High-resolution experiments on projectile fragments – A new approach to the properties of nuclear matter

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Fundamental questions: How does the nuclear matter „look like"? How does it behave under extreme conditions: high densities and temperatures, extreme N/Z ratio...?

Why high-resolution experiments?

Heavy residues → Liquid phase: Sensitivity to the temperature of a possible phase transition. *Needs* : full identification in MASS and NUCLEAR CHARGE over whole nuclear chart!

Transport theory (Shi et al., PRC 64 (2001) 034061) → Longitudinal momentum of heavy fragmentation residues is selectively sensitive to the momentum dependence of the nuclear mean field. *Needs* : high-precision momentum measurements!

⇒ High-resolution magnetic spectrometer FRS-GSI

New observables:

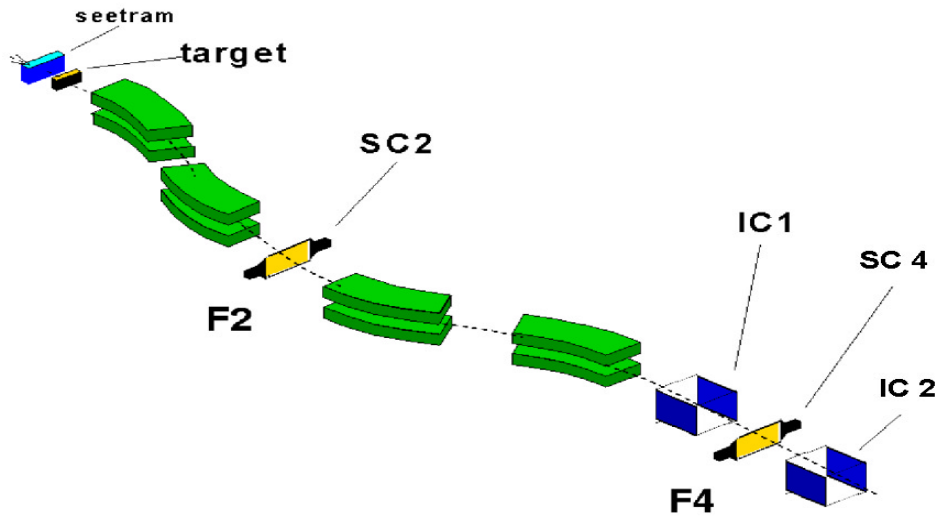
- Isospin thermometer (*K.H. Schmidt et al., NPA 710 (02) 157*) → Thermal instabilities in nuclear matter.
- Spectator response to the participant blast (*M.V. Ricciardi et al, PRL90 (03) 212302*) → Momentum dependence of the nuclear mean field.

Experiment at the FRS - GSI

- **TOF (F2 → F4):** $\Delta TOF \sim 100$ ps

$\Rightarrow \quad \Delta(\beta\cdot\gamma)/(\beta\cdot\gamma) \sim 2.5 \cdot 10^{-3}$

- **x(F2), x(F4):** $\Delta x \sim 3$ mm
- **B_1, B_2:** $\Delta B/B \sim 5 \cdot 10^{-4}$
- **$\Delta E \rightarrow$ Z (fully resolved)**



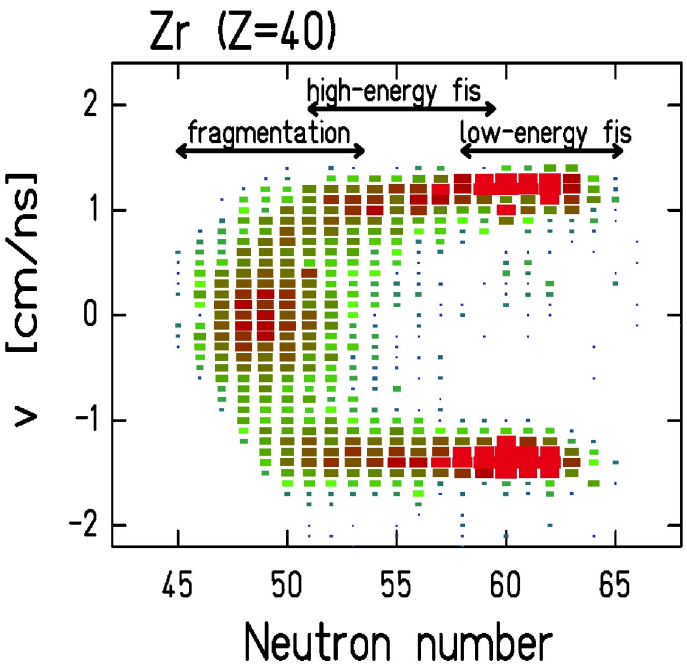
$$\frac{A}{Z} = \frac{e}{m_0 c} \cdot \frac{B\rho}{\beta \cdot \gamma}$$

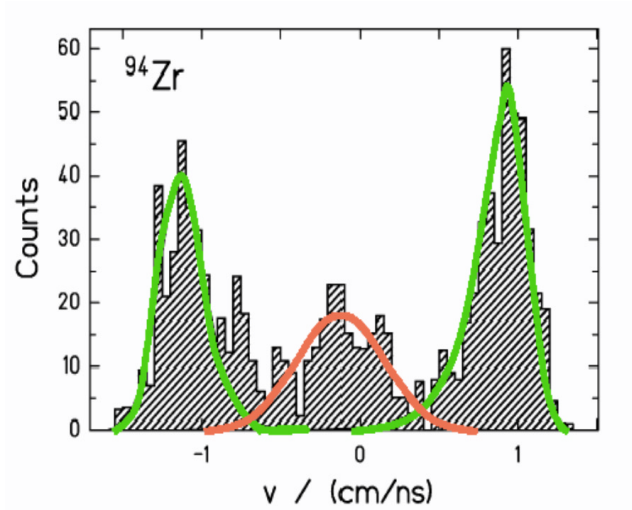
$\Delta A/A \sim 2.5 \cdot 10^{-3}$

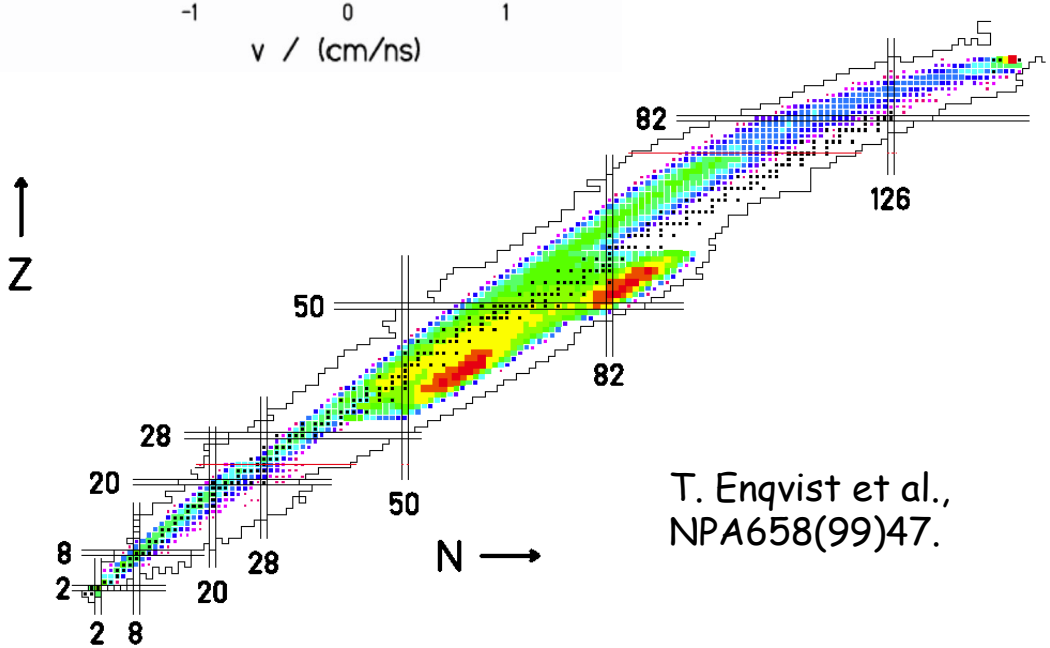
After identification of Z and A (Z and A are integer numbers) Bρ provides velocity with high precision → resolution of $5 \cdot 10^{-4}$ in $\beta\cdot\gamma$!

But: No correlation to other products, low acceptance for fission fragments and very light fragmentation residues ($A \lesssim 18$).

Experimental results – e.g. ^{238}U + Pb 1 A GeV





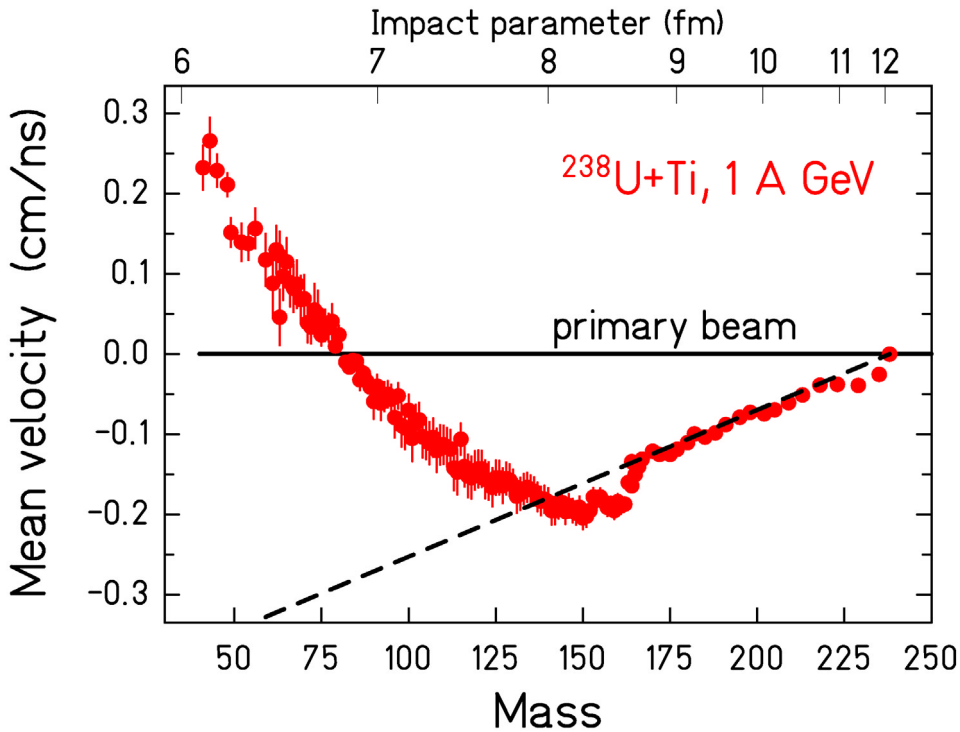


T. Enqvist et al., NPA658(99)47.

Systematic information on nuclide distributions and velocities!

Response of the spectator to the participant blast

-M.V. Ricciardi et al., PRL 90 (2003) 212302 -



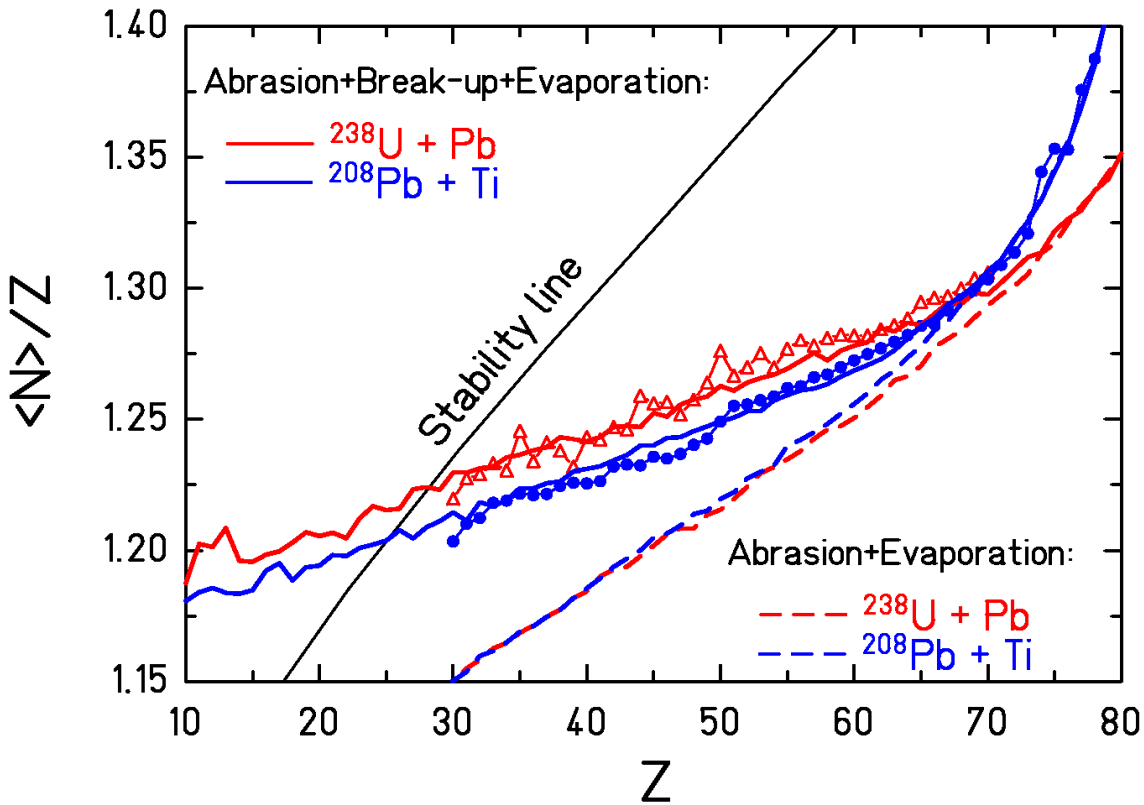
More details ⇒ Poster V. Henzl

The data give an early signature (the acceleration of the spectator is acquired during contact with the fireball). Sensitivity to the momentum dependence of the nuclear mean field.

Valuable basis for general verification of transport calculations!

Isospin thermometer – tracing-back T at the freeze-out

– K.-H. Schmidt et al., NPA A 710 (2002) 157 –



More details ⇒ Talk D. Henzlova

Light residues keep the memory of the initial $N/Z \Rightarrow$ Isospin thermometer

$T_{freeze\text{-}out} \approx 5$ MeV $\Rightarrow$ Compatible with the caloric curve of ALADIN.

Conclusion

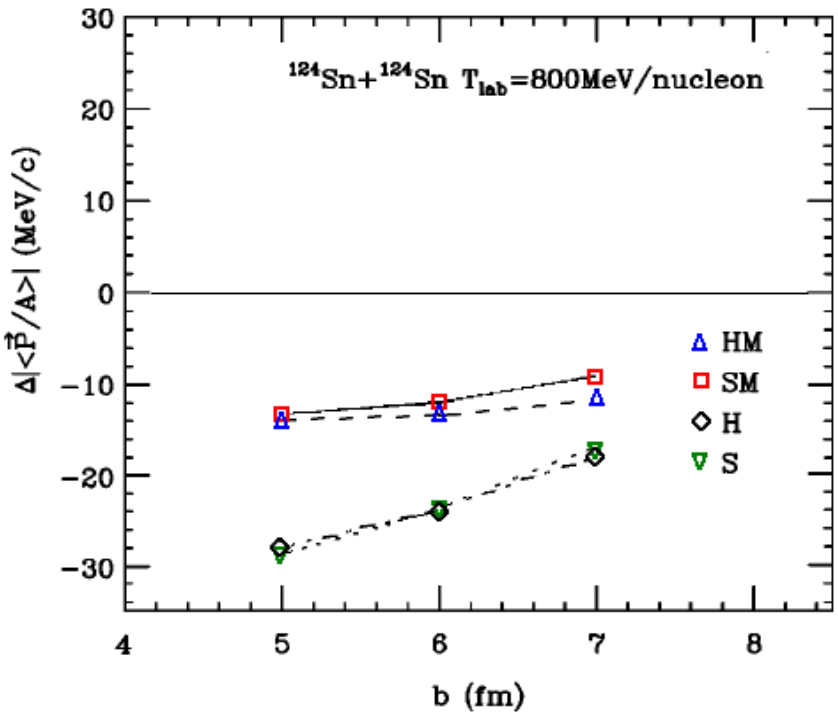
Valuable complementary information on the properties of hot and dense nuclear matter with high-resolution magnetic spectrometers.

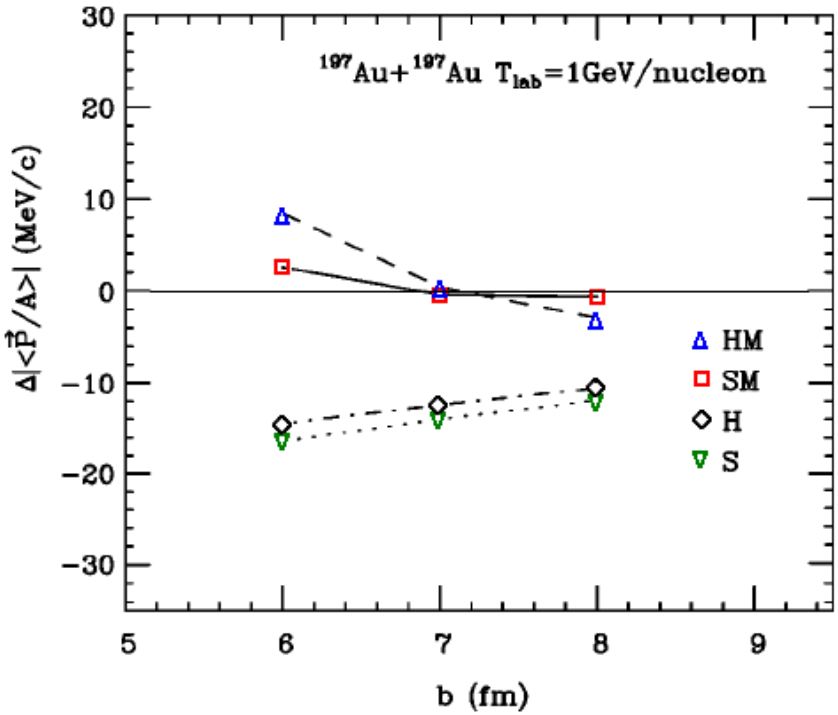
More $\Rightarrow$ http://www-w2k.gsi.de/kschmidt/

Response of the spectator to the participant blast

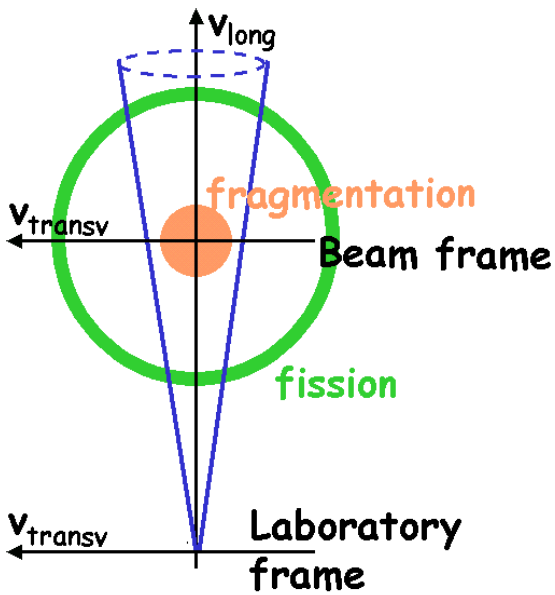
L. Shi, P. Danielewicz, R. Lacey, PRC 64 (2001)

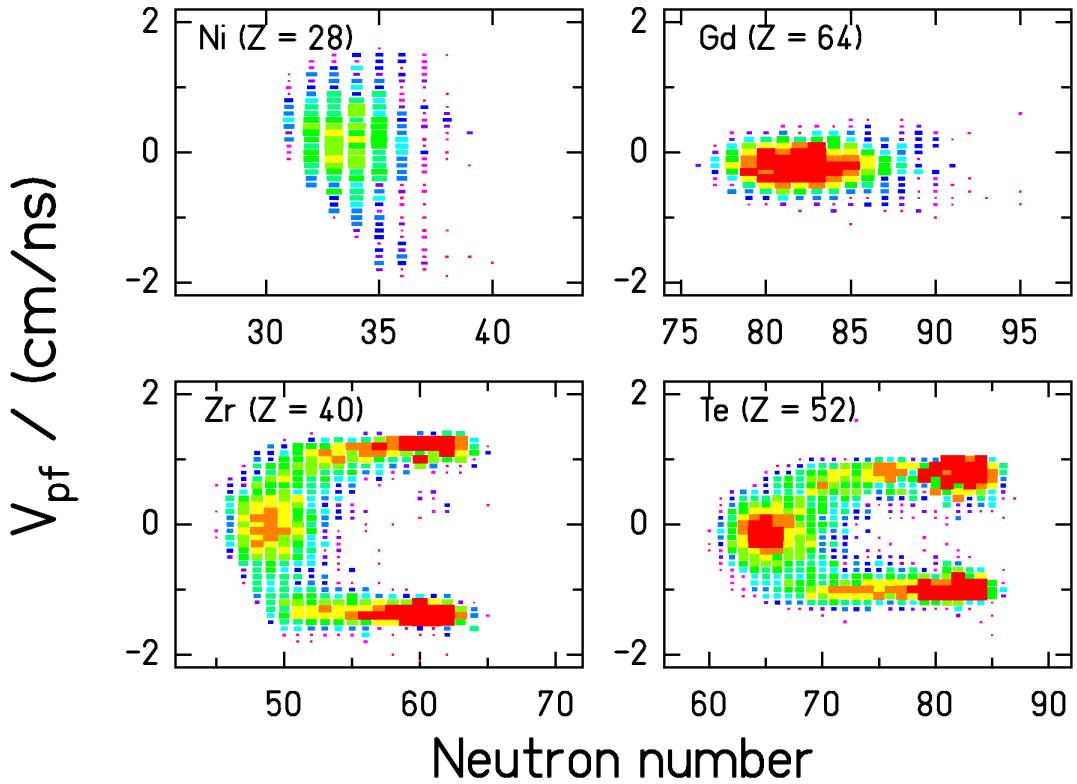
BUU calculations : ^{124}Sn +^{124}Sn (0.8 GeV/u) and ^{197}Au + ^{197}Au (1 GeV/u)





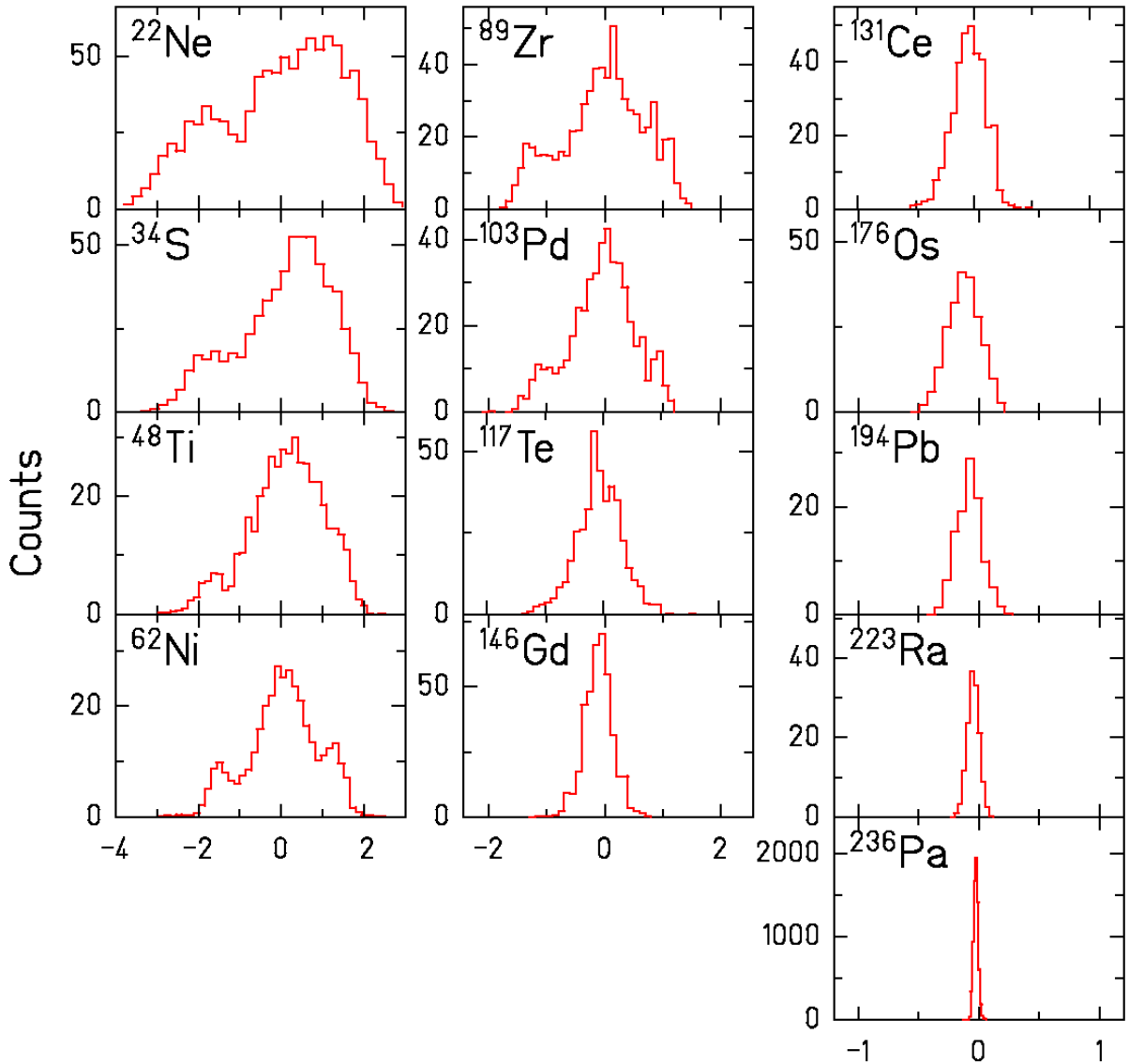
How to distinguish fragmentation and fission?





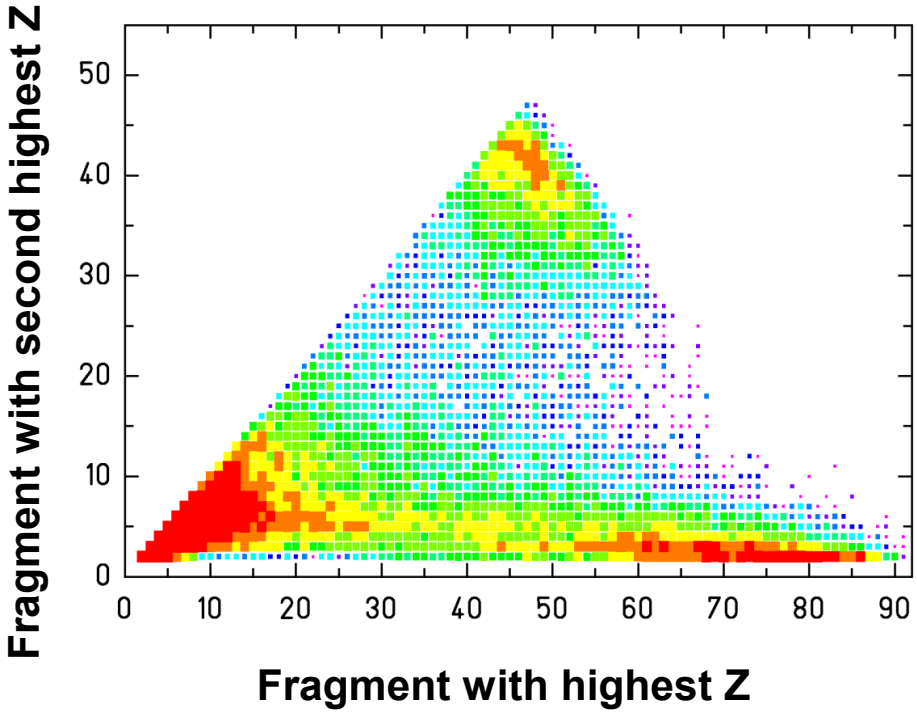
Fragmentation: Almost always fully accepted.
Fission: Only forward and backward component accepted.

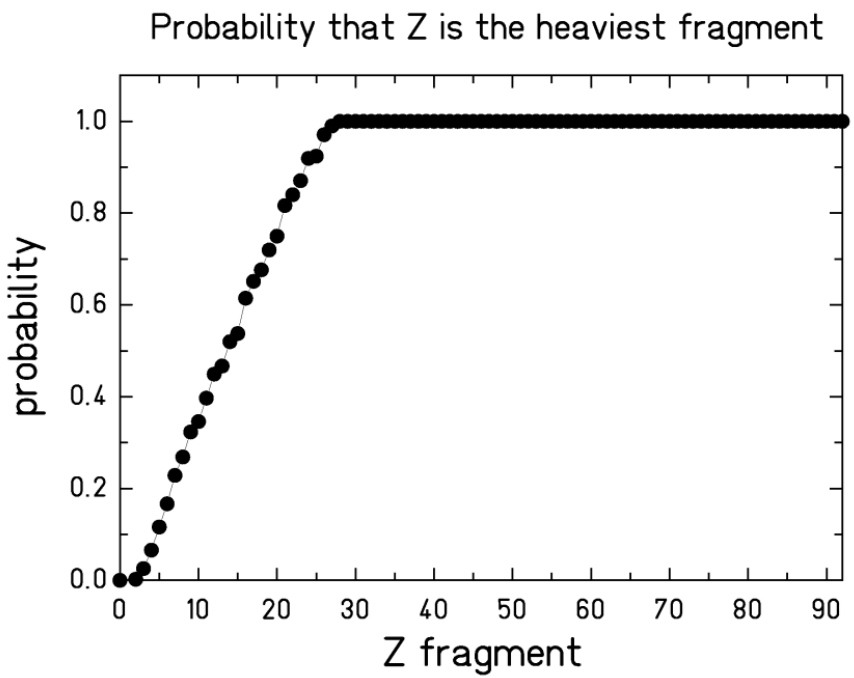
^{238}U + Ti, 1 *A* GeV: M.V. Ricciardi, J. Pereira, PhD-Thesis



List-mode data provided by the ALADIN group and analysed by M. V. Ricciardi

^{238}U + Cu, 1 A GeV





Separation between multifragmentation and fragmentation.

Z > 20 is the heaviest fragment in the reaction