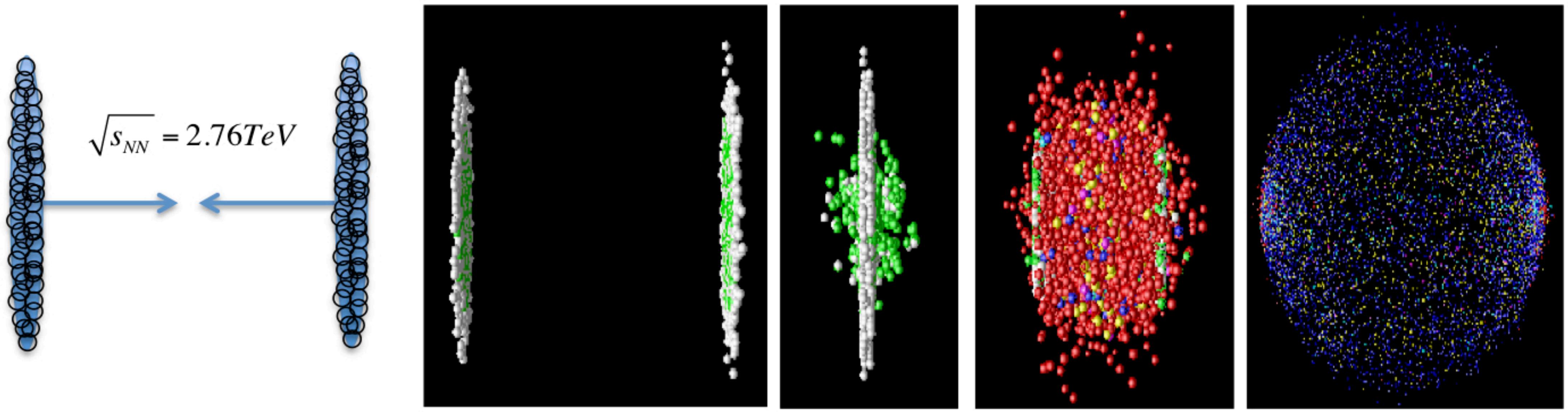
‘2+1’ CORRELATIONS IN Pb+Pb and p+p COLLISIONS IN ALICE@LHC

Raghava Varma
IIT Bombay



Conceived, Formulated & Executed by Greeshma K M

Krishna Rajagopal’s opening talk in Quark Matter @ Annecy

“One of the most striking results obtained from heavy ion collisions at the LHC is the strong suppression of high energy jets observed in Pb-Pb collisions by both ATLAS & CMS”

ATLAS Phys. Rev. Lett. 105, 252303 (2010).
CMS Phys. Rev. C 84, 024906 (2011).

Why Jets?

Production at very high energy scales, $Q >> \Lambda_{QCD}$,

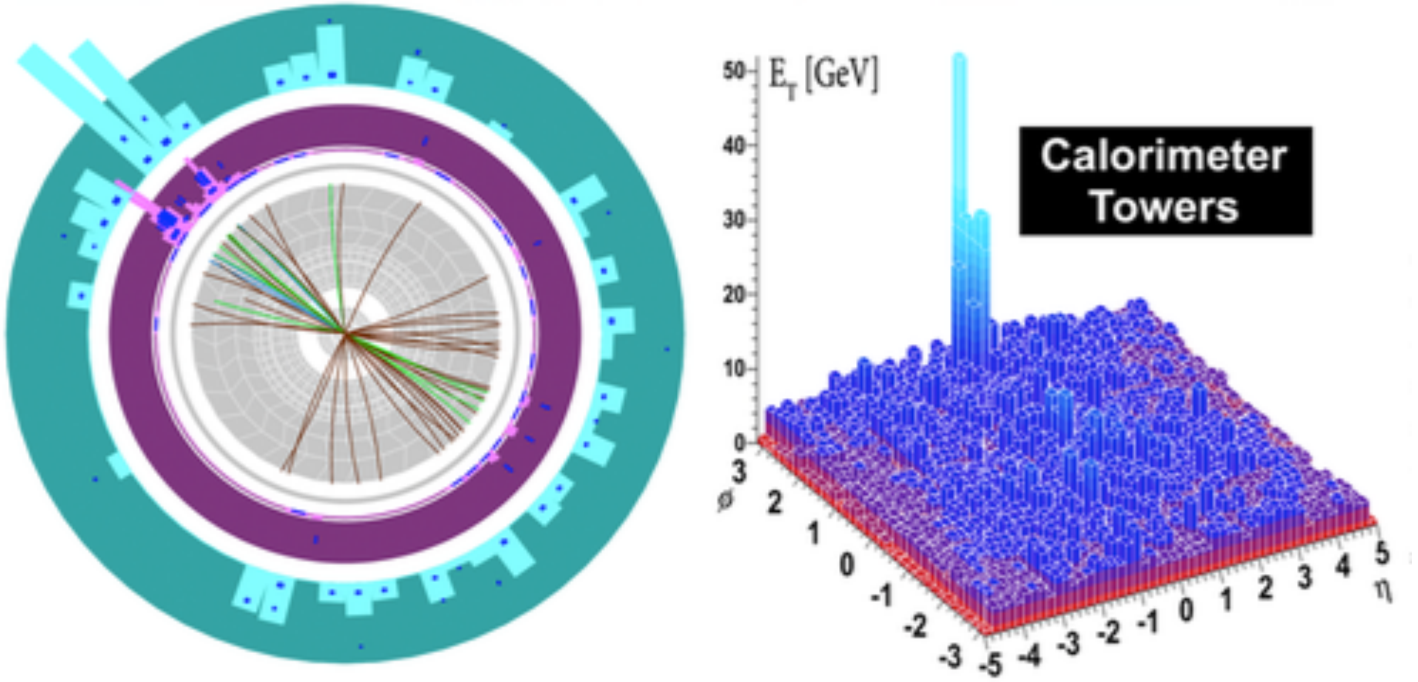
Production spectrum determined by perturbative QCD.

Deviations in a heavy ion environment must be due to the interaction of the different jet components with the hot hadronic medium

Use these deviations to study the properties of the medium.

MOTIVATION

Dijet asymmetry observed in ATLAS and CMS

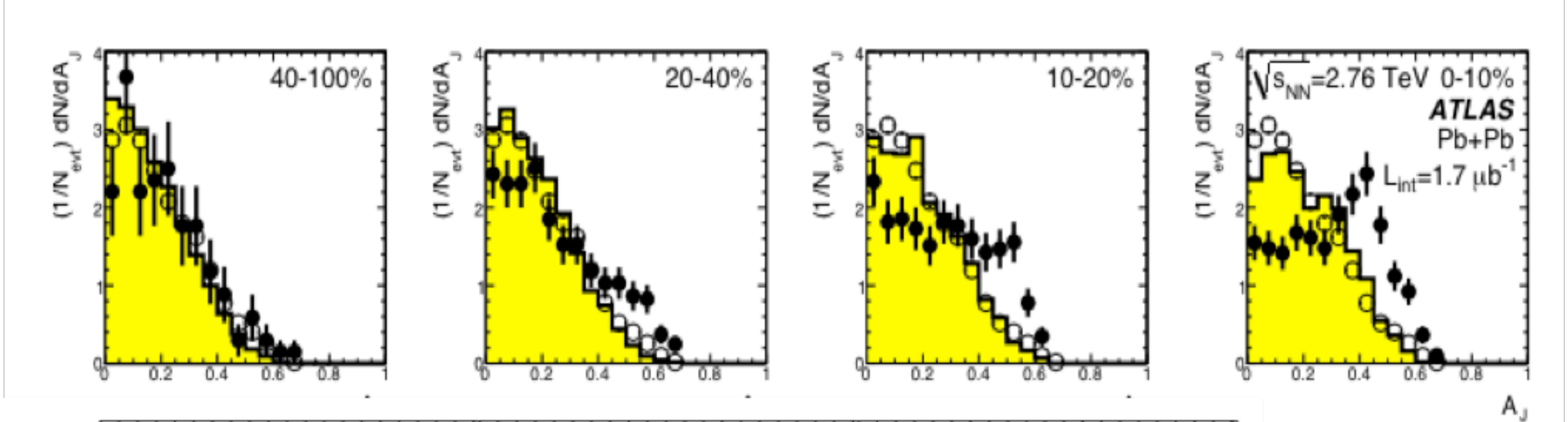


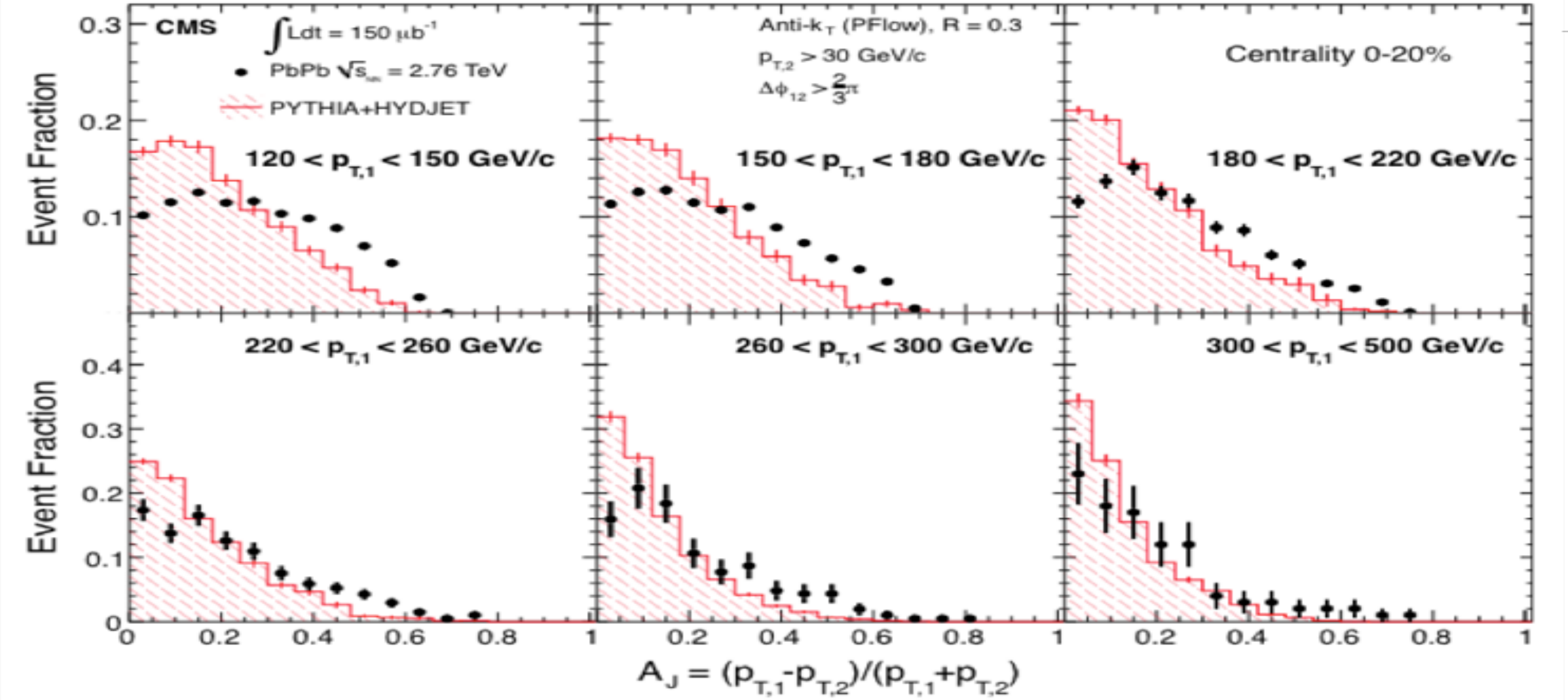
The event display of a highly asymmetric dijet event, with one jet with ET > 100 GeV and no evident recoiling jet, and with high energy calorimeter cell deposits distributed over a wide azimuthal region, in ATLAS

The transverse energies of dijets in opposite hemispheres was observed to become systematically more unbalanced with increasing event centrality leading to a large number of events which contain highly asymmetric dijets, which can be interpreted in terms of strong jet energy loss in a hot, dense medium. Both CMS and ATLAS have quantified their results using the quantity AJ, where

$$A_J = (E_{T1} - E_{T2}) / (E_{T1} + E_{T2})$$

where E_{T1} and E_{T2} energies of the dijets.





Even at very pt dijet asymmetry persits

Dijet asymmetry distributions for data (points) and unquenched HIJING with superimposed PYTHIA dijets (solid yellow histograms), as a function of collision centrality (left to right from peripheral to central events). Proton-proton data from $\sqrt{s}$ = 7 TeV, analyzed with the same jet selection, is shown as open circles.

Production of a hard parton that will become a jet, and the fragmentation of that parton as it propagates, are controlled by weakly coupled physics at high momentum scales.

The physics of the medium produced in experimentally realizable heavy ion collisions is not weakly coupled.

At sufficiently high temperatures the quark-gluon plasma must be a weakly coupled plasma of quark and gluon quasi-particles.

In the temperature ranges explored by LHC & RHIC (T ~ 150-600 MeV) it is not. Experimental observables as well as relativistic viscous hydrodynamics show that it is a droplet of strongly coupled liquid that expands and flows collectively, hydrodynamically.

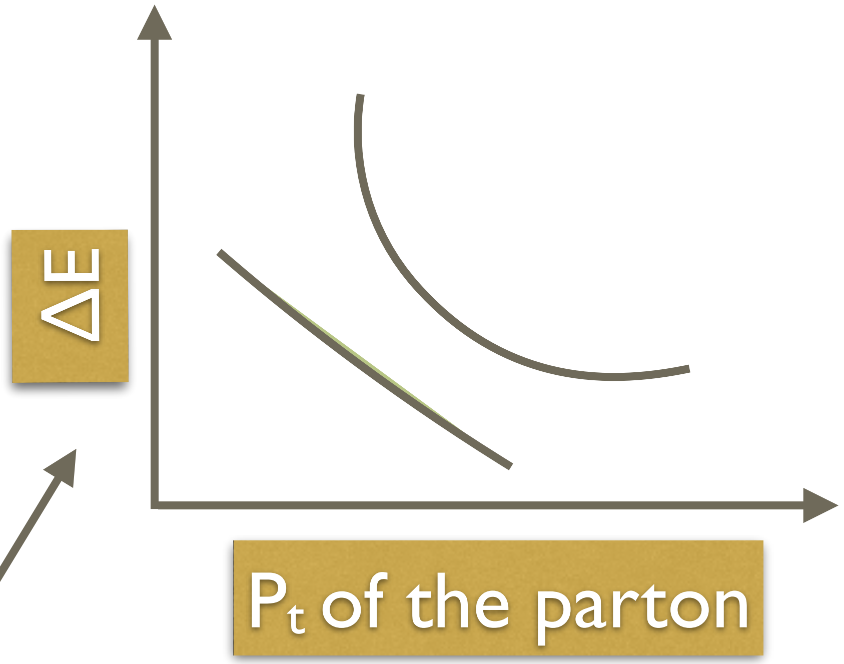
RICH PHYSICS

Thus there is a rich interplay of weakly and strongly coupled physics in the same system. If we could control it we could diagnose the medium better.

Final aim to have a ΔE vs p_t plot

Give some work to the theorists!

With limited statistics we should still be able do put some constraints to various models



For this I must know the p_t of the parton traversing the medium

Why Dijets?

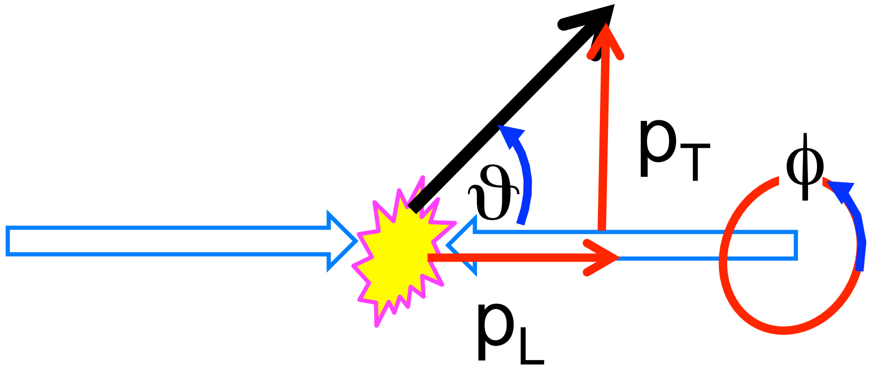
The Diet asymmetry provides the y axis

Take the p_t from the near side jet as the initial energy of the parton traversing the medium.

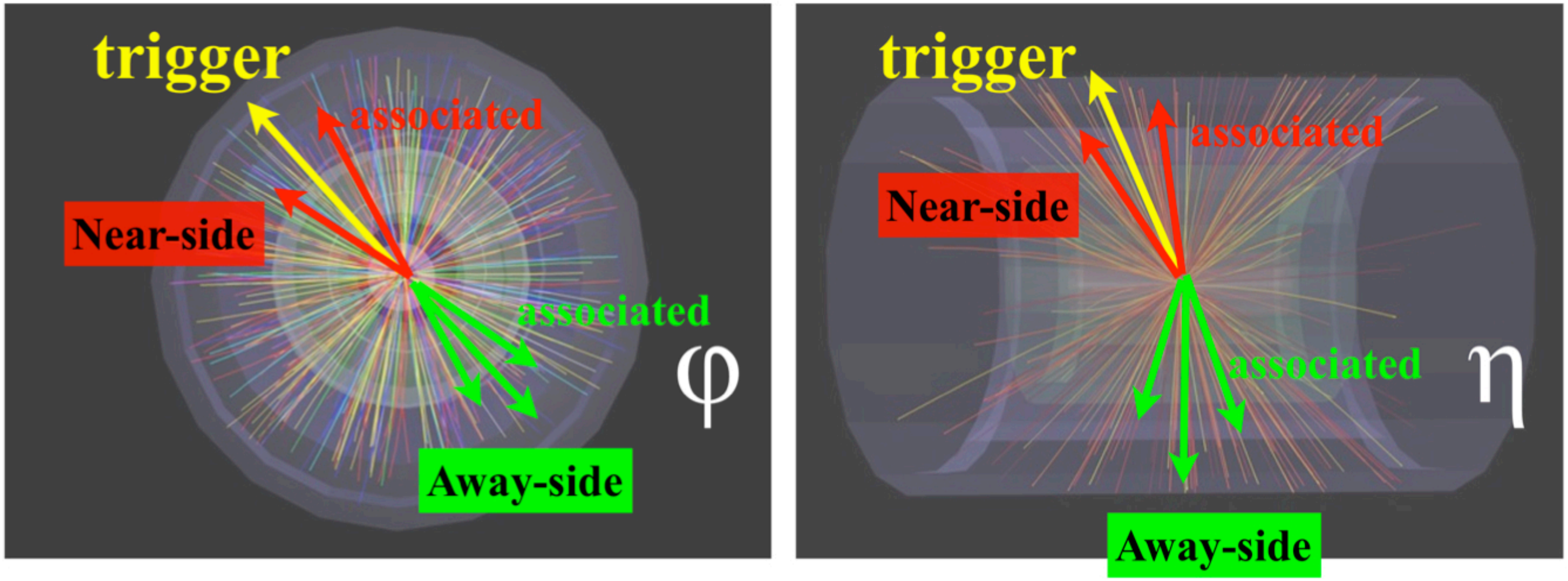
But for this one has to assume that the near side is produced at surface

Jet Reconstruction or Two-particle Correlation

- **Relativistic Kinematic Variables**
  - ⇨ Transverse Momentum **$p_T = p \sin(\vartheta)$**:
  - ⇨ Polar angle ϑ => **pseudo-rapidity η** = - ln tan(ϑ/2)
    rapidity y = atanh(p_L/E)
  - ⇨ Azimuthal Angle ϕ



$$y = \frac{1}{2}\ln\frac{E+p_z}{E-p_z} = \ln\frac{E+p_z}{\sqrt{E^2-p_z^2}} = \ln\frac{E+p_z}{m} \approx \ln\frac{2E}{m}$$

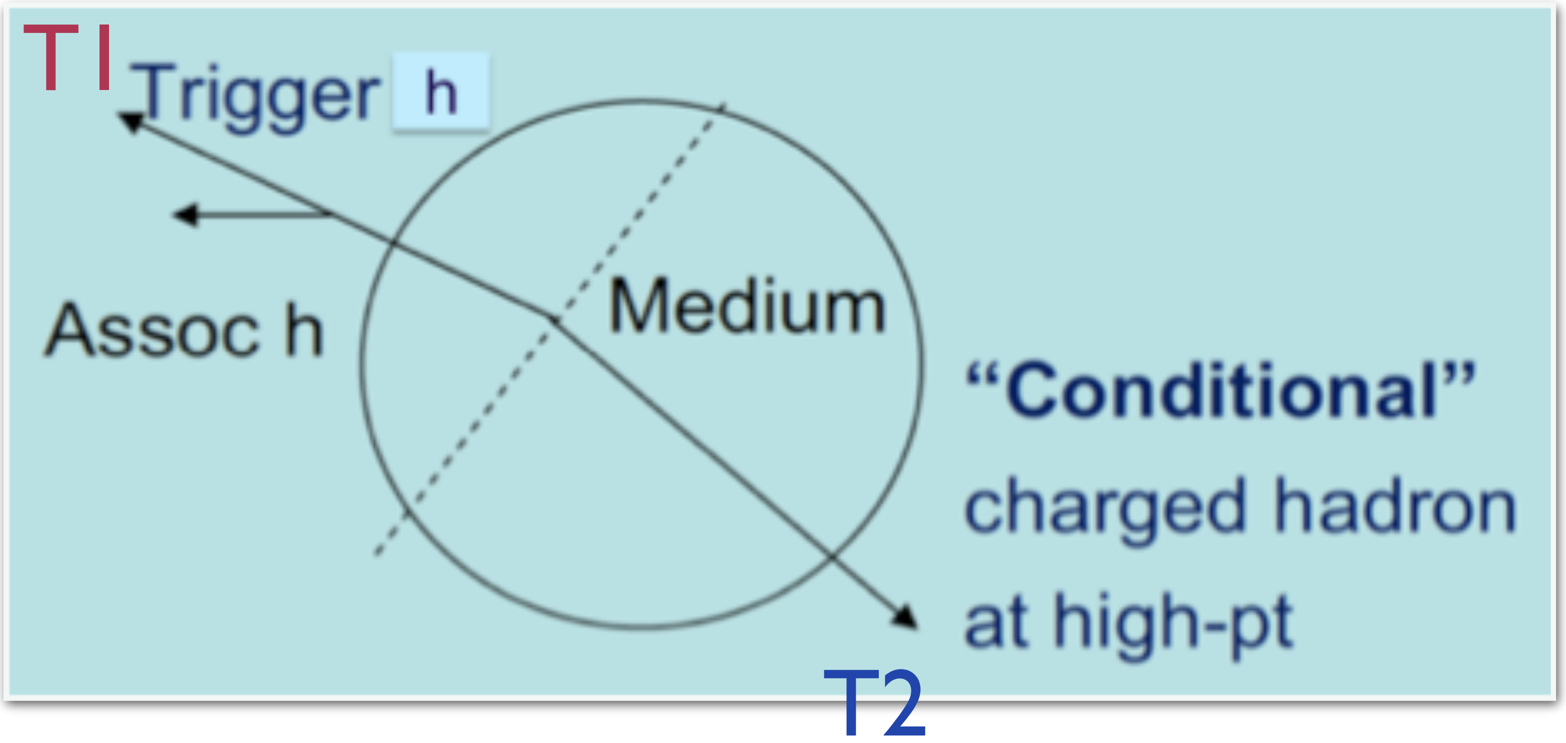


For each trigger particle, count the number of associated particles with p_T, $\Delta\varphi$ and $\Delta\eta$.

Surface Phenomenon

Calibrated Probe to estimate energy loss as a function of length travelled in the medium

2+1 correlation



Varying the energy of T2 should allow us to explore different regions of the fireball.

Centrality would also change the size of the Fire Ball and also the physics interactions within.

Selecting events with back-to-back high-pT hadrons

$(\varphi_1 - \varphi_2 - \pi < |\pi/8|.)$

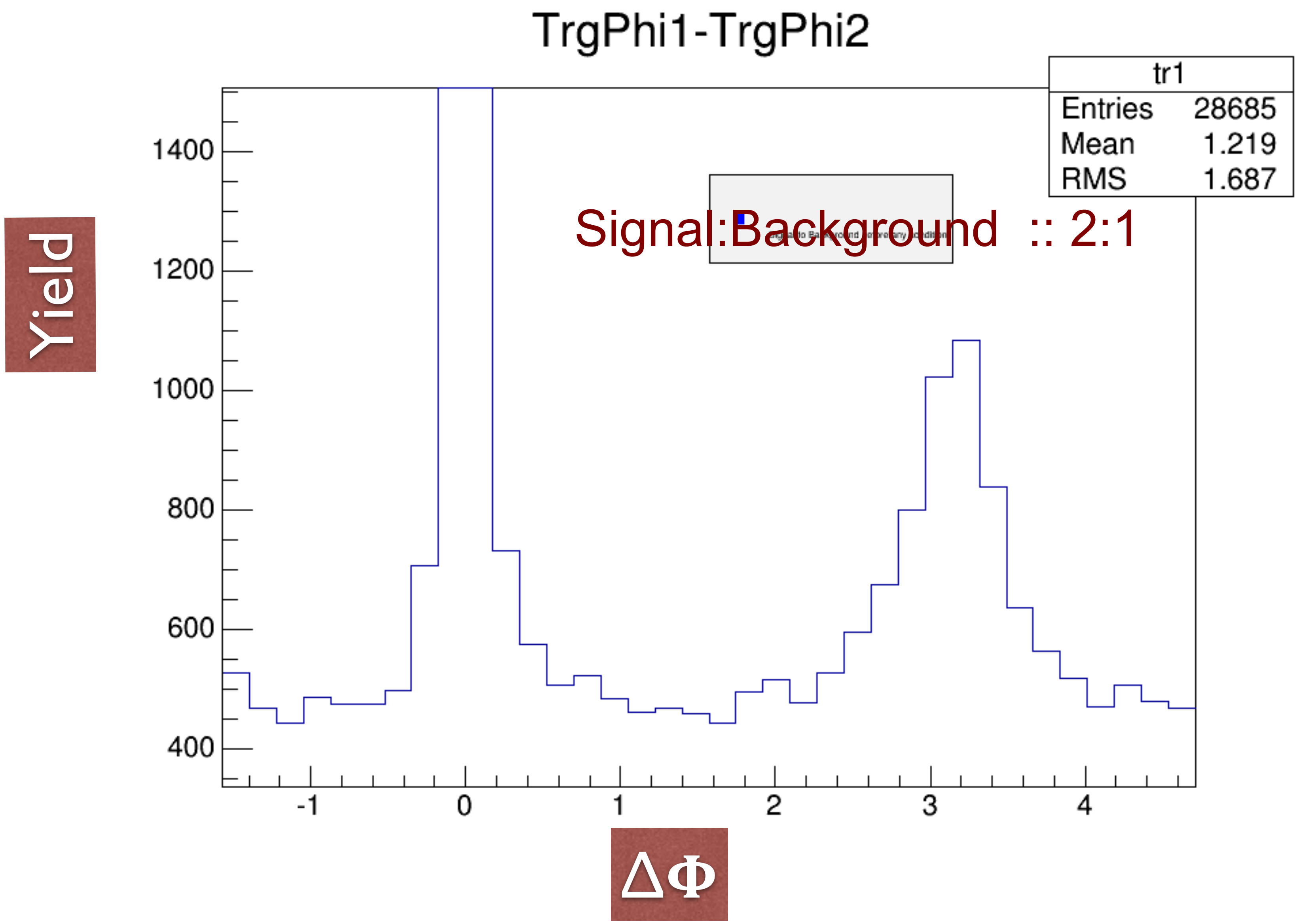
What is the probability that the event chosen is a Di-Jet?

Optimising the Energy of T1 & T2

Plot ΔΦ between T1 & T2

T_1 is between 12 & 30 GeV

T_2 is also between 5 & 8 GeV

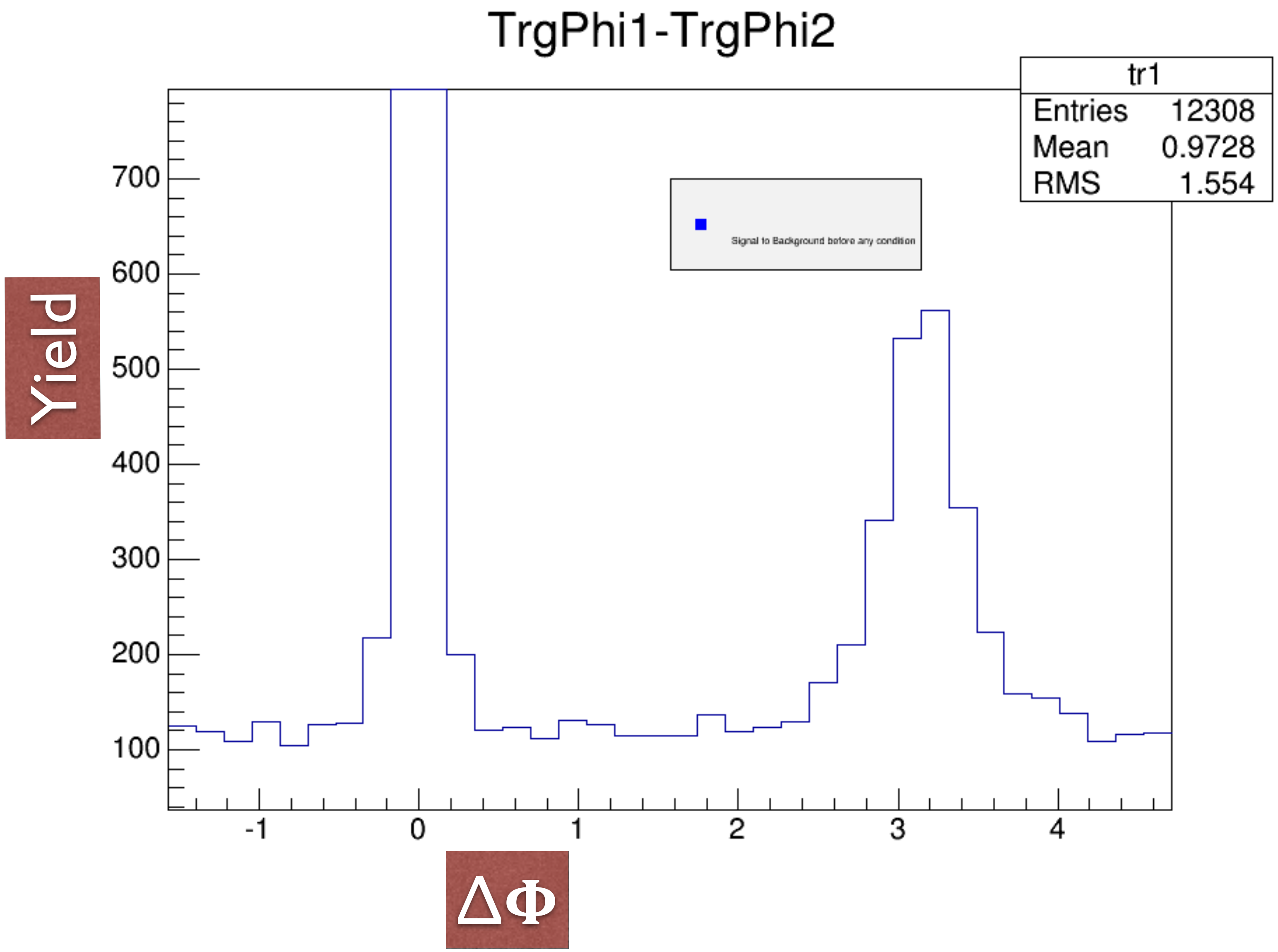


Signal:Background :: 2:1

Optimisation of T1 & T2

T_1 is between 12 & 30 GeV
T_2 is also between 8 & 12 GeV

Signal:Background :: 5:1

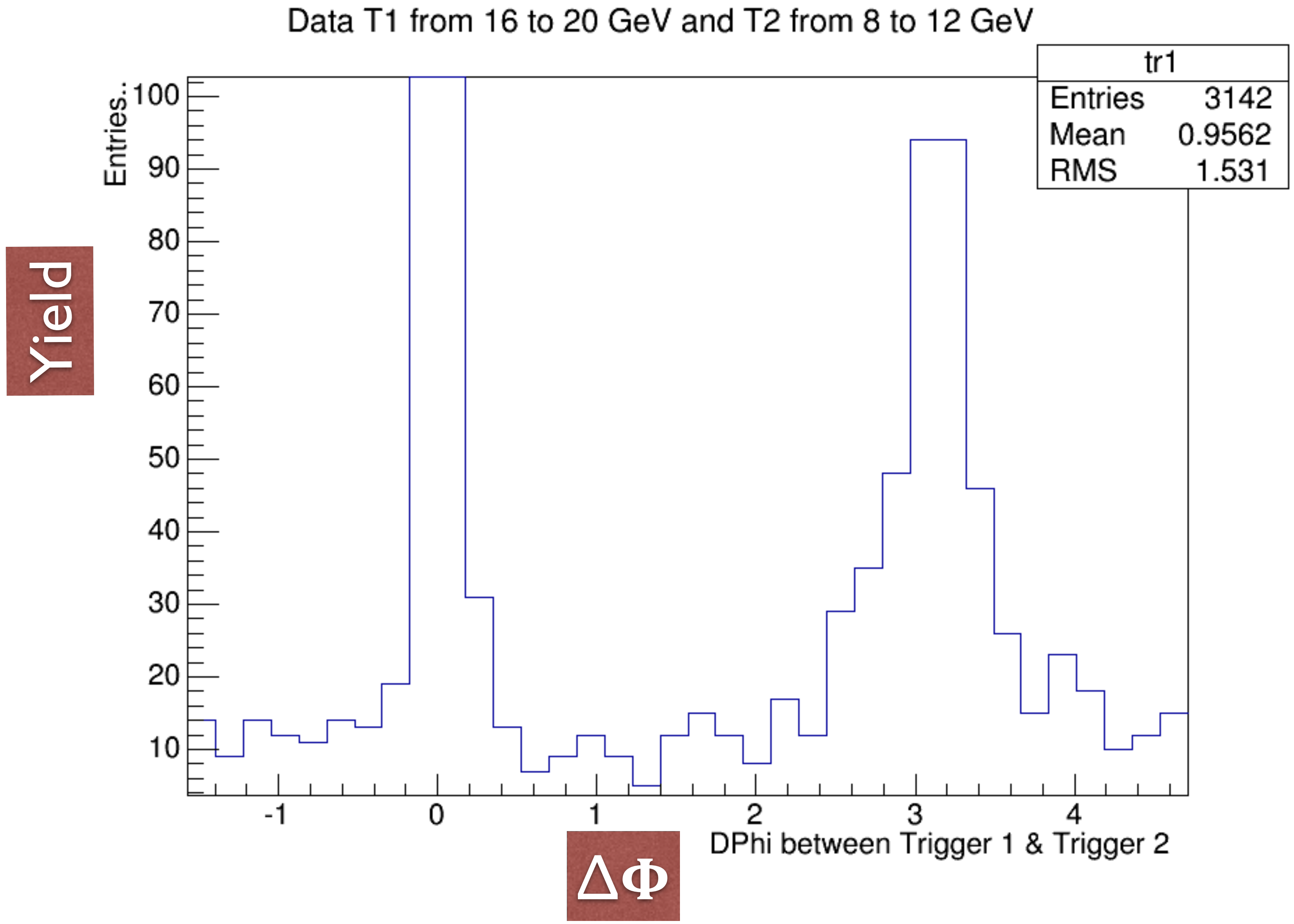


Optimisation of T1 & T2

How the energies of T1 & T2 were determined to determine a well calibrated probe

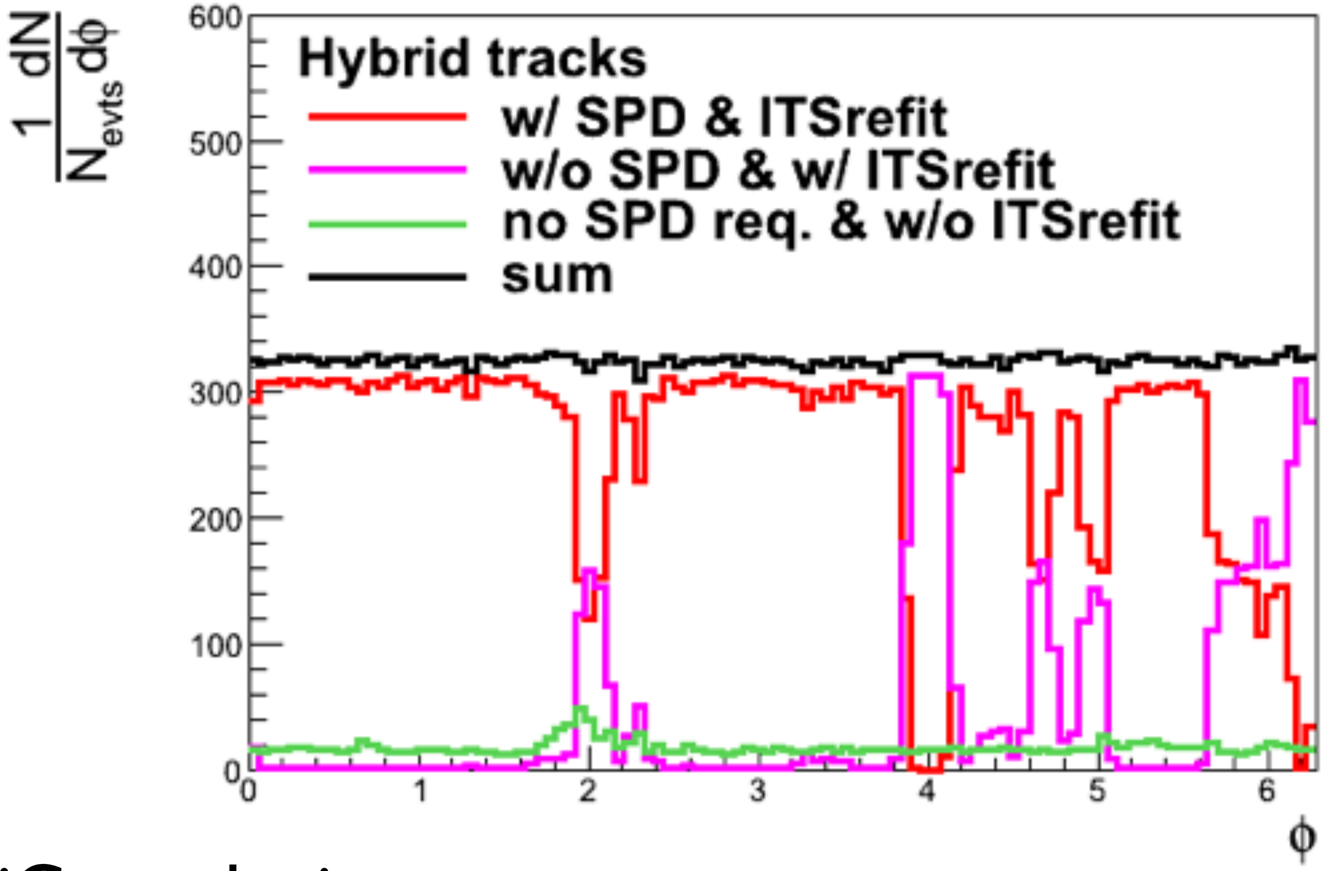
T1 frozen at 16 to 20 GeV & T2 (variable window)

Signal:Background :: 10:1



Data Set

- Pb + Pb @ 2.76TeV ~ 46 M events
  - LHC10h, Pass2, AOD086
  - LHC11h, Pass2, AOD145.
- p + p @ 2.76 TeV, LHC11a, AOD113



Cuts Applied

- AliVEvent::kMB | kCentral | kSemiCentral trigger.
- Reconstructed vertex within |Vtx-z| < 10 cm chosen.
- Centrality selection using V0.
- Track Cuts:

☑ Filterbit 768 (LHC11h, AOD-145) – hybrid tracks
Filterbit 272 (LHC11a, AOD113)

☑ $|\eta| < 0.8$

☑ Associated particle : $pT_{asso} < pT$ trigger1 or 2

Analysis Steps

- T1 (primary trigger) is chosen from a pT range. T2 is searched for in another pT region with the condition that $|\Delta\varphi - \pi| <= \pi/8$.

S1. **Raw Correlation** with associated tracks in same event (w/ condition assoc pT < Trigger particle T1 or T2) : $(\Delta\varphi, \Delta\eta)$ ✓Done

S2. **Corrections:** Mixed event correction, single track efficiency correction, correction for two track effects, and resonances and conversions. ✓Done

S3. **Background Subtraction:** Subtract background from uncorrelated triggers. ✓Done

S4. **Flow Subtraction via "Eta Gap":** $(1.0 < \Delta\eta < 1.4)$. ✓Done

- **Observable/Results** : Integrated yield for $|\Delta\varphi| < 0.5$ ✓Done

In the slides,

near side refers to correlation w.r.t T1, and

away side is correlation w.r.t T2.

Based on the analysis the following window of p_t were chosen for T1 & T2

Different pT combinations of triggers which are analysed

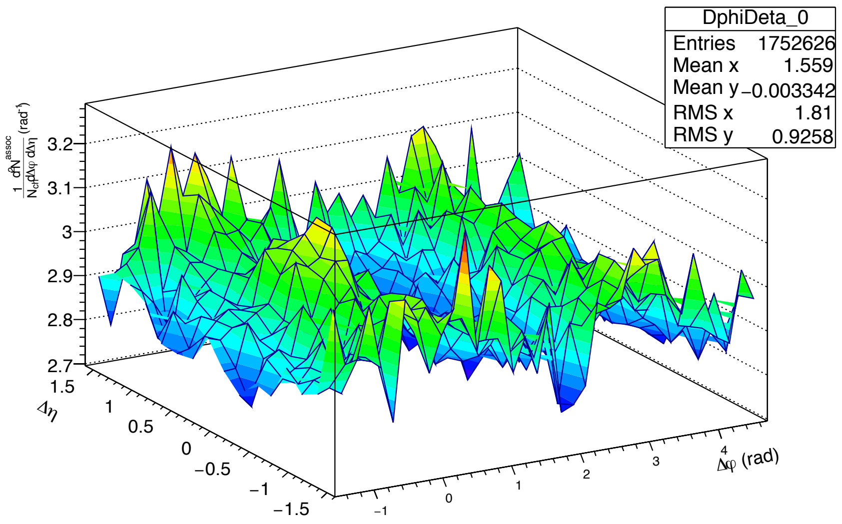
Trigger-1 pT GeV/c	**Trigger-2 pT GeV/c**	Centrality
16 – 20	4-8, 8–12, 12-16	0-7.5% 30-50%
8 – 12	4-8	

T1: 8-12 GeV/c, T2: 4-8 GeV/c

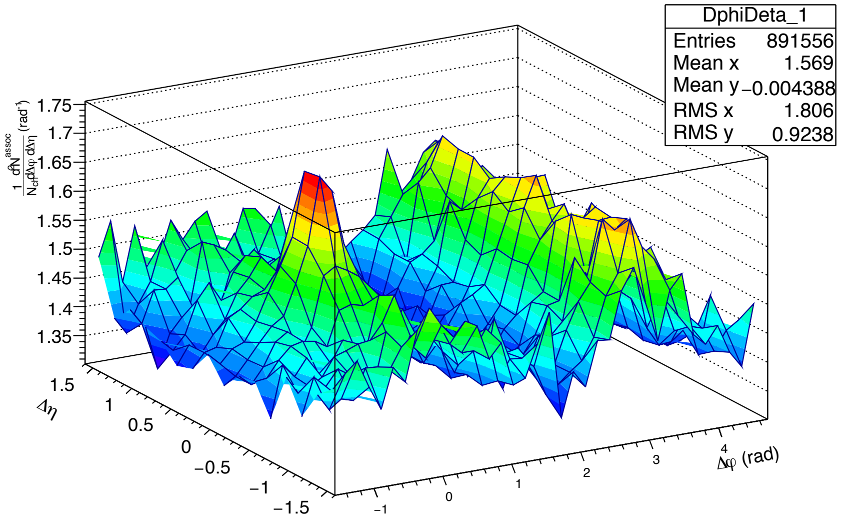
Raw Correlation

(Corrected for detector acceptance (ME), single track efficiency, and two track effects)

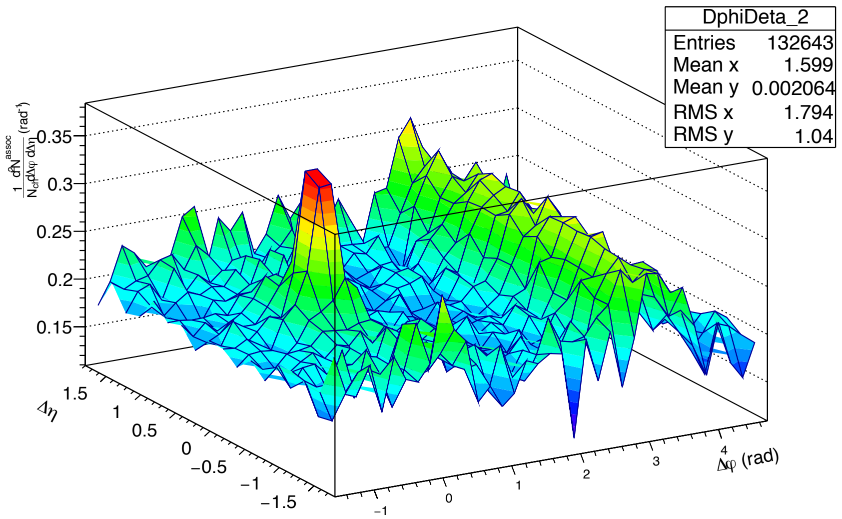
pt assoc: 0.5 -1GeV/c



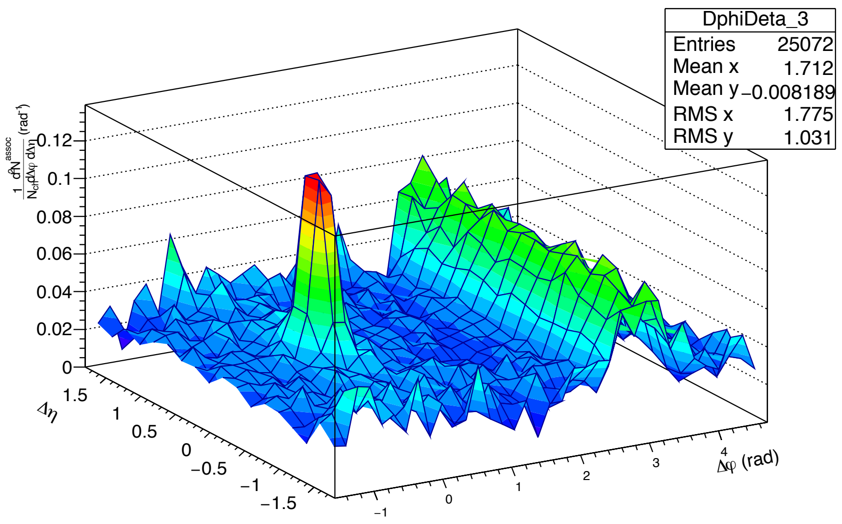
pt assoc: 1 - 2 GeV/c



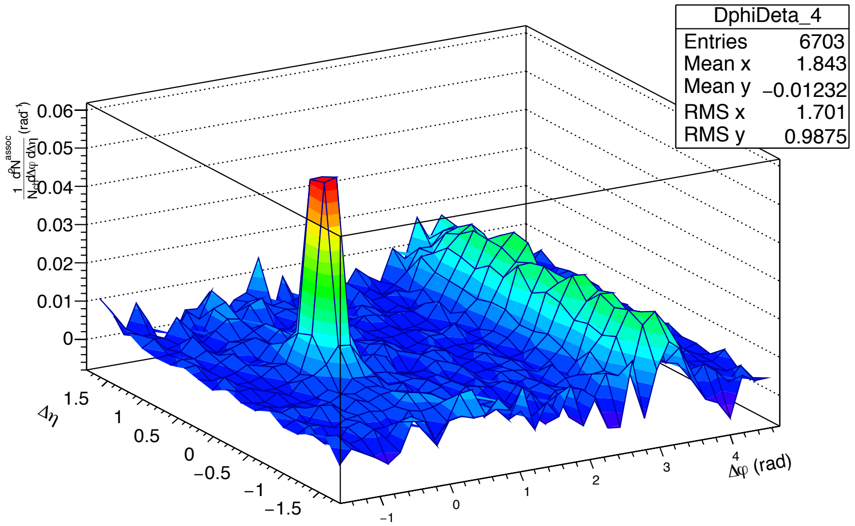
pt assoc: 2 - 3GeV/c



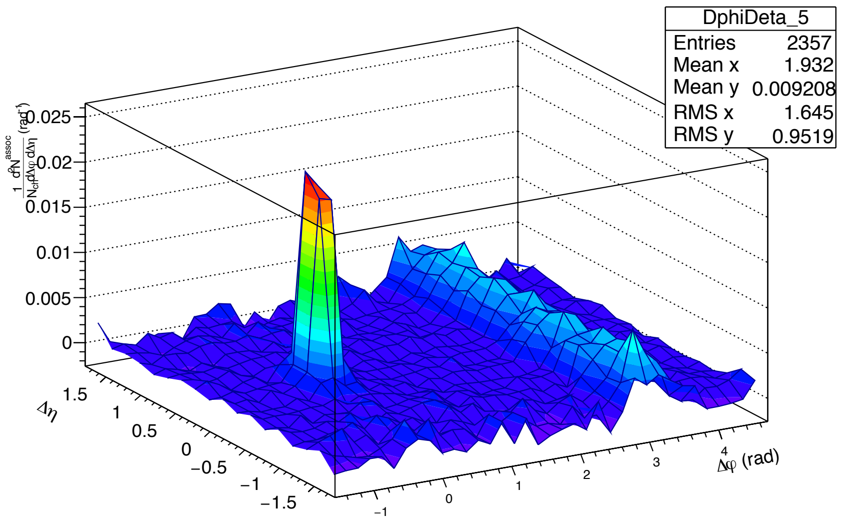
pt assoc: 3 - 4 GeV/c



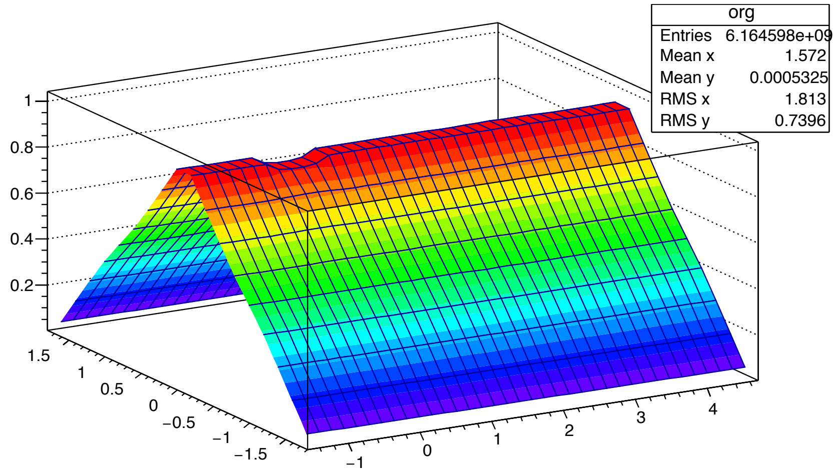
pt assoc: 4 - 5 GeV/c



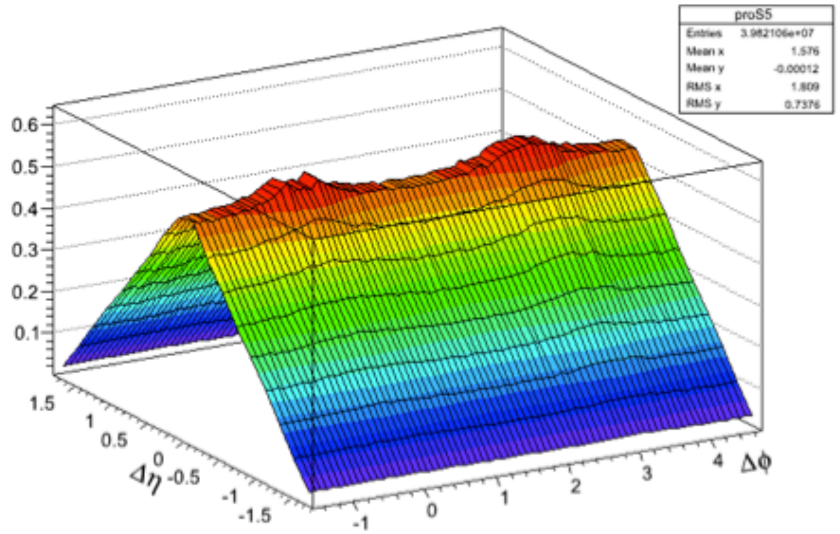
pt assoc: 5 -6GeV/c



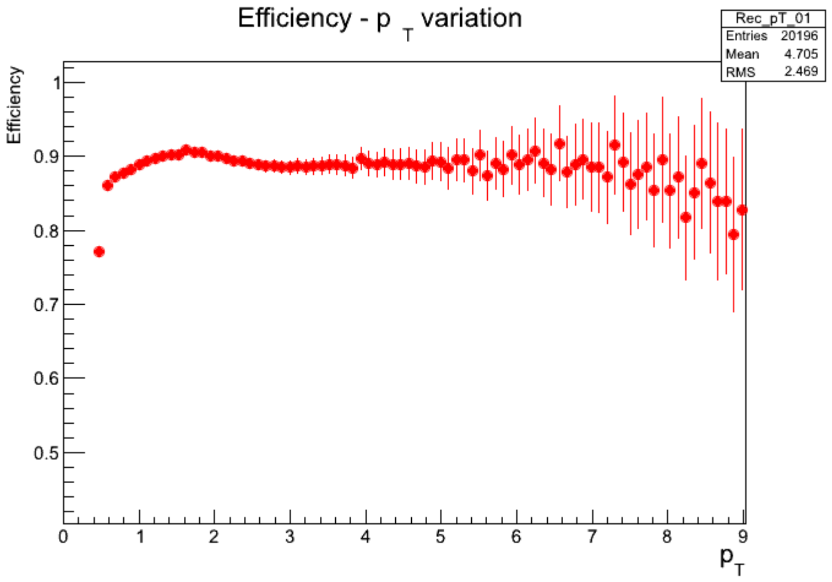
1)Mixed Event Correction: Correct for detector acceptance and inhomogeneities.



2)Correction for resonances and two track effects: Particle pairs, which are likely to come from γ-conversion, or K_s^0, Λ decays, are removed by a cut on invariant mass of the pair.
Particle reconstruction effects, track splitting and track merging : by a cut on track separation.



2)Single track efficiency correction: Ratio of the number of accepted tracks from primary particle (reconstructed level) to number of all primary particle (kinematic level). Efficiency variation is calculated with centrality, z-vertex, η, and p_T.



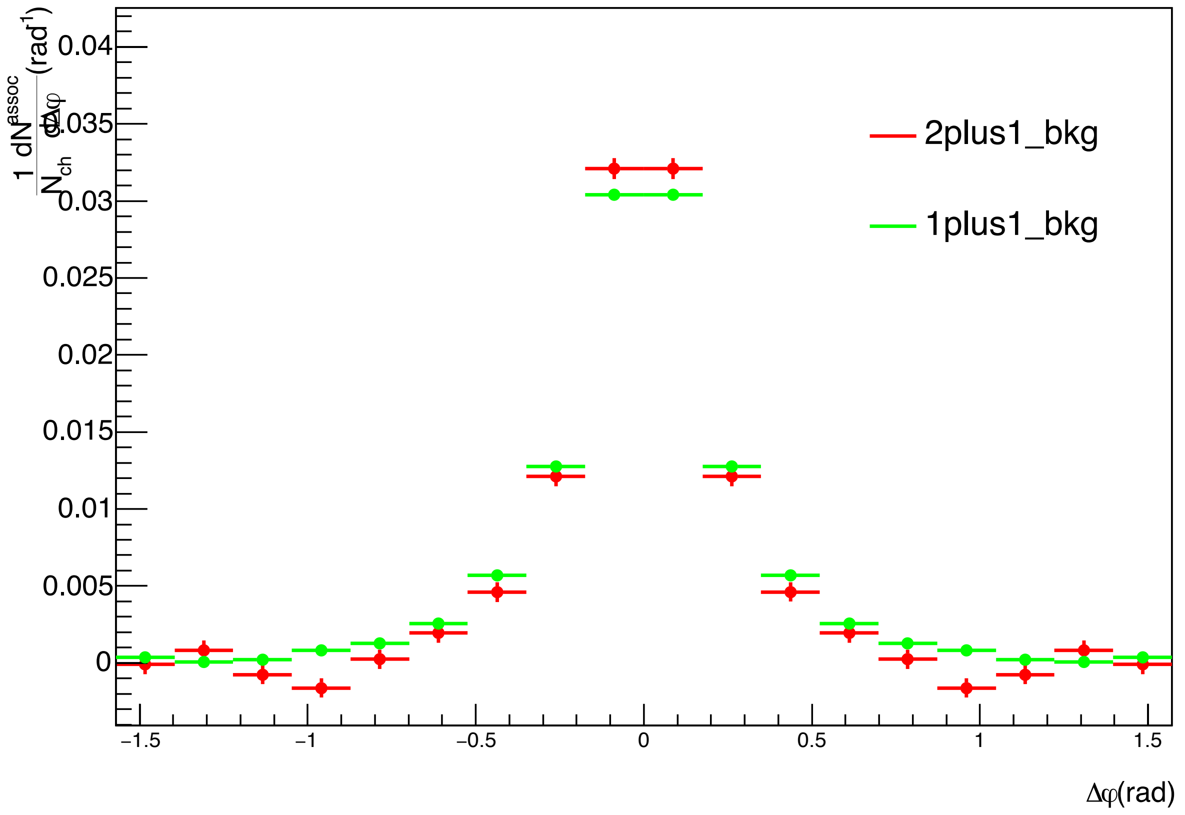
Background from uncorrelated triggers

Method 1:

T1 and T2 triggers at $|\Delta\varphi - \pi/2| <= \pi/8$ are chosen. Associated particles too are chosen from the same event and correlations are build around T1 and T2, and scaled with the number of triggers.($1/T_{bkgSE}$).

Method 2:

1+1 correlation: Trigger and associated particles are chosen from the same event and correlations are build. No condition of secondary trigger. This is scaled with the number of triggers T_{bkgSE}/T_{1+1}.



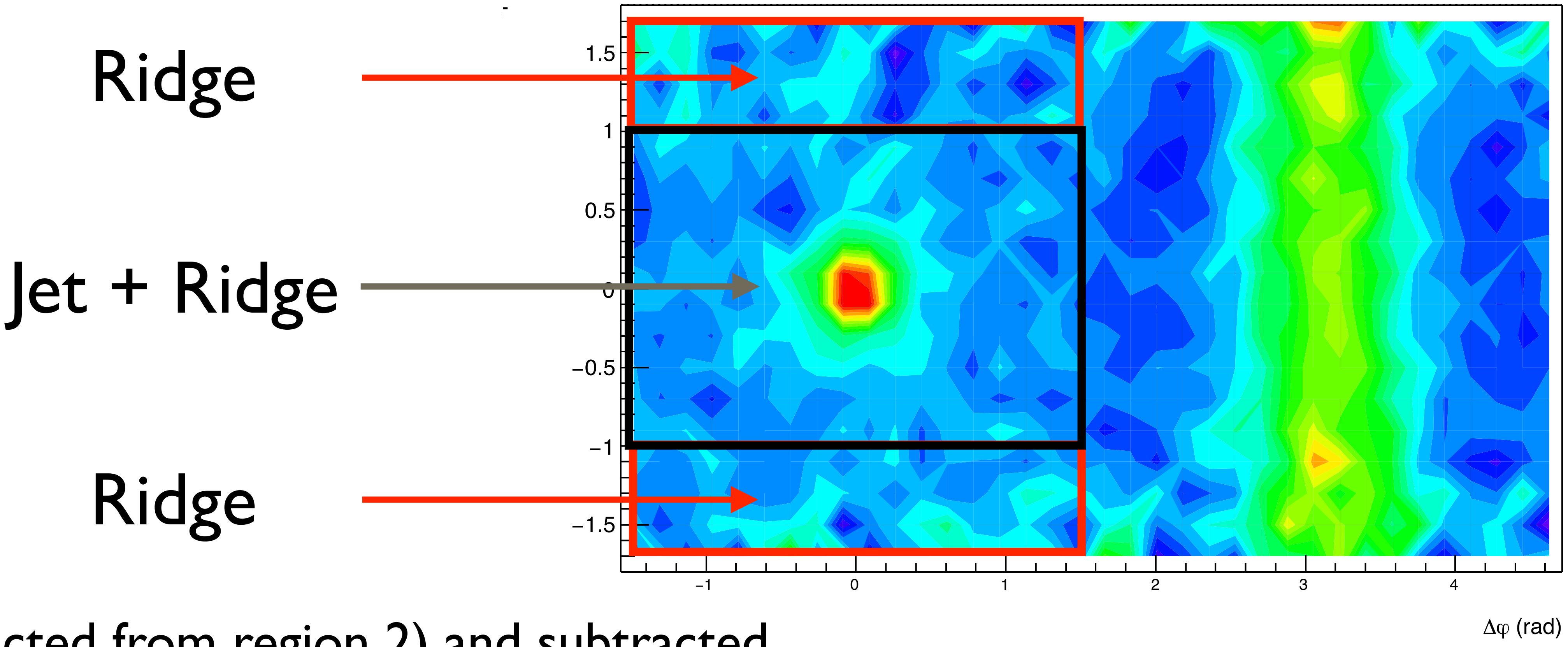
Method 2 used because of good statistics. Method 1 is used to obtain the number of uncorrelated triggers for scaling the 1+1 bkg correctly.

Eta Gap Method: Flow subtraction.

Different areas in the $(\Delta\eta, \Delta\varphi)$ distribution are defined with the corresponding contributions (near side):

1)($-\pi/2 < \Delta\varphi < \pi/2$, $\Delta\eta < 1.0$): near-side jet + ridge

2)($-\pi/2 < \Delta\varphi < \pi/2$, $\Delta\eta > 1.0$): nearside ridge

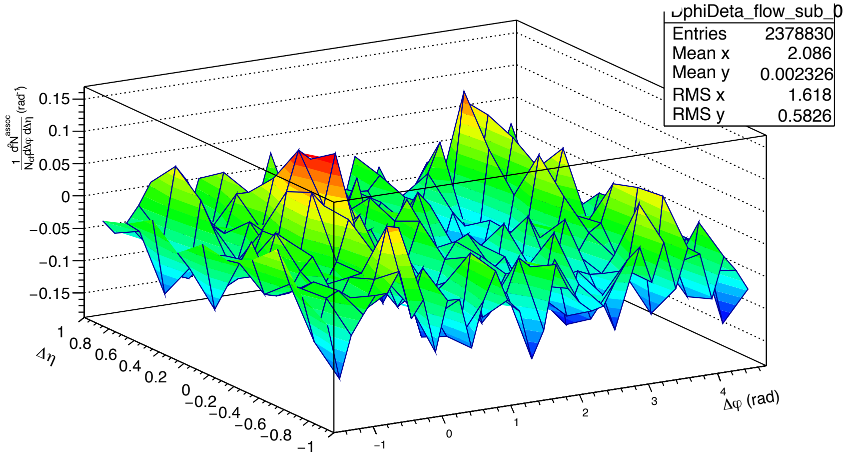


The ridge is extracted from region 2) and subtracted from yields in region 1), ($1.0 < \Delta\eta < 1.4$ is considered for ridge extraction).

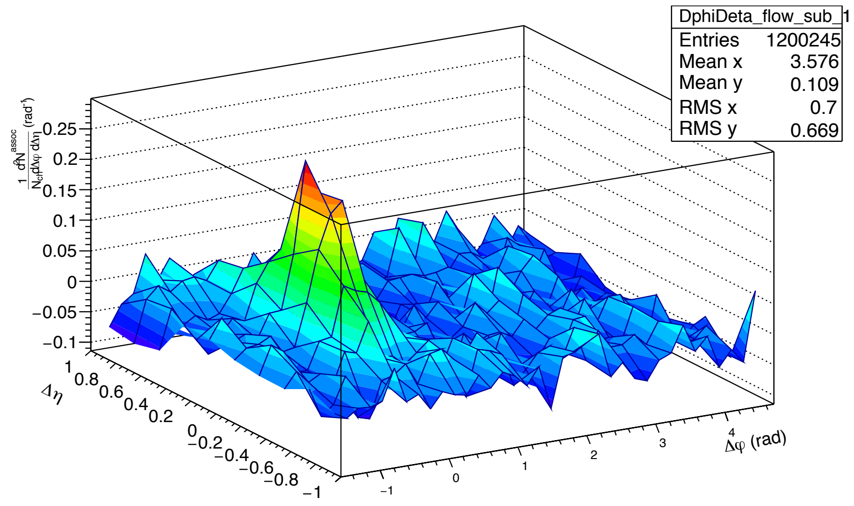
Fully corrected correlation (w.r.t T1)

Centrality 0-7.5%

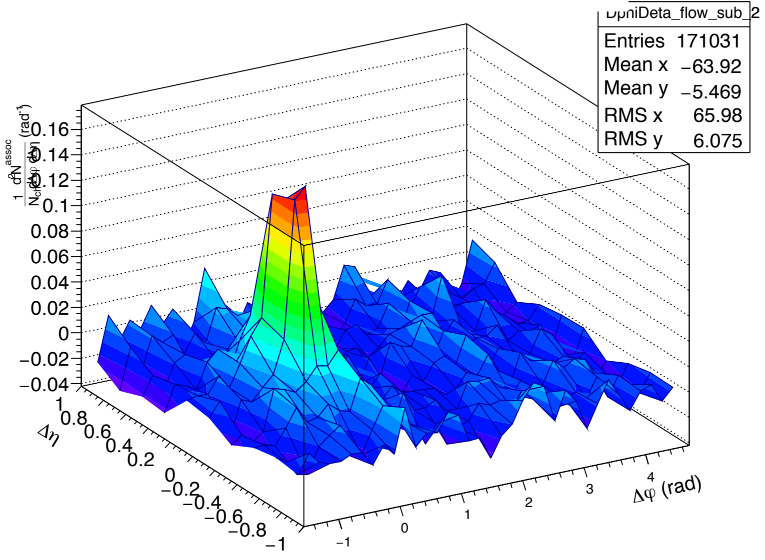
pt assoc: 0.5 -1GeV/c



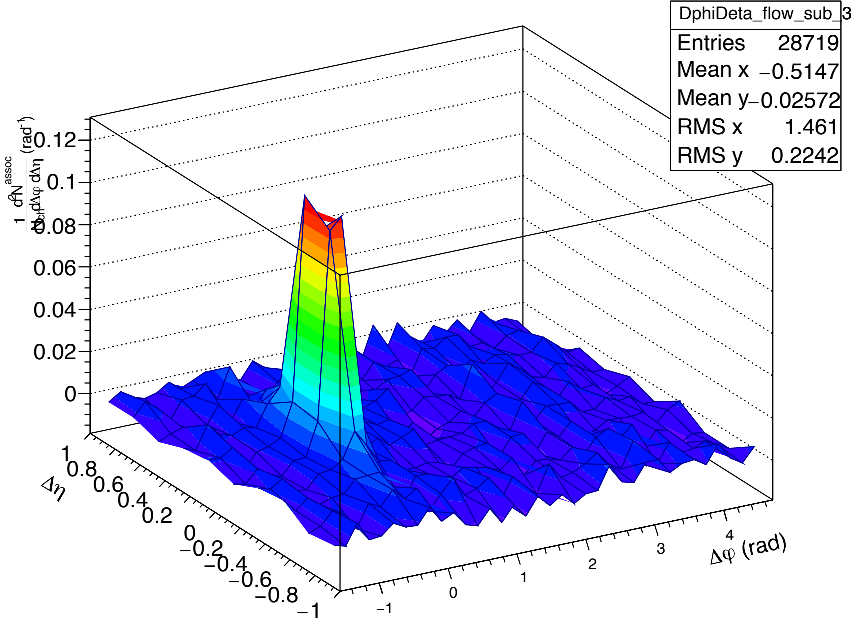
pt assoc: 1 - 2 GeV/c



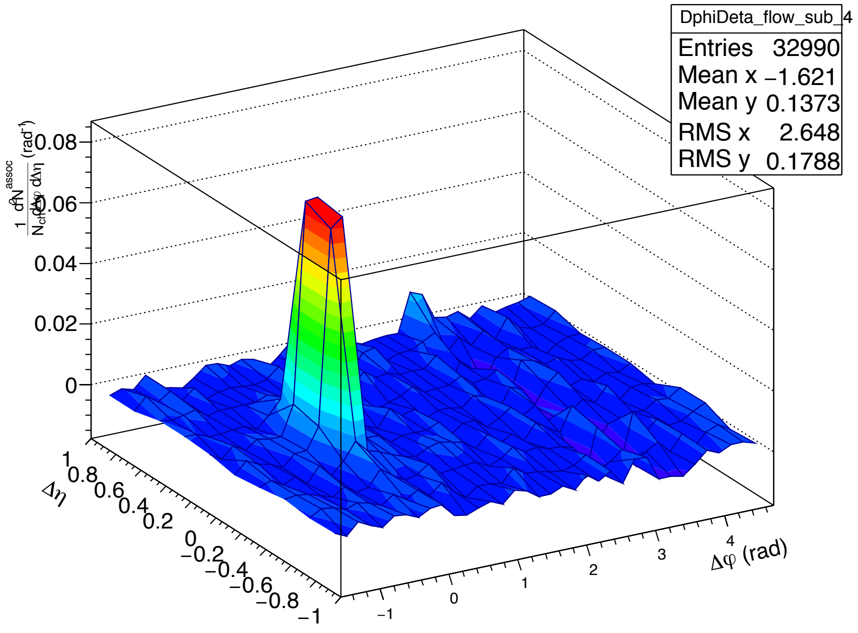
pt assoc: 2 - 3GeV/c



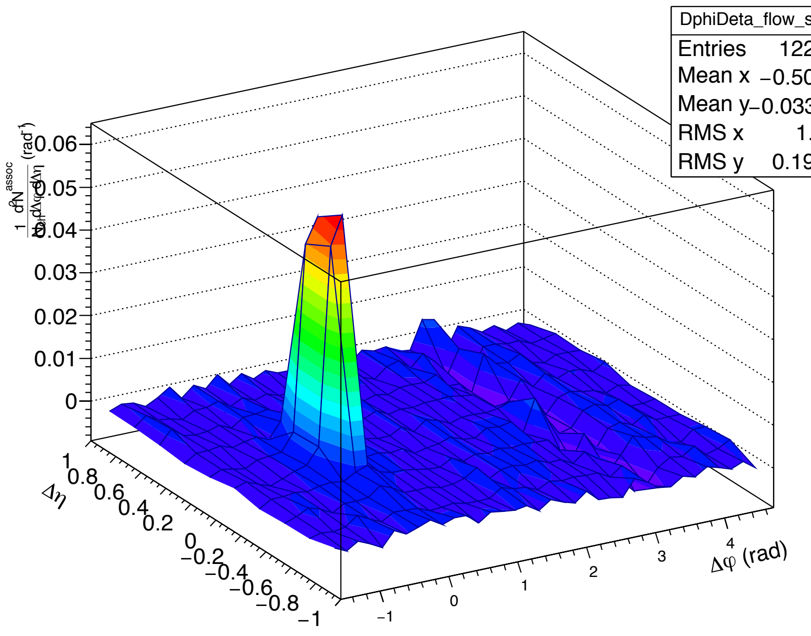
pt assoc: 3 - 4 GeV/c



pt assoc: 4 - 5 GeV/c



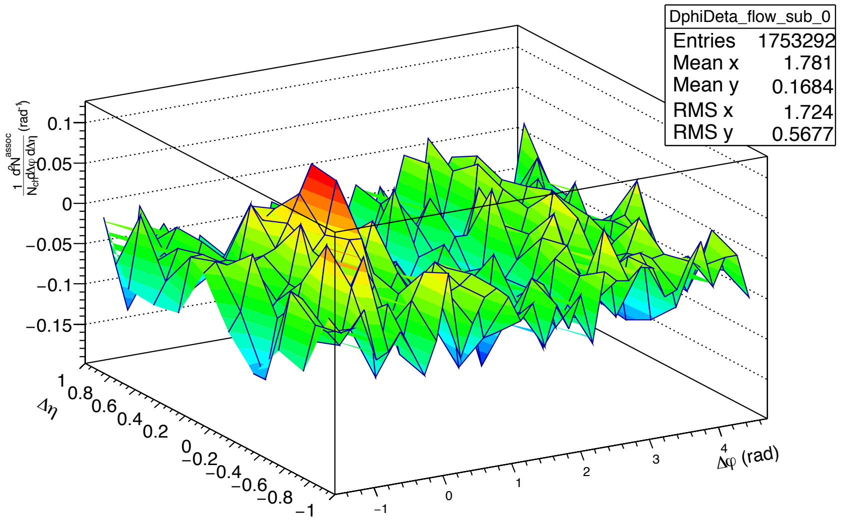
pt assoc: 5 -6GeV/c



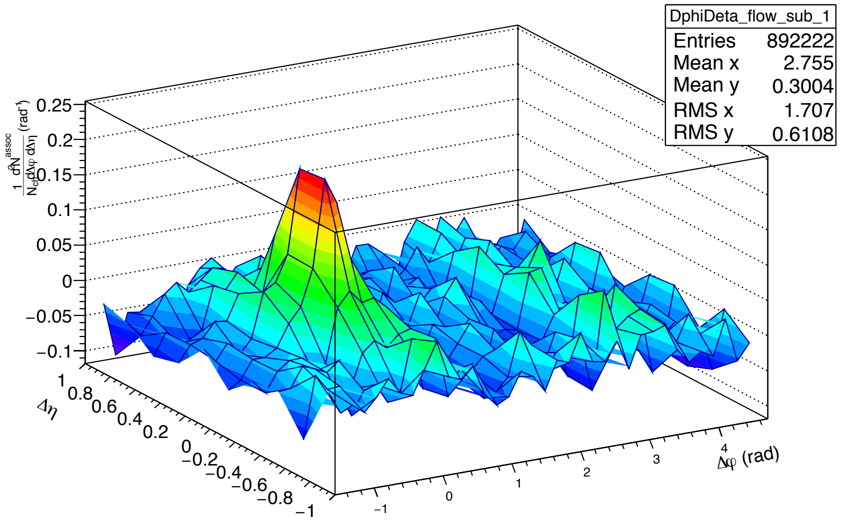
Fully corrected correlation (w.r.t T2)

Centrality 0-7.5%

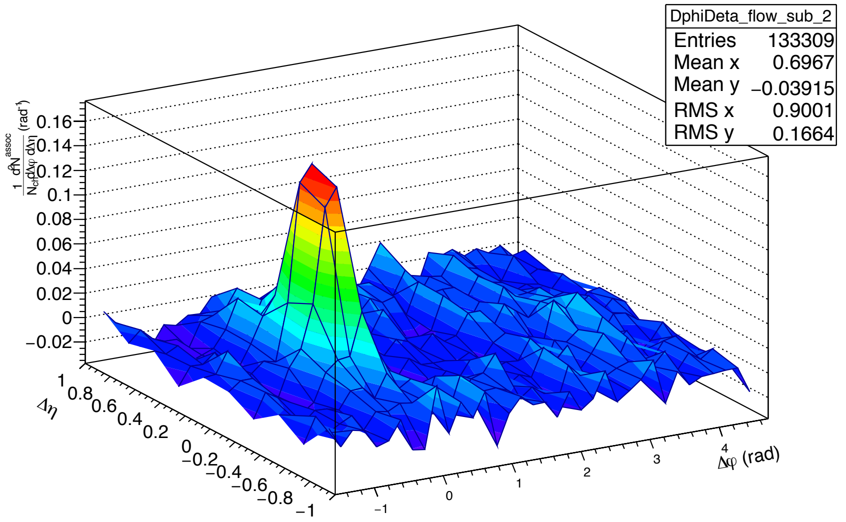
pt assoc: 0.5 -1GeV/c



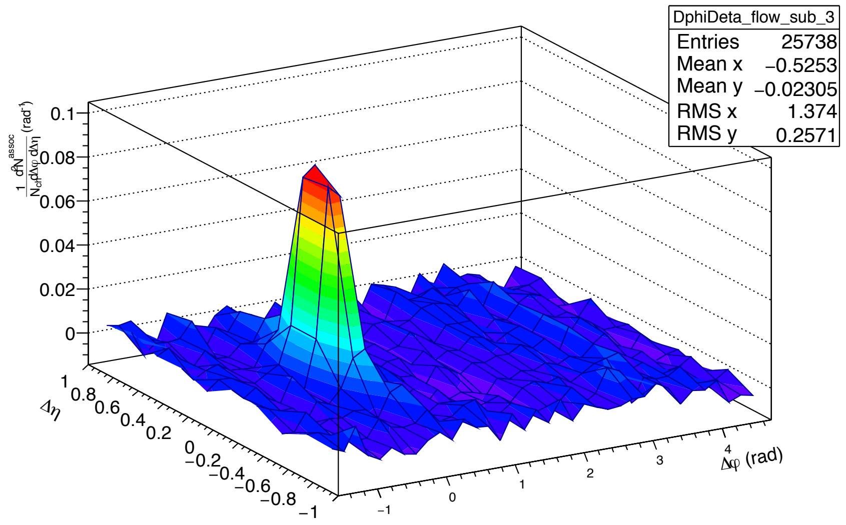
pt assoc: 1 - 2 GeV/c



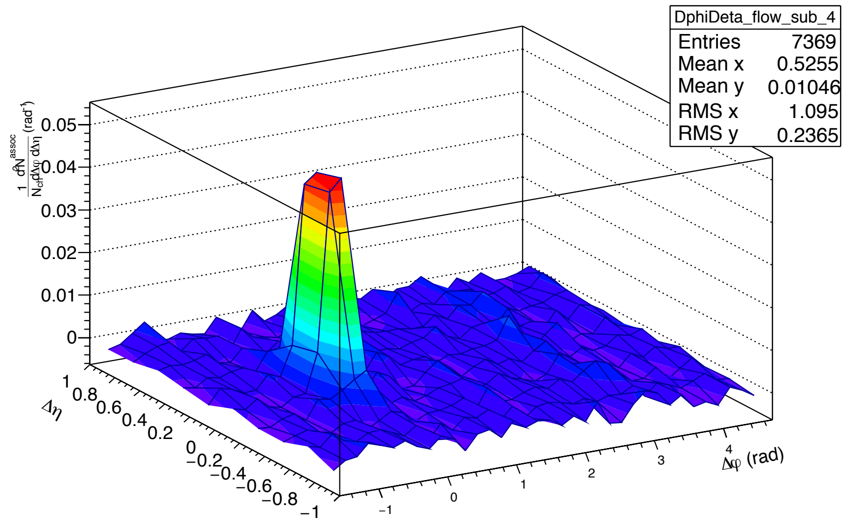
pt assoc: 2 - 3GeV/c



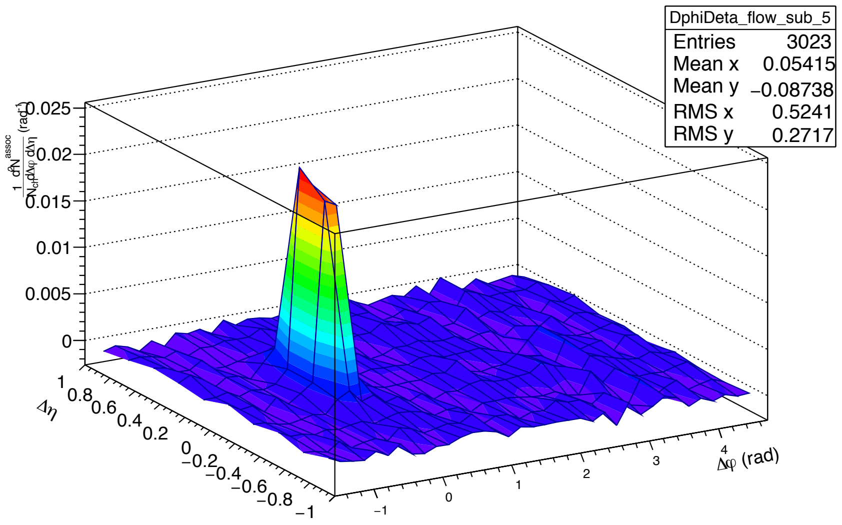
pt assoc: 3 - 4 GeV/c



pt assoc: 4 - 5 GeV/c

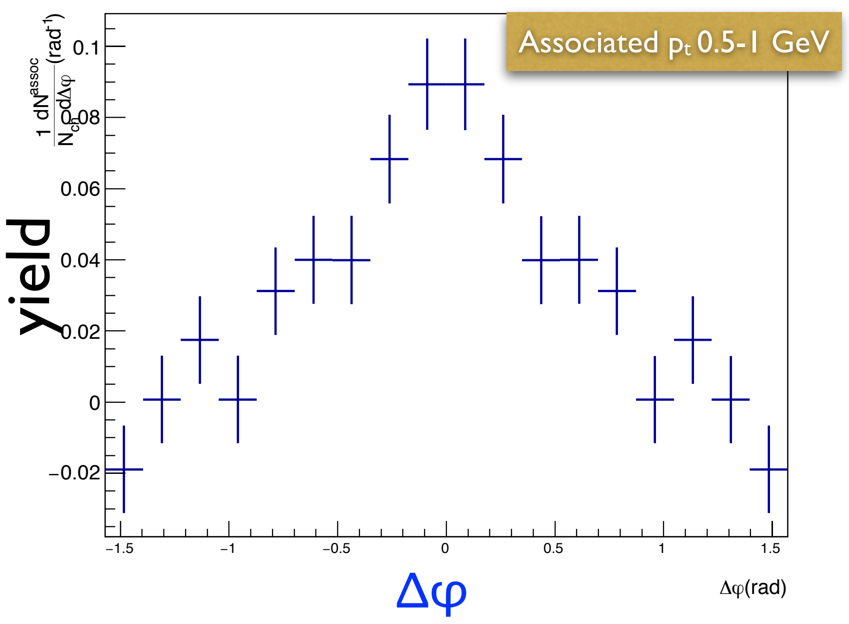


pt assoc: 5 -6GeV/c

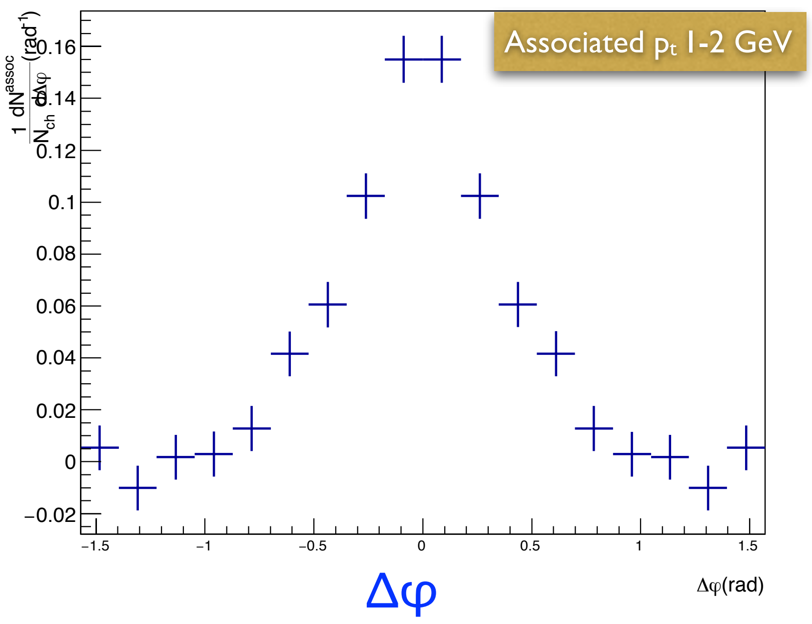


Δφ projections for T2($|\Delta\eta| < 0.5$) Centrality 0-7.5%

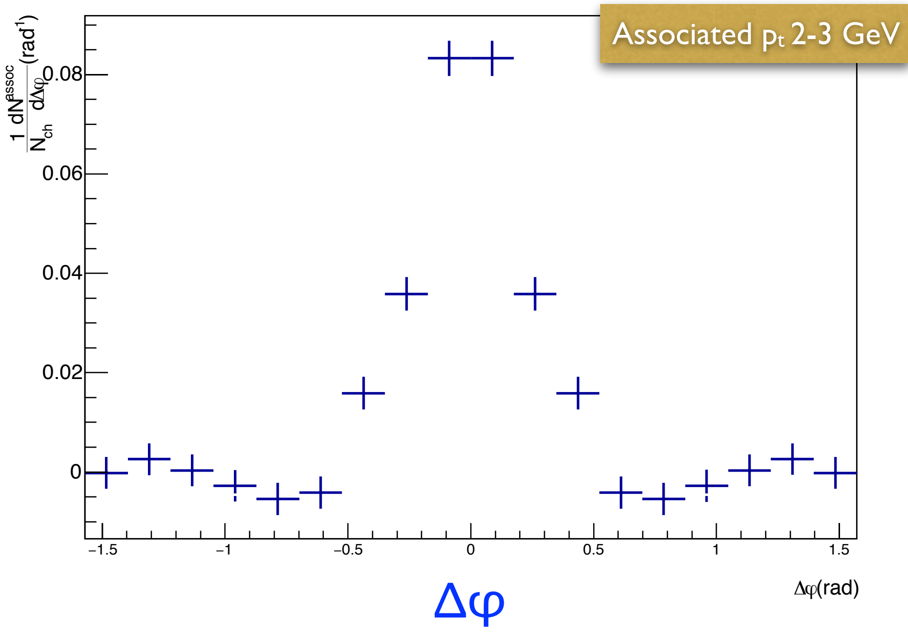
correlations2D_Trigger2_0



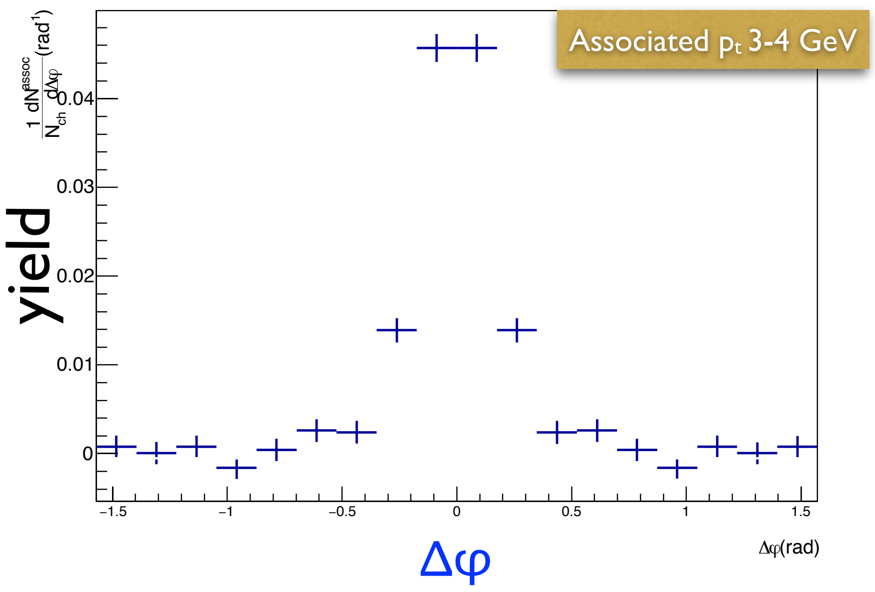
correlations2D_Trigger2_1



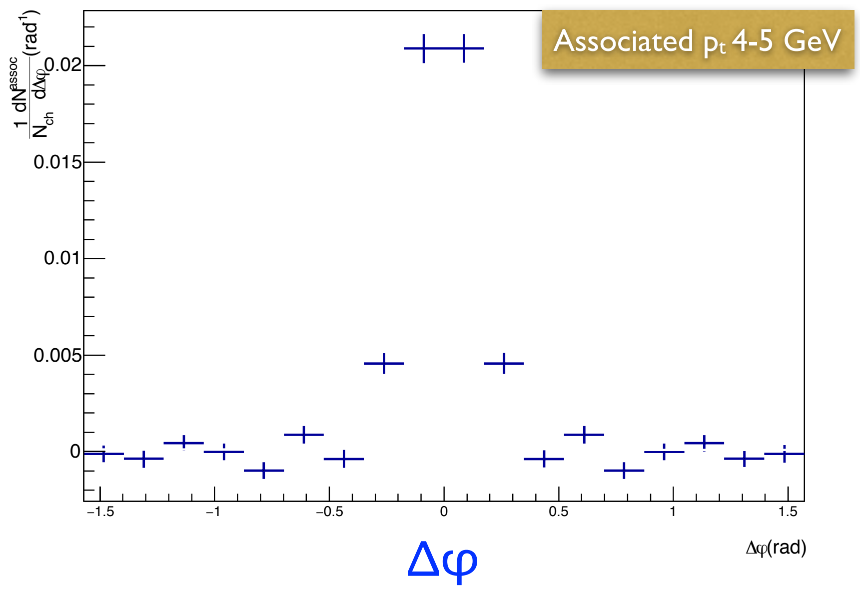
correlations2D_Trigger2_2



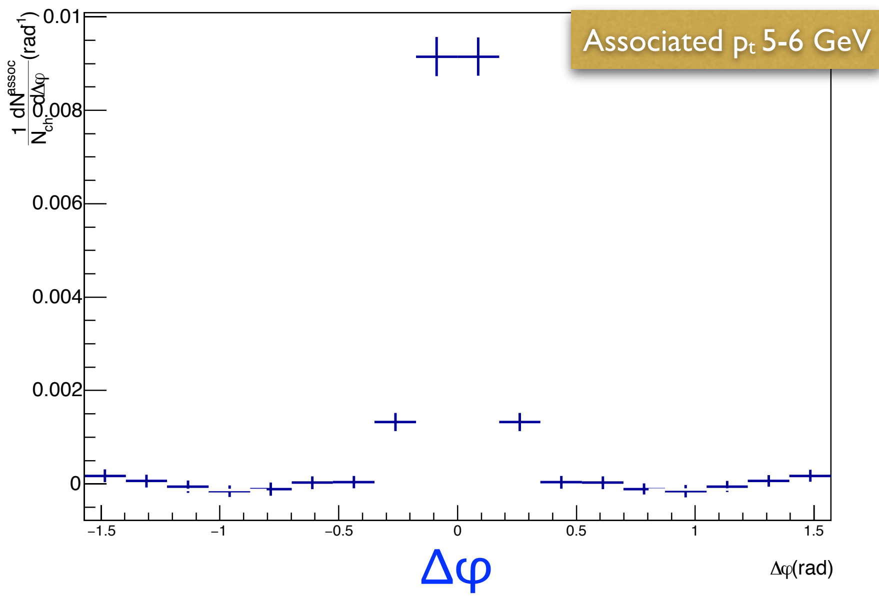
correlations2D_Trigger2_3



correlations2D_Trigger2_4



correlations2D_Trigger2_5



Analysis Steps: New flow to reduce fluctuations

- T1 (primary trigger) is chosen from a pT range. T2 is searched for in another pT region with the condition that $|\Delta\varphi - \pi| <= \pi/8$.

S1. **Raw Correlation** with associated tracks in same event (w/ condition assoc pT < Trigger particle T1 or T2) : $(\Delta\varphi, \Delta\eta)$

S2. **Corrections:** Mixed event correction, single track efficiency correction, correction for two track effects, and resonances and conversions.

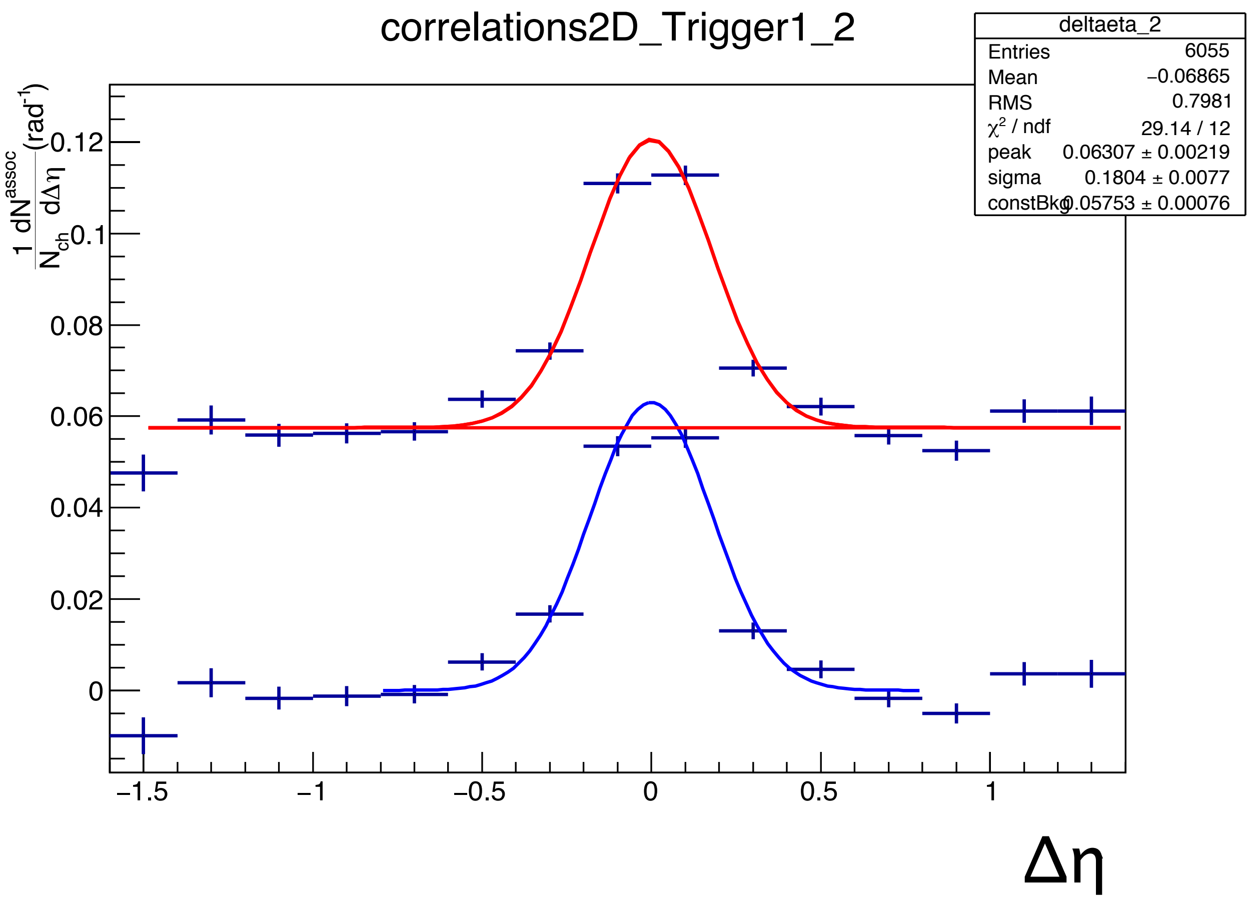
S3. **Background Subtraction:** Subtract background from uncorrelated triggers.

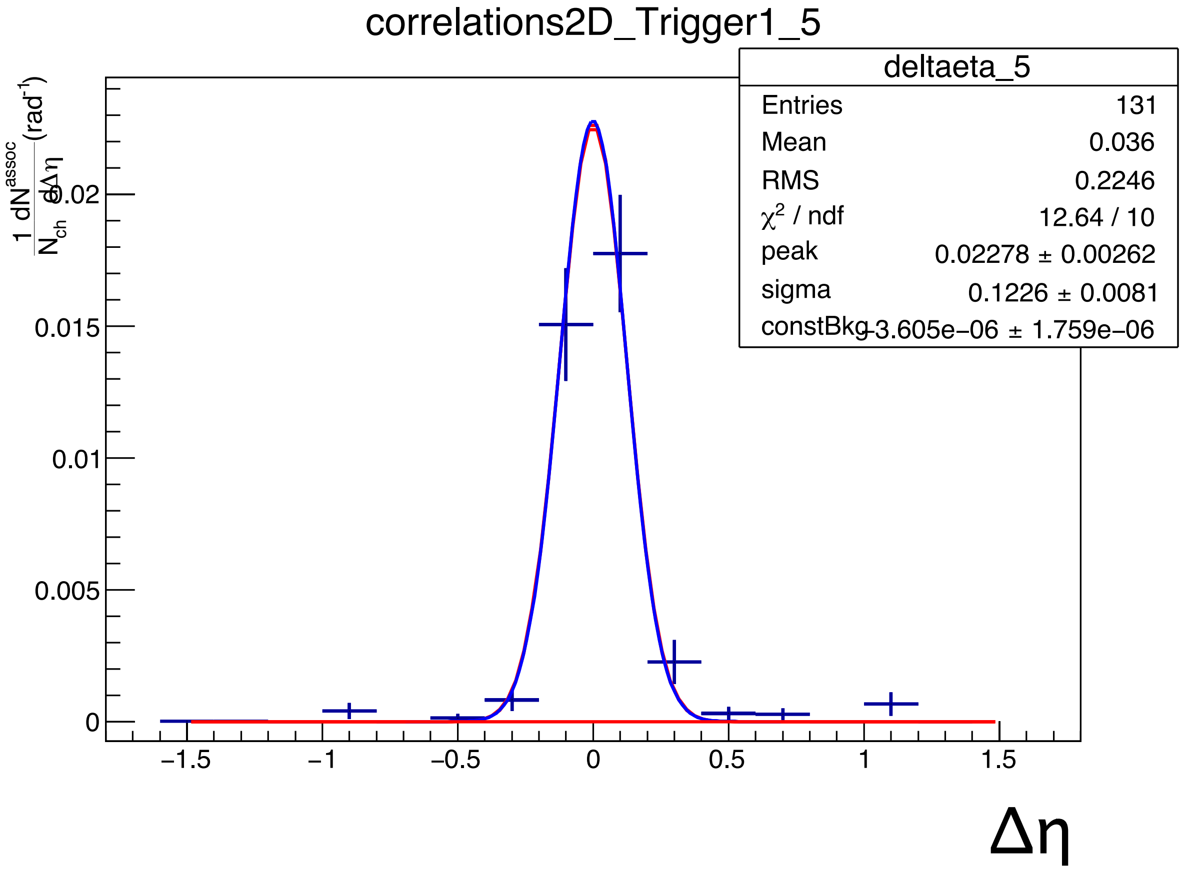
S4. Flow Subtraction via "Eta Gap": $(1.0 < \Delta\eta < 1.4)$.

S5. Observable/Results : Integrated yield for $|\Delta\varphi| < 0.5$

S4. Get the $\Delta\eta$ distribution for $|\Delta\varphi| = 0.5$, fit the $\Delta\eta$ distribution with sum pf two Gaussians (narrow for the peak and less narrow for the tails) + constant for the combinatorial background and get the yield from the fit.

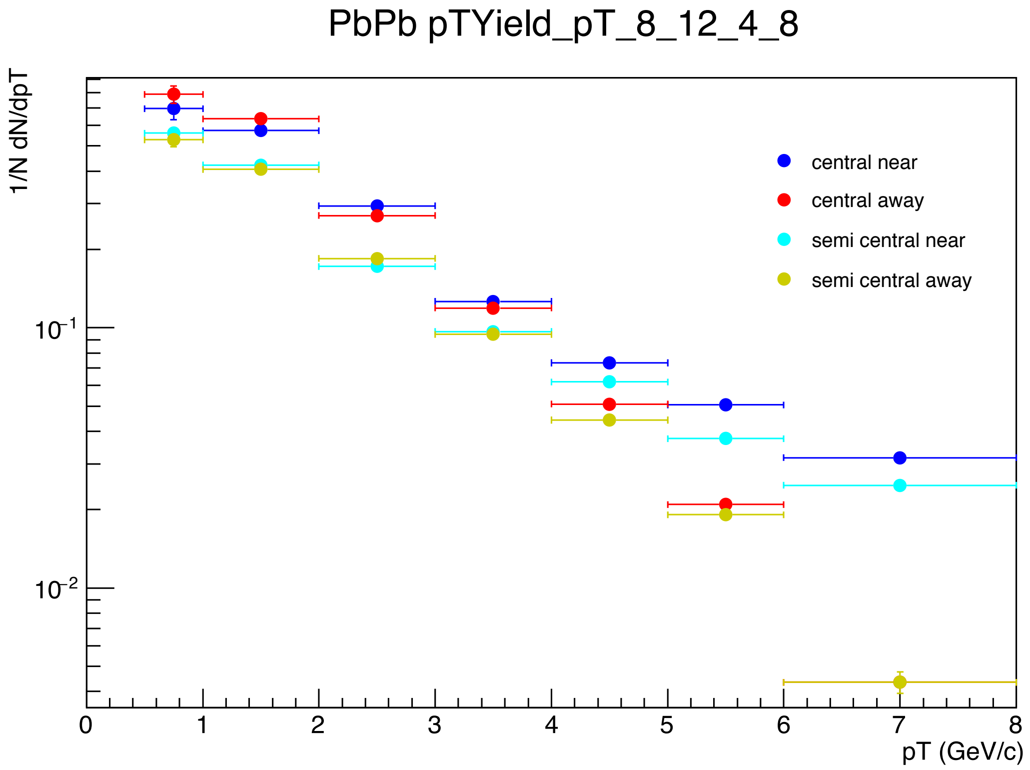
Δη distribution



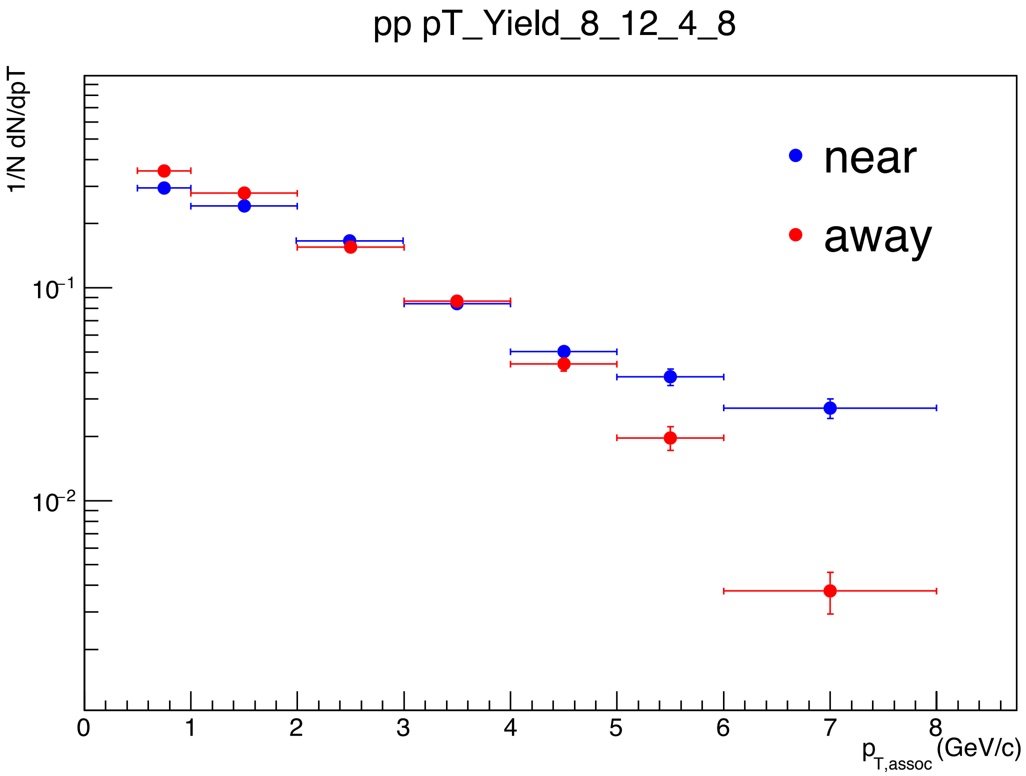


Per Trigger asso p_T Yield

T1 8-12 Gev T2 4-8 GeV



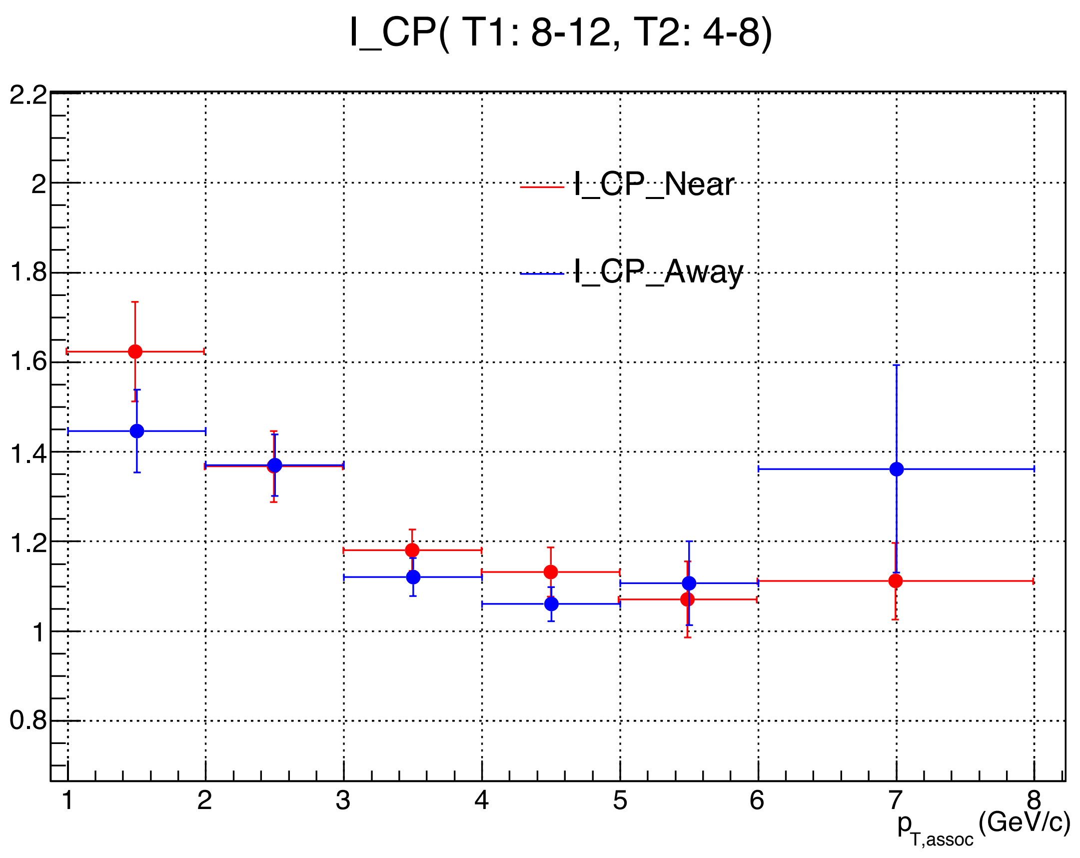
Pb+Pb: Two centrality classes
1) 0 - 7.5 %
2) 30 - 50%

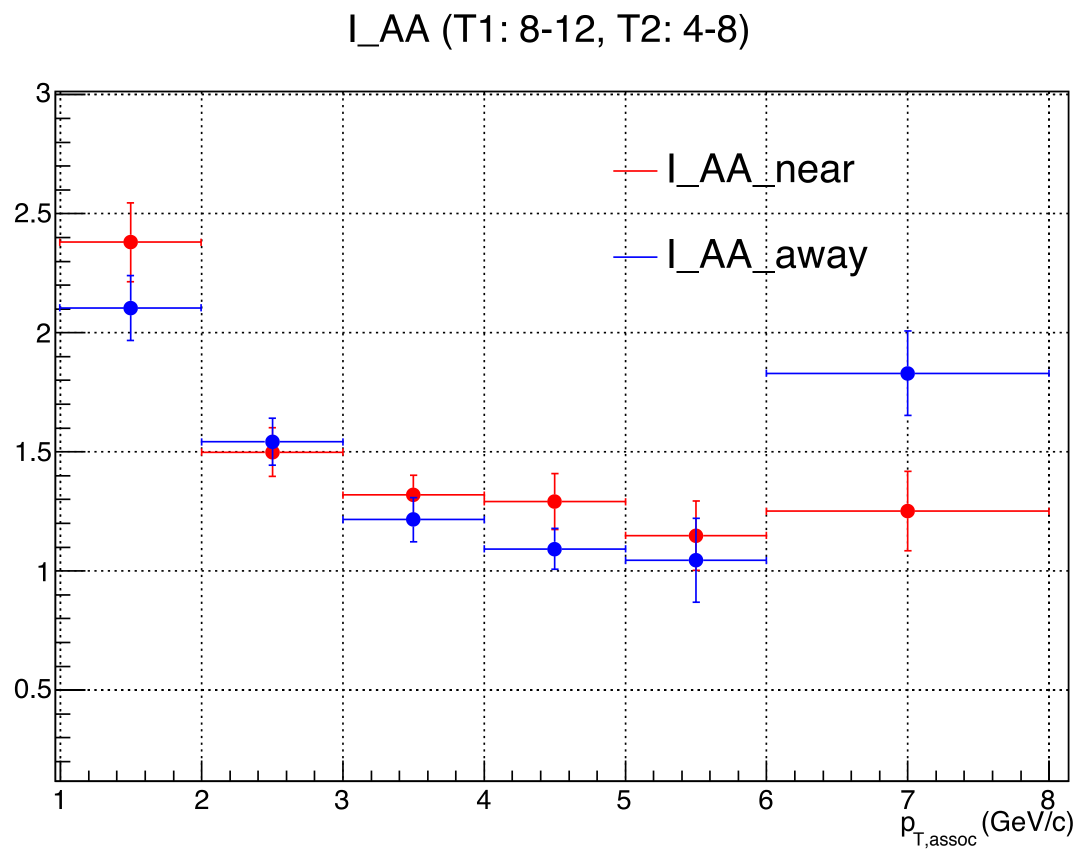


p+p: Integrated multiplicity

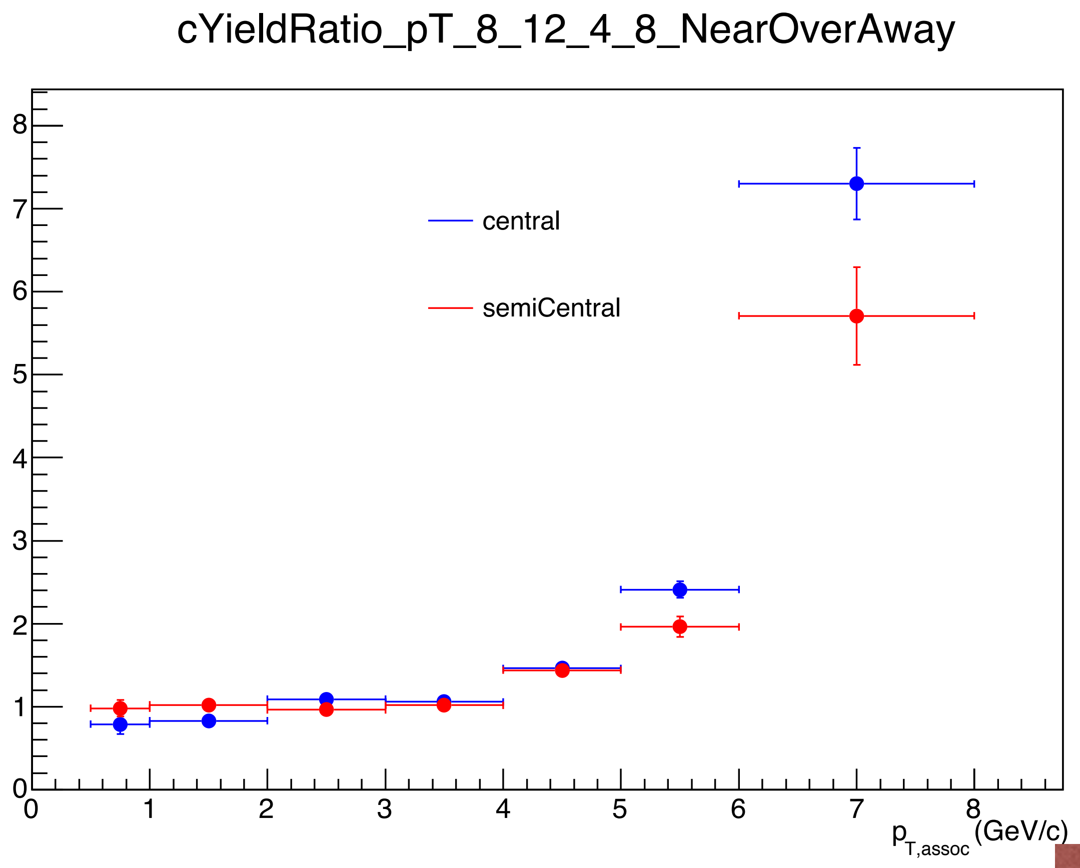
Both T1 & T2 loose energy in central event

1)





2)



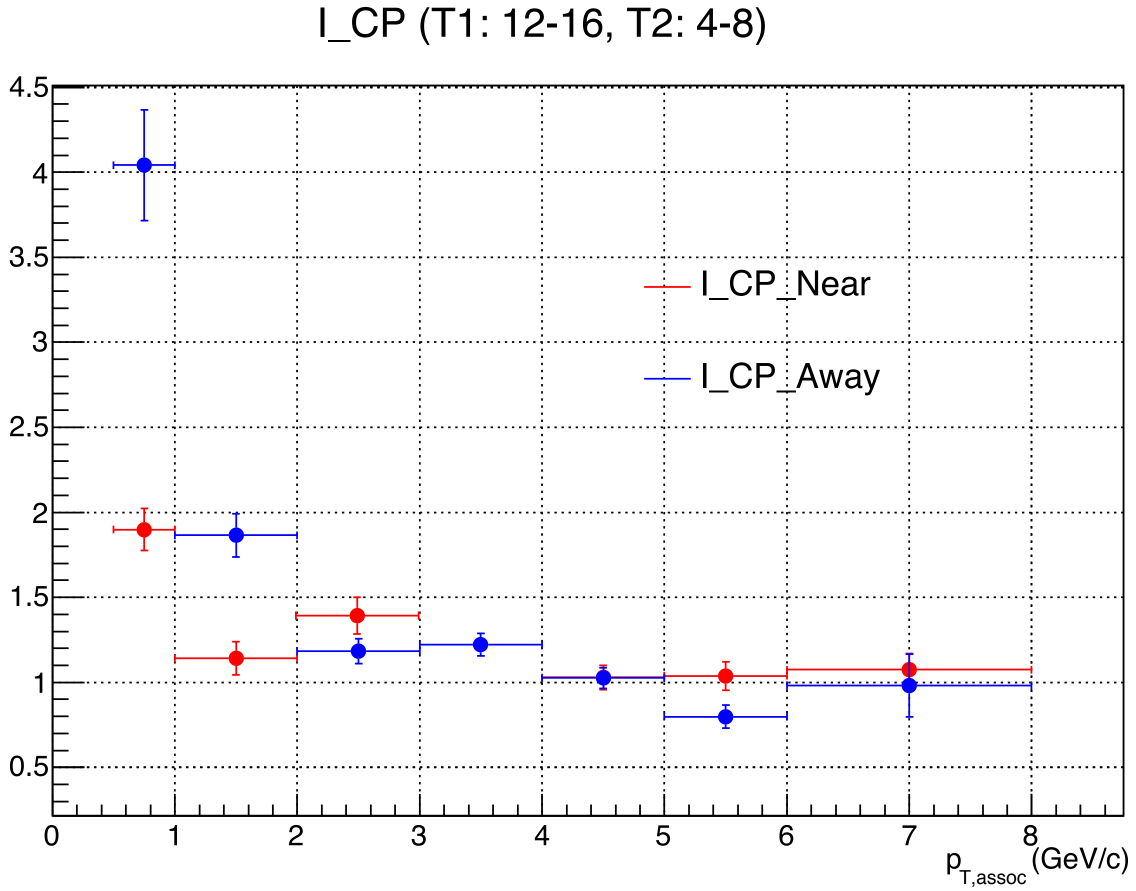
1) I_{CP} (central yield over semi-central yield): The near side as well as the away side values show a systematic decreasing trend which points to the softening of near side as well as away side jets due to QGP formation. As the trigger combinations are symmetric, this is expected.

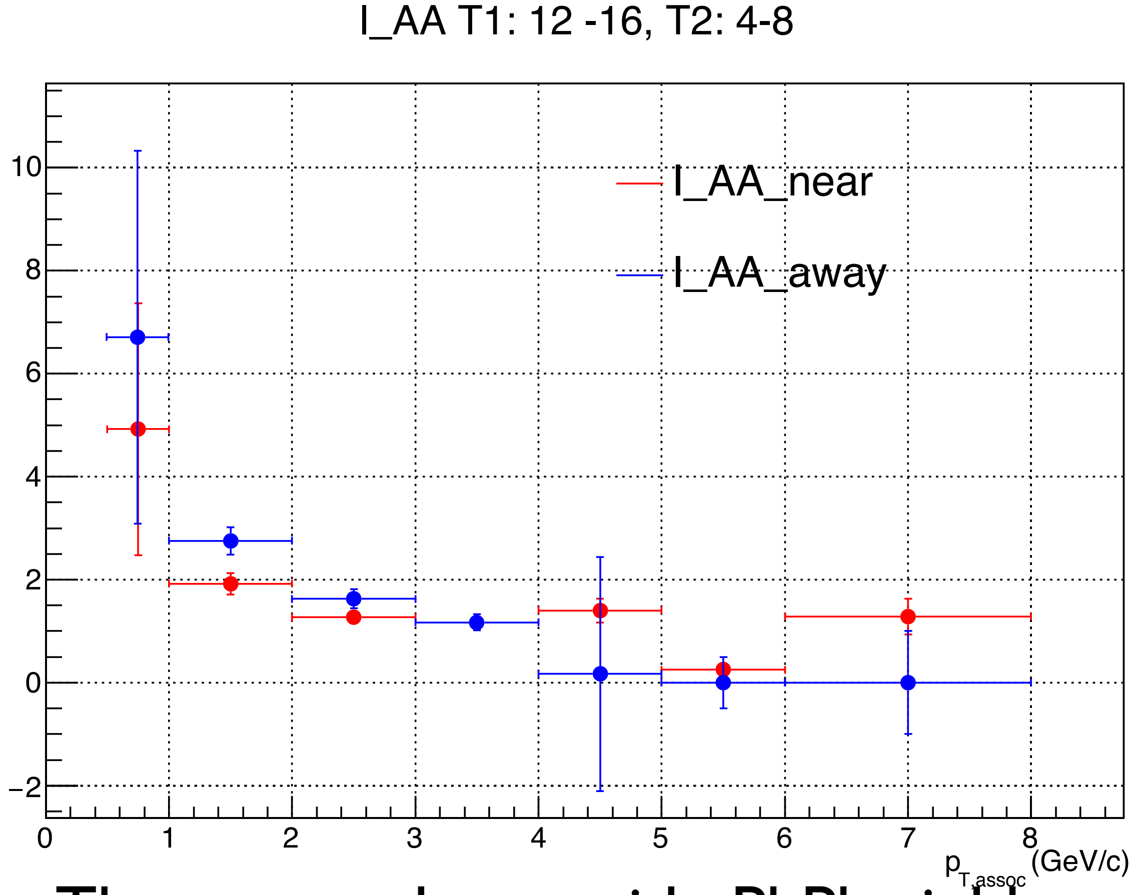
2) Near over away: The central case shows a higher increase than the semi: central has more hard jets than the semi-central.

3) I_{AA}: per trigger yield in PbPb/per trigger yield in pp

Both T1 & T2 loose energy in central event

The Technique Seems to be working



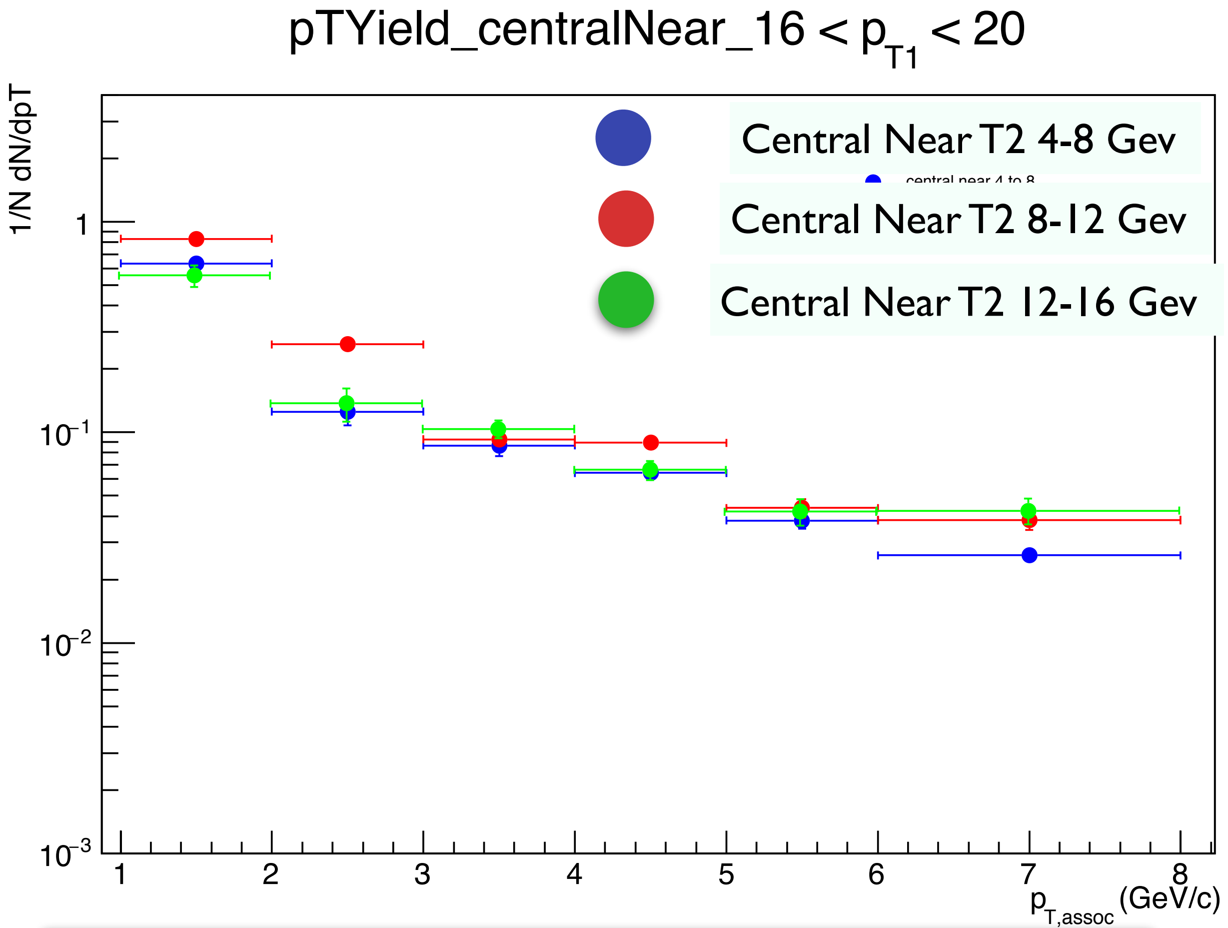


Away side softer than the near side, as expected for asymmetric trigger combinations.

The near and away side PbPb yields are changed with respect to pp. Both the near and away side are softer wrt pp. When going to higher pTass, the I_aa goes below 1.00 indicating that the jets are harder in pp, which indicates towards the formation of a medium.

As you increase the dijet asymmetry the away side more soft than near side

The actual data for the variation of energy loss with p_t of the parton

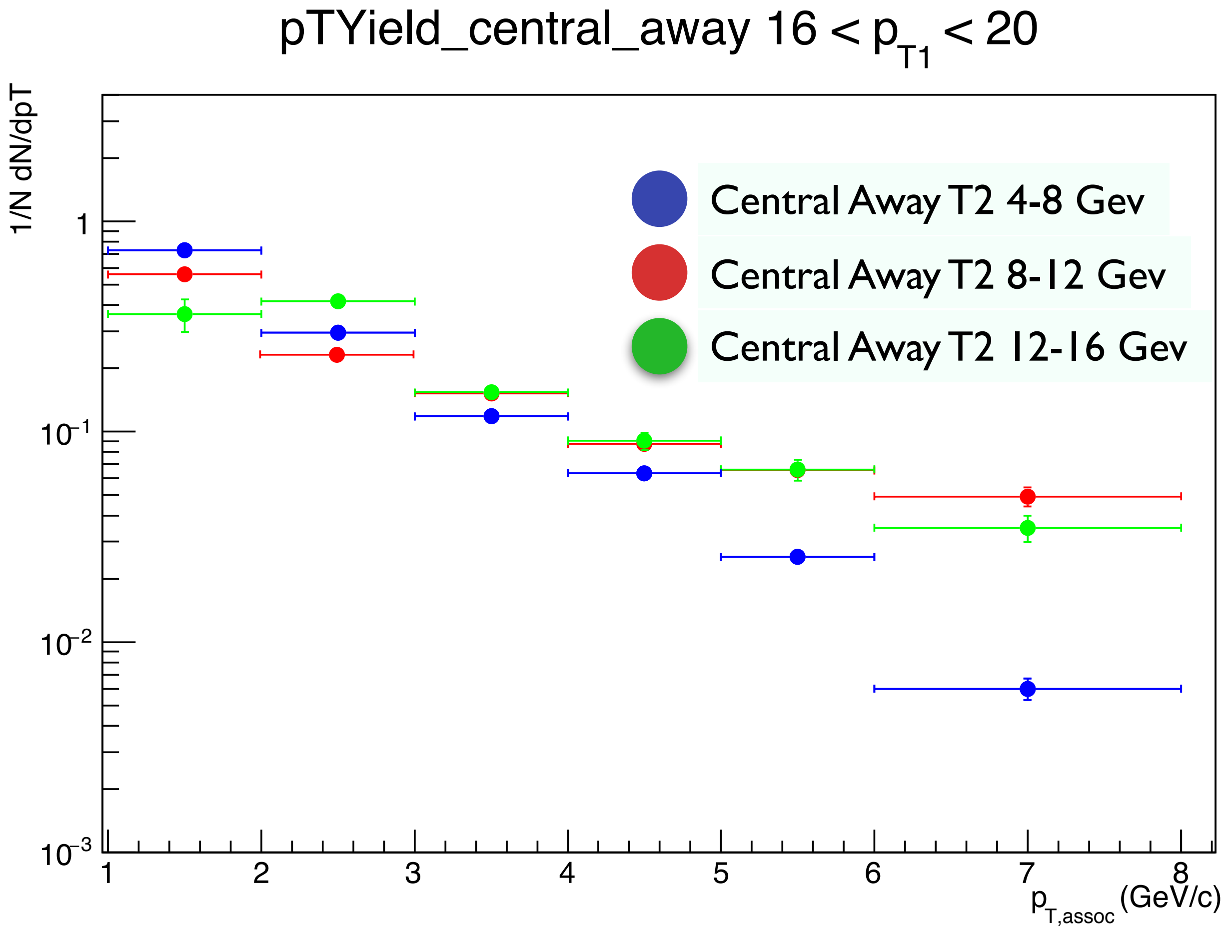


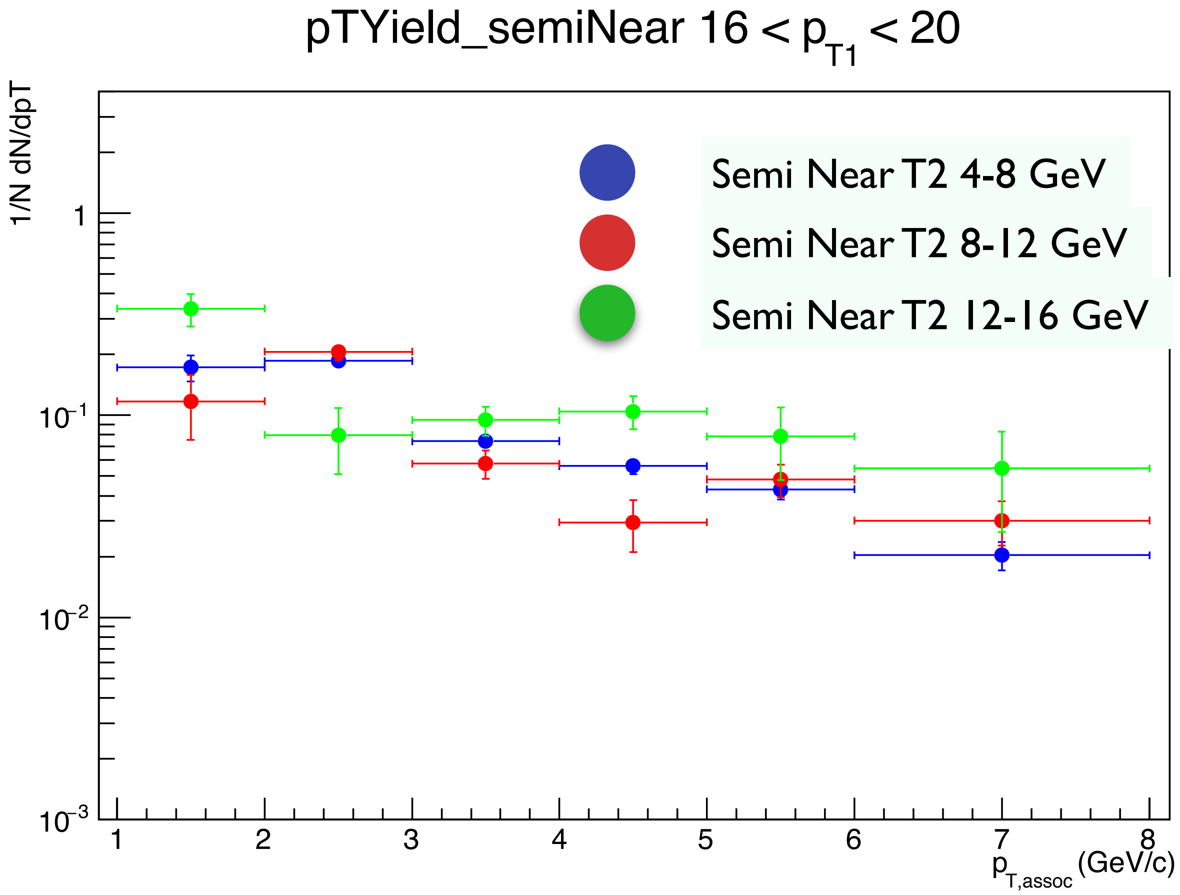
T1: 16 -20
T2: 4 – 8, 8 – 12, 12 - 16

From the slopes of the yield for different away side pT, one can infer about the softening of away side jets.

For 4-8 GeV/c, the softening is the highest, which then reduces for 8-12, and further for 12-16.

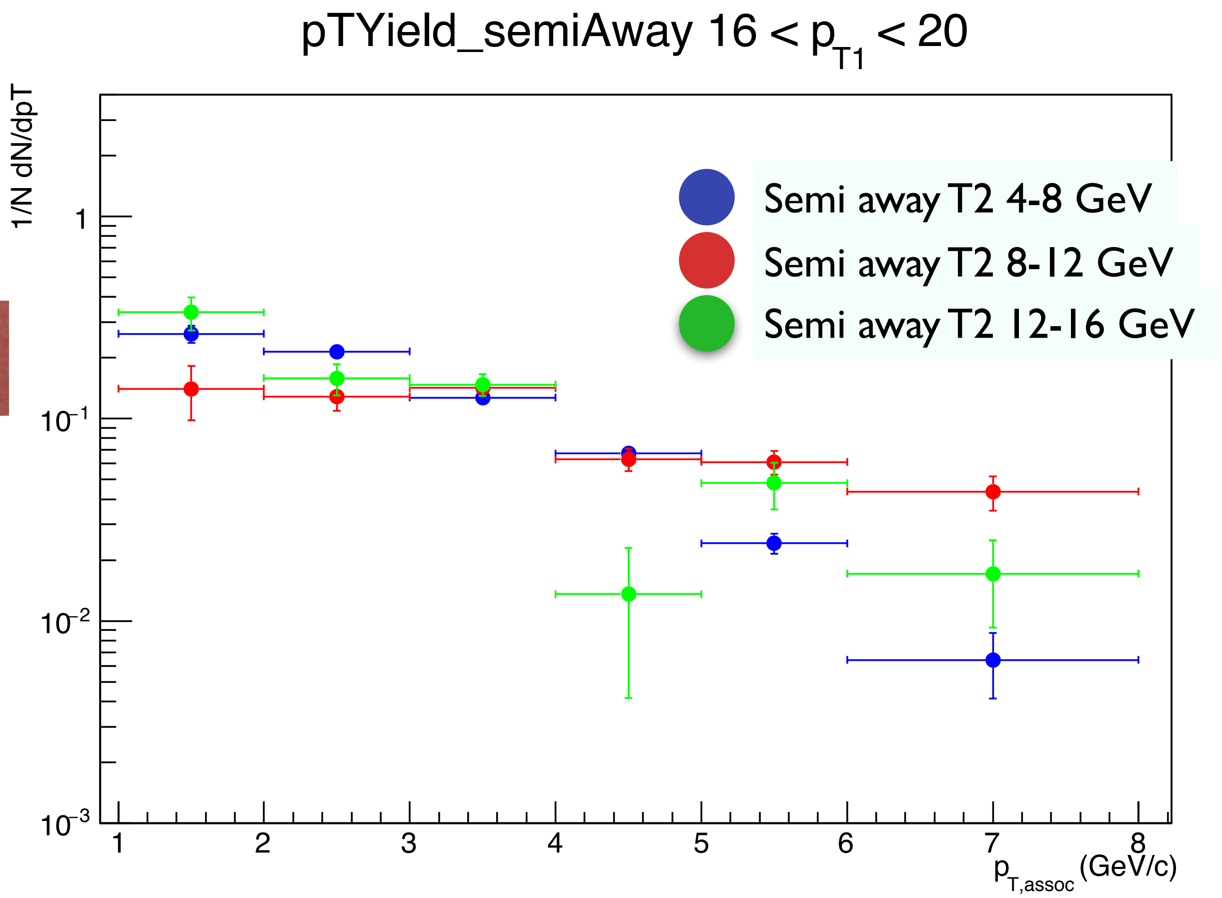
This difference in softening with away side trigger pT implies 2+1 correlation probes different region of the medium formed.





For semi central away, where the medium created is not as dense as in case of central, the yields for all pT are within error bars, and no definite inference can be made.

Nature behaves as we thought it should



Summary

2+1 correlations in Pb+Pb and p+p collisions at 2.76 TeV have been done.

Fully corrected distribution has been obtained – corrected for uncorrelated triggers, mixed event, single track efficiency and two track efficiency.

The results obtained so far from the analysis (only statistical uncertainties), looks really positive.

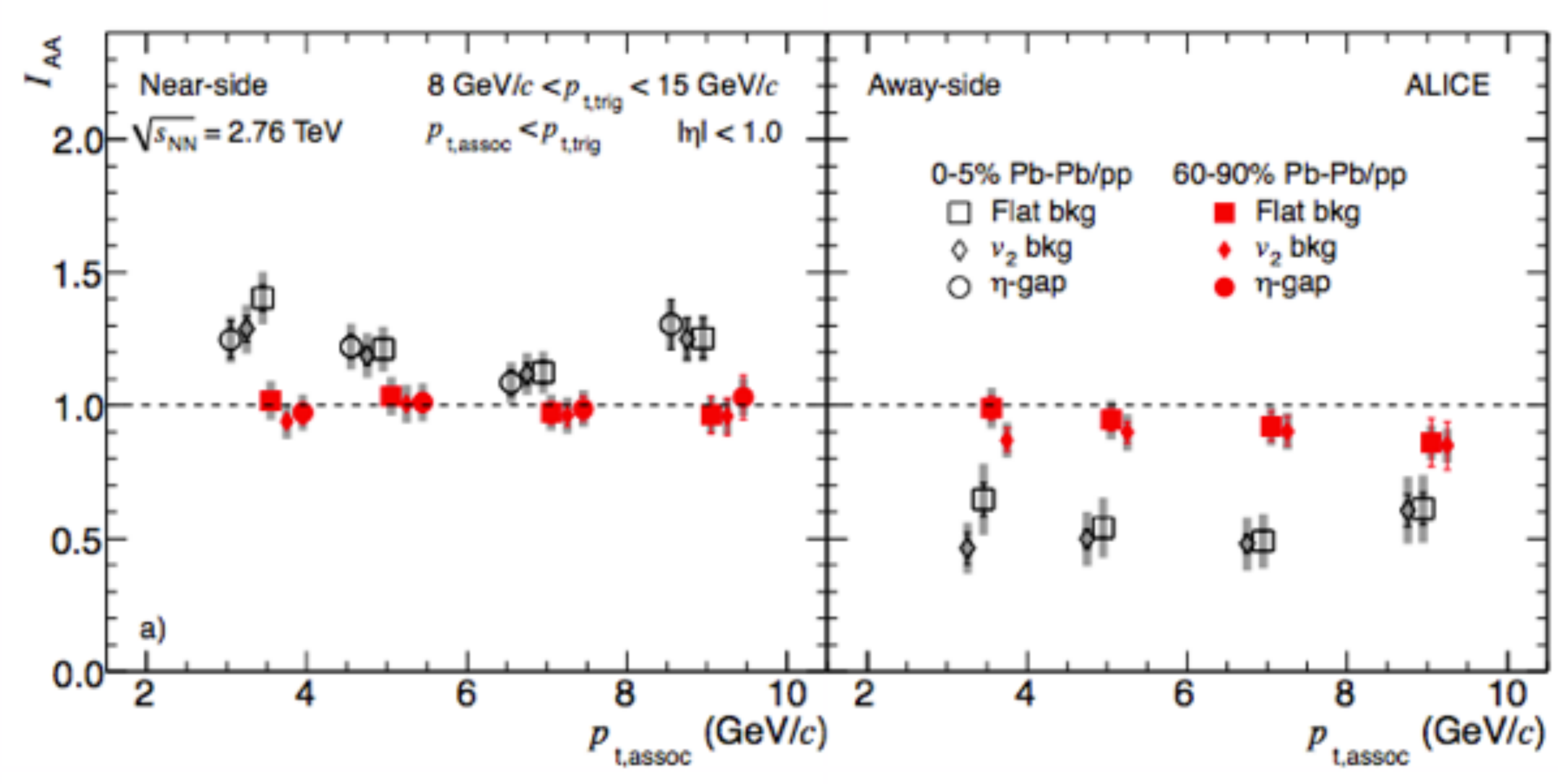
→ Confirms the presence of a medium formation in central collisions.

→ Analysis with different combinations of T1 and T2 reveals it is possible to scan different regions of the fireball.

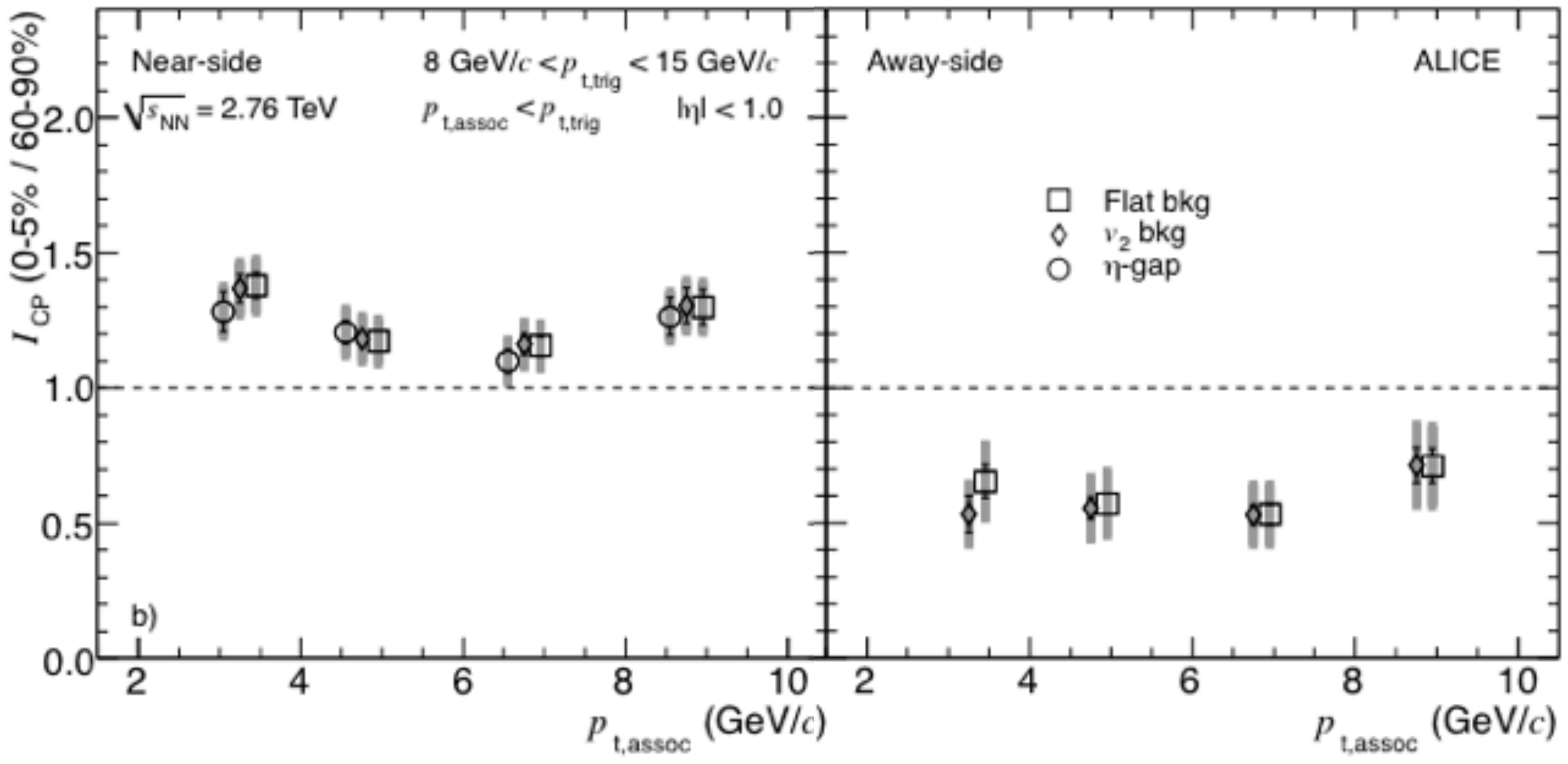
Systematic uncertainties – ongoing.

Dijet Assymetry has to be evaluated

Thank You.



I_{AA}
Near-side
$\sqrt{s_{NN}} = 2.76$ TeV
8 GeV/c < $p_{t,trig}$ < 15 GeV/c
$p_{t,assoc} < p_{t,trig}$
$|\eta| < 1.0$
Away-side
ALICE
0-5% Pb-Pb/pp
□ Flat bkg
◊ v_2 bkg
○ η-gap
60-90% Pb-Pb/pp
■ Flat bkg
♦ v_2 bkg
● η-gap
a)
0.0
0.5
1.0
1.5
2.0
2
4
6
8
10
$p_{t,assoc}$ (GeV/c)



I_{CP} (0-5% / 60-90%)
Near-side
$\sqrt{s_{NN}} = 2.76$ TeV
8 GeV/c < $p_{t,trig}$ < 15 GeV/c
$p_{t,assoc} < p_{t,trig}$
$|\eta| < 1.0$
Away-side
ALICE
□ Flat bkg
◊ v_2 bkg
○ η-gap
b)
0.0
0.5
1.0
1.5
2.0
2
4
6
8
10
$p_{t,assoc}$ (GeV/c)