Latest Heavy Flavour fragmentation results

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On behalf of the ATLAS, LHCb and CMS collaborations

SM@LHC2022 : Standard Model at the LHC 2022, 11-14 April 2022, CERN, Geneva (Switzerland)

Outline

Physics results

★ **Measurement of b-quark fragmentation properties.** **ATLAS**
JHEP 12 (2021) 131, CERN-EP-2021-123.
Phys. Rev. Lett. 115 (2015) 262001, CERN-PH-EP-2015-165.

★ **Measurement of the fragmentation fraction ratios and its dependence on B meson kinematics.**
JHEP 1304 (2013) 001, CERN-PH-EP-2013-006.
Phys.Rev. D100 (2019) no.3, 031102, CERN-EP-2019-016. **LHCb**
Phys. Rev. Lett. 124, 122002 (2020), CERN-EP-2019-209.
LHCb-TALK-2022-051 (LHCb-PAPER-2022-001).

★ **Using Bu, Bs, and Bc mesons for studies of heavy quark dynamics** **CMS**
arXiv:2109.01908, CERN-EP-2021-141.
arXiv:2201.02659, CERN-EP-2021-259.

JHEP 12 (2021) 131

Measurement of b-quark fragmentation properties in jets using the decay $B^{\pm} \rightarrow J/\psi K^{\pm}$ in pp collisions at 13 TeV with the ATLAS detector.

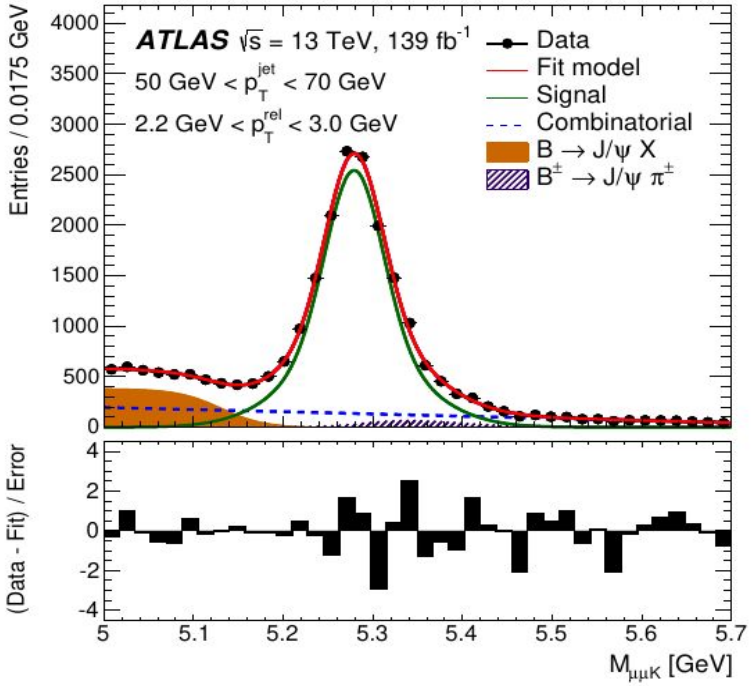
The fragmentation of heavy quarks is a crucial aspect of quantum chromodynamics (QCD).

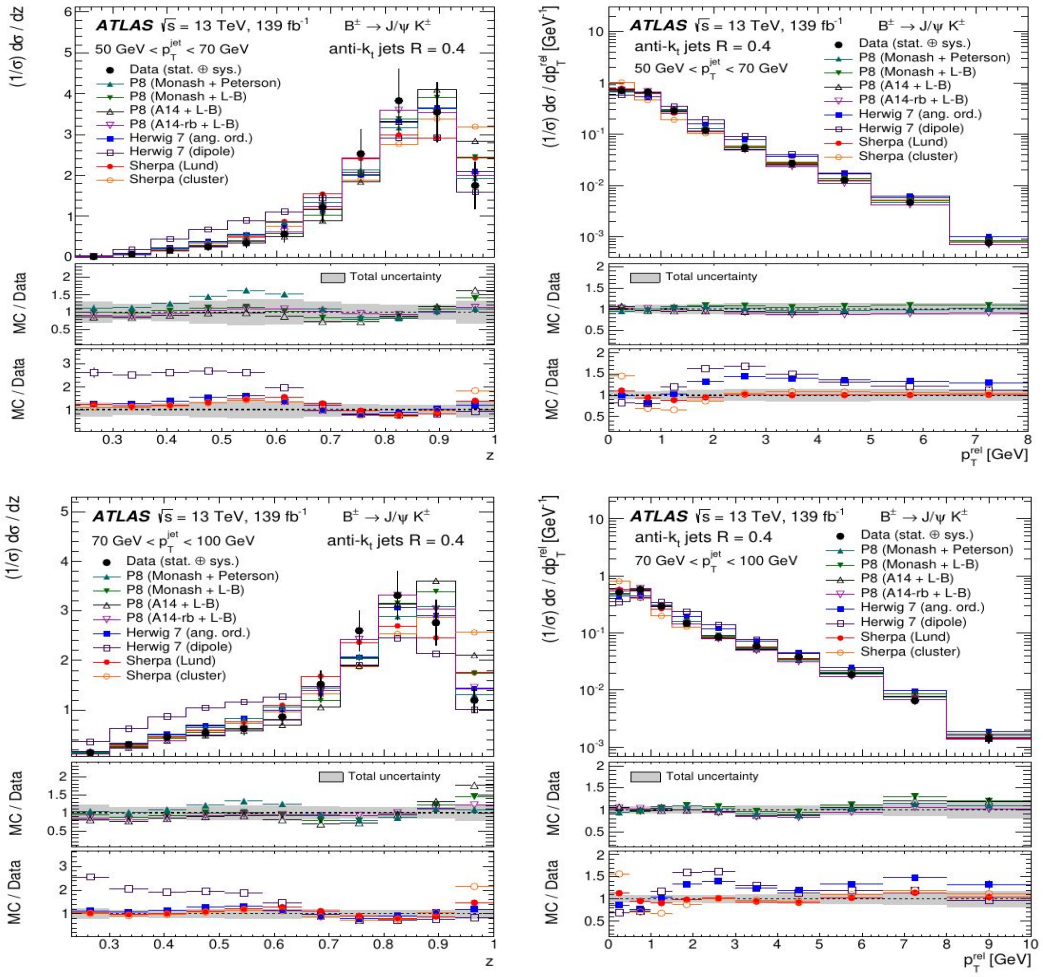
- ➔ **Test of QCD at LHC energy; We can improve the MC.**
- ➔ **Can be dominant uncertainty on Higgs bosons production and other channels with b-jet signatures.**

longitudinal (z) and transverse (p_T^{rel}) projections of the $B^{\pm}$ momentum to jet axis.

$$z = \frac{\vec{p}_B \cdot \vec{p}_j}{|\vec{p}_j|^2}; \quad p_T^{rel} = \frac{|\vec{p}_B \times \vec{p}_j|}{|\vec{p}_j|},$$

$B^{\pm}$ invariant mass is used to extract differential cross section in each **z** or **p_T^{rel}** bins, for the lower and higher intervals of jet momenta: **50 GeV < pT < 70 GeV and pT > 100 GeV.**





For both, transverse and longitudinal profiles, similar comments apply

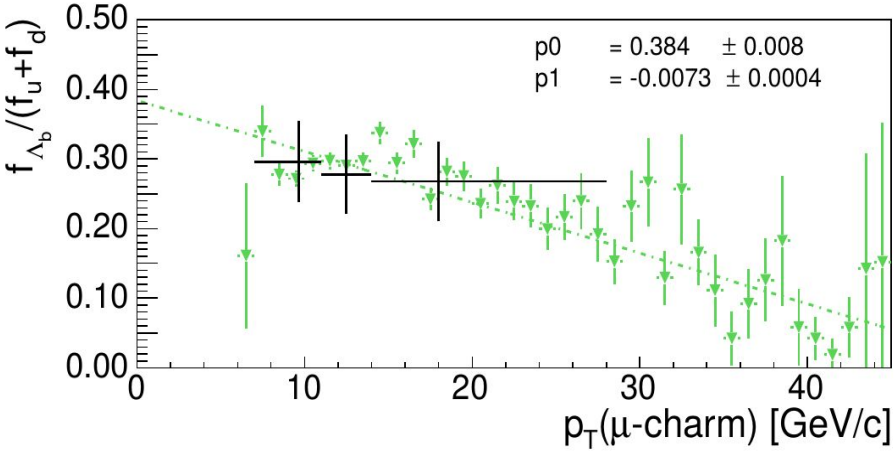
- The best description is provided by Pythia.
- Sherpa and Herwig7 models have shown deviations from data.

Including the present measurements in a future tune of the MC predictions may help to improve the description and reduce the theoretical uncertainties.

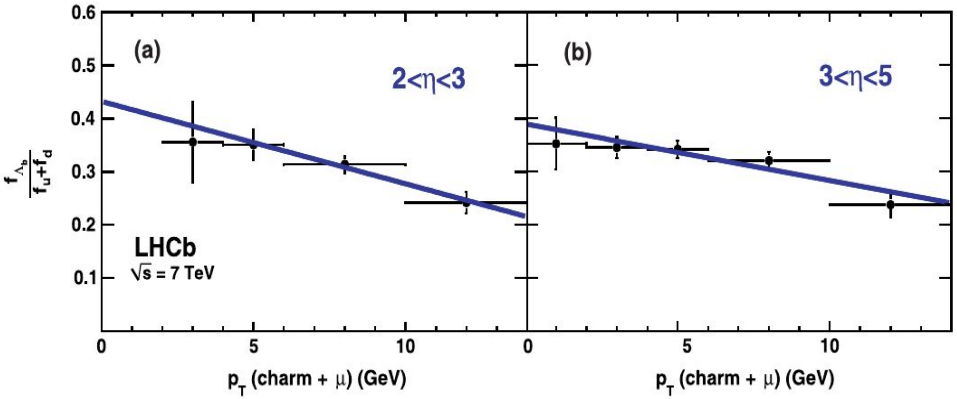
Motivation: non-universality

$$f_u = f_d \quad \text{and} \quad f_u + f_d + f_s + f_{\text{baryon}} = 1$$

CDF: Phys. Rev. D77 , 072003 (2008)



Phys. Rev. D85, 032008 (2012)



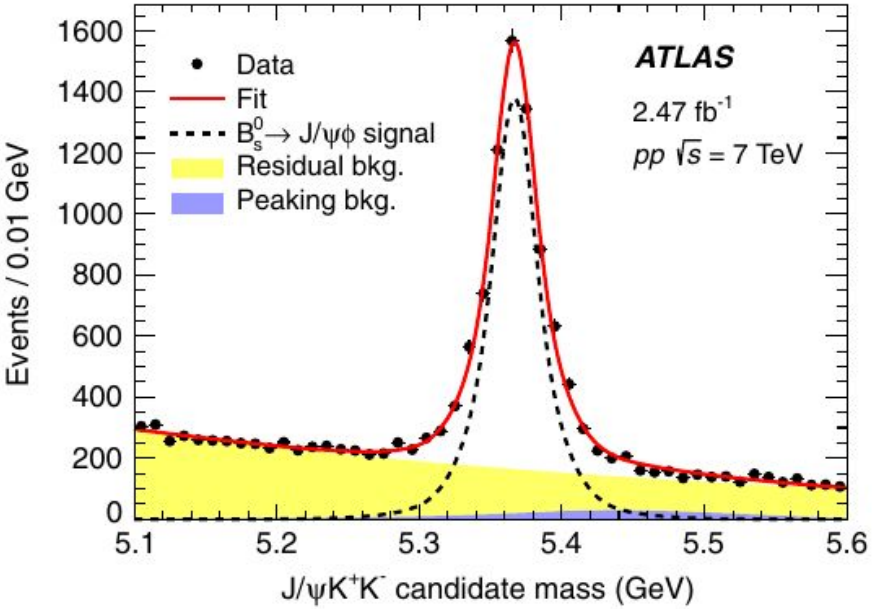
Fragmentation fractions were considered with no kinematical dependency.

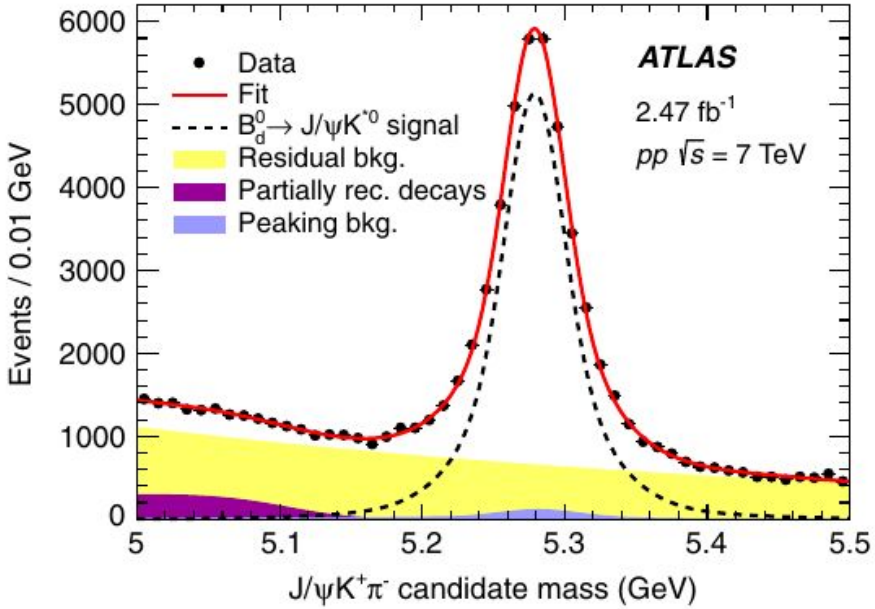
This seems not to hold anymore.

Phys. Rev. Lett. 115 (2015) 262001

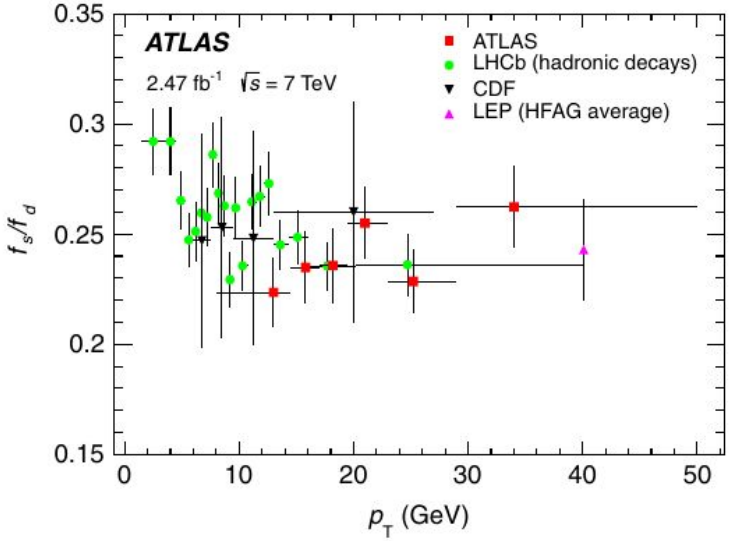
Determination of the ratio of b-quark fragmentation fractions fs/fd in pp collisions at 7 TeV with the ATLAS detector.

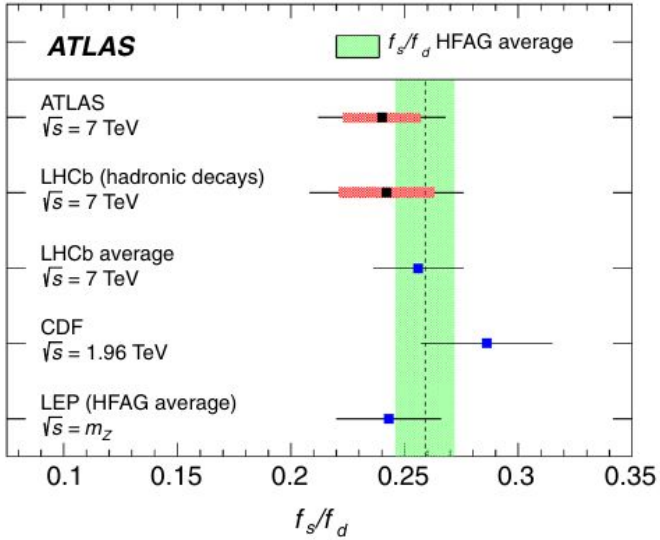
- ➔ $B_s \rightarrow J/\psi\phi$ and $B_d \rightarrow J/\psi K^*$ used to determine ratio of b-quar fragmentation fractions fs/fd.
- ➔ The ratio is extracted from the measured B meson signal yields.
- ➔ Correction for acceptance and selection efficiency ratios in the two modes.





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

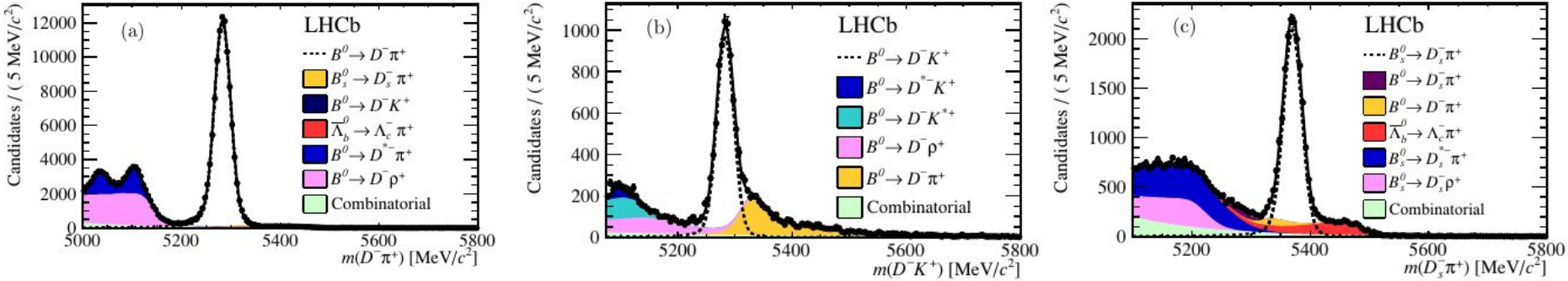




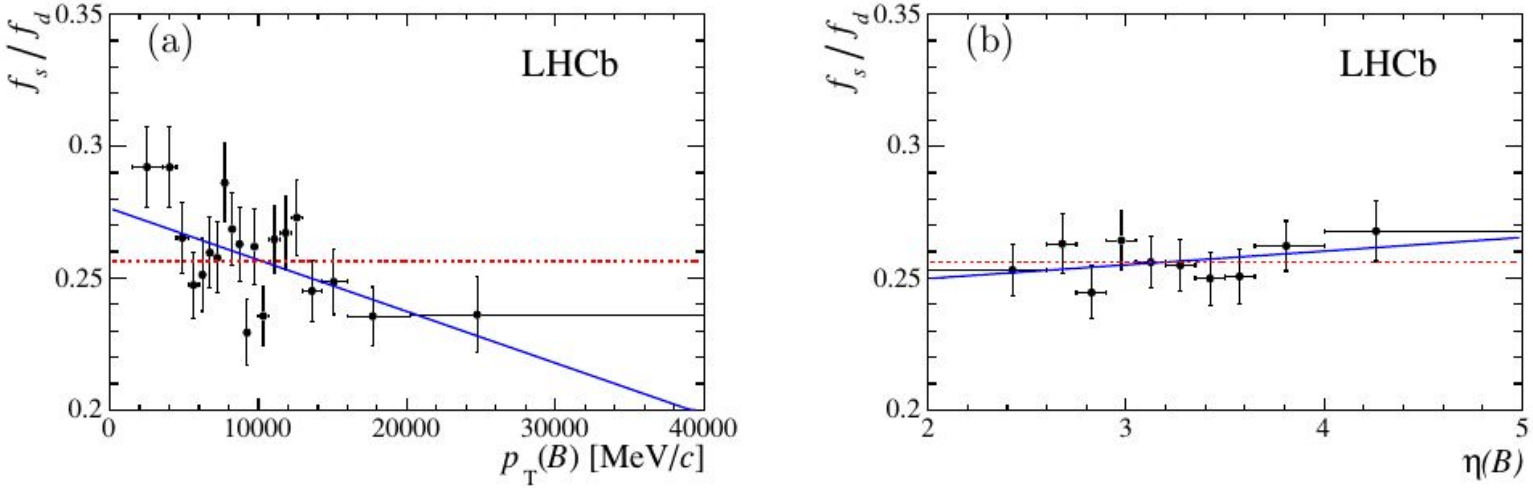
- **Uses perturbative QCD calculation of branching fractions ratio [arXiv:1309.0313]**
- **Measurement has been done in pT and pseudorapidity intervals: No dependence is observed.**
- **Results compared to previous experimental results (historical tension between LEP/CDF)**

JHEP 1304 (2013) 001, CERN-PH-EP-2013-006.
Phys.Rev. D100 (2019) no.3, 031102, CERN-EP-2019-016.
Phys. Rev. Lett. 124, 122002 (2020), CERN-EP-2019-209.
LHCb-TALK-2022-051 (LHCb-PAPER-2022-001).

Measurement of the fragmentation fraction ratios and its dependence on B meson kinematics.



JHEP 1304 (2013) 001



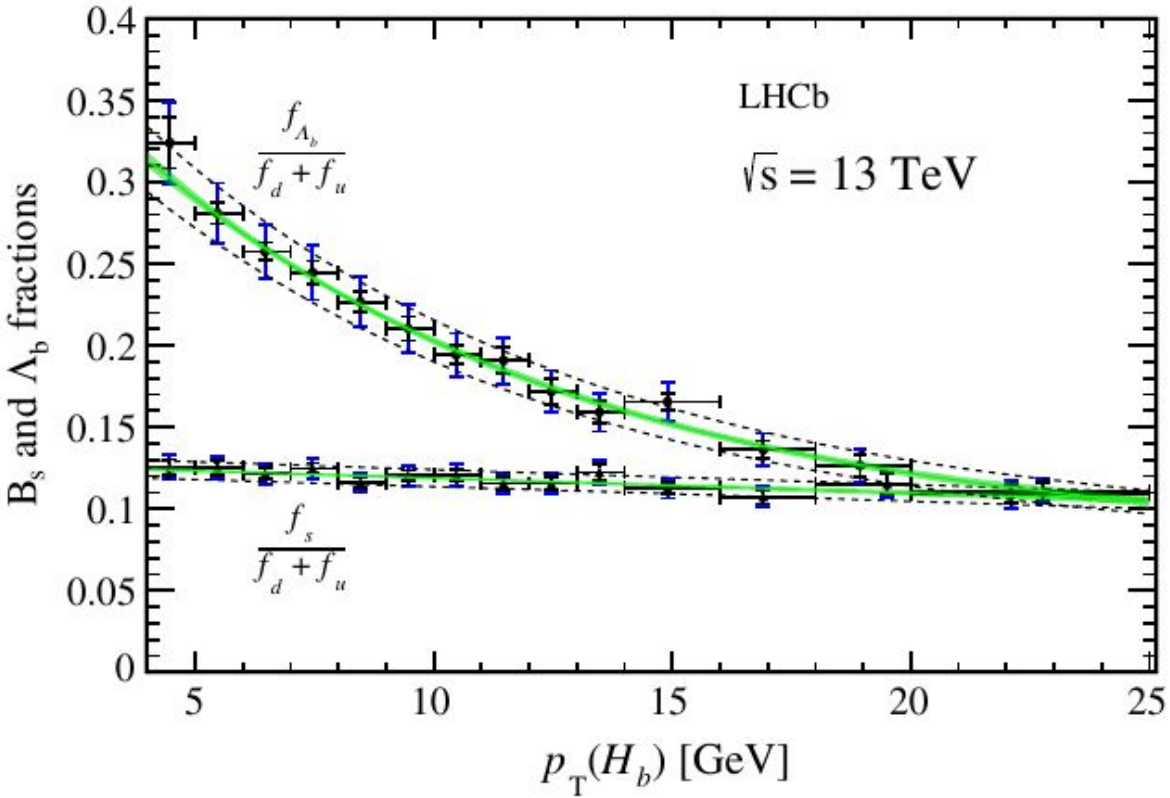
Variation consistent with a linear dependence on the pT is observed, with a significance of 3σ.

Measurement of b hadron fractions in 13 TeV pp collisions

$$\frac{f_{\Lambda_b^0}}{f_u + f_d} = 0.259 \pm 0.018$$

$$\frac{f_s}{f_u + f_d} = 0.122 \pm 0.006$$

Semileptonic decays to minimize theoretical uncertainties.



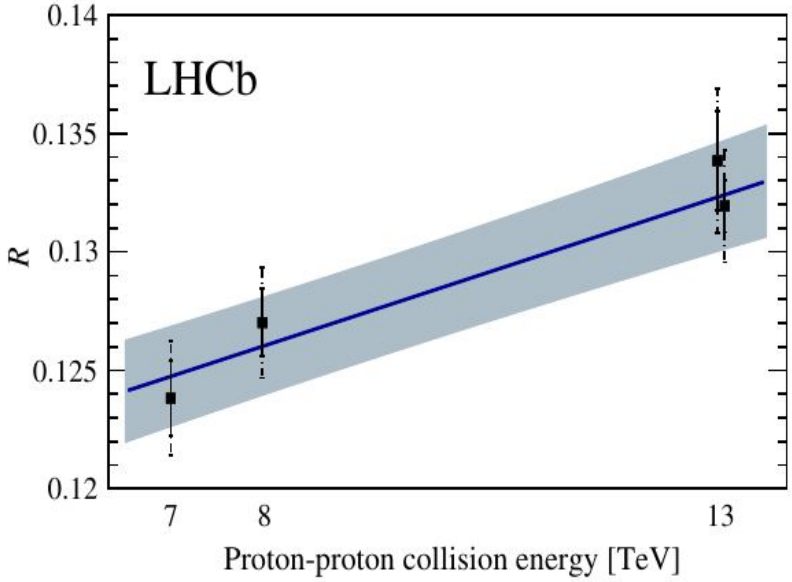
Phys.Rev. D100 (2019) no.3, 031102

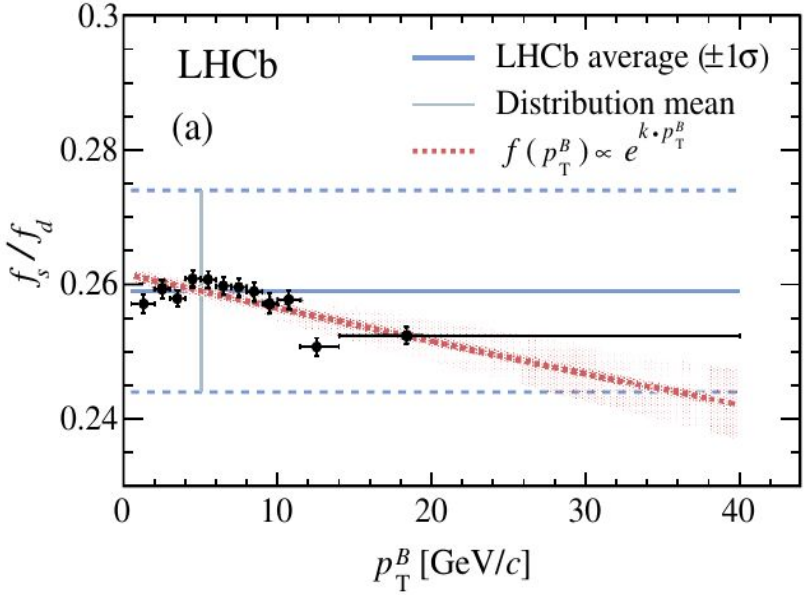
Λ_b ratio depends strongly on transverse momentum.

Bs ratio shows a mild dependence.

Efficiency-corrected $B_s \to J/\psi\phi$ and $B^+ \to J/\psi K^+$ yield ratio

Phys. Rev. Lett. 124, 122002 (2020)





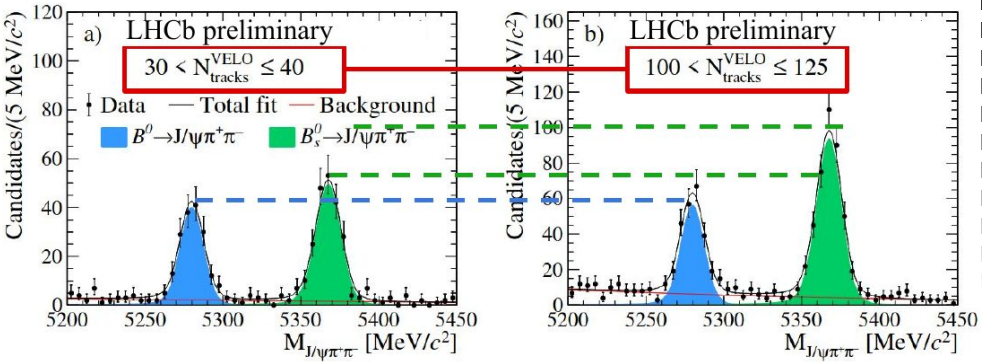
$$\mathcal{R} \equiv \frac{N(B_s^0 \to J/\psi\phi)}{N(B^+ \to J/\psi K^+)} \frac{\epsilon(B^+ \to J/\psi K^+)}{\epsilon(B_s^0 \to J/\psi\phi)} \propto \frac{f_s}{f_u}$$

A 4.8σ evidence is seen for a fs/fu dependence on the collision energy and fs/fu is observed to depend on the B-meson transverse momentum.

Enhancement in the strangeness content of the medium formed in heavy-ion collisions is expected when the medium temperature lies above the strange quark mass.

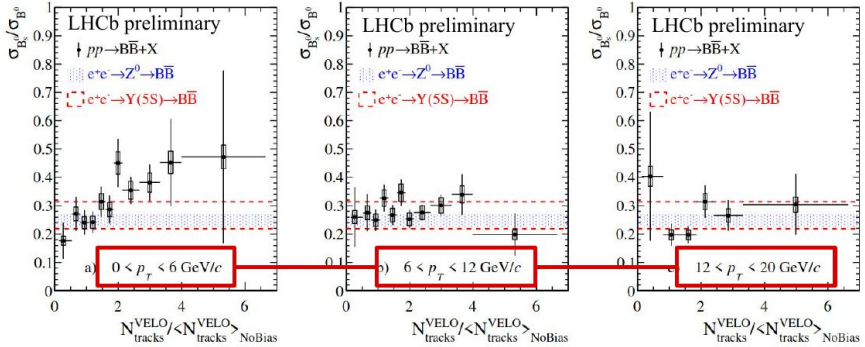
$$\frac{\sigma(B_s^0)}{\sigma(B^0)} \qquad B^0_{(s)} \to (J/\psi \to \mu^+\mu^-)\pi^+\pi^-$$

$$pp : \sqrt{s} = 13\,\mathrm{TeV}\,(5.4\,\mathrm{fb}^{-1})$$



By "raw" inspection, increase of the production ratio with the multiplicity

LHCb-TALK-2022-051

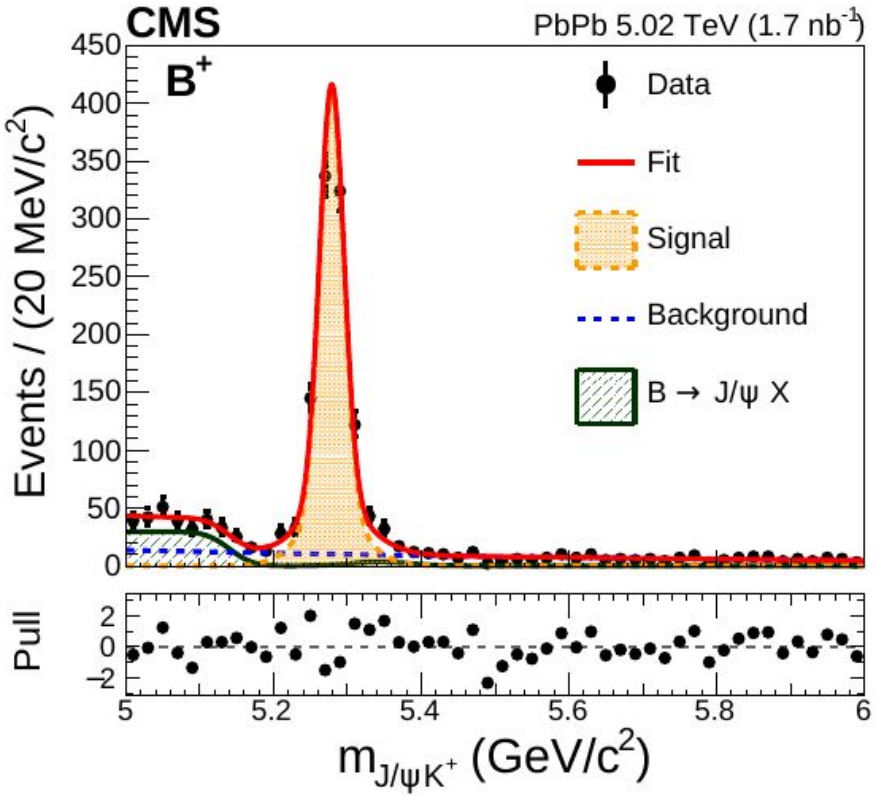


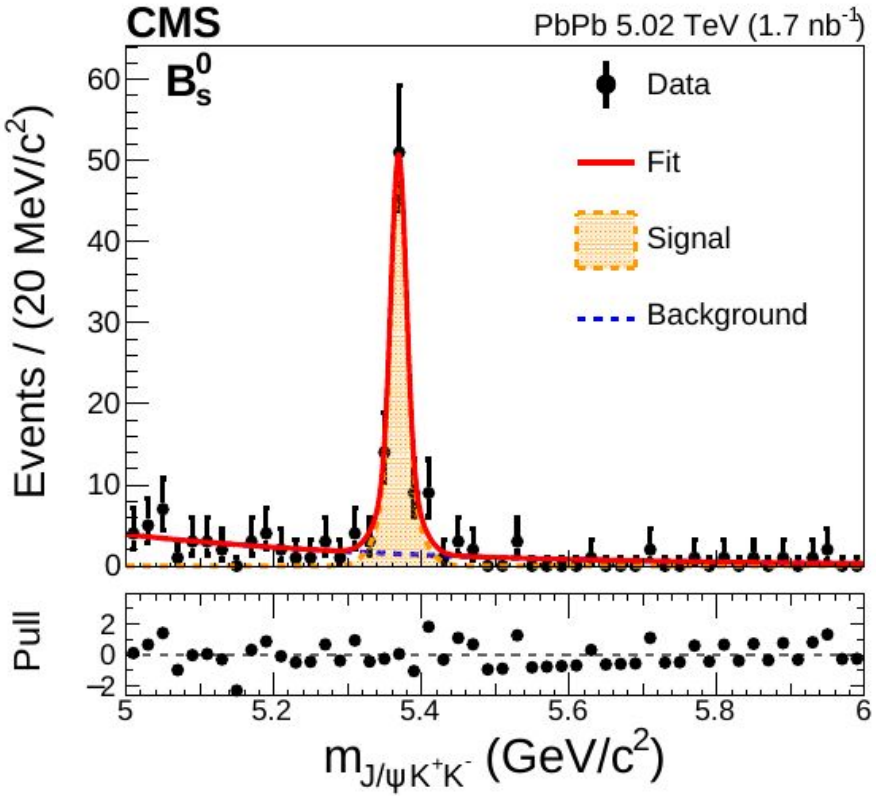
- At low-multiplicity it is **Consistency with previous ee measurements.**
- **Production ratio enhancement with collision multiplicity at low pT → qualitatively hints at quark coalescence as an additional hadronization mechanism other than fragmentation.**

arXiv:2109.01908, CERN-EP-2021-141.
arXiv:2201.02659, CERN-EP-2021-259.

Using Bu, Bs, and Bc mesons for studies of heavy quark dynamics.

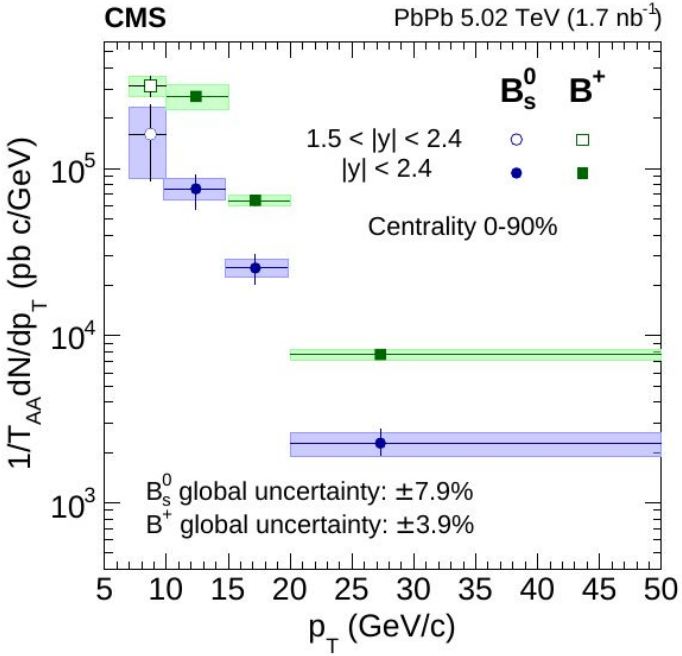
First 5σ observation of the Bs meson in nucleus-nucleus collisions

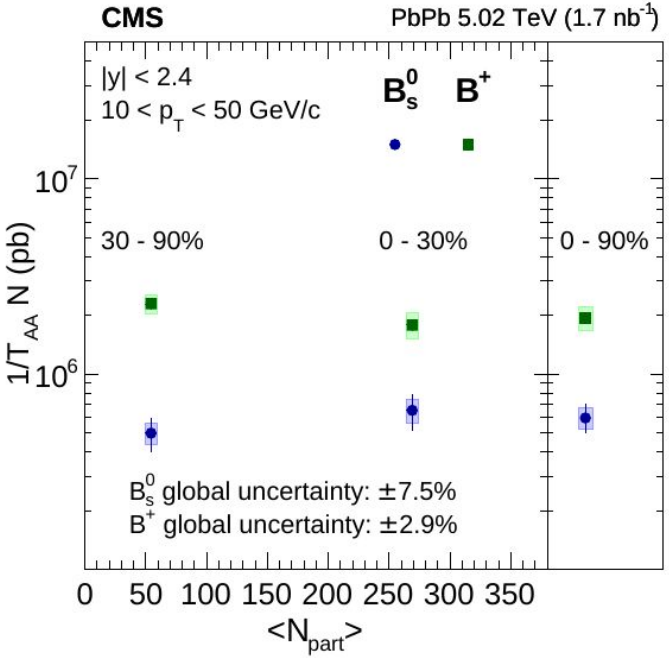




arXiv:2109.01908, Accepted for publication in Phys. Lett. B.

Production yields

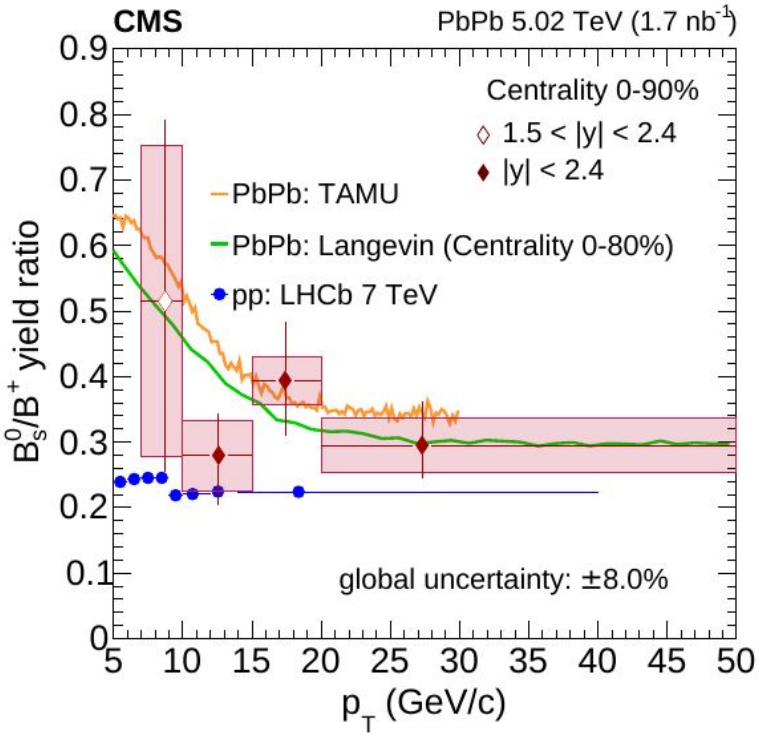


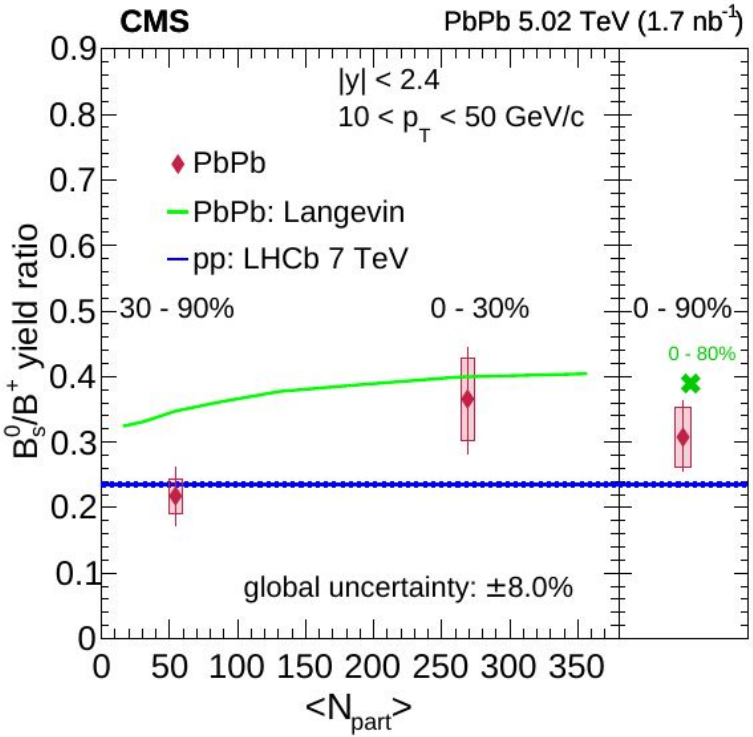


➔ **Presented as functions of the meson pT and, for the first time, of the event centrality.**

➔ **Results extend, and are compatible with, those previously reported by the CMS [Phys. Lett. B 796 (2019) 168, Phys. Rev. Lett. 119, 152301 (2017)].**

Yields Ratio

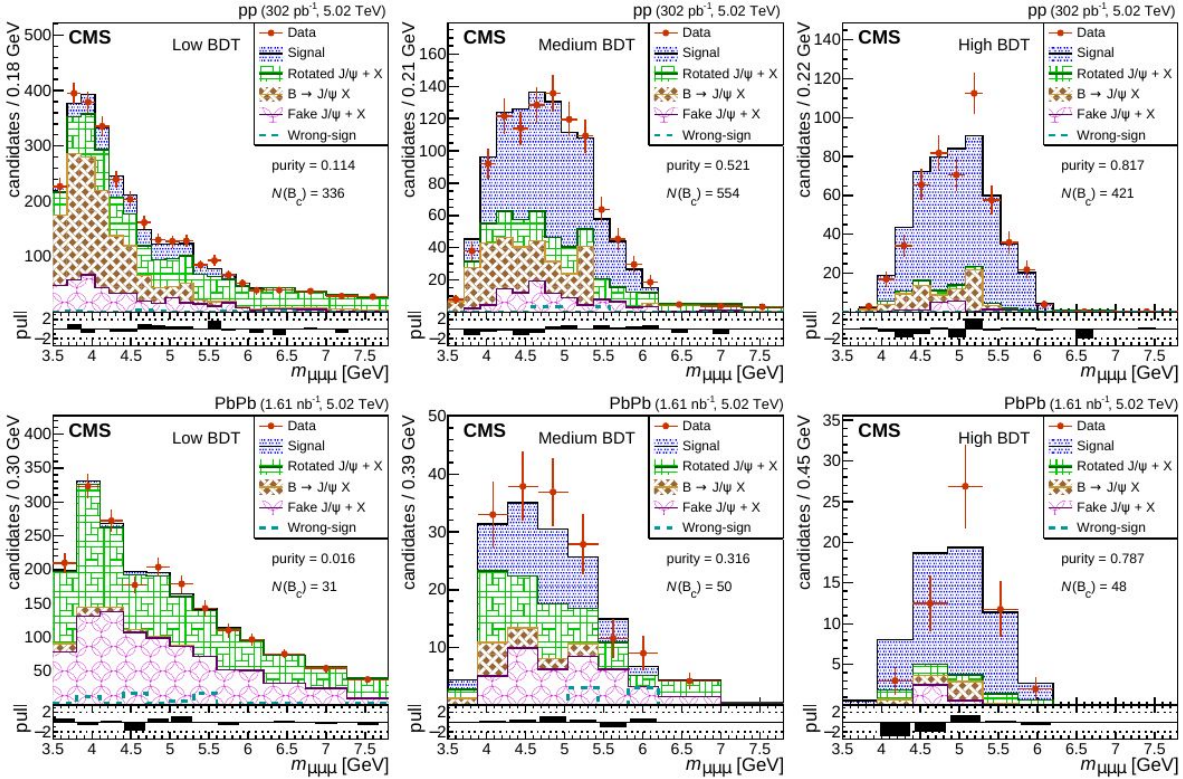




Compatible with PbPb recombination models and pp data.
No significant pT dependence can be established with the precision allowed by the current data.

Indicate higher ratio in central events, but the results are compatible within uncertainty.

$B_c^+ \rightarrow J/\Psi\mu^+\nu$: Trimuon template fit

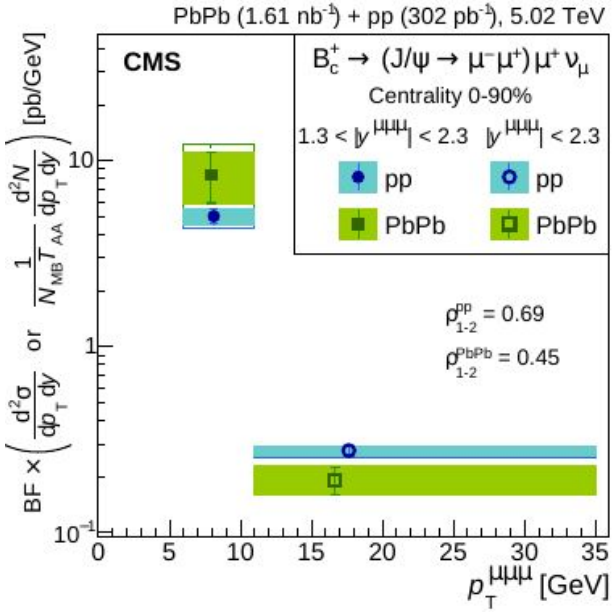


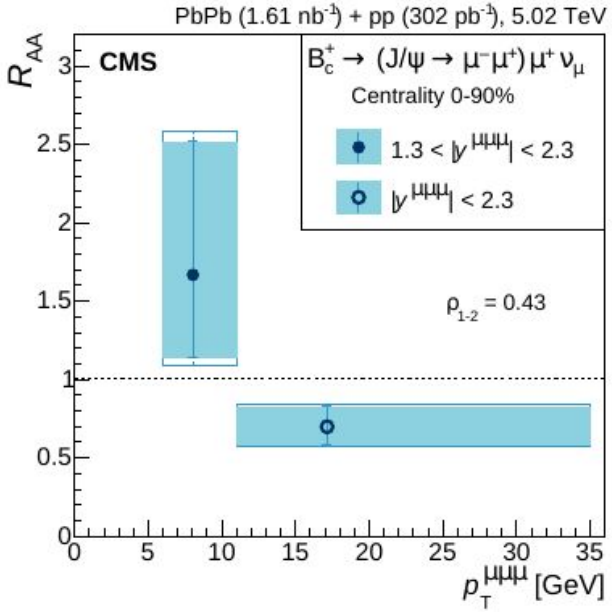
Three main background sources

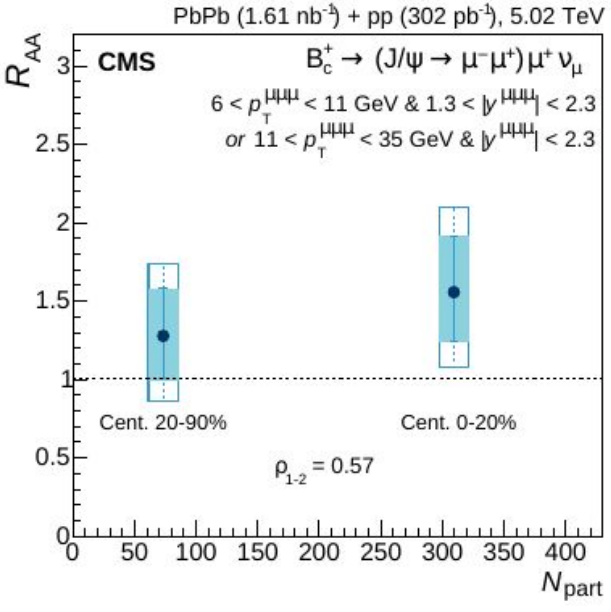
- **Rotated J/ψ + X: rotating J/ψ candidates around the PV.**
- **B → J/ψ + X: simulation.**
- **Fake J/ψ + X: interpolating dimuon mass sidebands from data.**

First observation of the B_c^+ meson in heavy ion collisions

B_c^+ meson production and nuclear modification factor







- ➔ R_{AA} at low pT higher than unity (1σ) and high pT (1.6σ).
- ➔ moderate suppression at high pT compared to pp result.
- ➔ No significant variation is observed as a function of centrality.

Backup slides

The Heavy Flavor Averaging Group

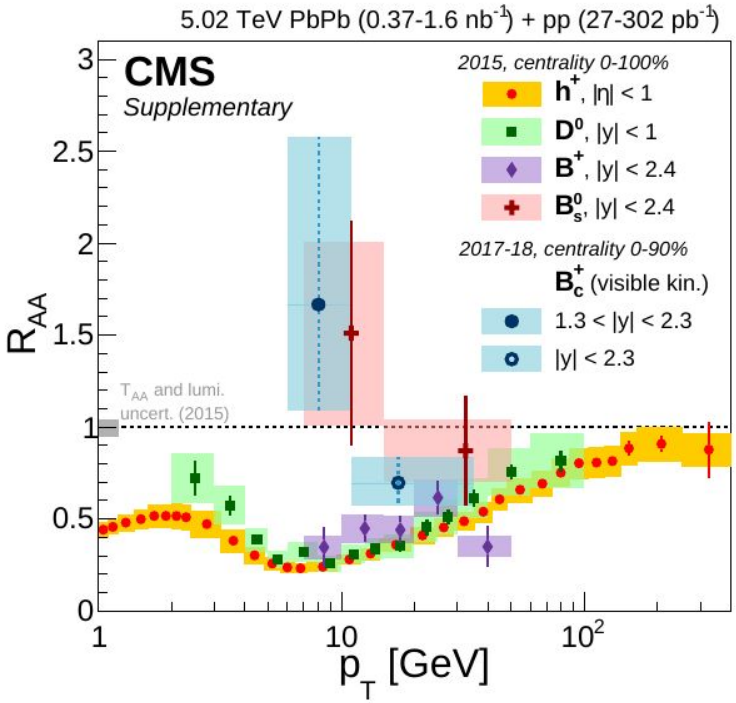
Table 6: Time-integrated mixing probability $\overline{\chi}$ (defined in Eq. (32)), and production fractions of the different b-hadron species in an unbiased sample of weakly decaying b hadrons, obtained from both direct and mixing measurements. The correlation coefficients ρ between the fractions are also given.

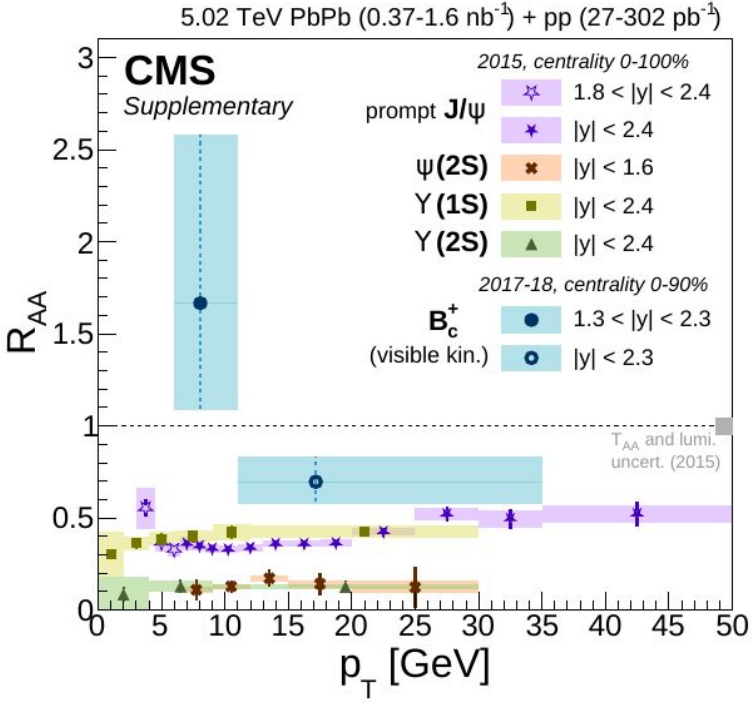
Quantity		Z decays	Tevatron	ATLAS [51]	LHCb [49]
Mixing probability	$\overline{\chi}$	0.1259 ± 0.0042	0.147 ± 0.011		
B^+ or B^0 fraction	$f_u = f_d$	0.407 ± 0.007	0.344 ± 0.021		
B_s^0 fraction	f_s	0.101 ± 0.008	0.115 ± 0.013		
b-baryon fraction	f_{baryon}	0.085 ± 0.011	0.198 ± 0.046		
B_s^0/B^0 ratio	f_s/f_d	0.249 ± 0.023	0.334 ± 0.040	0.240 ± 0.020	0.256 ± 0.020^u
	$\rho(f_s, f_u) = \rho(f_s, f_d)$	-0.628	$+0.159$		
	$\rho(f_{\text{baryon}}, f_u) = \rho(f_{\text{baryon}}, f_d)$	-0.817	-0.960		
	$\rho(f_{\text{baryon}}, f_s)$	$+0.065$	-0.429		

^{u} This value has been updated with new inputs by LHCb to yield 0.259 ± 0.015 [56].

Eur. Phys. J. C (2021) 81: 226, arXiv:1909.12524

B_c^+ R_{AA} Compared to charged hadron, D0, B, and quarkonia





Except for the Bs, other heavy mesons in these pT ranges typically show more suppression than CMS measurement.