

# Event Shape Engineering with the ALICE Detector

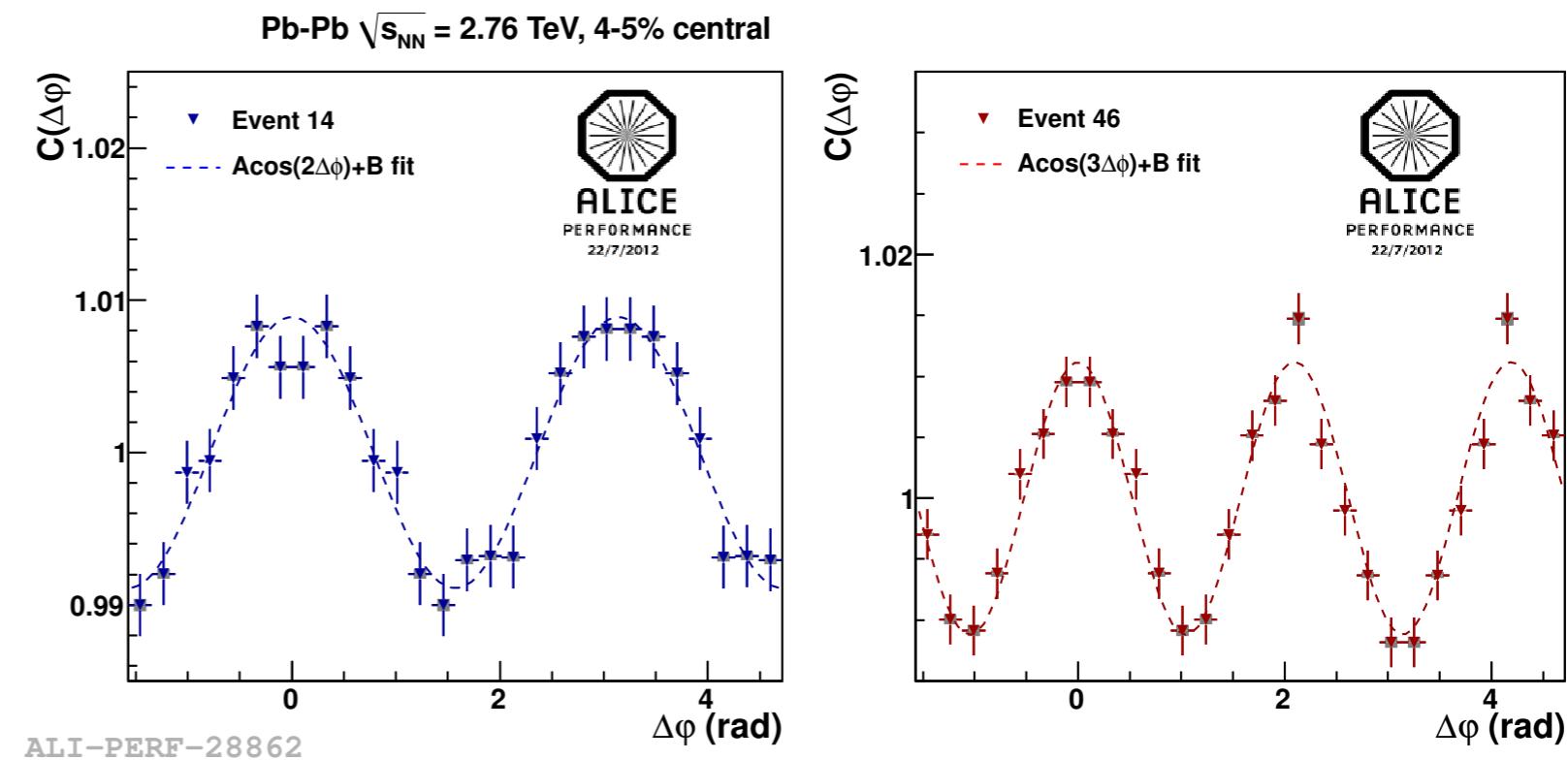
Anthony Timmins for the ALICE Collaboration



*Results from paper submitted to PRC (arXiv:1507.06194)*

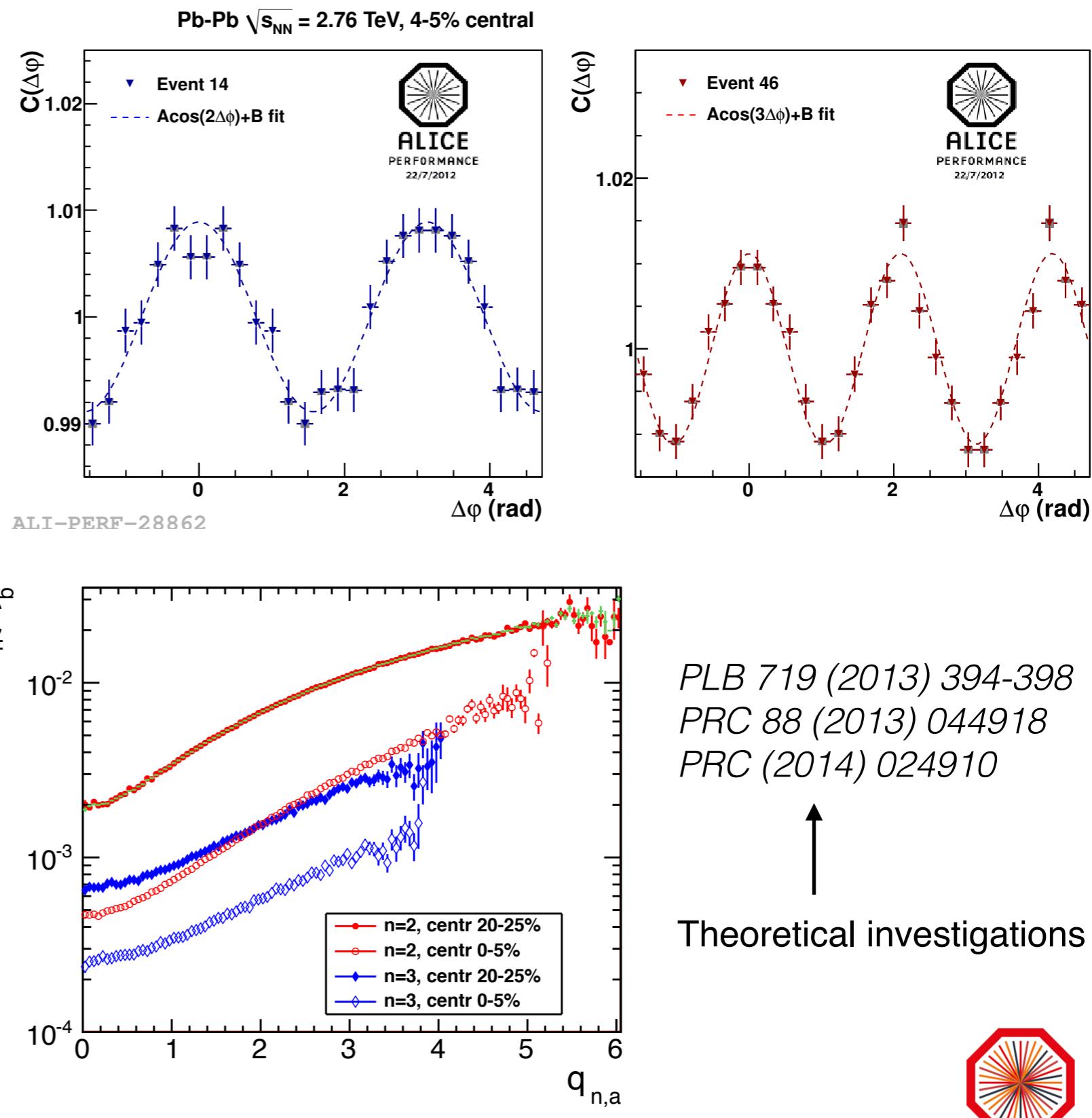
# Event Shape Engineering (ESE)

- Large anisotropic flow fluctuations in Pb-Pb collisions at LHC
- Some events dominated by  $v_2$ , others  $v_3$
- ✓  $v_n = K_n \varepsilon_n$  (n=2 or 3)



# Event Shape Engineering (ESE)

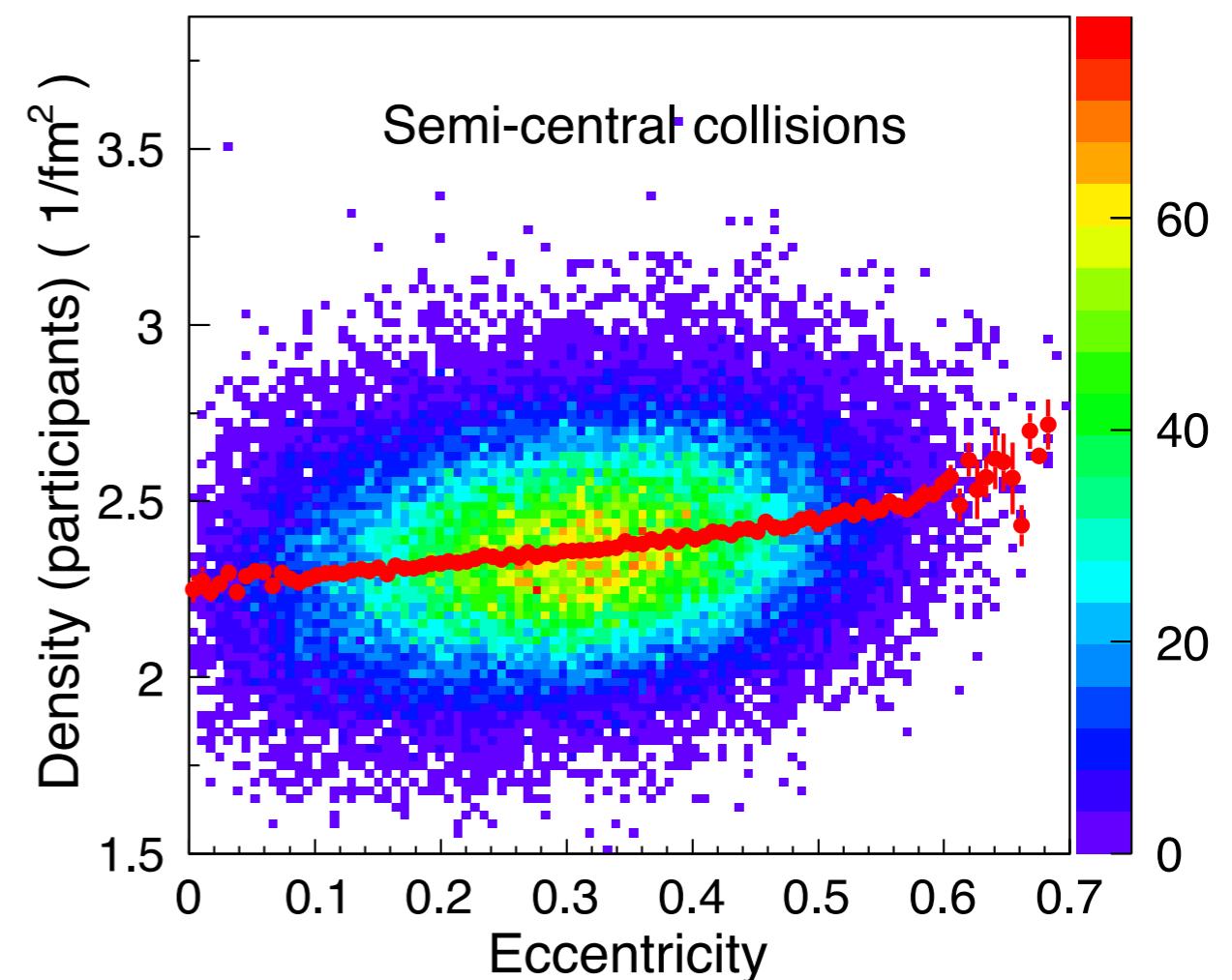
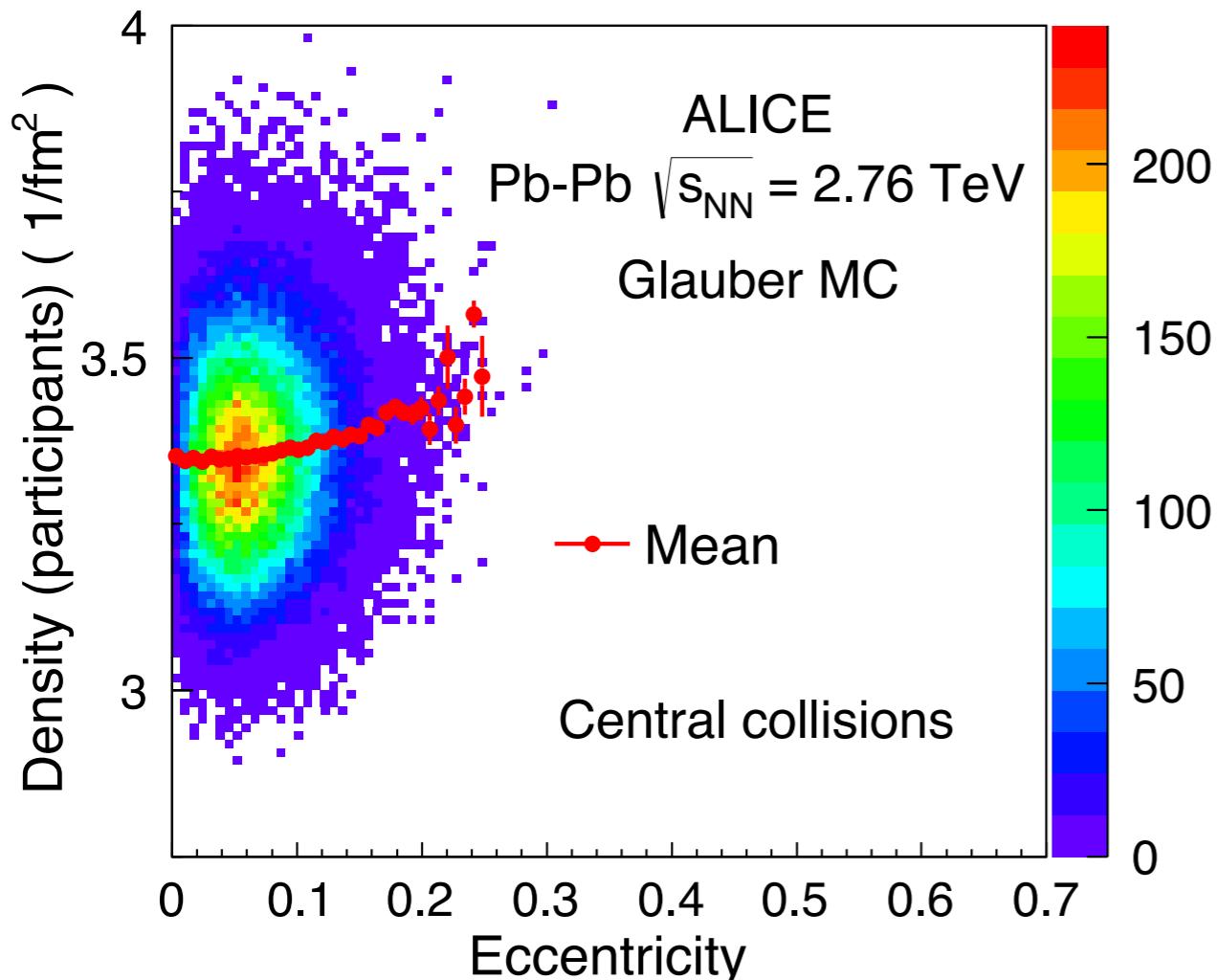
- Large anisotropic flow fluctuations in Pb-Pb collisions at LHC
- Some events dominated by  $v_2$ , others  $v_3$ 
  - ✓  $v_n = K_n \varepsilon_n$  ( $n=2$  or  $3$ )
- Event Shape Engineering
  - ✓ Select events based on anisotropic flow/eccentricity
  - ✓ Study other observables w.r.t. to selection



$$\langle q_n^2 \rangle \simeq 1 + \langle M - 1 \rangle \langle v_n^2 \rangle$$



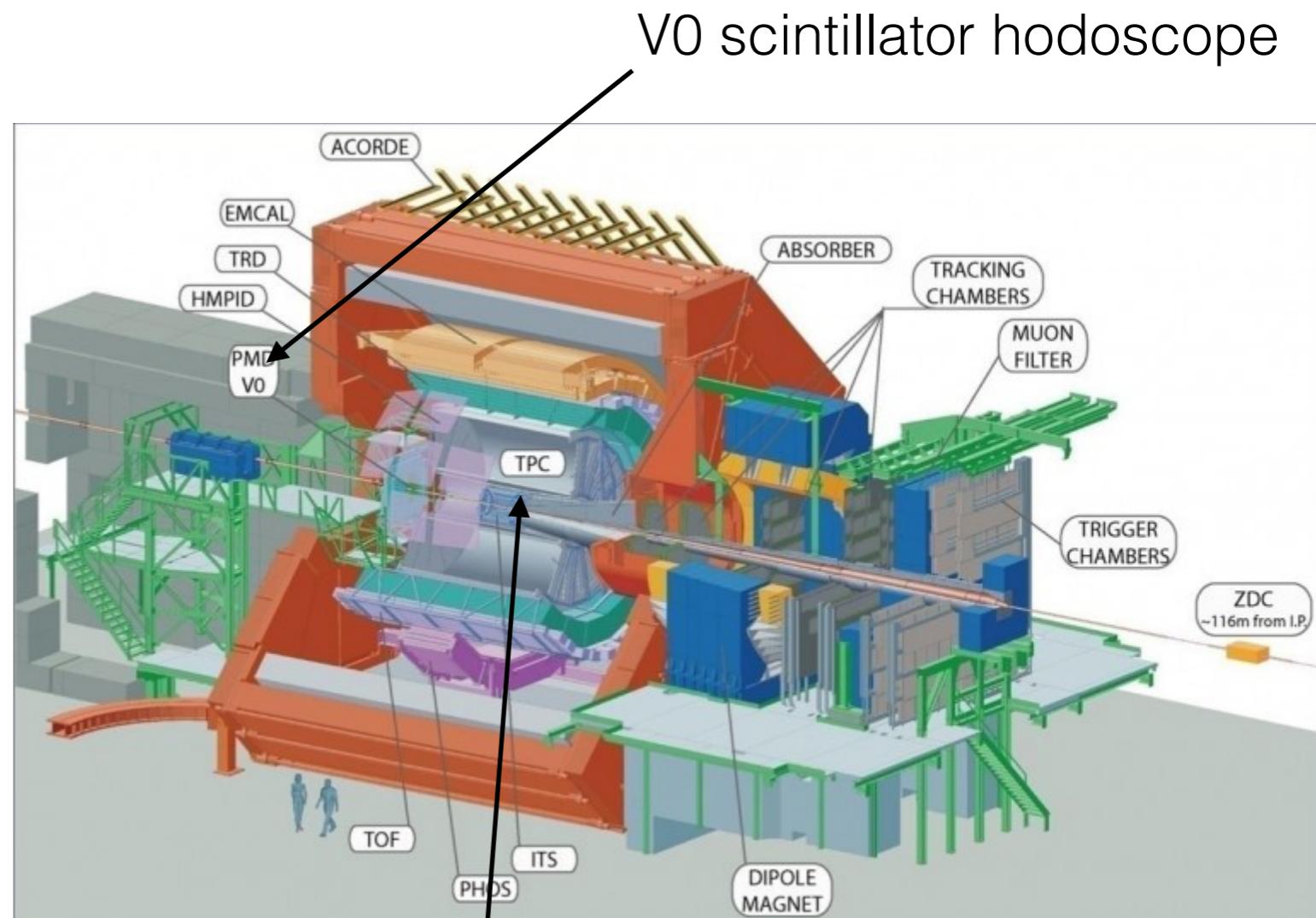
# Correlations between elliptic and radial flow?



- Participant density grows with eccentricity:
  - ✓ Correlations between radial and elliptic flow in data?
  - ✓ Extra constraints on initial conditions and transport properties?

# Experimental details

- V0 used for triggering & centrality
  - ✓  $| \text{Primary Vertex } z \text{ pos.} | < 10 \text{ cm}$
  - ✓  $\sim 16 \text{ M minbias events after all cuts.}$
- V0 and TPC used to select events based on  $q_2$ 
  - ✓  $q_2^{\text{VOC}}: -3.7 < \eta < -1.7$
  - ✓  $q_2^{\text{TPC}}: |\eta| < 0.4$
- TPC, ITS, TOF, used to measure spectra
  - ✓ ITS points  $> 2$ , TPC clusters  $> 70$
  - ✓ TPC and TOF used for PID
  - ✓  $0.5 < |\eta| < 0.8$

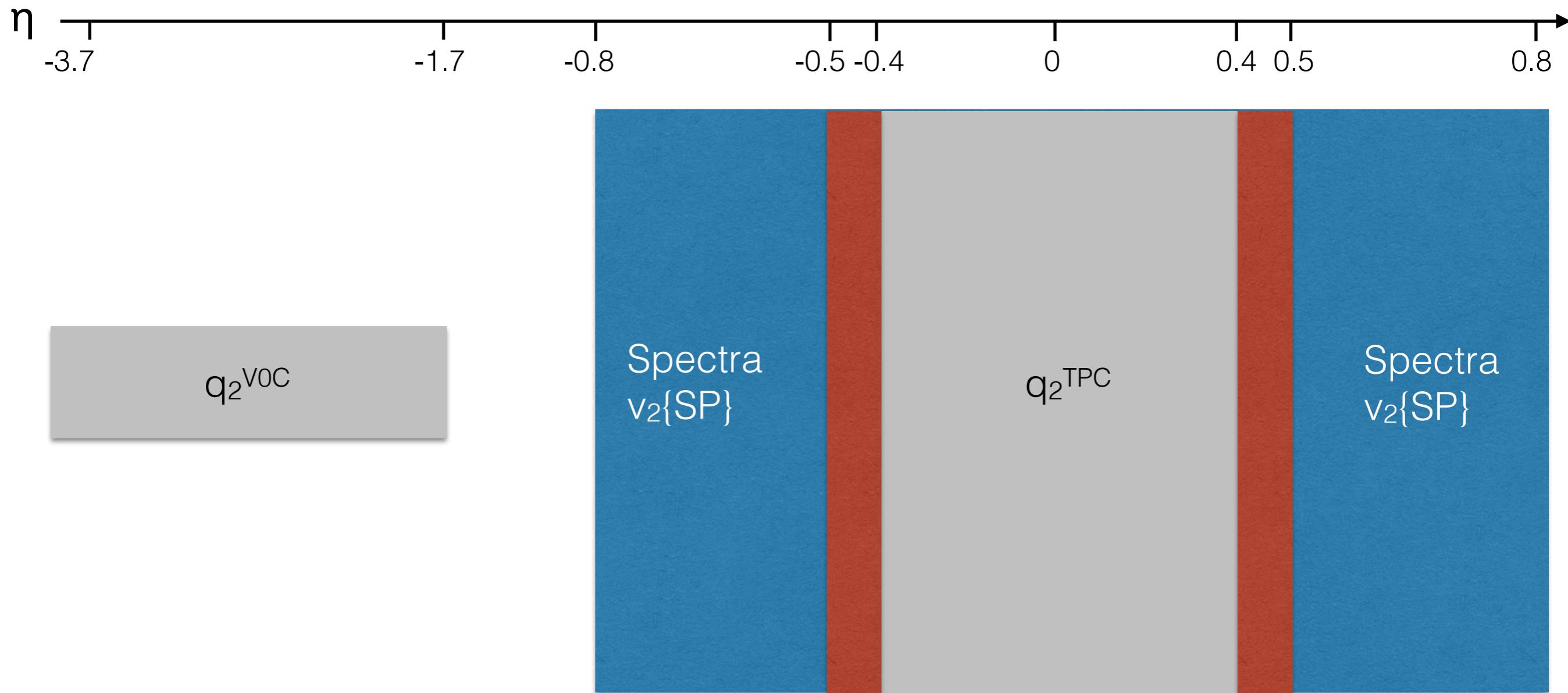


*See paper/backup for summary of systematic uncertainties*

Time Projection Chamber

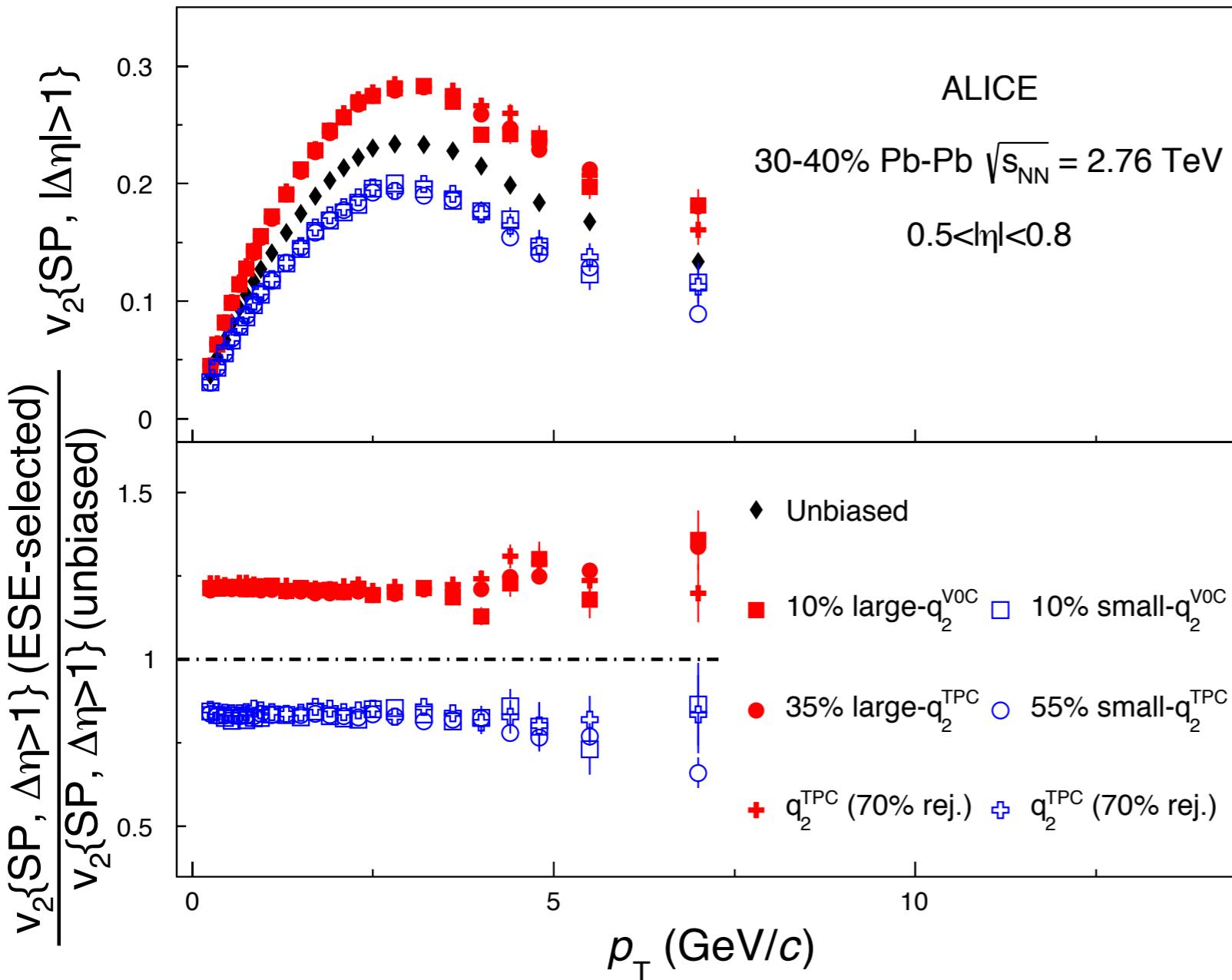


# Flow vector selection and spectra measurements



- $q_2$  used to select events based on length of flow vector
  - ✓ Spectra and  $v_2\{\text{SP}\}$  measured in different part of event

# Ability of event shape selection



$$v_2\{\text{SP}\} = \frac{\langle u_{2,k} Q_2^*/M \rangle}{\sqrt{Q_2^A Q_2^{B*}/M^A M^B}}$$

arXiv:0809.2949

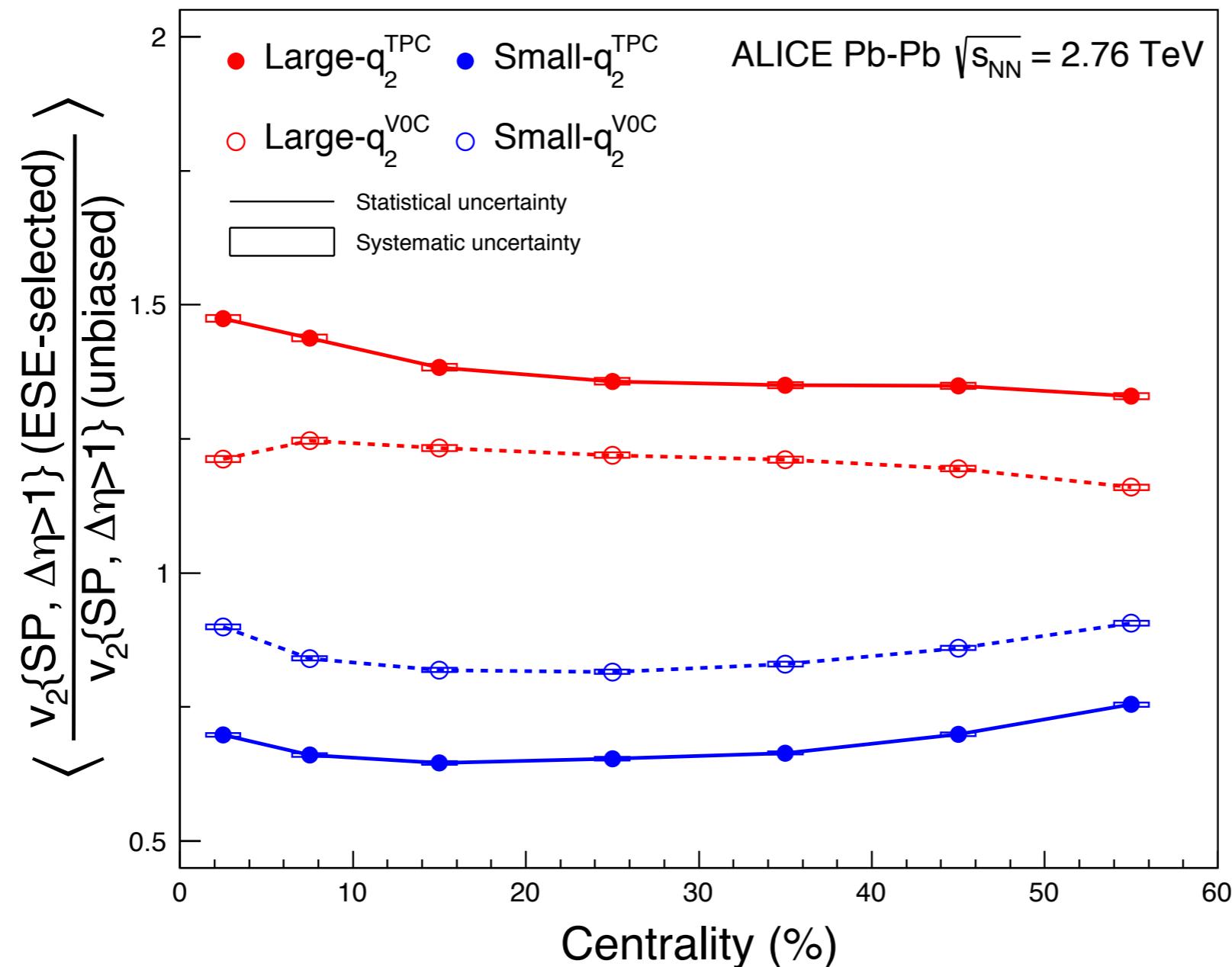
$v_2\{\text{SP}\}$  obtained from spectra  
 $\eta$  region

$|\Delta\eta| > 1$  between particle of  
 interest and reference flow

- Possible to change  $v_2$  by same amount with TPC or V0  $q_2$ 
  - Flatness of ratio indicates non-flow does not influence selection



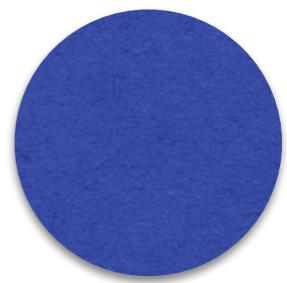
# Ability of event shape selection



Large- $q_2$ : Top 10%

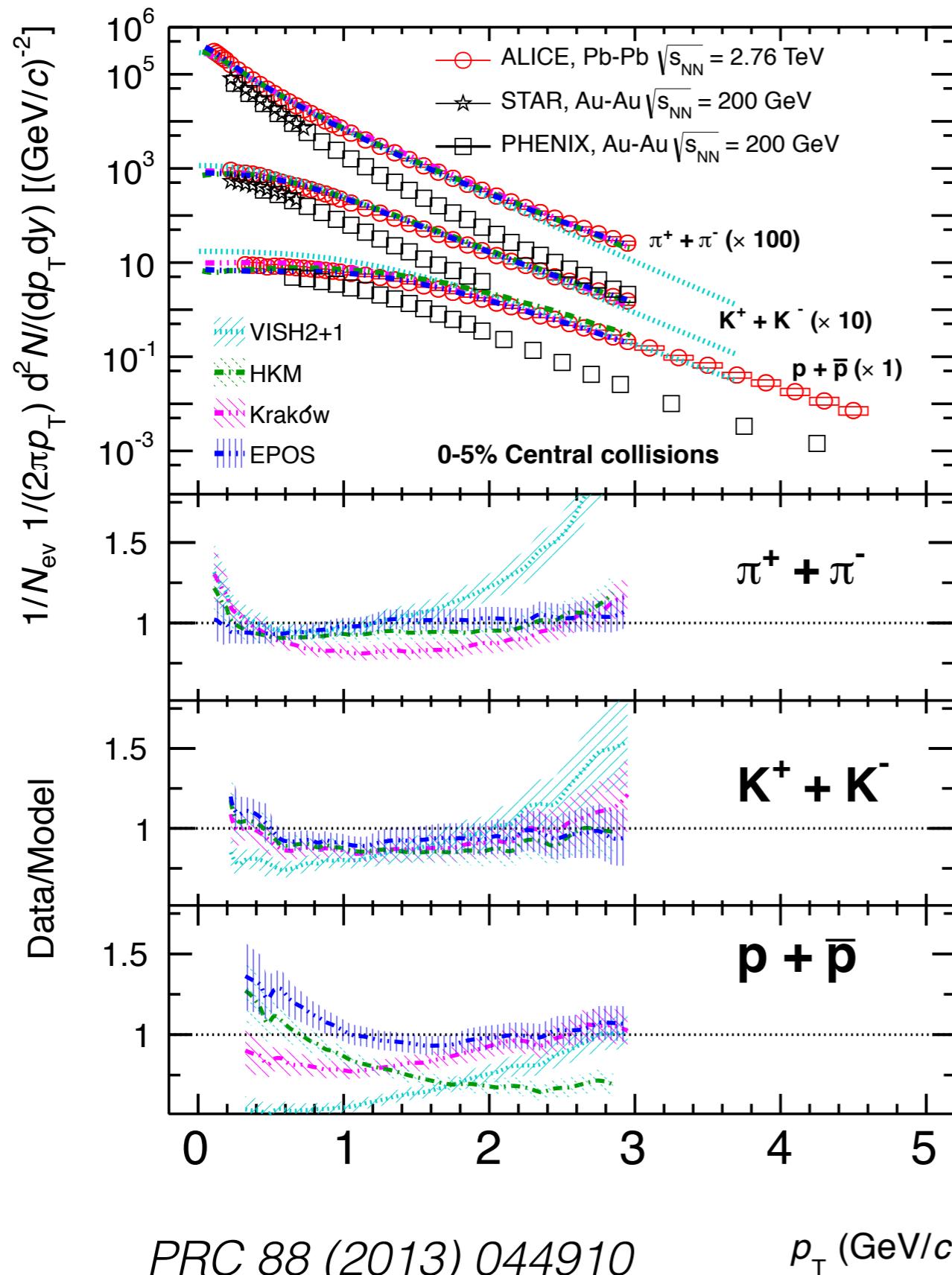


Small- $q_2$ : Bottom 10%



- Possible to increase  $v_2$  by ~50% or decrease by ~30%
  - ✓ TPC better than VOC
  - ✓ Selection ability reduces for peripheral collisions

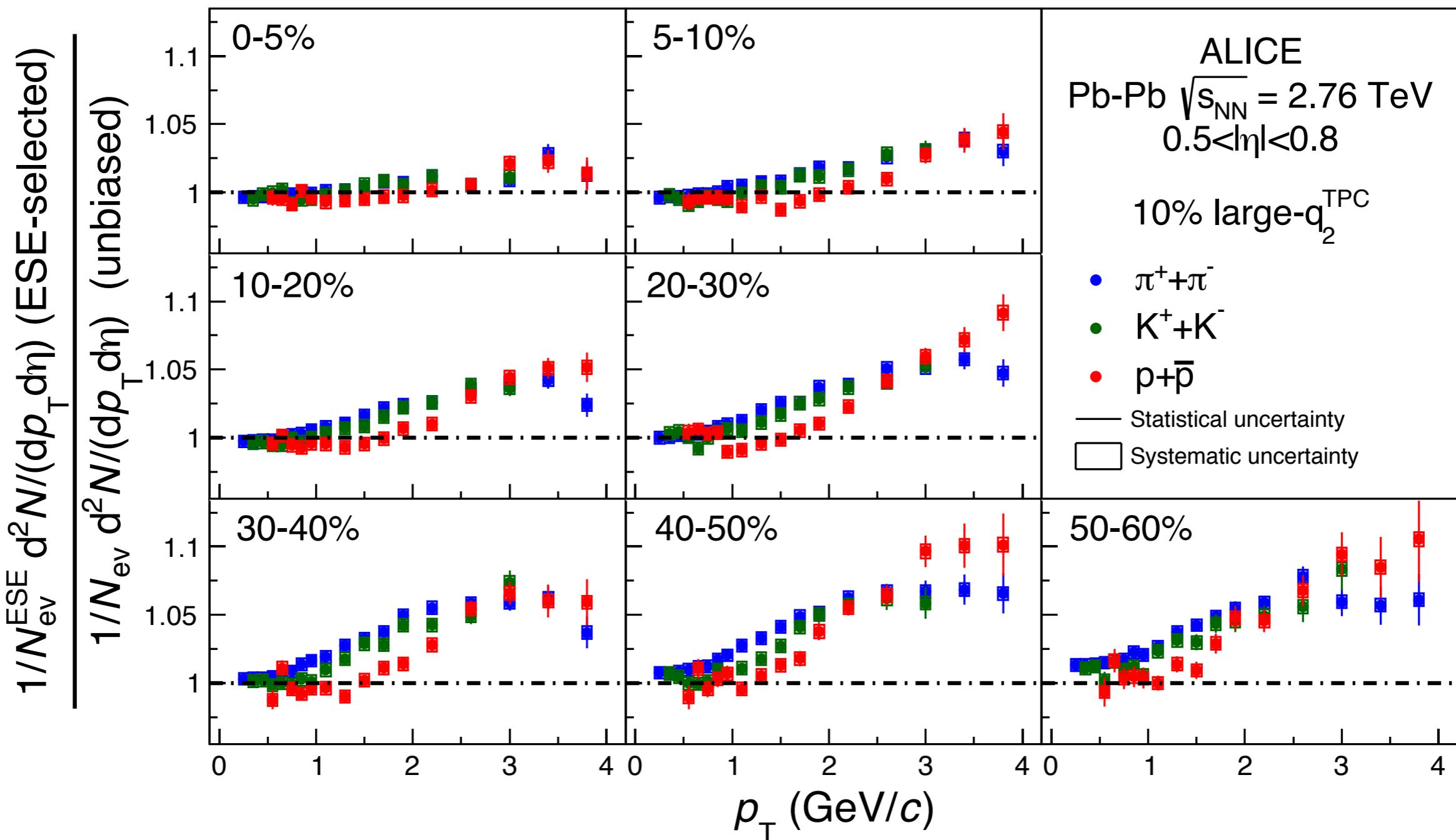
# Determination of spectra ratios



- Measure spectra from unbiased events
- Measure spectra in events with low/high  $q_2$  ( $\langle v_2 \rangle$ )
- Form ratio. Advantages:
  - ✓ No efficiency corrections needed
  - ✓ Many systematic uncertainties cancel

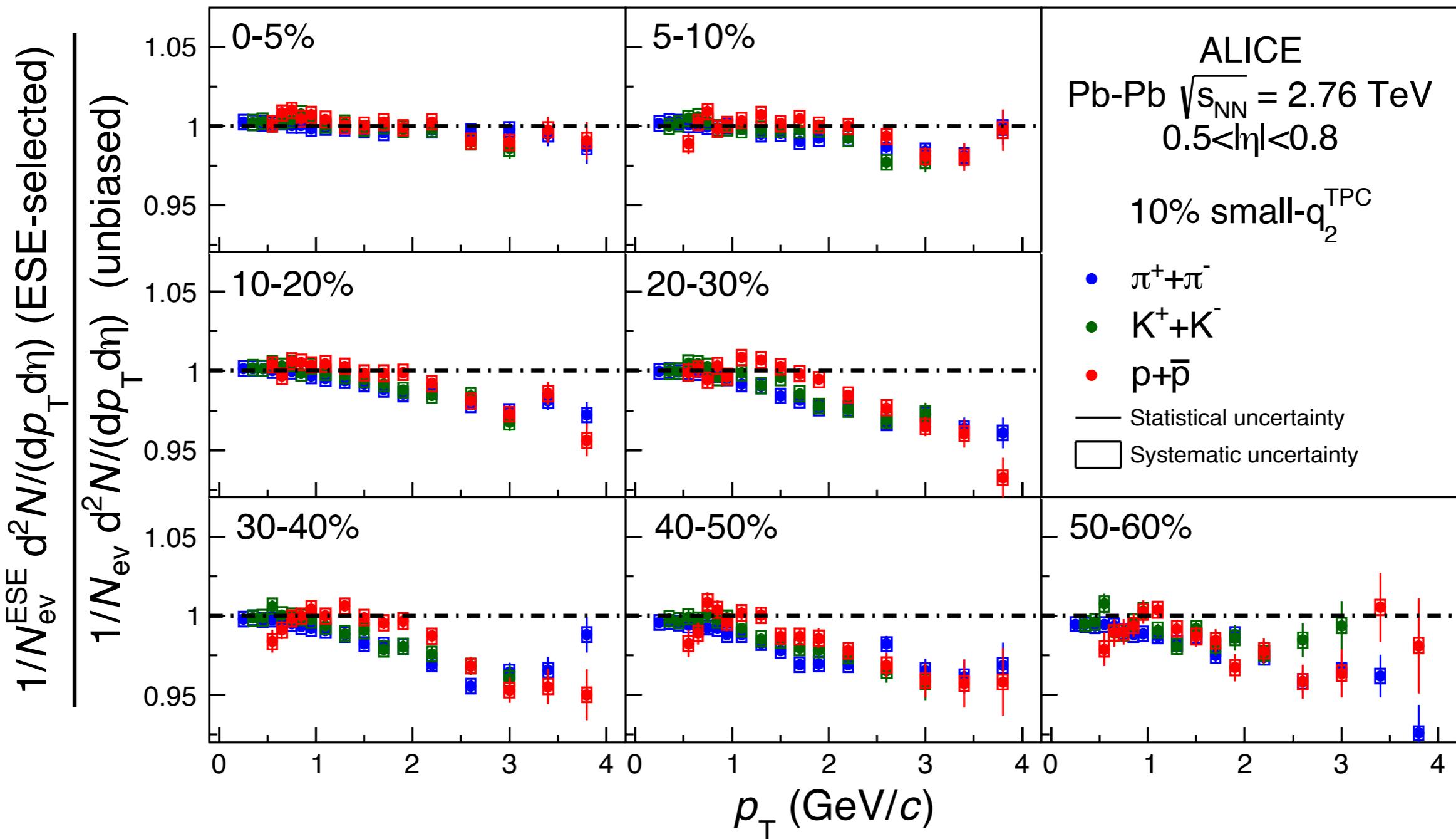


# Spectra in events with larger $\langle v_2 \rangle$



- Ratio of spectra for events with large  $q_2$  and no selection
  - ✓ Events with larger  $\langle v_2 \rangle$  have larger  $\langle p_T \rangle$
  - ✓ Strongest effect in mid-central collisions

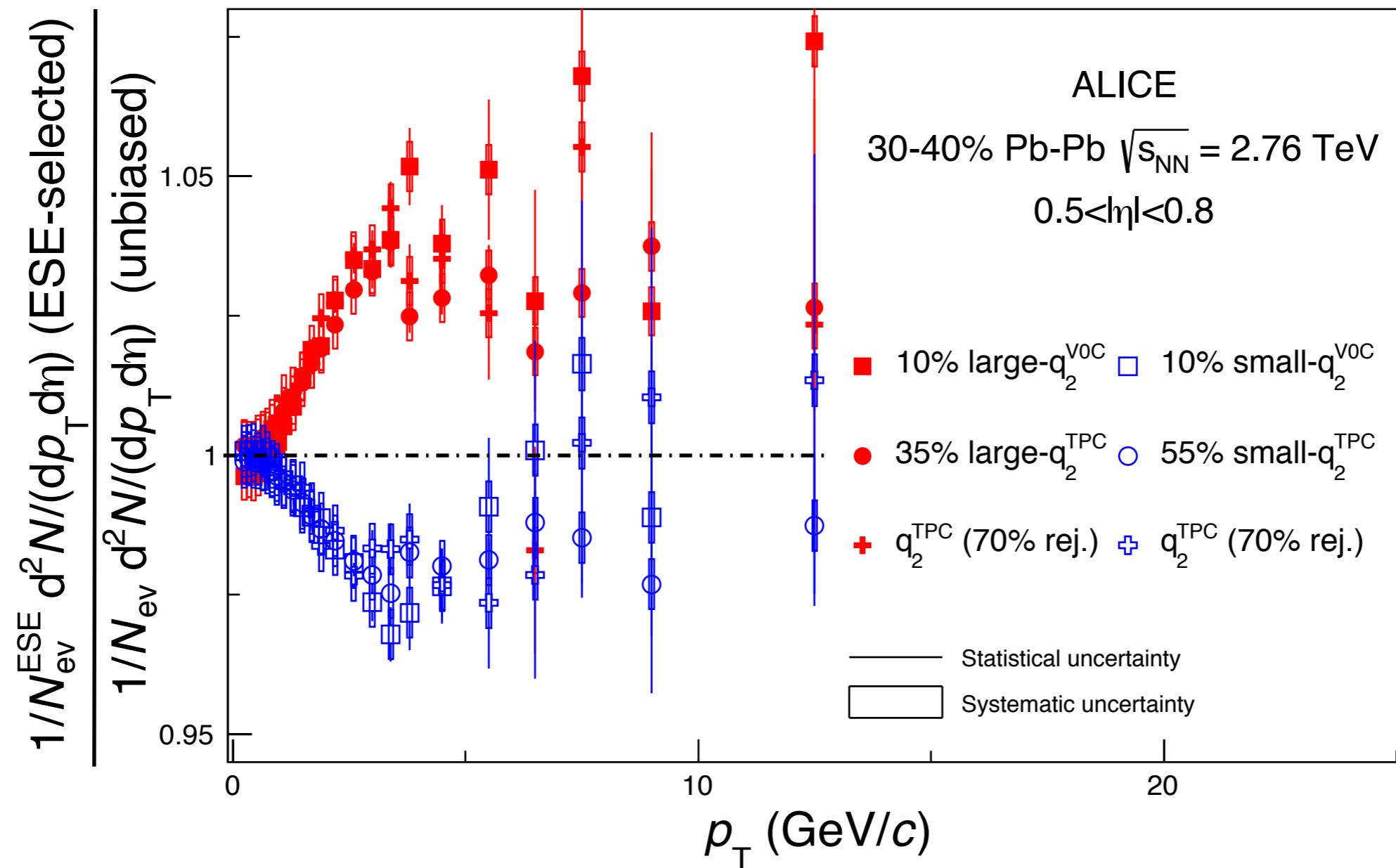
# Spectra in events with smaller $\langle v_2 \rangle$



- Opposite trend observed for small  $q_2$  selection

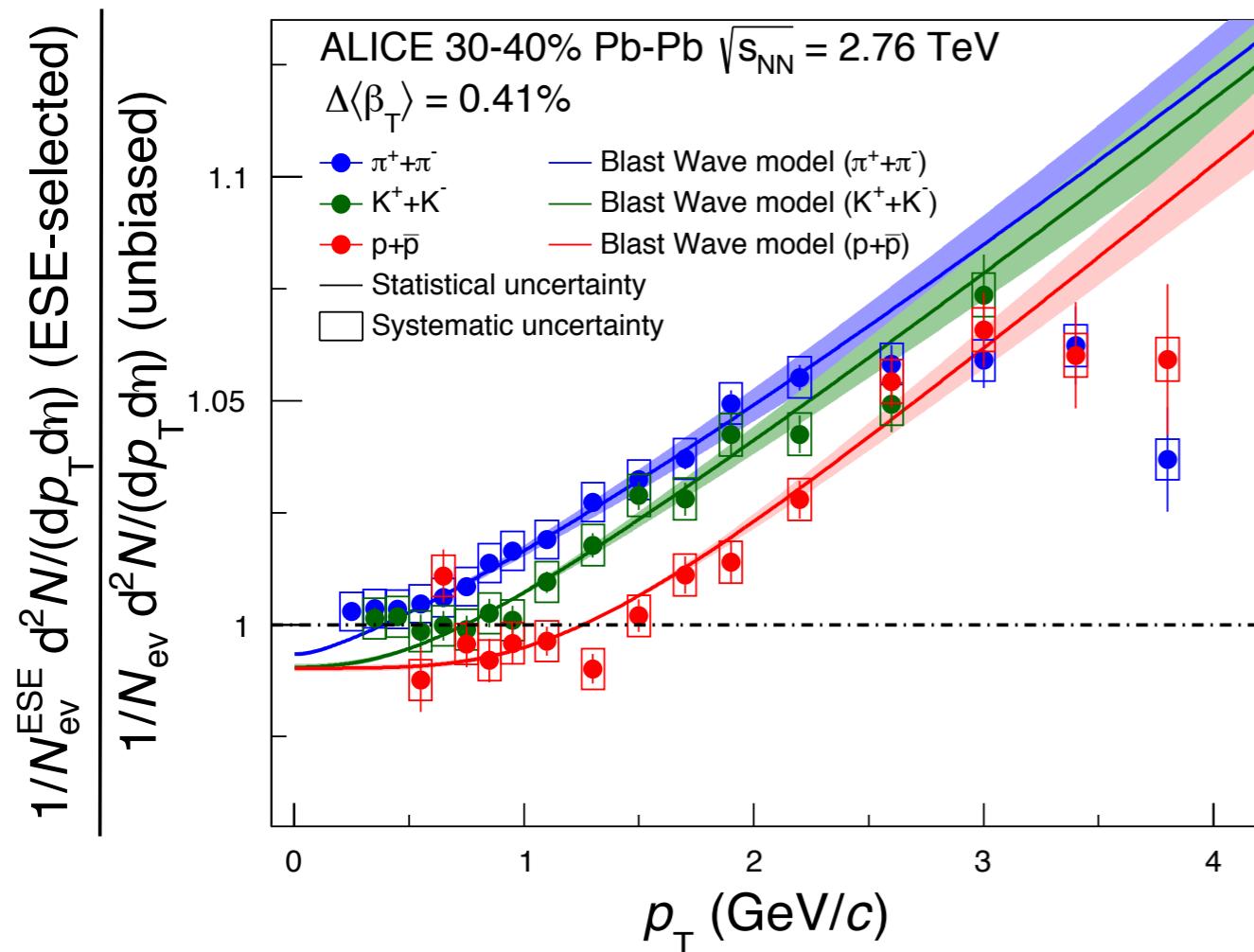


# Spectra shapes vs. type of event shape selection



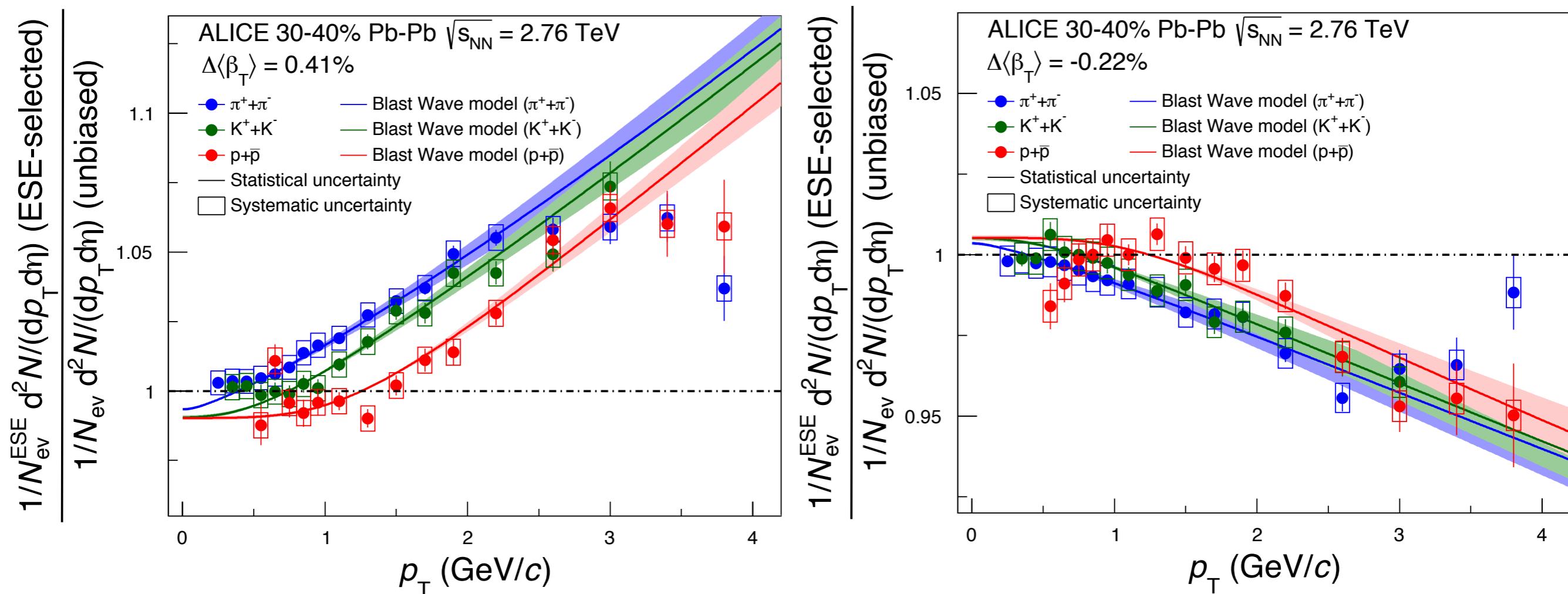
- Equivalent changes in  $\langle v_2 \rangle$  via TPC/V0C selections show equivalent changes in spectra
  - ✓ Effect does not depend on detector used for  $q_2$  selection

# Spectra changes really due radial flow?



- Use blast-wave (BW) model to investigate. Modest changes in radial flow velocity:
  - ✓ Reproduce increases and decreases in ratios
  - ✓ Reproduce mass dependence

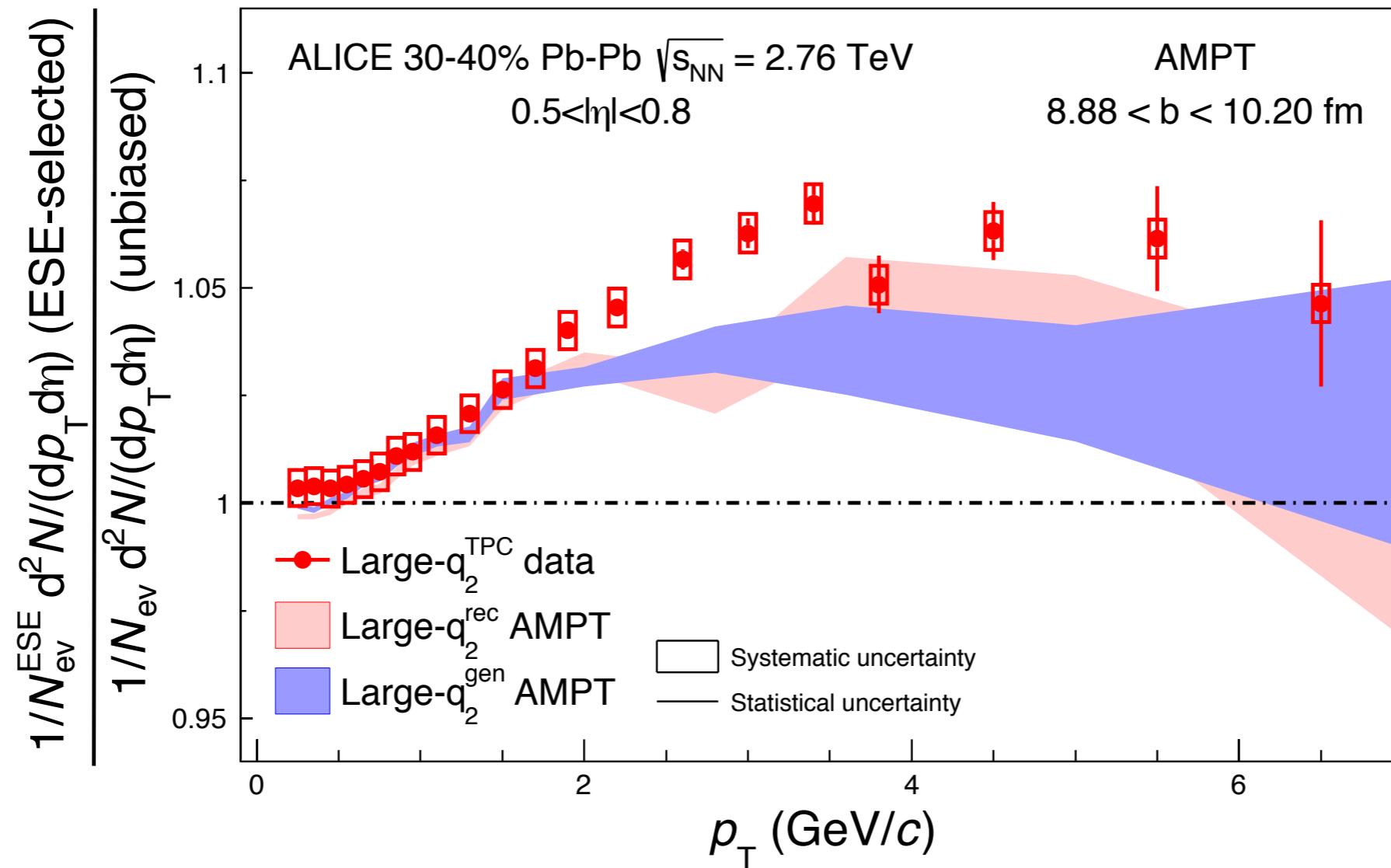
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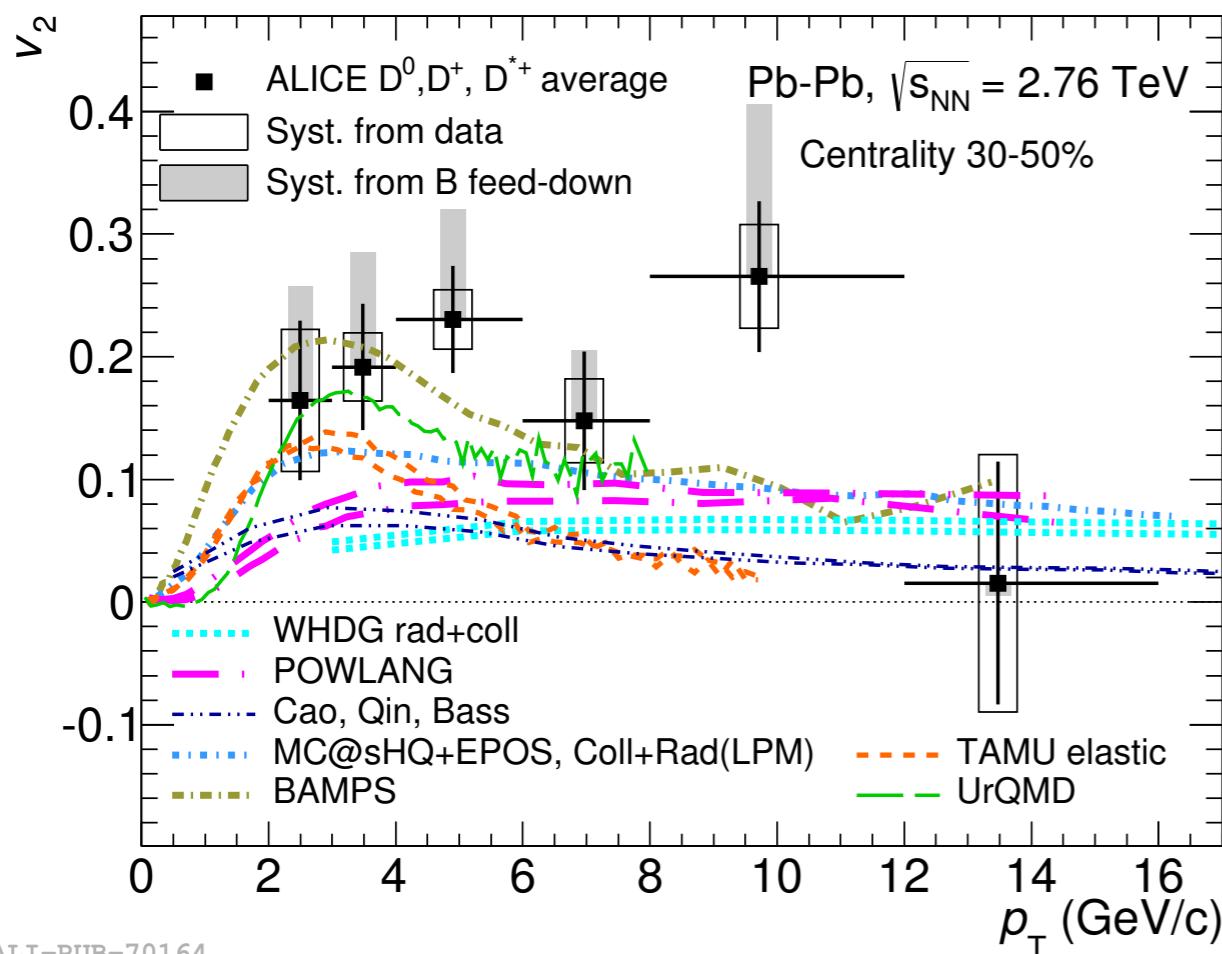
# Comparison of spectra shapes from AMPT



- Charged hadrons well reproduced at low- $p_T$ .
  - ✓ AMPT shows more modest changes at mid- $p_T$  compared to BW
  - ✓ Non-equilibrium effects important?

# Further ESE studies

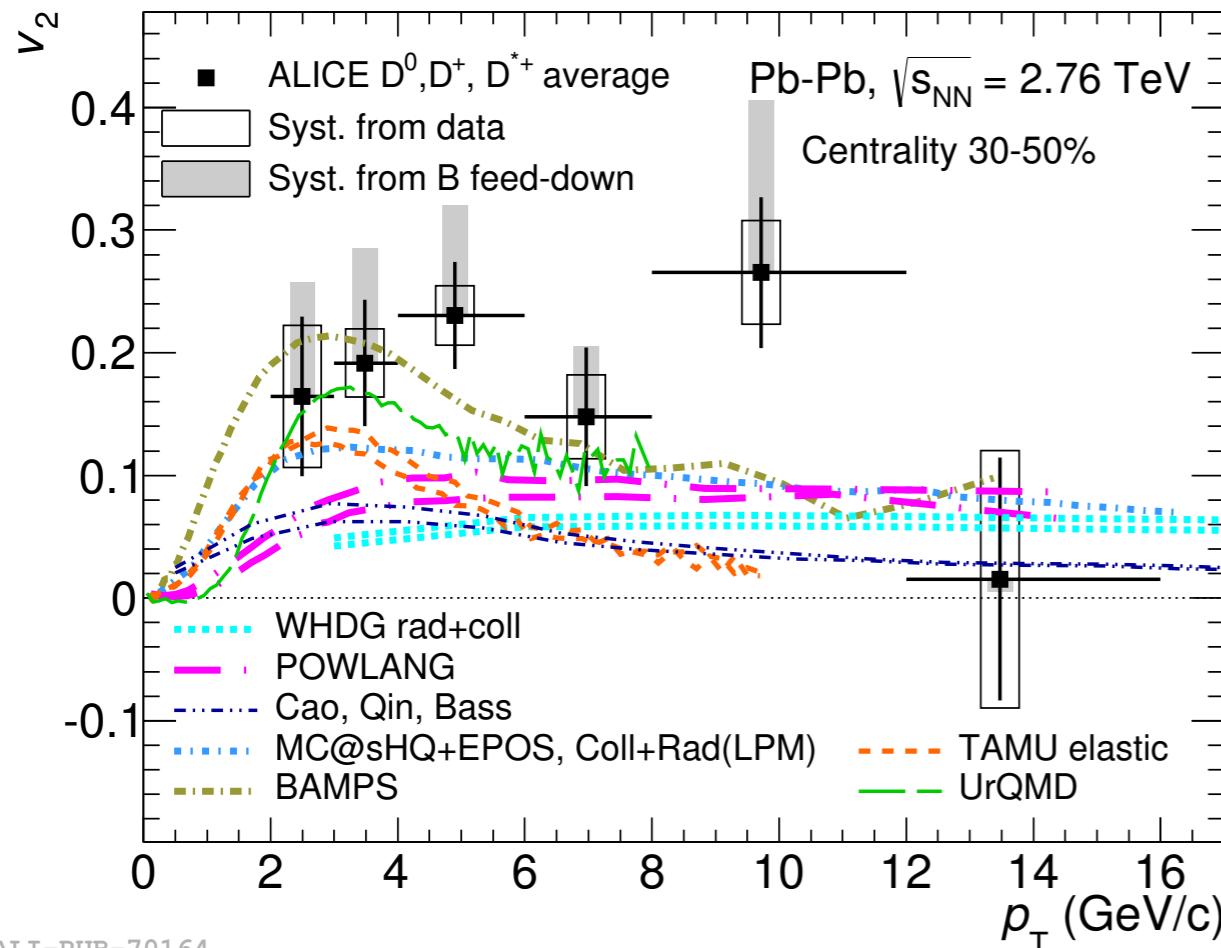
*PRC 90 (2014) 034904*



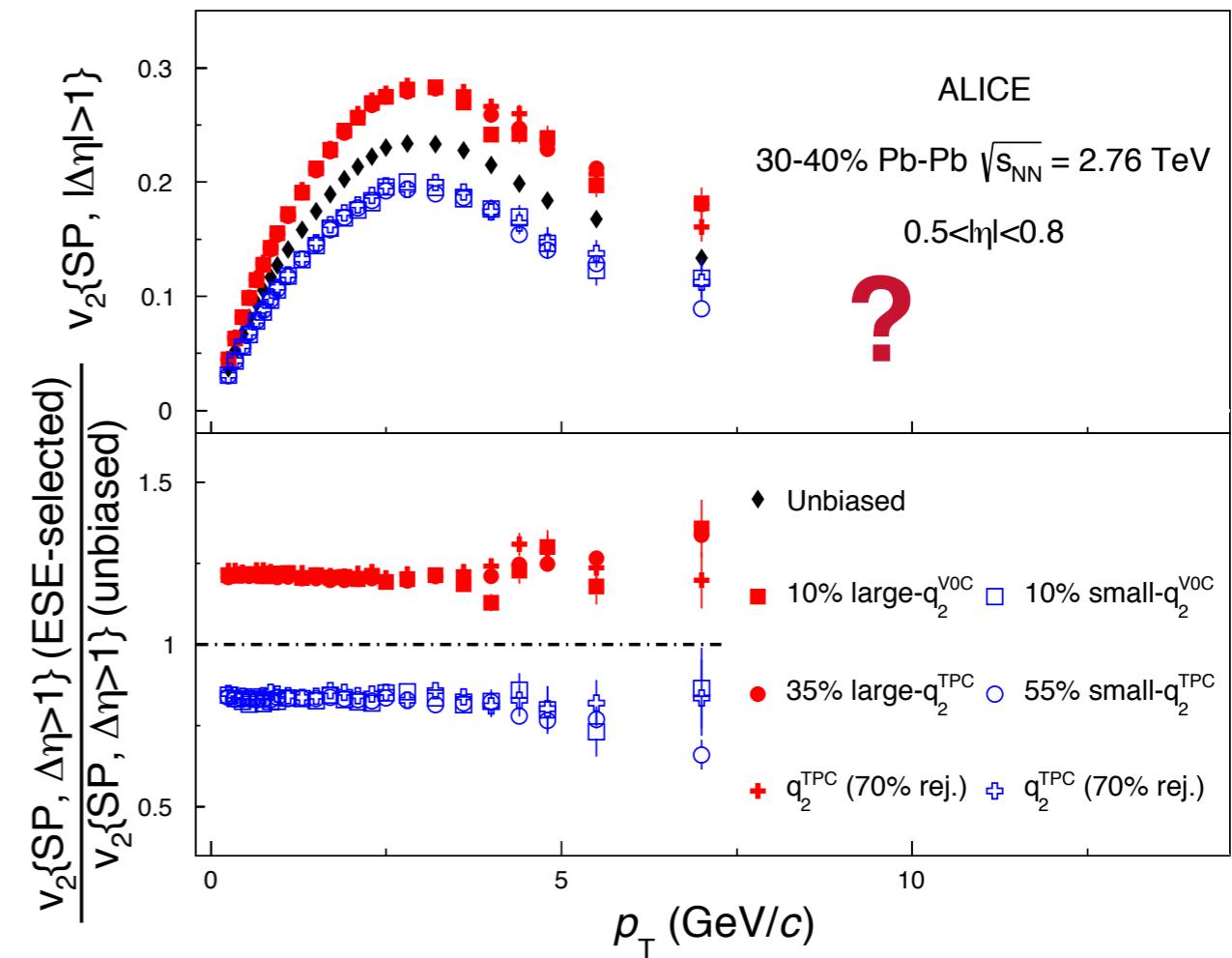
- Both RHIC and LHC entering high statistics era for HI collisions
  - ✓ Higher statistics - span large changes in  $\langle v_2 \rangle$
  - ✓ Will  $D^0 v_2$  increase in line with lighter particles?

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*PRC 90 (2014) 034904*



ALI-PUB-70164

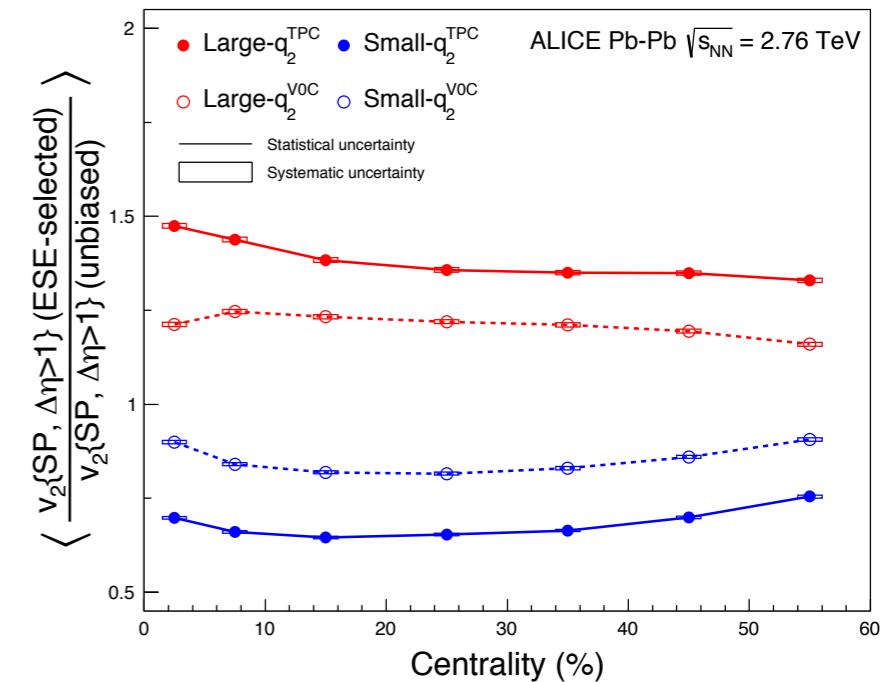


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  - ✓ Will  $D^0$   $v_2$  increase in line with lighter particles?
  - ✓ How will high  $p_T$   $v_2$  and path length dependent quenching change with  $q_2$ ?



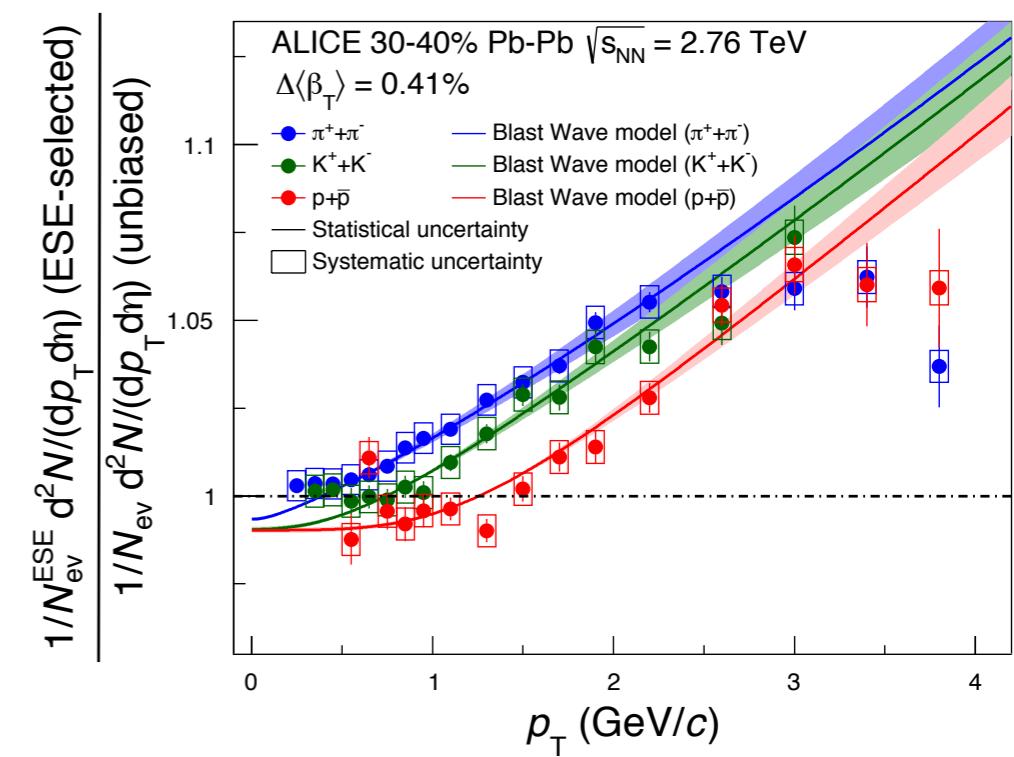
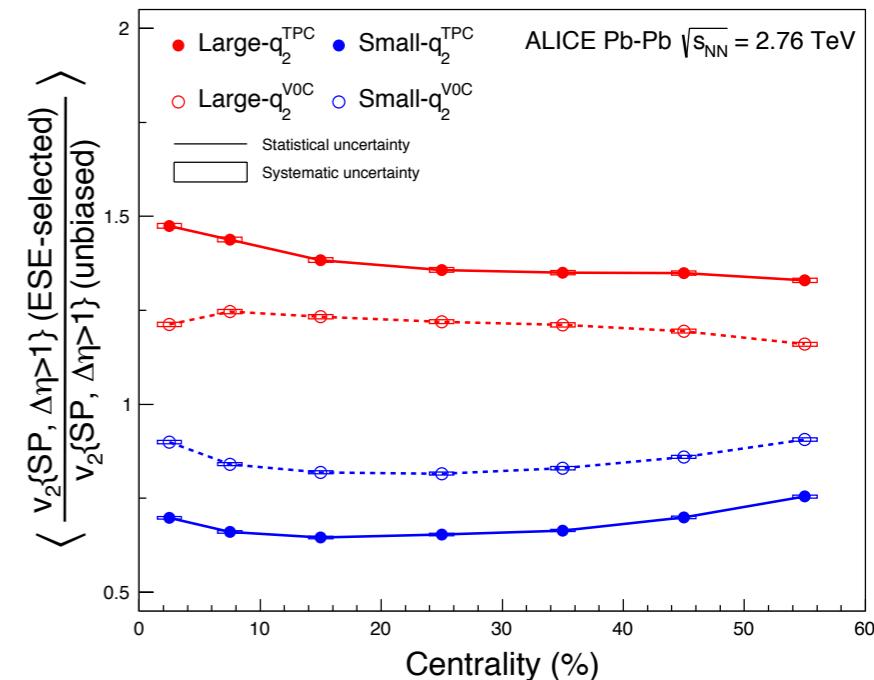
# Summary

- ESE works well with ALICE detector
  - ✓ Can increase  $v_2$  up to 50%
  - ✓ Non-flow does not influence results
  - ✓ Similar observations in ATLAS studies (PRC 92 (2015) 034903)



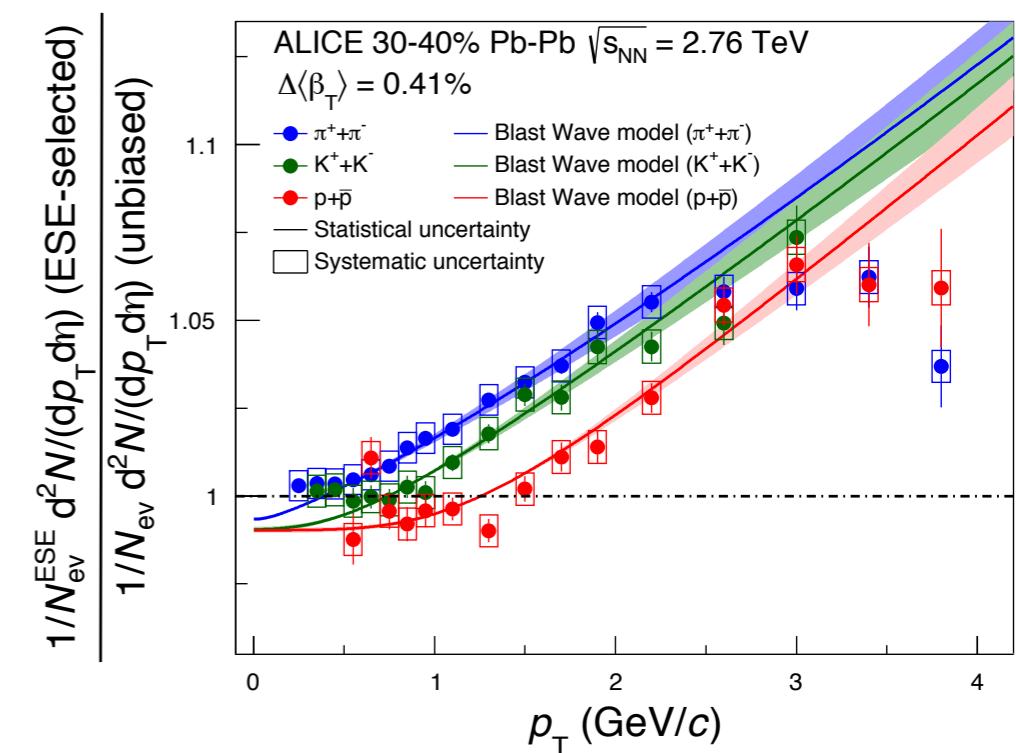
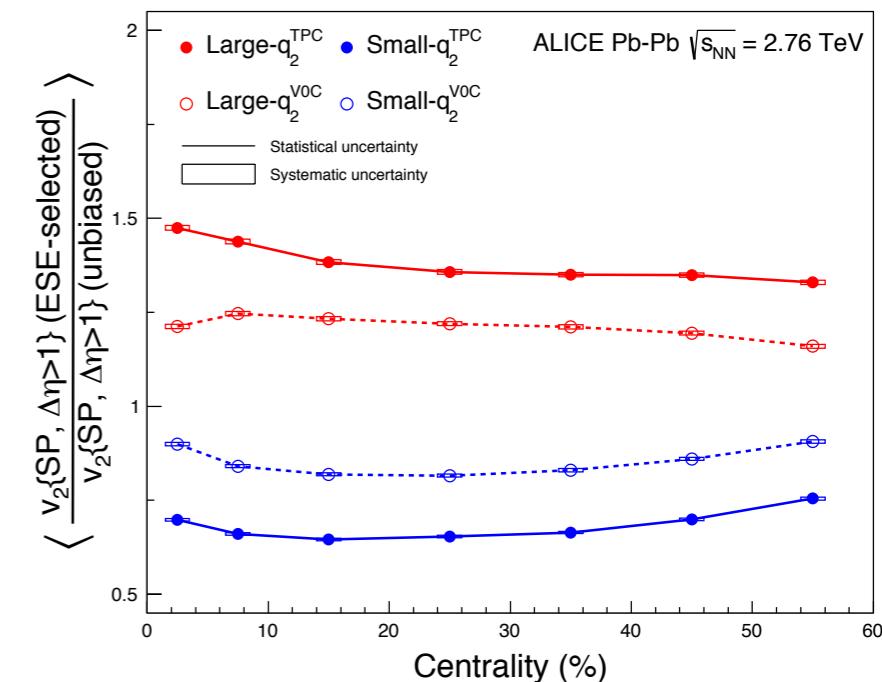
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  - ✓ Can increase  $v_2$  up to 50%
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- Positive correlations between  $\langle v_2 \rangle$  and  $\langle p_T \rangle$ 
  - ✓ Strongest for mid-central collisions
  - ✓ Blast wave study implies correlation between elliptic and radial flow
  - ✓ Glauber study indicates correlations induced from initial conditions



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  - ✓ Glauber study indicates correlations induced from initial conditions
- Comparisons to hydro models would be very useful
  - ✓ Increasing  $\eta/s$  decreases elliptic flow/increases radial flow
  - ✓ These measurements could therefore constrain  $\eta/s$  further



# Backup - $v_2\{\text{SP}\}$ systematic uncertainties

Effect	$v_2$	$v_2 \text{ large-}q_2$	$v_2 \text{ small-}q_2$
Track reconstruction	3.1% (0-20%)	3.1% (0-20%)	3.1% (0-20%)
	2.7% (20-60%)	2.7% (20-60%)	2.7% (20-60%)
	( $p_T = 0.2 \text{ GeV}/c$ )	( $p_T = 0.2 \text{ GeV}/c$ )	( $p_T = 0.2 \text{ GeV}/c$ )
	0.08% (0-20%)	0.08% (0-20%)	0.08% (0-20%)
	0.02% (20-60%)	0.02% (20-60%)	0.02% (20-60%)
	( $p_T = 1.5 \text{ GeV}/c$ )	( $p_T = 1.5 \text{ GeV}/c$ )	( $p_T = 1.5 \text{ GeV}/c$ )
Tracking efficiency	0.07%	0.35%	0.14 %
Centrality resolution	0.21%	0.35%	0.35%
Centrality estimator	0.57%	0.49%	0.57%
Secondary particles	3.56%	3.56%	3.56%
	( $p_T = 0.2 \text{ GeV}/c$ )	( $p_T = 0.2 \text{ GeV}/c$ )	( $p_T = 0.2 \text{ GeV}/c$ )
	0.8%	0.8%	0.8%
	( $p_T = 1.5 \text{ GeV}/c$ )	( $p_T = 1.5 \text{ GeV}/c$ )	( $p_T = 1.5 \text{ GeV}/c$ )
Magnetic field	NS	NS	NS
Charge	NS	NS	NS
Vertex	NS	NS	NS

**Table 1:** Summary of systematic errors on  $v_2\{\text{SP}\}$  measurement. NS = not statistically significant.

## Main contributors

Effect	$v_2 \text{ large-}q_2/\text{unbiased}$	$v_2 \text{ small-}q_2/\text{unbiased}$
Track reconstruction	0.14%	0.14%
Tracking efficiency	0.35 %	0.21%
Centrality resolution	0.14%	0.21%
Centrality estimator	0.14%	0.07%
Secondary particles	0.07%	0.35%
Magnetic Field	NS	NS
Charge	NS	NS
Vertex	NS	NS

**Table 2:** Summary of systematic errors on the  $v_2\{\text{SP}\}$  ratios. NS = not statistically significant.



# Backup - spectra ratio systematic uncertainties

Effect	$N_{ch}$	$\pi^\pm$	$K^\pm$	p and $\bar{p}$
Track reconstruction	< 0.035%	0.07%	0.07%	0.07%
Tracking efficiency	0.21%	0.21%	0.21%	0.21%
Centrality resolution	0.07% ( $p_T > 1.5 \text{ GeV}/c$ )	0.07% ( $p_T > 1.5 \text{ GeV}/c$ )	0.14%	0.14%
Centrality estimator	0.35%	0.35%	0.35%	0.35%
PID	-	0.07% ( $p_T > 1.5 \text{ GeV}/c$ )	0.07%	0.07%
Secondary particles	< 0.035%	< 0.035%	< 0.035%	0.07%
Normalization	1.1%	1.1%	1.1%	1.1%
Magnetic field	NS	NS	NS	NS
Charge	< 0.035%	< 0.035%	< 0.035%	< 0.035%
Vertex	0.07%	0.07%	0.07%	0.07%

**Table 3:** Summary of systematic errors for the ratio of  $p_T$  distributions between large- $q_2$  and unbiased events. NS = not statistically significant.

Main contributors

Effect	$N_{ch}$	$\pi^\pm$	$K^\pm$	p and $\bar{p}$
Track reconstruction	< 0.035%	0.07%	0.07%	0.07%
Tracking efficiency	0.28%	0.28%	0.28%	0.28%
Centrality resolution	0.07% ( $p_T > 1.5 \text{ GeV}/c$ )	0.07% ( $p_T > 1.5 \text{ GeV}/c$ )	0.14%	0.14%
Centrality estimator	0.35%	0.35%	0.35%	0.35%
PID	-	0.07% ( $p_T > 1.5 \text{ GeV}/c$ )	0.07%	0.07%
Secondary particles	< 0.035%	< 0.035%	< 0.035%	0.07%
Normalization	0.6%	0.6%	0.6%	0.6%
Magnetic field	NS	NS	NS	NS
Charge	< 0.035%	< 0.035%	< 0.035%	< 0.035%
Vertex	0.07%	0.07%	0.07%	0.07%

**Table 4:** Summary of systematic errors for the ratio of  $p_T$  distributions between small- $q_2$  and unbiased events. NS = not statistically significant.

