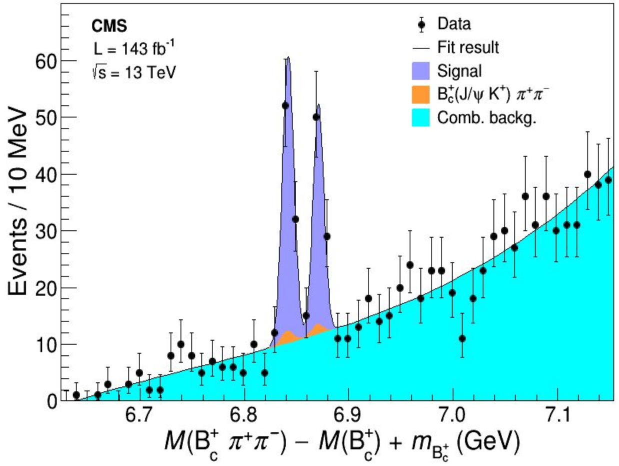
Measurement of $B_c(2S)^+$ and $B_c^*(2S)^+$ cross section ratios in proton-proton collisions



Manuel Alejandro Rodríguez

Grupo de Fenomenología e Interacciones Fundamentales (GFIF)
Instituto de Física - Universidad de Antioquia

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Introduction

Particle	Predicted M(MeV)
B_c	6247-6286
B_c^*	6308-6341
$B_c(2S)$	6835-6882
$B_c(2S)^*$	6881-6914

$B_c(2S)^* \rightarrow B_c^* \pi^+ \pi^-$ followed by $B_c^* \rightarrow B_c\ \gamma_{lost}$

Since the photon is not detected, we end up seeing

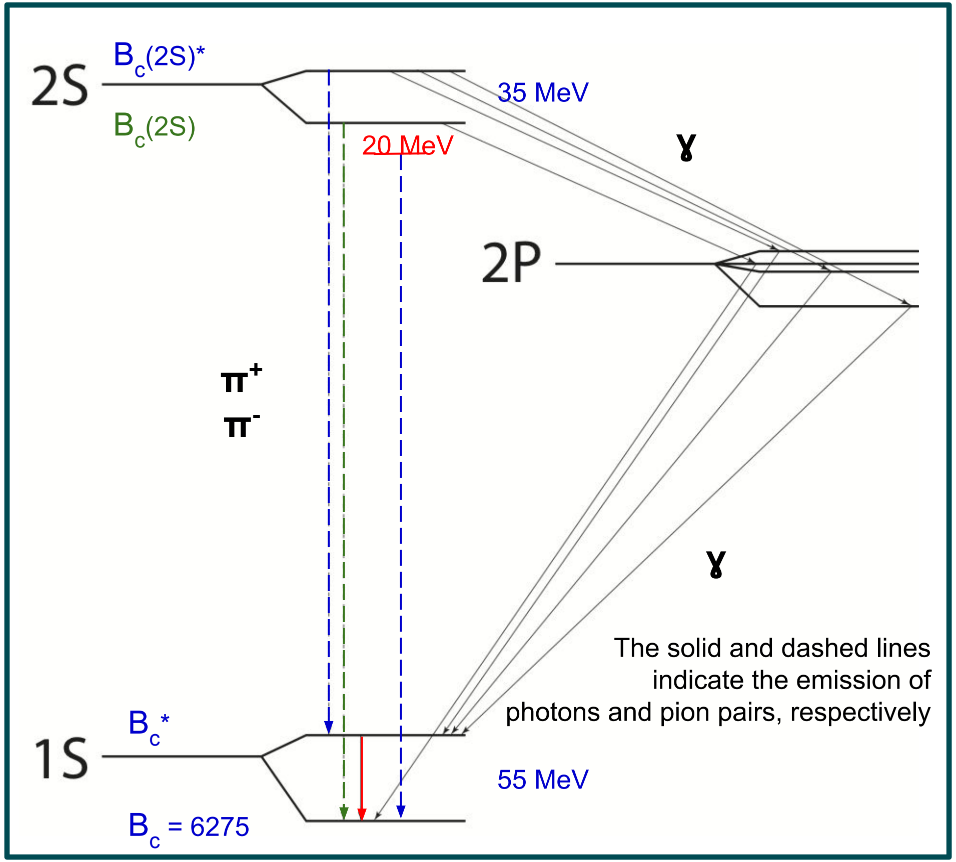
$B_c(2S)^* \rightarrow B_c \pi^+ \pi^-$ plus "missing energy"

Same final state as

$B_c(2S) \rightarrow B_c \pi^+ \pi^-$

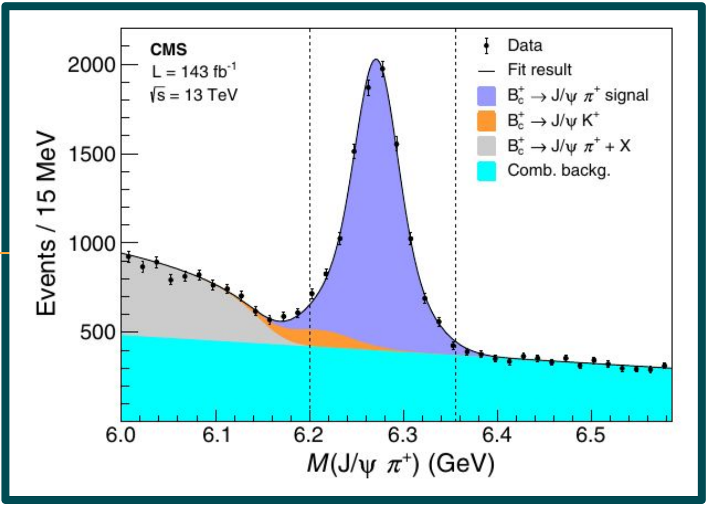
So, we see a two-peak structure in the $B_c \pi^+ \pi^-$ mass distribution, with the $B_c(2S)^*$ peak at a mass shifted by

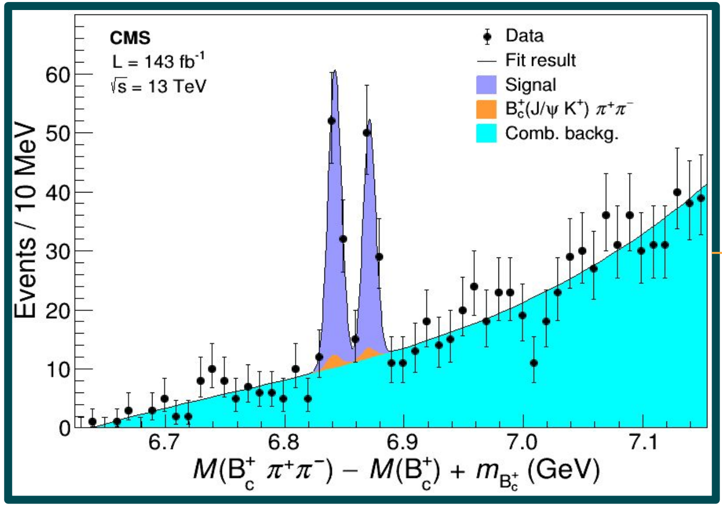
$$\Delta M = [\ M(B_c^*) - M(B_c)\ ] - [\ M(B_c(2S)^*) - M(B_c(2S))\ ]$$

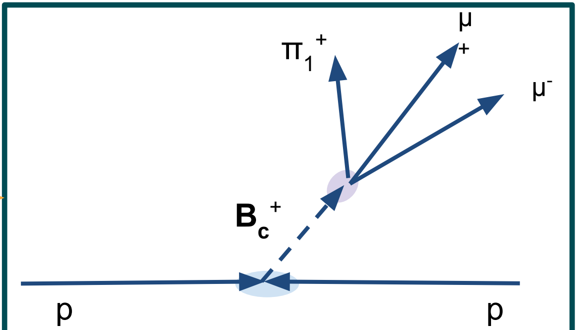


[*] PRD 49 (1994) 5845, PRD 51 (1995) 3613, PRD 52 (1995) 5229, PRD 53 (1996) 312, PLB 382 (1996) 131, PRD 160 (1999) 074006, PRD 67 (2003) 014027, PRD 70 (2004) 054017, PRL 104 (2010) 022001, PRD 86 (2012) 094510, PRL 121 (2018) 202002

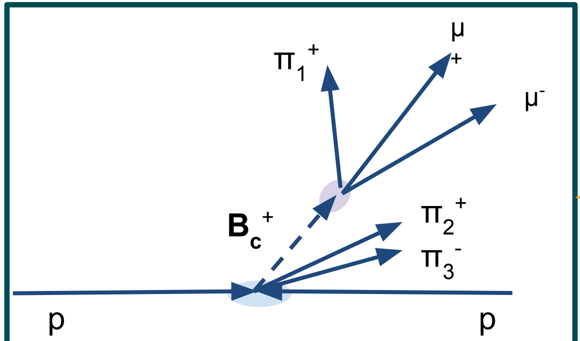
Reconstruction of the mass of B_c







$B_c \rightarrow J/\psi\pi \rightarrow \mu\mu\pi$



$B_c(2S) \rightarrow B_c\,\pi^+\pi^-$

Cross section ratios as functions of p_T and |y|

Efficiency

$$\epsilon_{B_c^*(2S)^+} = \frac{N^{rec}_{B_c^*(2S)^+ \to B_c^{*+}\pi^+\pi^-}}{N^{gen}_{B_c^*(2S)^+ \to B_c^{*+}\pi^+\pi^-}}$$

$$\epsilon_{B_c(2S)^+} = \frac{N^{rec}_{B_c(2S)^+ \to B_c^{+}\pi^+\pi^-}}{N^{gen}_{B_c(2S)^+ \to B_c^{+}\pi^+\pi^-}}$$

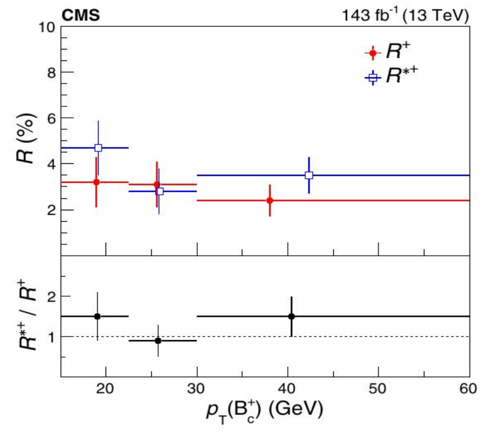
where $N^{rec}_{B_c(2S)^+ \to B_c^+\pi^+\pi^-}$ iis the number of reconstructed B_c (2S) → B_c $\pi^+\pi^-$ events after the full selection and $N^{gen}_{B_c(2S)^+ \to B_c^+\pi^+\pi^-}$ is the number of generated B_c (2S) → B_c $\pi^+\pi^-$ decays in the fiducial region of the analysis specified by the B_c kinematic window pT(B_c)>15 GeV and |y(B_c)|<2.4. Analogous efficiency definitions apply for B_c and B_c(2S)

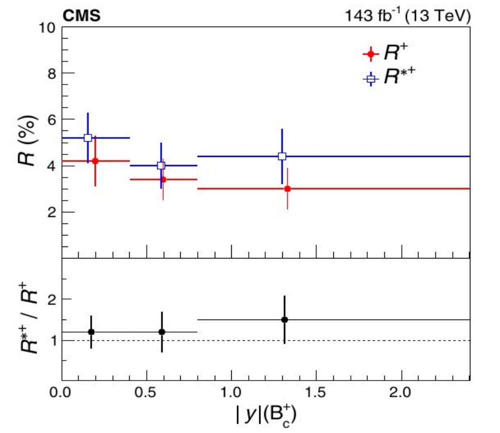
Cross section ratios

$$R^+ \equiv \frac{\sigma(B_c(2S)^+)}{\sigma(B_c^+)}\mathcal{B}(B_c(2S)^+ \to B_c^+\pi^+\pi^-) = \frac{N(B_c(2S)^+)}{N(B_c^+)}\frac{\epsilon(B_c^+)}{\epsilon(B_c(2S)^+)},$$

$$R^{*+} \equiv \frac{\sigma(B_c^*(2S)^+)}{\sigma(B_c^+)}\mathcal{B}(B_c^*(2S)^+ \to B_c^{*+}\pi^+\pi^-) = \frac{N(B_c^*(2S)^+)}{N(B_c^+)}\frac{\epsilon(B_c^+)}{\epsilon(B_c^*(2S)^+)},$$

$$R^{*+}/R^+ = \frac{\sigma(B_c^*(2S)^+)}{\sigma(B_c(2S)^+)}\frac{\mathcal{B}(B_c^*(2S)^+ \to B_c^{*+}\pi^+\pi^-)}{\mathcal{B}(B_c(2S)^+ \to B_c^+\pi^+\pi^-)} = \frac{N(B_c^*(2S)^+)}{N(B_c(2S)^+)}\frac{\epsilon(B_c(2S)^+)}{\epsilon(B_c^*(2S)^+)}.$$





Summary

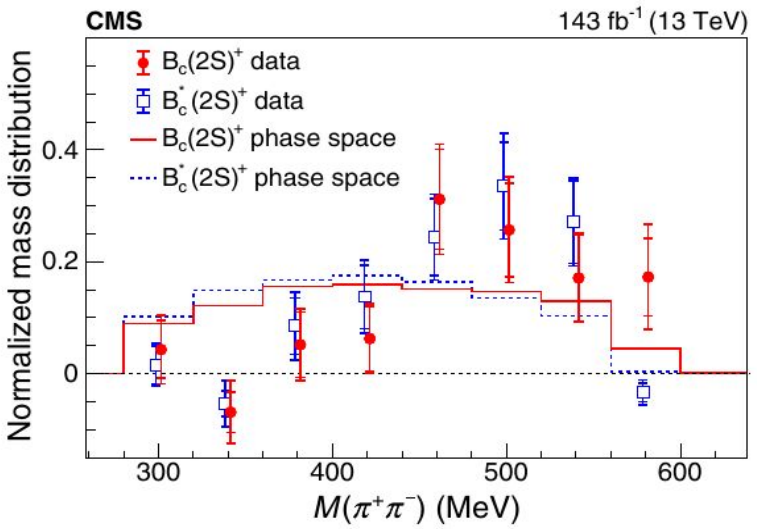
We have look at 2015, 2016, 2017 and 2018 data (143 fb^{-1}), looking for the excited states $B_c(2S)^{(*)\pm}$

- $B_c(2S)^\pm \rightarrow B_c^\pm\pi^+\pi^-$ followed by $B_c^\pm \rightarrow J/\psi\pi^\pm$ and $J/\psi \rightarrow \mu^+\mu^-$
- $B_c(2S)^{*\pm} \rightarrow B_c^{*\pm}\pi^+\pi^- \rightarrow (B_c^\pm\gamma)\pi^+\pi^-$ followed by $B_c^\pm \rightarrow J/\psi\pi^\pm$ and $J/\psi \rightarrow \mu^+\mu^-$

$R(B_c(2S)^+) = 0.034 \pm 0.007\ (stat) \pm 0.006\ (syst)$ for $p_T(B_c) > 15$ GeV and $|y(B_c)| < 2.4$

$R(B_c(2S)^{*+}) = 0.047 \pm 0.007\ (stat) \pm 0.004\ (syst)$ for $p_T(B_c) > 15$ GeV and $|y(B_c)| < 2.4$

$R(B_c(2S)^{*+}/B_c(2S)^+) = 1.394 \pm 0.349\ (stat) \pm 0.132\ (syst)$ for $p_T(B_c) > 15$ GeV and $|y(B_c)| < 2.4$



Systematic uncertainties

	R^+	R^{*+}	R^{*+}/R^+
$J/\psi\pi^+$ fit model	5.5	5.5	...
$B_c^+\pi^+\pi^-$ fit model	5.9	2.9	2.9
Efficiencies: statistical uncertainty	1.1	1.0	1.4
Efficiencies: spread among years	1.8	1.6	0.9
Efficiencies: pion tracking	4.2	4.2	...
Decay kinematics	1.5	6.9	4.2
Helicity angle	1.0	6.0	3.5
Total	9.5	12.0	6.4

https://journals.aps.org/prd/abstract/10.1103/PhysRevD.102.092007 PhysRevD.102.092007