Transverse Sphericity dependence of di-hadron angular correlations in pp collisions with ALICE

JUNIORS DAY

FILIP ERHARDT

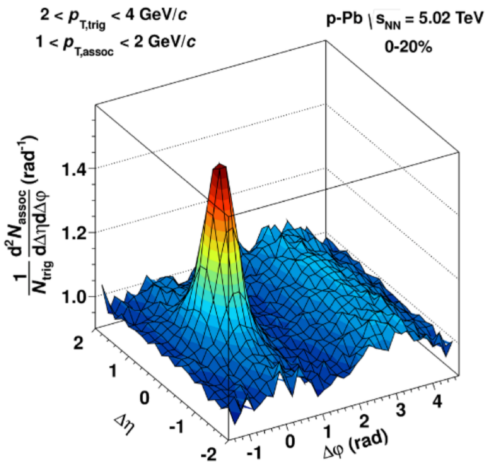
Motivation

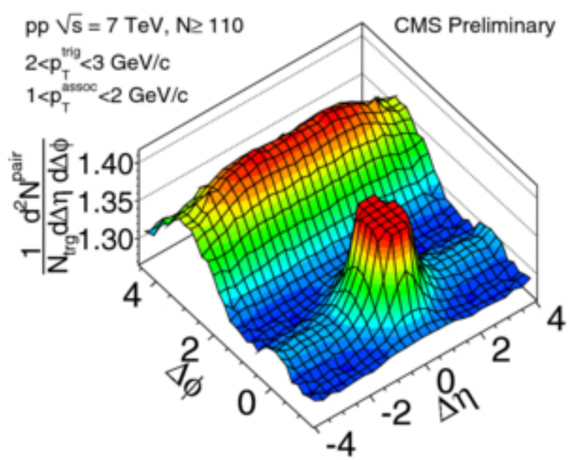
Starting from the near side Ridge (in p-p) as “the first surprising result from the LHC”

- It is only visible at high multiplicities
- High background from near side jet peak at low $\Delta\eta$
  (ALICE is at a disadvantage)

Could we introduce a way to remove some of the background from jets? (sphericity)

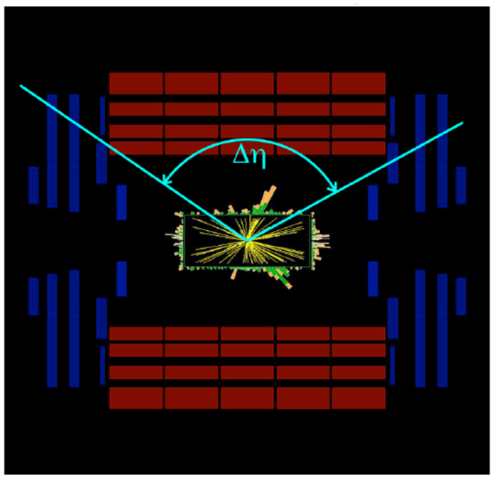
- Possibly enhance the signal in general, and even at lower multiplicities (increasing statistics)

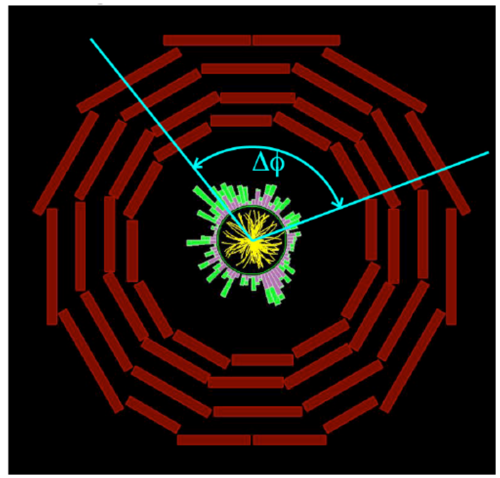


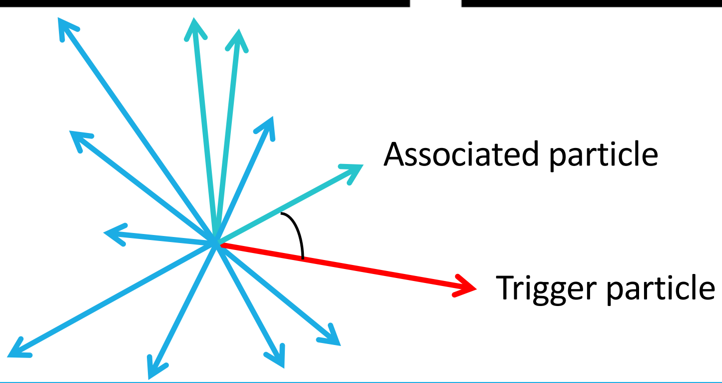


Di-hadron correlations

Correlation function C(Δη,Δφ)







$$C(\Delta\eta,\Delta\varphi) = \frac{S(\Delta\eta,\Delta\varphi)}{B(\Delta\eta,\Delta\varphi)}$$

$$S(\Delta\eta,\Delta\varphi) = \frac{1}{N_{trig}} \frac{d^2N^{same}}{d\Delta\eta\, d\Delta\varphi}$$

Same event!

- Sum over all pairs in p_T range
- 2 particle correlation information
- Background from detector + single particle information

$$B(\Delta\eta,\Delta\varphi) = \frac{1}{N_{trig}} \frac{d^2N^{mix}}{d\Delta\eta\, d\Delta\varphi}$$

Different events!

- 1 particle information
- Detector information
- No 2 particle correlation information

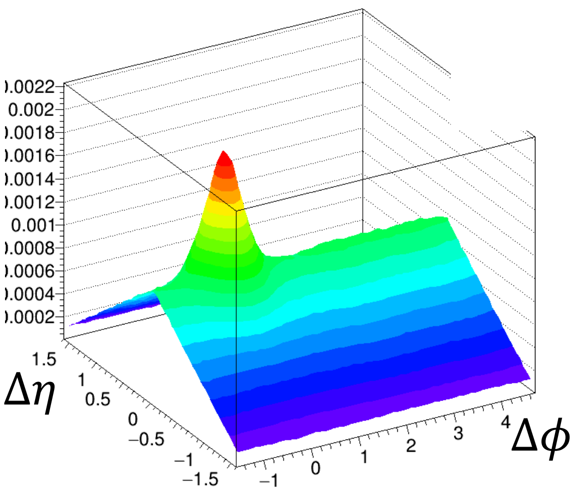
Di-hadron correlations

Correlation function used here: $\boxed{C(\Delta\eta,\Delta\varphi) = \frac{S(\Delta\eta,\Delta\varphi)}{B(\Delta\eta,\Delta\varphi)}}$

Only shape is relevant
(multiply by factor to get associated yield)

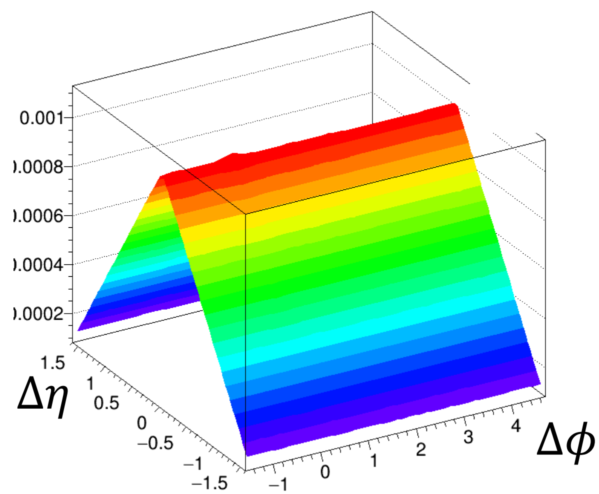
Signal

$$\boxed{S(\Delta\eta, \Delta\varphi) = \frac{1}{N_{trig}} \frac{d^2 N^{same}}{d\Delta\eta \, d\Delta\varphi}}$$



Background

$$\boxed{B(\Delta\eta, \Delta\varphi) = \frac{1}{N_{trig}} \frac{d^2 N^{mix}}{d\Delta\eta \, d\Delta\varphi}}$$



Di-hadron correlations

Correlation function used here: $\boxed{C(\Delta\eta,\Delta\varphi) = \frac{S(\Delta\eta,\Delta\varphi)}{B(\Delta\eta,\Delta\varphi)}}$

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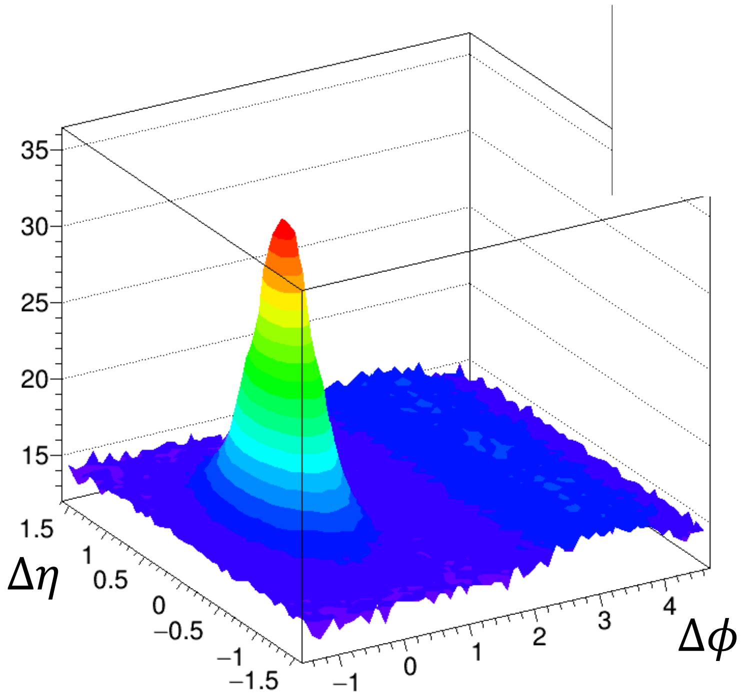
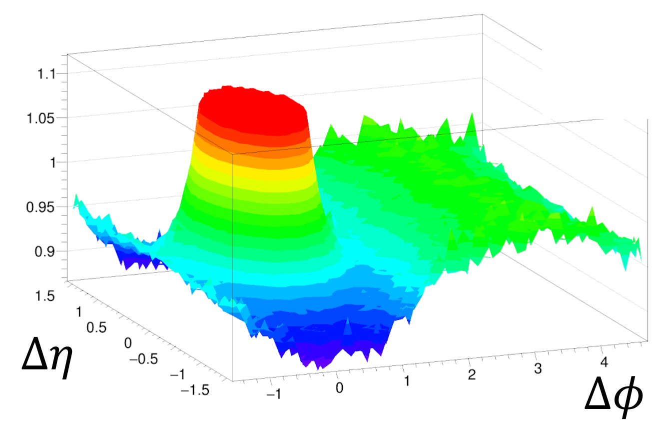
(multiply by factor to get associated yield)



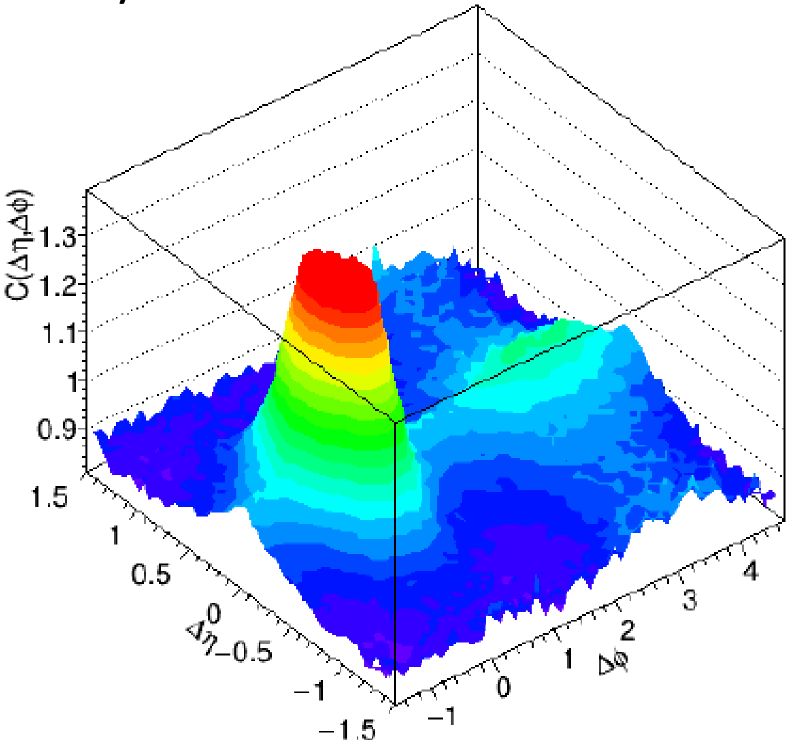
Often main peak is truncated to more clearly show other features



Correlation function structures

Structures in the correlation function are caused by:

- Conservation laws
- Jets
- Bose-Einstein correlations
- Resonances
- Photon conversion
- Gluon strings
- Coulomb interactions
- Flow (elliptic..)
- Ridge

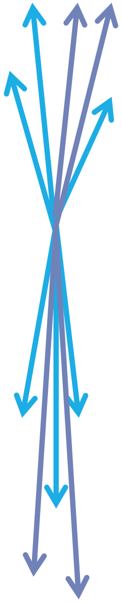


Idea: Selecting/isolating/enhancing certain structures could enable us to study that cause more thoroughly

Event Shape as a variable

On average, events dominated by certain processes responsible for structures in the correlation function should have noticeably different shapes.

Differentiating and isolating events by shape could lead to a purer data sample

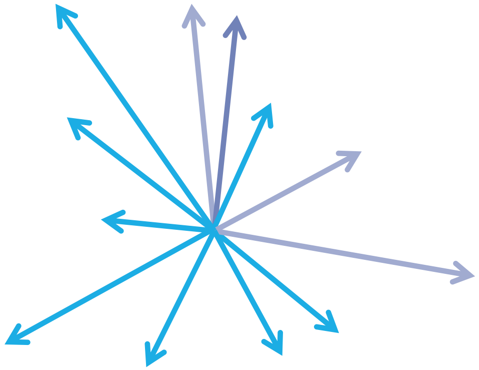


Jets

- Inititally a hard process, particle production dominated by jet hadronization, large jet collimation contribution to particle correlations

Spherical events

- Multiple soft processes, non-perturbative QCD production, no collimation contributions to particle correlations and no pair k_T dependence



Transverse sphericity (ST)

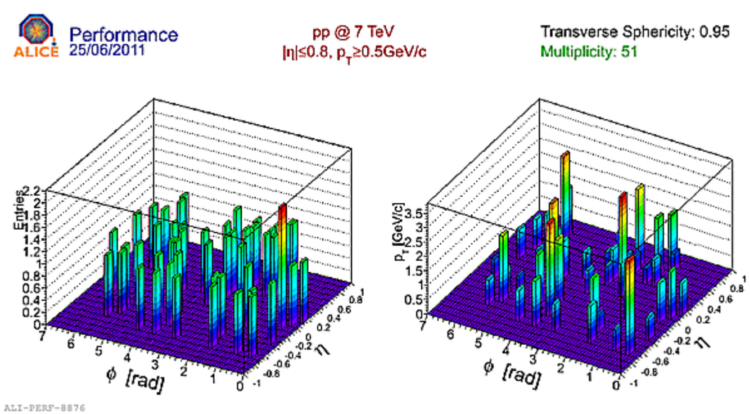
- Momentum space event shape variable
- Scalar with values $S_T \in [0,1]$

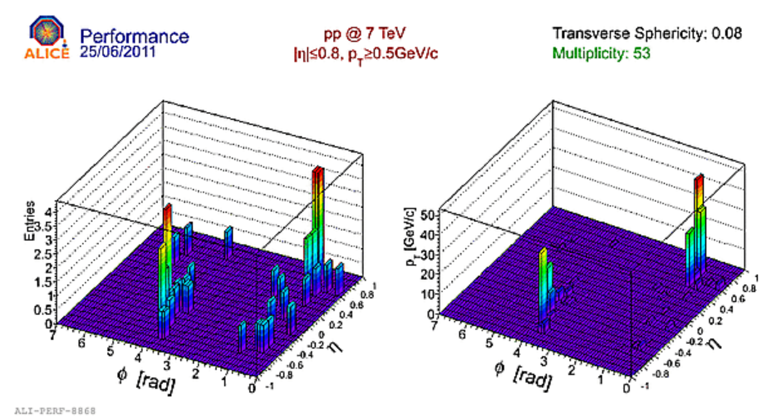
JHEP 0408 (2004) 062
Eur.Phys.J. C72 (2012) 2124

Transverse momentum matrix with eigenvalues $\lambda_1 > \lambda_2$

$$S^L_{xy} = \frac{1}{\sum_i p_{T\,i}} \sum_i \frac{1}{p_{T\,i}} \begin{pmatrix} p^2_{x\,i} & p_{x\,i} p_{y\,i} \\ p_{y\,i} p_{x\,i} & p^2_{y\,i} \end{pmatrix}$$

$$S_T = \frac{2\lambda_2}{\lambda_1 + \lambda_2} \Rightarrow S_T = \begin{cases} \approx 0 & \text{Pencil-like} \\ \approx 1 & \text{Isotropic} \end{cases}$$





Plan: Study the correlation function structures using transverse sphericity.

Sphericity-multiplicity correlations

How correlated are ST and multiplicity?
Does it make sense to use ST as a variable when we have mult?
Do different definitions of "multiplicity" correlate differently?

Calculate correlation coefficient:

$$r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{[n\Sigma x^2 - (\Sigma x)^2][n\Sigma y^2 - (\Sigma y)^2]}}$$

$0 \leq |r| \leq 1$ depending on how **linearly** correlated the 2 values are

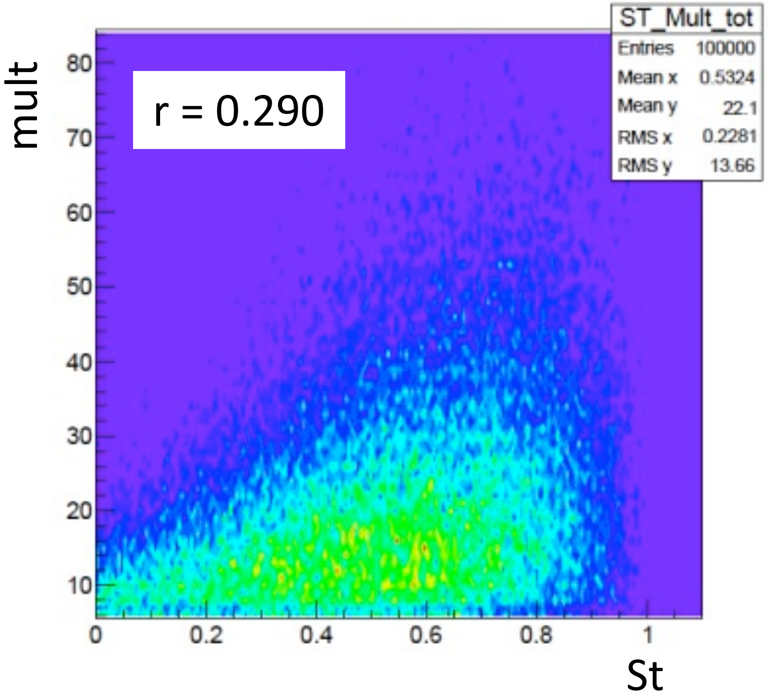
<u>Roughly</u>:
- $0 \leq |r| \leq 0.3$ no or weak correlation
- $0.3 \leq |r| \leq 0.7$ moderate correlation
- $0.7 \leq |r| \leq 1$ strong correlation

Sphericity-multiplicity correlations

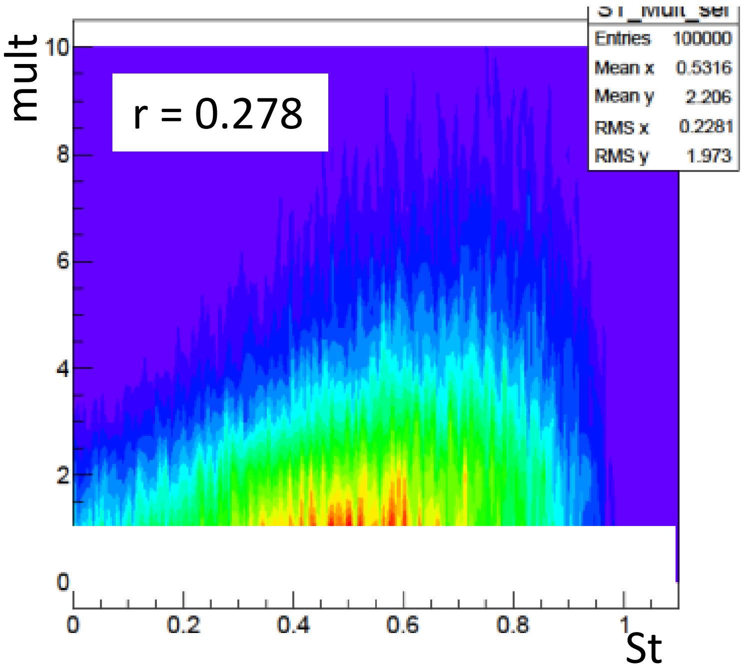
Using total number of tracks in event and number of tracks

All tracks from $|\eta| < 0.9, 0.15 < p_t < 10\,\frac{GeV}{c}$, charged and filterbits 5+6

Total tracks in event



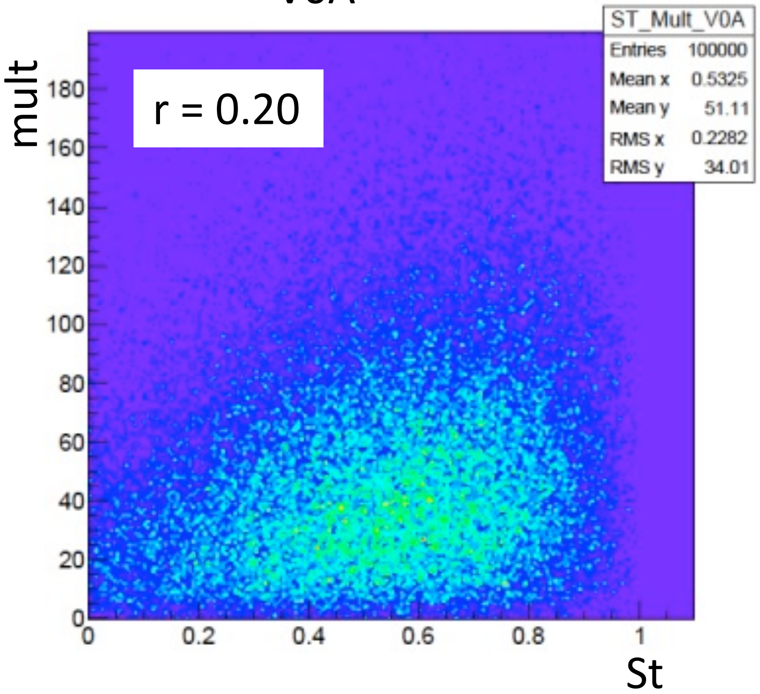
Only tracks used in analysis(stricter cuts)



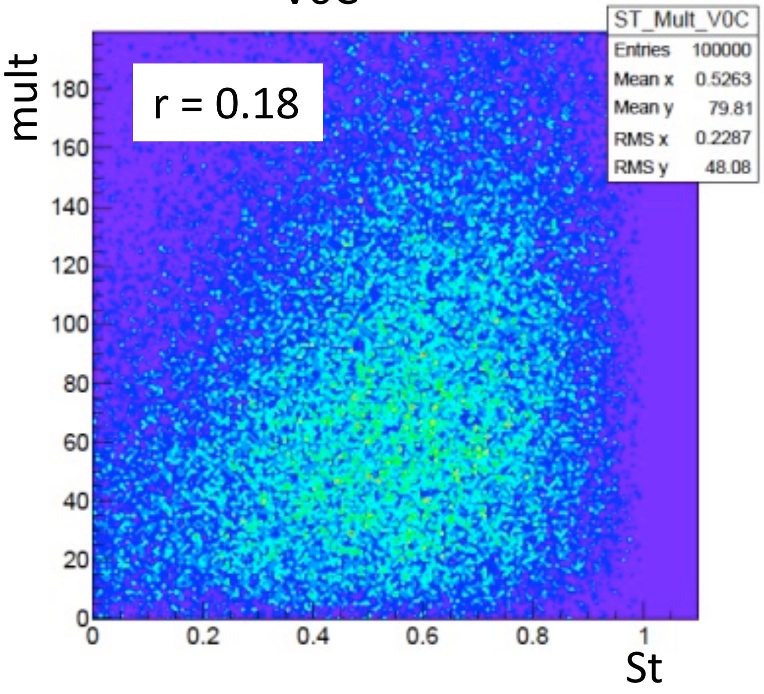
Sphericity-multiplicity correlations

Using V0A and V0C detectors as multiplicity estimators?
very similar so not needed!

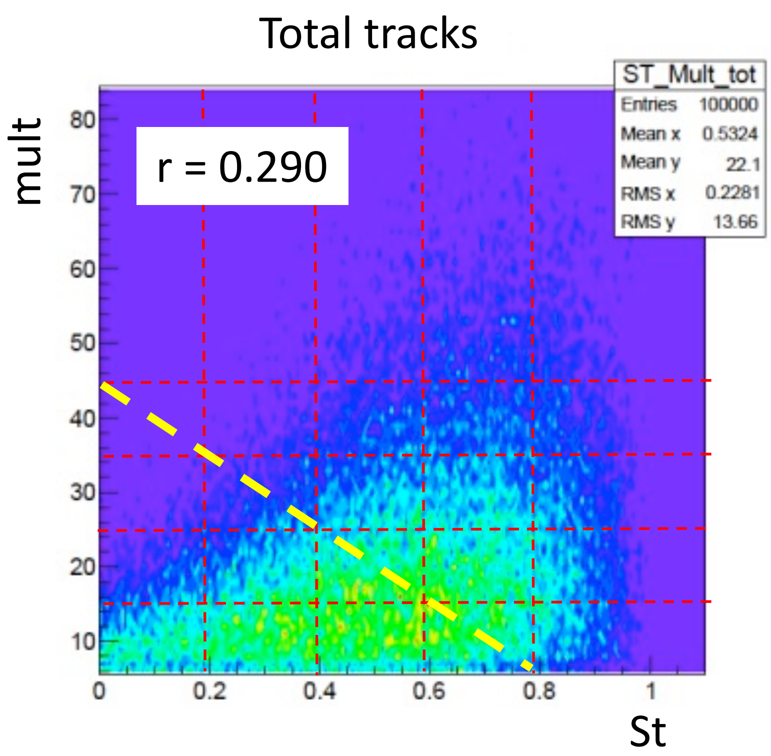
V0A



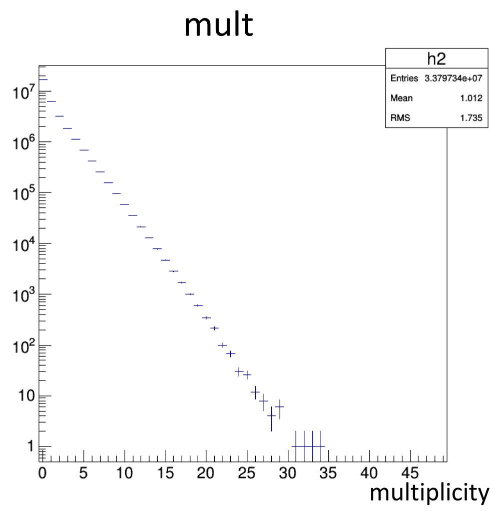
V0C

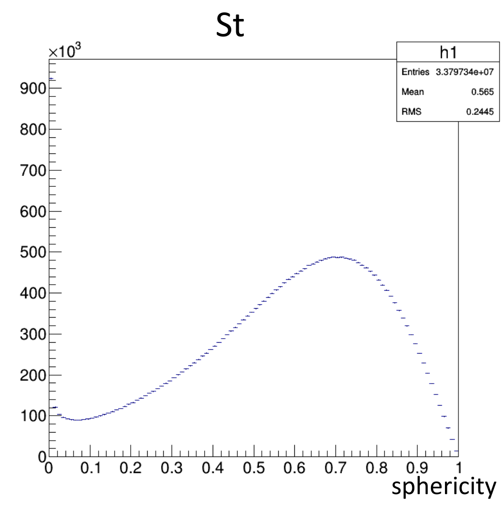


Sphericity-multiplicity correlations

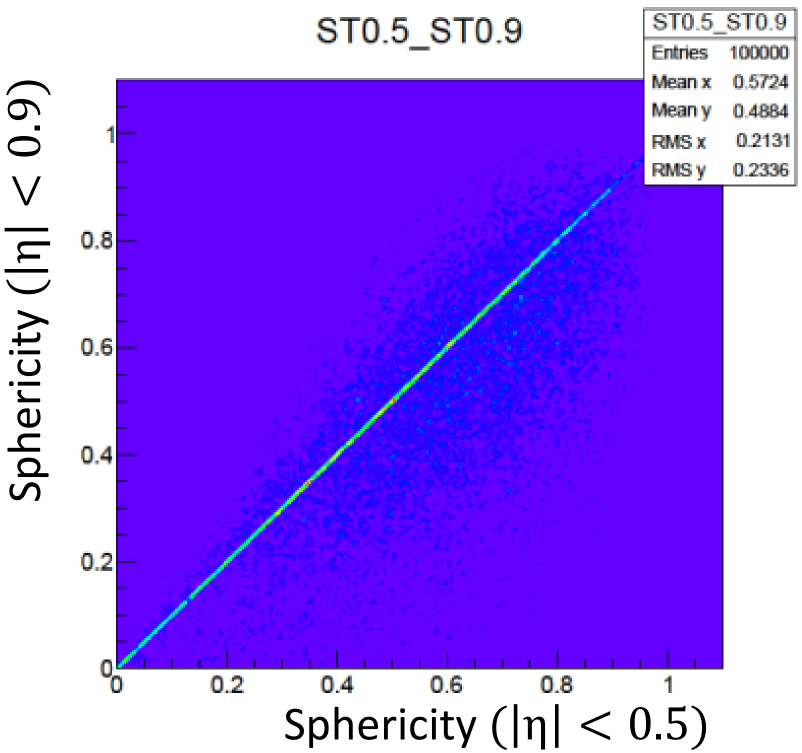


- All correlations are similar
- Higher mult ➔ (on average) higher St
- Opposite is not true
- Higher St $\nrightarrow$ high multiplicity
- Choosing high ST removes much less statistics than high multiplicity
- Possibly use a combination?





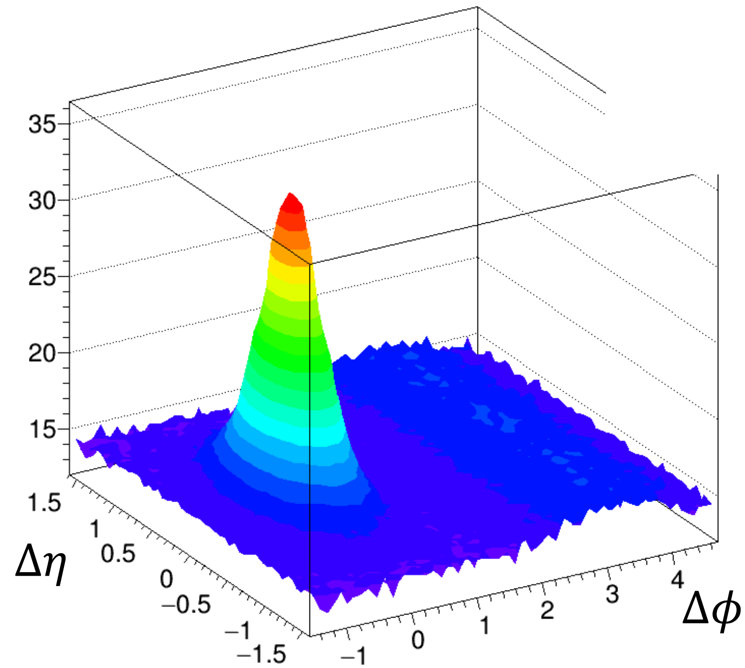
Stability of St with η



- Sphericity ($|\eta| < 0.9$) – Sphericity ($|\eta| < 0.5$) correlation
- Very high correlation coefficient
- Low dependence of Sphericity on $|\eta|$ cut
- $r = 1.00000$ (up to accuracy of float)

Measurements

- LHC2010d data set
- 10 Runs 126403-126432
- Proton-proton collisions at $7TeV$
- $33 \cdot 10^6$ events analysed
- $1\,GeV/c < p_t < 3\,GeV/c$
  (all particles)
- $|\eta| < 0.8$
- Charged tracks
- Filter bits 5+6

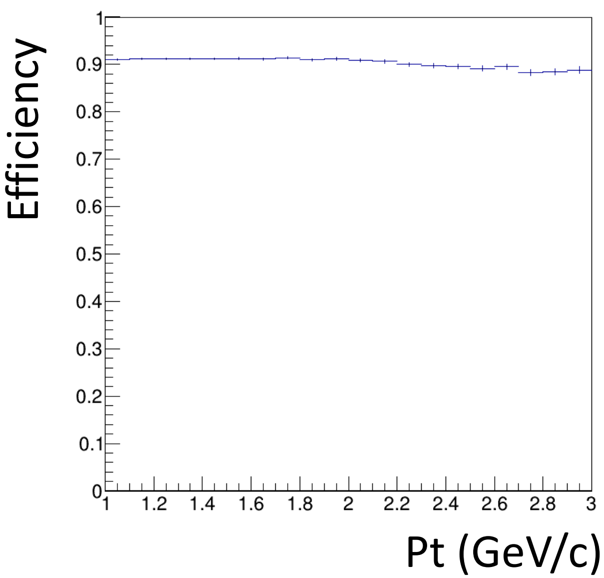


Correlation function minimum bias

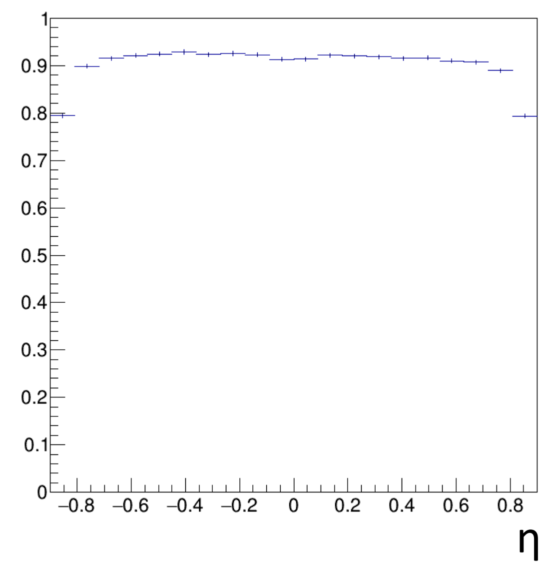
Efficiency plots

generated and reconstructed MC for LHC10f6a, filter bits 5+6

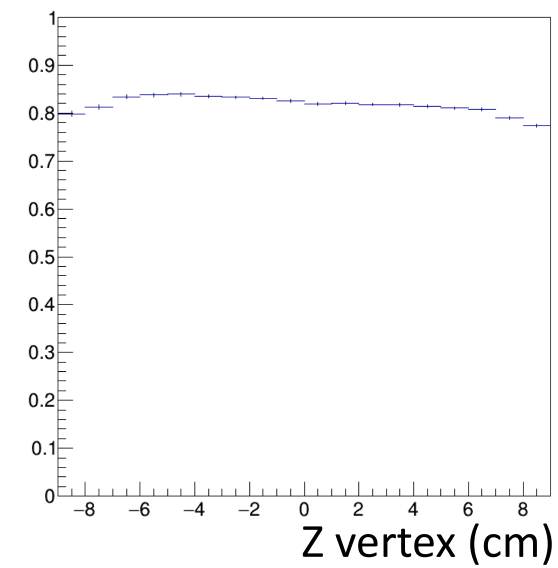
Projection onto Pt



Projection onto η

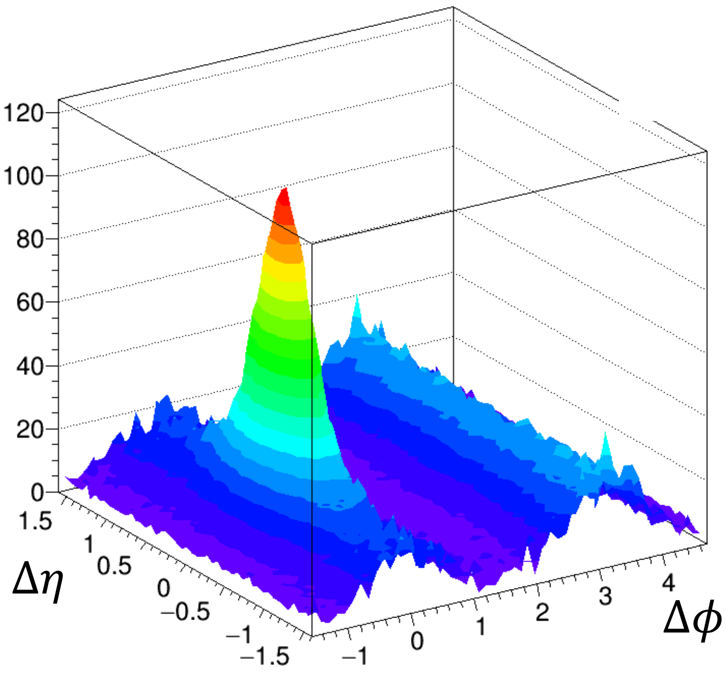


Projection onto Z vertex

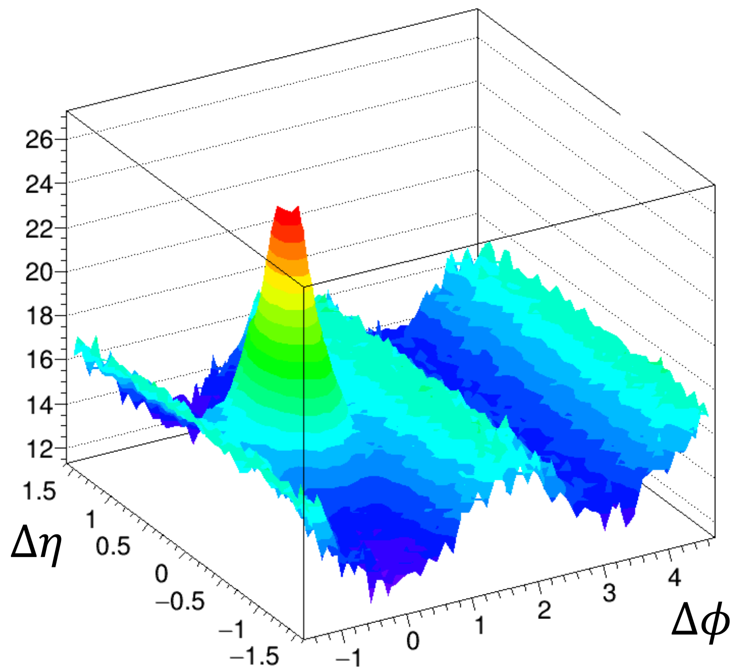


Correlation function in different ST bins

15% of events with the highest and lowest transverse sphericities



$0.0 < S_T < 0.351$

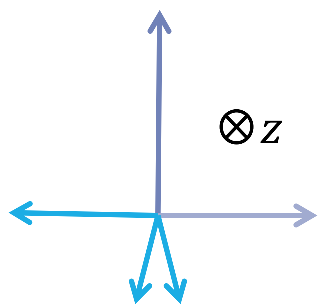


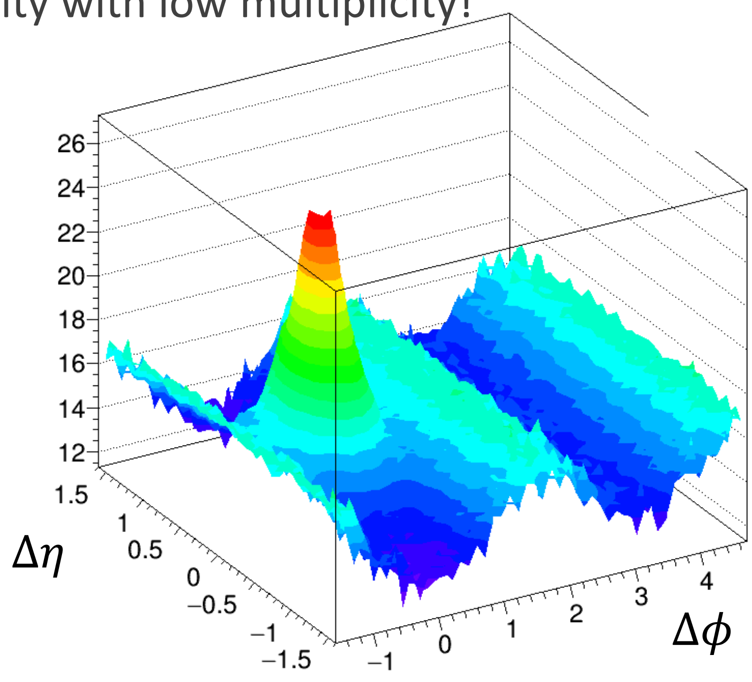
$0.795 < S_T < 1.0$

If the scale was the same it would look completely flat

Highest ST bins

- Strange ridges at $\phi = \frac{\pi}{2}, \frac{3\pi}{2}$?
- “you get what you ask for”
- Limited number of ways to get high sphericity with low multiplicity!



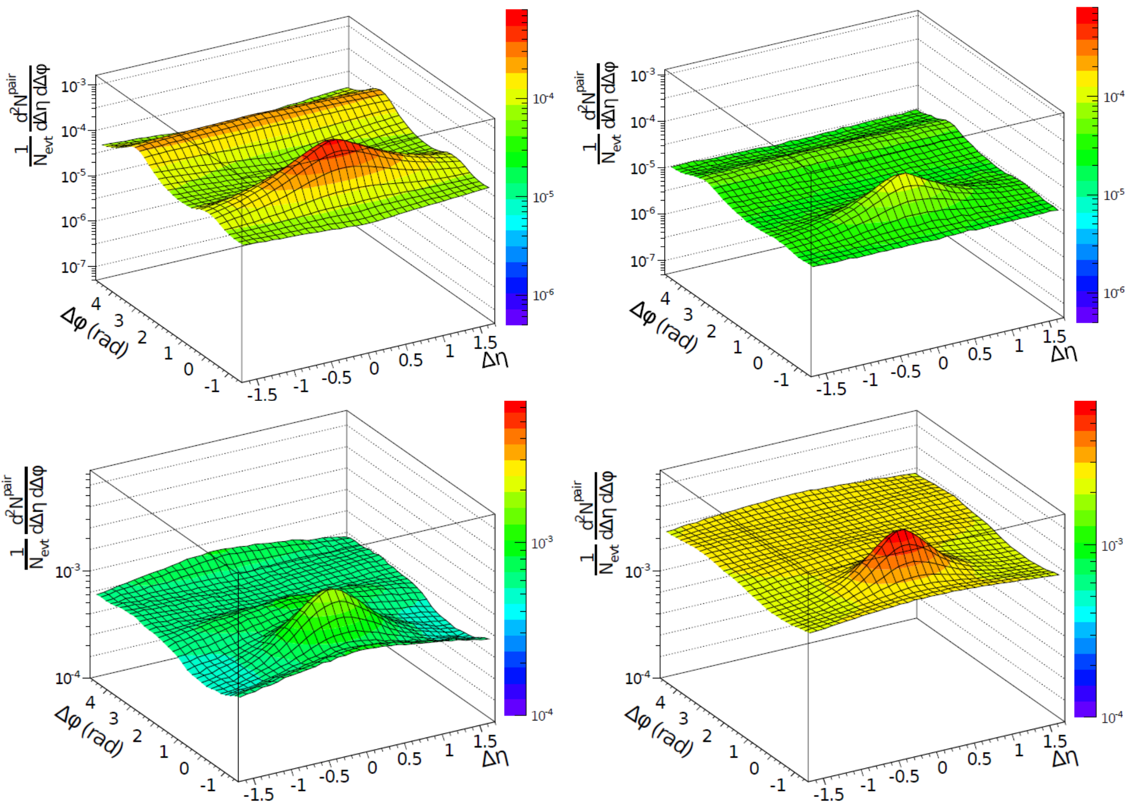


- Highest sphericity bins must be accompanied by high multiplicity

Simulation

$S_T < 0.1$

$S_T > 0.9$

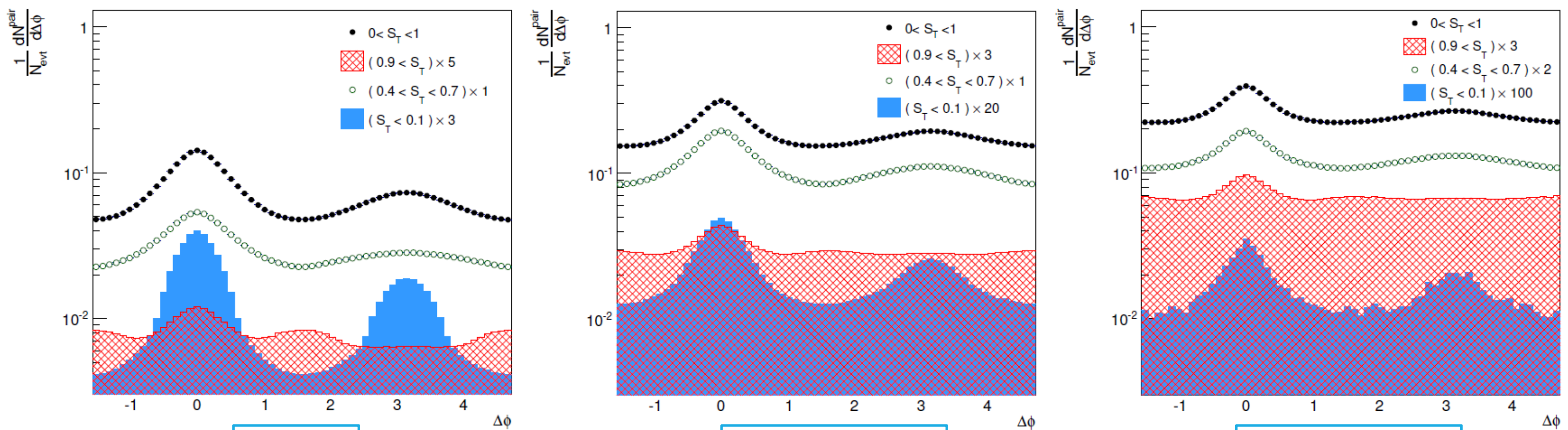


$n < \bar{n}$

$n > \bar{n}$

(2015) **J. Phys.: Conf. Ser.** 578 012005
E P´erez Lezama, G Paić, E Cuautle Flores, A Ortiz Velasquez

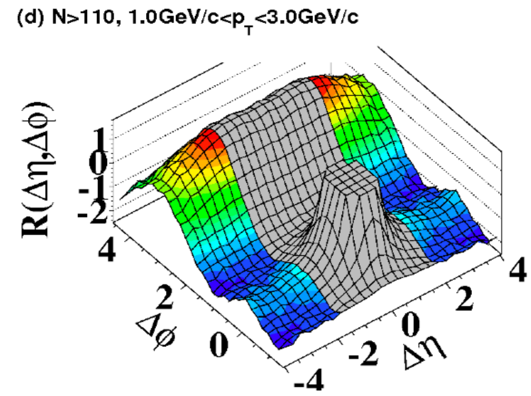
Simulation



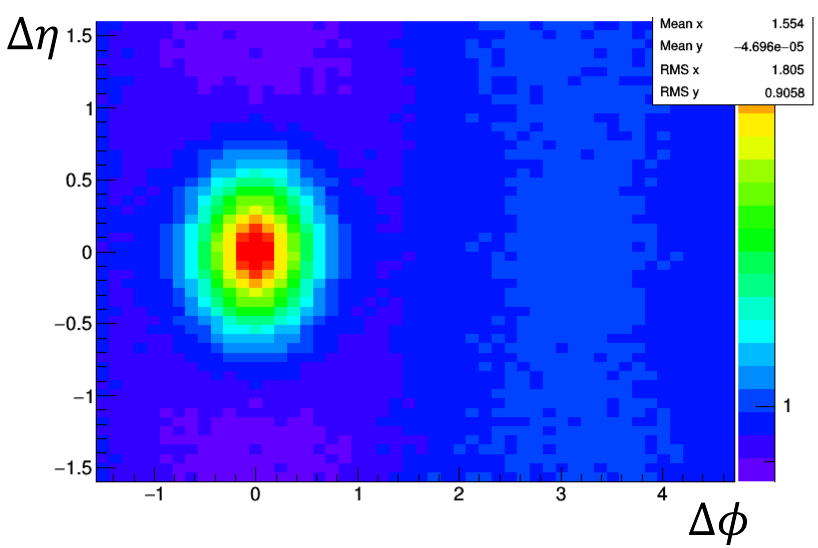
$n < \bar{n}$ $2\bar{n} < n < 3\bar{n}$ $3\bar{n} < n < 4\bar{n}$

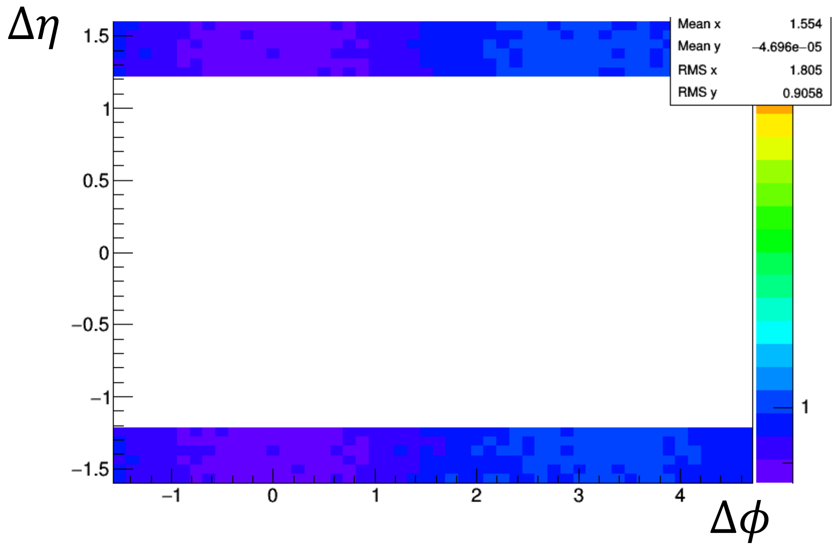
Reduction of ridges at $\phi = \frac{\pi}{2}, \frac{3\pi}{2}$ with increasing multiplicity

Possibilities of detecting ridge?



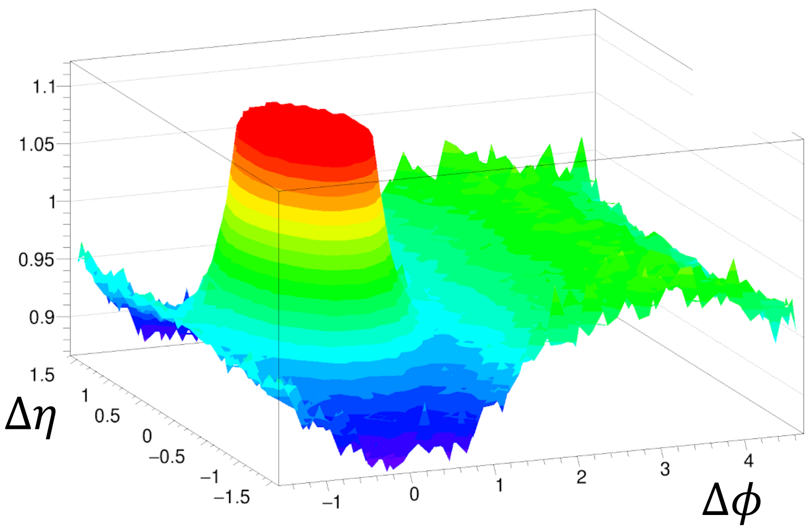
- Cut the most extreme $|\Delta\eta|$ values and make a projection onto $\Delta\phi$
- $1.2 < \Delta\phi < 1.5$

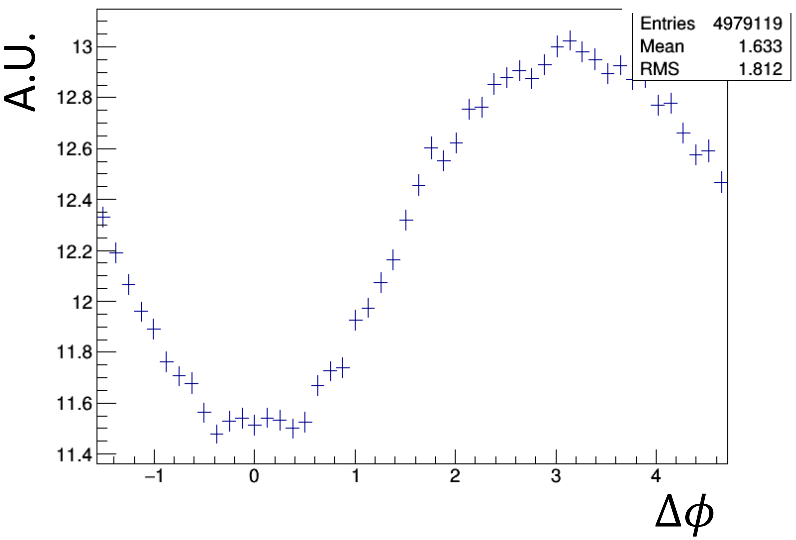




Min bias correlation function

- All multiplicities and Sphericites!
- concave shape is observed at $\Delta\phi \approx 0$
- This is the expected shape which given by most simulations

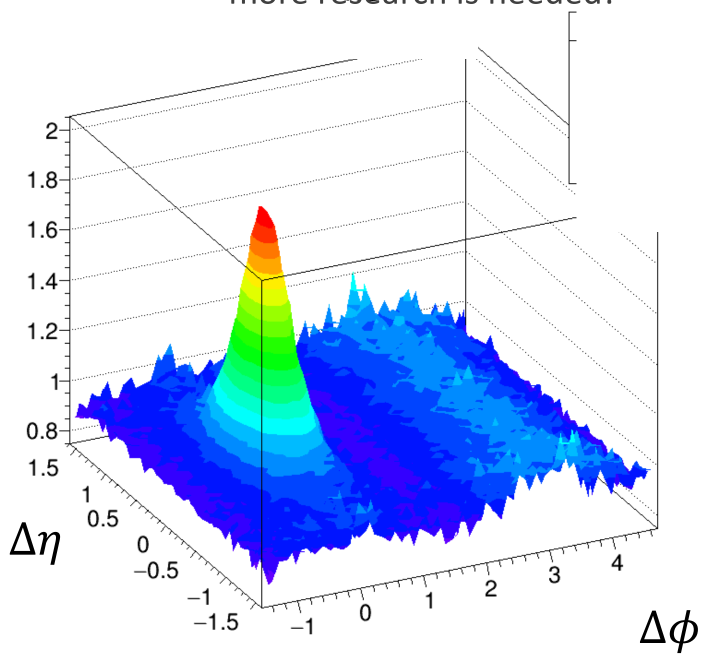


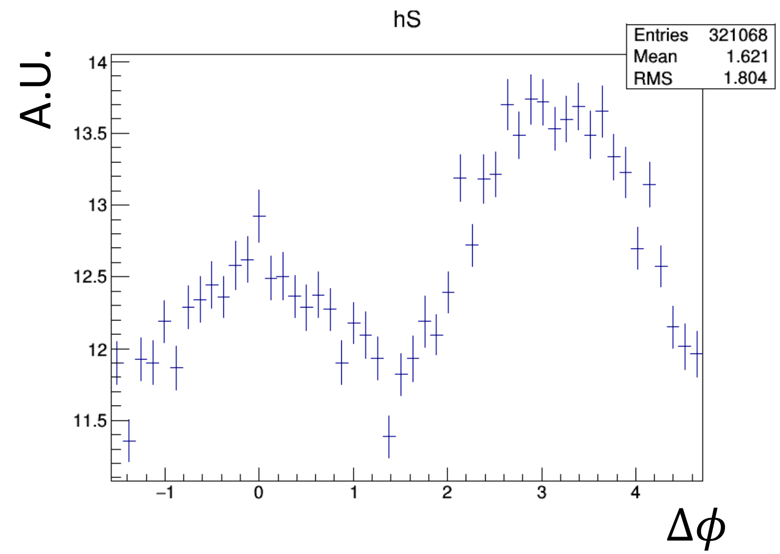


Mid Sphericities

- Multiplicity > 10 and $0.63 < St < 0.795$ give a ridge-like shape at $\Delta\phi \approx 0$
- Possibly a way of increasing statistics for observing/studying ridge?

more research is needed!





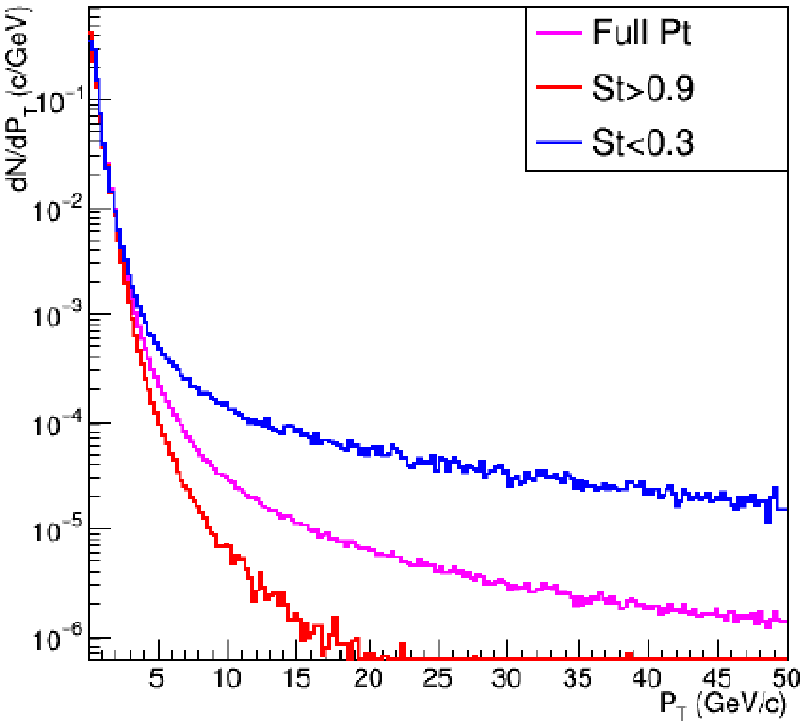
Summary and future plans

- Sphericity can be a powerful tool for cuts, different from multiplicity

- Hints of the ridge at $\Delta\phi \approx 0$ for long $\Delta\eta$ range in mid St!

- Plans:
  - Convert to per-trigger associated yield
  - Run on full set of 7TeV LHC2010d data and some 13 TeV data set (2015/2016)
  - Look at correlation function in all combinations of ST and mult bins
  - Look at projections on to $\Delta\eta$ and $\Delta\phi$ axes for all ST and mult bin combinations
  - Look at $\Delta\phi$ projections with main peak removed (use C_{ZYAM} subtraction)
    - Lowest $\Delta\eta$ cut out
    - Or fit function onto jet peak shape and removed that way
    - or ratio between events bins of different mult/ST
  - Compare everything with MC simulations

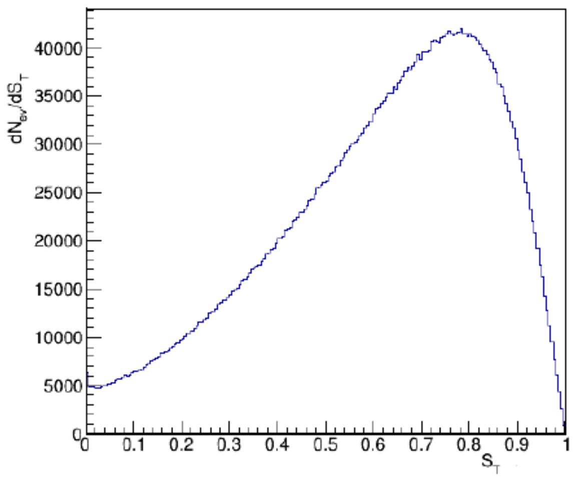
Backup



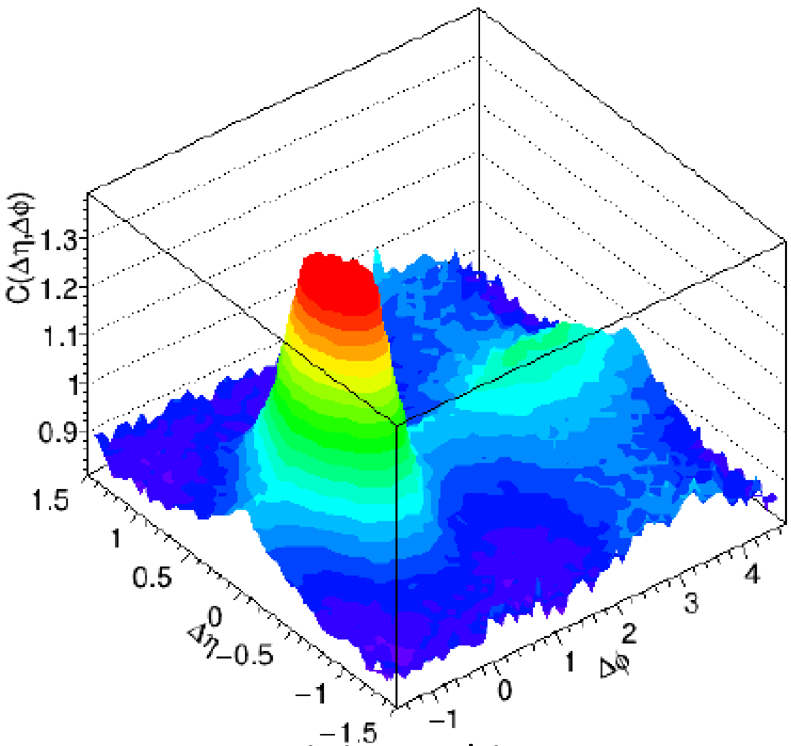
Full Pt
St>0.9
St<0.3
dN/dP_T (c/GeV)
P_T (GeV/c)

Preliminary measurements

- Proton-proton collisions at $13 TeV$
- $8 \cdot 10^6$ events analysed
- $1\, GeV/c < p_t < 3\, GeV/c$
- $|\eta| < 0.75$

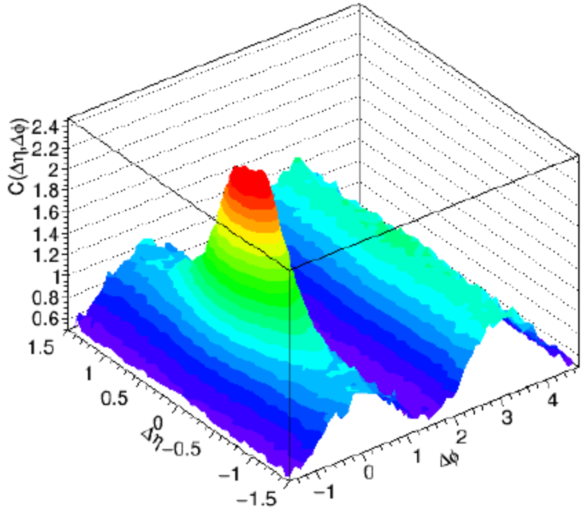


St distribution further leans towards spherical

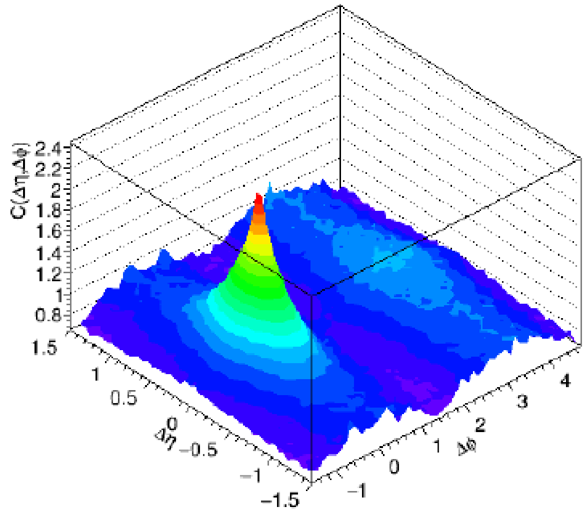


Minimum bias

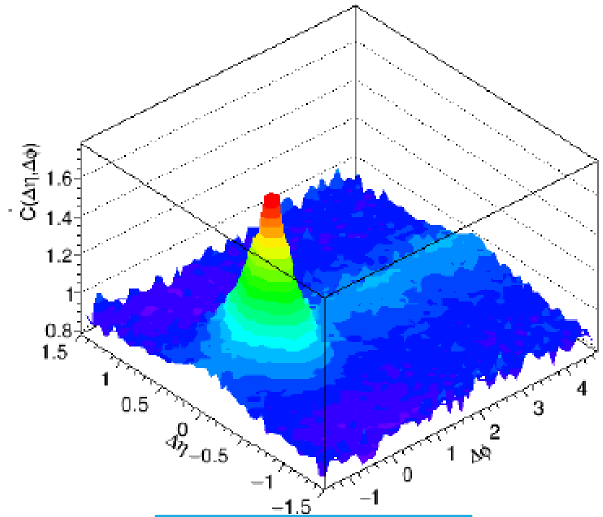
<u>Sphericity cuts,13TeV proof of concept</u> (coff func error?)



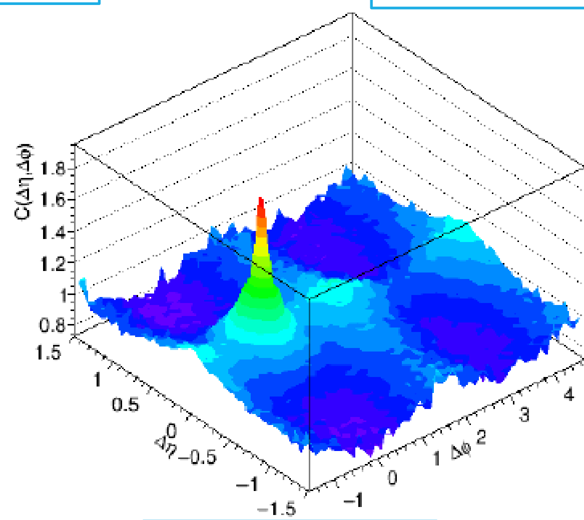
$0.0 < S_T < 0.593$



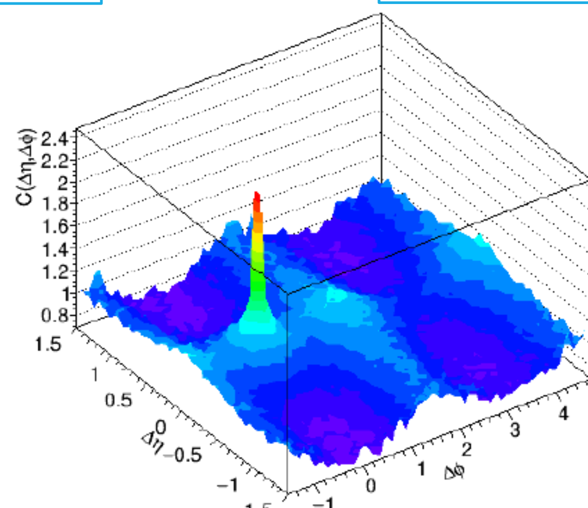
$0.593 < S_T < 0.73$



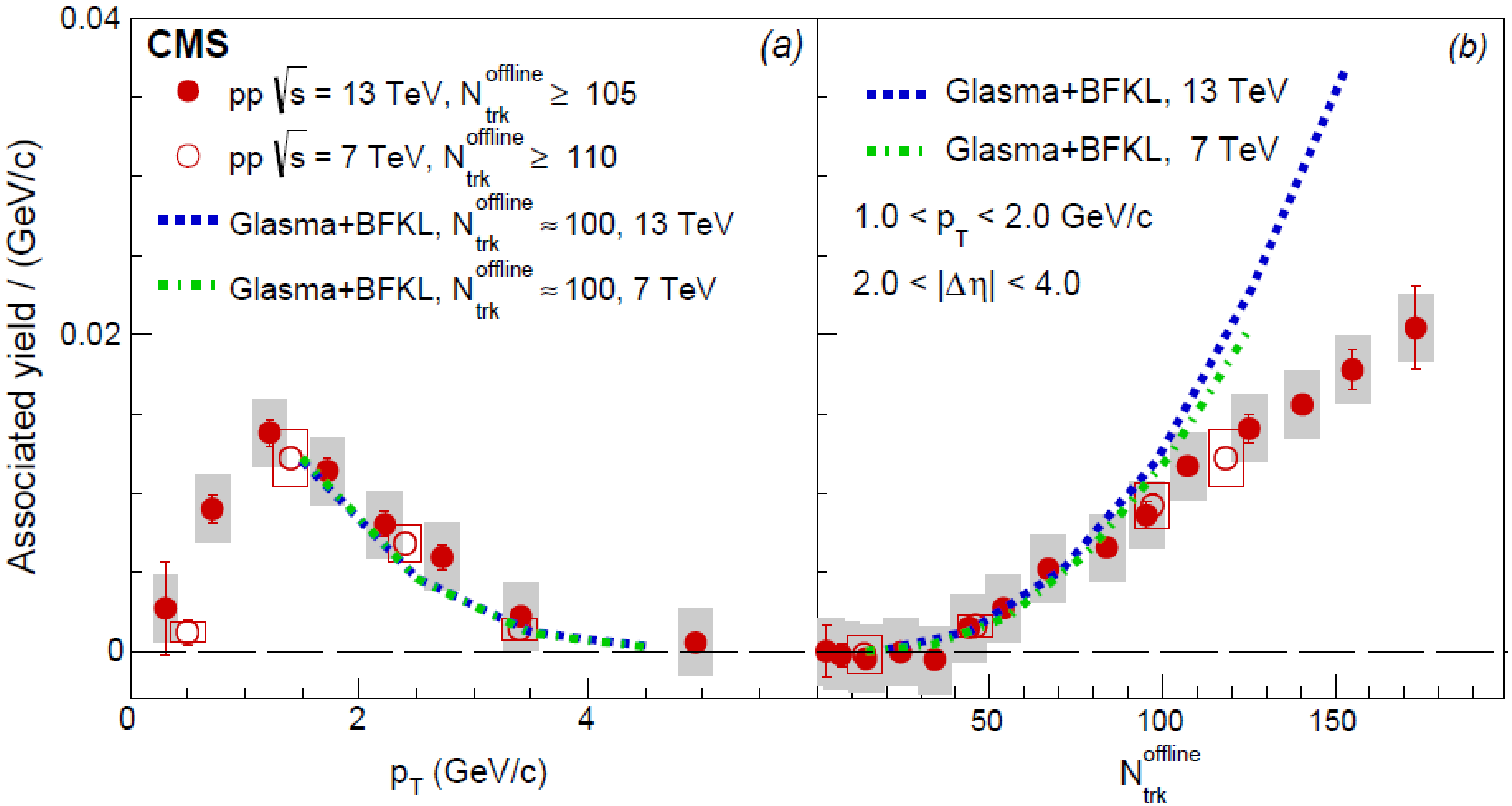
$0.73 < S_T < 0.81$

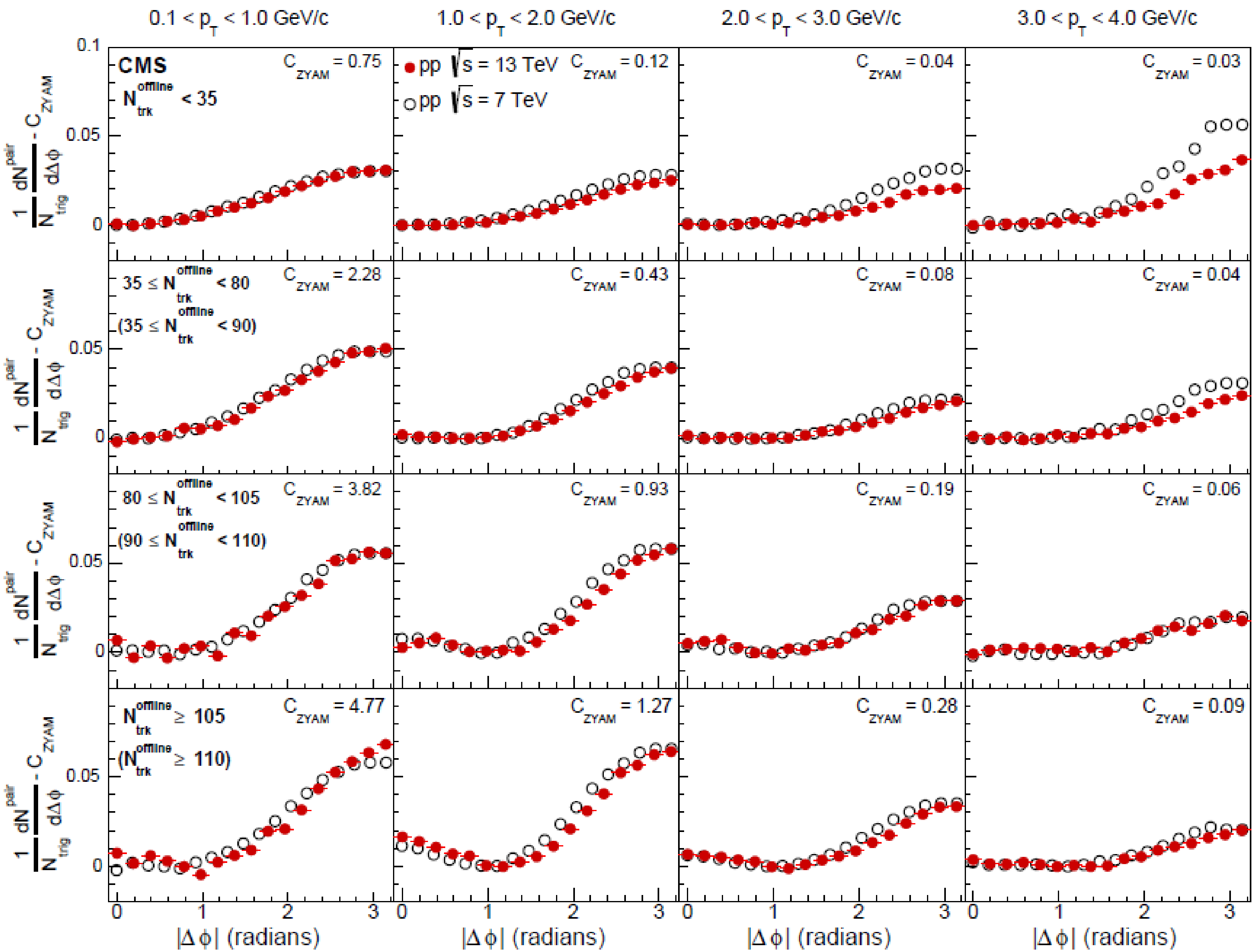


$0.81 < S_T < 0.9$

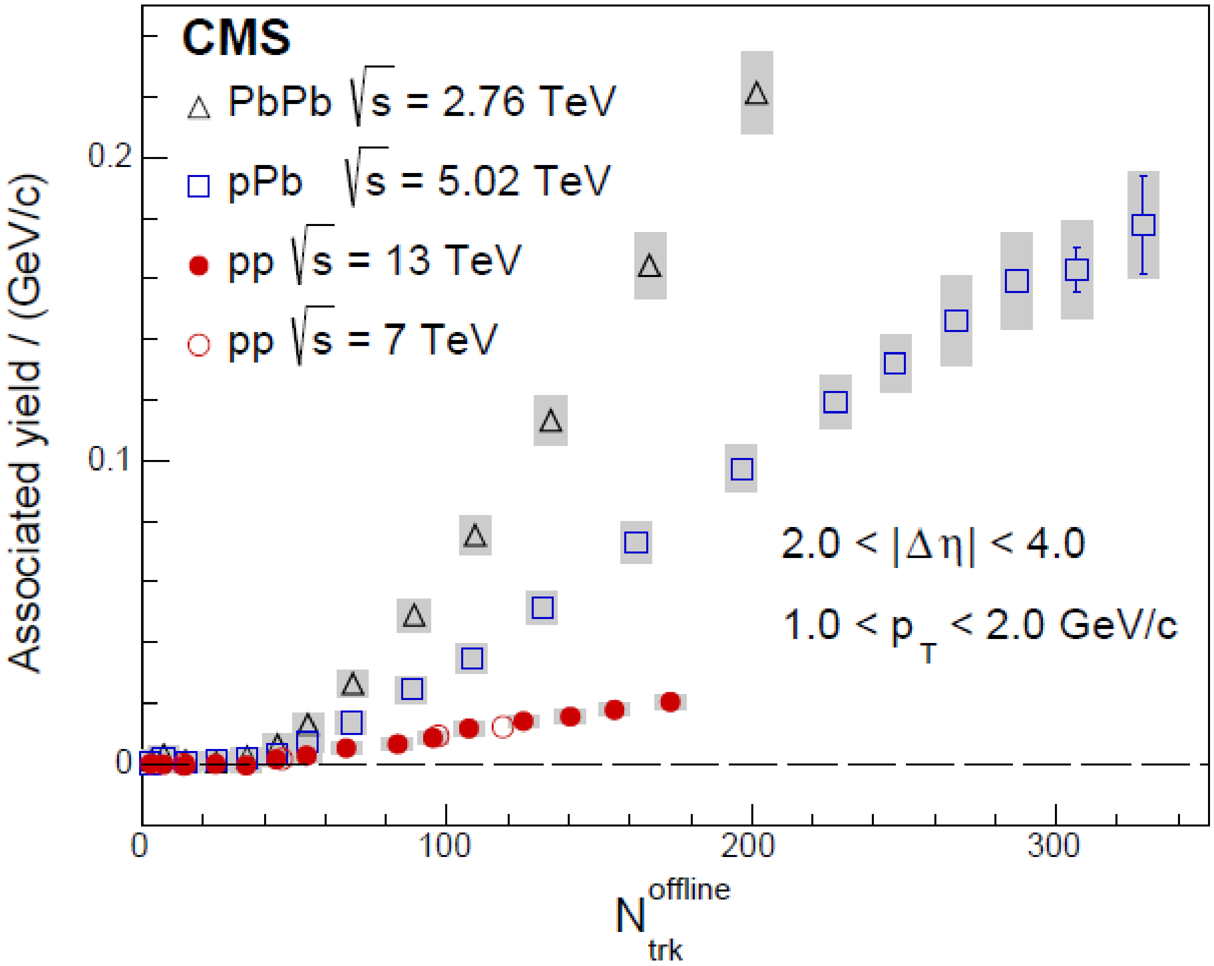


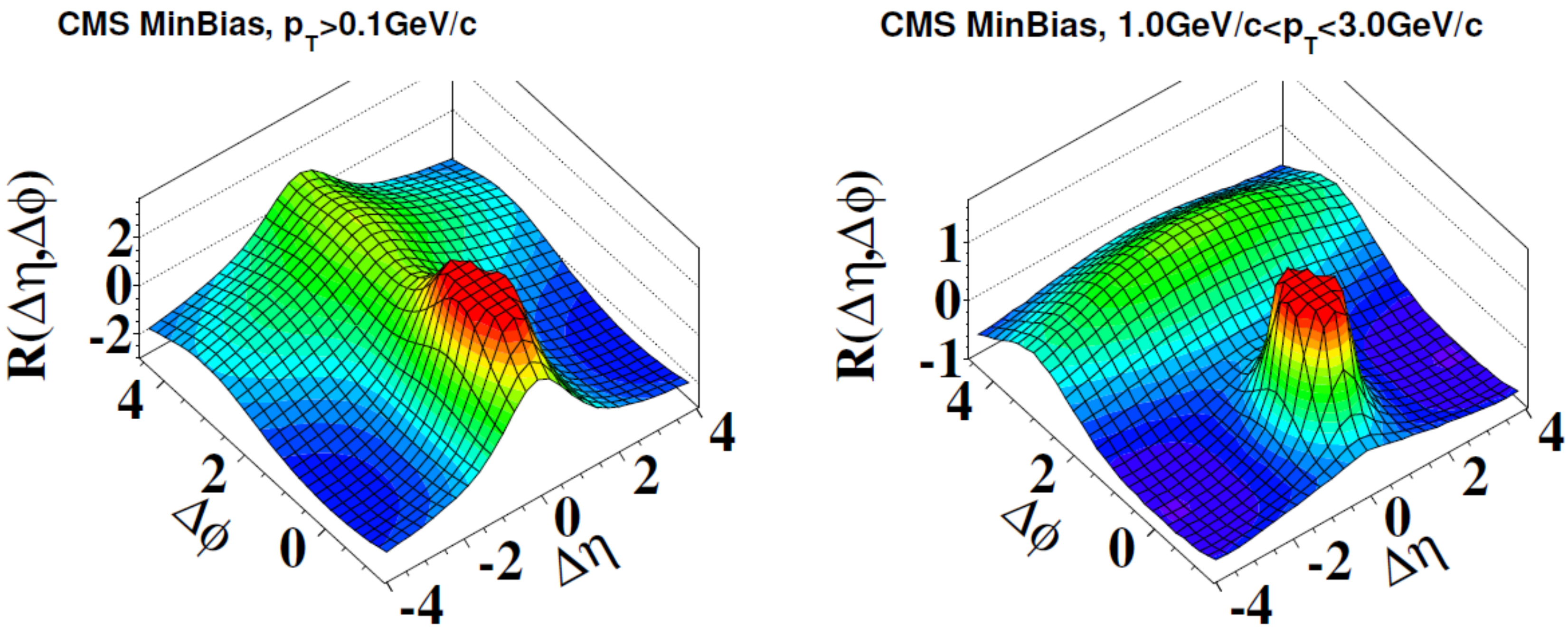
$0.9 < S_T < 1.0$

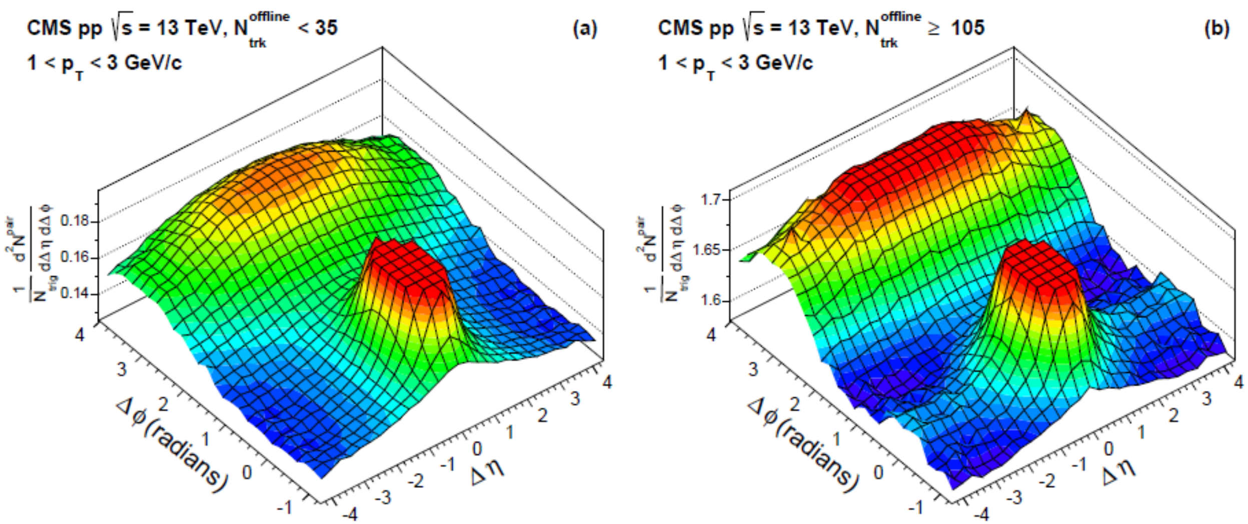

CMS
(a)
(b)
pp √s = 13 TeV, N_trk^offline ≥ 105
pp √s = 7 TeV, N_trk^offline ≥ 110
Glasma+BFKL, N_trk^offline ≈ 100, 13 TeV
Glasma+BFKL, N_trk^offline ≈ 100, 7 TeV
Glasma+BFKL, 13 TeV
Glasma+BFKL, 7 TeV
1.0 < p_T < 2.0 GeV/c
2.0 < |Δη| < 4.0
Associated yield / (GeV/c)
0.04
0.02
0
0
2
4
50
100
150
p_T (GeV/c)
N_trk^offline

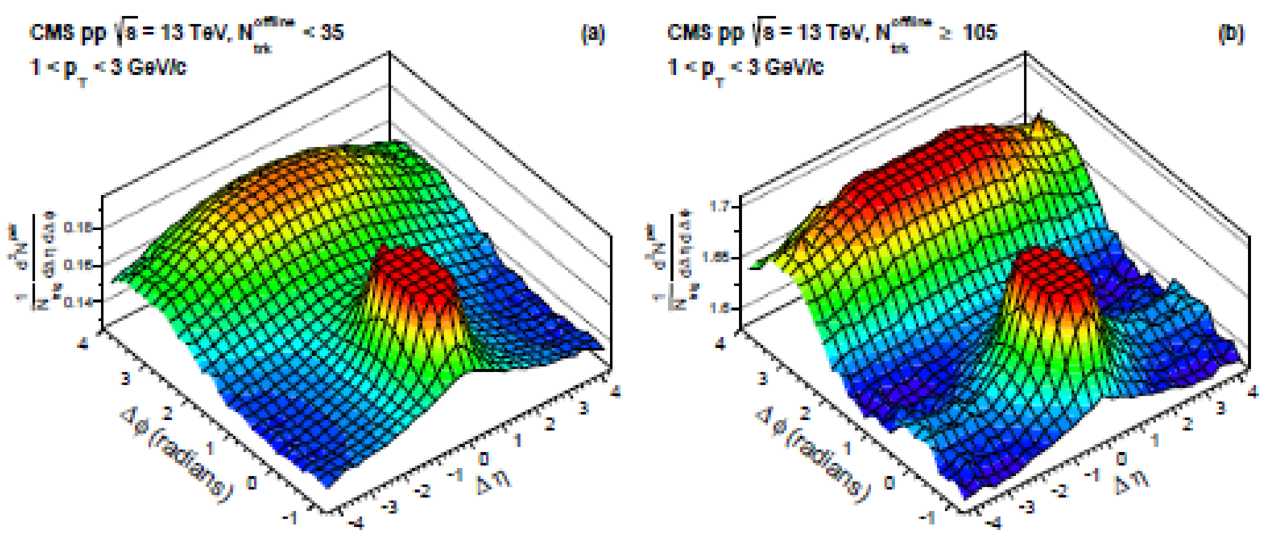


0.1 < p_T < 1.0 GeV/c
1.0 < p_T < 2.0 GeV/c
2.0 < p_T < 3.0 GeV/c
3.0 < p_T < 4.0 GeV/c
CMS
N_trk^offline < 35
pp √s = 13 TeV
pp √s = 7 TeV
35 ≤ N_trk^offline < 80
(35 ≤ N_trk^offline < 90)
80 ≤ N_trk^offline < 105
(90 ≤ N_trk^offline < 110)
N_trk^offline ≥ 105
(N_trk^offline ≥ 110)
C_ZYAM = 0.75
C_ZYAM = 0.12
C_ZYAM = 0.04
C_ZYAM = 0.03
C_ZYAM = 2.28
C_ZYAM = 0.43
C_ZYAM = 0.08
C_ZYAM = 0.04
C_ZYAM = 3.82
C_ZYAM = 0.93
C_ZYAM = 0.19
C_ZYAM = 0.06
C_ZYAM = 4.77
C_ZYAM = 1.27
C_ZYAM = 0.28
C_ZYAM = 0.09
1/N_trig dN^pair/dΔφ - C_ZYAM
|Δφ| (radians)

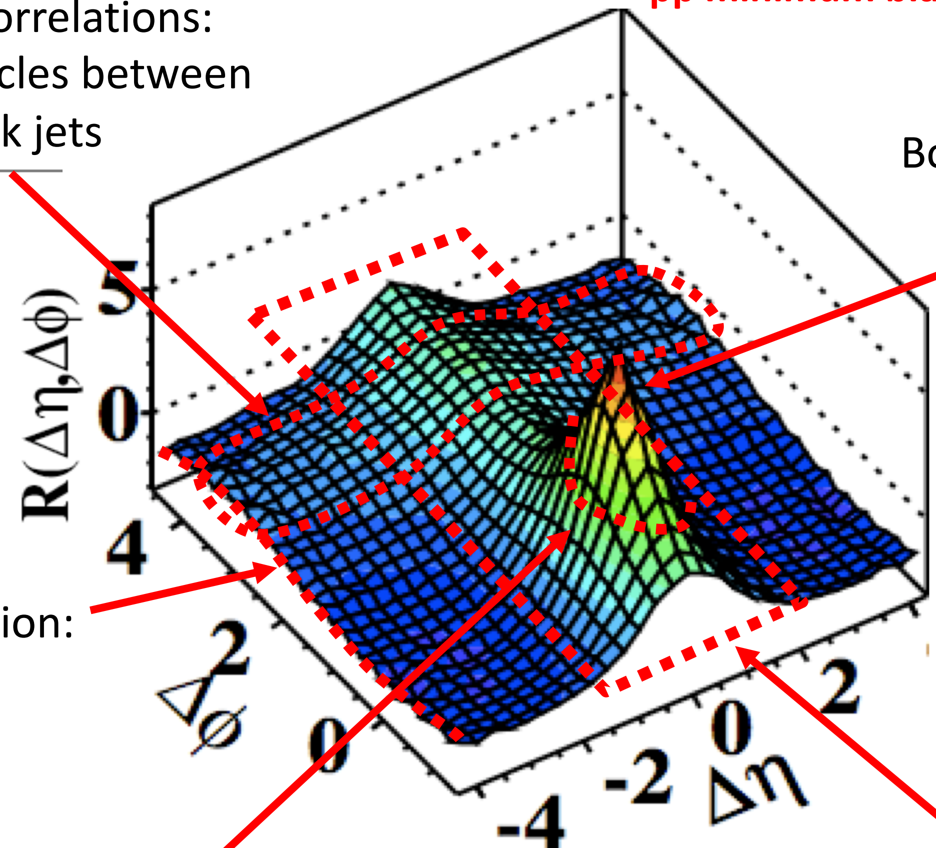

CMS
PbPb $\sqrt{s}$ = 2.76 TeV
pPb $\sqrt{s}$ = 5.02 TeV
pp $\sqrt{s}$ = 13 TeV
pp $\sqrt{s}$ = 7 TeV
2.0 < |Δη| < 4.0
1.0 < p_T < 2.0 GeV/c
Associated yield / (GeV/c)
0.2
0.1
0
100
200
300
$N_{trk}^{offline}$


CMS MinBias, p_T>0.1GeV/c
R(Δη,Δϕ)
2
0
-2
4
2
Δϕ
0
-4
-2
0
2
4
Δη
CMS MinBias, 1.0GeV/c<p_T<3.0GeV/c
R(Δη,Δϕ)
1
0
-1
4
2
Δϕ
0
-4
-2
0
2
4
Δη


CMS pp √s = 13 TeV, N_trk^offline < 35
(a)
1 < p_T < 3 GeV/c
CMS pp √s = 13 TeV, N_trk^offline ≥ 105
(b)
1 < p_T < 3 GeV/c
Δφ (radians)
Δη


CMS pp √s = 13 TeV, N_trk^offline < 35
(a)
1 < p_T < 3 GeV/c
CMS pp √s = 13 TeV, N_trk^offline ≥ 105
(b)
1 < p_T < 3 GeV/c
Δφ (radians)
Δη

Long and short range correlations



"Away-side" jet correlations:
Correlation of particles between
back-to-back jets

Bose-Einstein correlations:
(Δϕ,Δη) ~ (0,0)

Momentum conservation:
~ cos(Δϕ)

"Near-side", Δϕ~ 0 jet peak:
Correlation of particles
within a single jet

Short-range correlations
Resonances, string or cluster fragmentation