Interplay between jet and v_2

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Jet modification and large elliptic flow (v_2) are important experimental observables in order to understand the properties of the quark gluon plasma (QGP) created in heavy ion collisions at RHIC energies. Strong away side jet shape modification has been seen for angular correlations in the low- to mid- p_T region (1-4 GeV/c). There are several models trying to explain this phenomenon, including the idea that the quenched parton may create a shock wave in the high energy density matter. A strong dependence of the away-side correlation structures on the orientation of the jet fragments with respect to the reaction plane could give rise to an additional azimuthal anisotropy (v_2).

A new idea to analyze the two particle azimuthal correlations with respect to the reaction plane is discussed. For these correlations, the convention of the relative azimuthal angle is chosen such that for trigger particles traversing matter with similar path lengths, the associated particles most likely will encounter different amounts of matter. If this is the case, left-right asymmetry in the associate particle azimuthal distribution with respect to the trigger particle azimuthal angle could be expected.

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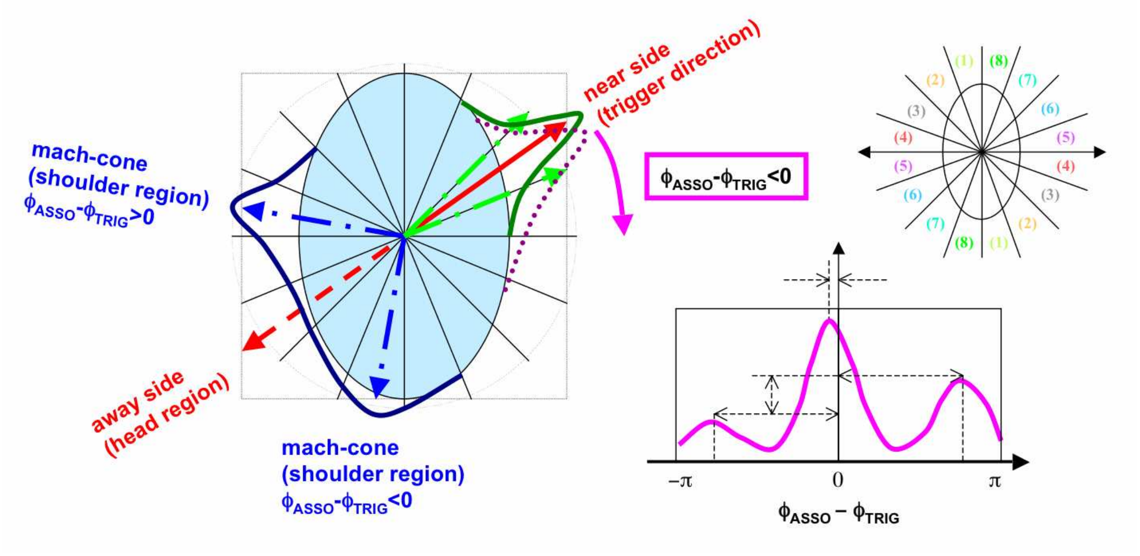

Figure 1: Trigger particle azimuthal angle selection with respect to the reaction plane and associate particle relative angle with respect to the trigger particle are described in the left schematic figure. Bottom-right figure shows one scenario of the associate particle relative angle distribution with respect to the trigger particle. Top-right figure defines the trigger particle angle selections with respect the reaction plane used in the following figures. (color online)

1. Introduction

Recent two- and three- particle jet correlation analysis at SPS/RHIC experiments tells us that there are some indications on mach-cone like particle emission away side, which shows double peak structure around ± 1 radian away from $\Delta\phi = \pi$. This effect is most pronounced at low- to mid- p_T region around 1-4 GeV/c for trigger and associate particles, where other important measurements like v2 and particle ratio show also interesting behaviors like baryon and meson difference. Amazing feature is that there is very little dependence on colliding beam energy and colliding system size, there is only gradual increase at peripheral collisions around N_{part} of 0-100. There seems to be also some difference in $\Delta\phi$ distribution between in-plane and out-of-plane trigger angle selections, which could come from path length dependence of trigger particle. However if there is any path length dependence in associate particle emission, there should also be left-right asymmetry in $\Delta\phi$ distribution, when the trigger angle is selected at positive and negative angle separately relative to the reaction plane as shown in the Fig. 1.

2. Analysis methods

A toy model simulation with pure flow (v_2, v_4) and embedded modifi ed jet (parameterized to describe the experimental measurements) has been used. In order to measure the trigger-associate azimuthal angle correlation, an usual technique is to make a ratio of measured $\Delta\phi$ distribution from the real events over one from the fake events, which is given by the event mixing. The points in the fi g. 2 shows the measured correlation function (with the modifi ed jet embedded flow simulation) as

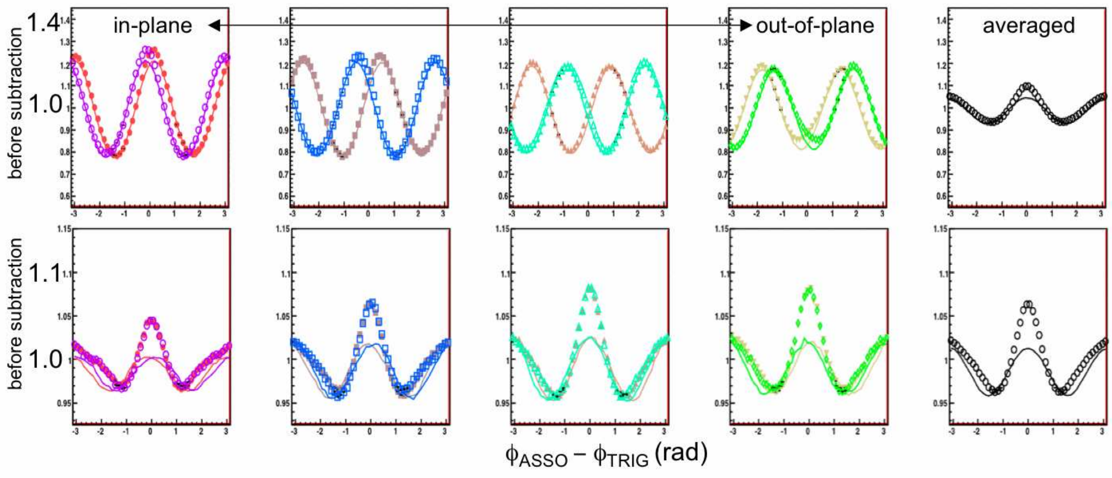

Figure 2: Two particle $\Delta\phi$ correlation function with different trigger angle selections (left-right) and with different event mixing methods (top-bottom, see text). Points are from flow+jet simulation, lines are from pure flow simulation.

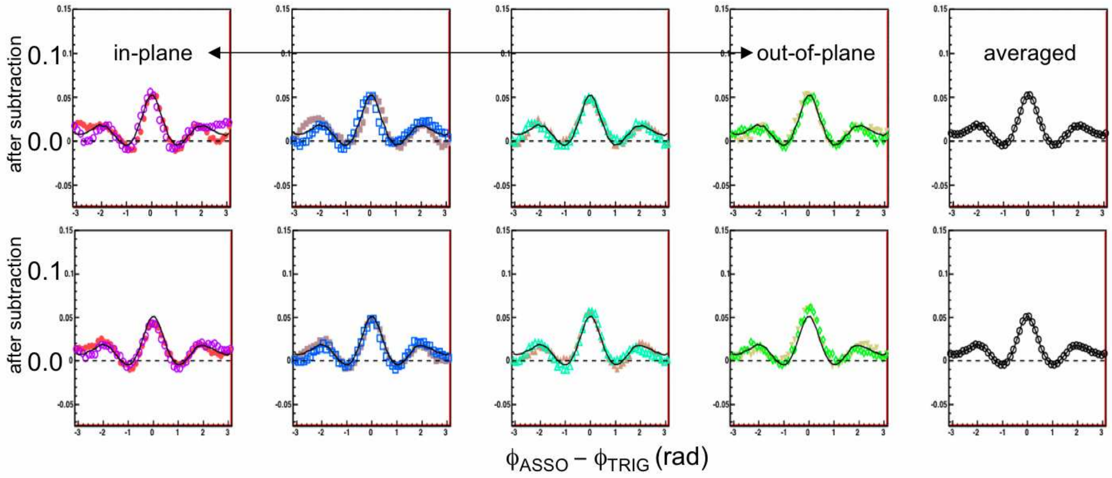

Figure 3: Extracted jet shape with different trigger angle selections (left-right) with different event mixing methods (top-bottom). Lines are same as the most right panel of trigger angle averaged data.

a function of $\Delta\phi$, which is defined as $\phi_{ASSO.}$ - $\phi_{TRIG.}$ for different trigger angle selections defined in Fig. 1. The two types of event mixing has been done, the top panels in Fig. 2 are done with random reaction plane in the mixed event, so that the strong flow modulation is seen in the correlation function depending on the trigger angle selection, while the bottom panels in Fig. 2 are done with similar orientation of reaction plane in the mixed event using the experimental event plane resolution, therefore the flow modulation is largely reduced, but it's still non-zero because of the finite event plane resolution. The line in each panel is the reference correlation function from pure flow simulation without embedding the jets but including the event plane resolution effect, which will

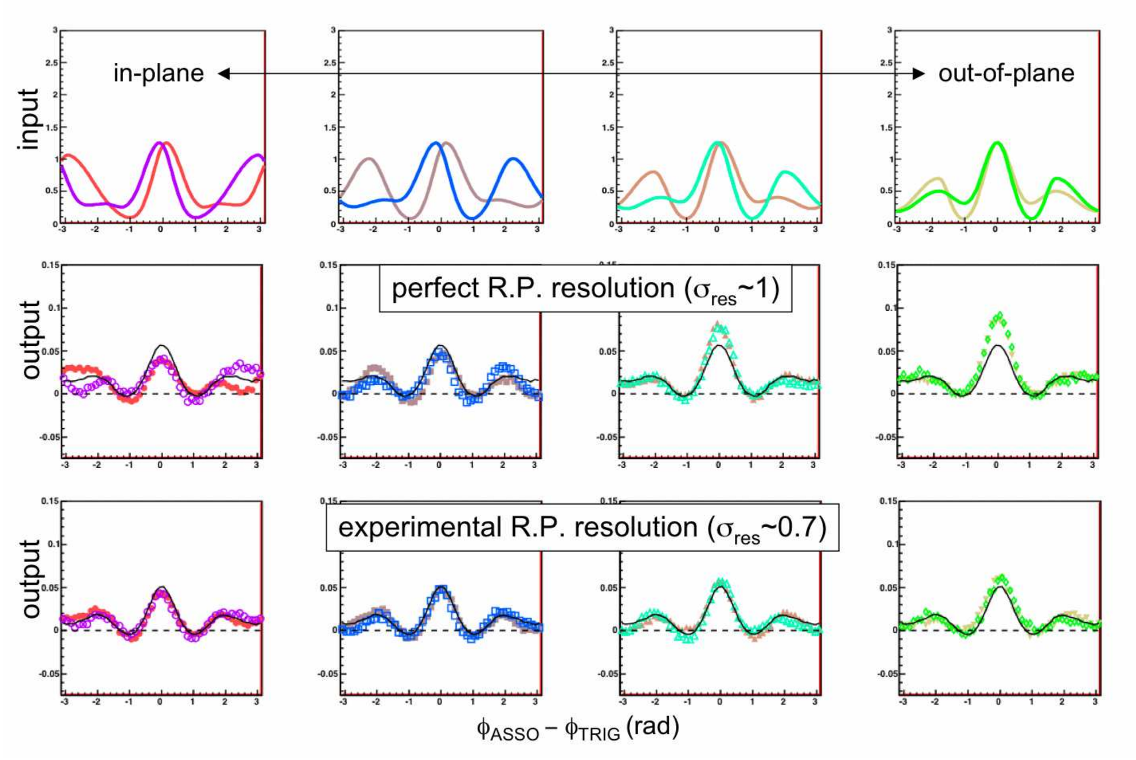

Figure 4: Top: input jet shape assumptions. Middle: extracted jet shape with perfect reaction plane resolution. Bottom: with experimental R.P. resolution.

be used to subtract the flow contribution from the measured correlation function in order to extract the jet shape. The subtracted jet shapes are shown in the Fig. 3 with the same panel definitions as in the Fig. 2, where trigger angle selections are varied from left to right, and two different event mixing for top (random R.P.) and bottom (aligned R.P.) cases.

3. Effect of reaction plane resolution

The effect of experimental reaction plane resolution on the extracted jet shape is shown in the Fig. 4. The left-right panels are different trigger angle selections as same as the previous Fig. 2 and Fig. 3. The top panels in the Fig. 4 are the input jet shapes which are assumed to depend on the trigger angle selection as well as the left-light asymmetry that is expected from the path length dependence of the associate particle production. The middle panels in the Fig. 4 are the output of extracted jet shapes via the flow subtraction using the perfect reaction plane resolution, while the bottom panels in the Fig. 4 are the same outputs using the experimental reaction plane resolution in the reaction plane aligned mixed event analysis. The Fig. 5 shows a dependence of the reaction plane resolution from left to right panels for one particular trigger angle selection at $\phi_{\mathrm{TRIG.}}$ - $\Psi_{\mathrm{R.P.}}$ = $\pm$ $|\pi/8 \sim \pi/4|$, where+ for open symbols (blue) and $-$ for solid symbols (gray). The very strong smearing of the jet shape is seen in the extracted jet signal. The top panels in the Fig. 5 are calculated with the reaction plane given by pure flow simulation, although the simulation includes

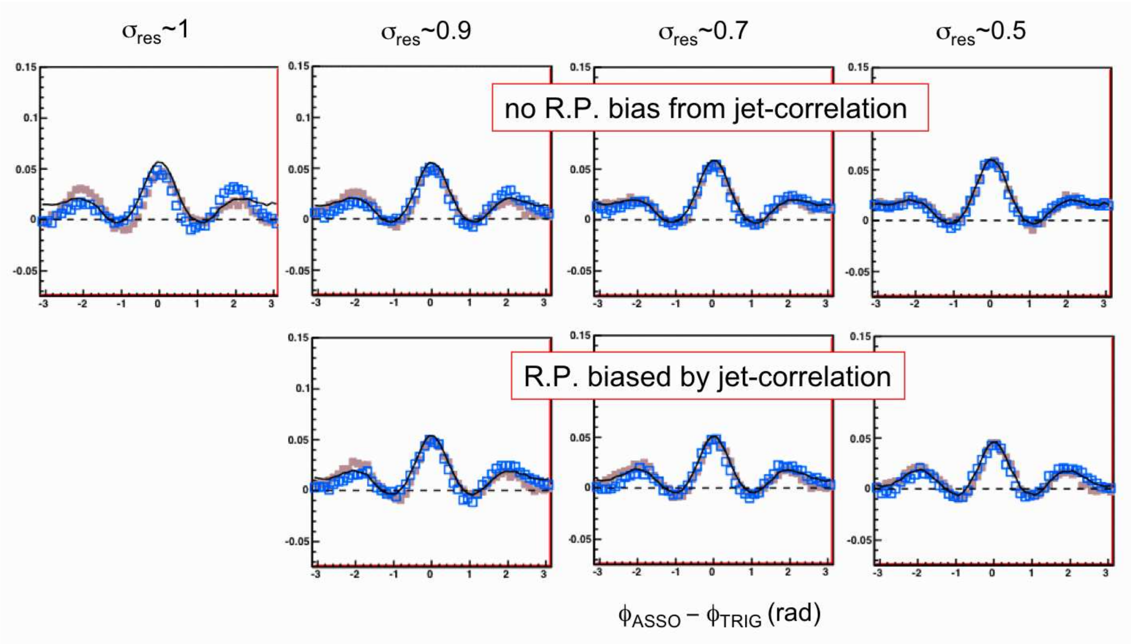

Figure 5: Extracted jet shape at one particular angle (see text), where reaction plane resolution is varied from left to right, 1.0, 0.9, 0.7 and 0.5. With(bottom) or without(top) jet bias in reaction plane determination.

the jet signal, but it does not influence the reaction plane determination. The bottom panels in the Fig. 5 includes some bias of the embedded jet in the reaction plane that is used in the inclusive flow measurements as well as trigger angle selections. Although the reaction plane could be determined in the different rapidity window away from the two particle correlation sample, this reaction plane bias effect might still be important, because the experimentally measured both mach-cone and ridge like structures do show the long eta range correlation.

4. Results

Four different jet shape assumptions (#1 $\sim$ #4) in terms of the trigger angle dependence are shown in the Fig. 6 in order to understand whether there is a sensitivity in this experimental method on the near-side and away-side modifi cation, especially on the left-right asymmetry. 4 panels in the Fig. 6 correspond to the 4 assumptions and different lines in one panel show the jet shapes varied from in-plane (top) to out-of-plane (bottom). Extracted jet shape are shown in the Fig. 7 and Fig. 8, with two different v_2 assumptions on the jet axis and on the associate particle yield par jet axis as indicated in the parameter table in both Fig. 7 and Fig. 8 using the same jet shape shown in the Fig. 6. 4 panels in both Fig. 7 and Fig. 8 are for 4 assumptions, and different data points in each panel are extracted jet shapes from in-plane (top) to out-of-plane (2nd from bottom), the trigger angle averaged data are shown at the bottom of each panel, which are also overlaid as solid lines on the other trigger angle selected data points for both Fig. 7 and Fig. 8. In the legend box on top of each panel in the Fig. 7 and Fig. 8, the pure flow input parameters (v_2 and v_4) are compared with inclusive flow parameters, which means that they are flow parameters before and after embedding

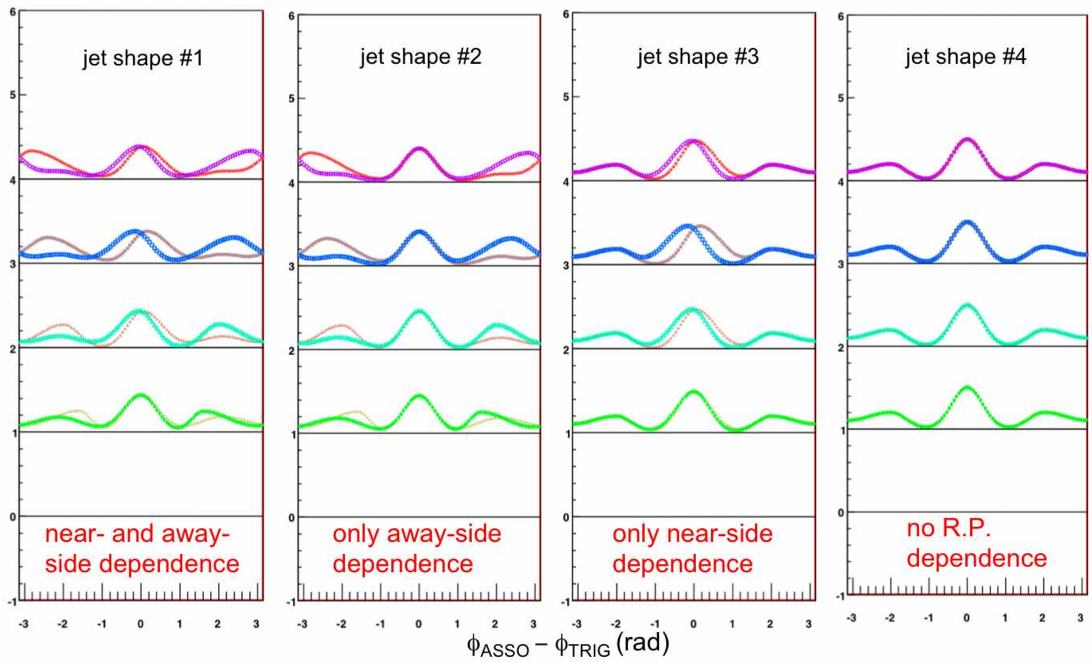

Figure 6: 4 assumptions on near- and/or away-side jet modification, (#1) trigger angle dependence on both near- and away-side jet shapes, (#2) trigger angle dependence only on away-side shape, (#3) trigger angle dependence only on near-side jet shape, and (#4) no trigger angle dependence on jet shape

the modified jet into the pure flow simulation. Depending on the assumptions, there could be a sizable effect on the inclusive flow measurement.

5. Summary

A new idea to analyze the two particle azimuthal correlations with respect to the reaction plane is proposed and tested with toy model simulation. When the trigger angle is chosen such that for trigger particles traversing matter with similar path lengths, that is $\phi_{\rm TRIG.}$ - $\Psi_{\rm R.P.}$ = $\pm|\Delta\phi|$, the associated particles most likely will encounter different amounts of matter given by the almond shape. If the associate particle production is affected by the thickness, the left-right asymmetry in the associate particle azimuthal ($\phi_{\rm ASSO.}$ - $\phi_{\rm TRIG.}$) distribution with respect to the trigger particle azimuthal angle should be expected. One should also note that this asymmetry can also caused by jet and flow correlation, which is same as azimuthal dependence of radial flow boost on the jet signal. Experimental signal on the left-right asymmetry might contain such both geometrical and dynamical origins. Since the asymmetry is determined by the reaction plane, it is clear that it should also affect the inclusive flow measurements, which is used to determine the flow back ground shape in the jet correlation signal and to subtract the flow contribution from the measured correlation function in order to extract the jet signal. The resulting extracted jet shape is smeared largely because of this interplay between jet and v_2 as well as the experimental reaction plane resolution. However, including both of them in the simulation, there should still be an experimental

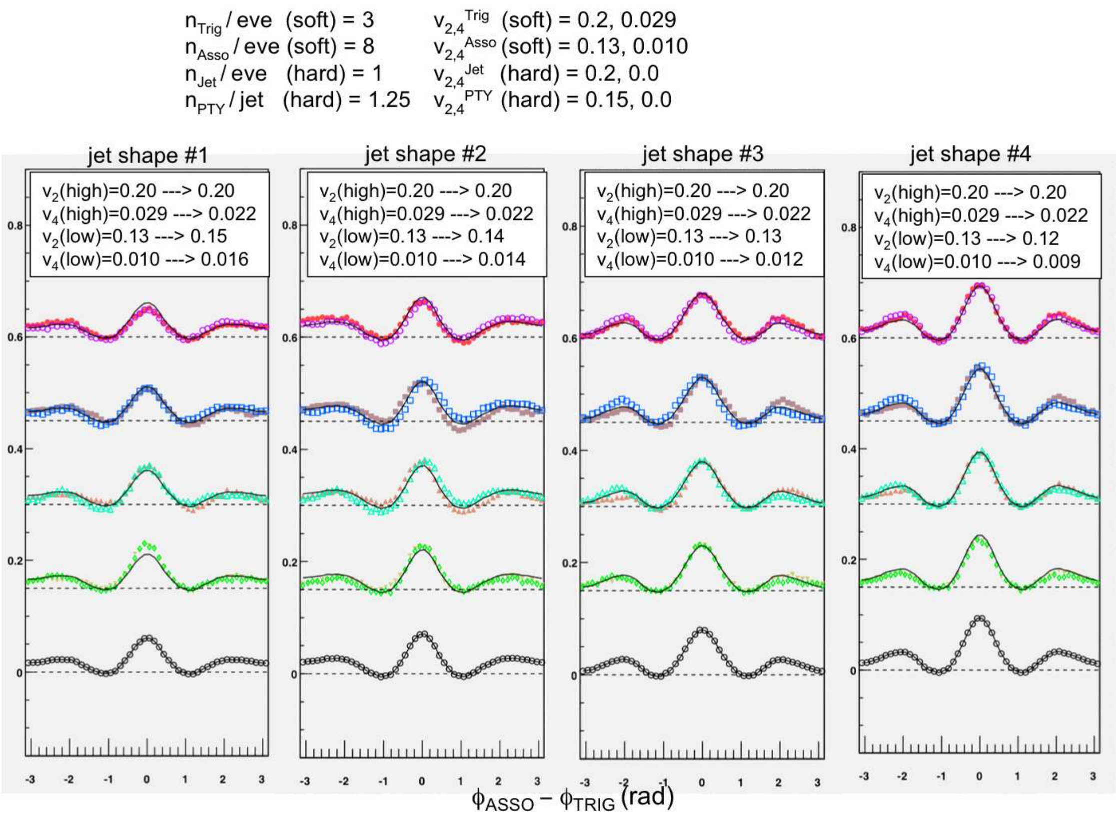

Figure 7: Extracted jet shapes with the 4 assumptions on the jet modification, the difference between different assumptions gets smaller in the extracted jet shape compared with input shape, however there is still some remaining difference, which would prove the experimental/method sensitivity. Here, v_2 of jet axis and v_2 of the associate particle yield par jet axis are both assumed to be similar to the bulk particles.

sensitivity to such measurement. The alternative approach to attack this problem is to look at "the triggered jet vs global event shape" correlation without subtracting the inclusive flow anisotropy, in order to investigate how the global event shape is modifi ed by the existence of jets, that is to analyze the jet modifi cation and underlying event modifi cation at the same time without any subtraction.

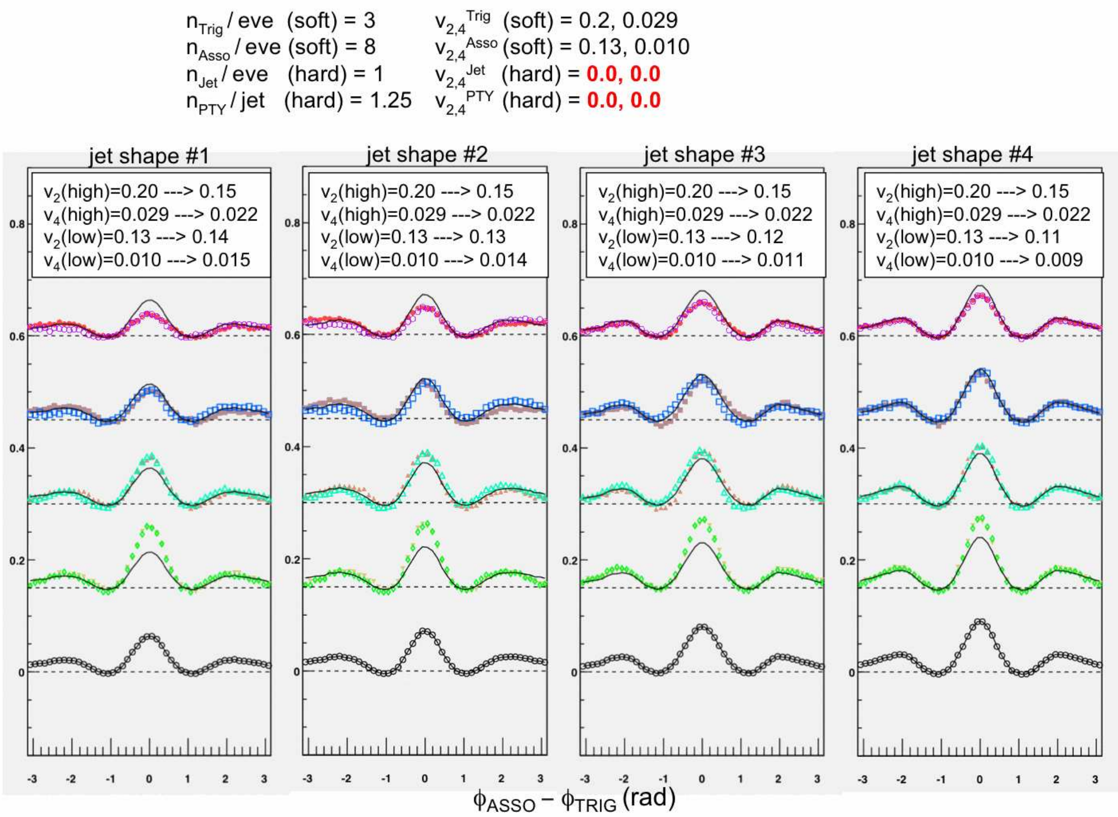

Figure 8: The same for Fig.7, except the v_2 of jet axis and v_2 of the associate particle yield par jet axis are both assumed to be zero.