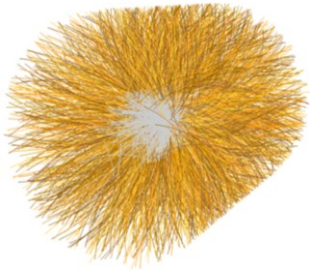


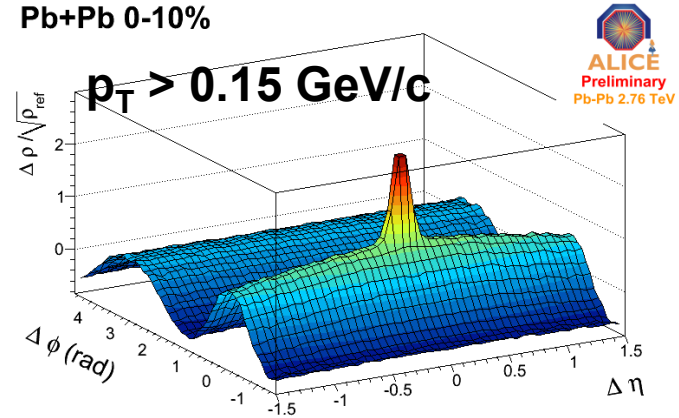
# Results from Correlations in ALICE

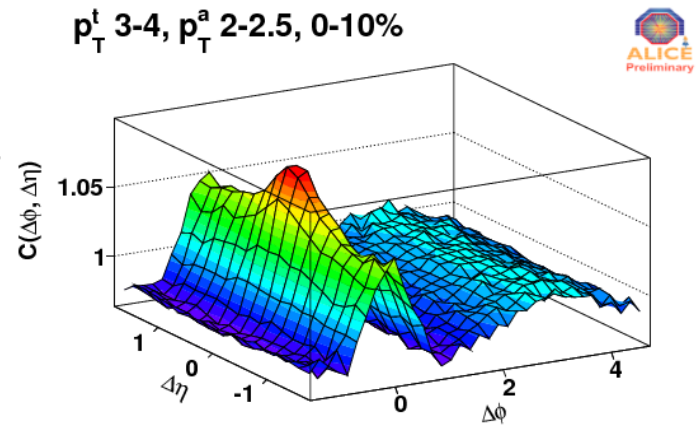
Jan Fiete Grosse-Oetringhaus, CERN/PH
for the ALICE collaboration

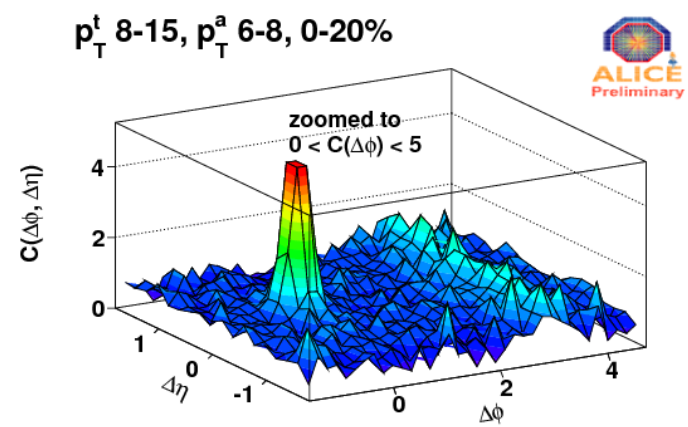
Quark Matter 2011, Annecy

# Correlations

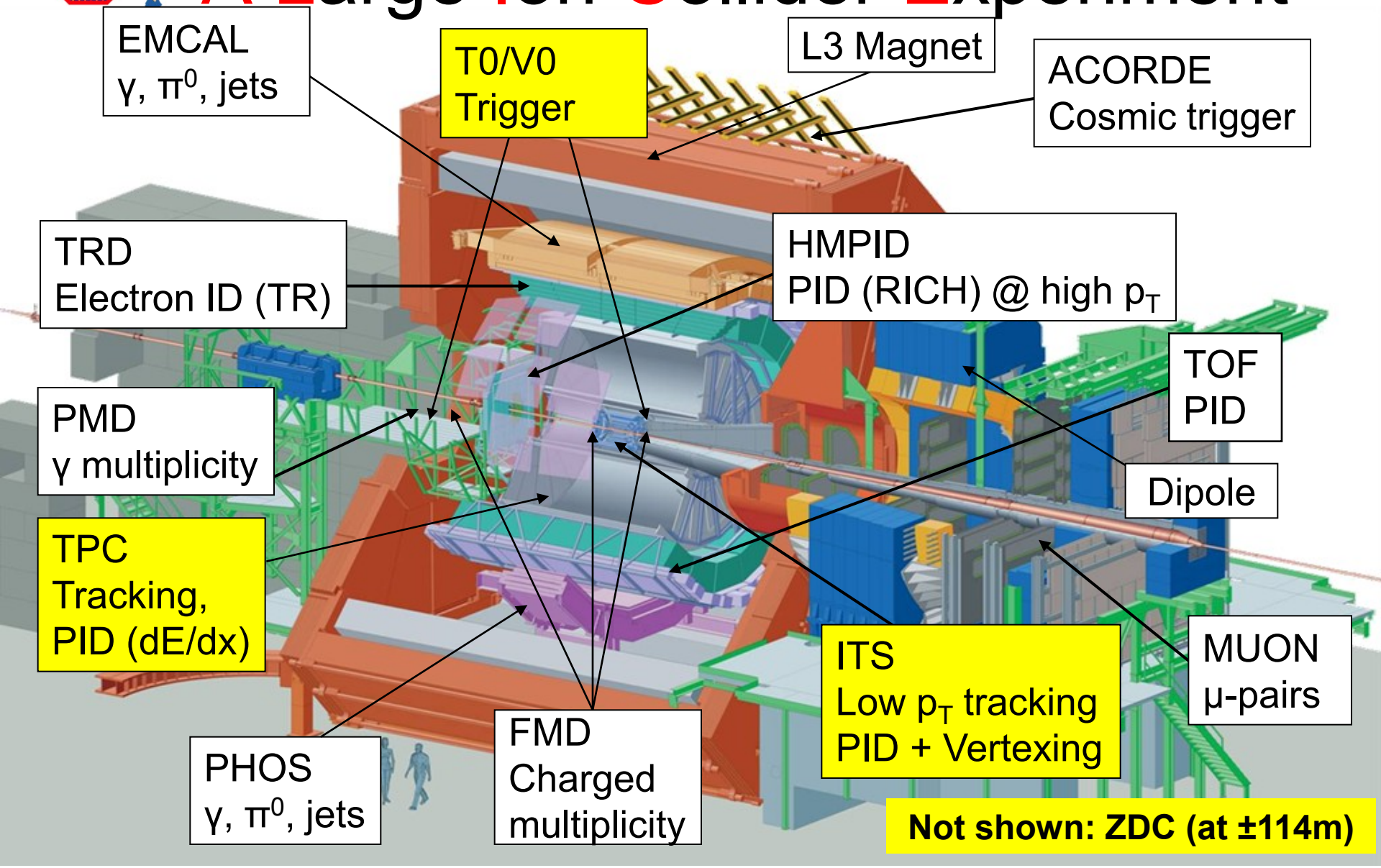
- Pb-Pb collisions at LHC produce very hot and dense matter ($\min(R_{AA}) \sim 0.14$)
- Study the medium further by correlations of two or more particles
- Lower $p_T$
  - Assess the bulk of the correlations
  - Dominated by hydrodynamics and flow
  - Ridge
- Higher $p_T$
  - Dominated by jets
  - Quenching/suppression, broadening
- How do these phenomena at LHC compare to RHIC?



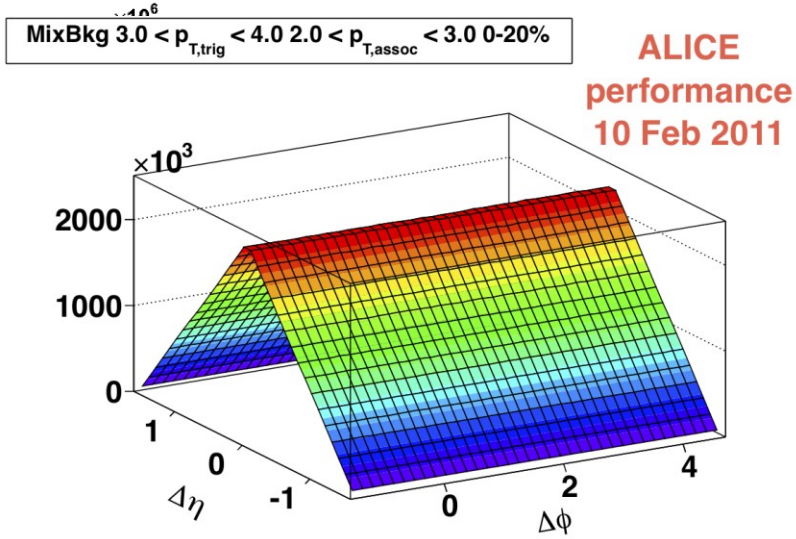



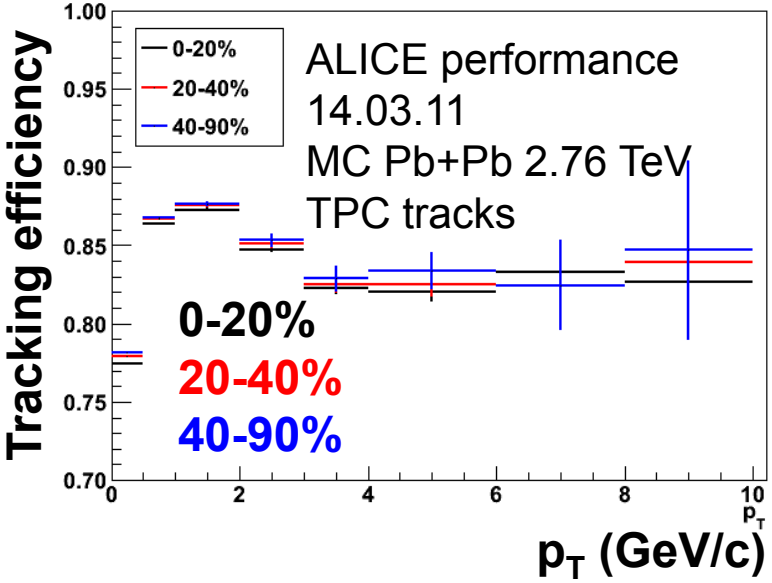
# A Large Ion Collider Experiment



# Analysis

- Up to 19M Pb+Pb MB collisions used
- Centrality determination with V0 (forward scintillators)
- Tracking with Time Projection Chamber and Inner Tracking System in $|\eta| < 0.9$
  - Flat $\phi$ acceptance → No mixed events needed for acceptance correction (in $\Delta\phi$ projection)
  - Tracking efficiency ~ 85%
- Efficiency and contamination
  - Weakly centrality dependent
  - Two-track effects small but considered



# Decomposition of Long-Range Correlations

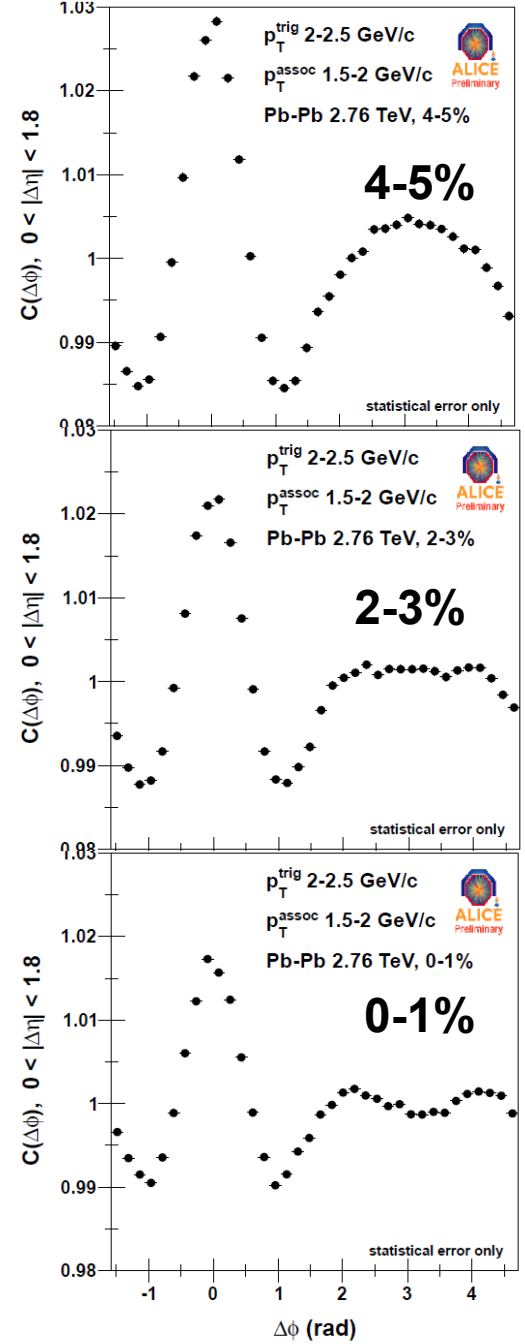
# Triggered Correlations

- Choose a particle from one $p_T$ region ("trigger particle") and correlate with particles from another $p_T$ region ("associated particles") where $p_{T,assoc} < p_{T,trig}$ in bins of $p_{T,trig}$ and $p_{T,assoc}$

$$N_{mixed}\left(\frac{1}{N_{trig}}\frac{d^2N_{assoc}}{d\Delta\varphi d\Delta\eta}\right)_{same} \Bigg/ N_{same}\left(\frac{1}{N_{trig}}\frac{d^2N_{assoc}}{d\Delta\varphi d\Delta\eta}\right)_{mixed}$$

- Study long-range correlation structure in $0.8 < |\Delta\eta| < 1.8$
  - Very central events (0-2%) show mach cone type structure (without any flow subtraction)
  - Fourier decomposition

**A Adare, Tu 15:00**

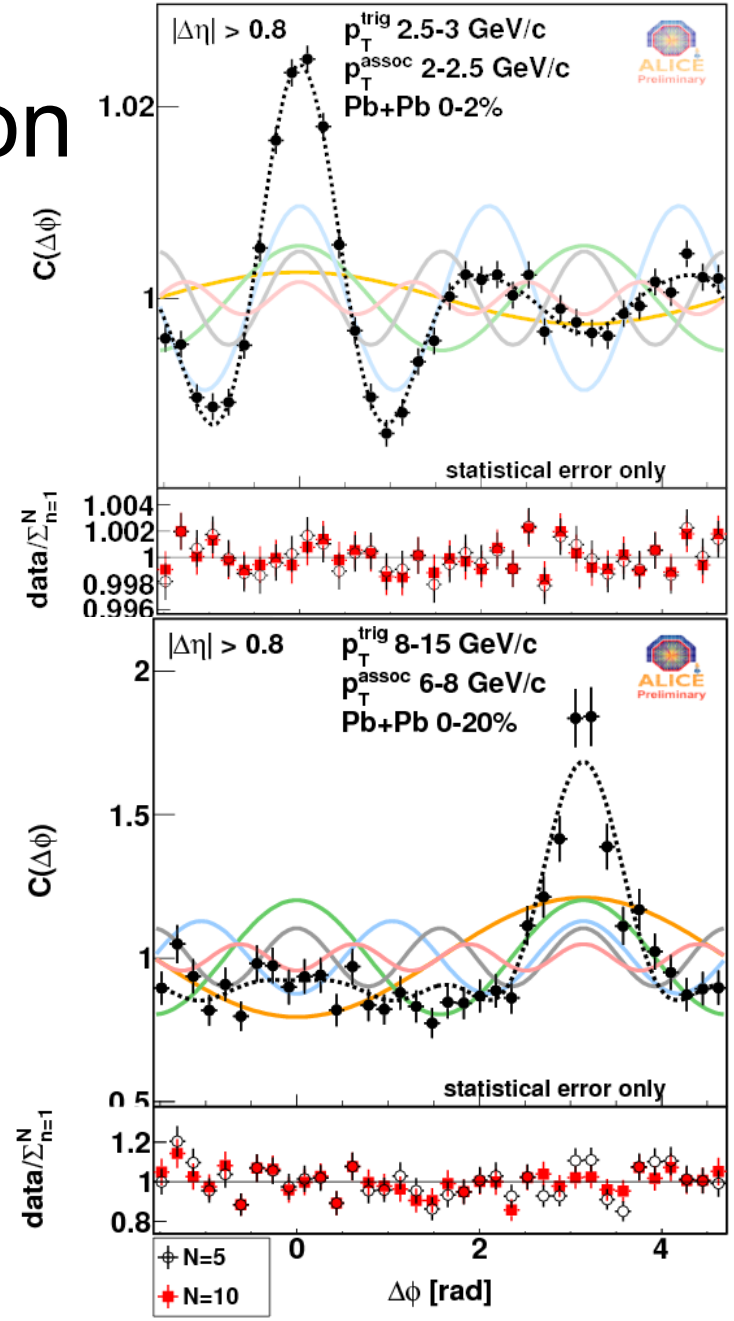


# Fourier Decomposition

- Fourier components are calculated

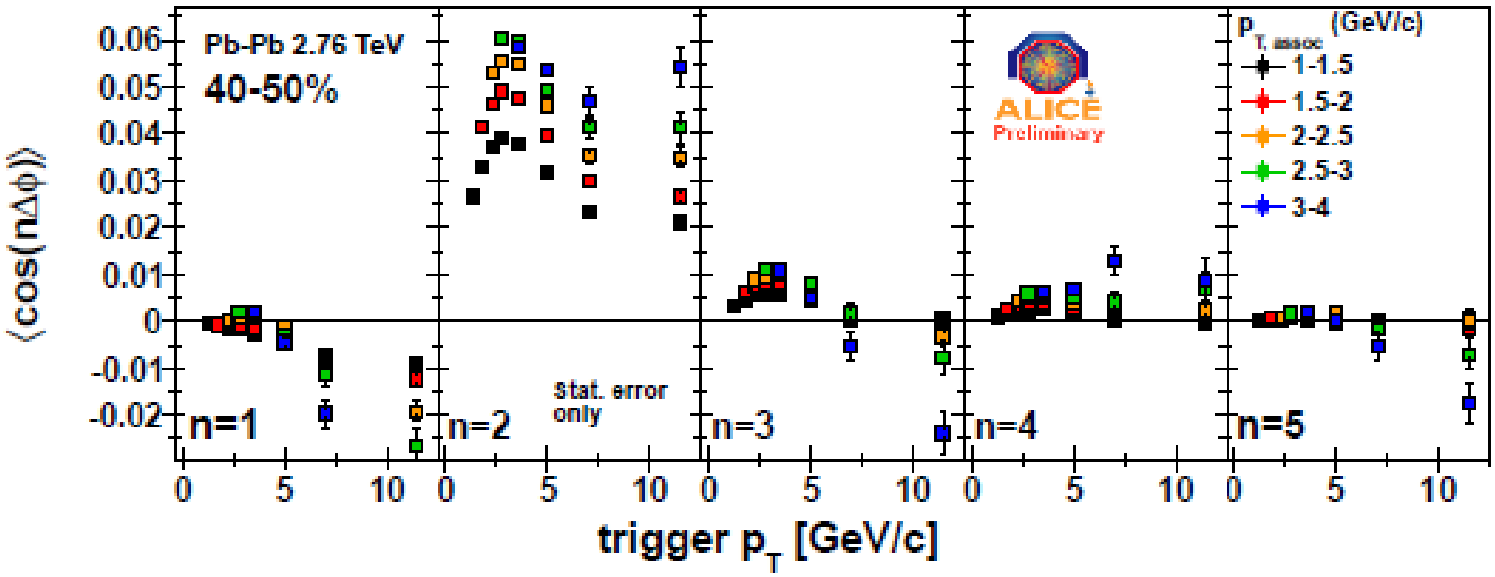
$$V_{n\Delta} = \langle \cos\, n\Delta\varphi \rangle = \frac{\int d\Delta\varphi C(\Delta\varphi) \cos\, n\Delta\varphi}{\int d\Delta\varphi C(\Delta\varphi)}$$

- 5 components describe correlation completely
  - Strong near-side ridge + double-peaked structure (in very central events) on away side at low $p_T$
  - Away-side peak dominated at high $p_T$



# Fourier Components

- Coefficients increase with increasing $p_T$
- Odd terms become negative at large $p_T$ (influence of away-side jet)
- From central to peripheral, $v_{2\Delta}$ rises most

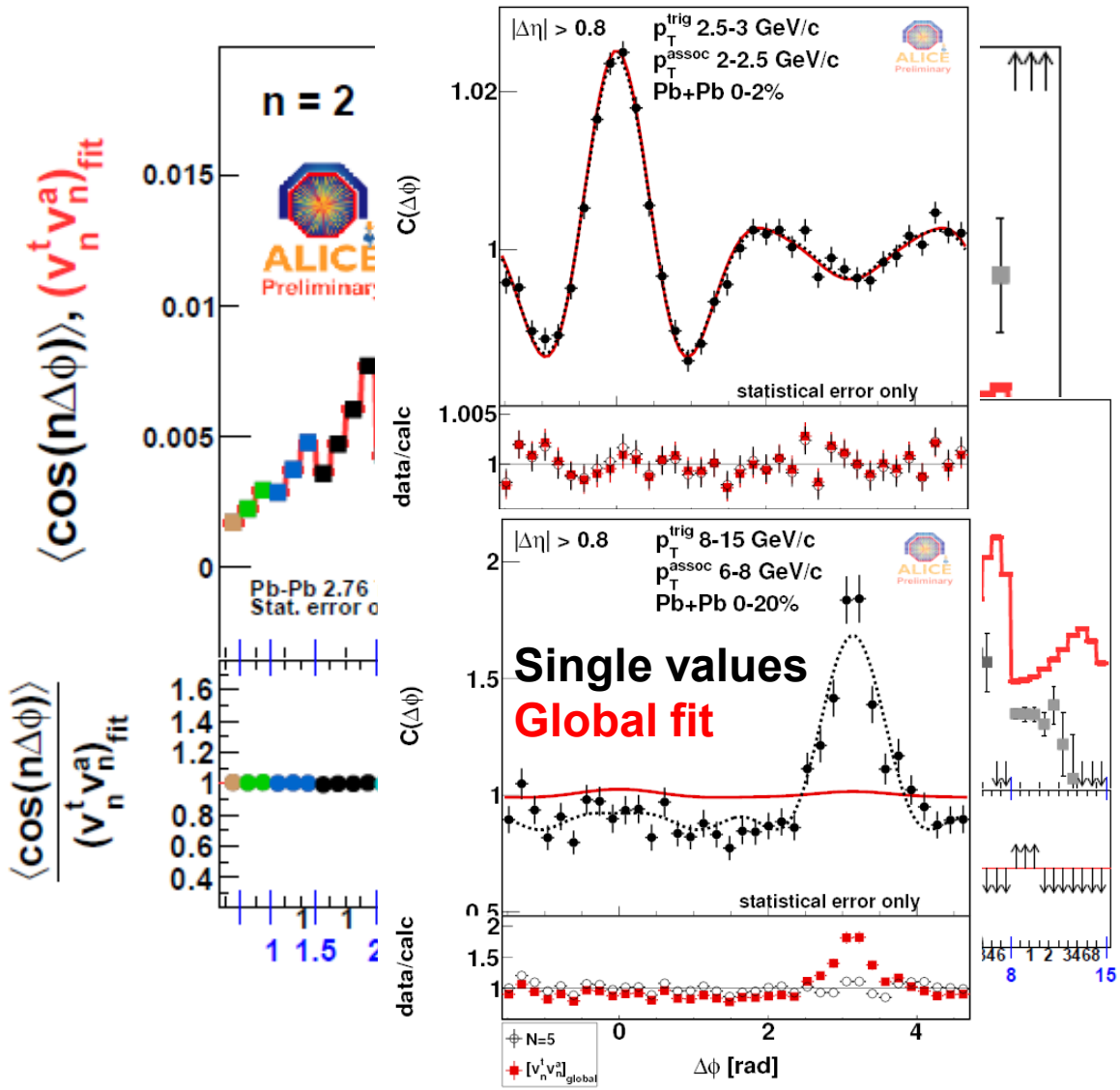


# Flow vs Non-Flow Correlations

- Flow-related effects imply correlation of two particles through a plane of symmetry $\psi_n$
  - $V_{n\Delta}$ factorizes: $V_{n\Delta} = v_n^{trig} v_n^{assoc}$
- Jets cause correlations of a few energetic particles by fragmentation
  - There can be indirect correlations: length-dependent quenching
  - Would be largest w.r.t. $\psi_2$ since it reflects the collision geometry
- Assess flow vs. non-flow by testing the collectivity relation $V_{n\Delta} = v_n^{trig} v_n^{assoc}$
  - Instead of calculating $V_{n\Delta}$ in each $p_{T,assoc}$ x $p_{T,trig}$ bin (N(N-1)/2=55 bins), allow only one $V_{n\Delta}$ per $p_T$ bin (11 parameters)

# Flow vs Non-Flow Correlations

- Compare single calculated values with global fit
- To some extent, a good fit suggests flow-type correlations, while a poor fit implies non-flow effects
- $v_{2\Delta}$ to $v_{5\Delta}$ factorize until $p_T$ ~ 3-4 GeV/c, then jet-like correlations dominate
- $v_{1\Delta}$ factorization problematic (influence of away-side jet)



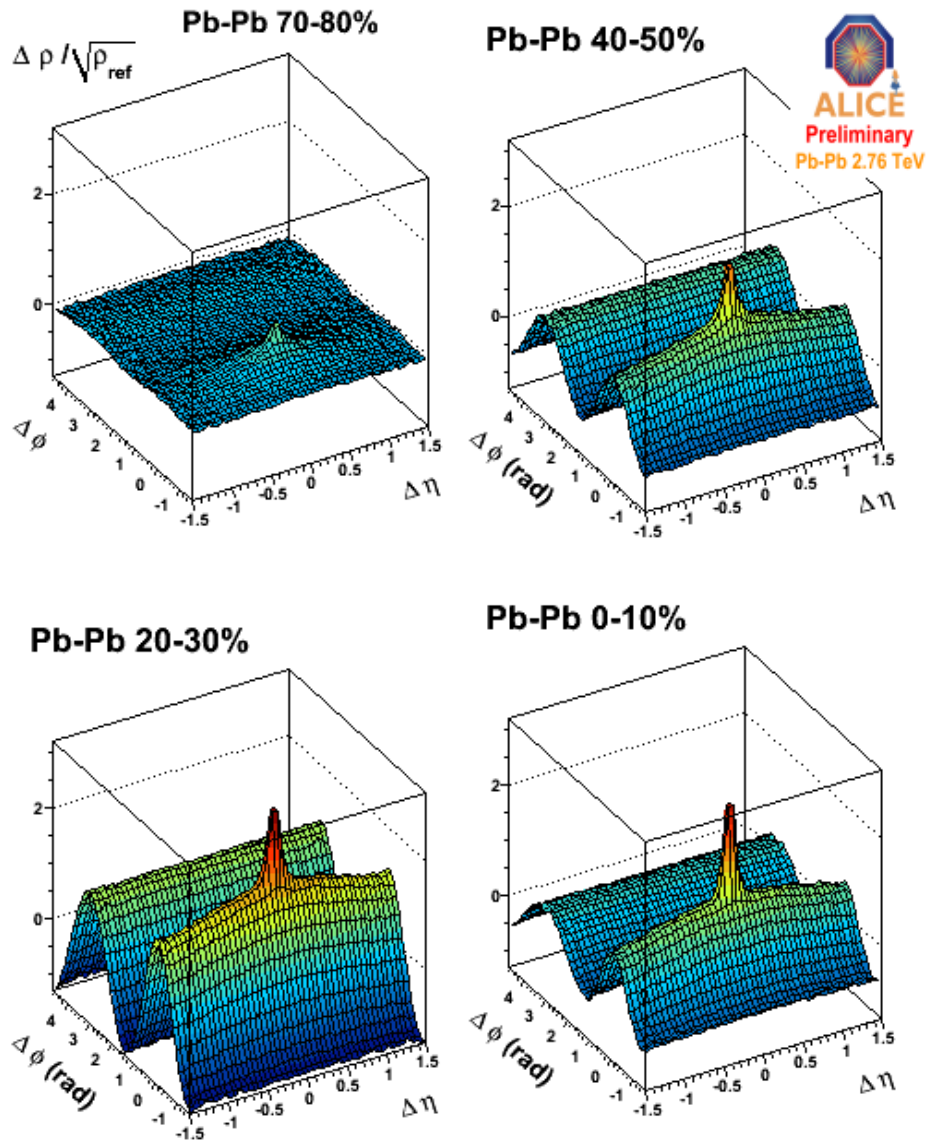
# Soft Near-Side Decomposition

# Untriggered Correlations

- Map out the centrality dependence of the bulk of the correlation
- Correlate all charged particles ($p_T$ > 0.15 GeV/c)

$$\frac{\Delta\rho}{\sqrt{\rho_{ref}}} = \frac{dN_{ch}}{d\eta}\left(\frac{\rho_{same}}{\rho_{ref}} - 1\right)$$

- Evolution of the correlation function
  - Sharp peak from HBT, conversions
  - Elliptic flow ($v_2$) dominates in mid-central collisions
  - Stronger correlation structures towards central collisions
  - Near-side long-range correlation structure "ridge" builds up towards central collisions



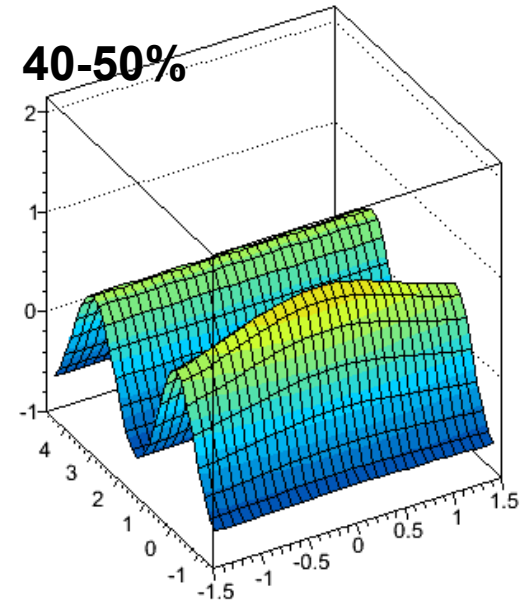

**A Timmins, Tu 15:40**

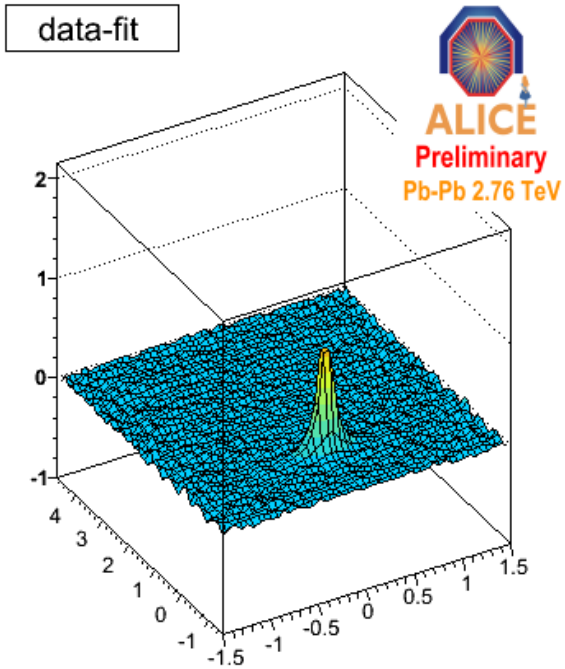
# Decomposition

- Quantify the near-side correlation by decomposing it with a fit

$$\frac{\Delta\rho}{\sqrt{\rho_{ref}}} = A + B\ Gauss\ (\Delta\phi, \Delta\eta) + \sum_n C_n \cos n\Delta\phi$$

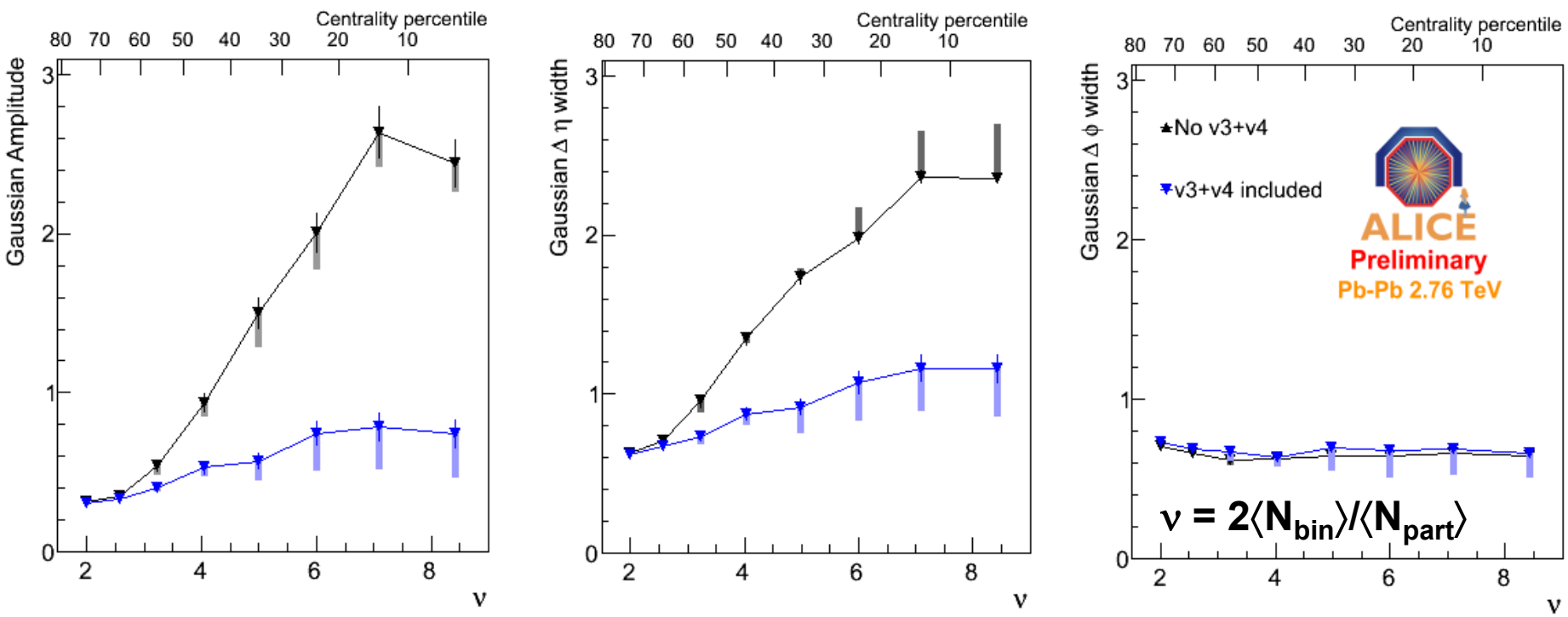
  - Gauss around near-side with independent width in $\Delta\phi$ and $\Delta\eta$
  - Only $v_1$ and $v_2$ as well as $v_1 \ldots v_4$
  - cos-terms only $\Delta\phi$ dependent
  - 0, 0 peak excluded from fit
- Fit with and without $v_3$ and $v_4$ describes correlation structures well
  - Long-range correlation "ridge" fully described by $v_n$-components
  - Remaining Gaussian on near-side



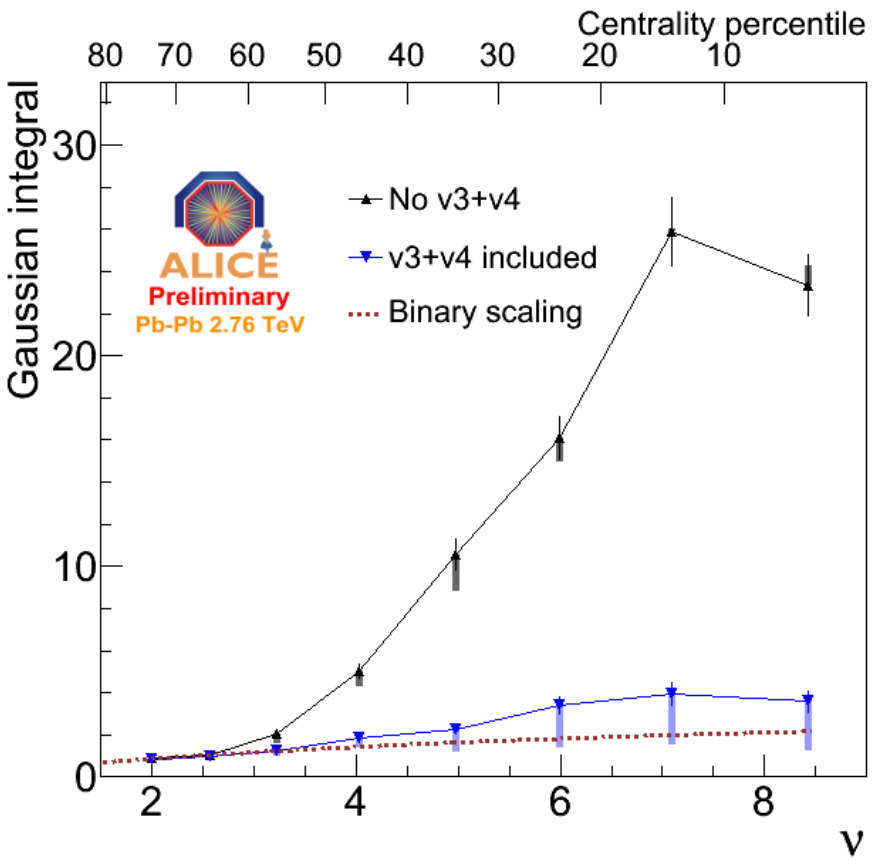
# Decomposition (2)

- Growth of amplitude and $\Delta\eta$-width significantly smaller when $v_3$ and $v_4$ are included ($\Delta\phi$-width independent)
- Structure has width of $\Delta\eta \sim 0.6 - 1.0$, $\Delta\phi \sim 0.6 - 0.7$



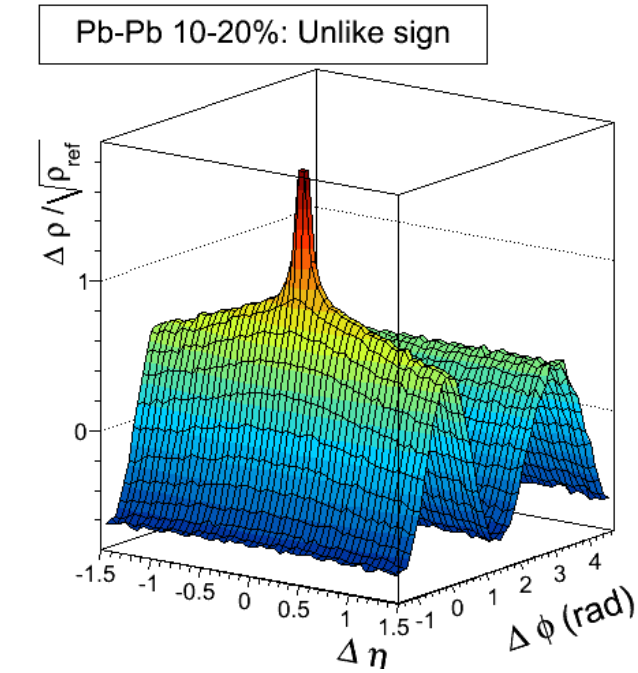
# Gaussian "Volume"

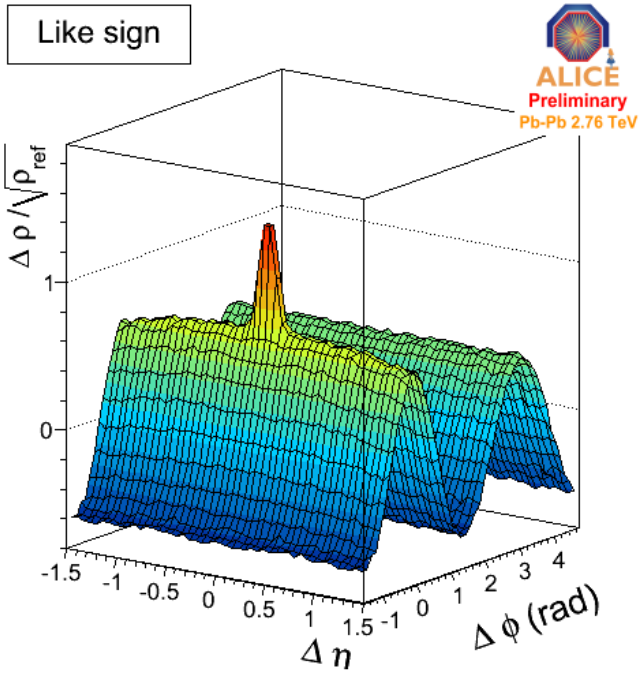
- Gaussian volume = $2\pi$ B $\sigma_{\Delta\phi}\ \sigma_{\Delta\eta}$
  - Measure of total number of pairs in near-side Gaussian
  - Magnitude of rise dictated by the inclusion of $v_3$ and $v_4$
- Within our systematics binary scaling $\langle N_{bin} \rangle$ scaling (number of pairs scales with $\langle N_{bin} \rangle$, calibrated in the most peripheral bin) is not excluded



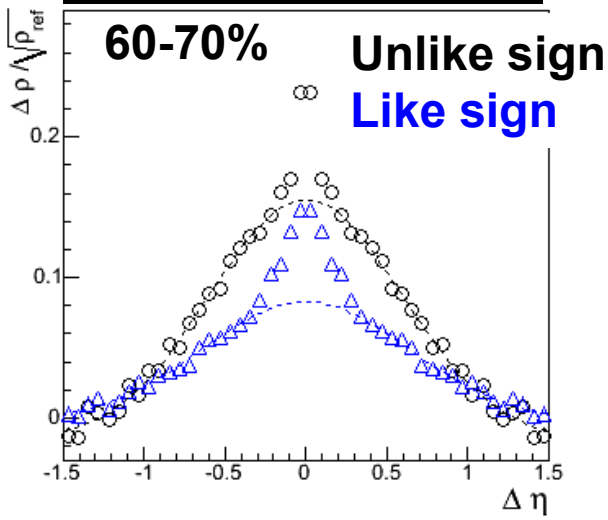
# Charge Dependence

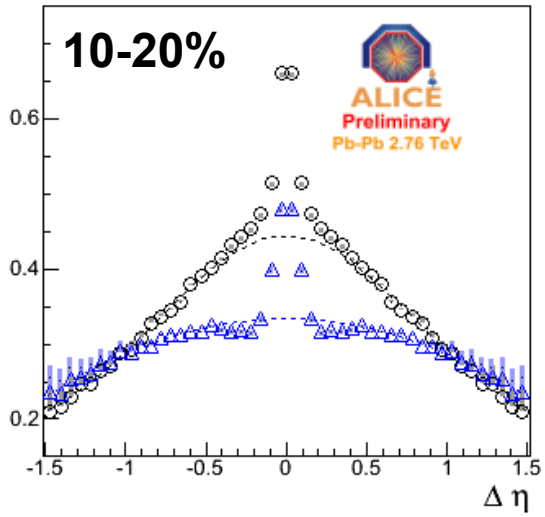
- Nearside 2D Gaussian shows strong charge dependence
- Large fraction of the structure stems from unlike sign pairs
- Like-sign near side structure wider




**Near-side projection:**



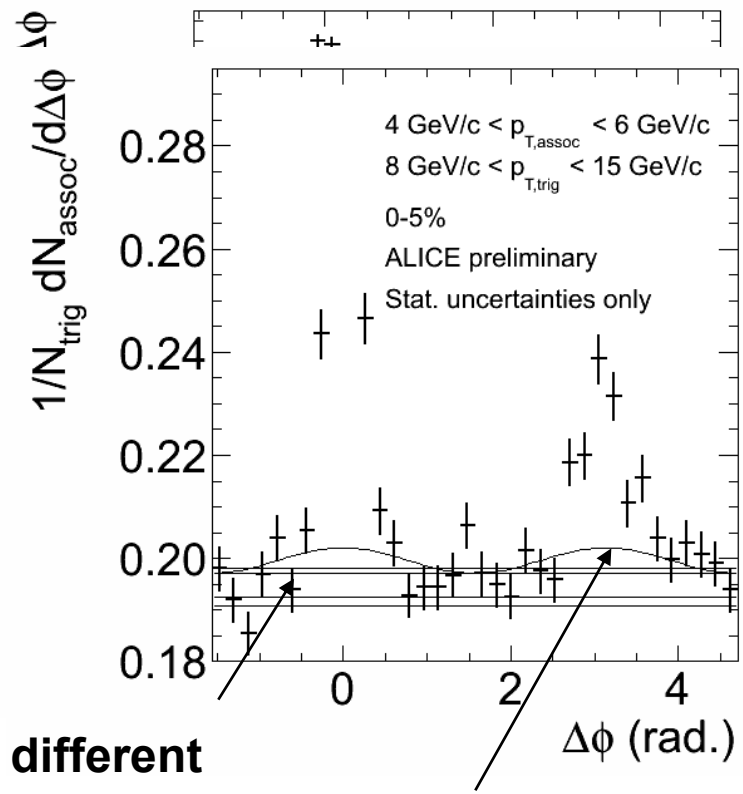



# Modification of the Jet Particle Yield $I_{AA}$ and $I_{CP}$

# Modification of Jet Particle Yield

- Extract near and away-side jet yields from per-trigger yields
  - Compare central and peripheral collisions → $I_{CP}$
  - Compare Pb+Pb and pp → $I_{AA}$
- Non-jet component (baseline) needs to be removed
  - No known assumption-free methods…
  - Determine pedestal by a fit around $\pi/2$ (ZYAM)
  - Estimate elliptic flow ($v_2$) contribution using ALICE flow measurement
- Measure in a region where the signal dominates over pedestal and $v_2$ modulation ($8\ \text{GeV/c} < p_{T,trig} < 15\ \text{GeV/c}$)
- Aim: constrain energy-loss mechanisms together with $R_{AA}$

$$\frac{1}{N_{trig}} \frac{dN_{assoc}}{d\Delta\varphi}$$

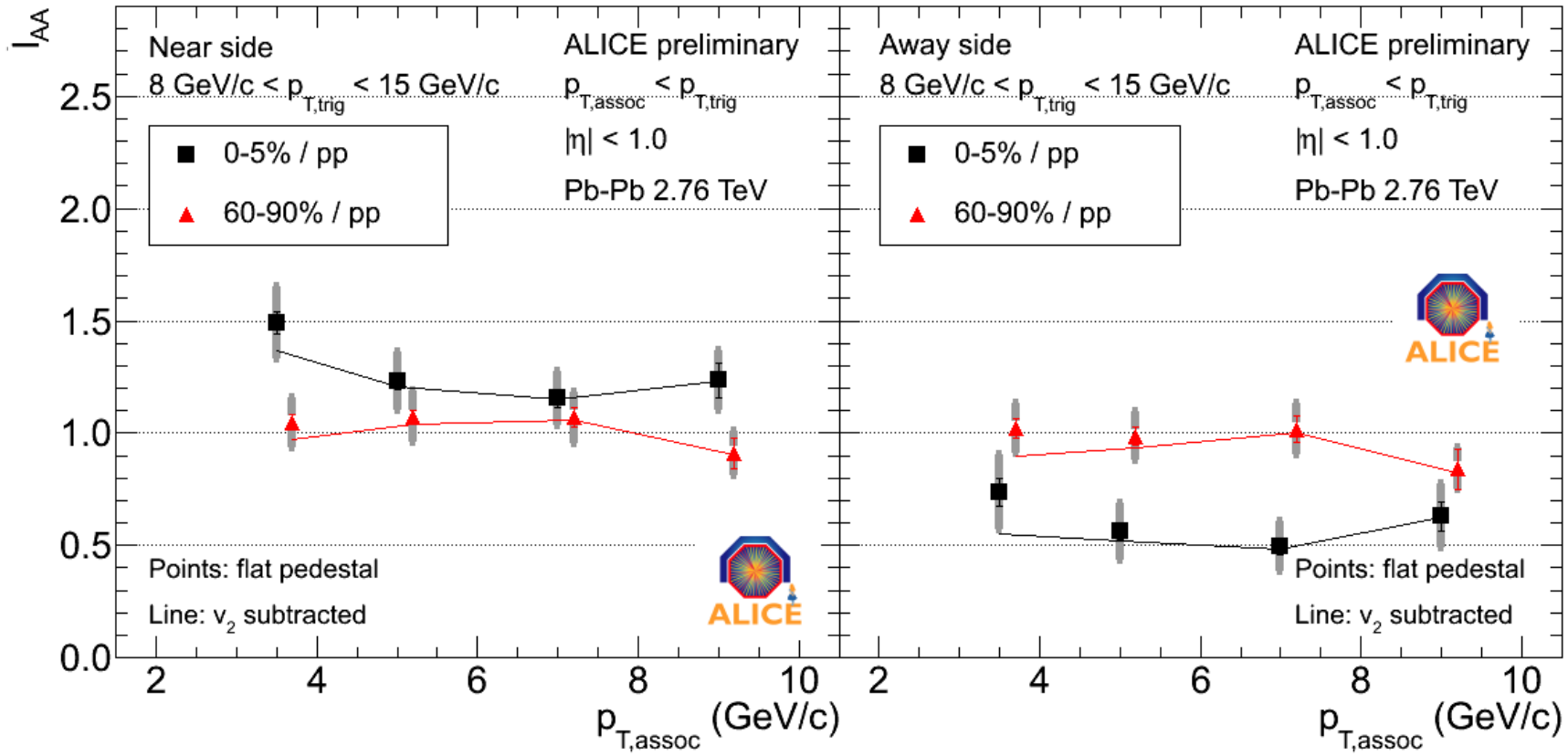



**different pedestals**

**$v_2$ contribution**

**A Adare, Tu 15:00**

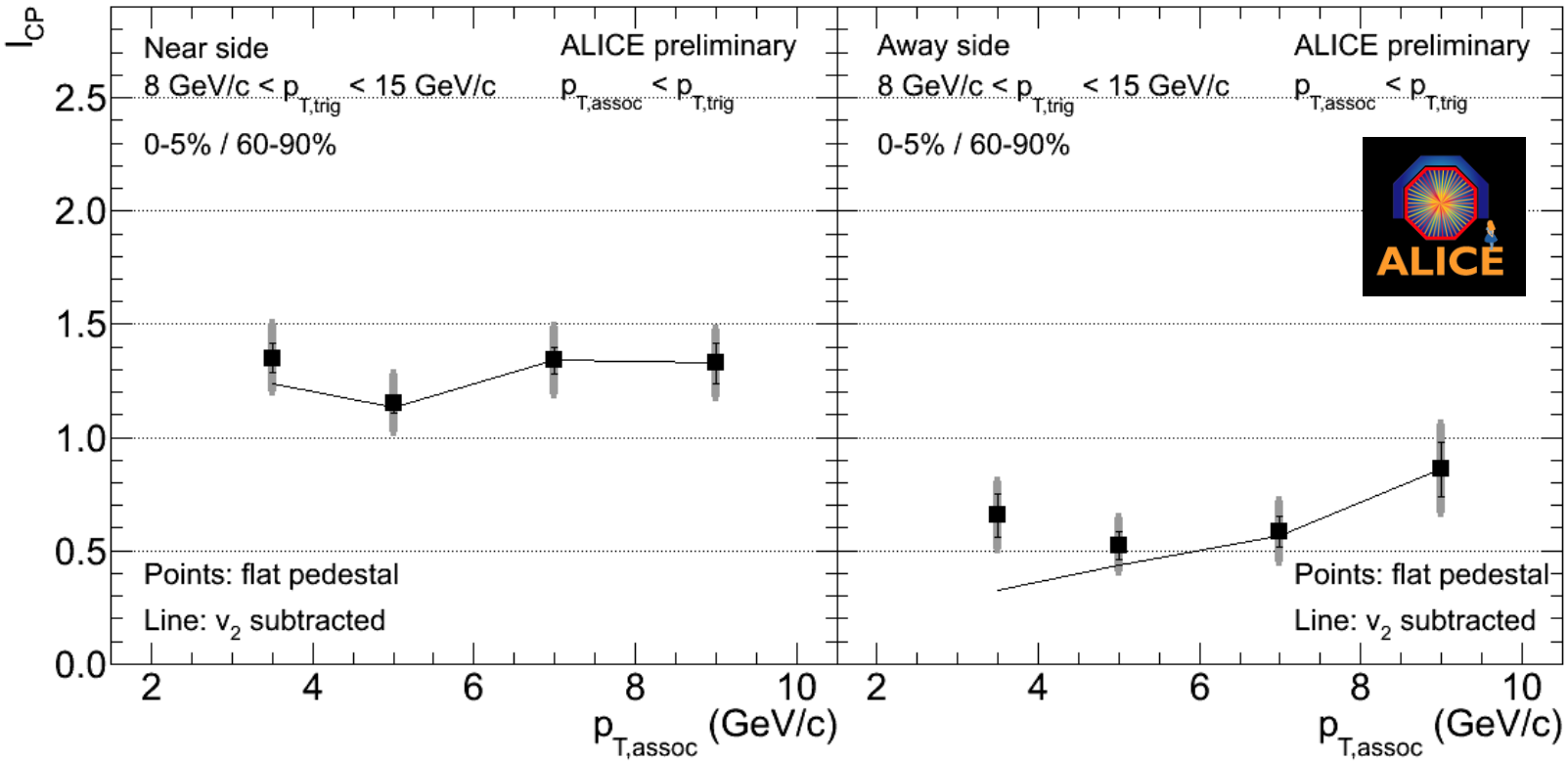
# $I_{AA}$




- **Near-side of central events slightly enhanced $I_{AA}$ ~ 1.2 … unexpected and interesting**
- **Away side of central events suppressed: $I_{AA}$ ~ 0.6 … expected from in-medium energy loss**

- **Peripheral events consistent with unity**
- **$v_2$ contribution small except in lowest bin, there $v_3$ of same order**

# $I_{CP}$

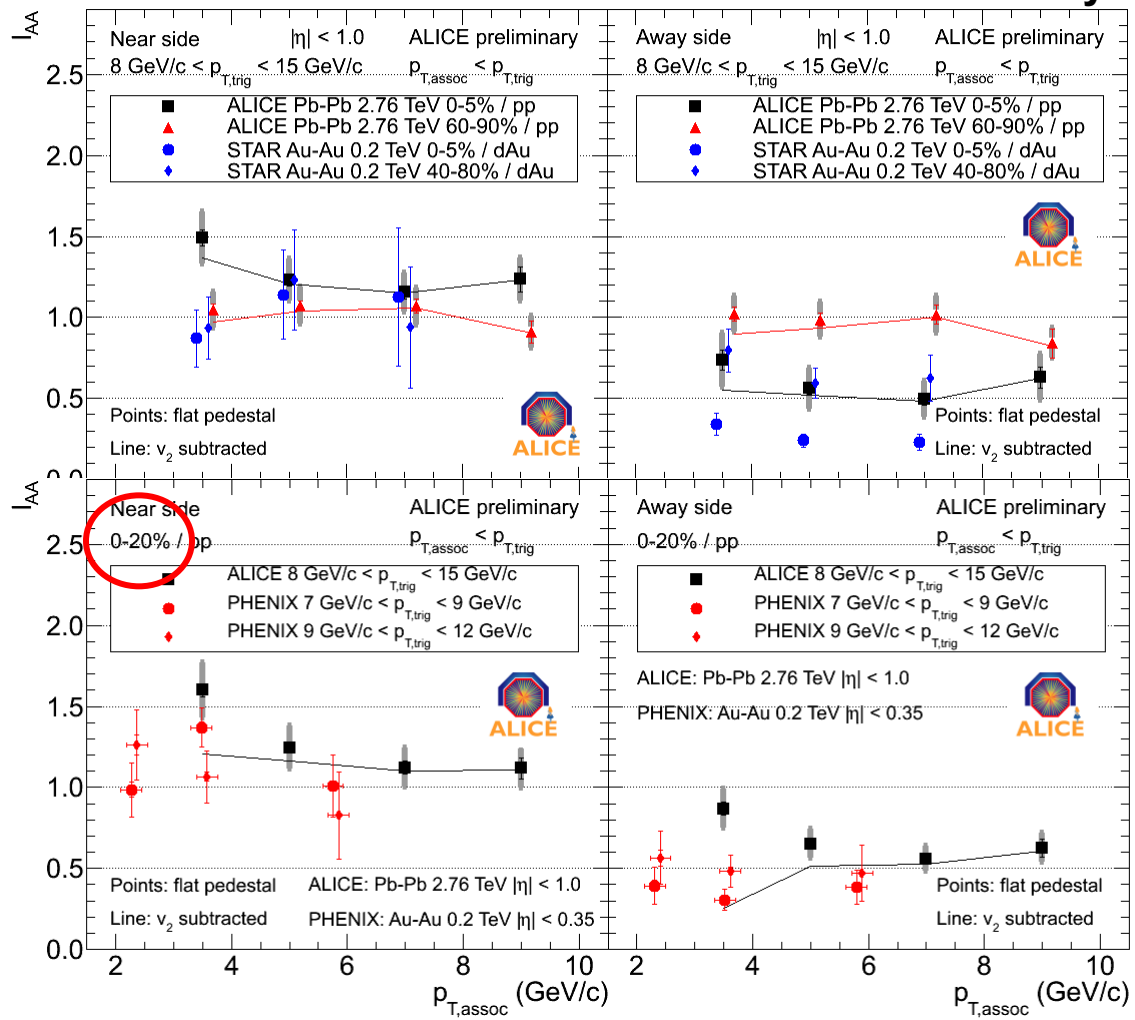



**$I_{AA}$(0-5%) consistent with $I_{CP}$ with respect to near-side enhancement and away-side suppression**

# Comparison with RHIC

- Caveat: same trigger $p_T$ probes different parton $p_T$ at different $\sqrt{s_{NN}}$
- STAR and PHENIX subtract $v_2$ → compare with ALICE line
  - STAR $I_{AA}$ w.r.t. to dAu reference
  - STAR has different centrality for peripheral events
  - Away side larger than at STAR
  - PHENIX has (slightly) different $p_{T,trig}$ ranges
- Near side enhancement not incompatible with RHIC

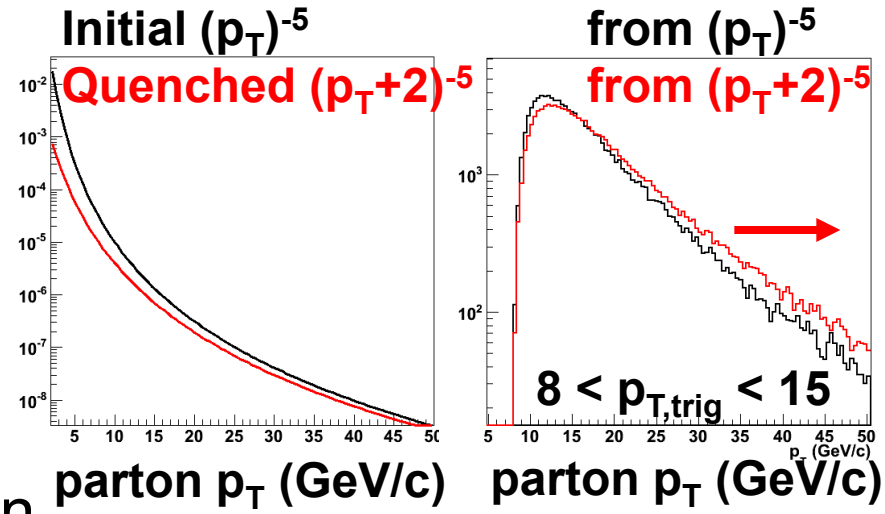
**STAR: stat. unc. only**

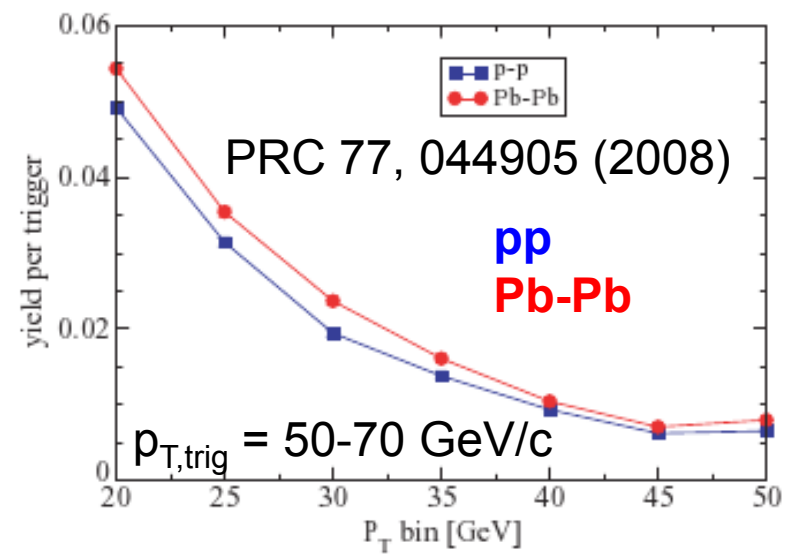



STAR, PRL97,162301 (2006) PHENIX, PRL 104, 252301 (2010)

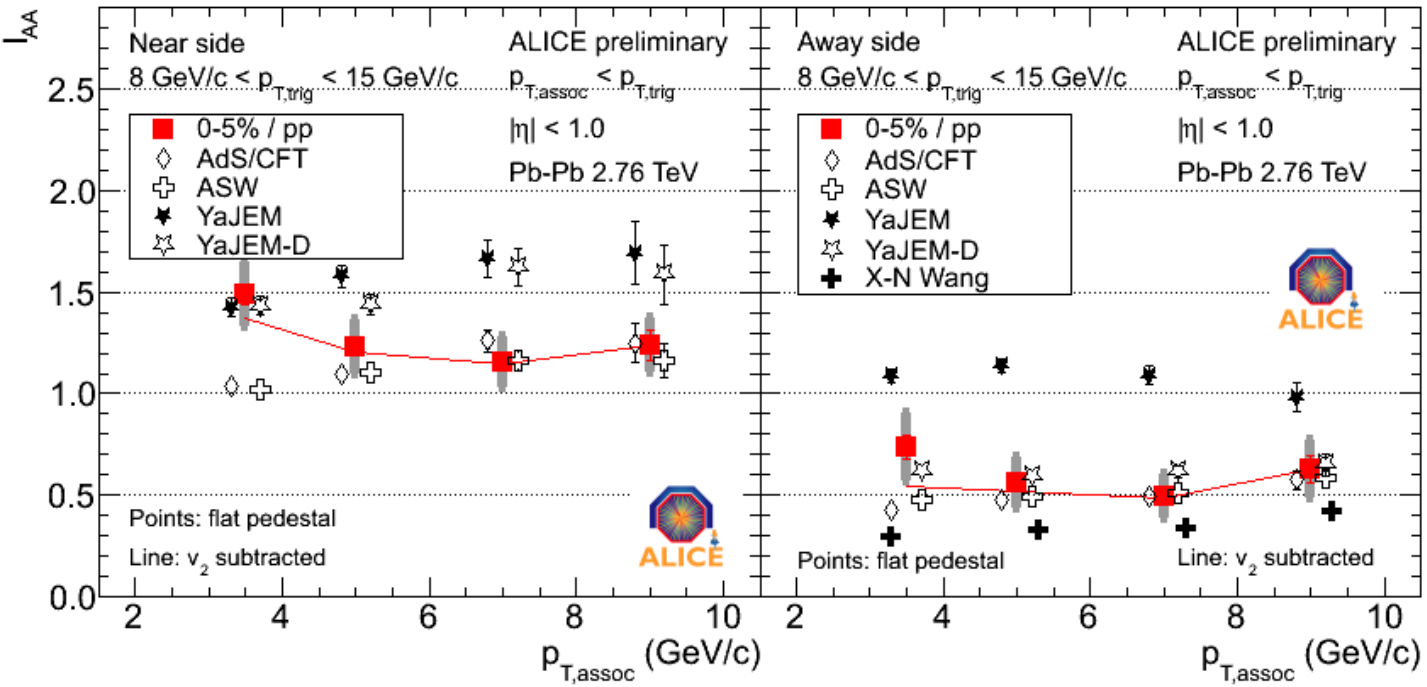
# Explanations for Near-Side Enhancement

- Same trigger $p_T$ in Pb-Pb collisions probes a different parton spectrum than in pp collisions
  - A harder/flatter spectrum causes more associated particles → $I_{AA} > 1$
- Larger energy loss of gluons in the medium and harder fragmentation of quarks [T Renk, PRC 77, 044905 (2008)]
  - Study for LHC energies: "we observe that the yield per trigger is enhanced by 10–20% in Pb-Pb relative to p-p collisions"
- $I_{AA}$ increase affects near and away side



# Theory Comparison




**AdS/CFT,ASW, Yajem(-D):**
- **LO pQCD**
- **WS matter dist.**
- **Ideal 2+1d hydro**
- **Different e-loss scenarios**

**X N Wang:**
- **Hard sphere matter dist.**
- **NLO pQCD**
- **Avg. e-loss**
- **1D expansion**

**Near-side enhancement:**
**- reproduced by AdS/CFT pQCD hybrid ($L^3$ path length dependence) and ASW ($L^2$ dependence)**
**- YaJEM(-D) too high**

**Away-side suppression:**
**- reproduced by AdS/CFT, ASW, YaJEM-D**
**- YaJEM too high (L dependence)**
**- X N Wang slightly too low**

AdS/CFT,ASW,YaJEM(-D) simulations from T Renk [private communication, to appear; talk Tu 16:40]
X N Wang [private communication, following calculation in PRL98:212301 (2007)]

# Summary

- Hadron correlations probe the hot and dense medium produced in LHC HI collisions
- Long-range correlations at ($0.8 < |\Delta\eta| < 1.8$) are well-described by the first 5 Fourier coefficients
  - The flow factorization $V_{n\Delta} = \langle v_{N,trig}\rangle\langle v_{N,assoc}\rangle$ holds at low to intermediate $p_T$ (< 3-5 GeV/c)
  - Jet correlations break the factorization at higher $p_T$
  - Method quantifies the transition from flow to jet dominated correlations
- Long-range correlation structure (aka "the ridge") at $\Delta\phi \sim 0$ fully described by $v_1$ to $v_4$ components
  - Remaining Gaussian near-side structure increases with centrality, compatible with binary scaling
    - A strong charge dependence is observed
- $I_{AA}$ Measurement
  - Away-side suppression (~0.6) and near-side enhancement (~1.2) is measured
  - The effect of the medium on the near side is visible at LHC

- **Talk, A Adare, Triggered correlations, Tu 15:00**
- **Talk, A Timmins, Untriggered correlations, Tu 15:40**
- **Poster, J Ulery, 3-particle correlations**