Heavy Flavor Workshop Report

Anthony Frawley

2024 RHIC/AGS Annual User's Meeting

June 11-14, 2024

Heavy Flavor Workshop
June 12, 2024

There were 9 presentations on open heavy flavor and heavy quarkonia.

- Open Heavy Flavor Physics - STAR, Ondrej Lomicky
- Open Heavy Flavor physics - PHENIX, Daniel Richford
- Open Heavy Flavor Physics - sPHENIX, Thomas Marshall
- Open Heavy Flavor Physics - (LHC) Preeti Dhankher
- Heavy Flavor Jets - sPHENIX, Jakub Kvapil
- HF Quarkonium Physics - STAR, Wei Zhang
- HF Quarkonium Physics - PHENIX, Ming Liu
- HF Quarkonium Physics - sPHENIX, Marzia Rosati
- HF Quarkonium Physics - (LHC) Minjung Kim

Introduction

A comprehensive summary of the large number of interesting results presented in the workshop is impossible here.

I will present selected highlights only - organized by topic.

Please see the original talk slides for details, and for proper referencing of sources.

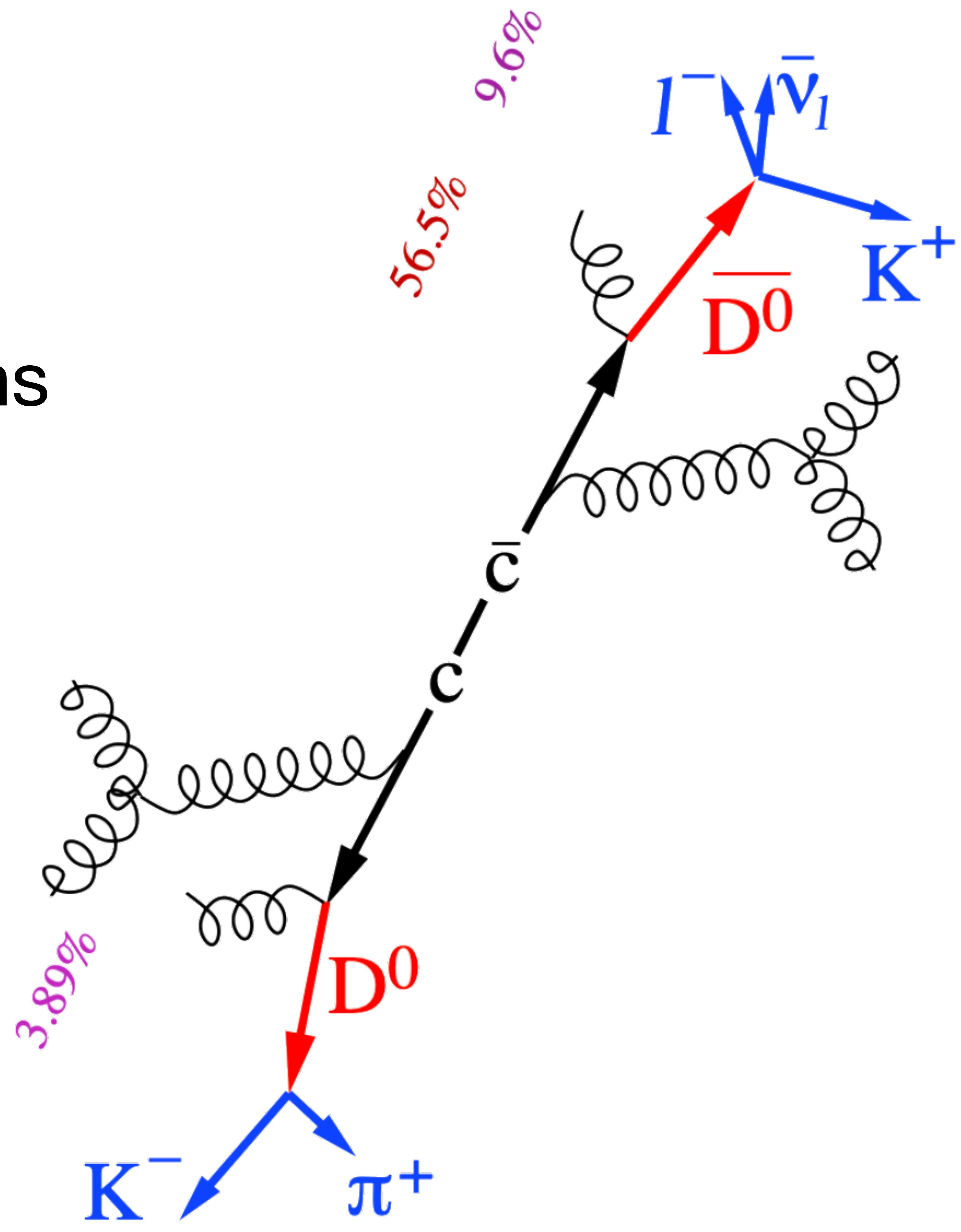
https://indico.bnl.gov/event/22687/

Open Heavy Flavor

Can be studied by measuring yields of:

- HF decay leptons
- Reconstructed hadronic decays of HF mesons
- Heavy flavor tagged jets

Good progress on all three fronts.

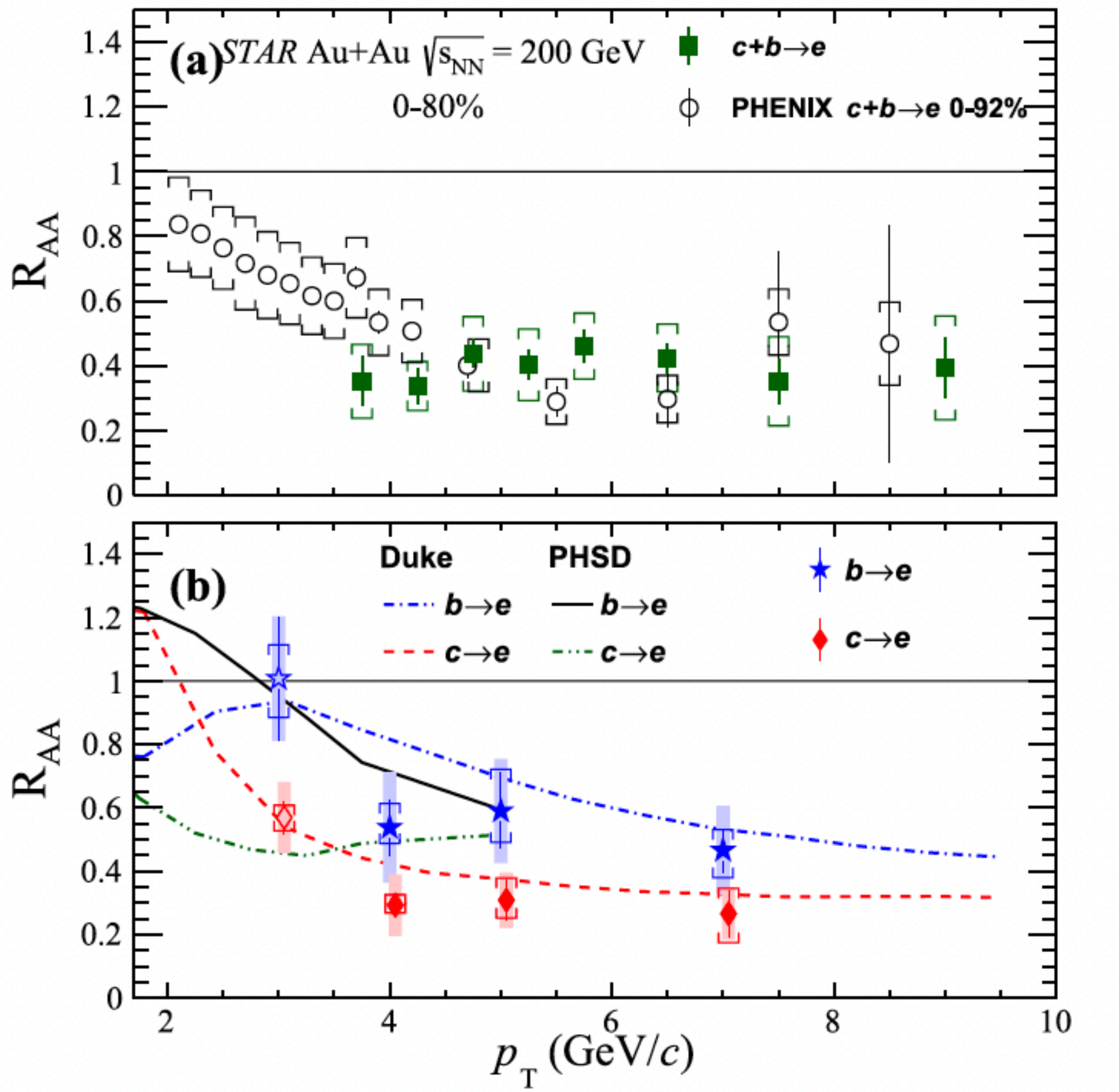


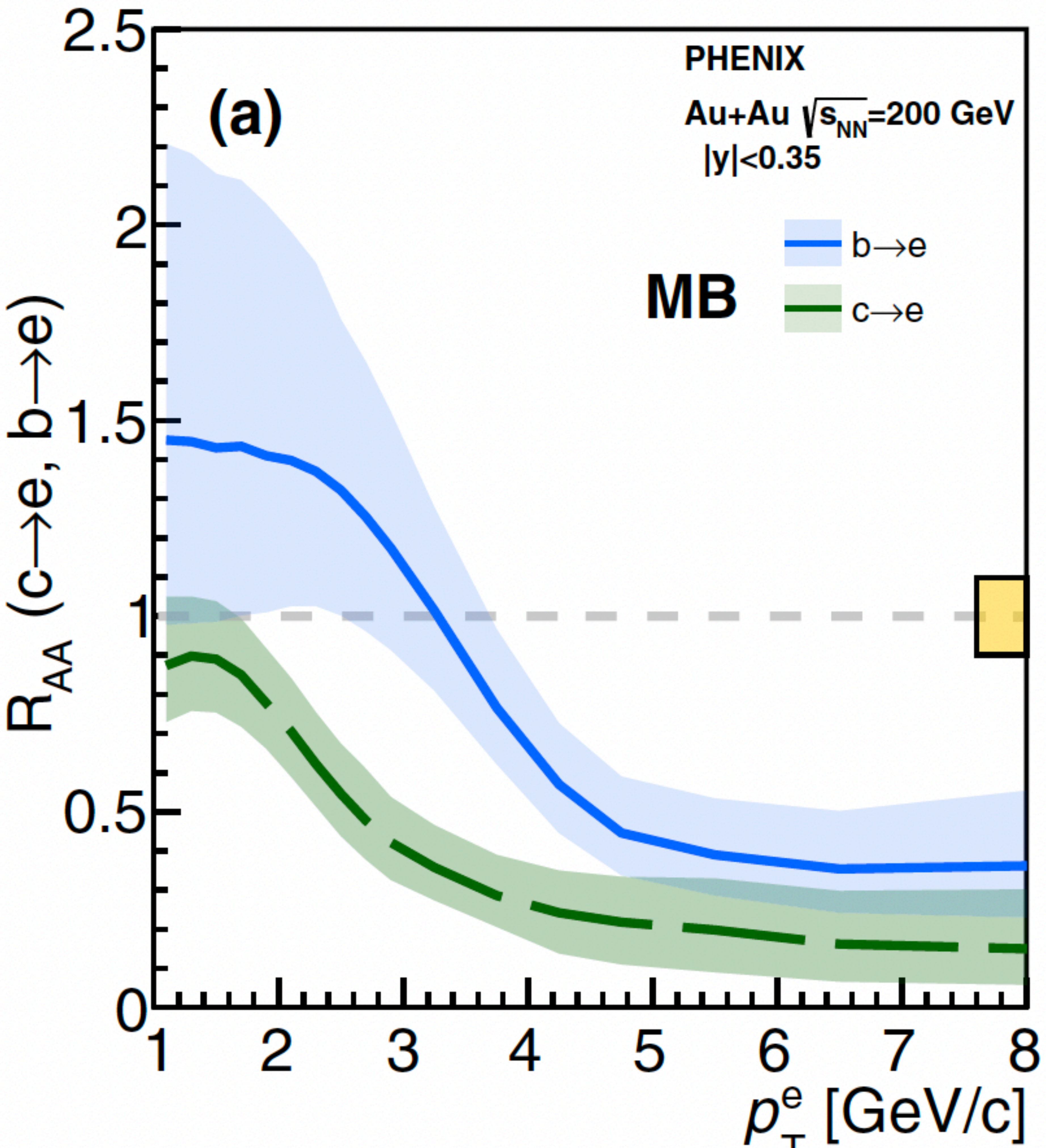
HF electrons at RHIC - b/c separation

Ondrej Lomicky

Separation of charm and bottom energy loss clear.
STAR & PHENIX agreement within uncertainties.

Daniel Richford

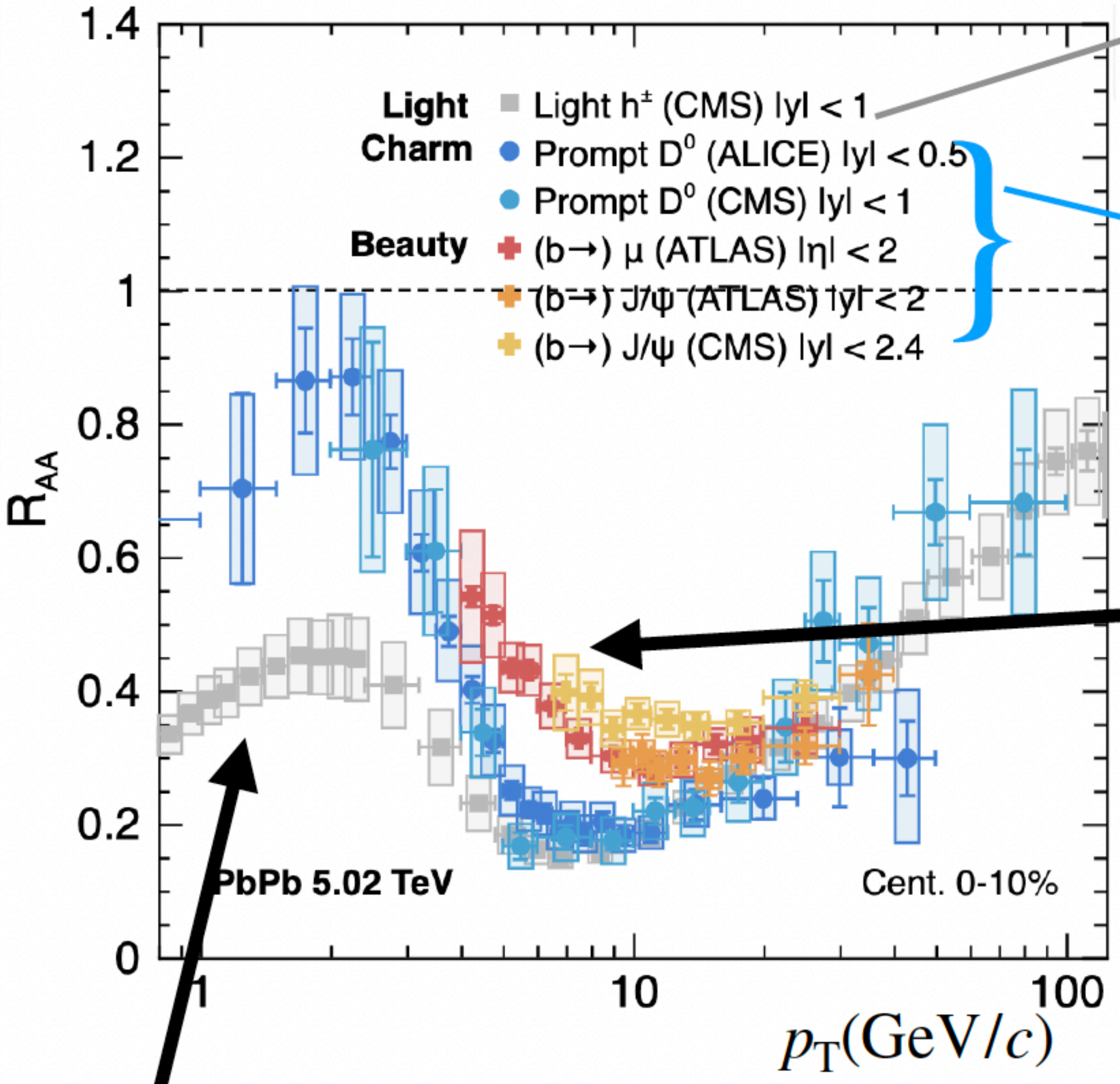


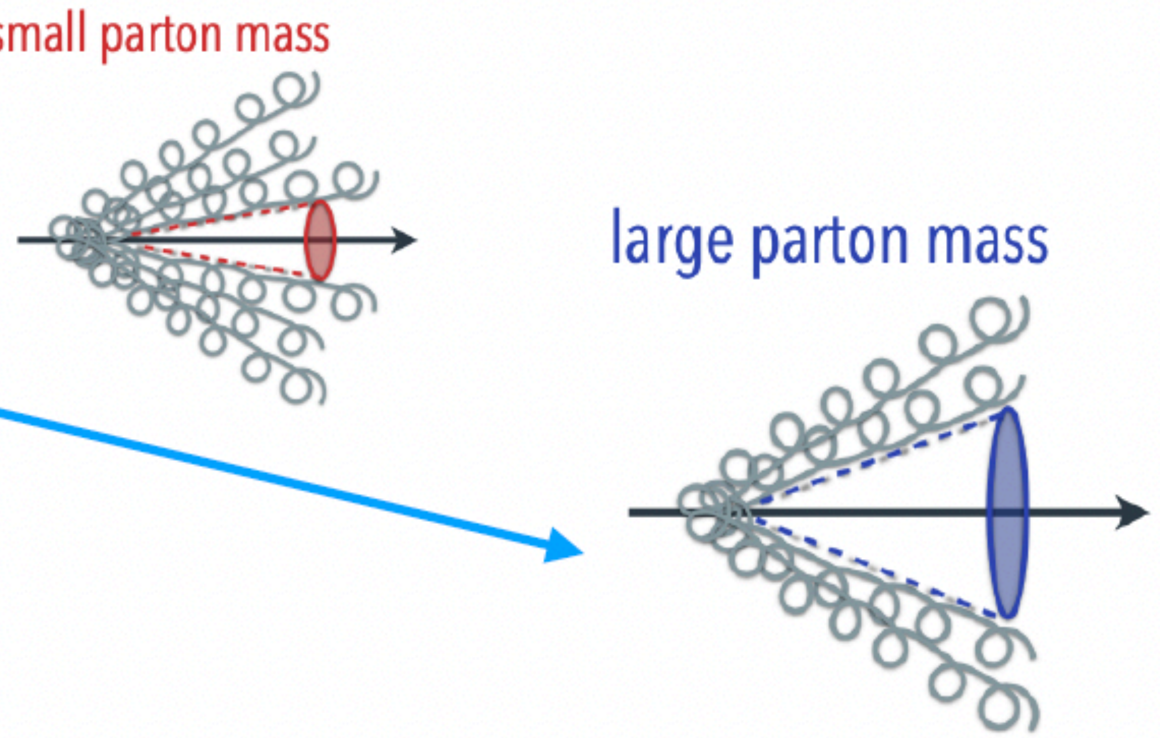


HF electrons at LHC - b/c separation

Preeti Dhankher

Interaction of heavy quarks with the QGP





Dead cone effect: gluon radiation suppressed at angles smaller than $\theta < m/E$

Consistent with mass dependent hierarchy!!!

RAA(q/g) < RAA(c) < RAA(b)

Probe modified by the medium!!

$$R_{AA} = \frac{dN_{AA}/dp_T}{< T_{AA} > d\sigma_{pp}/dp_T}$$

"Flow bump" due to (radial) flow of medium and coupling at small p_T

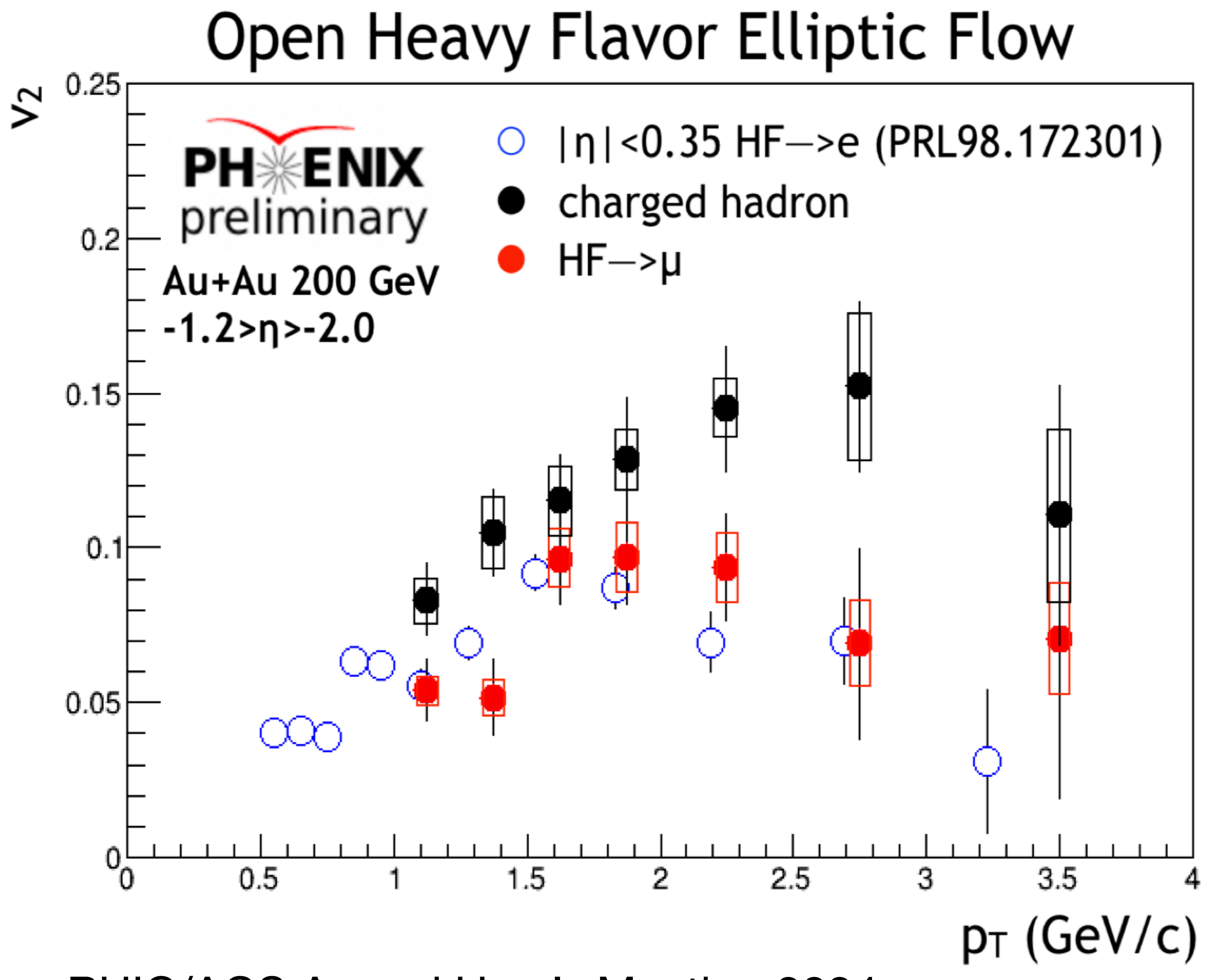
HF electron v_2 at RHIC

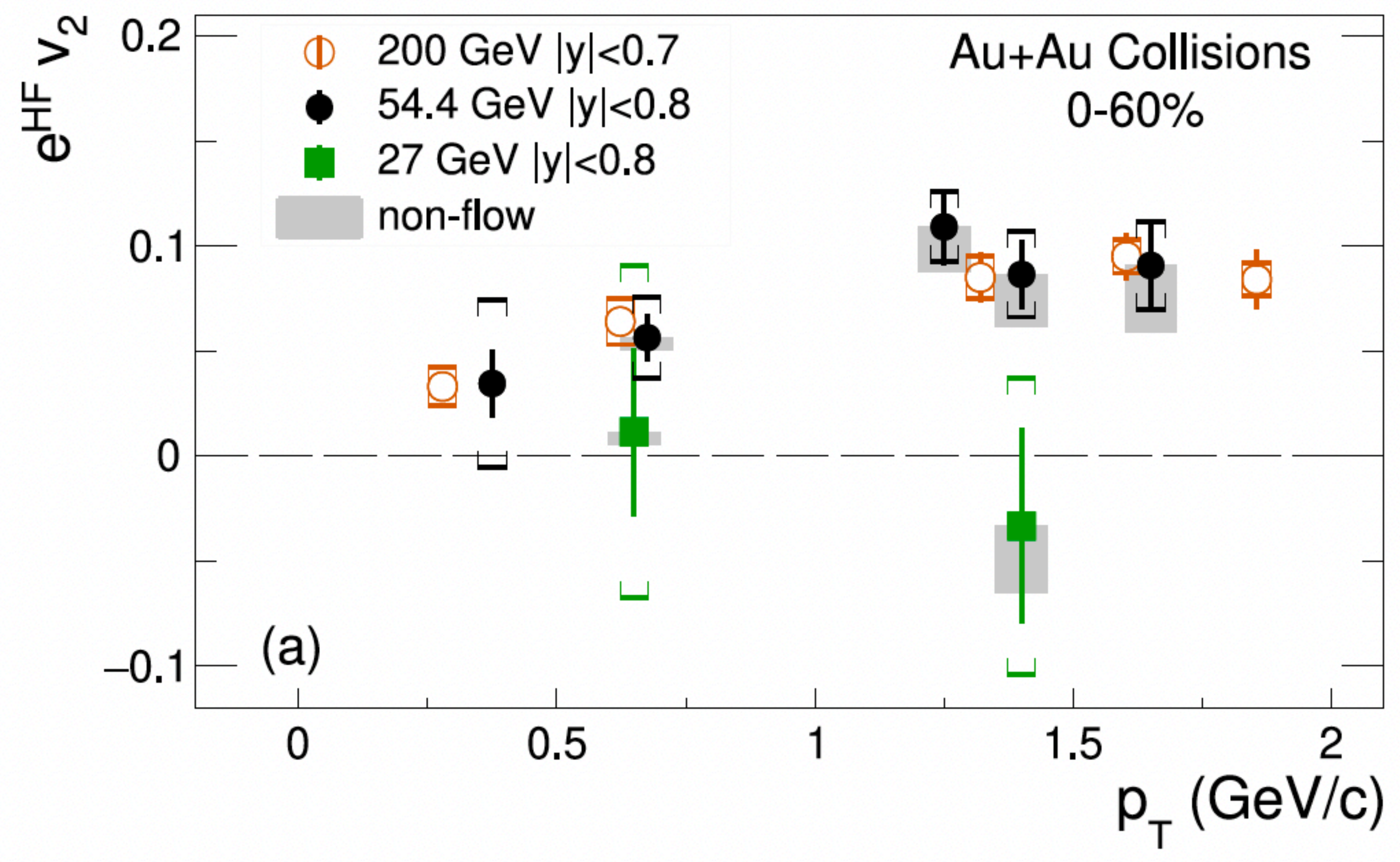
Daniel Richford

Ondrej Lomicky

Good agreement between PHENIX and STAR.

Similar v_2 at mid and forward rapidity in PHENIX.





STAR (27 & 54.4 GeV): Phys. Lett. B 844, 138071 (2023)
STAR (200 GeV): Phys. Rev. C 95, 034907 (2017)

Open HF hadrons

Ondrej Lomicky

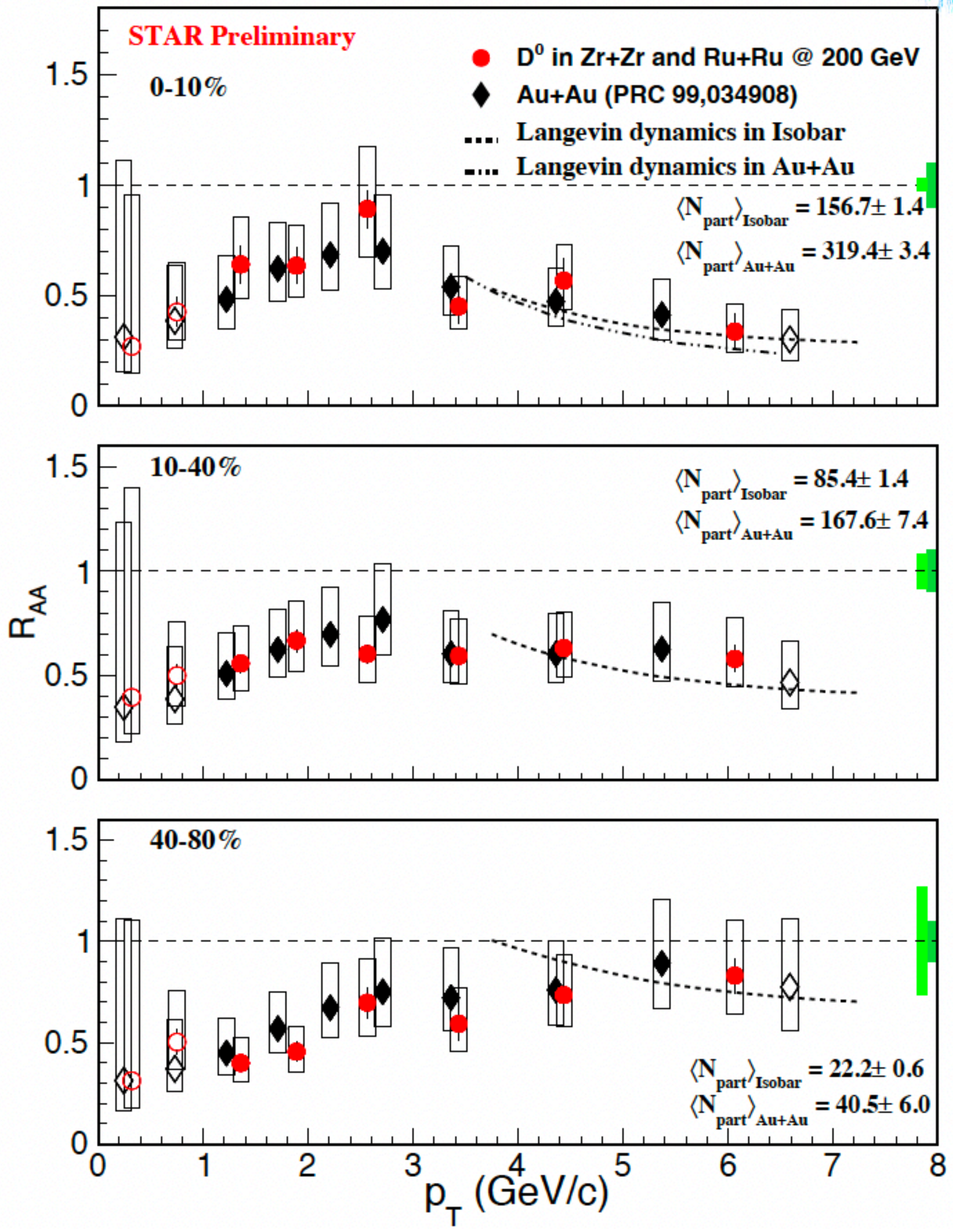
D^0 R_{AA} in isobar collisions @ 200 GeV

PRELIMINARY

Adding data from Zr+Zr and Ru+Ru collisions

- No obvious centrality dependence for the low p_T suppression
  - ⇒ Interplay of radial flow, the cold nuclear matter effects, and the charm hadrochemistry
- Suppression in central collisions at $p_T > 3$ GeV/c
  - ⇒ Significant energy loss of c quarks in the bulk QCD medium
  - ⇒ Centrality dependence of the high p_T suppression
- Good description by a Langevin model from 3 GeV/c
- Similar suppression in isobar and Au+Au collisions despite different $\langle N_{part} \rangle$ at a given energy

STAR: Phys. Rev. C 99, 034908 (2019)

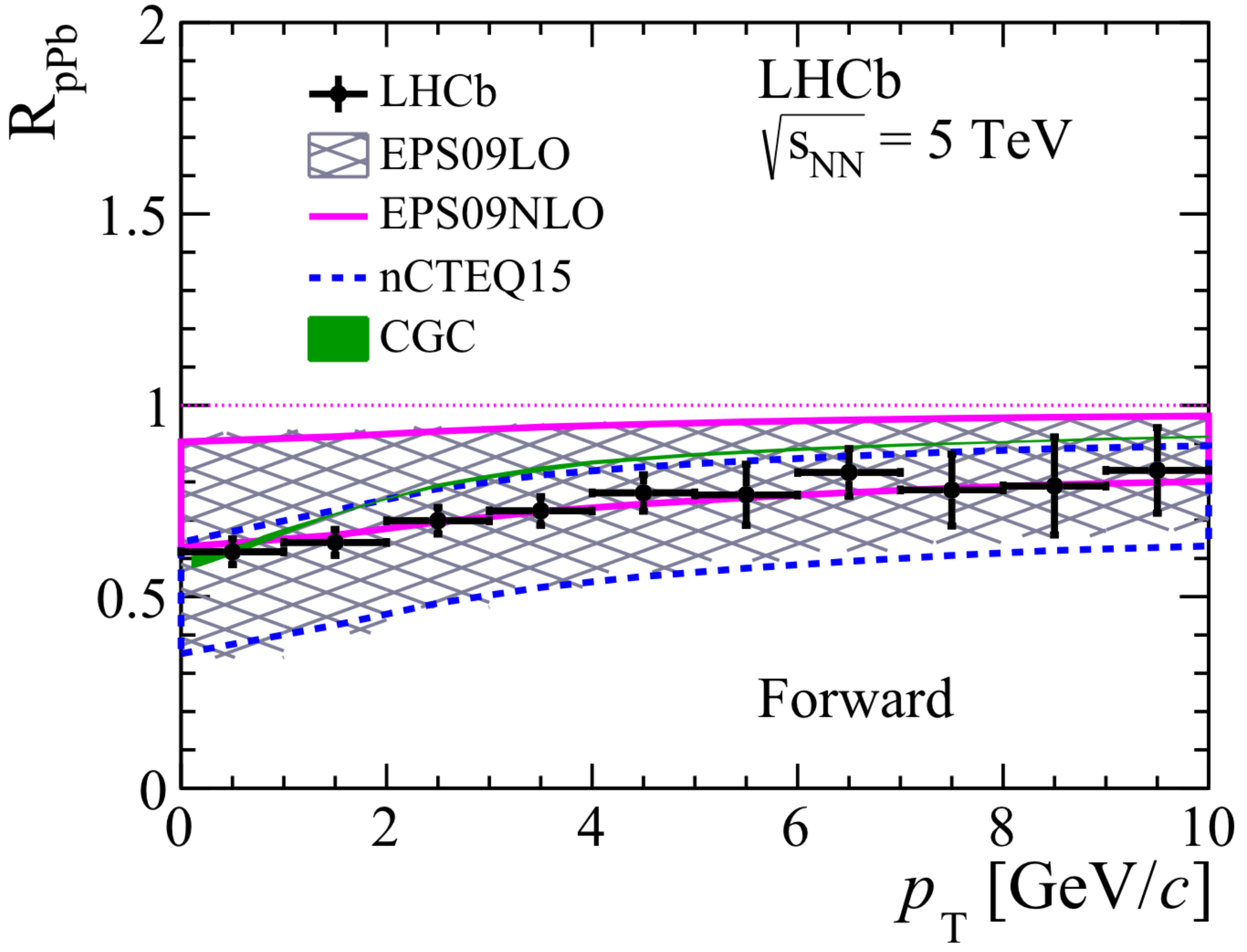


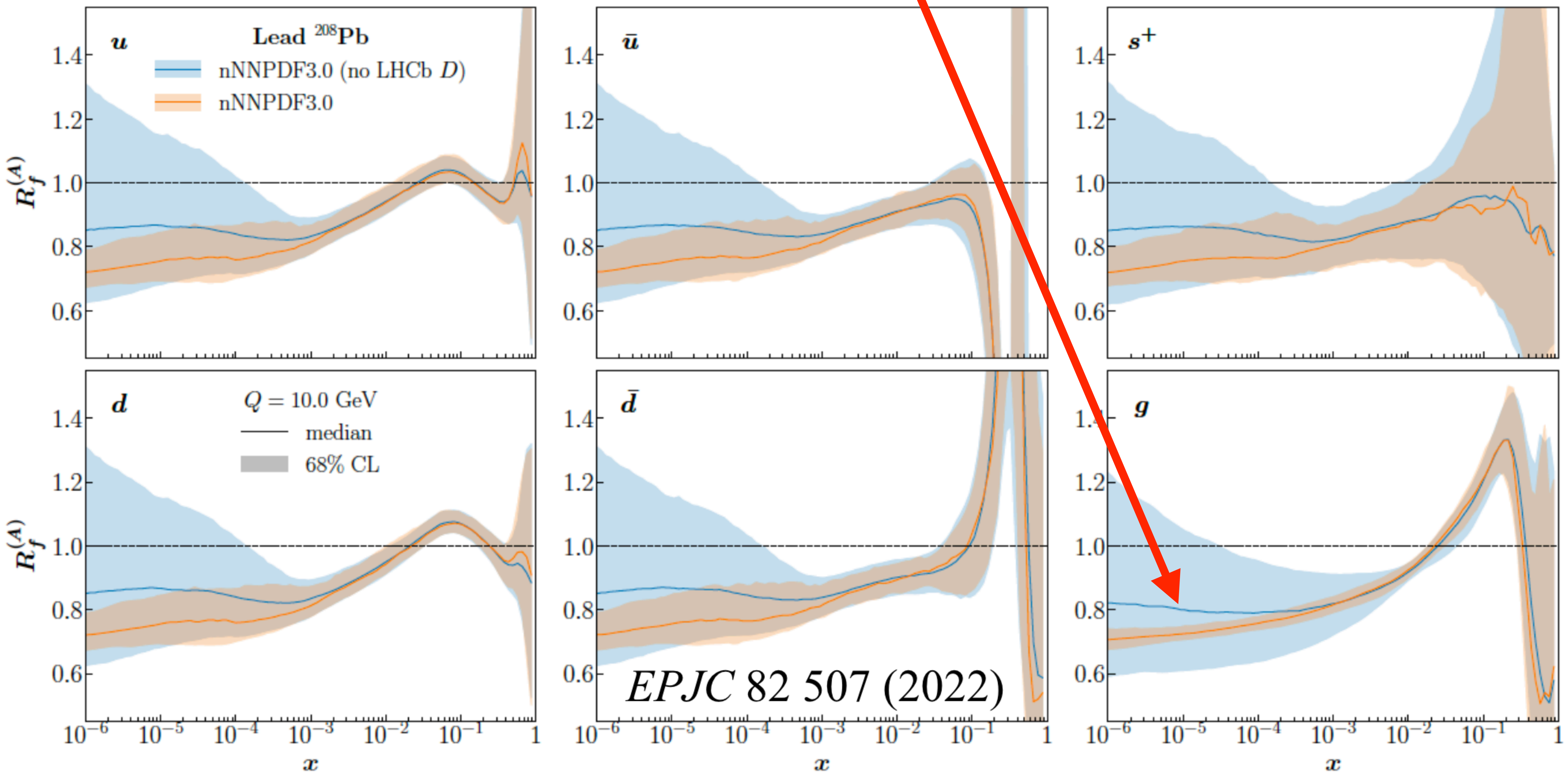
Constraining nPDFs

LHCb D^0 data places **very** stringent bounds on the gluon nPDF.

- Important step in constraining models of HF modification in nuclear targets!

Preeti Dhankhar

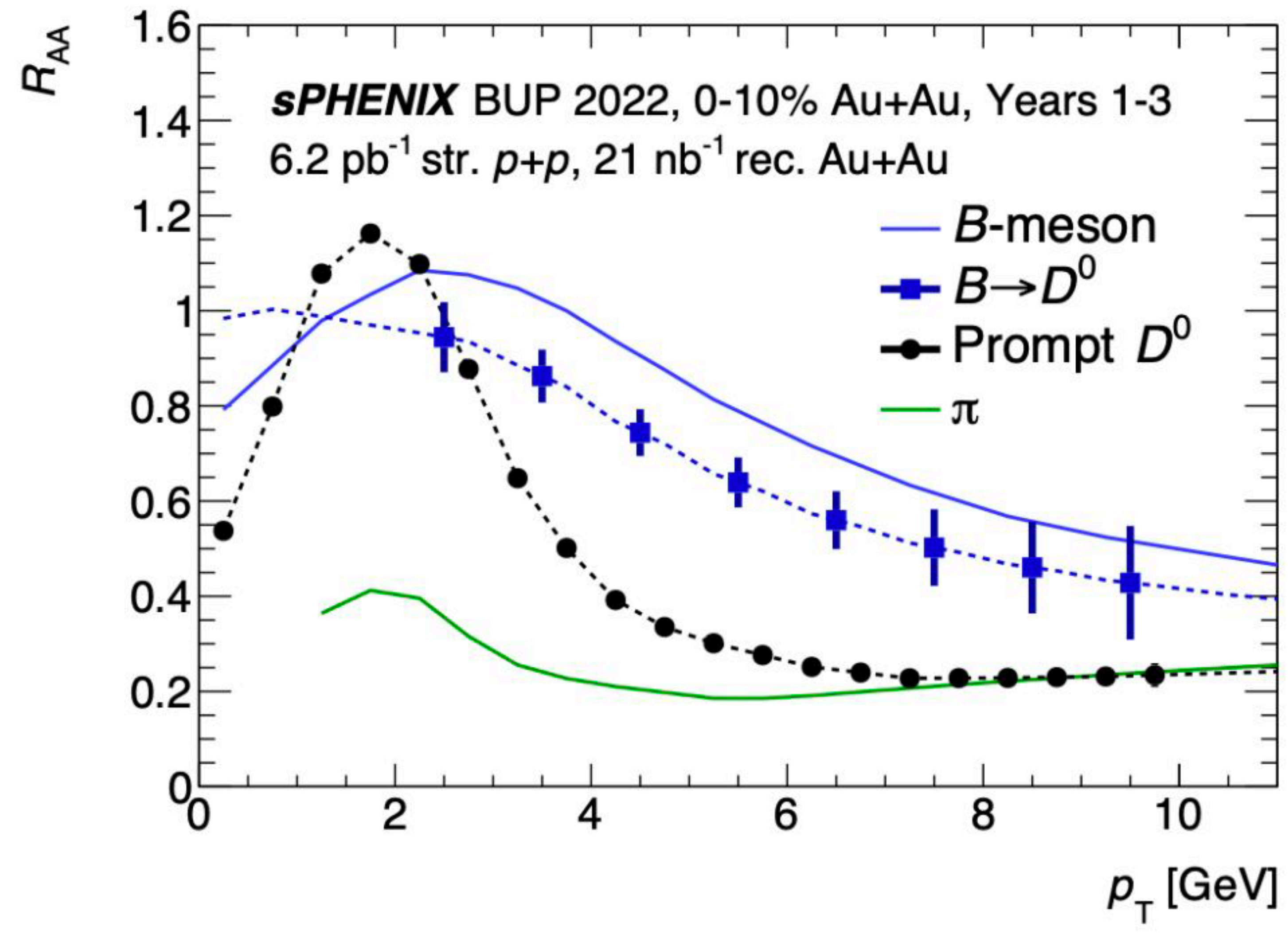


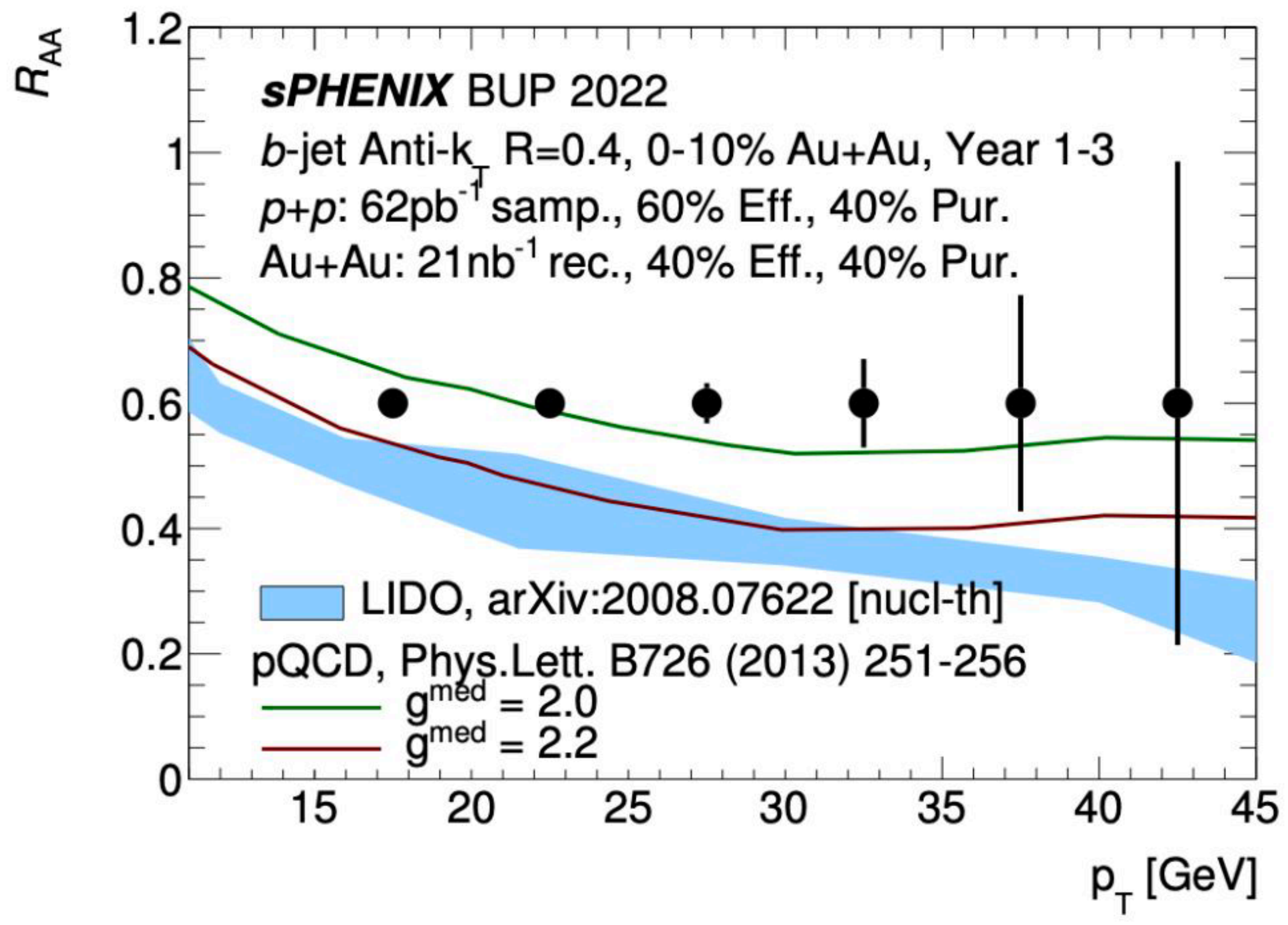


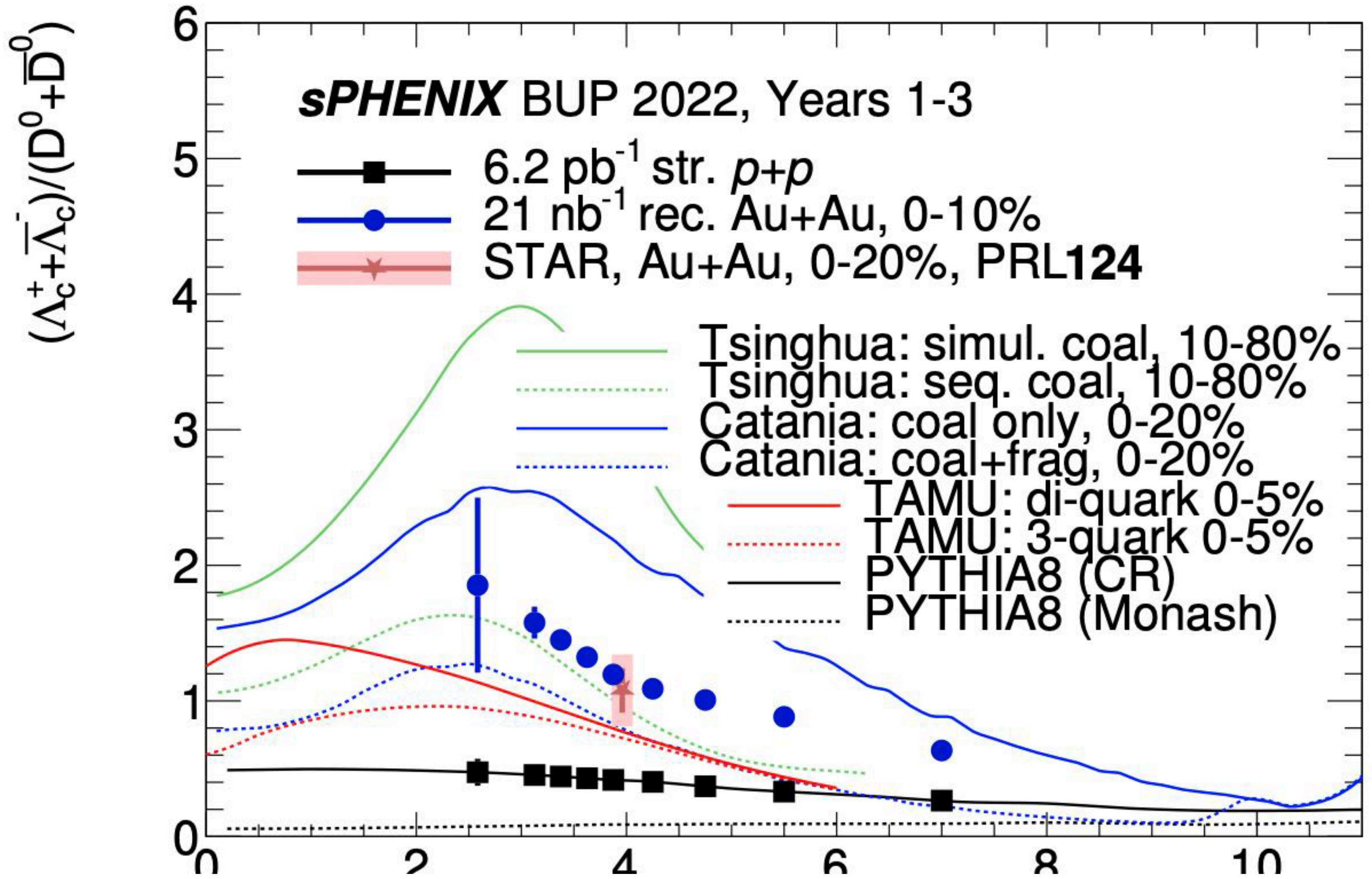
EPJC 82 507 (2022)

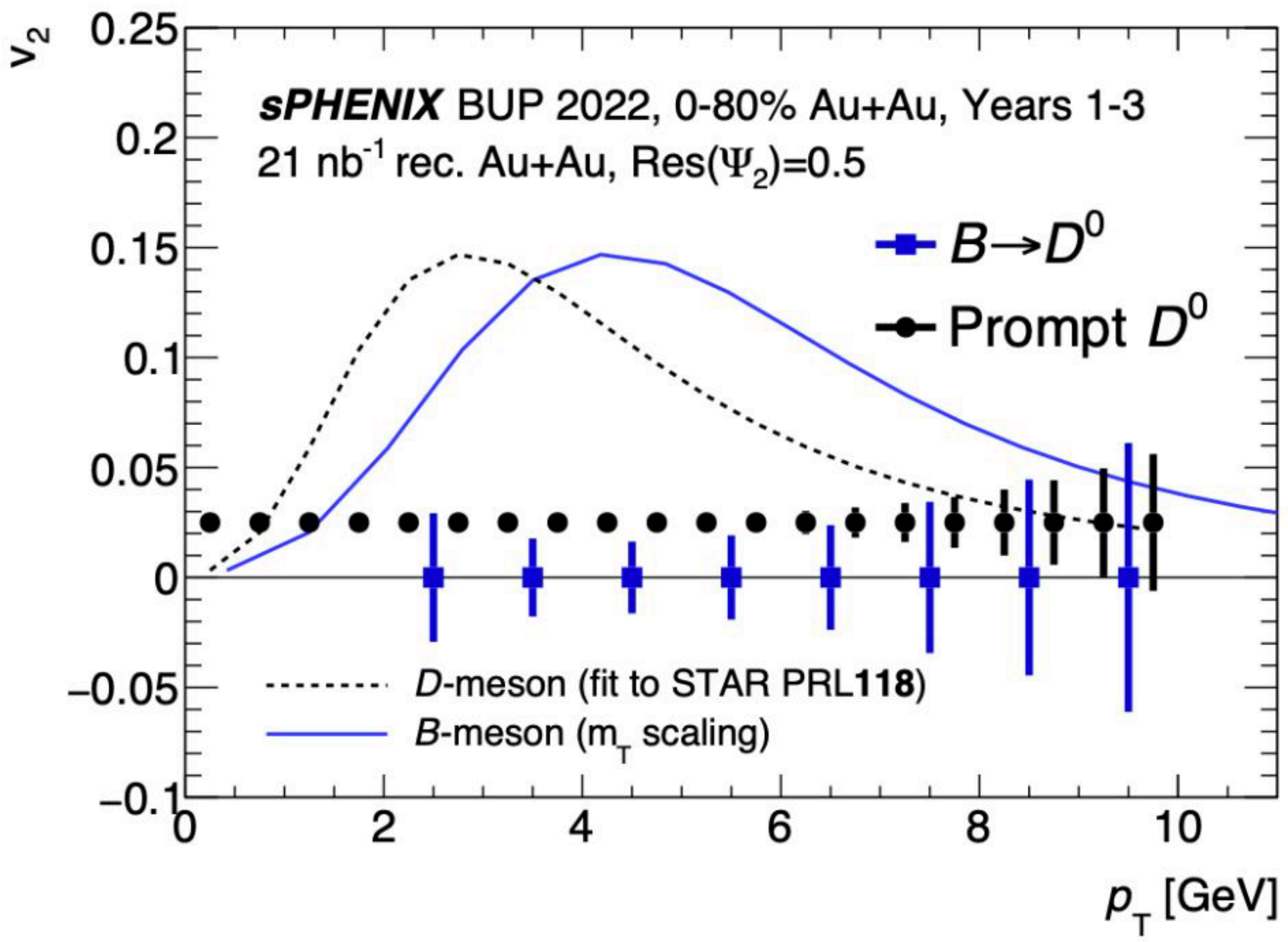
To come: open HF in sPHENIX

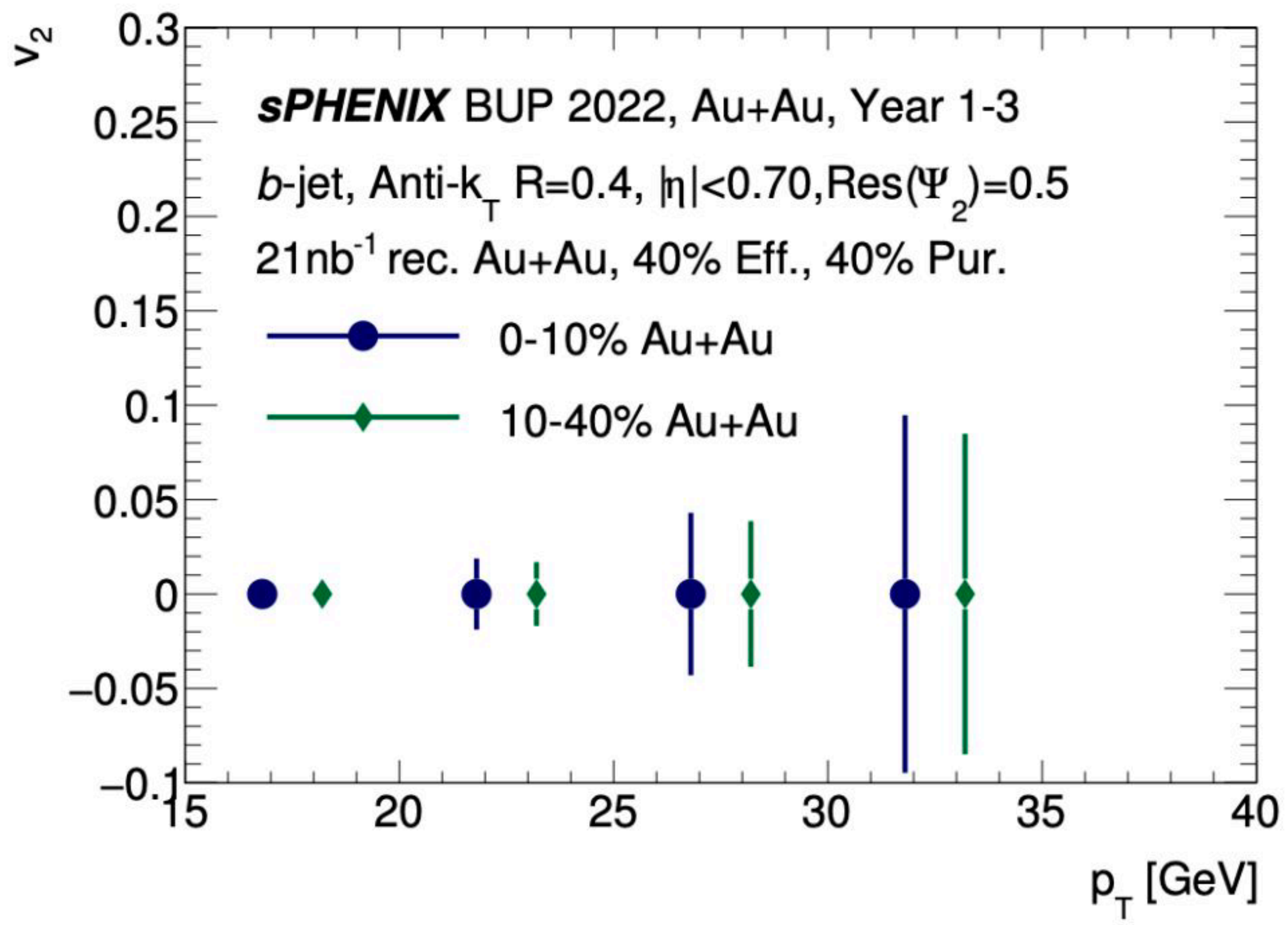
Thomas Marshall

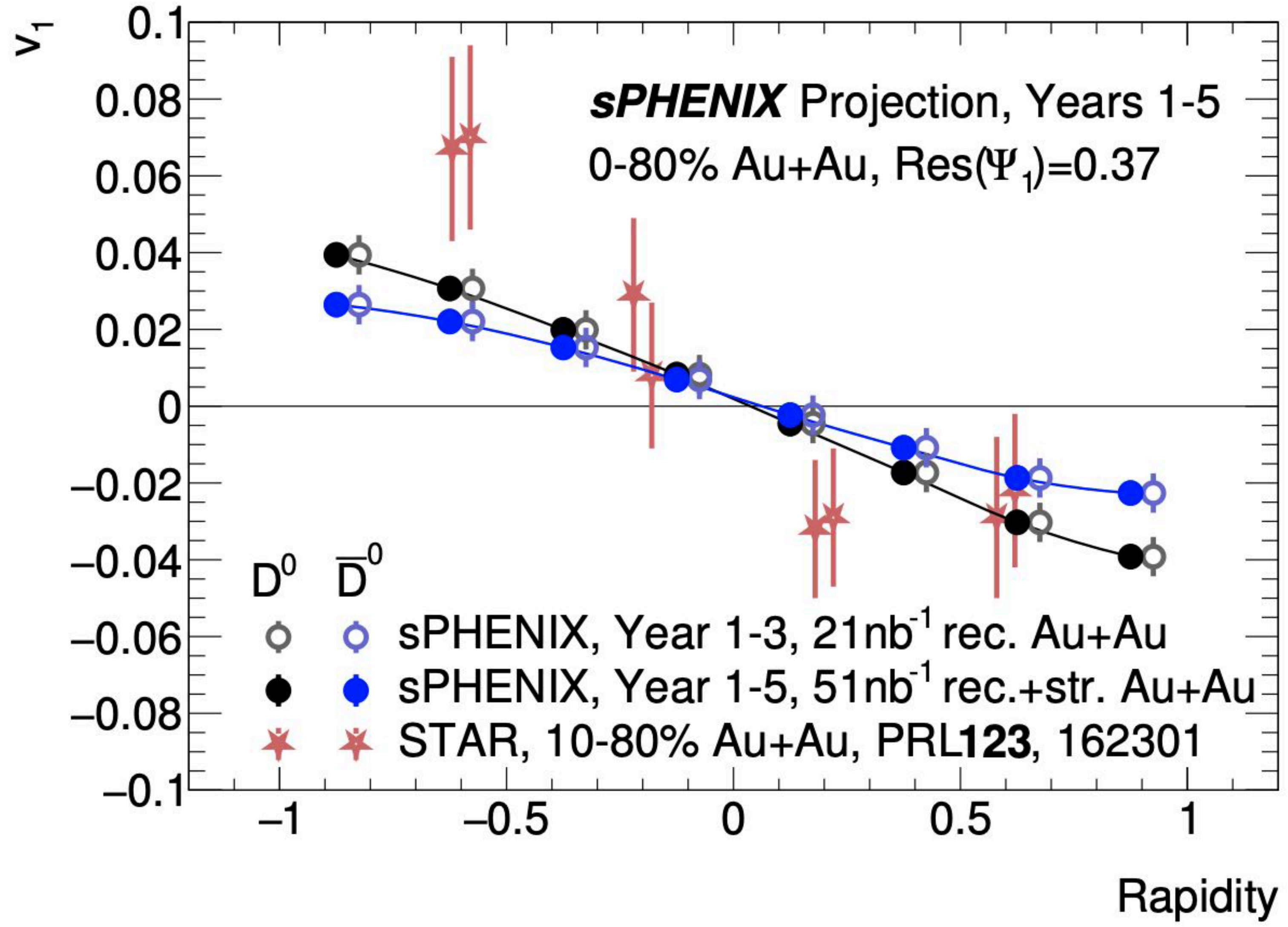








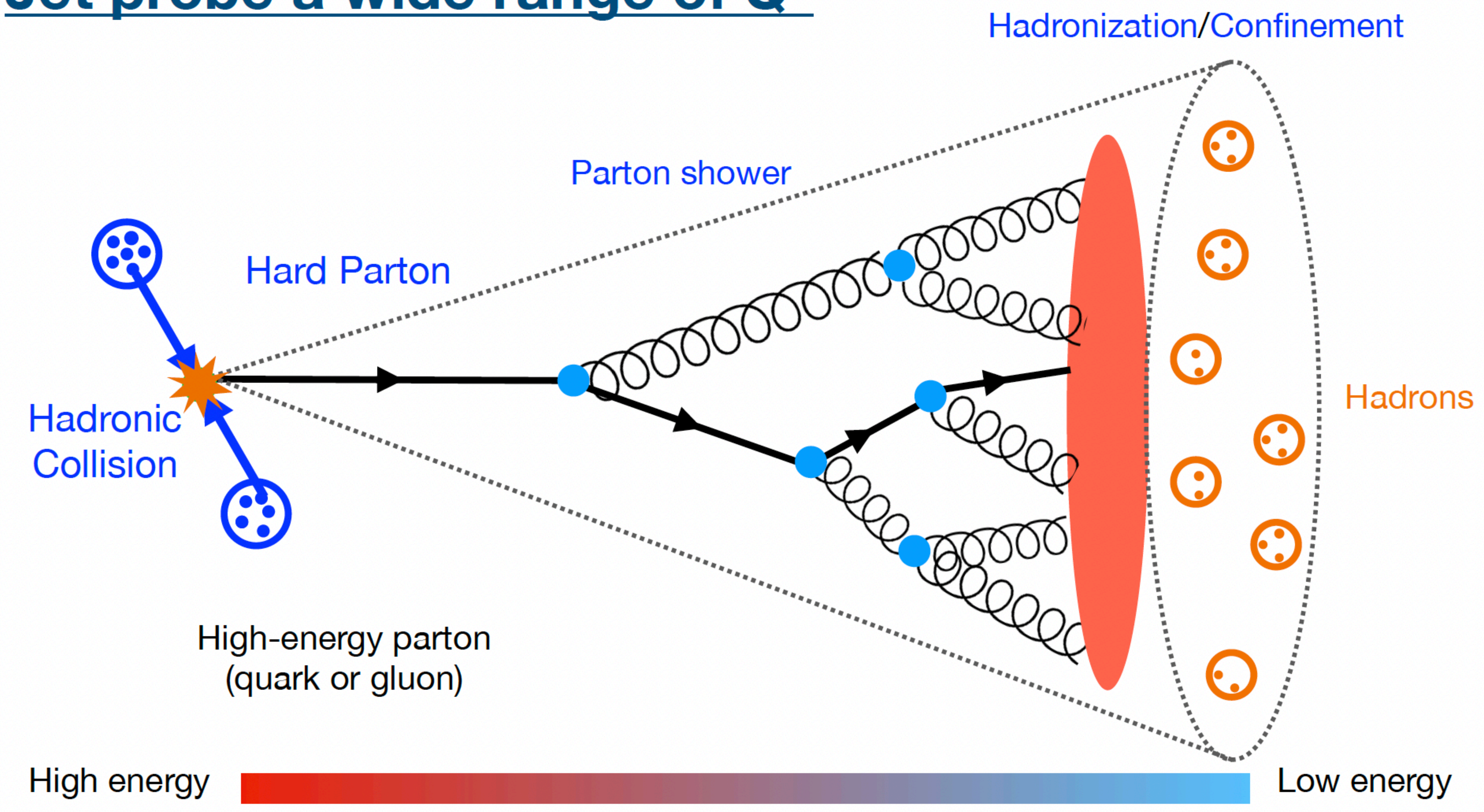




Jets

Preeti Dhankher

Jet probe a wide range of Q^2



D0 jet fragmentation - STAR

Ondrej Lomicky

D^0-jet fragmentation function in Au+Au @ 200 GeV

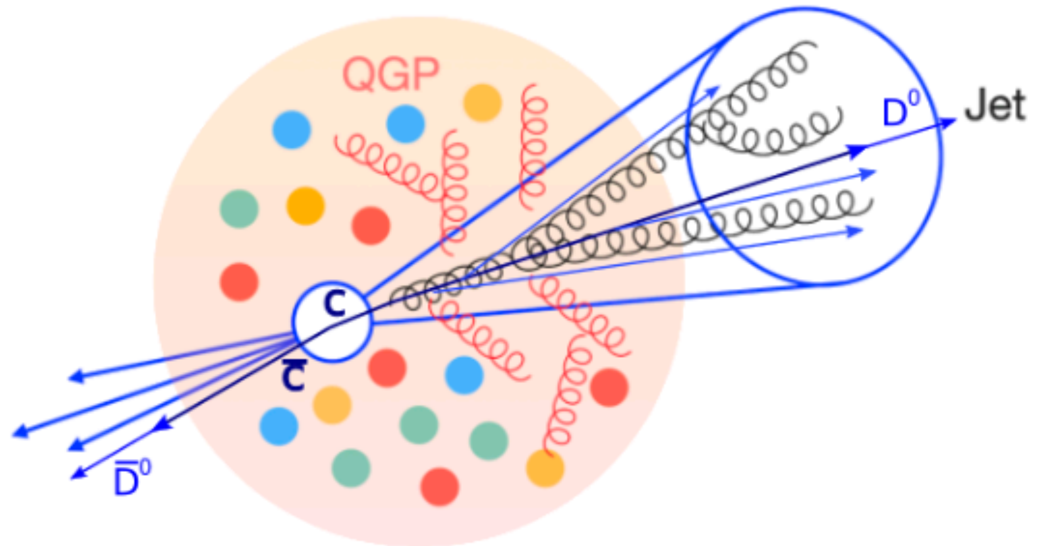
PRELIMINARY

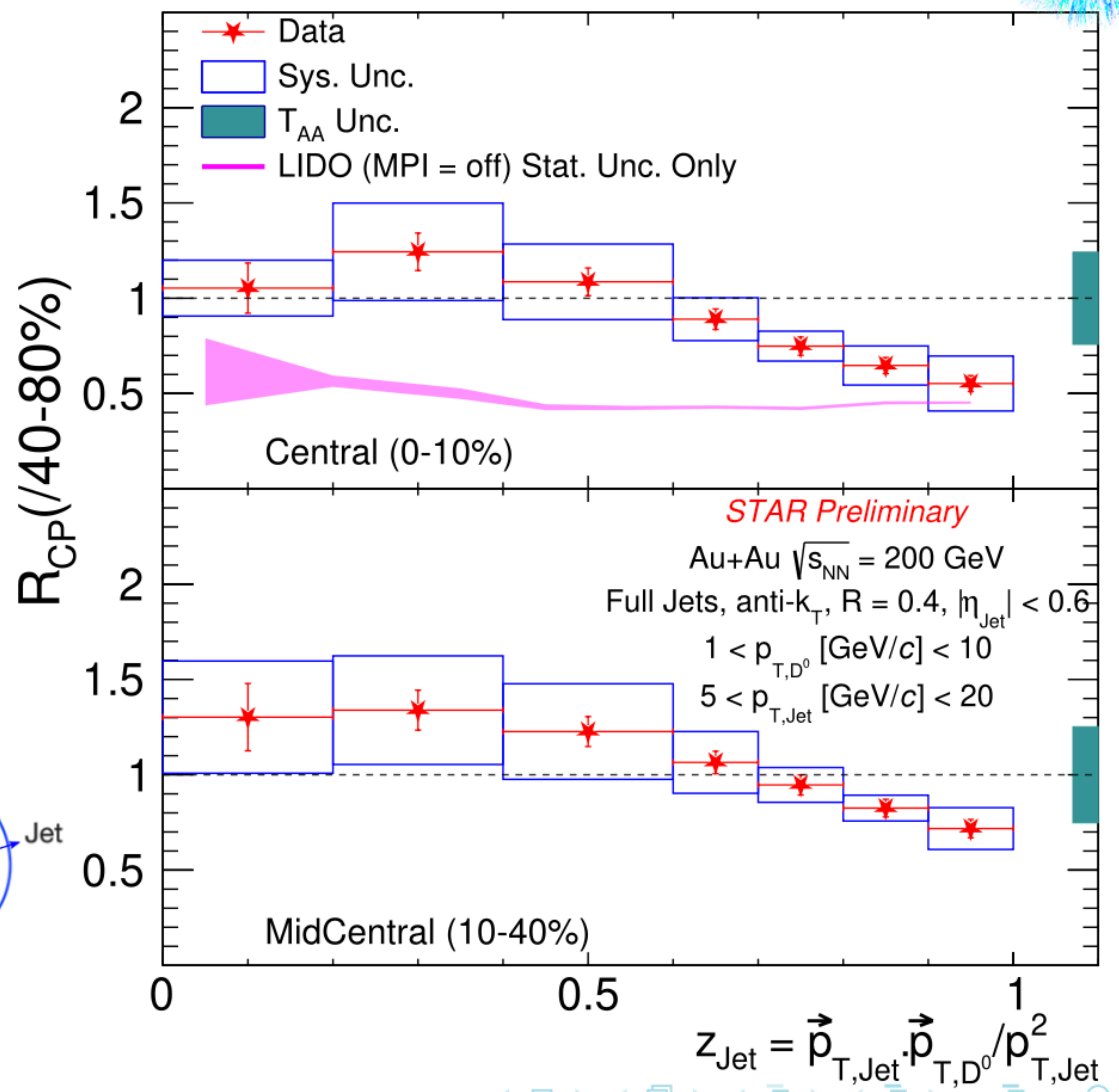
STAR

$$z_{\mathrm{Jet}} = \frac{\vec{p}_{\mathrm{T,Jet}} \cdot \vec{p}_{\mathrm{T},D^0}}{|\vec{p}_{\mathrm{T,Jet}}|^2}$$

- z_{Jet} related to fragmentation function in DGLAP equation
- Hard fragmented D^0-jet yield suppressed in central/midcentral events
- Soft fragmented D^0-jet yield ratio consistent with 1 in central/midcentral events
- LIDO agrees well with yield in peripheral events, slightly underpredicts yield in central events

LIDO, Phys. Rev. C 98, 064901



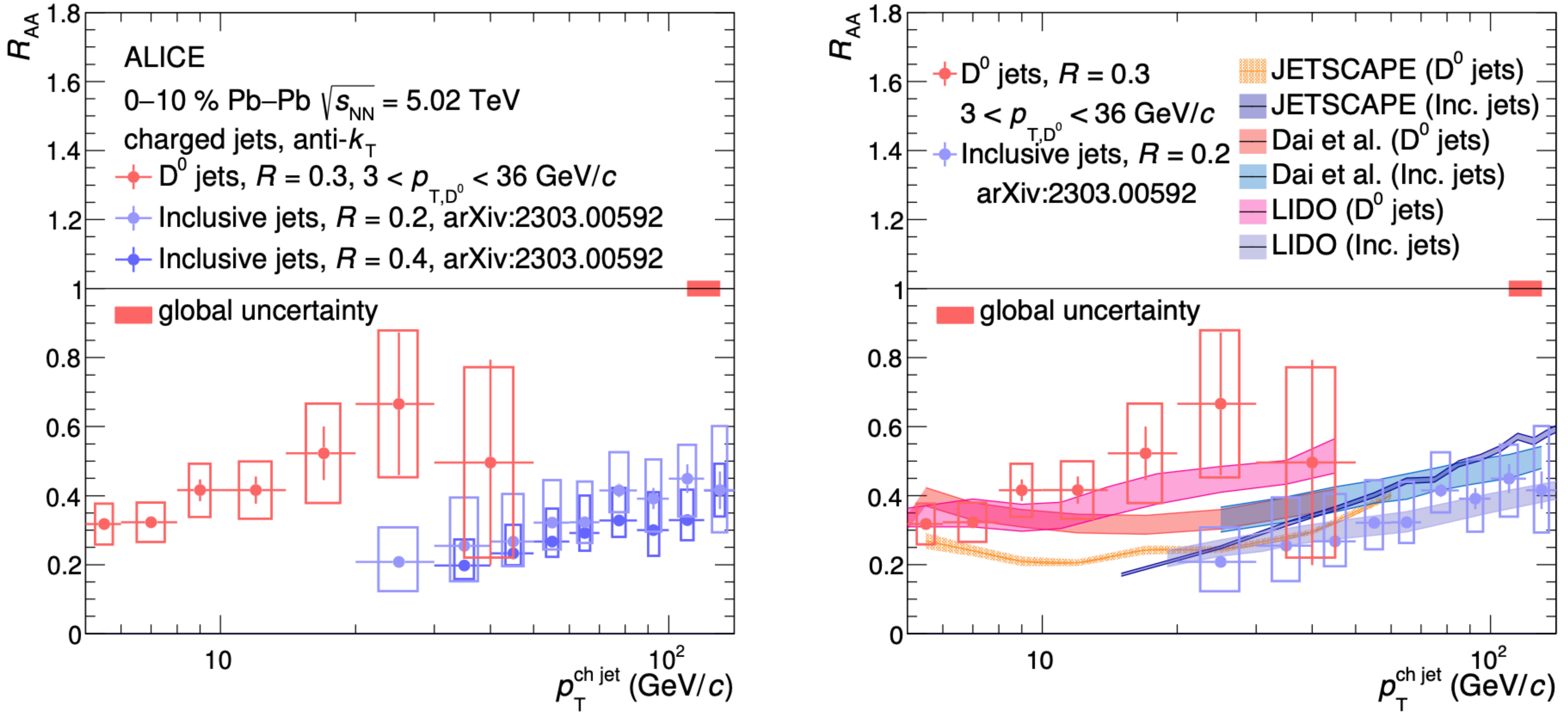


D^0 jets - ALICE

Preeti Dhankher

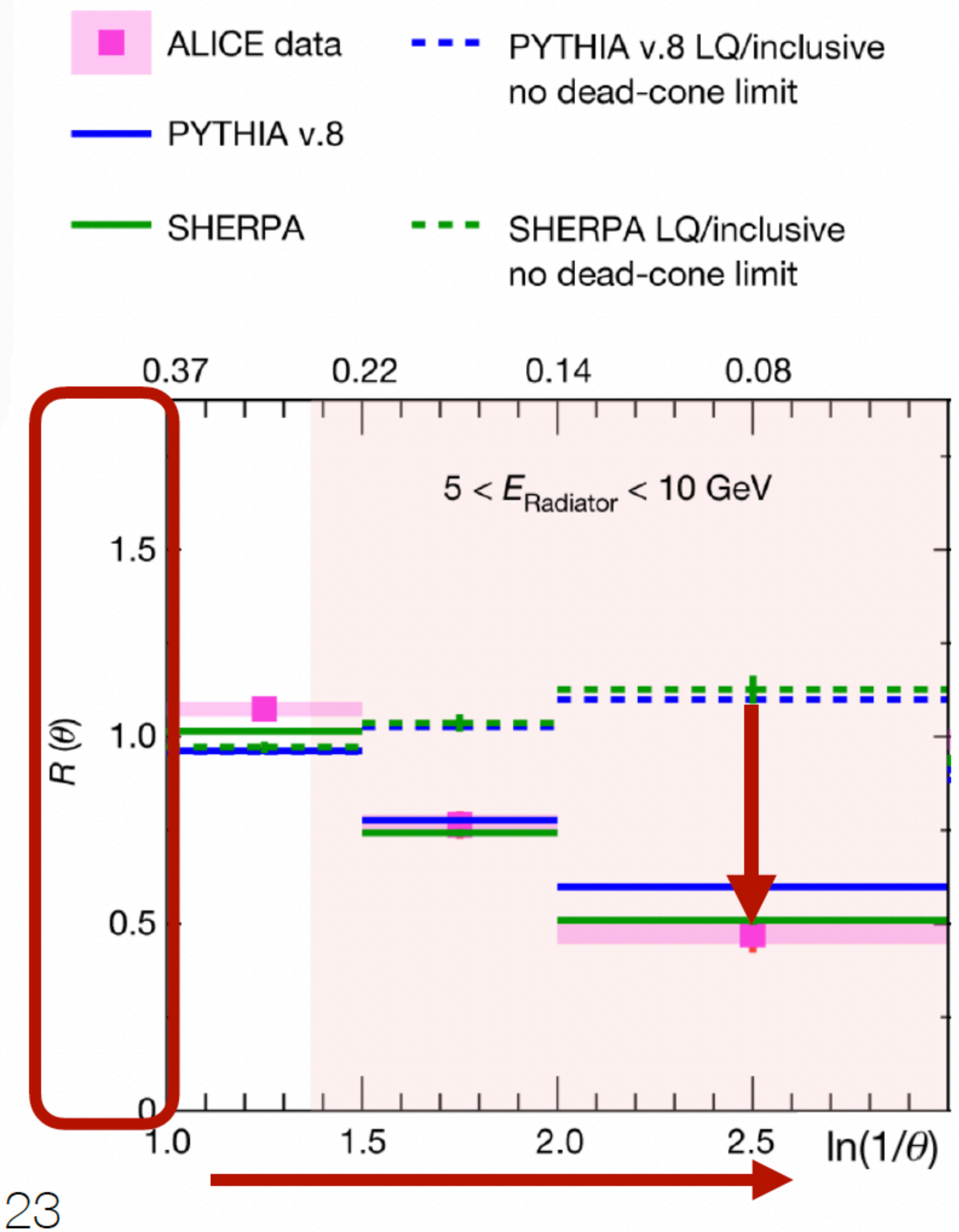
D^0 tagged jets compared with inclusive jets.

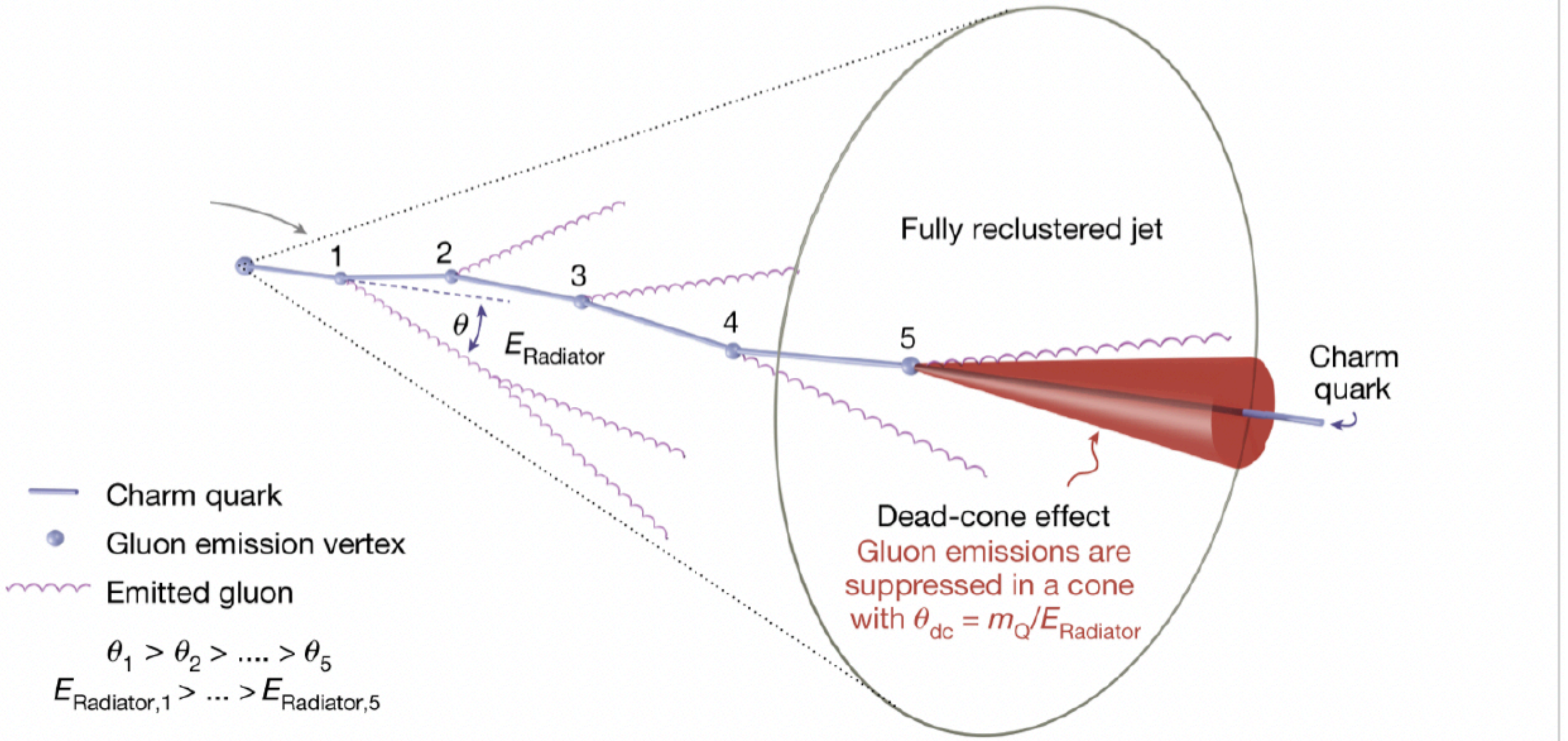
- Shows clearly the flavor dependence of jet energy loss.



Preeti Dhankher

First direct observation of dead-cone effect





ratio of the splitting angle (θ) distribution for D^0-tagged vs. inclusive jets, vs. $E_{\rm Radiator}$

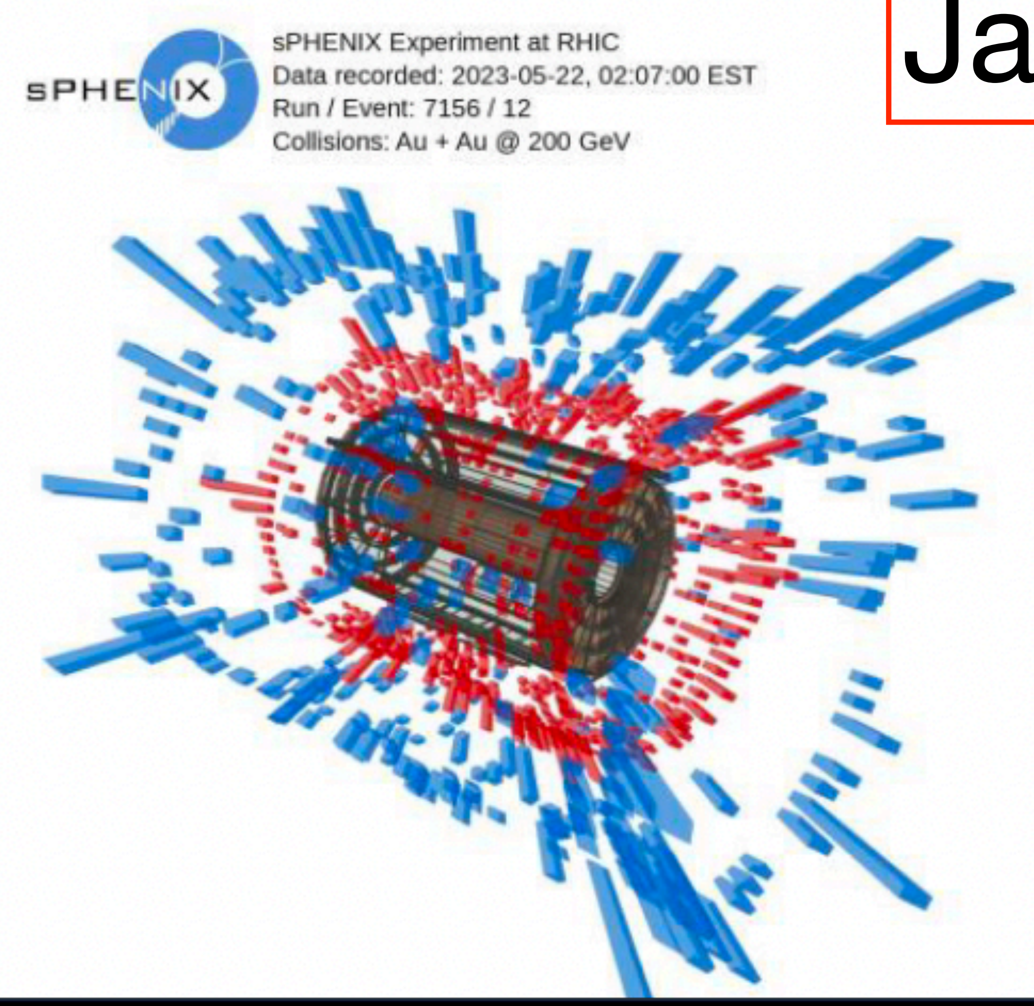
$$R(\theta) = \frac{1}{N^{\rm D^0 jets}} \frac{{\rm d}n^{\rm D^0 jets}}{{\rm d}\ln(1/\theta)} \Big/ \frac{1}{N^{\rm inclusive\ jets}} \frac{{\rm d}n^{\rm inclusive\ jets}}{{\rm d}\ln(1/\theta)} \Big|_{k_{\rm T}, E_{\rm Radiator}}$$

significant suppression of small-angle emissions

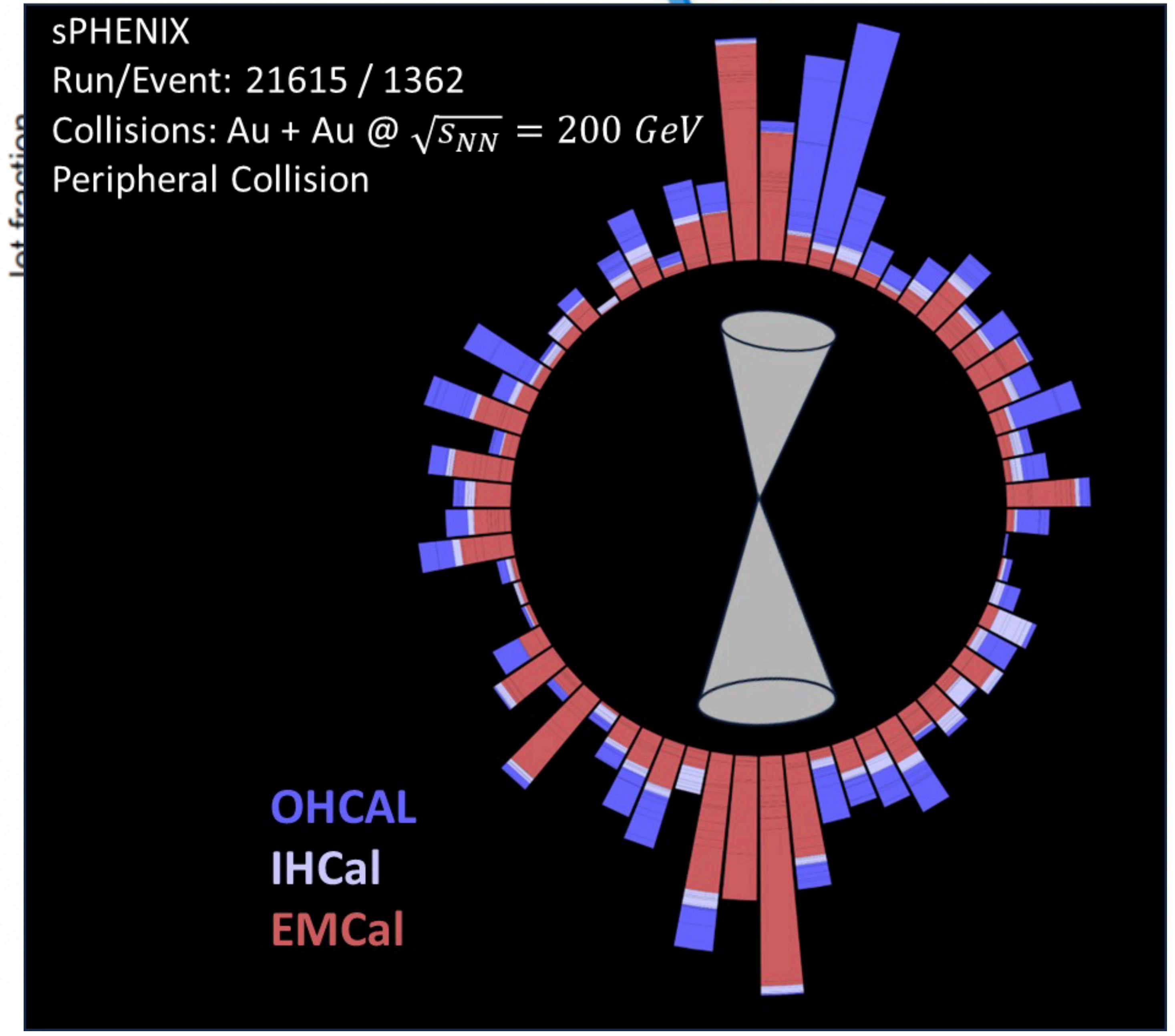
To come: HF tagged jets in sPHENIX

Particle flow

Jakub Kvapil



- Almost half of the jet energy is carried by the neutral particles
  - The importance to study full jets
  - sPHENIX has the first mid-rapidity HCAL at RHIC!
- Initial implementation of particle flow at sPHENIX to connect charged tracks and calorimeter information



Marzia Rosati

Los Alamos NATIONAL LABORATORY

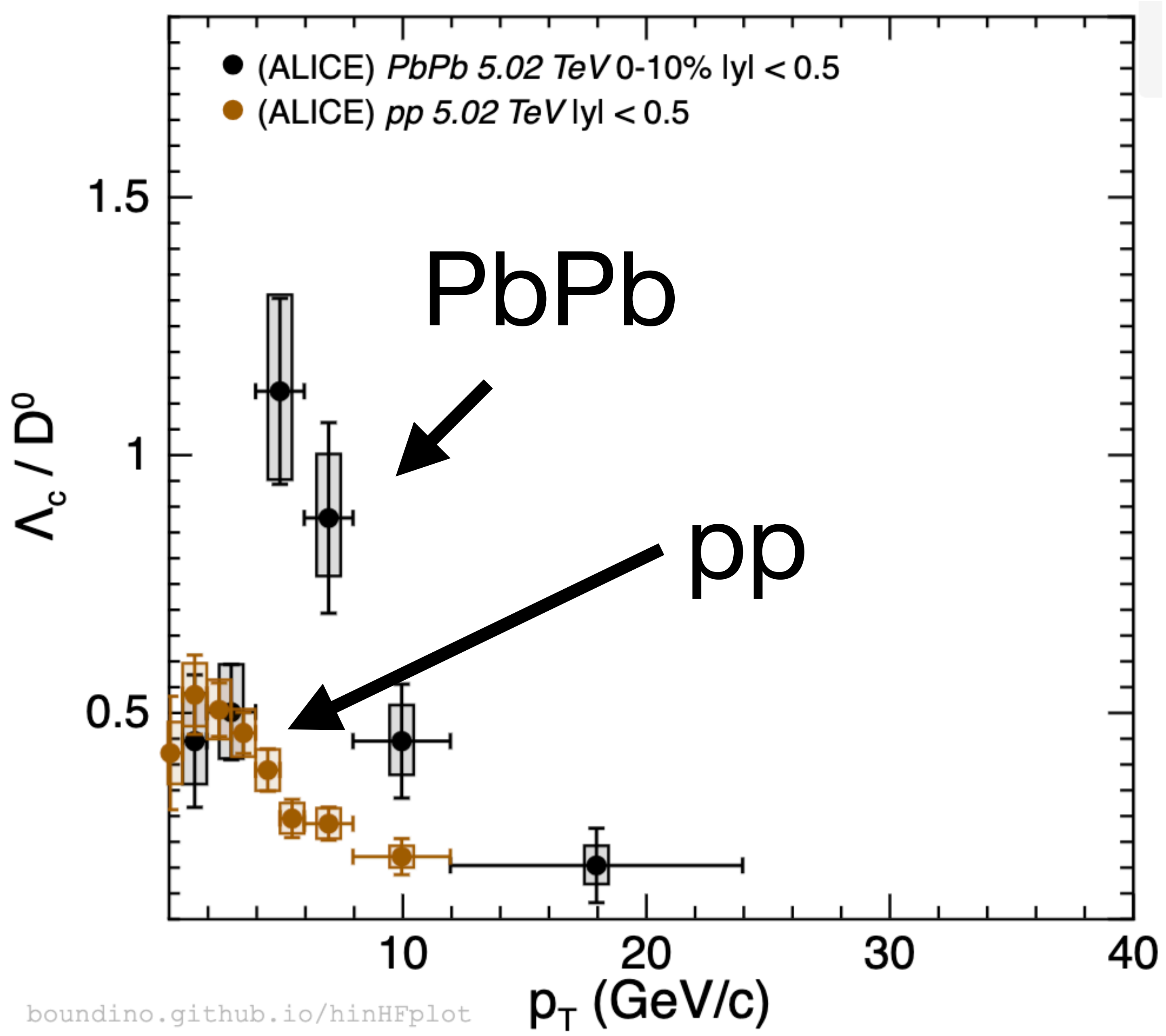
Hadronization of charm and bottom hadrons

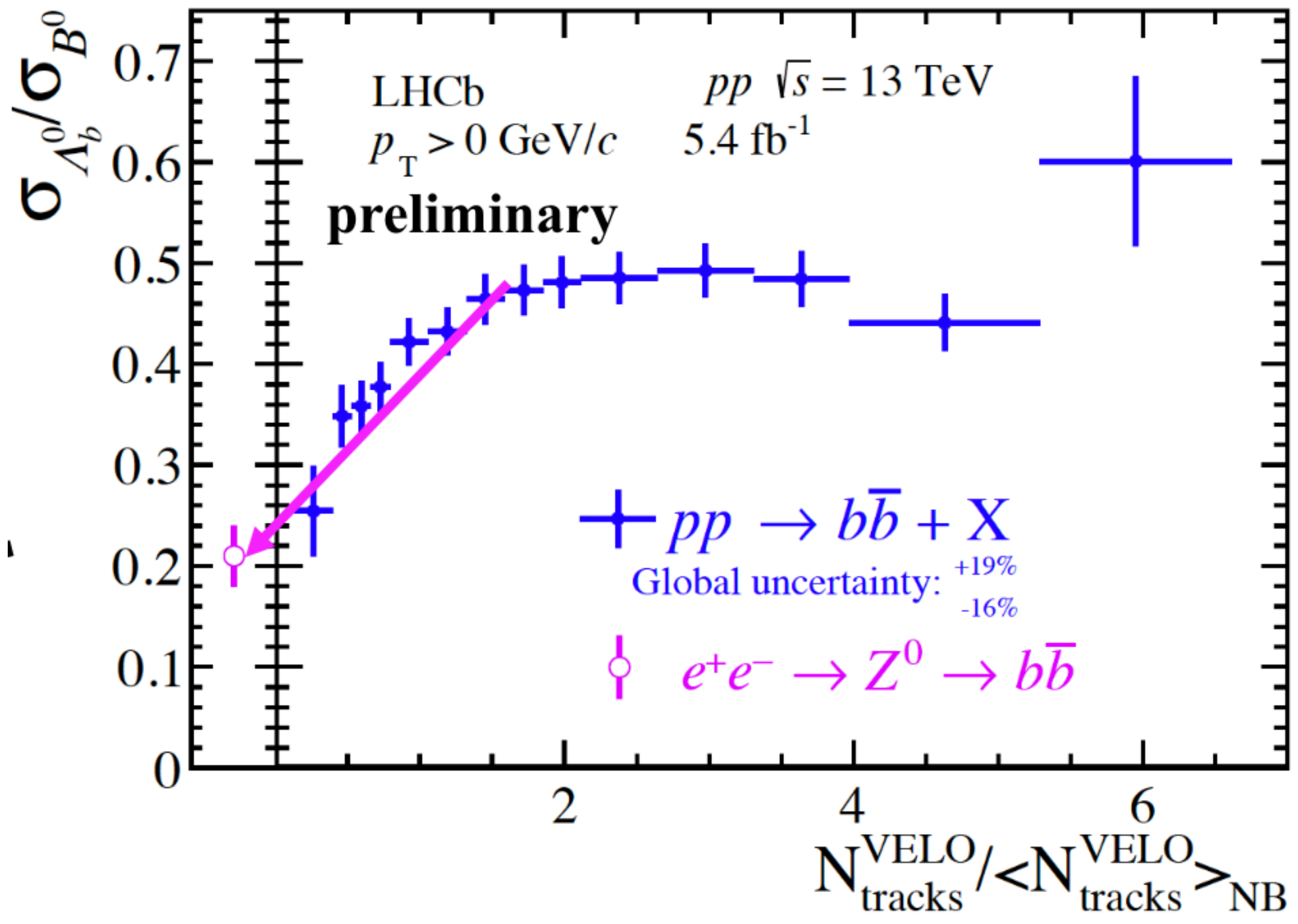
HF baryon/meson ratio enhancement

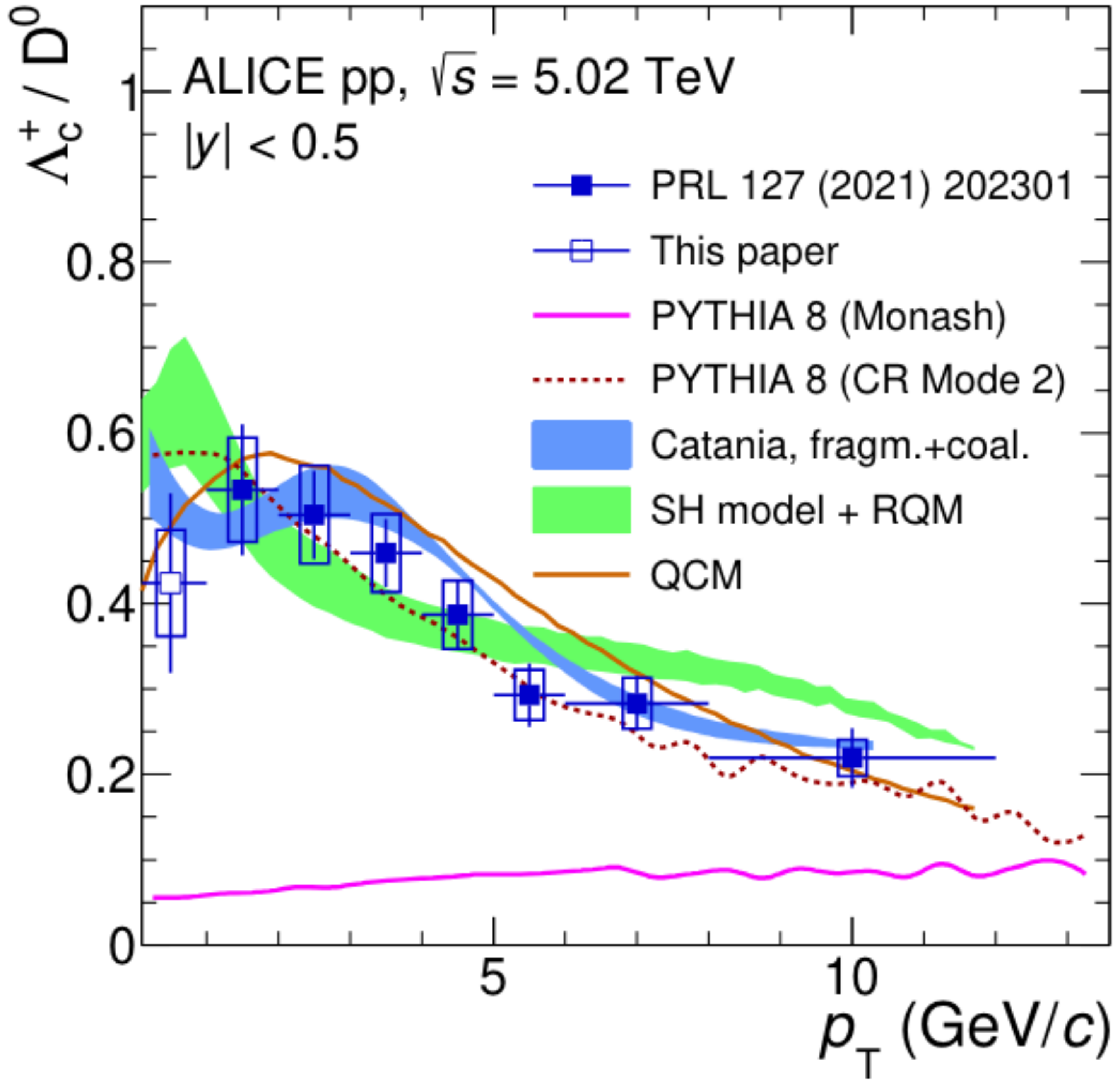
Preeti Dhankher

- The Λ_c/D^0 ratio is enhanced at low p_T even in pp collisions.
- The Λ_b/B^0 ratio is multiplicity dependent in pp collisions.

Described by color reconnection, quark-coalescence and statistical hadronization models.





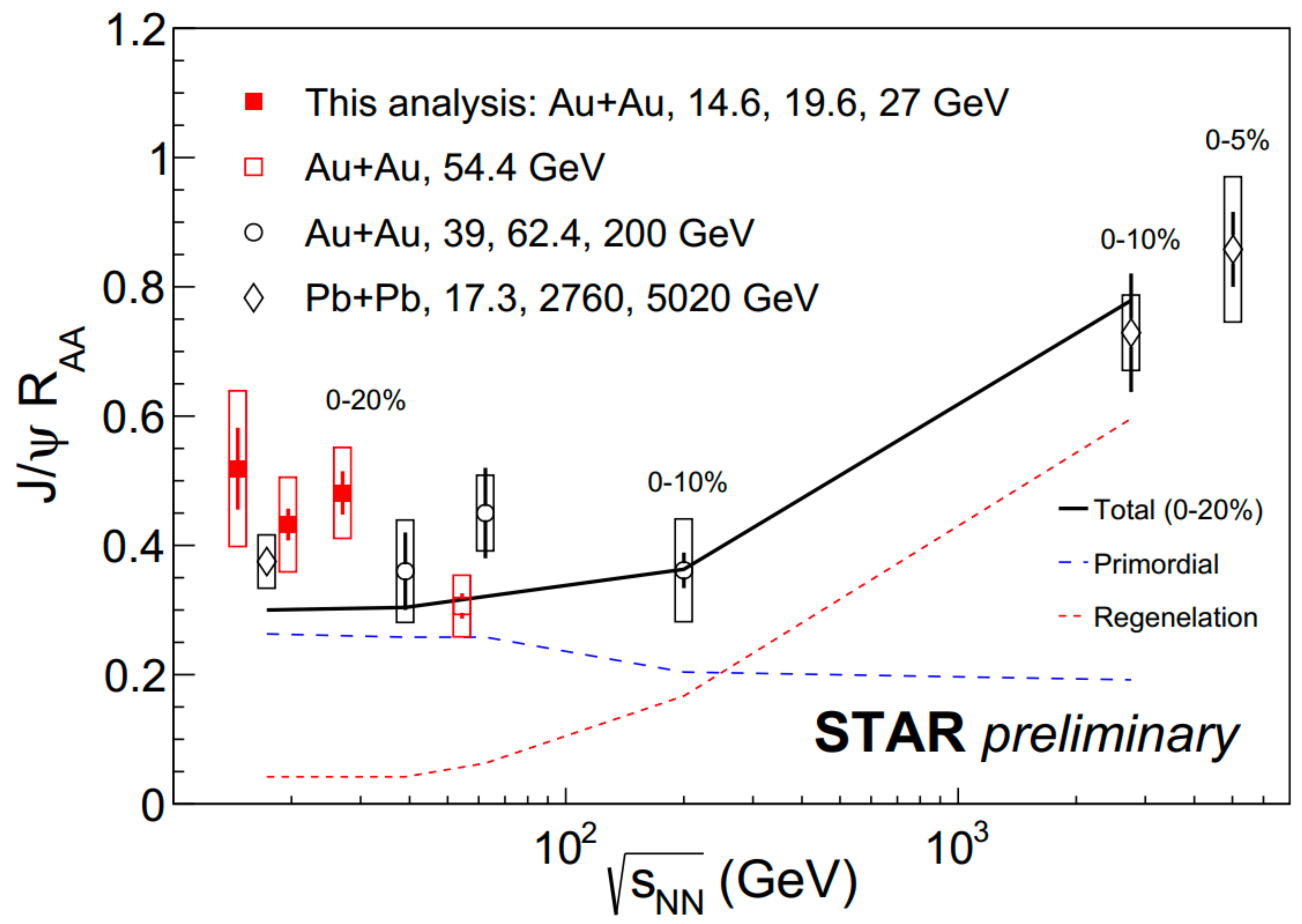


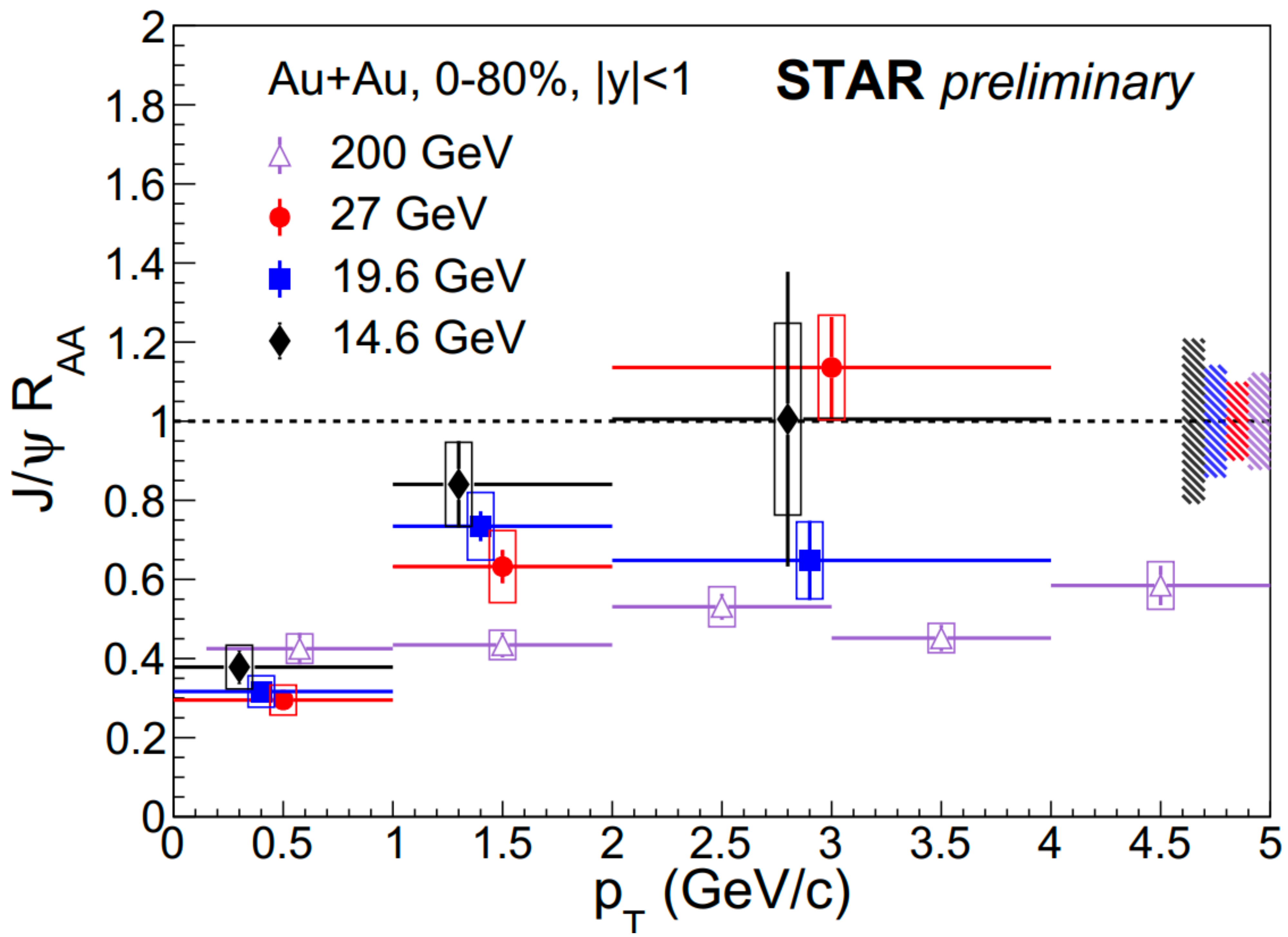
Energy dependence of J/ψ modification

The energy dependence is a mix of strongly energy dependent effects:

- Gluon nPDFs
- Nuclear absorption (collisions with nucleons)
- Hot matter effects
- charm coalescence at hadronization (huge charm production at LHC)

Wei Zhang

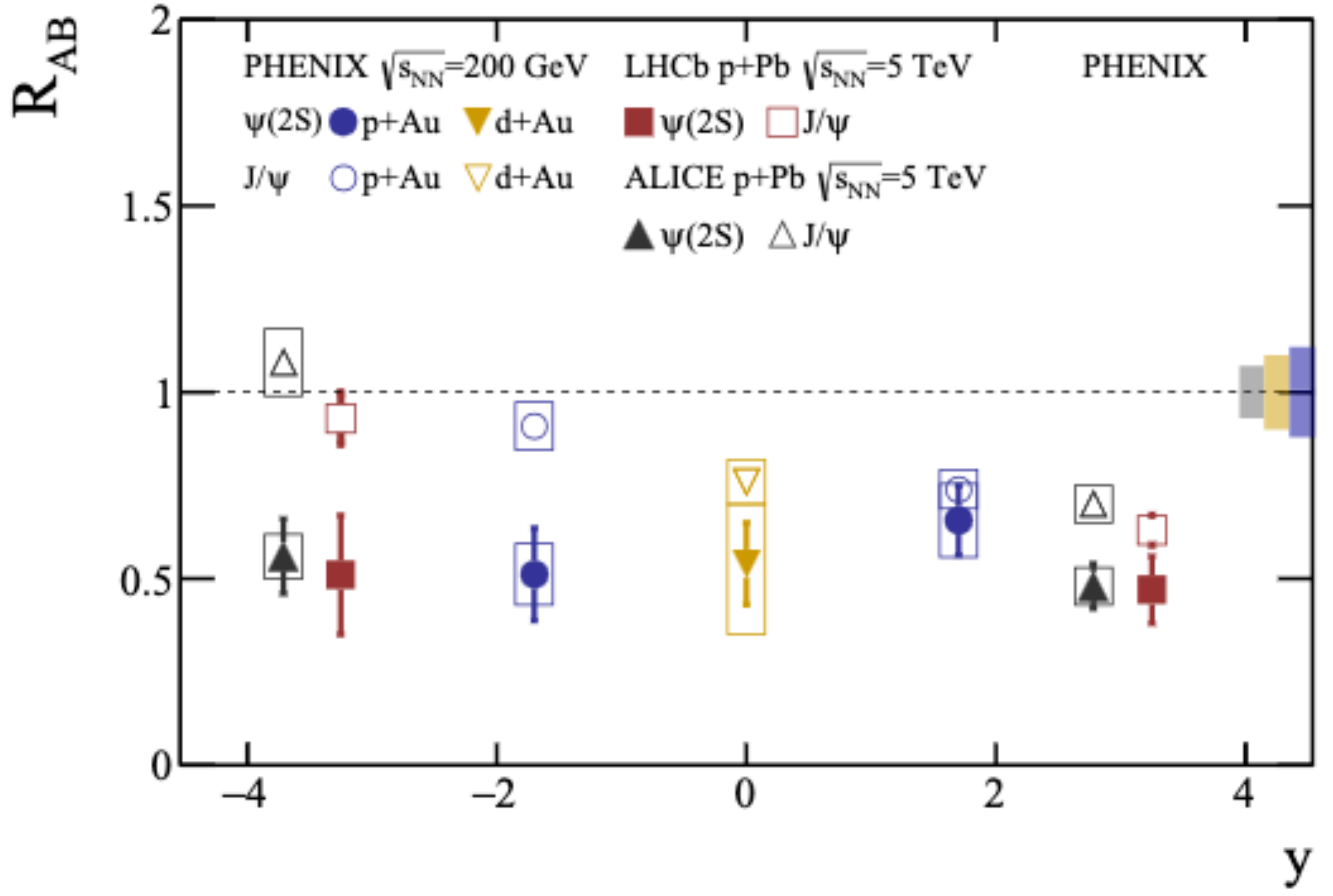




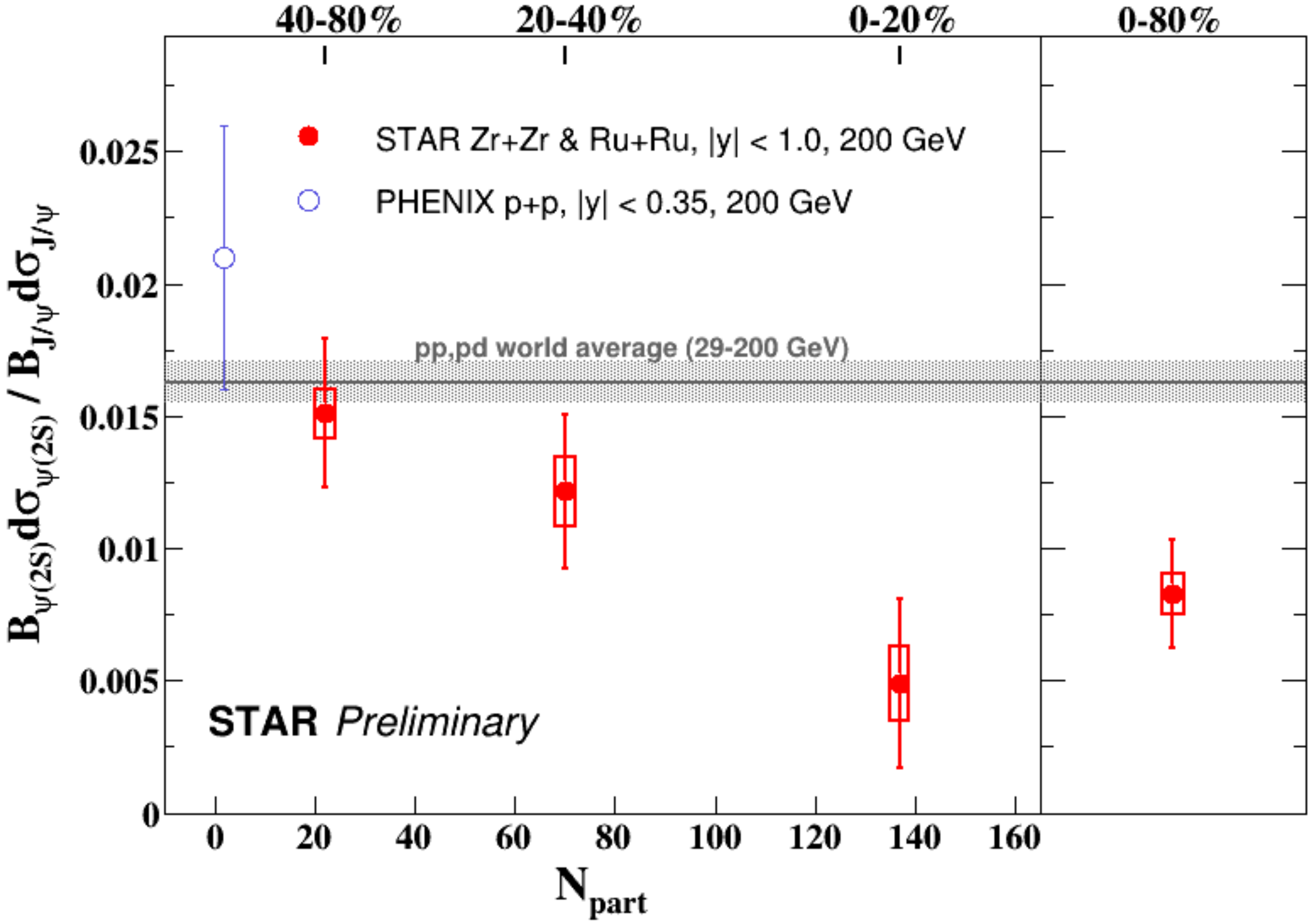
ψ(2S) / J/ψ ratio in small(er) systems

New measurements by STAR in **intermediate mass systems** show strong differential suppression of the ψ(2S) relative to the J/ψ.

Ming Liu



Wei Zhang

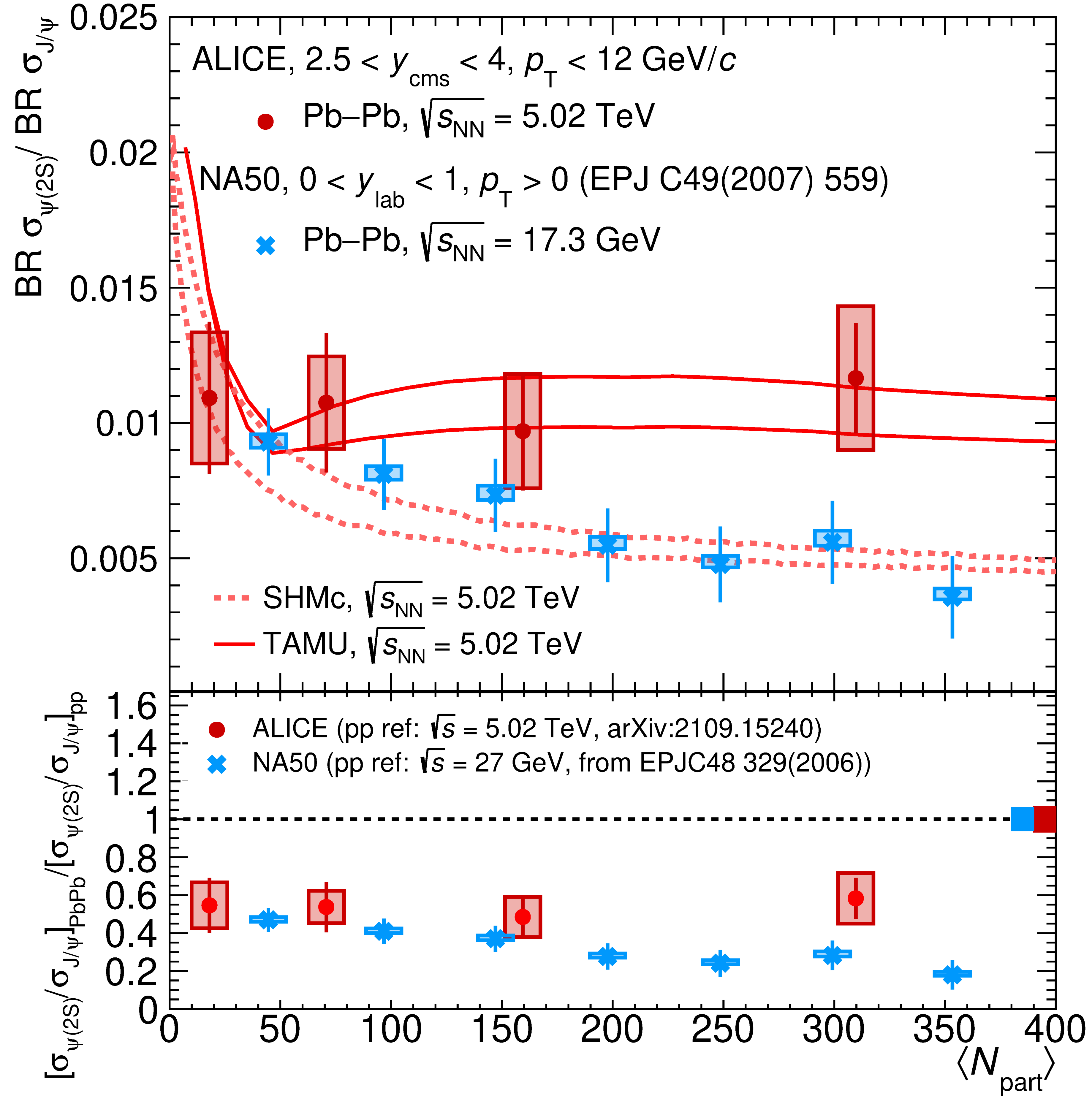


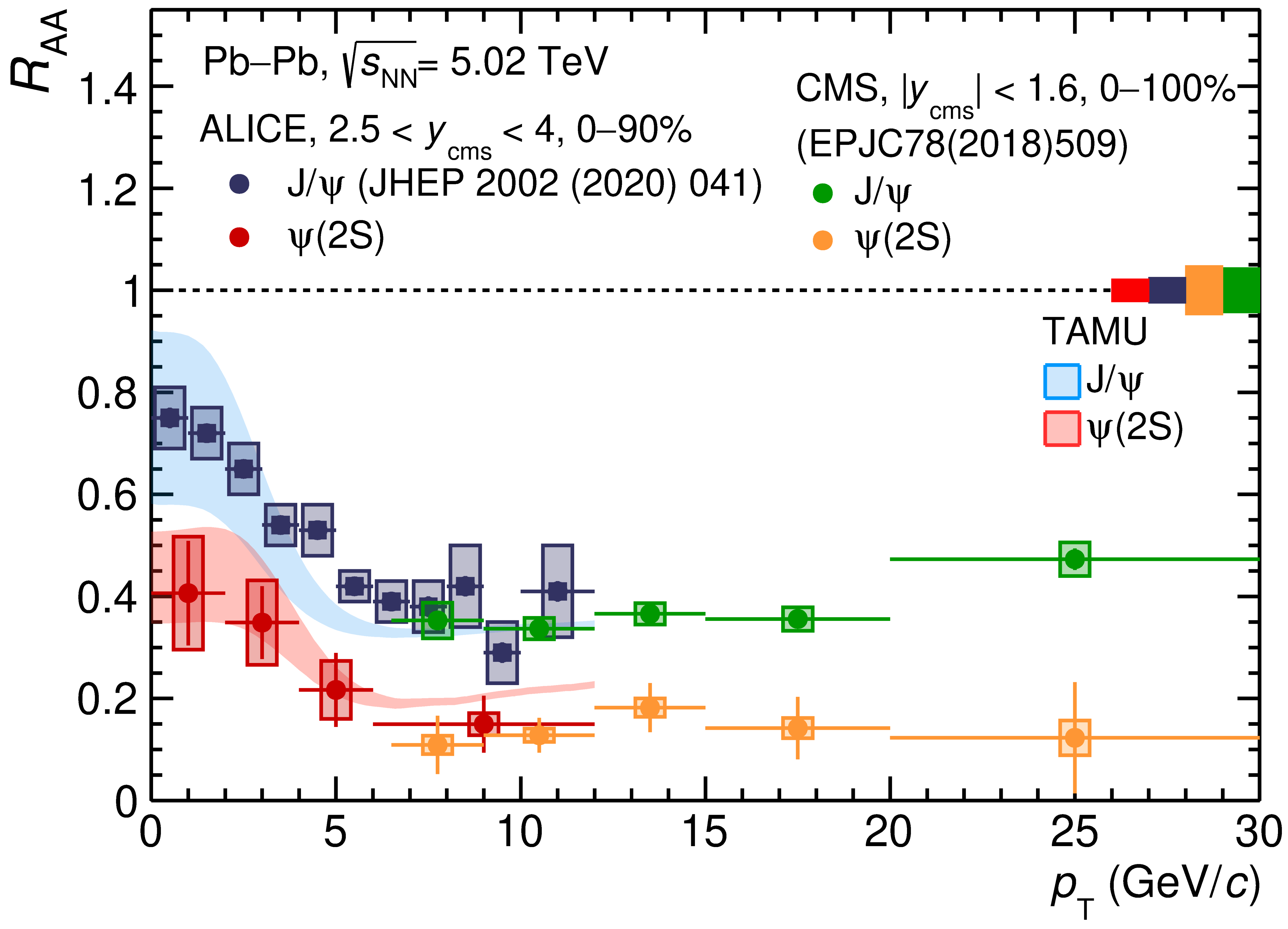
ψ(2S) in Pb-Pb at LHC

MInjung Kim

ψ(2S) behavior at LHC energies mirrors J/ψ behavior in PbPb.

- ψ(2S) regeneration at low p_T.
- Well described by transport model.



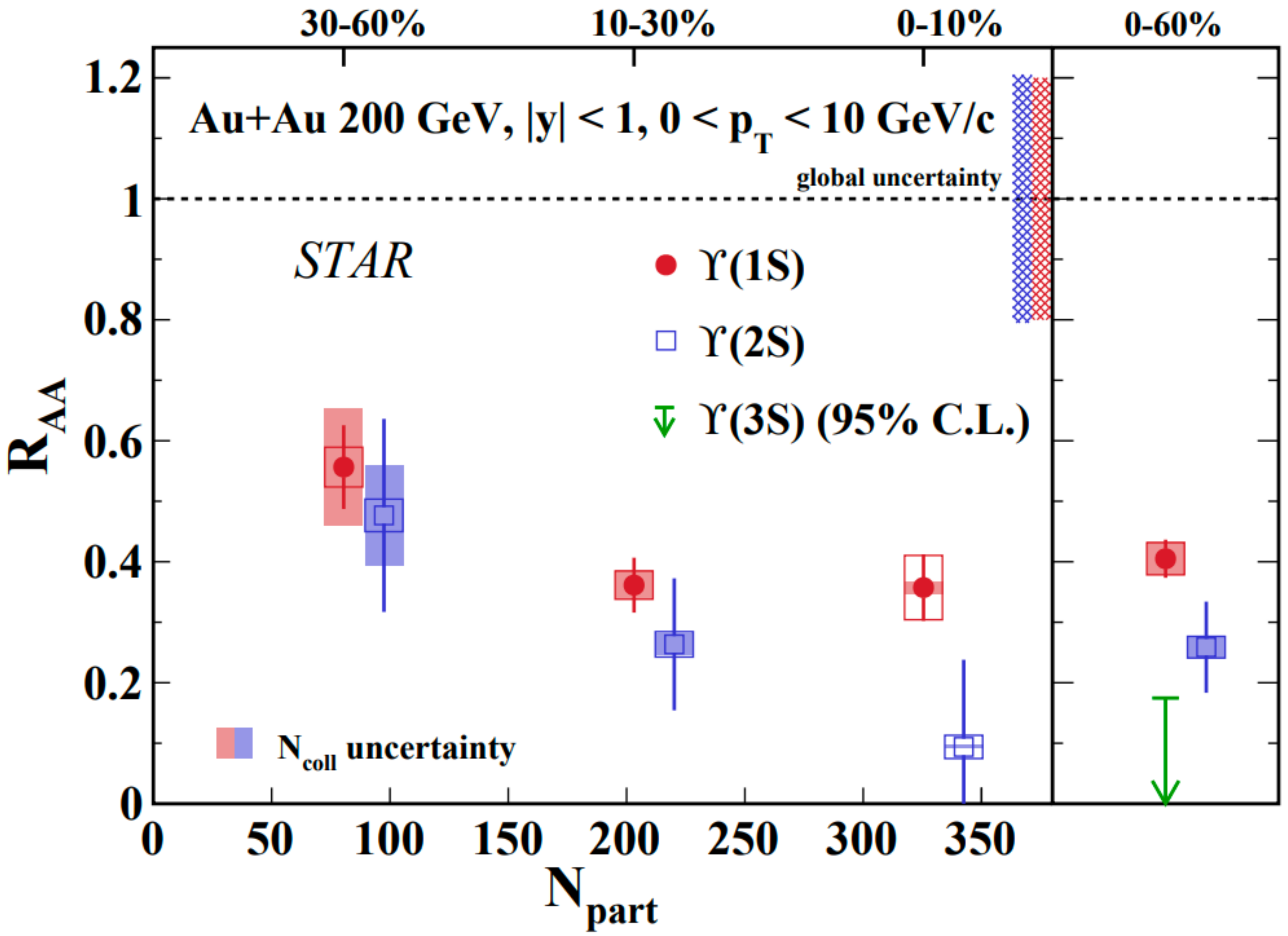


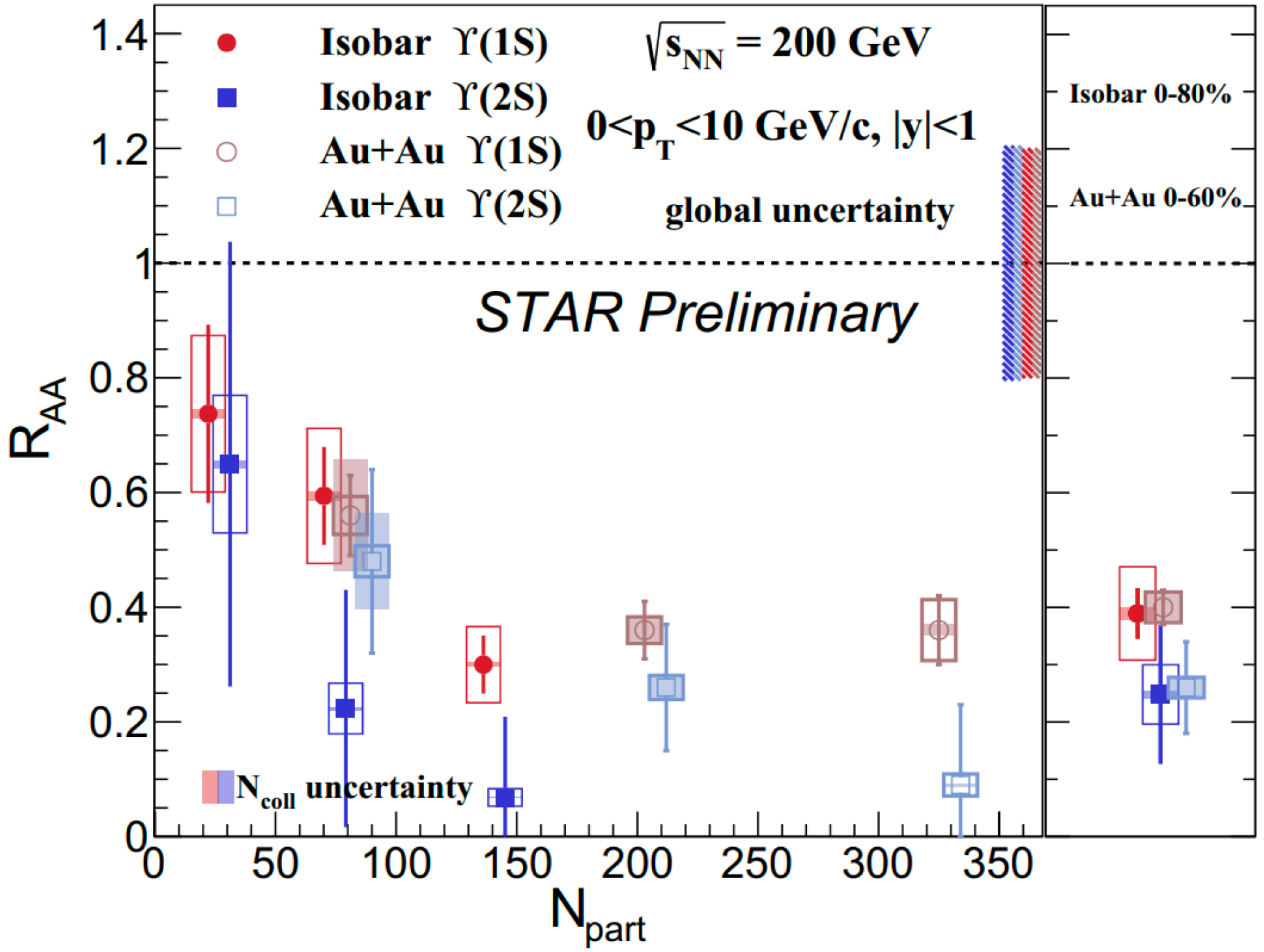
Bottomonium at RHIC

Wei Zhang

STAR measurements of Υ(1S) and Υ(2S)

- Extended to Zr+Zr and Ru+Ru collisions at 200 GeV collision energy.



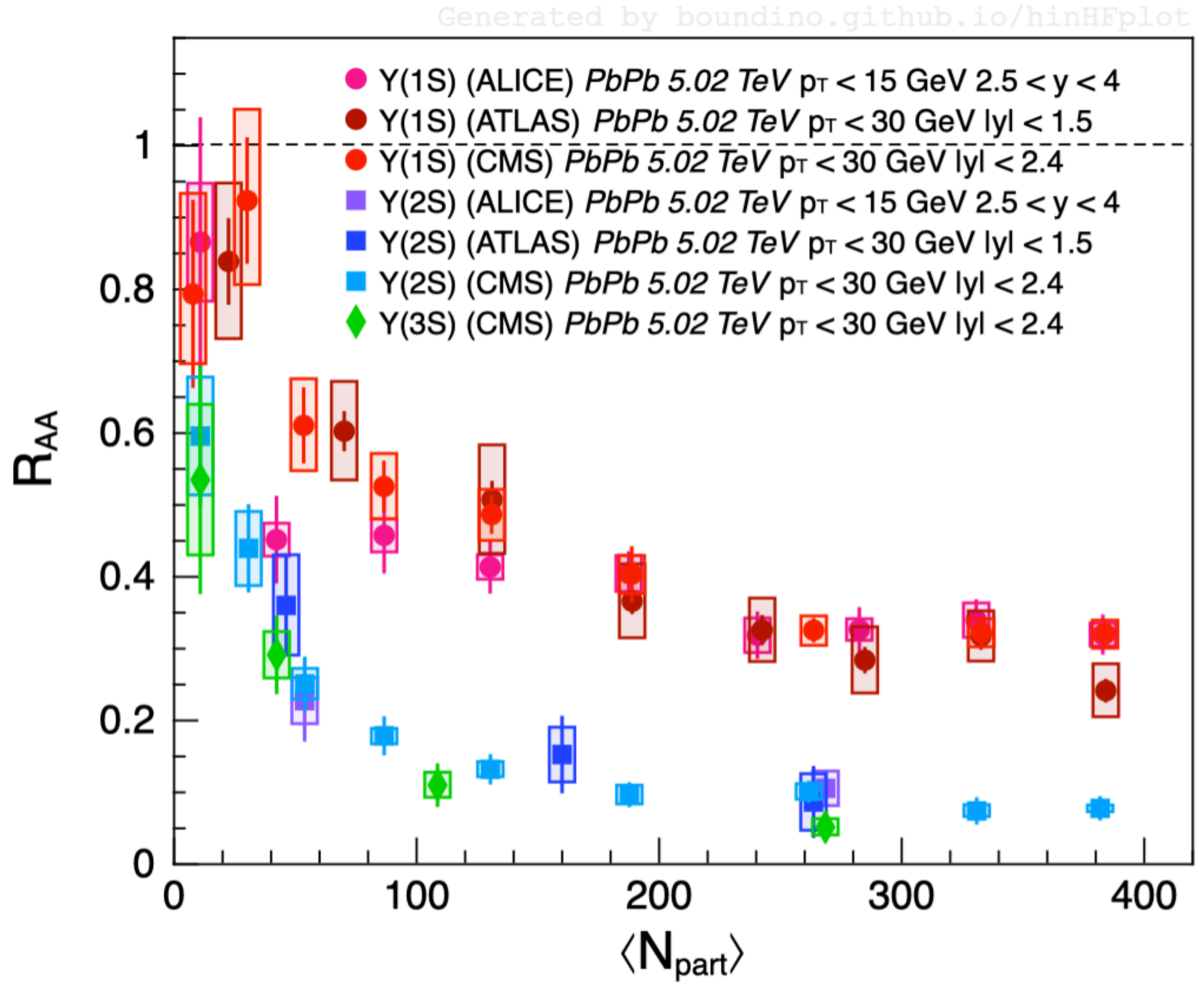


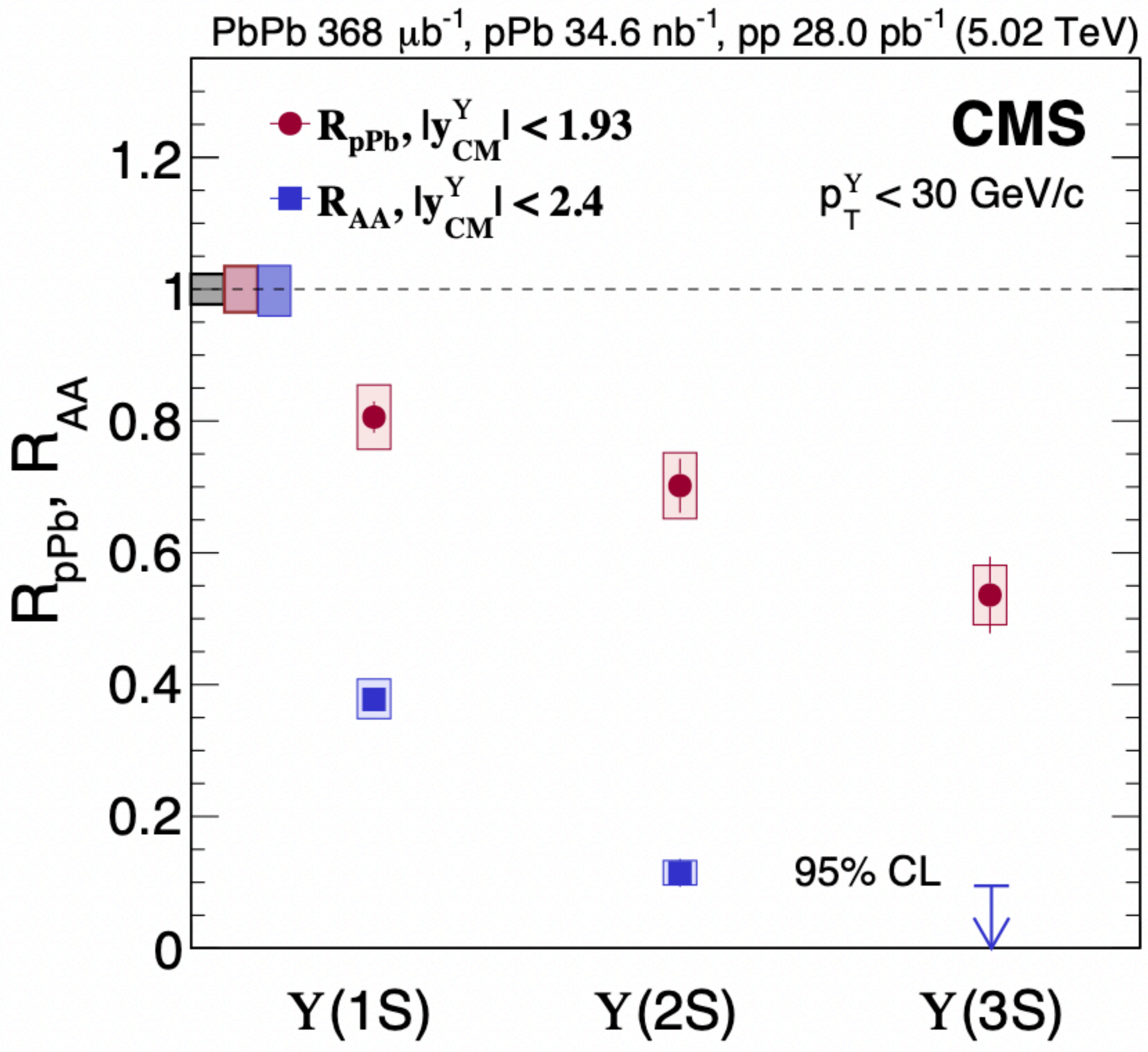
Bottomonium at LHC

Beautiful R_{AA} data from all experiments.

Ongoing campaign to increase precision for Υ(2S) and Υ(3S).

Minjung Kim





Ming Liu

J/ψ event multiplicity at RHIC

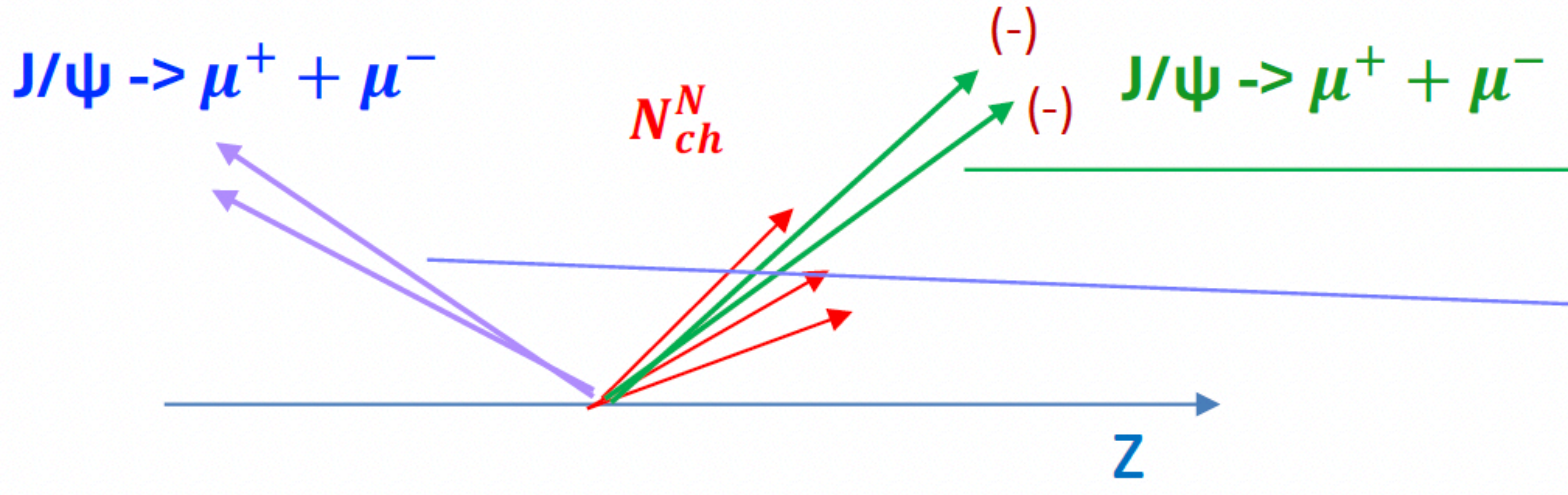
PHENIX

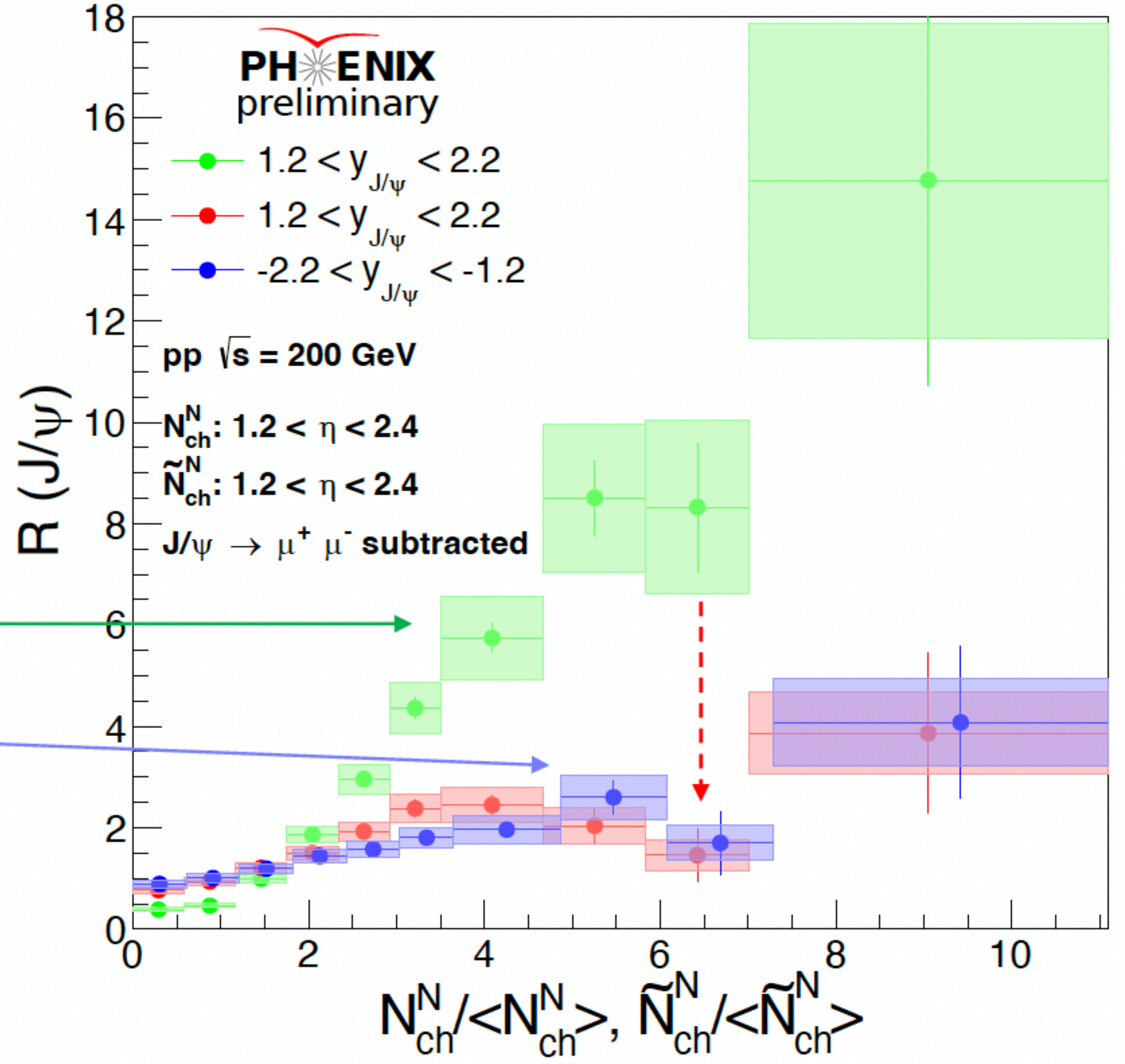
J/ψ Yields vs Event Multiplicity: All Together

RED = Tracklets $N^N_{ch}(1.2 < \eta < 2.4)$ [inclusive, dimuon subtracted]

Green = J/ψ (1.2 < y < 2.2)

Blue = J/ψ (-2.2 < y < -1.2)



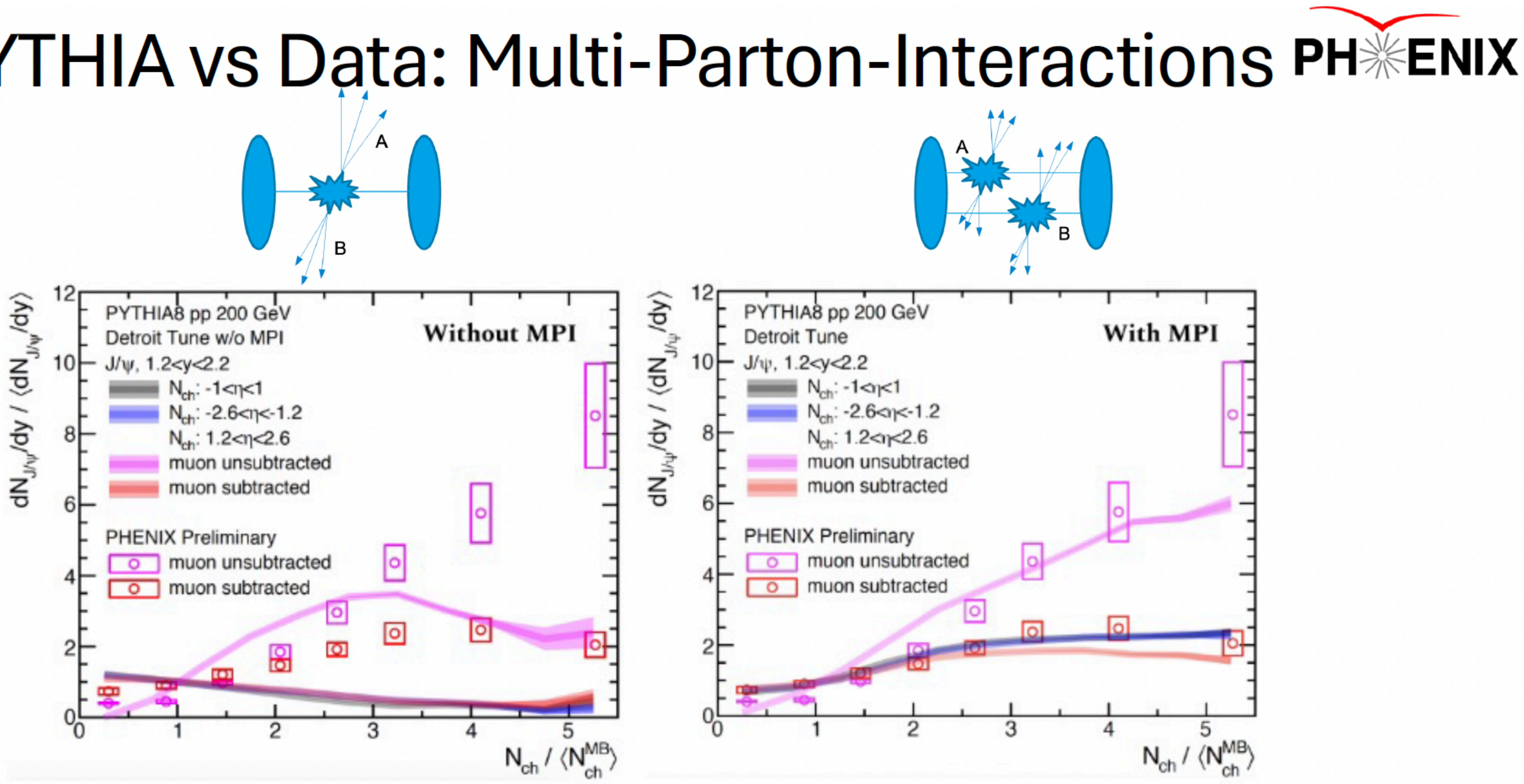


- Less MPI contribution to the forward **J/ψ** production?

J/ψ event multiplicity at RHIC

Ming Liu

PYTHIA vs Data: Multi-Parton-Interactions

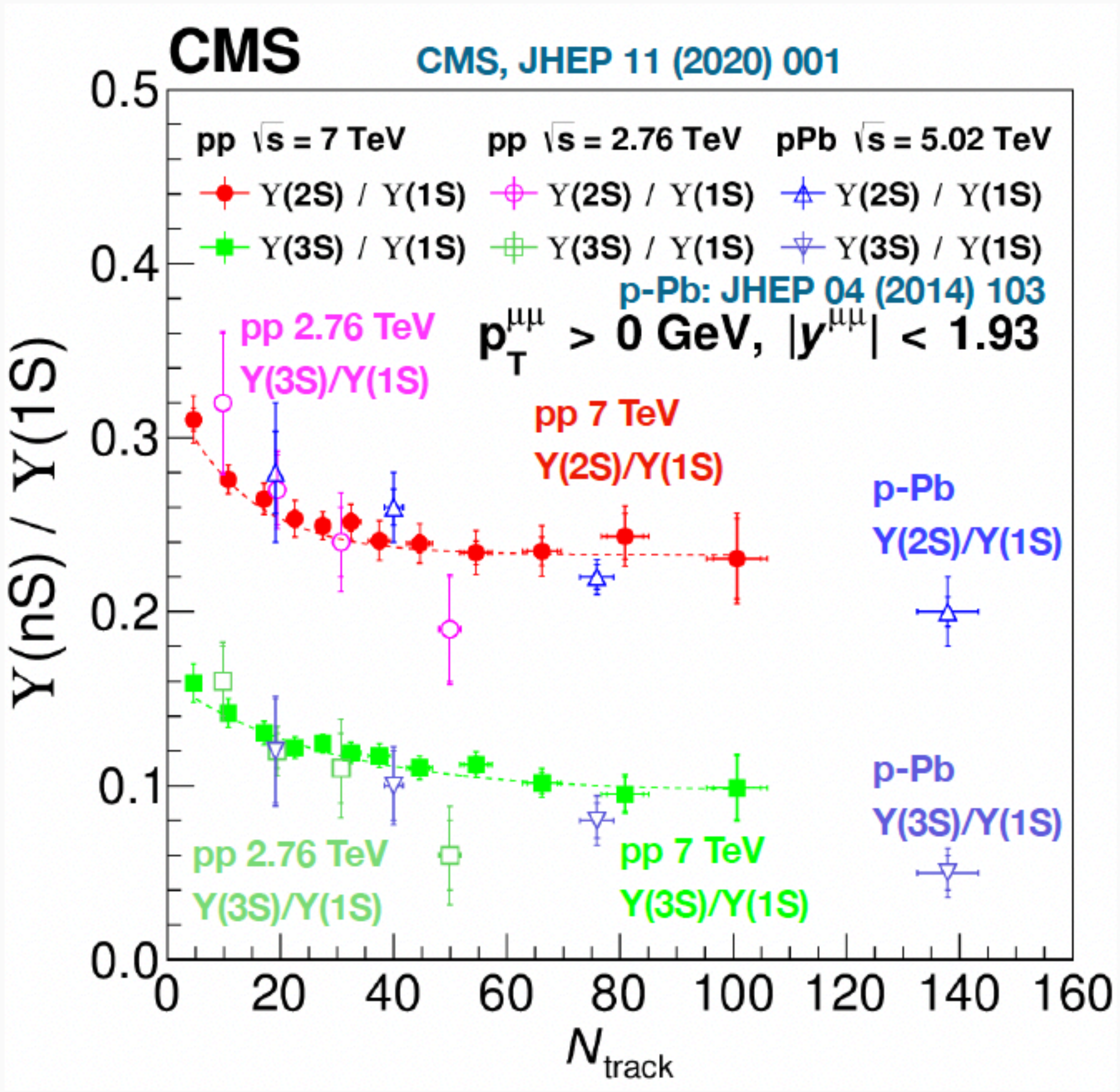


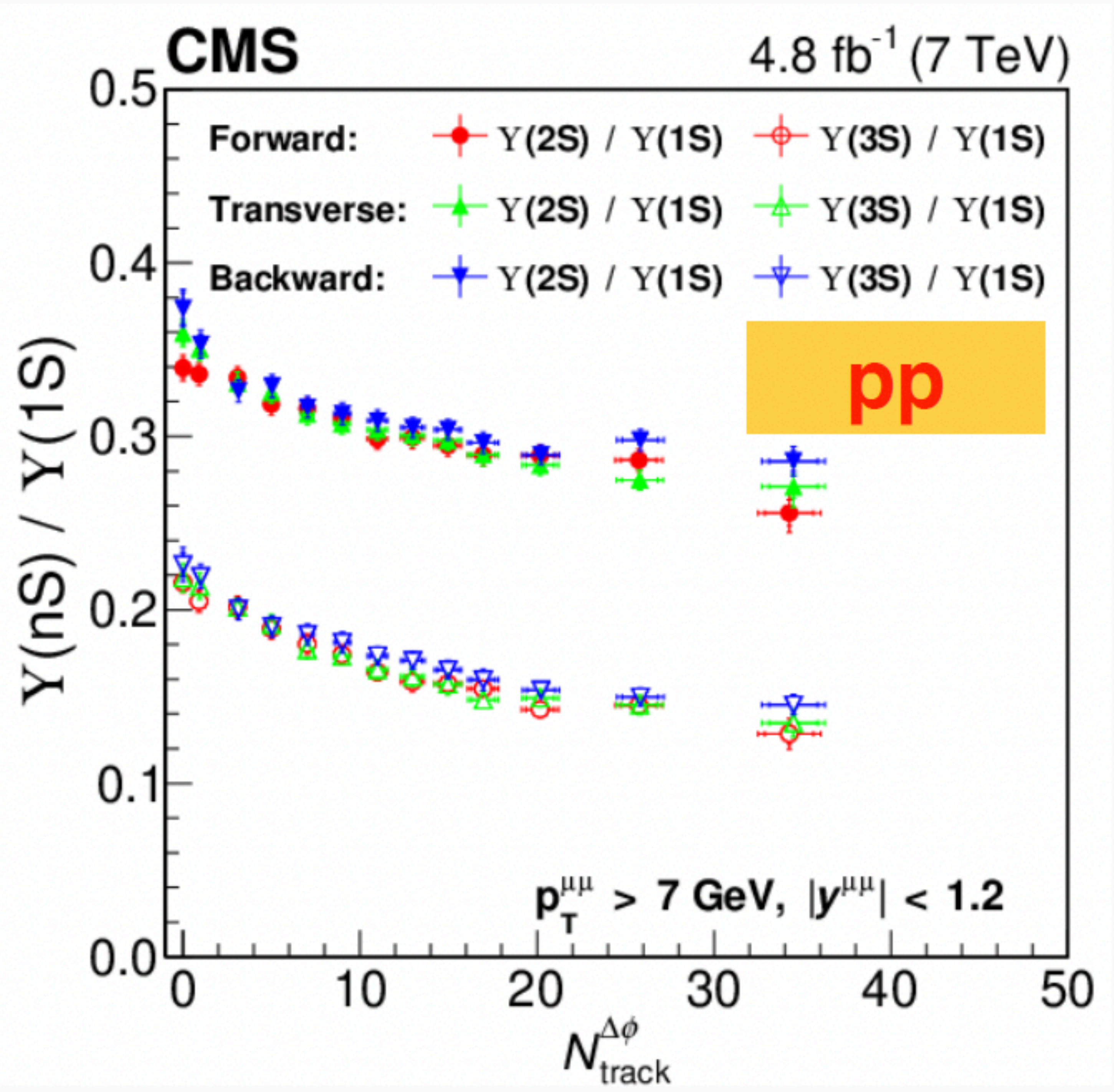
- PYTHIA8 Detroit tune reasonably agree with PHENIX data, with MPI
  - ➢ w/o MPI, fit failed badly
- Proper understanding of the Underline Events is important

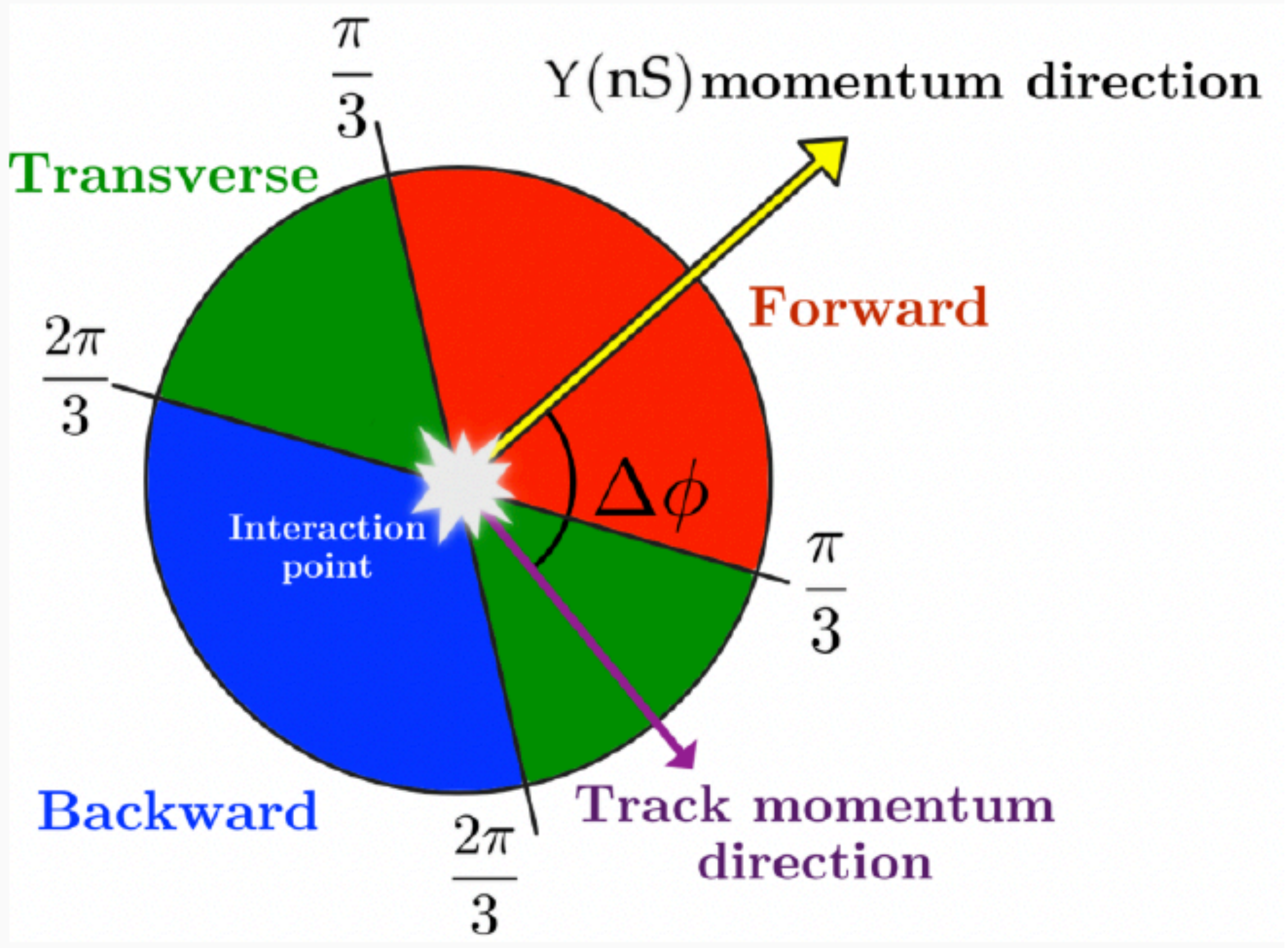
6/12/24 HF Quarkonium Physics @PHENIX 20

MInjung Kim

Bottomonium production vs. event activity







- Υ(2S)/Υ(1S) and Υ(3S)/Υ(1S) decreases with multiplicity in pp as well as in p-Pb collisions
- Decreasing trend with multiplicity seen for all azimuthal angles at high p_T
  → Connection to underlying event (UE)

Minjung Kim
UC Berkeley
27
RHIC/AGS Annual Users' Meeting12. June. 2024 (Wed.)

To come: sPHENIX Bottomonium

Mass resolution of ~ 100 MeV/c² enables the separation of all three Upsilon states.

Anticipated performance (assumes Υ(3S) suppression similar to LHC energy):

Marzia Rosati