



**Wydział  
Fizyki**

POLITECHNIKA WARSZAWSKA



# $\Delta\eta$ - $\Delta\phi$ correlations of identified particles in the Beam Energy Scan

*Andrzej Lipiec (WUT)*

**Supported by:**



NATIONAL SCIENCE CENTRE  
POLAND

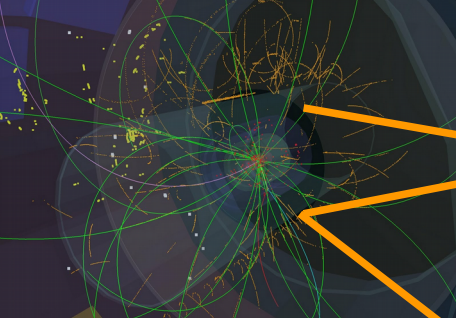
**Project number: UMO-2016/21/N/ST2/00315**

# Angular correlation function:

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

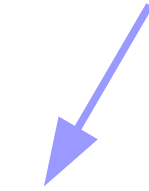
$$\Delta\phi = \phi_1 - \phi_2$$

Event 1



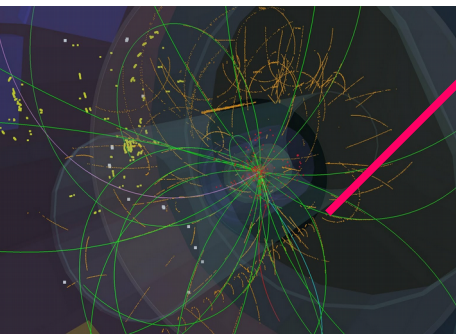
$$\rho_{sib}(\Delta\eta, \Delta\phi) = \frac{d^2 N_{sib}^{pairs}}{N_{sib}^{pairs} \cdot d(\Delta\eta \Delta\phi)}$$

# correlated pairs per pair



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

Event 2,3,4...



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

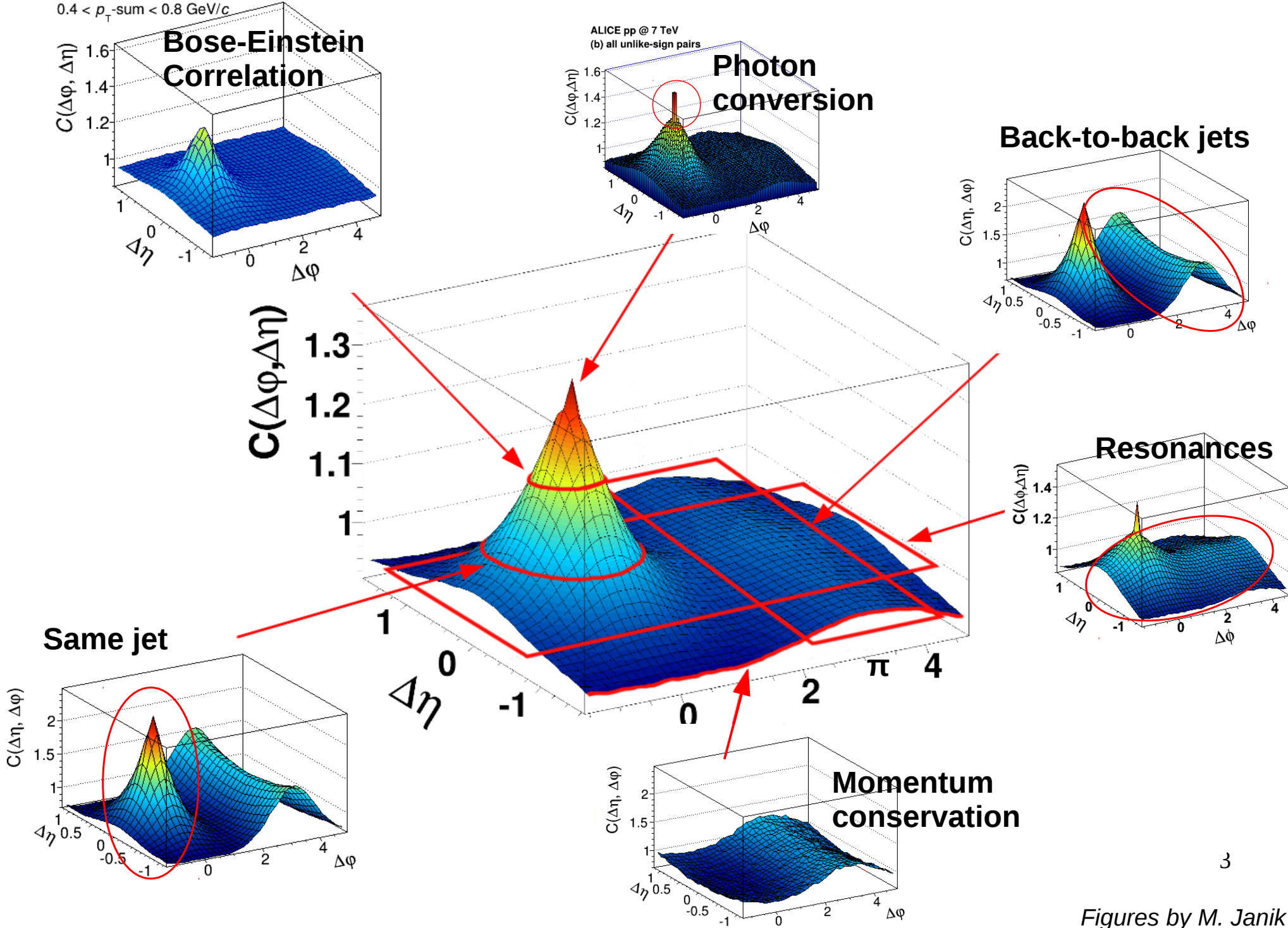
# correlated pairs per particle



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

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

# Correlation function: a tool to access different physical phenomena

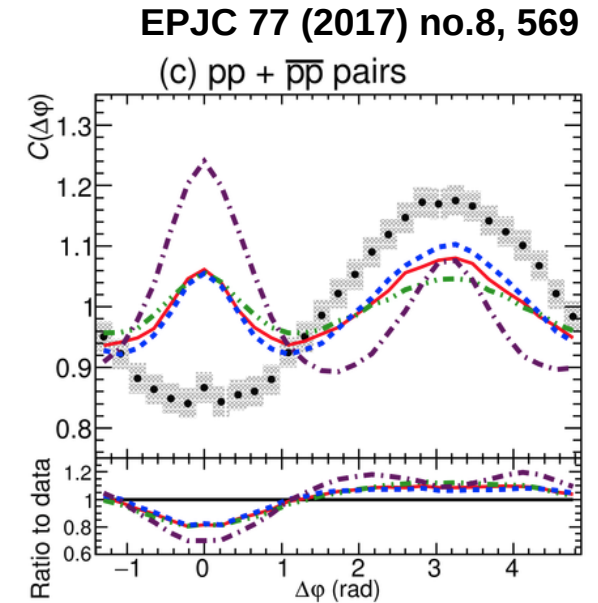
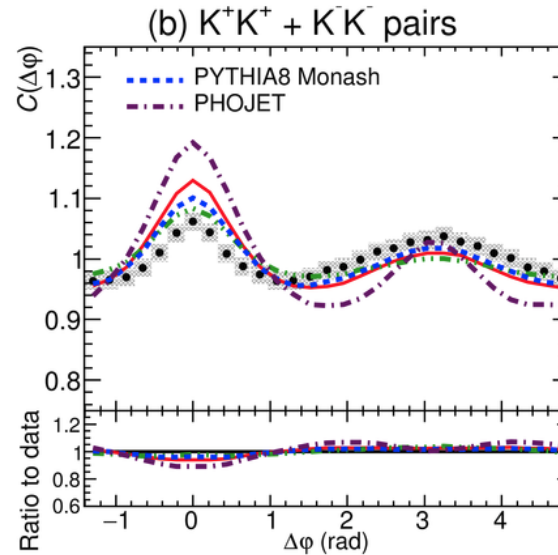
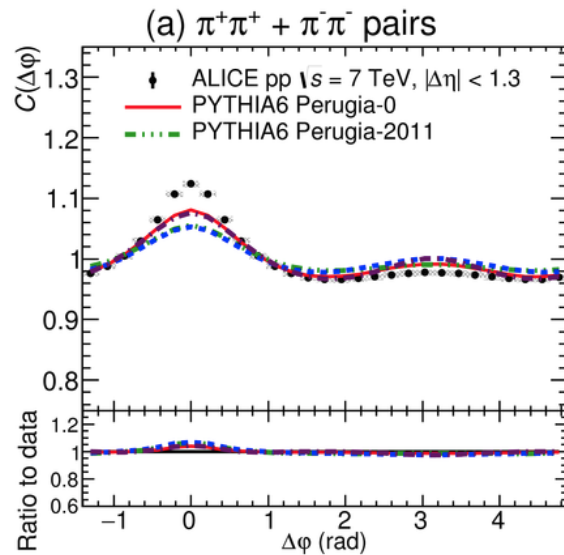


# Motivation: Why identified particles?

Why should we study identified particles?

- published  $\Delta\eta\Delta\phi$  results from BES – only 2-hadron correlations
- different shapes of correlation function for different particles
- intriguing results for two-proton correlations:

## ALICE p+p @ 7 TeV



- ALICE data are not perfectly described by well known MC models (different tunes of PYTHIA, PHOJET..)
- $pp + \overline{p\overline{p}}$  not described even qualitatively

Need of experimental data for further model development

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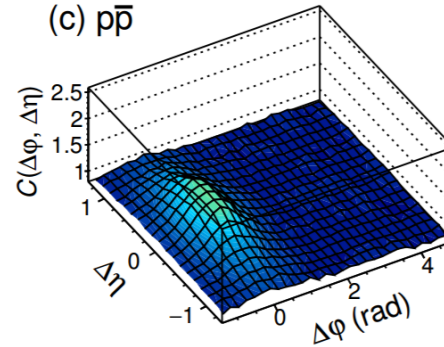
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- Coulomb repulsion ( $\Lambda$  is neutral)

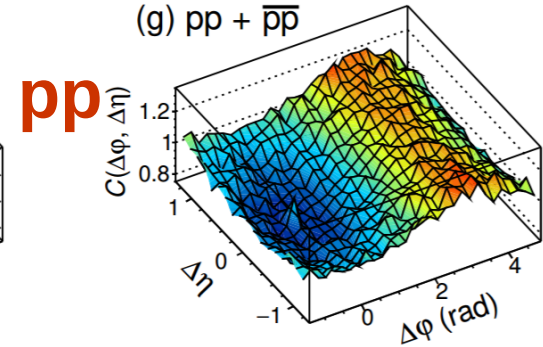
ALICE p+p @ 7 TeV:

(c)  $p\overline{p}$

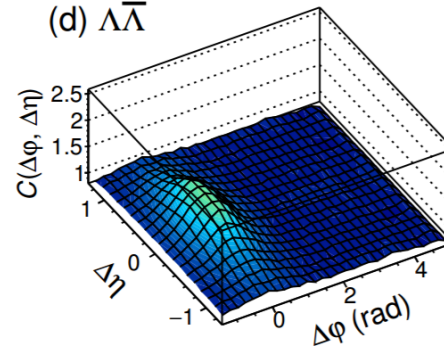


M. Janik @ WPCF 2017

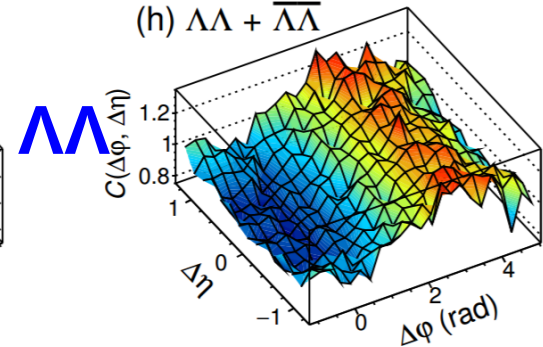
(g)  $pp + \overline{p\overline{p}}$



(d)  $\Lambda\overline{\Lambda}$



(h)  $\Lambda\Lambda + \overline{\Lambda\Lambda}$



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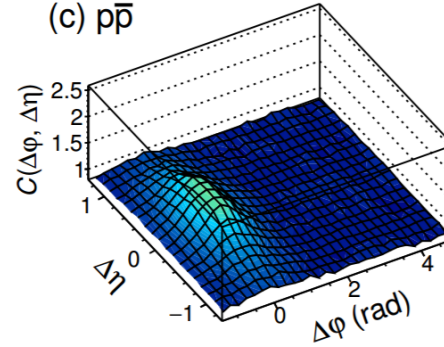
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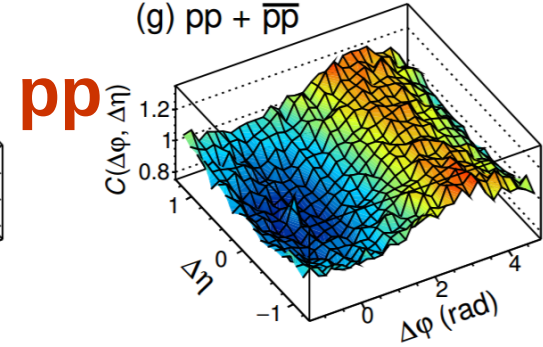
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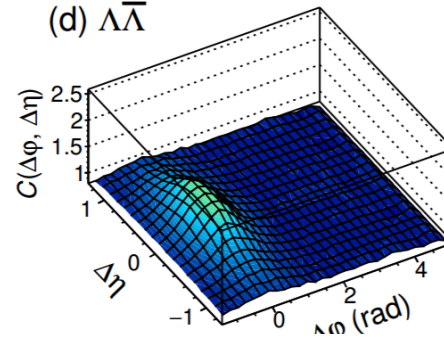


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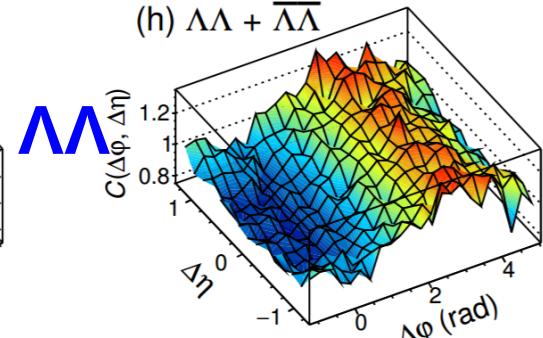
(g)  $pp + \bar{p}\bar{p}$



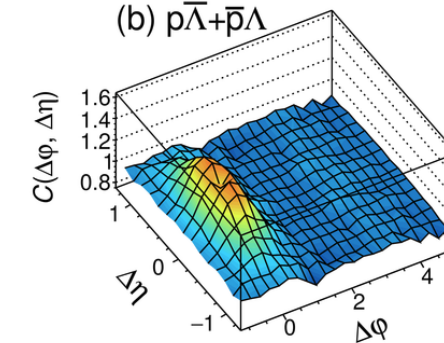
(d)  $\Lambda\bar{\Lambda}$



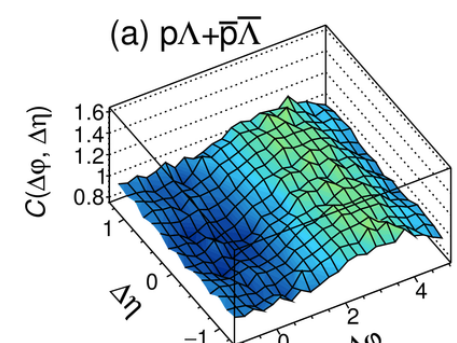
(h)  $\Lambda\Lambda + \bar{\Lambda}\bar{\Lambda}$



(b)  $p\bar{\Lambda} + \bar{p}\Lambda$



(a)  $p\Lambda + \bar{p}\bar{\Lambda}$



# Motivation: Why identified particles?

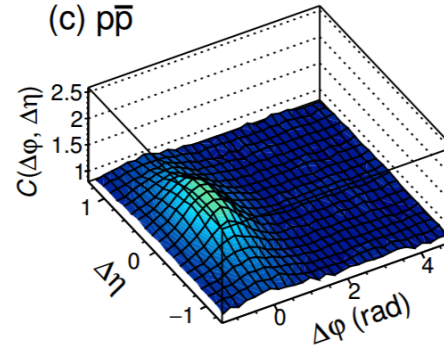
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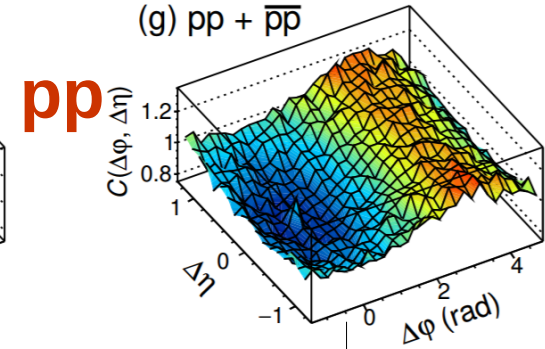
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(c)  $p\bar{p}$



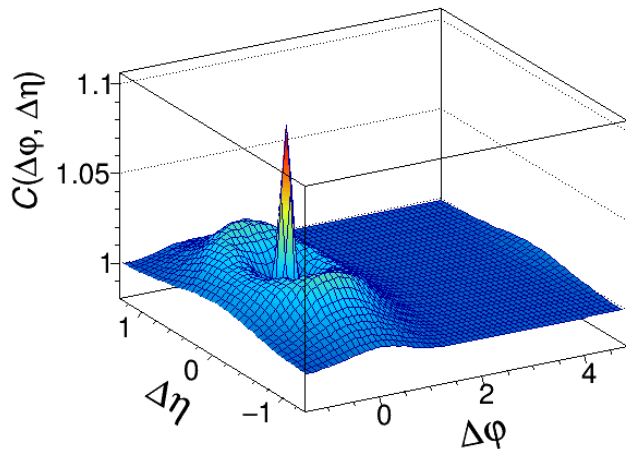
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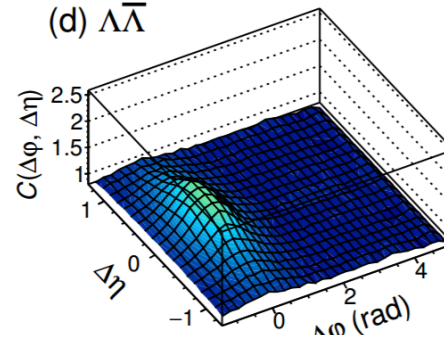
Depletion in  $pp + \bar{p}\bar{p}$  is **not** caused by:

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- Final State Interactions

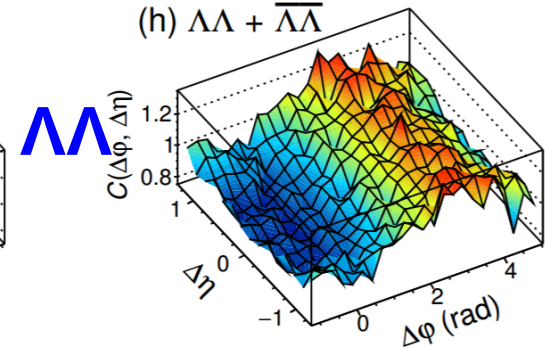
Transformed  $(\Delta\eta, \Delta\phi)$  corr. fcn from femto:



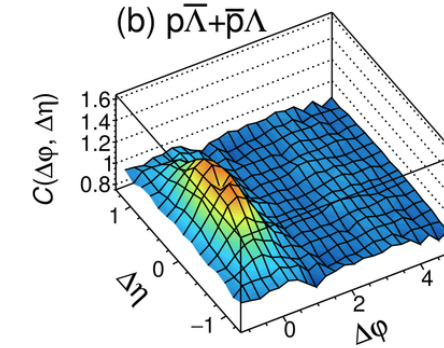
(d)  $\Lambda\bar{\Lambda}$



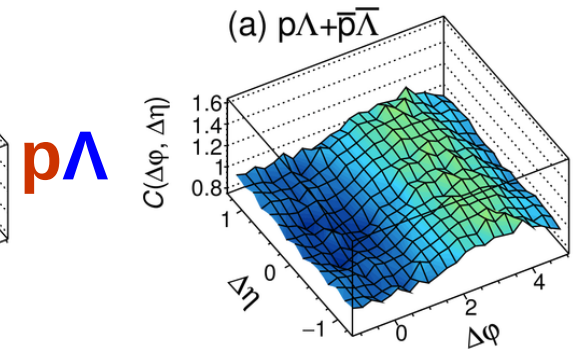
(h)  $\Lambda\Lambda + \bar{\Lambda}\bar{\Lambda}$



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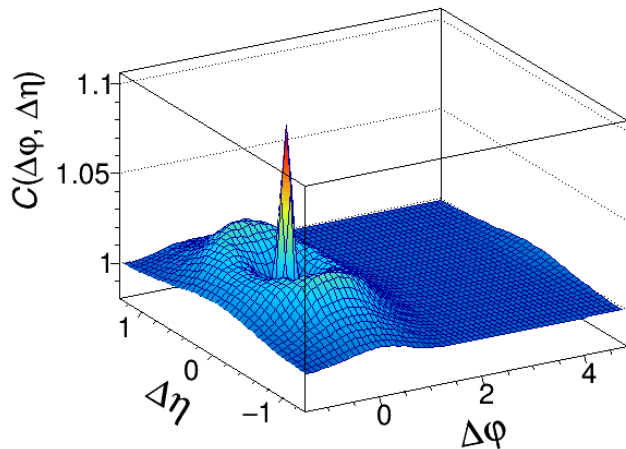
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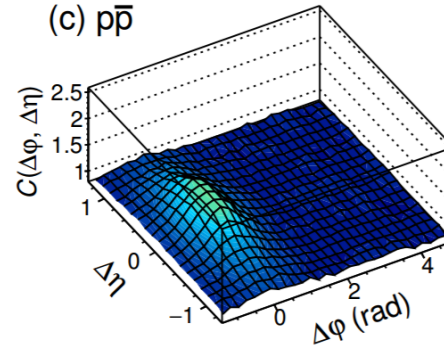
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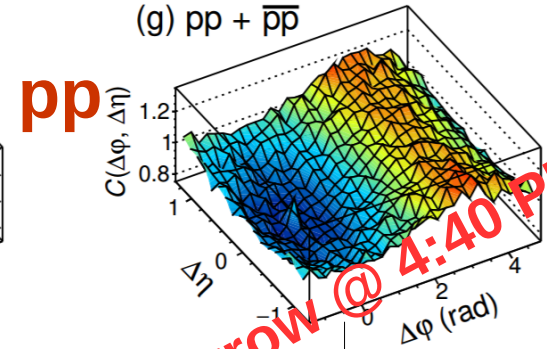
ALICE p+p @ 7 TeV:

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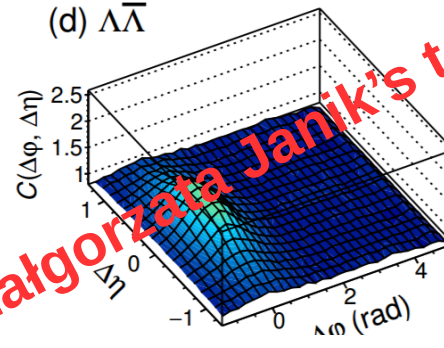


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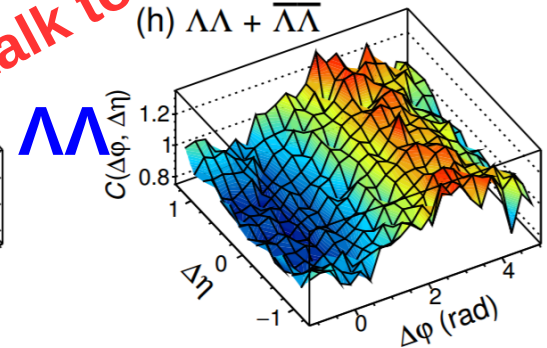
(g)  $pp + \bar{p}\bar{p}$



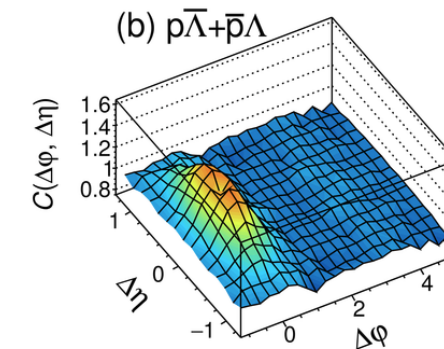
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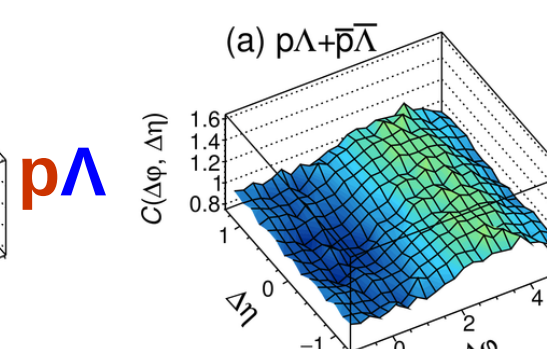
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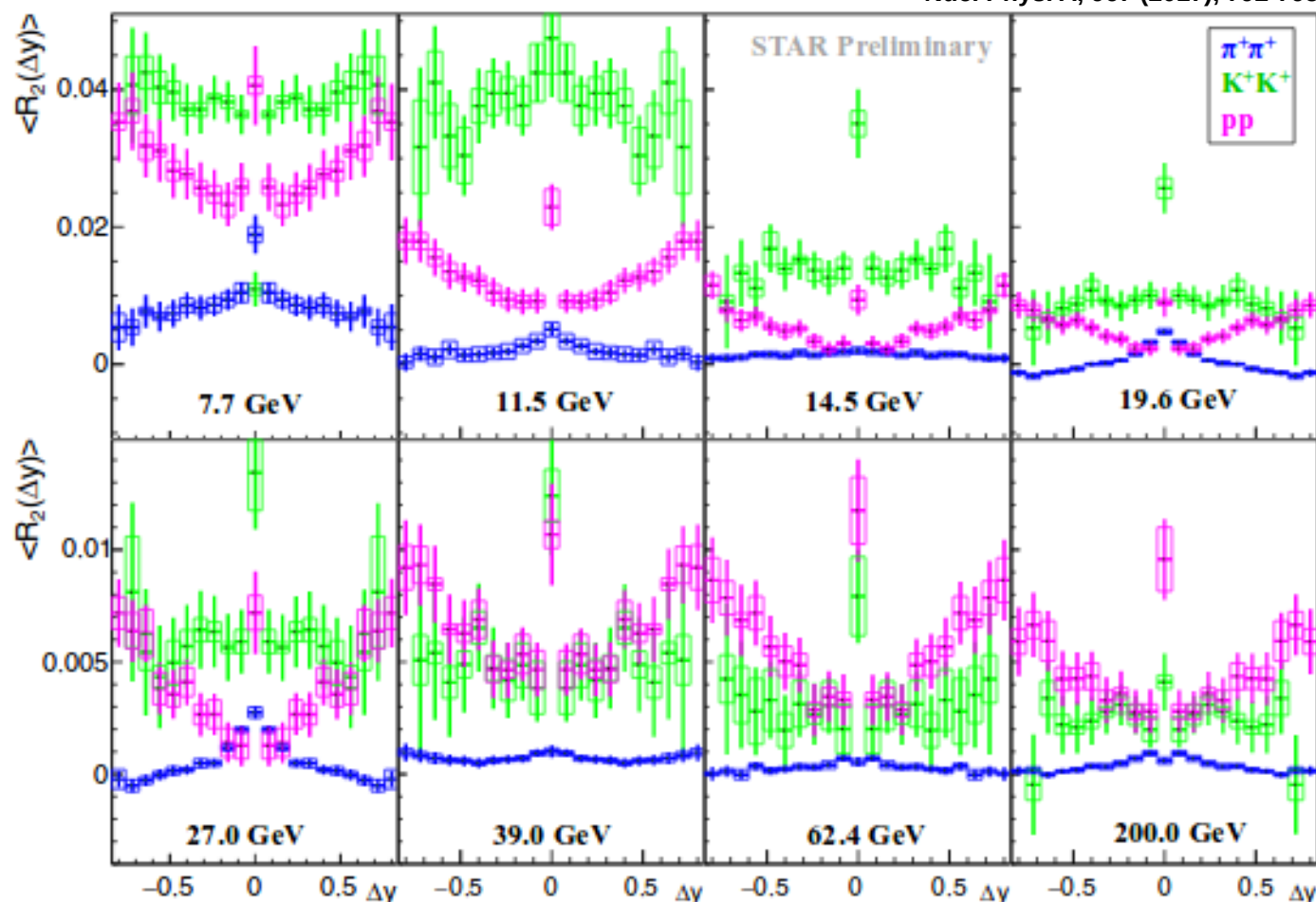
See Małgorzata Janik's talk tomorrow @ 4:40 PM



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

STAR, 0-5% Au+Au @ BES  
 $\pi^+\pi^+$ ,  $K^+K^+$  and  $p p$ , 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

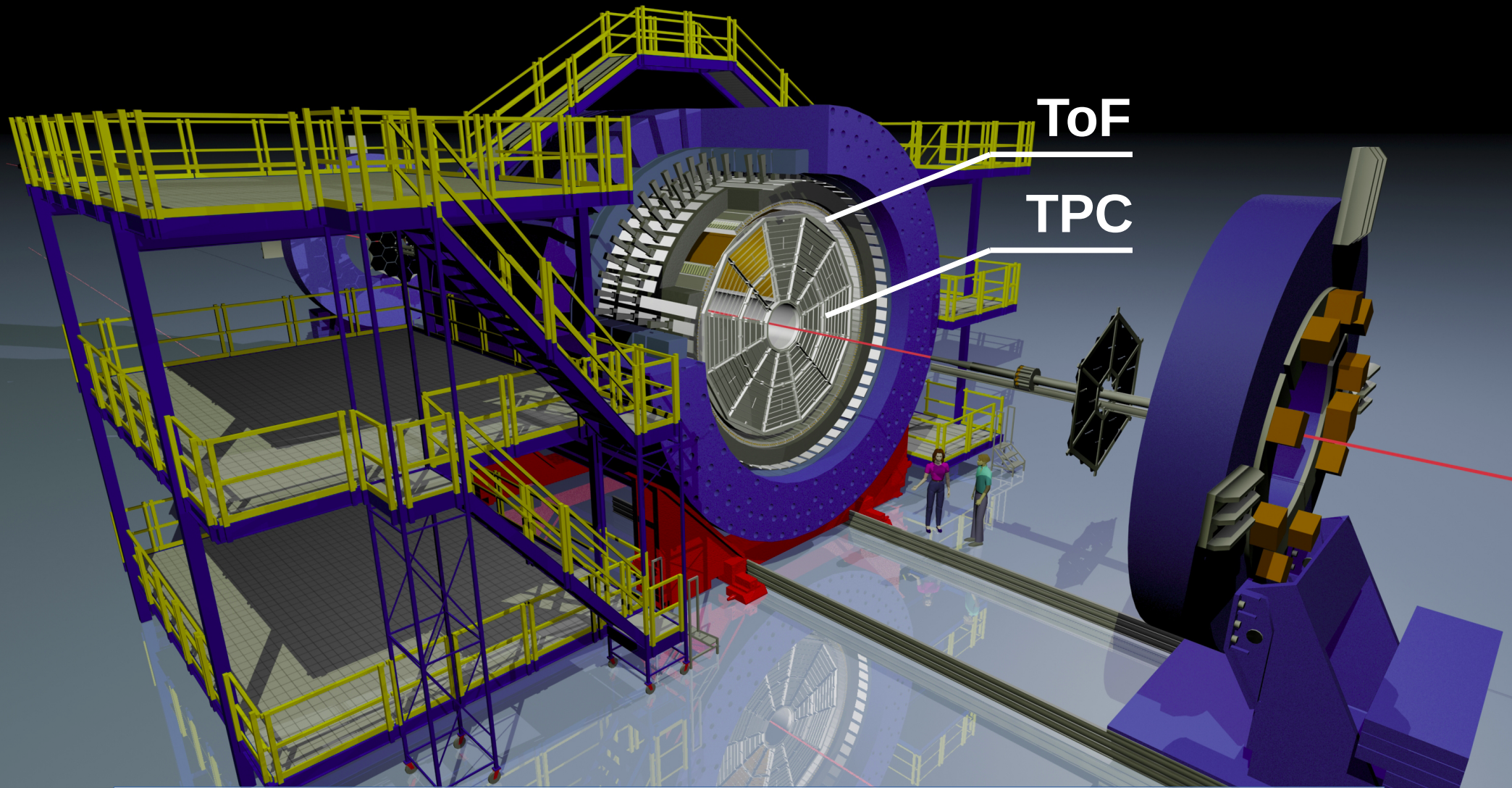
\*)

- $p_T > 0.2$  GeV/c
- PID via TPC + ToF

- **This analysis:**

- Extend results to full TPC acceptance:  $-2 < \Delta\eta < +2$
- Disentanglement and evolution of “correlation structures” in: collision energy, centrality, particle specie and charge combination

# SOLENOIDAL TRACKER AT RHIC



ToF

TPC

**TPC:  $-1 < \eta < +1$ , full azimuthal angle coverage**  
**ToF:  $-0.9 < \eta < +0.9$ , full azimuthal angle coverage**

# SOLENOIDAL TRACKER AT RHIC

## **BES at STAR:**

### Charge combination:

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

Unlike-Sign (US: + - )

### Particle species:

Protons

Kaons

Pions

Centrality: 80% – 0 %

Collision energy 7.7 – 200 GeV

## **This talk: Au+Au @ 19.6 GeV**

### Kinematic cuts:

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

### PID (TPC only): for each POI

- $|\ n\sigma_{\text{POI}}^{\text{dE/dx}} | < 2$
- $|\ n\sigma_{\text{others}}^{\text{dE/dx}} | > 3$

### Centrality:

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

**TPC:  $-1 < \eta < +1$ , full azimuthal angle coverage**  
**ToF:  $-0.9 < \eta < +0.9$ , full azimuthal angle coverage**

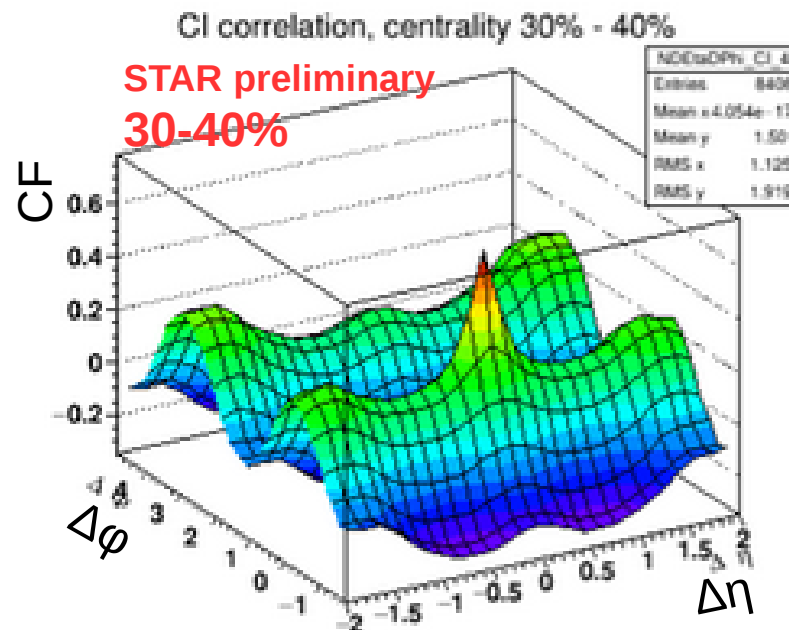
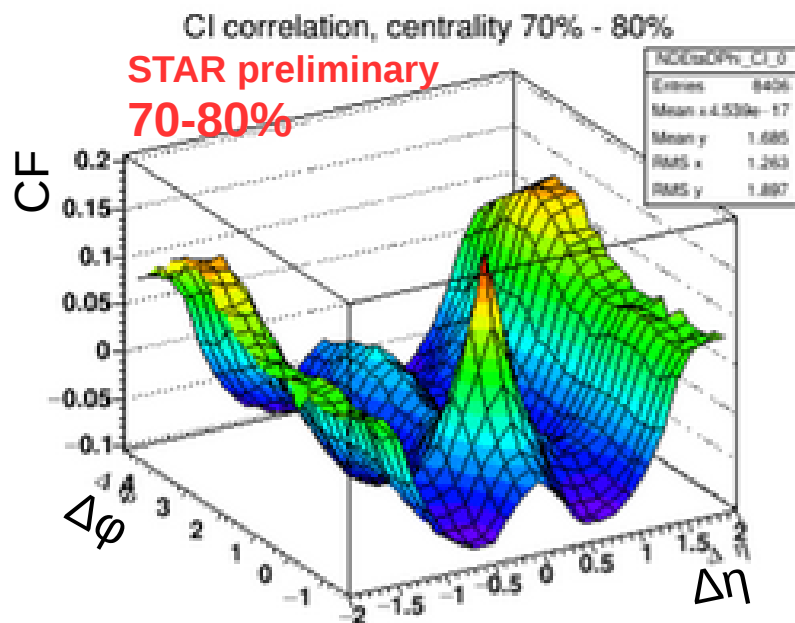
# Centrality selection:

Correlation  $\rightarrow$  normalized variance  $\rightarrow$  offset related to multiplicity fluctuations

Example: h-h correlations, Au+Au @ 200 GeV:

Centrality based on:  $N_{ch}$  in  $|\eta| < 0.5$

Centrality based on:  $N_{ch}$  in  $|\eta| > 0.5$



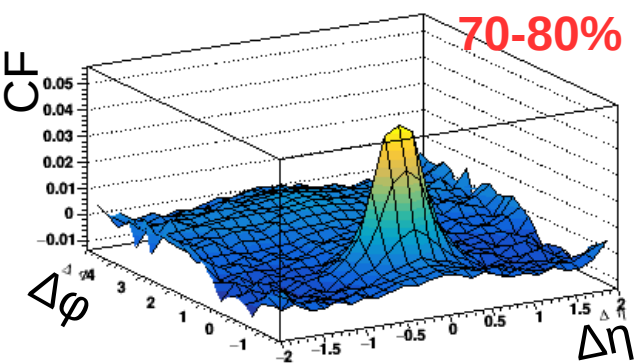
Either use two different  $\eta$  regions (no CF suppression) or use the same  $\eta$  range (constant suppression  $\rightarrow$  offset in CF)

This analysis:

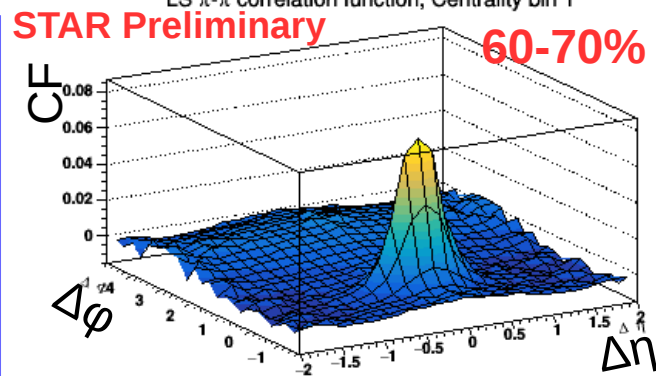
- Centrality based on corrected\*  $N_{ch}$  in  $|\eta| < 1$
- Extend analysis to +/- 2 units of  $\Delta\eta$

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

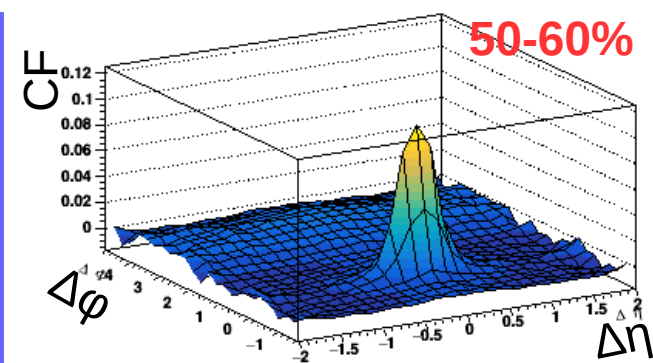
LS  $\pi$ - $\pi$  correlation function, Centrality bin 0



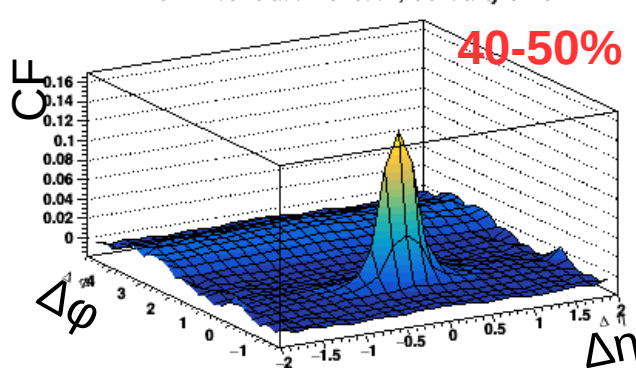
LS  $\pi$ - $\pi$  correlation function, Centrality bin 1



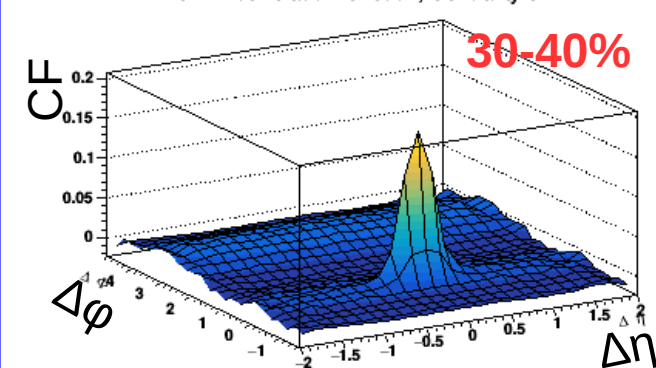
LS  $\pi$ - $\pi$  correlation function, Centrality bin 2



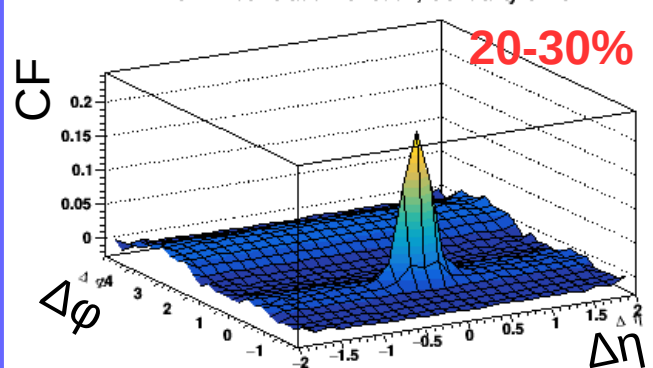
LS  $\pi$ - $\pi$  correlation function, Centrality bin 3



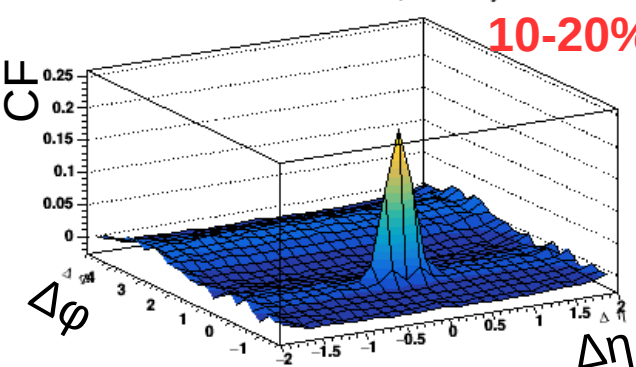
LS  $\pi$ - $\pi$  correlation function, Centrality bin 4



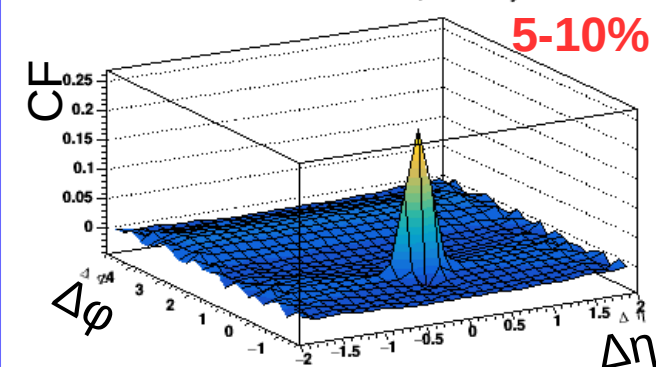
LS  $\pi$ - $\pi$  correlation function, Centrality bin 5



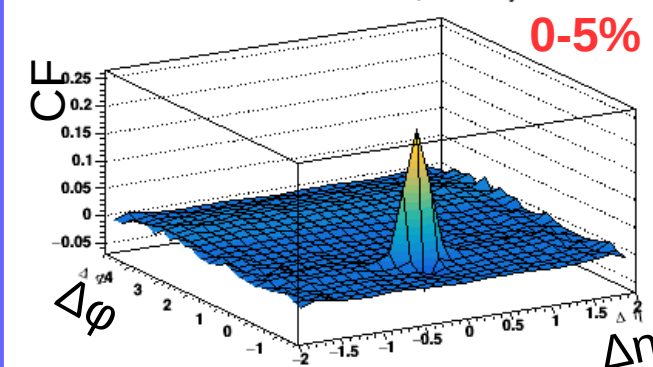
LS  $\pi$ - $\pi$  correlation function, Centrality bin 6



LS  $\pi$ - $\pi$  correlation function, Centrality bin 7



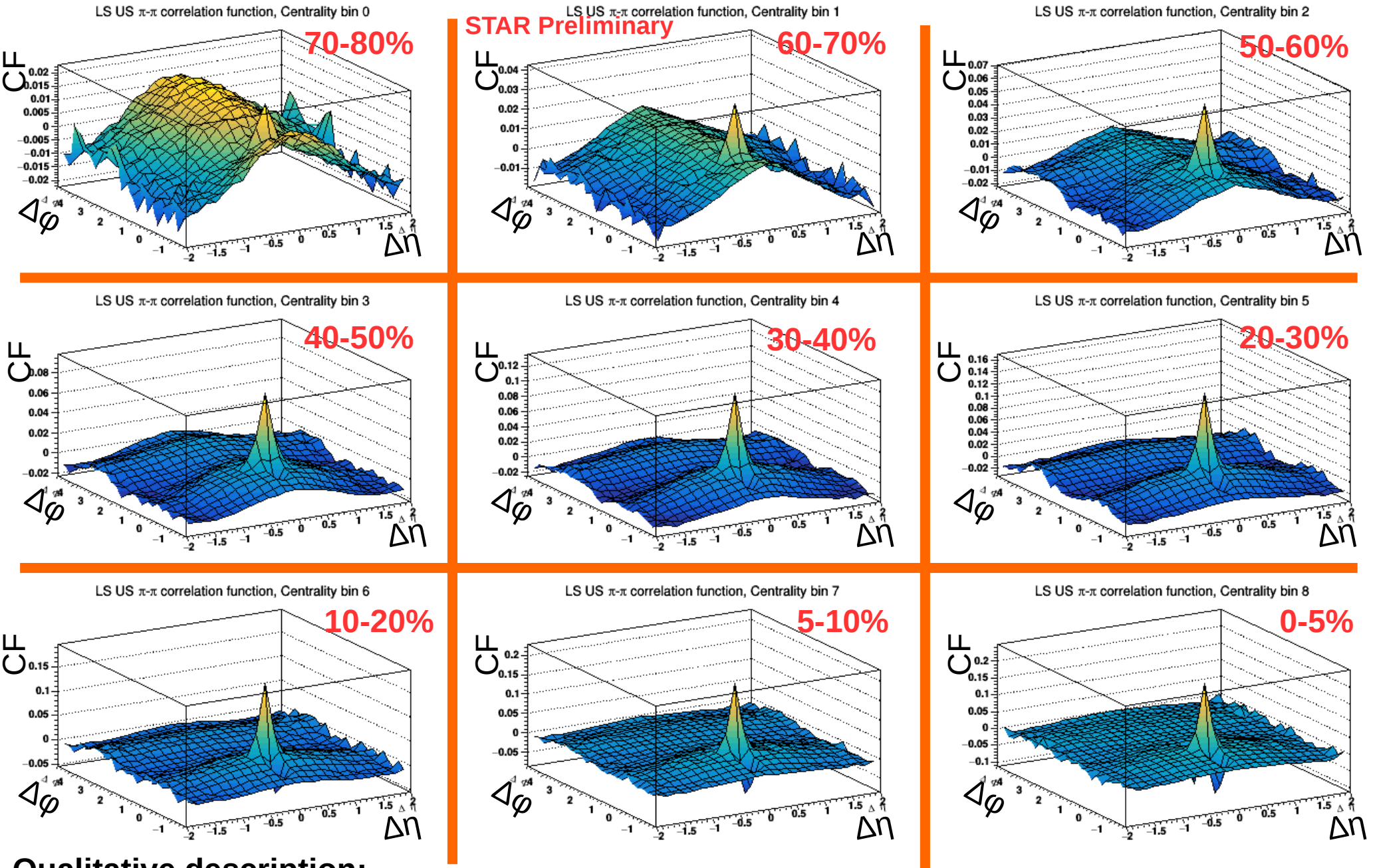
LS  $\pi$ - $\pi$  correlation function, Centrality bin 8



Qualitative description:

- Peak at small relative azimuthal angle (Near-Side)
- $\Delta\phi$  modulation strongest in mid-central collisions

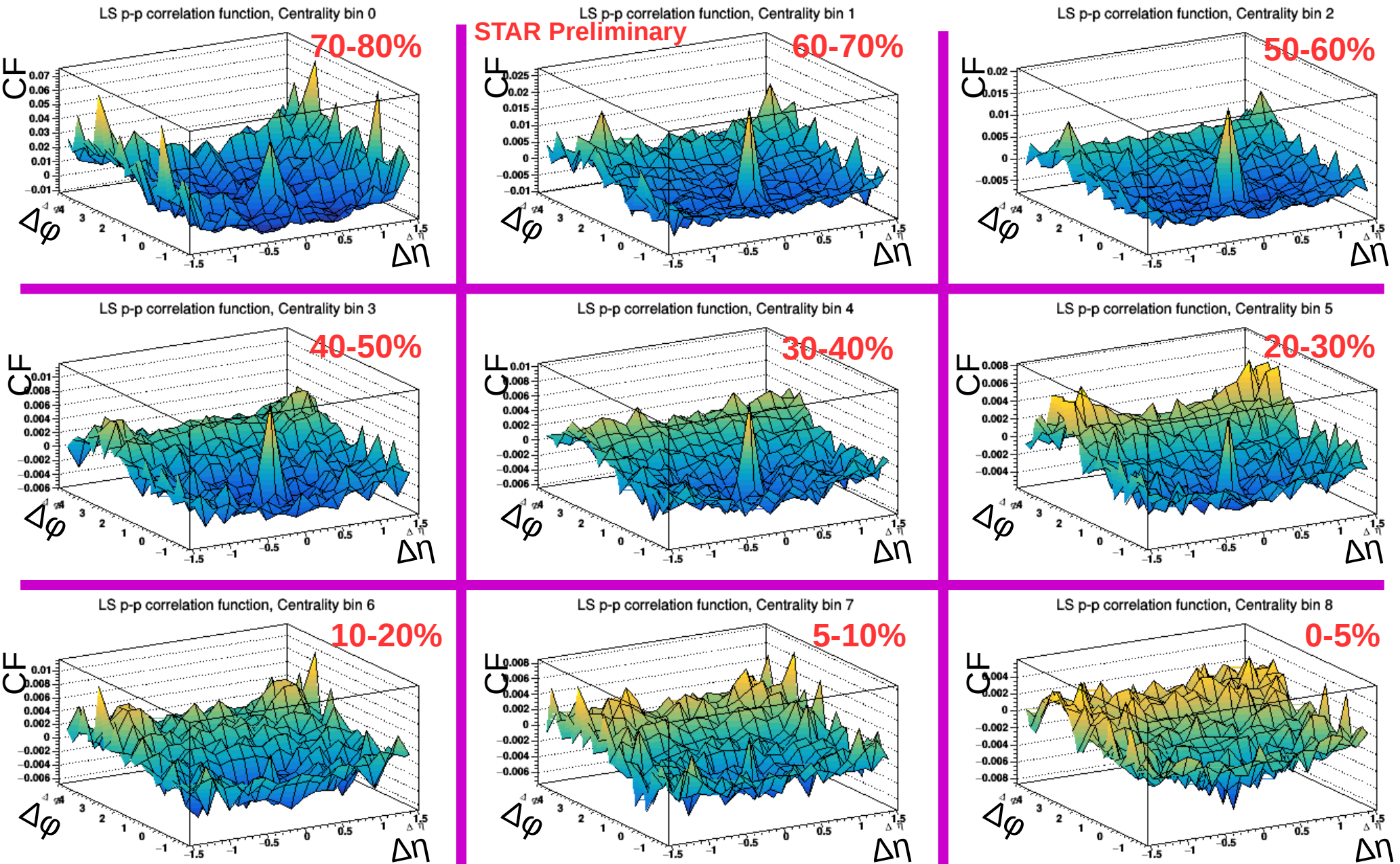
# Unlike-sign pion correlations, Au+Au @ 19.6 GeV



## Qualitative description:

- Clear, broad  $\Delta\phi$  ridge in more peripheral collisions
- Peak at small relative azimuthal angle (Near-Side)
- $\Delta\phi$  modulation strongest in mid-central collisions

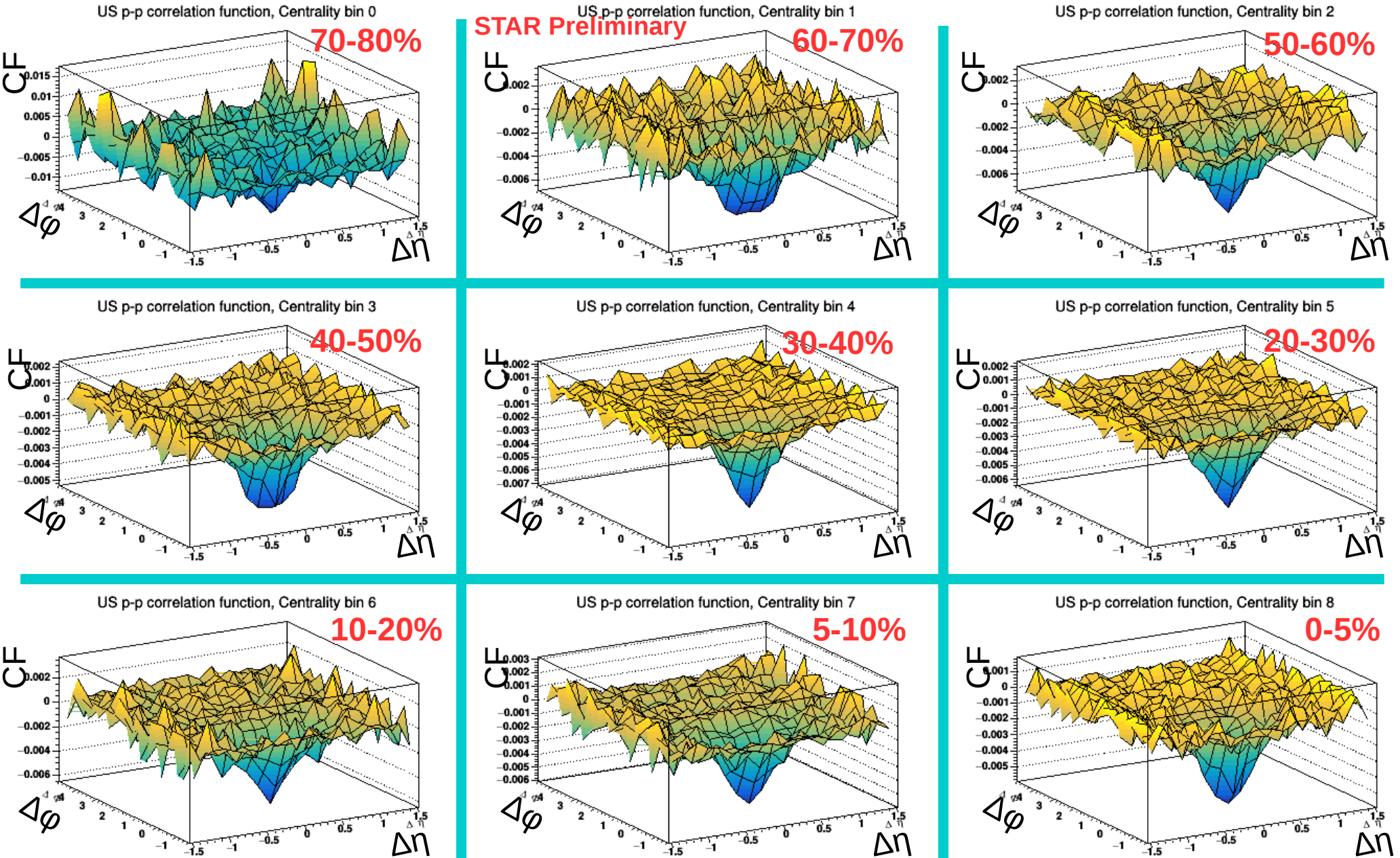
# p-p + $\bar{p}$ - $\bar{p}$ correlations, Au=Au @ 19.6 GeV



Qualitative description:

- Generally negatively correlated on the near-side
- Sharp peak at  $(\Delta\eta; \Delta\phi) \approx (0; 0)$
- Visible away-side ridge

# p-p̄ correlations, Au+Au @ 19.6 GeV



## Qualitative description:

- Negative correlation on the near-side, not as broad as in LS
- Lack of spike at  $(\Delta\eta; \Delta\phi) \approx (0; 0)$
- Lack of away-side ridge



# Summary

## Ongoing analysis showed:

- Results for **two-pion** correlations:
  - Correlation measurement extended to 2 units in  $|\Delta\eta|$  correlations @ 19.6 GeV:
  - $\text{Cos}(2\Delta\phi)$  shape observed in LS and US that strengthens in mid-central collisions
  - A broad  $\Delta\phi$  ridge in US that persists in peripheral and mid-central collisions

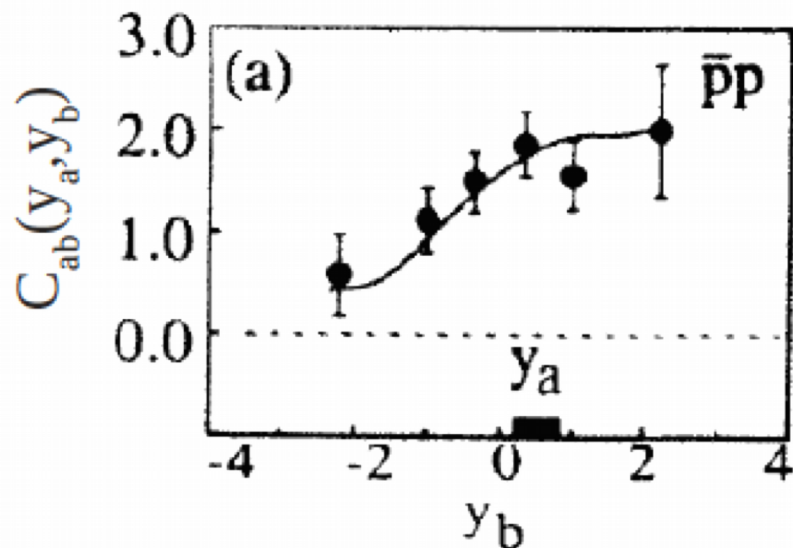
- Results for **two-proton** correlations:
  - **p-p +  $\bar{p}$ -p**:
    - Visible anti-correlation in all centrality classes in Au+Au @ 19.6 GeV
    - Observed also in 0-5% Au+Au @ 7.7 - 200 GeV
    - Resembles ALICE results (p+p @ 7 TeV, Nucl. Phys. A926 (2014))
  - **p- $\bar{p}$** :
    - Anti-correlation at  $\Delta\eta, \Delta\phi \sim 0$ , 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:

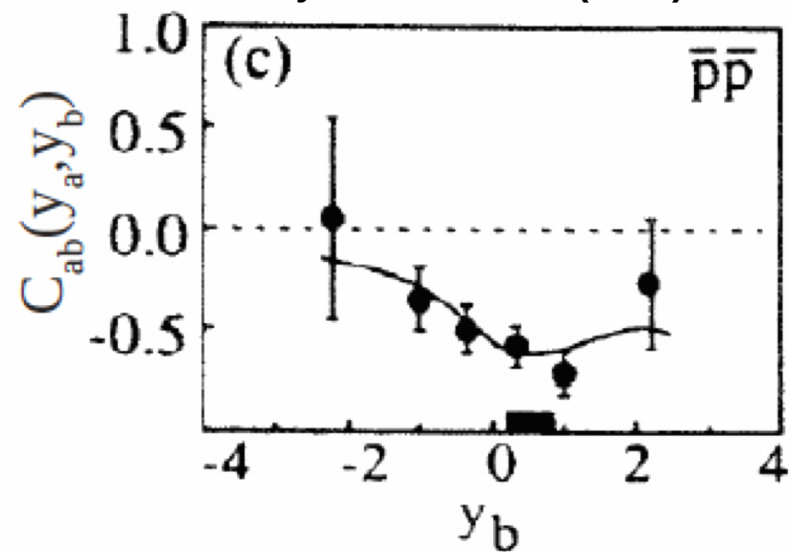
- Analysis in other BES energies
- Disentanglement of observed structures → study of various physical phenomena as a function of centrality and collision energy

**BACKUP**

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



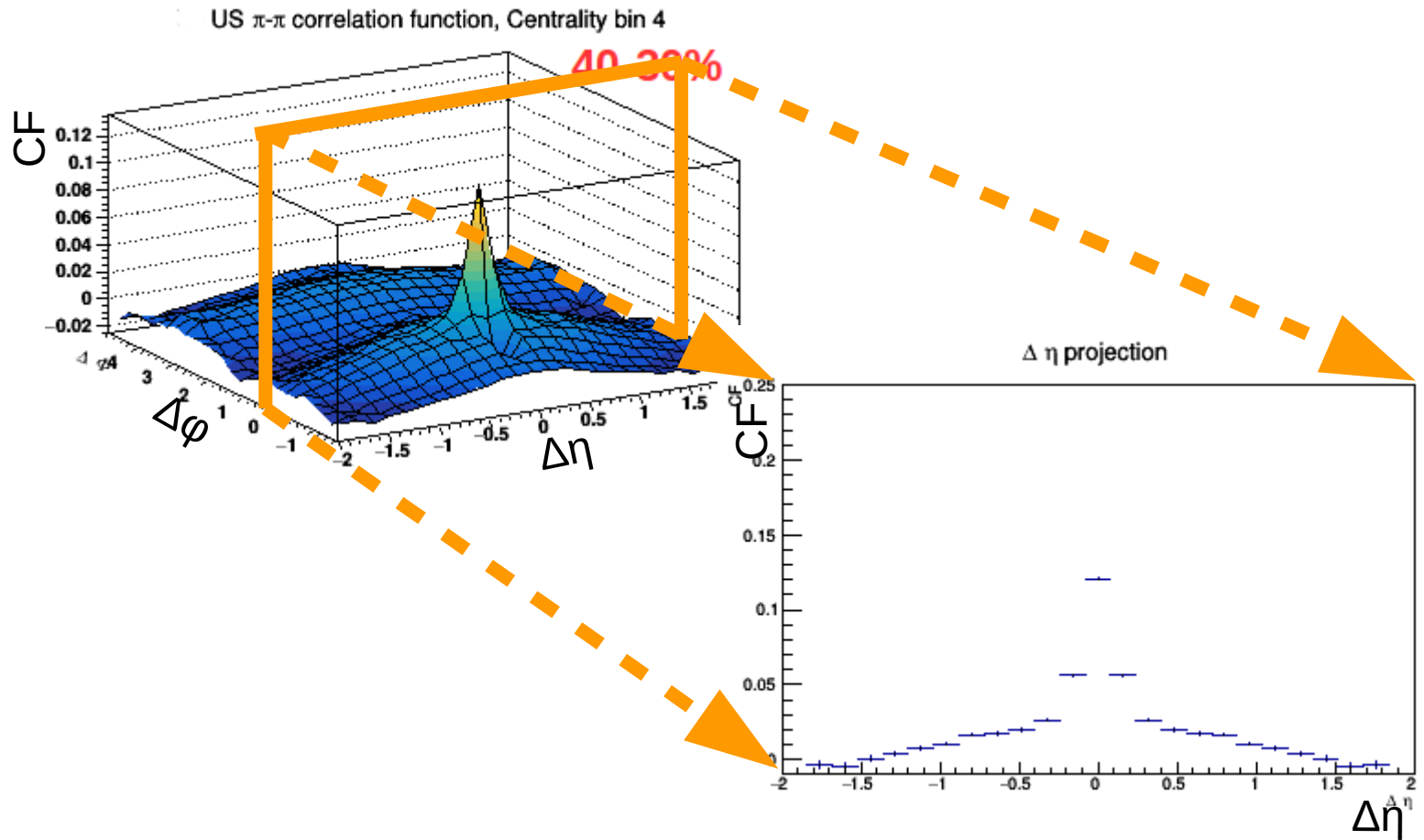
H. Aihara et al. Phys. Rev. Lett. 57(1986) 3140



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

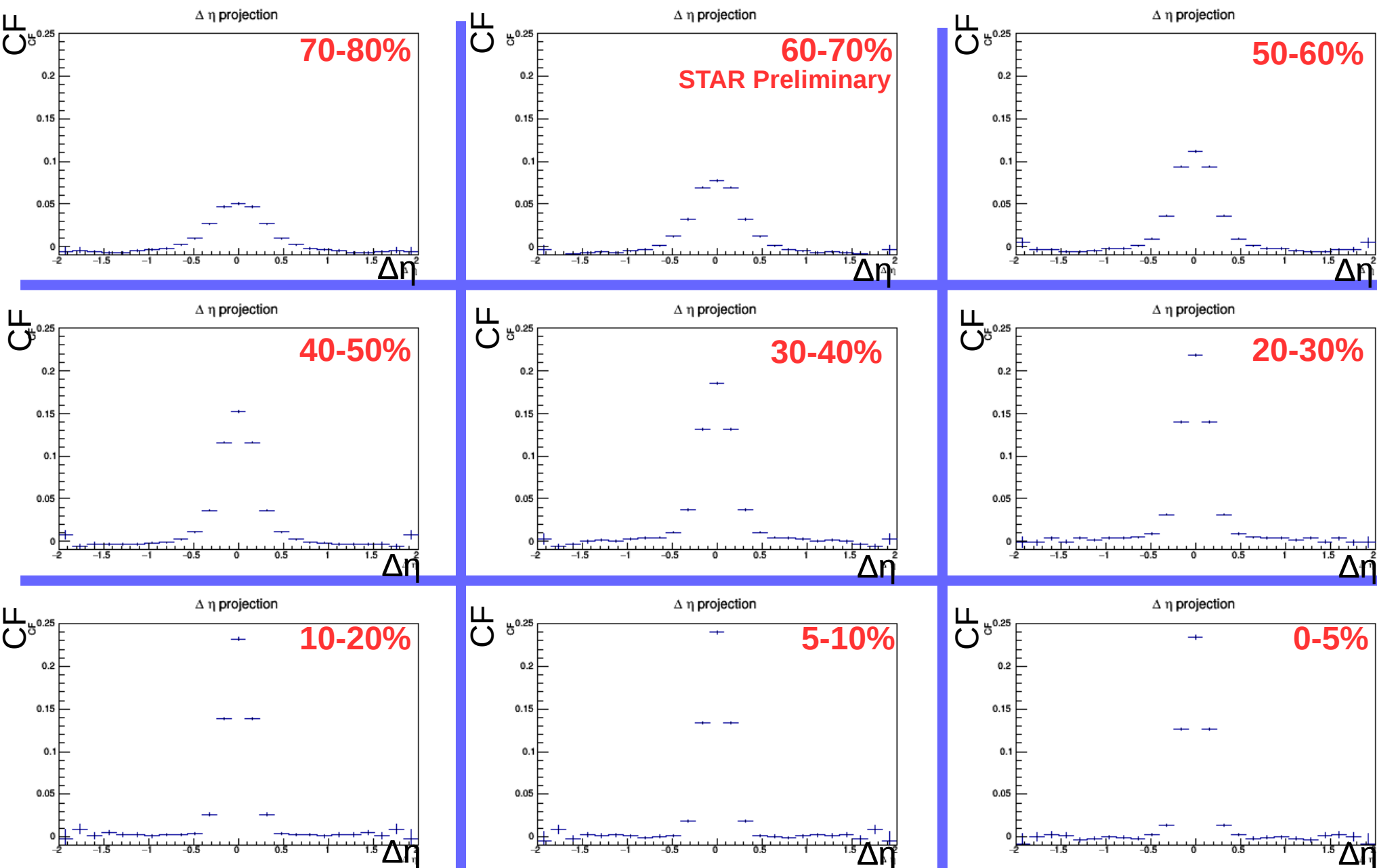
- Baryon number conservation: 2 protons and 2 anti-protons in single process
- 4 baryons  $\rightarrow$  high E  $\rightarrow$  less likely
- Current MC models  $\rightarrow$  E conservation + B conservation  $\rightarrow$  but data not reproduced!

# Projections of bin at $\Delta\varphi \sim 0$ : $-7.2^\circ < \Delta\varphi < +7.2^\circ$ :



# Like-sign pion correlations, AuAu @ 19.6 GeV

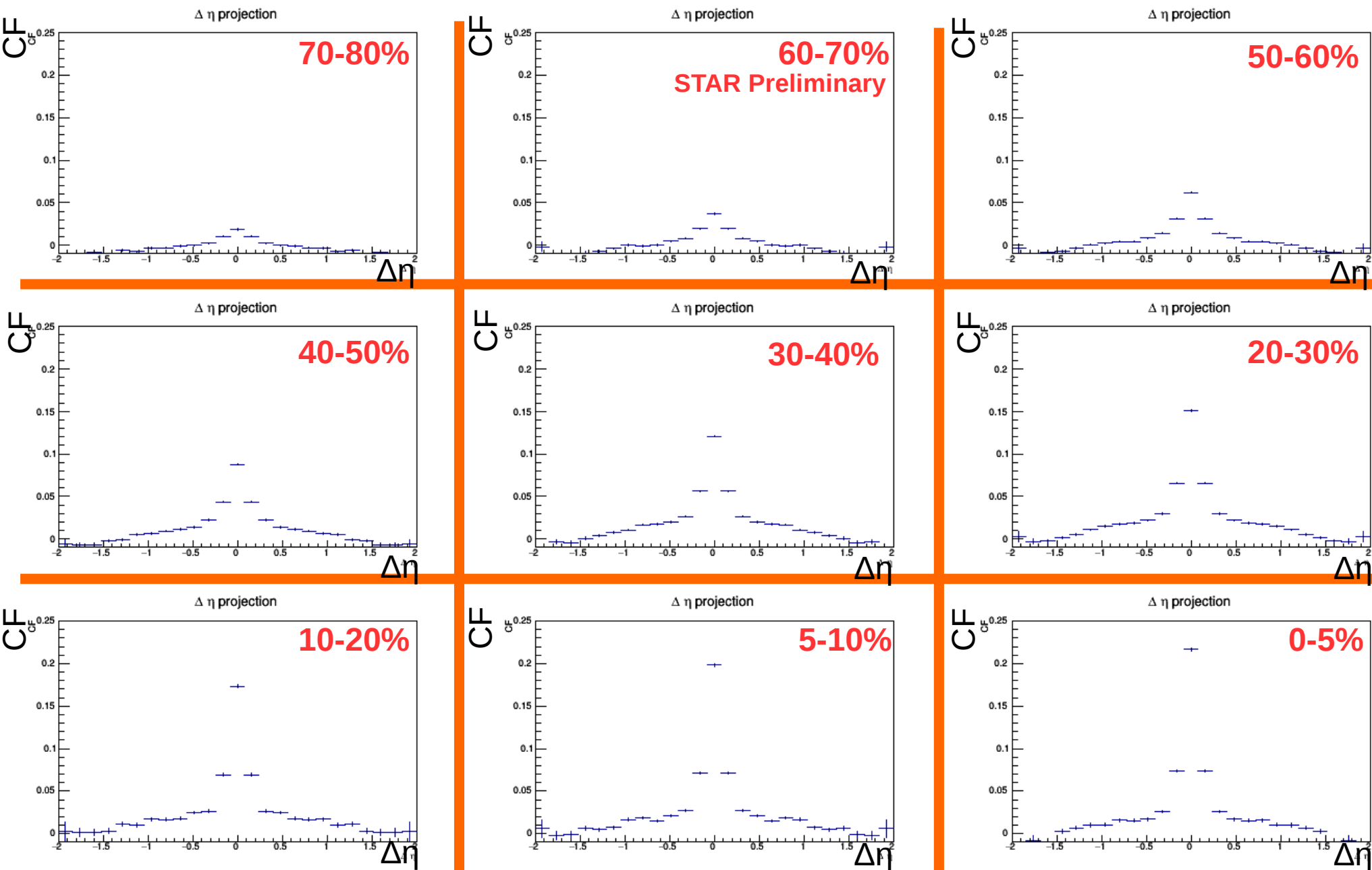
-  $7.2^\circ < \Delta\phi < +7.2^\circ$  :



- Amplitude of the peak grows with more central events
- Width smaller with more central events

# Unlike-sign pion correlations, AuAu @ 19.6 GeV

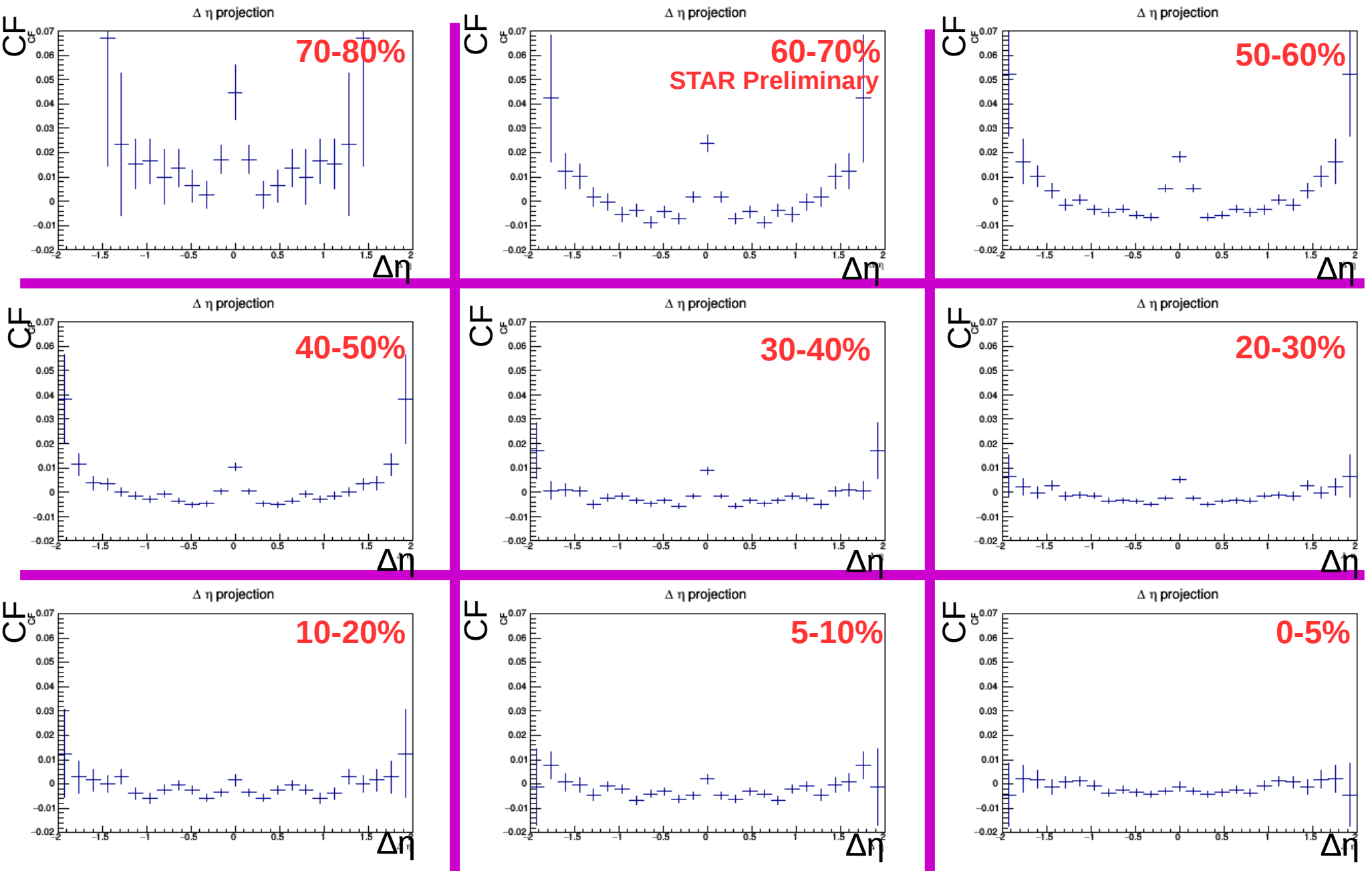
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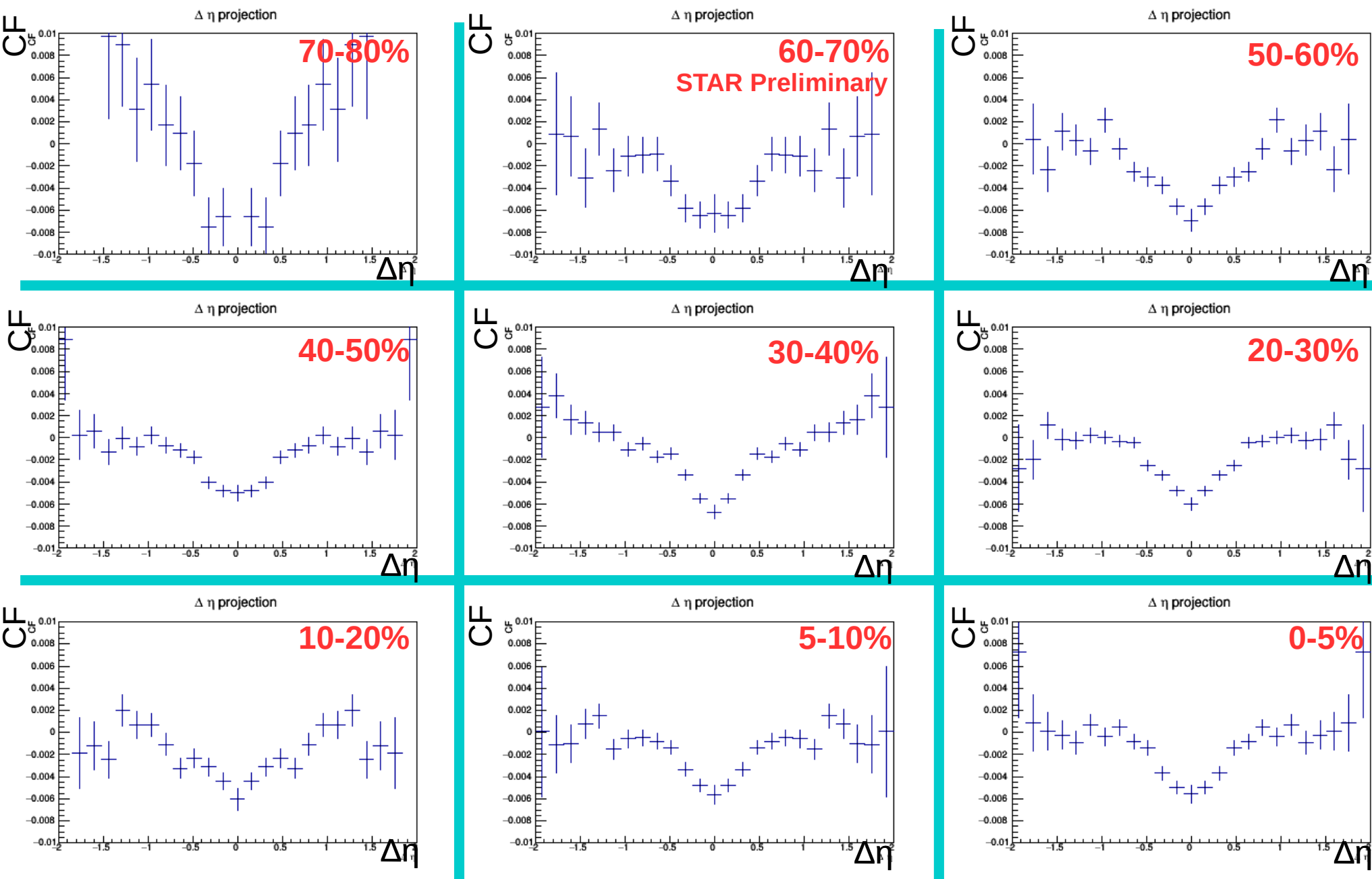
-  $7.2^\circ < \Delta\phi < +7.2^\circ$  :



→ Amplitude of peak lowers with more central events

# proton-antiproton correlations, AuAu @ 19.6 GeV

-  $7.2^\circ < \Delta\phi < +7.2^\circ$  :



→ Anti-correlation similar in each centrality bin