# Triggered dihadron correlations in Pb-Pb collisions from the ALICE experiment

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Yale University
on behalf of
The ALICE collaboration

**Quark Matter 2011**
Annecy, FR - 24 May 2011

# Some analysis details

## Dataset

Pb-Pb at 2.76 TeV

13.5 M events after physics selection in 0-90%

pp reference at 2.76 TeV

## Centrality

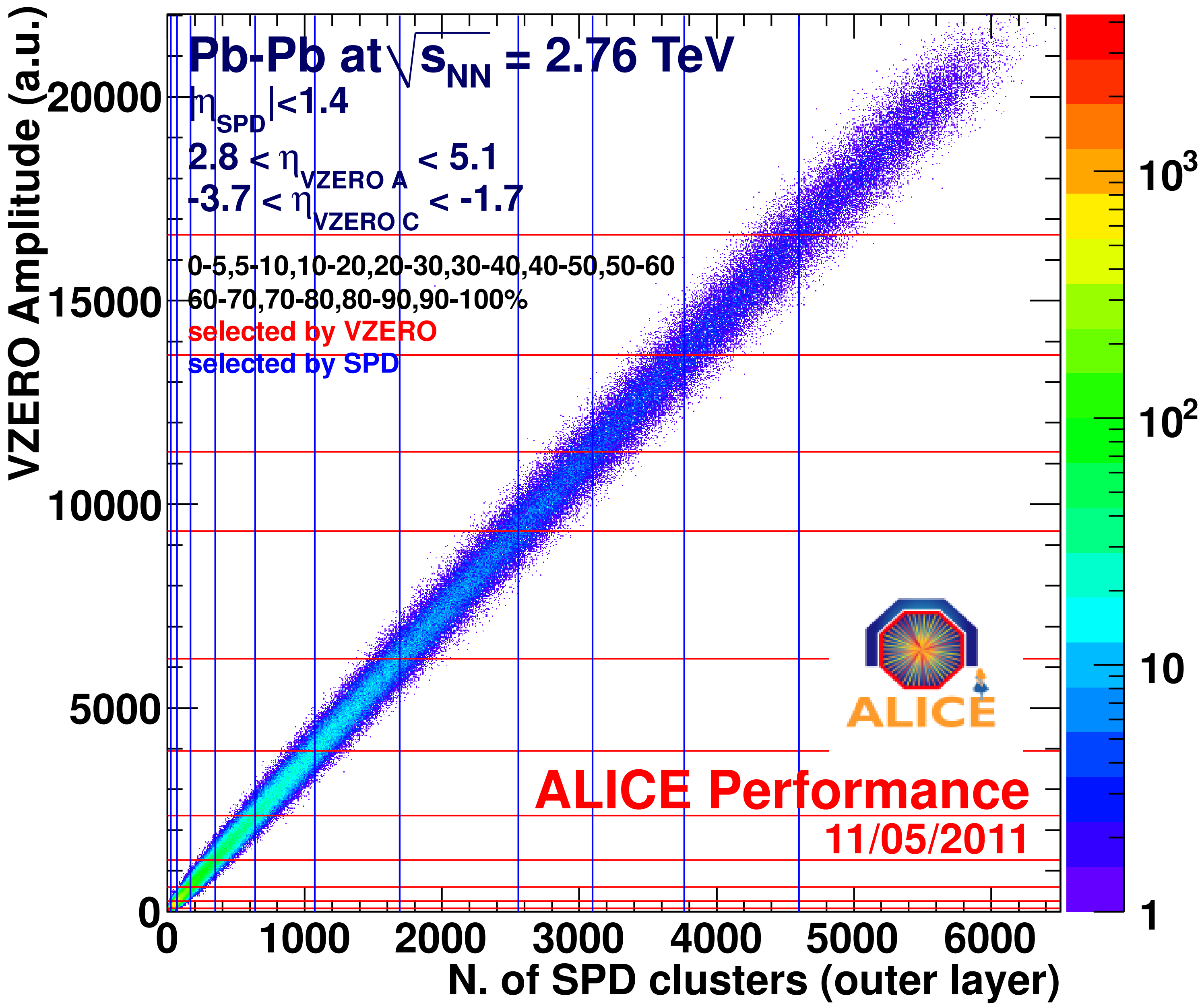
VZERO

Enables 1% binning

## Tracking

TPC points + ITS vertex

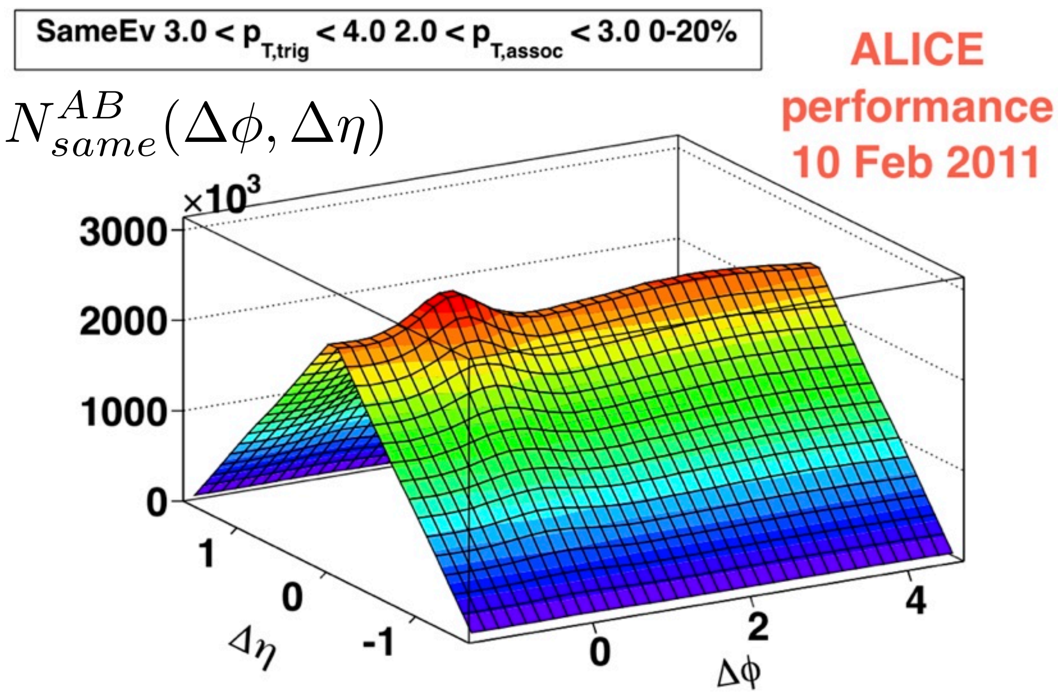
= optimum acceptance + precision for correlations

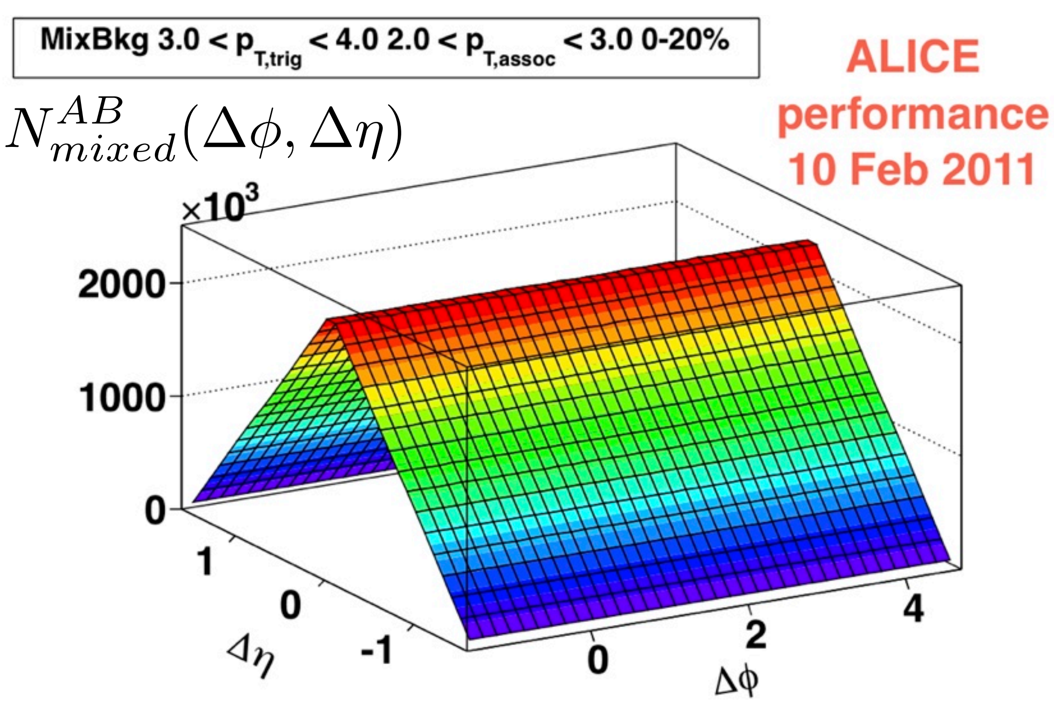


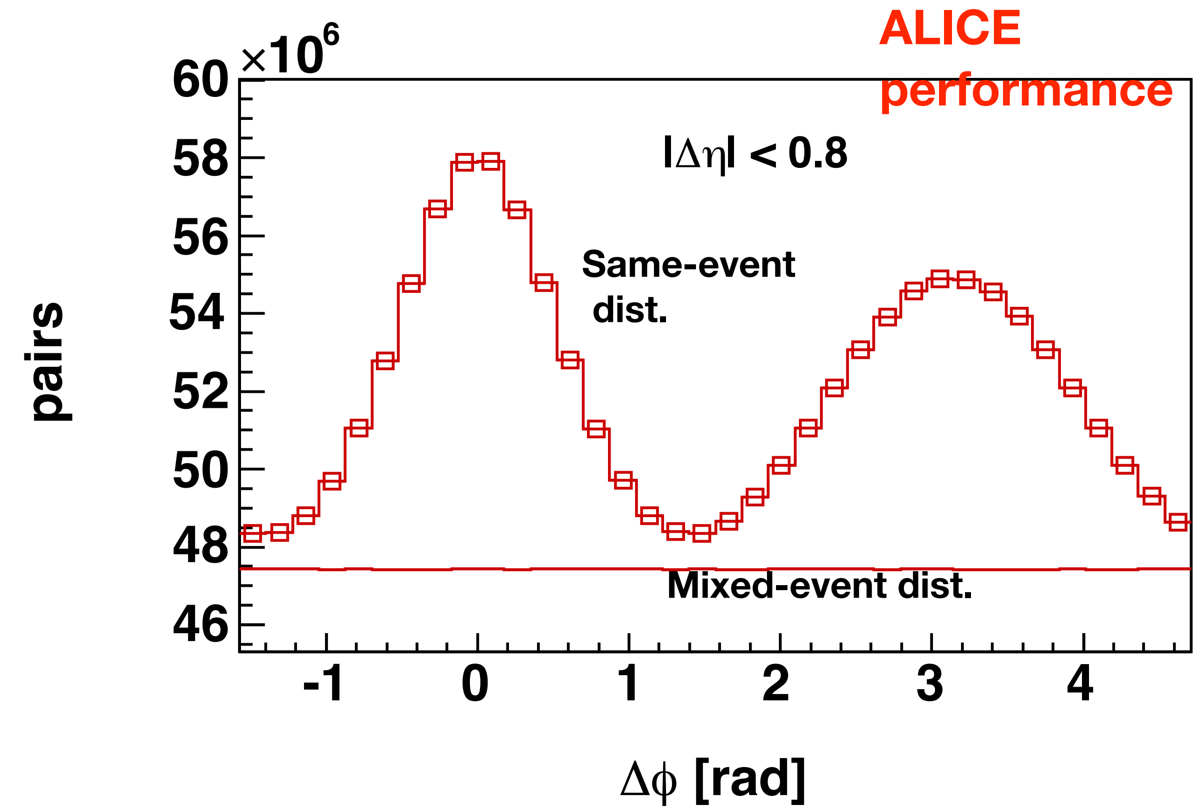
# Two-particle correlations

## Same and mixed event pair distributions

$$\Delta\phi = \phi_A - \phi_B \qquad \Delta\eta = \eta_A - \eta_B$$




## Simplest observable: correlation function

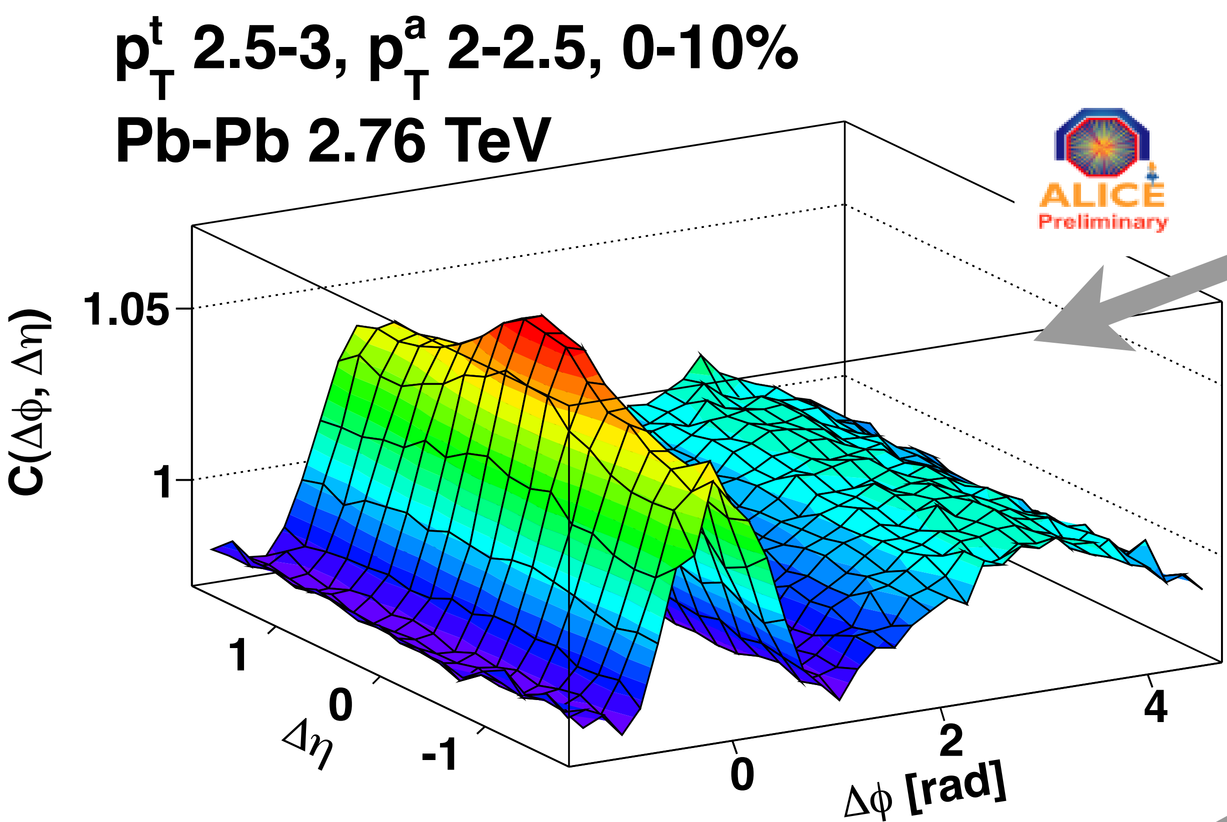
$$C(\Delta\phi) \equiv \frac{N^{AB}_{mixed}}{N^{AB}_{same}} \cdot \frac{dN^{AB}_{same}/d\Delta\phi}{dN^{AB}_{mixed}/d\Delta\phi}$$

**Conditional yield: Y ∝ C(Δφ) / trigger particle.**

**$I_{AA}$: the 2-particle version of $R_{AA}$**

$$I_{AA}(p_{T,trig}; p_{T,assoc}) = \frac{Y^{AA}(p_{T,trig}; p_{T,assoc})}{Y^{pp}(p_{T,trig}; p_{T,assoc})}$$

# Event structure evolution

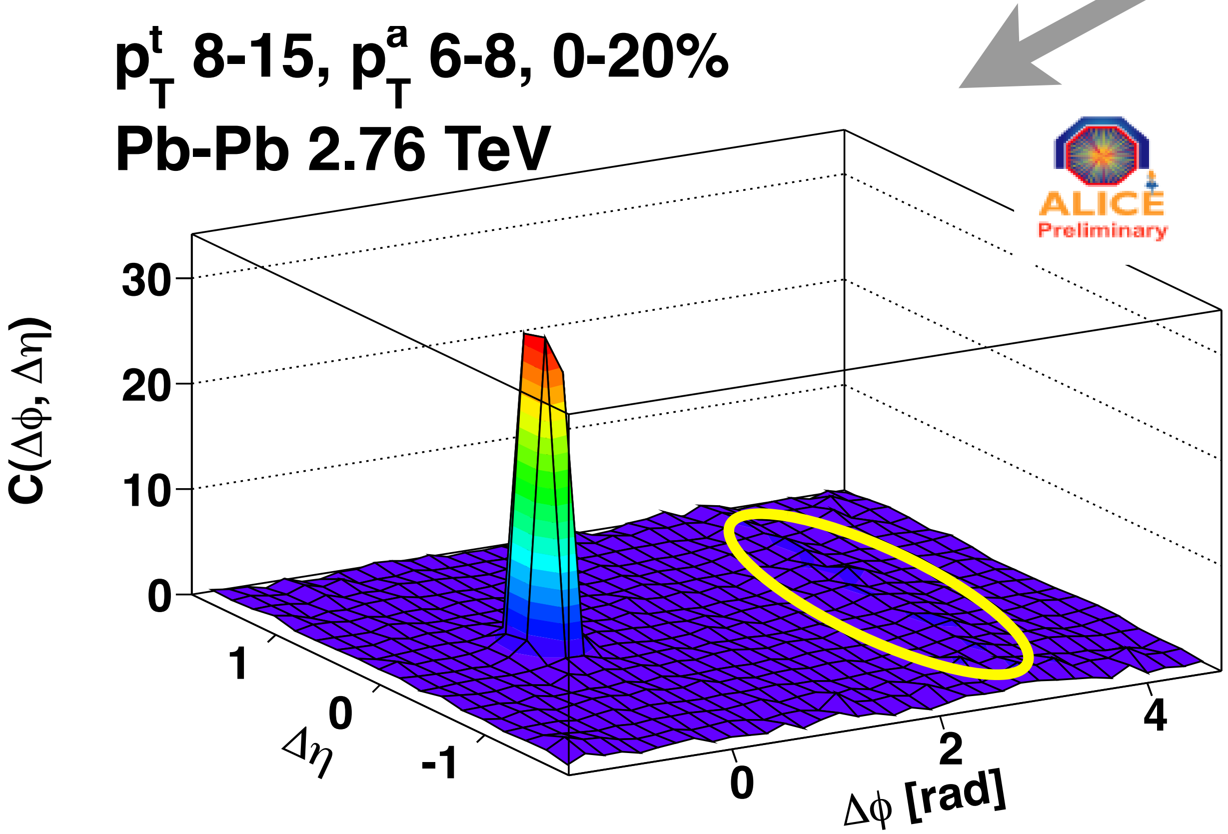


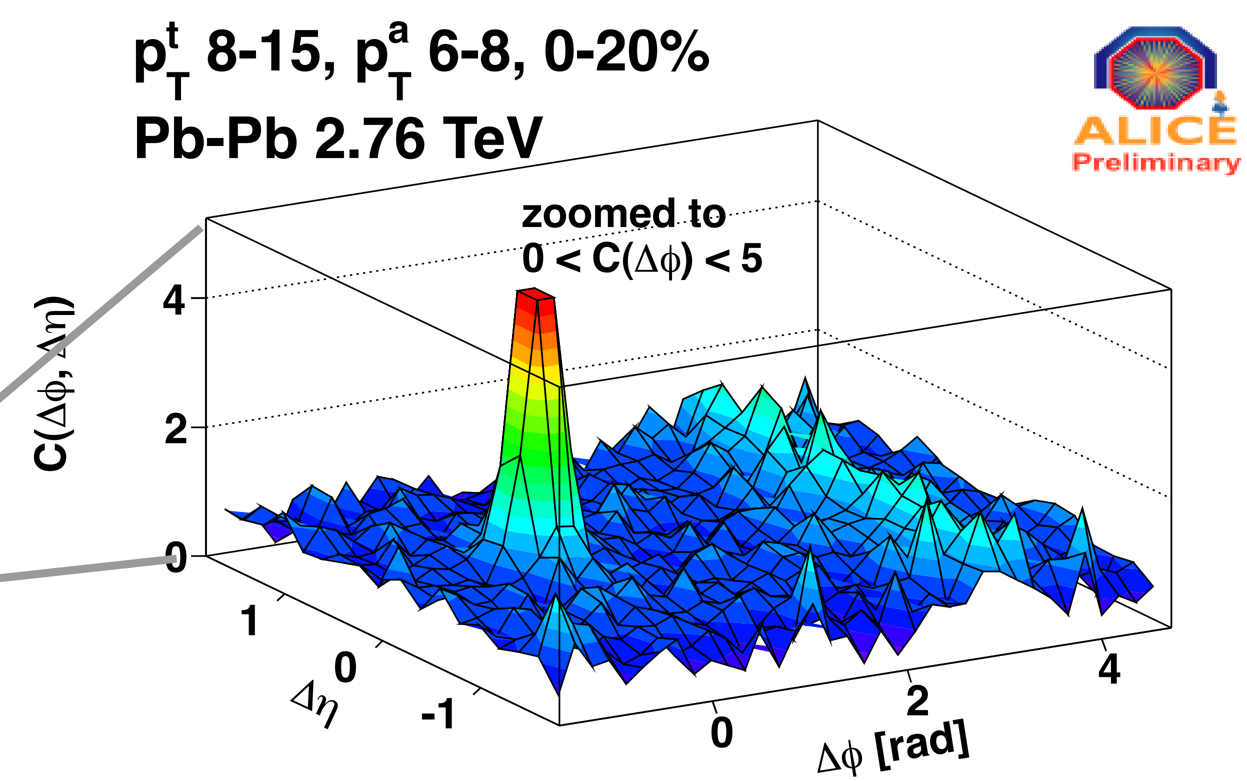

**Low-intermediate $p_T$**

- Distinct near-side ridge
- Broad away side

**High pt:**

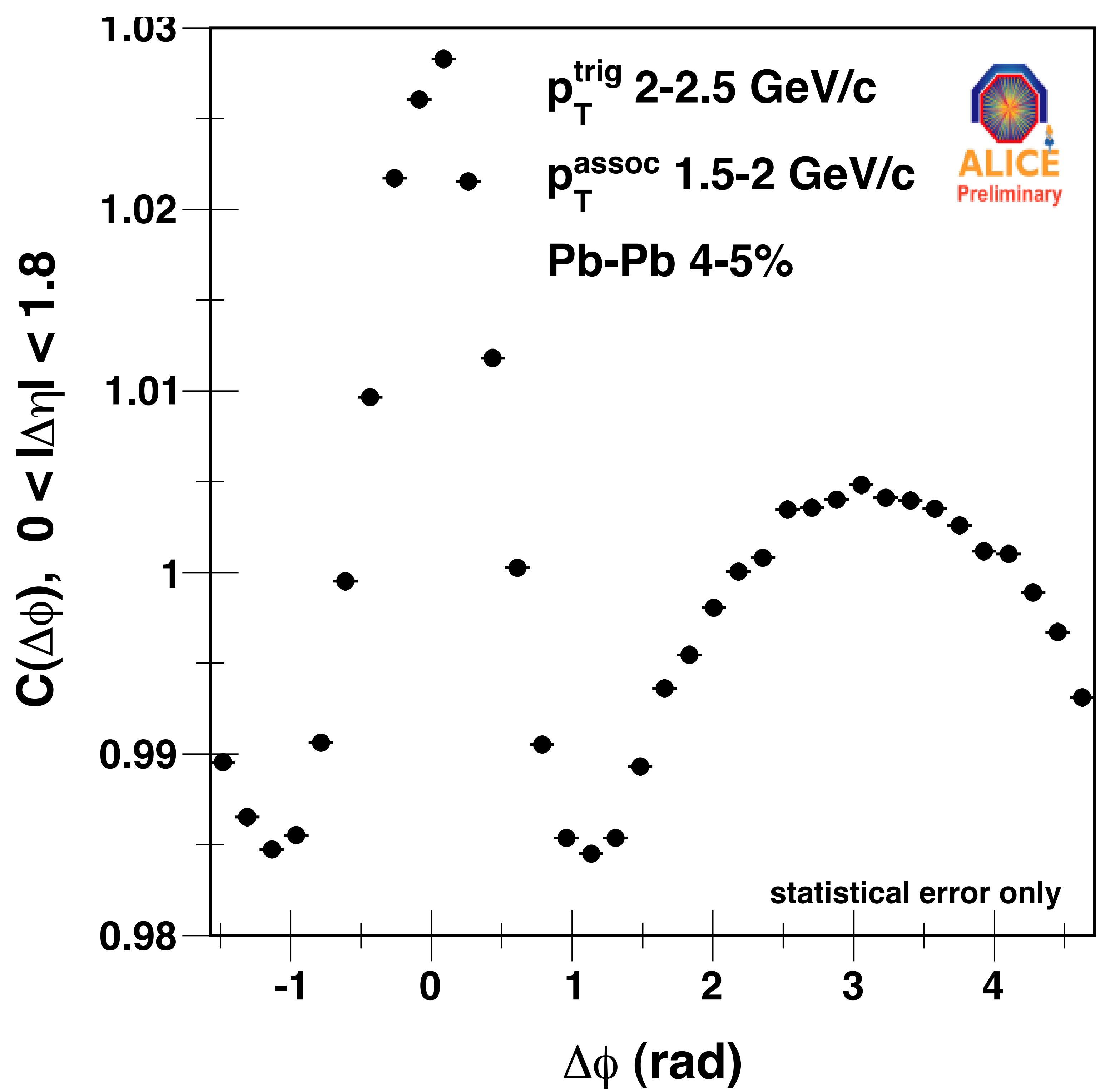
- Near side jet dominates
  - ridge indistinct from background
- Elongated away-side structure
  - from swinging recoil jet



# Approaching ultracentral Pb+Pb events

**At 1-3 GeV/c, a dramatic shape evolution is observed within a small centrality range.**

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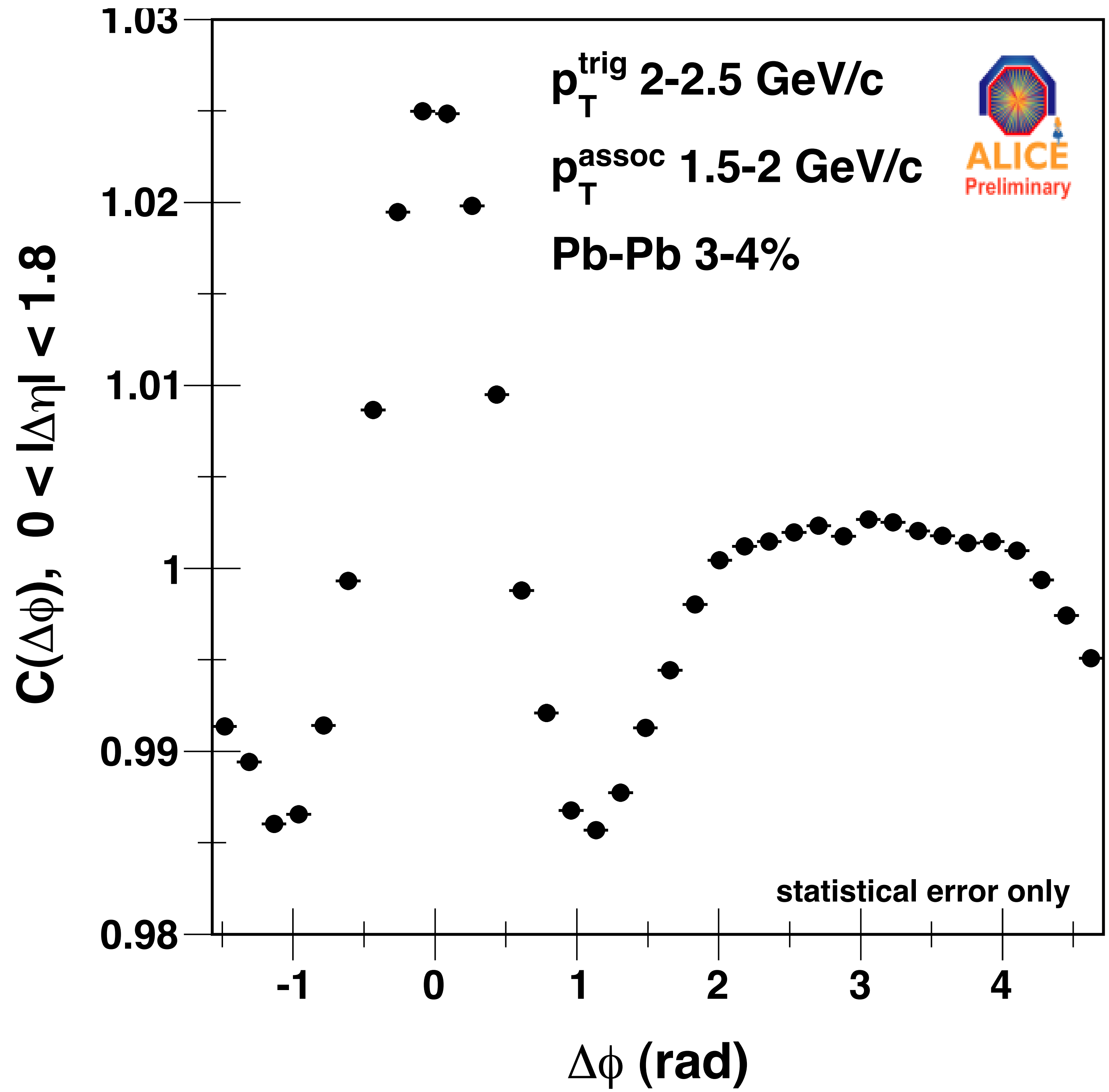


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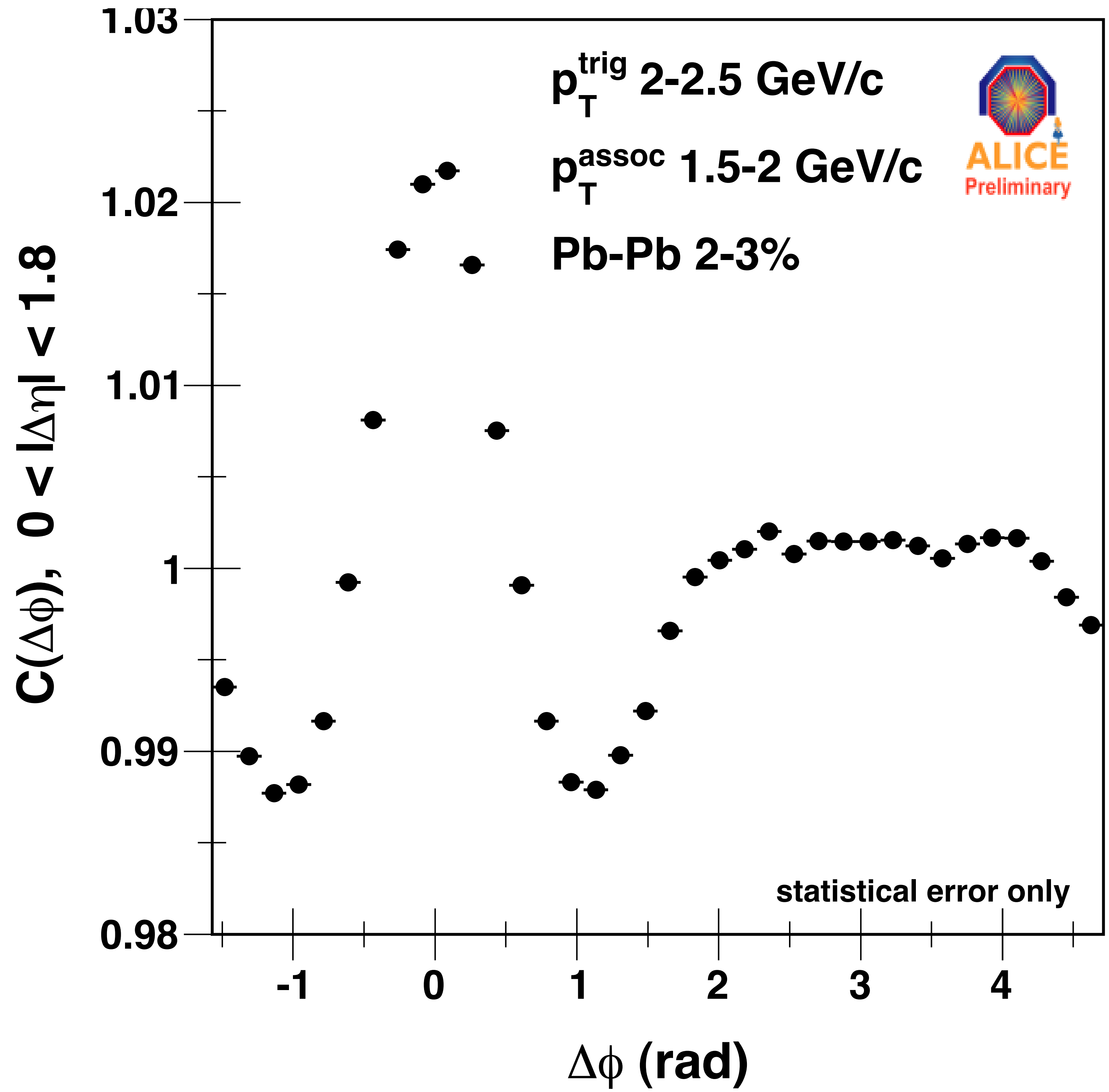


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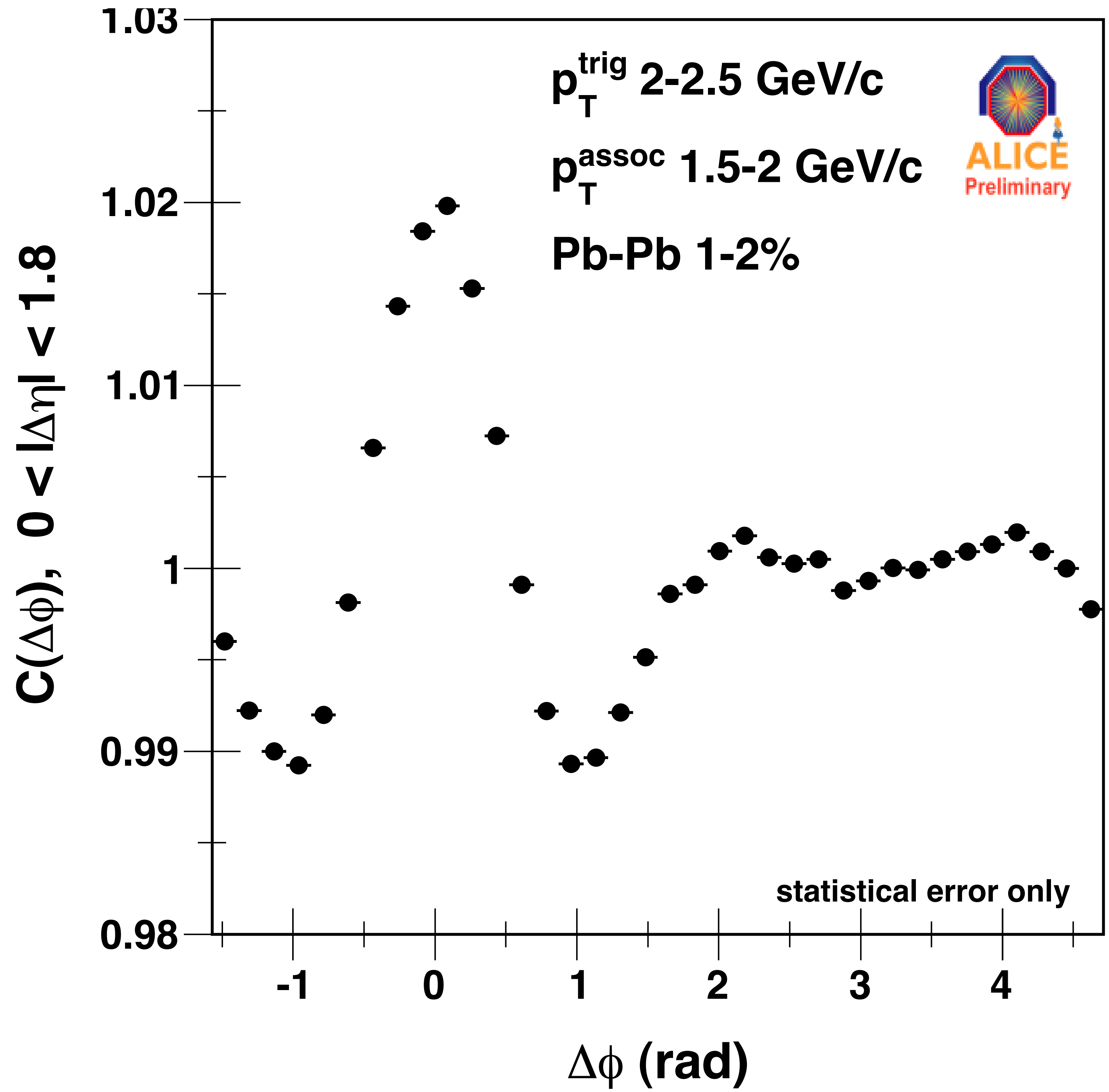


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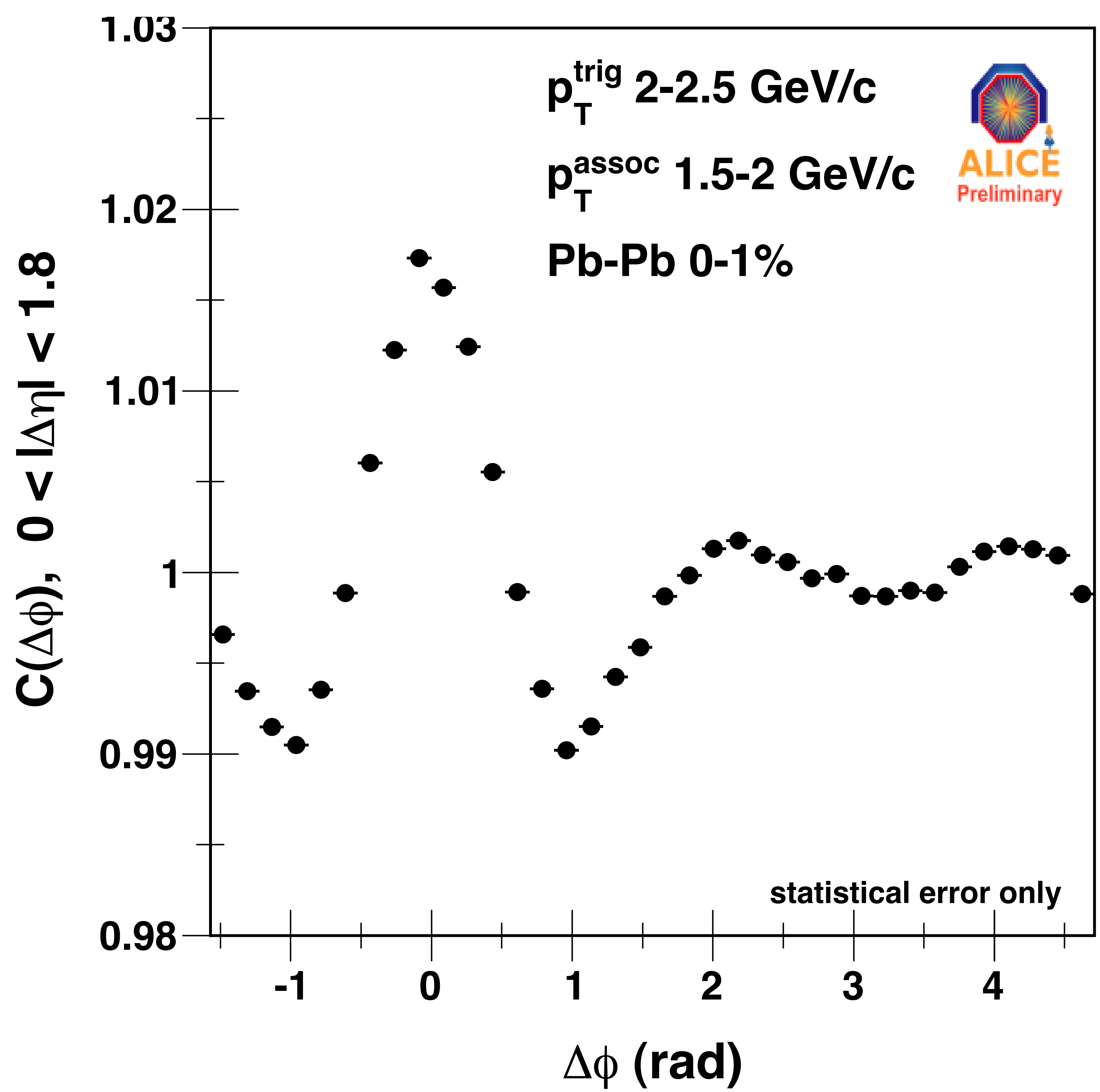


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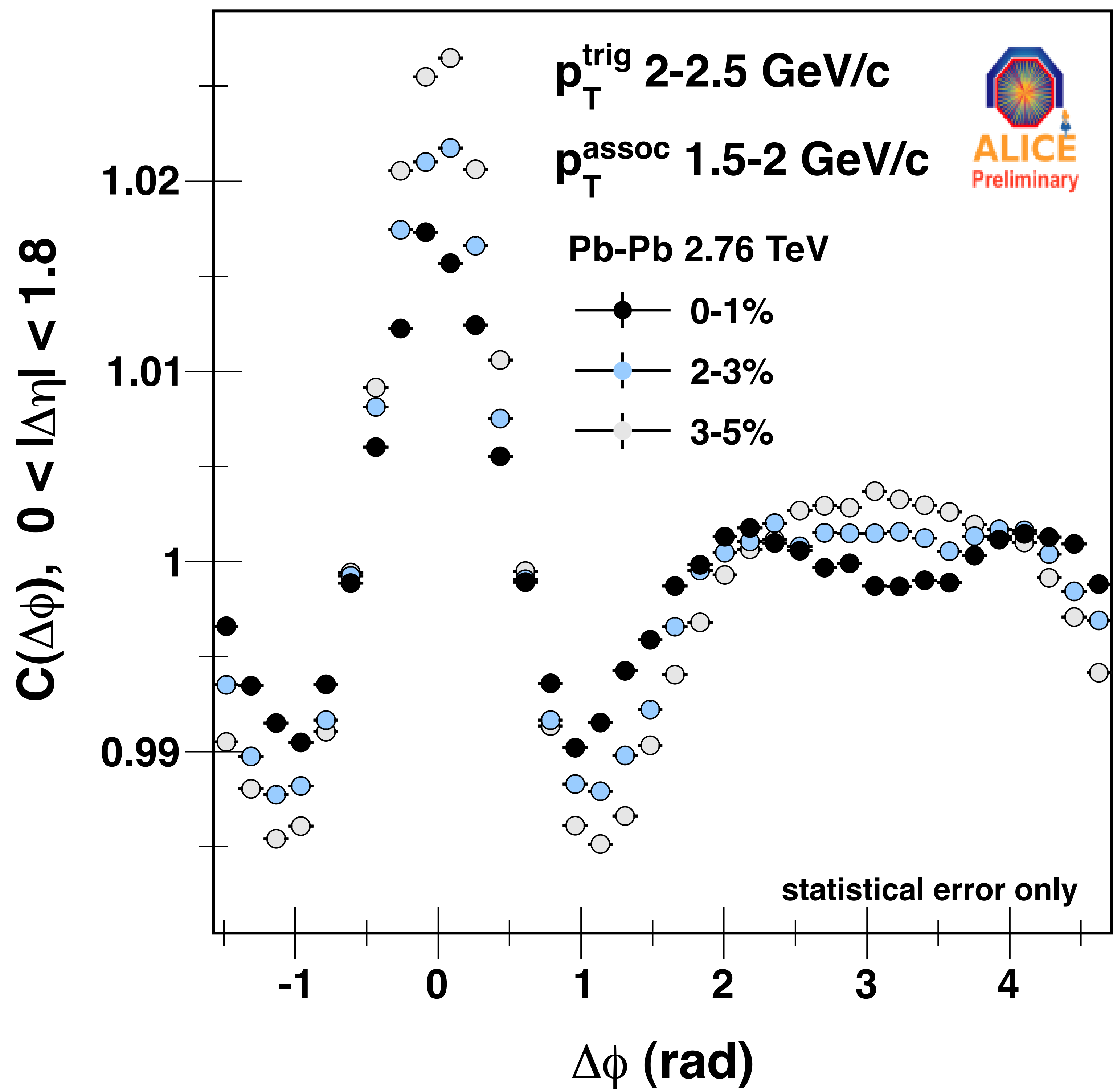


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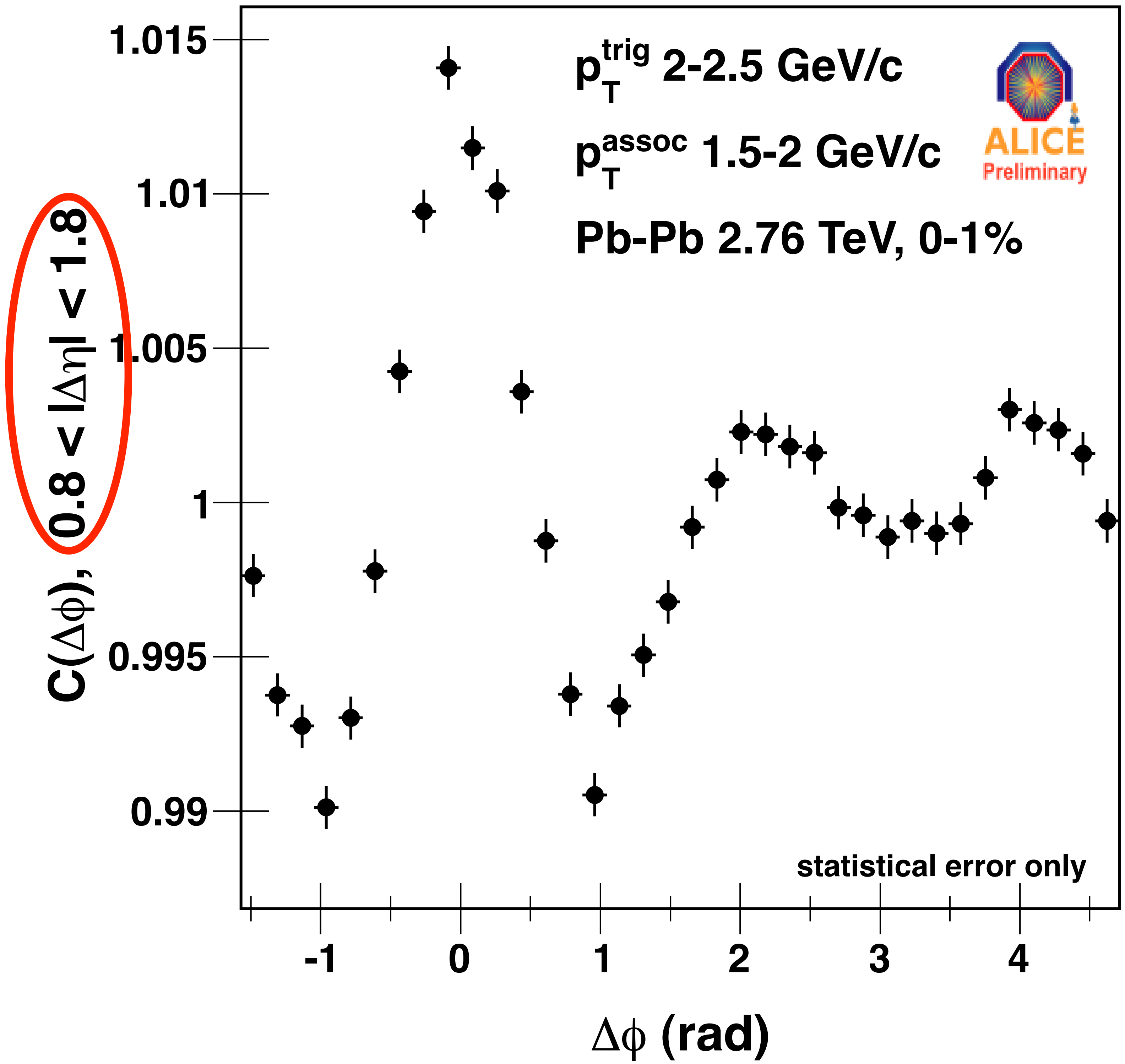
**Near side jet excluded by |Δη| > 0.8 gap**

Ridge at Δφ=0 remains



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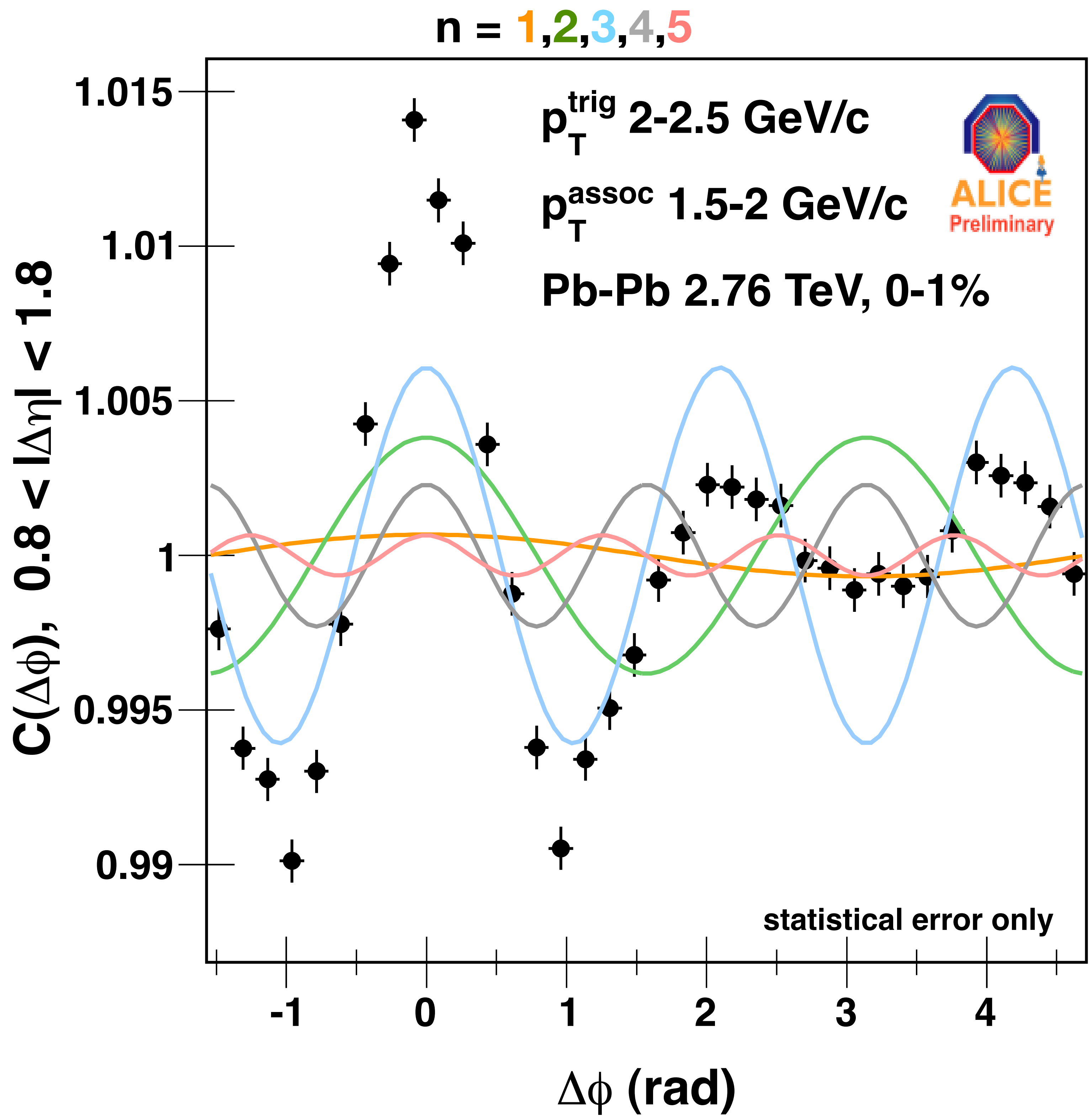

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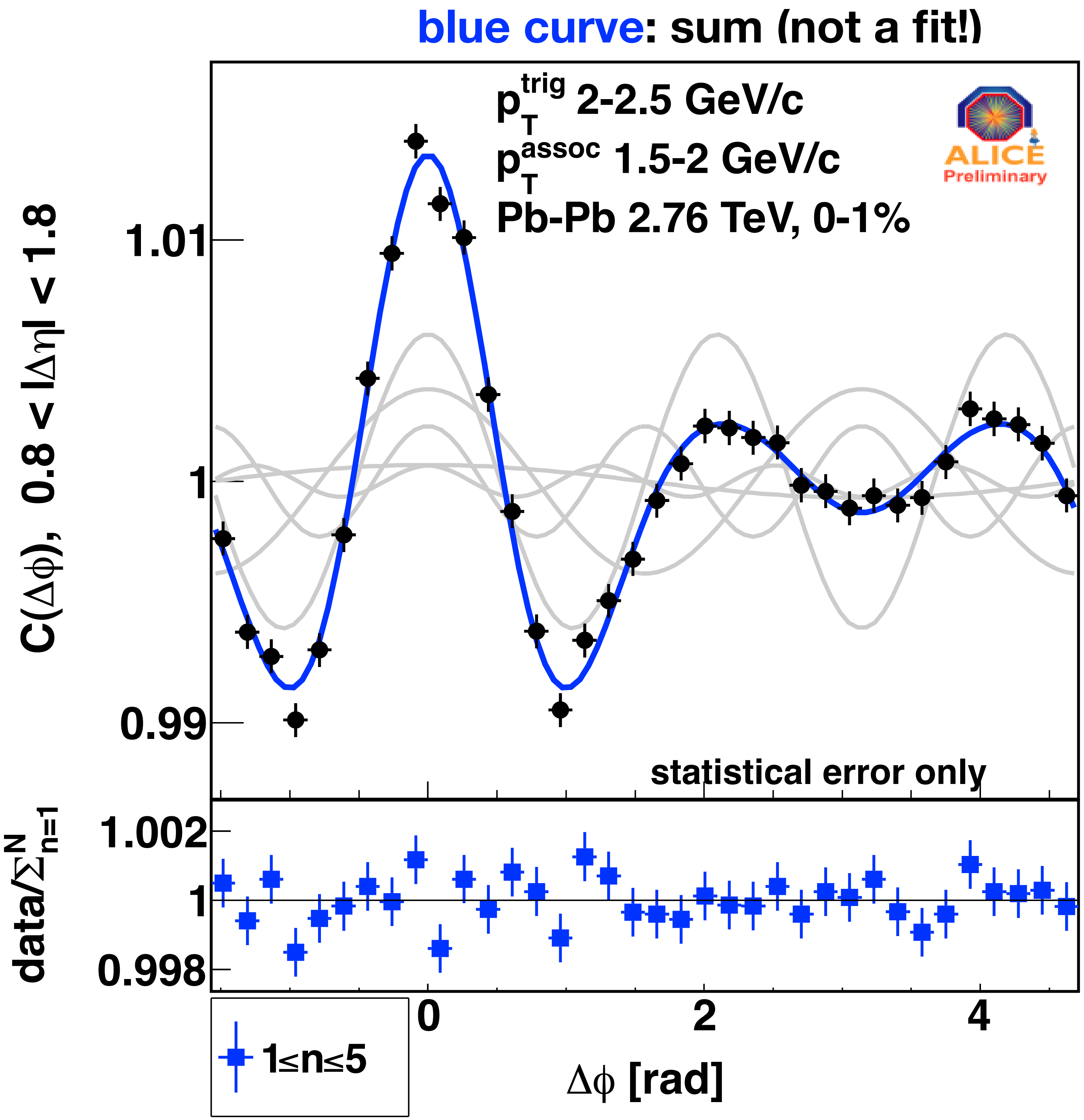

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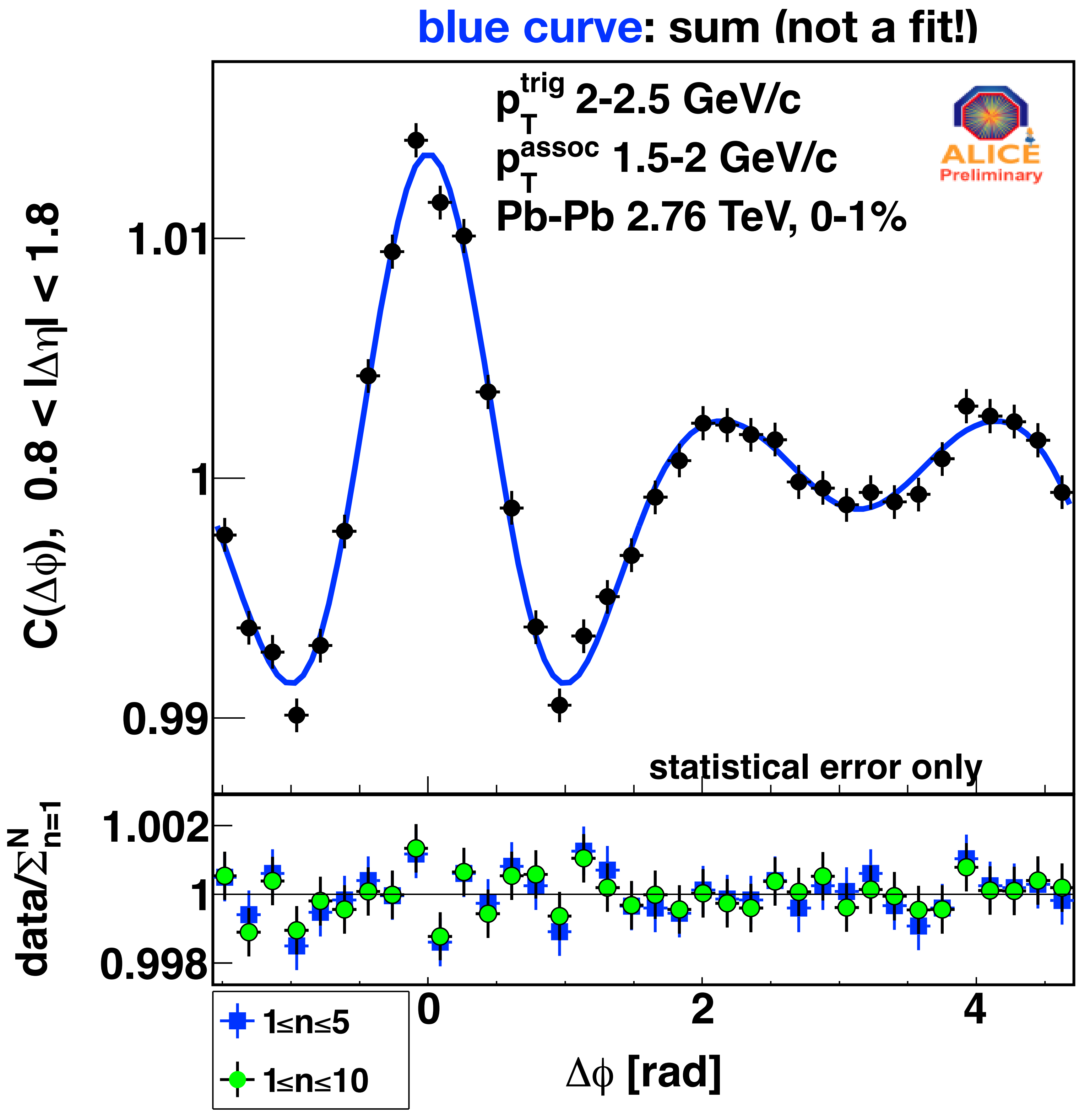
Little gained by using 10-term series vs. 1<n<5.



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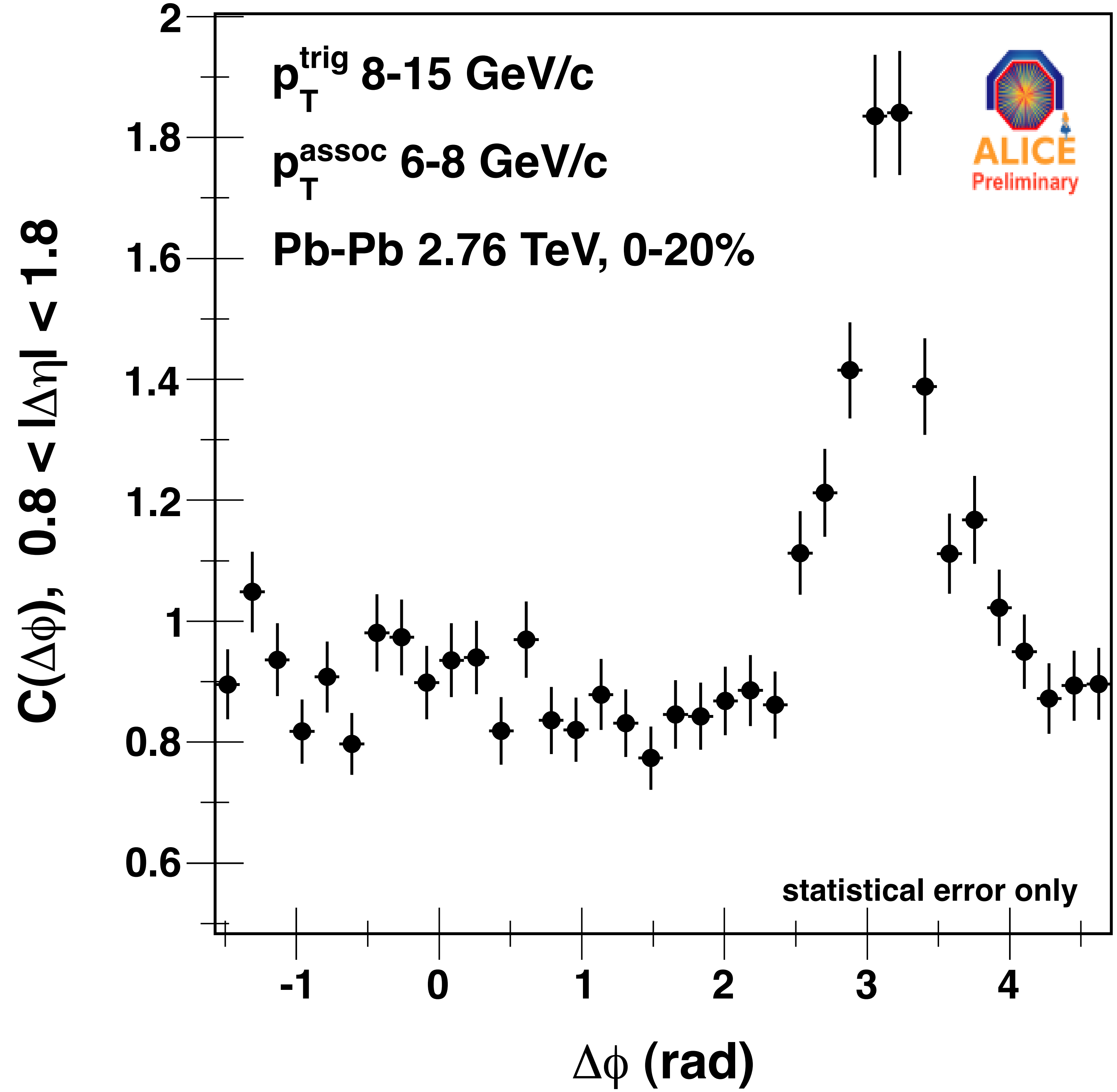

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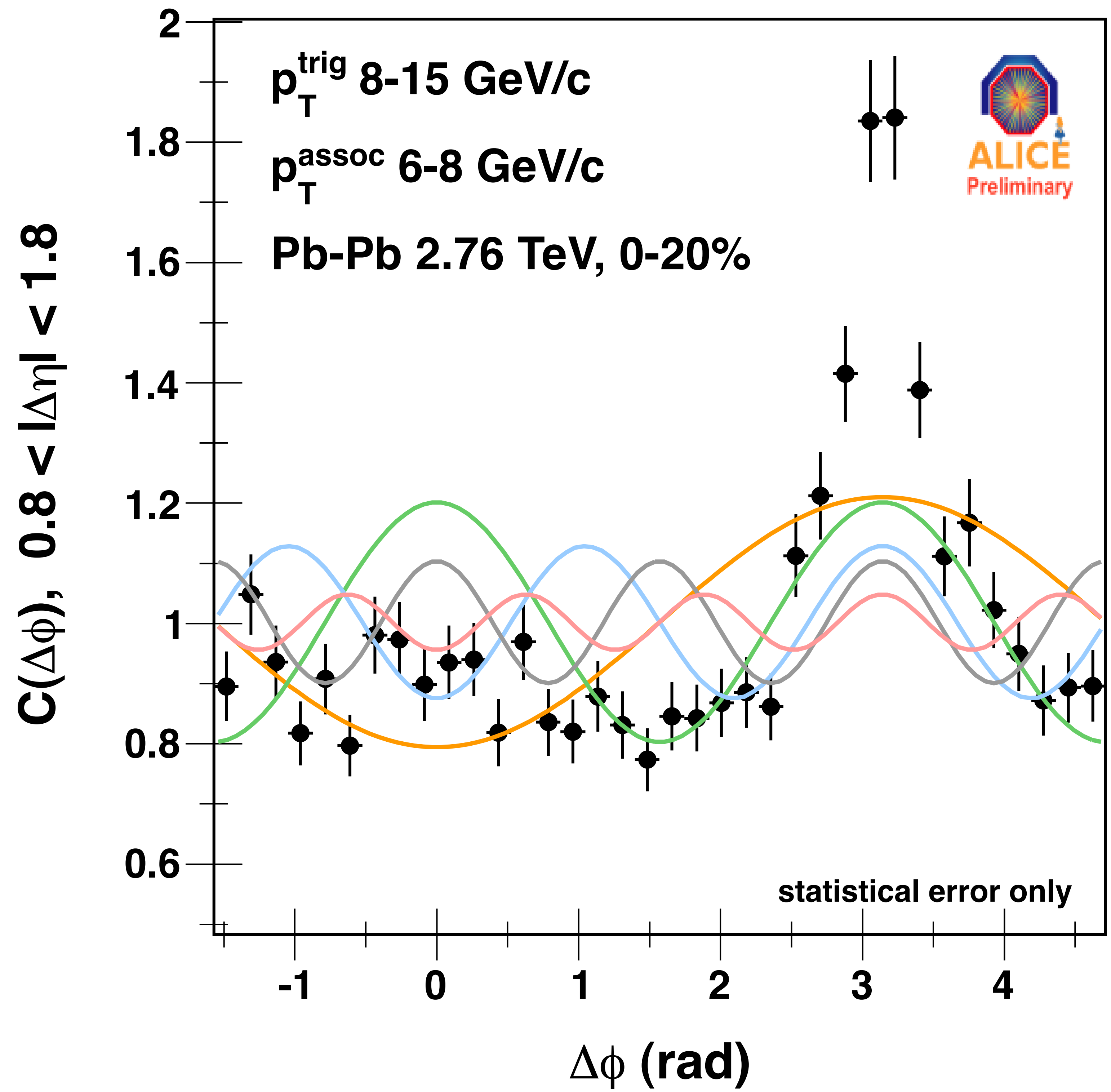

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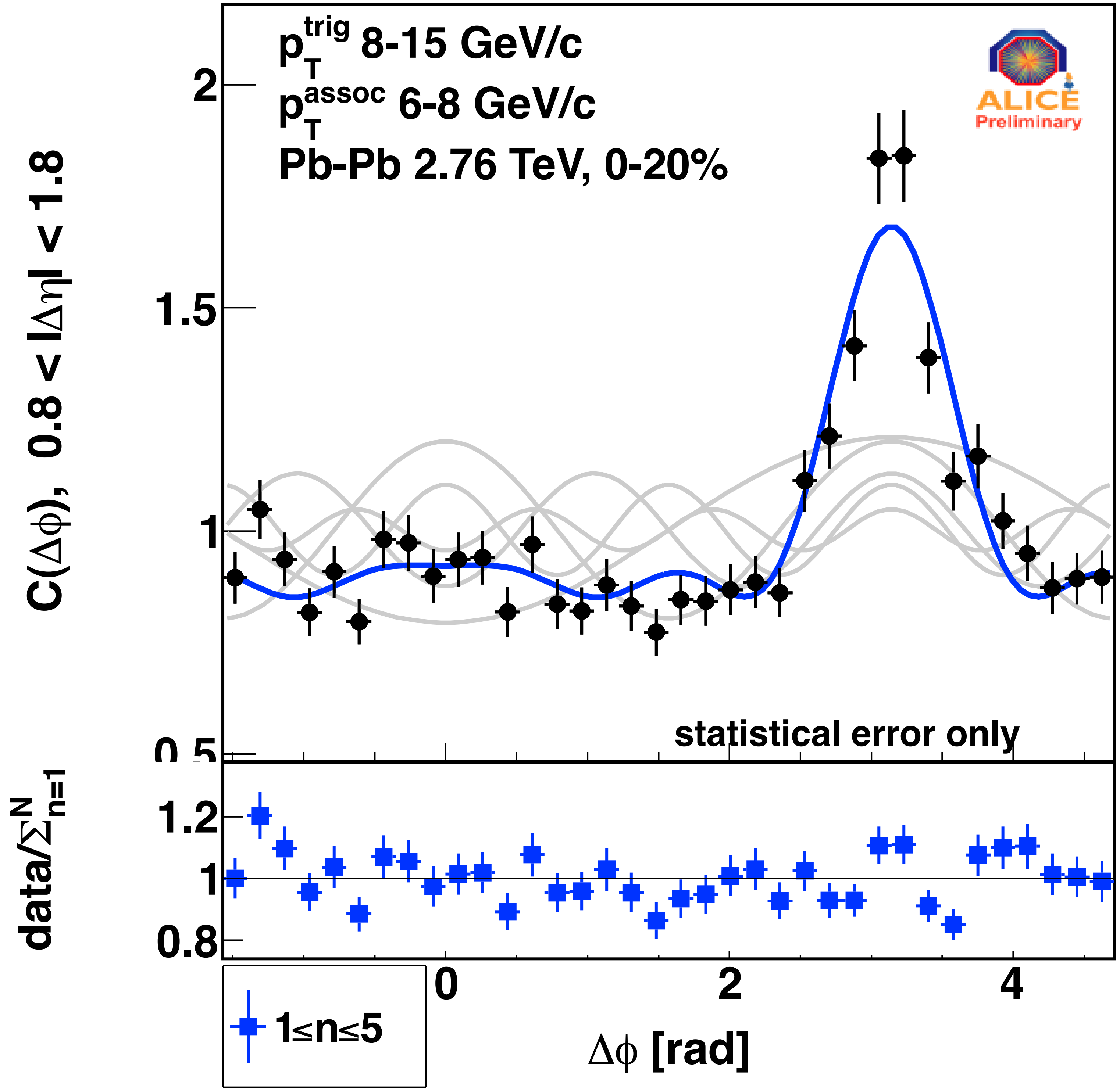

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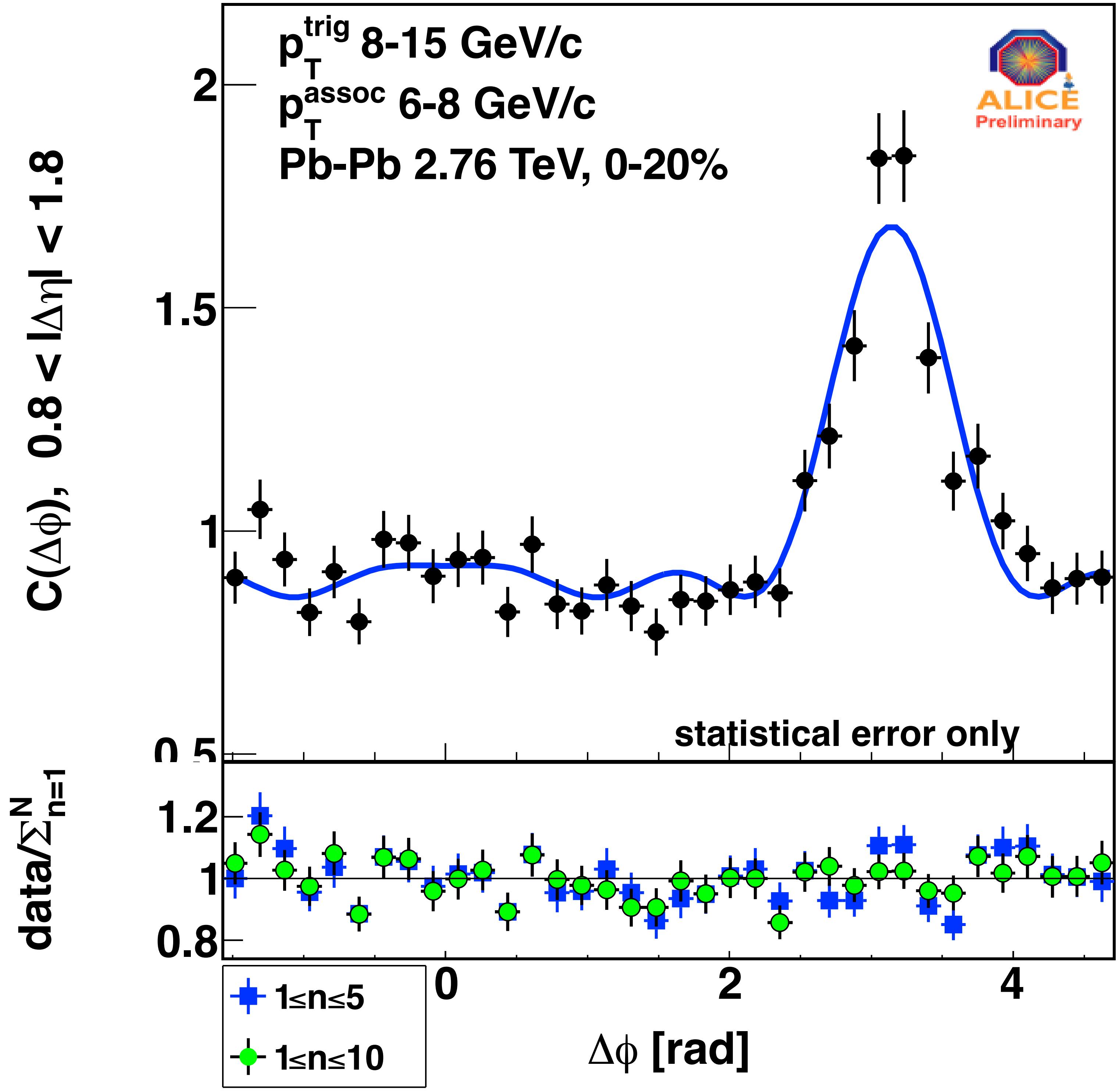
Including 1≤n≤10 improves description vs 1≤n≤5.

Sharp features require higher moments



# Flow vs. non-flow correlations

## Collective effects

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## Jet-related effects

A few energetic particles are highly correlated by fragmentation, but not directly through $\psi_n$.

Caveat: there can be indirect correlations, i.e. length-dependent quenching. Would be largest w.r.t. $\psi_2$ since it reflects the collision geometry.

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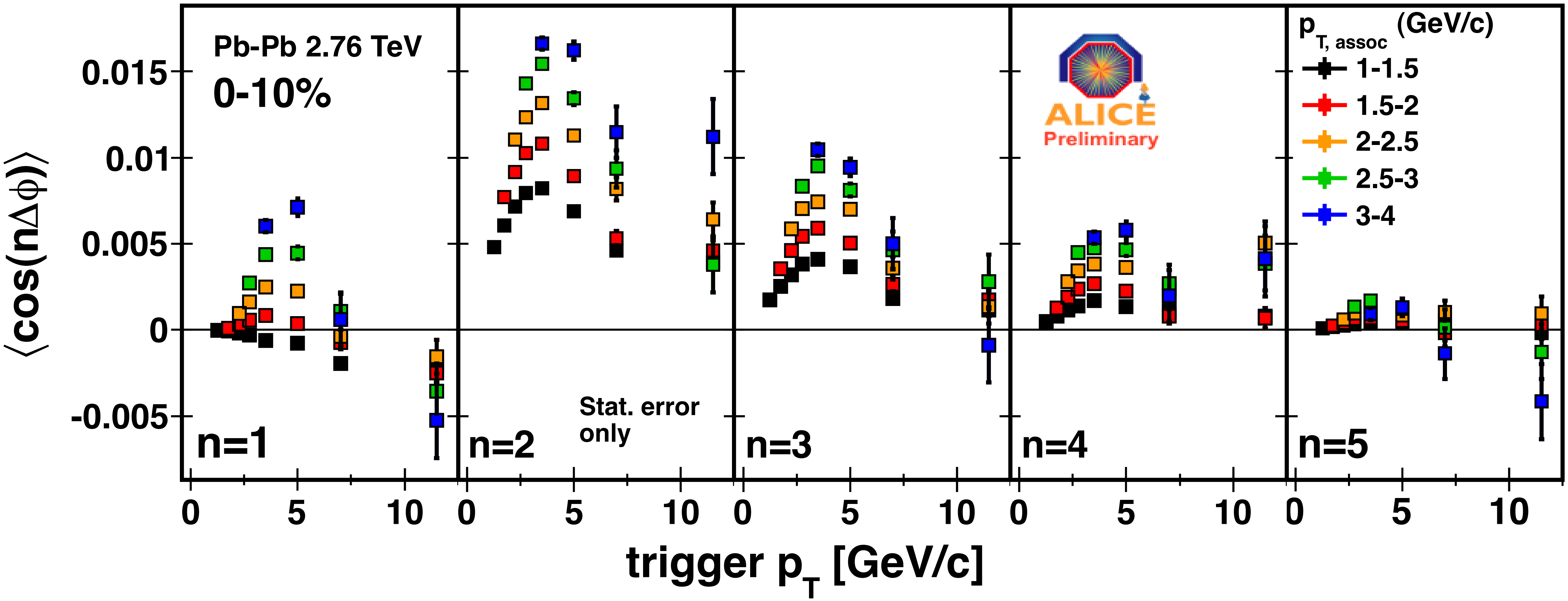
**The collectivity relation**

$$\langle \cos n\Delta\varphi \rangle \stackrel{?}{=} v_n(p_{Ttrig})\, v_n(p_{Tassoc})$$

**is a quantitative hypothesis that can be tested!**

# Fourier coefficients vs. trigger $p_T$




**With rising associated $p_T$…**

Anisotropy rises at all orders in central events.

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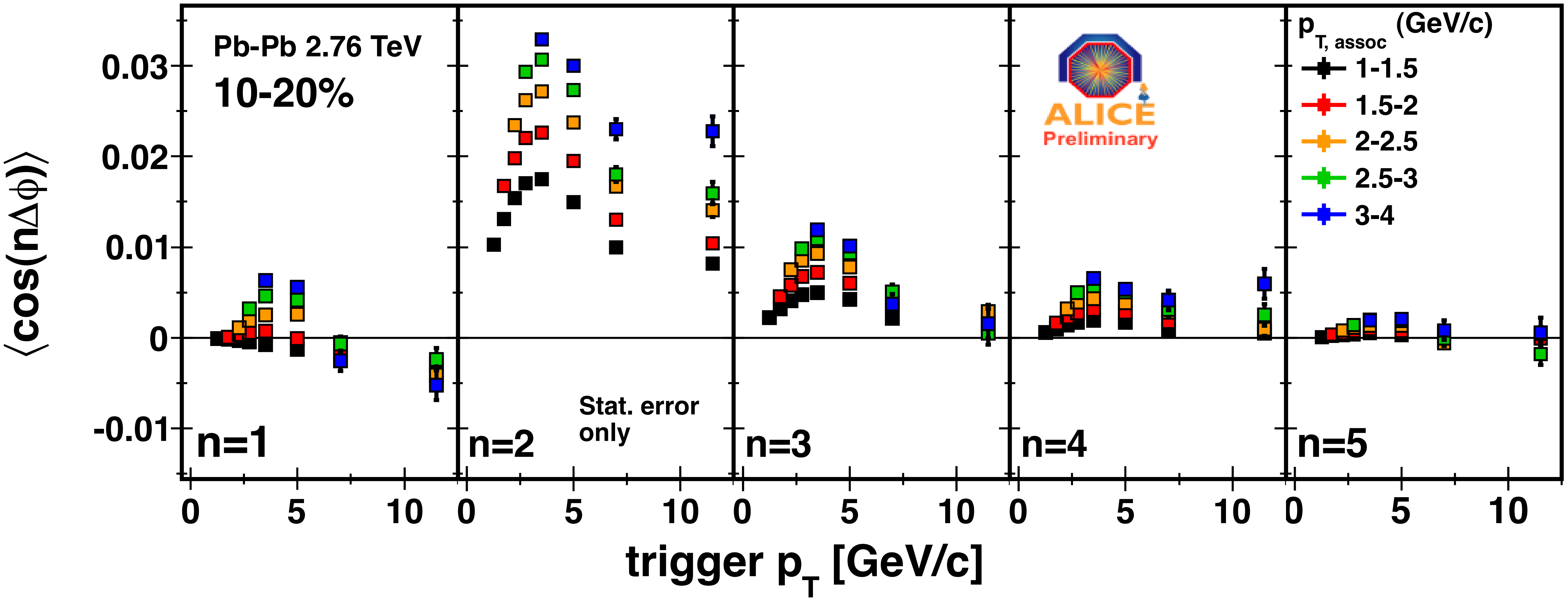


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## With increasing centrality...

n=2 amplitudes:

Comparable to other terms in central events, but dominant in mid-central...reasonable.

Odd terms become negative with rising pt, centrality

Due to the away-side jet

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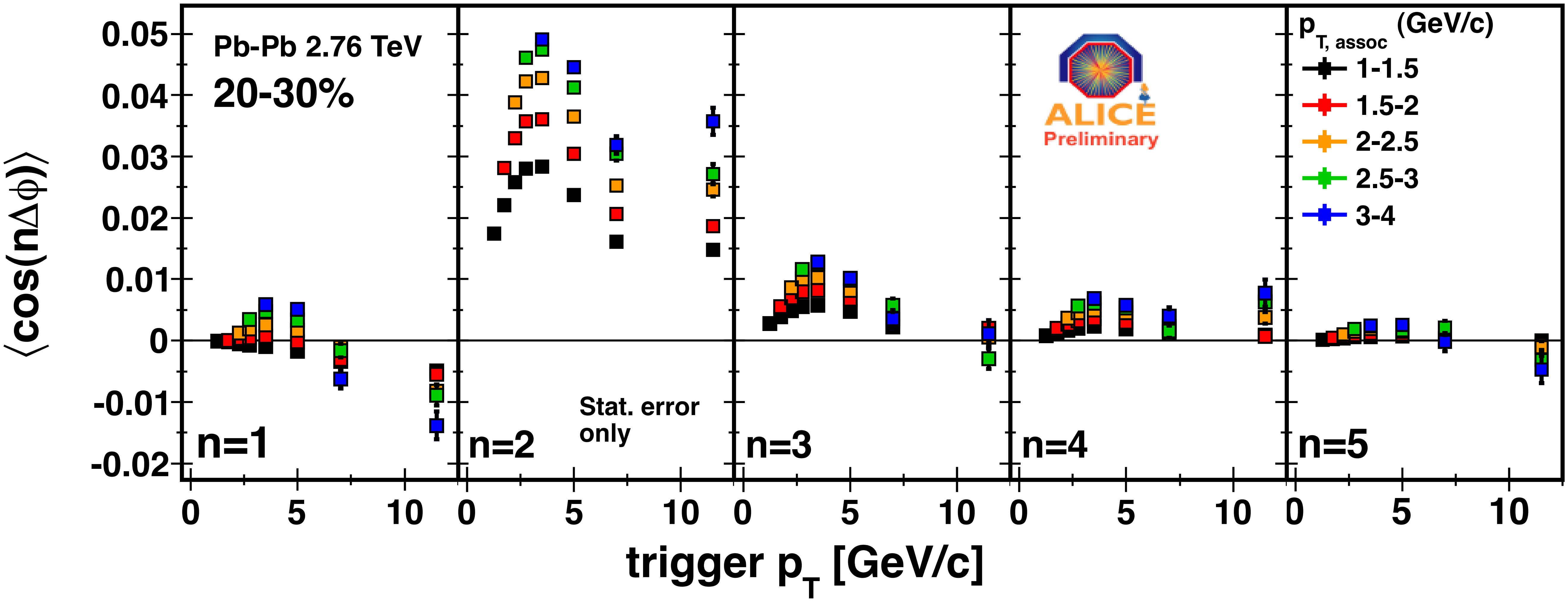


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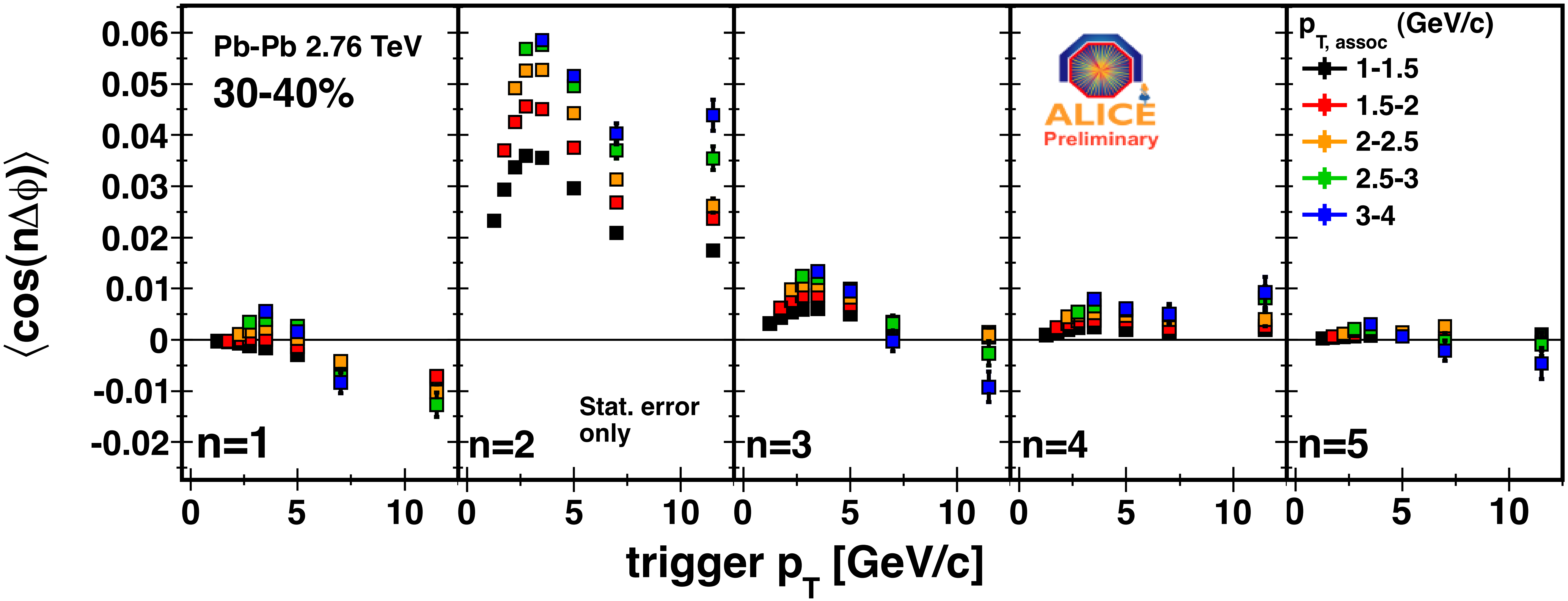


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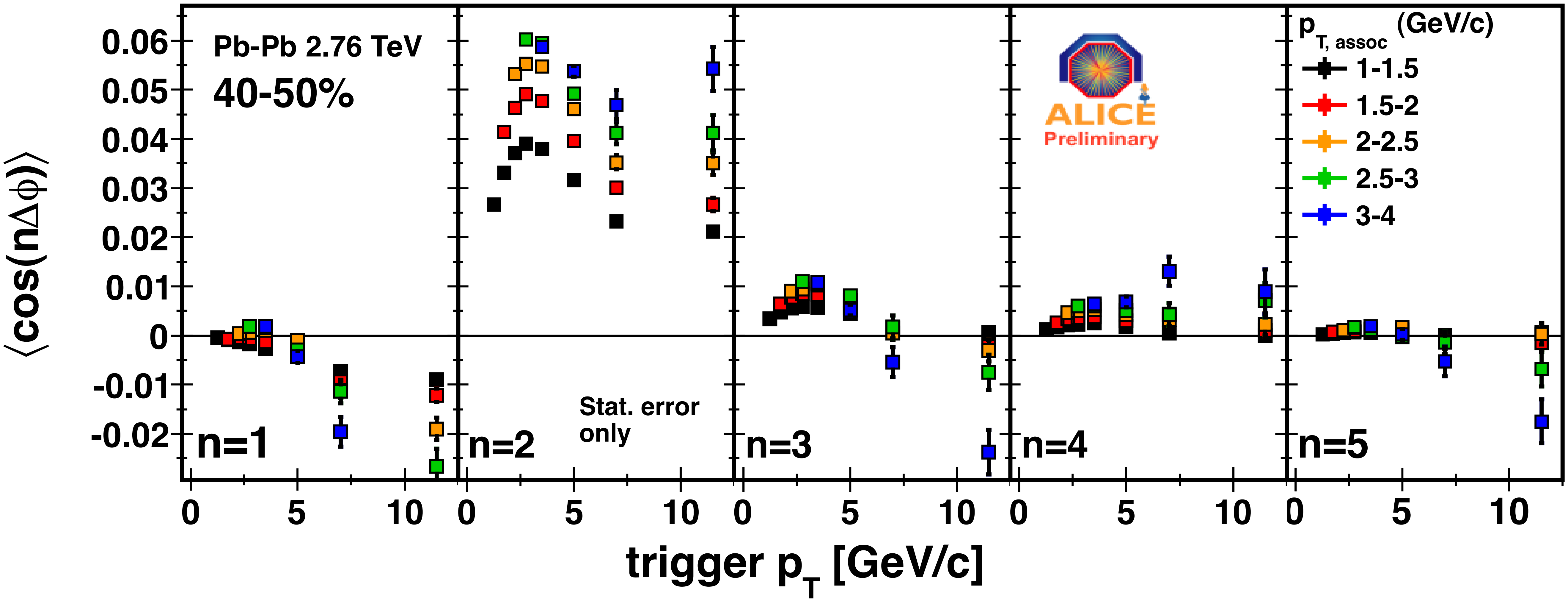


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# Global fit of 2-particle Fourier moments

**Find best $v_n(p_T)$**

**Fit <cos nΔφ> for all $p_T$ bins simultaneously**

**Fit function: $V_{n\Delta} = v_n^t\, v_n^a$.**

**Fit breaks at high $p_T$, where jets dominate.**

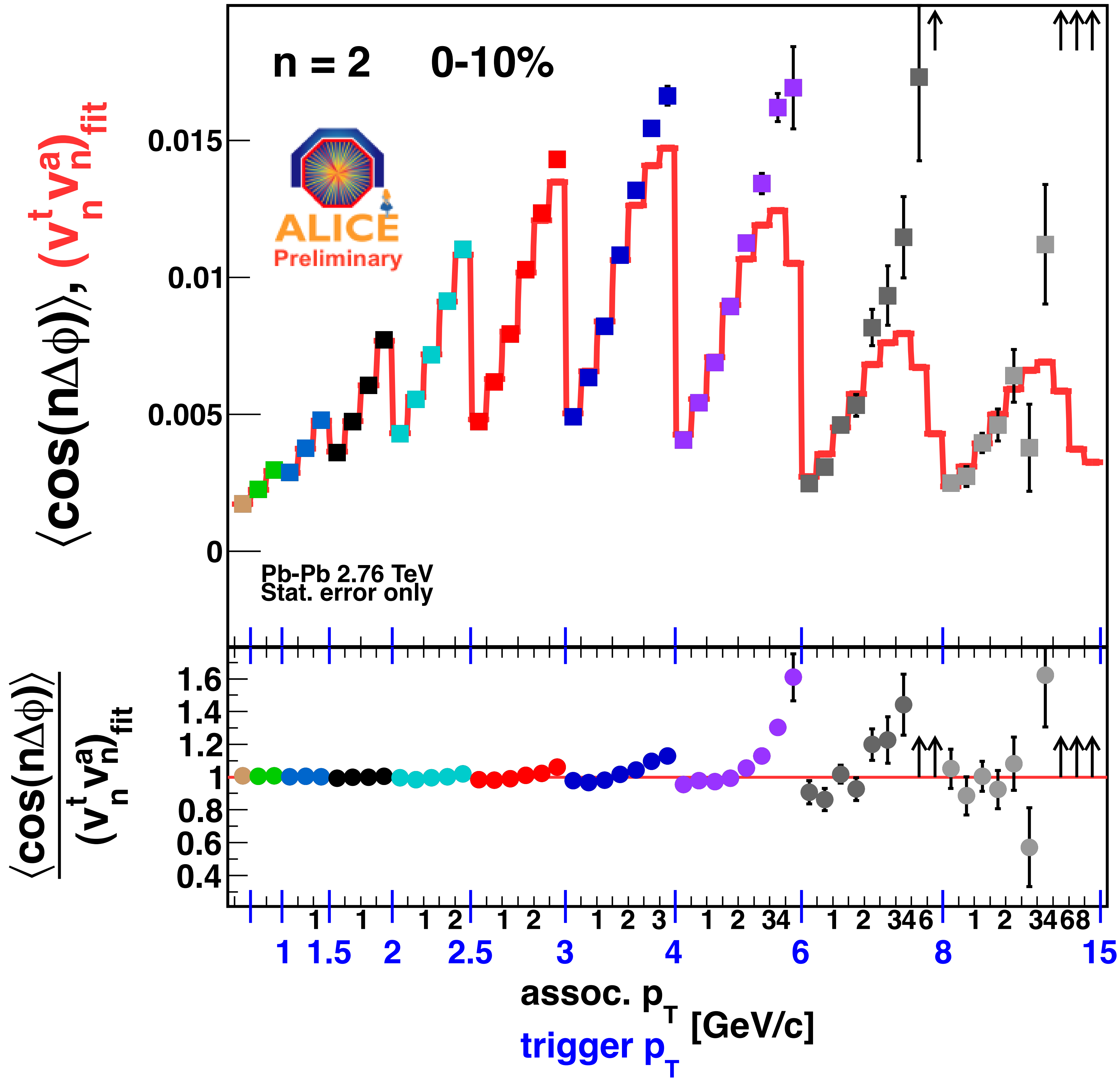
**Key idea**

**If fit matches data**

**suggests flow-type correlations**

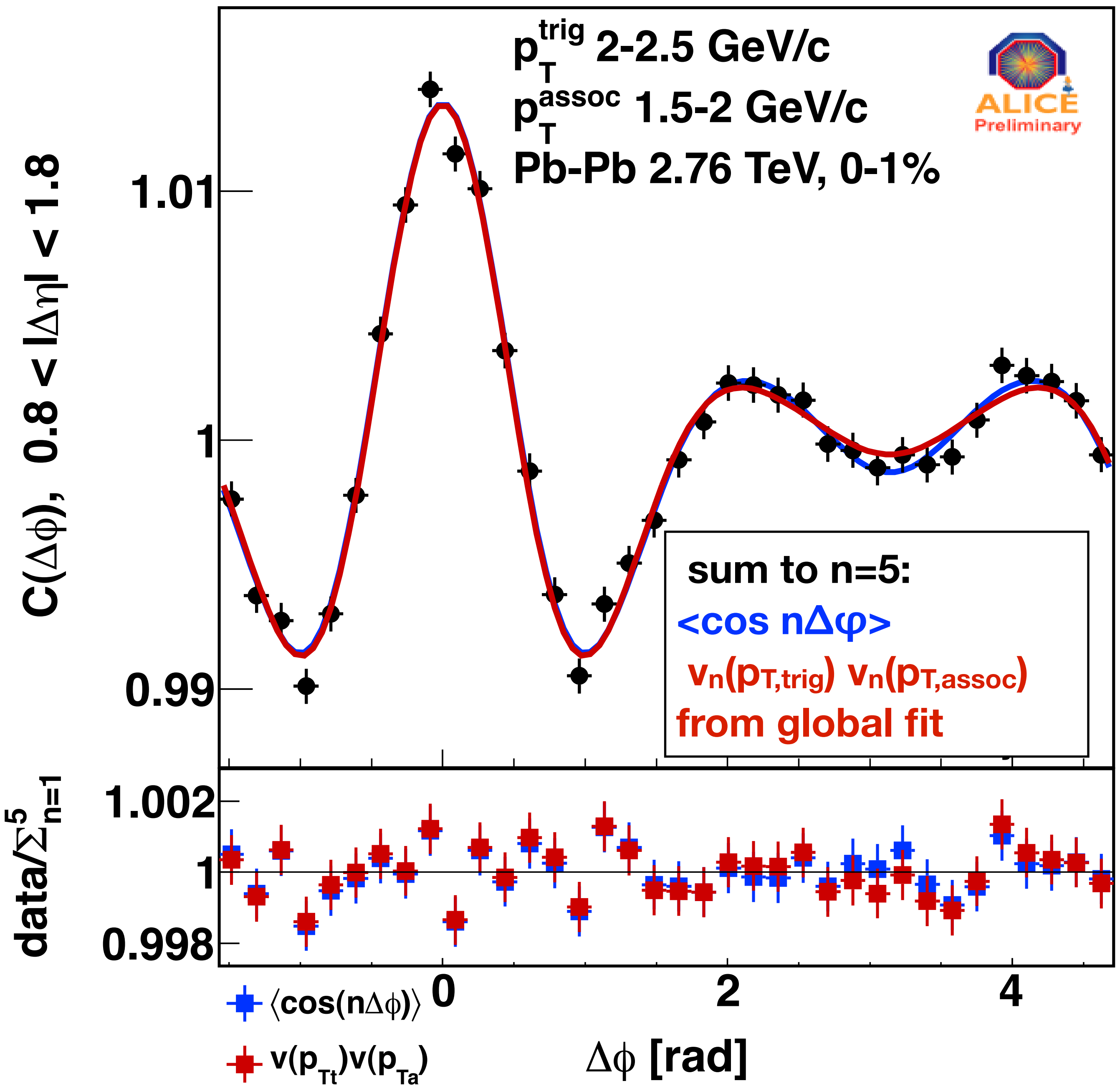
**If fit diverges**

**collective description less appropriate.**




**Transition between cases follows clear trends.**

# Large-Δη global fit results



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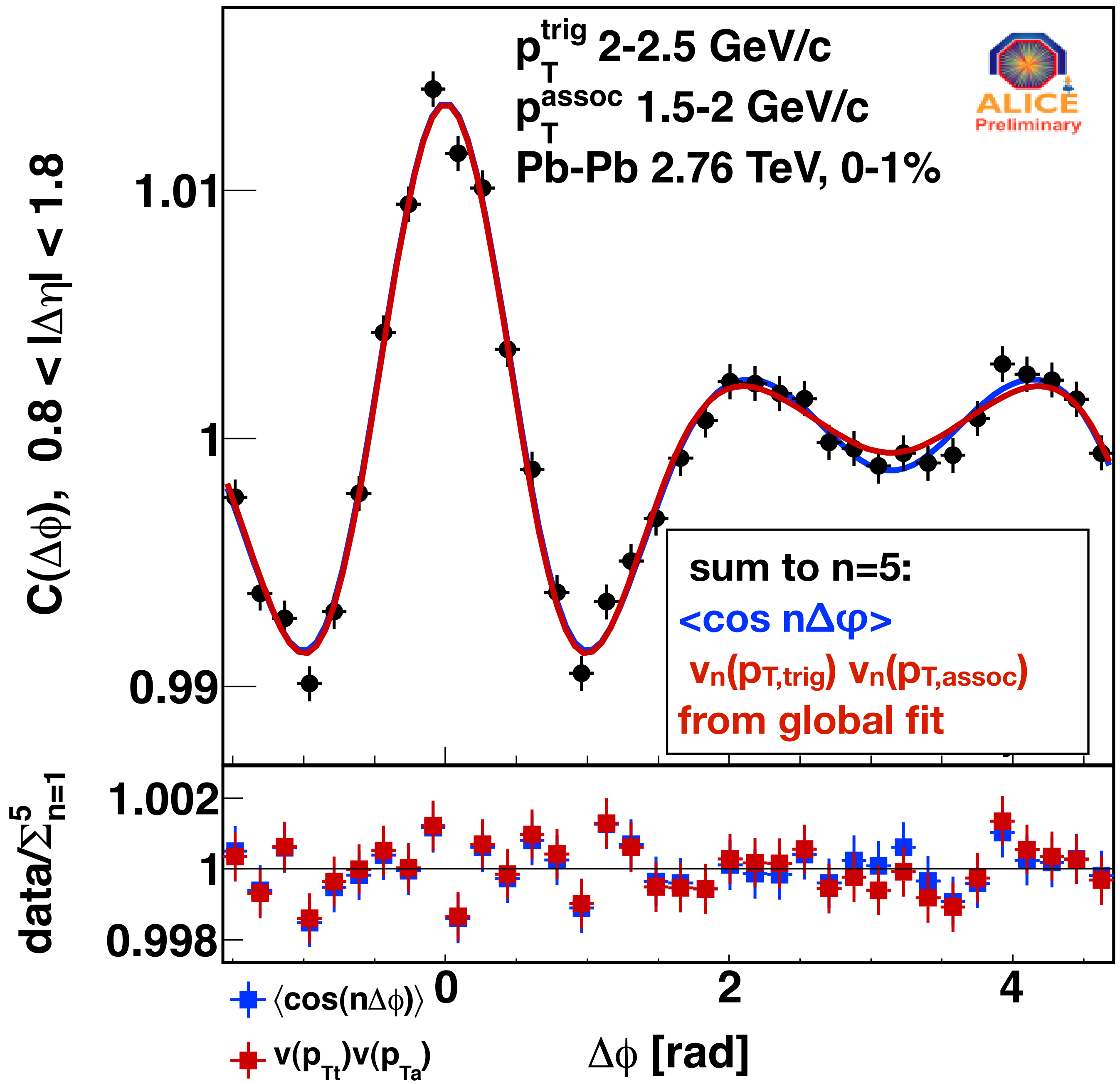


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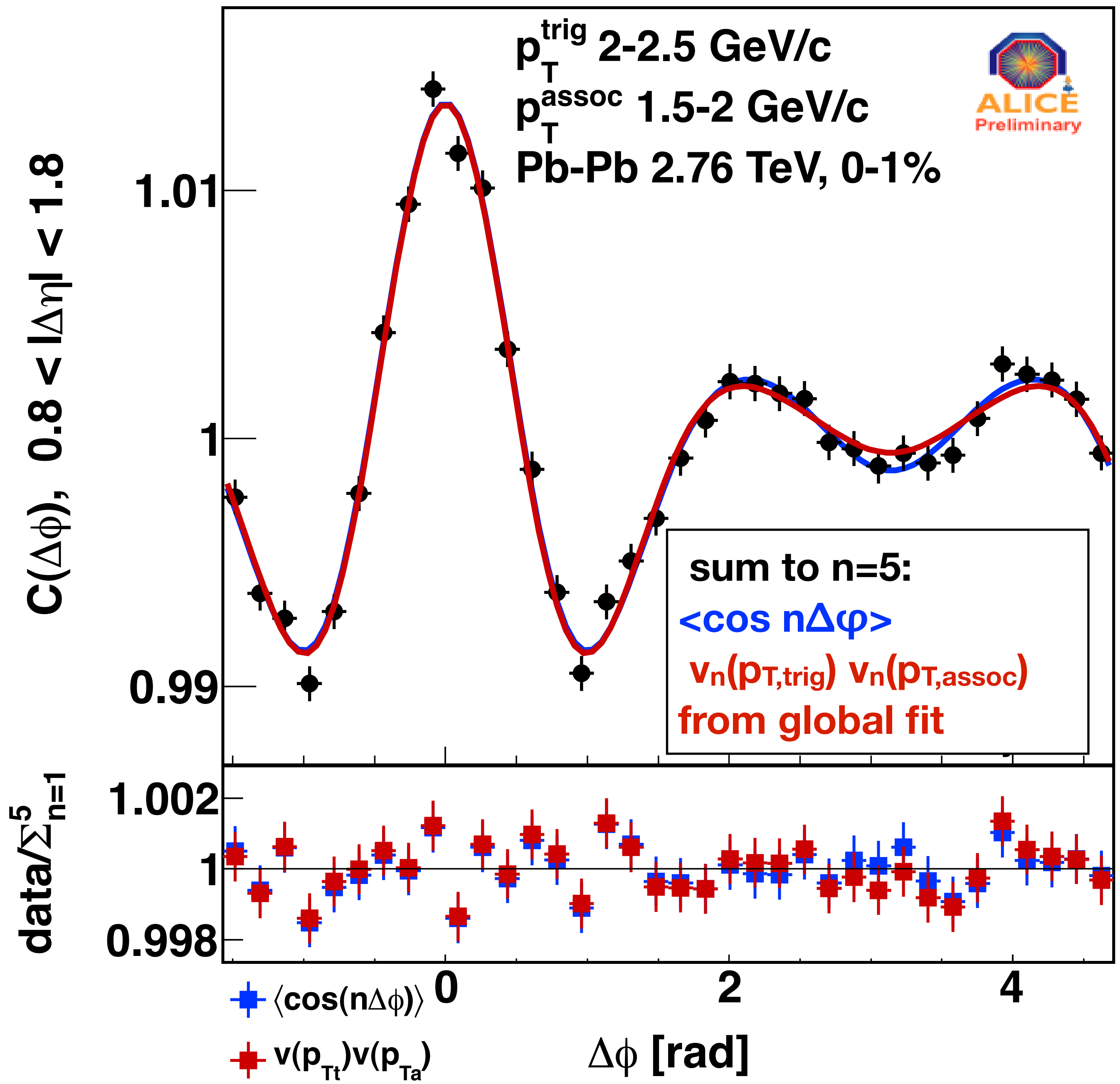
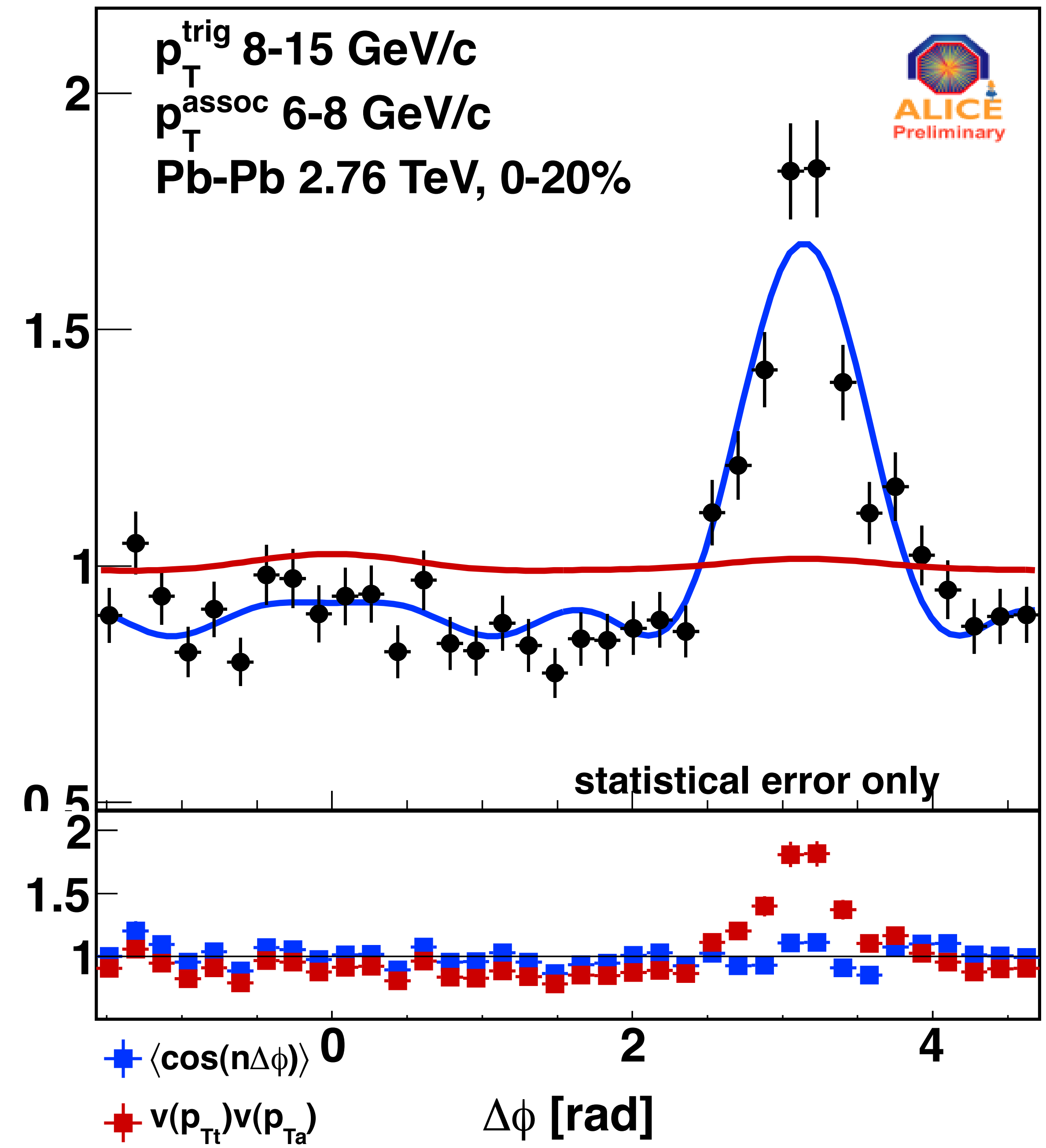


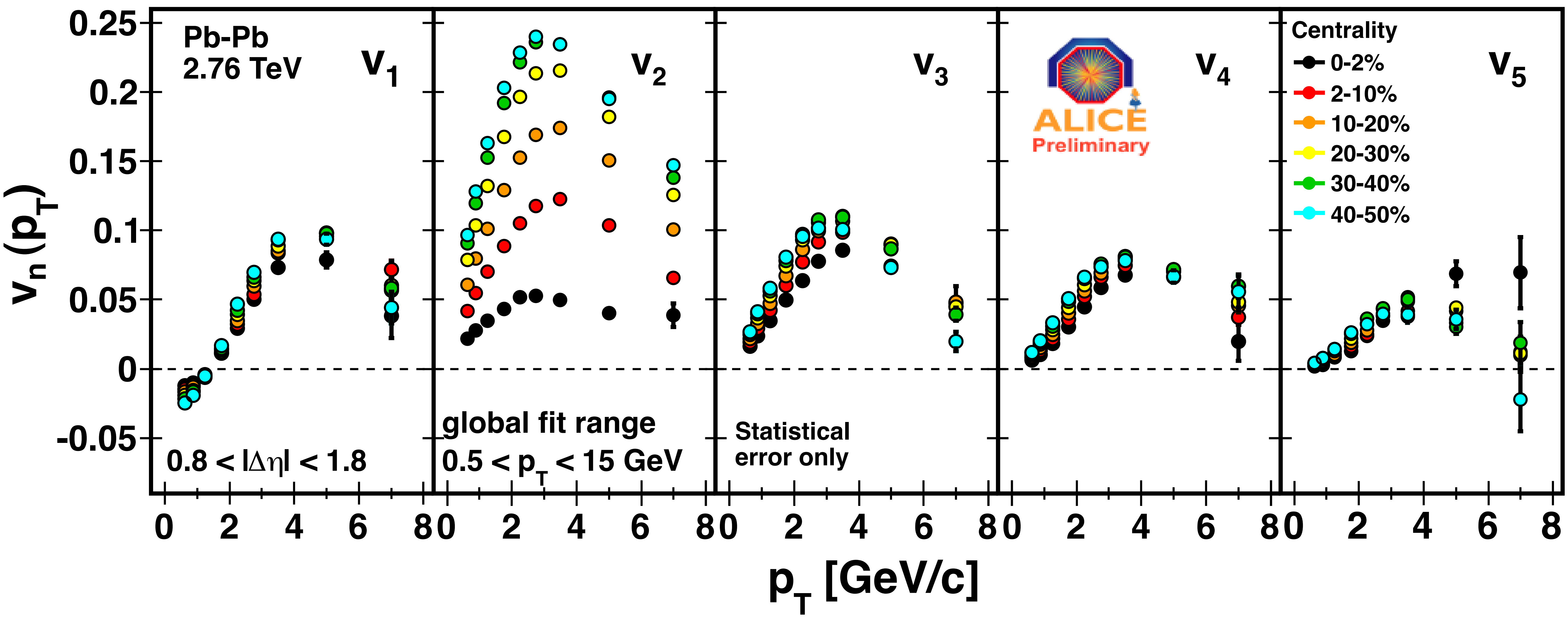




**Good description for central, low/intermediate $p_T$ correlations.**

**Not even close at high $p_T$, where away-side jet dominates.**

# Global fit results: $v_n$\{GF\} vs. $p_T$

## A new $v_n$ determination with high statistical precision




**Comparable magnitudes for central events**

**$v_2$ dominates in mid-central events - reflects collision geometry**

**For 0-2%, v3 > v2: natural description of away-side double hump**

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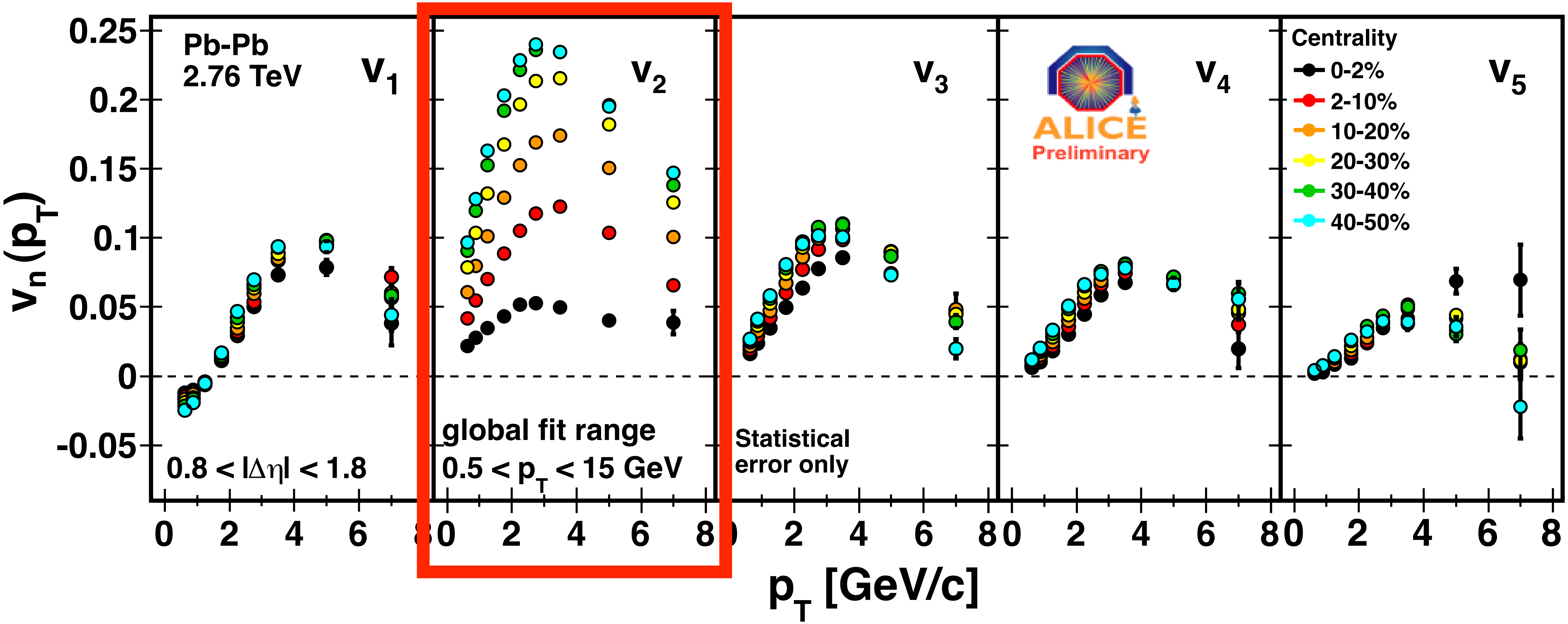


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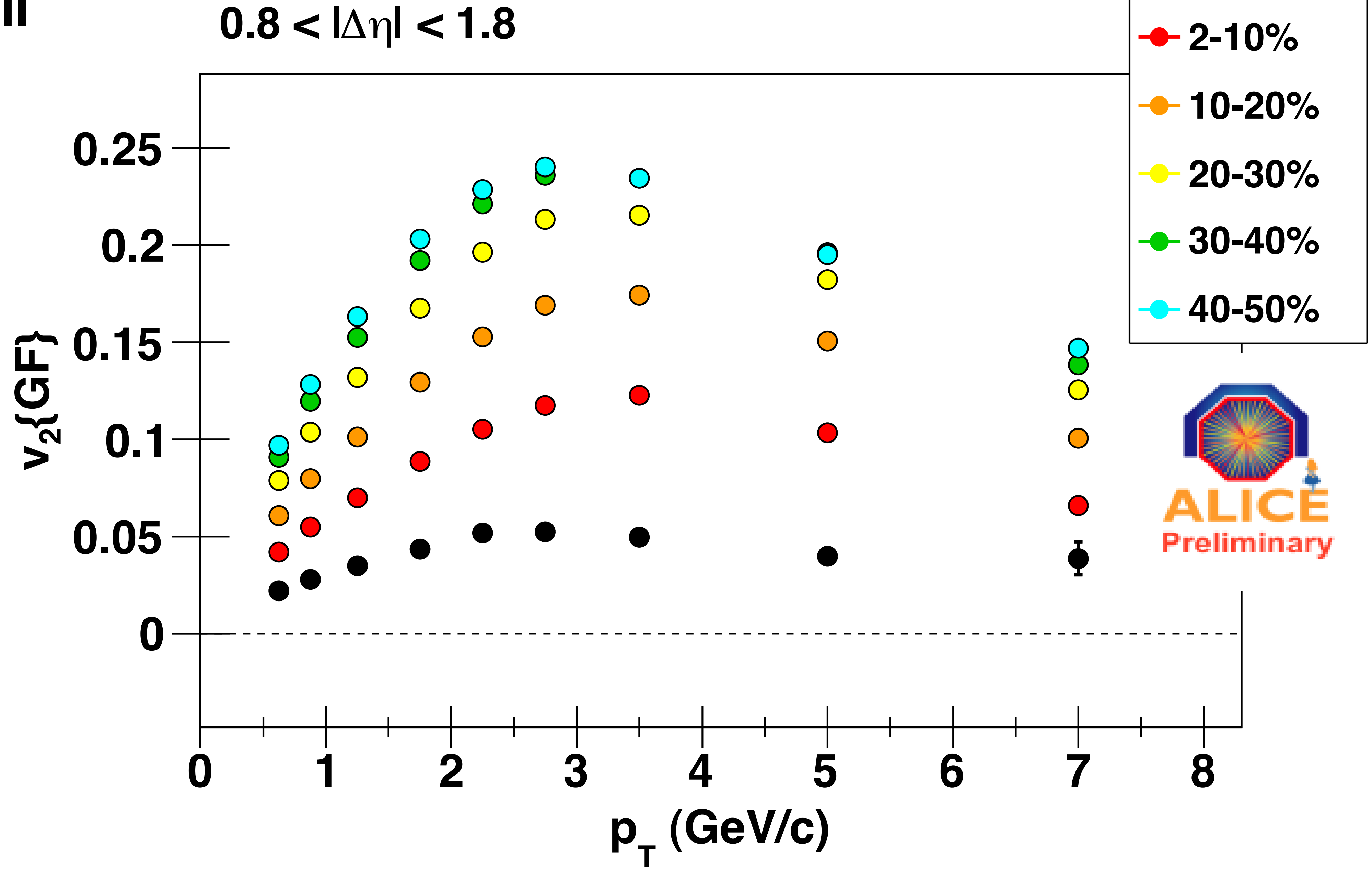
# Comparison with conventional $v_2$ results

$v_2${global fit} in more detail



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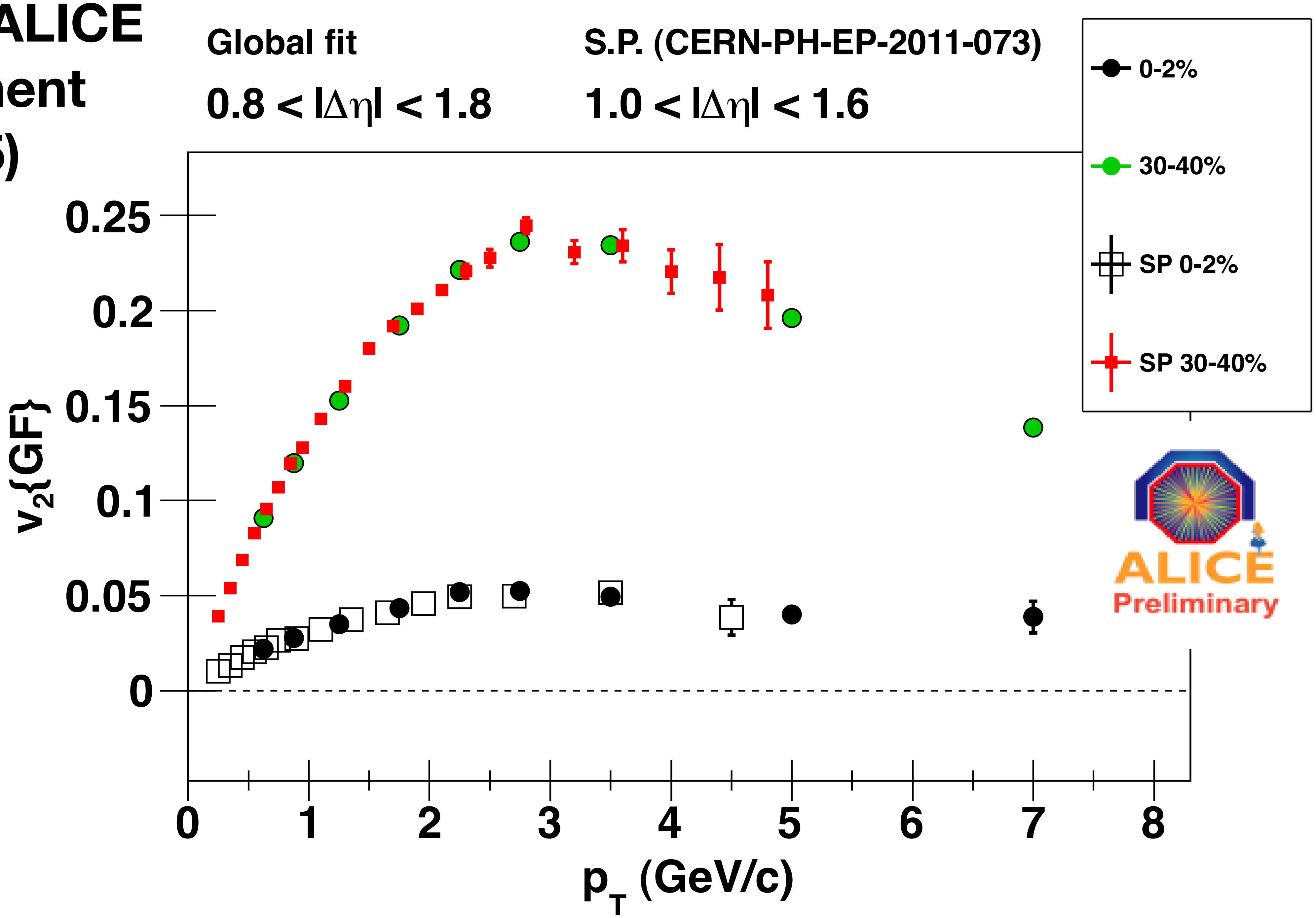
**With new ALICE measurement (1105.3865)**

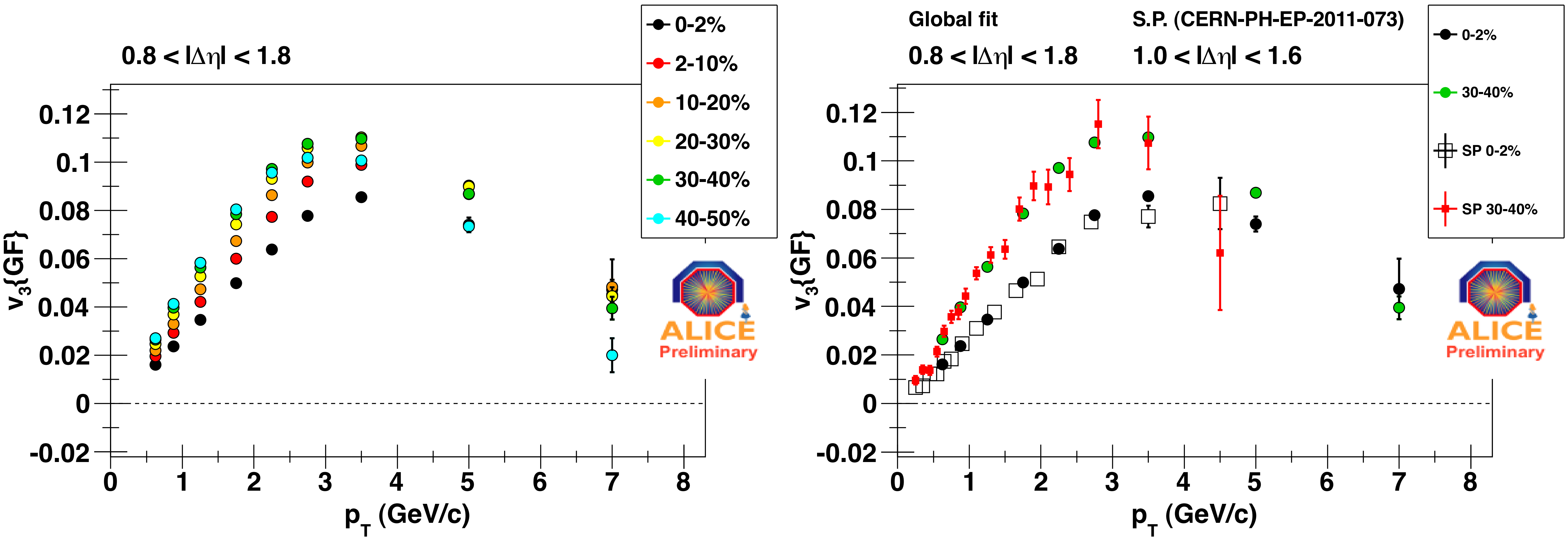



**Global fit gives excellent agreement with scalar-product method**

At moderate $p_T$, large $|\Delta\eta|$ correlations appear completely dominated by flow!

# Comparison with conventional $v_n$ results

## v3 also agrees closely!




## $v_3$ from large Δη correlations matches established flow methods

Great care is taken to control nonflow in scalar-product result

Hydro naturally describes the double hump--no need for conical emission

Agreement persists for $v_4$ and $v_5$.

# Yield modification: $I_{cp}$ and $I_{AA}$

**Compare $1/N_{trig}$ dN/dΔφ in Pb+Pb with:**

peripheral for Icp

p+p for $I_{AA}$

Integrate yields in selected Δφ range

Here, 0 (π) ± 0.7 for near (away) side

$$I_{AA}(p_{T,trig}; p_{T,assoc}) = \frac{Y^{AA}(p_{T,trig}; p_{T,assoc})}{Y^{pp}(p_{T,trig}; p_{T,assoc})}$$

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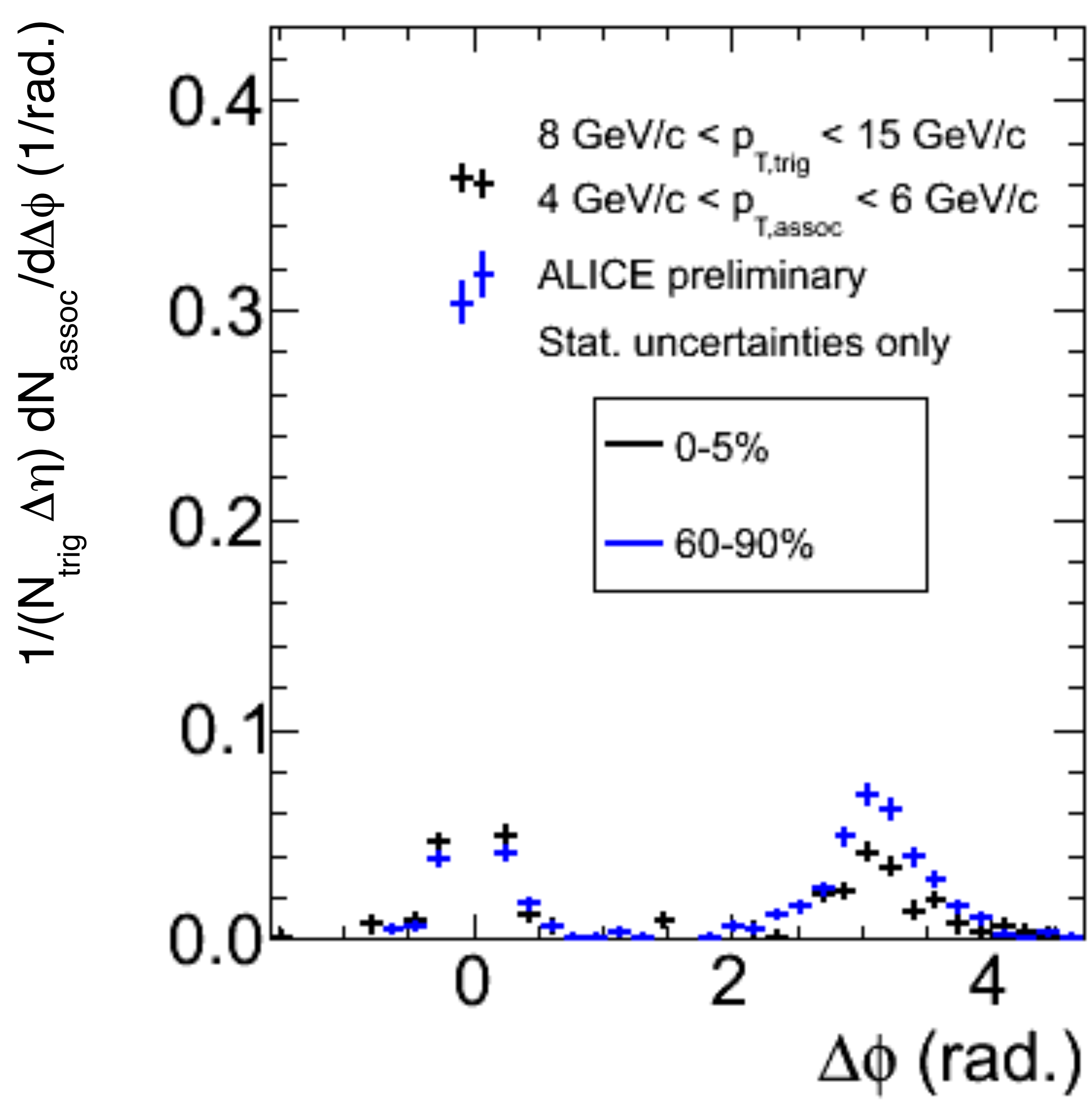
**Pb+Pb**

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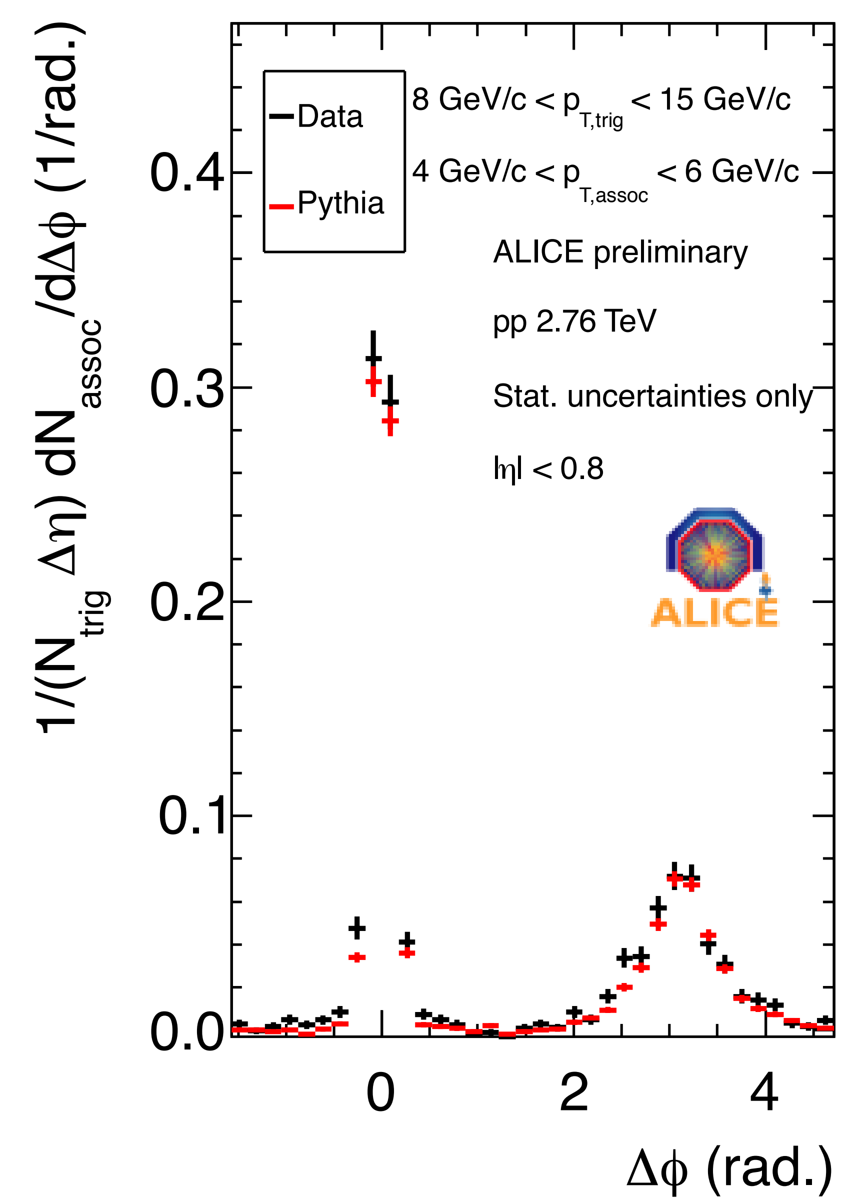

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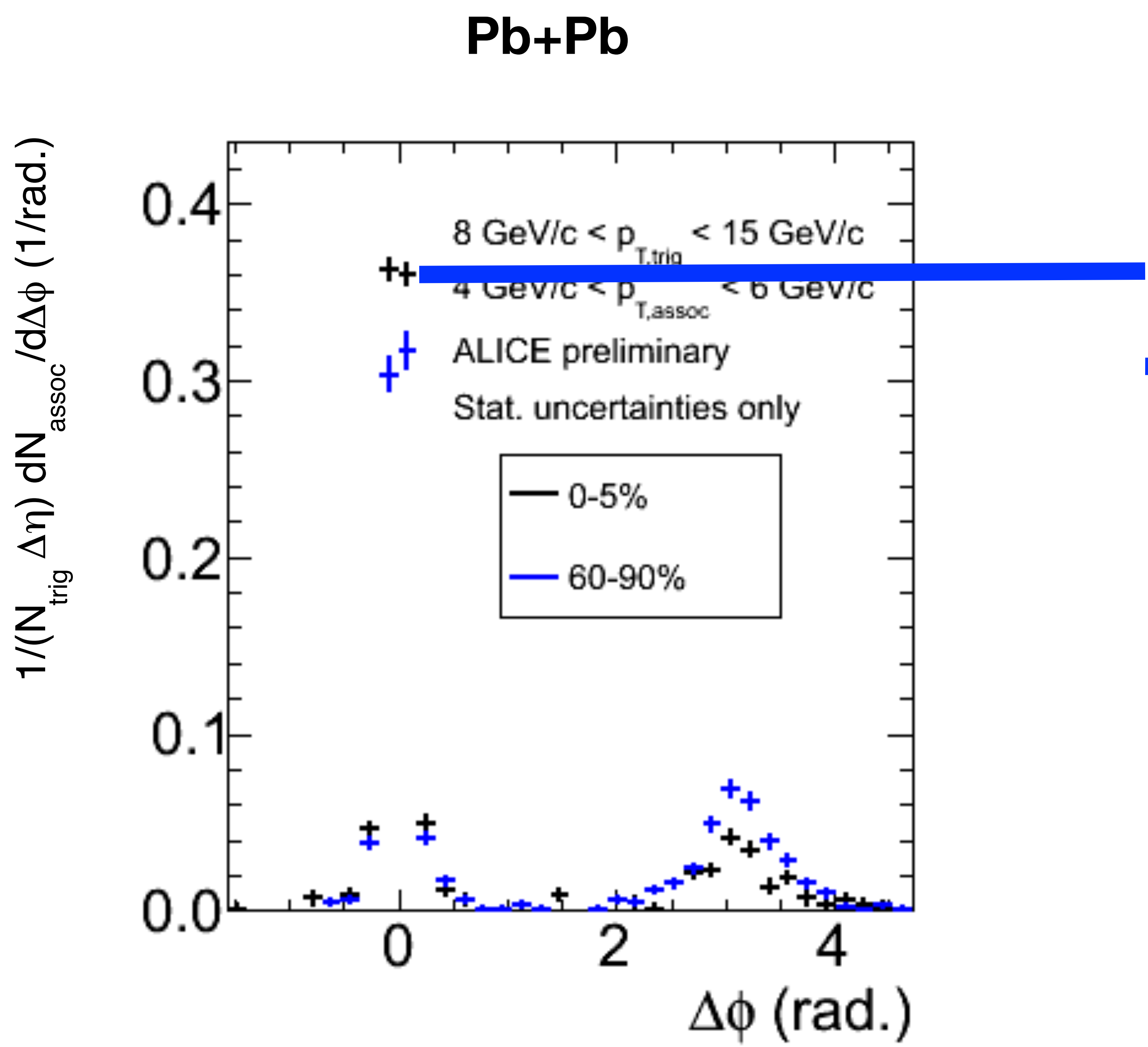


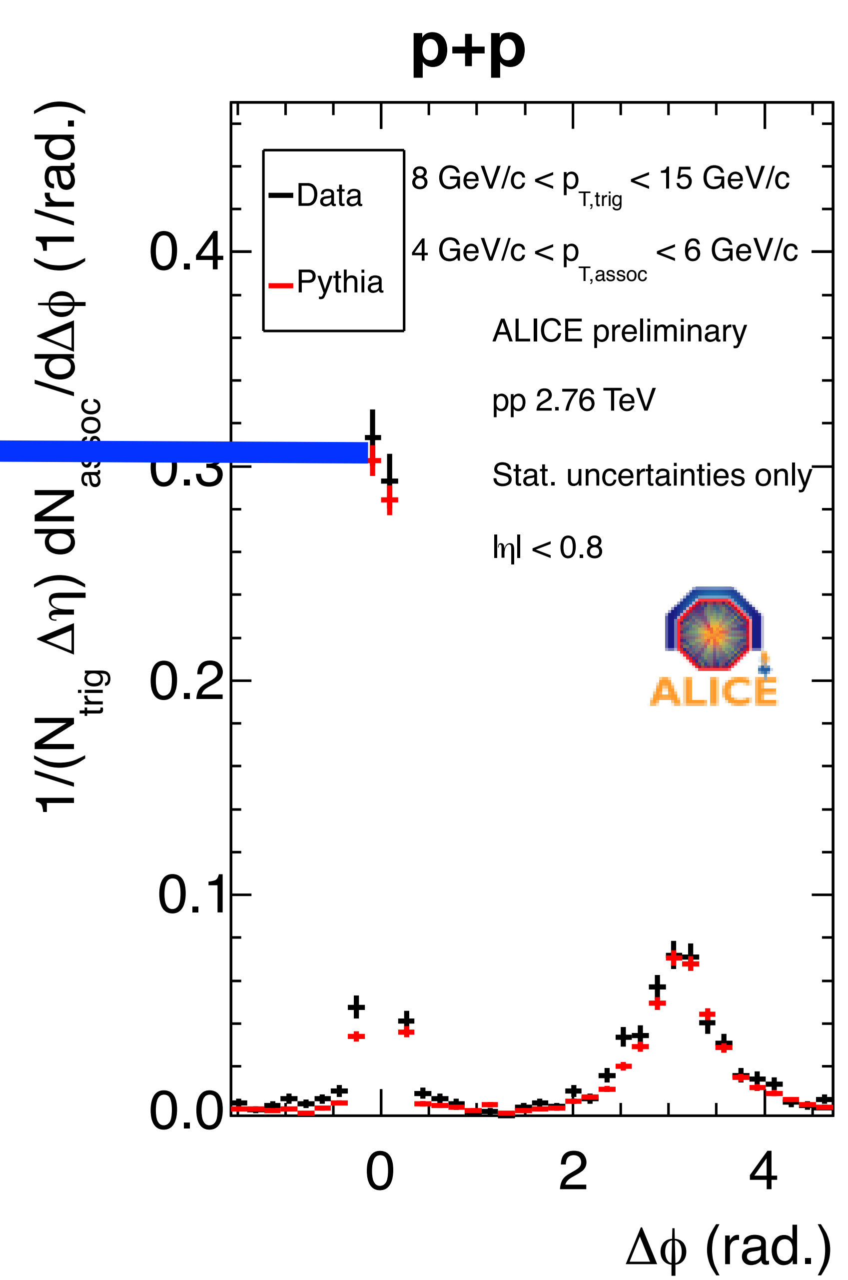

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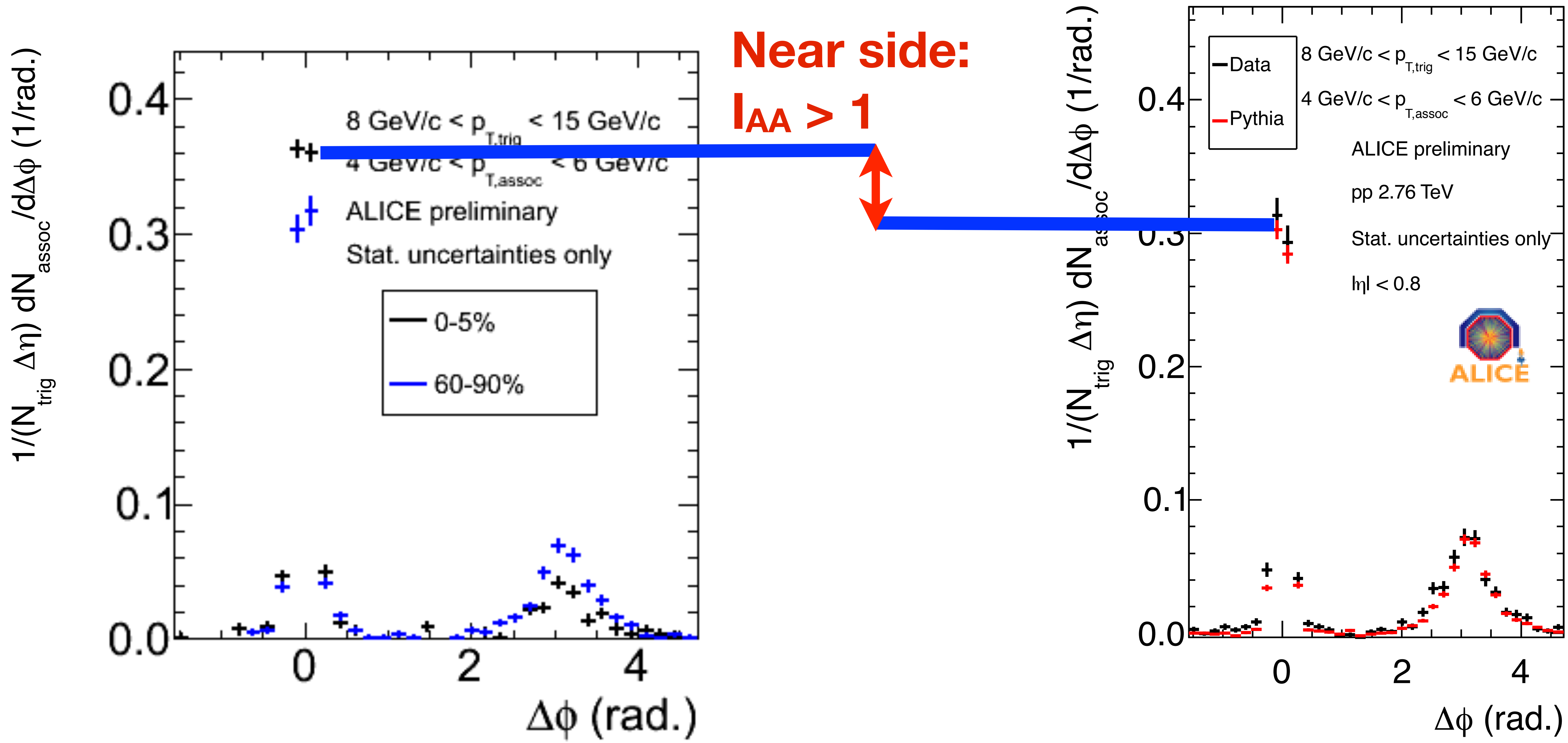
**Pb+Pb** **p+p**



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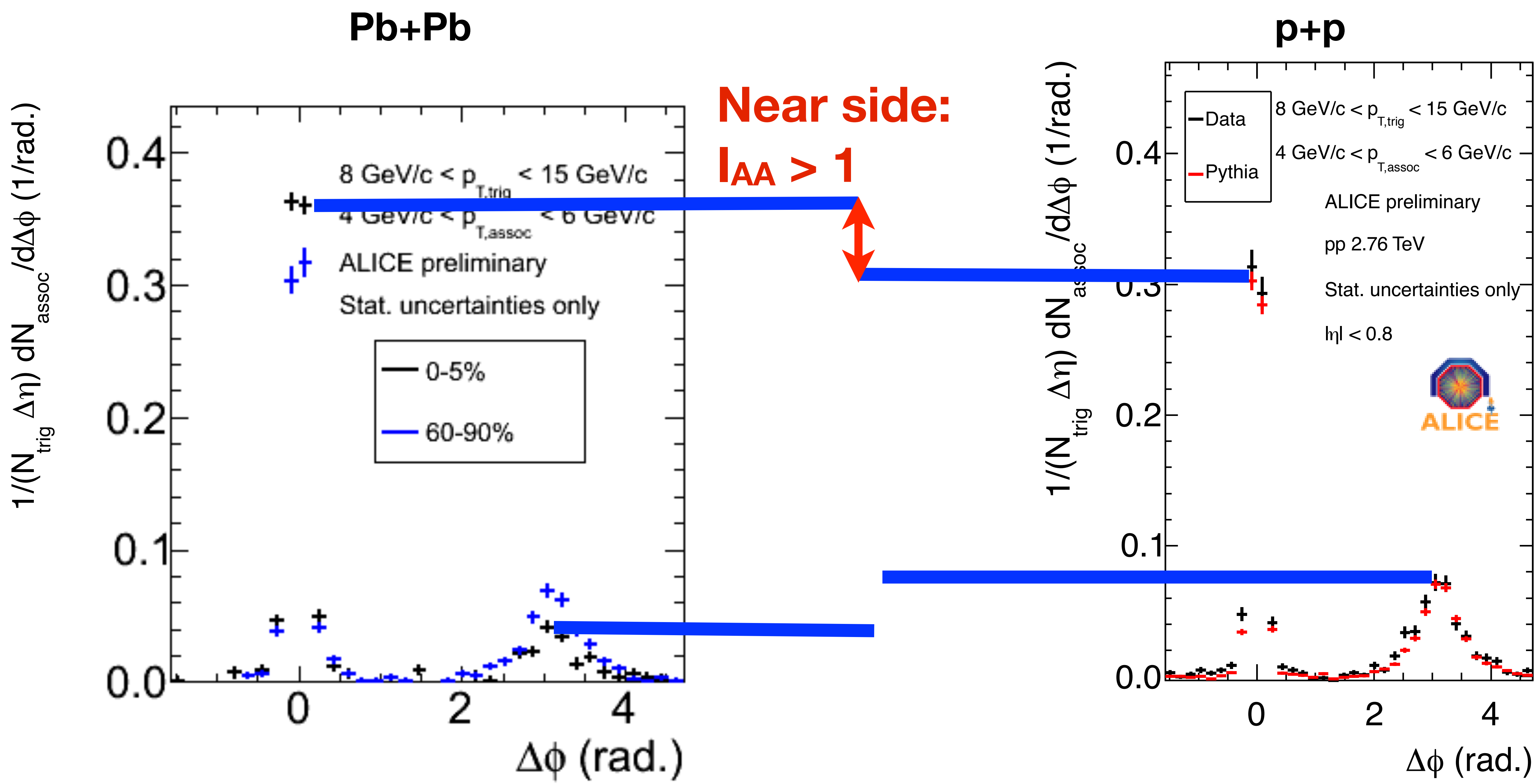
  - Integrate yields in selected Δφ range
    - Here, 0 (π) ± 0.7 for near (away) side

$$I_{AA}(p_{T,trig};p_{T,assoc}) = \frac{Y^{AA}(p_{T,trig};p_{T,assoc})}{Y^{pp}(p_{T,trig};p_{T,assoc})}$$

$$I_{CP}(p_{T,trig};p_{T,assoc}) = \frac{Y^{AA}_{central}(p_{T,trig};p_{T,assoc})}{Y^{AA}_{peripheral}(p_{T,trig};p_{T,assoc})}$$



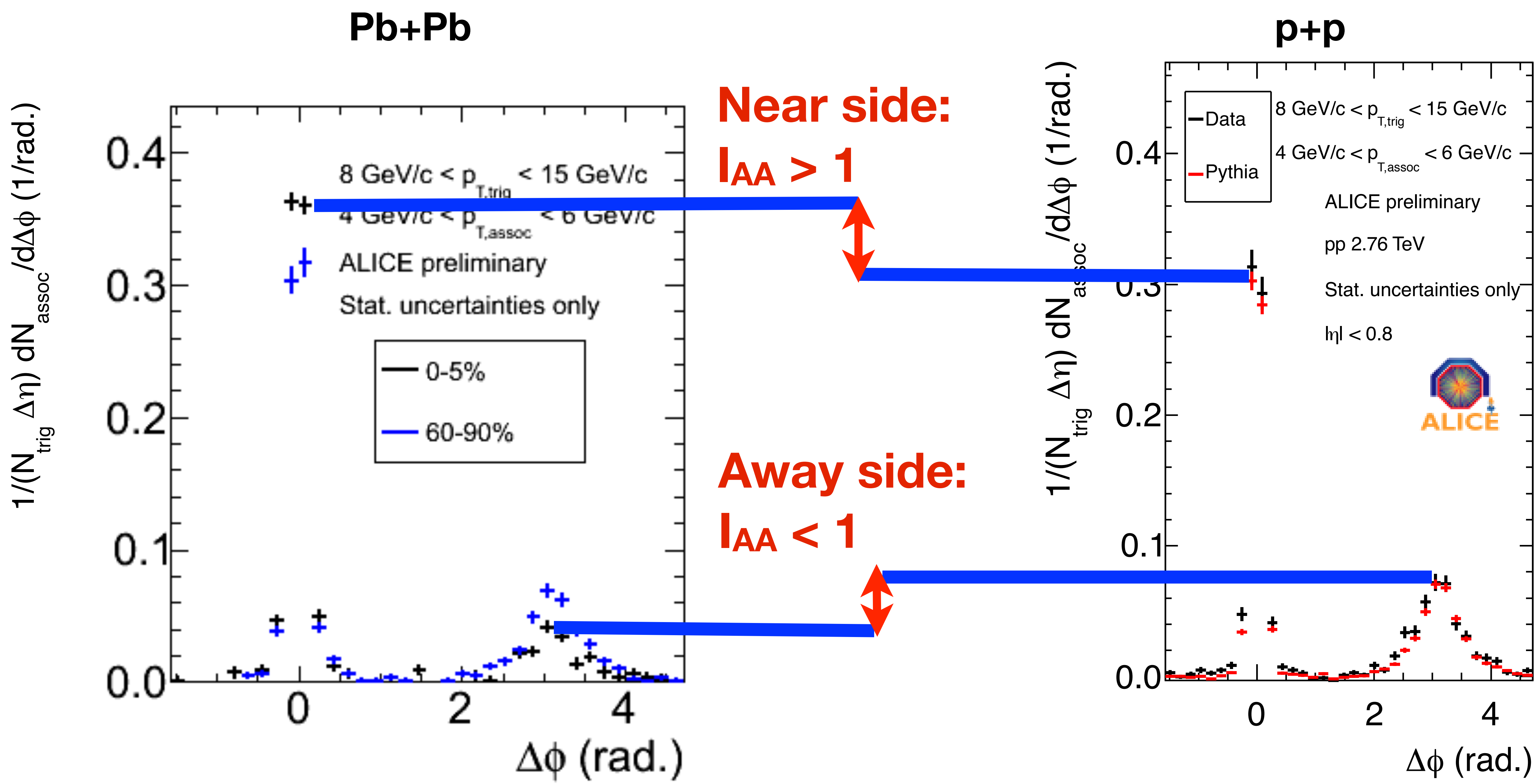
# Yield modification: $I_{cp}$ and $I_{AA}$

**Compare $1/N_{trig}\, dN/d\Delta\varphi$ in Pb+Pb with:**

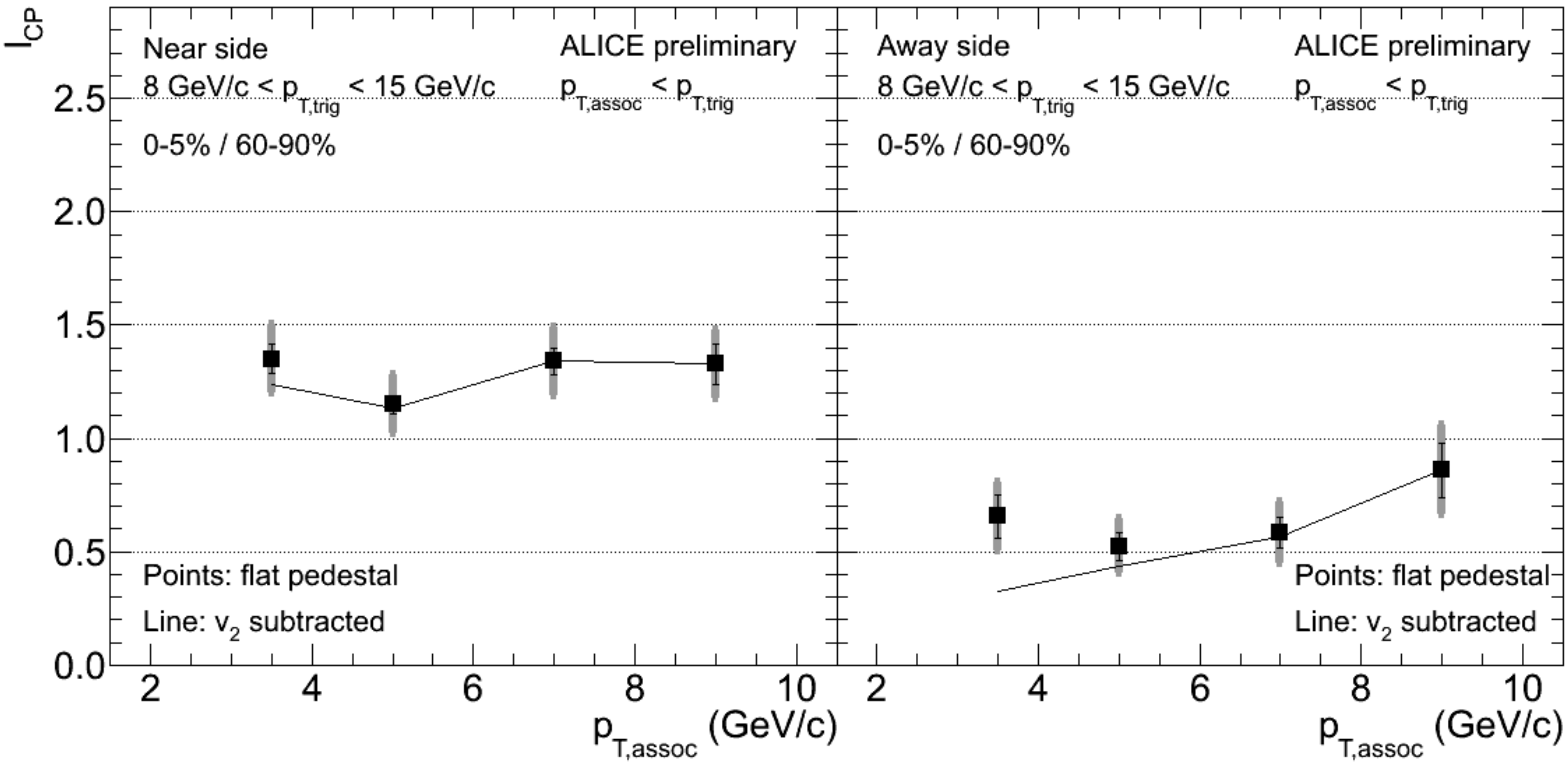
- peripheral for Icp
- p+p for $I_{AA}$
  - Integrate yields in selected Δφ range
    - Here, 0 (π) ± 0.7 for near (away) side

$$I_{AA}(p_{T,trig}; p_{T,assoc}) = \frac{Y^{AA}(p_{T,trig}; p_{T,assoc})}{Y^{pp}(p_{T,trig}; p_{T,assoc})}$$

$$I_{CP}(p_{T,trig}; p_{T,assoc}) = \frac{Y^{AA}_{central}(p_{T,trig}; p_{T,assoc})}{Y^{AA}_{peripheral}(p_{T,trig}; p_{T,assoc})}$$



# $I_{CP}$ on near and away side



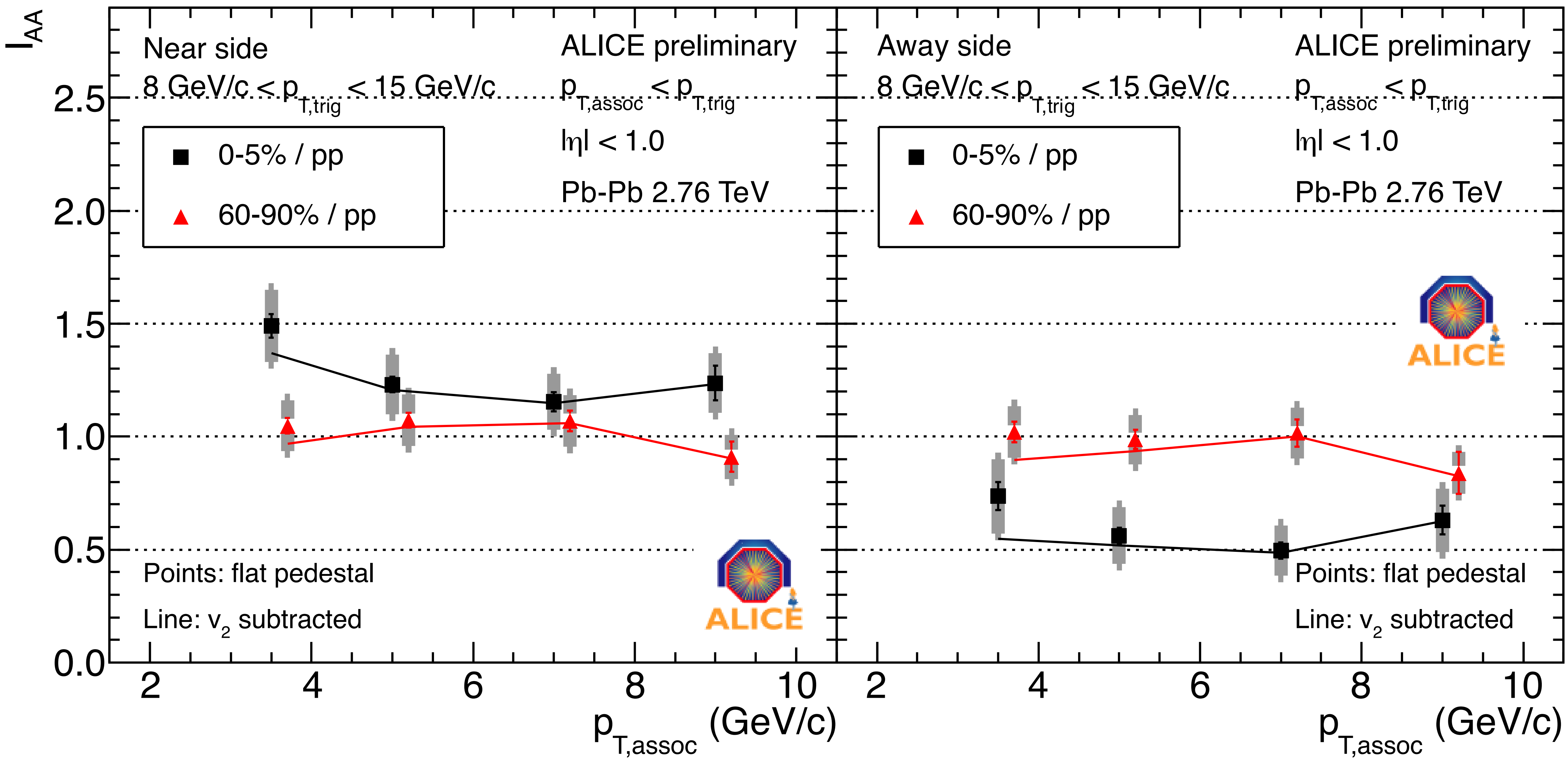

**Enhancement on near side, suppression on away side**

**Flat or $v_2$-only bkg. assumptions give same results above 5 GeV**

**Away side $I_{AA}$ ~ 0.6 at intermediate $p_T$**

**Note on rise at last point: $p_{T,\,trig} > p_{T,\,assoc}$ requirement in overlapping $p_T$ bin influences kinematics: interpret with care.**

# $I_{AA}$ at 2.76 TeV




## Observations

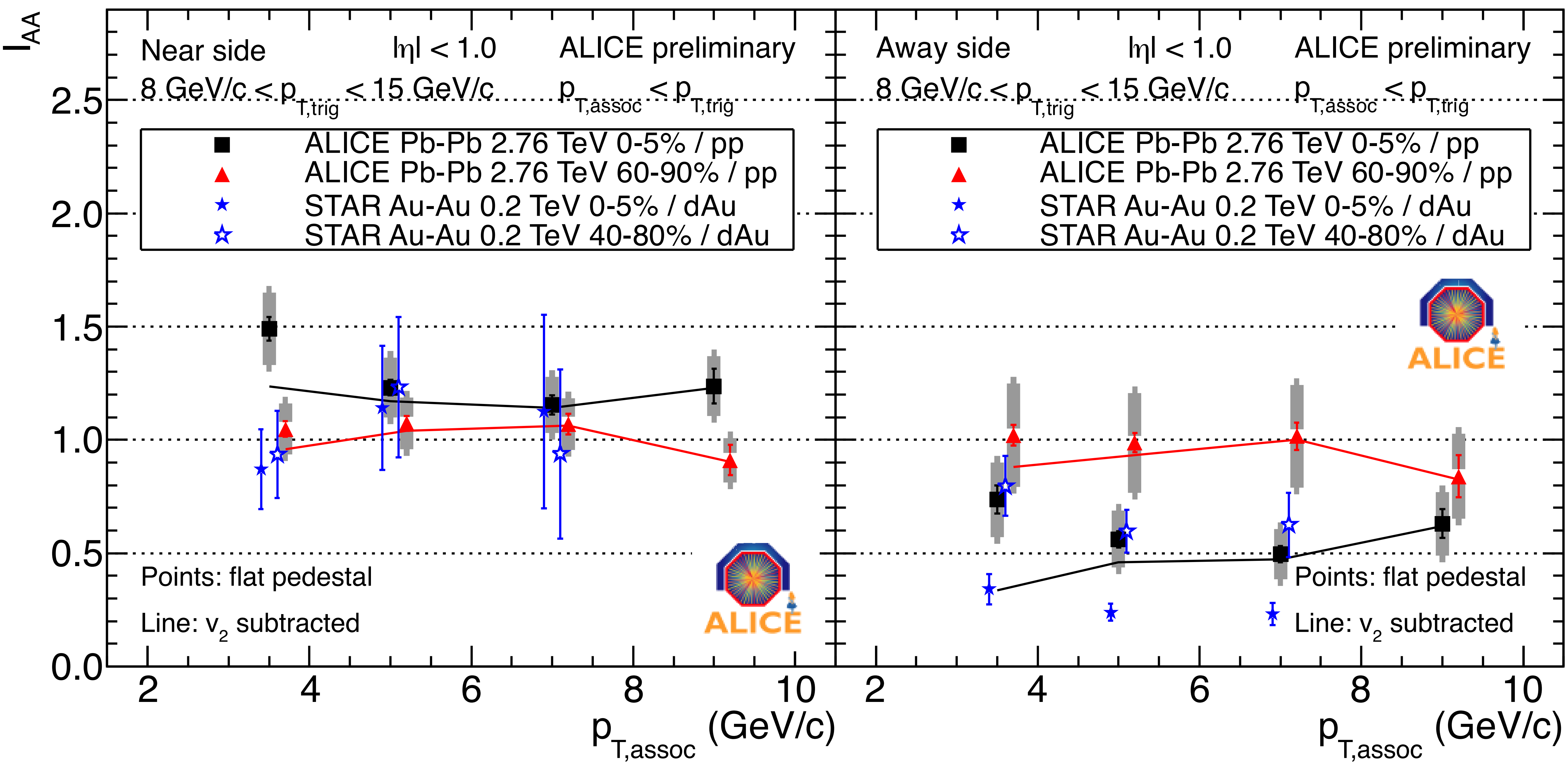
**Near side yields enhanced by 1.2-1.3 for $p_{T,\,assoc}$ > 3 GeV/c in central events**

**Some peripheral data consistent with 1**

**Away side 0.5-0.6 for central, ~1 for peripheral**

# RHIC comparison

## $I_{AA}$ consistent with STAR on both near and away side



# In summary:

**Ultracentral 2-peak away-side structure**

Fully described by Fourier moments

No need to invoke conical emission

**Long-range anisotropy**

Low pt: fully consistent w/ std. flow techniques

High pt: break from collective behavior -->Recoil jet

**First LHC $I_{AA}$, $I_{CP}$**

Near side: moderate enhancement

Away-side: significant suppression

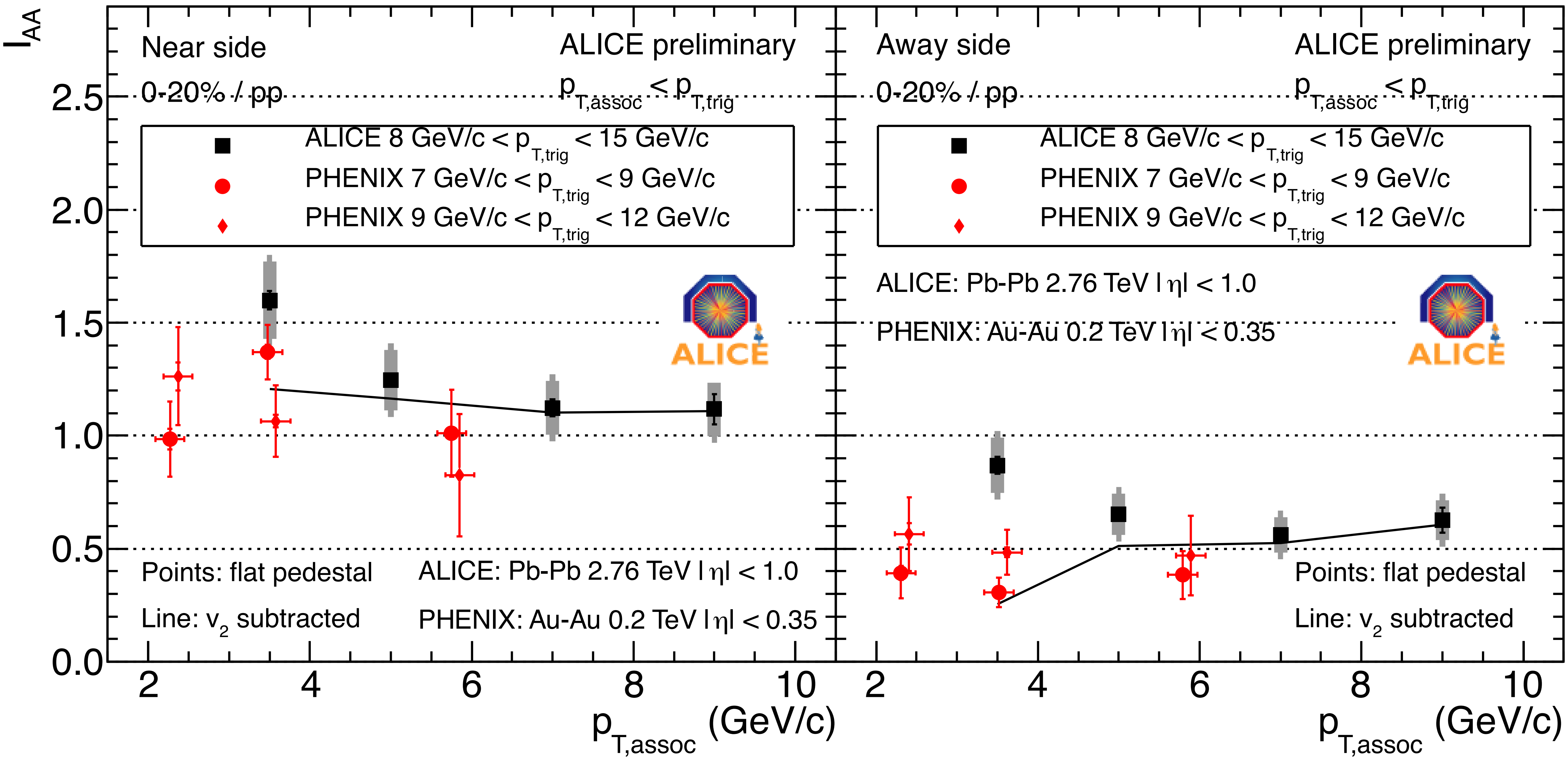
Consistent with RHIC

# Backups

# PHENIX comparisons

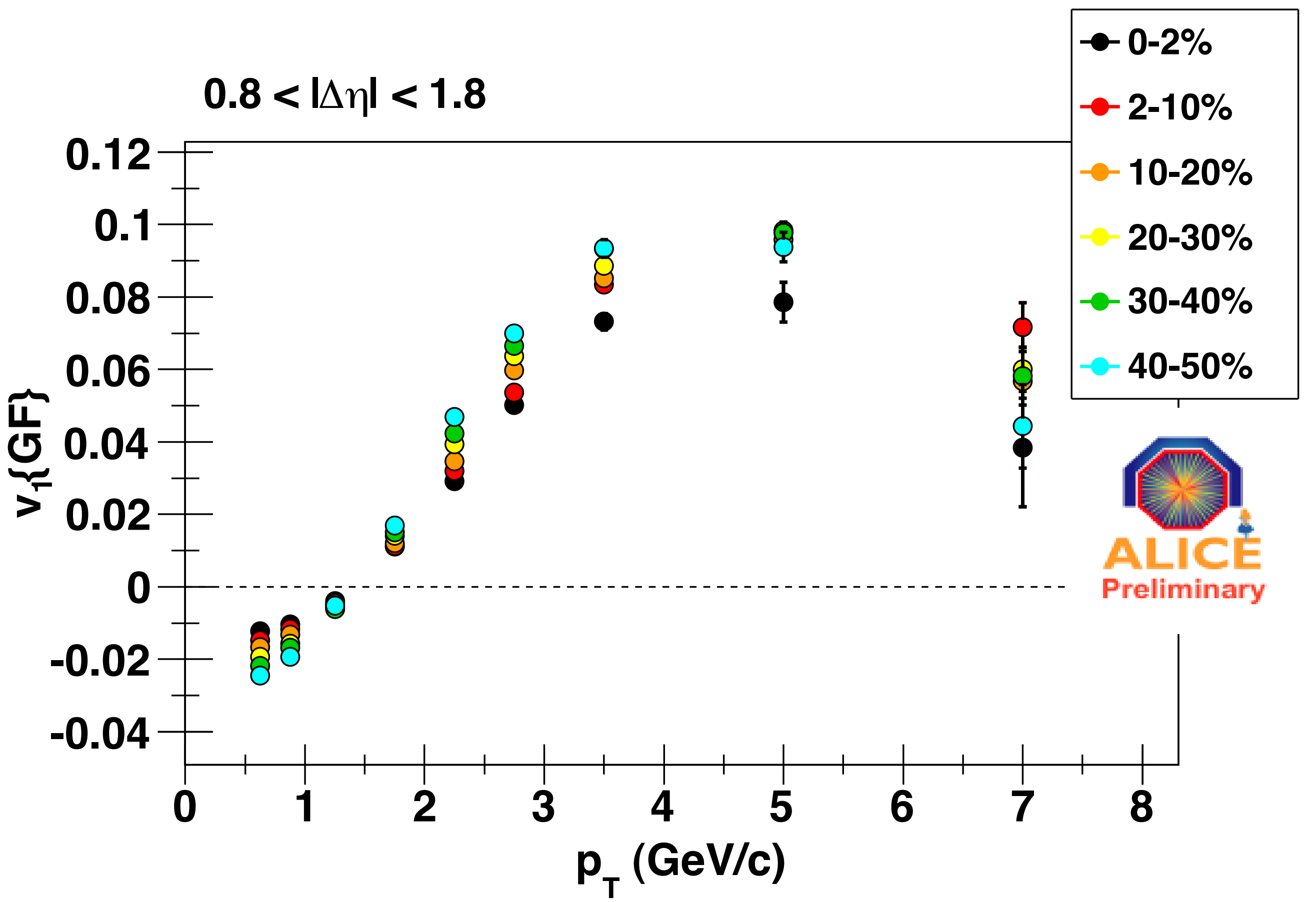
## $I_{AA}$ moderately higher than in PHENIX

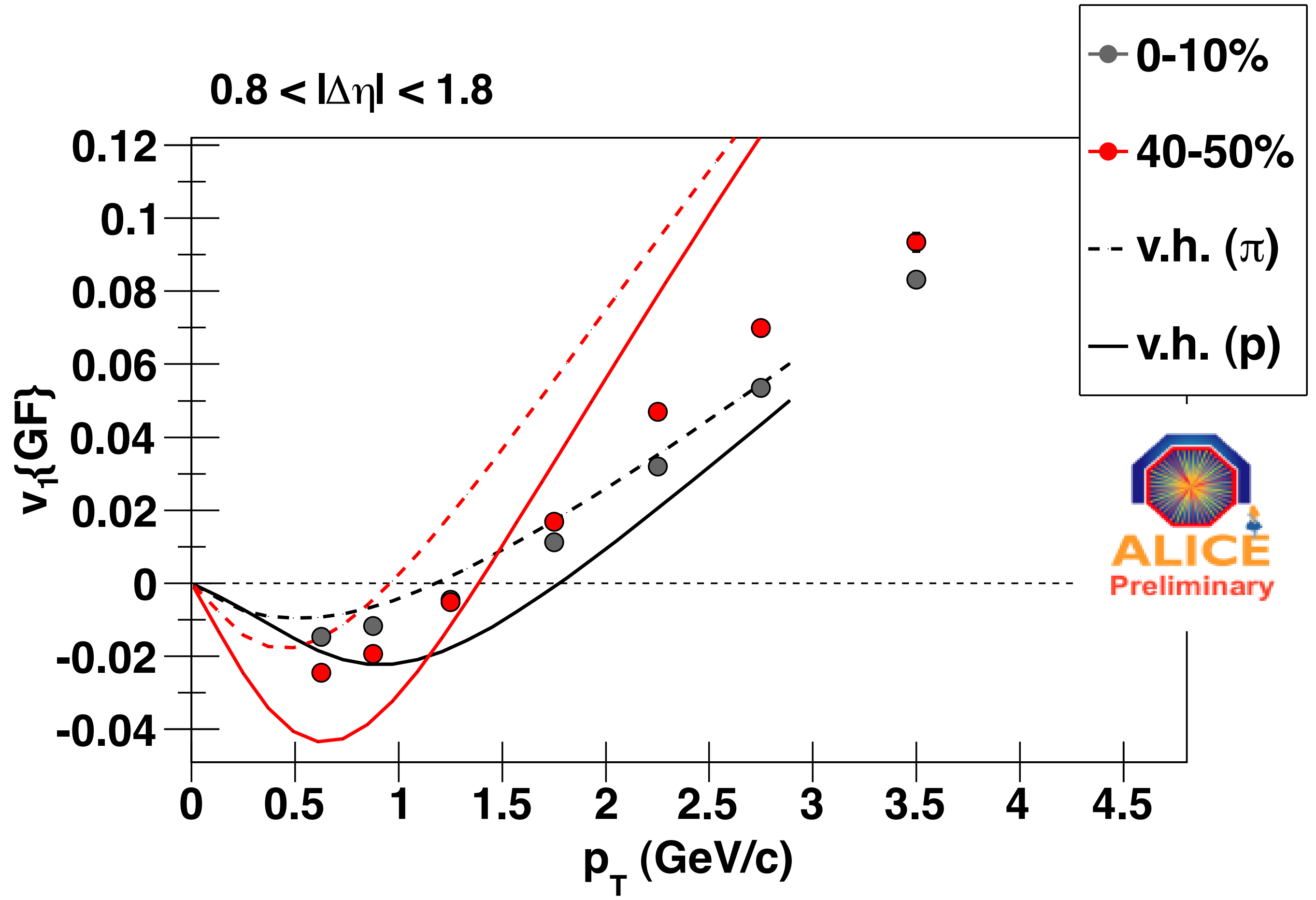
**With limited statistical significance**



# $v_1\{GF\}$ with $v_1$ hydro prediction

Very interesting, unfortunately no time




## Viscous hydro model by M. Luzum

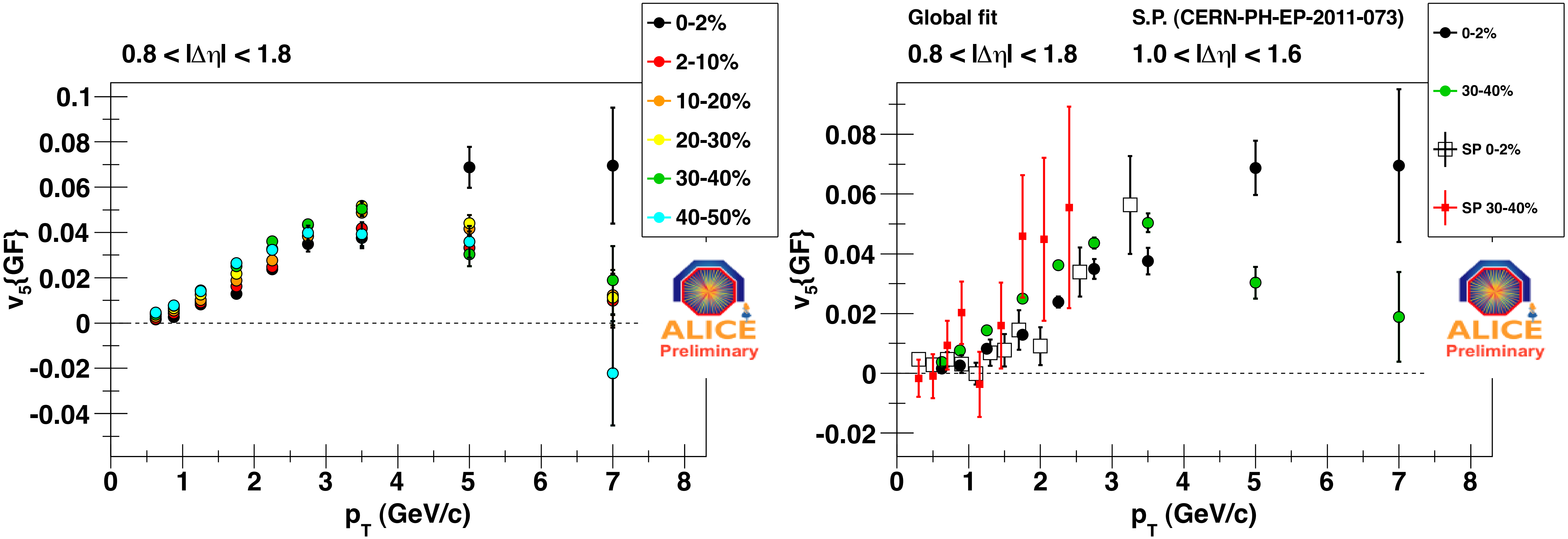
Calculation from same framework as $v_3$ result (arXiv:1007.5469)

η/s = 0.08 for π, K (not shown), p using PHOBOS Glauber ICs

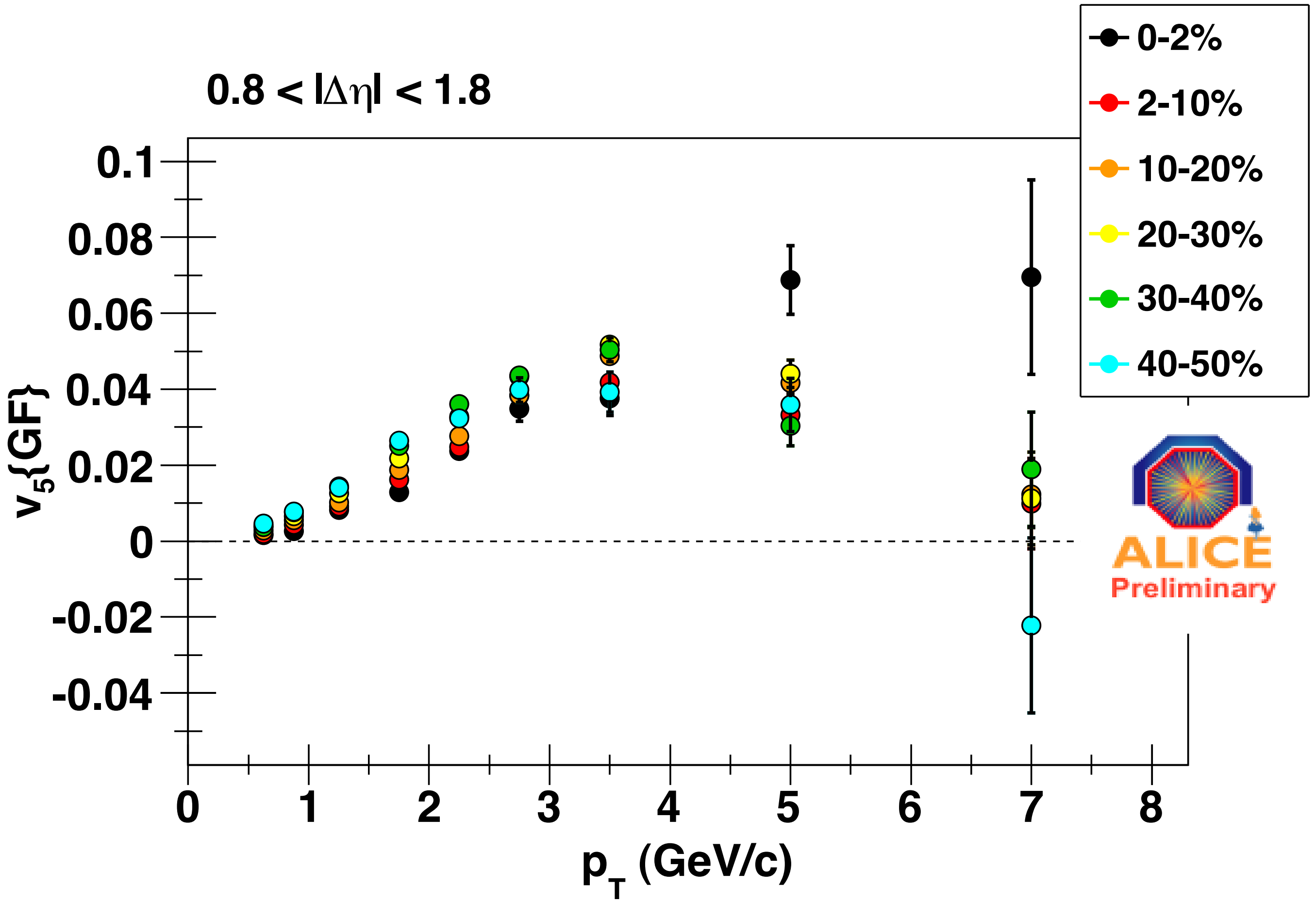
Good agreement for central data, less so for mid-central

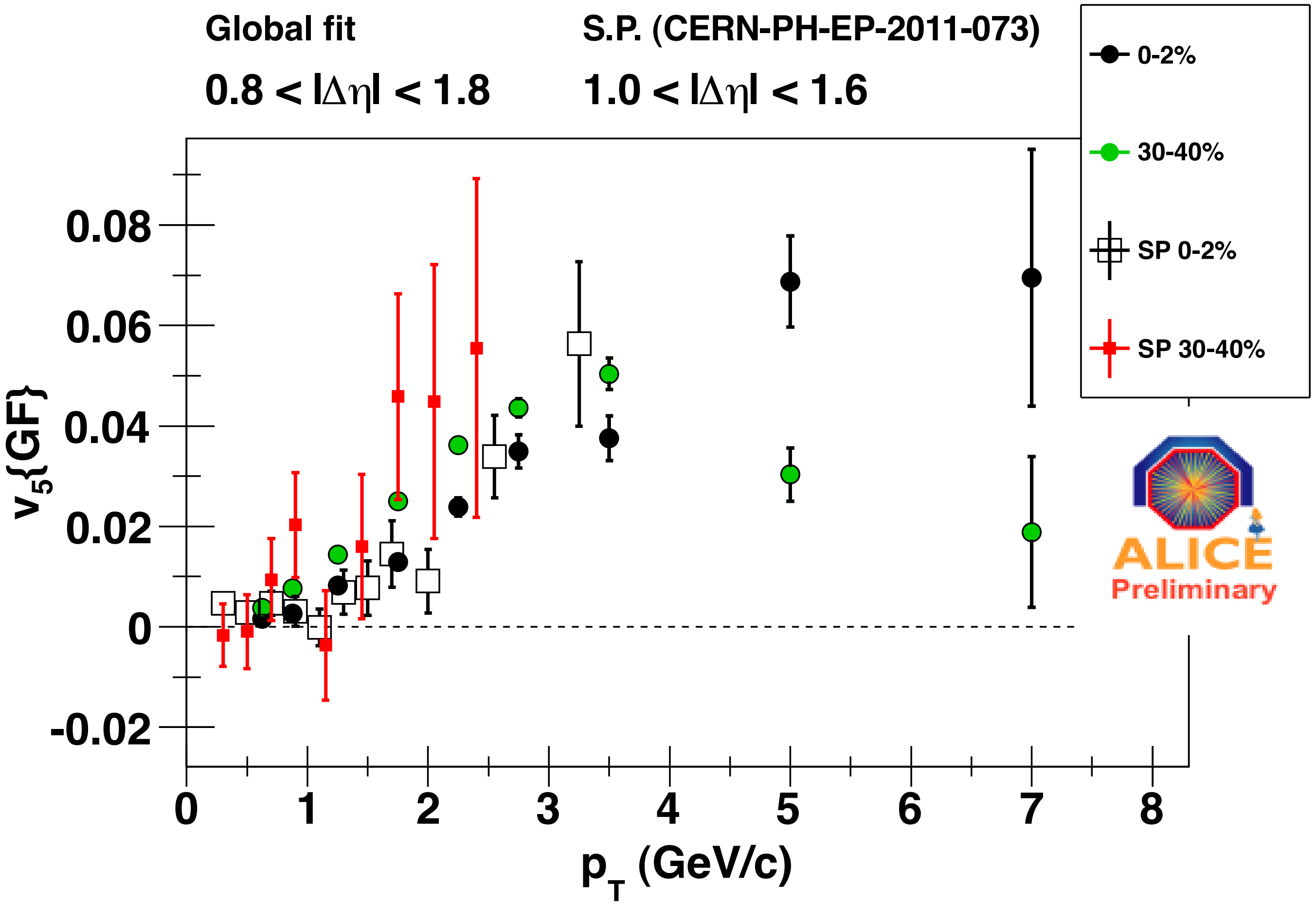
Note: global fit includes particles only above 0.5 GeV, model uses all pt

# $v_4$\{GF\}

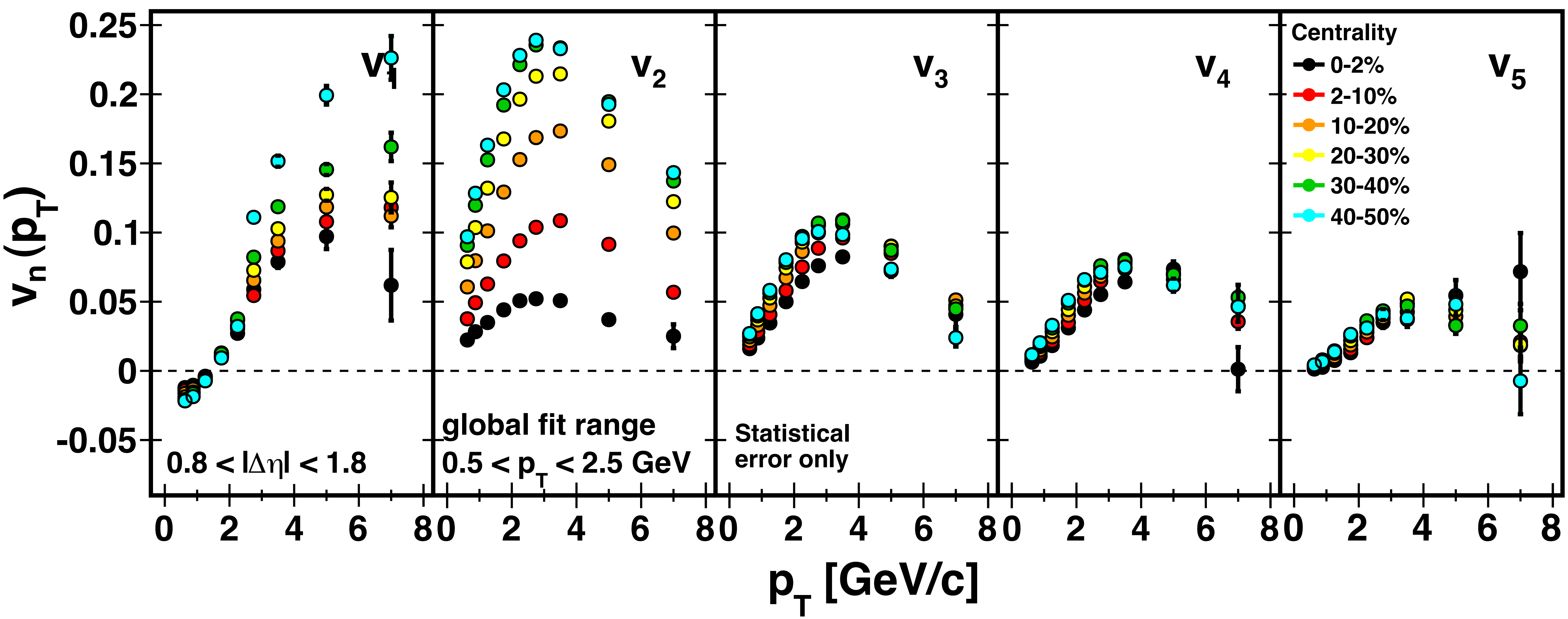

0.8 < |Δη| < 1.8
0-2%
2-10%
10-20%
20-30%
30-40%
40-50%
ALICE
Preliminary
v5{GF}
pT (GeV/c)
Global fit
0.8 < |Δη| < 1.8
S.P. (CERN-PH-EP-2011-073)
1.0 < |Δη| < 1.6
0-2%
30-40%
SP 0-2%
SP 30-40%
ALICE
Preliminary
v5{GF}
pT (GeV/c)

# $v_5\{GF\}$


0.8 < |Δη| < 1.8
0-2%
2-10%
10-20%
20-30%
30-40%
40-50%
v5{GF}
pT (GeV/c)
ALICE
Preliminary


Global fit
0.8 < |Δη| < 1.8
S.P. (CERN-PH-EP-2011-073)
1.0 < |Δη| < 1.6
0-2%
30-40%
SP 0-2%
SP 30-40%
v5{GF}
pT (GeV/c)
ALICE
Preliminary

# What if the high-$p_T$ points are excluded?

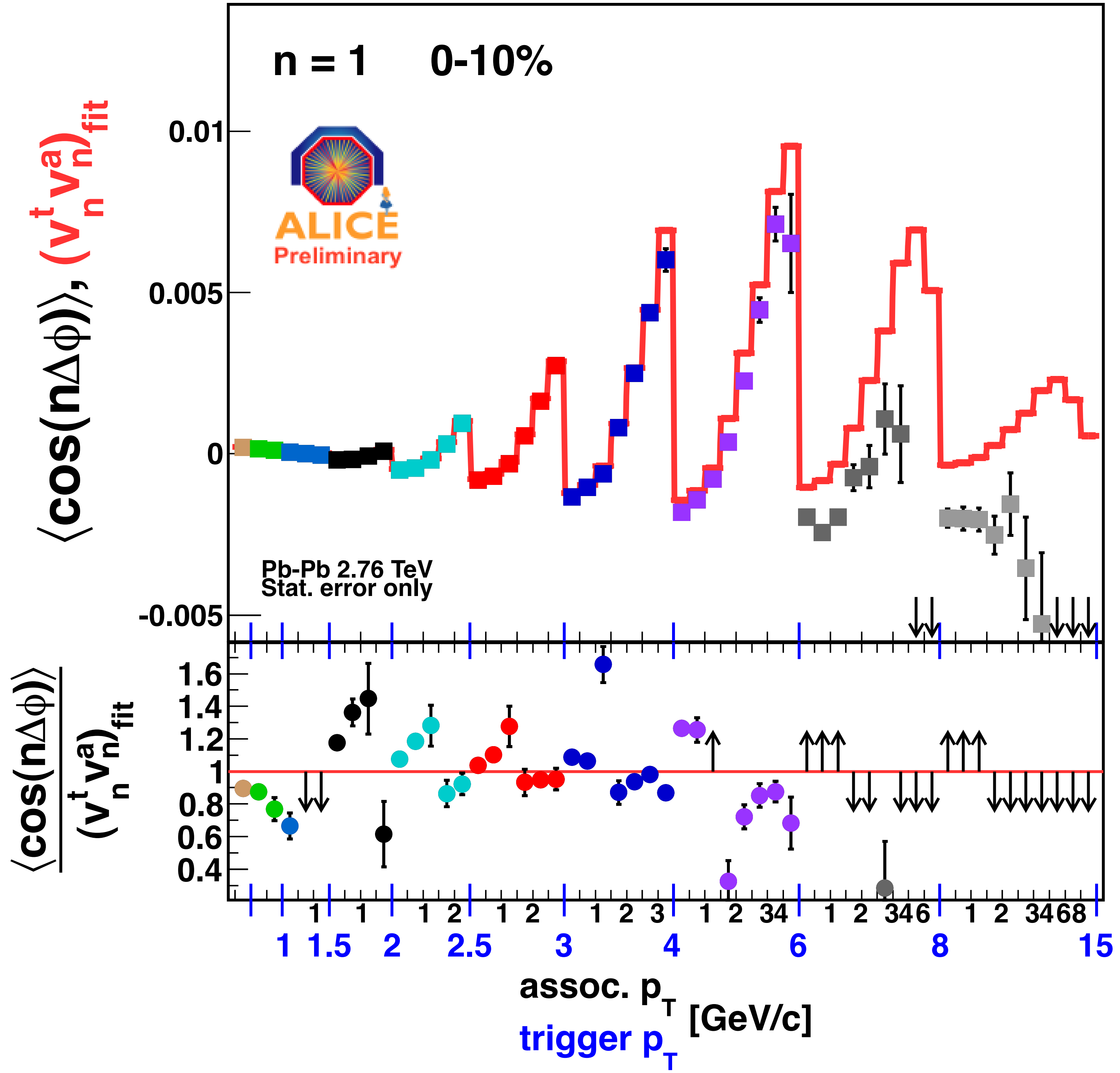


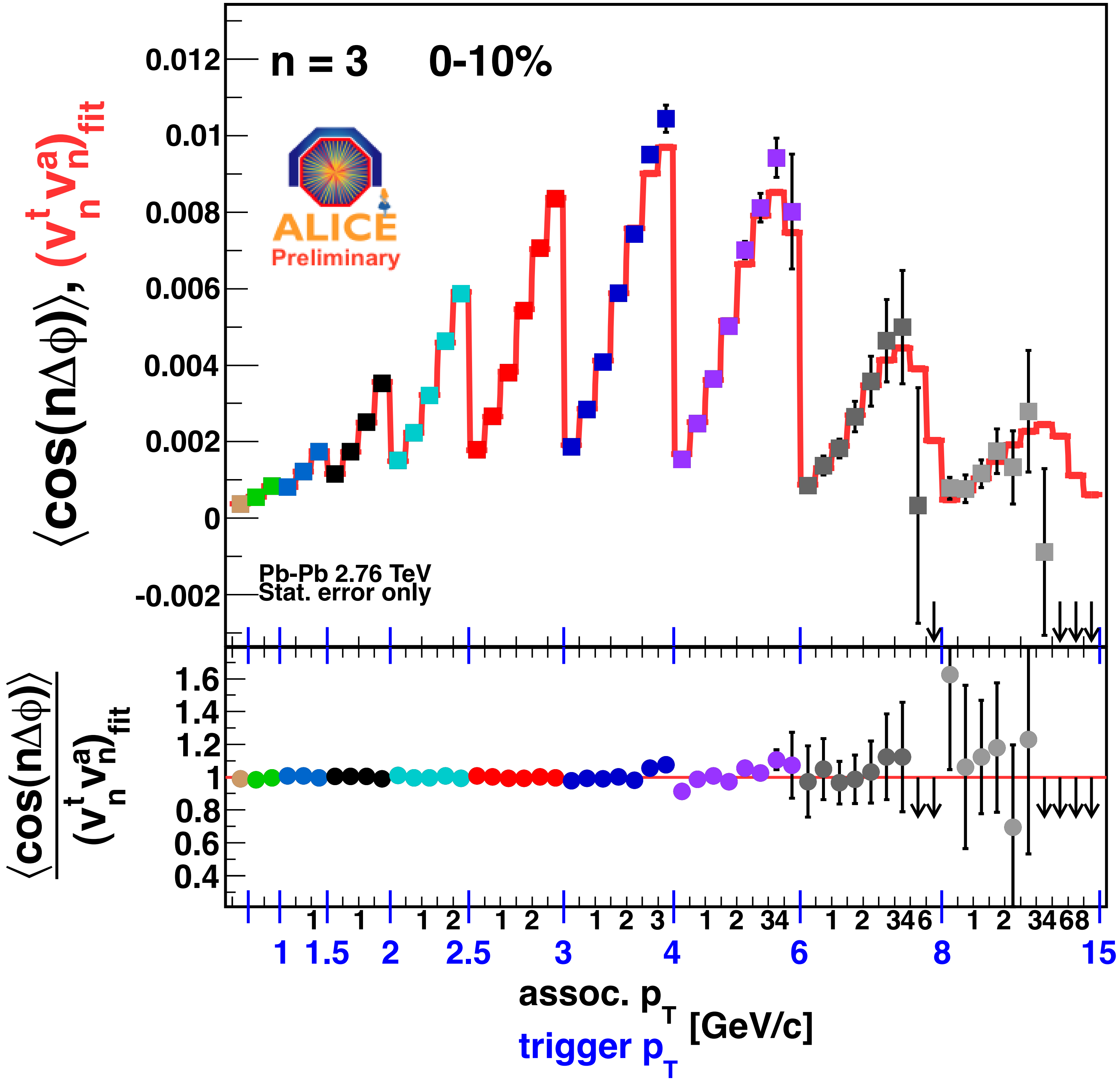

**Here, information from pt < 2.5 GeV/c is used to constrain the fit.**

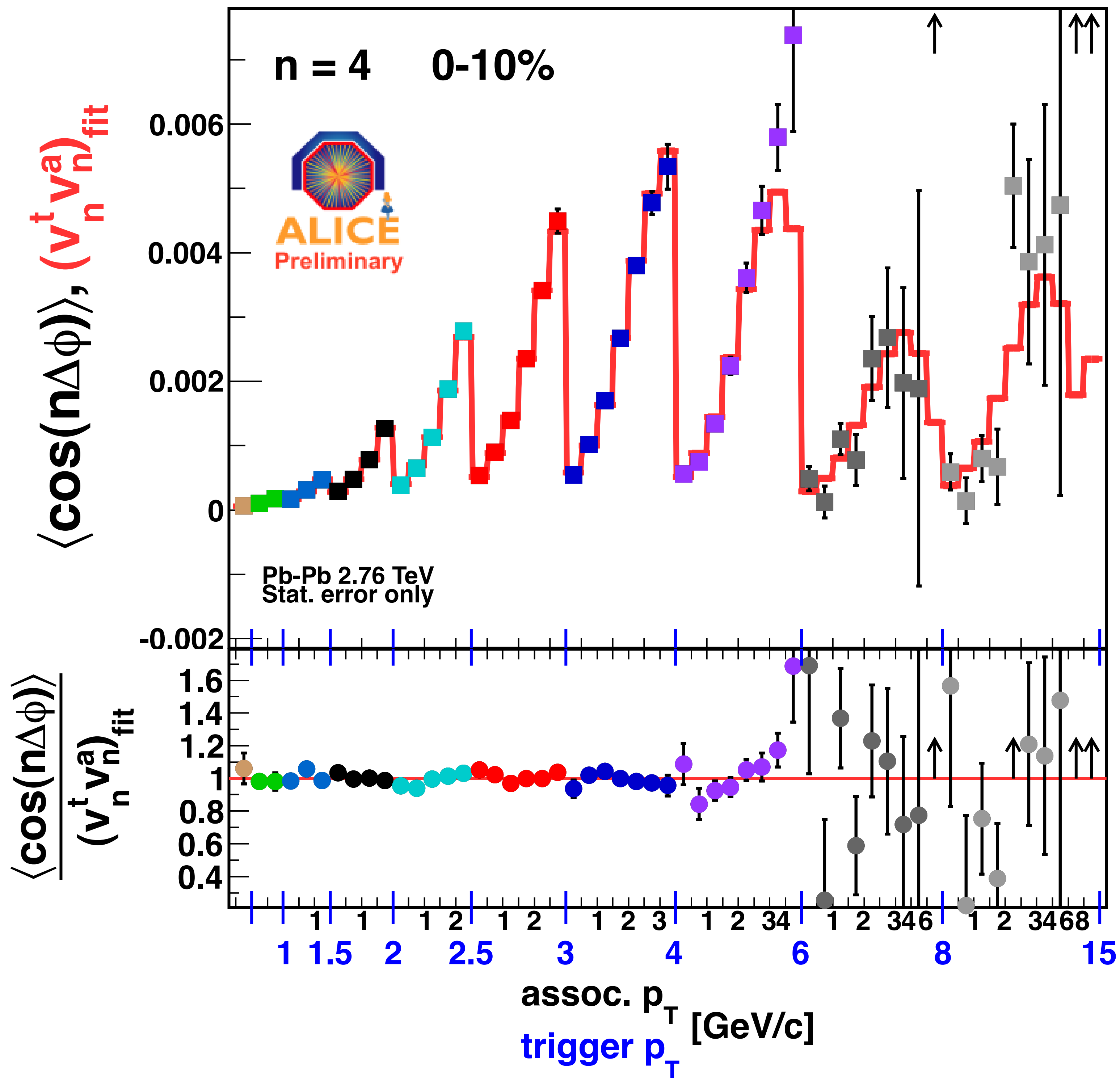
**v2-v5 only weakly affected**

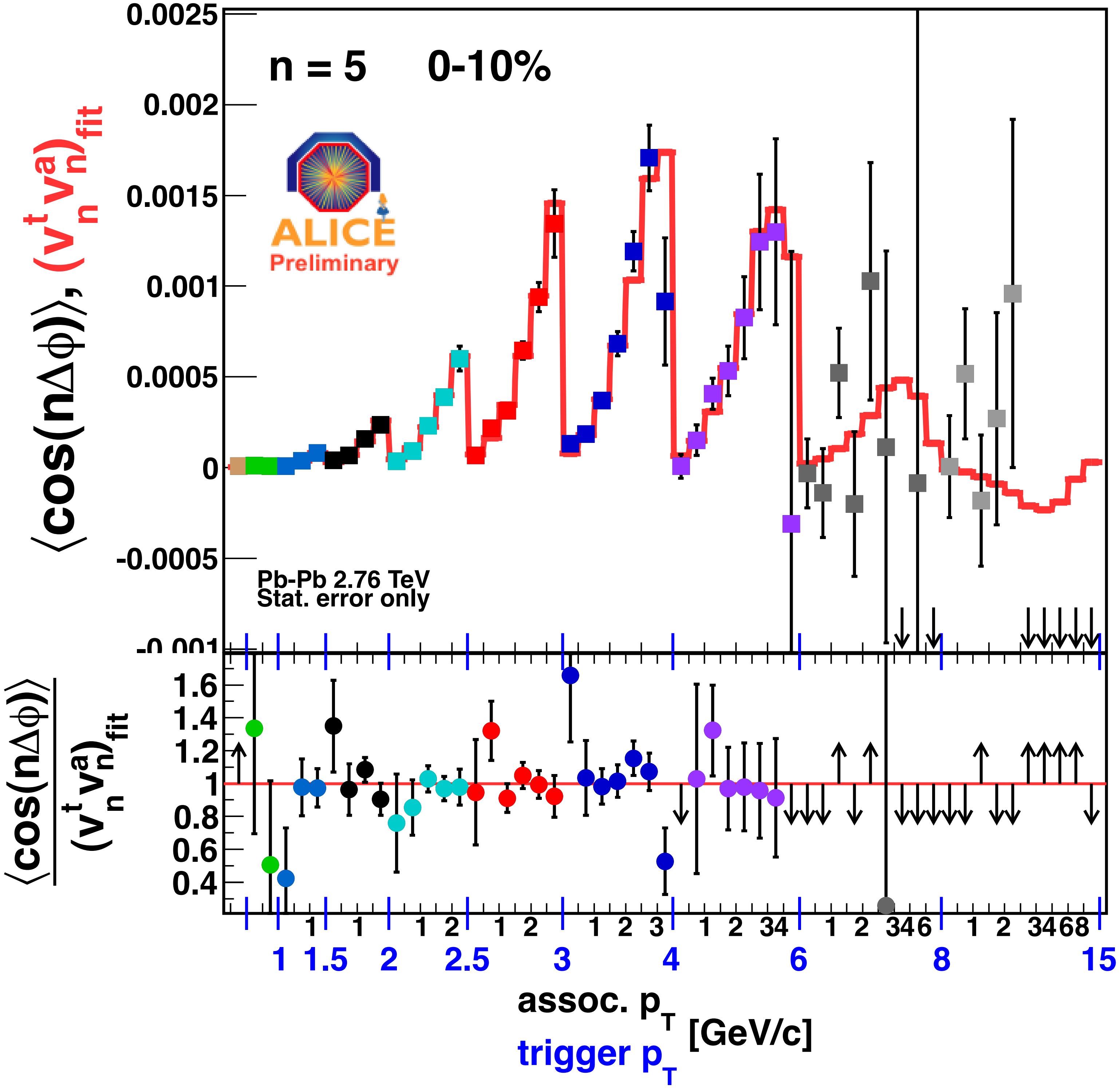
**v1 rises sharply at high pt**

**reflects momentum conservation?**


n = 1 0-10%
ALICE
Preliminary
Pb-Pb 2.76 TeV
Stat. error only
0.01
0.005
0
-0.005
1.6
1.4
1.2
1
0.8
0.6
0.4
1 1.5 2 2.5 3 4 6 8 15
assoc. p_T [GeV/c]
trigger p_T


n = 3 0-10%
ALICE Preliminary
Pb-Pb 2.76 TeV
Stat. error only
⟨cos(nΔφ)⟩, (v^t_n v^a_n)_fit
⟨cos(nΔφ)⟩ / (v^t_n v^a_n)_fit
assoc. p_T [GeV/c]
trigger p_T
1 1.5 2 2.5 3 4 6 8 15
0.012
0.01
0.008
0.006
0.004
0.002
0
-0.002
1.6
1.4
1.2
1
0.8
0.6
0.4


n = 4 0-10%
ALICE Preliminary
Pb-Pb 2.76 TeV
Stat. error only
⟨cos(nΔφ)⟩, (v^t_n v^a_n)_fit
⟨cos(nΔφ)⟩ / (v^t_n v^a_n)_fit
0.006
0.004
0.002
0
-0.002
1.6
1.4
1.2
1
0.8
0.6
0.4
1 1.5 2 2.5 3 4 6 8 15
assoc. p_T [GeV/c]
trigger p_T


n = 5 0-10%
ALICE
Preliminary
Pb-Pb 2.76 TeV
Stat. error only
⟨cos(nΔφ)⟩, (v_n^t v_n^a)_fit
⟨cos(nΔφ)⟩ / (v_n^t v_n^a)_fit
0.0025
0.002
0.0015
0.001
0.0005
0
-0.0005
-0.001
1.6
1.4
1.2
1
0.8
0.6
0.4
1 1.5 2 2.5 3 4 6 8 15
assoc. p_T [GeV/c]
trigger p_T

# Understanding the near side

**If $\Delta E$ leads to $I_{AA}^{near} > 1$, then why wasn't this also seen at RHIC?**

1. Phase space considerations

Steeper parton production at RHIC. There, high-pt triggers have larger z, lower assoc. yields.

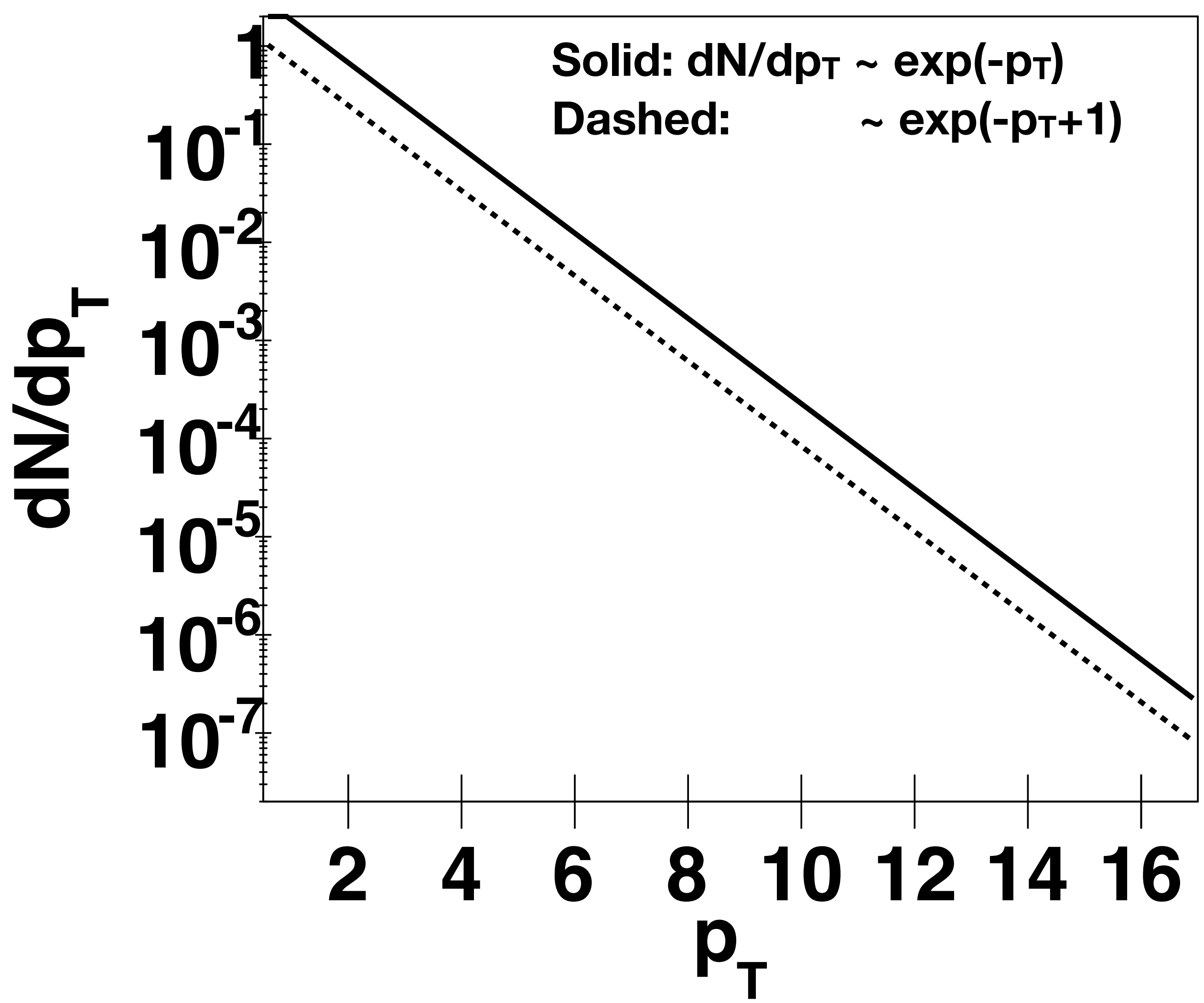
2. Parton spectral shape:

Consider a fixed $\Delta E$

(i.e. every parton loses 1 GeV)

For an exponential, the slope is unchanged. Energy loss is independent of E.

Probing different parton energy by requiring a trigger particle does not change the associated per-trigger yield.




Thus $I_{AA}$ can be 1 even for large $\Delta E$. Under these conditions, surface bias cannot be inferred from $I_{AA}=1$.

# Understanding the near side

## If ΔE leads to $I_{AA}^{near} > 1$, then why wasn't this also seen at RHIC?

**1. Phase space considerations**

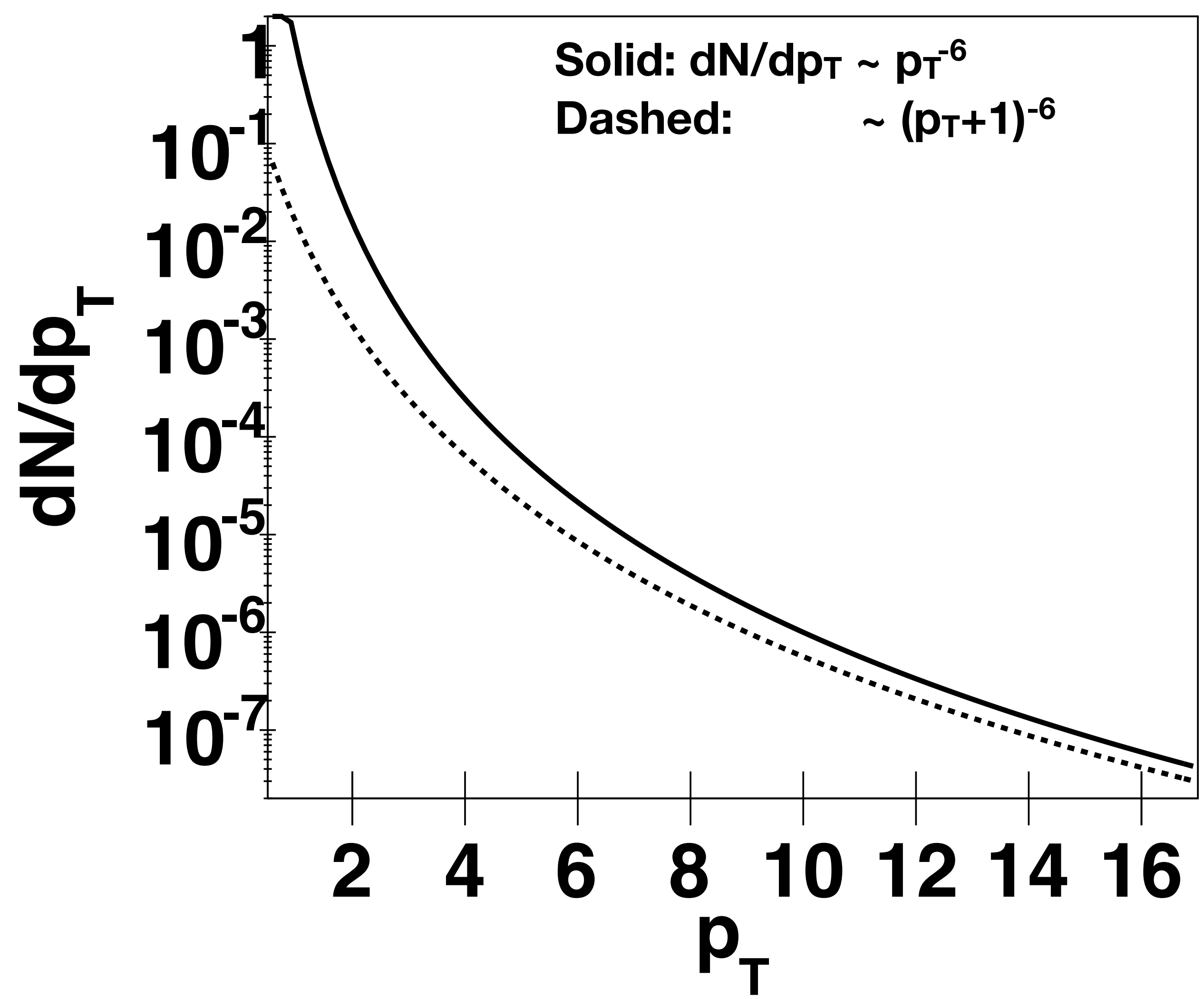
Steeper parton production at RHIC. There, high-pt triggers have larger z, lower assoc. yields.

**2. Parton spectral shape:**
**Consider a fixed ΔE**
**(i.e. every parton loses 1 GeV)**

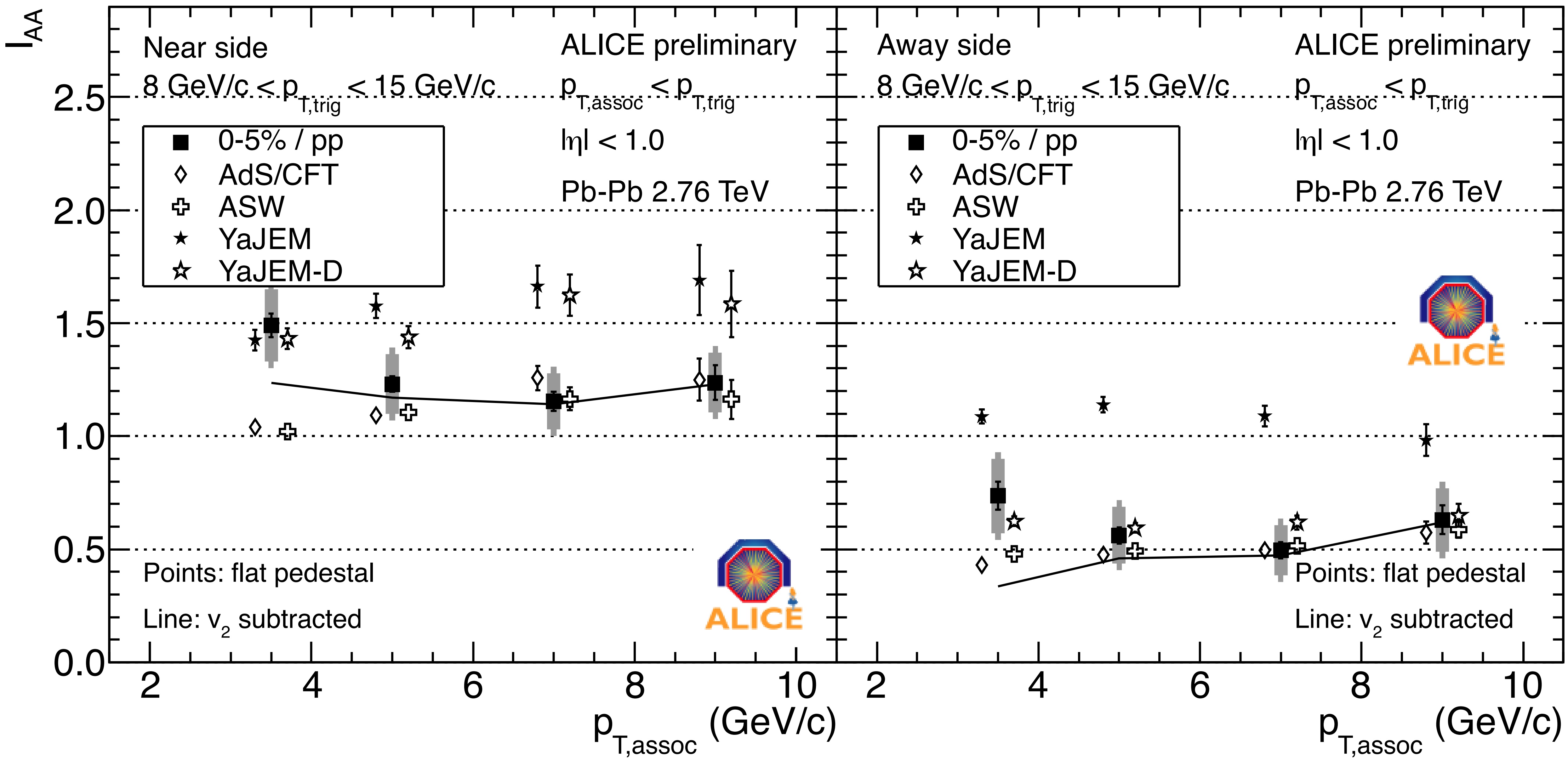
For a power law, the slope becomes flatter.

If phase space permits, the trigger requirement can lead to increased per-trigger associated yield.

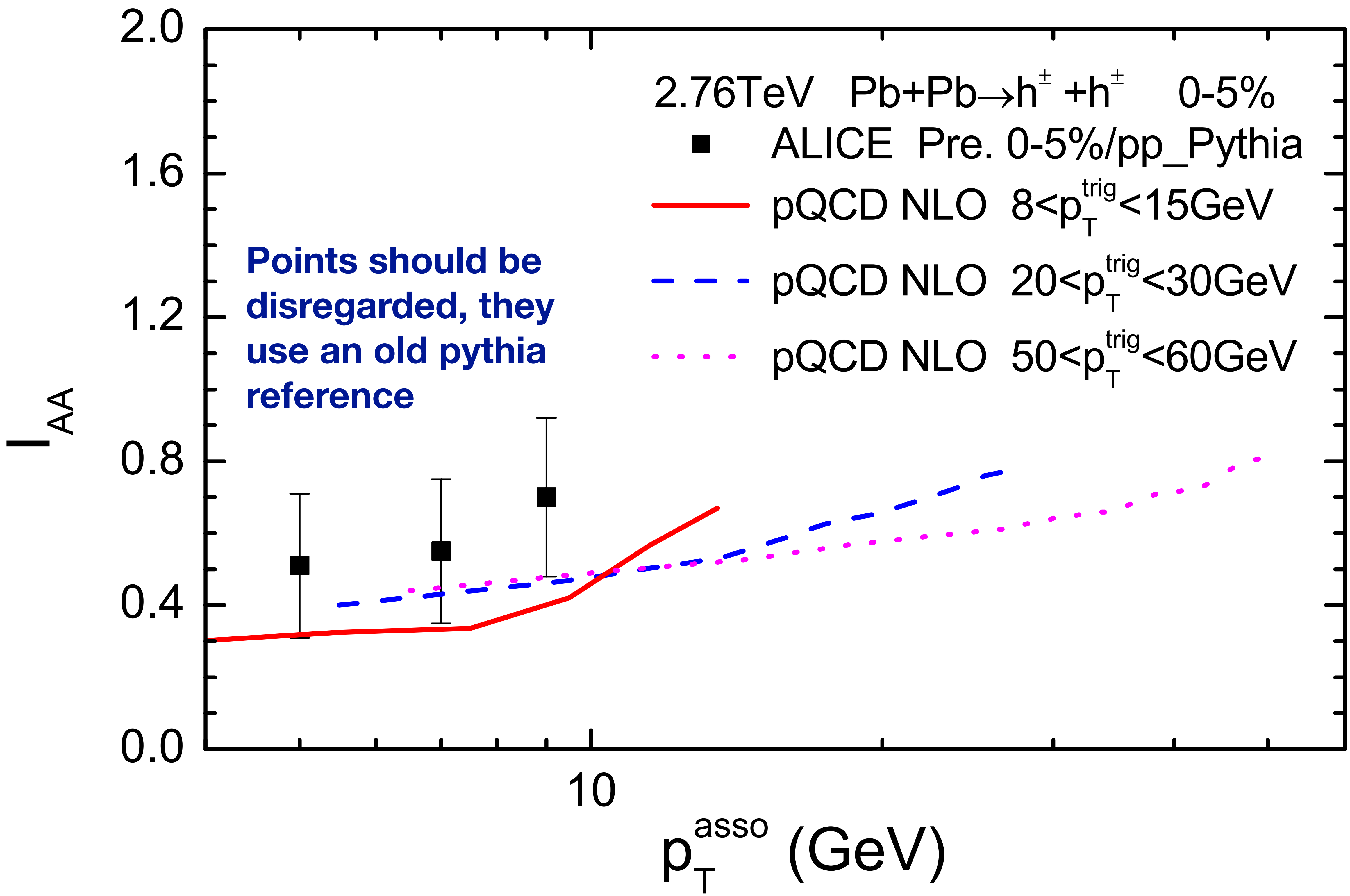
Thus $I_{AA}$ can be > 1.



# YaJEM comparison



# From Xin-Nian Wang



# Jet yield extraction

## Handling background

The non-jet component must be characterized and removed

- No known assumption-free methods…

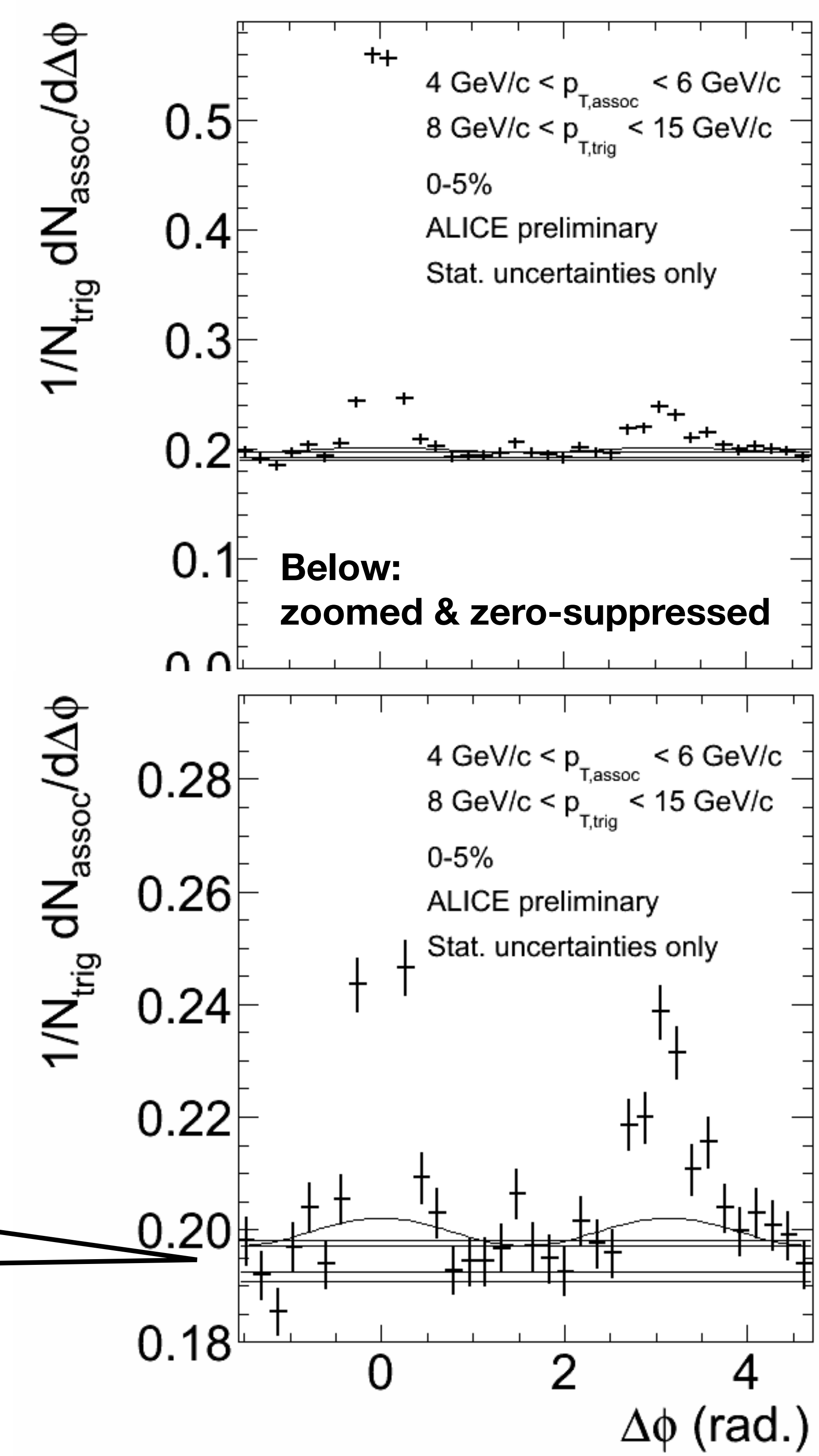
Go to high pt for reduced bias

- Trigger pt 8-15 GeV/c
- Associated pt > 4GeV/c, always with ptt > pta

## Work with several bkg. shape/ normalization schemes, compare

Differences gauge systematics

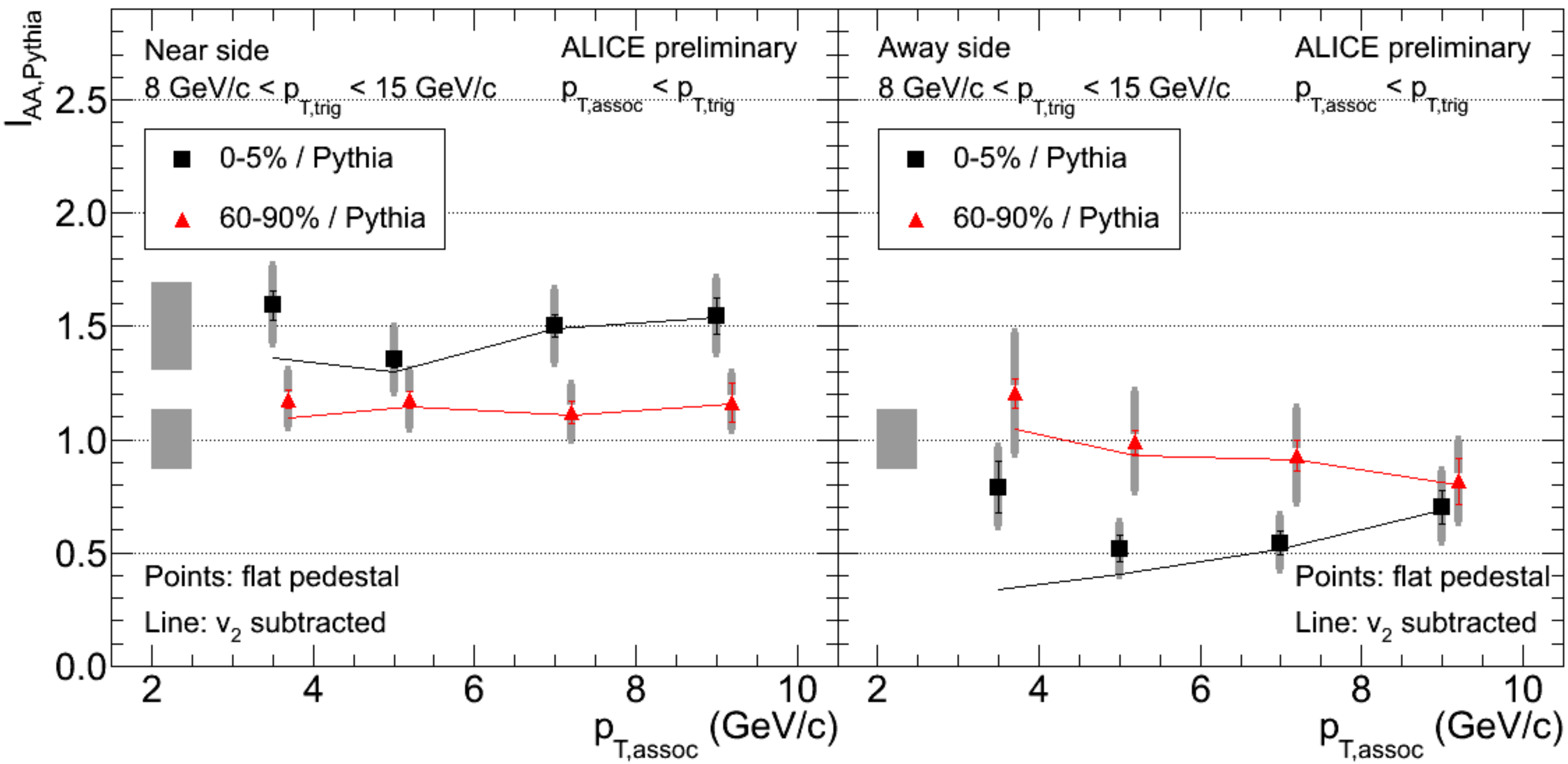
- Ultimately ZYAM is used
- Different “M” definitions --> sys. uncertainty




**Different bkg shape ansatzes:**
- $v_2$-only
- flat pedestal

**Different ZYAM levels:**
- n-lowest-bin averages
- const. fit over transverse region

# Utrecht :: $I_{AA}$ using pythia reference




## Observations

**Near side yields enhanced by 1.3-1.5 for $p_{T,\,assoc}$ > 4 GeV/c in central events**

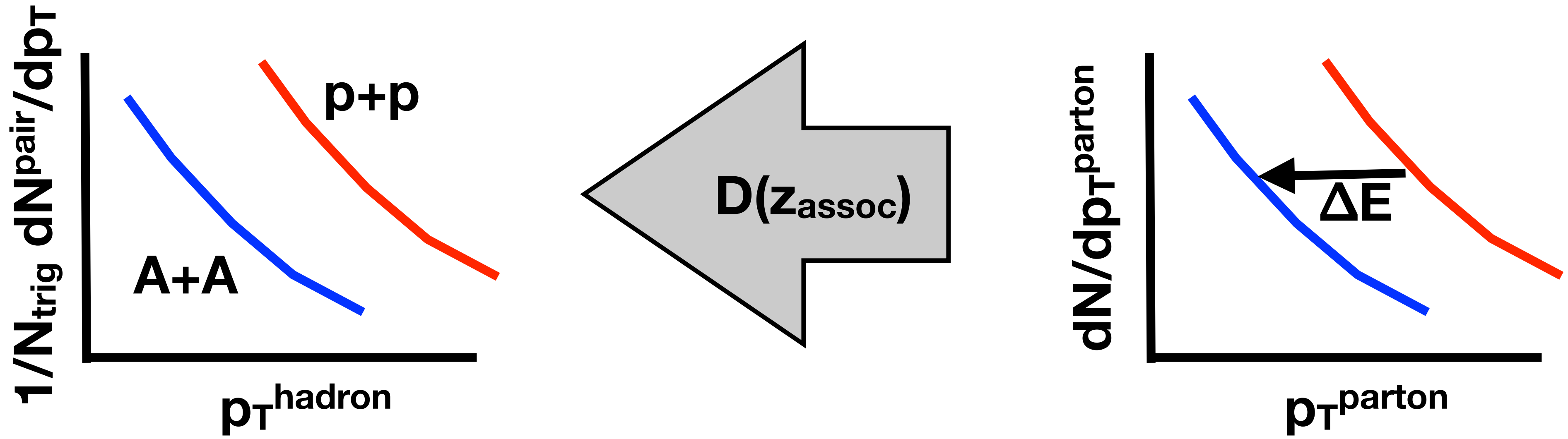
**Some enhancement measured even in peripheral data**

**Away side 0.5-0.7 for central, ~1 for peripheral**

# Near-side vs. away-side $I_{AA}$

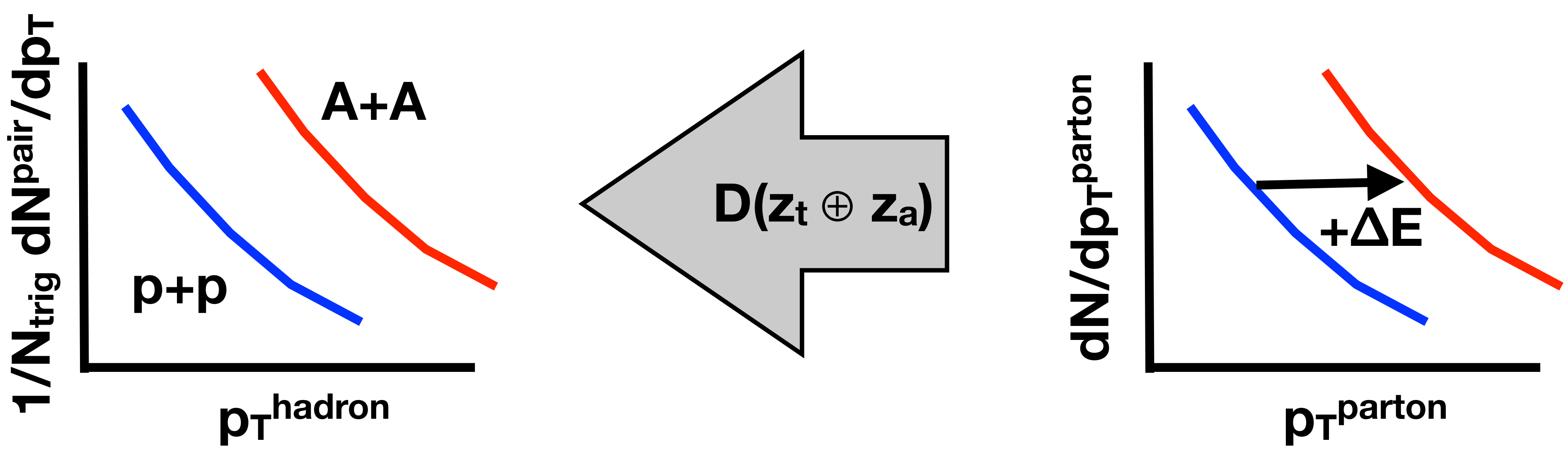
**Consider partons losing ΔE, then fragmenting in vacuum.**

**Away side:**




**ΔE lowers parton <pt> ⇒ fewer pairs/trigger in A+A on away side.**

**Near side:**




**Including the trigger particle requires partons at higher initial energies.**

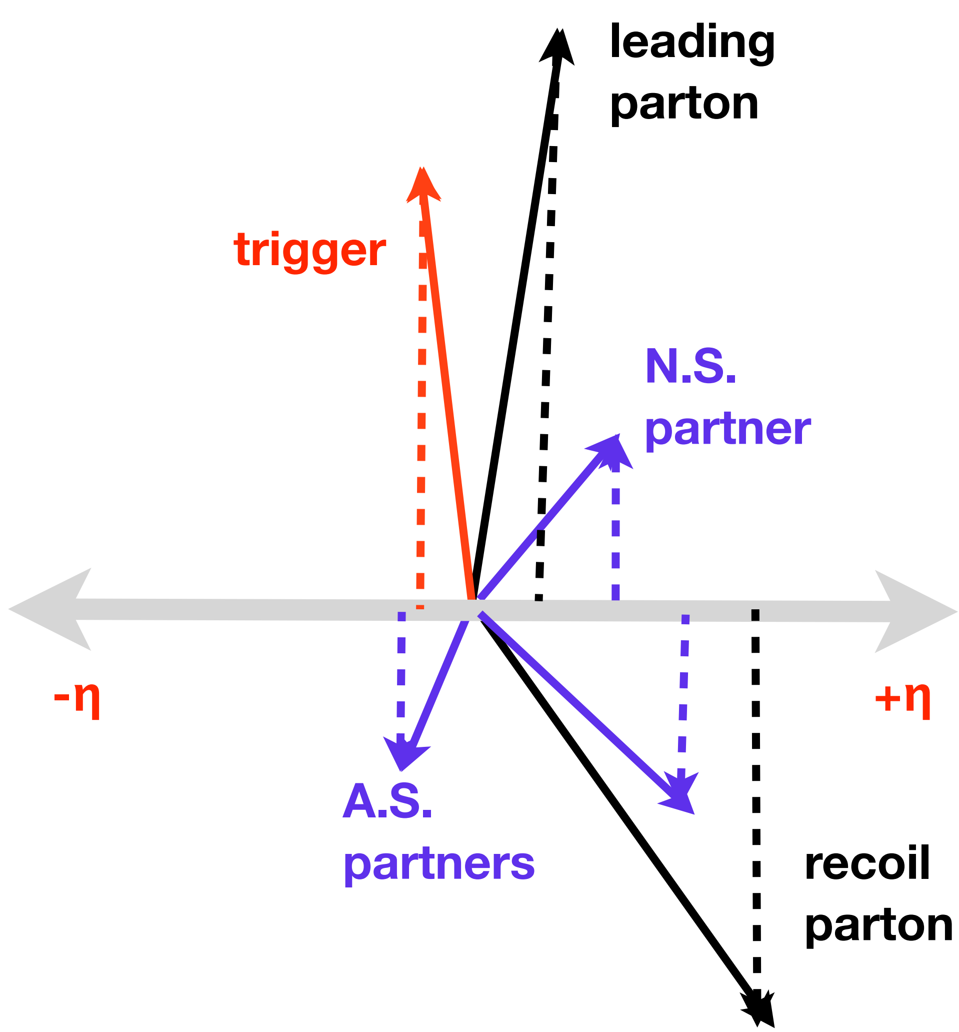
# Kinematics at the LHC vs. RHIC

## Near-side correlations

Requiring a trigger particle means $p_{T,parton} > p_{T,trig} + p_{T,assoc}$.

## On the recoil side

No trigger: $p_{T,parton} > p_{T,assoc}$.



# Kinematics at the LHC vs. RHIC

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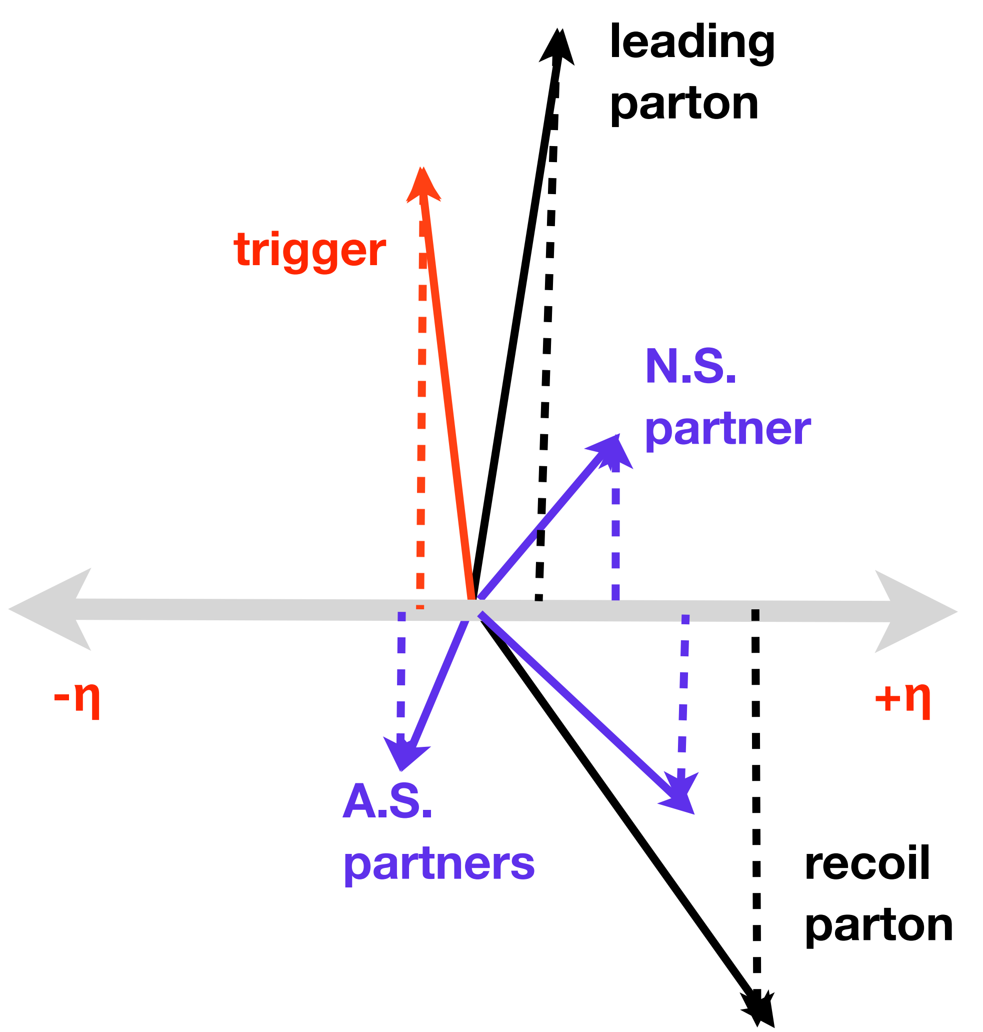
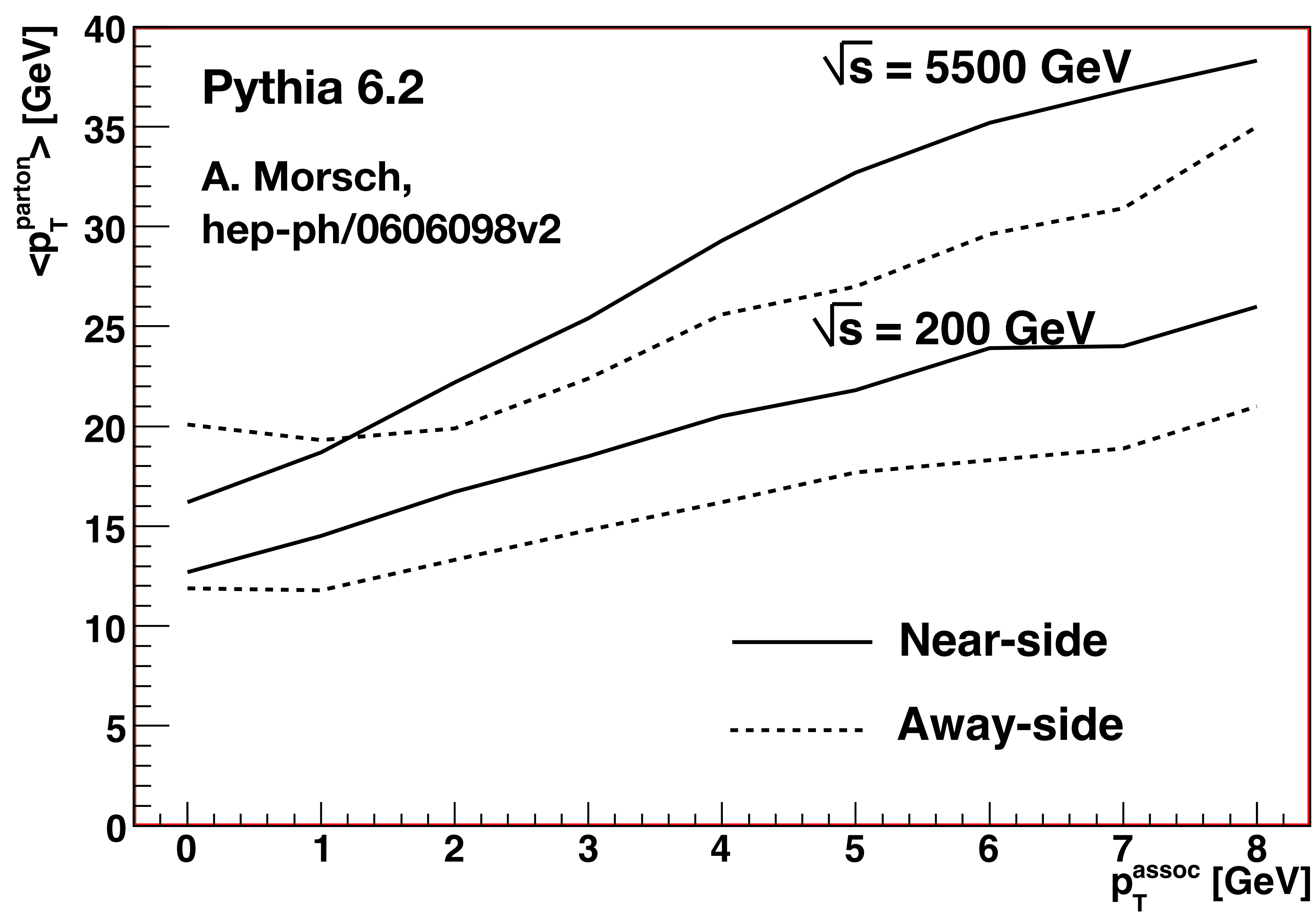



**Parton $p_T$ vs. associated $p_T$ - $p_{T,trig}$ > 8 GeV/c:**

- Near side samples higher $p_{T,parton}$ than away side
- At fixed $p_{T,trig}$ & $p_{T,assoc}$, much larger $p_{T,parton}$ at LHC



ALICE

# Systematic Uncertainties

- Detector efficiency and two-track effects
- Different detectors for centrality determination
- $p_T$ resolution
  - Fold associated $p_T$ distribution with momentum resolution
- Different pedestal determination schemes
- Integration window (between ±0.5 rad. and ±0.9 rad.)

| | |
|---|---|
| **Detector efficiency** | **5-8%** |
| **Centrality selection** | **2-8%** |
| **$p_T$ resolution** | **3%** |
| **Pedestal calculation** | **7-20%** |
| **Integration window** | **0-3%** |

**Ranges indicate different values for $I_{CP}/I_{AA,Pythia}$ and near/away side**