ATLAS Measurements of CP Violation and Rare Decays in Beauty Mesons

Weimin Song

Rutherford Appleton Laboratory, Oxford, UK

wesong@cern.ch

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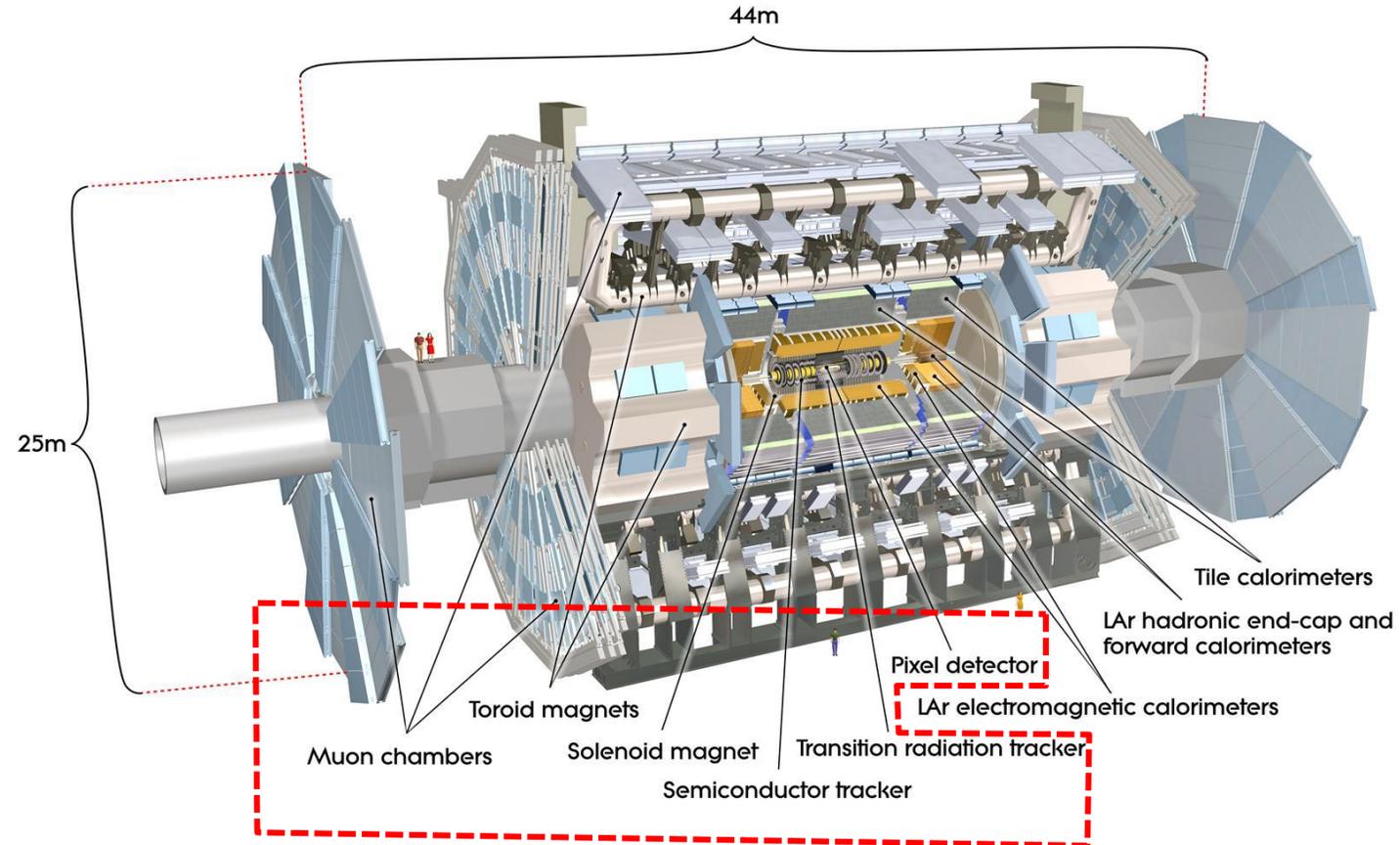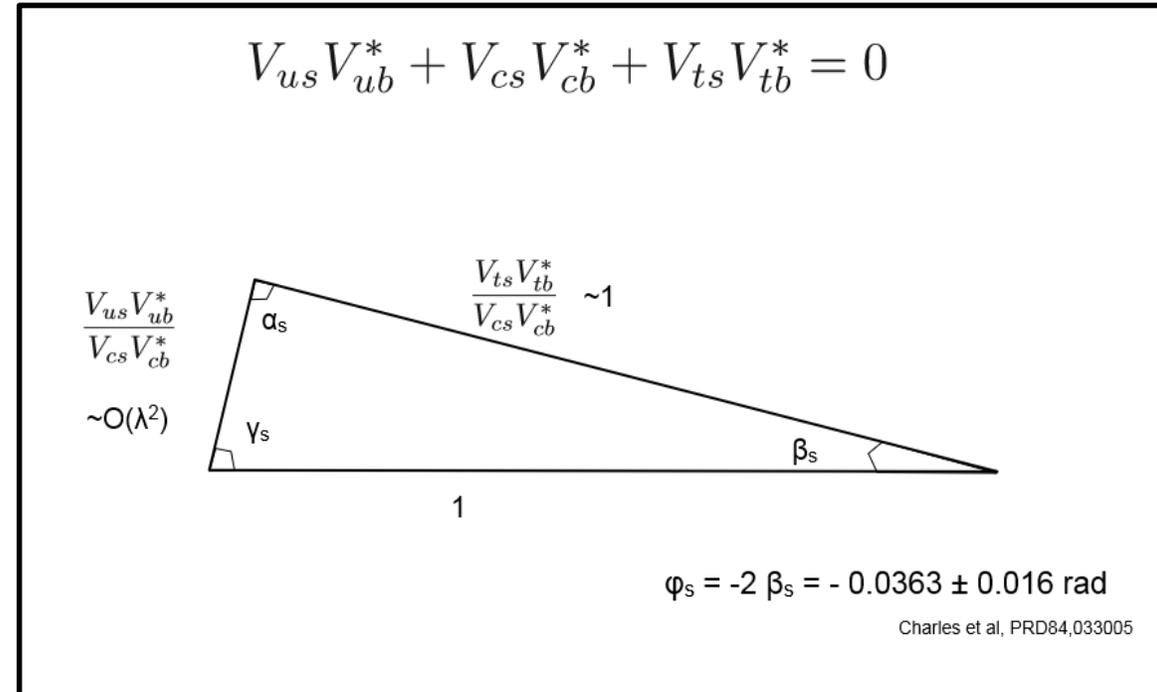University of Pittsburgh

Outline

❑ **Introduction of heavy flavour physics program at ATLAS**

❑ ϕ_s **and** $\Delta\Gamma_s$ **measurement in the** $B_s^0 \to J/\Psi\ \phi$ **channel** (JHEP 08 (2016) 147, ATLAS-CONF-2019-009)

❑ B_s^0 **(and** B^0**)** $\to \mu\mu$ **measurement** (JHEP 04 (2019) 098)

❑ **Summary**

Heavy Flavour physics program at ATLAS

❖ Precision measuremenst to find hints of derivation from SM: rare decays, such as $B_s^0 \to \mu^+\mu^-$

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

❖ Usually, muon information is used as trigger and to reduce the background: the inner tracker and muon detector are used
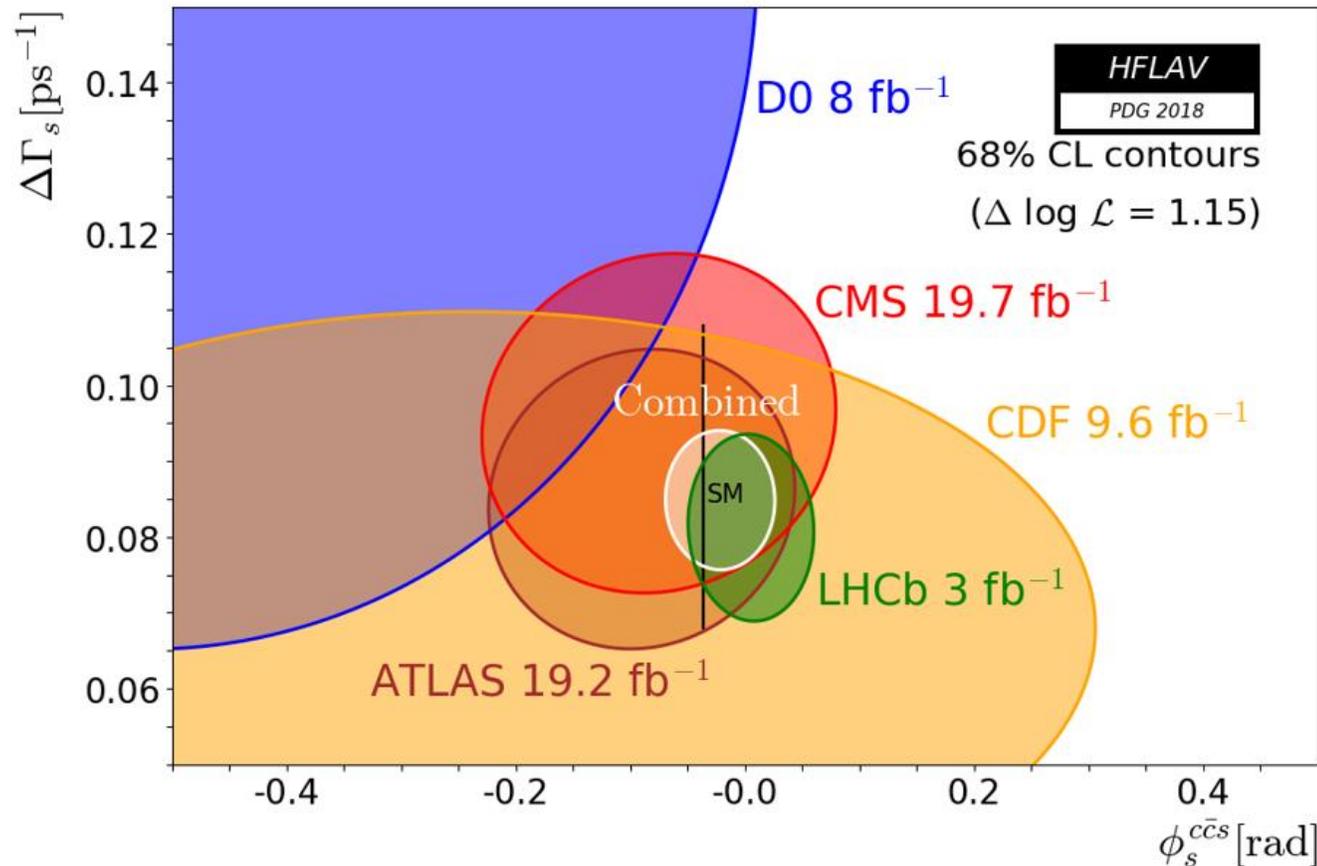

44m

25m

Tile calorimeters

LAr hadronic end-cap and forward calorimeters

Pixel detector

LAr electromagnetic calorimeters

Toroid magnets

Solenoid magnet

Transition radiation tracker

Muon chambers

Semiconductor tracker

ϕ_s and $\Delta\Gamma_s$ measurement in the $B_s^0 \to J/\Psi \; \phi$

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

$\dfrac{V_{us}V_{ub}^*}{V_{cs}V_{cb}^*}$

$\sim O(\lambda^2)$

α_s

γ_s

$\dfrac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}$ ~1

β_s

1

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

Charles et al, PRD84,033005

ϕ_s, 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.

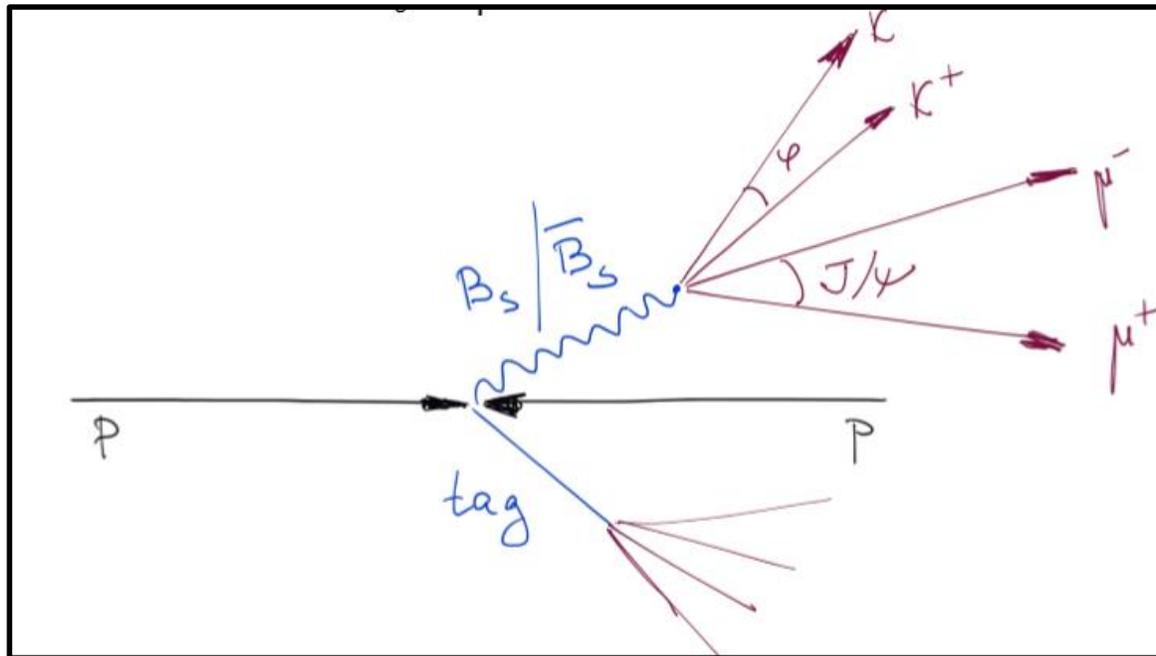# **World averaged results before Moriond 2019**

From HFLAV

New result based on 80 fb^{-1} at 13 TeV will be discussed here
Released 2 months ago

Methodology

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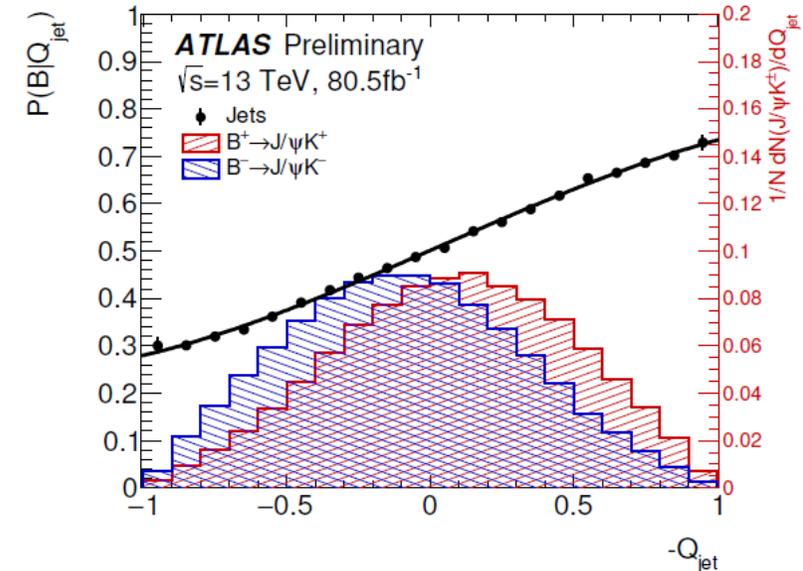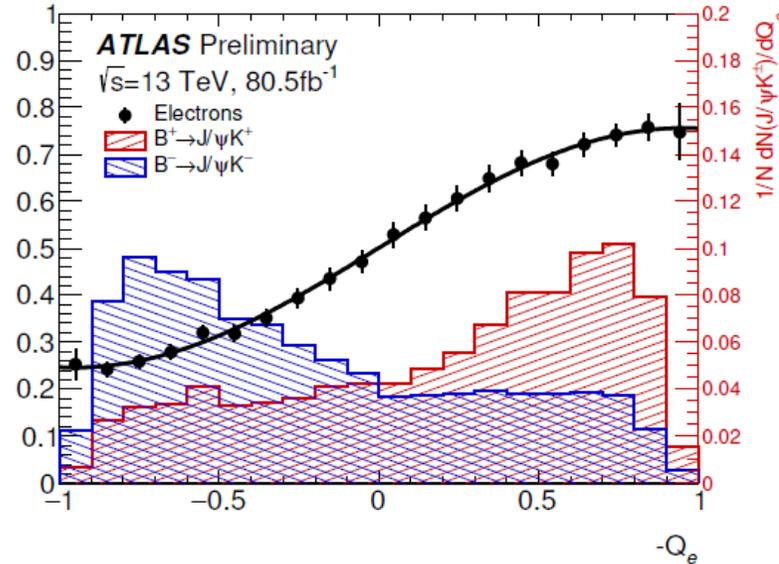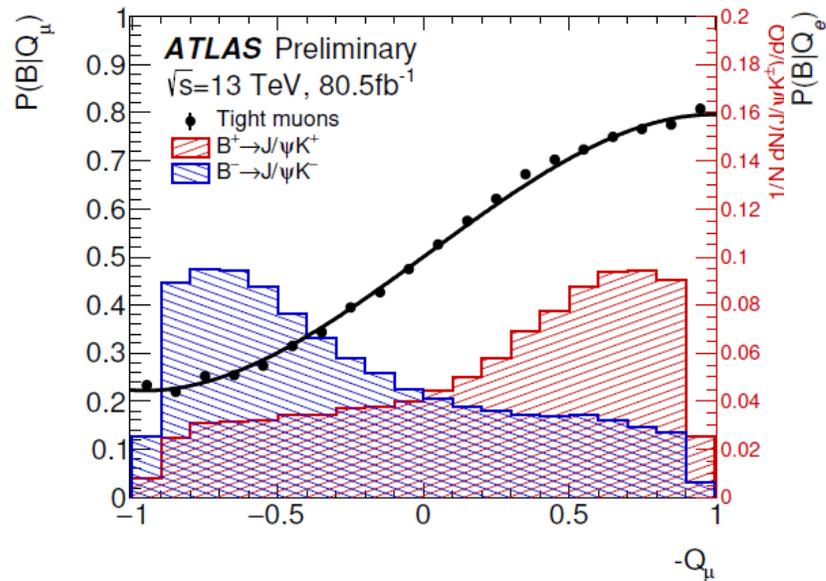

CP State tagger: CP even if L = 0 or 2; CP odd if L =1. L is the orbital angular momentum.

Tagger: weighted sum of charge in a cone

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

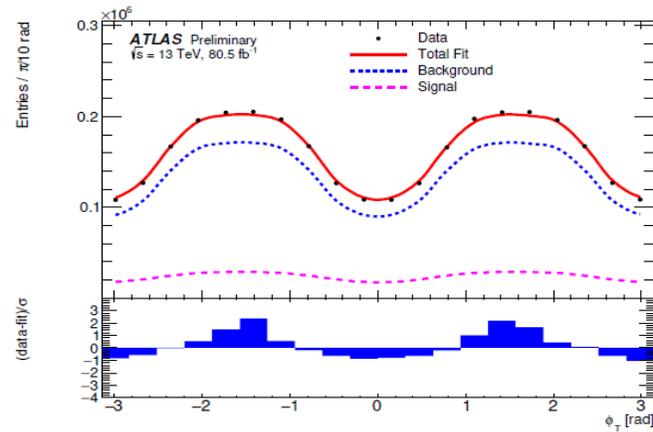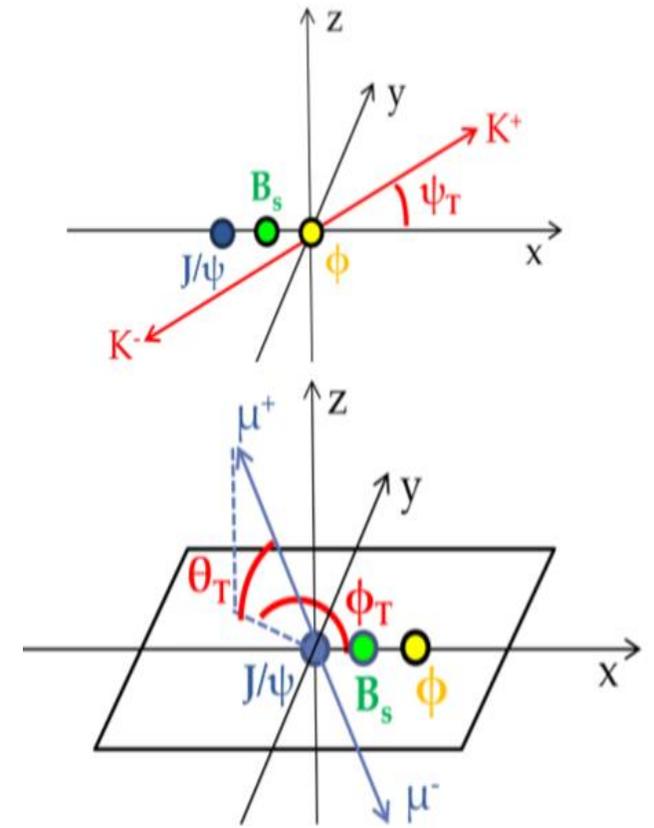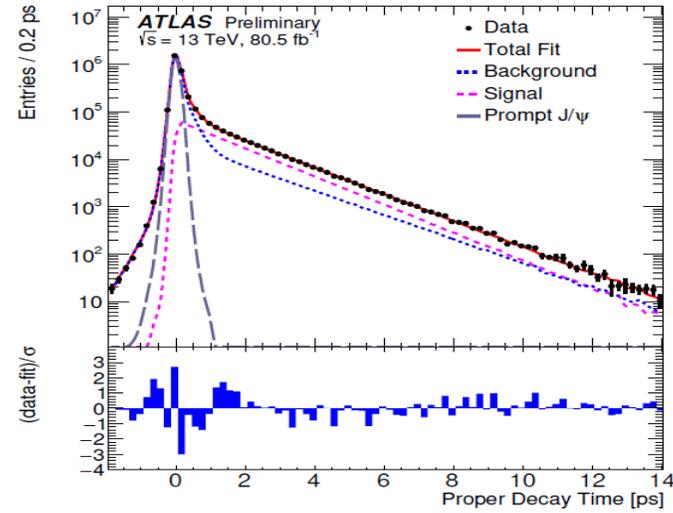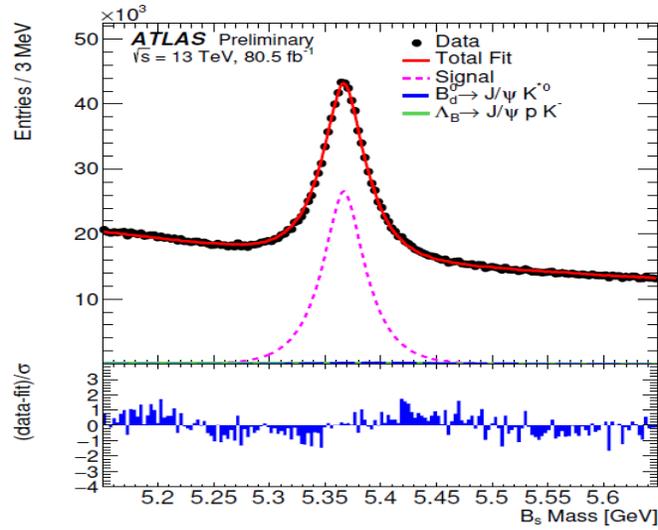| Tag method	Efficiency [%]	Effective Dilution [%]	Tagging Power [%]
Tight muon	4.50 ± 0.01	43.8 ± 0.2	0.862 ± 0.009
Electron	1.57 ± 0.01	41.8 ± 0.2	0.274 ± 0.004
Low-p_T muon	3.12 ± 0.01	29.9 ± 0.2	0.278 ± 0.006
Jet	5.54 ± 0.01	20.4 ± 0.1	0.231 ± 0.005
Total	14.74 ± 0.02	33.4 ± 0.1	1.65 ± 0.01

Fit results with RUN 2 data

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

$$\Delta\Gamma_s, \; \phi_s, \; \Gamma_s, \; |A_0(0)|^2, \; |A_\parallel(0)|^2, \; \delta_\parallel, \; \delta_\perp, \; |A_S(0)|^2 \text{ and } \delta_S.$$
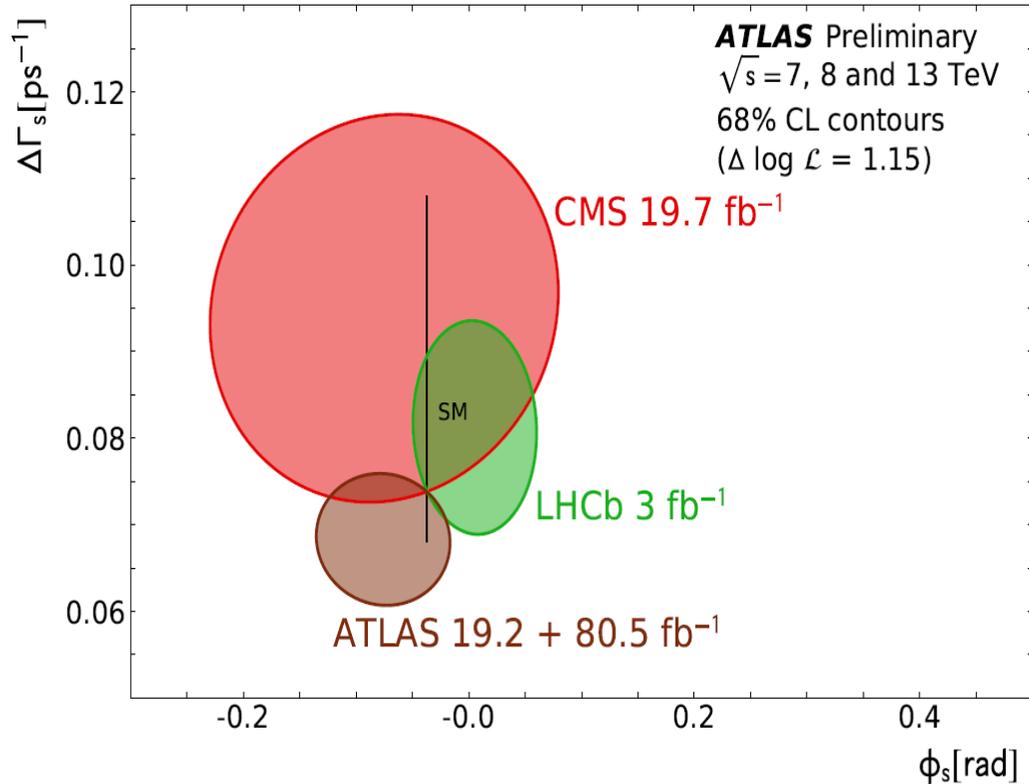
Information used in the fit: mass of B_s^0; proper decay time and its uncertainty; tagging probability; the transversity angles (defined in the next page)

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
$|A_\parallel(0)|^2$	0.220	0.002	0.002
$|A_0(0)|^2$	0.517	0.001	0.004
$|A_S|^2$	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

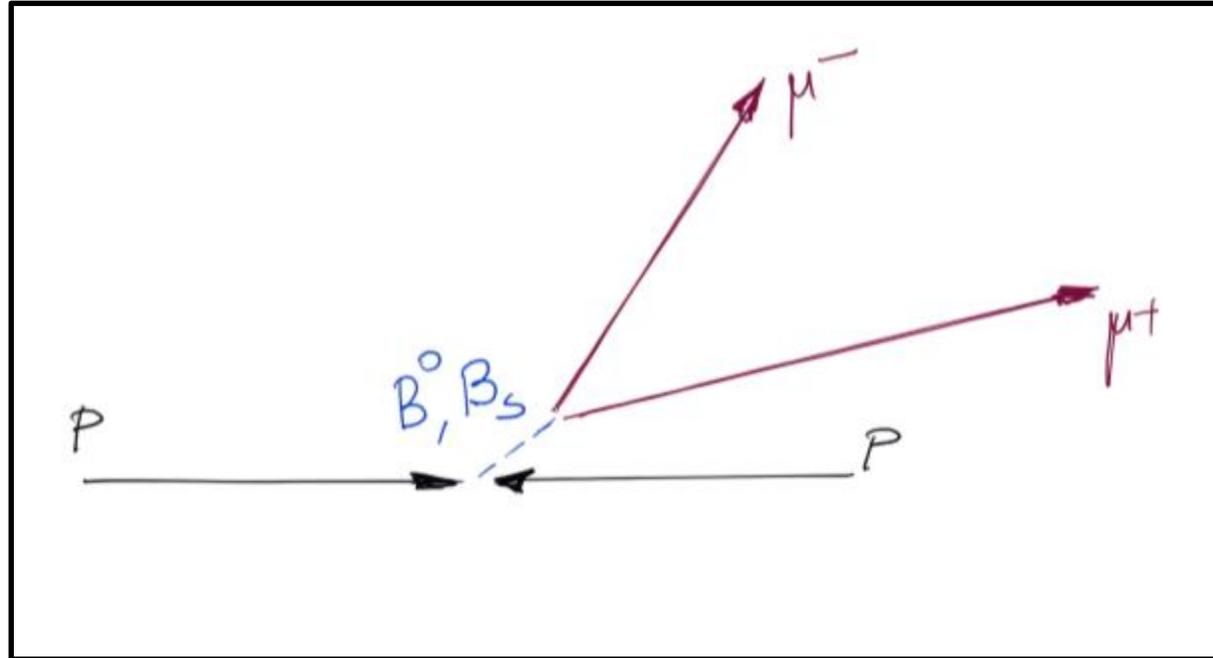New HFLAV average
$$\phi_s = -0.0544 \pm 0.0205$$
$$\Delta\Gamma_s = 0.0762 \pm 0.0033\,\mathrm{ps}^{-1}$$
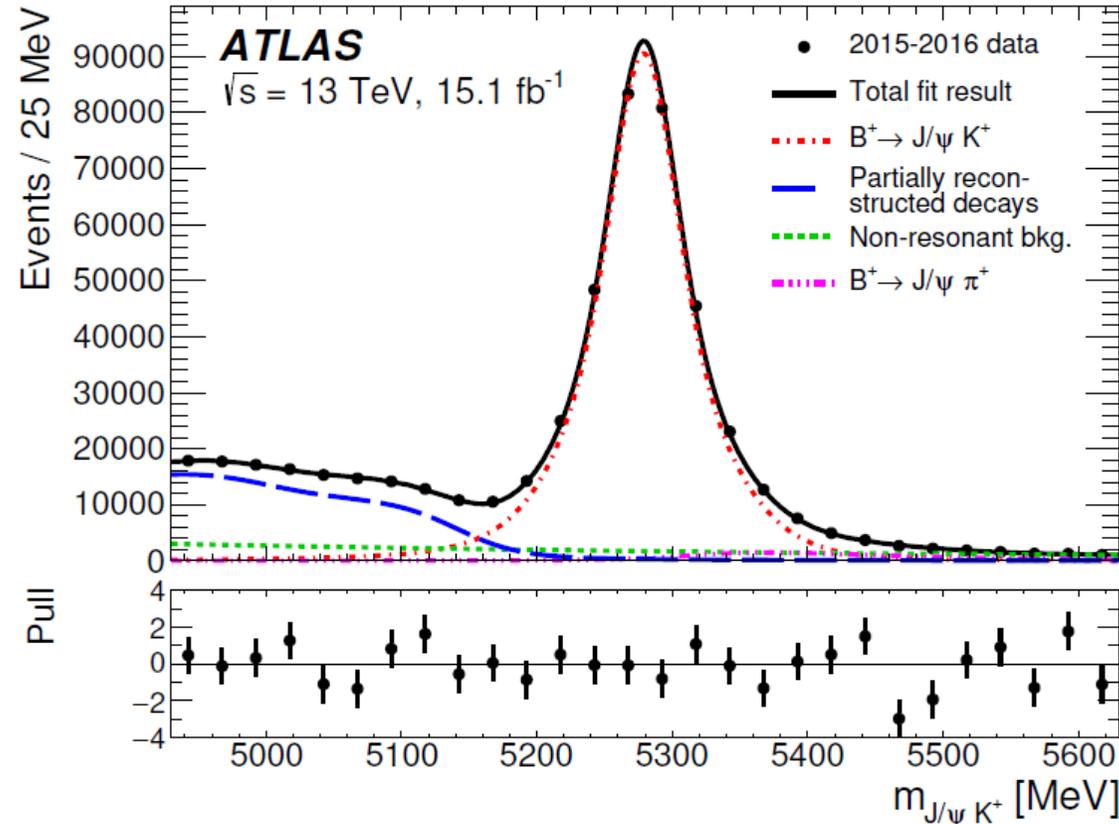
ATLAS HL-LHC projection

B_s^0 (and B^0) → μμ measurement

**New result based on 26 fb⁻¹ at 13 TeV
2015+2016**

Methodology: take B⁺→J/ΨK⁺ as reference

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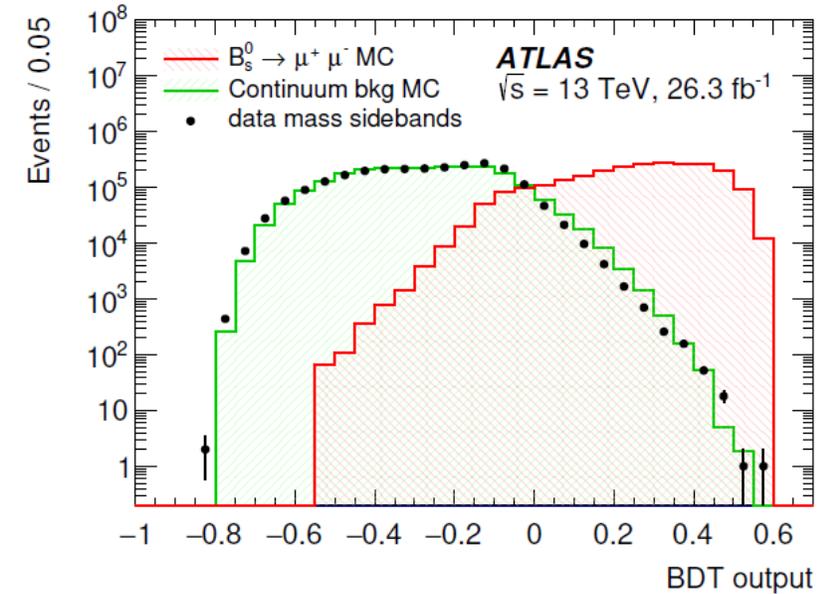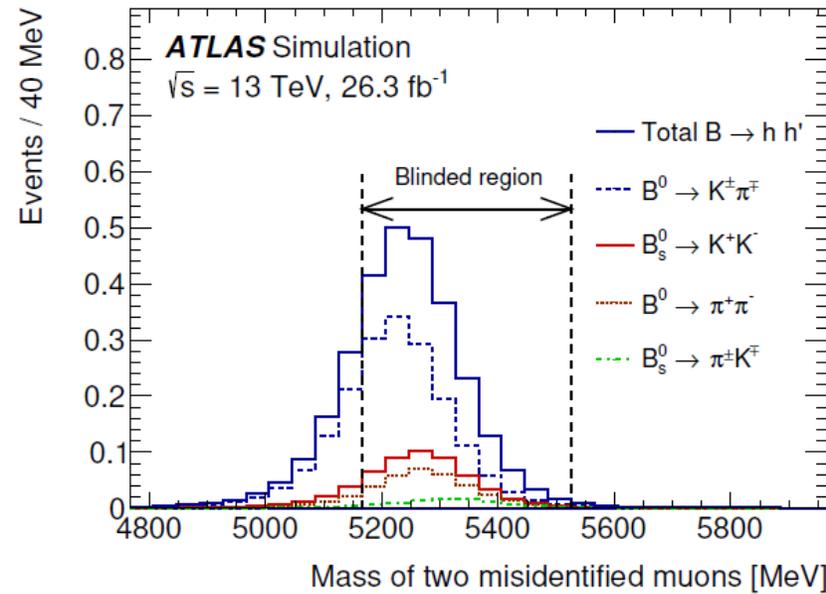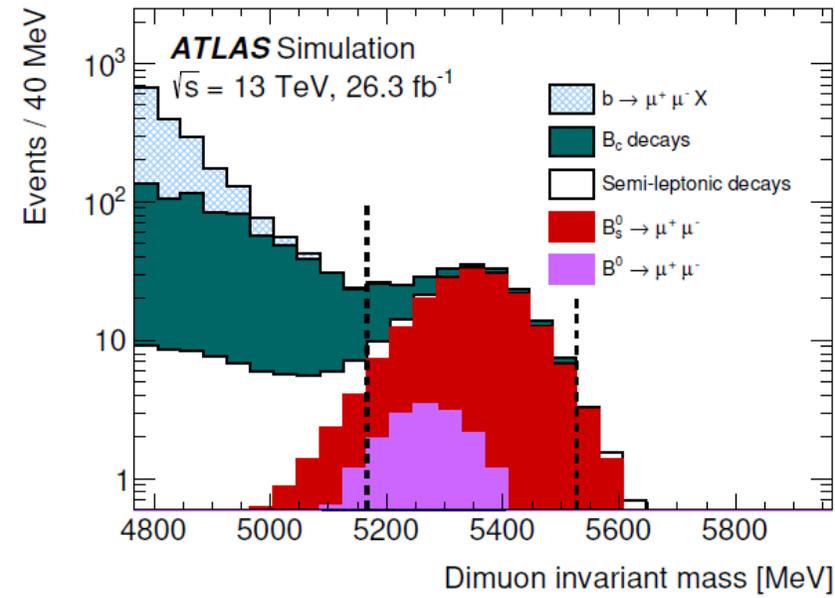

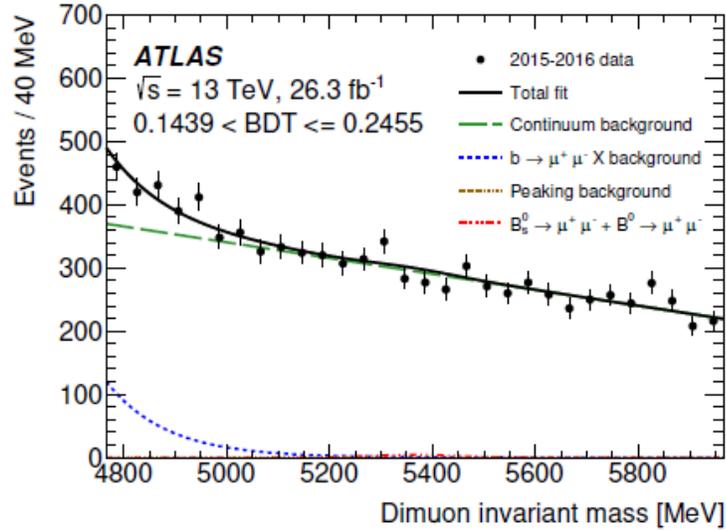Abundant and well measured branching fraction!

Background

(Left) Particle reconstructed decays: lower dimuon invariant mass

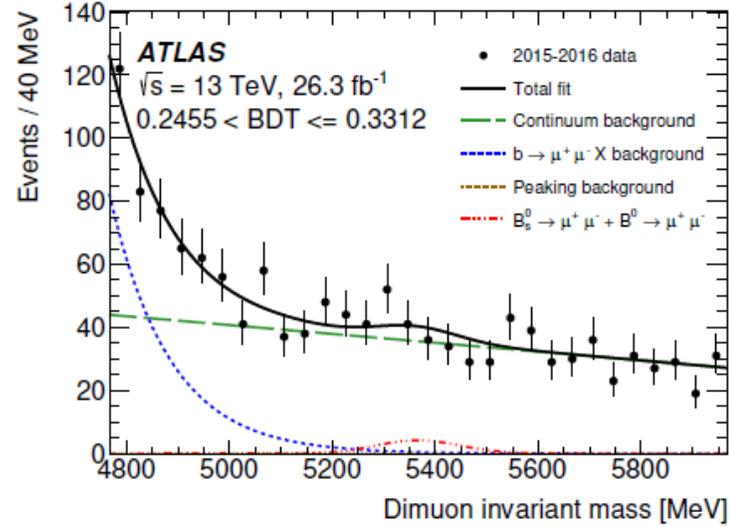(Middle) Peaking background: from muon misidentification

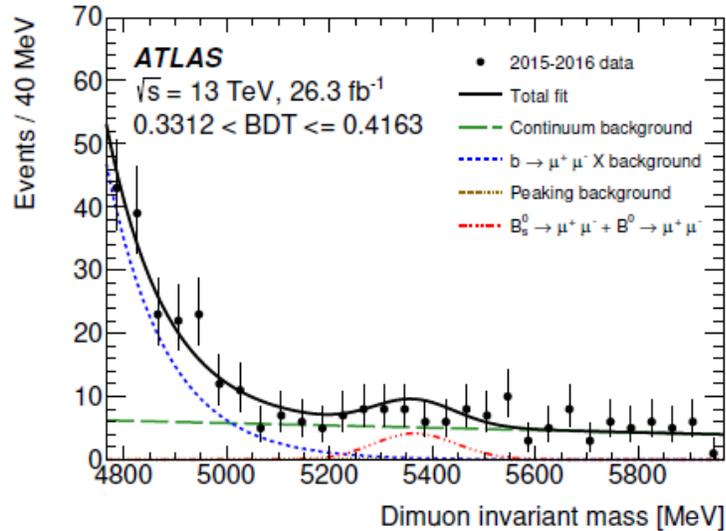(Right) Continuum background: dominant, flat distribution; reduced with BDT.
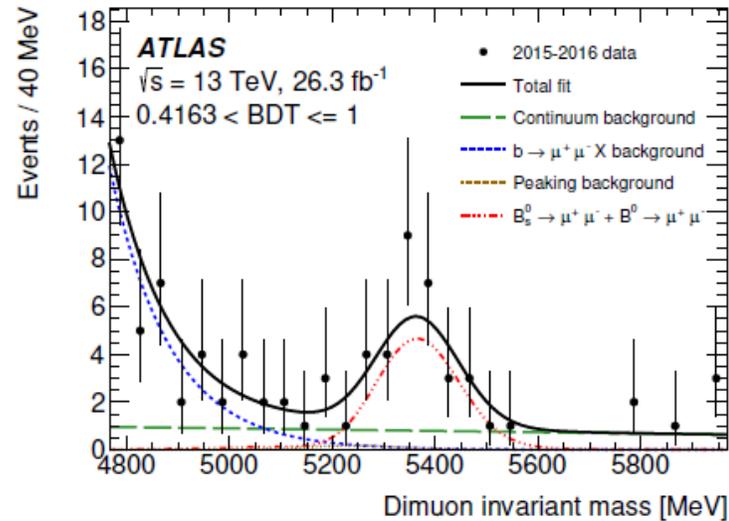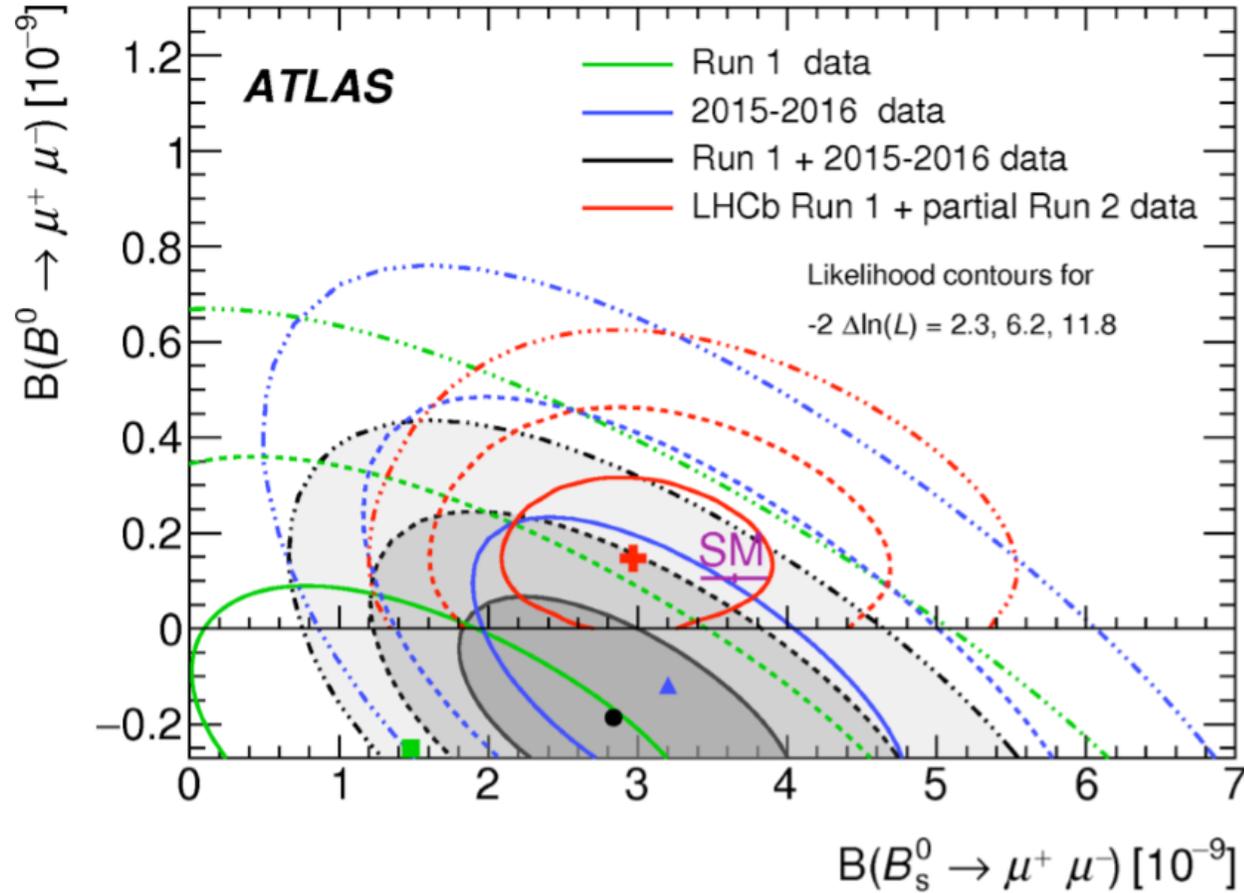
Fits

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

Results

- SM :

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

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

- Best fit of Run 2 data :

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

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

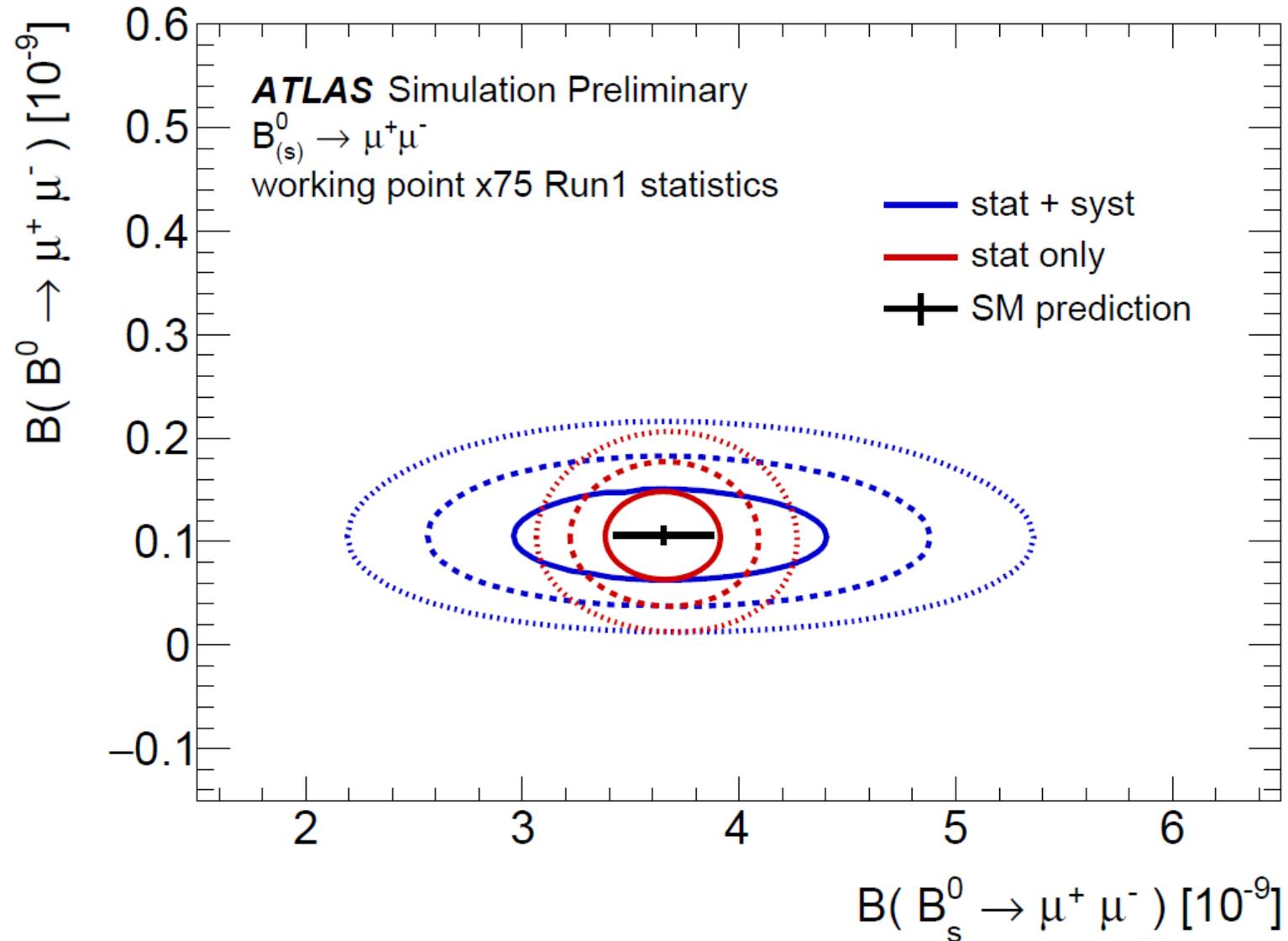- Run 1 + Run 2 result @ 95% CL

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

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

B^0 limit is most stringent at the moment

ATLAS HL-LHC projection

Summary

❑Based on ATLAS data, $B_s^0 \to J/\Psi \phi$ and B_s^0 (and B^0) $\to \mu\mu$ are studied with higher precision, but no signal beyond SM is observed

❑More data are being analysing, more data are coming, and HL-LHC is on the way

Thank you very much!

BACK UP