HINDAS

High- and Intermediate-energy Nuclear Data for Accelerator-driven Systems

Studies of spallation reactions above 200 MeV

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Abstract: Nuclear data of spallation reactions above 200 MeV, needed for the design of the ADS, are scarce. Experiments with proton beams in the appropriate energy regime have been made at SATURNE (Saclay) and COSY (Jülich) to obtain detailed data on light charged-particle and neutron production. Nuclide identification in-flight of heavy residues requires the application of inverse kinematics and a powerful spectrometer. For this purpose, the GSI facility has been used. In addition, this experiment provides the recoil energies of the heavy residues. The data on systematic investigations of a few representative systems, which are already partly available, put important constraints on the models to be improved or developed for this energy regime. A new-generation experiment is in preparation which intends to determine the light-particle production in coincidence with the production of heavy residues. This technique will allow to better determine the characteristics of the nuclear-collision phase and of the deexcitation phase independently.

3 Work packages:

(dedicated to specific reaction channels)

- **Light charged particles** (Jülich, Saclay)
- **Neutrons** (Saclay, Bruyères, Jülich, Cean)
- **Heavy residues** (GSI, Santiago, Saclay)

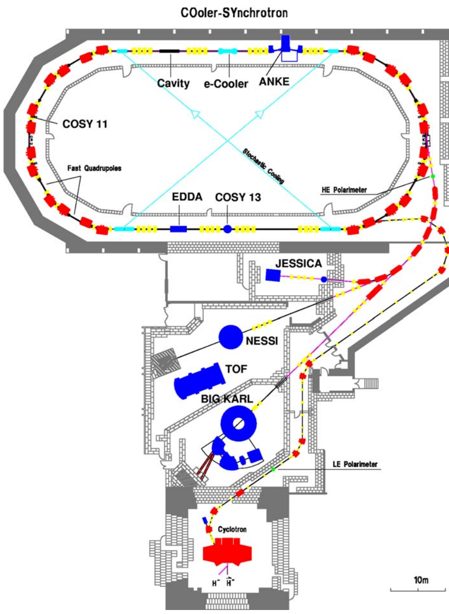
Aim:

Complete understanding and modeling of spallation reactions at 200 - 2000 A MeV.

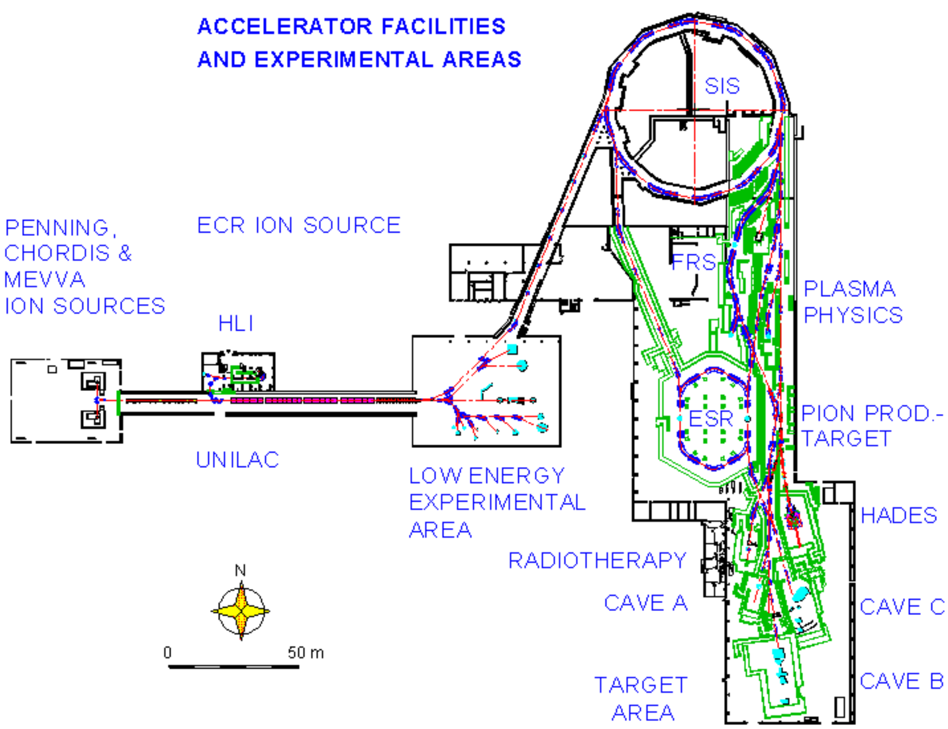
Program:

Measurements for a few targets (Fe, Pb, and U), covering all reaction channels.

Experiments performed at best-equipped European facilities.

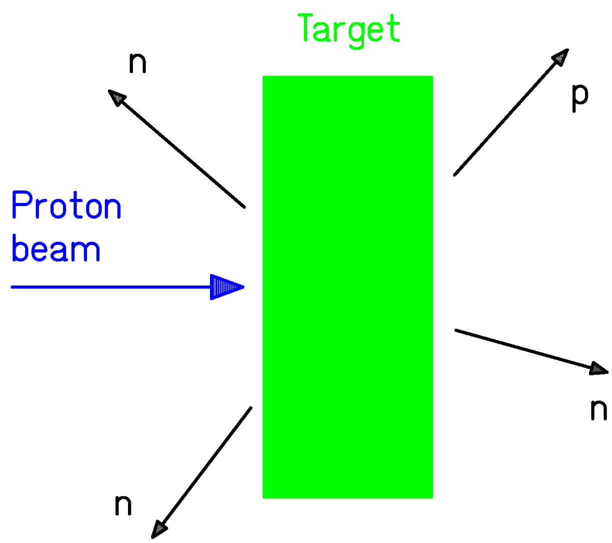


COSY, Jülich (proton beam)



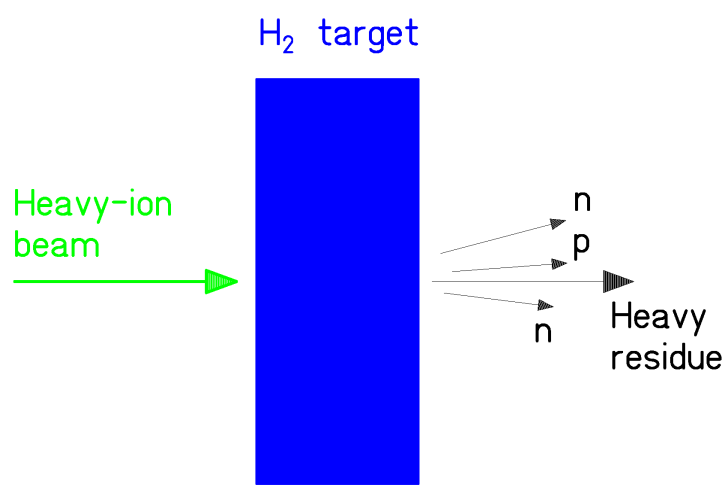
GSI, Darmstadt (heavy-ion beam, ≈1AGeV)

Two different approaches



Normal kinematics

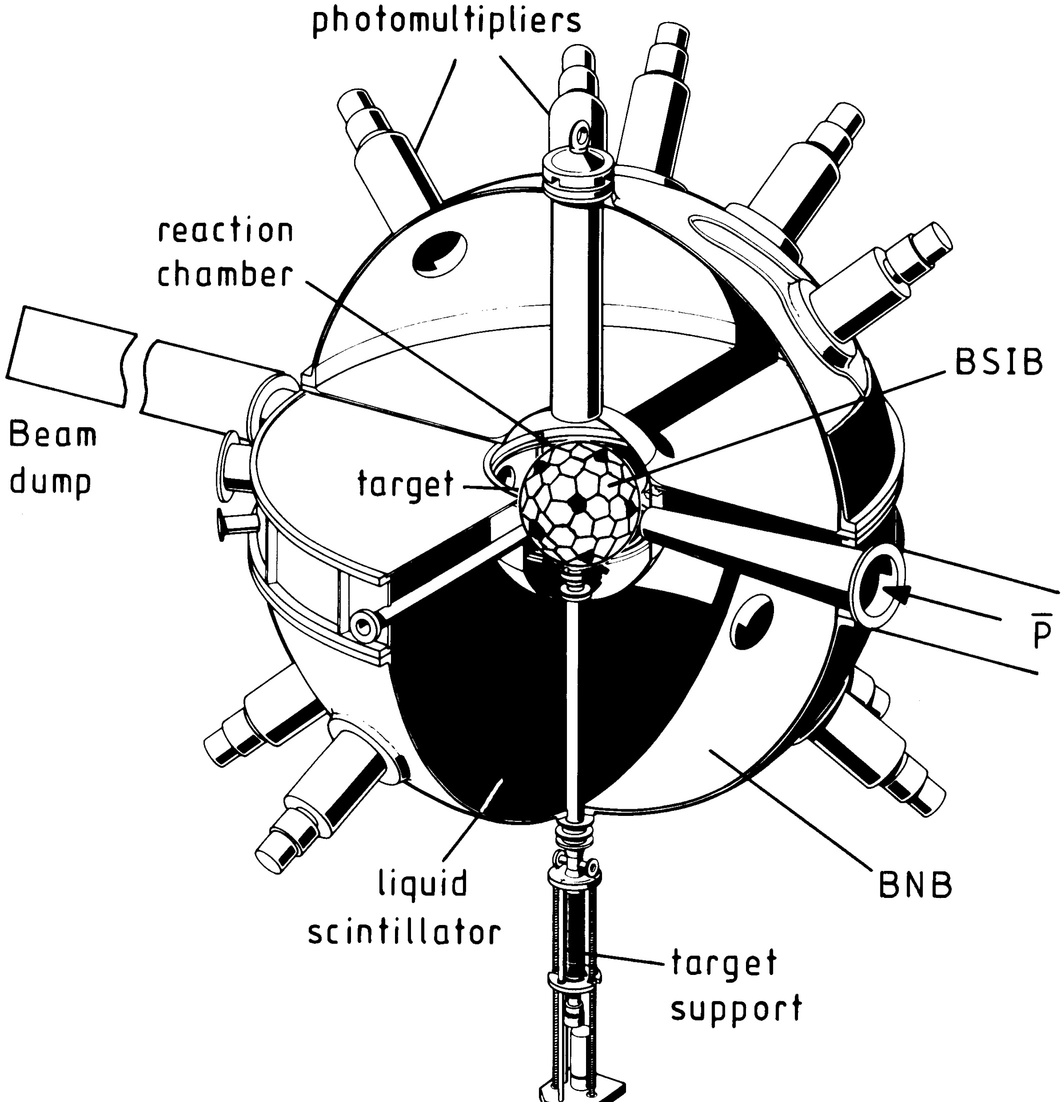
- **Light particles emitted in all directions.**
- **Heavy residues stick in the target.**



Inverse kinematics

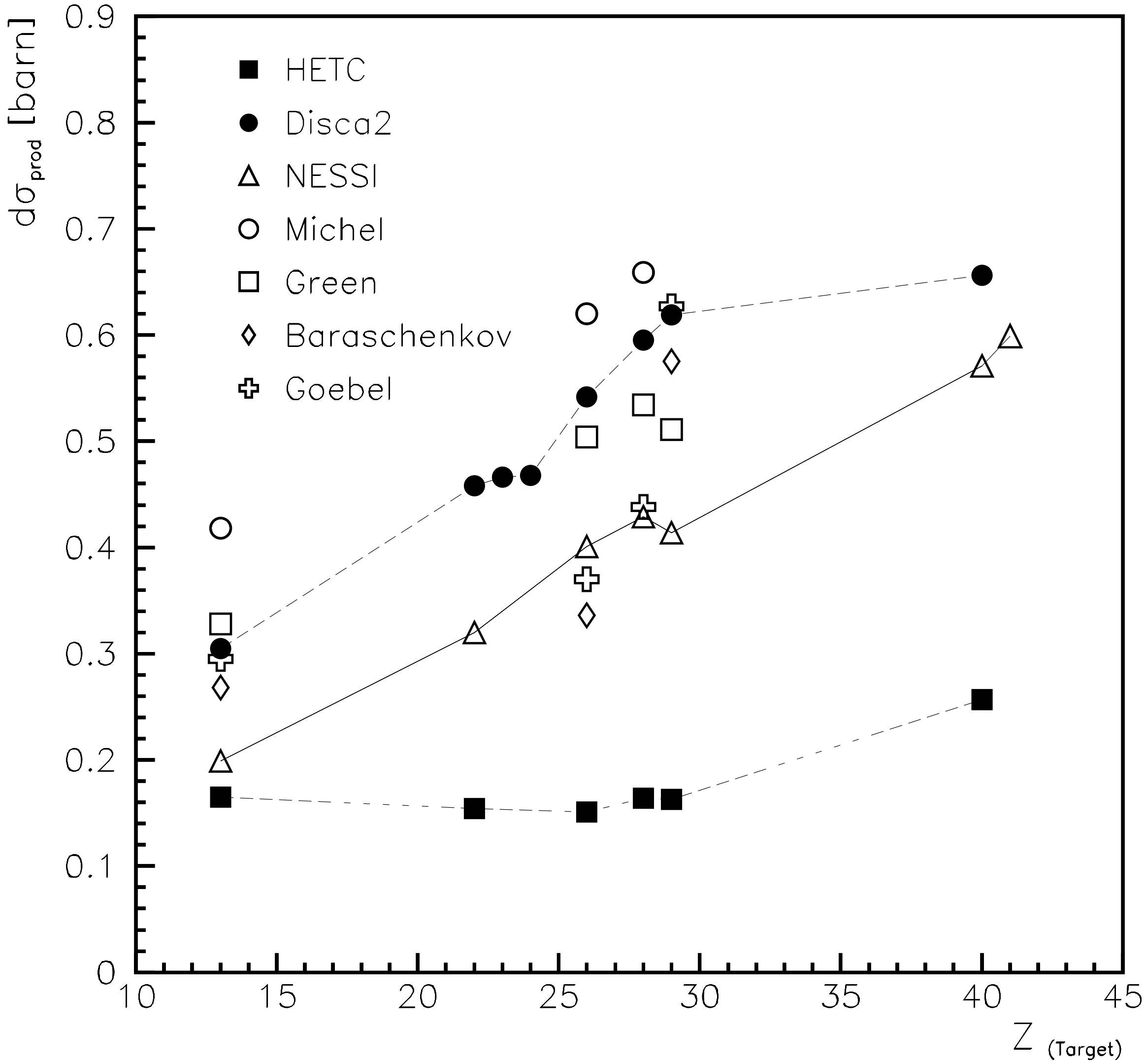
- **All reaction products in forward direction.**

The BNB - BSiB Detector



A 4 π detector for neutrons and charged-particles

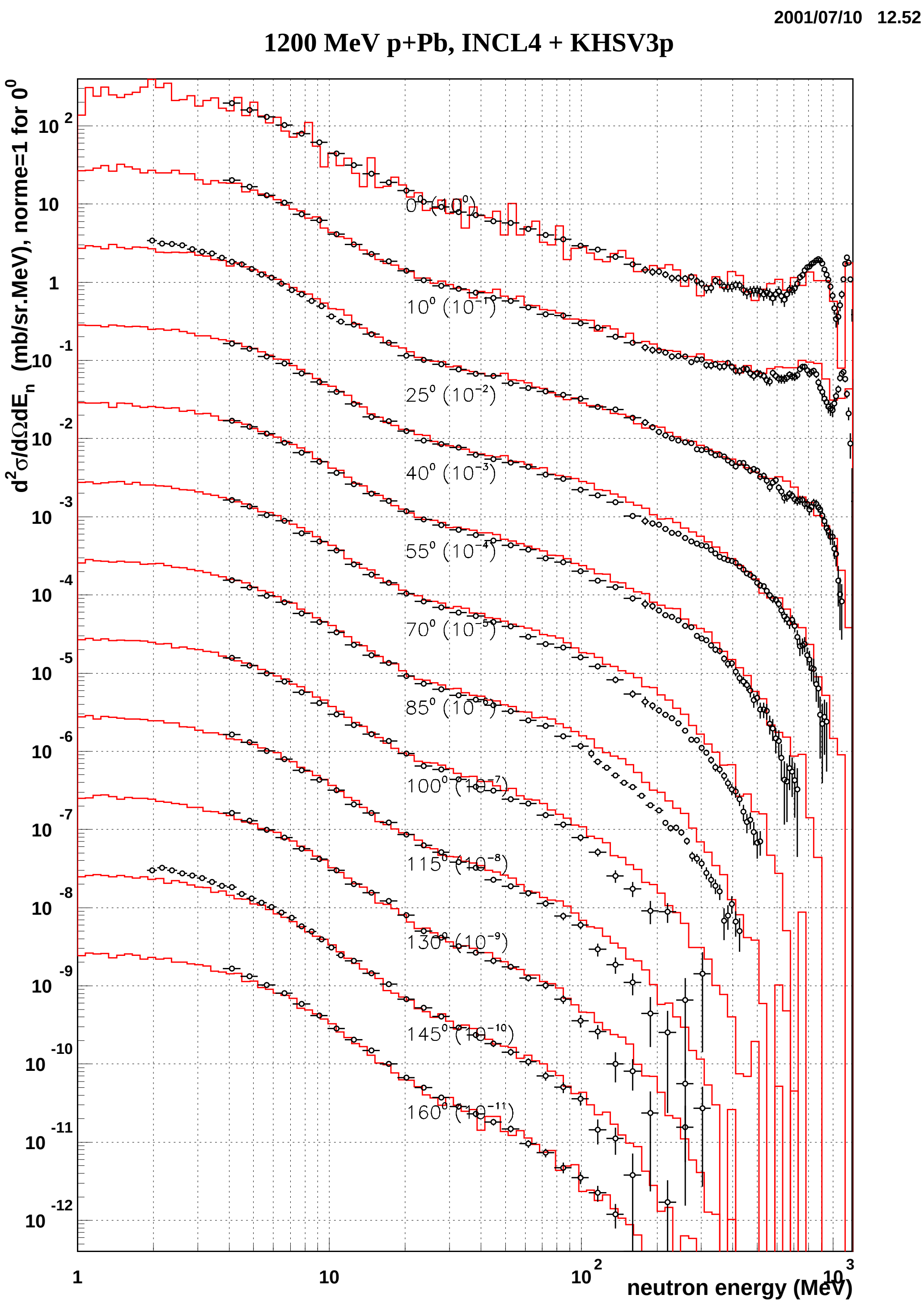
Production of He
by 0.8 GeV protons



Large discrepancies between theories (■, ●) and experiments (△, ○, □, etc.).

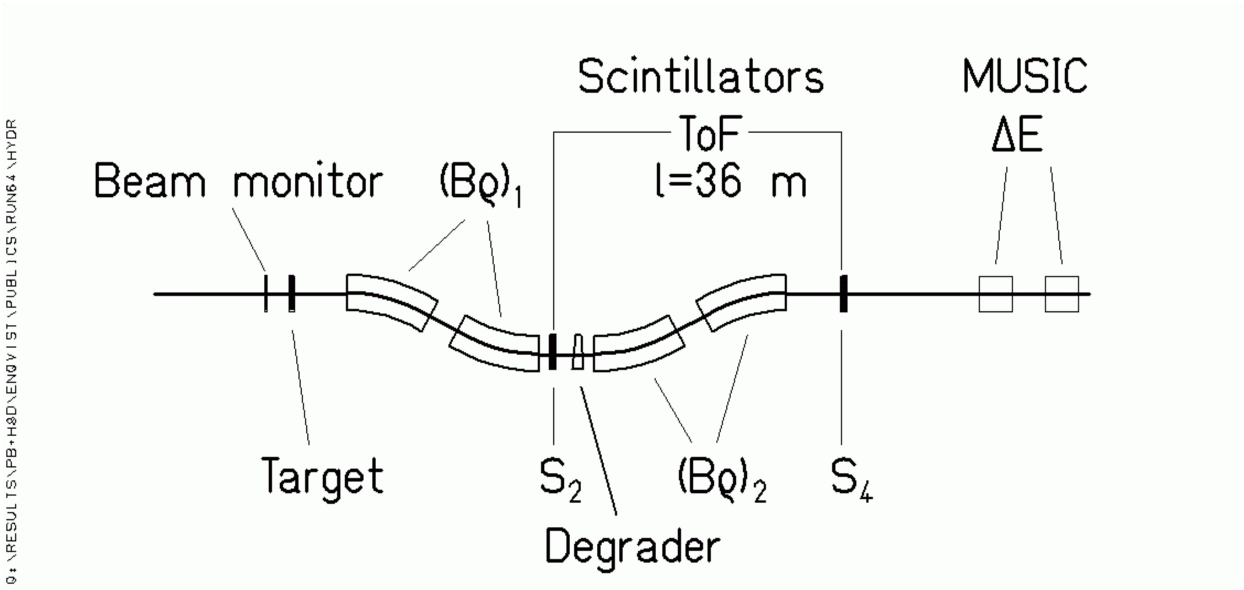
D. Filges et al., Eur. Phys. Journ. A 11 (2001) 467

Double-differential neutron cross sections (1.2 GeV protons on lead)

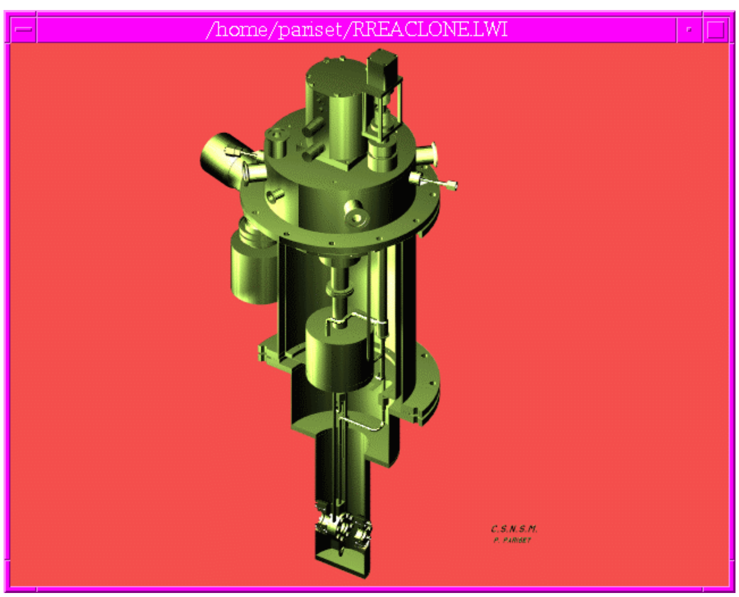


A. Boudard et al., Nucl. Phys. A663-664 (2000) 1061c

The GSI Fragment Separator



In-flight identification of heavy residues.

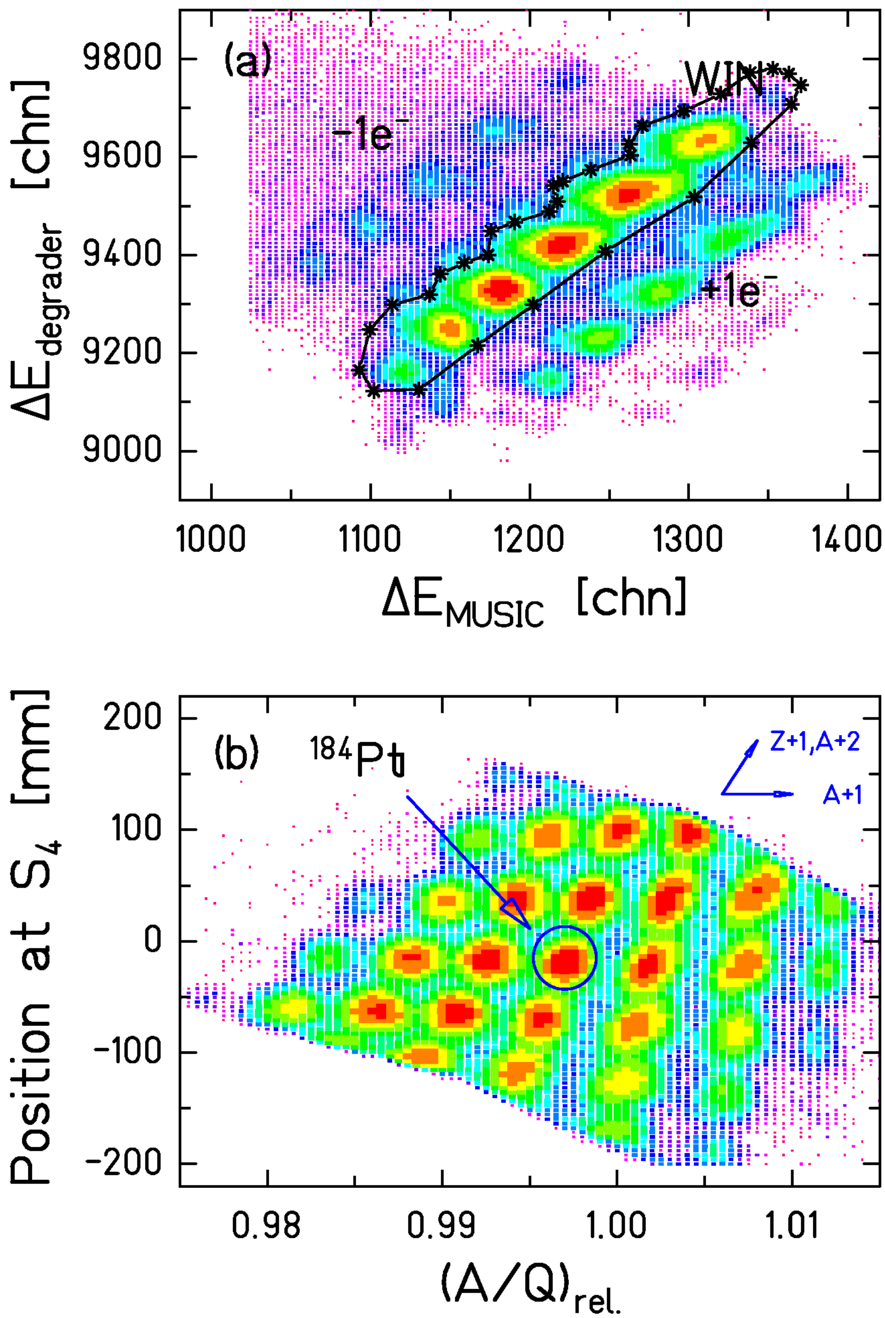


Filling:
H_2: 90 mg/cm^2

Windows:
Ti: 36 mg/cm^2

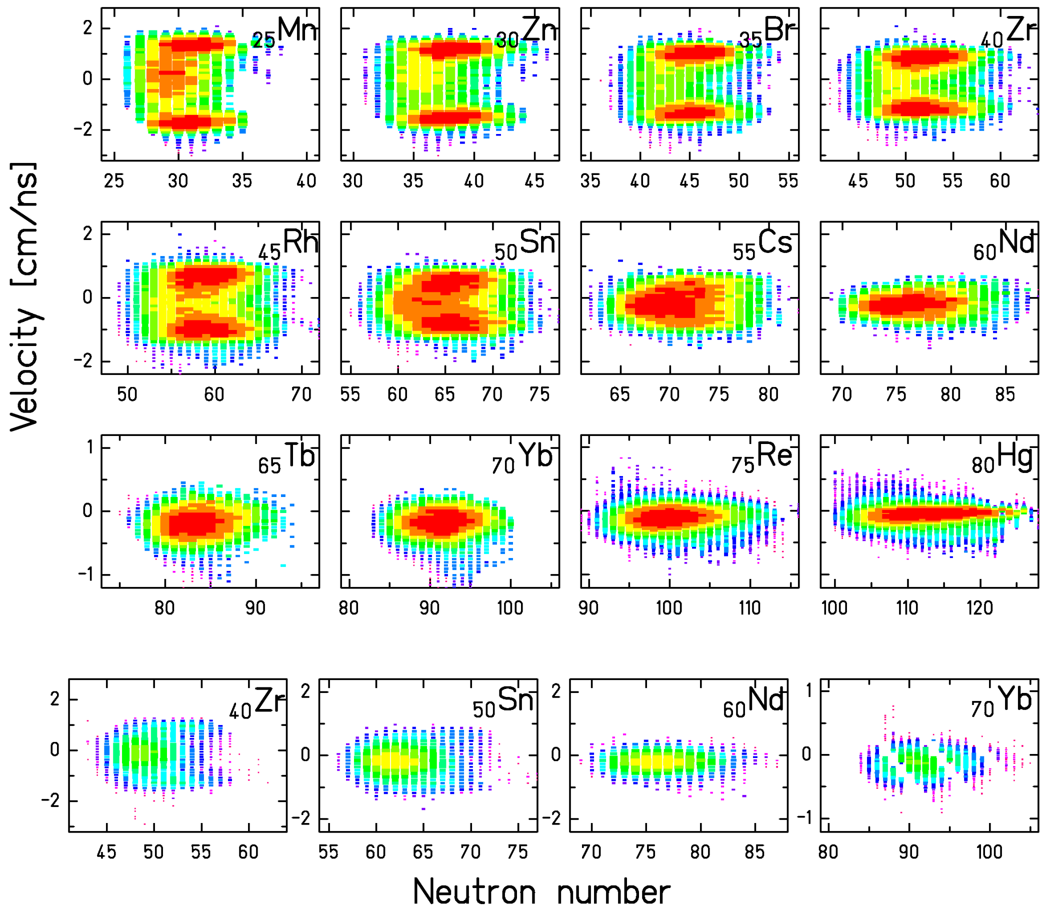
The liquid-hydrogen target (CEA Saclay).

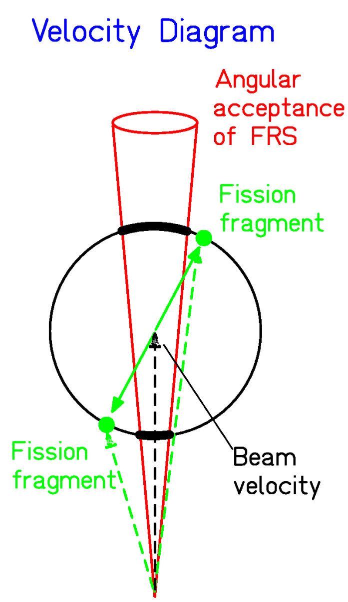
Identification pattern ($^{208}Pb + {}^{1}H$)



(a) Identification of ionic charge states
(b) Separation in A and Z

Kinematics (^{208}Pb + ^{1}H)





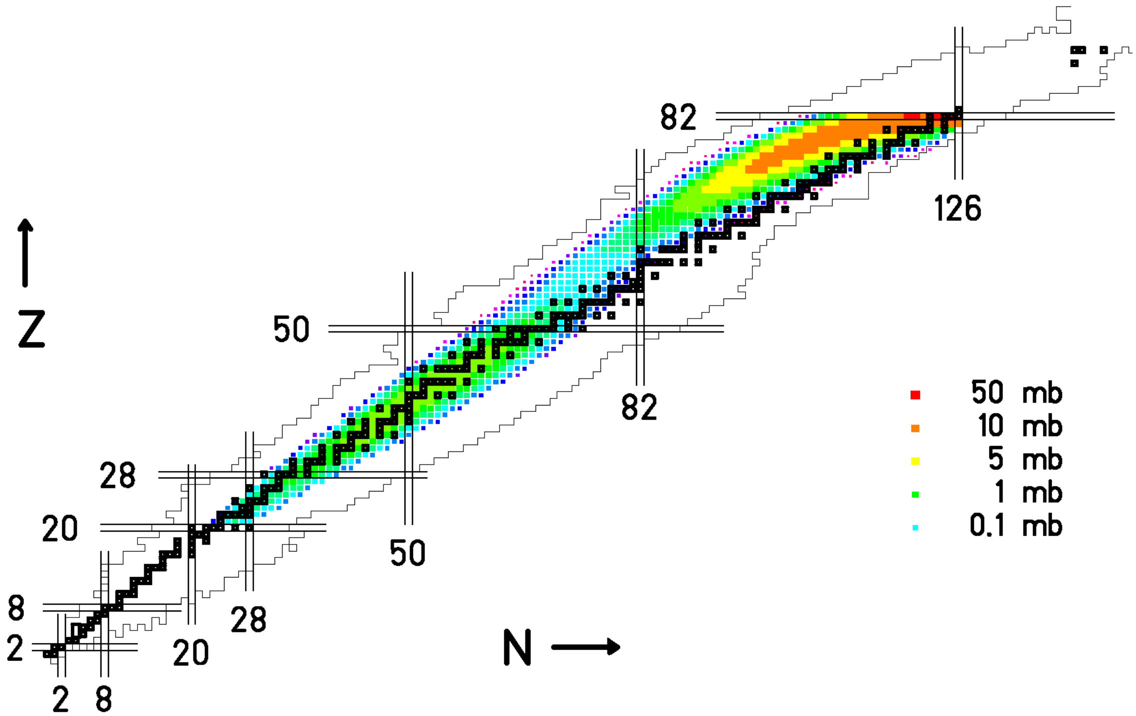
<u>Velocity distribution of every nuclide</u>

➔ **Recoil energy**
➔ **Production mechanism**

Sideward emission suppressed.

Production cross sections

^{208}Pb (1 A GeV) + proton



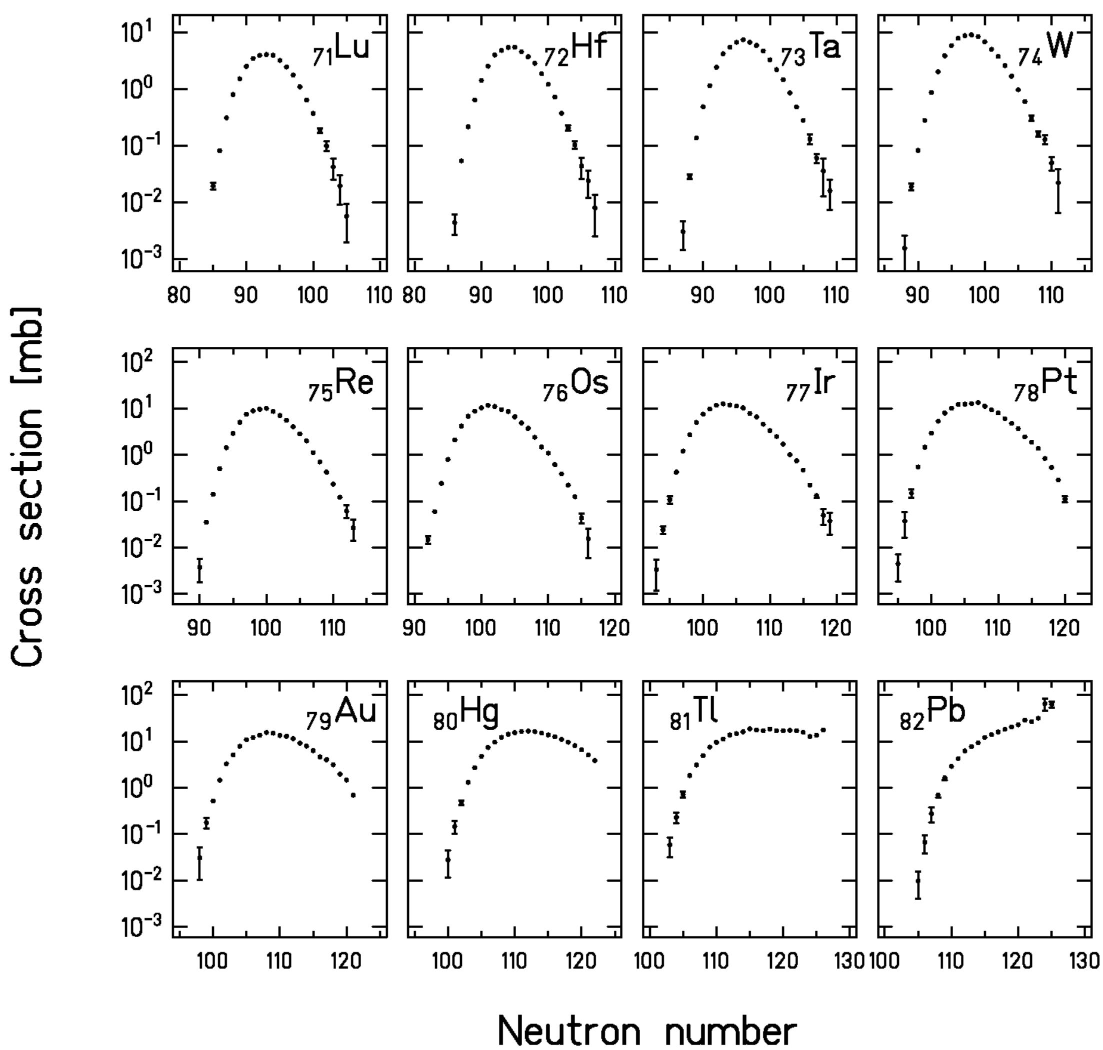
For the first time:
Full coverage of all nuclides produced by fragmentation and fission.
(Uncertainties ≤ 10% in most cases.)

T. Enqvist et al., Nucl. Phys. A 686 (2001) 481-524

Production cross sections

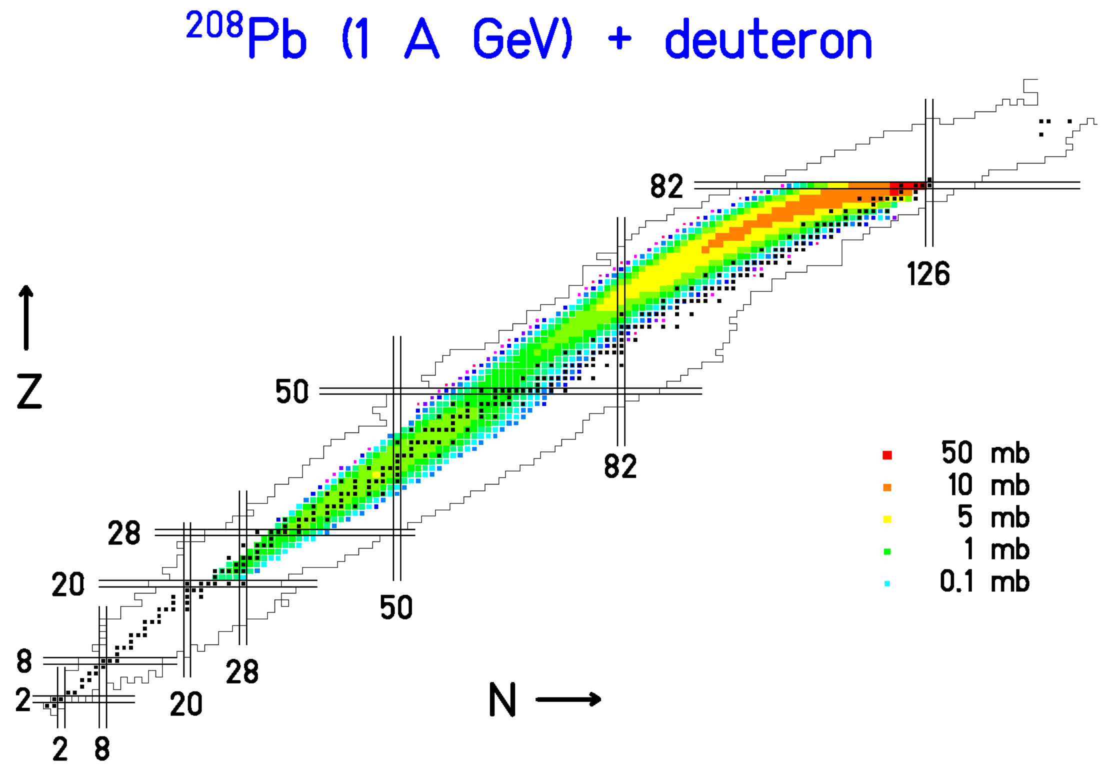
^{208}Pb (1 A GeV) + proton

(Some isotopic sequences)



T. Enqvist et al., Nucl. Phys. A 686 (2001) 481-524

Production cross sections

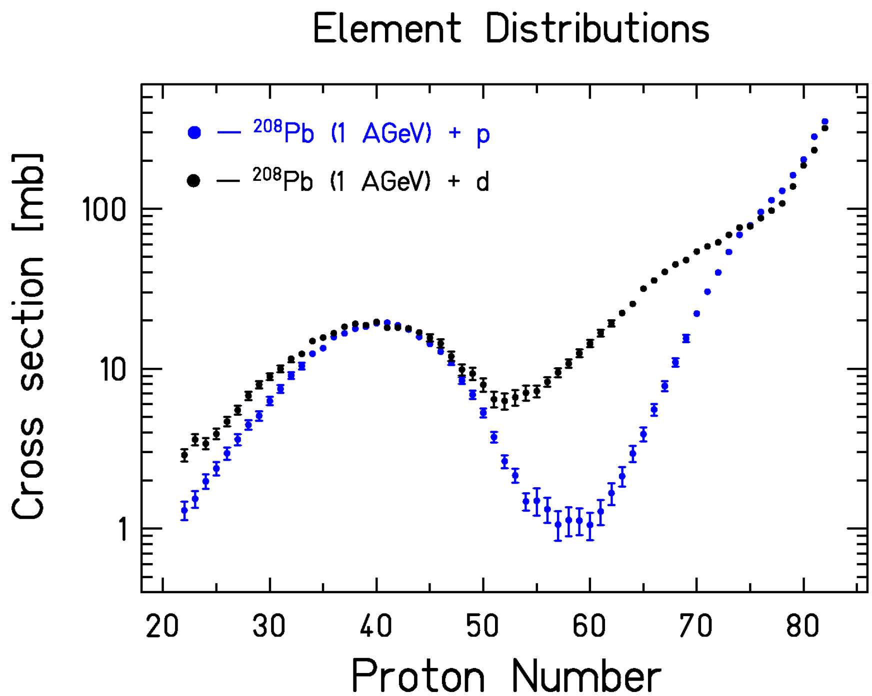


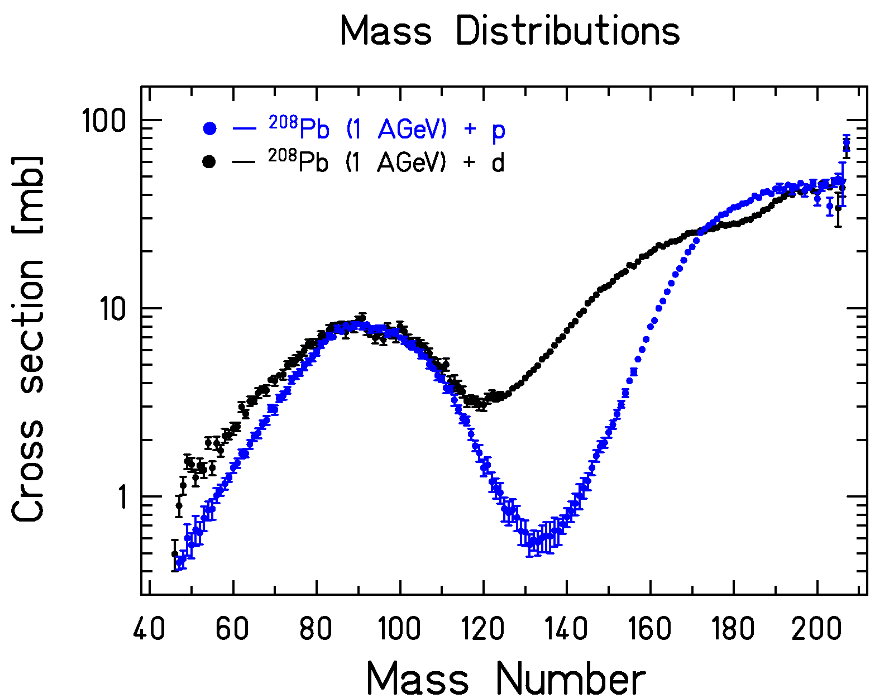
T. Enqvist et al., Nucl. Phys. A, in print

Data evaluation in progress for:

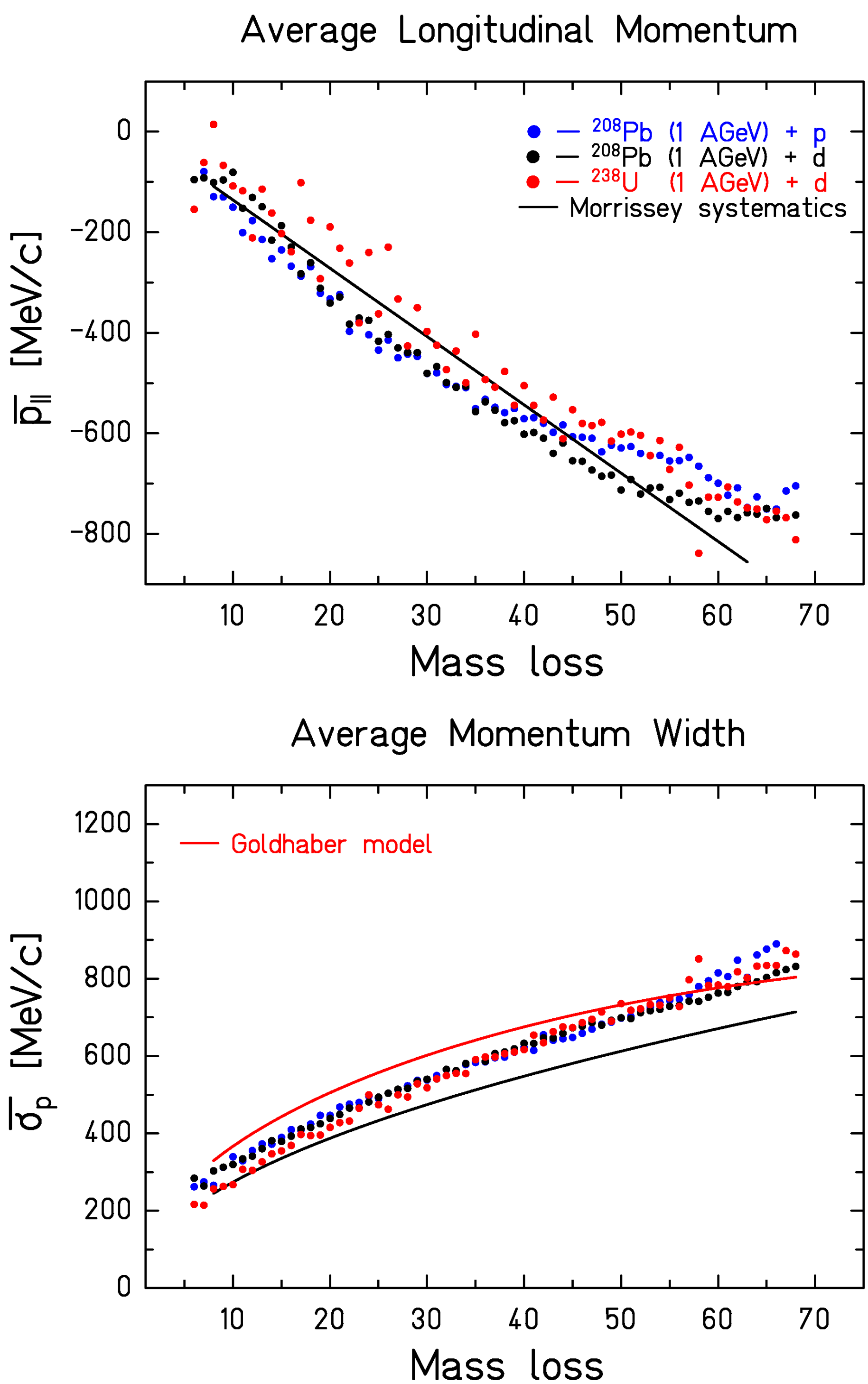
^{238}U (1 A GeV) + proton

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

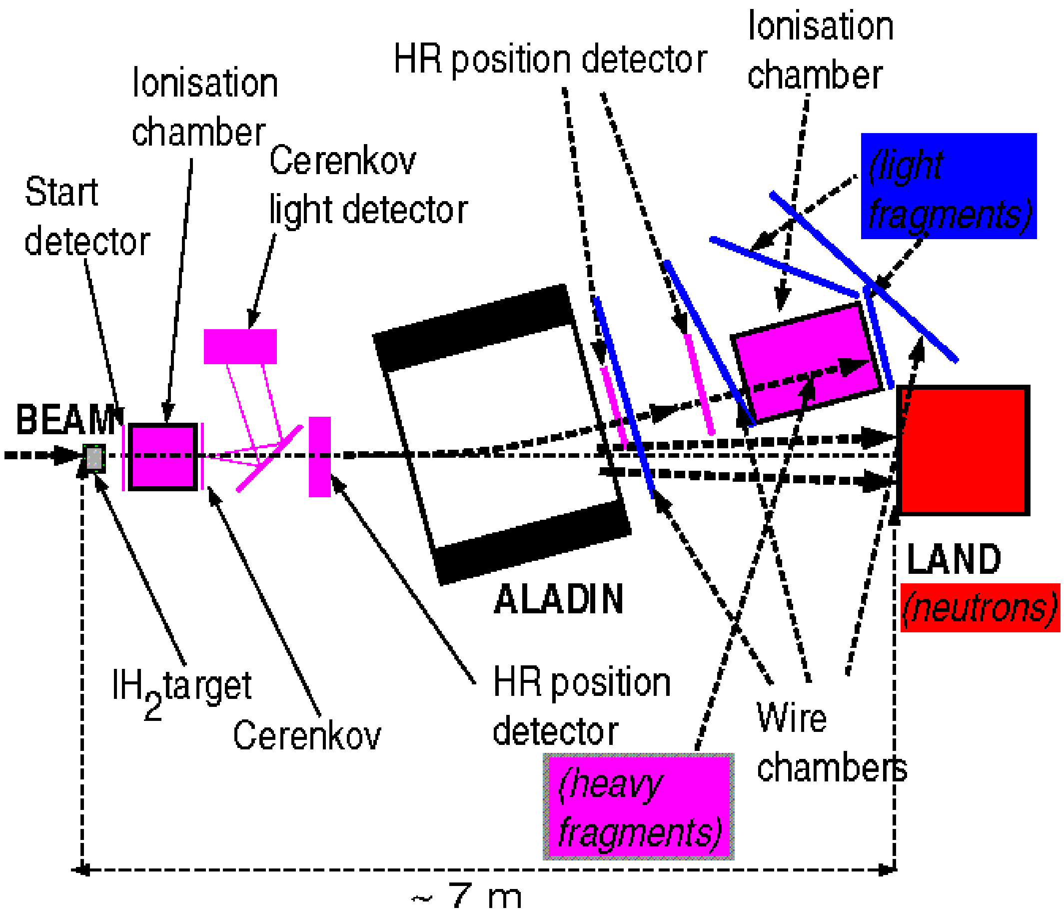

Element Distributions
208Pb (1 AGeV) + p
208Pb (1 AGeV) + d
Cross section [mb]
Proton Number


Mass Distributions
208Pb (1 AGeV) + p
208Pb (1 AGeV) + d
Cross section [mb]
Mass Number

Recoil velocities



Preparation of 2nd generation experiment



Measurement of residues in coincidence with neutrons and light charged particles

(Saclay, GSI, München, Orsay, Bordeaux, Santiago)

Summary

Experimental goal:

Full coverage of yields and velocities of

- light charged particles
- neutrons
- heavy residues

for a few systems.

Status:

- Most complete set of relevant data measured.
- First results published.
- 2nd generation experiment in preparation.

New information on critical topics:

- Energy deposit in INC phase.
- Thermal instability of nuclei.
- Barriers of charged particles.
- Dissipative hindrance of fission.

An excellent basis for improved nuclear models.