Response of the Spectators to the Participants Blast as a Probe of the Momentum-Dependent Nuclear Mean Field

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General motivation

Fundamental questions:

- *how does the nuclear matter „look like“?, how does it behave ? ...*

Astrophysical interest:

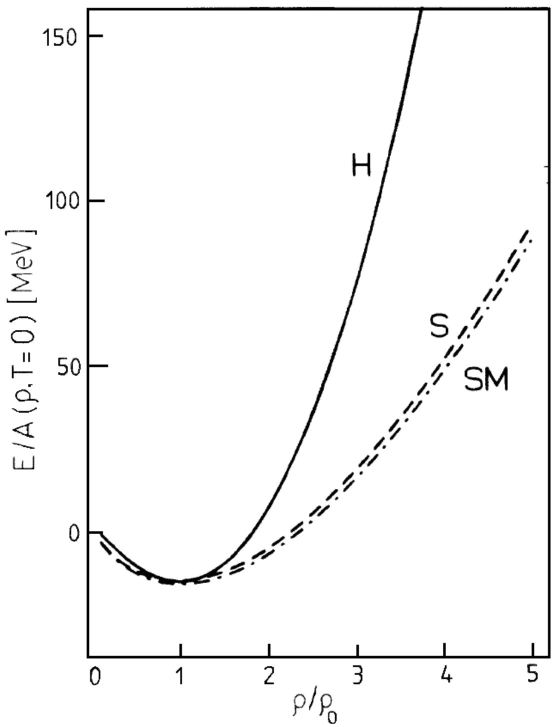
- evolution of the early universe
- supernovae explosions
- formation and stability of neutron stars

➡ influenced by properties of the NM under extreme conditions (high T, P, ρ)

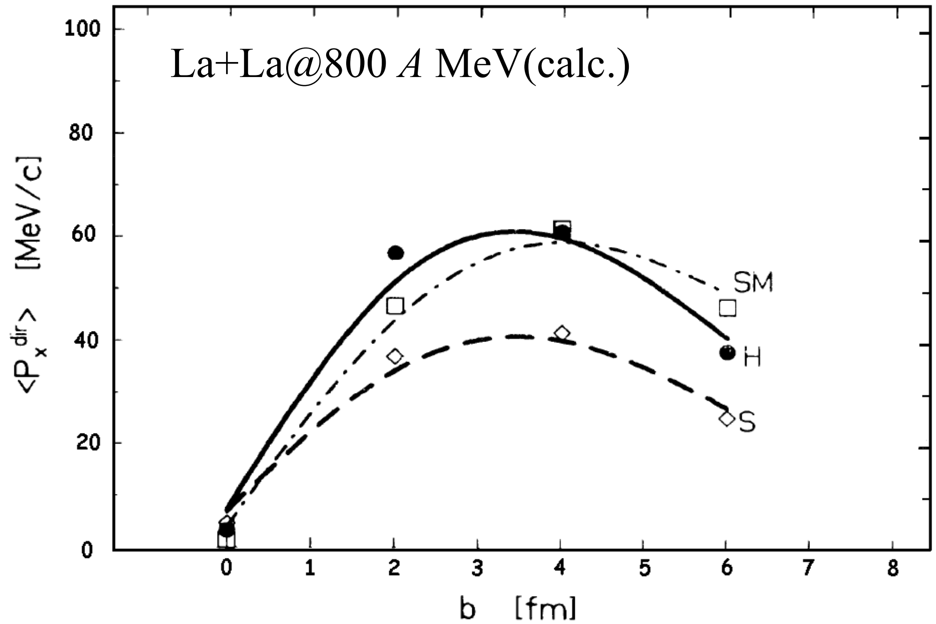
Properties of the NM:

- ***static*** – (in)compressibility, phase transitions, excitation…
- ***dynamic*** – viscosity, ***momentum dependence of the mean field*** …

Static *vs*. dynamic properties



Aichelin et al. PRL 58(1987)1926



Static properties are studied in dynamical processes !!!

<u>Problem:</u> most of the experimental observables are not selective;

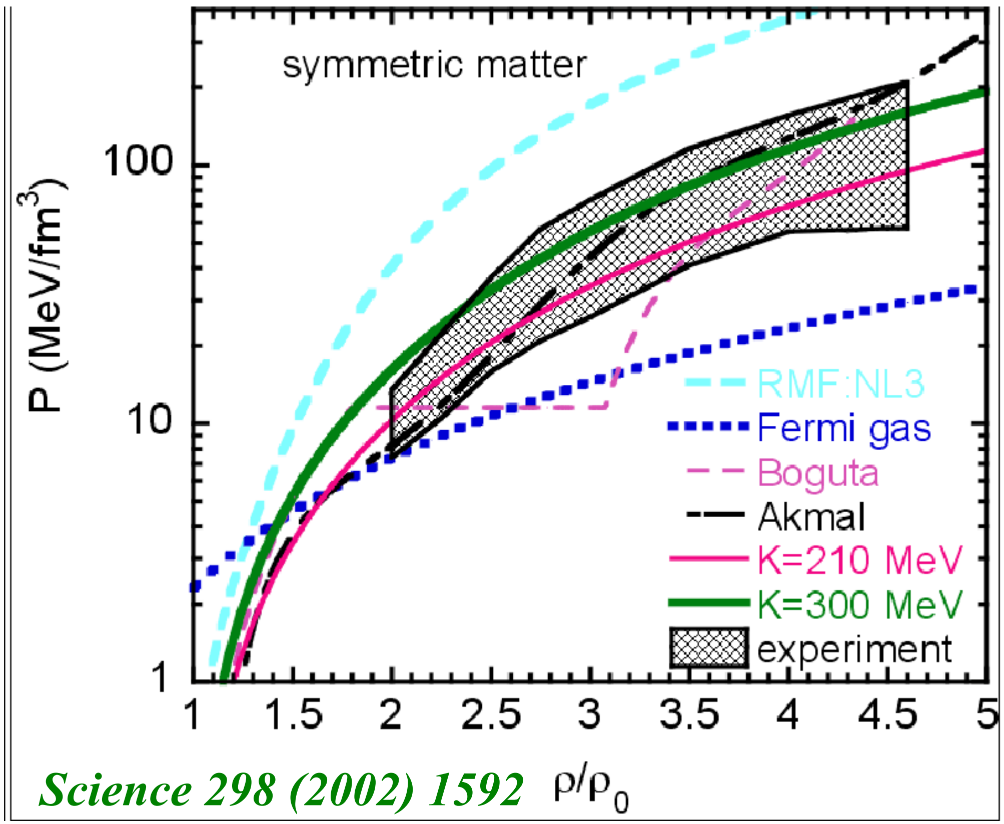
=> *the interpretation is influenced by competing phenomena*,

!!! The results are very often ambiguous !!!

Present knowledge

Recent analysis:
(Danielewicz et al.)

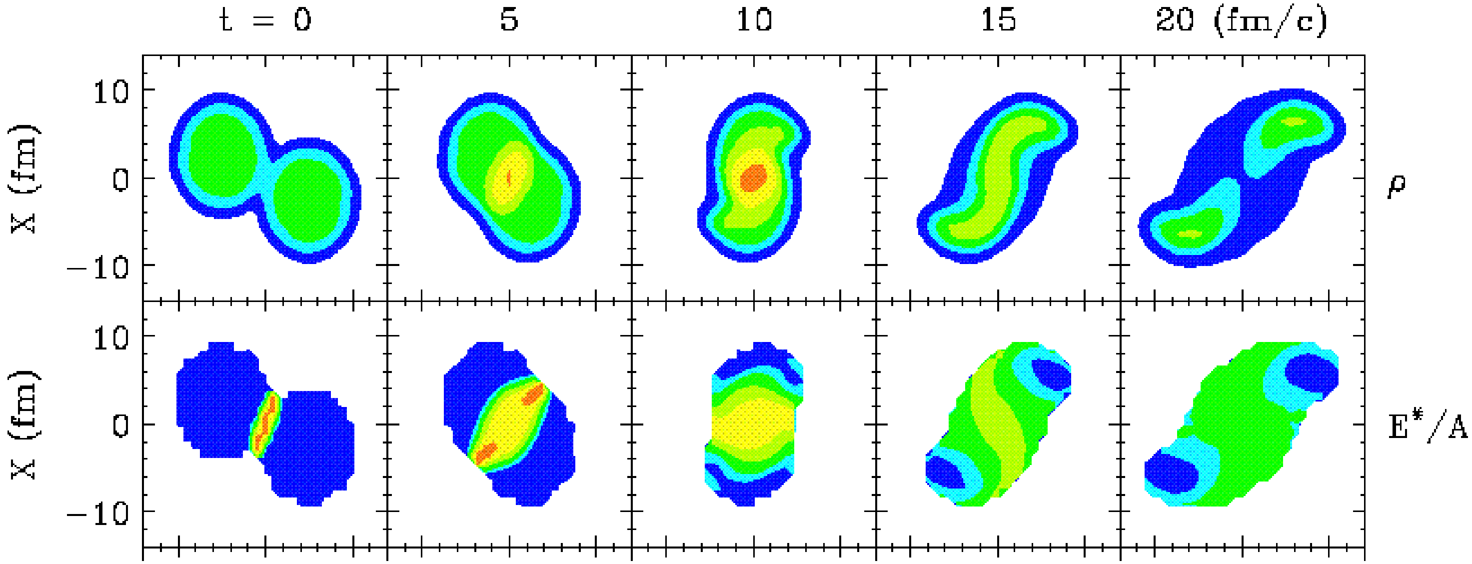
Possible values of the nuclear incompressibility constrained by the experiments.



Science 298 (2002) 1592

Only the most extreme models could be excluded by the experiment

Tools to investigate the nuclear matter



BUU calculations : $^{124}Sn + ^{124}Sn$ T_{lab}= 800 MeV/u   b = 5 fm

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

Standard tools: elliptic flow, sideward flow, transverse momentum, kaon production, …

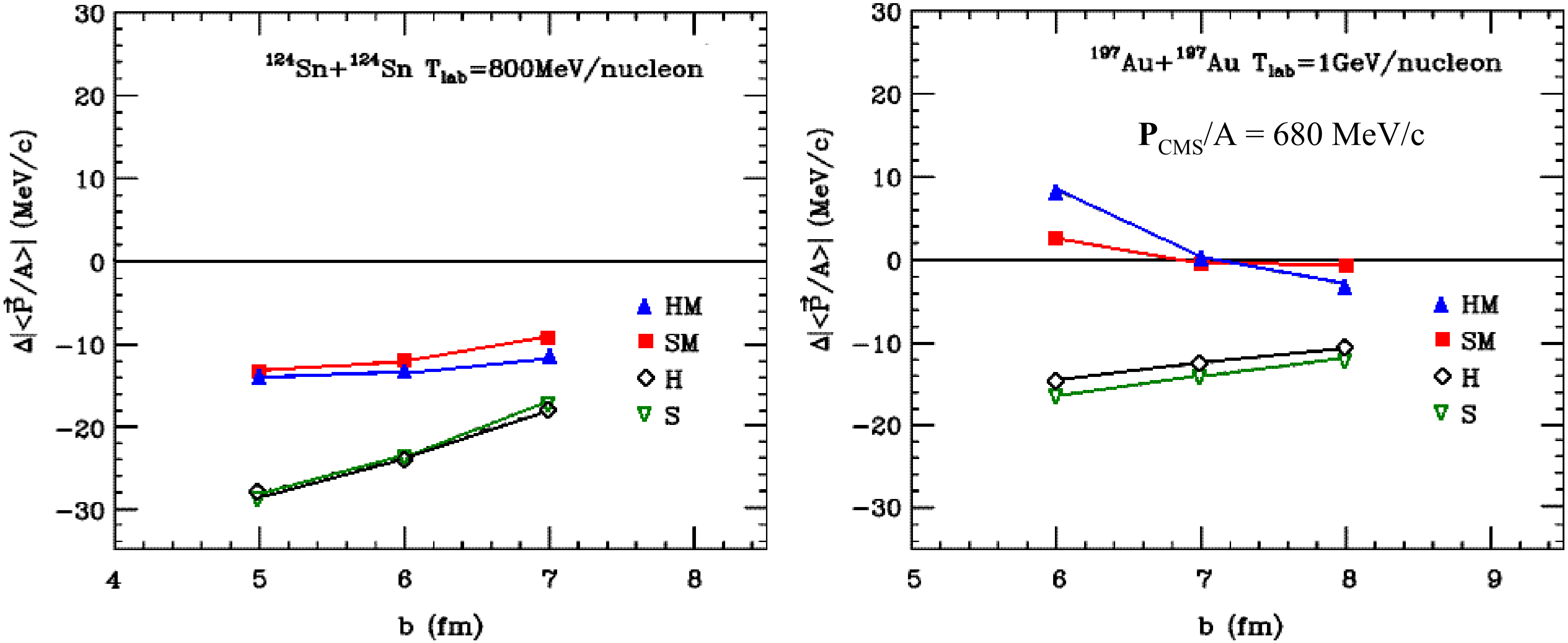
Spectator response: the ***spectator*** is not a ***passive witness,*** but rather a ***victim*** of a violent participants explosion!

- **L. Shi, P. Danielewicz, R. Lacey, PRC 64 (2001)**
- **M.V.Ricciardi *et al.* PRL 90(2003)212302**

! New !

*What can we learn from the **spectator response**?*

Theoretical calculations for 4 different EoS: *(Shi, Danielewicz, Lacey)*



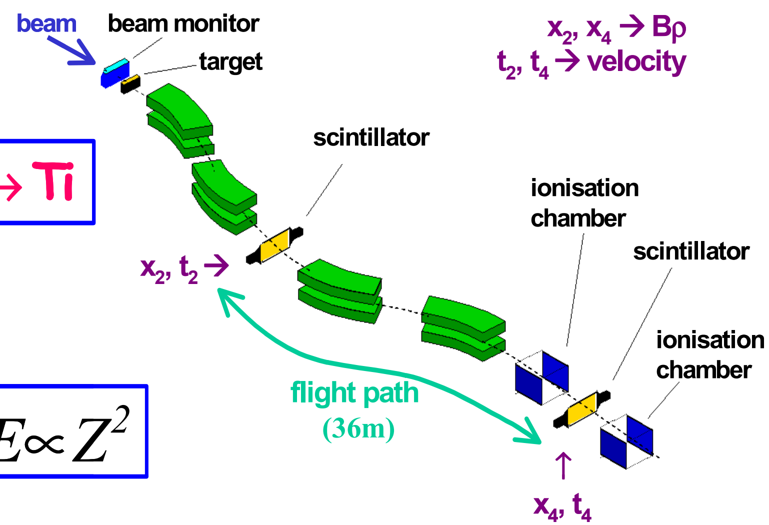
1) Change of the net momentum per nucleon (NM) depends on momentum dependence of the nuclear mean field (MF)
2) Dependence of NM change on stiffness of EOS is very small

Spectator response reflects the MD properties of the nuclear MF !!!

Experiment at the Fragment Separator

Inverse kinematics:

1 A·GeV ^{238}U → Ti



Z from IC: $\Delta E \propto Z^2$

A/Z from time and position: $\frac{A}{Z} = \frac{e}{m_0} \frac{B\rho}{c\beta\gamma}$

From ToF:

$\beta \cdot \gamma / \Delta\beta \cdot \gamma \approx 400$

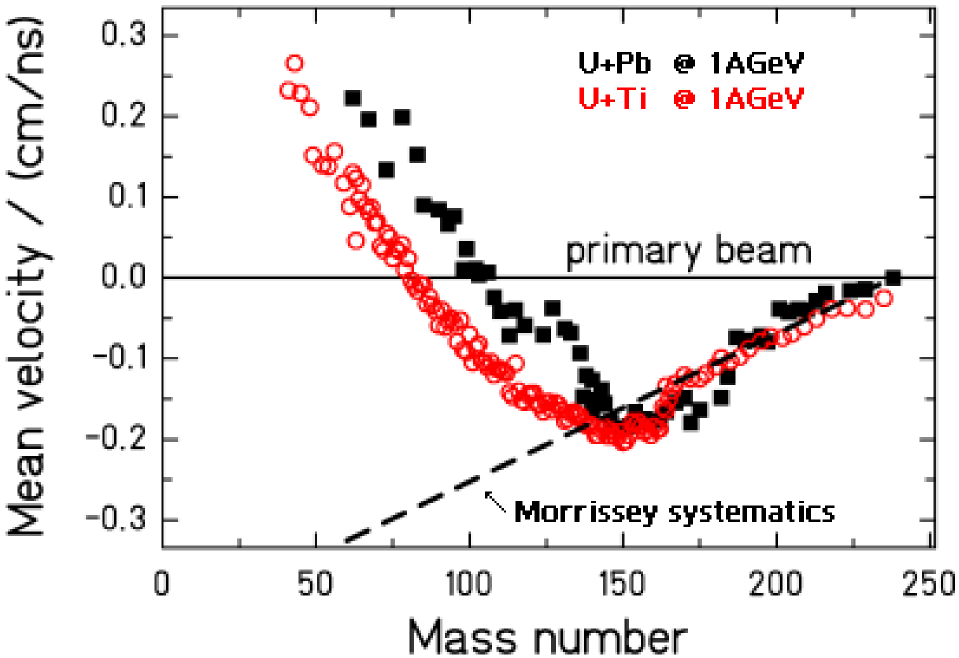
$\Rightarrow$ $A/\Delta A \approx 400$

Once mass and charge are identified (A, Z are integer numbers) the velocity is calculated from $B\rho$ => very precise determination!

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

$\beta \cdot \gamma / \Delta\beta \cdot \gamma = B\rho / \Delta B\rho \approx 2000$

Mean velocities of fragmentation residues



T.Enqvist *et al.*
NPA658(1999)47

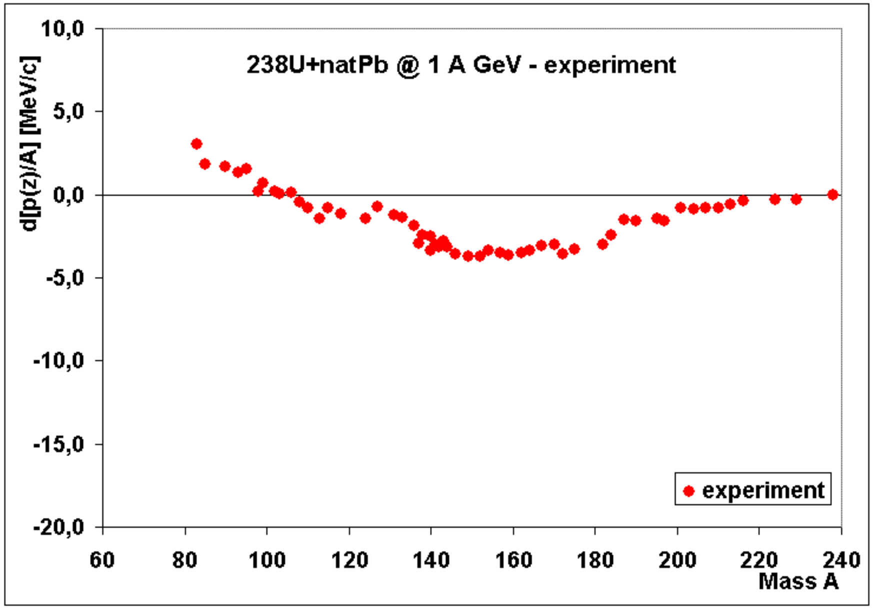
M.V.Ricciardi *et al.*
PRL 90(2003)212302

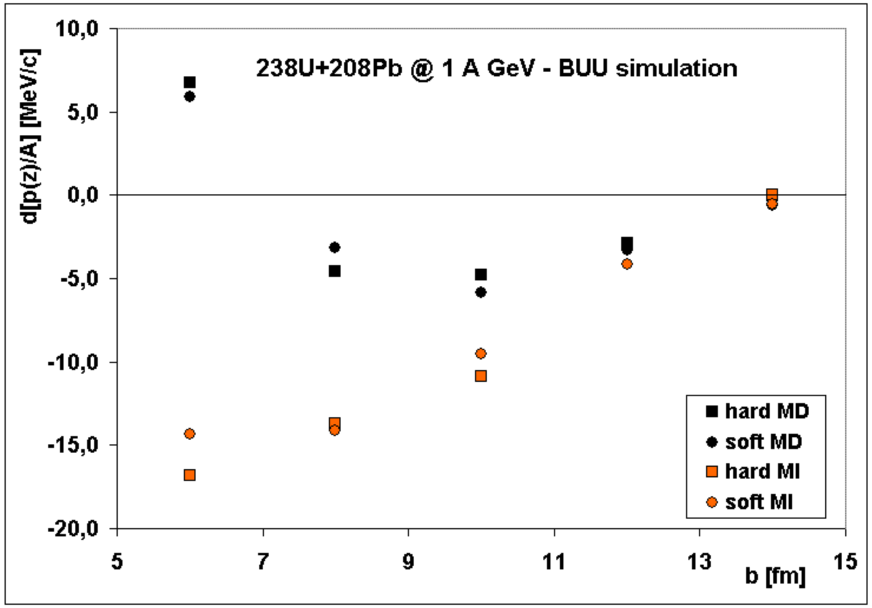
Fission events excluded !!!

• Experimental evidence for the **postulated response of the spectators to the participant blast.**

• Precise velocity measurement of projectile fragments provides **a novel access to investigate the MD of nuclear mean field**

Experiment vs. simulations *(op. I)*

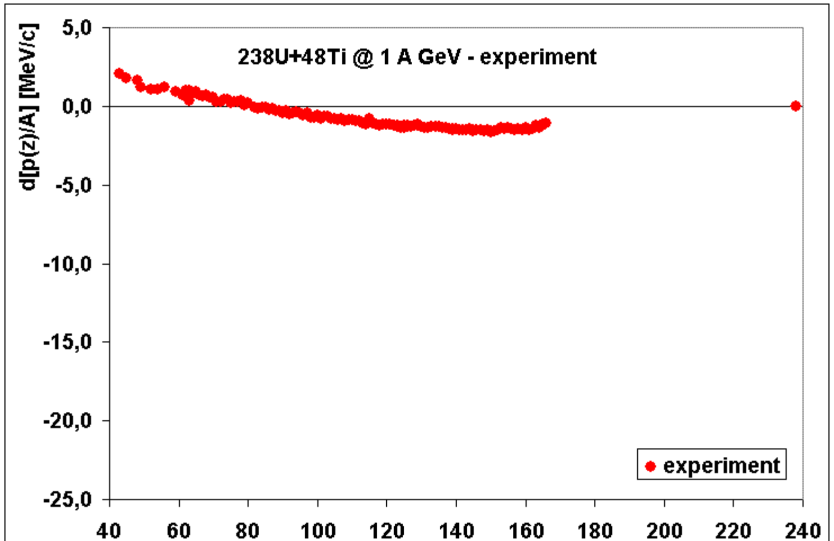




T.Enqvist *et al.* NPA658(1999)47

- BUU in qualitative agreement with the experiment
- Only MD MFs induce recovery of the fragment velocities with decreasing impact parameter
- **Spectator response is a selective tool** to access MD properties of MF.

Experiment vs. simulations *(op. II)*



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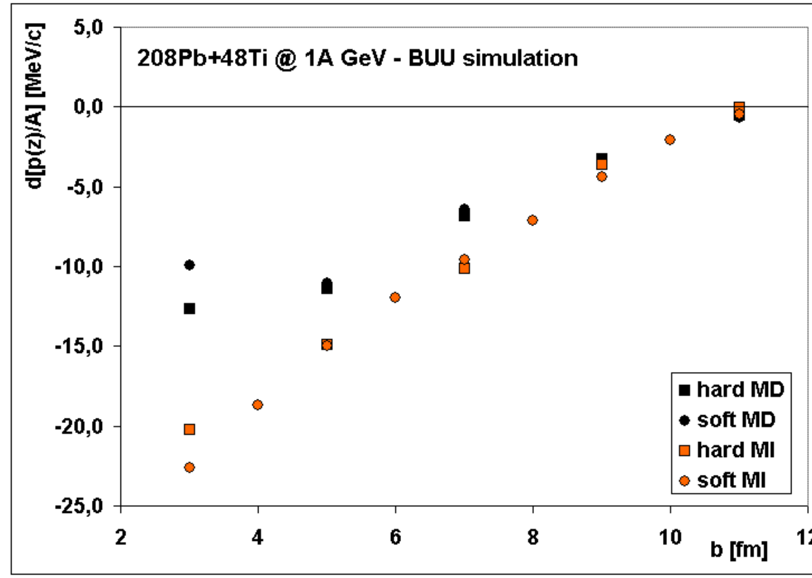
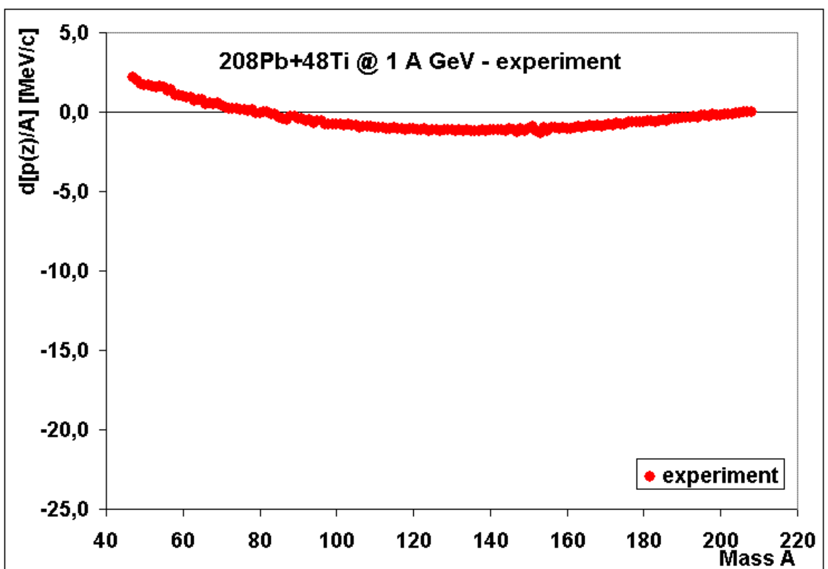
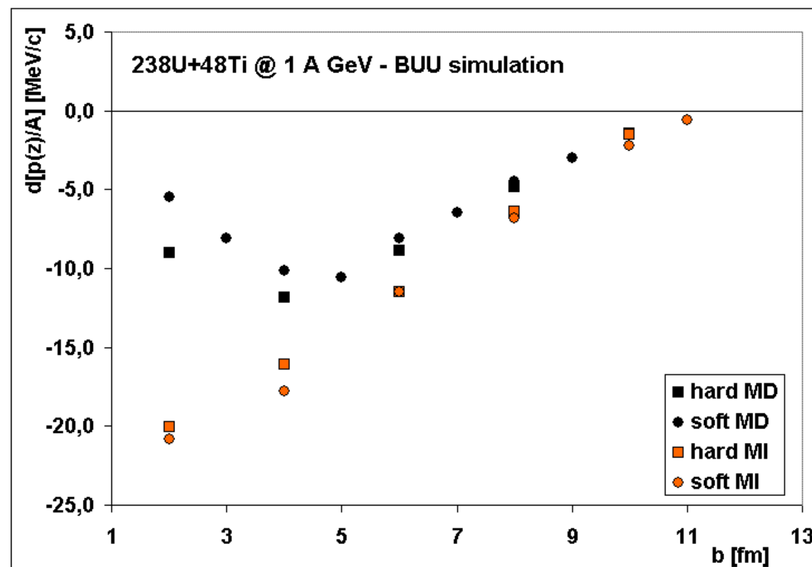
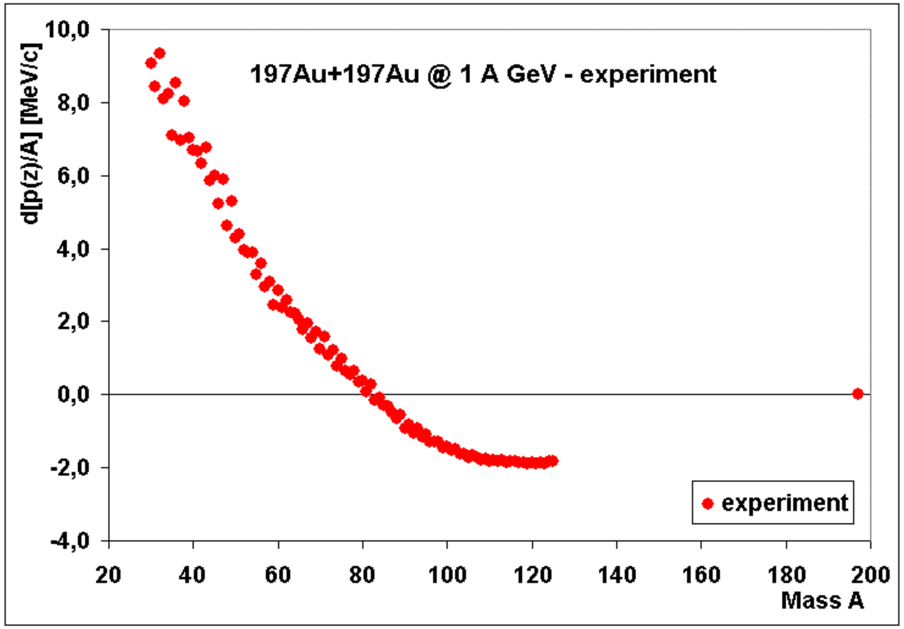
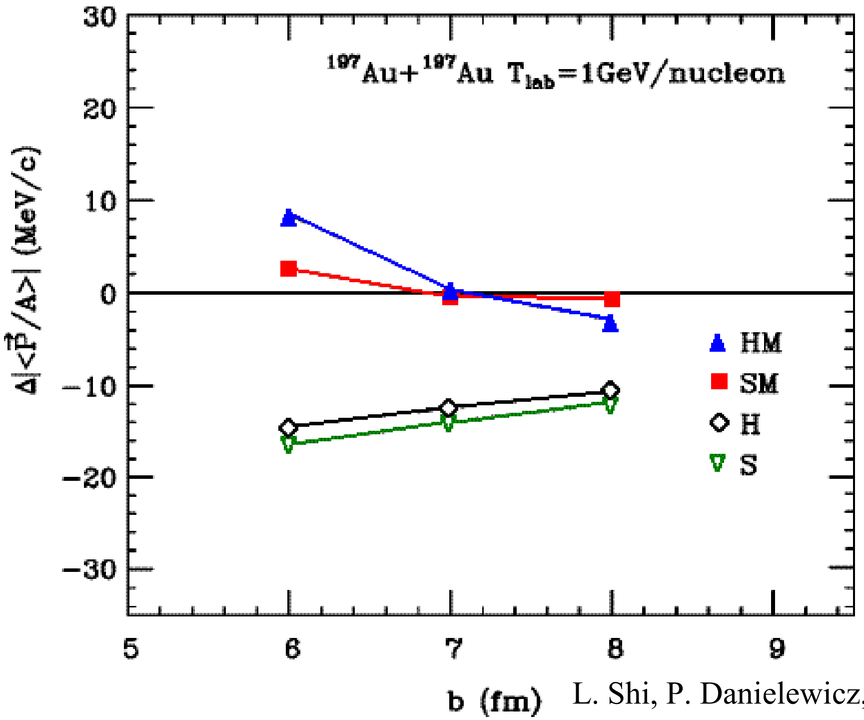






The Outlook – dedicated experiments





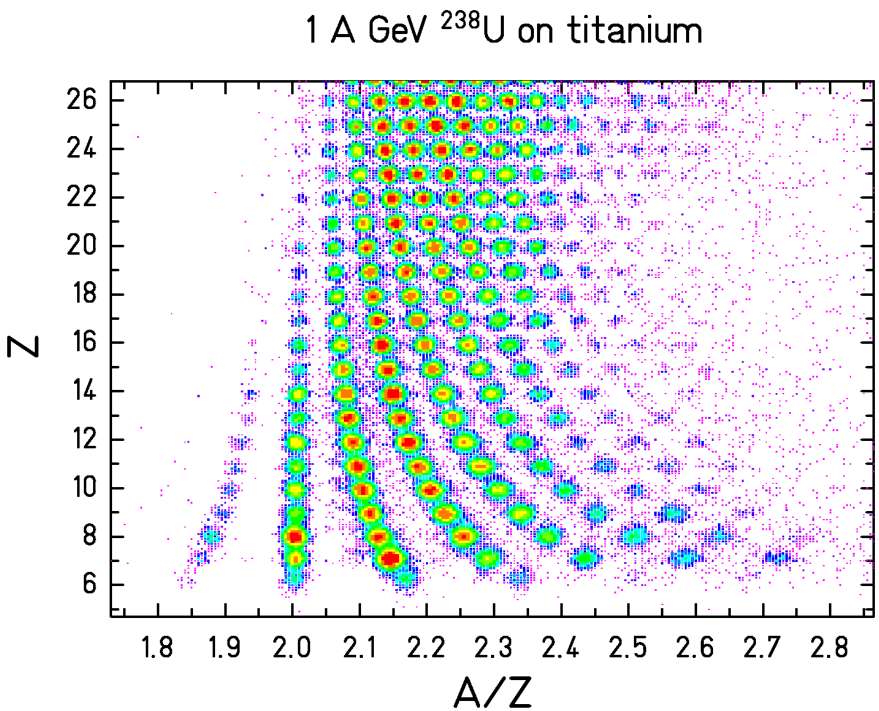
L. Shi, P. Danielewicz, R. Lacey, PRC 64 (2001)

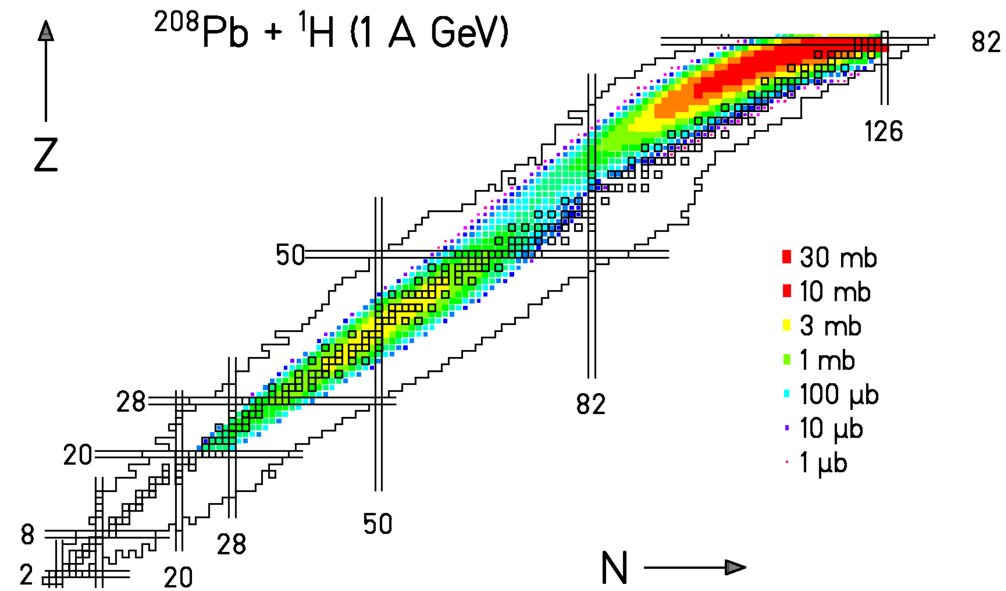
<u>April 2004:</u> ^{197}Au+^{197}Au @ 1*A* GeV

<u>August 2004:</u> ^{197}Au+^{197}Au @ 500 *A* MeV

<u>2005:</u> ^{112,124}Sn+^{112,124}Sn @ 1 *A* GeV

Fragment Separator, GSI-Darmstadt op.II





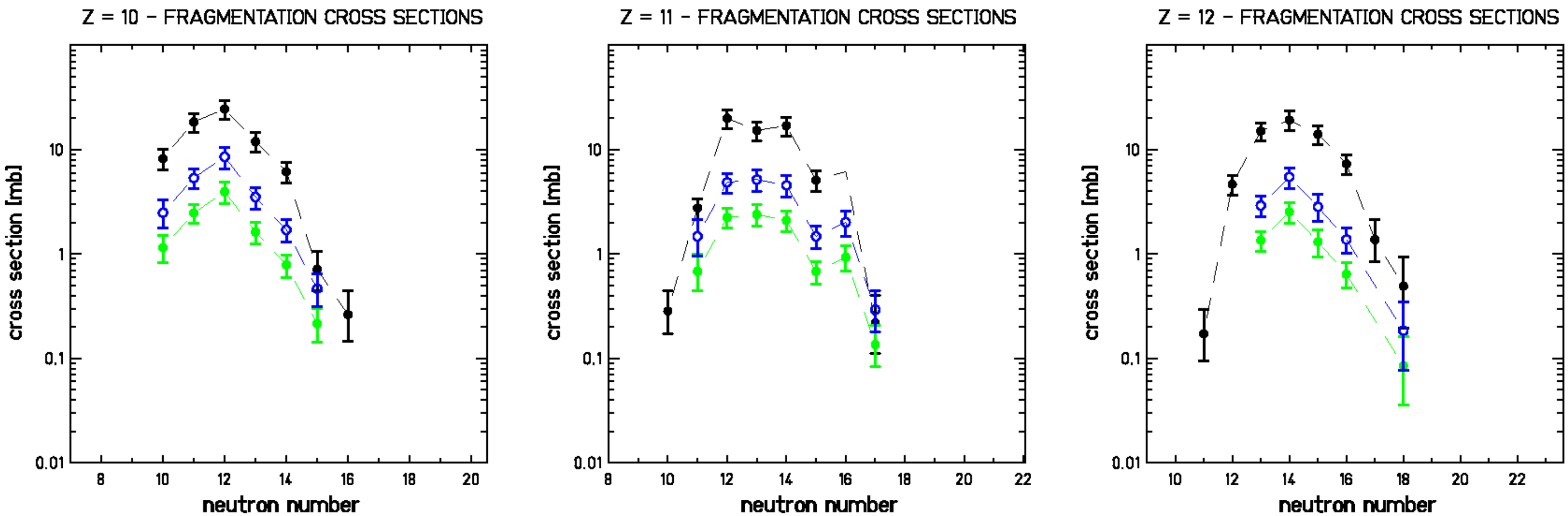
Advantages of the FRS:

- unambiguous identification and precise longitudinal momenta
- full acceptance of most of the fragments

Disadvantages of the FRS:

- Only one fragment in one reaction measured, no correlations, no multiplicity
- Low acceptance for light and fission fragments (~10%)

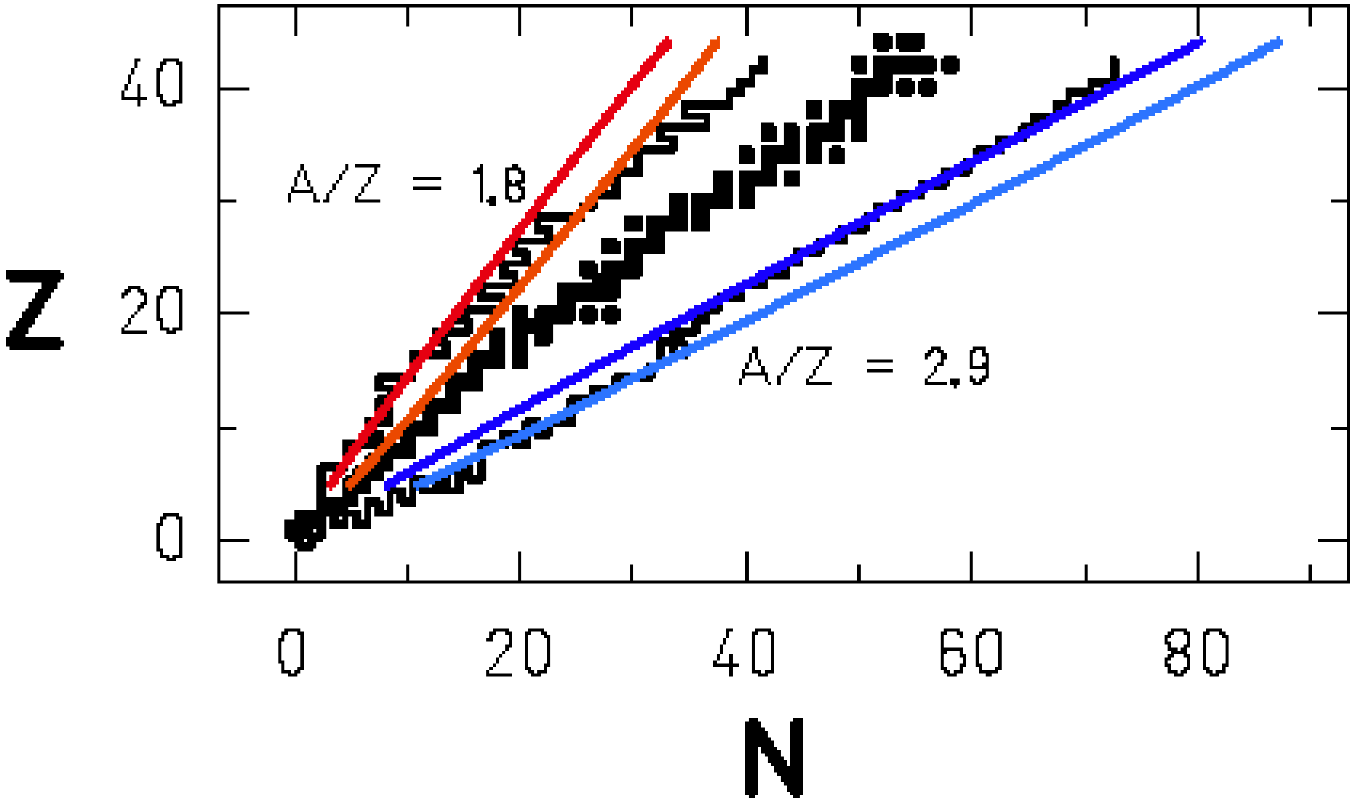
Isotopic distributions



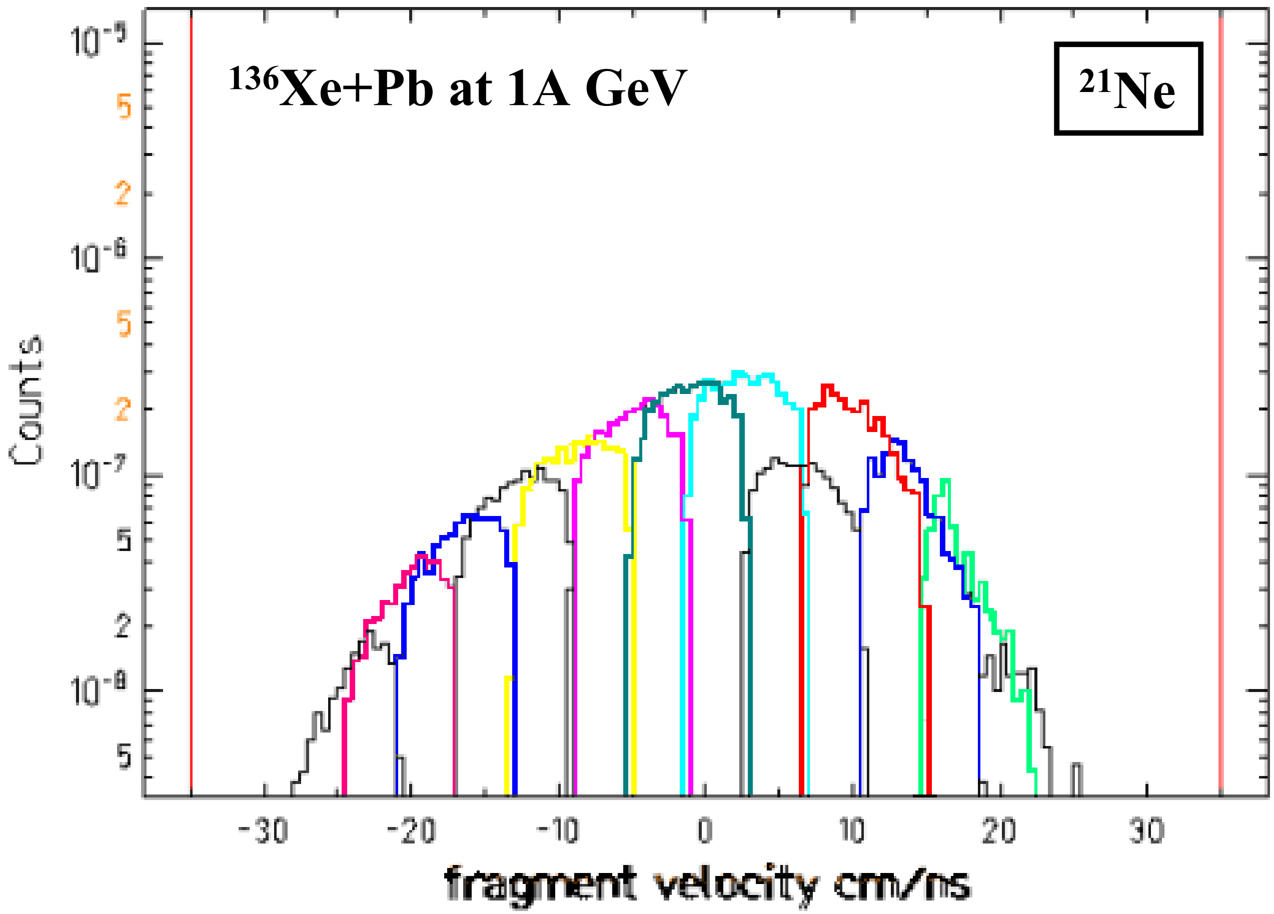
*Isotopic distribution for elements produced in the **fragmentation of 1·A GeV ^{238}U on titanium**. The fragmentation residues are represented by the symbol ●, the residues from the side-peak by the symbols ○ (transmission from) and ● (transmission from).*

M.V.Ricciardi – PhD thesis

Brho selection by FRS



Constructing the velocity distribution



D. Henzlova – PhD. thesis

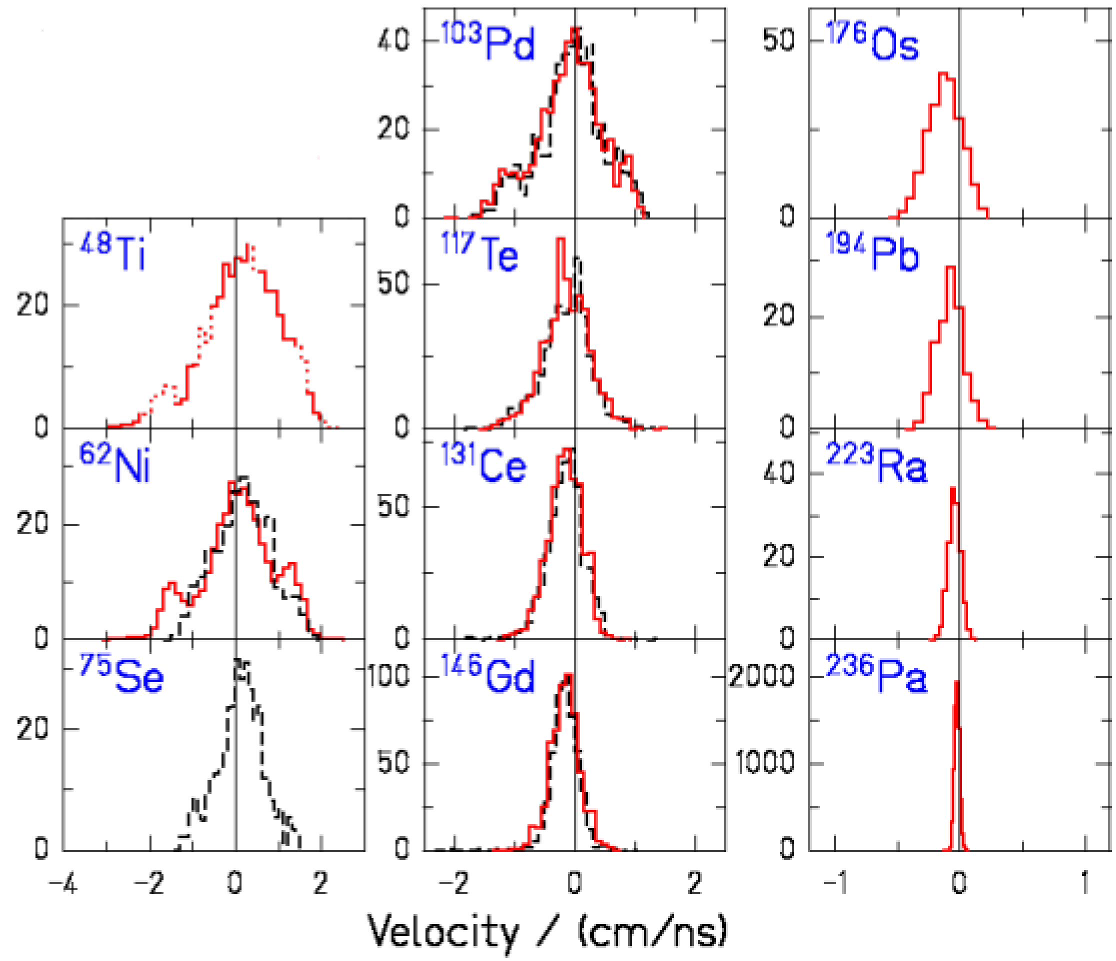
Velocity distributions of fragmentation residues

^{238}U+Pb @ 1 *A*GeV

T.Enqvist *et al.*
NPA658(1999)47

^{238}U+Ti @ 1 *A*GeV

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



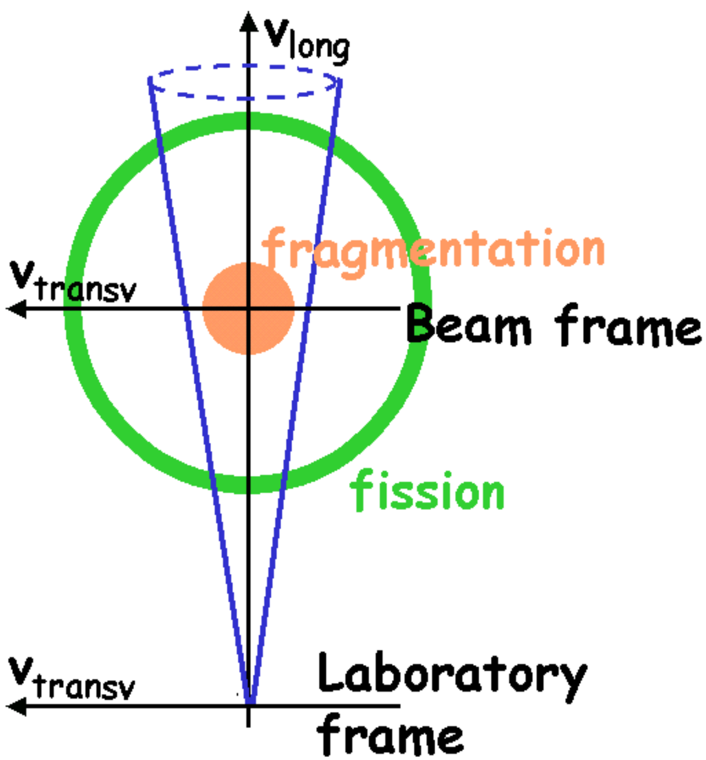
<u>Basic characteristics:</u>

- width
- position
- shape

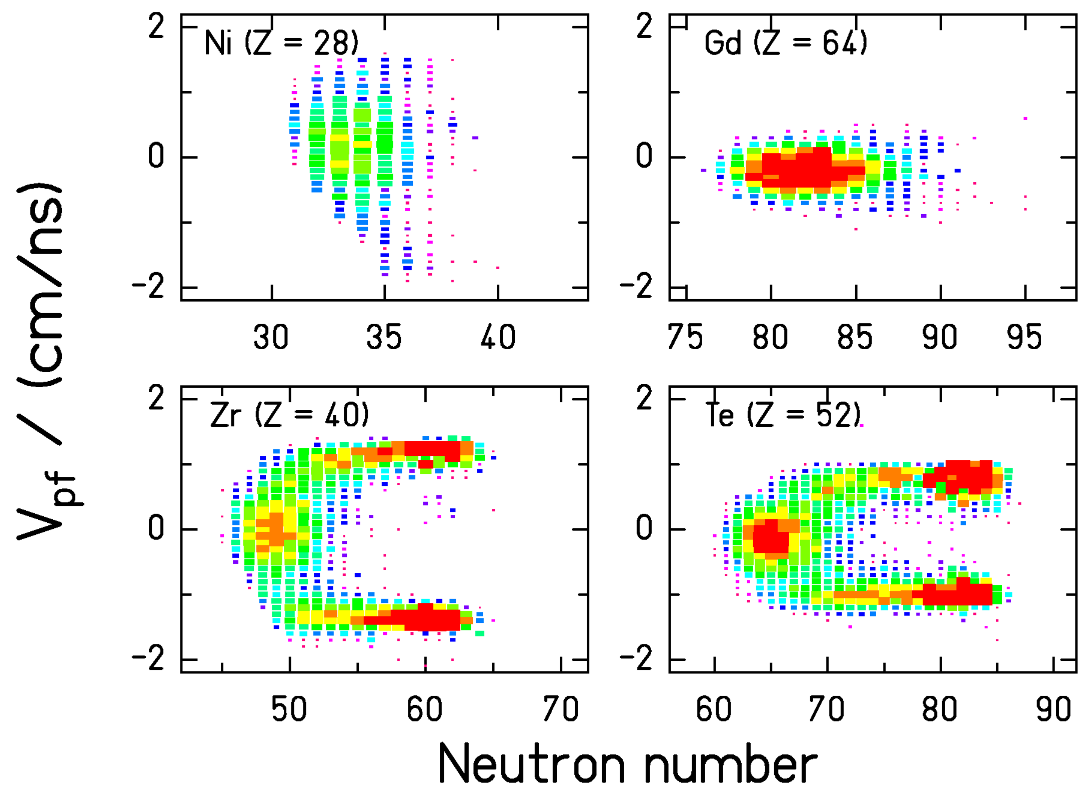
Information on reaction mechanism !!!

Velocity distributions

How to distinguish fragmentation and fission?



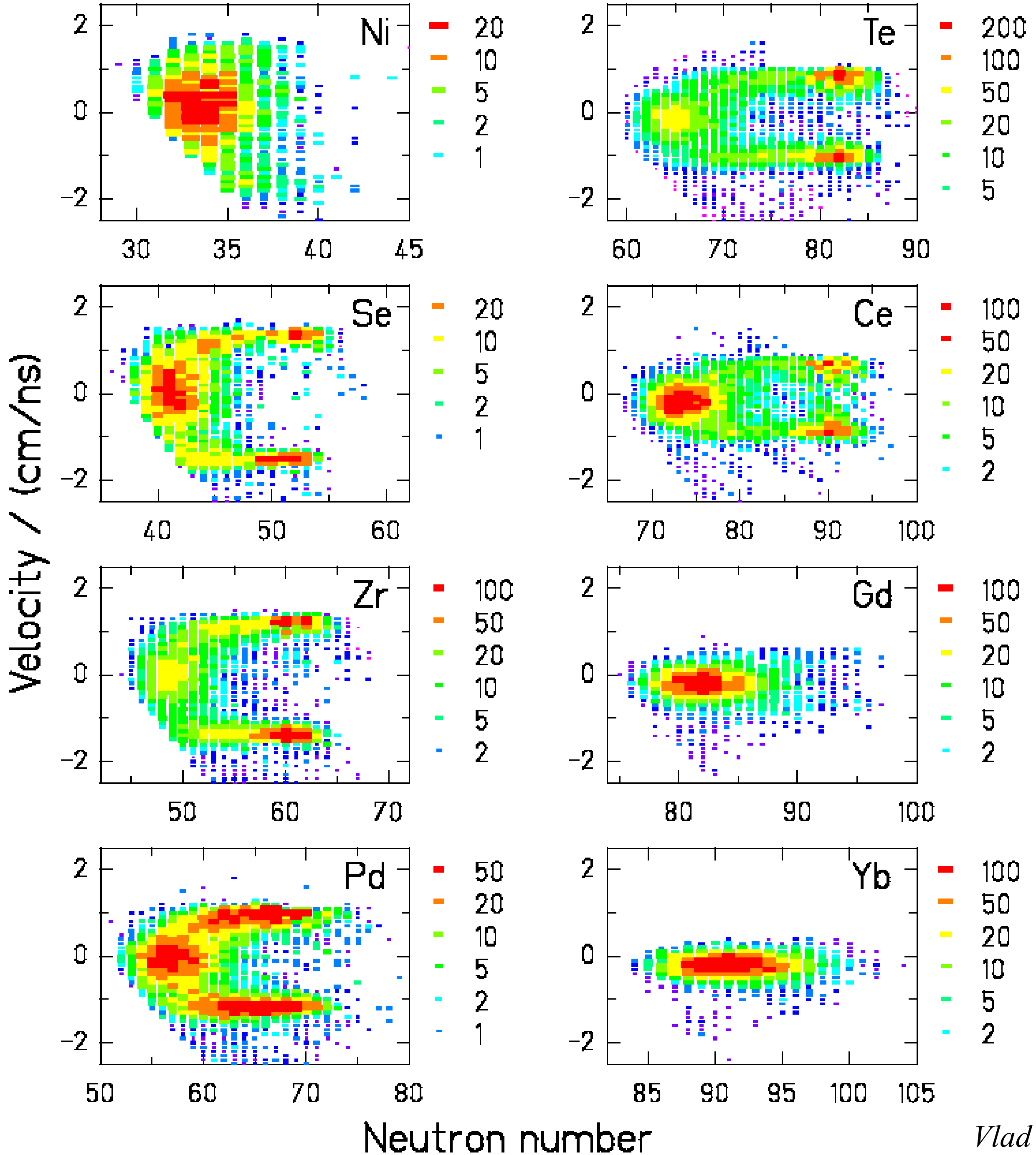
^{238}U (1 A GeV) + Pb



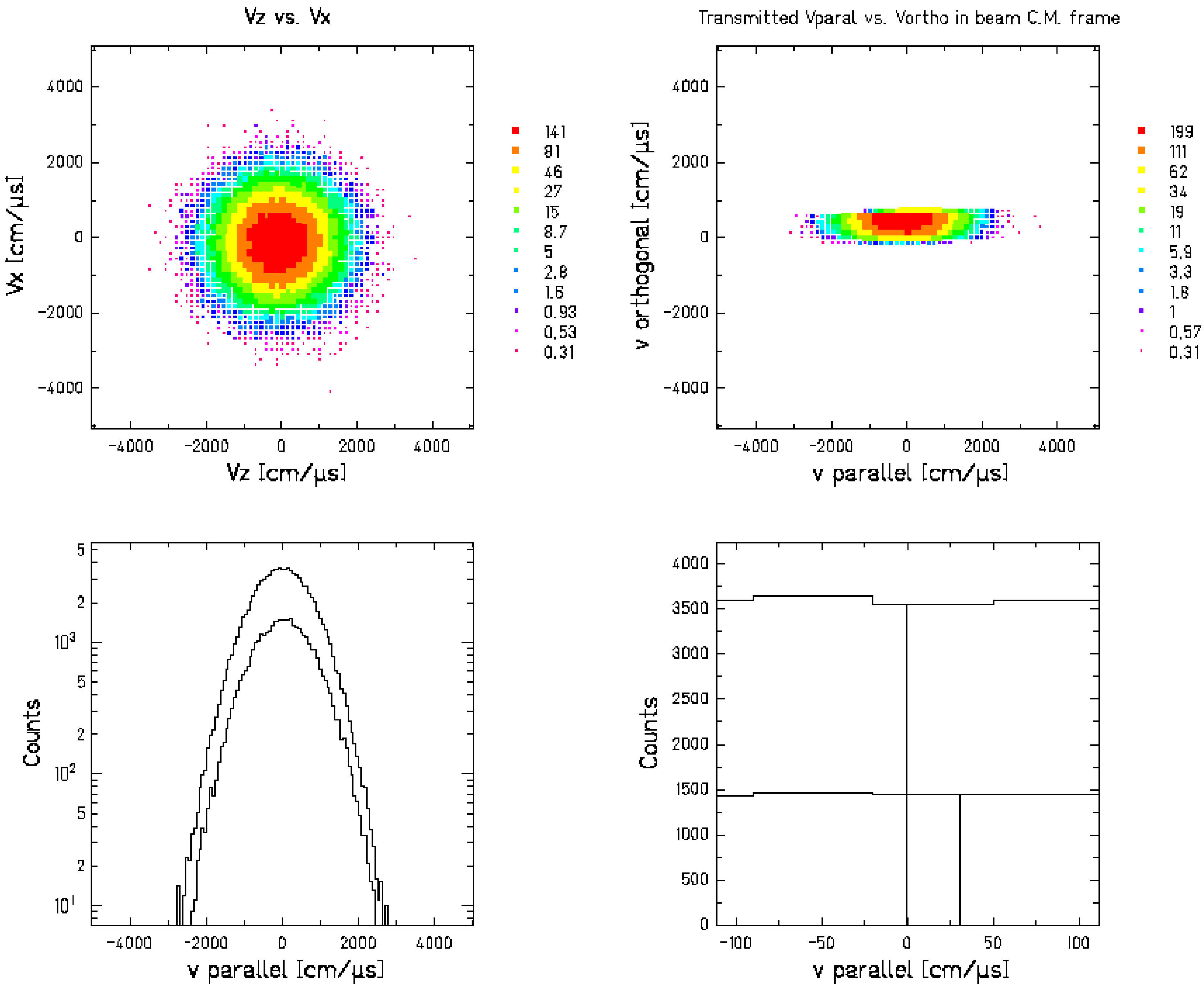
(T. Enqvist et al., Nucl. Phys. A 658 (1999) 47)

Fragmentation: Almost always fully accepted

Fission: Only forward and backward component accepted



Vlad Henzl for CHARMS



Vlad Henzl for CHARMS

CHARMS ***& re-acceleration***

(**C**ollaboration for **H**igh-**A**ccuracy Experiments on Nuclear **R**eaction **M**echanisms with the FR**S**)

V. Henzl[1], J. Benlliure[2], A. Boudard[3], P.Danielewicz[4], T. Enqvist[5], M. Fernandez[2], A. Heinz[6], D. Henzlova[1], A. Junghans[7], B. Jurado[8], A. Kelic[1], A. Kugler[9], J. Pereira[2], M. V. Ricciardi[1], K.-H. Schmidt[1], C. Schmitt[1], L.Shi[10], J. Taïeb[3], C. Volant[3], A. Wagner[7], V. Wagner[9], O. Yordanov[1]

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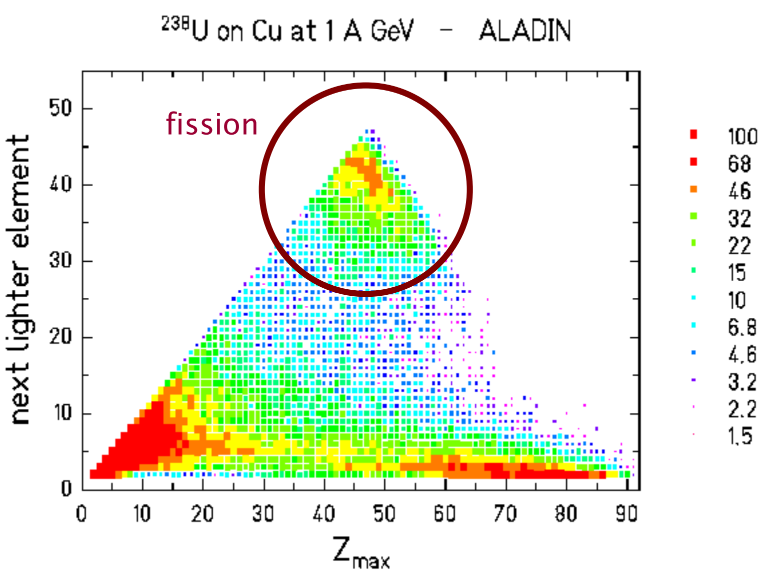

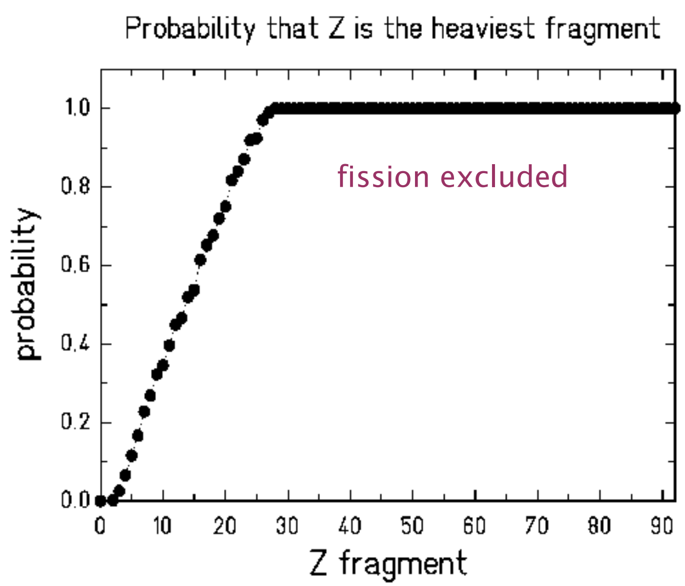

list-mode data provided by the ALADIN group