Jets and their role in modification $v4/(v2)^2$ ratio

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TORIC workshop, Heraklion, Crete, Greece 2011

Outline

I. $v4/(v2)^2$ **ratio**

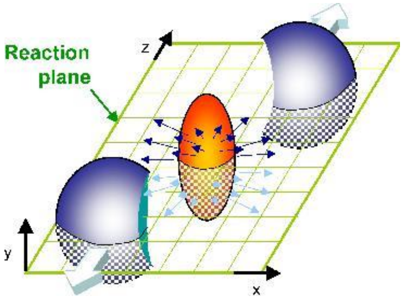
II. **HYDJET++ model**

III. **Results**

I. *v4/(v2)^2* ratio

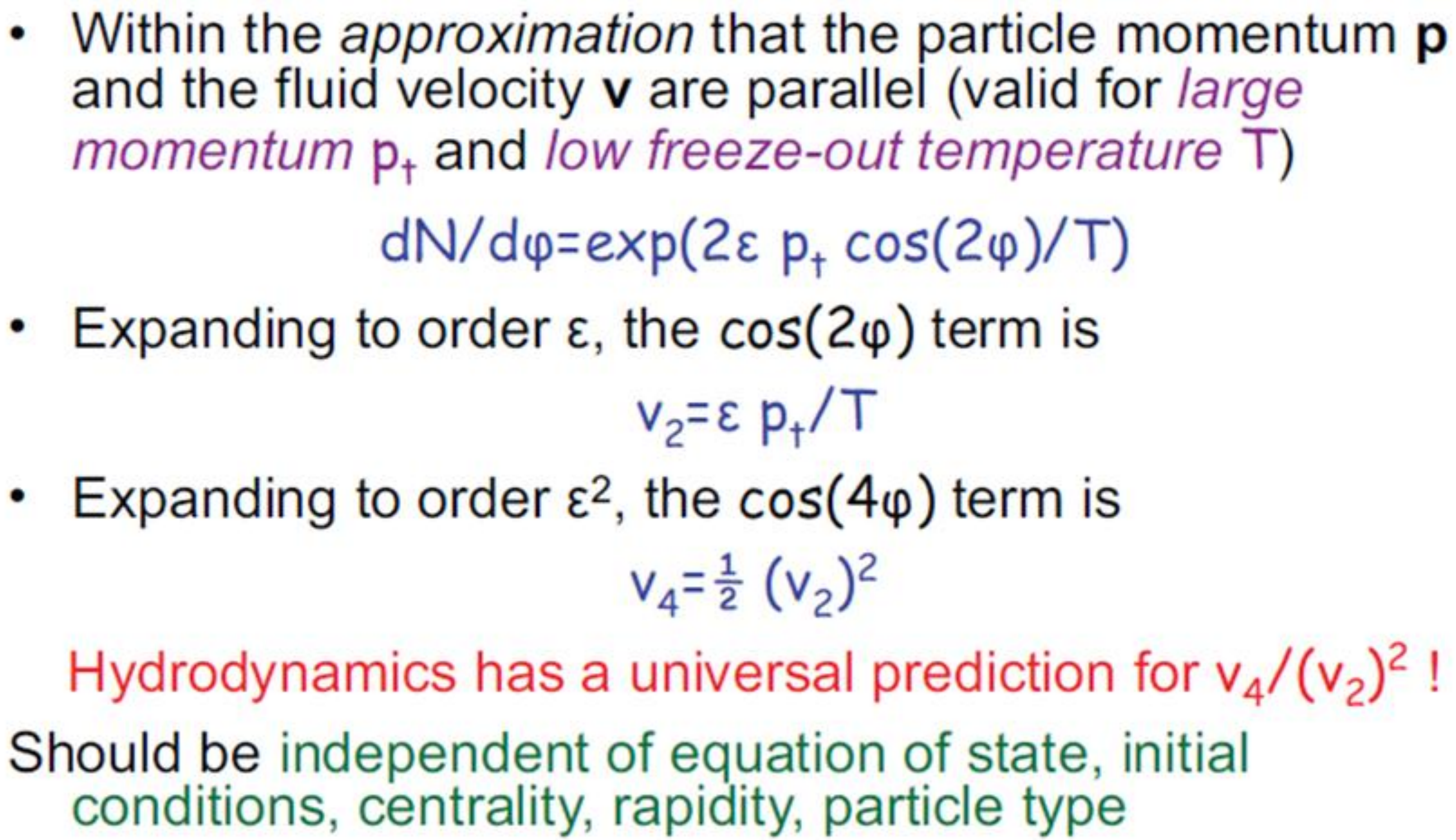
Anisotropic flow

$$\frac{dN}{d\varphi}=\frac{1}{2\pi}(1+\sum_{n=1}^{\infty}2v_n(p_t)\cos[n(\varphi-\psi_r)])$$



Predictions

N. Borghini, J.-Y. Ollitrault, PLB 642 (2006) 227



- Within the *approximation* that the particle momentum **p** and the fluid velocity **v** are parallel (valid for *large momentum* p_t and *low freeze-out temperature* T)

$$dN/d\varphi = \exp(2\varepsilon\, p_t \cos(2\varphi)/T)$$

- Expanding to order ε, the $\cos(2\varphi)$ term is

$$v_2 = \varepsilon\, p_t/T$$

- Expanding to order ε^2, the $\cos(4\varphi)$ term is

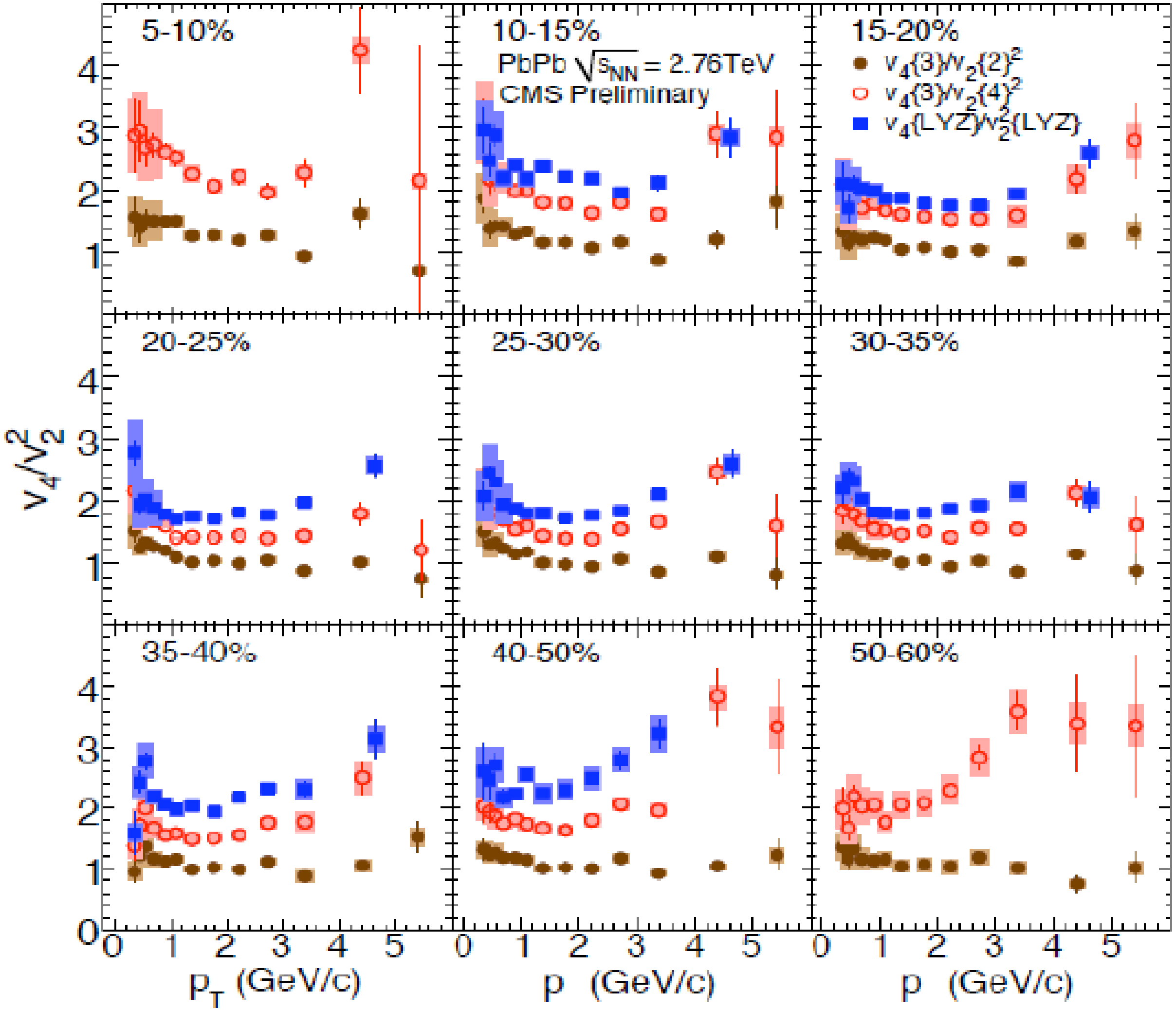
$$v_4 = \tfrac{1}{2}\,(v_2)^2$$

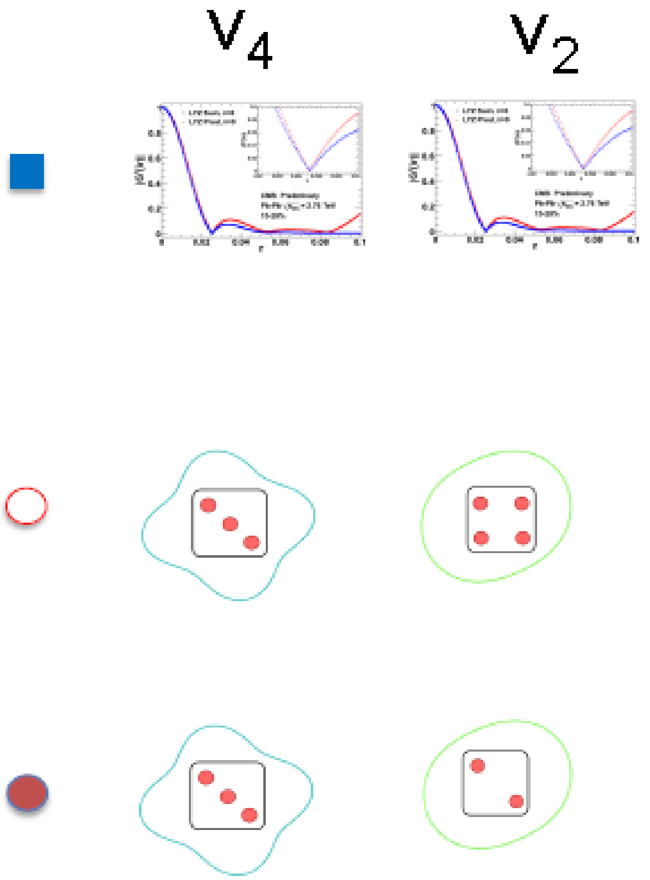
Hydrodynamics has a universal prediction for $v_4/(v_2)^2$!

Should be independent of equation of state, initial conditions, centrality, rapidity, particle type

Experiment

$v_4 / v_2^2(p_T)$ at mid-rapidity $|\eta|< 0.8$

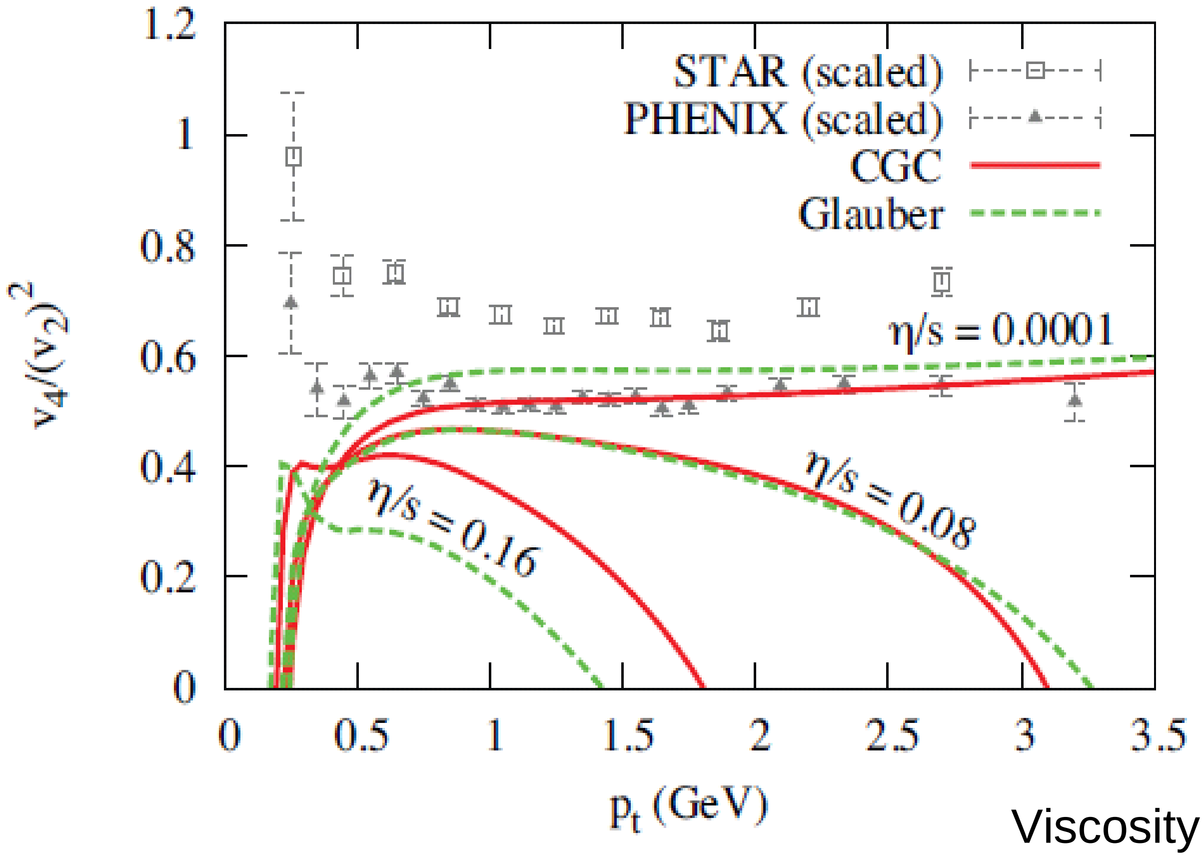




Significantly higher than RHIC: experimental method dependent

M. Luzum, C. Gombeaud, J.-Y. Ollitrault, PRC 81 (2010) 054910

Effects of initial profile and viscosity



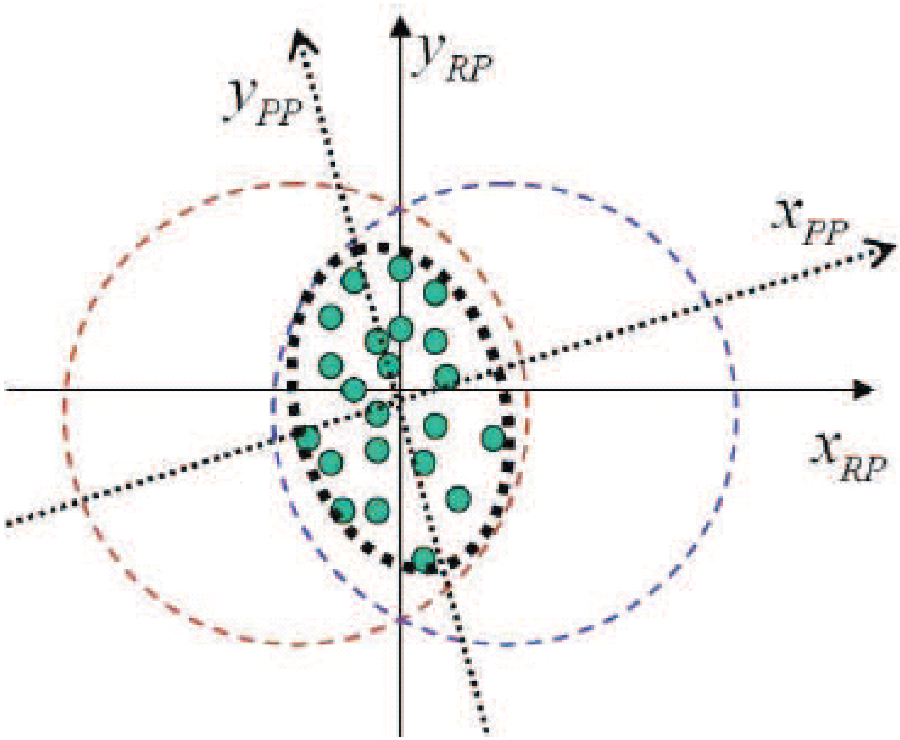
Initial profile has little effect although eccentricities differ.

results strongly depend on viscosity

Viscosity lowers v4 /(v2 $)^2$ for a realistic T_f

Matthew Luzum, Clement Gombeaud, Jean-Yves Ollitrault,
Phys.Rev.C81:054910,2010.

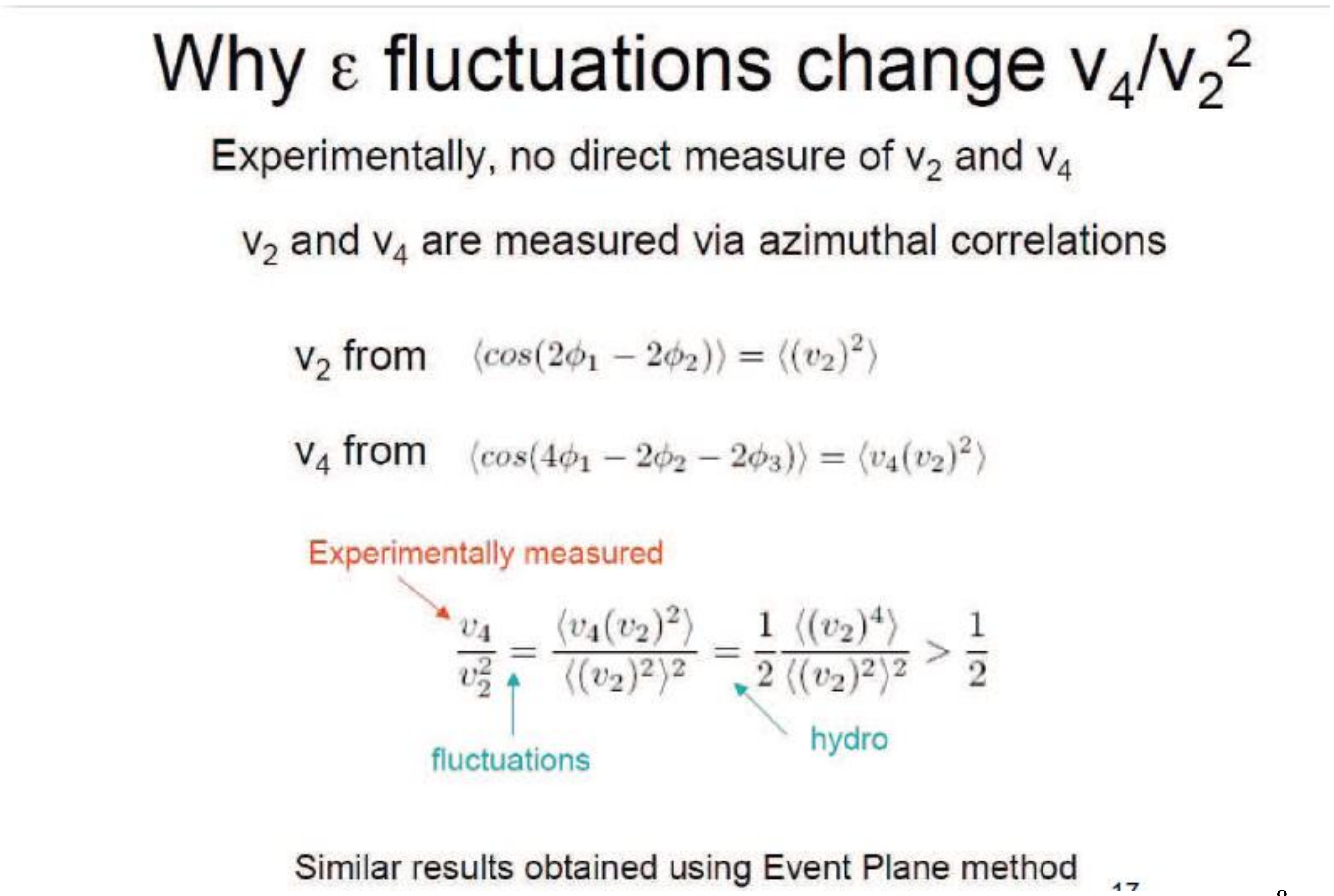
Eccentricity fluctuations



Depending on where the participant nucleons are located within the nucleus at the time of the collision, the actual shape of the overlap area may vary: the orientation and eccentricity of the ellipse defined by participants fluctuates.

Assuming that v_2 scales like the eccentricity, eccentricity fluctuations translate into v_2 fluctuations

Eccenttricity fluctuation can be computed in MC Glauber model or derived from experiment by comparing different methods for flow calculation.



Why ε fluctuations change v_4/v_2^2

Experimentally, no direct measure of v_2 and v_4

v_2 and v_4 are measured via azimuthal correlations

v_2 from $\langle cos(2\phi_1 - 2\phi_2)\rangle = \langle (v_2)^2\rangle$

v_4 from $\langle cos(4\phi_1 - 2\phi_2 - 2\phi_3)\rangle = \langle v_4 (v_2)^2\rangle$

Experimentally measured

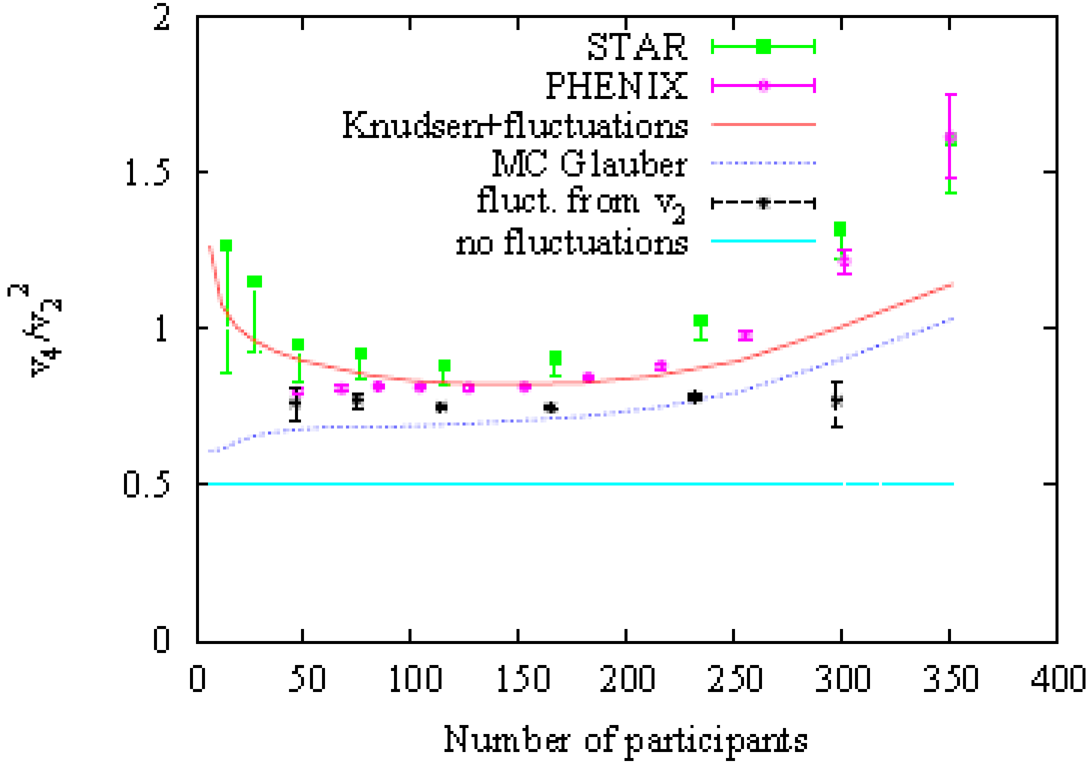
$$\frac{v_4}{v_2^2} = \frac{\langle v_4 (v_2)^2\rangle}{\langle (v_2)^2\rangle^2} = \frac{1}{2}\frac{\langle (v_2)^4\rangle}{\langle (v_2)^2\rangle^2} > \frac{1}{2}$$

fluctuations

hydro

Similar results obtained using Event Plane method

Effects of flow fluctuations and partial thermalization



Stars: with fluctuations inferred from the difference between v2{2} and v2{LYZ}.
Dotted line: eccentricity fluctuations from a Monte-Carlo Glauber

M. Luzum, C.Gombeaud, J.Y Ollitrault, **Phys.Rev.C81:054910,2010**.

II. HYDJET++ model

The Ratio was proposed to be investigated within HYDJET++ by K. Redlich at last TORIC workshop (Sardinia, 2010)

HYDJET++ Monte-Carlo model for relativistic heavy ion collisions

HYDJET++ (HYDrodynamics + JETs) merges two components :

- soft hydro-type component
- hard multi-parton component

N.S.Amelin, R.Lednisky, T.A.Pocheptsov, I.P.Lokhtin, L.V.Malinina, A.M.Snigirev, Yu.A.Karpenko, Yu.M.Sinyukov, Phys. Rev. C 74 (2006) 064901

N.S.Amelin, R.Lednisky, I.P.Lokhtin, L.V.Malinina, A.M.Snigirev, Yu.A.Karpenko, Yu.M.Sinyukov, I.C.Arsene, L.Bravina, Phys. Rev. C 77 (2008) 014903

I.P.Lokhtin, A.M.Snigirev, Eur. Phys. J. 45 (2006) 211

K.Tywoniuk, I.Arsene, L.Bravina, A.Kaidalov and E.Zabrodin, Phys. Lett. B 657 (2007) 170

HYDJET++(hard): PYQUEN (PYthia QUENched)

PYQUEN event generator is used for simulation of rescattering, radiative and collisional energy loss of hard partons in expanding quark-gluon plasma

HYDJET++ includes nuclear shadowing correction for parton distributions
Impact-parameter dependent parameterization of *nuclear shadowing*

HYDJET++(soft): FASTMC generator

Not really hydro evolution
But fast MC procedure

- A hydrodynamic expansion of the fireball is supposed ends by a sudden system breakup at given T and chemical potentials. Momentum distribution of produced hadrons keeps the thermal character of the equilibrium distribution.
- multiplicities are determined assuming thermal equilibrium
- hadrons are produced on the hypersurface represented by a parameterization of relativistic hydrodynamics with given freeze-out conditions
- chemical and kinetic freeze-outs are separated
- decays of hadronic resonances are taken into account (360 particles)

HYDJET++ (hard): input parameters

initial QGP temperature T_0, at LHC: T0=1 GeV, at RHIC(200 AGeV) T0=0.300 GeV
QGP formation time τ_0 , at LHC: tau0=0.1 fm/c, at RHIC(200 AGeV) tau0=0.4 fm/c
number of active quark flavors in QGP N_f (+ minimal p_T of hard process Ptmin)

HYDJET++ (soft): input parameters

1-5. Thermodynamic parameters at chemical freeze-out: T^{ch} , $\{\mu_B, \mu_S, \mu_C, \mu_Q\}$ (option to calculate T^{ch}, μ_B and μ_s using phenomenological parameterization $\mu_B(\sqrt{s})$, $T^{ch}(\mu_B)$ is foreseen).

6-7. Strangeness suppression factor $\gamma_S \leq 1$ and charm enchancement factor $\gamma_c \geq 1$ (options to use phenomenological parameterization γ_S (T^{ch}, μ_B) and to calculate γ_c are foreseen).

8-9. Thermodynamical parameters at thermal freeze-out: T^{th} , and μ_π- effective chemical potential of positively charged pions.

10-12. Volume parameters at thermal freeze-out: proper time τ_f , its standard deviation (emission duration) $\Delta\tau_f$, maximal transverse radius R_f .

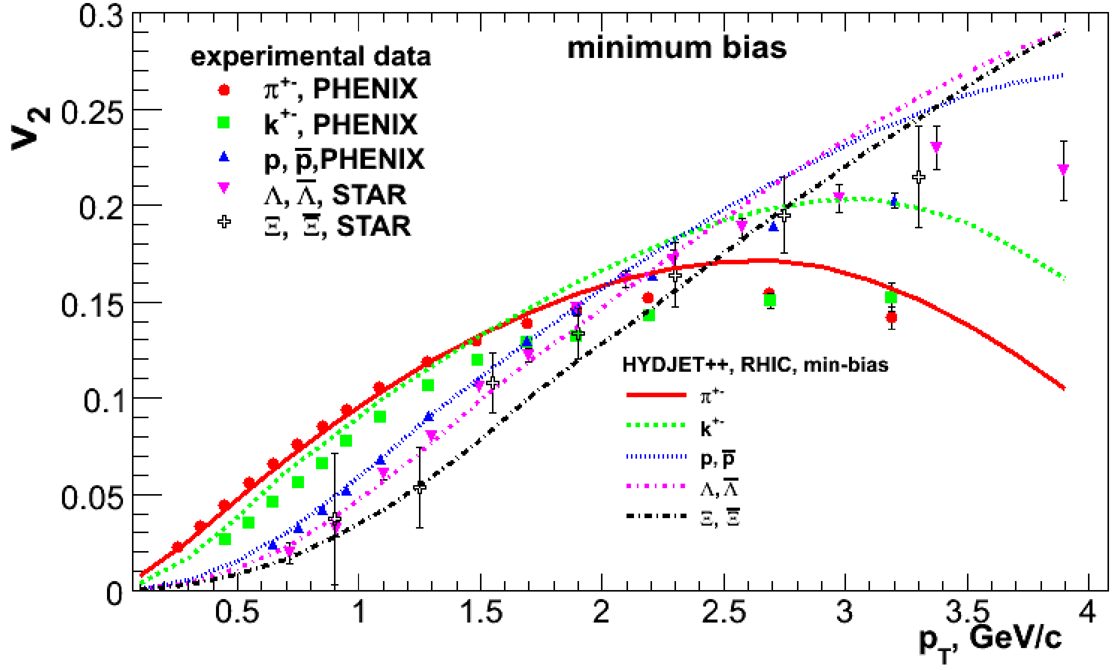
13. Maximal transverse flow rapidity at thermal freeze-out ρ_u^{max} .

14. Maximal longitudinal flow rapidity at thermal freeze-out η^{max} .

15. Flow anisotropy parameter: δ(b) $\rightarrow u^\mu = u^\mu\ (\delta(b),\varphi)$

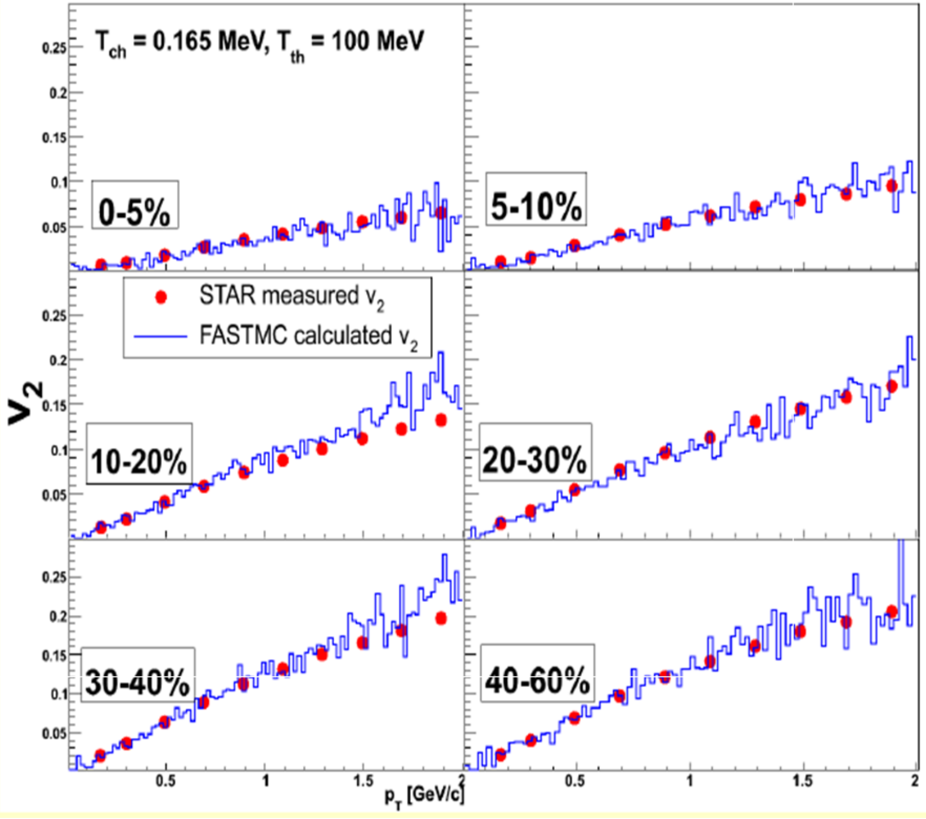
16. Coordinate anisotropy: ε(b) $\rightarrow R_f(b)=R_f(0)[V_{eff}(\varepsilon(0),\delta(0))/V_{eff}(\varepsilon(b),\delta(b))]^{1/2}[N_{part}(b)/N_{part}(0)]^{1/3}$

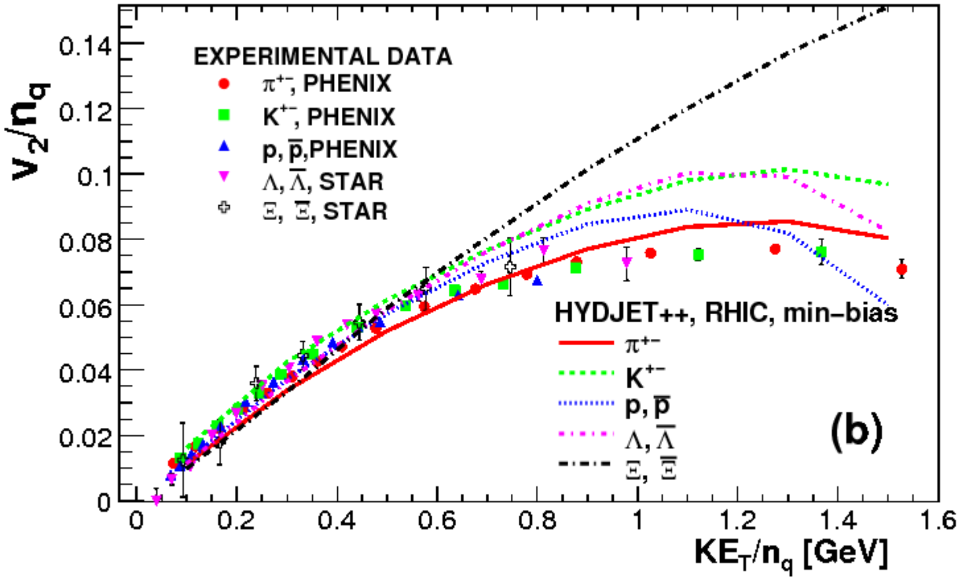
RHIC data vs. HYDJET++ model



Elliptic flow

G. Eyyubova et al., PRC 80 (2009) 064907;
N.S. Amelin et al., PRC 77 (2008) 014903

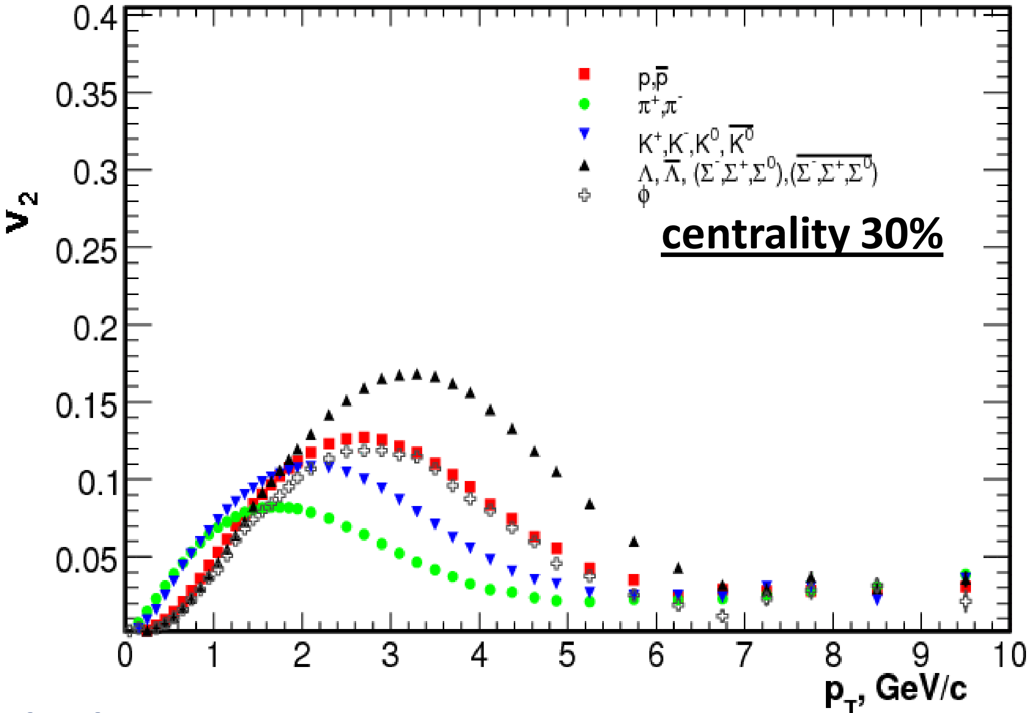




G. Eyyubova, L.V. Bravina, V.L. Korotkikh, I.P.Lokhtin, L.V. Malinina, S.V. Petrushanko, A.M. Snigirev, E. Zabrodin, Phys. Rev. C 80 (2009) 064907

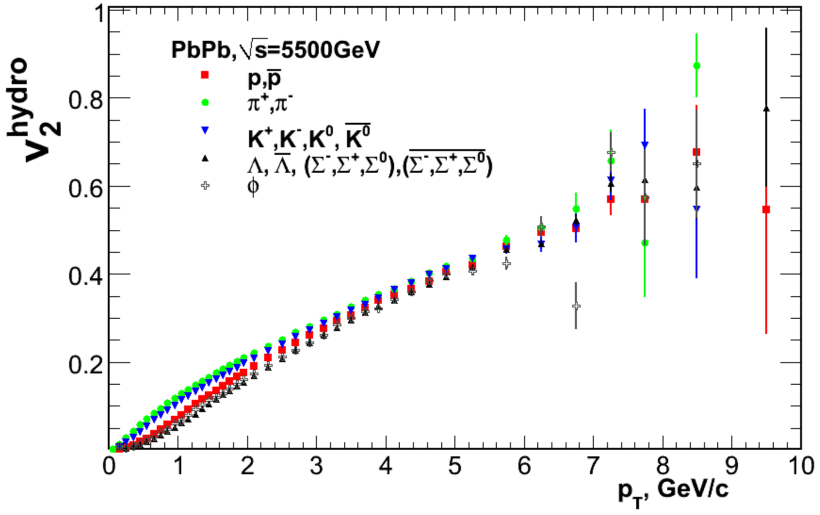
III. Results

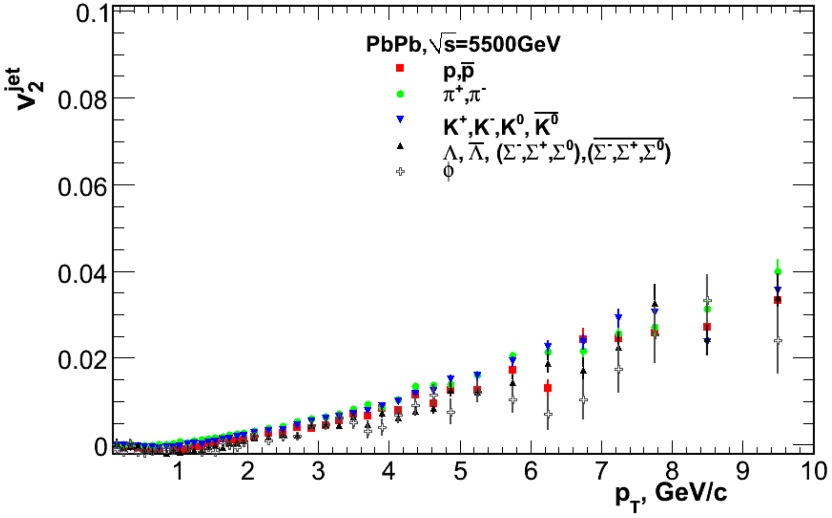
Interplay between hydro and jet part in the model



Hydrodynamics

Jet part +quenching

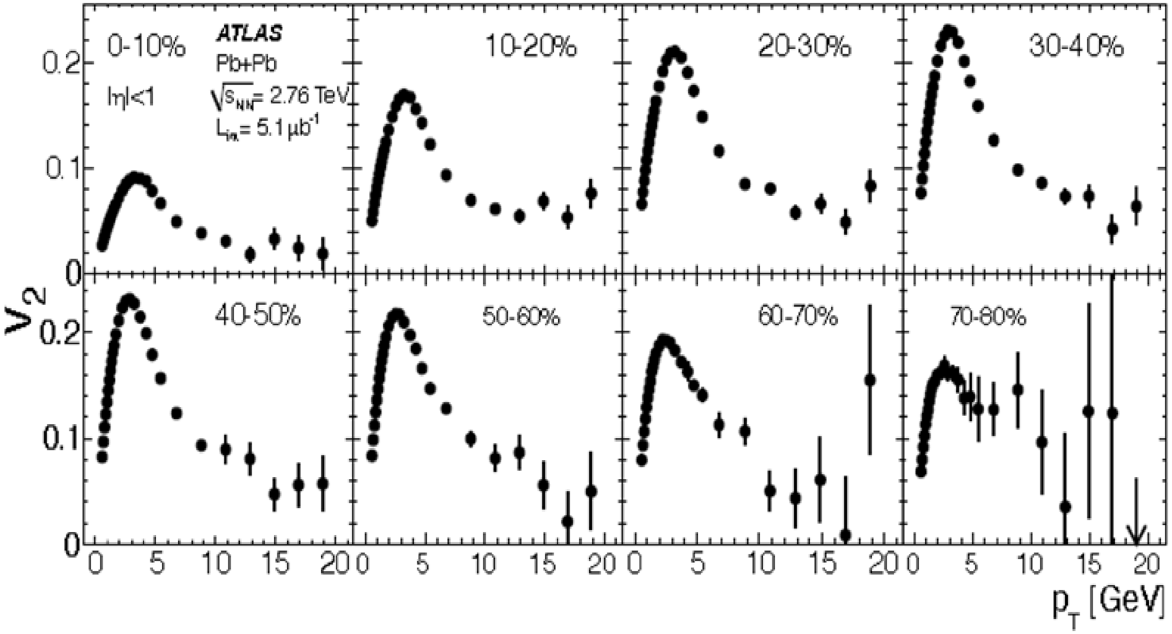


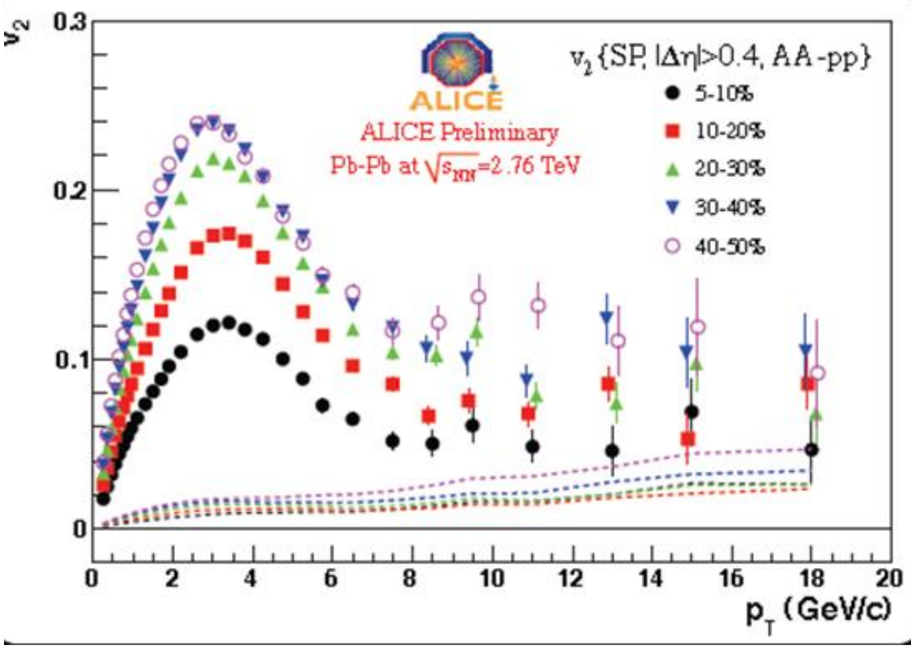


Experimental results

Centrality and pt dependence

ATLAS, CMS and ALICE have measured v2





Rapid rise up to 3-4 GeV/c

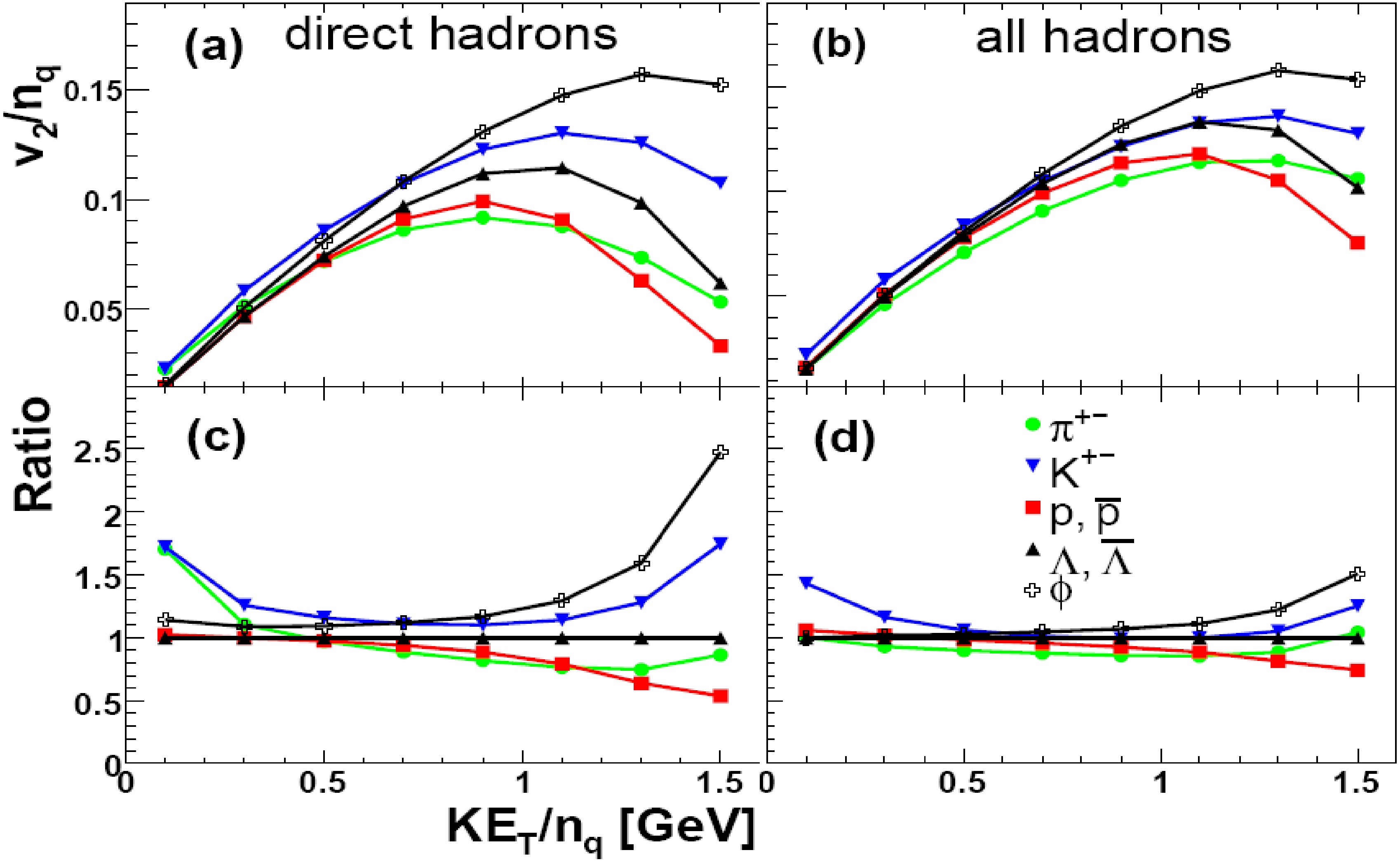
Decrease up to 8-9 GeV/c

Weak pt dependence up to 20 GeV/c

Number of constituent quark scaling at RHIC

G. Eyyubova, L. Bravina, V.L. Korotkih, I.P. Lokhtin, L.V. Malinina, S.V. Petrushanko, A.M. Snigirev, E. Zabrodin, **Phys.Rev.C80:064907,2009**.

Direct particles: scaling is not good. All particles: KE_T/n_q scaling



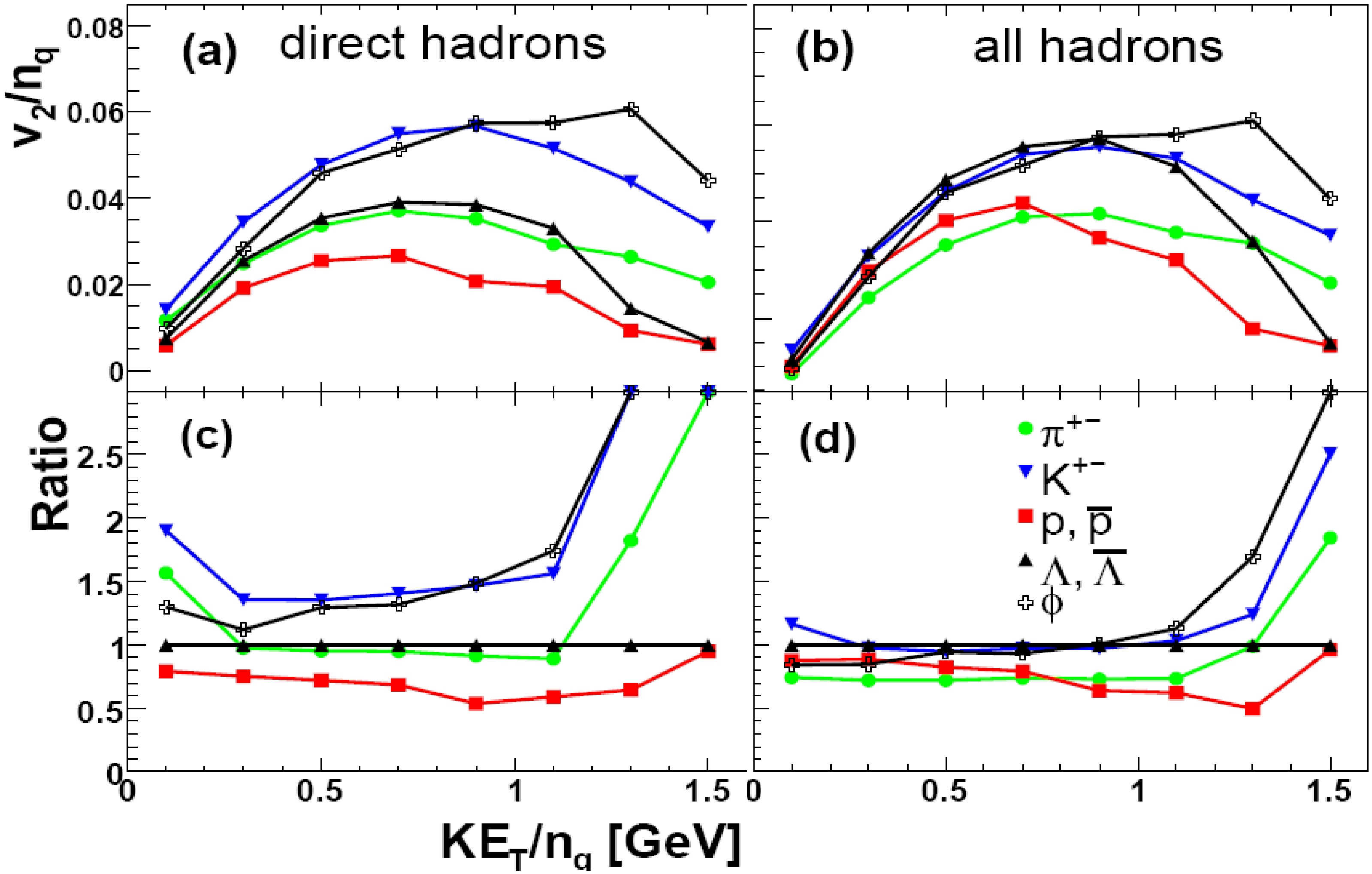
One of the explanations of KE_T/n_q scaling is partonic origin of the elliptic flow.

However, final state effects (such as resonance decays and jets) may also lead to appearance of the scaling

NCQ scaling at LHC

No scaling for
direct particles

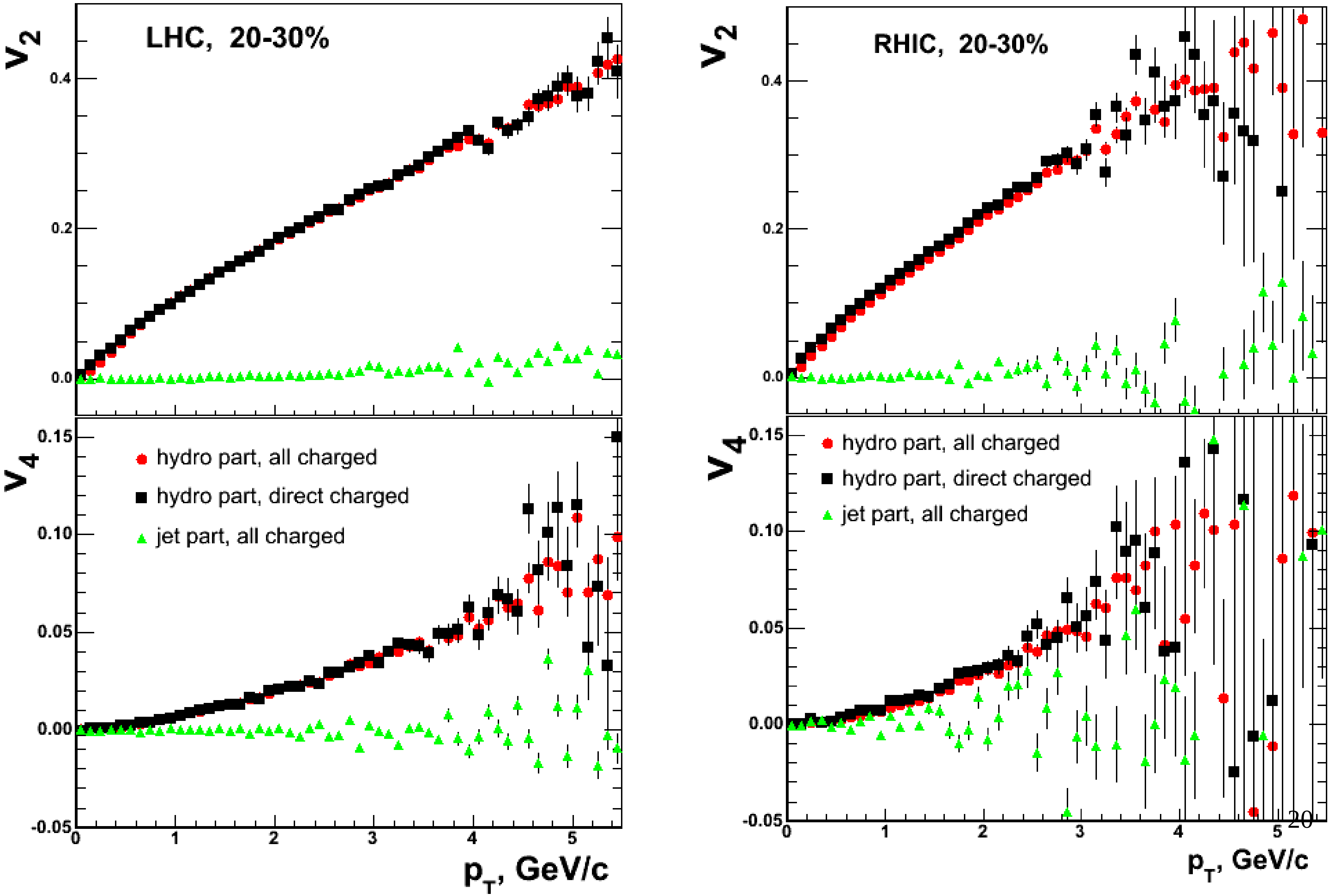
Appearance of the approximate
scaling for all particles



LHC: NCQ scaling will be only approximate

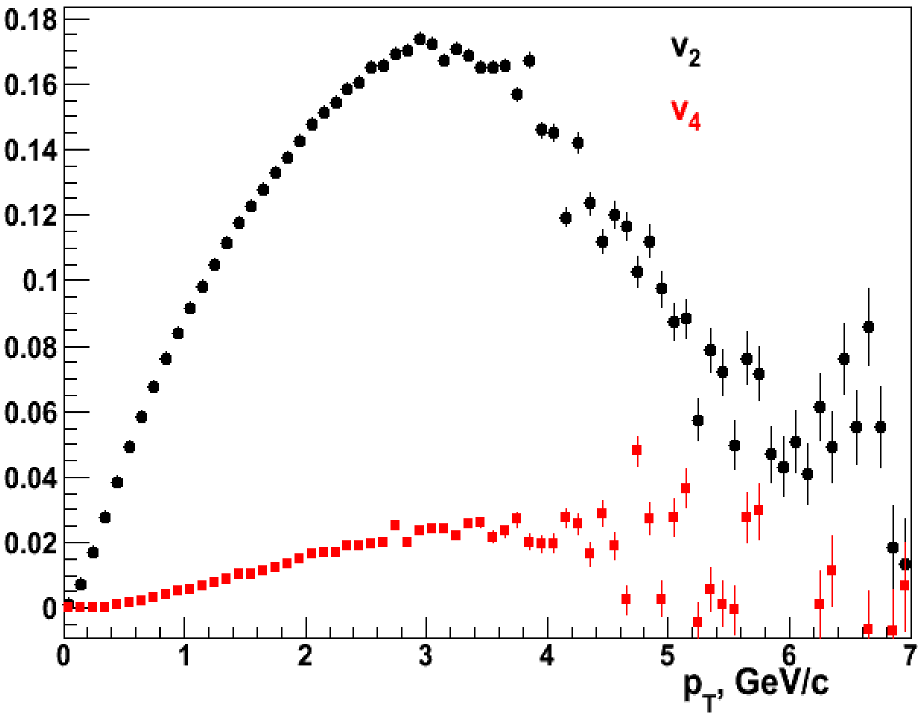
HYDJET++ RESULTS

Effects to be studied: resonance decay
hard part influence



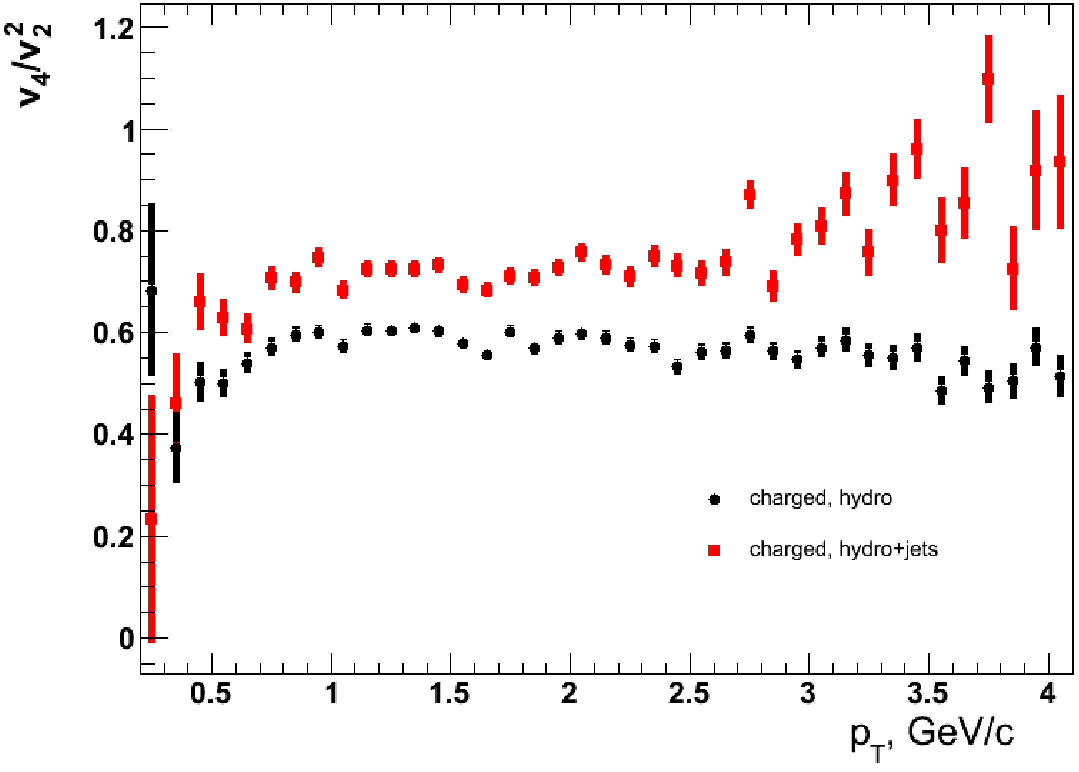
HYDJET++ RESULTS for LHC

Flow coefficients



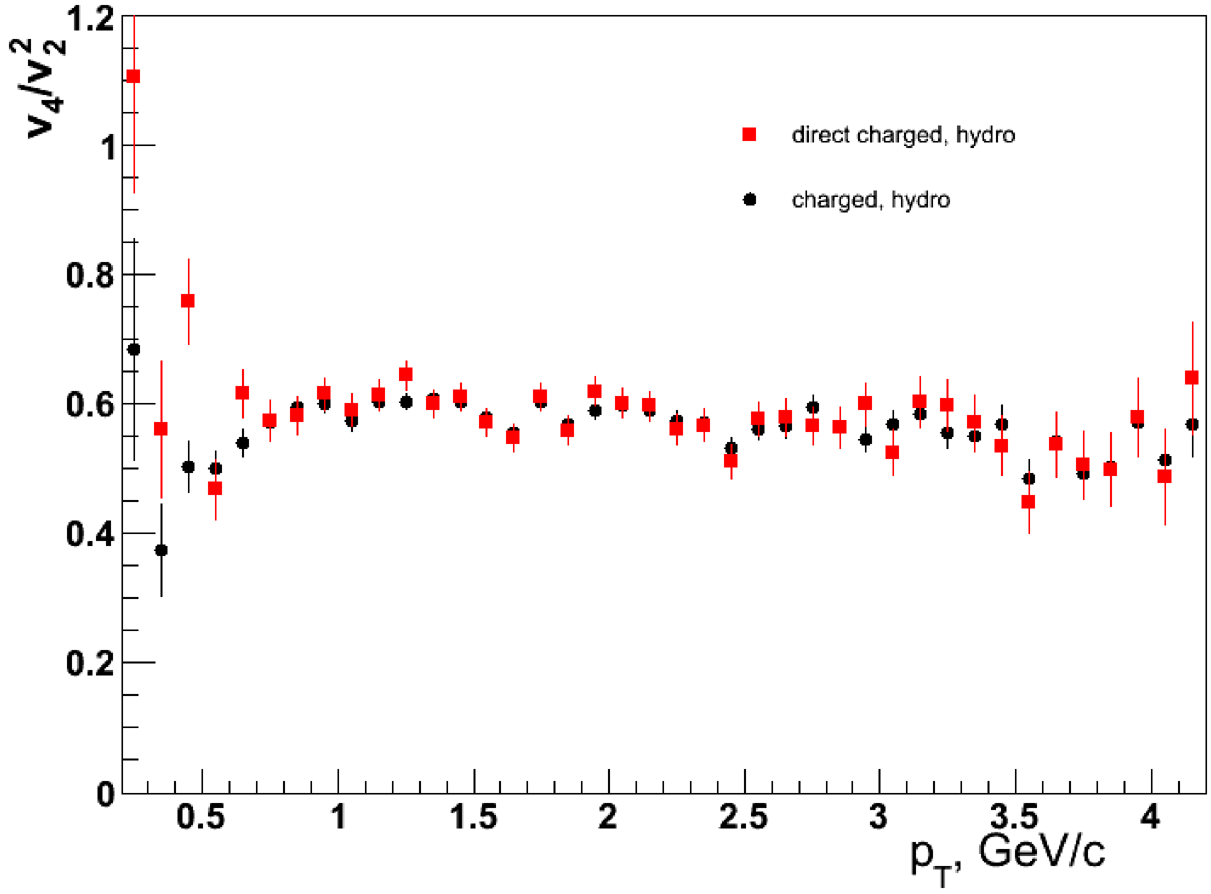
Hydro + jet parts

Ratio

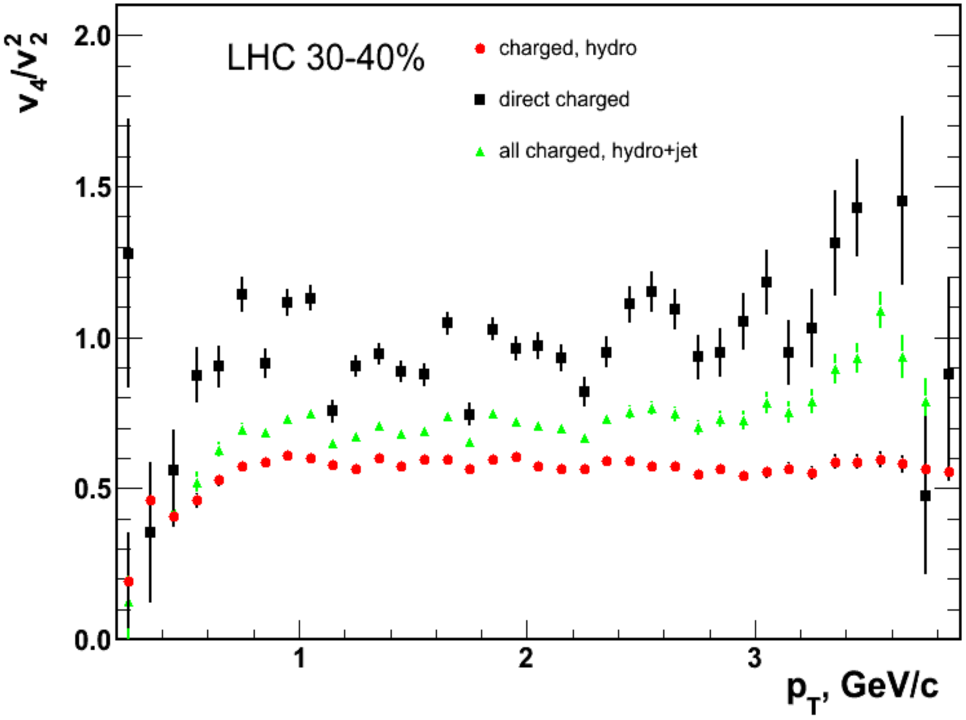


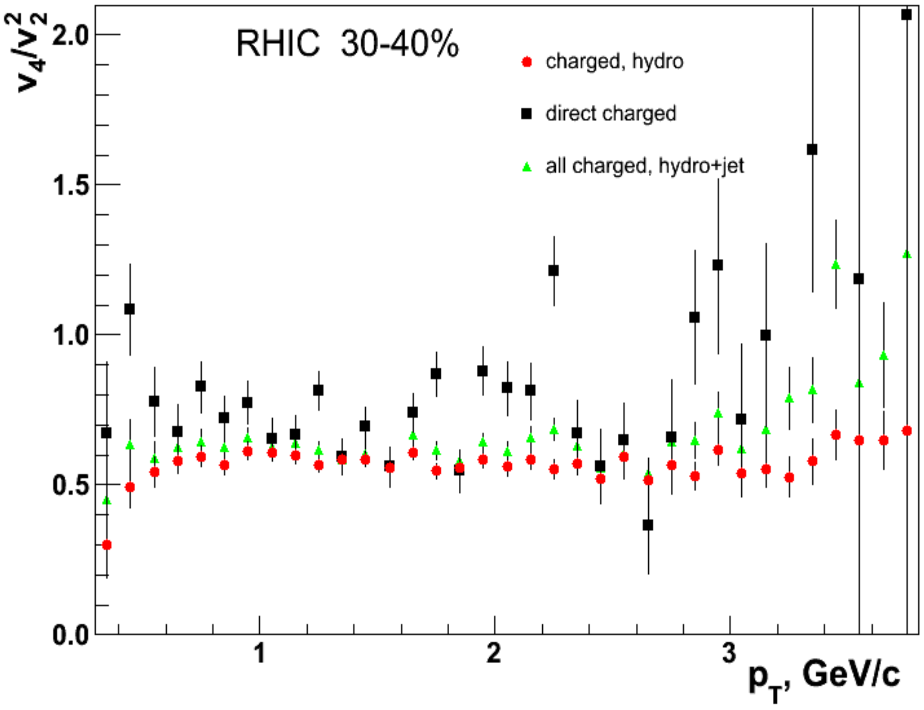
Still, the ratio is below 1

Decays of resonances play minor role



Contribution from jet part increases the ratio





Larger contribution of jets at LHC

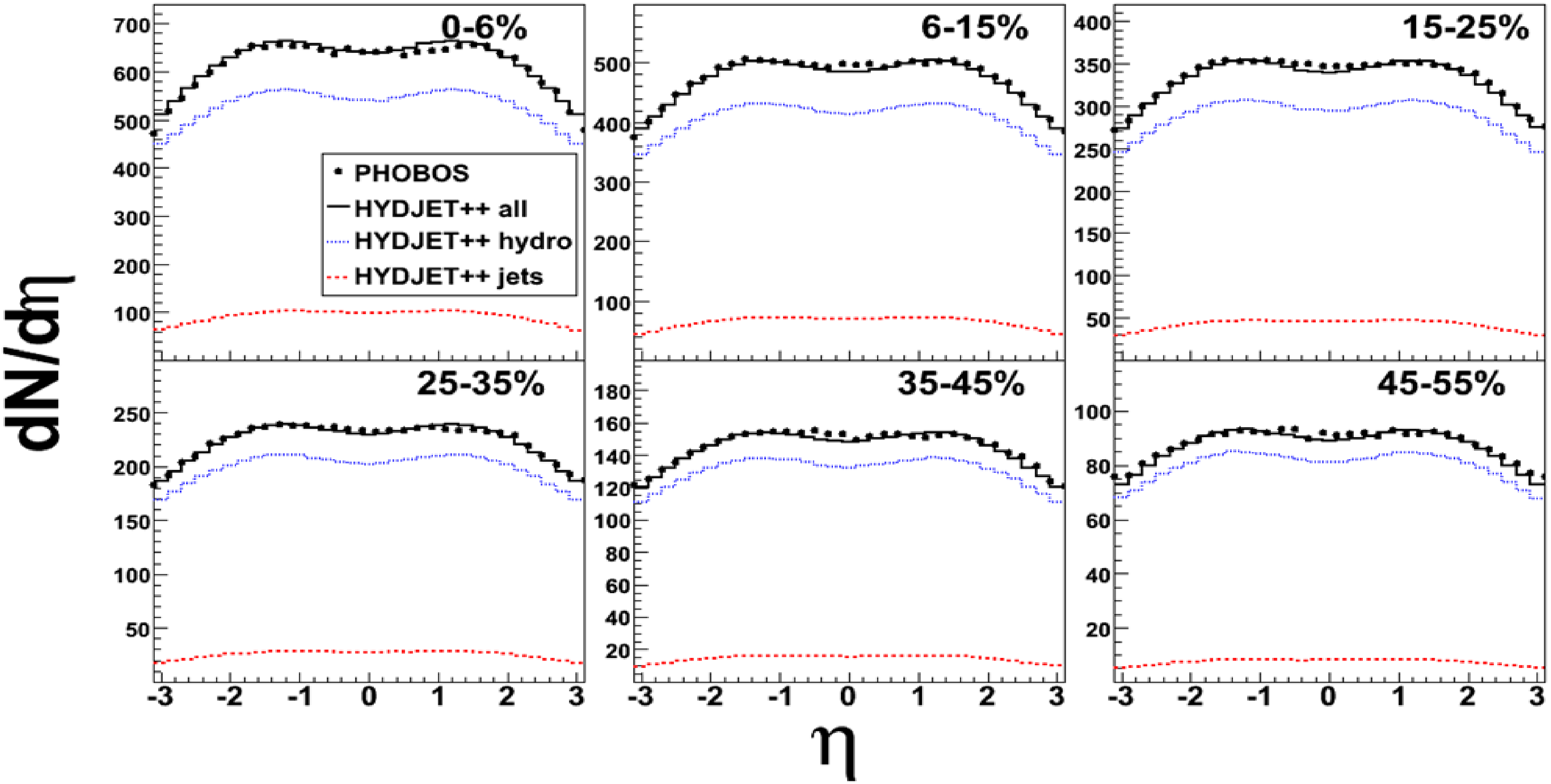
Conclusions

The HYDJET++ model allows to investigate hydro and jet parts separately,
for example, to look at reconstruction of pure hydro flow and its modification due to jet part.

- ***Jets result to increase by 25% - 30% of the ratio v4/(v2*v2)***
- ***Eccentricity fluctuations can increase the ratio by factor 1.5***
- ***Jets + eccentricity fluctuations are enough to explain RHIC data***
- ***For LHC we can explain 75% of the signal. Other effects are needed.***

Backup slides

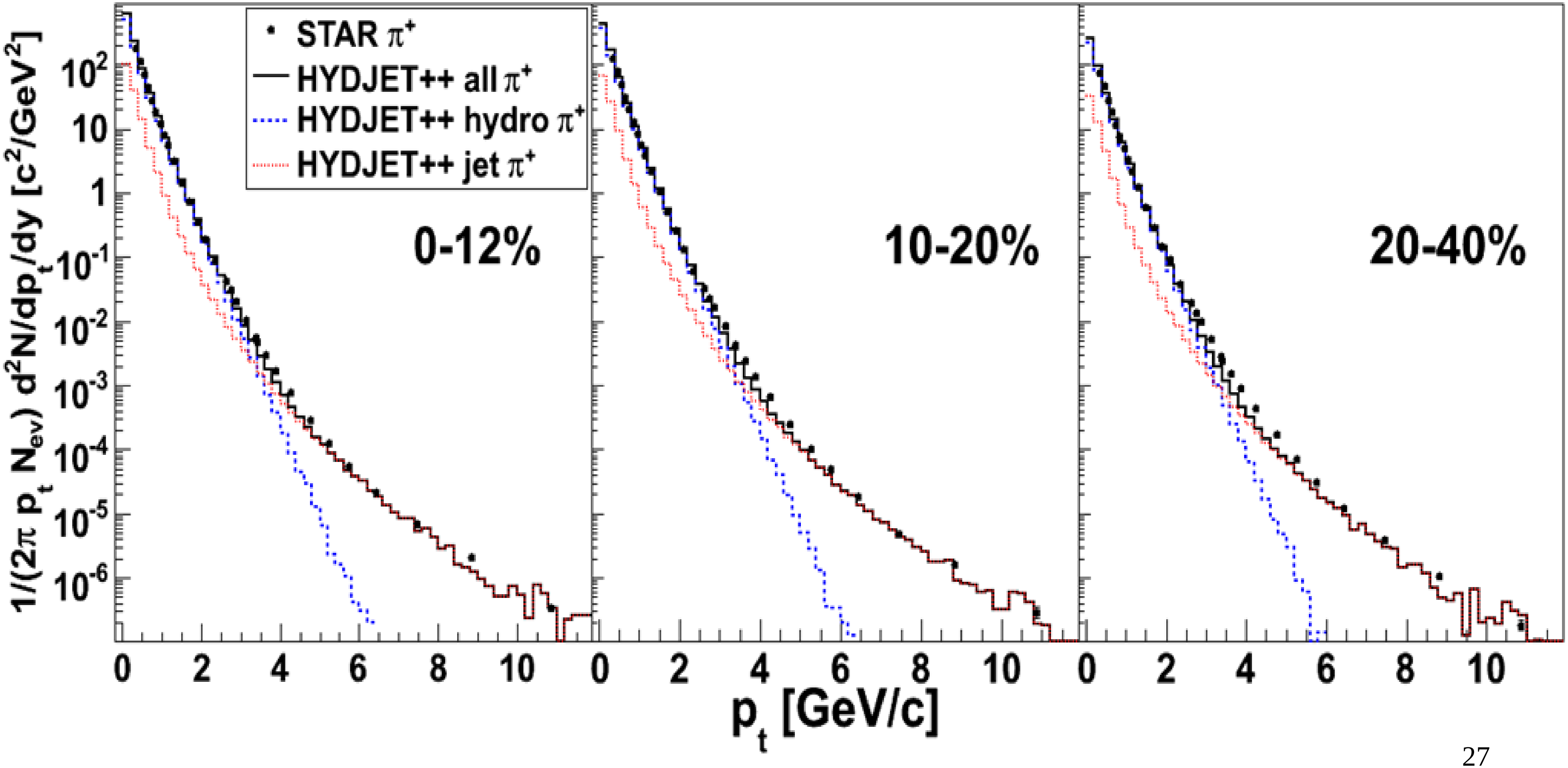
HYDJET++: rapidity spectra vs. event centrality at RHIC



Width of the spectra allows one to fix η^{max} =3.3,
Centrality dependence of multiplicity allows one to fix ptmin=3.4 GeV/c and μ_π=0.06

HYDJET++: transverse momentum spectra at RHIC

PYQUEN energy loss model parameters: T_0(QGP)=300 MeV, τ_0(QGP)=0.4 fm/c, N_f=2



HYDJET++ (soft): hadron multiplicities

1. The hadronic matter created in heavy-ion collisions is considered as a hydrodynamically expanding fireball with EOS of an ideal hadron gas.

2. “Concept of effective volume” T=const and μ=const: the total yield of particle species is $N_i = \rho_i(T,\mu_i)V_{eff}$.

3. Chemical freeze-out : T, $\mu_i = \mu_B B_i + \mu_S S_i + \mu_c C_i + \mu_Q Q_i$; T, μ_B – can be fixed by particle ratios, or by phenomenological formulas

$$T(\mu_B) = a - b\mu_B - c\mu_B^4; \mu_B(\sqrt{s_{NN}}) = \frac{d}{1+e\sqrt{s_{NN}}}$$

4. Chemical freeze-out: all macroscopic characteristics of particle system are determined via a set of equilibrium distribution functions in the fluid element rest frame:

$$f_i^{eq}(p^{0*};T,\mu_i) = \frac{1}{(2\pi)^3}\frac{g_i}{\exp([p^{0*}-\mu_i]/T)\pm 1}$$

$$\rho_i^{eq}(T,\mu_i) = \int_0^\infty d^3\vec{p}^{\,*} f_i^{eq}(p^{0*};T(x^*),\mu(x^*)_i) = 4\pi\int_0^\infty dp^* p^{*2} f_i^{eq}(p^{0*};T,\mu_i)$$

HYDJET++ (soft): main physics assumptions

A hydrodynamic expansion of the fireball is supposed ends by a sudden system breakup at given T and chemical potentials. Momentum distribution of produced hadrons keeps the thermal character of the equilibrium distribution.

Cooper-Frye formula: $$p^0 \frac{d^3N_i}{d^3p} = \int\limits_{\sigma(x)} d^3\sigma_\mu(x) p^\mu f_i^{eq}(p^\nu u_\nu(x); T, \mu_i)$$

- HYDJET++ avoids straightforward 6-dimensional integration by using the special simulation procedure (like HYDJET): momentum generation in the rest frame of fluid element, then Lorentz transformation in the global frame → uniform weights → effective von-Neumann rejection-acception procedure.

Freeze-out surface parameterizations

1. The Bjorken model with hypersurface $\tau = (t^2 - z^2)^{1/2} = const$

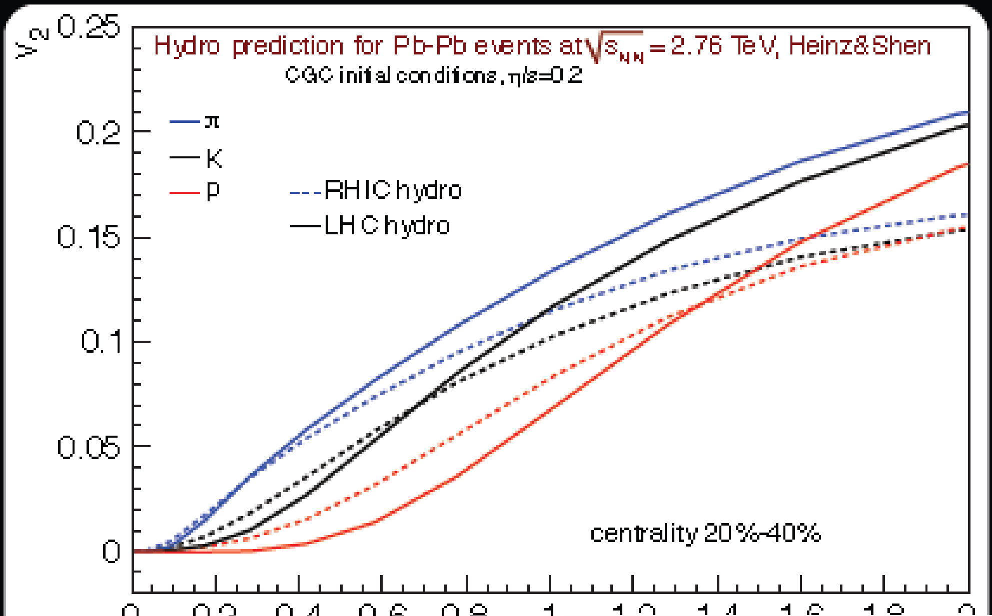
2. Linear transverse flow rapidity profile $\rho_u = \frac{r}{R} \rho_u^{\max}$

3. The total effective volume for particle production at

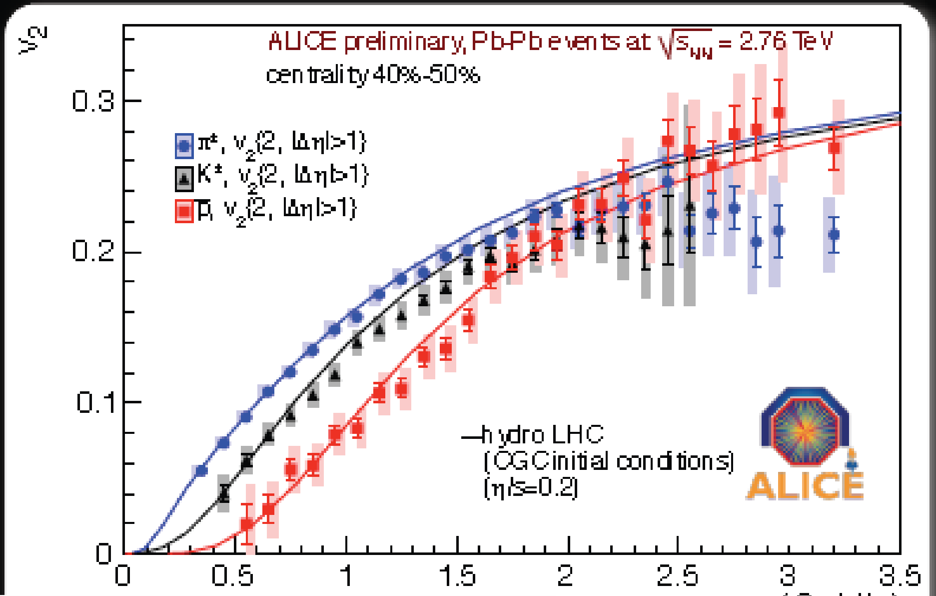
$$- \; V_{eff} = \int\limits_{\sigma(x)} d^3\sigma_\mu(x) u^\mu(x) = \tau \int\limits_0^R \gamma_r r dr \int\limits_0^{2\pi} d\phi \int\limits_{\eta_{\min}}^{\eta_{\max}} d\eta = 2\pi\tau\Delta\eta \left(\frac{R}{\rho_u^{\max}}\right)^2 (\rho_u^{\max} \sinh \rho_u^{\max} - \cosh \rho_u^{\max} + 1)$$

v_2 for identified particles

Hydro: Shen, Heinz, Huovinen & Song, arXiv:1105.3226



& Song, arXiv:1105.3226



hydro models predi

splittin

data shows mass split

well with hydro predi

central coll

for more central coll

proton flow is not de

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