CALCULATING AZIMUTHAL FLOWS IN PB–PB AND XE–XE COLLISIONS WITH THE HYDJET++ MONTE CARLO GENERATOR AT THE LHC ENERGIES

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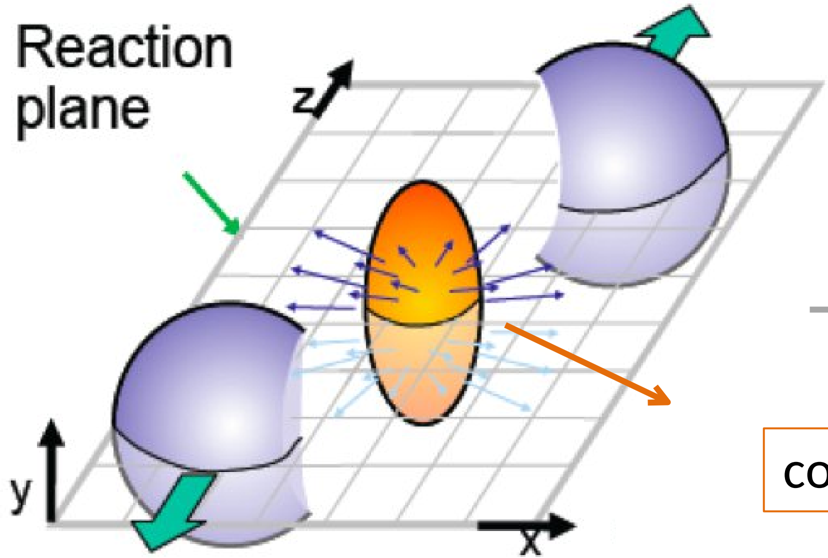
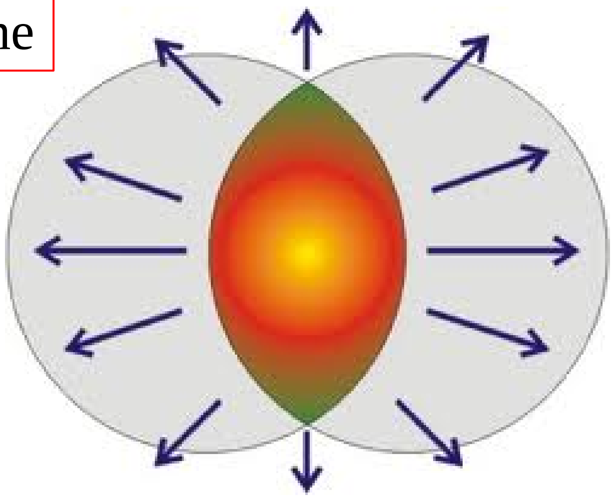
Azimuthal correlations and flows



Reaction Plane

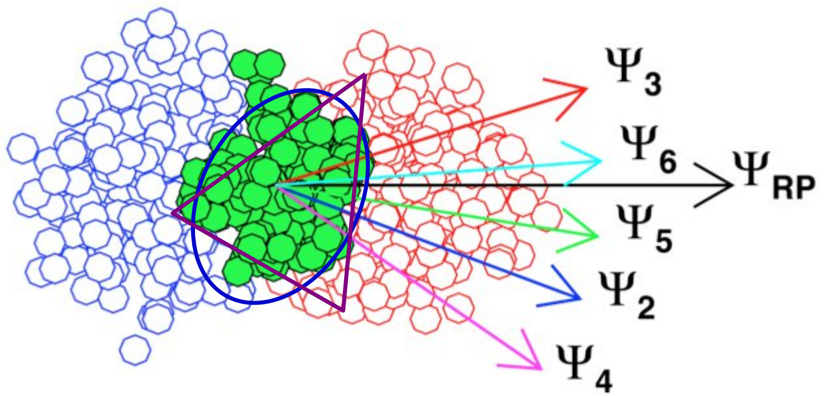


colliding ions

initial evolution state

Fourier decomposition of the azimuthal particle distribution

$$E\frac{d^3N}{d^3p} = \frac{1}{\pi}\frac{d^2N}{dp_t^2dy}\left[1 + 2\sum_{n=1}^{\infty} v_n \cos n(\phi - \Psi_n)\right]$$



Initial state fluctuations

Elliptical flow v_2

Triangular flow v_3

...

Methods for calculating azimuthal anisotropy (i.e. flows)

The method of the true reaction plane. The HYDJET++ model

In the generator, the reaction plane is known in advance — it is set by the internal code of the generator.

Thus, it is possible to immediately calculate elliptical, triangular and other flows using the formula:

$v_n = \left\langle \cos\left[n\left(\phi - \psi_{r.p.}\right)\right]\right\rangle$, where $\varphi_{r.p.}$ — the azimuthal angle of the true reaction plane.

We used this method in our analysis with the Monte Carlo generator HYDJET++.

Reaction Plane method

The method involves calculating the angle of the reaction plane to calculate the flows

1) define two independent groups of particles

2) Calculate the reaction plane angle with first group of particles using formula:

$$\Psi_n = \left(\tan^{-1}\frac{\sum_i w_i \sin(n\phi_i)}{\sum_i w_i \cos(n\phi_i)}\right)/n.$$

3) Calculate the flows with the second group of particles using formula:

$$v_n = \left\langle \cos\left[n\left(\phi - \Psi_{n.}\right)\right]\right\rangle$$

This method is used in the CMS experiment see Phys. Rev. C 100 (2019) 044902

HYDJET and HYDJET++ generators for relativistic heavy ion collisions

HYDJET

(HYDrodynamics + JETs)

Monte Carlo event generator simulating heavy ion collisions as a mixture of two independent components (soft hydrodynamic part and rigid multiparticle processes)

http://cern.ch/lokhtin/hydro/hydjet.html

(последняя версия 1.9)

I.Lokhtin, A.Snigirev, Eur. Phys. J. C 46 (2006) 2011

HYDJET++

Further development of HYDJET

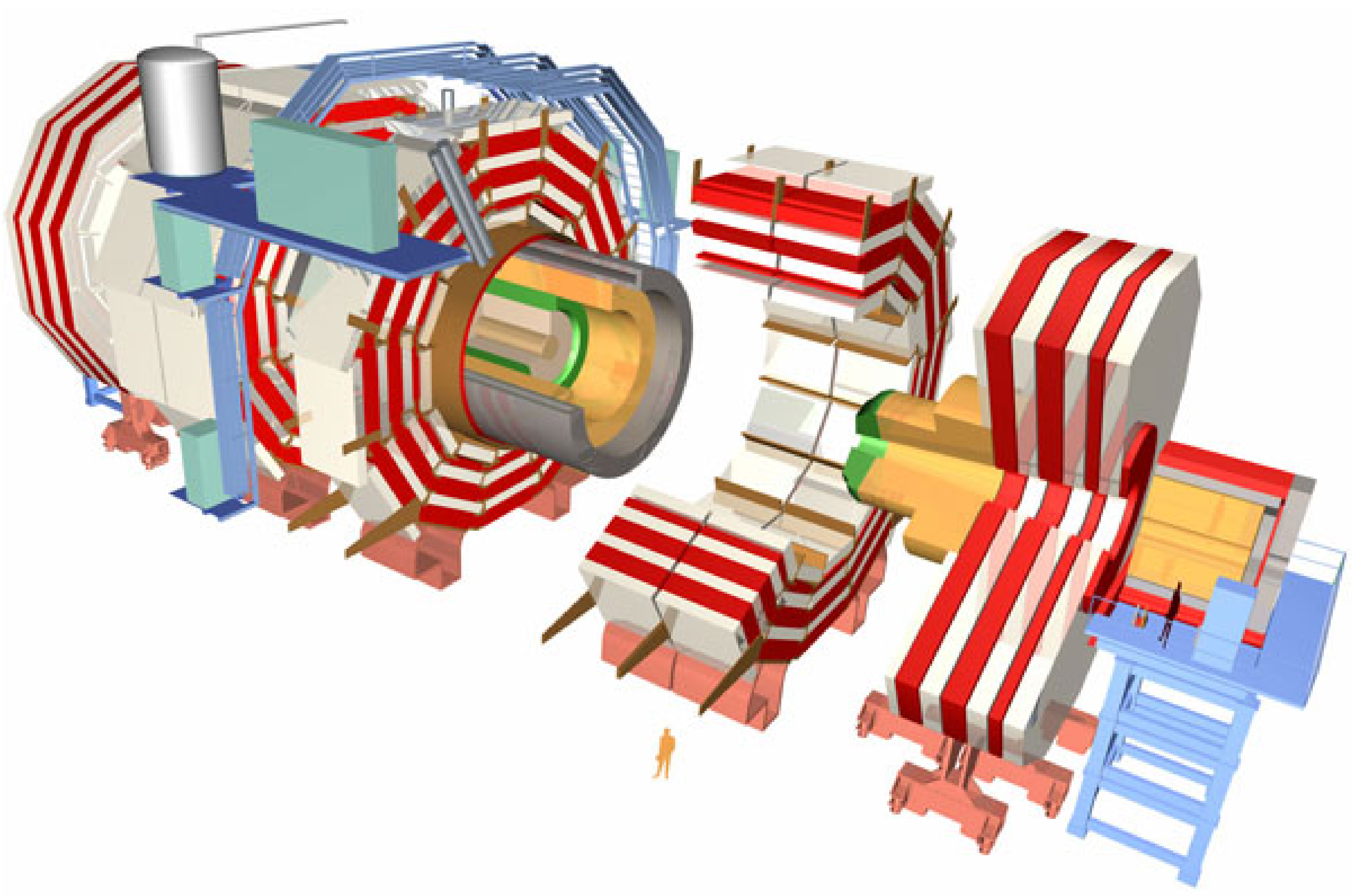
(improved soft component based on FAST MC + identical HYDJET hard component PYQUEN)

http://cern.ch/lokhtin/hydjet++

(последняя версия 2.4.3)

I.Lokhtin, L.Malinina, S.Petrushanko, A.Snigirev, I.Arsene, K.Tywoniuk, Comp.Phys.Comm. 180 (2009) 779

Compact Muon Solenoid (CMS) At Large Hadron Collider (LHC)



Tracker detector
$|\eta| < 2.4$
ECal
$|\eta| < 3.0$
HCal
$|\eta| < 3.0$
with HF up to
$|\eta| < 5.2$
Muon chambers
$|\eta| < 2.4$
+ CASTOR
$5.2 < |\eta| < 6.6$

Magnetic field: 3.8 T

previous results: Flows relations $v_n\,[XeXe]/v_n\,[PbPb]$ at 5.44 TeV and 5.02 TeV respectively per nuclon in c.m.s. in Monte-Carlo generator HYDJET++

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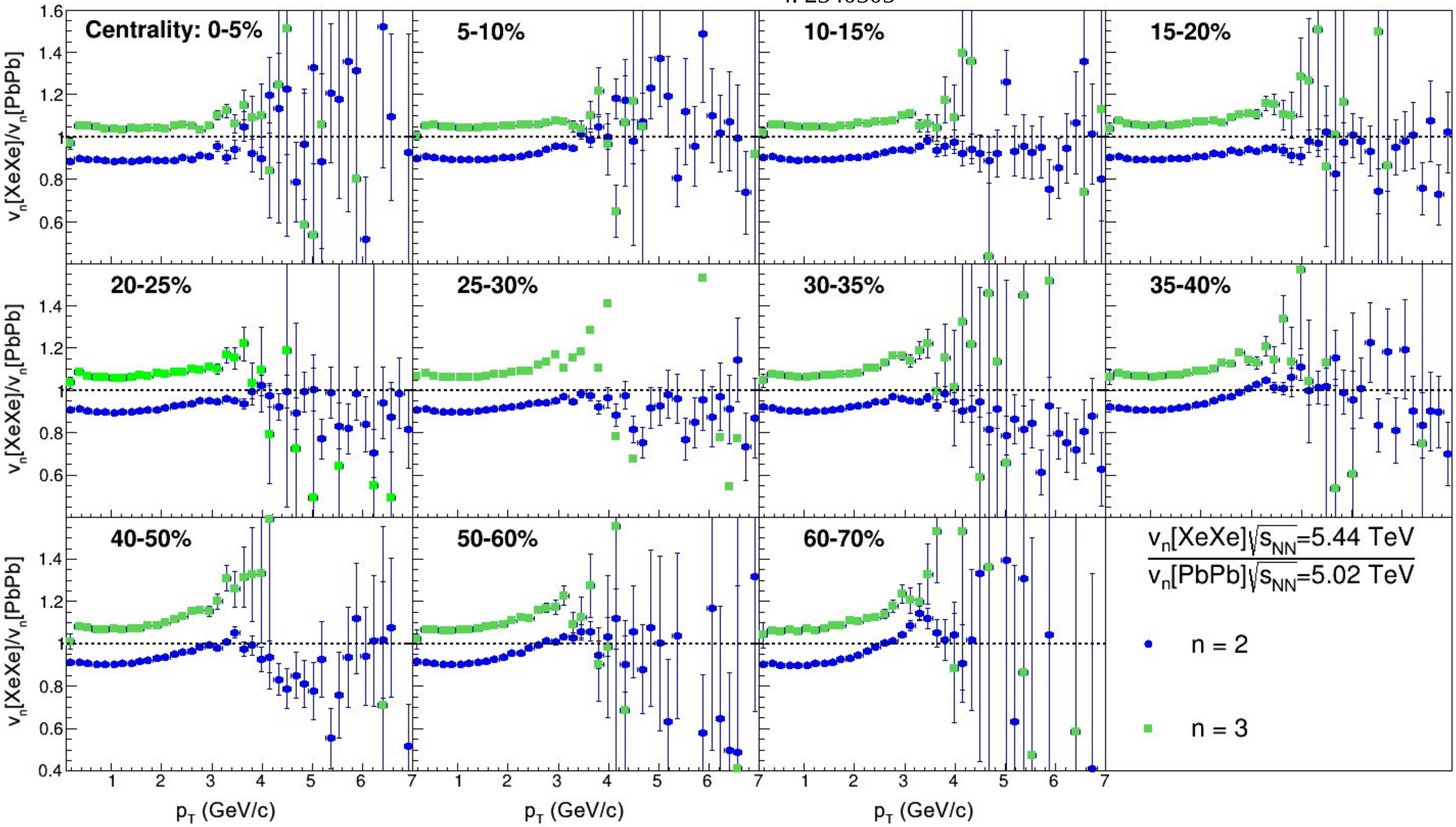
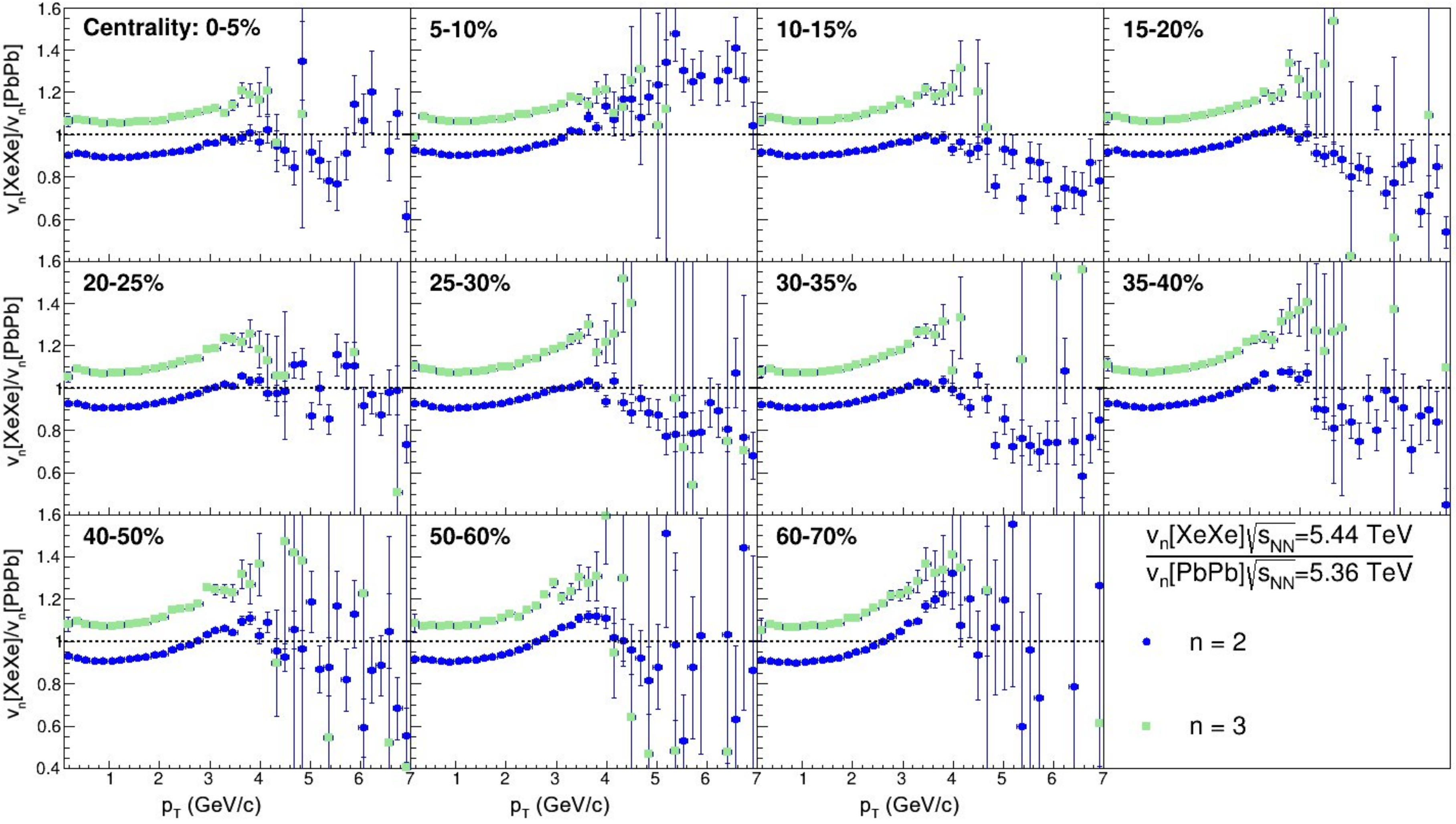


The results for the flows were obtained in the HYDJET++ generator relative to the true plane of the reaction (statistics approx. 1 million. events for each centrality).

Flows relations $v_n\,[XeXe]/v_n\,[PbPb]$ at 5.44 TeV and 5.36 TeV respectively per nuclon in c.m.s. in Monte-Carlo generator HYDJET++



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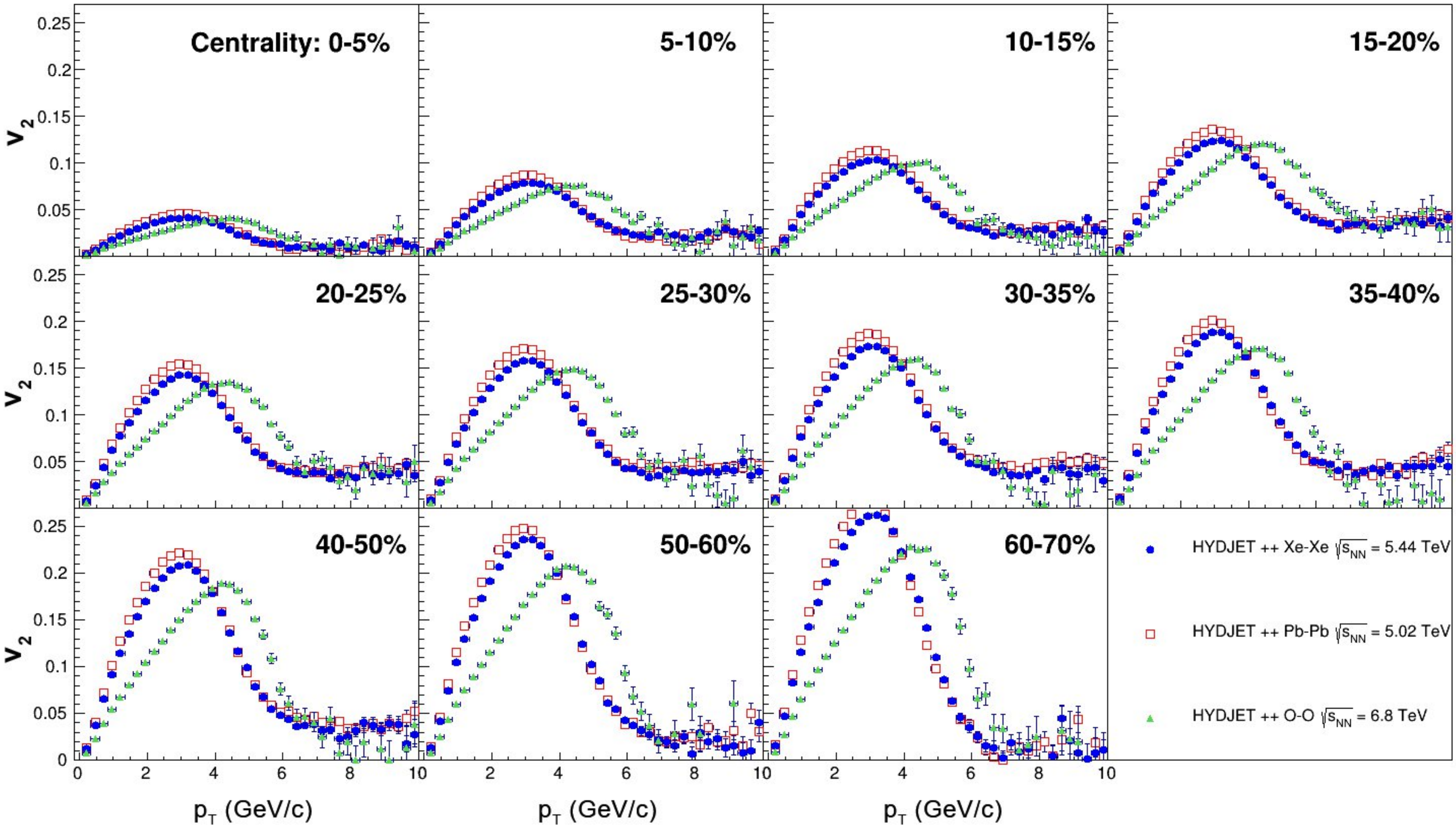
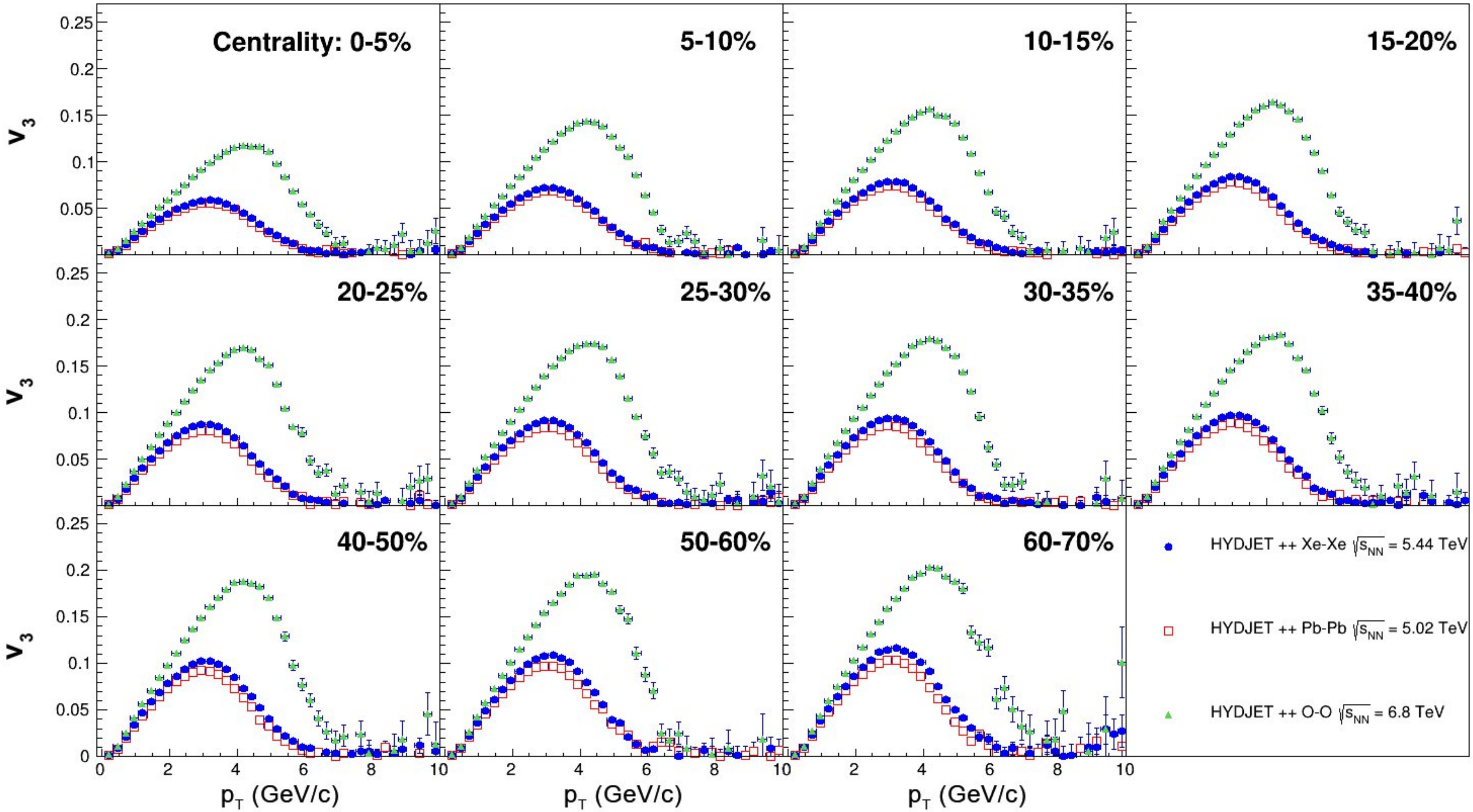
Predictions for v_2 distributions for O—O collisions with an energy of 6.8 TeV per nucleon in the c.m.s. in the Monte Carlo generator HYDJET++



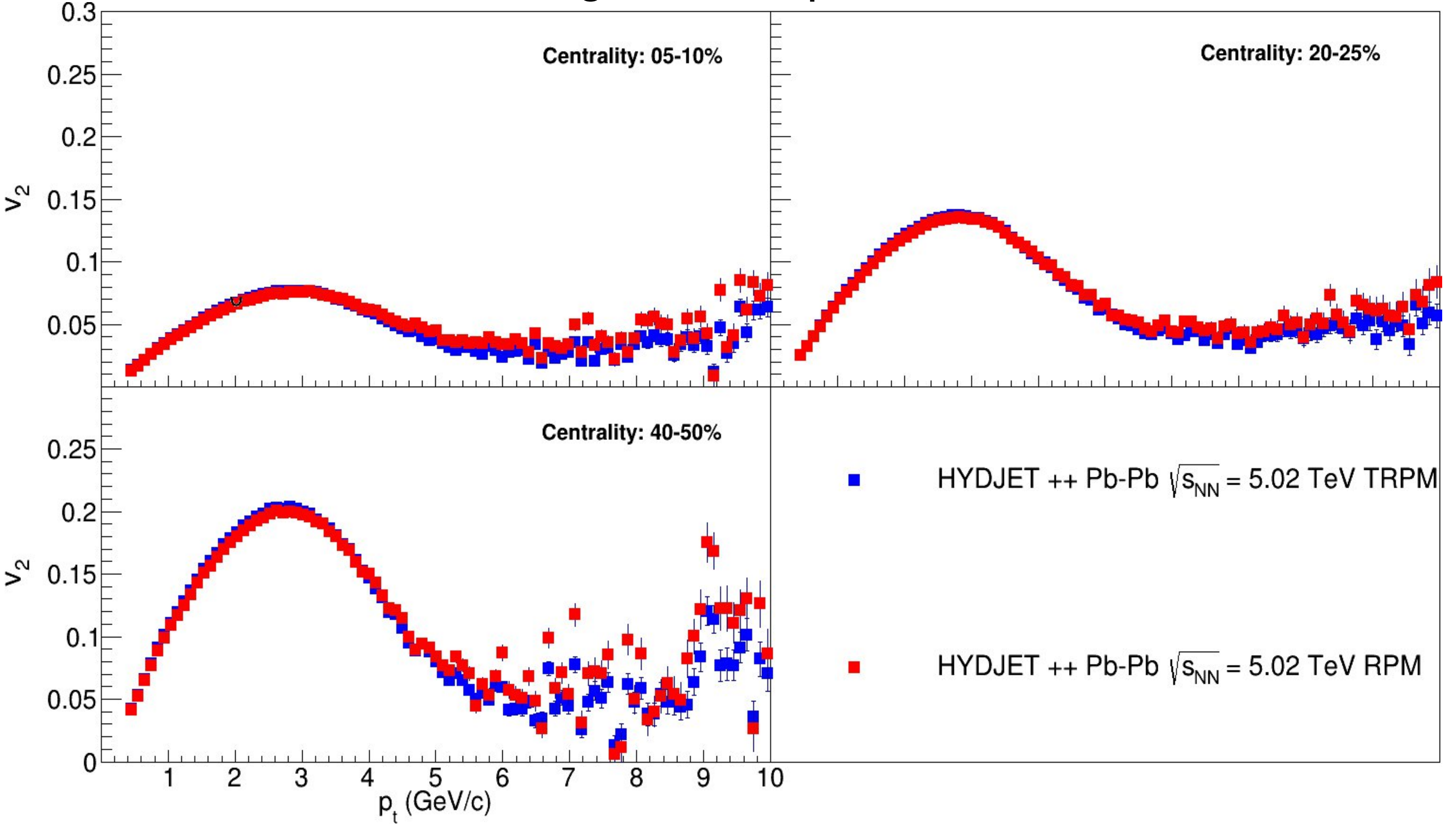
- The form of dependence differs from those for Pb and Xe
- In order of magnitude, the distributions are similar
- The peak of the distribution is shifted towards higher p_T than that of Pb and Xe

Predictions for v_3 distributions for O—O collisions with an energy of 6.8 TeV per nucleon in the c.m.s. in the Monte Carlo generator HYDJET++



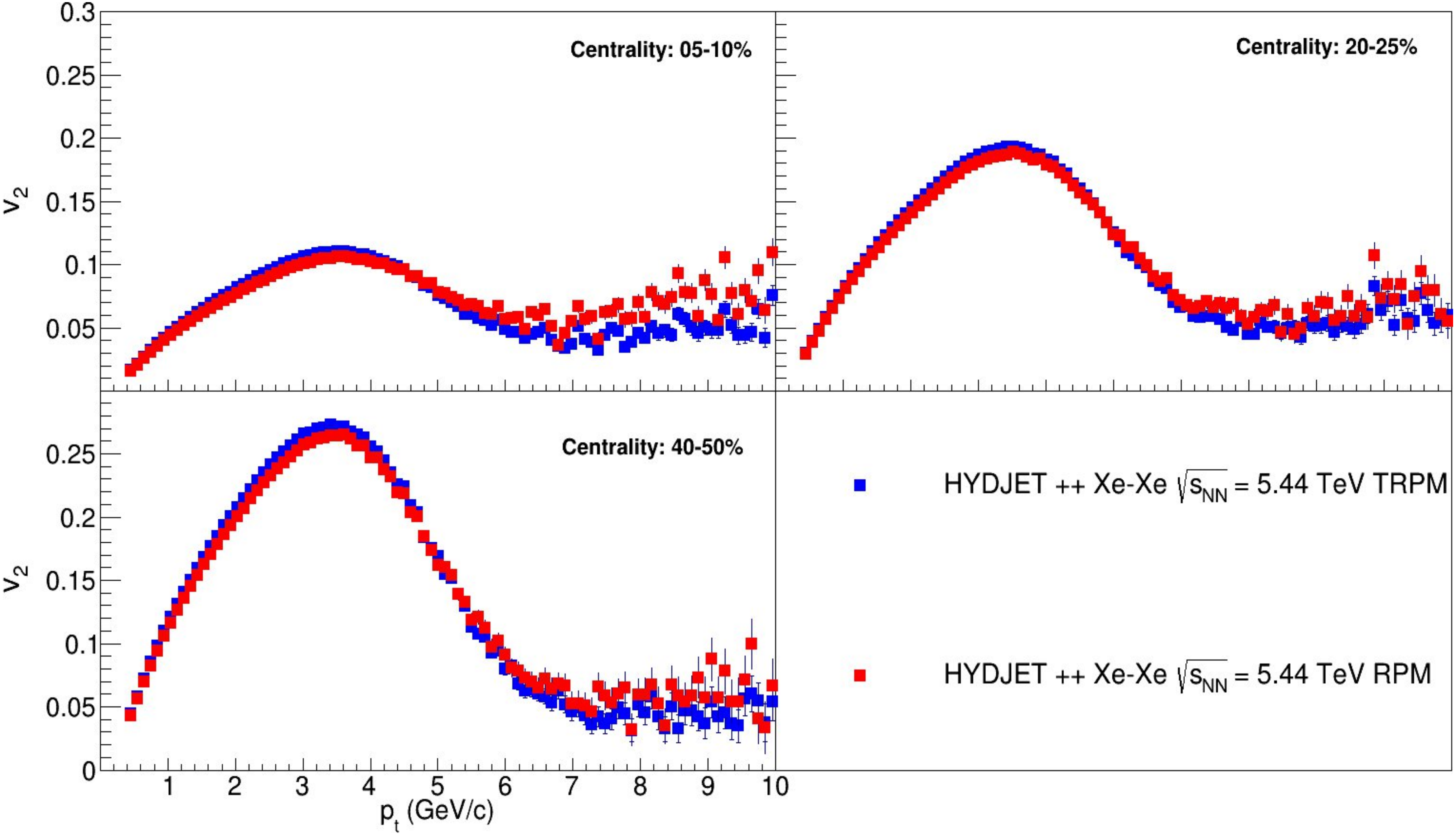
- The form of dependence differs from those for Pb and Xe
- The peak of the distribution is shifted towards higher p_T than that of Pb and Xe
- In magnitude, the triangular flow is similar to the elliptical one, which was not observed earlier

Calculations for v_2 in Pb—Pb collisions at the 5.02 TeV in c.m.s. using reaction plane method



The results for the flows were obtained in the HYDJET++ generator (statistics approx. 1 million. events for each centrality true and calculated).

Calculations for v_2 in Xe—Xe collisions at the 5.44 TeV in c.m.s. using reaction plane method



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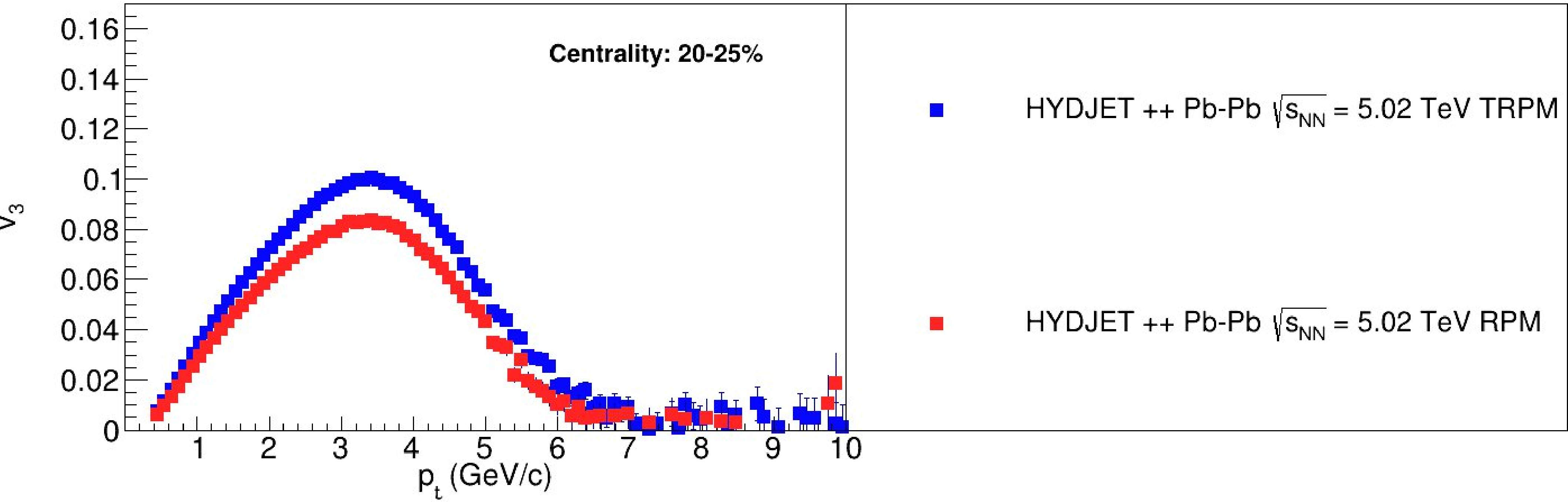
Calculations for v_3 in Pb—Pb collisions at the 5.02 TeV in c.m.s. using reaction plane method



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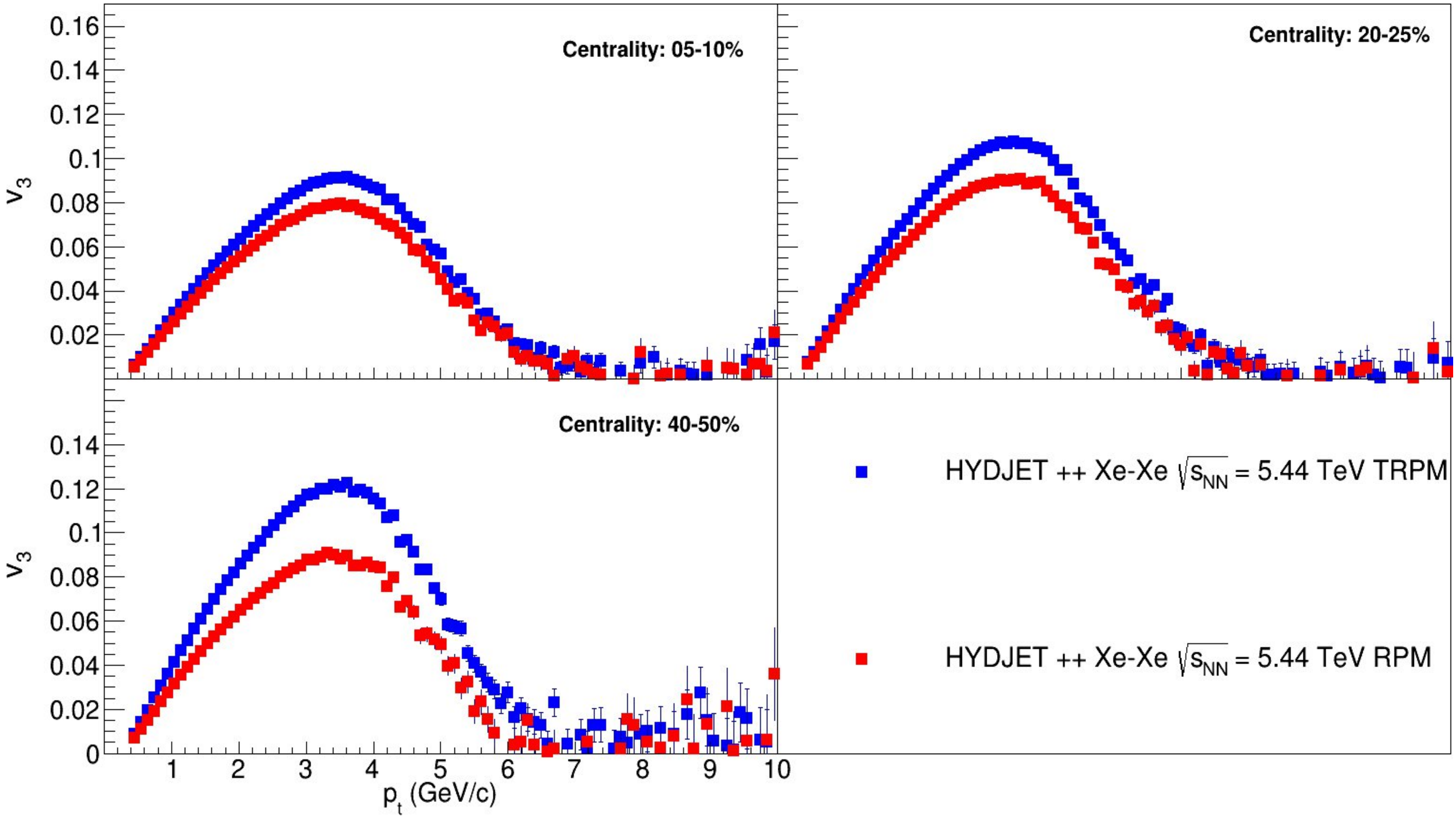

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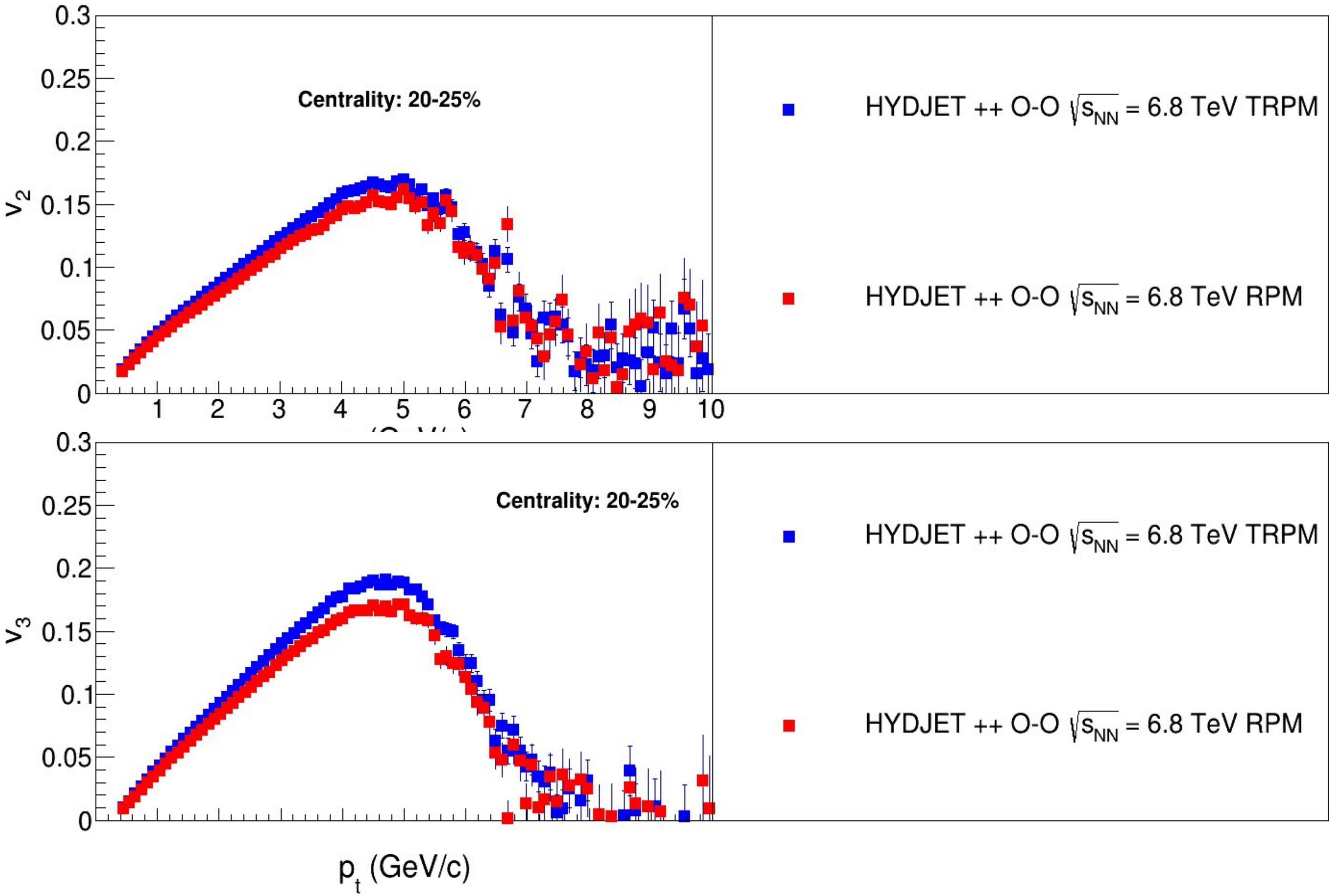
Calculations for v_2 and v_3 in O—O collisions at the 6.8 TeV in c.m.s. using reaction plane method



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SUMMARY

- Azimuthal flows and its relations in collisions of xenon and lead with an energy of 5.44 TeV and 5.02 TeV respectively per nuclon in c.m.s. were compared using the standard generator method
- The reaction plane method — method for calculating azimuthal flows used in CMS — was mastered and put into operation of the HYDJET++ generator
- Relativistic collisions of lead and xenon ions with an energy of 5.44 TeV and 5.02 TeV respectively per nuclon in c.m.s. were generated in new HYDJET++ settings and azimuthal flows were calculated using a new method
- As a result, it turned out that for all collisions and all centralities, the magnitude of the elliptical v_2 and triangular v_3 flows appear to be lower when calculating the latter by the reaction plane method
- The biggest difference in the magnitude of the flows when calculated by the two methods is observed in the calculation of triangular flows in xenon collisions

v_2 для столкновений Xe-Xe с энергией 5.44 ТэВ и Pb-Pb с энергией 5.02 ТэВ на нуклон в СЦМ в эксперименте CMS

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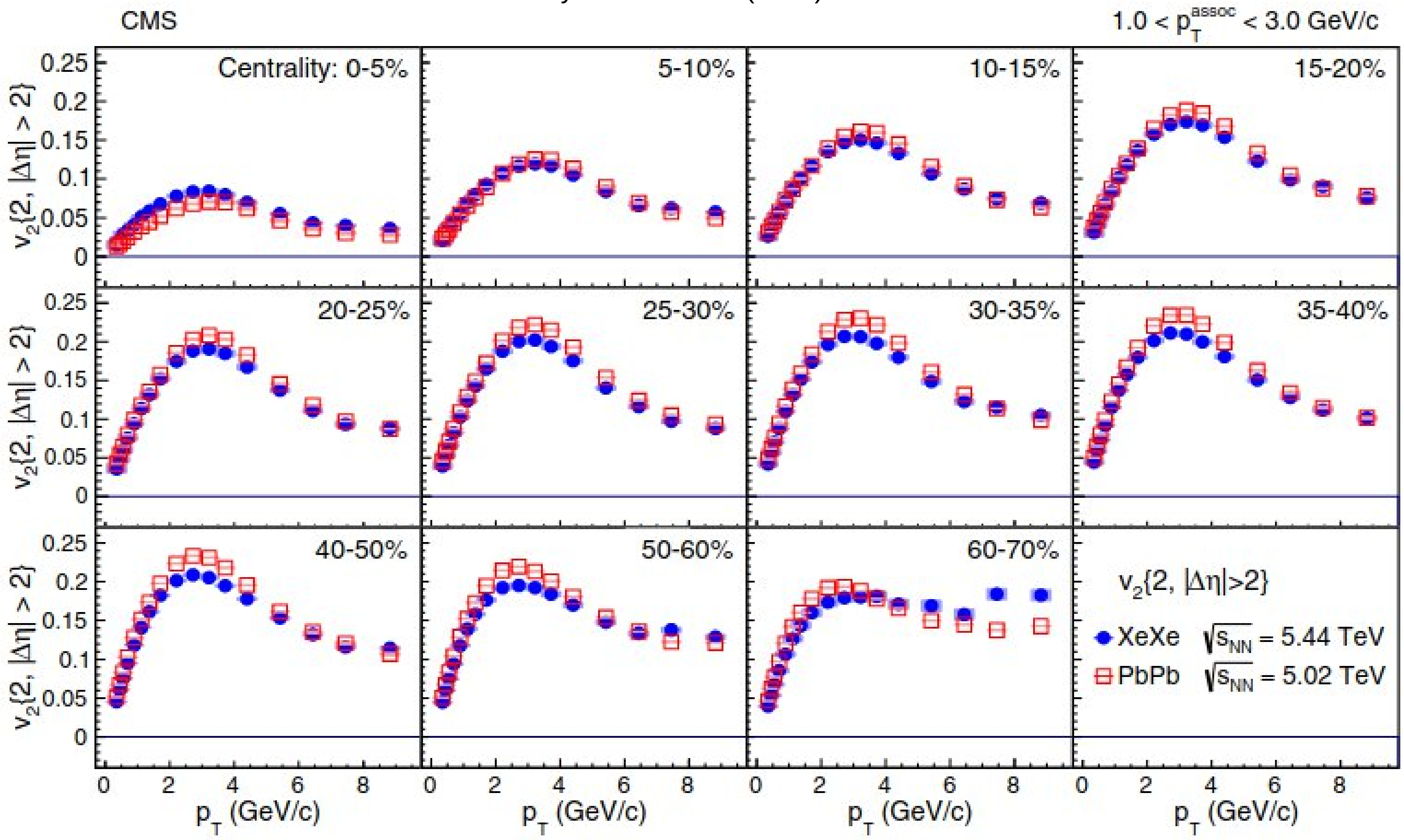
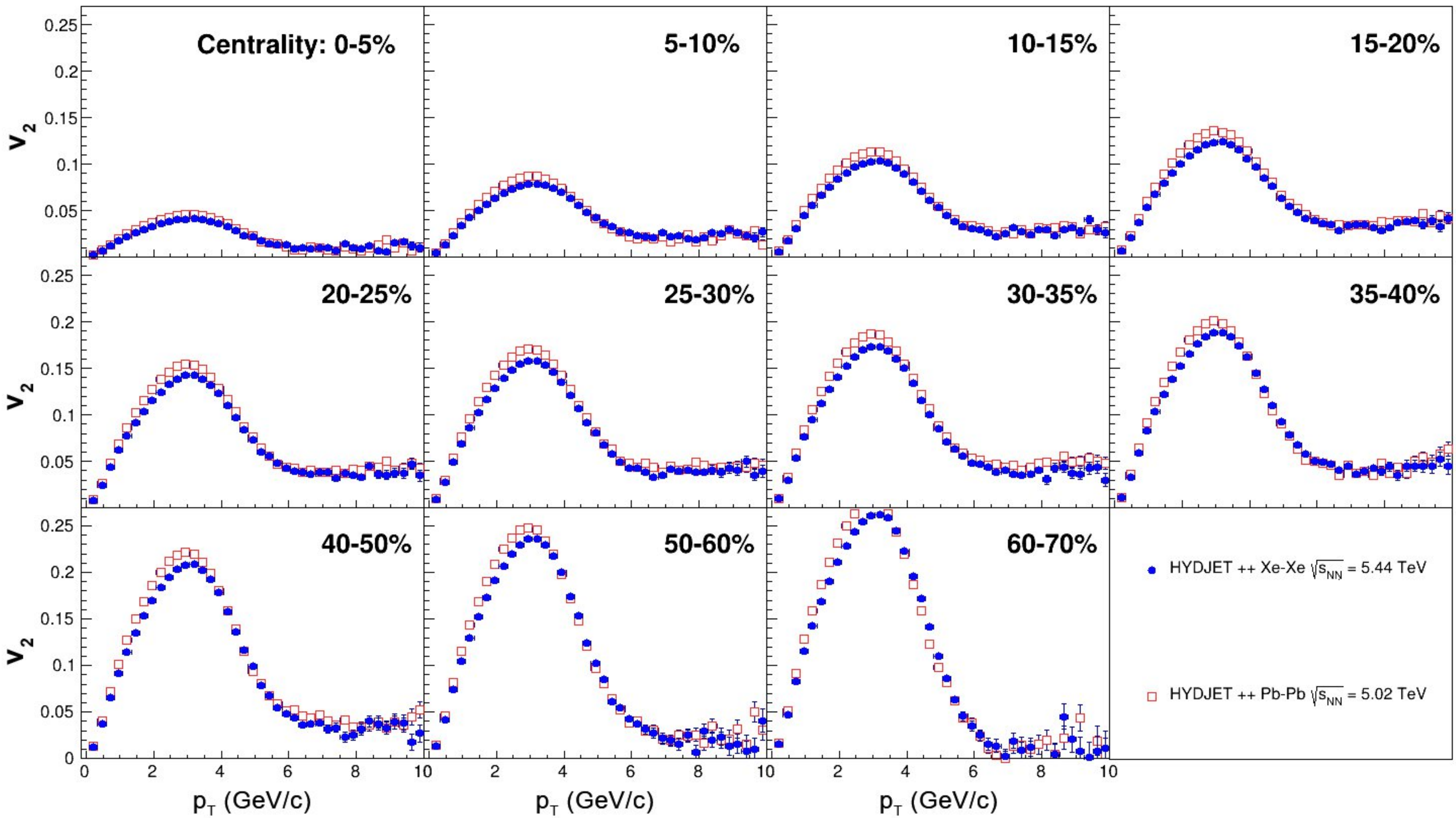


Результаты для v_2, полученные в эксперименте CMS методом двухчастичных корреляций.

v_2 для столкновений Xe-Xe с энергией 5.44 ТэВ и Pb-Pb с энергией 5.02 ТэВ на нуклон в СЦМ в Монте-Карло генераторе HYDJET++



Результаты для v_2, полученные в генераторе HYDJET++ относительно истинной плоскости реакции (статистика ок. 1 млн. событий для каждой центральности).

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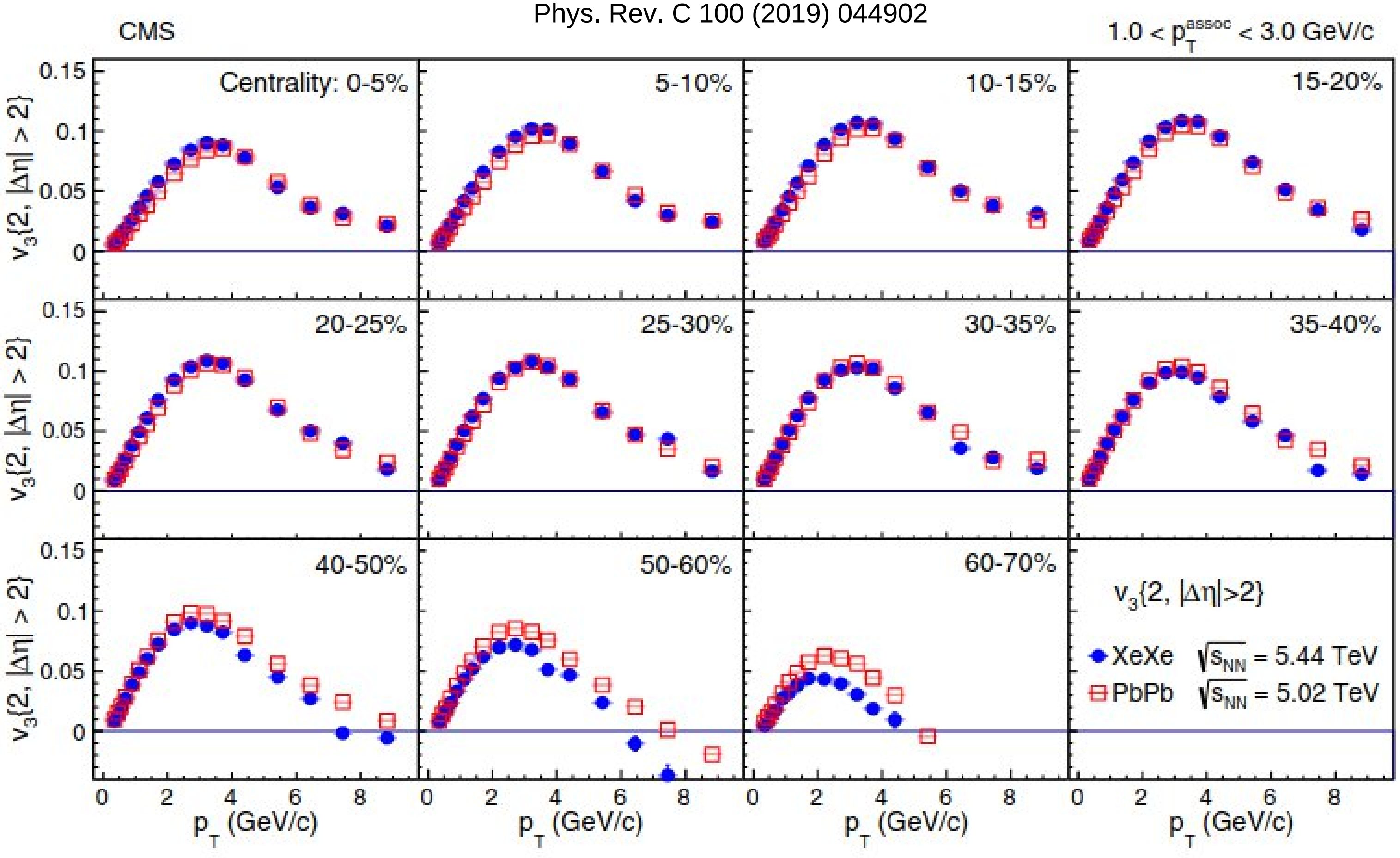

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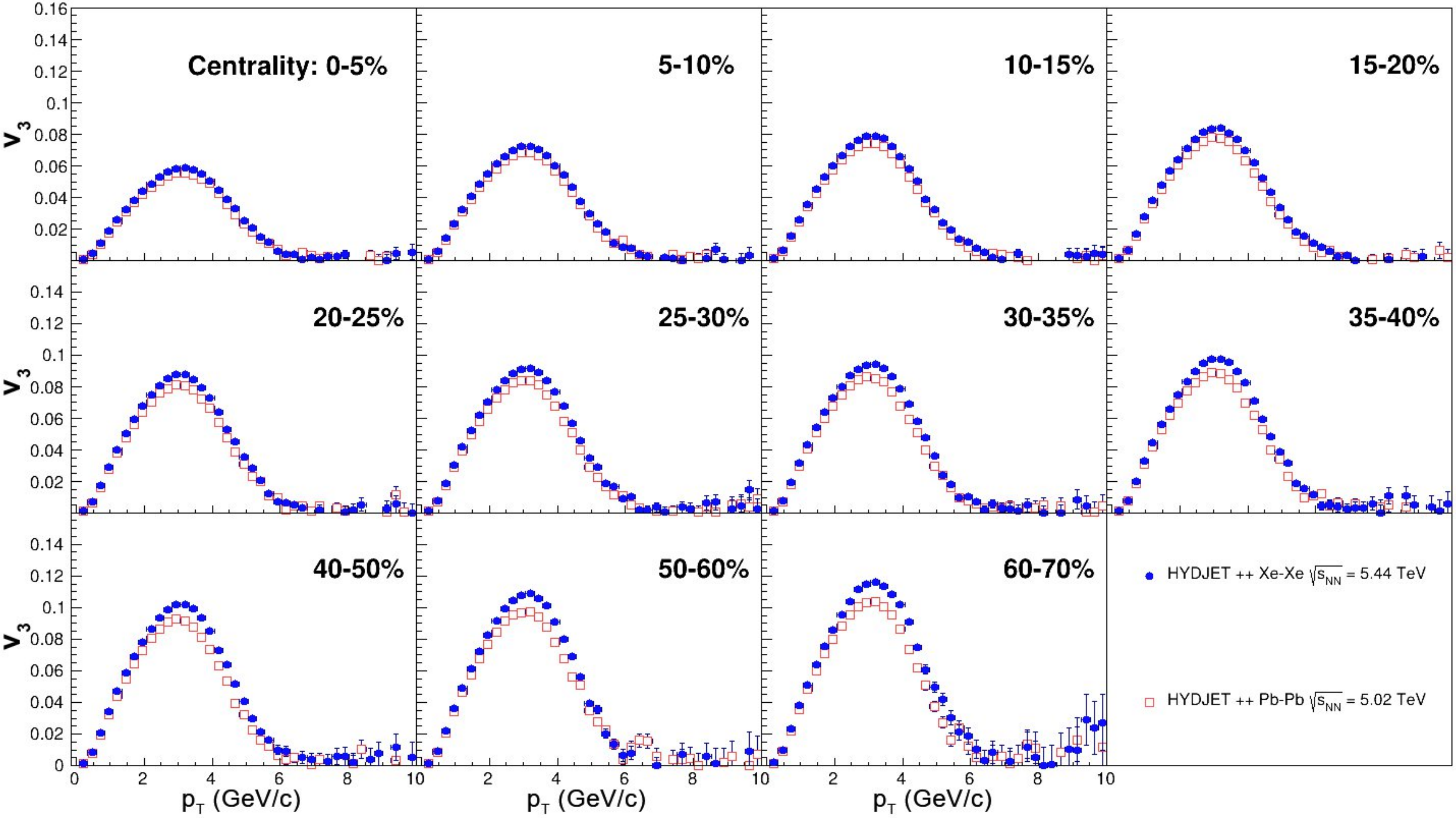

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Сравнение отношений гармоник v_2 в столкновениях XeXe и PbPb в эксперименте CMS и Монте-Карло генераторе HYDJET++

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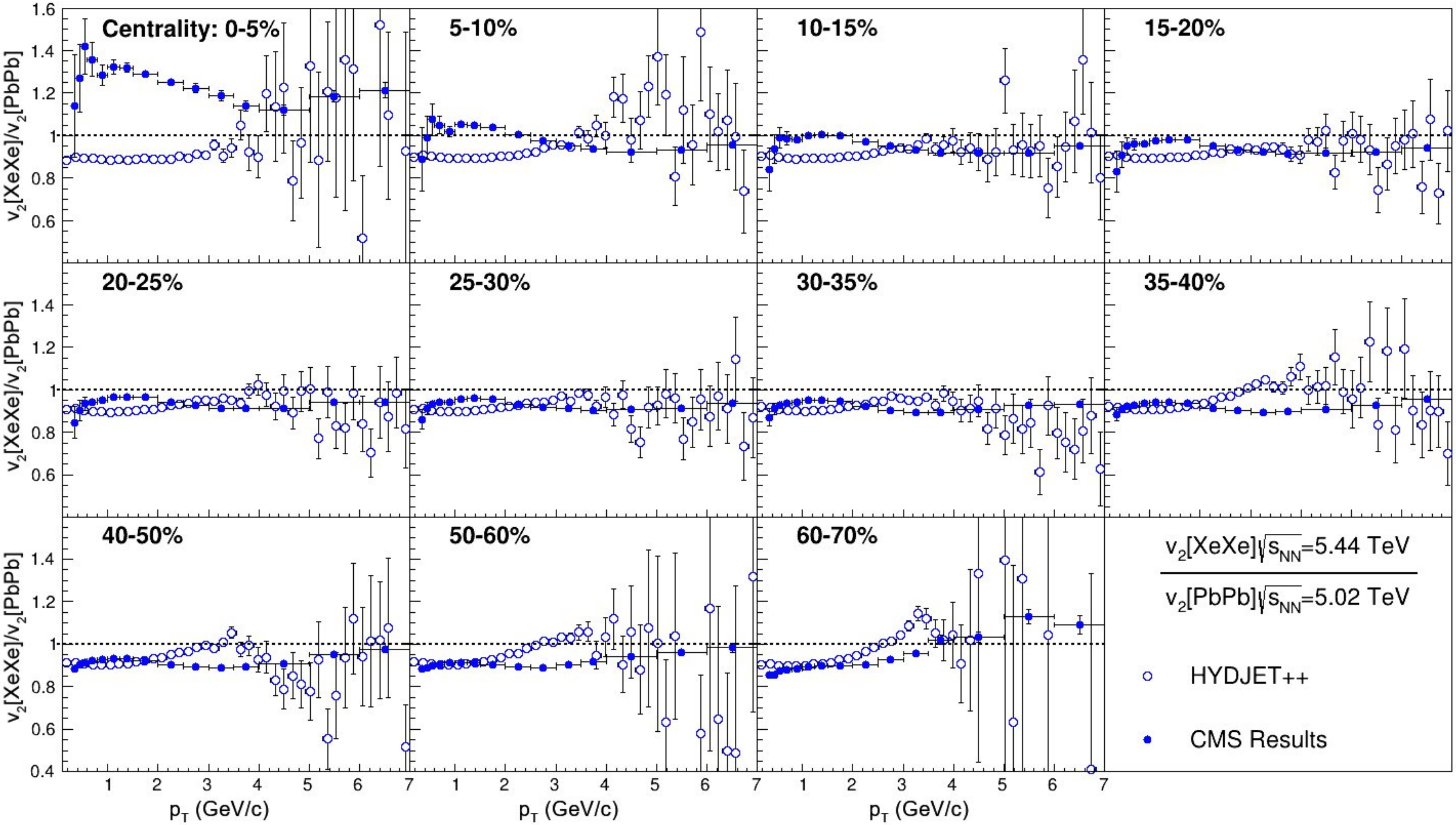

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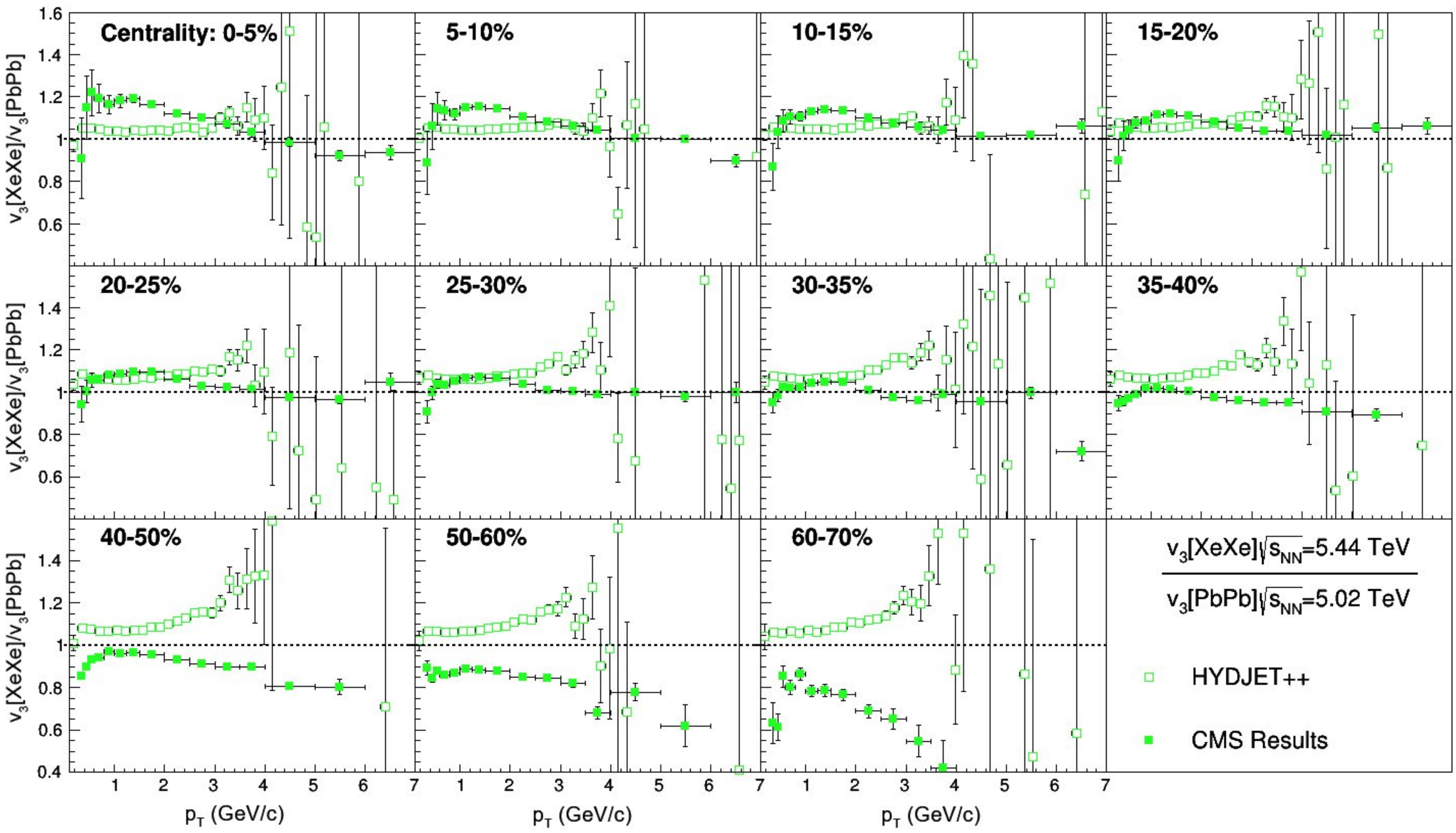

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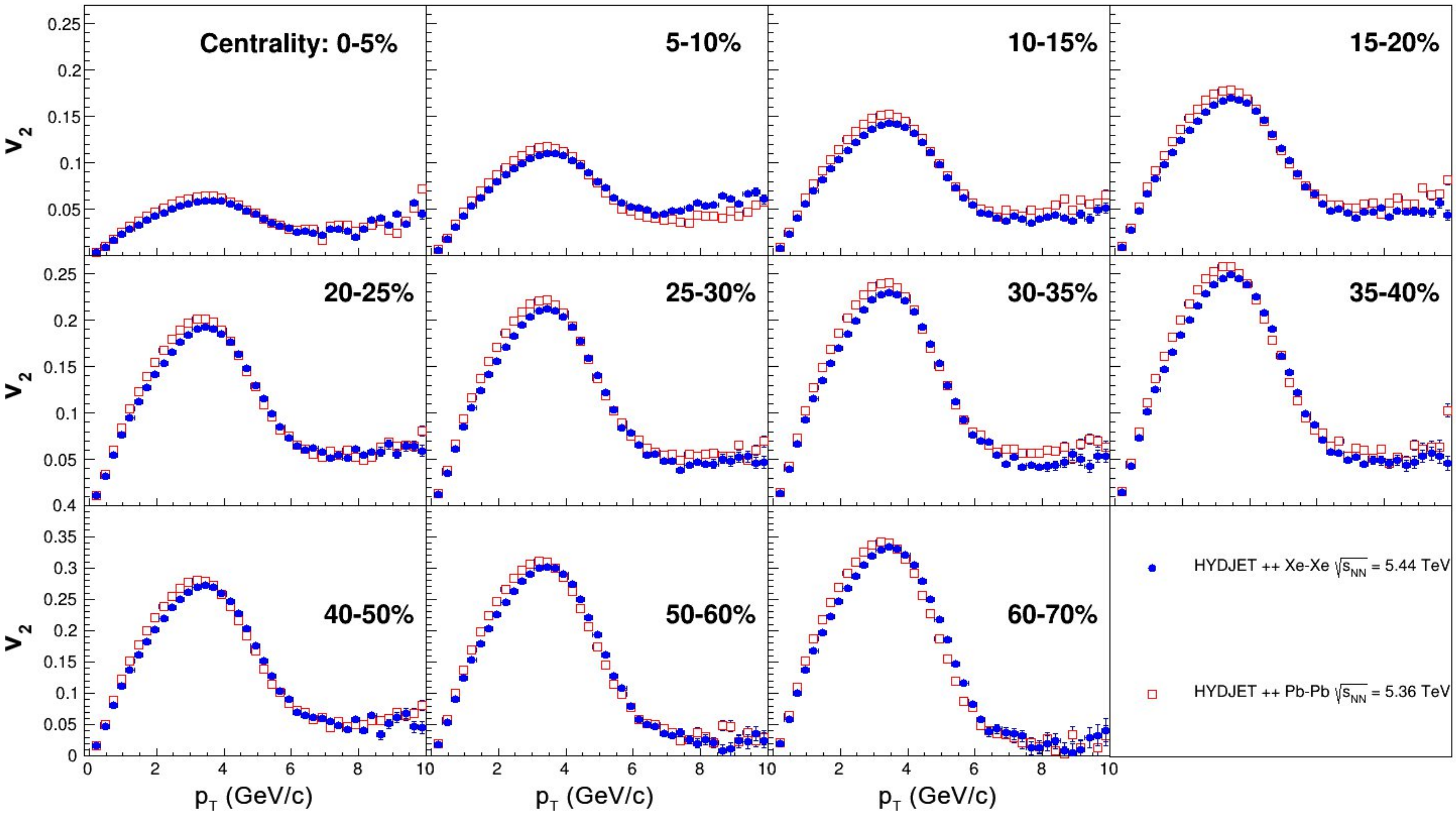

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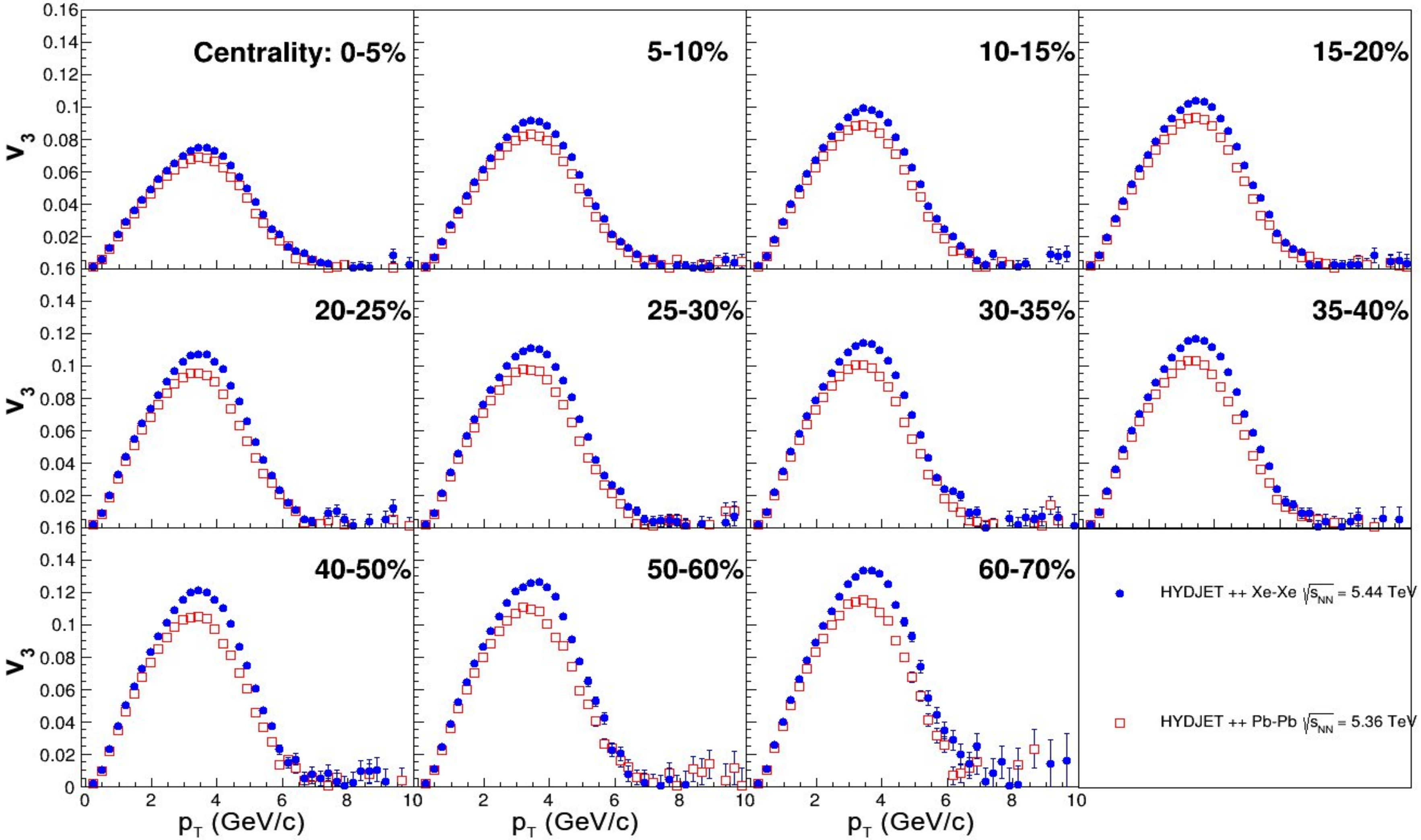

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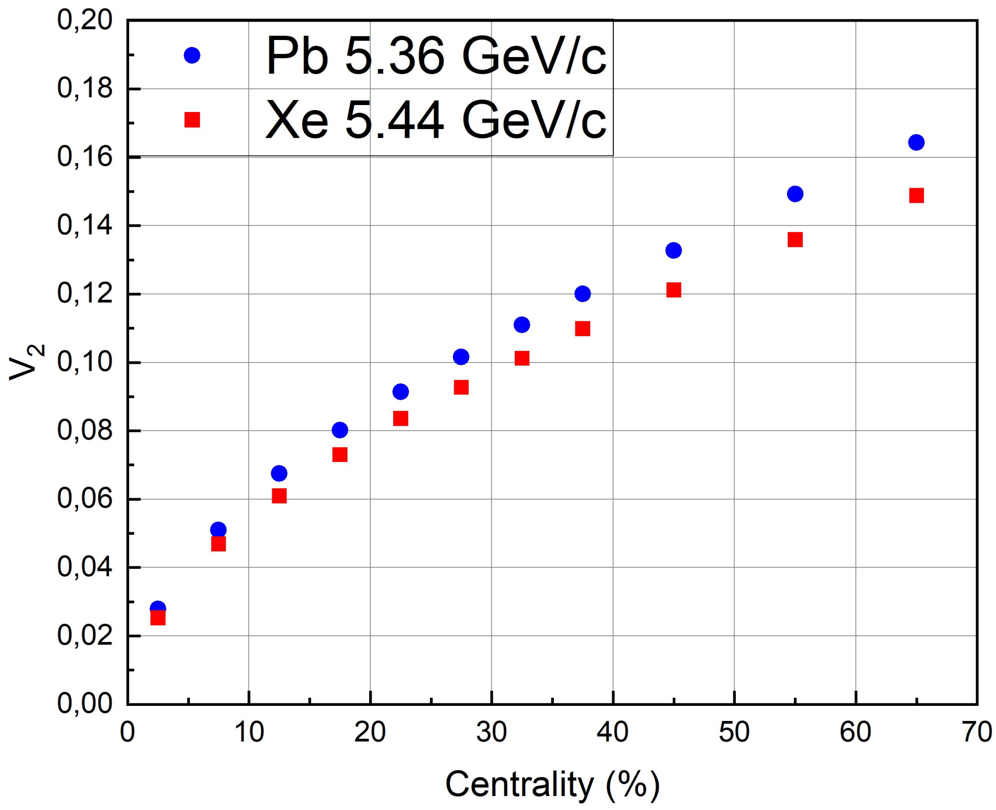
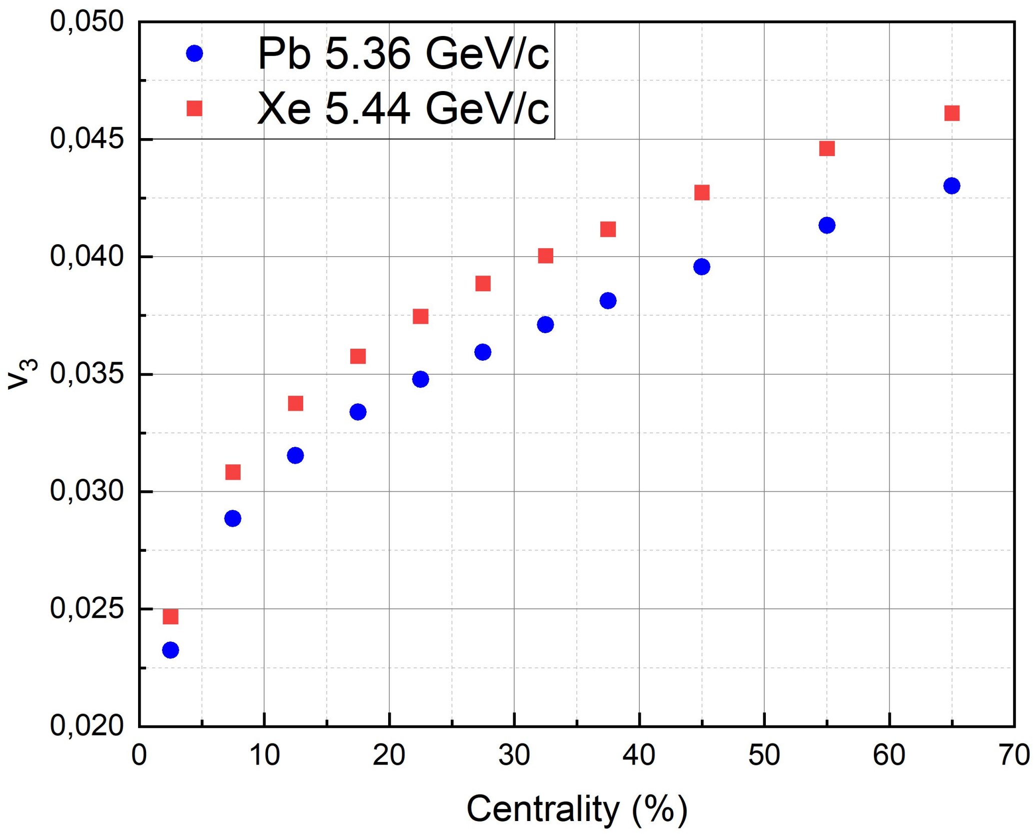
Integral values of elliptical and triangular flows for 11 centralities for Pb—Pb collisions at an energy of 5.36 TeV per nucleon and Xe—Xe at an energy of 5.44 TeV per nucleon in the c.m.s.





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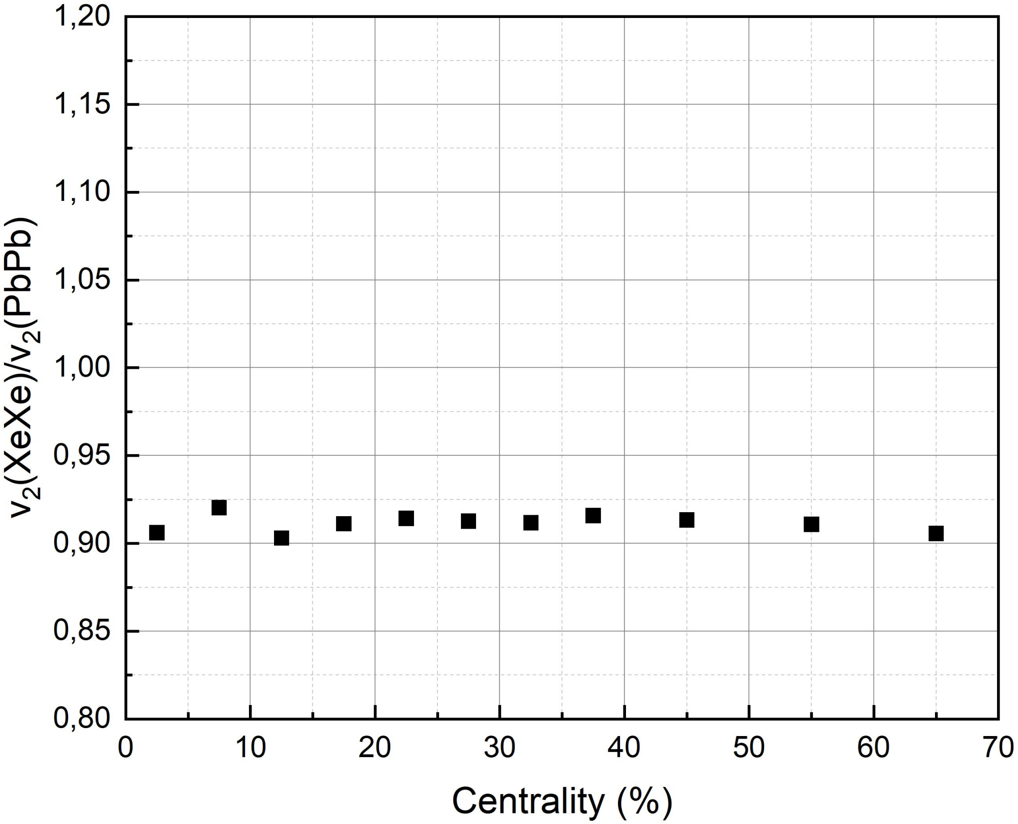

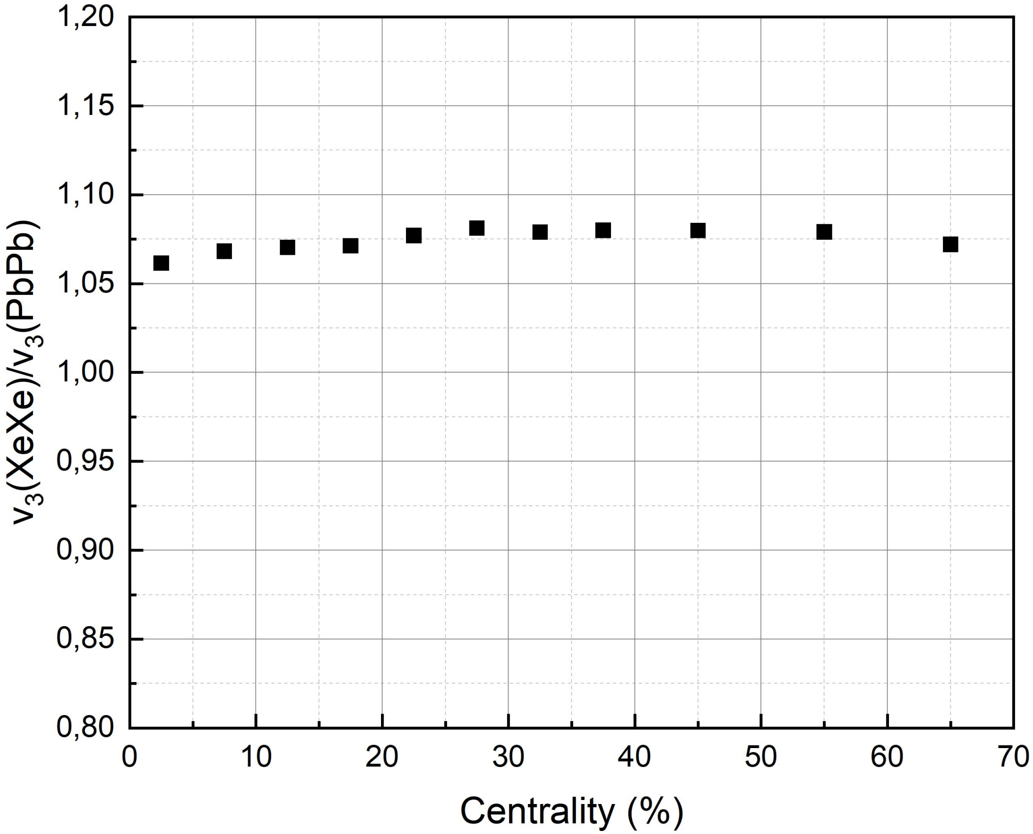

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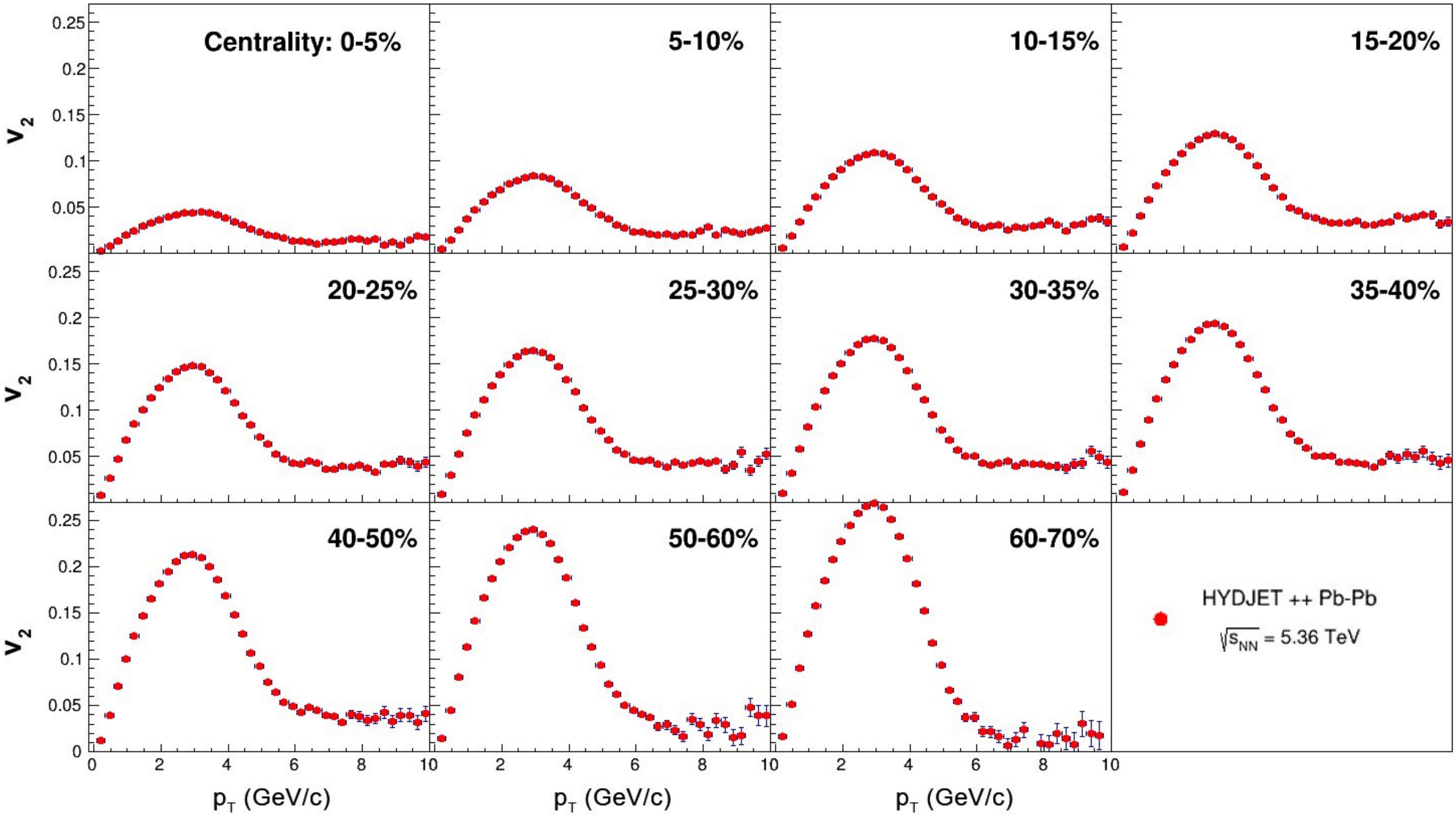
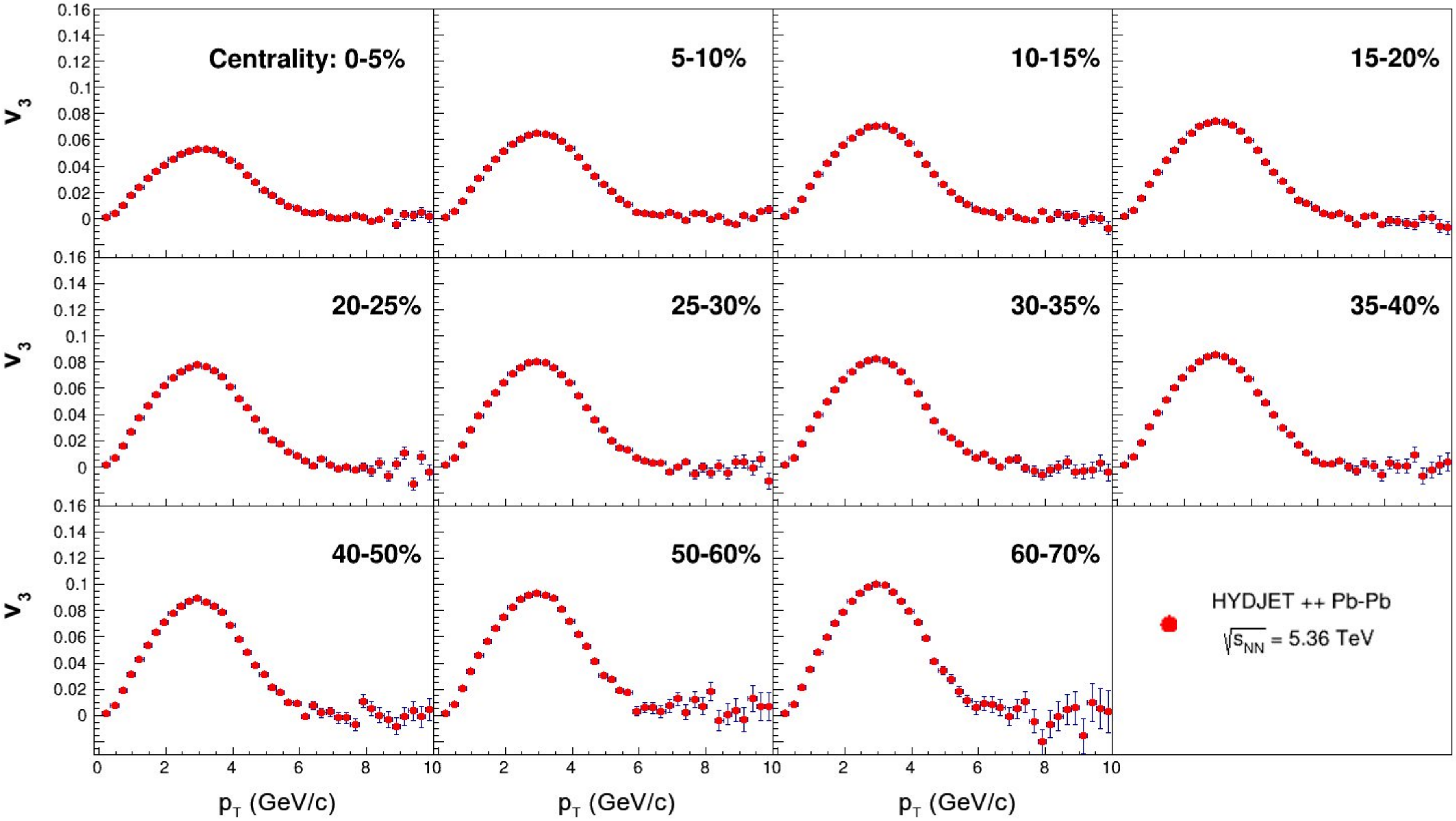
Предсказания распределений v_2 для столкновений Pb—Pb с энергией 5.36 ТэВ на нуклон в СЦМ в Монте-Карло генераторе HYDJET++



- Форма и величина зависимости мало отличаются от аналогичных для Pb при энергии 5.02 ТэВ

Предсказания распределений v_3 для столкновений Pb—Pb с энергией 5.36 ТэВ на нуклон в СЦМ в Монте-Карло генераторе HYDJET++



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