Intermediate pT Results in PHENIX

Workshop on Strangeness and Exotica at RHIC
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Richard Seto
UC, Riverside

for the PHENIX Collaboration

12 Countries; 57 Institutions; 460 Participants

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Why intermediate p_T?

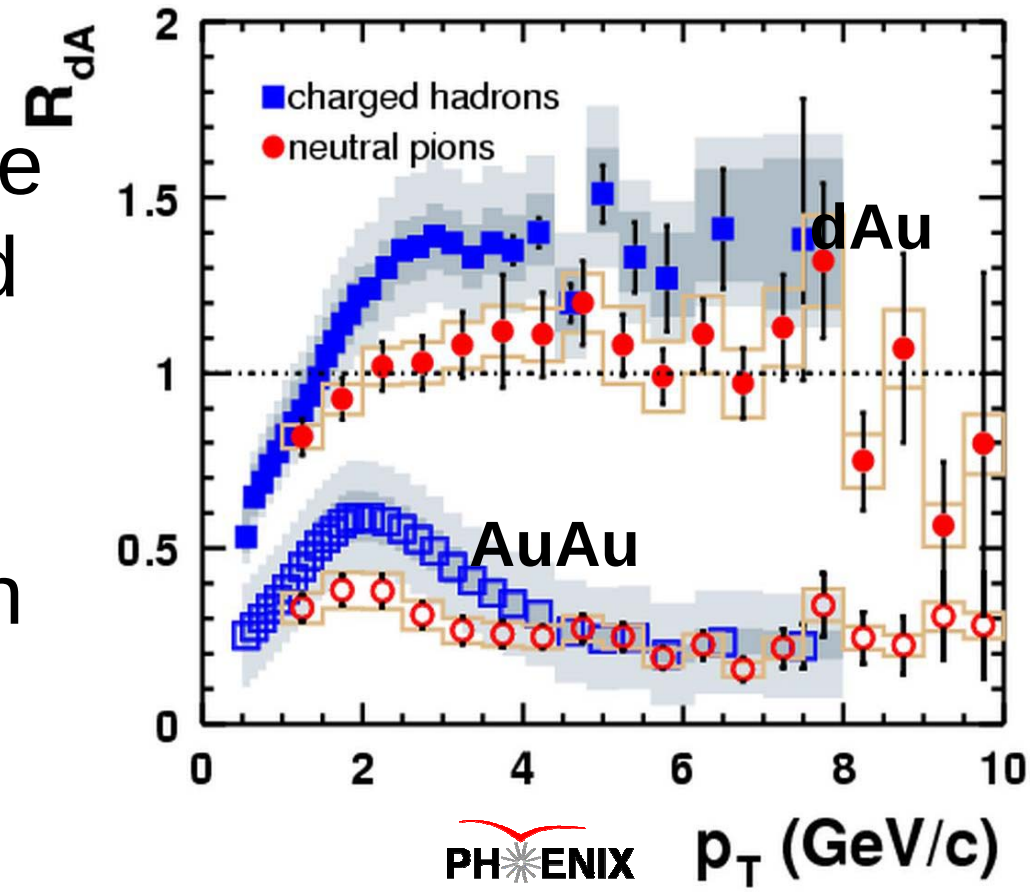
- Chemical freezeout analysis➔ hadron formation at Tc
  - No further inelastic collisions
  - **But – how do hadrons form?**
- Recombination
  - Coalescence (or recombination) of ~ thermal flowing quarks at T_C
    - a simple picture of non-perturbative physics
    - More complex ideas, may include a non thermal (hard) component
  - assumes constituent quarks
  - explains many things in a single model
  - implies quark system? tantalizing - DOF
    - if bulk of particles are formed by the recombination of thermal partons ➔quark DOF!
  - not only model: baryon junctions, hydro at hadronic level, modified FF (another way to say recomb-Hwa?…)

The data

- Observables
  - p/π - surrogate $h/\pi=(p+K+\pi)/\pi \sim p/\pi+1$
  - R_{CP}
  - elliptic flow
  - correlations, i.e. jetiness
- Data sets
  - PHENIX + (other RHIC, e^+e^-)
    - 200 AuAu (The real thing)
    - 200 dAu (a control- cold nuclear effects)
    - 200 pp (control – baseline)
    - 63 AuAu (energy dependence) (PHENIX-prelim)

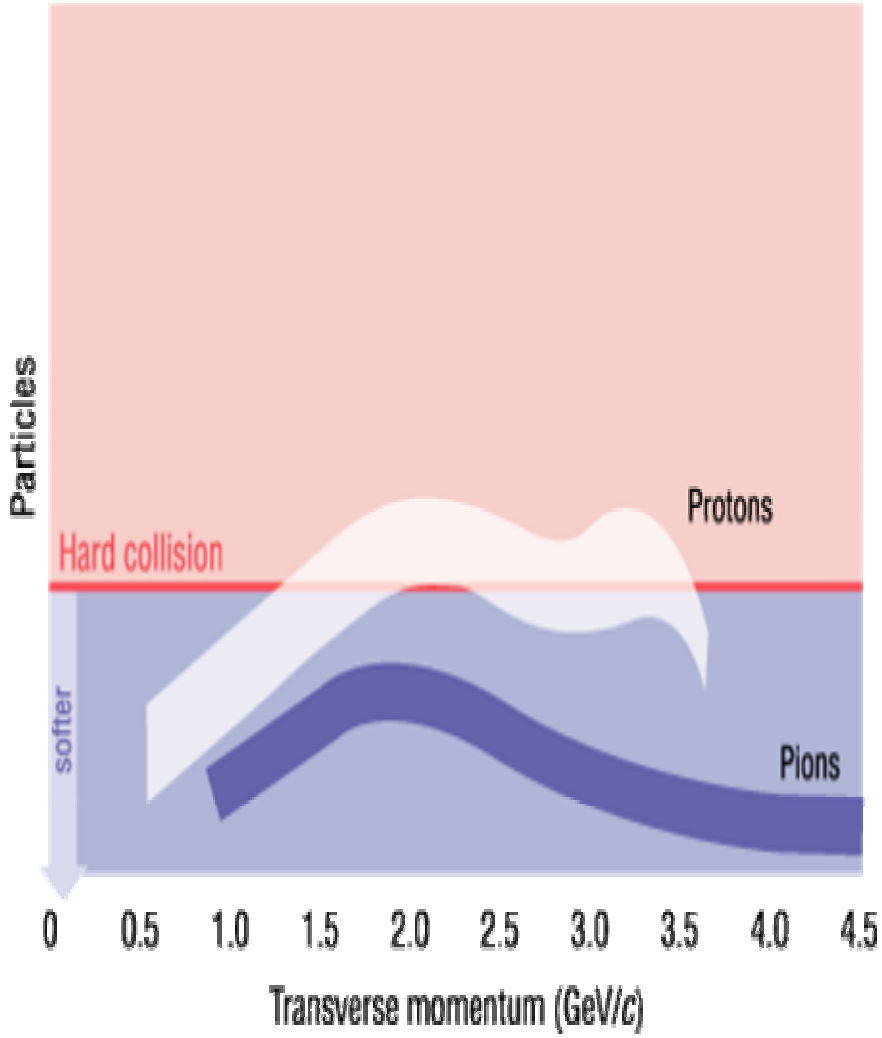
Starting point – high p_T suppression in central AuAu

- high p_T mesons are clearly suppressed
- cleanest interpretation energy loss of high p_T partons

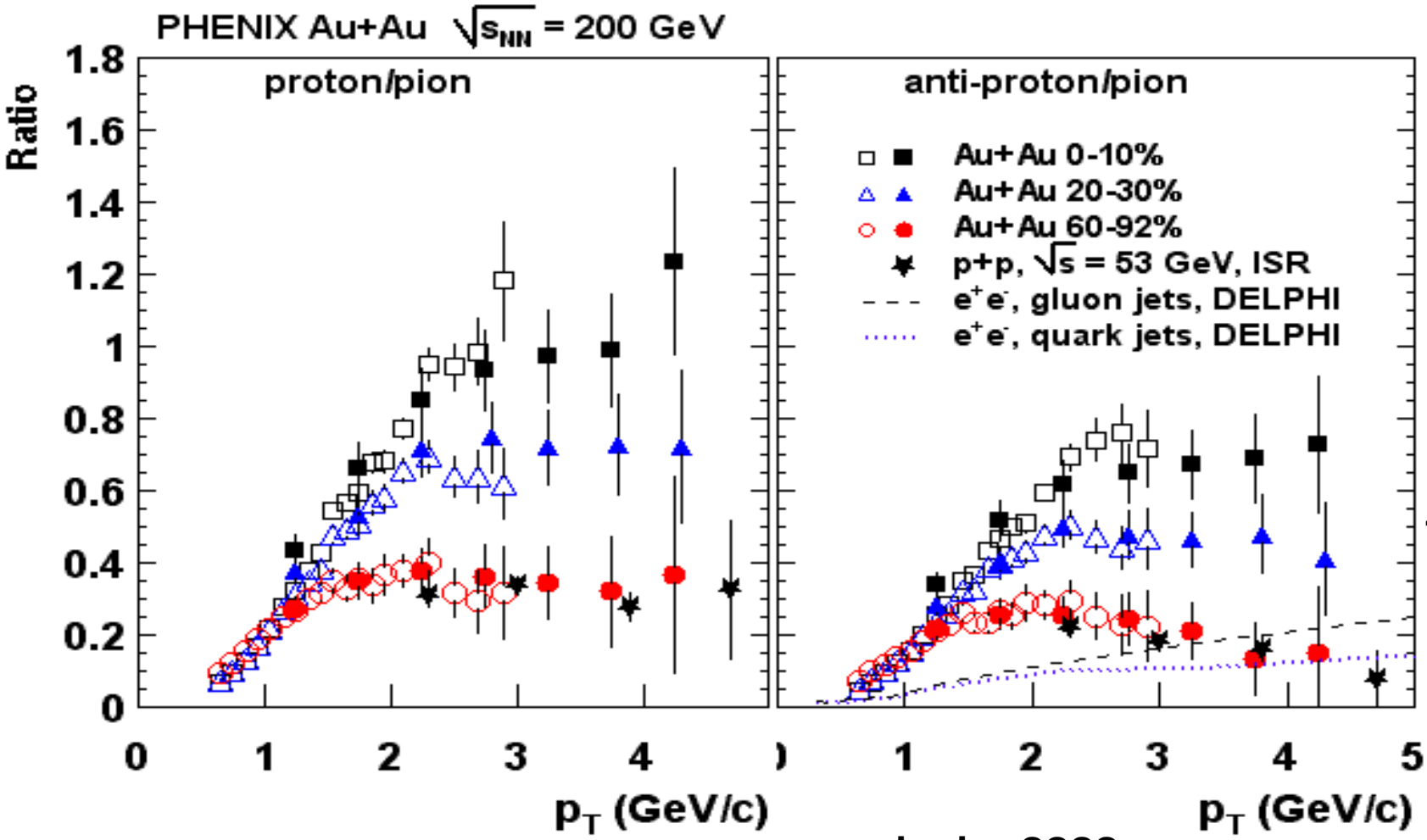


- BUT

Protons do strange things!



"The more I think about it, the more I think it's not completely wacko," William Zajc of Columbia University, spokesperson for one of the four particle detectors at RHIC, said privately at the conference. Zajc ruminated for a few moments and then corrected himself. "Well, it *is* completely wacko," he said.



nominal p/π ~0.2-0.4

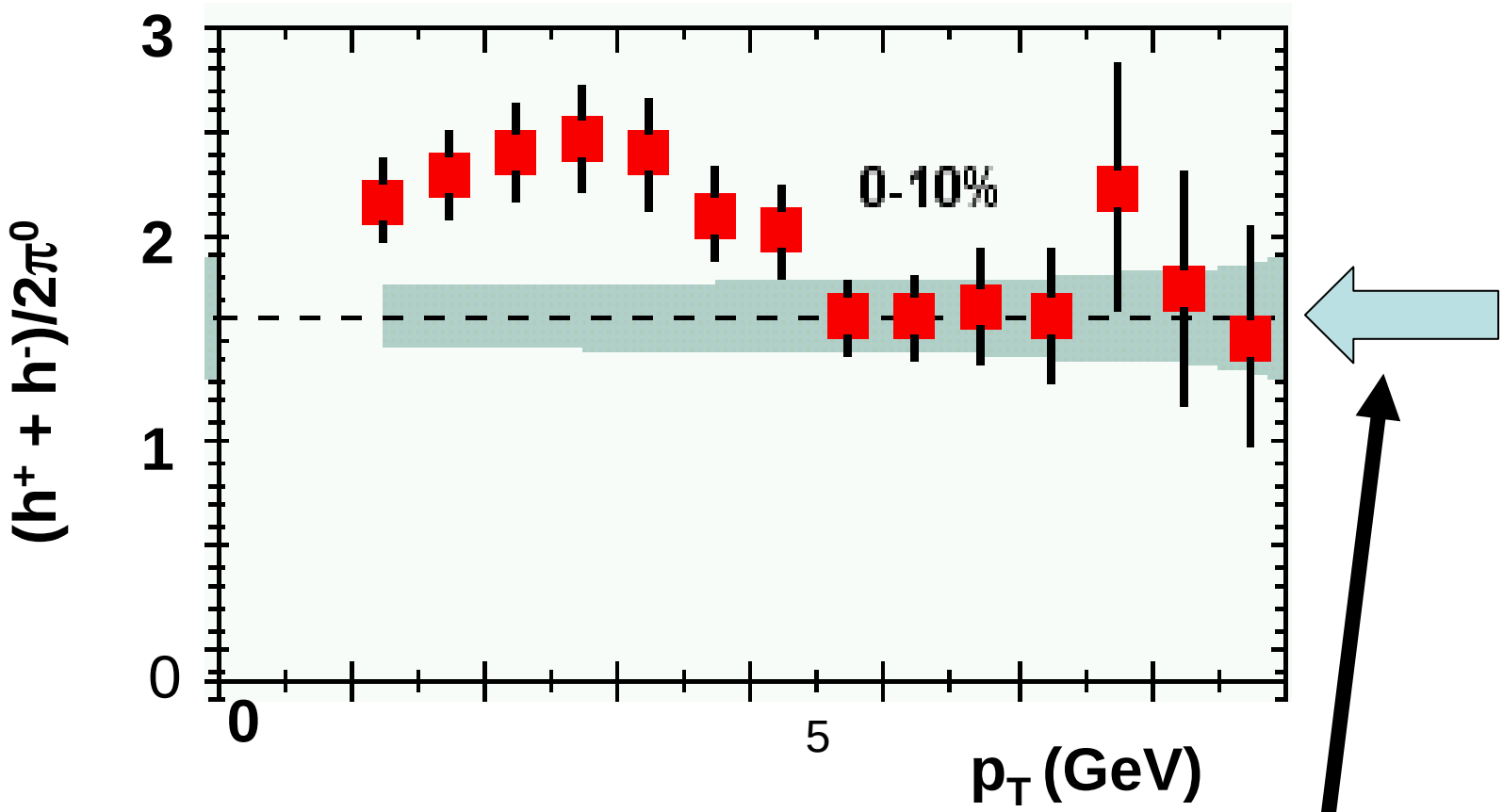
- hard scattering + fragmentation
  ➔ universal fragmentation function
  ➔ baryons ~ 20% at high p_T

NO

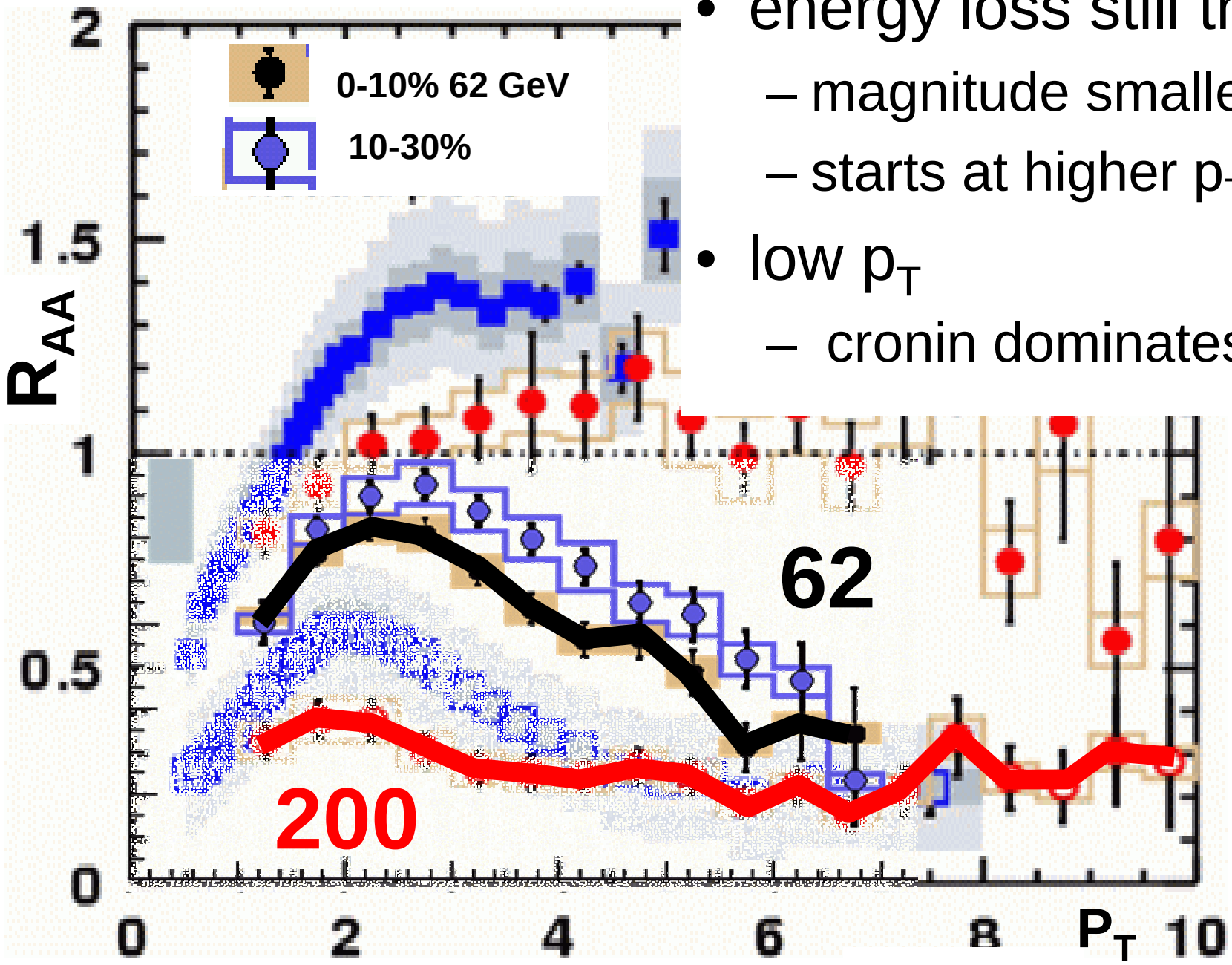
- p/π ~1

- hydro ????
  - reproduces increasing p/π
  - BUT not applicable for pT> 2 GeV/c (T>>T_C)???

h/π (200) at high p_T

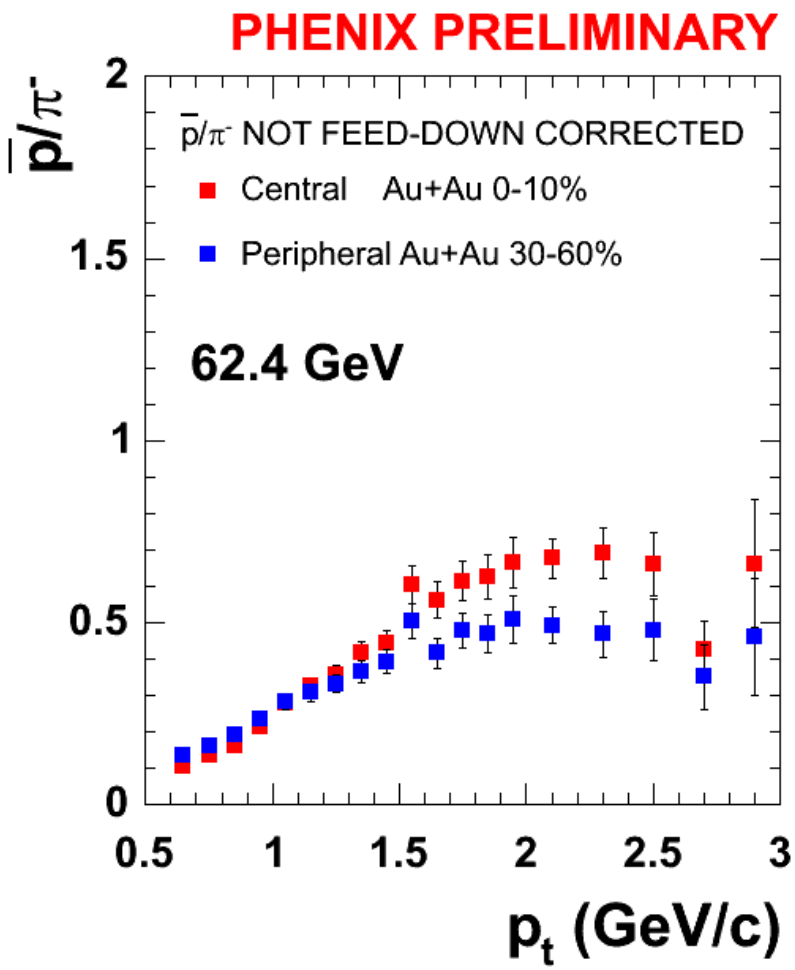


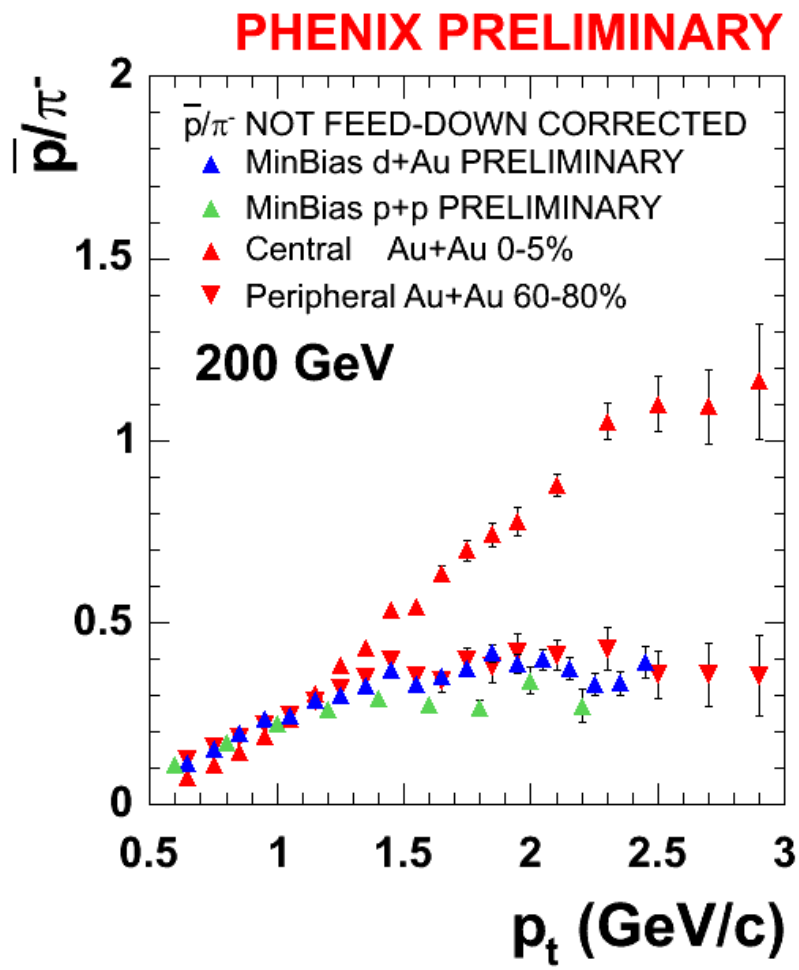
- h/π ~ p/π +1 (+K/π)
- at pt > 5 GeV – back to “normal”



- energy loss still there
  - magnitude smaller
  - starts at higher p_T
- low p_T
  - cronin dominates

$\bar{p}/\pi$ (62)

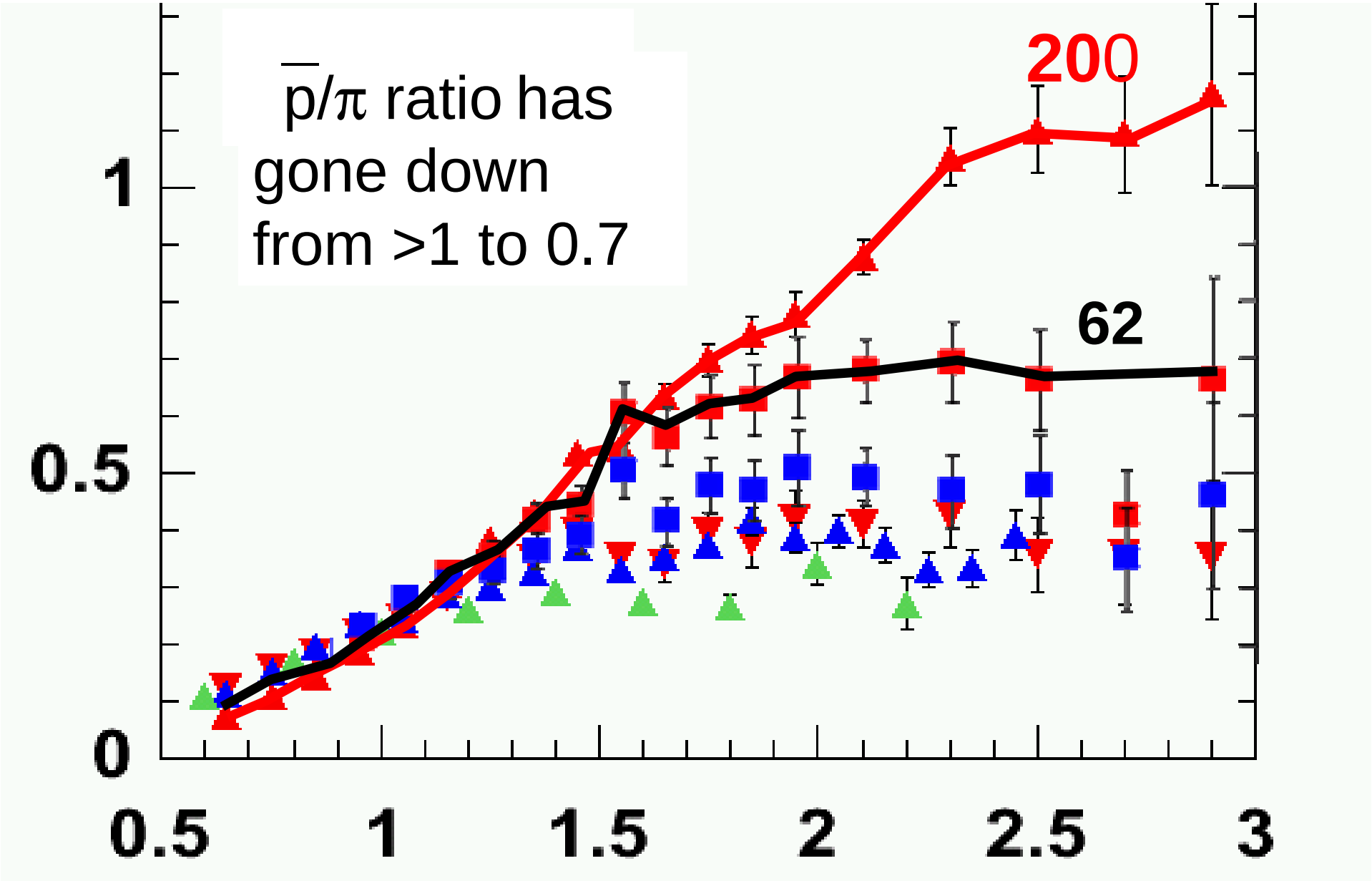




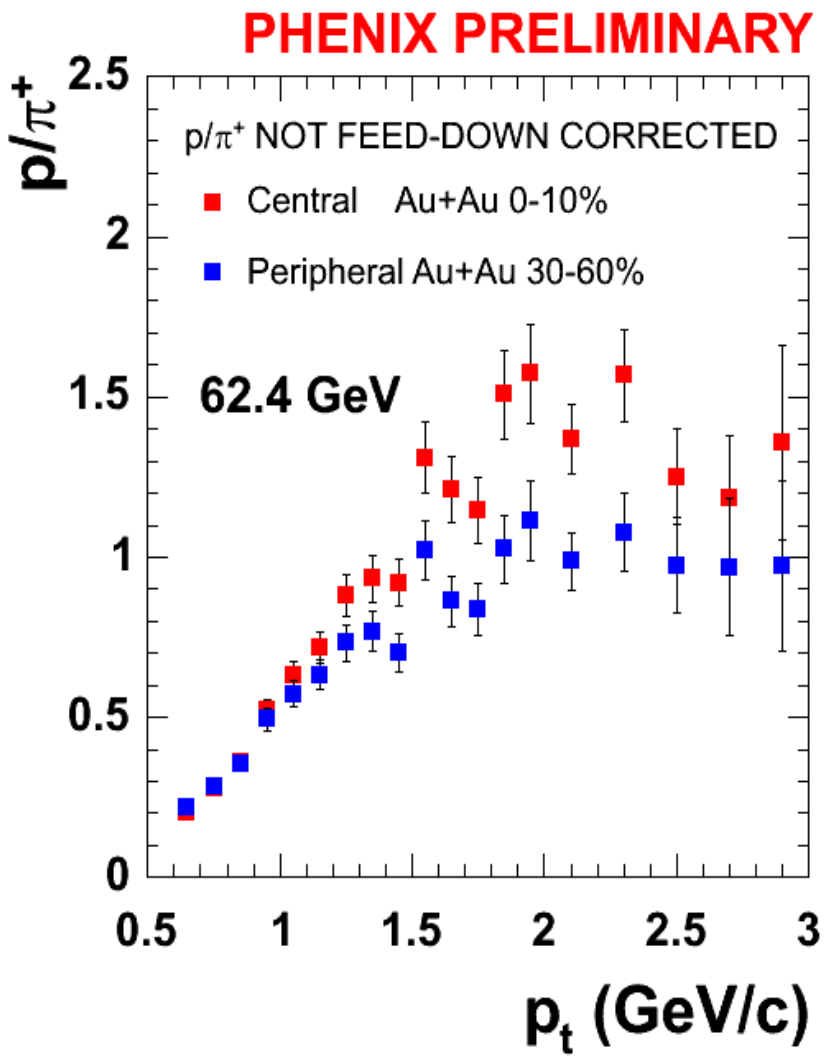
$\bar{p}/\pi$ ratio has gone down from >1 to 0.7

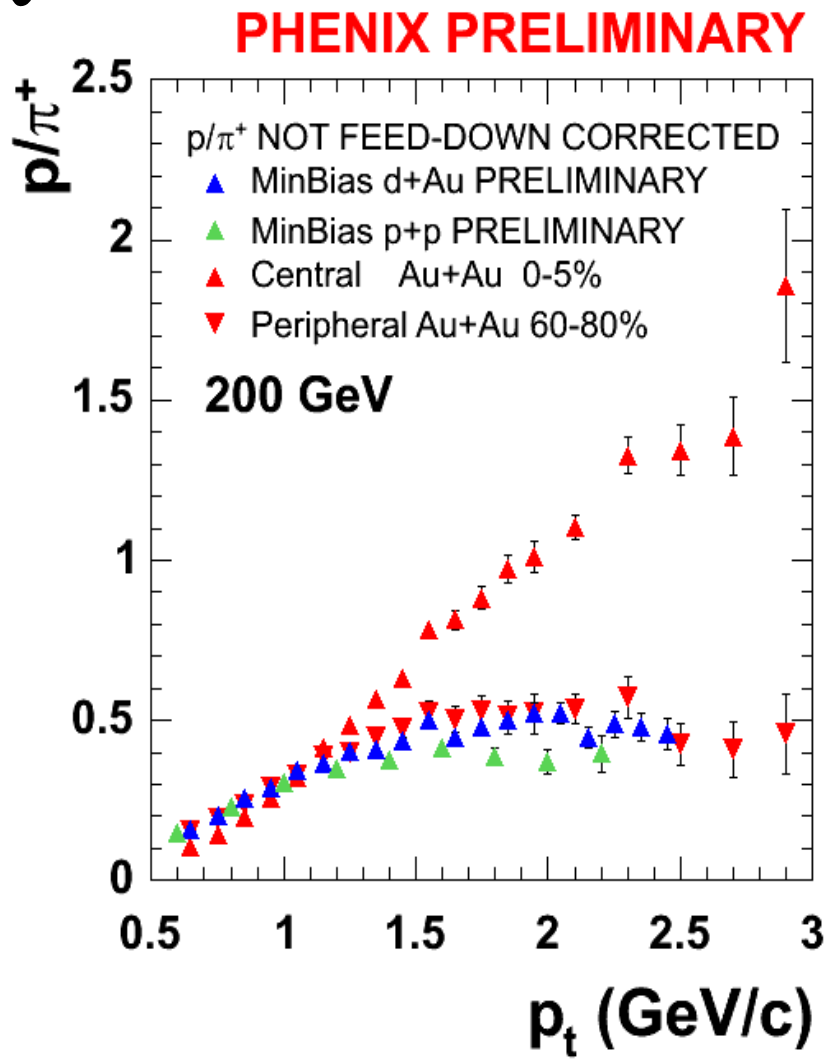
63 GeV 30-60% ~ 200 GeV min bias pp, dAu, peripheral AuAu

$\bar{p}/\pi$ (62)



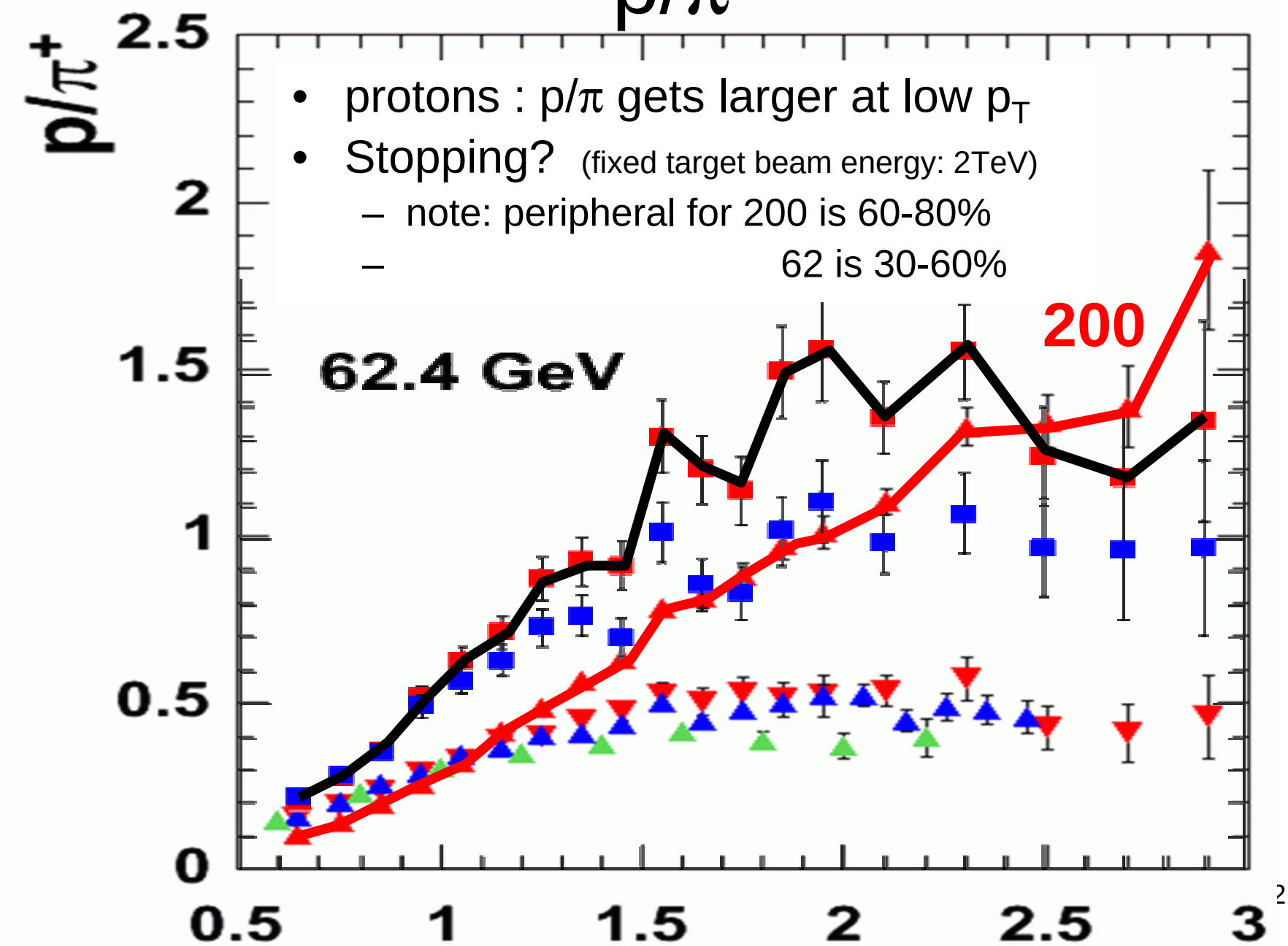
p/π





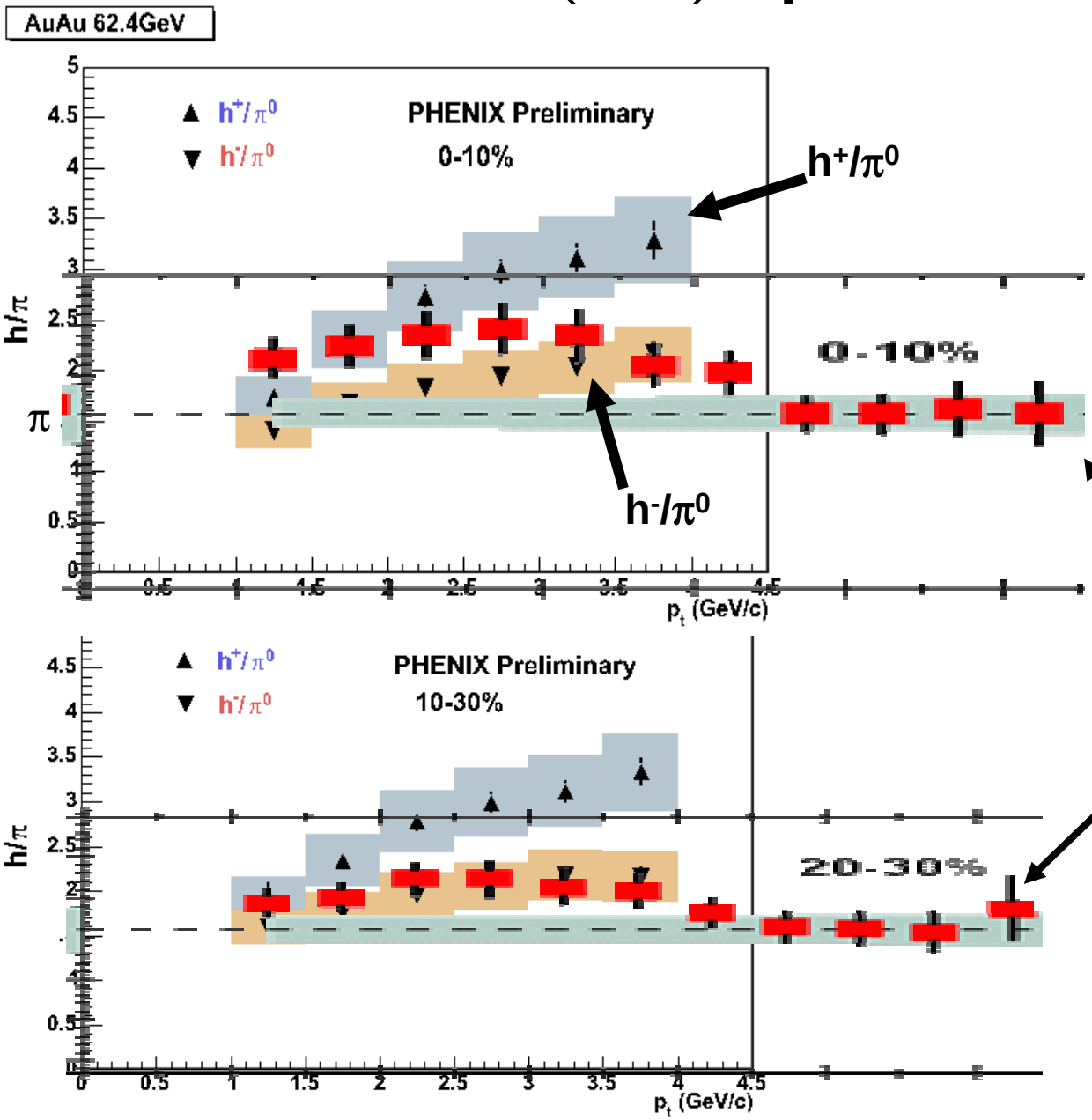
- p/π and $\bar{p}$/π behaves differently at 62 GeV
- p/π seems to go up at 62 at least at low pt

p/π



- protons : p/π gets larger at low p_T
- Stopping? (fixed target beam energy: 2TeV)
  - note: peripheral for 200 is 60-80%
  - 62 is 30-60%

h-/π^0 (62)=pbar/π+1



- Does h^-/π^- come down to the baseline at 62 GeV?

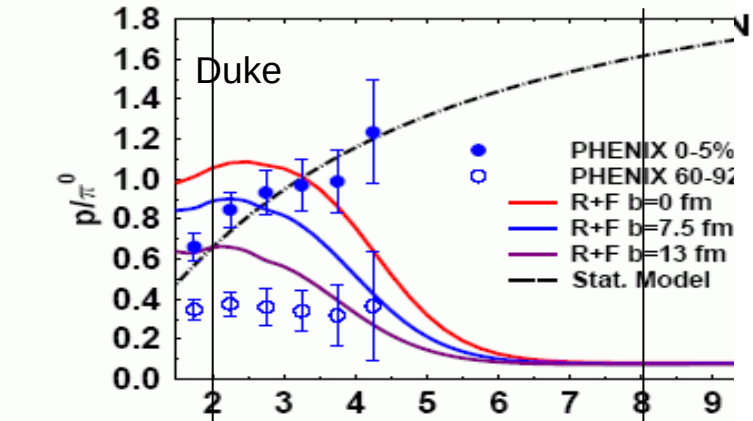
need higher p_T

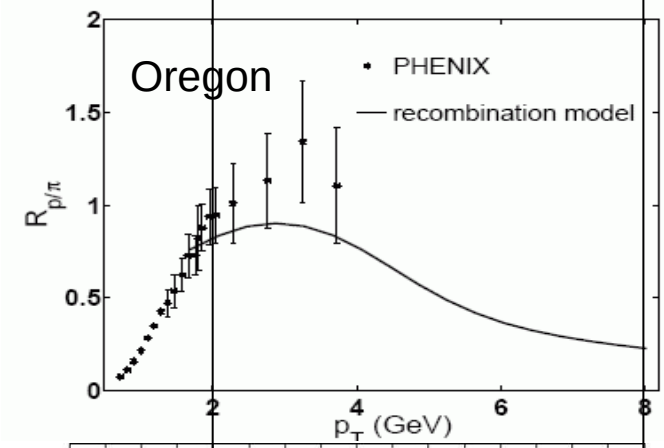
$(h^+ + h^-)/2\pi^0$ (200)

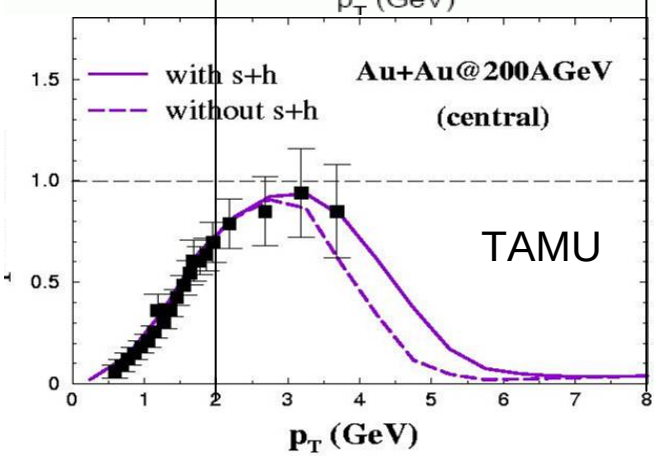
Recombination models

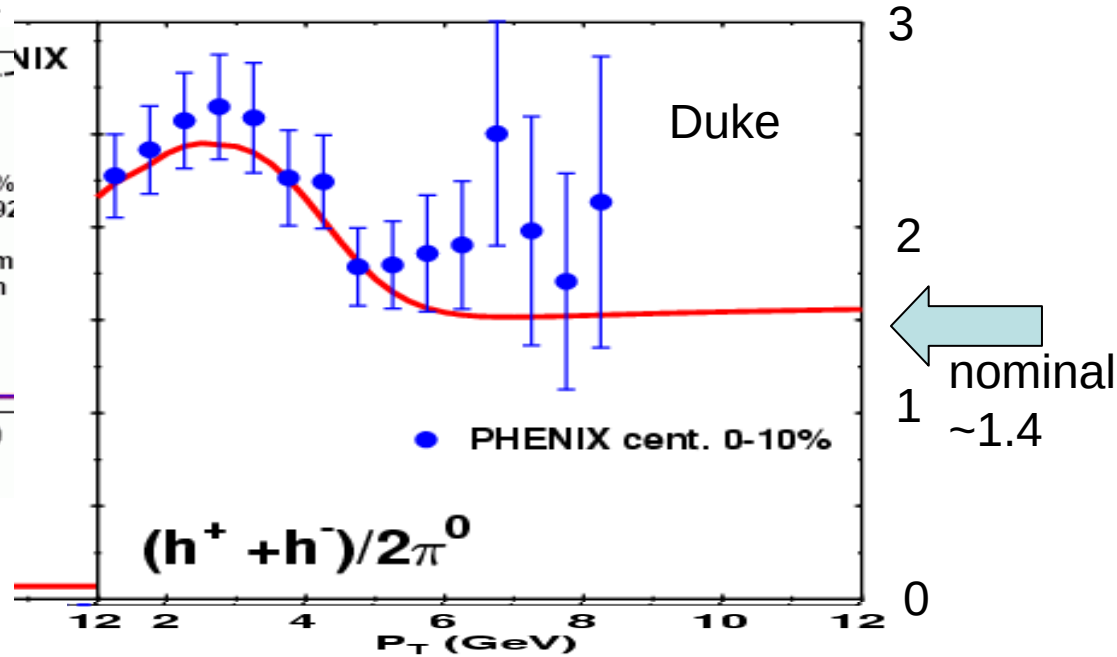
- 3 implementations [Duke, TAMU, Oregon]
  - Duke - Fries, Nonaka, Muller,Bass: PRC **68**, 044902
  - TAMU – Greco, Ko, LEvai PRL 20,202302
  - Oregon – Hwa, Yang: nucl:th/0401001
- All use thermal flowing constituent quarks plus hard quarks
  - Duke
    - only thermal quarks recombine
    - hard component - fragmentation
    - apply only to p_T>2 GeV/c
  - Oregon, TAMU
    - also include thermal+fragmentation quark

Compare p/π to models









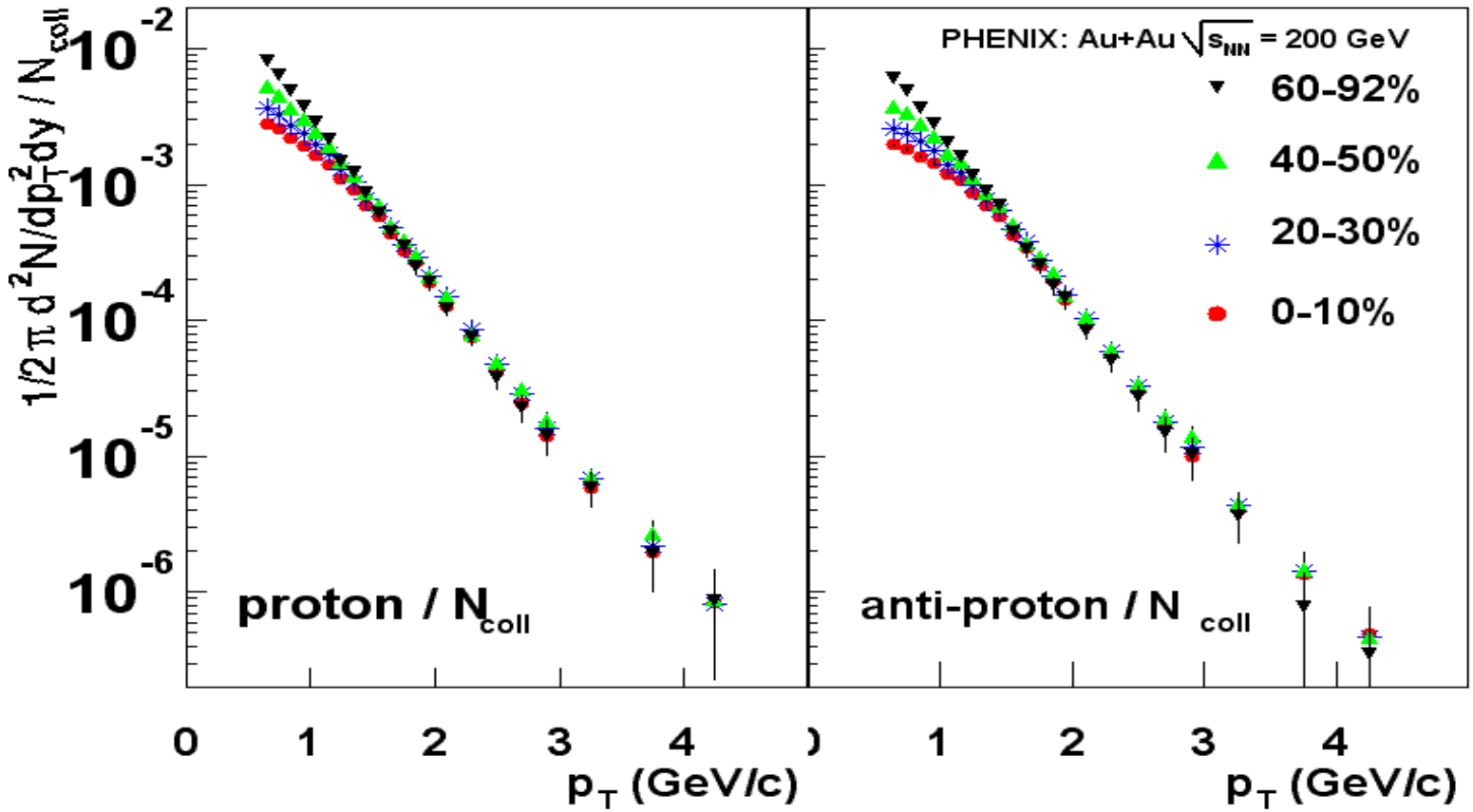
The recombination models can nicely explain the p/π ratio

- baryons with 3 valence quarks are boosted to a higher pT than mesons.
- for exponential spectrum recombination dominates over fragmentation at moderate p_T.

The simplest of the models (Duke) fails on getting the detailed shape correctly.

•All models return to baseline- nice test

Baryons scale ~ as Ncoll at intermediate pT



- Hydrodynamic radial expansion at low pT in central collisions
- At pT > 1.5 – 2 GeV/c all curves of baryon yield per collision merge

Accident?

OR

High pT baryons arise from hard processes with no energy loss?

R_{CP}

- protons scale with N_{Coll} - Accident or not?

  ~mass OR ~ number of valence quarks

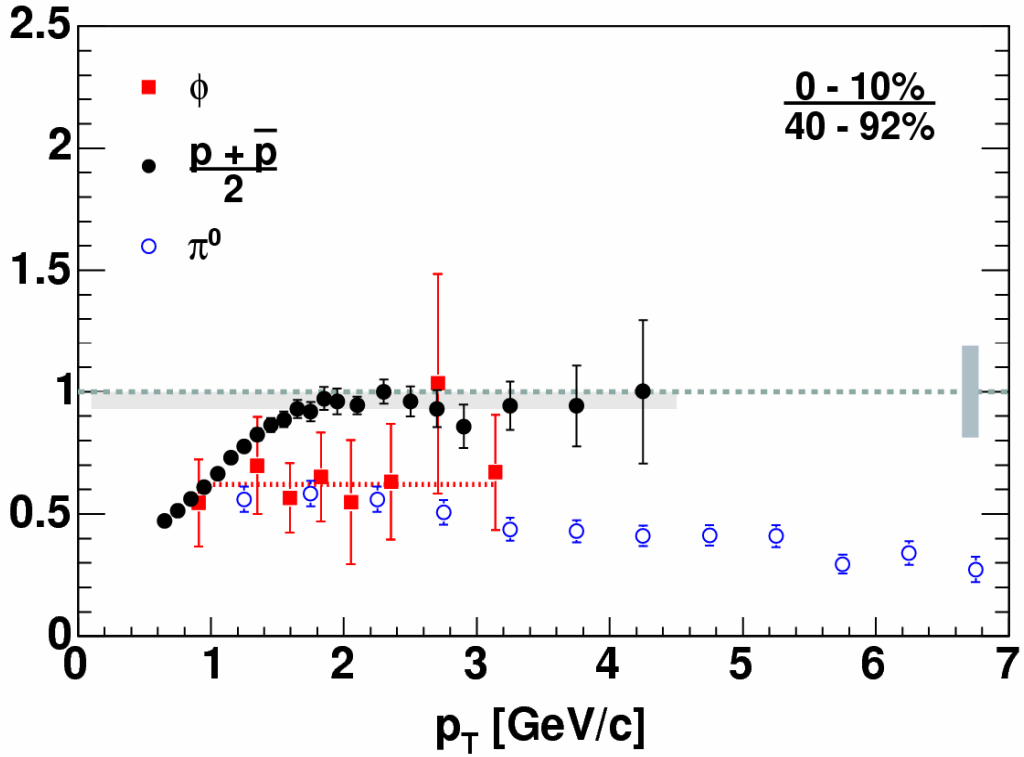
  – Check hypothesis of partonic stage flow + recombination using particle with the same number of valence quarks as the pion, but the mass of the proton.

$$m_{\phi}=m_{proton} \quad \text{and} \quad n_{\phi}=n_{\pi}$$

  – Look at $R_{CP}(\phi)$

$$R_{CP} = \frac{Yield(central)/<N_{coll}(central)>}{Yield(peripheral)/<N_{coll}(peripheral)>}$$

Rcp (data)



- Proton R_{CP}~1
  - protons ~ N_{Coll}
- π R_{CP}< 0.5
  - Suppression
- Phi R_{CP}
  - more like π than protons
  - ➔ difference dictated by number of valence quarks, not mass

Not consistent with the hypothesis that R_{CP} and p/π is due to hydrodynamical flow developed in the hadronic stage

Caveats:

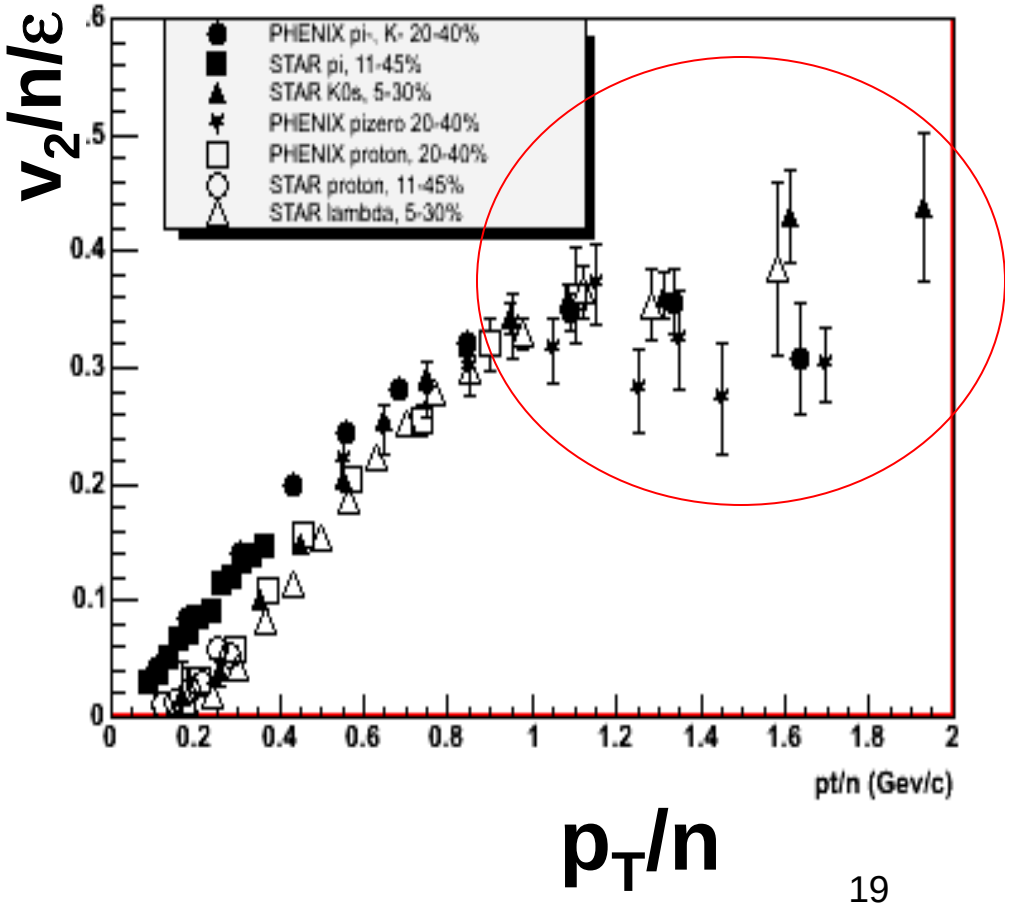
➢ hydro applicable for 40-92%?

➢ ϕ may freeze out early

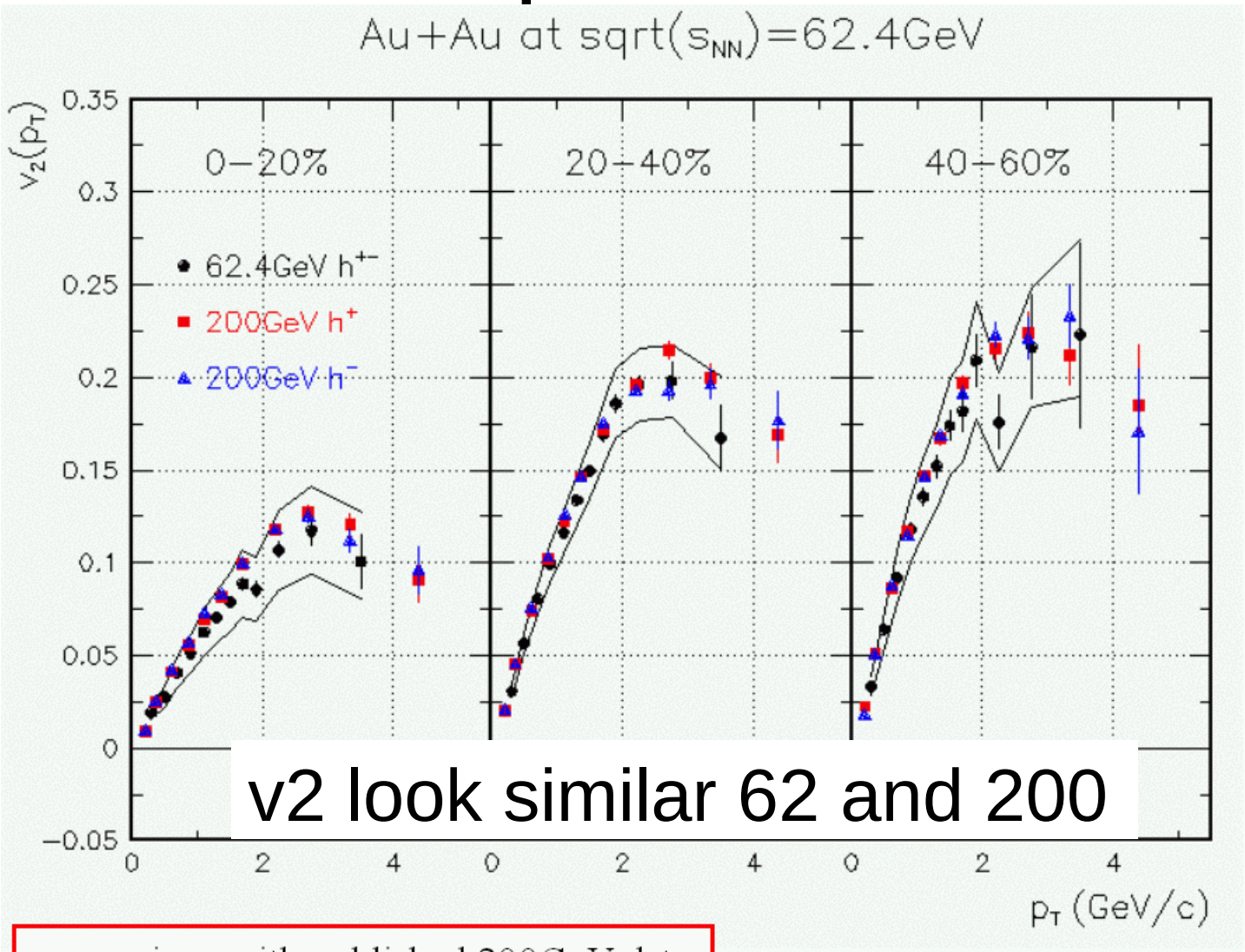
PID v2/n/ε (200)

- for $p_T/n>1$ GeV, particles plateau
- lower p_T particles fall on universal curve except for pions
- Recombination:
  - Flow is built up in the partonic stage
  - v_2 at intermediate pt should scale with the number of quarks.

n=number of valence quarks



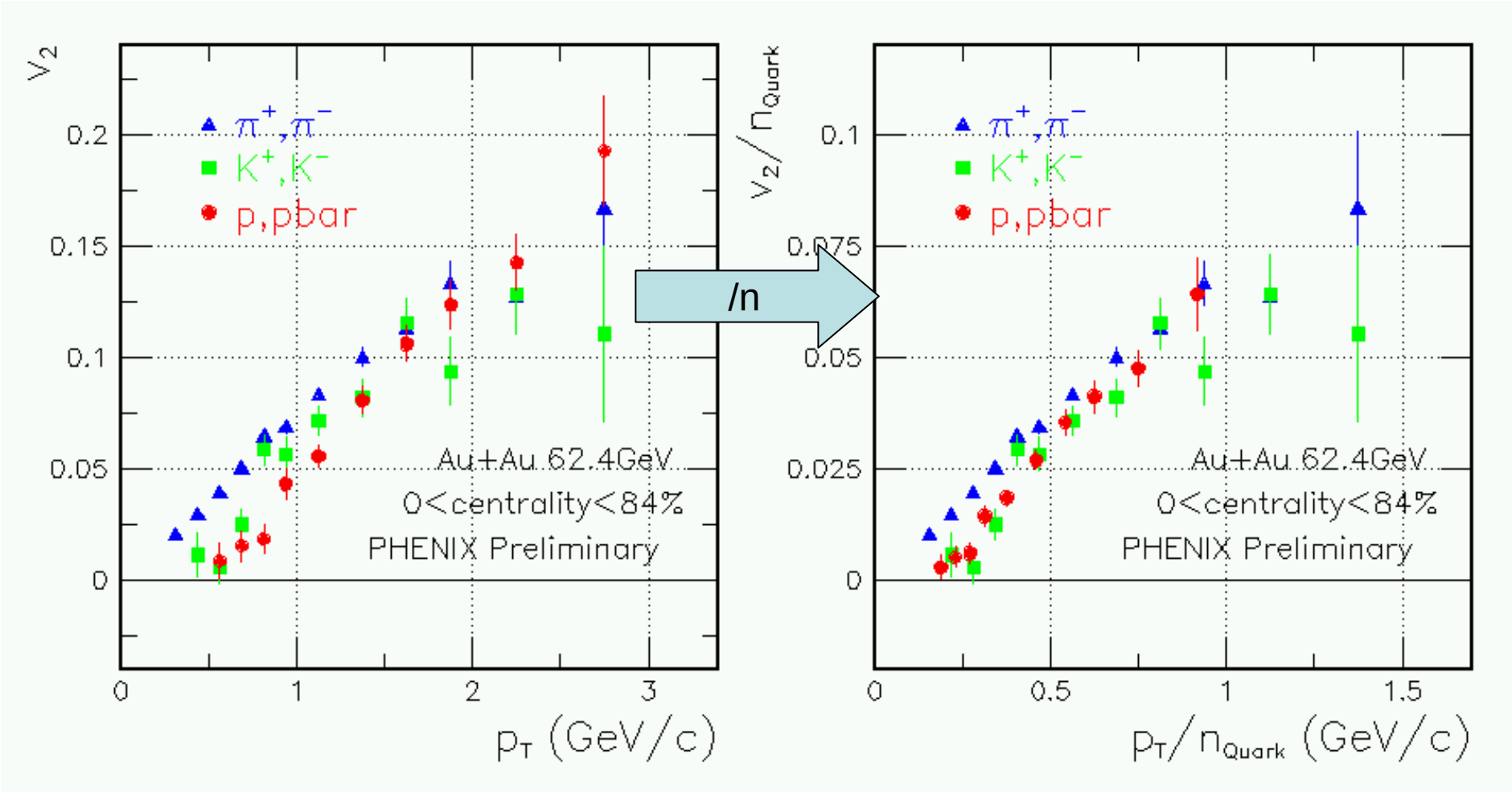
non pid v2 at 62



v2 look similar 62 and 200

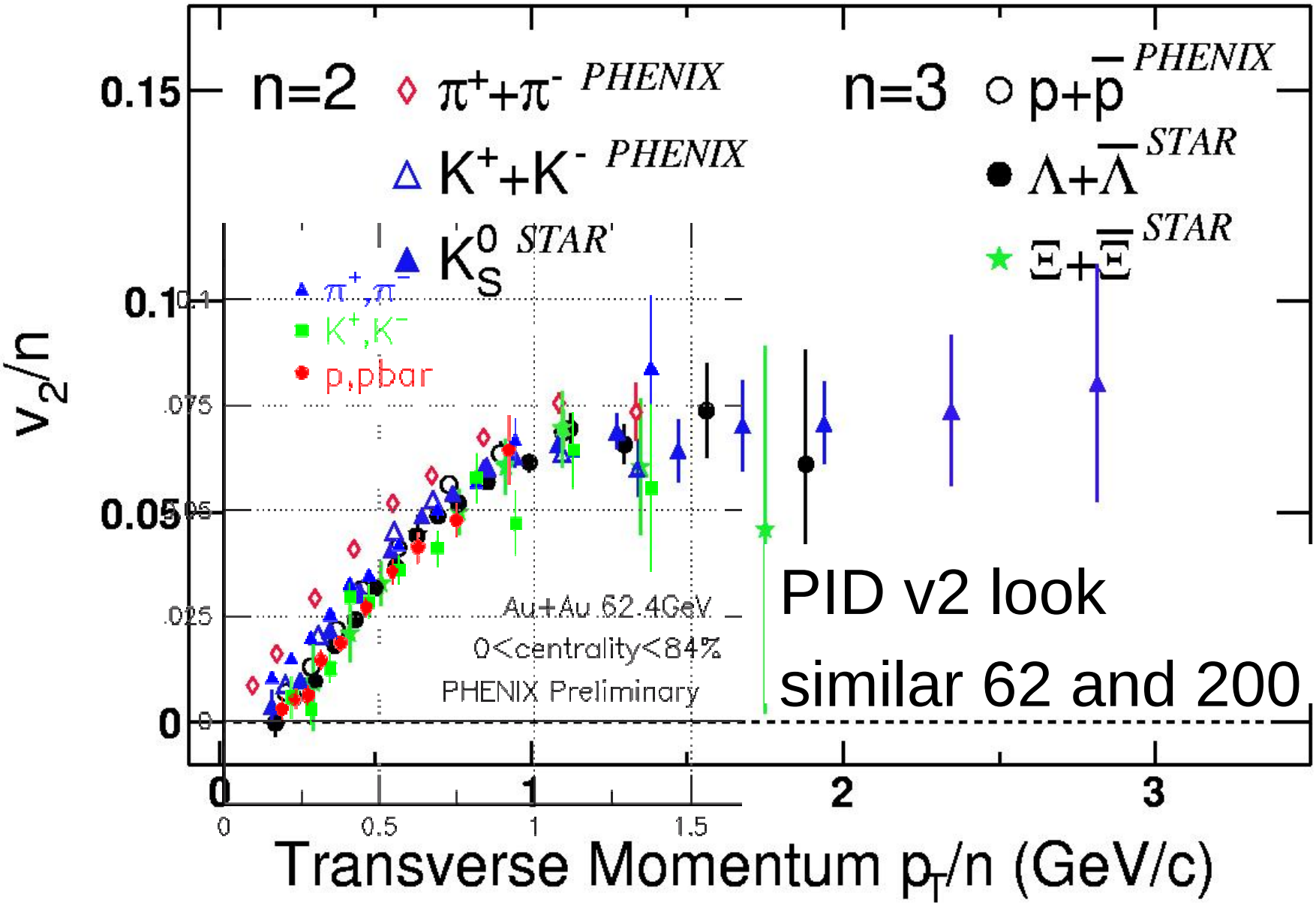
comparison with published 200GeV data

PID v2 at 62



- Need higher p_T data to tell if there is a plateau
- pion excess at low p_T as in 200 GeV data

Compare PID 200 and 62 GeV data



PID v2 look similar 62 and 200

The models- associated jet particles

Thermal quarks
Temperature + Flow

recombination of thermal quarks
should not give “jettiness”

recombination of thermal +
fragmentation quarks
should give jettiness

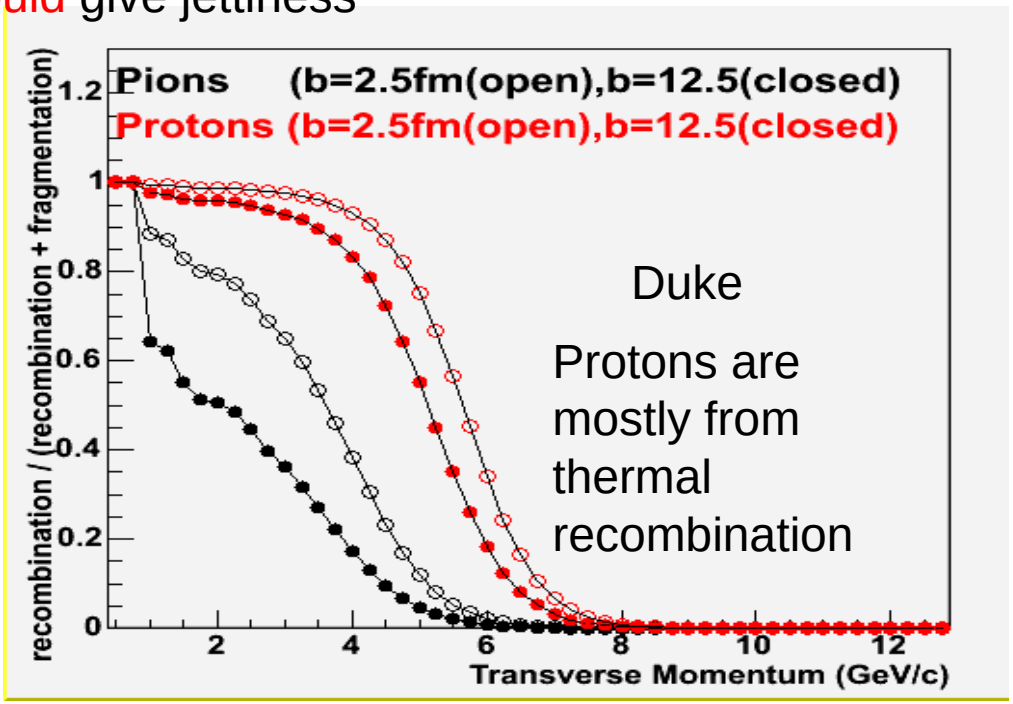
Hard quarks
pQCD calculation

fragmentation of hard quarks
should give jettiness

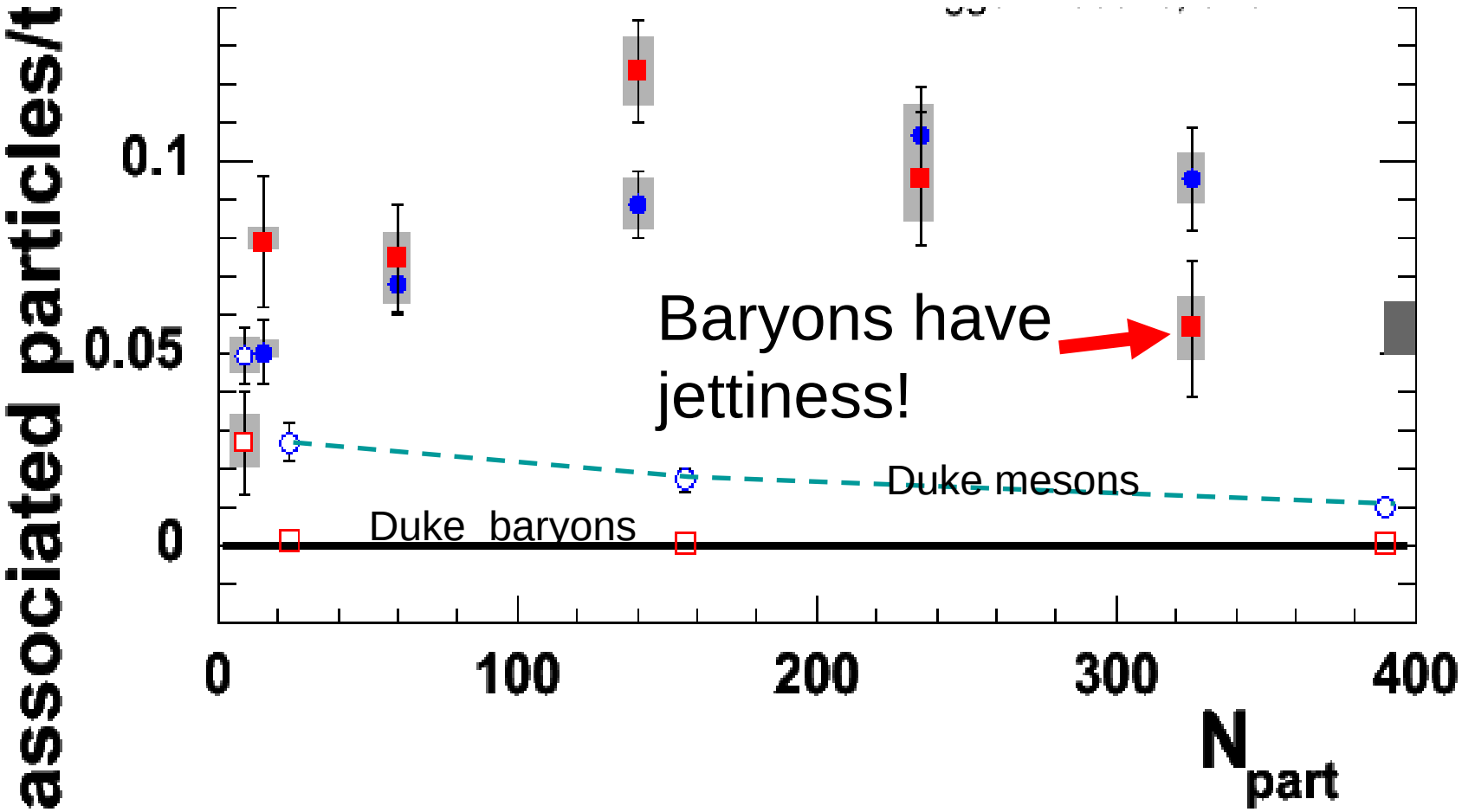
idea

PID Trigger particle
p_T=2.5-4 GeV

Associated particle
“jettiness”



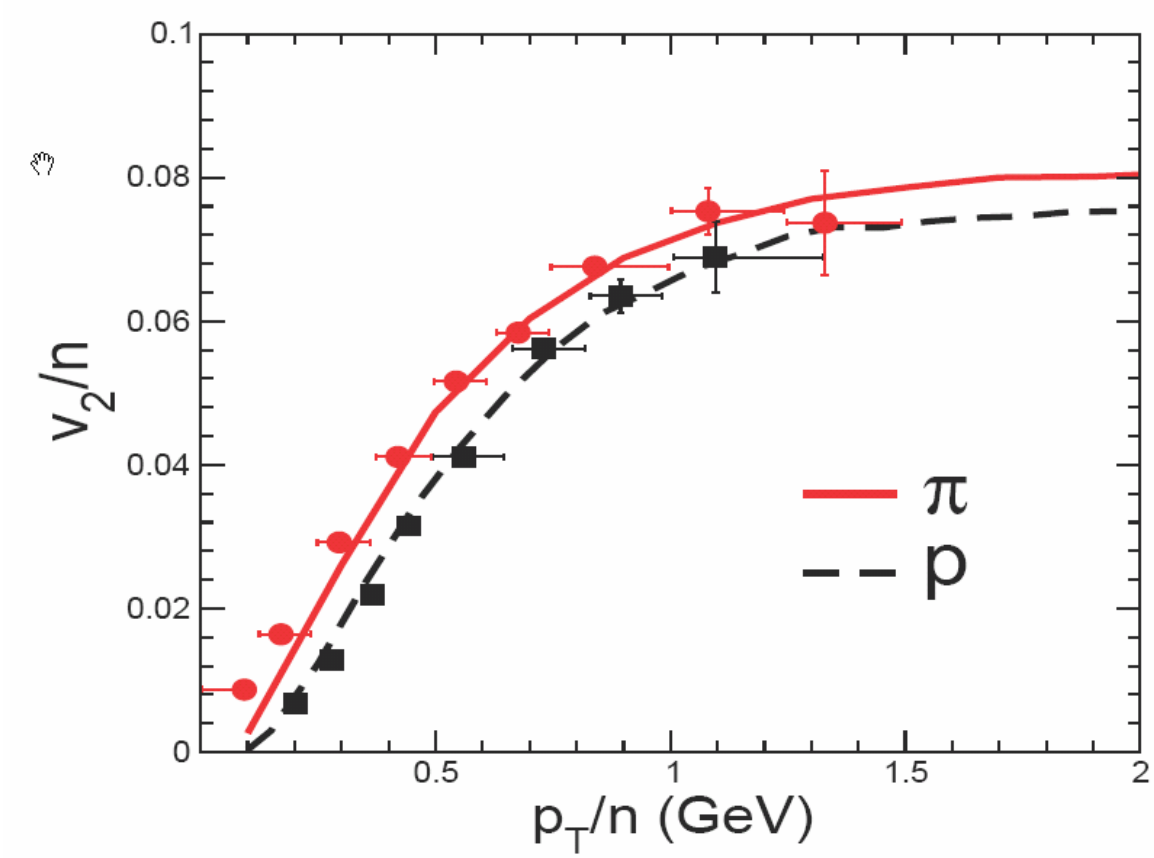
- Recombination of thermal quarks only is ruled out
- Requires recombination of thermal+hard quarks
- Will this destroy the agreement with v_2?



A more complex model (TAMU)

– TAMU adds hard+thermal
– Also adds decay of higher mass resonances

- V_2 still OK
- seems to explain the pion excess



Conclusions-Data

- p/π enhanced at intermediate p_T (200)
  - effect is less for 62
- h/π indicates it returns to baseline $p_T>5$
  - at 62 – need more data
- R_{CP} of ϕ ~ number of valence quarks, not mass
  - Hydro?
- v2 at 62 similar to 200
- baryons appear to have some jettiness

Conclusions – Recombination

- Can explain
  - Abundance of baryons at moderate pt
    - gets the return to baseline correct
  - The correlation of the strength of the elliptic flow with the number of valence quarks
  - The thermal nature of the spectrum (including flow) to higher p_T than one might expect

Challenges to recombination

- ASK - IS IT
  - fundamental flaw in the recombination or
  - detail of the implementation
- Data question: Jettiness of baryons
  - baryons as recombination of purely thermal quarks is ruled out except in the case of the most central collisions
- Conceptual questions
  - Low p_T
  - entropy
  - models assume constituent quarks, where does chiral symmetry breaking come in?
  - gluons?
- Practical question
  - Normalization between soft and hard component

Conclusions-Data⇔Recomb

- ✓ p/π enhanced at intermediate p_T(200)
  - effect is less for 62
- ✓ h/π indicates it returns to baseline p_T>5
  - at 62 – need more data
- ✓ Rcp of ϕ ~ number of valence quarks, not mass
  - Hydro?
- ✓ v2/n scales with p_T/n
  - 62 similar to 200
- ? baryons appear to have some jettiness