Measurements of strange and non-strange beauty hadron production in PbPb collisions at 5.02 TeV with the CMS detector

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• Physics motivations
• Data analysis techniques
  – Beauty measurements via decay D and J/ψ
  – Full reconstruction of B and $B_s$ decays
• Results
• Summary
Physics motivation

- Heavy quark energy loss, coalescence/hadronization
- Heavy, predominantly produced in early hard scatterings, carry information about QGP evolution history
- Heavy quarks lose energy in QGP medium by collisional and radiative interactions
- Beauty: heavier and cleaner than Charm
- $B_s/B$: strangeness enhancement, coalescence
CMS detector

precise all-silicon trackers: reconstruct heavy flavor using their decay length

all fast detector

calorimeters: high $p_T$ trigger

CMS DETECTOR
- Total weight: 14,000 tonnes
- Overall diameter: 15.0 m
- Overall length: 28.7 m
- Magnetic field: 3.8 T

STEEL RETURN YOKE
- 12,500 tonnes

SILICON TRACKERS
- Pixel (100x150 µm) ~16m² ~66M channels
- Microstrips (80x180 µm) ~200m² ~9.6M channels

SUPERCONDUCTING SOLENOID
- Niobium titanium coil carrying ~18,000A

MUON CHAMBERS
- Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
- Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

PRESHOWER
- Silicon strips ~16m² ~137,000 channels

FORWARD CALORIMETER
- Steel + Quartz fibres ~2,000 Channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
- ~76,000 scintillating PbWO₄ crystals

HADRON CALORIMETER (HCAL)
- Brass + Plastic scintillator ~7,000 channels
B measurement via decay D

**B→D⁰ and prompt-D⁰ separation**

- B→D⁰: non-zero DCA (Distance of Closest Approach) due to B decay
- Prompt-D⁰: DCA only from track and vertex resolution

**B → D⁰**

- cτ~500μm
- BR~59%

**Non-prompt D**

- D⁰→Kπ⁺
  - BR = 3.9%
  - cτ = 123 μm

**Assume Kπ and πK**

1. Track pair fit to a common vertex → D candidates
2. Signal extraction in DCA interval → DCA distribution
3. Template fit (from simulation) on DCA to extract non-prompt D

CMS, arXiv:1810.11102
B → J/ψ and prompt-J/ψ separation

B → J/ψ
• cτ~500μm
• BR~1%

1. Muon pair fit to a common vertex → J/ψ candidates
2. 2D Fit on invariant mass and decay length spectra
3. Extracted yields corrected by a data-driven approach (tag & probe)

prompt J/ψ: direct production + feed down (ex ψ’)
non-prompt J/ψ: from B decays (ex B → J/ψ X)

CMS, EPJC 78 (2018) 509
Full reconstruction of B

**Signal channel:** \( B^+ \rightarrow J/\psi + K^+ \)

- \( B^+ \rightarrow J/\psi + K^+ \)
  - \( c\tau \sim 500\mu m \)
  - \( BR \sim 0.06\% \)

- Muon pair + track (kaon mass) \( \rightarrow \) common vertex fitting
- fit on invariant mass spectra (maximum likelihood)
- Peaking background: \( B^+ \rightarrow J/\psi + K^{*+}, \ B^0 \rightarrow J/\psi + K^{*0} \) etc

- \( b \) quark \( \rightarrow B^+, \ B^-, \ B^0 \)
Full reconstruction of $B_s$

Signal channel: $B_s \rightarrow J/\psi + \phi$

$B_s \rightarrow J/\psi + \phi$
- $c\tau \sim 500\mu$m
- $BR \sim 0.03\%$

$B$ decay

Primary vertex → $b$ quark $\rightarrow B_s$

- Muon pair + track (kaon mass) $\rightarrow$ common vertex fitting
- fit on invariant mass spectra (maximum likelihood)
- Narrow natural width of $\Phi$ meson $\rightarrow$ no peaking

background components
$R_{AA}$ of beauty from decay $D^0$ & $J/\psi$

CMS, arXiv:1810.11102
Jiechen et al., JHEP2 (2016) 169
Gossiaux et al NPA931 (2014) 581
He et al. PLB 735 (2014) 445
Song et al. PRC 92 (2015)

- High $p_T$: need collisional + rad. energy loss (e.g., CUJET), only collisional energy loss (PHSD) not seem to work.
- Low $p_T$: hint of stronger suppression than models: baryon enhancement? $\text{BR (b baryon} \rightarrow D^0) \ll (B \rightarrow D^0)$
Suppression of $B^+$ meson

• $B^+$ meson $R_{AA} \sim 0.3$ to 0.6 with no obvious trend within uncertainty

• Compatible with theory within uncertainty for $p_T$ 10-50 GeV/c

• Necessity for high $p_T$ measurement: distinguishing pQCD vs AdS/CFT base models

CMS, PRL 119 (2017) 152301

He et al. PLB735(2014)445
Djordjevic, PRC94(2016)044908
Xu et al. JHEP02(2016)169
Horowitz, PRD91(2015)085019
Gossiaux et al NPA931(2014)581
**R_{AA} zoo: B vs. D vs. light**

- Compatible results: non-prompt D, non-prompt J/ψ and B^+

- **Beauty** seems to separate from charm and light flavor up to ~ 20 GeV
  - quark mass ordering
  - parent B p_T ≠ daughter D^0 or J/ψ p_T

- **Beauty, charm and light merging** ~ 20 GeV
• Large stat. and syst. uncertainties. Correlated syst. cancel in $B_s / B^+$ $R_{AA}$ ratio.
• Hint of less $B_s$ suppression
• 2018 HI data and beyond → more precise measurement
Summary and Outlook

• CMS beauty measurements: results are consistent

• Suppression for $B^+$, non-prompt $J/\psi$, and non-prompt $D$

• Beauty hadrons appear less suppressed than charm and light flavor up to ~20 GeV

• First $B_s$ measurement in heavy ion collision

• HL-LHC data with more precise measurements
  • ~4x increase in luminosity in year 2018
  • ~20x MB data statistics in year 2018
  • Pixel detector upgrade: 3 $\rightarrow$ 4 layers