CALCULATIONS OF AZIMUTHAL FLOWS IN RELATIVISTIC COLLISIONS OF HEAVY IONS WITH THE REACTION PLANE AND TWO-PARTICLE CUMULANT METHODS AT THE MONTE-CARLO GENERATOR HYDJET++ FOR LHC ENERGIES

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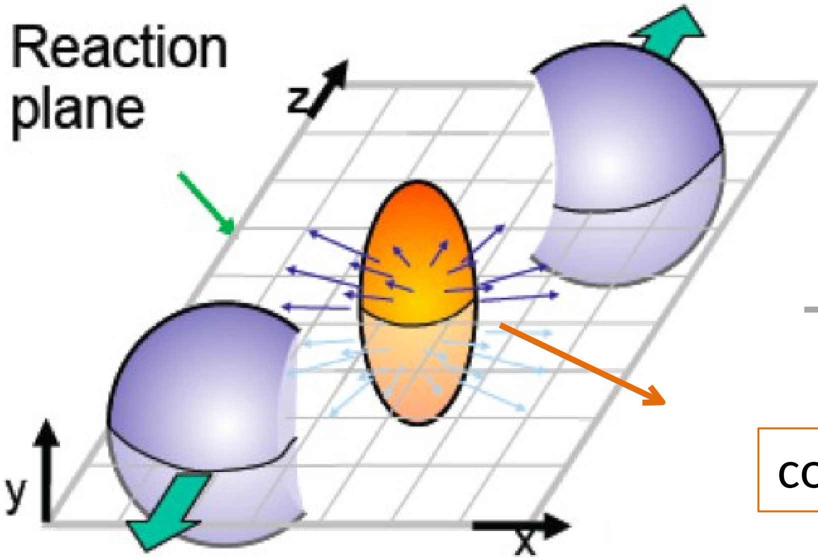
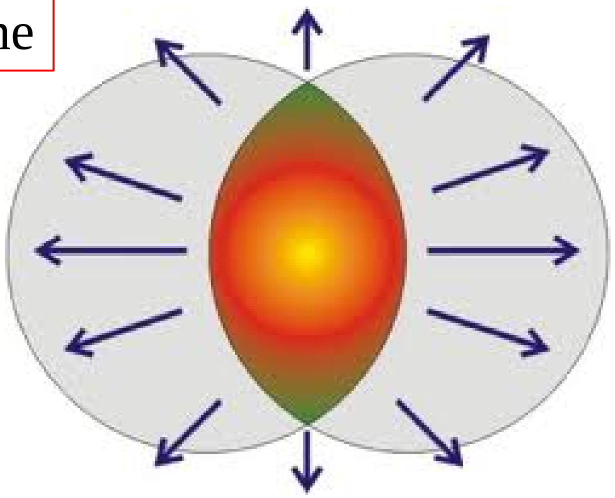
Azimuthal correlations and flows

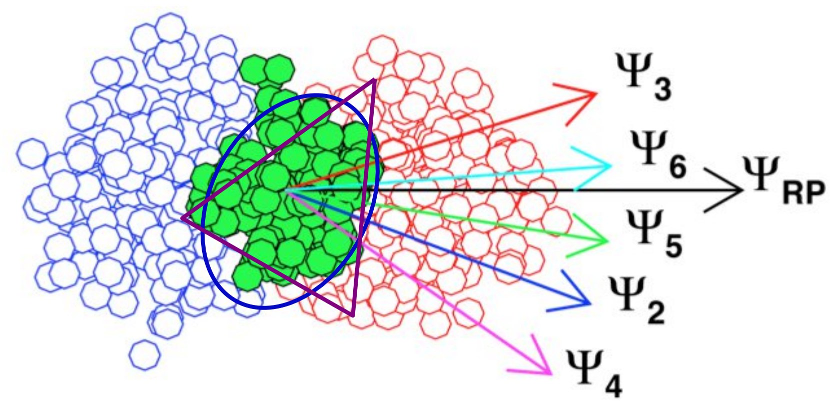
Reaction Plane





colliding ions

initial evolution state



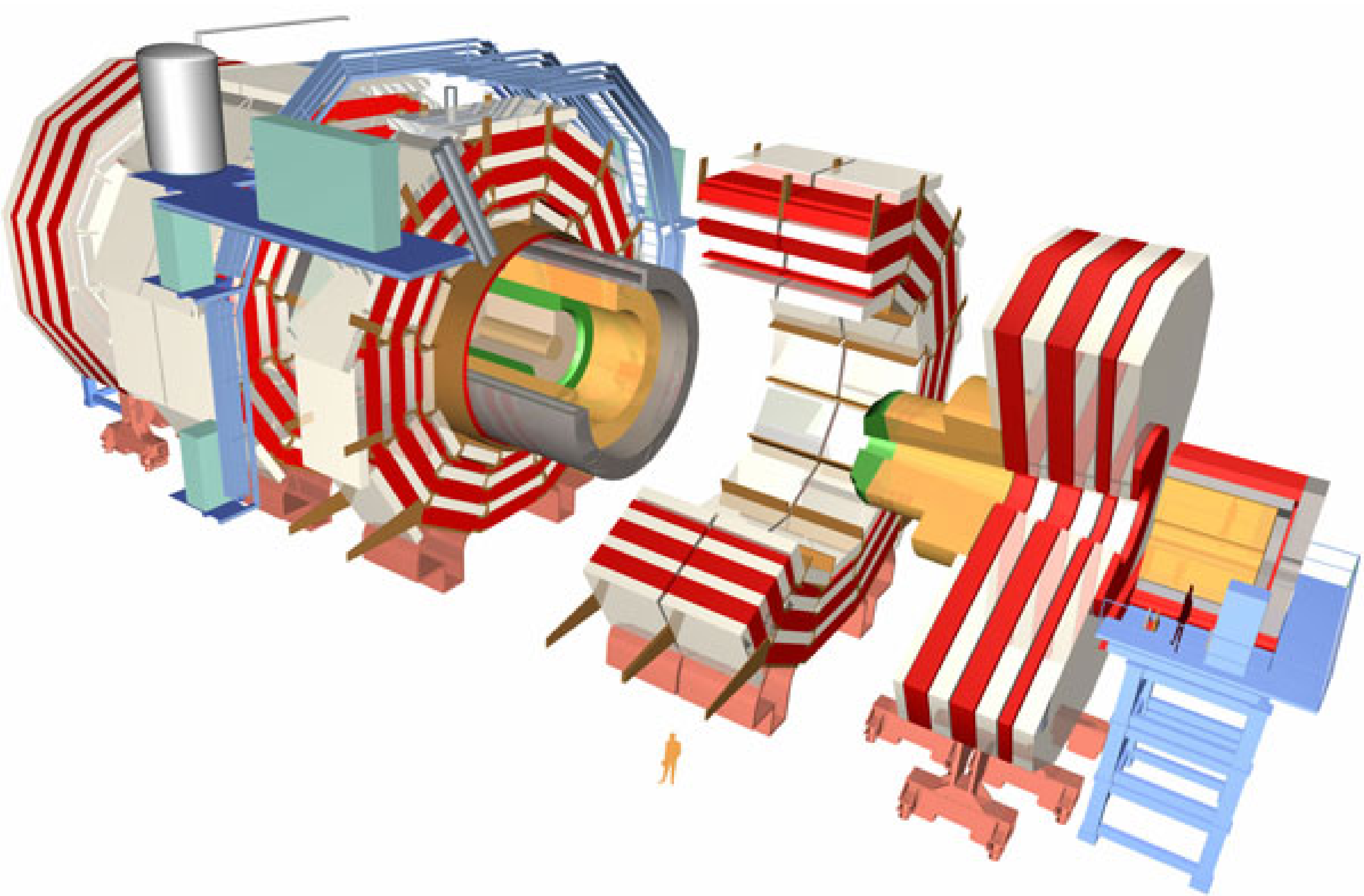
Initial state fluctuations

Fourier decomposition of the azimuthal particle distribution

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

Elliptical flow v_2 Triangular flow v_3 ...

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

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

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

The cummulant method. CMS experiment

2-nd and 4-th particle correlations in the cummulant method can be described as:

$$\langle\langle 2\rangle\rangle = \left\langle\left\langle e^{in(\varphi_1-\varphi_2)}\right\rangle\right\rangle \qquad \langle\langle 4\rangle\rangle = \left\langle\left\langle e^{in(\varphi_1+\varphi_2-\varphi_3-\varphi_4)}\right\rangle\right\rangle$$

Here double brackets are for averaging by particles and by events

Cummulants 2-nd и 4-th order:

$$c_n\{2\} = \langle\langle 2\rangle\rangle \qquad c_n\{4\} = \langle\langle 4\rangle\rangle - 2*\langle\langle 2\rangle\rangle^2$$

$$d_n\{4\} = \left\langle\left\langle 4'\right\rangle\right\rangle - 2*\left\langle\left\langle 2'\right\rangle\right\rangle*\langle\langle 2\rangle\rangle$$

Here stroke is for diferential correlationsЗдесь штрихом обозначены дифференциальные корреляции — it is assumed that one of the particles is in a given p_T bin

Thus elliptical flow by 4-th order cummulants:

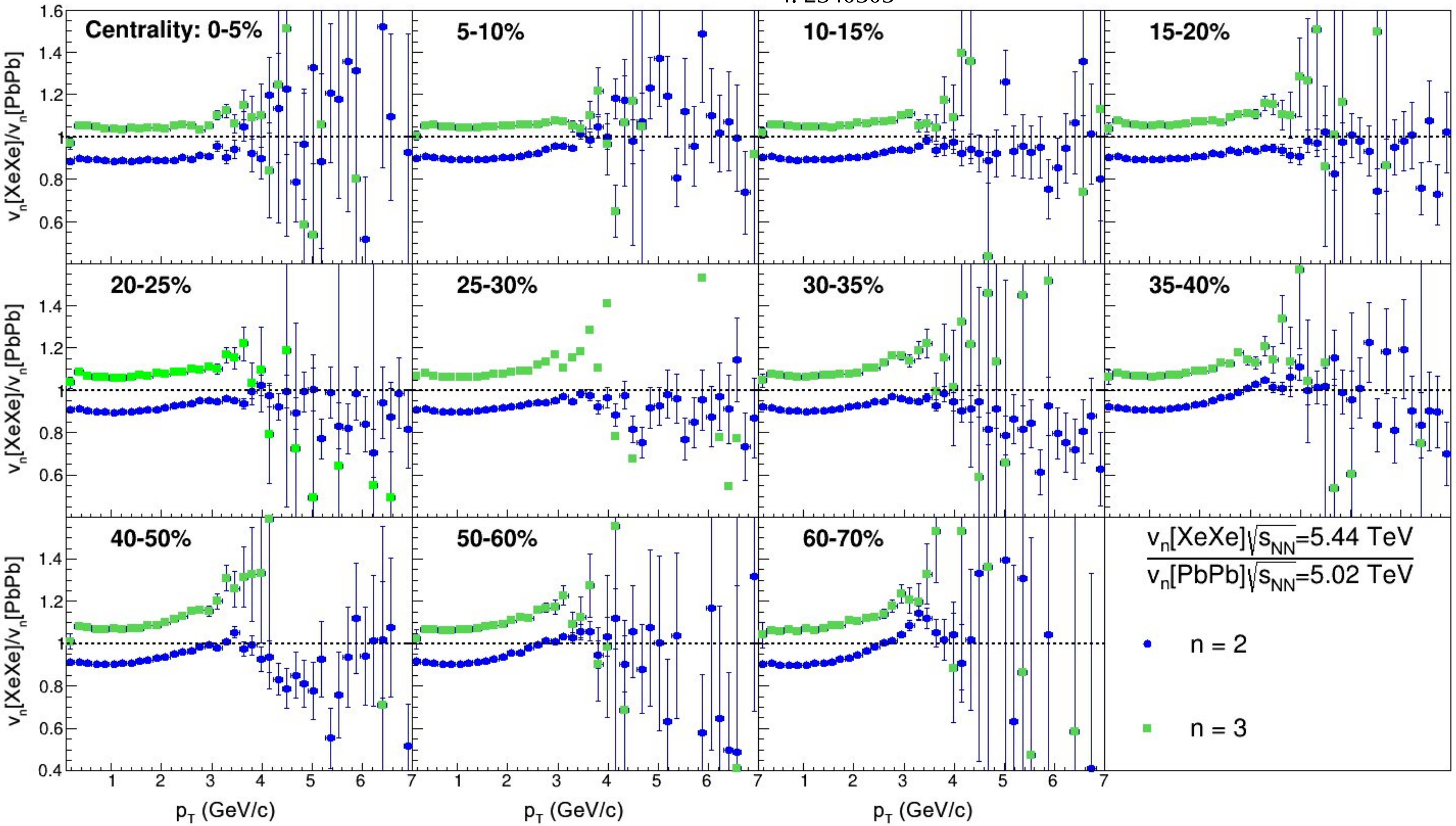
$$v_n\{4\}(p_T) = -d_n\{4\}*(-c_n\{4\})^{-3/4}$$

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

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++

DOI:10.1134/S1063778824010113 Physics of Atomic Nuclei

ISSN:2307-9665 Учен. зап. физ. фак-та Моск. ун-та. 2023. № 4. 2340305



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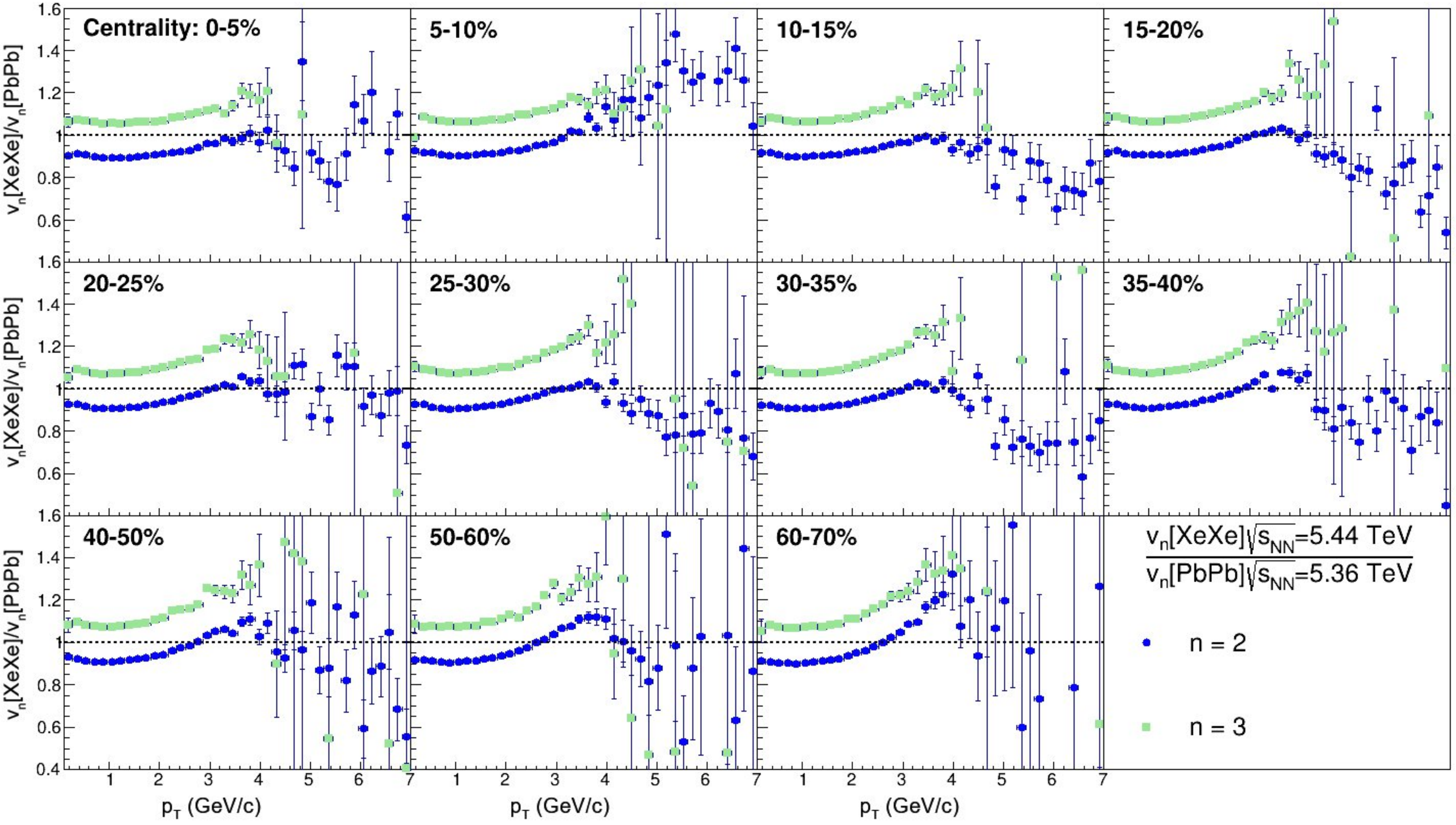

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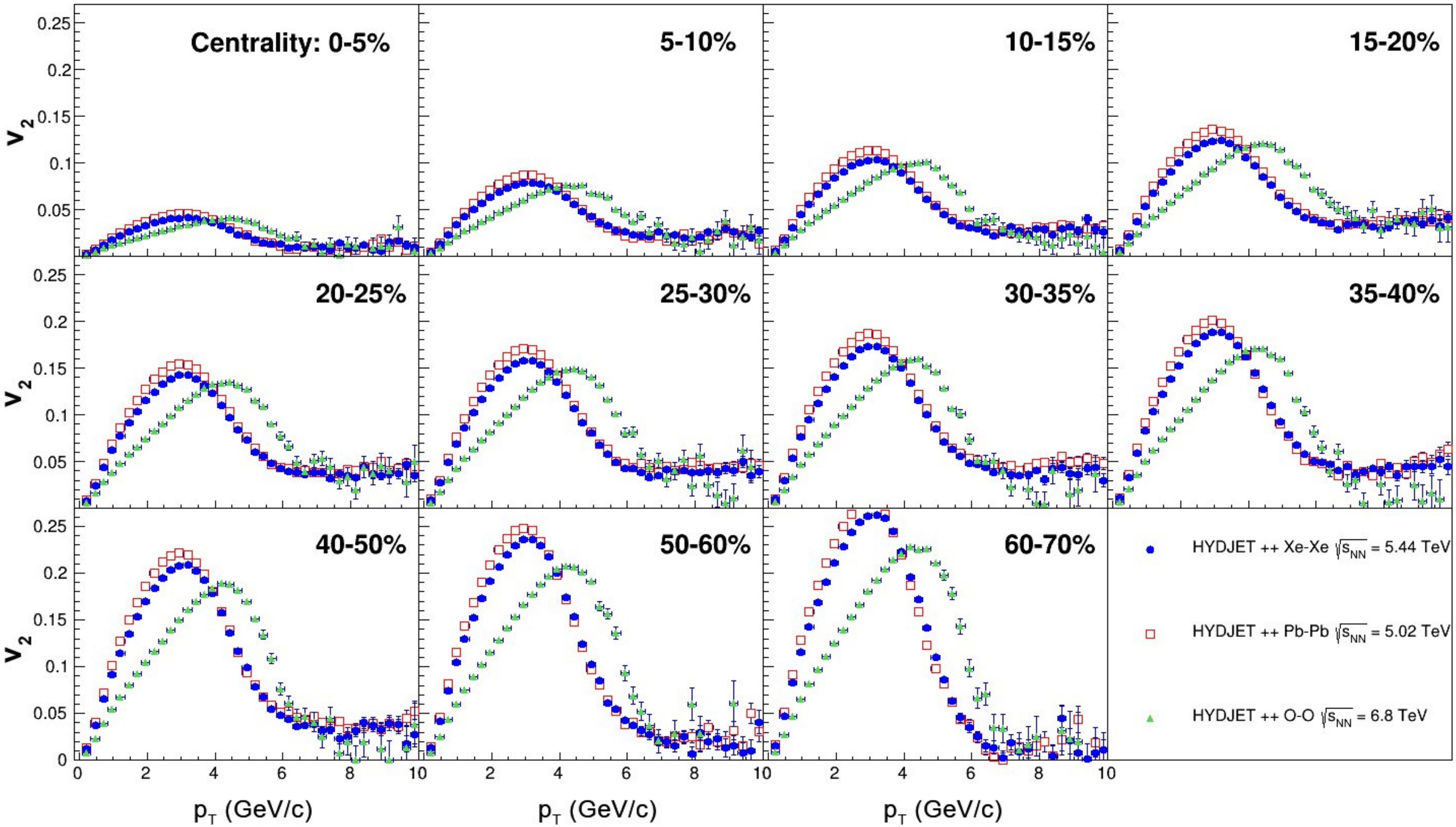
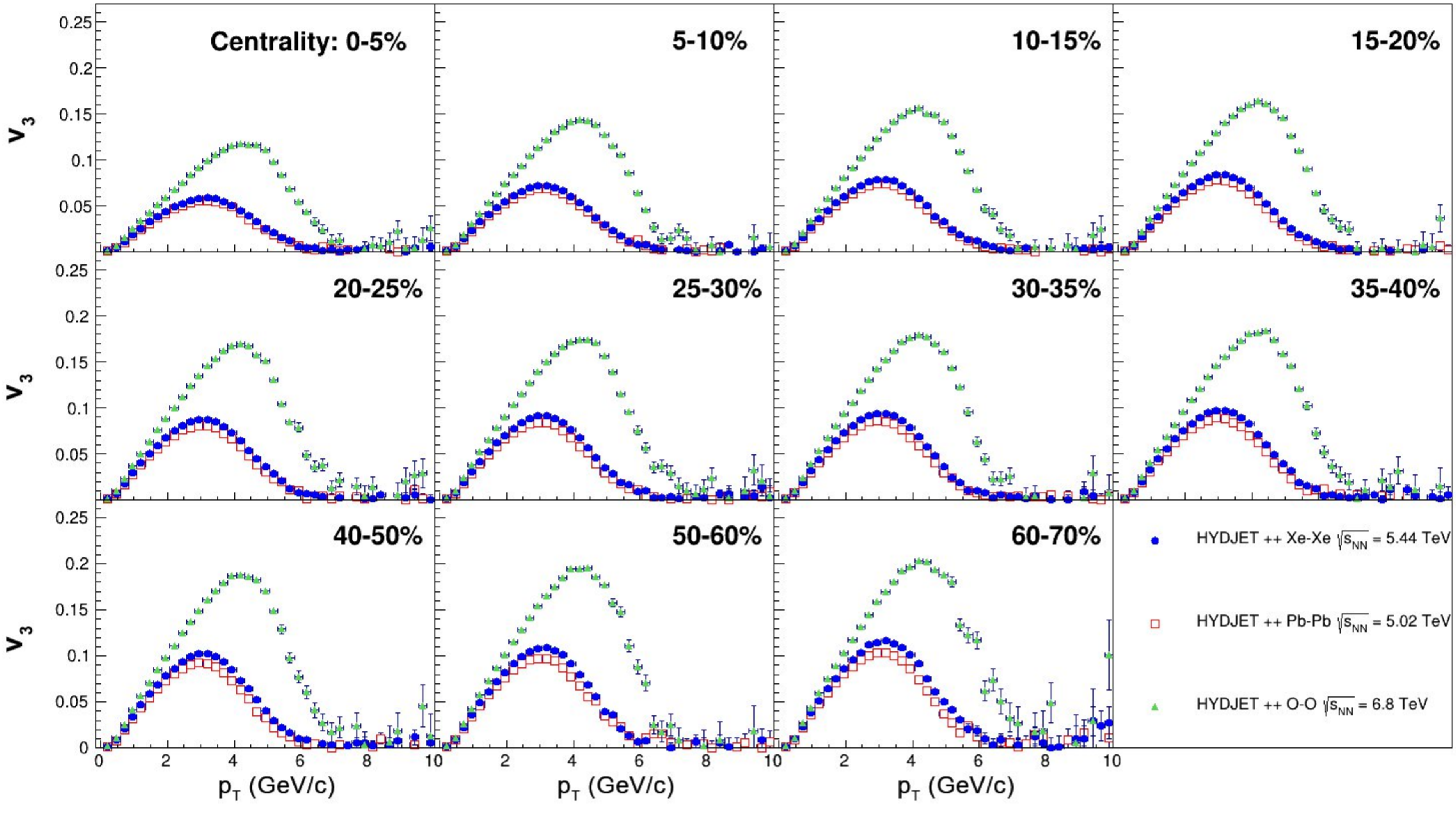
Predictions for v_2 distributions for O—O collisions with an energy of 6.8 TeV per nucleon in the c.m.s. in the Monte Carlo generator HYDJET++



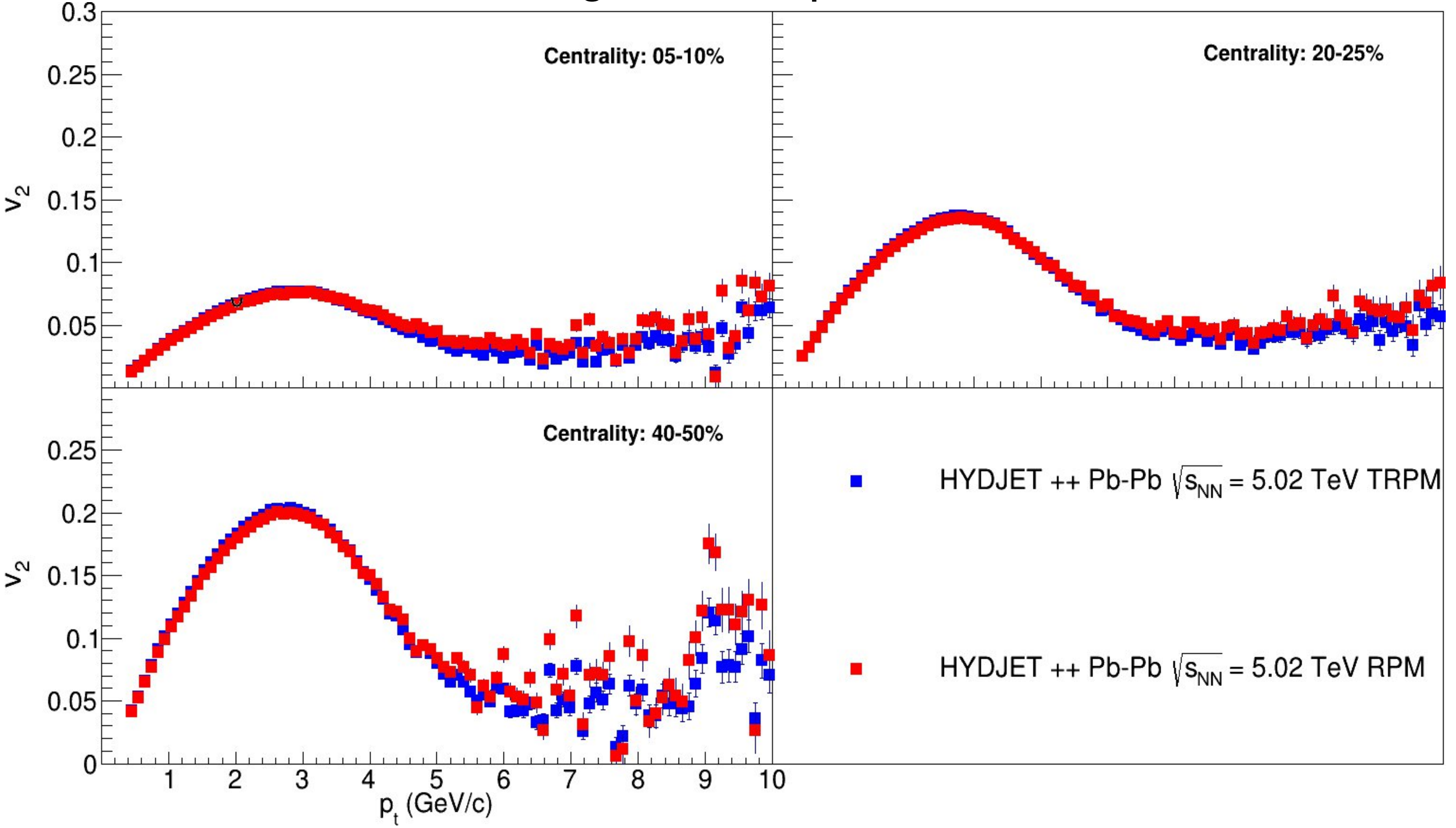
- The form of dependence differs from those for Pb and Xe
- In order of magnitude, the distributions are similar
- The peak of the distribution is shifted towards higher p_T than that of Pb and Xe

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++



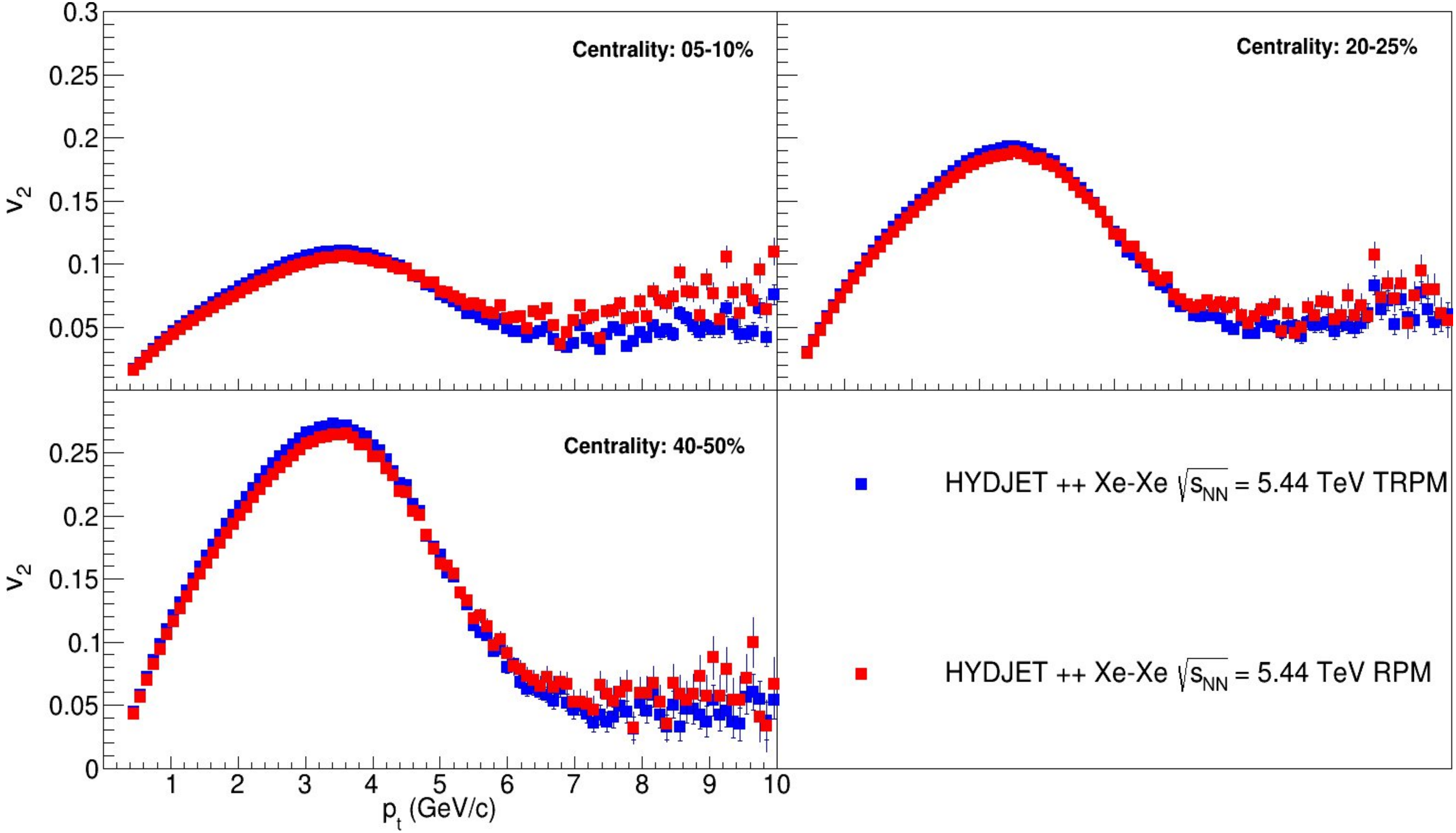
- The form of dependence differs from those for Pb and Xe
- The peak of the distribution is shifted towards higher p_T than that of Pb and Xe
- In magnitude, the triangular flow is similar to the elliptical one, which was not observed earlier

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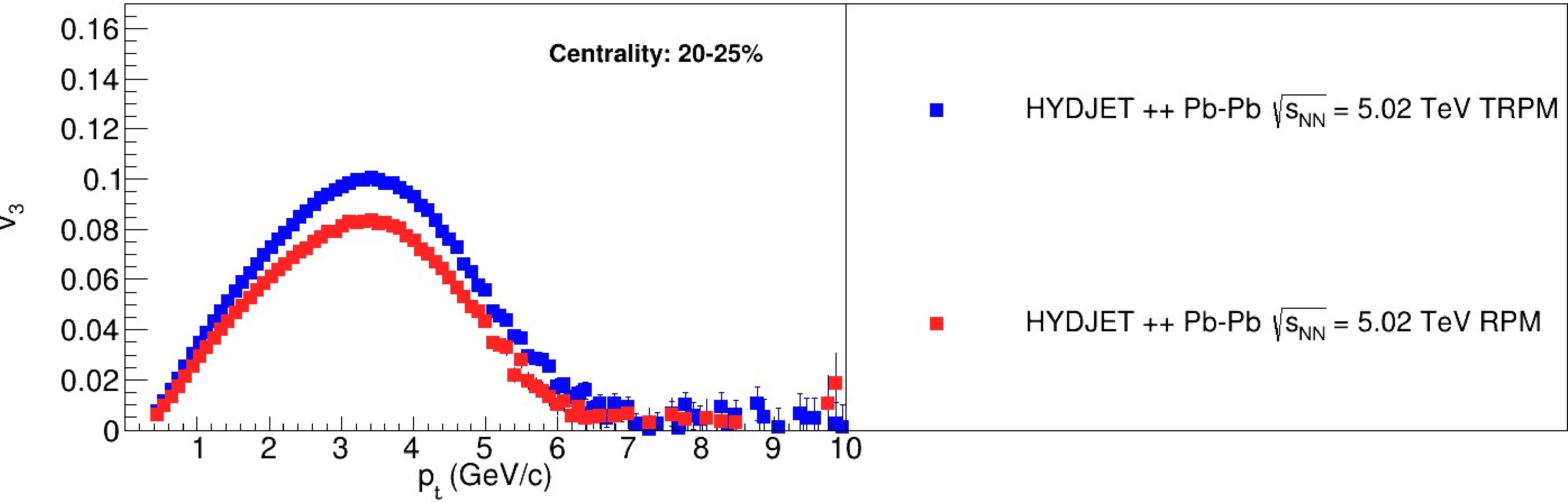
Calculations for v_3 in Pb—Pb collisions at the 5.02 TeV in c.m.s. using reaction plane method



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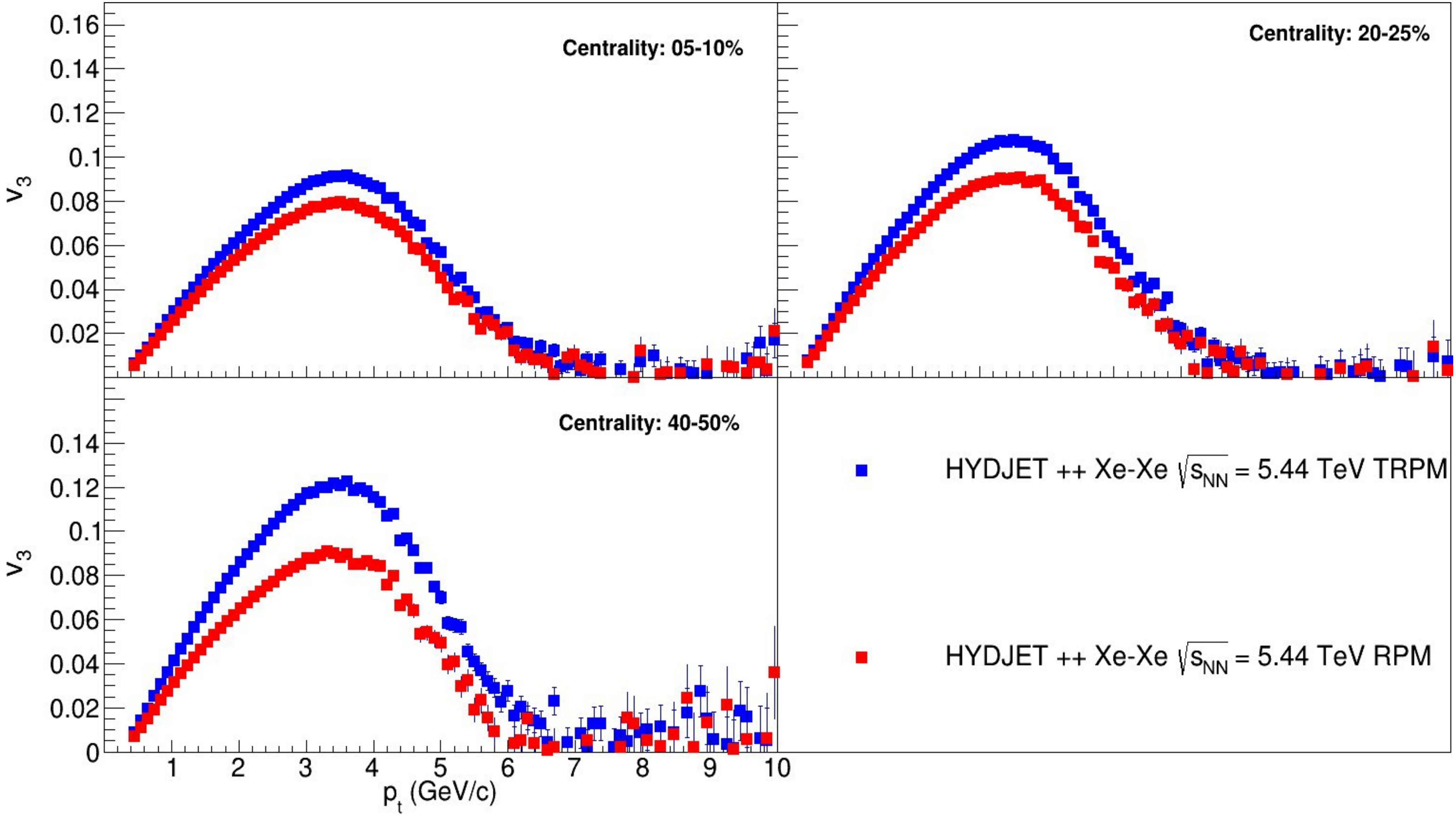
Calculations for v_3 in Xe—Xe collisions at the 5.44 TeV in c.m.s. using reaction plane method



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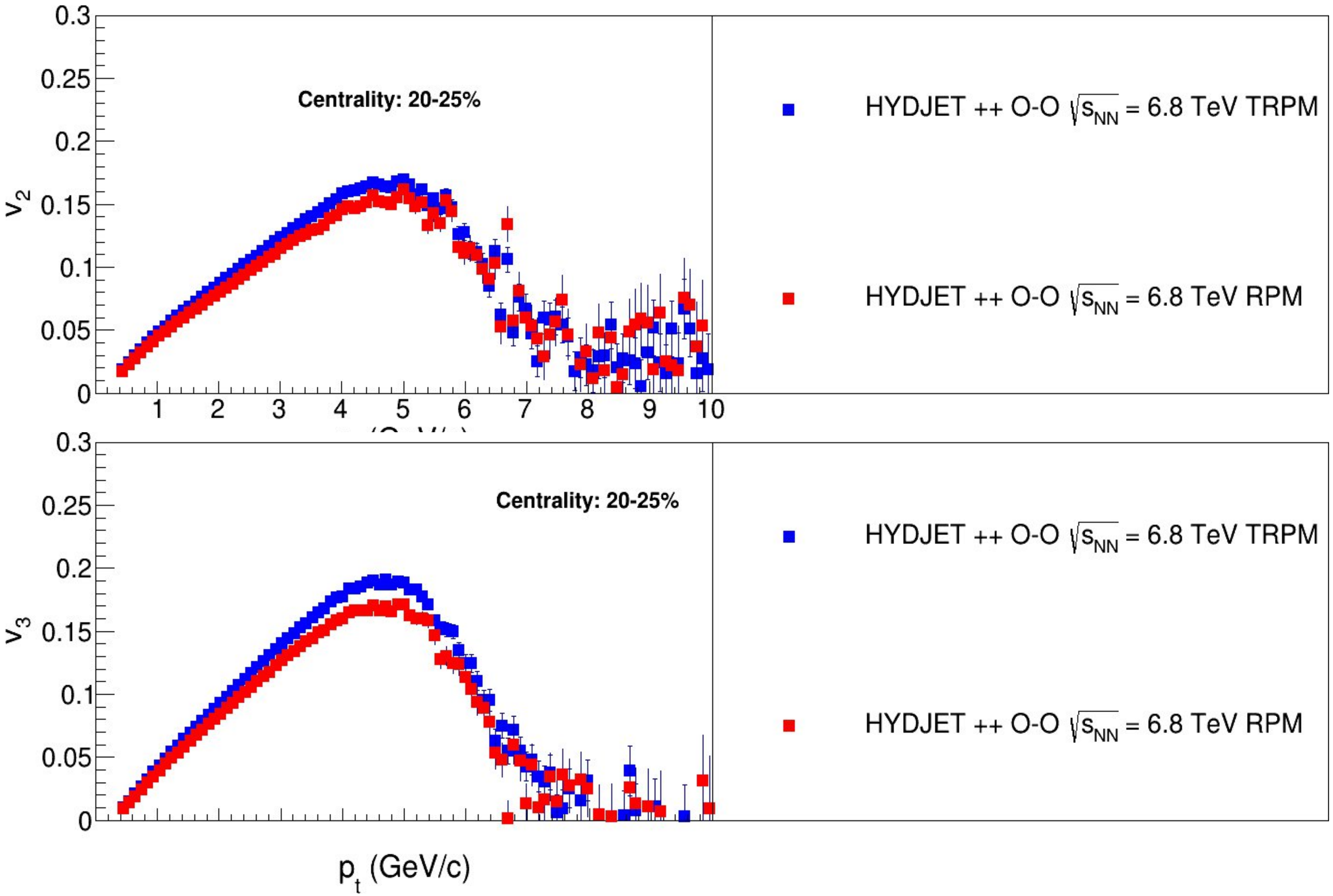
Calculations for v_2 and v_3 in O—O collisions at the 6.8 TeV in c.m.s. using reaction plane method



The results for the flows were obtained in the HYDJET++ generator
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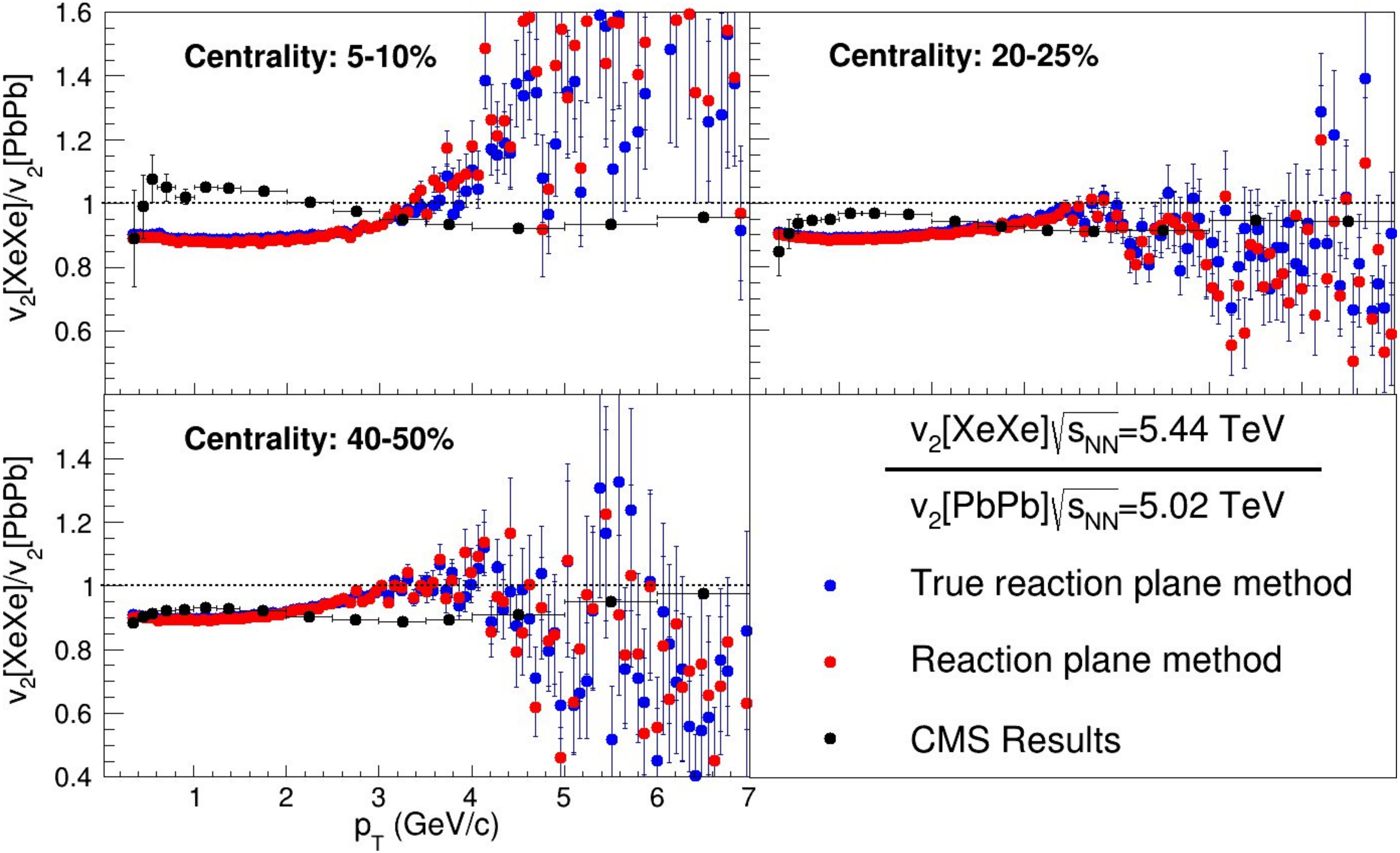
Flows relations $v_2[XeXe]/v_2[PbPb]$ at 5.44 TeV and 5.02 TeV respectively per nucleon in c.m.s. in Monte-Carlo generator HYDJET++ by two different methods



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

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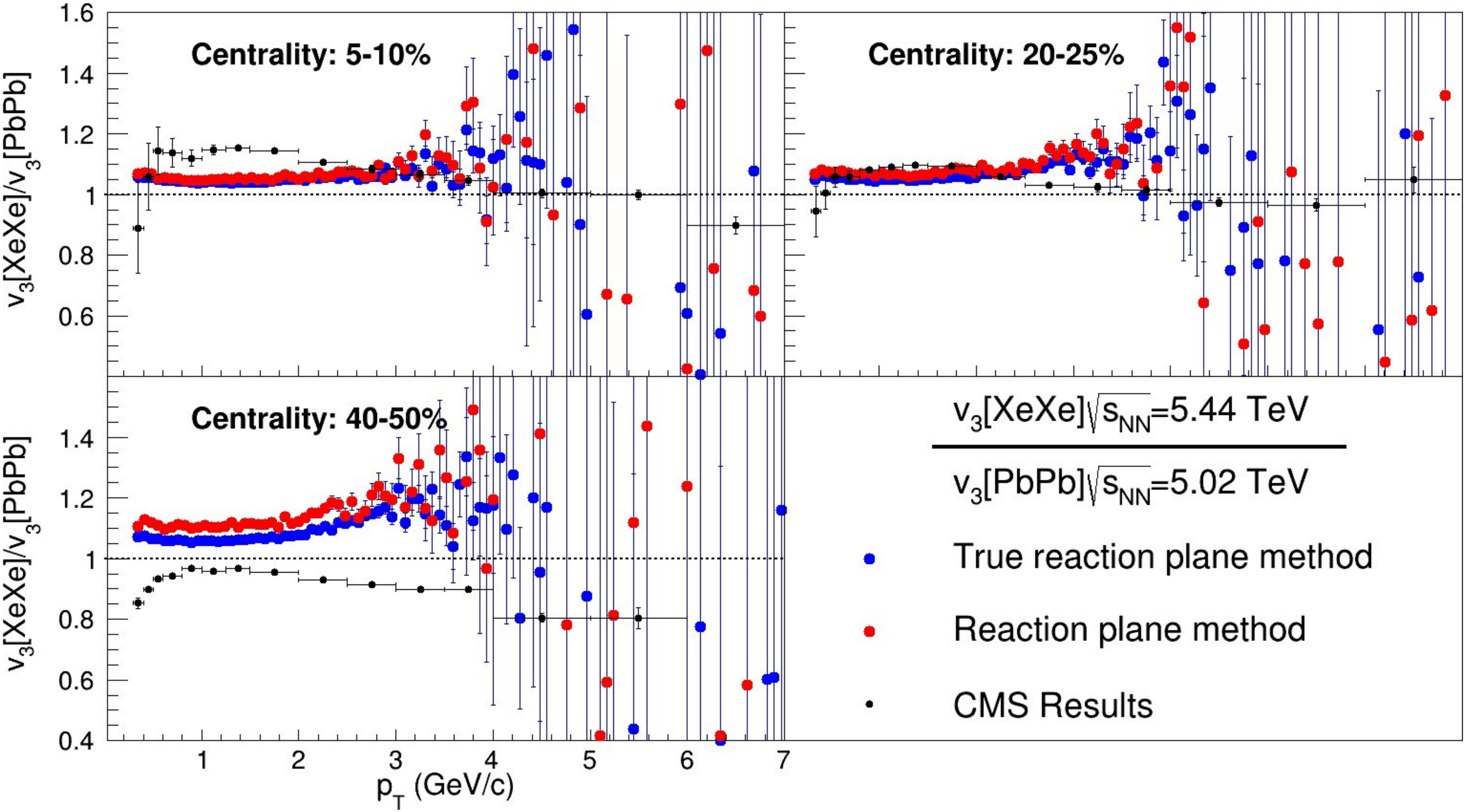
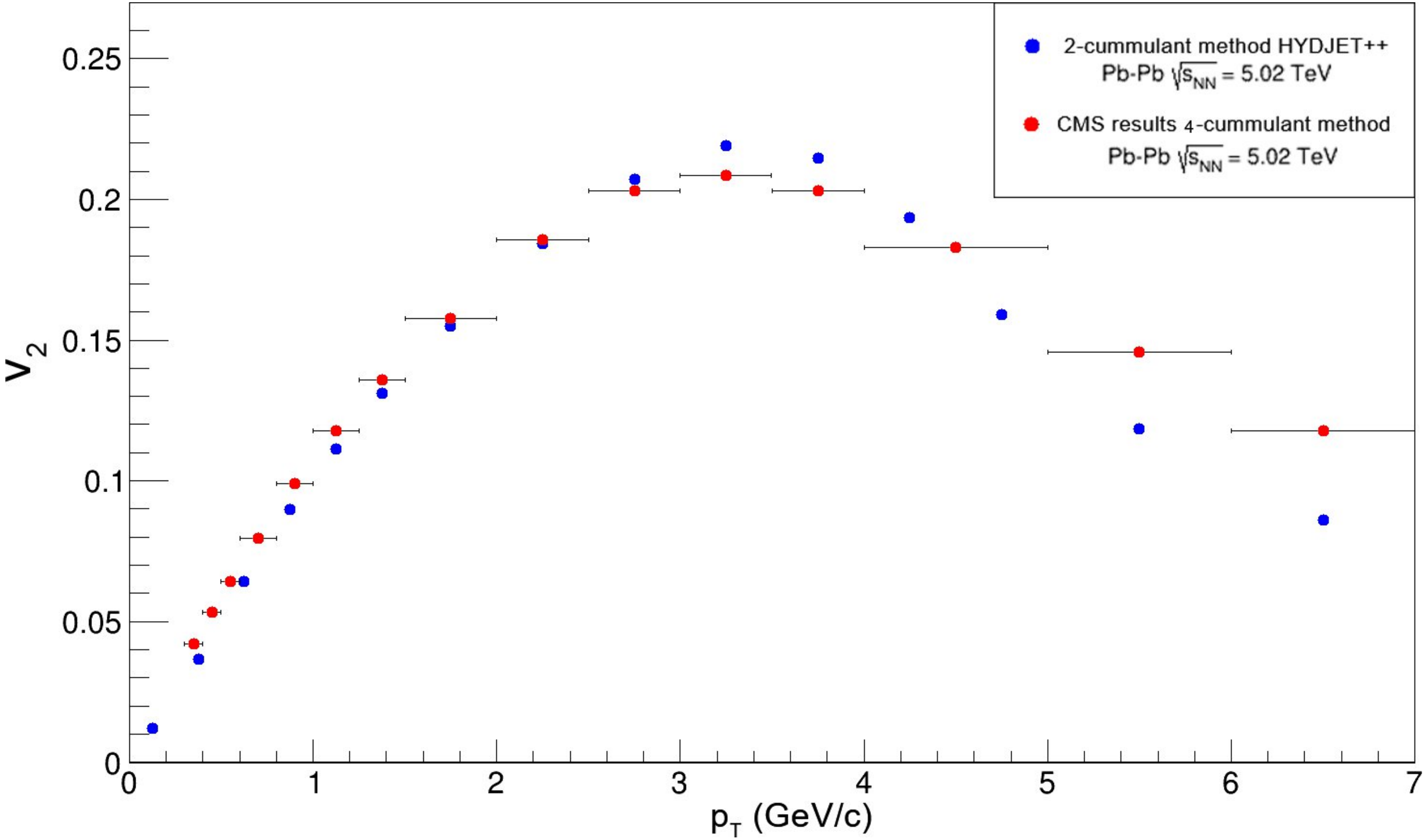


The results for the flows were obtained in the HYDJET++ generator by true reaction plane method and reaction plane method (statistics approx. 1 million. events for each centrality).

Calculations for v_2 in Pb—Pb collisions at the 5.02 TeV in c.m.s. using 2nd order cummulant method



The results for the flows were obtained in the HYDJET++ generator by2nd order cummulant method (statistics approx. 1 million. events for each centrality).

SUMMARY

- Azimuthal flows calculated using the standard generator method and its relations in collisions of xenon and lead with an energy of 5.44 TeV and 5.02 TeV respectively per nucleon in c.m.s. were compared to relative CMS results

- The ranges of centrality in which the generator most accurately describes the results of the experiment were found

- The reaction plane method 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

- As a result, it turned out that the reaction plane method does not significantly affect elliptical v_2 flows in collisions

- The 2-nd order cummulant method was mastered and put into HYDJET++ generator. As a result of generation of semi-central lead collisions 5.02 TeV it turned out that generator describes well the results of the experiment for LHC energies

THANKS FOR YOUR ATTENTION

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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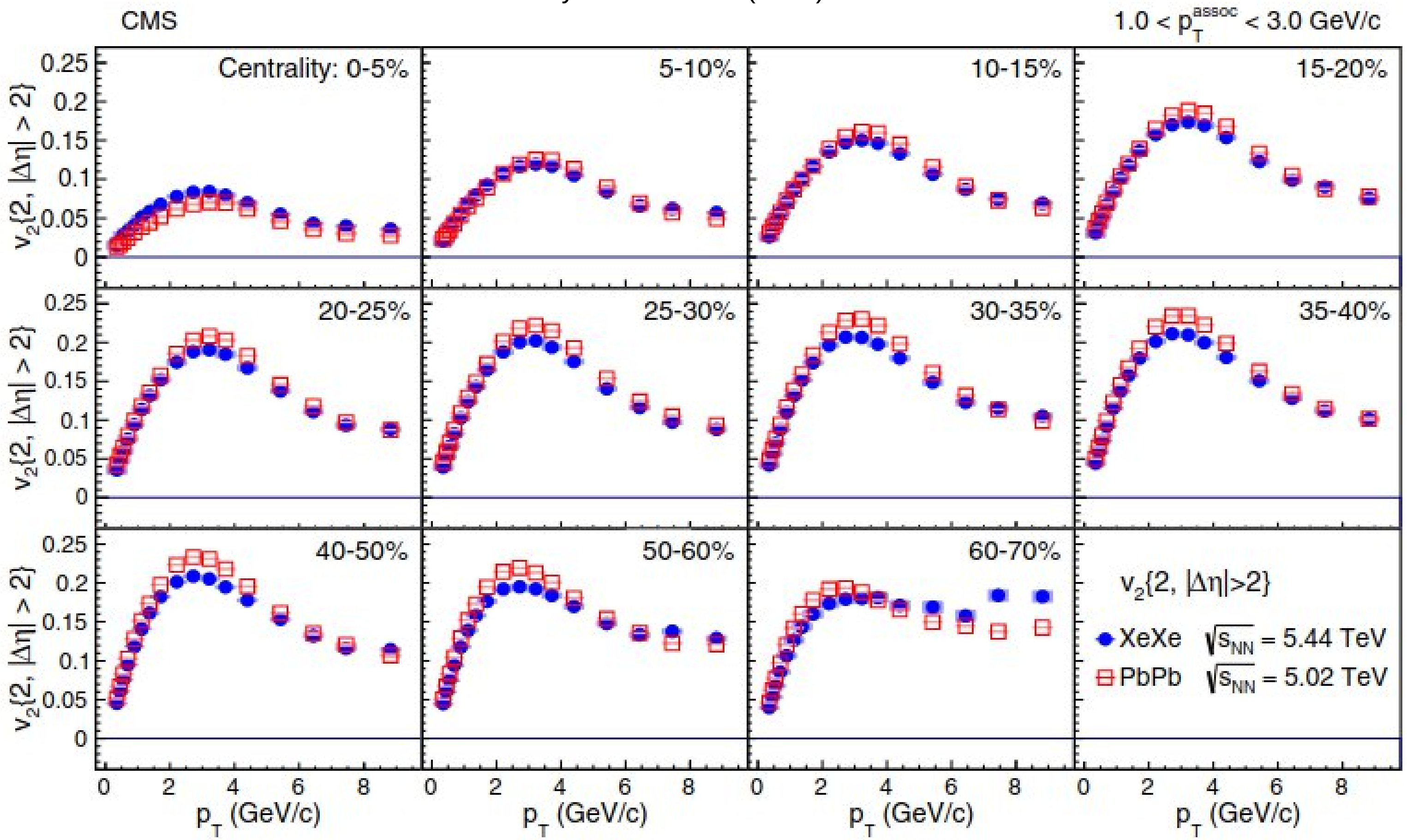
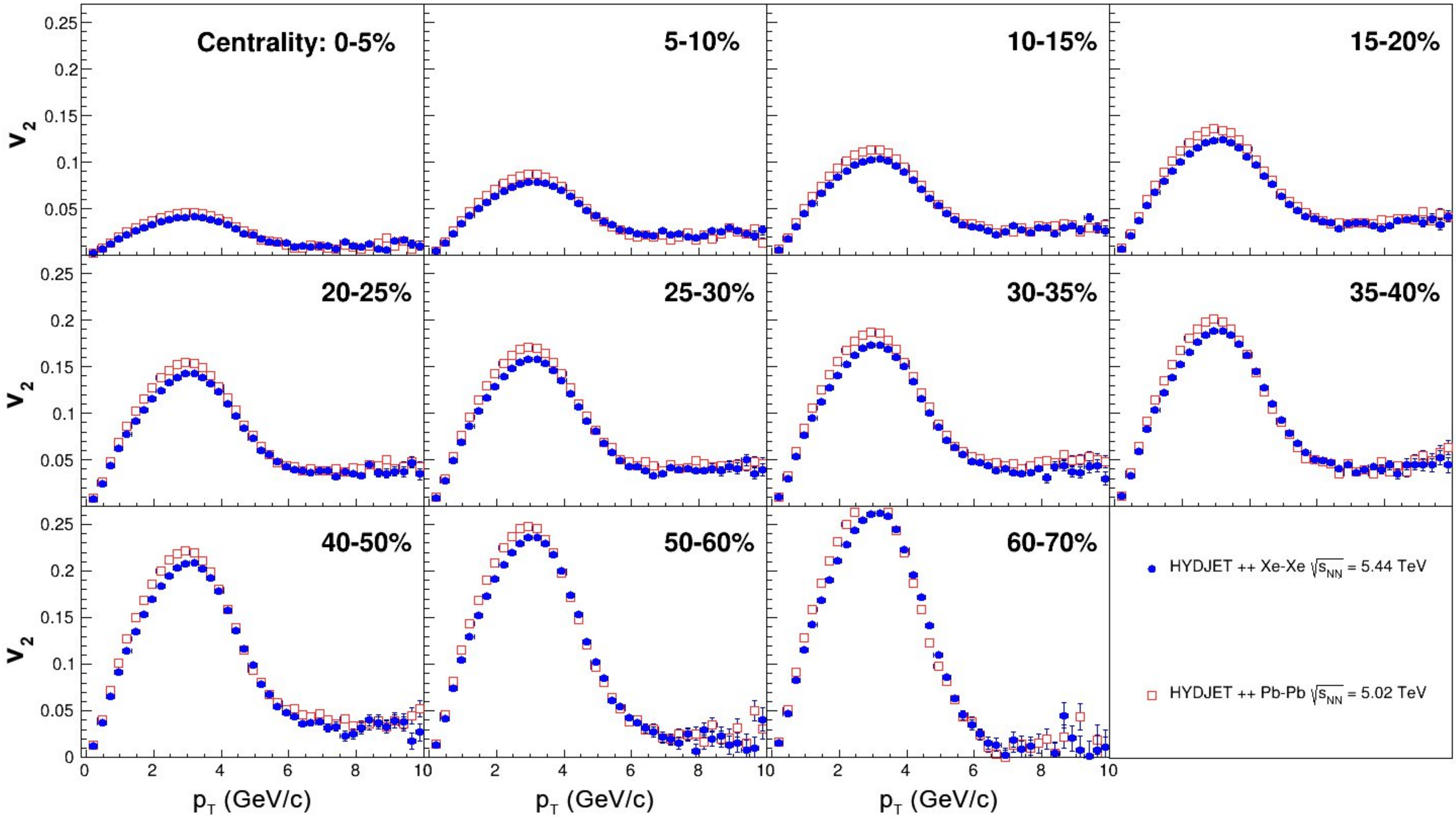


Результаты для v_2, полученные в эксперименте CMS методом двухчастичных корреляций.

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).

v_3 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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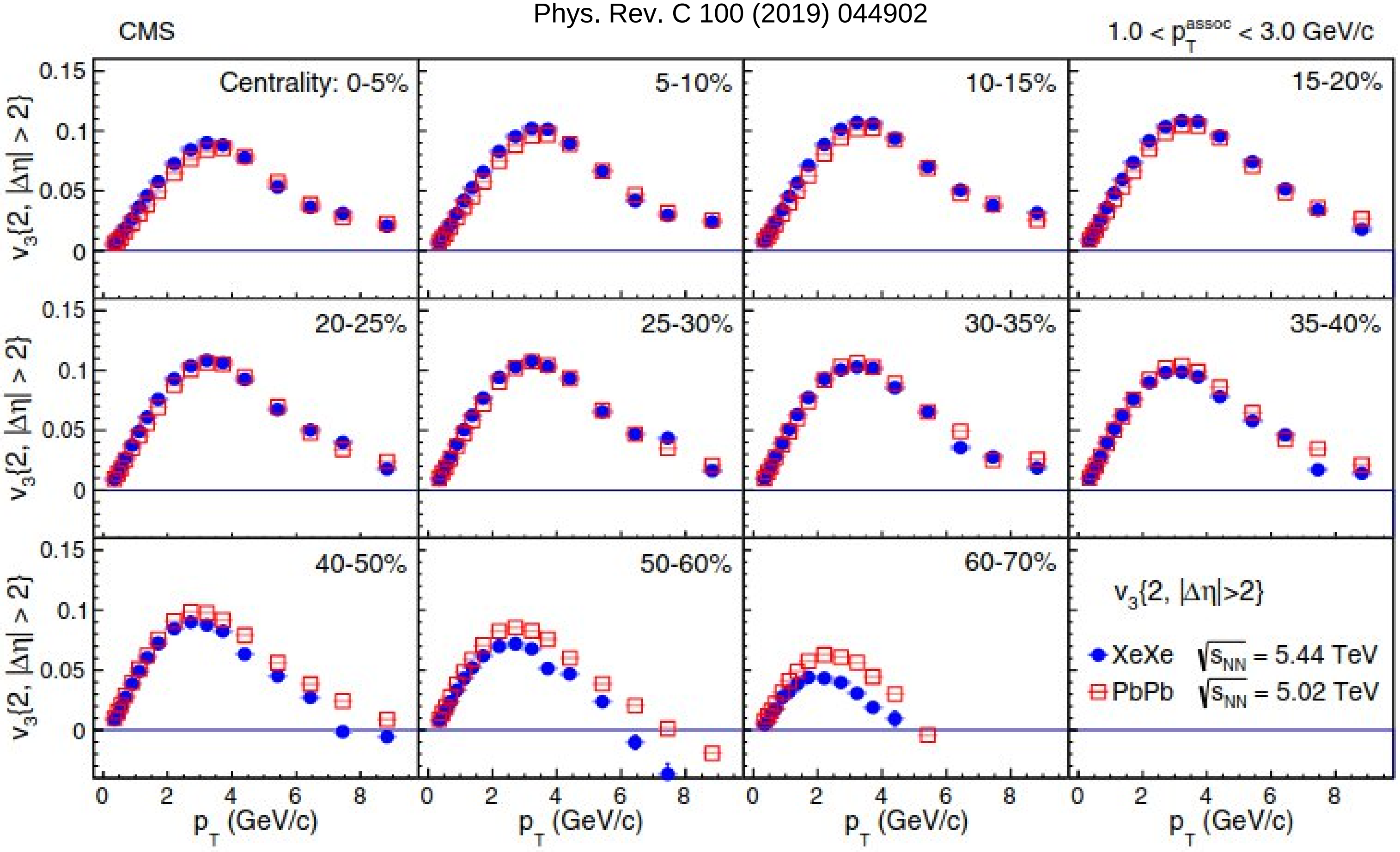

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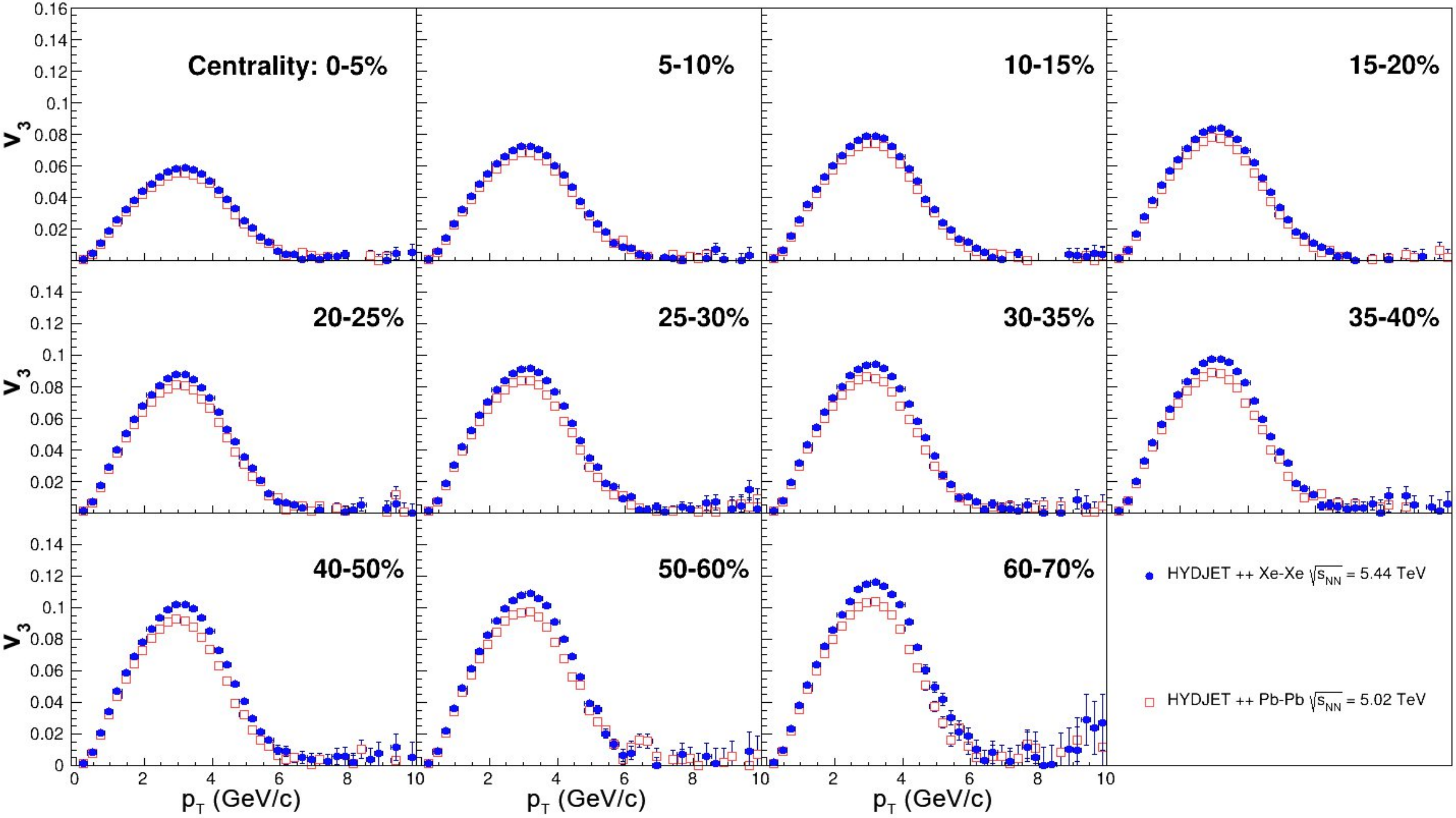

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Сравнение отношений гармоник v_2 в столкновениях XeXe и PbPb в эксперименте CMS и Монте-Карло генераторе HYDJET++

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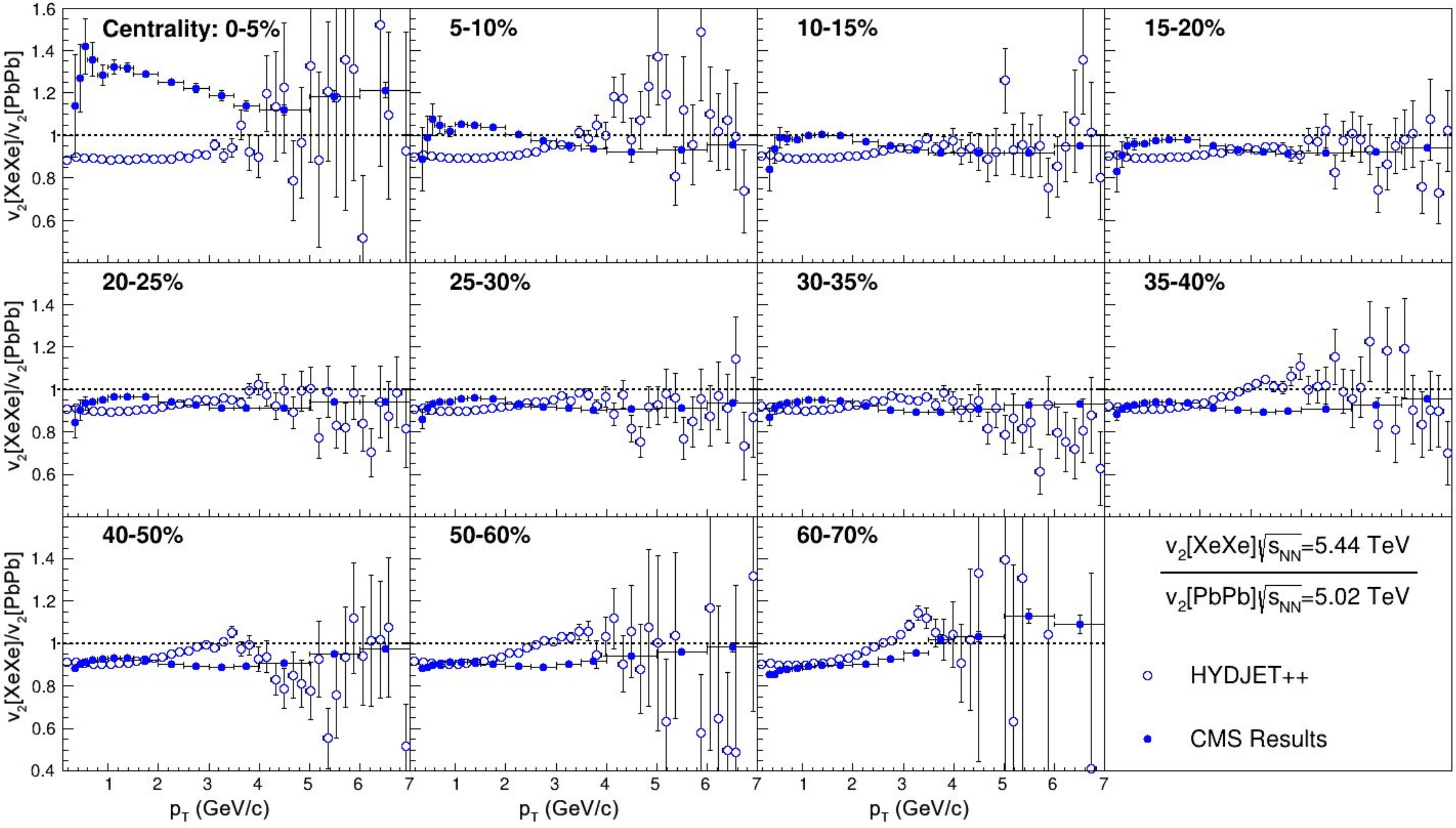

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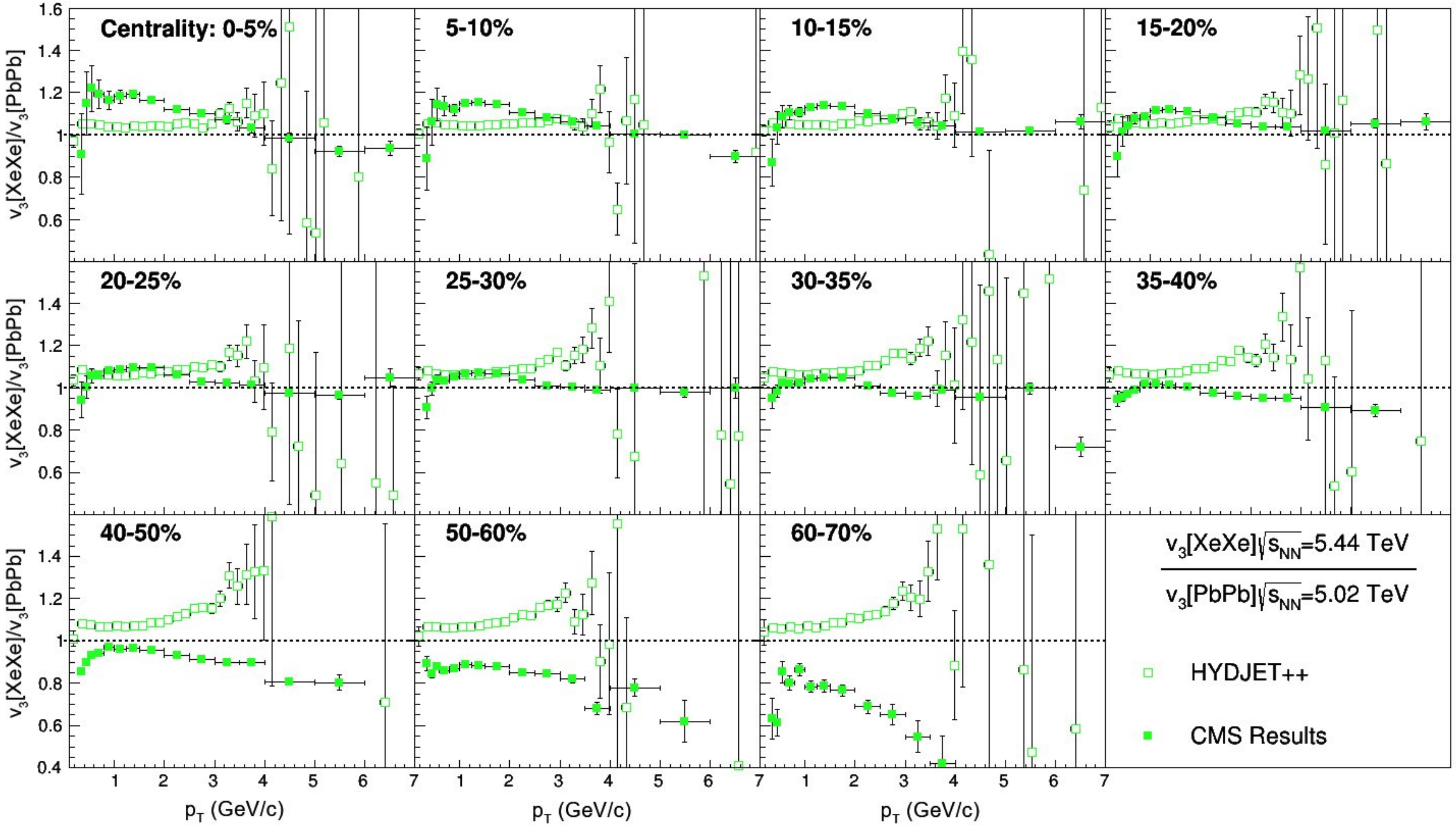

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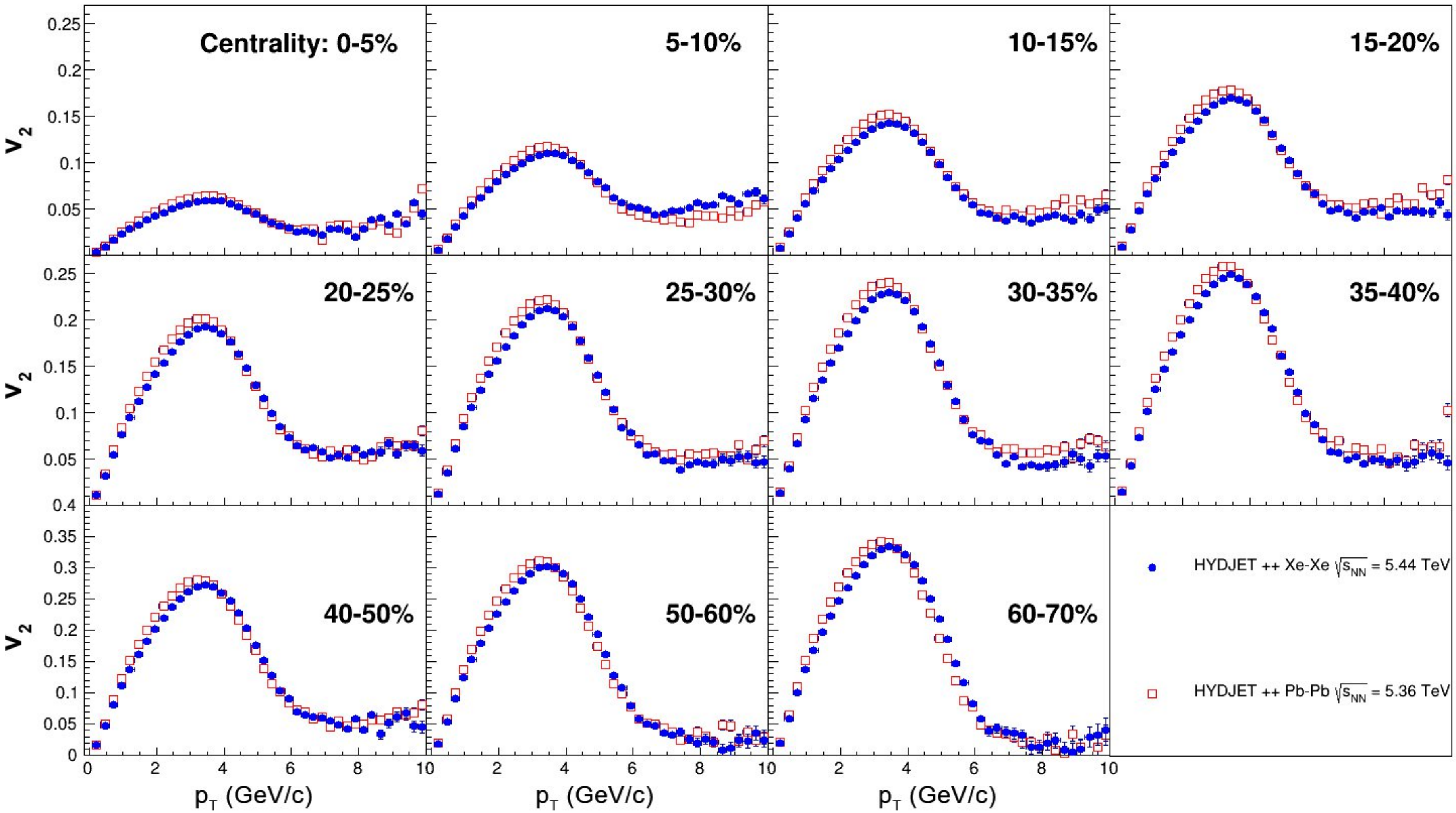
Predictions for v_2 distributions for Pb—Pb collisions with an energy of 5.36 TeV and Xe—Xe with an energy of 5.44 TeV per nucleon in the c.m.s. in the Monte Carlo generator HYDJET++



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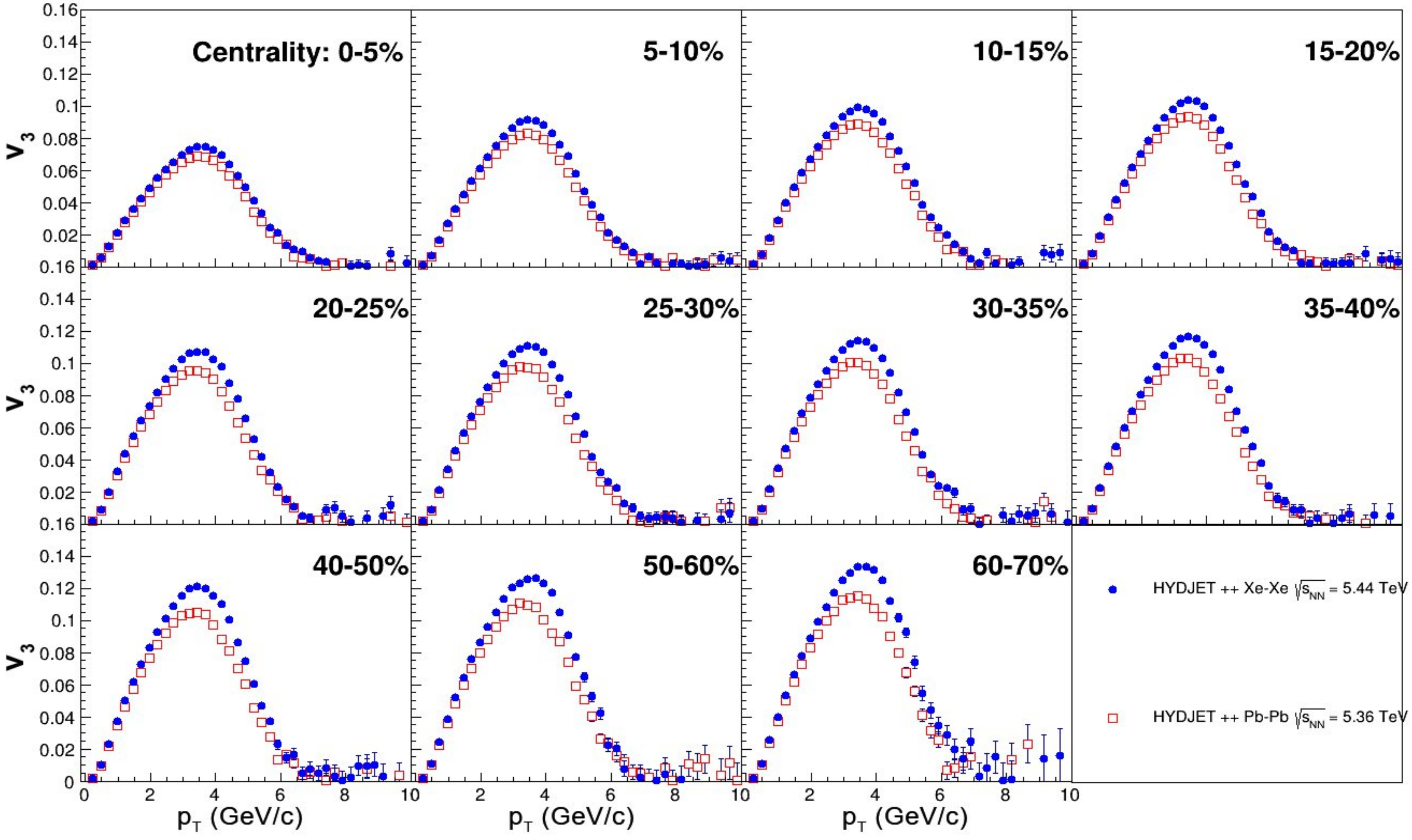

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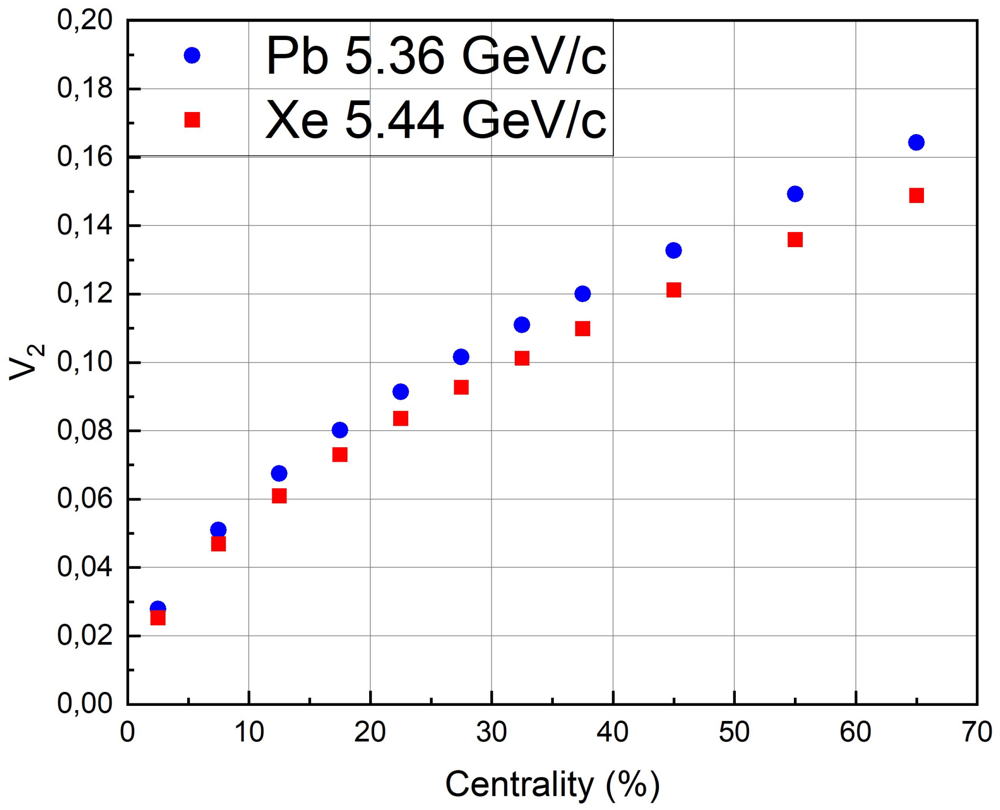
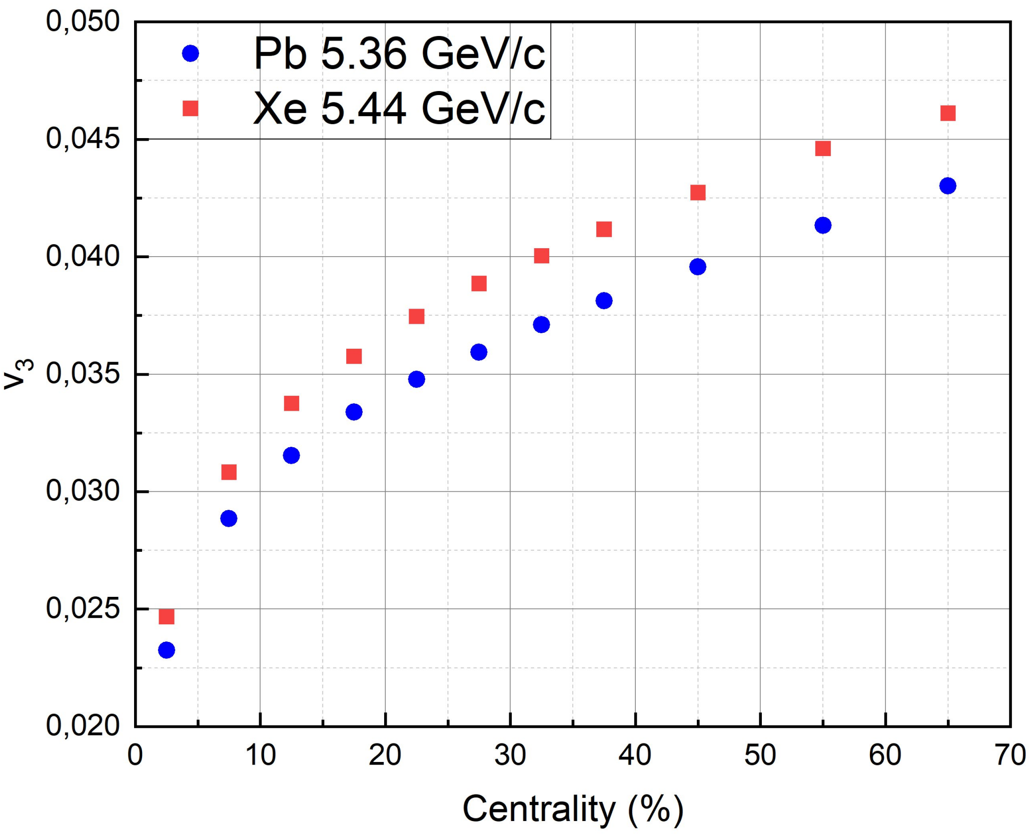
Integral values of elliptical and triangular flows for 11 centralities for Pb—Pb collisions at an energy of 5.36 TeV per nucleon and Xe—Xe at an energy of 5.44 TeV per nucleon in the c.m.s.





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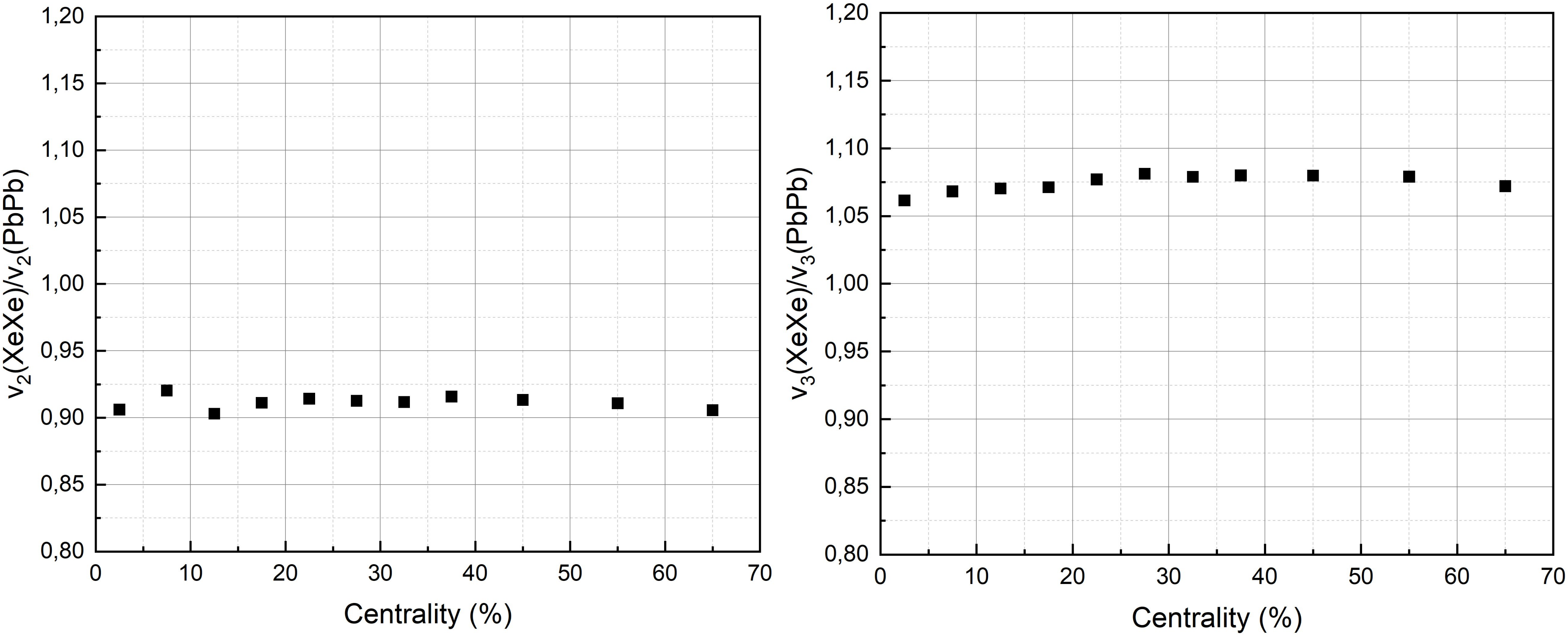

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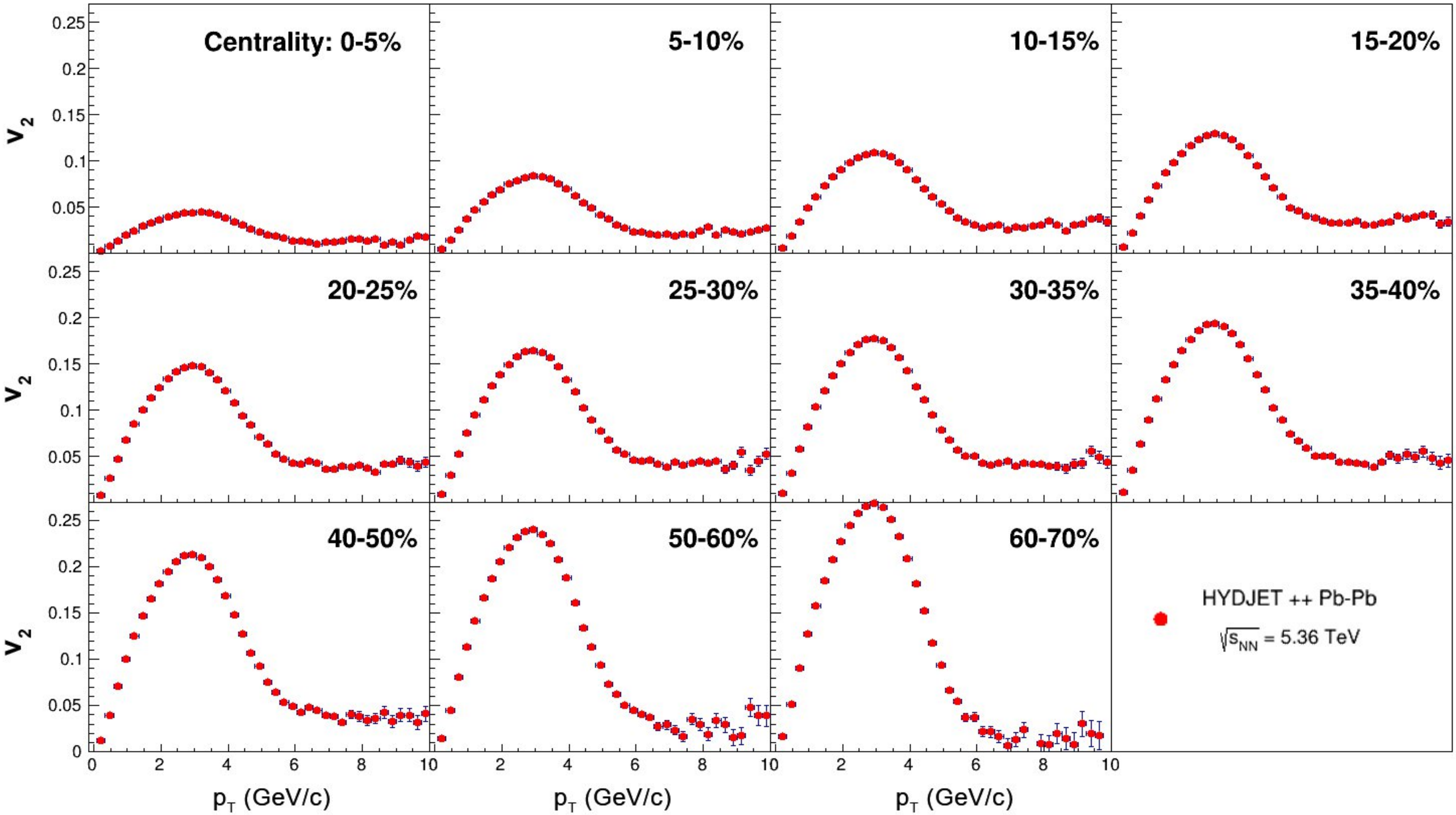
Предсказания распределений v_2 для столкновений Pb—Pb с энергией 5.36 ТэВ на нуклон в СЦМ в Монте-Карло генераторе HYDJET++



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

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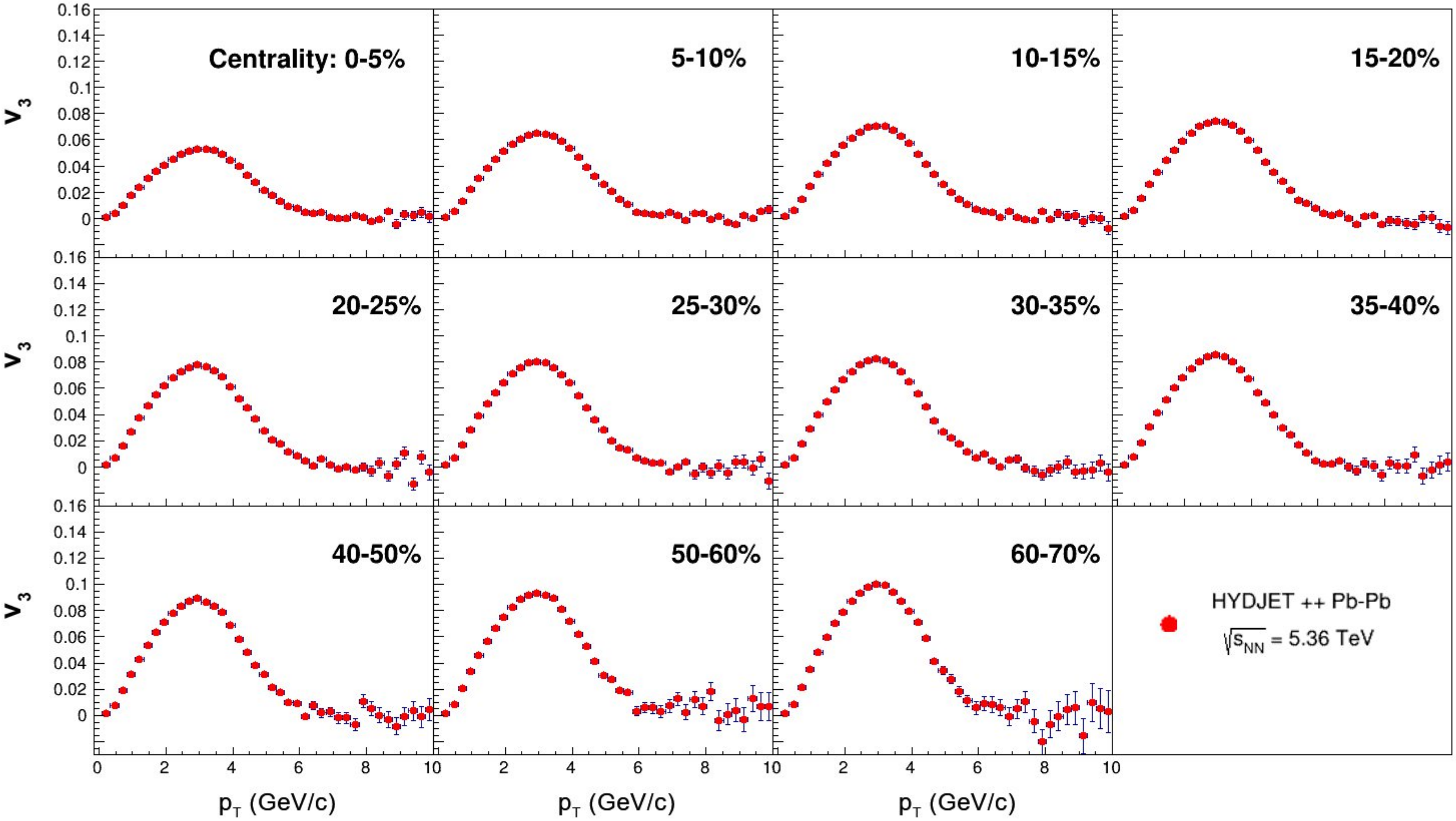

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