Wydział Fizyki

POLITECHNIKA WARSZAWSKA

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

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Beam Energy Scan program

BES goals:

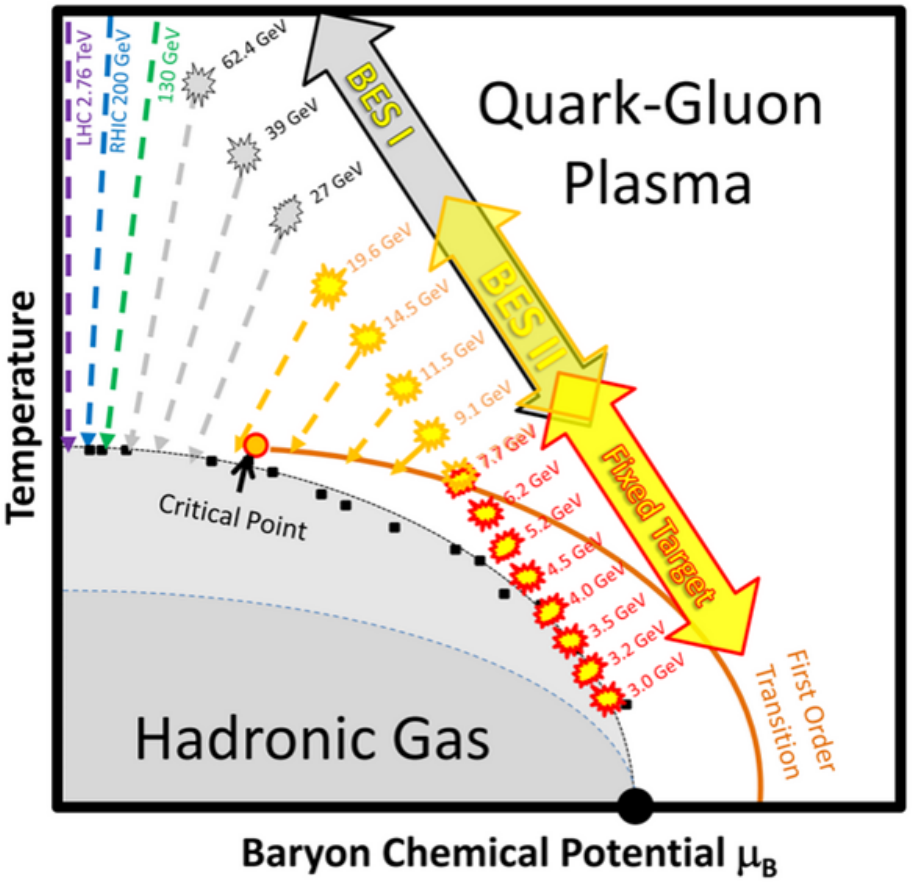
Exploring the phase diagram of strongly interacting matter:

1. Search for turn-off of sQGP signatures
2. Search for the signals of phase transition/phase boundary
3. Search for the QCD critical point

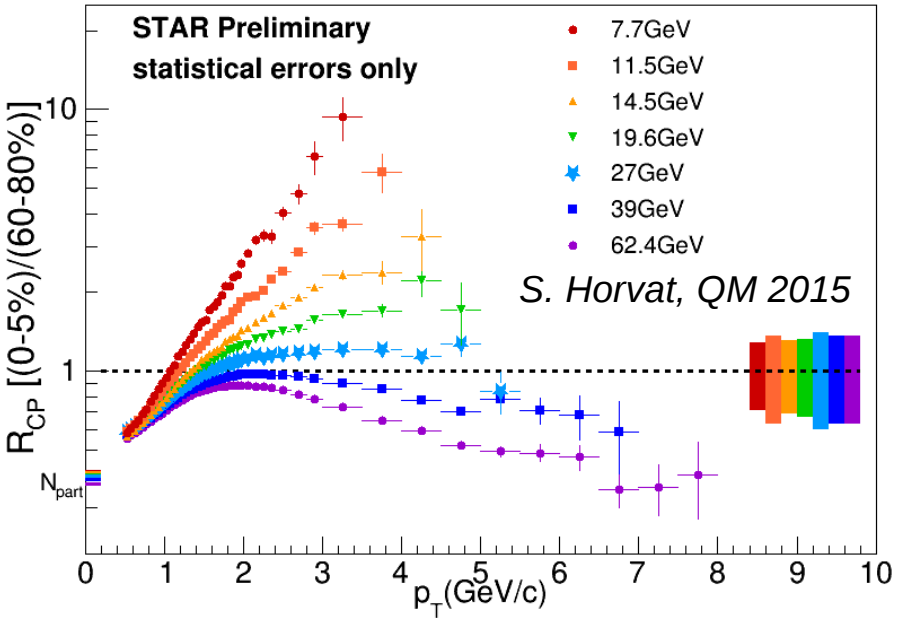
Data collected by STAR at RHIC:

Year	$\sqrt{s_{NN}}$ (GeV)	μ_B (MeV)	Events (10^6)
2010	200	20	350
2010	62.4	70	67
2010	39	115	130
2011	27	155	70
2011	19.6	205	36
2014	14.5	260	20
2010	11.5	315	12
2010	7.7	420	4

Chi Yang, QM 2017



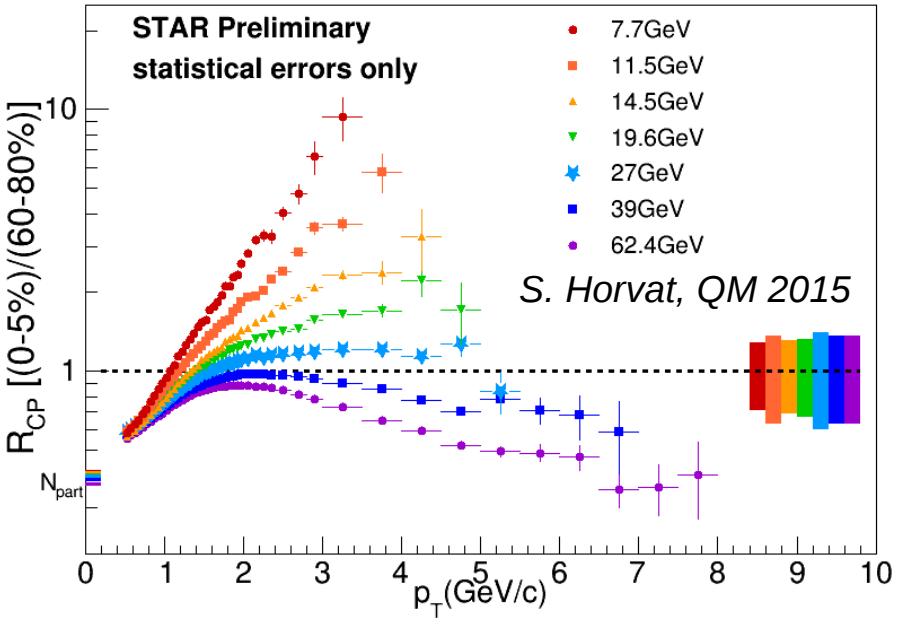
BES: studied observables



Disappearance of sQGP signatures: R_{CP}

- **R_{CP} > 1 in Au+Au 27 GeV and lower**
- **Evidence of lack of jet quenching**
- **Possible convolution with Cronin Effect**

BES: studied observables



Disappearance of sQGP signatures: R_{CP}

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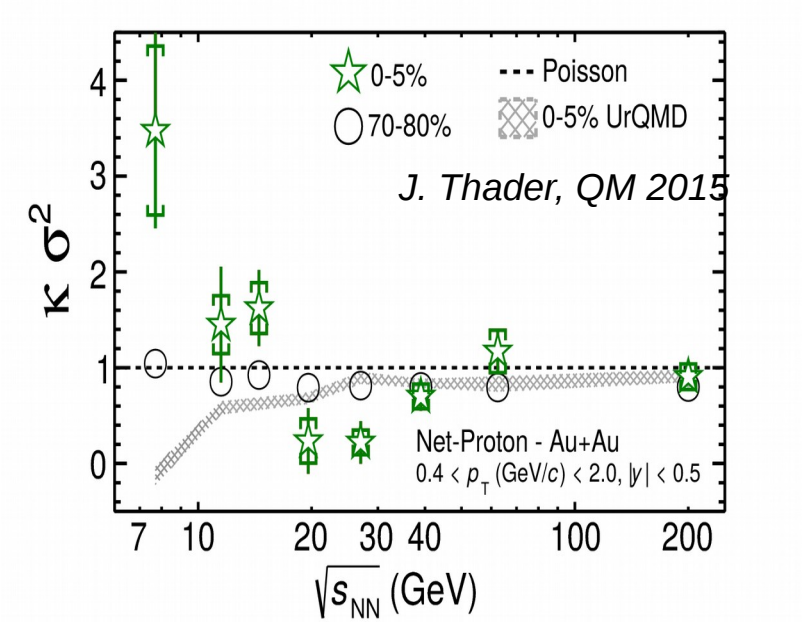
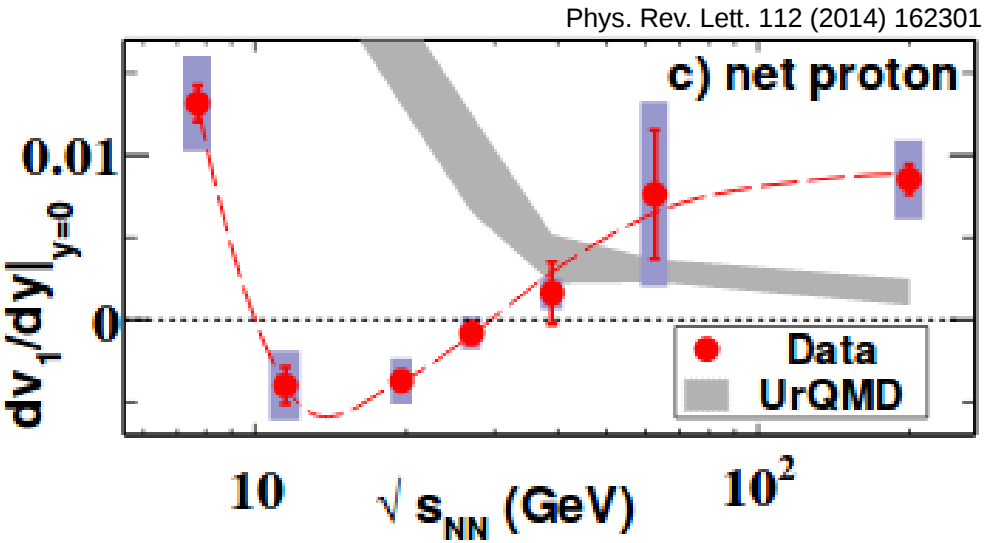
Other measurements: fluctuations and dv_1 / dy of net-protons, ...



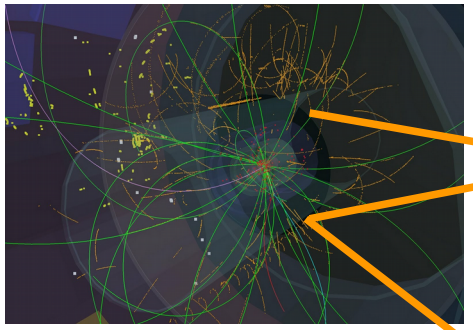


Angular correlation function:

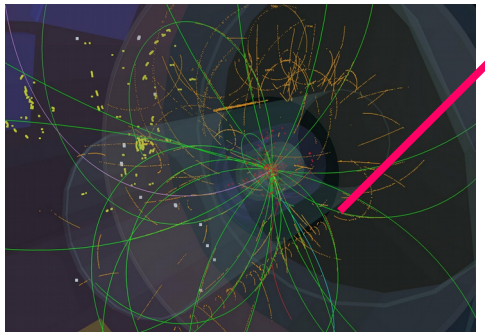
$\Delta\eta = \eta_1 - \eta_2$

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

Event 1



Event 2,3,4...



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

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

 # correlated pairs per pair

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

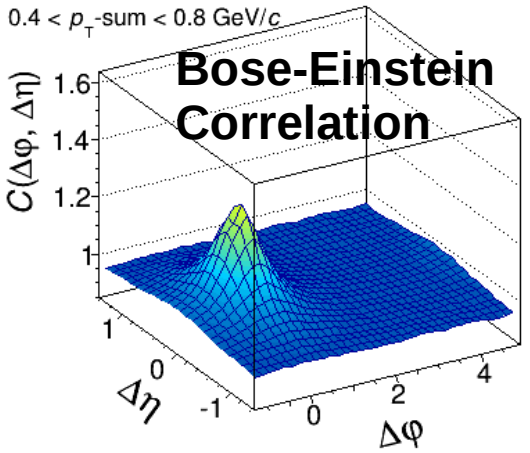
 # correlated pairs per particle

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

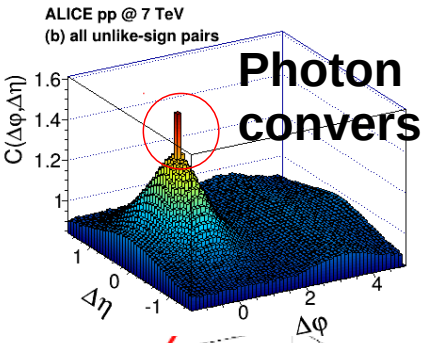
$\sqrt{\rho'_{ref}} \approx d^2\hat{N}/d\eta d\phi$ is approximately single charged particle density averaged over angular acceptance

Figures by M. Janik

Correlation function: a tool to access different physical phenomena

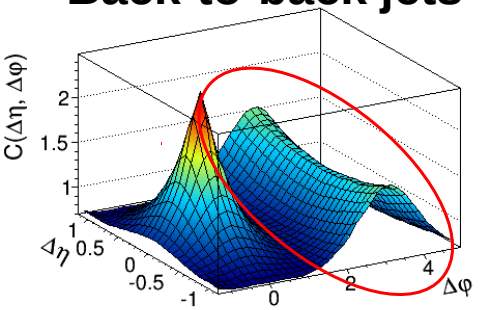


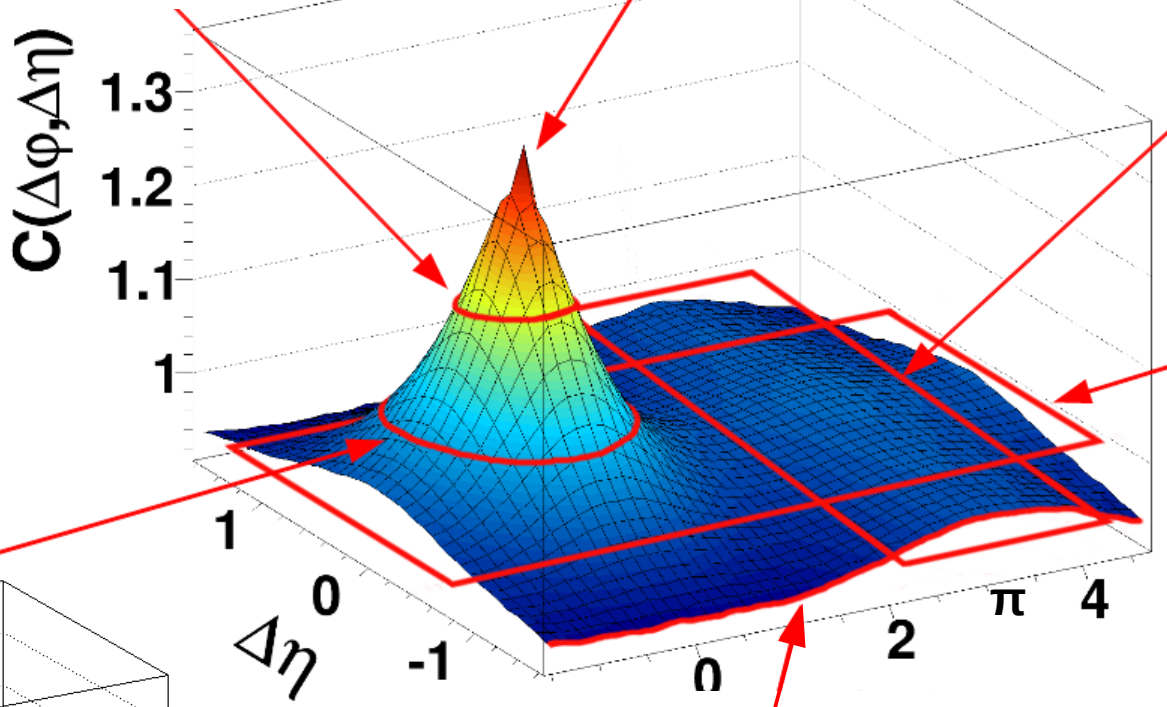
Bose-Einstein Correlation



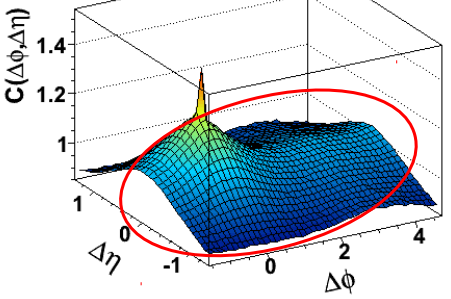
Photon conversion

Back-to-back jets

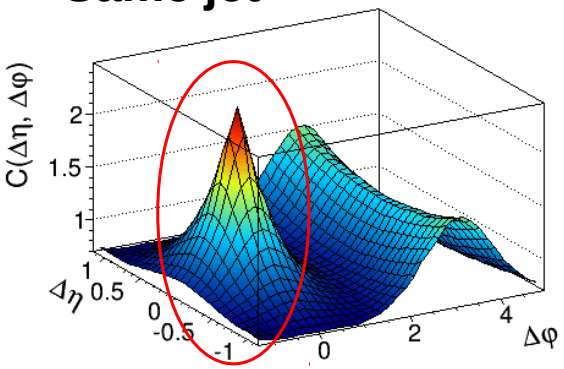




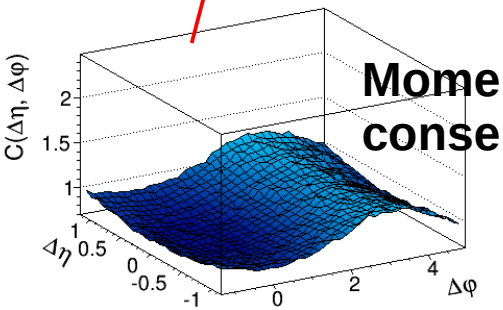
Resonances



Same jet



Momentum conservation



Figures by M. Janik

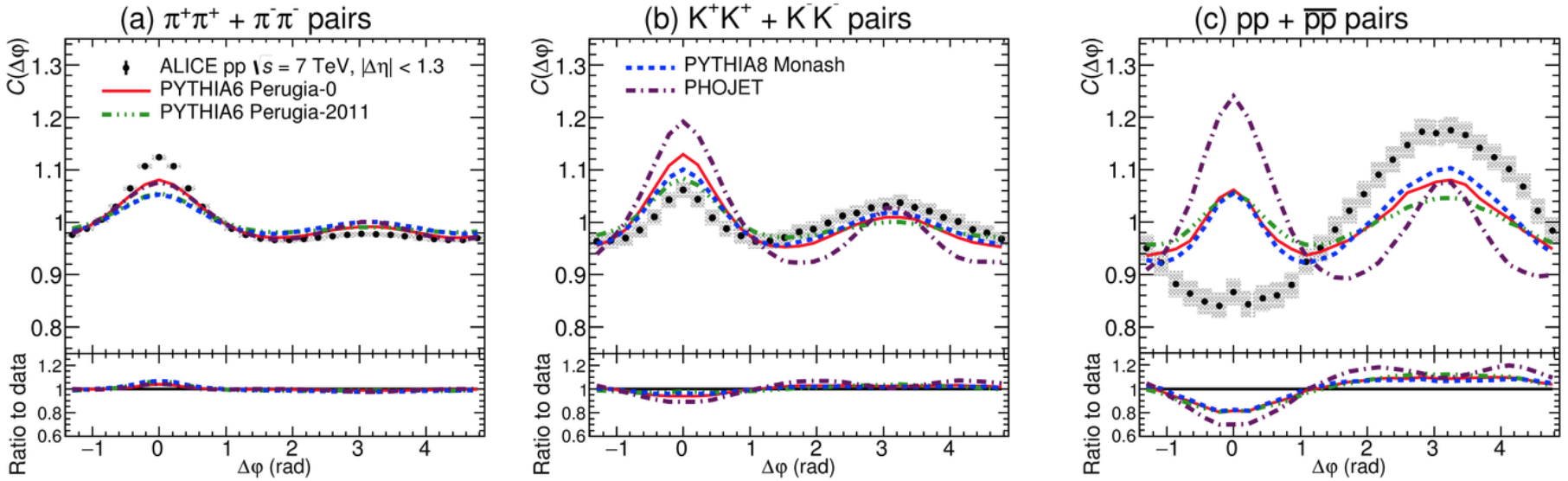
Motivation: Why identified particles?

Why should we study identified particles?

- **published ΔηΔφ 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

EPJC 77 (2017) no.8, 569



- ALICE data are not perfectly described by well known MC models (different tunes of PYTHIA, PHOJET..)

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

Need of experimental data for further model development

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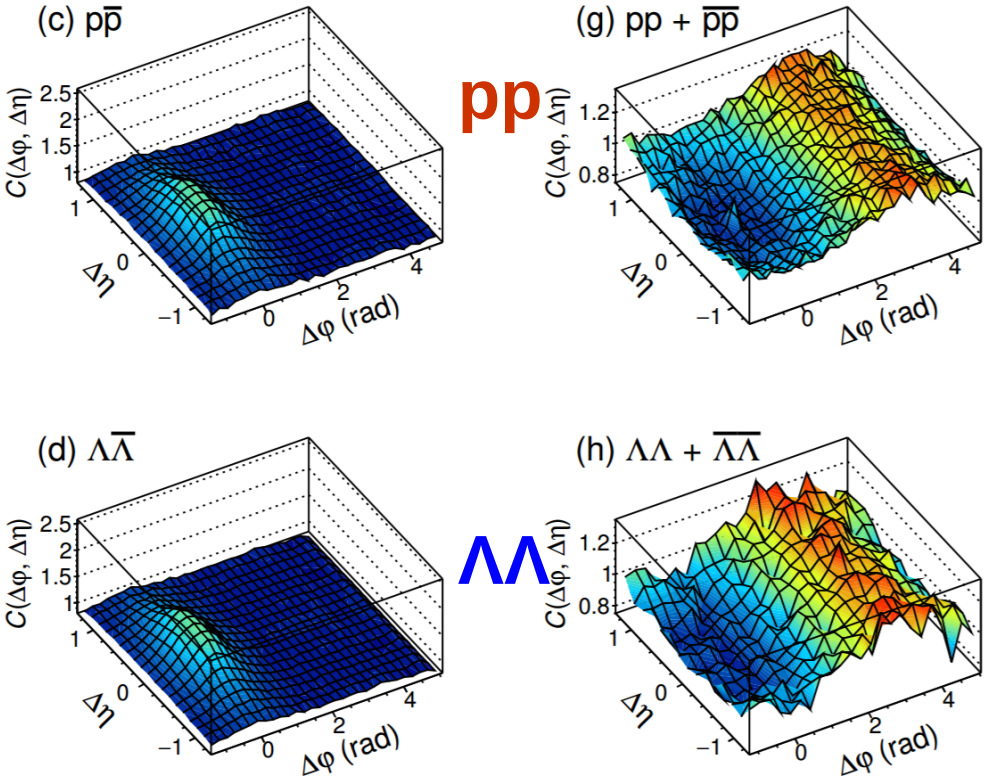
Depletion in pp + $\overline{pp}$ is **not** caused by:

- Coulomb repulsion (Λ is neutral)

ALICE p+p @ 7 TeV: *M. Janik @ WPCF 2017*



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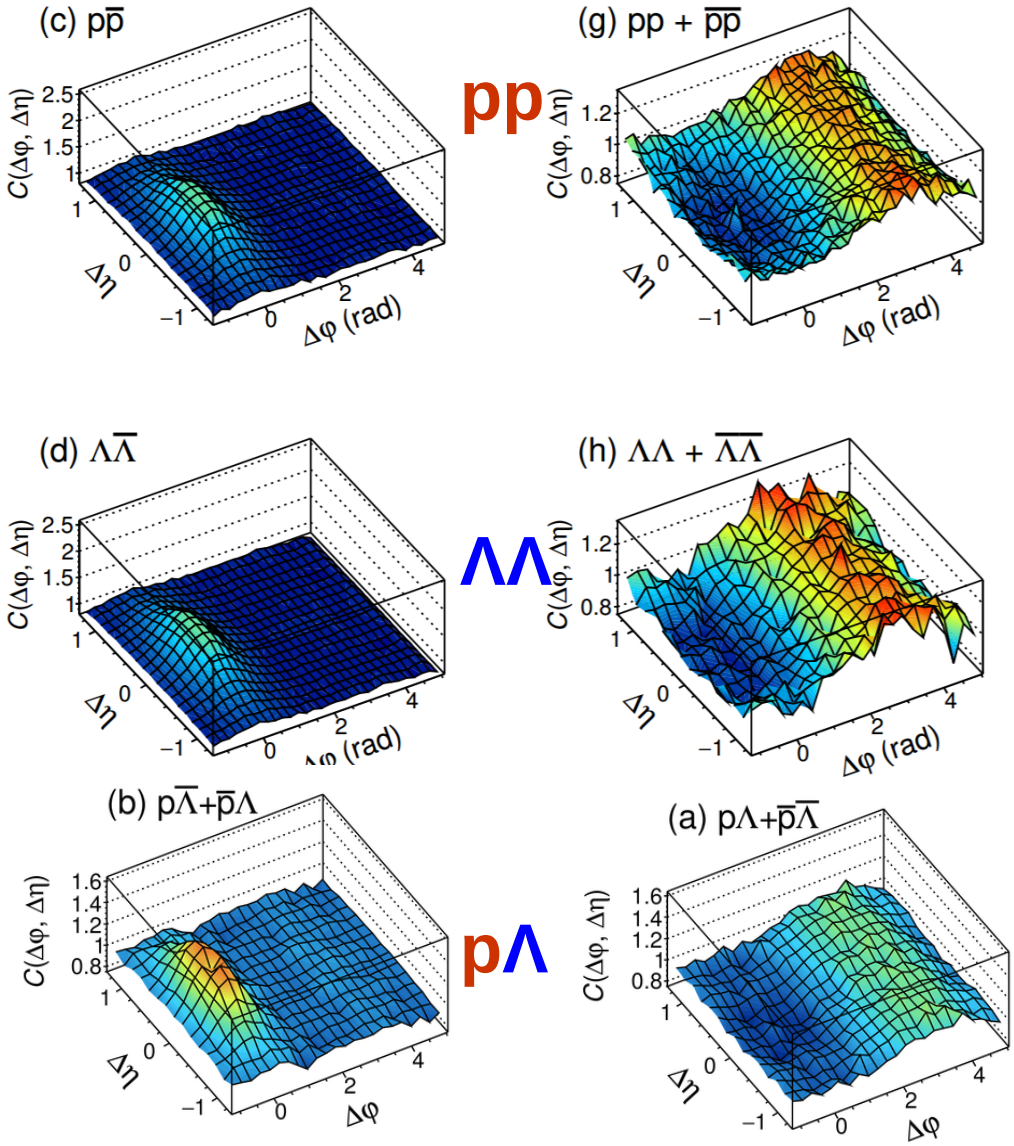

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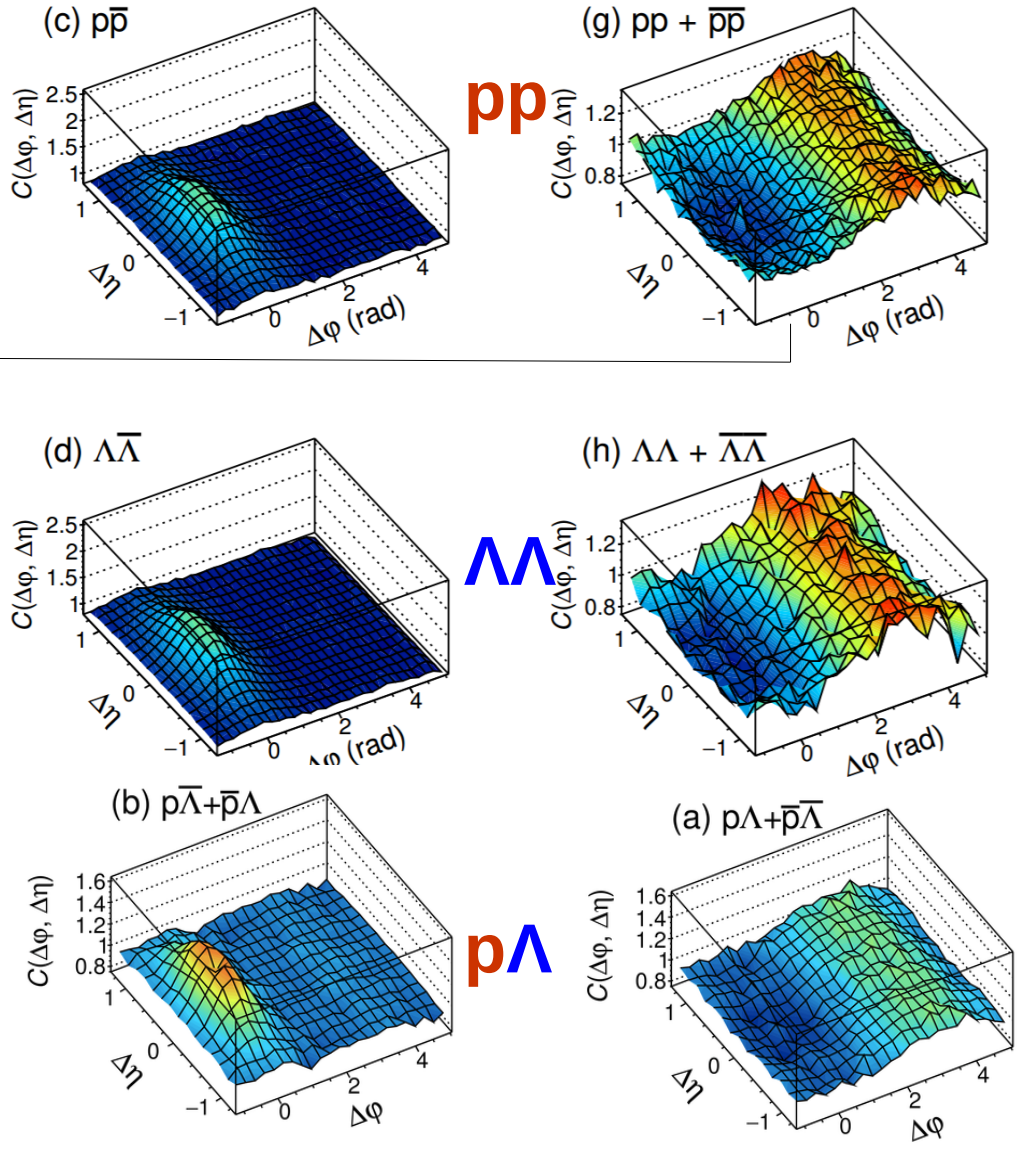


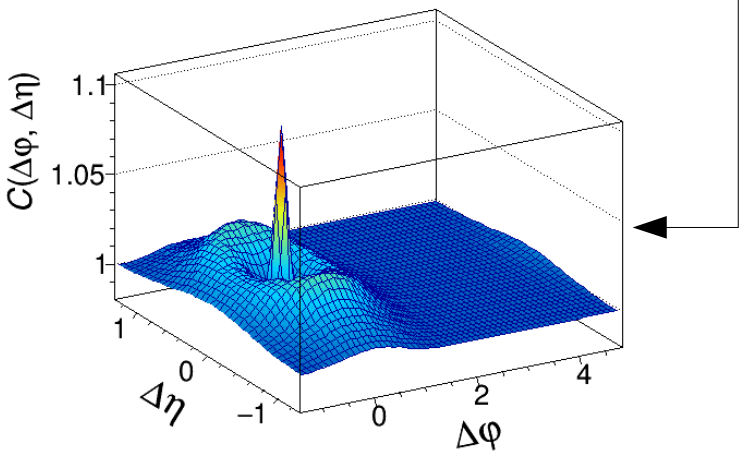
Depletion in pp + $\overline{pp}$ is **not** caused by:

- Coulomb repulsion (Λ is neutral)

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

- Final State Interactions

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



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- **published ΔηΔφ results from BES – only 2-hadron correlations**
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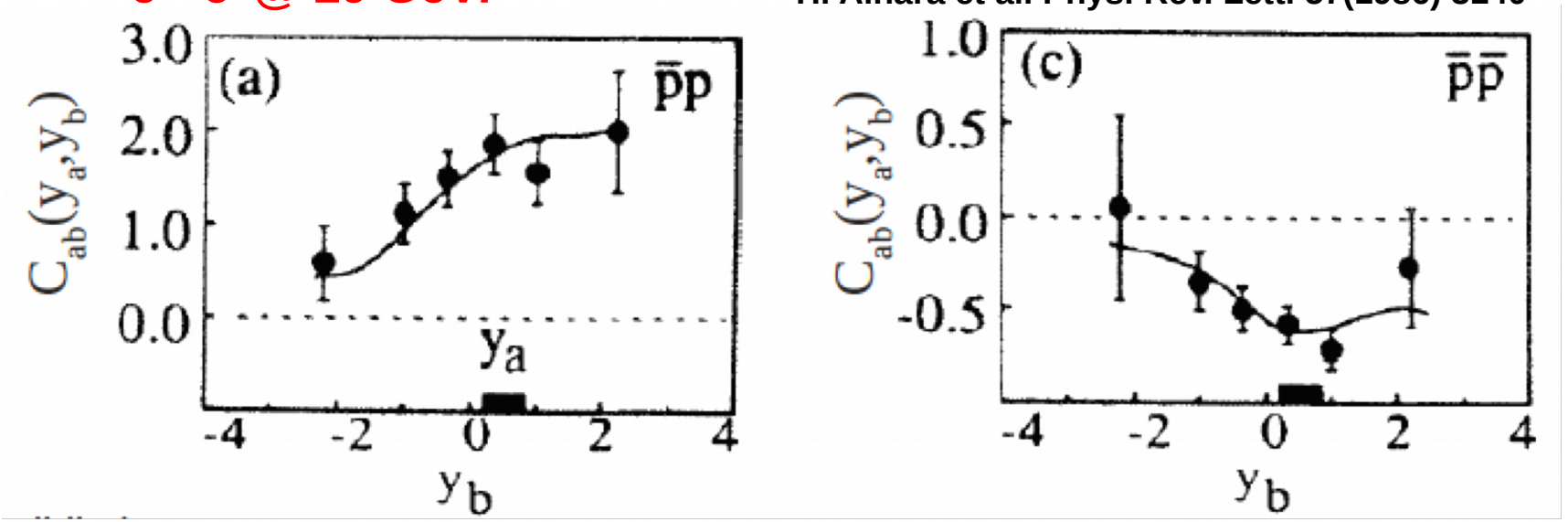
- **intriguing results for two-proton correlations:**

$e^+ + e^-$ @ 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

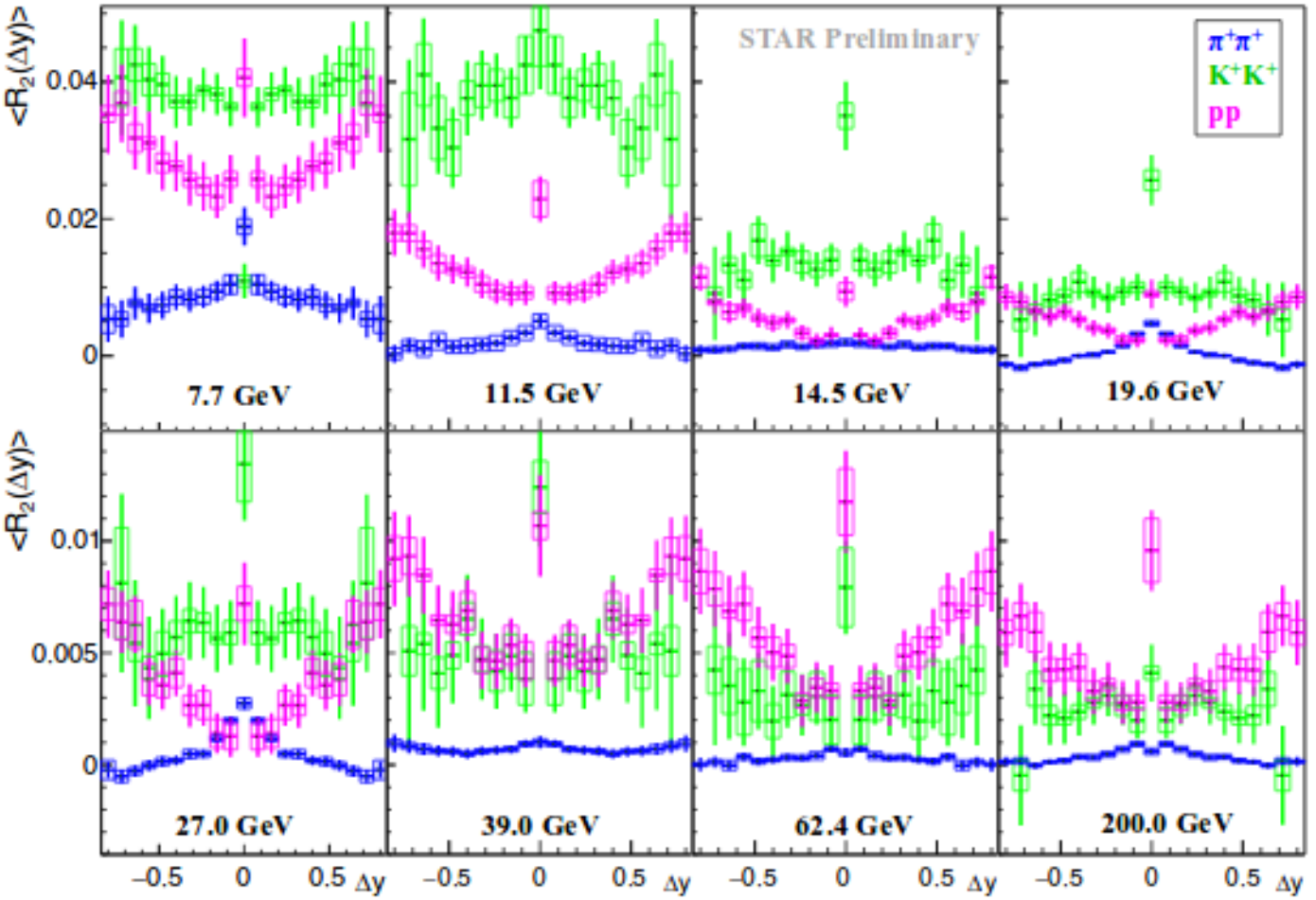
- Baryon number conservation: 2 protons and 2 anti-protons in single process
- 4 baryons → high E → less likely
- Current MC models → E conservation + B conservation → but data not reproduced!

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

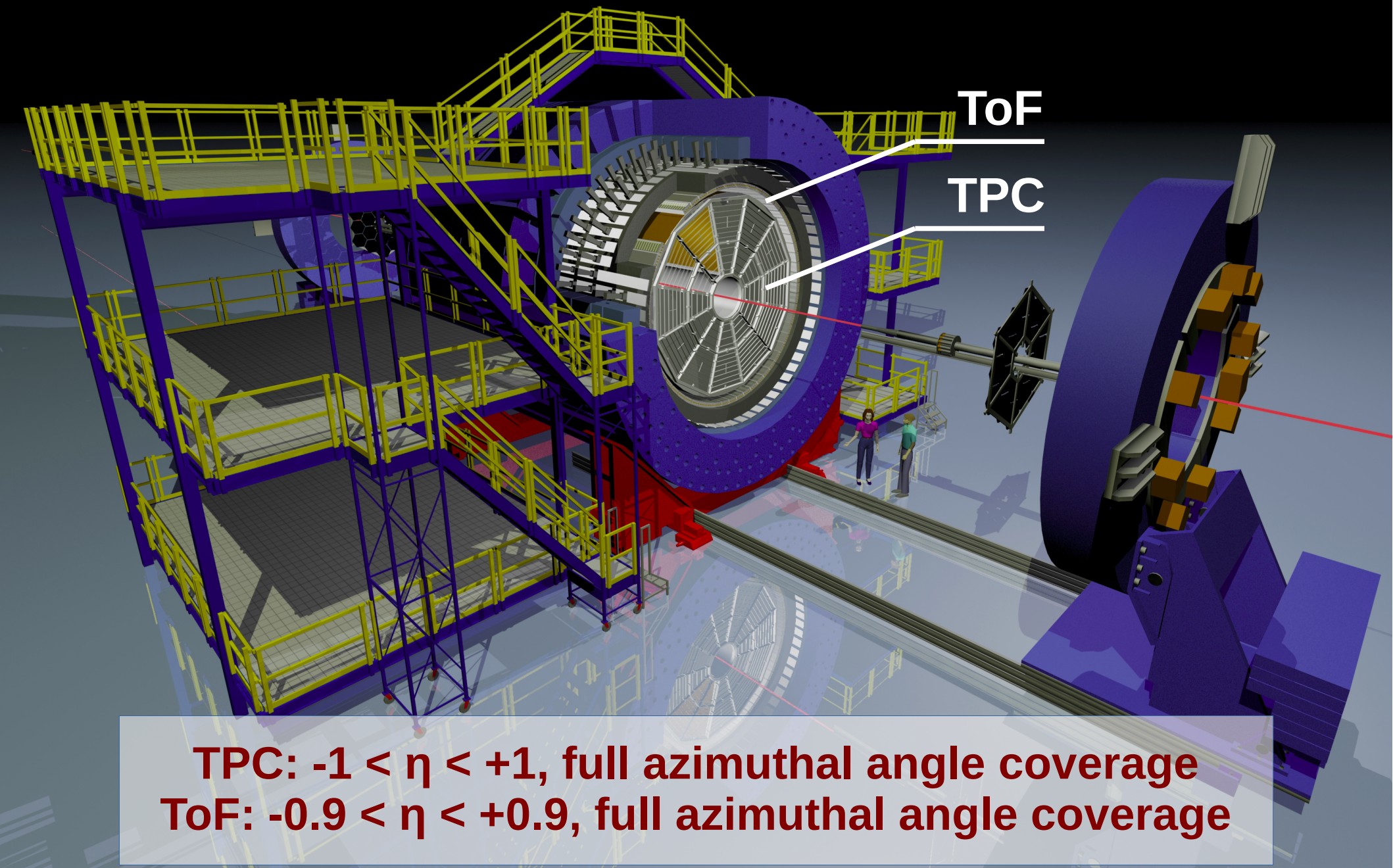


- **QM 2017*:**
  - Minima for p-p correlations seen in all BES energies in 0-5% Au+Au

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

- **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

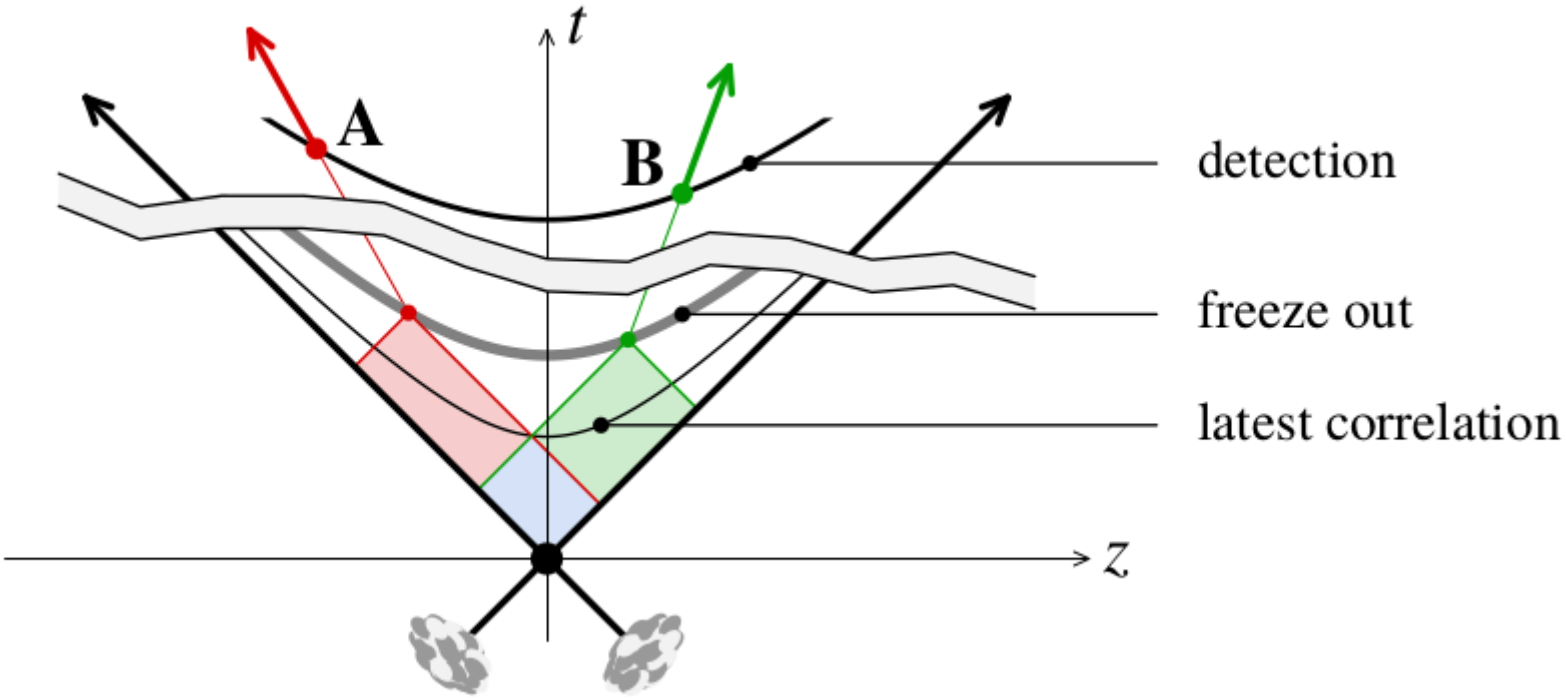
SOLENOIDAL TRACKER AT RHIC



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

by Maria & Alex Schmah

SOLENOIDAL TRACKER AT RHIC



The process that caused correlation must have occured before time:

arXiv:0804.3858v1

$$\tau \leqslant \tau_{Freeze\,out}\, e^{-\frac{1}{2}|y_A - y_B|}$$

e.g:

particles with $1.5 < \Delta y < 2$ were interacting at $0.47 - 0.37\ \tau_{freeze\ out}$ or earlier

Extending to ± 2 units of Δη:
Access to earlier stages of HI collision

by Maria & Alex Schmah

Following results: Au+Au @ 19.6 GeV

Kinematic cuts:

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

PID (TPC only): for each POI

- Accept particles with $\mathbf{|\, n\sigma_{POI}| < 2}$
- Reject particles with $\mathbf{|\, n\sigma_{others}\,| > 3}$

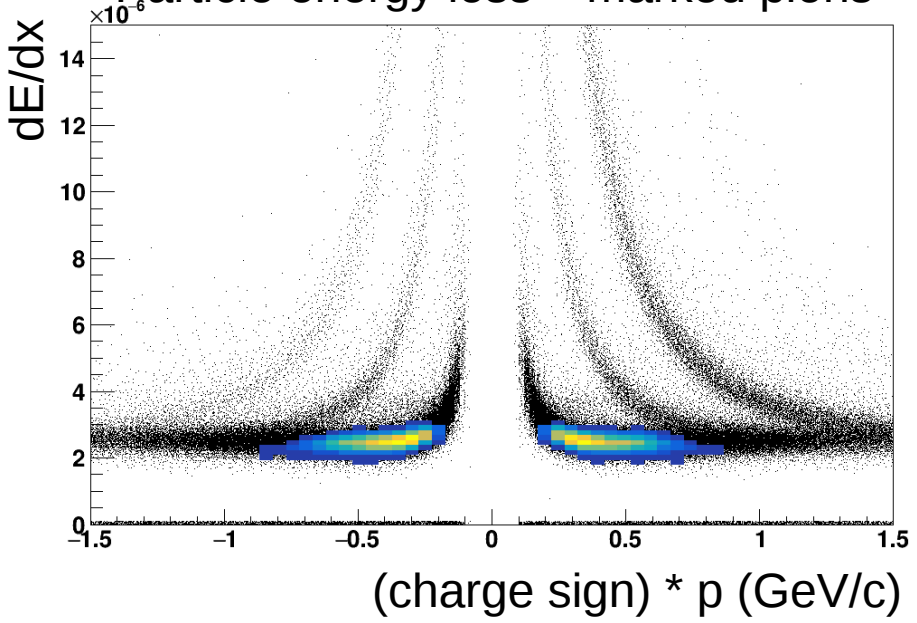
Event mixing:

- Number of mixed events: 8
- V_Z bins: 2cm wide
- N_{ch} bins: 40-50 particles wide

Centrality:

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

Particle energy loss – marked pions



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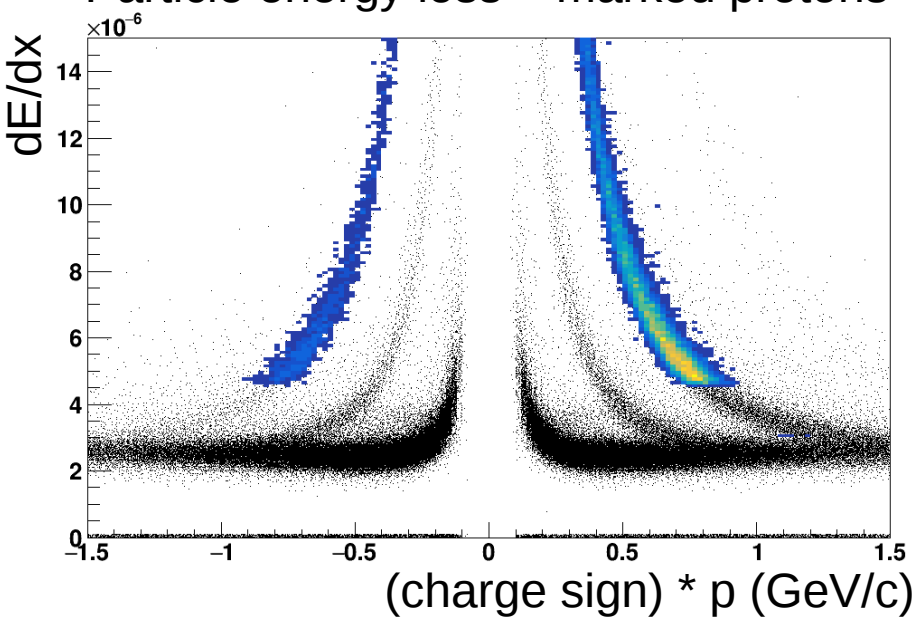
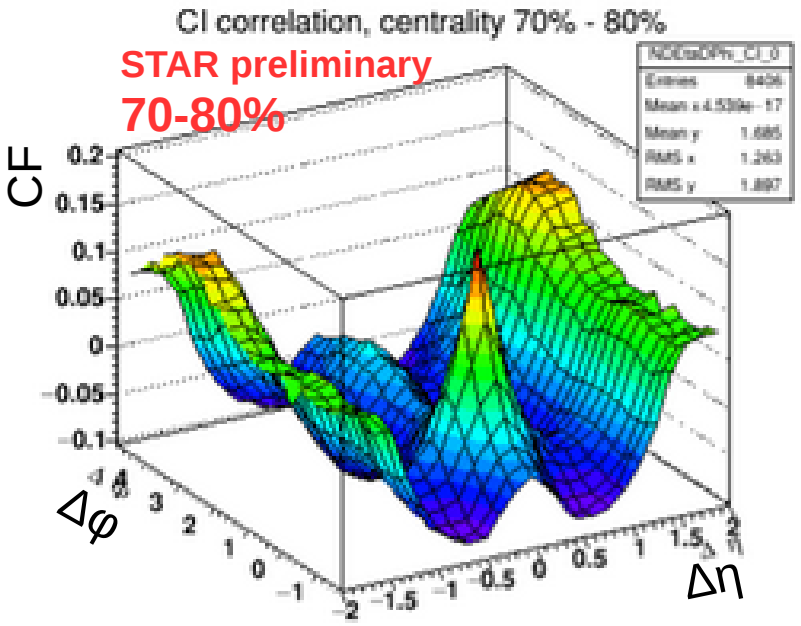


Centrality selection:

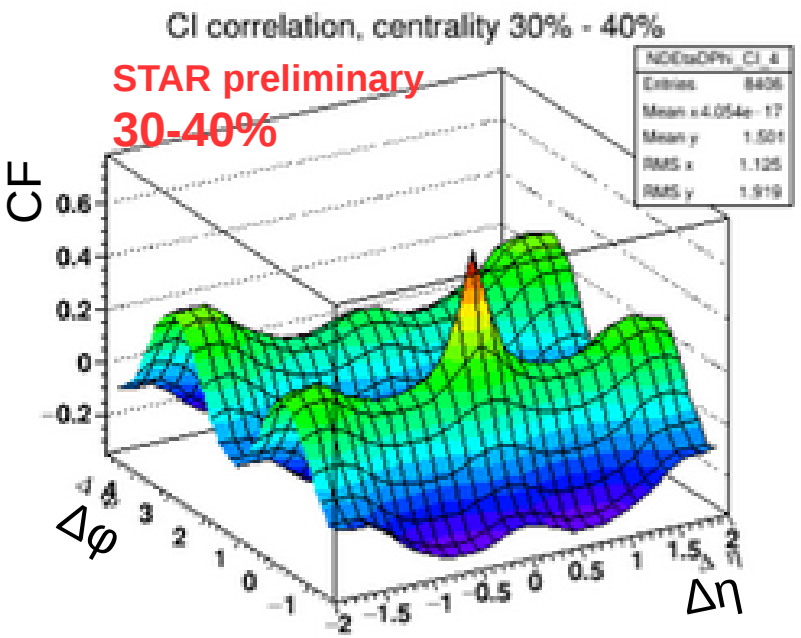
Correlation → normalized variance → offset related to multiplicity fluctuations

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

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



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



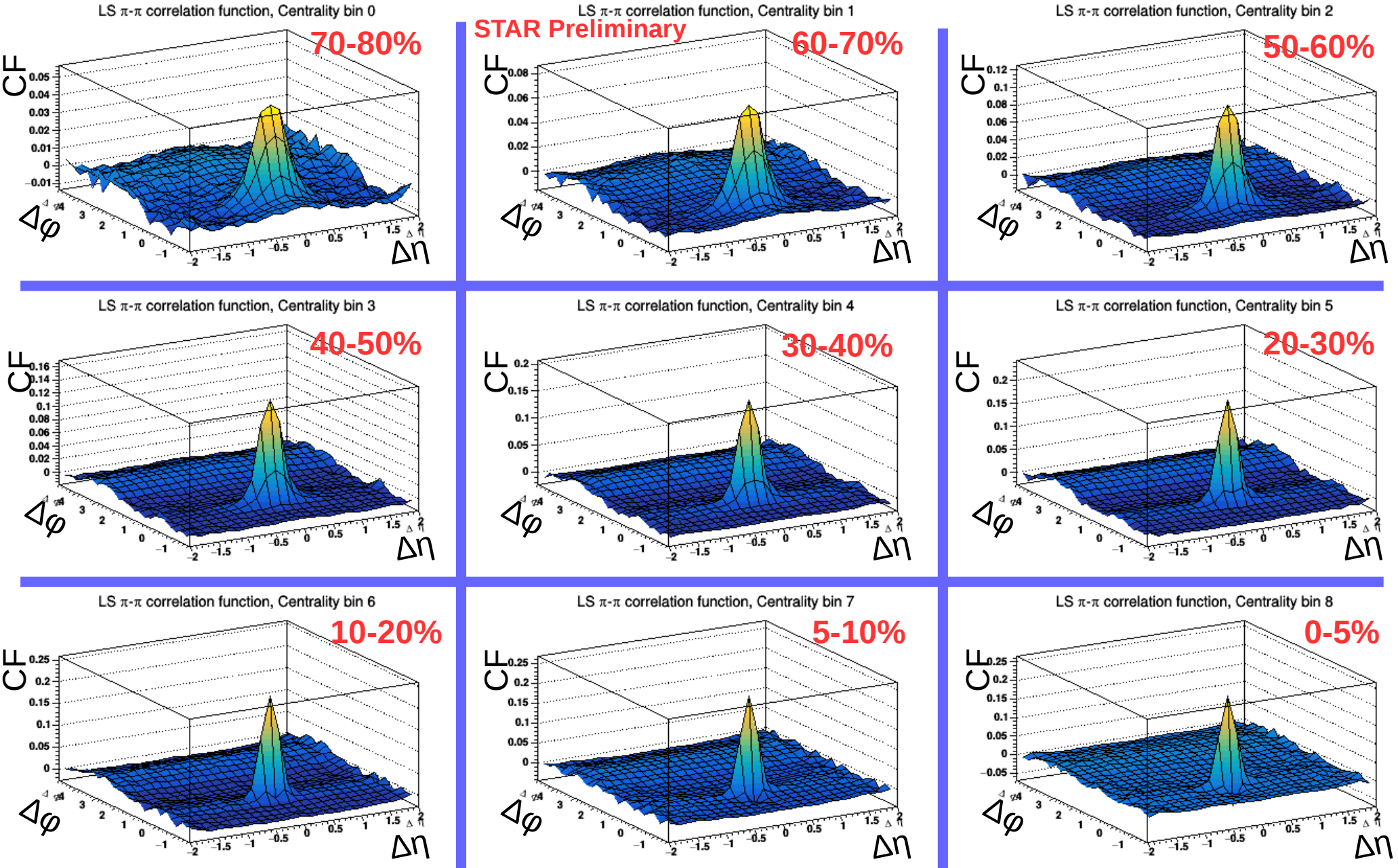
Either use two different η regions (no CF suppression) or use the same η range (constant suppression → offset in CF)

This analysis:

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

*) V_z and trigger inefficiency corrections

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

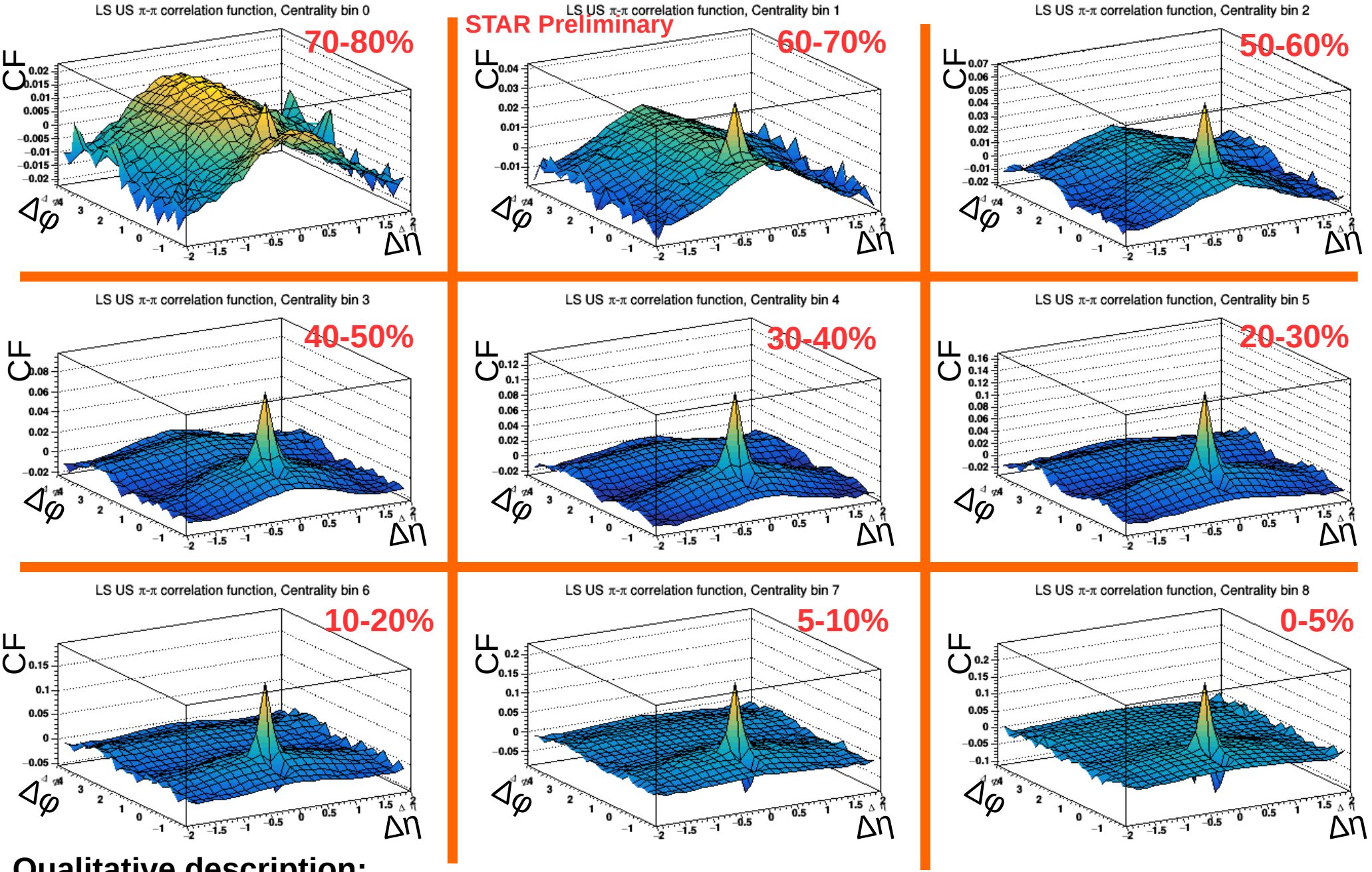


Qualitative description:

→ **Peak at small relative azimuthal angle (Near-Side)**

→ **Δφ modulation strongest in mid-central collisions**

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



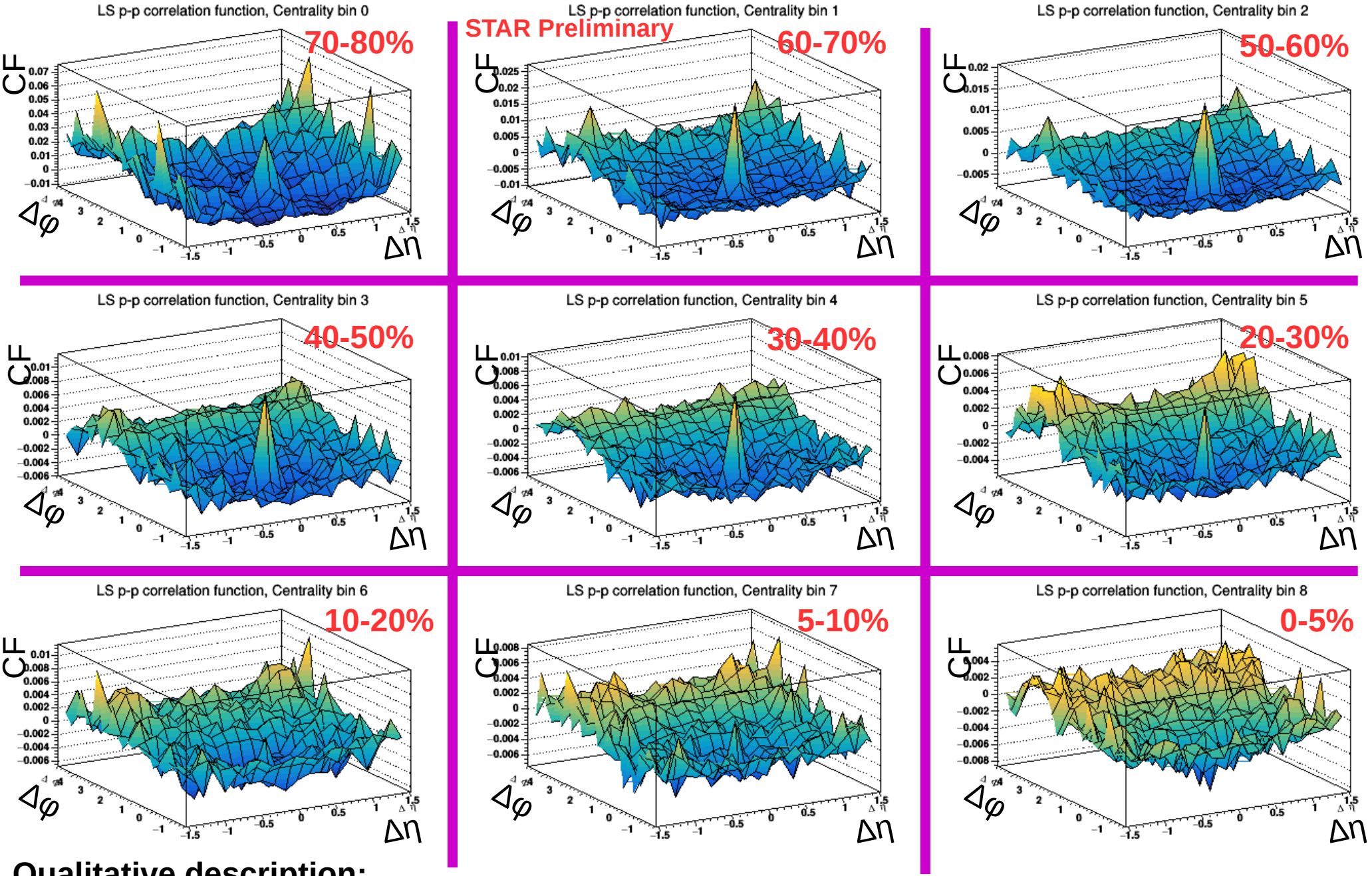
Qualitative description:

→ **Clear, broad Δφ ridge dominant in more peripheral collisions**

→ **Peak at small relative azimuthal angle (Near-Side)**

→ **Δφ modulation strongest in mid-central collisions**

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



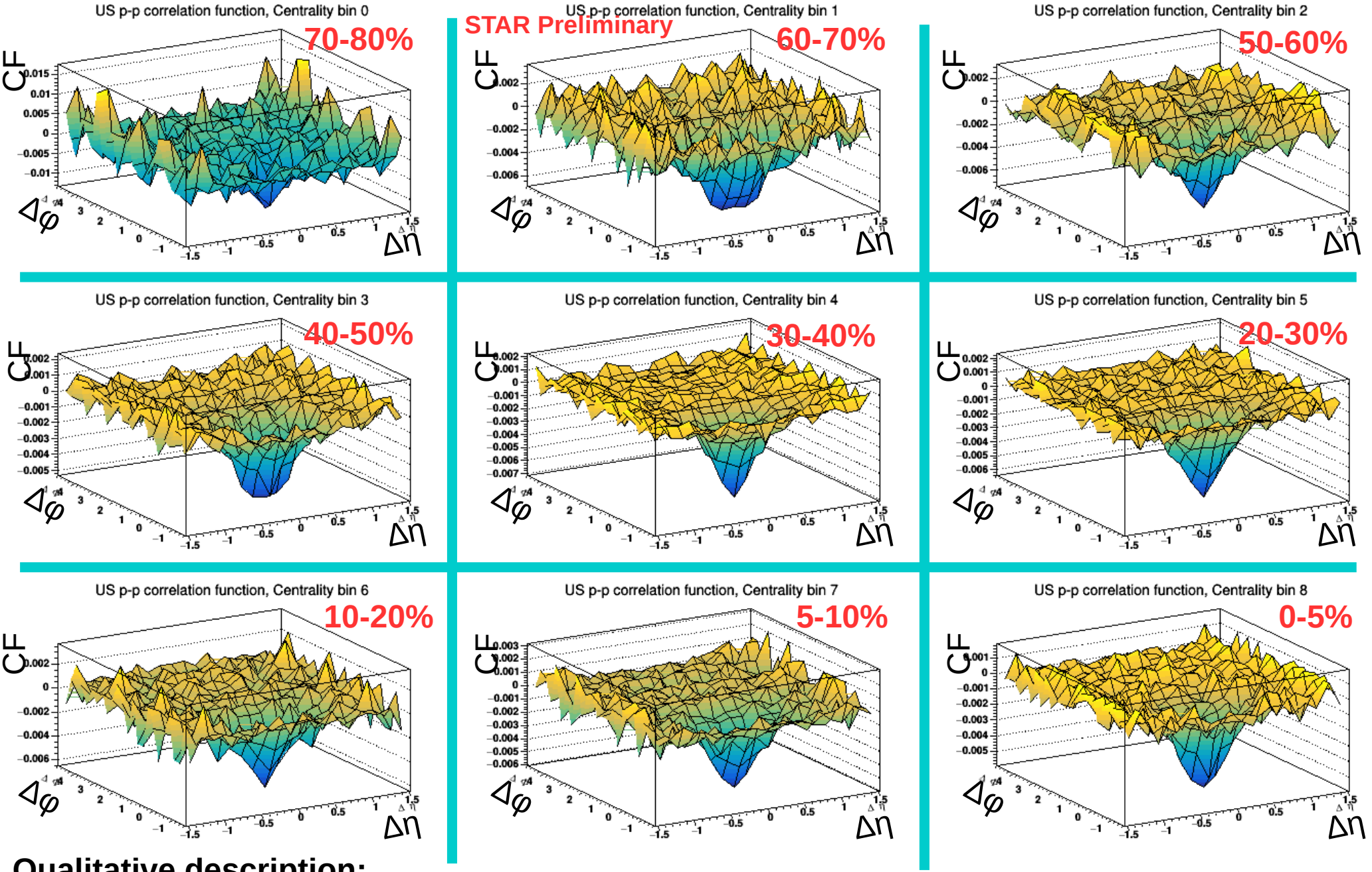
Qualitative description:

→ **Generally negatively correlated on the near-side**

→ **Sharp peak at (Δη;Δφ) ≈ (0;0)**

→ **Visible away-side ridge**

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



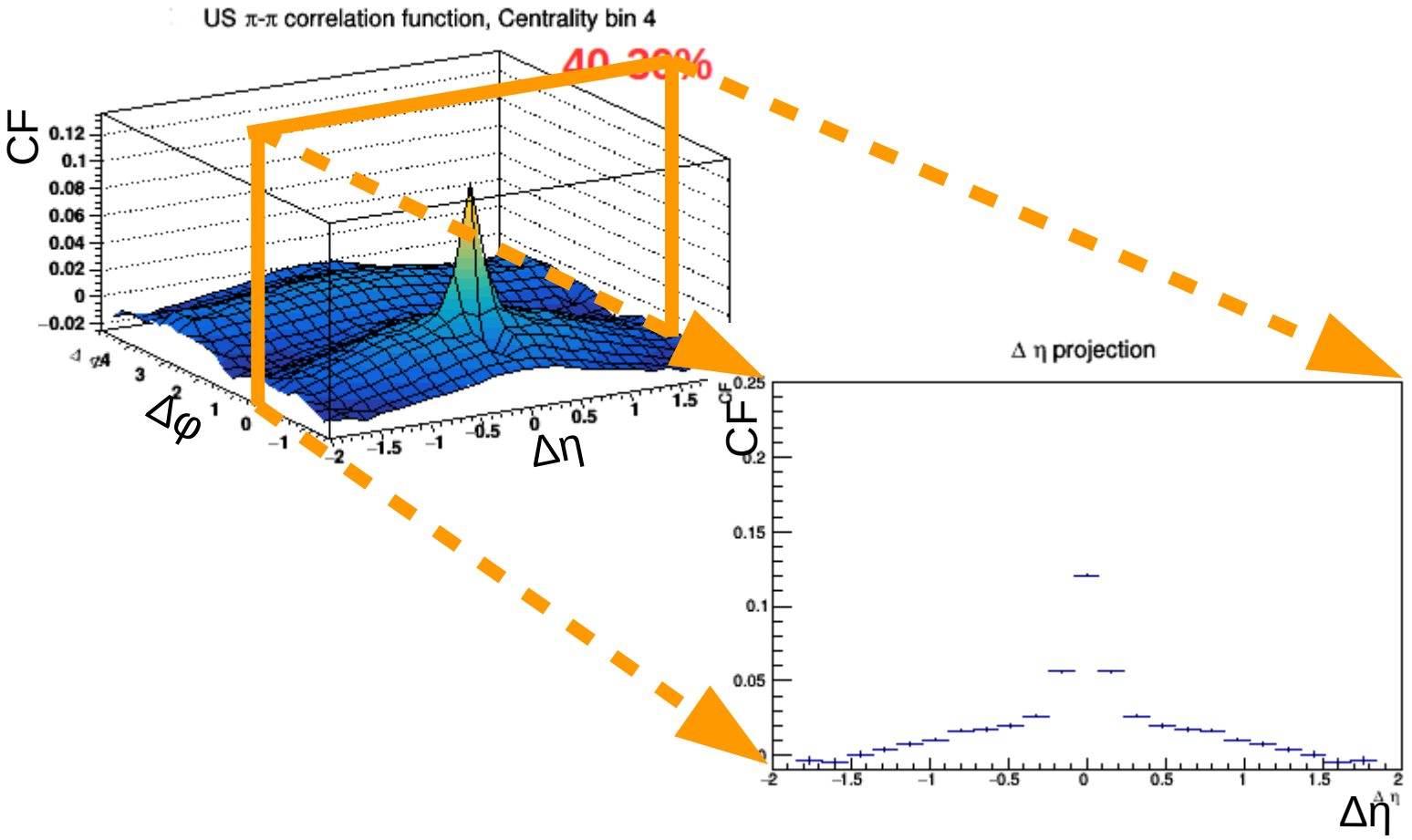
Qualitative description:

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

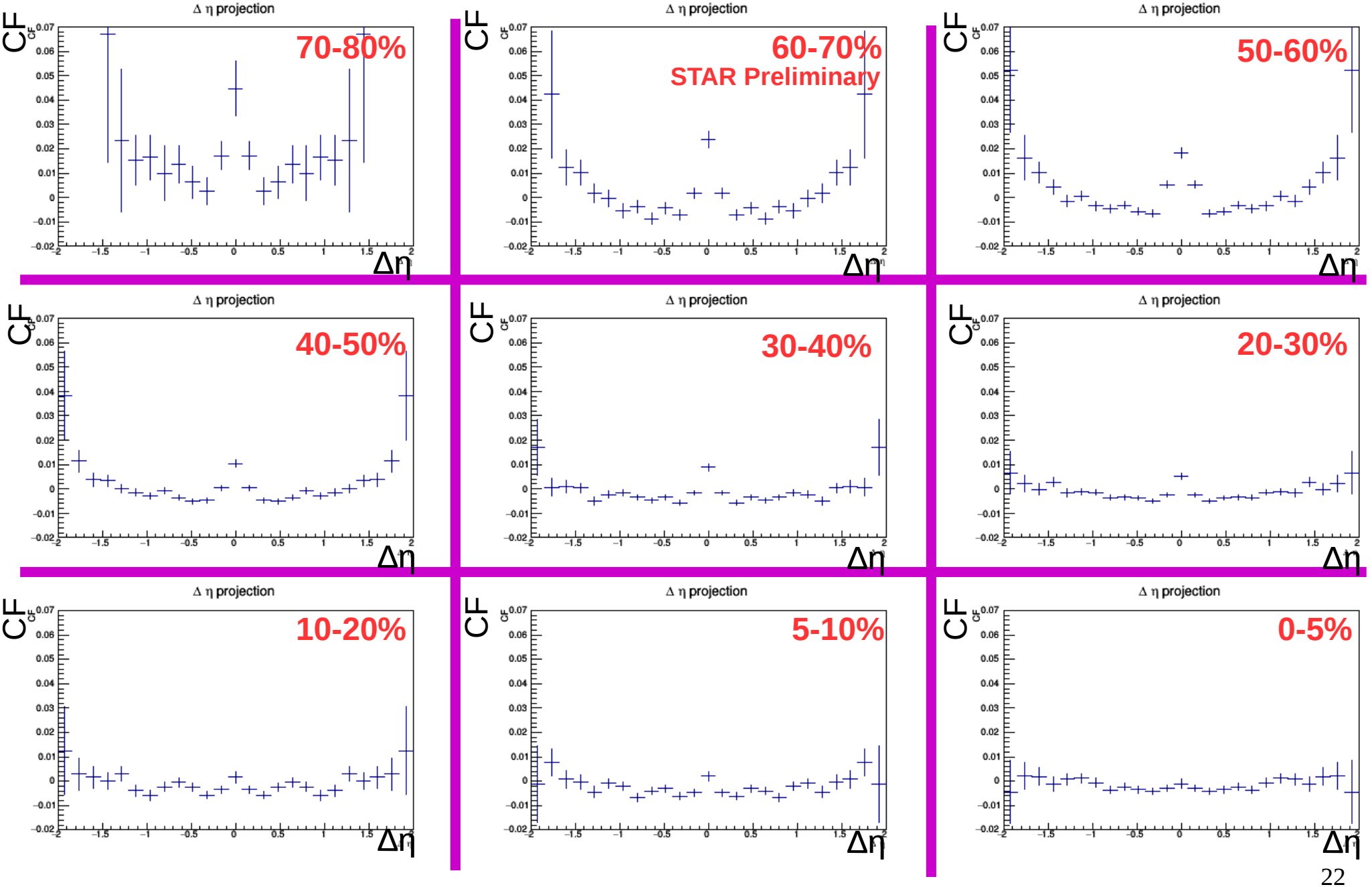
→ **Lack of spike at (Δη;Δφ) ≈ (0;0)**

→ **Lack of away-side ridge**

Projections of bin at Δφ ~ 0 : - 7.2° < Δφ < + 7.2° :

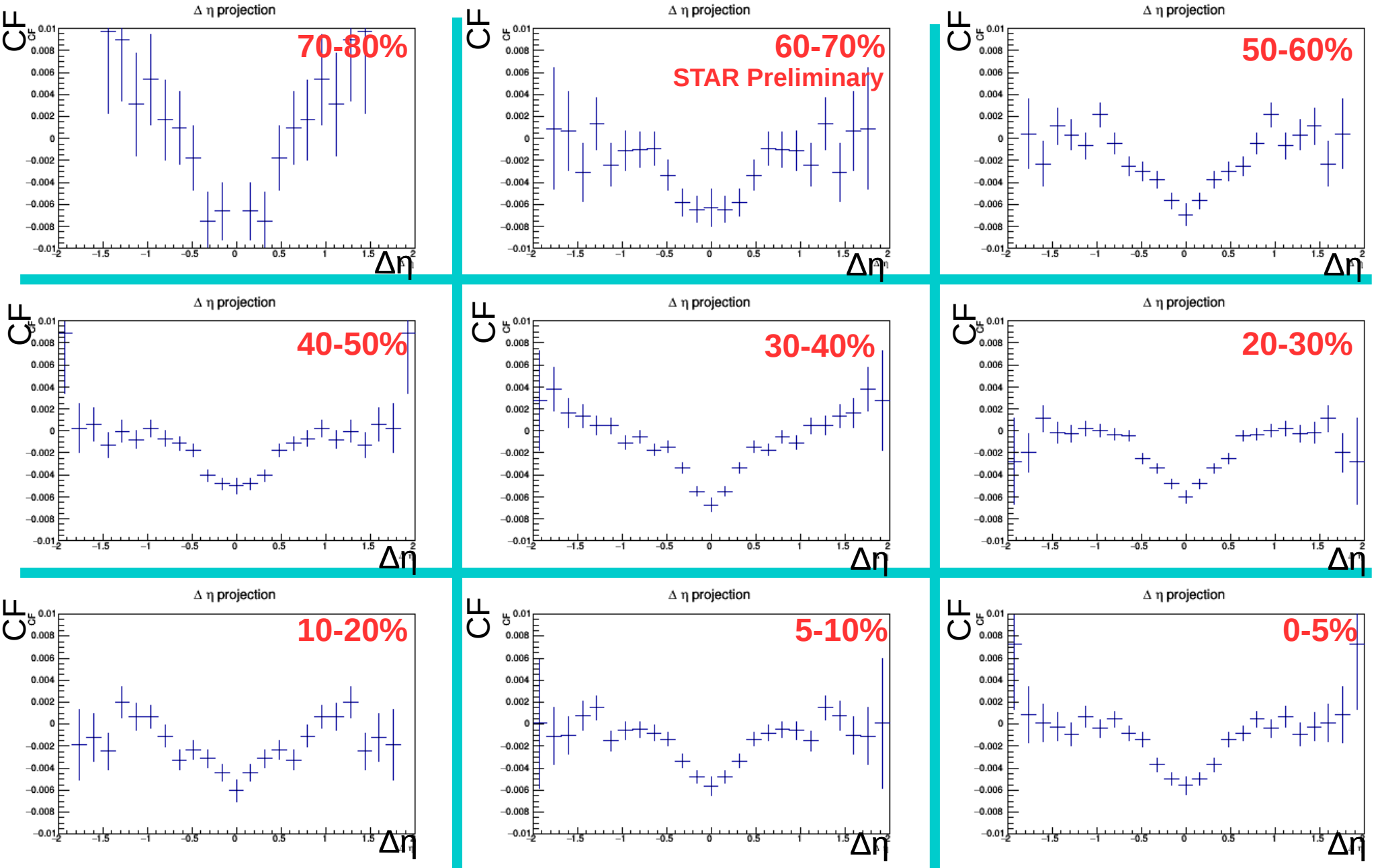


(anti-)proton-(anti-)proton correlations, AuAu @ 19.6 GeV
- 7.2° < Δφ < + 7.2° :



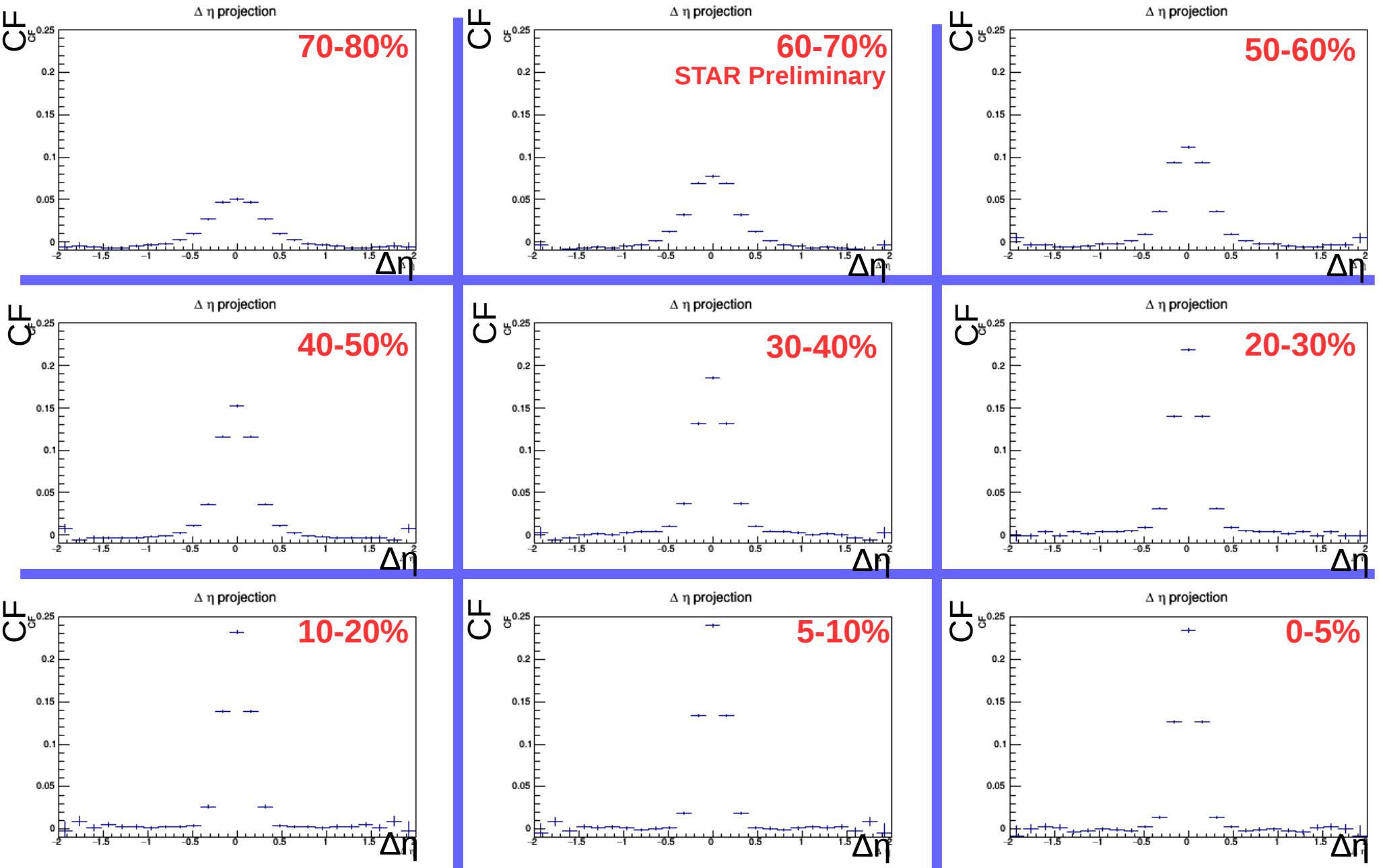
→ **Fit to data: $a*\Delta\eta^2 + b*\Delta\eta + c + A_e * \exp[-(\Delta\eta^2 / \omega^2)]$**

proton-antiproton correlations, AuAu @ 19.6 GeV
- 7.2° < Δφ < + 7.2° :



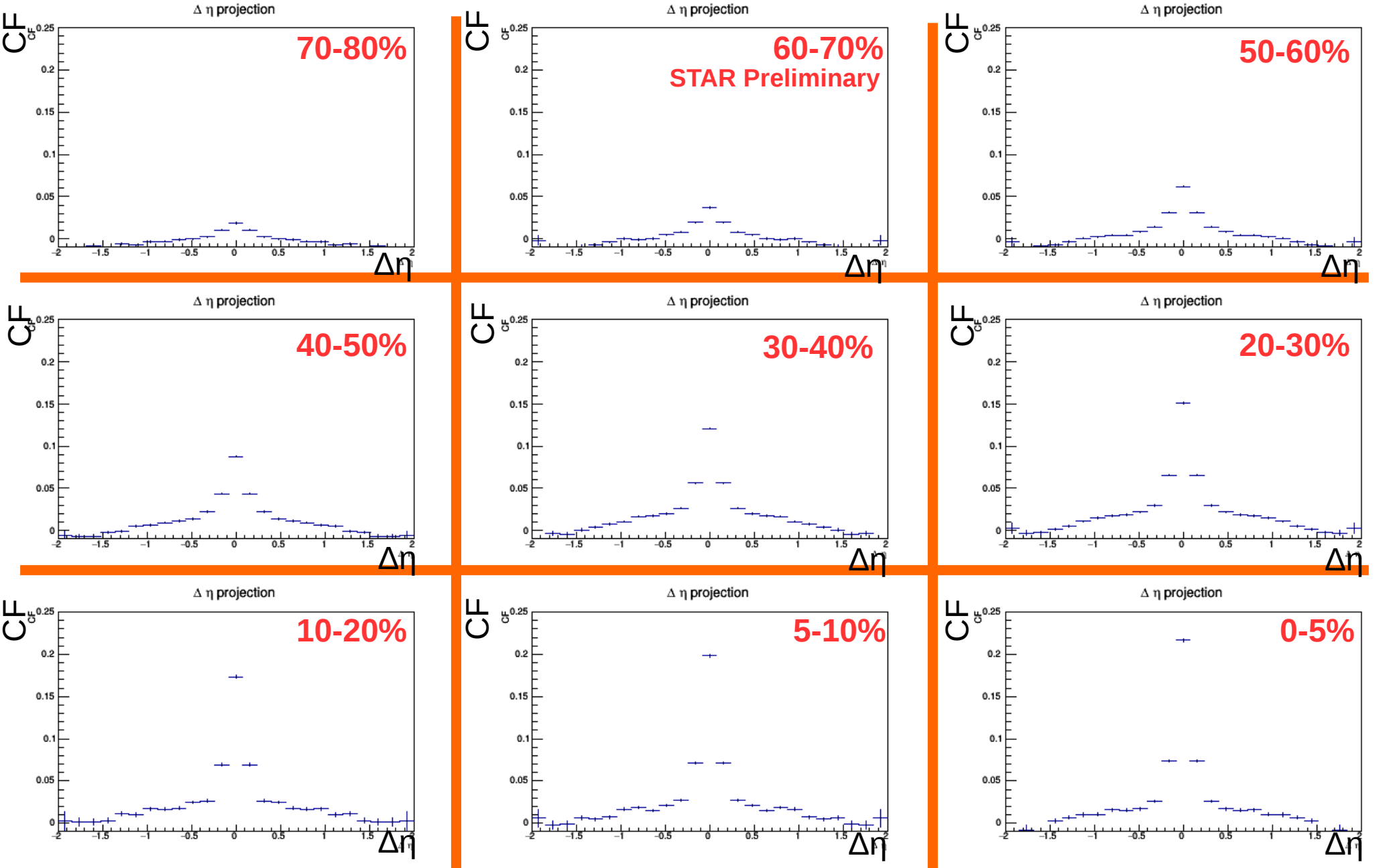
→ **Fit to data: c + A_e* exp [- ($\Delta\eta^2$ / ω^2)]**

Like-sign pion correlations, AuAu @ 19.6 GeV
- 7.2° < Δφ < + 7.2° :



→ **Amplitude of the peak grows with more central events**
→ **Width smaller with more central events**

Unlike-sign pion correlations, AuAu @ 19.6 GeV
- 7.2º < Δφ < + 7.2º :



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Summary

Ongoing analysis showed:

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

- Results for **two-proton** correlations:
  - **p-p + $\bar{p}$-$\bar{p}$:**
    - 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 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:

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

BACKUP