# Dihadron angular correlations in PbPb collisions with HYDJET++ model

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The hybrid model HYDJET++, which includes soft and hard physics, is employed for the analysis of azimuthal anisotropy harmonics and dihadron angular correlations measured in PbPb collisions at $\sqrt{s_{NN}}$= 2.76 TeV. The soft part of the model represents a thermal hadron production at the freeze-out hypersurface in accordance with hydrodynamical calculations. The possible triangular shape fluctuation of the initial overlap density of the colliding nuclei was implemented in HYDJET++ by the modulation of the final freeze-out hypersurface with the appropriate triangular coefficient, which results in triangular flow $v_3$. Along with elliptic flow $v_2$, it generates higher order flow coefficients, as well as a specific structure of dihadron angular correlations on relative azimuthal angle in a broad range of relative pseudoraidities (ΔφΔη). The comparison of model results with the LHC data on short- and long-range angular correlations is presented for different collisions centralities and transverse momenta intervals.

## HYDJET++ model[1]

### Hard part

**Initial parton configuration**
PYTHIA w/o hadronization
↓
**Parton rescattering & energy loss**
PYQUEN
↓
**Hadronization**
PYTHIA w hadronization

### Flow

Due to jet quenching.
Only elliptic flow:

$v_2$(jet) ≠0, $v_3$(jet)=0

### Soft part

Hadronization at freeze-out stage with distribution function:

$$f_i^{eq}(p^{*0};T^{ch},\mu_i,\gamma_s)=\frac{g_i}{\gamma_s^{-n_s^i}\exp\left([p^{*0}-\mu_i]/T^{ch}\right)\pm 1}$$

### Flow[2] ($v_2$ & $v_3$)

Space modulation of freeze-out surface:

$$\epsilon(b)=\frac{R_y^2-R_x^2}{R_y^2+R_x^2}$$

$$R(b,\phi)=R_f(b)\frac{\sqrt{1-\epsilon^2(b)}}{\sqrt{1+\epsilon(b)\cos 2\phi}}[1+\epsilon_3(b)\cos 3(\phi+\Psi_3^{RP})]$$

and modulation of 4-velocity $u$ at freeze-out stage:

$$\frac{u^y}{u^x}=\sqrt{\frac{1-\delta(b)}{1+\delta(b)}}\tan\varphi,$$

φ: spatial azimuthal angle of the surface element.

Interference of $v_2$ and $v_3$ flow harmonics leads to appearance of higher order harmonics.

1. I.P. Lokhtin, L. Malinina, S. Petrushanko, A. Snigirev, I. Arsene, K. Tywoniuk, Comp. Phys. Comm. 180 (2009) 779, http://cern.ch/lokhtin/hydjet++
2. L.V. Bravina et al., Eur. Phys. J. C74 (2014) 2807

## Dihadron correlations

The signal and background function:

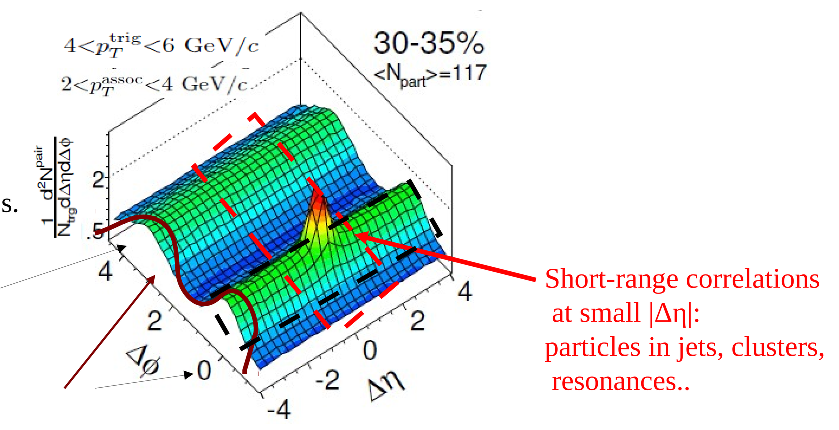
$$S(\Delta\varphi,\Delta\eta)=\frac{1}{N_{trig}}\frac{d^2N^{same}}{d\Delta\varphi d\Delta\eta}\qquad B(\Delta\varphi,\Delta\eta)=\frac{1}{N_{trig}}\frac{d^2N^{mixed}}{d\Delta\varphi d\Delta\eta}$$

Definition 1: $C(\Delta\phi,\Delta\eta)\equiv\frac{N_{mixed}}{N_{same}}\times\frac{N_{same}(\Delta\phi,\Delta\eta)}{N_{mixed}(\Delta\phi,\Delta\eta)}$ $\quad \Delta\varphi=\varphi_1-\varphi_2$, $\Delta\eta=\eta_1-\eta_2$

$N_{trig}$ : number of trigger particles.

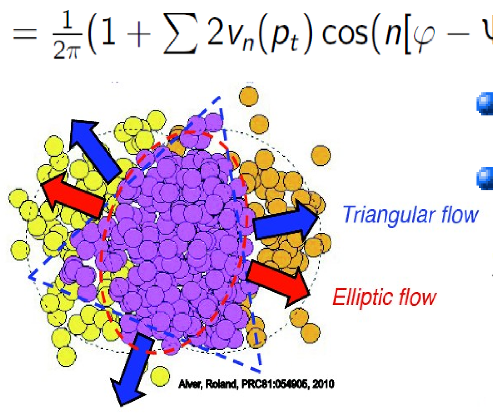
Definition 2: $\frac{1}{N_{trig}}\frac{d^2N}{d\Delta\varphi d\Delta\eta}=B(0,0)\frac{S(\Delta\varphi,\Delta\eta)}{B(\Delta\varphi,\Delta\eta)}$

CMS, PbPb 2.76TeV J.Phys. G38 (2011) 124092




### Flow and dihadron correlations:

$$\frac{dN}{d\varphi}=\frac{1}{2\pi}\left(1+\sum 2v_n(p_t)\cos(n[\varphi-\Psi_n])\right)$$

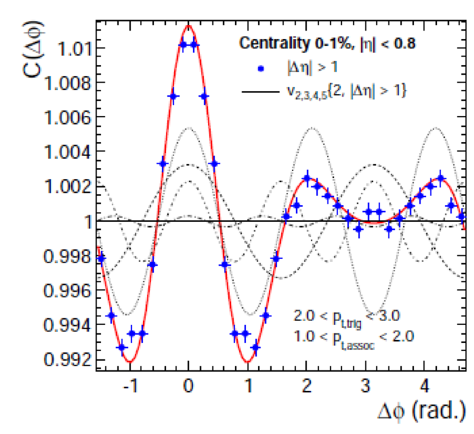



- Even $v_n$ due to ellipticity of initial state.
- Odd $v_n$ due to fluctuation of initial state.

$$\frac{dN^{pairs}}{d\Delta\phi}\propto 1+\sum_{n=1}^{\infty}2V_{n\Delta}(p_T^t,p_T^a)\cos(n\Delta\phi)$$

$$V_{n\Delta}=\langle\cos(n\Delta\varphi)\rangle$$

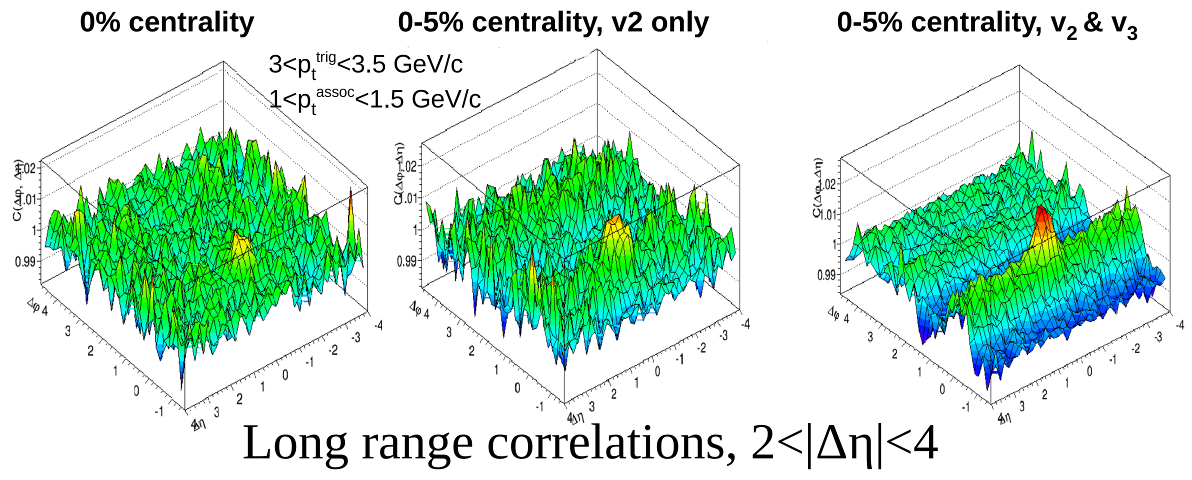
K. Aamodt, et al., (ALICE), Phys. Rev. Lett. 107 (2011) 032301




- In low $p_t$ region, a factorization $V_{\Delta n}$ is fulfilled into $v_n\{2\}$ ($v_n$ by two-particle cumulant method)
  $V_{n\Delta}\approx\langle v_n\{2\}(p_t^{tr})v_n\{2\}(p_t^{ac})\rangle$.
- The combination of $v_2$-$v_5$ harmonics describes a 2-particle correlation function.

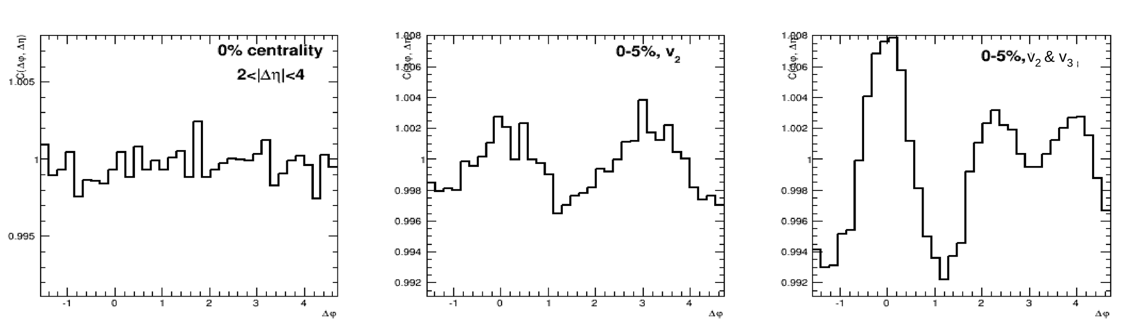
**The nature of ridge in *PbPb*: only flow?**

## Dihadron correlations in HYDJET++ model




2D

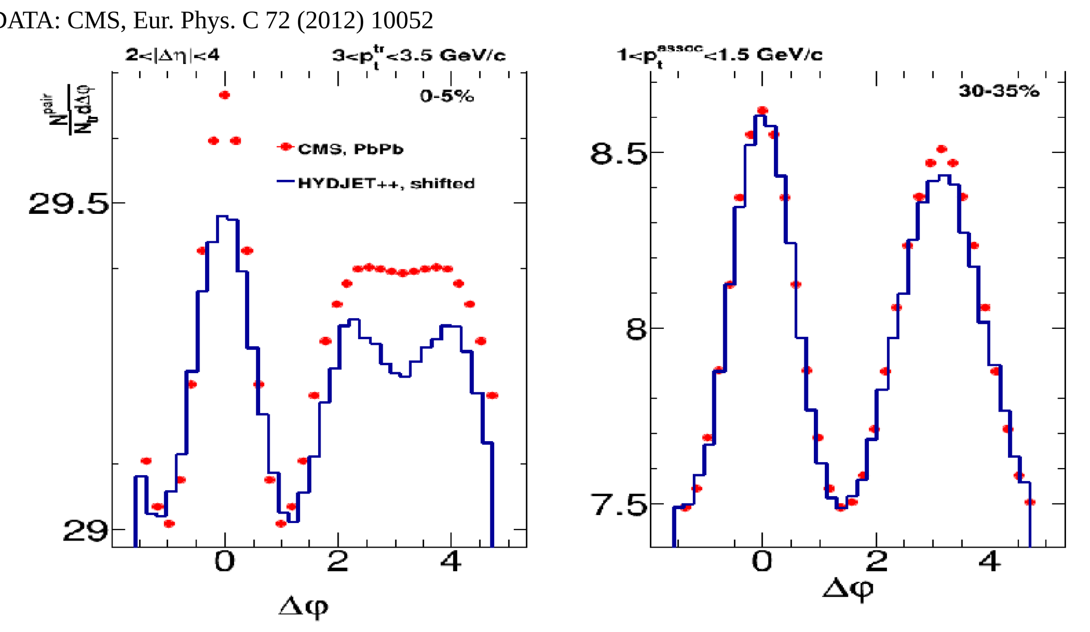
### Long range correlations, 2<|Δη|<4



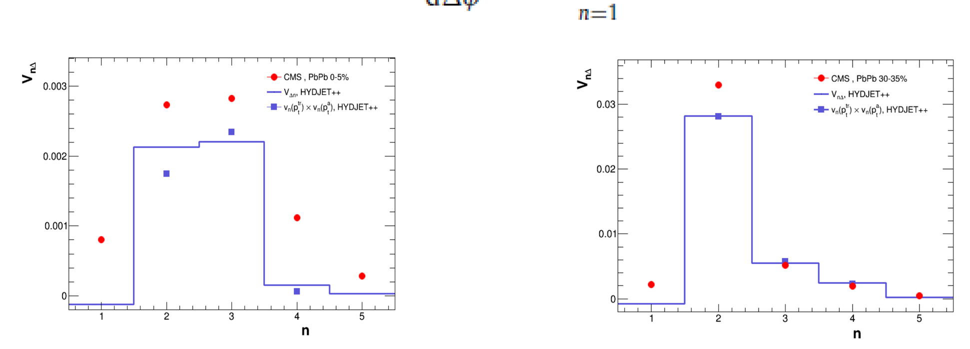

1D

- Long-range correlations appear due to flow.
- $v_3$ leads to double-peak structure at away side over Δφ.

DATA: CMS, Eur. Phys. C 72 (2012) 10052

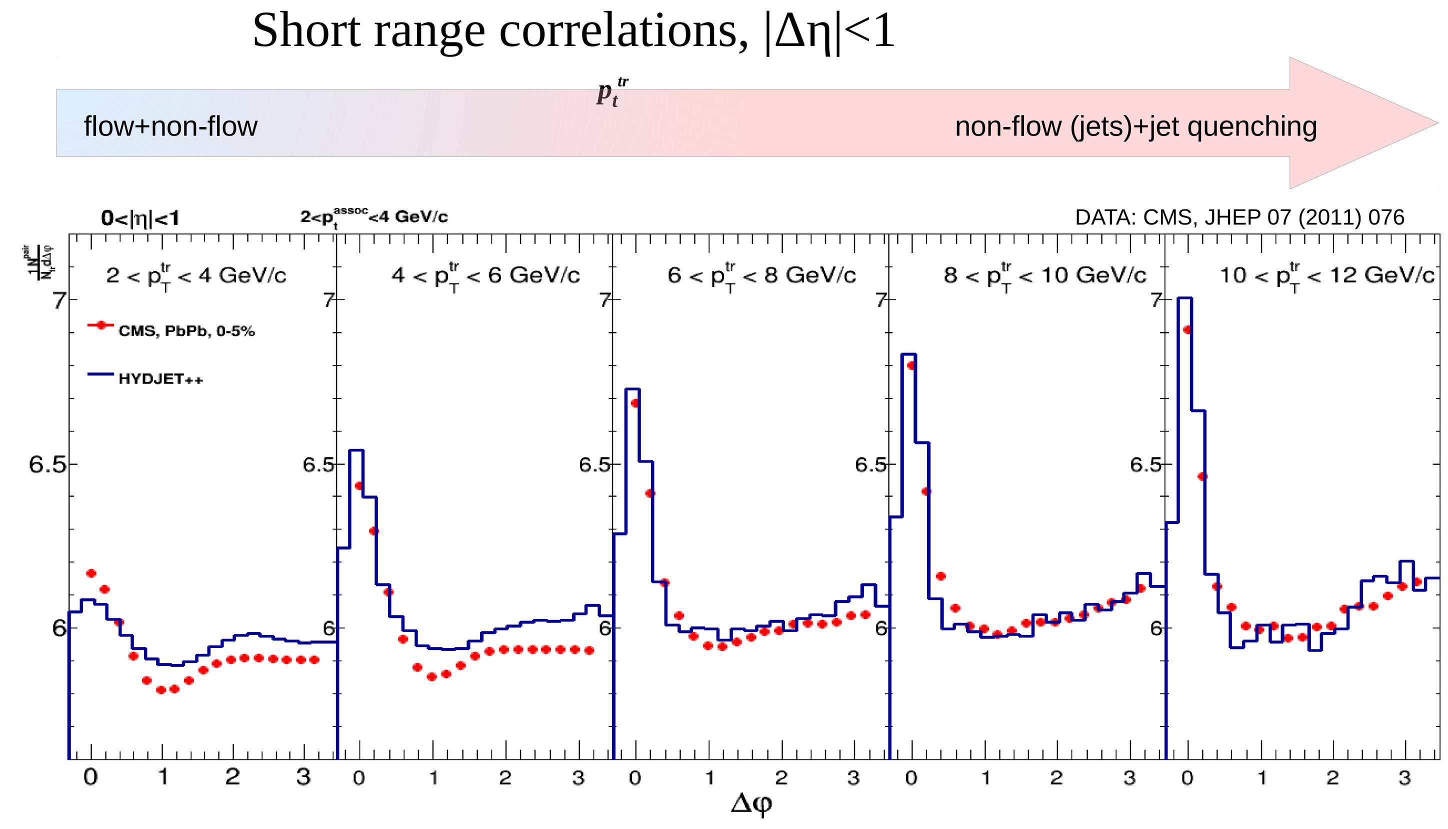



Fourier coefficients: $\frac{dN^{pairs}}{d\Delta\phi}\propto 1+\sum_{n=1}^{\infty}2V_{n\Delta}(p_T^t,p_T^a)\cos(n\Delta\phi)$



- Central collisions: $V_{\Delta4}$, $V_{\Delta5}$ coefficients are much less that in data, $V_{\Delta n}\approx v_n(p_t^{tr})*v_n(p_t^{a})$ (+- non-flow).
- Mid-peripheral collisions: $V_{\Delta n}$ coefficients are described well.

### Short range correlations, |Δη|<1




- At 0-5% centrality, HYDJET++ does not reproduce flow harmonics $v_n$ (n>2) very well, neither it reproduces dihadron correlations at low $p_t^{tr}$.
- At high $p_t^{tr}$ HYDJET++ describes data.

### Test of factorization: $V_{\Delta n}\approx v_n\{2\}(p_t^{tr})*v_n\{2\}(p_t^{a})$

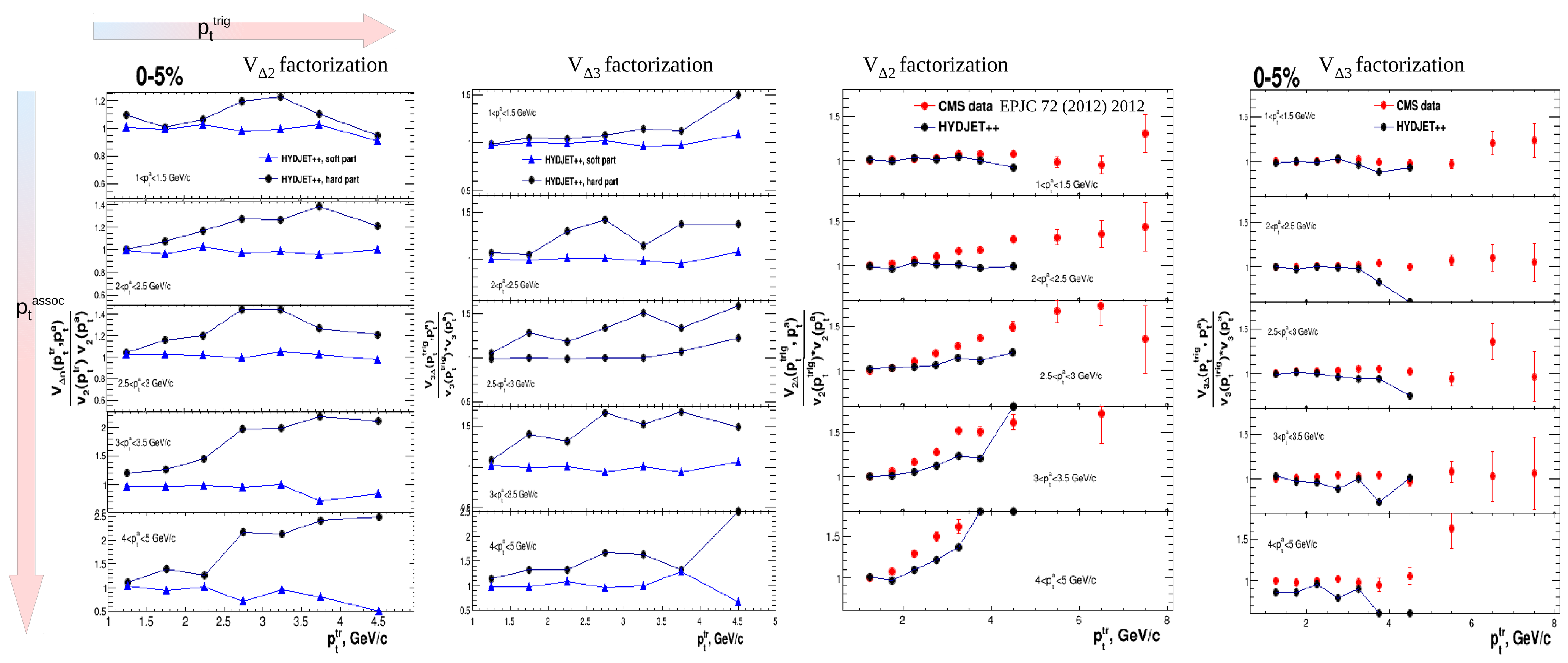
At low $p_t$ one neglects non-flow and estimates:
$v_n(p_t^{low})=\sqrt{V_{\Delta n}(p_t^{low},p_t^{low})}$

$v_n(p_t)=V_{\Delta n}(p_t,p_t^{low})/v_n(p_t^{low})$ **(1)**

(here $v_n$ is effectively equivalent to $v_n\{2\}$ )

It is shown[1] that jet-correlations from PYTHIA simulations of *pp* collisions also approximately factorize.

1. D. Kikola, L. Yi, S. Esumi, F. Wang, W. Xie, Phys. Rev. C 86 (2012) 014901.




$V_{\Delta n}$ factorization only for soft and only for hard part of the model. $v_n(p_t^{tr})$, $v_n(p_t^{a})$ are found by Eq. (1).

$V_{\Delta n}$ factorization for data (Eur. Phys. C 72 (2012) 10052 ) and the model.

- The correlations of soft particles factorize well at all $p_t$.
- The correlations of hard (jet) particles doesn't factorize at $p_t$>2 GeV/c .

- Factorization for $V_{\Delta3}$ holds both in data and in model in a large $p_t$ range.
- Factorization for $V_{\Delta2}$ breaks in data at lower $p_t$ compared to HYDJET++. This could be due to $v_2$ flow fluctuations, not present in the model.

## CONCLUSIONS:

- In HYDJET++ single-particle flow $v_2$ & $v_3$ are tuned to describe data at low $p_t$. The resulting from $v_2$ & $v_3$ interference higher order flow harmonics describes data well at semi-central collisions well but underestimate data at more central events.
- Similarly it has been found that dihadron correlations (both long-range and short range) are described well at semi-central collisions.
- The factorization of Fourier coefficients of dihadron correlation onto single-particle flow coefficients at low $p_t$ may be fulfilled also in a presence of non-flow (or other than flow sources of correlations).

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