

Nuclear Modification in pPb Collisions with CMS

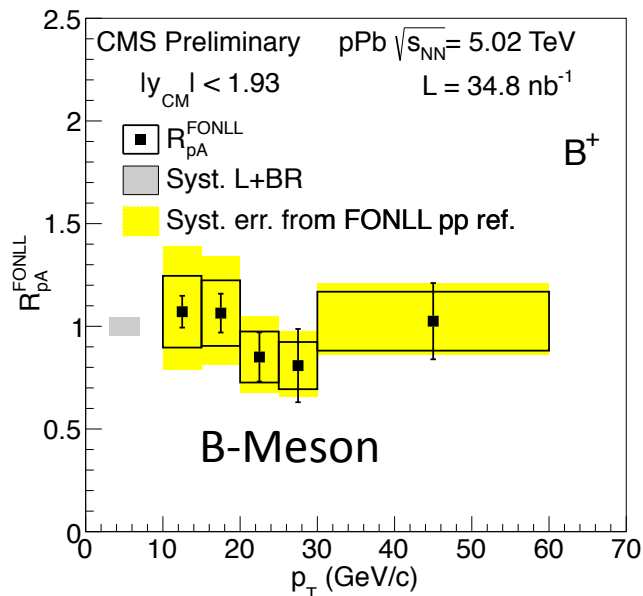
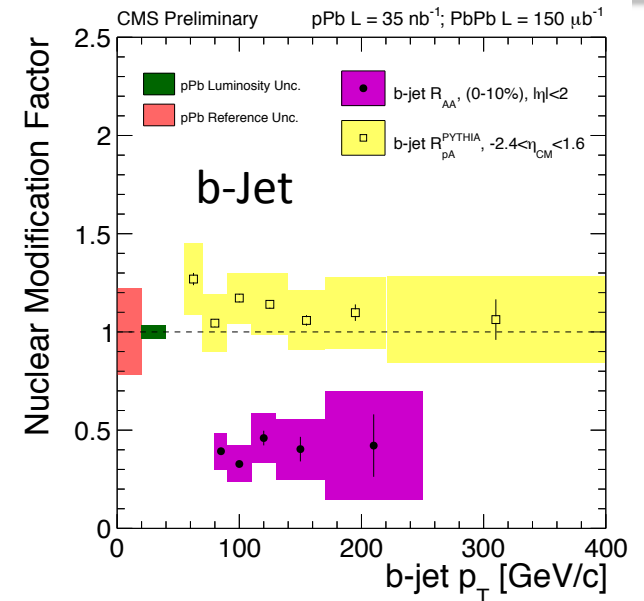
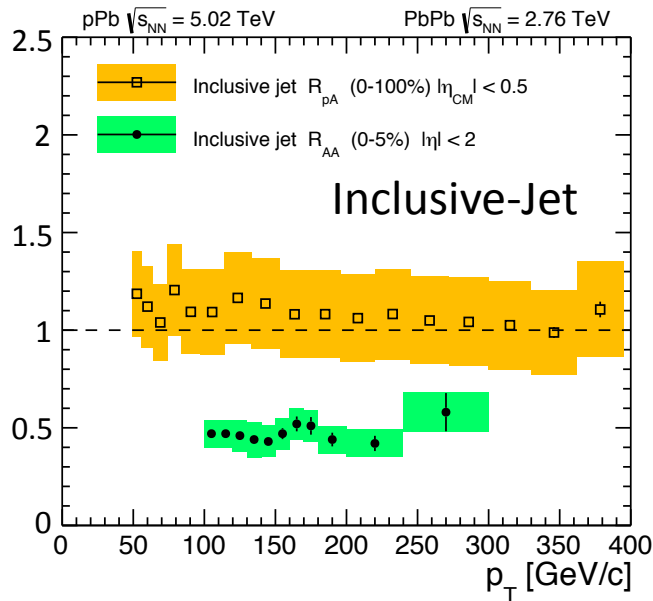
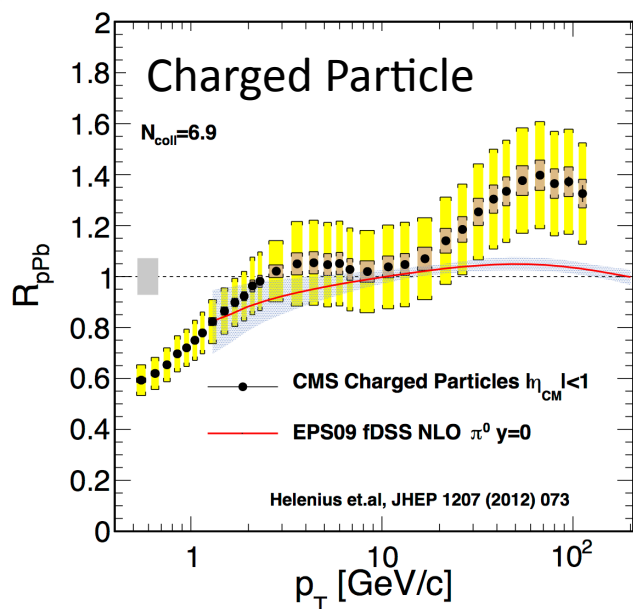
Kurt Jung

[Purdue University]

January 26, 2015

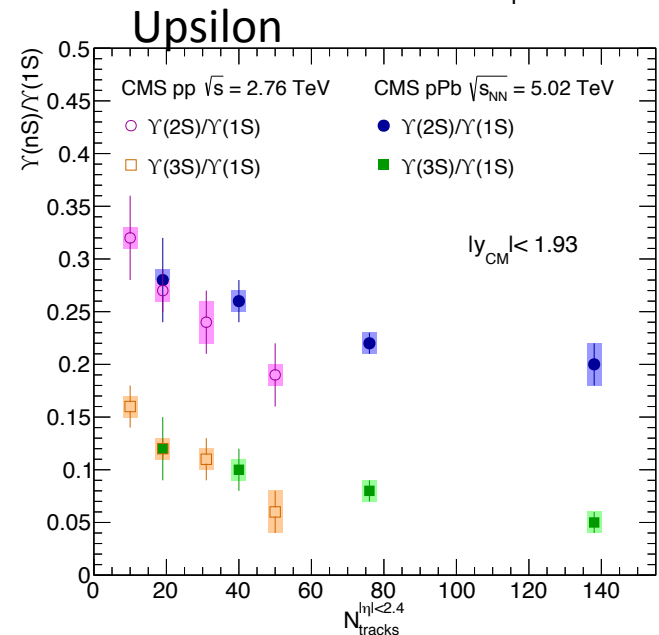
WWND 2015: Keystone, CO

Summary of CMS RpA Results



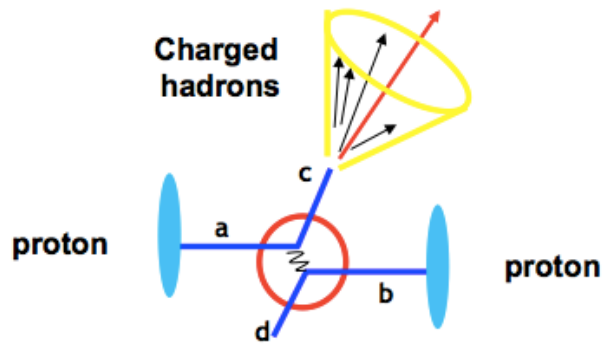
(Almost) all results consistent with **no modification!**

Charged Particles and **Quarkonia** are the glaring exceptions



Jet Expectations in Heavy Ion Collisions

Proton-Proton

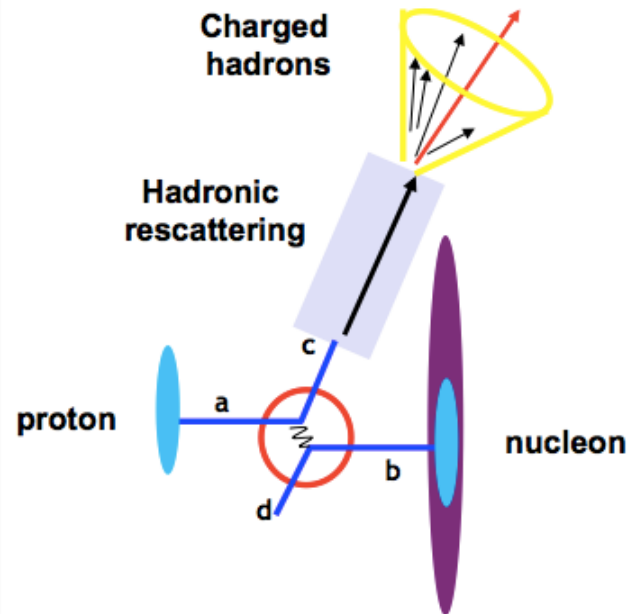


Parton Distribution Function

Hard-scattering cross-section

Fragmentation function

Proton-Nucleus



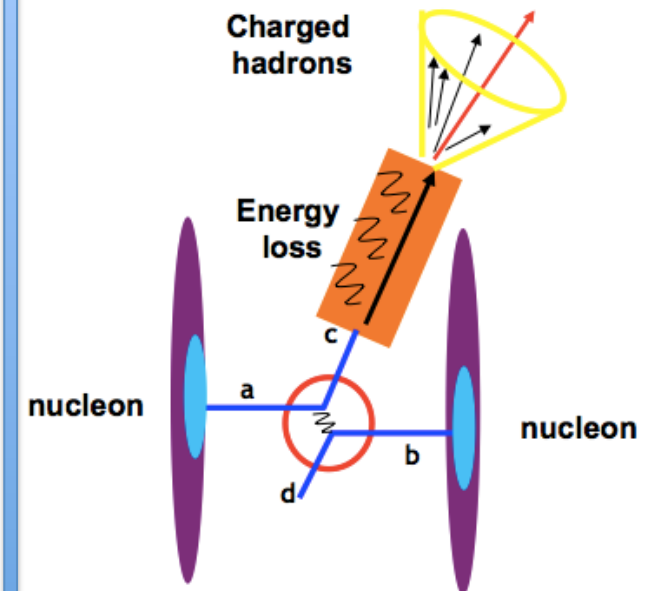
Nuclear PDF

Hard-scattering cross-section

Cold Nuclear Matter Effects

Fragmentation function

Nucleus-Nucleus



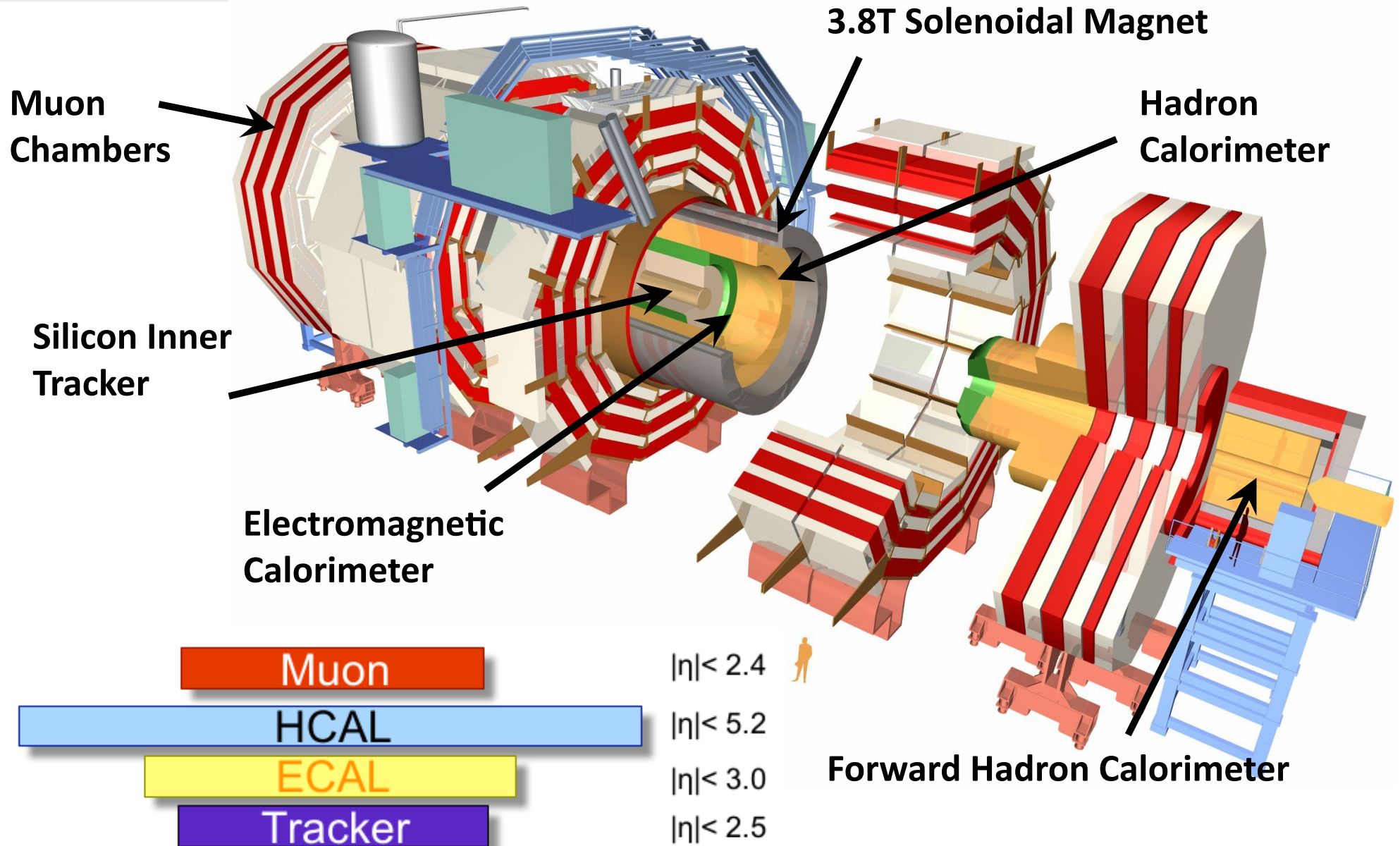
Nuclear PDF

Hard-scattering cross-section

Energy Loss in Medium

Fragmentation function

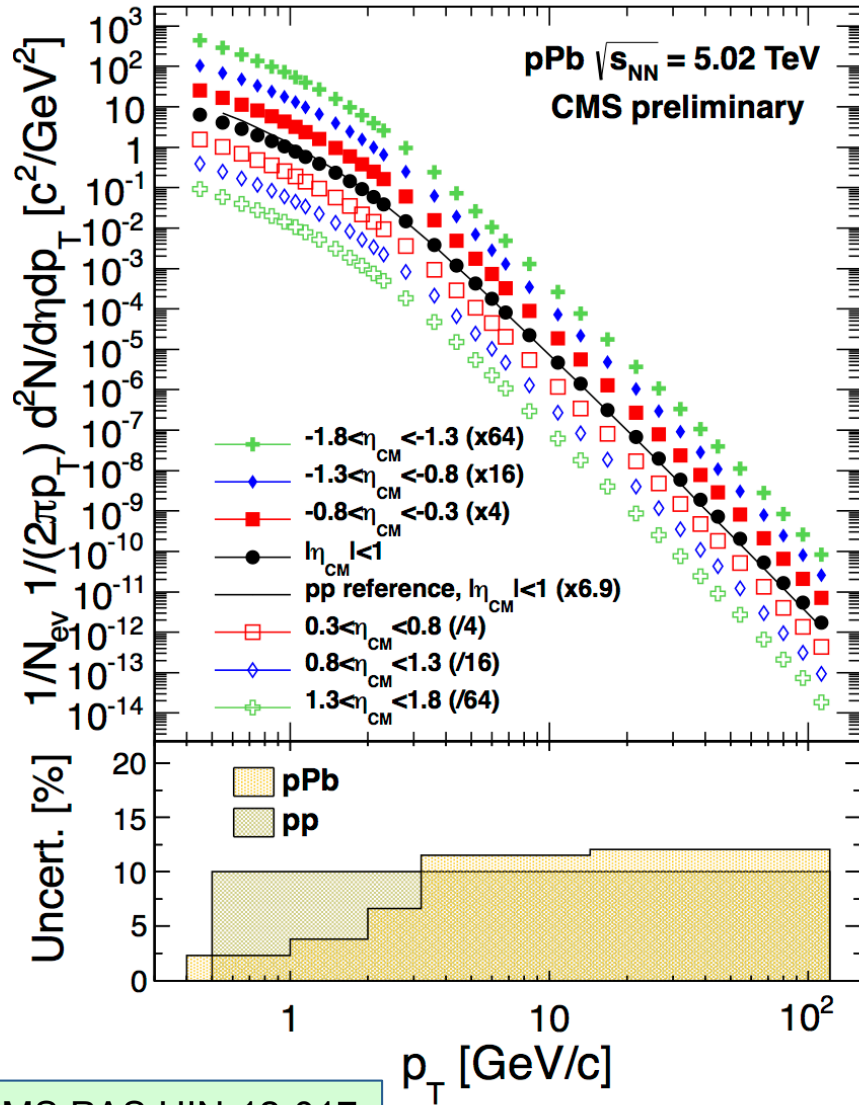
The CMS Detector



Light Flavor Results: (Inclusive-Jet & Charged Particle)

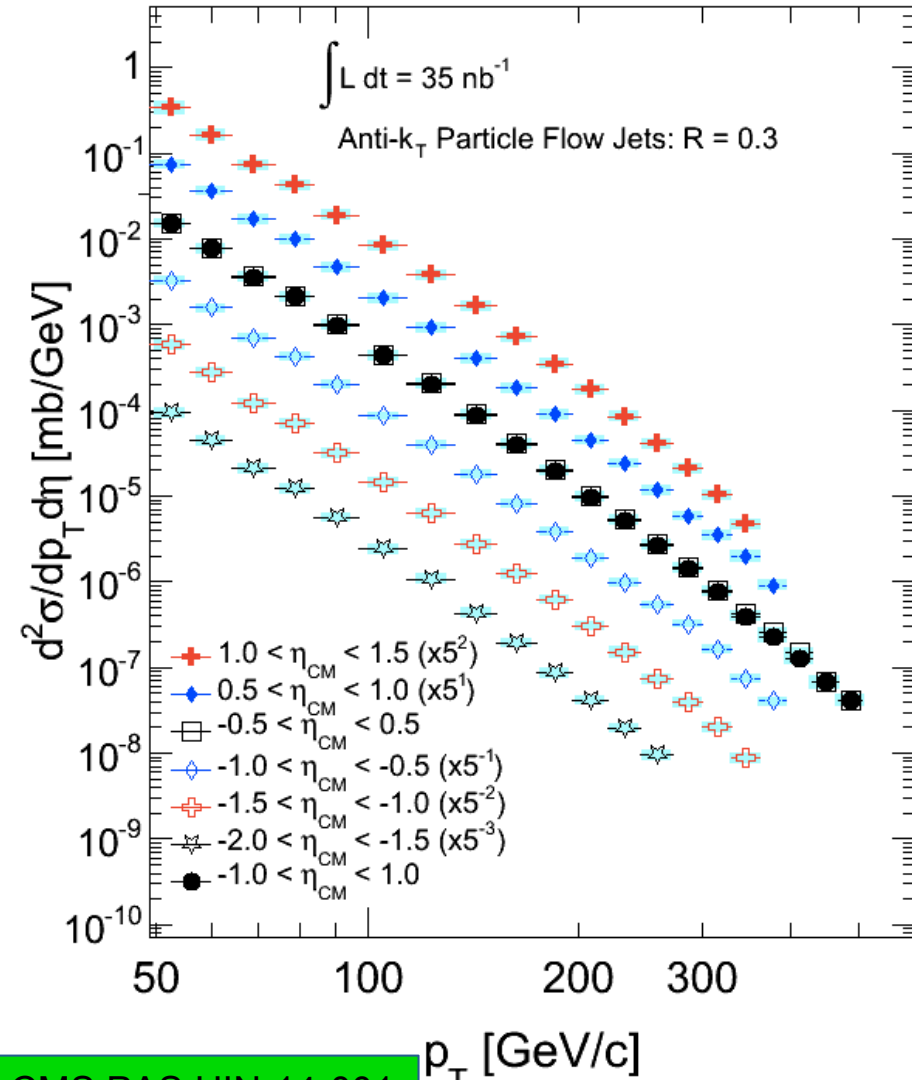
Measured pPb Spectra

Charged Particles



Anti- k_T R=0.3 Jets

CMS Preliminary, pPb $\sqrt{s_{NN}} = 5.02$ TeV



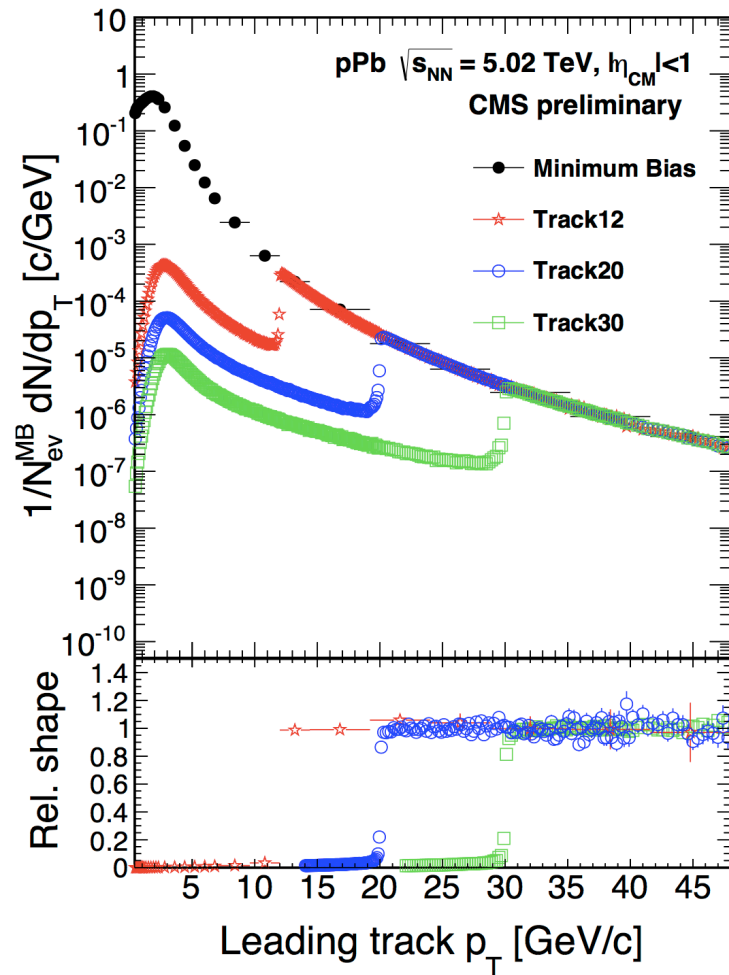
CMS PAS HIN-12-017

CMS PAS HIN-14-001

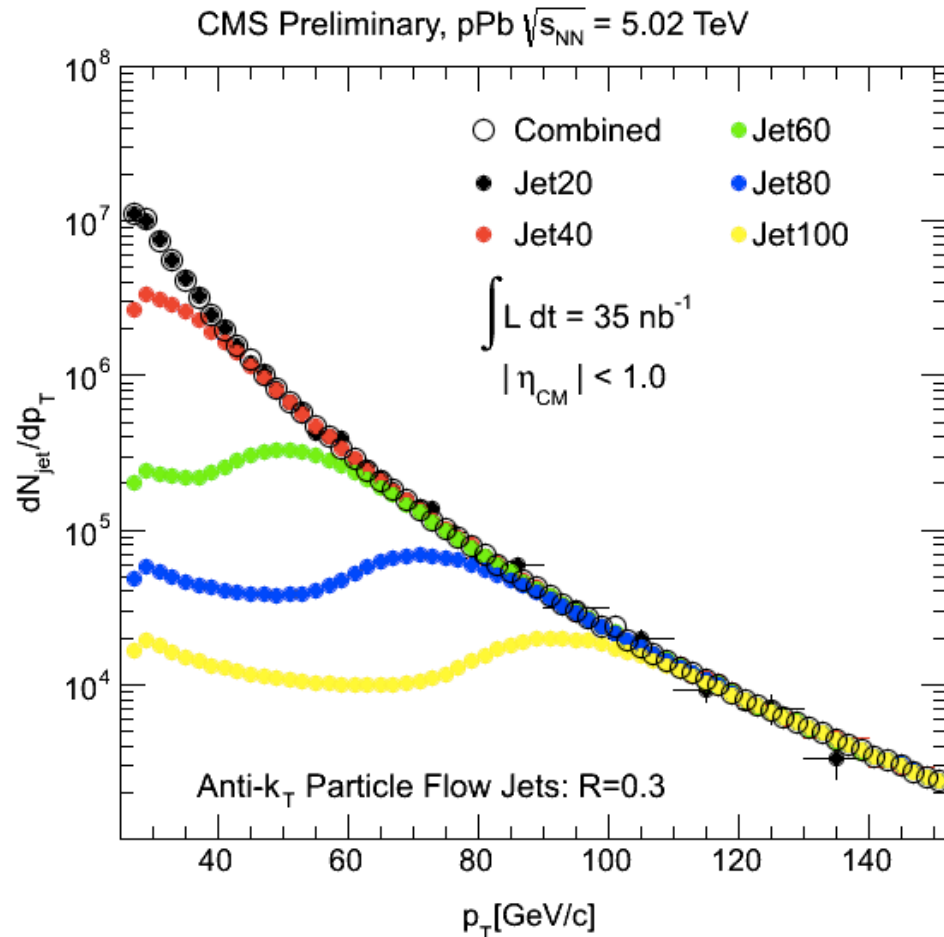


Trigger Combinations

Charged Particles



Anti- k_{T} R=0.3 Jets

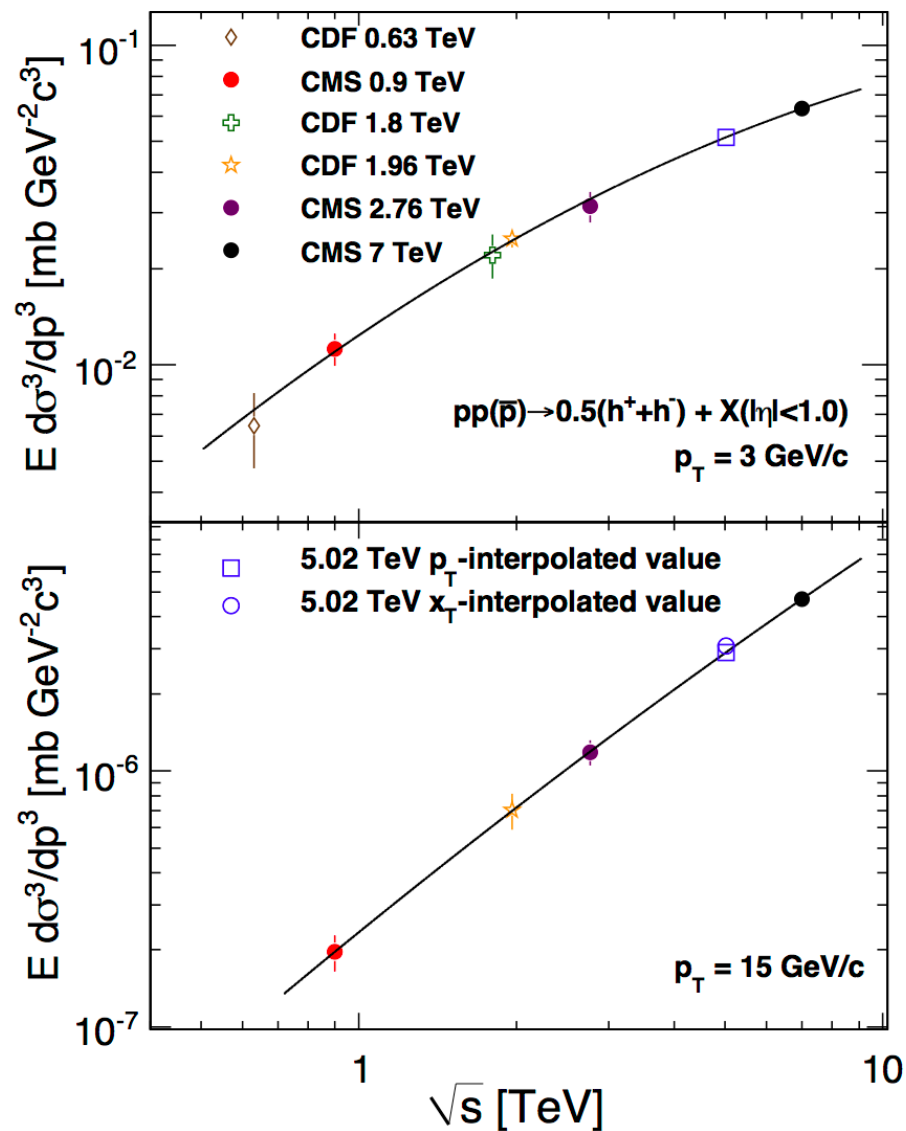


CMS PAS HIN-12-017

CMS PAS HIN-14-001



Charged Particle pp Reference Spectrum



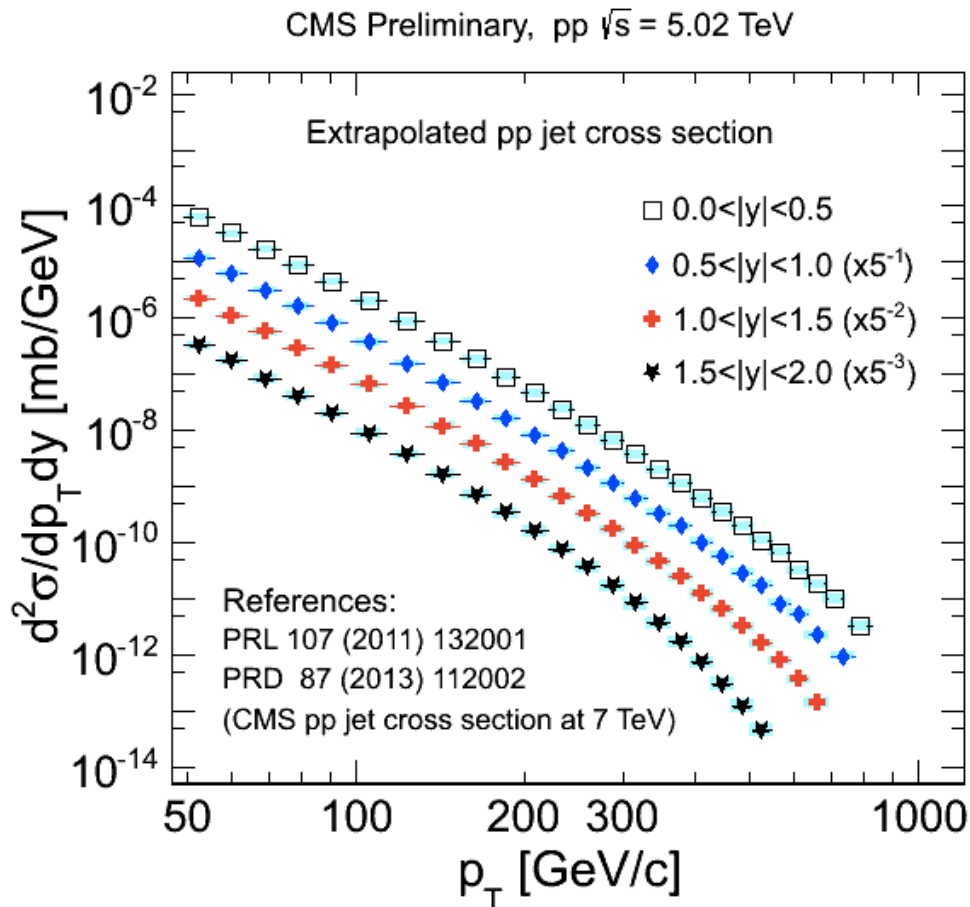
Direct Interpolation Method

- Six datasets used from 0.63 to 7 TeV
- Only the 2.76 and 7 TeV data extend beyond 30-40 GeV/c
- Technique for high- p_T interpolation:
Use $x_T = 2 p_T / \sqrt{s}$
- Total uncertainty: 10%

CDF: [PRL 61 \(1988\) 1819](#), [PRD 82 \(2010\) 119903](#)
 CMS: [JHEP 08 \(2011\) 086](#), [EPJC 72 \(2012\) 1945](#)

Anti- k_T R=0.3 Jet pp Reference Spectrum

Interpolation to R=0.3 and 5.02 TeV

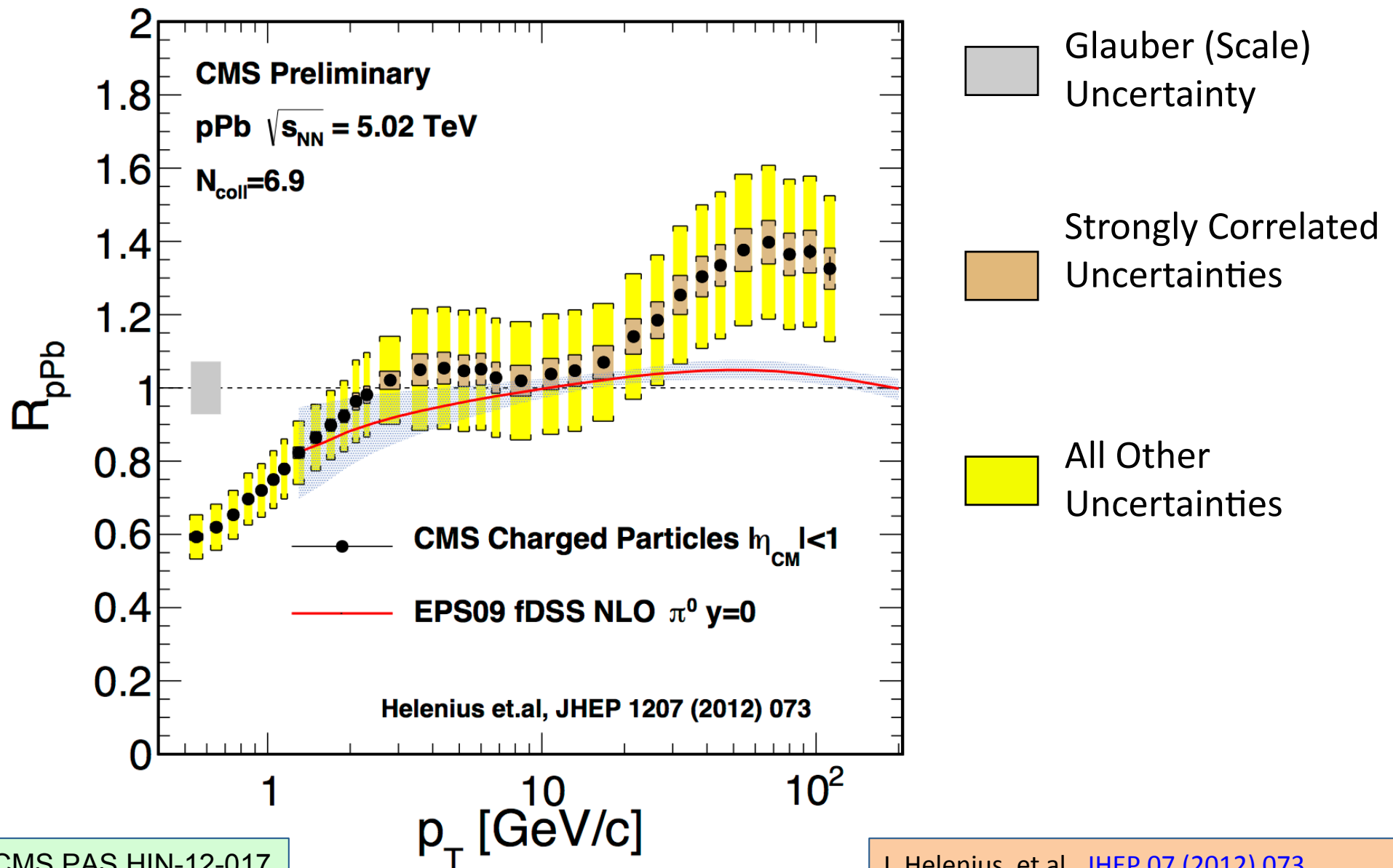


- CMS jet Spectra available for 7 TeV with R=0.5 and R=0.7
- PYTHIA Z2 correctly describes ratio of R=0.7/R=0.5, used to scale CMS results to R=0.3
- PYTHIA Z2 ratio of 5.02/7 TeV used to scale CMS results to lower energy
- Systematic uncertainties taken from use of different PYTHIA tunes, shifting underlying measured spectra, changing the underlying data set used.
- Total uncertainty range: 12-20%

CMS: [PRL 107 \(2011\) 132001](#), [PRD 87 \(2013\) 112002](#)



Nuclear Modification Factor (Charged Particles)



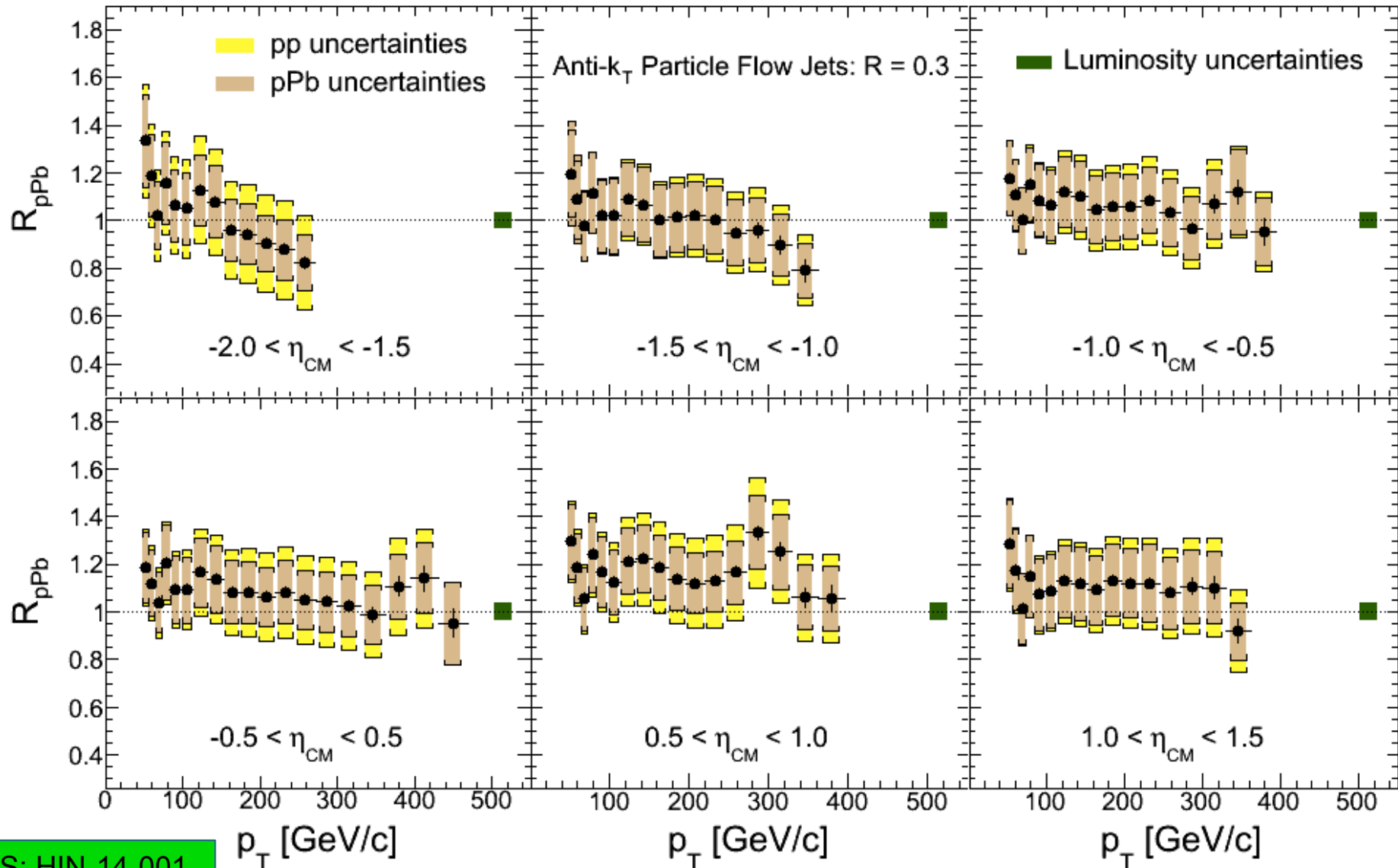
CMS PAS HIN-12-017

I. Helenius, et al. [JHEP 07 \(2012\) 073](https://arxiv.org/abs/1207.073)



Nuclear Modification Factor (Jets)

CMS Preliminary pPb $\sqrt{s_{NN}} = 5.02$ TeV $L_{int} = 35$ nb $^{-1}$

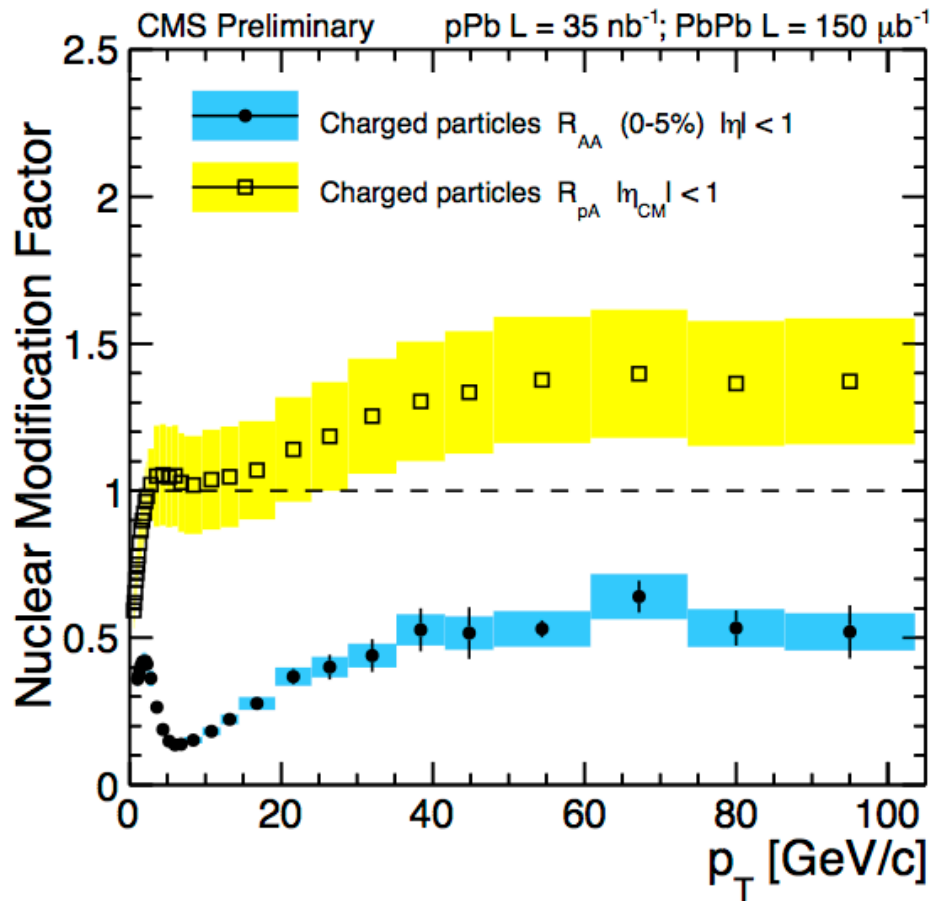


CMS: HIN-14-001

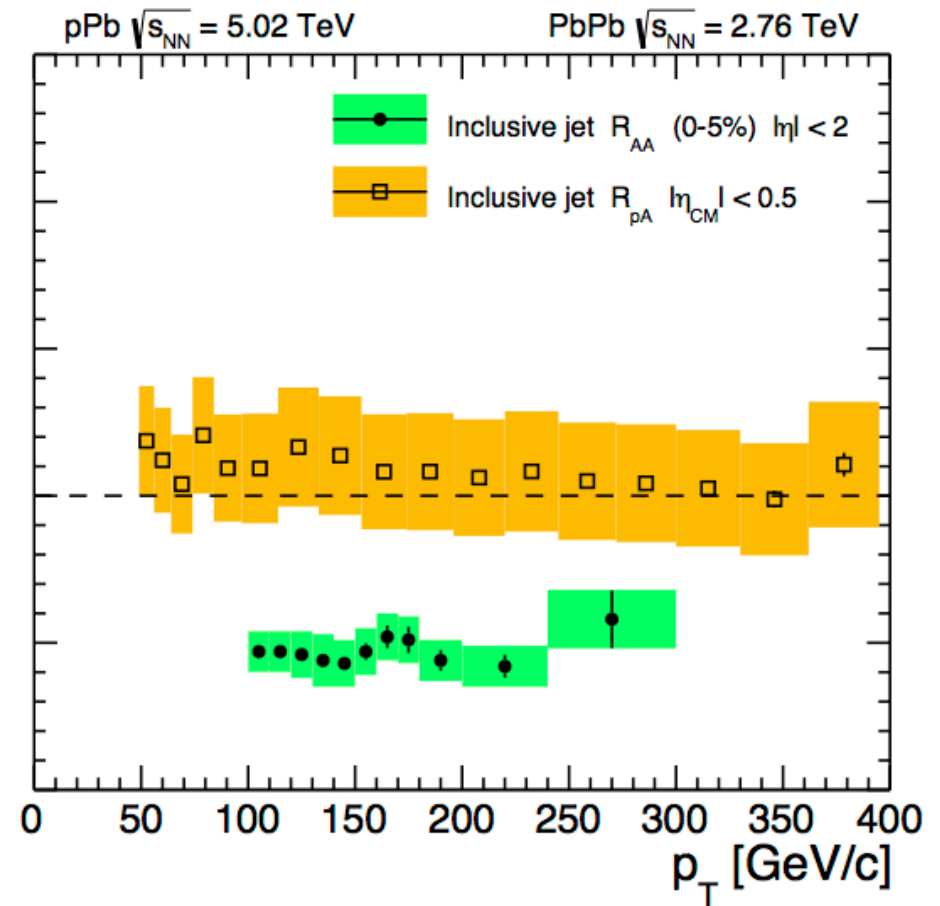


Comparison of R_{pPb} and R_{PbPb} Results

Charged Particles



Anti- k_T R=0.3 Jets



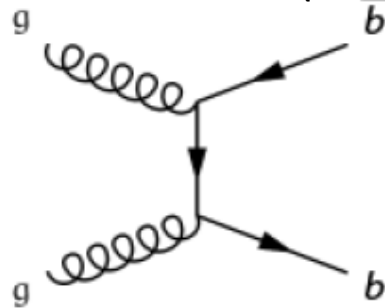
CMS: [EPJC 72 \(2012\) 1945](#) ; PAS HIN-12-004, HIN-12-017, HIN-14-001



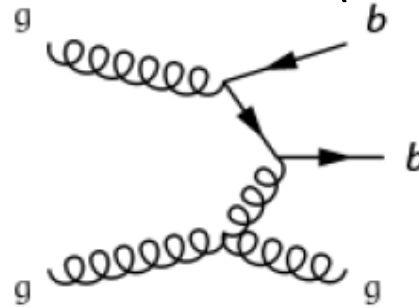
Heavy Flavor Results: (b-Jets, B-Mesons, Upsilon)

b Production Mechanisms

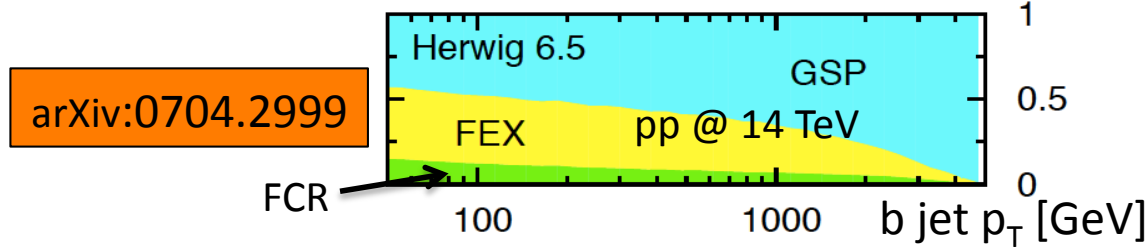
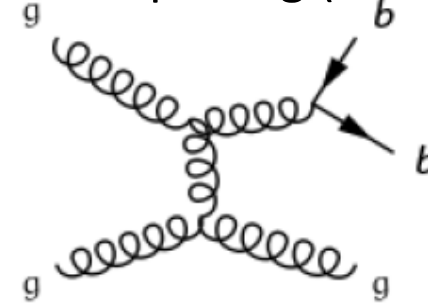
Flavor Creation (“FCR”)



Flavor Excitation (“FEX”)

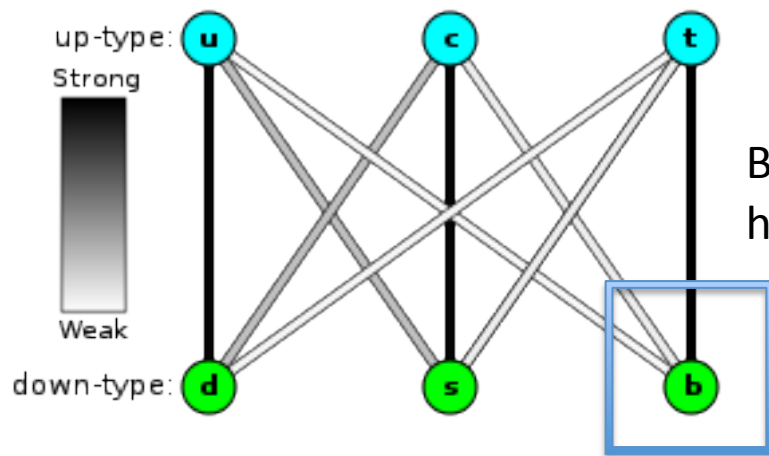


Gluon Splitting (“GSP”)

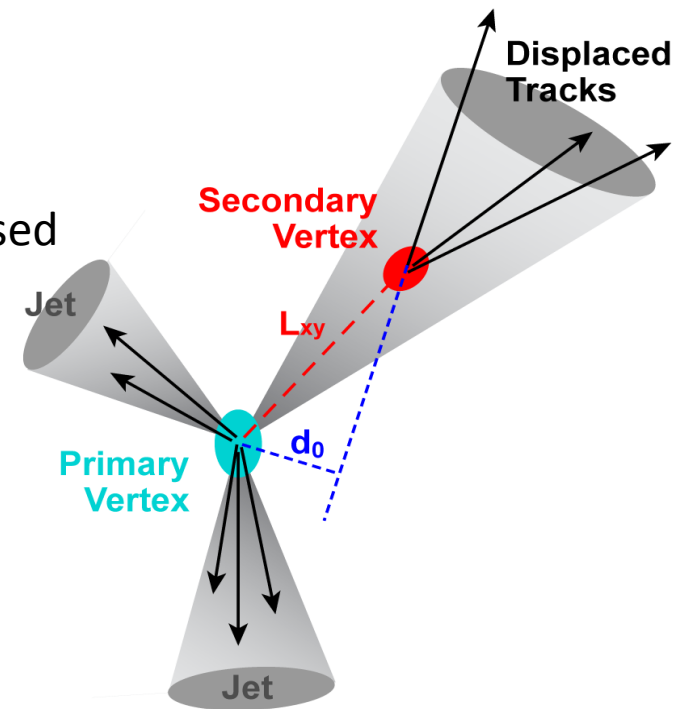


- The current CMS heavy flavor measurements do not distinguish between different b quark production mechanisms
- NLO (through Herwig) predicts non-negligible contributions from all three production mechanisms in the p_T range that we measure
 - Gluon can split anywhere from early to late in the collision -> convolutes energy loss measurements!
- This **first LHC b-jet measurement** is a critical starting point for the future
 - **di-b-jet** and **b jet-track correlations** can shed additional light

Identifying B-Jets



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



- Primary identification method is using a **Secondary Vertex** (“SV”)
 - Long lifetime of b = mm or cm vertex displacement
- Flight distance (L_{xy}) 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

Calculating the b-jet Fraction

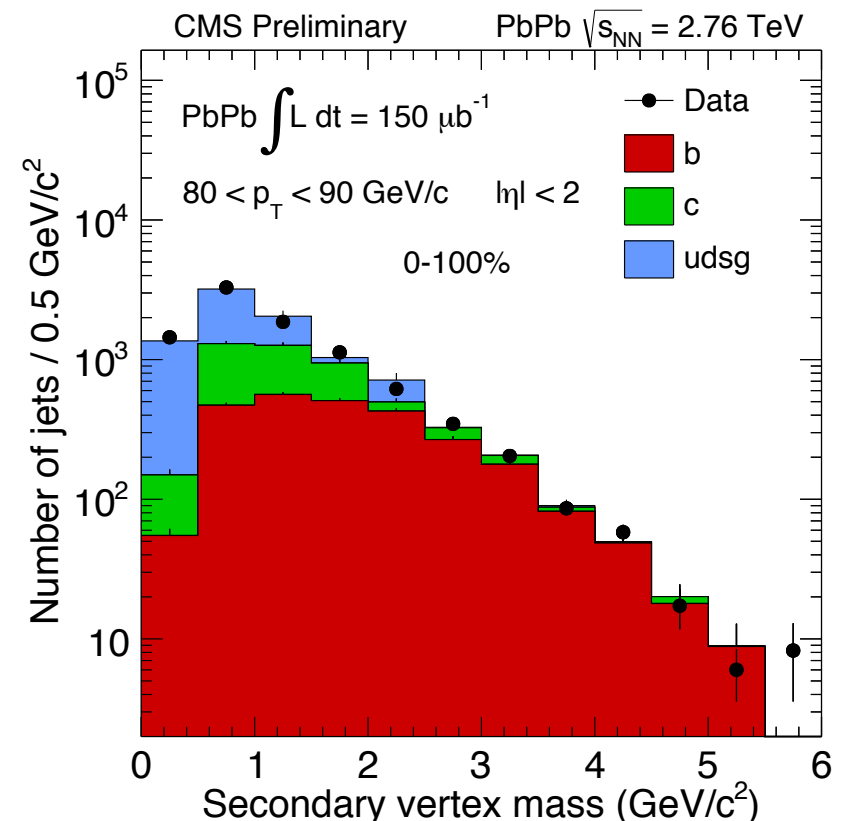
$$\epsilon_b = \frac{f_b^{btag} N_{jets}^{btag}}{f_b^{untagged} N_{jets}^{untagged}} \quad (1)$$

f_b = purity from template fit
 ϵ_b = efficiency of b-tagger

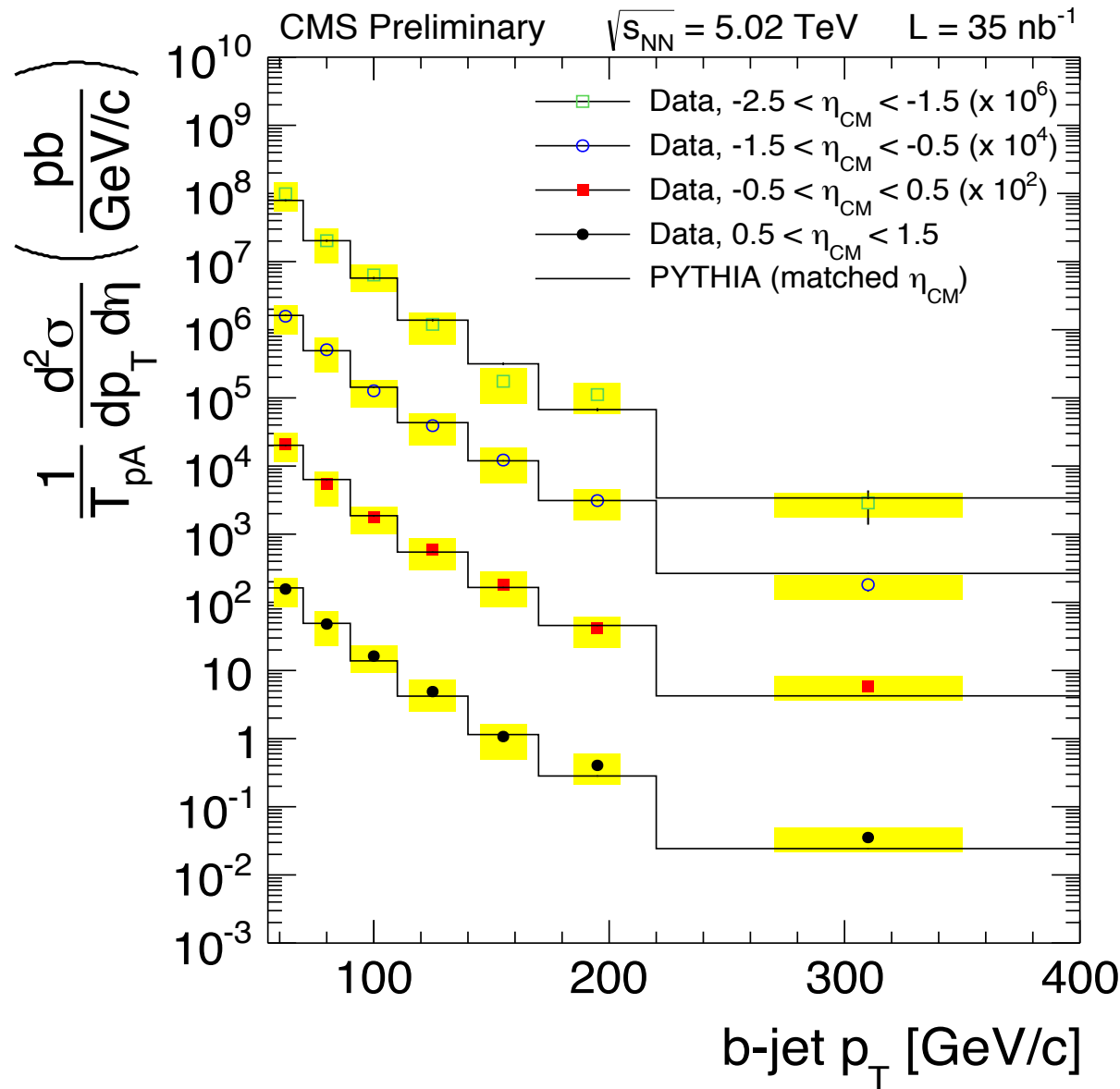
$$N_{jets}^{btag} = N_{jets}^{total} \frac{f_b}{\epsilon_b} \quad (2)$$

$N_{untagged}$ = Jets that do not pass the tagger
 $f_b^{untagged}$ = Purity of anti-tagged jets

- Purity (f_b) is found via fitting two very different distributions:
 - Distribution of SV mass is primary extraction method
 - Track impact parameter used as data-driven cross-check
- Efficiency (ϵ_b) is found via the tagging and anti-tagging purity [eq. 1]



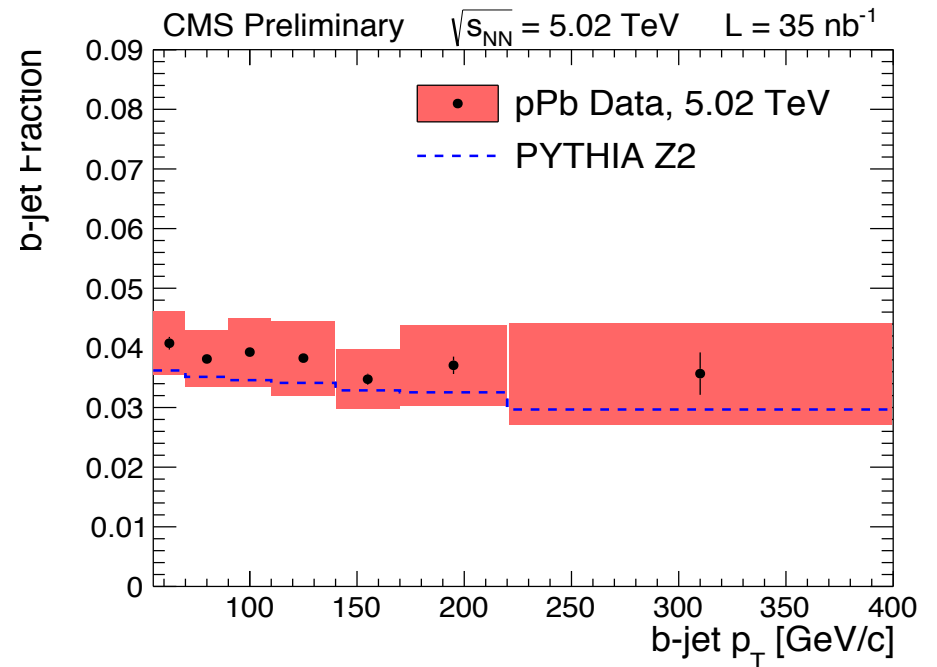
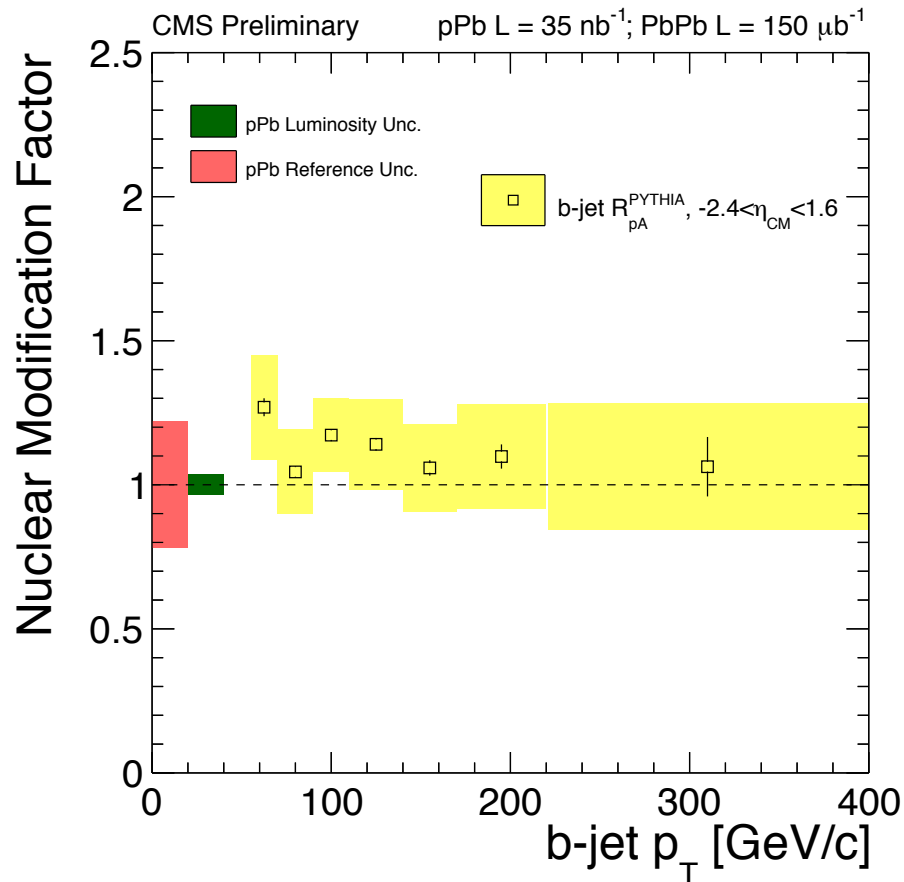
pPb B-jet Spectra



- B-jet spectra shown for various selections in η_{CM}
- Spectra scaled by T_{pA} such that pp & pPb are directly comparable
- Minimal suppression or enhancement is observed

CMS PAS HIN-14-007

B-Jet R_{pA} [PYTHIA]



- Result is **consistent with a small Cronin enhancement** from *but effects are quite minimal*
- pPb b-jet fraction is consistent with PYTHIA at high p_T

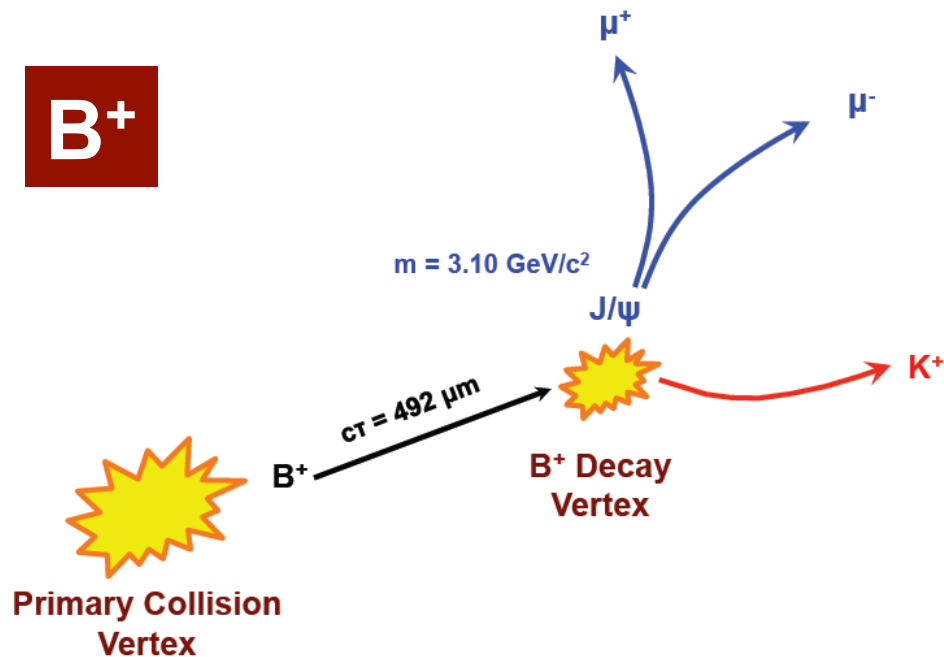
CMS PAS HIN-14-007



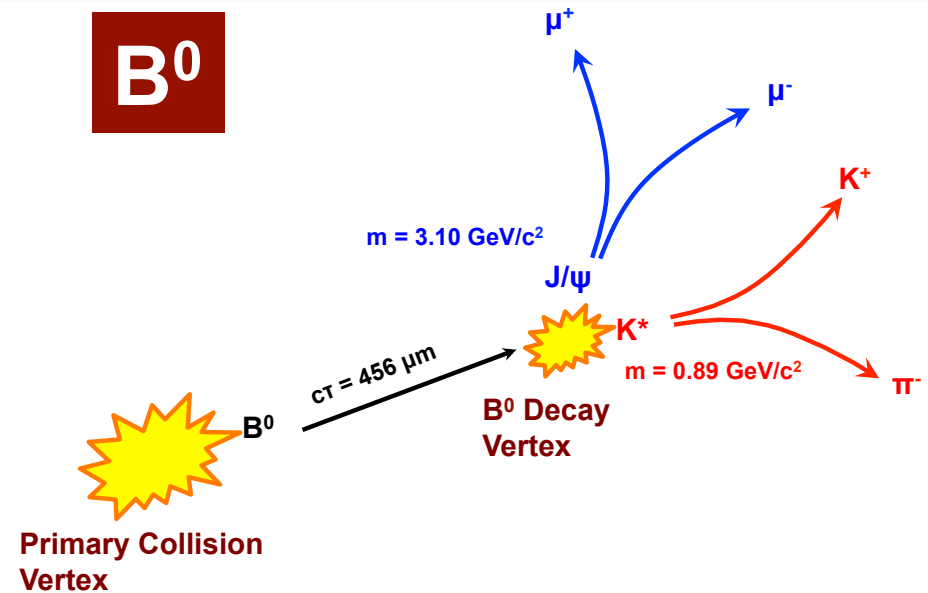
B-Meson Analysis Channels

- B-Mesons reconstructed through a combination of J/ψ (\rightarrow di-muons) + Kaons and pions

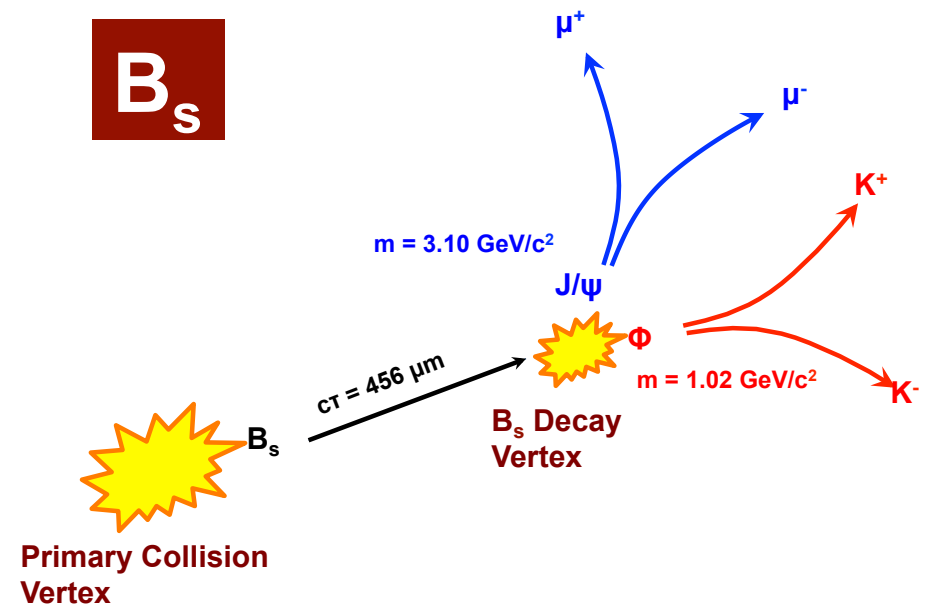
B⁺



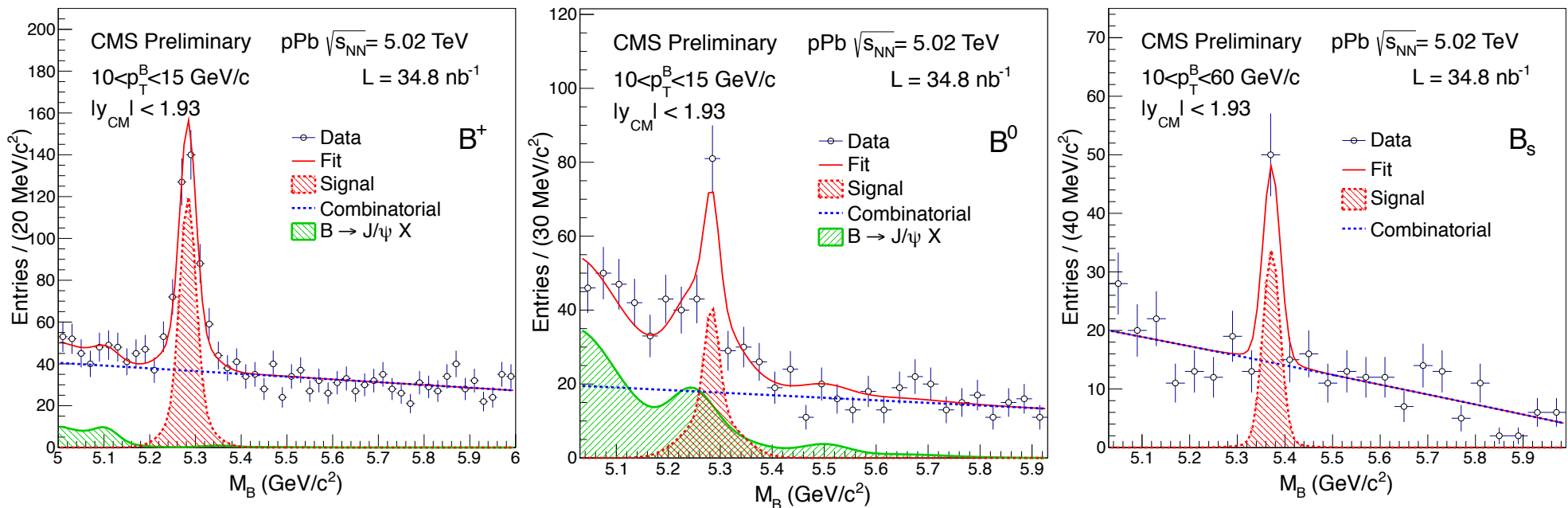
B⁰



B_s



B-Meson Signal Extraction



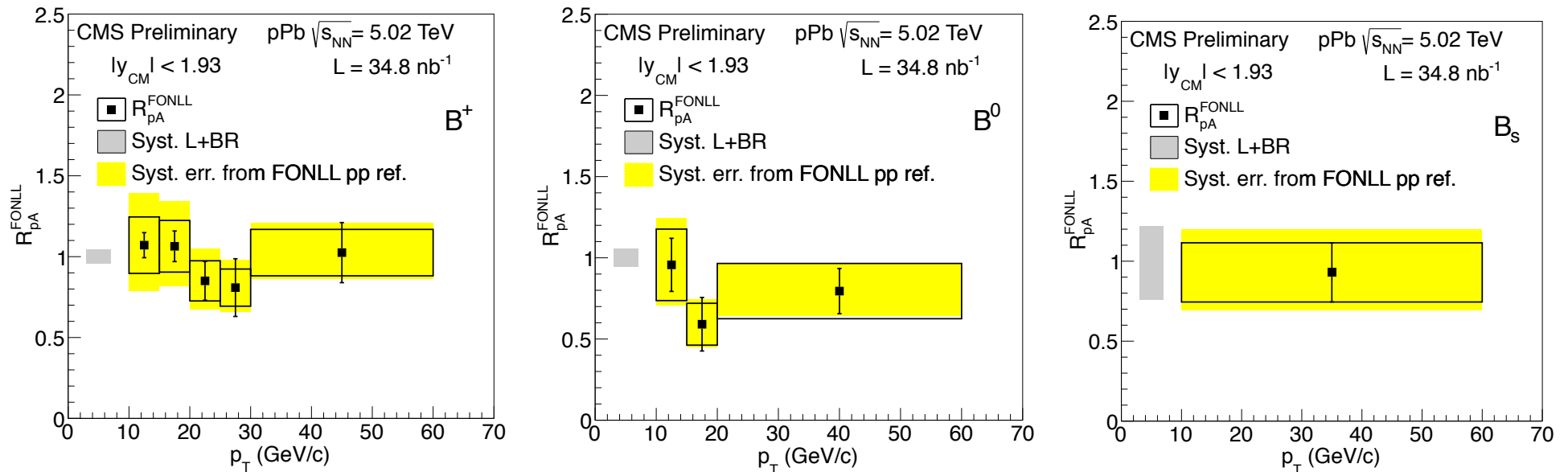
- **Signal fit** to double-gaussian
- **Combinatorial background** fit to a first-order polynomial
- **Peaking background** obtained from J/ψ + bg track
 - B_s has no peaking background

CMS PAS HIN-14-004



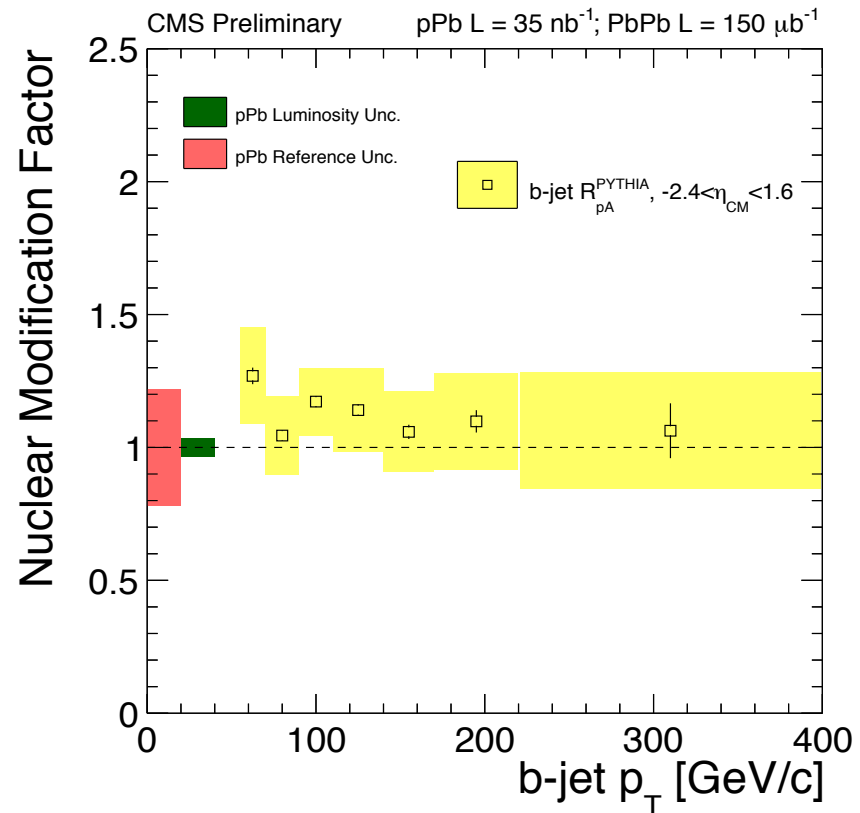
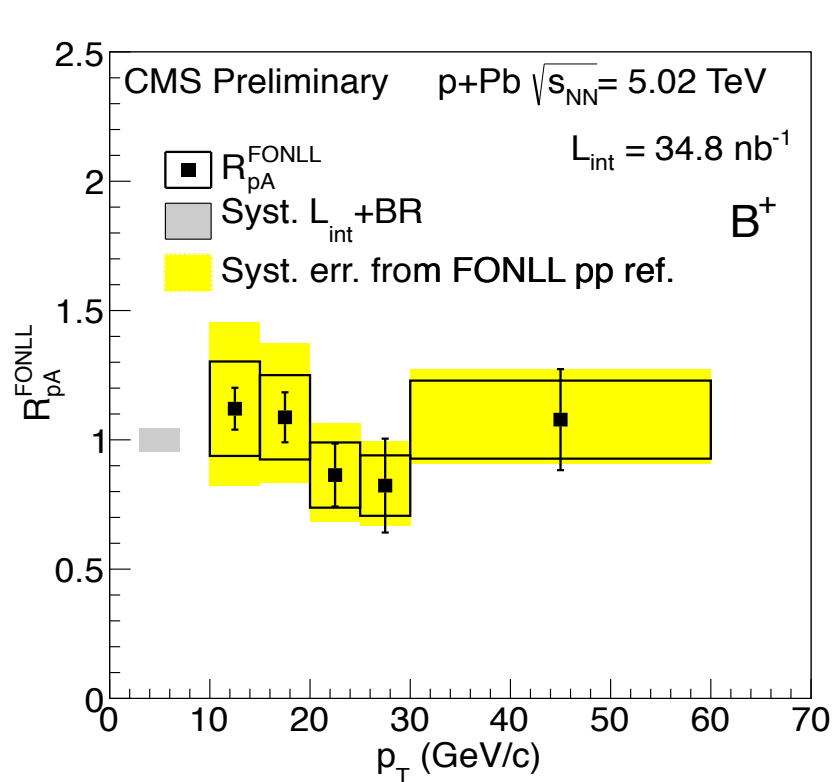
B-Meson RpA [FONLL]

$$R_{pA}^{FONLL}(p_T) = \frac{(d\sigma/dp_T)_{pPb}}{A \times (d\sigma^{FONLL}/dp_T)_{pp}}$$



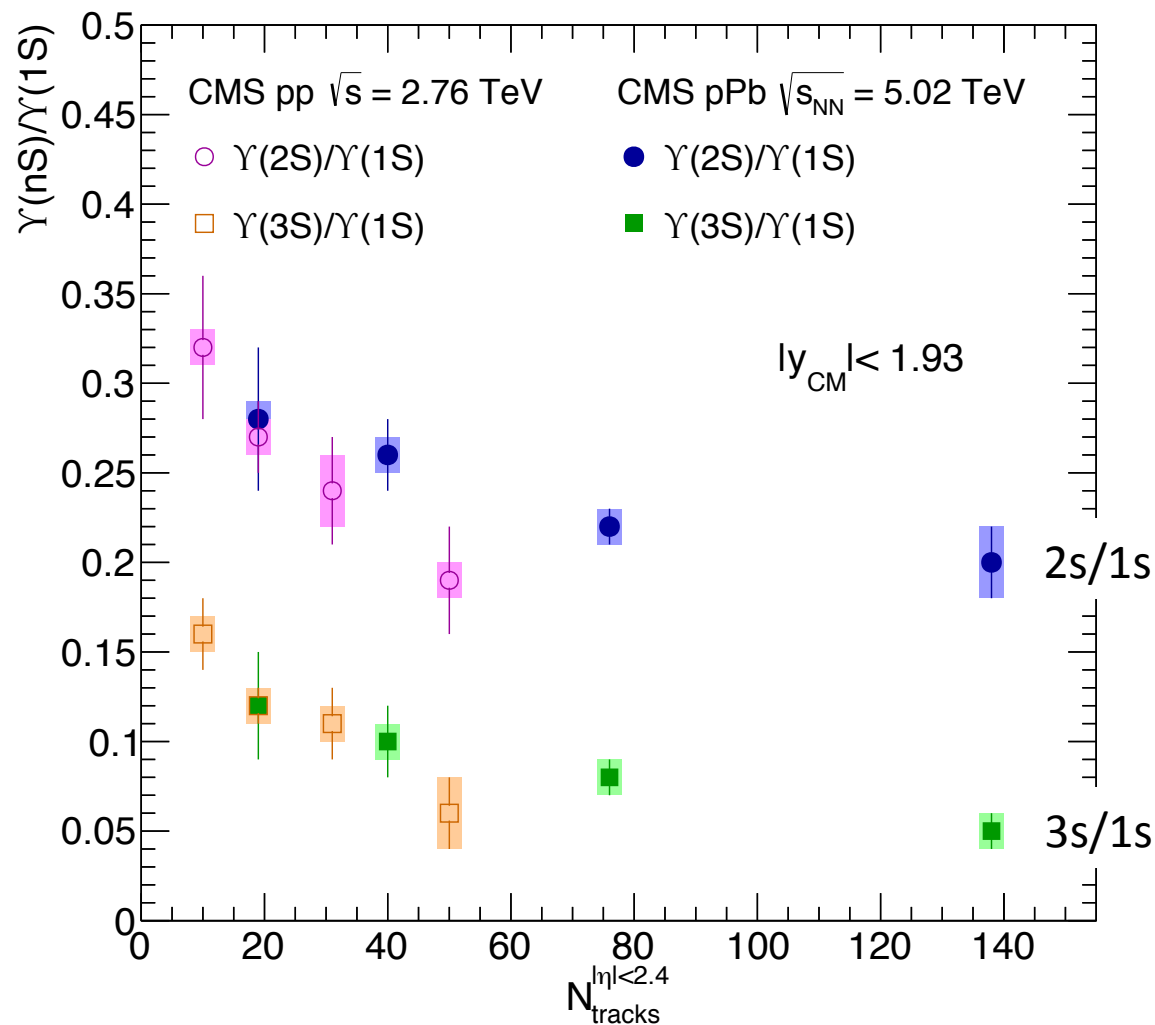
- RpA [FONLL] compatible with unity for all B-Meson types over a wide range in p_T

B Mesons vs b jets



- Measurements in conjunction with B mesons show consistency with over a very wide range in p_T !
- B Mesons in pPb show similar suppression w.r.t. pp simulation as do the b jets

Final State Effects in Upsilon?

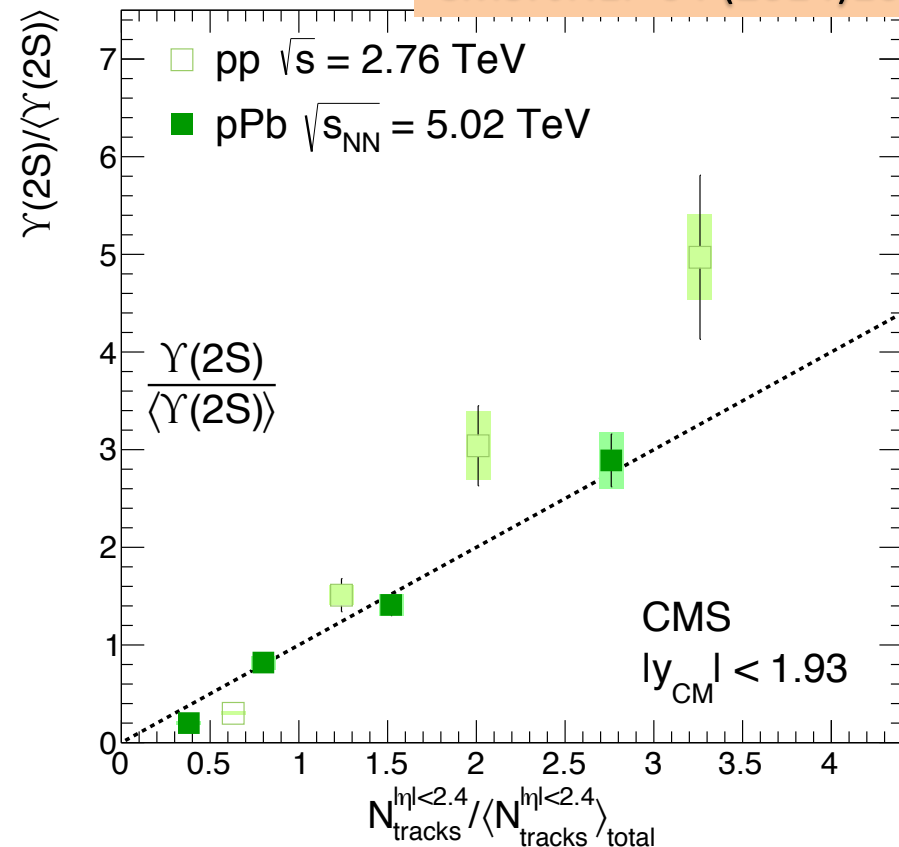
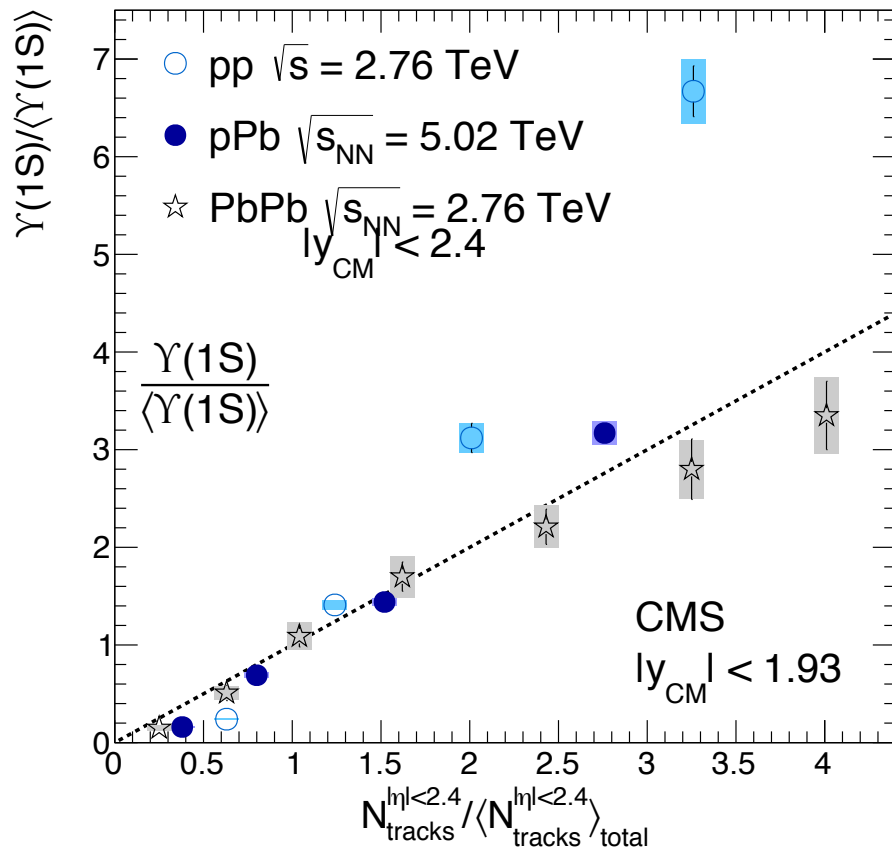


- Initial state effects should affect all upsilon types equally
- $Y(ns)/Y(1s)$ ratio decreases with increasing multiplicity
- Excited state = weaker binding energy
- Suppression of excited states *as function of multiplicity* indicates final state effects

CMS: JHEP 04 (2014)103

Upsilon Enhancement in high-mult. pp

CMS: JHEP 04 (2014)103



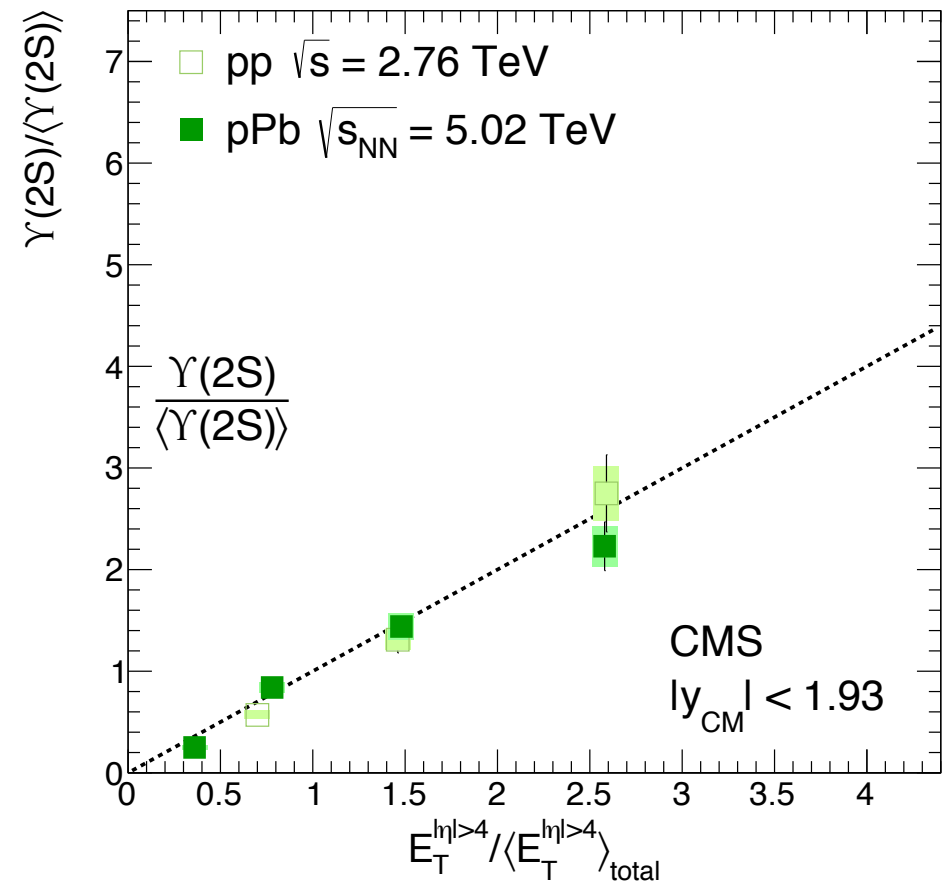
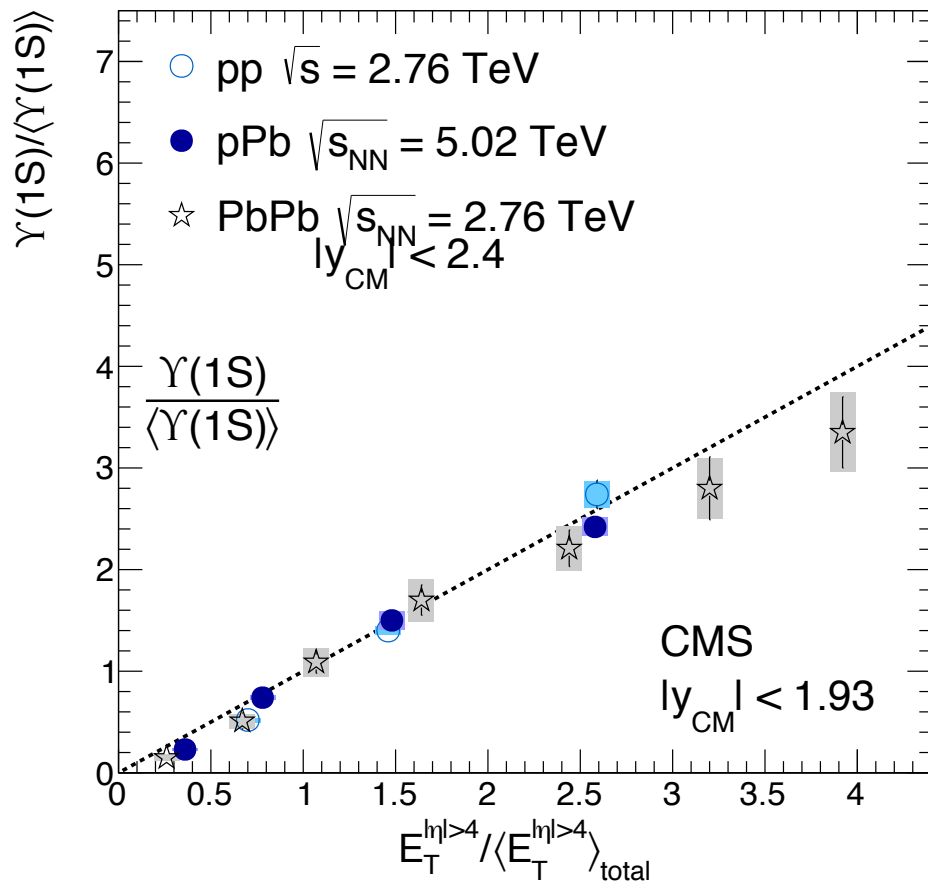
- $Y(ns)/\langle Y(ns) \rangle$ vs $N_{\text{trk}}/\langle N_{\text{trk}} \rangle$ has a different trend in pp than pPb & PbPb
- Huge pp enhancement indicative of multi-parton interactions? CGC?
 - Do the ground state Upsilon's simply get preferentially produced with higher mult. **OR**
 - Do the excited states break up more easily due to the higher multiplicity?

Conclusions

- All RpA species measured at CMS are consistent with unity, EXCEPT charged particles
 - Indicative of interesting fragmentation behavior?
- Heavy Flavored measurements (mesons+jets) also consistent with unity
 - Confirms measurements in Pb+Pb of no flavor dependence of suppression at high p_T
 - B-Meson cross-sections calculated for the first time in heavy ion collisions at the LHC
- Quarkonia measurements indicate interesting final state effects!

BACKUP

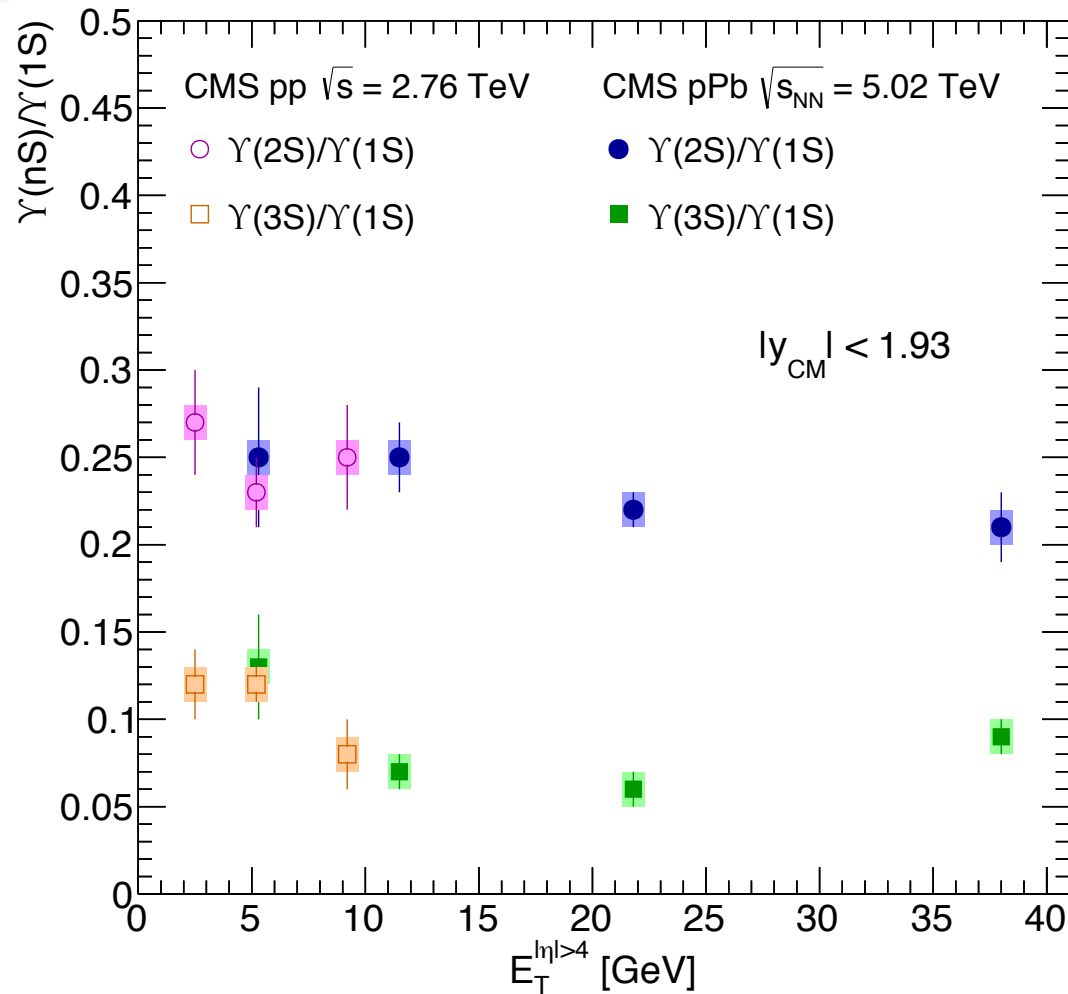
Upsilon Measurements vs ET



pp enhancement less pronounced vs E_T (event activity in forward region)

- something special about the multiplicity dependence

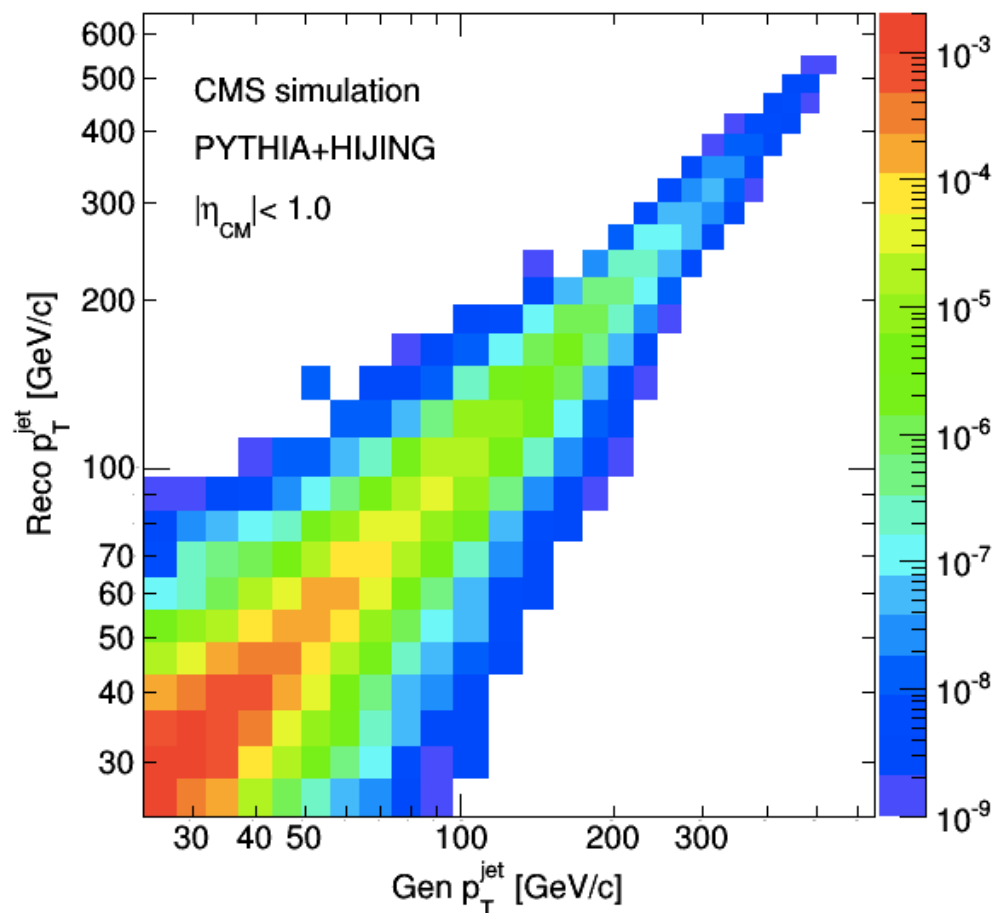
Upsilon Measurements vs E_T



- Suppression effects less pronounced vs E_T

Jet Reconstruction

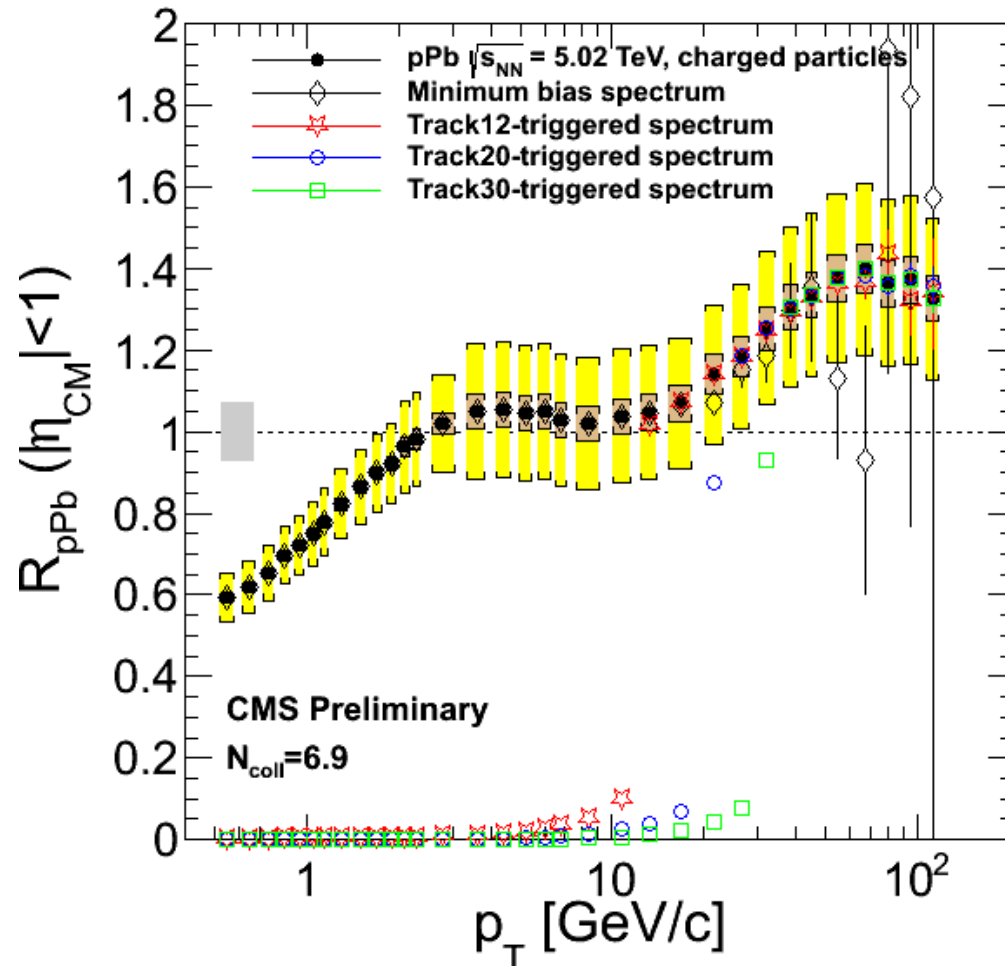
Detector Response Matrix



- Anti- k_{T} algorithm with $R=0.3$ cone size applied to projections from particle-flow candidate objects
- Iterative Pileup subtraction method applied to remove background.
- Jet energies corrected to final state particle jets
- Smearing effects of the finite- p_{T} resolution corrected using an “unfolding” procedure with MC-derived response matrix.

CMS: HIN-14-001

Triggered Charged Particle RpA

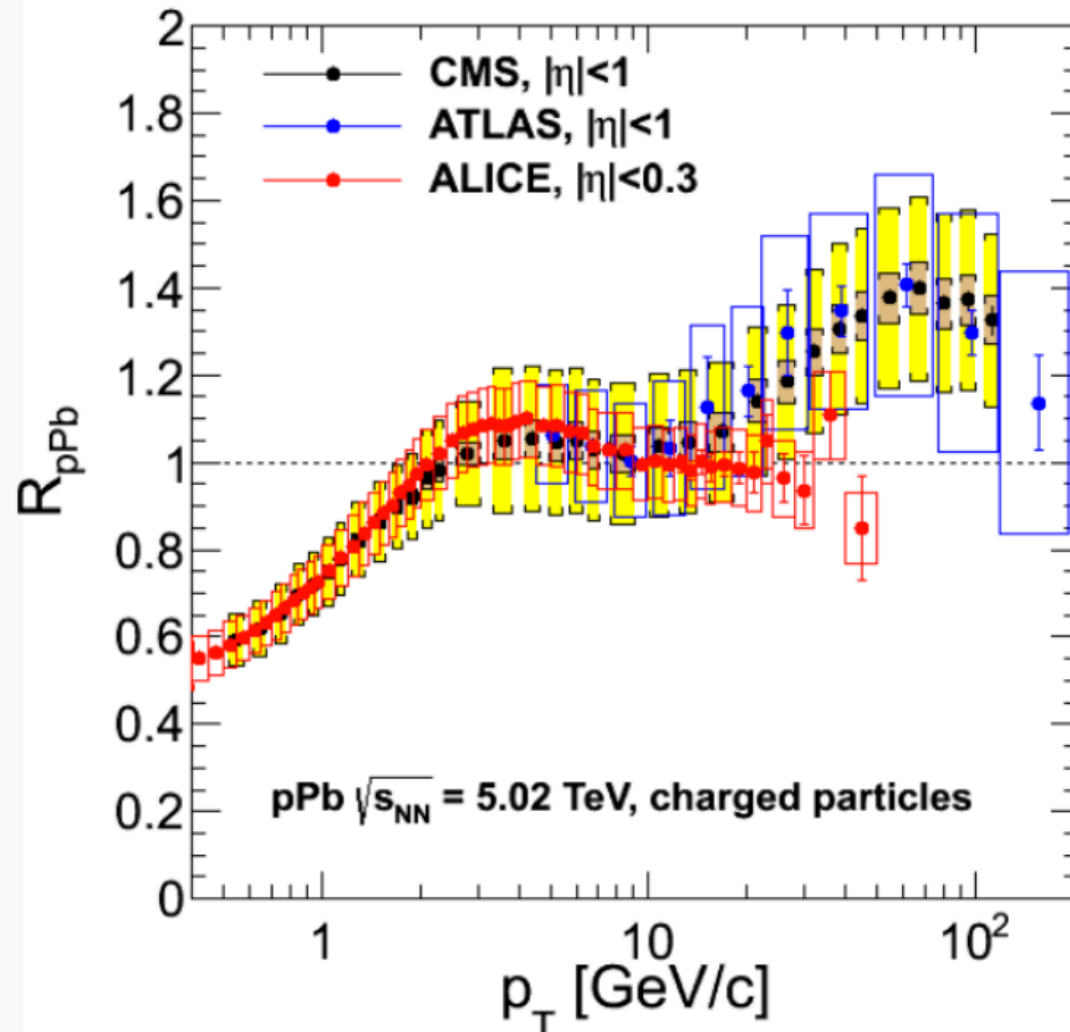


- Individual trigger results all self-consistent

B-Meson Peaking Background Sources

- B^+
 - lower mass : B^+ decays J/ψ + resonant meson decayed to kaon + X
 - B^+ mass : B^+ decays J/ψ + pion misidentified as kaon
- B^0
 - B decayed to J/ψ + track + track
 - (e.g. $B^0 \rightarrow J/\psi K(1270)^0$, $B^+ \rightarrow J/\psi K(1270)^+$)
 - $B_s^0 \rightarrow J/\psi \phi$ (K misidentified as π), $B^0 \rightarrow J/\psi K^+ \pi^-$
 - B^+ decays J/ψ + X
- B_s^0
 - no peaking structure

Charged Particle RpA at ALICE and ATLAS



- Extremely consistent with ATLAS results
- Consistent within 2σ to ALICE results