Model predictions for deep inelastic reactions: towards high Z and A.

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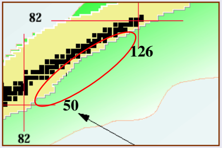
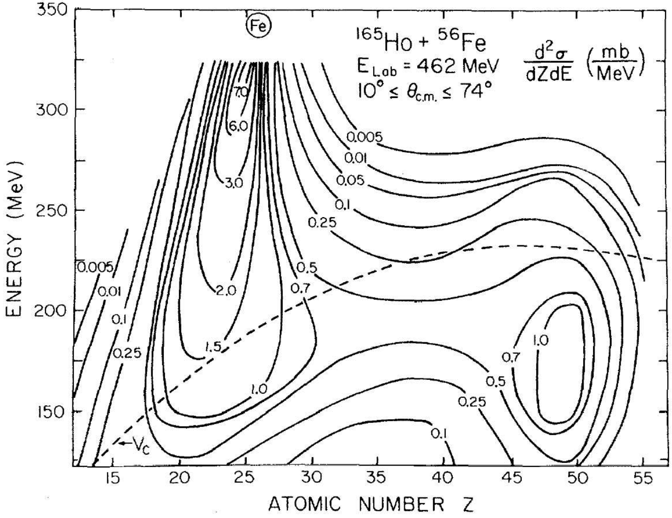


NUSTAR Annual Meeting At GSI, Darmstadt, Germany

February 25th - March 1st 2013

HI reactions, a short overview



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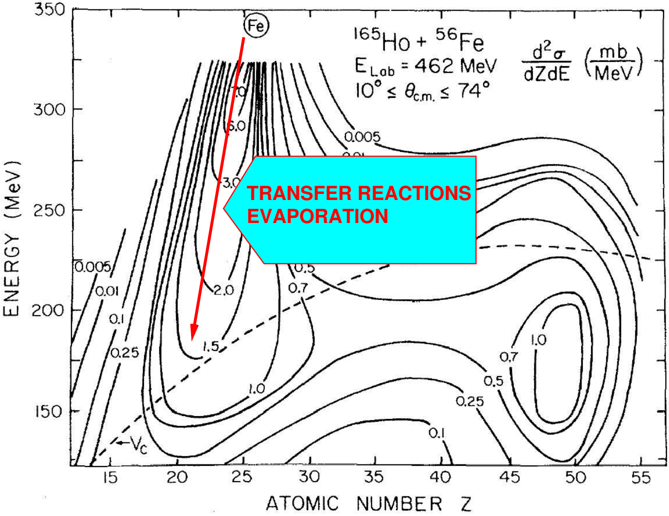

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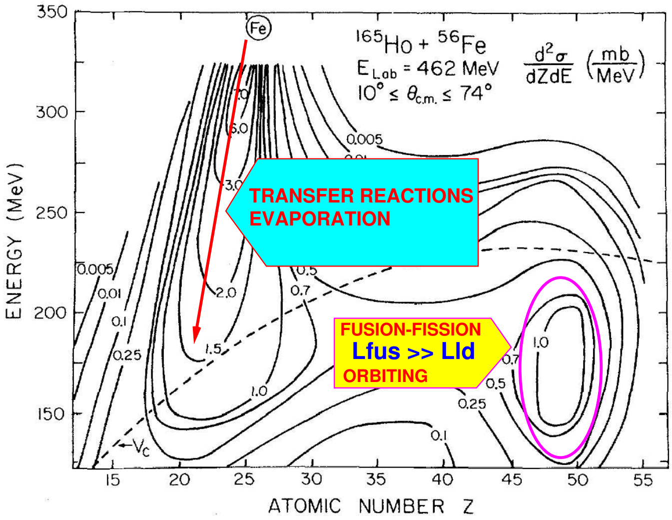

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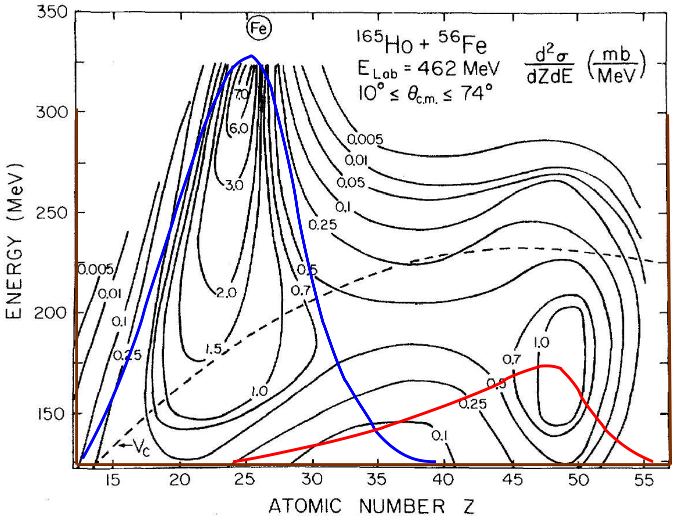

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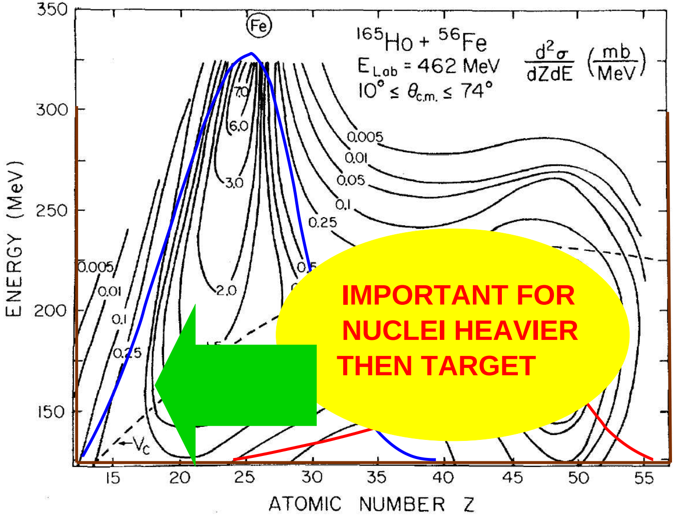

The model - surface modes

To explain the large deformations of the fragments prior the separation one has to introduce degrees of freedoms describing **the shape** of the fragments.
This is usually done by indroducing:

Surface degrees of freedom (*collision time* $\tau = \sqrt{a/\ddot{r}_o}$)

- **INELASTIC** $f_{in}(r) \sim e^{-r/a_{in}}$ $a_{in} = 0.65\ fm$
  (few channels but strong)
  - low lying: mass (D) large, force (C) small — NON adiabatic, coupled-channels
  - high lying: mass (D) small, force (C) large — adiabatic

Of course also the exhange of nucleons is important-**TRANSFER**

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The model - transfer

The exchange of nucleons is characterized by the presence of channels that are **weak but very numerous**. The transfer process is governed by:

- a matrix element of the form:

$$M_{\beta\alpha'} \sim \int d^3r' \psi^\dagger_{i'}(\bar{r}') V_a(|\bar{r}'|) \psi_j(\bar{\mathcal{R}} - \bar{r}') \propto e^{-\kappa_{tr}\mathcal{R}}$$

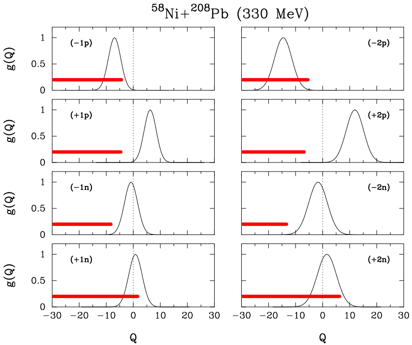
Where V_a is the shell model potential binding the nucleon to the projectile or target (post/prior simmetry). The range parameter κ_{tr} is related to the binding-energy $\mathcal{E}$ of the nucleon

$$\kappa_{a'_1} = \frac{1}{\hbar}\sqrt{2m_o(-\mathcal{E}_{a'_1})} \sim 0.6\mathrm{fm}$$

The model - transfer

- Optimun Q-value conditions:

$$P_{\beta\alpha'} \sim |M_{\beta\alpha'}(r_o)|^2 \exp\left(- \frac{(Q - Q_{opt})^2}{\hbar^2 \ddot{r}_o \kappa_{a'_1}} \right)$$



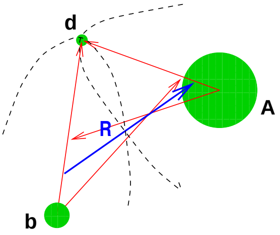
GRAZING

The time evolution of a heavy-ion reaction is described by the following system of coupled equations :

$$i\hbar\dot{c}_\beta(t) = \sum_\alpha < \beta|H_{int}|\alpha > c_\alpha(t) e^{\frac{i}{\hbar}(E_\beta - E_\alpha)t + i(\delta_\beta - \delta_\alpha)}$$

$$i\hbar\dot{\Psi}(t) = (H_0 + H_{int})\Psi(t)$$

$$\Psi(t) = \sum_\beta c_\beta(t)\psi_\beta e^{\frac{i}{\hbar}E_\beta t}$$



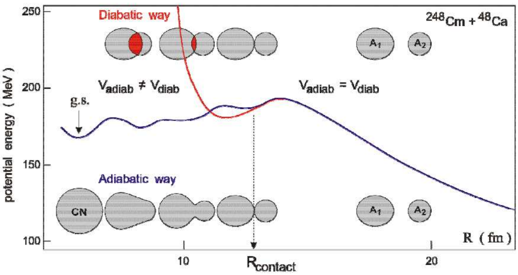
where ψ_α are the channels wave function (asymptotic states)

$$\psi_\alpha(t) = \psi^a(t)\psi^A(t)e^{i\delta(\vec{R})}$$

A. Winther Nucl.Phys. **A572** (1994)191, Nucl.Phys. **A594** (1995)203

The potential (frozen-density, diabatic)

$$V_{diabat}(R,\beta_1,\beta_2,\alpha,\ldots) = V_{12}^{folding}(Z_1,N_1,Z_2,N_2;R,\beta_1,\beta_2,\ldots) + M(A_1) + M(A_2) - M(Proj) - M(Targ)$$



$$V_{adiabat}(R,\beta_1,\beta_2,\eta,\ldots) = M_{TCSM}(R,\beta_1,\beta_2,\eta,\ldots) - M(Proj) - M(Targ)$$

Time-dependent driving potential has to be used

$$V(t) = V_{diab}(\xi)\cdot\exp\left(-\frac{t_{int}}{\tau_{relax}}\right) + V_{adiab}(\xi)\cdot\left[1-\exp\left(-\frac{t_{int}}{\tau_{relax}}\right)\right]$$

$\tau_{relax} \sim 10^{-21}$ s

the same degrees of freedom ($\xi = R, \theta, \varphi_1, \varphi_2, \beta_1, \beta_2, \eta_Z, \eta_N$) *!*
All forces, $F_i(t) = -\partial V/\partial\xi_i$, *are quite smooth*

Borrowed from Valery Zagrebaev (IRIS10 Workshop, March 2010)

The actinides (Cm target)

PHYSICAL REVIEW C VOLUME 33, NUMBER 6 JUNE 1986

Production of cold target-like fragments in the reaction of $^{48}Ca + ^{248}Cm$

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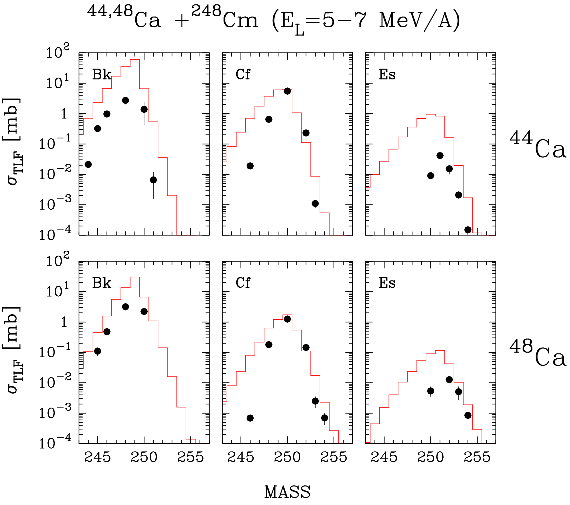
Gesellschaft für Schwerionenforschung, D-6100 Darmstadt, Federal Republic of Germany

J. V. Kratz, M. Lerch, Th. Blaich, G. Herrmann,† N. Hildebrand, and N. Trautmann

99	Es247 4.55 m (7/2+) EC,α	Es248 27 m (2-,0+) EC,α	Es249 102.2 m 7/2(+) EC,α	Es250 8.6 h (6+) * EC,α	Es251 33 h (3/2-) EC,α	Es252 471.7 d (5-) EC,β-,α,...	Es253 20.47 d 7/2+ α,sf	Es254 275.7 d (7+) * EC,β-,α,...	Es255 39.8 d (7/2+) β-,α,sf,...	Es256 25.4 m (1+) * β-	Es257
98	Cf246 35.7 h 0+ EC,α,sf,...	Cf247 3.11 h (7/2+) EC,α	Cf248 333.5 d 0+ α,sf	Cf249 351 y 9/2- α,sf	Cf250 13.08 y 0+ α,sf	Cf251 898 y 1/2+ α	Cf252 2.645 y 0+ α,sf	Cf253 17.81 d (7/2+) β-,α	Cf254 60.5 d 0+ α,sf	Cf255 85 m (9/2+) β-	Cf256 12.3 m 0+ β-,α,sf,...
97	Bk245 4.94 d 3/2- EC,α	Bk246 1.80 d 2(-) EC,α	Bk247 1380 y (3/2-) α	Bk248 9 y (6+) * α	Bk249 320 d 7/2+ β-,α,sf,...	Bk250 3.217 h 2- β-	Bk251 55.6 m (3/2-) β-,α	Bk252	Bk253	Bk254	
96	Cm244 18.10 y 0+ * α,sf	Cm245 8500 y 7/2+ α,sf	Cm246 4730 y 0+ α,sf	Cm247 1.56E+7 y 9/2- α	Cm248 3.40E+5 y 0+ α,sf	Cm249 64.15 m 1/2(+) β-	Cm250 9000 y 0+ β-,α,sf,...	Cm251 16.8 m (1/2+) β-	Cm252 2 d 0+ β-		
	Am243 7370 y 5/2- α,sf	Am244 10.1 h (6-) * β-	Am245 2.05 h (5/2)+ β-	Am246 39 m (7-) * β-	Am247 23.0 m (5/2) β-	Am248	Am249				

The actinides (Cm target)



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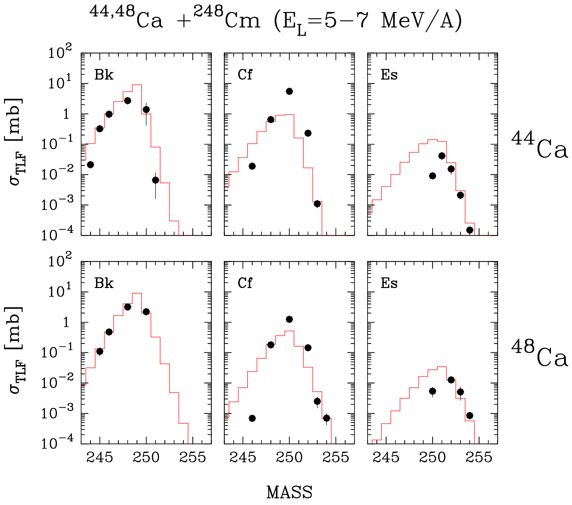
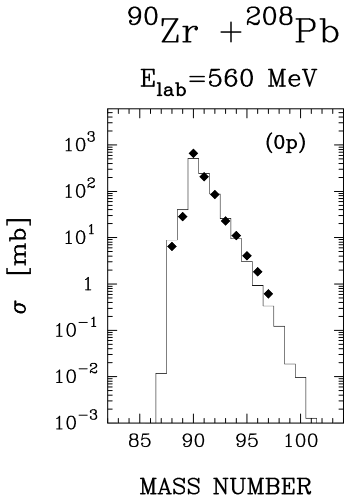


The ^{90}Zr+^{208}Pb system



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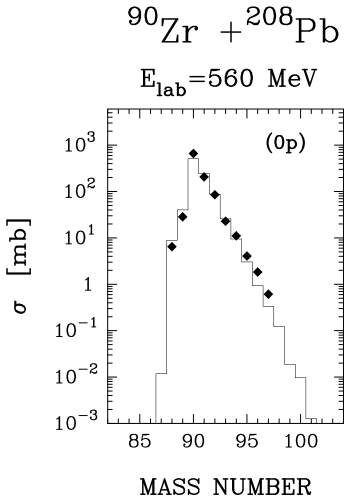

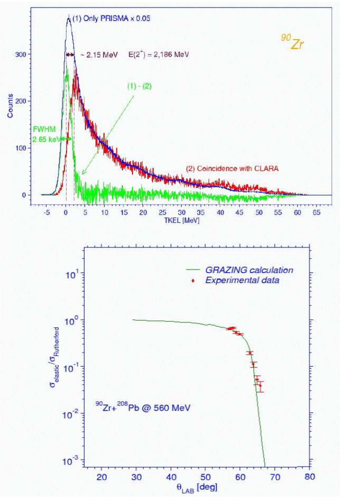

Toward heavier then target nuclei

What we have seen up to now concern stable projectile. To populate **heavier then target nuclei** besides:

- proton stripping (-1p)
- neutron pick-up (+1n)

(these reactions populate nuclei with larger **Z** but smaller **MASS**) we have to **OPEN** also the:

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- neutron stripping (-1n)

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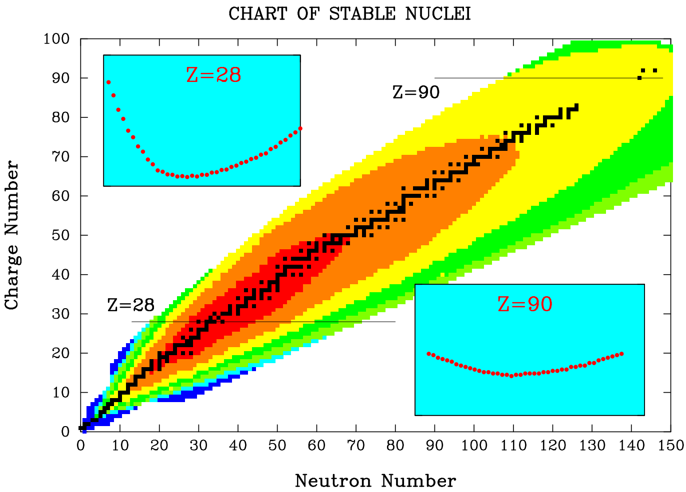
N-rich projectiles

Bindind energy

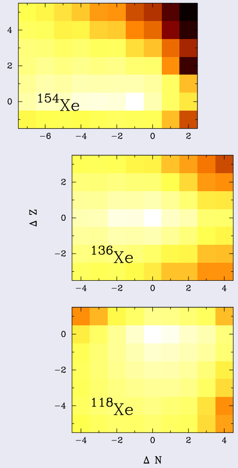


The Xe + ^{208}Pb reaction at $E_{c.m.}$=700 MeV

The population of projectile-like fragments (corrected by evaporation of the light)

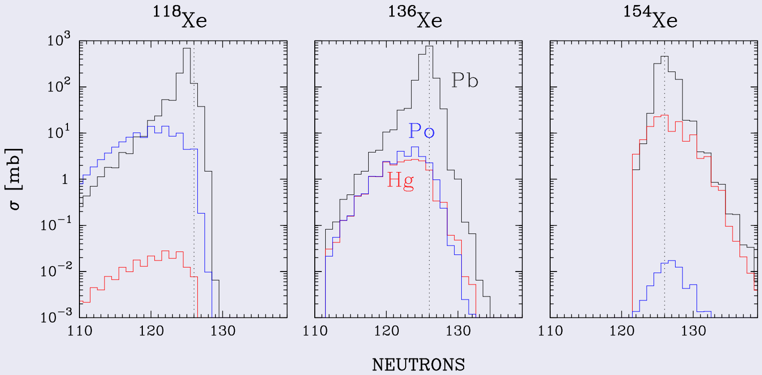
For stable nuclei the $Q_{opt}(N, Z)$ is such that only:
- proton stripping (-1p)
- neutron pick-up (+1n)

are possible.

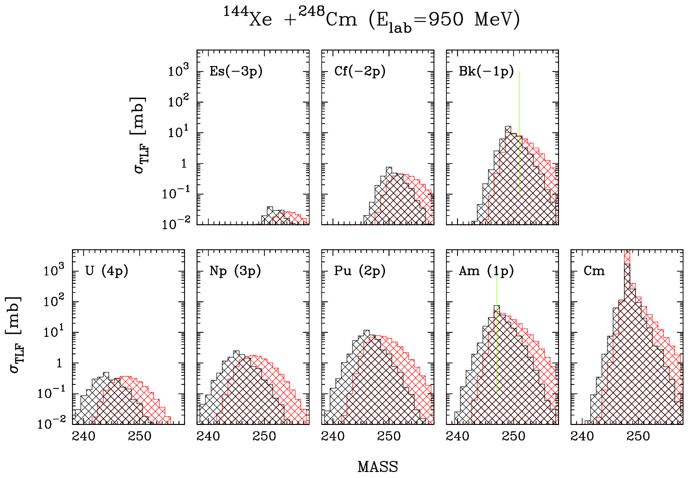


The Xe + ^{208}Pb reaction at $E_{c.m.}$=700 MeV

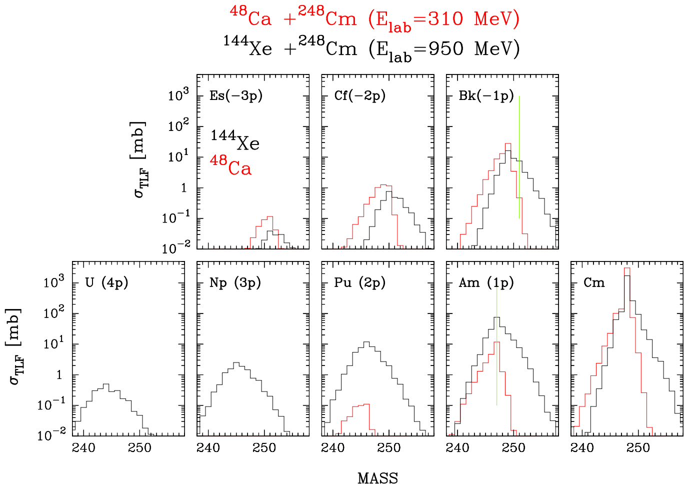
The population of the target-like fragments:



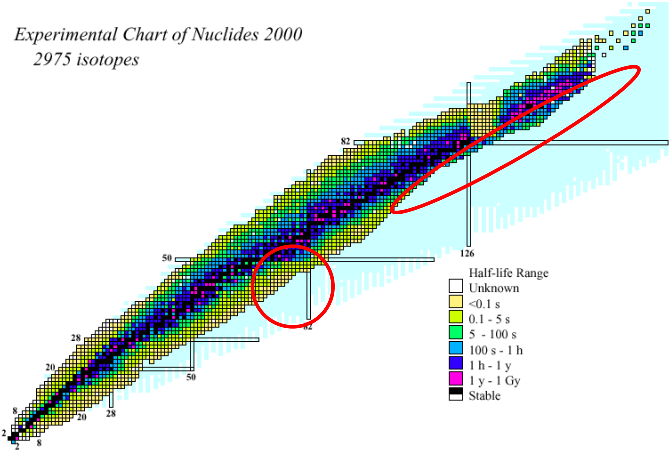
The ^{144}Xe + ^{248}Cm



^{144}Xe versus ^{48}Ca



Where multinucleon-transfer



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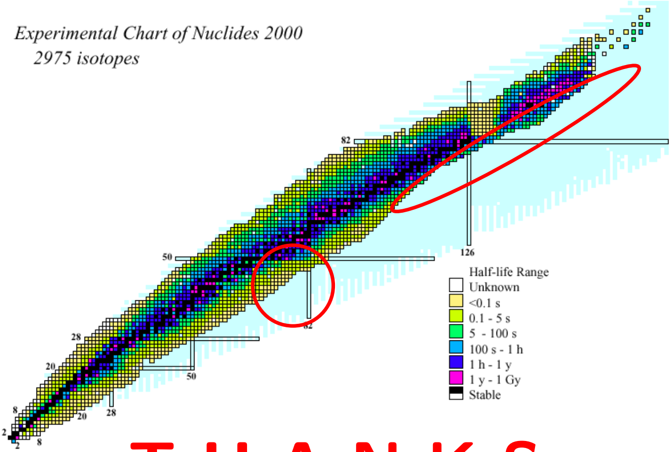
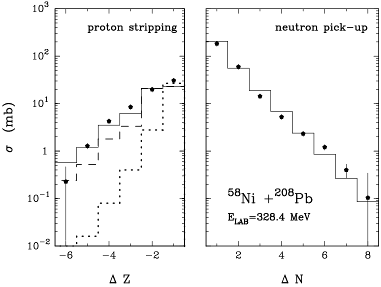
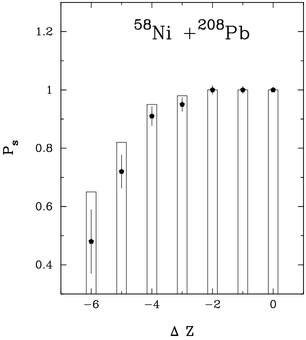


THANKS

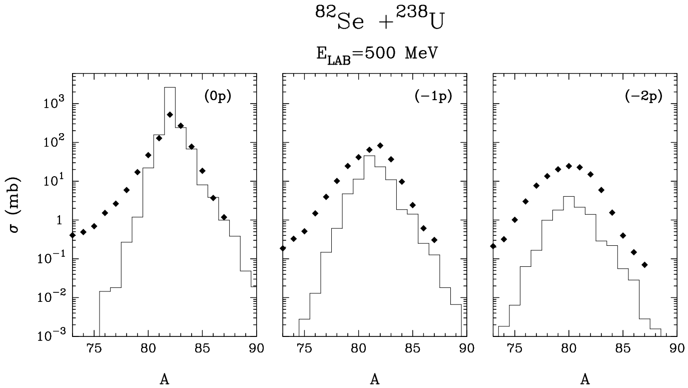
^{58}Ni + ^{208}Pb





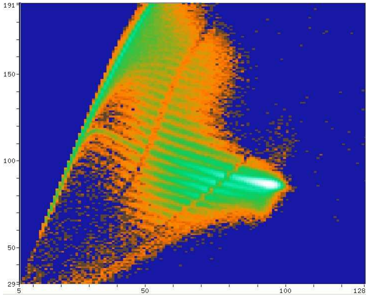
Data from
Legnaro National Lab. (INFN)
L. Corradi, et al.

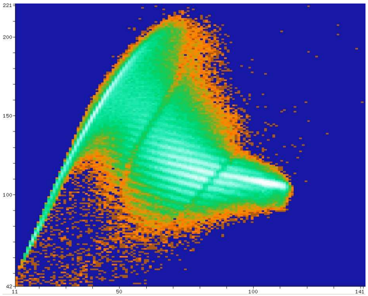
^{82}Se + ^{248}U



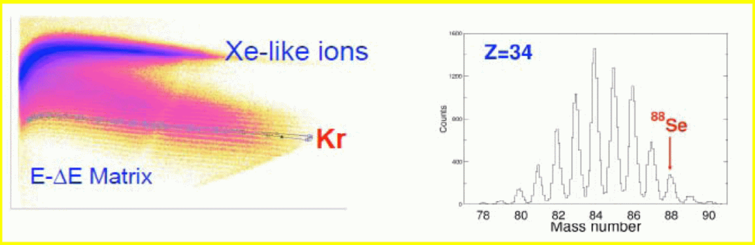
82Se + 238U
ELAB=500 MeV
(0p)
(−1p)
(−2p)
σ (mb)
10^3
10^2
10^1
1
10^−1
10^−2
10^−3
75
80
85
90
A

The $^{64}Ni + ^{248}U$ and $^{82}Se + ^{248}U$



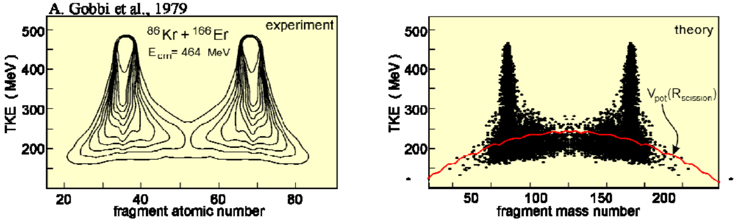


The ^{136}Xe + ^{248}U

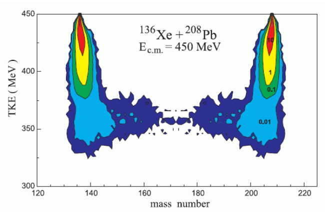


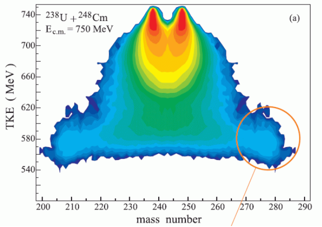
The ^{86}Kr+ ^{166}Er

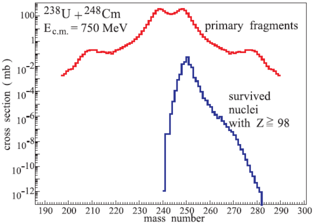
^{86}Kr + ^{166}Er collision at $E_{c.m.}$ = 464 MeV (Coulomb barrier = 260 MeV)



^{136}Xe + ^{208}Pb and ^{238}U+^{248}Cm







V.I. Zagrebaev and W. Greiner Phys. Rev. C (2011) 044618