"PRE-EQUILIBRIUM DIPOLE RADIATION WITH PROTON-RICH BEAMS"

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LNS - INFN

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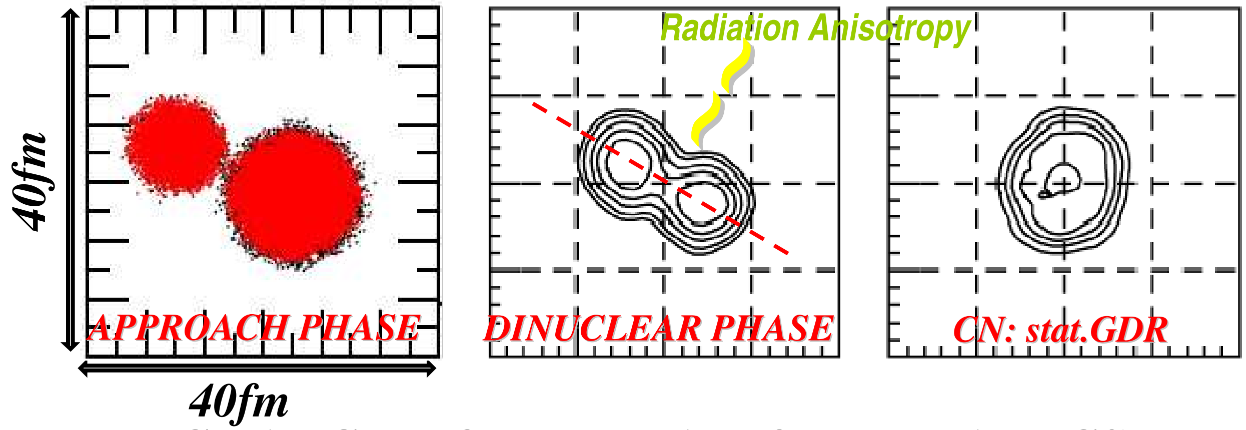


CHARGE EQUILIBRATION DYNAMICS:

•STOCHASTIC → Diffusion.

VS.

•COLLETTIVE → Dipole Oscillations of the Di-Nuclear System in Fusion Dynamics between colliding ions with different N/Z ratios.

DYNAMICAL DIPOLE: Pre-equilibrium dipole mode in phase dinuclear give rise to a prompt γ-ray emission which depends:

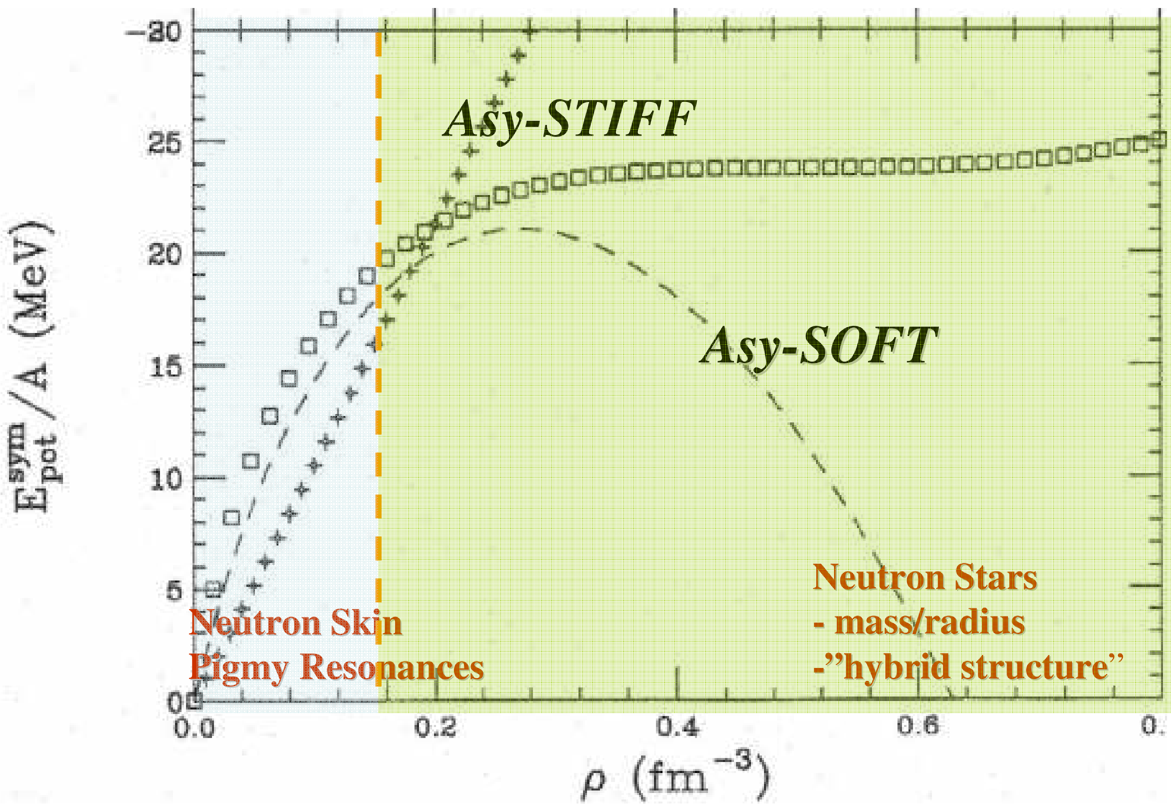
- on initial dipole moment, $D(t_0) = \frac{Z_1 Z_2}{A}\left(\frac{N_1}{Z_1} - \frac{N_2}{Z_2}\right)(R_1 + R_2);$
- on the symmetry term ($< \rho_0$), Isovector Restoring Force → Centroid, Yield
  Neutron emission, NN cross sections → Damping
- on the fusion dynamics, Neck Dynamics (Mass Asymmetry)
  Anisotropy
  Cooling on the way to Fusion

Reactions have been simulated by considering a stochastic extension of microscopic trasport equation BNV, following a test-particle evolution:

•VLASOV + NN-COLLISIONS and PAULI CORRELATIONS

$$\frac{E}{A}(\rho,I)=\frac{E}{A}(\rho,0)+\frac{E_{sym}}{A}(\rho)I^2$$

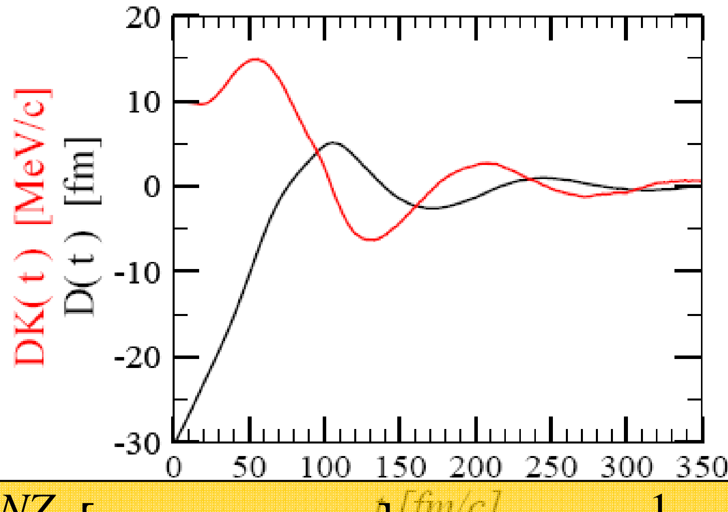
$$\frac{E_{sym}}{A}(\rho)=\frac{E_{sym}^{KIN}}{A}(\rho)+\frac{E_{sym}^{POT}}{A}(\rho)$$

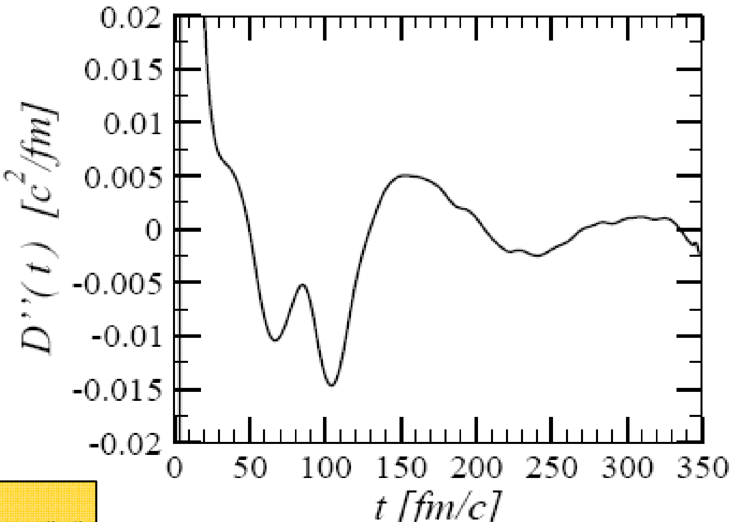


- **The isoscalar section of the EoS is the same in both cases, corresponding to a compressibility around 220MeV.**
- **Numerical approach with 200 gaussian test particles per nucleon.**
- **In the collision integral in medium N-N cross sections are considered.**
- **To reduce the numerical noise we run fifty events for each set of macroscopic initial conditions and the displayed quantities are the averages over this ensemble**

Pre-equilibrium dipole emission →Bremsstrahlung - Quantitative estimations

^{36}Ar + ^{96}Zr 16AMeV b = 4fm Asystiff

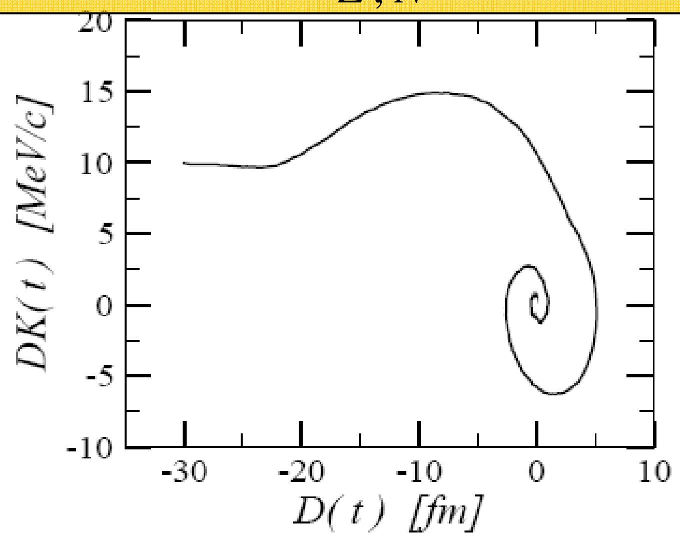


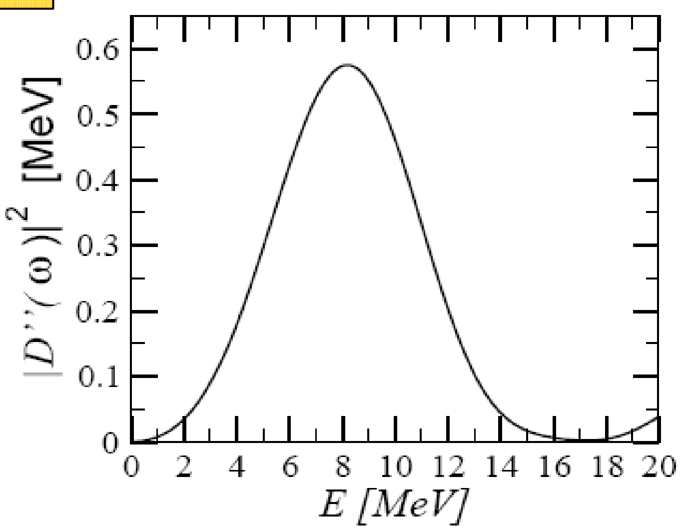


$$D(t) \equiv \frac{NZ}{A}\left[X_p(t) - X_n(t)\right] \rightarrow X_{p,n} \equiv \frac{1}{Z,N}\Sigma x_i^{p,n}$$

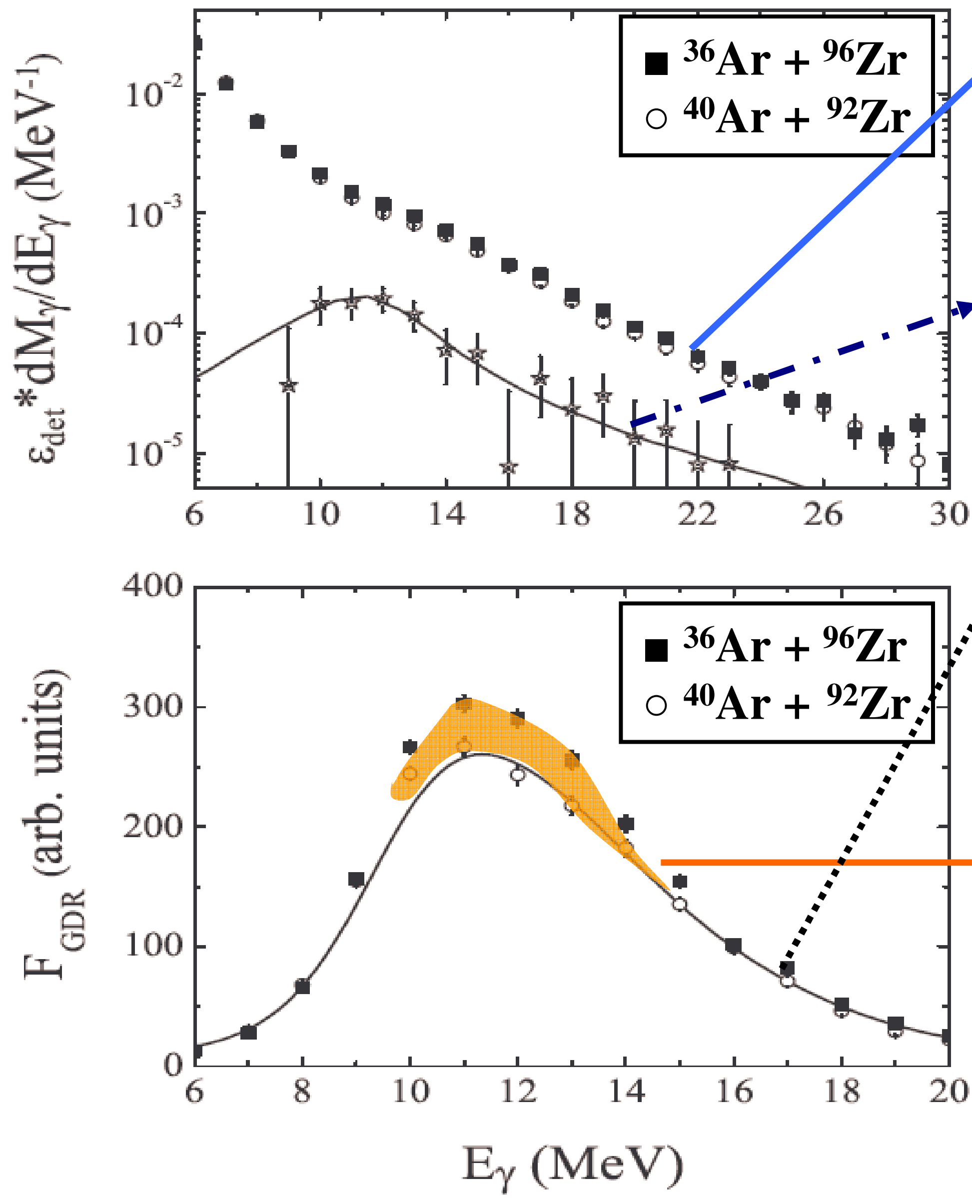
$$DK(t) \equiv P_p - P_n \rightarrow P_{p,n} \equiv \frac{1}{Z,N}\Sigma p_i^{p,n}$$

$$\frac{dP}{dE_\gamma} = \frac{2e^2}{3\pi\hbar c^3 E_\gamma}\left(\frac{NZ}{A}\right)^2 \left|D''(\omega)\right|^2$$





$^{36}Ar+^{96}Zr$ *vs.* $^{40}Ar+^{92}Zr$ at *16AMeV beam energy. Fusion events: same CN selection*



•**Bremsstrahlung-subtracted γ-ray spectra at $\theta_\gamma=90^o$ (vs. Beam Axis) in coincidence whit the evaporation residues.**

•***Difference.***

The data are linearized by theoretical γ-ray spectrum of the charge symmetric reaction calculated with the statistical decay code CASCADE results without a CN GDR

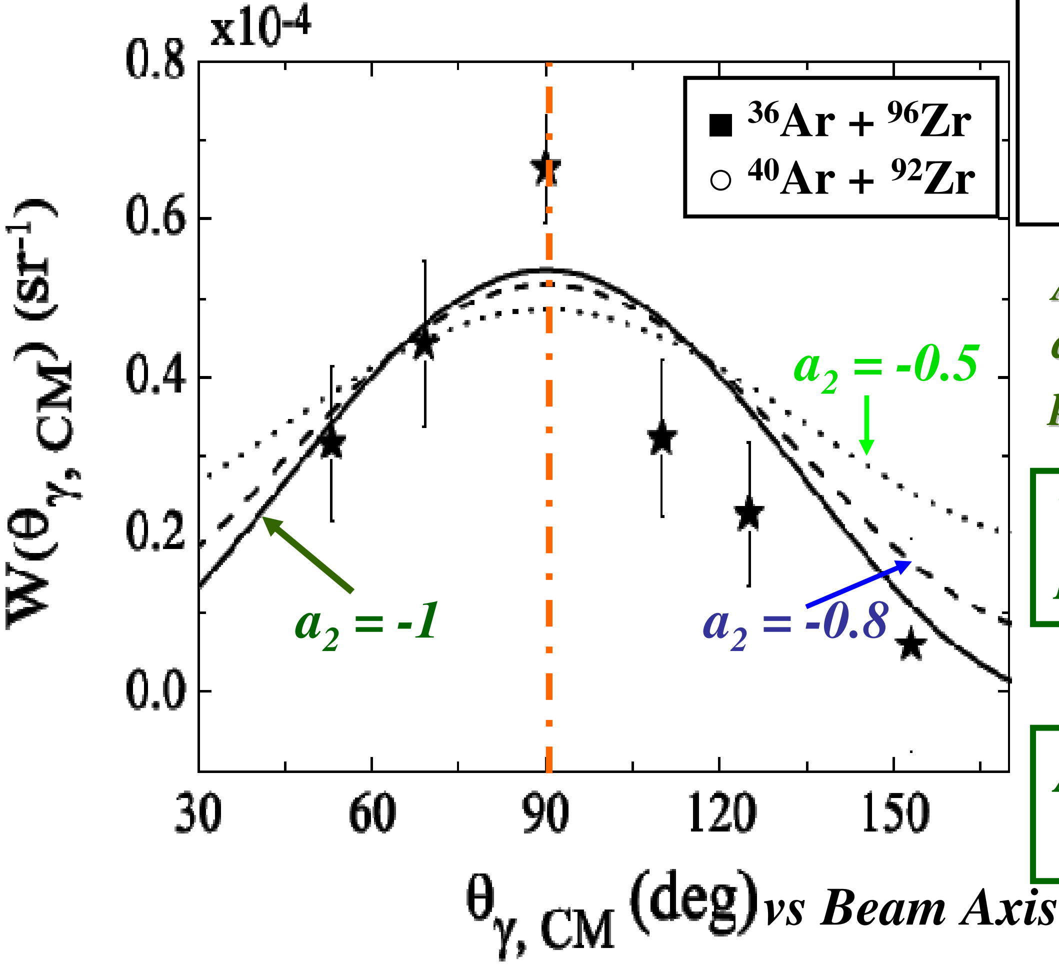
An increase of the GDR γ-ray intensity is found by going toward the more charge asymmetic system.
θ_γ- study of the extra-yield with MEDEA

D.Pierroutsakou et al.,

$^{36}Ar+^{96}Zr$ *vs.* $^{40}Ar+^{92}Zr$ at *16AMeV beam energy. Fusion events: same CN selection*

Gamma Angular Distribution, 10<E_γ<15 MeV

$$W(\vartheta_\gamma) = W_0[1 + a_2 P_2(\cos\vartheta_\gamma)]$$



$W(\Theta_{\gamma,CM})$ is anisotropic with a maximum around 90° and it is consistent with emission from a dipole oscillating along the beam axis.

A strong dipole-like photon angular distribution has been observed, with the parameter a_2 = -1, $W(\Theta_{\gamma,CM}) \sim \sin^2\Theta_{\gamma,CM}$

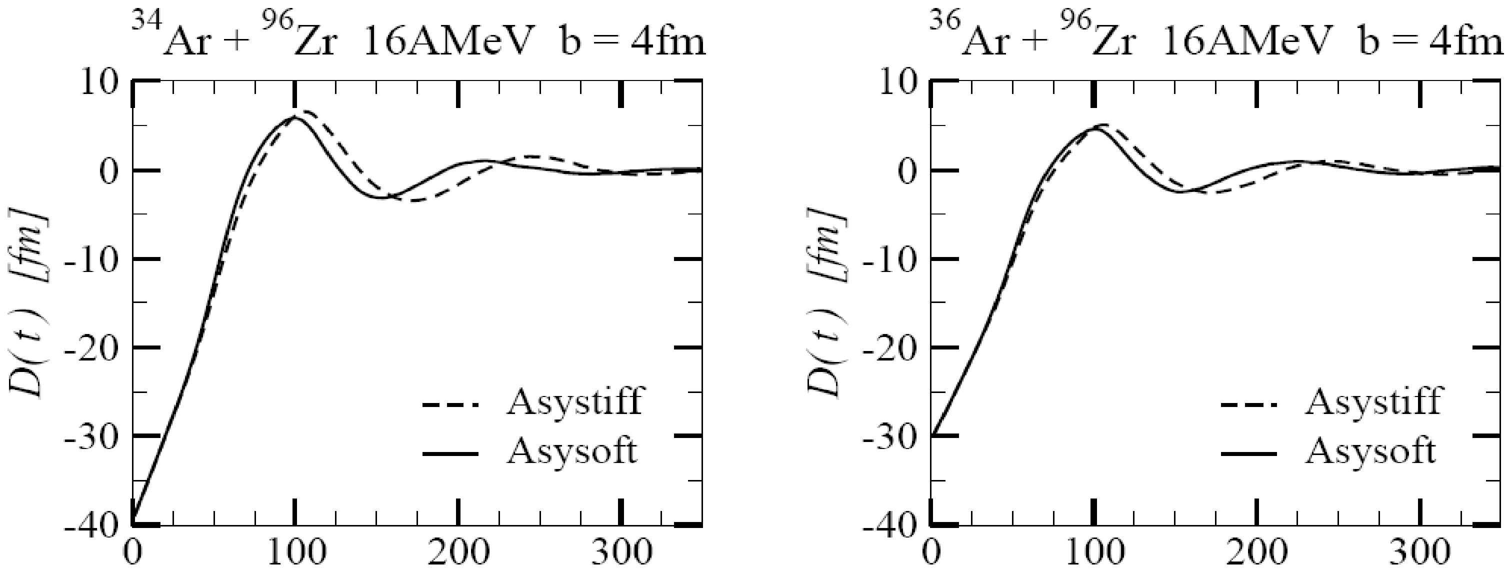
Widening: rotation of the Prompt Dipole Axis vs the Beam Axis

Accurate Angular Distrib. Measure: Dipole Clock!

B.Martin et al., PLB 664 (2008) 47

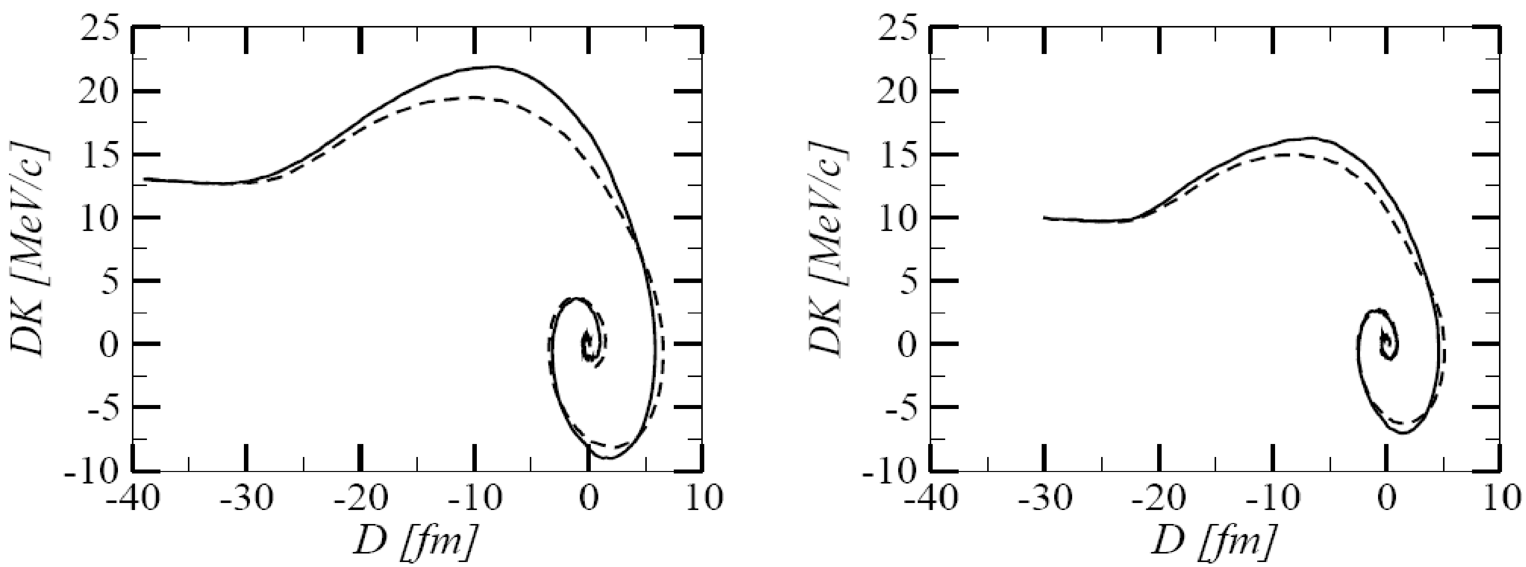
We study the features of the preequilibrium dipole considering the reaction ***36Ar+96Zr*** at ***16AMeV***, as referred to the same reaction induced by a ***p-rich 34Ar beam***.

Prompt Dipole Oscillations

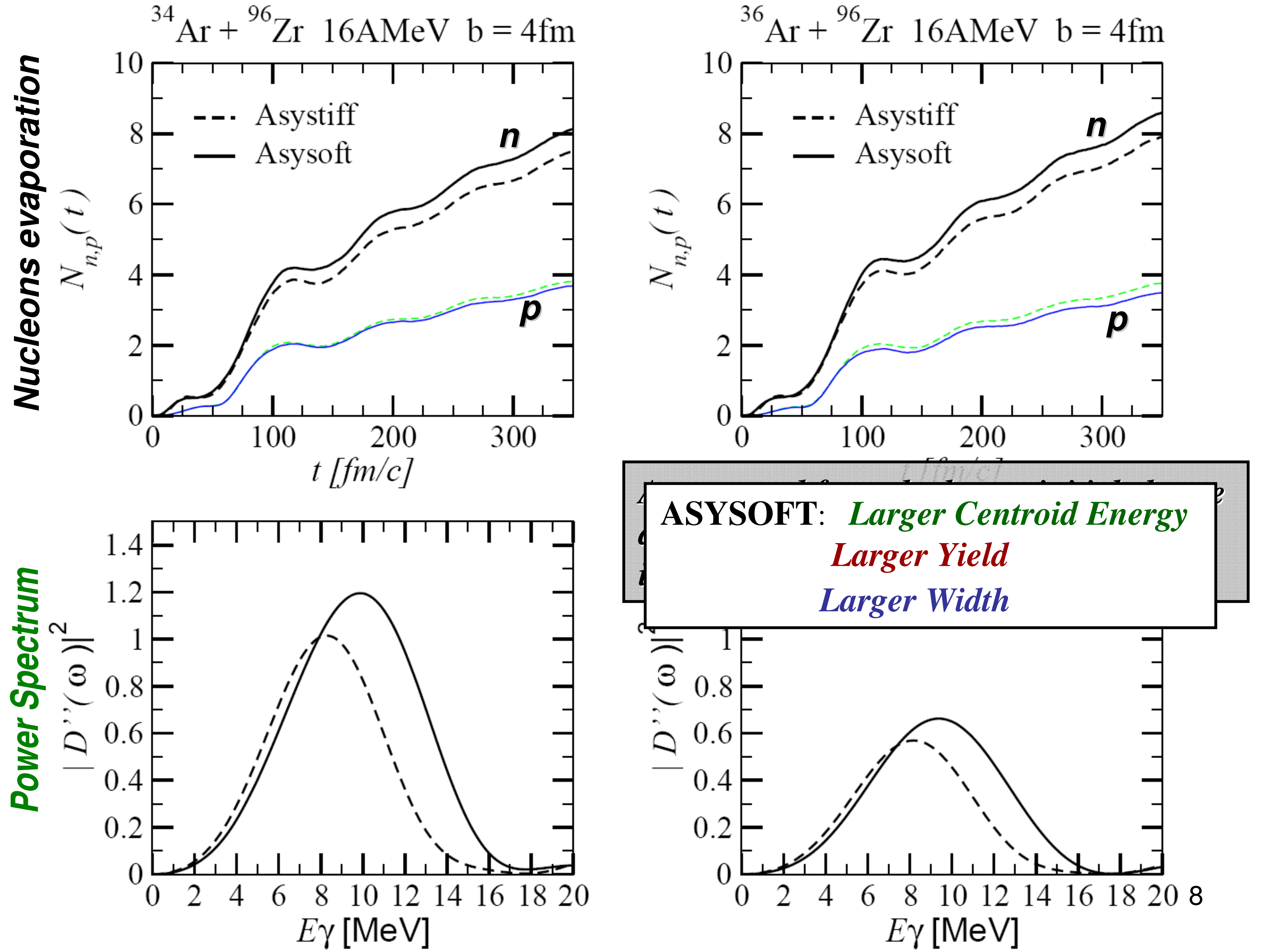


$D(t_o)$ has a value around ***27fm*** for the ***34Ar*** beam, and a value ***20fm*** for the ***36Ar*** beam

Phase Space Correlations



ASYSOFT: Neutrons see a more repulsive Symmetry Potential below ρ_0

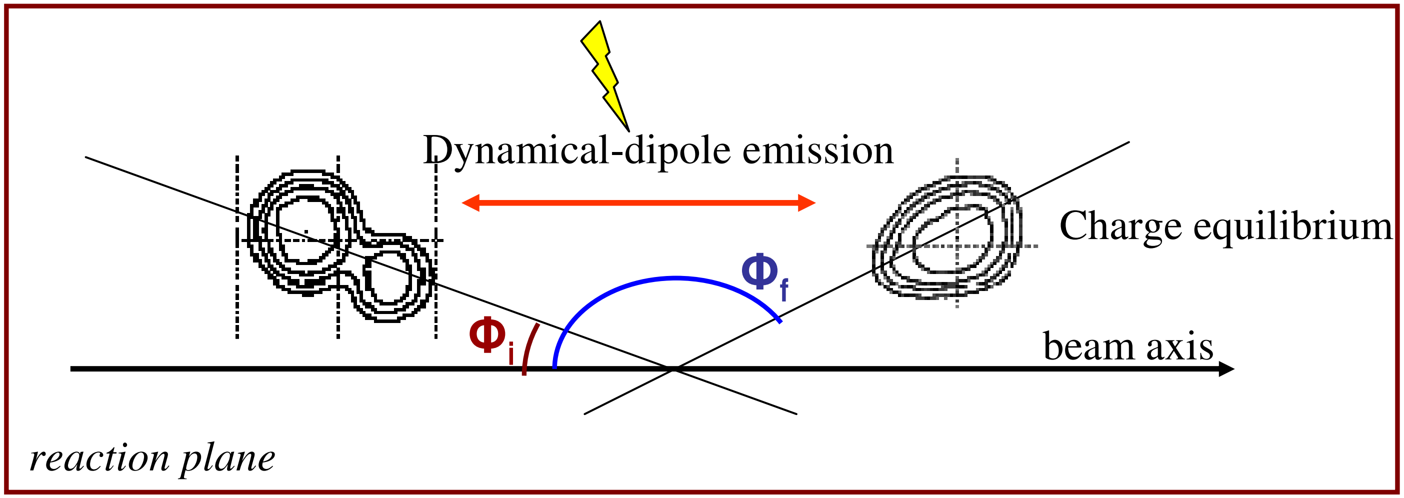


ASYSOFT: *Larger Centroid Energy*

Larger Yield

Larger Width

Angular distribution: Rotation on the Reaction Plane of the Emitting Dinuclear System



$$W(\vartheta_\gamma) = W_0\left[1 + a_2 P_2(\cos\vartheta_\gamma)\right] \quad , a_2 = -\left(\frac{1}{4} + \frac{3}{4}x\right)$$

θ_γ : photon angle vs. beam axis

$$x = \cos(\Phi_i + \Phi_f)\frac{\sin(\Delta\Phi)}{\Delta\Phi} \quad , \Delta\Phi = \Phi_f - \Phi_i$$

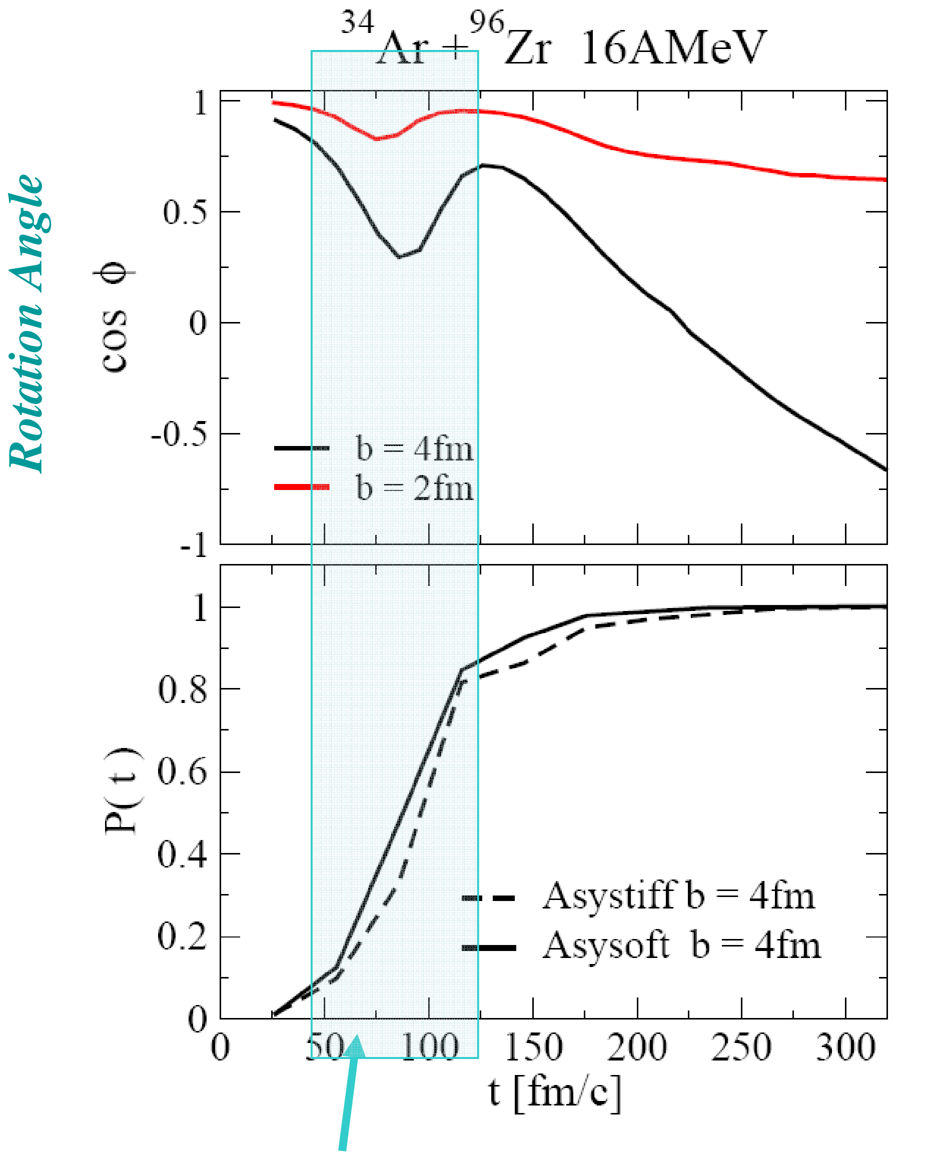
•All probed Rotating angles: $\Delta\Phi = 2\pi \rightarrow x = 0 \rightarrow a_2 = -1/4$

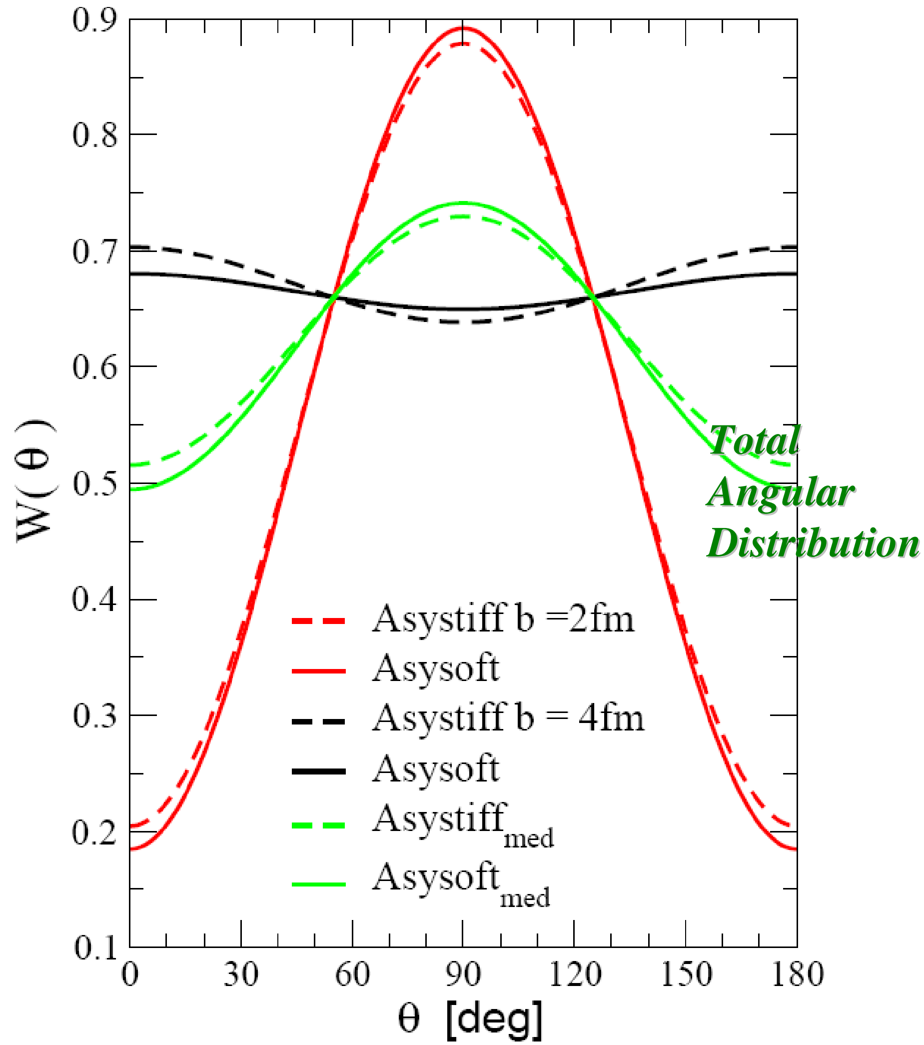
⇨ Statistical result, Collective Prolate on the Reaction Plane

•Fixed Rotating angle: $\Delta\Phi = 0 \rightarrow \Phi_i = \Phi_f = \Phi_0$ ⇨ $W(\vartheta_\gamma) \propto \left[1 - (1 - \sin^2\Phi_0)P_2(\cos\vartheta_\gamma)\right]$

•No rotation: $\Phi_0 = 0 \rightarrow \sin^2\theta_\gamma$
Pure Dipole

⇨ **Dominant since the prompt dipole is rapidly damped? Angular Distribution**
→ Dynamic Dipole Lifetime





Emission Probability: delayed with asystiff

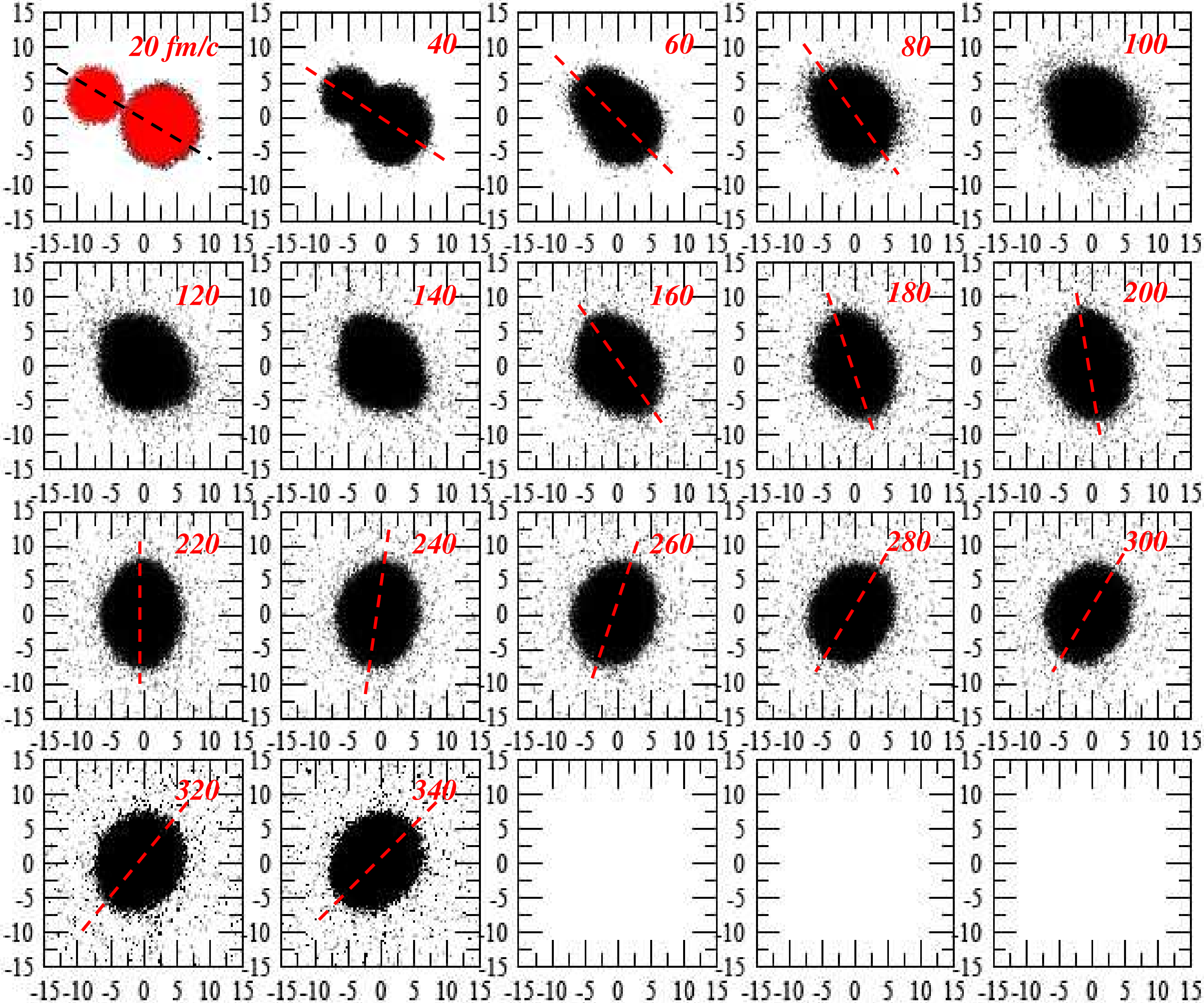
$$P(t) = \int_{t_0}^{t} \mid D''(t) \mid^2 \, dt / P_{tot}$$

Weighted anisotropies:

$$W(\theta) = \sum_{i=1}^{t_{max}} \beta_i W(\theta, \Phi_i)$$

$$\beta_i = P(t_i) - P(t_{i-1})$$

$^{34}Ar + ^{96}Zr$ 16AMev b = 4fm Asystiff



<u>*Conclusions*</u>

The dynamical dipole mode appears to be a suitable probe to test the symmetry energy term in the nuclear EoS as well as to scrutinize the early entrance channel dynamics in dissipative reactions with p-rich beams

The angular distributions are also sensitive to the fusion dynamics and dipole excitation mechanism and lifetime.

We can get the total yield for the two Iso-EoS and the two systems :

- ***We obtain 1.22 for 34Ar reaction and 1.17 for 36Ar in the Asysoft/Asystiff case;***
- ***We obtain a value around 1.7 for Asystiff choice and 1.8 for Asysoft in the 34Ar/36Ar reaction case.***
- ***Use of a more symmetric reference system 40Ar + 90zr, $D(t_0)$=1.6fm.***

Beam intensity problem:

- ***exp. Medea 36Ar + 96Zr intensity 2nA → ~10^9pps;***
- ***new exp with 34Ar → 10^6-10^8 ??***