Open Heavy Flavor Results from RHIC and the LHC

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SECOND CONFERENCE ON HEAVY ION COLLISIONS IN THE LHC ERA AND BEYOND

Why Study Heavy Quarks?

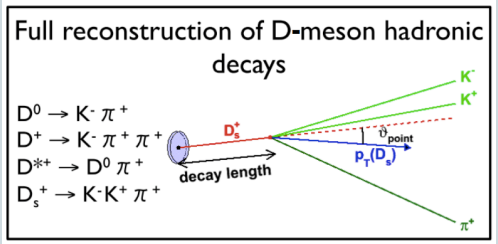
- Charm ($m_c \sim 1.5$ GeV) & Bottom ($m_b \sim 5$ GeV)

- $m_{c,b} >> \Lambda_{QCD}$
  - Large mass → short formation time
  - Medium doesn't change flavor, but can modify phase-space distribution
  - Difficult to destroy or create in medium

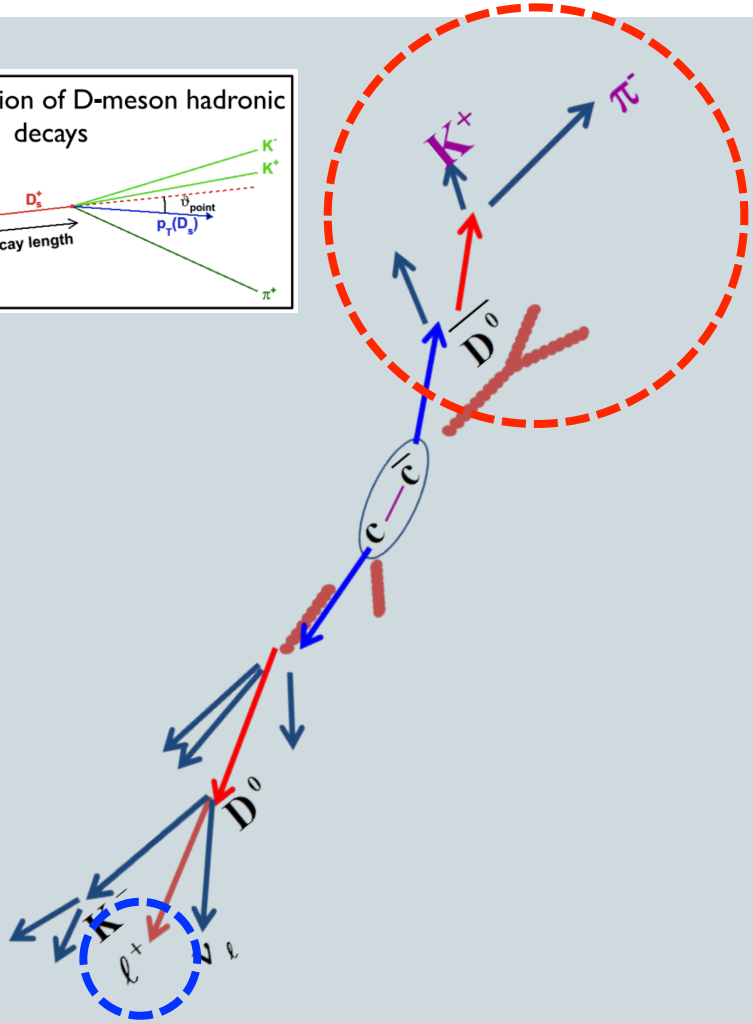
- Experience full evolution of medium
  - Describe medium and interaction
  - Measure intrinsic transport properties

Measuring Heavy Flavor

- Direct
  - Full hadron kinematics
  - Hard to trigger
  - Large combinatorial background

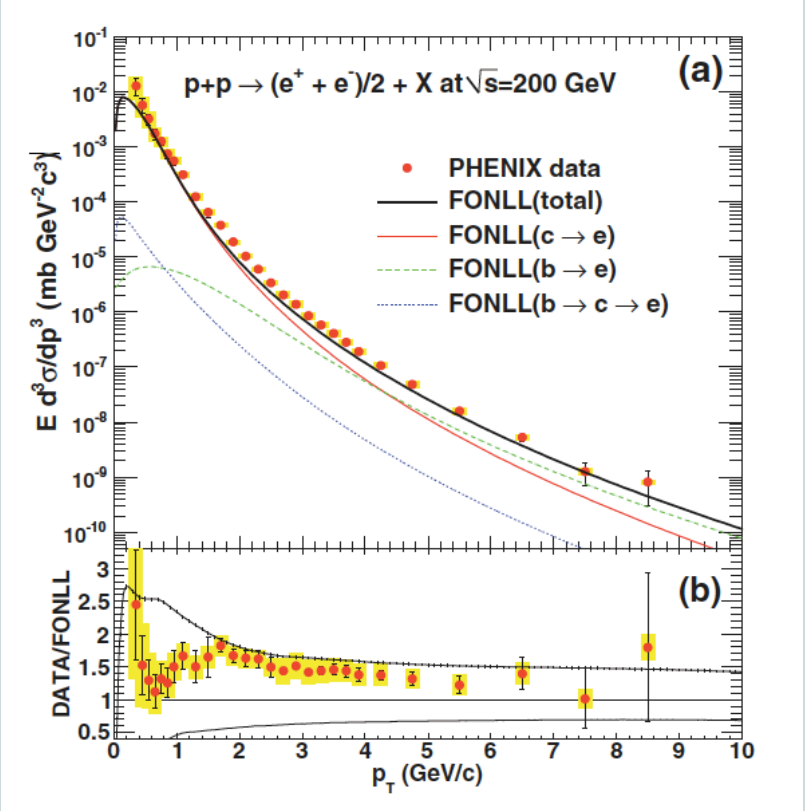


- Indirect
  - Kinematic smearing
  - Easy to trigger – high statistics
  - Lots of background sources
  - Branching ratios ~10%



p+p collisions

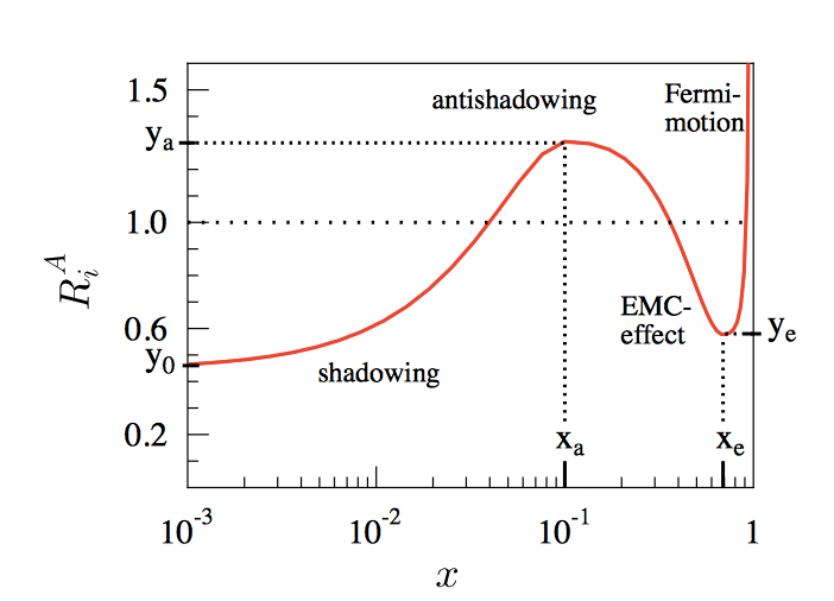
- Test pQCD predictions
  - Results in good agreement w/FONLL predictions
- Baseline for p(d)+A and A+A collisions



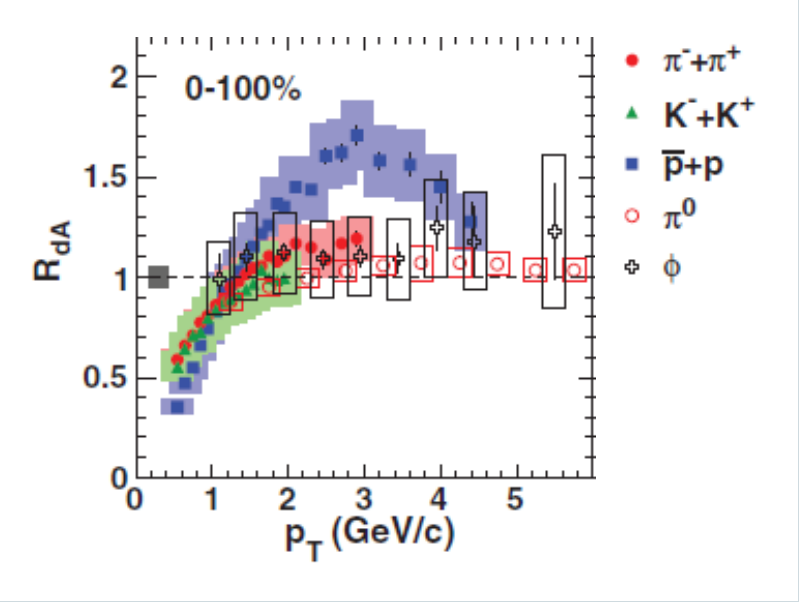
p(d)+A collisions

- Another baseline system?
- Cold nuclear matter effects?

Modification to the nPDF

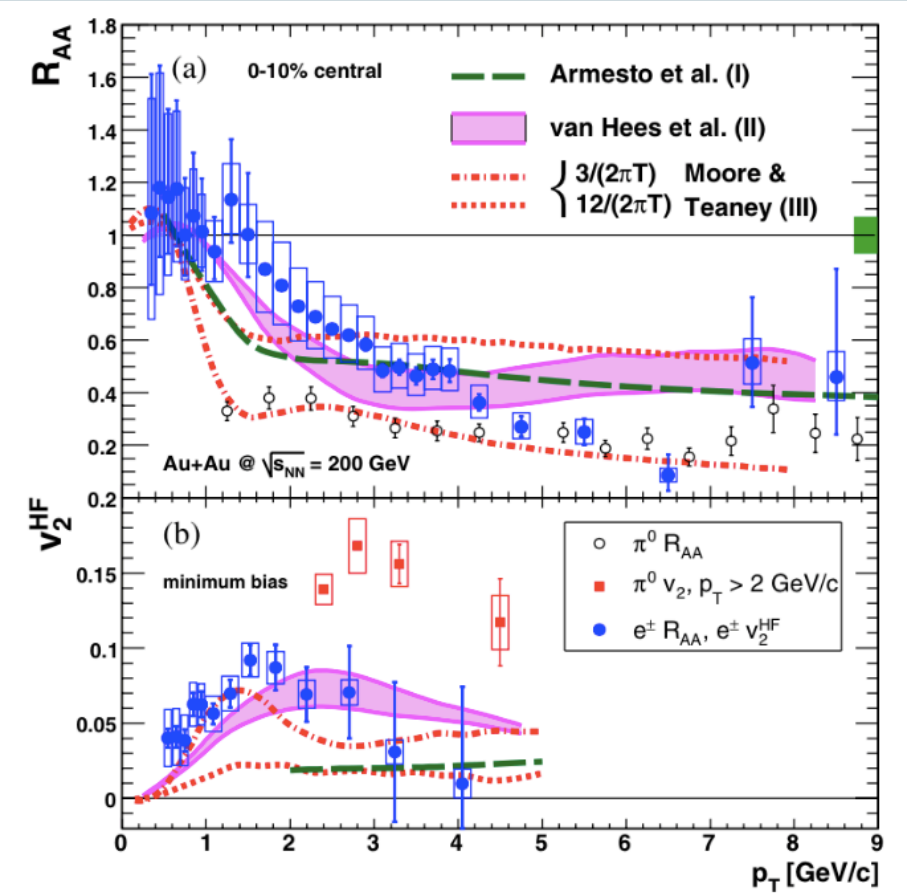


p_T broadening



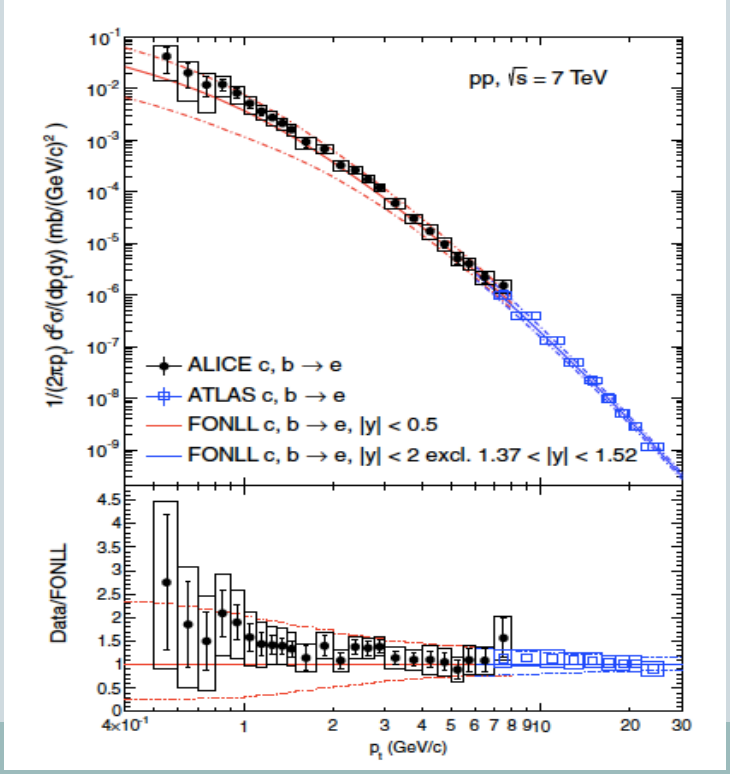
A+A collisions

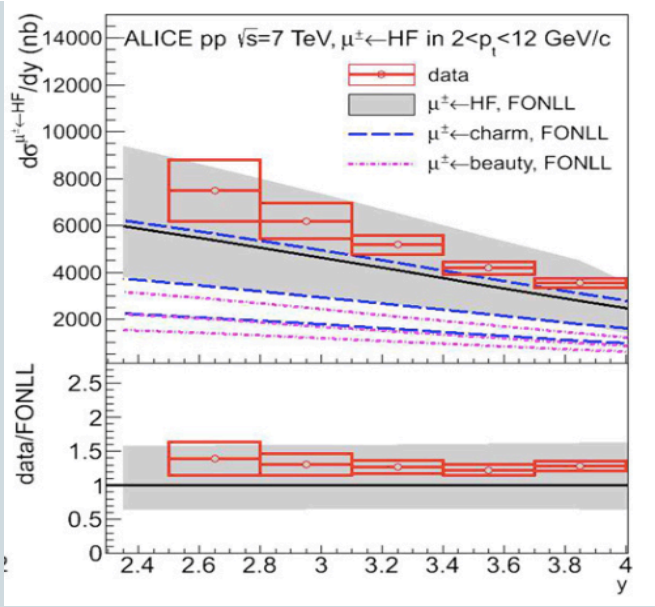
- Energy loss in the medium
- "Dead cone" effect
  - $\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b$
- Collectivity
  - Heavy quarks flow
  - Thermalization

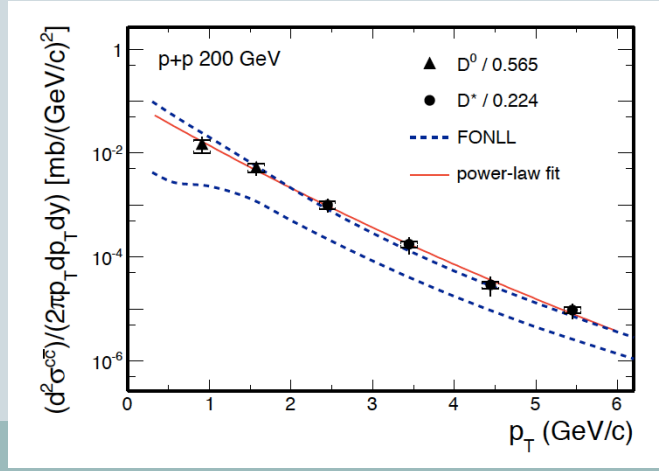


Charm in p+p

- Data consistent with pQCD FONLL calculations
  - Multiple √s energies, experiments, rapidities

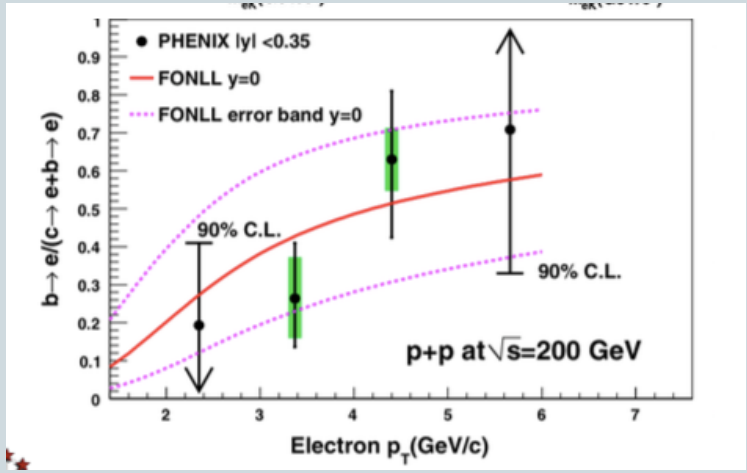


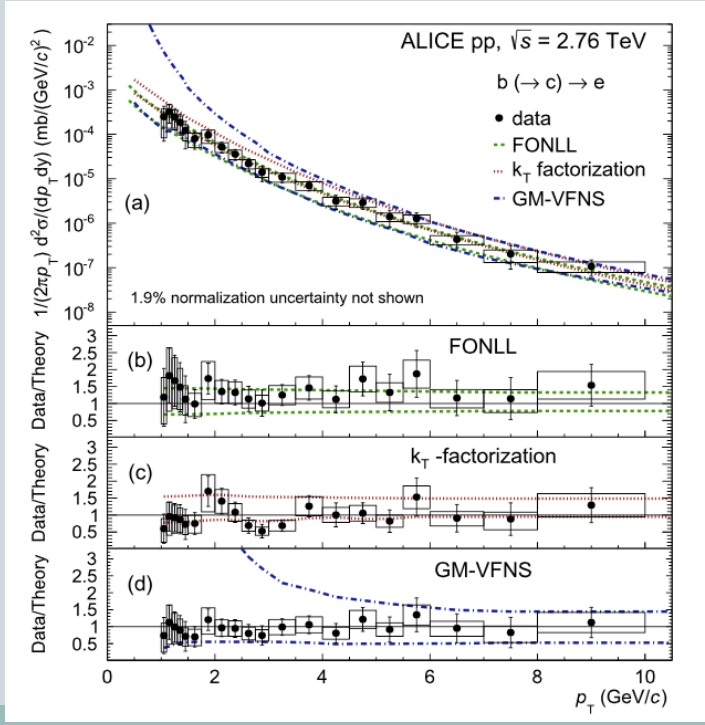


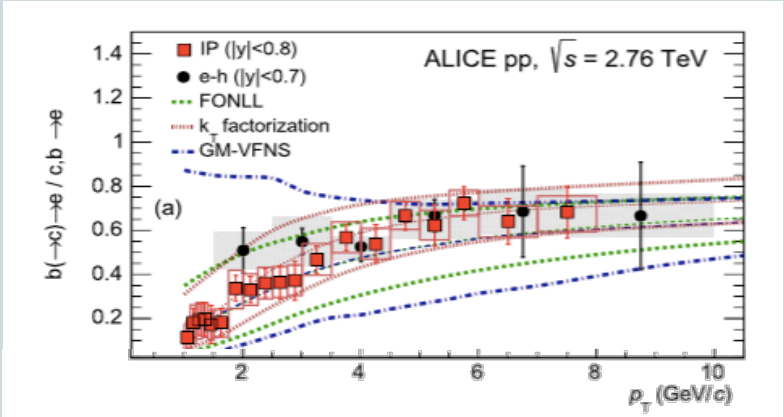


Bottom in p+p

- Data consistent with pQCD FONLL calculations
  - Multiple √s energies, experiments, rapidities

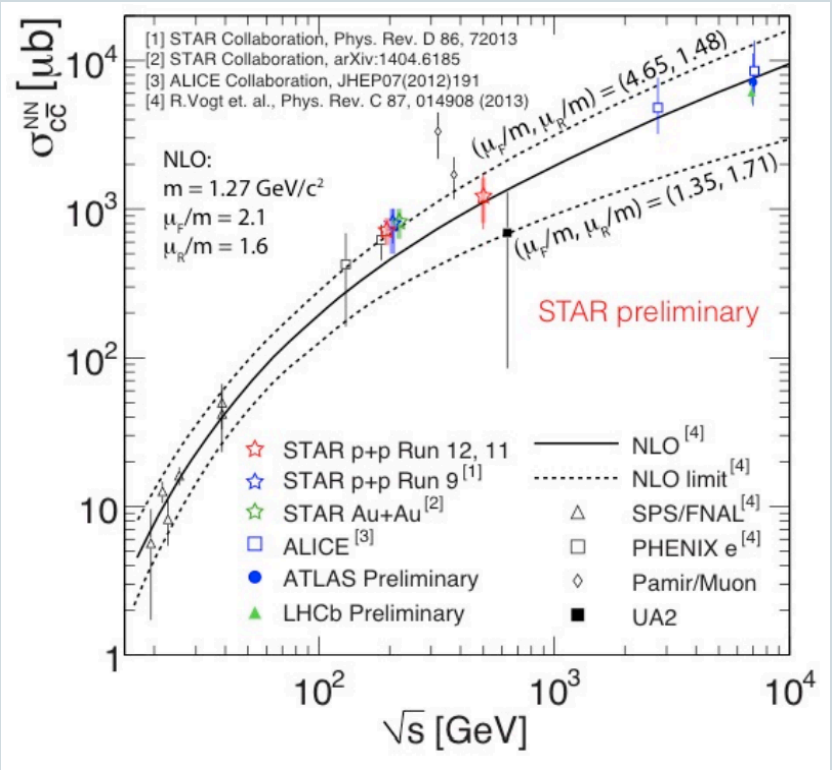


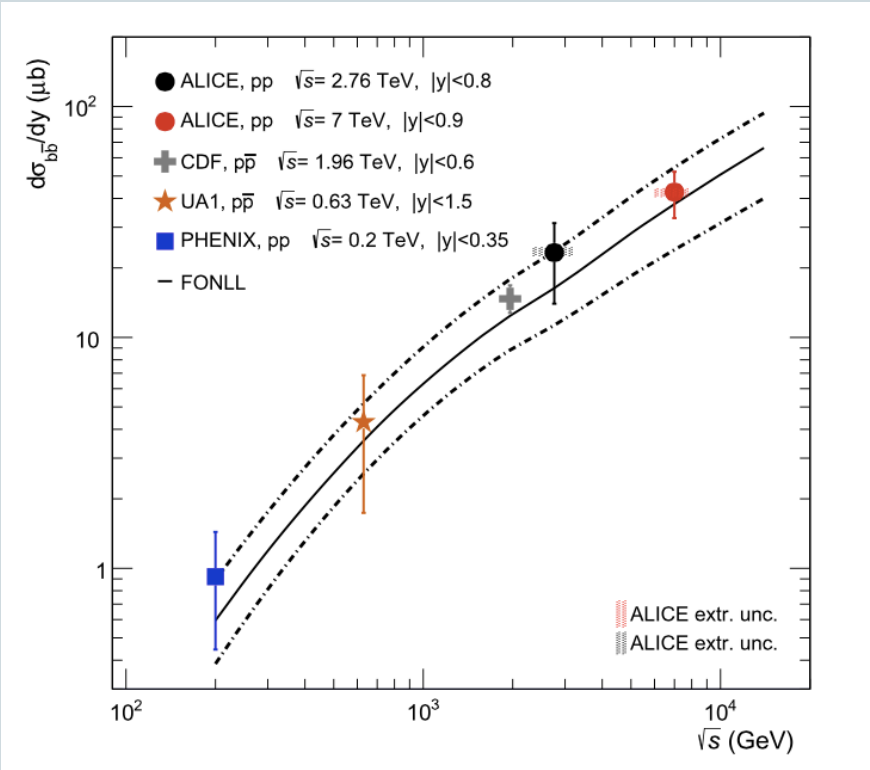




Total Cross Sections

- Data consistent with pQCD FONLL calculations

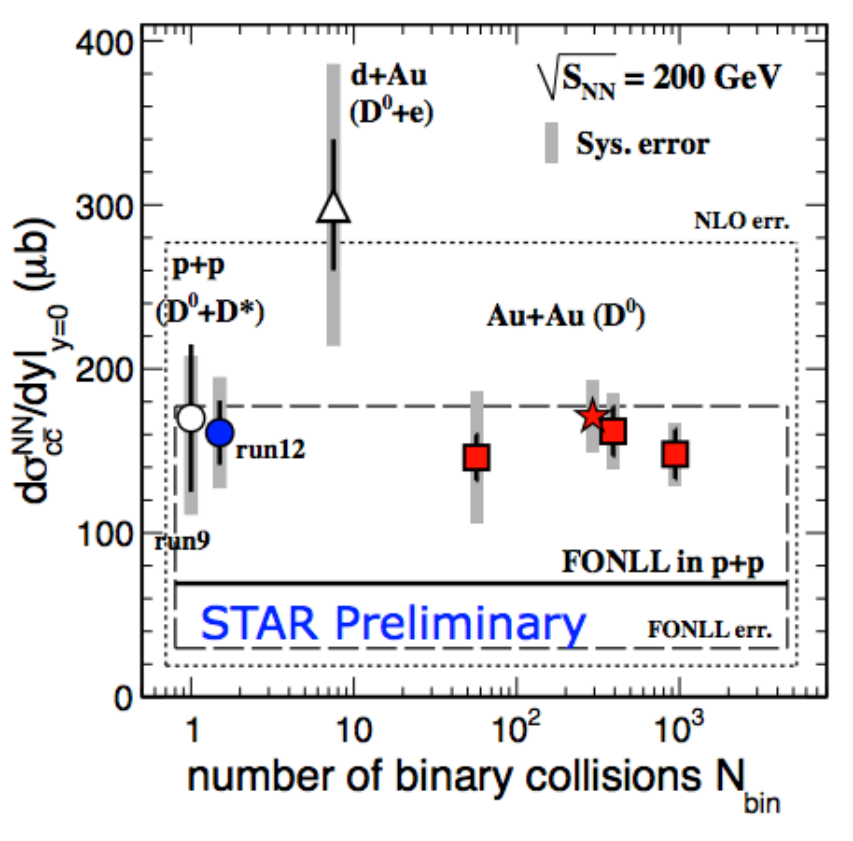




Charm **Bottom**

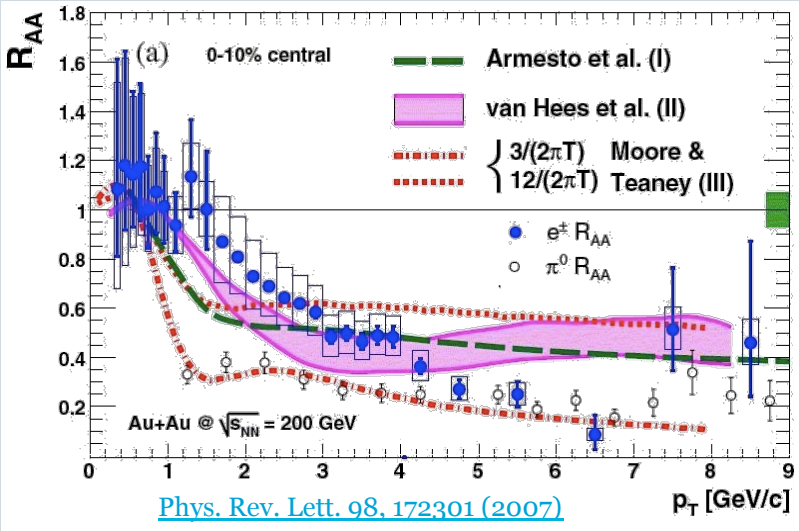
Heavy Flavor in A+A

- Total charm cross section (RHIC mid-rapidity) scales with number of binary collisions

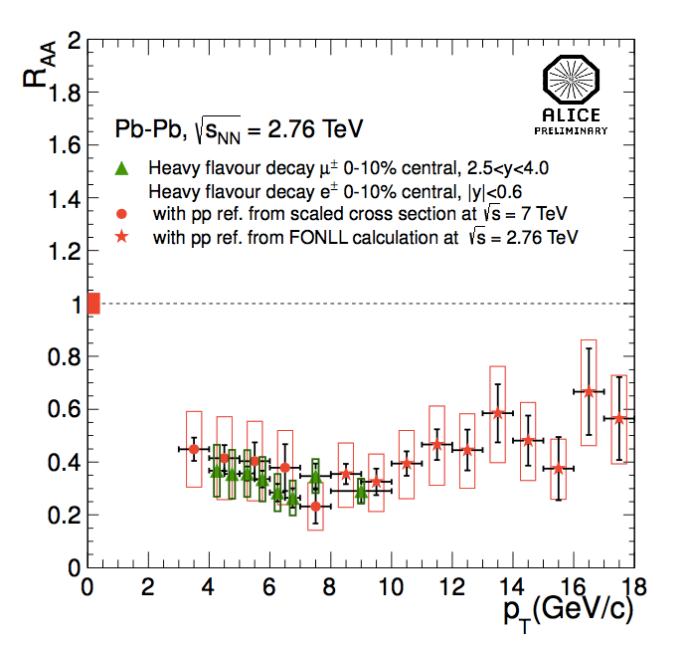


Heavy flavor leptons in A+A

- Significant energy loss in the medium
  - $R_{AA} < 1$ for $p_T > 2$GeV/c
  - $R_{AA}(HF) \sim R_{AA}(LF)$



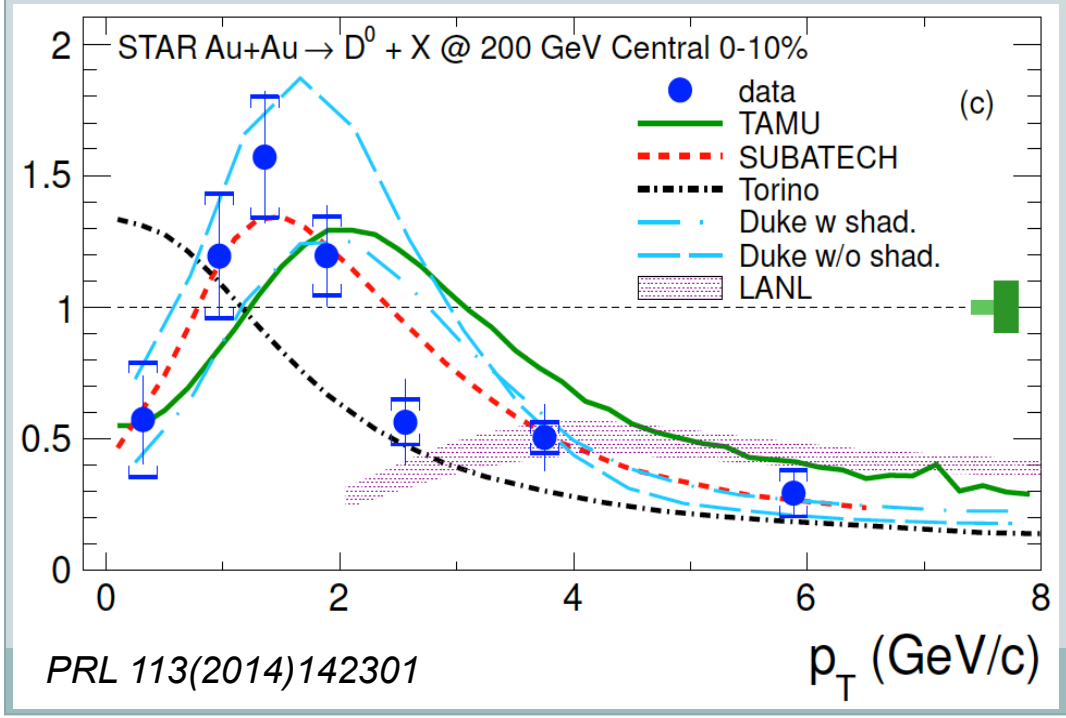
Phys. Rev. Lett. 98, 172301 (2007)



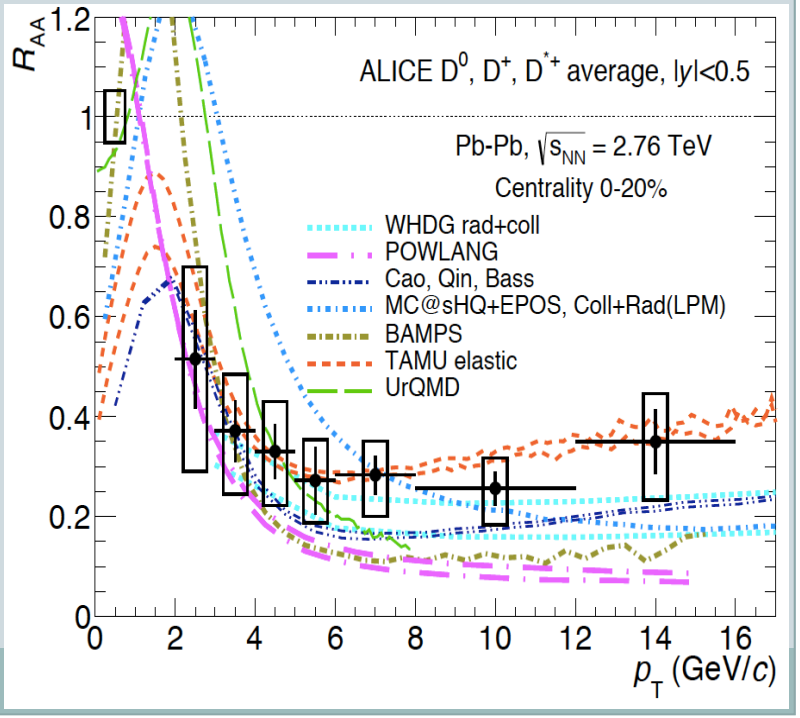
- $R_{AA}(e) \sim R_{AA}(\mu)$
  - No rapidity dependence

Charm modification

- High p_T: $R_{AA}(D) \sim R_{AA}(e)$
- Low p_T at RHIC: Enhancement

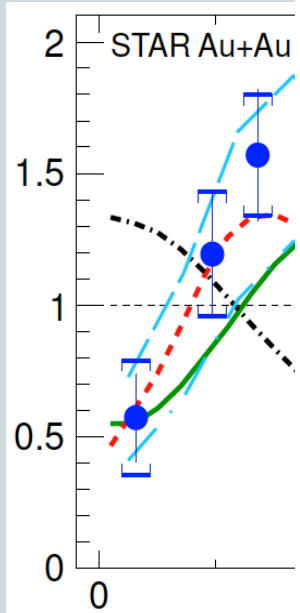


PRL 113(2014)142301

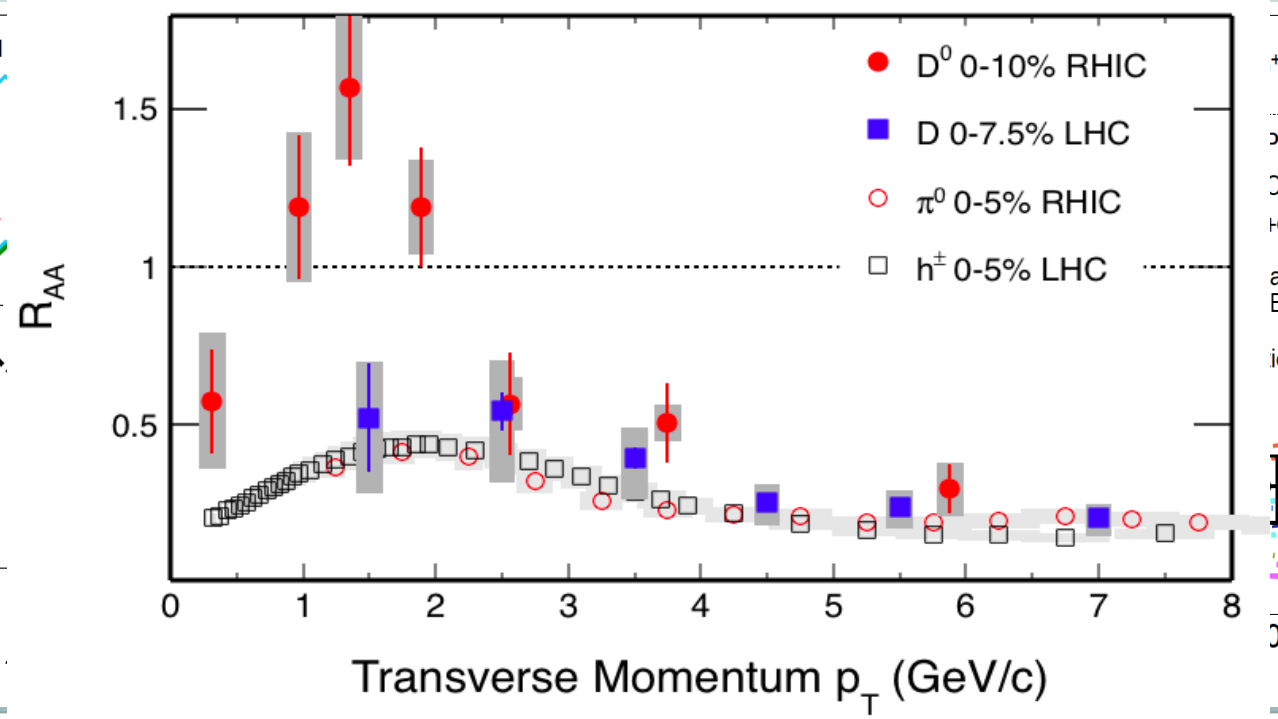


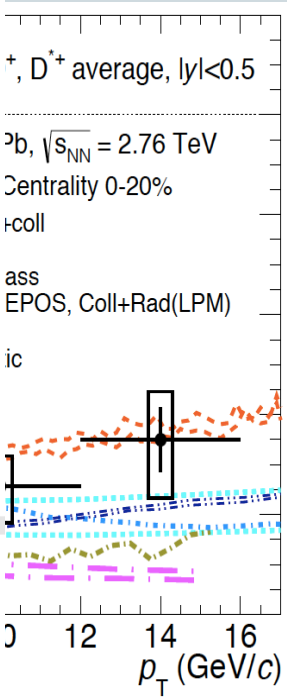
Charm modification

- High p_T: Similar suppression at RHIC & LHC
- Low p_T: CNM?
  - Probing different x-regions (~10^{-3} LHC & 10^{-2} RHIC)
  - Charm flow?

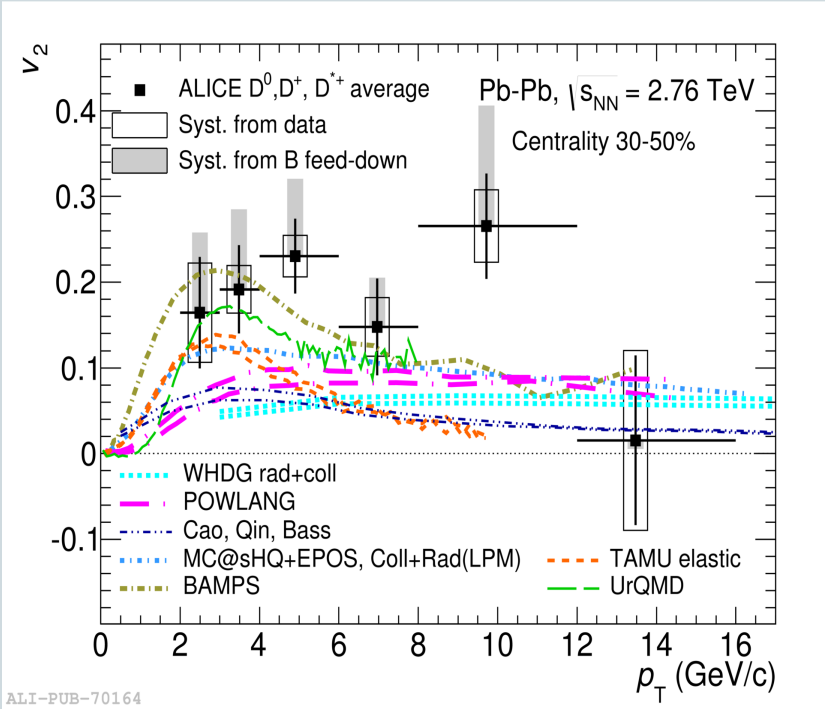


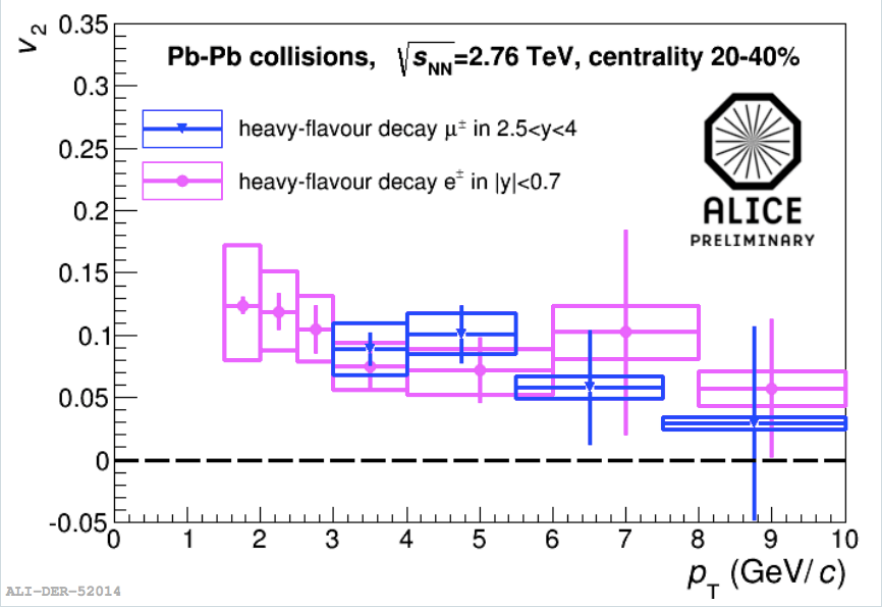
PRL 113(2014)





Charm Flows?

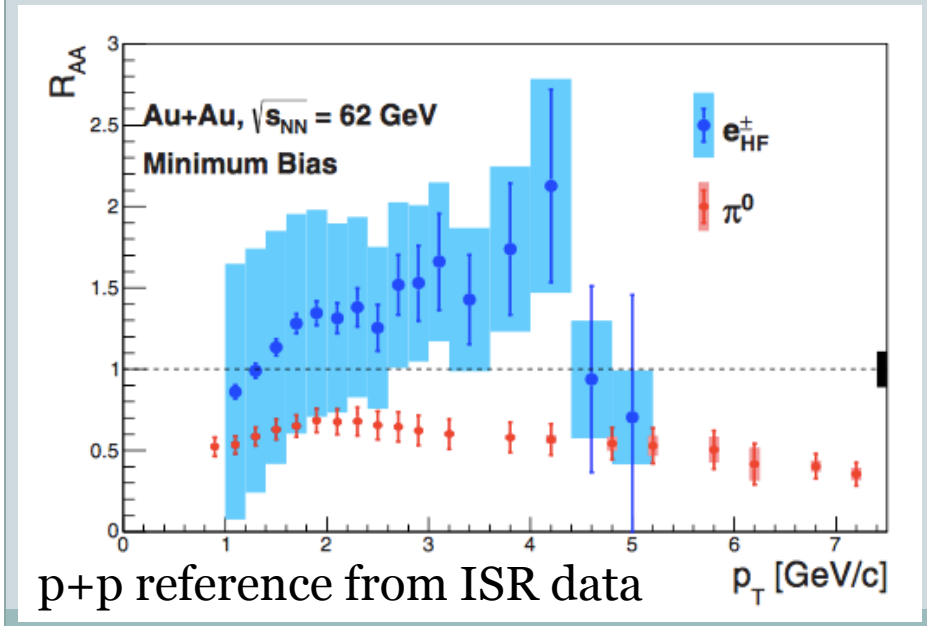




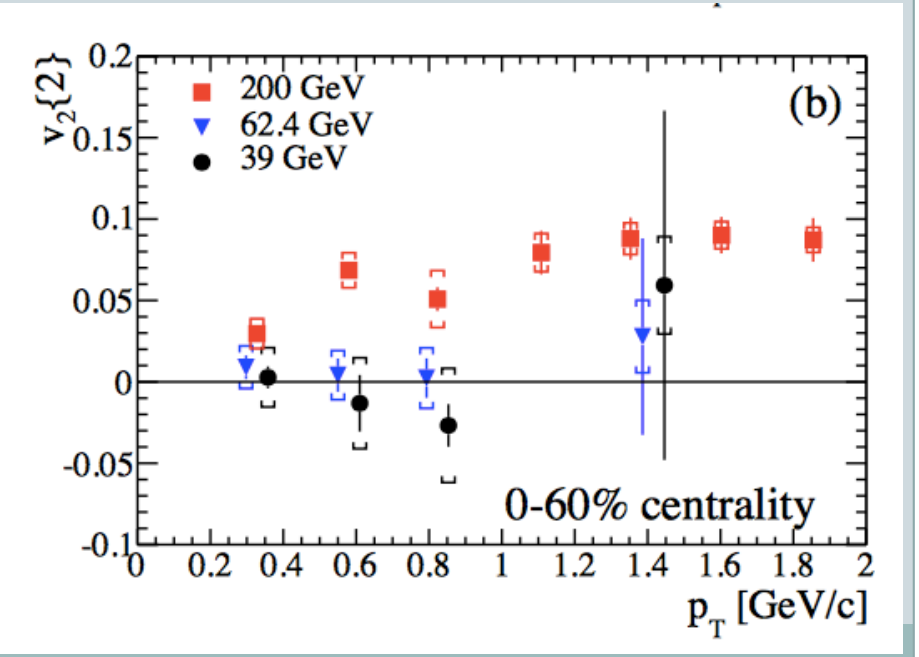
- Possibly with the medium
- Need better precision data at low p_T

Dependence on collision energy

- No suppression at high p_T observed
  - π^0 still suppressed
- v_2(62.4/39 GeV) < v_2(200 GeV)
  - Reduced/no strong interaction with the medium?

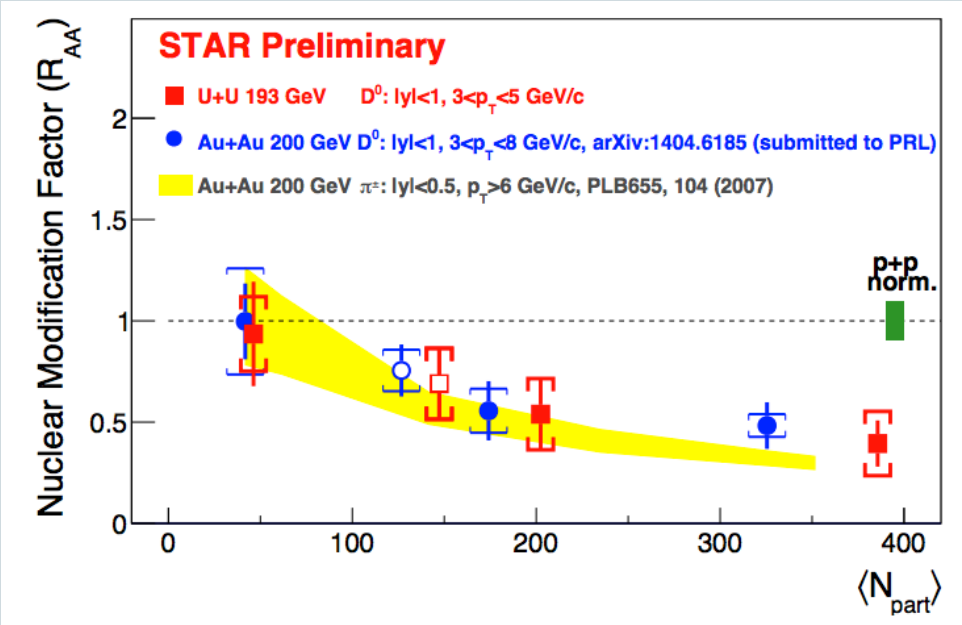


p+p reference from ISR data

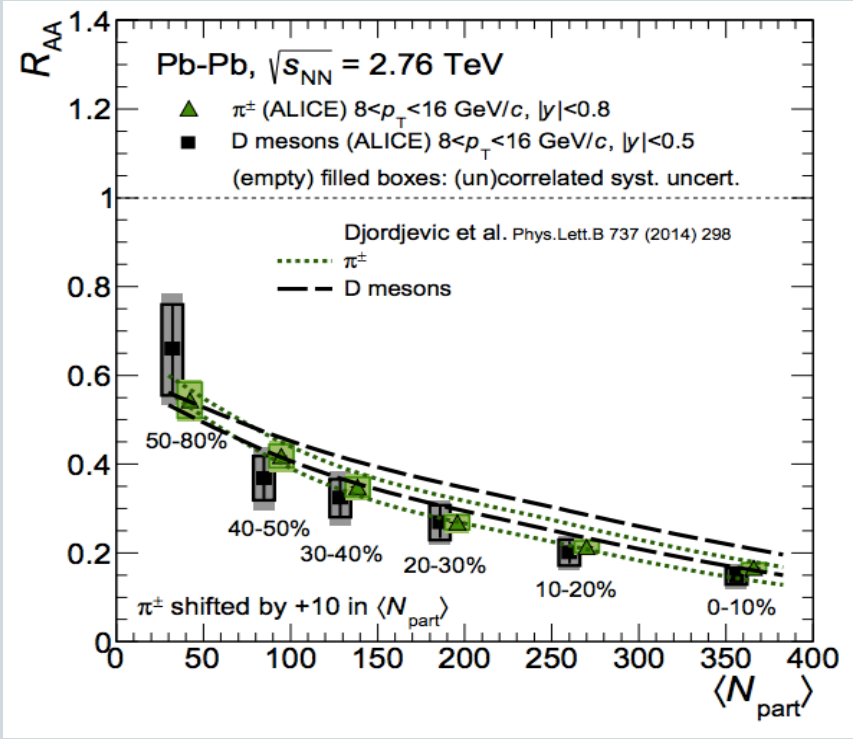


Suppression across systems

RHIC



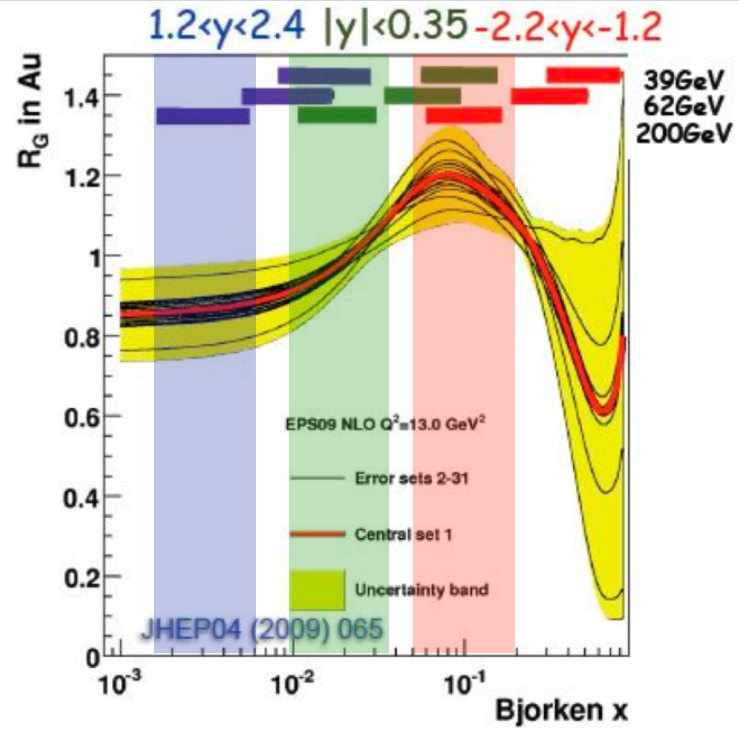
LHC



- $R_{AA}(HF) \sim R_{AA}(LF)$
- $R_{AuAu} \sim R_{UU}$ for similar N_{part}
- Several models consistent with the data
  - Should also describe v_2 and correlations

What about the other "small" systems?

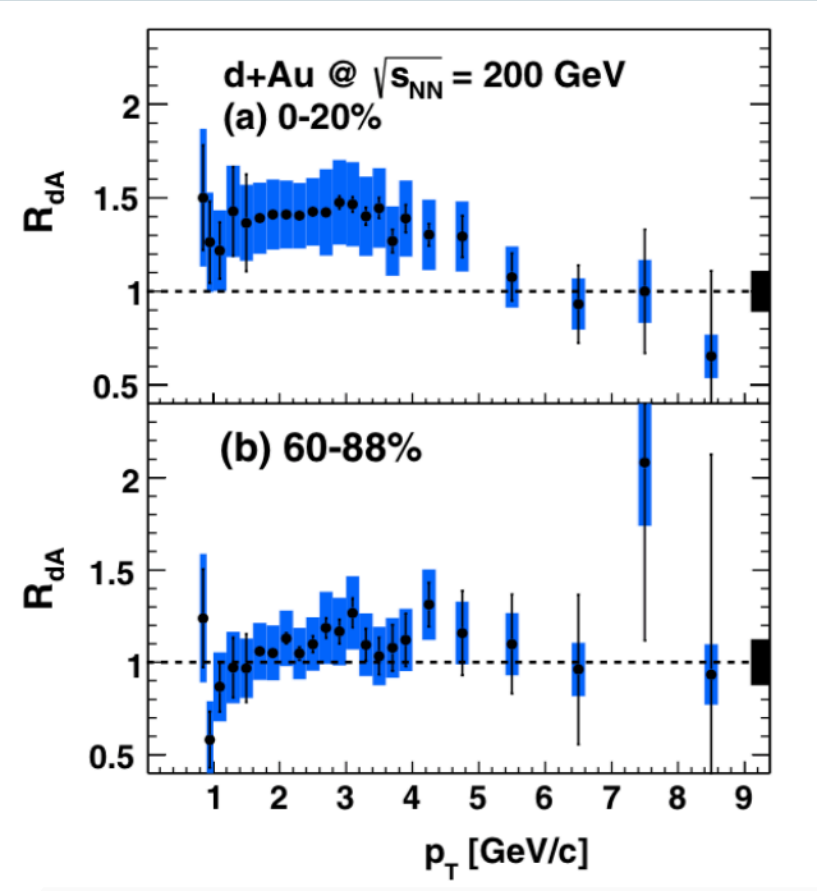
- RHIC
  - Mid-rapidity
    - No modification
  - Forward rapidity
    - Shadowing
  - Backward rapidity
    - Anti-shadowing
- LHC
  - Mid-rapidity: low-x



RHIC mid-rapidity d+Au

- Peripheral $R_{dA} \sim 1$
- Central $R_{dA} > 1$

- CNM effects?
  - Cronin?
  - p_T broadening?

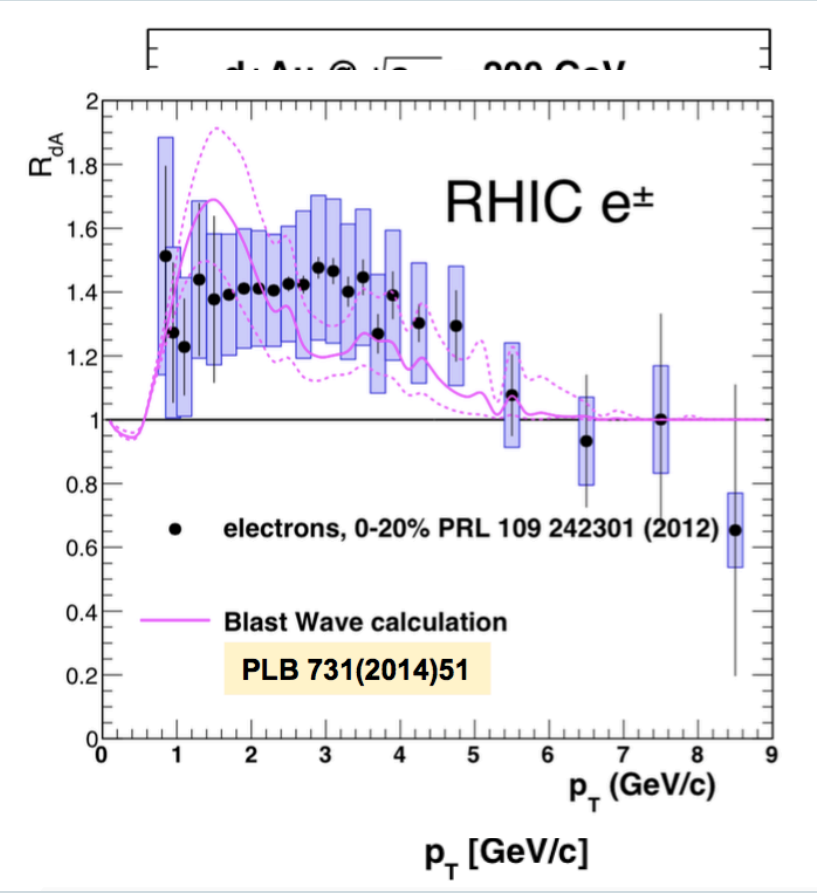


RHIC mid-rapidity d+Au

- Peripheral $R_{dA} \sim 1$
- Central $R_{dA} > 1$

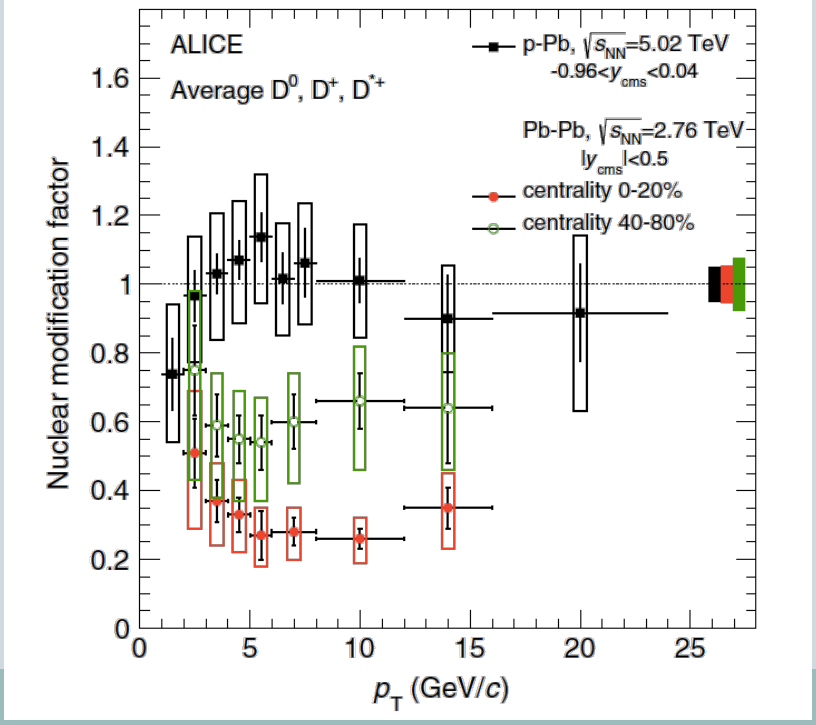
- CNM effects?
  - Cronin?
  - p_T broadening?

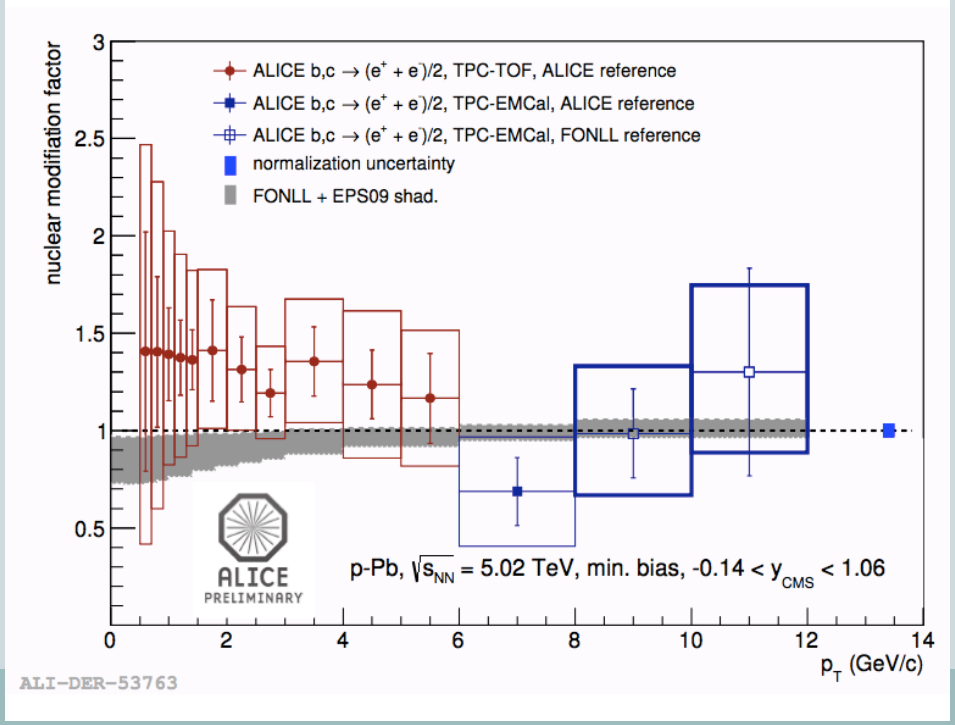
- Or a small drop of HNM?



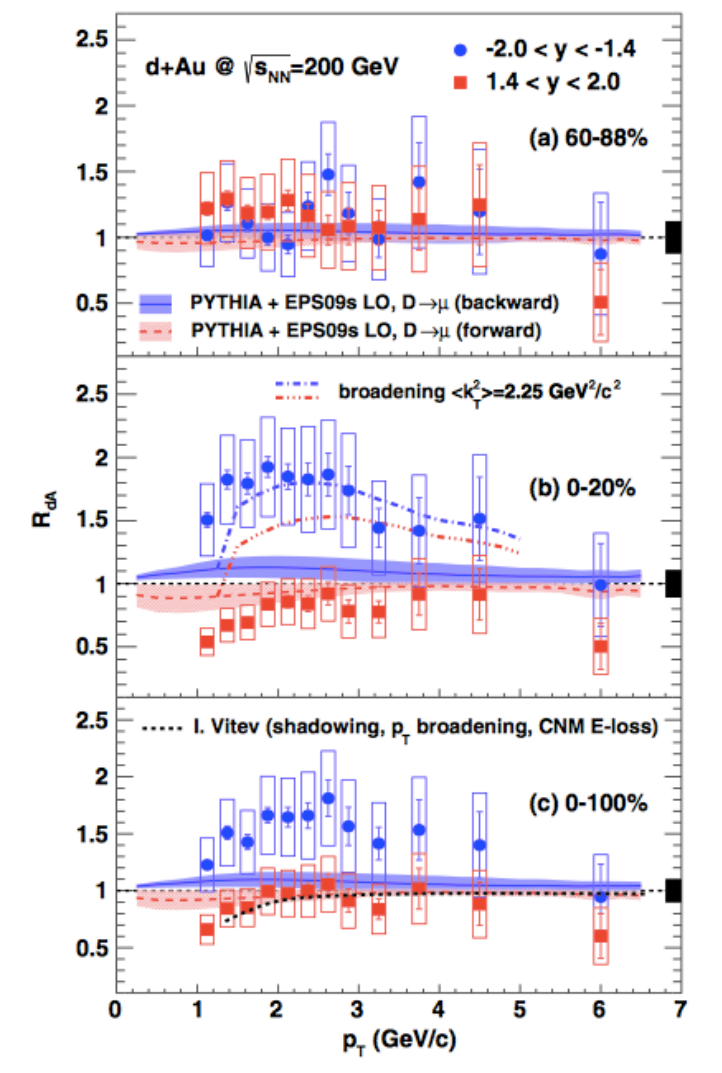
LHC heavy flavor in p+Pb

- R_{pPb} consistent w/1
  - Systematically higher
- $R_{pPb} \sim R_{dAu}$
- Pb+Pb suppression mainly a final state effect



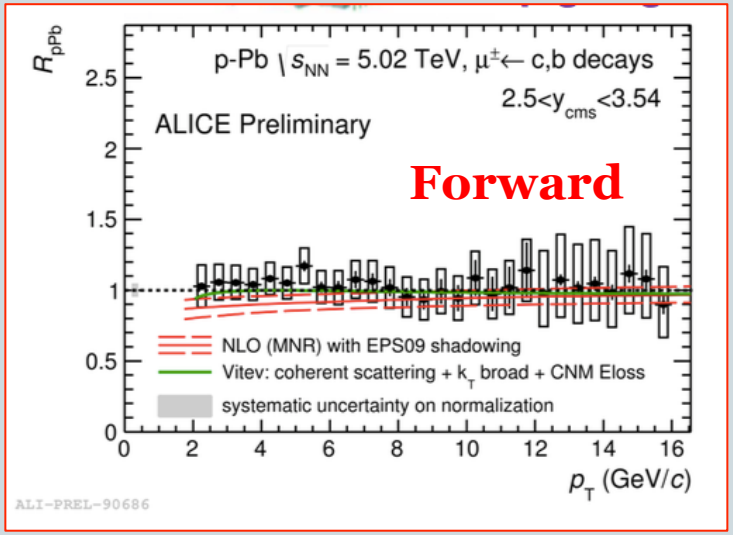


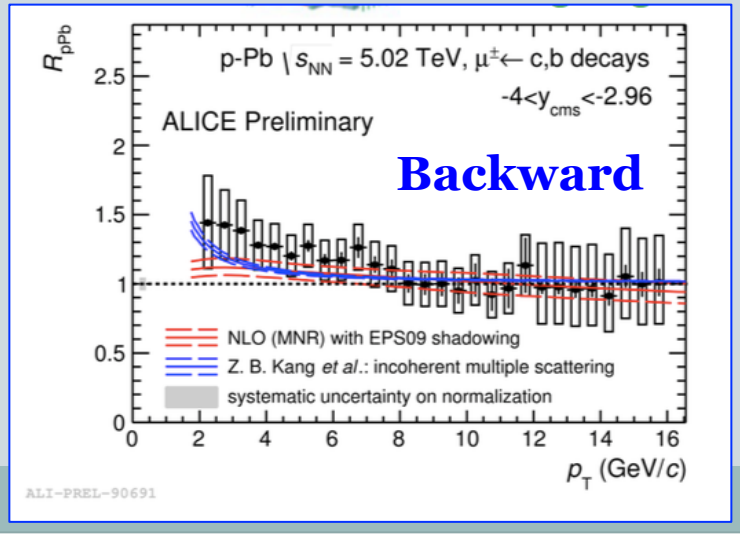
Forward Rapidities: RHIC d+Au



- Peripheral
  - R_{dA} ~ 1 for all rapidities
- Central
  - Forward: $R_{dA} < 1$
    - Consistent with pQCD +shadowing
  - Backward: $R_{dA} > 1$
    - Consistent with additional k_T broadening
  - Backward & Forward not described simultaneously

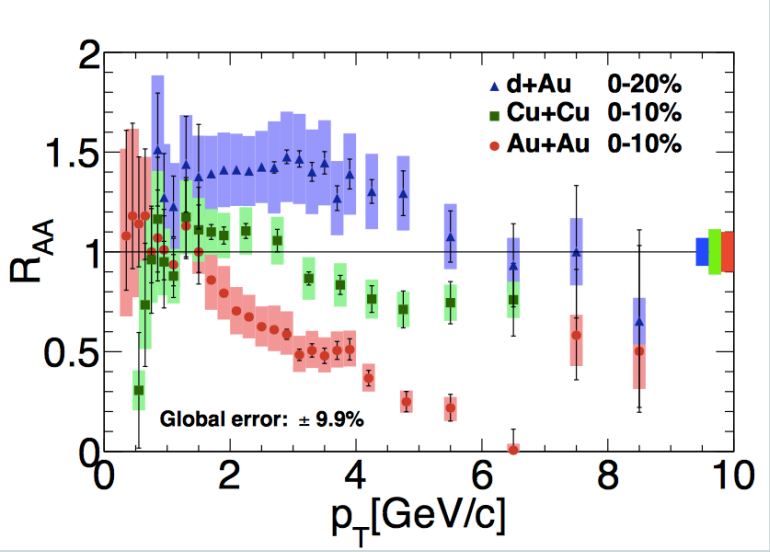
Forward Rapidities: LHC p+Pb



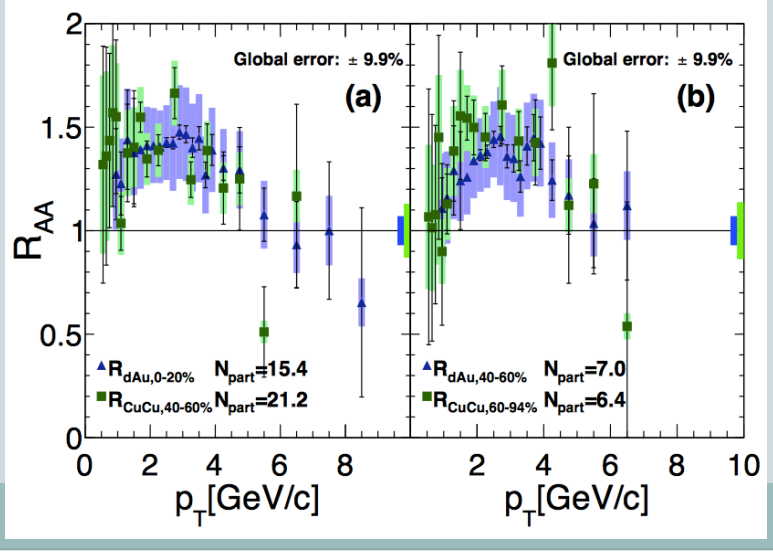


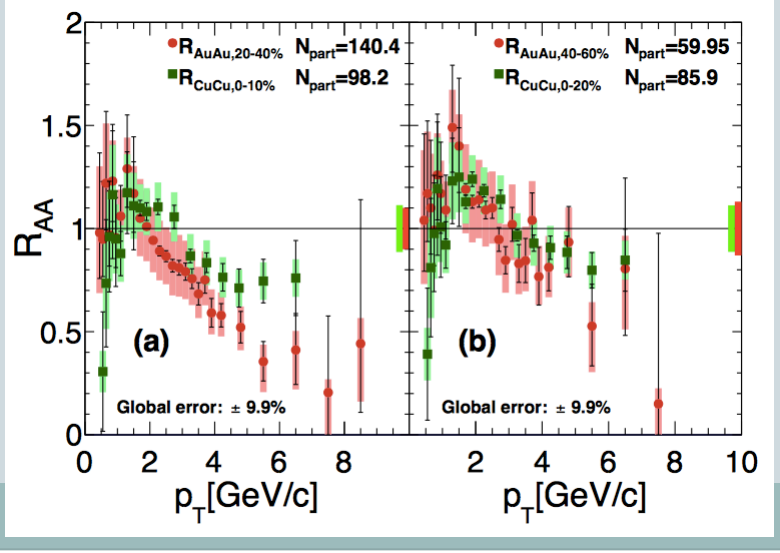
- Forward: $R_{pPb} \sim 1$
  - No modification
- Backward: R_{pPb} slightly larger than 1 at low p_T
- Consistent with RHIC results
- Consistent with pQCD models that include CNM effects

System Size Dependence

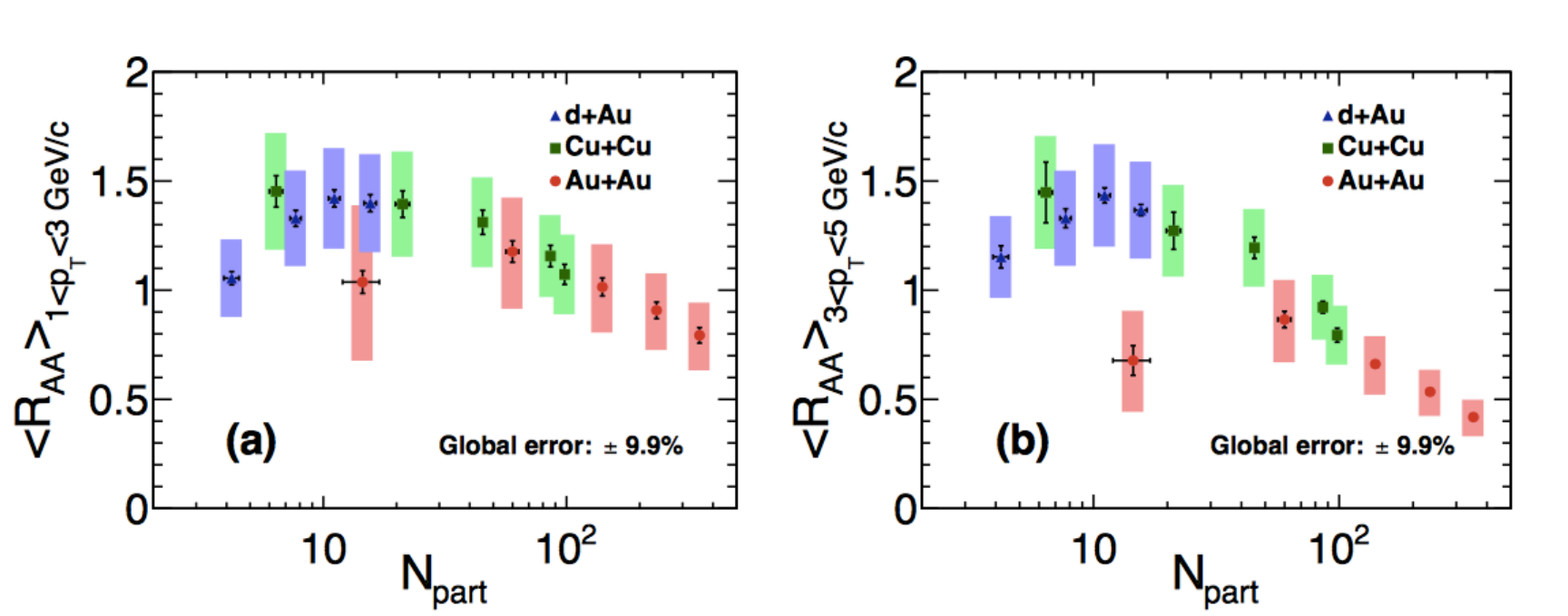


- Suppression
  - Central Cu+Cu & Au+Au
- Enhancement
  - Central d+Au & Peripheral Cu+Cu
- Same trend for similar N_{part}





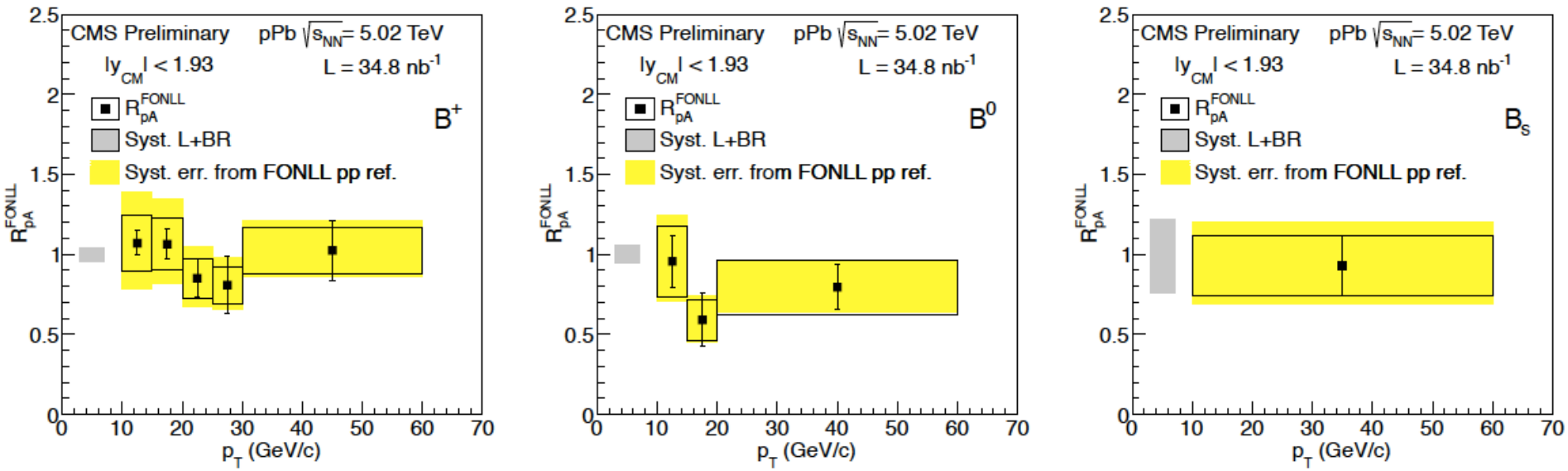
System Size Dependence



- Smooth trend from enhancement (central d+Au, peripheral Cu+Cu) to suppression (central Cu+Cu and Au+Au)

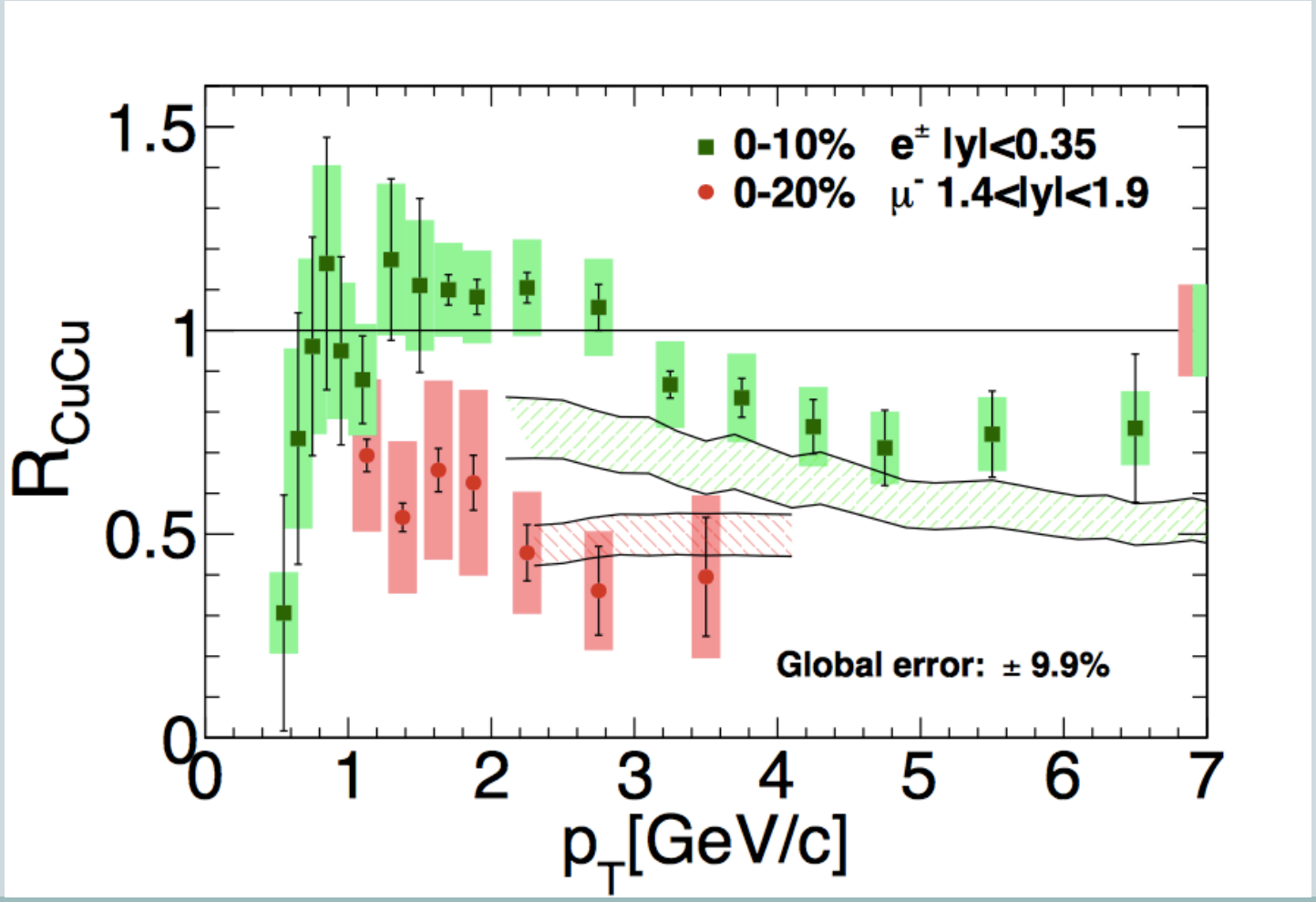
B mesons in p+Pb

- p+p reference from FONLL
- $R_{pPb} \sim 1$
- Pb+Pb suppression not coming from CNM effect



Summary

- Open heavy flavor (direct & indirect) give us insight into the medium produced in heavy ion collisions


0-10% e± |y|<0.35
0-20% μ- 1.4<|y|<1.9
Global error: ± 9.9%
R_CuCu
p_T [GeV/c]
0
0.5
1
1.5
0
1
2
3
4
5
6
7