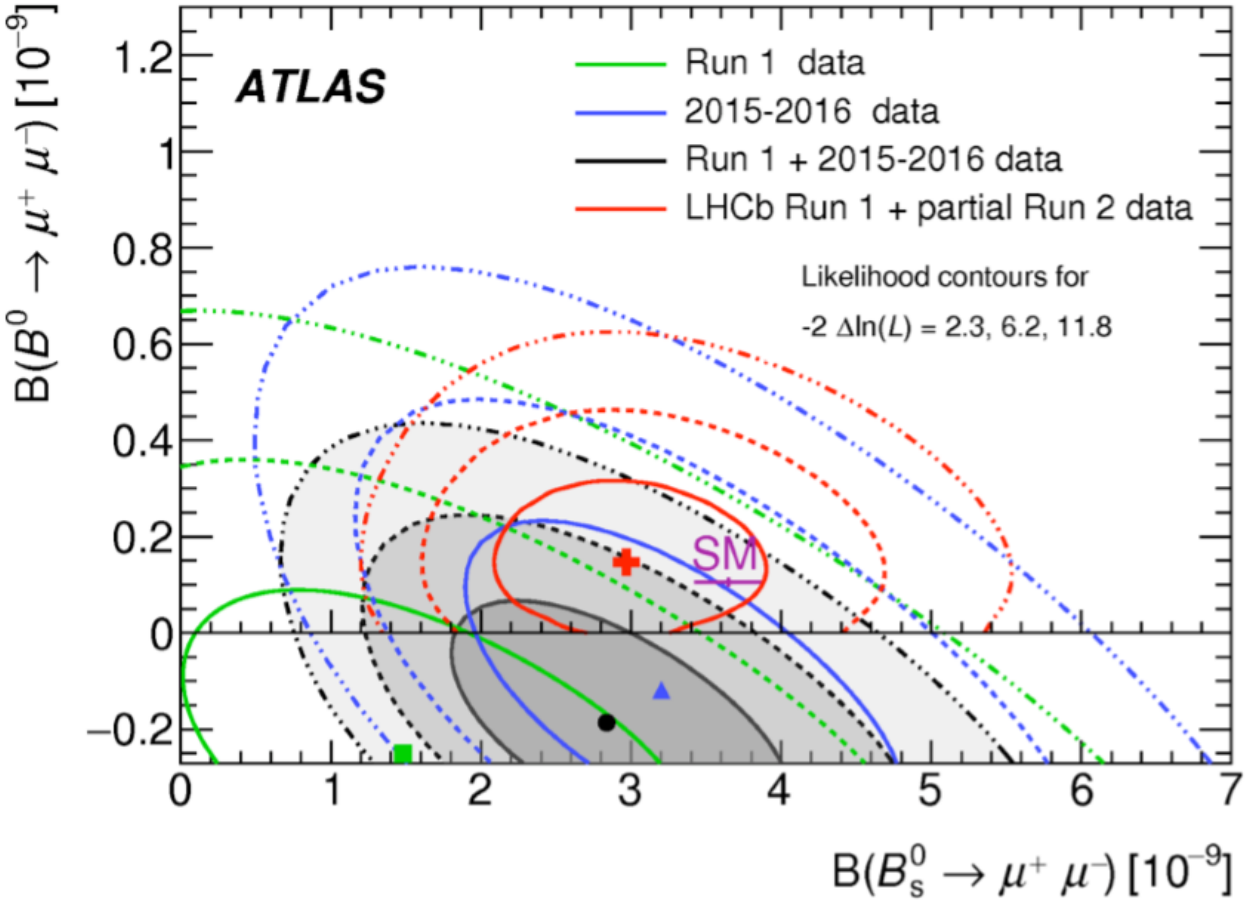


Fits



4 BDT intervals, and the first two contribute mostly to background modelling

Results



- SM :

  $Br(B_s \to \mu\mu) = (3.65 \pm 0.23) \times 10^{-9}$

  $Br(B^0 \to \mu\mu) = (1.06 \pm 0.09) \times 10^{-10}$

- Best fit of Run 2 data :

  $Br(B_s \to \mu\mu) = (3.2 \pm 0.9) \times 10^{-9}$

  $Br(B^0 \to \mu\mu) = (-1.3 \pm 2.1) \times 10^{-10}$

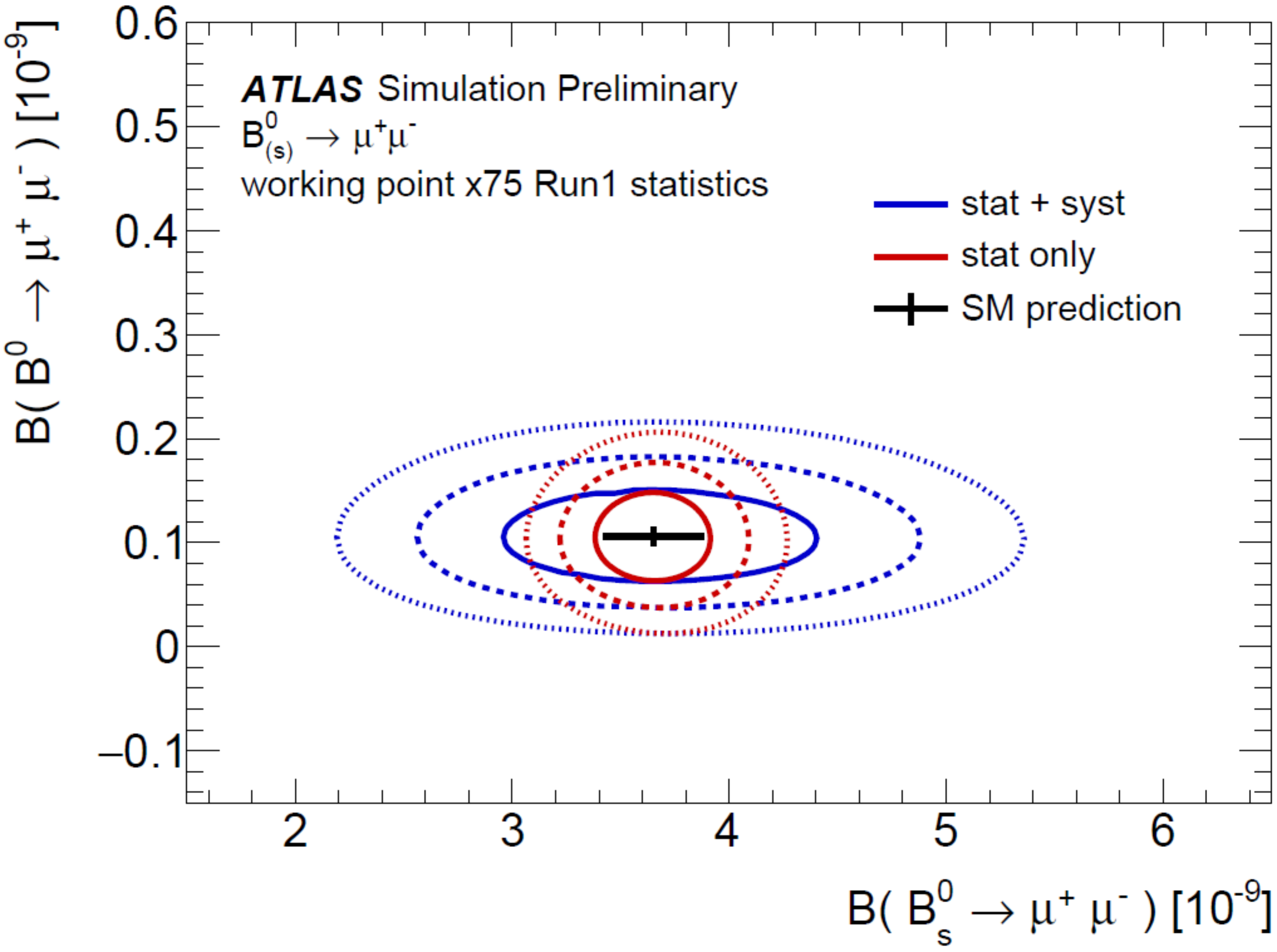
- Run 1 + Run 2 result @ 95% CL

  $Br(B_s \to \mu\mu) = (2.8 \pm 0.8) \times 10^{-9}$

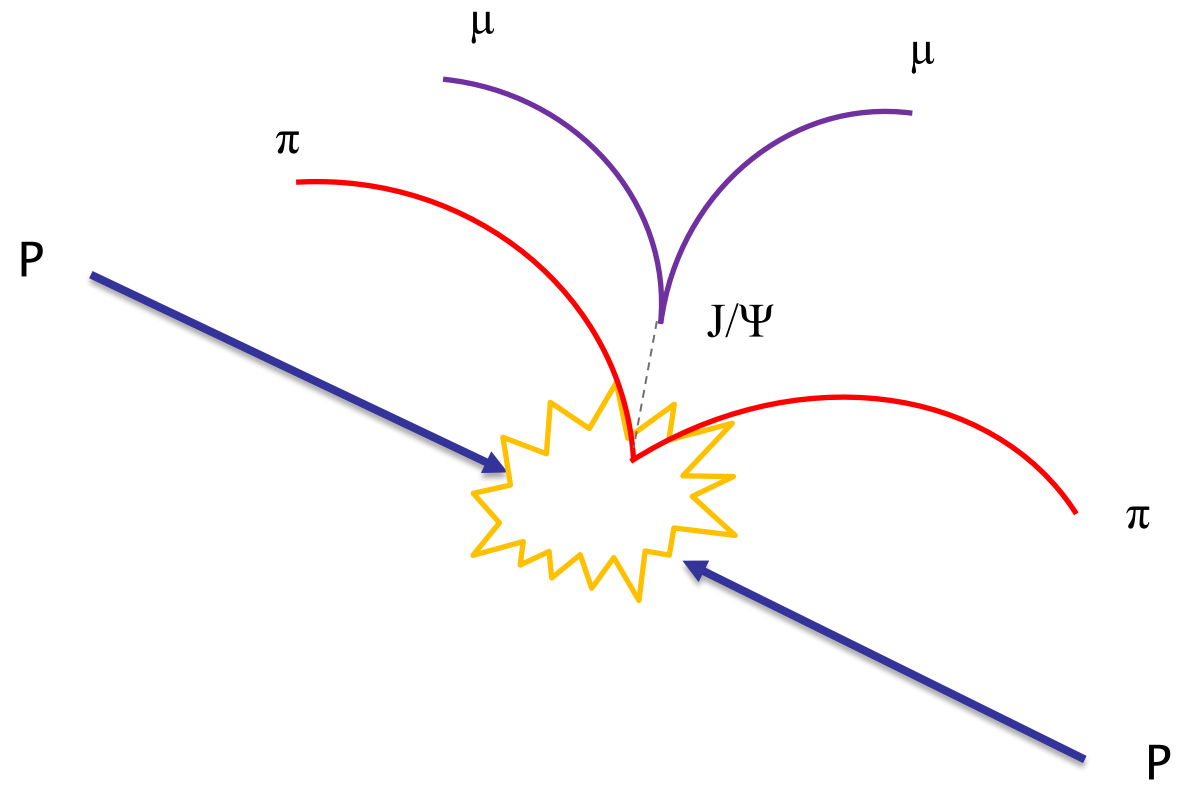
  $Br(B^0 \to \mu\mu) < 2.1 \times 10^{-10}$

B^0 limit is most stringent at the moment

ATLAS HL-LHC projection

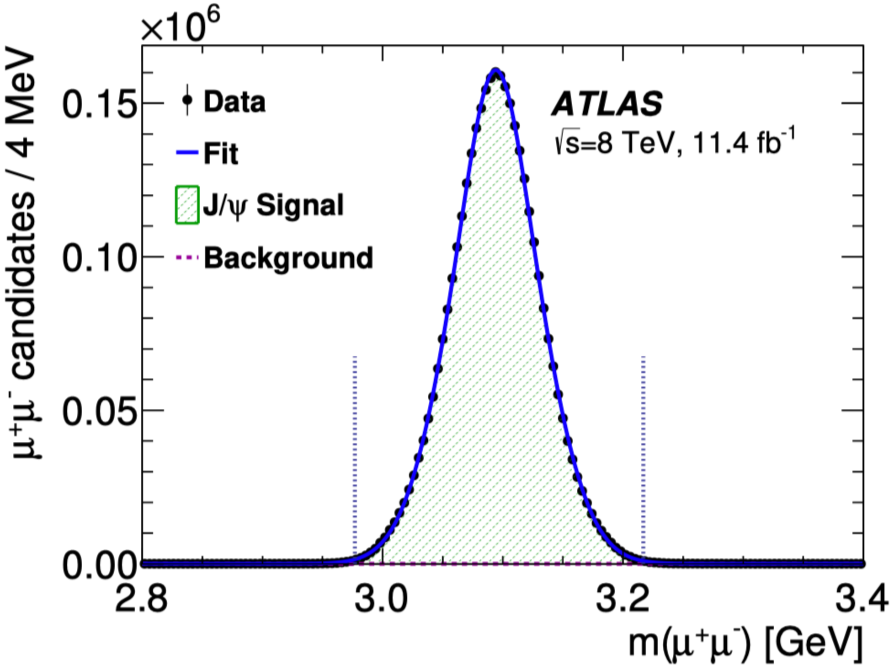


Ψ(2S) and X(3872) production

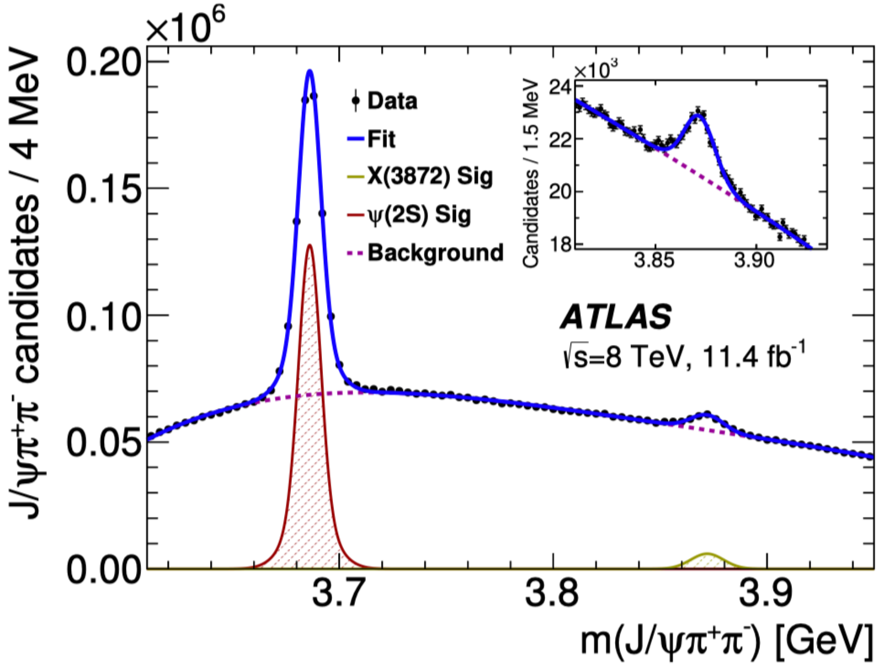


Based on 11.4 fb^{-1} at 8 TeV

Ψ(2S) and X(3872) production



(a)

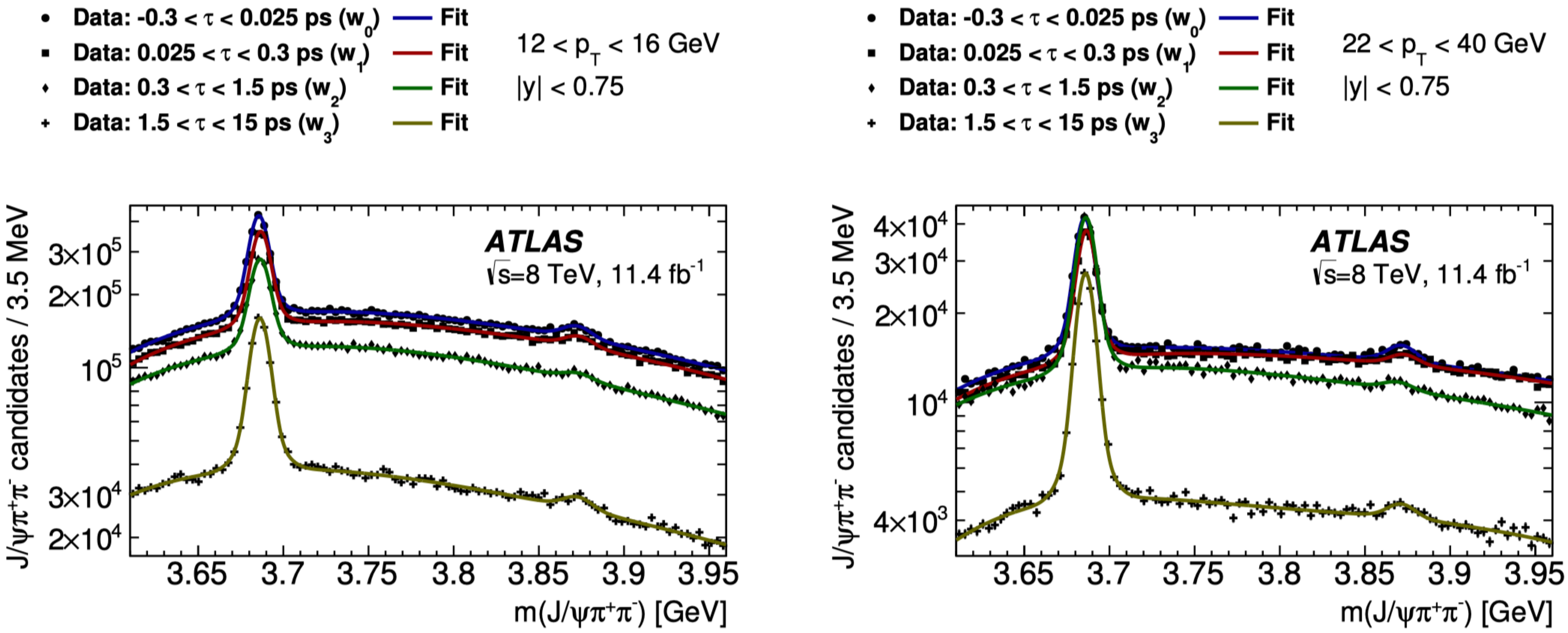


(b)

pT(μ)>4 GeV

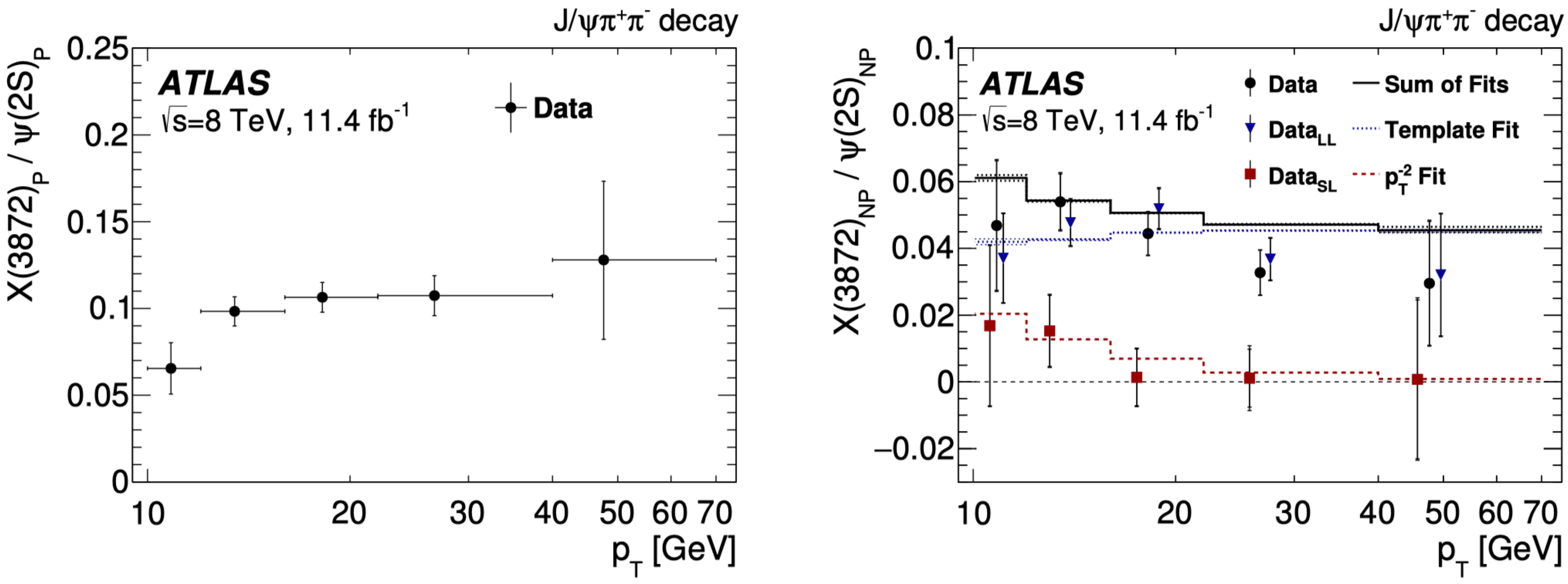
10<pT(ππ J/Ψ)<70 GeV

Ψ(2S) and X(3872) production



Use pseudo-proper lifetime to separate prompt and non-prompt production.

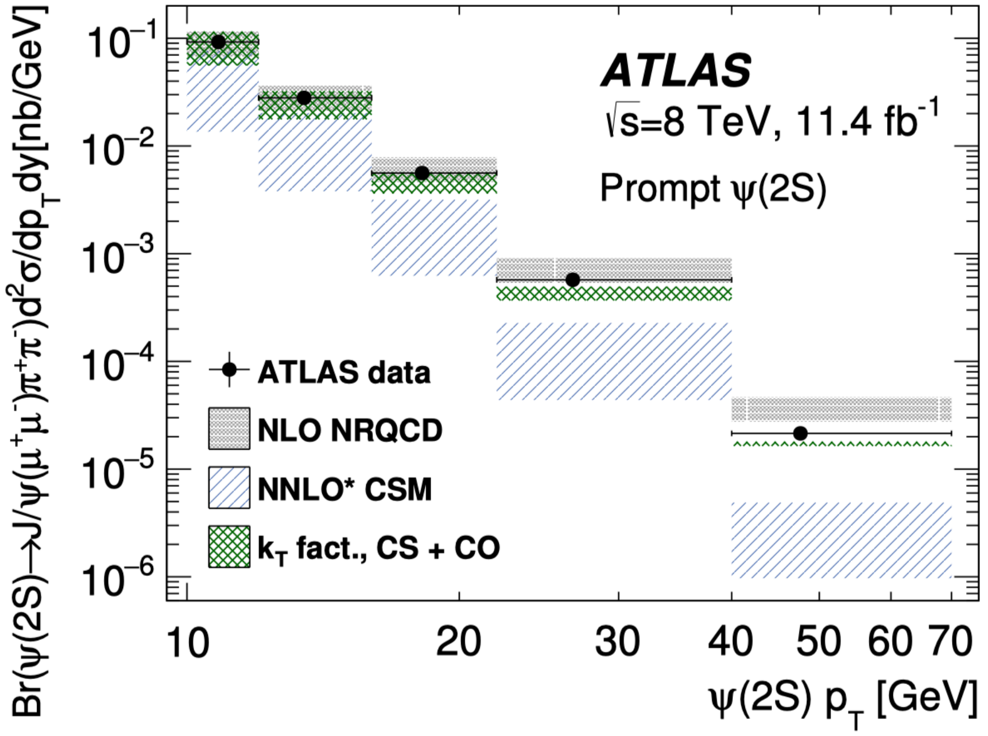
Ψ(2S) and X(3872) production

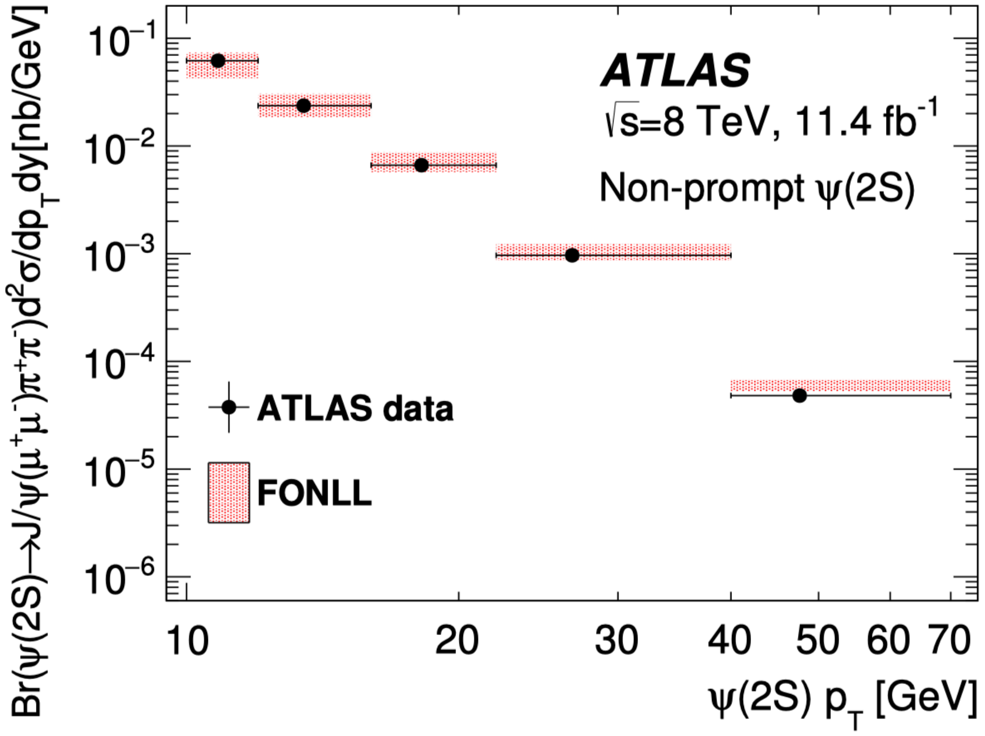


(a) (b)

Production ratio for prompt (a) and non-prompt (b); for non-prompt, long-lived and short-lived are separated also, where the later is from Bc.

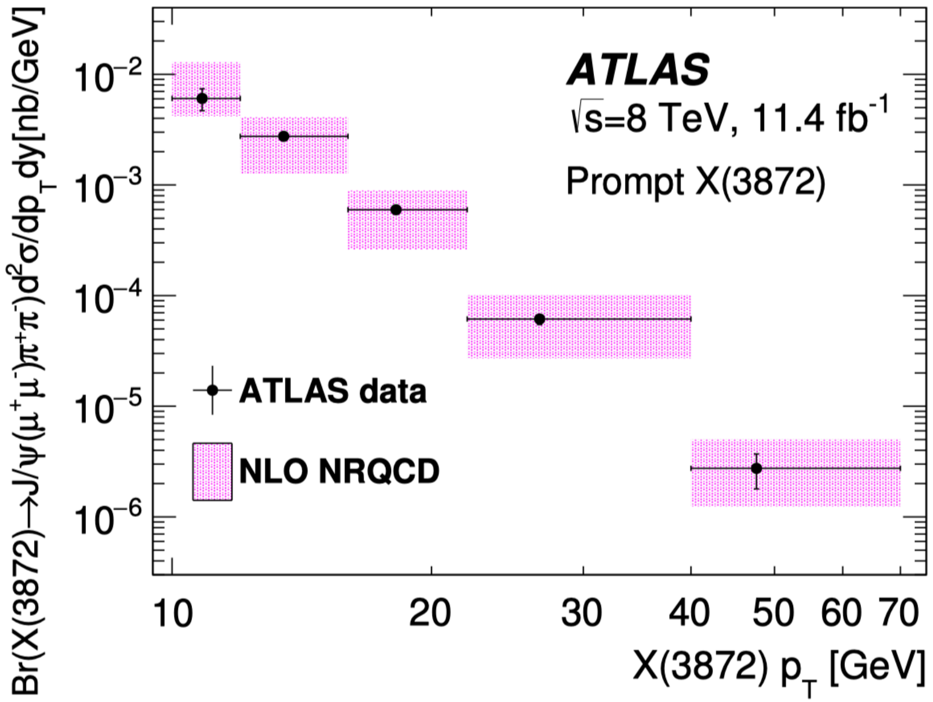
Ψ(2S) and X(3872) production

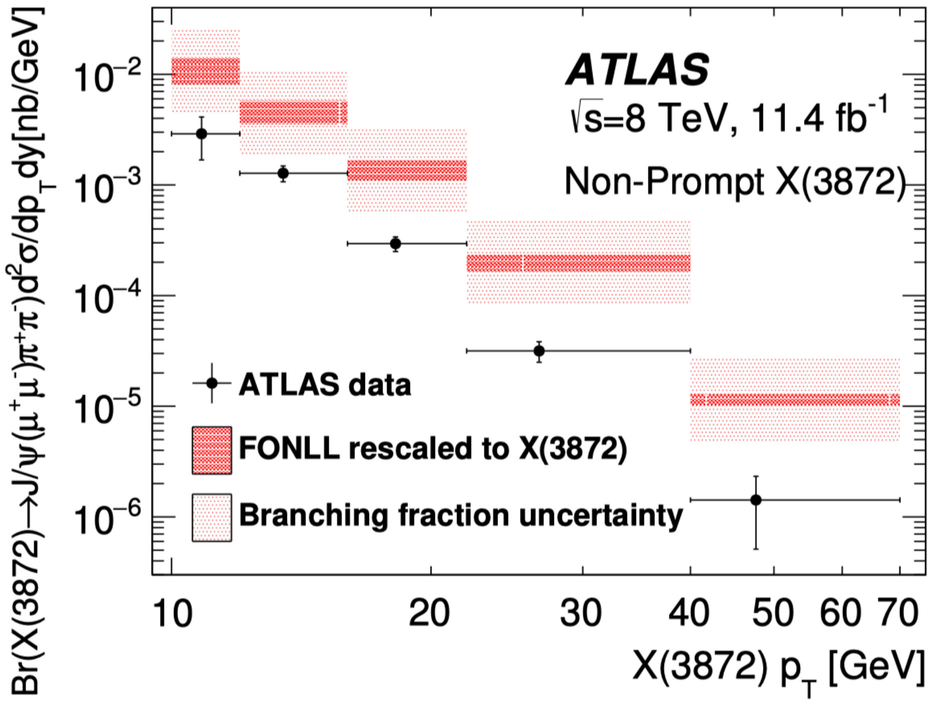




The NLO-NRQCD describes the prompt Ψ(2S) pretty well; FONLL (Fixed Order+Next-Leading Log) works well for non-prompt part.

Ψ(2S) and X(3872) production





The NLO-NRQCD describes the prompt X(3872) well by assuming it is mixture of χ_{C1}(2P) and DD* molecular; FONLL overestimates the non-prompt part.

Summary

1. X(5568) is searched with ATLAS data, but no hint;
2. Excited $B_c^{\pm}$ Meson State is observed with ATLAS data;
3. ϕs and $\Delta\Gamma s$ are measured in the $Bs^0 \to J/\Psi\ \phi$, and results are consistent with SM
4. Bs^0 (and B^0) $\to \mu\mu$ are measured, no surprise
5. $\Psi(2S)$ and X(3872) production are studied with pp collision

Thank you very much!