To study the two particle correlation functions $R_2(\Delta\eta, \Delta\varphi)$ and $P_2(\Delta\eta, \Delta\varphi)$ in p-p collisions at $\sqrt{s}$ = 13 TeV as a function of charged particle multiplicity and transverse spherocity

Subhadeep Roy[1], Dibakar Bauri[1],

Baidyanath Sahoo[1], Sadhana Dash[1] ,

Basant Kumar Nandi[1], Sumit Basu[3] and Claude A. Pruneau[2]

[1]IIT Bombay, India

[2]Wayne State University, USA

[3] Lund University

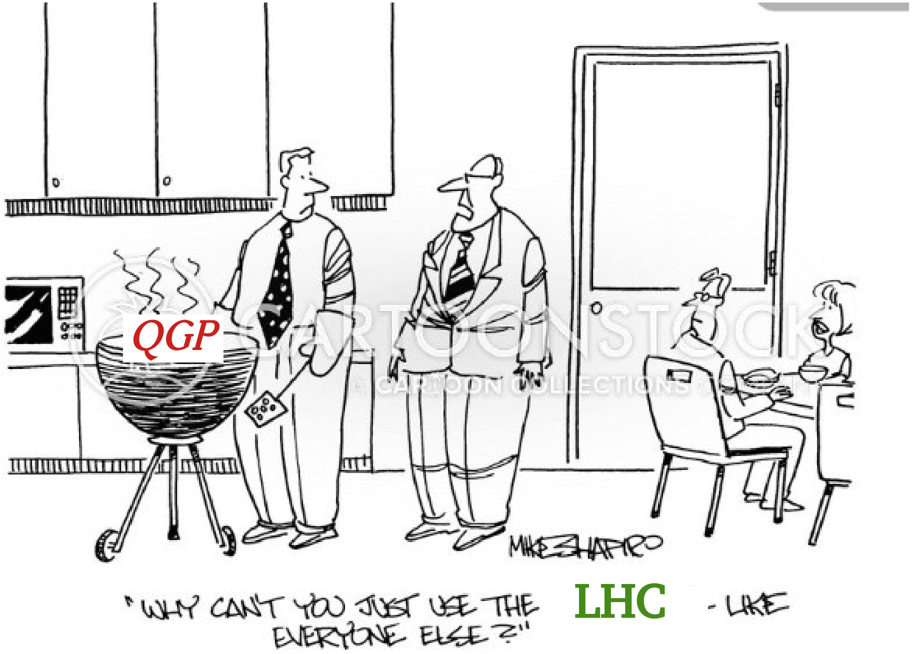
ALICE-STAR India Collaboration meeting

22/11/2023

Outline

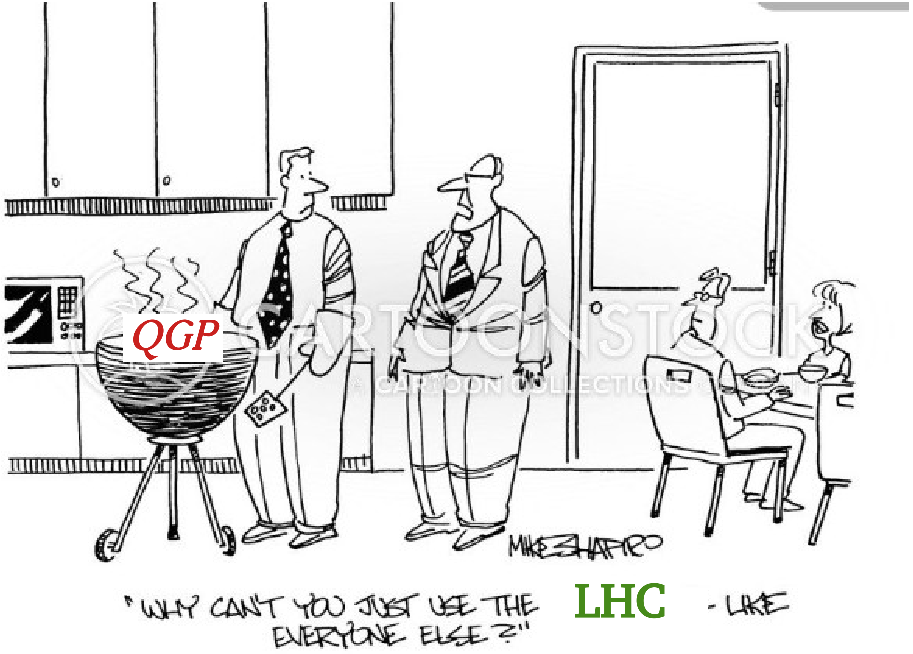
- Introduction and Motivation
- Results
  - ➢ Multiplicity dependent study
  - ➢ Spherocity dependent study

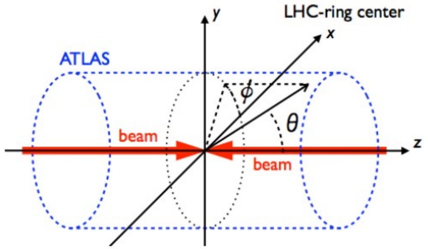
High energy collision and QGP

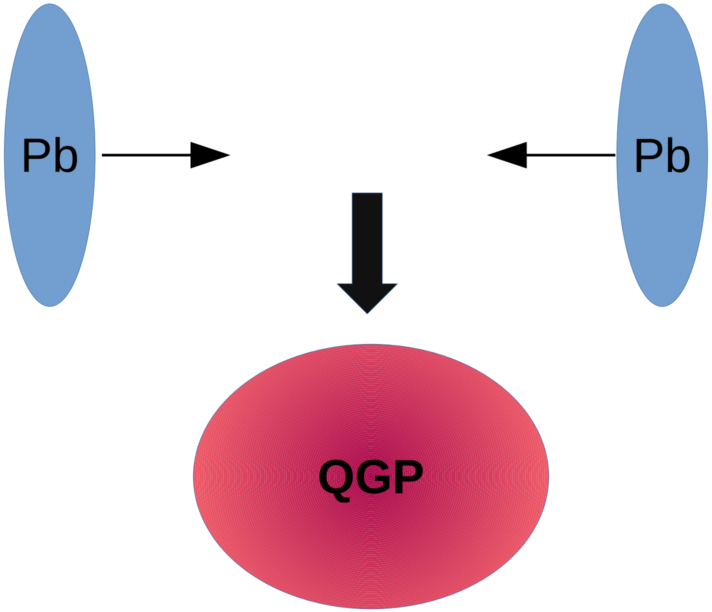


Credit: Cartoonstock

High energy collision and QGP

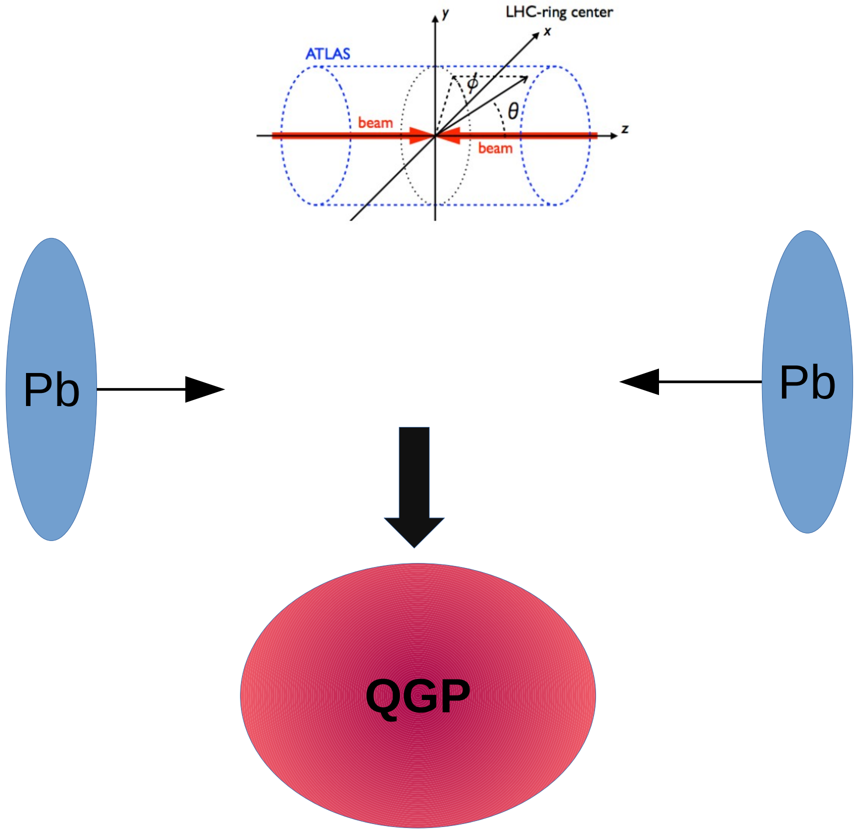






Credit: Cartoonstock

High energy collision



- Two particle correlation studied in terms of $\Delta\eta$ and $\Delta\varphi$ of a pair helped in characterising the medium formed with during high energy collisions

- Specially, observations like anisotropic flow, jet-quenching etc. revealed several interesting properties of the medium

Observables

Normalized two-particle cumulant :

$$R_2(\eta_1,\varphi_1,\eta_2,\varphi_2) = \frac{\rho_2(\eta_1,\varphi_1,\eta_2,\varphi_2)}{\rho_1(\eta_1,\varphi_1)\rho_1(\eta_2,\varphi_2)} - 1$$

Number correlation

Where ,

$$\rho_1(\eta,\varphi) = \frac{1}{\sigma_1}\frac{d^2\sigma_1}{d\eta d\varphi},$$ **No. of particles**

$$\rho_2(\eta_1,\varphi_1,\eta_2,\varphi_2) = \frac{1}{\sigma_2}\frac{d^4\sigma_2}{d\eta_1 d\varphi_1 d\eta_2 d\varphi_2},$$

No. of pairs

Transverse Momentum Correlator :

$$P_2(\eta_1,\varphi_1,\eta_2,\varphi_2) = \frac{\langle \Delta p_T \Delta p_T\rangle(\eta_1,\varphi_1,\eta_2,\varphi_2)}{\langle p_T\rangle^2}.$$

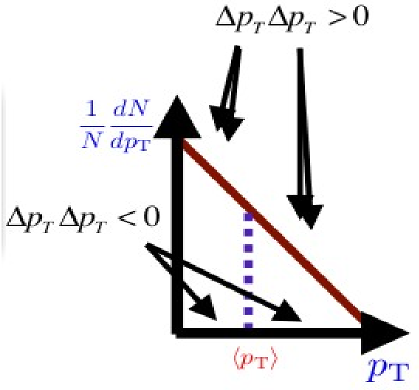
Momentum correlation

Where ,

$$\langle \Delta p_T \Delta p_T\rangle(\eta_1,\varphi_1,\eta_2,\varphi_2) = \frac{\int_{p_{T,\min}}^{p_{T,\max}} \Delta p_{T,1}\Delta p_{T,2}\, \rho_2(\vec{p}_1,\vec{p}_2)\, dp_{T,1}dp_{T,2}}{\int_{p_{T,\min}}^{p_{T,\max}} \rho_2(\vec{p}_1,\vec{p}_2)\, dp_{T,1}dp_{T,2}}$$

and

$$\Delta p_{T,i} = p_{T,i} - \langle p_T \rangle$$

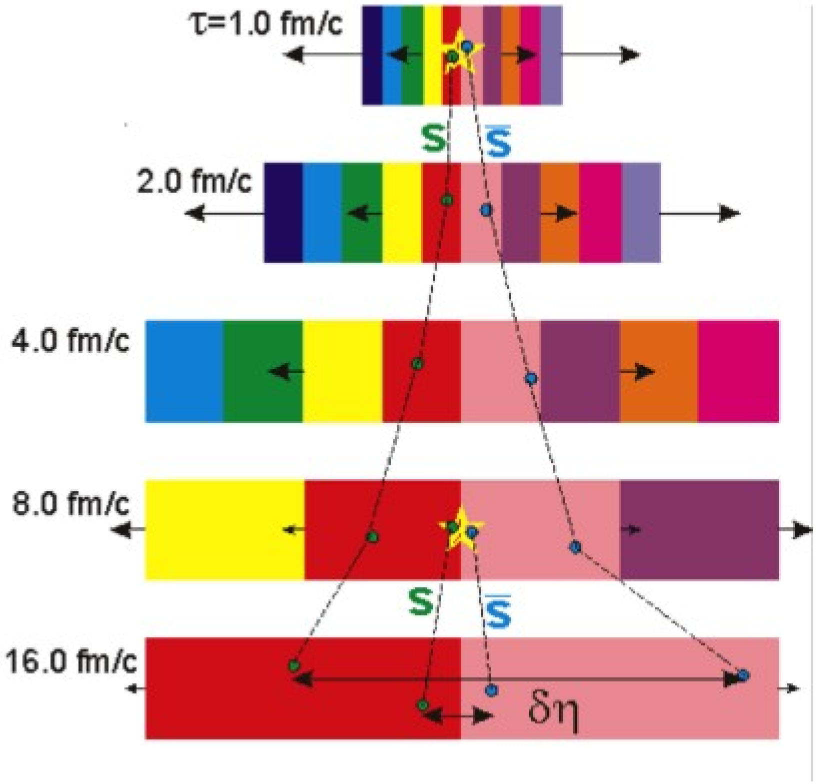


- LS : Like-sign pairs $\quad O^{(LS)} = \frac{1}{2}\left(O^{(++)} + O^{(--)}\right)$
- US : Unlike-sign pairs $\quad O^{(US)} = \frac{1}{2}\left(O^{(+-)} + O^{(-+)}\right)$
- CI : Charge Independent $\quad O^{(CI)} = \frac{1}{2}\left(O^{(LS)} + O^{(US)}\right)$
- CD: Charge Dependent $\quad O^{(CD)} = \frac{1}{2}\left(O^{(US)} - O^{(LS)}\right)$

C. Pruneau, S. Gavin, and S. Voloshin
Phys. Rev. C66, 044904 (2002)

Motivation

Delayed hadronisation and QGP with R_2^{CD}



Early-Stage Production:
More Diffusion due to more scattering
➡ **Wider width**

Late-Stage Production:
Less Diffusion due to less scattering
➡ **Smaller width**

S. Bass, P. Danielewicz, and S. Pratt
[Phys.Rev.Lett. 85, 2689 (2000)]

Results

Correlation structures in different Multiplicity classes

The Apparatus (ALICE)

Analysed in pp collisions

Energy ($\sqrt{s}$) : 13 TeV

Data set : LHC18

Events selection : Trigger: kINT7 (MB)

$|V_z| \leq 8.0$ cm

Multiplicity estimation : V0M

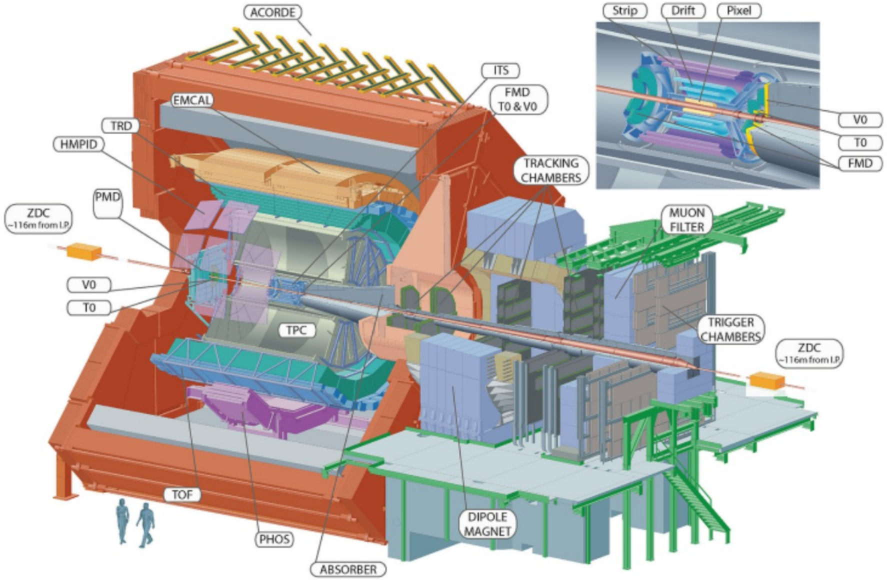
Multiplicity classes: 0-5%, 15-20%, 40-50%, 70-80%

Filter Bit : 96 (Global tracks, ITS+TPC)

$|DCA_z| \leq 0.2$ cm, $|DCA_{xy}| \leq 0.2$ cm;

No. of Cluster : (TPC) ≥ 70

$0.2 \leq p_T \leq 2.0$ (GeV/c); $|\eta| \leq 0.8$

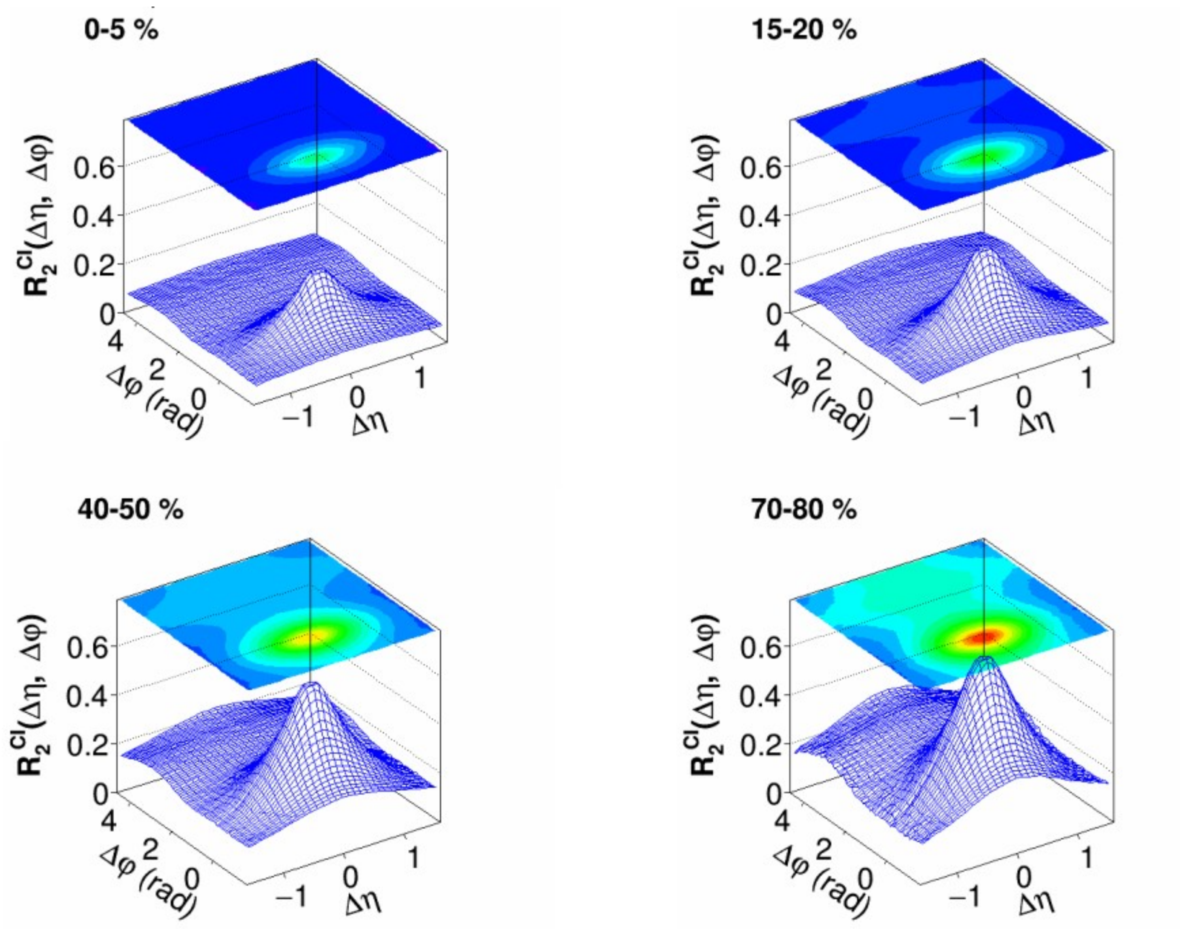


$\varepsilon(p_T)$ *correction*

MC Closure Test (Within reasonable precision)

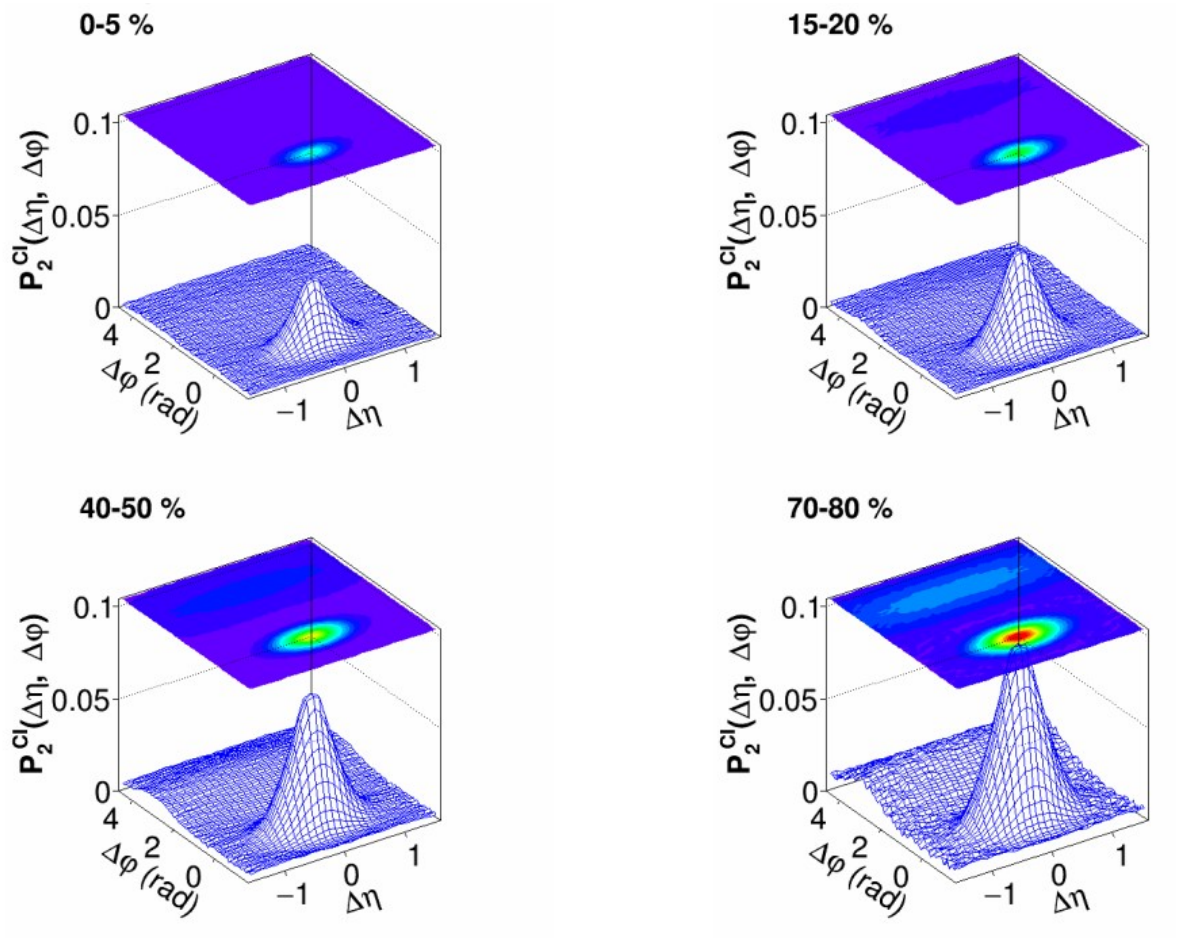
Credit : ALICE

Evolution of R_2^{CI} with multiplicity



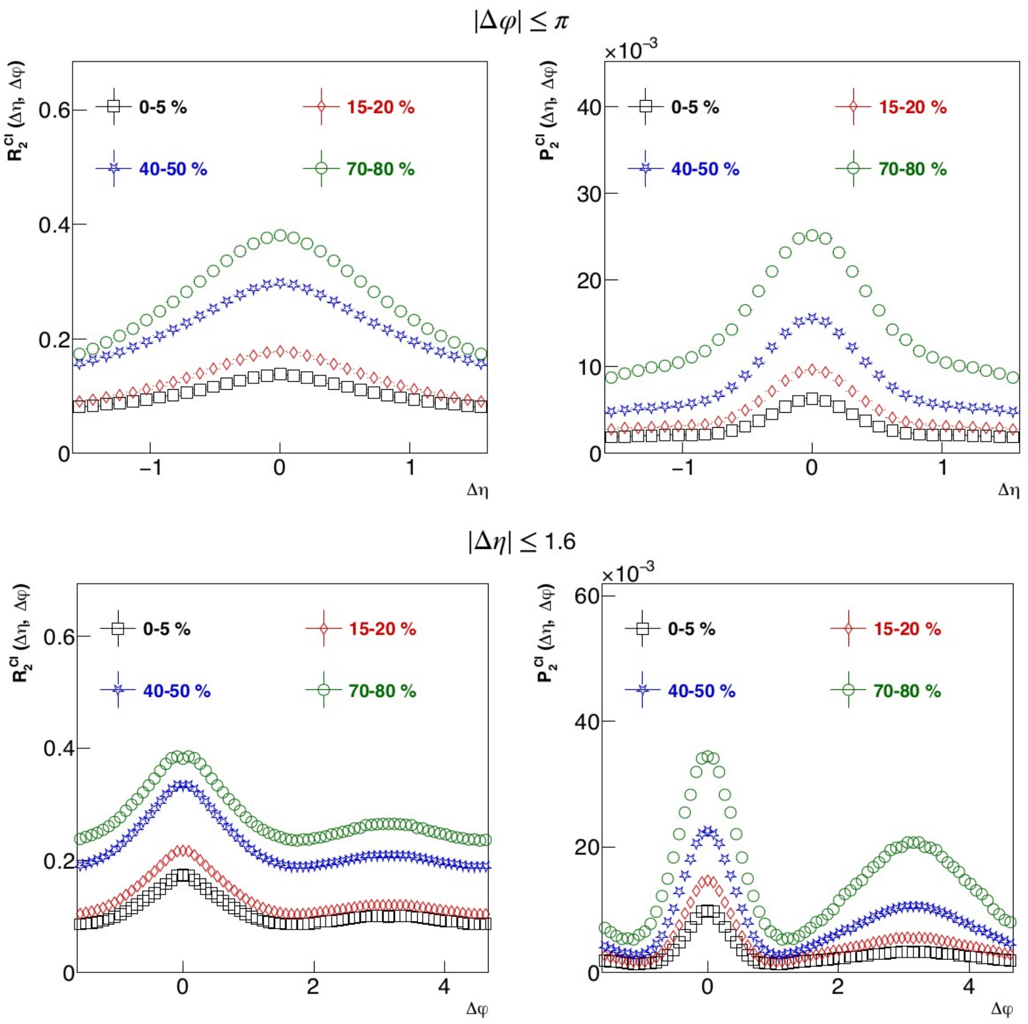
The correlation function feature a prominent near-side peak centered at ($\Delta\eta$, $\Delta\varphi$)=(0,0) as well as a small away-side structure centered at $\Delta\varphi$ = π and the amplitude increases with decreasing multiplicity

Evolution of P_2^{CI} with mutiplicity



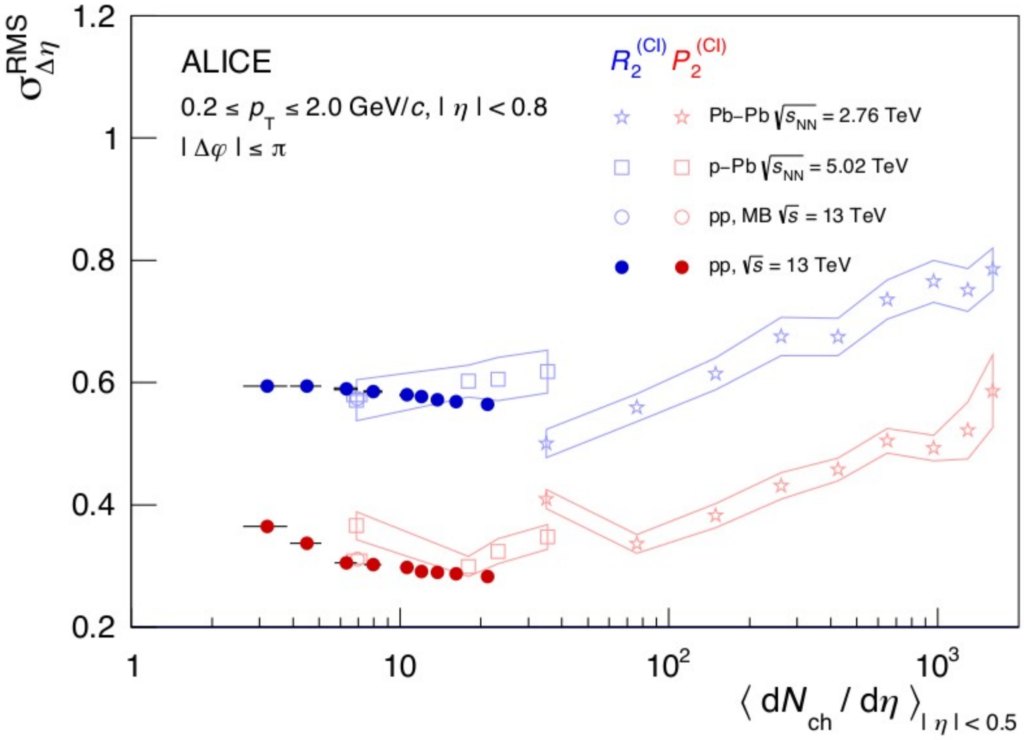
The correlation function feature a prominent near-side peak centered at ($\Delta\eta$, $\Delta\varphi$)=(0,0) as well as a small away-side structure centered at $\Delta\varphi = \pi$ and the amplitude increases with decreasing multiplicity

Projection plots



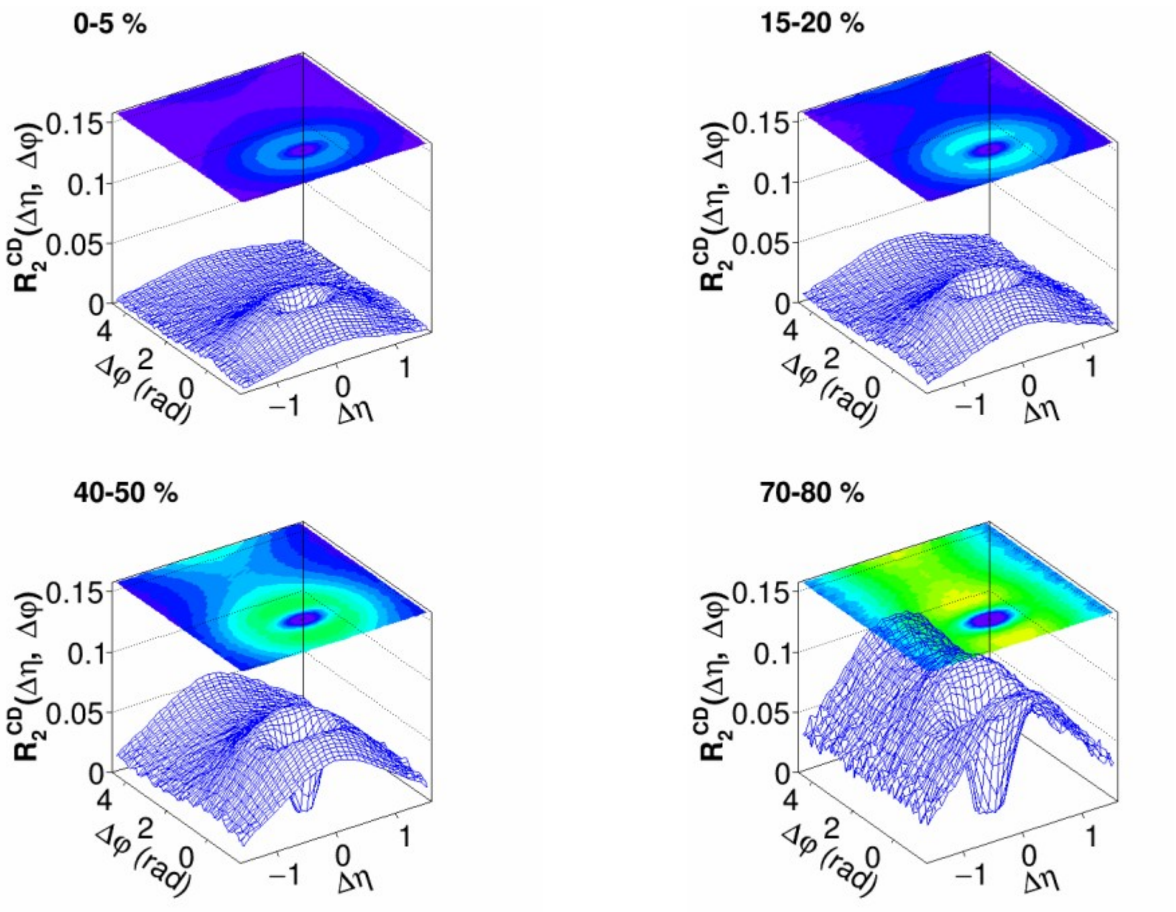
The amplitudes of $R_2^{CI}(\Delta\eta, \Delta\varphi)$ and $P_2^{CI}(\Delta\eta, \Delta\varphi)$ Increases monotonically from high to low multiplicity classes

Evolution of the correlation peak widths



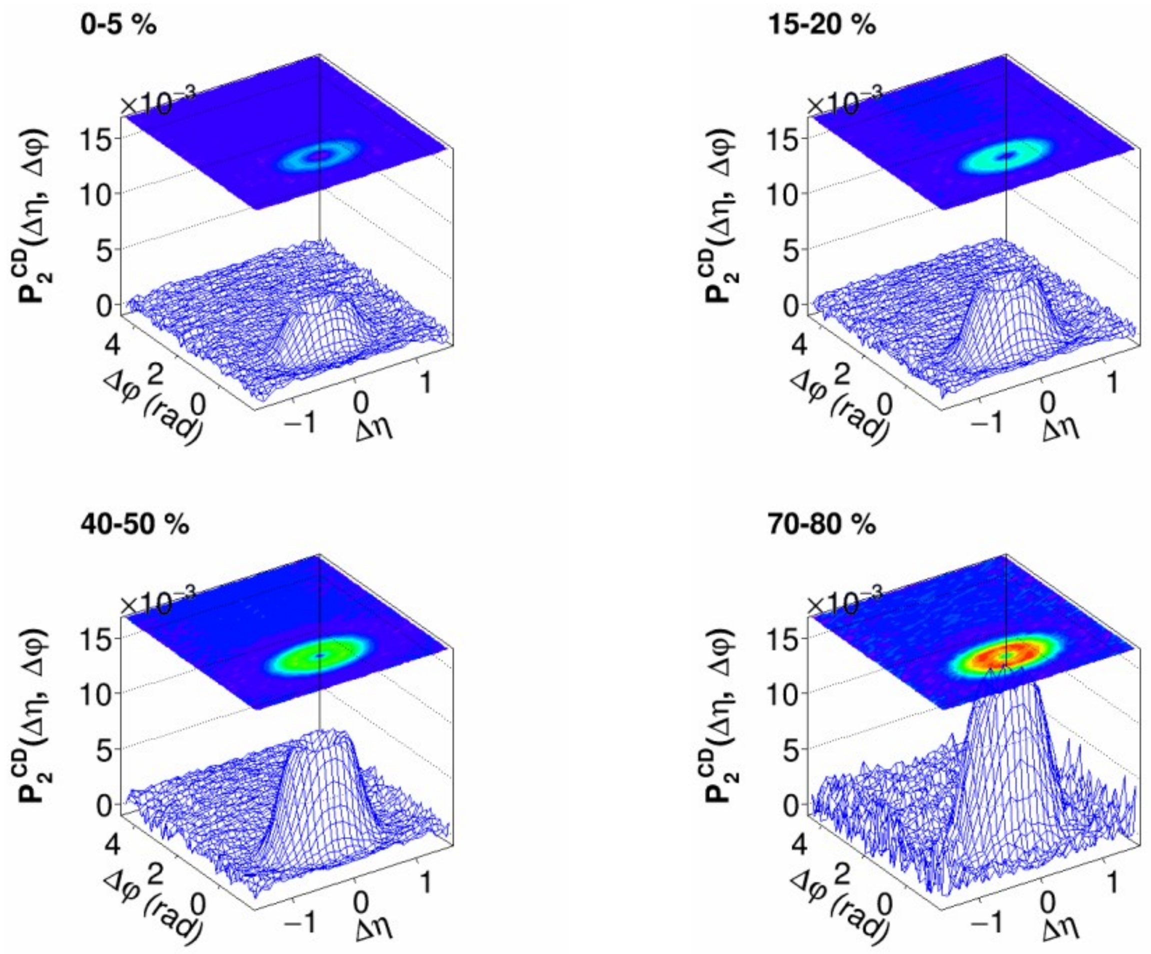
- The widths increase monotonically in Pb-Pb collisions from peripheral to central regions for both R_2 and P_2 except for P_2 in peripheral region
- For p-Pb case, the widths have weak dependence
- For pp case, widths decrease monotonically from low to high multiplicity bins

Evolution of R_2^{CD} with mutiplicity



We see a dip at ($\Delta\eta$, $\Delta\varphi$)=(0,0) is expected largely from HBT effect and the amplitude Increases with decreasing multiplicity

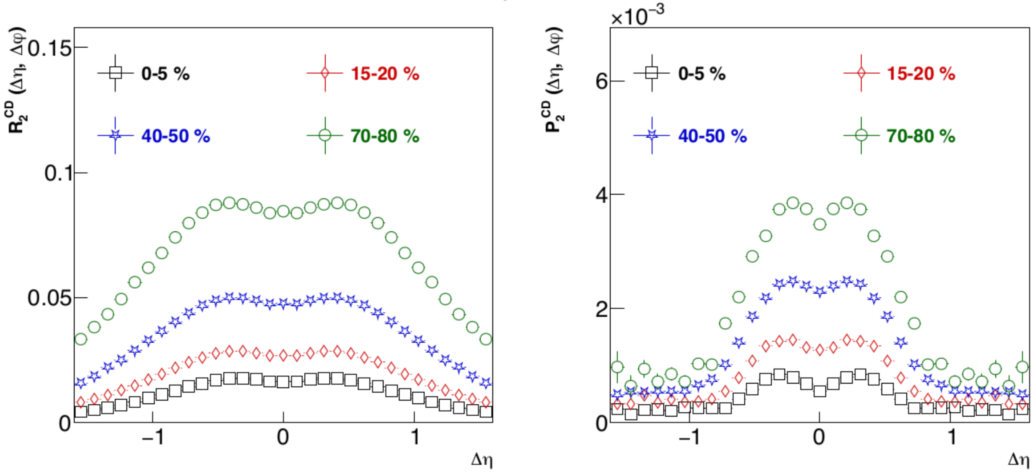
Evolution of P_2^{CD} with mutiplicity



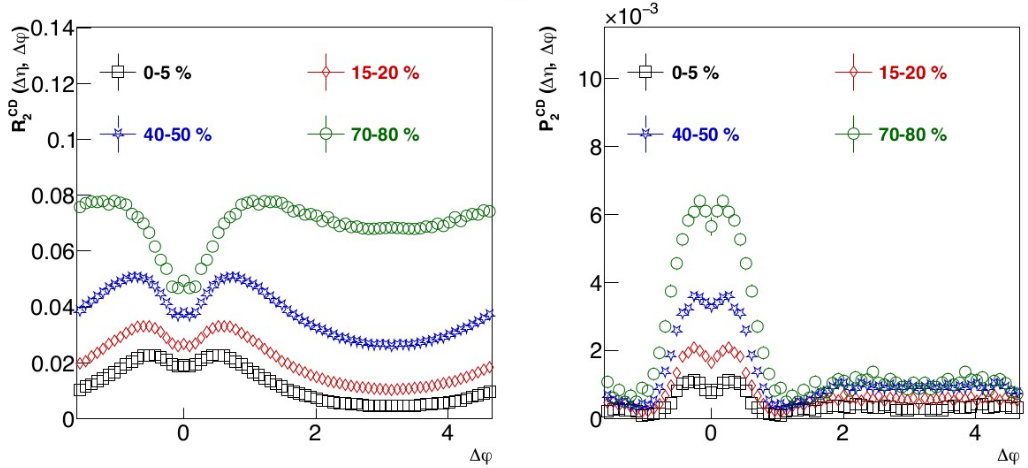
We see a dip at ($\Delta\eta$, $\Delta\varphi$)=(0,0) is expected largely from HBT effect and the amplitude Increases with decreasing multiplicity

Projection plots

$|\Delta\varphi| \leq \pi$

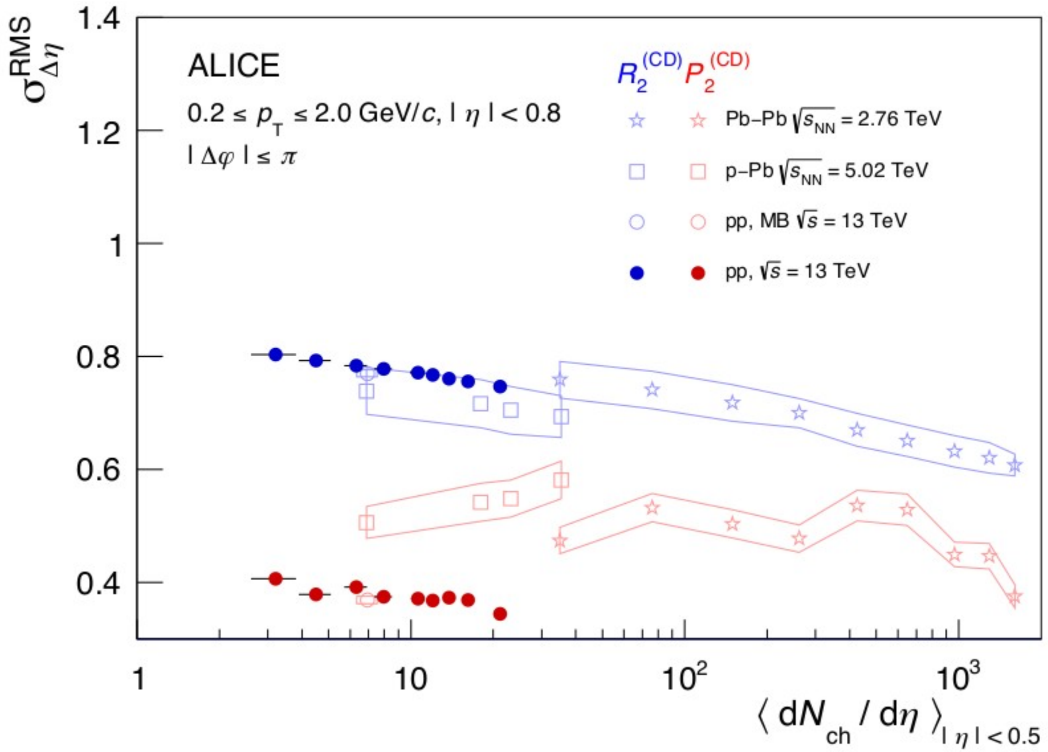


$|\Delta\eta| \leq 1.6$



The amplitudes of $R_2^{CD}(\Delta\eta, \Delta\varphi)$ and $P_2^{CD}(\Delta\eta, \Delta\varphi)$ increases monotonically from high to low multiplicity classes

Evolution of the correlation peak widths

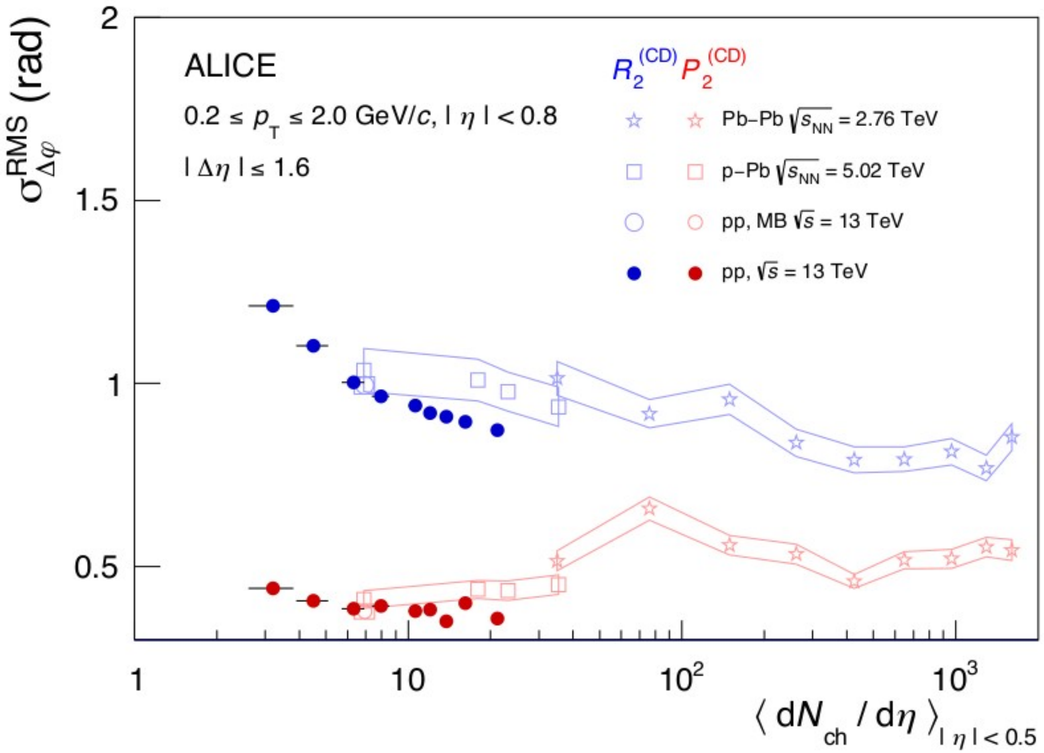


- The width decrease monotonically in Pb-Pb collisions from peripheral to central regions for R_2 and P_2

- For p-Pb case, the widths have noticeable reduction for R_2 whereas widths of P_2 have reverse trend

- For pp case, R_2 width decreases monotonically from low to high multiplicity bins while P_2 width has weak dependence on multiplicity

Evolution of the correlation peak widths



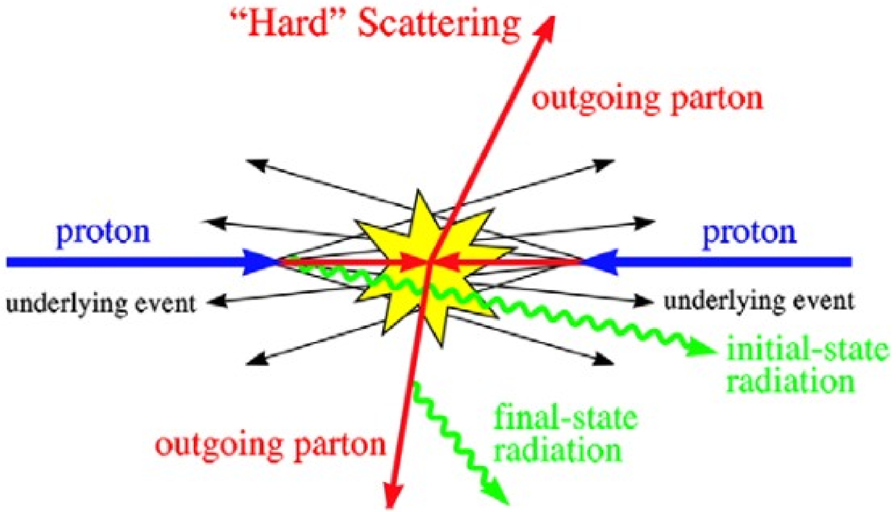
- The width decrease monotonically in Pb-Pb collisions from peripheral to central regions for R_2 and P_2
- For p-Pb case, the widths have noticeable reduction for R_2 whereas widths of P_2 have reverse trend
- For pp case, R_2 width decreases monotonically from low to high multiplicity bins while P_2 width has weak dependence on multiplicity

Study with transverse spherocity

Proton-Proton collisions: Interesting?

- High multiplicity p-p collisions has produced similar observations like heavy-ion collisions (long range near-side correlation structure, strangeness enhancement and collective flow etc.)

Dissecting a p-p collision :

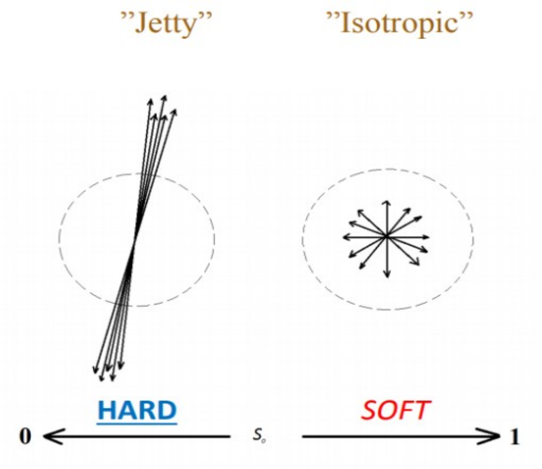


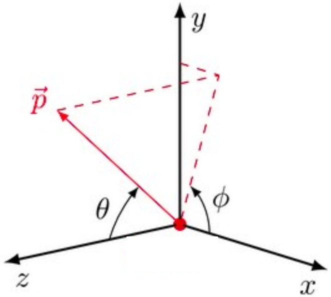
- MPI driven UE are expected to produce QGP like effects even in small systems

Transverse spherocity

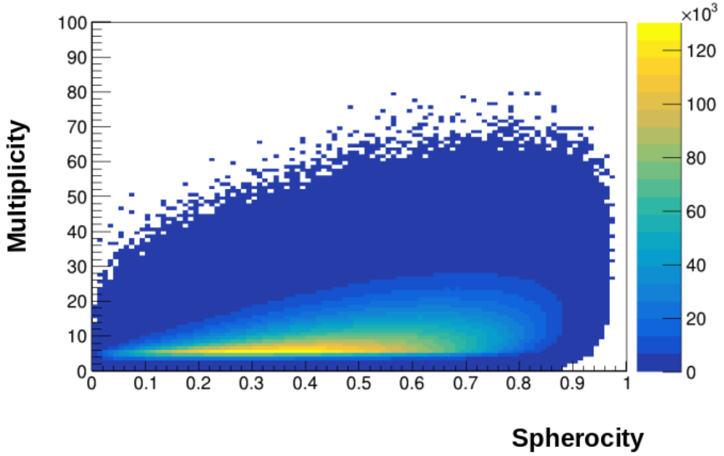
Unique tool to distinguish events based on their geometrical shape in the transverse plane (XY)

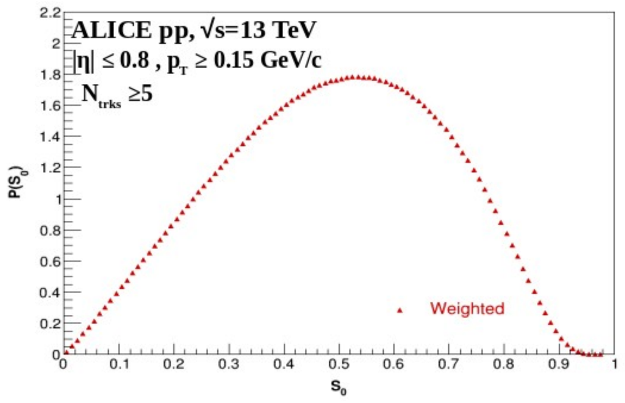
$$S_0 = \frac{\pi^2}{4}\left(\frac{\Sigma_i\ |\vec{p}_{T_i} \times \hat{n}|}{\Sigma_i\ p_{T_i}}\right)^2$$





Multiplicity Vs. Spherocity





The Apparatus (ALICE)

Analysed in pp collisions

Energy ($\sqrt{s}$) : 13 TeV

Data set : LHC18

Events selection : Trigger: kINT7 (MB)

$|V_z| \leq 8.0$ cm

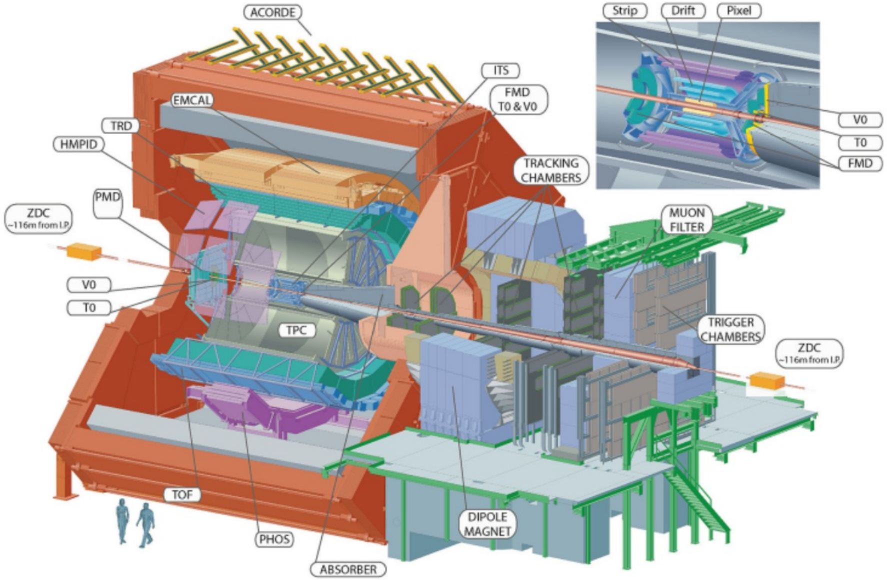
Multiplicity estimation : V0M

Filter Bit : 96 (Global tracks, ITS+TPC)

$|DCA_z| \leq 0.2$ cm, $|DCA_{xy}| \leq 0.2$ cm;

No. of Cluster : (TPC) ≥ 70

$0.2 \leq p_T \leq 2.0$ (GeV/c); $|\eta| \leq 0.8$



☑ $\varepsilon(p_T)$ correction

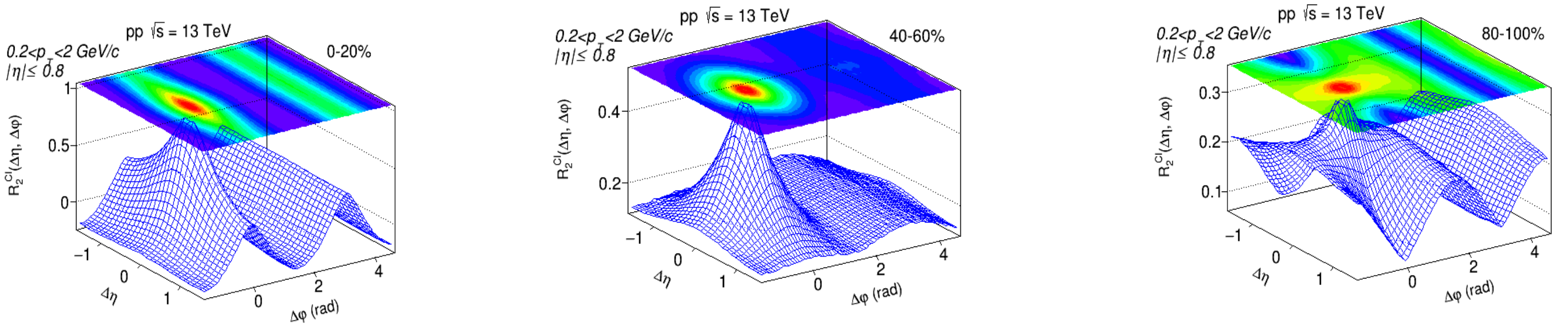
✓ MC Closure Test (Within reasonable precision)

Results

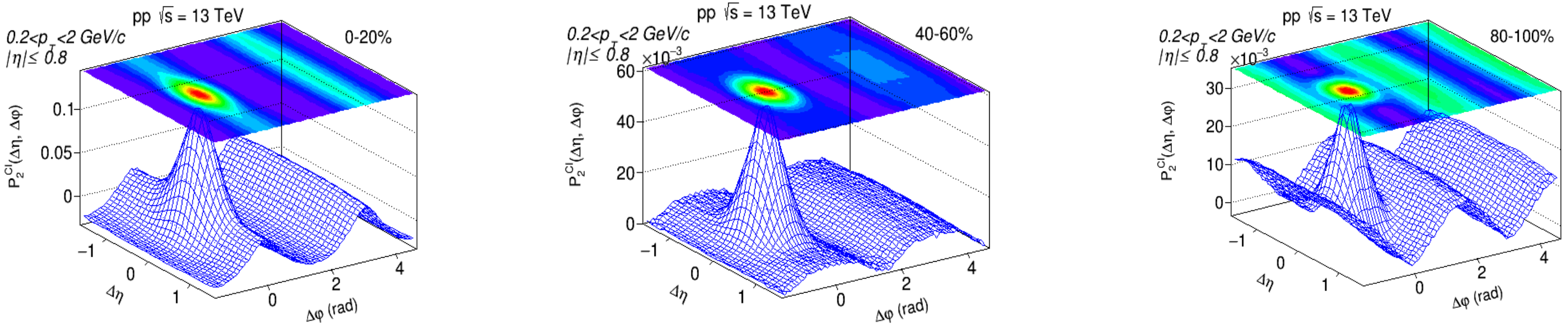
Correlation functions

$R_2^{CI} = 1/2(R_2^{US} + R_2^{LS})$

Jet dominated | Equiv. MB | MPI dominated



$P_2^{CI} = 1/2(P_2^{US} + P_2^{LS})$



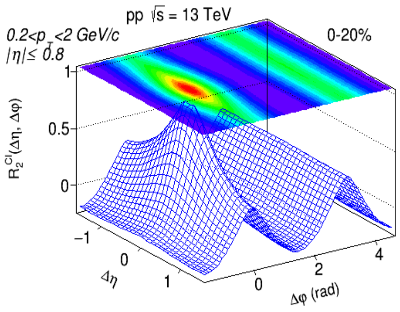
Correlation functions

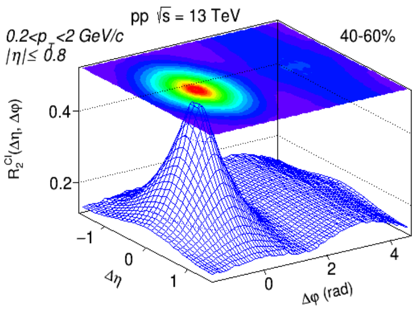
$R_2^{CI} = 1/2(R_2^{US} + R_2^{LS})$

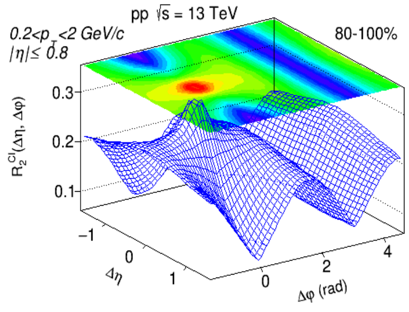
Jet dominated

Equiv. MB

MPI dominated

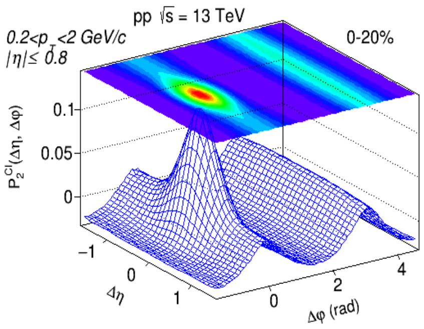


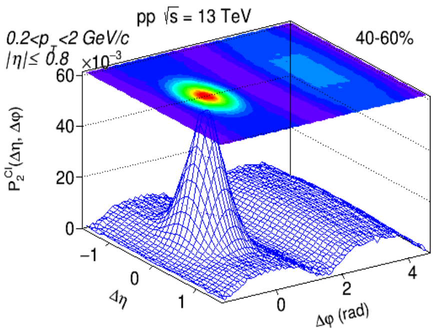


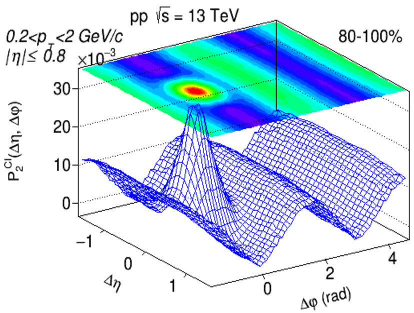


Extreme isotopic class

$P_2^{CI} = 1/2(P_2^{US} + P_2^{LS})$







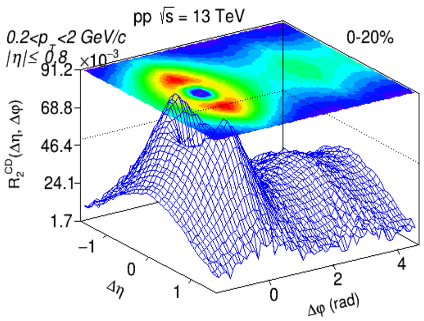
Correlation functions

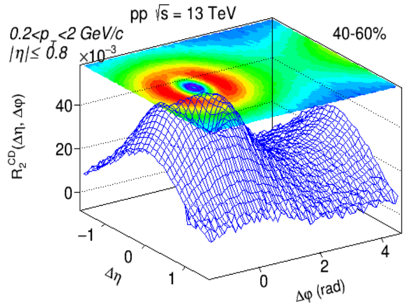
$R_2^{CD} = 1/2(R_2^{US} - R_2^{LS})$

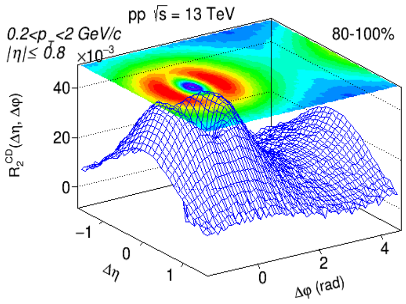
Jet dominated

Equiv. MB

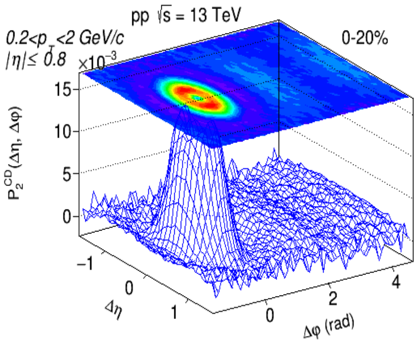
MPI dominated

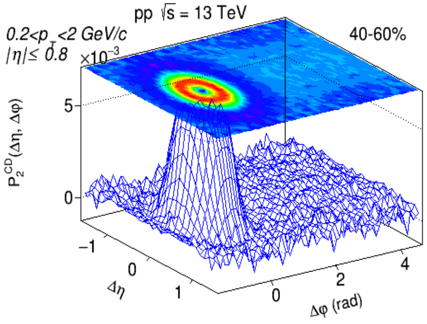


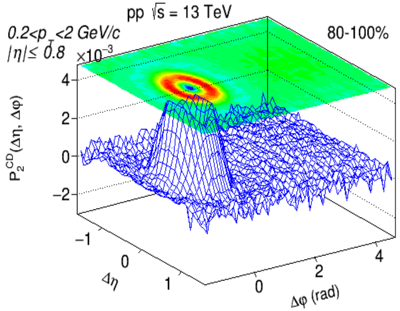




$P_2^{CD} = 1/2(P_2^{US} - P_2^{LS})$

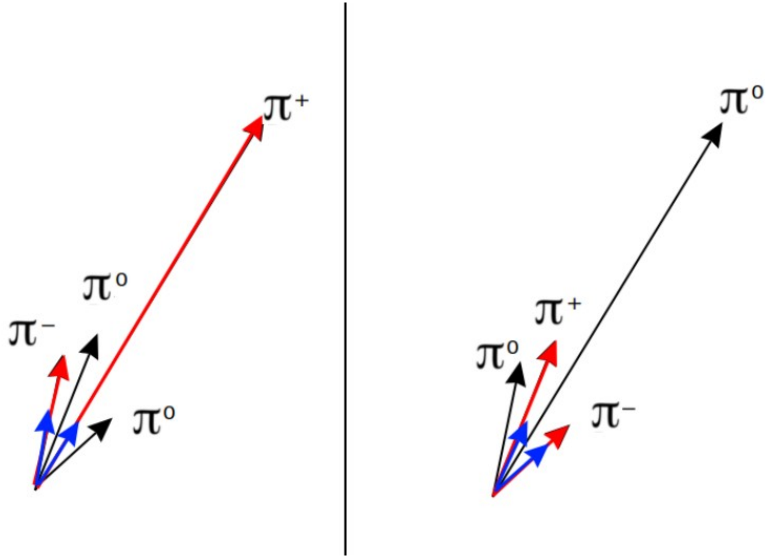






Spherocity definition : A step towards the solution

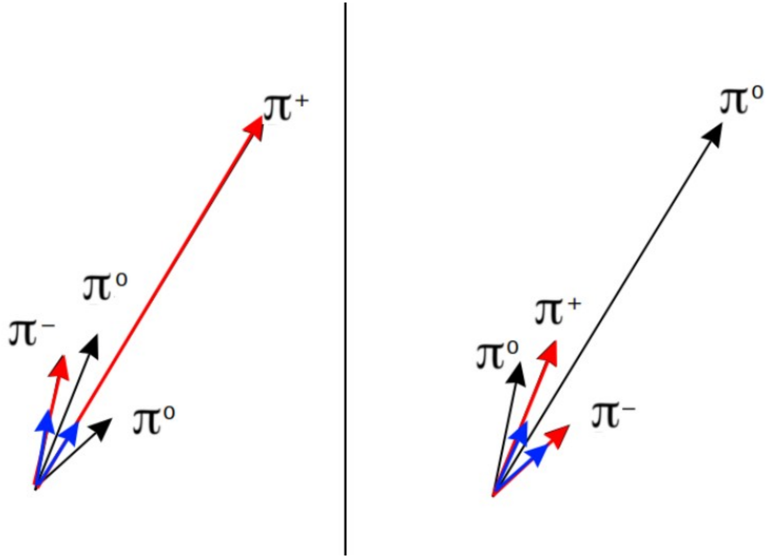
Spherocity : $$S_0 = \frac{\pi^2}{4} \left(\frac{\Sigma_i \ |\vec{p}_{T_i} \times \hat{n}|}{\Sigma_i \ p_{T_i}} \right)^2$$



1. For isotropically distributed events a single high-p_T track can drive the entire S_0 calculation towards 0

2. Only a single high-p_T charged particle can carry en- -ormous weight in spherocity calculation but not a neutral particle (pions).

Removal of the bias

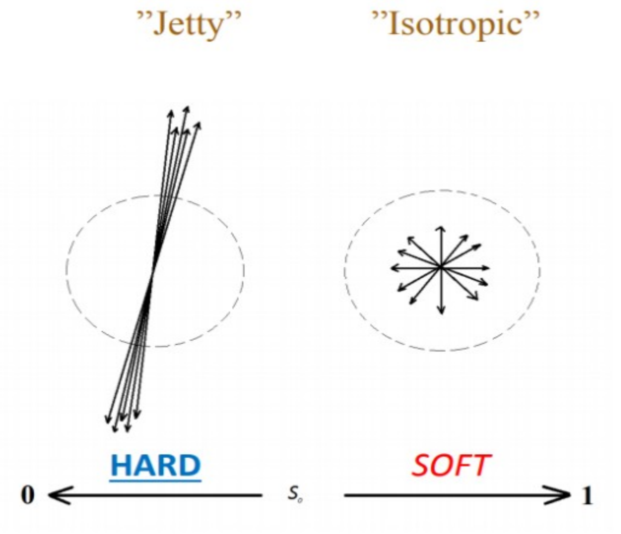


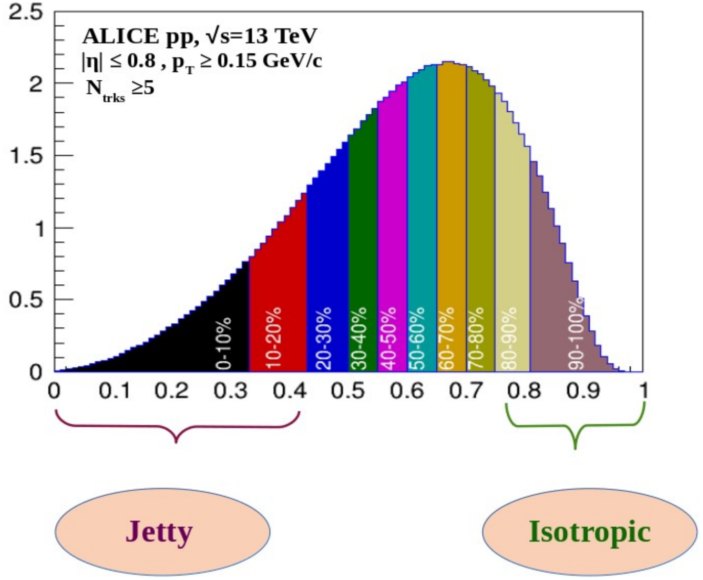
- Re-normalise the weights by setting $|\vec{p_T}| = 1.0\mathrm{GeV}/c$
- Measurement becomes more robust against individual tracks with large p_T
- The charged particles can be used as a proxy of the event topology for neutral particles

Transverse spherocity

Distinguishes events based on their geometrical shape in the transverse plane (XY)

$$S_0 = \frac{\pi^2}{4}\min_{\hat{n}}\left(\frac{\sum_i |\overrightarrow{p_{\mathrm{T_i}}}_{;p_{\mathrm{T_i}}=1} \times \hat{n}|}{\sum_i |\overrightarrow{p_{\mathrm{T_i}}}|_{p_{\mathrm{T_i}}=1}}\right)^2$$



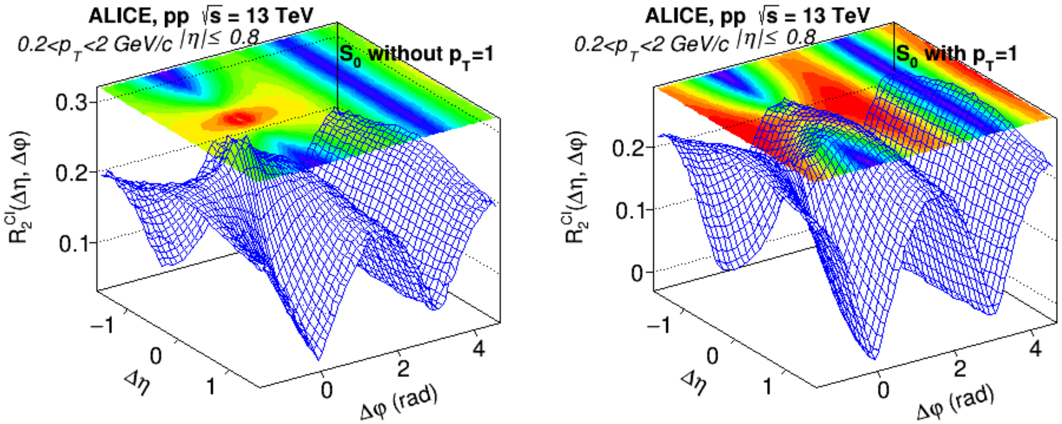


ALICE Collaboration
arXiv:2310.10236

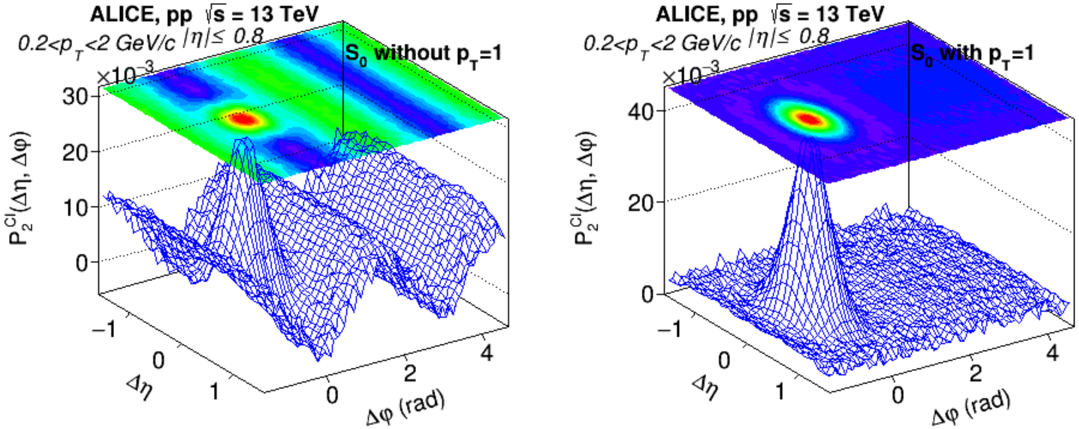
$R_2^{(CI)}$ and $P_2^{(CI)}$

Spherocity: 90-100%
(Extreme isotropic)

$R_2^{CI} = 1/2(R_2^{US} + R_2^{LS})$



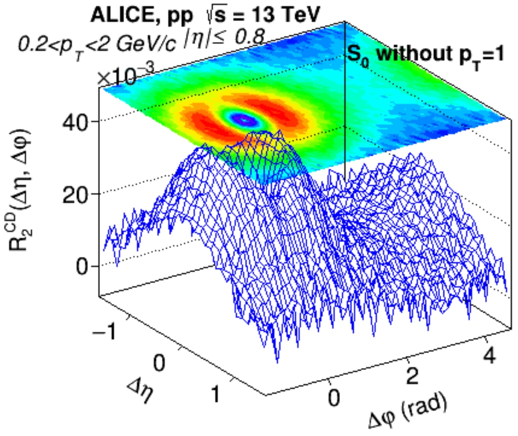
$P_2^{CI} = 1/2(P_2^{US} + P_2^{LS})$

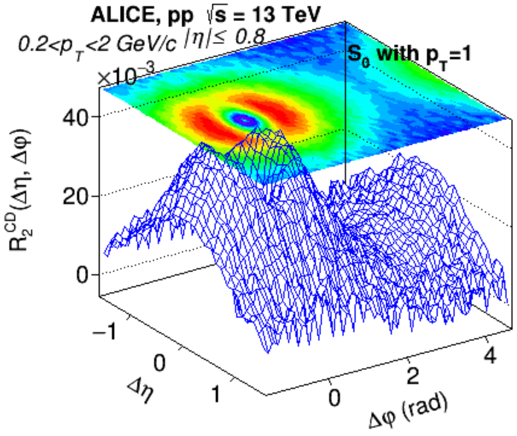


$R_2^{(CD)}$ and $P_2^{(CD)}$

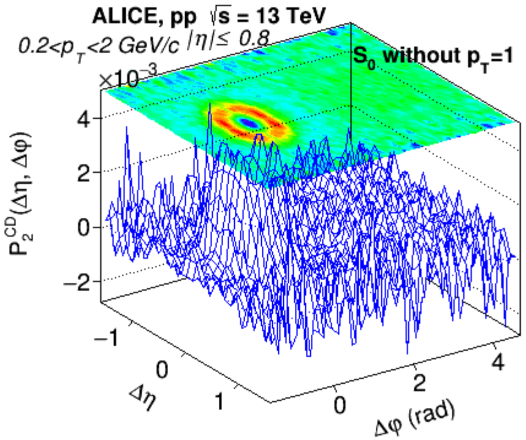
Spherocity: 90-100%
(Extreme isotropic)

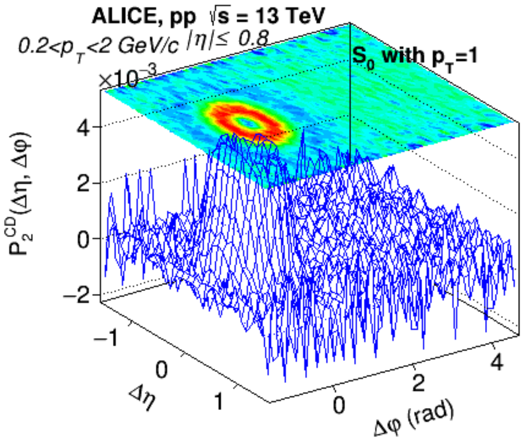
$R_2^{CD} = 1/2(R_2^{US} - R_2^{LS})$





$P_2^{CD} = 1/2(P_2^{US} - P_2^{LS})$





A wise choice

$$S_0 = \frac{\pi^2}{4}\left(\frac{\Sigma_i\ |\vec{p}_{T_i} \times \hat{n}|}{\Sigma_i\ p_{T_i}}\right)^2$$

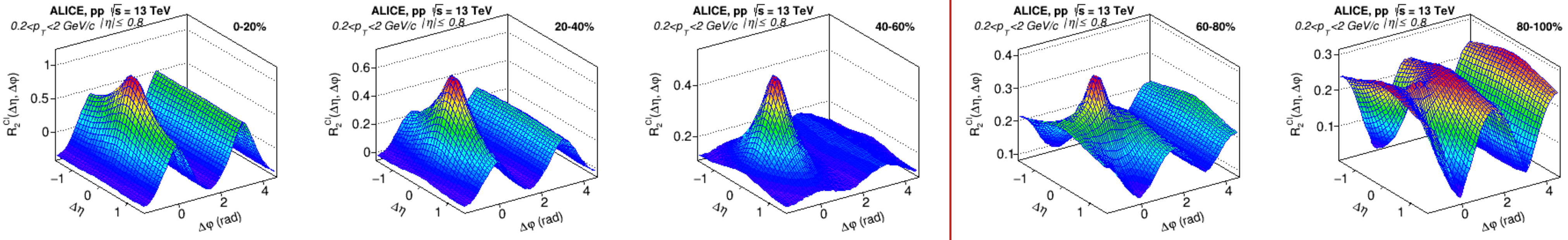
$$S_0 = \frac{\pi^2}{4}\min_{\hat{n}}\left(\frac{\sum_i |\overrightarrow{p_{\mathrm{T_i}; p_{\mathrm{T_i}}=1}} \times \hat{n}|}{\sum_i |\overrightarrow{p_{\mathrm{T_i}}}|_{p_{\mathrm{T_i}}=1}}\right)^2$$

with p_T =1

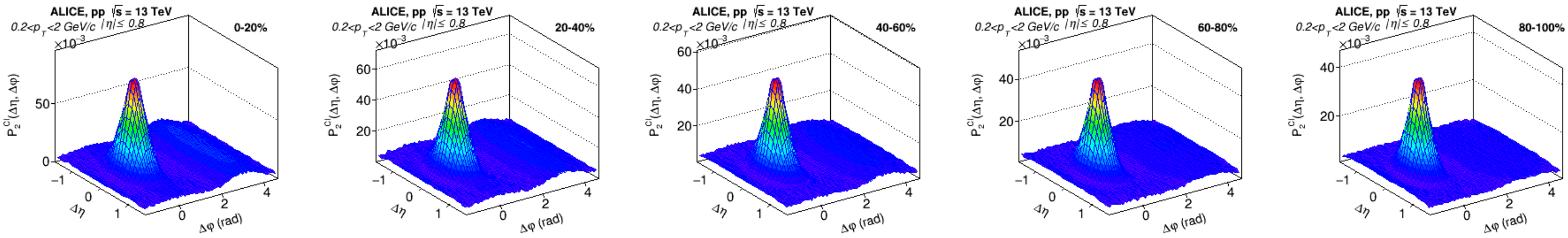
Data Results

Data Results

$R_2^{CI} = 1/2(R_2^{US} + R_2^{LS})$

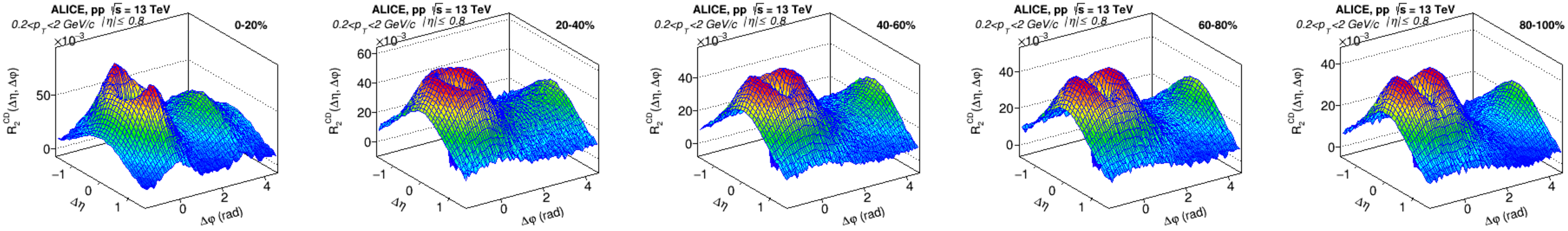


$P_2^{CI} = 1/2(P_2^{US} + P_2^{LS})$

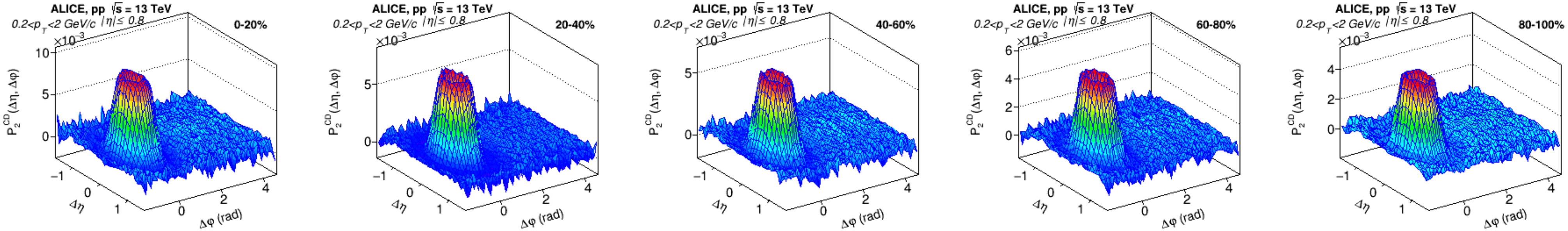


Data Results

$R_2^{CD} = 1/2(R_2^{US} - R_2^{LS})$

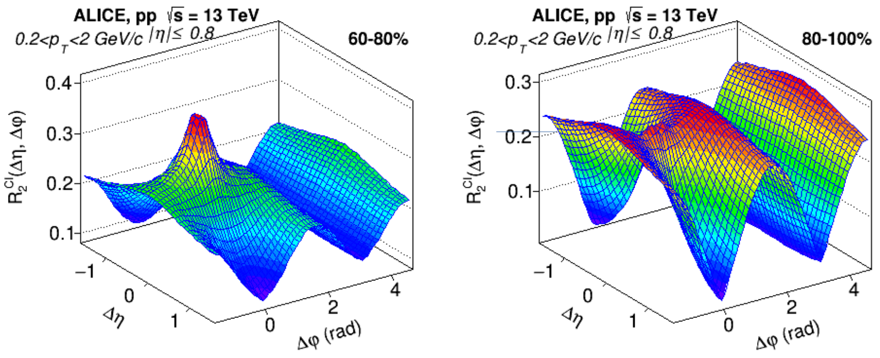


$P_2^{CD} = 1/2(P_2^{US} - P_2^{LS})$



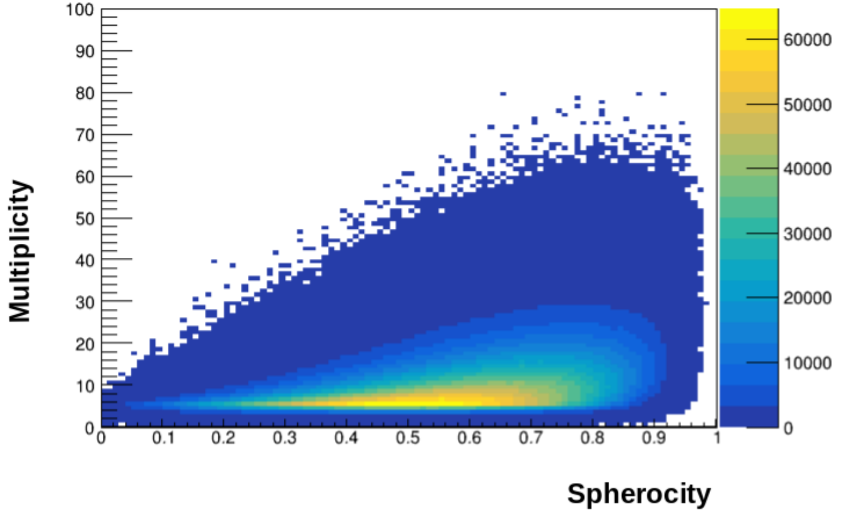
Further investigation

$R_2^{CI} = 1/2(R_2^{US} + R_2^{LS})$



The plan is to investigate these correlation structure for different multiplicity event classes

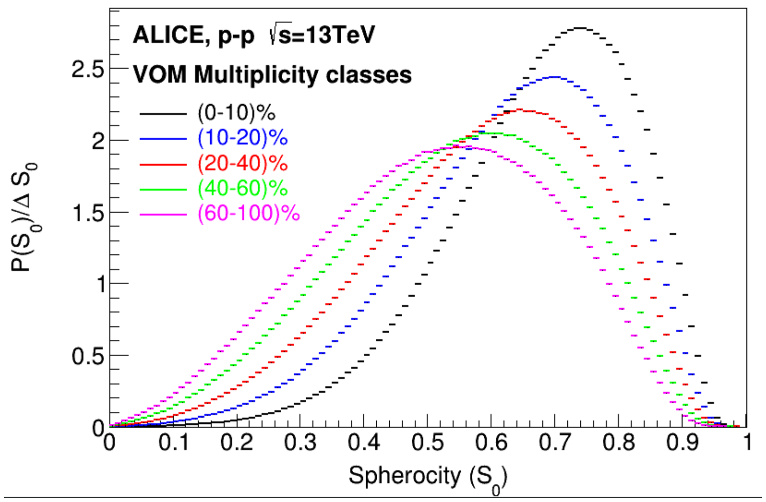
Correlation plot

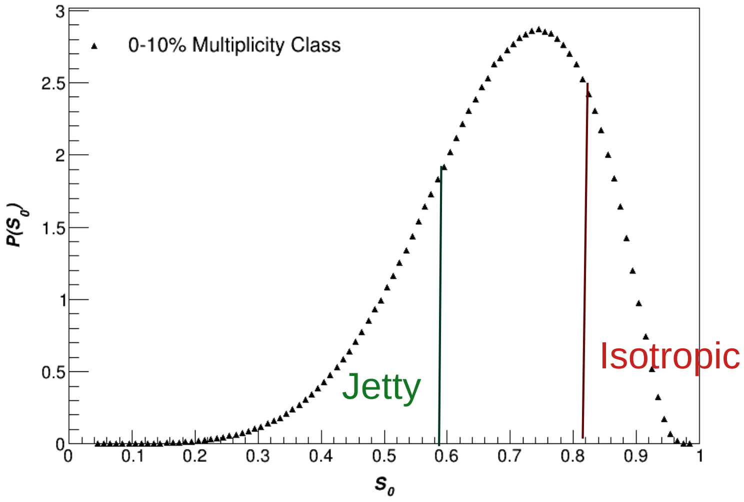


A bit of modification

$$S_0 = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\sum_i |\overrightarrow{p_{T_i}}_{;p_{T_i}=1} \times \hat{n}|}{\sum_i |\overrightarrow{p_{T_i}}|_{p_{T_i}=1}} \right)^2$$

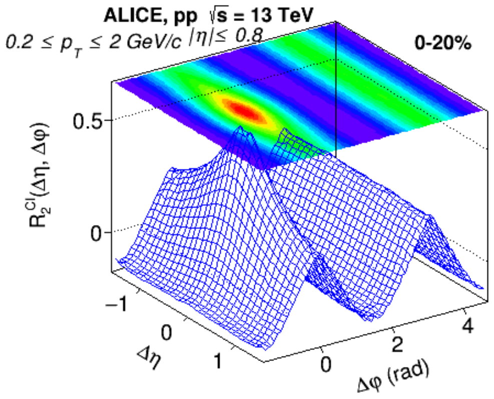
Calculation of spherocity with $N_{ch} \geq 10$

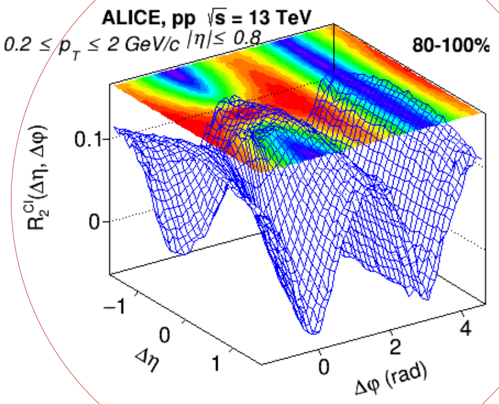


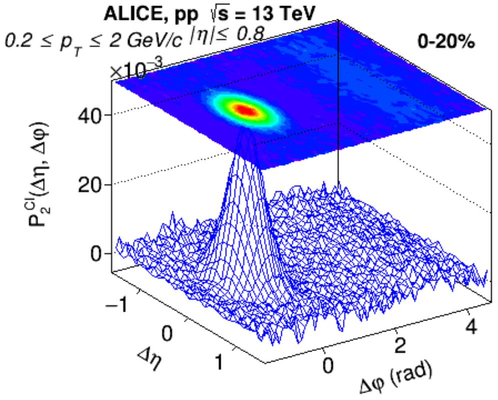


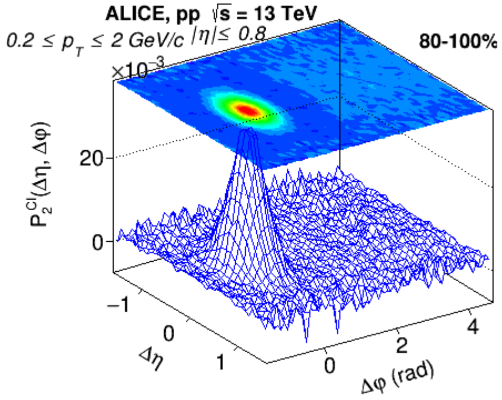
Correlation functions

R_2^{CI}





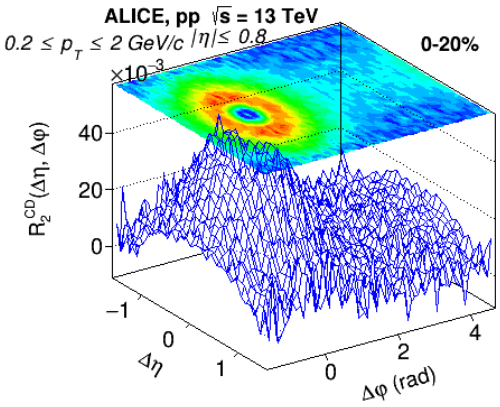


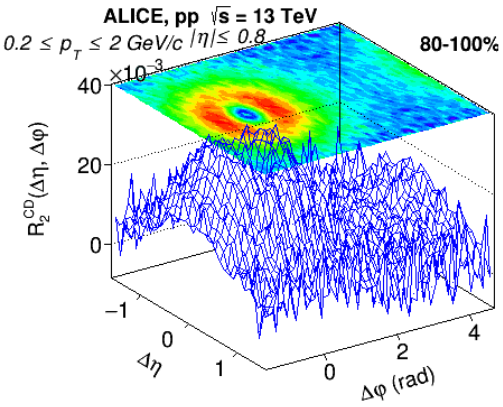


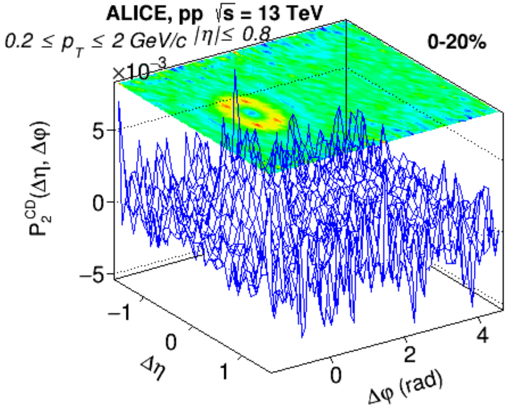
P_2^{CI}

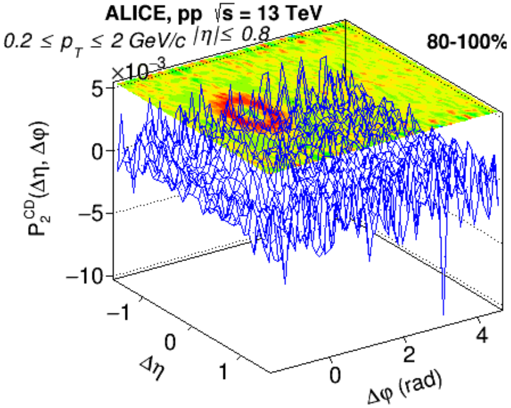
Correlation functions

R_2^{CD}









P_2^{CD}

Outlook

- Fix the baseline and study the systematic variations
- Paper proposal

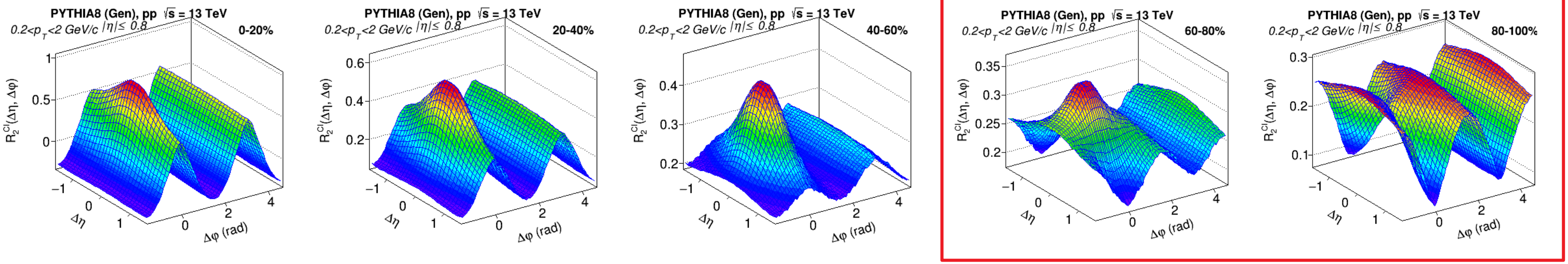
Thank you!

Spare Slides

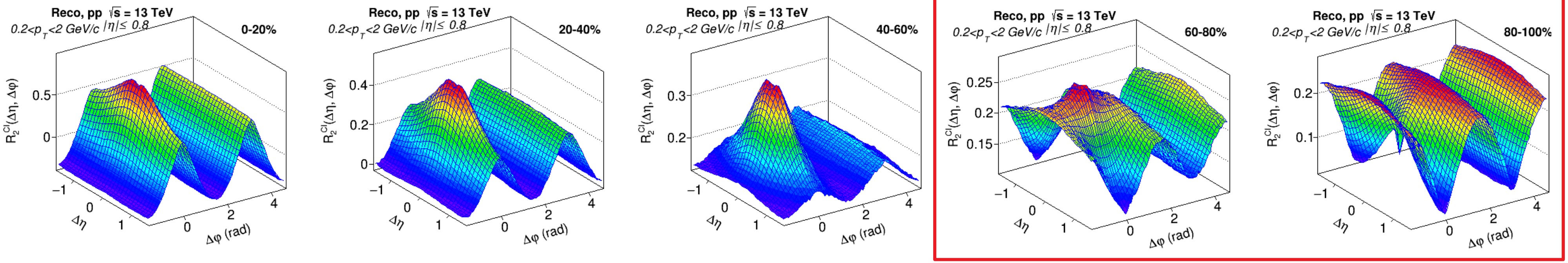
MC predictions (PYTHIA8)

$$R_2^{CI} = 1/2(R_2^{US} + R_2^{LS})$$

Generator level :



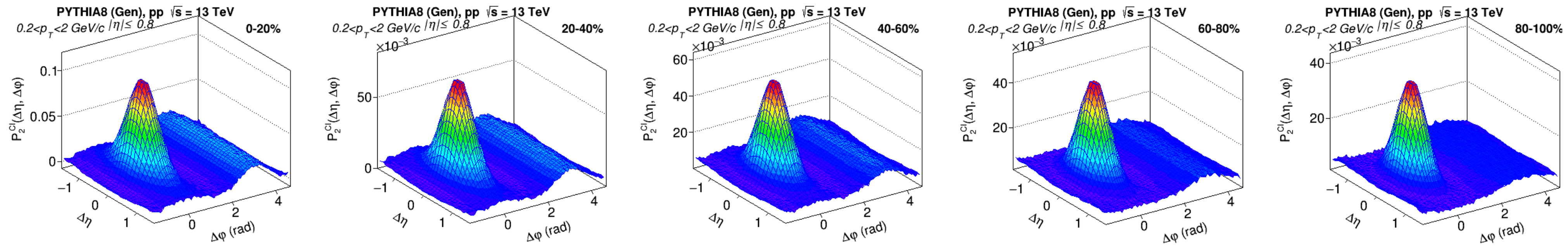
Reconstructed level :



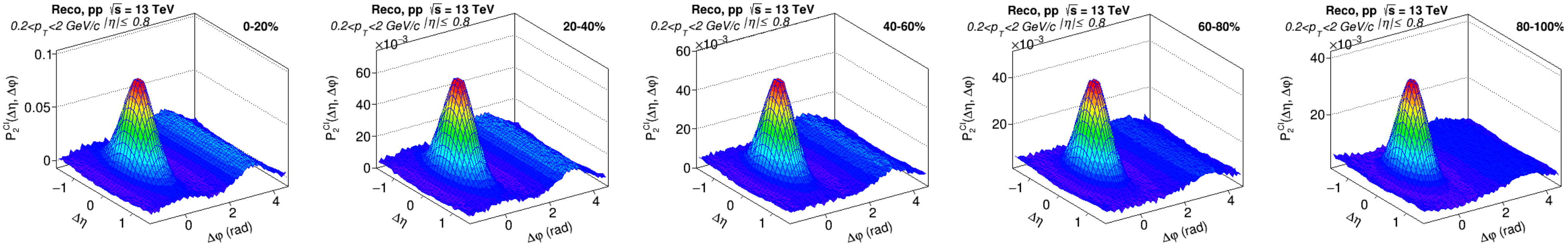
MC predictions (PYTHIA8)

$$P_2^{CI} = 1/2(P_2^{US} + P_2^{LS})$$

Generator level :



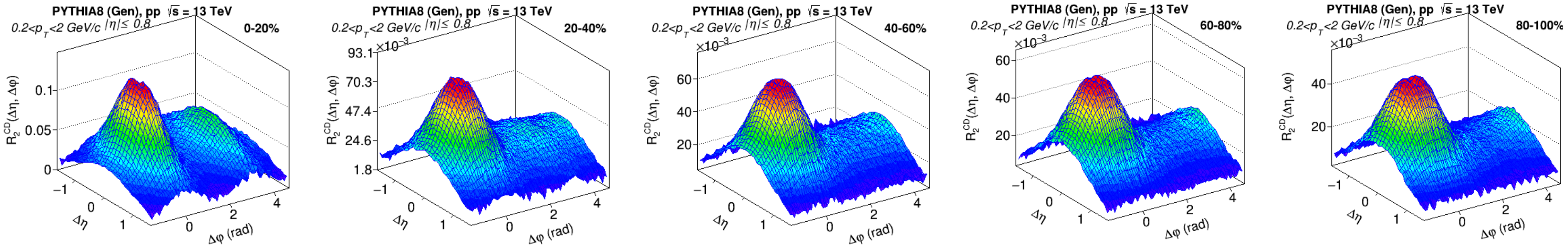
Reconstructed level :



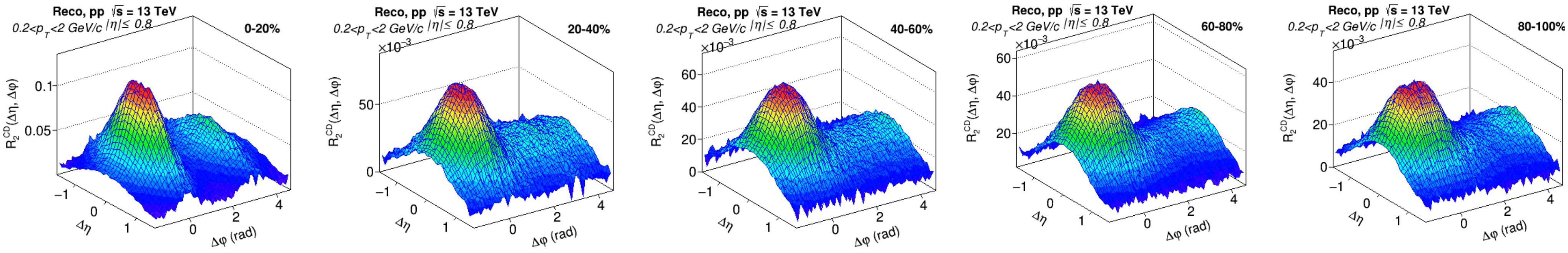
MC predictions (PYTHIA8)

$$R_2^{CD} = 1/2(R_2^{US} - R_2^{LS})$$

Generator level :



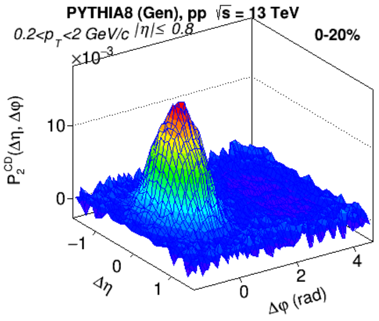
Reconstructed level :

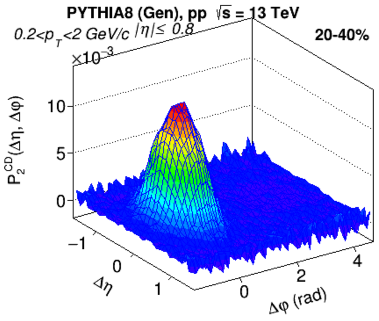


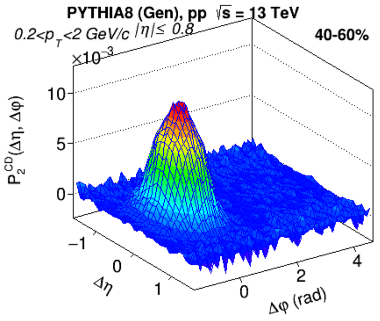
MC predictions (PYTHIA8)

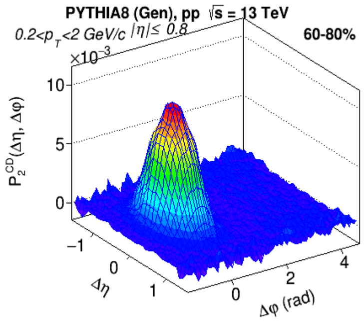
$$P_2^{CD} = 1/2(P_2^{US} - P_2^{LS})$$

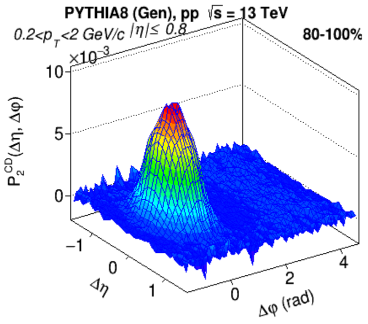
Generator level :



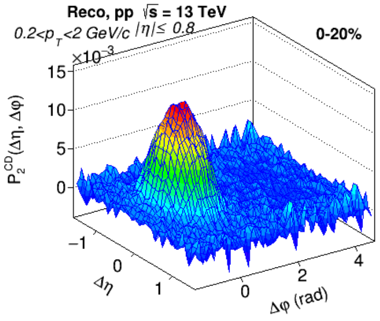


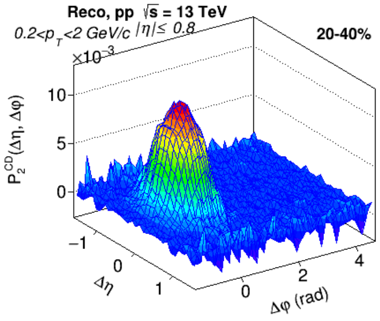


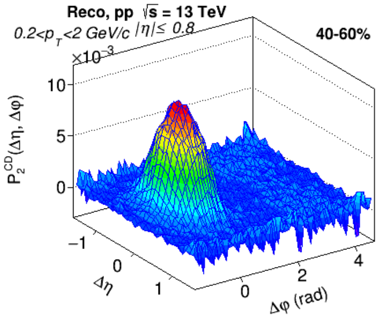


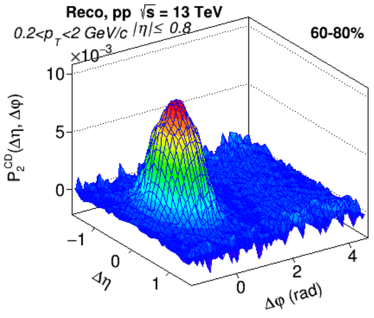


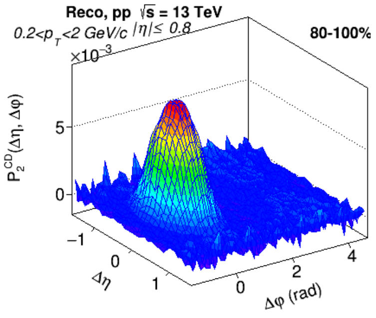
Reconstructed level :





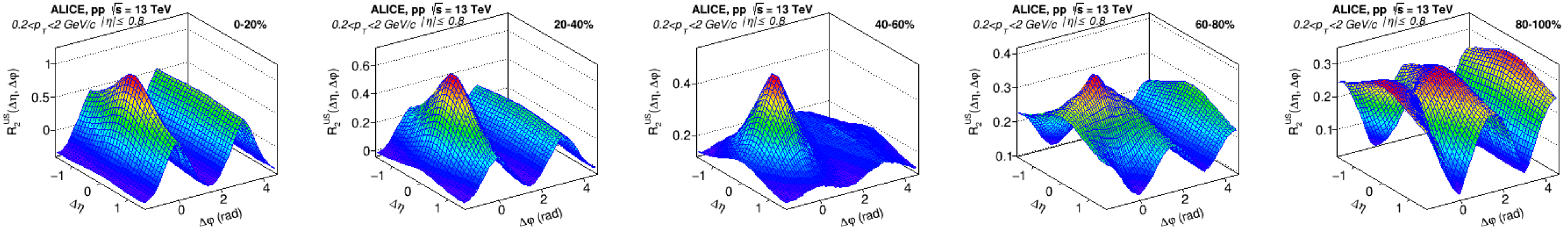




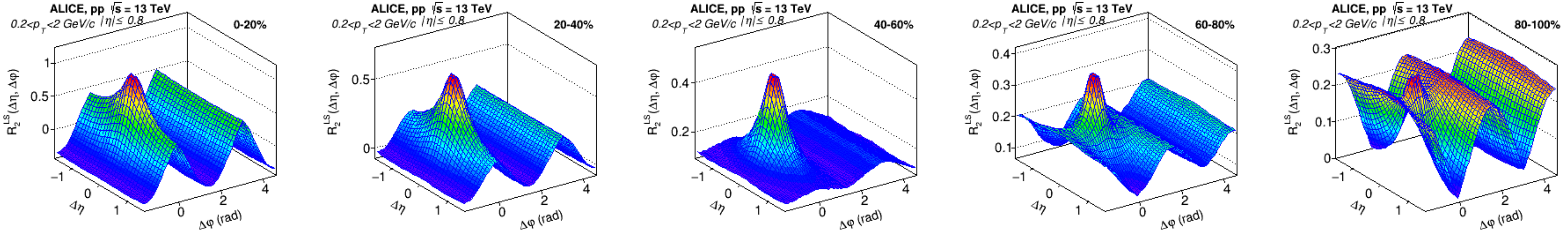


R_2^{US} & R_2^{LS} Contribution to R_2^{CI}

R_2^{US}

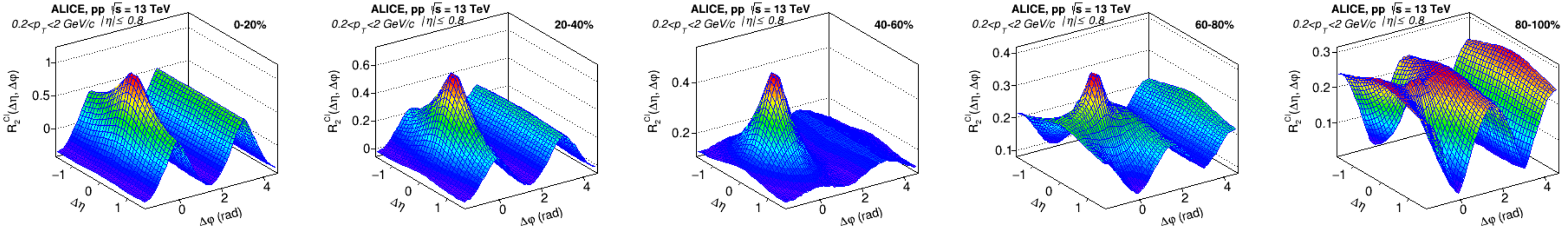


R_2^{LS}



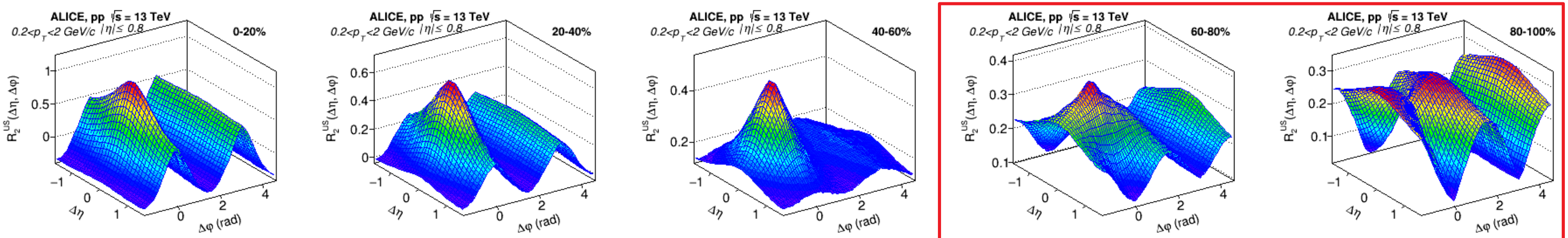
$R_2^{CI} = 1/2(R_2^{US} + R_2^{LS})$

R_2^{CI}

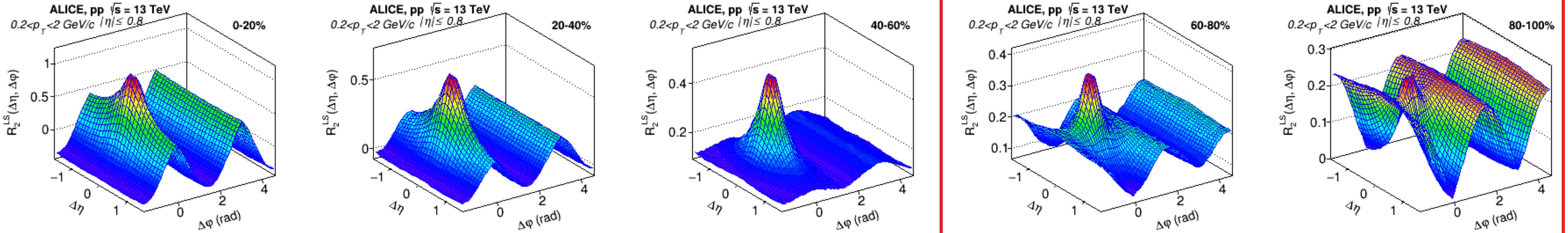


R_2^{US} & R_2^{LS} Contribution to R_2^{CI}

R_2^{US}



R_2^{LS}



$$R_2^{CI} = 1/2(R_2^{US} + R_2^{LS})$$

R_2^{CI}