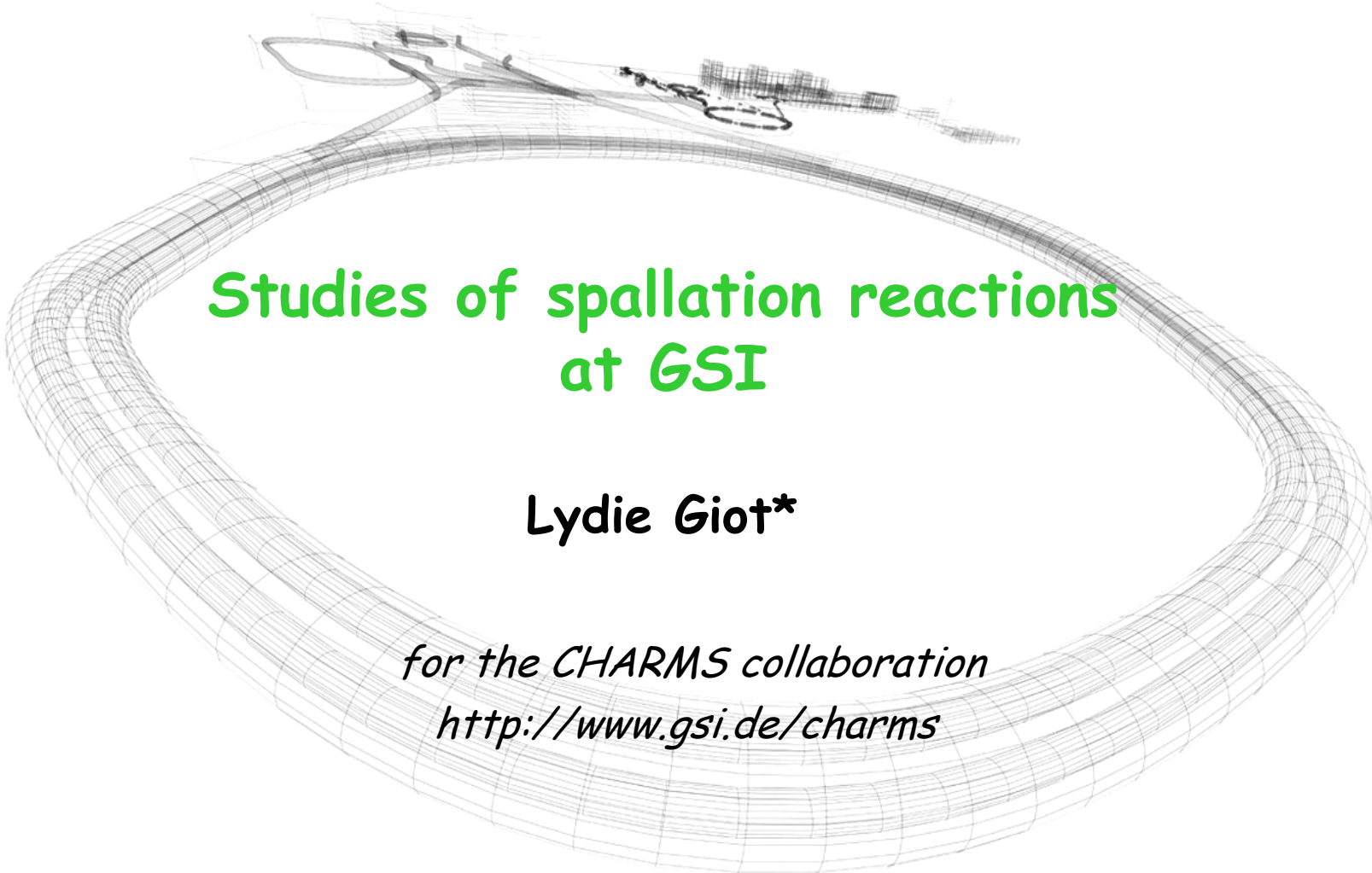


Studies of spallation reactions at GSI

Lydie Giot*

for the CHARMS collaboration
http://www.gsi.de/charms

* EURATOM Fellowship (FP6)

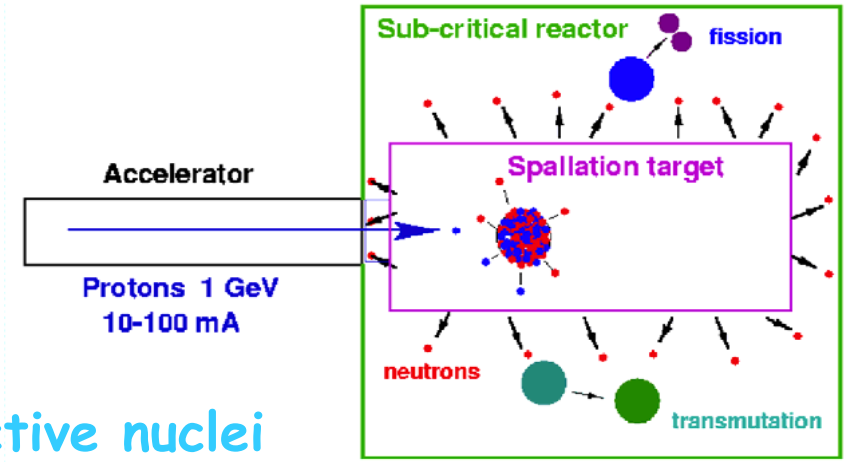
Spallation studies

- Intense neutrons sources needed for

  Accelerator Driven Systems

  for transmutation of waste

  Material physics



- Production of high intensity radioactive nuclei

  ex: EURISOL

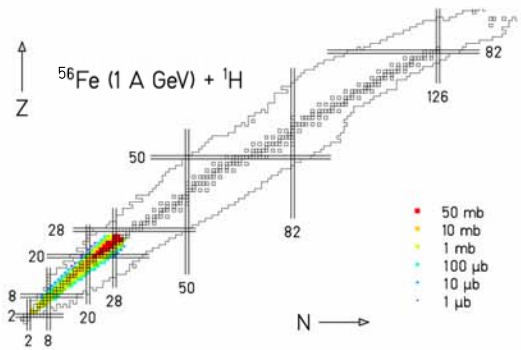
  The EURISOL report, available at www.ganil.fr/eurisol/Final-Report.html

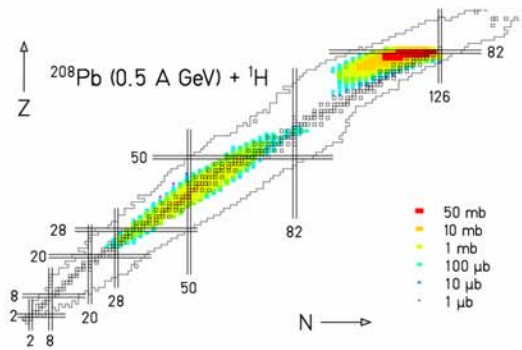
- Astrophysics: interaction of cosmic rays in the interstellar medium

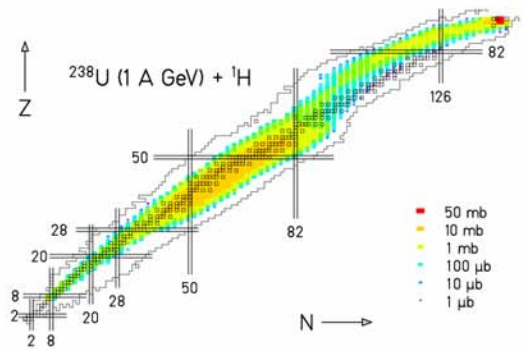
  J. R Arnold et al, J. Geophys. Res. 66 (1961) 3519

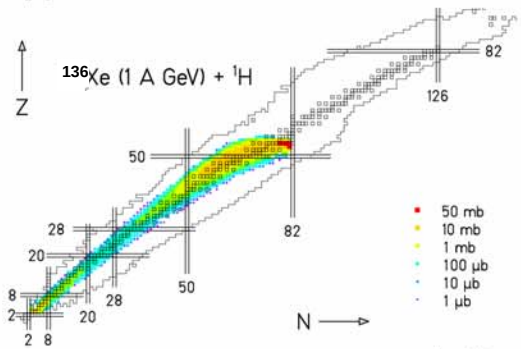
All these perspectives have triggered a long-range research dedicated program at GSI, devoted to reach a full comprehension of the proton and deuteron induced spallations reactions by measurements of evaporation and fission fragments.

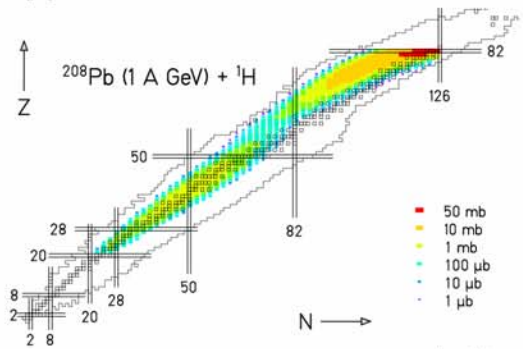
Some systems investigated (7732 measured production cross sections)

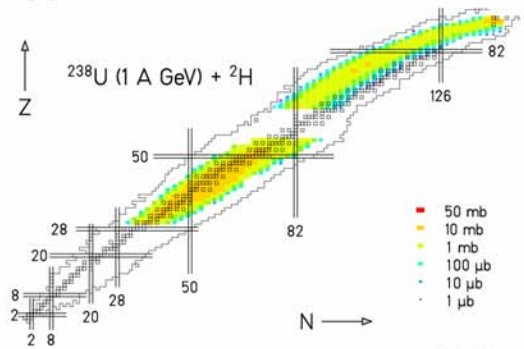


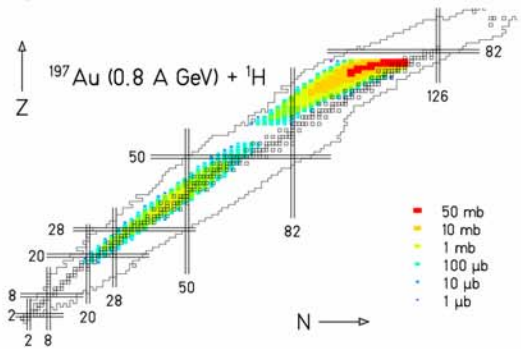


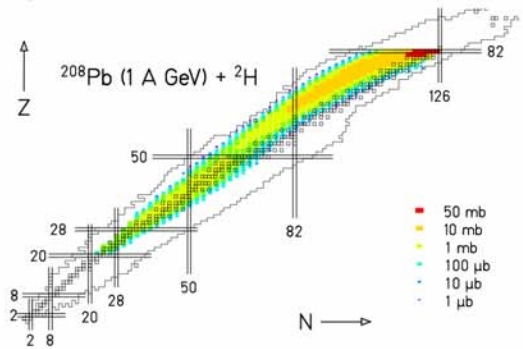


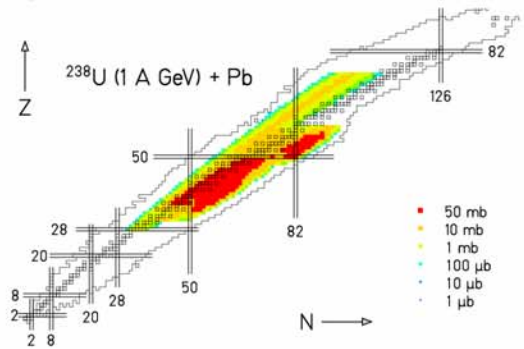






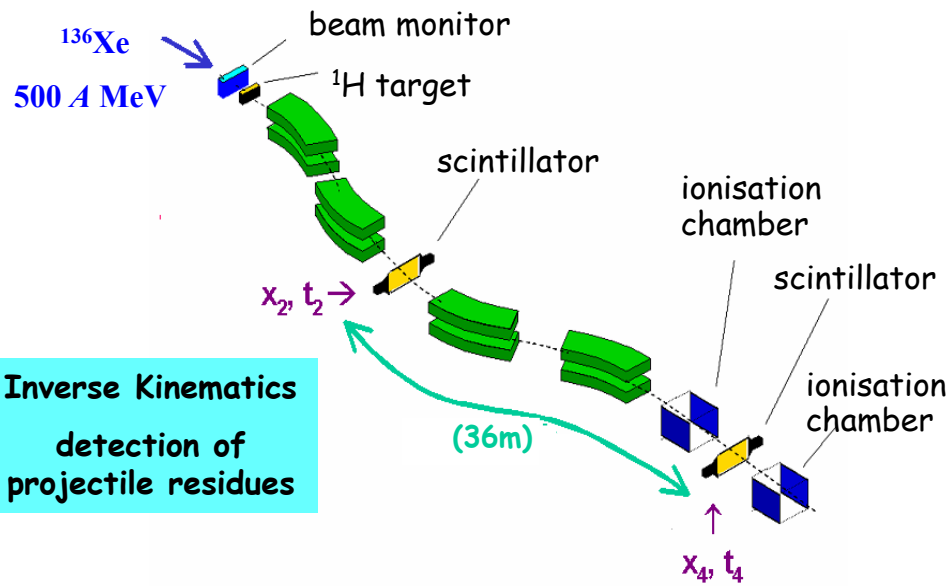






http://www-w2k.gsi.de/charms/

Experimental setup



Inverse Kinematics

detection of projectile residues

mass identification

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

dE ionisation chamber

positions in scintillators

ToF

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

$A/\Delta A \approx 400$

$\Delta Z \approx 0.4$

When the nuclear charge and the mass are identified

(A, Z integers)

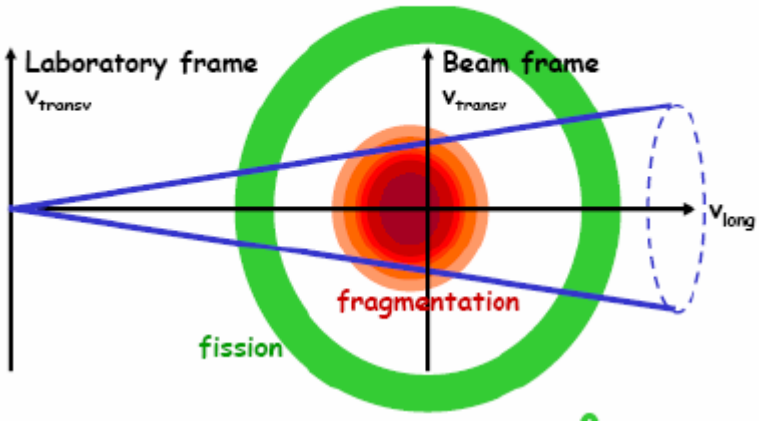
the velocity is calculated from $B\rho$

$$\beta\gamma = \frac{e}{cu}\frac{A}{Z}B\rho$$

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

precise determination !

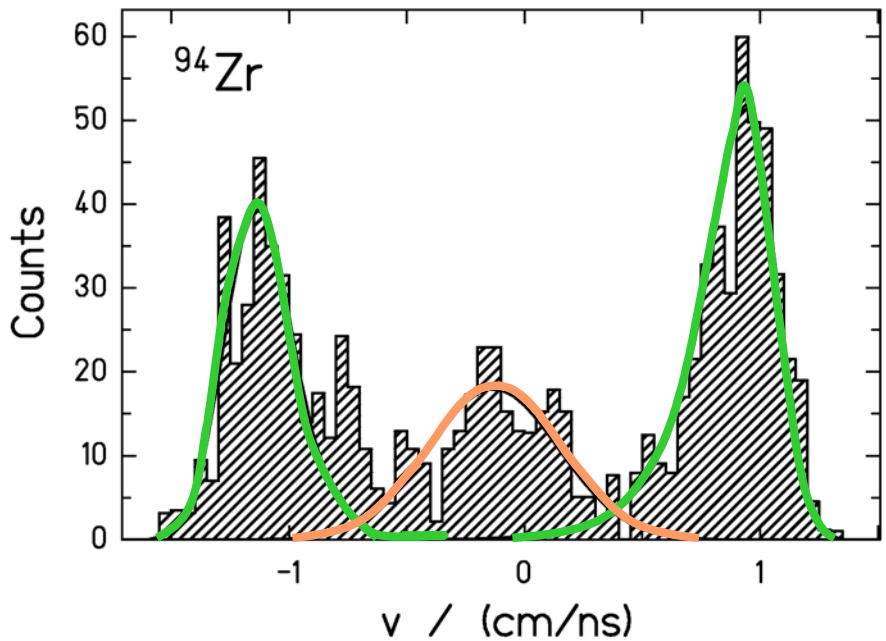
Velocity distribution



For each nuclei:

- ✓ production cross section
- ✓ Production mechanism
  fission or fragmentation

$^{238}U + {}^{1}H$ 1 *A* GeV



Energy dependence of the spallation process

- Energy loss of the proton beam in the spallation target

  production cross sections depend on the energy of the incident proton

- Importance of secondary reactions

  initiated by particles emitted in the primary reactions

- Projects to demonstrate the components of an ADS

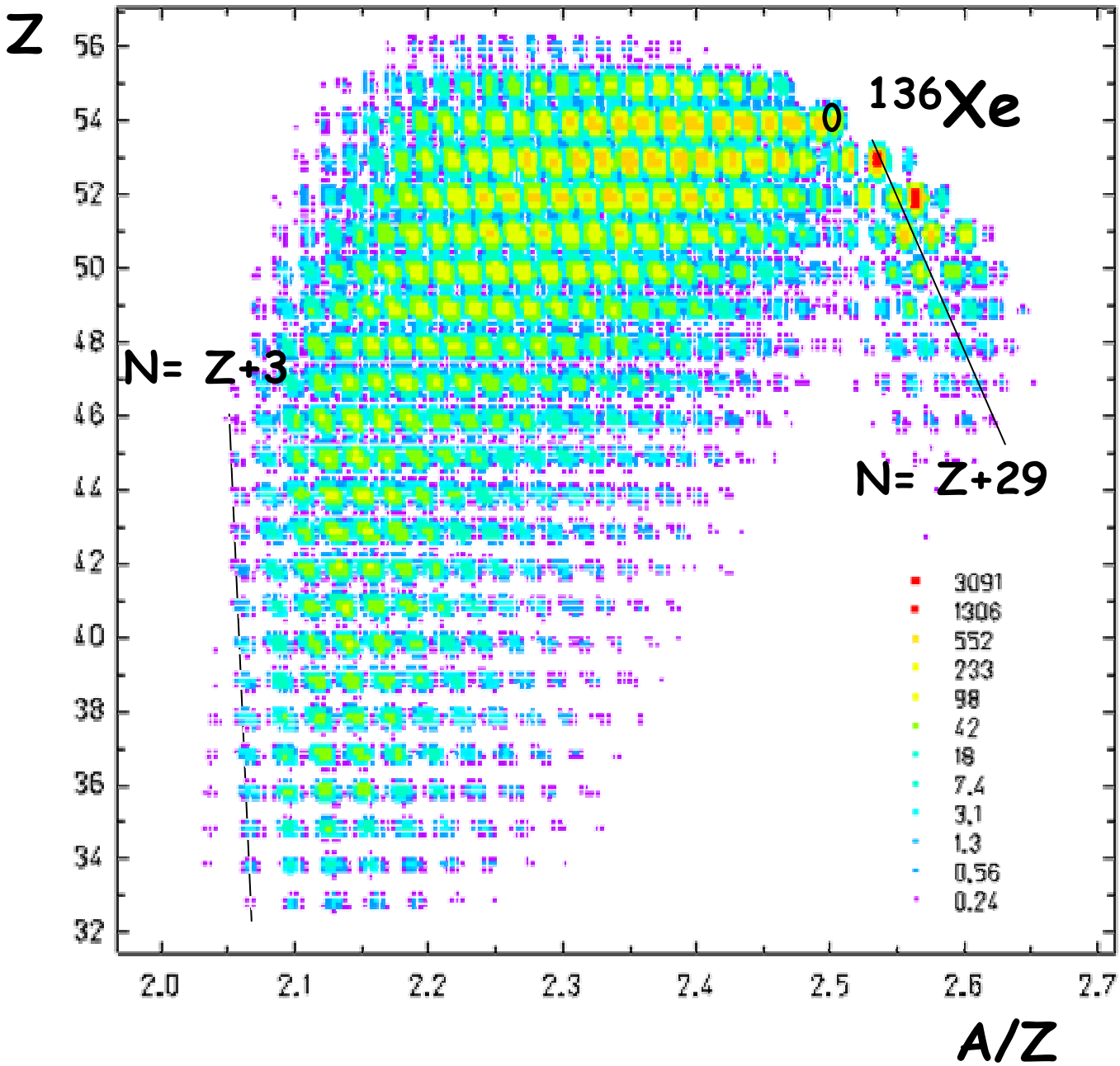
MEGAPIE at PSI, Switzerland: 590 MeV proton beam *F. Groeschel et al., Journal of Nucl. Mat 335 (2004) 156*

MYRRHA at MOL, Belgium: 360 MeV proton beam *H. Ait Abderrahim et al., NIM A463 (2001) 487*

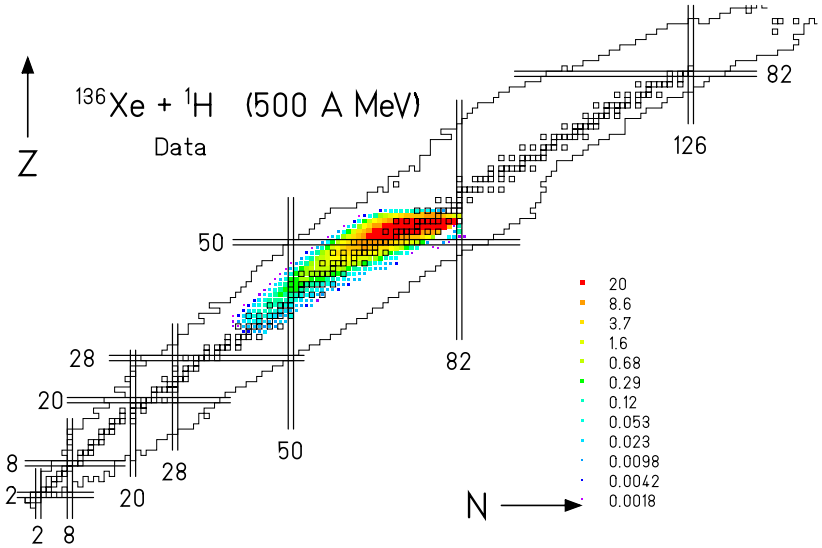
with ^{136}Xe + ^{1}H at 200, 500, 1000 *A* MeV

- Technically feasible to go down in energy without ionic charge states problems
- As neutron rich as lead, contribution of fission is negligible

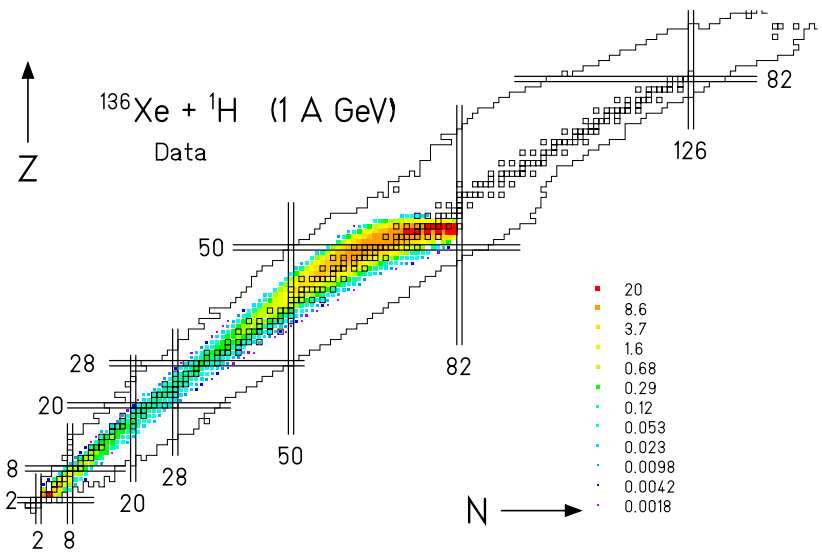
Ideal experimental case to study the evaporation process, in the region of the heavy masses.


136Xe + 1H 500 A MeV
Z
56
54
52
50
48
46
44
42
40
38
36
34
32
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
A/Z
136Xe
0
N= Z+3
N= Z+29
3091
1306
552
233
98
42
18
7.4
3.1
1.3
0.56
0.24

Dependence in energy

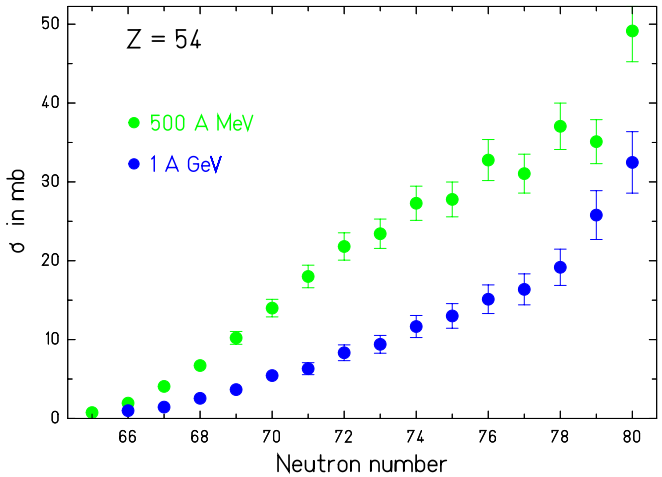


L. Giot et al., in preparation



P. Napolitani, M. F. Ordonez et al., in preparation

^{136}Xe + ^{1}H 500 *A* MeV



σ_R = 1263 mb ^{136}Xe + ^{1}H 500 *A* MeV

σ_R = 1353 mb ^{136}Xe + ^{1}H 1 *A* GeV

P. J. Karol, PRC 11 (1975) 1203

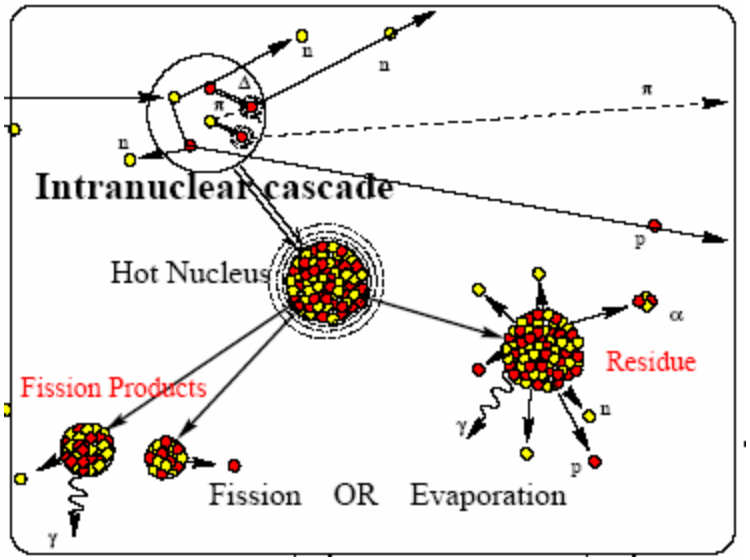
To complete this study

^{136}Xe + ^{1}H 200 *A* MeV C. Paradela

^{136}Xe + ^{2}H 500 *A* MeV L. Giot

analysis under progress...

Spallation



- **Intranuclear cascade**

ISABEL *Y. Yariv et al., PRC 20 (1979) 2227*

INCL4 *A. Boudard, J. Cugnon et al., PRC 66 (2002) 044615*

- **Desexcitation**

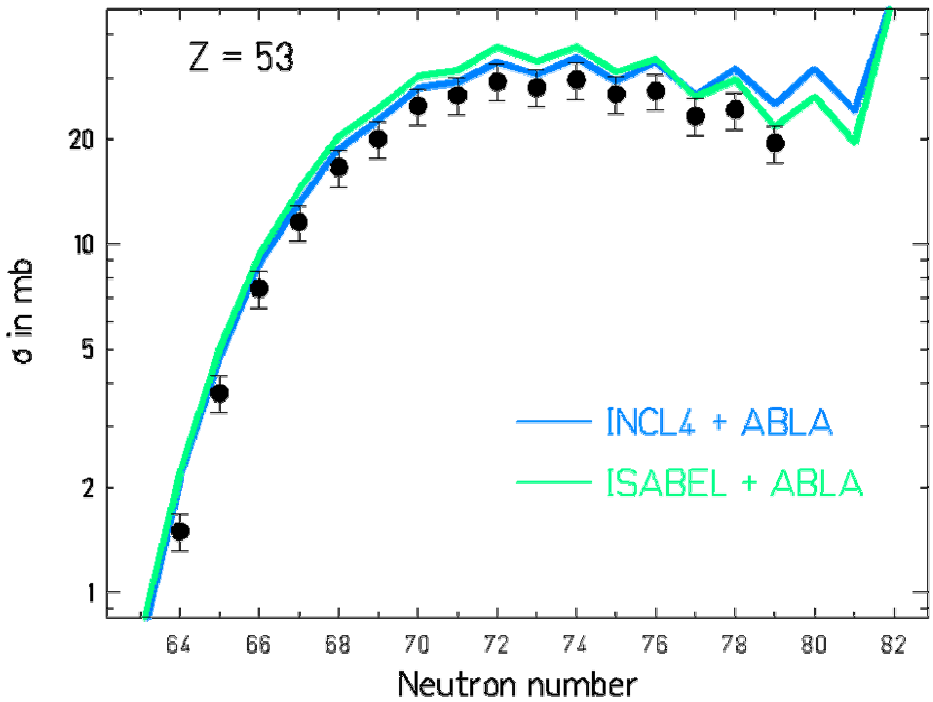
Statistic code ABLA

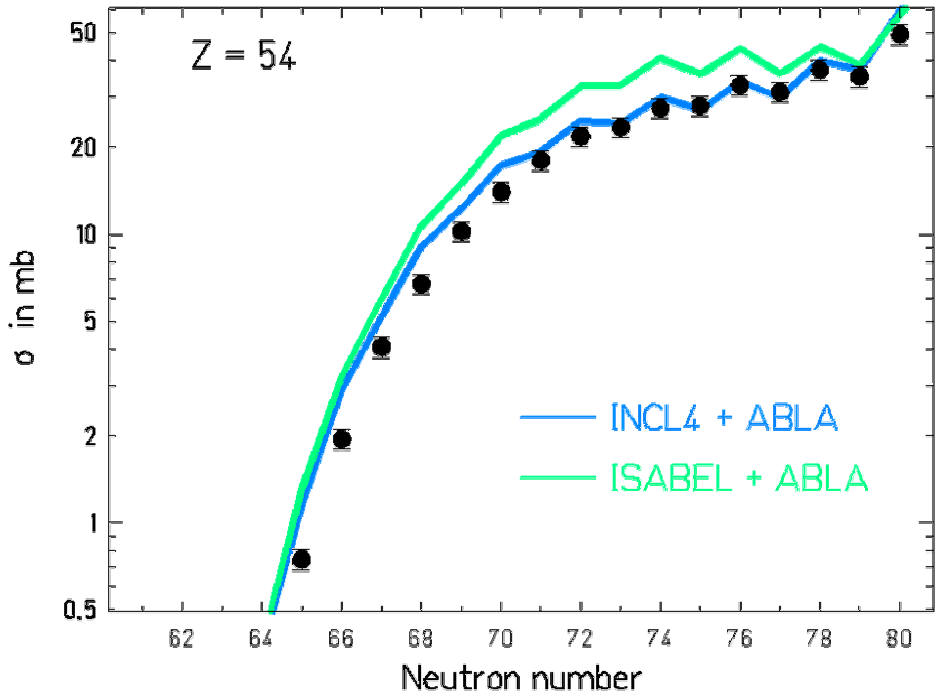
J.-J. Gaimard and K.-H. Schmidt, NPA 531 (1991)187

	ISABEL	INCL4
nucleus	continue medium	discrete
propagation of the cascade	step in time	step in time
collision criterium	mean free path	minimal distance of approach
stopping criterium	energy	time
nuclear density distribution	diffuse in 16 régions	Wood-Saxon type

Comparison with nuclear reaction codes

$^{136}Xe + {}^{1}H$ 500 *A* MeV





- **Intranuclear cascade**

  INCL4 *A. Boudard, J. Cugnon et al., PRC 66 (2002) 044615*

  ISABEL *Y. Yariv et al., PRC 20 (1979) 2227*

- **Desexcitation: Statistical code ABLA**

  J.-J. Gaimard and K.-H. Schmidt, NPA 531 (1991)187

- **Even odd effects restored at the end of the evaporation process**

  M. V. Ricciardi et al., NPA 733 (2004) 299

Summary and Outlook

- The results obtained at GSI are the only full-coverage data on nuclide production (production cross sections and velocities) available. More than 1000 individual nuclides investigated for each system.

- Energy dependence of the spallation

⇨ **Modelling of spallation in a thick target.**

- $^{136}Xe + {}^{1}H$ 500 *A* MeV, 1 *A* GeV : production cross sections available

⇨ **Best reproduction with INCL4 + ABLA**

- Even odd effects observed in the production cross sections

⇨ **Qualitatively understood with a evaporation statistical model**

- 2^{nd} generation experiment in preparation in GSI: Measurement in coincidence of fragments, neutrons, light charged particles with SPALADIN.

Nuclear-data measurements at relativistic energies in inverse kinematics

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