Charge asymmetry dependence of K v_2 in Au+Au collisions at STAR

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2016 RHIC & AGS Annual Users' Meeting
Jun 2016

BROOKHAVEN NATIONAL LABORATORY

STAR

SINAP

Outline

Introduction

The search of Chiral Magnetic Wave (CMW) at STAR

Why K v_2 ?

Results

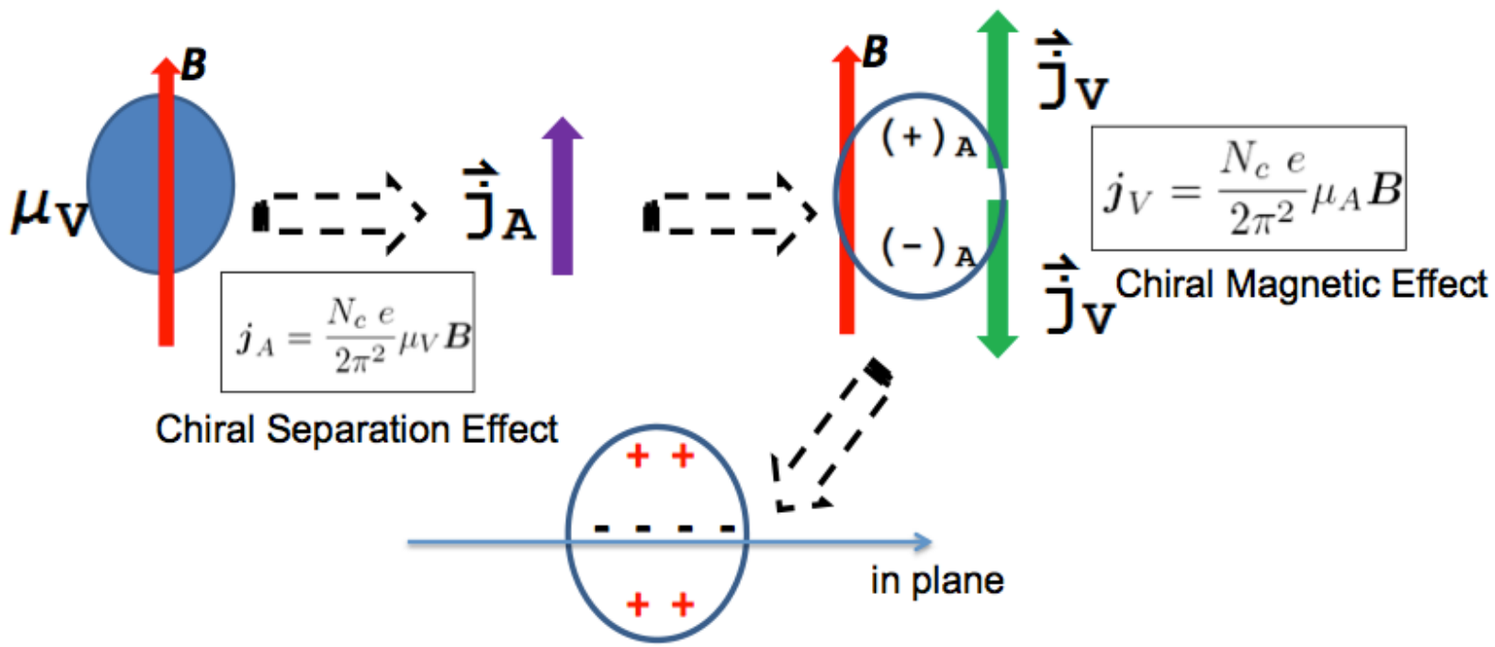
Charge asymmetry dependence of K v_2 in 200 GeV

Charge asymmetry dependence of K v_2 in 27, 39, 62 GeV

Summary

Chiral magnetic wave (CMW)

Theoretical



Experimental

$$\frac{dN_\pm}{d\phi} = N_\pm \left[1 + 2v_2 \cos(2\phi)\right]$$
$$\approx \bar{N}_\pm \left[1 + 2v_2 \cos(2\phi) \mp A_\pm r \cos(2\phi)\right]$$

$$\boxed{\Delta v_2^{\mathrm{CMW}} \equiv v_2(\pi^-) - v_2(\pi^+) \approx r A_\pm}$$

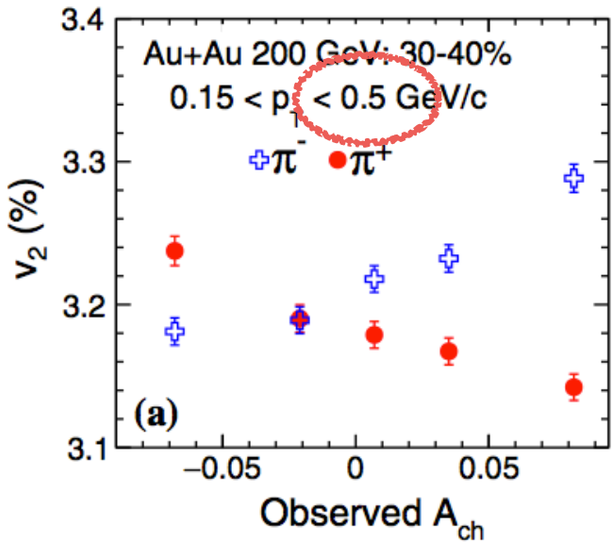
Y. Burnier, D. E. Kharzeev, J. Liao and H-U Yee, Phys. Rev. Lett. 107, 052303 (2011)

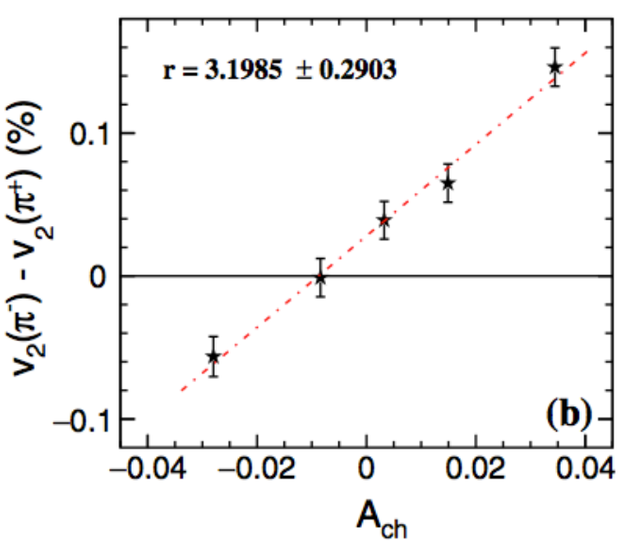
The measurement of CMW at STAR

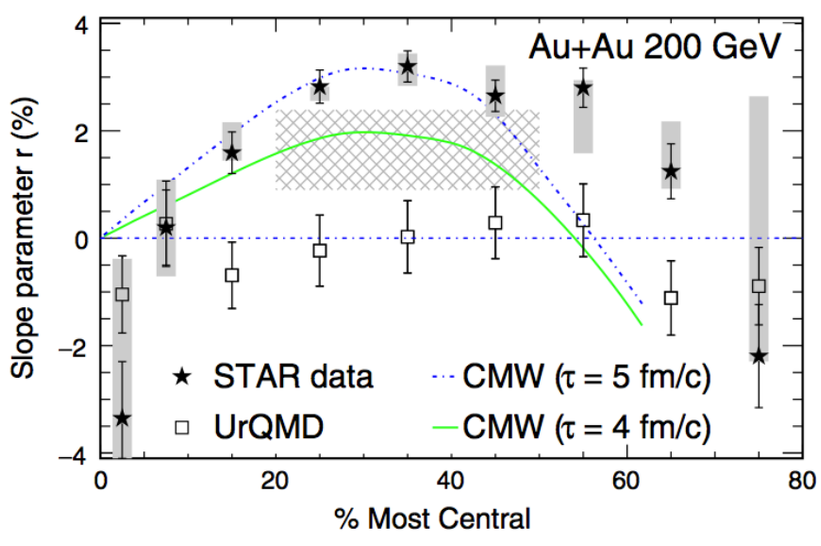
STAR Published

PRL 114, 252302 (2015) PHYSICAL REVIEW LETTERS week ending 26 JUNE 2015

Observation of Charge Asymmetry Dependence of Pion Elliptic Flow and the Possible Chiral Magnetic Wave in Heavy-Ion Collisions







CMW measurements are of high interest recently

π are suggested to be the best probe to study CMW

Why use K to test CMW?

- Pions are suggested to be the best probe to study CMW

> *"We think the main contribution should come from pions… However at this point we cannot make definite statements about the ratios protons to pions or kaons to pions"*
>
> ***— D.E. Kharzeev et al. Nuclear Physics A 803 (2008) 227–253***

> *"… the large differences in the absorption cross sections… of negative and positive kaons in hadronic matter at finite baryon density, are likely to mask or reverse this difference in the hadron resonance "afterburner" phase of a heavy ion collision…"*

> *"… the smaller difference in the absorption cross sections of negative and positive pions potentially may make it possible to detect the electric quadrupole moment of the plasma through the difference of elliptic flows of pions"*
>
> ***— Y. Burnier et al. Phys. Rev. Lett. 107, 052303 (2011)***

- Kaons serve as an important check

  Can strange quark be affected by chiral effect?

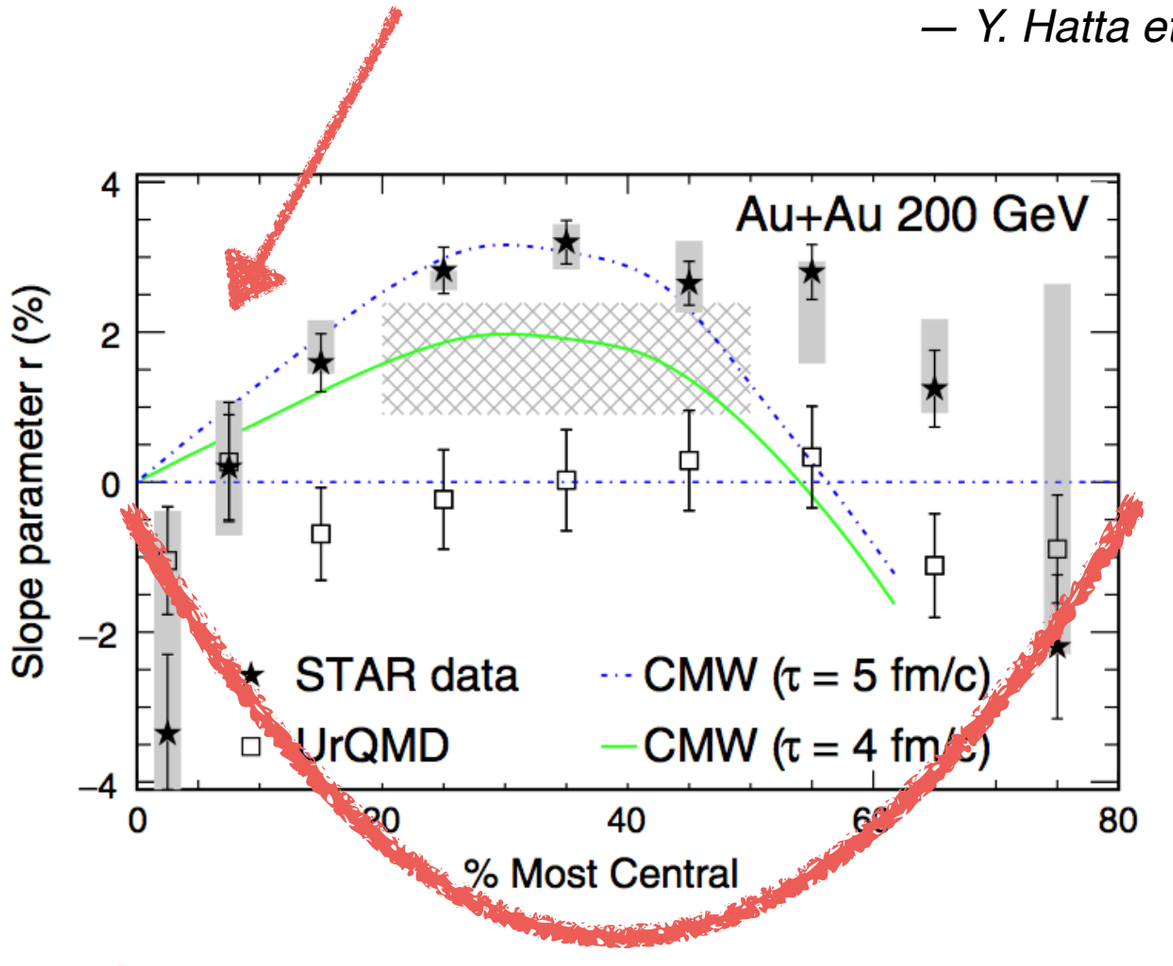
  Does the large difference in absorption cross section affect the measurement?

Why use K to test CMW?

"… We demonstrate that the STAR results can be understood within the standard viscous hydrodynamics without invoking the CMW…"

"… the slope r for the kaons should be negative, in contrast to the pion case, and the magnitude is expected to be larger… Note that in these predictions are integrated over $0 < p_T < \infty$. In order to properly test them, a wider p_T coverage is necessary…"

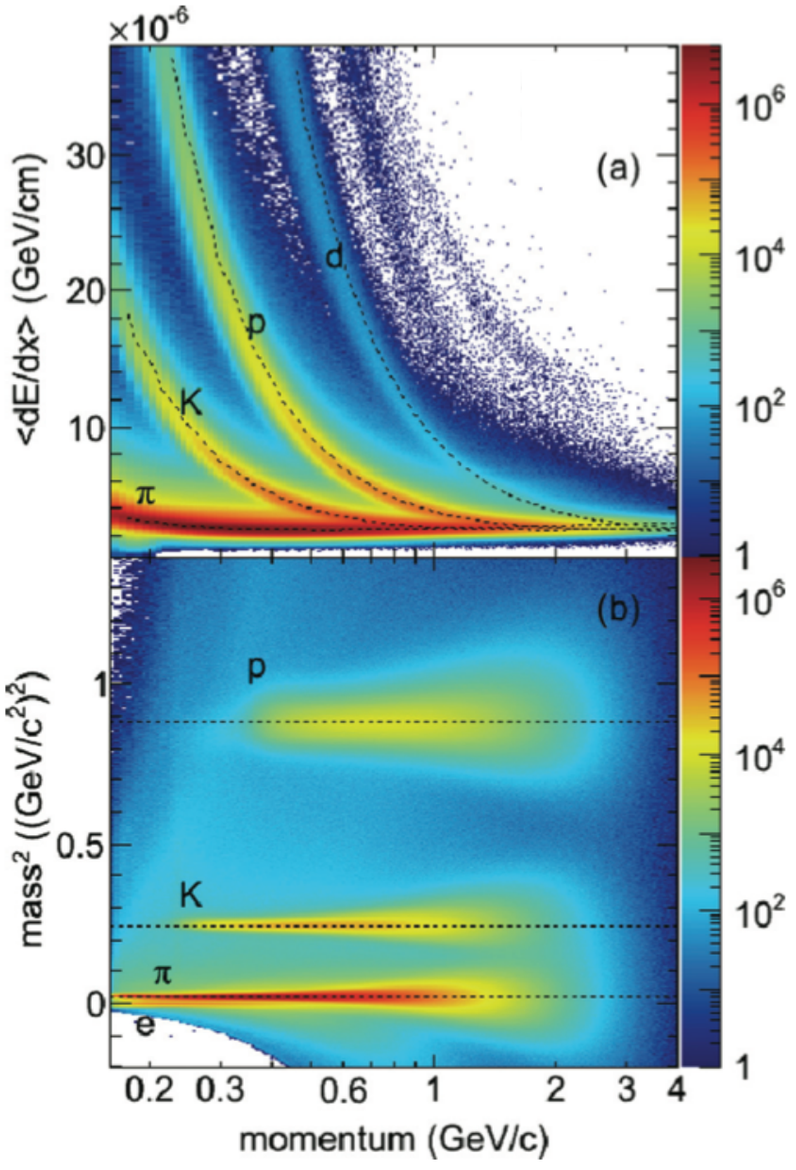
— Y. Hatta et al. Nuclear Physics A 947 (2016) 155–160

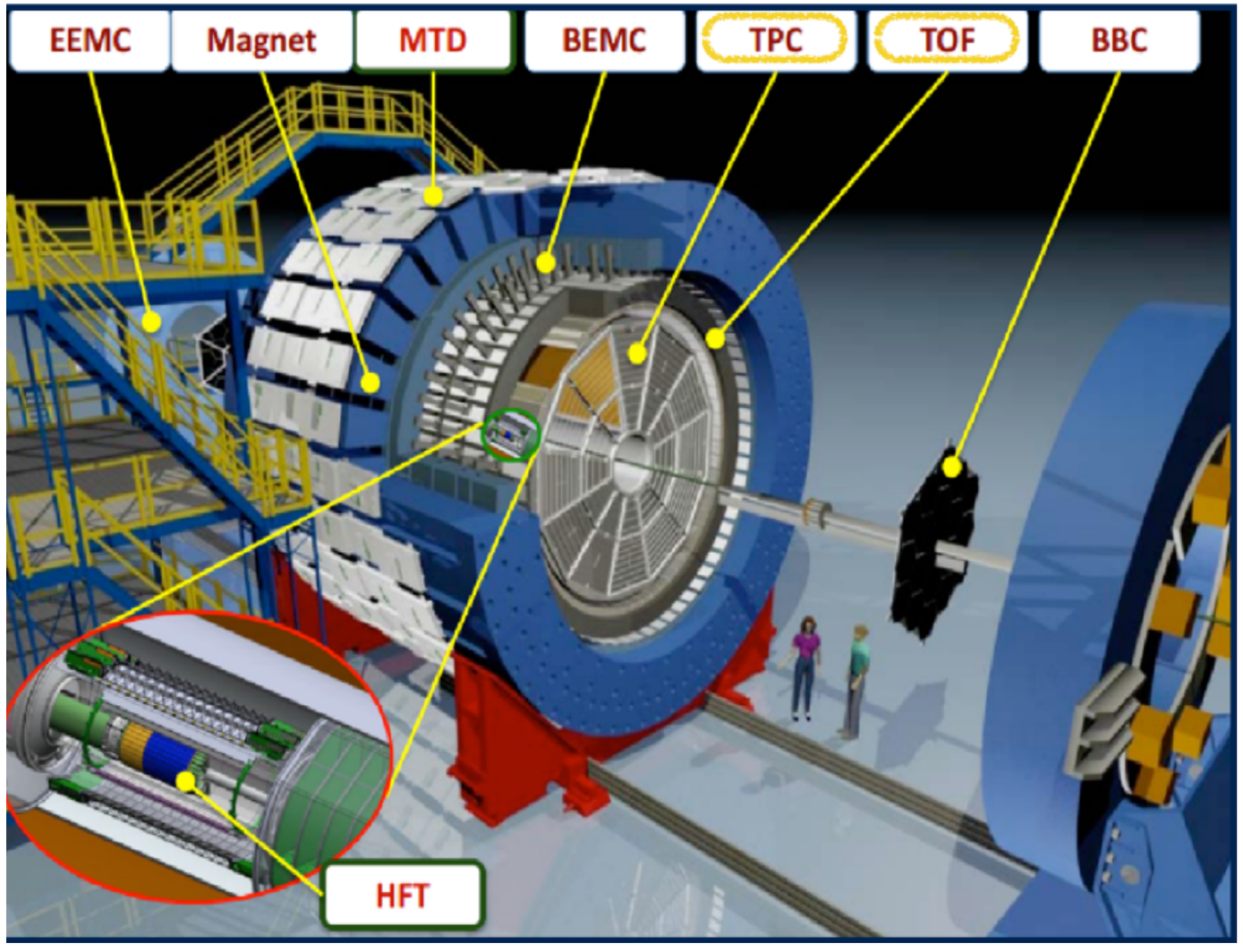


Hydrodynamics study suggests that, with wider p_T coverage, K slope should be opposite to π slope with larger magnitude, since

$$v_2(\pi+) < v_2(\pi-)$$
$$v_2(K+) > v_2(K-)$$

RHIC-STAR


×10^-6
<dE/dx> (GeV/cm)
30
20
10
(a)
d
p
K
π
10^6
10^4
10^2
1
(b)
mass² ((GeV/c²)²)
1
0.5
0
p
K
π
e
0.2 0.3 0.6 1 2 3 4
momentum (GeV/c)


EEMC
Magnet
MTD
BEMC
TPC
TOF
BBC
HFT

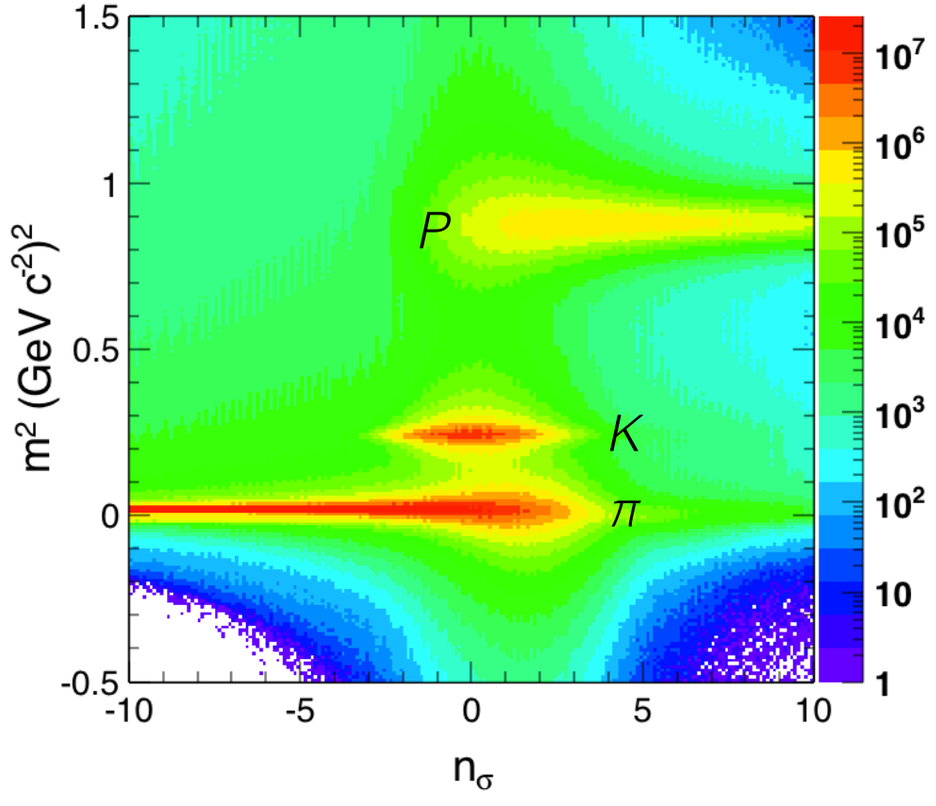
Analysis strategy

- For each event:
  calculate A_{ch}, v_2

- For the whole data sample:
  A_{ch} correction, extract linear relationship and slope, error estimation

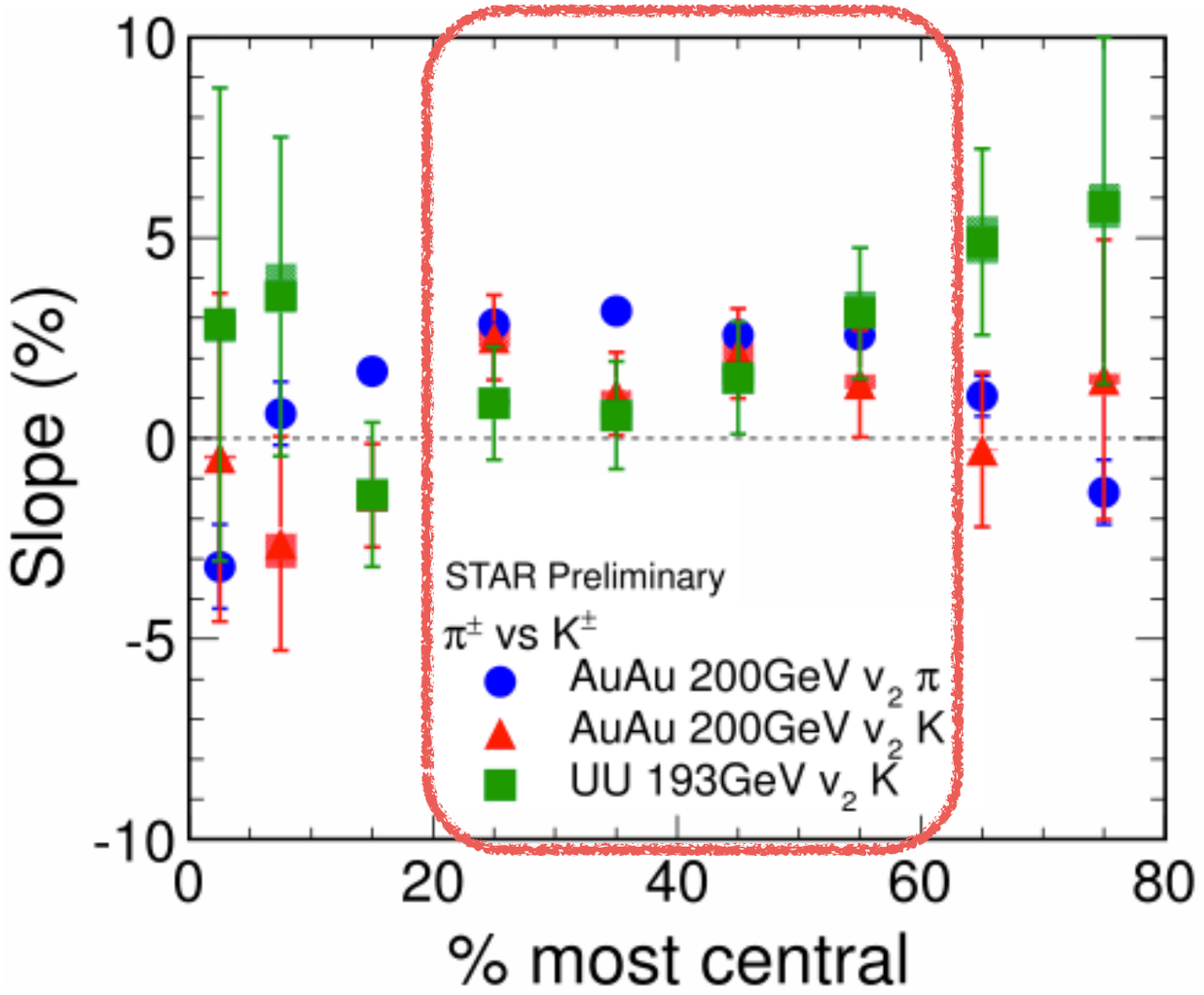
- A_{ch}: $|\eta| < 1$, DCA < 1 cm,
  low p_T (anti)proton removed

- v_2: Q-Cumulants method (2 sub-events)
  with 0.3 η gap between POI and RFP
  PID(π, K) is applied by TPC+ToF



Previous Kaon result at STAR (presented in SQM2013, QM2014)

Q.-Y. Shou [for the STAR Collaboration], Nuclear Physics A 931, 758 (2014)



$(0.15 < p_T(K) < 0.5$ GeV/c)

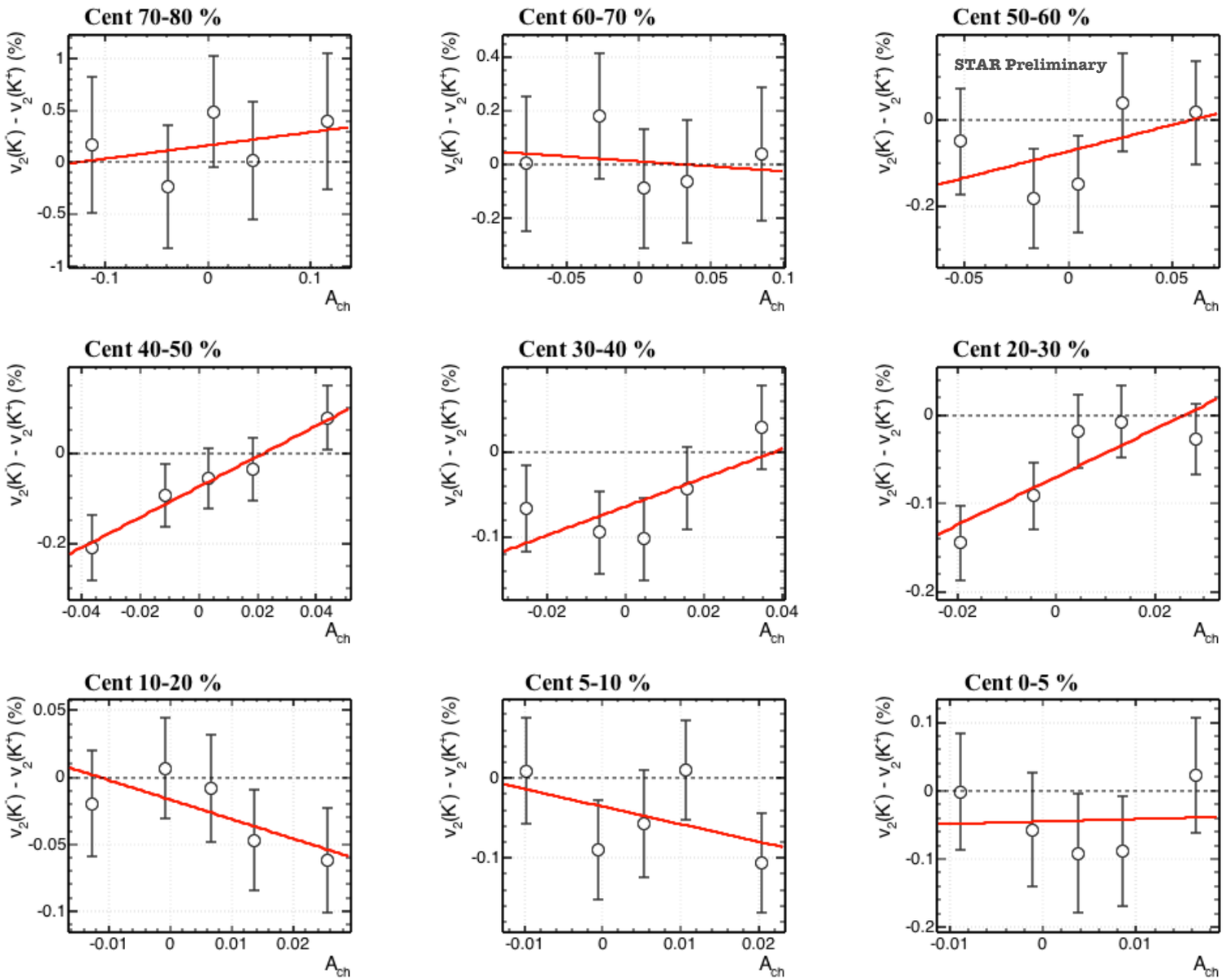
Our previous point:
combining mid-central bins (20-60%)
slightly above zero
within CMW prediction

Biggest issue: statistics

"… given the narrow coverage in p_T they are not sufficient to draw firm conclusions."

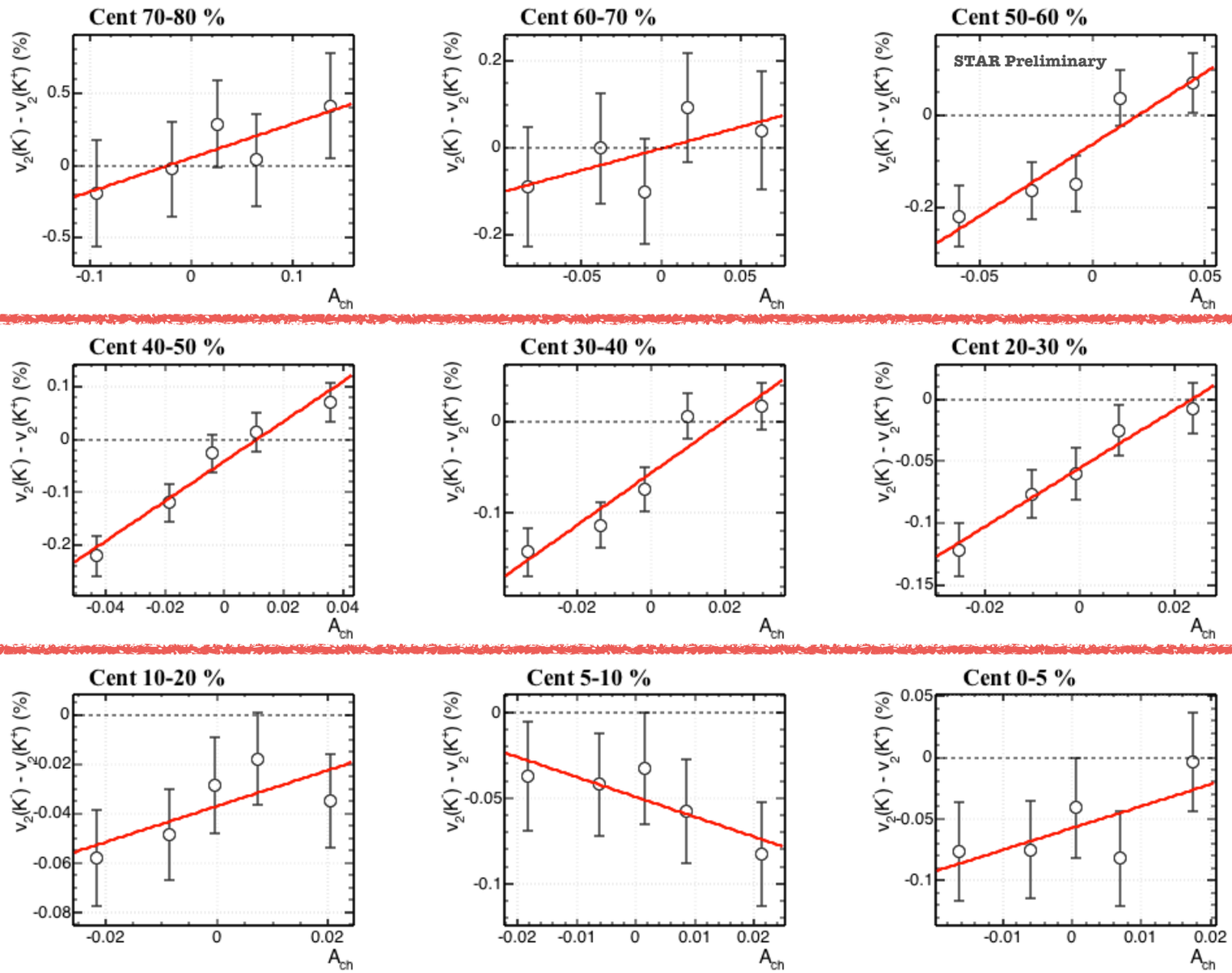
— Y. Hatta et al. Nuclear Physics A 947 (2016) 155–160

Previous Kaon result at STAR



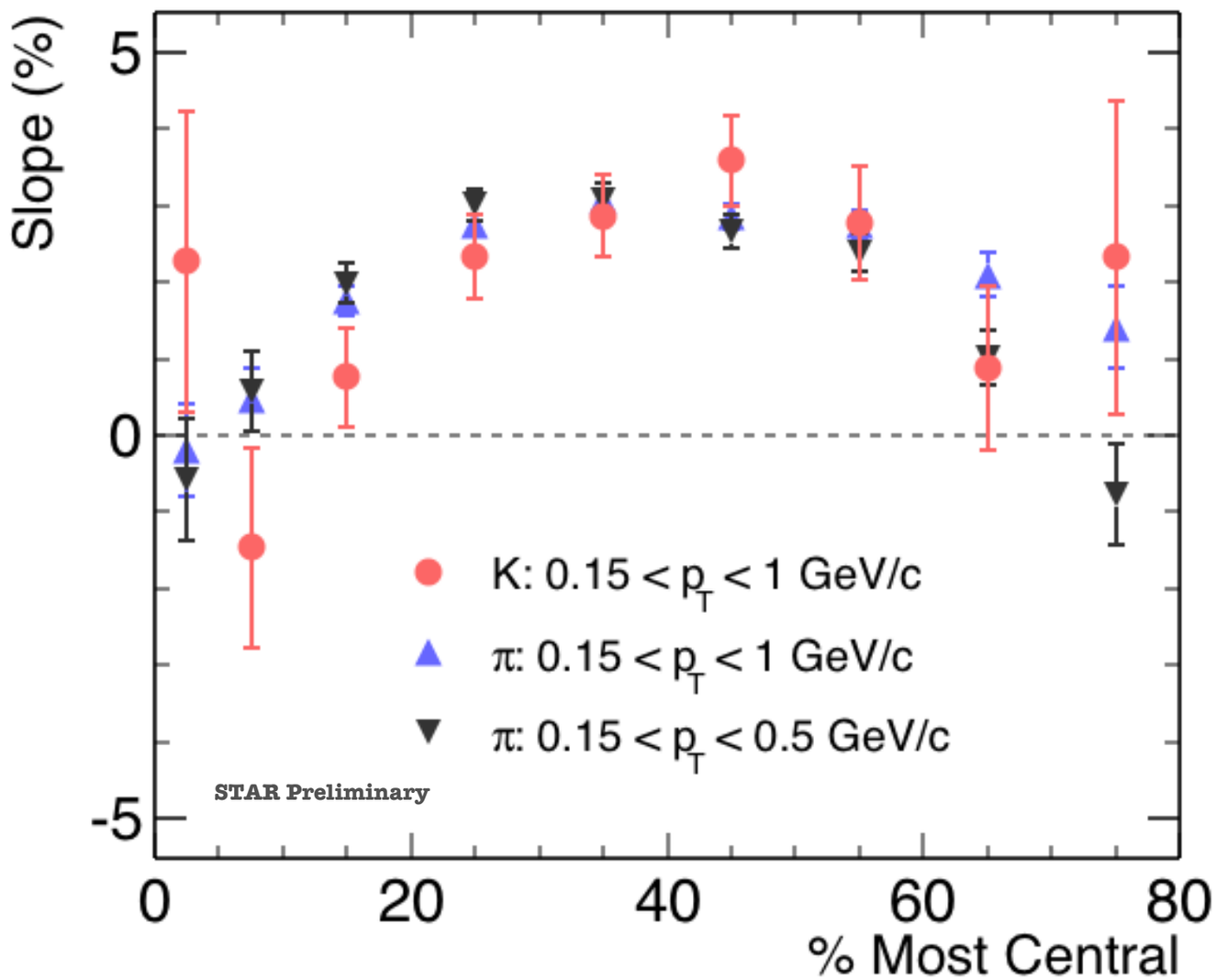
(0.15 < p_T(K) < 0.5 GeV/c) Fitting with large uncertainties

If p_T upper limit goes to 1 GeV/c



Comparing with preliminary results, linear relationship largely improved with negative intercept

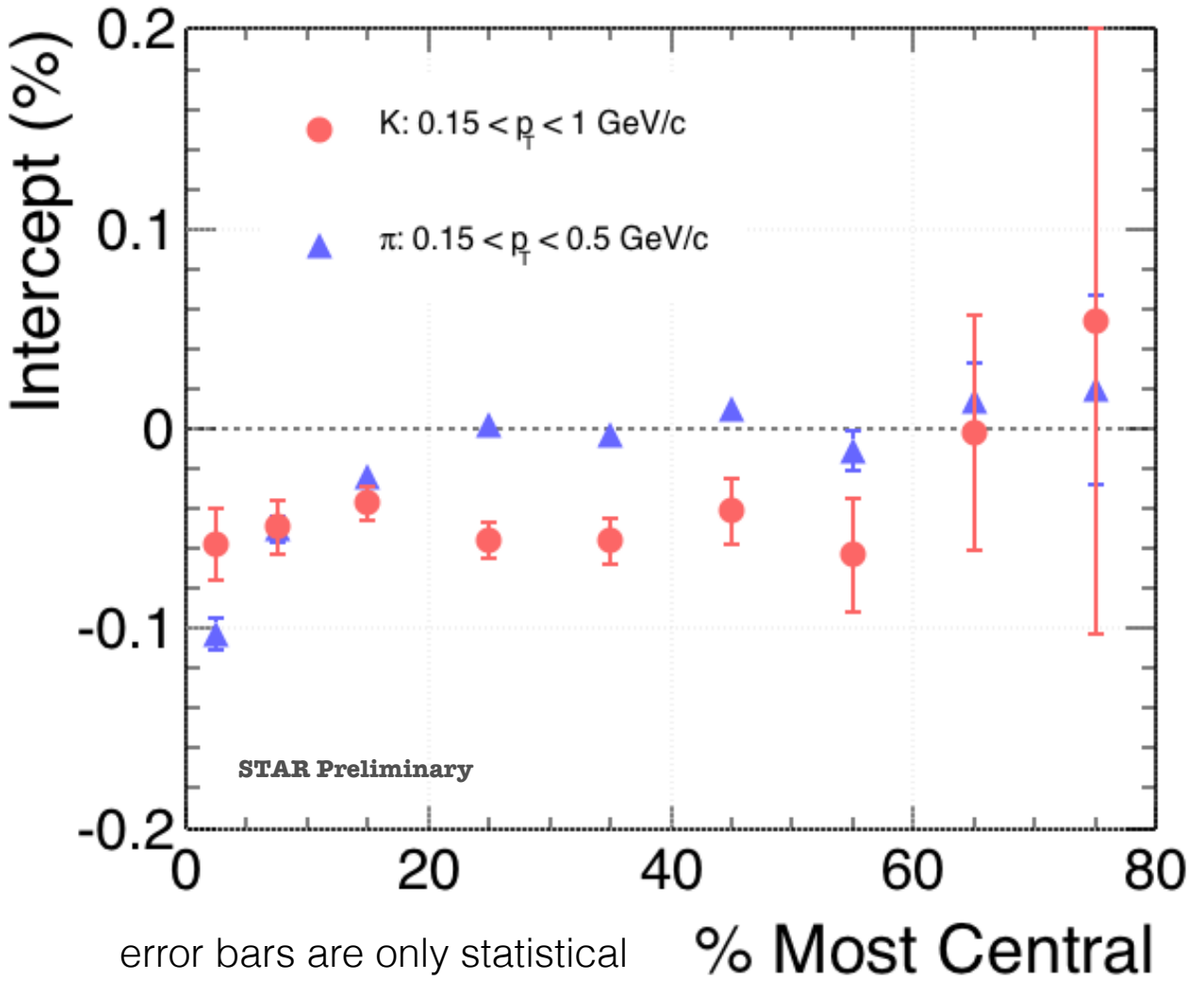
Slope(K) in $\sqrt{s_{NN}}$ 200 GeV



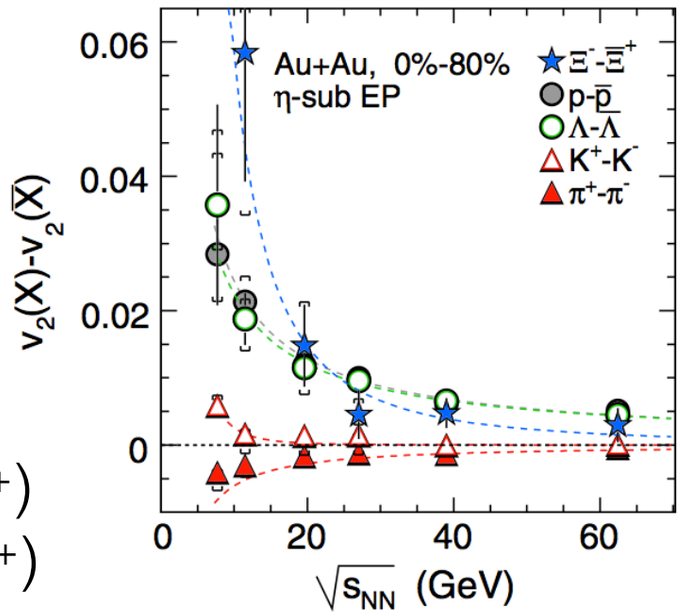
Centrality dependence of slope parameters for K behave similarly to that of π, indicating that K could be another possible probe?

error bars are only statistical

Intercept(K) in $\sqrt{s_{NN}}$ 200 GeV



error bars are only statistical



We know
$v_2(\pi^-) > v_2(\pi^+)$
$v_2(K^-) < v_2(K^+)$

so both

Slope (>0)

$v_2(\pi^-) - v_2(\pi^+) = v_2^{\pi}(\text{base}) + rA_{ch} > 0$
$v_2(K^-) - v_2(K^+) = v_2^{K}(\text{base}) + rA_{ch} < 0$

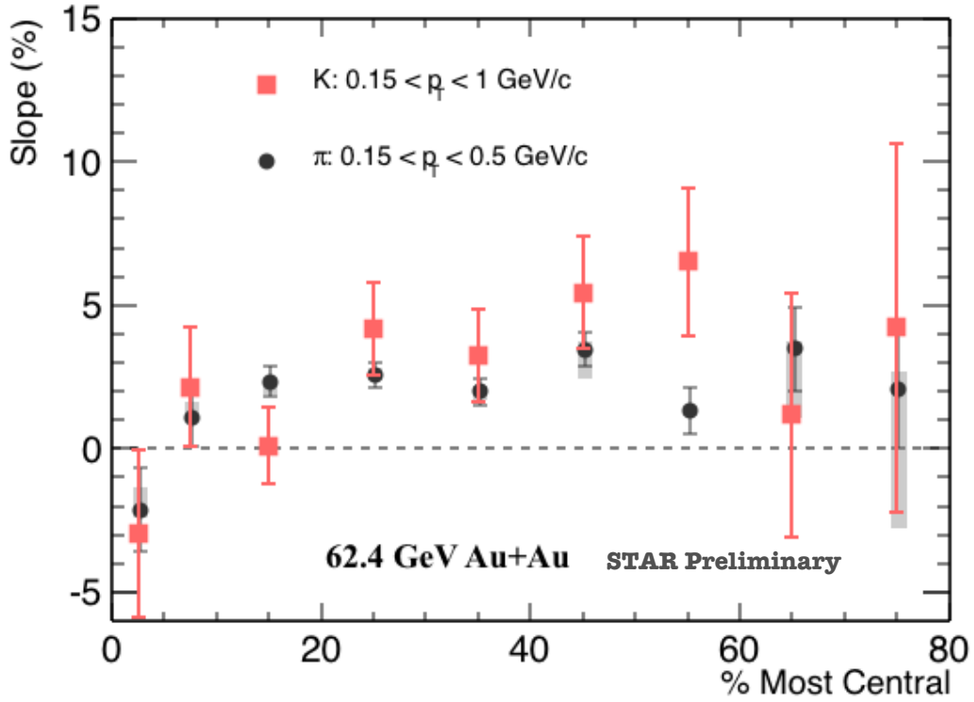
Intercept

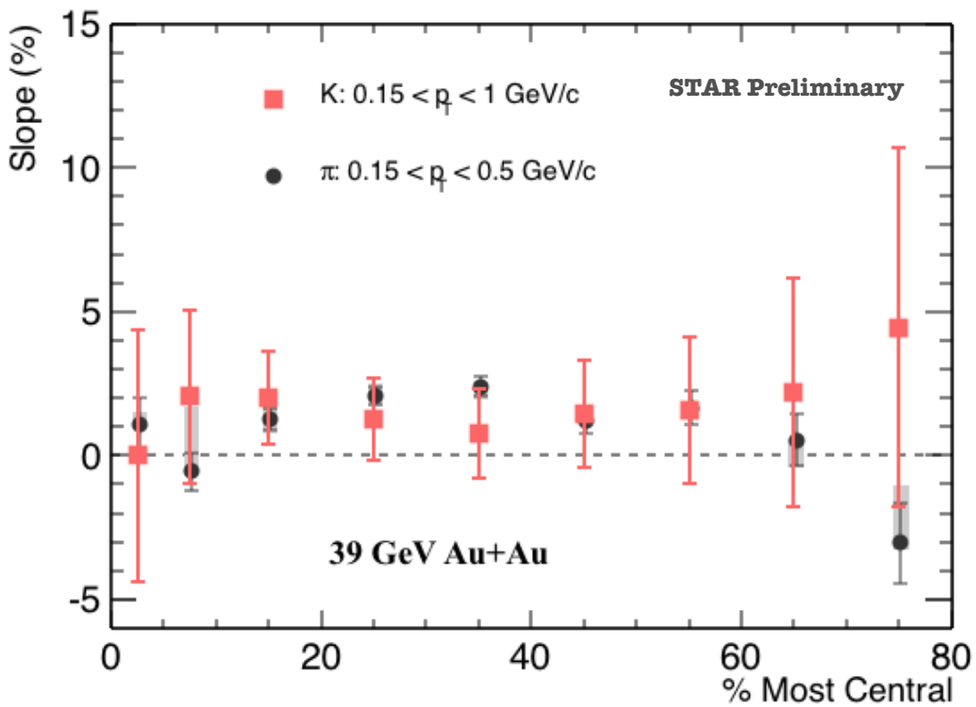
are valid

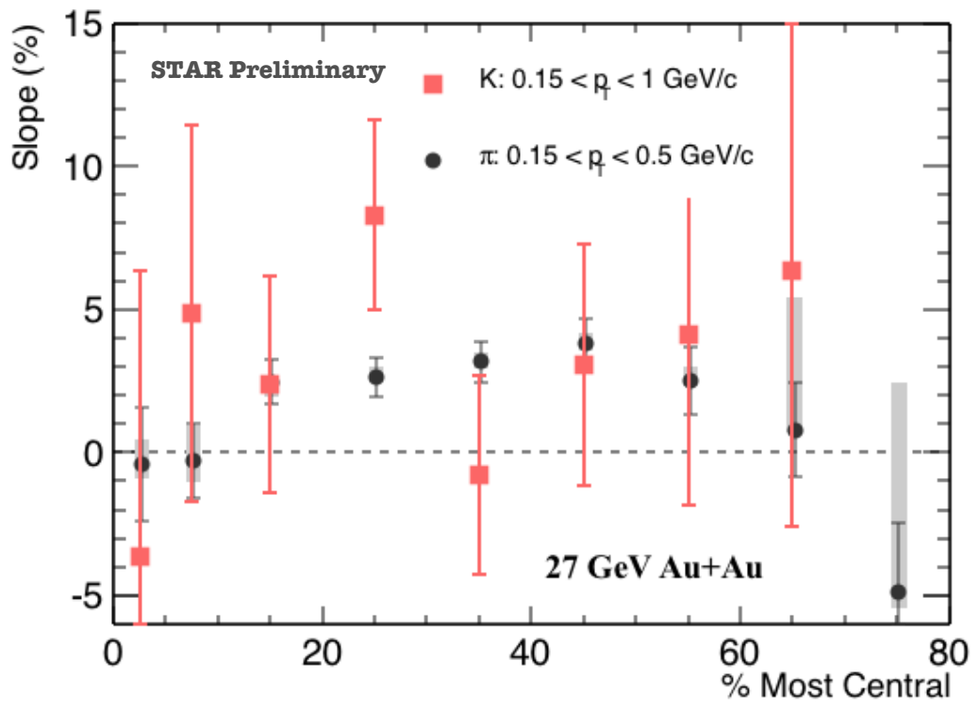
Does this observation conflict with our knowledge of (anti-)particle flow?
No, since the intercepts are negative.

L. Adamczyk et al. (STAR Collaboration) Phys. Rev. Lett. 110, 142301 (2013)

Slope(K) in $\sqrt{s_{NN}}$ 62.4, 39, 27 GeV



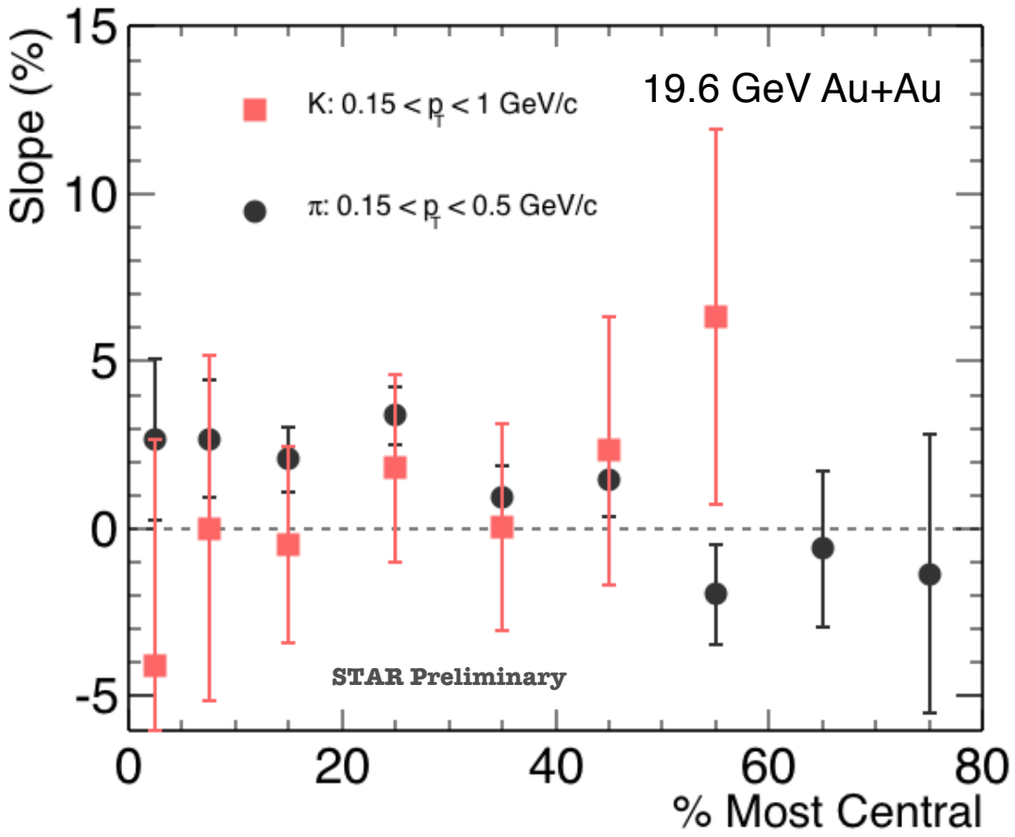


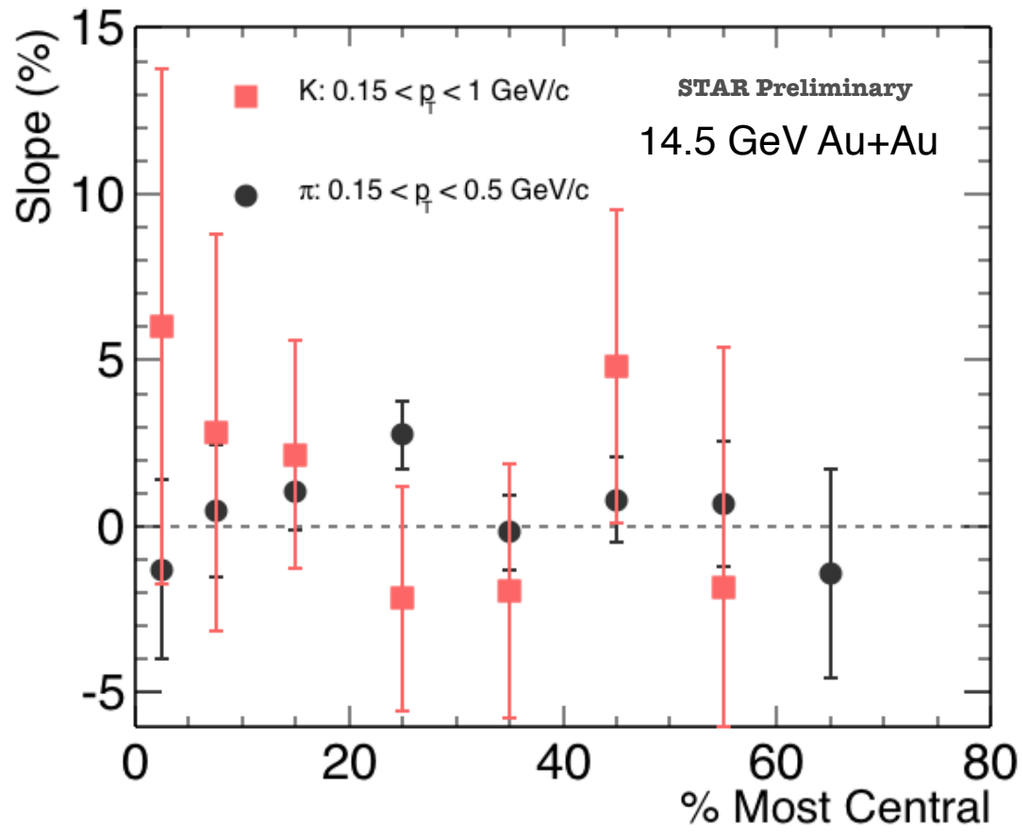


Within errors, slope(K) are consistent with the published slope(π), particularly in semi-central collisions

error bars are only statistical
shaded band (π) are systematical error, including track efficiency, DCA, Δv_2 calculation/extraction method

Raw slope(K) in $\sqrt{s_{NN}}$ 19.6, 14.5 GeV





In $\sqrt{s_{NN}}$ 14.5, 19.6 GeV, slope(K) fluctuate with large errors
In $\sqrt{s_{NN}}$ 7.7, 11.5 GeV, statistics are too low to extract useful information for K

error bars are only statistical
raw slope - no A_{ch} correction applied

Summary

- The linear relationship between A_{ch} and Δv_2(K) (with widened p_T range) are studied in Au+Au collisions in different energies, which are quite similar to the case of π

- In 200 GeV collisions, the centrality dependence of slope(K) (with widened p_T range) shows the same behavior as that of π, in both trend and order of magnitude

- In 27~62.4 GeV collisions, particularly in semi-central collisions, slope(K) (with widened p_T range) are consistent with slope(π) within the uncertainties. At energies less than 27 GeV, due to the statistics, it's hard to draw solid conclusion so far.

- This observation doesn't conflict with our knowledge of (anti-)particle flow since the intercepts are negative.

Thank you for your attention!

Backup

Data selection

- 200 GeV (Run10, Run11), 62.4 GeV (Run10), 39 GeV(Run10), 27 GeV(Run11) 19.6 GeV (Run11), 14.5 GeV (Run14), 11.5 GeV (Run10), 7.7 GeV (Run10)

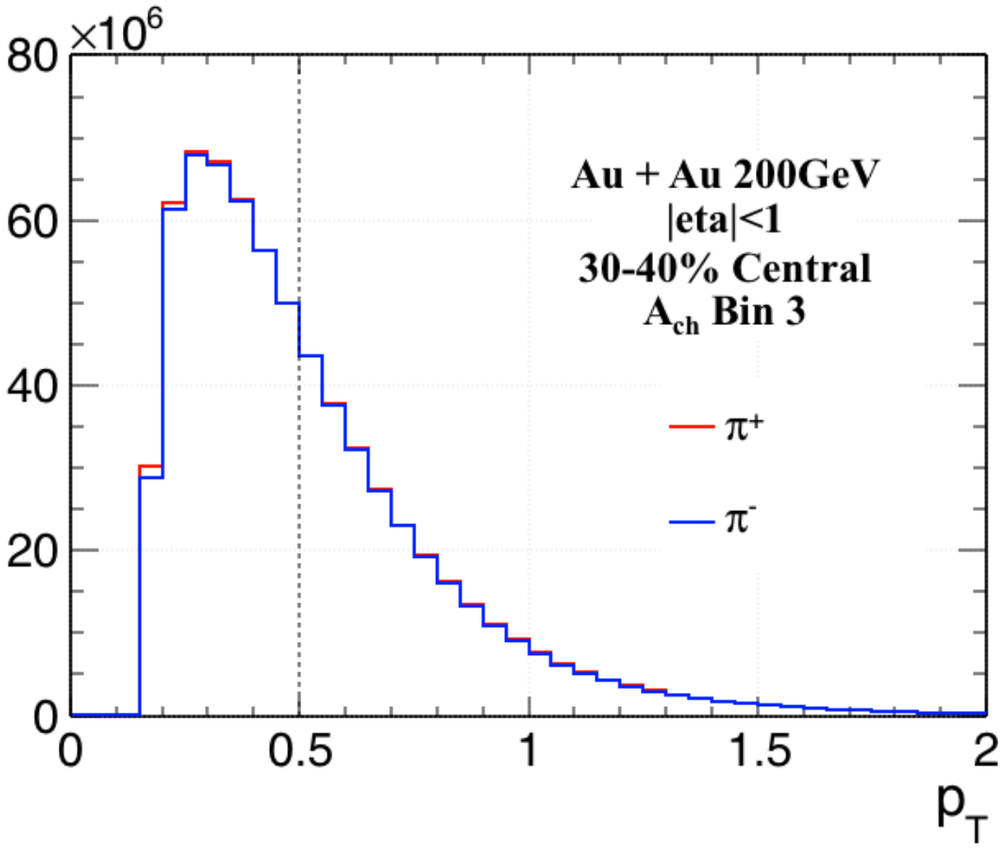
- Event: MB trigger, Vz < 30 cm, Vr < 2 cm

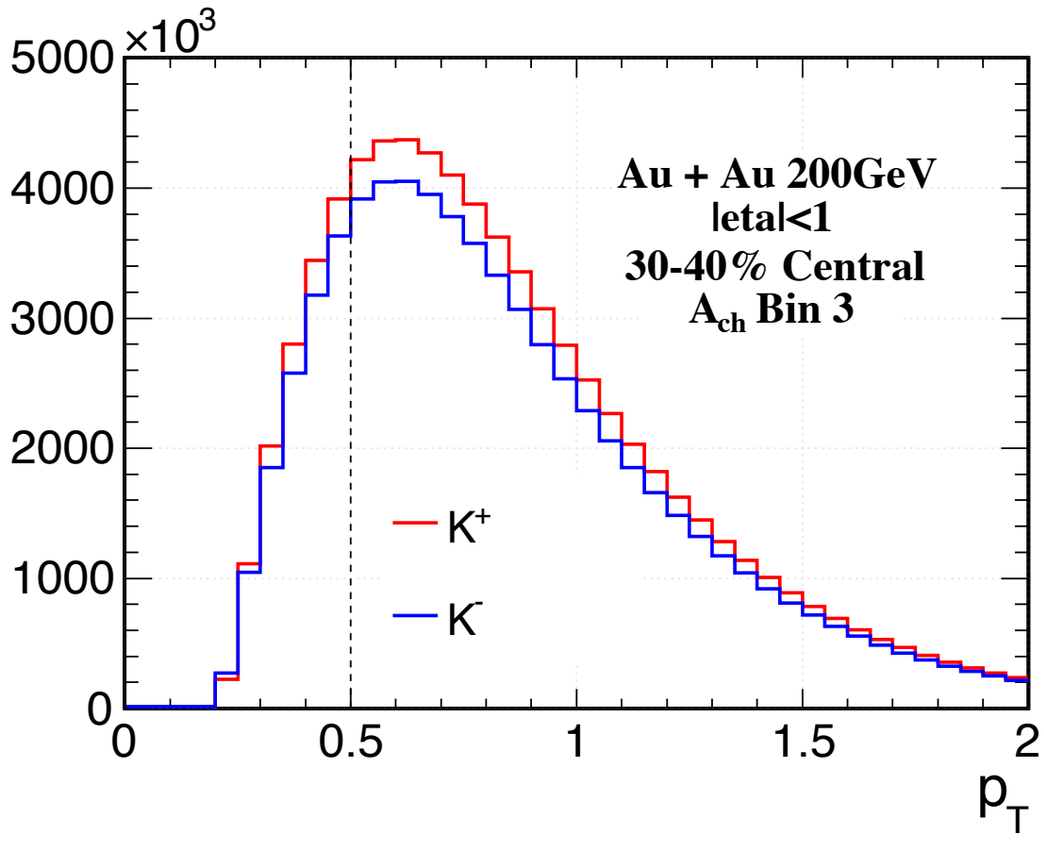
- A_{ch}: $|\eta| < 1$, DCA < 1 cm, low p_T (anti)proton removed ($|n\sigma|<3$)

- v_2: Q-Cumulants method (2 sub-events) with 0.3 η gap between POI and RFP PID(π, K) is applied by TPC+ToF in all p_T

π p_T spectra

K p_T spectra

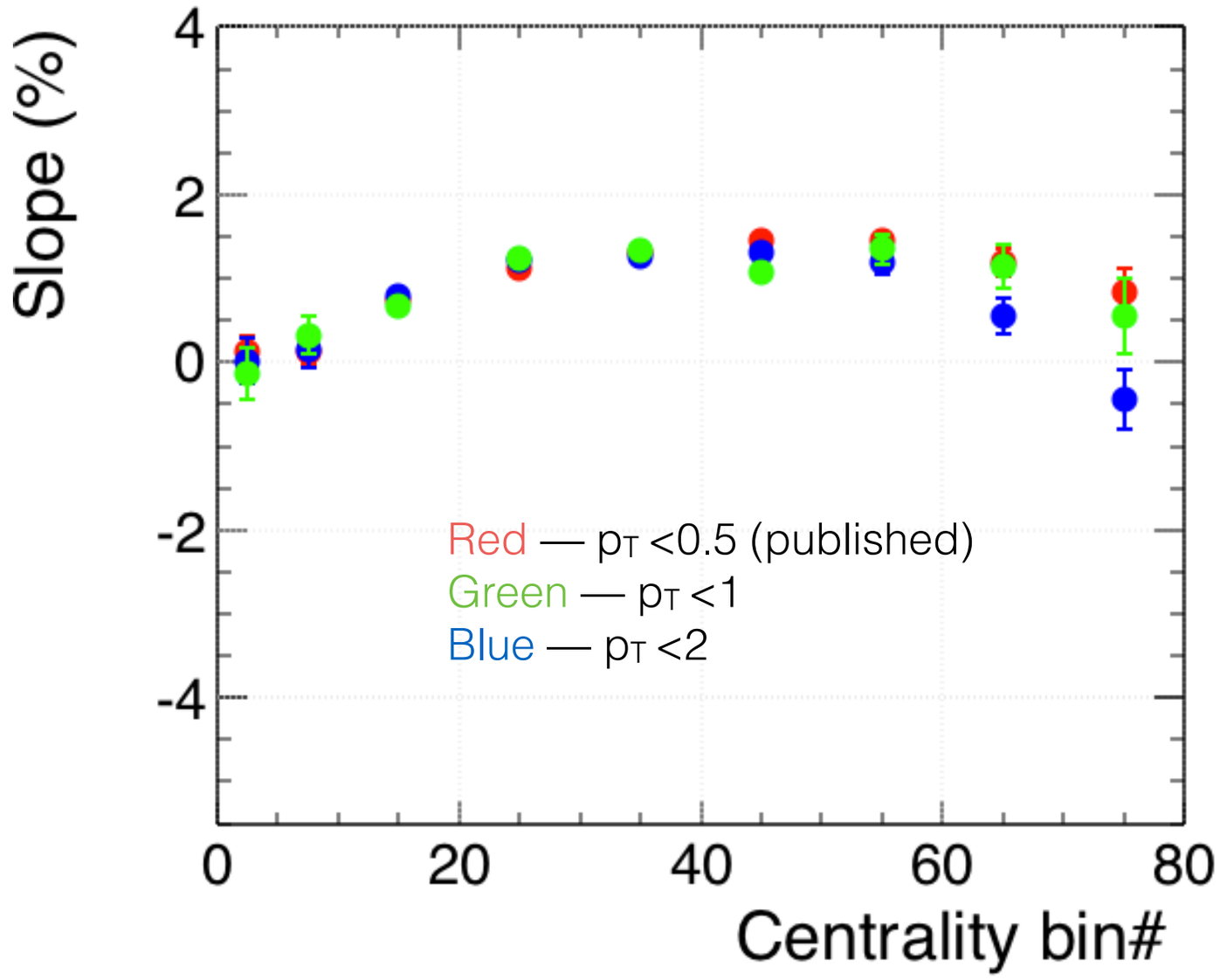




p_T cut at 0.5 already includes most of π,
but not enough for K

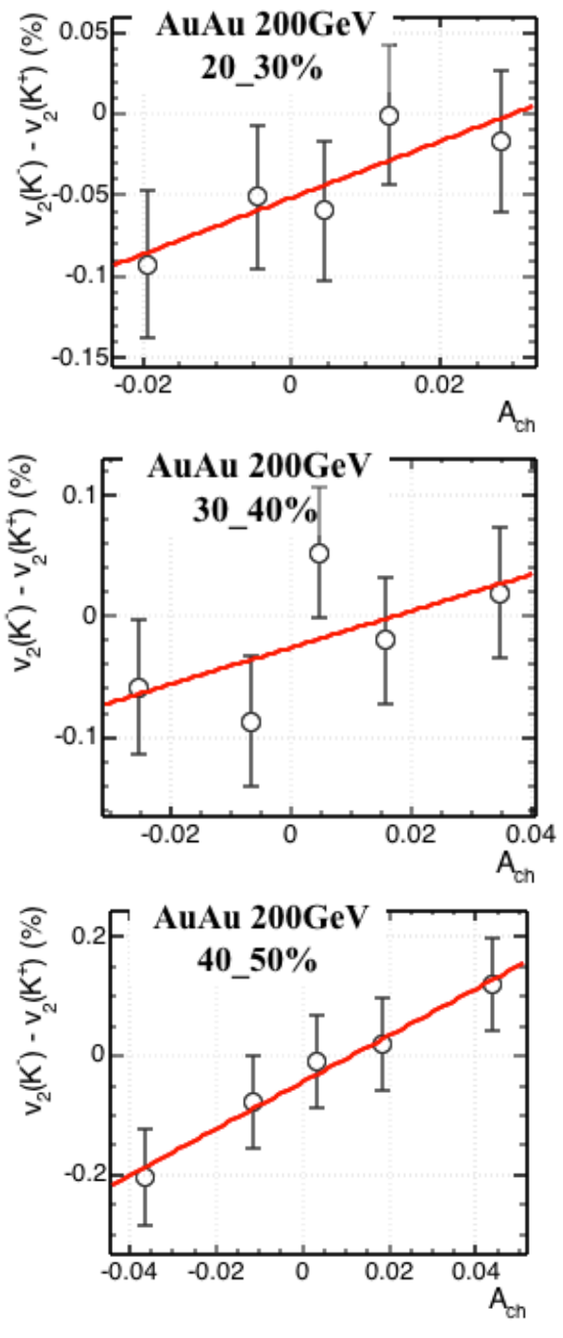
PID: TPC+TOF for all p_T range

Raw slope(π, various p_T) in $\sqrt{s_{NN}}$ 200 GeV

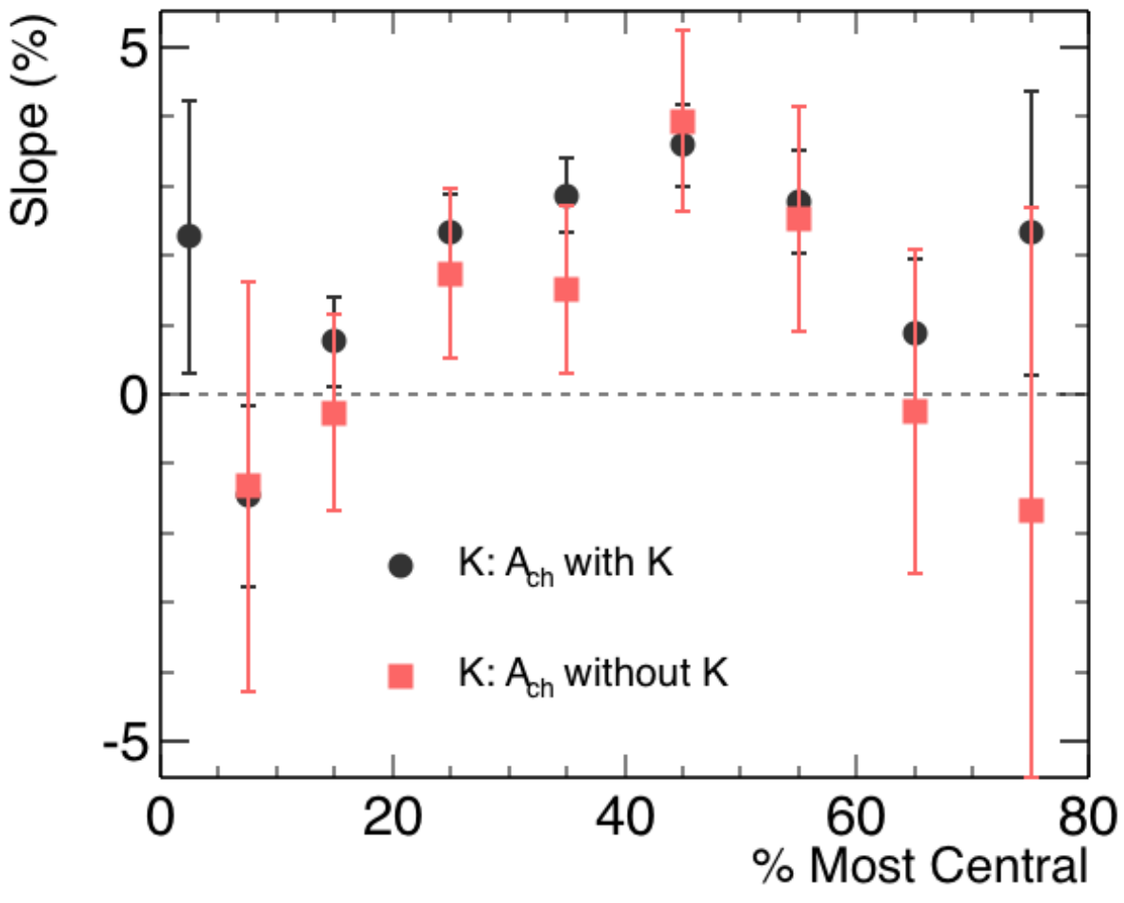


Changing p_T range doesn't effect slope results,
since p_T cut at 0.5 already includes most of π

Test of autocorrelation



$\sqrt{s_{NN}}$ 200 GeV, $p_T(K)$ ~ (0.15, 1) GeV/c

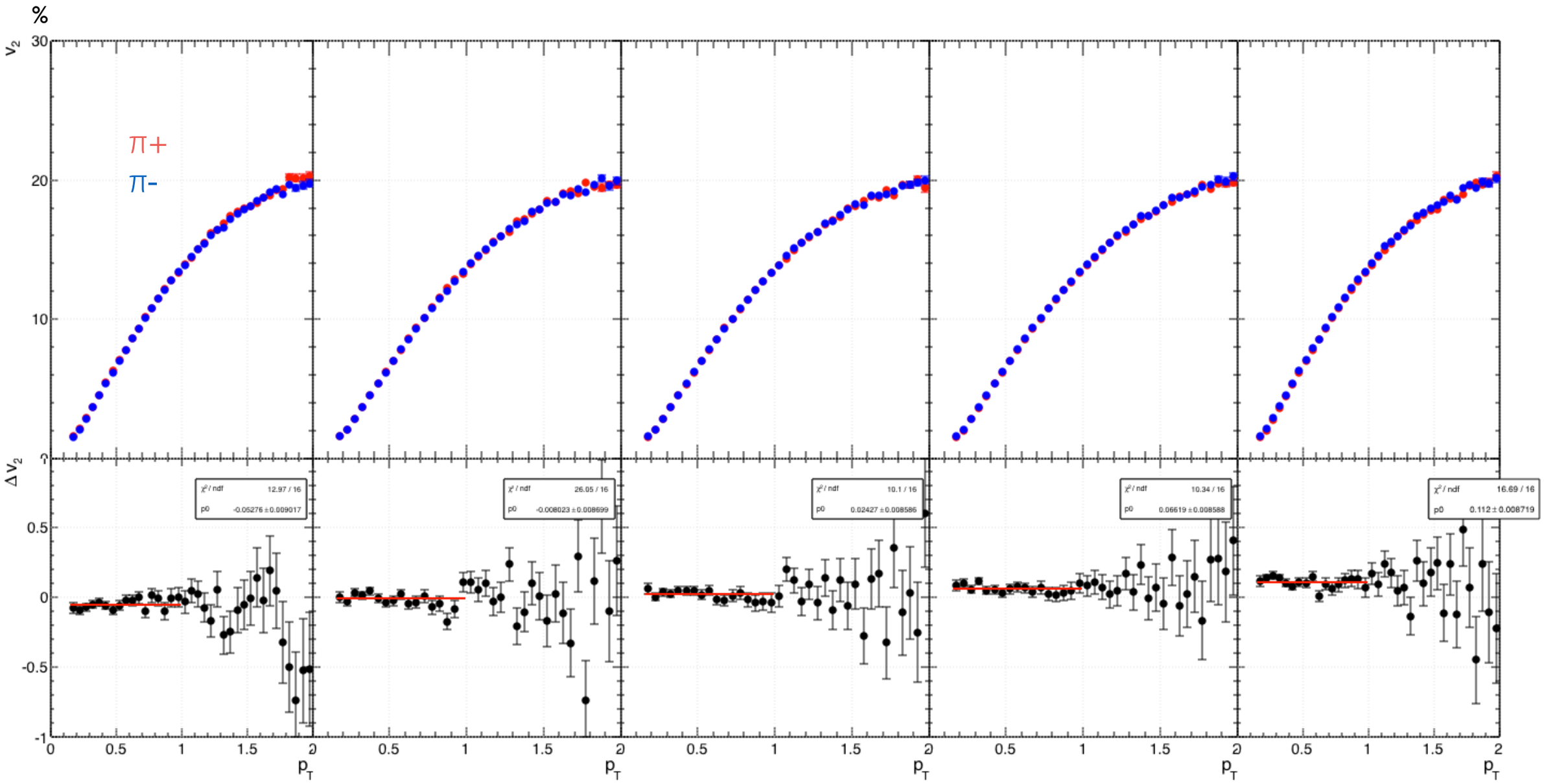


To test trivial autocorrelation between A_{ch} and v_2, K are removed when calculating A_{ch}

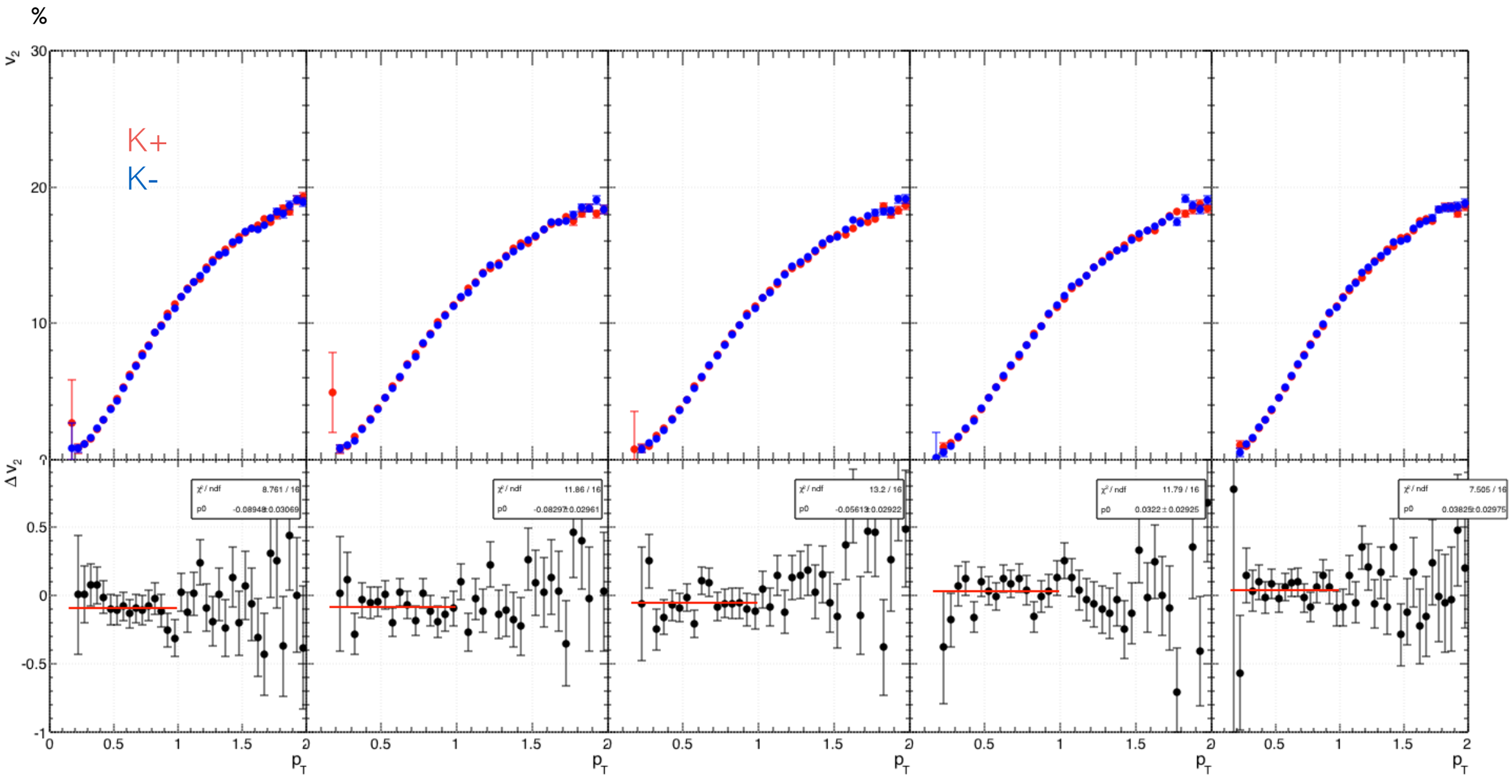
- The linear relationship can still be observed
- Centrality dependence of slope doesn't change much

error bars are only statistical

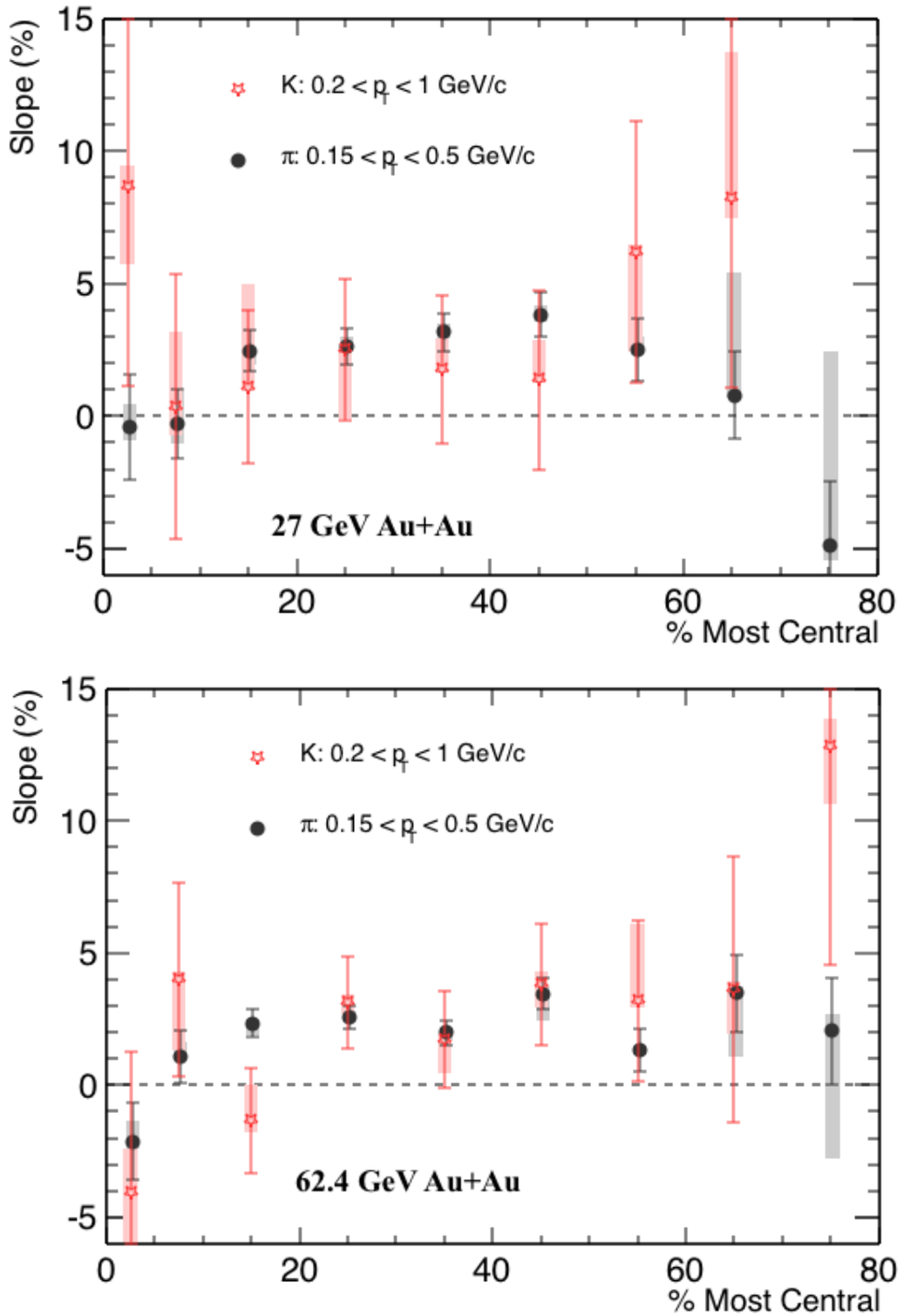
Differential v_2

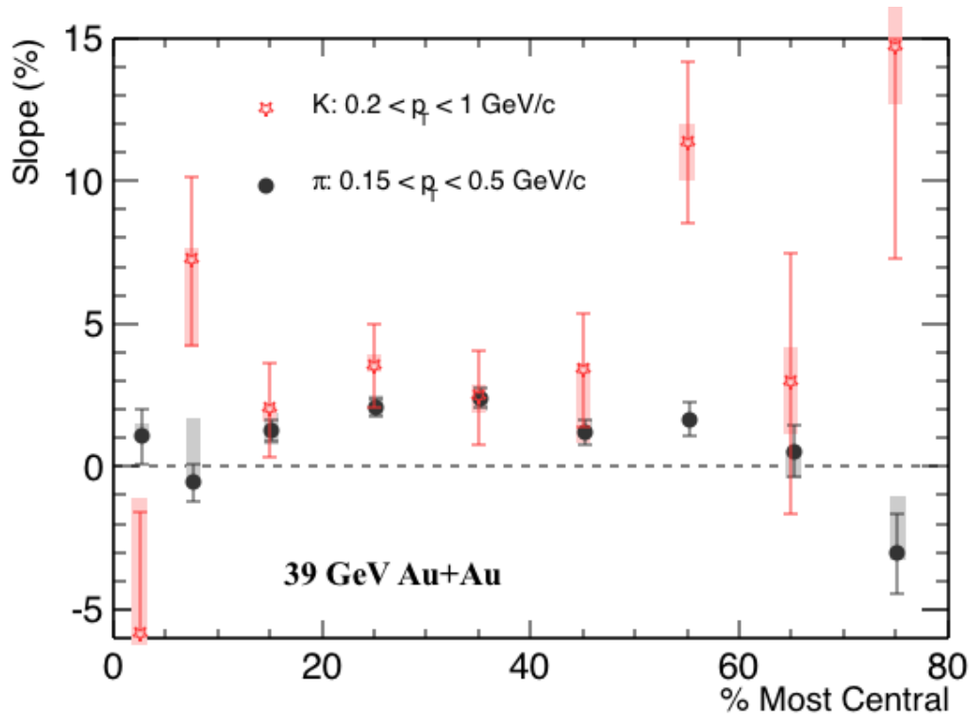


Differential v_2



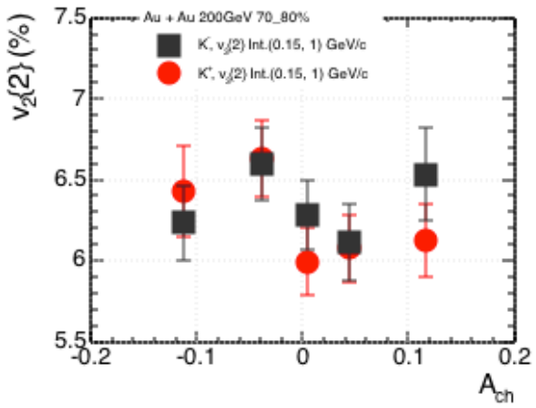
Another set of slope(K) in $\sqrt{s_{NN}}$ 27, 39, 62.4 GeV

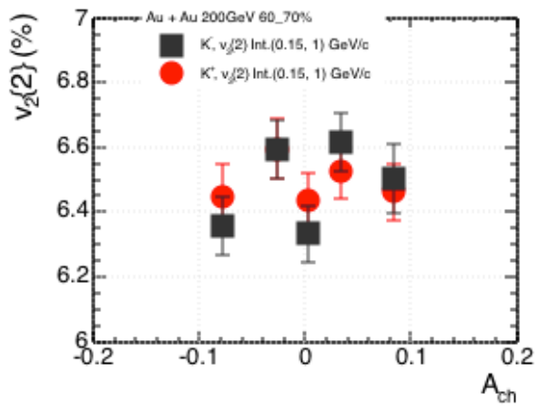


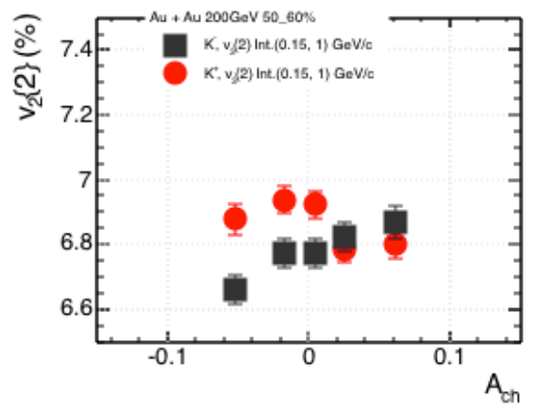


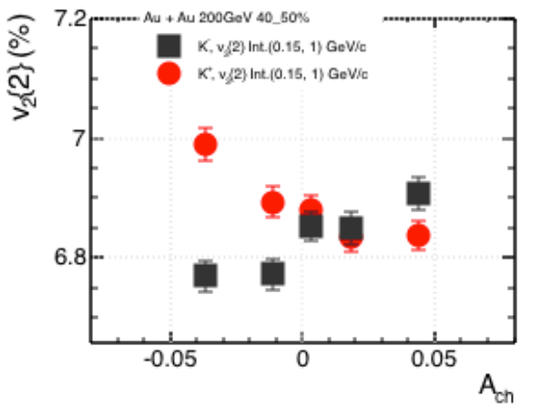
error bars are only statistical
shaded band are systematical error, including track efficiency, DCA(K), Δv_2 extraction method (from Gang Wang)

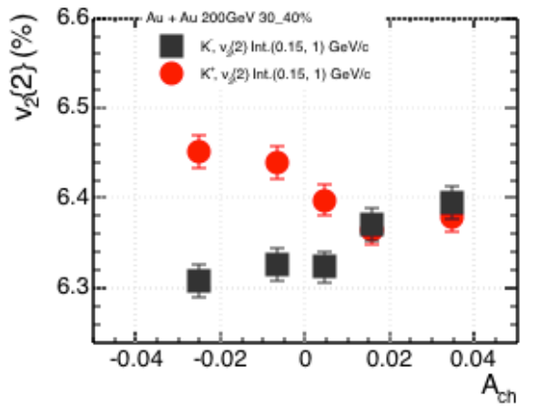
A_{ch} dependence of K^{+-} v_2 in $\sqrt{s_{NN}}$ 200 GeV

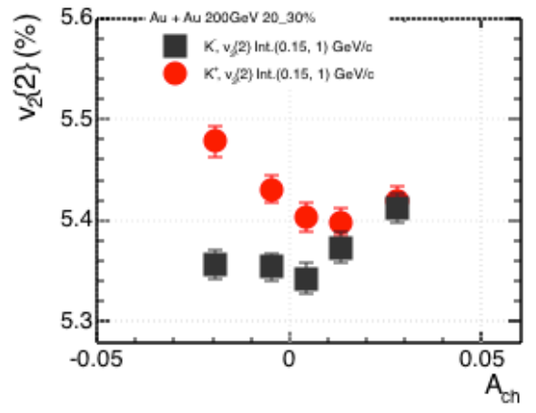


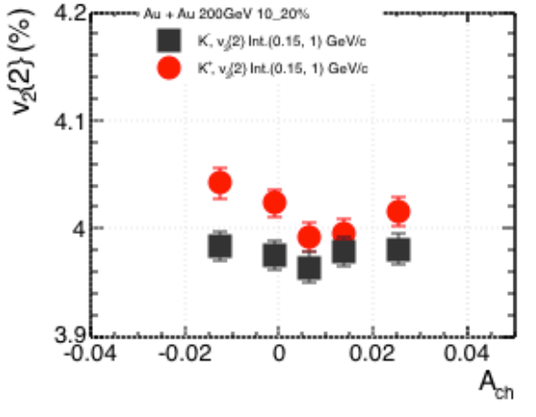


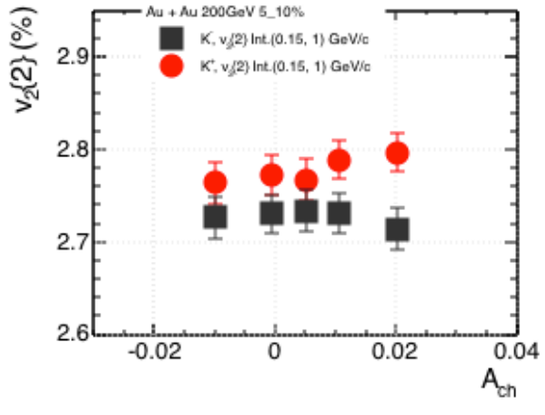


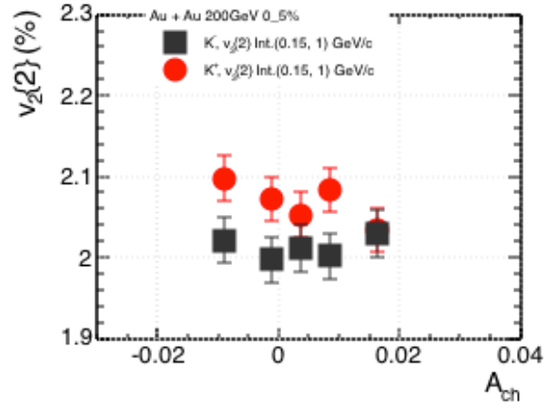








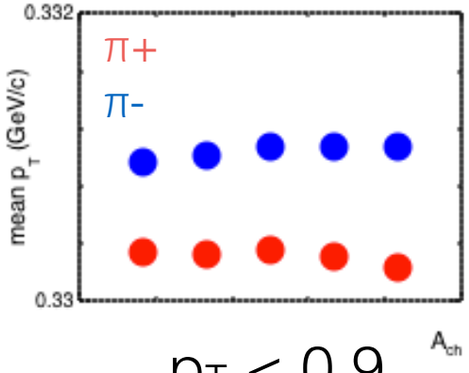




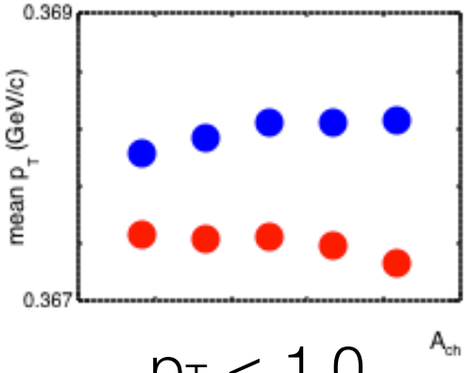
π Mean p_T for different p_T upper limits

very small error bars (negligible)

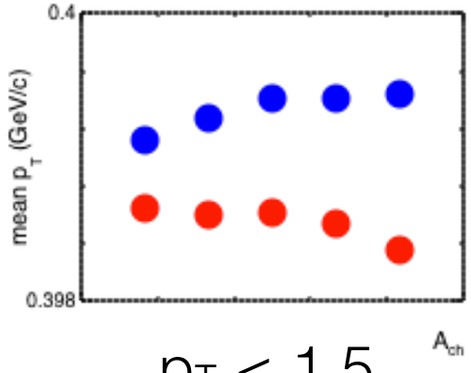
$p_T < 0.5$



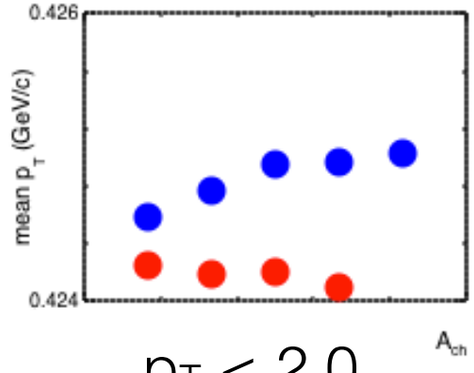
$p_T < 0.6$



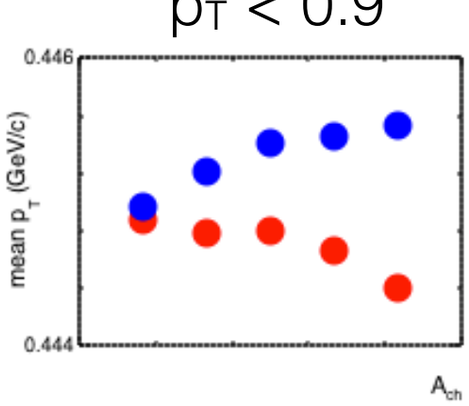
$p_T < 0.7$



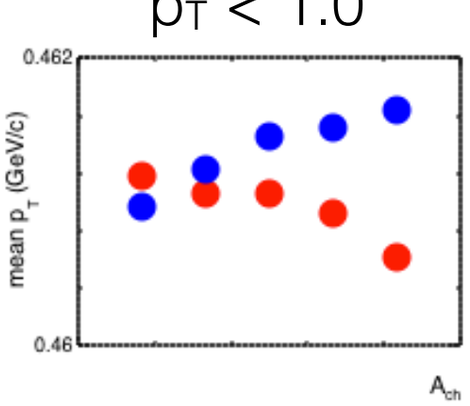
$p_T < 0.8$



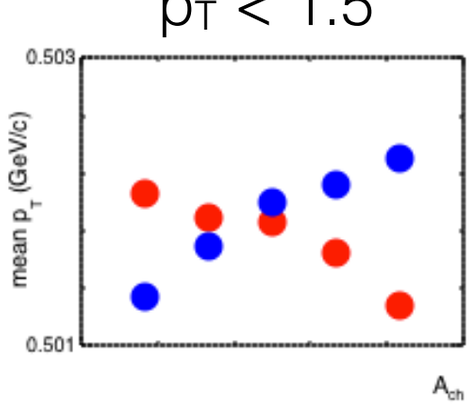
$p_T < 0.9$



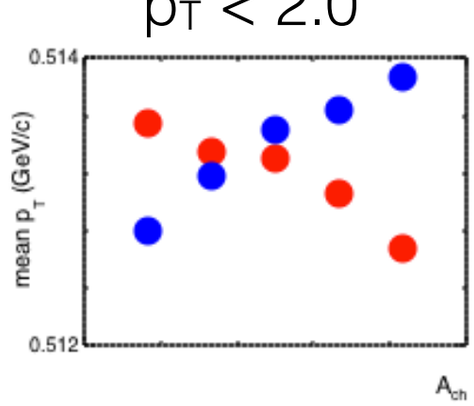
$p_T < 1.0$



$p_T < 1.5$



$p_T < 2.0$

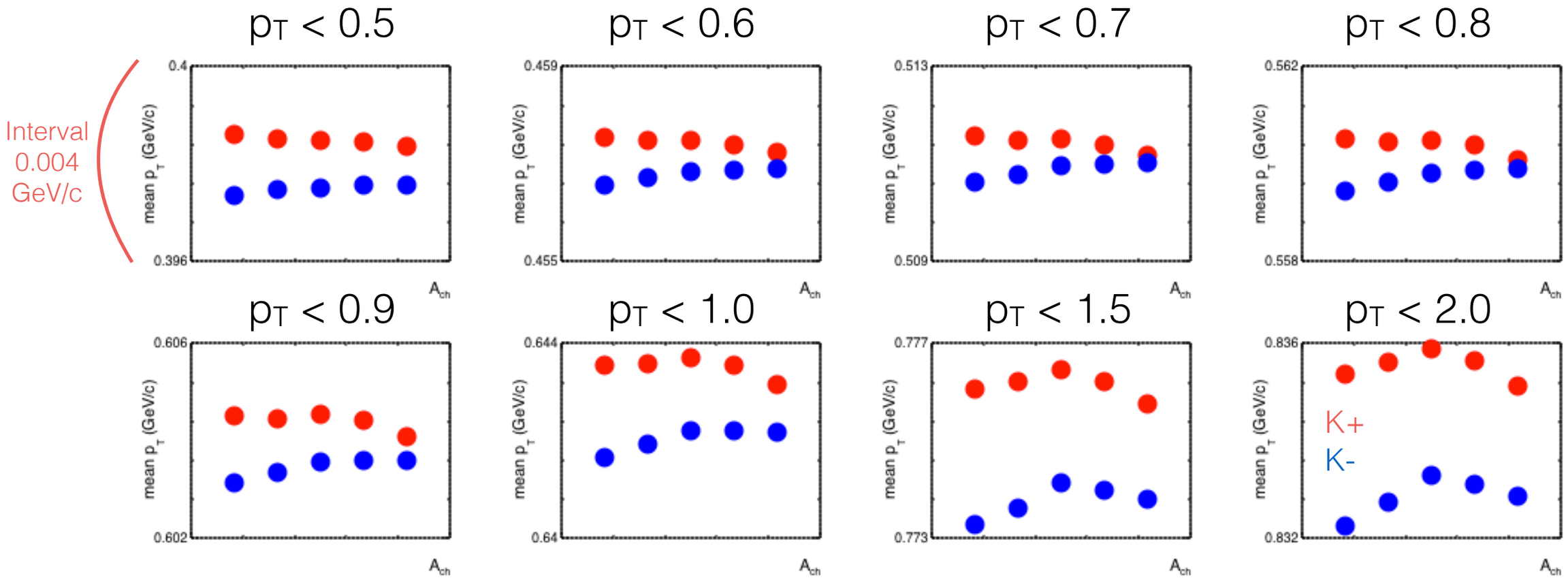


Q: Why we integrate p_T in [0.15, 0.5] GeV/c in previous analysis ?
A: Keep mean p_T effect at a minimum

We know ($v_2 \sim 0.1 * p_T$) so ($0.002 * 0.1 < 0.1\%$) ← $\Delta v_2(\pi)$

K Mean p_T for different p_T upper limits

very small error bars (negligible)



Mean p_T in five A_{ch} bins are supposed to be stable,
but become fluctuant if p_T upper edge increase

However, it's still reasonable if we go higher on p_T to get more statistics