Thermal pressure in heavy-ions collisions around Fermi energy "Exploration of the phase diagram of nucleus"

Eric Bonnet (GANIL)

ESnT Workshop

Fluctuations and Temporal Evolution in Heavy-Ion Collisions

9-10 of May, 2012

Guidelines

- In this work, the exploration of the phase diagram of nucleus is addressed with the Heavy Ion Collisions (HIC) as exploration tools.
- Assuming that different production modes imply different trajectories in phase diagram, one can ask for the possible link between properties of multifragmenting source and the region where it undergoes to multifragmentation.
- Comparison between sources produced in peripheral and central collisions will be presented. I will show you that the fragmentation degree of multifragmenting sources is directly link to the amount of expansion energy during the multifragmentation process. In the same time, we find a coherent picture of more expansion energy, larger volume at Freeze-Out time.
- From these results we can define the region of (V-E*) phase diagram where sources undergo to multifragmentation for each initial conditions we have considered.
- In parallel, applying E* and V constraints bring out general properties of multifragmenting sources and specially that the charge partitions of multifragmentation events are totally determined by these two ingredients.

Transition: from one phase to another

Object of study:
Nucleus

T=0,
$\rho = \rho_0$

Tool:
Heavy Ion
Collisions

Liquid Phase

Evaporation

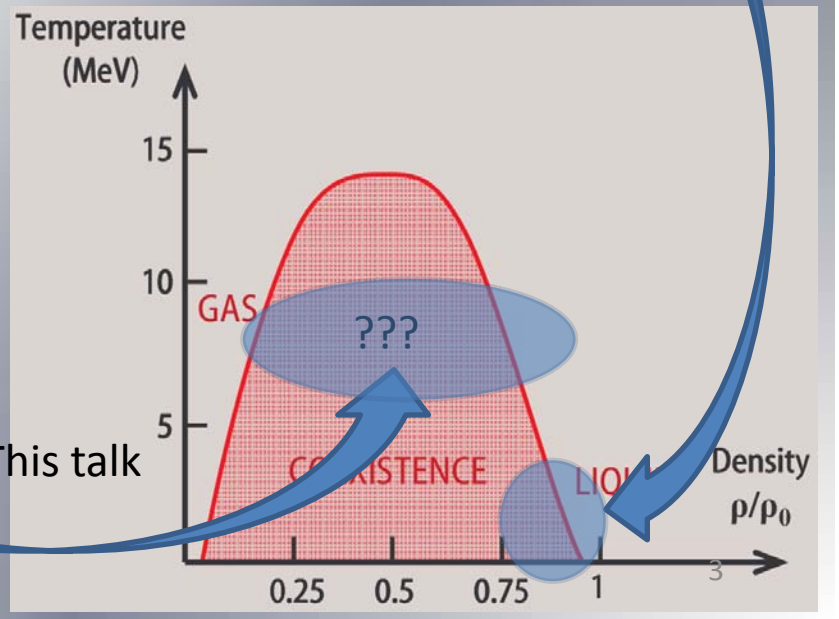
Fission

Gas Phase

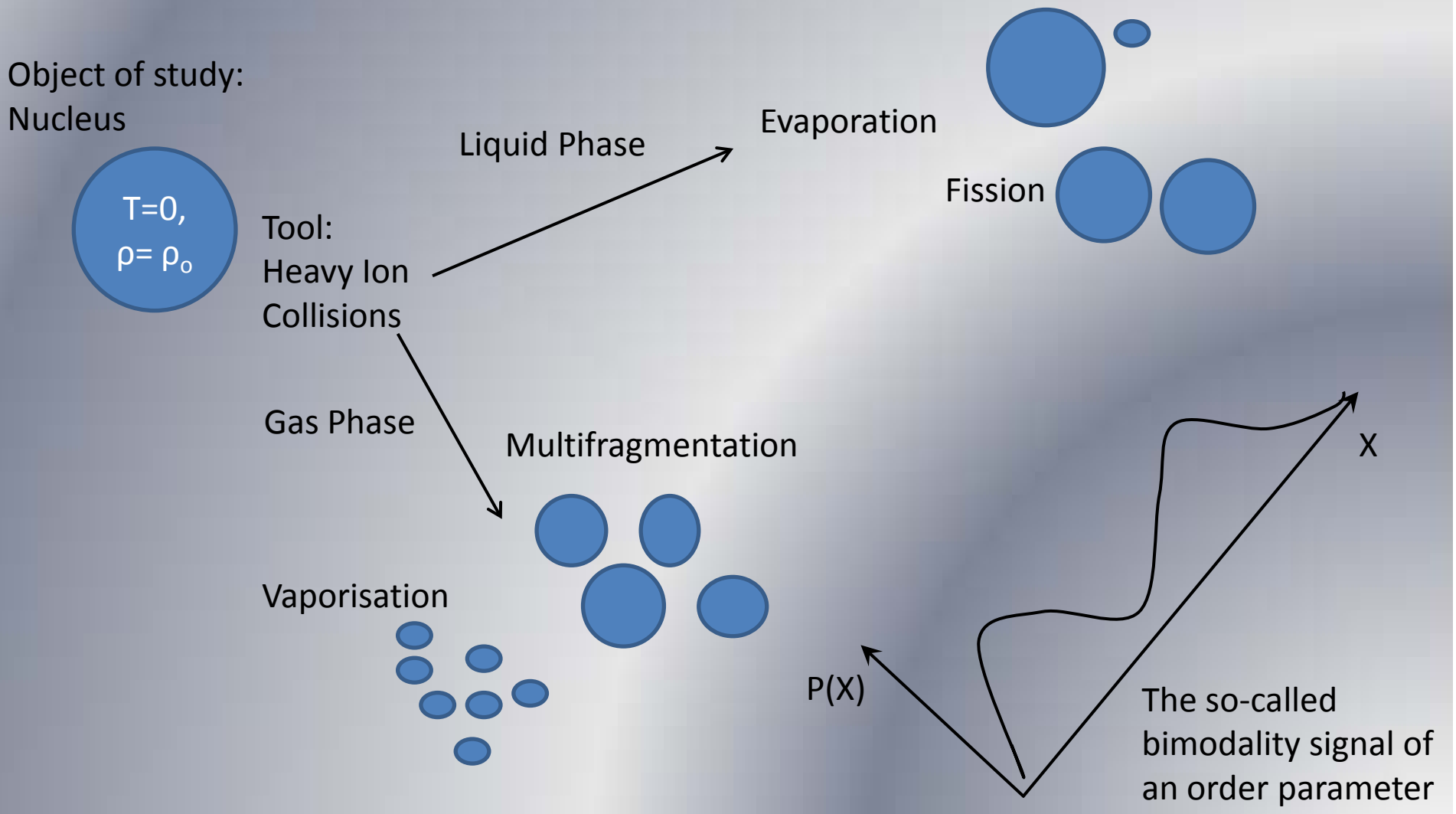
Multifragmentation

Vaporisation

This talk



Transition: from one phase to another



Transition: from one phase to another

- Phase transition occurring in nuclei is a thermal transition.
- Latent heat is estimated as

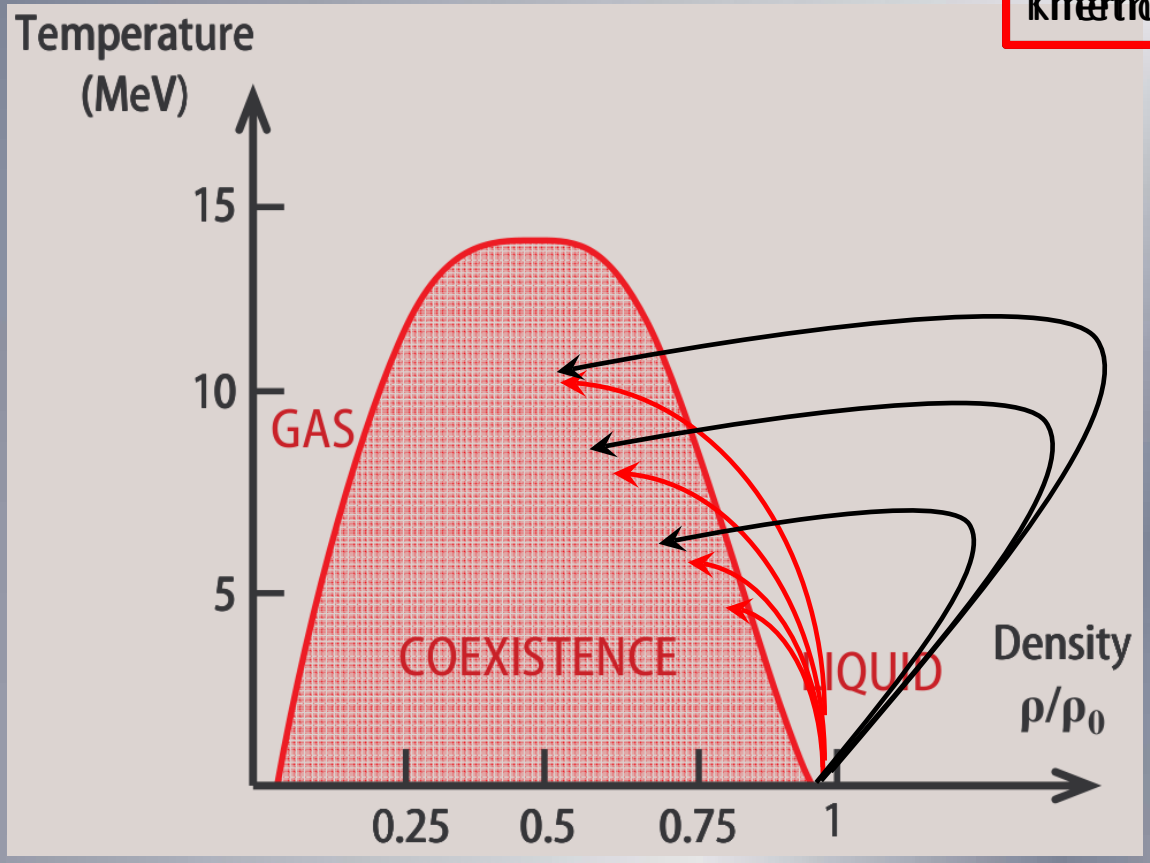
$$\Delta E(MeV.A) = E_g - E_l = 8.1\ (\pm 0.4)_{stat}\ (+1.2 - 0.9)_{syst}$$

- As in VdW fluid, the temperature (T) and density (ρ) are key parameters to define the phases.
- For that reason, we want to make the link between these quantities and observables of multifragmenting sources considered as the realization of the gas phase of the phase transition.

Heavy Ion Collision tool

Prepare nuclei with different initial conditions using:

- Bombarding energy
- Impact parameter (a posteriori)



Central collisions: total overlap

Initial bombarding energy

Thermal pressure drives the expansion

Peripheral collisions: partial overlap

Projectile and target

Different compression energy

Different “evaporator” region

Production modes

↓

Different trajectories

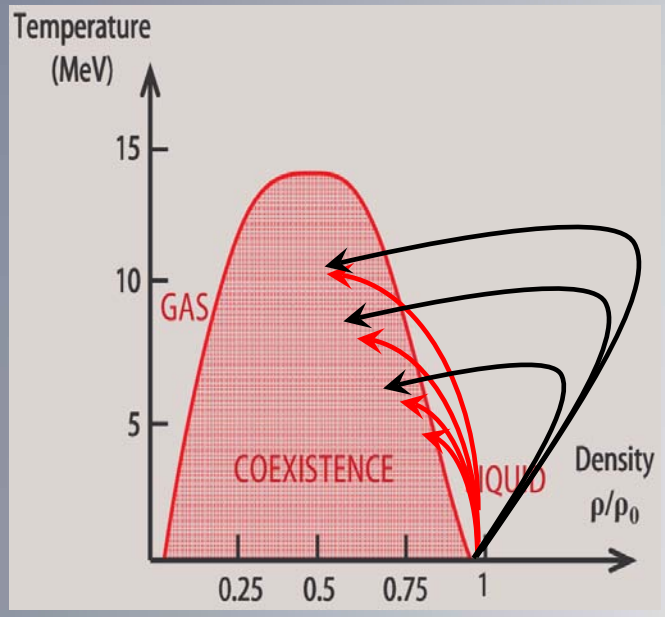
↓

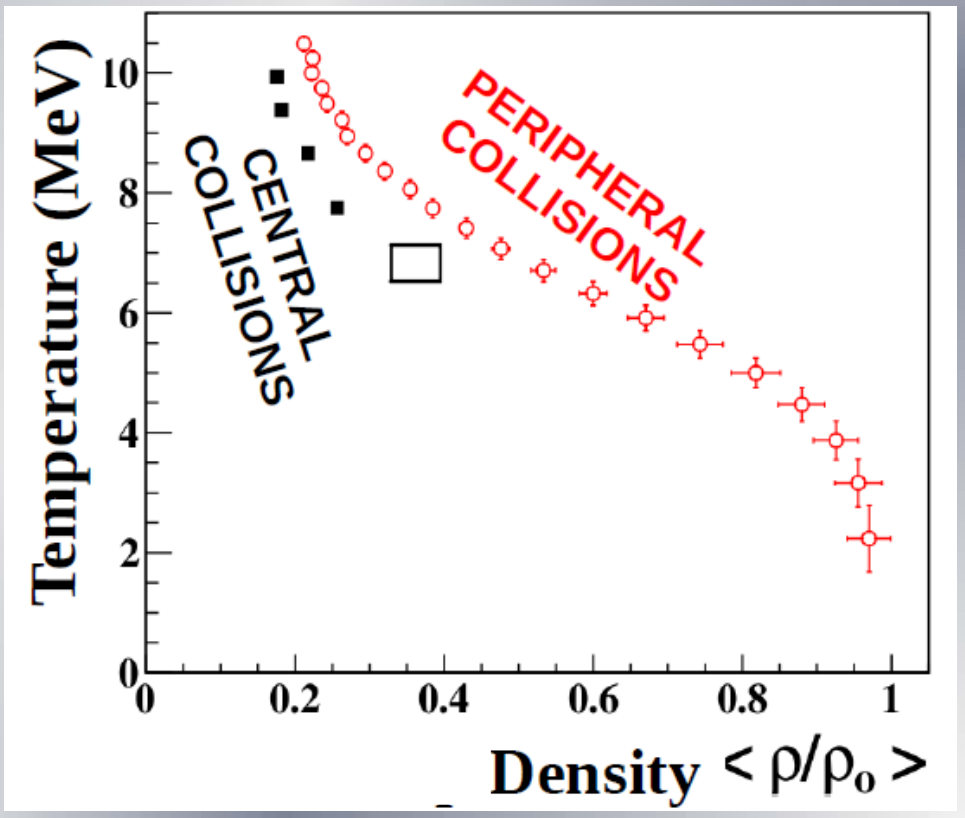
Different Regions explored

Heavy Ion Collision tool

Central Collisions → « Quasi Fusion » events
GANIL, Xe+Sn → QF* (E_{Xe} = 25, 32, 39, 45, 50 MeV/A)

Peripheral Collisions → « Quasi Projectile » events
GSI, Au+Au → QP* + QC* (E_{Au} = 80, 100 MeV/A)





Heavy Ion Collision tool

After collecting the data, selection of the production modes

Starting from set of (INDRA) detected events

{Z, E, <θ>, <ϕ>} i = 1, charged products multiplicity

Event by event analysis, selection of the interesting events, reconstruction of the story

Charge (Size) observables:

how the total initial charge is shared among final products

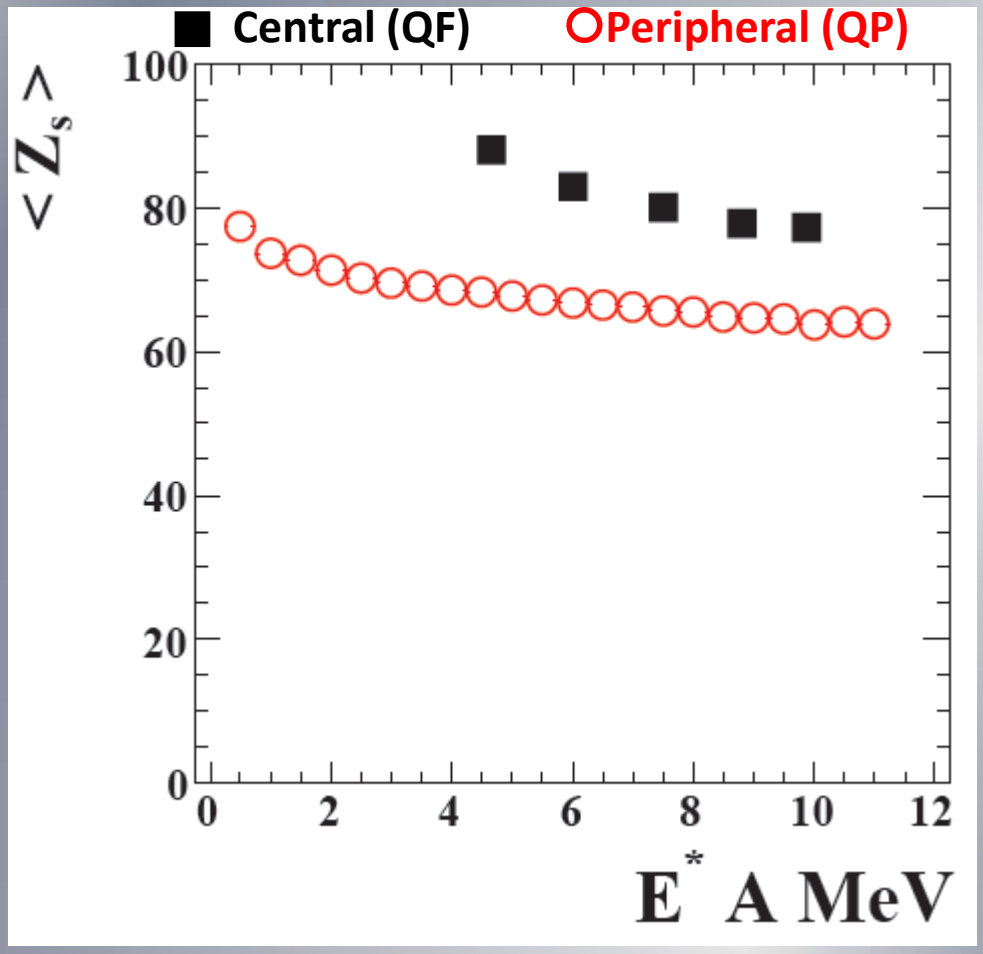
Kinematic observables:

topology of events in velocity/momentum space

Energy observables:

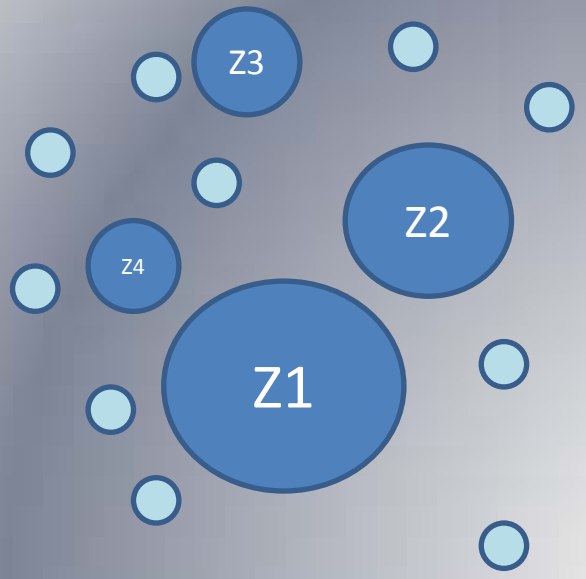
related to total energy deposited in the hot primary sources

Expansion energy, fragmentation degree and volume in a coherent picture



Overlap of two set of events in the excitation energy (E*) range [4 ; 10] MeV/A

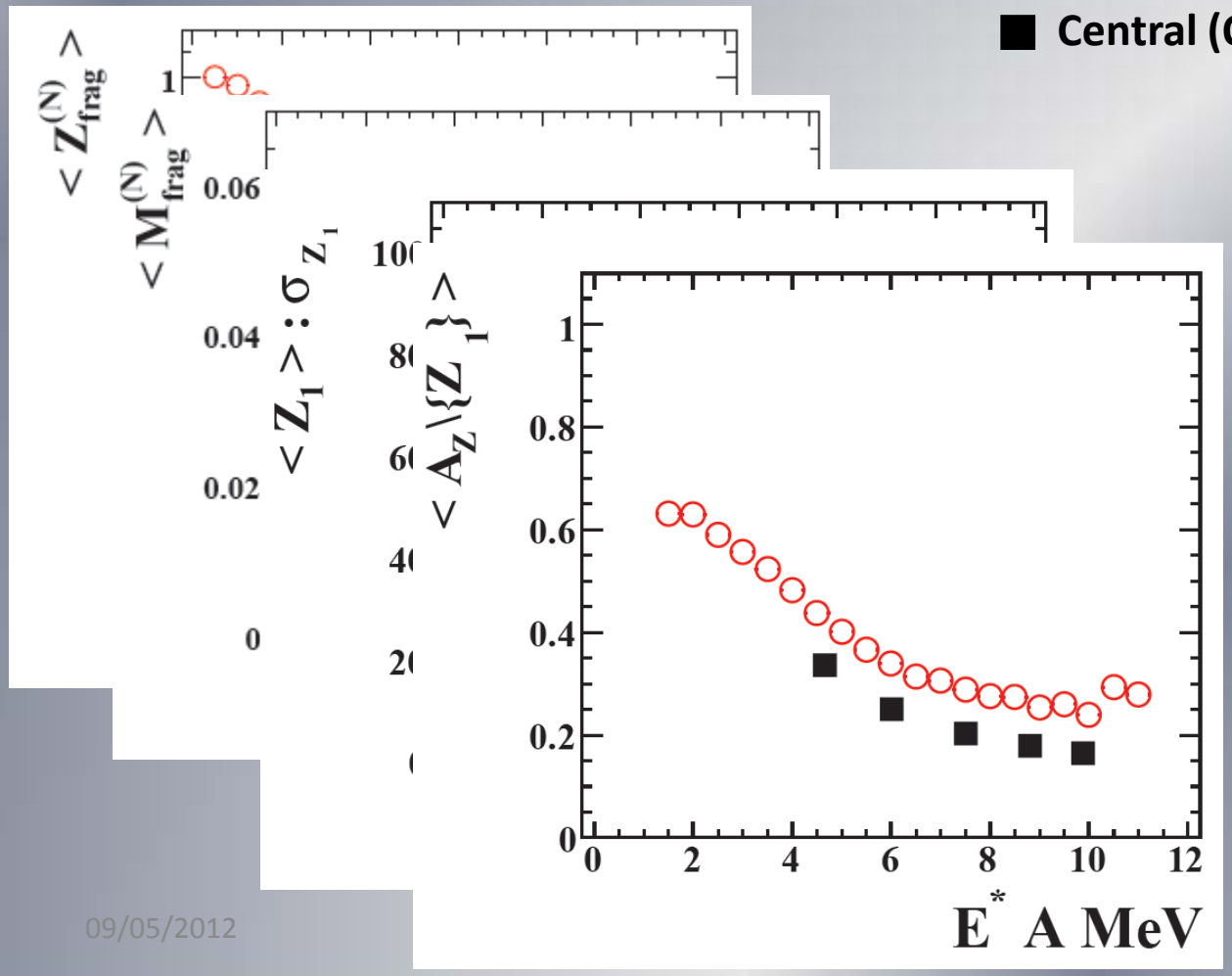
Multifragmenting source size (Zs) is in the range [70;90]



Expansion energy, fragmentation degree and volume in a coherent picture

Looking at charge partition of fragments

■ Central (QF) ○Peripheral (QP)



Expansion energy, fragmentation degree and volume in a coherent picture

Looking at charge partition of fragments

Similar total charge bound in fragments
More fragments produced in the central case

Charge of the biggest fragment of each event:
- Similar values
- Fluctuations larger for peripheral case

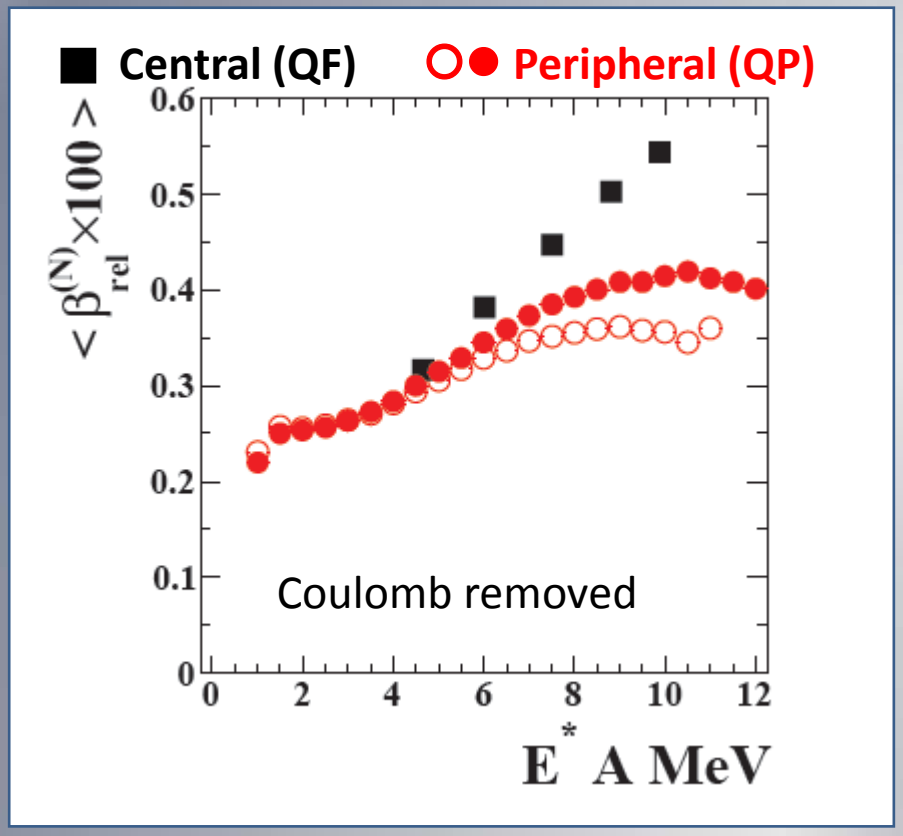
More symmetric partitions for central case

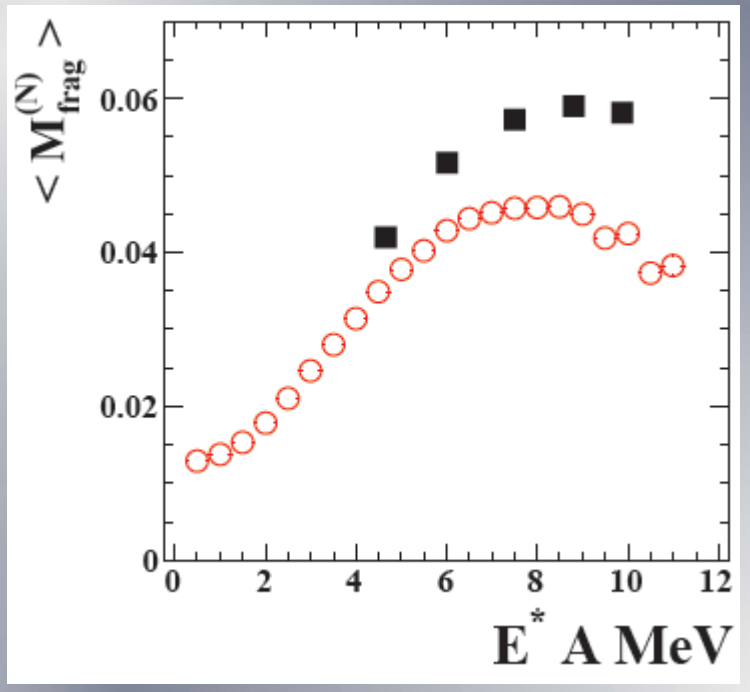
Expansion energy, fragmentation degree and volume in a coherent picture

Go back to multifragmentating sources
at Freeze-Out time

$\langle E_R \rangle = f(\langle \beta^{(N)}_{rel} \rangle)$

$\langle V/Vo \rangle = f(\langle M^{(N)}_{frag} \rangle)$





Expansion energy, fragmentation degree and volume in a coherent picture

Go back to multifragmentating sources
at Freeze-Out time

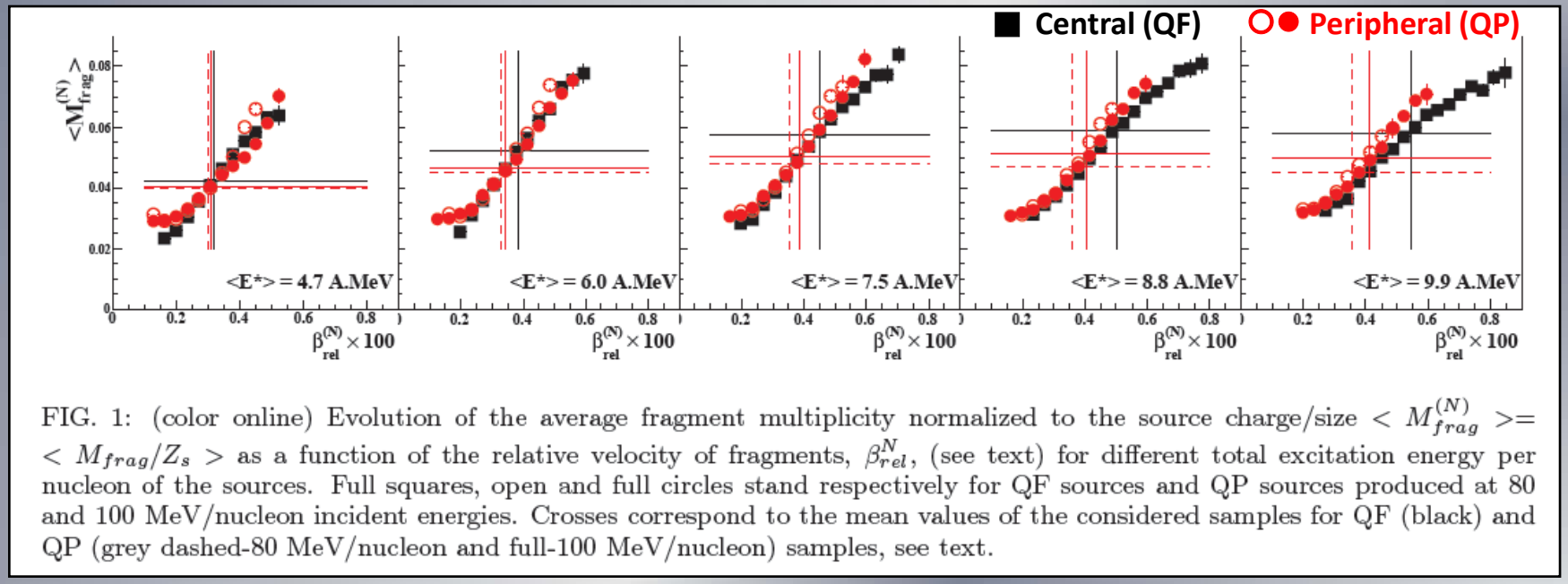


FIG. 1: (color online) Evolution of the average fragment multiplicity normalized to the source charge/size $< M^{(N)}_{frag} >= < M_{frag}/Z_s >$ as a function of the relative velocity of fragments, β^N_{rel}, (see text) for different total excitation energy per nucleon of the sources. Full squares, open and full circles stand respectively for QF sources and QP sources produced at 80 and 100 MeV/nucleon incident energies. Crosses correspond to the mean values of the considered samples for QF (black) and QP (grey dashed-80 MeV/nucleon and full-100 MeV/nucleon) samples, see text.

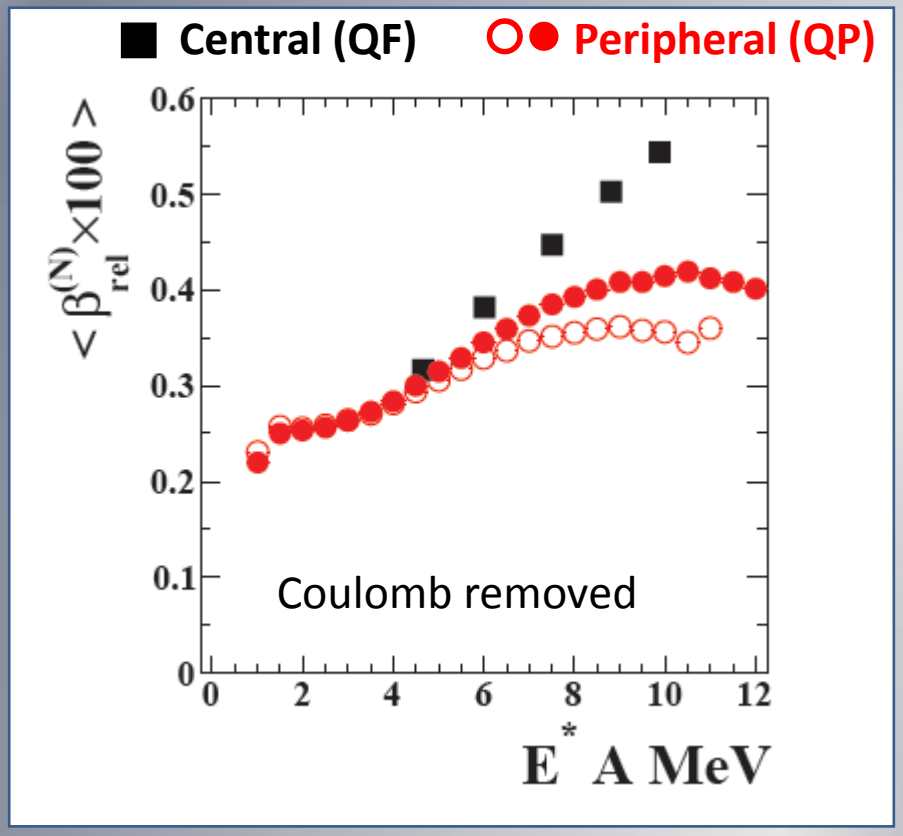
Volume (V/Vo)

Expansion energy (E_R)

Expansion energy, fragmentation degree and volume in a coherent picture

Estimation of the expansion energy

$$\langle E_R \rangle = f(\langle \beta^{(N)}_{rel} \rangle)$$



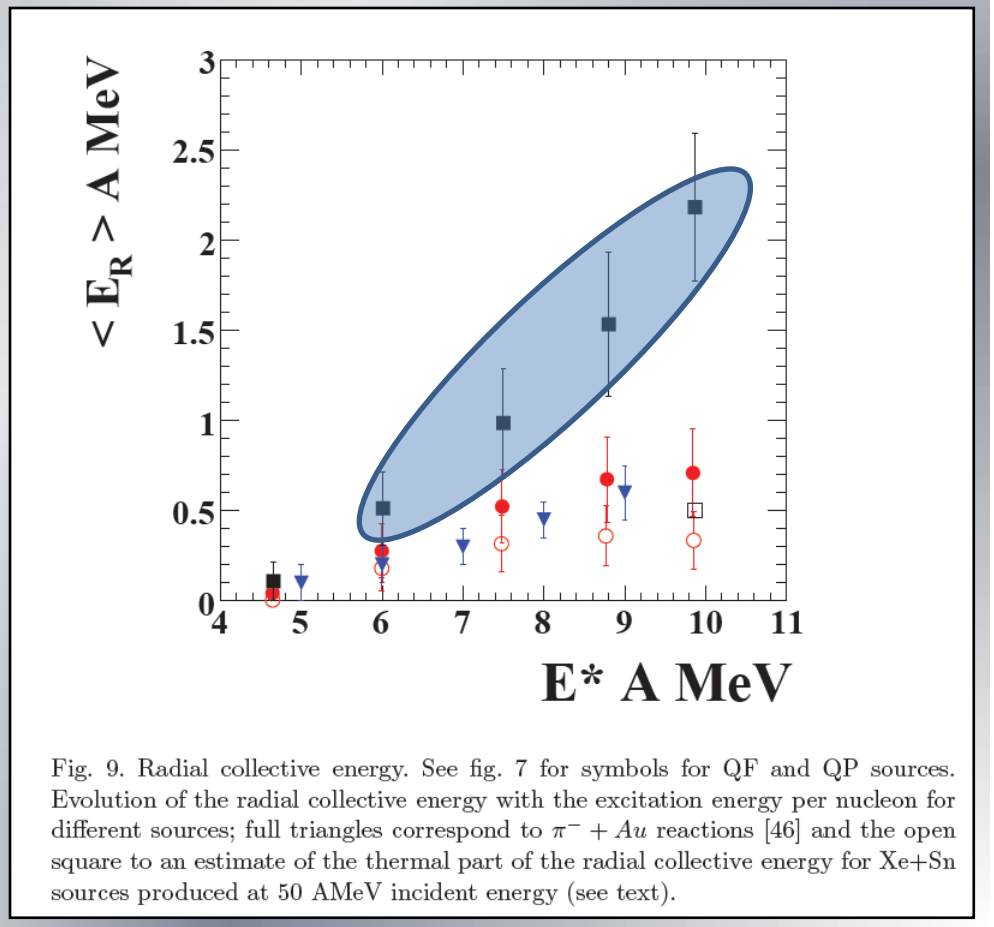
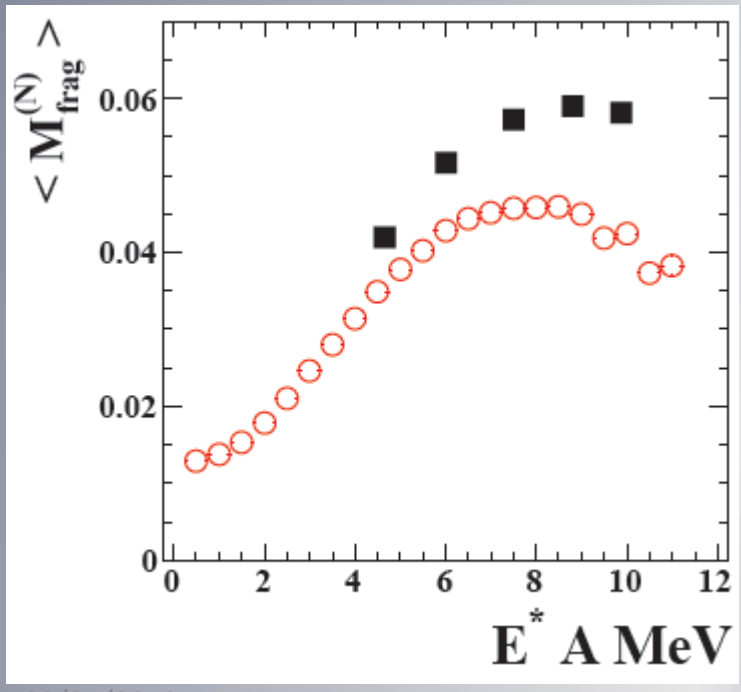


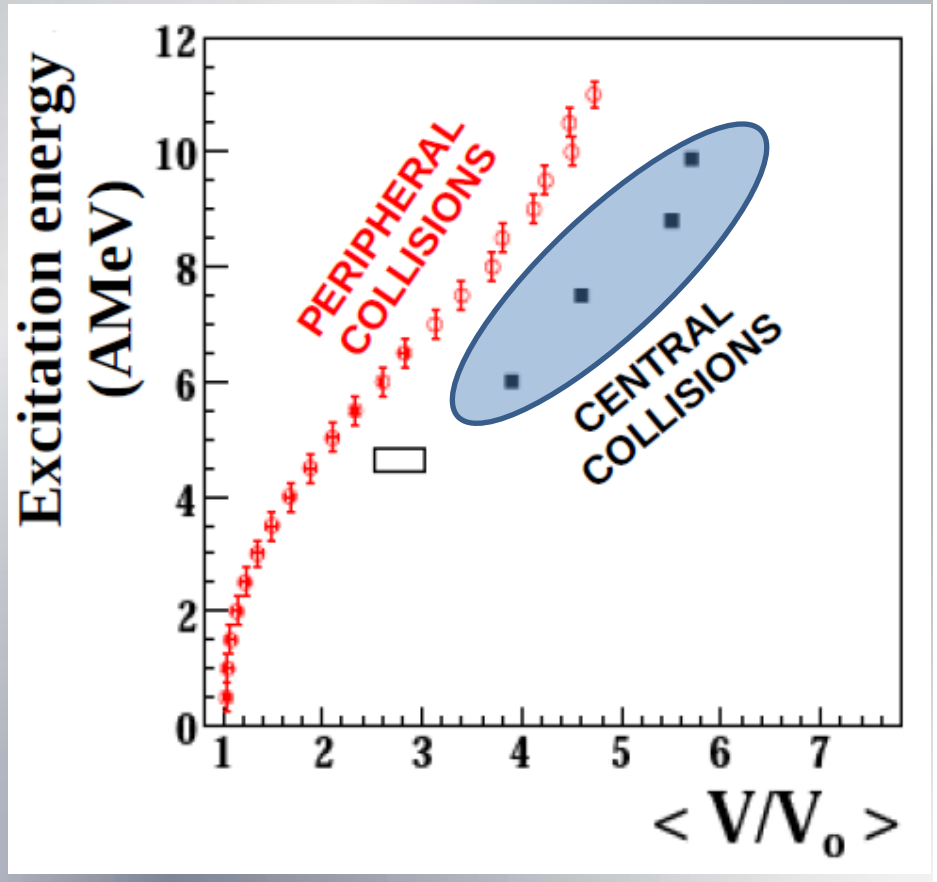
Fig. 9. Radial collective energy. See fig. 7 for symbols for QF and QP sources. Evolution of the radial collective energy with the excitation energy per nucleon for different sources; full triangles correspond to $\pi^- + Au$ reactions [46] and the open square to an estimate of the thermal part of the radial collective energy for Xe+Sn sources produced at 50 AMeV incident energy (see text).

Expansion energy, fragmentation degree and volume in a coherent picture

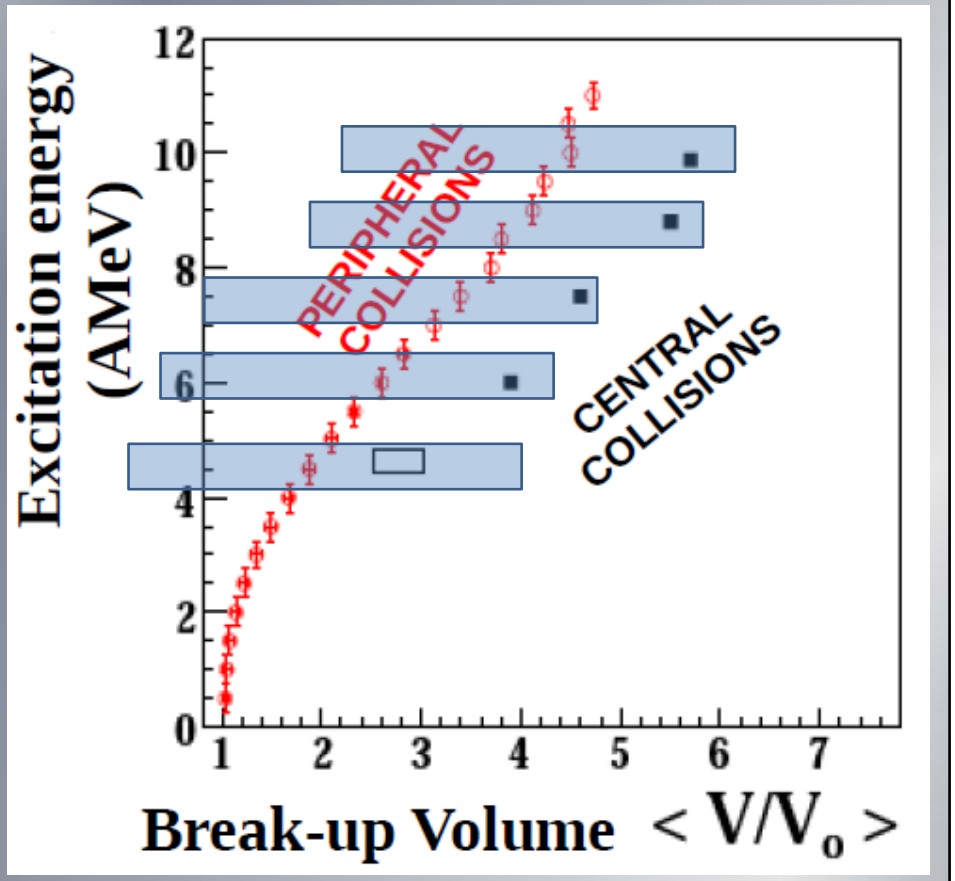
Estimation of the Freeze-Out volume

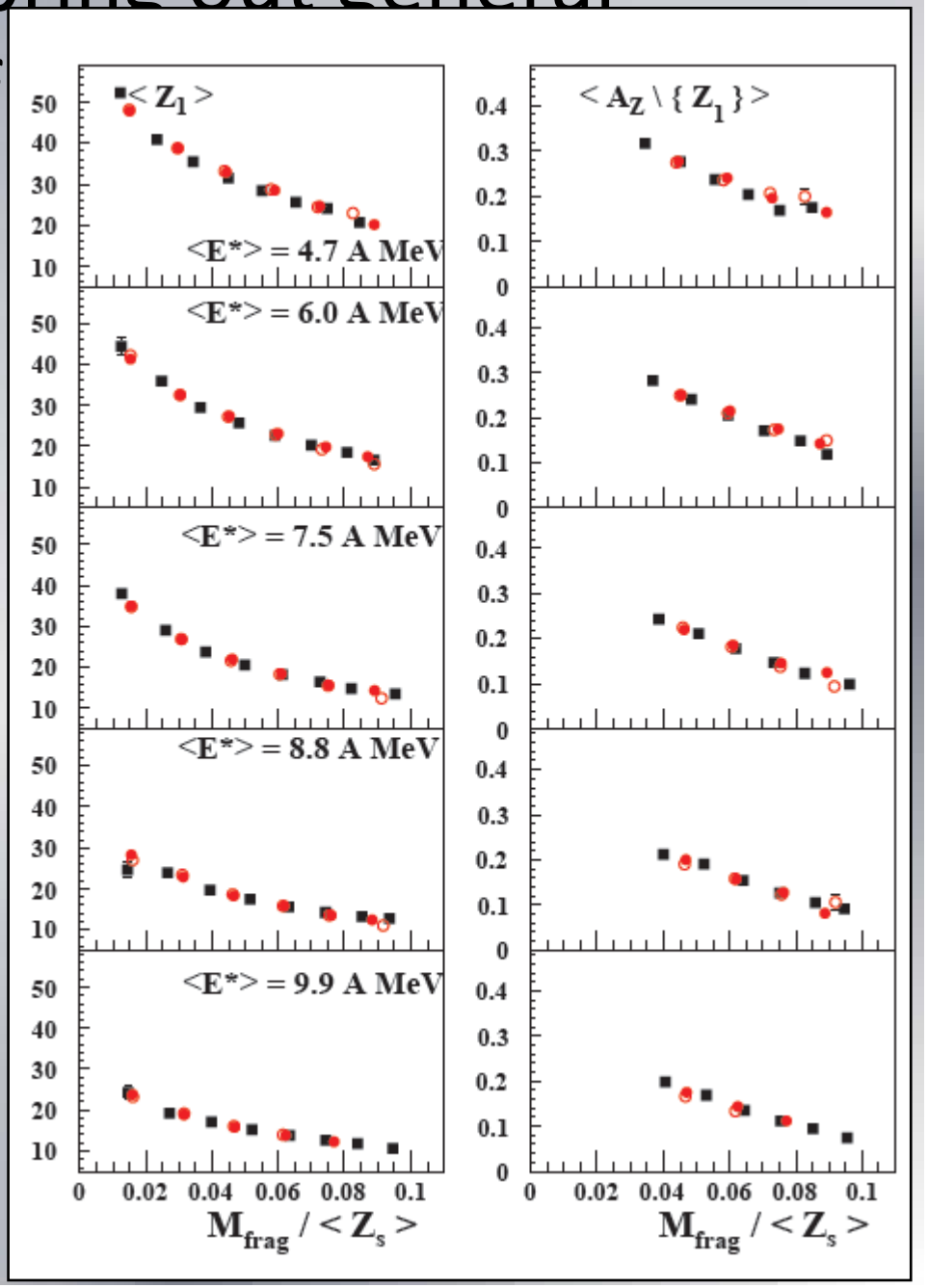
$\langle V/V_o \rangle = f(\langle M^{(N)}_{frag} \rangle)$





(E*- V) constraints bring out general properties of multif





Conclusion

- In this work, the exploration of the phase diagram of nucleus is addressed with the Heavy Ion Collisions (HIC) as exploration tools.
- Assuming that different production modes imply different trajectories in phase diagram, one can ask for the possible link between properties of multifragmenting source and the region where it undergoes to multifragmentation.
- Comparison between sources produced in peripheral and central collisions will be presented. I will show you that the fragmentation degree of multifragmenting sources is directly link to the amount of expansion energy during the multifragmentation process. In the same time, we find a coherent picture of more expansion energy, larger volume at Freeze-Out time.
- From these results we can define the region of (V-E*) phase diagram where sources undergo to multifragmentation for each initial conditions we have considered.
- In parallel, applying E* and V constraints bring out general properties of multifragmenting sources and specially that the charge partitions of multifragmentation events are totally determined by these two ingredients.

References

E. Bonnet et al, PRL 105, 142701 (2010)
E. Bonnet et al, PRL 103, 072701 (2009)
E. Bonnet et al, Nuclear Physics A 816 (2009) 1–18
S. Piantelli et al, Nuclear Physics A 809 (2008) 111–128
S. Piantelli et al, Physics Letters B 627 (2005) 18–25