Δη-Δφ correlations of identified particles in the Beam Energy Scan

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Supported by:

NATIONAL SCIENCE CENTRE POLAND

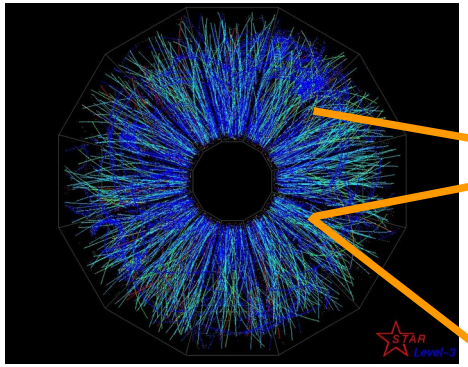
Project number: UMO-2016/21/N/ST2/00315

Angular correlation function:

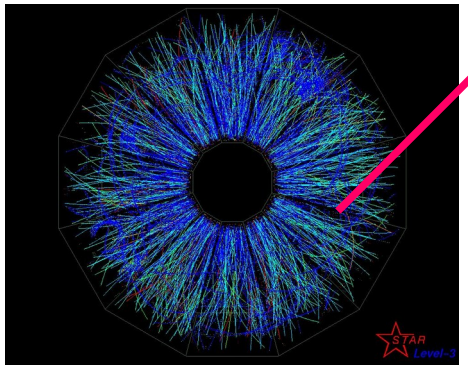
$\Delta\eta = \eta_1 - \eta_2$

$\Delta\varphi = \varphi_1 - \varphi_2$

Event 1



Event 2,3,4...



 # correlated pairs per pair

$$\rho_{sib}(\Delta\eta,\Delta\phi) = \frac{d^2 N^{pairs}_{sibling}}{N^{pairs}_{sibling}\cdot d(\Delta\eta\Delta\phi)}$$

$$\rho_{ref}(\Delta\eta,\Delta\phi) = \frac{d^2 N^{pairs}_{ref}}{N^{pairs}_{ref}\cdot d(\Delta\eta\Delta\phi)}$$

$$r = \frac{\rho_{sib}}{\rho_{ref}} \approx \frac{P(\eta_1\phi_1,\eta_2\phi_2)}{P(\eta_1,\phi_1)\cdot P(\eta_2,\phi_2)}$$

 # correlated pairs per particle

This talk: $$\frac{\Delta\rho}{\sqrt{\rho_{ref}}} = \sqrt{\rho'_{ref}}\cdot\frac{\rho_{sib}-\rho_{ref}}{\rho_{ref}} = \sqrt{\rho'_{ref}}\cdot(r-1)$$

In experiment:

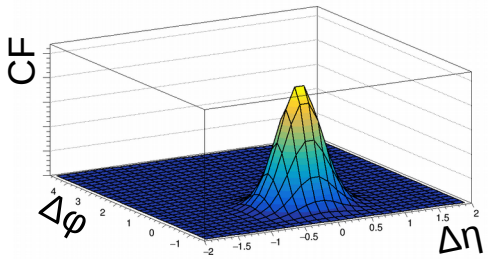
$\sqrt{\rho'_{ref}} \approx d^2\hat{N}/d\eta d\phi$ is single charged particle density averaged over angular acceptance

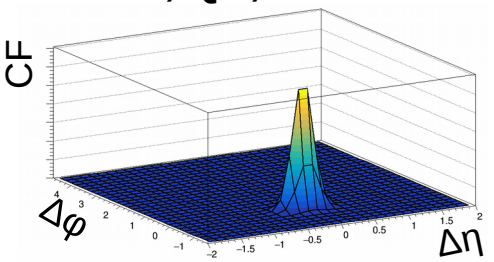
Event images: www.star.bnl.gov

Correlation function: a tool to access different physical phenomena

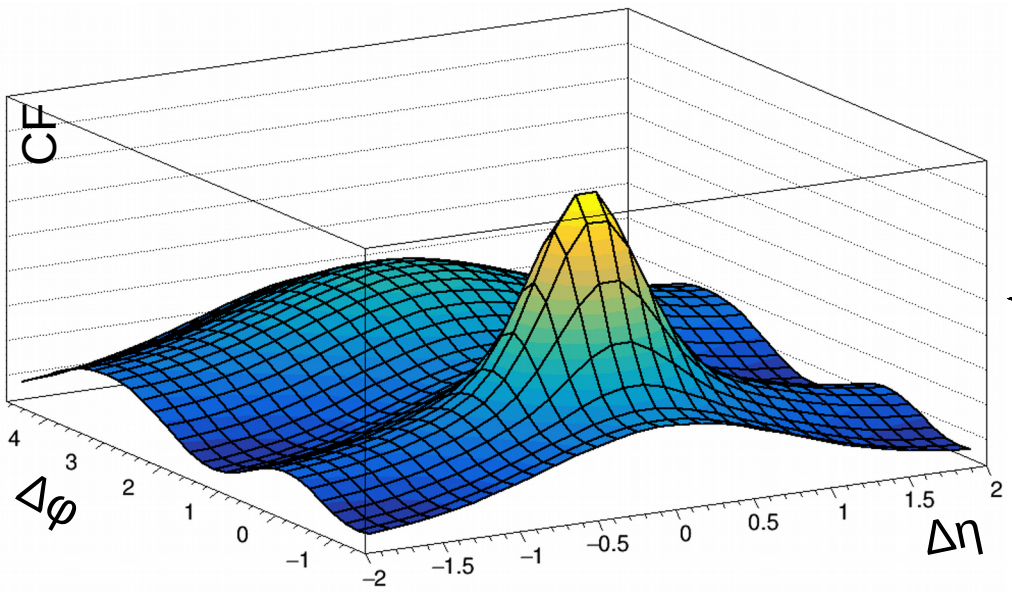
Short-range correlations

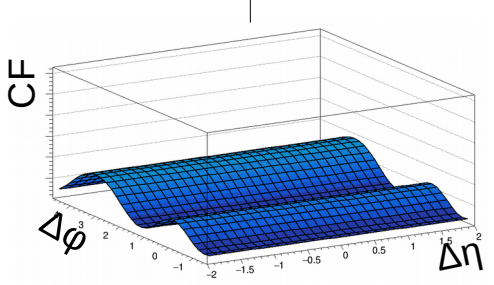
Correlations within single jet + FSI, QS, Coulomb + ...

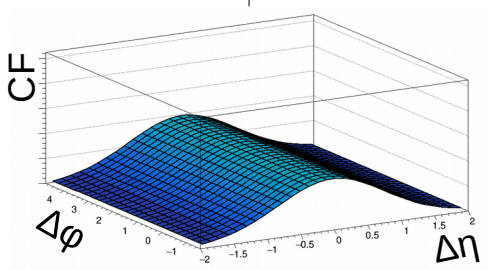




Model of 2D correlation function







Collective flow + String fragmentation + ...

Long-range correlations

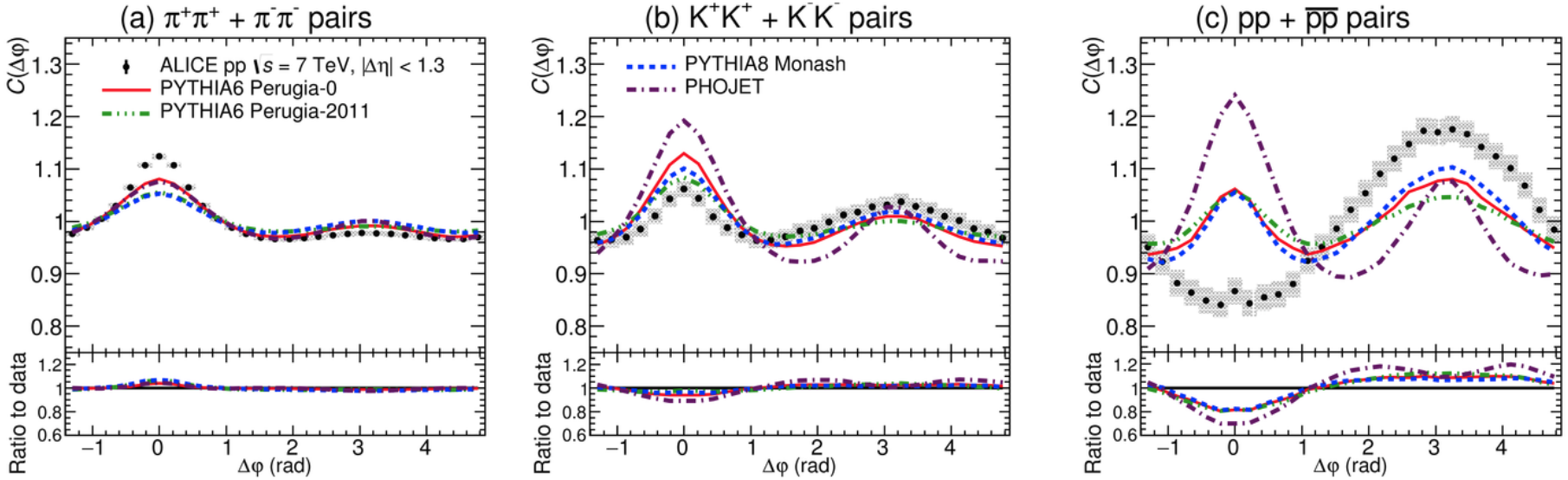
Motivation

Why should we study correlations of identified particles?

- **Systematic study of di-hadron correlations in the STAR BES program**
- **Different shapes of correlation functions for different particles and charge combinations**
- **Intriguing results for two-proton correlations:**

ALICE p+p @ 7 TeV

EPJC 77 (2017) no.8, 569



- pp + $\overline{pp}$ not described even qualitatively

Observed in:

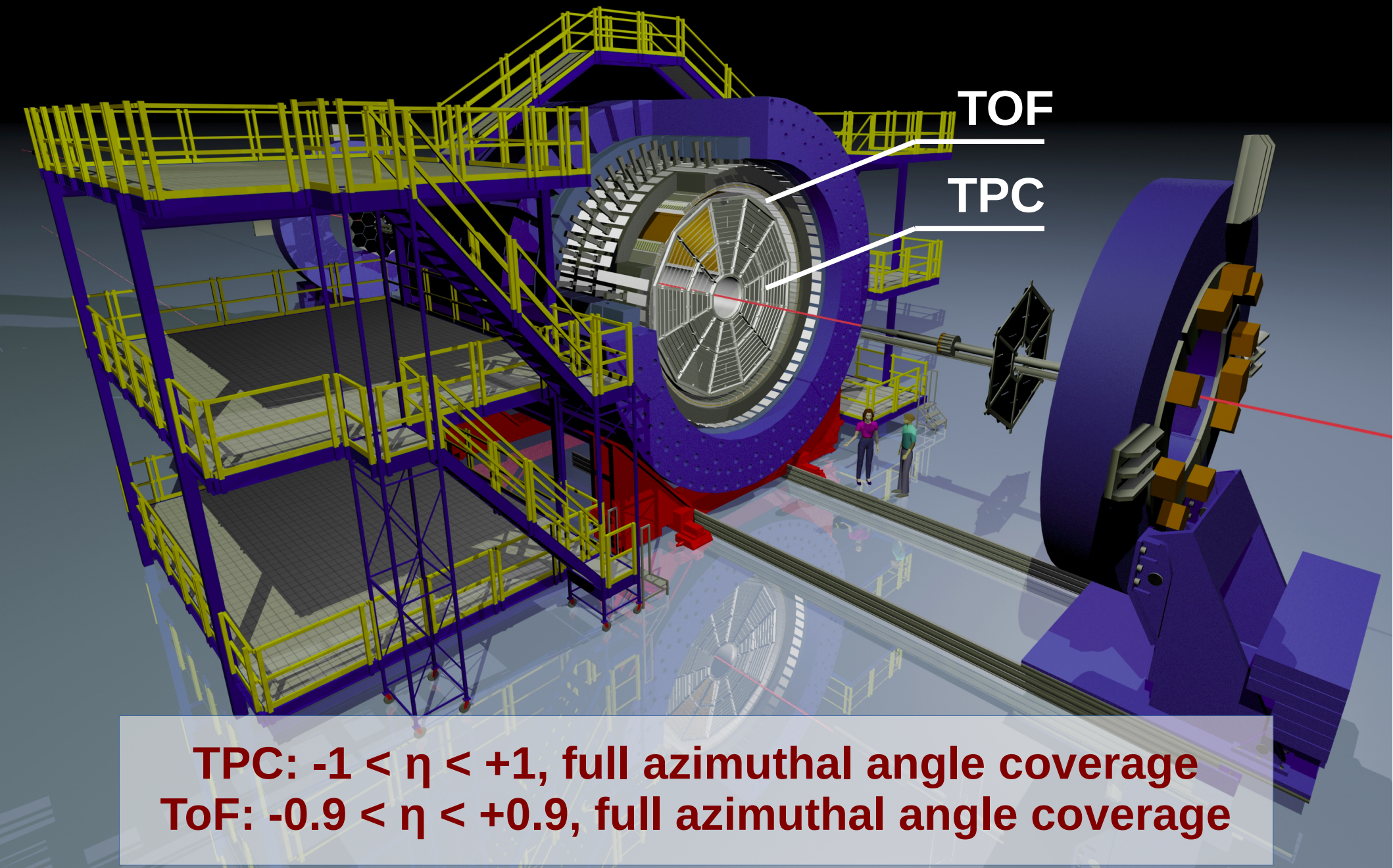
- $e^+ + e^-$ @ 29 GeV (*Phys. Rev. Lett. 57(1986) 3140*)
- p + p @ 7 TeV (*EPJC 77 (2017) no.8, 569*)
- Au + Au @ 7.7 – 200 GeV (*Nuc. Phys. A, 967 (2017), 792-795; PoS(EPS-HEP2017)173*)

Need of experimental data for further model development!

Future work:

- Disentanglement of correlation sources,
- Study of collision energy and centrality dependence

THE SOLENOIDAL TRACKER AT RHIC



TPC: -1 < η < +1, full azimuthal angle coverage
ToF: -0.9 < η < +0.9, full azimuthal angle coverage

by Maria & Alex Schmah

Analysis details

BES at STAR:

Charge combination:

- Like-Sign (LS: + + and - -)
- Unlike-Sign (US: + -)

Particle species:

- Protons
- Kaons
- Pions

Centrality: 0% – 80 %

Collision energy 7.7 – 200 GeV

Kinematic cuts:

- $0.2 < p_T < 0.8$ GeV/c
- $|\eta| < 1$

PID (TPC only): for each POI

- $| n\sigma^{dE/dx}_{POI} | < 2$
- $| n\sigma^{dE/dx}_{other} | > 3$

Centrality:

- Based on N_{ch} in $|\eta| < 1$

Corrections:

- 2 cm wide V_z bins
- 50 particles N_{ch} bins

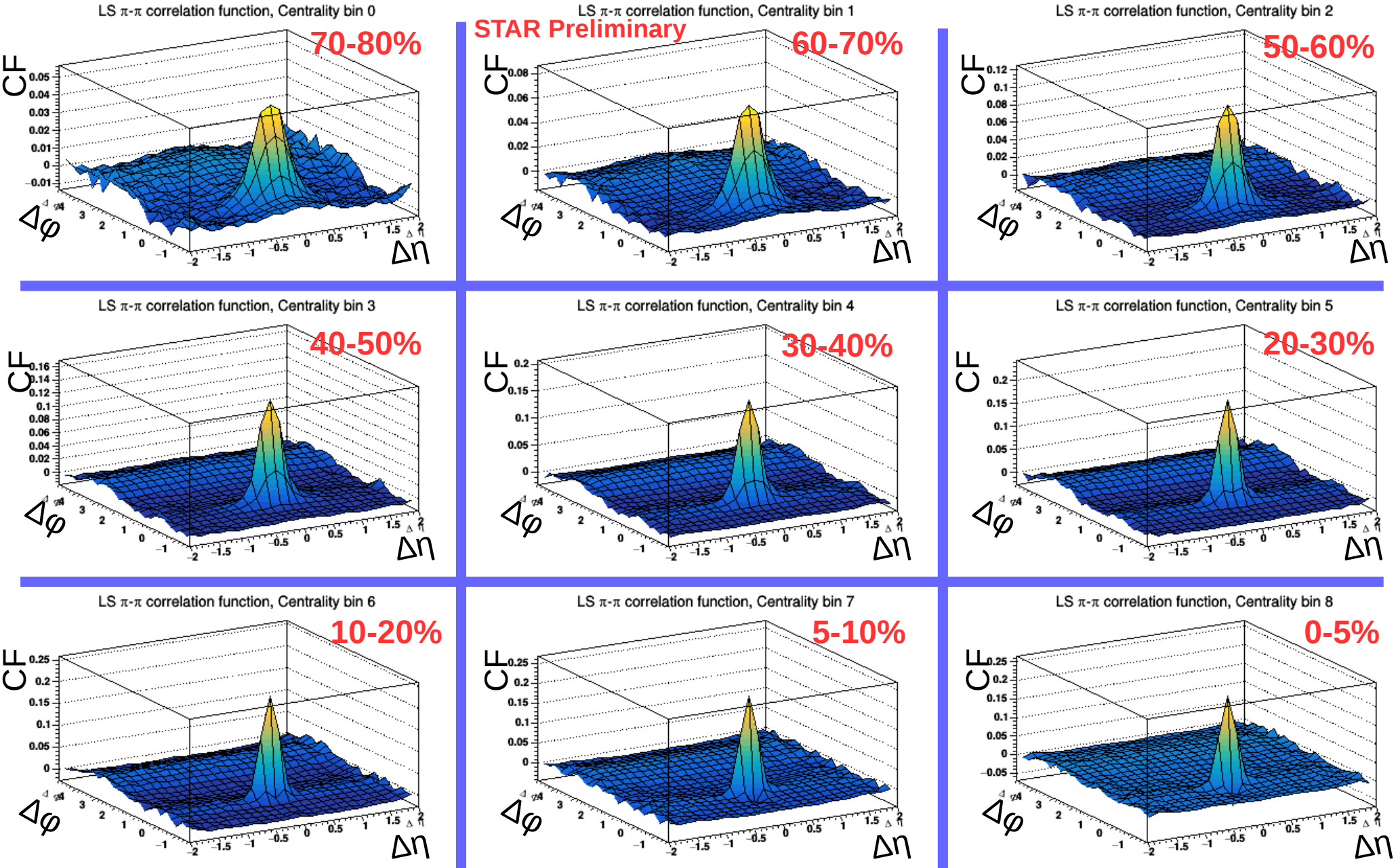
TPC: -1 < η < +1, full azimuthal angle coverage

ToF: -0.9 < η < +0.9, full azimuthal angle coverage

by Maria & Alex Schmah

π π correlations

Like-sign pion correlations, Au+Au @ 19.6 GeV

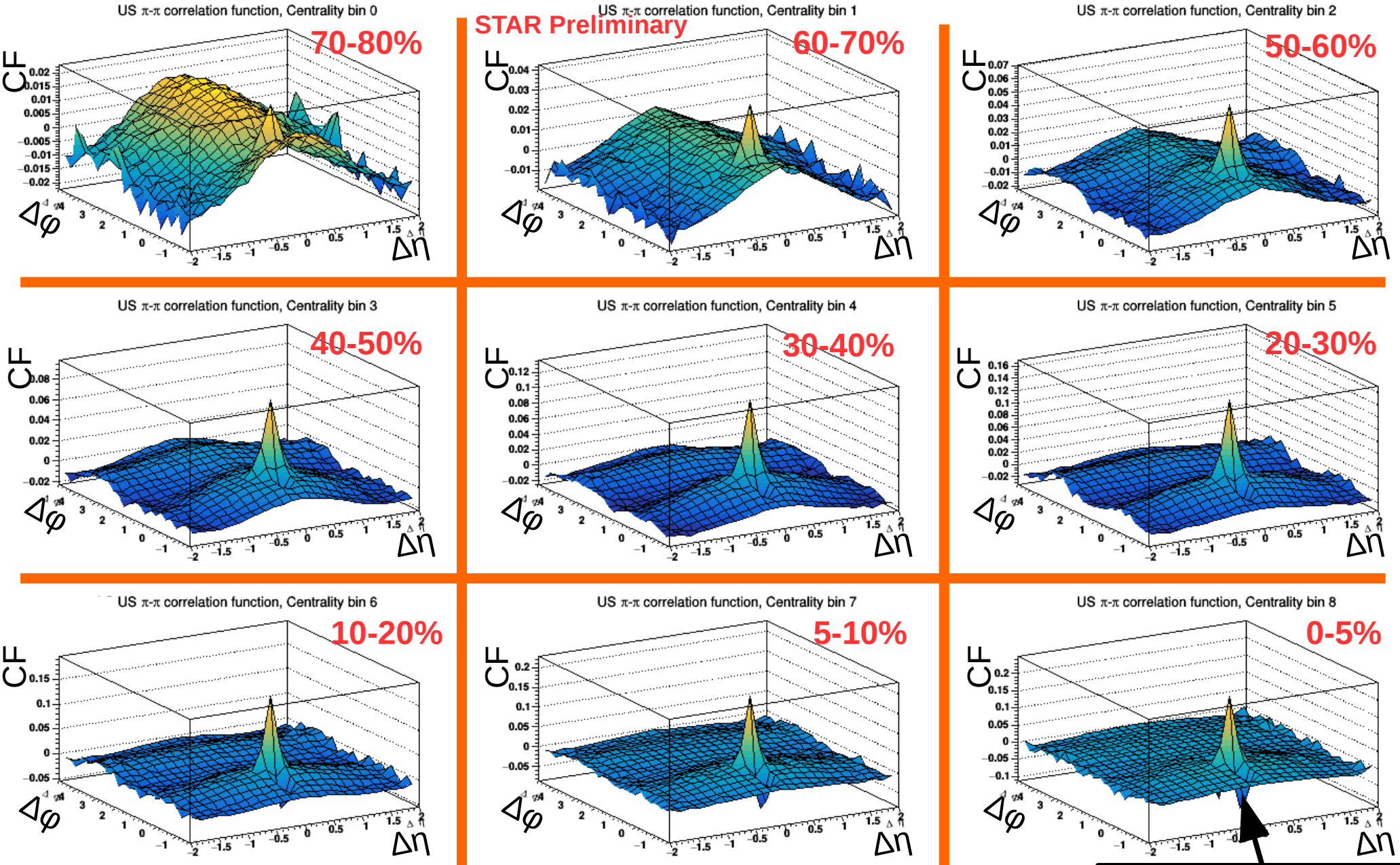


Qualitative description:

→ **Peak at small relative azimuth and pseudorapidity (Near-Side)**

→ **Δφ modulation from elliptic flow is the strongest in mid-central collisions**

Unlike-sign pion correlations, Au+Au @ 19.6 GeV



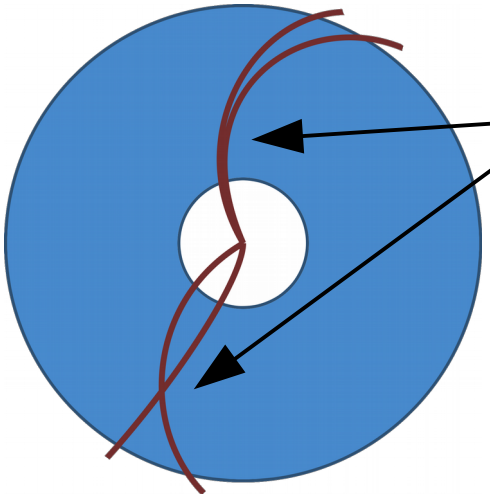
Qualitative description:

→ **Peak at small azimuth and pseudorapidity (Near-Side)**

→ **Δφ modulation from elliptic flow is the strongest in mid-central collisions**

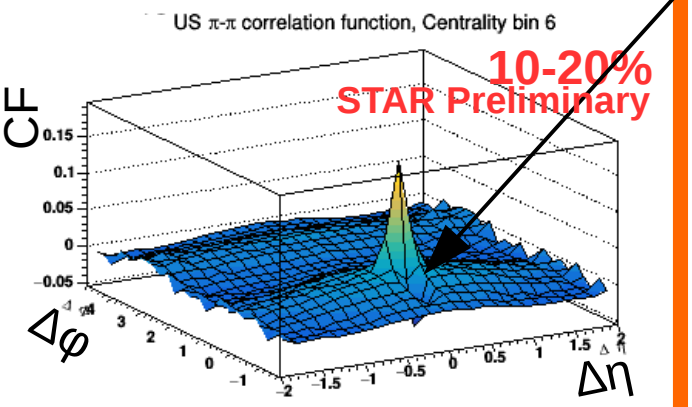
→ **Clear, broad Δφ ridge → charge ordering**

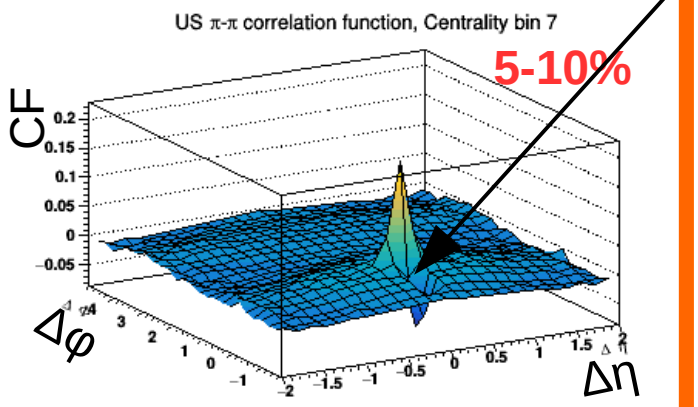
Correction for the TPC track crossing pair inefficiency not yet performed

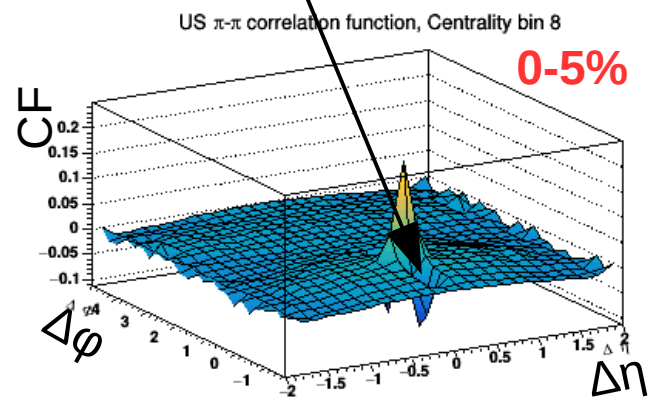


TPC hit merging:

- TPC hits from tracks close in space might be merged
- This results in pair losses in the nominator of CF
- This effect causes negative correlation at small Δη



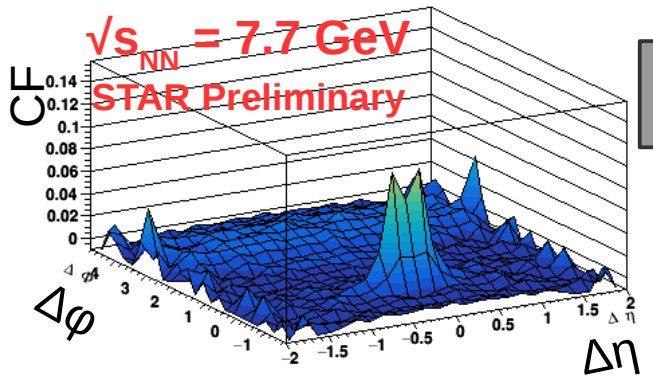


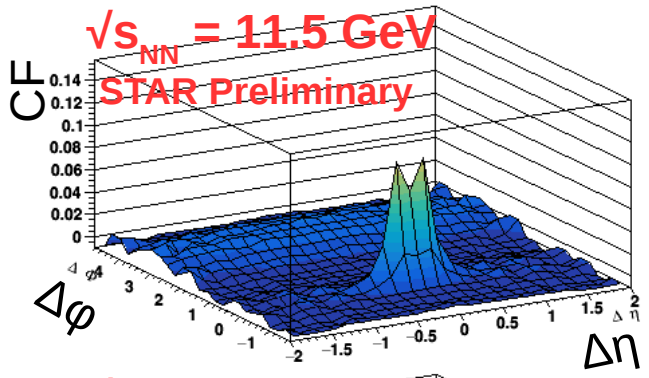


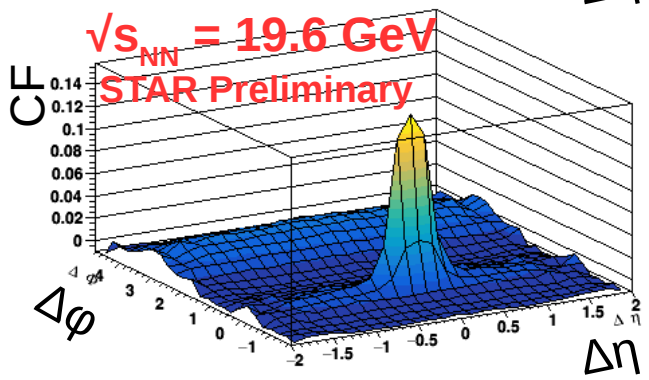
- Larger track crossing pair inefficiency with increasing centrality
- Visible in LS and in US
- Corrections are in progress

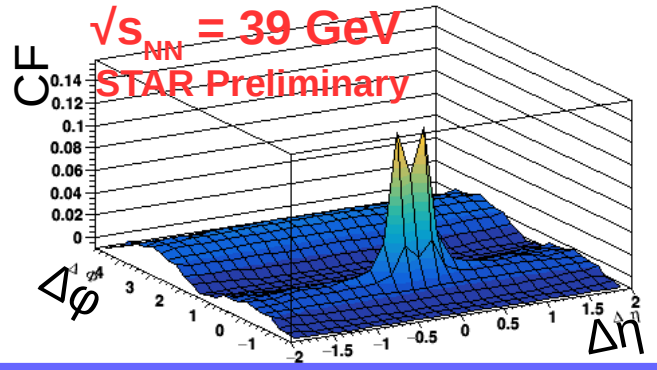
Energy dependence of correlation function

$\pi^+\pi^+$
$\pi^-\pi^-$





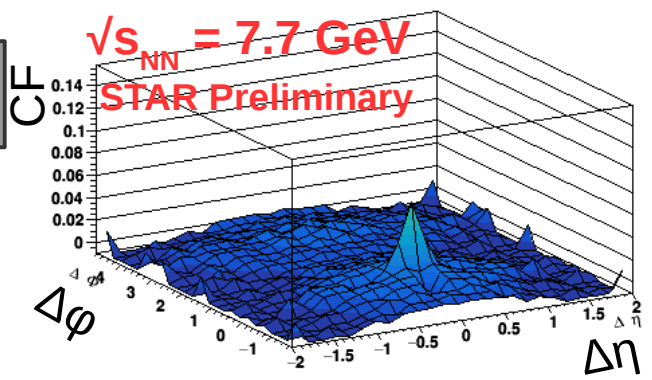


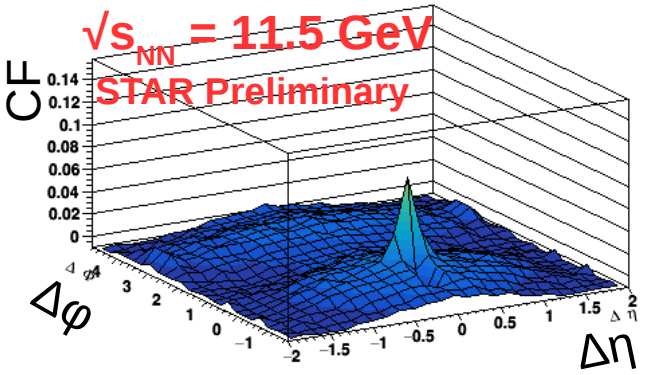


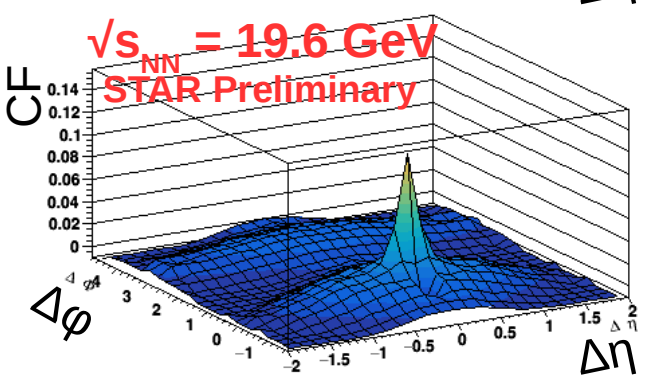
30-40%

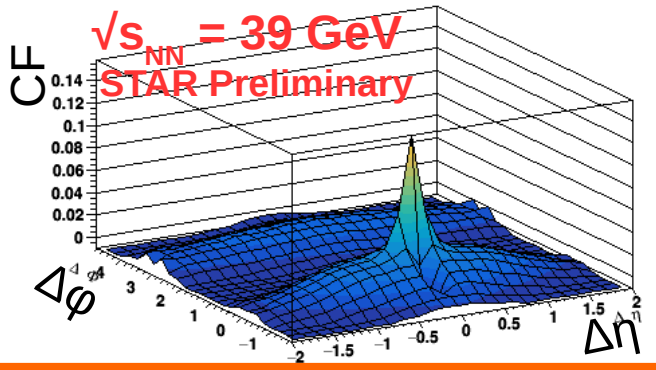
Au+Au collision energy

$\pi^+\pi^-$

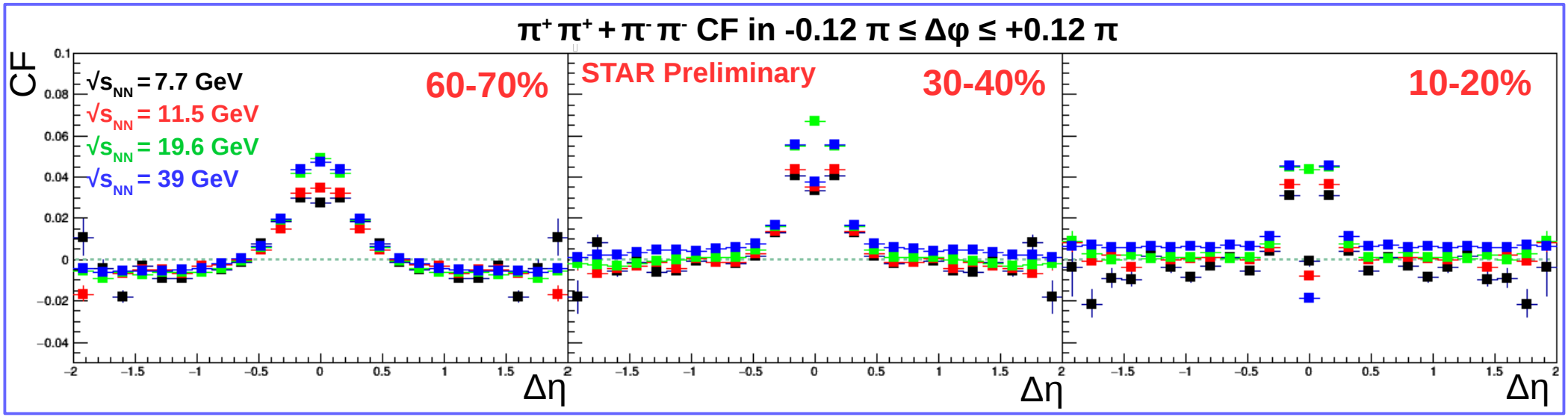


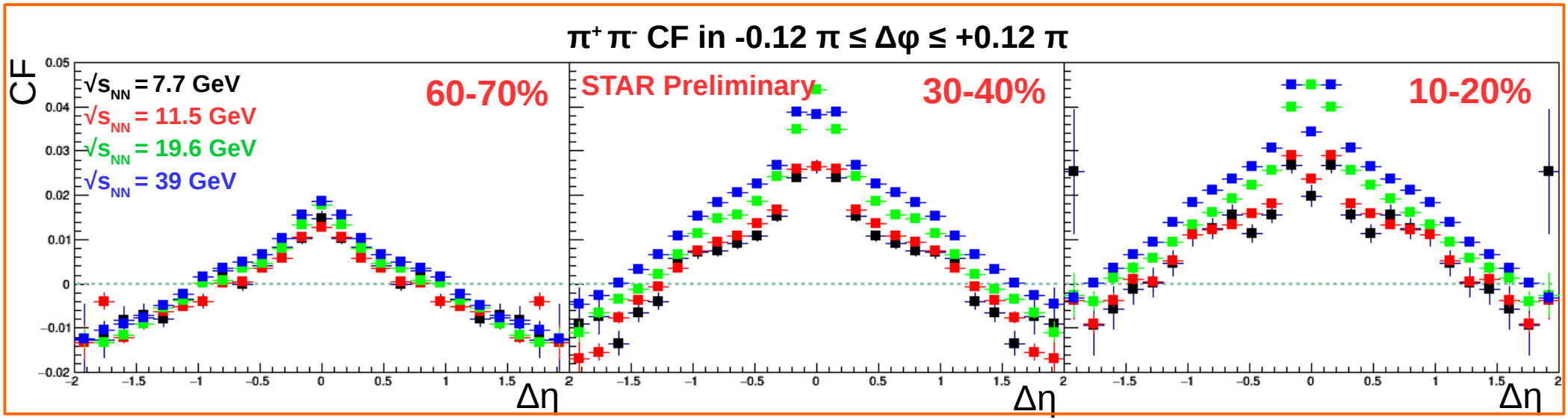






Near-side Δη projections of CF





ππ correlations:

- Weak collision energy dependence
- No non-monotonic changes vs. beam energy
- In LS ππ: strong short-range correlations
- In US ππ: short-range and long-range correlations

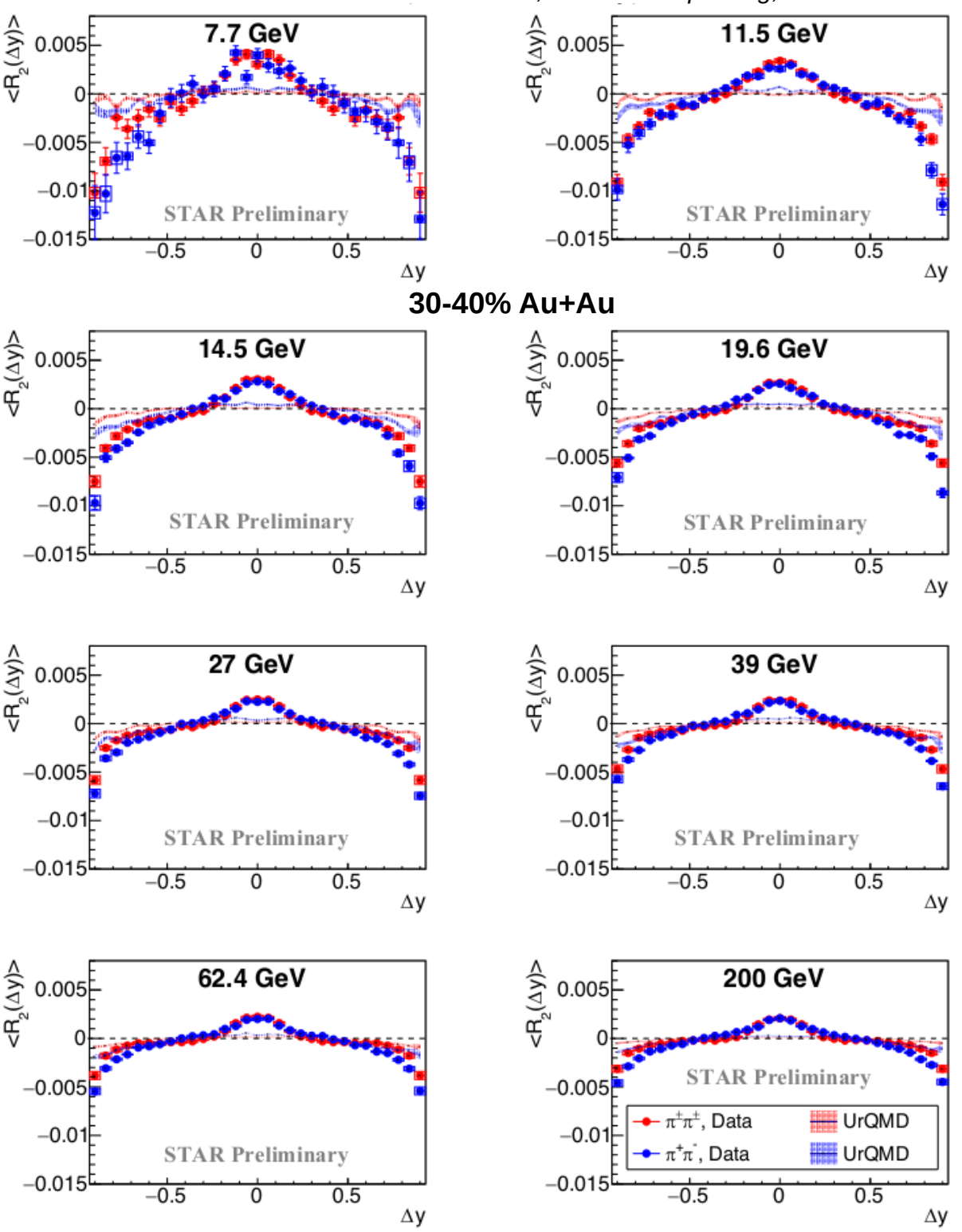
Correction for the TPC track crossing pair inefficiency not yet performed (visible in Δη ~ 0 points)

Parallel STAR analysis:

- Different correlator,
- Different Δη acceptance
- Different centrality selection
- Tracks crossing effect corrected
- $0.2 \leq p_T \leq 2.0$ GeV/c

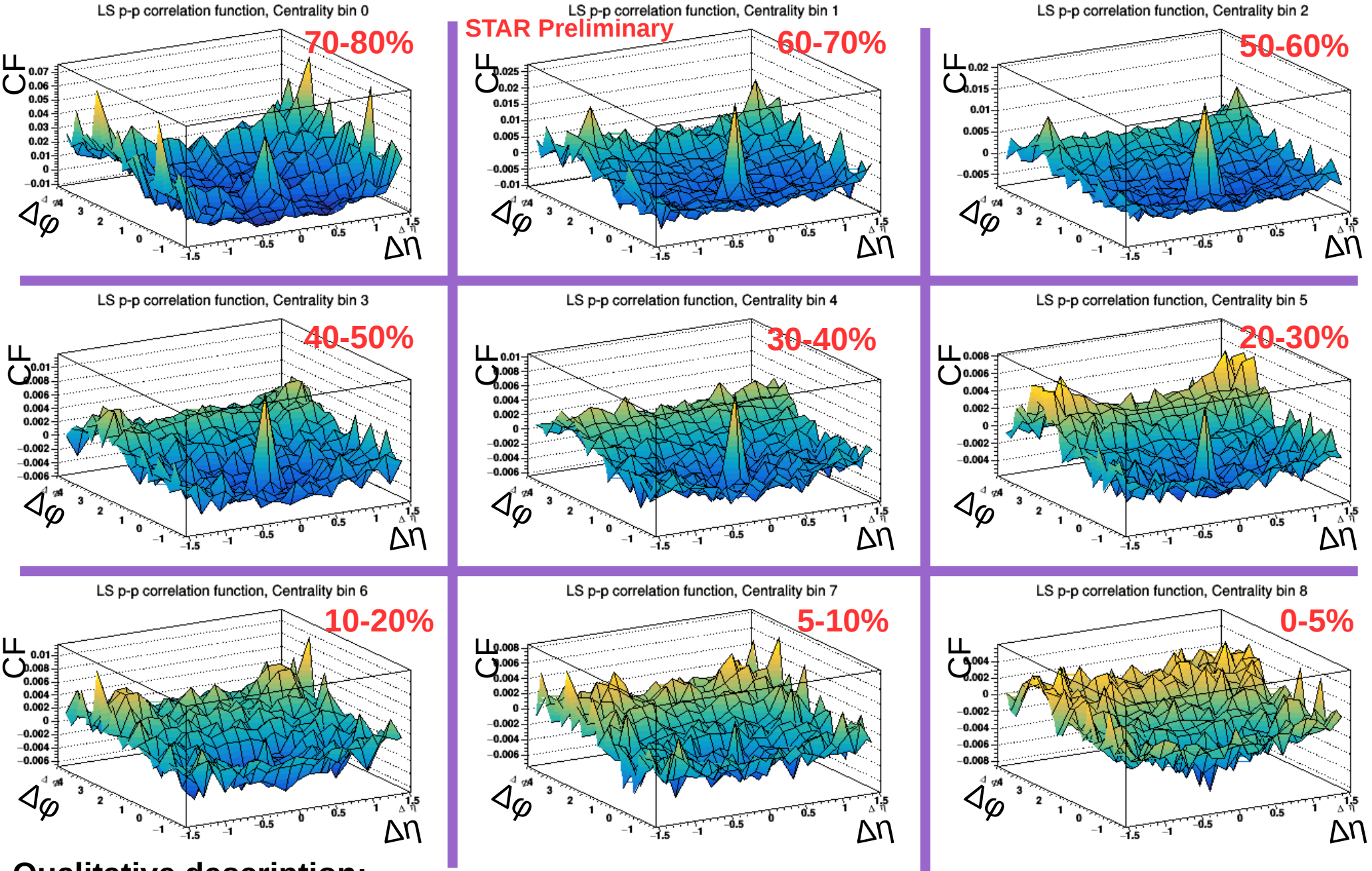
Here:

- Projection over whole Δφ acceptance
- General conclusions consistent between analyses



p p correlations

p-p + $\bar{p}$-$\bar{p}$ correlations, Au=Au @ 19.6 GeV



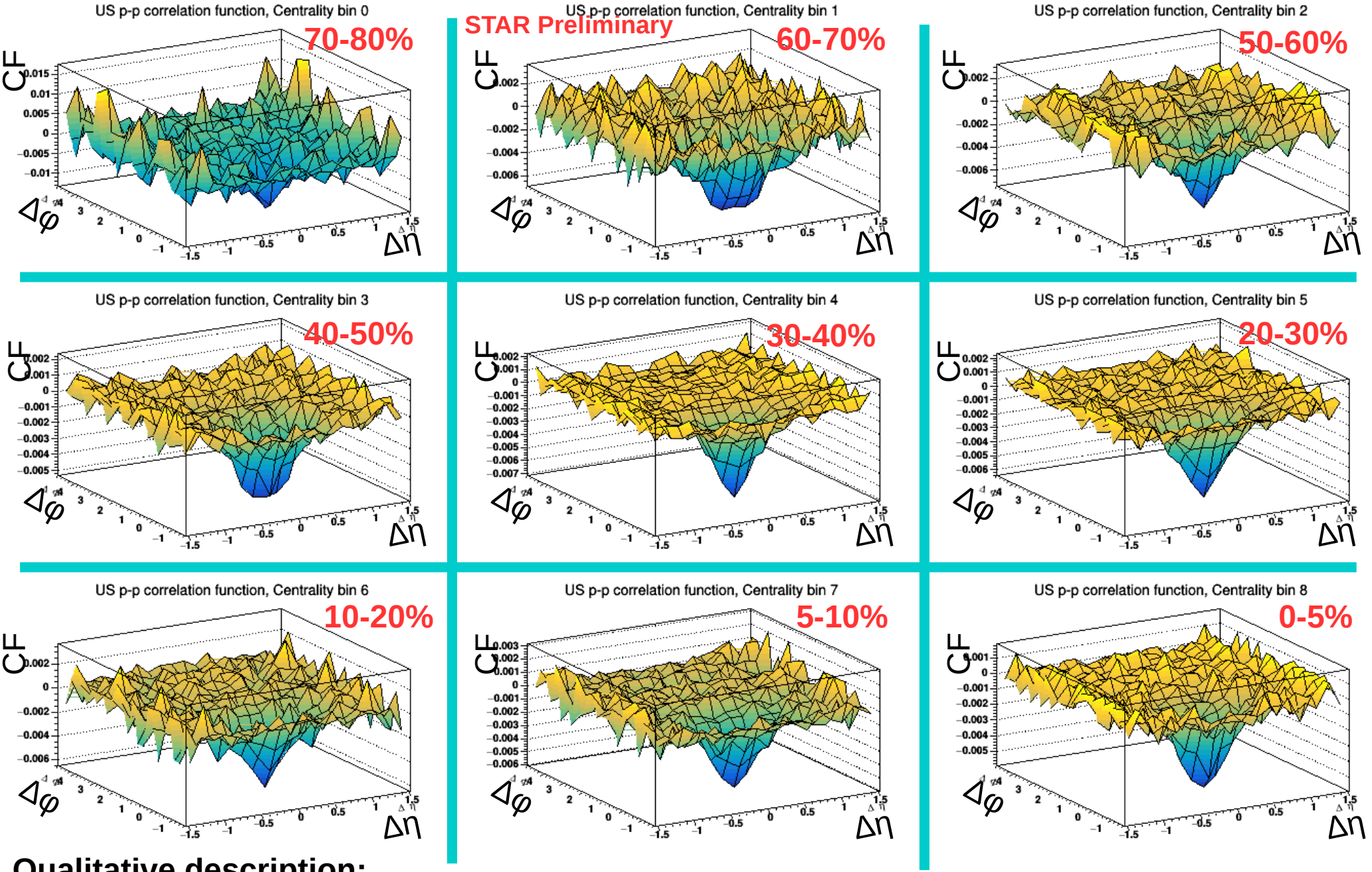
Qualitative description:

→ **Anti-correlated on the near-side**

→ **Sharp peak at (Δη;Δφ) ≈ (0;0)**

→ **Visible away-side ridge**

p-$\bar{p}$ correlations, Au+Au @ 19.6 GeV



Qualitative description:

→ **Negative correlation on the near-side, not as broad as in LS**

→ **Lack of spike at (Δη;Δφ) ≈ (0;0)**

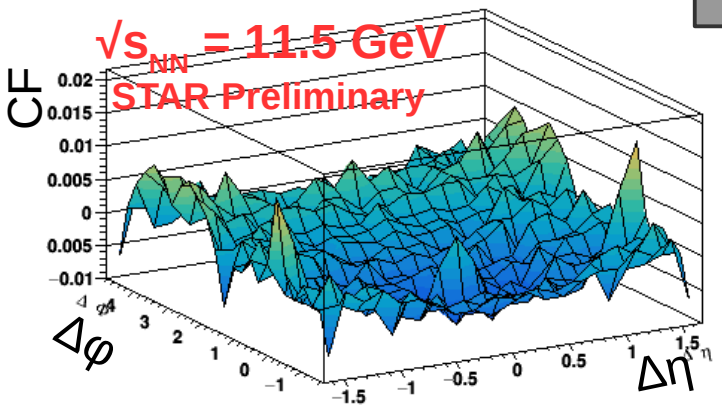
→ **Lack of away-side ridge**

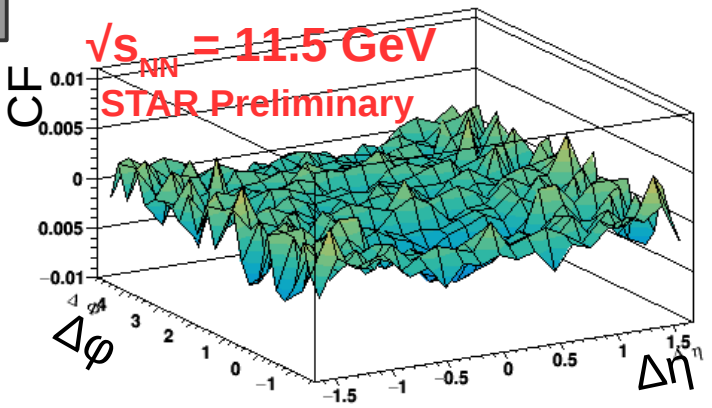
Energy dependence of correlation function

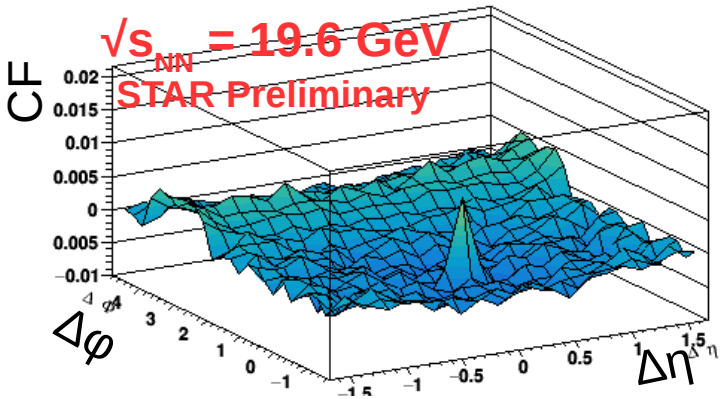
p p
$\bar{p}$ $\bar{p}$

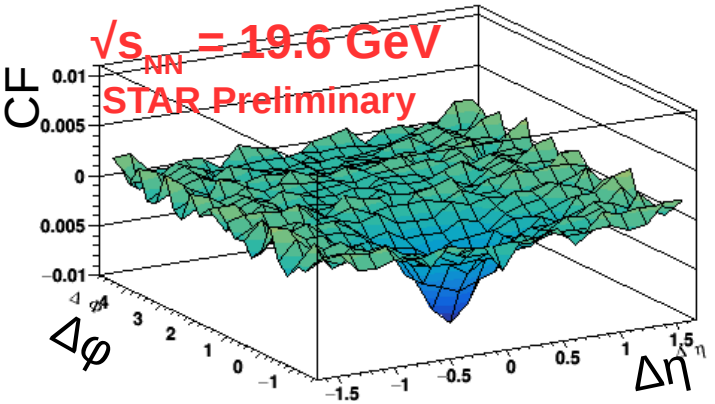
30-40%

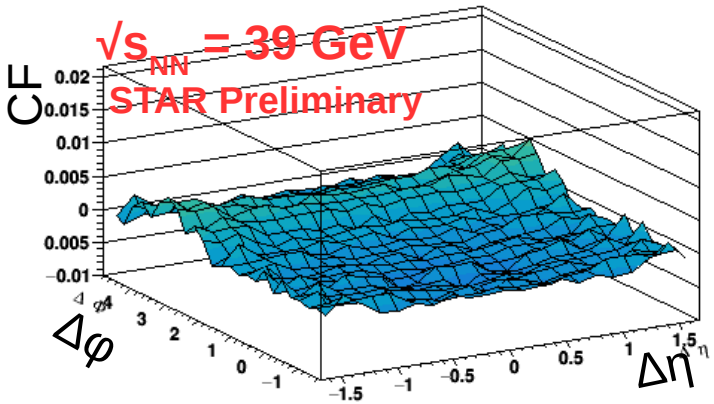
p $\bar{p}$

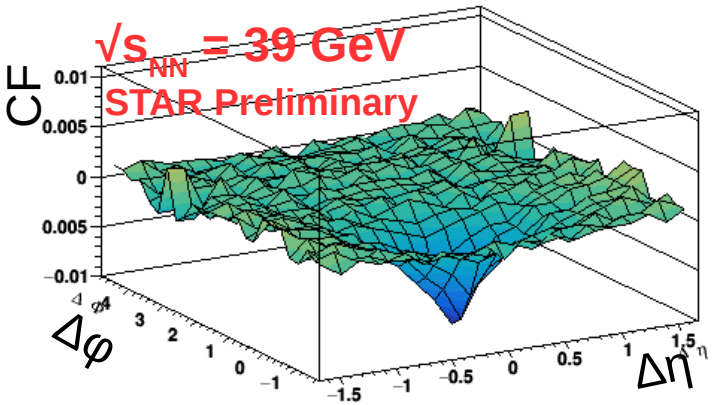






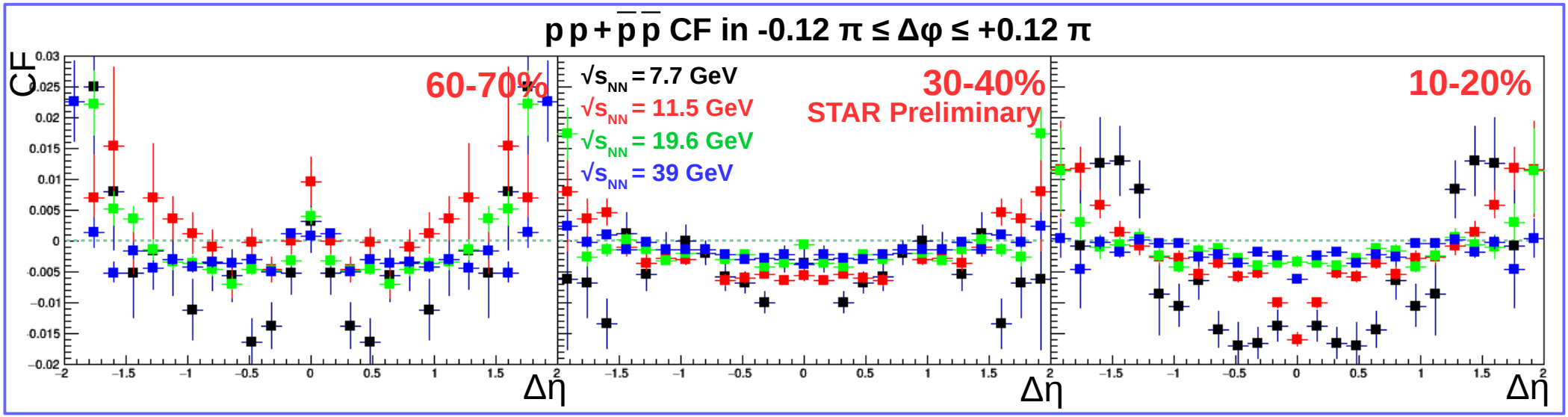


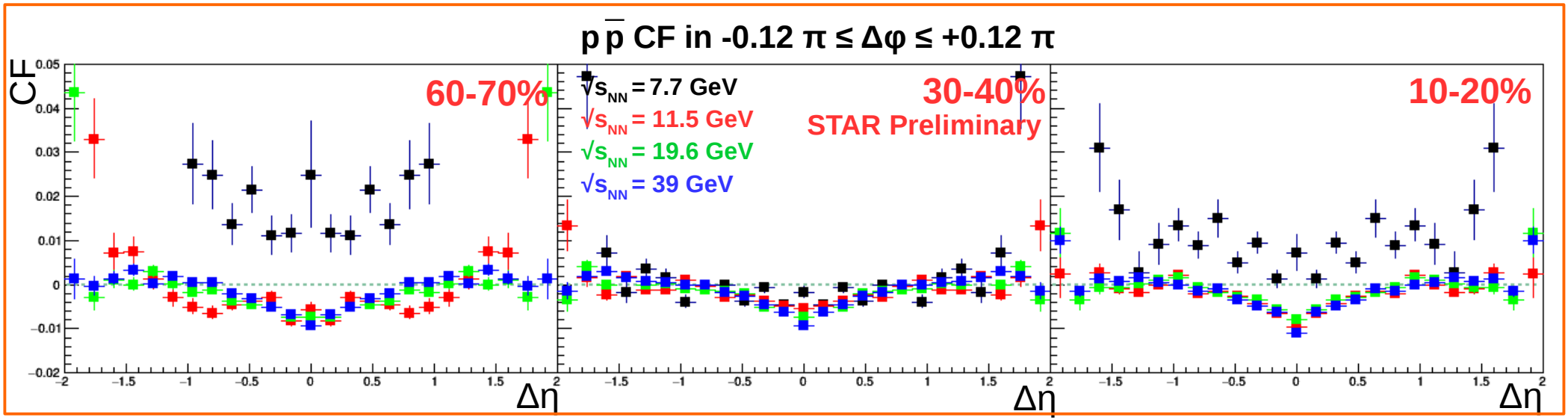




Au+Au collision energy

Near-side Δη projections of CF





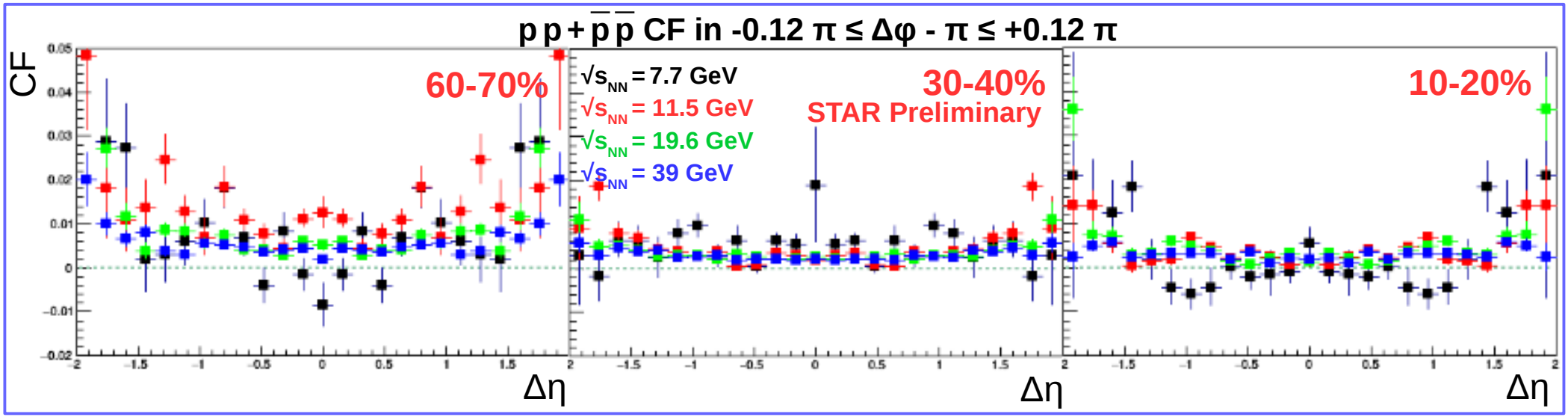
pp correlations:

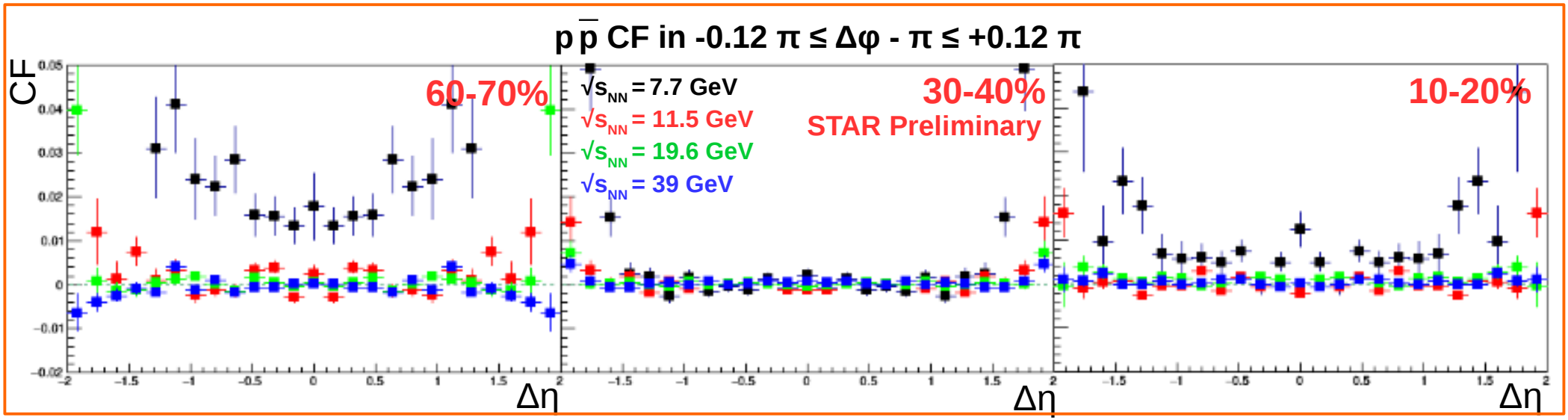
- Anti-correlation observed
  - ➔ in all centralities
  - ➔ in all collision energies
- Weak dependence on centrality and collision energy

p$\bar{p}$ correlations:

- Anti-correlation not as wide as in pp
  - ➔ in all centralities
  - ➔ in all collision energies
- Centrality and collision energy independent

Away-side Δη projections of CF





p p + p̄ p̄ correlations:

- Away-side ridge present
- Negative correlation is localised on near-side only

p p̄ correlations:

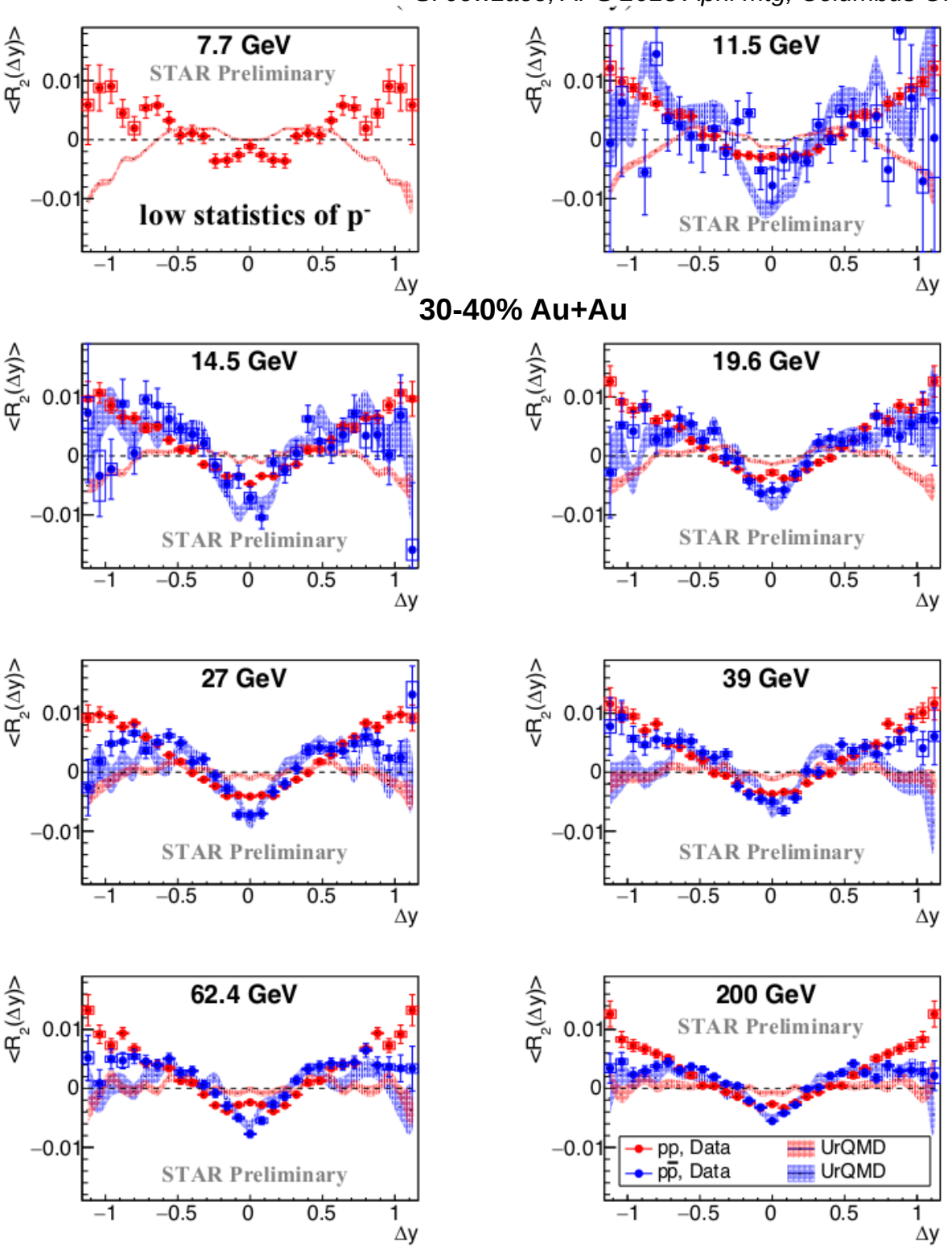
- Lack of away-side ridge

Parallel STAR analysis:

- Different correlator,
- Different Δη acceptance
- Different centrality selection
- Tracks crossing effect corrected
- $0.4 \leq p_T \leq 2.0$ GeV/c

Here:

- Projection over whole Δφ acceptance
- General conclusions consistent between analyses
- UrQMD can reproduce negative correlation in pp



Summary

Ongoing analysis (Au+Au @ 7.7, 11.5, 19.6, and 39 GeV):

- Results for **two-pion** correlations:
  - ➔ No non-monotonic behavior vs collision energy observed
  - ➔ Strong short-range correlations in LS
  - ➔ A broad Δφ ridge in US

- Results for **two-proton** correlations:
  - **p-p + $\bar{p}$-$\bar{p}$:**
    - ➔ Anti-correlation observed in all studied energies and centrality classes of Au+Au collisions
    - ➔ Resembles ALICE results (p+p @ 7 TeV, EPJC 77 (2017) no.8, 569)
  - **p-$\bar{p}$:**
    - ➔ Anti-correlation at Δη,Δφ ~ 0, but different than in p-p + $\bar{p}$-$\bar{p}$
    - ➔ Lack of away-side ridge for low-p_T p-$\bar{p}$

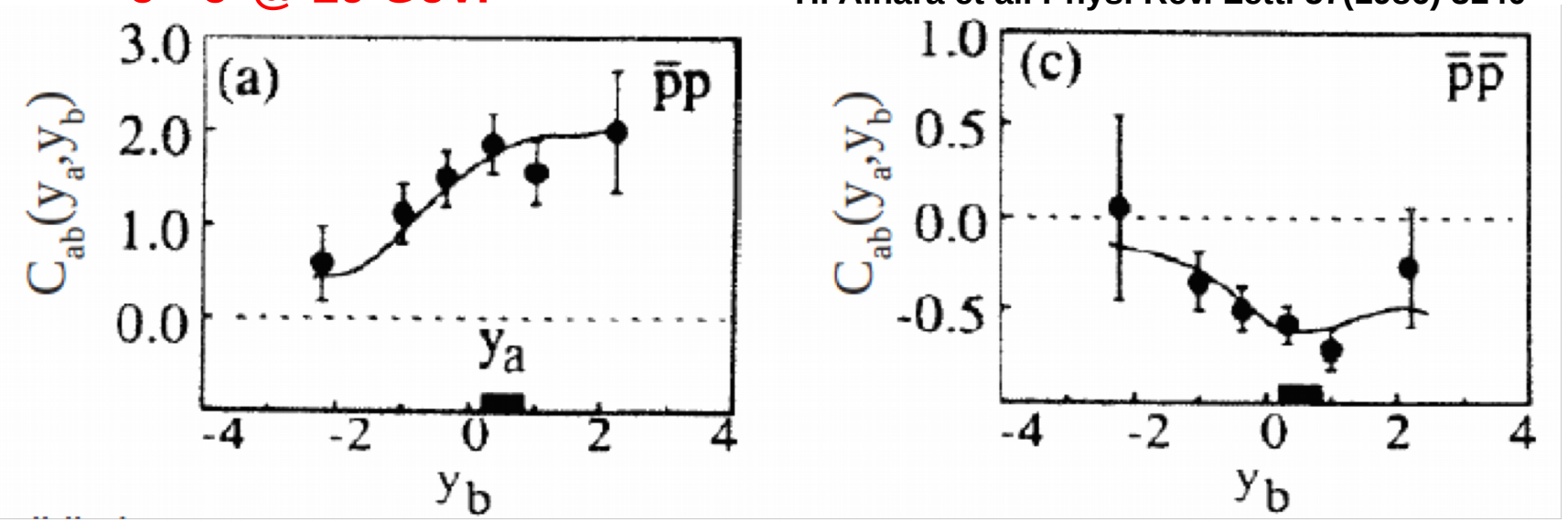
Plans for the future:

- Track crossing pair inefficiency corrections
- Analysis in other BES energies
- Disentanglement of observed structures → study of various physical phenomena as a function of centrality and collision energy

BACKUP

$e^+ + e^-$ @ 29 GeV:

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



Anti-correlation of two antiprotons at small relative rapidity was observed a long time ago

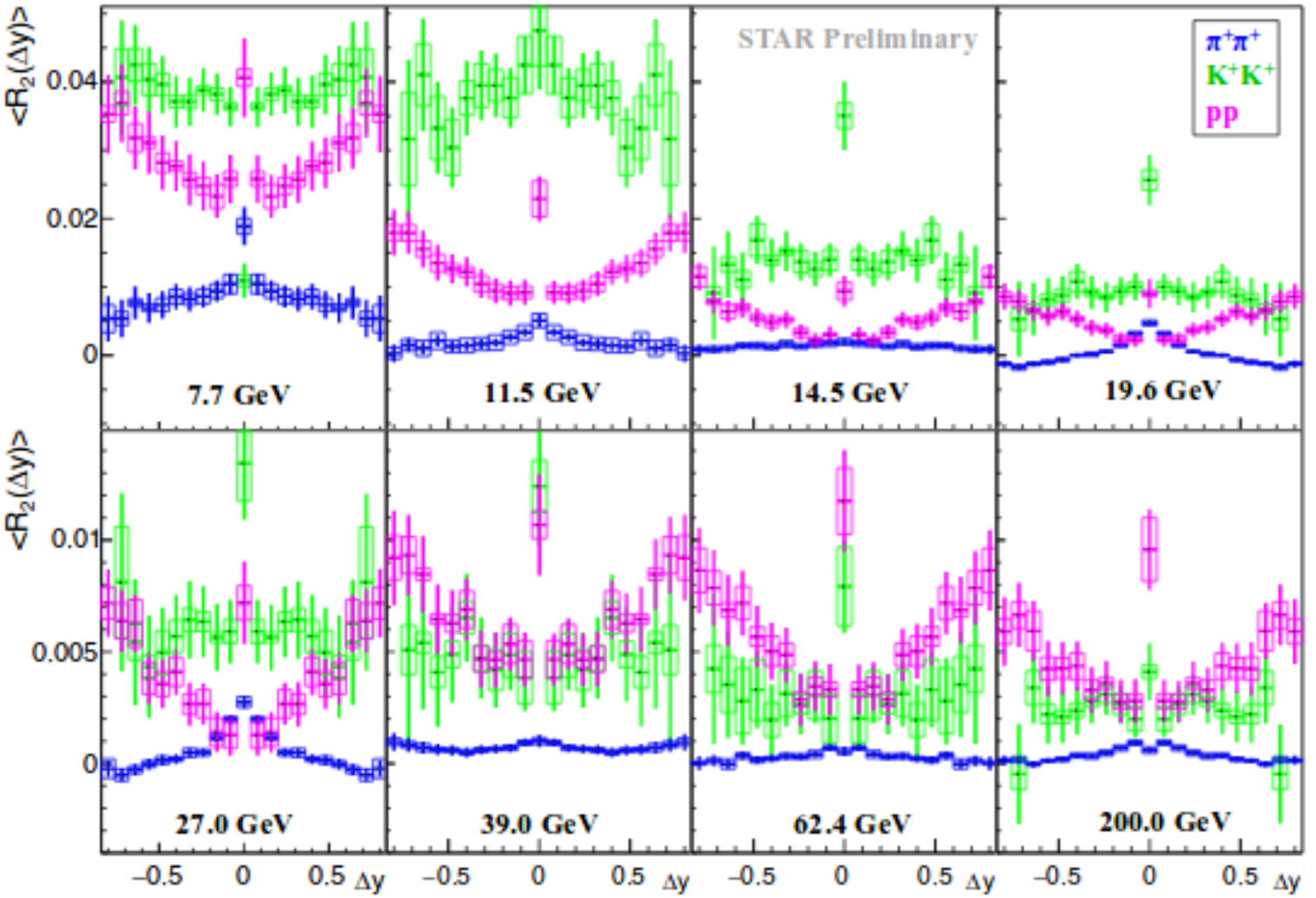
- Baryon number conservation: 2 protons and 2 anti-protons in single process
- 4 baryons → high E → less likely
- Current MC models → E conservation + B conservation → but data not reproduced!

QM 2017: first results on angular correlations of identified hadrons in BES:

STAR, 0-5% Au+Au @ BES

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

Nuc. Phys. A, 967 (2017), 792-795



- **QM 2017*:**
  - Minima for p-p correlations seen in all BES energies in 0-5% Au+Au

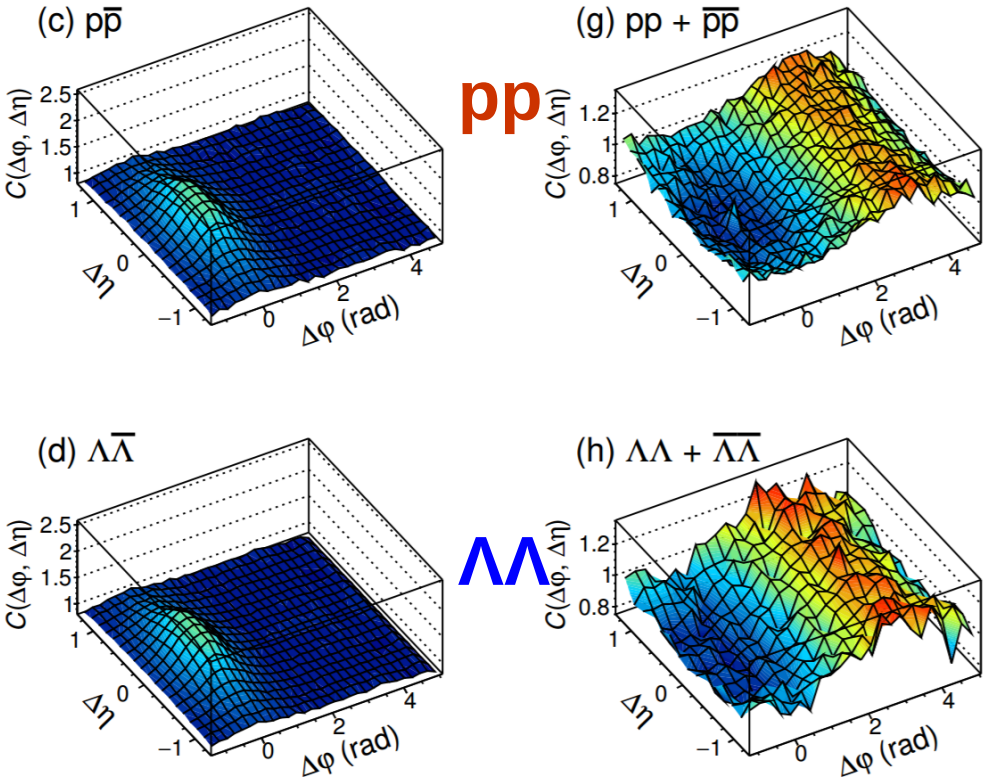
*)
→ $p_T > 0.2$ GeV/c
→ PID via TPC + ToF

Depletion in pp + $\overline{pp}$ is **not** caused by:

- Coulomb repulsion (Λ is neutral)

ALICE p+p @ 7 TeV:

EPJC 77 (2017) no.8, 569



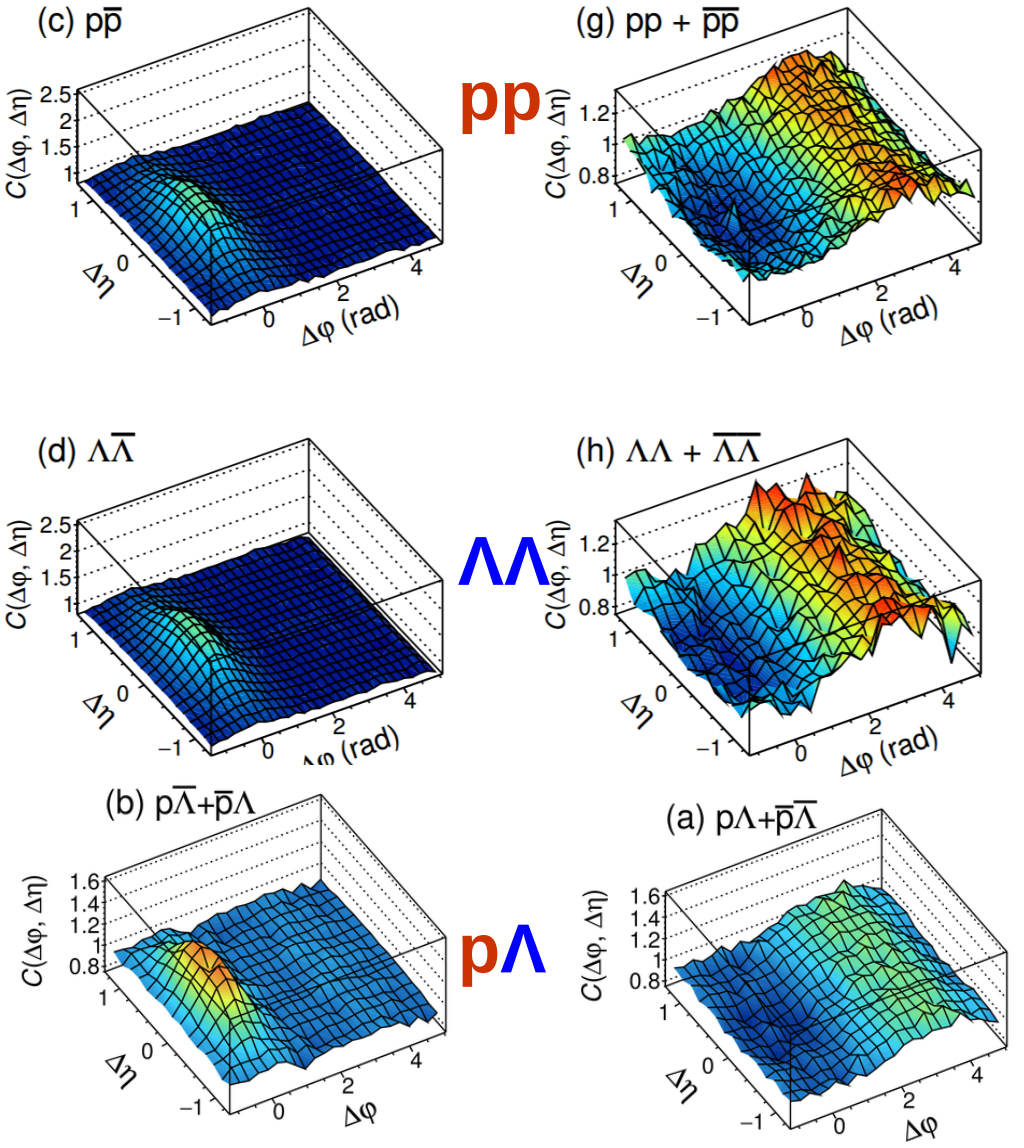
Depletion in pp + $\overline{pp}$ is **not** caused by:

- Coulomb repulsion (Λ is neutral)

- Fermi-Dirac statistics (p and Λ are different particles)

ALICE p+p @ 7 TeV:

EPJC 77 (2017) no.8, 569



Depletion in pp + $\overline{pp}$ is **not** caused by:

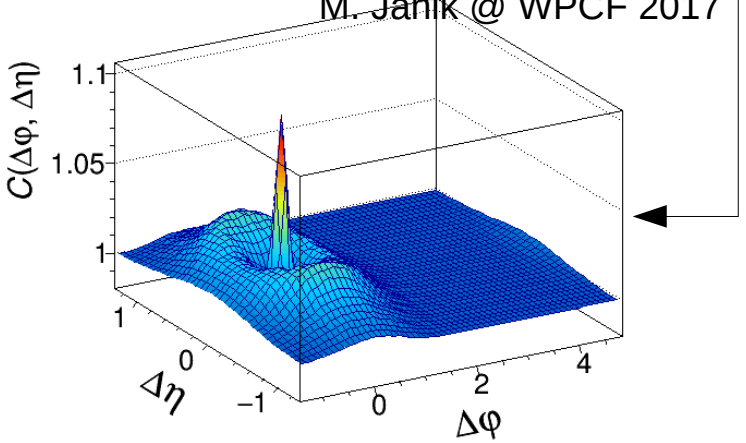
- Coulomb repulsion (Λ is neutral)

- Fermi-Dirac statistics (p and Λ are different particles)

- Final State Interactions

Transformed (Δη, Δφ) corr. fcn from femto:

M. Janik @ WPCF 2017



ALICE p+p @ 7 TeV:

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