

Recent Open Heavy Flavor Results from ATLAS and CMS Experiment at LHC

Yen-Jie Lee (MIT)

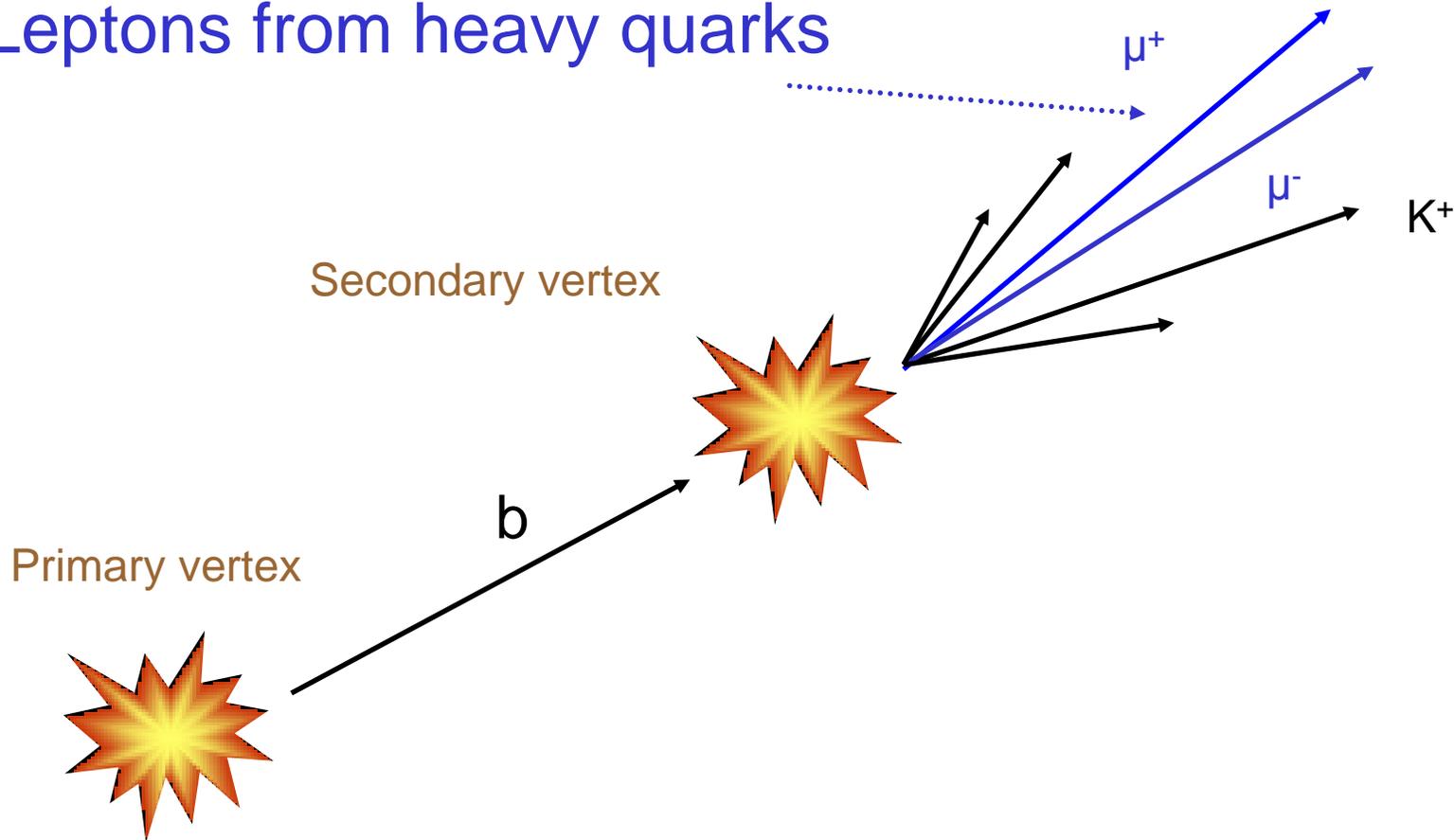
For the ATLAS and CMS collaboration

RHIC & AGS Annual Users' Meeting

BNL, Upton, USA

18 June, 2014

Leptons from heavy quarks

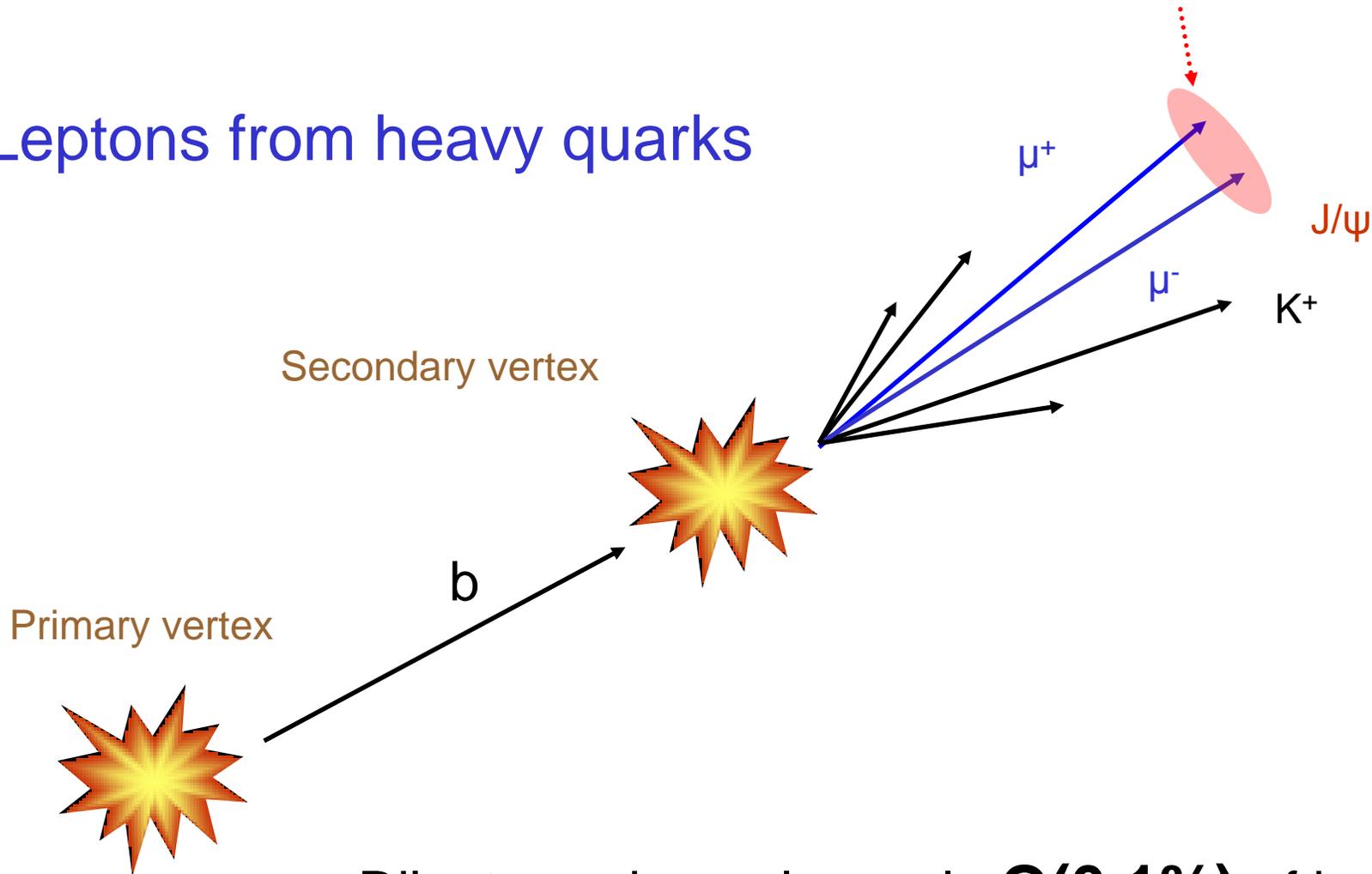


Sample **O(10%)** of b cross-section

Study of open heavy flavor production at the LHC (2/4)

Leptons from heavy quarks

Non-prompt J/ψ

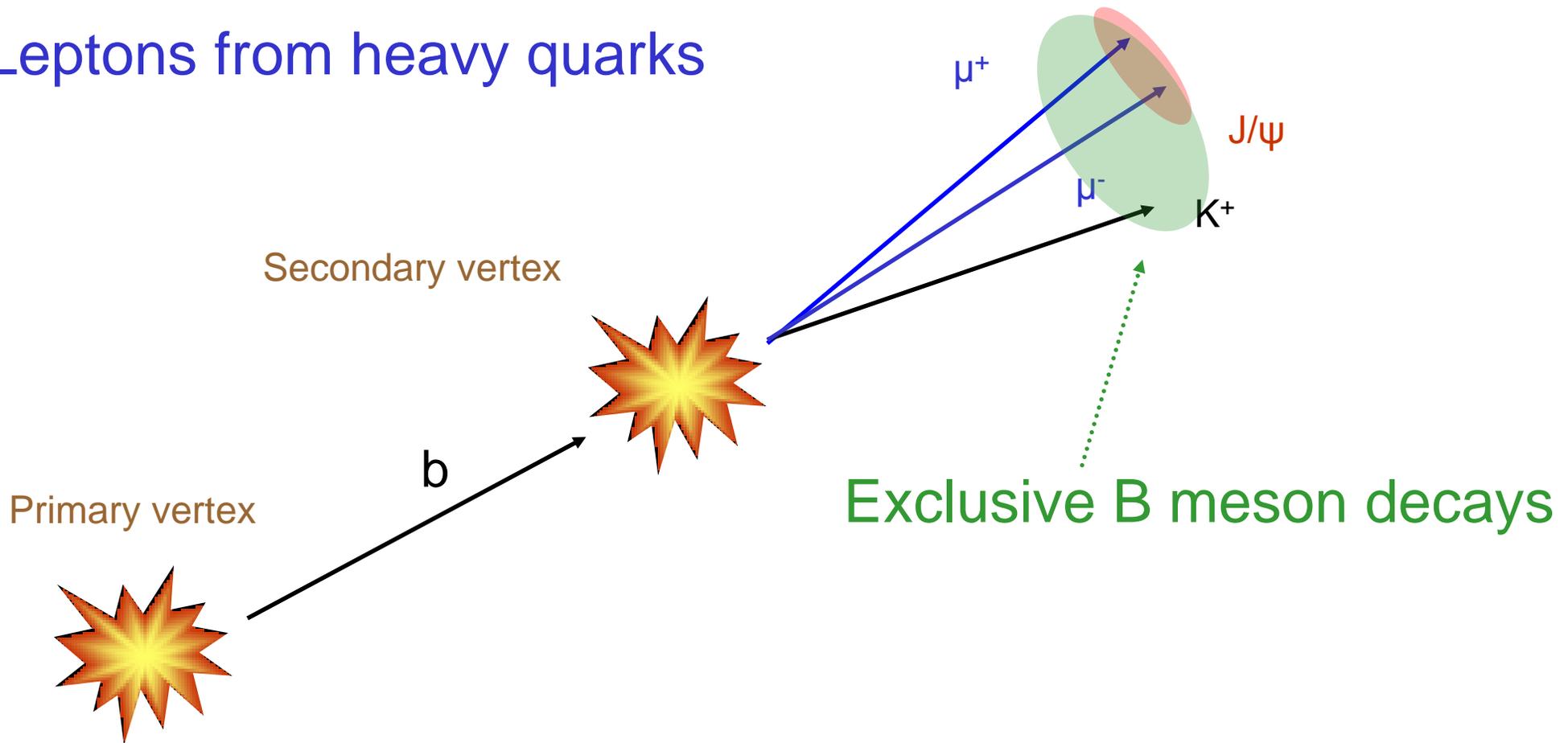


Dileptons channel sample **$O(0.1\%)$** of b cross-section

Study of open heavy flavor production at the LHC (3/4)

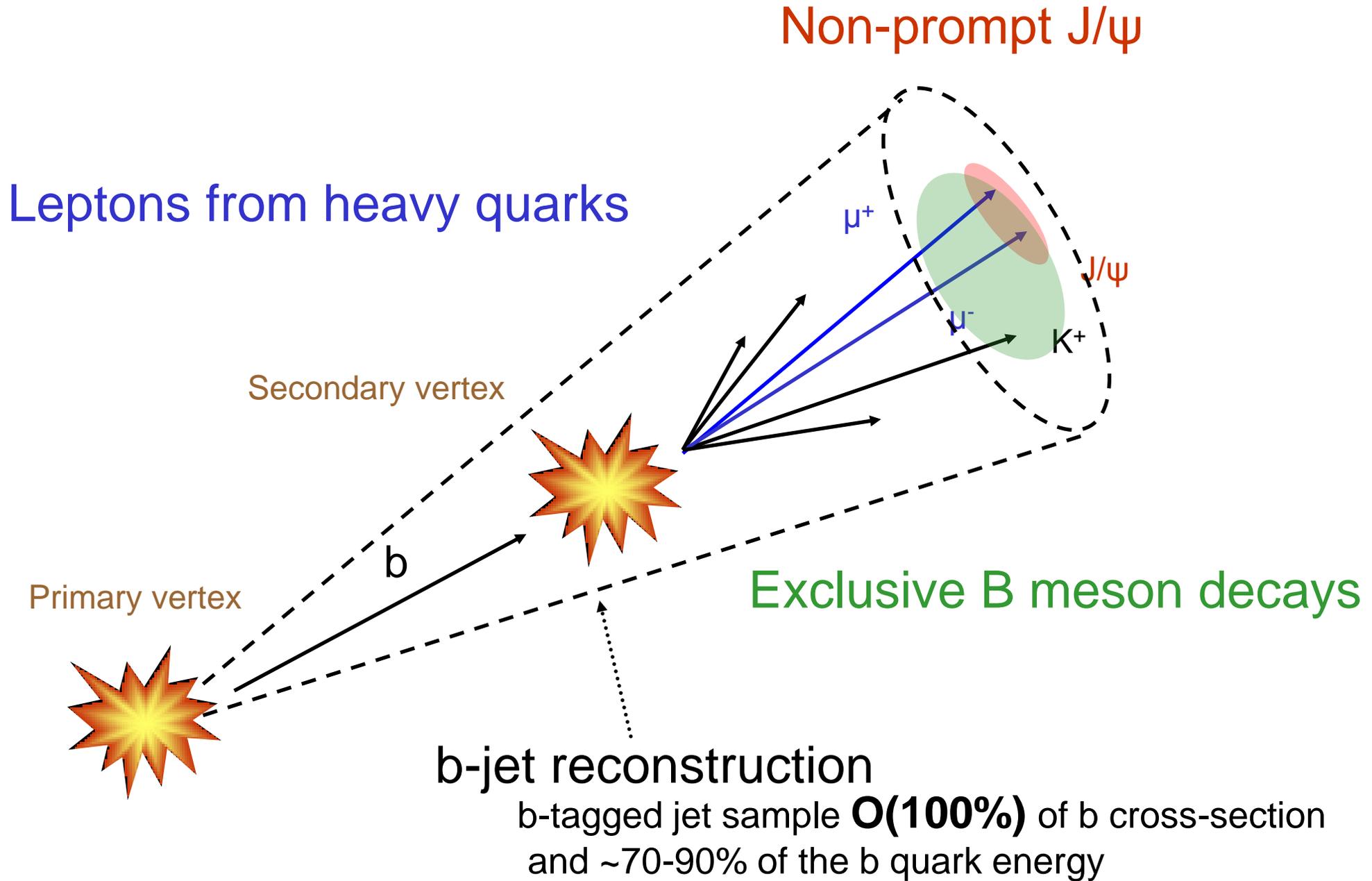
Non-prompt J/ψ

Leptons from heavy quarks

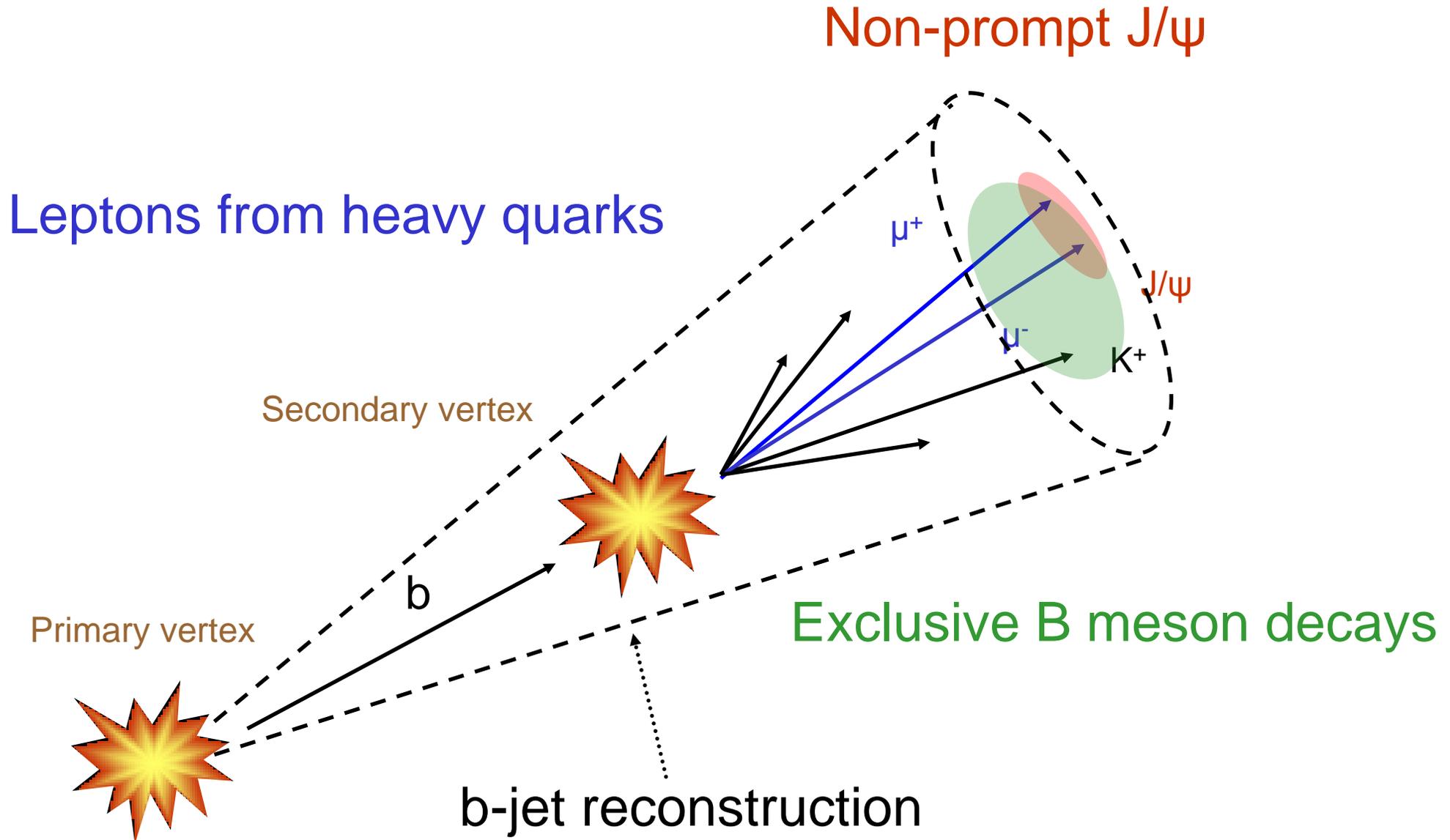


$J/\psi + 1(2)$ tracks decay channels sample **$O(0.01\%)$** of b cross-section

Study of open heavy flavor production at the LHC (4/4)



Requirements



Requirement: flexible trigger system, muon / electron detection, secondary vertex reconstruction, jet reconstruction

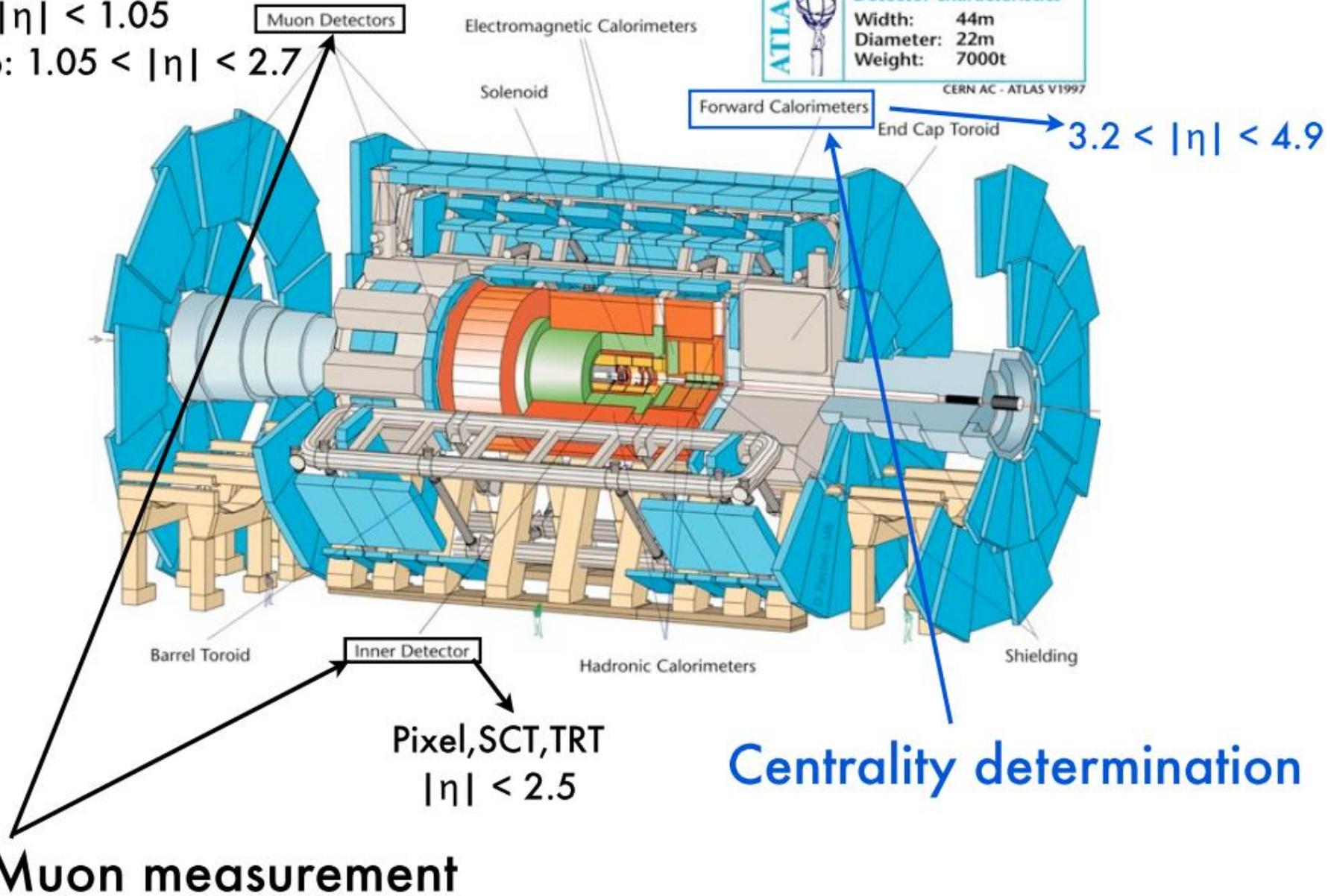
ATLAS detector

Barrel: $|\eta| < 1.05$

End cap: $1.05 < |\eta| < 2.7$

Detector characteristics	
Width:	44m
Diameter:	22m
Weight:	7000t

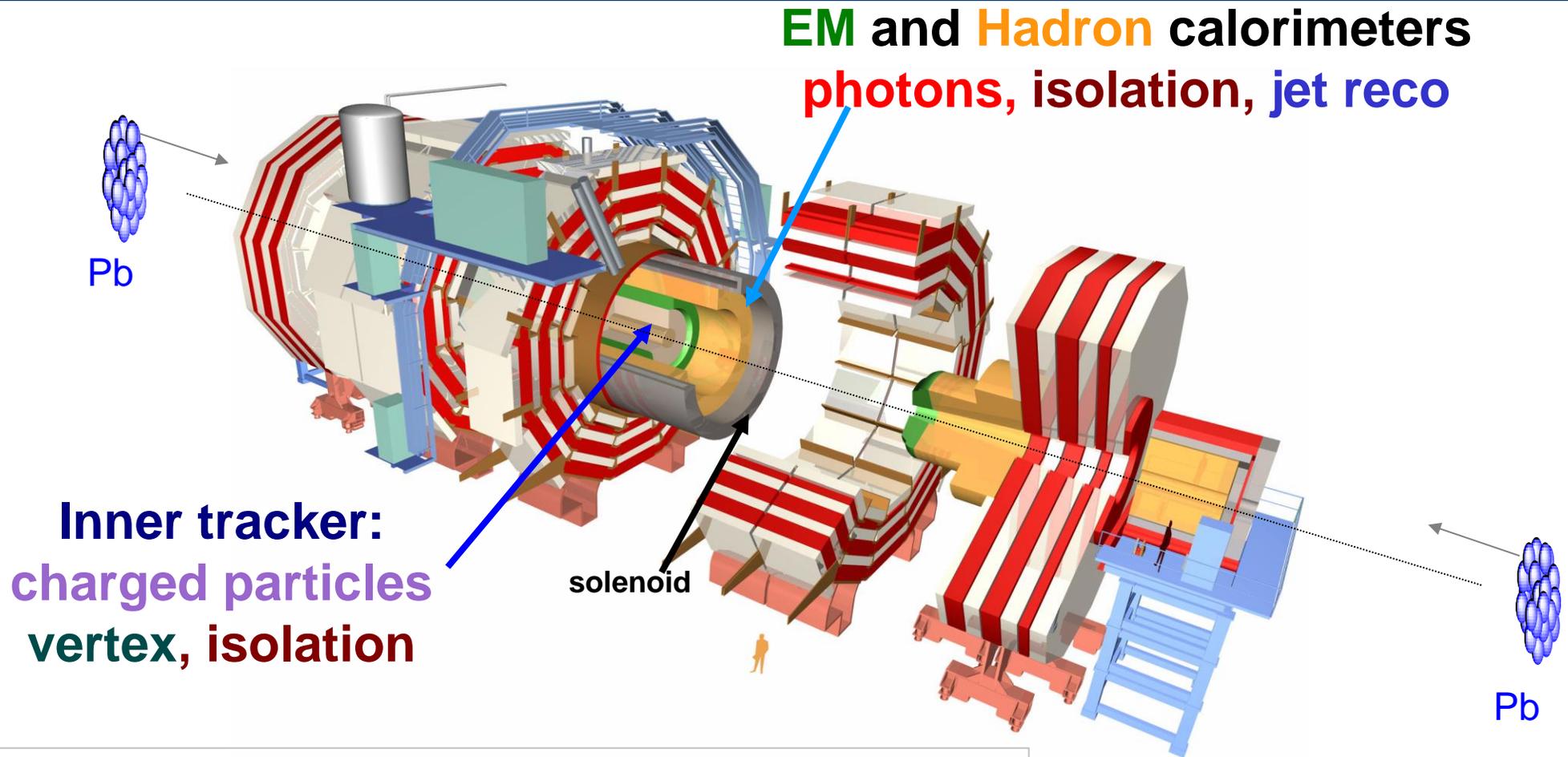
CERN AC - ATLAS V1997



Muon measurement

Centrality determination

CMS detector



Muon

$|\eta| < 2.4$

HCAL

$|\eta| < 5.2$

ECAL

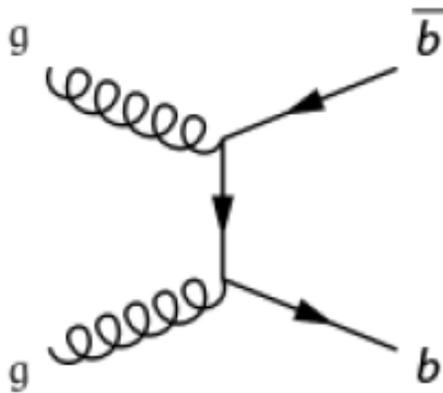
$|\eta| < 3.0$

Tracker

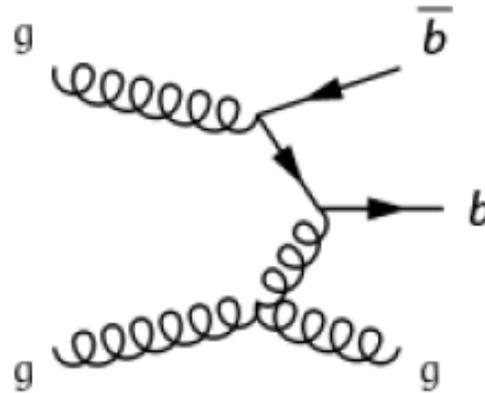
$|\eta| < 2.5$

Bottom production at the LHC

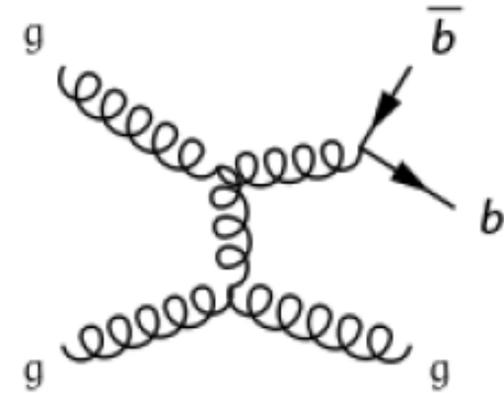
Flavor Creation (FCR)



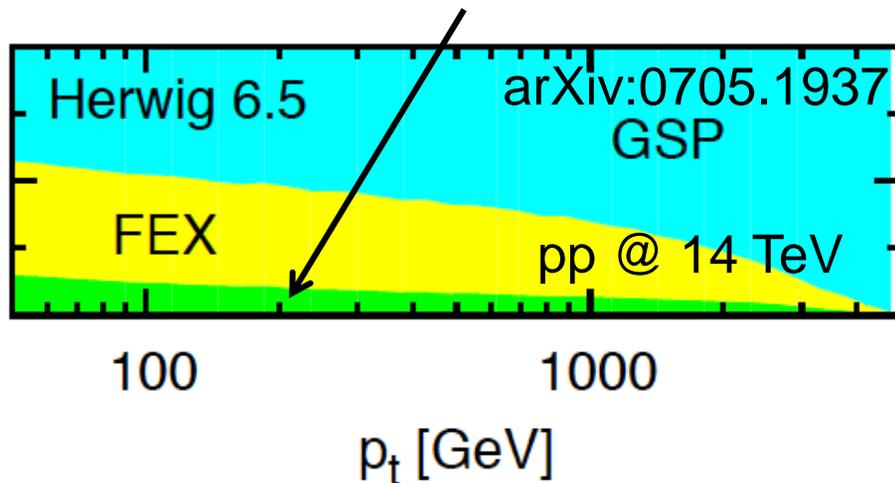
Flavor Excitation (FEX)



Gluon Splitting (GSP)



- LO $b\bar{b}$ production (FCR) not dominant at the LHC

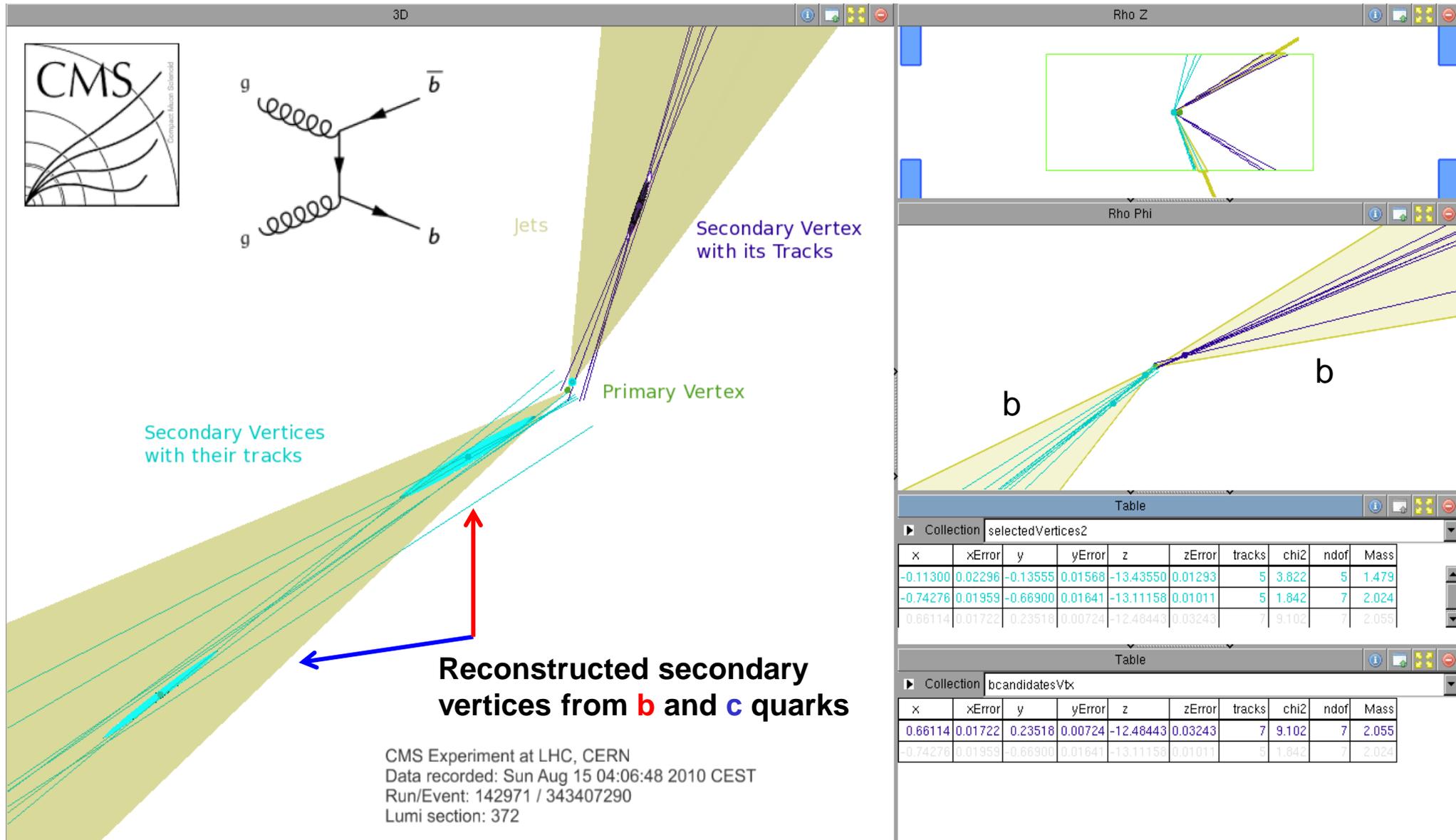


At NLO

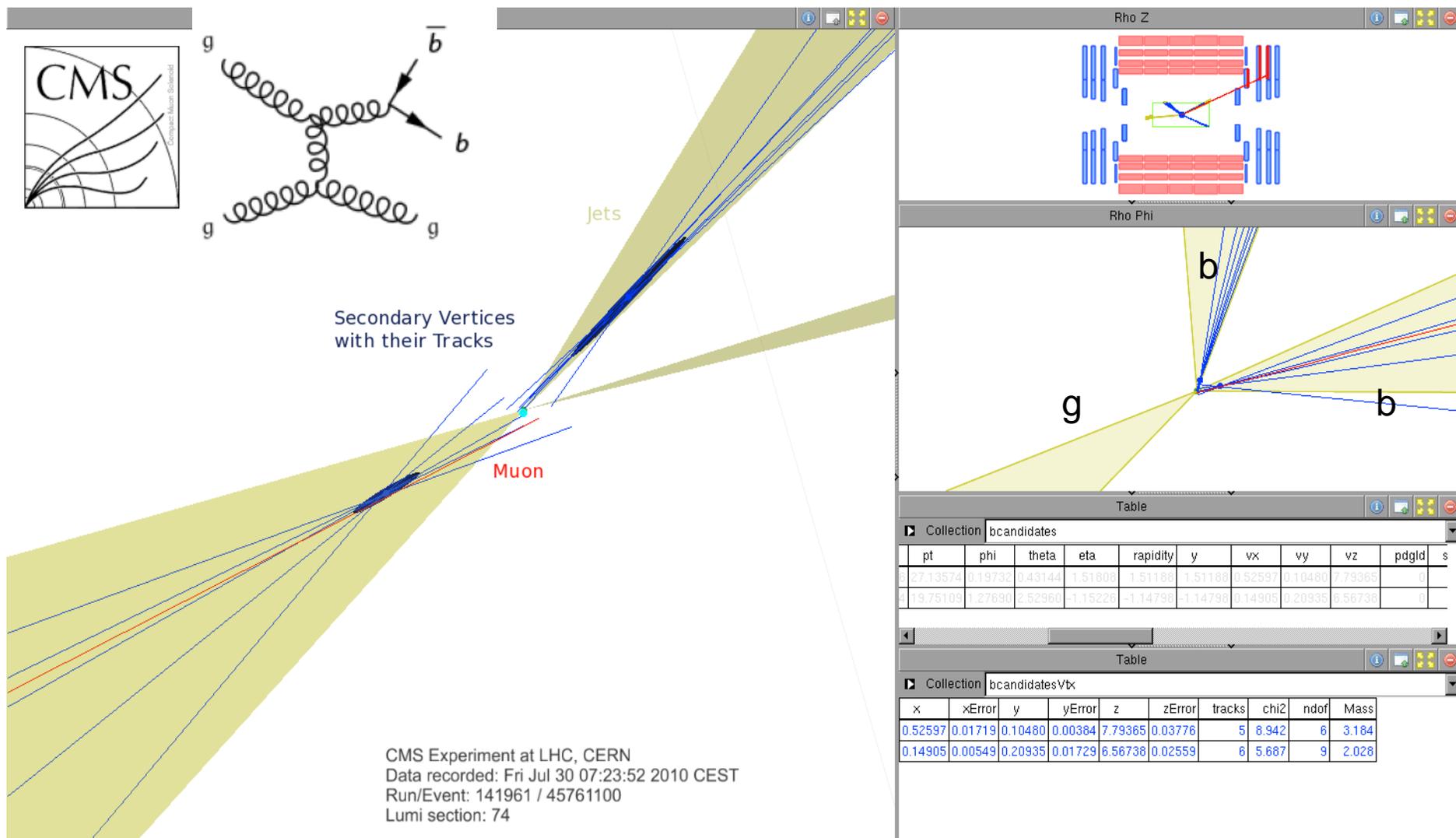
Excitation of sea quarks $\rightarrow b(\bar{b}) +$ light dijet, w/ $b(\bar{b})$ at beam rapidity

0.5
0
Gluon splitting into b and \bar{b} which can also be reconstructed as a single jet

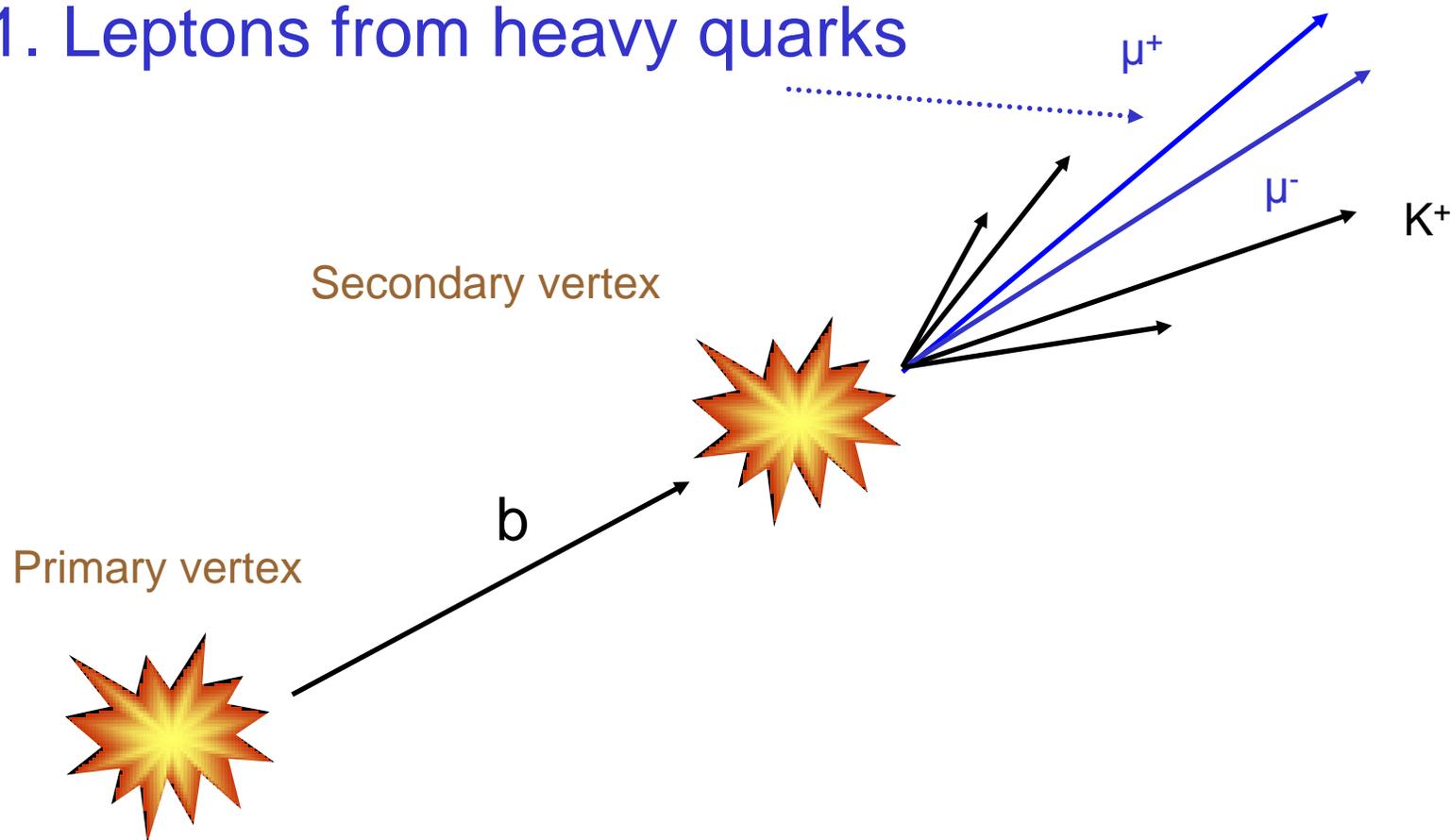
Flavor Creation Candidate (pp @ 7 TeV)



Gluon Splitting Candidate (pp @ 7 TeV)

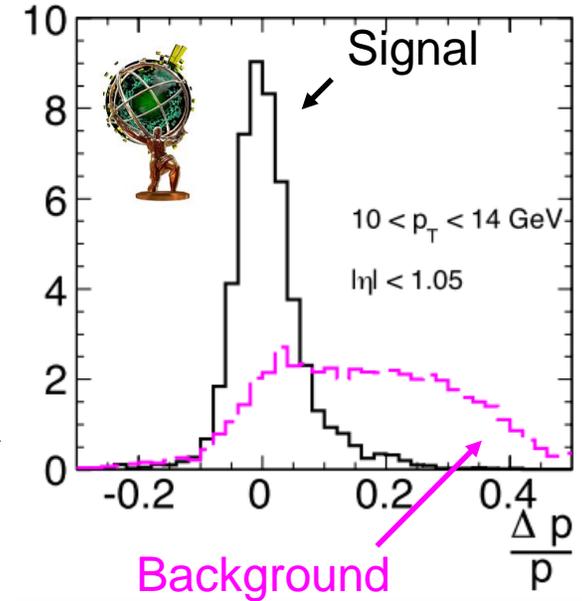
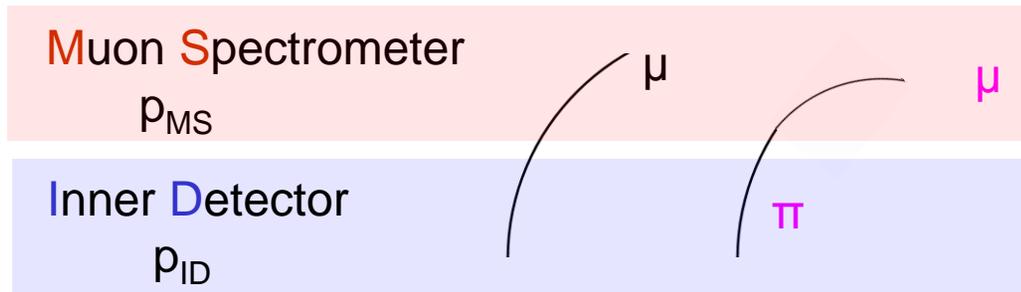


1. Leptons from heavy quarks



Heavy flavor muon identification

- Separate **signal muons** (heavy flavor meson decay) from **pion and kaon decays**



- Momentum balance

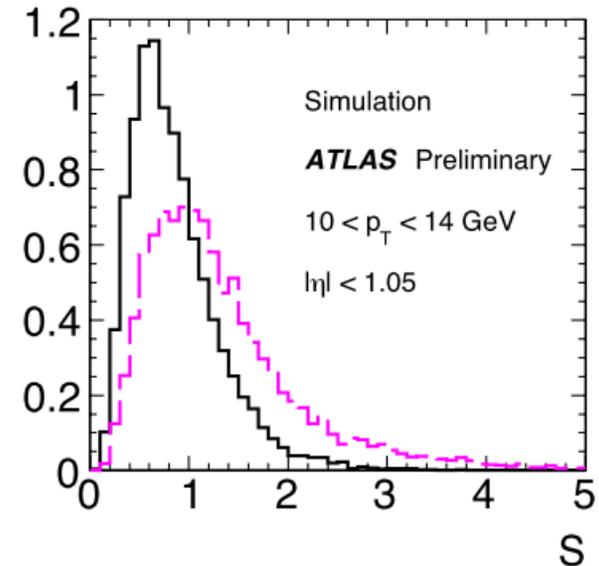
$$\frac{\Delta p_{\text{loss}}}{p_{\text{ID}}} = \frac{p_{\text{ID}} - p_{\text{MS}} - \Delta p_{\text{calo}}(p, \eta, \phi)}{p_{\text{ID}}}$$

- Scattering angle significance

$$s_i \equiv q \Delta \phi_i / \phi^{\text{msc}}$$

$$S(k) = \frac{1}{\sqrt{n}} \left(\sum_{i=1}^k s_i - \sum_{j=k+1}^n s_j \right)$$

Take the maximum: $S = \max \{|S(k)|, k = 1, 2, \dots\}$



ATLAS-CONF-2012-050

Heavy flavor muon signal extraction

- Composite discriminant

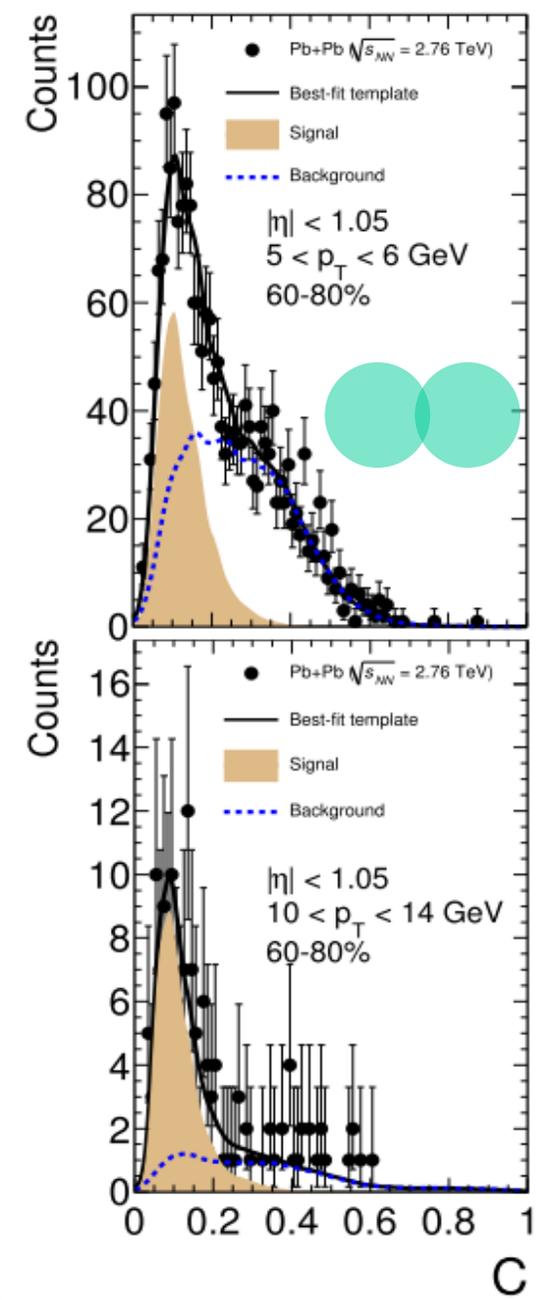
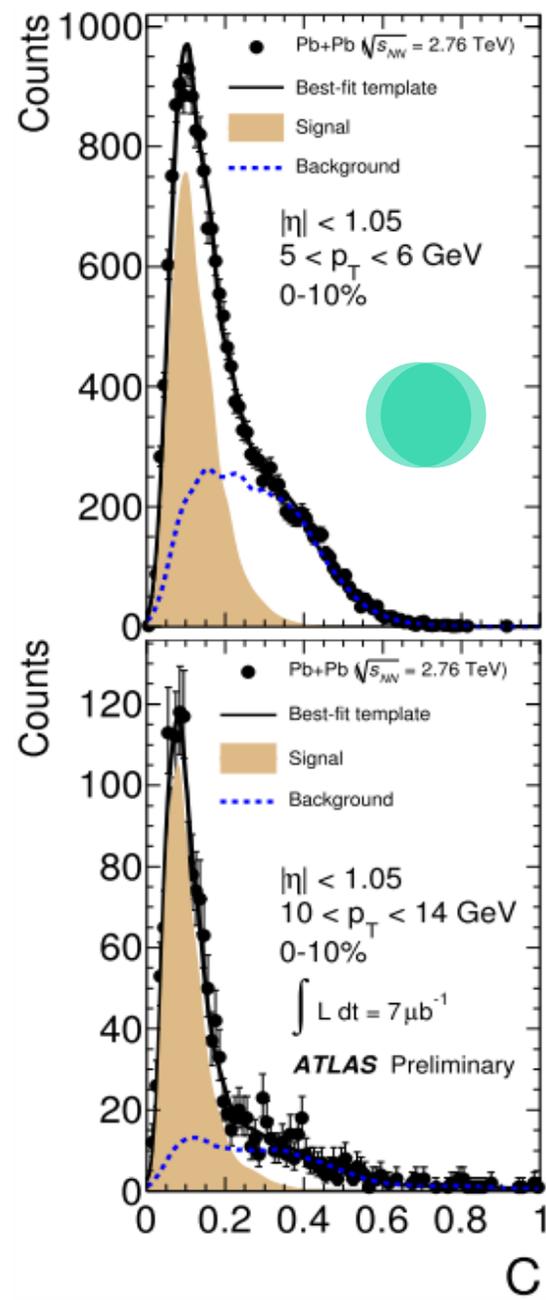
$$C = \left| \frac{\Delta p_{\text{loss}}}{p_{\text{ID}}} \right| + rS$$

$$r = 0.07$$

- **Signal** extracted from a two component fit



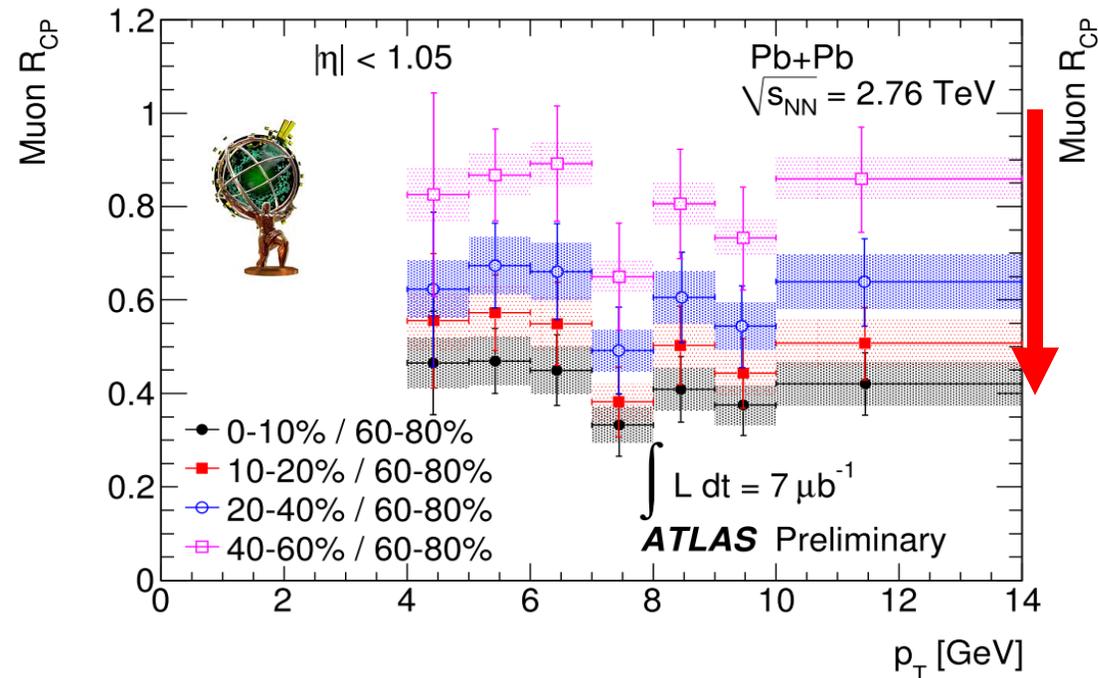
ATLAS-CONF-2012-050



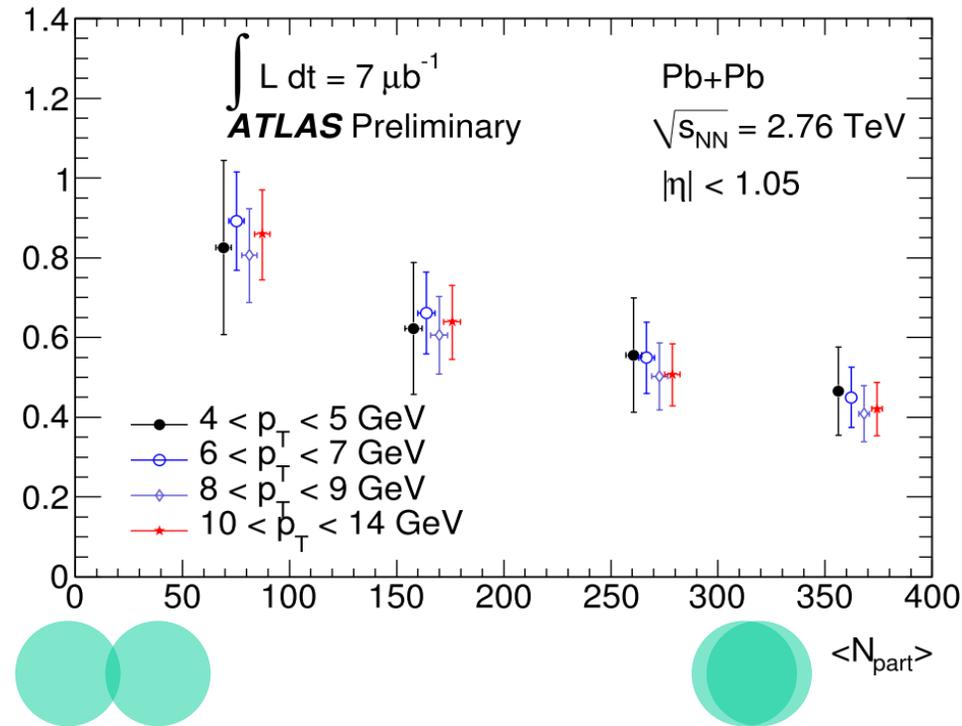
Suppression of heavy flavor muons in PbPb

ATLAS-CONF-2012-050

Muon R_{CP} vs muon p_T

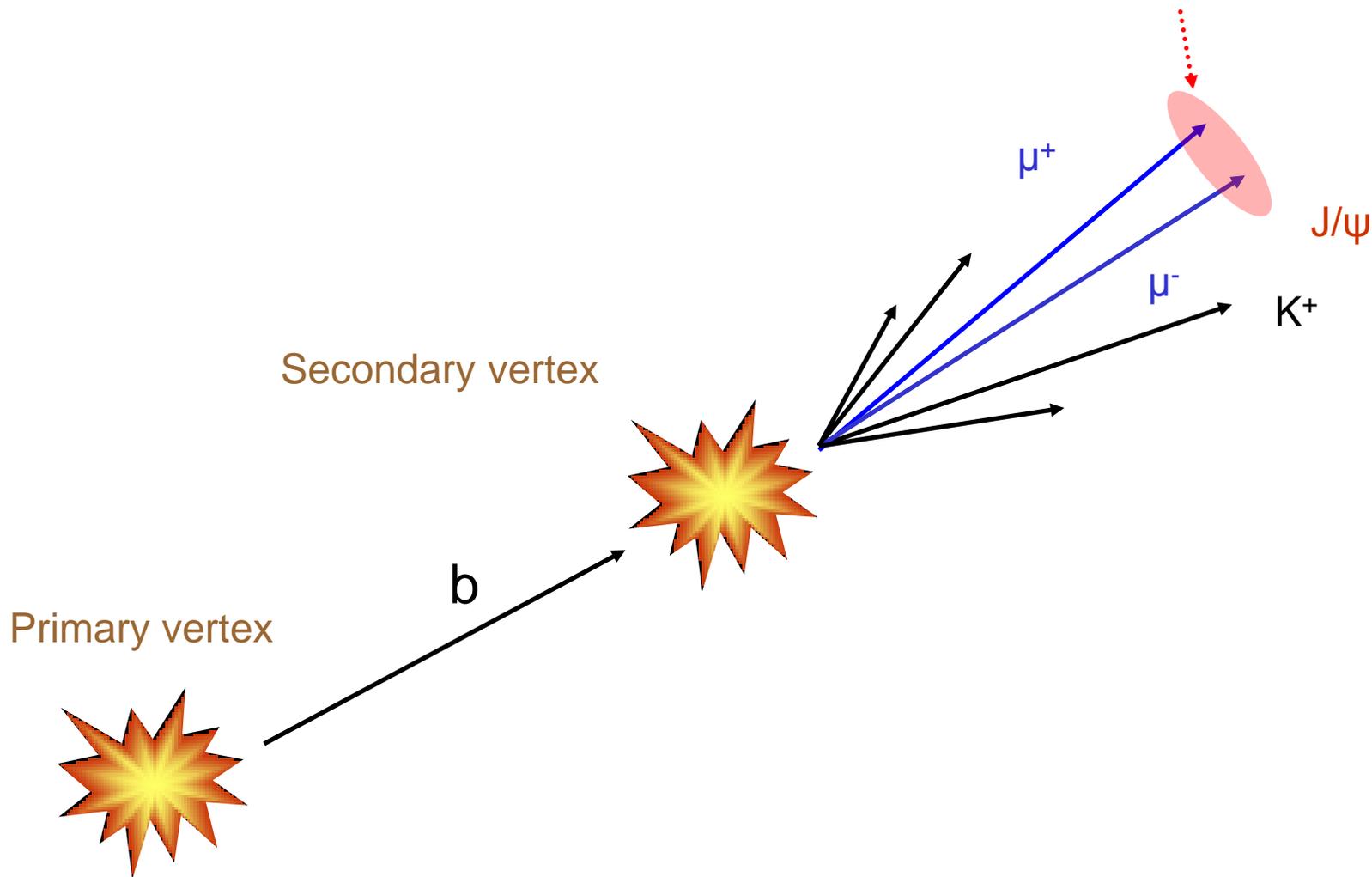


Muon R_{CP} vs N_{part} (60-80% as reference)

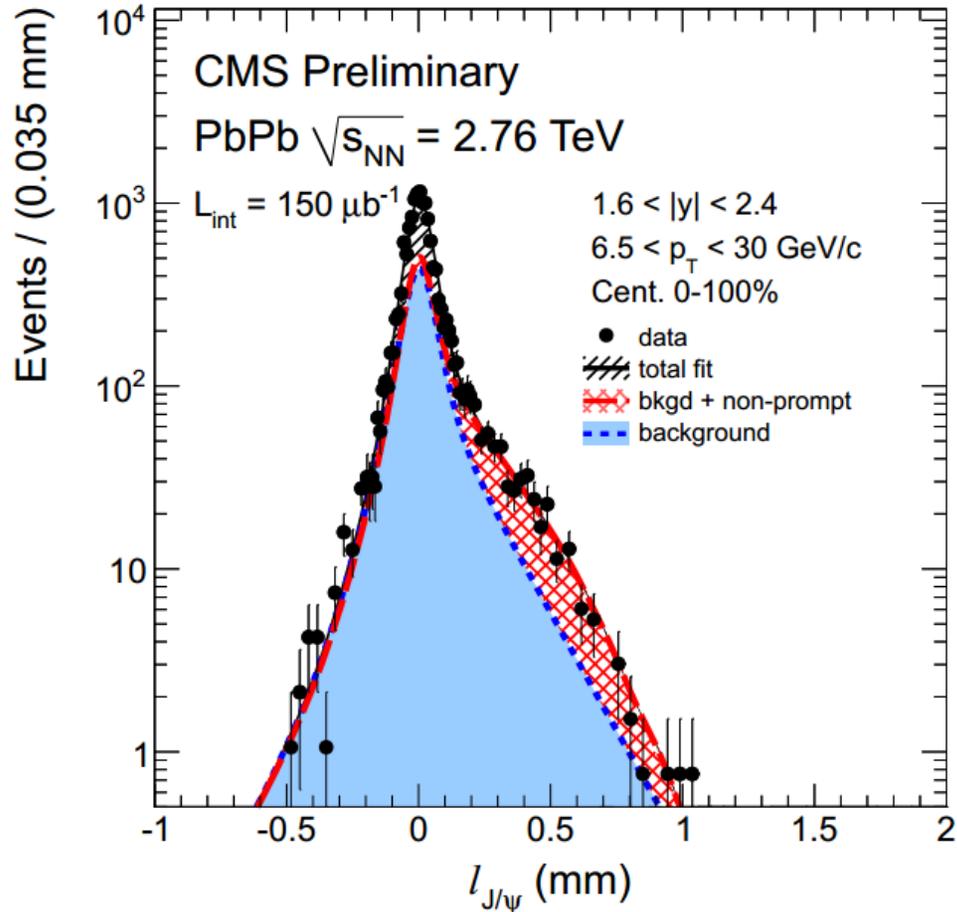
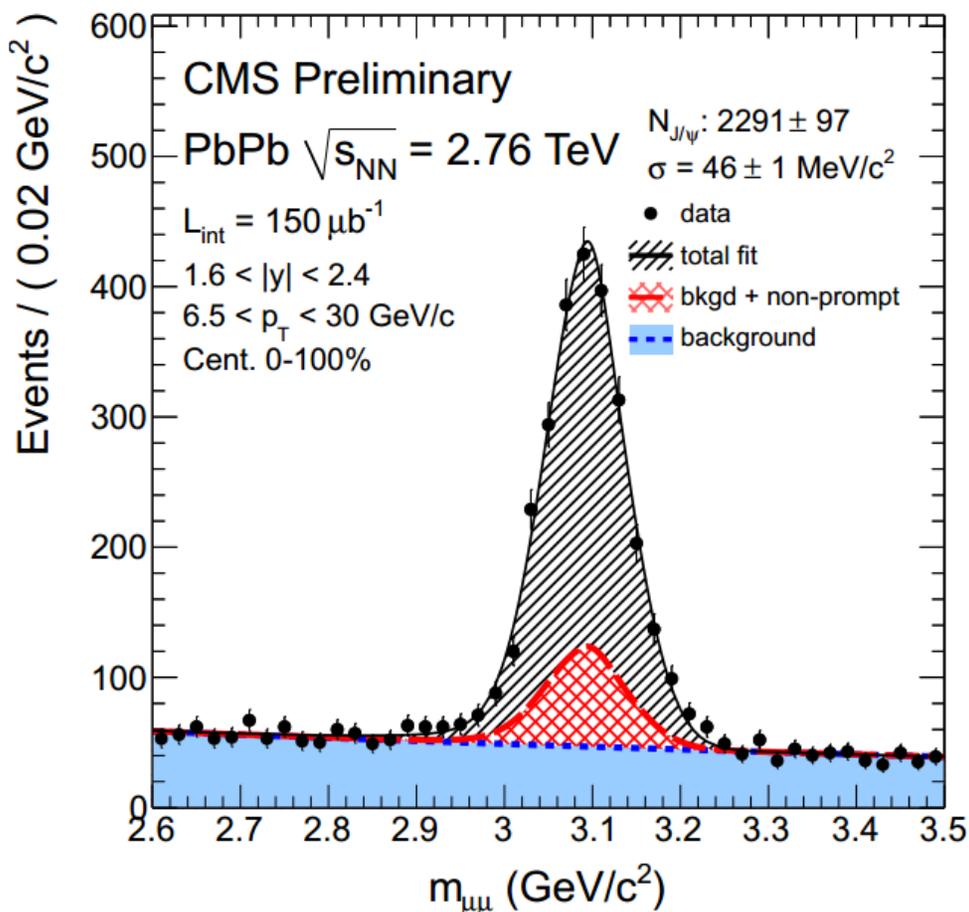


- Suppression of heavy flavor muons in central PbPb collisions with respect to peripheral events is observed ($R_{CP} \sim 0.4$)
- $R_{CP} \sim$ constant vs. muon p_T

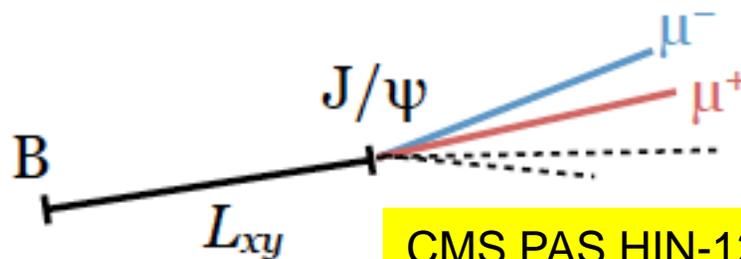
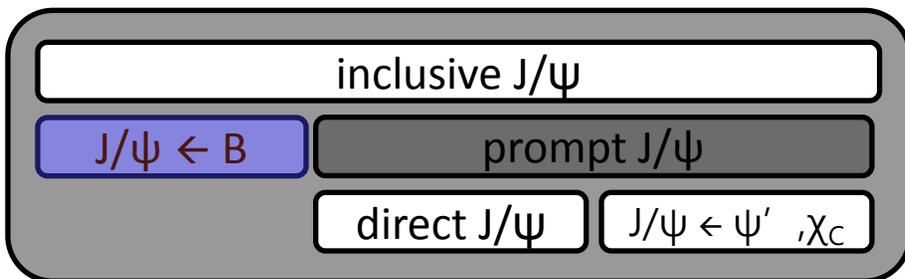
2. Non-prompt J/ψ



Inclusive J/ψ production in PbPb

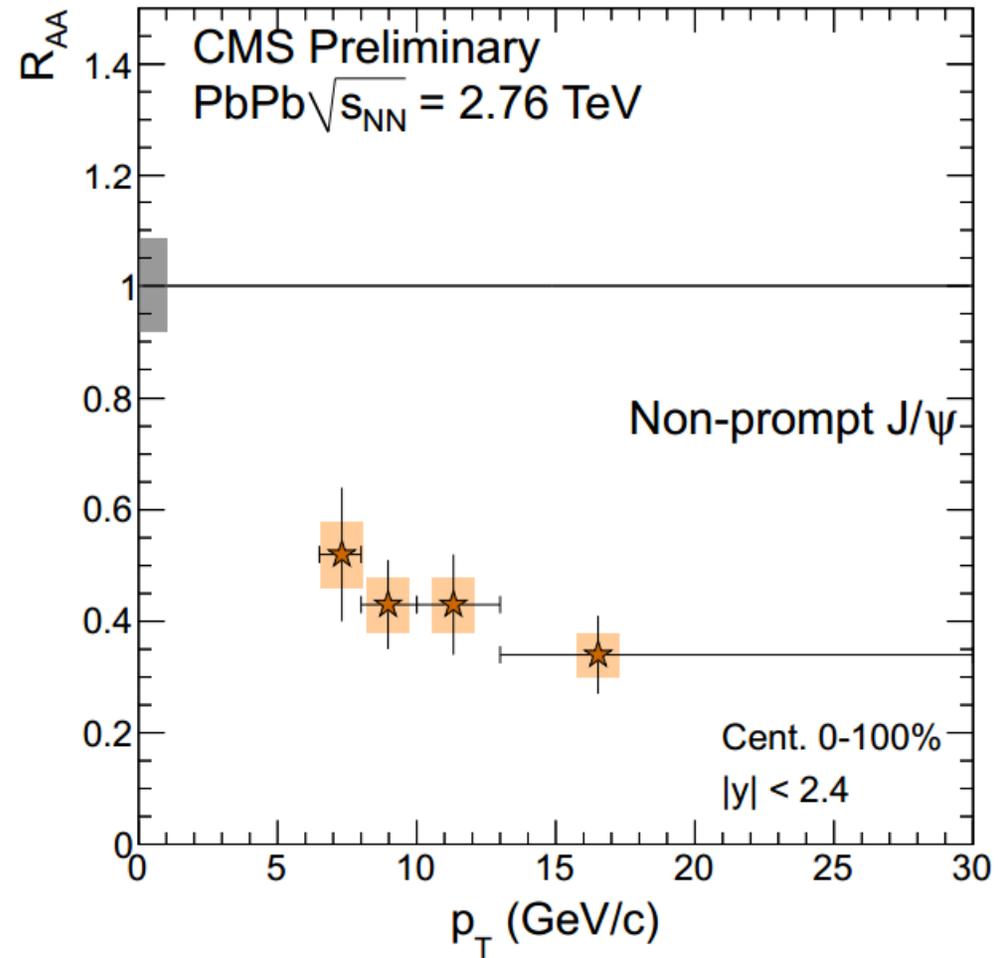
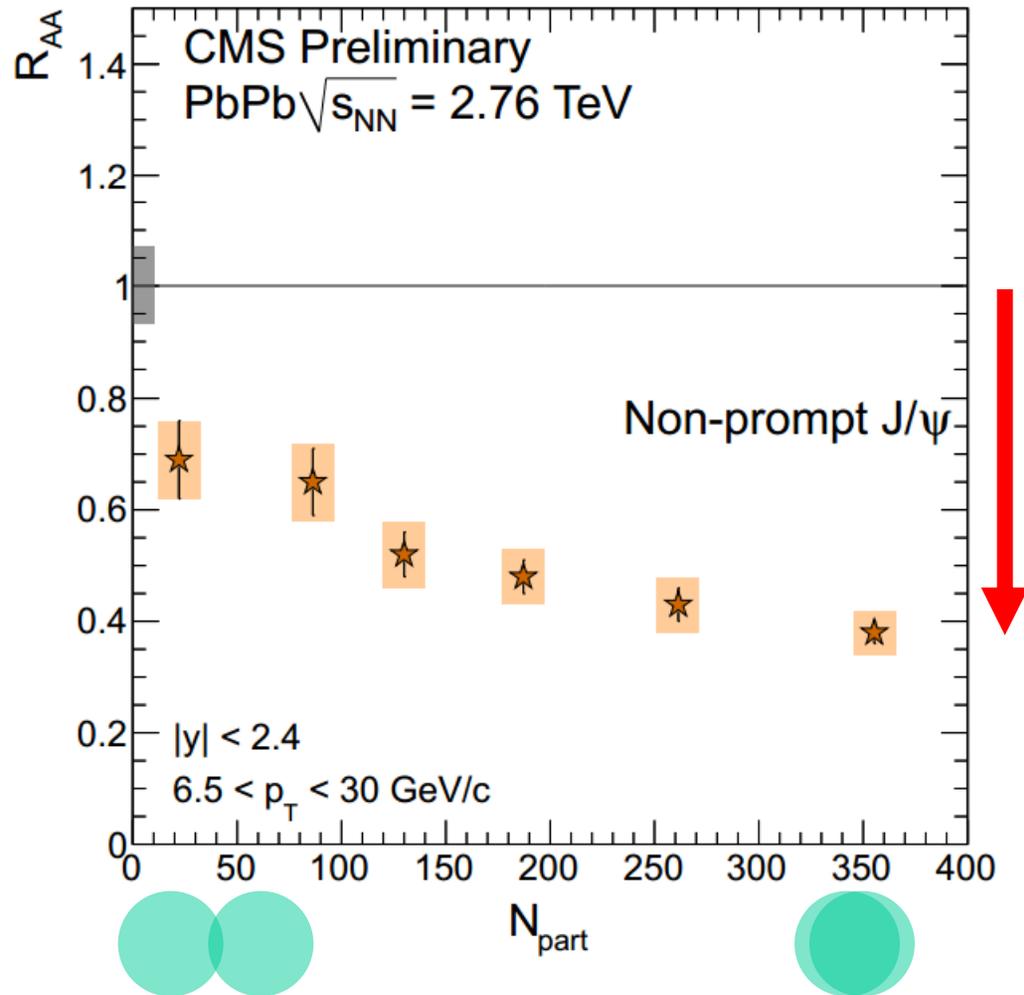


Non-prompt J/ψ to dimuon channel



CMS PAS HIN-12-014

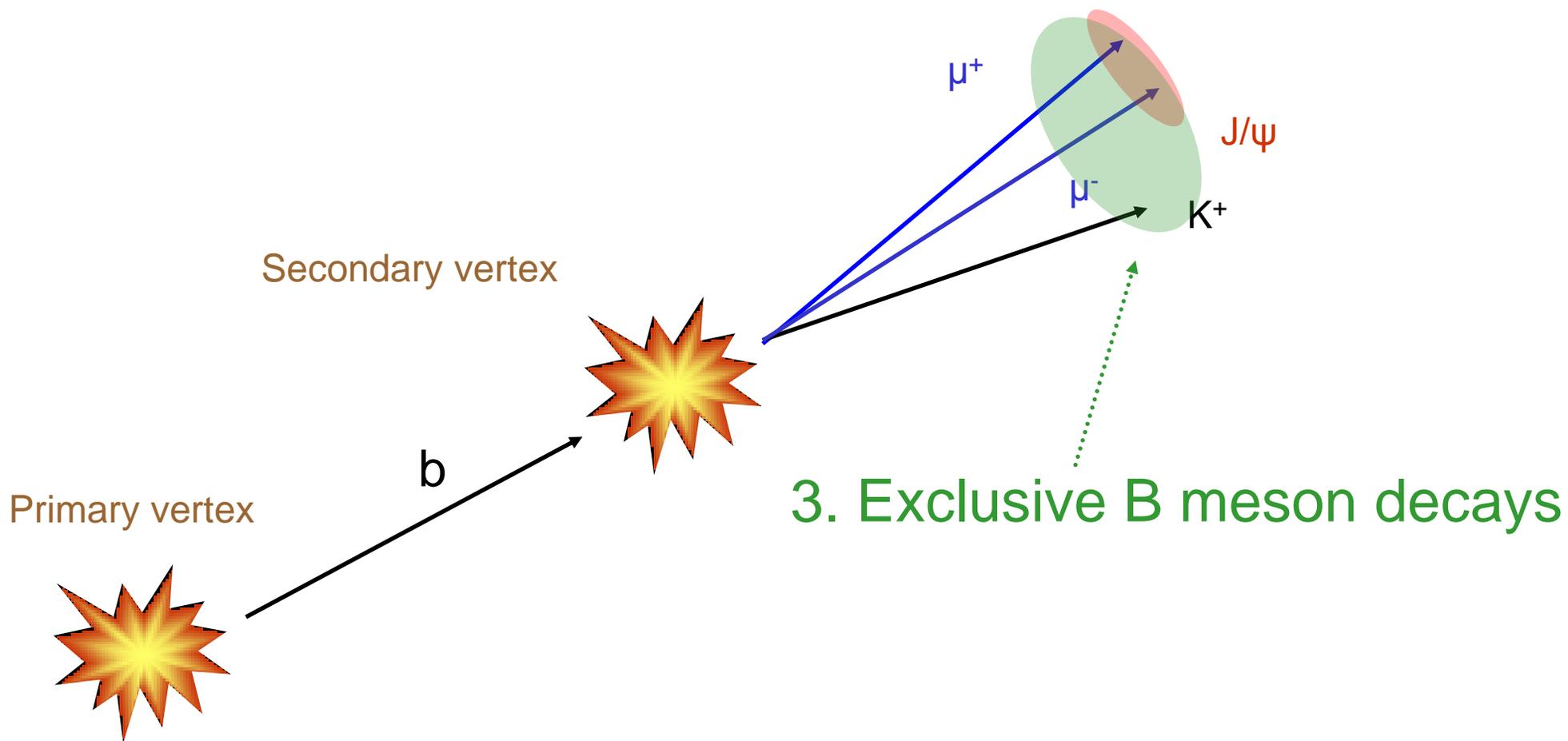
Non-prompt J/ψ suppression in PbPb



Suppression of non-prompt J/ψ in central PbPb collisions with respect to pp reference is observed ($R_{AA} \sim 0.4$)

CMS PAS HIN-12-014

Study of open heavy flavor production at the LHC (3/4)



3. Exclusive B meson decays

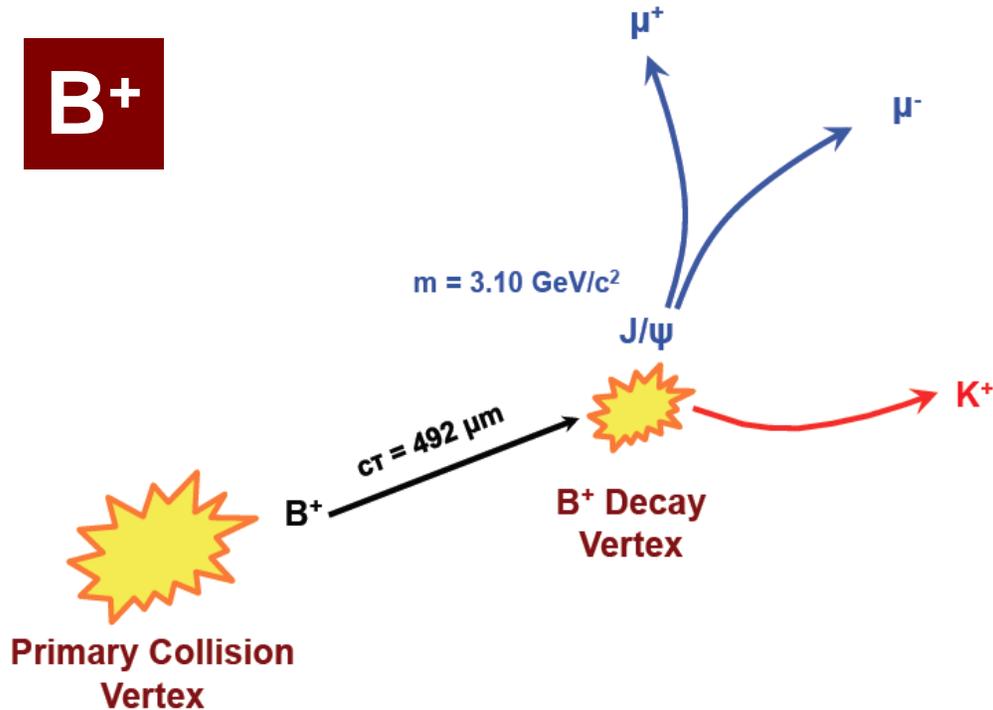
B meson reconstruction

- B-meson reconstructed by combination of

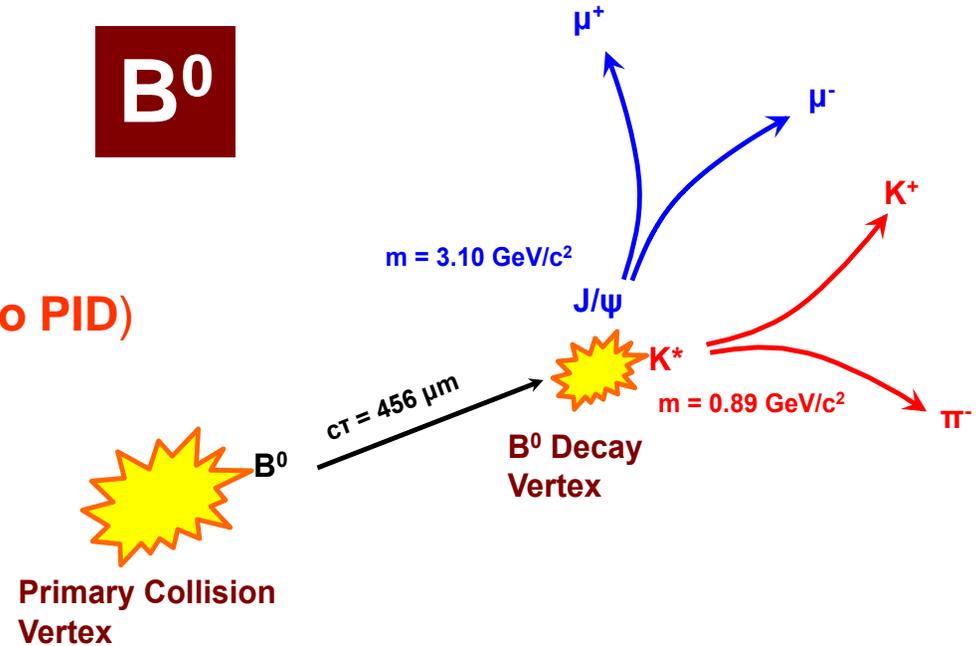
- J/ψ (decay to dimuon)
- tracks (assigned pion or kaon mass, **w/o PID**)

- $B^+ \rightarrow J/\psi K^+ \rightarrow \mu^+ \mu^- K^+$
- $B^0 \rightarrow J/\psi K^{0*} \rightarrow \mu^+ \mu^- K^+ \pi^-$
- $B_s \rightarrow J/\psi \phi \rightarrow \mu^+ \mu^- K^+ K^-$

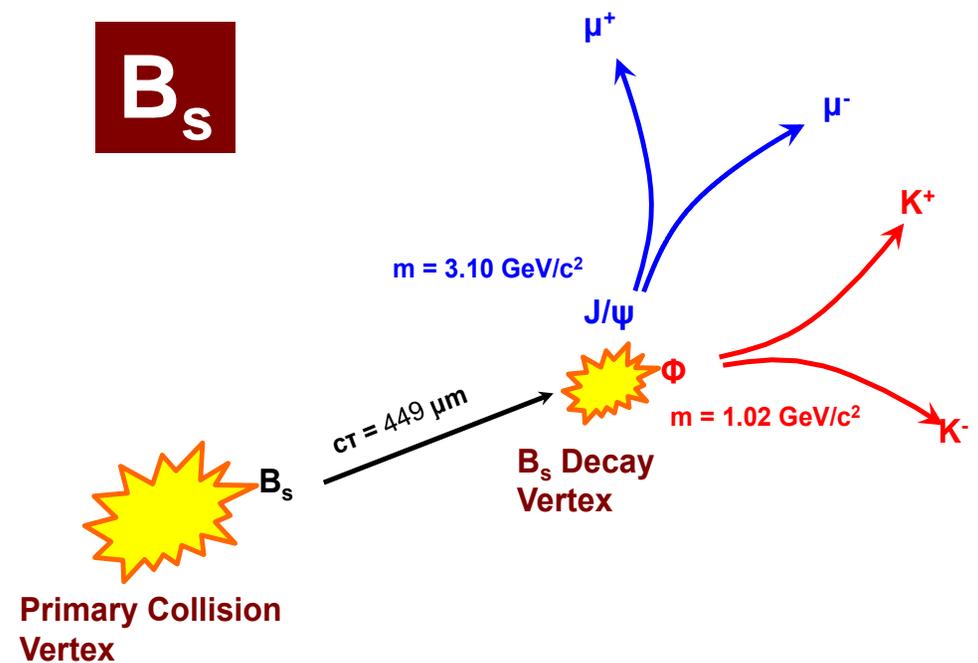
B⁺



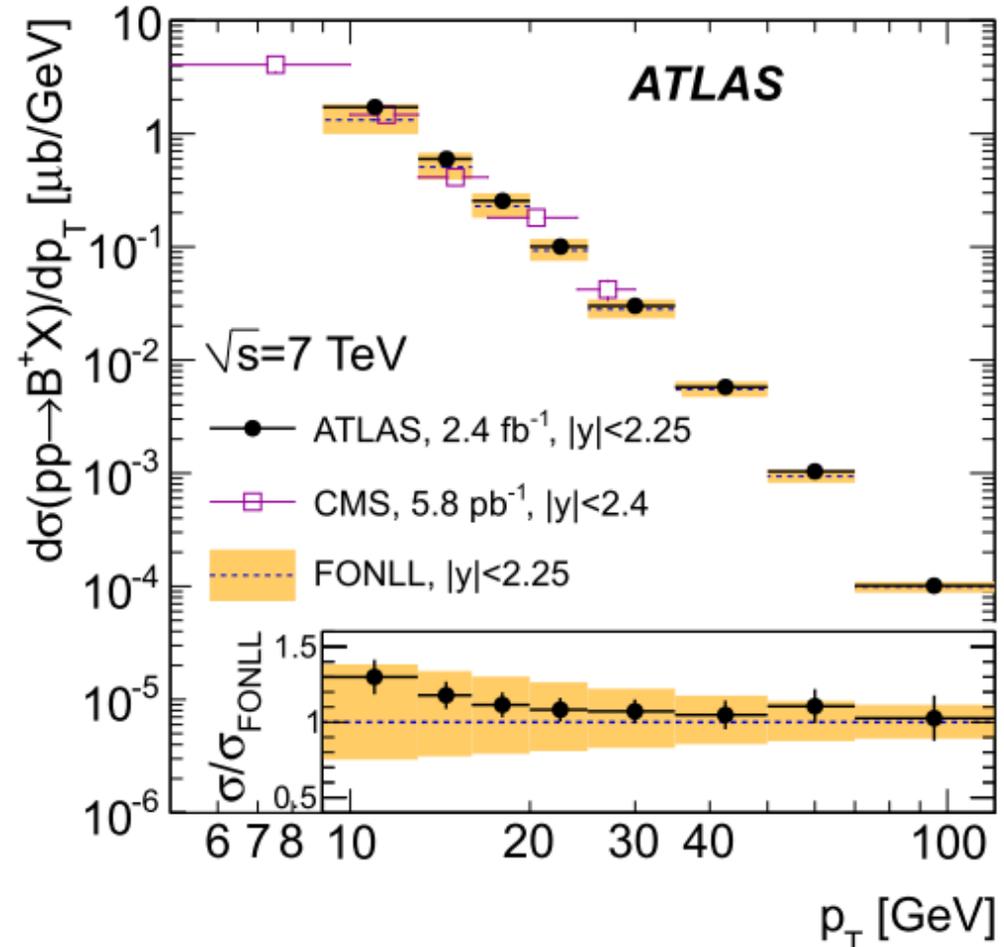
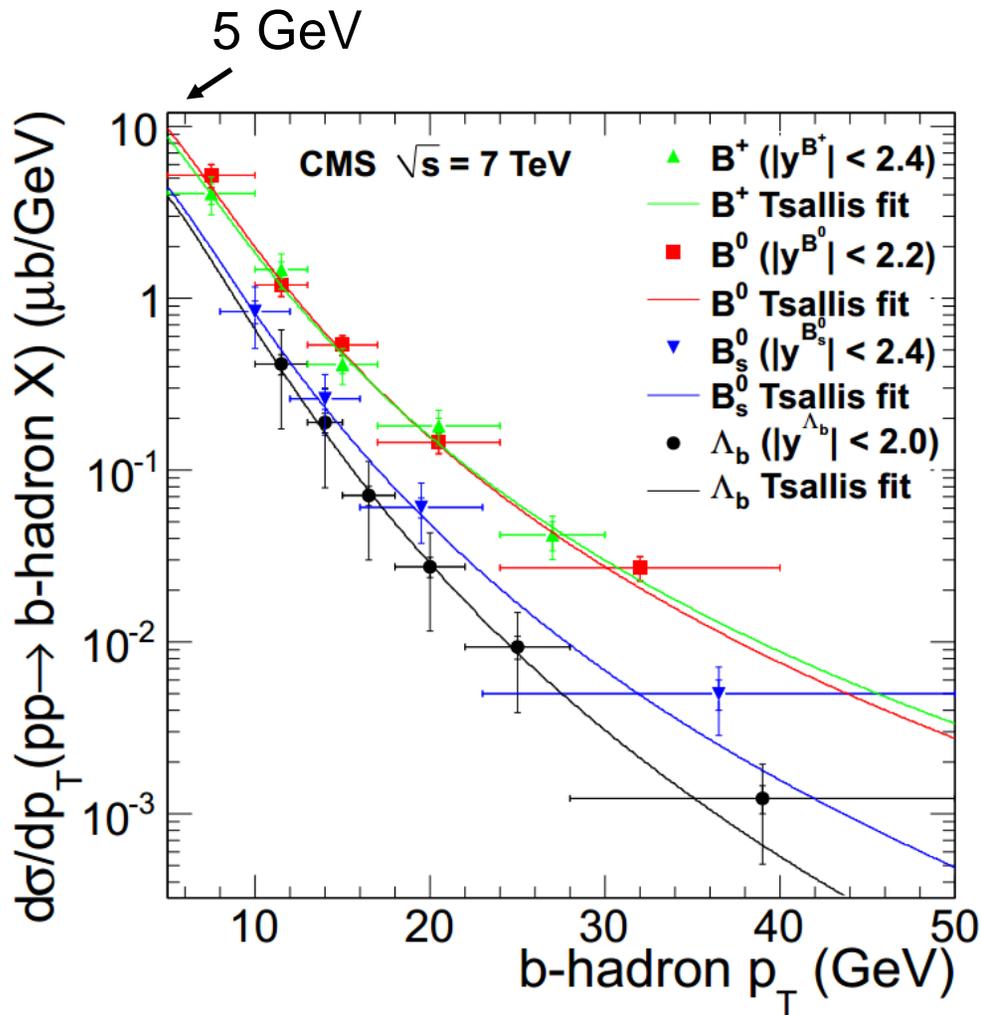
B⁰



B_s



Open heavy flavor production in pp collisions



ATLAS and CMS have reported B meson (b baryon) cross-section measurements in pp collisions ($p_T = 5$ GeV to 100 GeV)

Good agreement between pp data and FONLL calculation

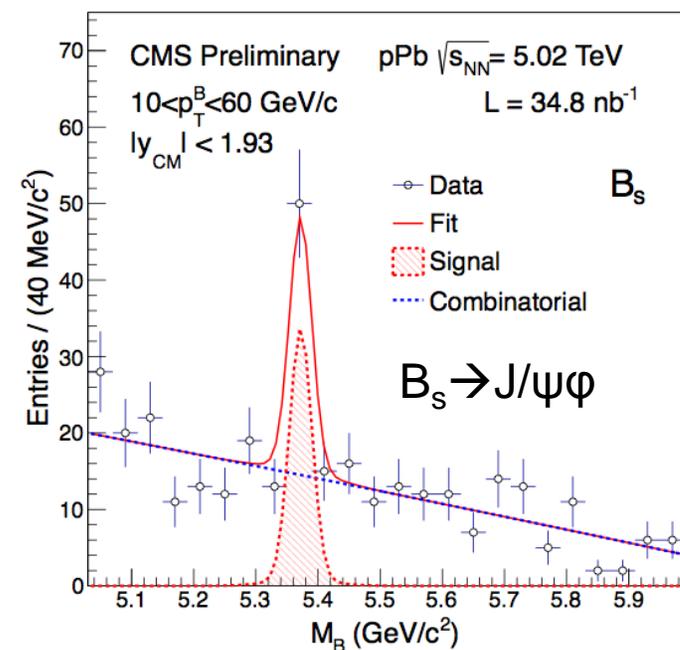
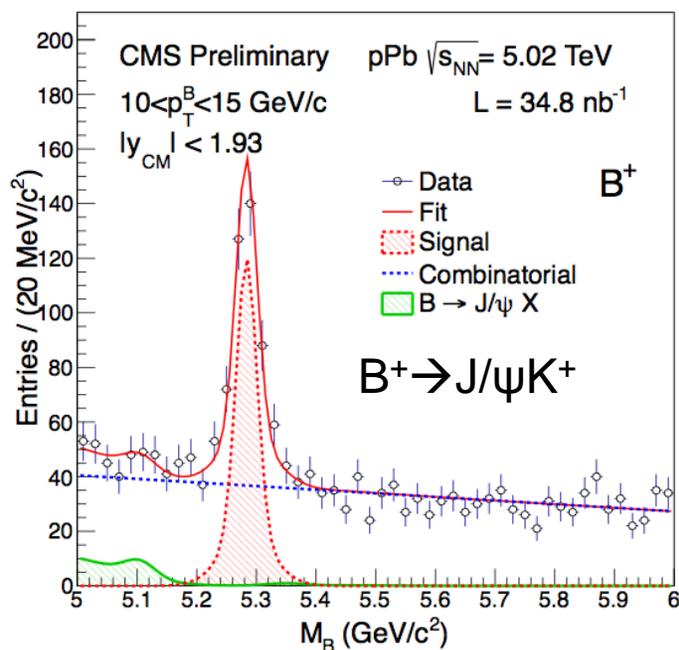
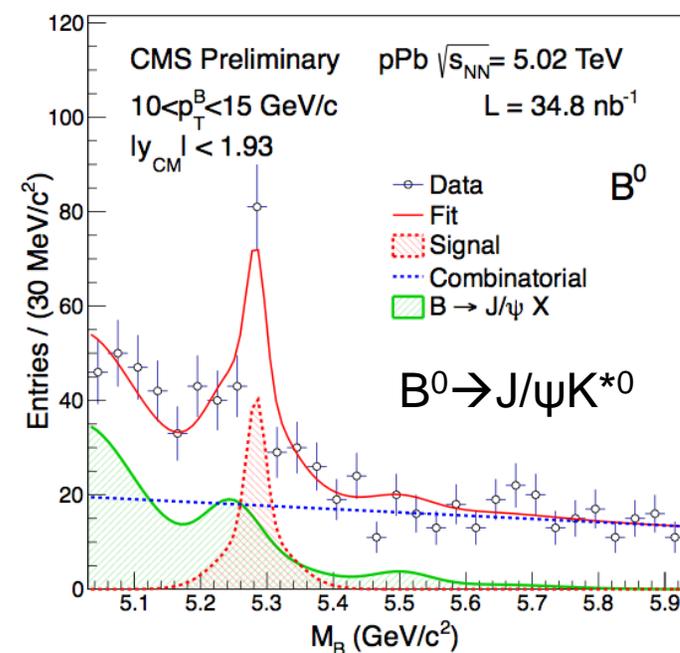
B meson production in pPb collisions at 5.02 TeV

CMS PAS HIN-14-004

Three component fit for signal extraction:

- **Signal**
- **Combinatorial background from J/ψ -track(s)**
- **Non-prompt component from other B-meson decays that form peaking structures (e.g. in B^+ analysis, bkg from $B^0 \rightarrow J/\psi K^{0*}$)**

First fully reconstructed B meson signal in heavy ion collisions!

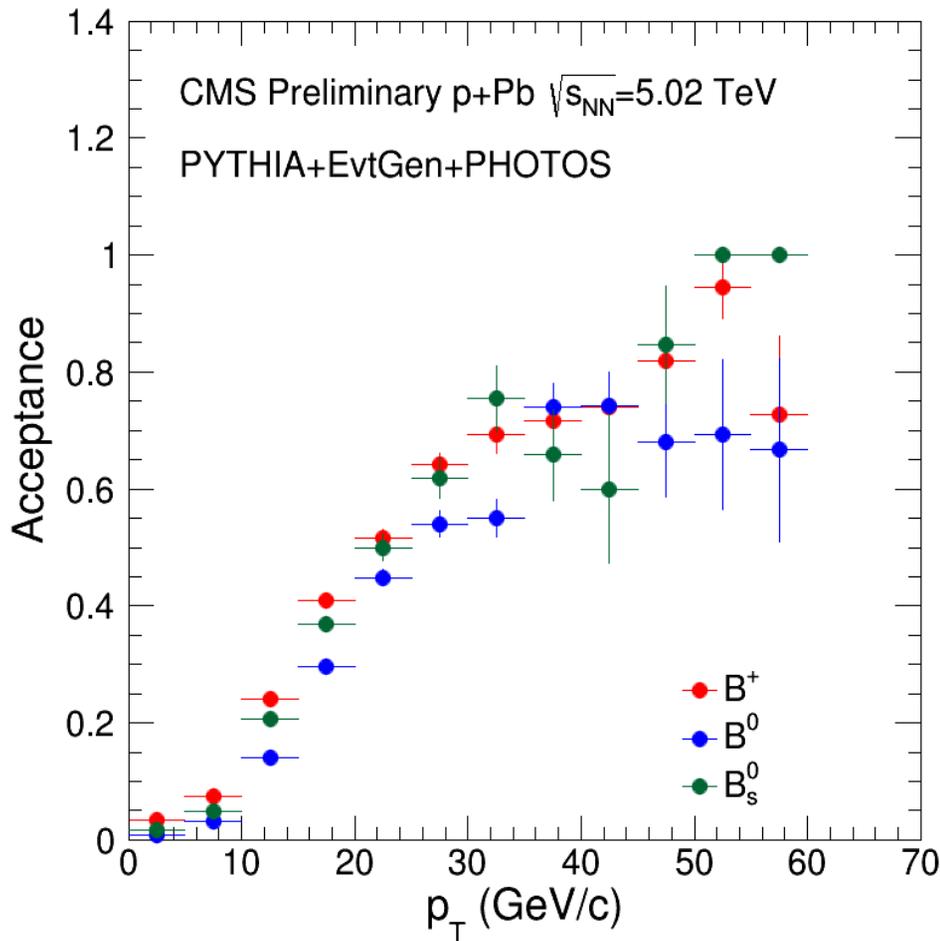


B meson production in pPb collisions

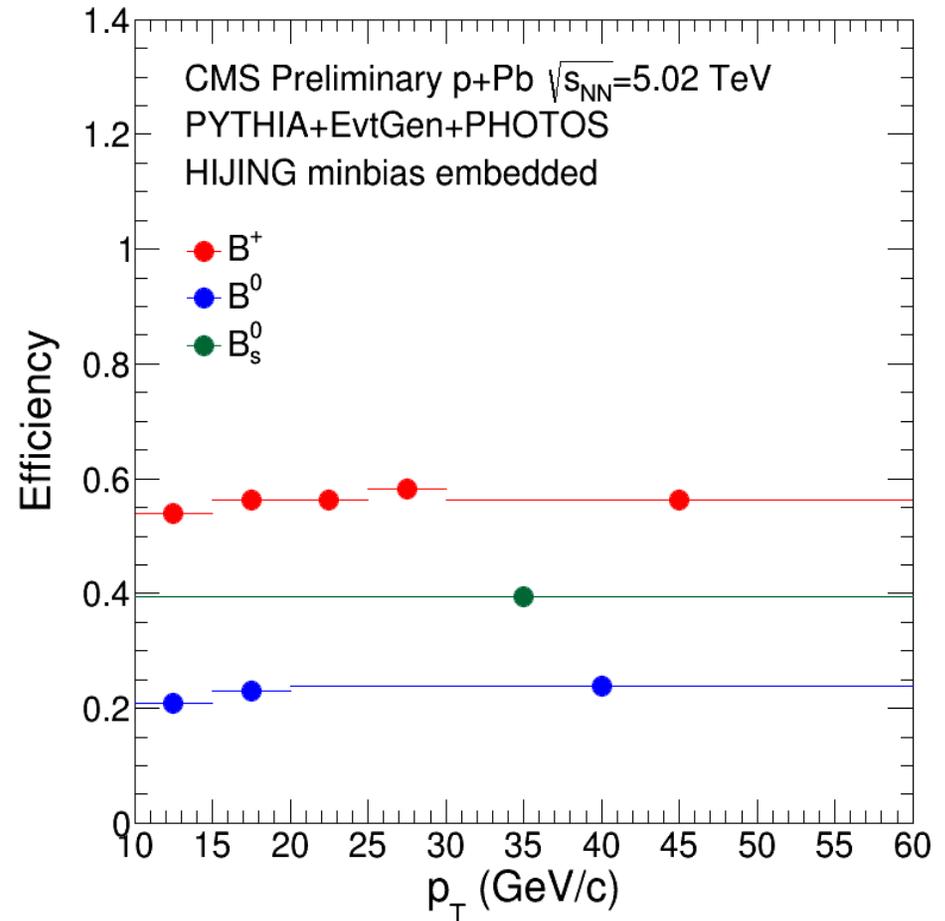
CMS PAS HIN-14-004

Raw yields are corrected by acceptance and efficiency

Acceptance



Efficiency

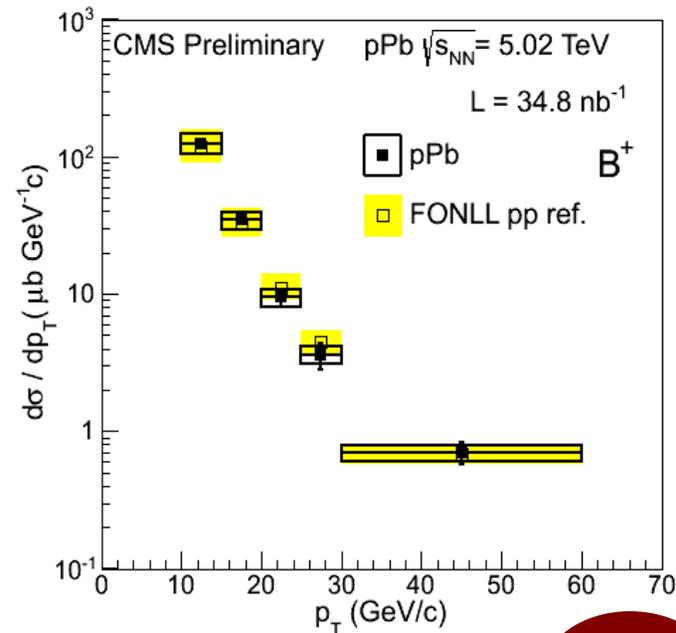


Differential cross-section

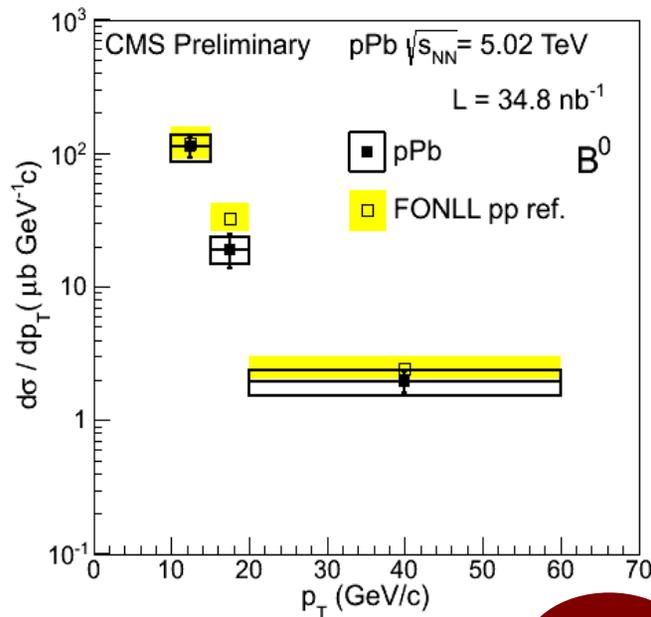
$$\left. \frac{d\sigma^B}{dp_T} \right|_{|y_{CM}| < 1.93} = \frac{1}{2} \frac{1}{\Delta y \Delta p_T} \frac{N^B}{(Acc \times \epsilon) \cdot BR \cdot L_{int}} \Big|_{|y_{CM}| < 1.93}$$

pp reference : FONLL calculation is used
(agreement with CDF, ATLAS and CMS data)

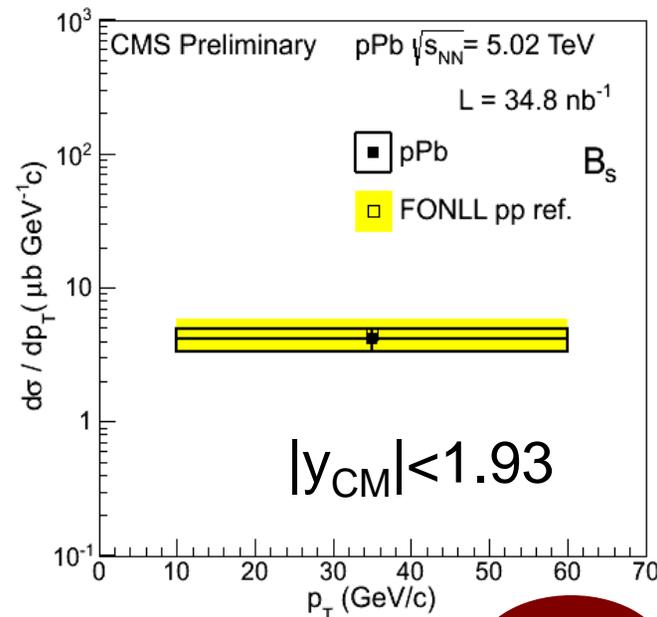
<http://www.lpthe.jussieu.fr/~cacciari/fonll/fonllform.html>



B⁺



B⁰

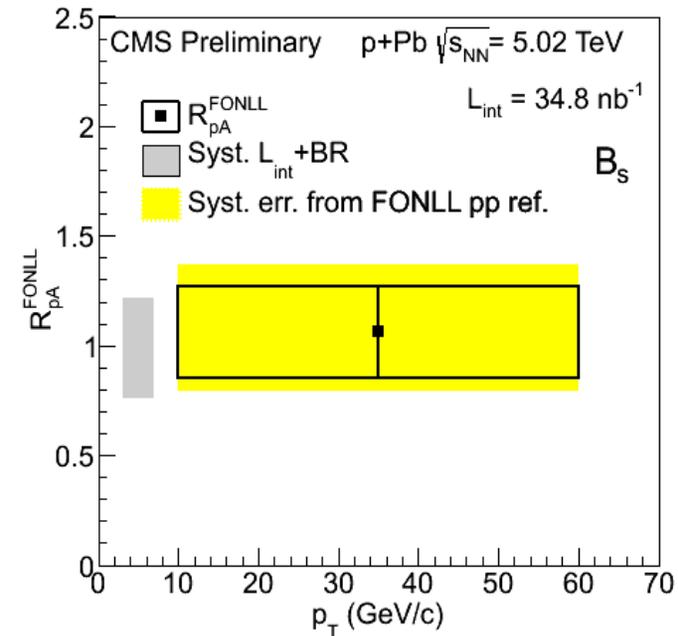
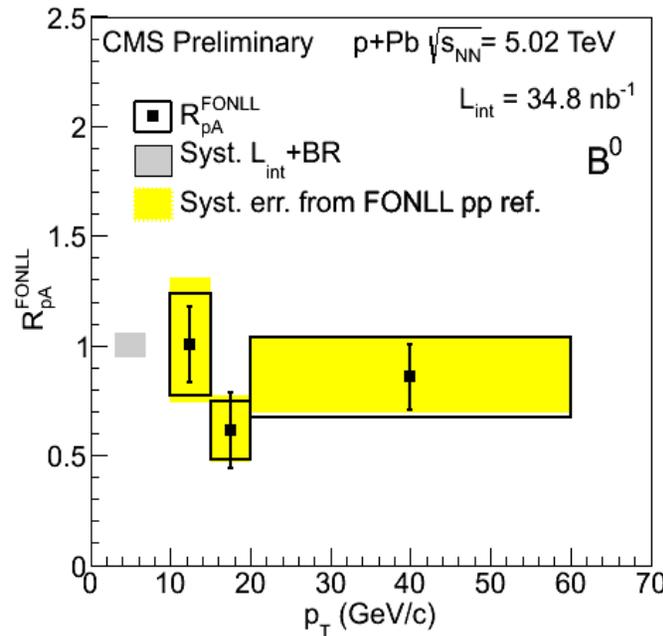
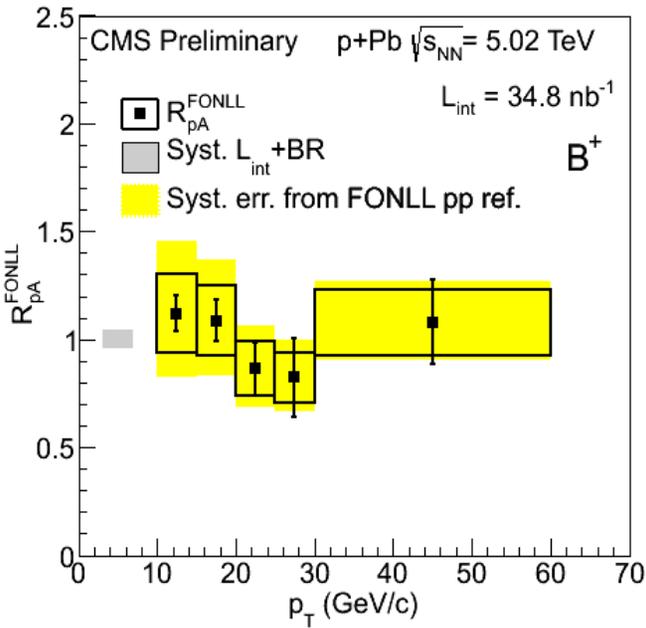


B_s⁰



Nuclear modification factor : R_{pA}^{FONLL}

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

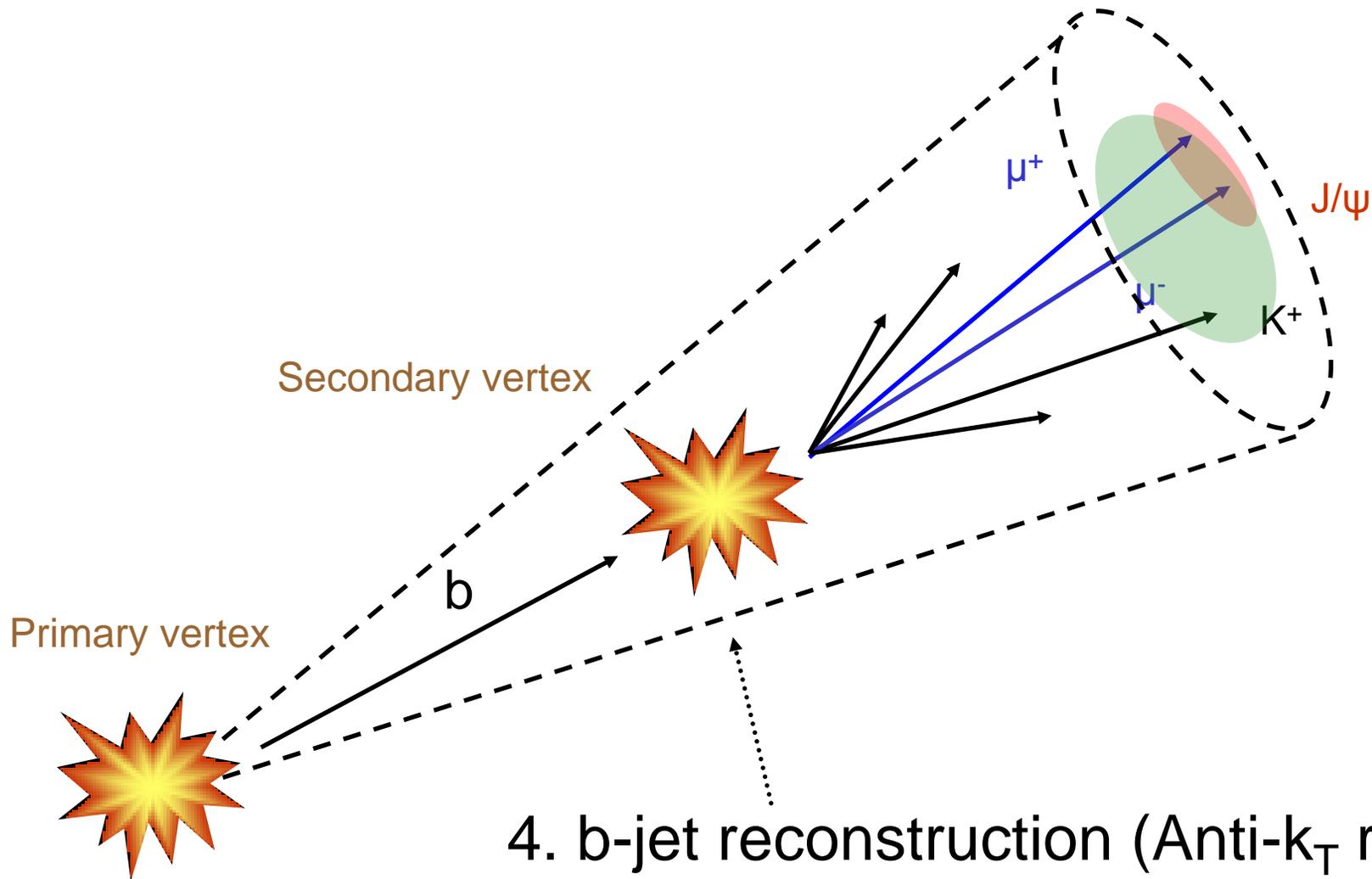


$|y_{CM}| < 1.93$

CMS PAS HIN-14-004

R_{pA}^{FONLL} is compatible with unity within given uncertainties for the three B-mesons

Study of open heavy flavor production at the LHC (4/4)



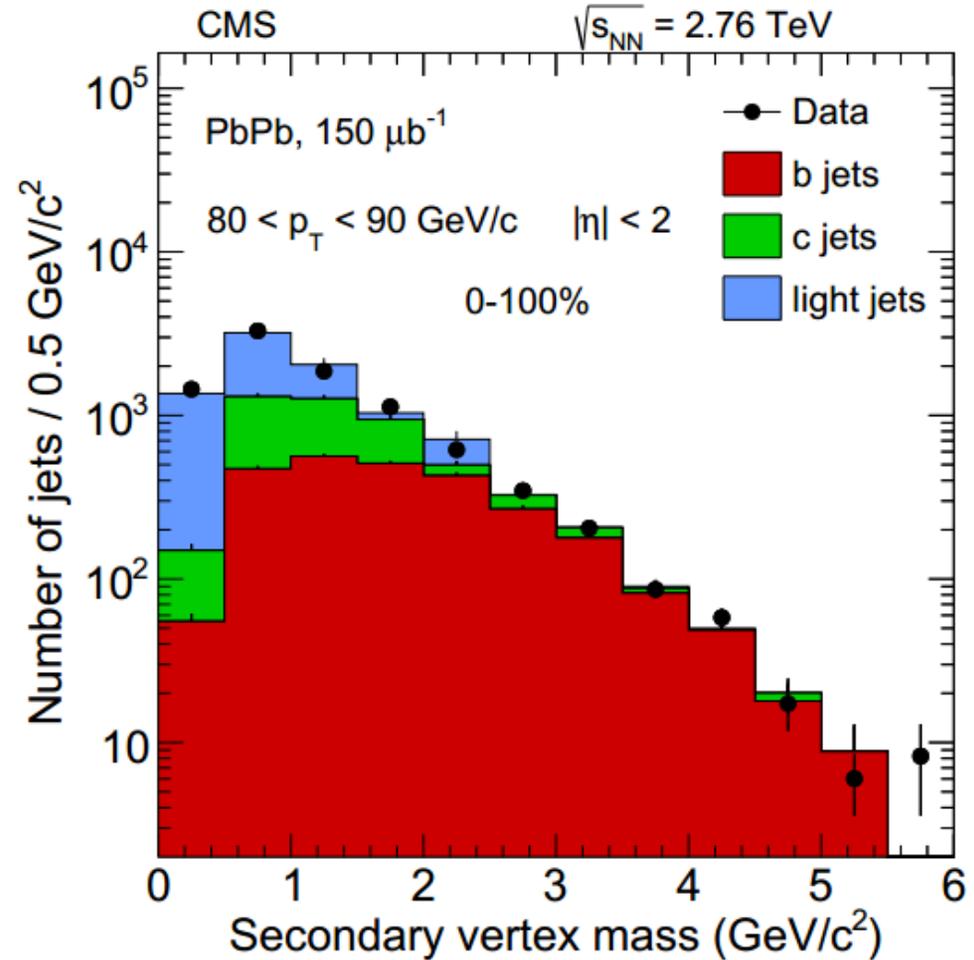
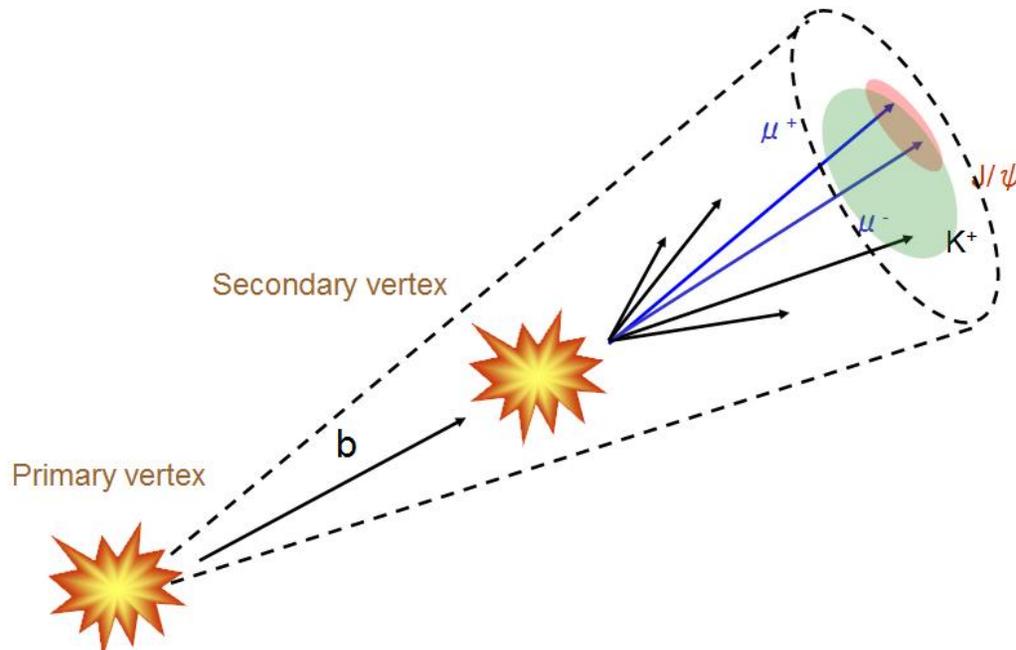
4. b-jet reconstruction (Anti- k_T $r=0.3$)
UE background subtracted

Tagging and counting b-quark jets

Secondary vertex tagged using **flight distance** significance

Tagging efficiency estimated
in a **data-driven** way

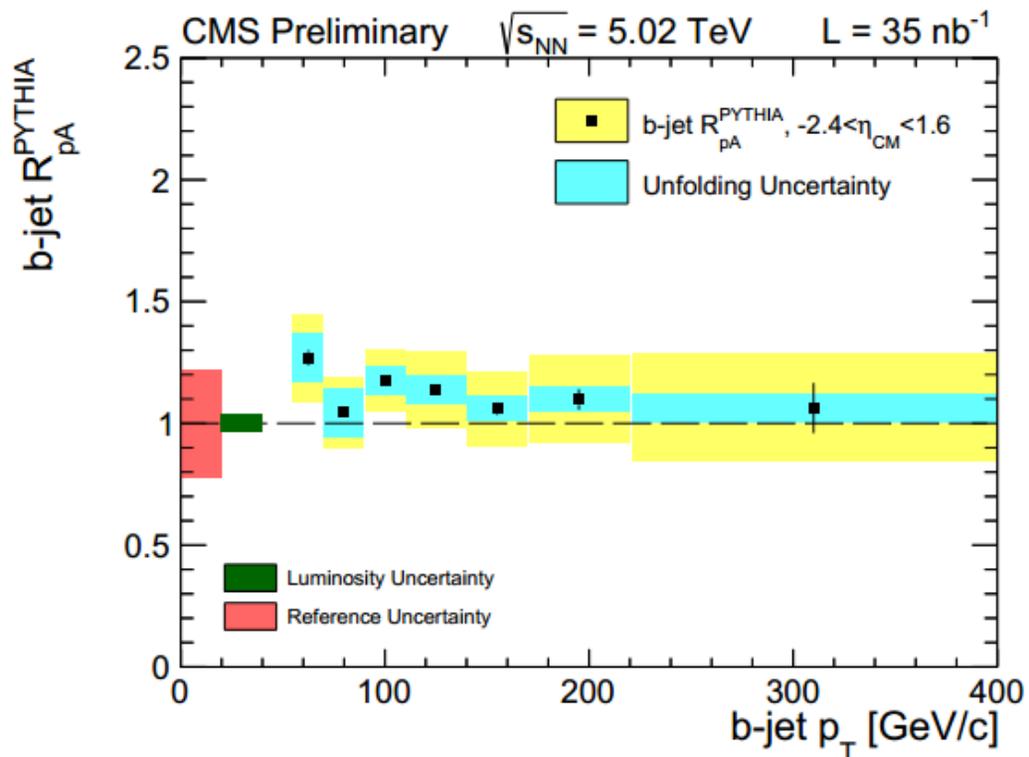
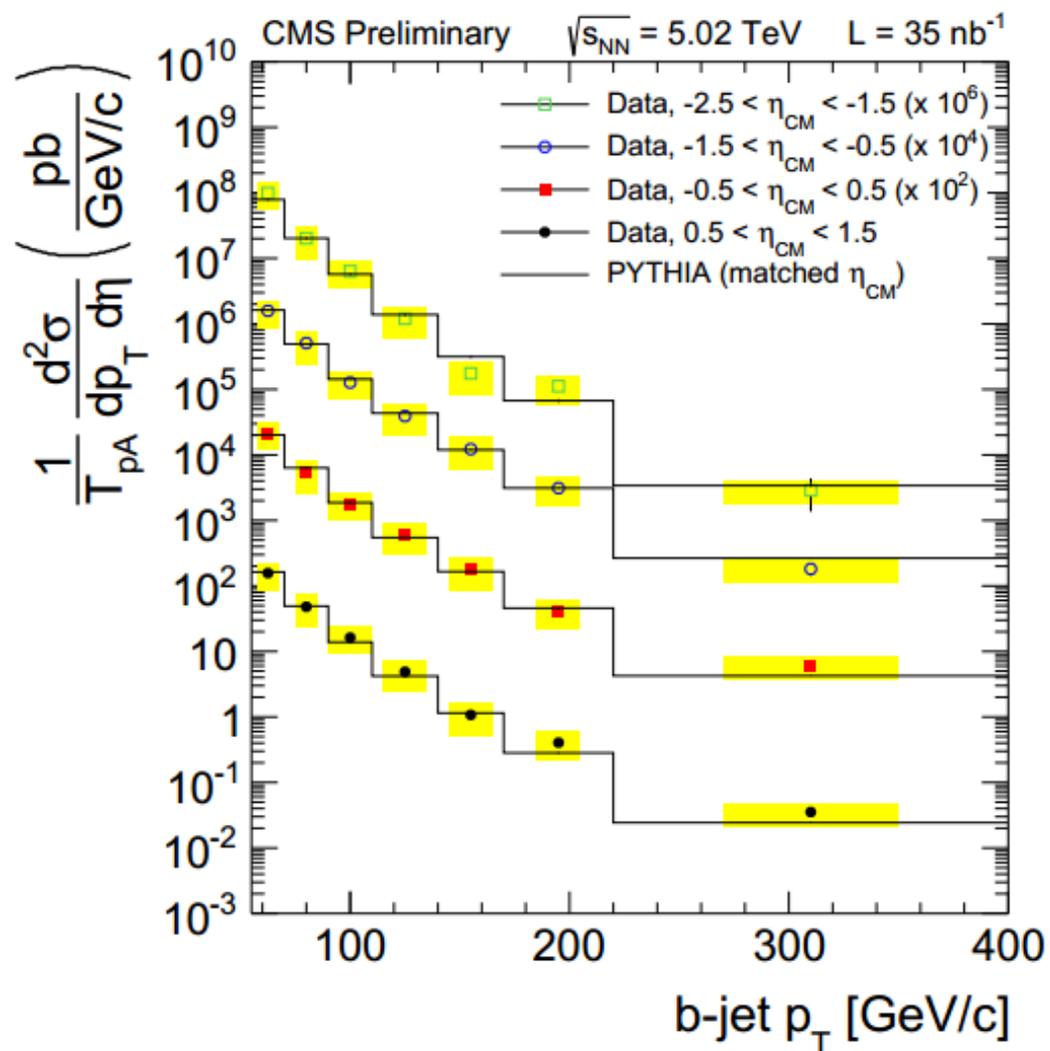
Purity from **template fits**
to (tagged) secondary vtx
mass distributions



CMS PAS HIN-14-007

CMS HIN-12-003
ArXiv 1312.4198

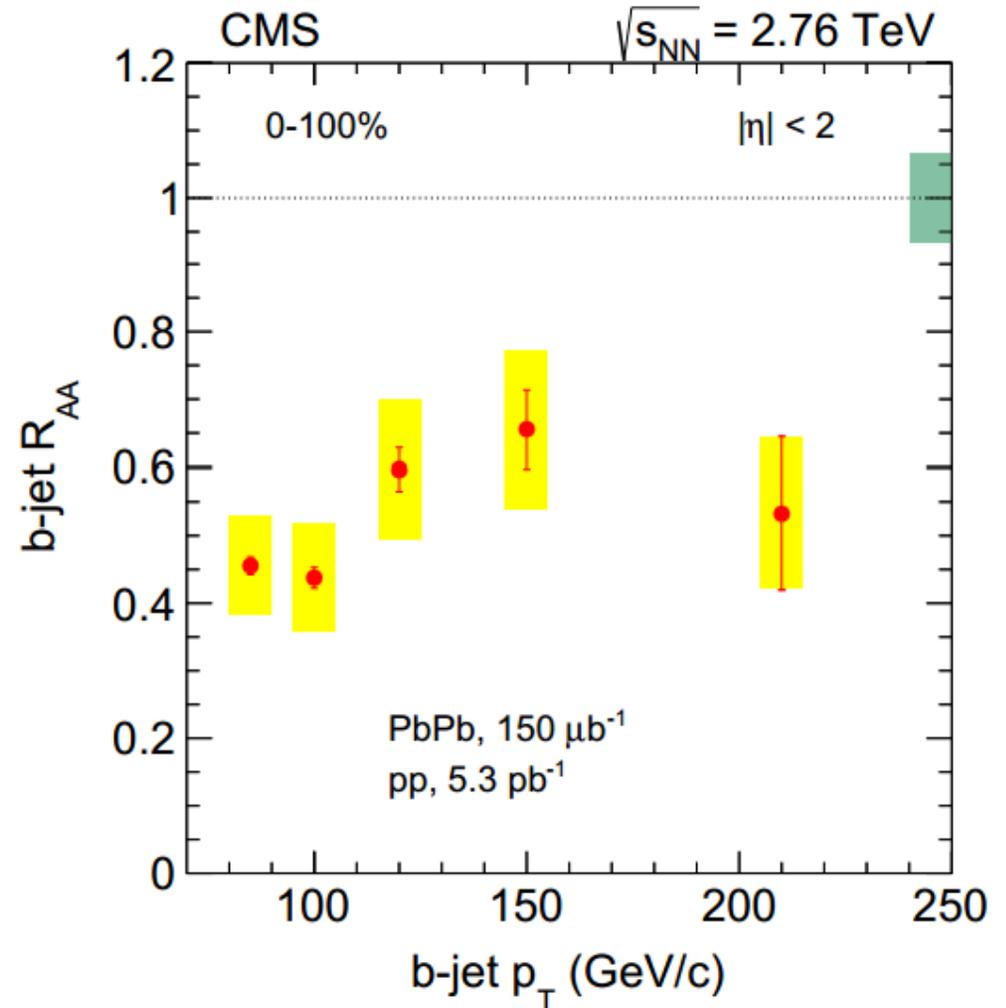
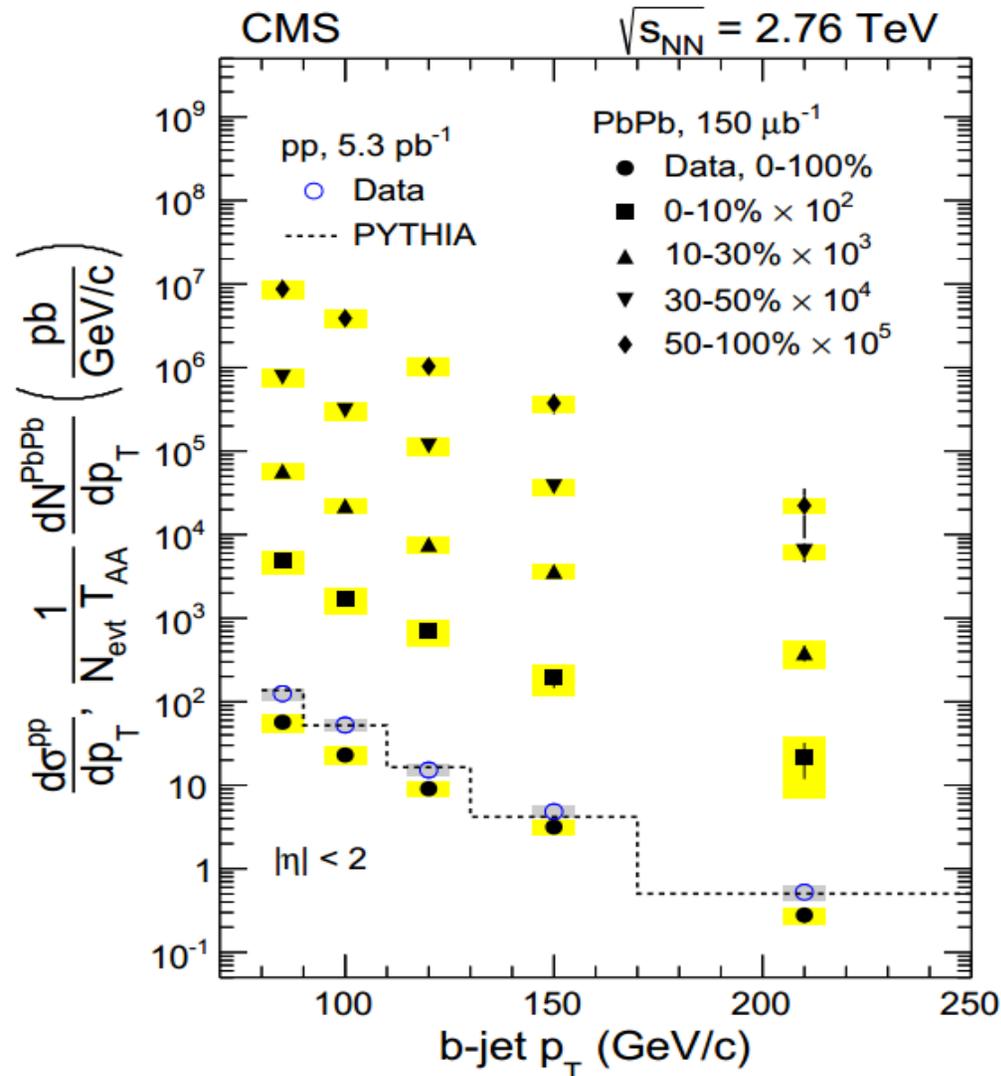
b-jet R_{pA}^{PYTHIA} in pPb collisions at 5.02 TeV



CMS PAS HIN-14-007

b-jet R_{pA}^{PYTHIA} is compatible with unity within given uncertainties

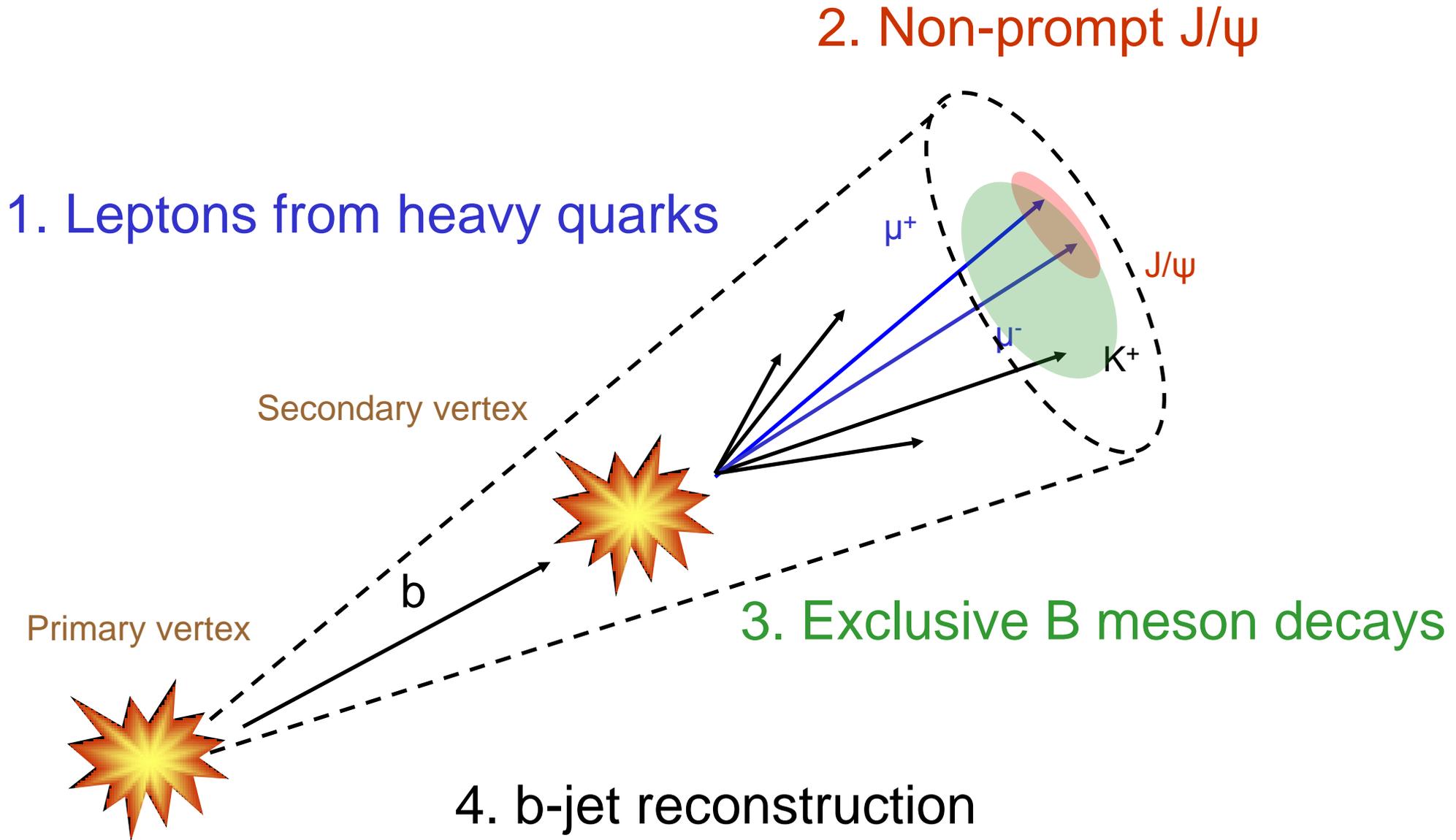
b-Jet R_{AA} in PbPb collisions at 2.76 TeV



Suppression of b-tagged jets in central PbPb collisions with respect to pp reference was observed ($R_{AA} \sim 0.5$)

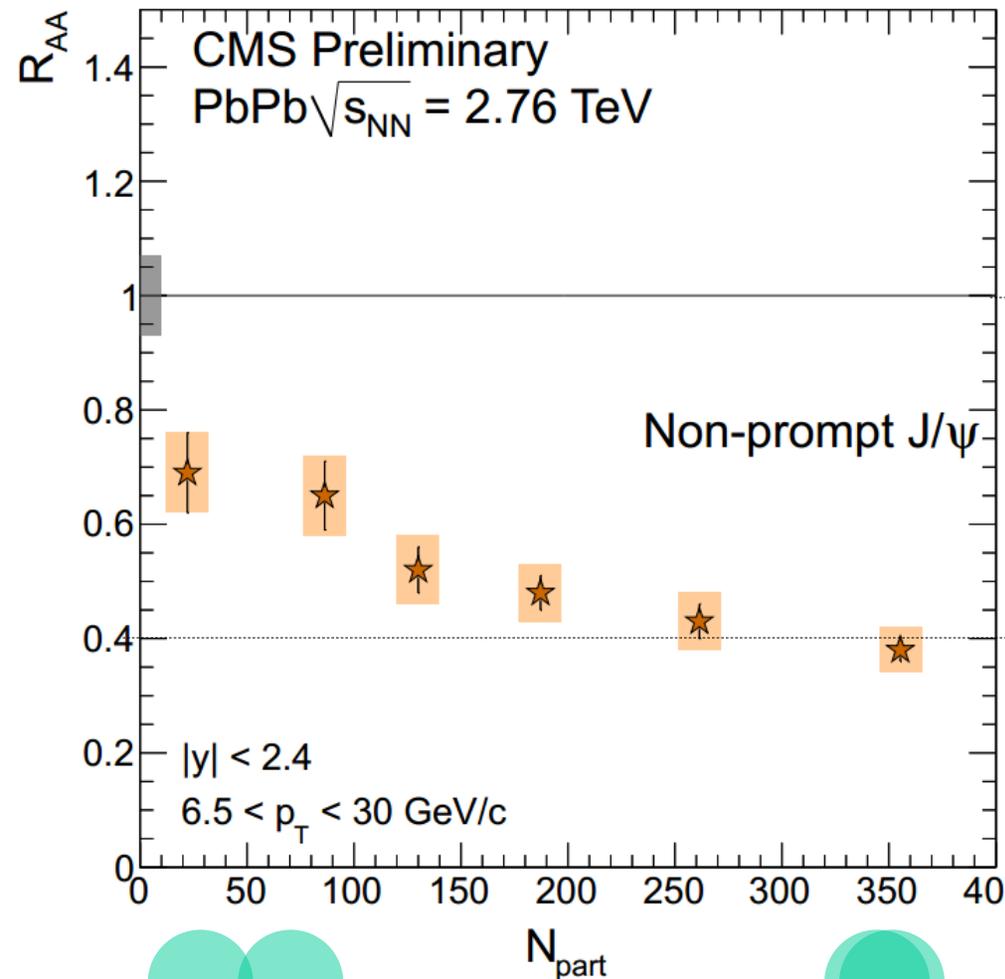
CMS HIN-12-003
ArXiv 1312.4198

Summary of open heavy flavor production in ATLAS and CMS

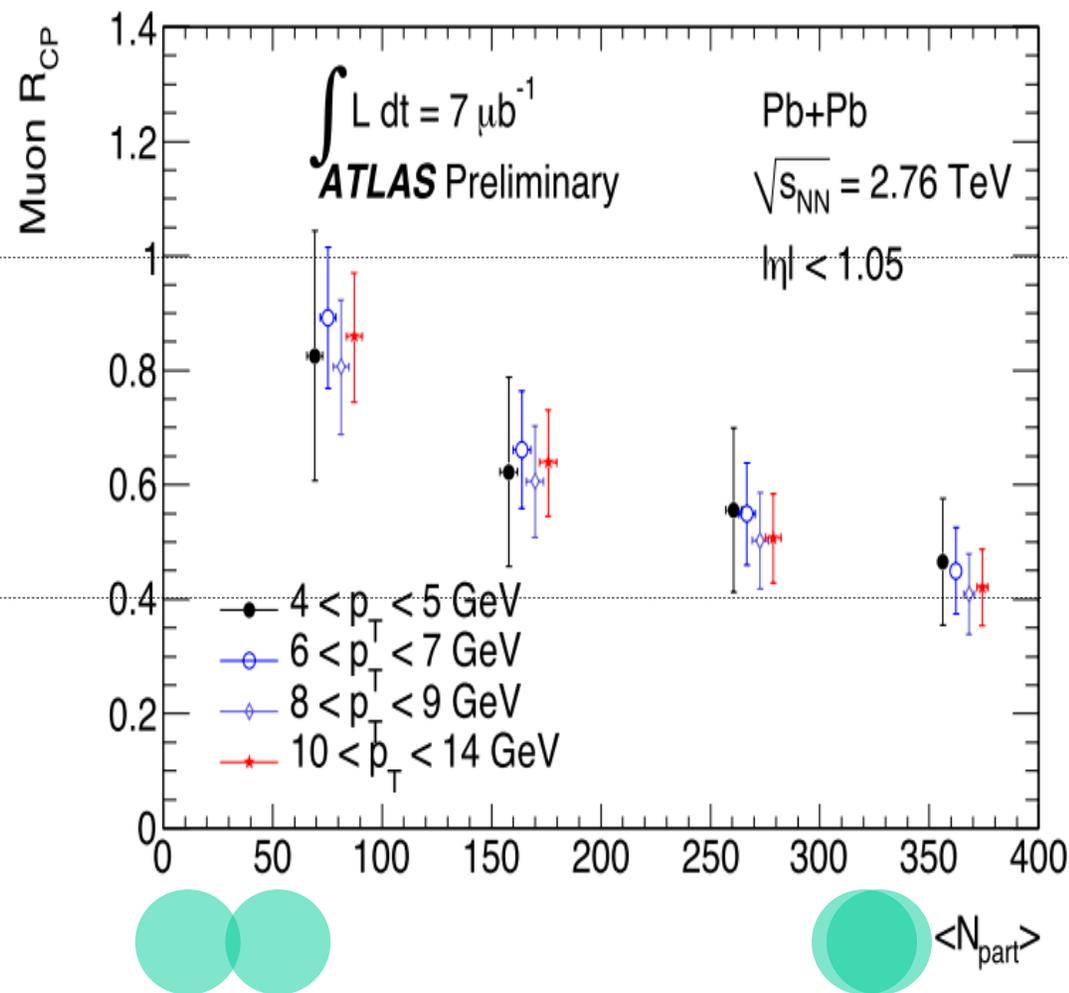


Summary: $R_{AA} (CP)$ vs N_{part}

CMS Non-prompt J/ψ R_{AA}



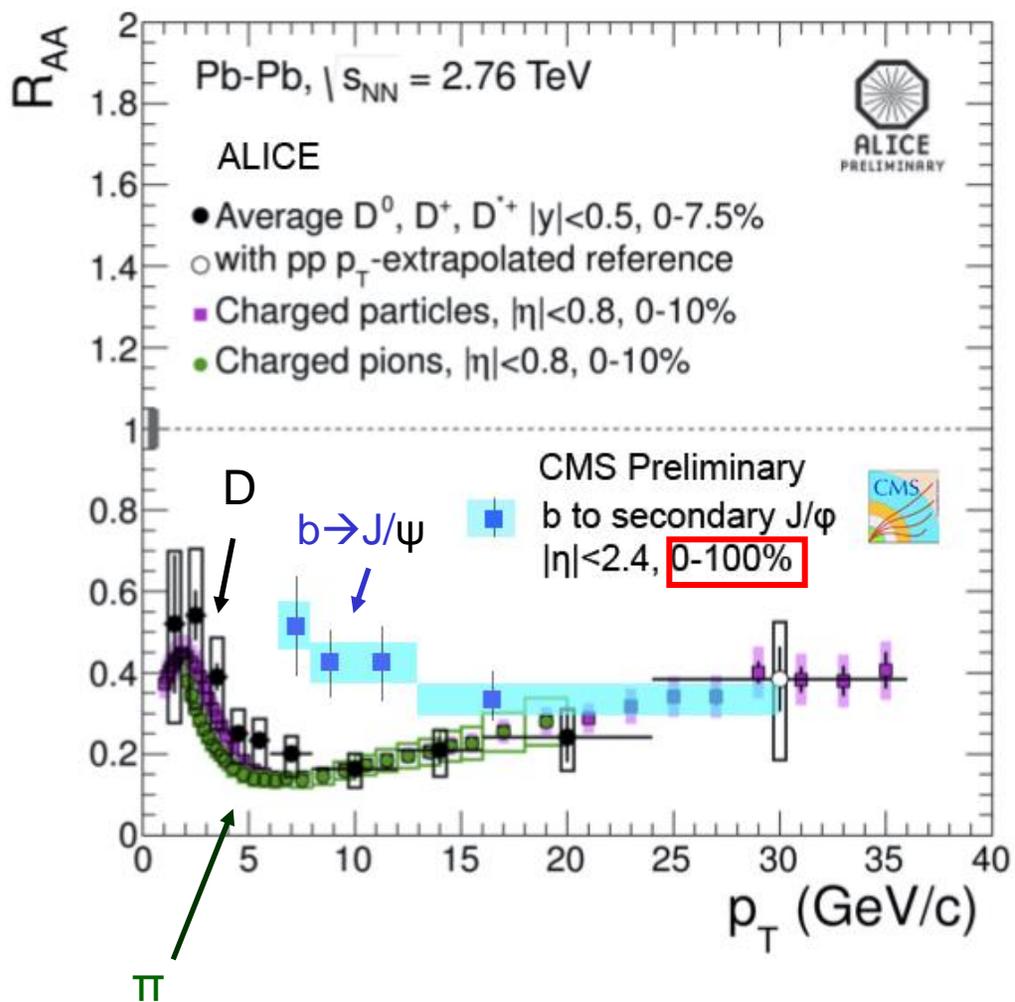
ATLAS Heavy Flavor Muon R_{CP} (60-80% as reference)



Summary: Flavor Dependence of Jet Quenching

Indication of $R_{AA}(B) > R_{AA}(D) > R_{AA}(\pi)$ at low p_T

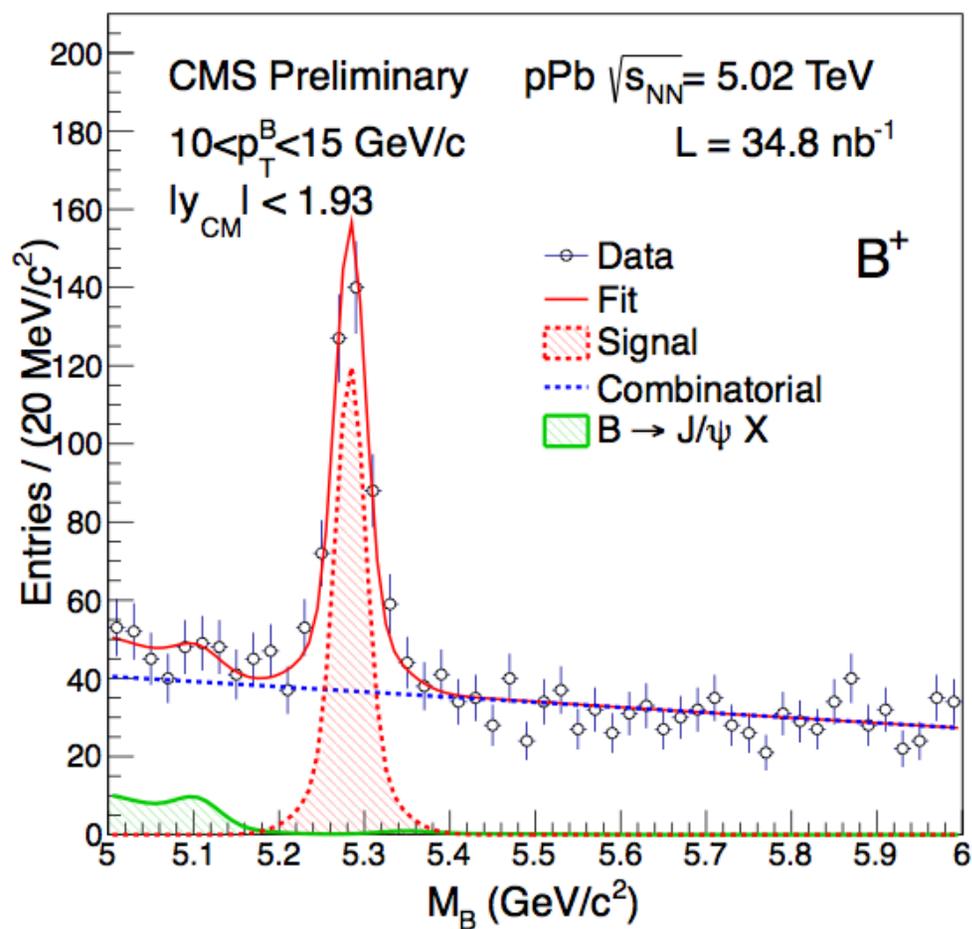
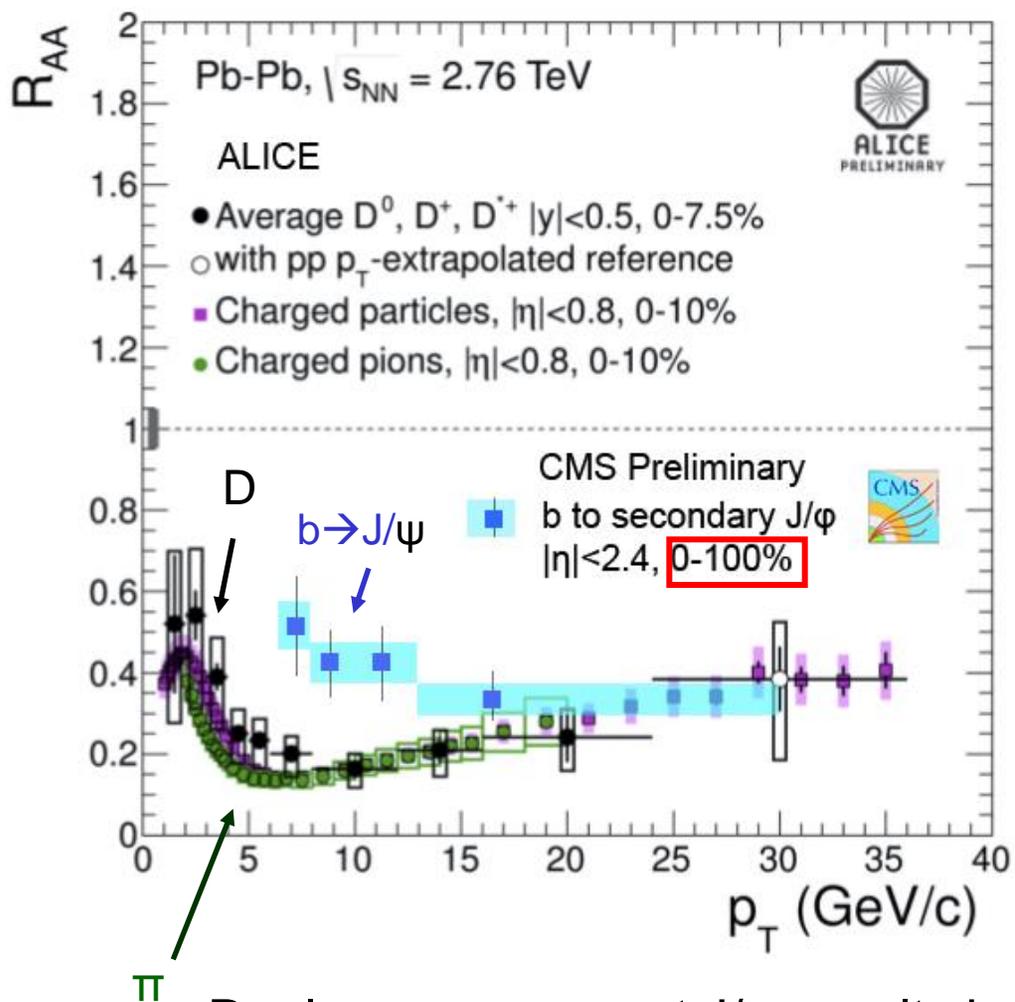
(However, spectra slope are different)



Summary: Flavor Dependence of Jet Quenching

Indication of $R_{AA}(B) > R_{AA}(D) > R_{AA}(\pi)$ at low p_T

(However, spectra slope are different)

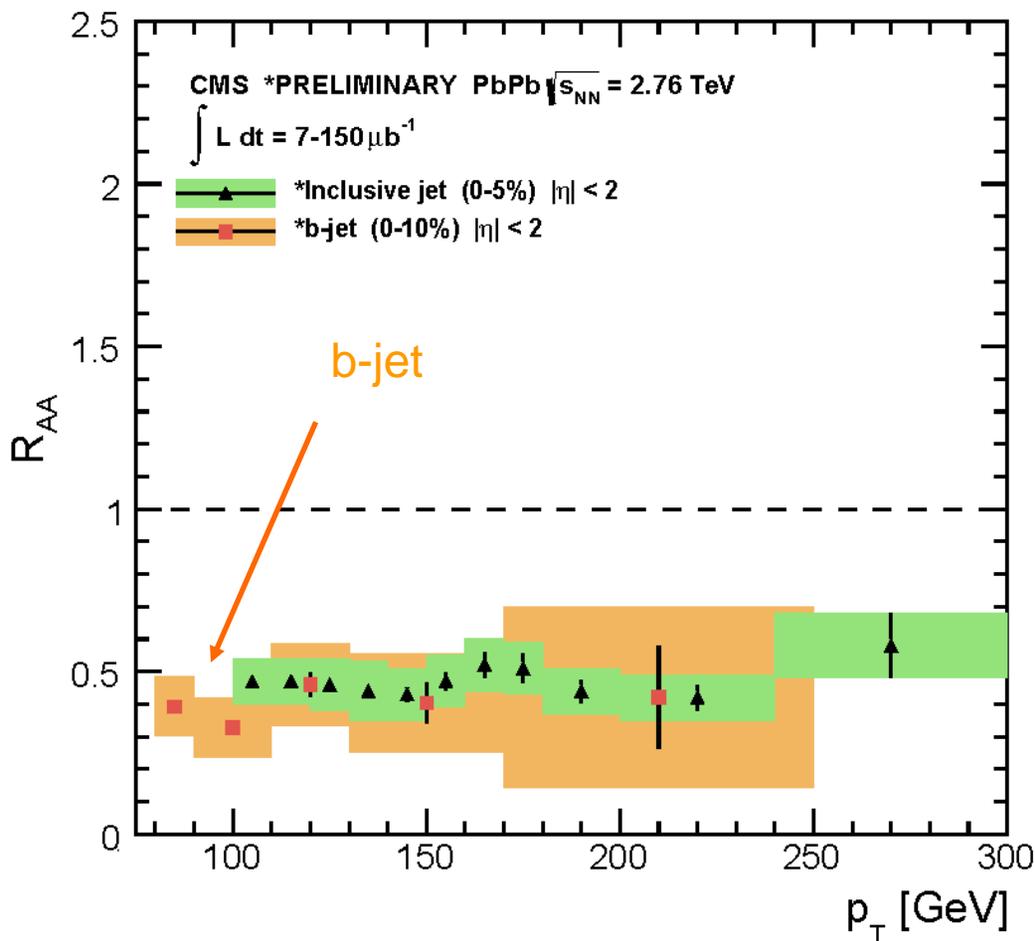
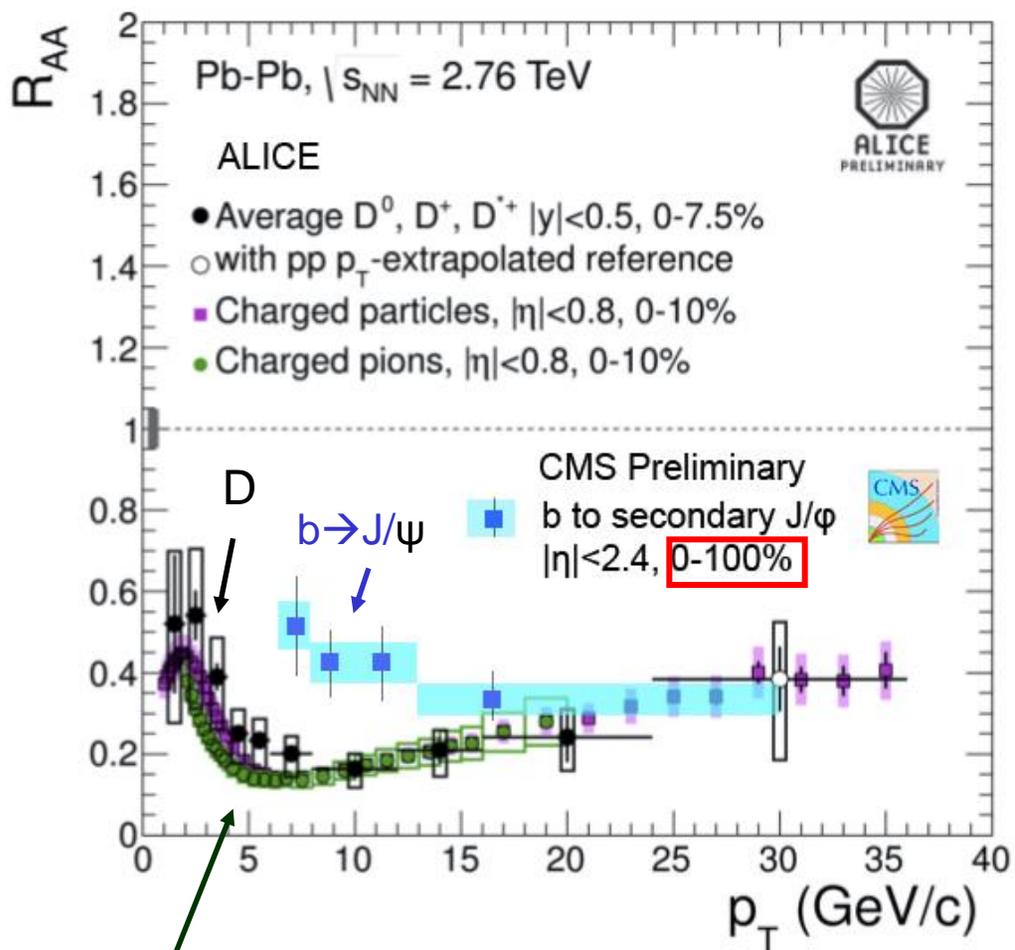


Replace non-prompt J/ ψ results by exclusive B meson to fix the x axis scale

Summary: Flavor Dependence of Jet Quenching

Indication of $R_{AA}(B) > R_{AA}(D) > R_{AA}(\pi)$ at low p_T
 (However, spectra slope are different)

Indication of $R_{AA}(b\text{-jet}) \sim R_{AA}(\text{all jets})$
 at high jet p_T



b quark jet \sim inclusive jet (mainly gluon jets), contribution from gluon splitting?

Outlook: Statistical Reach in 2015 and beyond

2011 2.76 TeV PbPb data (0.15/nb)

b-jet

2013 5.02 TeV pPb data (35/nb)

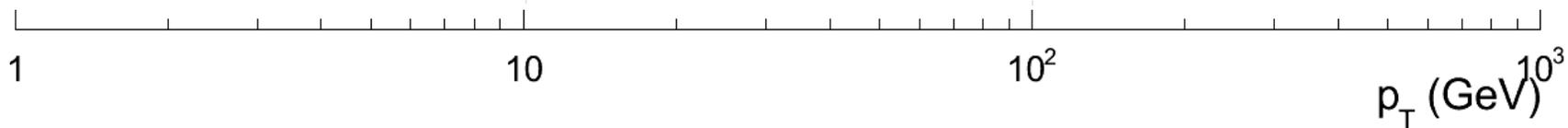
B meson

b-jet

2015-17 5.1 TeV PbPb data (1.5/nb)

B meson

b-jet



HL-LHC (10/nb): (b)-jet quenching at O(TeV)
ttbar production

... Stay tuned!

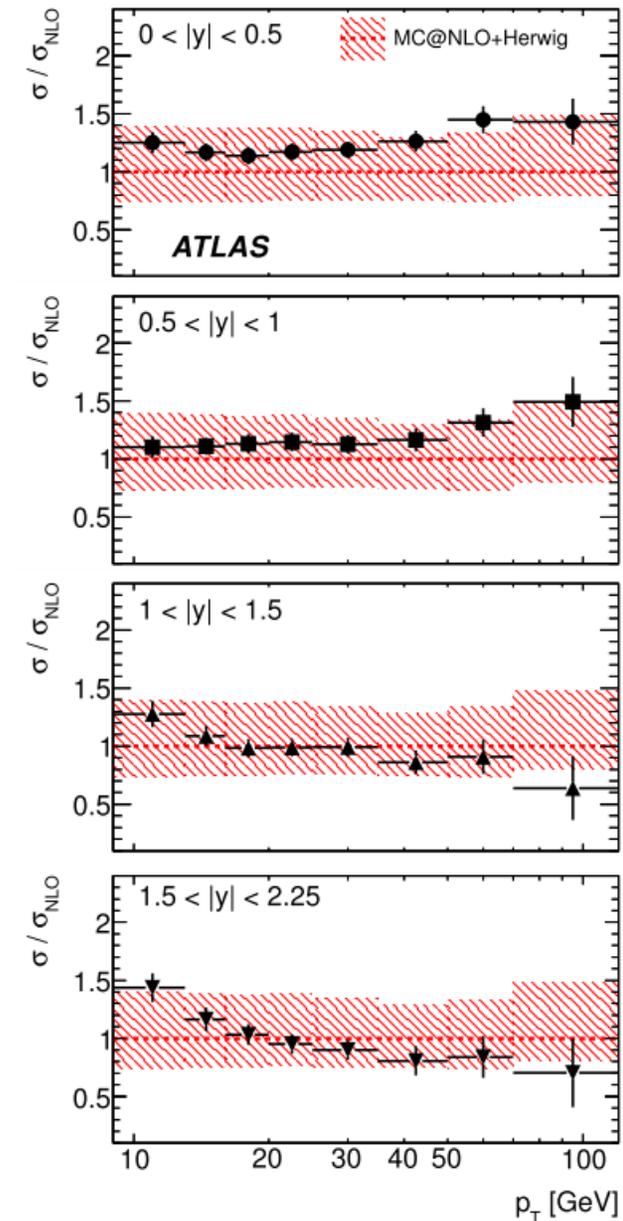
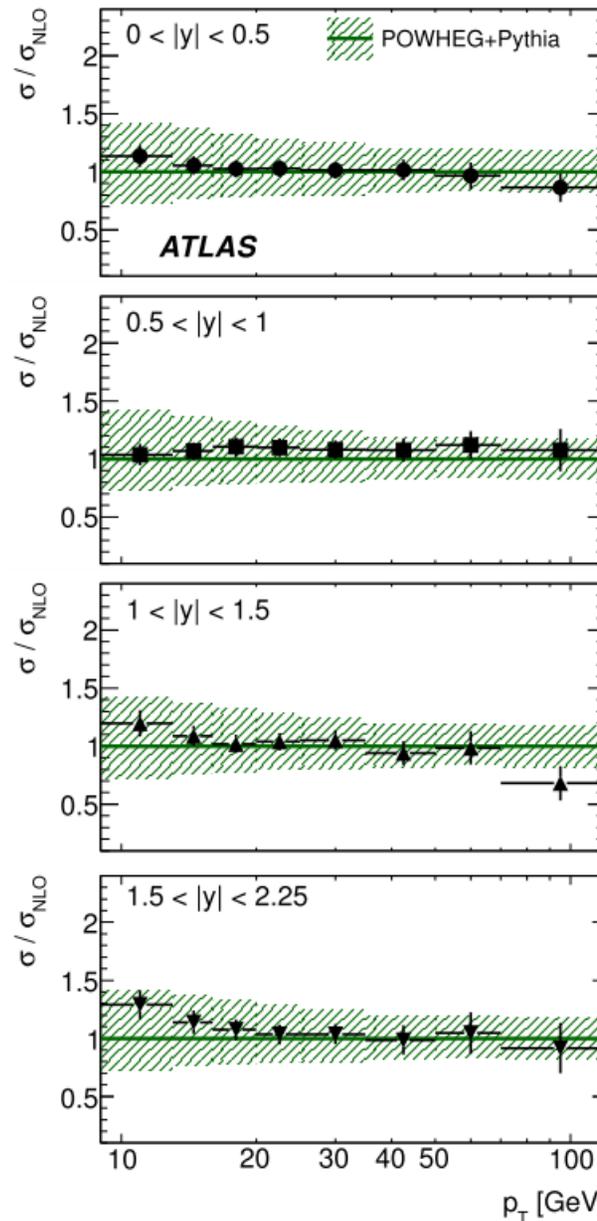
Backup slides



Open heavy flavor production in pp collisions

Good agreement between
POWHEG+PYTHIA and data

$B^+ \rightarrow J/\psi K^+$



B⁺ production in pp collisions at 7 TeV

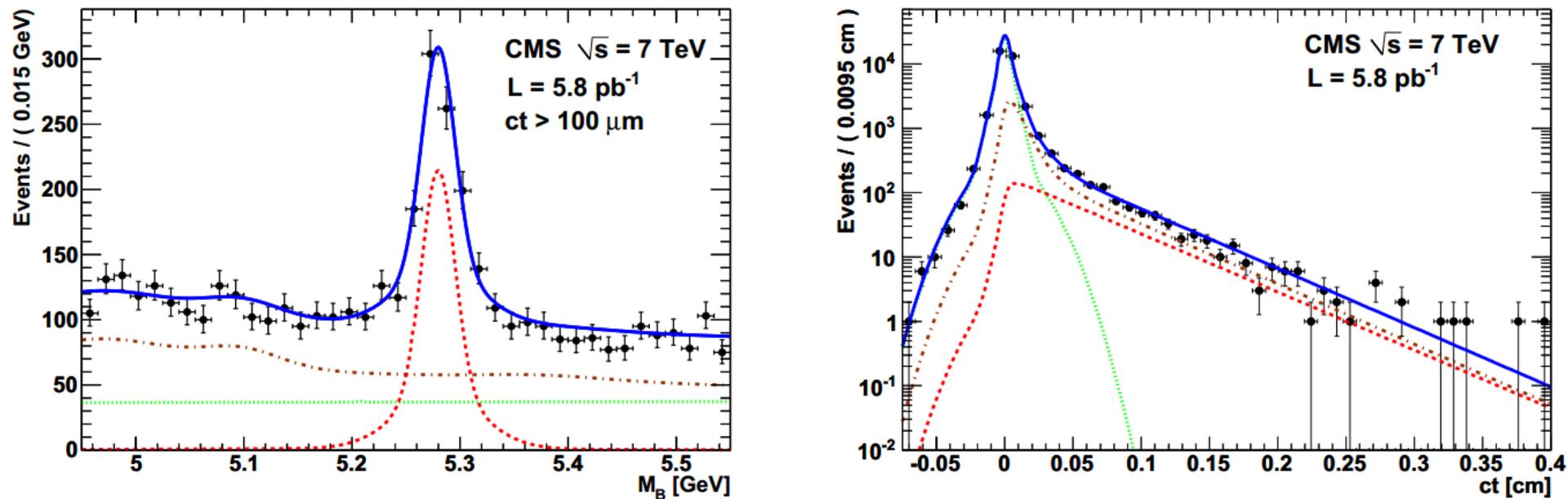
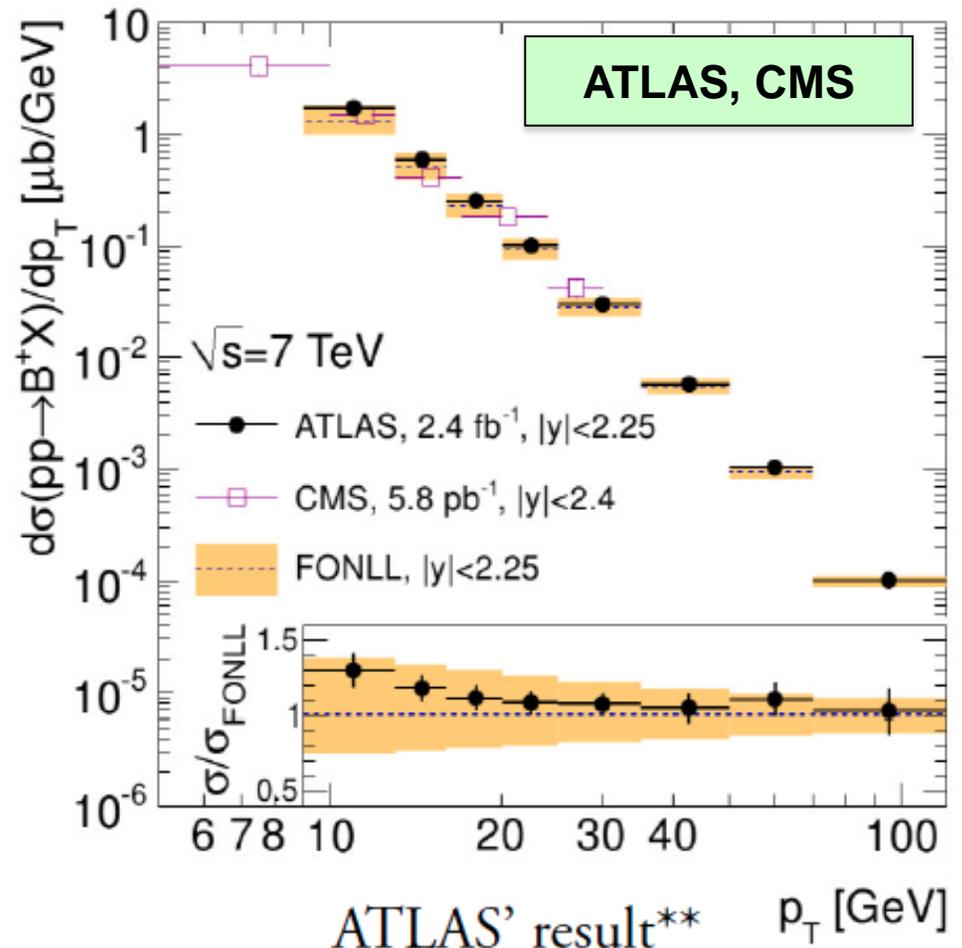
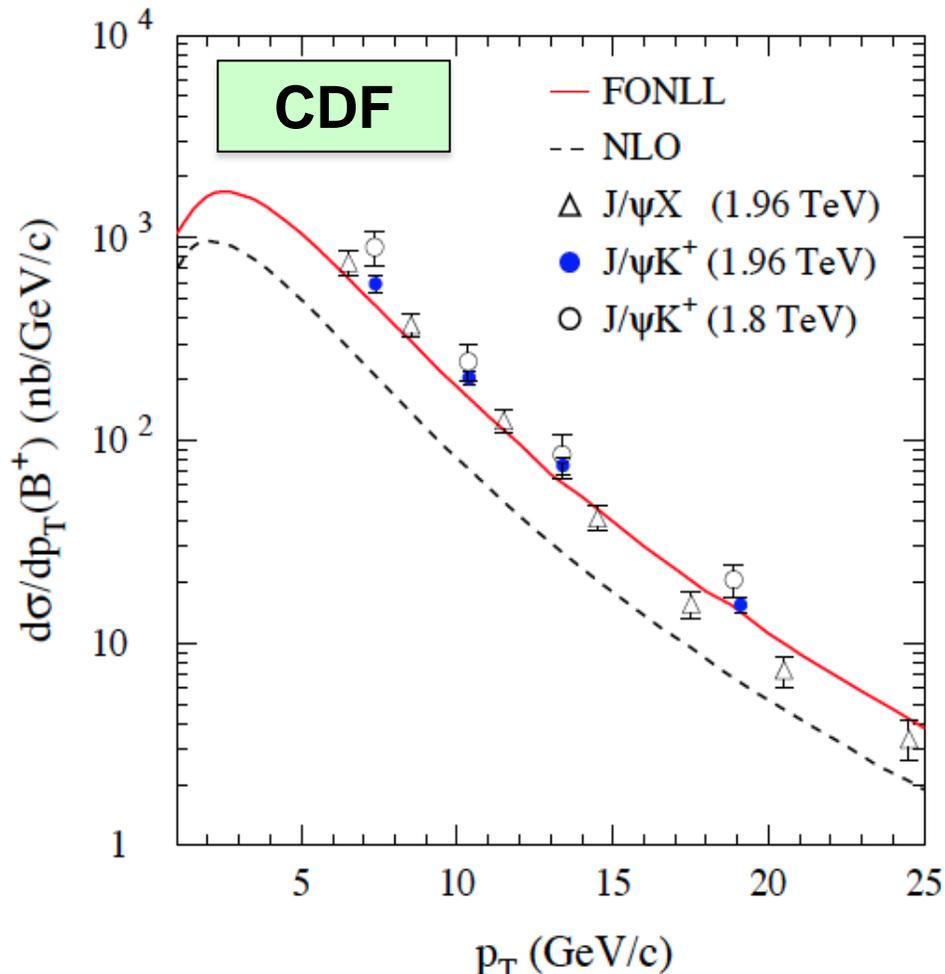


Figure 1: Projections of the fit results in M_B (left) and ct (right) for $p_T^B > 5$ GeV and $|y^B| < 2.4$. The curves in each plot are the sum of all contributions (solid blue line); signal (dashed red); prompt J/ψ (dotted green); and the sum of non-prompt J/ψ , peaking $b\bar{b}$, and $J/\psi\pi^+$ (dot-dashed brown). For better visibility of the individual contributions, the M_B plot includes a requirement of $ct > 100 \mu\text{m}$.

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

Summary of optimal cuts

Variable for B-meson selection	B ⁺	B ⁰	B _s
χ^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 ²)		<0.23	< 0.016