Intermediate and High-P_T Correlations in ALICE

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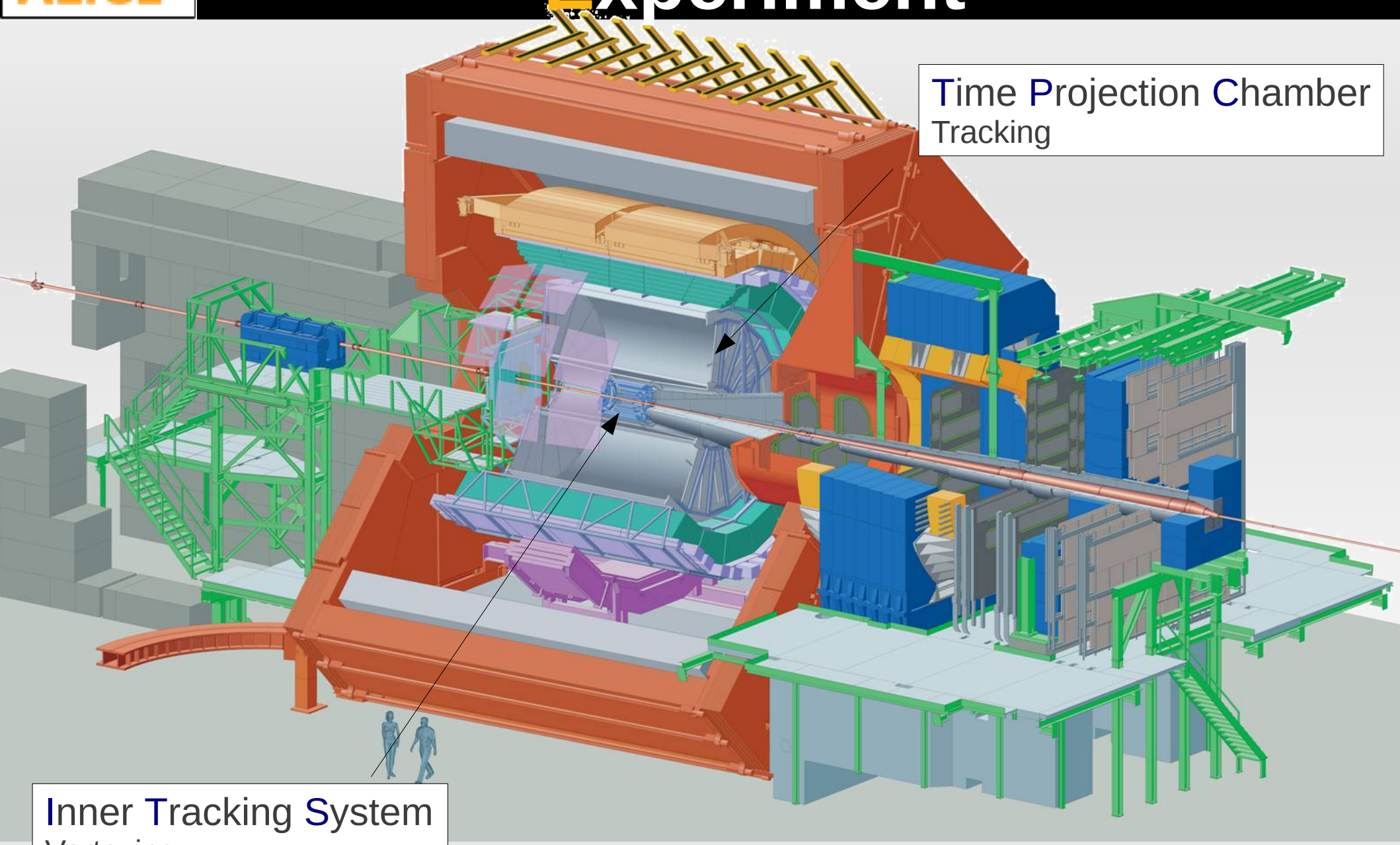
High-PT Probes of High-Density QCD at the LHC

Outline

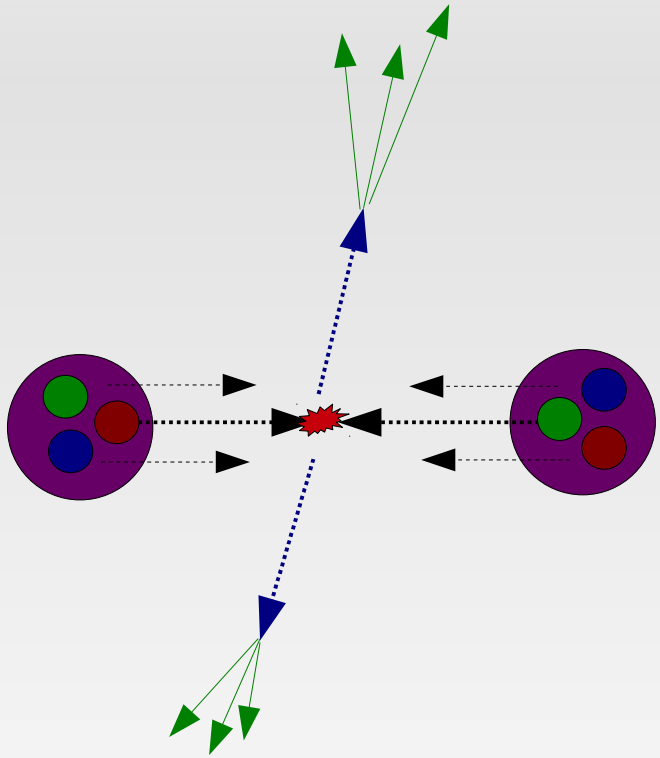
- Introduction
- I_{AA}
- Fourier Decomposition of Two-Particle Correlations
- Three-Particle Correlations
- Summary

A Large Ion Collider Experiment



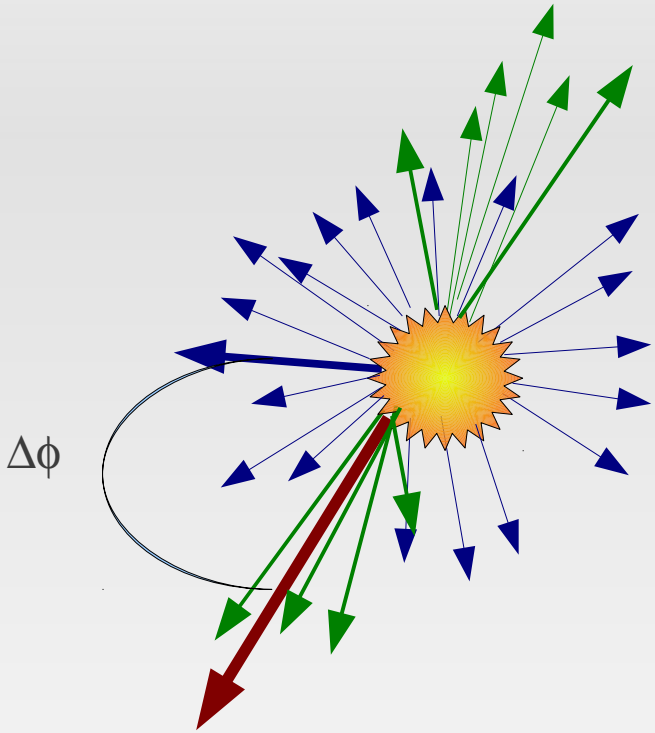
Motivation

- Jets: cone of hadrons produced from a hard scattering of partons.
  - calculable in pQCD
- Study in pp to understand fragmentation.
- Probe medium created in heavy-ion collisions.
  - Study jet ⇔ medium interaction.



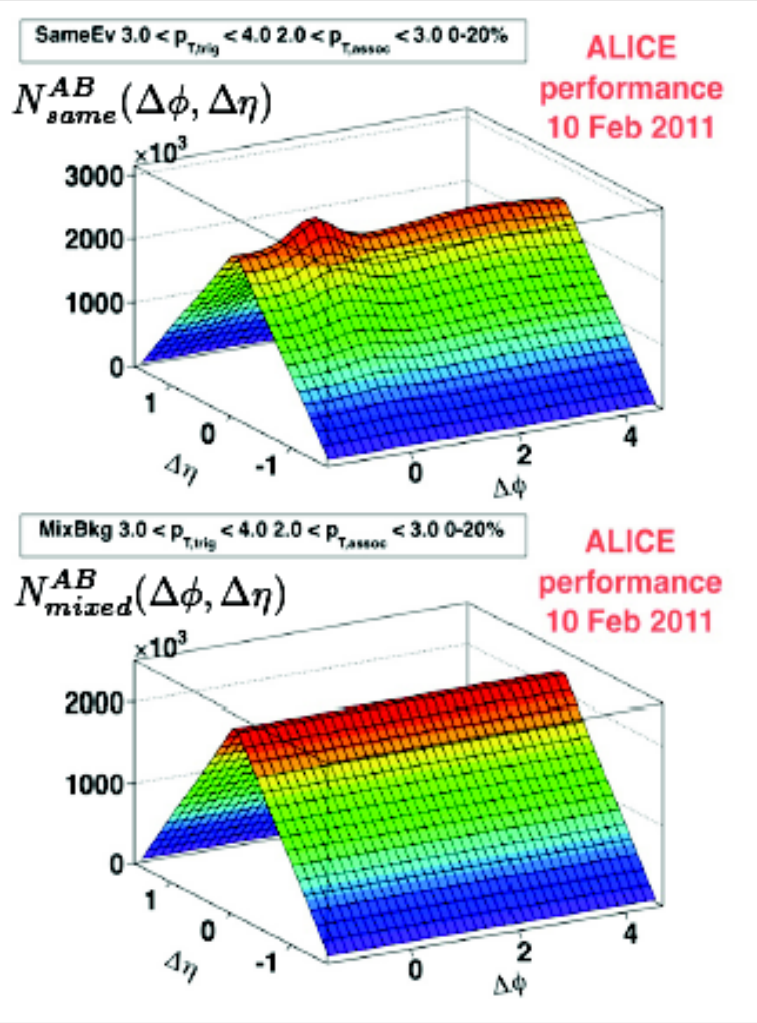
2-Particle Correlations

- Select intermediate or high-p_T trigger particles.
- Calculate angle between trigger and other particles.
  - $\Delta\phi=\phi_{Trigger}-\phi_{Assoc}$
  - $\Delta\eta=\eta_{Trigger}-\eta_{Assoc}$
- Background.
  - Flow correlated with trigger particle.



2-Particle Correlations

Adare QM11

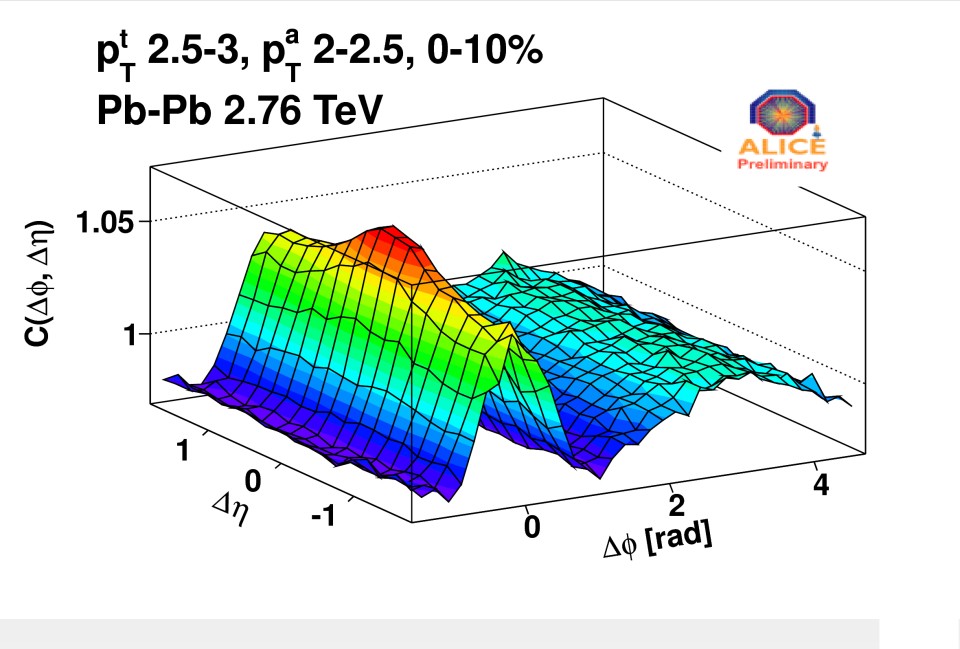


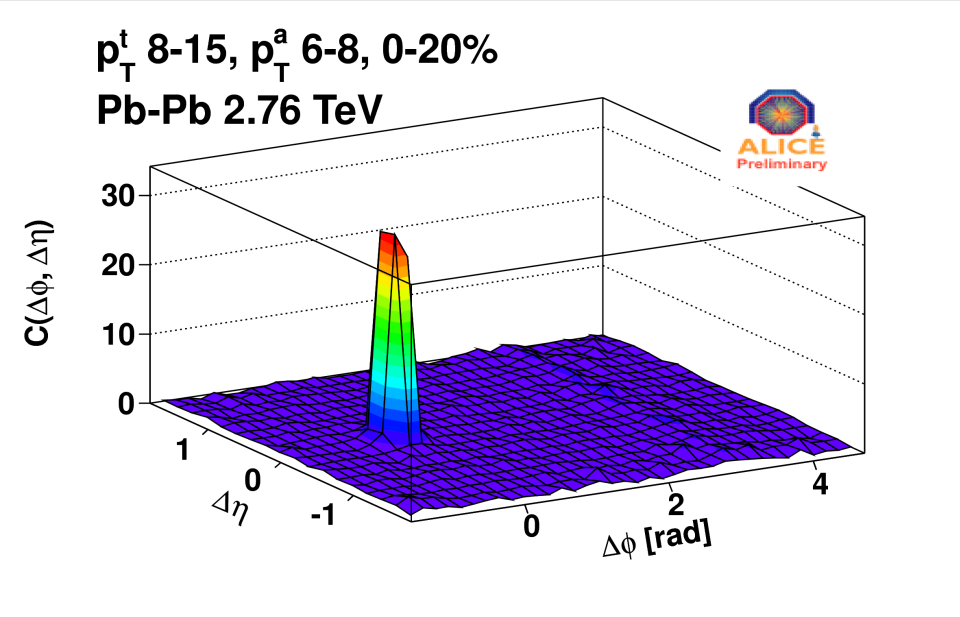
- Correlation function built from the ratio of the signal and mixed events.
  - Mixed events correct to detector acceptance and 2-particle pair acceptance.

$$C(\Delta\phi, \Delta\eta) = \frac{N_{mixed}}{N_{triggered}} \frac{d^2 N_{triggered}/d\Delta\phi\, d\Delta\eta}{d^2 N_{mixed}/d\Delta\phi\, d\Delta\eta}$$

P_T Evolution

Adare QM11



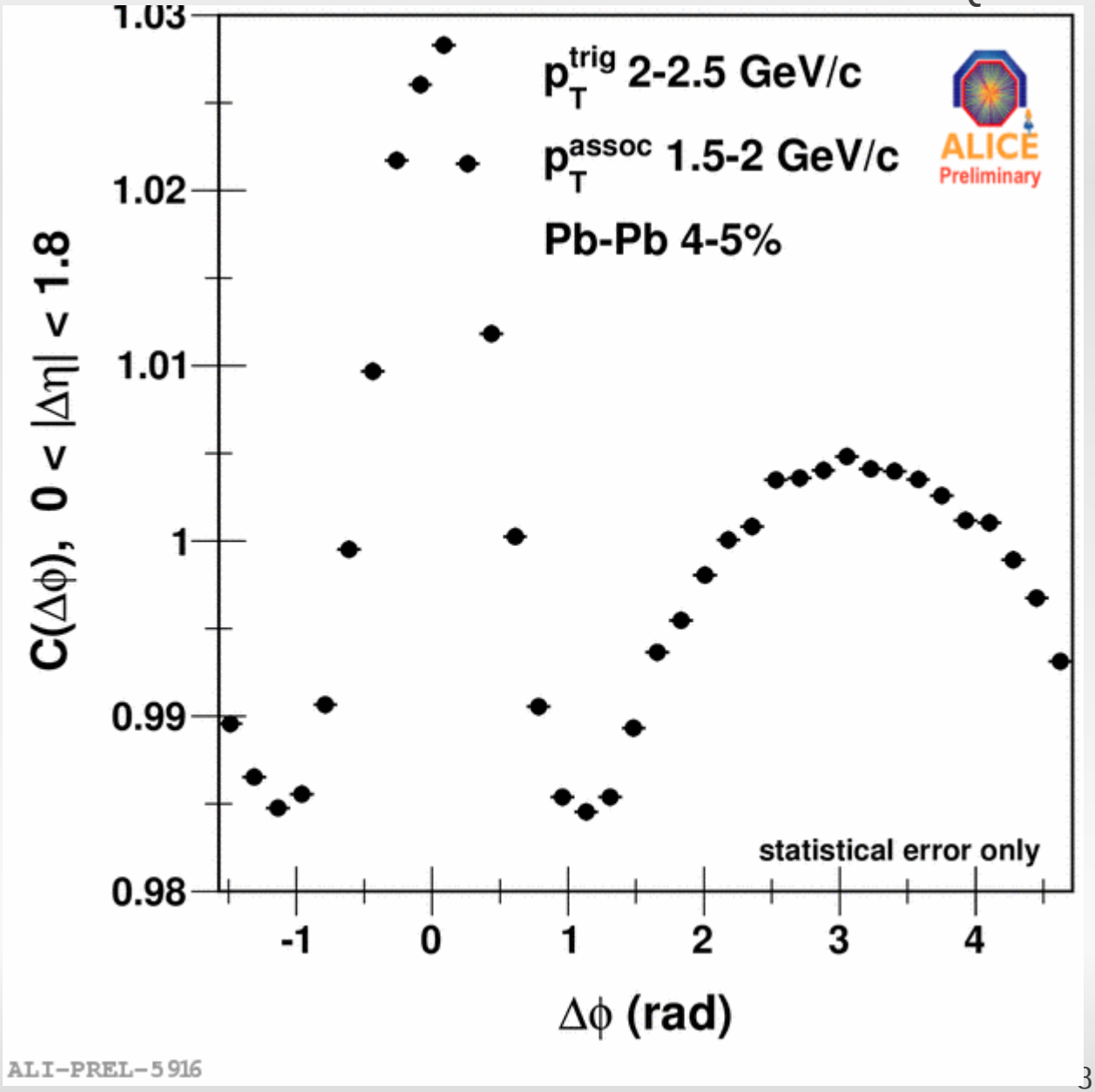


- No background subtraction.
- Low p_T shows near-side ridge and broad away-side.
- High p_T near-side peak dominated.

Approaching Ultra-Central PbPb

Adare QM11

- Change in **unsubtracted** correlation function for very small changes in centrality.



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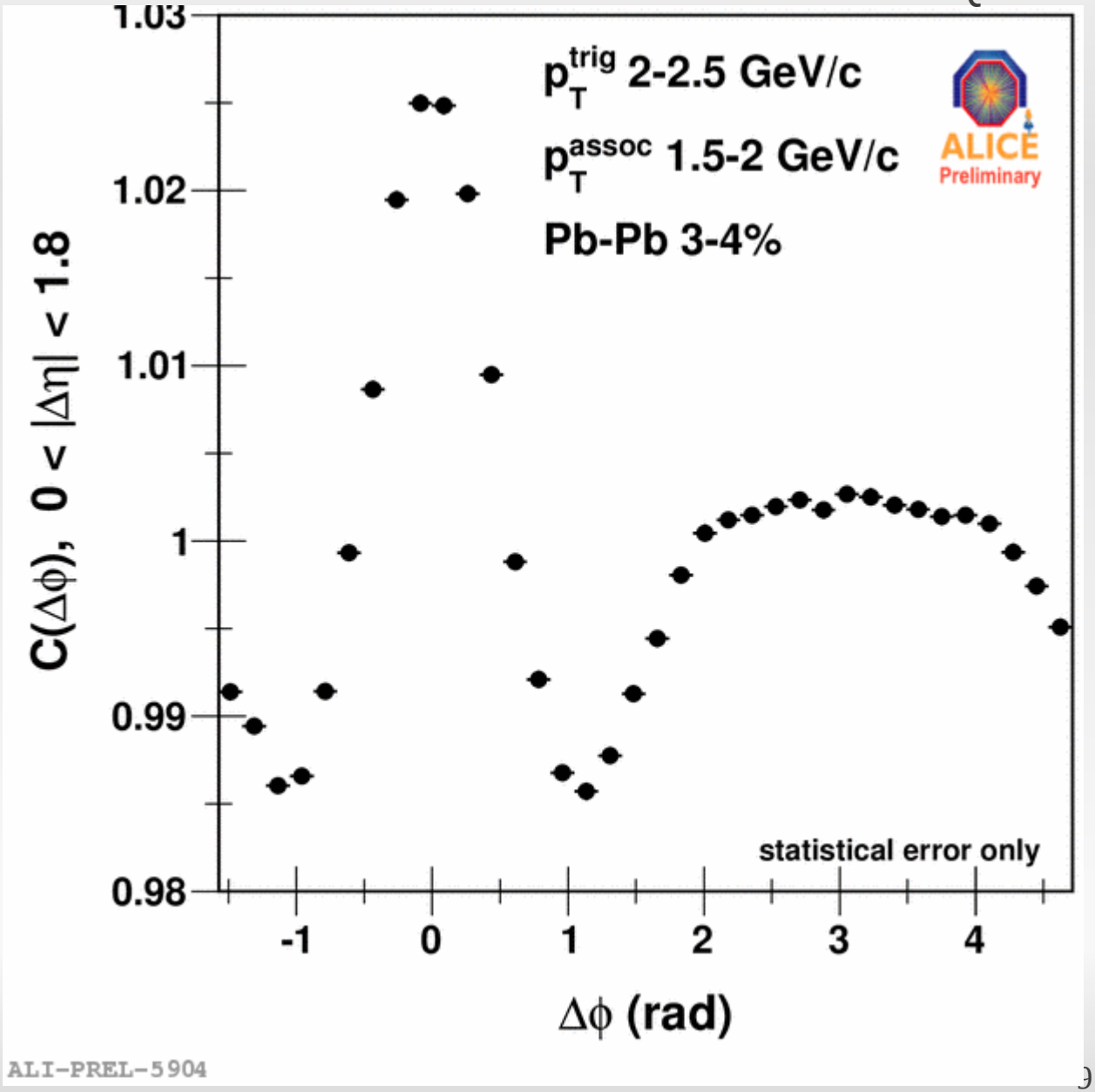

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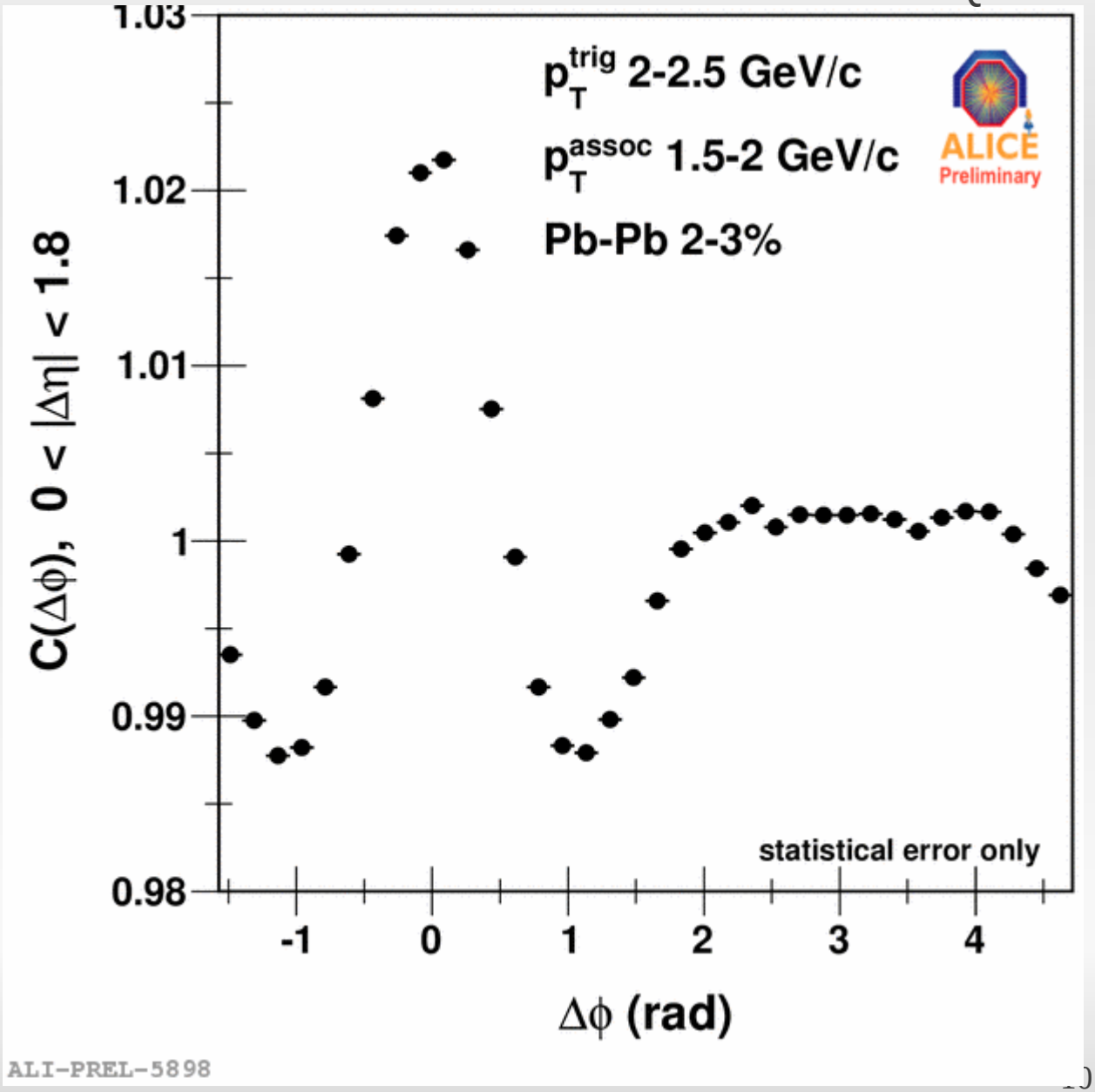

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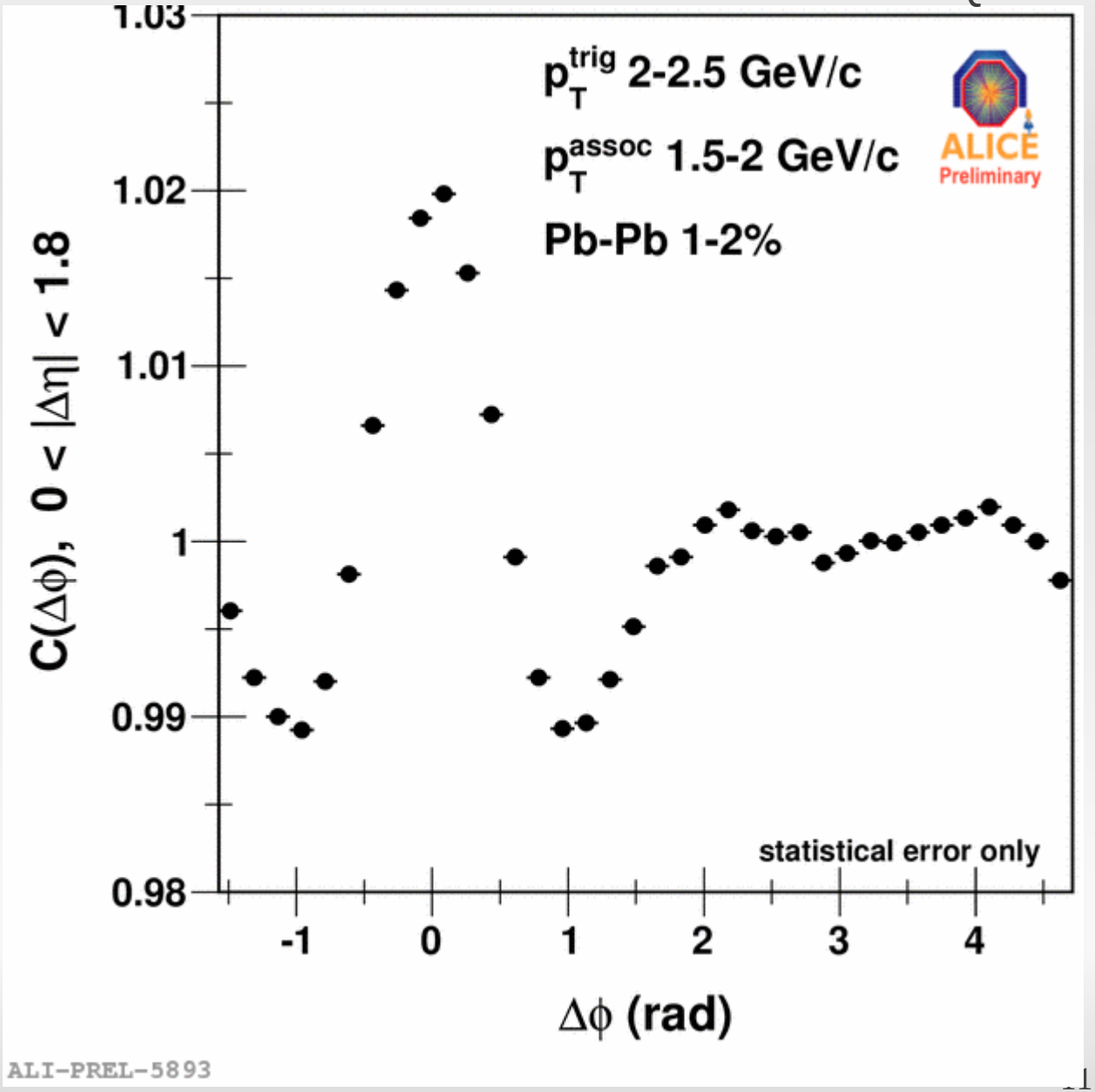
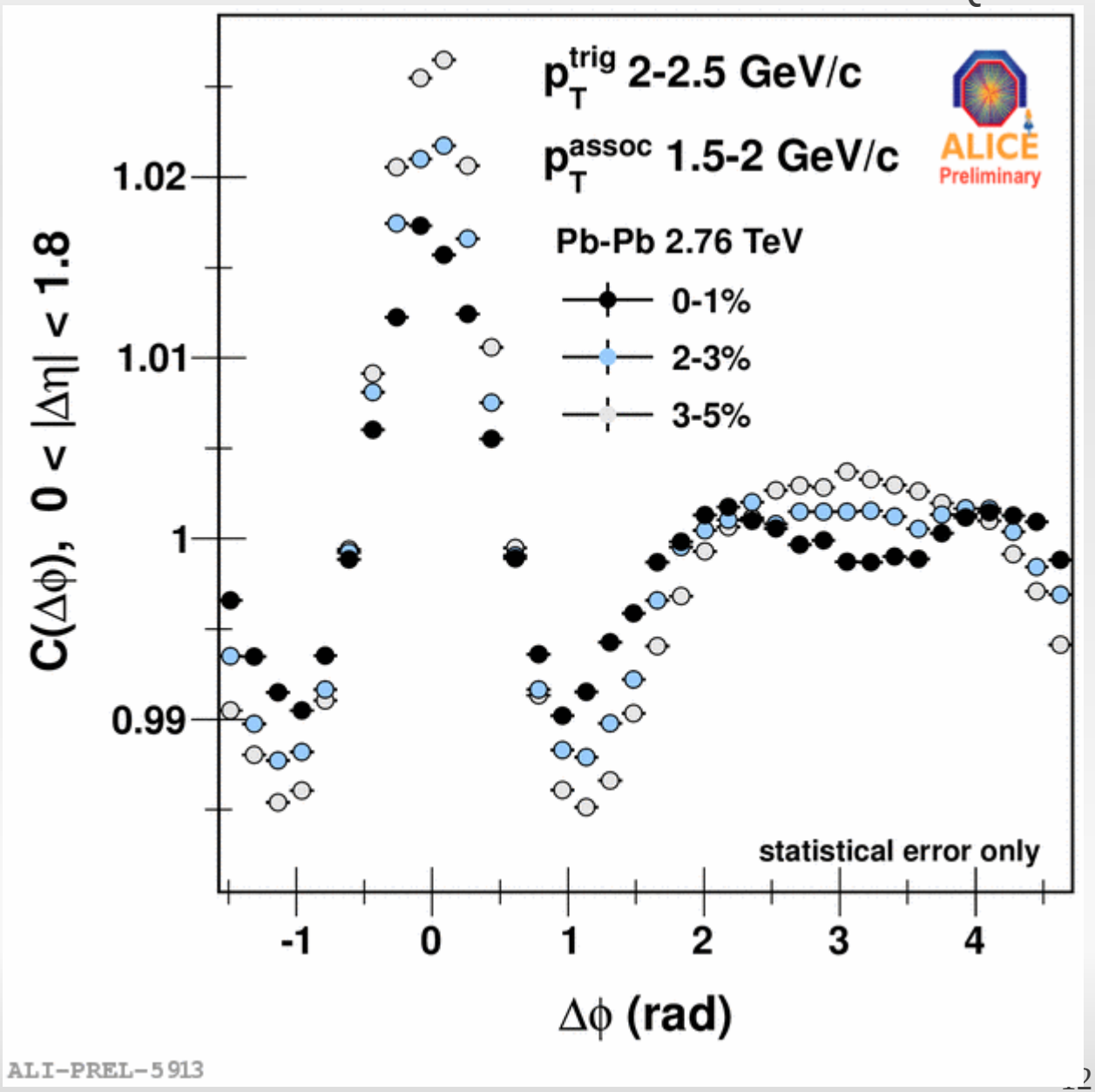


Approaching Ultra-Central PbPb

Adare QM11

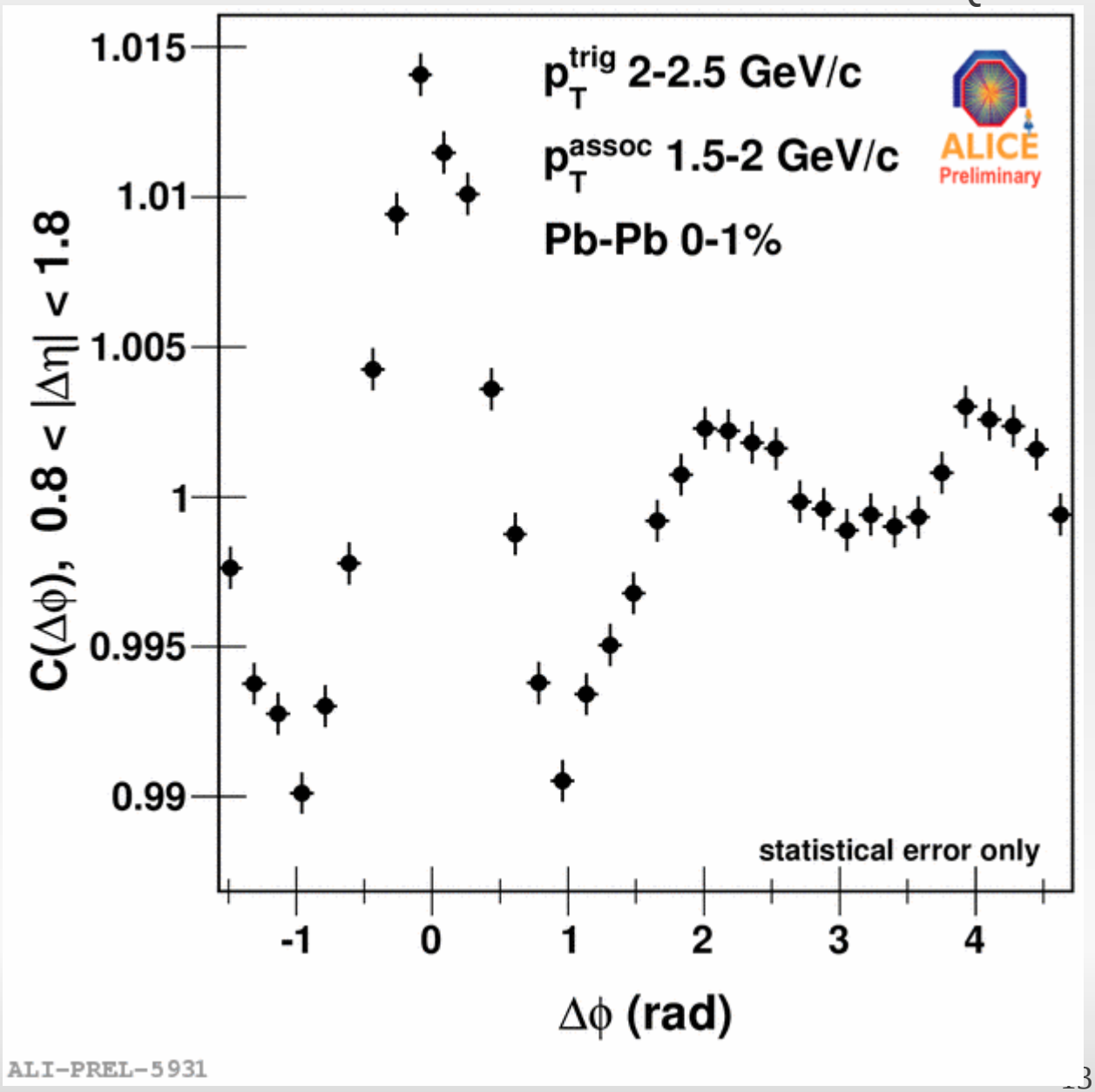
- Change in **unsubtracted** correlation function for very small changes in centrality.
- Double peaked structure observed in most central.



Δη Gap

Adare QM11

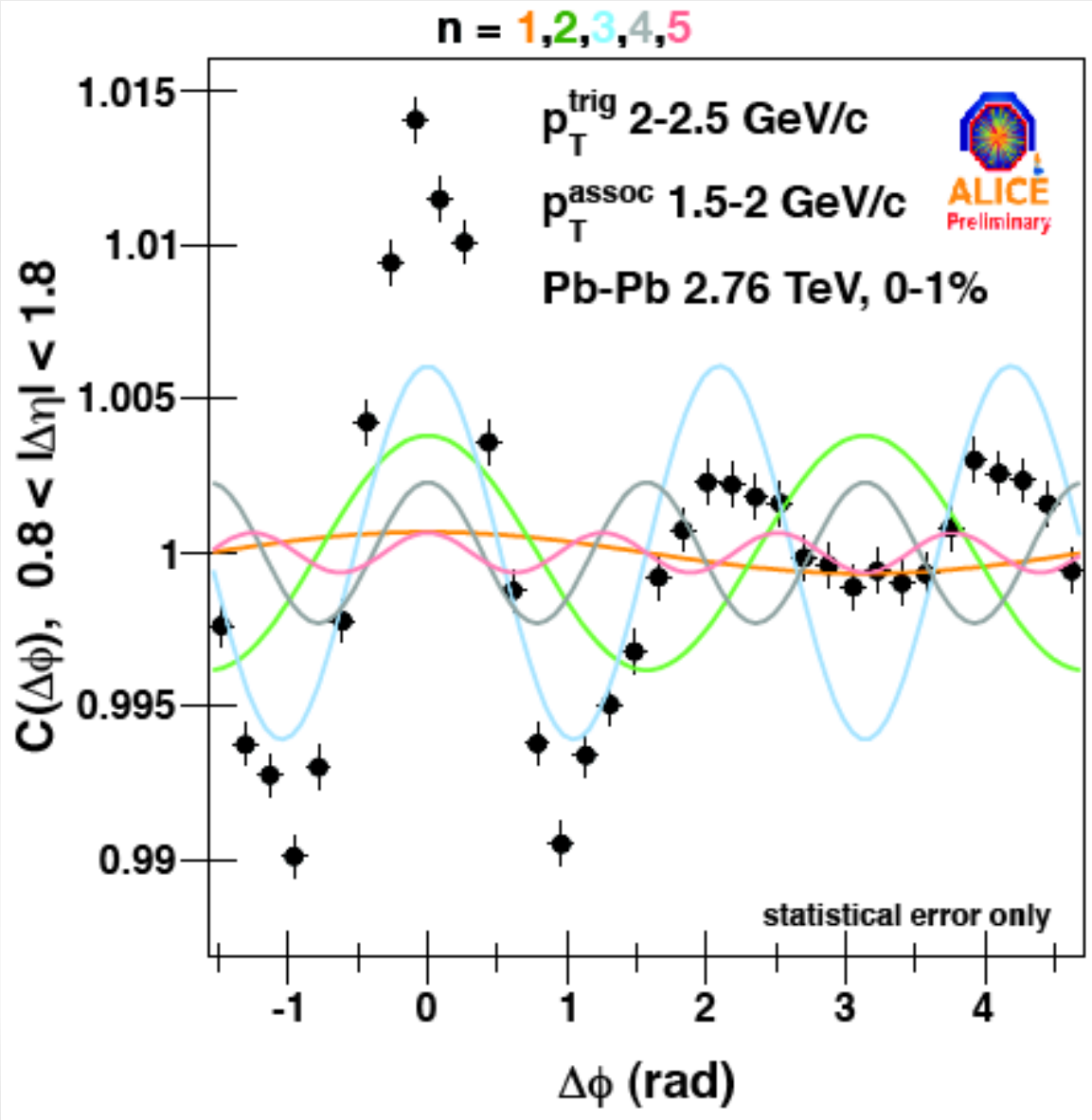
- Δη gap suppresses near-side peak
- Remaining near-side structure dominated by the ridge.



Fourier Analysis at Large Δη

Adare QM11

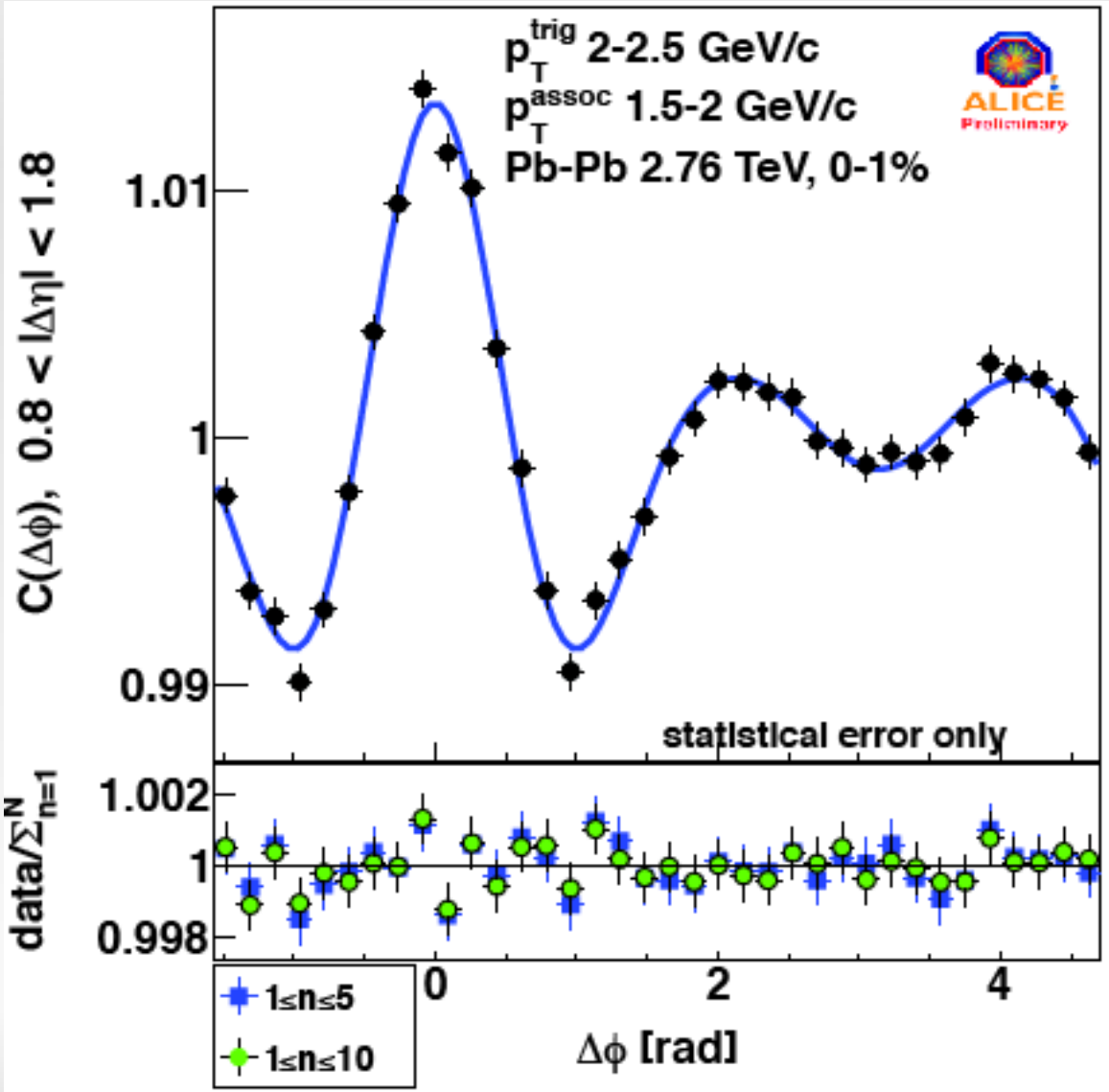
- Fit by <cos(nΔϕ)> 2-particle Fourier coefficients.
- Fitting up to the n=5 can describe shape to the 0.1% level.



Fourier Analysis at Large Δη

Adare QM11

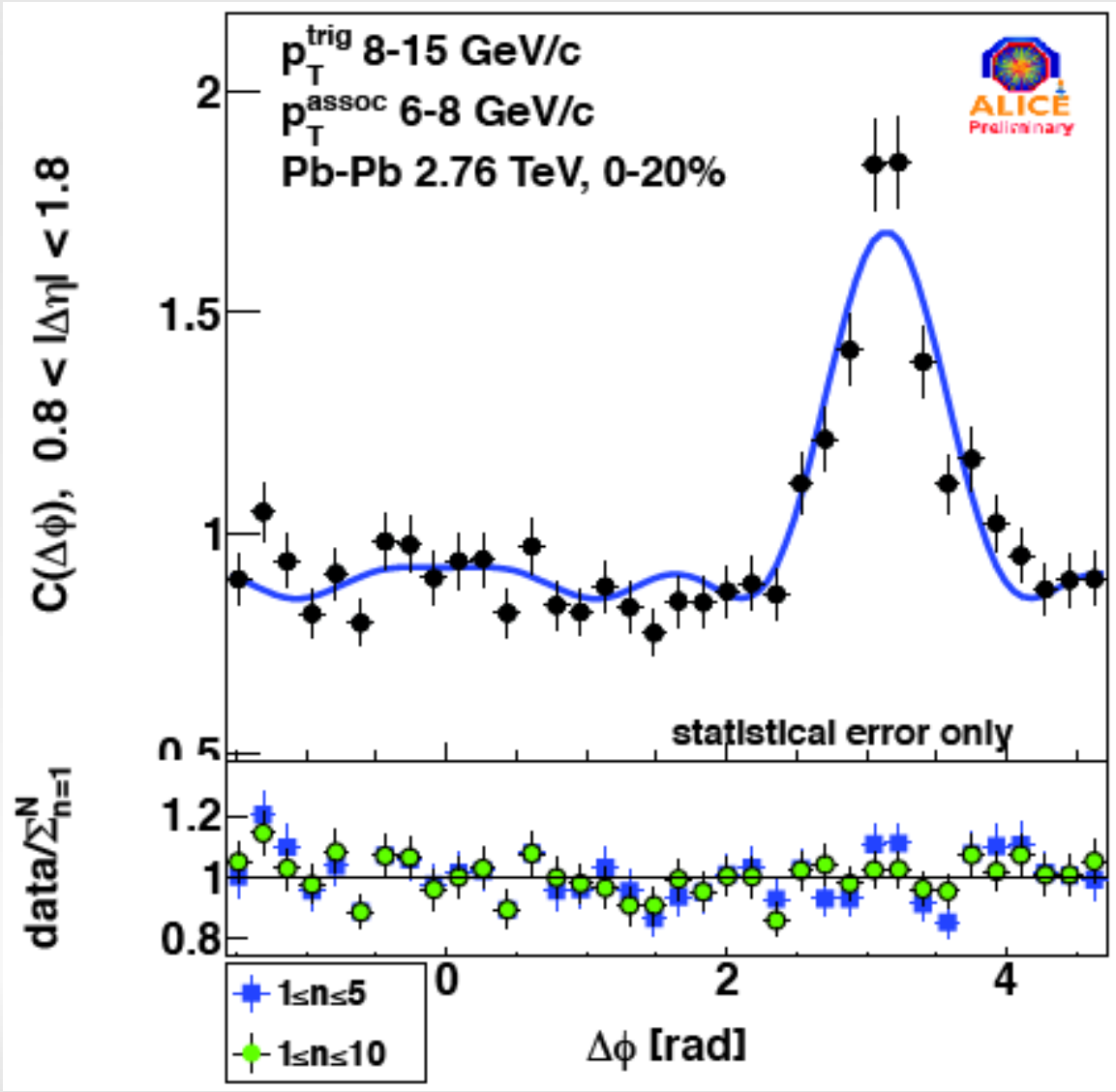
- Correlation well described by the first 5 Fourier coefficients.
- Almost no improvement with the addition of the next 5.



Fourier Analysis at Large Δη

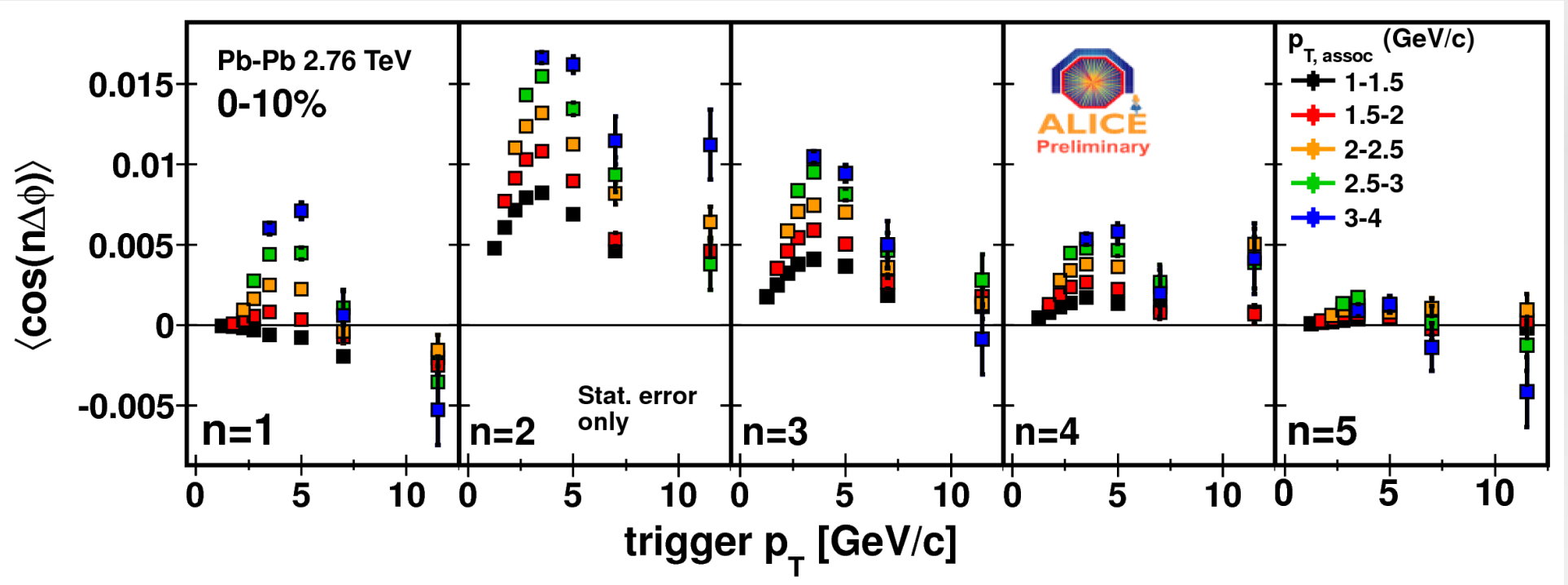
Adare QM11

- Expect away-side to be jet dominated at high p_T.
- Shape differs at high p_T but still well fit by first 5 Fourier coefficients, but improvement when using more coefficients.



Fourier Coefficients

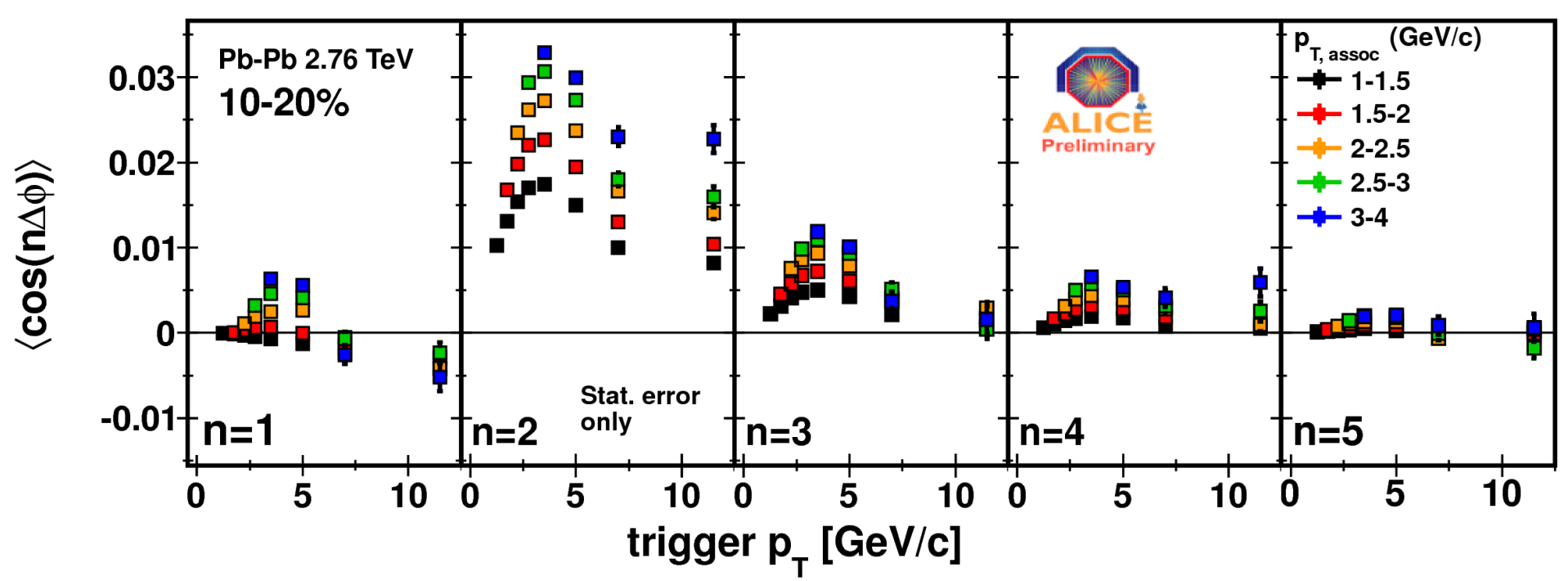
Adare QM11



- Fourier coefficients shown as a function of trigger p_T for different associated p_T.
- Coefficients increase with associated p_T.
- n=2 amplitude increase as we go towards mid-central.

Fourier Coefficients

Adare QM11



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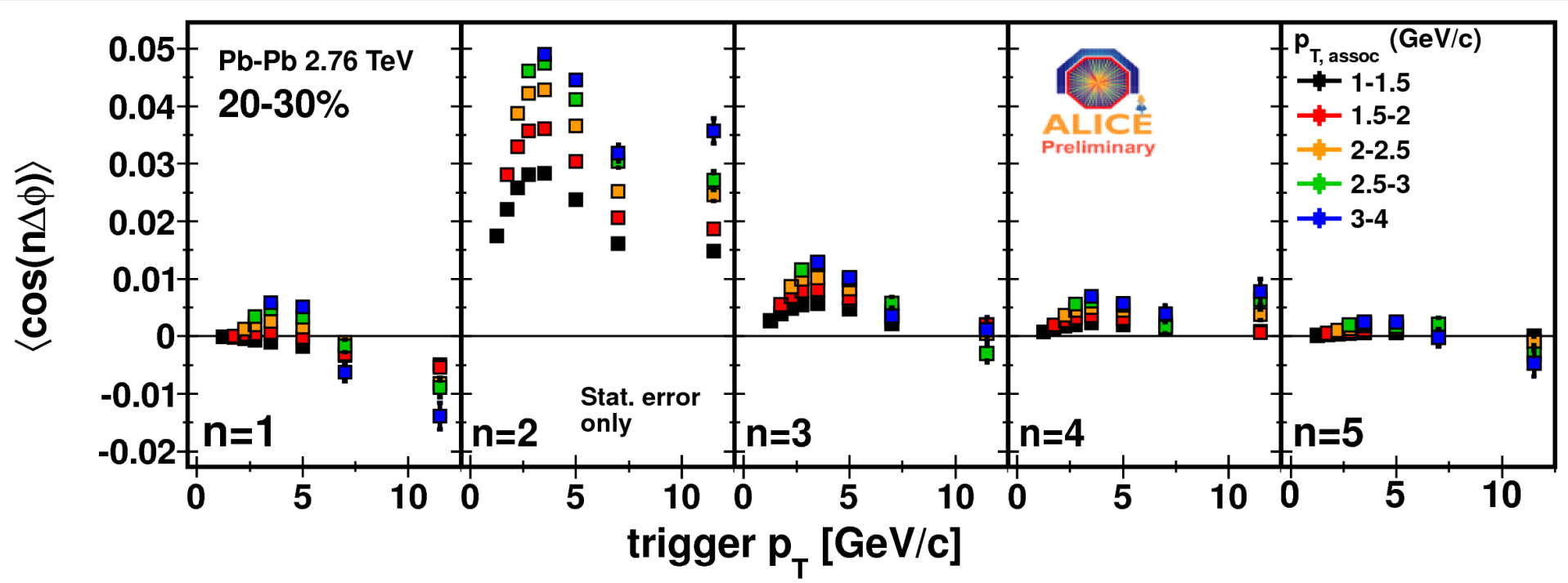

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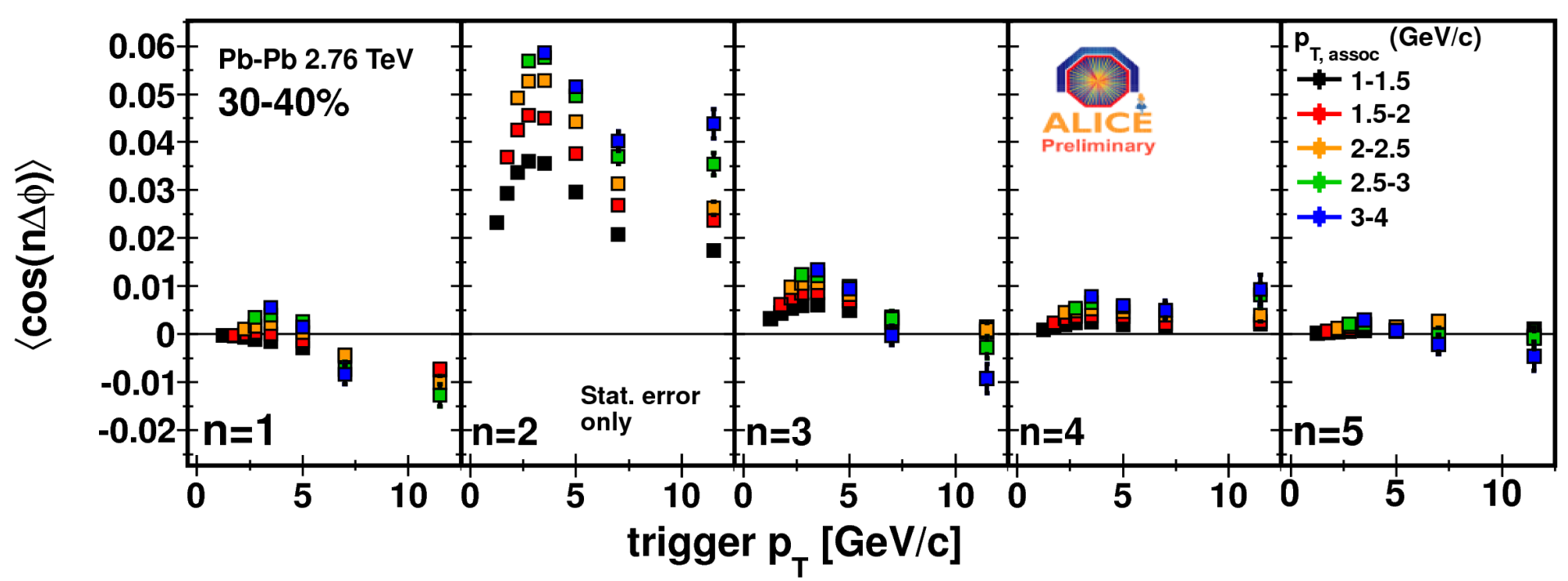

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Fourier Coefficients

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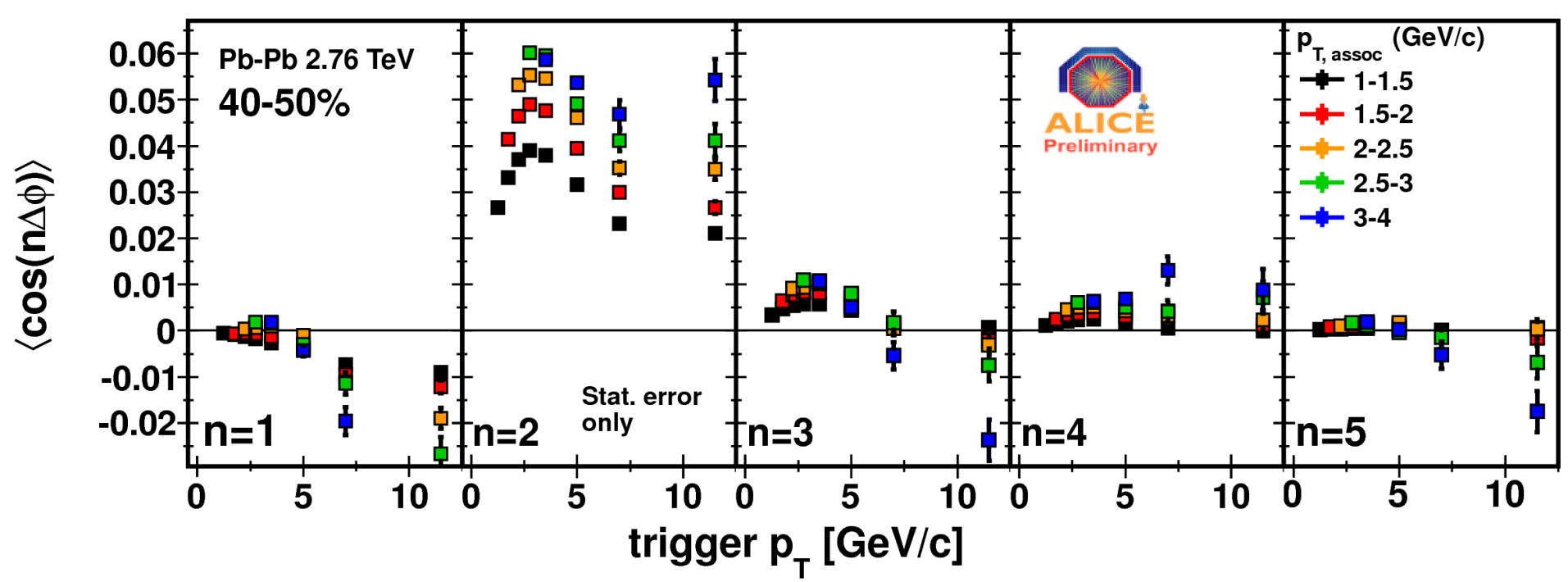
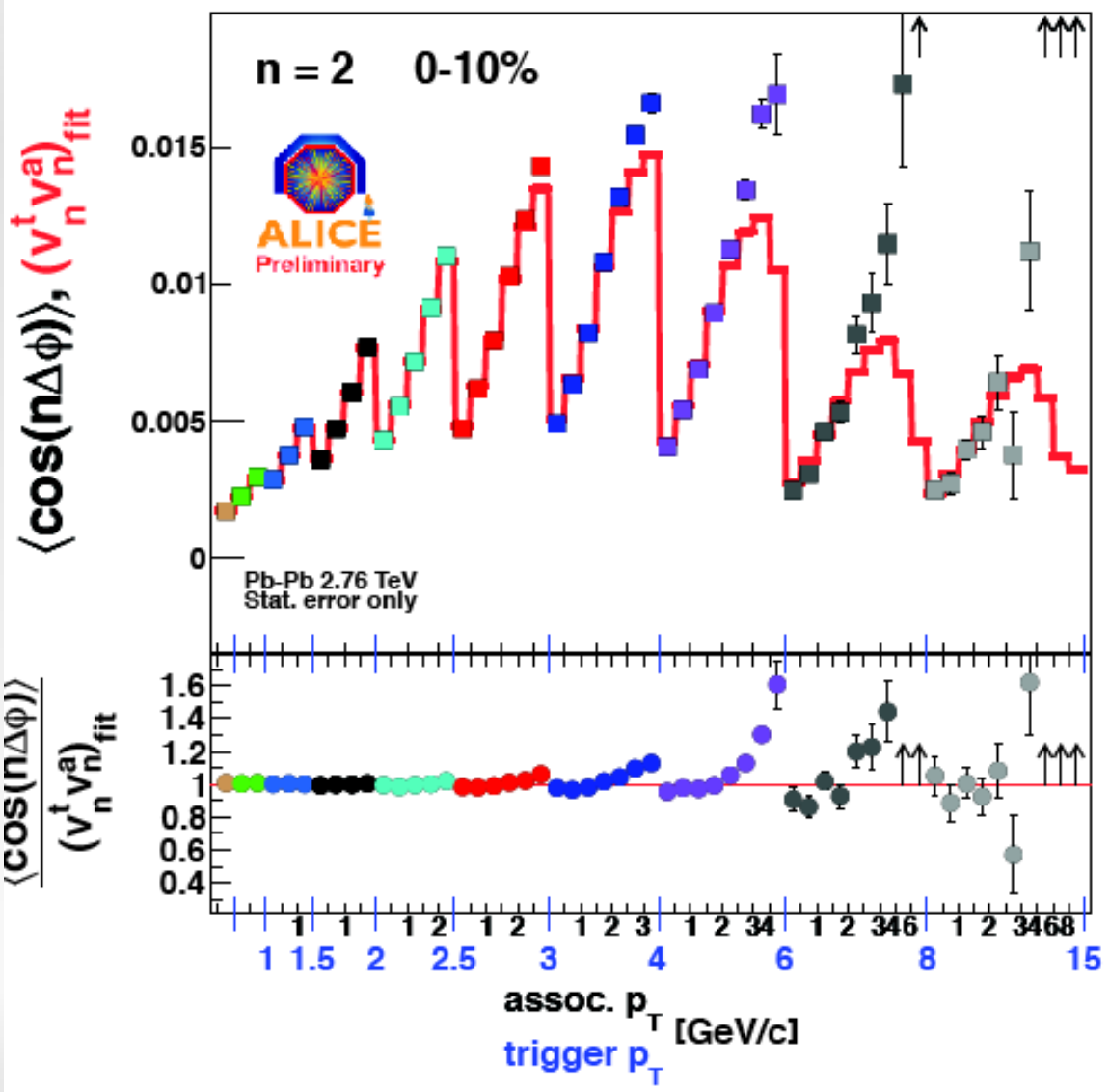


- Fourier coefficients shown as a function of trigger p_T for different associated p_T.
- Coefficients increase with associated p_T.
- n=2 amplitude increase as we go towards mid-central.

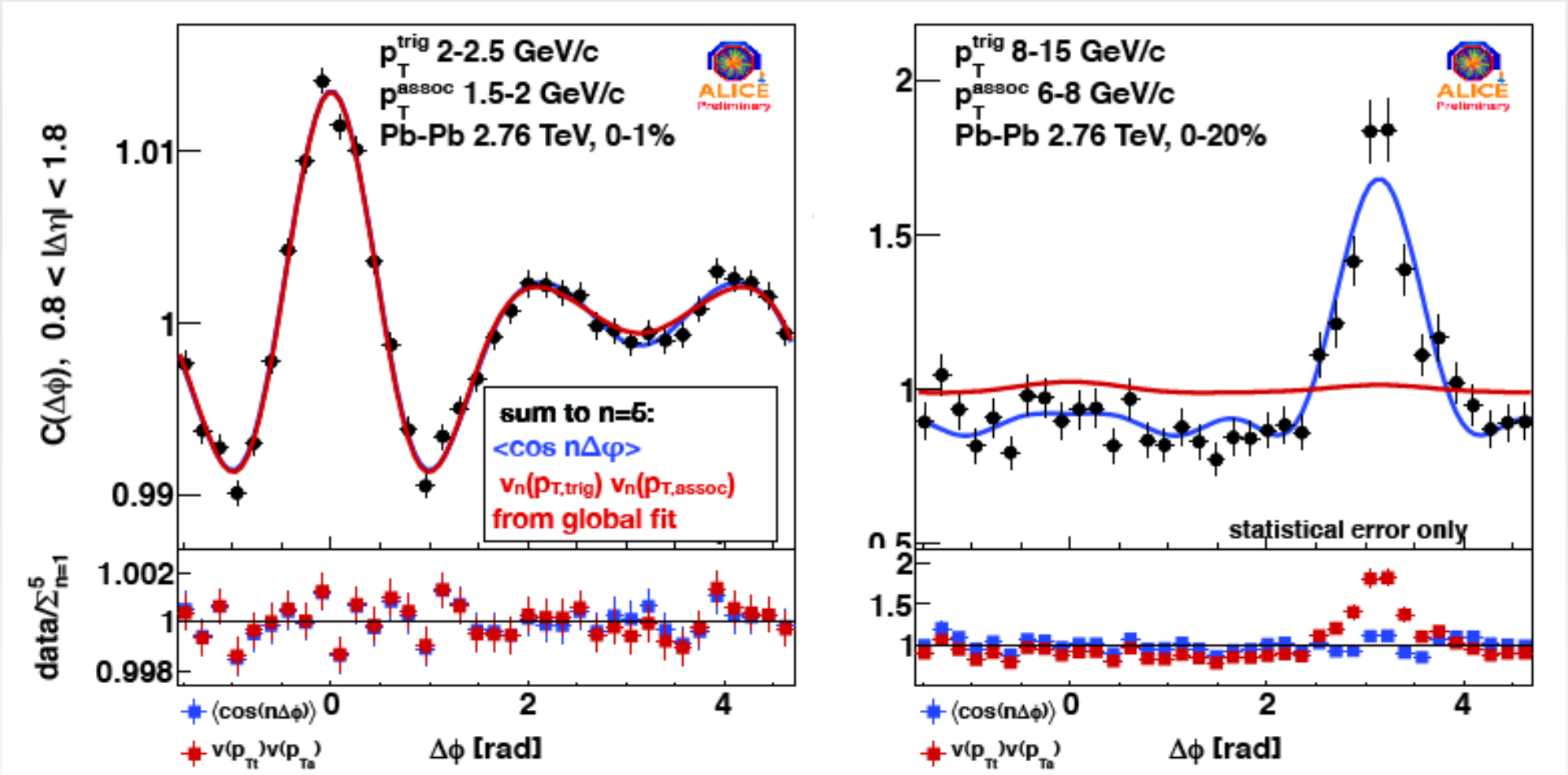
Global Fit

- Simultaneous fit of all trigger and associated p_T bins.
- Flow factorizes
  - Correlations should be flow dominated where the global fit matches the individual fits.
- Deviates at high p_T.



Global Fits

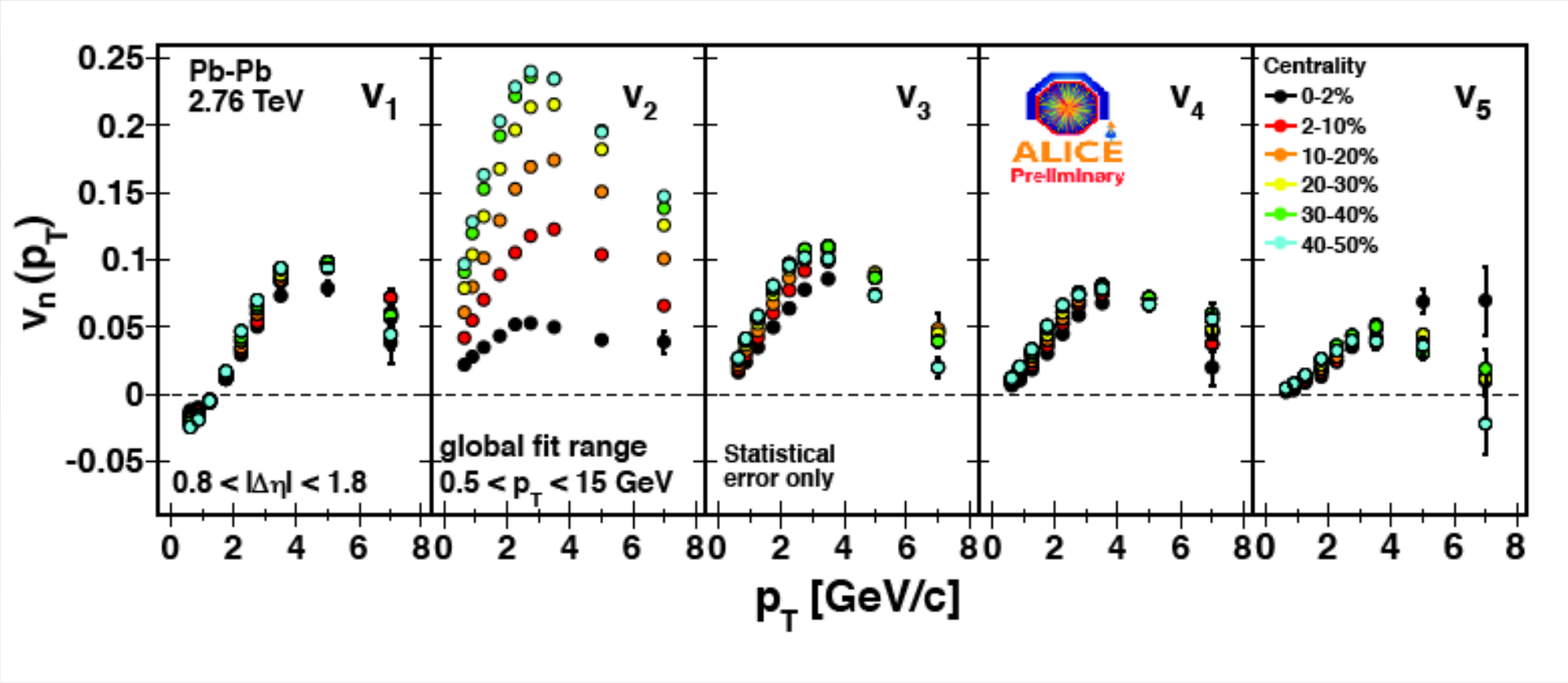
Adare QM11



- Low-p_T correlation well described by the global fit.
- High-p_T correlation not described by the global fit.

Global Fit v_n

Adare QM11



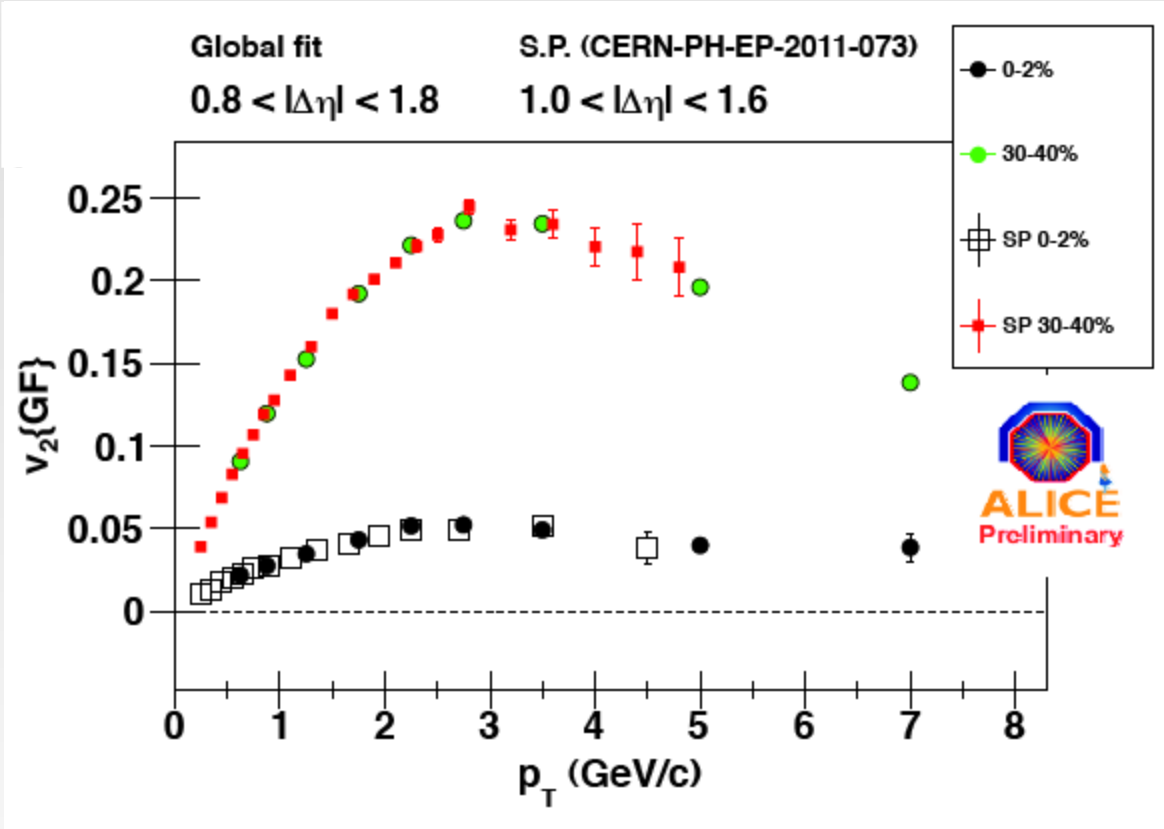
- v_2 dominates at mid-central as expected from collision geometry
- v_3 dominates in 0-2%
  - describes double humped away side

v_2 Comparison

Adare QM11

axriv: 1105.3865

- Global fit elliptic flow has good agreement with the 2-particle cumulant method.
- Both methods should contain similar non-flow and fluctuation effects.



v_3 Comparison

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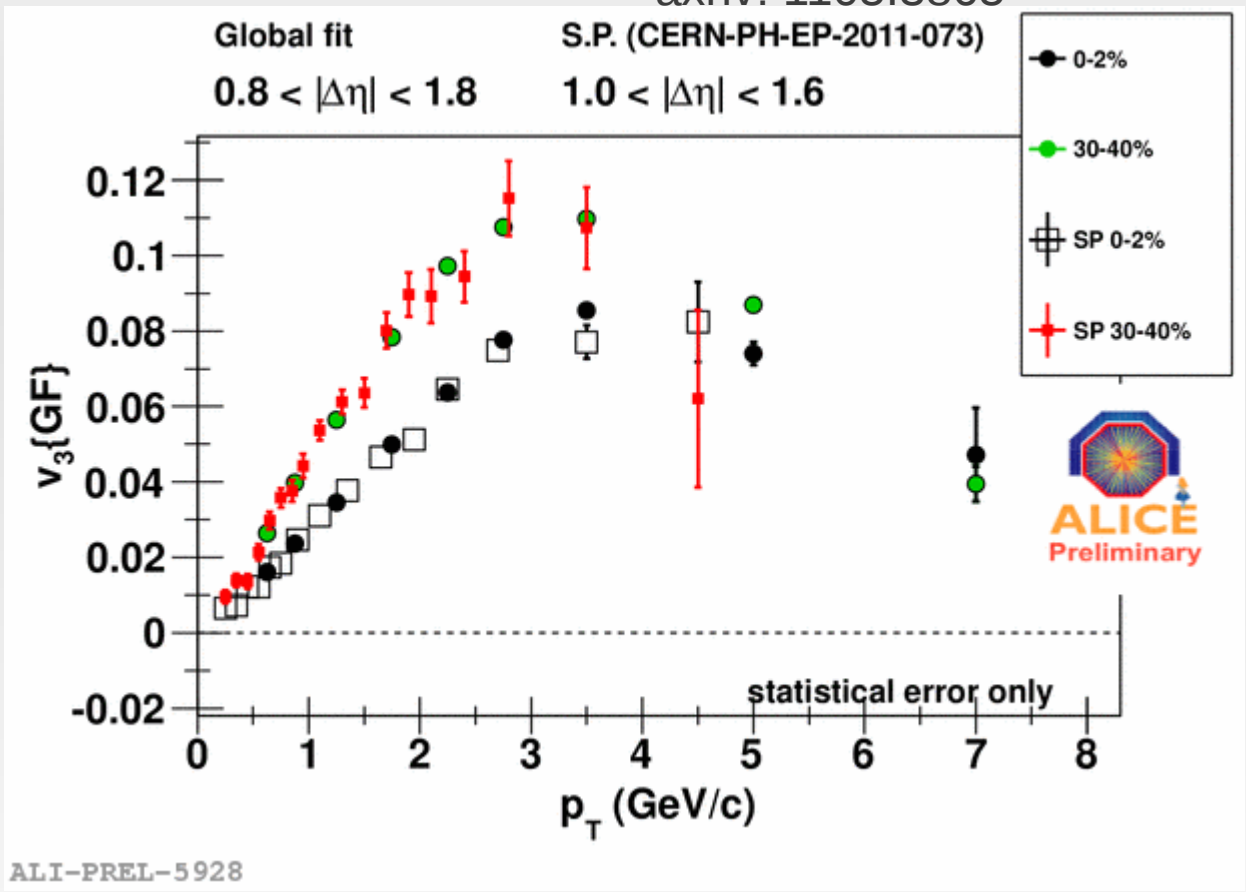
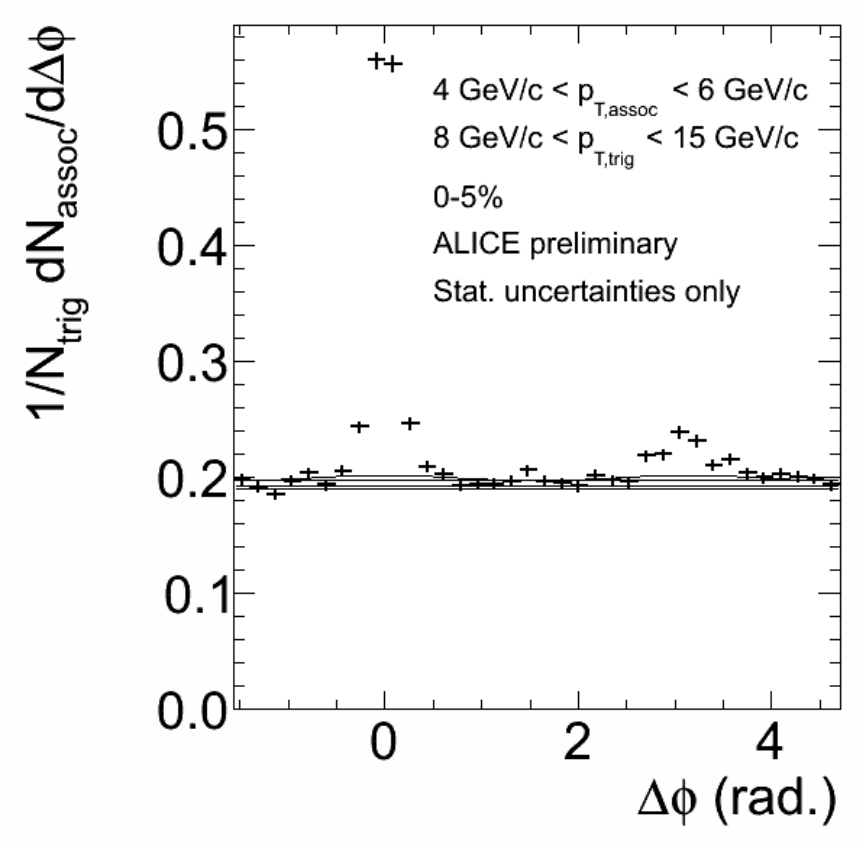


- Global fit triangular flow has good agreement with the 2-particle cumulant triangular flow measurements

I_{AA}

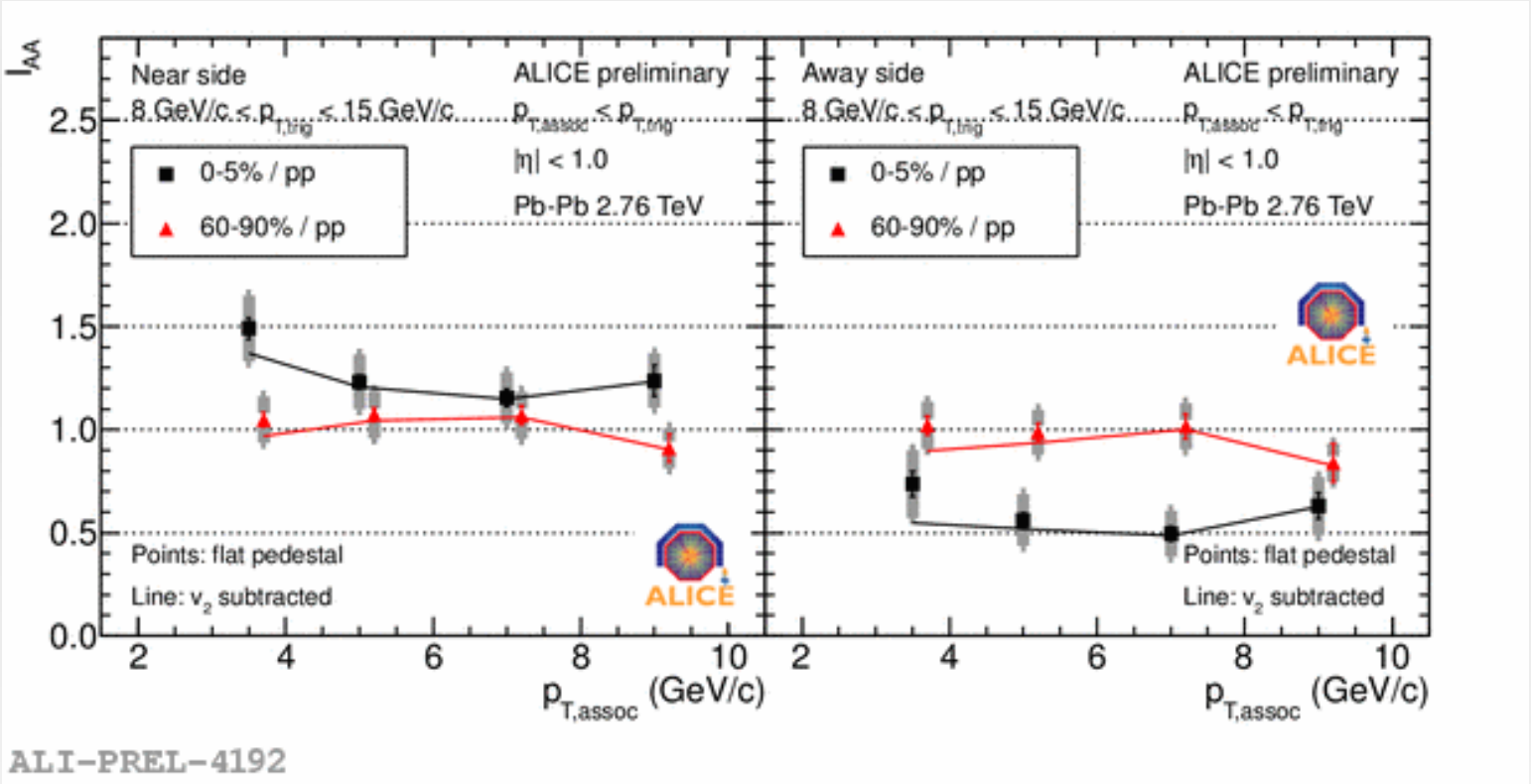
Grosse-Oetringhaus QM11

- Modification of the yields relative to:
  - pp for I_{AA}
  - peripheral Pb-Pb for I_{CP}
- ZYAM assumption for background subtraction.
  - v_2 from ALICE flow measurements.
  - done at high enough p_T that jet signal dominates over flow modulation in background.



I_{AA}

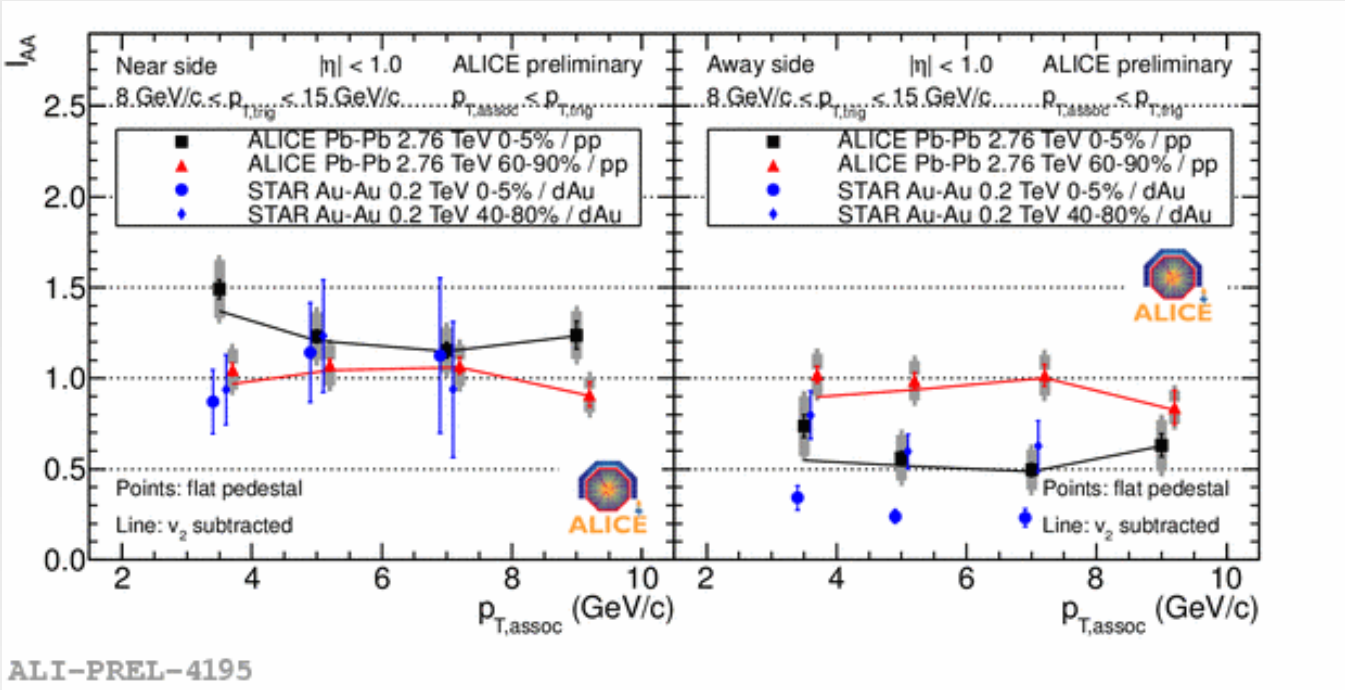
Points: no flow subtraction
Line: v_2 subtracted



- Central:
  - Near-side greater then 1
  - Away-side suppressed as expected for energy loss
- Peripheral – consistent with 1

STAR Comparison

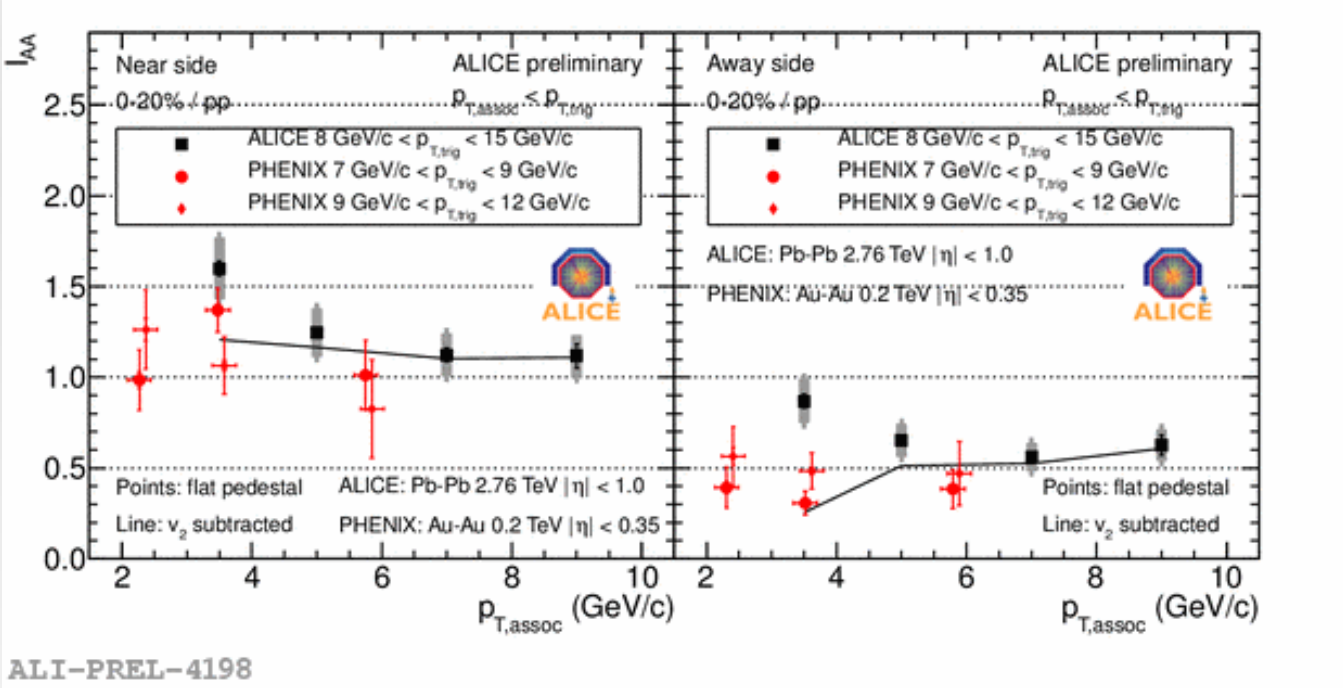
Grosse-Oetringhaus QM11



- STAR results v_n subtracted and compared to d+Au.
- Different trigger bias at different energies.
  - probing different energy jets with different fraction of energy in trigger particle

PHOENIX Comparison

Grosse-Oetringhaus QM11



- PHOENIX results v_n subtracted and compared to d+Au.
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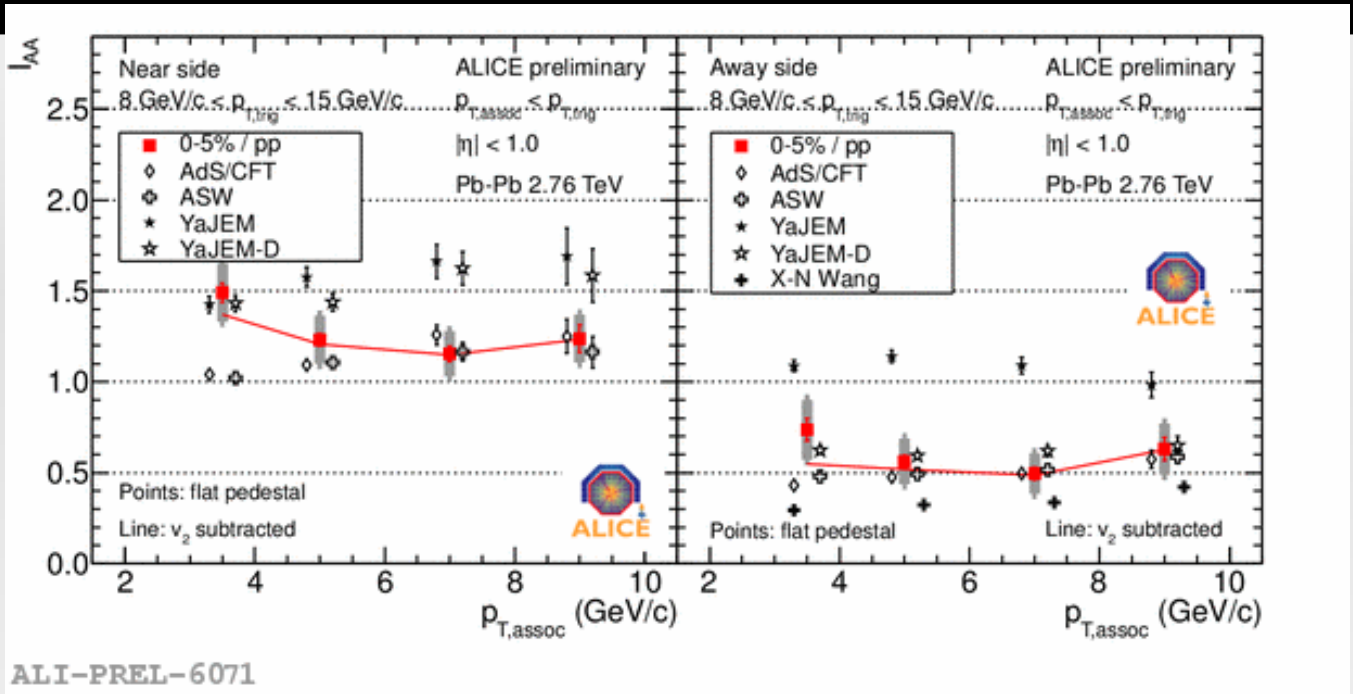
Theory Comparison



Near-side enhancement:

- **reproduced by AdS/CFT and ASW**
- **YaJEM overpredicts the enhancement**

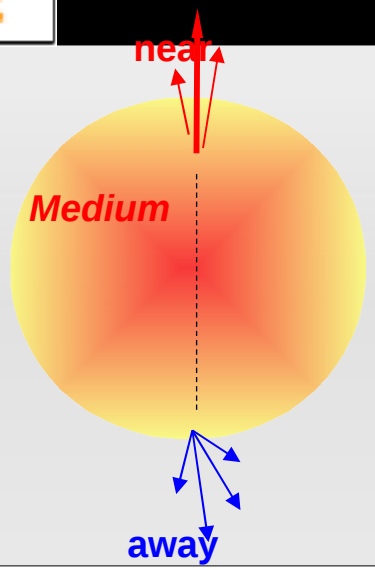
Away-side suppression:

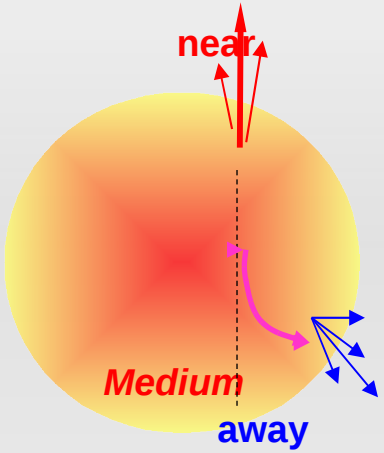
- **reproduced by AdS/CFT, ASW, YaJEM-D**
- **YaJEM over predicts the suppression**
- **X-N Wang under predicts the suppression**

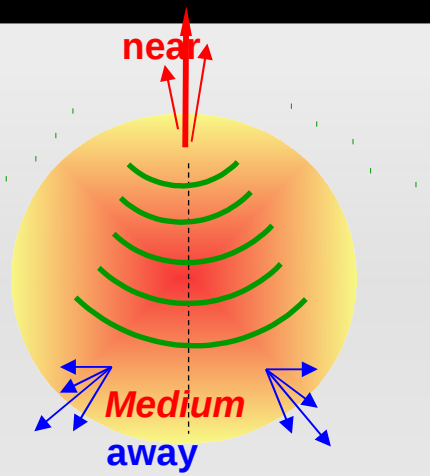
3-Particle Correlations

- Interested in studying the away side.
- Want to see what causes the double peaks structure.
  - Mach-cone
  - Cerenkov gluon radiation
  - Deflected Jets
    - deflected by radial flow
    - path length dependent energy loss
  - v_3

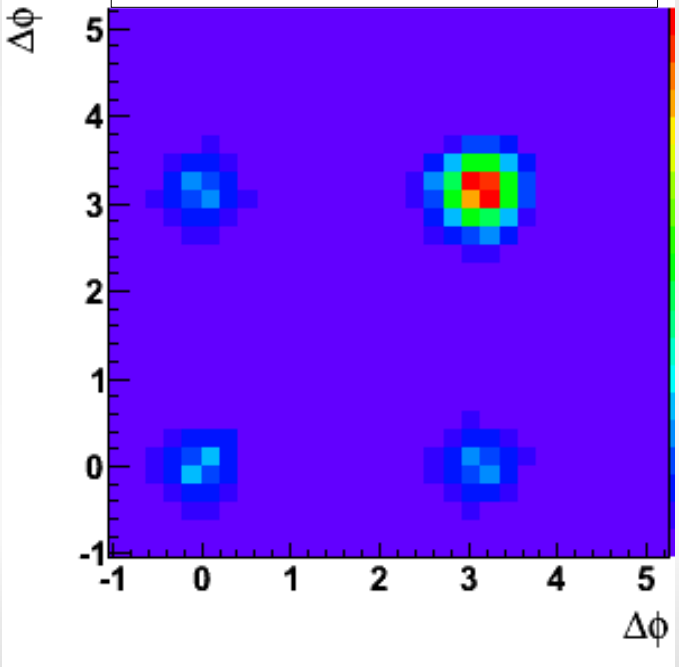
3-Particle Correlations



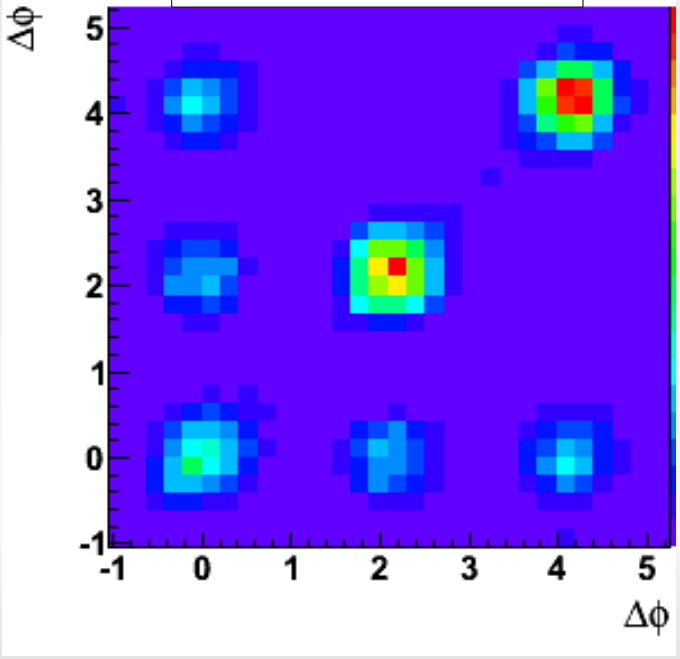




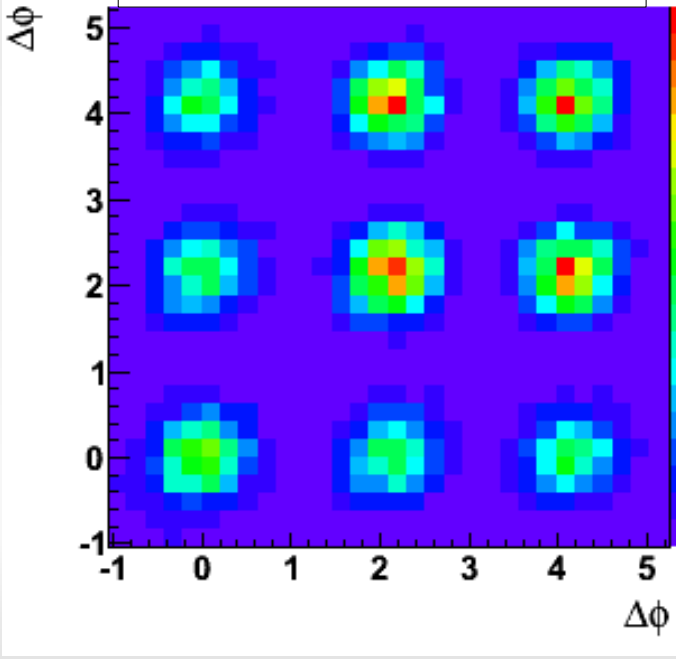
Unmodified Di-Jet



Deflected Jet



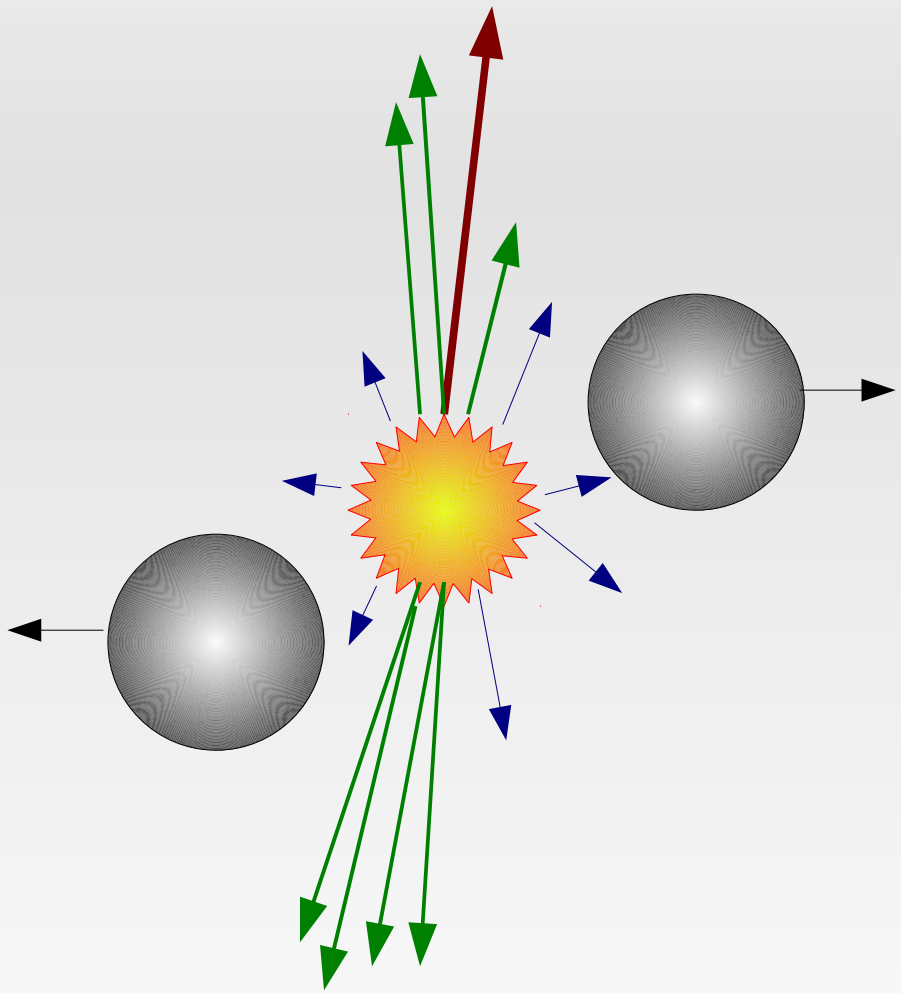
Conical Emission



3-Particle Correlations

- Select an intermediate or high-p_T trigger particle.
- Look at relative angles between trigger and 2 other particles.

$$\Delta\phi_1 = \phi_{Trigger} - \phi_{Associated,1}$$
$$\Delta\phi_2 = \phi_{Trigger} - \phi_{Associated,2}$$



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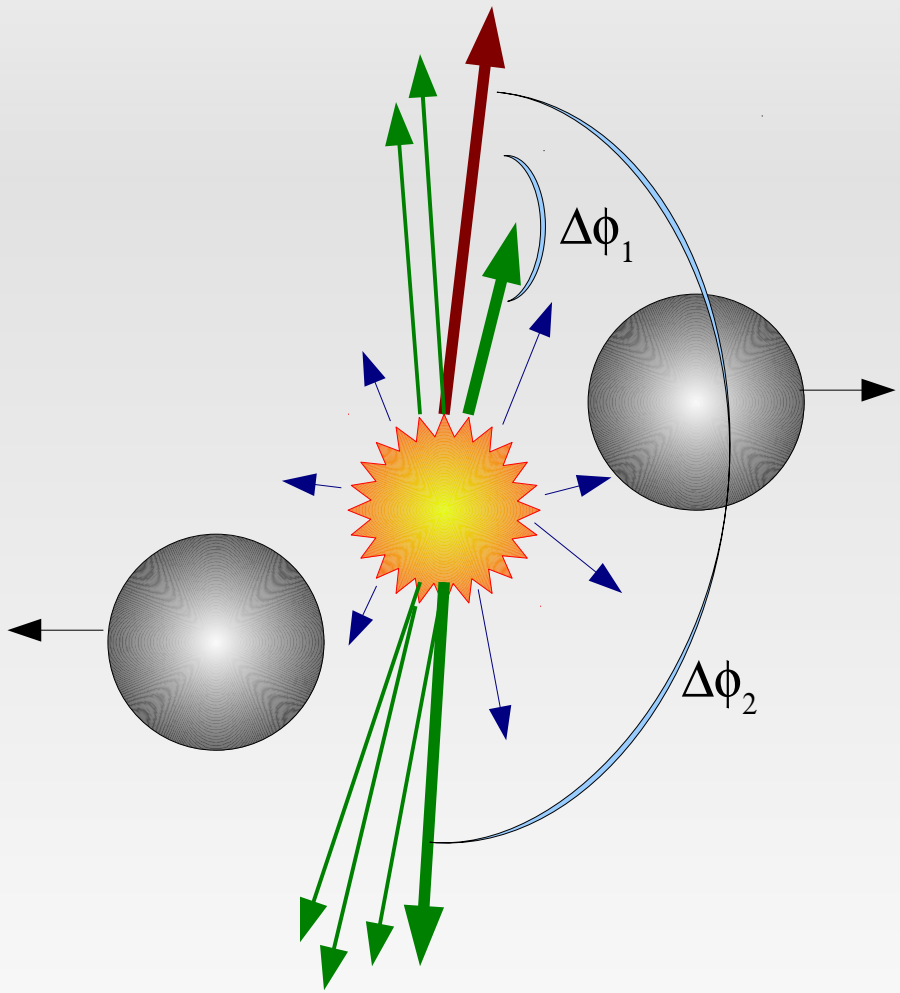

Both from jet:

$\Delta\phi_1 = \phi_{Trigger} - \phi_{Associated,1}$

$\Delta\phi_2 = \phi_{Trigger} - \phi_{Associated,2}$

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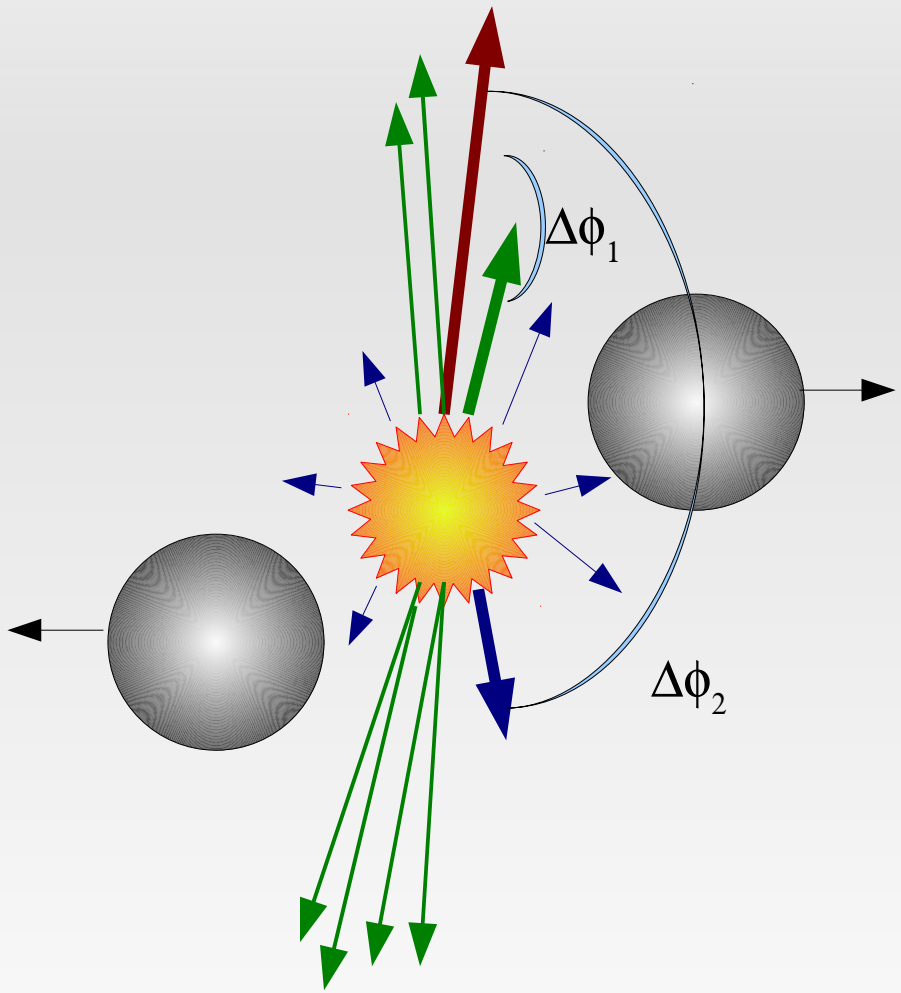

1 from jet and
1 from background:

$\Delta\phi_1 = \phi_{Trigger} - \phi_{Associated,1}$

$\Delta\phi_2 = \phi_{Trigger} - \phi_{Associated,2}$

3-Particle Correlations

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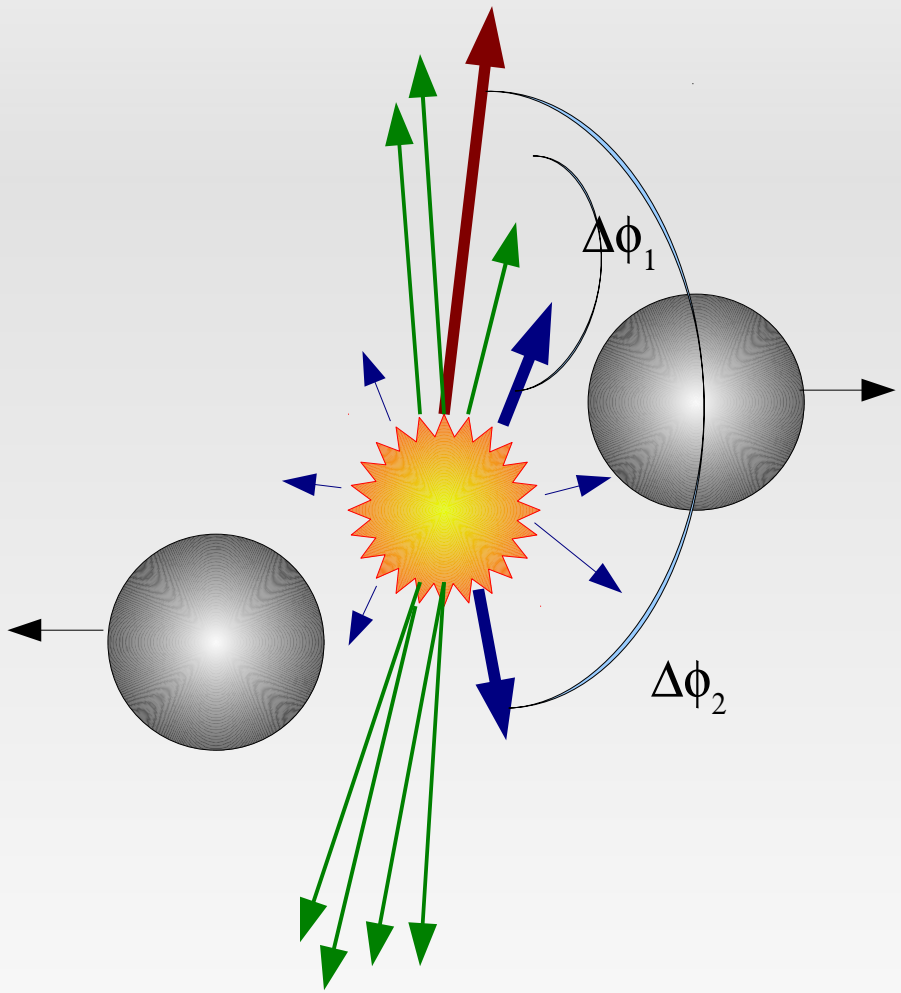


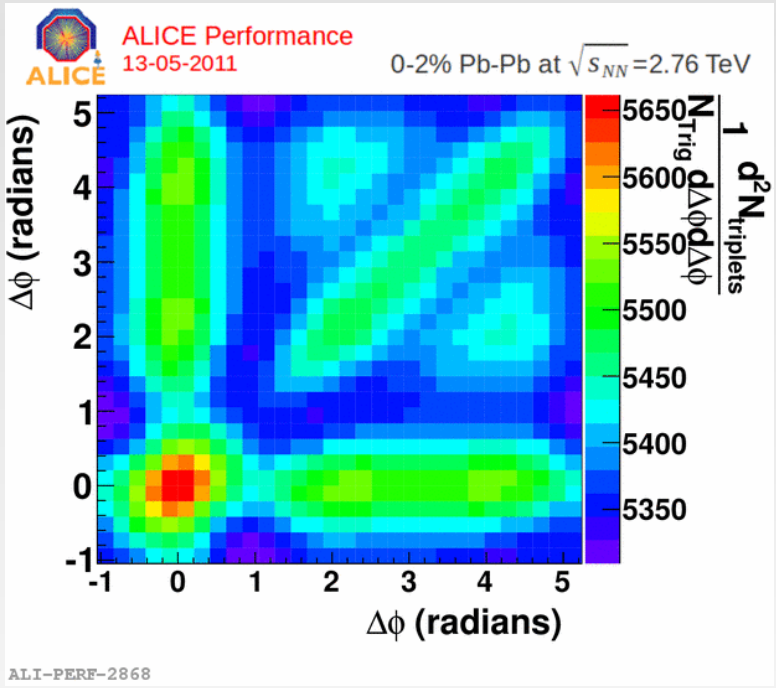
Both from background:

$\Delta\phi_1 = \phi_{Trigger} - \phi_{Associated,1}$

$\Delta\phi_2 = \phi_{Trigger} - \phi_{Associated,2}$

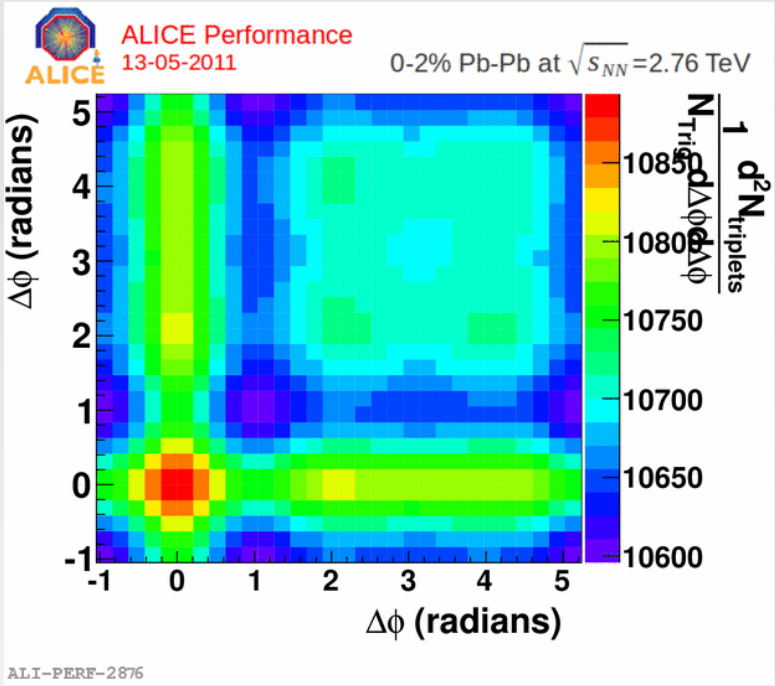
Unsubtracted Signal

- Contains
  - 3-particle jet-like correlations
  - 2-particle jet-like correlations
  - 2-particle flow correlations
  - 3-particle flow correlations
  - 2-particles jet-like correlated while 3rd is flow correlated



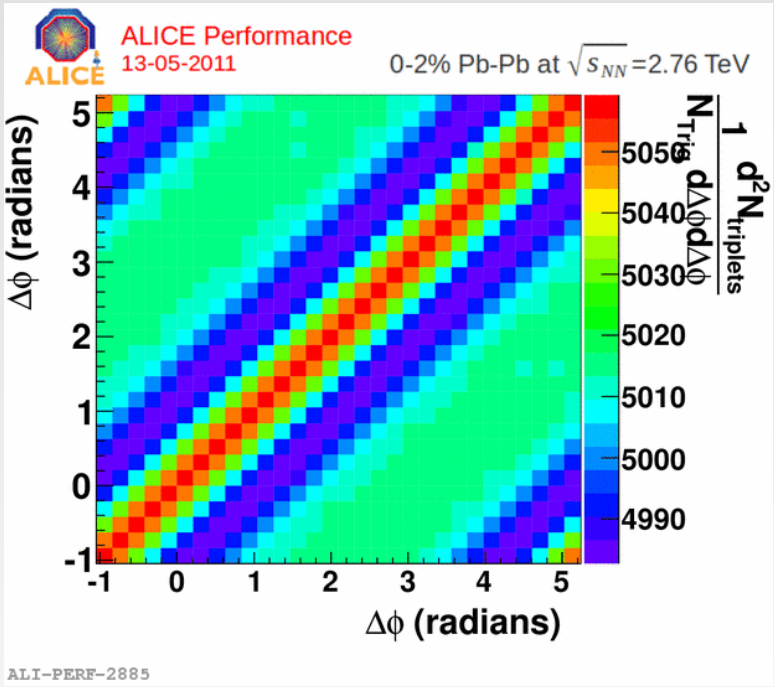
Trigger and Associated Correlated

- 2-Particle correlations between trigger and associated particle.
- Contains 2-particle jet-like and flow correlations.
- Unsubtracted 2-particle correlations folded with 3rd from mixed event.
- Mixed event is normalized using ZYAM assumption on the 2-particle correlation.
  - ALICE flow values used for ZYAM determination from v_2, v_3, and v_4.



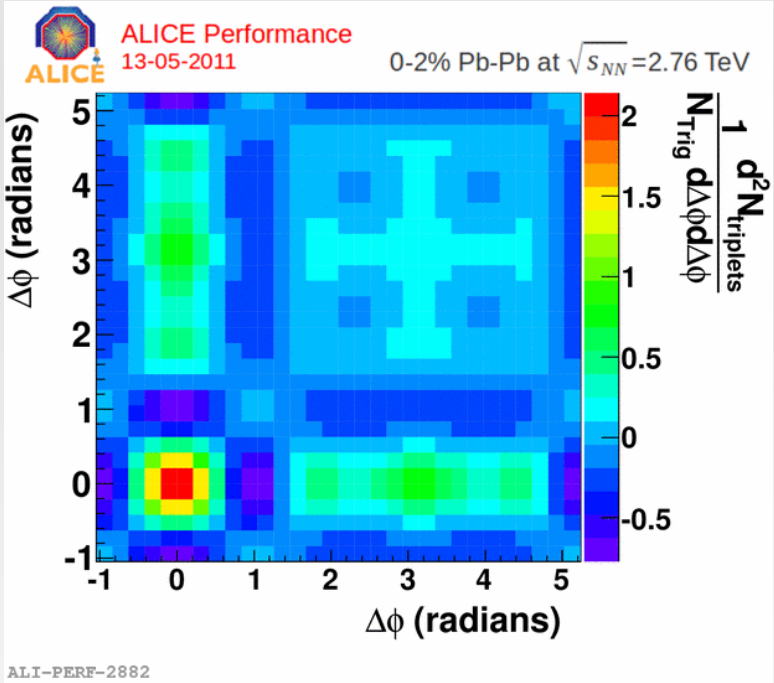
Associated-Associated Correlation

- 2-particle correlations between the two associated particles.
  - jet-like and flow correlations
- Constructed by mixing trigger particle with pairs of associated from a different event.
- Normalized such that background subtracted 3-particle correlation is ZYAM.



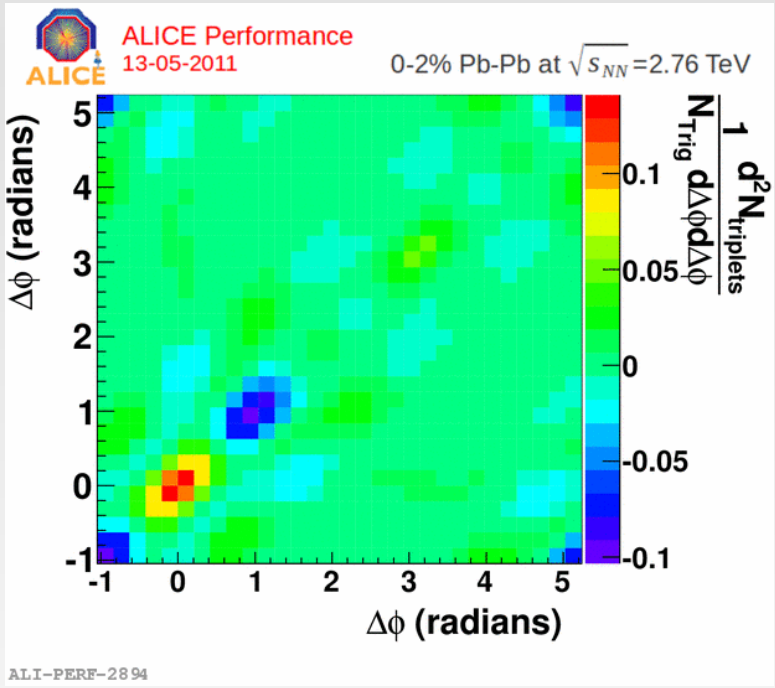
Trigger-Associated Jet-Like X Flow

- Jet like correlation could flow with the 3rd particle.
- Background subtracted 2-particle jet-like correlation folded with the trigger associated flow distribution.
  - Uncertainty in the jet-like flow, trigger v_n used.
  - ALICE flow values for v_2, v_3, and v_4 used.



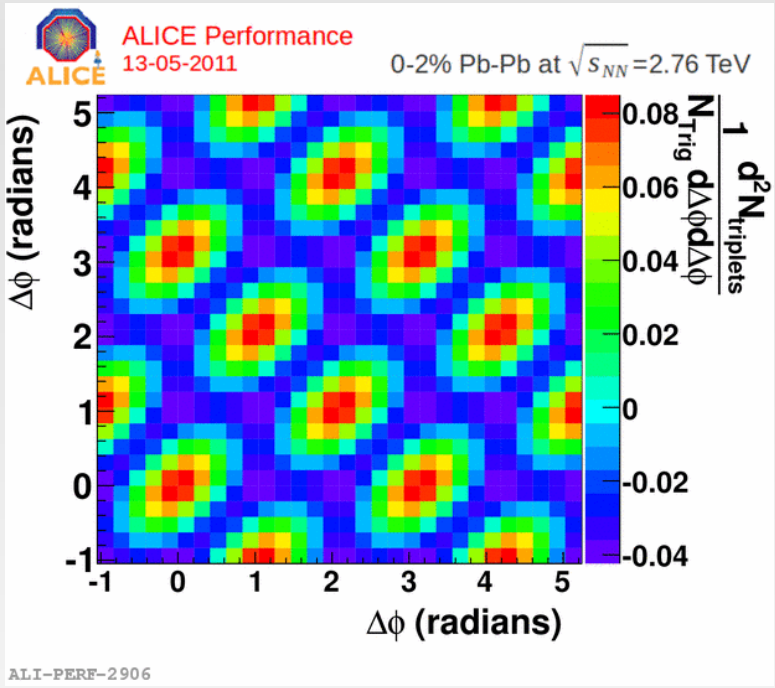
Associated-Associated Jet-Like X Flow

- Background subtracted Associated-Associated distribution may flow with trigger particle.
- Non-flow structure on the associated-associated correlation modulated with the flow between trigger and associated.
  - ALICE flow values for v_2, v_3, and v_4 used



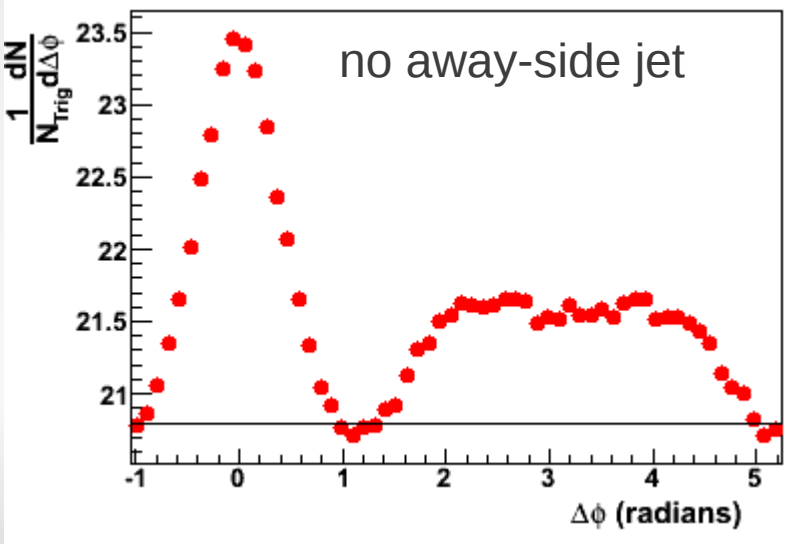
3-Particle Flow

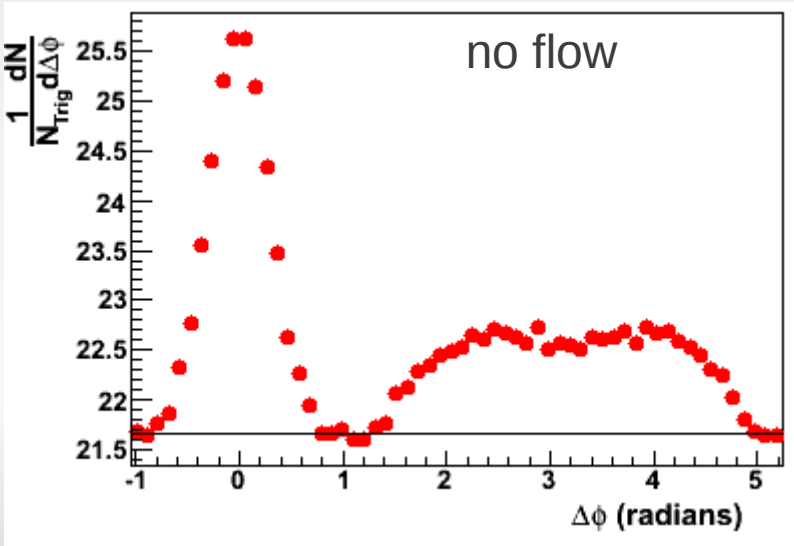
- All three particles can be flow correlated.
- When considering v_2, v_3, and v_4 flow components the 3-particle flow contains terms for:
  - $v_2^T v_2^{A1} v_4^{A2}$
  - $v_2^T v_4^{A1} v_2^{A2}$
  - $v_4^T v_2^{A1} v_2^{A2}$



Toy Model

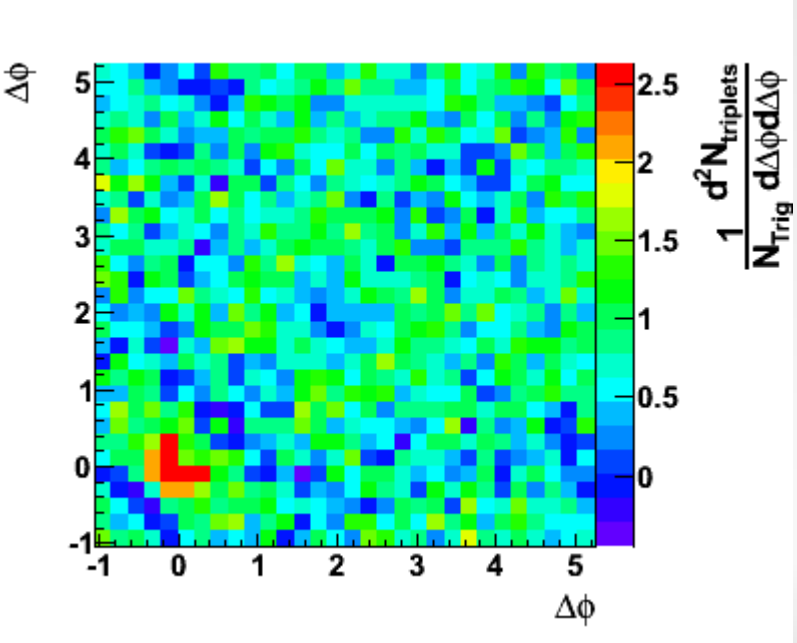
- Want to show with the model we can distinguish between jet correlations and flow.
- Similar 2-particle correlations:
  - 1 from small near-side jet + flow (v_2, v_3, v_4) – no away-side jet
  - 2 from near and away-side jet – no flow

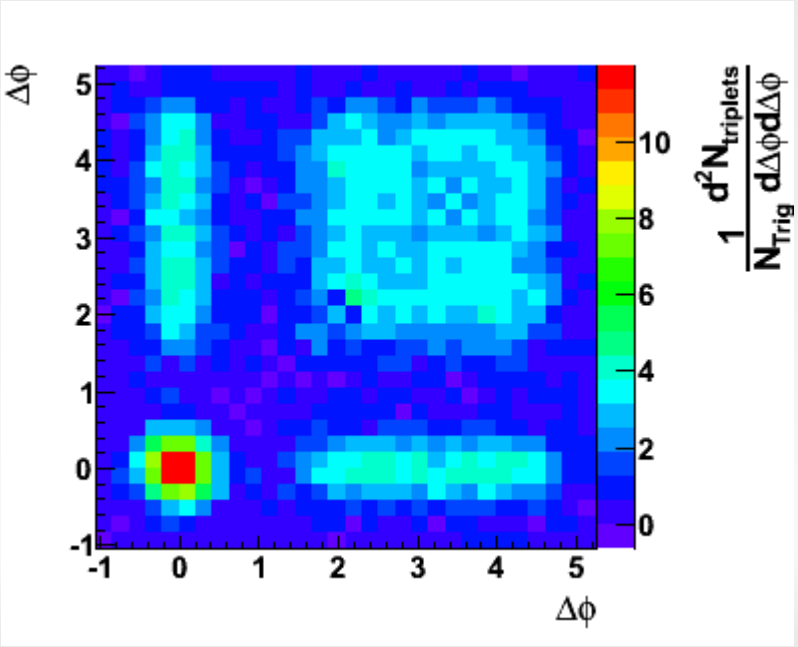




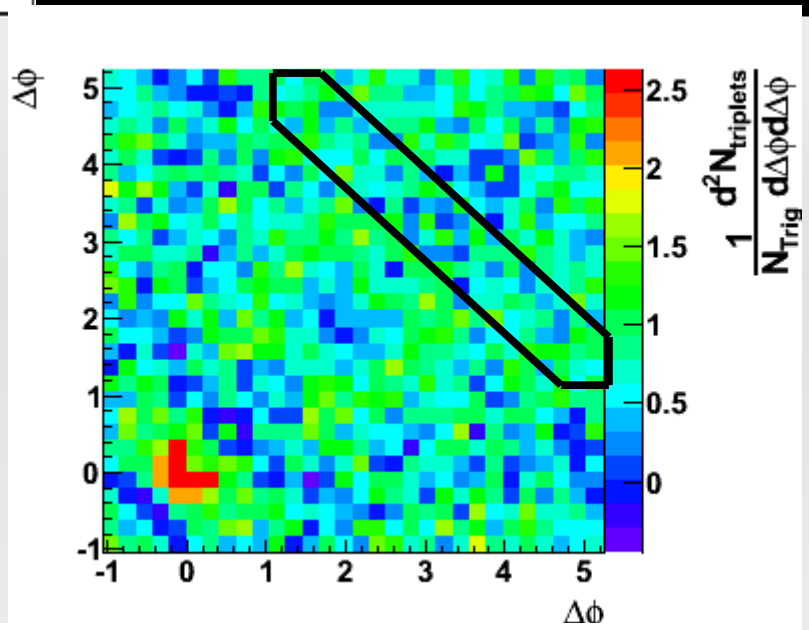
Toy Model 3-Particle Correlation

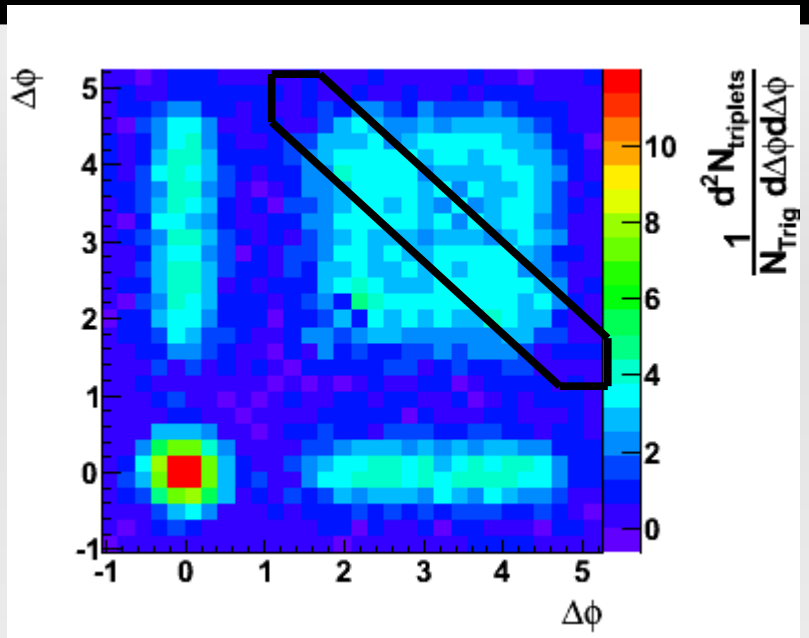
- No away-side 3-particle signal where away-side is only from flow.
- Away-side signal present where it is generated as a jet.

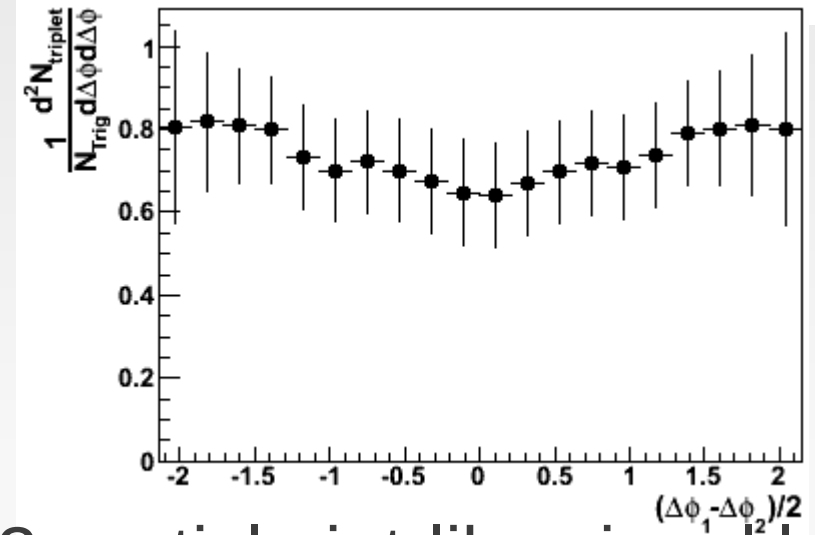


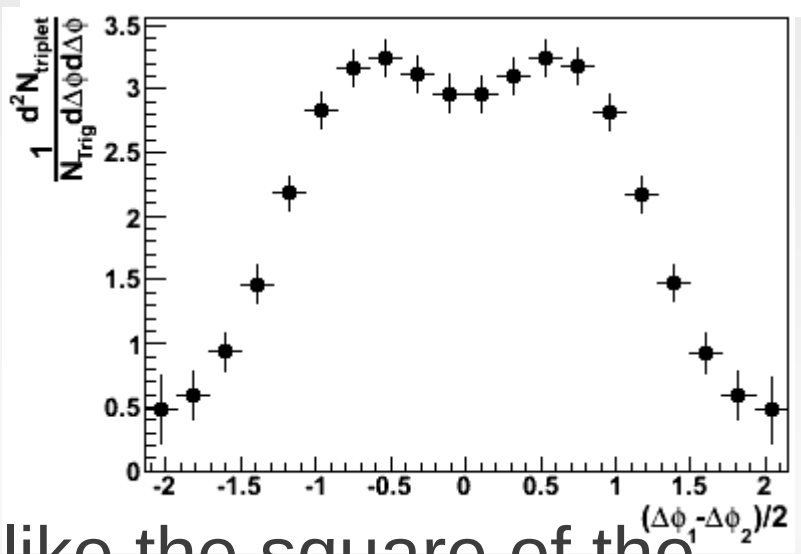


Projections





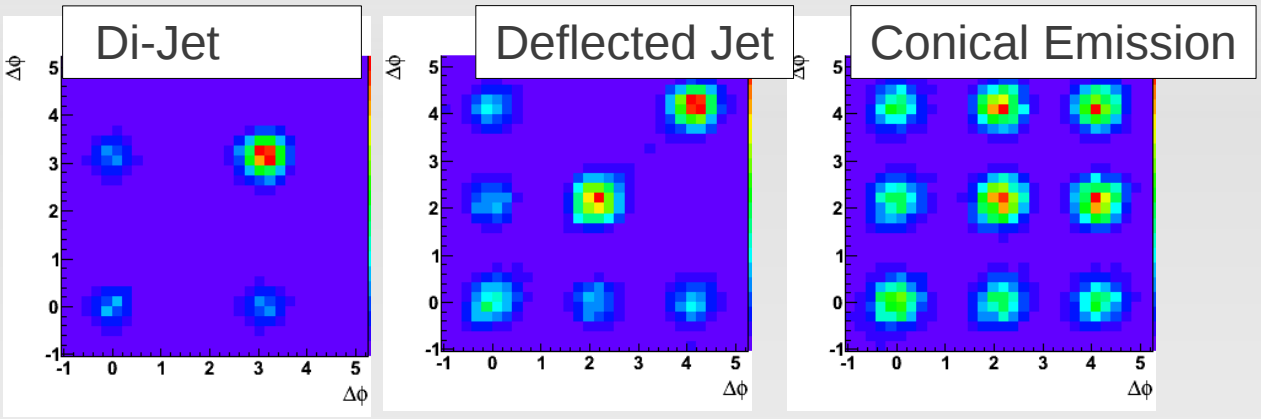


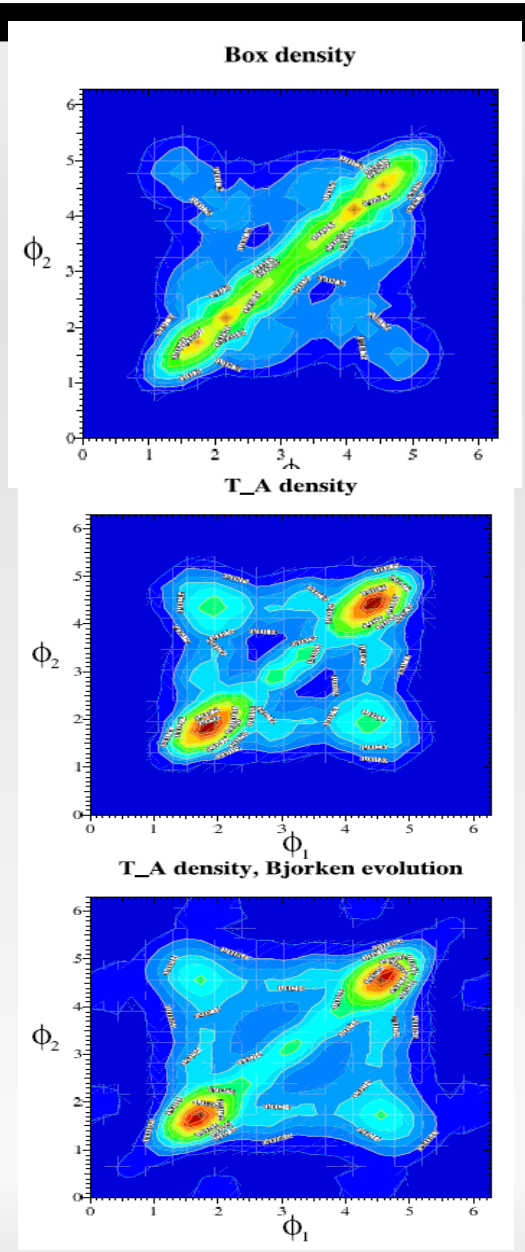


- 3-particle jet-like signal looks like the square of the generated 2-particle jet-like signal as expected.

Cone in Hydro

Renk, Ruppert,
Phys. Rev. **C76**, 014908 (2007)

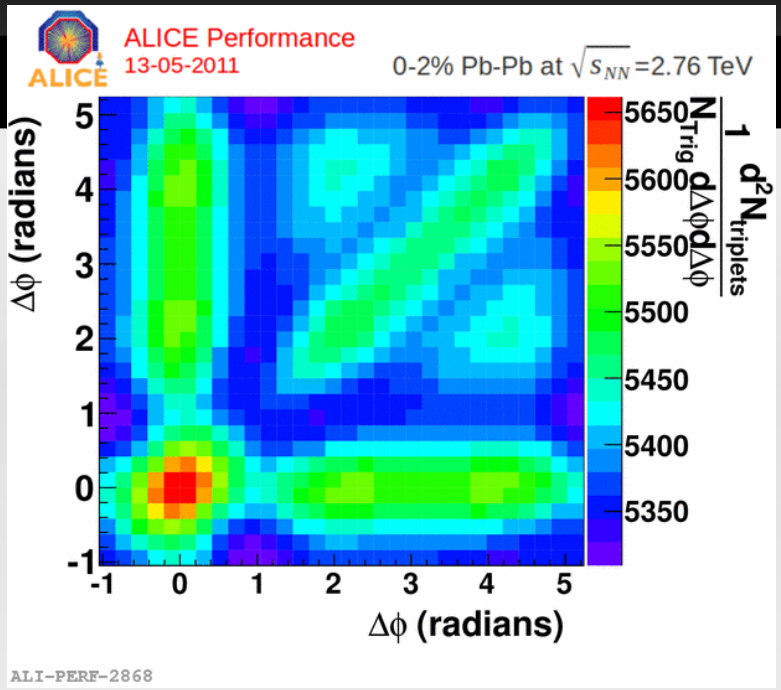


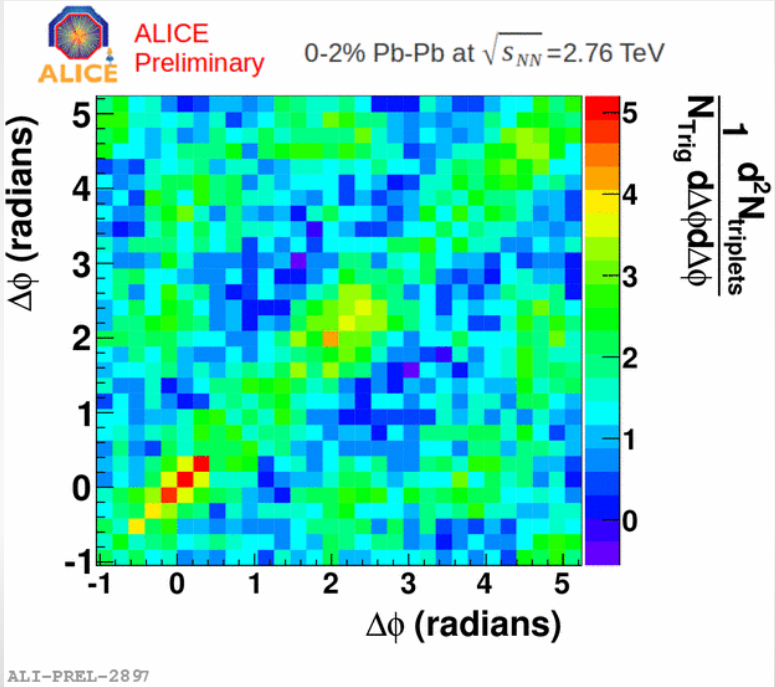


- Toy model expectations along with expectation for a cone in an hydrodynamicaly expanding medium.

Data Results

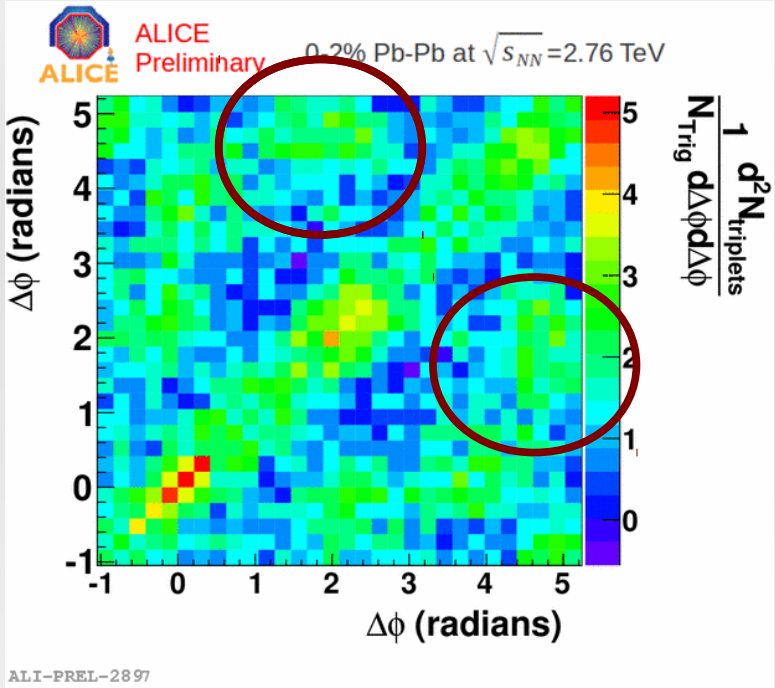
- 0-2% Pb-Pb
- $2.5<p_T^{Trig}<4$ GeV/c
- $1<p_T^{Assoc}<2$ GeV/c
- Half ALICE 2-particle flow values used for v_2, v_3, and v_4.
- Signal to background ~1/1000
- Contribution to the 2-particle signal not straight forward and depends on spread of away-side with respect to detector $\Delta\eta$ acceptance.





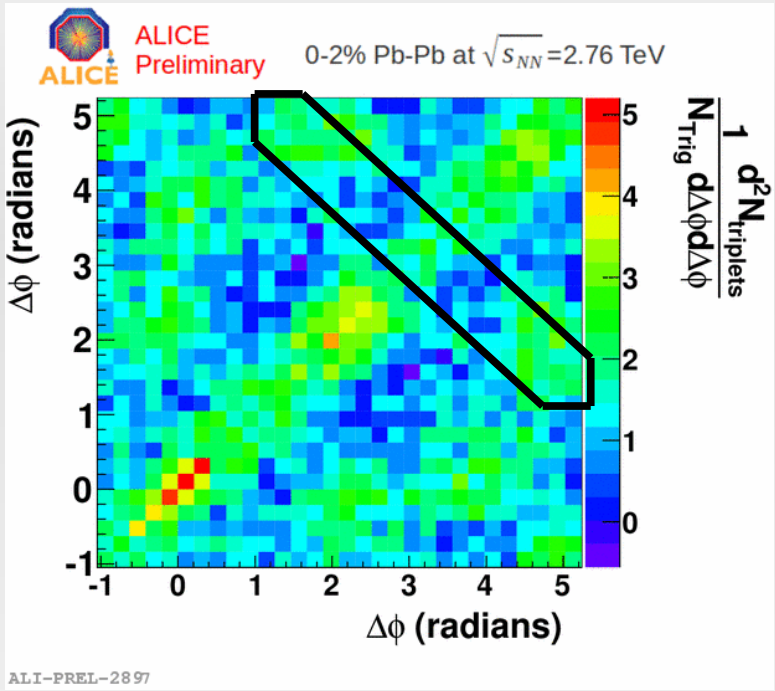
Data Results

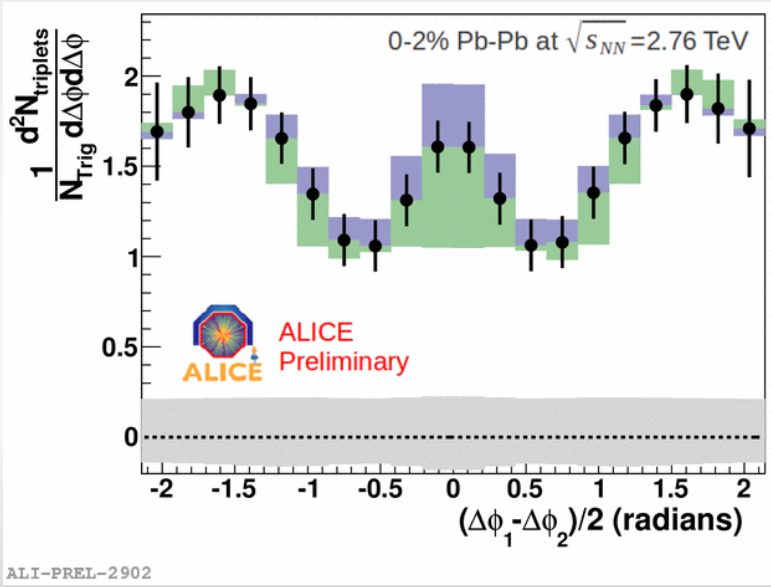
- 0-2% Pb-Pb
- $2.5<p_T^{Trig}<4$ GeV/c
- $1<p_T^{Assoc}<2$ GeV/c
- Half ALICE 2-particle flow values used for v_2, v_3, and v_4.
- Side peaks expected for conical emission seen.



Data Results

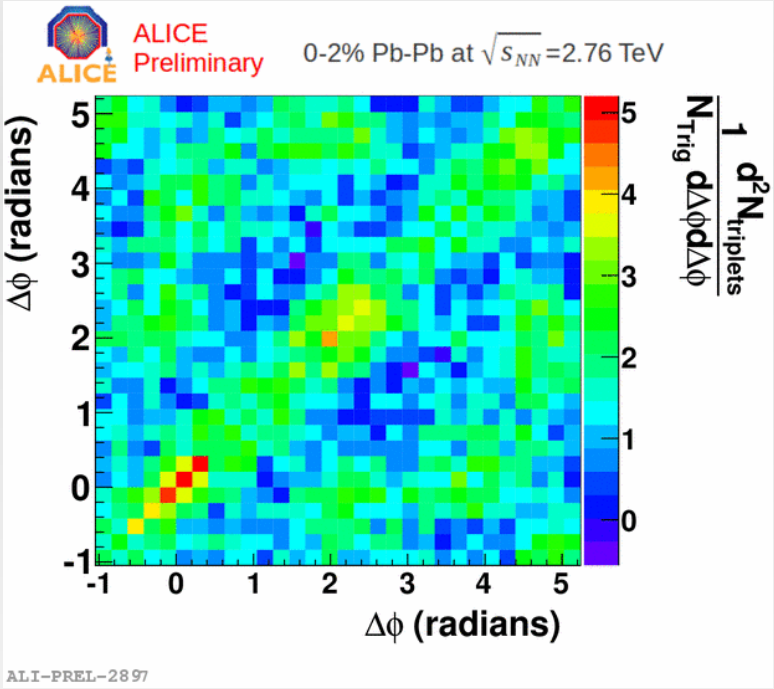
- 0-2% Pb-Pb
- $2.5<p_T^{Trig}<4$ GeV/c
- $1<p_T^{Assoc}<2$ GeV/c
- Systematic errors from:
  - Flow in blue and green varied between 0 and ALICE 2-particle cumulant
  - Normalization in gray

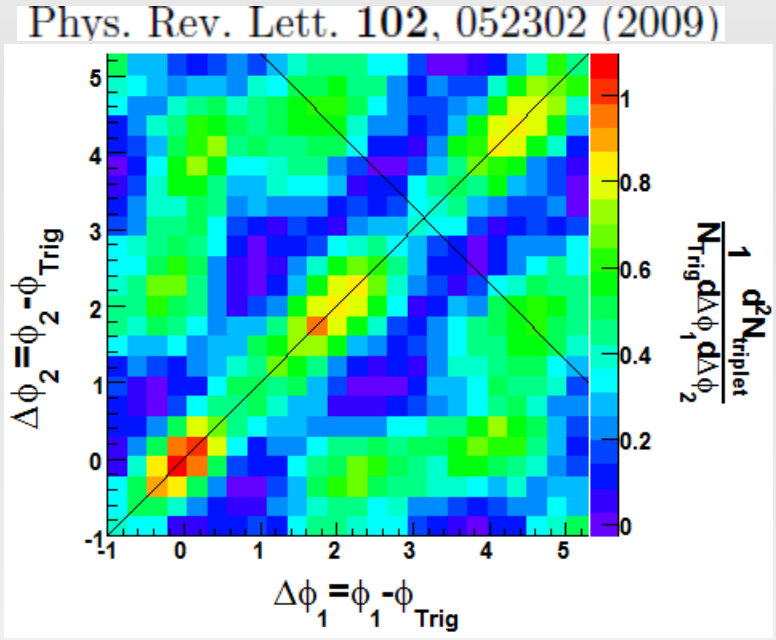




Comparison to STAR

0-2%
$2.5<p_T^{Trig}<4$
$1<p_T^{Assoc}<2$
Pb-Pb
2.76 TeV





0-12%
$3<p_T^{Trig}<4$
$1<p_T^{Assoc}<2$
Au+Au
200 GeV

- Similar correlation shape seen in ALICE as was seen in STAR.

Summary

- Fourier decomposition of $\Delta\eta$ separated 2-particle azimuthal correlations.
  - Flow factorization works at low p_T, but at higher p_T where the correlations are jet dominated.
  - Good agreement with other flow measurements
- I_{AA}
  - Away side suppression in central Pb-Pb
  - Near side enhancement in central Pb-Pb
- Three-particle azimuthal correlations
  - Similar structure as was seen in STAR
  - Consistent with conical emission.