Particle-Fragment correlations at intermediate energies

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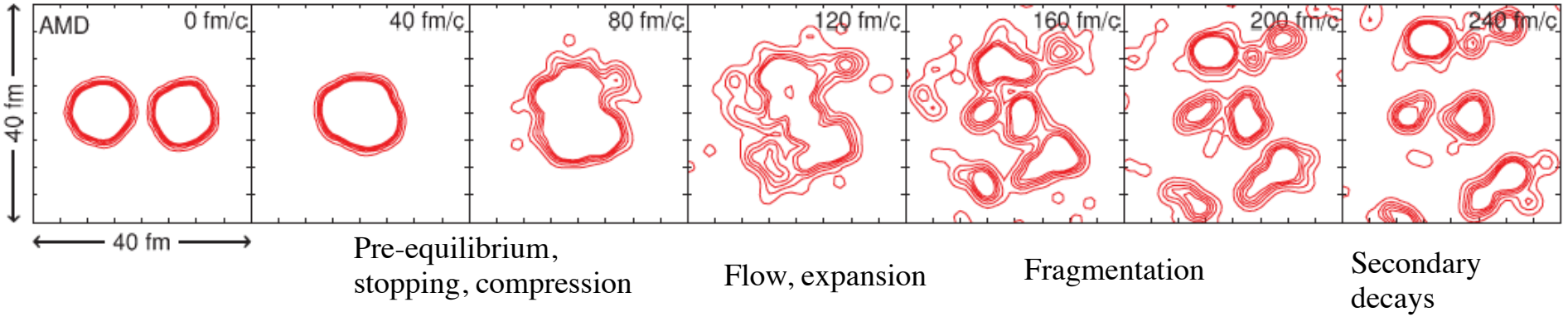
Xe+Sn @ E/A = 8 -150 MeV

Experiments performed @ GANIL and GSI with INDRA

- Introduction:
  - Production of the fragments and light particles
  - Information obtained from Particle-Fragment correlation
- Description of the method
- Results
  - Characteristics of fragment produced in central collisions
  - Estimation of thermal and dynamical contributions
  - Characteristics of the fission fragments and quasi-Projectile
- Conclusions

Time evolution of central collisions at intermediate energies

M. Colonna, A. Ono and J. Rizzo PRC82, 054613 (2010)



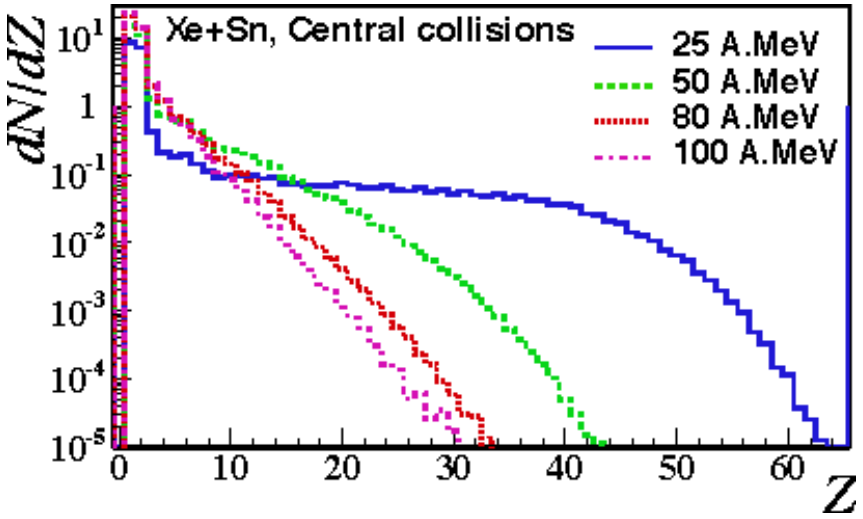
- At least 3 different stages to produce LP
  - Early stage of the collision : Pre-equilibrium emission (pp, γγ)
  - At the same time as the formation of the fragments (120 fm/c)
  - Decay of the excited fragments (IMF-LCP correlations)
- Information : E* and size of the primary fragments

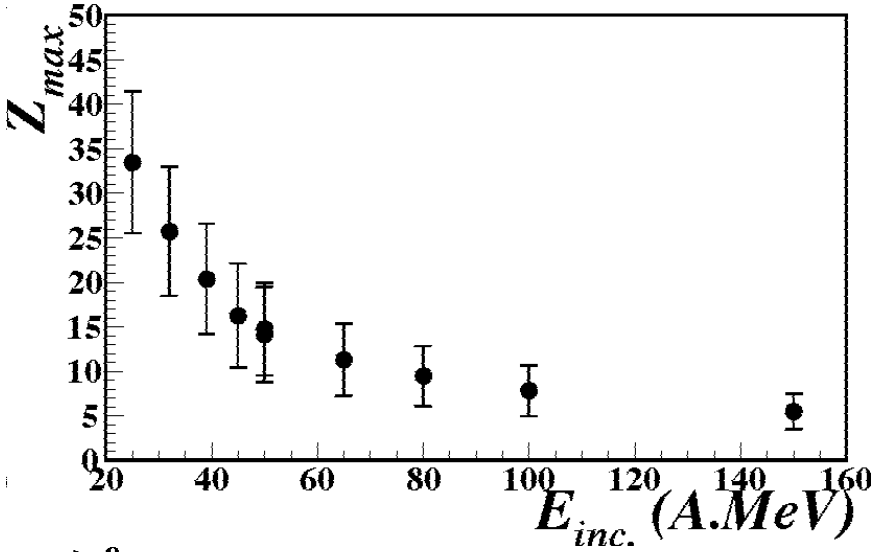
→ contribution of thermal emission,

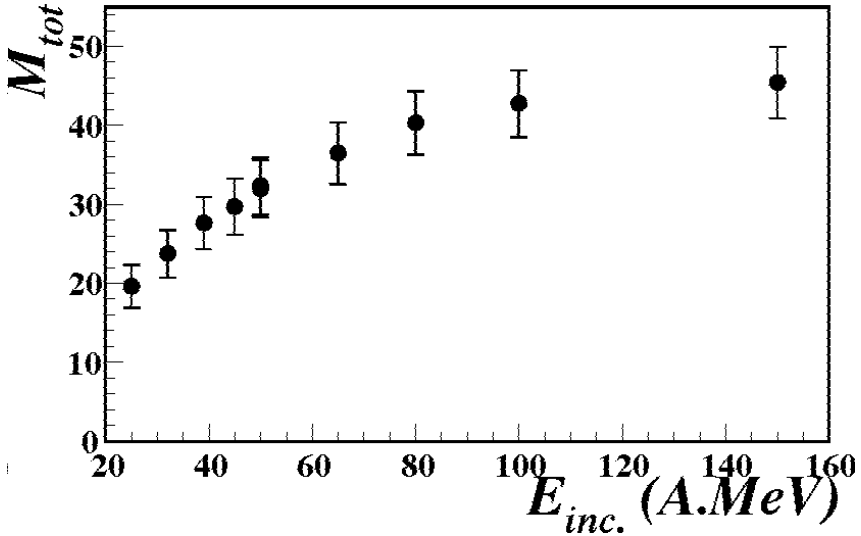
→ maximum excitation that can sustain the fragments, (limiting T),

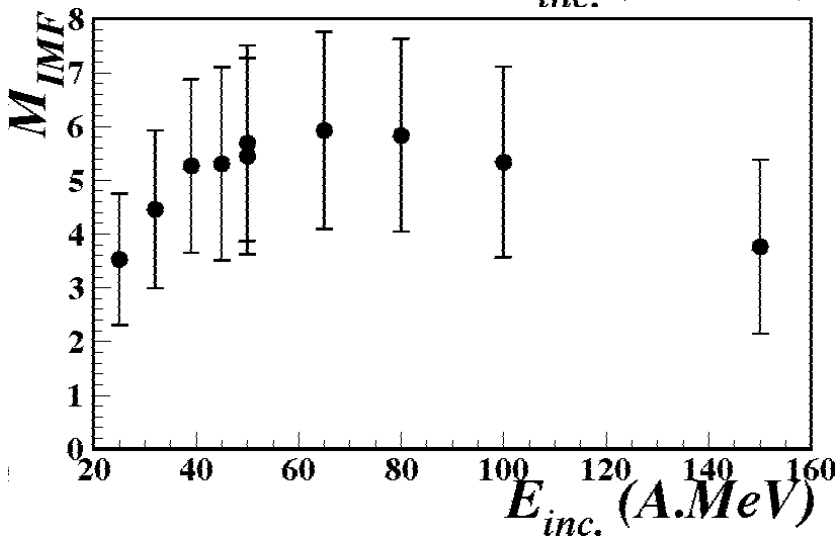
Overview of central collisions

Central collisions of Xe + Sn @ E/A = 25-150 MeV



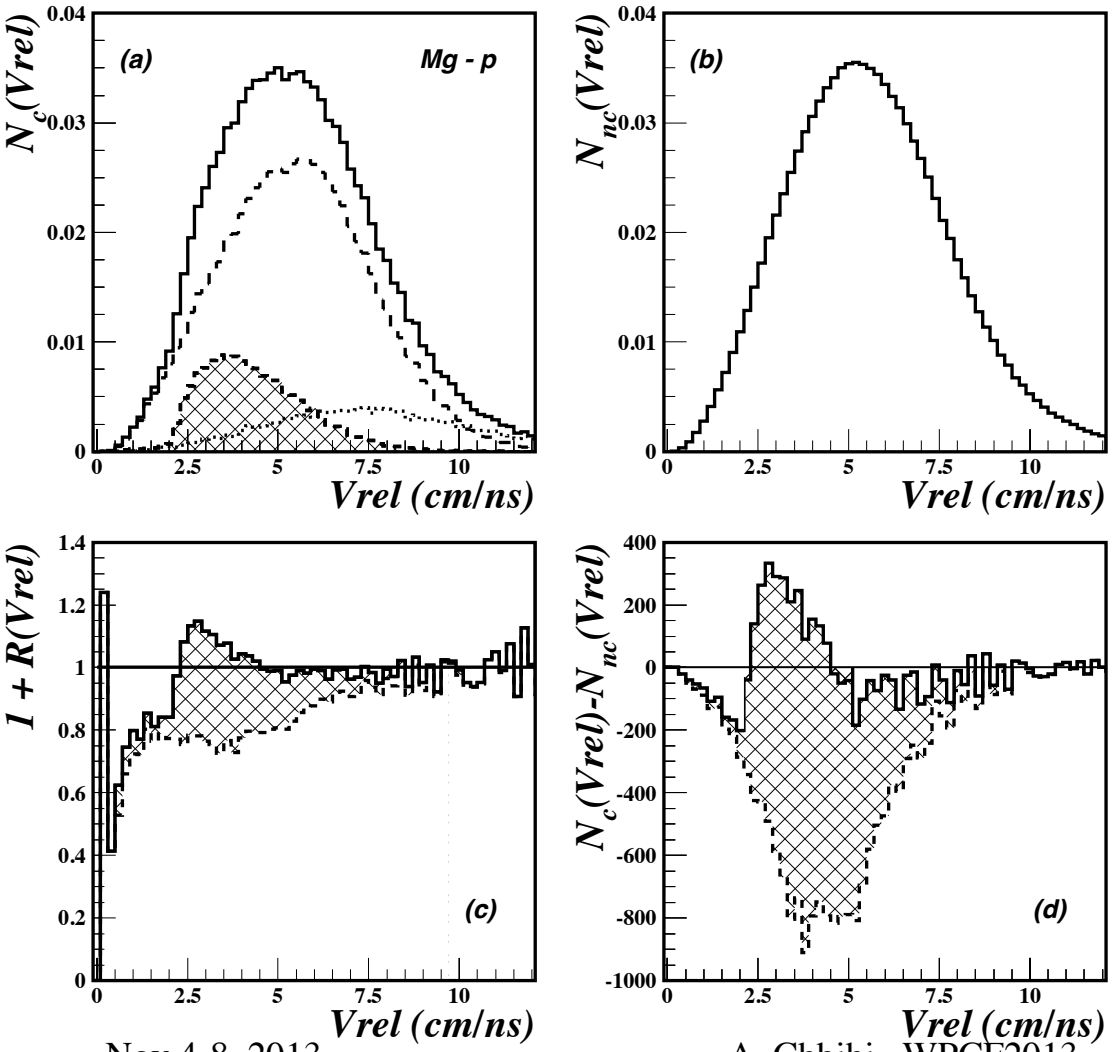






Parameterization of the background

Mg-proton correlation



Simulation with event generator (SIMON D. Durand):

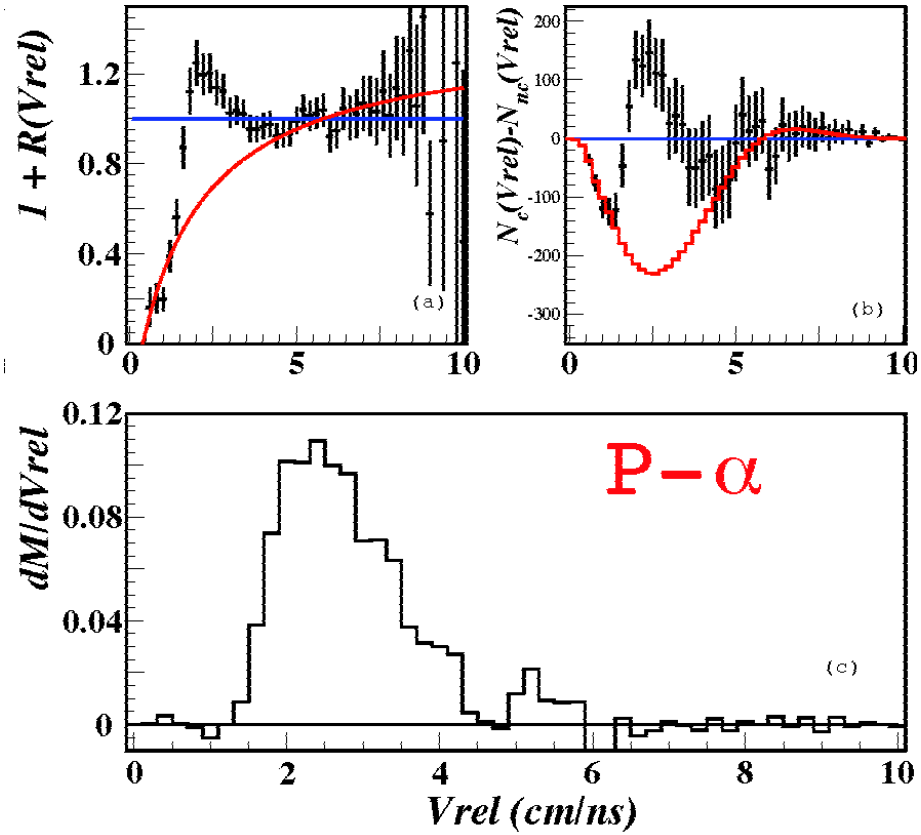
Assumption 3 steps :

1. Initial source Z1, E1* Cooling by LP decay : Pre-equilibrium emission →Z2, E*2
2. Fragmentation of Z2, E*2 shared between 6-7 frag
3. Decay of the excited fragments, moving apart under CB forces + initial radial velocity.

Primary fragment reconstruction method

Xe + Sn @ 32 A MeV
Phosphor – alpha correlation

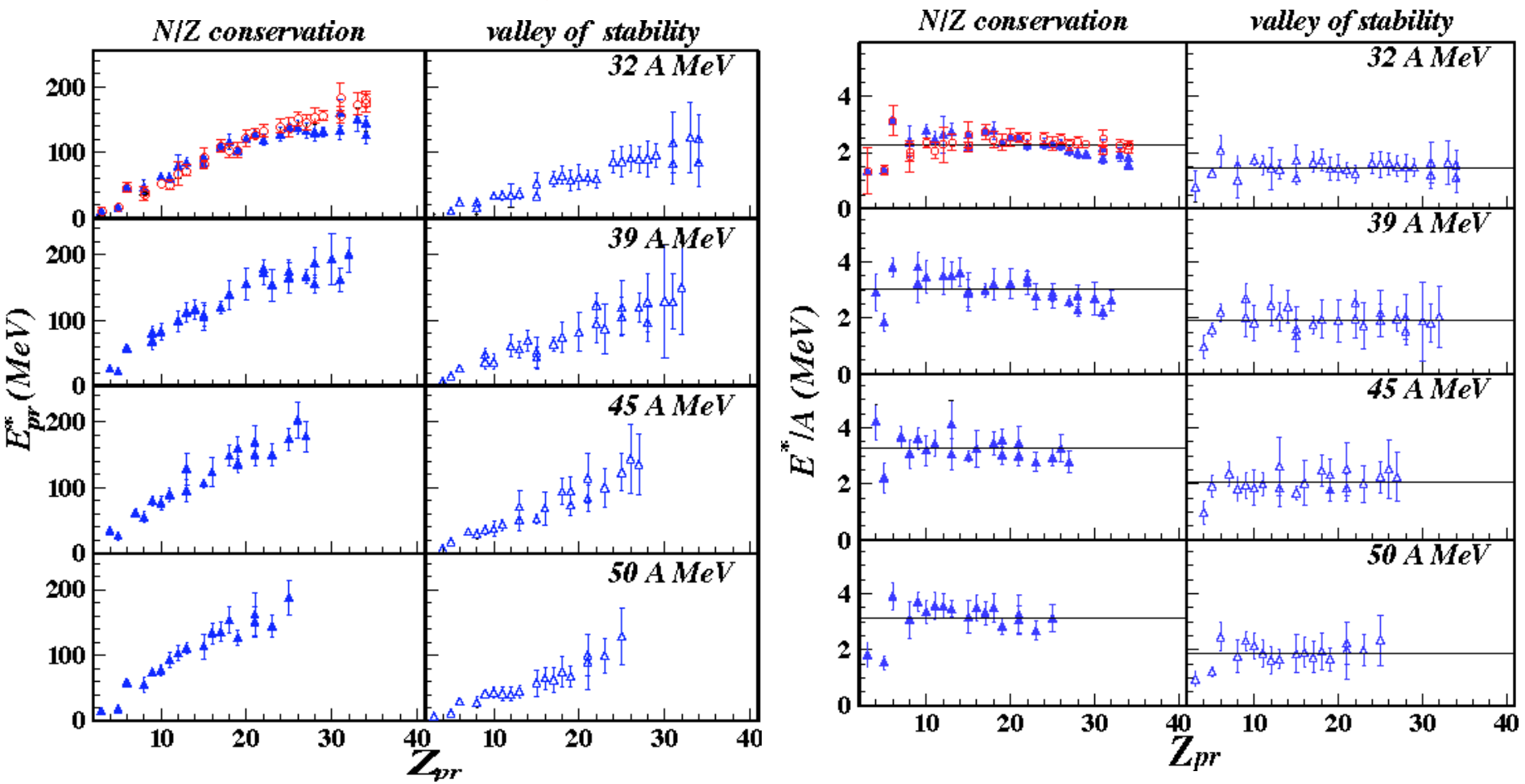
N. Marie et al., PRC 58, 256 (1998)
S. Hudan et al., PhD thesis and PRC67, 064613 (2003)



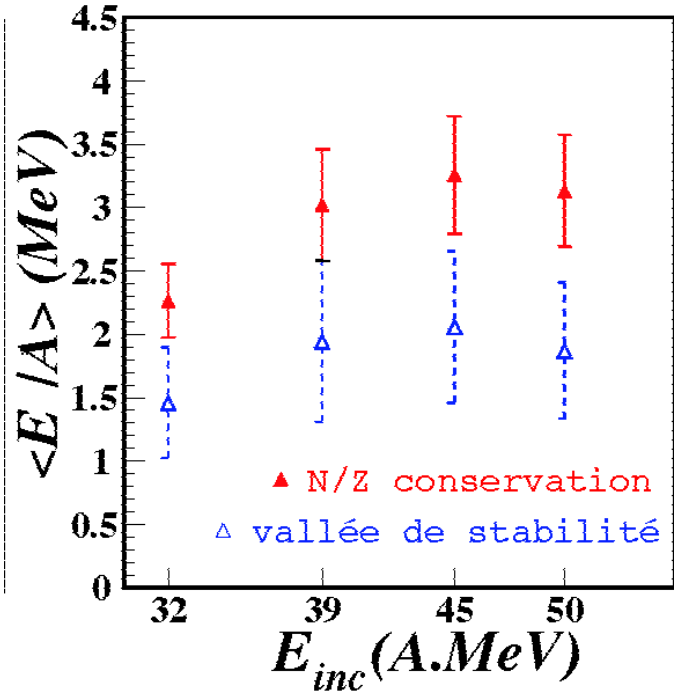
- IMF-LCP V_{rel} Correlations
  $1+R(V_{rel}) = N_c/N_{nc}$
- Background Parameterization
  $A-1/(BV_{rel}+C)$
- Extract the evaporated p, d, t, ^{3}He, α
- Zpr = Zfrag+sum(Mi*zi)
- Apr = Afrag+sum(Mi*ai) + Mn(n/z)sys
- Calorimetry : E*primary
- → Thermal Contribution

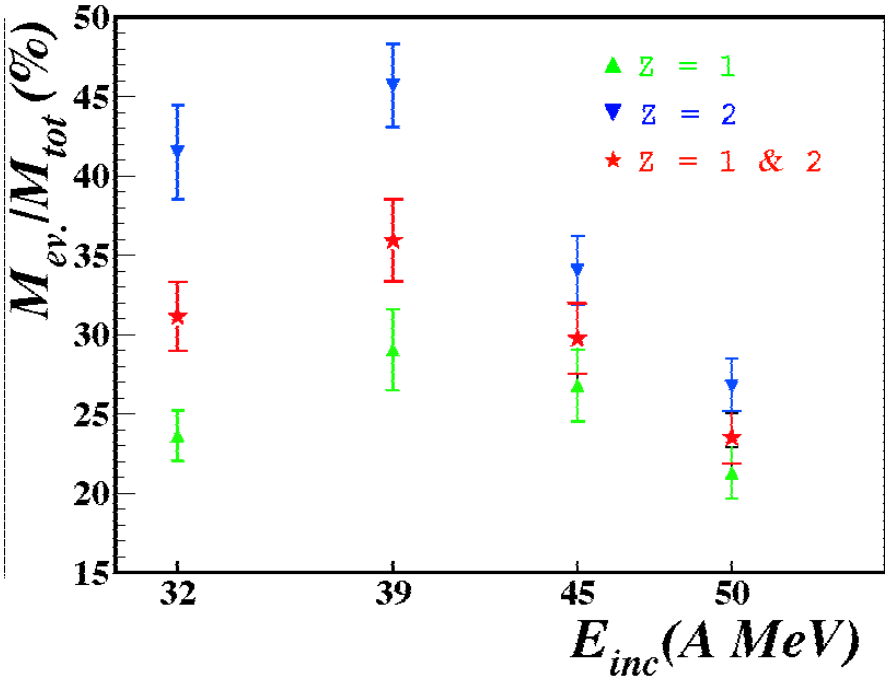
Excitation energy of the primary fragments

Primary fragment mass hypothesis



Proportion of thermal contribution



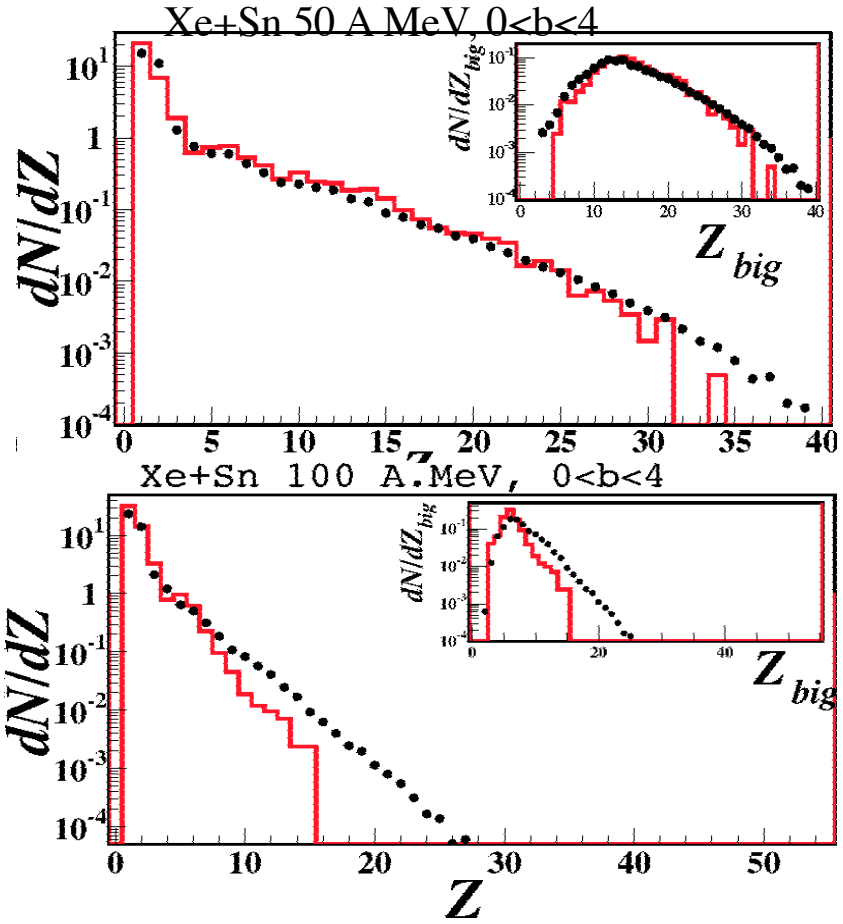


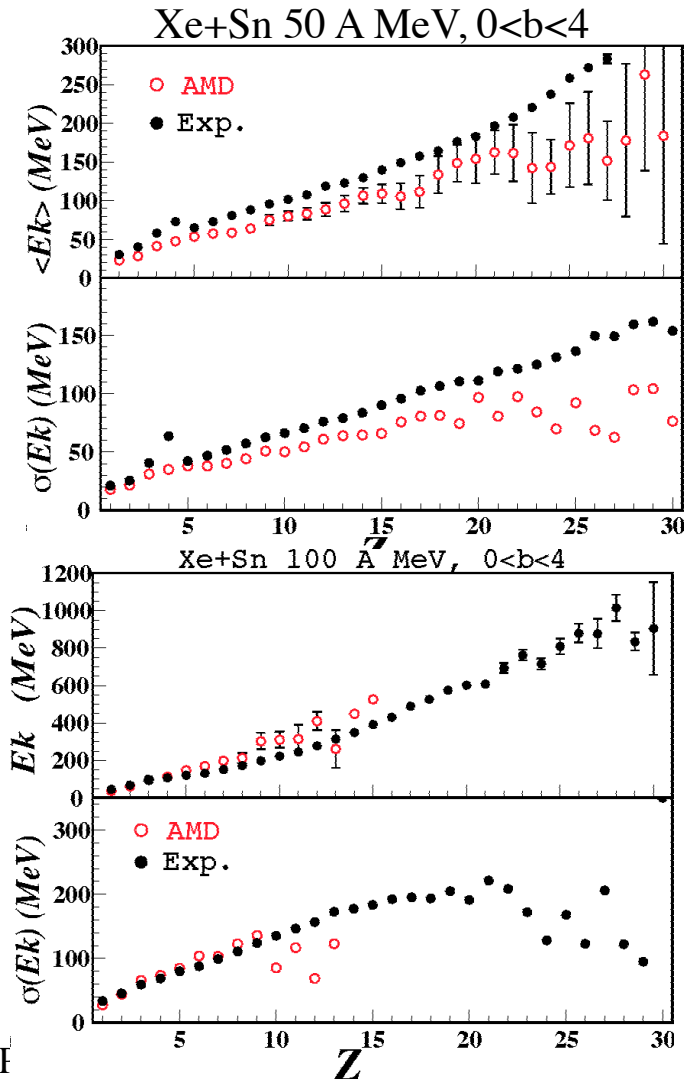
- Excitation energy saturates at 3 AMeV (limiting temperature)
- M_{ev}/M_{tot} fraction reflects <E*/A> of the primary fragments
- The majority of LCP are not evaporated by excited primary fragments. The remaining particles are emitted as pre-equilibrium or/and at the same time than formation of the fragments during the expansion phase (at the freezeout)

Data-AMD Comparison

S. Hudan PRC66, 014603 (2002)

Charge distribution for Xe + Sn at 50 and 100 A MeV





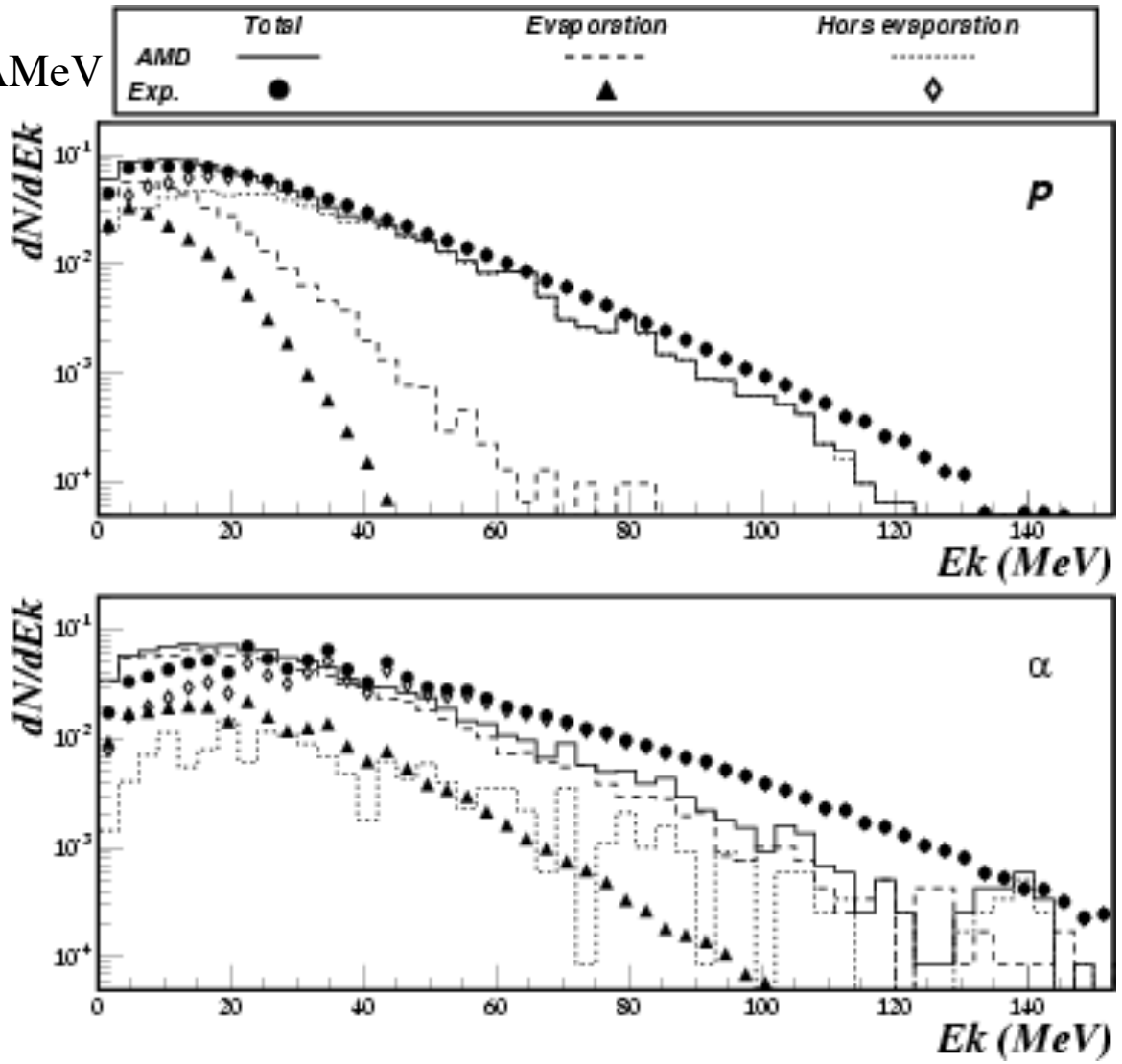
Reasonable agreement in the limit of the number of simulated events

(a huge cpu time)

Comparison to dynamical calculations

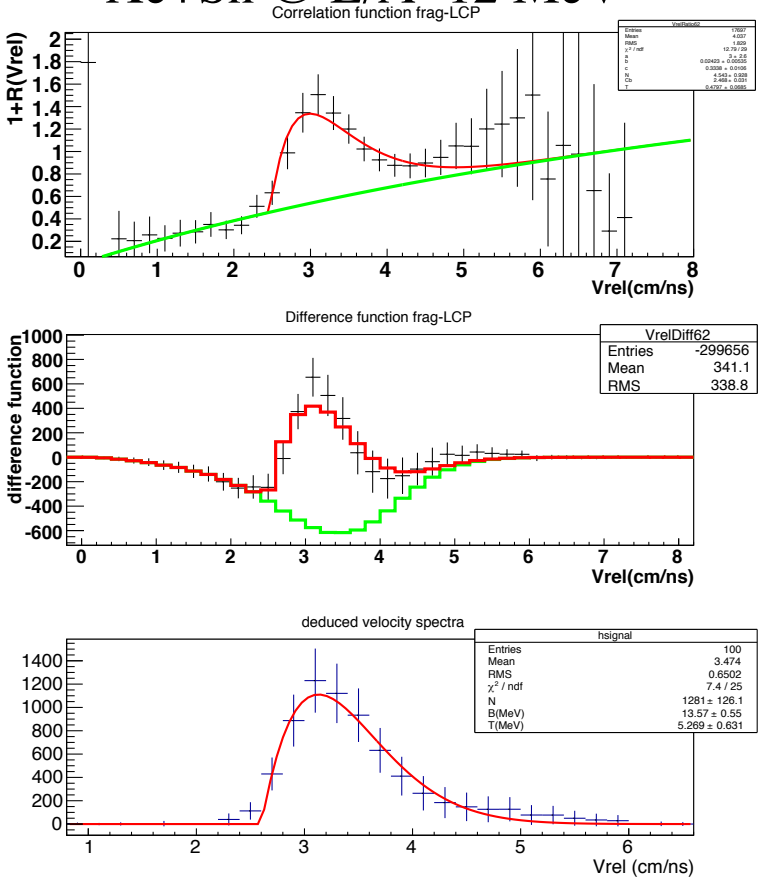
Xe + Sn @ 50 AMeV

AMD
+
Statistical
decay

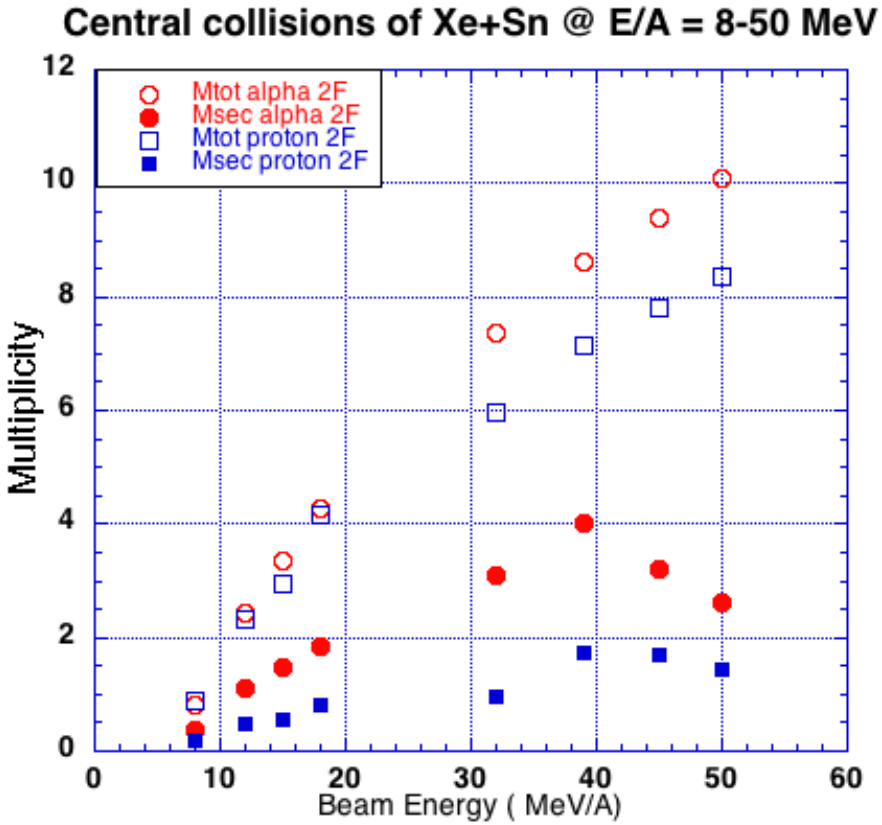


From fission to multifragmentation

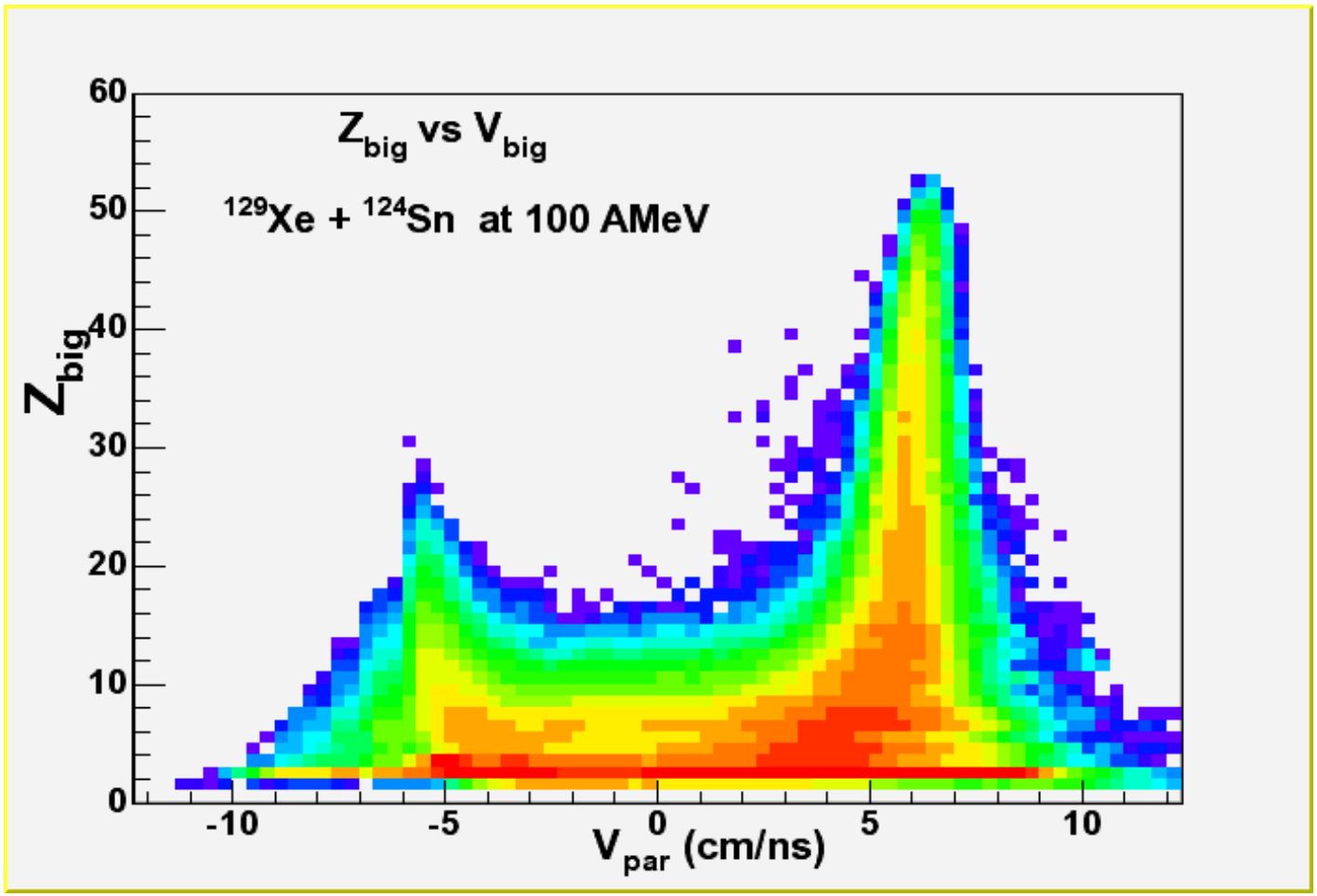
Xe+Sn @ E/A=12 MeV



$Z = 62 - \alpha$



Characteristics of the Quasi-Projectile

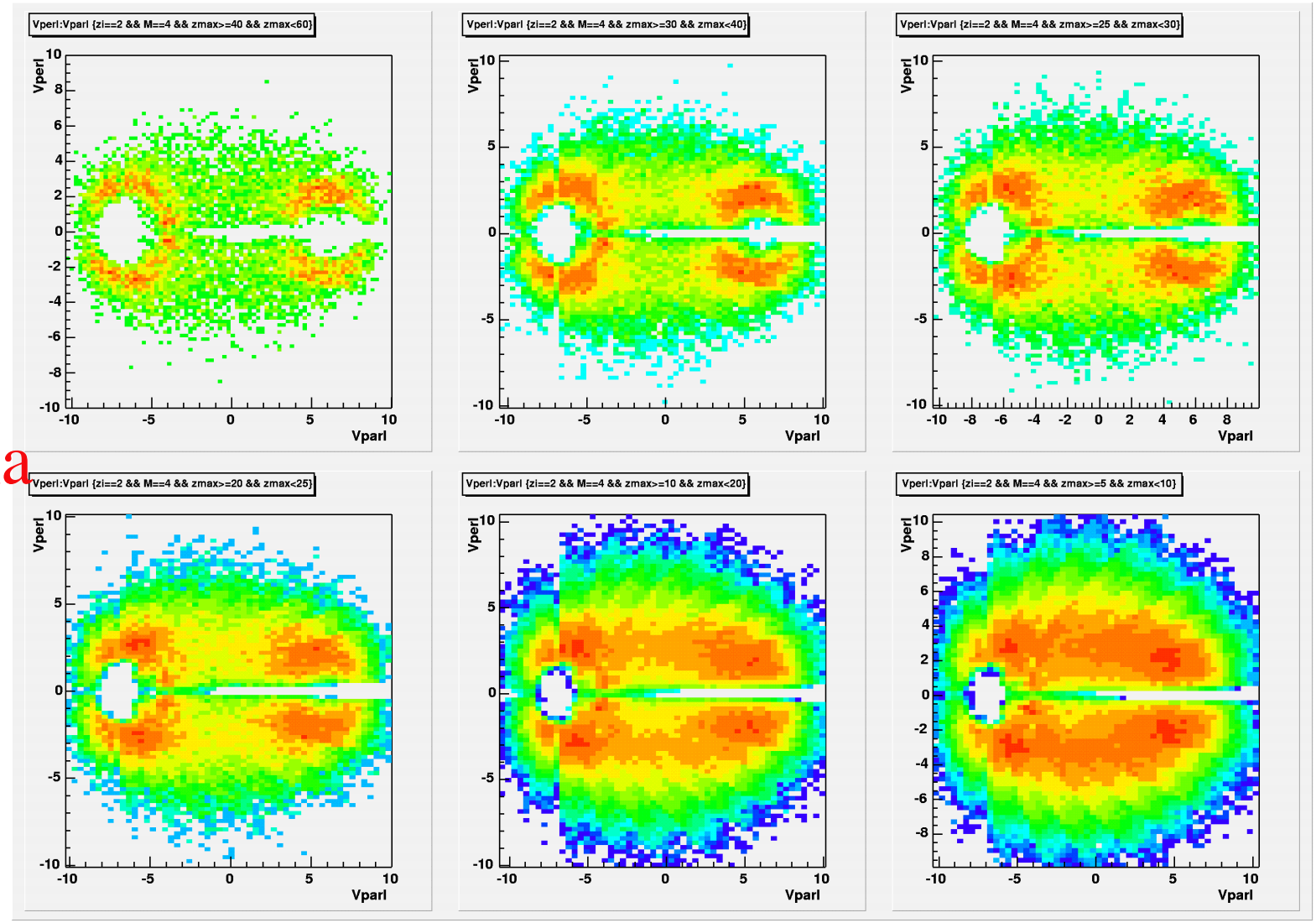


Zbig > 40

30 < Zbig < 40

25 < Zbig < 30

Alpha

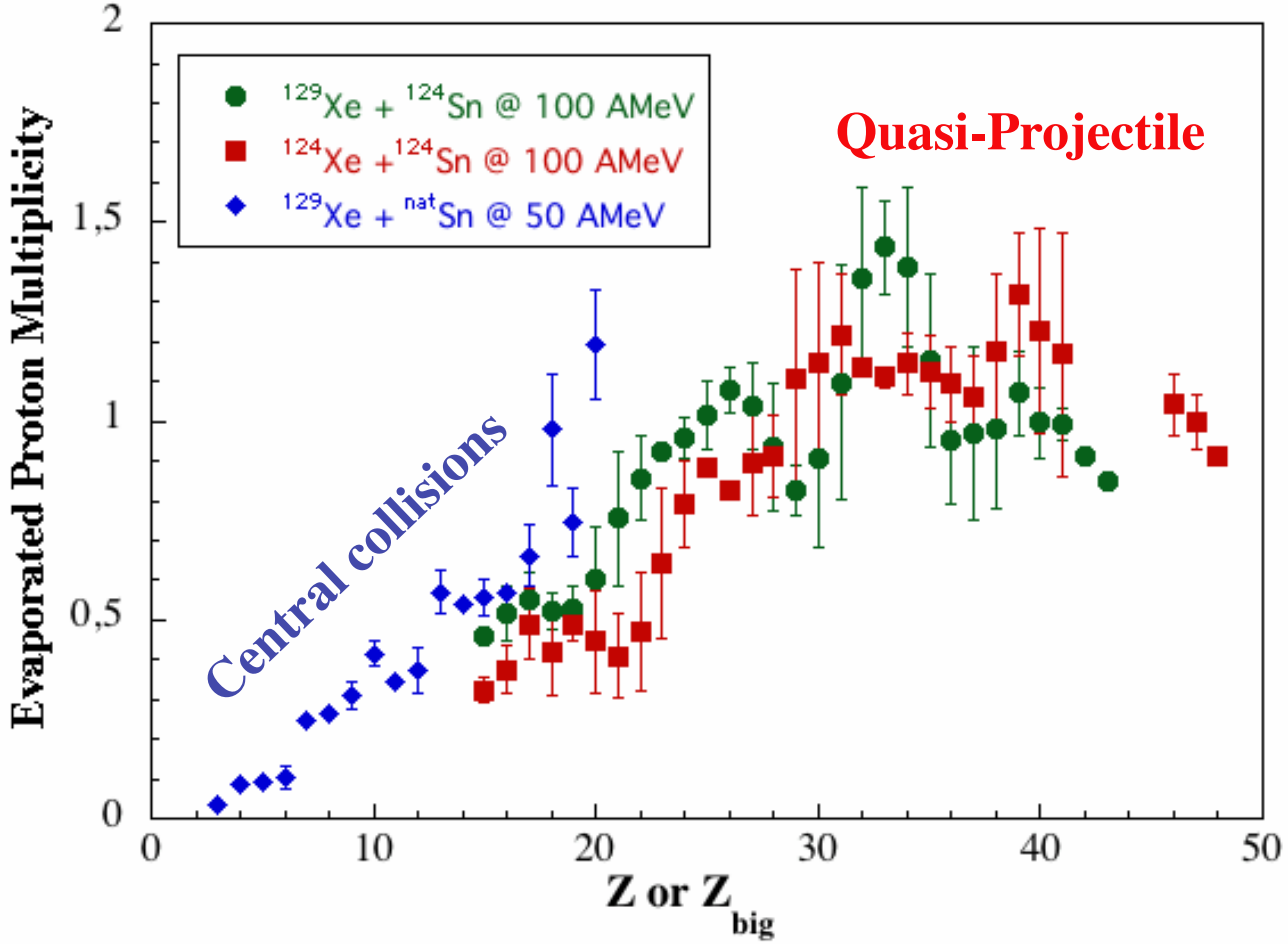


20 < Zbig < 25

10 < Zbig < 20

5 < Zbig < 10

evaporated protons



Conclusions

- Experiments :
  - Experimental study of the Xe + Sn system from the onset of multifragmentation
  - The fragments are excited and their E* saturates at 3 A MeV.
  - The proportion of thermal LCP does not exceed 35% and decreases with E_{inc}.
  - Reaction mechanism (HIC) is not able to heat the fragments more than 3A MeV.

  ⇘ **Strong constraints on the statistical and dynamical models.**

- Comparison with a statistical and dynamical model calculation :
  - The assumption that the system is in equilibrium at low densities reproduces the primary fragments excitation energies.
  - BUT it fails to predict the evolution of the evaporative LCP with the incident energy.
  - AMD predict almost the total energy spectra of protons (78% of total emission)
  - But it fails to reproduce the thermal contribution (22%).

- From fission to multifragmentation :
  - **The excitation energy of the fragments show a continuous increase from fission process to the Fermi energy and then saturate around 3 MeV/A → this a clear indication of thermal saturation (limiting temperature).**