Studies of Strange and Non-Strange Beauty Productions in PbPb Collisions with the CMS Detector

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Open Heavy Flavor Physics in Relativistic Heavy Ion Collisions

Heavy quarks as hard probes to study QGP

- Heavy quarks: $m_q \sim$ O(GeV)

➡ Creation in the early hard scattering process. Calculable in pQCD.

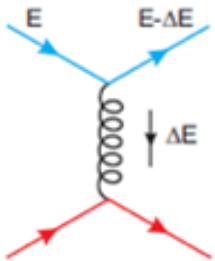
➡ Long thermal relaxation time

- Significant fraction of energy loss when propagating through QGP

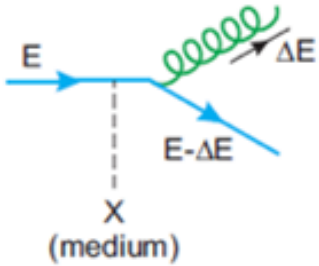
➡ Probe QGP by studying the energy loss mechanism

Energy loss mechanism of heavy quarks

Collisional



Radiative



Partons Energy Loss in the Medium

- **p_T spectrum and R_{AA}**

➡ Test the calculations of perturbative QCD in pp collisions

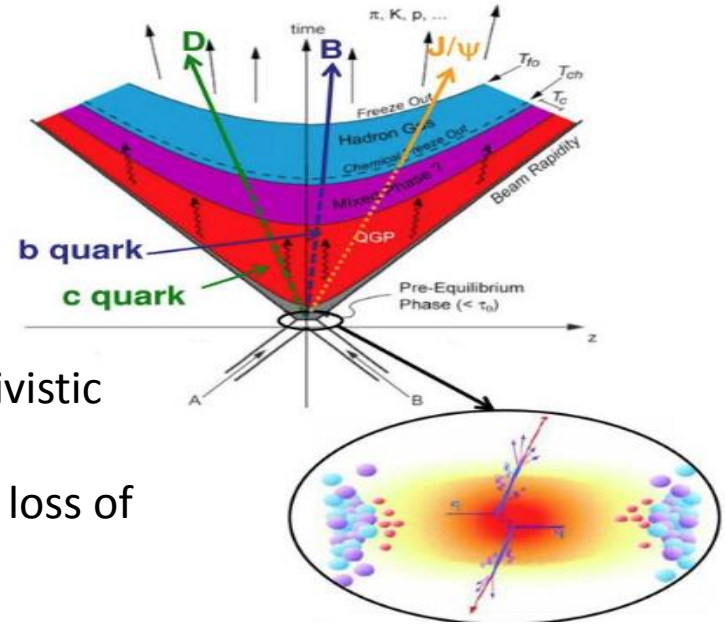
➡ Understand the QGP medium effects on heavy flavor quarks

- **Relevant physics**

➡ Partons lose energy in the QGP medium

➡ Flavor dependence of energy loss

➡ Dead cone effect [1]



- **Predictions**

➡ Suppression of heavy flavor hadrons productions in relativistic heavy-ion collisions

➡ R_{AA} of different hadrons reveals the difference in energy loss of different partons

[1] Phys. Lett. B 519 (2001) 199

Strangeness Enhancement for Hadronization with Medium

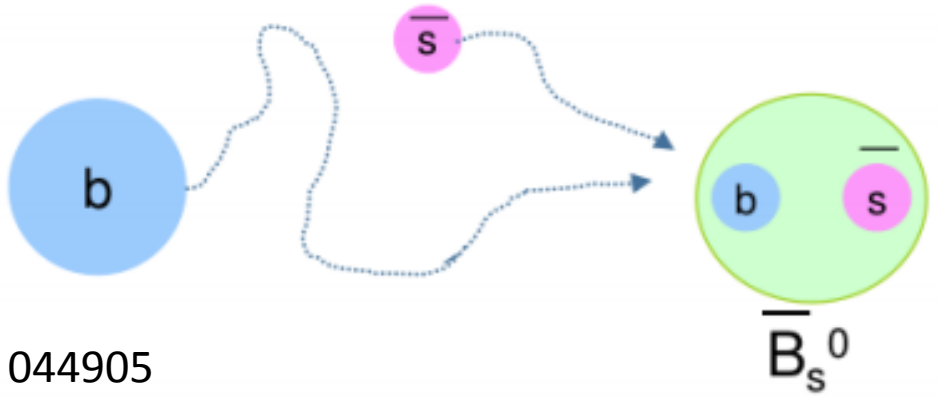
Thermally and chemically equilibrated QGP medium

➡ Temperature > strange quark mass

➡ Strange quark production is enhanced via $gg \rightarrow s\bar{s}$

➡ Expected strangeness enhancement in charm and bottom hadronization via the recombination mechanism [2]

➡ Understand the effects of the QGP medium on the hadronization of heavy quarks



[2] Phys. Rev. C79 (2009) 044905

Non–Prompt J/ψ and D^0

B^+ and B_s^0

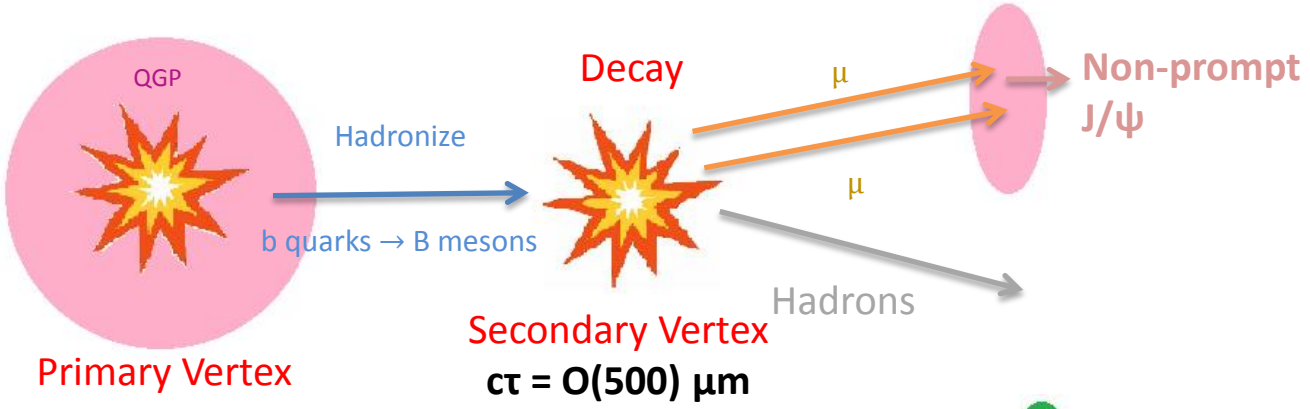
New: D_s and D^0

Non–Prompt J/ψ and D^0

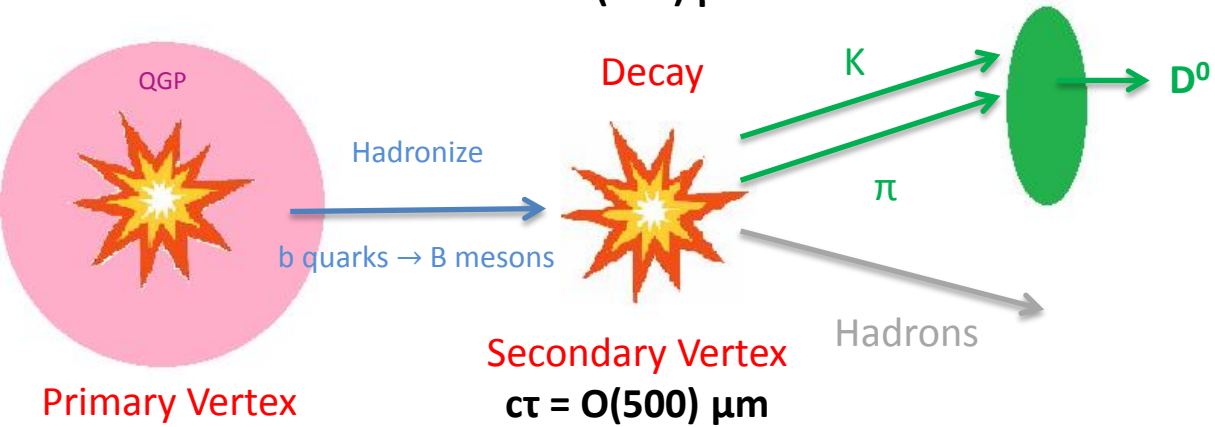
B^+ and B_s^0

New: D_s and D^0

Partial Decay: Non-Prompt J/ψ and D^0 Reconstruction



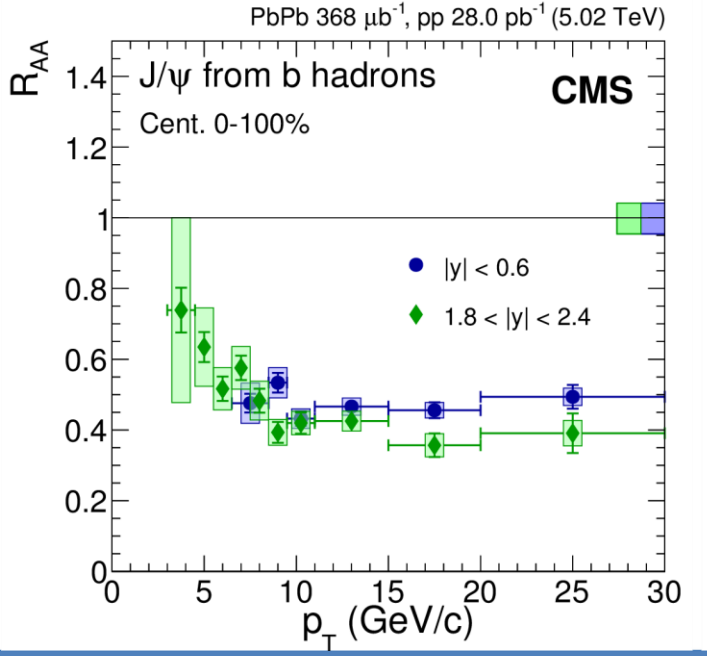
- Non-prompt J/ψ are reconstructed from muon pairs
- Muon identification, quality, acceptance are applied

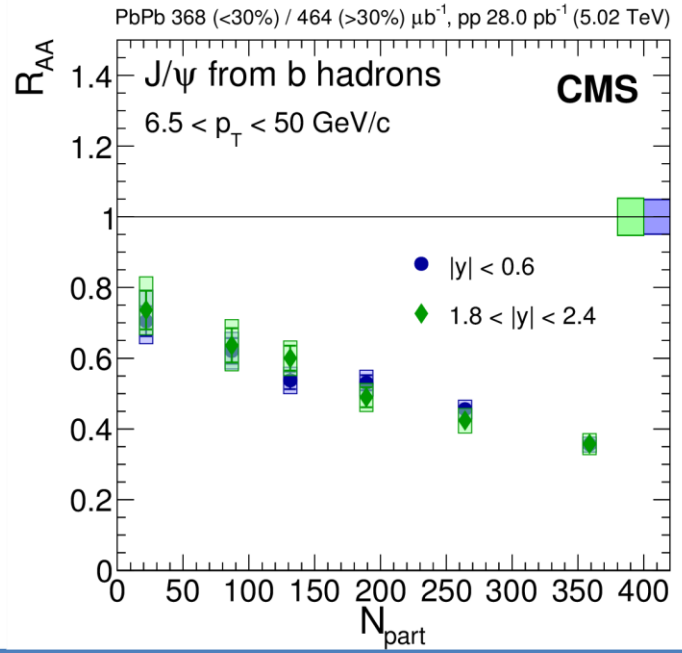


- Non-prompt D^0 are reconstructed from $K\pi$ pairs
- Optimize BDT selections on $K\pi$ tracks variables

Non-Prompt J/ψ R_{AA} vs p_T and N_{part}

- Significant suppression of non-prompt J/ψ
- Higher suppression of non-prompt J/ψ in more central collisions
- No p_T dependence of non-prompt J/ψ on at $p_T > 5$ GeV/c





Non-Prompt D^0 Reconstruction and Signal Extraction

D^0 invariant mass fit:

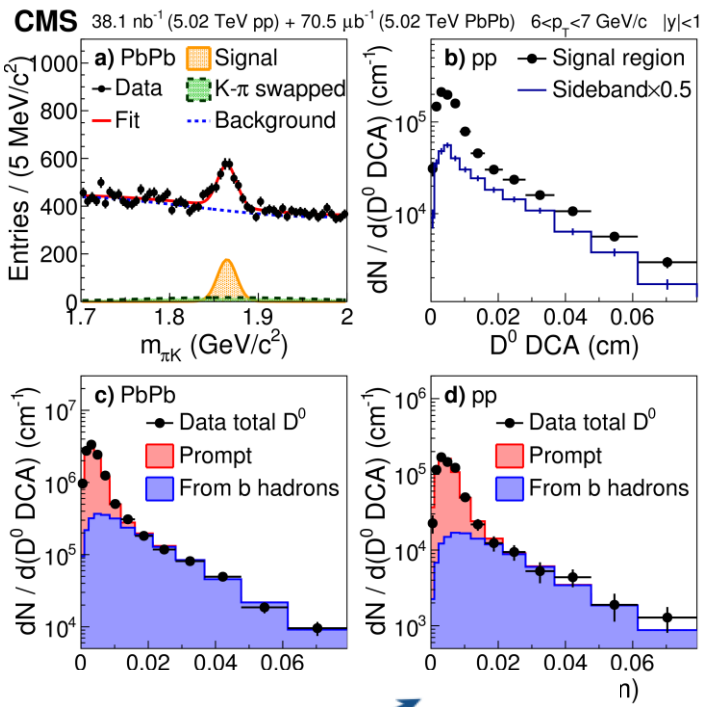
- Double Gaussian (Signal)
- 3rd order polynomial (Combinatorial)
- Single Gaussian (K-π swapped: candidates with wrong mass assignment)

➡ Not using PID

- **Non-prompt fraction of D^0 mesons Extraction (Data-Driven Method)**

➡ Fit the data DCA with **prompt** and **non-prompt** MC

➡ Correct the to inclusive D^0 spectra with the non-prompt fractions in pp and PbPb



Non-Prompt D^0 R_{AA} vs p_T

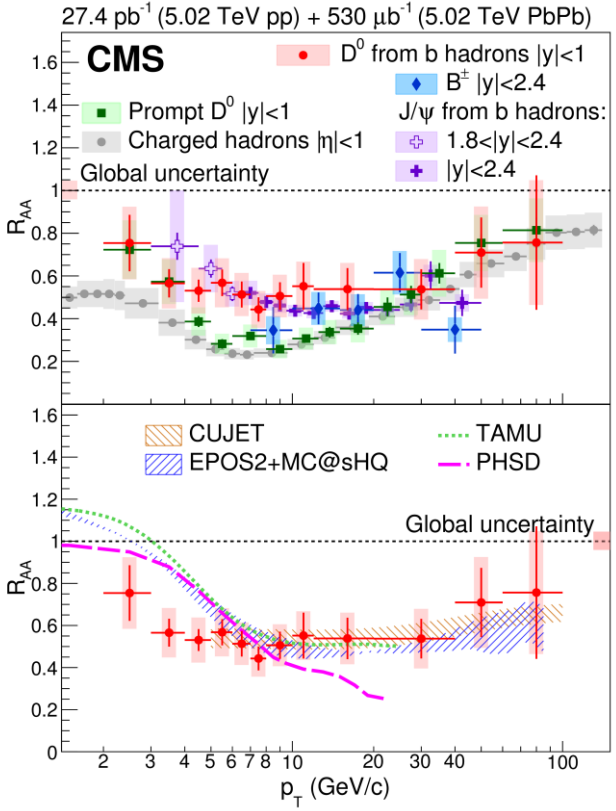
Comparison with other heavy flavor measurements

- **Non-prompt D^0 suppression** at 2 – 100 GeV/c
- **Non-prompt D^0 R_{AA}** is **comparable** to the **B^+ R_{AA}**
- **Non-prompt D^0 R_{AA}** is higher than **prompt D^0** below 20 GeV/c → **bottom quarks** lose less energy than **charm quarks** in the QGP medium

Comparison with theoretical predictions

- Compatible with theories including collisional and radiative energy loss (eg. **CUJET**)
- Models with only collisional energy loss have different predictions at high p_T (eg. **PHSD**)

X. Jiechen et al., JHEP **2** (2016) 169
P. B. Gossiaux et al, Nucl. Phys., A931 (2014) 581
M. He et al., Phys. Lett. B **735** (2014) 445 – 450
T. Song et al., Phys. Rev. C **92** (2015)



Open Heavy Flavor Physics Measurements

Non–Prompt J/ψ and D^0

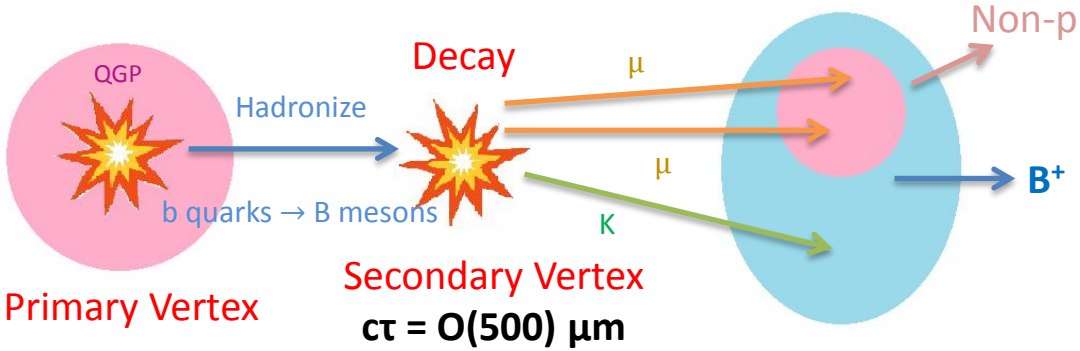
B^+ and B_s^0

New: D_s and D^0

B mesons Decay Chains and Full Reconstruction

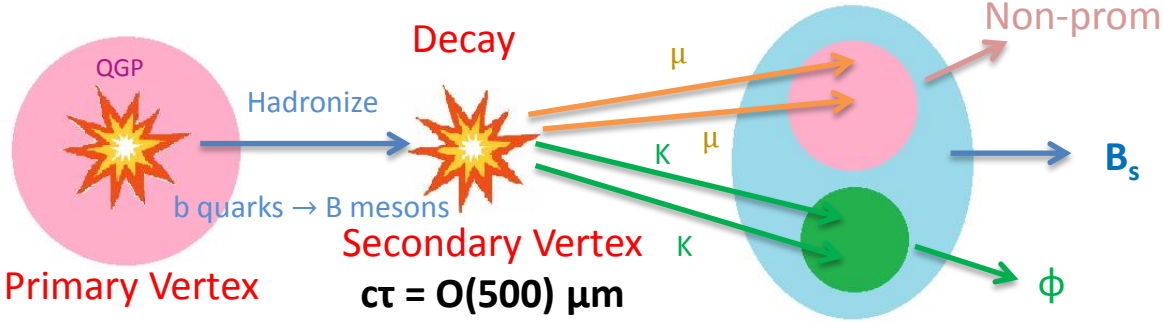
Reconstruction Strategies

- B^+: via the decay channel $B^+ \rightarrow J/\psi K^+ \rightarrow \mu^+\mu^- K^+$ (Branching Ratio = 1.01×10^{-3}).



- **Not using hadronic PID**
- **Precise vertexing and tracking**
- **Statistically enriched and dedicated dimuon triggered datasets**

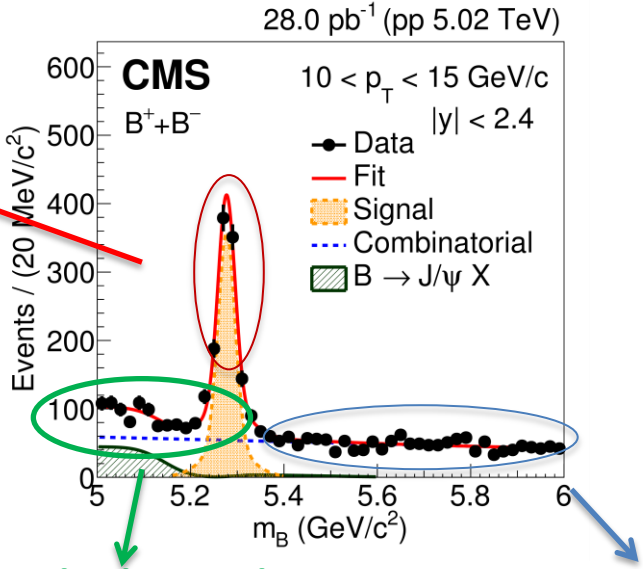
- B_s^0 : using the decay channel $B_s^0 \rightarrow J/\psi\phi \rightarrow \mu^+\mu^- K^+K^-$ (Branching Ratio = 1.08×10^{-3}).

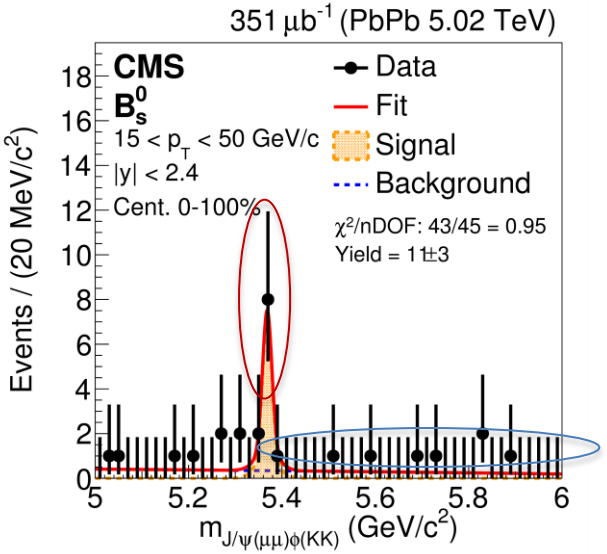


B^+ and B_s^0 Mesons Signal Extraction

- Signal extraction from fits on invariant mass distributions
- Background: combinatorial background + other B hadrons decays than our signal channels
  - $B^0 \to J/\psi K^*$ rejected with $|m_{KK} - m_\phi| < 0.015$ GeV/c² → No non-prompt B_s^0 background

Signal: Double Gaussian with the same mean



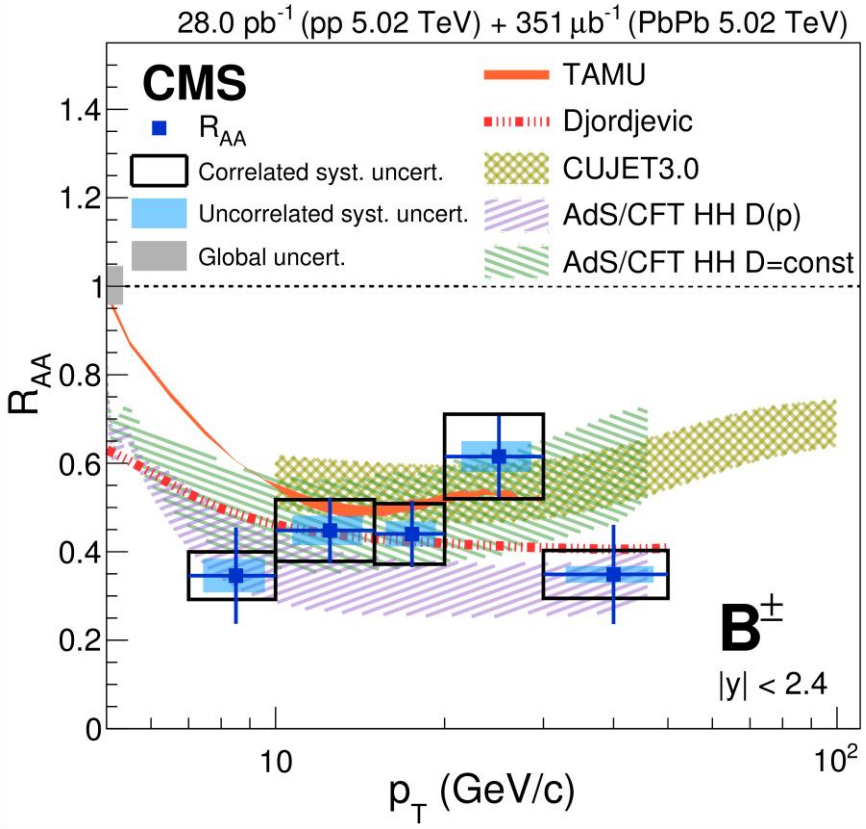


Non-prompt B decay background: Error function + 2 sided Gaussian

Combinatorial Background: Linear Function

B^+ Mesons R_{AA} and Comparison with Theoretical Predictions

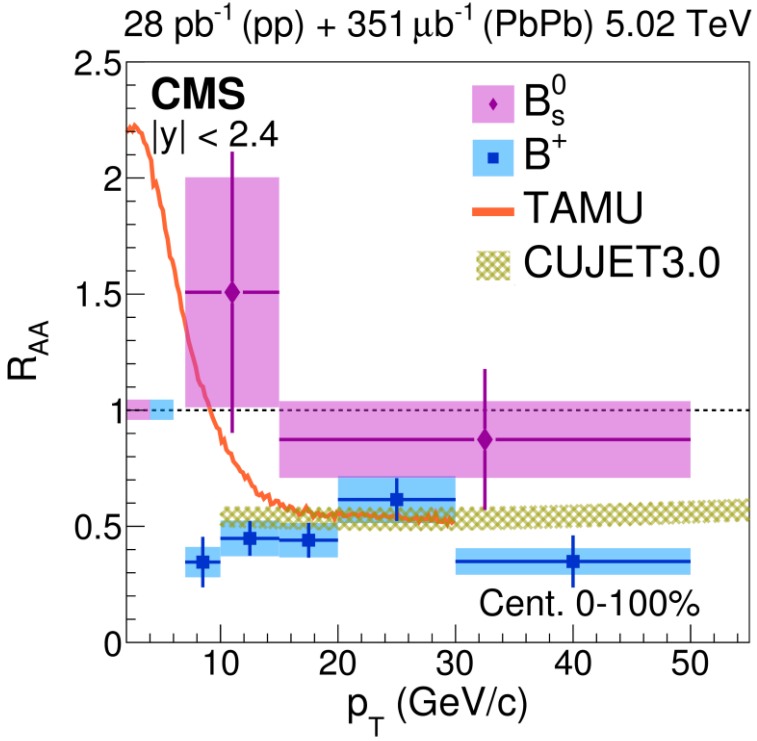
- **Supression of B^+ meson** production in PbPb collisions → b quarks lose energy in the QGP
- **No obvious p_T dependence** at 7 – 50 GeV/c
- **Consistent** with most theoretical predictions at 7 – 50 GeV/c



M. He et al., Phys. Lett. B **735** (2014) 445
M. Djordjevic, Phys. Rev. C **94** (2016) 044908
X. Jiechen et al., JHEP **2** (2016) 169
W. A. Horowitz, Phys. Rev. D 91 (2015) 085019
P. B. Gossiaux et al, Nucl. Phys., A931 (2014) 581

B_s^0 Mesons R_{AA} and Comparison with Theoretical Predictions

- Less suppression of B_s^0 mesons compared to B^+ mesons in PbPb collisions → potentially due to **strangeness enhancement** in QGP
- **Substantial statistical and systematic uncertainties** in B_s^0 measurement



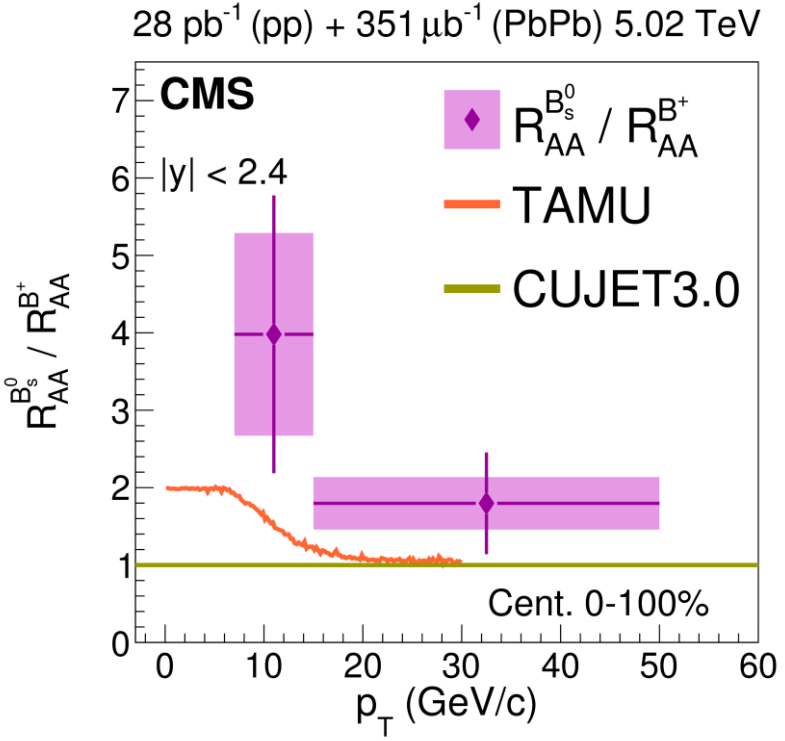
Phys. Letts. B. 796, 168

M. He et al., Phys. Lett. B **735** (2014) 445 – 450

X. Jiechen et al., JHEP **2** (2016) 169

B_s^0/B^+ R_{AA} and Comparison with Theoretical Predictions

- Complete cancelations of correlated systematic uncertainties of B_s^0 and B^+
- Indication of greater B_s^0/B^+ ratio than unity



Phys. Letts. B. 796, 168

M. He et al., Phys. Lett. B **735** (2014) 445 – 450

X. Jiechen et al., JHEP **2** (2016) 169

Open Heavy Flavor Physics Measurements

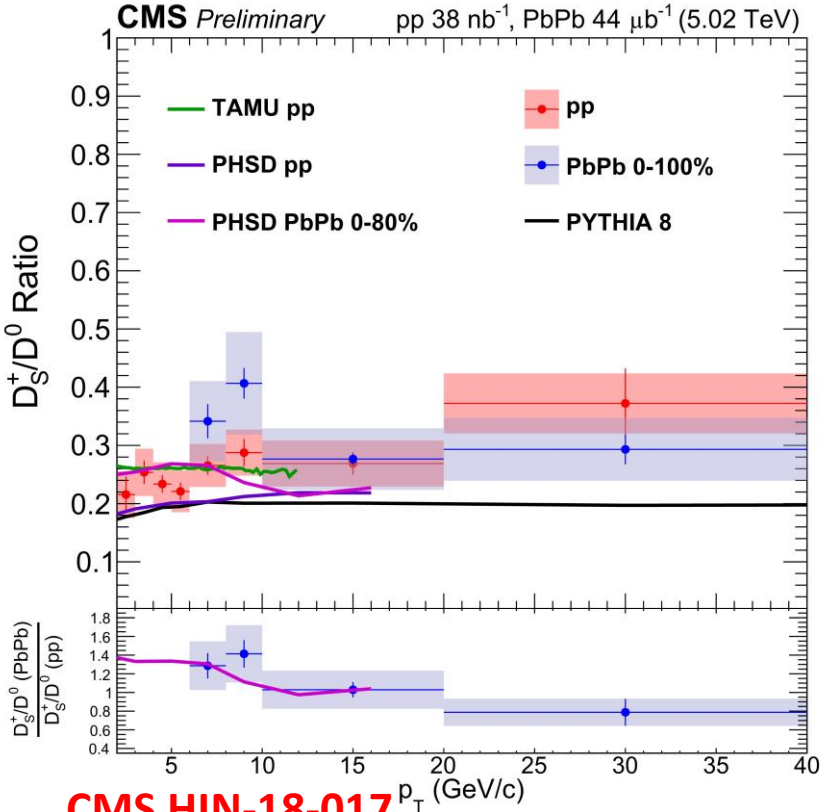
Non–Prompt J/ψ and D^0

B^+ and B_s^0

***New*: D_s and D^0**

New: Studies of D_s and D^0 Mesons

- Precise measurements of prompt $\boldsymbol{D_s}$ and $\boldsymbol{D^0}$ mesons productions in both **pp** above 3 GeV/c and **PbPb** above 6 GeV/c
- No significant strangeness enhancement at intermediate p_T 6 – 40 GeV/c in **PbPb** compared to **pp** within $\boldsymbol{D_s/D^0}$ **uncertainties**
- Both **TAMU** and **PHSD** agree reasonably well with D_s/D^0 in **pp**
- **PHSD** predictions are **comparable** to the $\boldsymbol{D_s\ /D^0}$ **double ratio**



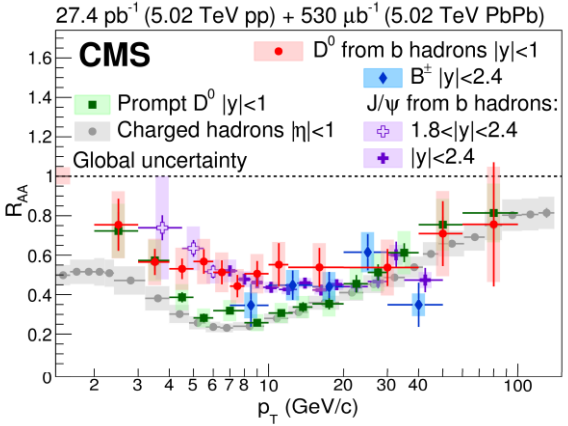
CMS HIN-18-017

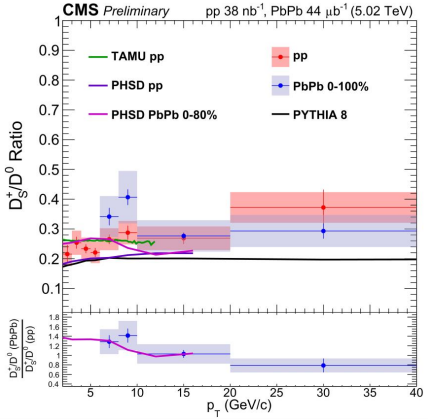
T. Song et al., Phys. Rev. C **93** (Mar, 2016) 034906

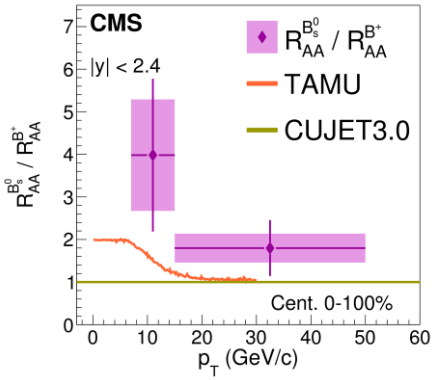
M. He and R. Rapp, Phys. Letts .B **795** (2019) 117 – 121

Summary and Future Outlook

- Suppressions for **B mesons**, **non-prompt J/ψ**, and **non-prompt D^0** productions in PbPb collisions
- Indication of flavor dependence of parton energy loss
- Hint of greater B_s^0/B^+ ratio than unity
- No significant strangeness enhancement at intermediate p_T 6 – 40 GeV/c in **PbPb** compared to **pp** within **D_s/D^0 uncertainties**
- **More precise and differential B mesons measurements** with **2017 pp** and **2018 PbPb** datasets in the future







Thank You

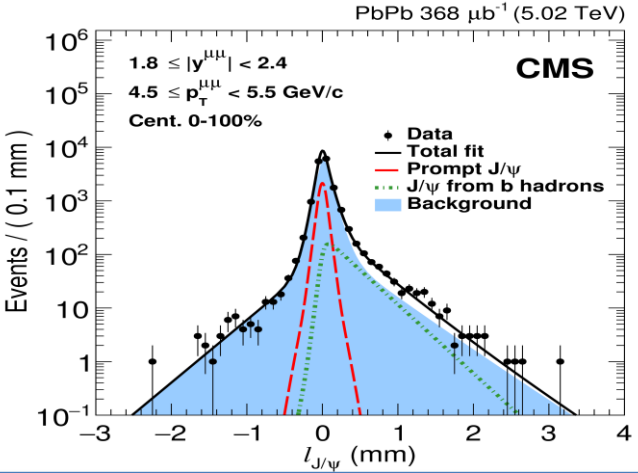
This MIT group's work was supported by US DOE-NP and NSF-GRFP

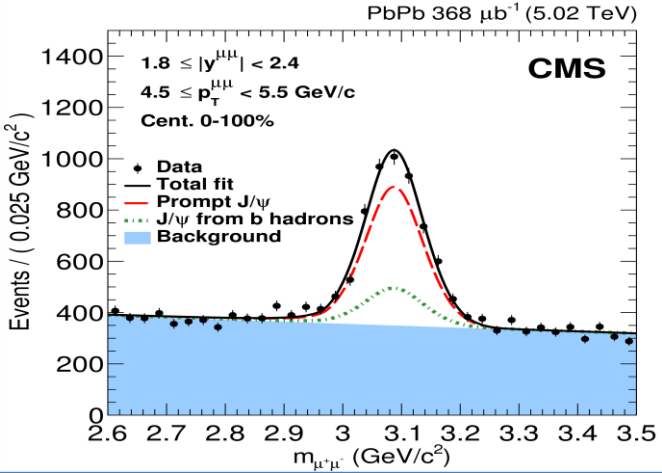
Back up

Non-Prompt J/ψ Reconstruction and Signal Extraction

Non-Prompt J/ψ analysis techniques

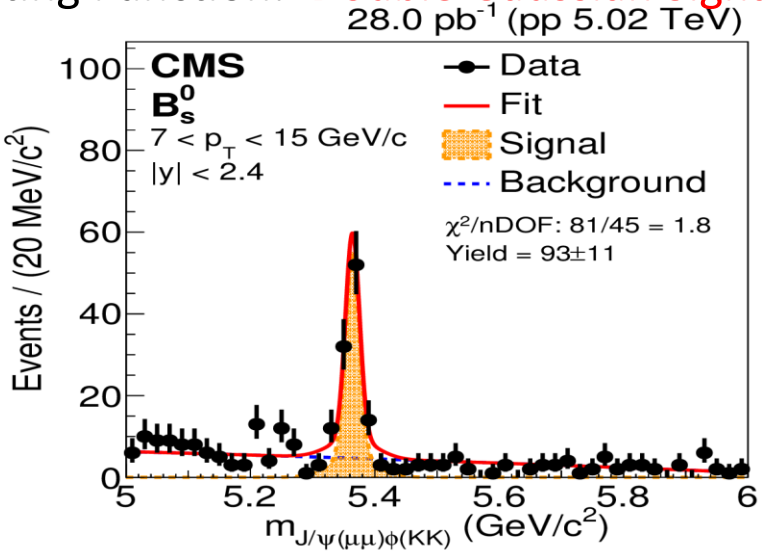
- Muon quality, identification, and acceptance applied to the muons selections
- Muons pairs fits to a comment vertex → J/ψ candidates
- Prompt J/ψ component are obtained from the proper decay length l_{xy} distribution
- Non-prompt J/ψ is exacted by subtracting the prompt J/ψ component from the inclusive $J/\psi \rightarrow \mu^+\mu^-$ decay channel
- Data-driven tag and probe scaling factor are applied to correct the extracted J/ψ yield

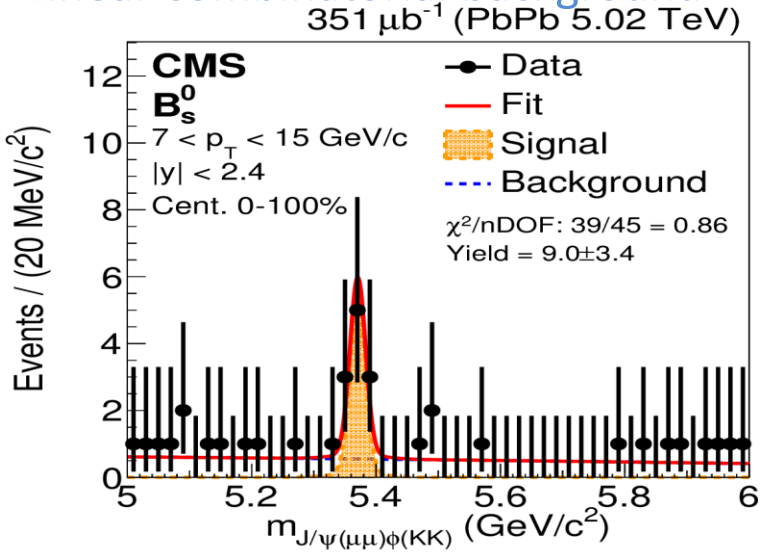




B_s^0 Mesons Signal Extraction

- Signal Extraction from unbinned fit (maximum likelihood) on the invariant distribution
- Rejecting $B^0 \rightarrow J/\psi K^*$ contribution by requiring 0.015 GeV/c^2 near ϕ meson PDG mass
- Background: combinatorial background only (no other contribution of B hadron decay that will affect our signal region)
- Fitting Function: Double Gaussian Signal + Linear combinatorial background





D_s Reconstruction and Signal Extraction

- Decay channel: $D_s \rightarrow \phi\pi \rightarrow K^+K^-\pi$
- Optimization of with rectangular cut decay length significance and vertex probability using TMVA framework in ROOT with the decay angle $\alpha < 0.12$ and ϕ meson mass window fixed
- Semi-data driven non-prompt D_s fraction extraction

  1) D_s to D^0 relative scale: fragmentation fraction from LHCb and branching ratio from PDG

  2) p_T differential spectra correction: from MC simulations to correct D^0 non-prompt fraction vs p_T to D_s

- Unbinned maximum likelihood fits for signal extraction:
  - Signal: double Gaussian with the same mean
  - Background: Second Order Chebyshev polynomial