Elie, a phenomenological model for reactions at intermediate energies: first comparisons with INDRA data (central collisions)

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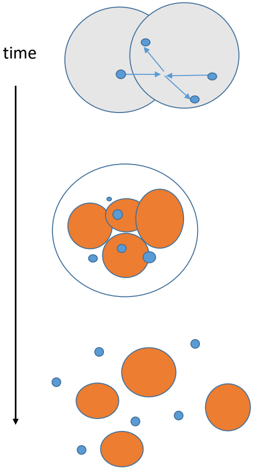
The Elie event generator: main hypothesis



Central collisions at intermediate energies:

- initial conditions (geometry: all nucleons, momentum distribution: **f(p)**)
- two-body dissipation by nucleon-nucleon collisions modifies **f(p)**
- n-n collisions driven by **σ in-medium** estimated by comparison with data

σ in-medium (ρ) is a key (highly discussed) quantity in nuclear physics

Compression phase:

- mean medium density **$\langle\rho\rangle$** as a free parameter of the model
- pre-fragments produced in high density phase by exploring random aggregation in momentum space depending on **f(p)** and **$\langle\rho\rangle$**
- persistency: pre-fragments survive expansion phase
- pre-fragments produced at temperature **Tlim**
- **Tlim** ~ 5.5 MeV limiting temperature determined by causality
- fragment life-time larger than reaction time

Final state interaction and secondary decay:

- Coulomb final state interaction (Vfreeze-out fixed by low beam energy data)
- additional collective energy (Ecollective) induced by compression phase
- Ecollective depends on EOS (K= 240 MeV, $\langle\rho\rangle$)
- secondary decay: light particle evaporation (**Tlim**)

Fragment (Z>2) production at high density

- assume pre-fragment of mass A by chosing randomly A nucleons among the participants (high density phase) and consider bulk effect only

$$E_A^{min}(\rho) = E_{kin}(\rho) + E_{pot}(\rho) \tag{1}$$

$$E_A^{max}(\rho) = E_{kin}(\rho) + E_{pot}(\rho) + a(\rho)\,T_{lim}^2 \tag{2}$$

$$a(\rho) = \frac{1}{10}\left(\frac{\rho}{\rho_0}\right)^{\frac{-2}{3}} \tag{3}$$

$$E_A^{Elie}(\rho) = E_{pot}(\rho) + E_{kin}^{Elie}(A) \tag{4}$$

$$E_{kin}^{Elie}(A) = \sum_{i=1}^{A} E_{kin}^{internal}(i) \tag{5}$$

- fragment is considered if and only if:

$$E_{kin}(\rho) < E_{kin}^{Elie} < E_{kin}(\rho) + a(\rho)\,T_{lim}^2 \tag{6}$$

- constraint (6) determines the fragment mass (charge) distribution
- small clusters (A=2,3,4) and free particles are also considered (no time to discuss this)

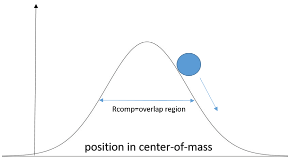
Compression effects and collective motion

- when ρ is larger than ρ_0: expansion is taken into account by a repulsive potential;
- chose an EOS (Skyrme) with a given compressibility modulus, K;

$$E_0 \simeq A_{zp} \frac{K}{18} \frac{(\rho - \rho_0)^2}{\rho_0^2} \tag{7}$$

- for a fragment of mass A

$$E_{coll} \propto A exp(-\frac{r^2}{2R_{comp}^2}), \sum E_{coll} = E_0 \tag{8}$$



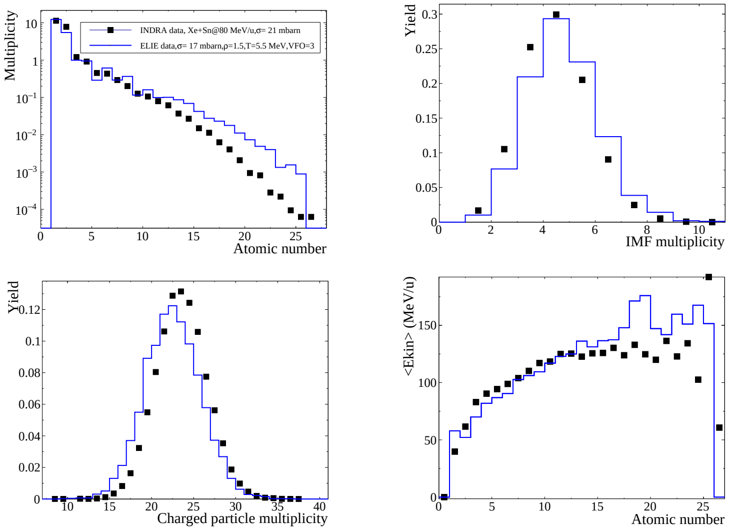
- the compression in the overlap zone adds a collective energy to the Coulomb repulsion between the fragments, this allows to estimate the density by comparison with the experimental data;

Comparison with INDRA data for central collisions

- comparaison with INDRA data: symetric collisions from Ni+Ni up to Au+Au collisions between 25 and 100 MeV/u
- selection criteria based on flow angle and completion of the events (only particles at forward angles in CM)
- results are expected to be not very sensitive to secondary decay model (barriers,level density) because excitation energy is moderate $\simeq 3MeV/u$;
- T_{lim} dependence is weak and mainly affects total particle multiplicity;
- freeze-out volume is fixed at low incident energy (no compression effects, $V_{FO} \simeq 3V(\rho_0)$) by studying fragment kinetic energy spectra;
- the only remaining free parameters are the density in the overlap zone and the value of σ_{NN}^{medium};
- $Y(Z) \propto \rho^{\frac{2}{3}}$;
- the amount of free nucleons depends on $E_{pot}(\rho)$ (EOS);
- $< E_{kin}(Z) > \propto \rho^2$;
- the number of NN collisions depends on σ_{NN}^{medium} (here $\propto \rho^{-\frac{2}{3}}$), it affects strongly the isotropy ratio (study of the stopping power);

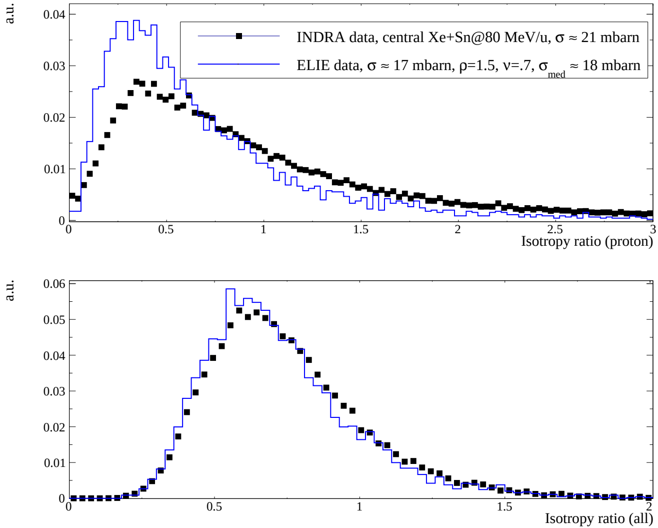
Results

- preliminary: Xe+Sn @80 MeV/u, $\frac{\rho}{\rho_0} \simeq 1.5$



In medium cross-section vs isotropy ratio

- isotropy ratio 'measures' stopping power and degree of thermalisation



Summary

- rather good agreement between INDRA and Elie data;
- results suggest that fragment production is a fast process occuring at high density (early instants of the reaction) governed by a random exploration of the non thermalised nucleon momentum distribution;
- study of isotropy ratio suggests evidence for nuclear transparency, $\lambda > R$, due to the quenching of the N-N in-medium cross-section and to Pauli blocking effects;
- 'universal' in-medium σ_{NN}^{medium} value may be reached at Fermi energies, independently of the σ_{NN}^{free} in vacuum
- $\sigma_{NN}^{medium} = \nu \rho^{-\frac{2}{3}} \simeq 20 mbarn$ with $\nu \simeq .7$ at $\rho = .17 fm^{-3}$
- evidence for compression effects (study of $< E_{kin}(Z) >$) modelized by a collective potential linked to ρ and K, the compression modulus;
- preliminary results: compression starts around 30 MeV/u, reaches (with K = 240 MeV) $\simeq$ 1.2 @50 MeV/u and $\simeq$ 1.5 @ 80-90 MeV/u;
- systematics of $\frac{\rho}{\rho_0}$ for Ni+Ni, Xe+Sn and Au+Au between 30 and 100 MeV/u
- link with the results of microscopic transport models
- application to reactions with varying N/Z systems
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