Open Heavy Flavor Measurements in Heavy Ion Collisions with CMS

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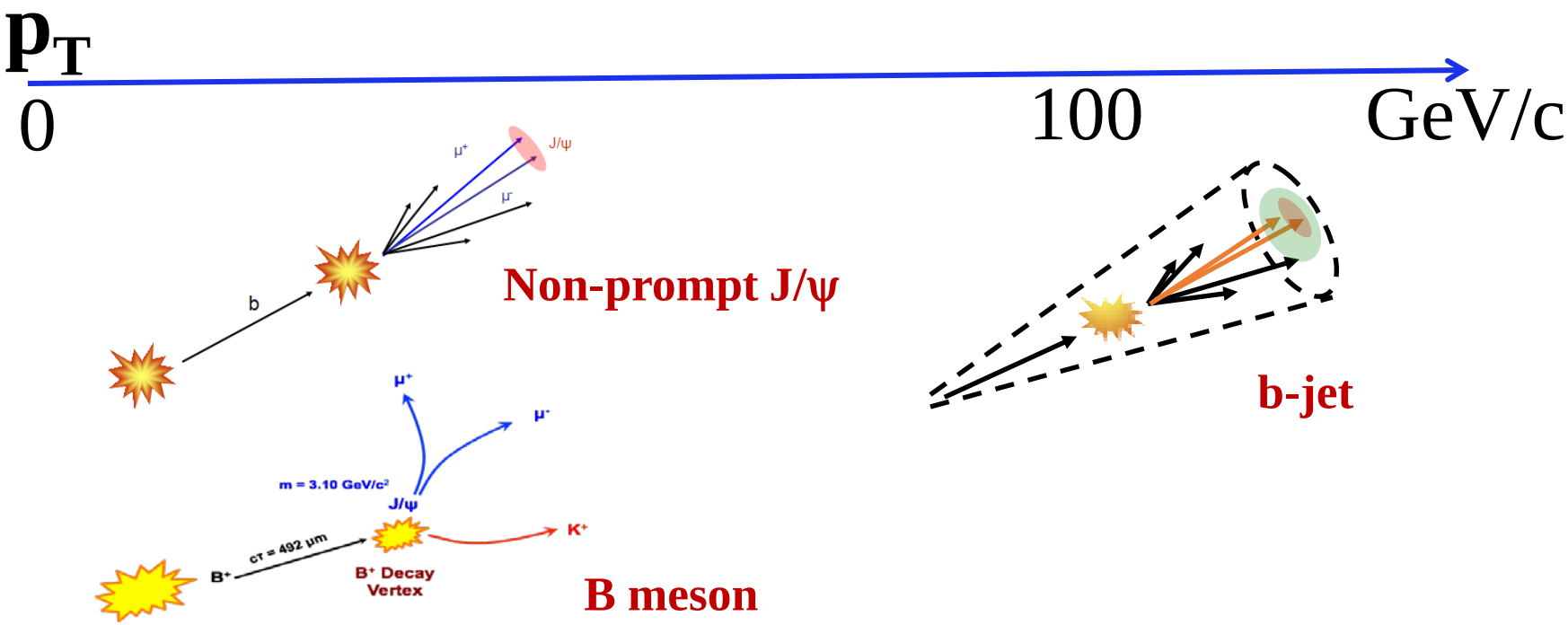
Outline

- Physics Motivation
- Open Heavy Flavor Measurements in PbPb and pPb

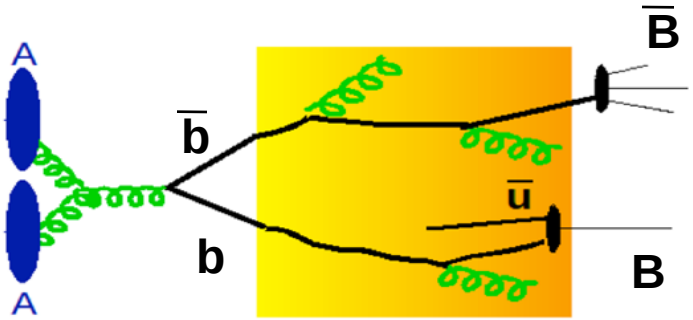


- Summary

Physics Motivation

- Heavy quarks are primarily produced at the early stages of the collisions

→Experience the full evolution of the medium



- Flavor dependence energy loss
  - Heavy quarks are expected to lose less energy than light quarks and gluons in medium due to color charge and dead cone effect [1]

$$\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b \xrightarrow{?} R_{AA}^{B} > R_{AA}^{D} > R_{AA}^{light}$$

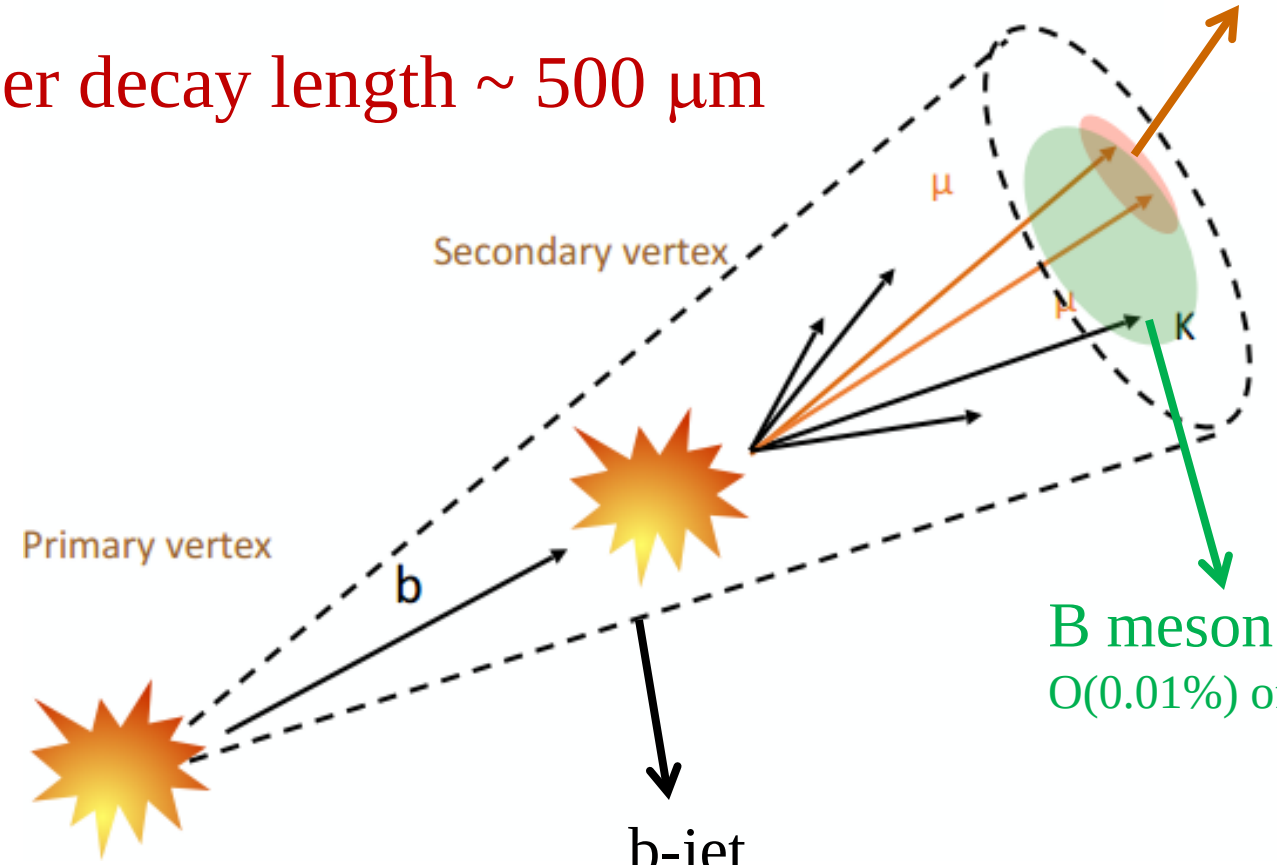
  - From light to heavy quark: ratio between radiative and collisional energy loss changes

[1] Y.L. Dokshitzer, D. E. Kharzeev, Phys. Lett. B 519 (2001) 199

- Cold nuclear matter effect: Gluon shadowing, Initial state Energy loss, etc

Open beauty measurements in CMS

- b-jet, B meson and non-prompt J/ψ
- Proper decay length ~ 500 μm



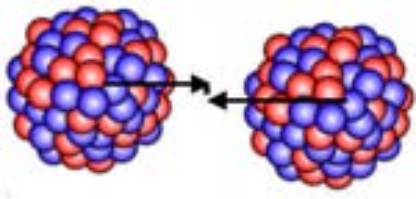
Non-prompt J/ψ
O(0.1%) of b cross section

B meson
O(0.01%) of b cross section

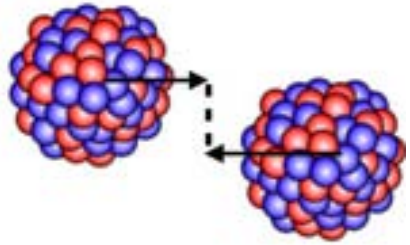
b-jet
O(100%) of total b cross section

Centrality and Nuclear modification factor

- Centrality: describes degree of overlap of AA collisions



Central collision

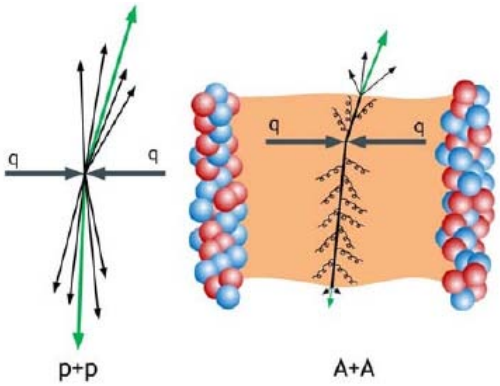


Peripheral collision

- **Centrality 0 to 100%, central collision to peripheral collision**
- **Normally represented by N_{part}**

  - N_{part}: number of participating nucleons
  - N_{coll}: number of the binary nucleon-nucleon collisions

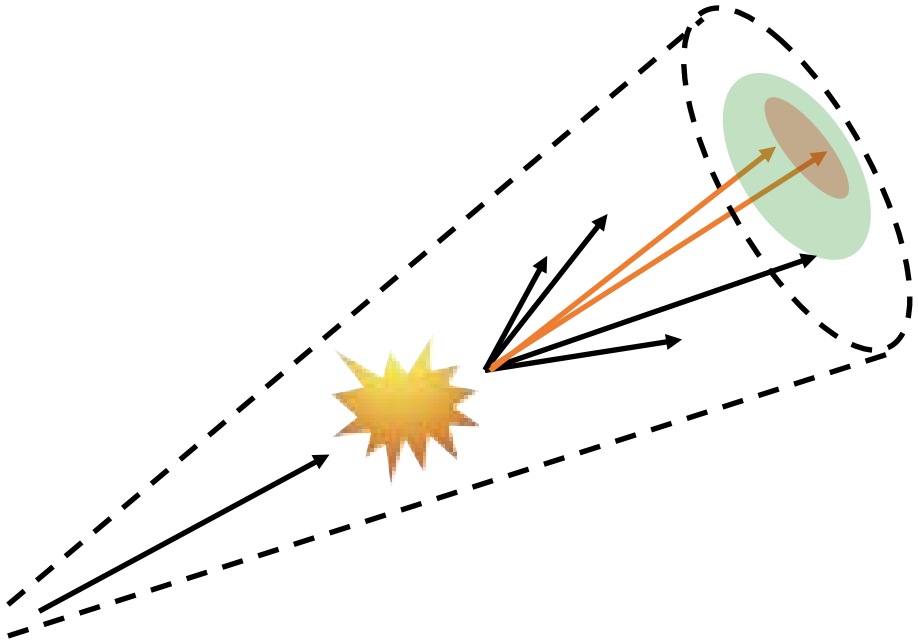
- Nuclear modification factor: describes production ratio to pp collision



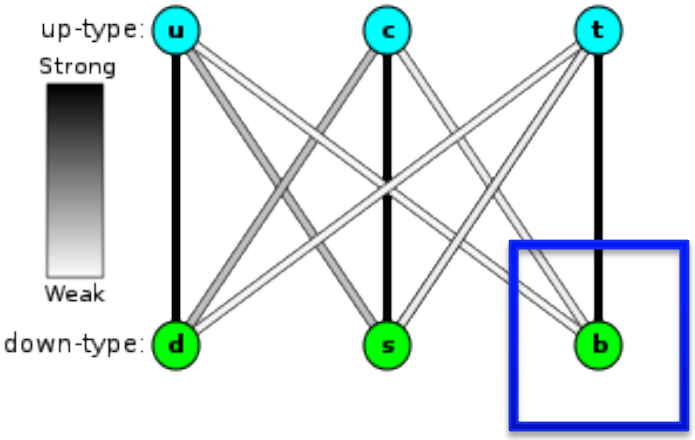
$$R_{AB} = \frac{1}{< N_{coll} >} \frac{d^2 N_{AB} / dp_T d\eta}{d^2 N_{pp} / dp_T d\eta}$$

- $R_{AB} > 1$: enhancement
- $R_{AB} = 1$: no medium effect
- $R_{AB} < 1$: suppression

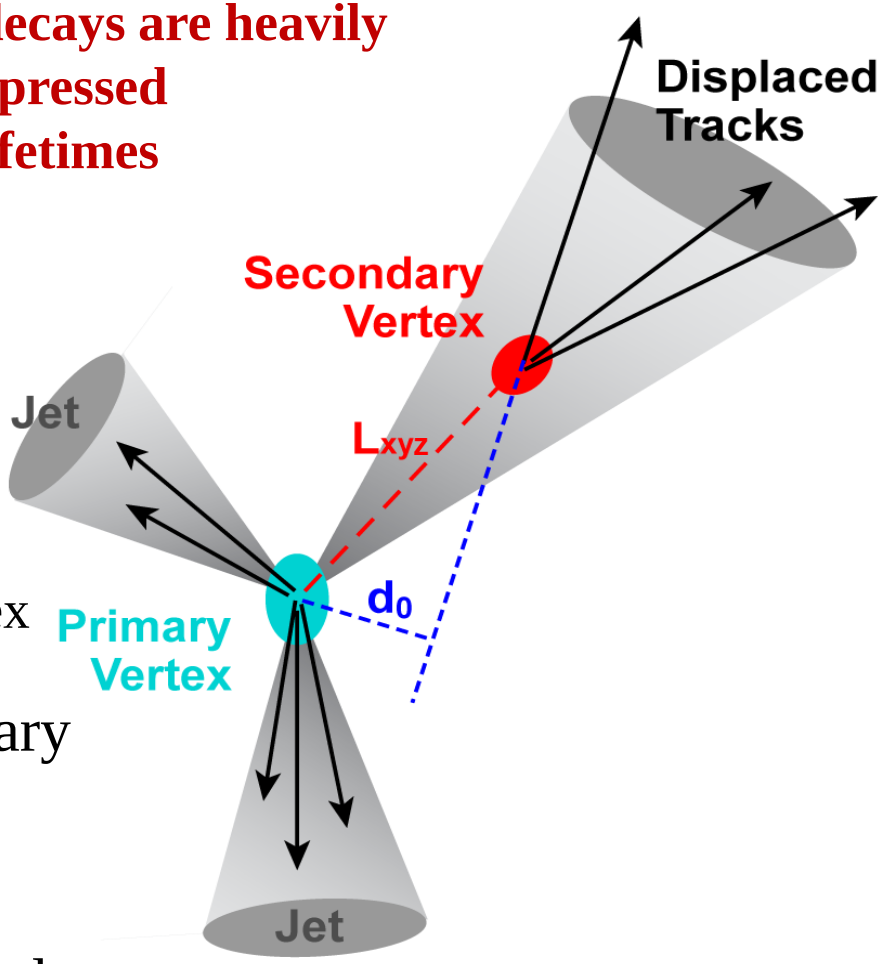
b-jet Measurements in PbPb and pPb



Identifying b-jet



B-quark decays are heavily CKM-suppressed
→ Long lifetimes

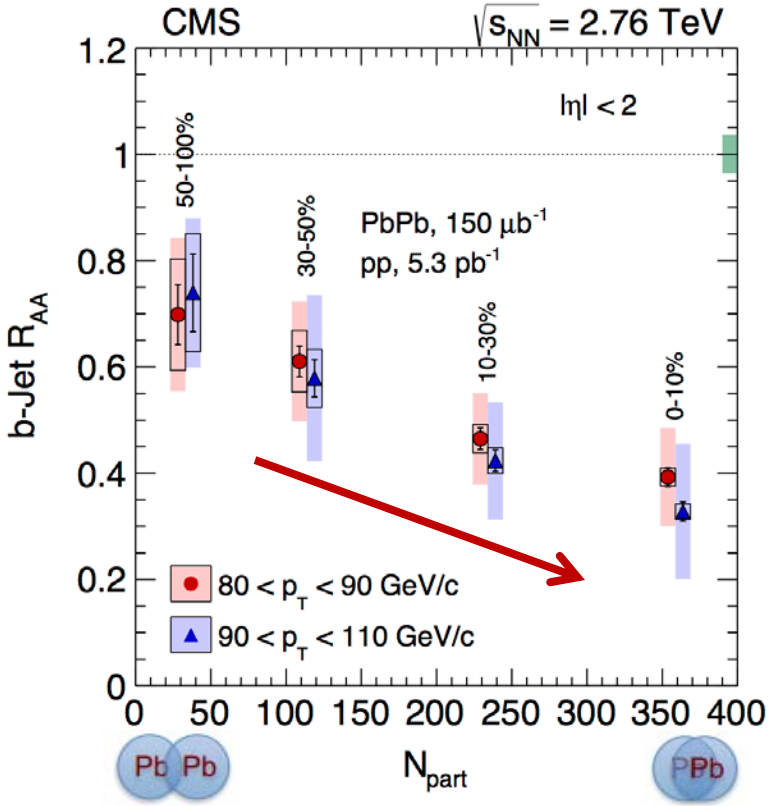


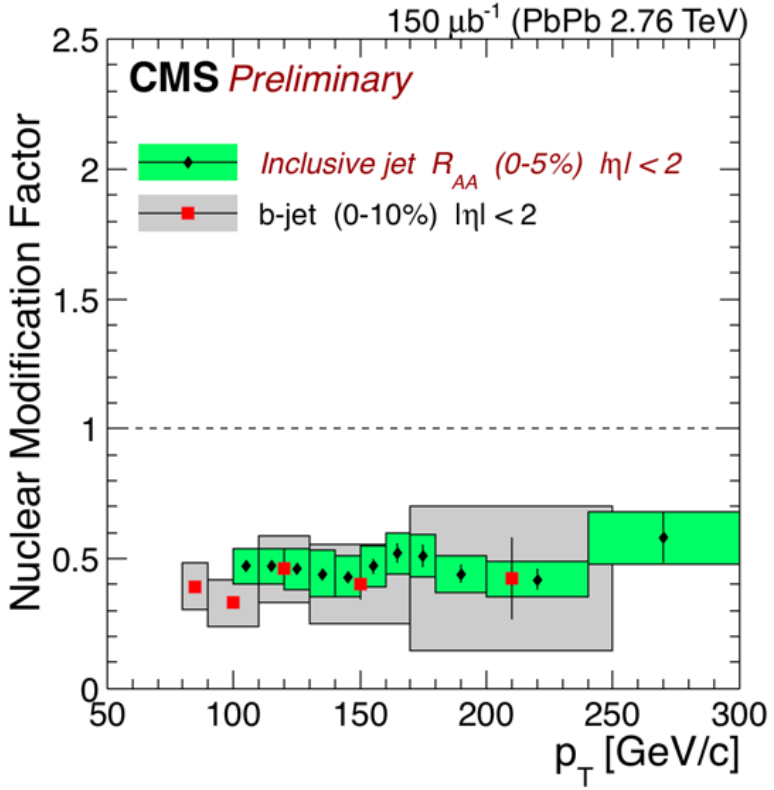
- Primary identification method is using a **Secondary Vertex**
  - Long lifetime of b = mm or cm vertex displacement
- Flight distance (L_{xyz}) of the secondary vertex used as a discriminating variable
- Tagging methods independent of secondary vertex reconstruction used as cross-check

Algorithms described in:
JINST 8 (2013) P04013

b-jet in PbPb: R_{AA}

- First measurement of heavy flavor jet R_{AA}
- Clear suppression of b-jet: R_{AA} shows clear trend as a function of centrality
- R_{AA}(b-jet)≈R_{AA}(inclusive jet): at high pt, no strong indication of flavor dependence within the uncertainties
  - Contributions from gluon splitting? Negligible quark mass at these energies?

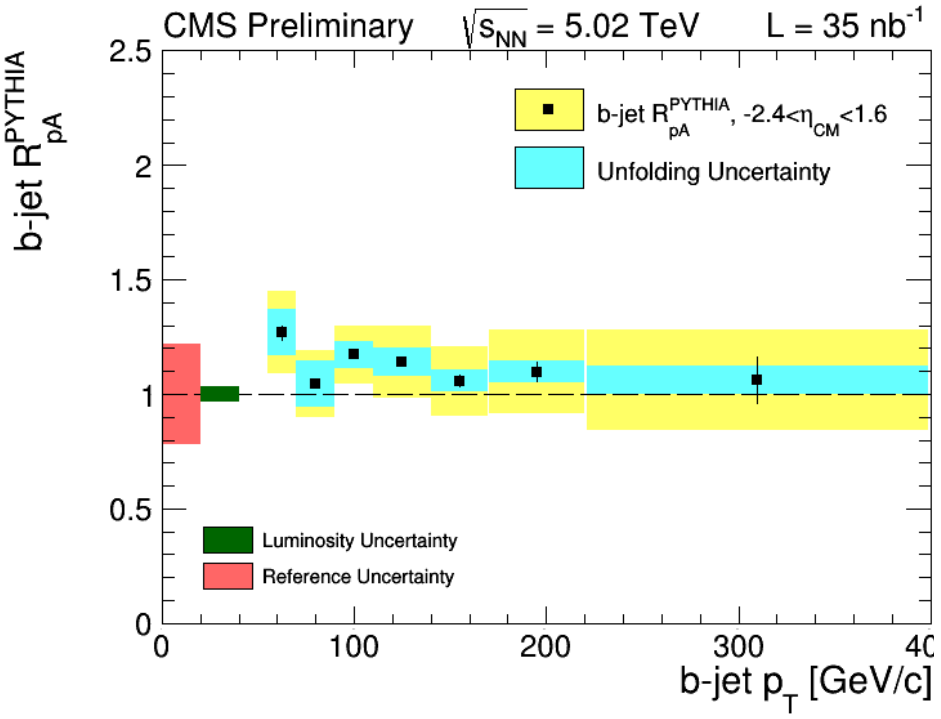


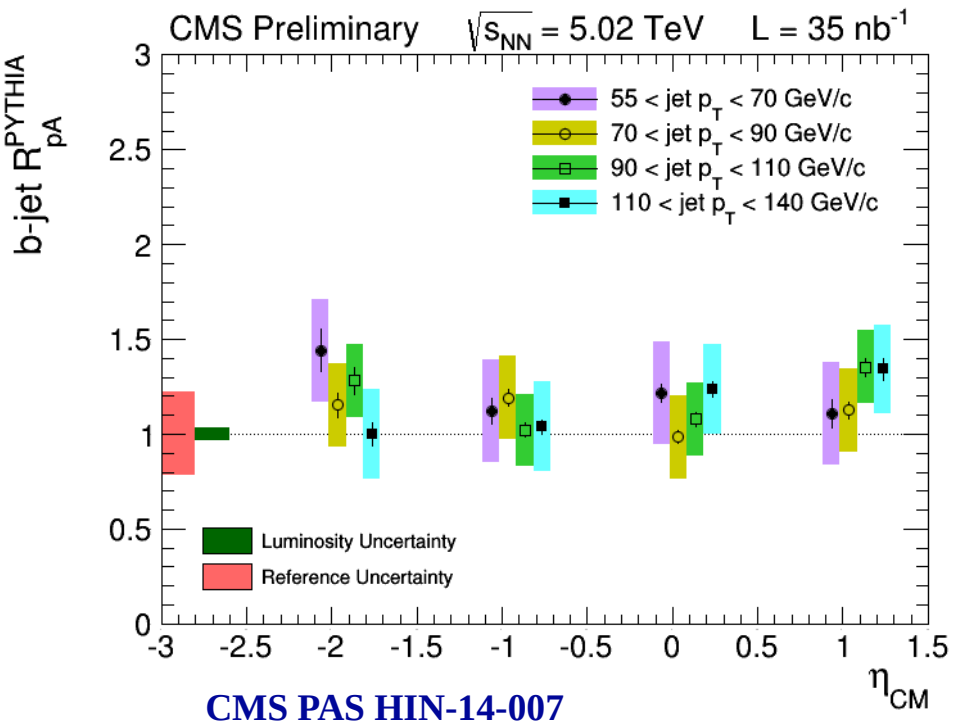


Phys. Rev. Lett. 113, 132301 (2014)
CMS-PAS-HIN-12-004

b-jet in pPb: R_{pA}^{PYTHIA}

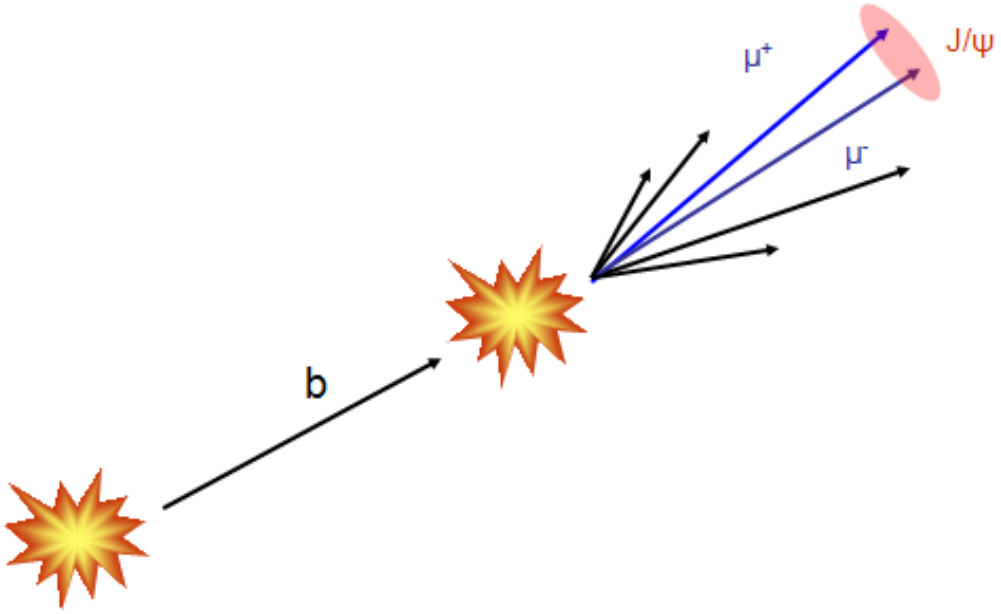
- pp reference from PYTHIA simulation (no data reference available)
- R_{pA} is consistent with unity within uncertainties
- No suppression observed in pPb collisions at 5.02 TeV
- No significant cold nuclear matter effects are observed within uncertainties. Suppression in PbPb is from medium effect.





CMS PAS HIN-14-007

Non-prompt J/ψ Measurements in PbPb and pPb

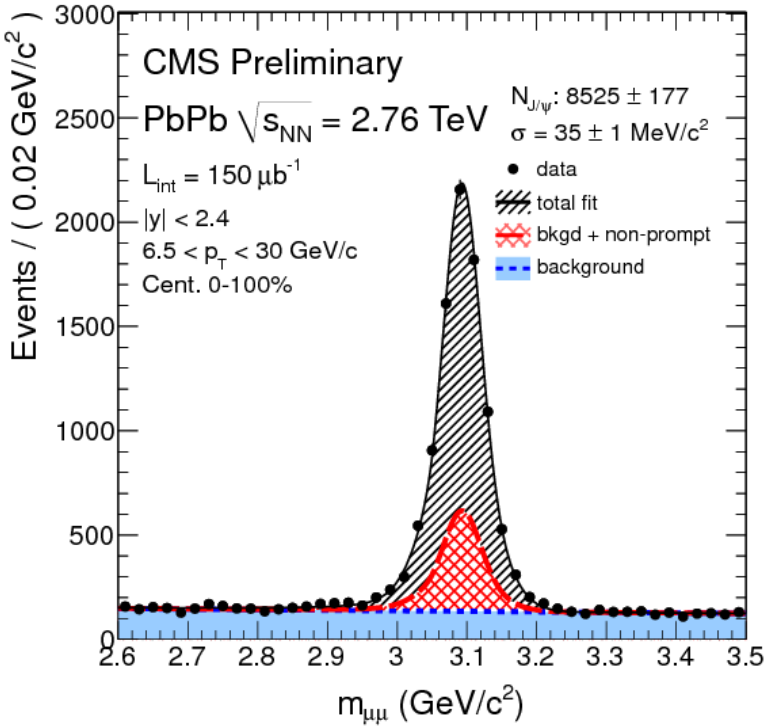


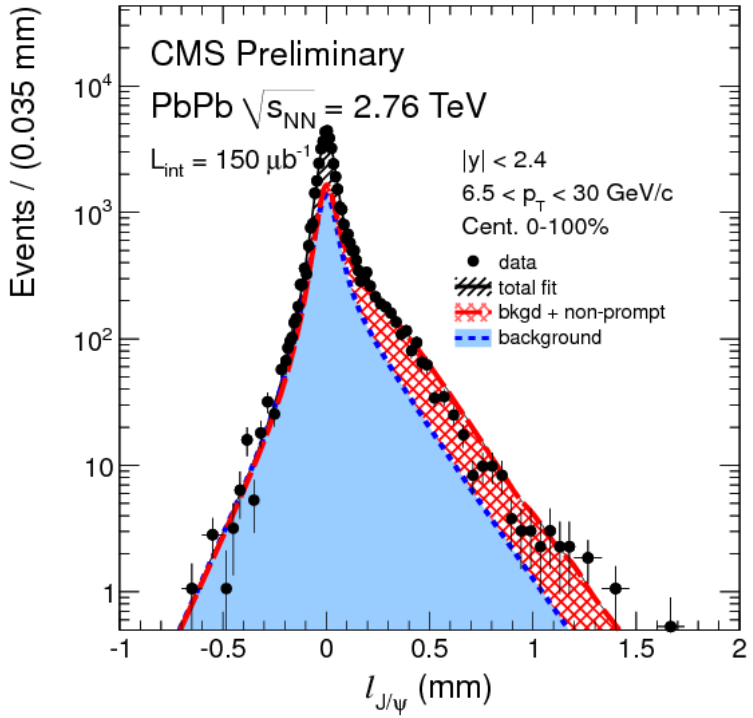
Non-prompt J/ψ reconstruction

- Fit muon pairs to a common vertex
- Simultaneous fit on invariant mass and pseudo-proper decay length for yield extraction

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

  - Yields of non-prompt and prompt J/ψ





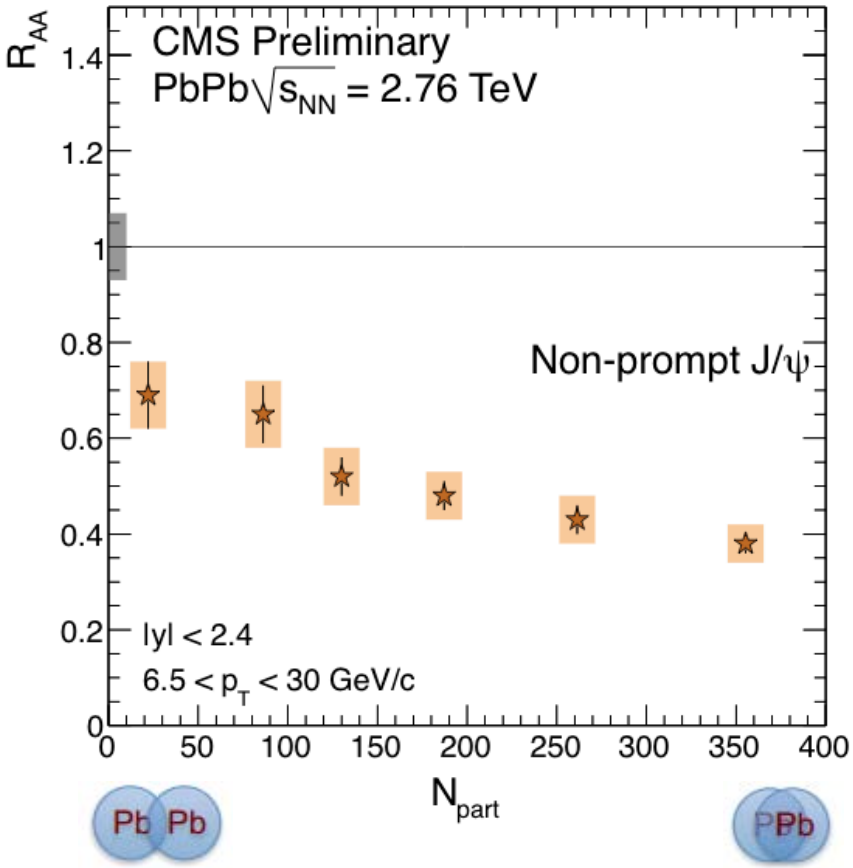
CMS PAS HIN-12-014

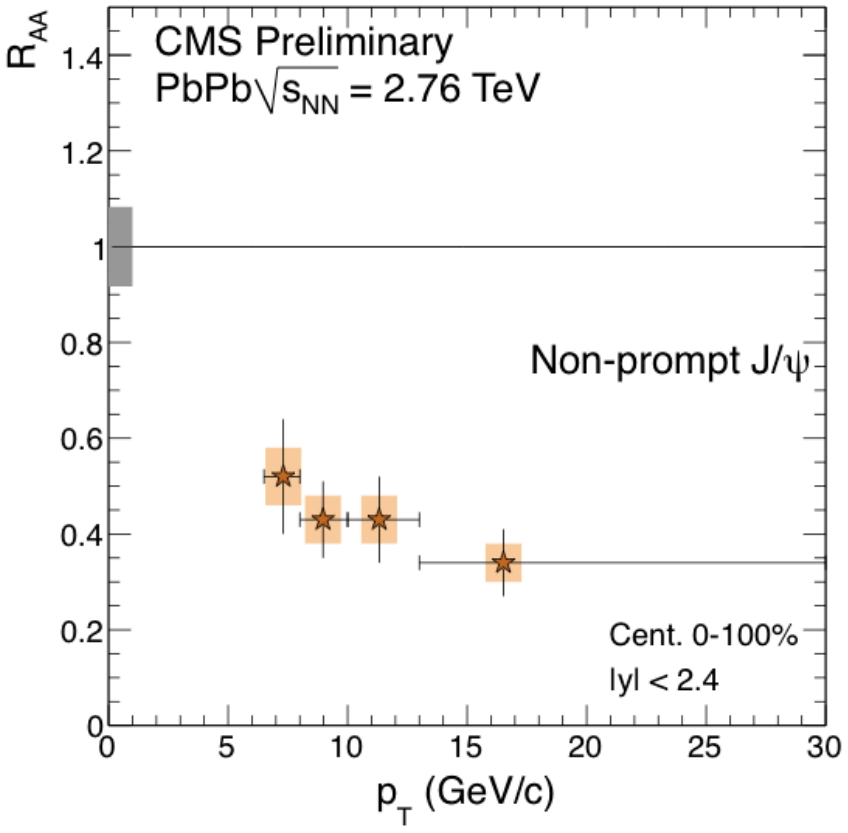
Non-prompt J/ψ in PbPb: R_{AA}

- A slow increase of the suppression is observed with increasing centrality of the collision.

CMS PAS HIN-12-014

- A hint of less suppression at low p_T

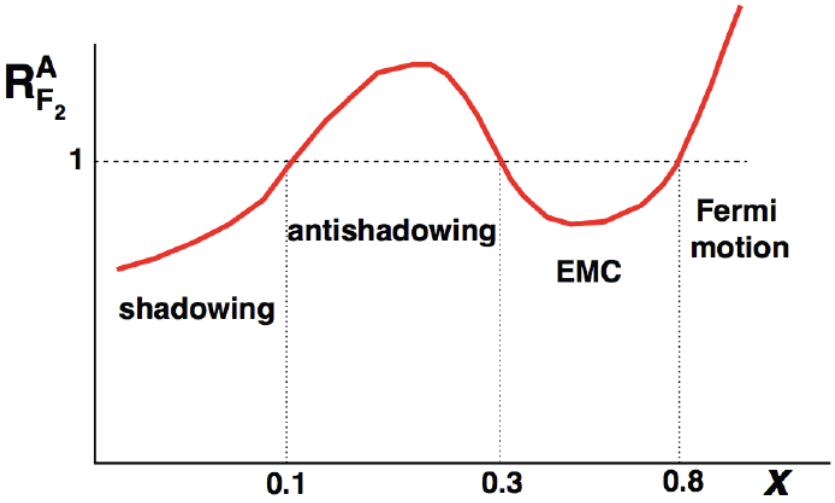


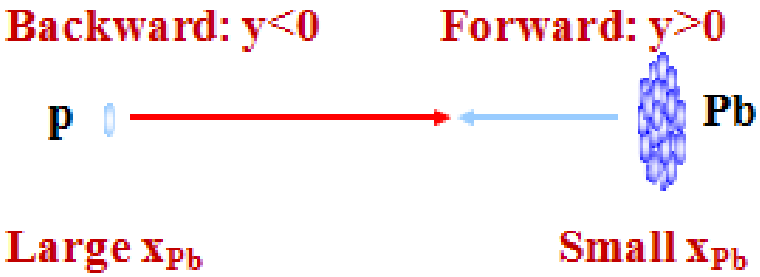


Non-prompt J/ψ in pPb: R_{FB}

- Why study R_{FB}?

$$R_{FB}(p_T, y) = \frac{d^2\sigma(p_T, y > 0)/dp_T dy}{d^2\sigma(p_T, y < 0)/dp_T dy}$$



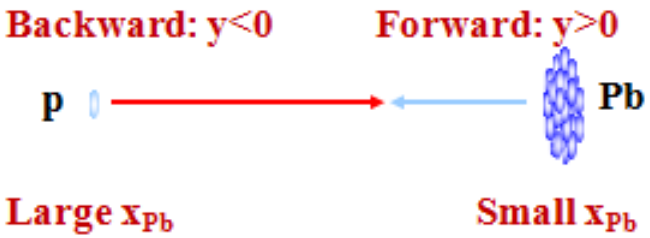


$$x_{1,2} = \frac{\sqrt{m^2_{J/\psi} + p^2_{TJ/\psi}}}{\sqrt{s}} \bullet e^{\pm y}$$

- At small x, partons in nucleus depleted compared to proton
  - Characterized by forward/backward asymmetry

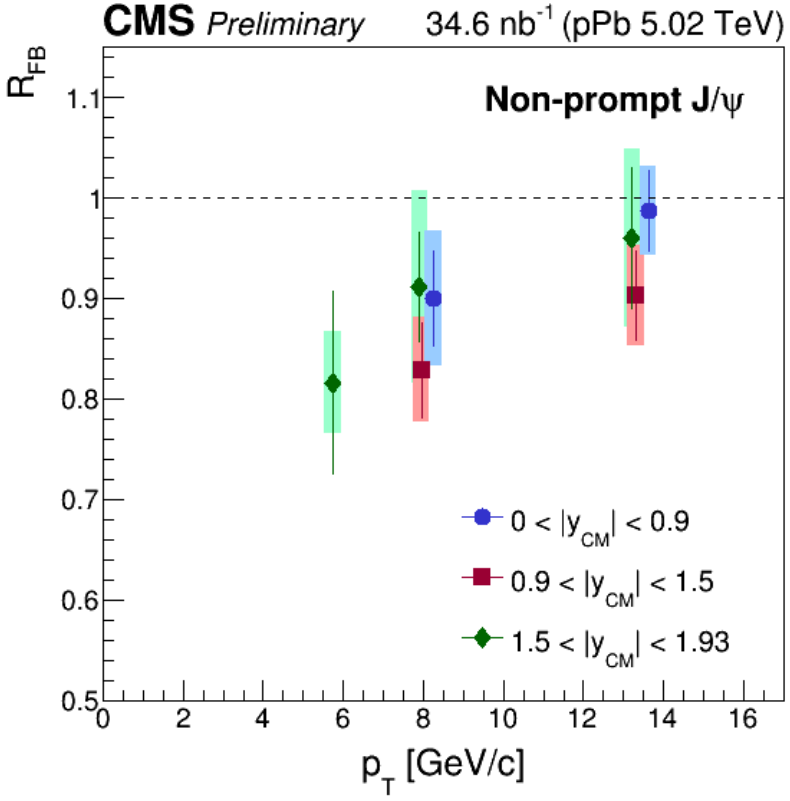
- Non-prompt J/ψ studied in shadowing range: $10^{-4}<x<10^{-2}$
  - R_{FB} is expected to be smaller than 1.0 in some range

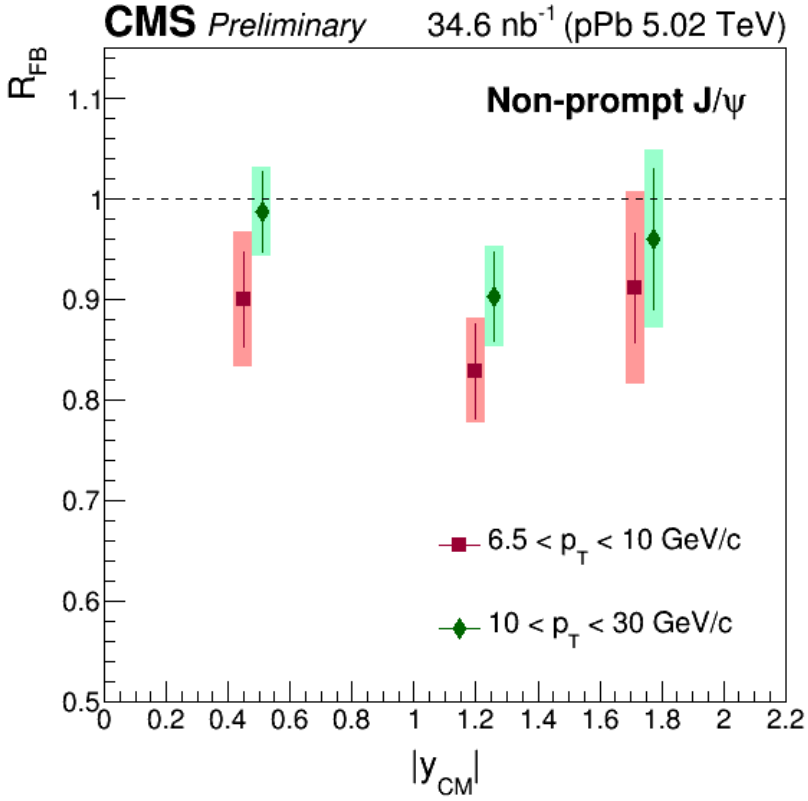
Non-prompt J/ψ in pPb: R_{FB}



$$R_{FB}(p_T, y) = \frac{d^2\sigma(p_T, y > 0)/dp_T dy}{d^2\sigma(p_T, y < 0)/dp_T dy}$$

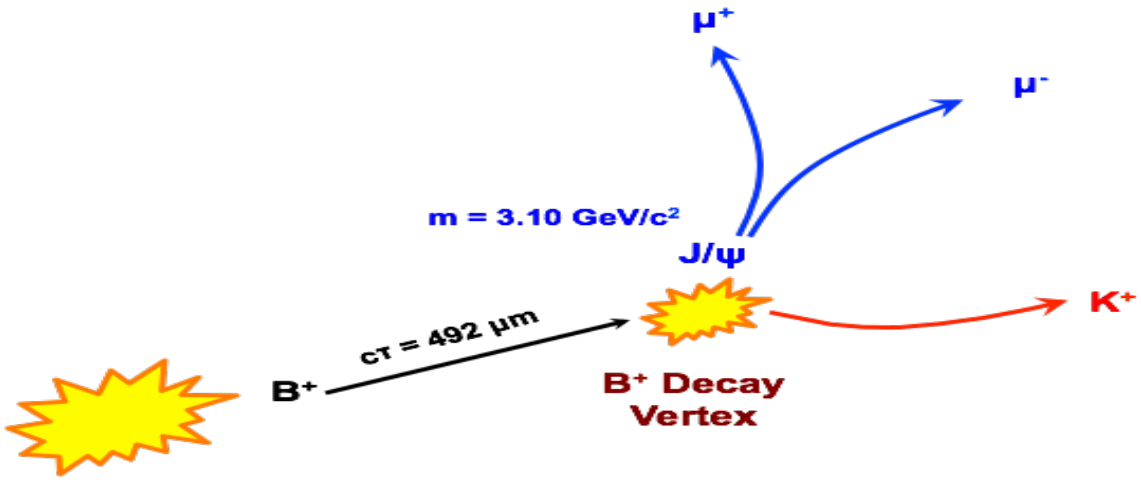
- Decreased yields at forward rapidity: consistent with presence CNM effects





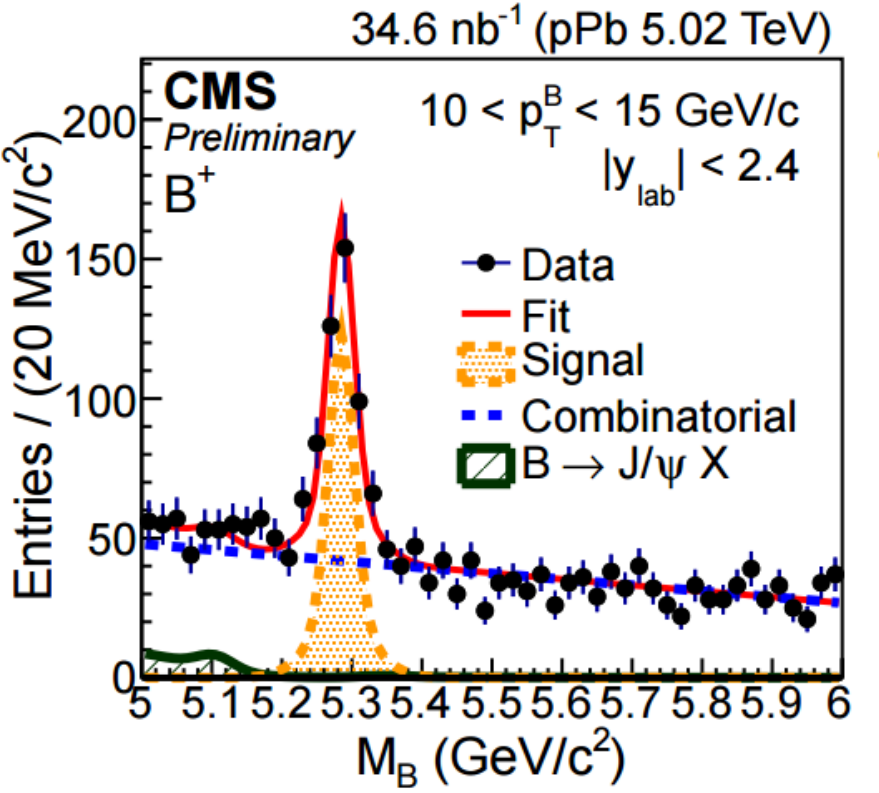
CMS PAS HIN-14-009

B Mesons Measurements in PbPb and pPb



B mesons in pPb

- **Fully reconstructed hadronic decays:**
  - $B^+ \rightarrow J/\psi\, K^+ \rightarrow \mu^+\mu^-\, K^+$
  - $B^0 \rightarrow J/\psi\, K^{0*} \rightarrow \mu^+\mu^-\, K^+\pi^-$
  - $B_s^0 \rightarrow J/\psi\, \varphi \rightarrow \mu^+\mu^-\, K^+K^-$



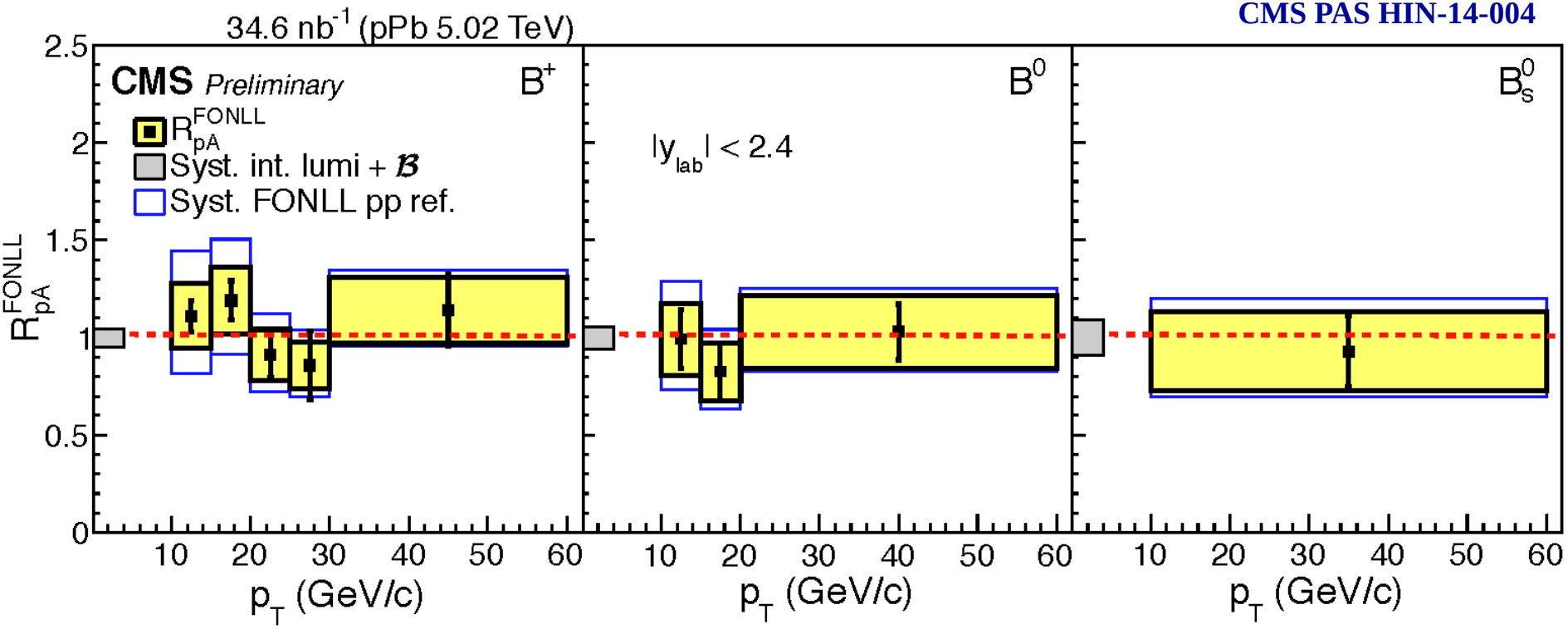
- B candidate reconstruction
  - $J/\psi \rightarrow \mu^+\mu^-$ reconstruction
  - Tracks are associated to J/ψ candidate to build B-meson candidates
- Candidate selection based on B kinematics
- Mass spectrum fit to get yields of B mesons

CMS PAS HIN-14-004

B mesons in pPb: R_{pA}^{FONLL}

- FONLL prediction as pp reference (no data reference available)
- R_{pA} is consistent with unity within uncertainty
- No significant cold nuclear matter effects are observed within uncertainties
- Important reference for PbPb analysis

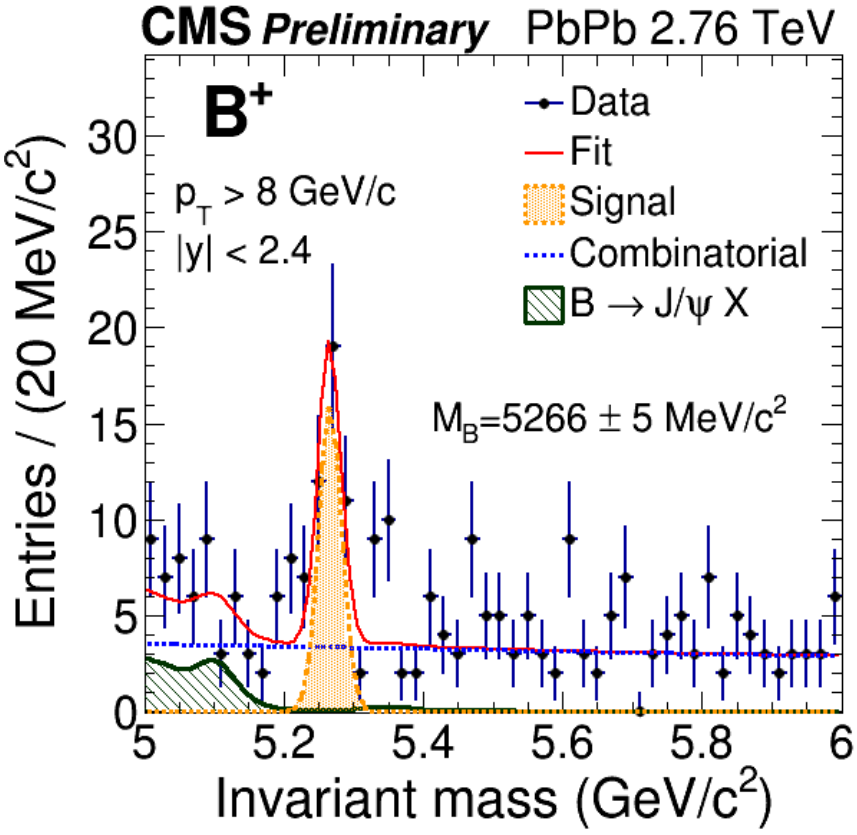
CMS PAS HIN-14-004



B mesons in PbPb

- Able to reconstruct B meson in PbPb with CMS
- First fully reconstructed B meson signal in PbPb!
- 2015 Run-2: 20x more statistics (Increased luminosity and higher collision energy)
- Potential measurements of B^+, B^0 and B_s^0 in PbPb

CMS detector performance plot



B^+ invariant mass spectrum in 2011 PbPb data

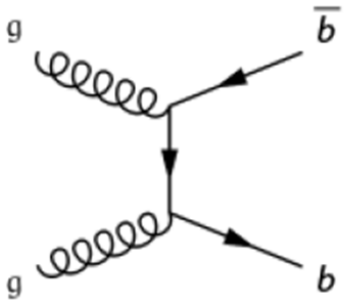
Summary

- Open beauty measurements with CMS
  - Suppression of b-jet and non-prompt J/ψ in PbPb
  - Cold nuclear matter effects are studied

- Perspective analysis
  - D and B meson measurements in PbPb
  - More differential heavy flavor jets measurements

Backup

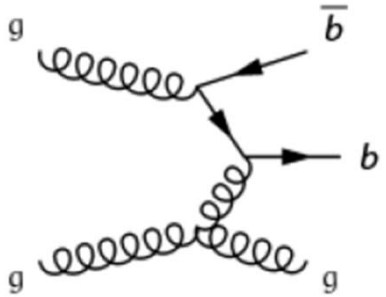
HF production in pp



LO process: Flavour Creation (FCR)

→ gluon fusion or light qq annihilation

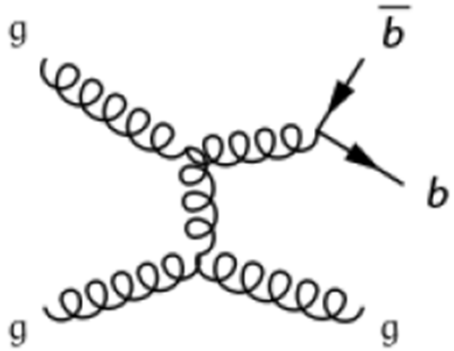
→ bb produced back-to-back in azimuthal plane and symmetric in p_T



NLO process: Flavour Excitation (FEX)

→ excitation of b/b̄ sea quark by gluon or light quark/anti-quark

→ bb pairs produced asymmetric in p_T and with a broad opening angle



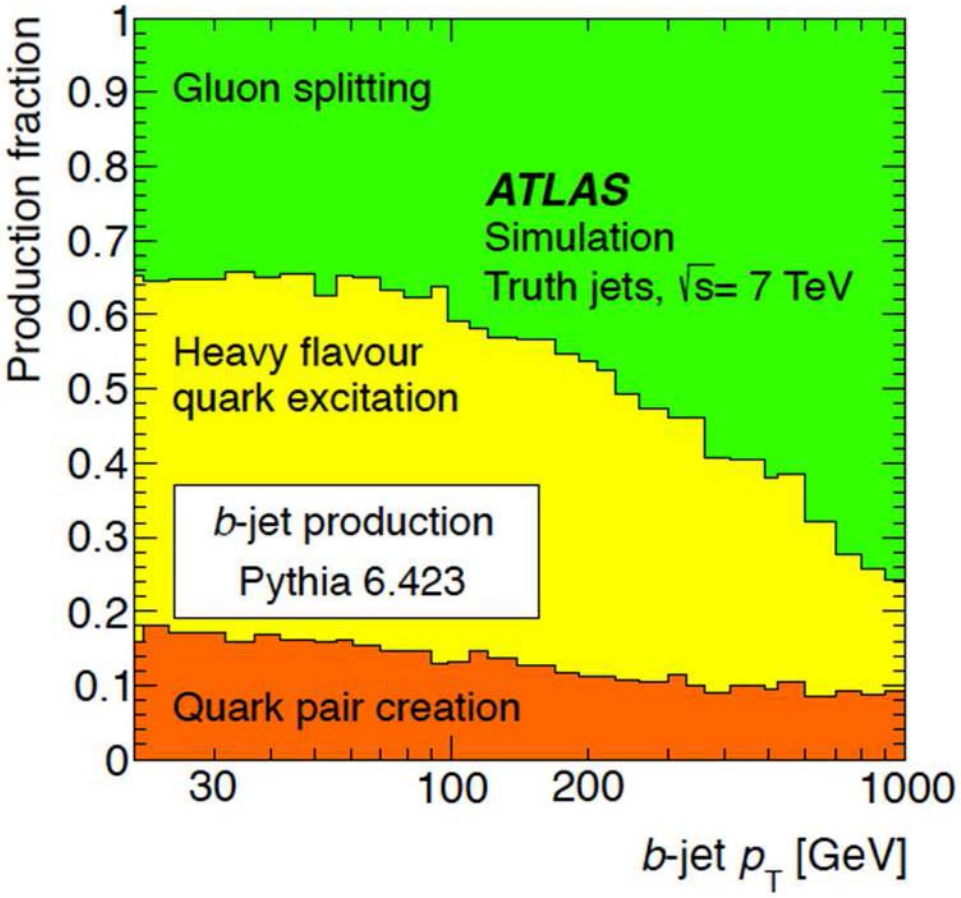
NLO process: Gluon splitting (GSP)

• gluon splits in a bb̄ pair

→ produced with small opening angles and asymmetric in p_T

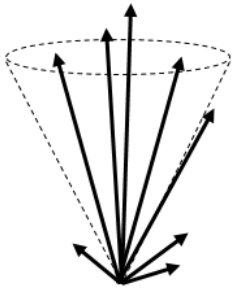
HF production in pp

EPJC 73 (2013) 2301



LO b-b production (FCR)
sub-dominant at the LHC

B-Jet reconstruction

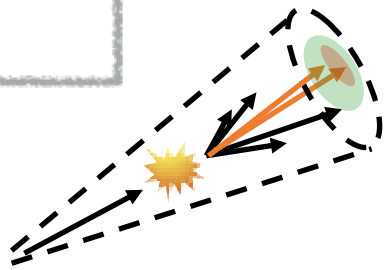


jet reconstruction/b-jet identification

SV tagger

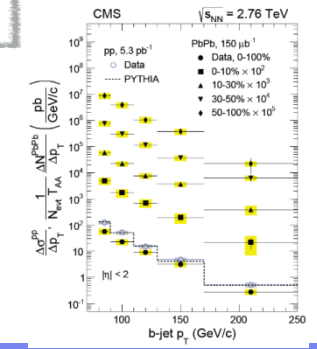
b jet purity determination

template (from simulation) fit on SV mass spectrum



Efficiency correction+resolution unfolding

from simulation, cross checked by data-driven method



B meson in pPb

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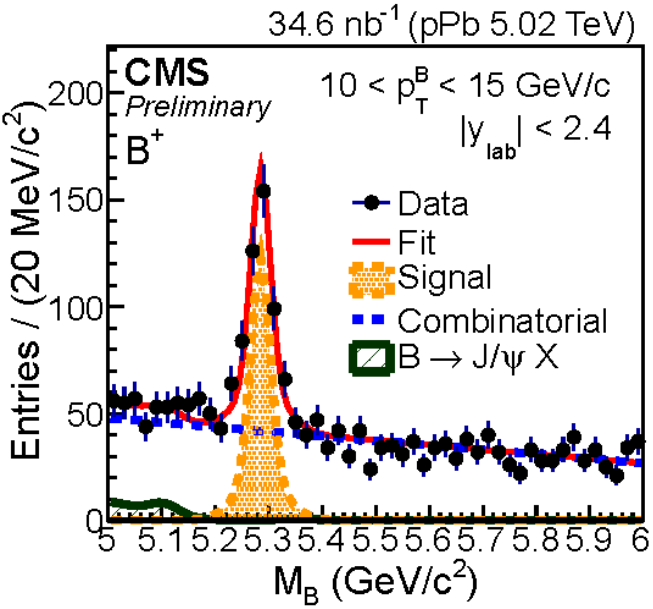
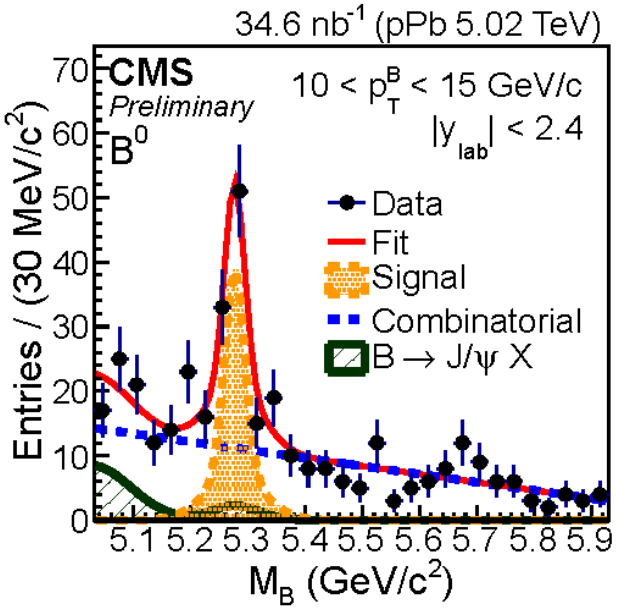
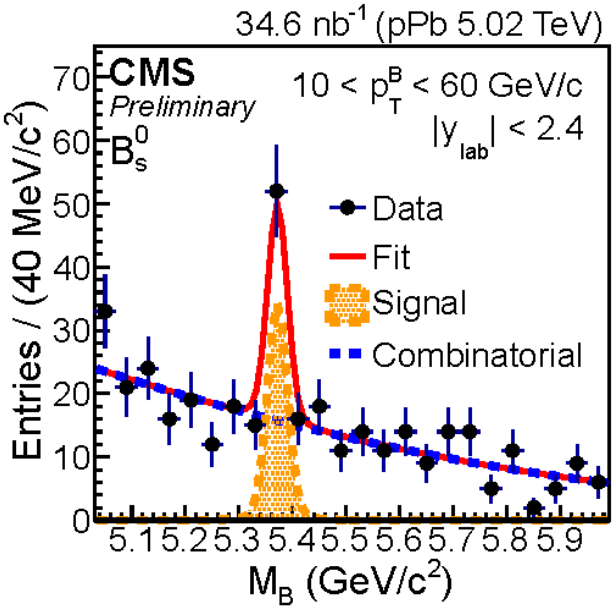
$B^+ \rightarrow J/\psi K^+$



$B^0 \rightarrow J/\psi K^{*0}$



$B_s \rightarrow J/\psi \varphi$



- Three component fit for signal extraction(Fully reconstructed B meson signal in heavy ion collisions):
  - **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 $B^0 \rightarrow J/\psi K^{0*}$)**

B meson non-prompt Bkg

- B^+:
  - $B^+ \rightarrow J/\psi\ \pi$ decays in which π misidentified as K
  - B^+ decays via resonant channels e.g., $B^+ \rightarrow J/\psi\ K^*(892)^+$. Kaons from $K^*(892)^+$ are then identified as genuine $B^+ \rightarrow J/\psi\ K$
  - Similar from $B^0 \rightarrow J/\psi\ K^*(892)^0$
- B^0:
  - Peaking BG at high mass from $B^+ \rightarrow J/\psi$ decays
  - Peaking BG at intermediate mass from $B_s \rightarrow J/\psi\ \varphi$ where a kaon is misidentified as π
  - Peaking BG at low mass is the sum of other contributions such as $B^0 \rightarrow J/\psi\ K(1270)^0$, $B^+ \rightarrow J/\psi\ K(1270)^+$ and other $B^0 \rightarrow J/\psi$ tracks decays
- B_s:
  - Potential contribution from $B^0 \rightarrow J/\psi$ + K*, but not observed in the final spectrum