Probing the nuclear EOS in heavy-ion collisions at Fermi energy in isospin-sensitive exclusive experiments

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Context

Which form for $\mathcal{S}(\rho)$? $\Rightarrow$ HI collisions with exotic beams

Relat. beams : $\rho > \rho_0$ great range of variation for $\mathcal{S}(\rho)$
but : m^* splitting, p dependence.

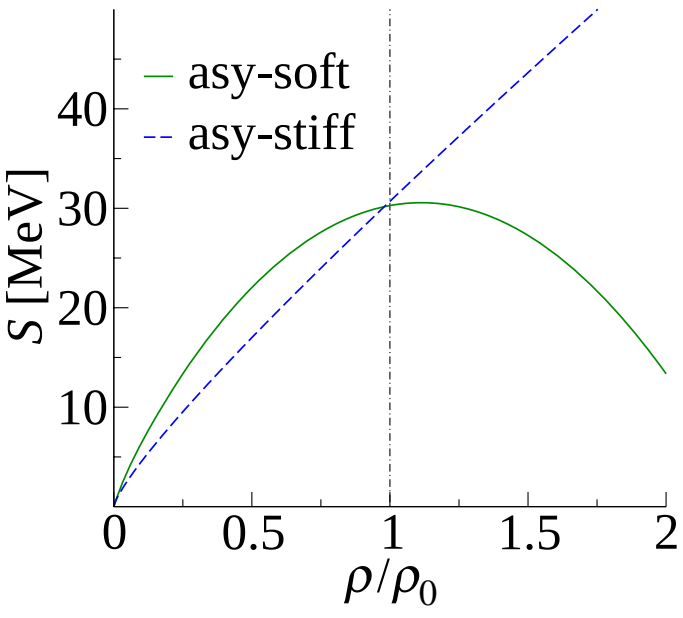
We focus on *Fermi energies* : $\rho \lesssim \rho_0$
but : small range of variation for $\mathcal{S}(\rho)$

challanges

Theory : predictions
Experiments : detection
Physics : secondary decay

Supposing we could measure A,Z of fragments up to a large extent, we are searching for

- Sensitive observables
- simulation protocol



Model

Stochastic Mean Field (M.Colonna)

- semi-classical *time-dependent*

I-dependent mean-field

- *nucl-nucl collisions*
- *fluctuations*

$\Rightarrow$ ~ 10 to ~ 200 A MeV

$\Rightarrow$ Heavy frag., IMF properties

$\Rightarrow$ preeq n, p but LCP not described

- *Interactions :*

$$\mathcal{S}_{\rm pot}(\rho) = \begin{cases} \propto \rho & \textit{Stiff} \\ = a\rho + b\rho^2 & \textit{Soft} \end{cases}$$

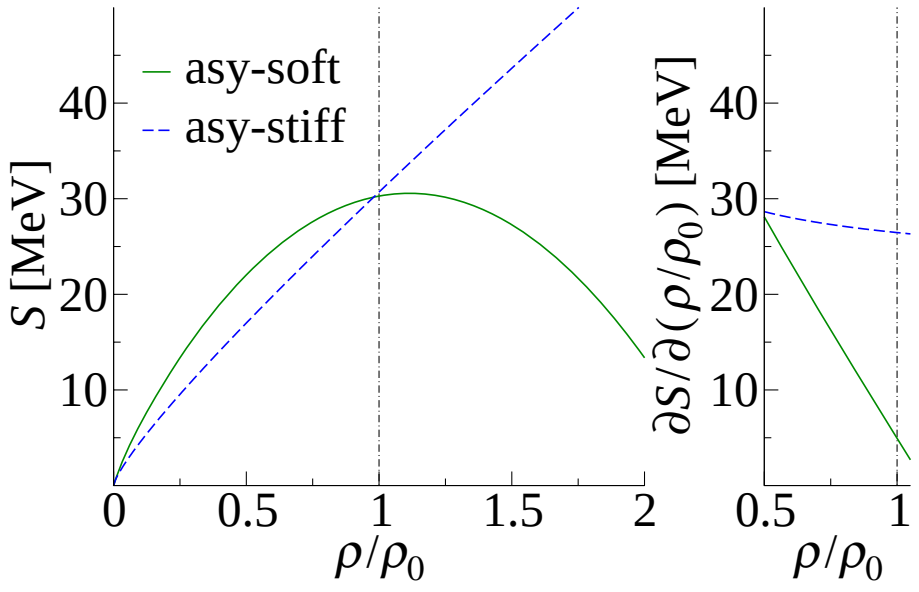
$$j_n - j_p \propto \underbrace{\mathcal{S}(\rho)\,\nabla I}_{\textit{diffusion}} + \underbrace{[\partial\mathcal{S}(\rho)/\partial\rho]\, I\,\nabla\rho}_{\textit{migration}}$$

We simulate different combinations :

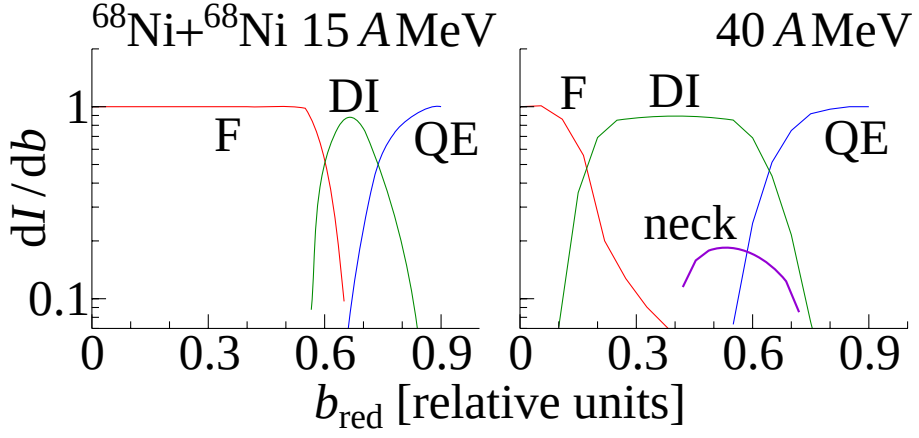
$^{58,\,68}$Ni+$^{58,\,68}$Ni at 15, 40 A MeV

- $b \rightarrow$ poor mechanism selection

Form of $\mathcal{S}$ and derivative :



Centrality selection :



EOS and the merciless decay

Dynamical stage (SMF)

- till break-up within 260 fm/c
- Hot fragments

Simple isospin observables discriminate among different $\mathcal{S}_{pot}$ forms (even N/Z in stable beams !)

$\rho < \rho_0 \rightarrow \mathcal{S}_{stiff} < \mathcal{S}_{soft} \Rightarrow$

Symmetric systems :

Asy-soft : larger reduction of N/Z

Asymmetric systems :

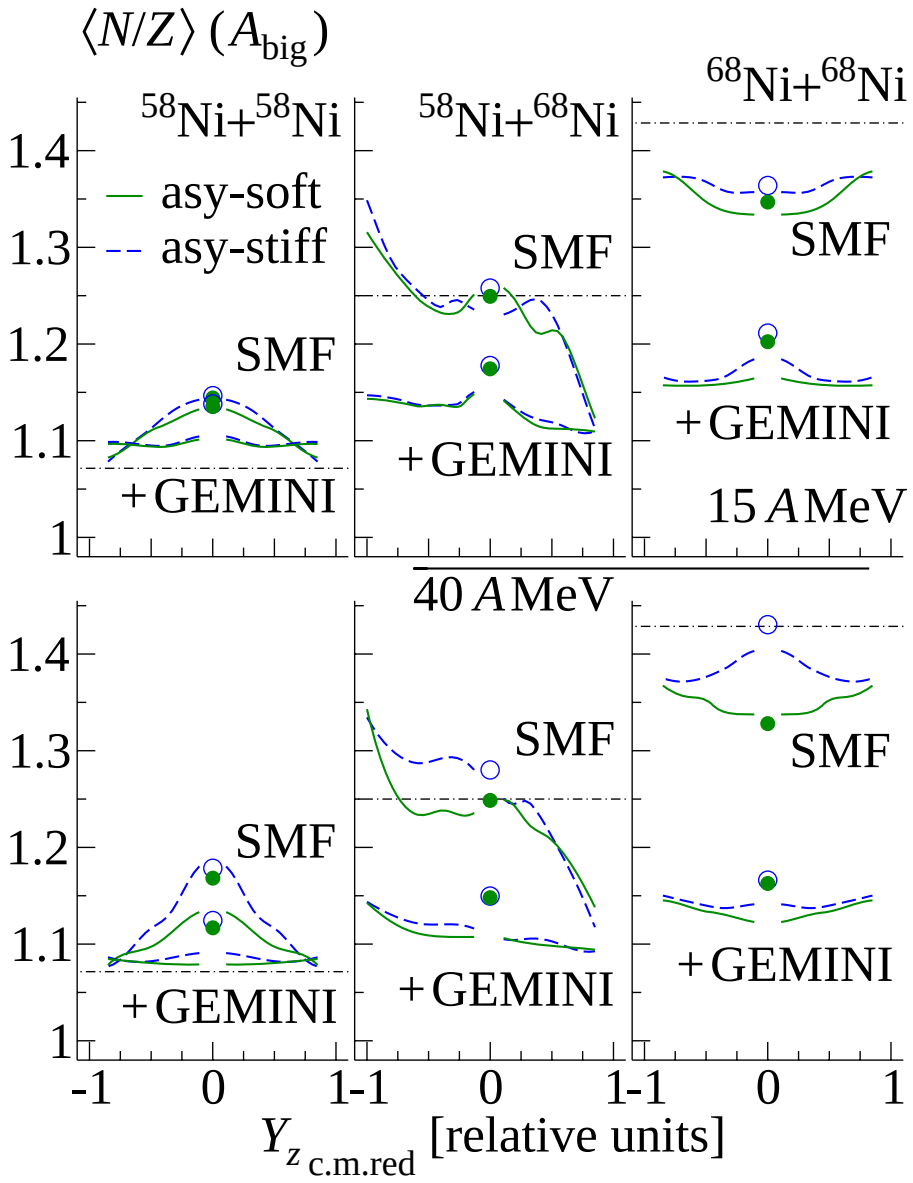
Asy-soft : Diffusion more effective

$\Rightarrow$ QP more similar to QT (mid Y)

Evaporation stage (Gemini)

- Model dependent
- Residue corridor

Severe blurring of isospin signals



Experimental filter (Panforte)

4π charged particle detector

two extreme situations :

FAZIA : Z, A measured

- |Si|Si|CsI|→if E_k+TOF⇒ Z, A

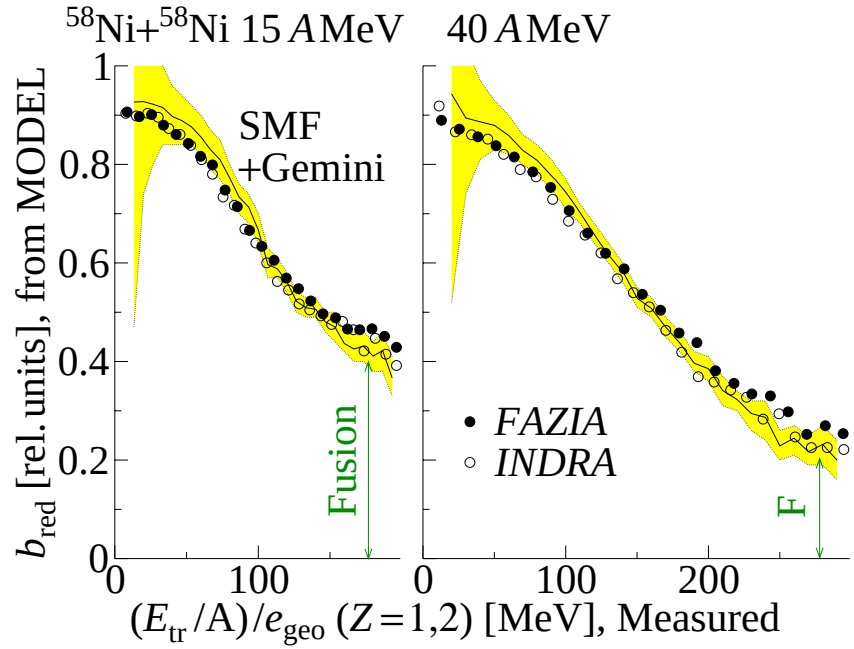
INDRA : Z measured, $A = f(Z)$

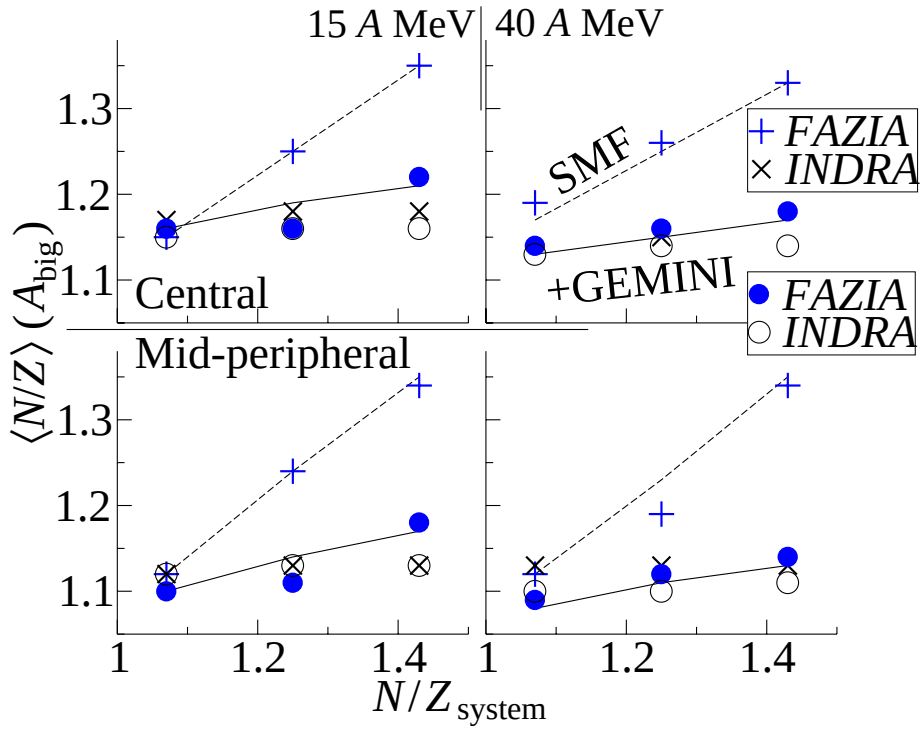
This is a lower-limit expectation compared to a real experiment

Basic data analysis

- $b \rightarrow$ any apparatus
- $\langle N/A \rangle (A_{\mathrm{big}}) \rightarrow I$ sensitive
- exotic : better retracing

We search for other observables less sensitive to the decay →





Imbalance ratios

Isotopic observable :

$x = \langle N/A \rangle (A_{big}) \neq$ *fusion*

(other works : isoscaling, isobaric yield ratios [MSU], N/Z(LCP)...)

x(rapidity) → more directly connected to dissipation

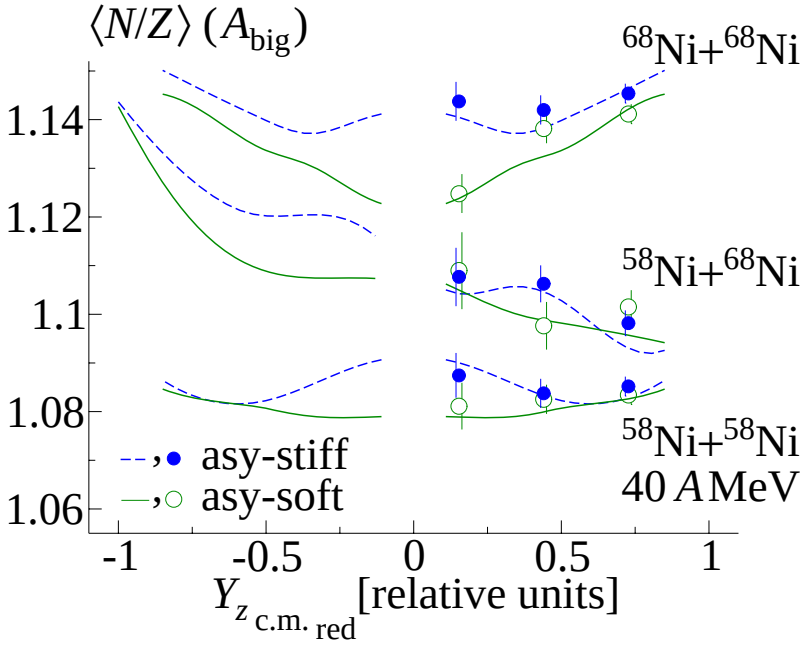
(E_{tr} affected by preequilibrium and cluster decay)

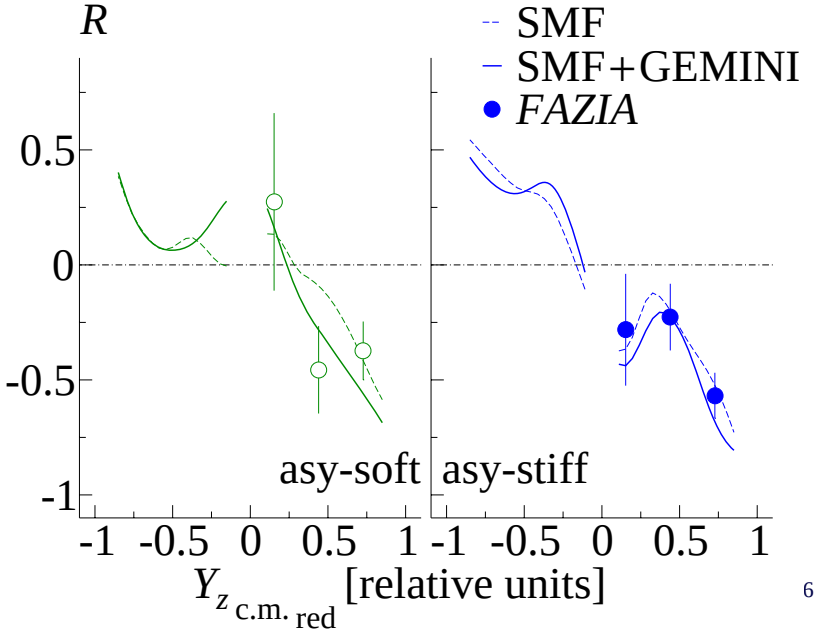
I equilibration

$$R = \frac{2x_{58+68} - x_{68+68} - x_{58+58}}{x_{68+68} - x_{58+58}}$$ (F.Rami)

- *Sensitivity to I diffusion enhanced*
- *preeq. effects removed*
- *I signals after decay preserved !*

but : essentially due to ^{68}Ni+^{68}Ni, where the residue corridor isn't reached





Preequilibrium emission

Analysis

- Restrict to *n, p*

(t, ^{3}He,. . .are model dependent and beyond SMF)

- *n* specra measured by DEMON (shape) + event reconstruction in FAZIA/INDRA (integral)
- Select high-energy side of specra
- Select fusion out

Observables

- *Asy-soft*, $\rho < \rho_0 \Rightarrow$ larger S

$\Rightarrow$ *Larger preeq. emission of n*

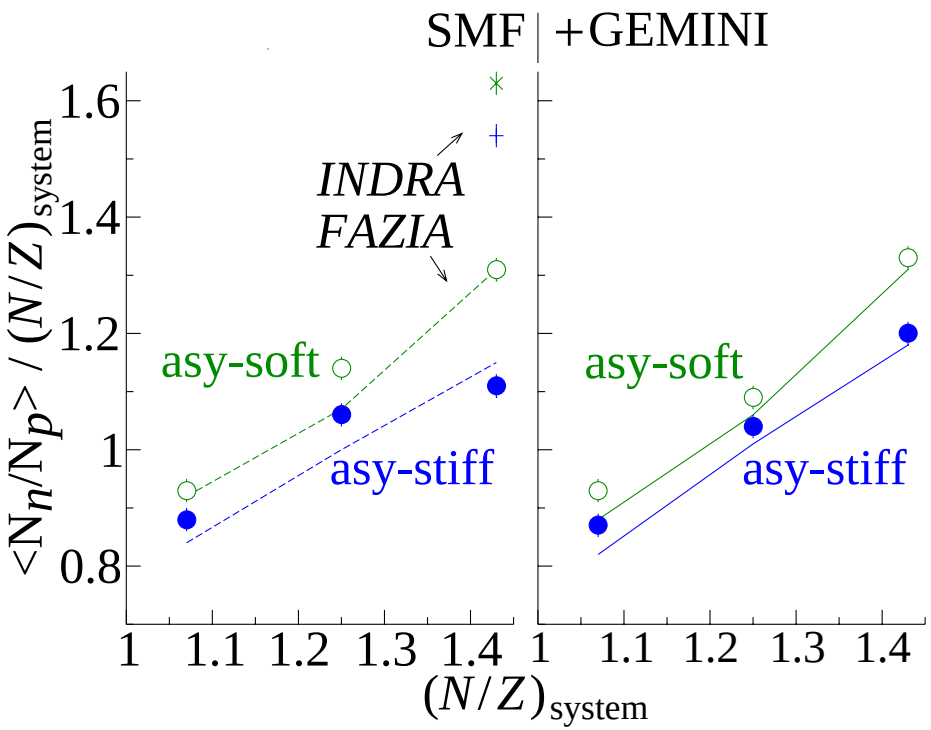
- *Decay feeds the residue corridor*

15 A MeV

Compression-expansion around ρ_0 reduced $\Rightarrow$ small signal

40 A MeV

Isotopic content of preeq. emission sensitive to $S(\rho < \rho_0)$ even for non-exotic systems :



Neck

I migration towards the diluted neck

Semiperiph ^{68}Ni+^{68}Ni 40 *A* MeV

Select ternary events : QP residue + QT residue + IMF ($Z > 5$) *at midY*

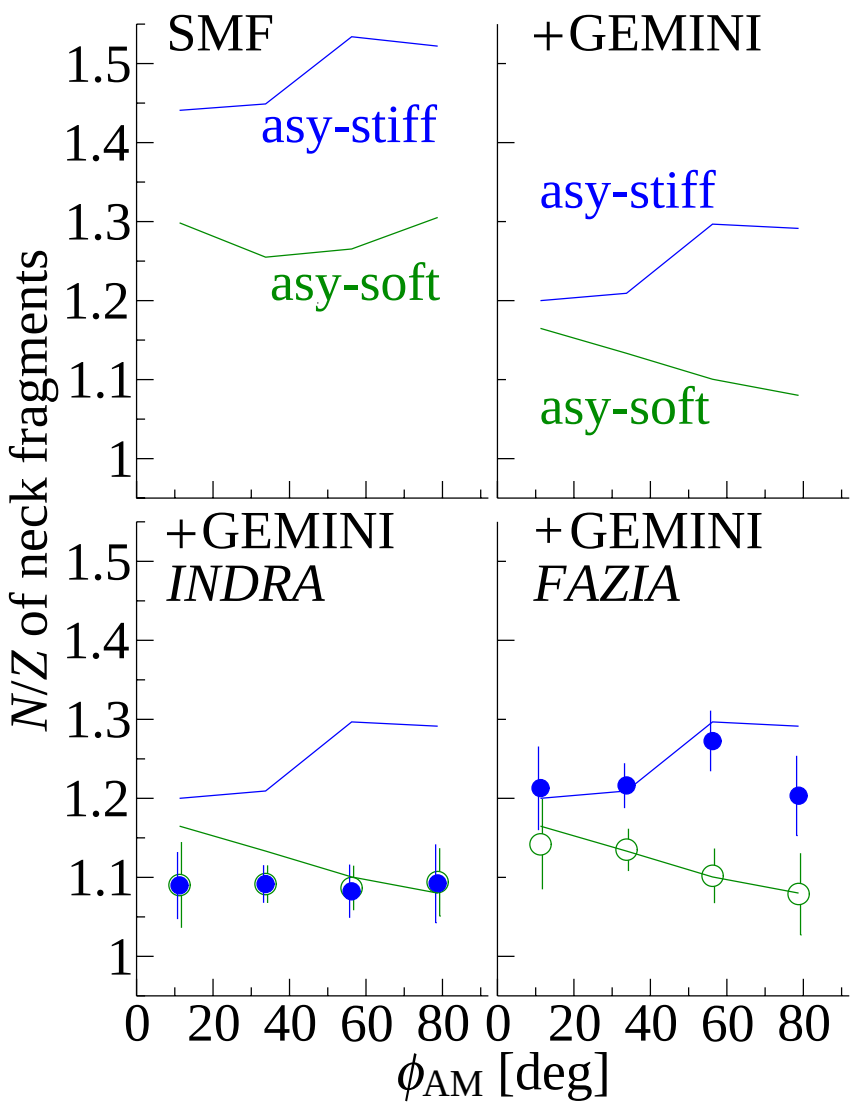
n enrichment $\propto$ dS/dρ driven by $\nabla\rho$

more effective when :

- *stiffer iso-EOS*
- *longer contact time* (and larger v_{tr})
  - this occurs at large ϕ_{AM} due to smaller *b* (asy-stiff)
  - But *at small b* E^* *is larger*

+ secondary decay

- *asy-stiff* : corridor not reached, systematic decrease
- *asy-soft* : longer decay towards the corridor for more excited fragments



ϕ_{AM} = smallest misalignment between $\vec{V}$ and QP-QT

Conclusions

Comparing I-blind to I-sensitive strategies at Fermi energies

Significant bias from secondary decay

to cure with :

- *Exotic systems* (longer path towards the corridor)
- Fragments which do not undergo long decays
- Suitable *combinations of isotopic observables* (*R*)
- Probing the *preequilibrium* phase
- *Neck dynamics*
  - greater effect with exotic system
  - *but also stable beams : De Filippo APPB40(2009)1199*
  - *Lower beam energies ?*

Measuring *A* of all reaction products

- more sophisticated *I* observables
- more observables to probe different reaction stages
- *Complete event reconstruction*, finer selections