Non-prompt J/ψ in CMS

+ more B measurements

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Introduction to open beauty

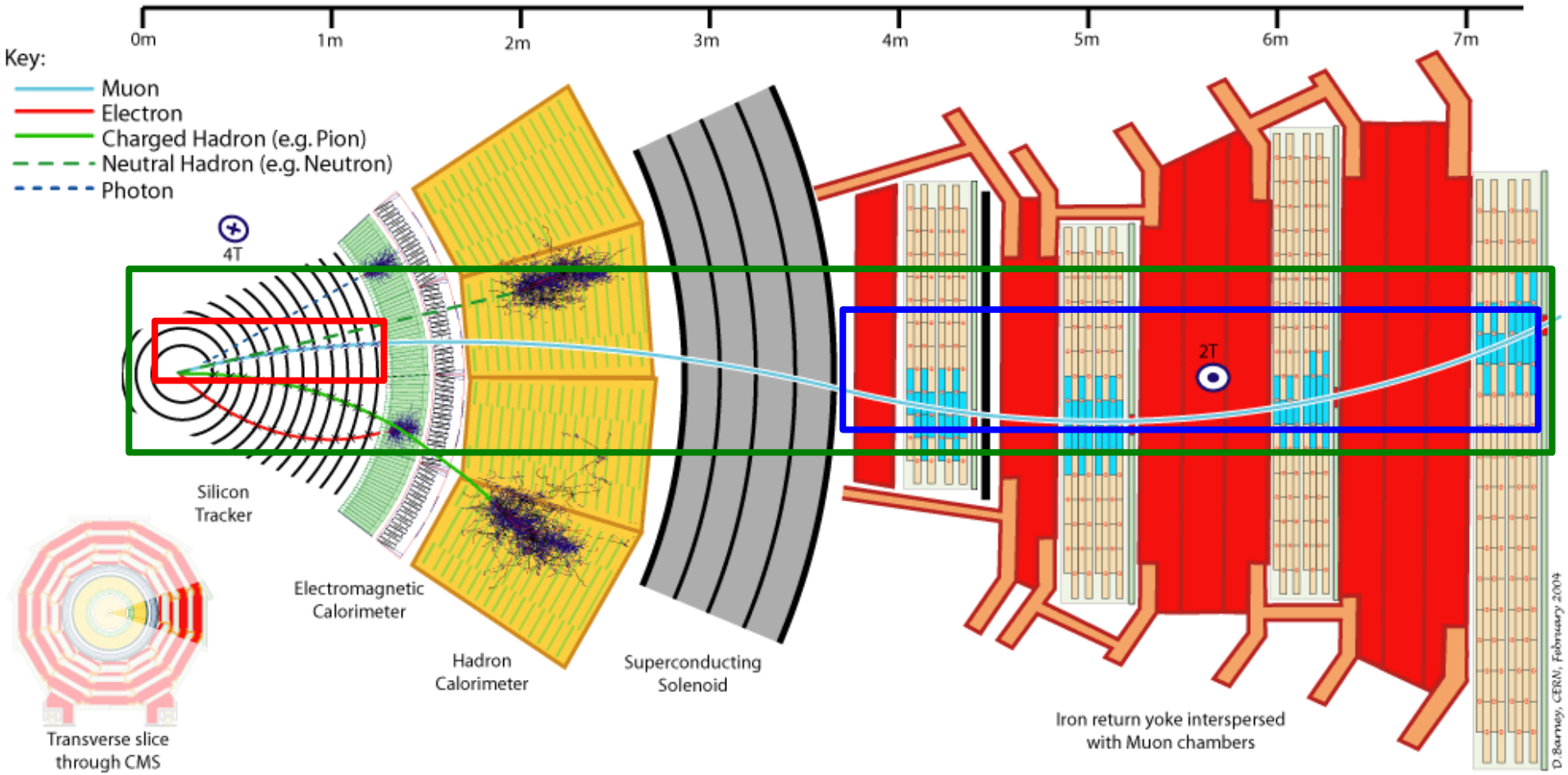
- Closed and open heavy-flavor interact with the QGP differently
  - For closed heavy-flavor: color screening, recombination(QQ) and/or energy loss
  - For open heavy-flavor: energy loss and/or recombination(Qq)

- Energy loss mechanisms of partons in the QGP:
  - Radiative energy loss
    - Dominant effect for fast partons in medium
  - Collisional energy loss
    - Heavy quarks might have considerable fraction of collisional energy loss

- R_{AA}(gluon) < R_{AA}(u,d,s hadrons) < R_{AA}(D) < R_{AA}(B) is expected
  - Dead-cone effect
    - Small-angle gluon radiation for heavy quarks is expected to be reduced
  - Need to separate open charm and beauty clearly

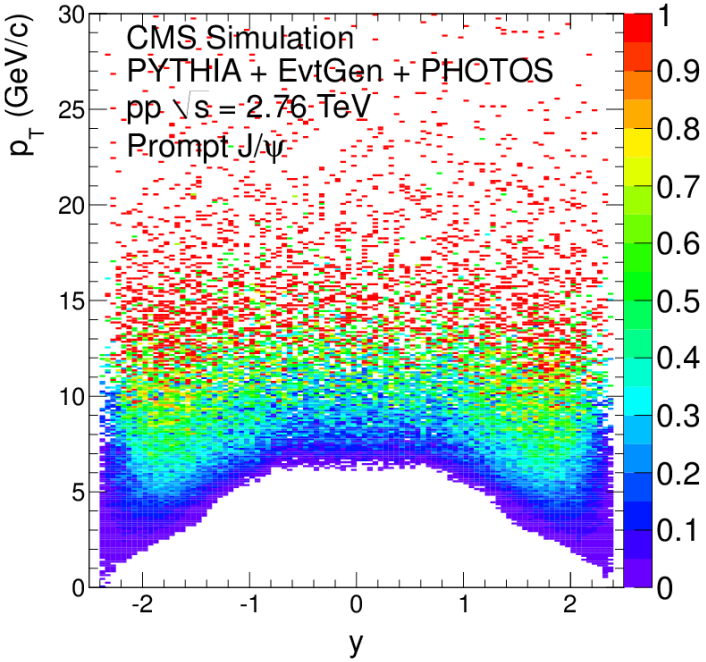
d'Enterria, David: 6.4 Jet quenching. Stock, R. (ed.). SpringerMaterials
Y.L. Dokshitzer, D.E. Kharzeev, Phys. Lett. B 519 (2001) 199

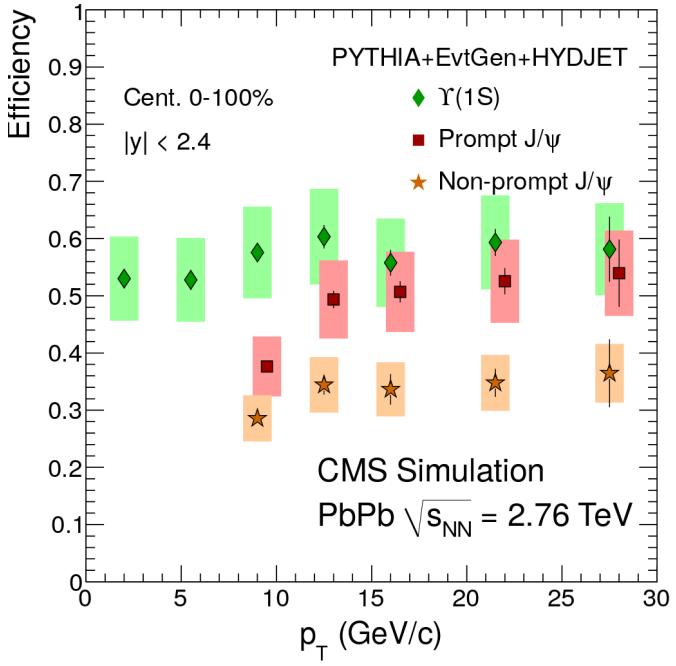
Muon reconstruction in CMS



- Excellent muon identification & triggering (DT, CSC, RPC)
- High mass/momentum resolution (Pixel & Strip silicon tracker)

Dimuon acceptance and efficiency





- Due to the strong magnetic field and energy loss in the absorber, minimum momentum to reach the muon stations and construct a global muon is 3~5 GeV/c
  - Even lower p_T regions can be reached with tracker muons → used for pA collisions
- J/ψ acceptance
  - Mid-rapidity: J/ψ p_T > 6.5 GeV/c
  - Forward rapidity: J/ψ p_T > 3 GeV/c
- J/ψ efficiency
  - Prompt J/ψ has higher efficiency than non-prompt J/ψ

More details in Emilien's talk!

J/ψ in PbPb at $\sqrt{s_{NN}}$ =2.76 TeV

Inclusive J/ψ

Prompt J/ψ

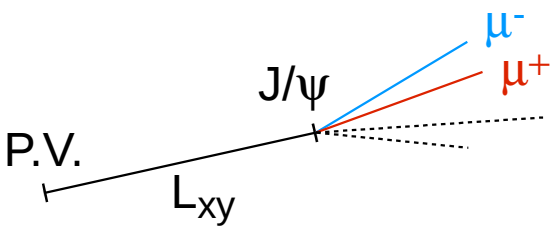
Direct J/ψ

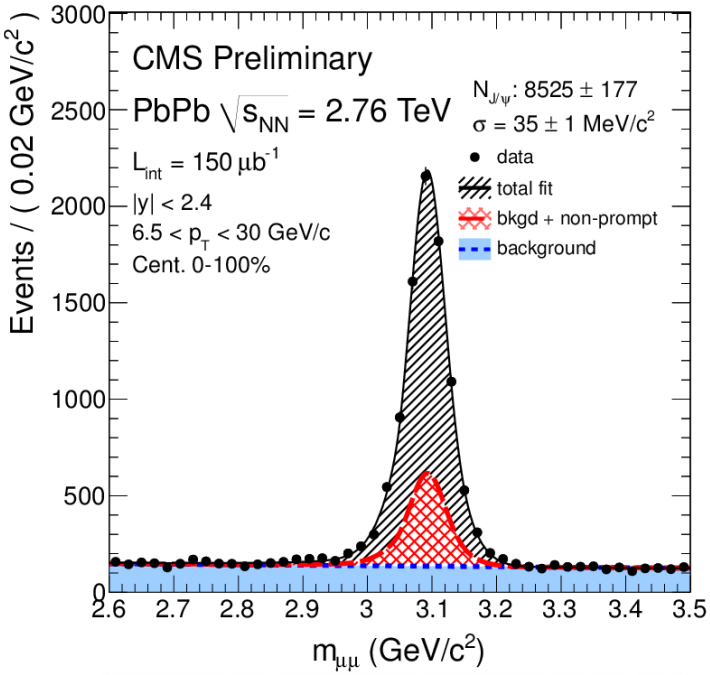
Feed-down from ψ(2S) and χ_c

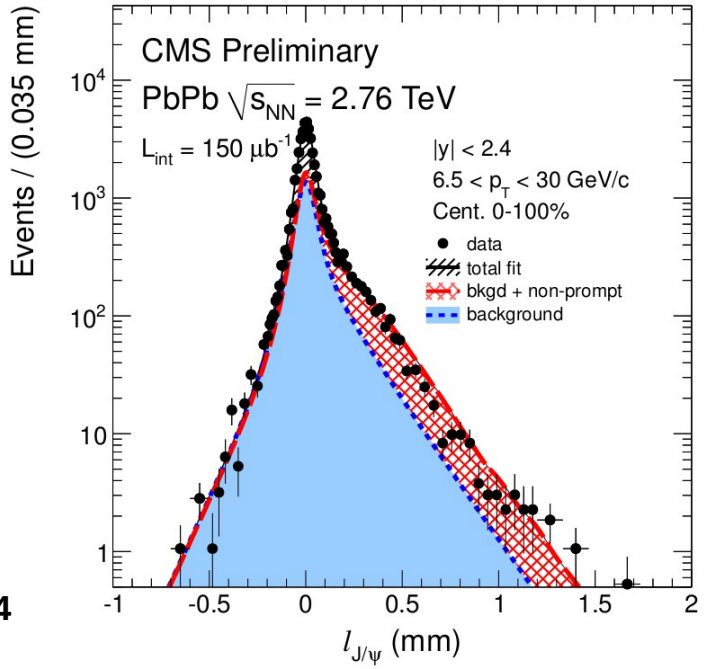
Non-prompt J/ψ from B decays

- Reconstruction of $\mu^+\mu^-$ vertex
- 2D simultaneous fit of $\mu^+\mu^-$ mass and pseudo-proper decay length $\ell_{J/\psi}$
- Extract the non-prompt J/ψ fraction

$$l_{J/\psi} = L_{xy} \frac{m_{J/\psi}}{p_T}$$







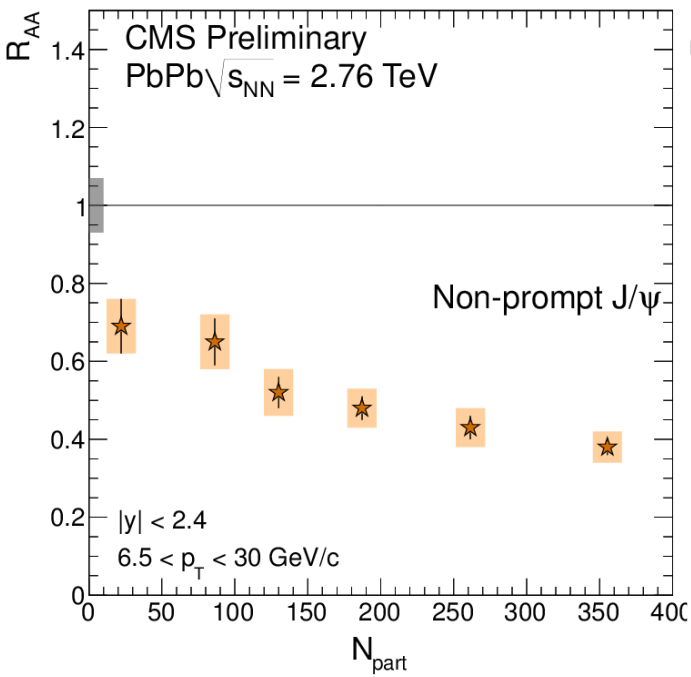
2010 PbPb data 7.28 μb^{-1}: JHEP 05 (2012) 063
2011 PbPb data 150 μb^{-1}: CMS PAS HIN-12-014

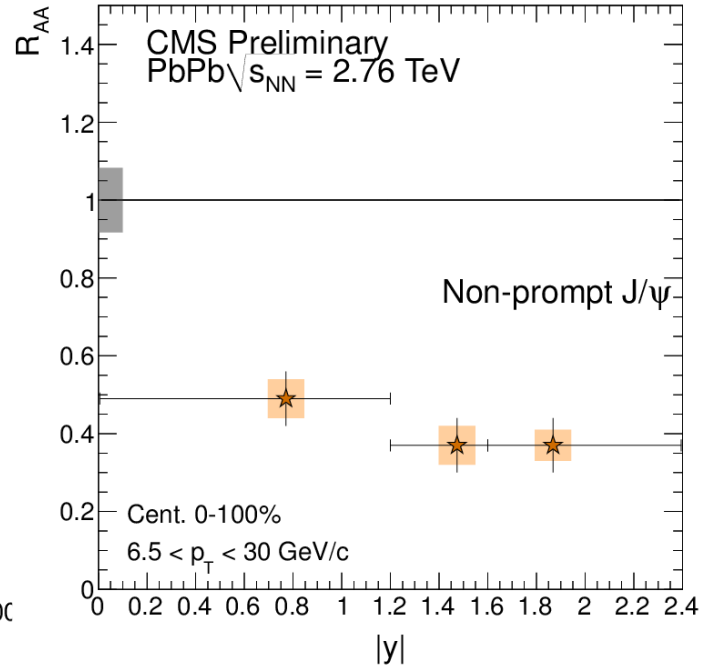
Systematic Uncertainty

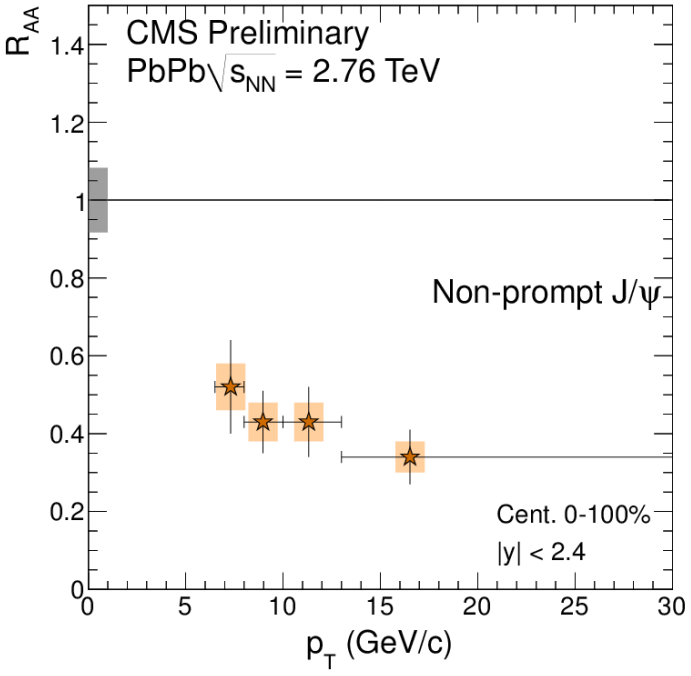
	prompt J/ψ (%)	non-prompt J/ψ (%)
PbPb yield extraction	0.2–1.7	0.6–4.5
pp yield extraction	0.3–1.6	1.7–8.4
$\mathrm{T\&P}^{recoValidation} \times (1 - \epsilon_{\mathrm{PbPb}}/\epsilon_{\mathrm{pp}})$	1–9	1–10
$\mathrm{T\&P}^{triggerCorrection}$	10	10
T_{AA}	4.1–18	4.3–15
Total	10.8–23	11.1–22.7

- Uncertainty related to muon reconstruction increases from peripheral to central collisions
- Uncertainty of T_{AA}, nuclear overlap function, decreases from peripheral to central collisions

Non-prompt J/ψ R_{AA}







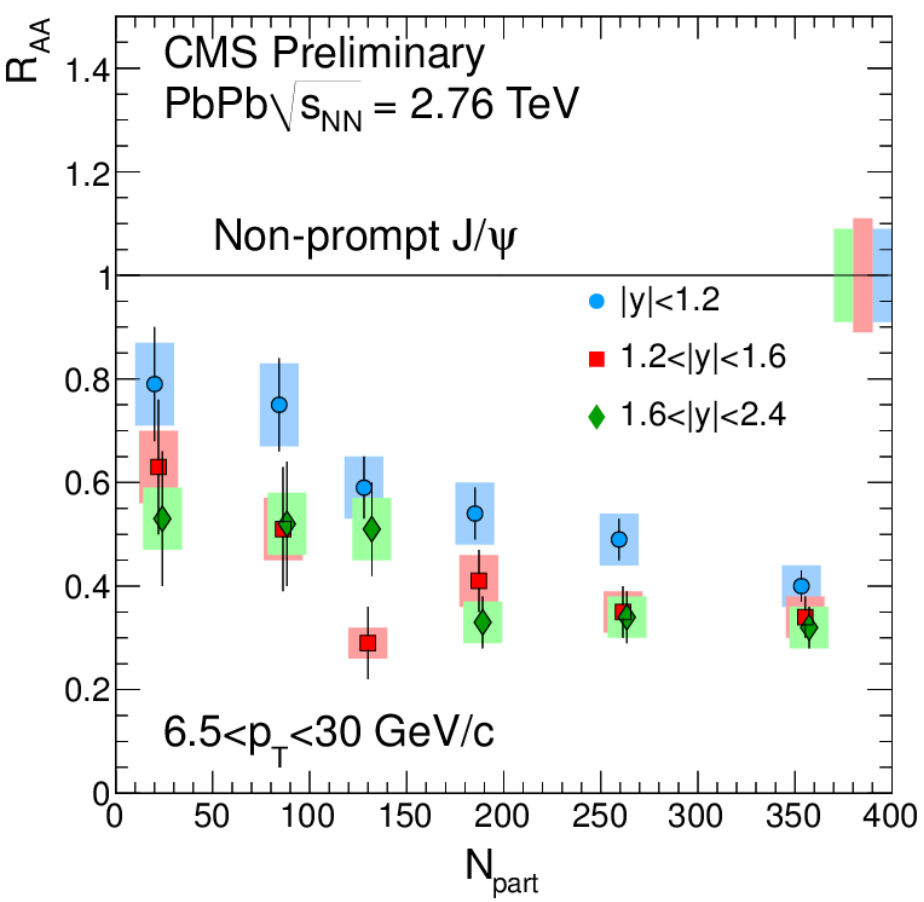
$$R_{AA} = \frac{L_{pp}}{T_{AA} N_{MB}} \frac{N_{PbPb}(J/\Psi)}{N_{pp}(J/\Psi)} \frac{\varepsilon_{pp}}{\varepsilon_{PbPb}(Cent.)} \qquad T_{AA} = \langle N_{coll} \rangle / \sigma_{nn}$$

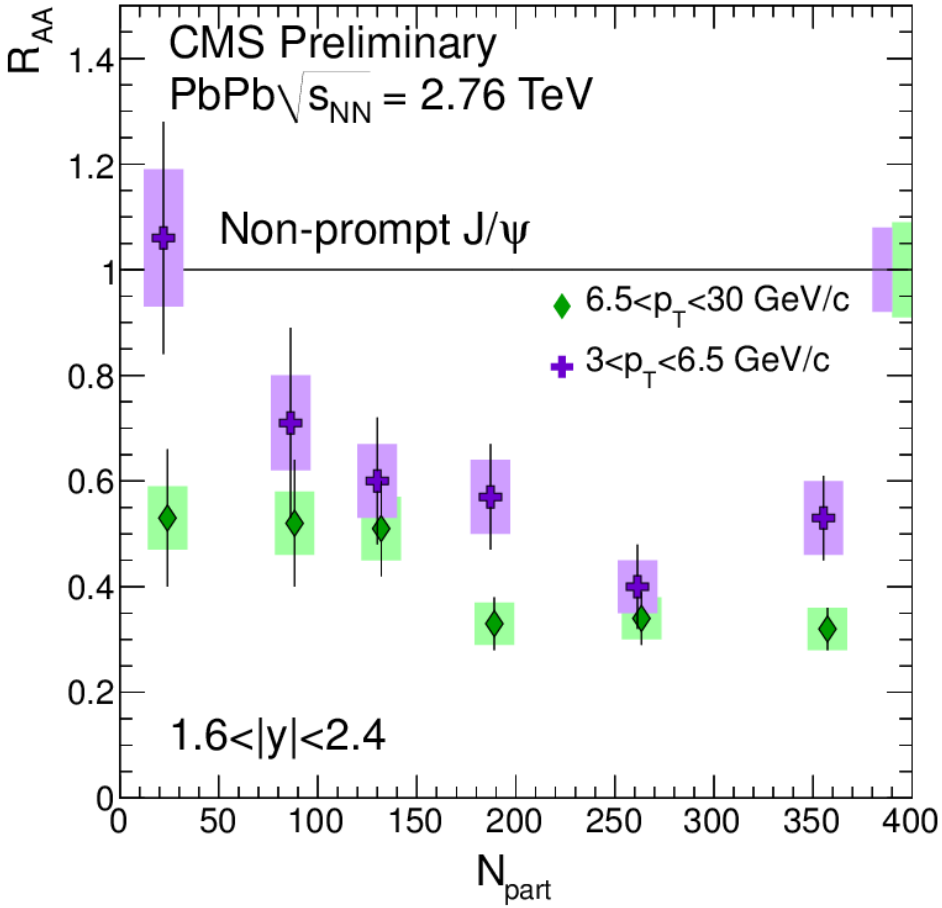
- Centrality dependent suppression on $6.5 < p_T < 30$ GeV/c, $|y| < 2.4$ region
  - 0-5% centrality events show suppression by a factor 2.5
- A hint of rapidity or p_T dependent suppression

CMS PAS HIN-12-014

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN12014

Non-prompt J/ψ R_{AA} : Double differential





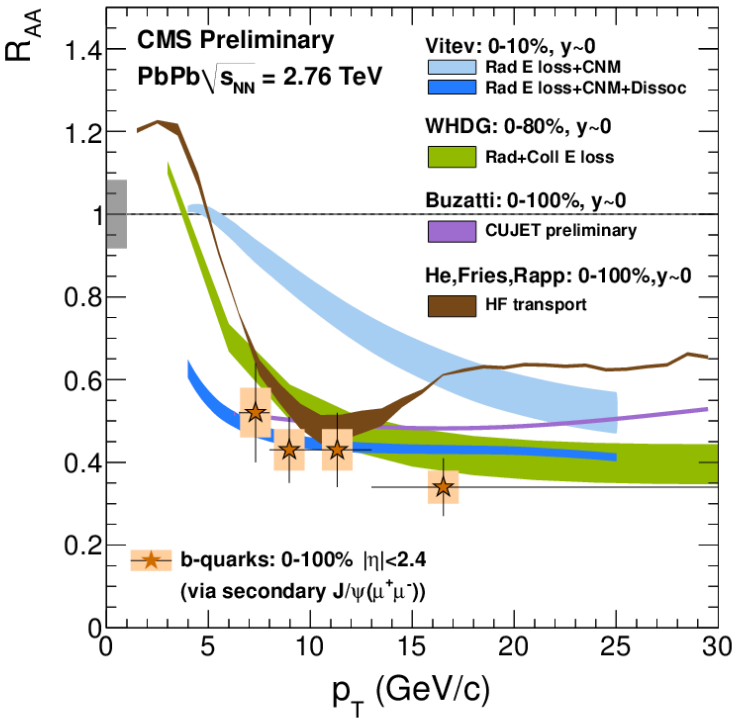
- Centrality dependence is observed on all rapidity region
- At forward rapidity, lower p_T ($3 < p_T < 6.5$ GeV/c) is accessible
  - Lower p_T is less suppressed than higher p_T

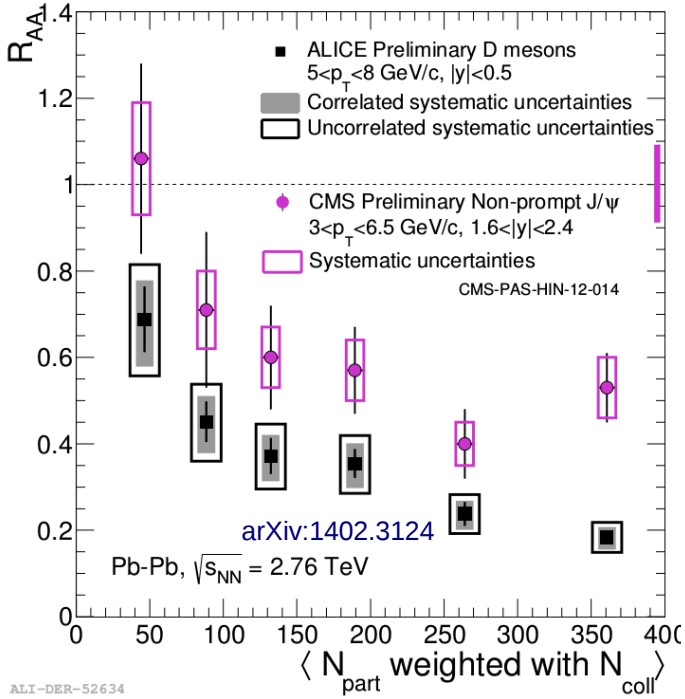
CMS PAS HIN-12-014

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN12014

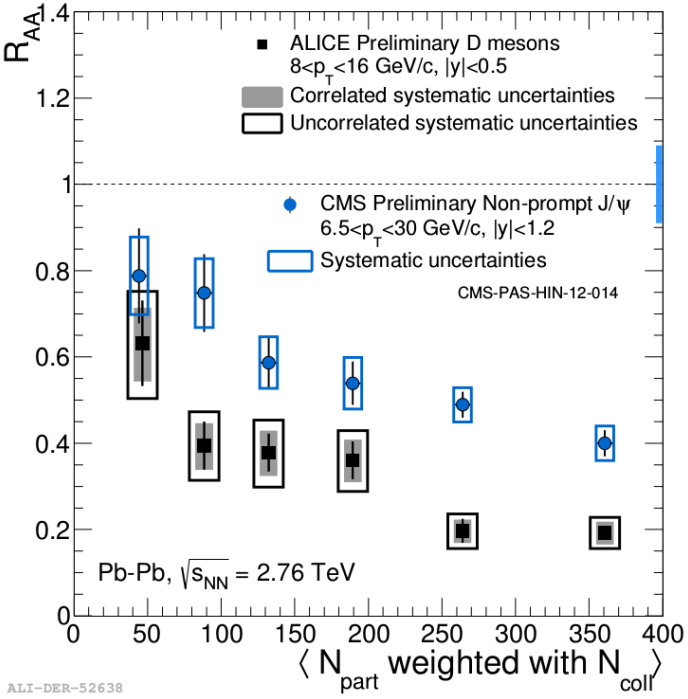
Non-prompt J/ψ R_{AA} : Comparison to theory

B: 3 < p_T < 6.5 GeV/c
D: 5 < p_T < 8 GeV/c





B: 6.5 < p_T < 30 GeV/c
D: 8 < p_T < 16 GeV/c



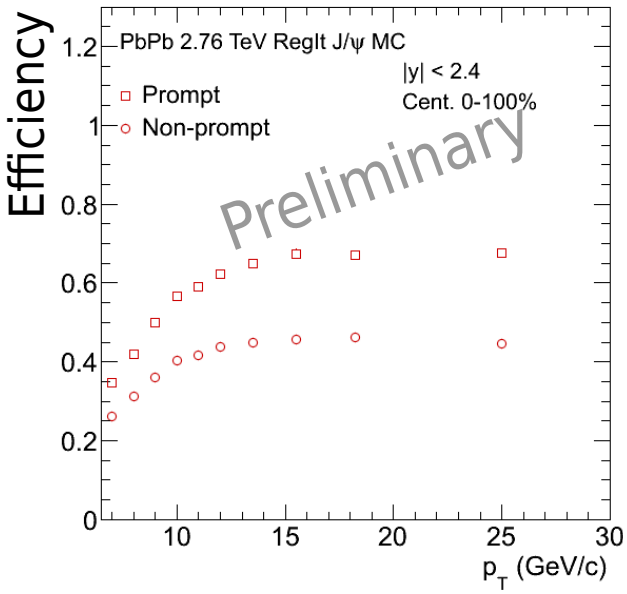
- R_{AA} of non-prompt J/ψ as a function of J/ψ p_T is compared to theoretical calculations as a function of B p_T (note: B p_T > J/ψ p_T)
- Radiative energy loss is not enough to describe b-quark energy loss
- D meson R_{AA} > Non-prompt J/ψ R_{AA} as a function of centrality

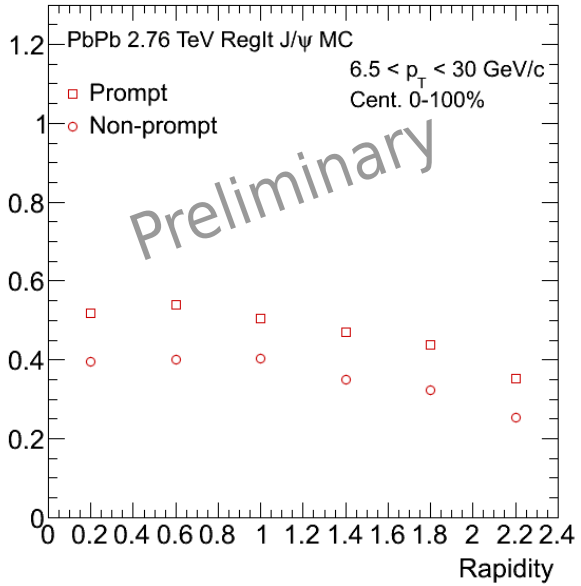
CMS PAS HIN-12-014 ALICE: JHEP 09 (2012) 112
Vitev: J. Phys. G35 (2008) 104011 + priv. comm.
Horowitz: arXiv:1108.5876 + priv. comm.
Buzzatti, Gyulassy: arXiv:1207.6020 + priv. comm.
He, Fries, Rapp: PRC86 (2012) 014903 + priv. comm.

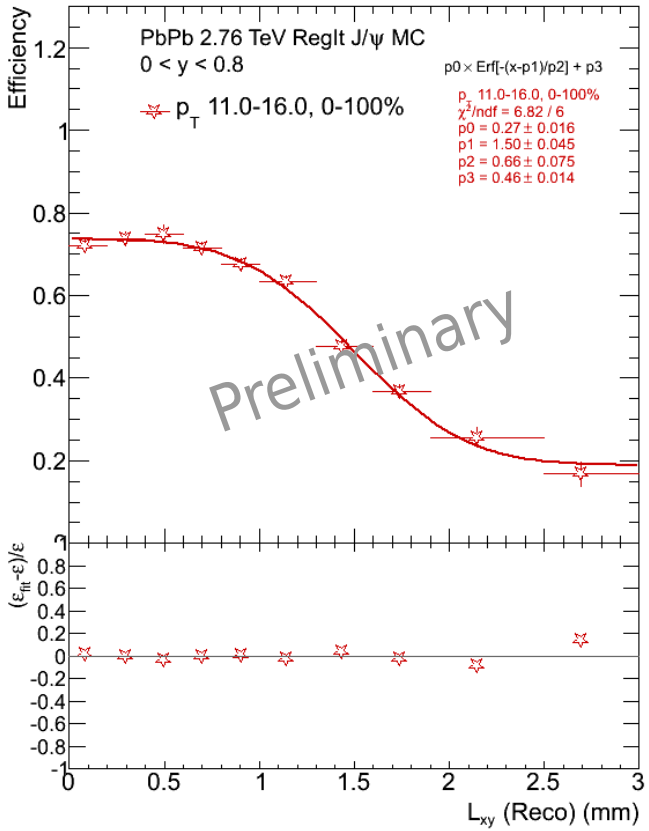
On-going developments

- Regional Iterative tracking (RegIt) in PbPb has higher efficiency than previous reconstruction algorithm

More details in Emilien's talk!







- Efficiency correction in L_{xy} is going to be applied for each events
  - Expect to have better description on fit models in lifetime distributions
- Non-prompt J/ψ R_{AA} with more statistics will come up!

Open beauty measurements in CMS

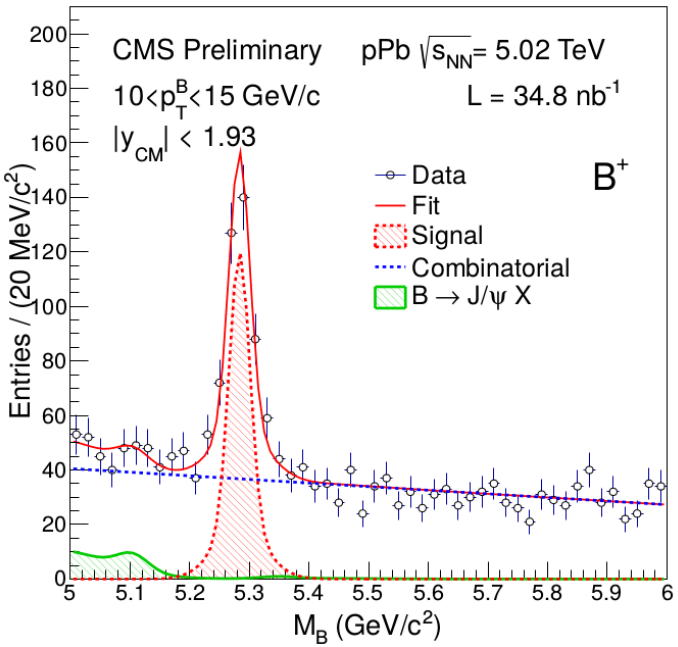
- Open beauty measurements in PbPb and pA collisions in CMS

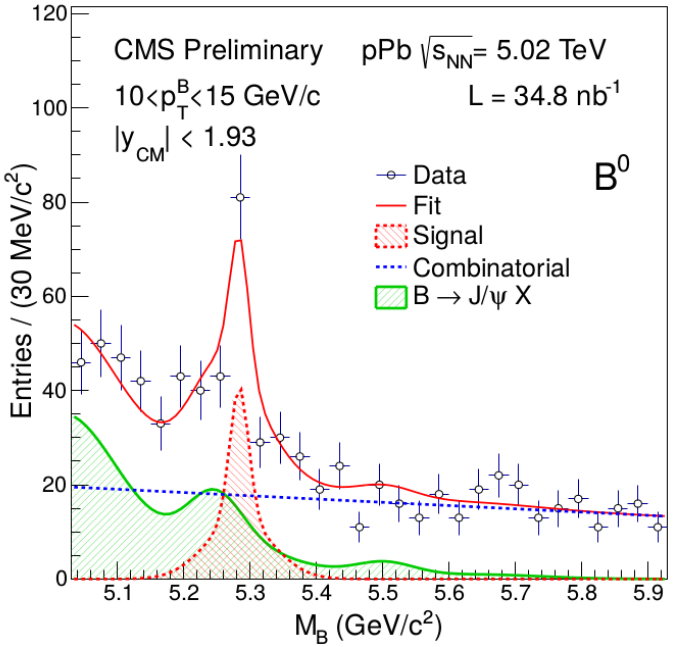
- Low p_T regions: Non-prompt J/ψ (~30 GeV/c) and B mesons (~70 GeV/c)
- High p_T regions: b jets (80~400 GeV/c)

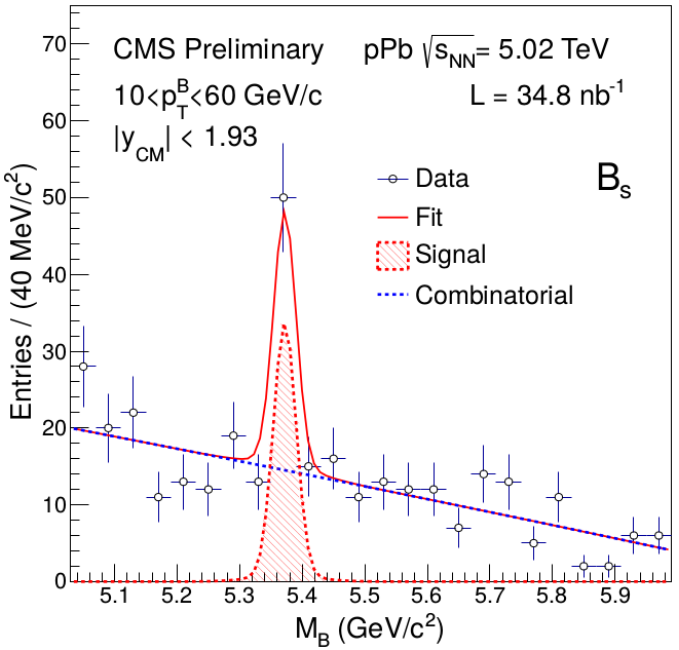
	PbPb Collisions	pPb Collisions
Non-prompt J/ψ	O	
B → J/ψ + K		O
b jets	O	O

Exclusive B mesons in pA collisions

- Charged B mesons are measured by J/ψ decay channels in pA collisions
  - $B^{+/-} \rightarrow J/\psi + K+ \rightarrow \mu^+\mu^- + K^{+/-}$
  - $B^0 \rightarrow J/\psi + K^* \rightarrow \mu^+\mu^- + K^+ + \pi^-$
  - $B_S \rightarrow J/\psi + \phi \rightarrow \mu^+\mu^- + K^+ + K^-$
- B meson candidates are obtained from J/ψ combined with a track (B^+) or two tracks (B^0, B_S)





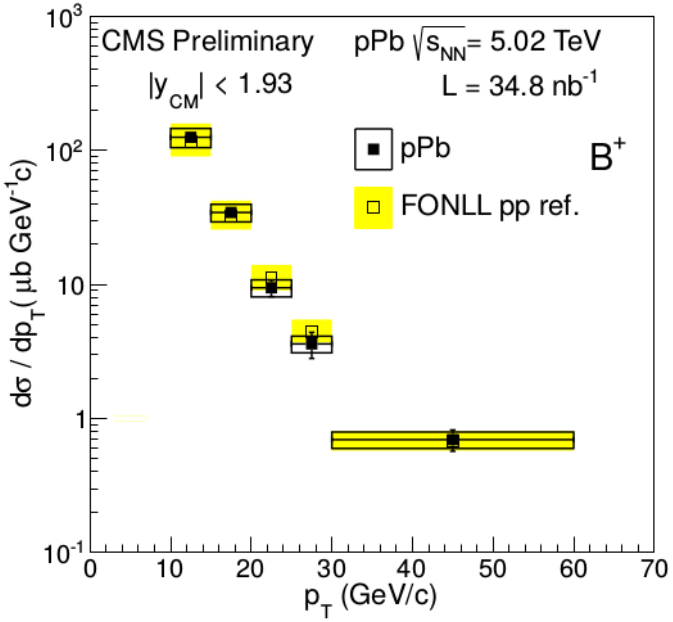


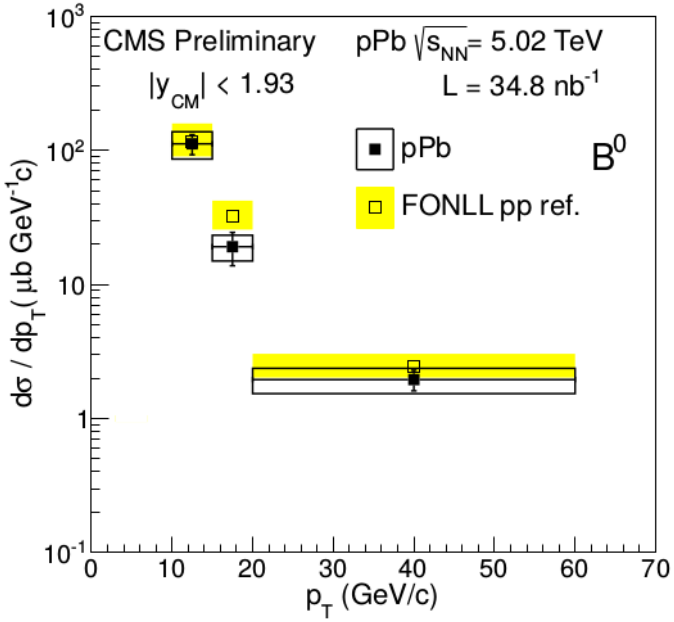
CMS PAS HIN-14-004

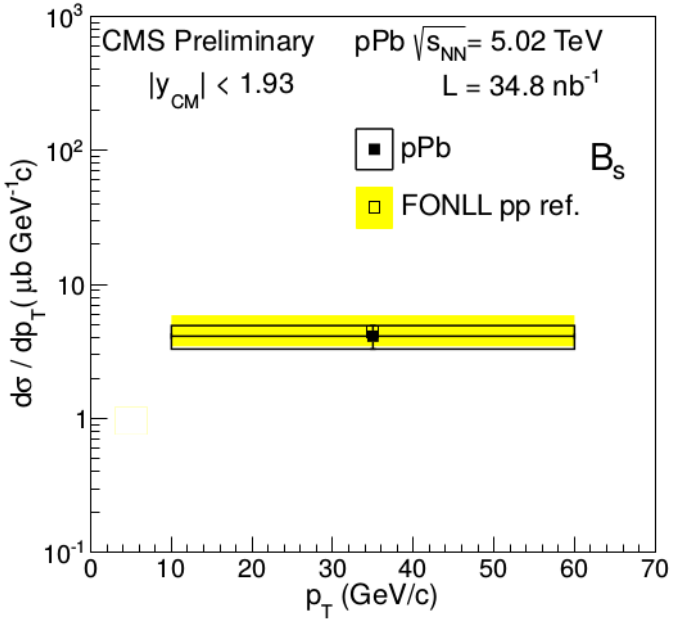
Systematics of B mesons in pA

Factors (%)	$B^+ \to J/\psi\, K^+$	$B^0 \to J/\psi\, K^*$	$B_s^0 \to J/\psi\, \phi$
Acceptance	0.5–1.0	0.7–2.0	5.6
Best candidate selection	3.2	3.1	2.4
B selection efficiency	9.0	13.5	13.5
p_T resolution correction(max.)	0.6	0.6	0.6
Trigger efficiency	1.3–5.9	1.8–6.8	4.9
Muon identification	2.4–5.2	2.8–5.6	4.6
Muon tracking efficiency	1.2–4.3	2.9–4.3	4.0
Hadron tracking efficiency	3.9	7.8	7.8
Signal and background shape variation	8.9	13.4	7.5
Sum	14.0–16.3	21.4–23.0	20.0
Luminosity	3.5	3.5	3.5
Branching fractions	3.2	4.6	+22.0, -24.0

Differential cross sections





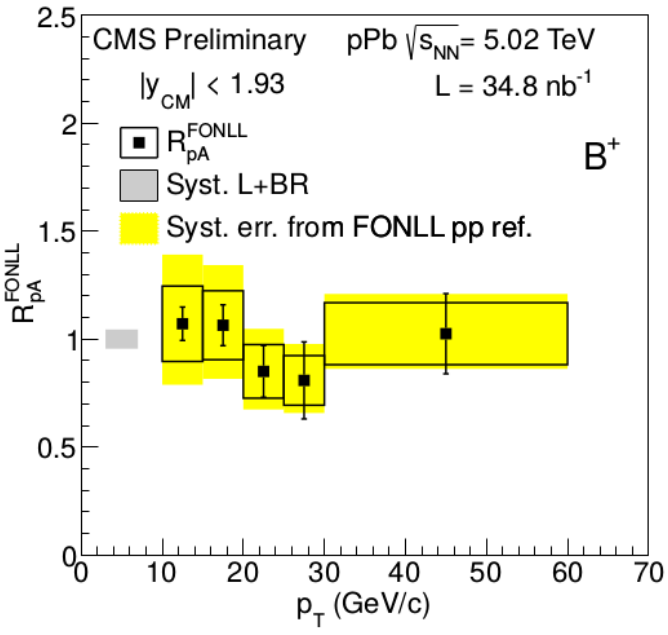


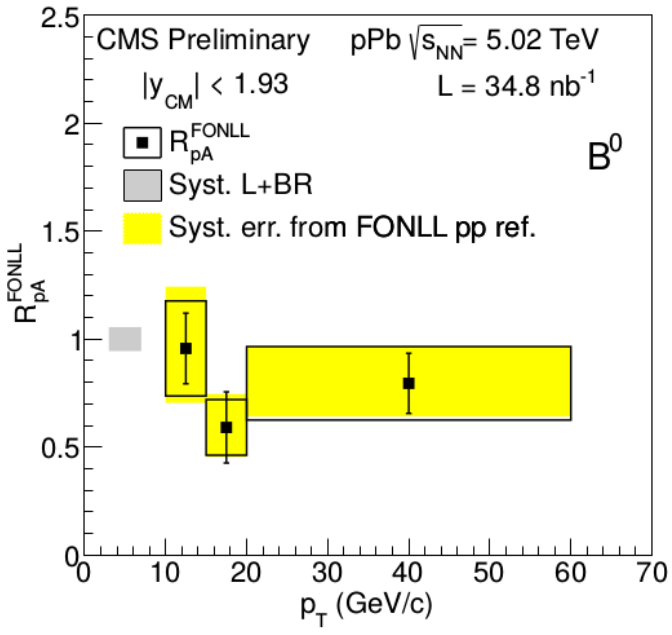
$$\left.\frac{\mathrm{d}\sigma^{\mathrm{B}}}{\mathrm{d}p_{\mathrm{T}}}\right|_{|y_{CM}|<1.93} = \frac{1}{2}\frac{1}{\Delta p_{\mathrm{T}}}\frac{N^{\mathrm{B}}\big|_{|y_{CM}|<1.93}}{(\mathrm{Acc}\times\epsilon)\cdot \mathrm{BR}\cdot\mathcal{L}}$$

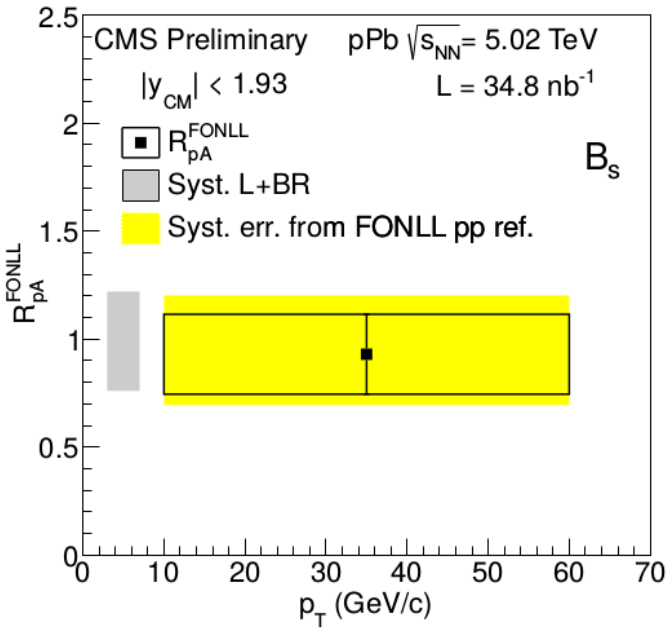
- Due to the asymmetry in the collision system, $|y_{CM}| < 1.93$ is measured
- FONLL calculation is used as pp reference and it is taken from http://www.lpthe.jussieu.fr/~cacciari/fonll/fonllform.html
- Good agreement with CDF and CMS results

CMS PAS HIN-14-004

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





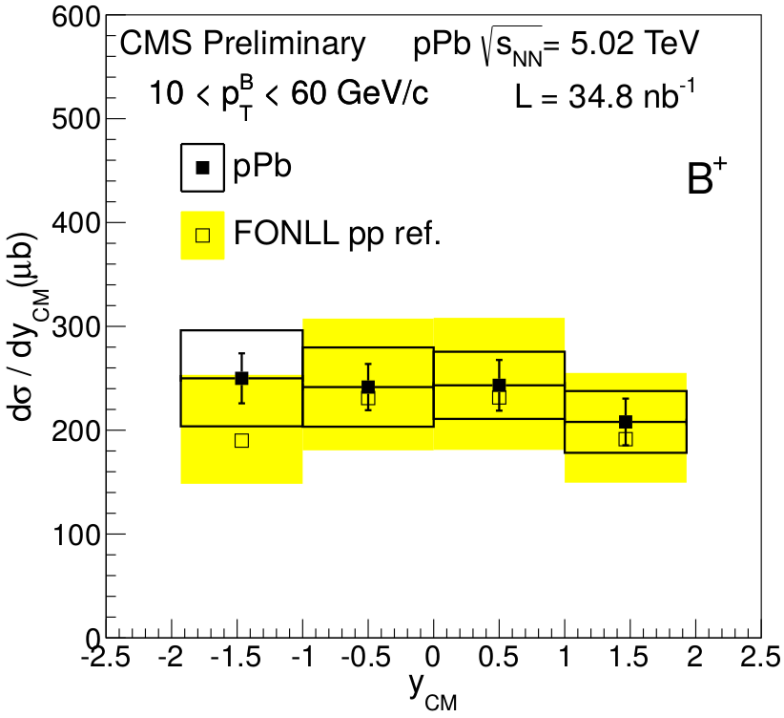


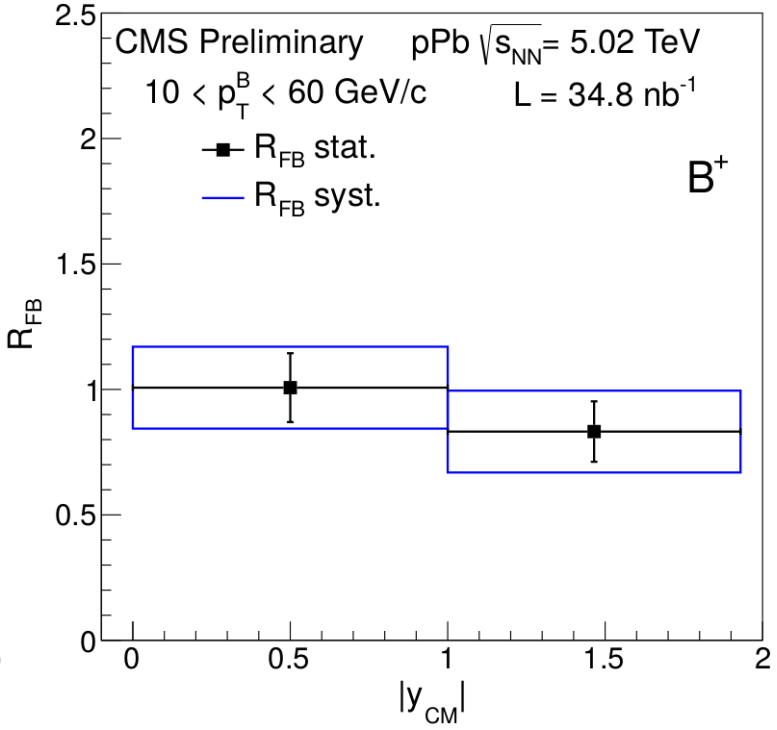
$$R_{pA}^{\mathrm{FONLL}}(p_{\mathrm{T}}) = \frac{\left(\frac{d\sigma}{dp_{\mathrm{T}}}\right)_{pPb}}{A \times \left(\frac{d\sigma}{dp_{\mathrm{T}}}\right)_{pp}}$$

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

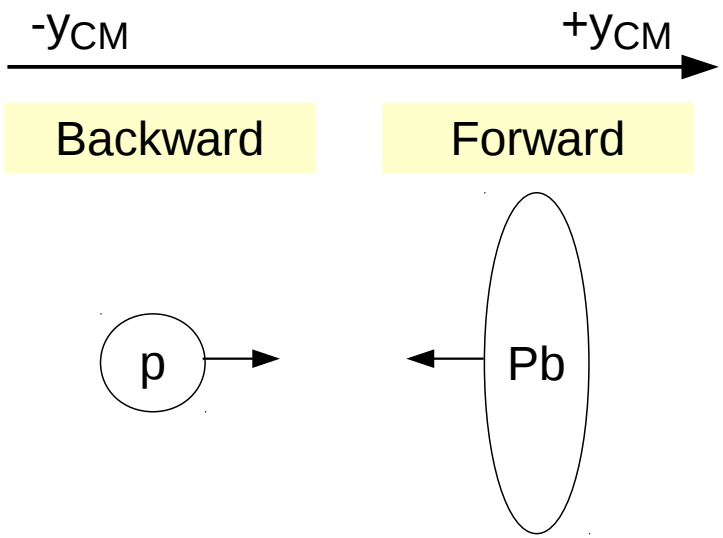
CMS PAS HIN-14-004

R_{FB} of B^+





$$R_{\mathrm{FB}} = \frac{N^{corr}_{forward}}{N^{corr}_{backward}}$$

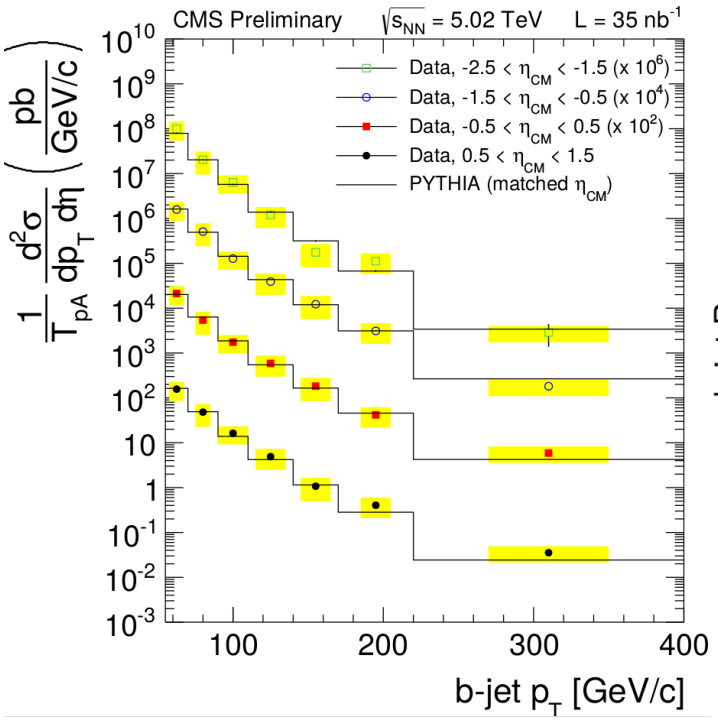


- Forward and backward ratio, R_{FB}, is unity within uncertainty

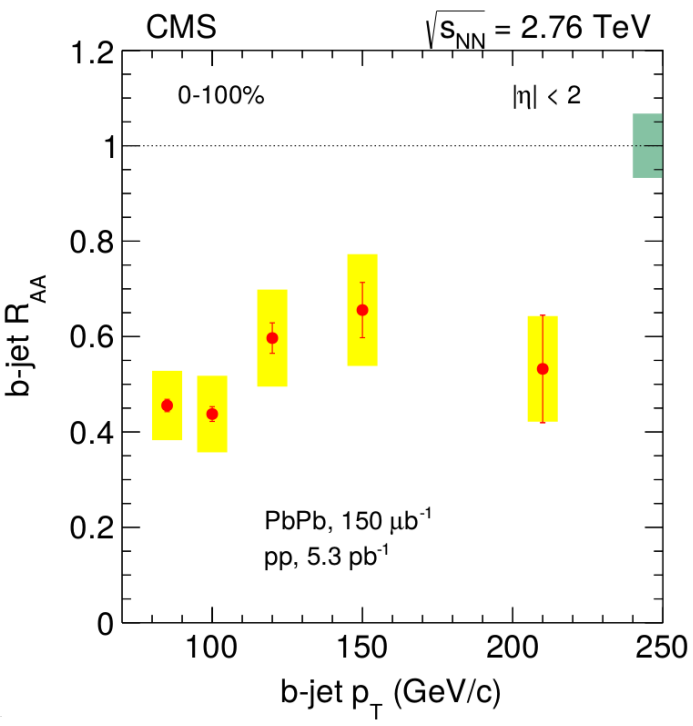
CMS PAS HIN-14-004

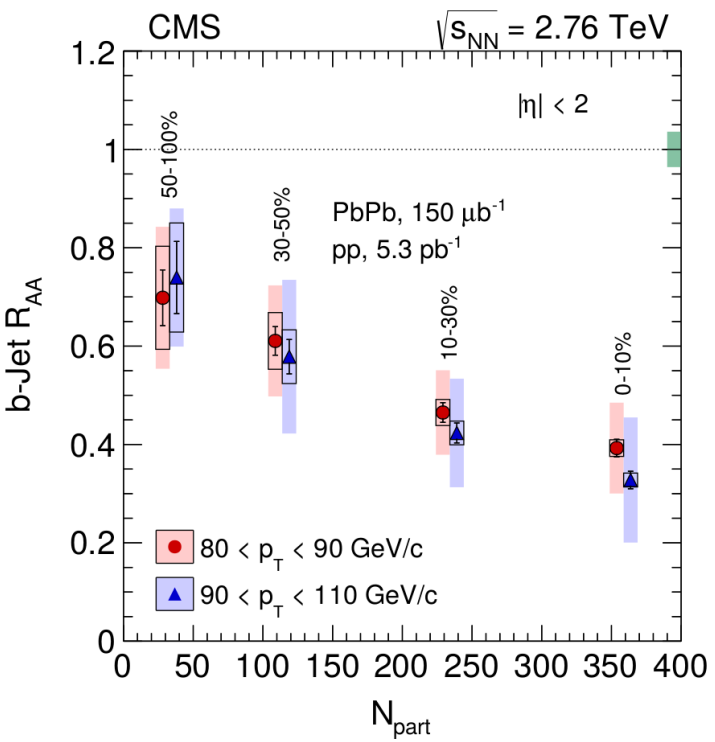
b jets in PbPb and pA collisions

pA



PbPb



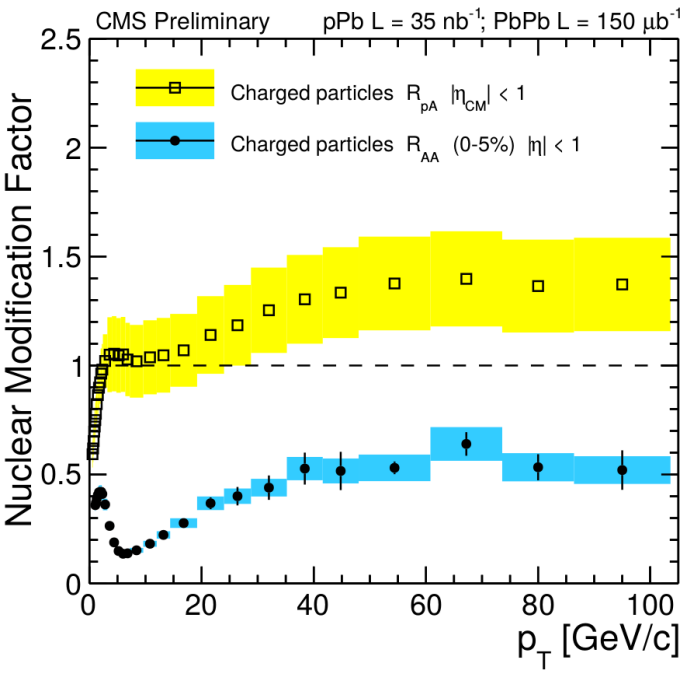


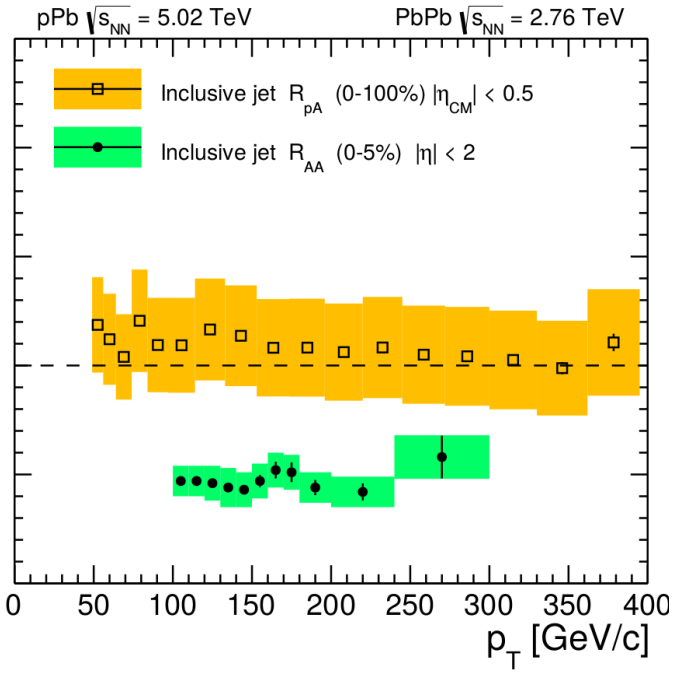
- Identify b jets by selecting charged tracks at reconstruct secondary vertex (SV) which are far enough from primary vertex (PV)

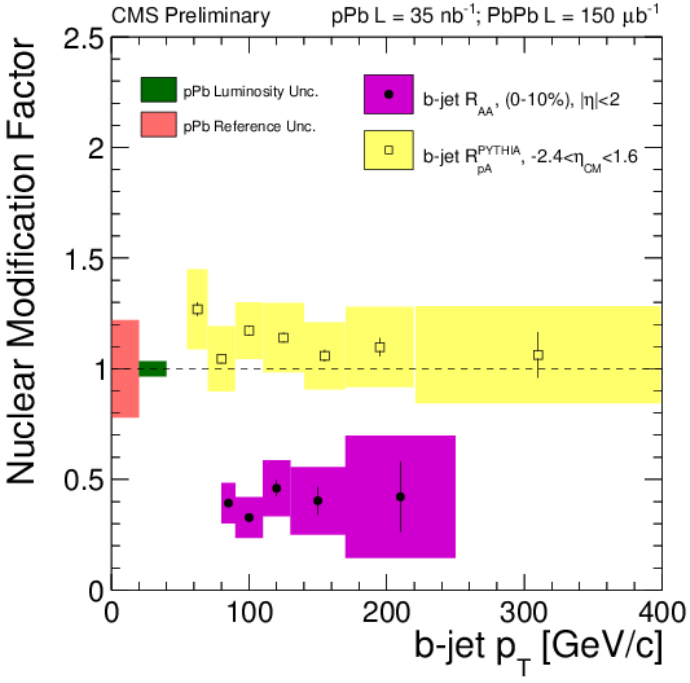
- Clearly b jets are modified by presence of medium
  - Centrality dependent suppression pattern is observed

(PbPb) arXiv: 1312.4198 : accepted by PRL
(pA) CMS PAS HIN-14-007

No flavor dependence at high p_T







- Charged particle and inclusive jet R_{AA} are suppressed in similar amount
  - No modification as a function of jet flavor has been observed at high p_T

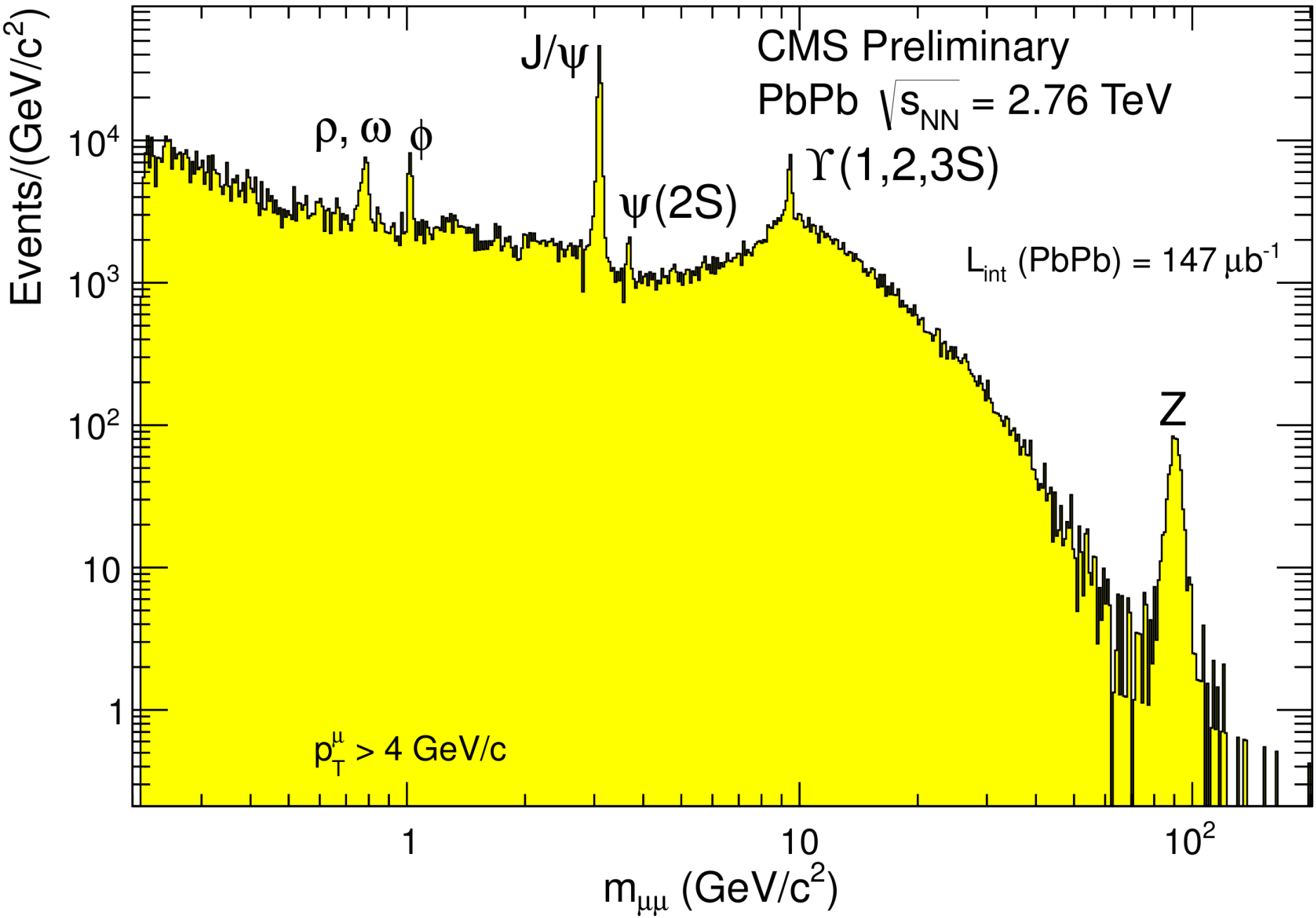
Charged particles:
(PbPb) EPJC 72 (2012) 1945, (pA) CMS PAS HIN-12-017
Inclusive jet:
(PbPb) CMS PAS HIN-12-004, (pA) CMS PAS HIN-14-001
b jet:
(PbPb) arXiv: 1312.4198(accepted by PRL), (pA) CMS PAS HIN-14-007

Summary

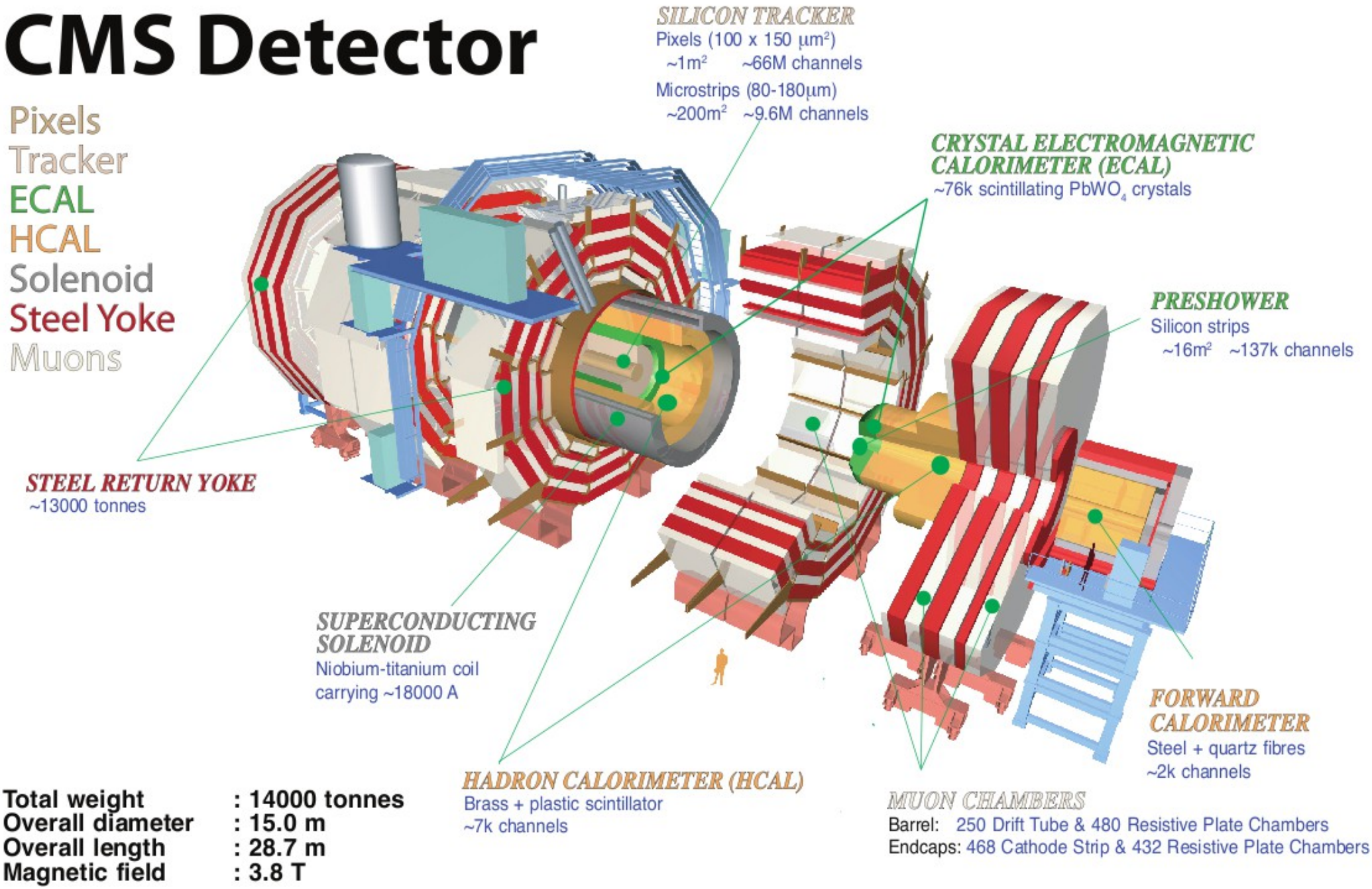
- CMS has measured open beauty in PbPb and pA collisions
- An unambiguous access to b-quark energy loss from low p_T to high p_T regions in PbPb collisions
  - Centrality dependent suppression for open beauty has been observed
- Open charm is more suppressed than open beauty at low p_T region
  - In order to estimate B hadron energy loss more explicitly
    - Different p_T spectra of parent c and b quarks need to be counted
- No flavor dependent suppression for jets at high p_T region
- No significant modifications in pA collisions for open beauty

BACK UP

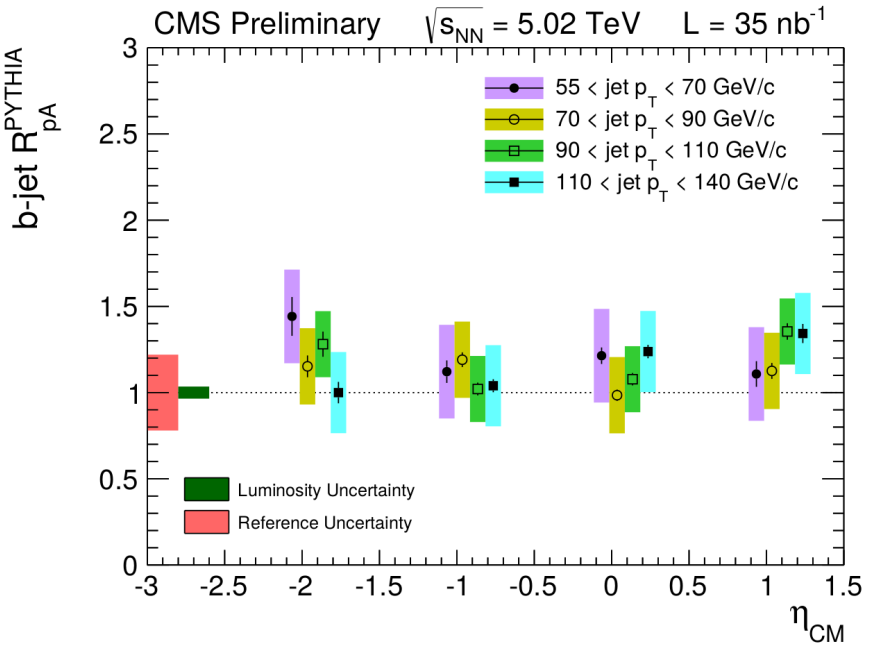
Dimuon spectrum in PbPb at $\sqrt{s_{NN}}$ =2.76 TeV

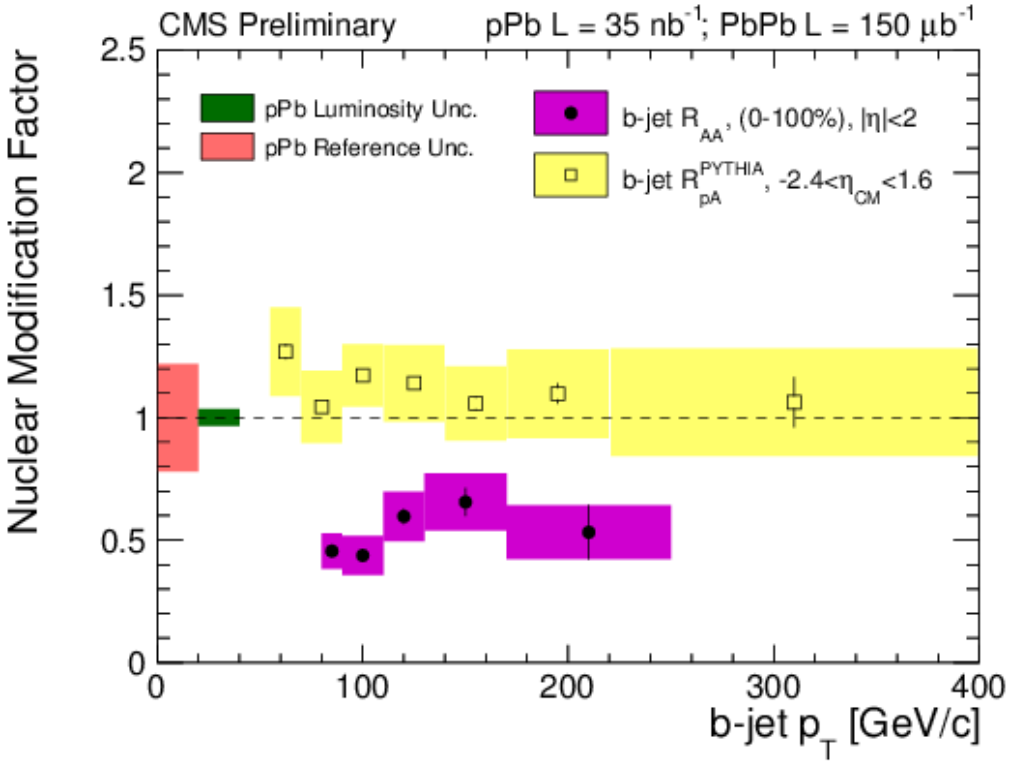


CMS Detector

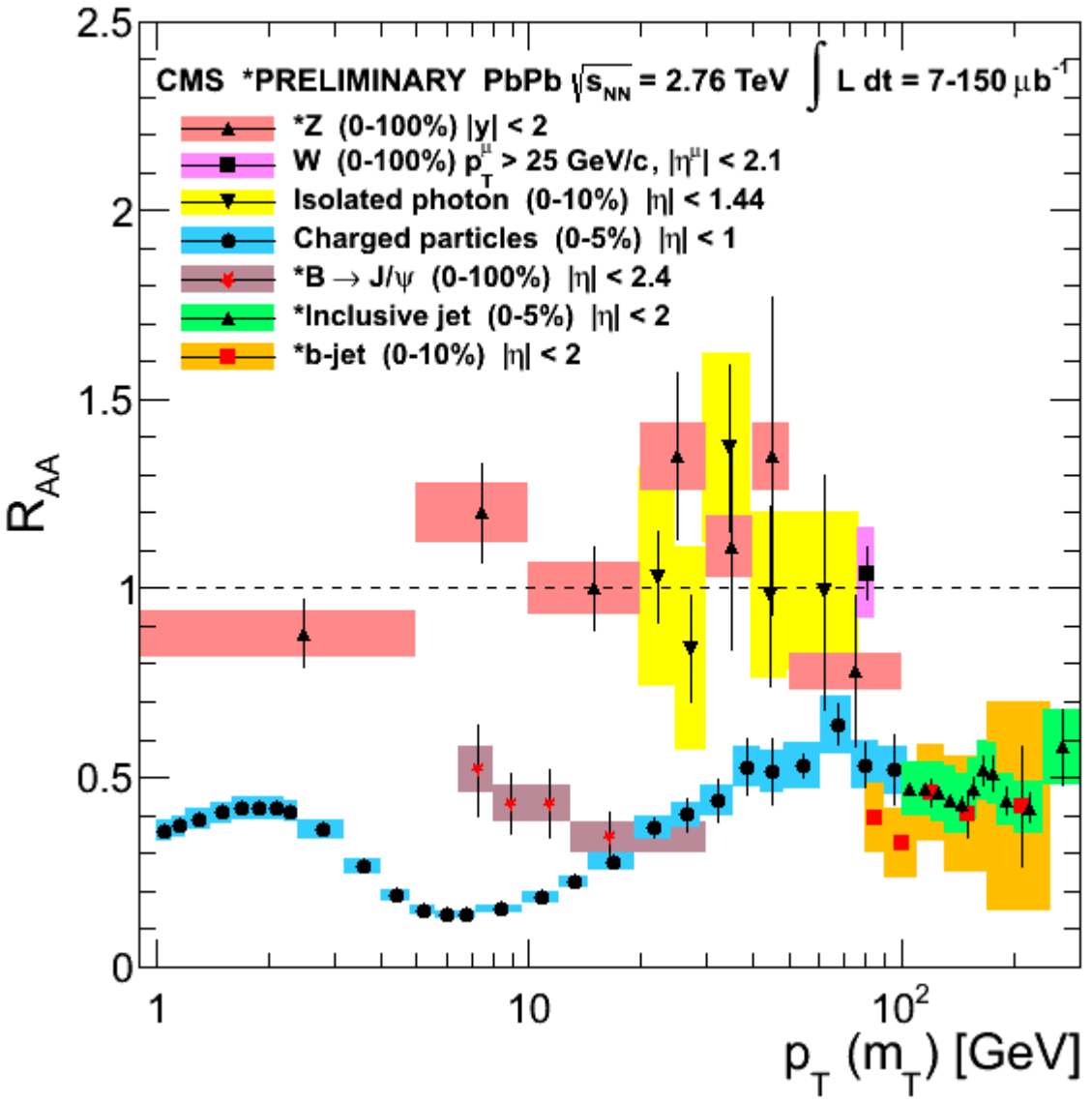


More b jet measurements





PbPb and pA R_{AA} zoo



More on uncertainty of B mesons

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