

# Open beauty measurements in pPb collisions with CMS

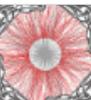


Hyunchul Kim  
(Korea University)



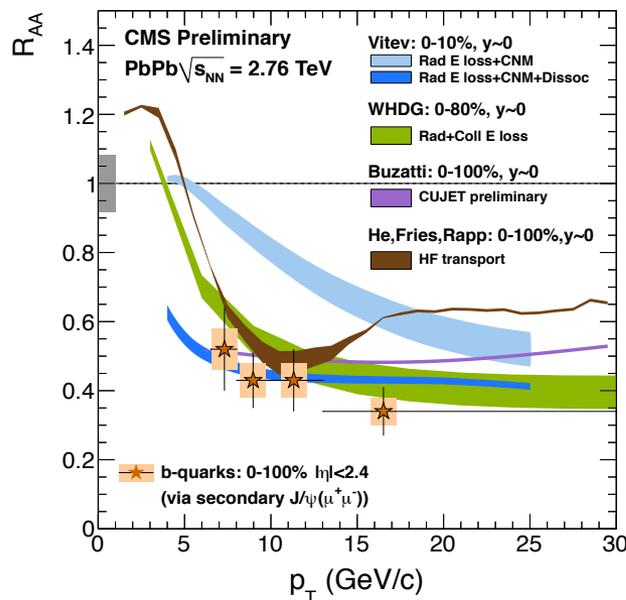
*for the CMS Collaboration*

Quark Matter conference, Darmstadt  
19<sup>th</sup> May, 2014



# Motivation of the analysis

- b-quarks produced in high energy pp collisions can be used to test pQCD calculations as they are produced in hard scattering processes
- In heavy-ion collisions, they are subject to final state interactions with the hot and dense medium
- So, combined with light quarks, they allow the study of flavor dependence of in-medium interactions via the measurement of B-meson
  - In PbPb collisions at 2.76 TeV, b-quark energy suppression was measured via non-prompt  $J/\psi$



CMS : PAS HIN-12-014

Vitev: J. Phys.G35 (2008) 104011 + private communications

Horowitz: arXiv:1108.5876 + private communications

Buzzatti, Gyulassy: arXiv: 1207.6020+ private communications

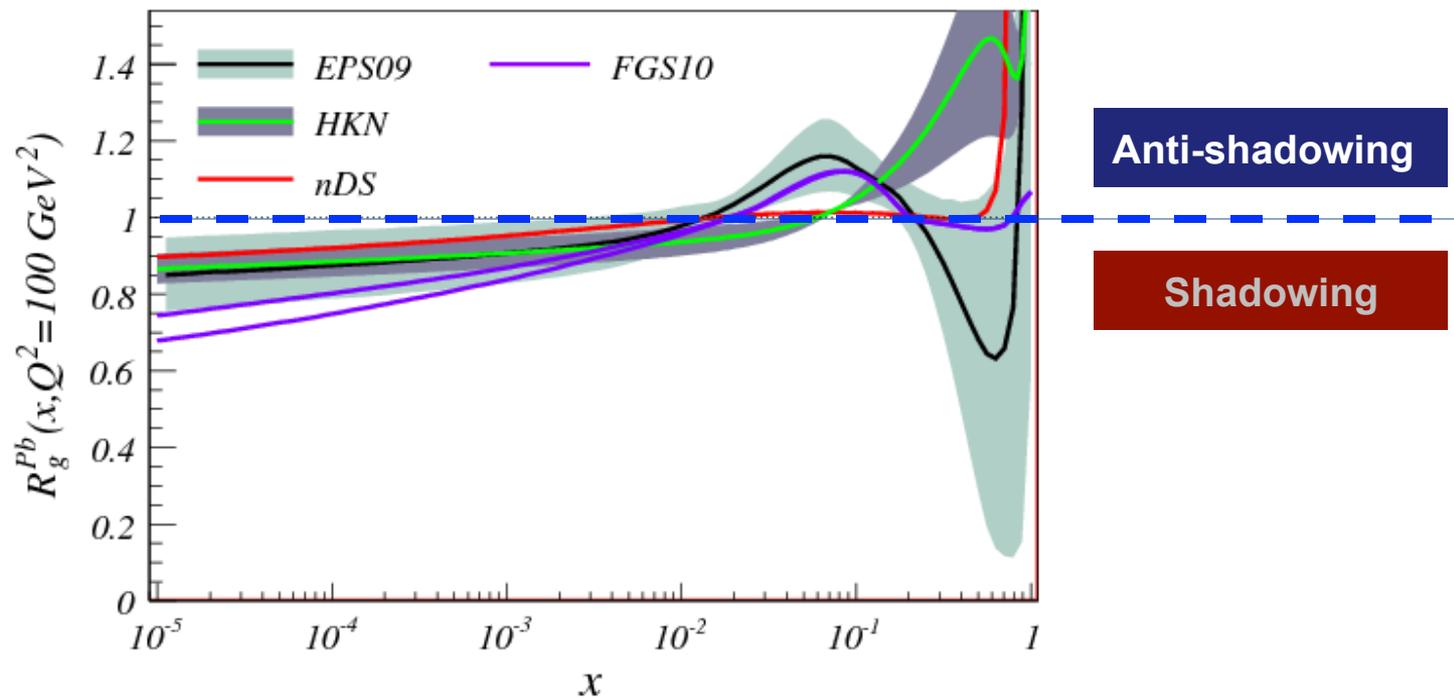
He, Fries, Rapp: PRC86(2012)014903+ private communications



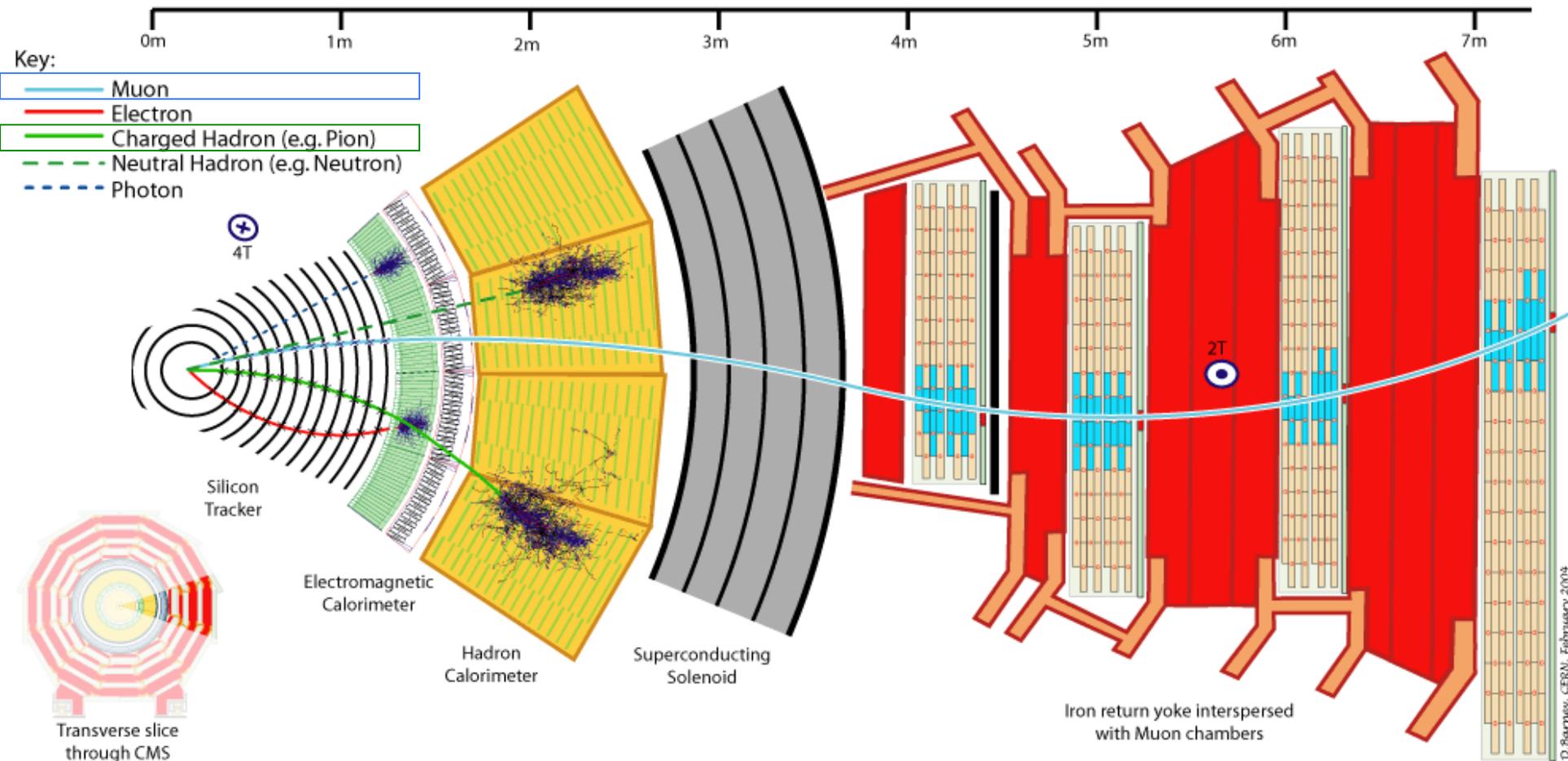
# Heavy quarks in pPb collisions

- pPb data is an essential reference in order to measure initial state modification of heavy quark production and cold nuclear matter effects
- First measurement of (**exclusive!**) B-meson production in pPb collisions at LHC

J. Phys. G 39 (2012) 015010



# CMS detector

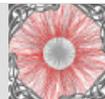


- Good momentum resolution provided by inner tracker
- Muon identification via muon systems



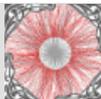
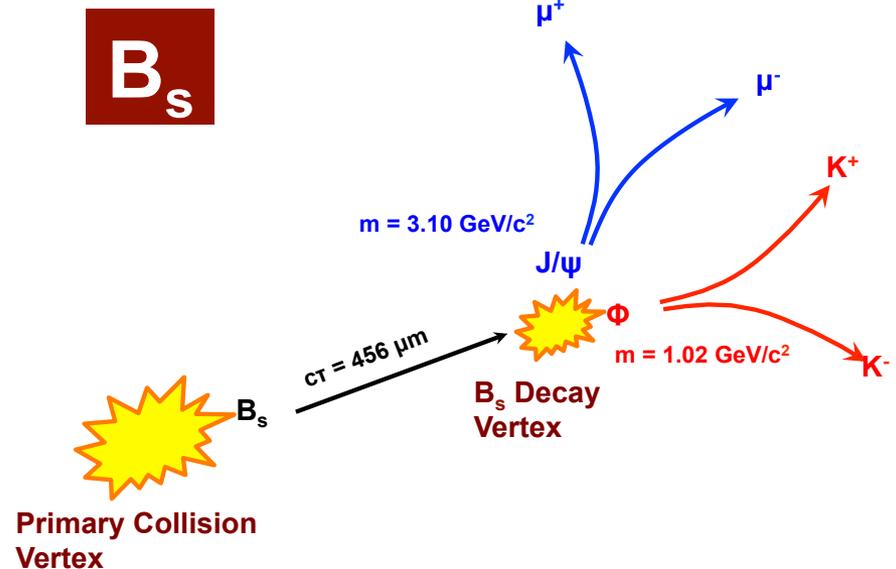
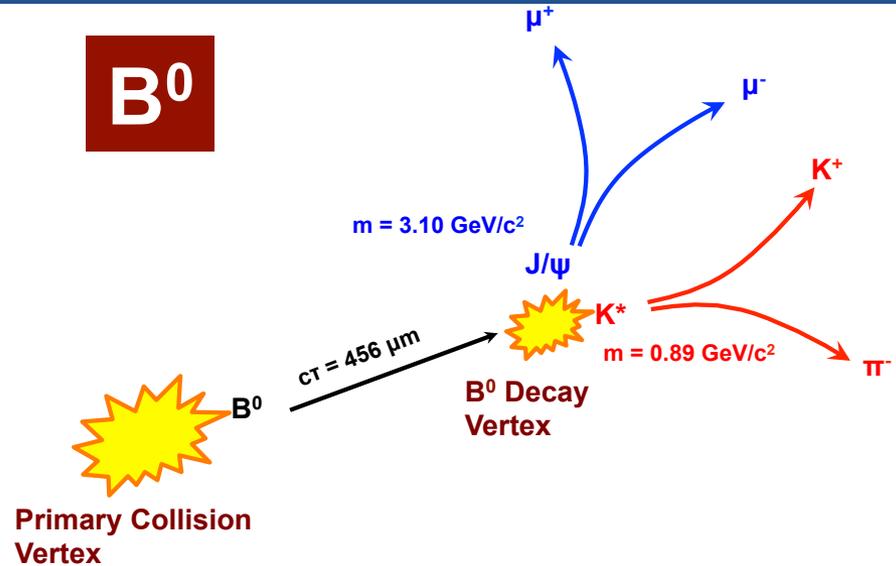
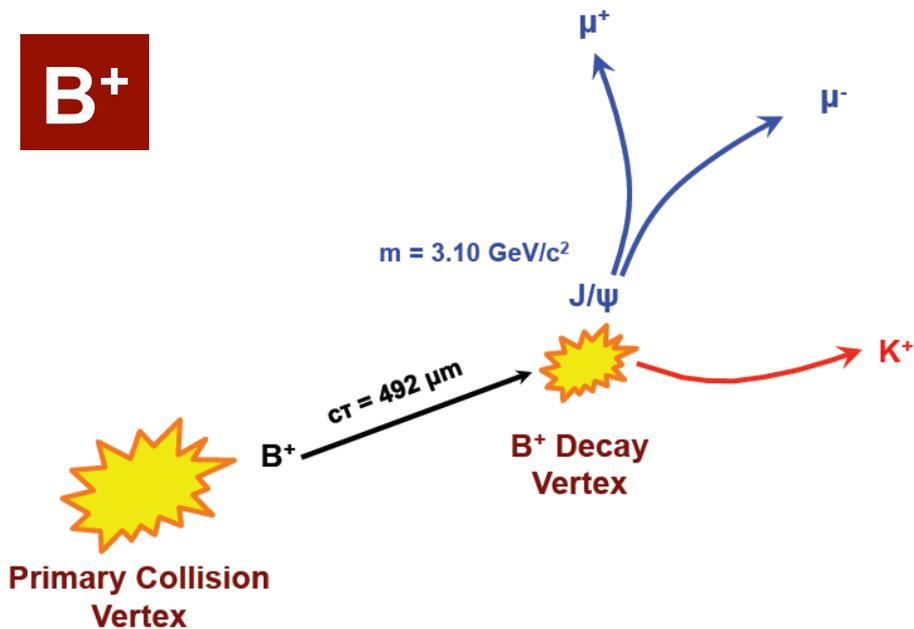
# Information for pPb collision analysis

- CMS pPb collision data recorded in 2013
  - LHC delivered 4 TeV (p) and 1.58 TeV/nucleon (Pb) beam
  - Integrated luminosity :  $34.8 \pm 1.2 \text{ nb}^{-1}$
  - Rapidity boosted to proton going side(forward) by 0.465 in lab frame
- $B^+$ ,  $B^0$ ,  $B_s$  trio is measured via  $J/\psi$  decay channels
- Kinematic range covered
  - $p_T$  : 10 – 60 GeV/c
  - rapidity :  $|y_{CM}| < 1.93$
- $B^+$  stands for both signs of charged B mesons from now on

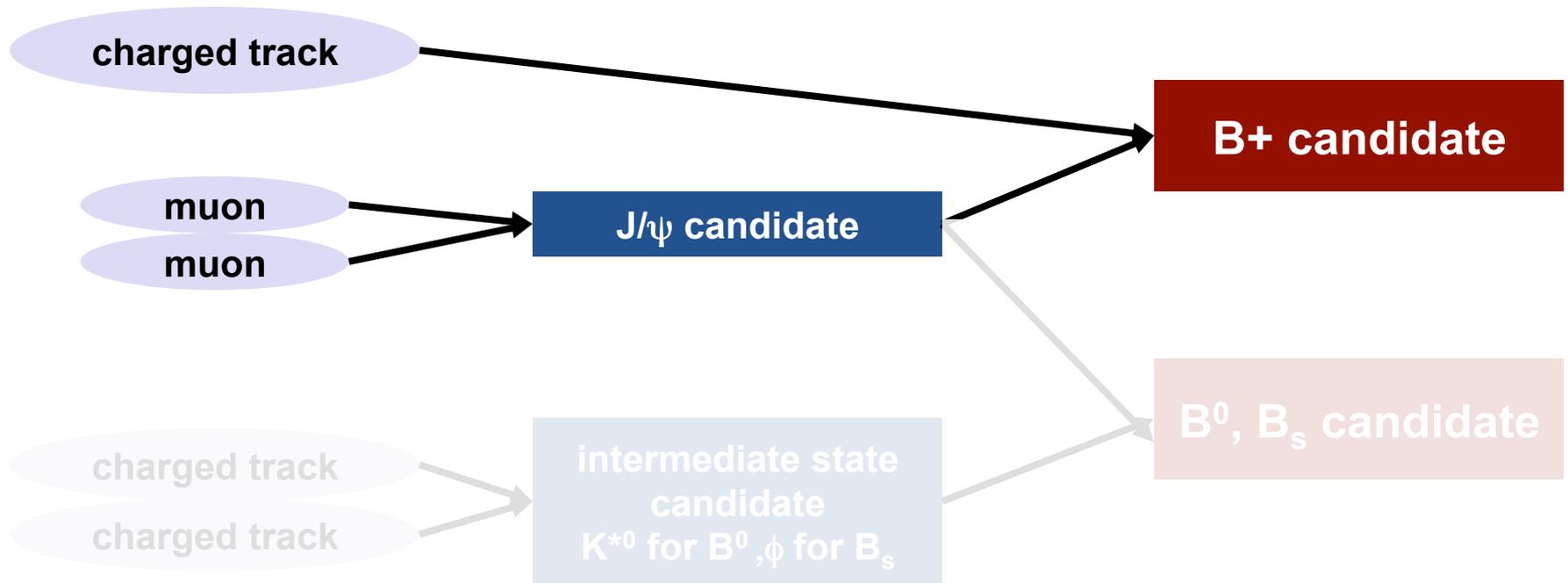


# B meson decay channels

- B-meson reconstructed by combination of
  - $J/\psi$  (decay to muon pair)
  - tracks (charged pion or kaon)



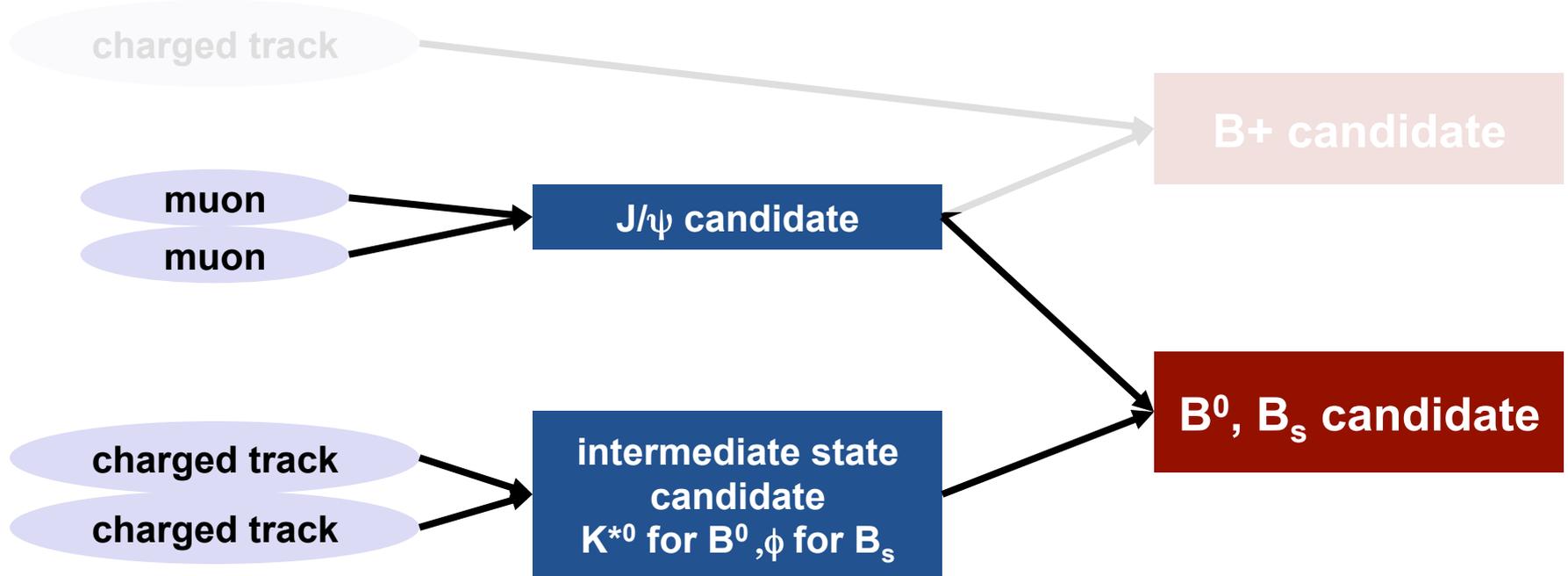
# Reconstruction of B mesons



- $B^+$  :  $J/\psi + 1$  track (kaon)
- $B^0$  :  $J/\psi + 2$  tracks (kaon + pion)
- $B_s$  :  $J/\psi + 2$  tracks (kaon + kaon)
- Charged tracks and muons are reconstructed within  $|\eta| < 2.4$
- Trigger on single muon  $p_T > 3$  GeV/c
- Assigned the mass of kaon or pion to charged track



# Reconstruction of B mesons



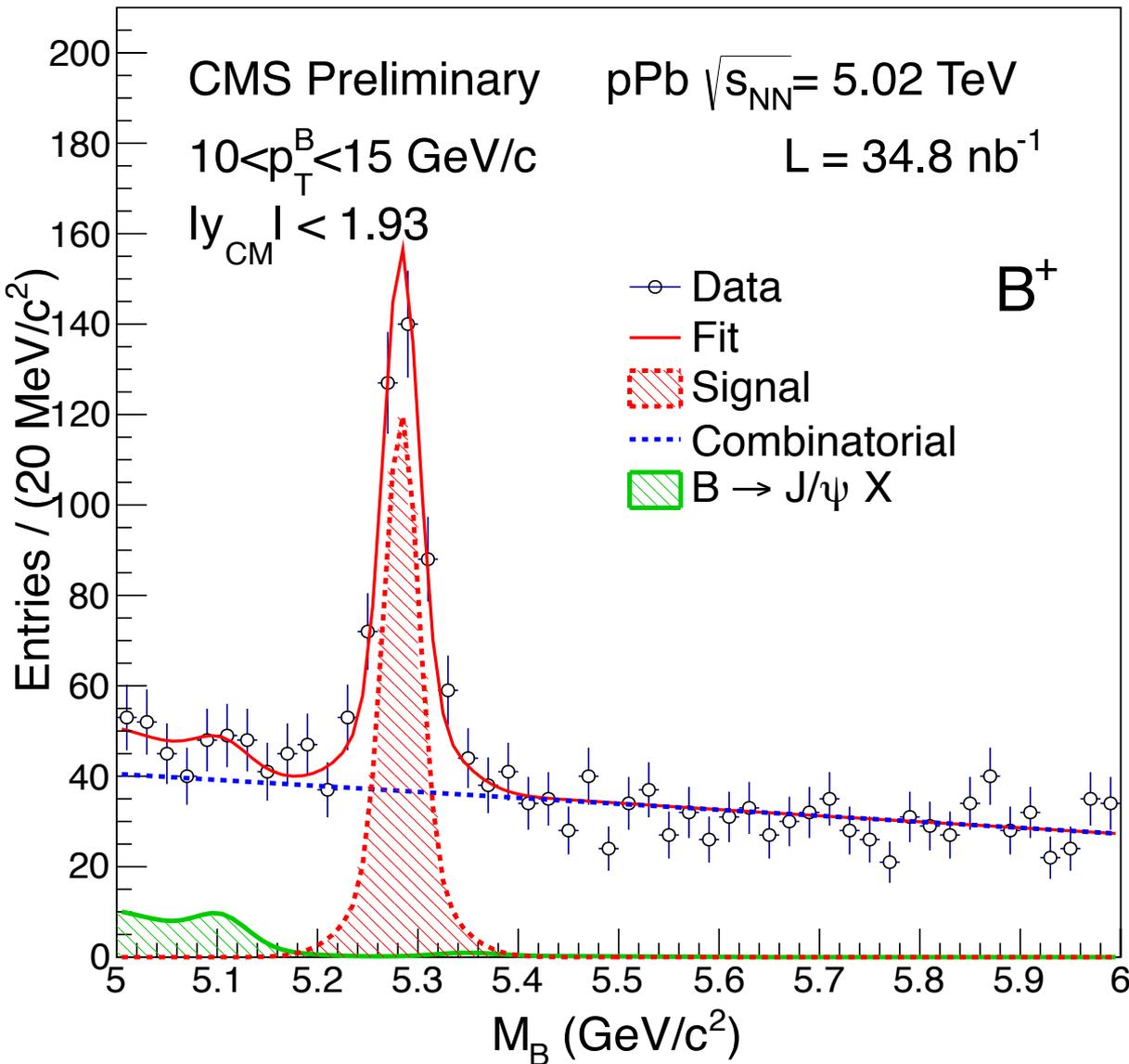
- $B^+$  :  $J/\psi + 1$  track (kaon)
- $B^0$  :  $J/\psi + 2$  tracks (kaon + pion)
- $B_s$  :  $J/\psi + 2$  tracks (kaon + kaon)
- Charged tracks and muons are reconstructed within  $|\eta| < 2.4$
- Trigger on single muon  $p_T > 3$  GeV/c
- Assigned the mass of kaon or pion to charged track



# Invariant mass spectra and signal extraction performance



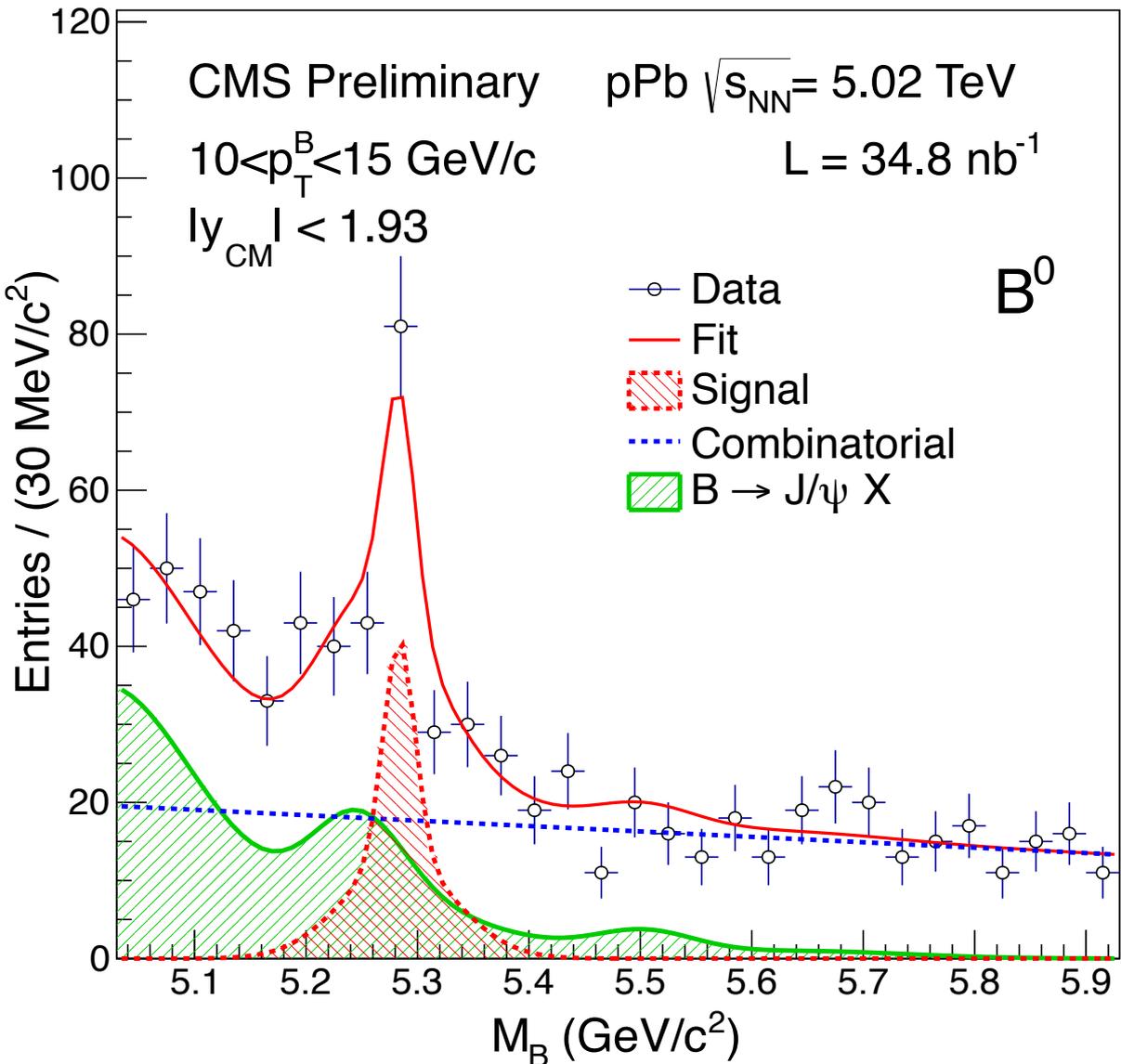
# Signal extraction 1 – $B^+$



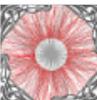
- **Signal** : double Gaussian
- **Background**
  - **Combinatorial background**  
1<sup>st</sup>-order polynomial
  - **Peaking structure**
    - $B^+ \rightarrow J/\psi +$   
(decayed to kaon + X)



# Signal extraction 2 – $B^0$

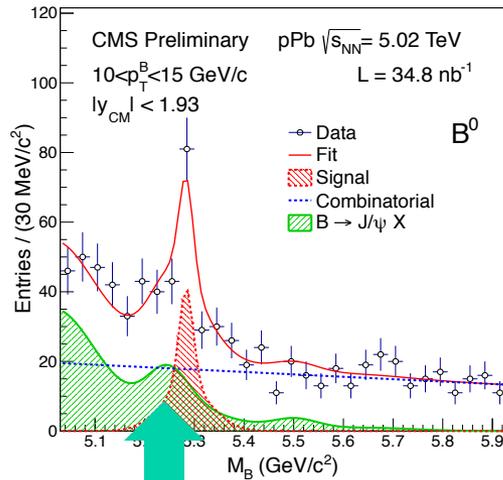


- **Signal** : double Gaussian
- **Background**
  - Combinatorial background
  - 1<sup>st</sup>-order polynomial
  - **Peaking structure**
    - $B \rightarrow J/\psi$  track + track
    - $B \rightarrow J/\psi + \text{phi meson}$  (kaon misidentified as pion)



# Signal extraction 2 – $B^0$

Lower mass peak due to  $B_s$  background



reconstructed as  $B_0$  meson with incorrect mass

$m = 3.10$  GeV/c $^2$

$J/\psi$

$\Phi$

$m = 1.02$  GeV/c $^2$

$B_s$  Decay Vertex

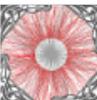
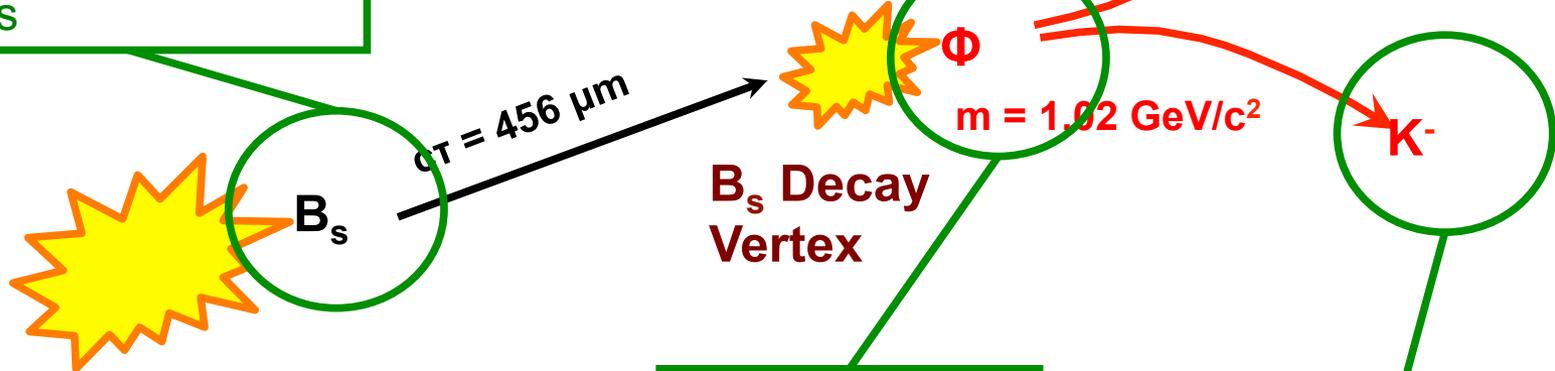
$K^+$

$K^-$

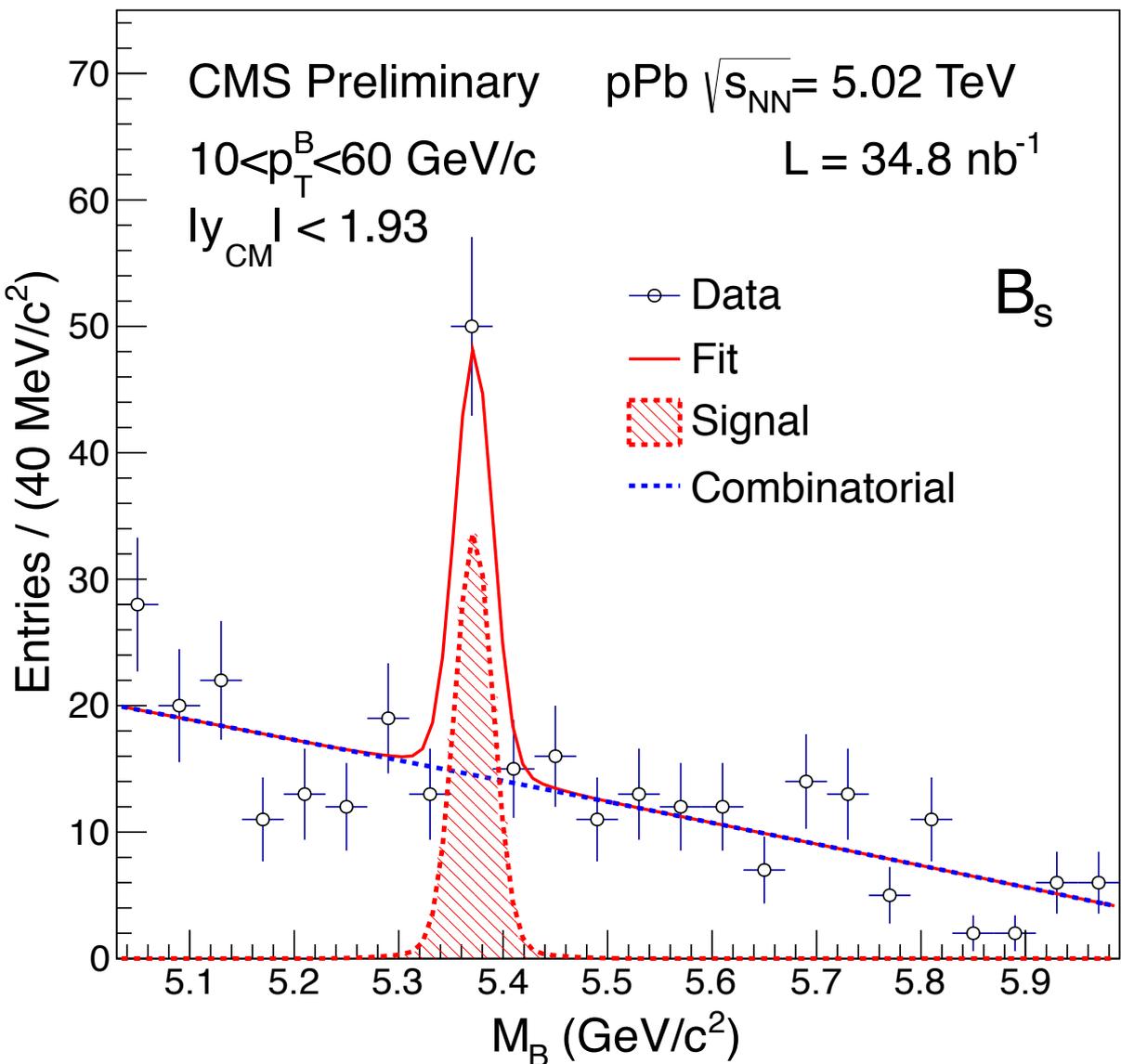
Primary Collision Vertex

Assumed to be a  $K^*$

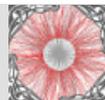
Assumed to be a pion



# Signal extraction 3 – $B_s$



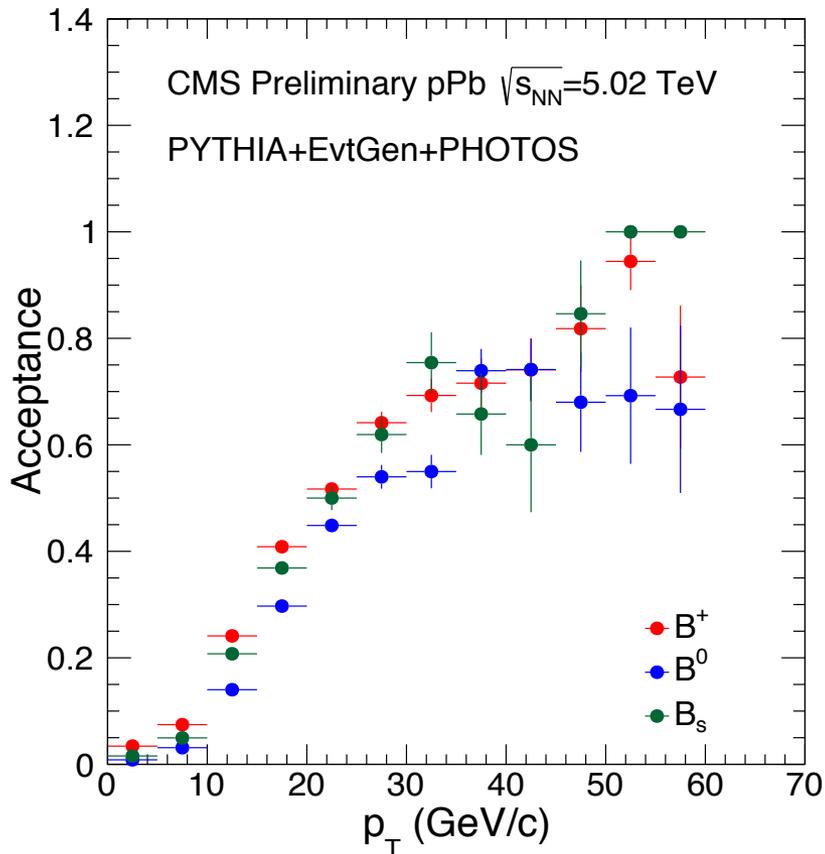
- **Signal** : double Gaussian
- **Background**
  - Combinatorial background
  - 2<sup>nd</sup>-order polynomial
  - no peaking background structure



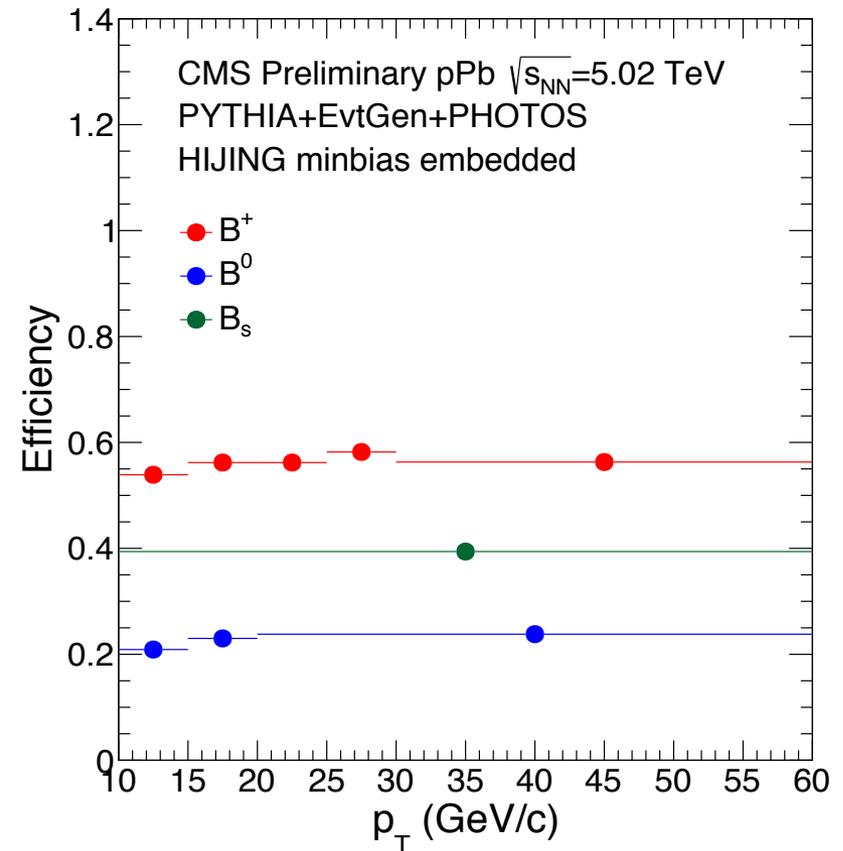
# Acceptance and efficiency

- Raw yields are corrected for acceptance and efficiency

## Acceptance



## Efficiency



# Results

1. Differential cross-section
2. Nuclear modification factor
3. Forward-to-backward ratio



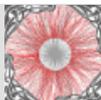
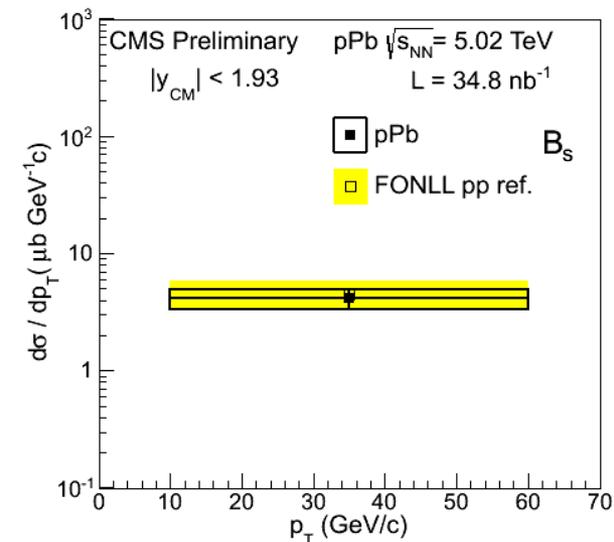
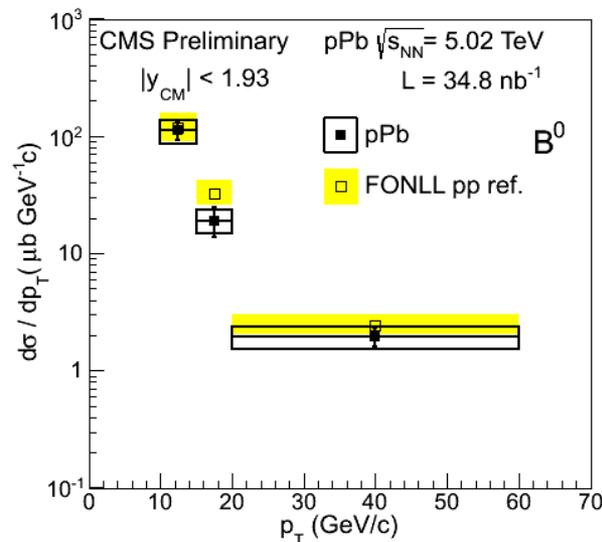
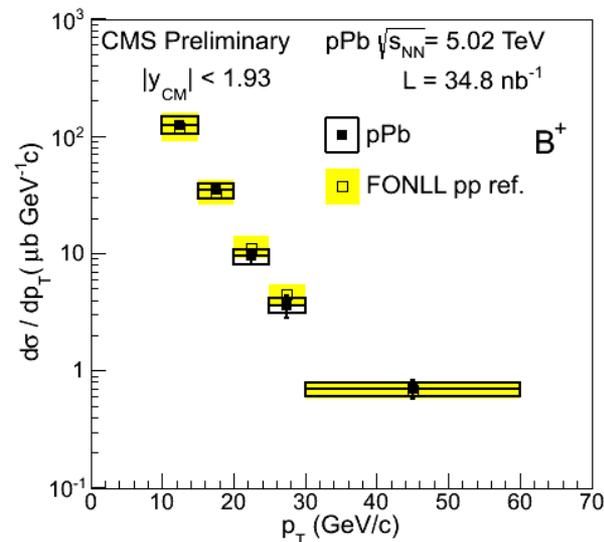
# Differential cross-section

$$\left. \frac{d\sigma^B}{dp_T} \right|_{|y_{CM}| < 1.93} = \frac{1}{2} \frac{1}{\Delta p_T} \frac{N^B}{(\text{Acc} \times \epsilon) \cdot \text{BR} \cdot L} \Big|_{|y_{CM}| < 1.93}$$

- pp reference : FONLL expectation is used

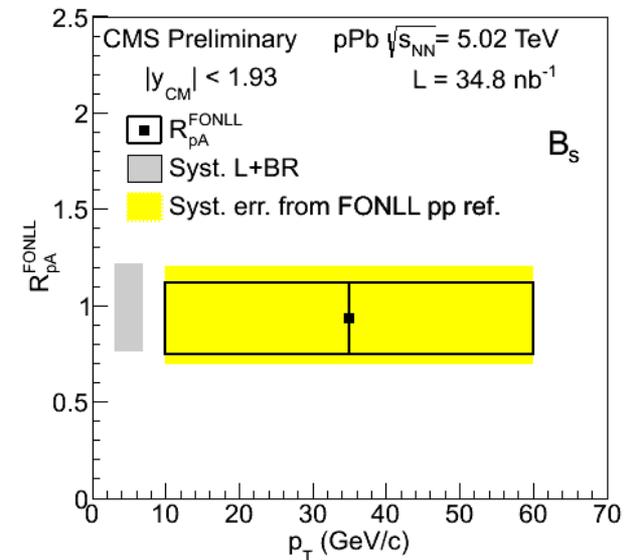
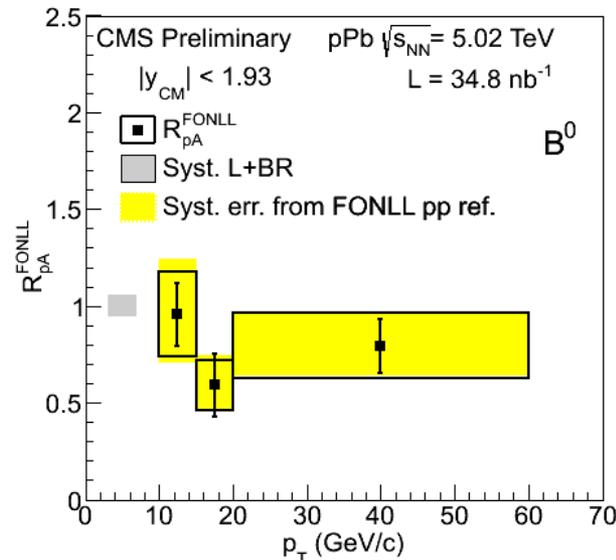
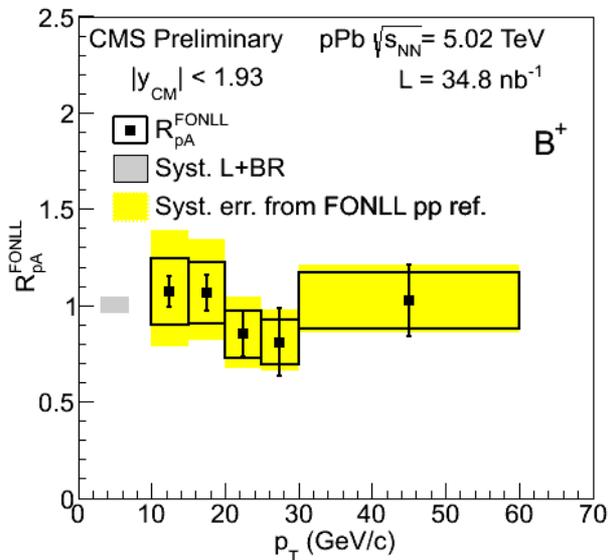
- agreement with CDF and CMS(ATLAS) data

- calculated in <http://www.lpthe.jussieu.fr/~cacciari/fonll/fonllform.html>



# Nuclear modification factor : $R_{pA}^{\text{FONLL}}$

$$R_{pA}^{\text{FONLL}}(p_T) = \frac{\left(\frac{d\sigma}{dp_T}\right)_{pPb}}{A \times \left(\frac{d\sigma^{\text{FONLL}}}{dp_T}\right)_{pp}}$$

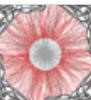
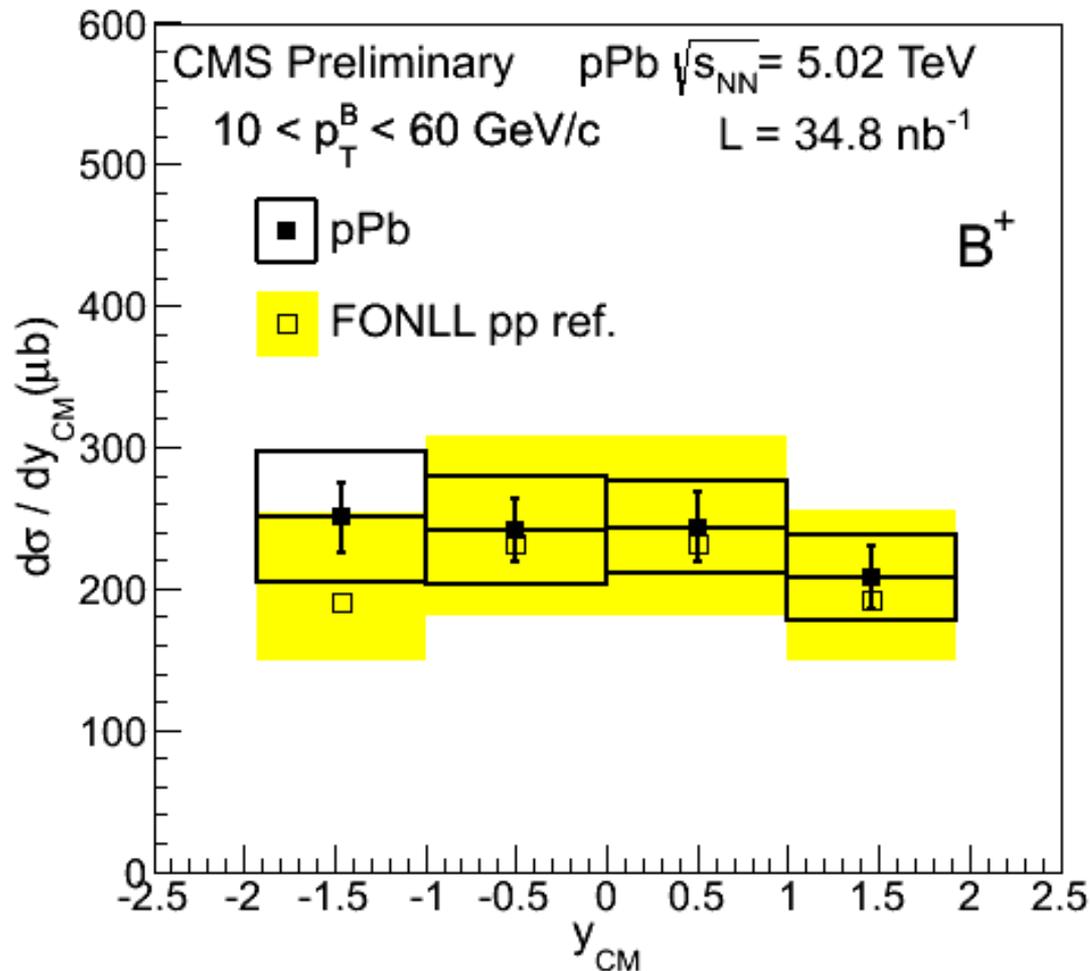


- $R_{pA}^{\text{FONLL}}$  is compatible with unity within given uncertainties for all three B-mesons



# Rapidity dependence

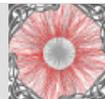
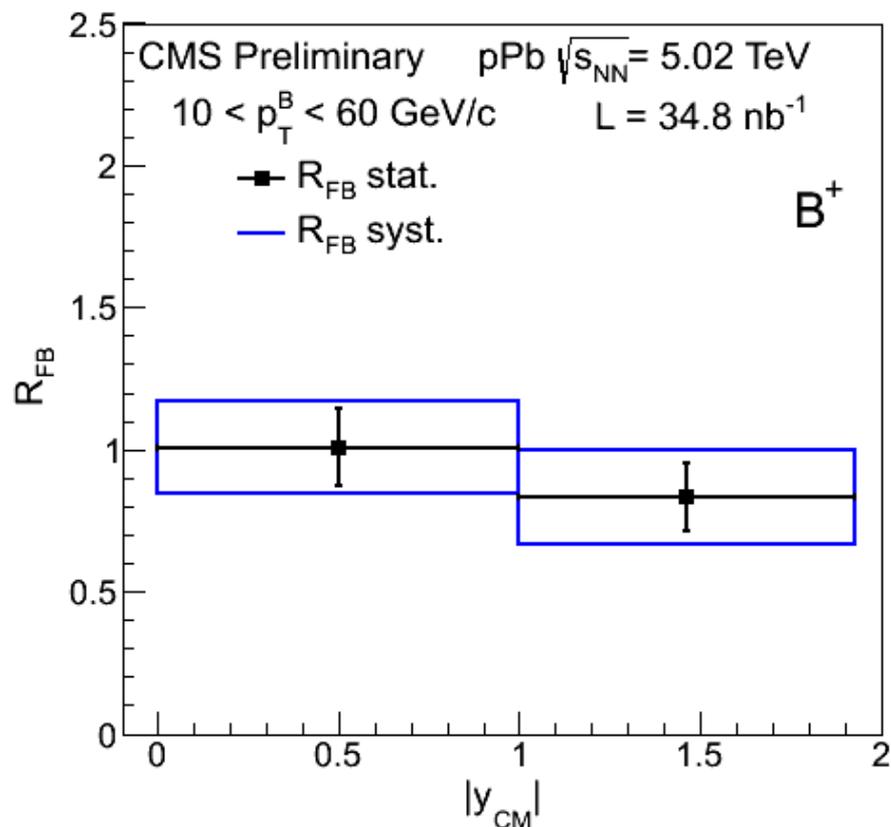
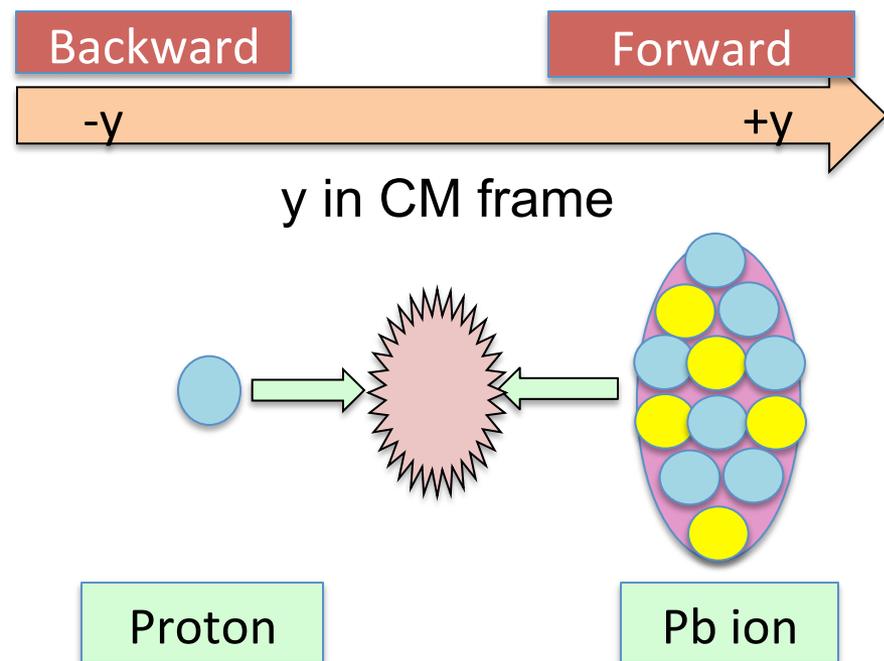
- Rapidity dependence of  $B^+$  production



# Rapidity dependence

- Forward-to-backward ratio  $R_{FB}$  is unity within large uncertainties.

$$R_{FB} = \frac{N_{forward}^{corr}}{N_{backward}^{corr}}$$

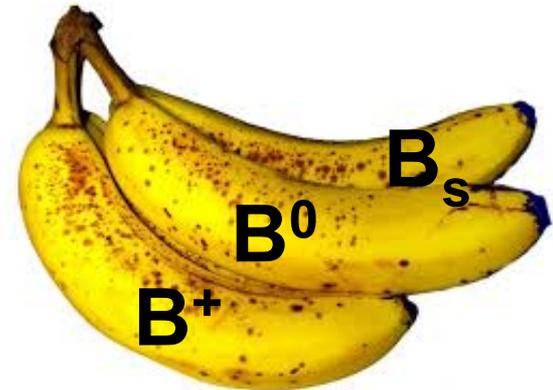


# Summary

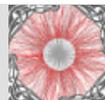
- In PbPb collisions, b-quark energy loss is measured
- Open beauty ( $B^+$ ,  $B^0$  and  $B_s$ ) are measured for the first time in heavy-ion collisions at LHC
- Nuclear modification factor calculated based on FONLL expectation is consistent with unity within uncertainties
- No significant modification is observed in forward-to-backward symmetry of charged B yield

poster by Gian Michele on Tuesday

Thank you for your attention



# BACK UP



# Prompt, non-prompt $J/\psi$ signal extraction

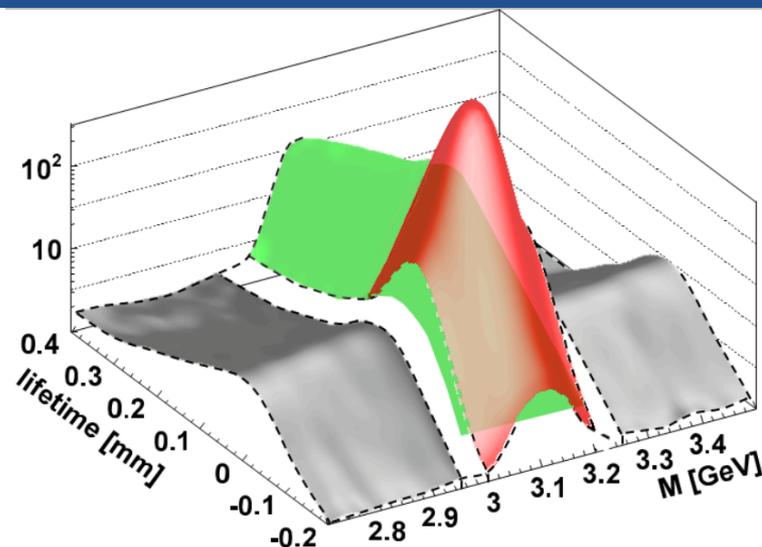
## Inclusive $J/\psi$

Prompt  $J/\psi$

Non-Prompt  $J/\psi$   
from B decays

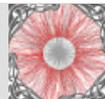
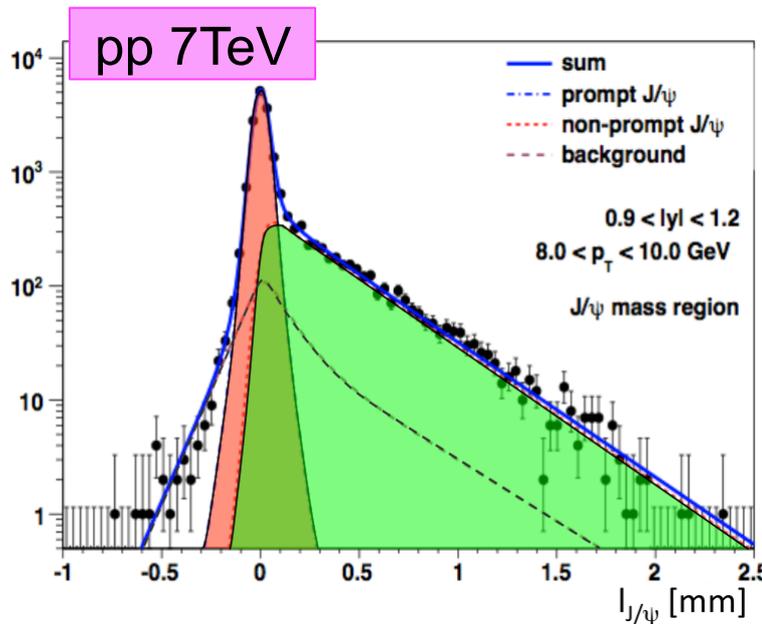
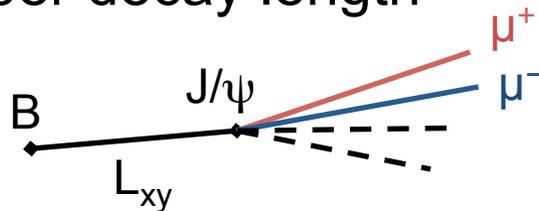
Direct  $J/\psi$

Feed-down  
from  $\psi'$  and  $\chi_c$



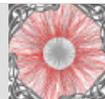
- Reconstruct  $\mu^+\mu^-$  vertex
- Separation of prompt and non-prompt  $J/\psi$ 
  - by 2D simultaneous fit of  $\mu^+\mu^-$  mass and pseudo-proper decay length

$$\ell_{J/\psi} = L_{xy} \frac{m_{J/\psi}}{p_T}$$



# Source of peaking background

- $B^+$ 
  - lower mass :  $B^+$  decays  $J/\psi$  + resonant meson decayed to kaon + X
  - $B^+$  mass :  $B^+$  decays  $J/\psi$  + pion misidentified as kaon
- $B^0$ 
  - B decayed to  $J/\psi$  + track + track
    - (ex.  $B^0 \rightarrow J/\psi K(1270)^0$ ,  $B^+ \rightarrow J/\psi K(1270)^+$ )
  - $B_s^0 \rightarrow J/\psi \phi$  (K misidentified as  $\pi$ ),  $B^0 \rightarrow J/\psi K^+ \pi^-$
  - $B^+$  decays  $J/\psi$  + X
- $B_s^0$ 
  - no peaking structure



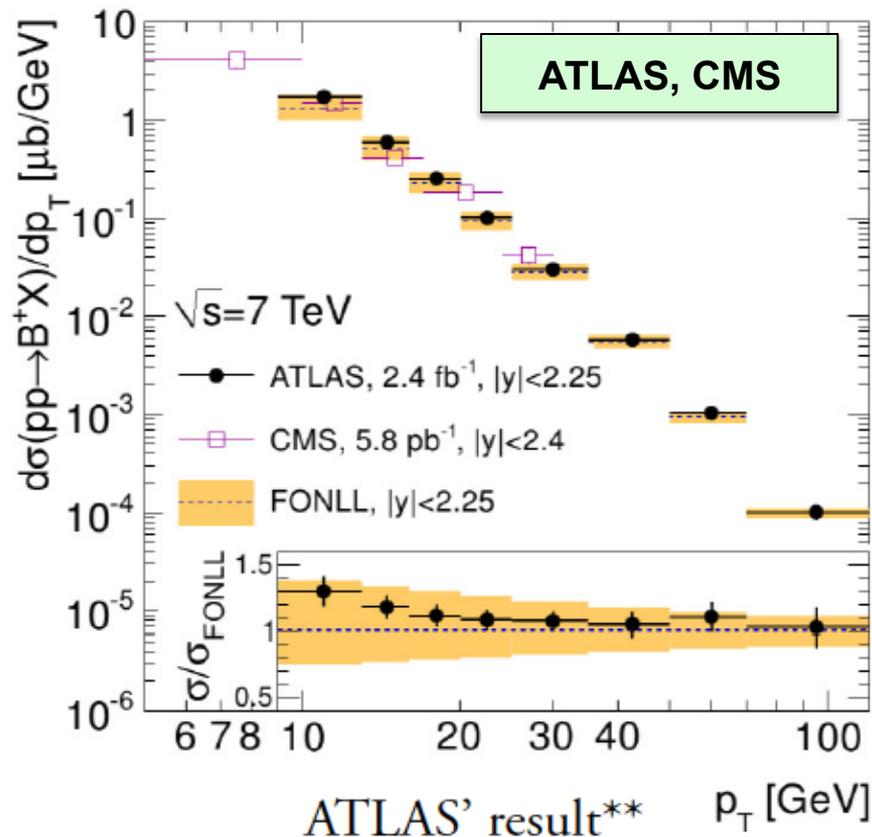
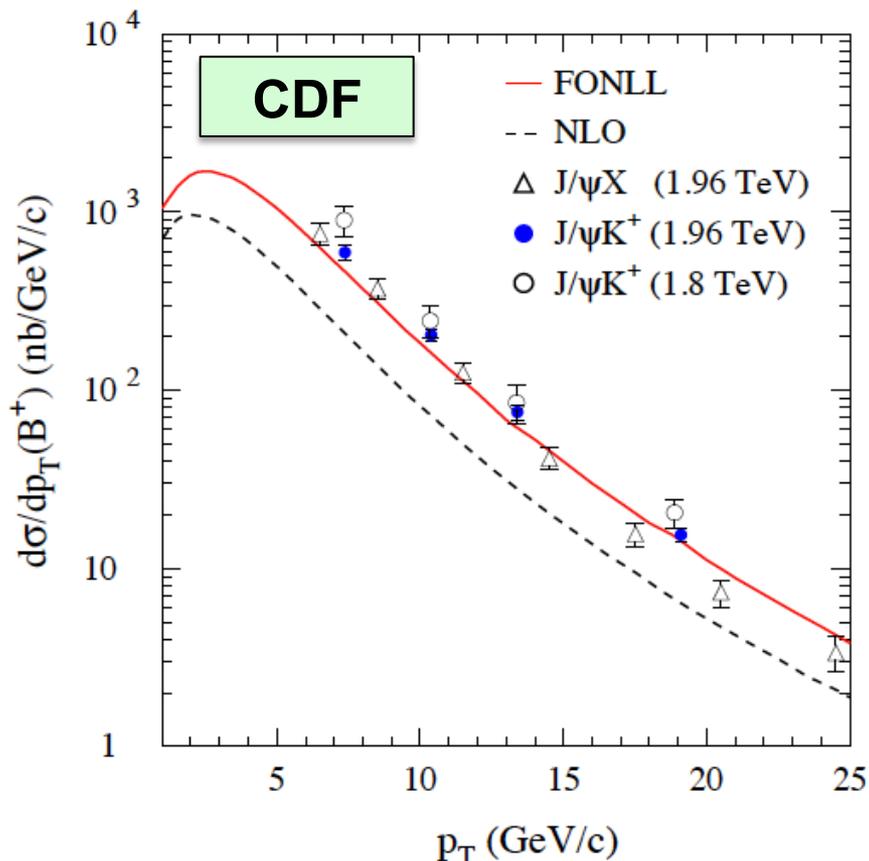
# Summary of optimal cuts

Variable for B-meson selection	B <sup>+</sup>	B <sup>0</sup>	B <sub>s</sub>
$\chi^2$ confidence level of B vertex fit	>0.013	>0.16	>0.037
distance between the primary and the B-decay vertices	>3.4	>4.2	>3.4
cosine value of angle between the displacement and the momentum of the B-meson in the transverse plane	> -0.35	> 0.75	> 0.26
difference of the mass between track-pair and resonant meson (unit : GeV/c <sup>2</sup> )		<0.23	< 0.016



# Supporting material for pp reference

- Data agrees with the FONLL expectation at 1.96(p-pbar, CDF) and 7 TeV(p-p, ATLAS,CMS)
- Expect the same agreement at 5TeV collision also



Phys. Rev. D 75, 012010 (2007)

arXiv: 1307.0126v2

