

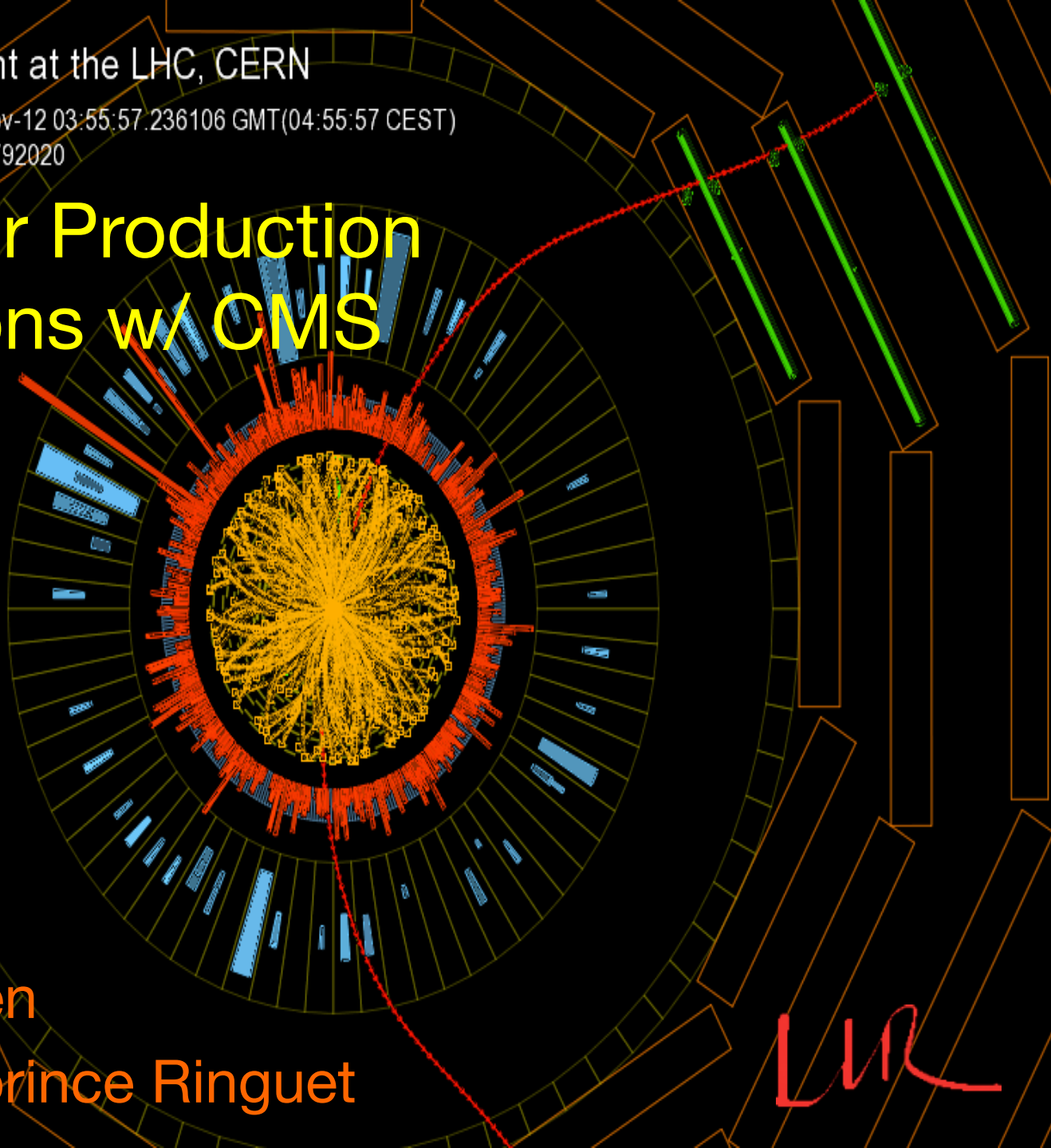


CMS Experiment at the LHC, CERN

Data recorded: 2010-Nov-12 03:55:57.236106 GMT(04:55:57 CEST)

Run / Event: 150887 / 1792020

Heavy Flavor Production in Heavy Ions w/ CMS



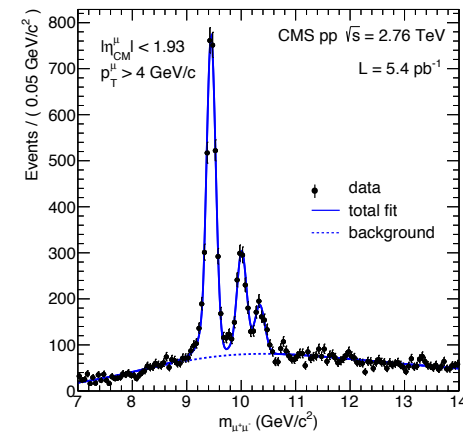
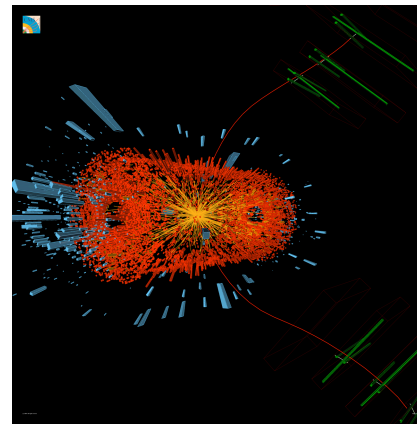
Matthew Nguyen
Laboratoire Leprince Ringuet

A handwritten signature in red ink, likely belonging to Matthew Nguyen.

Beauty in Heavy Ions

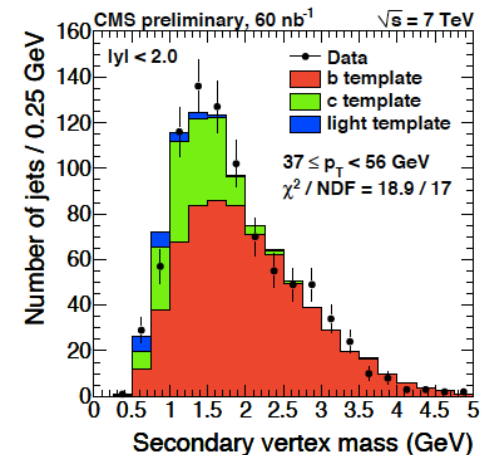
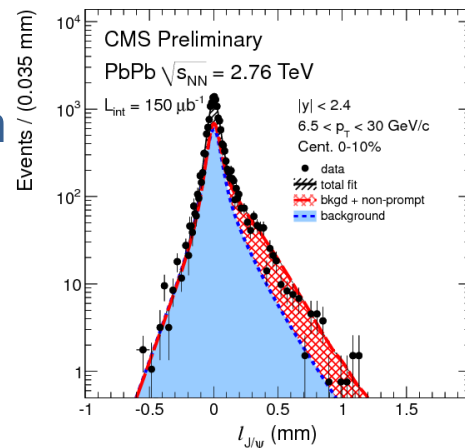
■ Bottomonia

- Bound state thermometry
- Clean separation of excited states w/ dimuons
- p_T coverage down to zero
- $b\bar{b}$ regeneration small



■ Open beauty

- Flavor dependence of parton energy loss
- Low p_T : B meson suppression via non-prompt J/ψ
- High p_T : b-tagged jets

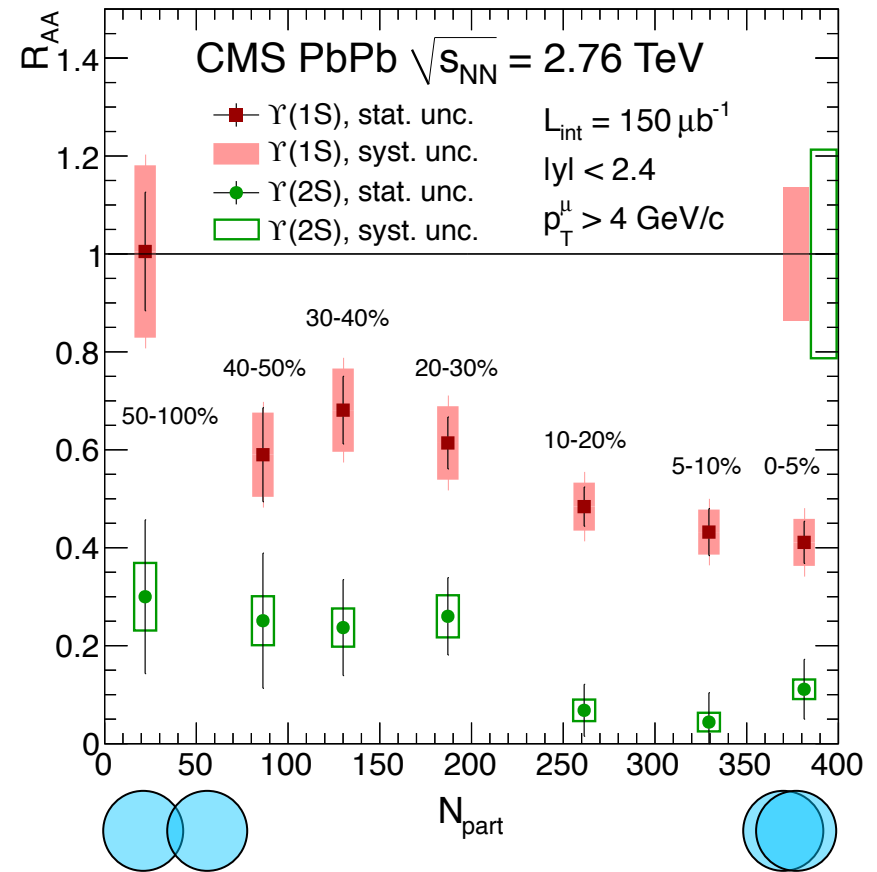
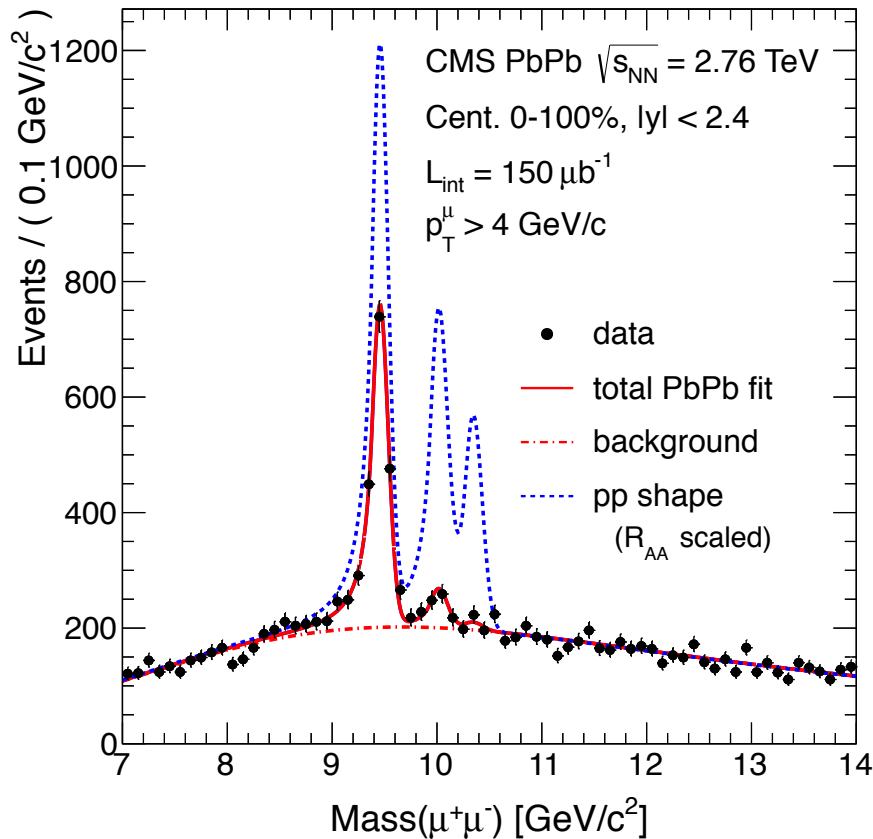


■ Charm not discussed here

Bottomonium

“Sequential Melting”

PRL 109 (2012) 222301

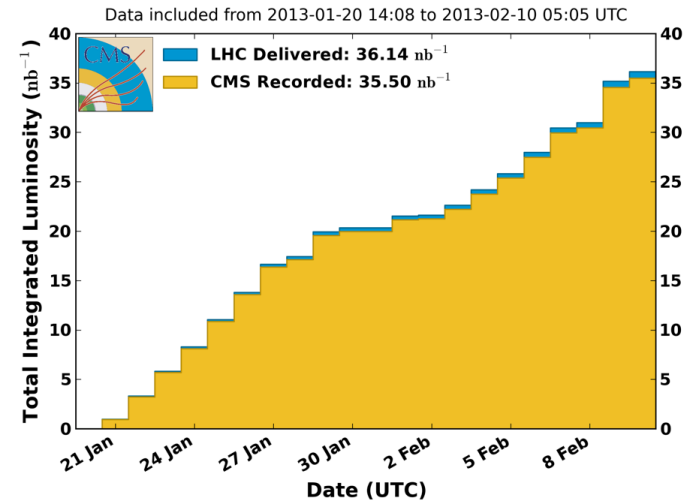


- $50.9 \pm 8.2 \pm 9\%$ of $\Upsilon(1s)$ from feed-down, mostly from p states
- Nuclear modification of $\Upsilon(1s)$ just melting of excited states?
- Are there other effects that could contribute to the dissociation of Υ states?

Proton-lead collisions

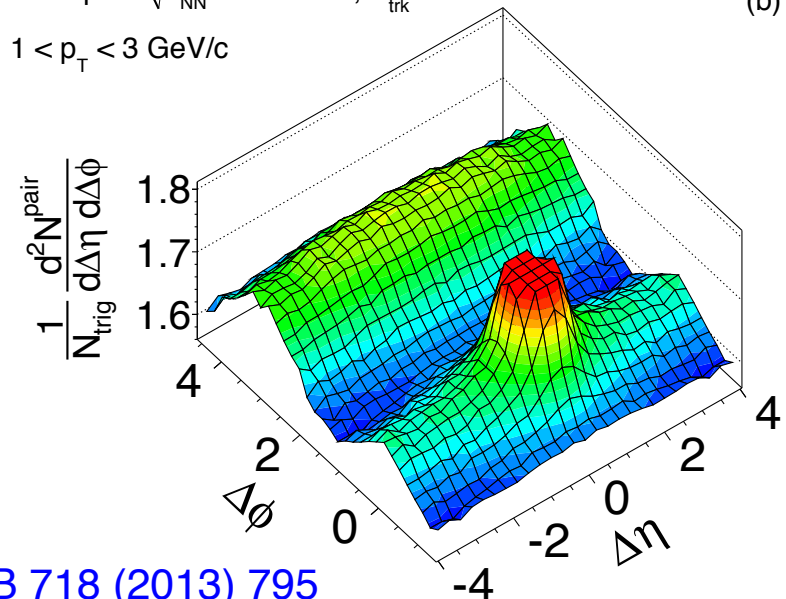
- pPb used to understand
 - Nuclear effects on parton distributions
 - Final state effects from cold nuclear matter
 - Other non-QGP effects
- Some effects thought to be related to hot QCD seen in high multiplicity pPb
 - Long-range ‘ridge’ correlations indicating flow
 - But no evidence of others, e.g., jet quenching
- How about heavy flavor?

CMS Integrated Luminosity, pPb, 2013, $\sqrt{s} = 5.02$ TeV/nucleon



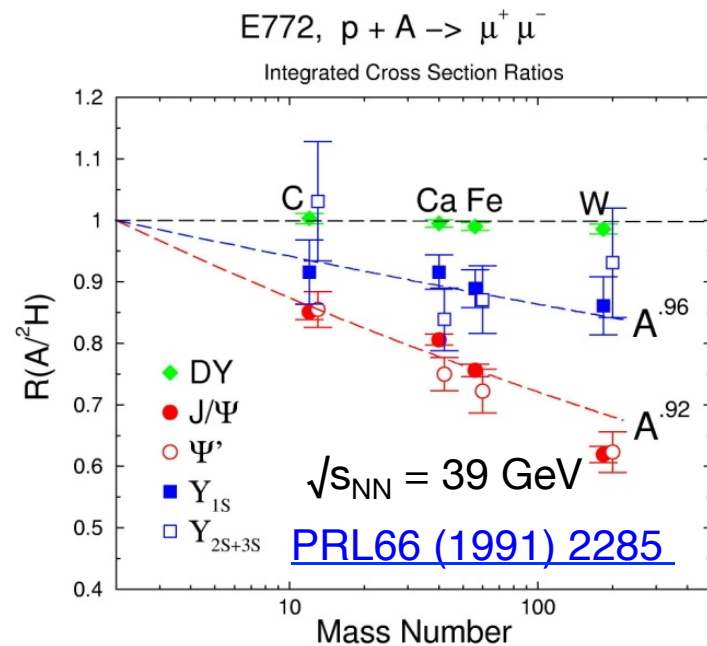
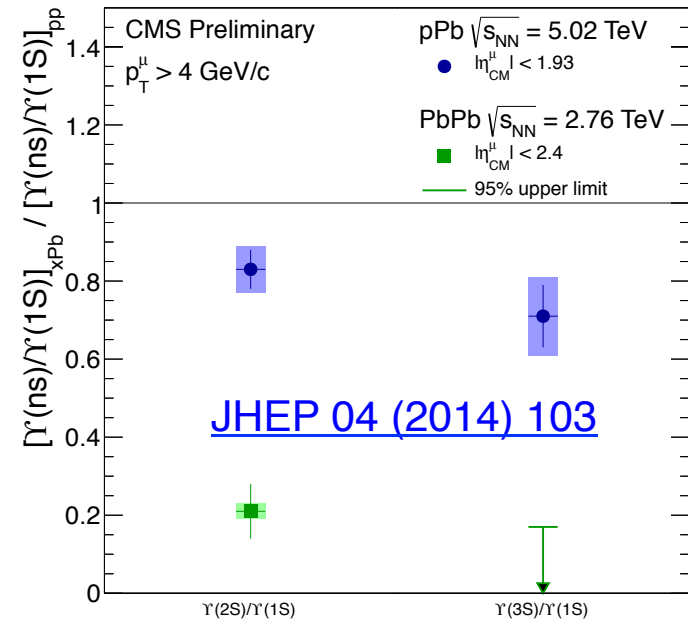
CMS pPb $\sqrt{s_{NN}} = 5.02$ TeV, $N_{\text{trk}}^{\text{offline}} \geq 110$

$1 < p_T < 3$ GeV/c



Υ in pA

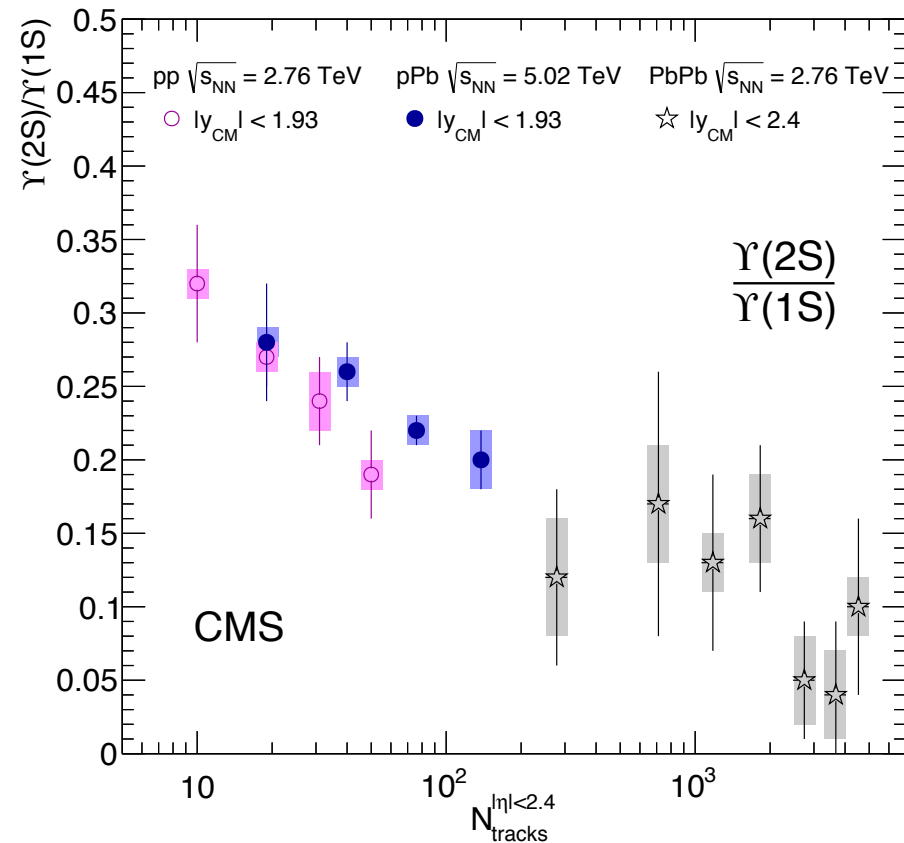
- Mild suppression of excited states (rel. to ground state) in pPb
- Effects of comparable size to previous observations at the SPS and at RHIC
- Extrapolation to PbPb is model dependent



Event activity dependence

[JHEP 04 \(2014\) 103](#)

- Unlike PbPb, weak correlation btwn. event activity and collision geometry
- $\Upsilon(2S)/\Upsilon(1S)$ decreases w/ multiplicity in pPb \rightarrow final state interactions?
- Similar (stronger?) dependence in pp
- Tempting to interpret a smooth progression from pp to PbPb, but statistics errors are large
- Alternative scenario: associated production smaller for excited states

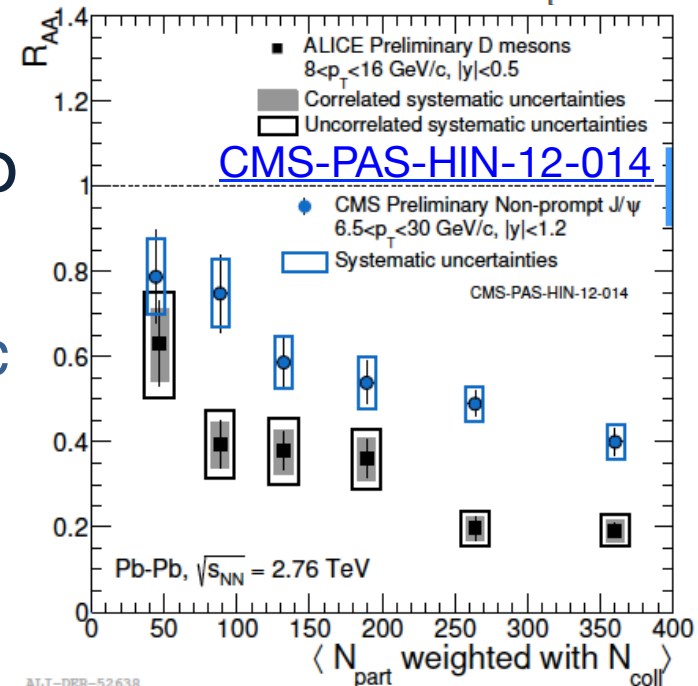
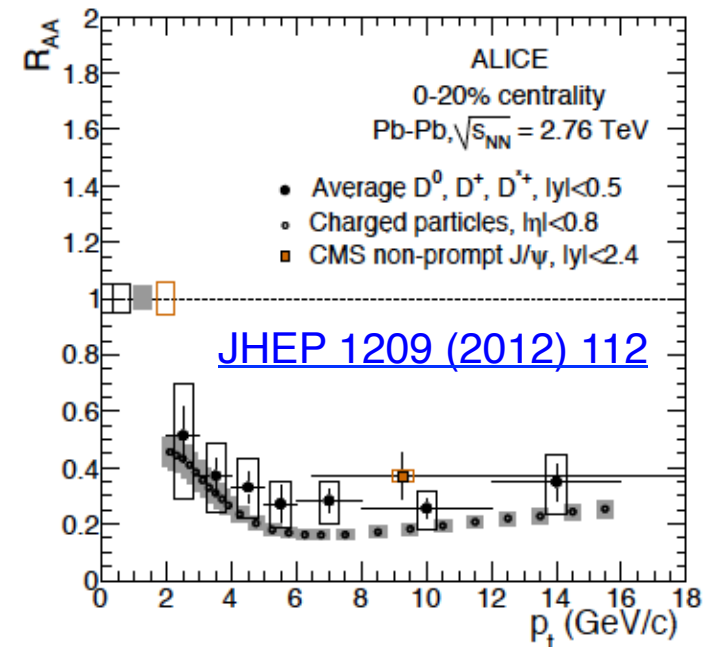


Larger statistics and further observables, e.g., epsilon-hadron correlations are needed to understand effect in pPb and extrapolate to PbPb

Open Beauty

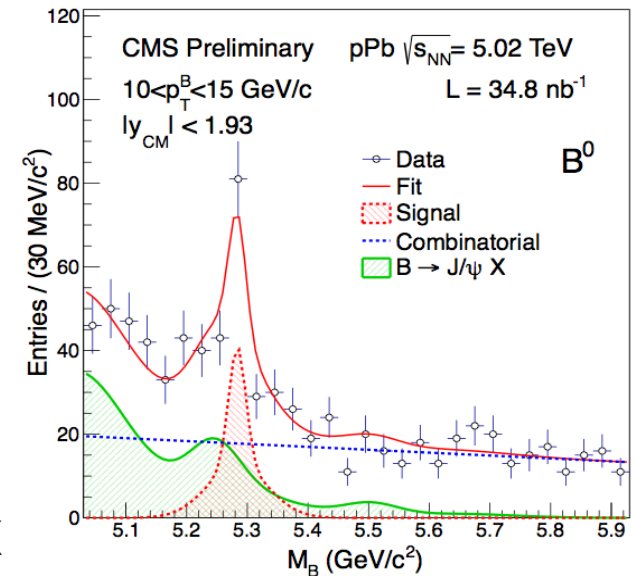
Heavy quark energy loss

- Interest is two-fold
 - Quark vs gluon e-loss
 - Mass effects (radiation damping)
- Non-prompt J/ψ R_{AA}
 - $> D$ meson $R_{AA} >? h R_{AA}$
- R_{AA} does not translate directly to parton energy loss
 - Different spectral shape for b and c
 - Harder fragmentation for b
 - Contamination from gluon splitting (expected to be larger for c than b)

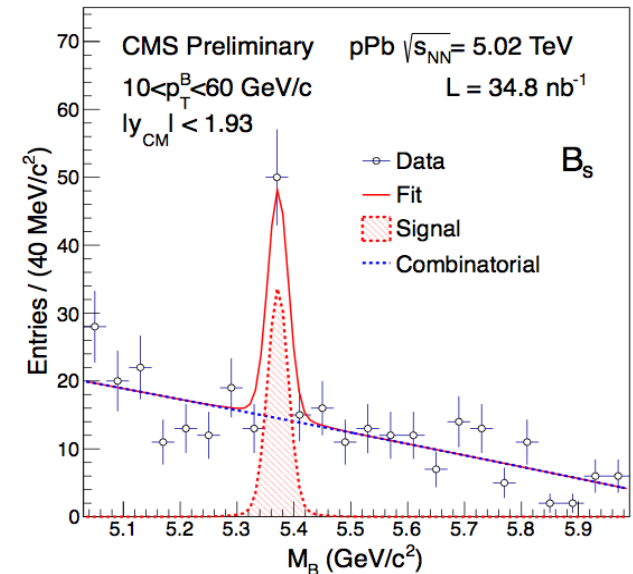
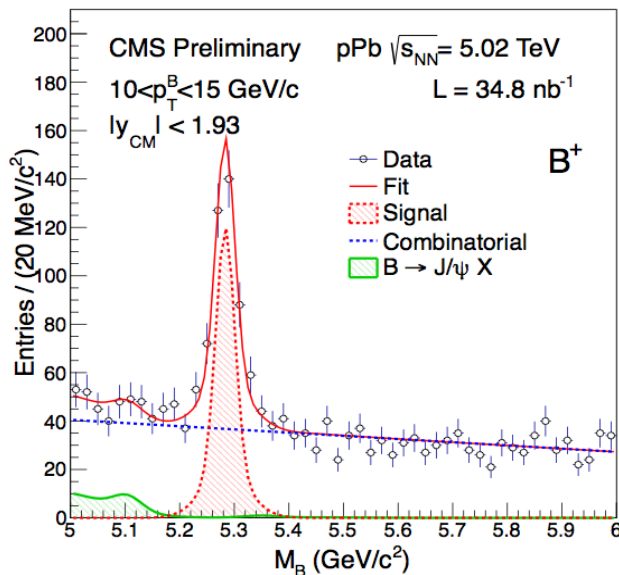


Open beauty in pPb

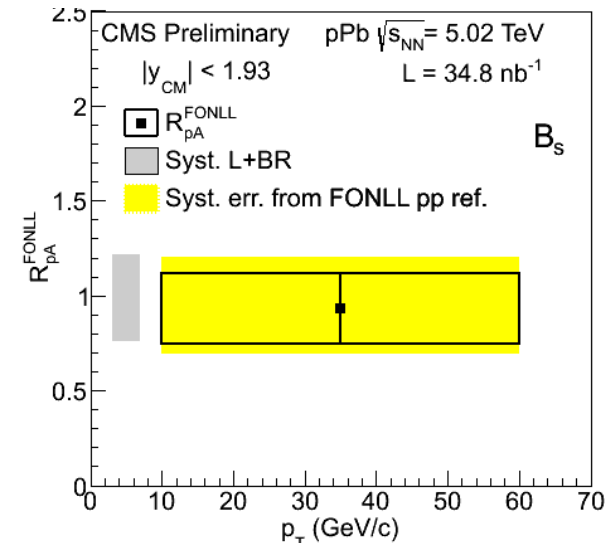
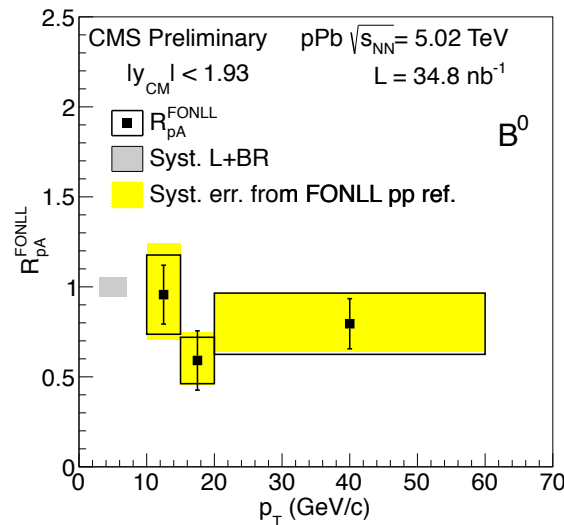
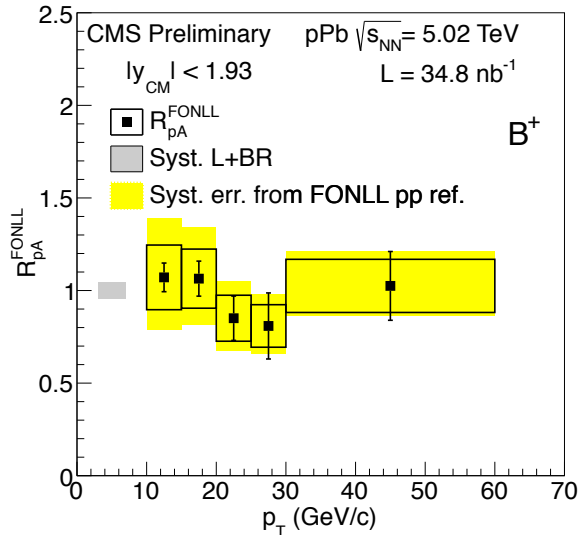
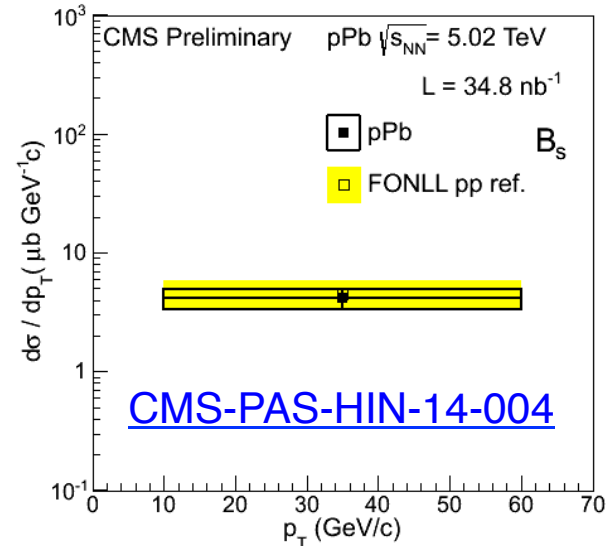
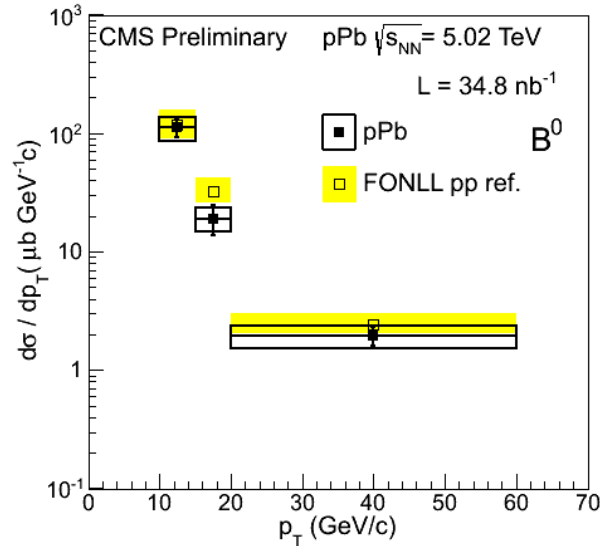
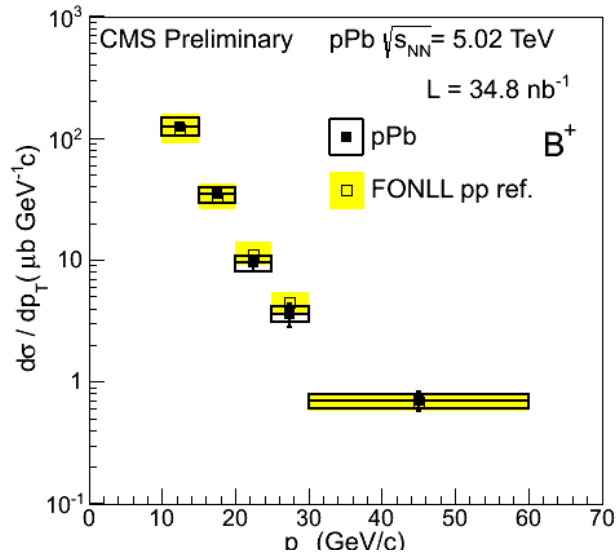
- 3 channels measured
 - $B^+ \rightarrow J/\psi + K^+$
 - $B^0 \rightarrow J/\psi + K^{*0}$
 - $B_s \rightarrow J/\psi + \phi$
- Background modeling
 - Combinatorial background from J/ψ -track(s)
 - Resonant background from other $B \rightarrow J/\psi + X$ (e.g. for B^+ , contribution from $B^0 \rightarrow J/\psi K^{*0}$)



[CMS-PAS-HIN-14-004](#)



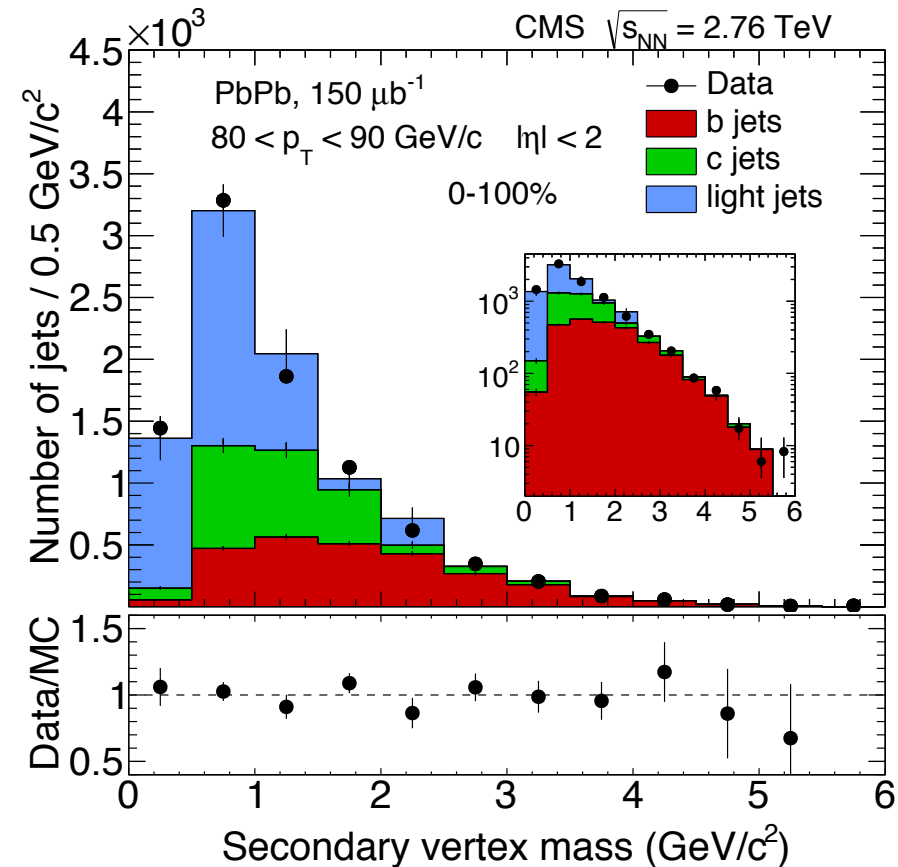
B mesons in pPb vs FONLL



Ratios w/ FONLL consistent w/ unity \rightarrow no large nuclear effect in pPb

b-jet tagging in PbPb

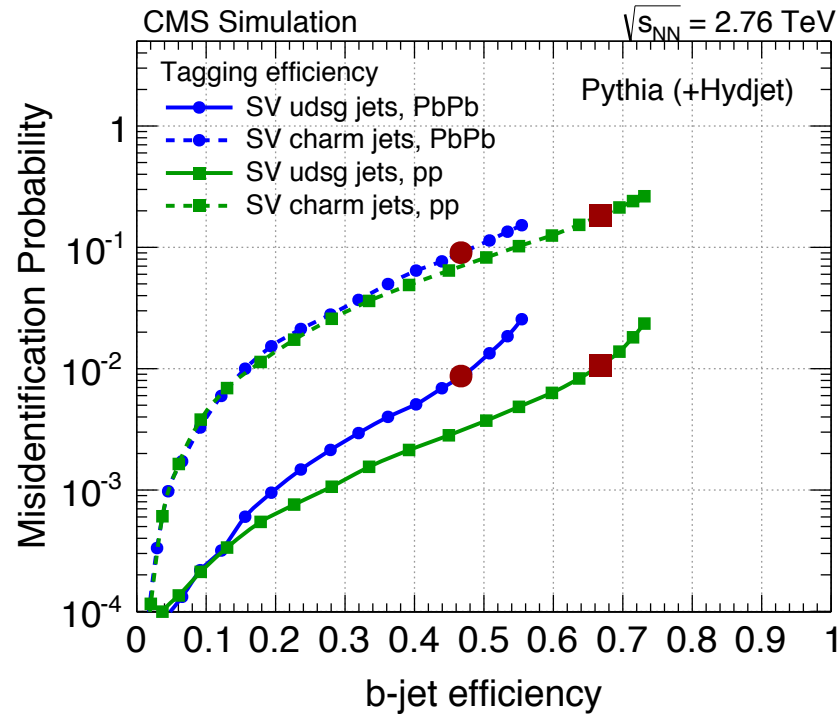
- Secondary vertex (SV) tagger
- Discriminating variable:
Flight distance significance
- b-jet purity from template fit using Pythia embedded in PbPb MC events (Hydjet)
- Small contribution from jets overlapping w/ b-hadron from underlying event
- Data-driven tagging efficiency using a reference tagger based on impact parameter



b tagging in CMS:

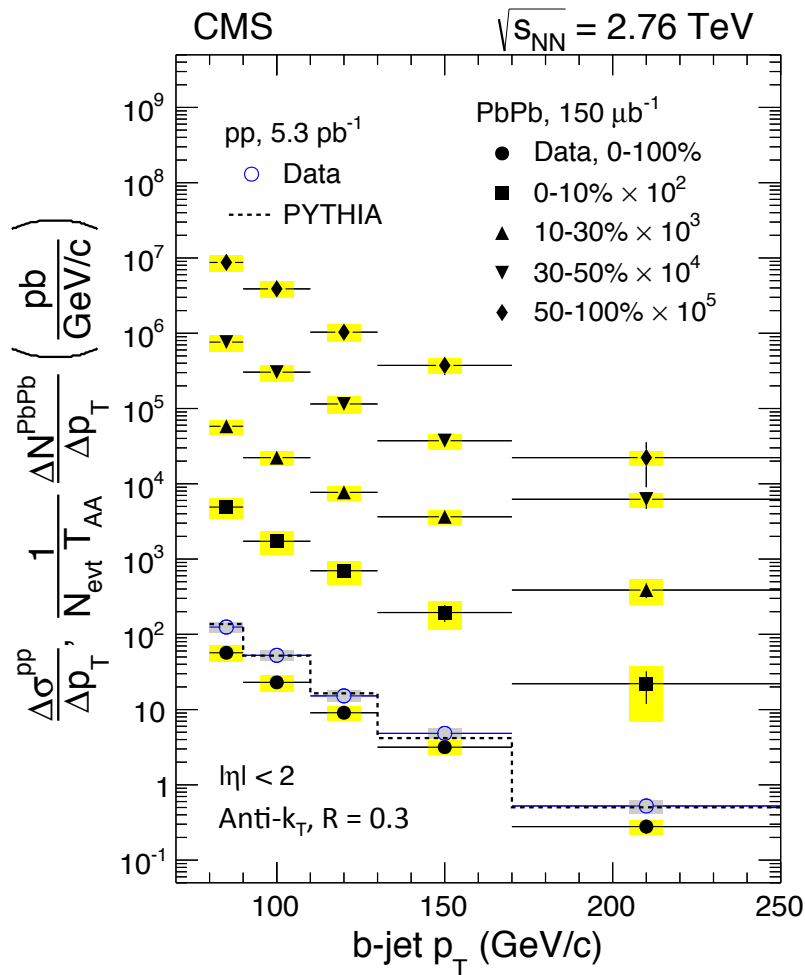
[JINST 8 \(2013\) P04013](#)

b-tagging (SV) performance in PbPb

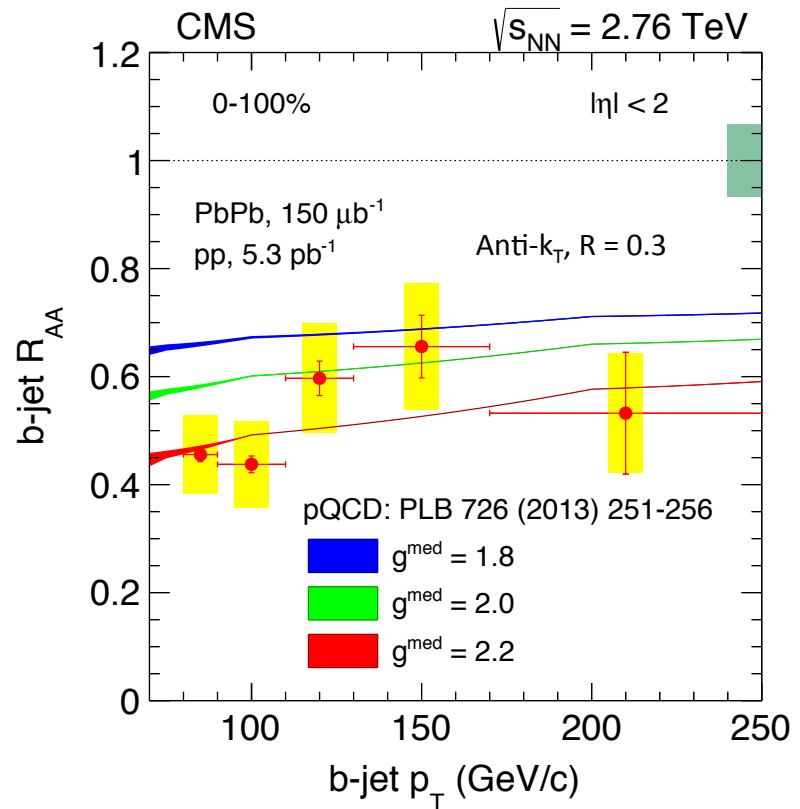


- Reduced efficiency in PbPb due to tighter track selections
- Larger light jet mis-ID in PbPb from combinatorics / UE
- Similar c-jet rejection

Inclusive b jets in PbPb

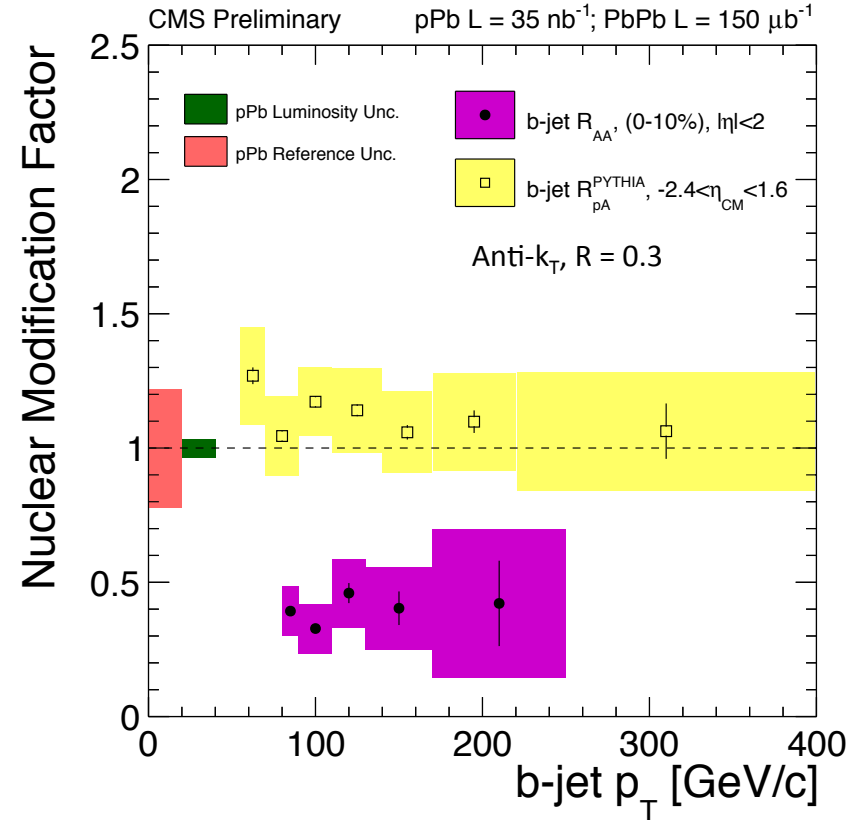
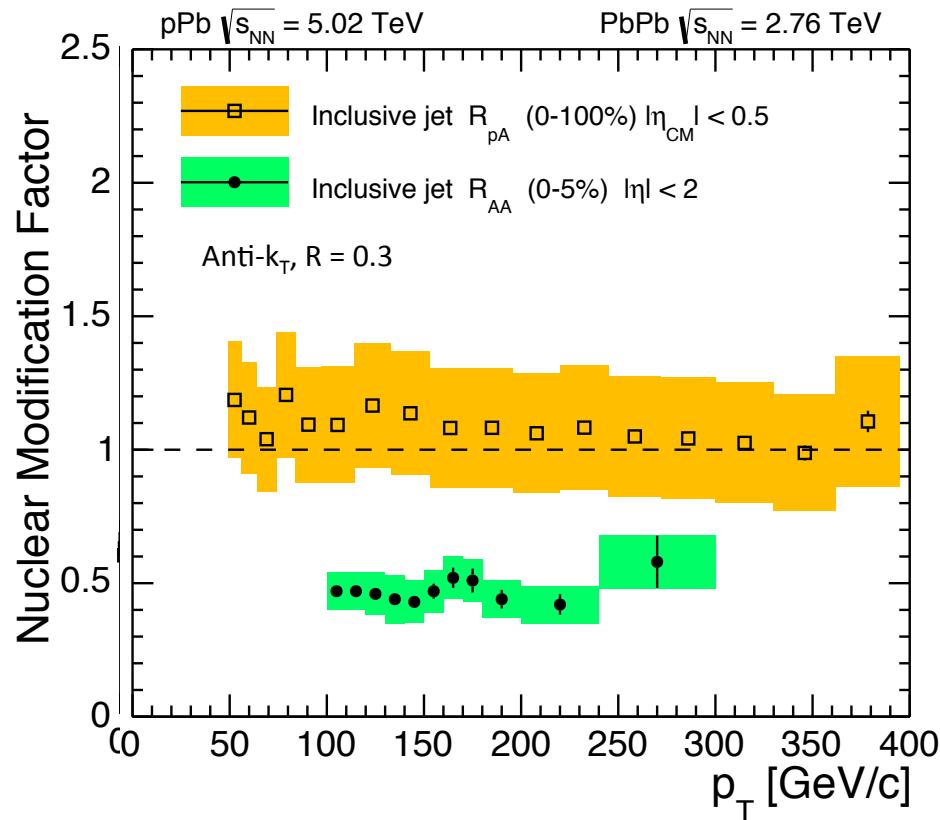


[arXiv:1312.4198](https://arxiv.org/abs/1312.4198)



- Unfolded jet spectra for several centrality selections and pp
- Suppression of ~ 2x, compatible w/ pQCD model expectations

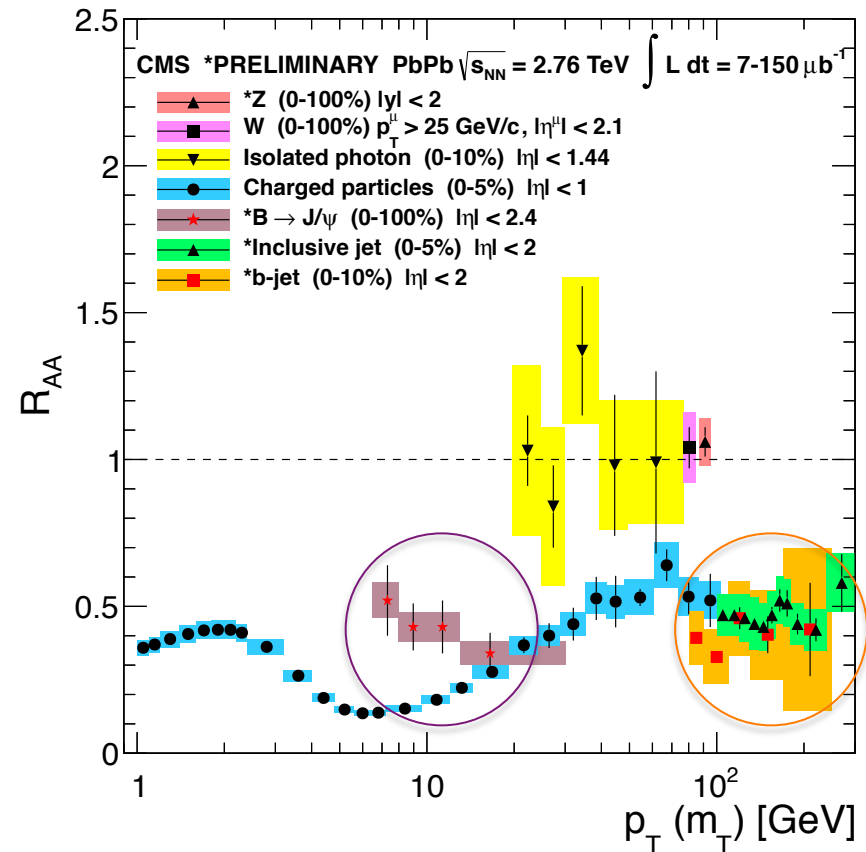
b-jet vs. inclusive jet quenching



- Similar b-jet and inclusive modification in PbPb, within still large errors
 - Inclusive jets dominated by gluons
 - b jets should tag quarks, but sizable contribution from gluon splitting
- pPb measurements consistent w/ no nuclear effect (w/ large errors)

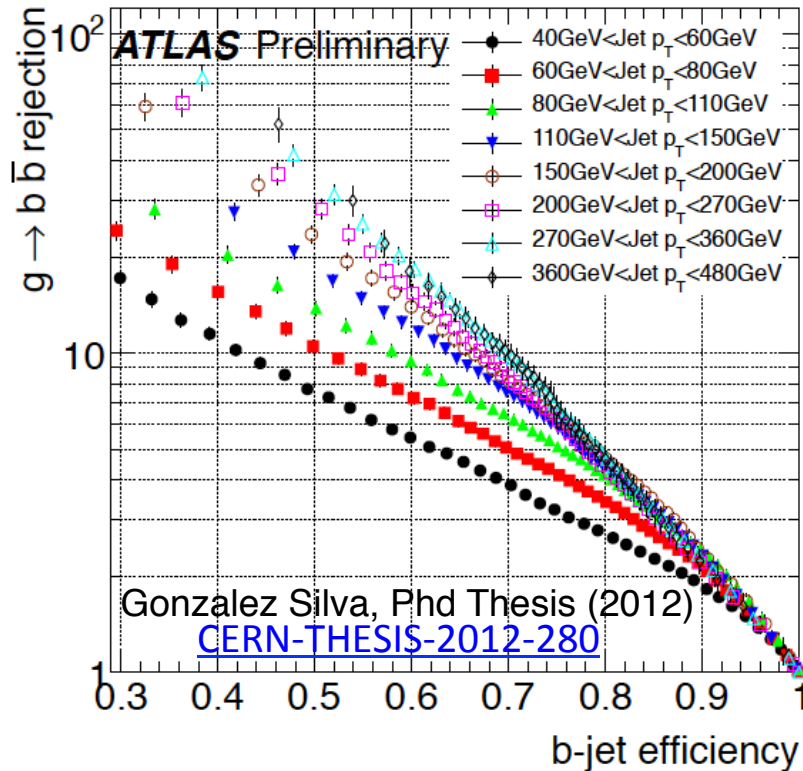
Species dependence vs p_T

- Indication that species dependence dies out \sim where mass stops distorting the spectrum
- Could be that mass effects on e-loss die out
- Are we probing flavor dependence of e-loss, i.e., quark vs gluon?



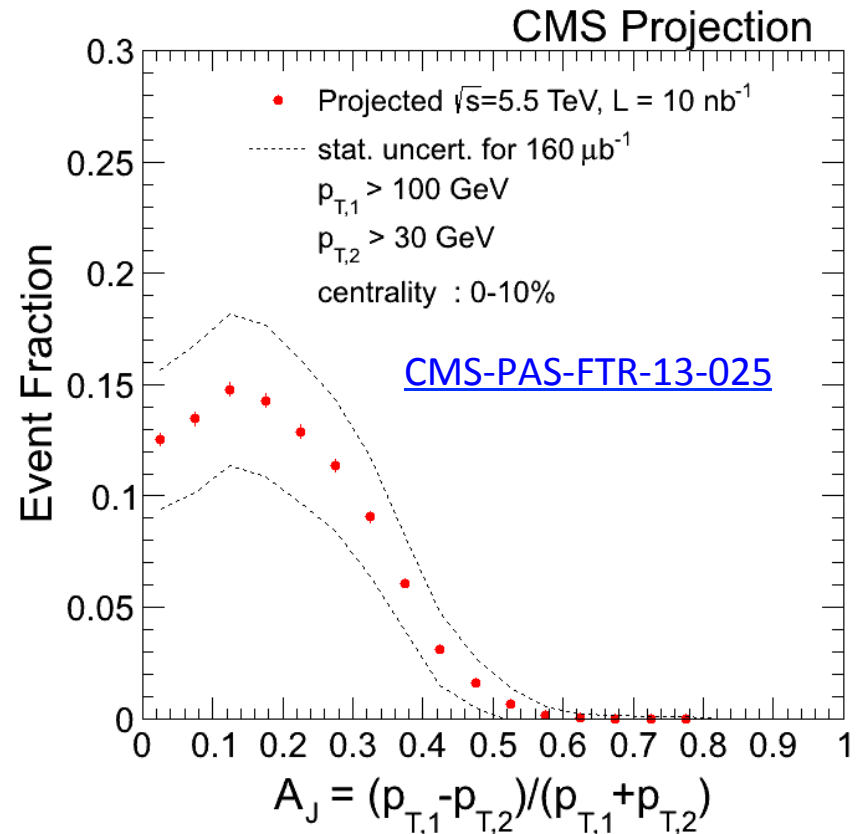
Beyond inclusive b-jet spectra

■ Merged jet ID



- Identifiable w/ jet substructure methods
- Also useful for q/g separation
- Never been tried in heavy ions

■ Double b-tagged dijets



- LO-like production, i.e., reduced gluon splitting
- Small systematics, can be compared to inclusive jets w/ high precision
- High purity, but low efficiency and x-section

Conclusions

- Bottomonia
 - PbPb: preferential dissociation of excited states
 - pPb/pp: important variation w/ event activity, important to evaluate effects not coming from hot QCD medium
- Open beauty
 - Hadrons (low p_T)
 - PbPb: Reduced suppression of $B \rightarrow J/\psi$ wrt lighter hadrons
 - pPb: No strong effect on B mesons
 - Jets (high p_T)
 - Same jet quenching as for light jets within errors
 - Important contribution from gluon splitting
- Run 2 will address open questions in heavy flavor in HI