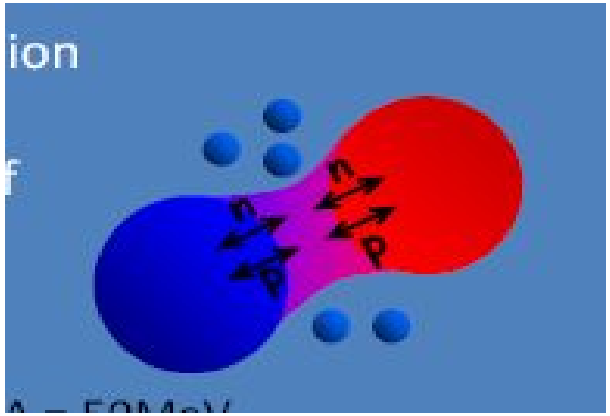
THE DYNAMICAL DIPOLE IN FUSION WITH EXOTIC BEAMS

A letter of intent for SPES subscribed by 32 authors (sent to SPES panels on april,19 2010)

two nuclei collide with different initial N/Z



Isospin Equilibration: Dynamical Dipole in Fusion Reactions

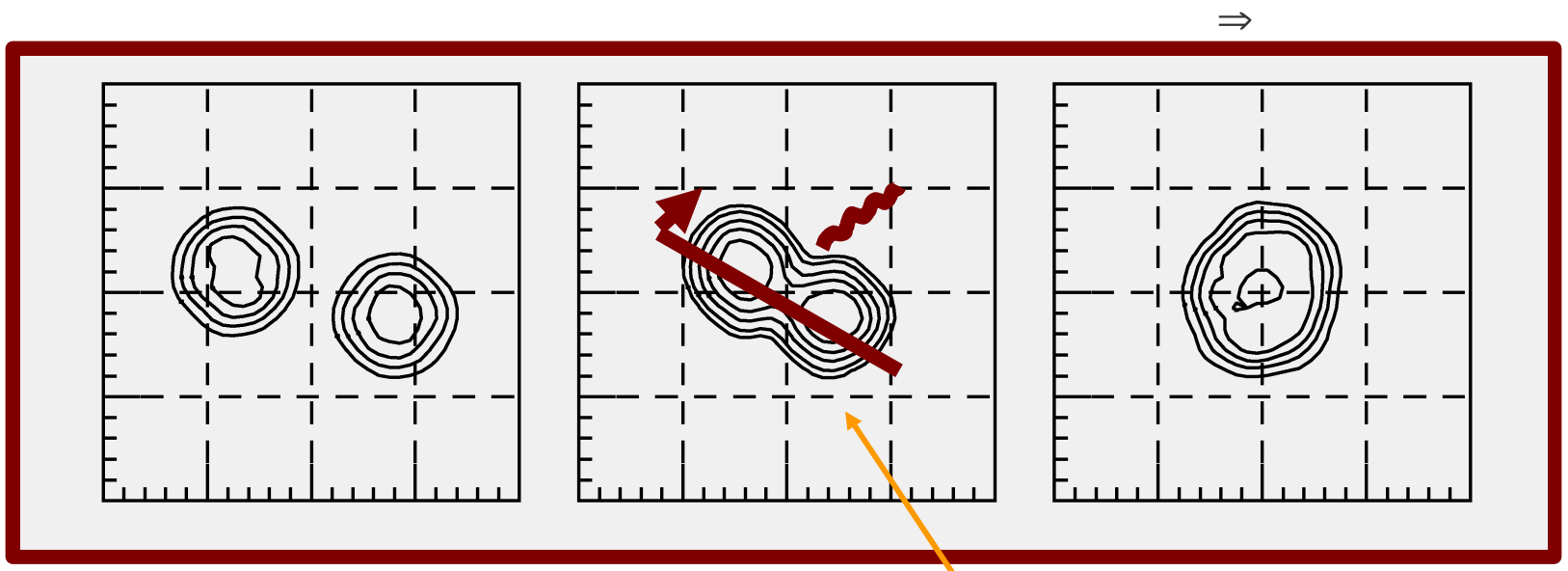
Charge Equilibration Dynamics:

Stochastic → Diffusion (nucleon exchange)

vs.

Collective → Dipole Oscillations of the di-nuclear System ruled by fusion dynamics

Slides prepared using DiToro's proposal at SPES-WS-2008



$$D_0 = \frac{Z_1 Z_2}{A}\left(\frac{N_1}{Z_1} - \frac{N_2}{Z_2}\right)\left(R_1 + R_2\right)$$

Initial Dipole

CN: Statistical GDR

D(t) : bremsstrahlung dipole radiation

like a tilting lighthouse!

DDR is an alternative way to particle preequilibrium to dissipate energy and cool the system on the way to Fusion ---> link to SHE physics

STOCHASTIC MEAN FIELD TRANSPORT EQUATION: VLASOV + NN-COLLISIONS and PAULI CORRELATIONS

Baran, DiToro, M.Colonna
Phys.Rep. 410 (2005) 335

Fluctuations

$$\frac{df(r,p,t)}{dt} = \frac{\partial f(r,p,t)}{\partial t} + \{f,h\} = I_{coll}[f] + \delta I_{coll}$$

$$h = \frac{p^2}{2m} + U[f]$$

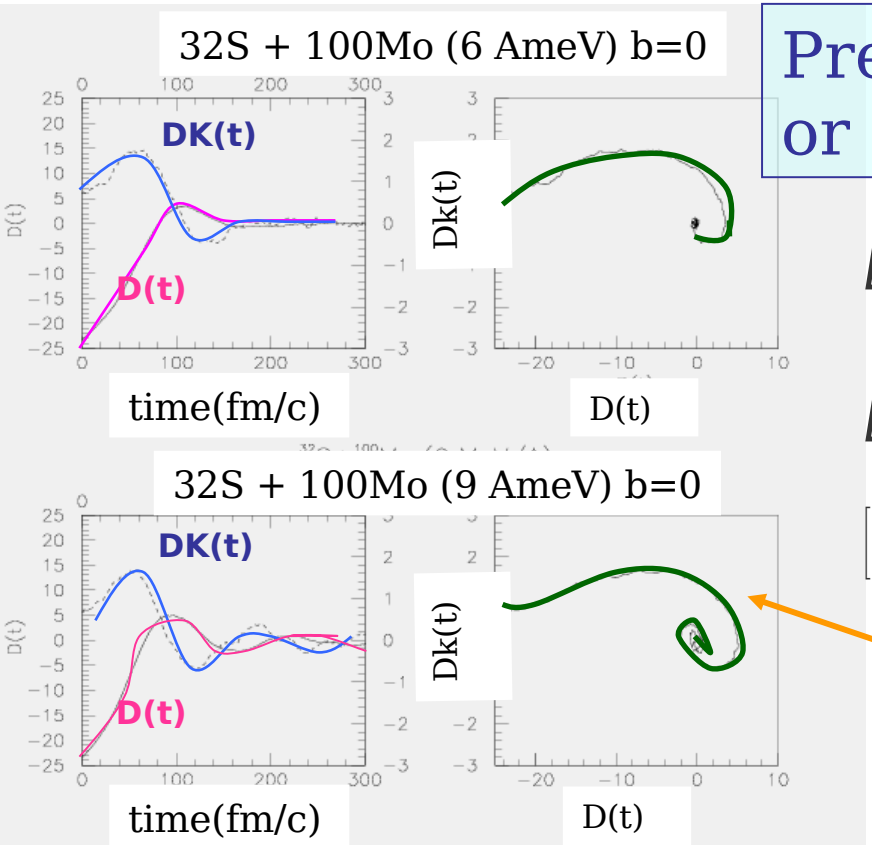
$$w^+(1-f) - w^- f$$

gain loss

In medium cross sections

Self-Consistent Mean Field ⟺ **Equation of State**

Pre-equilibrium dipole emission or DDR



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

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

$$\left[D, DK\right] = i\hbar$$

SPIRALS witness Collective Oscillations!

THEO: Baran, Brink, M.Colonna, Di Toro, PRL.87(2001)

Bremsstrahlung: Quantitative estimations

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

EXP: D.Pierroutsakou et al. PRC71(2005)

DDR: a brief experimental story

Flibotte *et al.*, Phys.Rev.Lett. 77, 1448 (1996)

1 charge asym

$^{32}S + ^{32}Mo$

6 to 9 AMeV Fusion events: same CN selection

D.Pierroutsakou et al. PRC71(2005)

2 charge asym and sym

$^{36}Ar + ^{96}Zr$

$^{40}Ar + ^{92}Zr$

16AMeV Fusion events: same CN selection

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

3 charge asym and sym

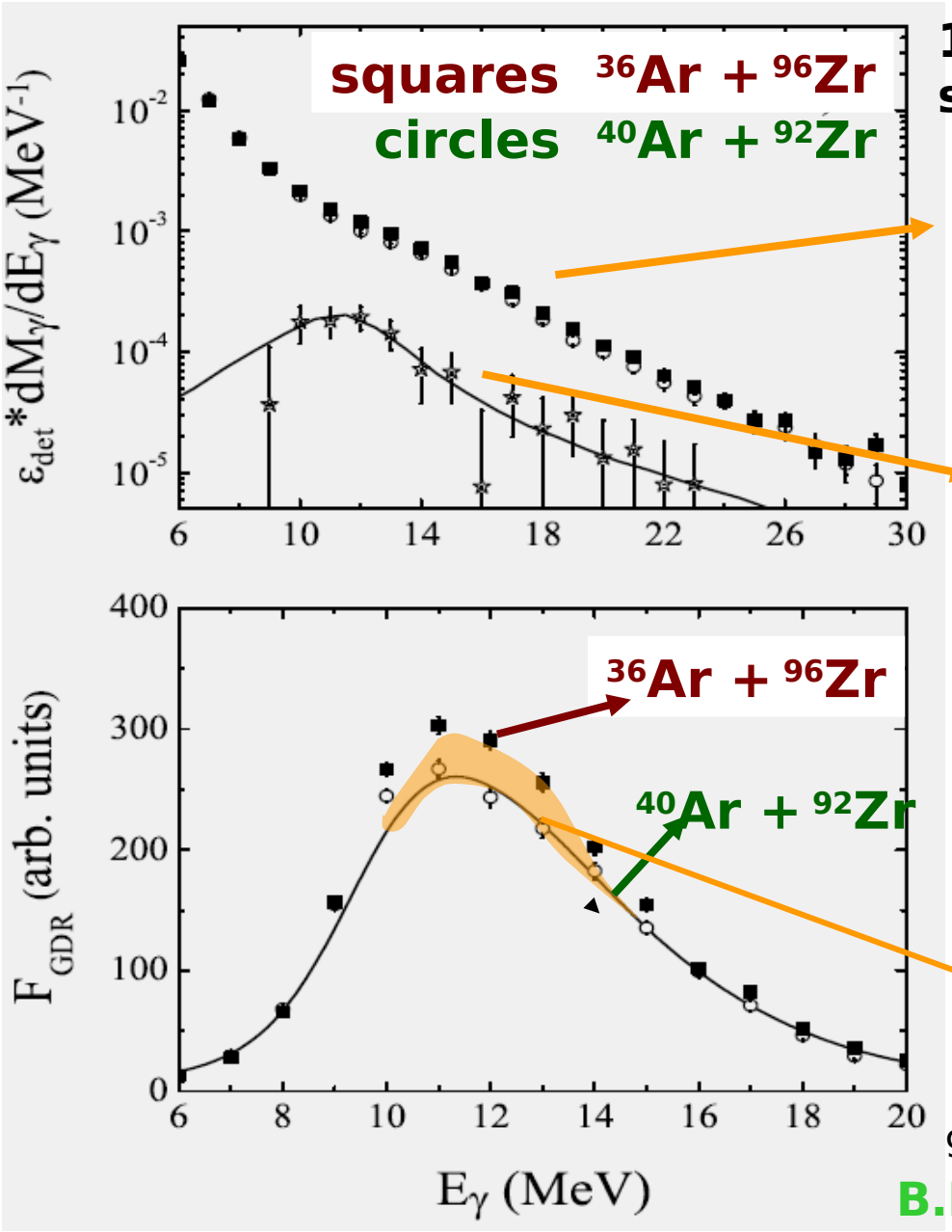
$^{16}O+^{116}Sn$ at 8.1 an 15.6 MeV/u

^{64}Ni (400 MeV) + ^{68}Zn

A.Corsi et al PLB679 (2009) 197

an experiment done by NUCLEX in 2009 O+116Sn at 12AMeV

D.Pierroutsakou et al., Medea Exp. at LNS

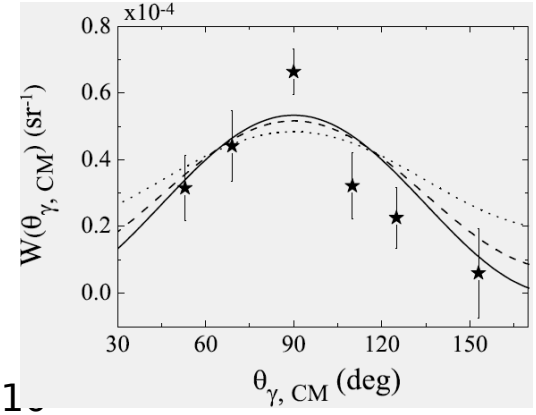


16AMeV Fusion events: same CN selection

(np)-bremsstrahlung subtracted spectra at θ_γ=90° vs. Beam Axis

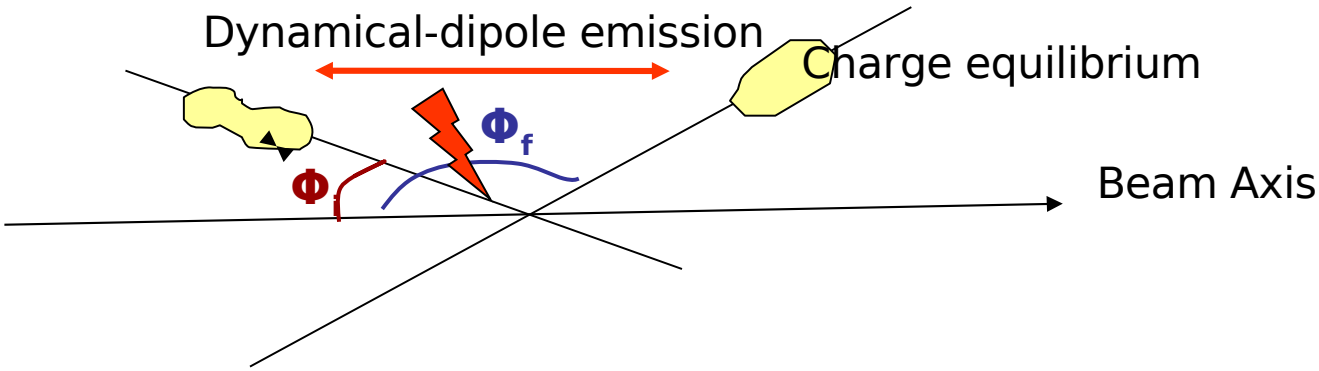
Difference Spectrum

Linearized spectra: i.e. divided by the no-GDR CN evaporation component



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

Rotation on the Reaction Plane of the Emitting Dinuclear System



Average over reaction planes:

θ_γ : photon angle vs beam axis

$$W(\vartheta_\gamma)=W_0\left[1+a_2P_2(\cos\vartheta_\gamma)\right],\ \ a_2=-\left(\frac{1}{4}+\frac{3}{4}x\right)$$

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

All probed Rotating angles

$\Delta\Phi=2\pi \rightarrow x=0 \rightarrow a_2=-1/4$: Statistical result, Collective Prolate on the Reaction Plane

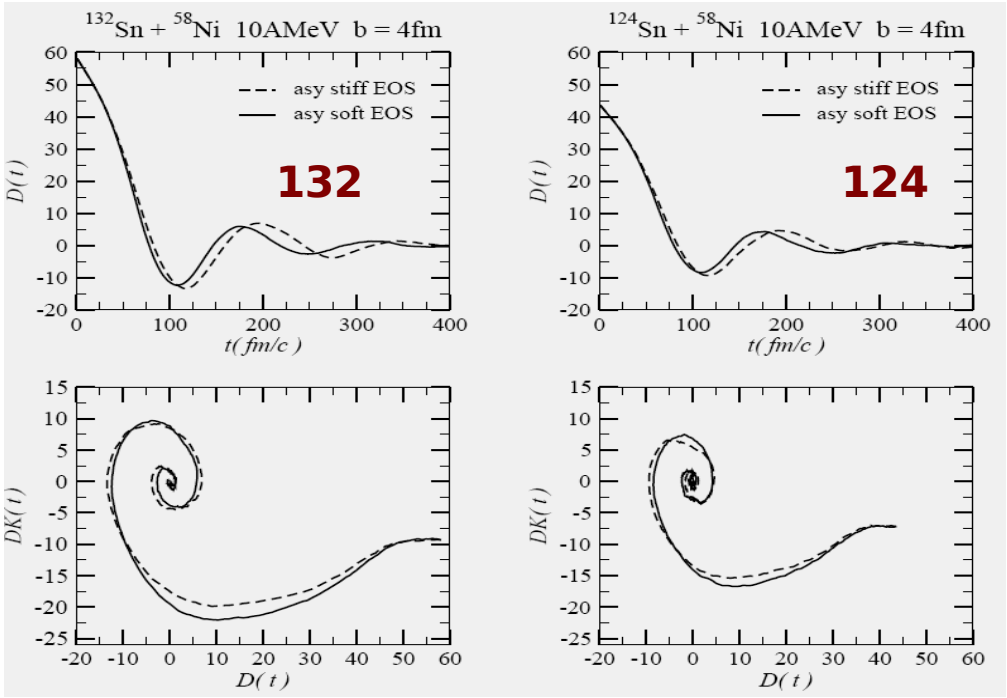
Fixed Rotating angle

$\Delta\Phi=0 \rightarrow \Phi_i=\Phi_f=\Phi_0$ $\longrightarrow$ $W(\vartheta_\gamma)\propto\left[1-(1-\sin^2\Phi_0)P_2(\cos\vartheta_\gamma)\right]$

No rotation: $\Phi_0=0 \rightarrow \sin^2\theta_\gamma$ pure dipole

Dominant since the prompt dipole is rapidly damped?
Angular Distribution → Dyn.Dipole Lifetime

The "Monster" ^{132}Sn Dynamical Dipole: Symmetry Energy



10AMeV, b=4fm

Prompt Dipole Oscillations

Asy soft

Asy stiff

PHENOMENON Asy-EOS sensitive

Power Spectrum

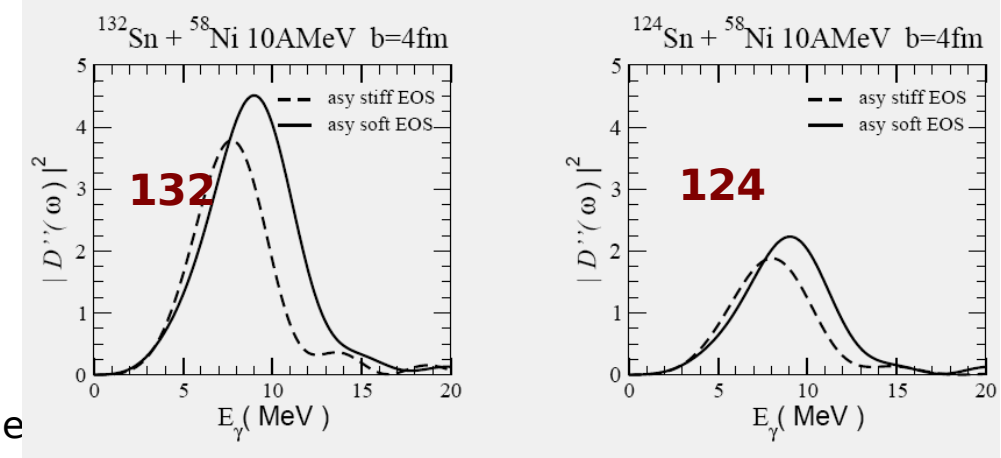
ASYSOFT: larger restoring force and therefore:

Larger Centroid Energy

Larger Yield

Larger Width

→ RIBs needed



GC Rome

Baran and Rizzo PRC2009

DYNAMICAL DIPOLE RADIATION and RIBs

SPES is fine from the bombarding energy point of view (rise-fall)

Our proposed experiments at SPES;
(M.Colonna and C.Rizzo started specific calculations)

$$133Cs + {}^{48}Ca \rightarrow {}^{181}Re\left(with \frac{N}{Z} = 1.42, 1.4D(0) = 1.2fm\right)$$

$$142Cs + {}^{40}Ca \rightarrow {}^{182}Re\left(with \frac{N}{Z} = 1.58, 1.0D(0) = 36fm\right)$$

Cs (and alkali beams) should be easier and more intense beam

$$124Sn + {}^{48}Ca \rightarrow {}^{172}Yb\left(with \frac{N}{Z} = 1.48, 1.40\right)$$

$$132Sn + {}^{40}Ca \rightarrow {}^{172}Yb\left(with \frac{N}{Z} = 1.64, 1.00\right)$$

Sn is the reference case for Rib Facility and SMF calculations
cfr. Maj LOI for Spiral2 (also italians there)
cfr. Monster DDR calculations
cfr. Inglima LOI for SPES

DYNAMICAL DIPOLE RADIATION and RIBs

There are predictions (from SMF) that the DDR depends on the mass asymmetry, too

Our proposed systems

$$^{124}Sn + ^{56}Fe \longrightarrow ^{180}Os$$

N/Z=1.48,1.15 D(0)=25fm

$$^{90}Kr + ^{90}Zr \longrightarrow ^{180}Os$$

N/Z=1.50,1.25 D(0)=21.5 fm

$$^{86}Kr + ^{94}Zr \longrightarrow ^{180}Os$$

N/Z=1.39,1.35 D(0)= low

Doubts and open points:
-mass symm and mass asym need different E/A to reach the same Ex!

What kind of apparatus?

for ER selection and LCP sampling?
PHOSWICH+GARFIELD+..

idea: anticorrelation DDR vs. PREEQ ?
idea: correlation DDR vs. Fusion yield?

and for energetic gammas:
HECTOR from Milan
TRASMA and SERPE from LNL-LNS (responsible people are open to detector transfer to Legnaro)

PROBLEMS
-needed big gamma efficiency otherwise we are lost! (comments by Alessia DiPietro SPES Su.Sci.)
-needed wide coverage to address the ang.distr. issue
-experiment duration with RIB (weeks, even with 10^8pps=0.016pnA !)

DYNAMICAL DIPOLE RADIATION and RIBs

Yield: **Entrance Channel Asymmetry**
Symmetry Energy → frequency
(collective response delay with Asy-stiff)
Damping Mechanisms

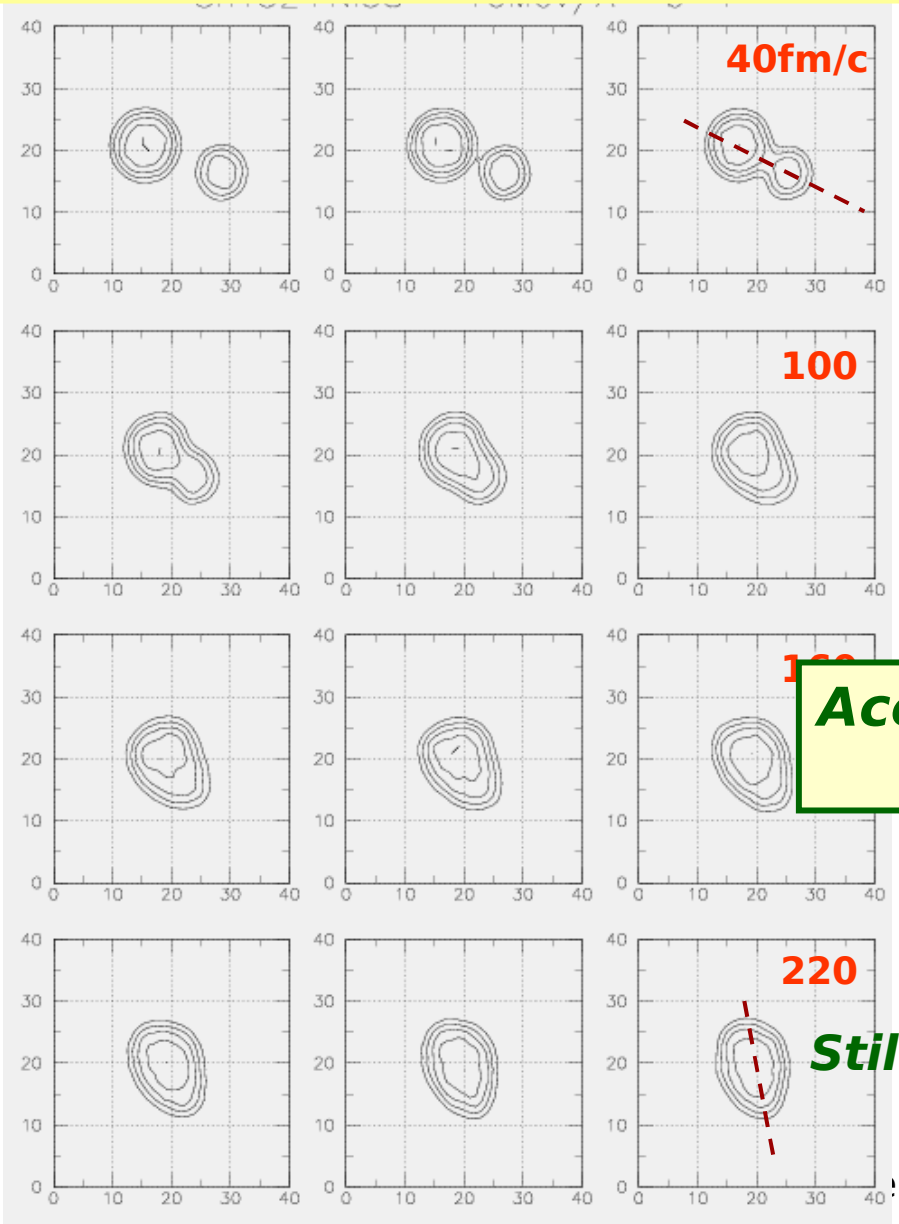
Centroid: **Restoring Force → symmetry energy at sub-saturation**
Dinuclear deformation → fusion dynamics

Angular distribution: **symmetry energy**
effect for large rotation → high spin selections

-competition with Neutron Emission
- tuning of In medium NN cross sections
- relaxation of the Dinuclear Mean Field and binary event competition

Other phenomenon:
Excitation Function should exhibit a Rise and Fall with Beam Energy
(low deceleration at low velocity whilst DDR is Overdamped at Fermi energies)

Density Plots on the Reaction Plane: Rotation of the Oscillation Axis vs the Beam Axis



132Sn:
The Monster Dipole *Case*

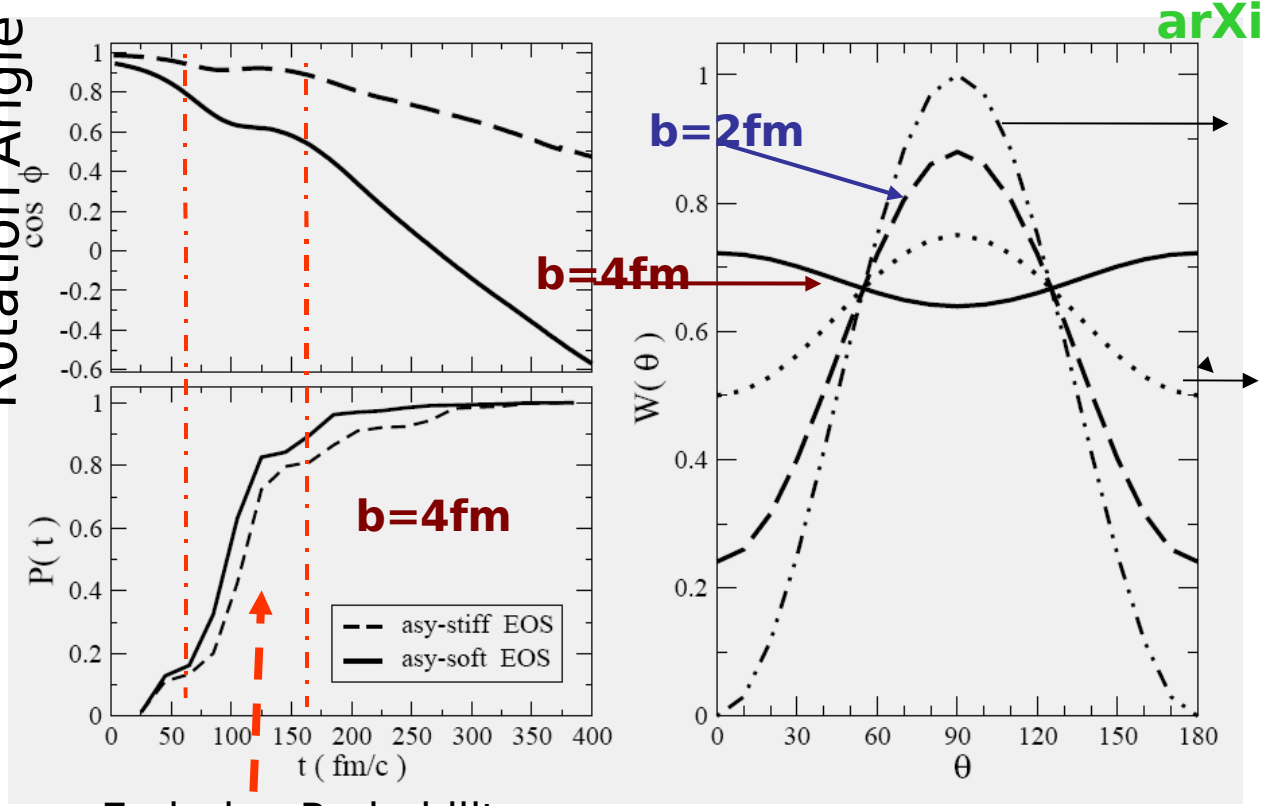
Accurate Angular Distrib. Measurem
Dipole Clock!

Still emitting,..although damped

arXiv:0807.4118[nucl-th]

The "Monster" ^{132}Sn DDR: Angular Distributions

arXiv:0807.4118[nucl-th]



a_2=-1, beam axis

a_2=-1/4, CN prolate

Constant Emission Prob.

Total Angular Distribution

Emission Probability:
delayed with asystiff choice

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

Weighted anisotropies:

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

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

C Rome