Rapidity Correlations in the RHIC Beam Energy Scan

Sedigheh Jowzaee

for the STAR Collaboration

Wayne State University

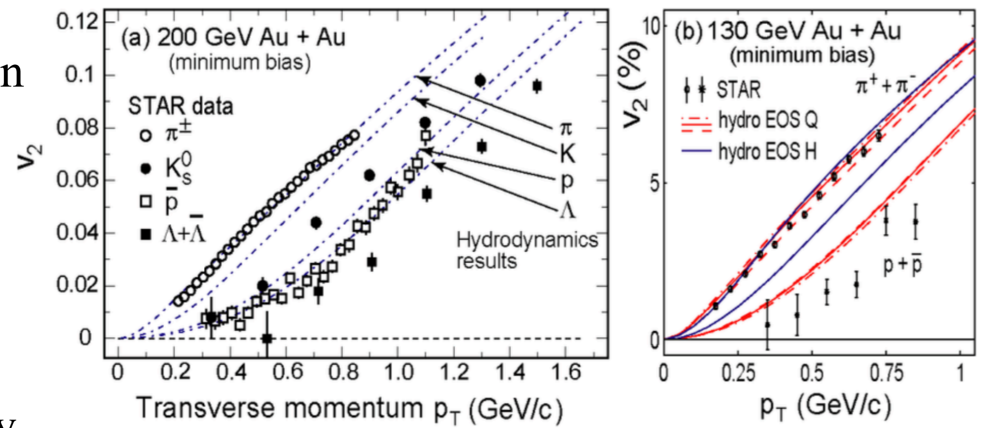
Introduction

- Effect of the initial density fluctuations on particle azimuthal distributions in heavy-ion collisions
  - Characterized by Fourier expansion

$$dN/d(\varphi-\Psi_{RP}) \propto 1+\sum_n 2v_n\cos[n(\varphi-\Psi_{RP})]$$

  - Azimuthal correlations provide a wealth of insights, e.g. the "perfect fluid" discovery

Increasing viscosity decreases the observed v_n



☆, NPA757 (2005) 102-183

- Effect of initial density fluctuations in the longitudinal direction in (pseudo)rapidity space

$$N(\eta)/\langle N(\eta)\rangle \propto 1+\sum_n \sqrt{n+\frac{1}{2}}\,a_n P_n(\eta/Y)$$

A. Bzdak *et al.*, Phys.Rev. C87 (2013)
J. Jia *et al.*, Phys. Rev. C93, 044905 (2016)

  - Long-range correlations from the asymmetry in forward-backward going participants
  - Short-range correlations from resonance decays, jet fragmentation, and Bose-Einstein correlation

Motivation: Explore rapidity correlations in the STAR Beam Energy Scan data

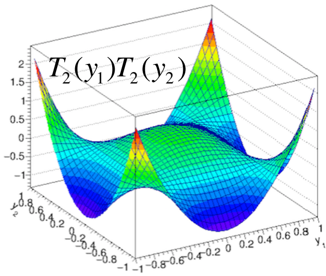
- Rapidity correlation observable: $R_2(y_1,y_2) = -1 + \dfrac{\langle \rho_2(y_1,y_2)\rangle}{\langle \rho_1(y_1)\rangle\langle \rho_1(y_2)\rangle}$ ← Same event pair distributions ← Mixed event

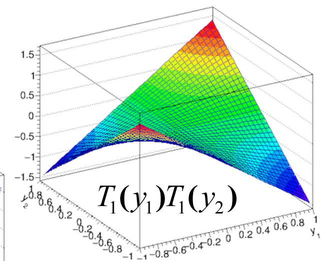
- Legendre Polynomials decomposition of $R_2(y_1,y_2)$
- A specific normalization is used to minimize the residual centrality dependence

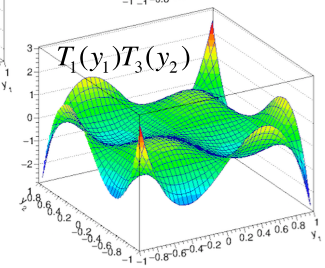
$$C_N(y_1,y_2) = \frac{R_2(y_1,y_2)+1}{C_p(y_1)C_p(y_2)} \approx 1 + \sum_{n,m=1}^{\infty} \langle a_n a_m \rangle \frac{T_n(y_1)T_m(y_2)+T_n(y_2)T_m(y_1)}{2}$$

$$T_n(\eta) = \sqrt{n+\frac{1}{2}}P_n(\eta/Y), \;\; \eta \in [-Y,Y]$$

$$C_p(y_1) = \frac{\int_{-Y}^{Y}(R_2(y_1,y_2)+1)dy_2}{2Y}, C_p(y_2) = \frac{\int_{-Y}^{Y}(R_2(y_1,y_2)+1)dy_1}{2Y}$$







$\langle a_1 a_1 \rangle$ – forward-backward fluctuations

$\langle a_2 a_2 \rangle$ – fluctuations of the width of dN/dy

$\langle a_n a_m \rangle$ – shorter range correlations (for m=n+2 and larger)

J. Jia *et al.*, Phys. Rev. C93, 044905 (2016)

- In a wounded nucleon model — A. Bzdak *et al.*, Phys.Rev. C87 (2013)

$$\rho(y; w_L, w_R) = w_R(a+by) + w_L(a-by),$$

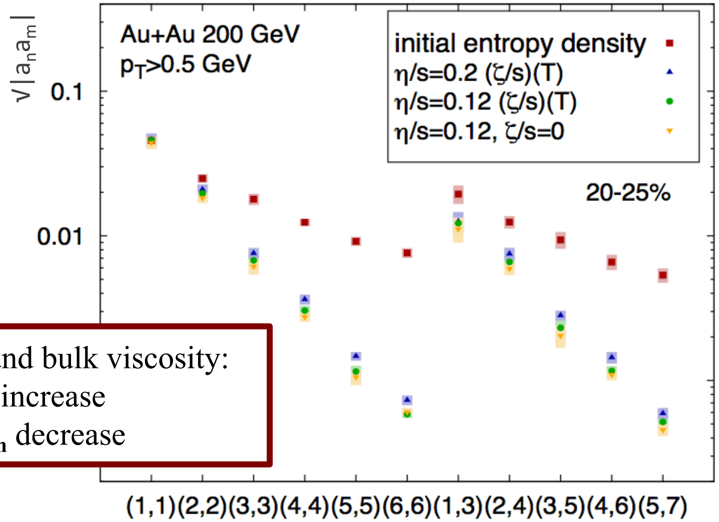
$$C(y_1,y_2) = \rho_2(y_1,y_2) - \rho(y_1)\rho(y_2) = \rho(y_1)\rho(y_2)[\sum_{i,k=0} \langle a_i a_k \rangle T_i(y_1/Y)T_k(y_2/Y)] \approx y_1 y_2 b^2 \langle w_-^2 \rangle$$

$w_- = (w_L - w_R)$

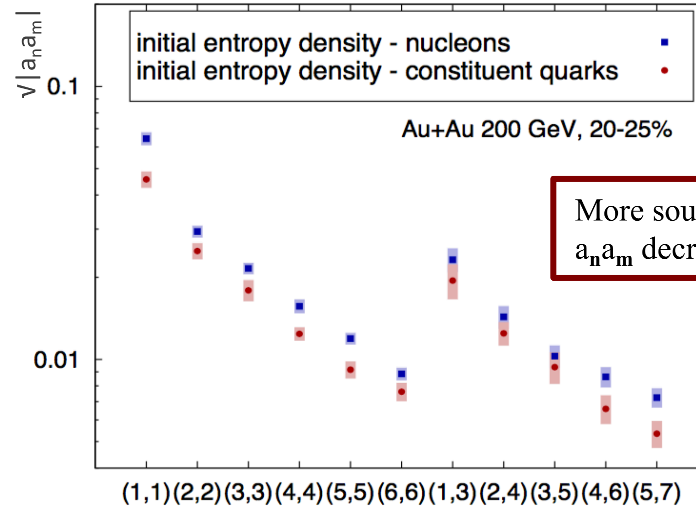
$$\boxed{\langle a_1 a_1 \rangle = Y^2 b^2 \langle w_-^2 \rangle}$$ ← **positive** $\langle a_1 a_1 \rangle$

- Recent results from viscous hydrodynamics model study

A. Monnai *et al.,* Phys.Lett. B752 (2016)



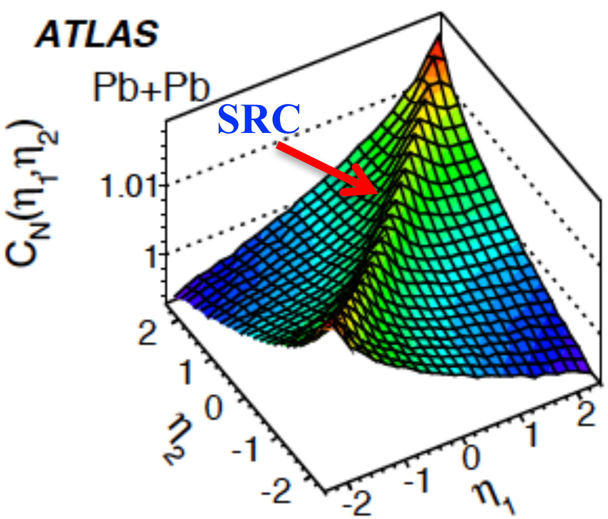
Including shear and bulk viscosity:
lower (m,n) $a_n a_n$ increase
higher (m,n) $a_n a_m$ decrease

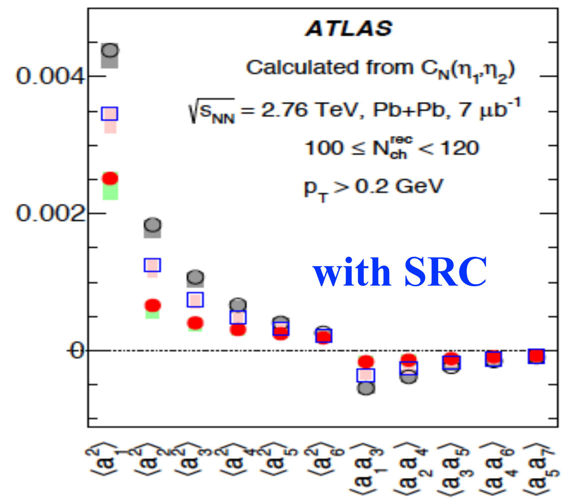


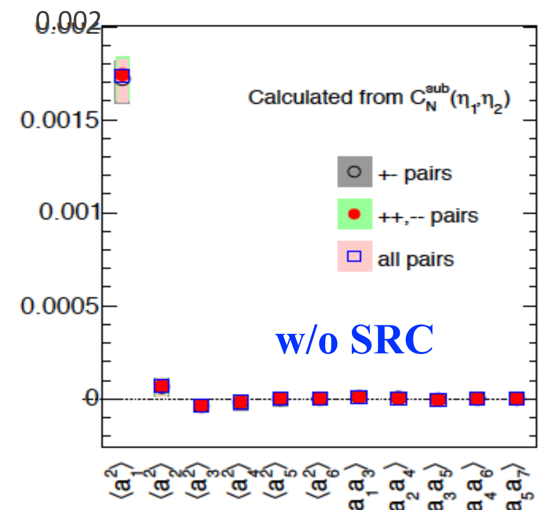
More sources:
$a_n a_m$ decrease

- ATLAS analysis results

ATLAS Collaboration, arXiv: 1606.08170v1 (2016)

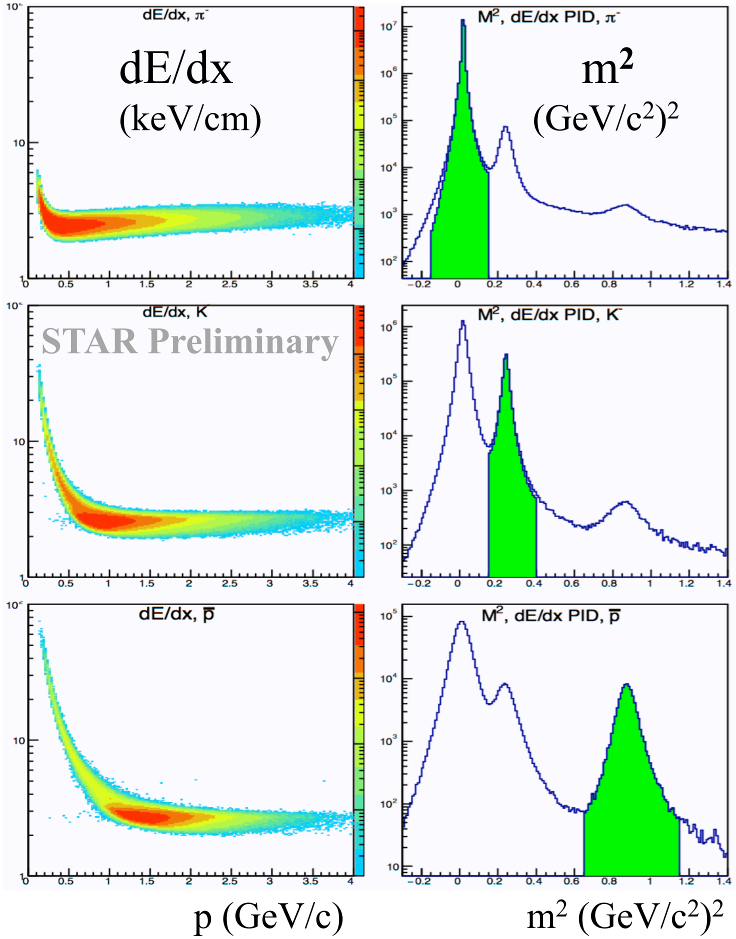






Dataset and Analysis Details

- BES-I dataset: Au+Au at $\sqrt{s_{NN}}$: 7.7, 11.5, 14.5, 19.6, 27, 39, 62.4, & 200 GeV
- Particles of interest: $h^{\pm}$, $\pi^{\pm}$, $K^{\pm}$, & $p^{\pm}$ (2σ cuts on dE/dx, & require correct TOF)
  - $0.2<p_T<2.0$ GeV/c, $p_{tot}<1.6$ GeV/c for $h^{\pm}$, $\pi^{\pm}$, $K^{\pm}$
  - $0.4<p_T<2.0$ GeV/c, $p_{tot}<3.0$ GeV/c for $p^{\pm}$
- Centrality
  - $N_{\mathbf{tracks}}$ with $0.5<|\eta|<1$ for $h^{\pm}$, $\pi^{\pm}$, $K^{\pm}$
  - $N_{\pi,K}$ with $0<|\eta|<1$ for $p^{\pm}$
  - Only 0-5% central events shown here
- Correction of pseudocorrelations
  - Z-vertex binning and Track merging
- Systematic uncertainties from track and event cuts
- Same analysis code used for UrQMD events



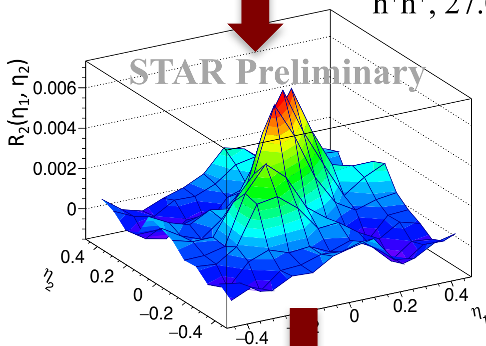
- Measurement of the correlation function in this analysis

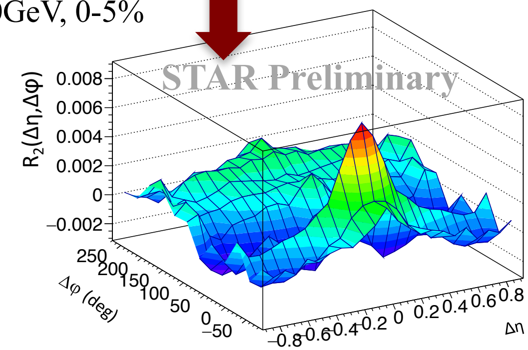
$$R_2(y_1,y_2,\Delta\varphi) = \frac{\langle \rho_2(y_1,y_2,\Delta\varphi)\rangle}{\langle \rho_1(y_1,\varphi_1)\rangle\langle \rho_1(y_2,\varphi_2)\rangle}$$

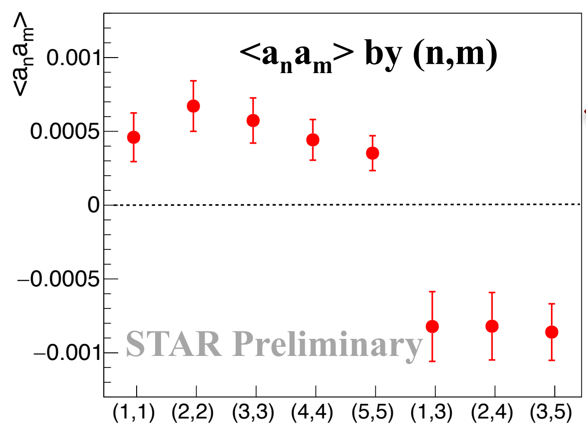
$$R_2(y_1,y_2) \quad , \quad R_2(\Delta y,\Delta\varphi) \qquad \Delta y = y_1 - y_2 \qquad \Delta\varphi = \varphi_1 - \varphi_2$$

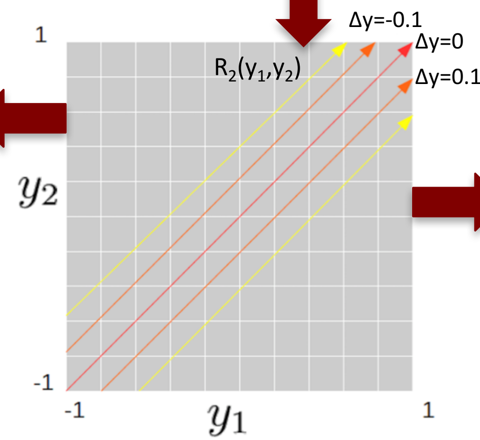
$$C_N(y_1,y_2) \longrightarrow \langle a_n a_m \rangle$$

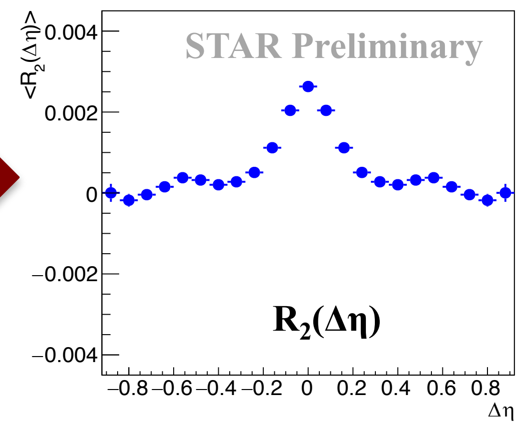
projections:





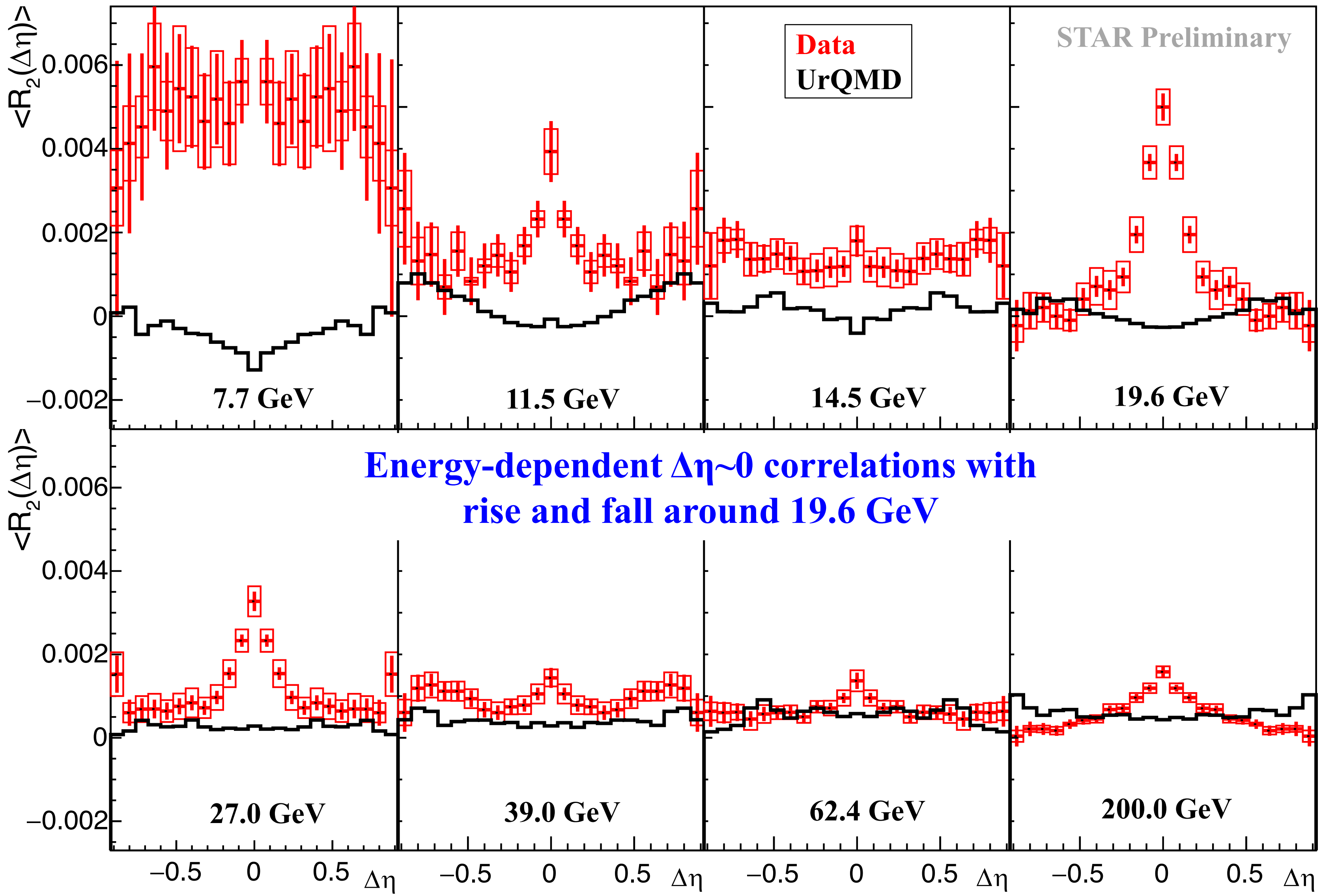






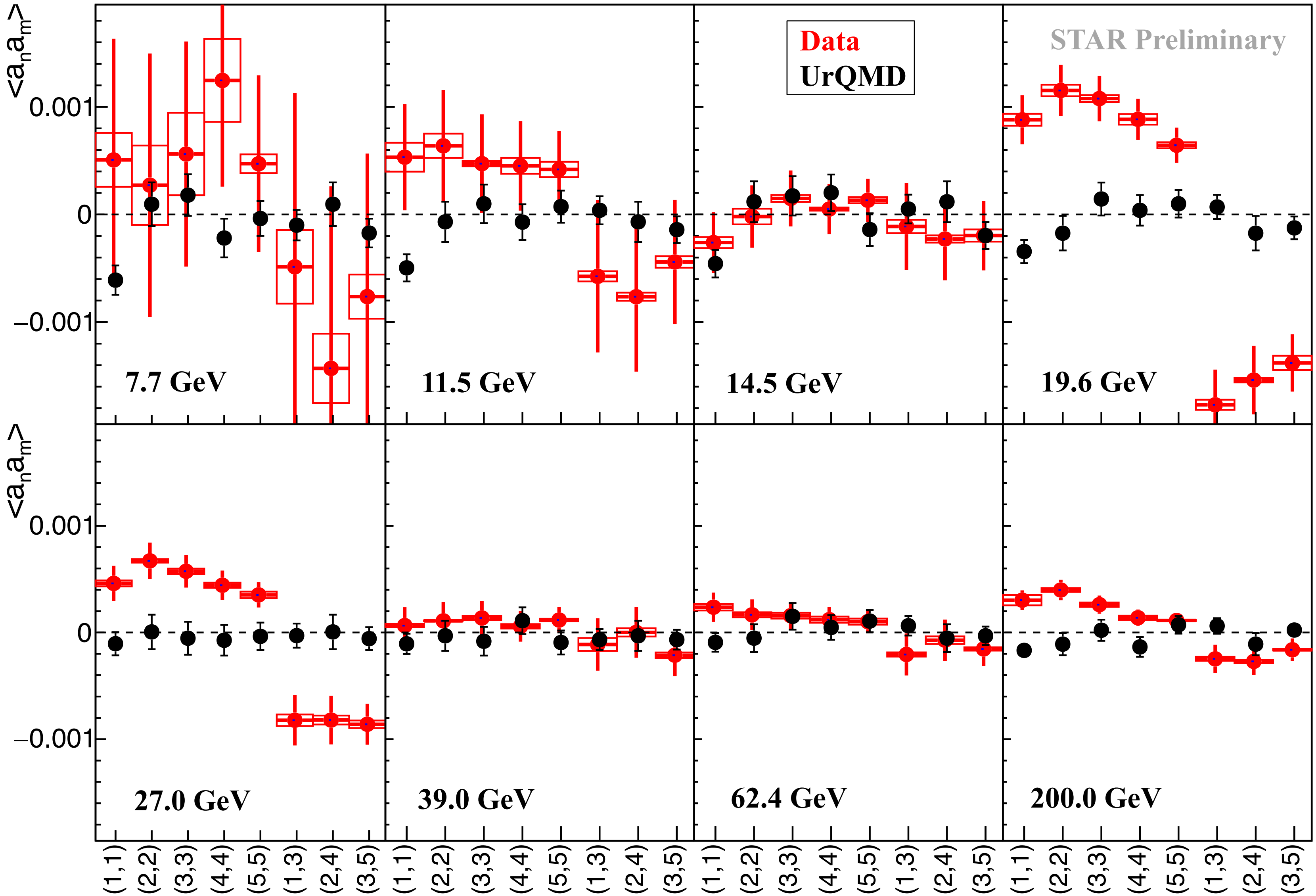
- Note:
  - fewer pairs/event in STAR BES-I data than at the LHC
  - Narrower rapidity acceptance in STAR compared to LHC
  - SRC was not subtracted as done by ATLAS

Like sign h^+h^+, 0-5% centrality for **Data** and **UrQMD** **SRC was not subtracted**



UrQMD generally does not reproduce the observed correlations

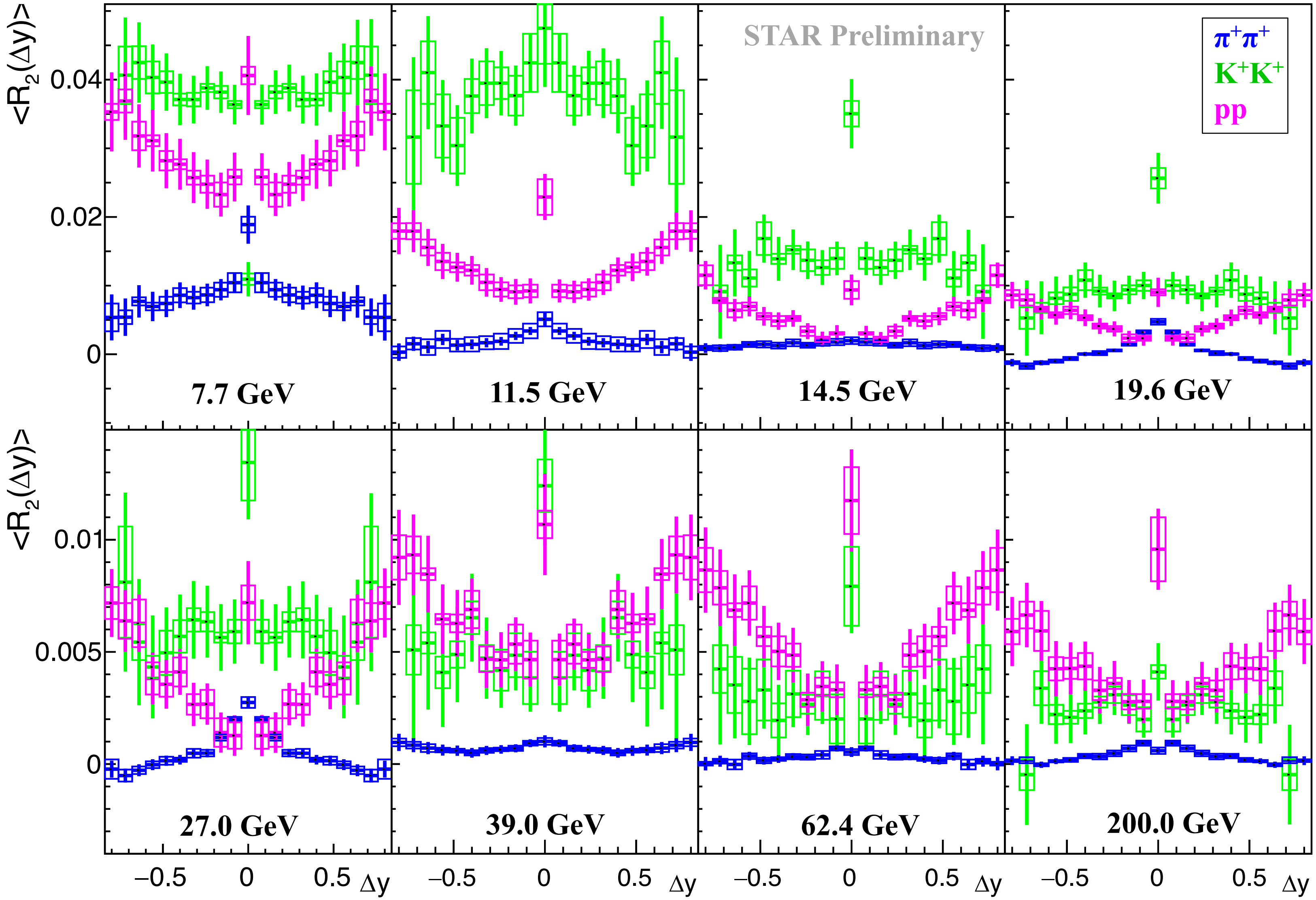
Like sign h^+h^+, 0-5% centrality for **Data** and **UrQMD** **SRC was not subtracted**



The diagonal $\langle a_n a_m \rangle$ (m=n) coefficients are generally positive for charged hadrons (correlations)

$\pi^+\pi^+$, K^+K^+ and pp, 0-5% centrality

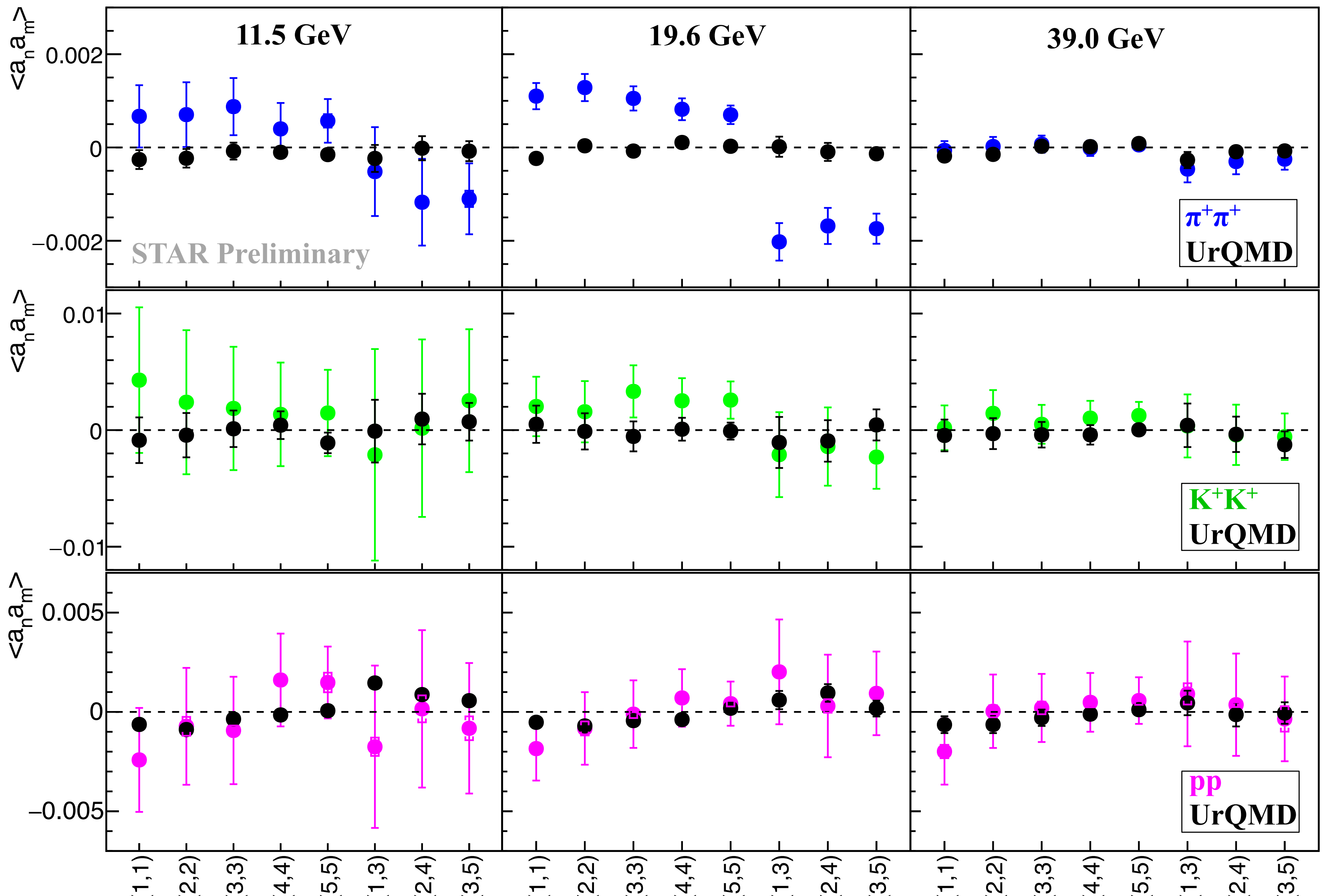
SRC was not subtracted



Minima in $<R_2>$ of protons around $\Delta y=0$ at all beam energies

Point at $\Delta y=0$ reflects combination of SRC and the removal of track merging effects

$\pi^+\pi^+$, K^+K^+ and **pp** for data and **UrQMD**, 0-5% centrality **SRC was not subtracted**

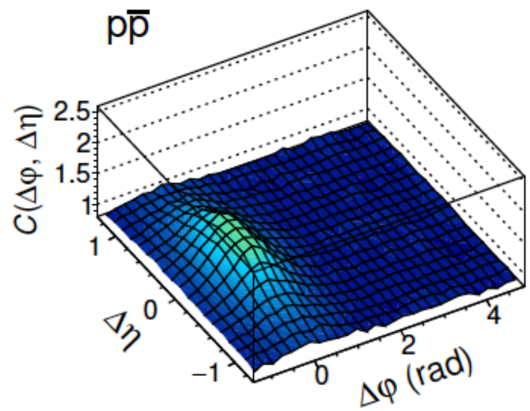


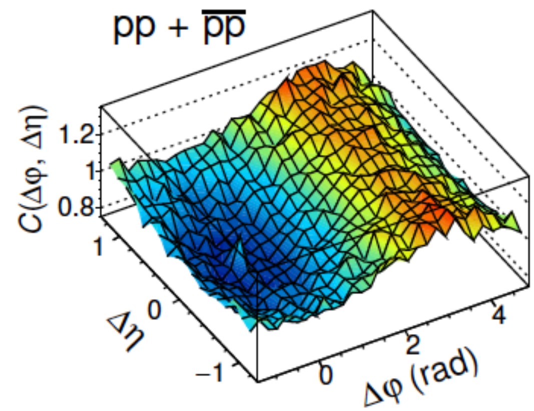
Unlike kaons and pions, the $<a_1a_1>$ coefficient of protons is negative (anti-correlations)

Baryon correlations

- ALICE analysis results ALICE Collaboration, arXiv:1612.08975v1

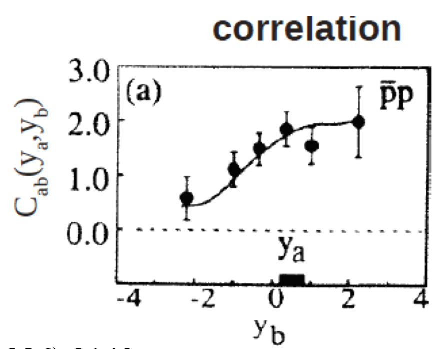
  p+p at $\sqrt{s_{NN}}$=7 TeV

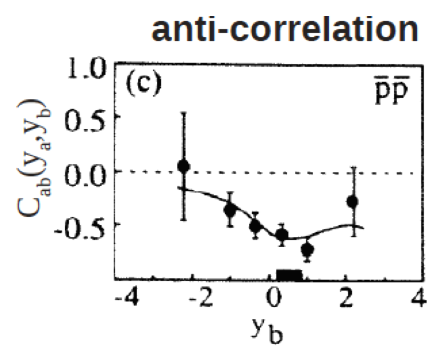




- TPC/Two-Gamma Collaboration (PEP, SLAC) results

  e^+e^- annihilation at 29 GeV





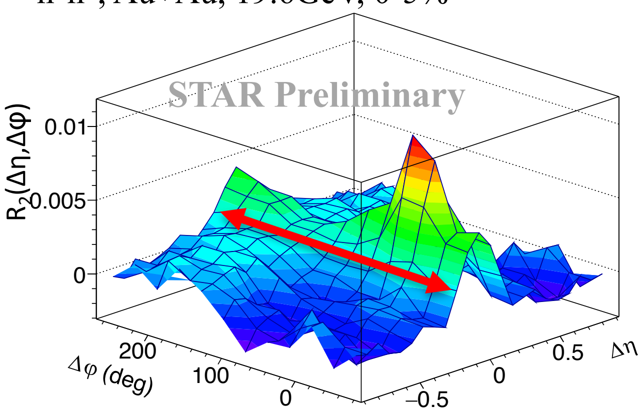
Not likely to find two baryons or two anti-baryons at the same rapidity

- y_a (black bar) rapidity range of first particle
- y_b rapidity of second particle
- C_{ab} correlation function

H. Aihara et al. Phys. Rev. Lett. 57(1986) 3140

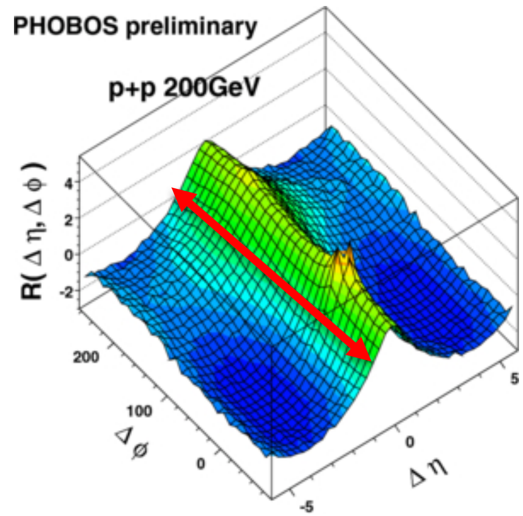
In BES-I data, simplest explanation is limited energy available to create 2nd nearby like-sign proton (requires 2 $p\bar{p}$ pairs produced)

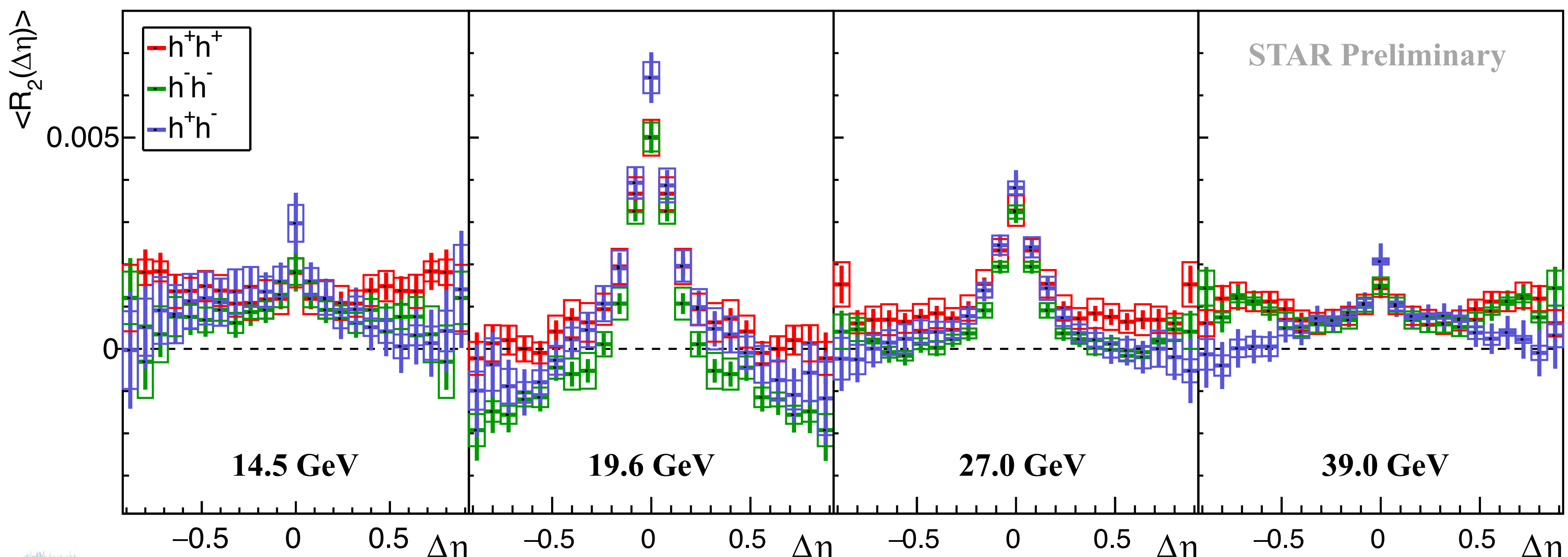
Δϕ "Ridge"



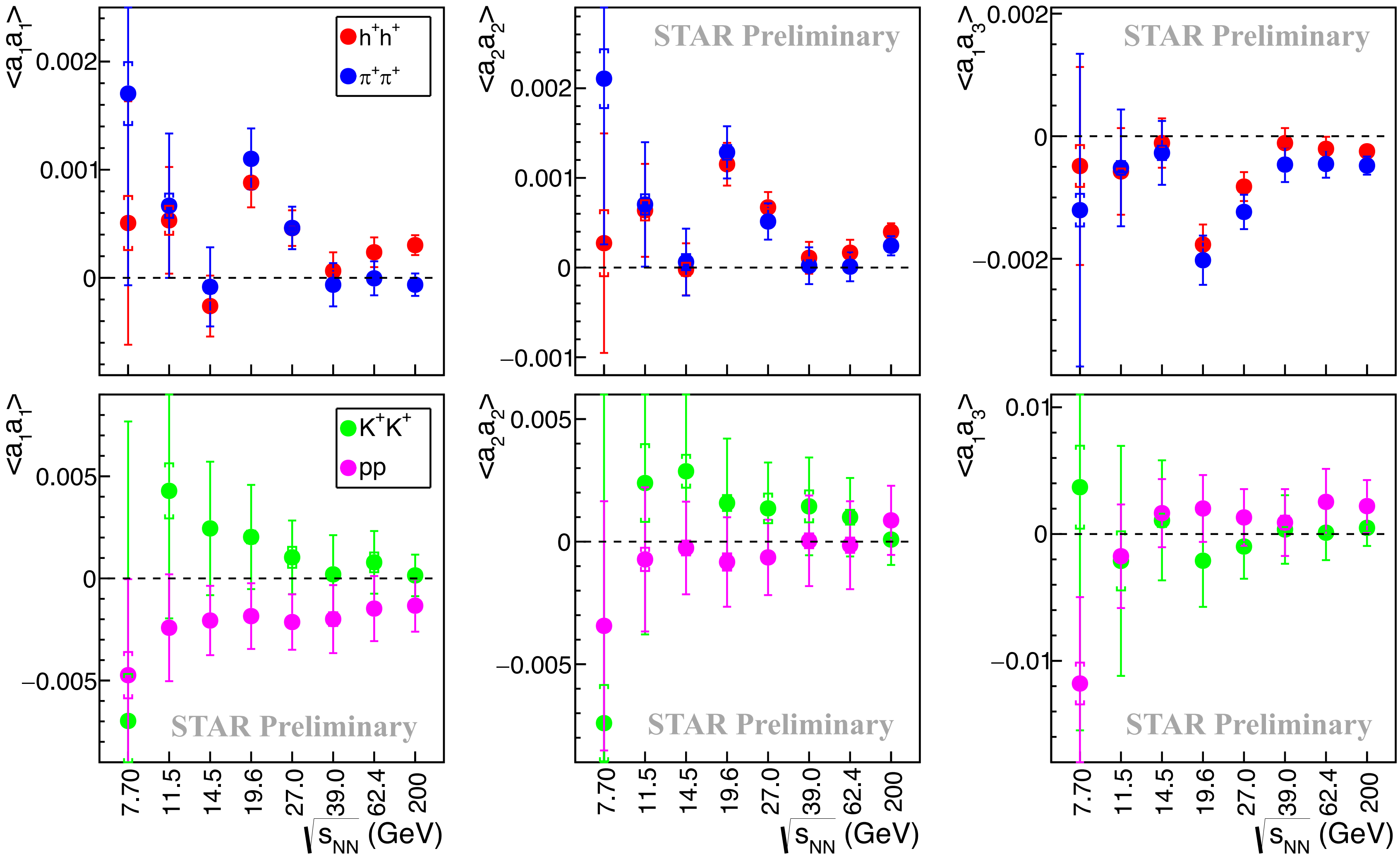
- A strong correlation structure is observed in R_2 of LS and US h & π at 19.6-27.0 GeV
- The observed structure is similar in shape to "cluster" emission observed in p+p at RHIC and the LHC

B. Alver *et al.*, Phys. Rev. C75, 054913 (2007)
CMS Collaboration, JHEP 1009, 091 (2010)

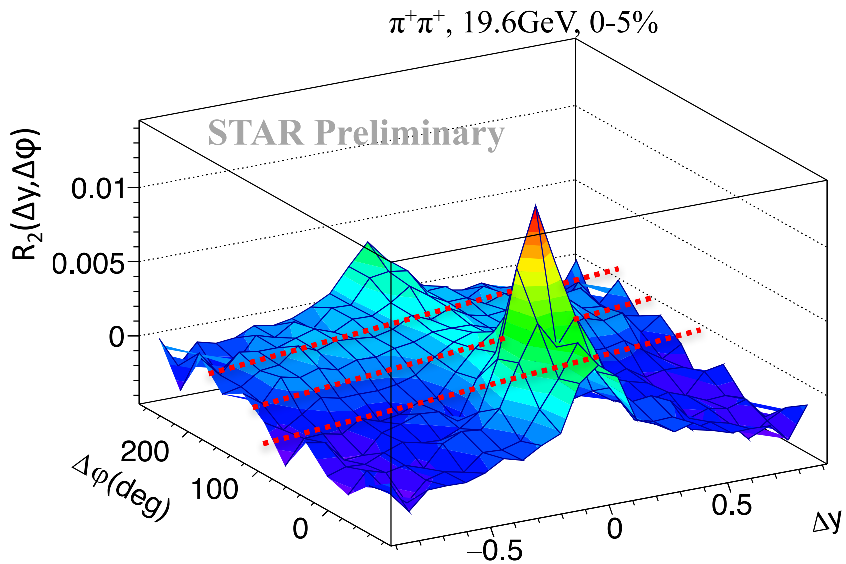


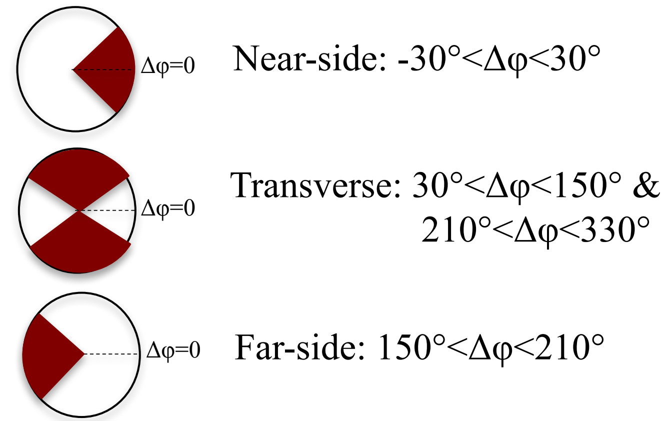


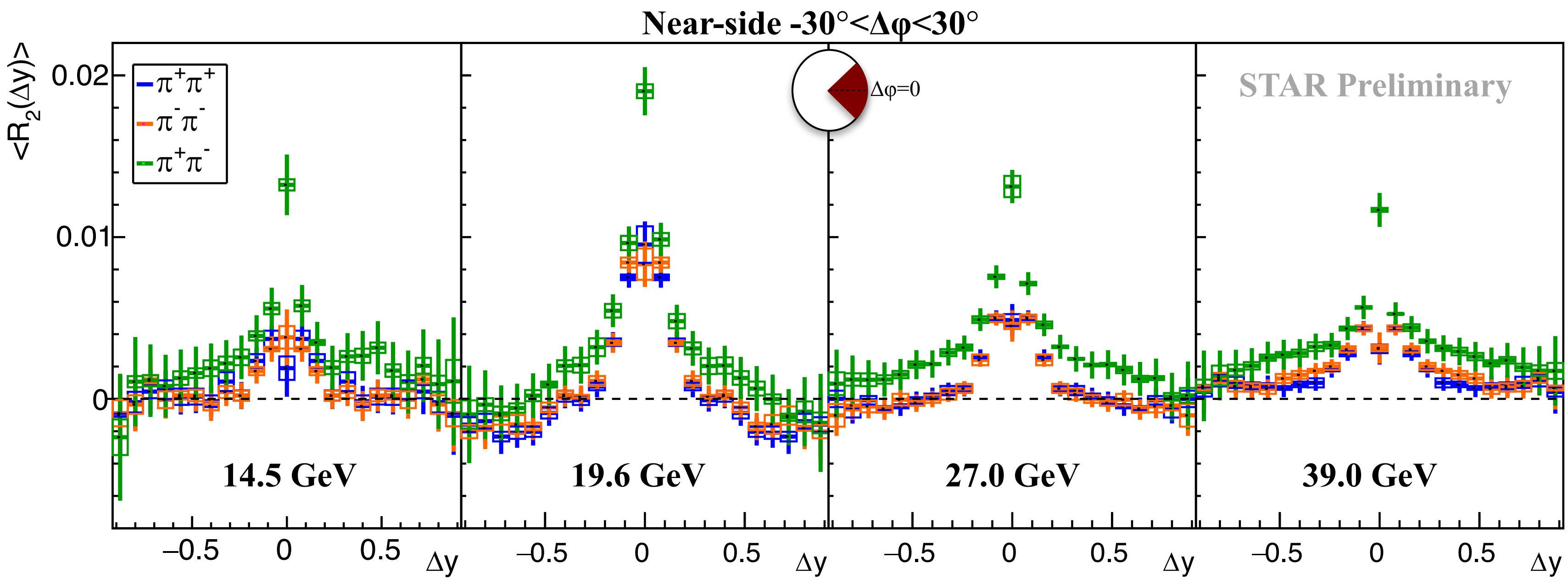
- The magnitude of the $|\langle a_n a_m \rangle|$ coefficients of h^+h^+ and $\pi^+\pi^+$ increases near 19.6 GeV
- In protons and kaons, $|\langle a_n a_m \rangle|$ coefficients does not change significantly near 19.6 GeV



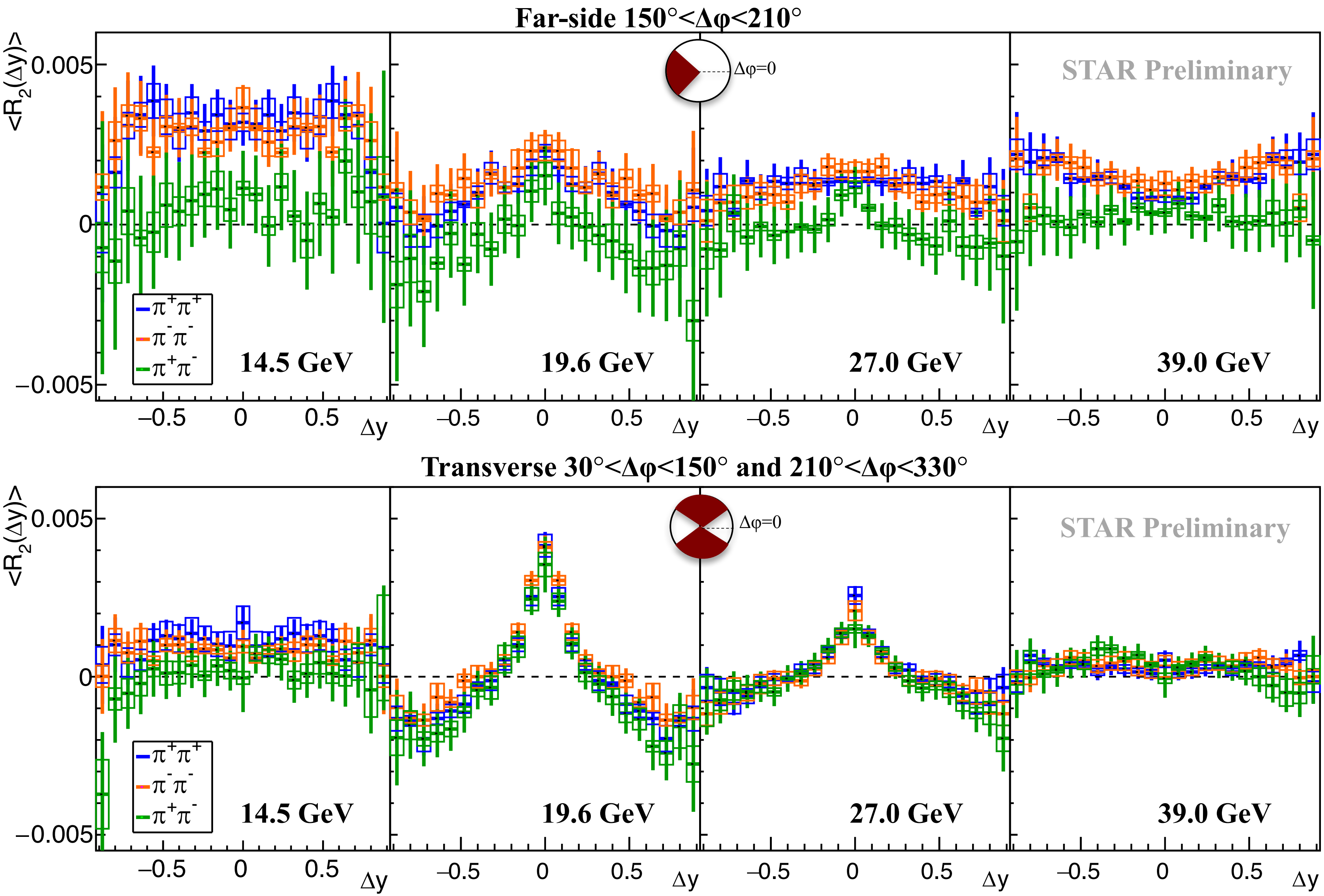
$\langle a_1 a_1 \rangle$ coefficient is negative for protons in all eight beam energies







SRC is dominant in near-side projection, and it is stronger for US pairs than for LS pairs



The observed structure is strong in transverse direction of Δφ and it is charge independent

Summary

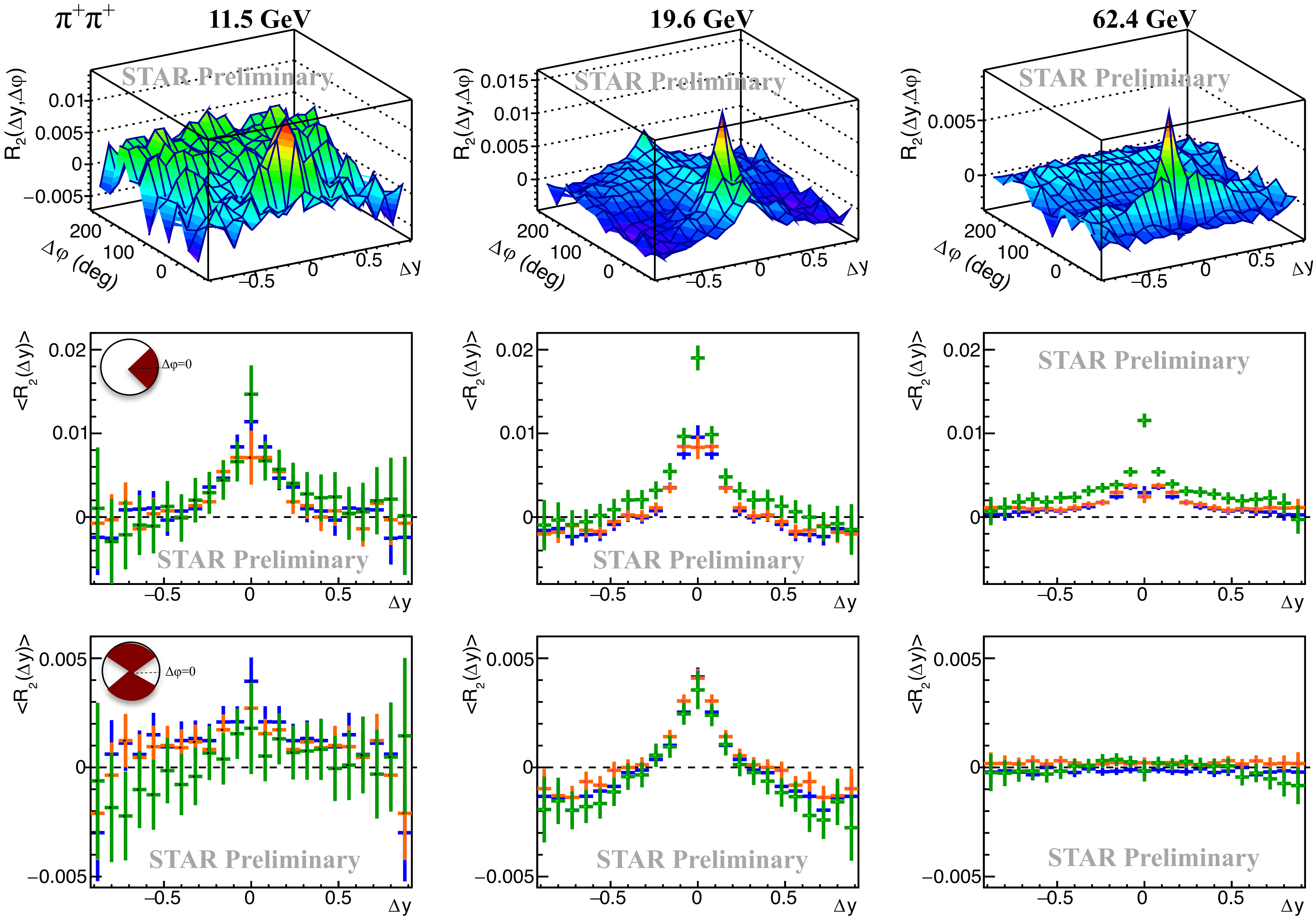
- Two-particle rapidity correlations studied for LS and US h, p, K and π in Au+Au in the STAR Beam Energy Scan data
- The shape of the rapidity correlations quantified by decomposing the correlation functions onto a basis set of Legendre polynomials
  - The sign of the $\langle a_1 a_1 \rangle$ coefficient indicates correlations *vs.* anti-correlations
- There are minima in the $\langle R_2(\Delta y) \rangle$ of protons around $\Delta y=0$
  - This was also observed at higher beam energies
  - $\langle a_1 a_1 \rangle$ is negative for protons (anti-correlations), and is positive for π and K (correlations)
  - It is an approximately 1σ effect, but is observed at all eight beam energies
  - Upcoming BES-II will provide larger and better datasets (broader rapidity acceptance) for these analyses
- A charge-independent and beam-energy localized (19.6 & 27 GeV) structure is observed in R_2 for pions

Thank you!

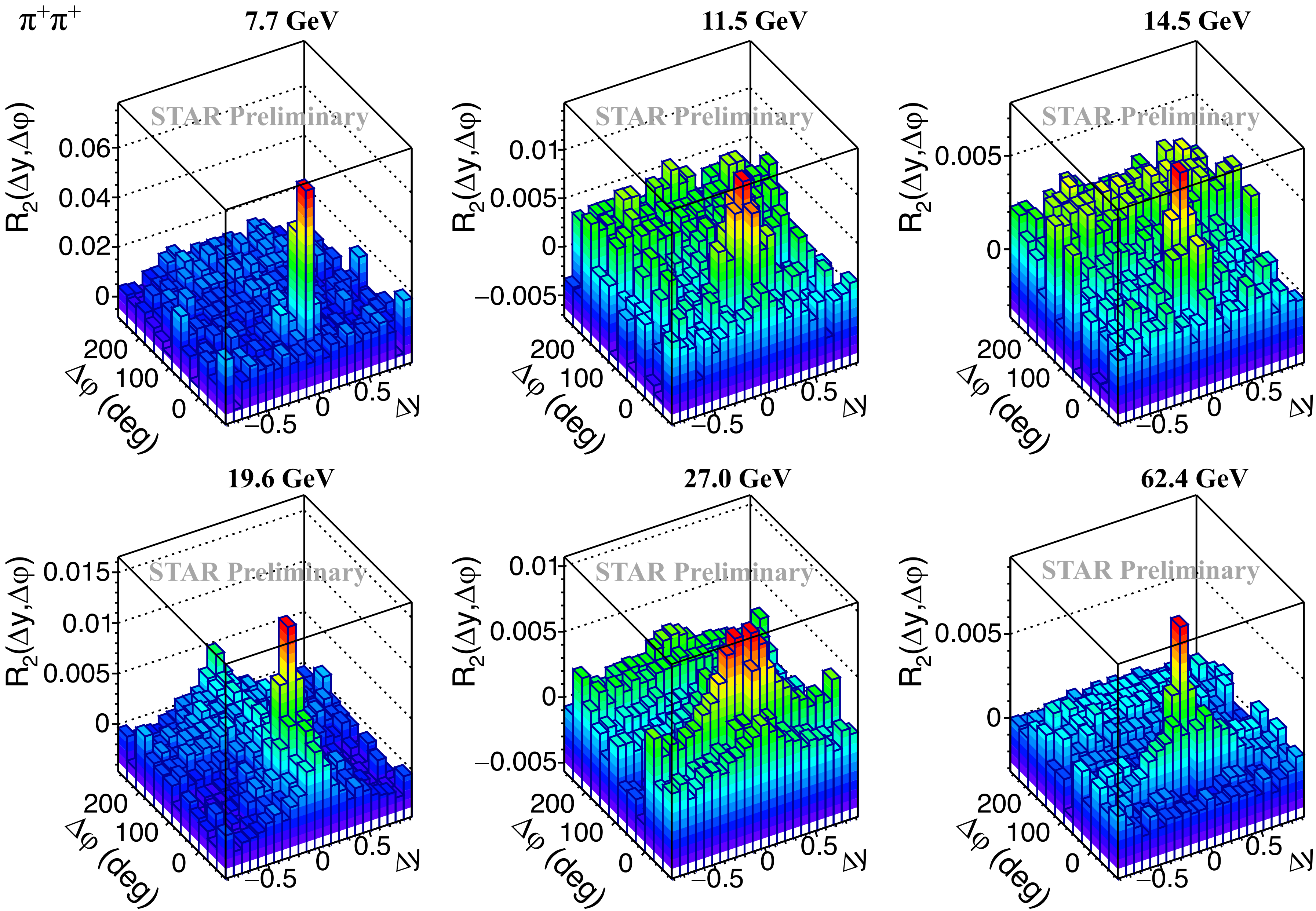
ajowzaee@wayne.edu

U.S. DEPARTMENT OF ENERGY | Office of Science

Back-up



$\pi^+\pi^+$
11.5 GeV
19.6 GeV
62.4 GeV
STAR Preliminary
$R_2(\Delta y,\Delta\varphi)$
$\Delta\varphi$ (deg)
Δy
$\langle R_2(\Delta y)\rangle$
$\Delta\varphi=0$



π+π+
7.7 GeV
11.5 GeV
14.5 GeV
19.6 GeV
27.0 GeV
62.4 GeV
STAR Preliminary
R2(Δy,Δφ)
Δφ (deg)
Δy
0.06
0.04
0.02
0
0.01
0.005
−0.005
0.015
200
100
0
−0.5
0.5