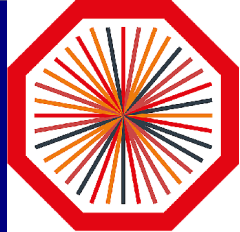


Jet-Medium Interactions In Pb-Pb Collisions



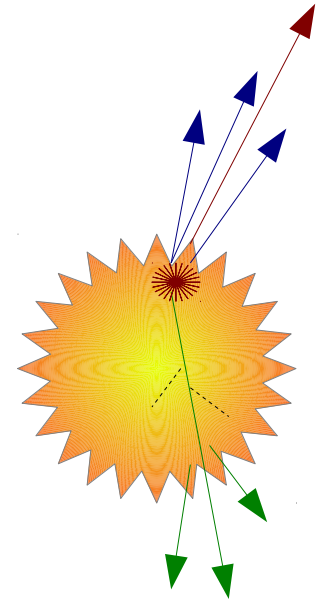
ALICE

Jason Glyndwr Ulery
for the ALICE Collaboration
University of Frankfurt
QM 2012 Draft
06 August 2012

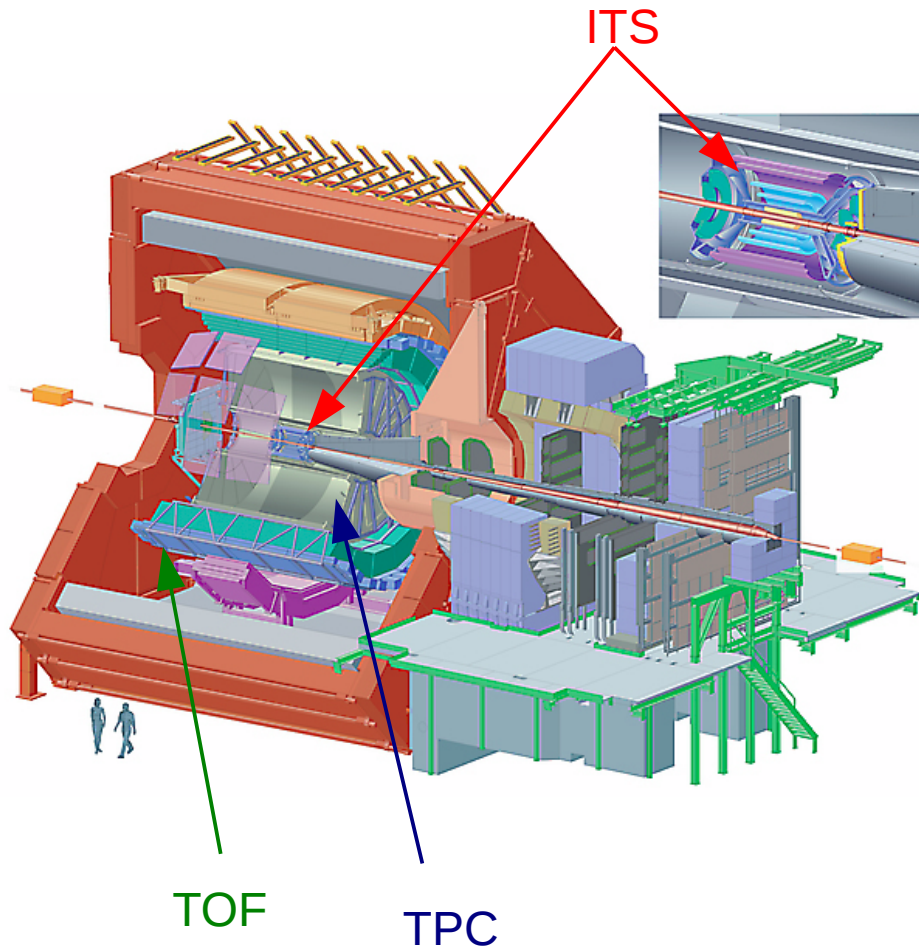
Jets and Medium Modification



- Near-side jet
 - Likely surfaced biased.
 - Implies likely little interaction with the medium.
 - Look at proton to pion ratio in this jet.
 - Does it differ from the medium?
- Away-side jet
 - Long path through the medium.
 - Potential for lots of medium interaction.
 - Look at 3-particle correlations.
 - Any indications of conical emission at the LHC?
- Medium
 - Look at $\Delta\phi$ - $\Delta\eta$ number and $\Delta p_T \Delta p_T$ distributions.
 - Fourier decompose these distributions, v_n .

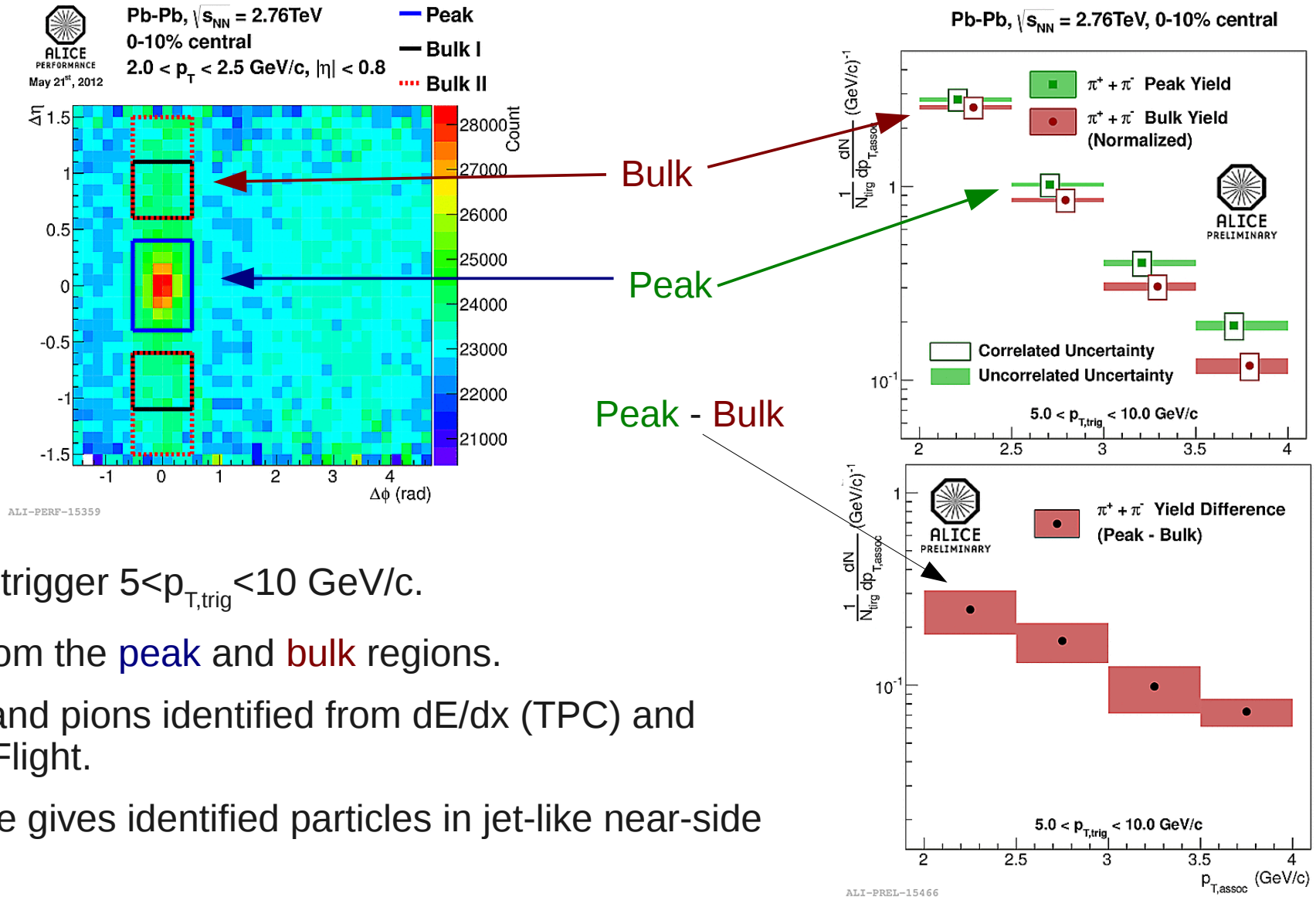


ALICE Detector



- Charged particle tracks from the **Time Projection Chamber** used.
- Particle identification from **TPC** and **Time Of Flight**.
- Vertex from **Inner Tracking System**.
- $\sim 10^7$ minimum bias Pb-Pb events from 2010.

Identified 2-Particle Yields



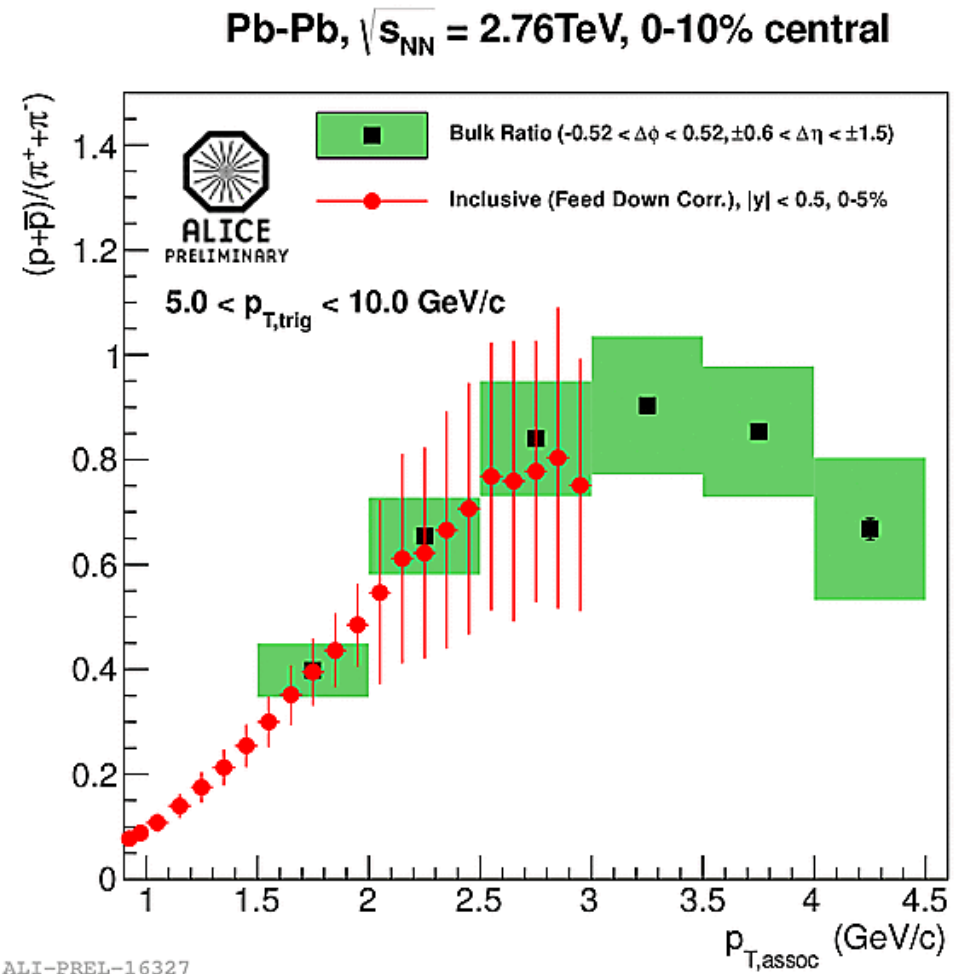
- Charged trigger $5 < p_{T,\text{trig}} < 10\text{ GeV/c}$.
- Yields from the **peak** and **bulk** regions.
- Protons and pions identified from dE/dx (TPC) and Time Of Flight.
- Difference gives identified particles in jet-like near-side peak.

Proton/Pion Ratio



- Bulk

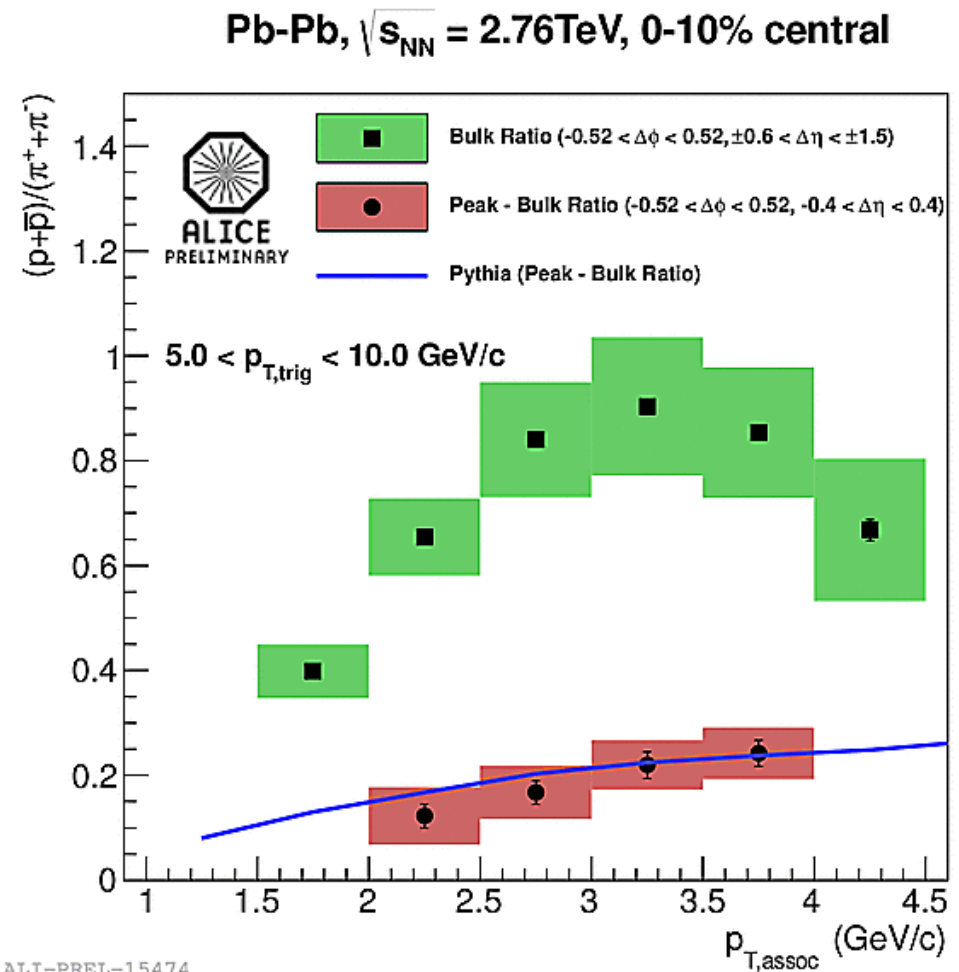
- consistent with ratio from **inclusive spectra**.



Proton/Pion Ratio



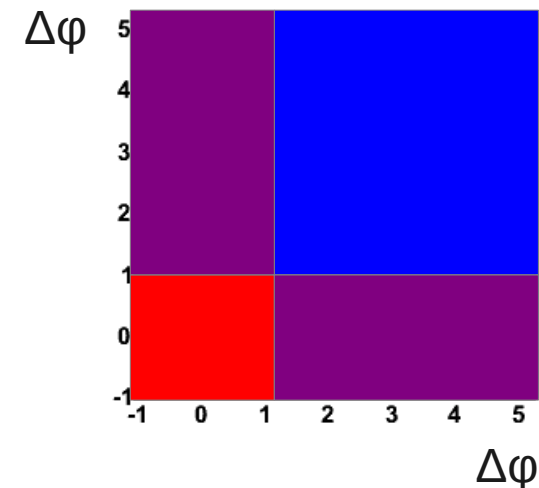
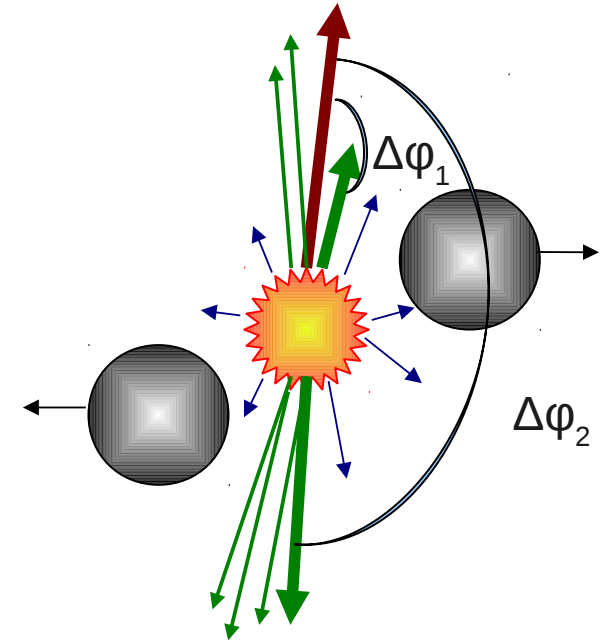
- Bulk
 - consistent with ratio from inclusive spectra.
- Near-side peak
 - consistent with Pythia.
 - therefore consistent with vacuum fragmentation.



3-Particle Azimuthal Correlations



- Angles between trigger particle and two associated particles.
 - $\Delta\varphi = \varphi_{\text{associated}} - \varphi_{\text{trigger}}$
- Symmetrized wrt. $\Delta\varphi_1$ and $\Delta\varphi_2$.
- Three regions
 - **Near side**
 - Both associated near the trigger.
 - **Away side**
 - Both associated opposite the trigger.
 - Area of interest in this analysis.
 - **Near-Away**
 - One associated near the trigger and the other opposite.

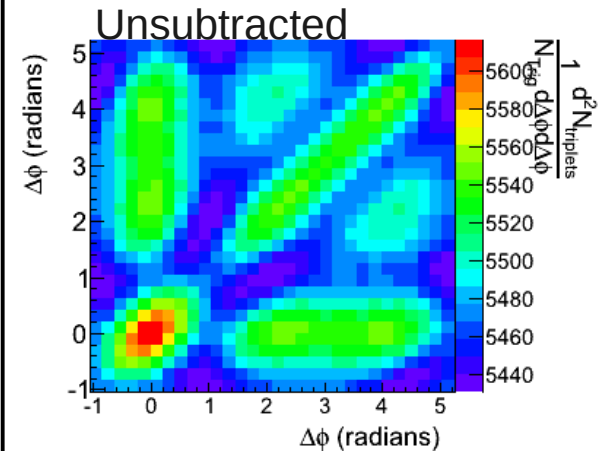


3-Particle Jet-Like Correlations

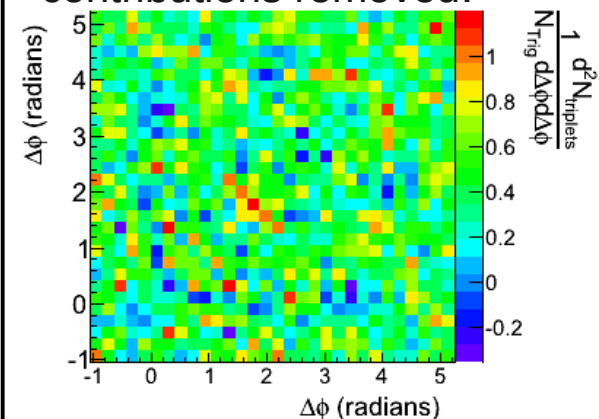


- Provides more information than 2-particle correlations.
 - Different 3-particle signals for deflected jets and conical emission.
- Model dependent background subtraction.
 - Reproduces expected signals in simulations.

0-5% Glauber Model Flow

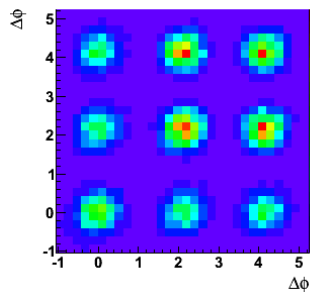


Background subtracted
All significant flow contributions removed.

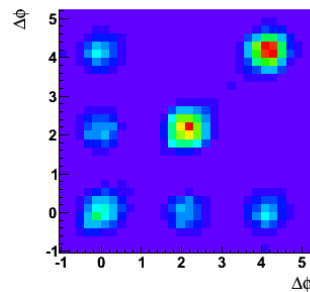


Toy Model 3-Particle Signals with Same 2-Particle Correlation

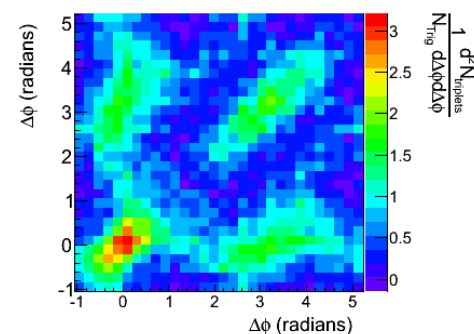
Conical Emission



Deflected Jet



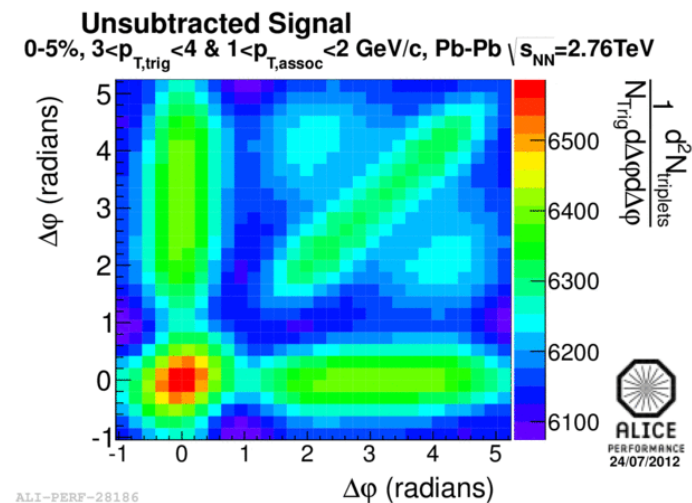
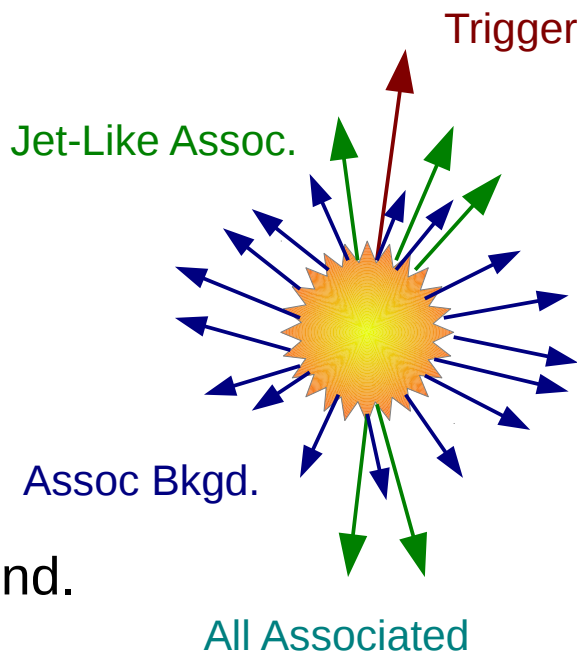
AMPT 40-50% consistent with k_T broadened di-jet



Signal Before Background Subtraction



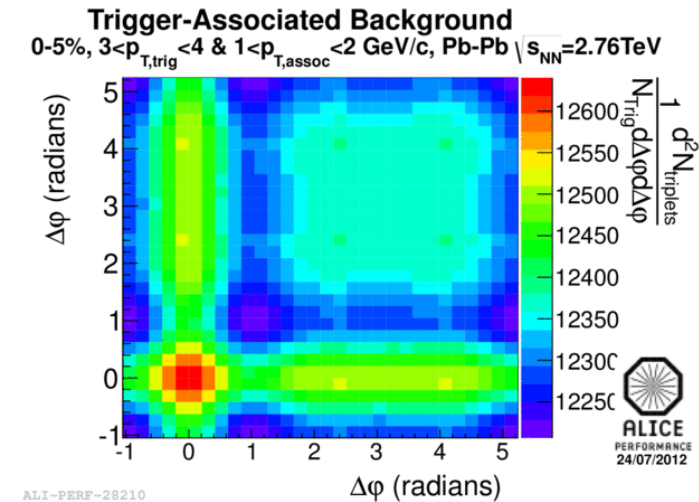
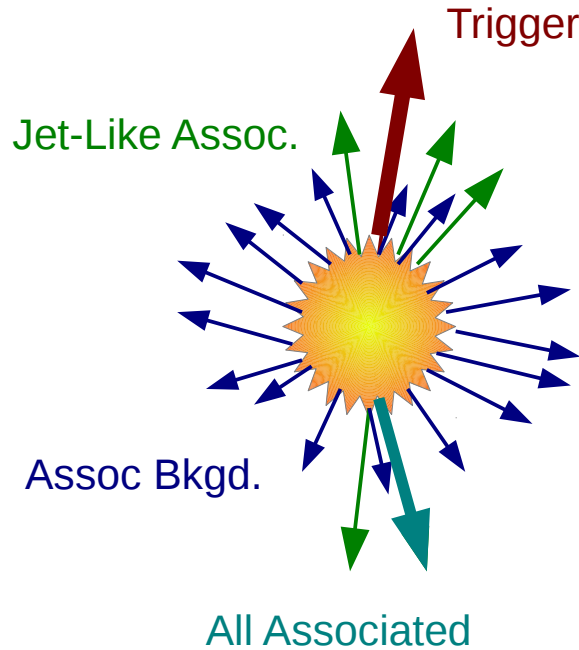
- Contains:
 - 3-particle jet-like correlations **T-A-A**
 - 2-particle backgrounds
 - 3-particle backgrounds
- Assume:
 - Decompose into jet-like correlations and background.
 - Zero Yield At Minimum normalization.
- Flow measurements v_2 , v_3 , and v_4 used in backgrounds.



Trigger-Associated Background



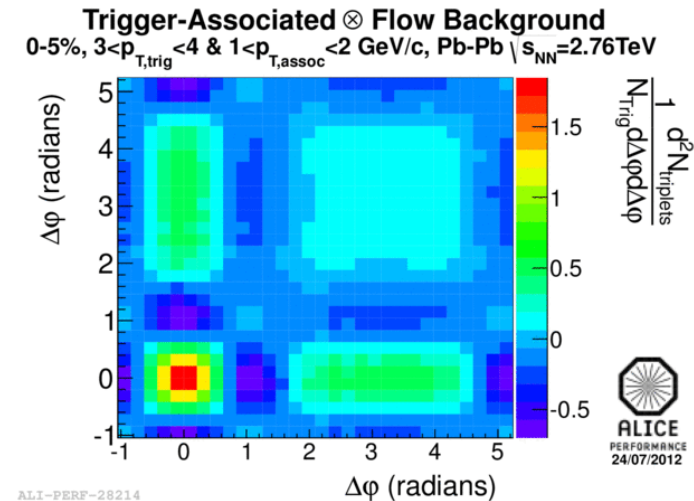
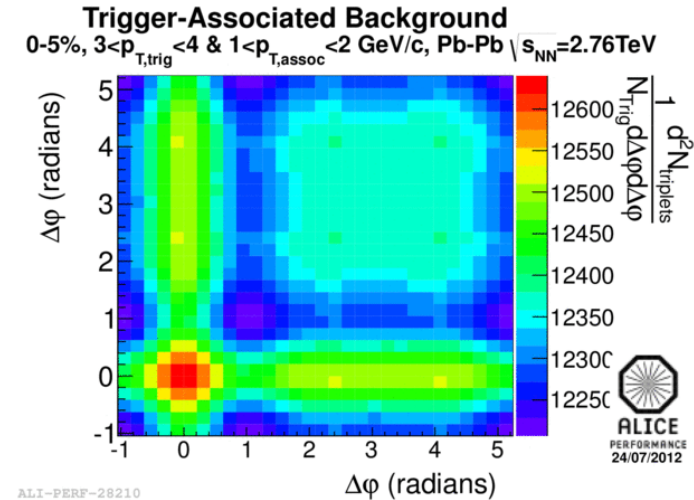
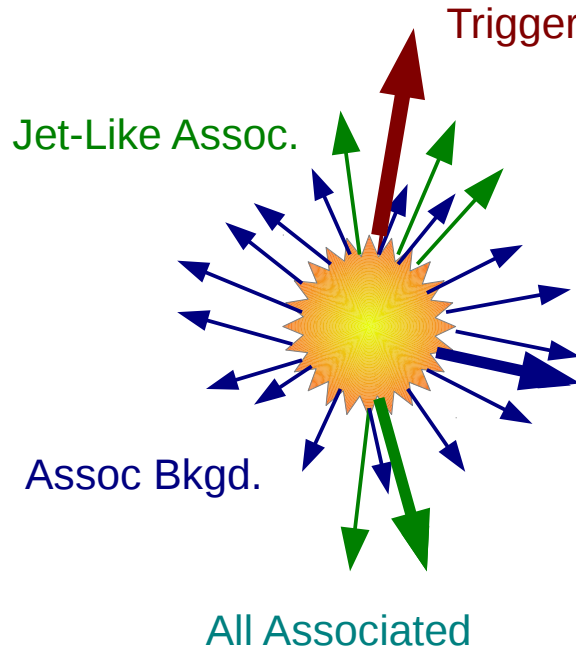
- 2-particle correlations between trigger and one associated T-A folded with mixed event.
 - Contains all T-A 2-particle correlations:
 - jet-like correlations
 - flow
 - resonances



Trigger-Associated \otimes Flow Background



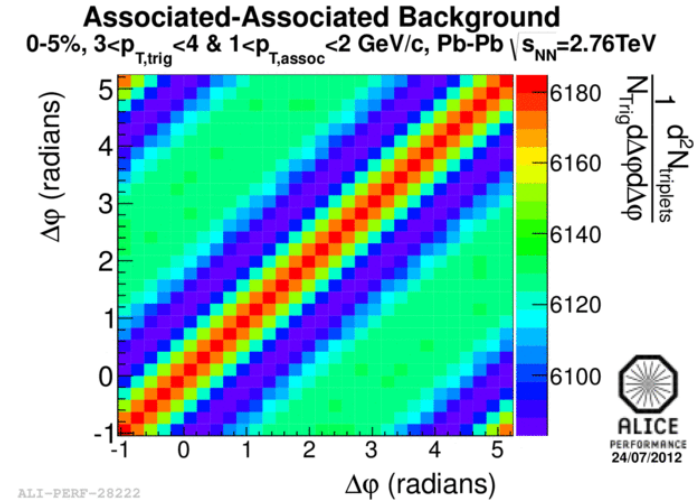
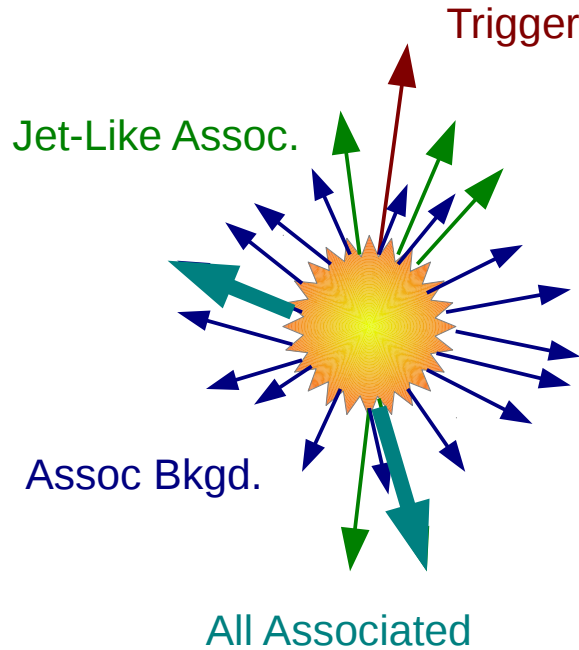
- 2-particle correlations between trigger and one associated T-A folded with mixed event.
 - Contains all T-A 2-particle correlations
 - jet-like correlations
 - flow
 - resonances
- Non-flow component, T-A, can have flow correlation with 3rd particle.



Associated-Associated Background



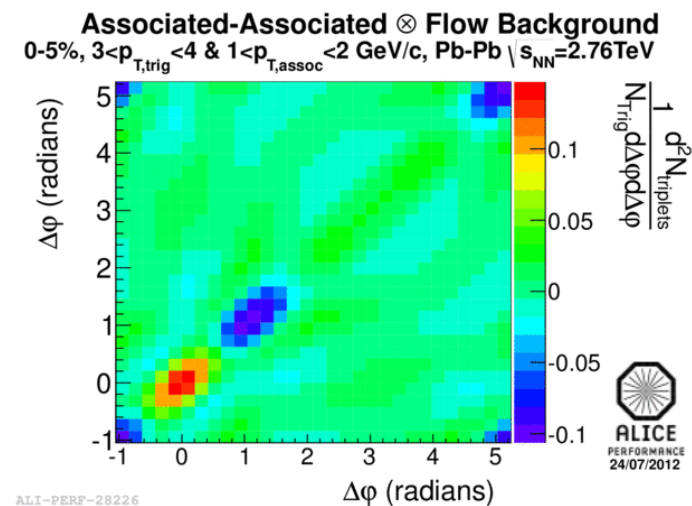
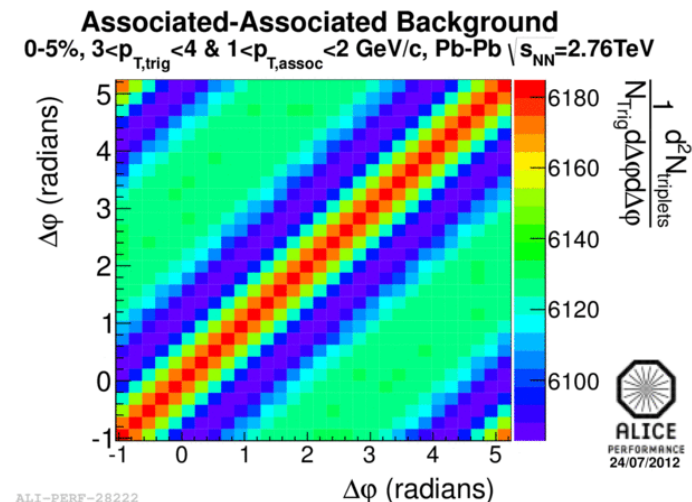
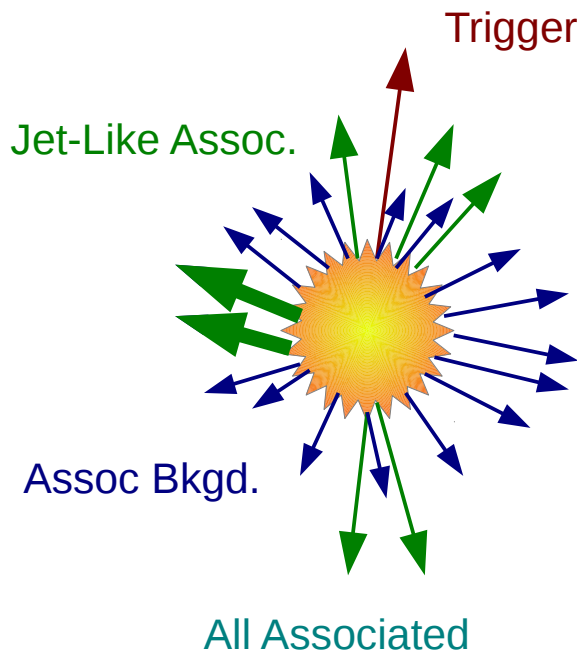
- Two associated particles A-A from one event mixed with a trigger from another event.
 - Contains all A-A 2-particle correlations including:
 - jet-like correlations
 - flow
 - resonances



Associated-Associated \otimes Flow Background

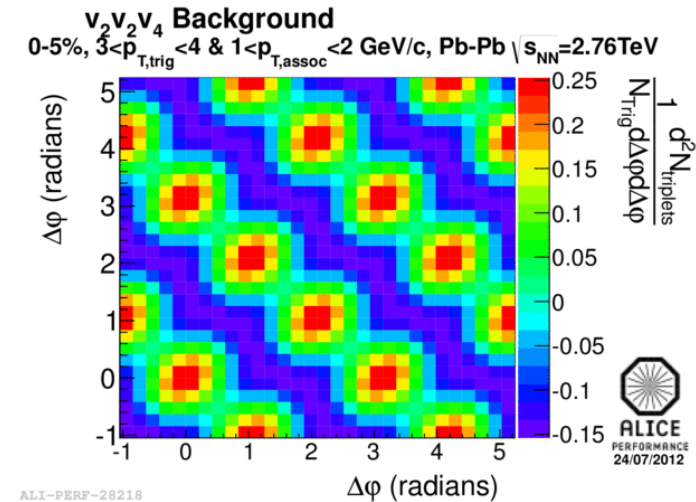
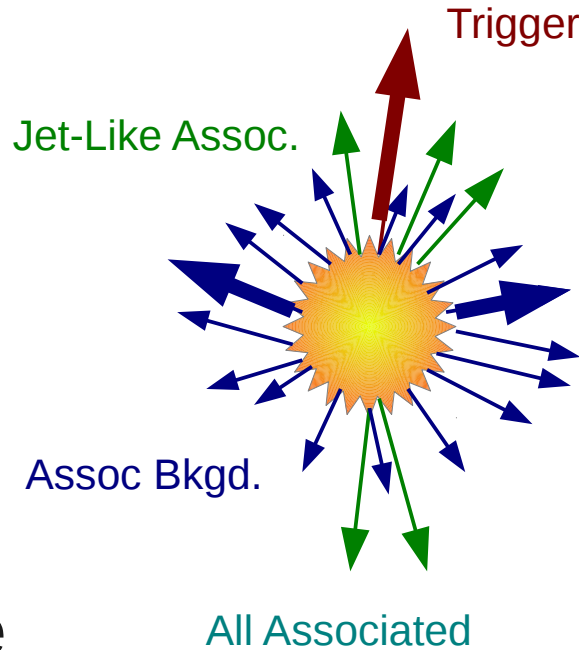


- Two associated particles A-A from one event mixed with a trigger from another event.
 - Contains all A-A 2-particle correlations including:
 - jet-like correlations
 - flow
 - resonances
- Non-flow component flowing with the trigger particle.



3-Particle Flow Background

- 3-particle flow correlation. **T-A-A**
- Only $v_2 v_2 v_4$ is subtracted.
 - Largest of the 3-particle flow terms.
 - Small relative to the signal.



$v_2 v_2 v_4$ Flow

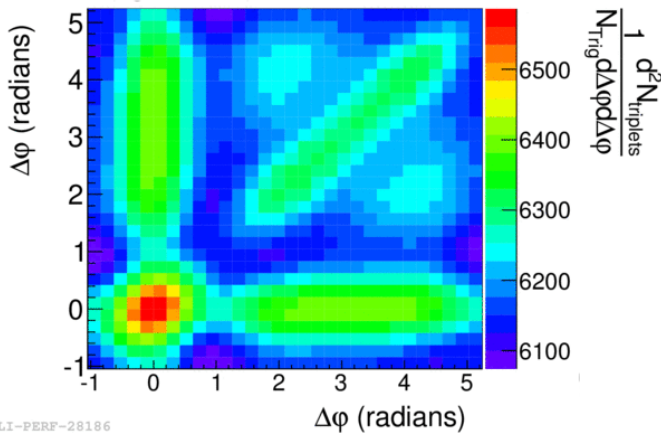
$$\begin{aligned}
 & 2v_{2,T}v_{2,1}v_{4,2}\cos(4\Delta\varphi_2 - 2\Delta\varphi_1) \\
 & + 2v_{2,T}v_{2,2}v_{4,1}\cos(4\Delta\varphi_1 - 2\Delta\varphi_2) \\
 & + 2v_{2,1}v_{2,2}v_{4,T}\cos(2\Delta\varphi_1 + 2\Delta\varphi_2)
 \end{aligned}$$

3-Particle Terms

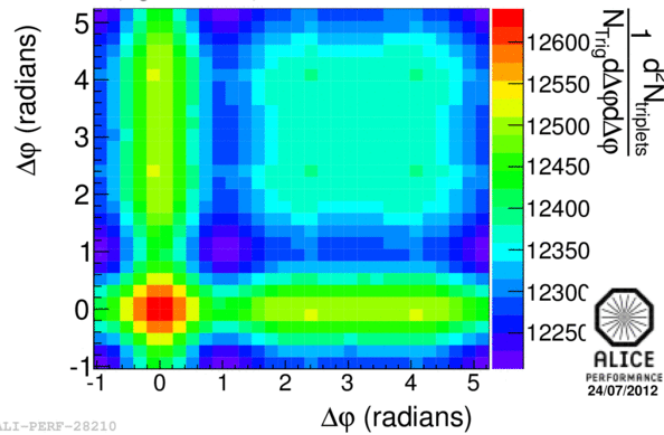
$3 < p_{T, \text{trig}} < 4 \text{ GeV}/c$
 $1 < p_{T, \text{assoc}} < 2 \text{ GeV}/c$
 0-5% Pb-Pb



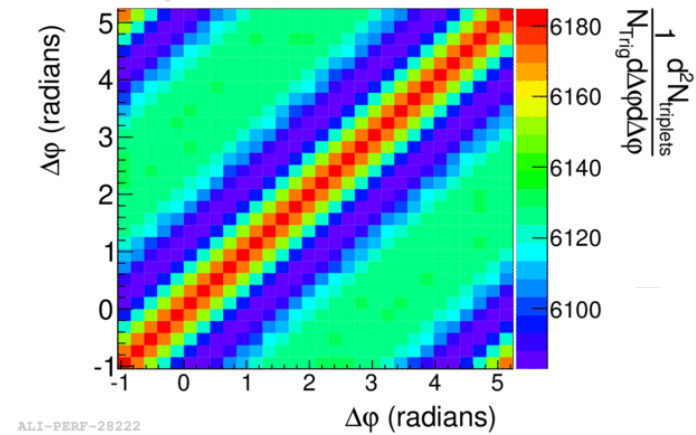
Unsubtracted Signal



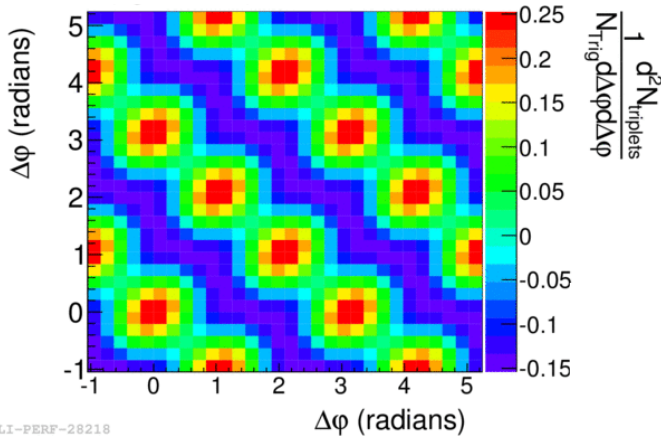
Trigger-Associated Background



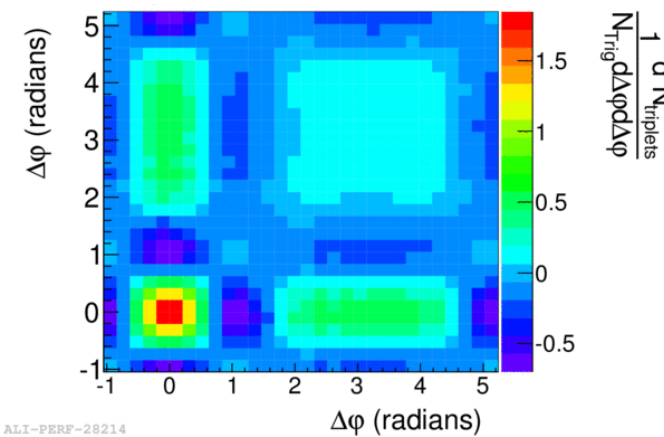
Associated-Associated Background



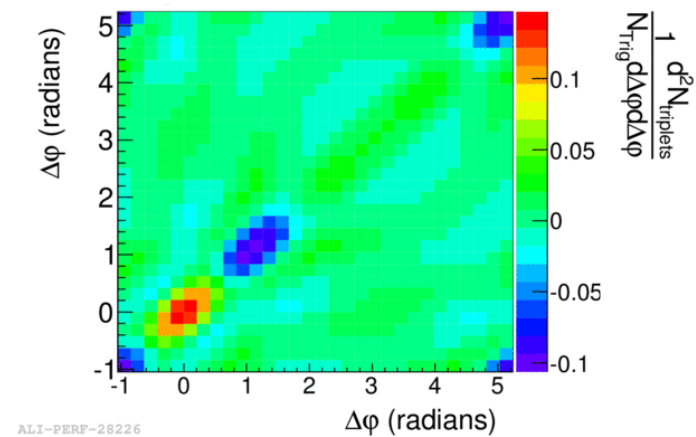
$v_2 v_2 v_4$ Background



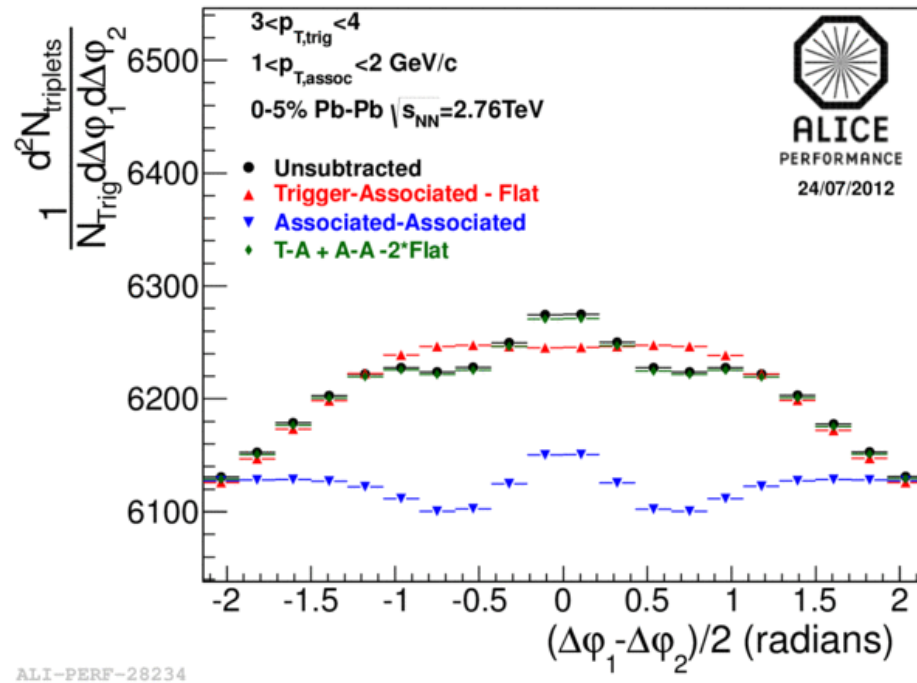
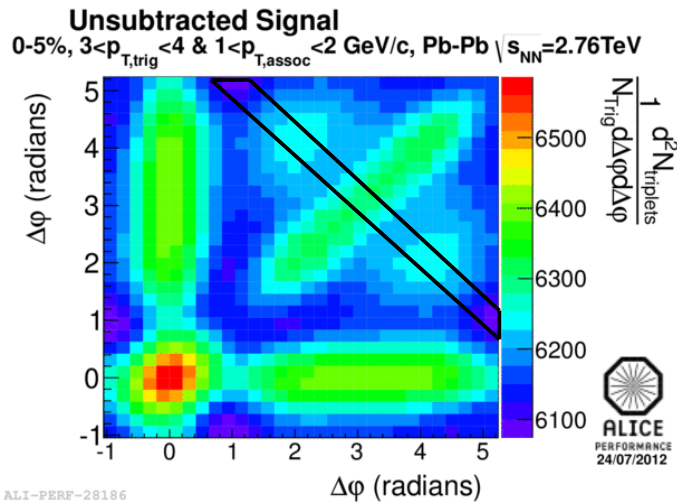
Trigger-Assoc. \otimes Flow Background



Associated-Assoc. \otimes Flow Background

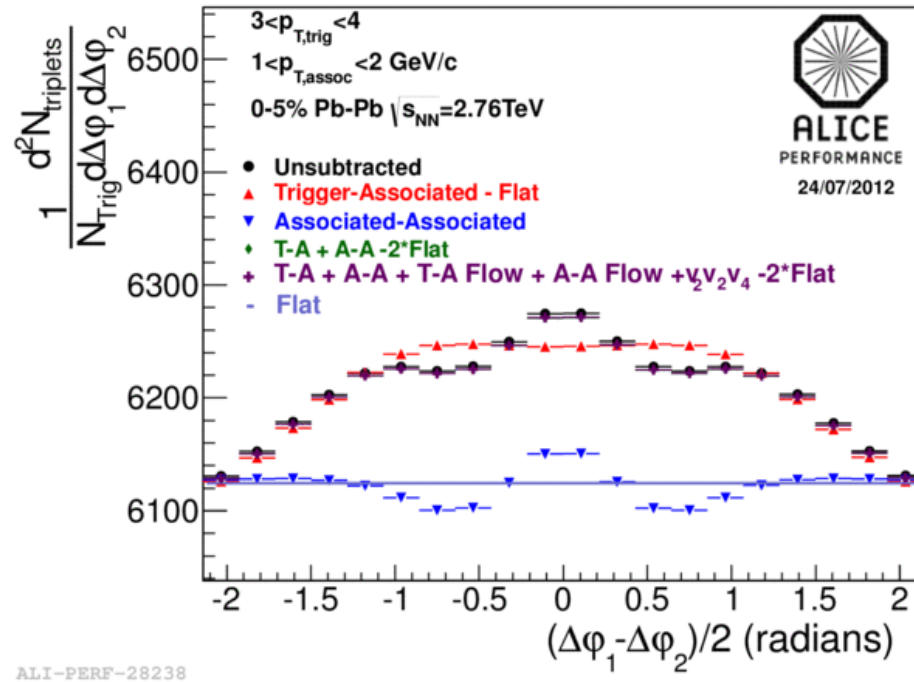
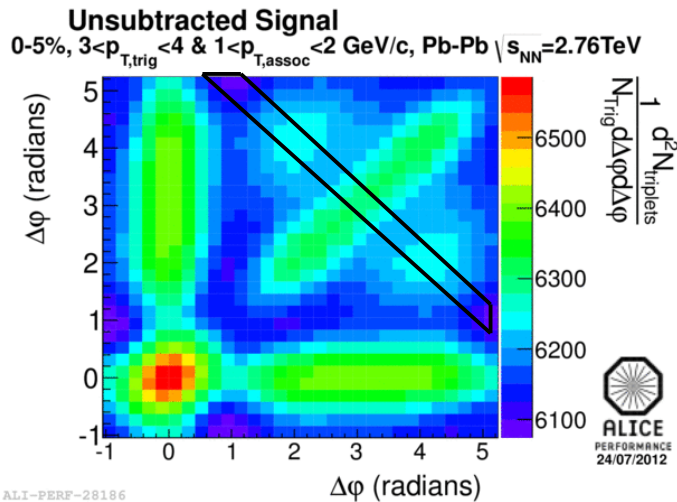


3-Particle Terms Projections



- Sum of 2-particle backgrounds nearly reproduces the signal.

3-Particle Terms Projections



- Sum of 2-particle backgrounds nearly reproduces the signal.
- 3-particle backgrounds relatively very small.

Background Subtracted 3-Particle Correlations

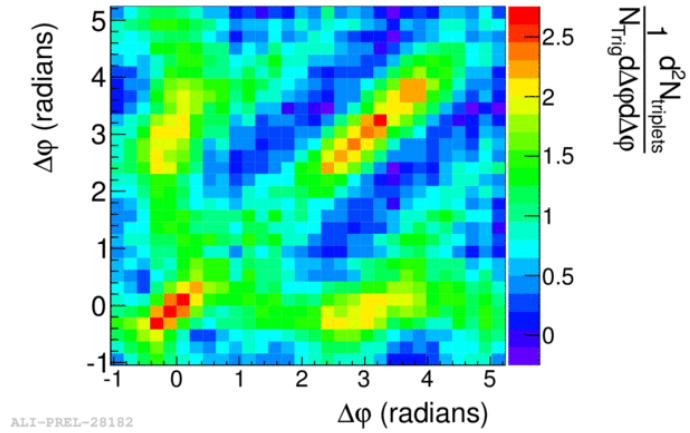
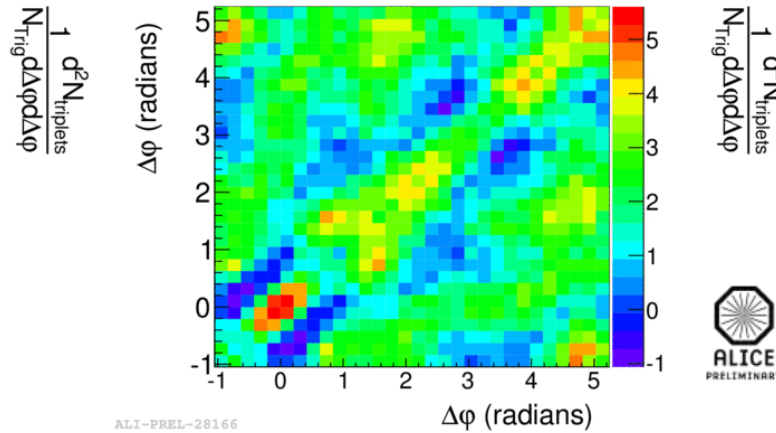
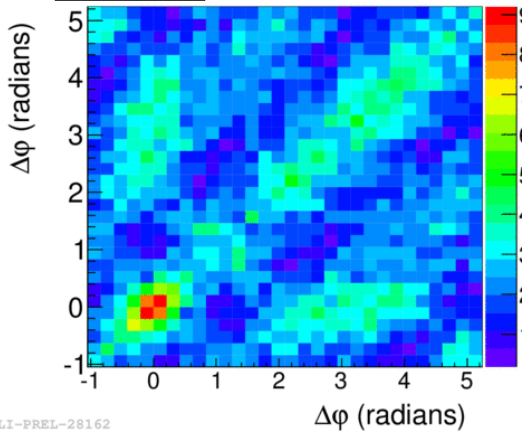
$3 < p_{T, \text{trig}} < 4 \text{ GeV}/c$
 $1 < p_{T, \text{assoc}} < 2 \text{ GeV}/c$
 Pb-Pb



0-5%

5-10%

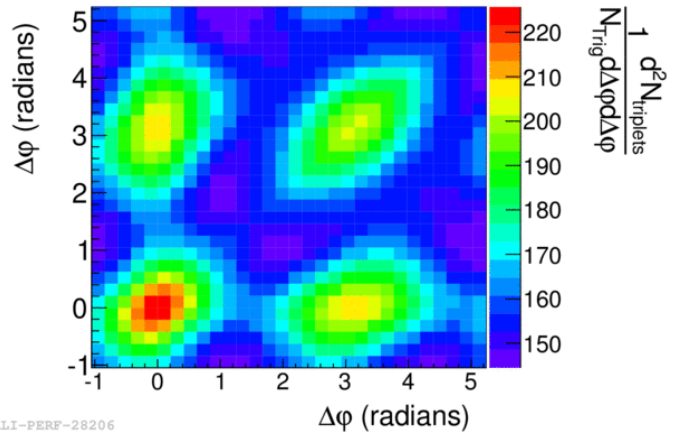
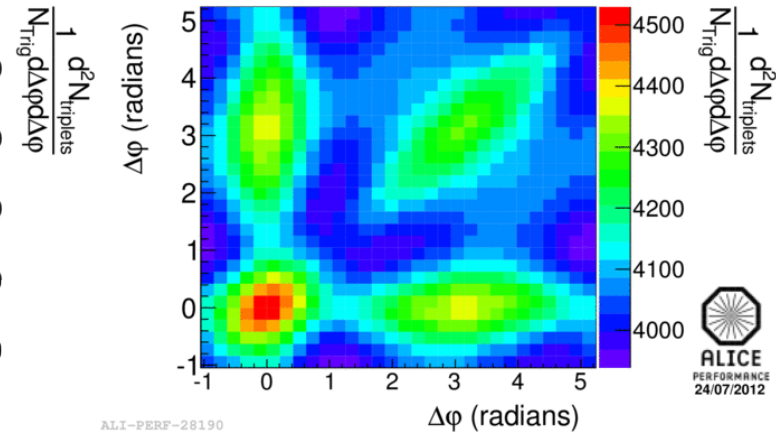
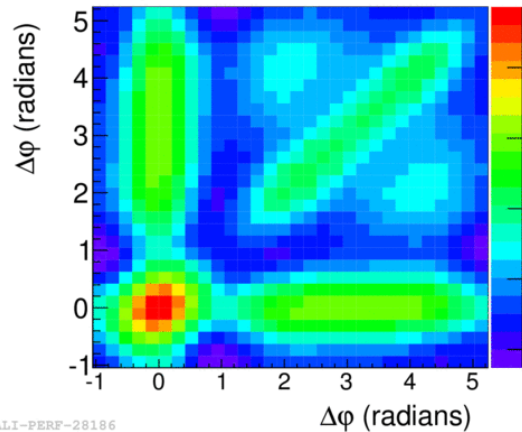
40-50%



Unsubtracted Signal

Unsubtracted Signal

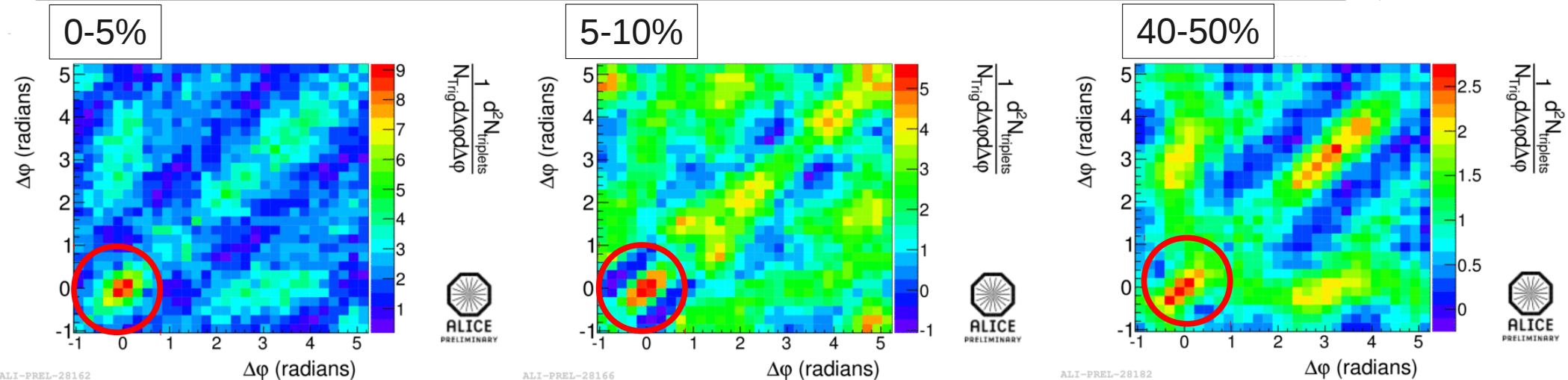
Unsubtracted Signal



- Background subtracted signal is small relative to the unsubtracted signal.

Background Subtracted 3-Particle Correlations

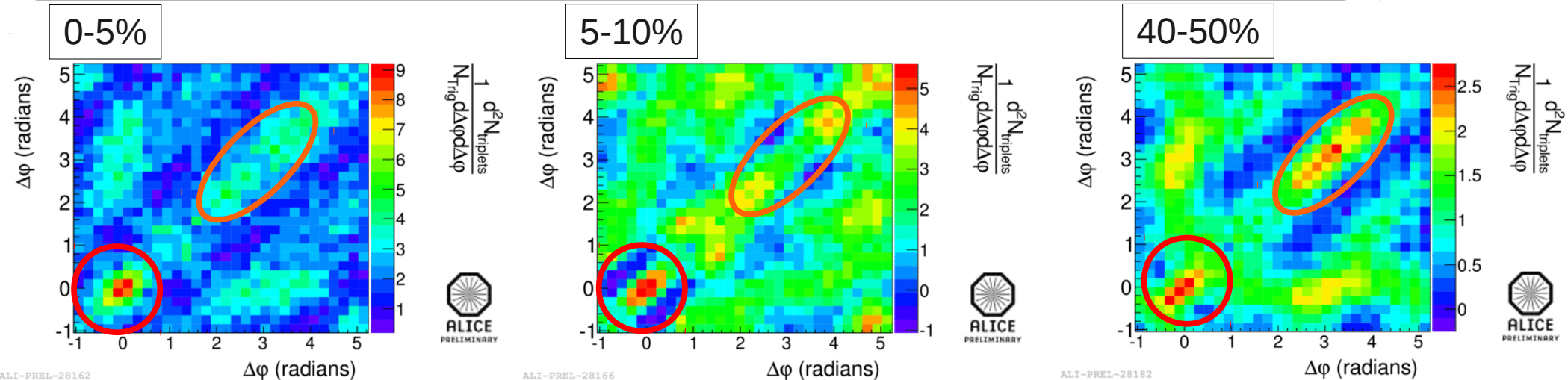
$3 < p_{T, \text{trig}} < 4 \text{ GeV}/c$
 $1 < p_{T, \text{assoc}} < 2 \text{ GeV}/c$
 Pb-Pb



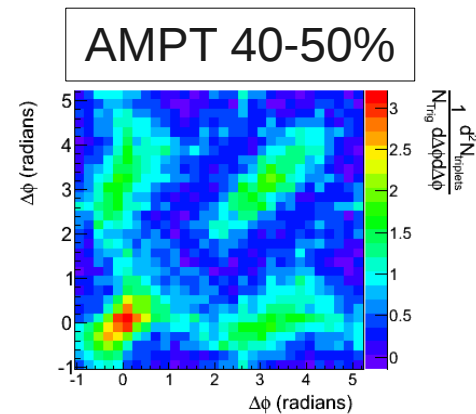
- **Near-side** peak at (0,0).

Background Subtracted 3-Particle Correlations

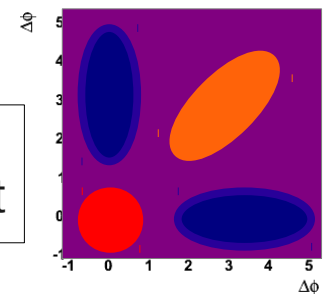
$3 < p_{T, \text{trig}} < 4 \text{ GeV}/c$
 $1 < p_{T, \text{assoc}} < 2 \text{ GeV}/c$
 Pb-Pb



- **Near-side** peak at $(0,0)$.
- **Away-side** peak at (π, π) .
 - Elongation along the diagonal expected from k_T broadening.
 - 40-50% consistent with k_T broadened di-jet.



Cartoon
 k_T broadened di-jet

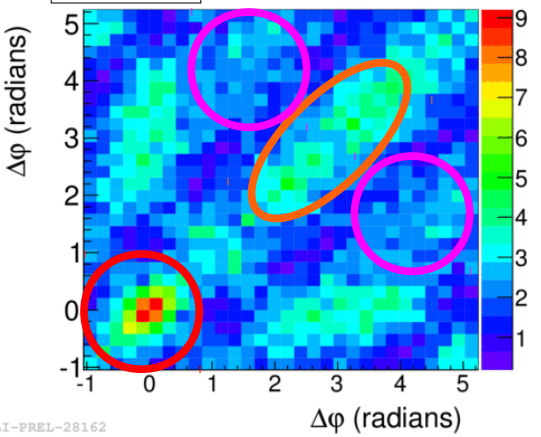


Background Subtracted 3-Particle Correlations

$3 < p_{T, \text{trig}} < 4 \text{ GeV}/c$
 $1 < p_{T, \text{assoc}} < 2 \text{ GeV}/c$
 Pb-Pb



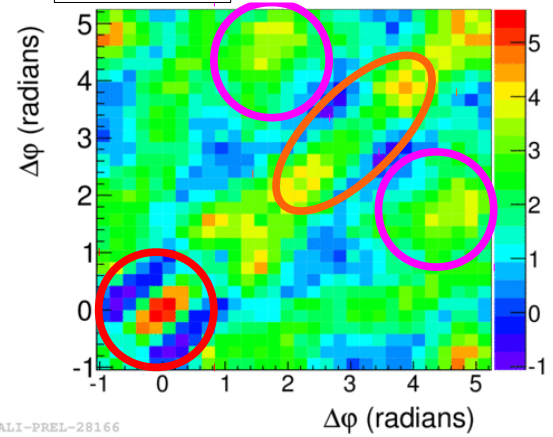
0-5%



$$\frac{1}{N_{\text{trig}}} \frac{d^2 N_{\text{triplets}}}{d\phi d\Delta\phi d\Delta\phi}$$



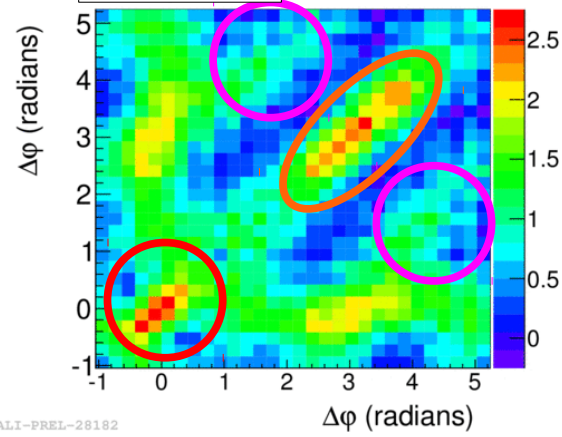
5-10%



$$\frac{1}{N_{\text{trig}}} \frac{d^2 N_{\text{triplets}}}{d\phi d\Delta\phi d\Delta\phi}$$



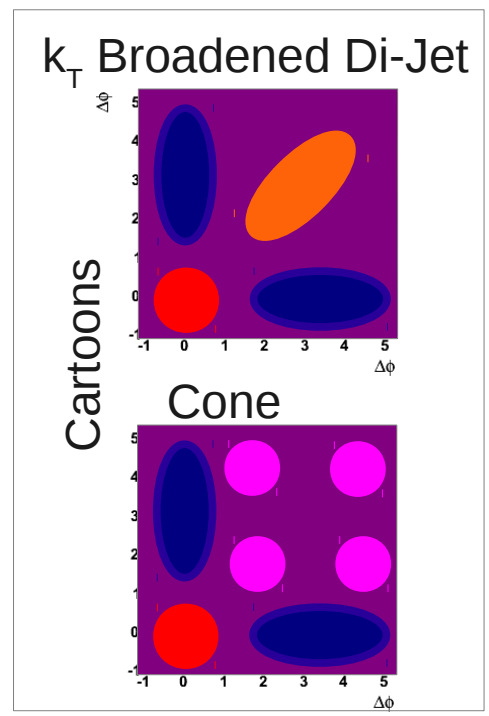
40-50%



$$\frac{1}{N_{\text{trig}}} \frac{d^2 N_{\text{triplets}}}{d\phi d\Delta\phi d\Delta\phi}$$



- **Near-side** peak at (0,0).
- **Away-side** peak at (π,π).
 - Elongation along the diagonal expected from k_T broadening.
 - 40-50% consistent with k_T broadened di-jet and with AMPT.
- **Off-diagonal structures** seen.



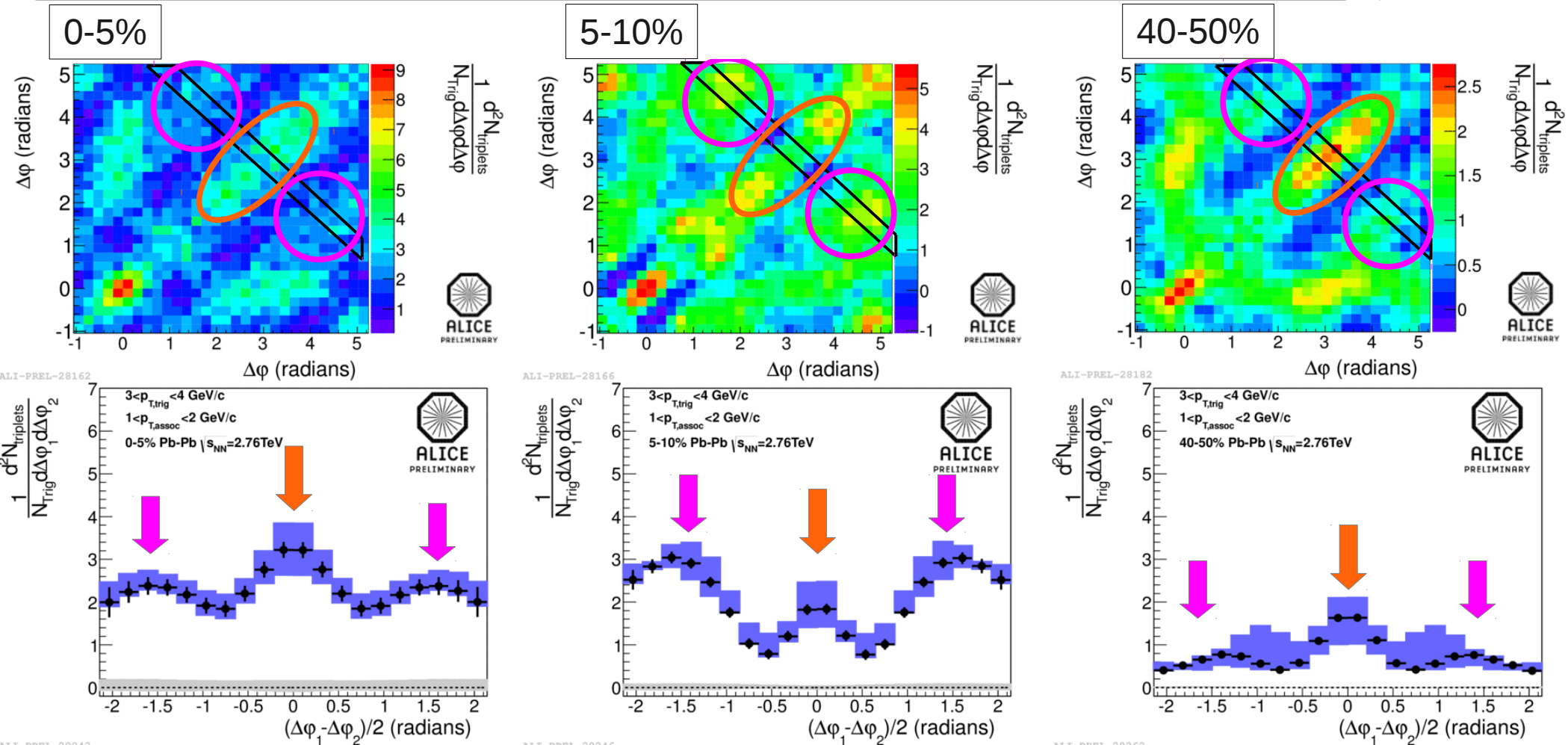
Ulery: Poster 236

15 Aug 2012

Jason Glyndwr Ulery - University of Frankfurt

Background Subtracted 3-Particle Correlations

$3 < p_{T, \text{trig}} < 4 \text{ GeV}/c$
 $1 < p_{T, \text{assoc}} < 2 \text{ GeV}/c$
 Pb-Pb



- **Away-side peak** significant for all centralities.
- **Off-diagonal structures** significant in central collisions but not 40-50%.

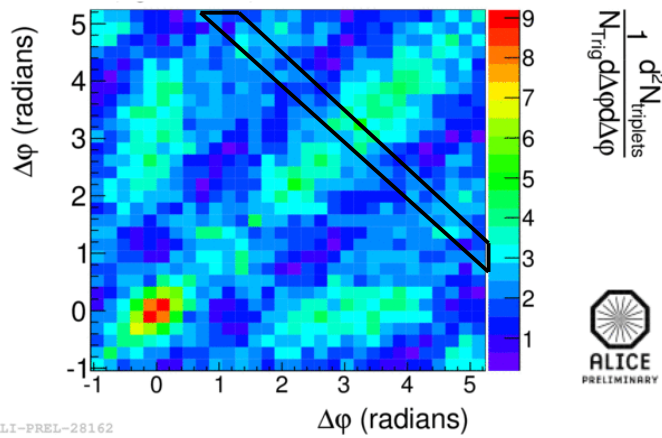
Ulery: Poster 236

Comparison To STAR

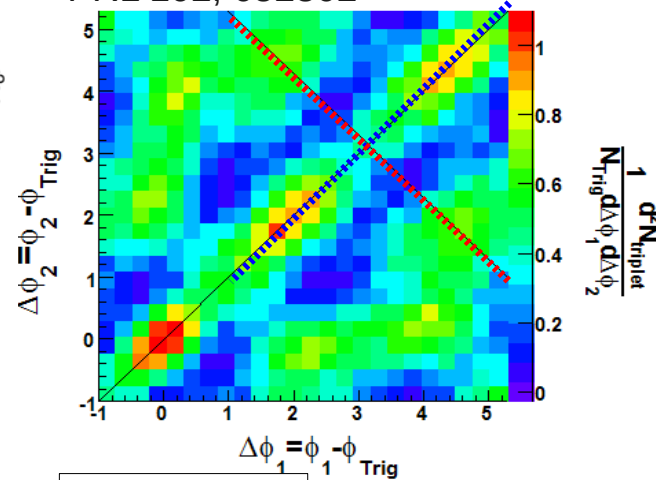
$3 < p_{T, \text{trig}} < 4 \text{ GeV}/c$
 $1 < p_{T, \text{assoc}} < 2 \text{ GeV}/c$



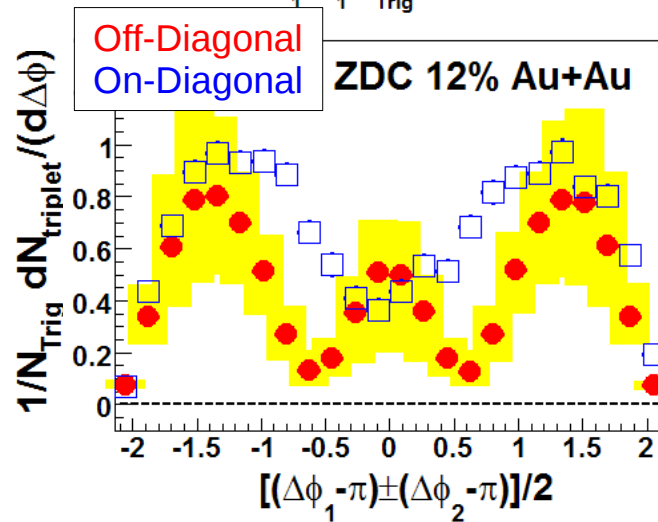
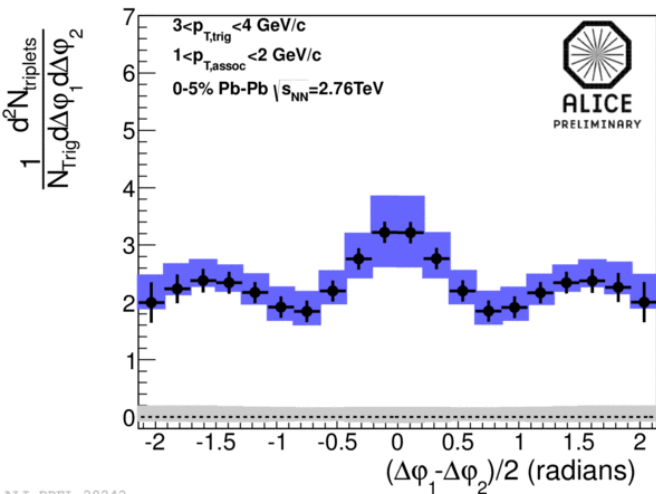
ALICE 0-5% Pb-Pb 2.76 TeV



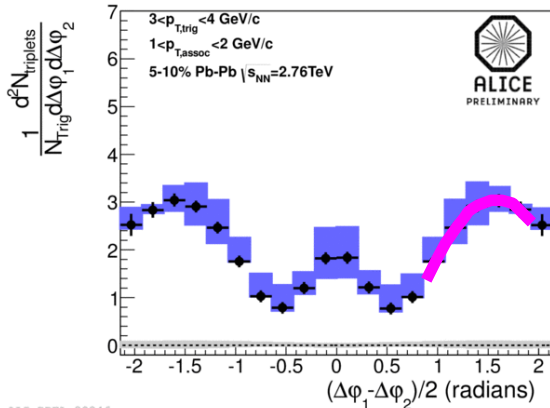
STAR 0-12% Au+Au 200 GeV
 PRL 102, 052302



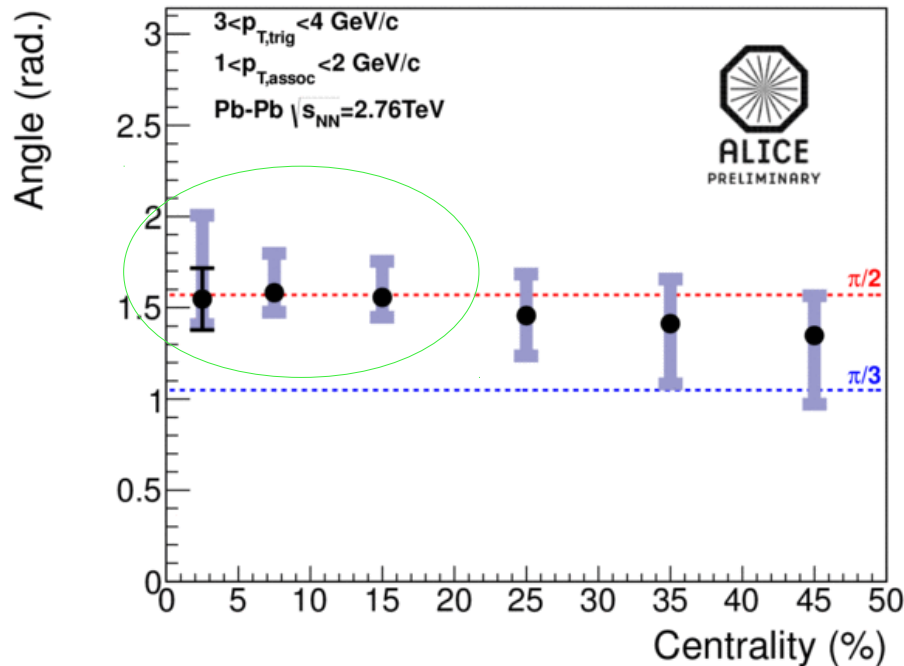
- Same model dependences.
- Different methods of flow subtraction.
- Larger near-side and away-side peaks seen in ALICE.
- Similar side peak magnitude (peak to valley).



Centrality Dependence of the Angle



ALI-PREL-28246



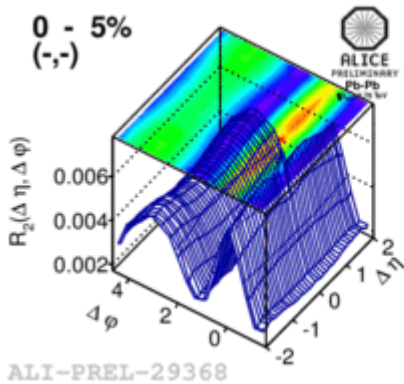
ALI-PREL-29215

- Side-peak angle from Gaussian fit to the projection.
- Systematically significant peaks in 0-5%, 5-10%, and 10-20%.
- No significant centrality dependence.
- Inconsistent with a v_3 peak.
 - Would have an angle of $\pi/3$.

Low- p_T Number and $\Delta p_T \Delta p_T$ Correlations



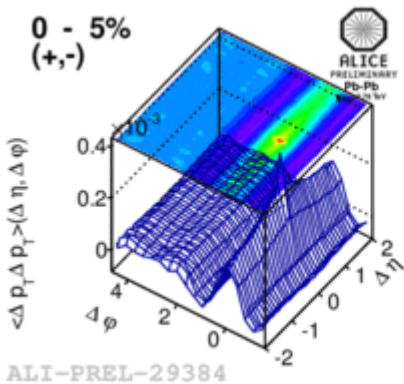
Number Correlation



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

- $\Delta\eta$ - $\Delta\varphi$ correlations.
 - Expands published results with **different charge combinations (+,+),(-,-),(+,-)** and $\Delta\eta$ regions.
 - $0.2 < p_T < 2$ GeV/c.

$\Delta p_T \Delta p_T$ Correlation



$$\Delta p_T = p_T(\eta, \varphi) - \langle p_T(\eta, \varphi) \rangle$$

$$\langle \Delta p_{T,1}, \Delta p_{T,2} \rangle = \frac{\sum_{\text{events accepted}} \sum \Delta p_{T,1}(\eta_1, \varphi_1) \Delta p_{T,2}(\eta_2, \varphi_2)}{\sum_{\text{events}} n_2(\eta_1, \varphi_1, \eta_2, \varphi_2)}$$

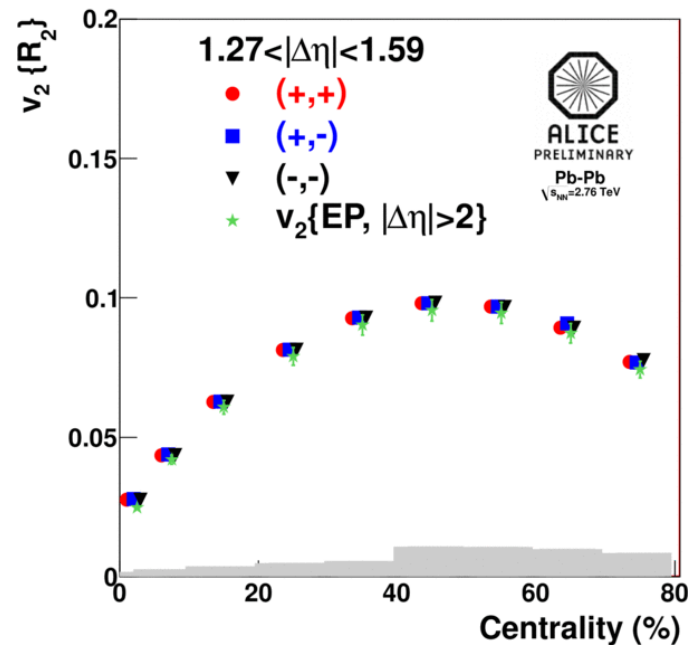
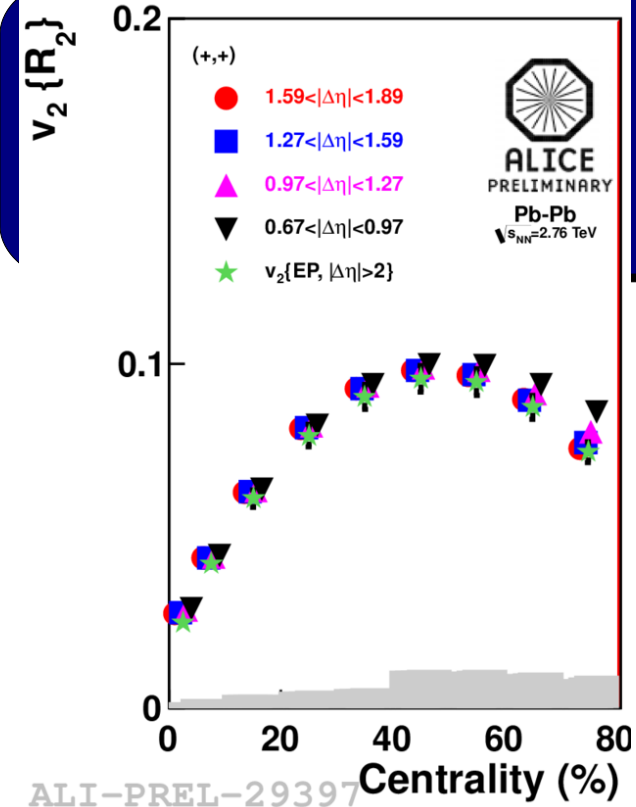
- Decompose into Fourier coefficients.
 - At large $\Delta\eta$ should be equivalent to other v_n measurements.

$$c(\Delta\varphi) = a_0 + \sum_{n=1}^6 a_n \cos(n\Delta\varphi)$$

$$v_n = \text{sign}(a_n) \sqrt{\frac{|a_n|}{2}}$$

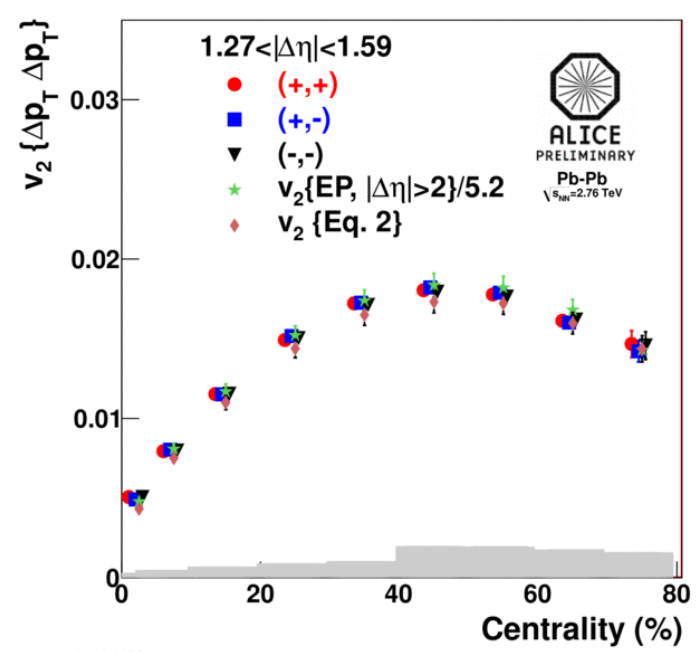
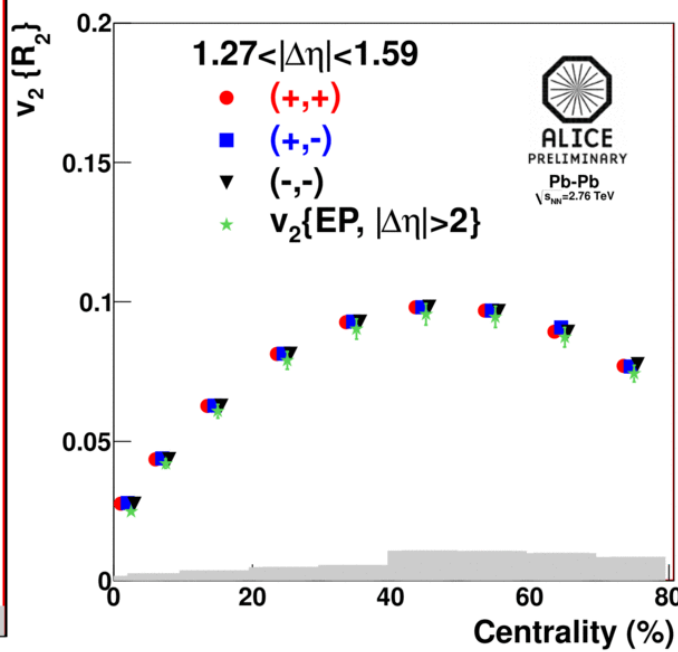
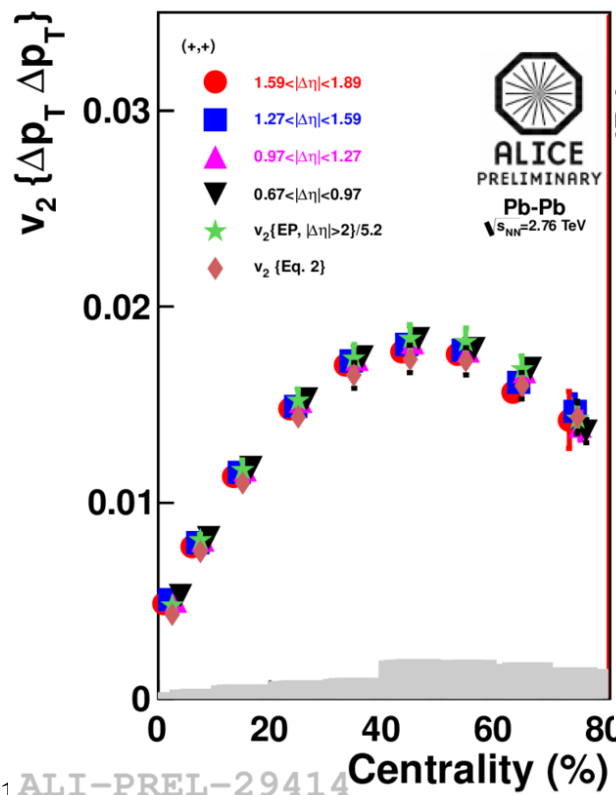
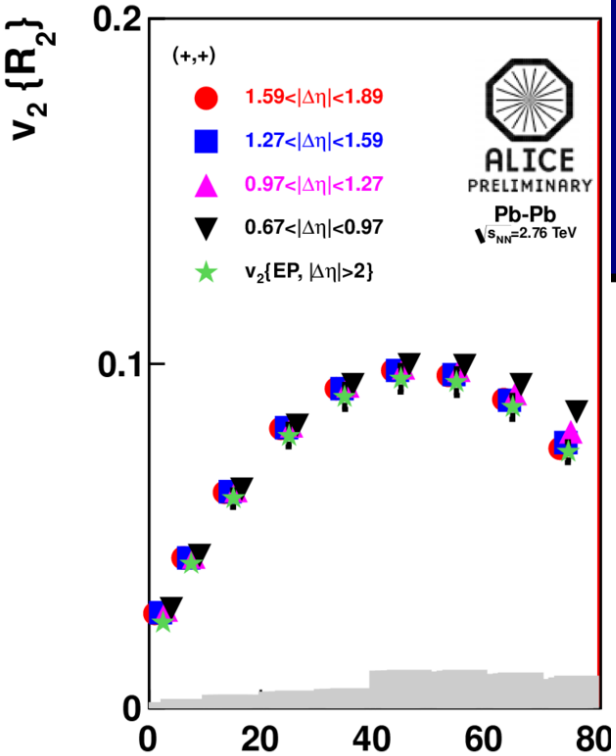
Decomposition v_2

- No dependence on pair charge or $\Delta\eta$.
- $v_2\{R_2\}$ is consistent with event plane measurement.

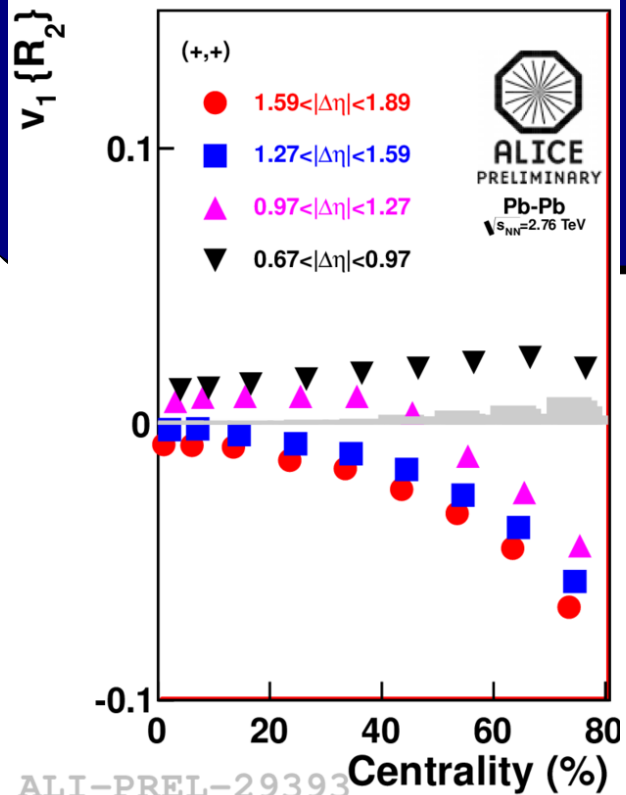


Decomposition v_2

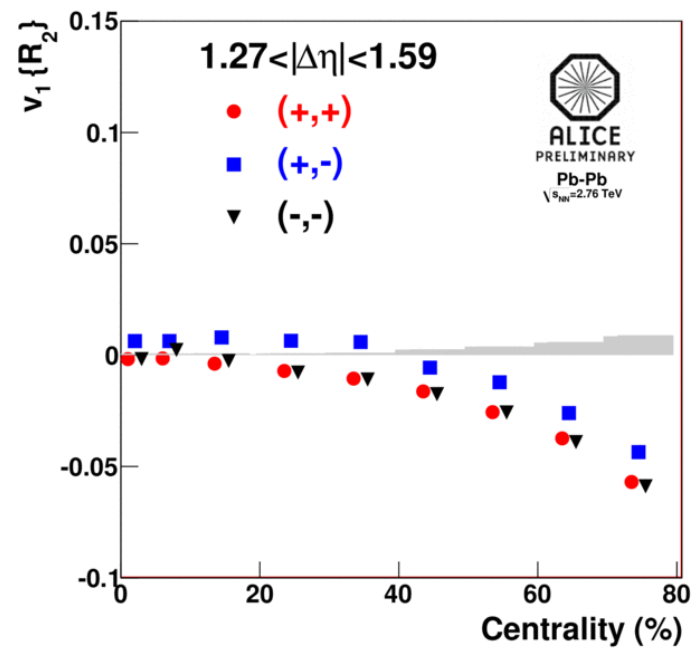
- No dependence on pair charge or $\Delta\eta$.
- $v_2\{R_2\}$ is consistent with event plane measurement.
- $v_2\{\Delta p_T \Delta p_T\}$ consistent with constant times $v_2\{R_2\}$.
- Agreement with flow dominance and factorization:
 - Eq.2 : $v_n\{\Delta p_T \Delta p_T\} \approx v_n^{pT} - \langle p_T \rangle v_n$
- Similar results for v_3 and v_4 .



Decomposition v_1

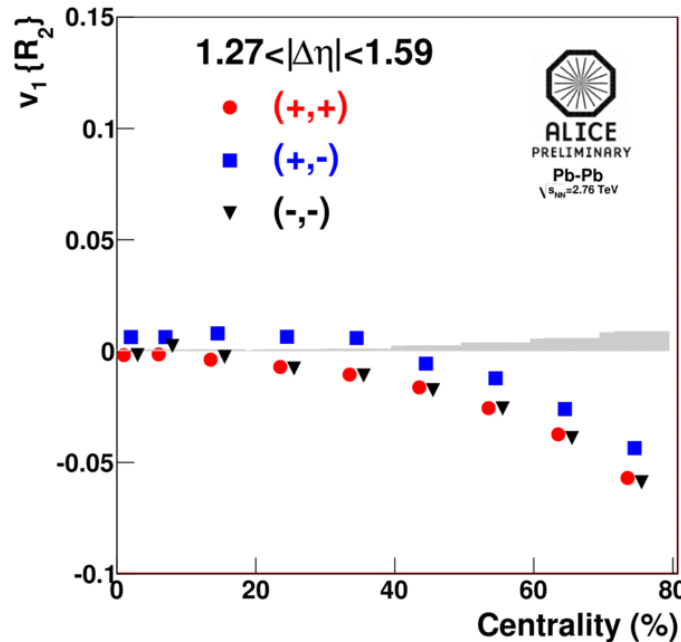
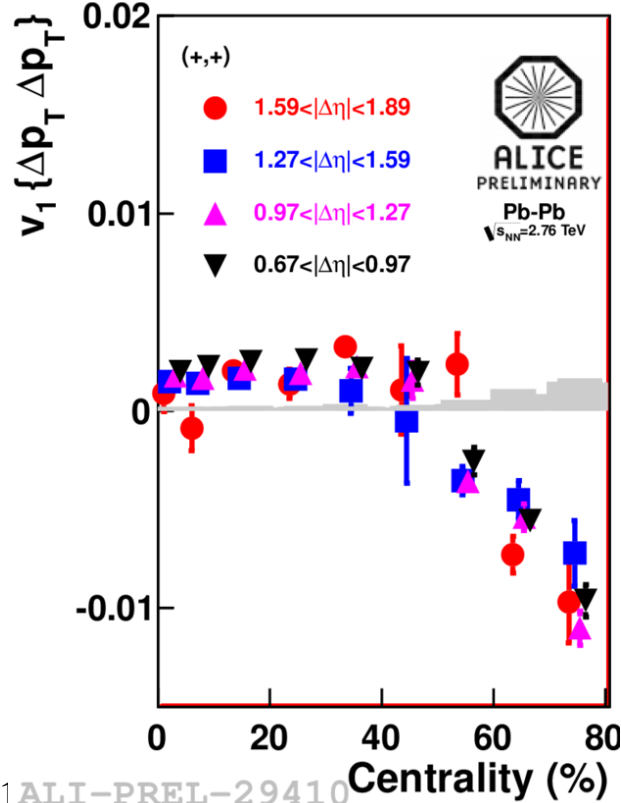
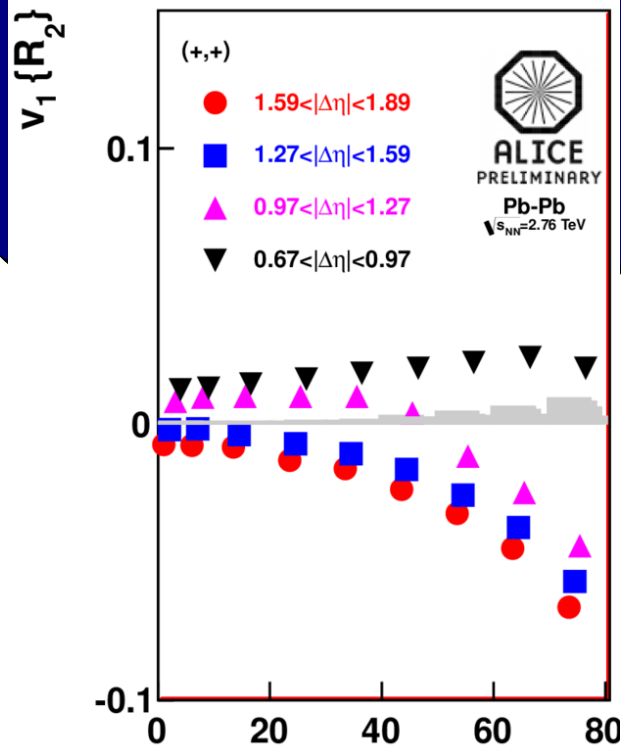


- Number Correlation
 - $\Delta\eta$ and charge dependence of v_1 seen in number correlation.

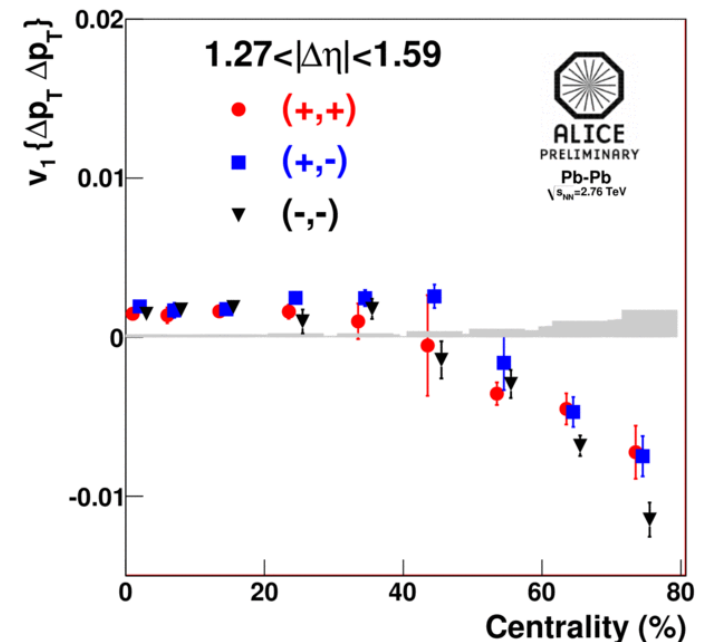


Decomposition v_1

- Number Correlation
 - $\Delta\eta$ and charge dependence of v_1 seen in number correlation.
- $\Delta p_T \Delta p_T$ Correlation
 - No $\Delta\eta$ or charge dependence for v_1 .
- Momentum conservation effect.

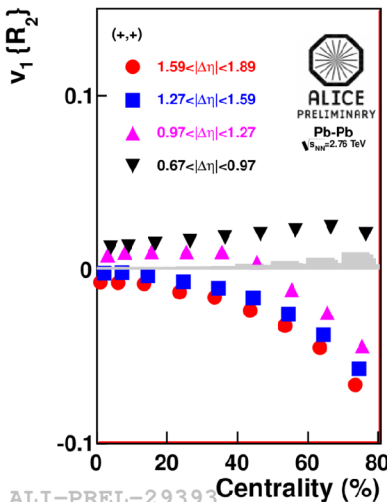
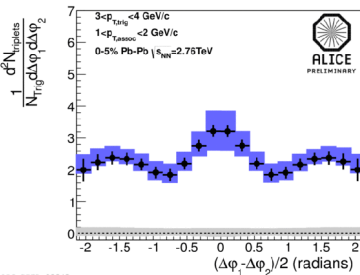
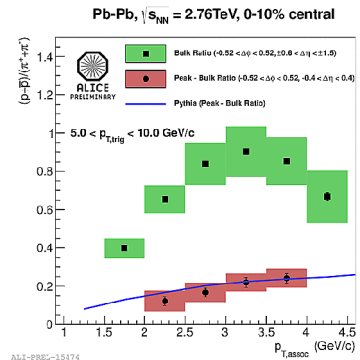


ALI-PREL-29429



ALI-PREL-29449

Conclusions



- Proton to pion ratio in near-side peak **consistent with vacuum fragmentation** in central Pb-Pb collisions.
- Three-particle jet-like azimuthal correlations show:
 - **Non-di-jet residual signal** in central Pb-Pb.
 - Constant with di-jet and with AMPT in 40-50% Pb-Pb.
 - Under the strong assumptions of:
 - Can decompose into jet-like and flow correlations.
 - ZYAM background normalization.
- ♦ See J.G. Ulery Poster 236 for more details.
- v_n obtained from Fourier decomposition of low- p_T number and $\Delta p_T \Delta p_T$ correlations:
 - No $\Delta\eta$ or pair charge dependence for v_2 through v_4 .
 - v_1 has $\Delta\eta$ and pair charge dependence in number correlations and not in $\Delta p_T \Delta p_T$ correlations.
- ♦ See C. Pruneau Poster 253 for more details.



ALICE



ALICE

Decomposition v_3 & v_4

- No charge or $\Delta\eta$ dependence for v_3 and v_4 either.

