

B_s^0 and B^+ meson nuclear modification factor in PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with CMS detector

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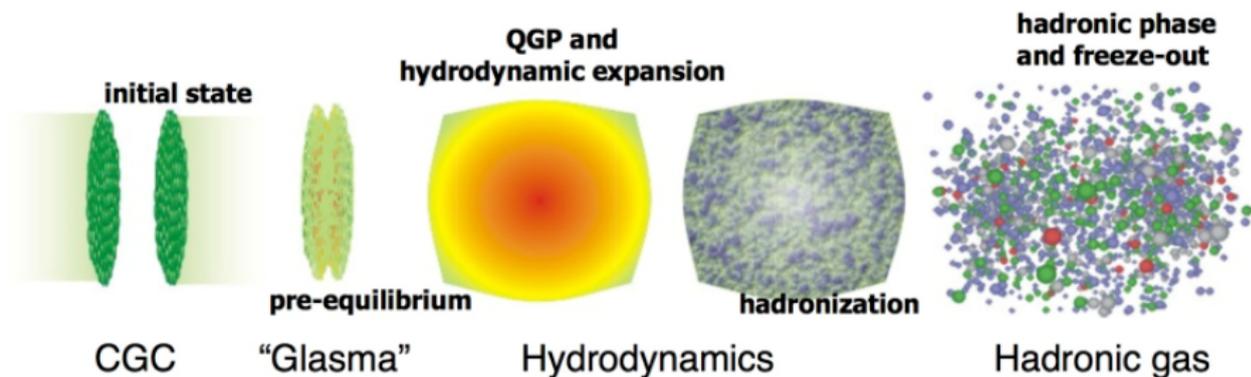
On behalf of the CMS collaboration



Hard Probes 2018
October 1st – 5th

The quark-gluon plasma **probed by heavy quarks**

- QCD at very high temperature \rightarrow **deconfinement**
 \rightarrow quarks and gluons move freely in a quark-gluon plasma



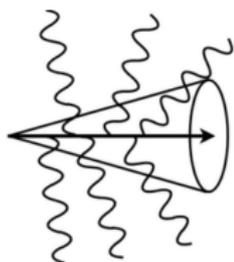
- **Heavy quarks** produced on smaller time scales than QGP expansion
 \rightarrow brings information on the **whole QGP history**

Flavour dependence of energy loss

- Heavy quarks **lose energy** in the QGP (gluon radiation, elastic collisions).

However:

- Smaller energy loss than gluons, due to **smaller color charge**
- Smaller energy loss than light quarks, due to possible **dead-cone effect** (relevant at low p_T)

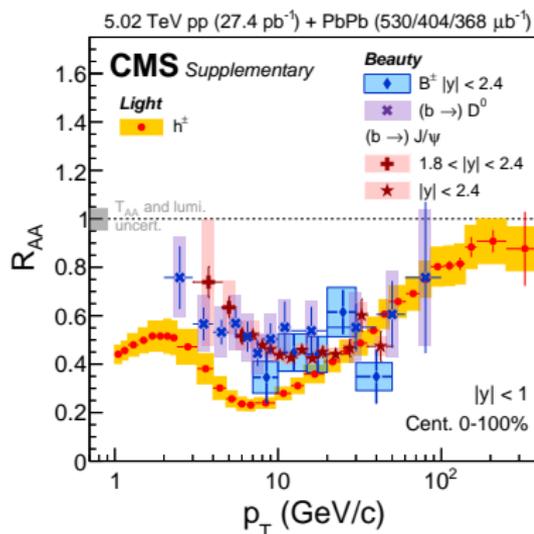


PLB 782 (2018)

EPJC 78 (2018)

JHEP 04 (2017)

$$\rightarrow 1 > R_{AA}(B) > R_{AA}(D) > R_{AA}(h^\pm) \dots$$



A strange story for heavy mesons

• How strange is the QGP?

Known strangeness enhancement in the QGP

→ Enhancement of **strange heavy mesons**?

Recombination of heavy quark with a s from the medium?

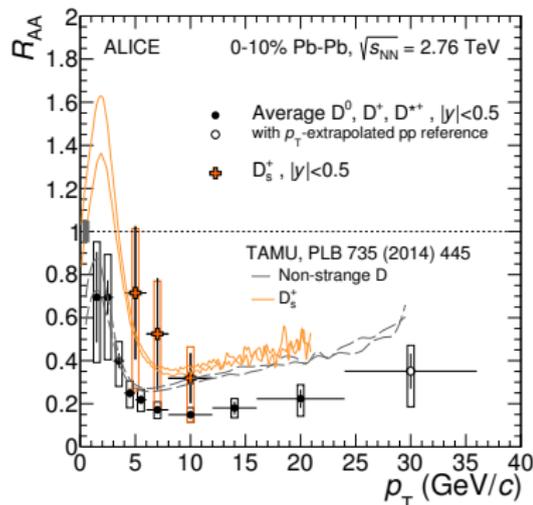
→ Compare B^+ and B_s^0 suppression, to isolate recombination effects



Hint in ALICE: $R_{AA}(D_s^+) > R_{AA}(D)$

(JHEP 03 (2016) 082)

→ Measure **double ratio** $\frac{R_{PbPb}(B_s^0)}{R_{PbPb}(B^+)}$



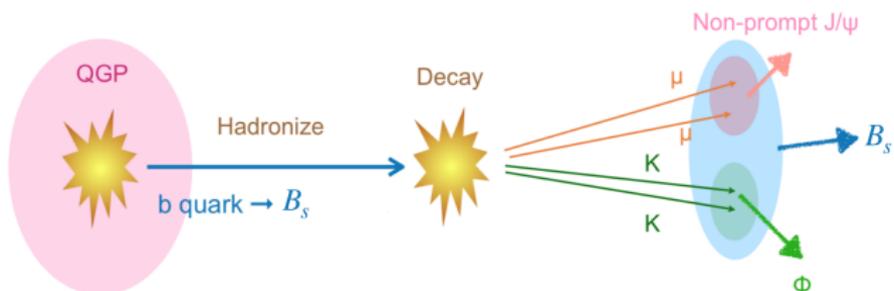
Analysis strategy

- $R_{\text{PbPb}}(B^+)$ already measured ($B^+ \rightarrow J/\psi K^+$ channel) (PRL 119 (2017))
 → **New analysis:** $R_{\text{PbPb}}(B_s^0)$ at $\sqrt{s_{\text{NN}}} = 5.02$ TeV

$B_s^0 \rightarrow J/\psi \phi$ channel

$J/\psi \rightarrow \mu^+ \mu^-$

$\phi \rightarrow K^+ K^-$

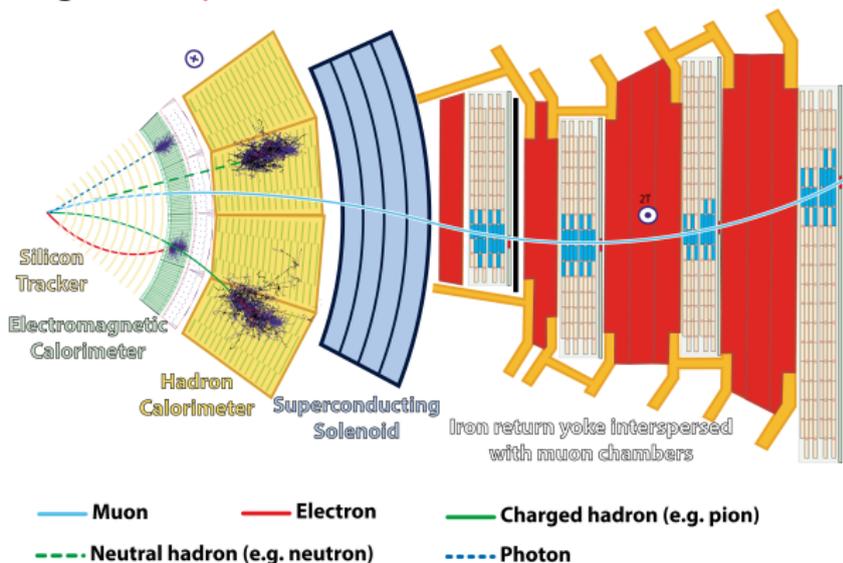


- Measurement of pp and PbPb cross sections of B_s^0 in $|y| < 2.4$ and $p_T > 7$ GeV
 → $R_{\text{PbPb}}(B_s^0)$, i.e. **first measurement of B_s^0 in heavy ion collisions**
- Displaced vertex reconstruction, signal selection with a MultiVariate Analysis, acceptance + efficiency + background with MC

CMS data and MC samples

- Extensive use of CMS good **displaced vertex reconstruction**

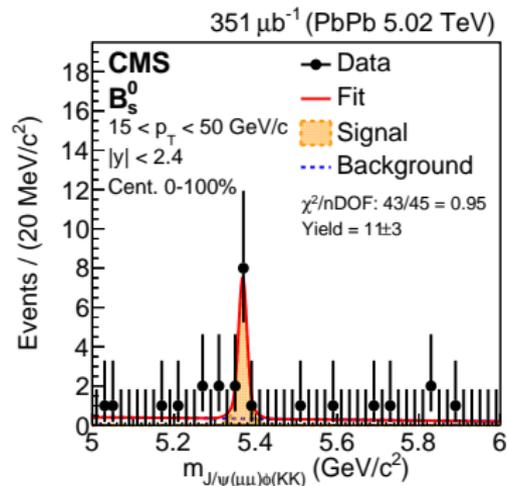
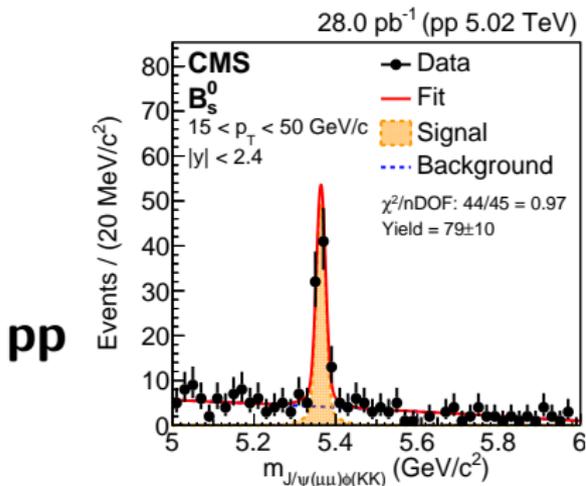
- Kaons:** tracker
- Muons:** tracker + muon chambers



- data: 2015 RunII at $\sqrt{s_{NN}} = 5.02$ TeV, pp and PbPb
- MC: PYTHIA8 + GEANT4 + EVTGEN + PHOTOS + HYDJET
- ➔ evaluate background and signal efficiencies + acceptance corrections

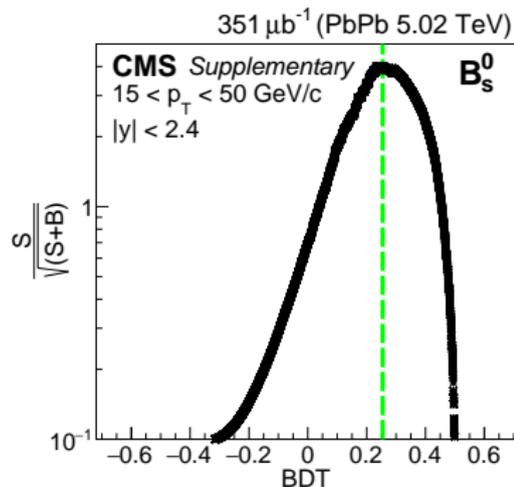
Reconstruction and selection

- $J/\psi = \text{dimuon}$ in $m_{J/\psi} \pm 150 \text{ MeV}$, with displaced vertex probability > 0.01
- $\phi =$ displaced vertex fit of opposite-charge **selected tracks**, with invariant mass in $m_\phi \pm 15 \text{ MeV}$ (optimised range for signal significance)
- $B_s^0 =$ a J/ψ and a ϕ from same vertex (fixed J/ψ and K^\pm masses)
- **Final selection** done with **BDT** with discriminant variables



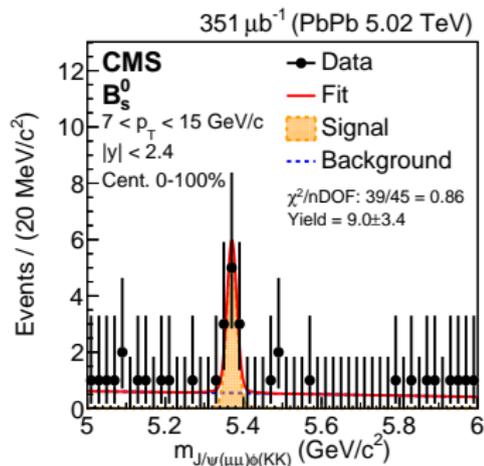
Focus on the Boosted Decision Tree

- Goal: **maximize the statistical significance** of B_s^0 signal
- Signal sample: B_s^0 **MC** (scaled to FONLL prediction)
Background sample: B_s^0 **mass sidebands** in data
(describes well the bkg from random J/ψ and ϕ combinations)
- Input for BDT = variables with distinct signal and background shapes
- Gives **BDT variable**, which is cut to get the highest significance
- Checks with MC prompt J/ψ sample that (combinatorial) background is **not artificially peaking** due to BDT



Signal extraction: fit of raw yields

- Fit with unbinned extended maximum likelihood method B_s^0 mass
- **Double gaussian** (same means) for signal + **linear** function for combinatorial background
- Signal shapes from MC
- **Non-prompt** J/ψ background (from other B mesons) **negligible** thanks to tight ϕ mass cut



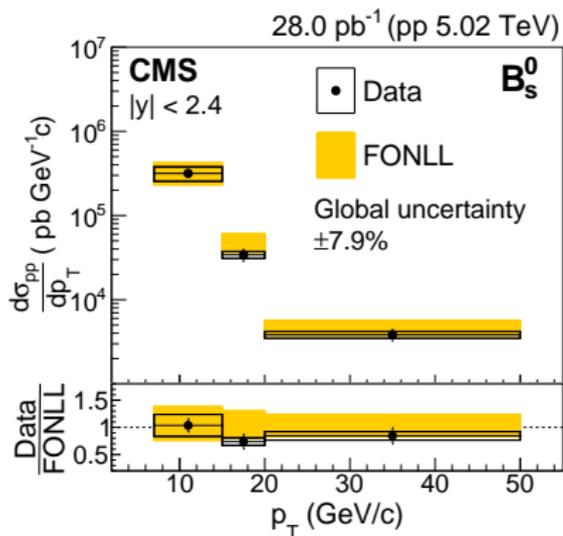
Getting the cross sections and R_{PbPb}

$$\left. \frac{d\sigma_{pp}^{B_s^0}}{dp_T} \right|_{|y|<2.4} = \frac{1}{2} \frac{1}{\mathcal{B}} \frac{1}{\mathcal{L}} \frac{1}{\Delta p_T} \frac{N_{pp}^{(B_s^0 + \bar{B}_s^0)}(p_T)}{\alpha_{pp}(p_T)\varepsilon_{pp}(p_T)} \Big|_{|y|<2.4}$$

$$\left. \frac{1}{T_{AA}} \frac{dN_{PbPb}^{B_s^0}}{dp_T} \right|_{|y|<2.4} = \frac{1}{2} \frac{1}{\mathcal{B}} \frac{1}{N_{MB}} \frac{1}{T_{AA}} \frac{1}{\Delta p_T} \frac{N_{PbPb}^{(B_s^0 + \bar{B}_s^0)}(p_T)}{\alpha_{PbPb}(p_T)\varepsilon_{PbPb}(p_T)} \Big|_{|y|<2.4}$$

- $N_{pp,PbPb}$ from the fits
- **Branching fraction** from PDG: $\mathcal{B} = (3.12 \pm 0.24) \times 10^{-5}$
- **Acceptance** α and **efficiency** ε corrections calculated with MC
 - Comparison of MC and data distributions for discriminant variables
 → no bias for BDT

Proton-proton cross section: comparison to FONLL



- Spectrum calculated for all b-quark hadrons. Uncertainty from variation of m_b , m_c , μ_R , and μ_F .
- Apply (constant) production fraction of B_s : 10.3% from PDG (hypothesis checked with PYTHIA)

Systematics on pp and PbPb cross sections

Done separately for each p_T bin:

	source	Rel. error on R_{PbPb}
	luminosity / N_{MB} / T_{PbPb}	2-3%
	branching fractions	8%
	kaon tracking efficiency	8-12%
	muon efficiency	3-5%
	B_s^0 BDT selection efficiency	3-19%
	Signal and background fit models	1-9%
	Correction of B_s^0 p_T shape in MC	1-8%
	B_s^0 acceptance difference in MC/data	1-2%

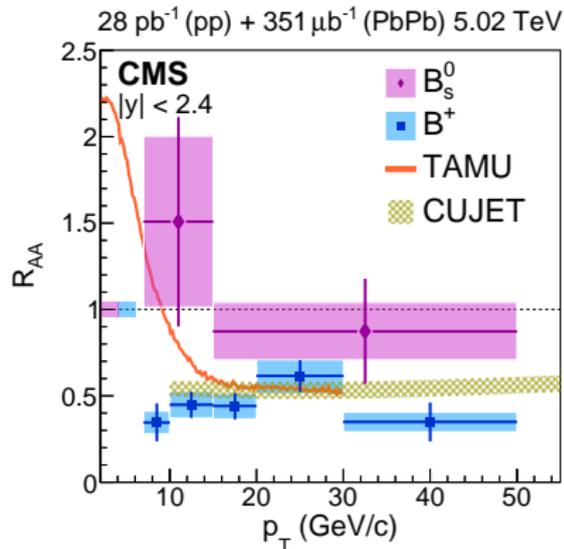
Results: B_s nuclear modification factor

$$R_{AA}(p_T) = \frac{1}{T_{AA}} \frac{dN_{\text{PbPb}}^{B_s^0}}{dp_T} \bigg/ \frac{d\sigma_{\text{PP}}^{B_s^0}}{dp_T}$$



Comparison with:

- TAMU: Langevin transport model, with recombination
- CUJET: pQCD-based, without recombination



→ $R_{AA}(B_s^0)$ consistent with 1,

but uncertainties leave room for significant enhancement or suppression

Results: ratio of B_s and B modification factors

Some uncertainties cancel in double ratio $R_{PbPb}(B_s^0) / R_{PbPb}(B^+)$

→ allows for quantifying how B_s^0 mesons are suppressed w.r.t. B^+

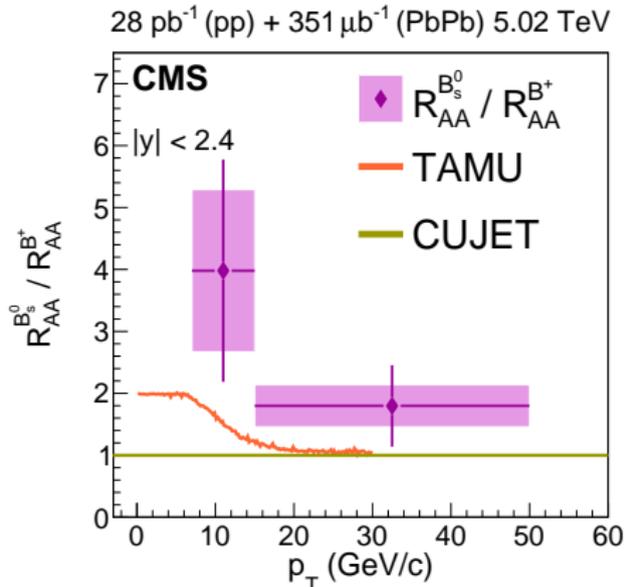
→ significant contribution of beauty recombination with strange quarks in heavy ion collisions ?

Indication of B_s^0/B^+ enhancement

(p-value 18% - 28%)

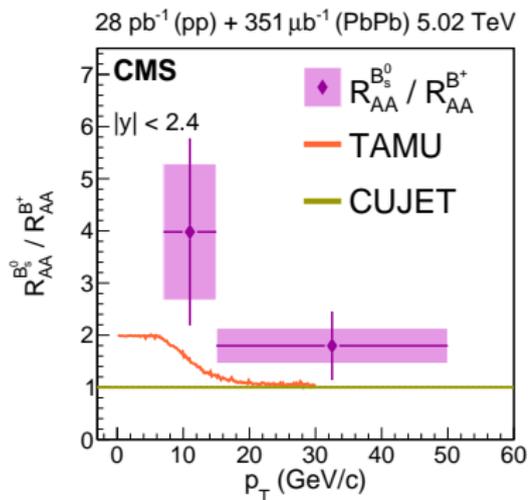
Not significant yet

→ need more statistics
(coming in 2018)



Conclusion

- First observation of B_s^0 in heavy ion collisions
- B_s^0 cross section in pp is consistent with FONLL predictions
- Measurement of $R_{\text{PbPb}}(B_s^0)$, consistent with 1
- Comparison with $R_{\text{PbPb}}(B^+)$ gives a **hint of lesser suppression for strange beauty mesons**, but is still consistent with no strange enhancement due to **large uncertainties**.



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THANK YOU!

