Jets Evolution in Au+Au Nuclear Collisions at CBM Energies

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Abstract

- The CBM experiment aims the study of the QCD phase diagram at low temperatures and high baryonic densities, mainly to find out the order of the phase transition between hadrons and partons under these conditions.
- There are many predictions about signals to detect the phase transition point: fluctuations [1], hydrodynamics [2], baryon-baryon correlations [3], etc.
- In our previous studies [4-5] we found as an interesting tool for the analysis of relativistic nuclear collisions: the "*nuclear matter jets*". Having a non-partonic origin, the number of jets indicates the centrality of the collision, i.e. the amount of incident energy pumped into the system, and the jet-kinematic and dynamic properties allowed us to make assumptions about their origin. A liquid-gas nuclear phase transition was indicated by the disappearance of jets.
- The *cumulativity number*[4] is another useful variable for detecting phase transitions. *Mutatis mutandis,*at CBM energies we expect a similar behavior for nuclear matter and partonic jets. For this, we made *jetology and cumulative number* studies on UrQMD simulations for Au+Au collisions at 4, 10 and 15GeV/nucleon. We will compare our results with the experimental ones to make definitive conclusions.

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Contents

- Jets in He+Cu at 4.5 A Gev/c;
- CBM experiment at FAIR;
- Jets, Flow and Cumulative Number in Au+Au at 4, 10, 20 and 30 A GeV UrQMD simulations;
- Conclusions.

Eu N
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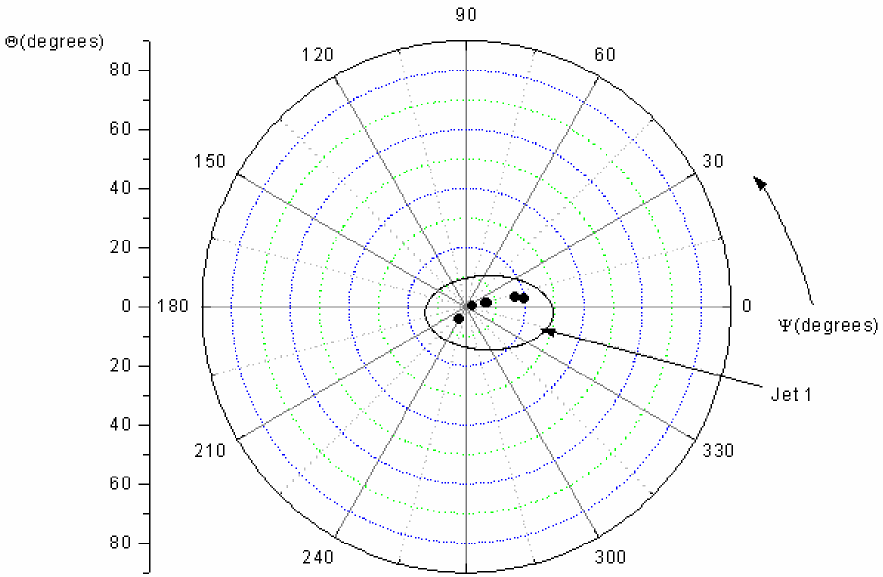
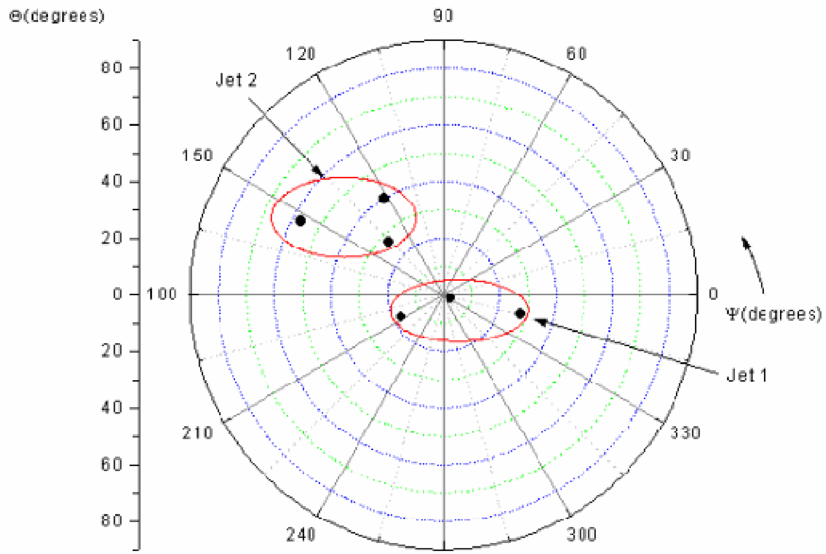
Jets in He+Cu at 4.5 A Gev/c;

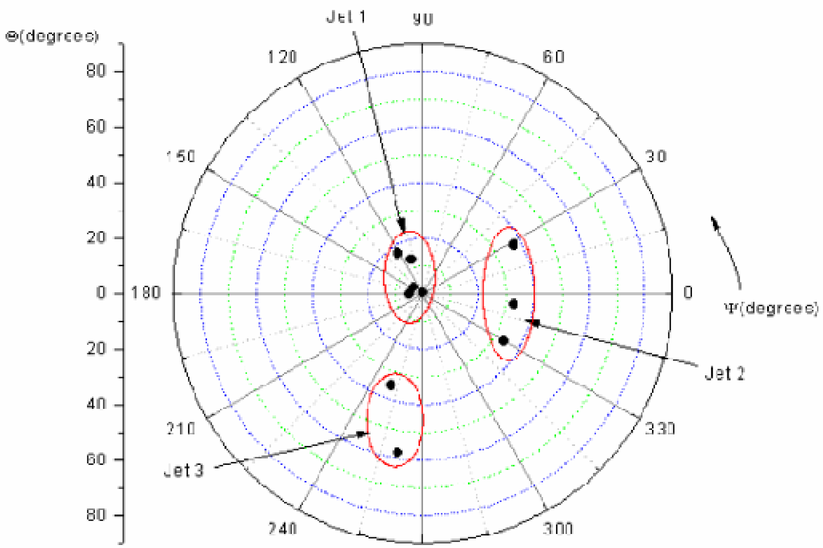
- In our previous studies we found jets of nuclear matter in nucleus–nucleus collisions at 4.5 A GeV/c (He+AT SKM200, JINR Dubna). Hadronic jets, **"spray of hadrons with momenta collimated into a narrow cone",** appeared in high energy physics as signals of the partonic structure of hadrons. At Dubna Syncrophazotron energies, we do not consider the partonic degrees of freedom as the origin of the nuclear matter jets. These jets, or **spikes** of charged particles, could bring information about the geometry and dynamics of the interaction. There are many sources of angular particle and fragment emission anisothropy: the disintegration of an excited fragment in relativistic motion [2], the explosion of a fireball in relativistic motion [3], the flow of viscous and hot participant matter through the cold projectile and target spectator zones [4], nuclear cascades on the direction of the of the independent projectile nucleons trajectories [5], exotic phenomena like quark-gluon fluctons, exotic resonances whose disintegration products are emitted into a narrow cone [6], or, random association of the emitted particles from different sources, identified by the jet-finder algorithm as jets [7].
- In the asymmetric reactions He+Cu at 4.5 A GeV/c collisions (SKM200-JINR Dubna), the number of jets was associated with the centrality of the collisions and the characteristics of them allowed us to consider Jet1 as projectile remnant disintegration and Jet2 and Jet3 as target remnant disintegration. In the most central collisions the jet structure disappears, we have the **nonjet** structure of total disintegration of the target (multifragmentation).



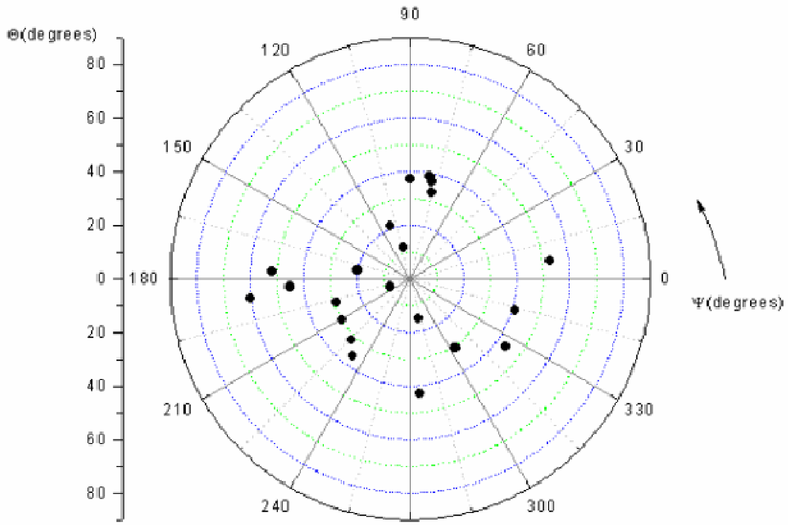
Projections of the particles momenta on the forward hemisphere in a He+Cu single jet event



Projections of the particles momenta on the forward hemisphere in a He+Cu two-jet event



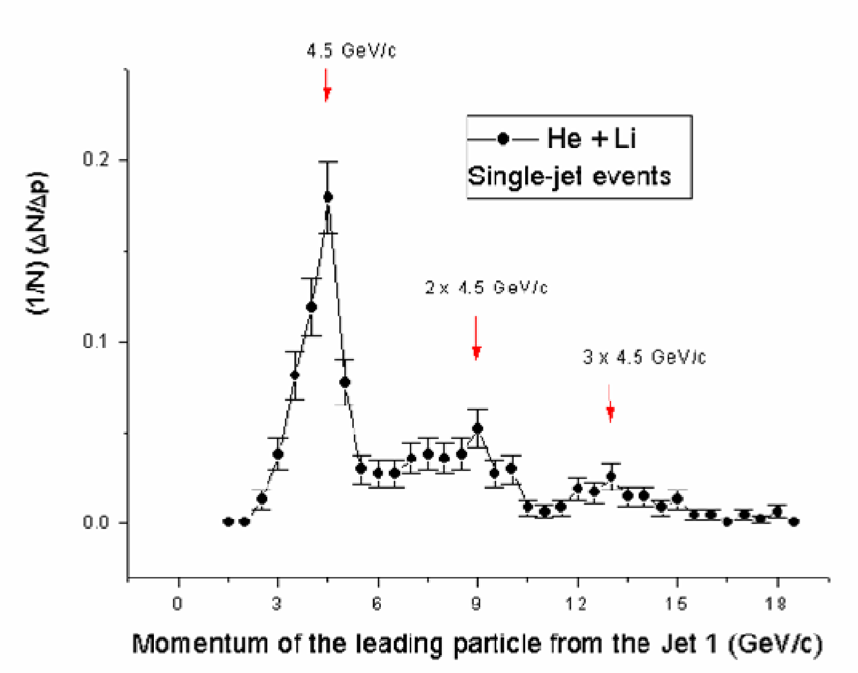
Projections of the particles momenta on the forward hemisphere in a He+Cu three jet event

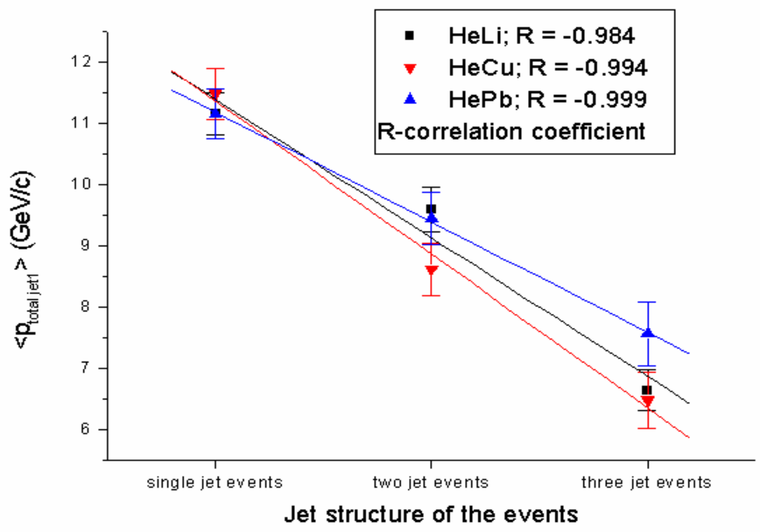


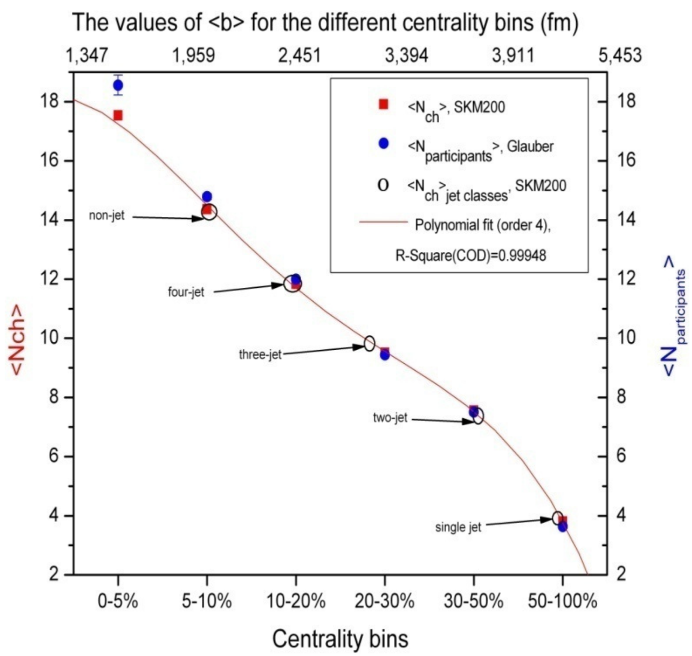
Projections of the particles momenta on the forward hemisphere in a He+Cu non-jet event

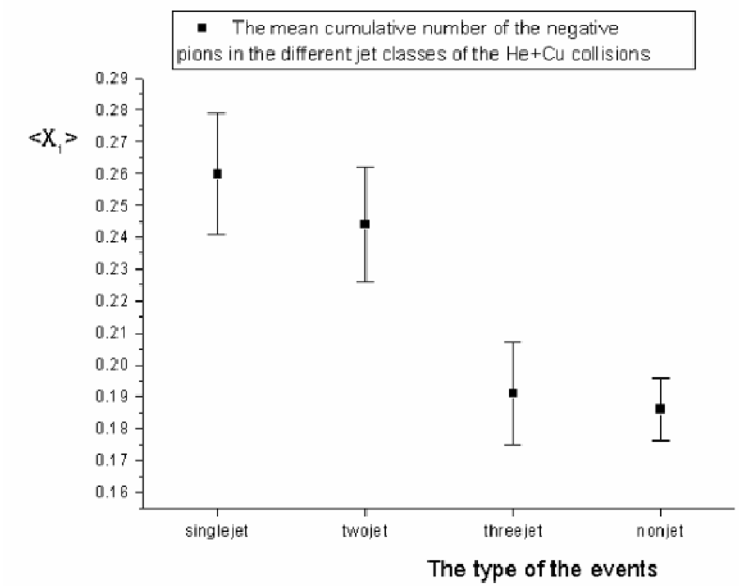
Comments

- **Jet Structures**: projection of the particles momenta onto the forward hemisphere of the collision;
- Among the different jet-finding techniques, we chose a non-hierarchic method – Klaus von Lanius-Preprint DESY 80/36(1980), the **"weight center method"** (a cone jet-finding algorithm)


4.5 GeV/c
2 x 4.5 GeV/c
3 x 4.5 GeV/c
He + Li
Single-jet events
(1/N) (ΔN/Δp)
0.2
0.1
0.0
0
3
6
9
12
15
18
Momentum of the leading particle from the Jet 1 (GeV/c)


HeLi; R = -0.984
HeCu; R = -0.994
HePb; R = -0.999
R-correlation coefficient
<p_total jet1> (GeV/c)
12
11
10
9
8
7
6
single jet events
two jet events
three jet events
Jet structure of the events


The values of <b> for the different centrality bins (fm)
1,347
1,959
2,451
3,394
3,911
5,453
<Nch>
<N_participants>
<N_ch>, SKM200
<N_participants>, Glauber
<N_ch>_jet classes, SKM200
Polynomial fit (order 4),
R-Square(COD)=0.99948
non-jet
four-jet
three-jet
two-jet
single jet
18
16
14
12
10
8
6
4
2
0-5%
5-10%
10-20%
20-30%
30-50%
50-100%
Centrality bins

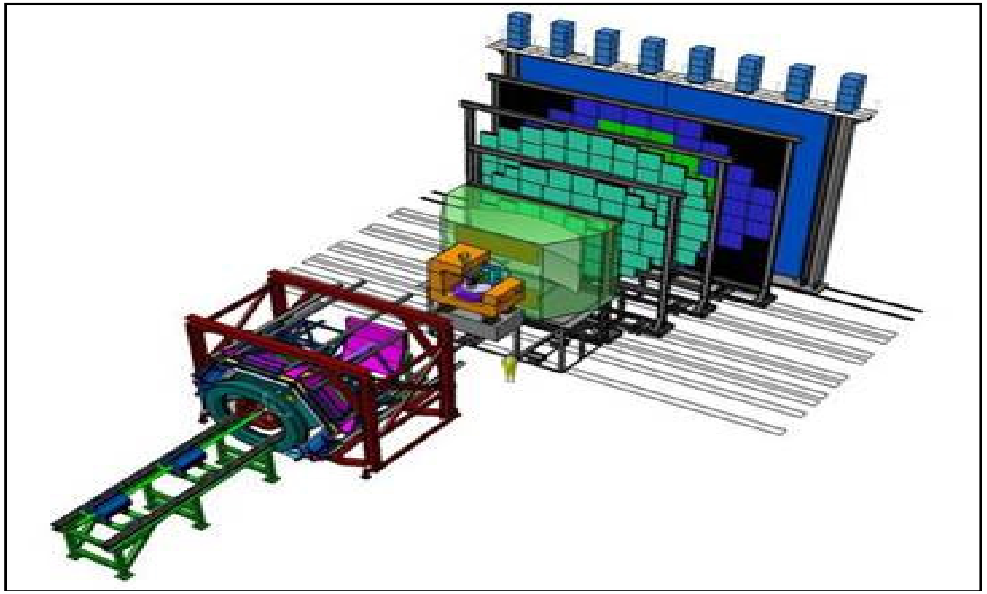

The mean cumulative number of the negative
pions in the different jet classes of the He+Cu collisions
<X_i>
0.29
0.28
0.27
0.26
0.25
0.24
0.23
0.22
0.21
0.20
0.19
0.18
0.17
0.16
singlejet
twojet
threejet
nonjet
The type of the events

Comments

1) Jet 1 contains projectile spectator fragments;
2) Jet 1 total momentum decreases from single-jet to three-jet events: the centrality increases and the projectile transfers more energy to the target;
3) A Glauber analysis of the events show us that the jet structure can be associated with the centrality of the collisions: singlejet events are the most peripheral and the nonjet events are the most central ones.
4) The decrease of the mean value of cumulative number for negative pions from single-jet to nonjet events indicate a higher degree of the thermalisation (thermal equillibrium) in nonjet events, as we associate the magnitude of cumulative number with nonequillibrium processes.

The *Compressed Baryonic Matter Experiment at FAIR*

- The CBM experiment is designed for the detection of signals from the high-density phase. Heavy-ion beams in the energy range between 2 and about 14 A GeV are ideally suited to explore the properties of dense baryonic matter. According to transport calculations, energy densities up to 2.5 GeV /fm3 and baryon densities of 2-7 times saturation density ρ_0 are expected to be reached in the center of the reaction zone. Such conditions prevail in core collapse supernovae and in the core of neutron stars. Measurements at SIS100 energies will focus on the investigation of the properties of resonance matter in the vicinity of the phase boundary, and, therefore, will provide important information on this transition region of the QCD phase diagram;
- Theorists found that the freeze-out value of the net baryon density exhibits a maximum as the collision energy is being scanned, thus suggesting that there may be an optimal collision energy (range) for the exploration of compressed baryonic matter. In a fixed-target configuration, this optimal beam kinetic energy is 20–30 GeV/A, which appears to be ideal for the planned FAIR at GSI.



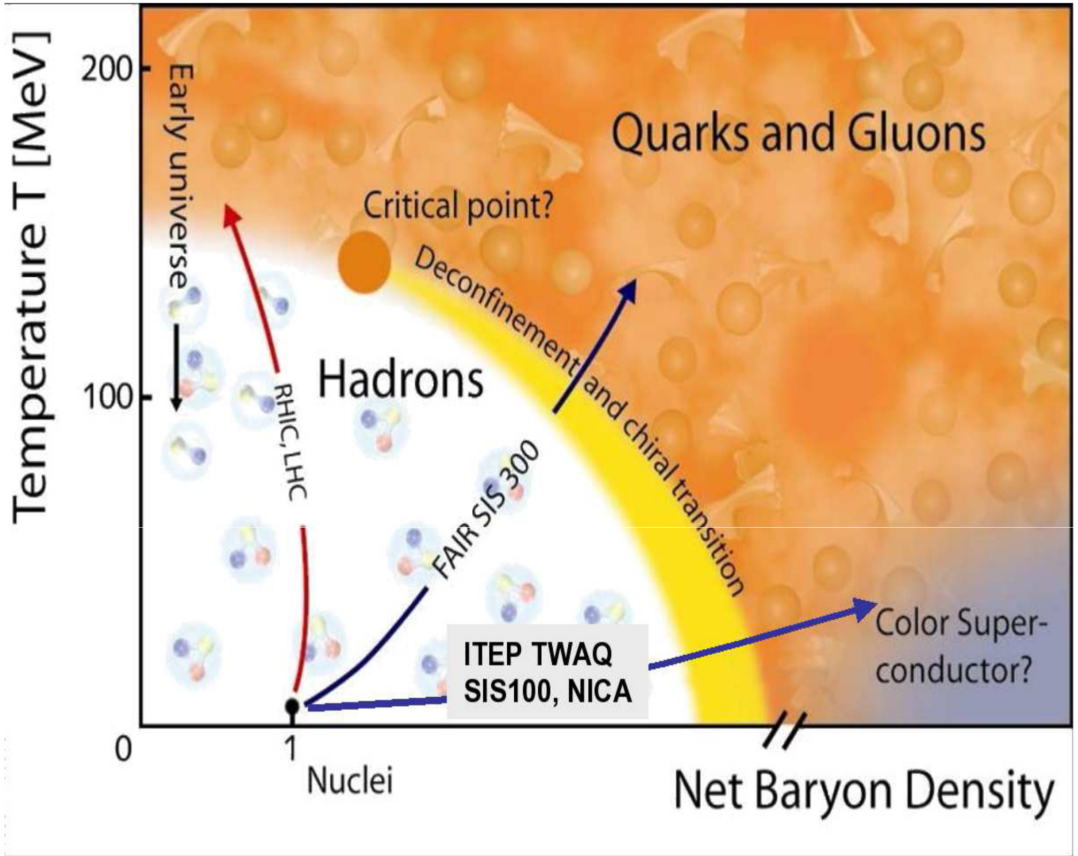
CBM

CBM physics program:

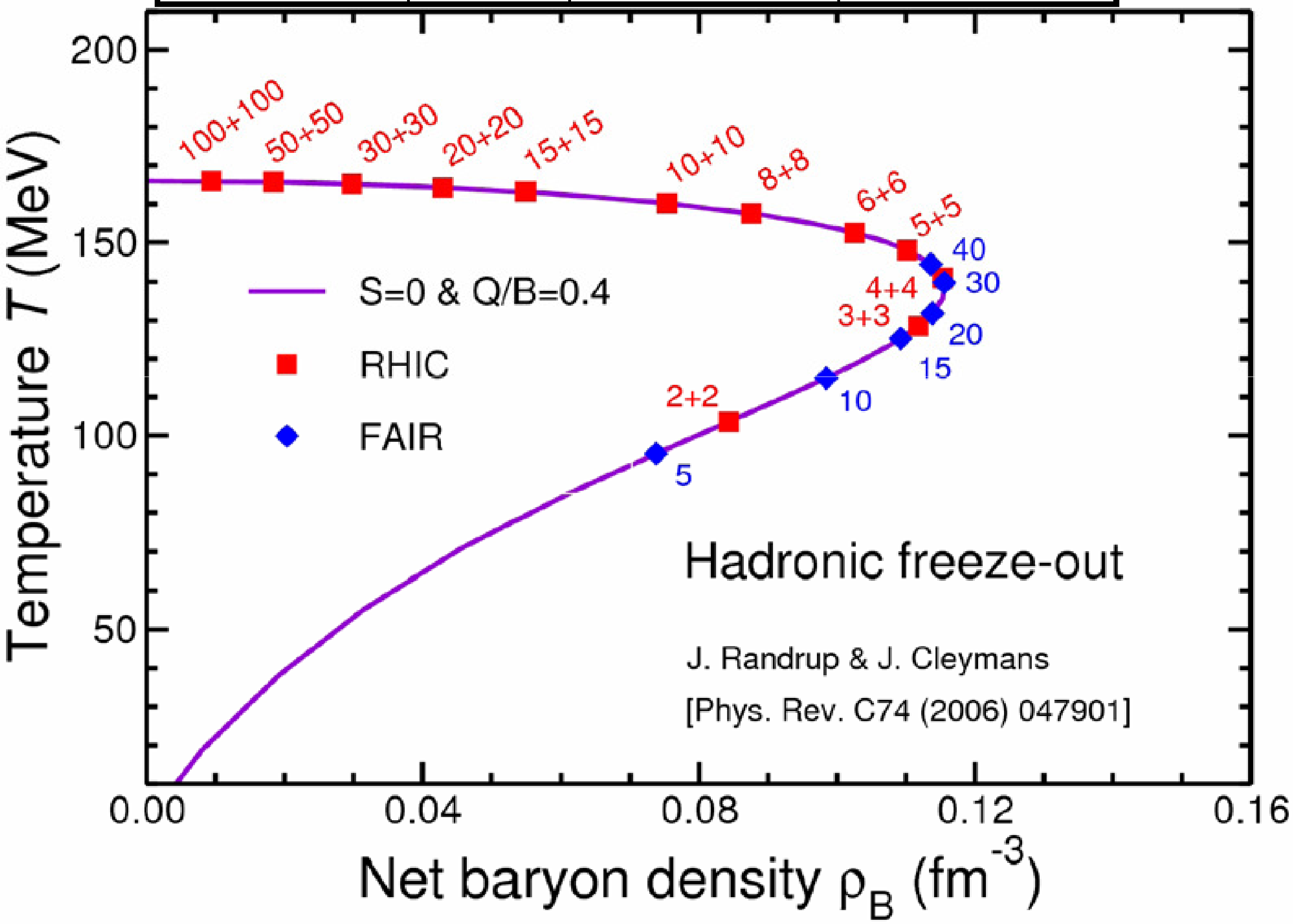
- *Equation-of-state at high ρ_B;*
- *Deconfinement phase transition;*
- *QCD critical endpoint;*
- *Chiral symmetry restoration*

Diagnostic probes of the high-density phase:

- *open charm, charmonia;*
- *low-mass vector mesons;*
- *Multistrange hyperons;*
- *flow, fluctuations, correlations [8]*



beam energy	max. ρ/ρ_0	max ε [GeV/fm³]	time span ~FWHM
5 AGeV	6	1.5	~ 8 fm/c
40 AGeV	12	> 10	~ 3.5 fm/c



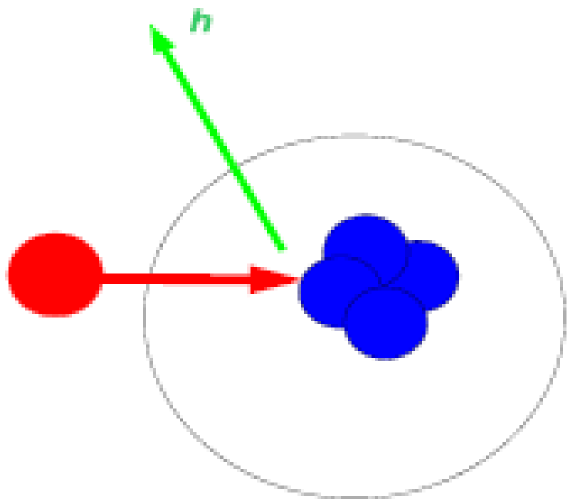
Jets, Flow and Cumulative Number (1)

Equation of state at high ρ_B can be studied using flow anisotropy and the aim of this presentation is that jets can be correlated with flow. There are theoretical predictions [10-11] about a phase transition from hadrons (confined) to plasma (deconfined) by critical fluctuations **which might leave signatures visible even within the daunting environment around heavy ion fireballs. The flow, the nuclear matter jets and the cumulative number can be influenced by fluctuations and can be a useful instrument for analysis.**

Cumulative particles are the particles produced in the kinematical region forbidden for free nucleon-nucleon interactions . Such particles can be produced only in the processes with participation of nuclei. Production of such particles does not contradict momentum conservation laws. The interest in the study of cumulative processes is motivated by searching for signatures of the phase transition in the high-compressed nuclear matter.

Jets, Flow and Cumulative Number (2)

- The cumulative region corresponds to the regime of particle production in the strongly compressed nuclear matter. We assume that a nucleus size could be of the order of a nucleon size in the deep cumulative region (the region near the kinematic boundary of the reaction). For the process the momentum of the inclusive particle should be fully balanced by the momentum of the recoil system consisting of very slow constituents. The system in the state should demonstrate the property of collectivity. Therefore, a transition regime from single constituent interactions to collective phenomena is expected.
- S.S.Shimanskiy, arXiv: nucl-ex/0604014v
  "The flucton picture of the backward cumulative particle production":

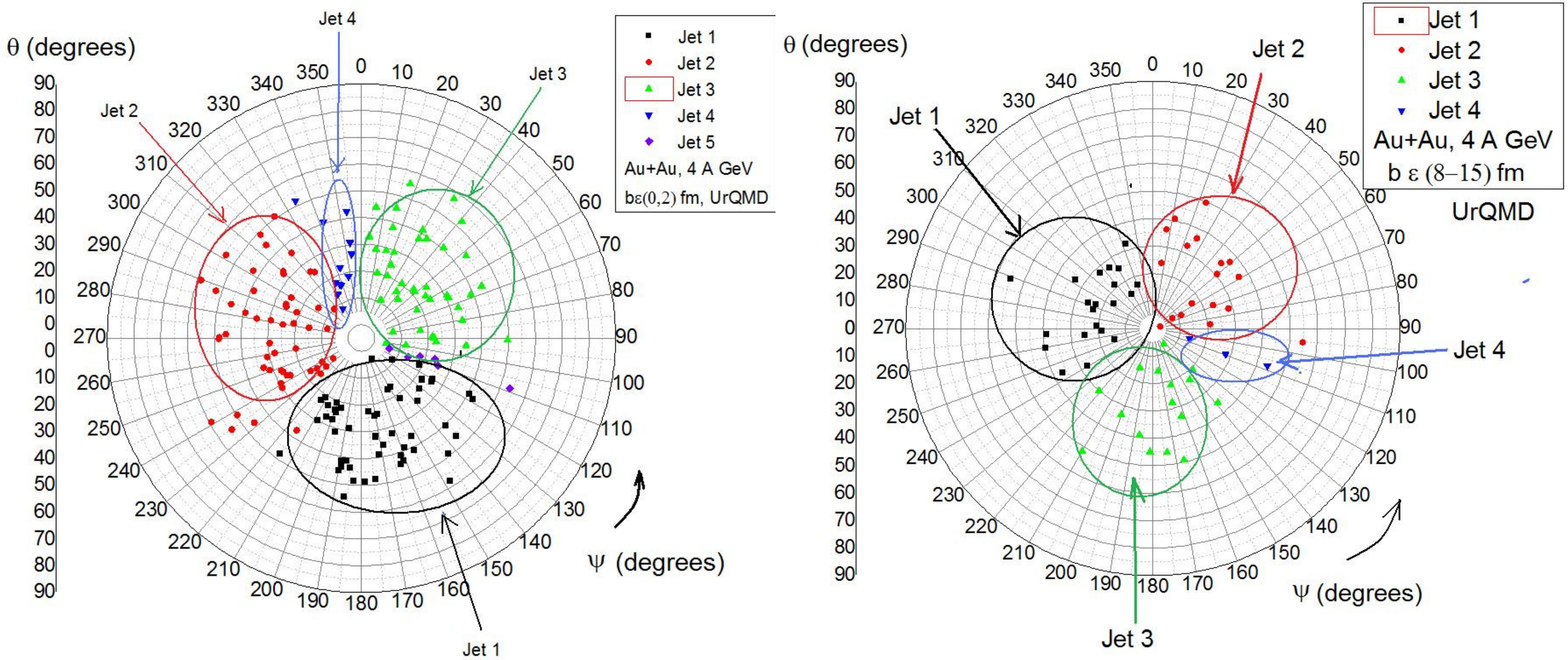


Results (1)

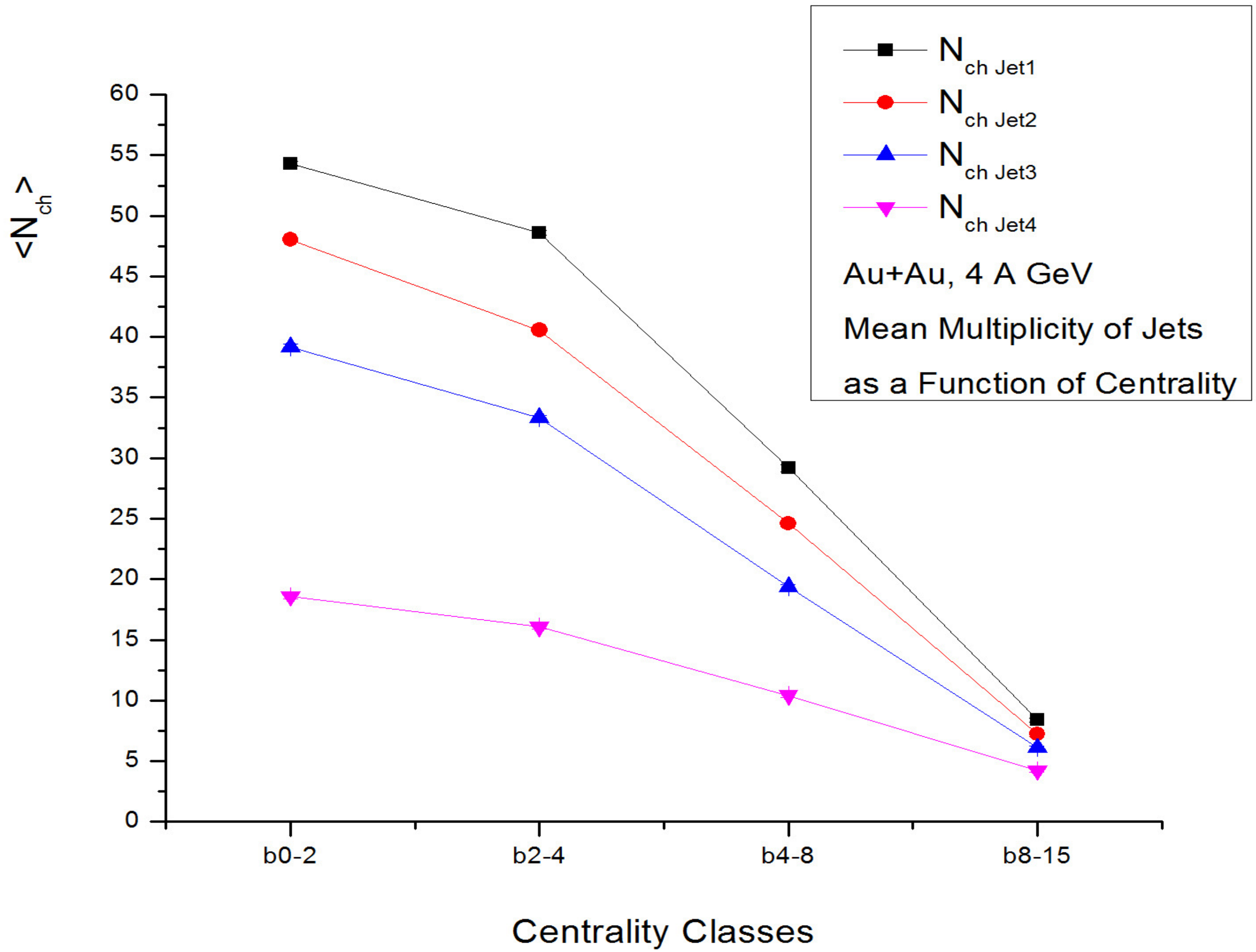
- Au+Au collisions were simulated UrQMD at 4, 10 and 15 A GeV in four centrality classes:

  bЄ[0,2) fm; bЄ[2,4) fm; bЄ[4,8) fm; bЄ[8,15) fm

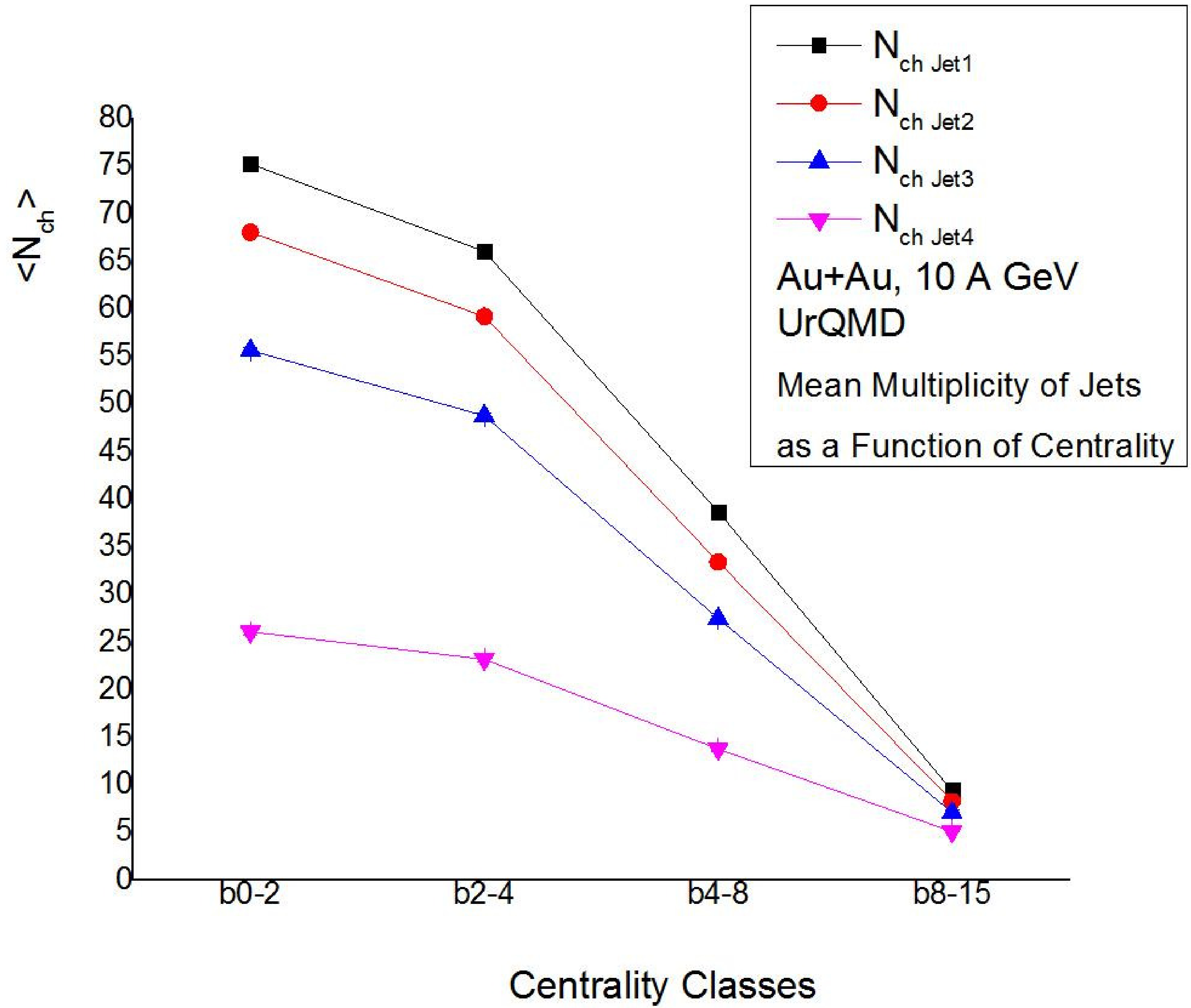
  (central, semi-central, semi-peripheral and peripheral).
- The Anti-KT Alghoritm jet finder, with R=1, was used for jet detection (and the results were compared with “the weight center method” of K.van Lanius);
- The midrapidity charged particles were selected for analysis at each of the three energies.



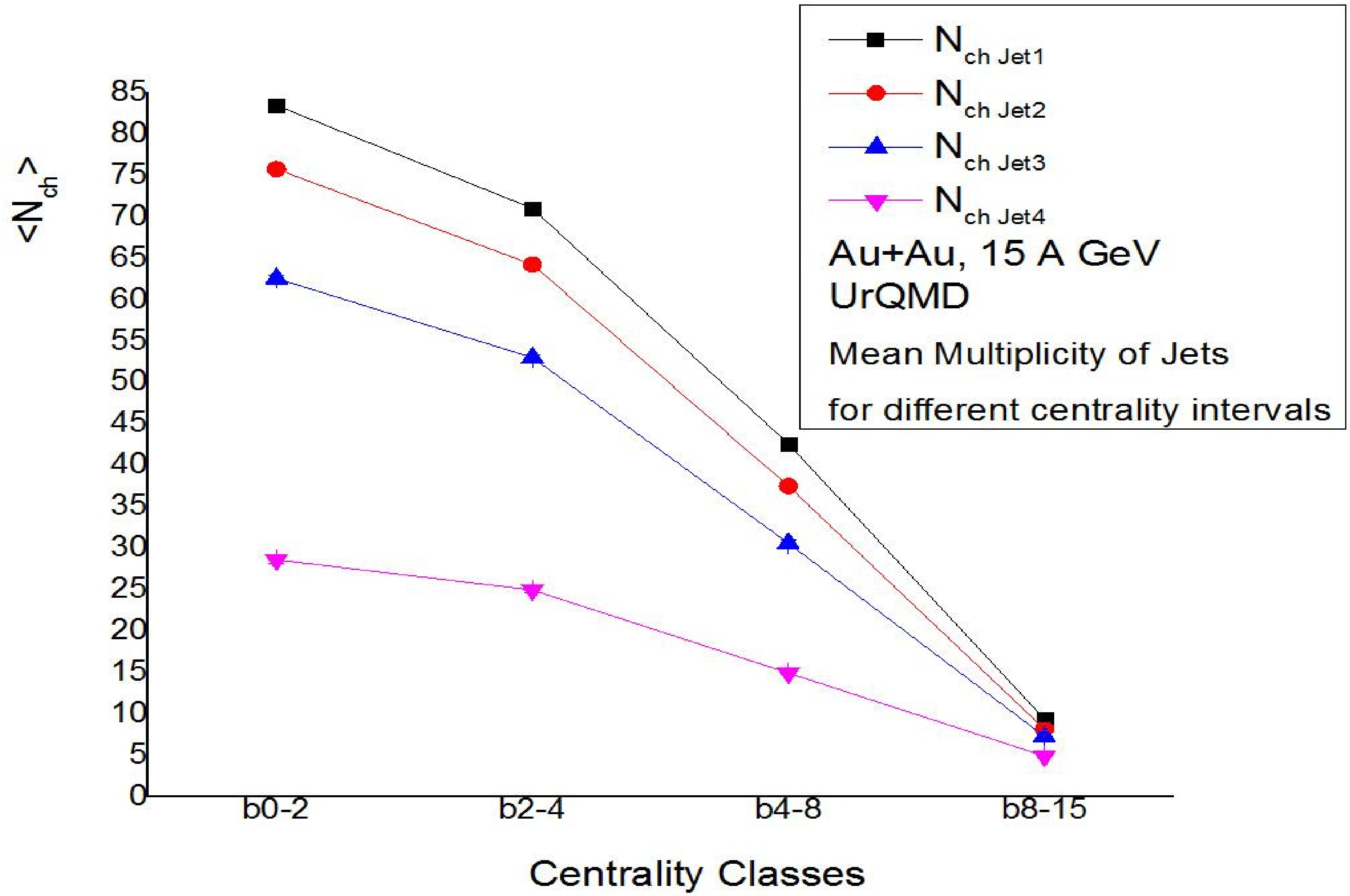
Intersection of particles momenta with the forward hemisphere in Au+Au at 4 A GeV
in central (left) and peripheral collisions (right)



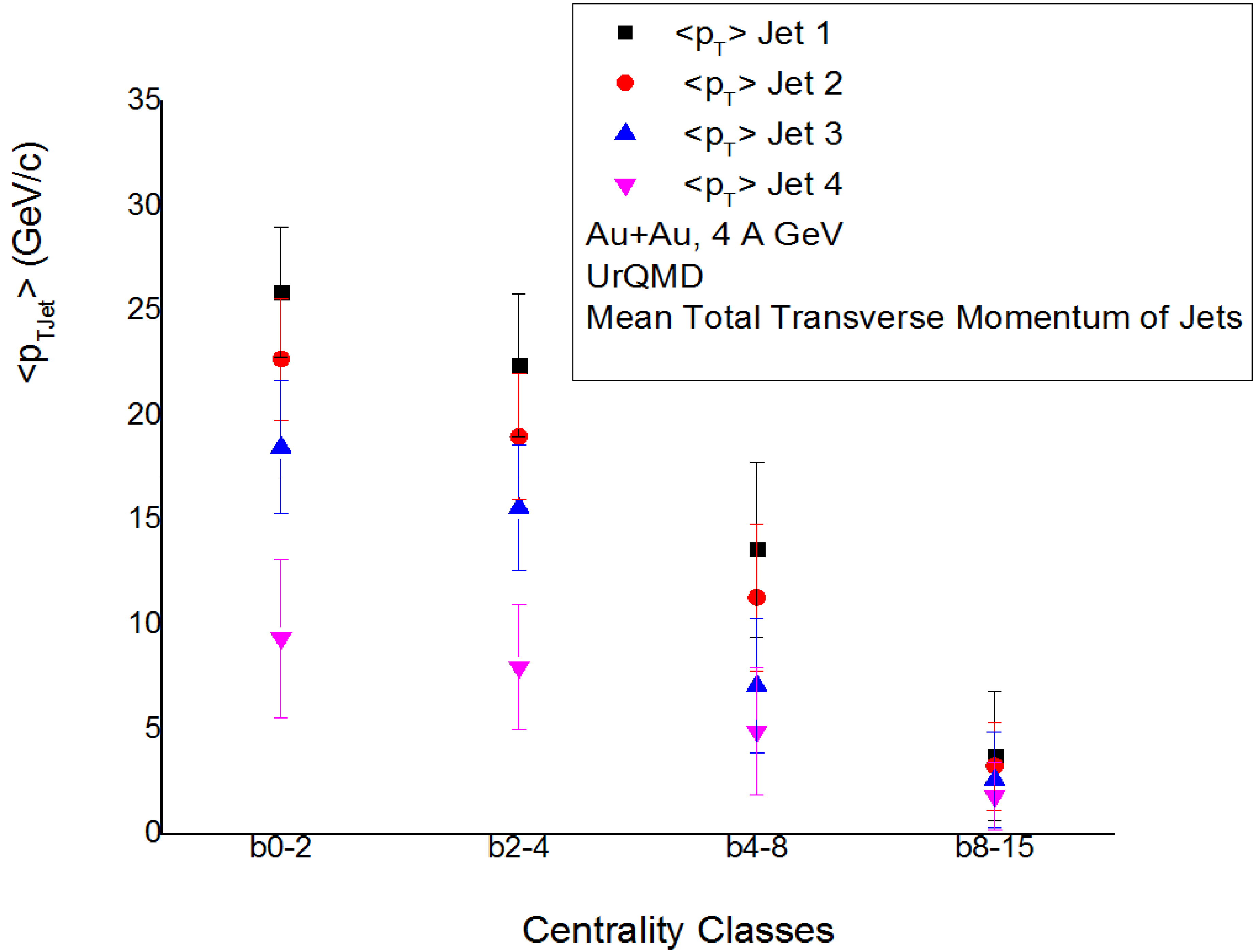
The mean multiplicity of jets depends on the centrality of the collisions.



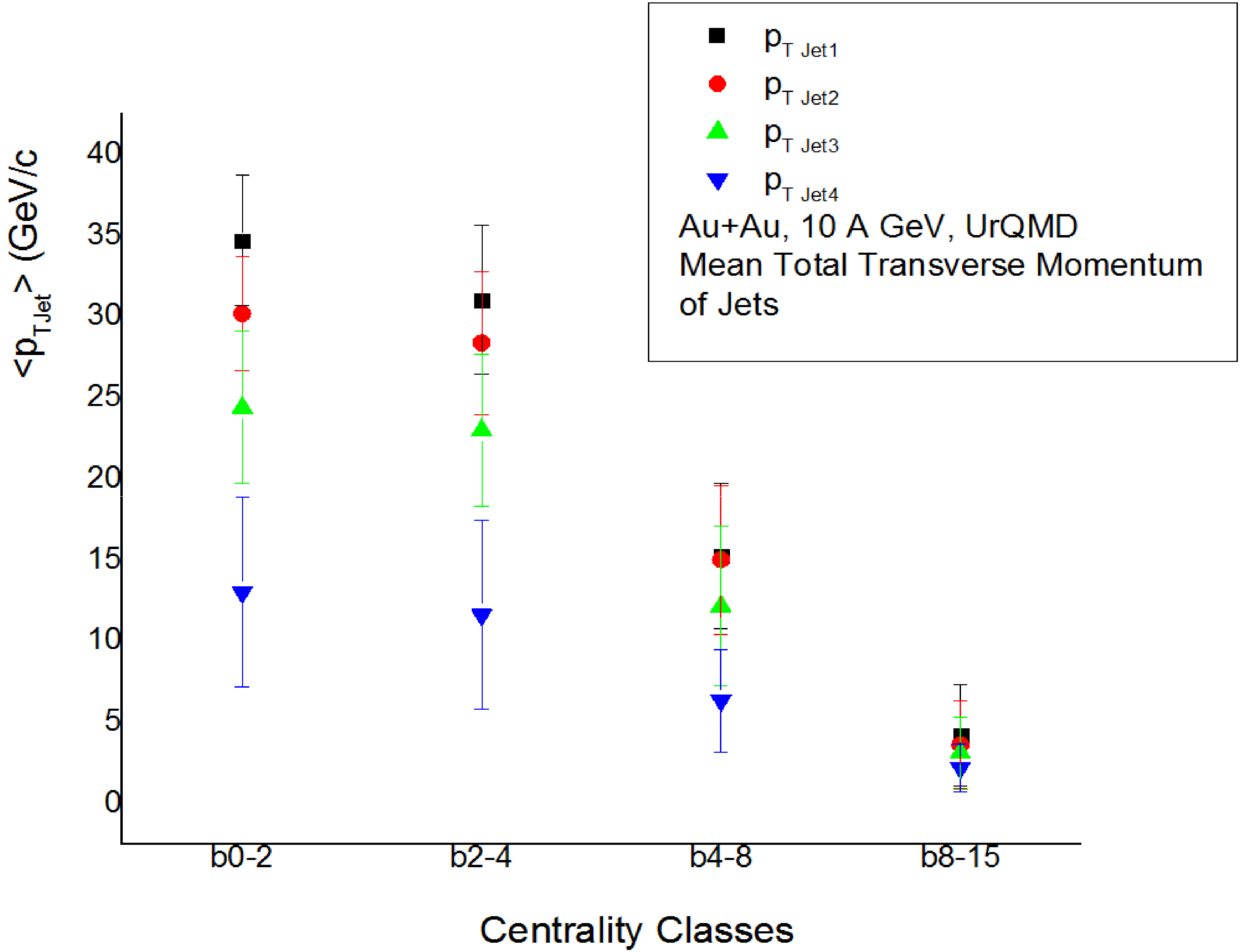
$N_{ch\ Jet1}$
$N_{ch\ Jet2}$
$N_{ch\ Jet3}$
$N_{ch\ Jet4}$
Au+Au, 10 A GeV
UrQMD
Mean Multiplicity of Jets
as a Function of Centrality
$<N_{ch}>$
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
b0-2
b2-4
b4-8
b8-15
Centrality Classes



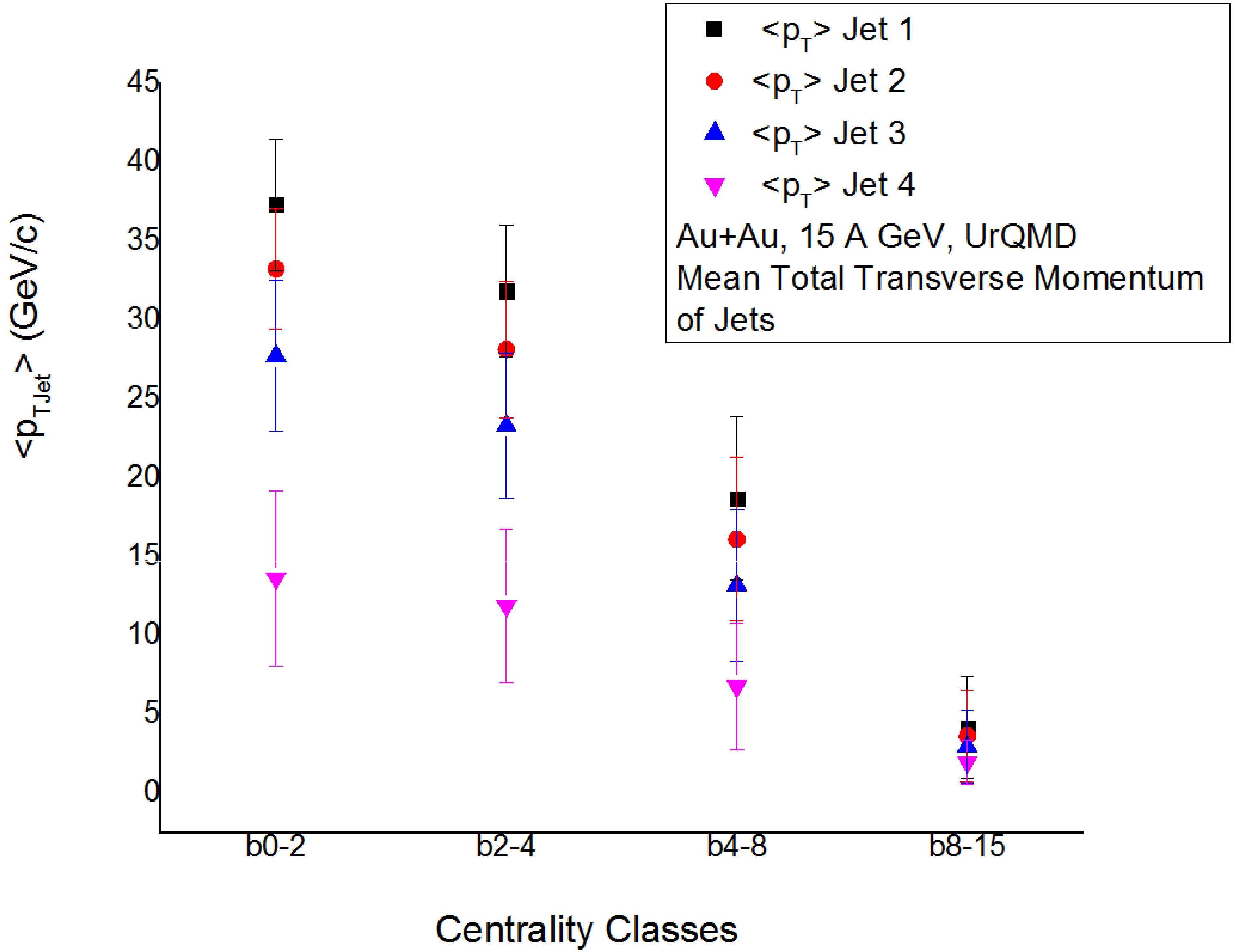
The mean multiplicity of jets also depends on the energy of the projectile.



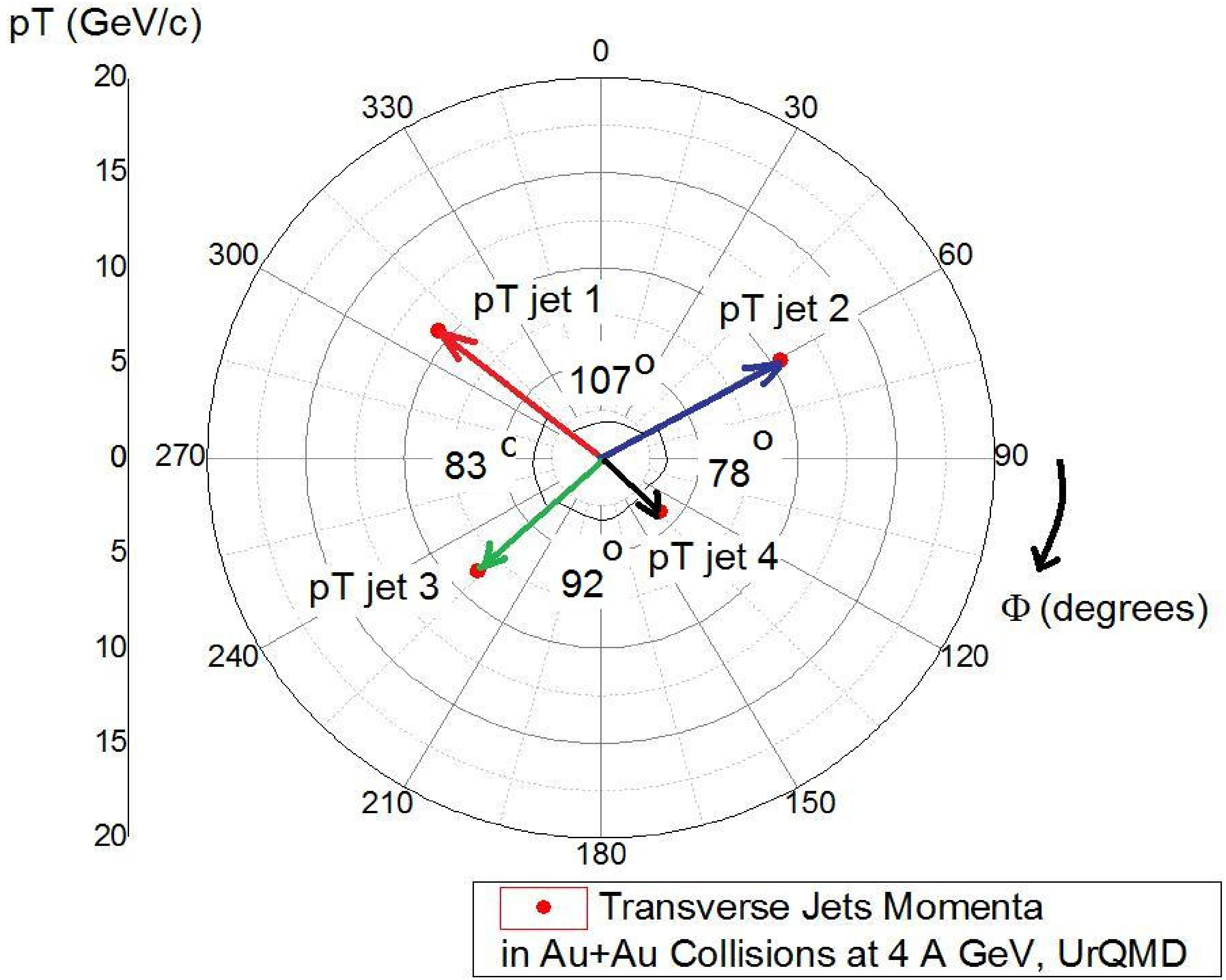
$\langle p_T \rangle$ Jet 1
$\langle p_T \rangle$ Jet 2
$\langle p_T \rangle$ Jet 3
$\langle p_T \rangle$ Jet 4
Au+Au, 4 A GeV
UrQMD
Mean Total Transverse Momentum of Jets
$\langle p_{TJet} \rangle$ (GeV/c)
35
30
25
20
15
10
5
0
b0-2
b2-4
b4-8
b8-15
Centrality Classes



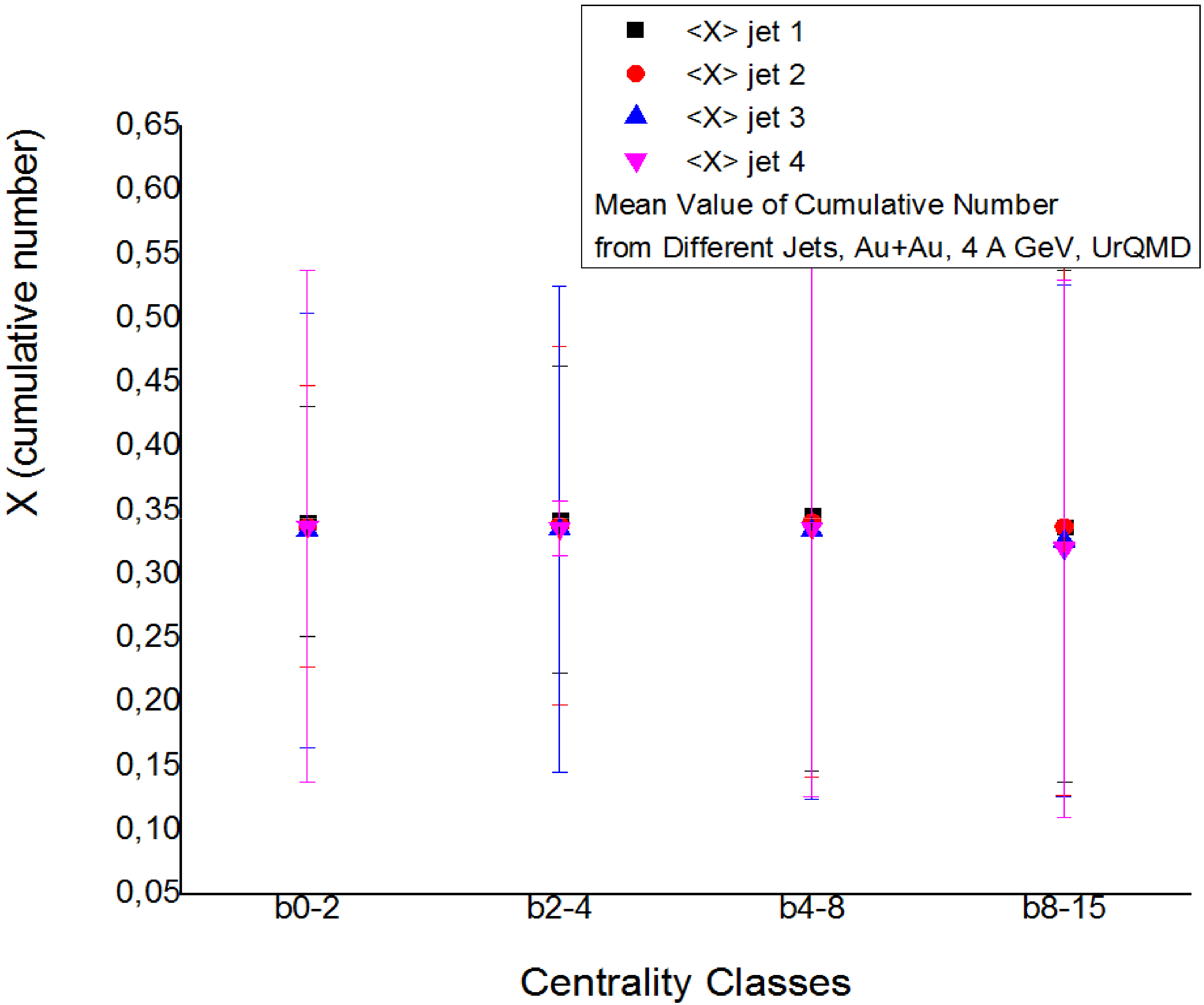
$p_{T\ Jet1}$
$p_{T\ Jet2}$
$p_{T\ Jet3}$
$p_{T\ Jet4}$
Au+Au, 10 A GeV, UrQMD
Mean Total Transverse Momentum
of Jets
$<p_{TJet}>$ (GeV/c
40
35
30
25
20
15
10
5
0
b0-2
b2-4
b4-8
b8-15
Centrality Classes



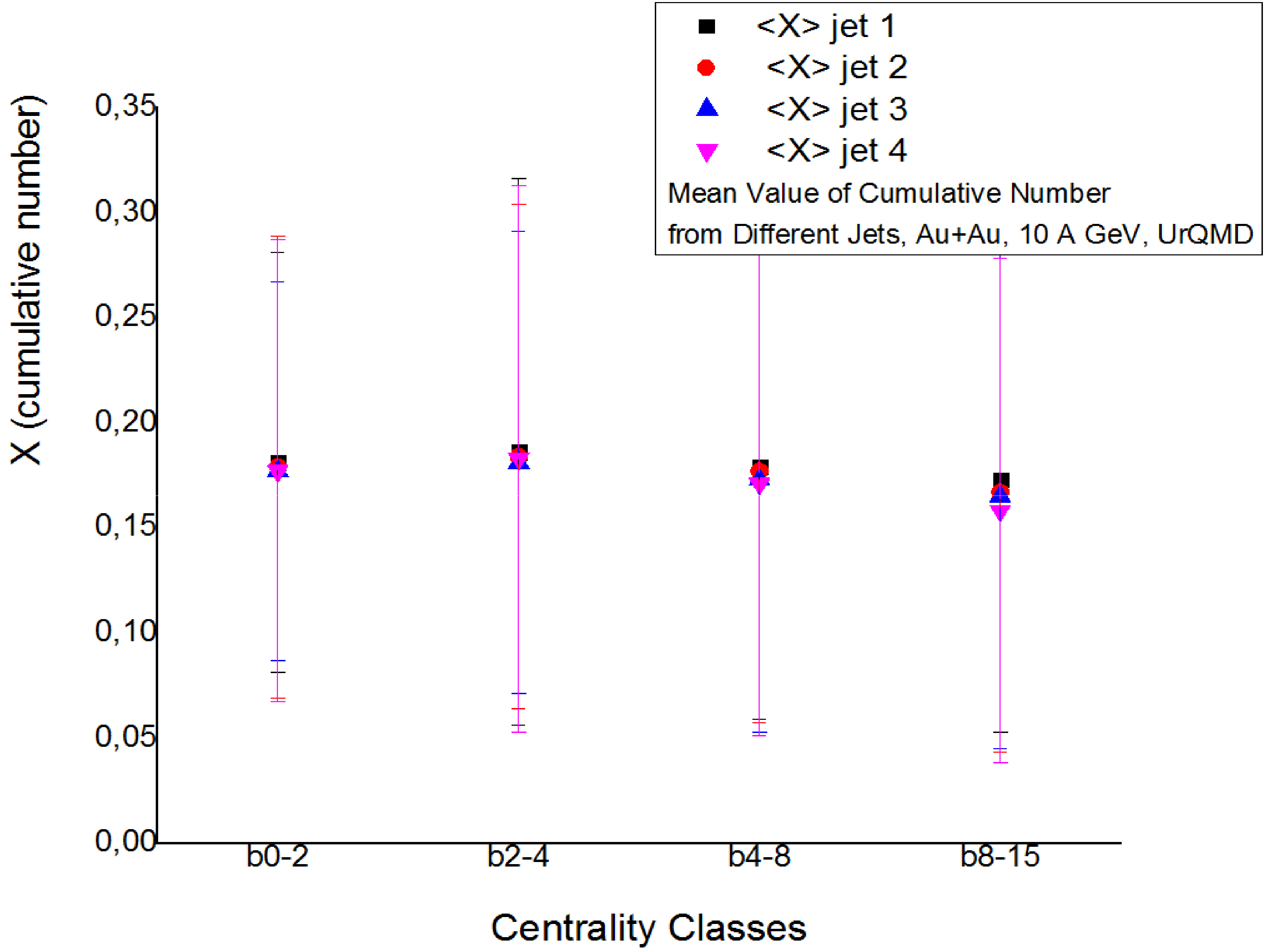
Mean transverse momentum decreases from central to peripheral collisions.
The differences between jet 1 and jet 2, and between jet 2 and jet 4, also decrease when projectile energy increases.



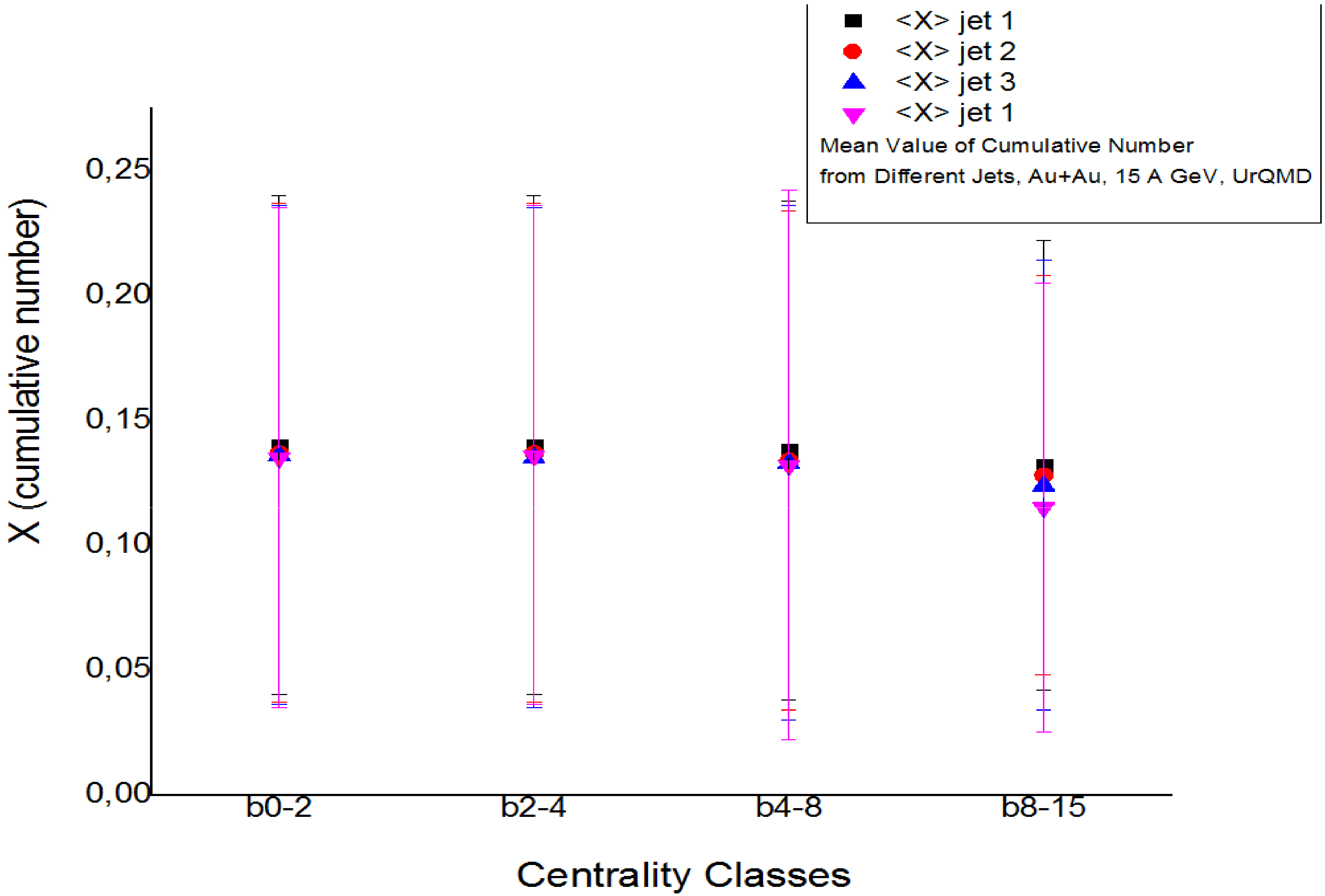
Relative angles between total momenta of jets



<X> jet 1
<X> jet 2
<X> jet 3
<X> jet 4
Mean Value of Cumulative Number
from Different Jets, Au+Au, 4 A GeV, UrQMD
X (cumulative number)
0,65
0,60
0,55
0,50
0,45
0,40
0,35
0,30
0,25
0,20
0,15
0,10
0,05
b0-2
b2-4
b4-8
b8-15
Centrality Classes



<X> jet 1
<X> jet 2
<X> jet 3
<X> jet 4
Mean Value of Cumulative Number
from Different Jets, Au+Au, 10 A GeV, UrQMD
X (cumulative number)
0,35
0,30
0,25
0,20
0,15
0,10
0,05
0,00
b0-2
b2-4
b4-8
b8-15
Centrality Classes



The mean cumulative number do not depends on centrality, but decreases with the projectile energy.

Conclusions

- Jetology, in this domain of energies can help flow studies, offering us visual patterns of the anisothropy of transverse flow, discriminating between different tipes of flow and offering us information about the dense QGP at the CBM energies. The multiplicity of the jets and the total transverse momentum depends on energy and on centrality of the collision.
- Cumulativity studies may provide a quantitative image about the mixed phase which precedes a phase transition in conditions of high baryonic density. In UrQMD simulations we observed that each jet has the same mean cumulative number for all impact parameters, and this number decreases when energy increases.

Eu N
P C

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THANK YOU!