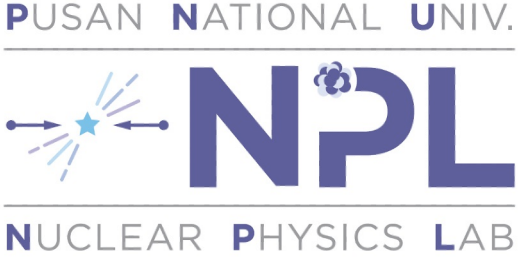
Toward Unbiased Flow Measurements in LHC pp Collisions

S.J. Ji[1], M. Virta[2], S.H. Lim[1], D.J. Kim[2]

1. Pusan National University
2. University of Jyväskylä

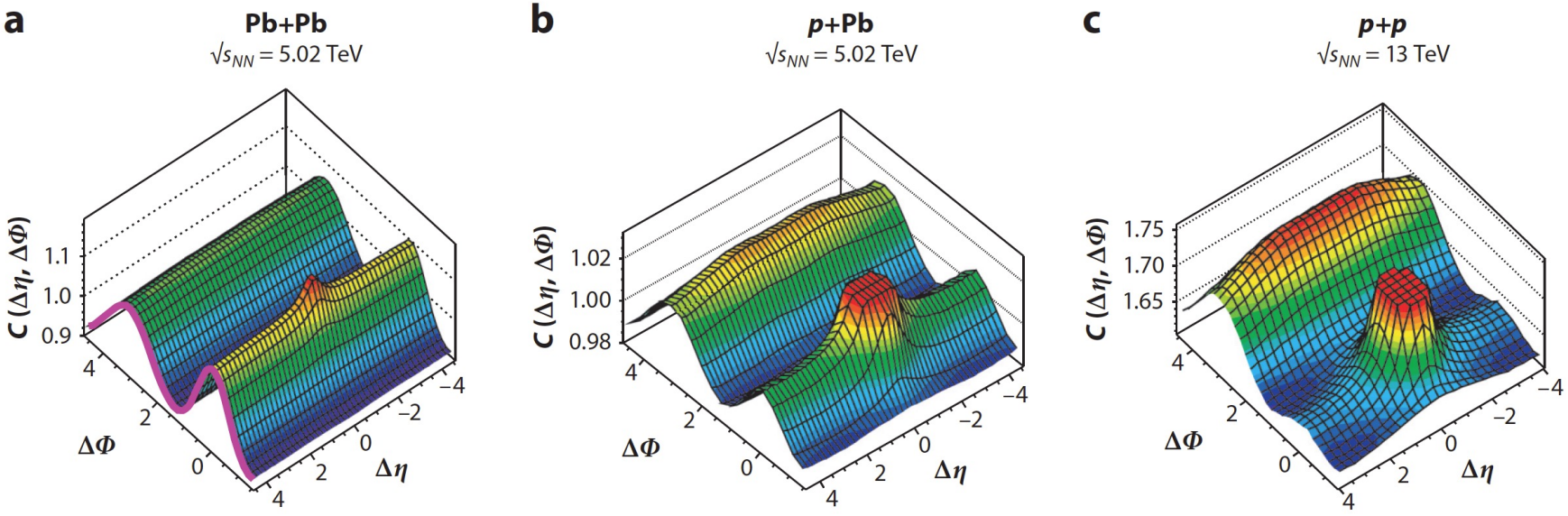
WWND 2023, Feb 9th

UNIVERSITY OF JYVÄSKYLÄ



1. Motivation Two-particle correlations

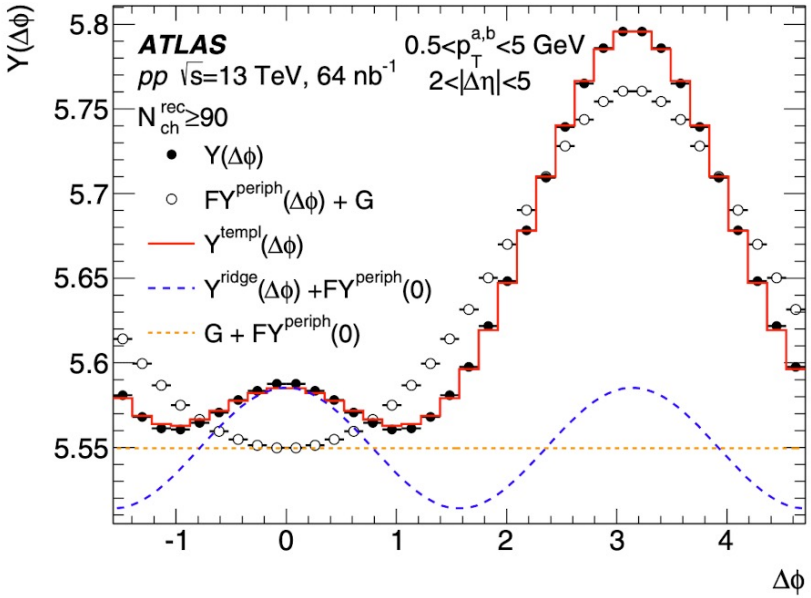
Annu. Rev. Nucl. Part. Sci. 2018. 68:211-35



- Flow measurements via two-particle correlations method.
- Long-range azimuthal correlation : observed also in small systems, not only in large systems.
- Understanding the jet components in the small systems is crucial due to the large non-flow contribution.

1. Motivation Flow measurement in small systems

PRC 96, 024908 (2017)

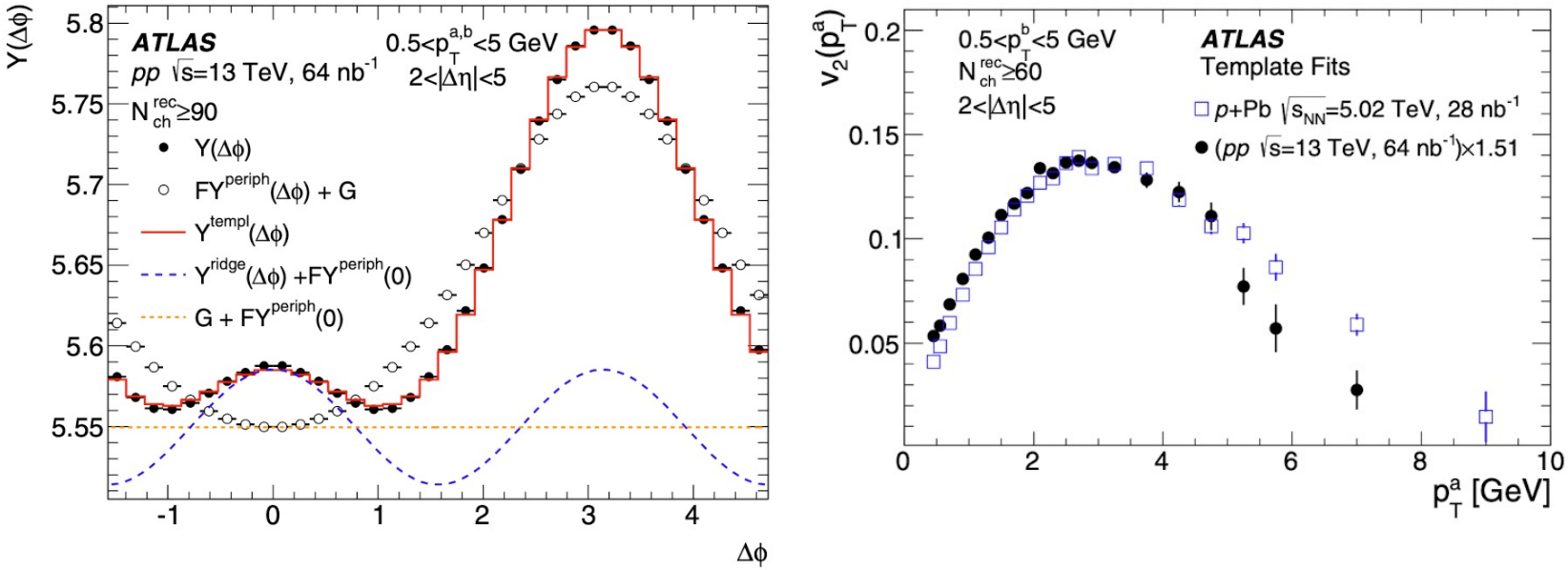


- Assumptions
  - No ridge or flow in the LM-template
  - No away-side jet modifications (quenching) in HM events relative to the LM-template

- To handle the non-flow in small systems, ATLAS has developed the template fit method.
- The template fit method describes the HM correlation function by the simultaneous fit of LM templates and flow components.

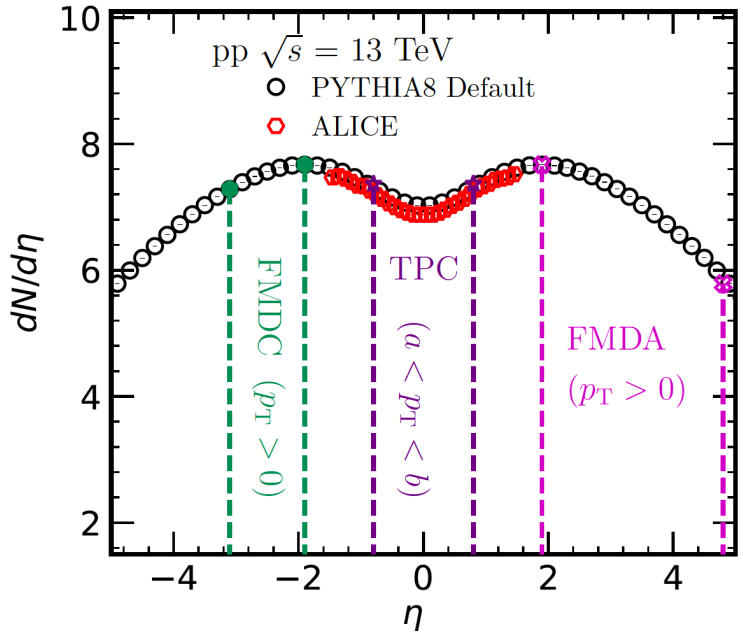
1. Motivation Flow measurement in small systems

PRC 96, 024908 (2017)

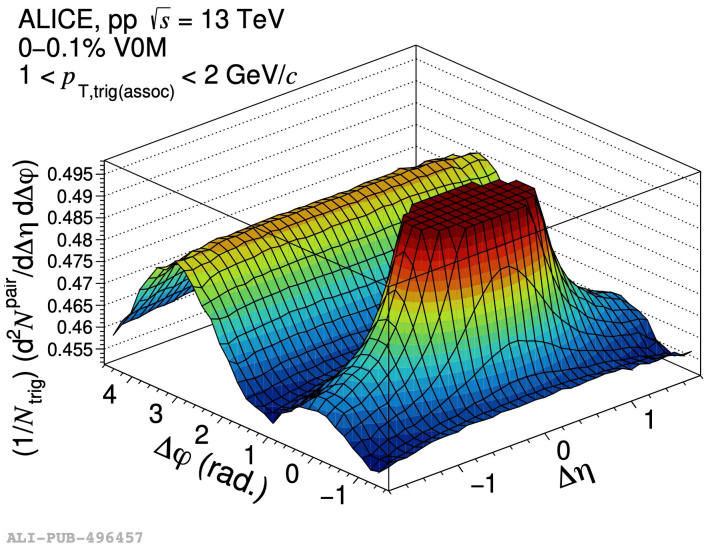


- To handle the non-flow in small systems, ATLAS has developed the template fit method.
- The template fit method describes the HM correlation function by the simultaneous fit of LM templates and flow components.
- The right figure is the v_2 using the template fit method in pp and p–Pb collisions and the similar shapes for both systems are seen as function of p_T.

1. Motivation Flow measurements in small systems

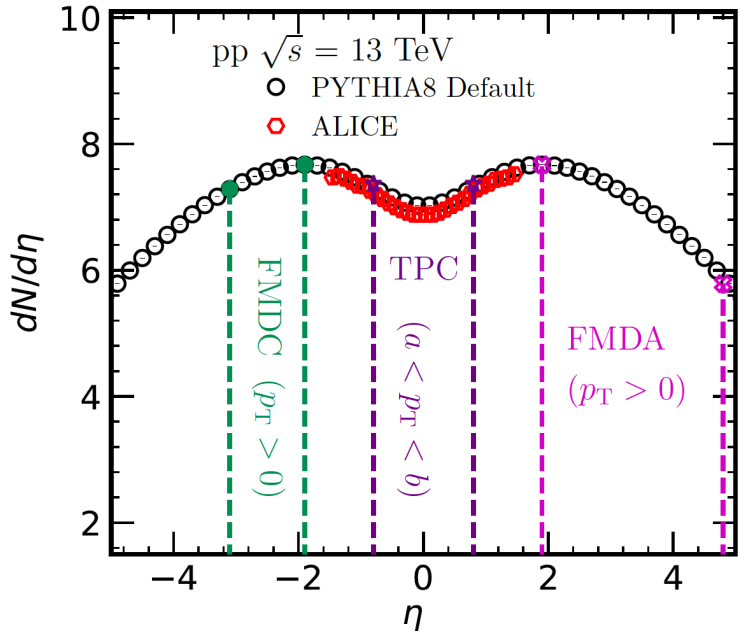


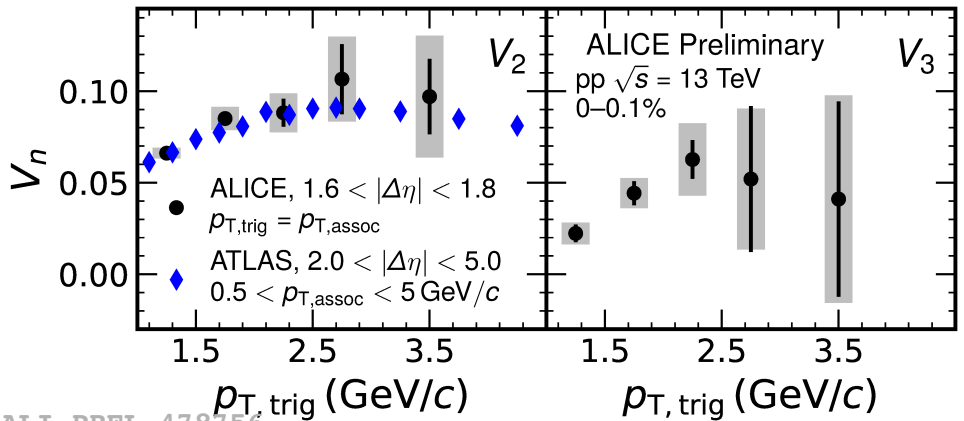
JHEP 05 (2021) 290



- ALICE has also measured the flow in small systems via the two-particle correlations method using the template fit method.
- However, the ALICE tracking detector, the TPC, has smaller acceptance than ATLAS and CMS.

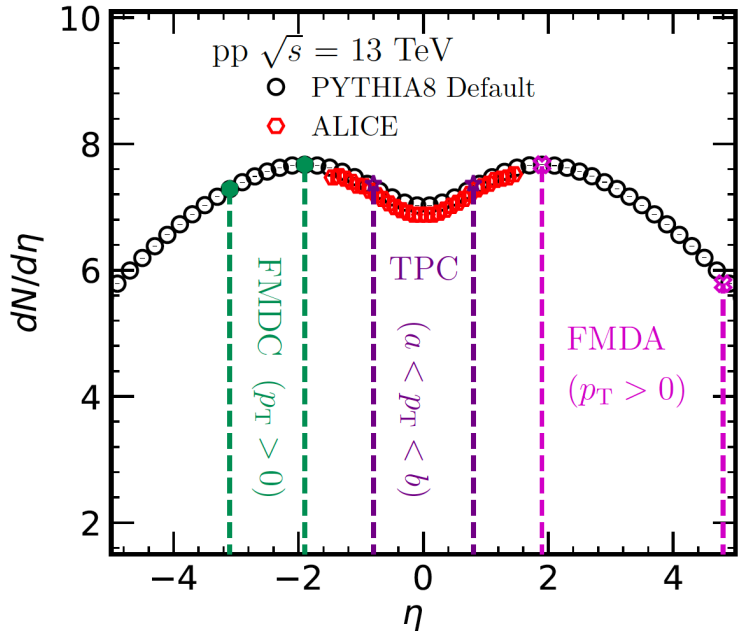
1. Motivation Flow measurements in small systems

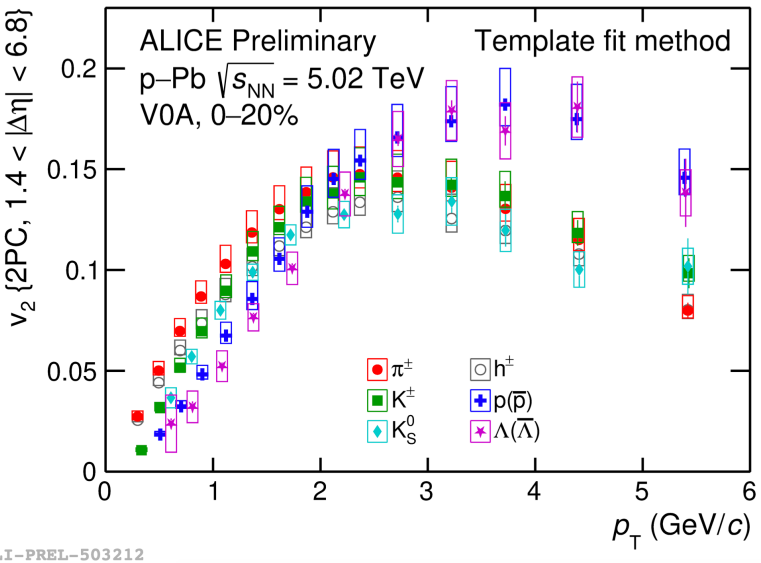




- ALICE has also measured the flow in small systems via the two-particle correlations method using the template fit method.
- However, the ALICE tracking detector, the TPC, has smaller acceptance than ATLAS and CMS.
- The right figures show the v_2 and v_3 with ALICE and v_2 is compared with the ATLAS result, and similar v_2 results are seen.

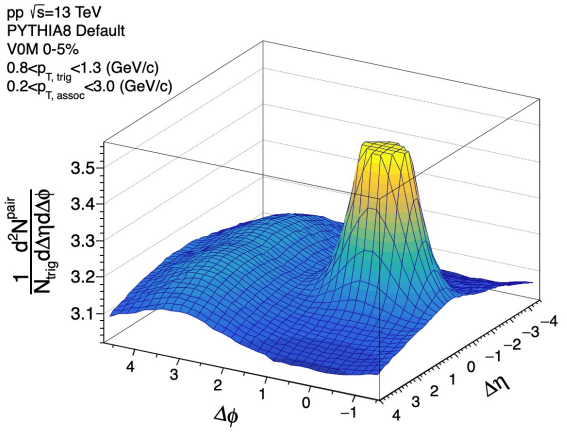
1. Motivation Flow measurements in small systems

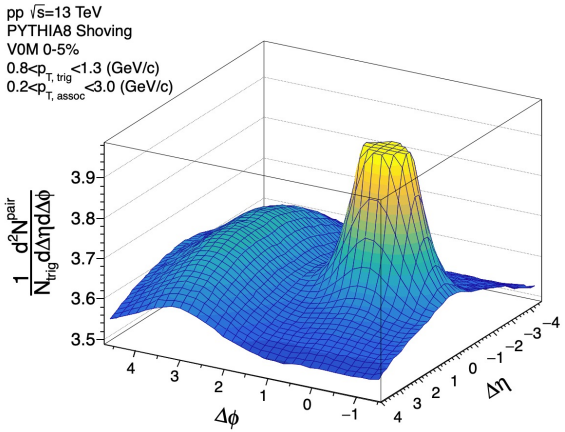


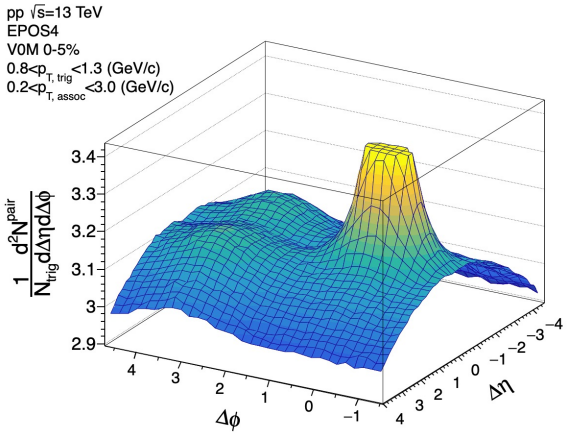


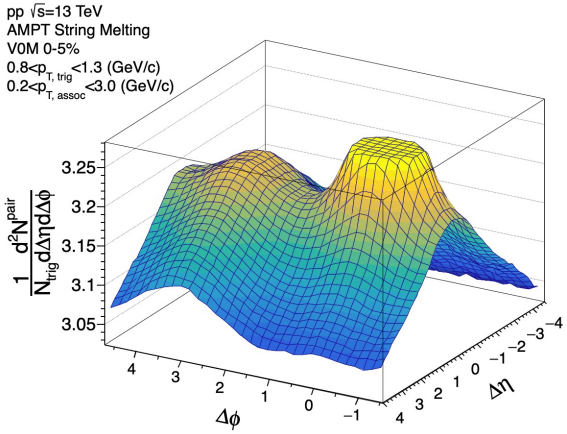
- There is an attempt to measure the flow coefficient by correlating the particles in TPC with FMD in pp and p–Pb collisions for the better statistics.
- Not only measuring the flow of the charged hadrons but also the measurement of PID flow is on going with the ability of the particle identification of the ALICE detector.
- We conducted a detailed study on the acceptance and model dependence of the template fit method.

1. Motivation Model description



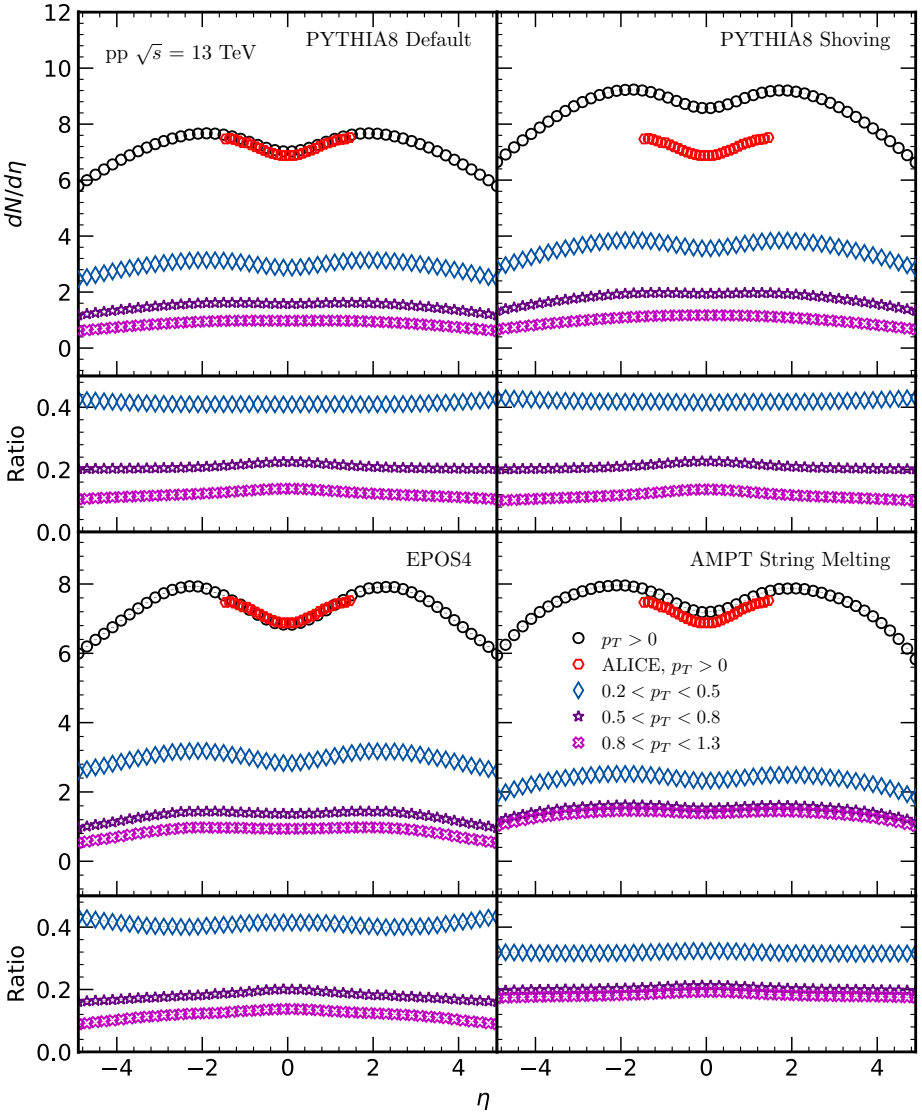






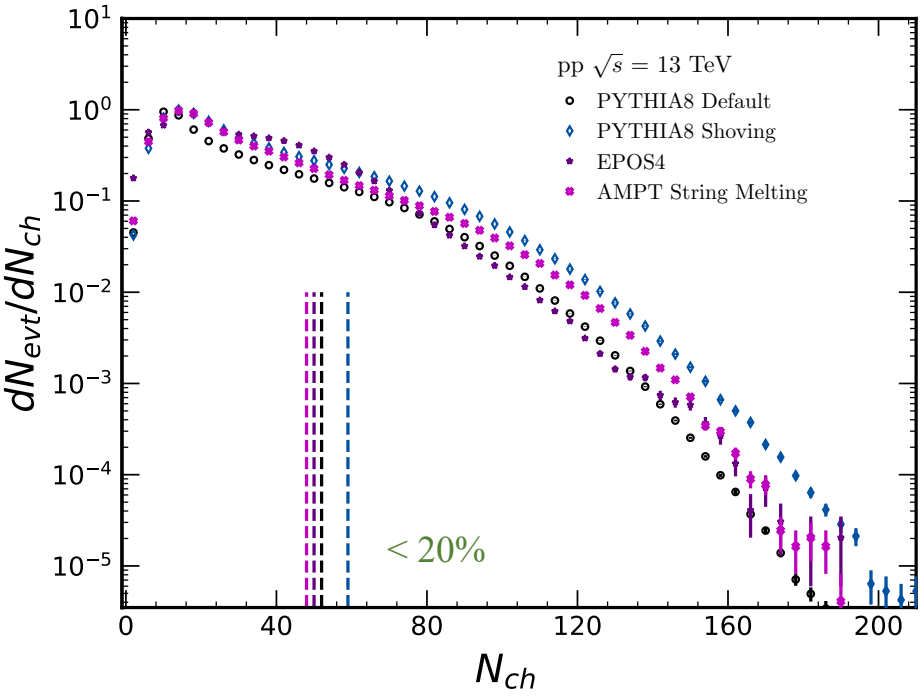
- PYTHIA8 Default
  : Only contains non-flow components
- PYTHIA8 String Shoving
  : Long-range correlation exists from the interactions between the strings.
- EPOS4
  : Contains flow components based on the hydrodynamics.
- AMPT String Melting
  : Long-range correlation exists from the scatterings between partons.

2. Analysis Model comparison



- MB events of all the inelastic events are selected.
- Similar η distribution is seen in every model with the data apart from Shoving.
- Shoving overestimates dN/dη but p_T dependence are similar with PYTHIA8 and EPOS.
- p_T dependence in AMPT is smaller.

2. Analysis Model comparison

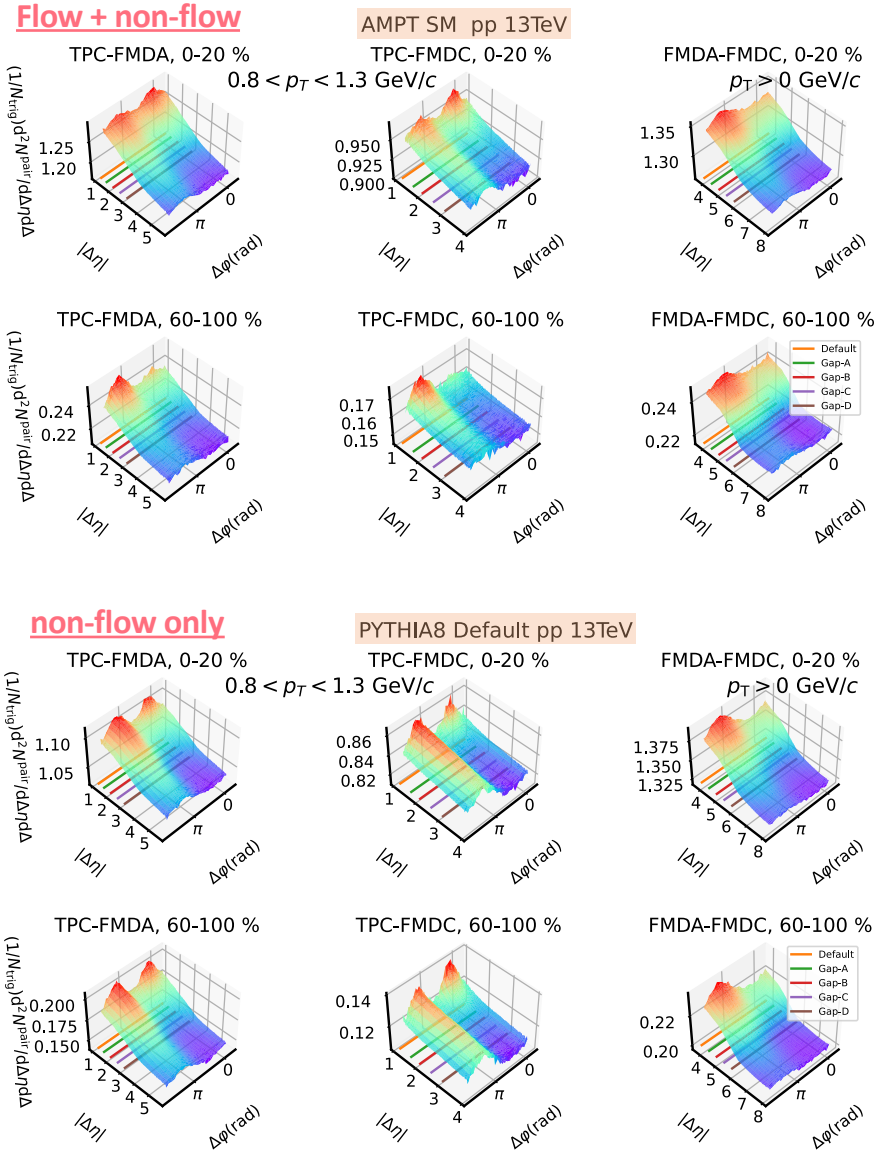


- The multiplicity is selected in V0M acceptance .
- The vertical lines show the event multiplicity of 20% of V0M percentile of each model.
- More HM events are generated with Shoving than others and less in PYTHIA8 and EPOS4.

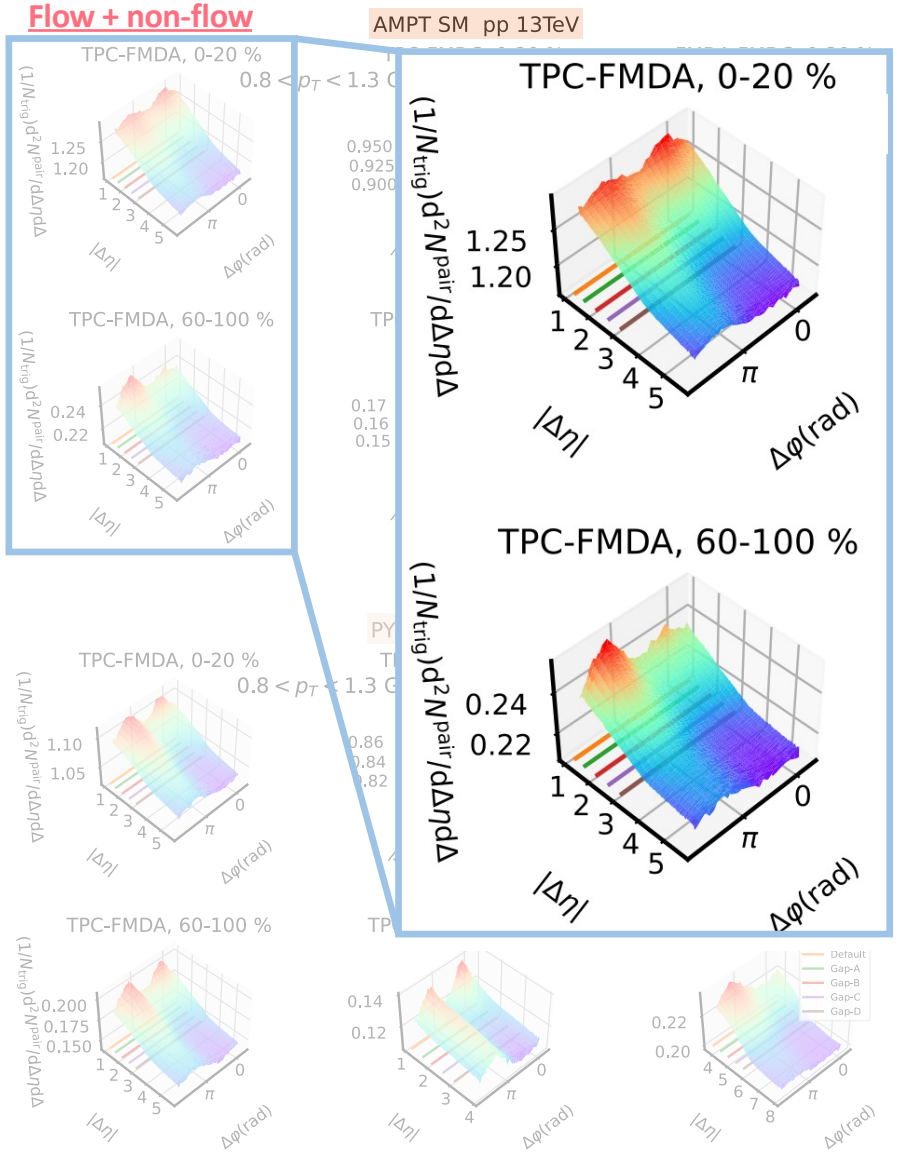
2. Analysis Correlation functions

TPC	FMDA	FMDC
[-0.8, 0.8]	[1.9, 4.8]	[-1.9, -3.1]

- Correlation functions of AMPT SM and PYTHIA8 Default are seen.
- Each model describes the structure of the correlation in different ways.



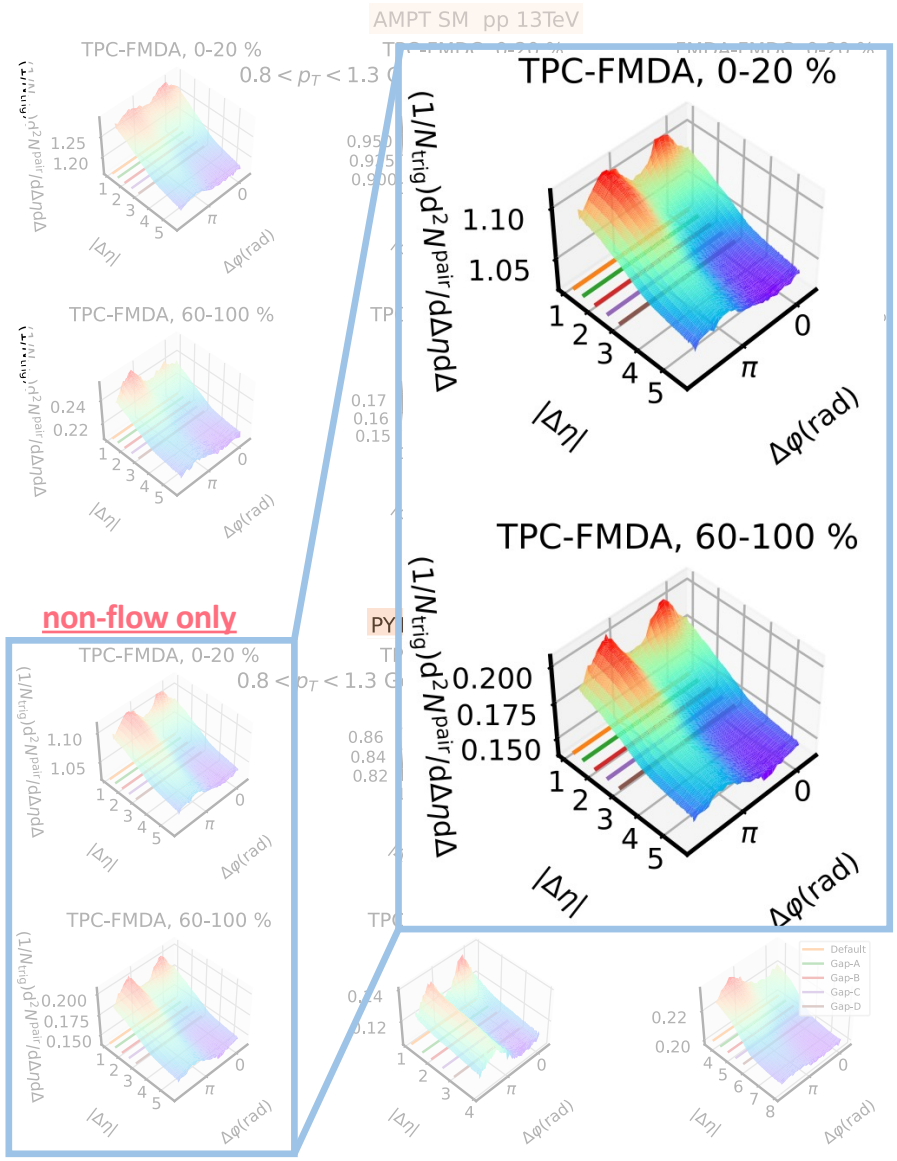
2. Analysis Correlation functions



TPC	FMDA	FMDC
[-0.8, 0.8]	[1.9, 4.8]	[-1.9, -3.1]

- Correlation functions of AMPT SM and PYTHIA8 Default are seen.
- Each model describes the structure of the correlation in different ways.
- As AMPT model contains flow, the near-side structure in shorter range is seen in HM unlike LM events.

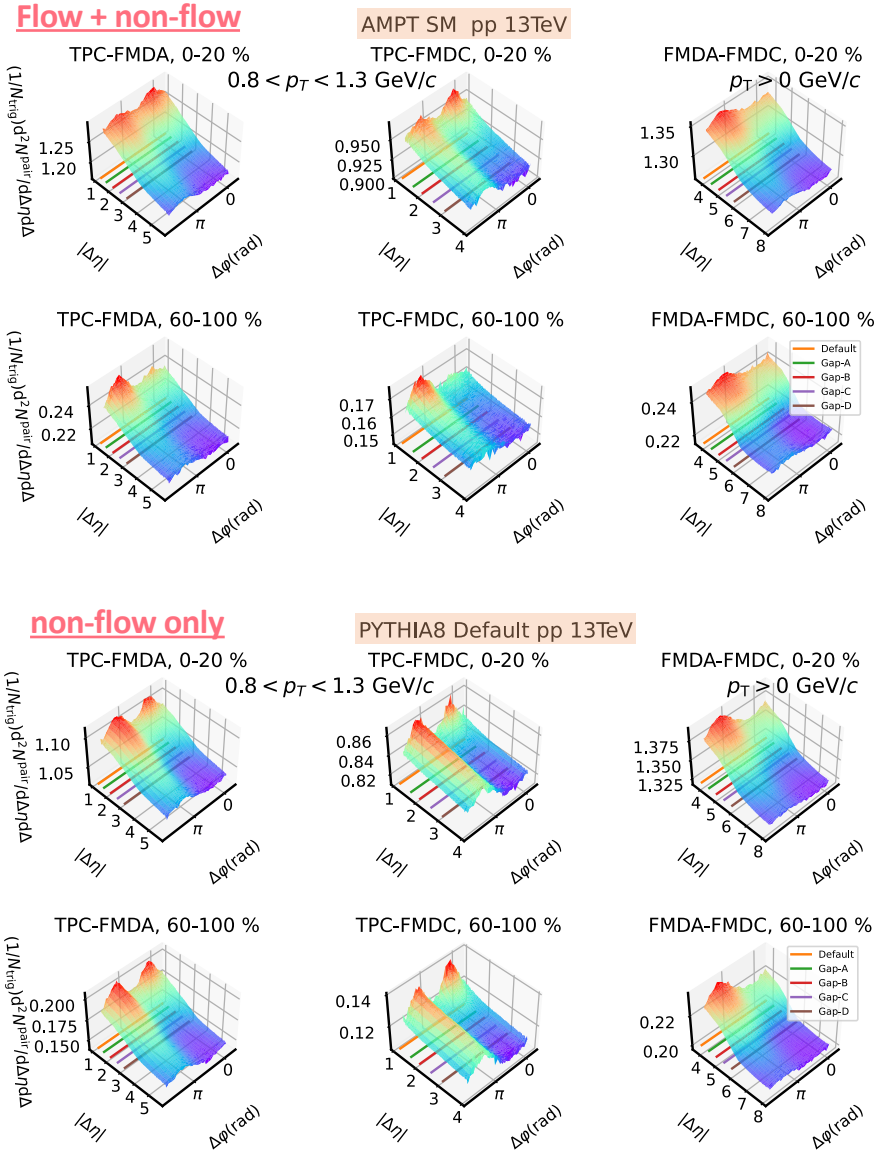
2. Analysis Correlation functions



TPC	FMDA	FMDC
[-0.8, 0.8]	[1.9, 4.8]	[-1.9, -3.1]

- Correlation functions of AMPT SM and PYTHIA8 Default are seen.
- Each model describes the structure of the correlation in different ways.
- As AMPT model contains flow, the near-side structure in shorter range is seen in HM unlike LM events.
- PYTHIA8 model shows similar structure for both LM and HM events.

2. Analysis Correlation functions

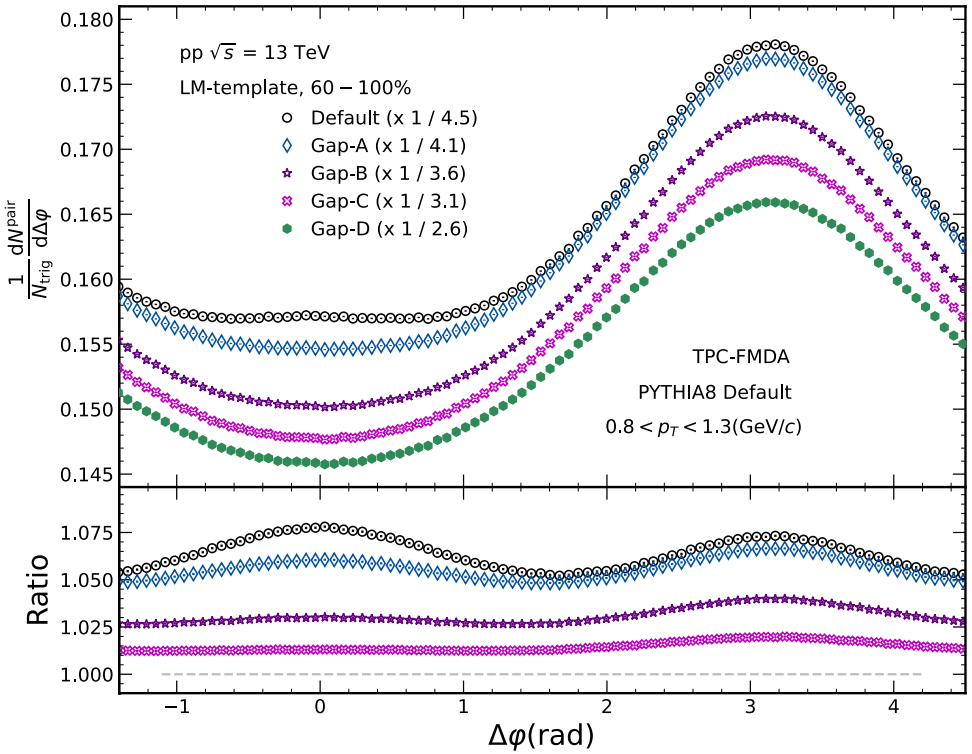


TPC	FMDA	FMDC
[-0.8, 0.8]	[1.9, 4.8]	[-1.9, -3.1]

- Correlation function of AMPT SM and PYTHIA8 Default is seen.
- Each model describes the structure in different ways.
- As AMPT model contains flow, the near-side structure in shorter range is seen in HM unlike LM events.
- PYTHIA8 model shows similar structure for both LM and HM events.
- We selected five Δη gaps to test the gap dependence of $v_2(v_{22})$.

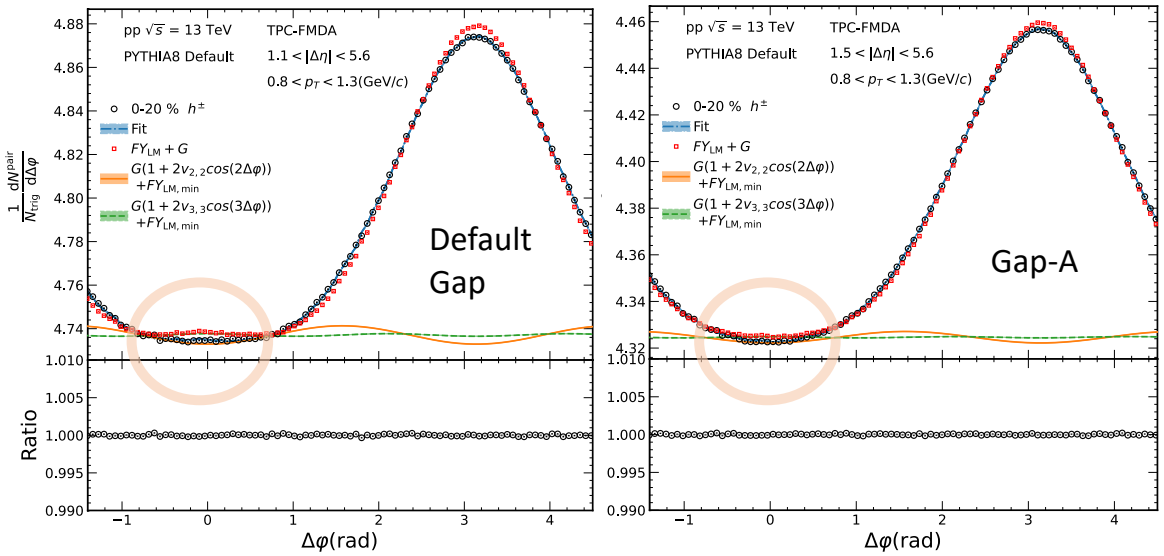
Correlations	$\Delta\eta$ range	Gap-A	Gap-B	Gap-C	Gap-D
TPC-FMDA	[1.1, 5.6]	[1.5, 5.6]	[2.0, 5.6]	[2.5, 5.6]	[3.0, 5.6]
TPC-FMDC	[-3.9, -1.1]	[-3.9, -1.6]	[-3.9, -2.0]	[-3.9, -2.5]	[-3.9, -3.0]
FMDA-FMDC	[-7.9, -3.8]	[-7.9, -4.3]	[-7.9, -4.8]	[-7.9, -5.3]	[-7.9, -5.8]

2. Analysis Δη gap dependence

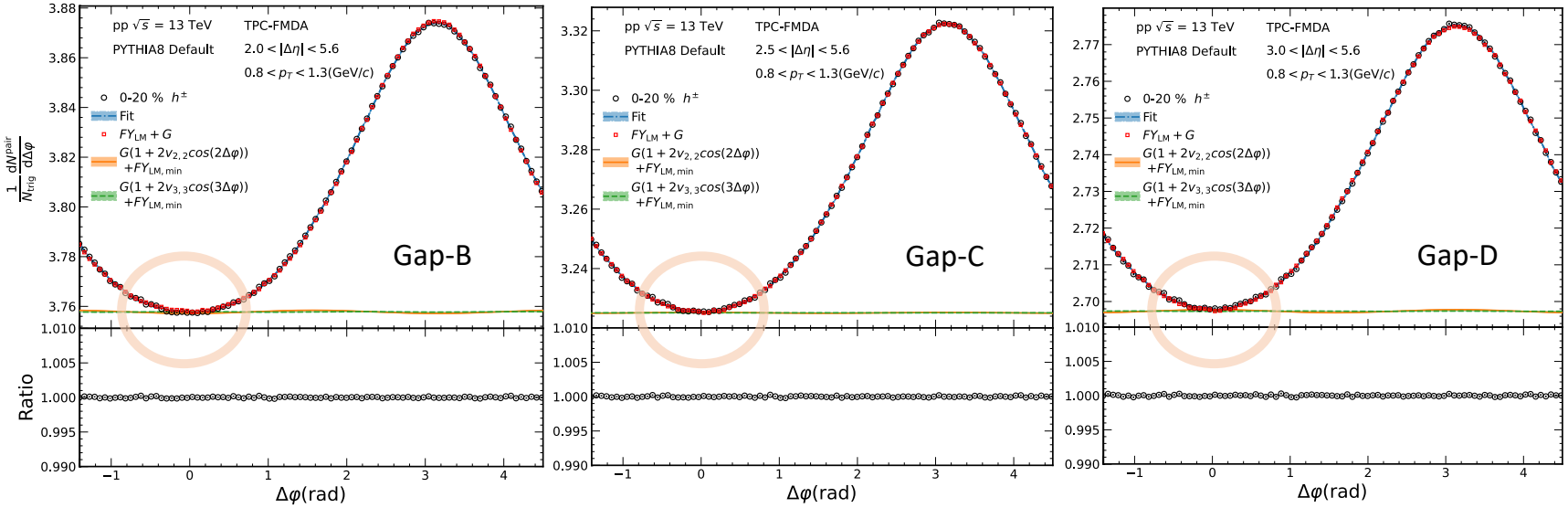


- The Δη gap dependence of the LM templates with PYTHIA8 is seen.
- Each histogram is normalised by Δη.
- The near-side yield becomes smaller as the Δη gap becomes larger.
- Also, the away-side jet fragments becomes smaller with increasing Δη gap.

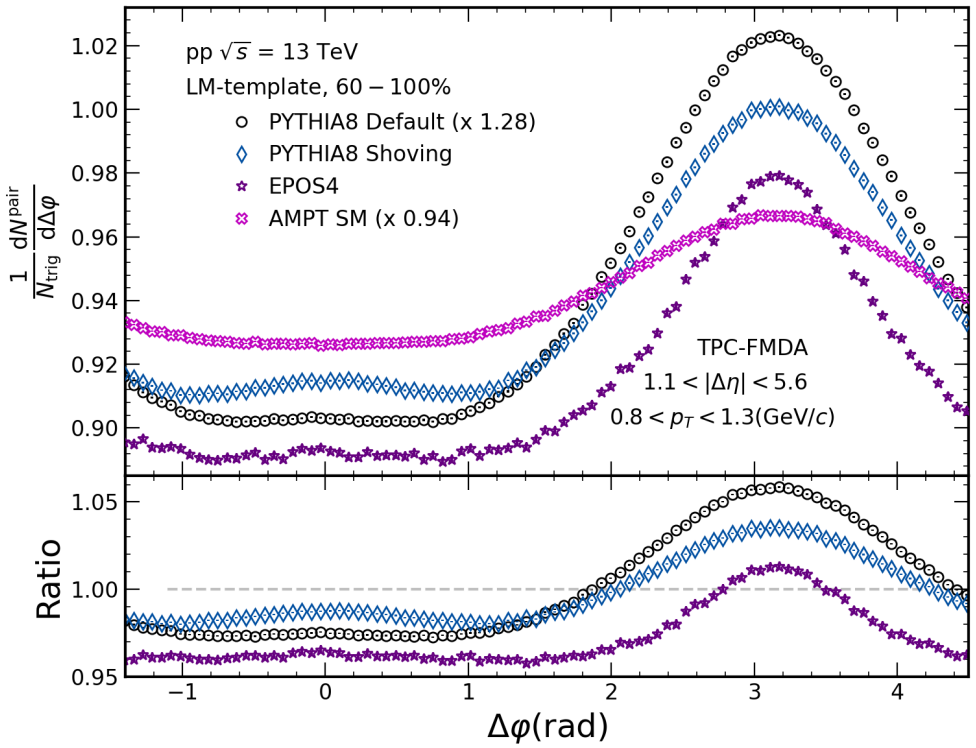
2. Analysis Δη gap dependence



- Template fit results of PYTHIA8 model in TPC-FMDA correlations are seen.
- The second order modulation is negative in the default gap and it becomes nearly zero in gap-B, C, and D with this p_T bin.

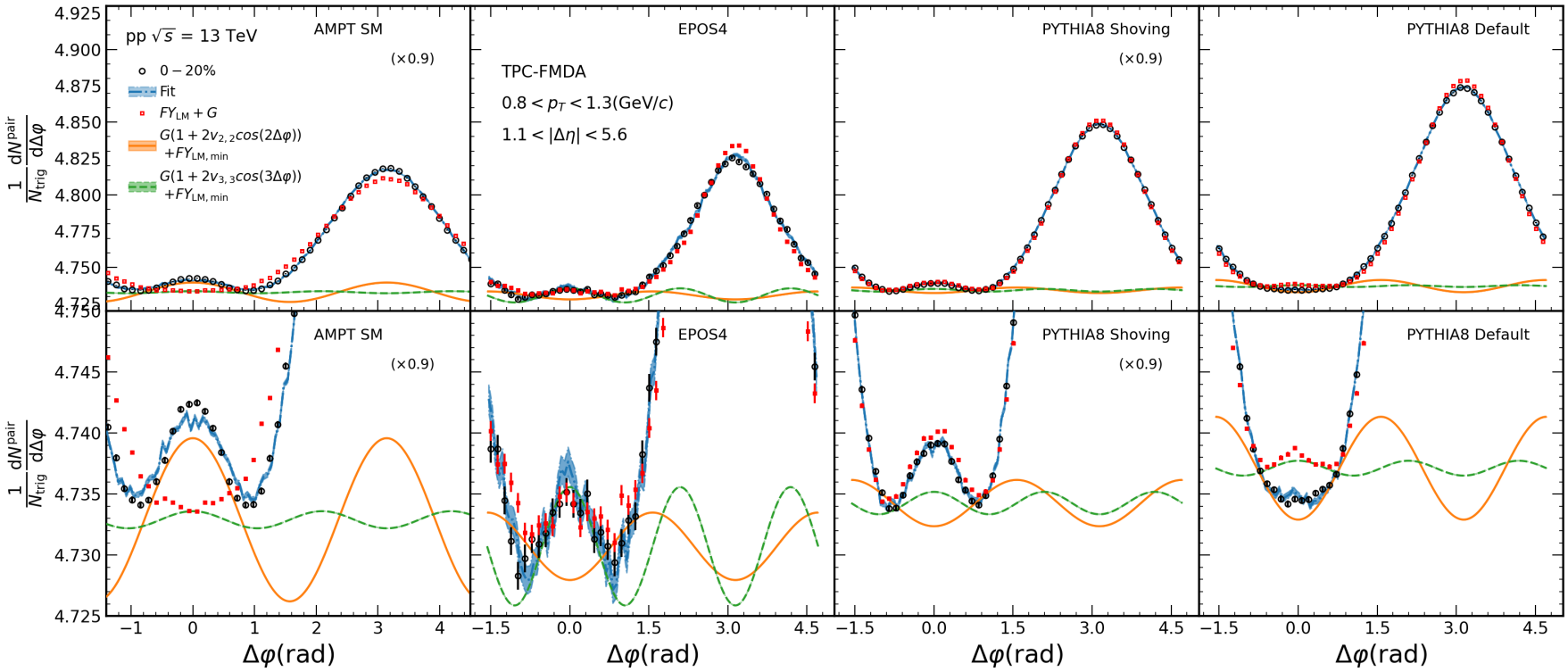


2. Analysis Model dependence



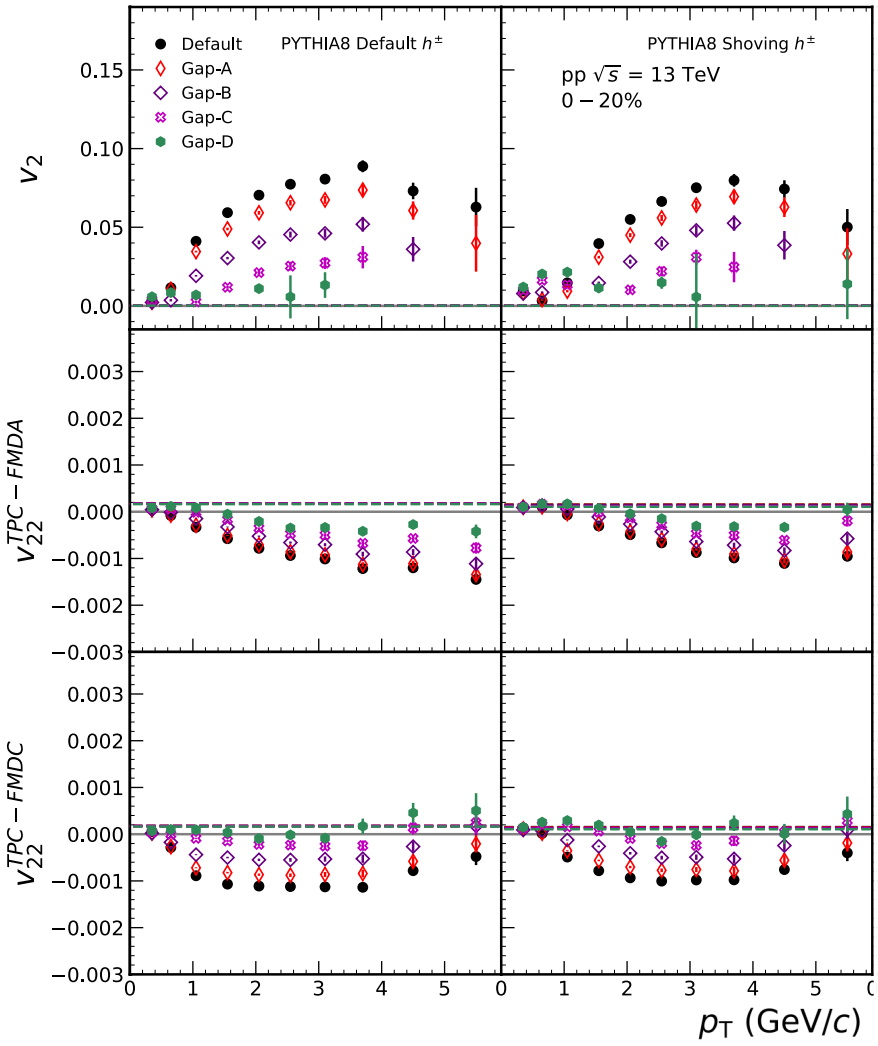
- The LM template in default Δη gap for each model is seen.
- Unlike AMPT, there are near-side yield for PYTHIA8 Default and Shoving.
- PYTHIA8 Default generates more correlated jets than others and AMPT generates less.
- The broad jet shape is seen for AMPT and narrow shape for EPOS4.

2. Analysis Model dependence



- The template fit results and zoomed near-side yields are seen in each column.
- Every model has near-side yield in LM events apart from AMPT and show the negative second order modulation.

2. Analysis Δη dependence of v_2, v_{22}

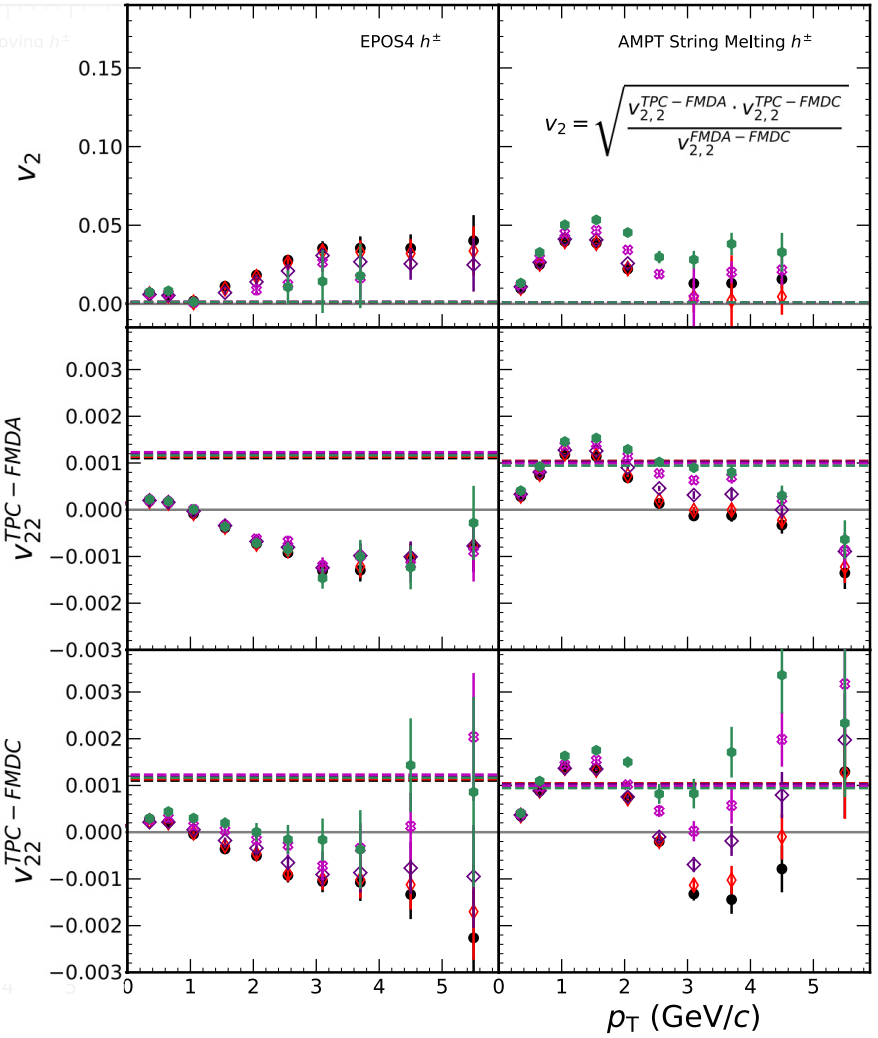


$$v_2 = \sqrt{\frac{v_{2,2}^{TPC-FMDA} \cdot v_{2,2}^{TPC-FMDC}}{v_{2,2}^{FMDA-FMDC}}}$$

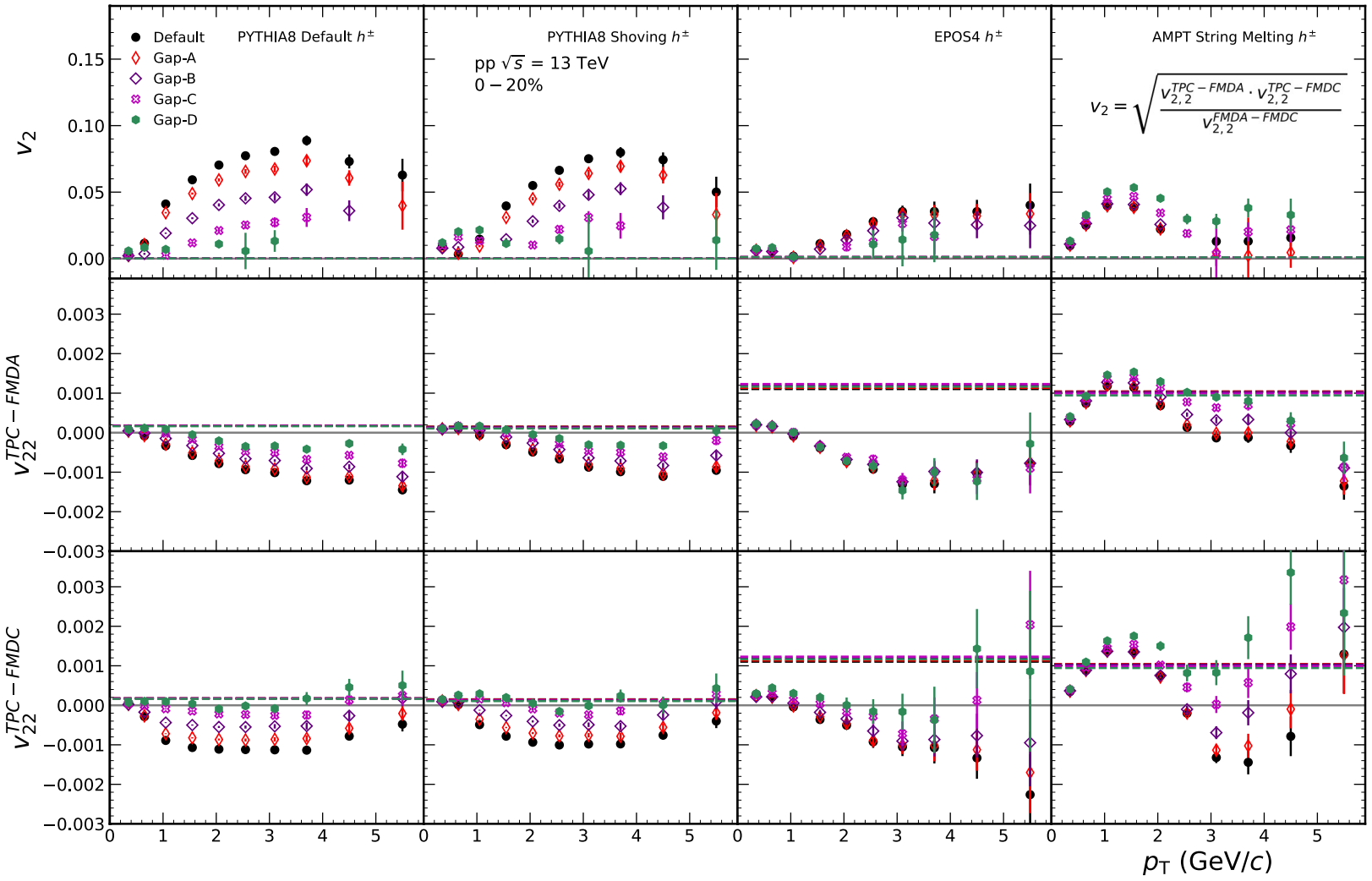
- Strong Δη dependence is seen for both PYTHIA8 Default and Shoving.
- The v_{22} is closer to zero as the Δη gap becomes larger.

2. Analysis Δη dependence of v_2, v_{22}

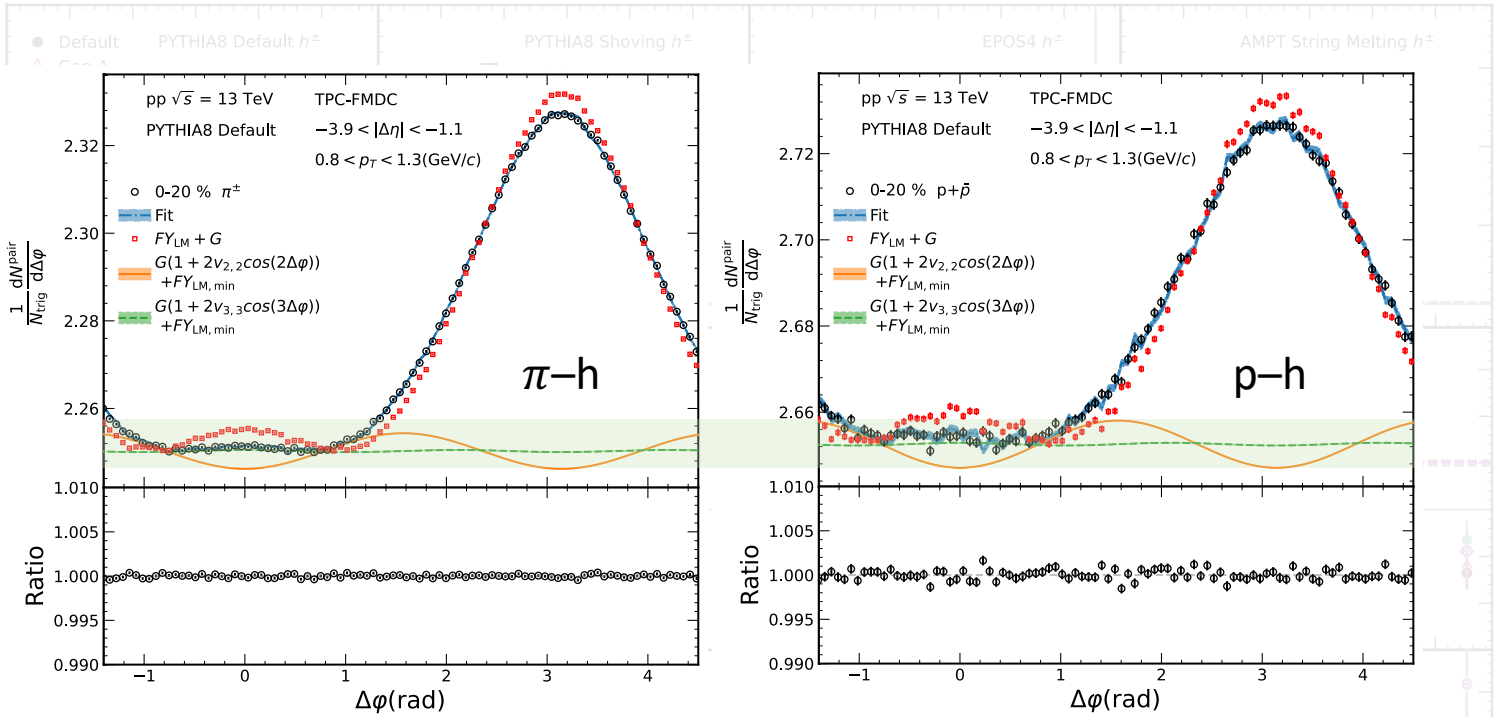
- PYTHIA-like v_2 and v_{22} are seen with EPOS4.
- Slight Δη dependence is seen for AMPT and v_2 becomes larger as Δη gap becomes wider.



2. Analysis Δη dependence of v_2, v_{22}

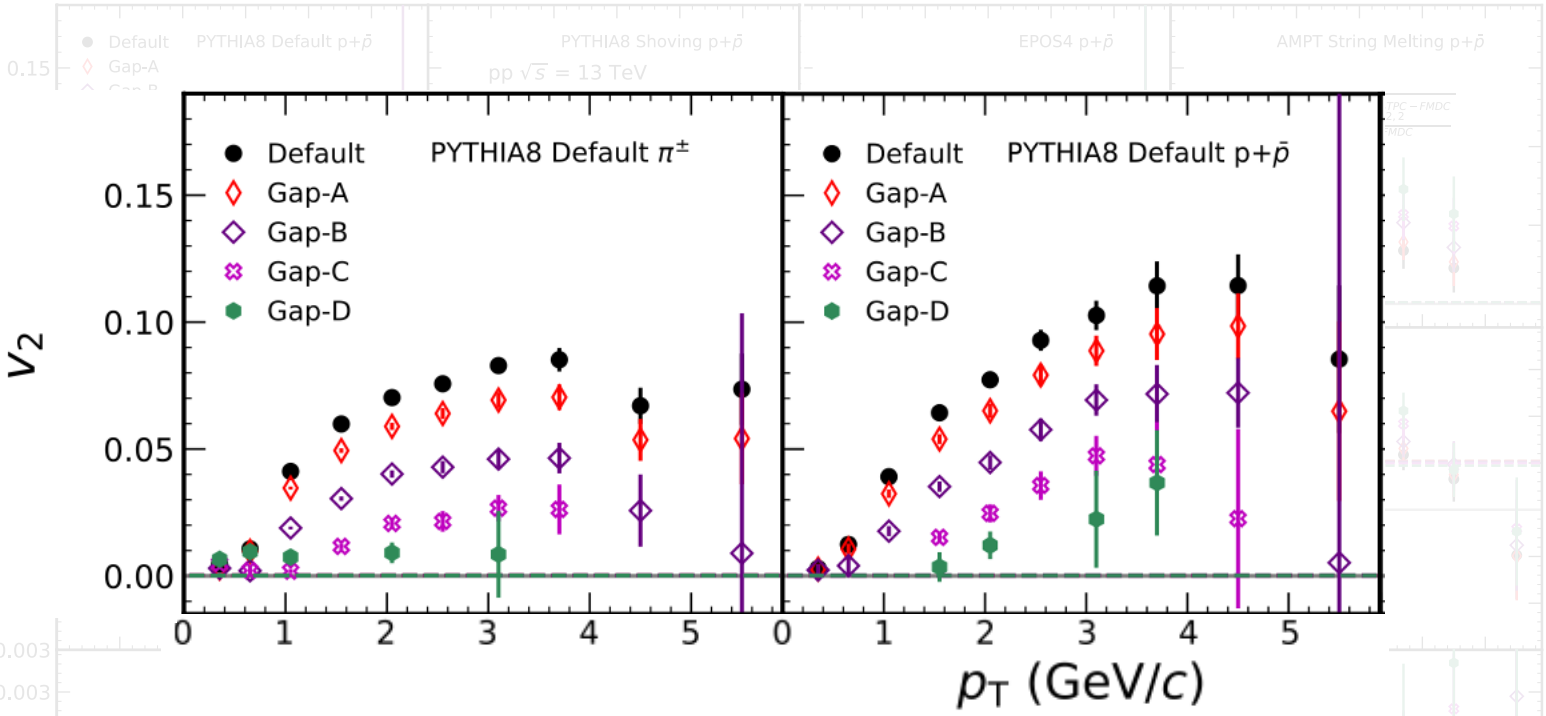


2. Analysis Δη dependence of v_2, v_{22}



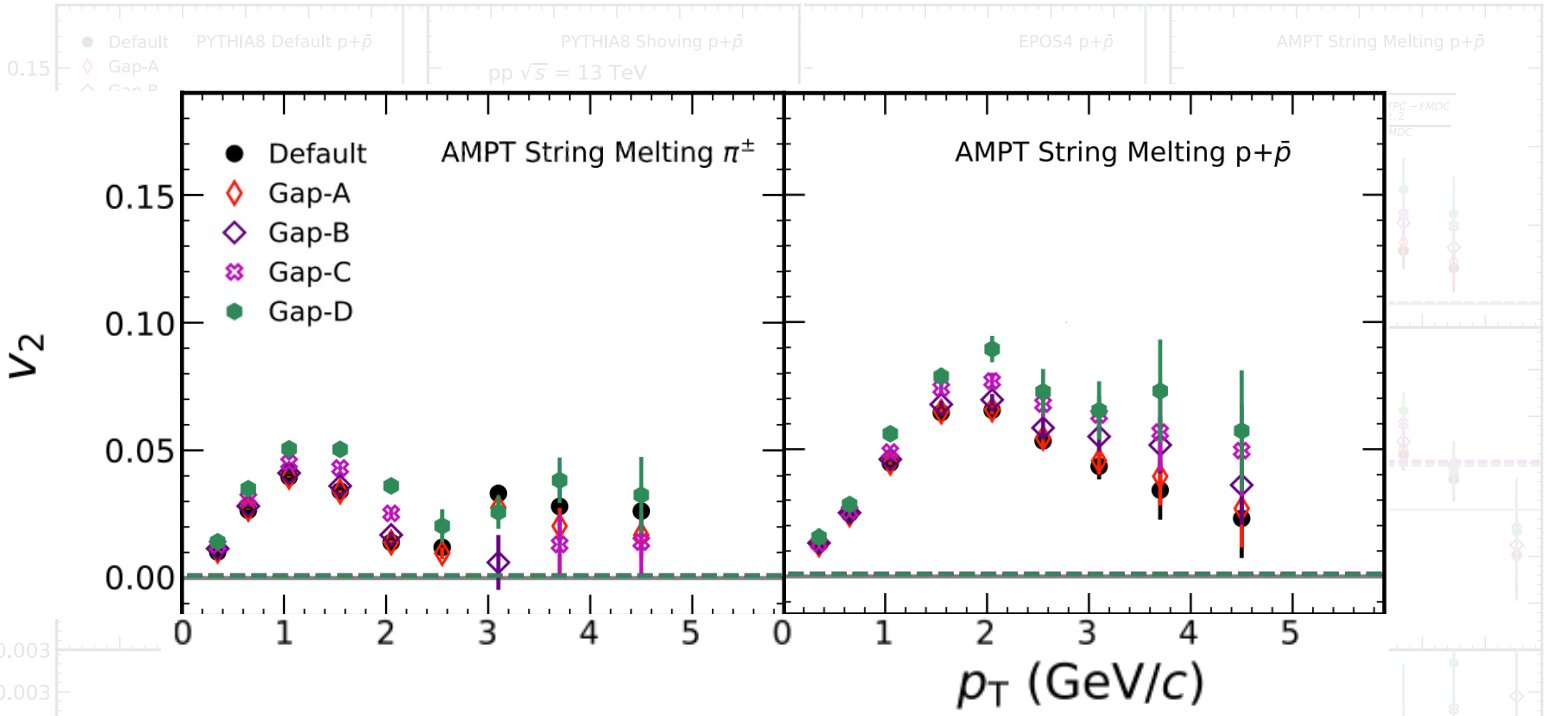
- Larger near-side yield and second modulation are seen in p–h correlations than π–h correlations.

2. Analysis Δη dependence of v_2, v_{22}



- Interestingly, the proton's v_2 is larger than pion's even with the PYTHIA8 Default which contains non-flow components only.
- There is a chance that the PID dependent non-flow might amplify the mass order effect in high p_T region.

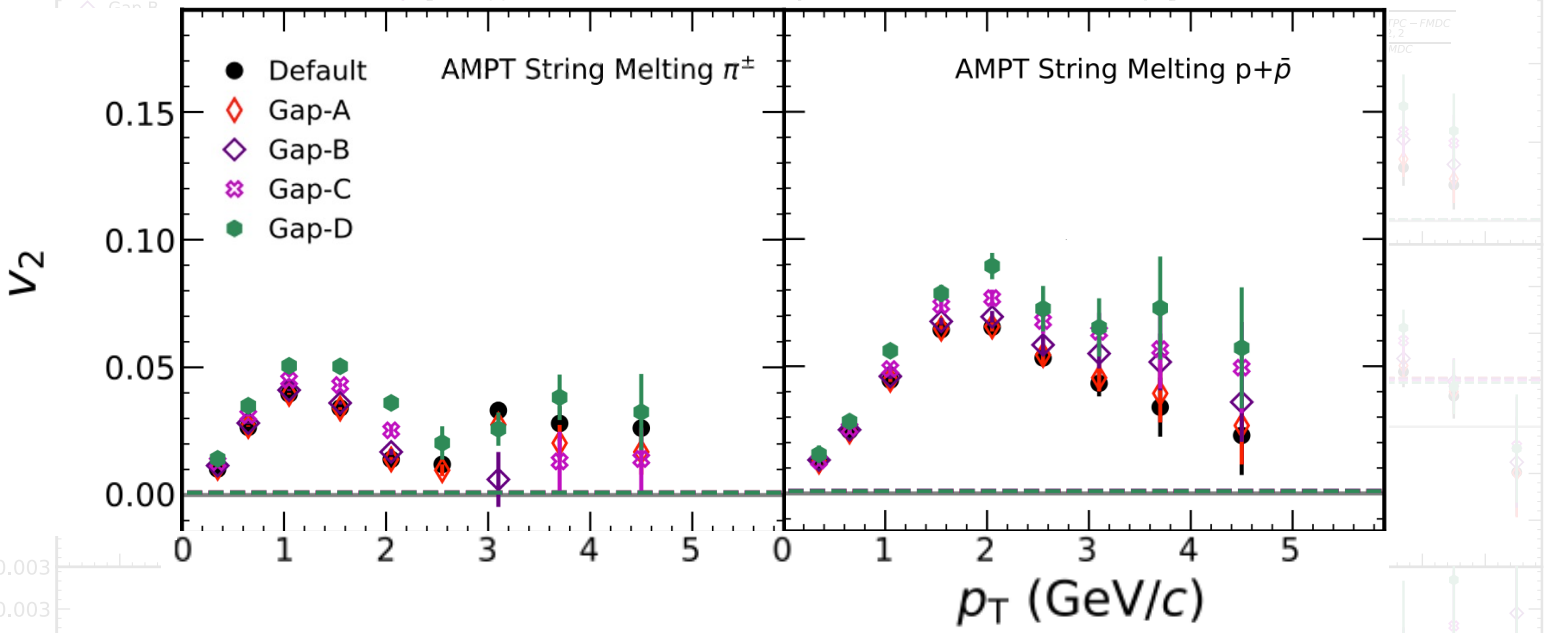
2. Analysis $\Delta\eta$ dependence of v_2, v_{22}



- Different v_2 is seen for different particles in AMPT model.
- The gap dependence is larger in high p_T region, implying that the non-flow component affects more as p_T goes higher.
- However, as the gap dependence is not very strong unlike PYTHIA8, we can think that still the flow component is dominant in AMPT model.

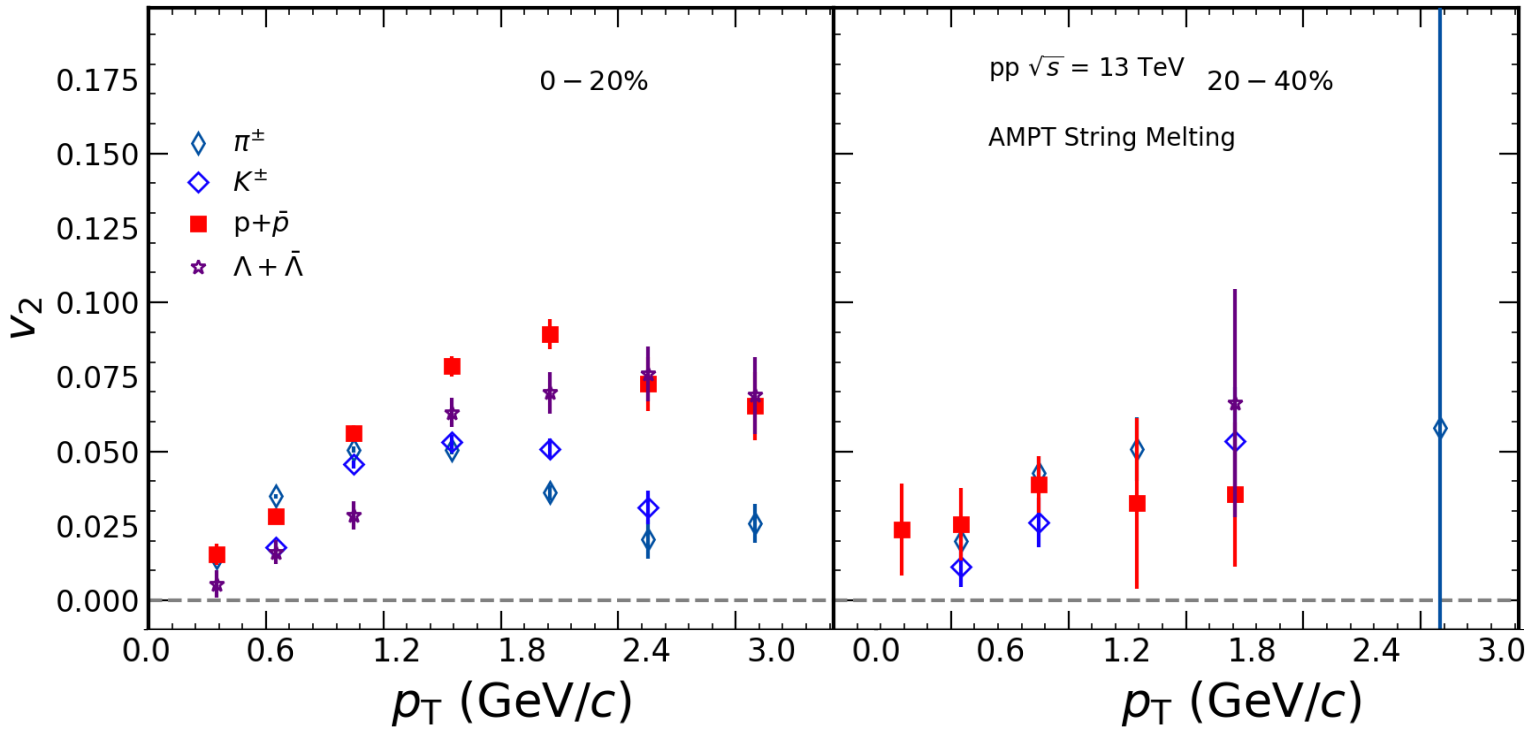
2. Analysis $\Delta\eta$ dependence of v_2, v_{22}

We selected the Gap-D for further discussions on PID v_2 with the AMPT model.



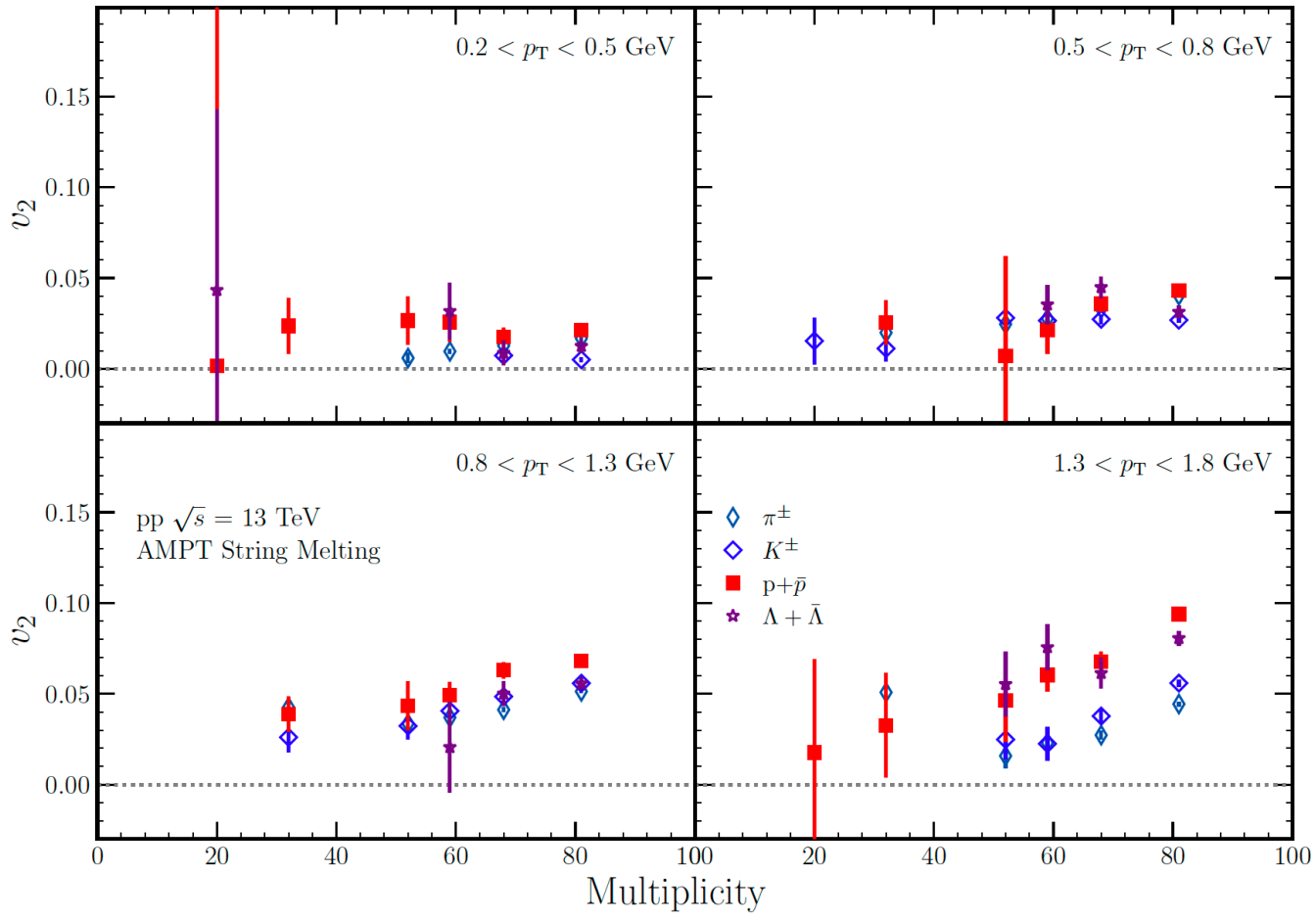
- Different v_2 is seen for different particles in AMPT model.
- The gap dependence is larger in high p_T region, implying that the non-flow component affects more as p_T goes higher.
- However, as the gap dependence is not very strong unlike PYTHIA8, we can think that still the flow component is dominant in AMPT model.

3. Results p_T dependence of v_2



- The PID v_2 as function of p_T with AMPT model is seen.
- Clear mass ordering is seen in 0–20%.
- As v_2 becomes smaller in 20–40% compared to 0–20%, we also checked the multiplicity dependence of v_2.

3. Results Multiplicity dependence of v_2



- The larger v_2 is seen with the increasing p_T and multiplicity.
- The PID seems to split more as the p_T becomes higher.

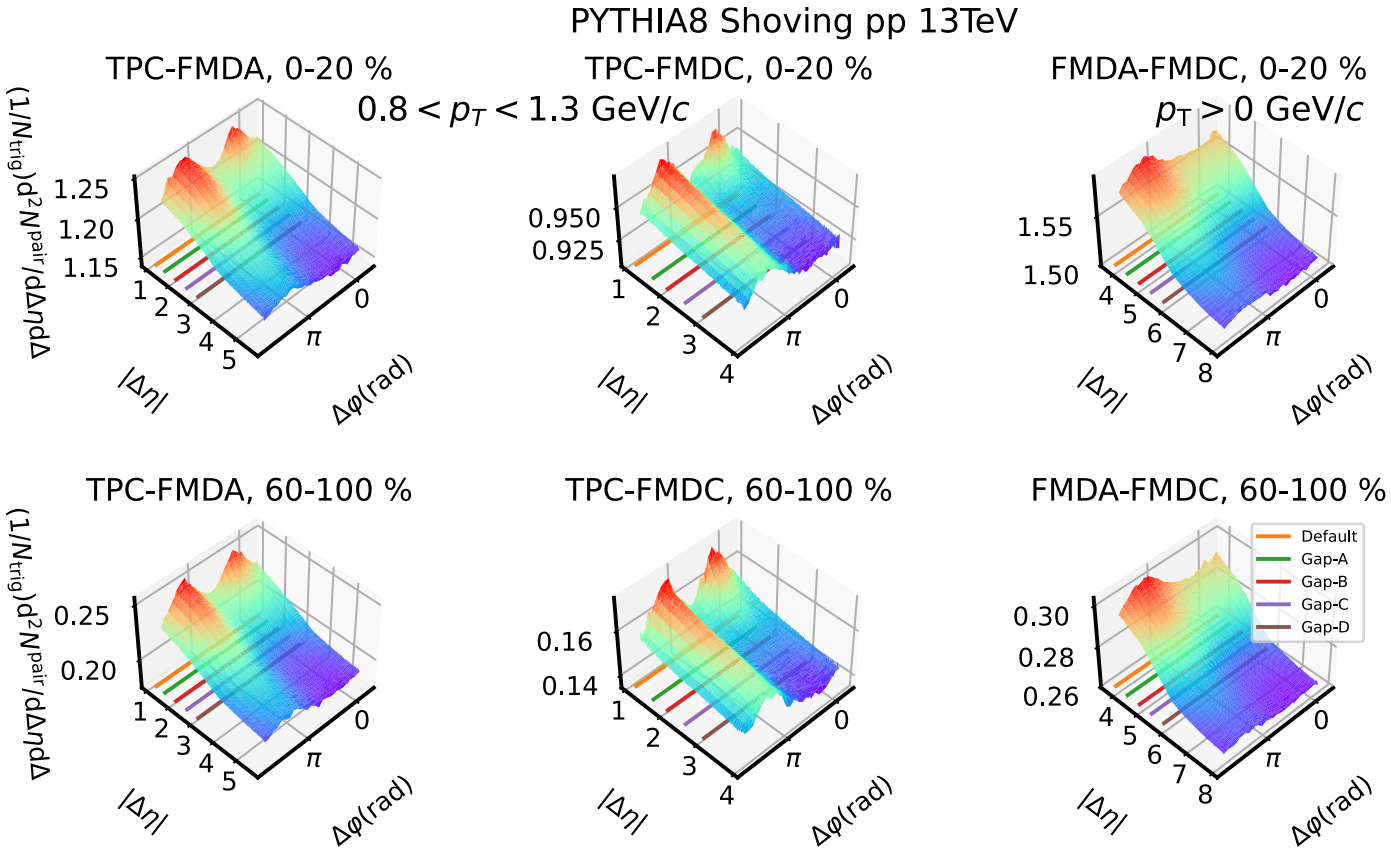
Summary

- LM-template fit method worked well in the experiments for the flow extraction in small systems.
- $v_2(v_{22})$ of identified hadrons were obtained using the template fit method in pp collisions with the MC event generators at the ALICE acceptance.
- Three dependencies of v_2 are studied – Δη gap, p_T and multiplicity.
- Every model showed Δη gap dependence, therefore we used the largest Δη gap for the PID flow.
- Clear mass ordering was seen for 0–20% events not only in AMPT but also in PYTHIA8 model.
- Increasing v_2 with increasing multiplicity was observed.
- However, we have to study more on the origin of the PID flow because there is a chance that the PID dependent non-flow might amplify the mass order effect in high p_T region.

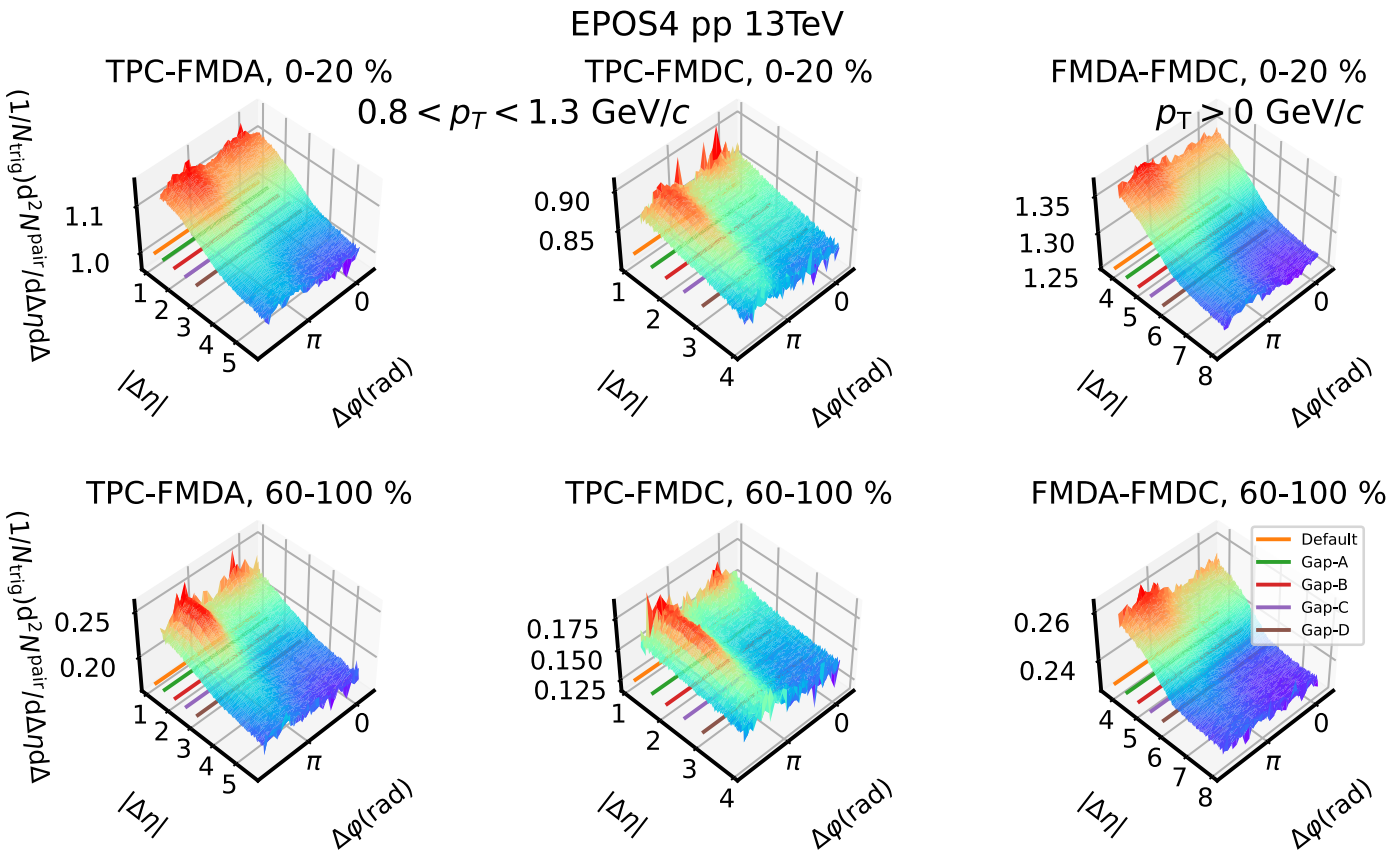
Thank you!

Back-up

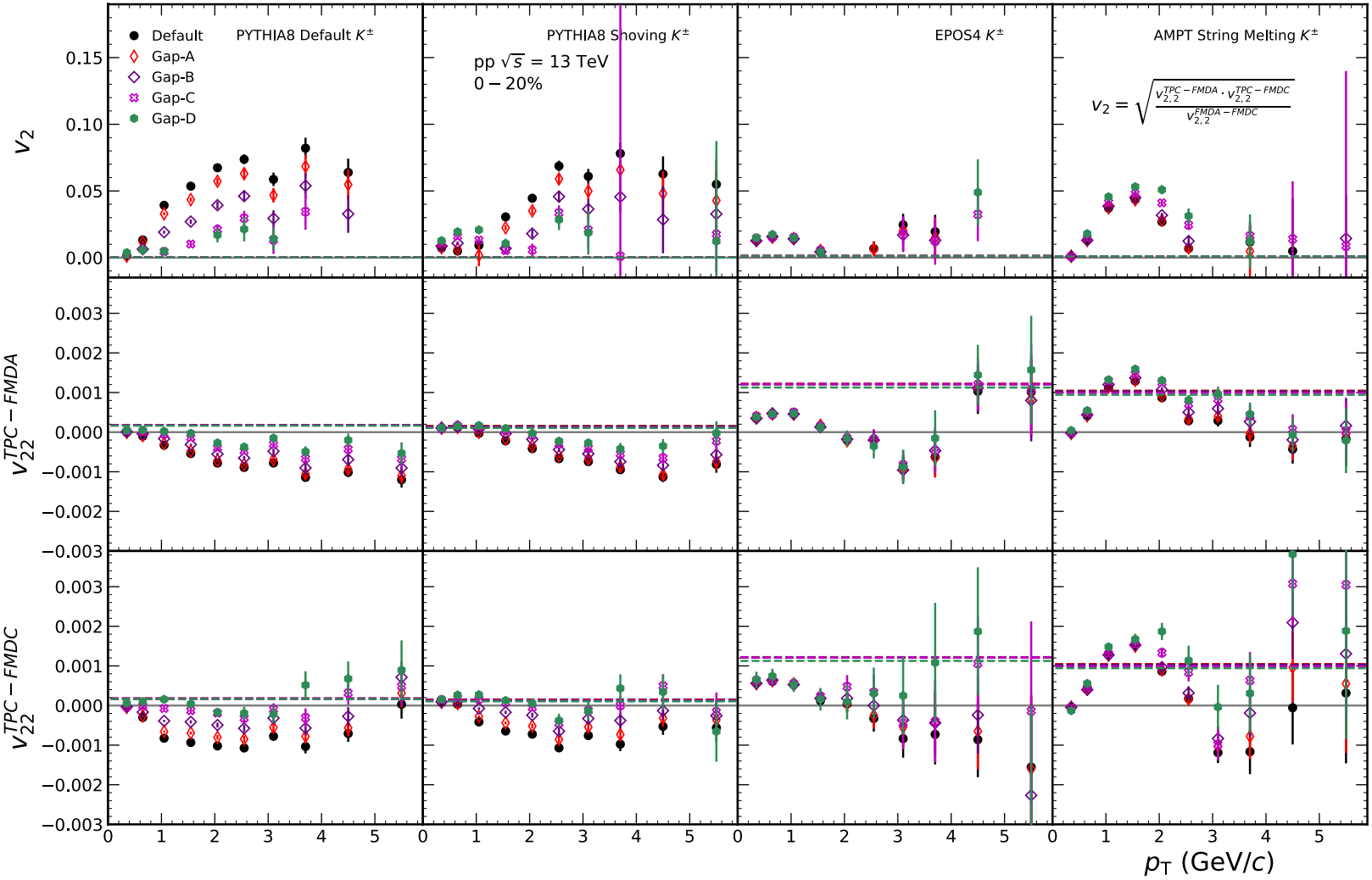
Back-up PYTHIA8 String Shoving



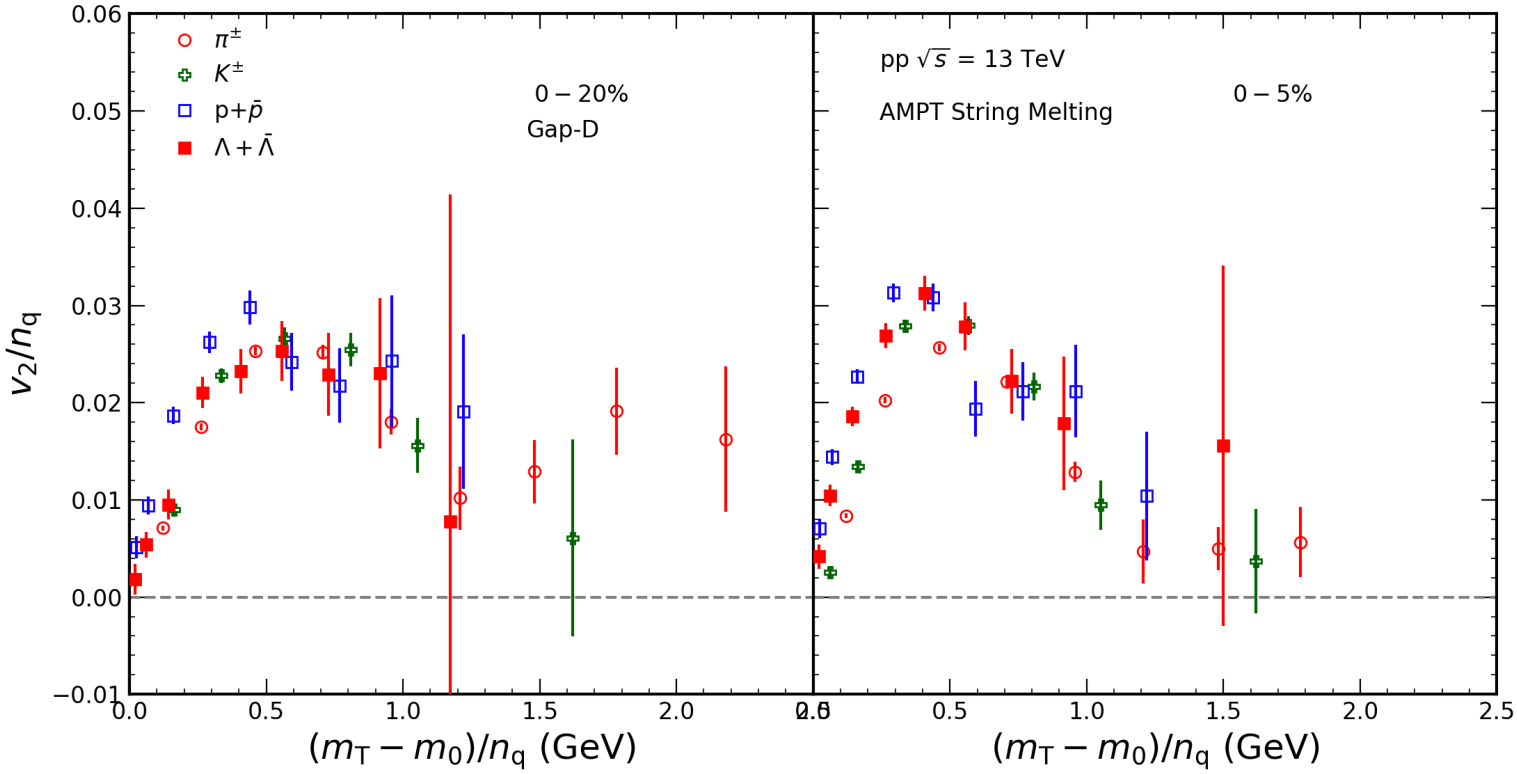
Back-up EPOS4



Back-up $\Delta\eta$ dependence of v_2, v_{22}



Back-up m_T dependence of v_2 (NCQ scaled)



- The PID v_2 as function of p_T with AMPT model is seen.
- Clear mass ordering is seen in 0–20%.
- As v_2 becomes smaller in 20–40% compared to 0–20%, we also checked the multiplicity dependence of v_2.