

Timo Enqvist

Department of Physics, University of Jyväskylä
(JYFL)
Finland

MEASUREMENT of
SPALLATION RESIDUES using
INVERSE KINEMATICS at GSI

P. Armbruster, J. Benlliure, M. Bernas, A. Boudard,
E. Casarejos, S. Czajkowski, J.P. Dufour, T. Enqvist,
R. Legrain, S. Leray, B. Mustapha, M. Pravikoff,
J. Pereira, F. Rejmund, K.-H. Schmidt, C. Stephan,
J. Taieb, L. Tassan-Got, C. Volant, F. Vives, W. Wlazlo

GSI-Darmstadt, Germany

CEA/Saclay, France

IPN-Orsay, France

CENBG-Bordeaux, France

University of Santiago de Compostela, Spain

University of Jyväskylä, Finland

INCINERATION EXPERIMENTS at GSI

TEST EXPERIMENTS

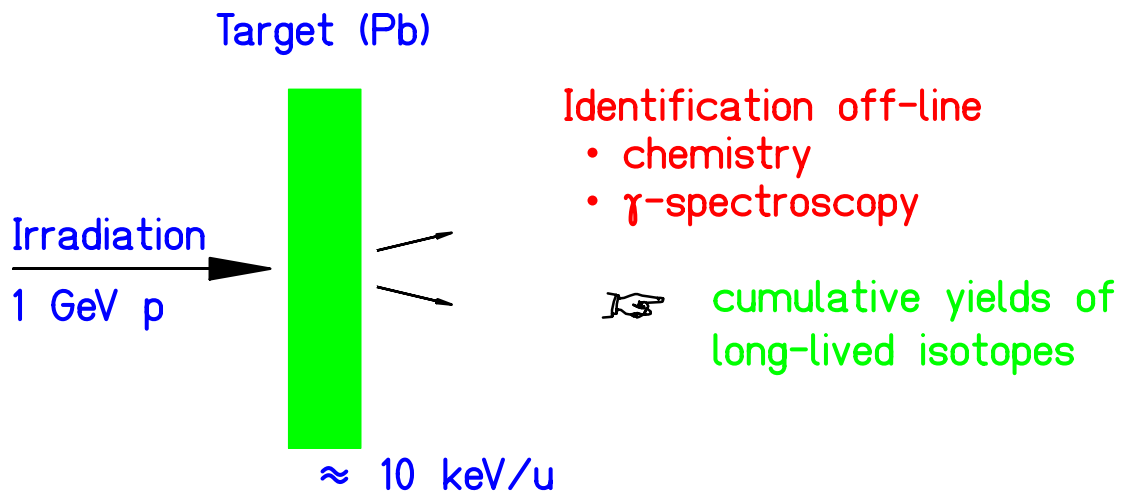
- $\times$ ^{238}U (1 A GeV) + ^{208}Pb (Nov 1996) ①
- $\times$ ^{197}Au (0.8 A GeV) + p (Feb 1997) ③ ④ ⑥

MAIN EXPERIMENTS

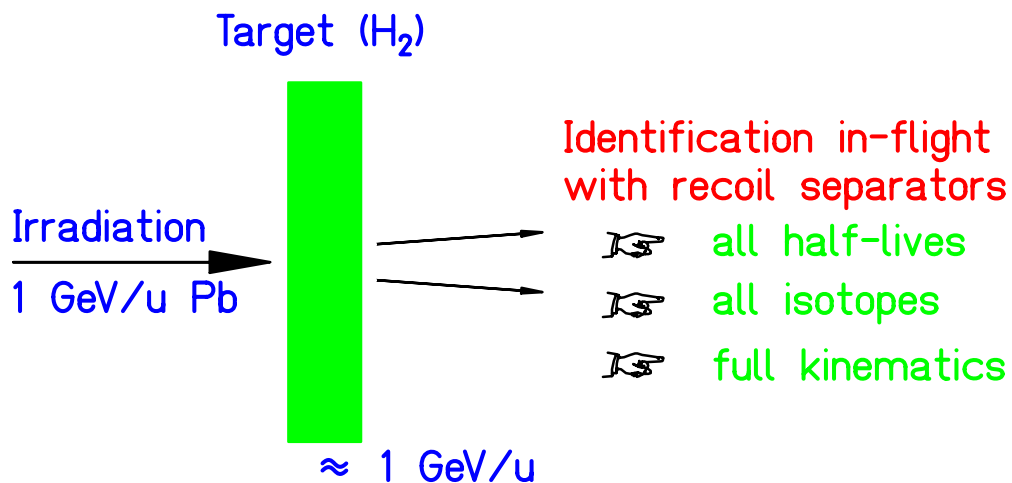
- ✓ ^{238}U (1 A GeV) + p, d (July 1996) ⑦ ⑧
- $\times$ ^{208}Pb (1 A GeV) + p, d (Oct 1997) ② ⑤
- ^{208}Pb (0.5 A GeV) + p, d (April 1999)
- ^{56}Fe , ^{60}Ni (0.3 ... 1.5 A GeV) + p, d (Oct 2000)

- ① T.Enqvist et al., Nucl. Phys. A 658 (1999) 47.
- ② W. Wlaził et al., Phys. Rev. Lett. 84 (2000) 5736.
- ③ J. Benlliure et al., Nucl. Phys. A 683 (2001) 513.
- ④ F. Rejmund et al., Nucl. Phys. A 683 (2001) 540.
- ⑤ T. Enqvist et al., Nucl. Phys. A 686 (2001) 481.
- ⑥ B.Mustapha, Ph.D. Thesis, 1999.
- ⑦ J. Taieb, Ph.D. Thesis, 2000.
- ⑧ E. Casarejos, Ph.D. Thesis, 2001.

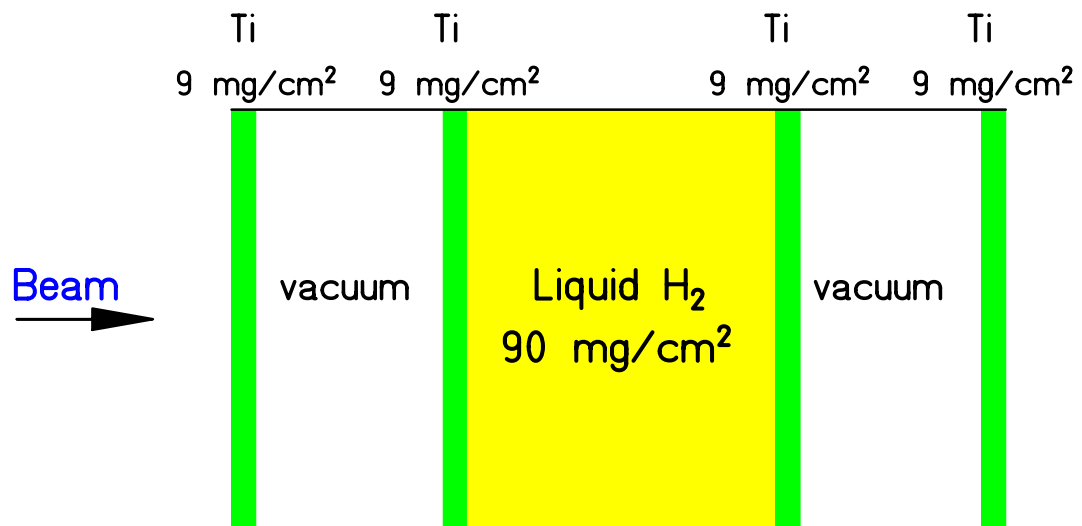
EXPERIMENTS with NORMAL KINEMATICS



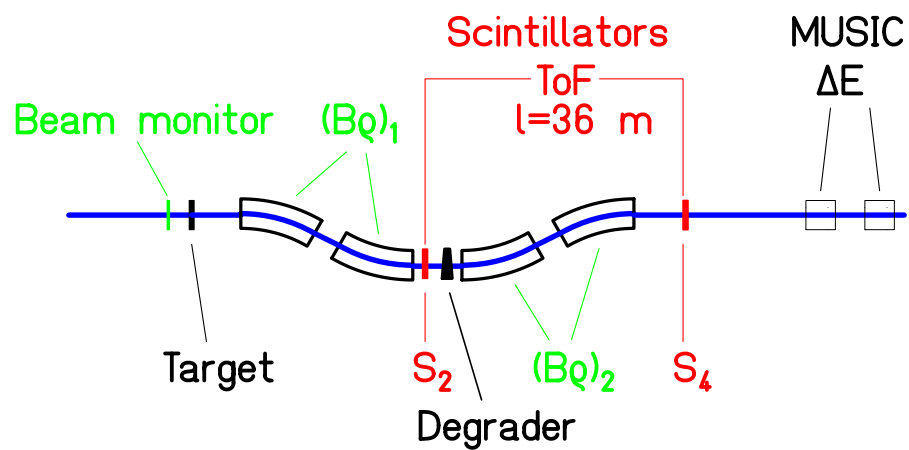
ADVANTAGE of INVERSE KINEMATICS



Liquid H₂-target

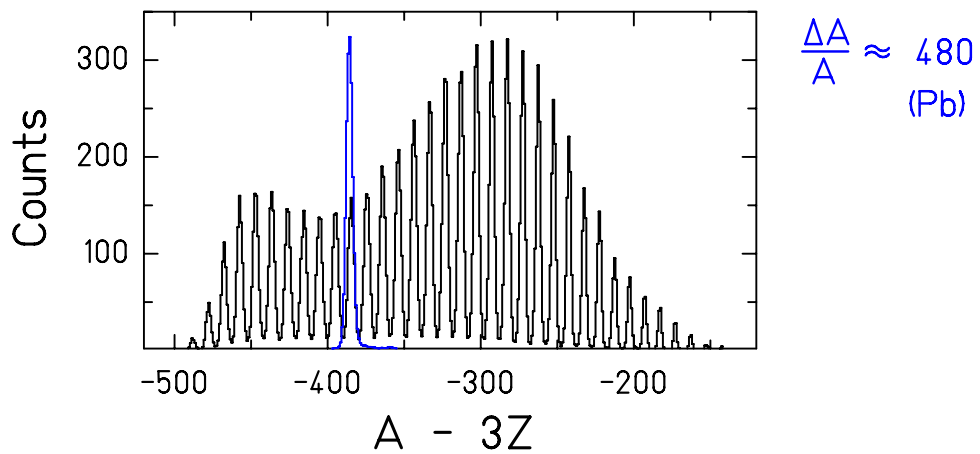
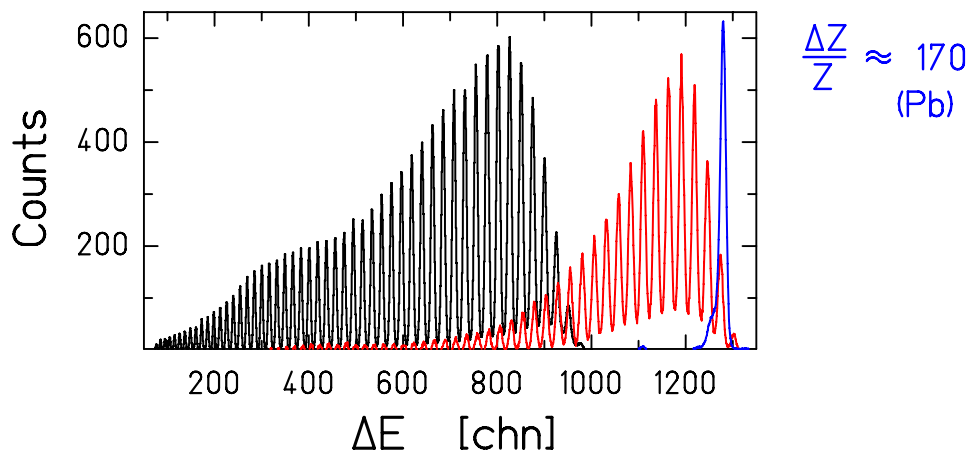


The FRagment Separator



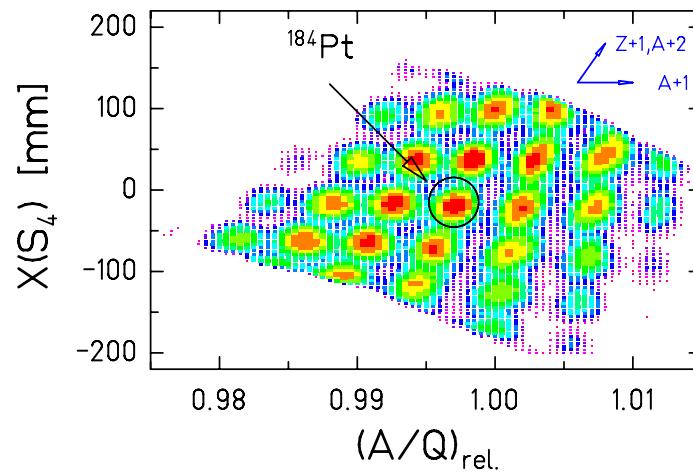
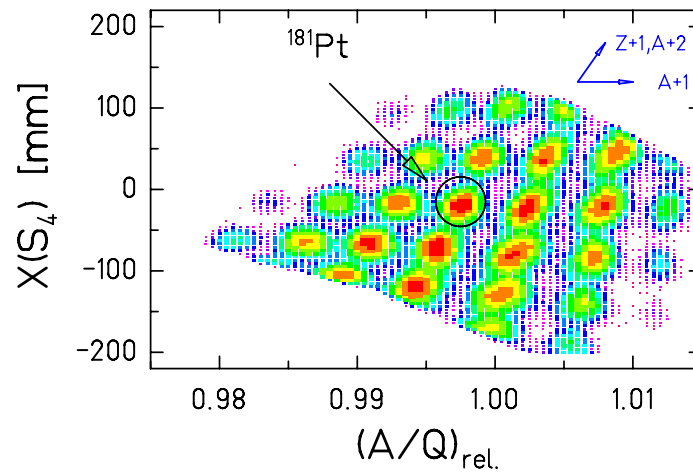
Charge and Mass Calibration

settings without degrader



Charge and Mass Calibration

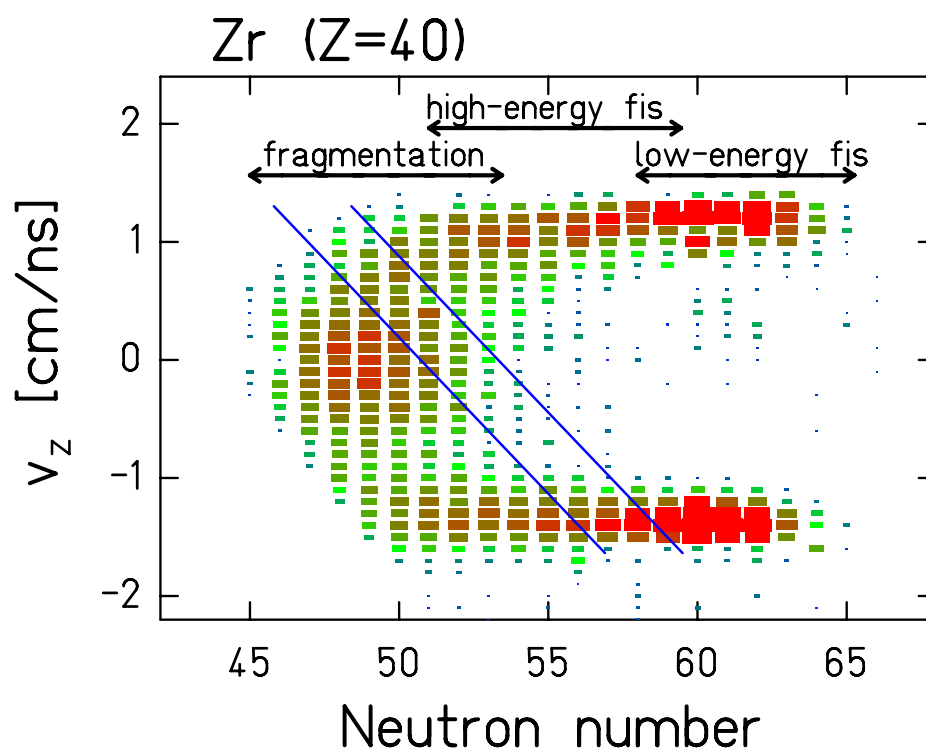
settings with degrader



VELOCITY DISTRIBUTIONS

Combination of several different
B_q-settings of the FRS

$^{238}\text{U}(1 \text{ AGeV}) + \text{Pb}$

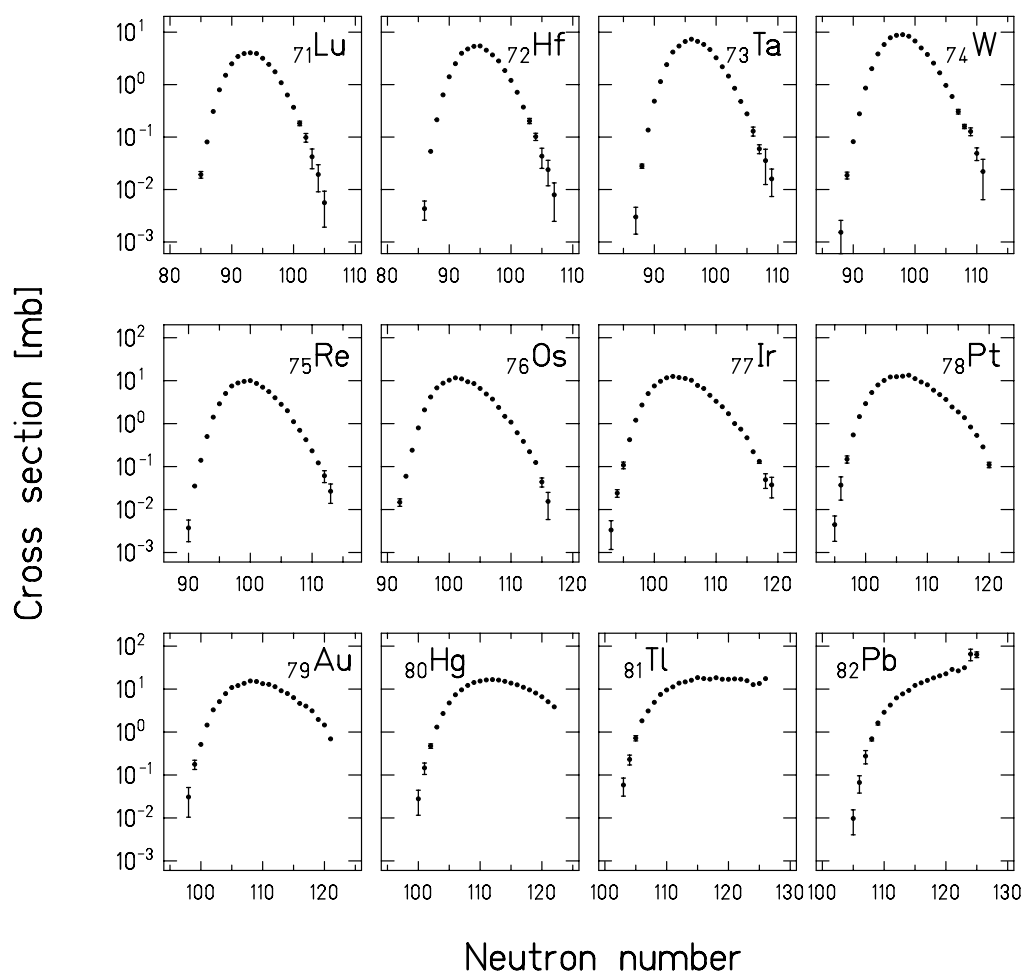


ACCURACY of the DATA

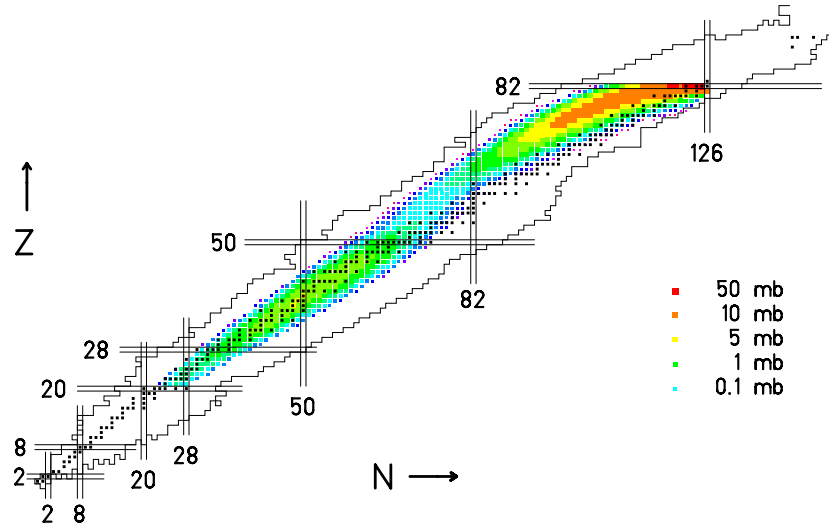
- Statistics: better than 3% above 1 mbarn
 - Beam Intensity: better than 5%
 - Transmission: between 5% and 10%
 - Target Windows: small contribution
 - Secondary Reactions (beam-line & target):
better than 5% in most cases
 - Charge States: around 3%
- 👉 total systematic error between 9% and 15%

Spallation-residue Cross Sections

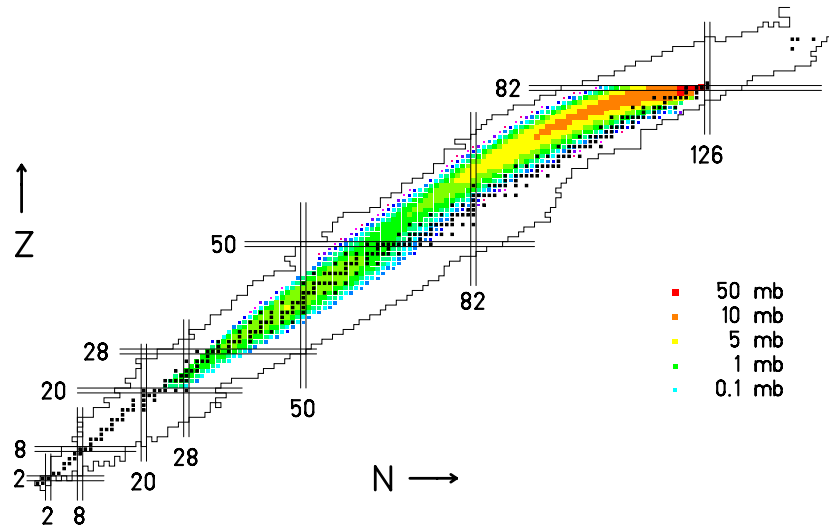
^{208}Pb (1 A GeV) + proton

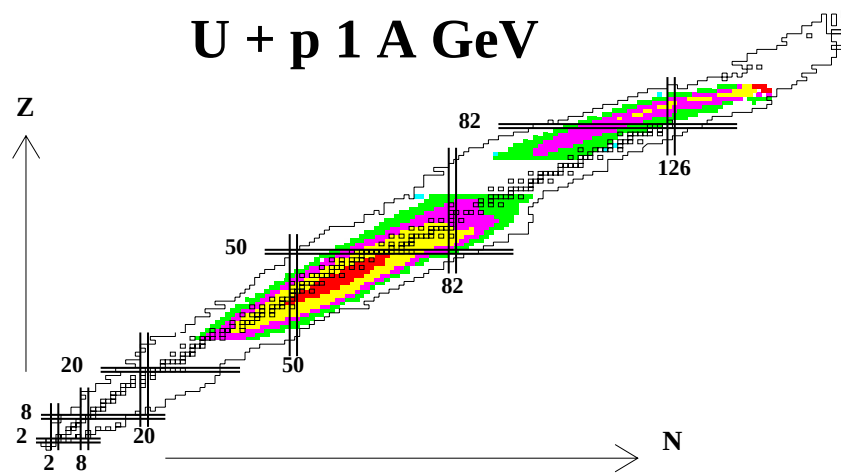


^{208}Pb (1 A GeV) + proton

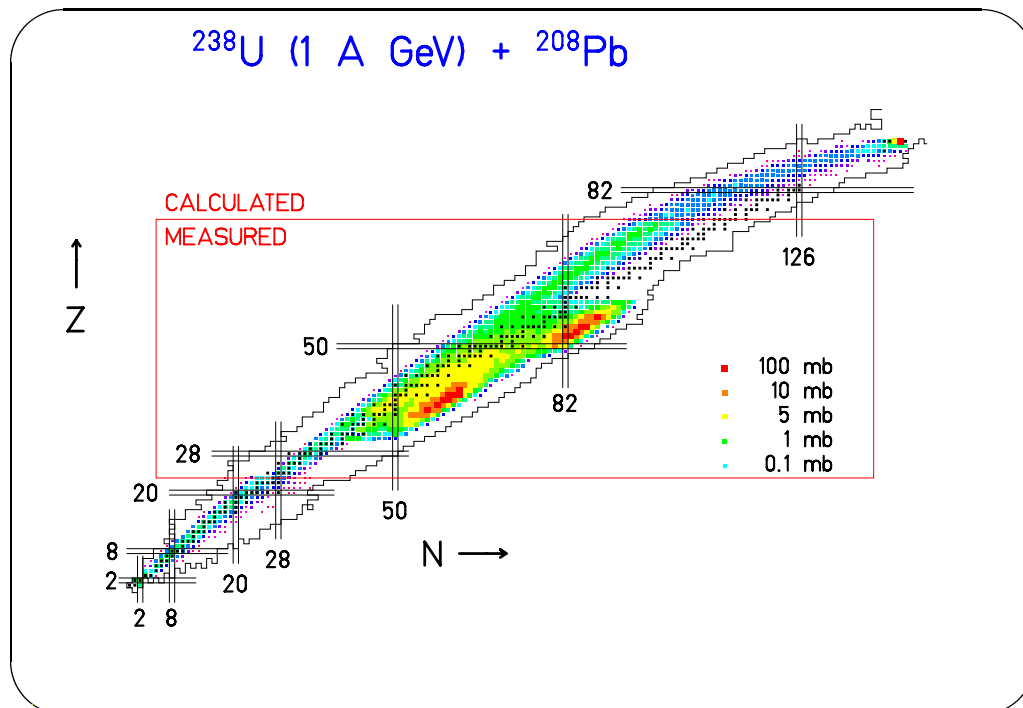


^{208}Pb (1 A GeV) + deuteron

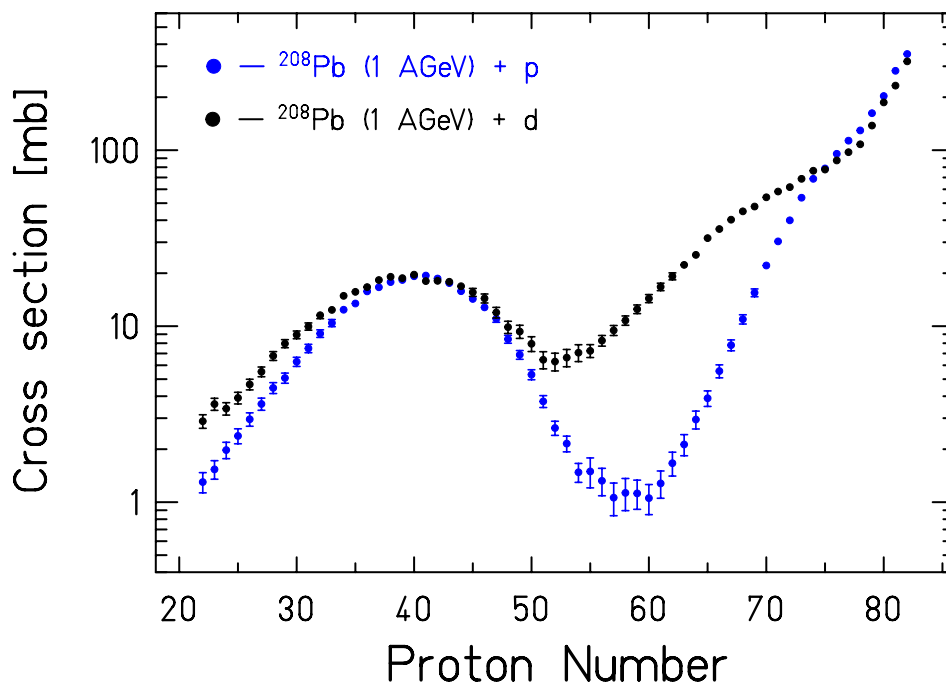




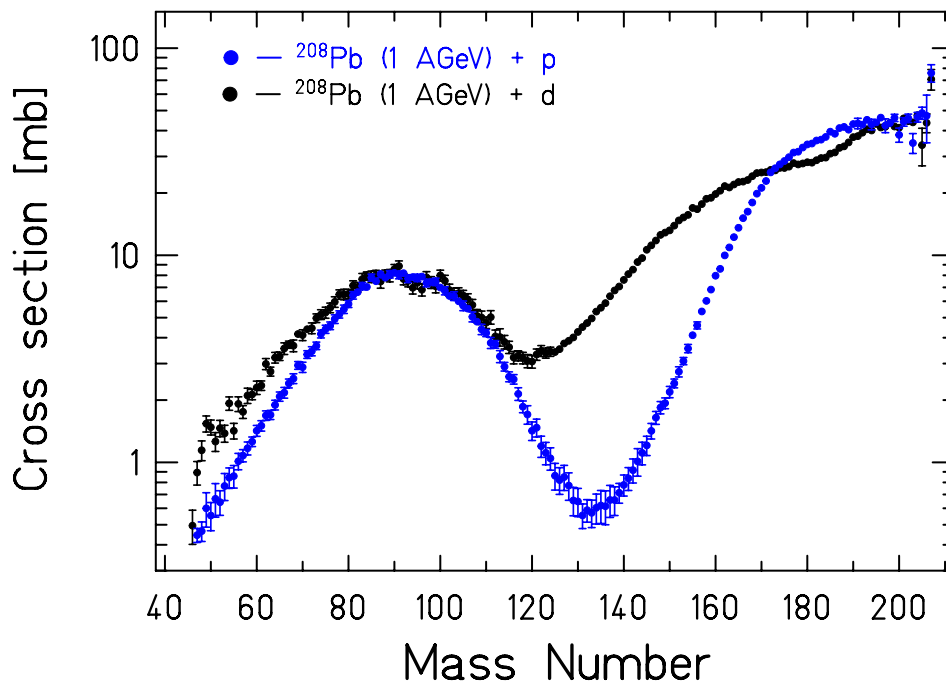
J. Taieb, PhD Thesis 2000, IPN Orsay
M. Bernas, IPN Orsay



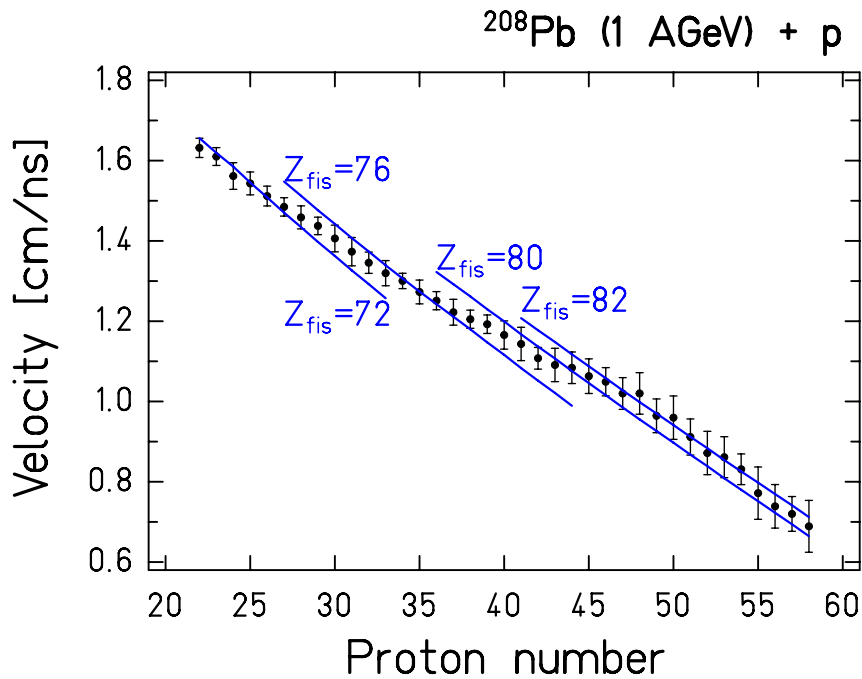
Element Distributions



Mass Distributions



Fission Velocities & Fissioning Systems



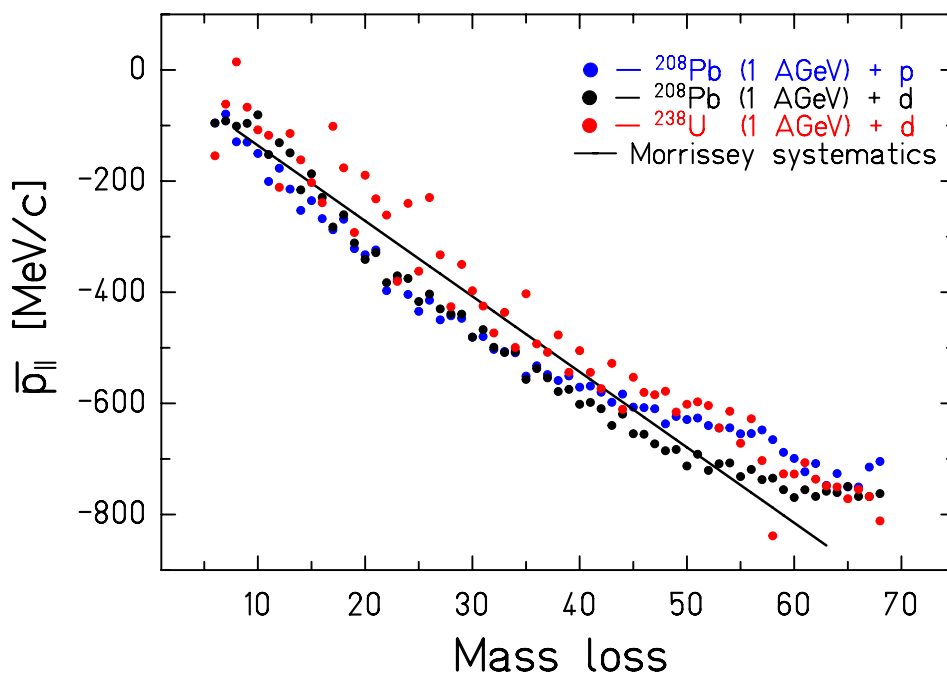
using the liquid-drop description

$$\text{TKE} = \frac{Z_1 Z_2 e^2}{D}$$

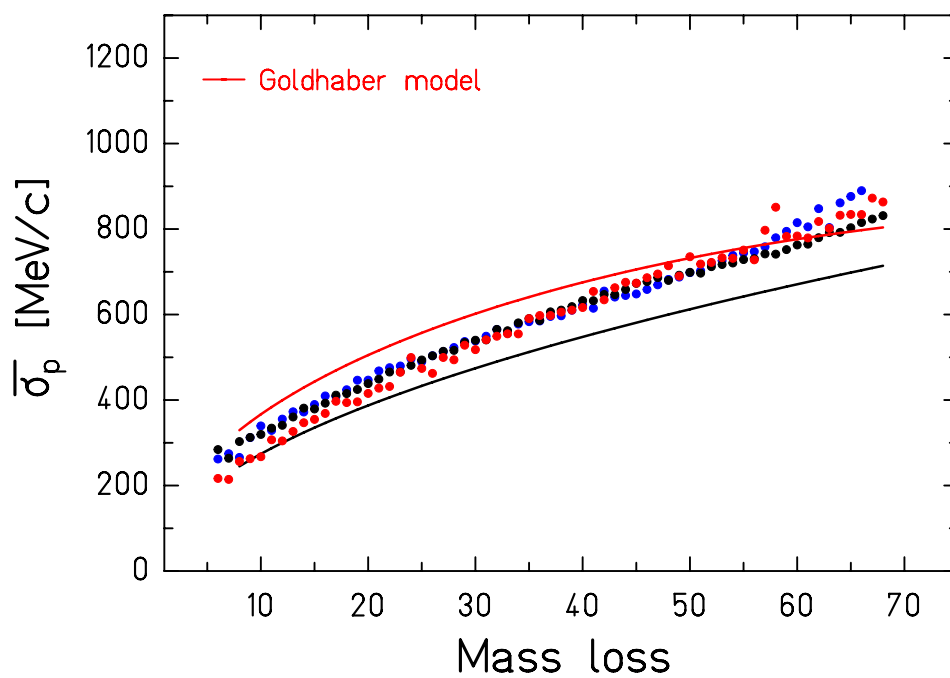
$$D = r_0 A_1^{1/3} \left(1 + \frac{2\beta_1}{3}\right) + r_0 A_2^{1/3} \left(1 + \frac{2\beta_2}{3}\right) + d$$

$$(r_0 = 1.16 \text{ fm}, d = 2.0 \text{ fm}, \beta_1 = \beta_2 = 0.625)$$

Average Longitudinal Momentum



Average Momentum Width



CONCLUSIONS

^{197}Au , ^{208}Pb and ^{238}U (~ 1 A GeV) + p,d

➡ ~ 1000 isotopes produced above 0.1 mb

Accurate experimental device & inverse kinematics

➡ Z , A and v of each reaction product

Large scan in $B\rho$

➡ whole velocity distribution of each isotope

➡ disentangling reaction mechanisms

Applications

➡ Accelerator-Driven Systems

➡ Radioactive-Beam Facilities

➡ better reaction models

➡ ...