

# Study of the $B_c \rightarrow [(\eta_c \rightarrow p\bar{p}) \mu^+ \nu_\mu]$ decay

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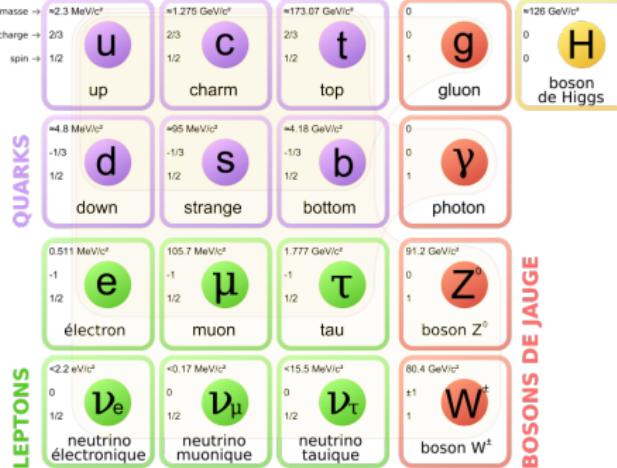
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# Motivation: Why $B_c \rightarrow [\eta_c \rightarrow p\bar{p}] \mu^+ \nu_\mu$ ?



**Figure:** Standard model has a feature called Lepton Flavor Universality.

- This decay mode will help to expand the knowledge of the  $B_c^+$  meson, which is a particle with very interesting characteristics.
- This decay mode can be used to perform a leptonic universality test

$$\frac{\mathcal{B}(B_c \rightarrow \eta_c \mu^+ \nu_\mu)}{\mathcal{B}(B_c \rightarrow J/\psi \mu^+ \nu_\mu)} = ?$$

$$\frac{\mathcal{B}(B_c \rightarrow \eta_c \tau^+ \nu_\tau)}{\mathcal{B}(B_c \rightarrow J/\psi \tau^+ \nu_\tau)} = ?$$

The first step is to measure the branching fraction of the decay

# Analysis strategy

For branching fraction measurement, we use  $B_c \rightarrow [(J/\psi \rightarrow p\bar{p}) \mu^+ \nu_\mu]$  as normalization channel. The advantages of using this decay mode are:

- Same final state.
- Similar kinematic distribution.

$$\frac{N_{B_c \rightarrow \eta_c \mu^+ \nu_\mu}}{N_{B_c \rightarrow J/\psi \mu^+ \nu_\mu}} = \frac{\mathcal{B}(B_c^+ \rightarrow \eta_c \mu^+ \nu_\mu) \times \mathcal{B}(\eta_c \rightarrow p\bar{p}) \times \epsilon(B_c^+ \rightarrow \eta_c \mu^+ \nu_\mu)}{\mathcal{B}(B_c^+ \rightarrow J/\psi \mu^+ \nu_\mu) \times \mathcal{B}(J/\psi \rightarrow p\bar{p}) \times \epsilon(B_c^+ \rightarrow J/\psi \mu^+ \nu_\mu)}$$

Available in PDG.

Obtained by fitting  $B_c^+$  corrected mass and  $m(p\bar{p})$  distribution.

Obtained from MC

# Data set and MC samples

- **Data set:** LHCb data from run 2  $pp$  collision from the year 2015, 2016 and 2017.
- **MC samples:** The list of simulation samples is shown in the next table:

SIGNAL	$B_c^+ \rightarrow J/\psi \mu^+ \nu_\mu$ $B_c^+ \rightarrow \eta_c \mu^+ \nu_\mu$	BACKGROUND	$B_c^+ \rightarrow (\psi(2S) \rightarrow J/\psi \pi^+ \pi^-) \mu^+ \nu_\mu$ $B_c^+ \rightarrow (\chi_{c0} \rightarrow J/\psi \gamma) \mu^+ \nu_\mu$ $B_c^+ \rightarrow (\chi_{c1} \rightarrow J/\psi \gamma) \mu^+ \nu_\mu$ $B_c^+ \rightarrow (\chi_{c2} \rightarrow J/\psi \gamma) \mu^+ \nu_\mu$ $B_c^+ \rightarrow J/\psi (\tau^+ \rightarrow \mu^+ \nu_\mu \bar{\nu}_\tau) \nu_\tau$ $B_c^+ \rightarrow \eta_c (\tau^+ \rightarrow \mu^+ \nu_\mu \bar{\nu}_\tau) \nu_\tau$ $B_c^+ \rightarrow (hc \rightarrow \eta_c \gamma) \mu^+ \nu_\mu$ $b \rightarrow J/\psi X$ $b \rightarrow \eta_c X$
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- **Stripping:** For the analysis we use selection that merges  
B2PPbarMuForTauMuTopoLine and B2PPbarMuForTauMuLine.

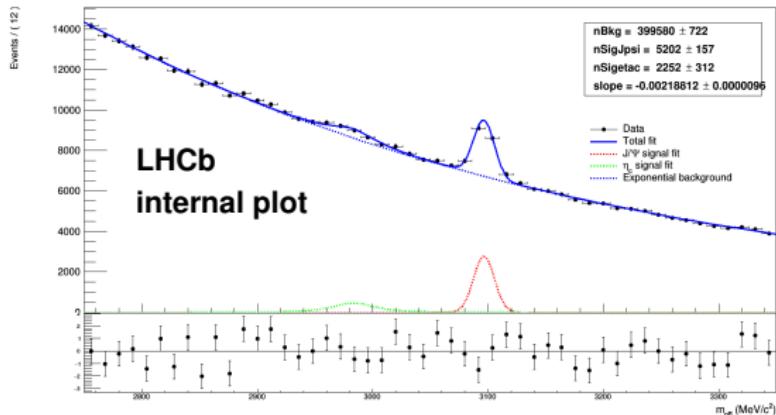
- **Trigger:**

Level 0	HadronDecision TOS MuonDecision TOS
High Level Trigger 1	TwoTrackMVADecision TOS
High Level Trigger 2	TopoMu2BodyDecision TOS TopoMu3BodyDecision TOS Topo2BodyDecision TOS Topo3BodyDecision TOS SingleMuonDecision TOS XcMuXForTauB2XcMuDecision TOS

# Selection: Preselection

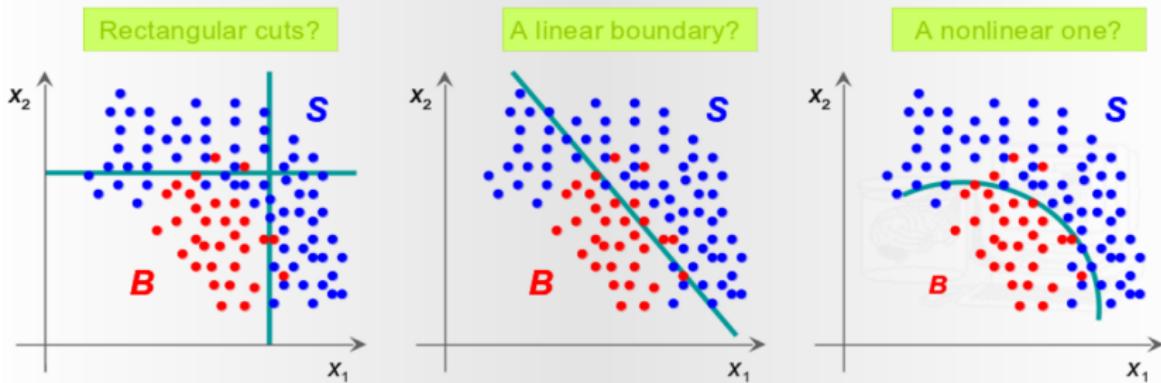
## Preselection

$p\bar{p}$	$M$	$2750-3350 \text{ MeV}/c^2$	$\mu$	ProbNNmu	$>0.2$
	$M(p\bar{p} \rightarrow \pi^+\pi^-)$	$(< 1770 \text{ or } > 1805) \text{ MeV}/c^2$			$< 150 \text{ GeV}/c$
	$M(p\bar{p} \rightarrow k^+k^-)$	$(< 1920 \text{ or } > 1950) \text{ MeV}/c^2$			$< 900 \text{ MeV}/c^2$



# Selection: Multivariate analysis

## Multivariate analysis:

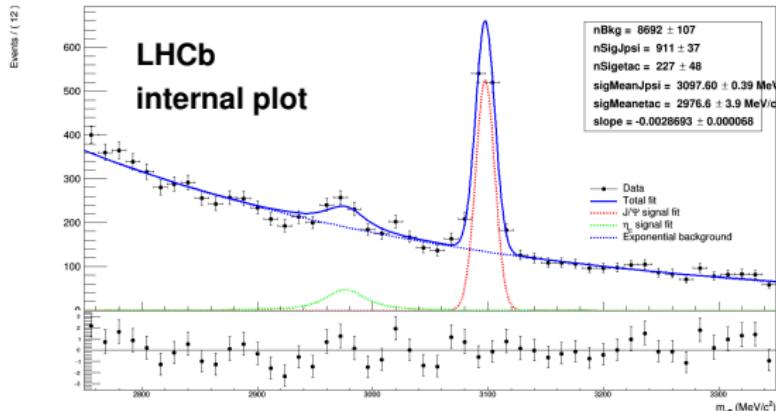
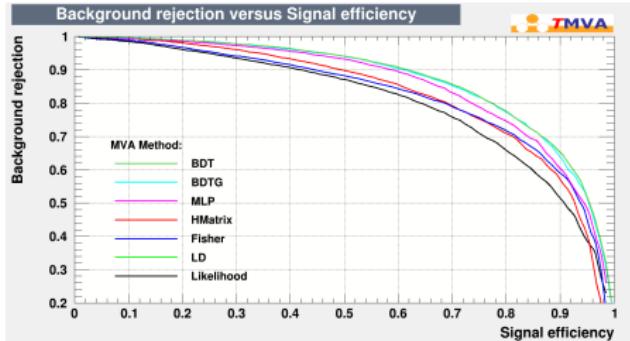


- Signal sample:
  - MC for signal channel
- Background sample:
  - Stage 1: Real data using the  $m(p\bar{p})$  right sideband: ( $m(p\bar{p}) > 3130 \frac{MeV}{c^2}$ )
  - Stage 2: Real data using the  $B_c$  corrected mass sideband,  
 $(B_c\_MCORR < 5000 \frac{MeV}{c^2})$

# Selection: Multivariate analysis

TRAINING VARIABLES	
Ranking	Variable
Stage 1	
1	Minimal ProbNNp of the $p\bar{p}$ from $\eta_c$
2	Minimal $p_T$ of the $p\bar{p}$ from $\eta_c$
3	Maximal track $\chi^2$ ndof $p\bar{p}$ from $\eta_c$
4	Maximal track ghost probability $p\bar{p}$ from $\eta_c$
Stage 2	
1	ProbNNmu of the $\mu$ from $B_c$
2	Log of Minimal IPCHI2 of the $p\bar{p}$ from $\eta_c$
3	Log of SmallestDeltaChi2OneTrack of the $B_c$
4	$p_T$ of the $\mu$ from $B_c$
5	Log of flight distance to the PV of the $B_c$
6	Cosine of the angle between $\eta_c$ and the $\mu$
7	End vertex chi2 of the $B_c$

ROC curve is used to identify the best method



## $B_c$ corrected mass analysis

Signal yields will be determined by fit to corrected mass of  $B_c$ . Corrected mass is defined as:

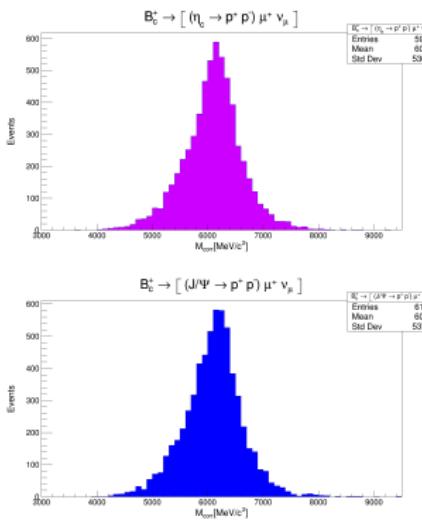
$$M^{corr} \equiv \sqrt{m^2(p\bar{p}\mu) + p_{\perp}^2} + p_{\perp}$$

where  $p_{\perp}$  is the momentum component of  $p\bar{p}\mu$  transverse to  $B_c$  flight direction. The  $B_c$  corrected mass is being analysed through the fitting of the  $\eta_c$  and  $J/\psi$  yields extracted from the  $p\bar{p}$  invariant mass fits in  $B_c$  corrected mass bins.

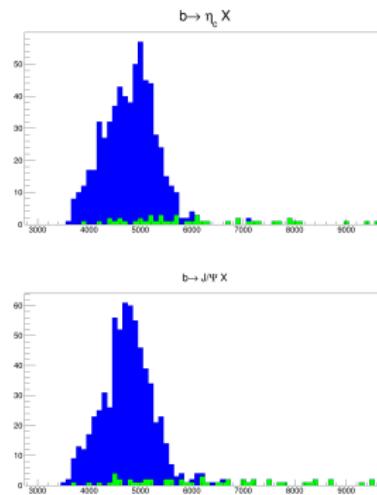
The mass window that we are analyzing in the  $B_c$  corrected mass is between [3250,9750] MeV/ $c^2$  with a bin size equal to 500 MeV/ $c^2$ .

# $B_c$ corrected mass distributions for MC samples

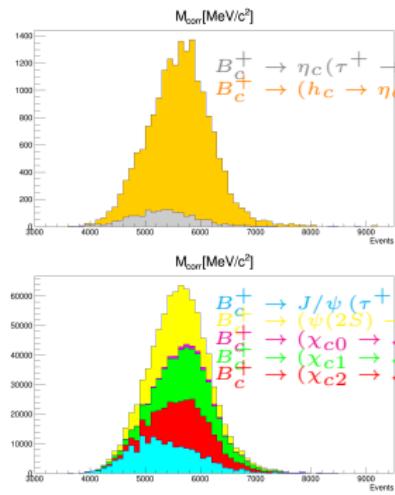
$B_c \rightarrow \eta_c \mu^+ \nu_\mu$  &  
 $B_c \rightarrow J/\psi \mu^+ \nu_\mu$   
**Signals**



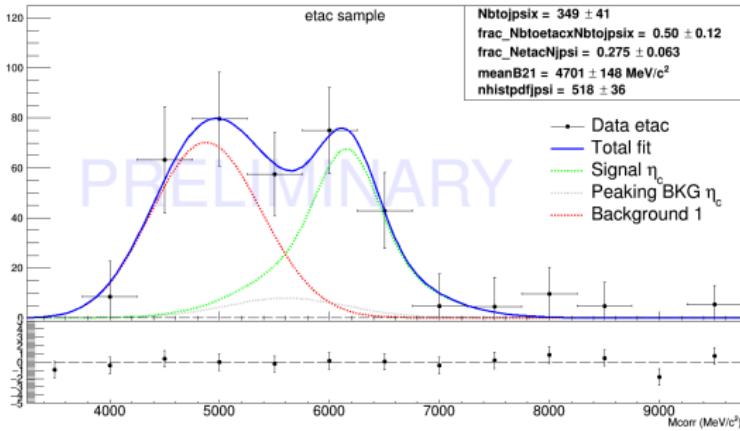
$b \rightarrow \eta_c X$  and  $b \rightarrow J/\psi X$   
**backgrounds**



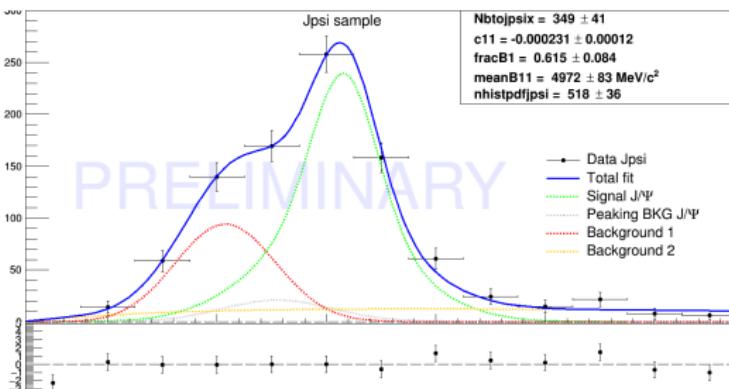
**Peaking backgrounds**



## $B_c$ corrected mass analysis



$$\frac{N_{B_c \rightarrow \eta_c \mu^+ \nu_\mu}}{N_{B_c \rightarrow J/\Psi \mu^+ \nu_\mu}} = (2,75 \pm 0,63_{stat}) \times 10^{-1}$$



Using this result, we can already estimate the branching ratio of our signal

# Branching fraction measurement

## BRANCHING FRACTION

$$\frac{\mathcal{B}(B_c^+ \rightarrow \eta_c \mu^+ \nu_\mu)}{\mathcal{B}(B_c^+ \rightarrow J/\psi \mu^+ \nu_\mu)} = \frac{N_{B_c \rightarrow \eta_c \mu^+ \nu_\mu}}{N_{B_c \rightarrow J/\psi \mu^+ \nu_\mu}} \times \frac{\mathcal{B}(J/\psi \rightarrow p\bar{p})}{\mathcal{B}(\eta_c \rightarrow p\bar{p})} \times \frac{\epsilon_{tot}(B_c^+ \rightarrow J/\psi \mu^+ \nu_\mu)}{\epsilon_{tot}(B_c^+ \rightarrow \eta_c \mu^+ \nu_\mu)}$$

$$= (2,75 \pm 0,63_{stat} \pm ???_{syst}) \times 10^{-1} \times (1,472 \pm 0,144) \times (1,025 \pm 0,023)$$

$$= (4,15 \pm 1,04_{stat} \pm ???_{syst}) \times 10^{-1}$$

Now we have to calculate the systematic error of our measurement.

The different sources of systematic errors that we have identified are the following:

SYSTEMATIC ERRORS of $\frac{N_{B_c \rightarrow \eta_c \mu^+ \nu_\mu}}{N_{B_c \rightarrow J/\psi \mu^+ \nu_\mu}}$		
Source	Variables	Values ( $\times 10^{-1}$ )
$B_c \rightarrow J/\psi \mu \nu$	Shapes	0,0386
$B_c \rightarrow \eta_c \mu \nu$		
Peaking BKG of $J/\psi$ Peaking BKG of $\eta_c$	Shapes	0,002796
	Normalizations	0,0489
Fits in $m(p\bar{p})$ for $M_{corr}$ bins	Masses	0,0394
	Resolutions	0,00256
	Decay width of $\eta_c$	0,0197
	Background shape under $p\bar{p}$ spectrum	Work in progress
$b \rightarrow J/\psi X$ and $b \rightarrow \eta_c X$	Shapes	0,0901
	Threshold of the distributions	Work in progress
		<b>0,12</b>

## Ongoing work

- Calculate the value of the systematic error for the sources that we have not calculated and analyze if there are other important sources of systematic error and calculate them.
- Evaluate the stability of the fits, in order to see if those fits have convergence problems or if they are biased.

Thank you for your attention!