Nuclear-Data* Experimental Programs at GSI

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* We understand nuclear-data experiments in an extended sense:

- Provide high-quality data,
- Enable a good understanding of the physics.

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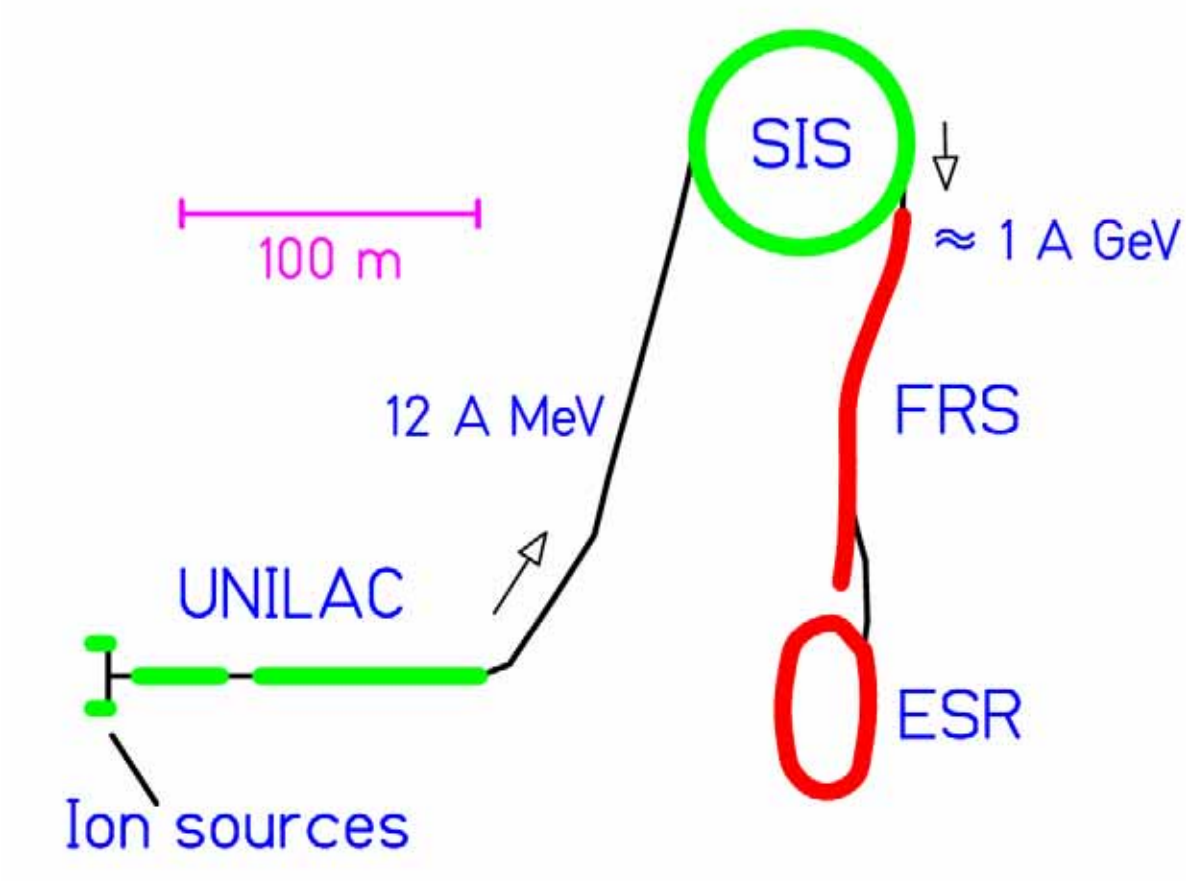
The GSI Facility

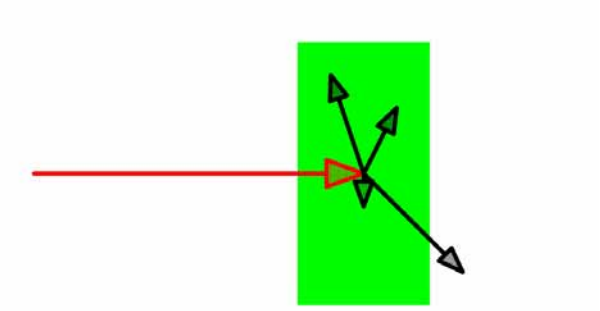
Installations used for the experiments on nuclear data:



Universal linear accelerator	UNILAC
Heavy-ion synchrotron	SIS
Fragment separator	FRS
Experimental storage ring	ESR

The Experimental Approach: Inverse Kinematics

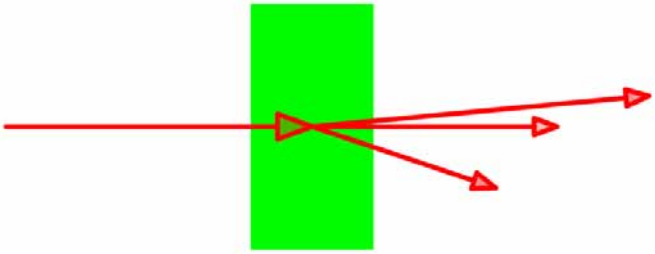
Conventional experiments detect target-like reaction products



Suffer from:

- Stopping of the products in the target
- Insufficient energy to register or identify the products

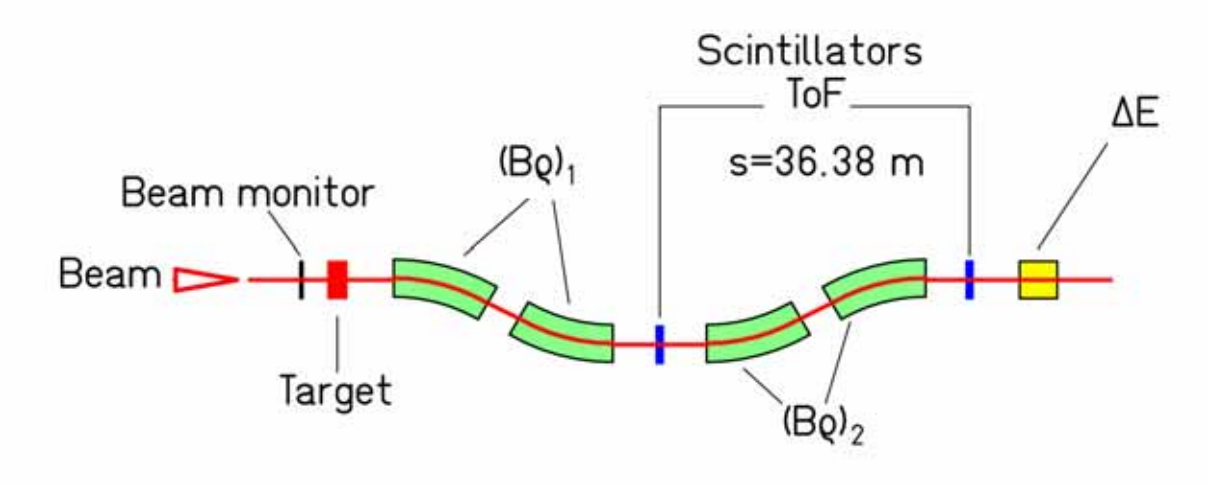
GSI-experiments investigate projectile-like reaction products in-flight



Requires:

- A powerful heavy-ion accelerator
- Adapted high-resolution in-flight detection devices

The Fragment Separator (FRS)



- A/Z identified by $(B\rho)_2$ and ToF in FRS

  $B\rho = p/q \sim A \cdot \gamma \cdot v/Z$

- Z identified by ΔE in ionization chamber

  $\Delta E \sim Z^2 / v^2$

  → Z and A are exactly known.

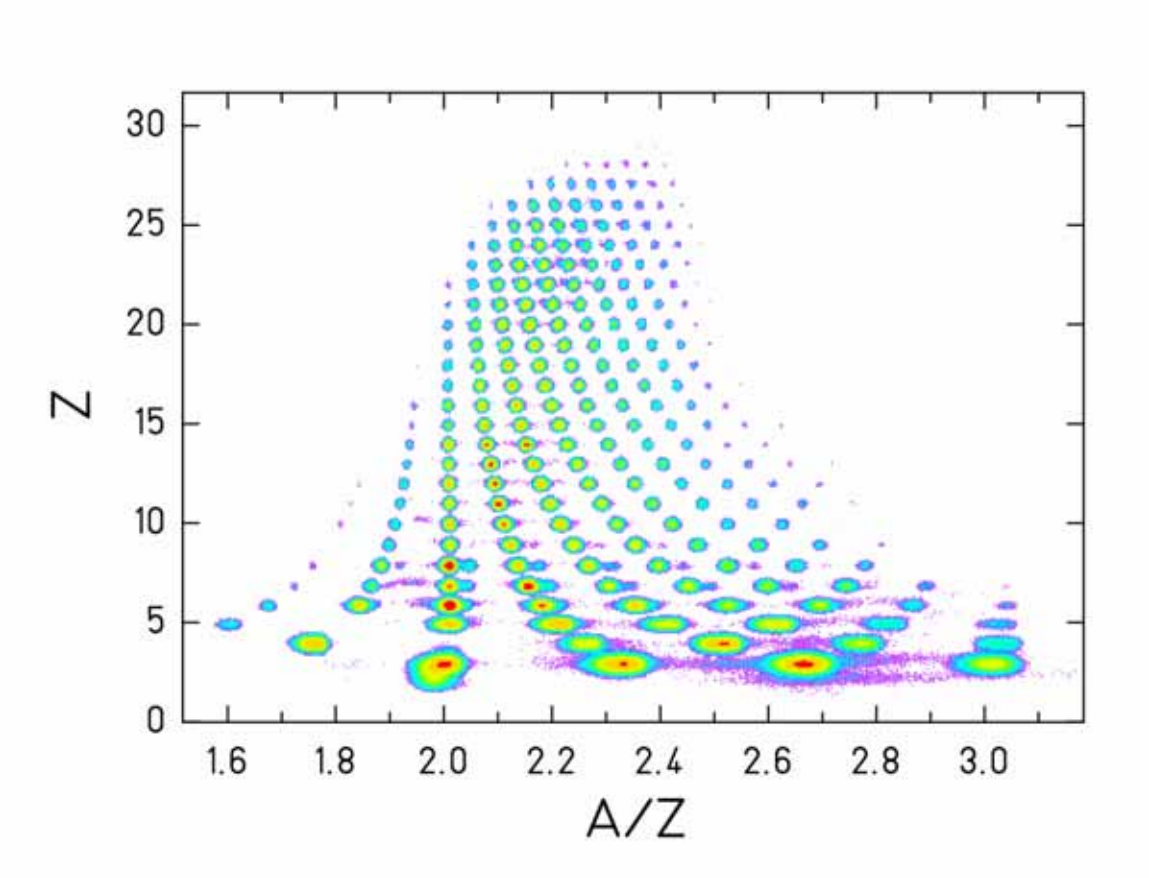
- Velocity precisely determined by $(B\rho)_1$

  $B\rho = p/q \sim A \cdot \gamma \cdot v/Z$

  → Relative precision $5 \cdot 10^{-4}$

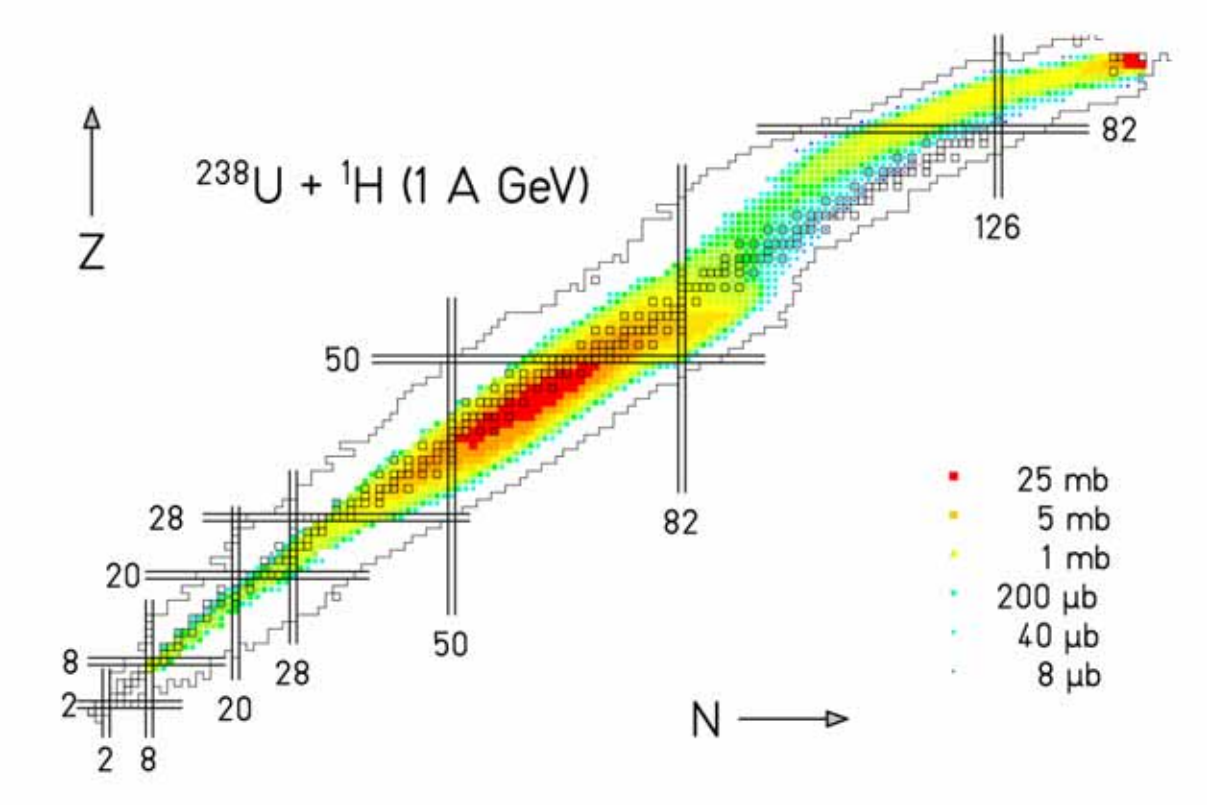
Nuclide Identification Pattern

^{136}Xe + Pb, 1 A GeV



D. Henzlova, PhD thesis

Nuclide distributions



J. Taieb et al., Nucl. Phys. A 724 (2003) 413

M. Bernas et al., Nucl. Phys. A 725 (2003) 213

M. V. Ricciardi et al., in preparation

Systems investigated: (analyzed by)

^{238}U + ^{1,2}H,Ti,Pb (J. Taieb*, M. Bernas, M. V. Ricciardi*, E. Casarejos*, J. Pereira*, T. Enqvist)

^{208}Pb + ^{1,2}H, Ti (T. Enqvist, B. Fernandez*, A. Kelic)

^{197}Au + ^{1}H (F. Rejmund, J. Benlliure)

^{124,136}Xe + ^{1}H,^{208}Pb (P. Napolitani*, D. Henzlova*, M. Fernandez*)

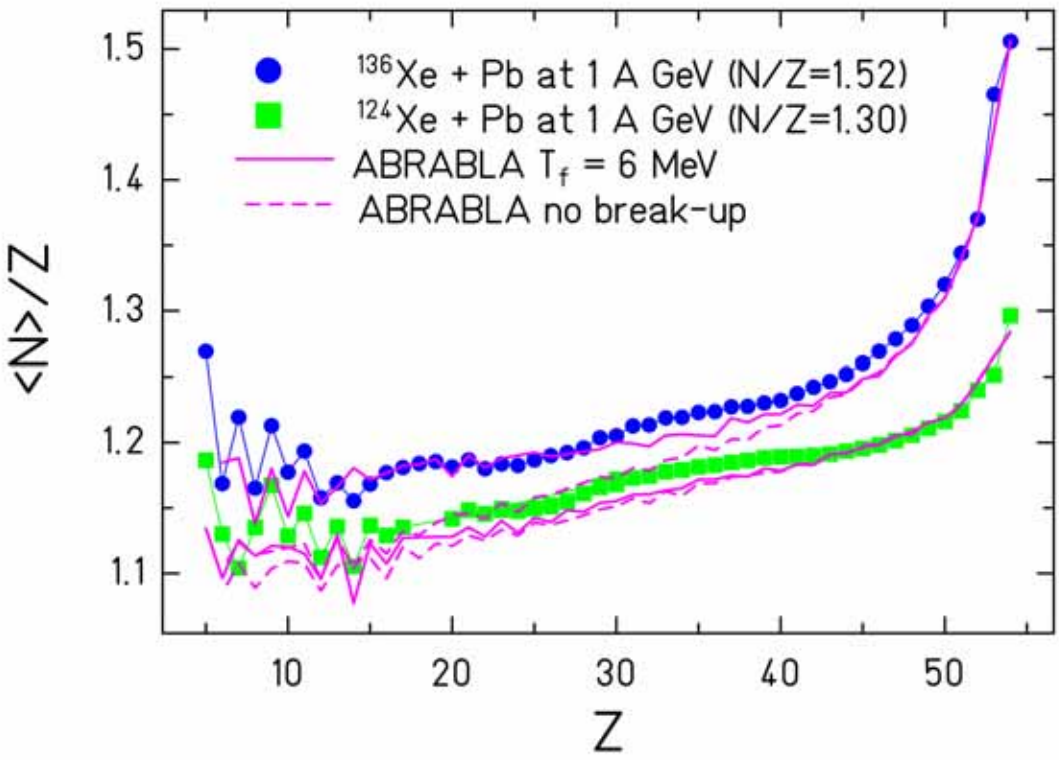
^{56}Fe + ^{1}H,Ti (C. Villagrasa*, P. Napolitani*)

^{197}Au + ^{197}Au (V. Henzl*)

Energies: 0.2 to 1.5 A GeV

*PhD thesis

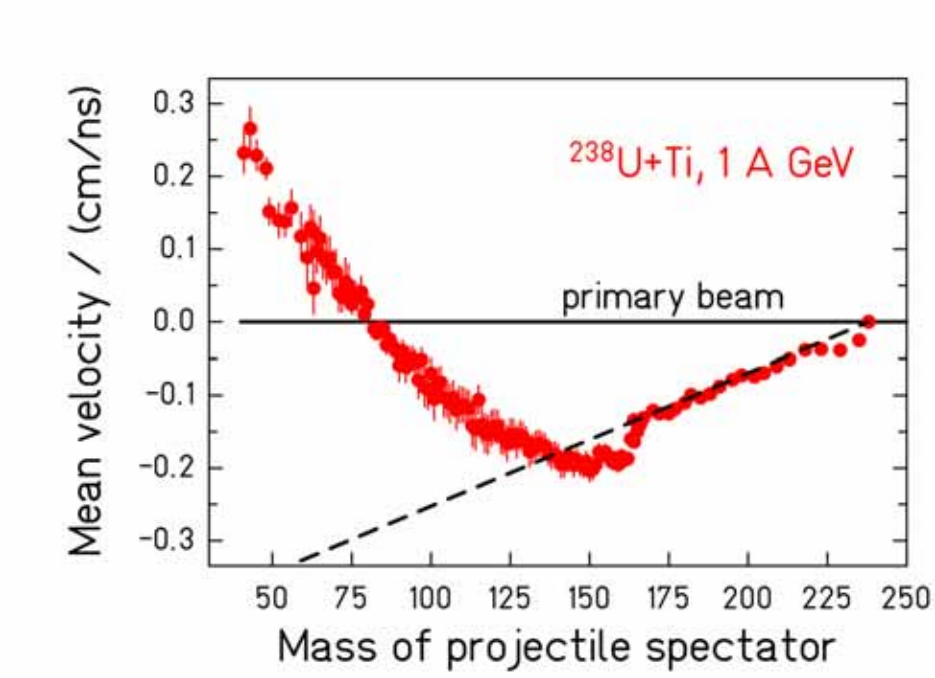
The Isospin Thermometer

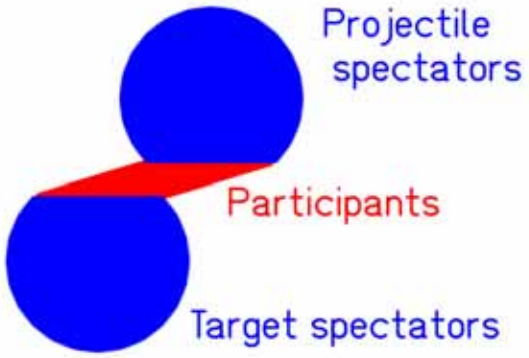


- Memory on N/Z of projectile is preserved for all fragments.
- The data are reproduced with a three-stage model: Abrasion – Break-up – Evaporation.
- The freeze-out temperature after break-up is 6 MeV.

M. V. Ricciardi, D. Henzlova, PhD theses
K.-H. Schmidt et al., Nucl. Phys. A 710 (2002) 157

Participant's blast on the spectators

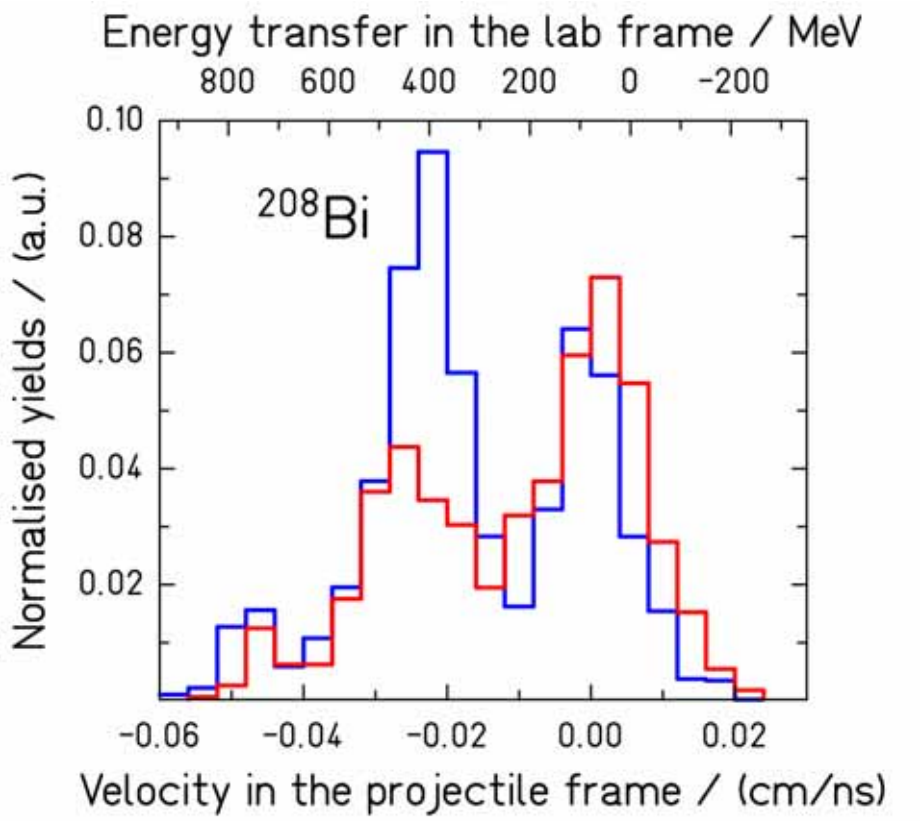




- Unexpected acceleration in violent collisions.
- Valuable information on the EOS of nuclear matter.

M.V. Ricciardi, V. Henzl, PhD theses
M. V. Ricciardi et al., Phys. Rev. Lett. 90 (2003) 212302

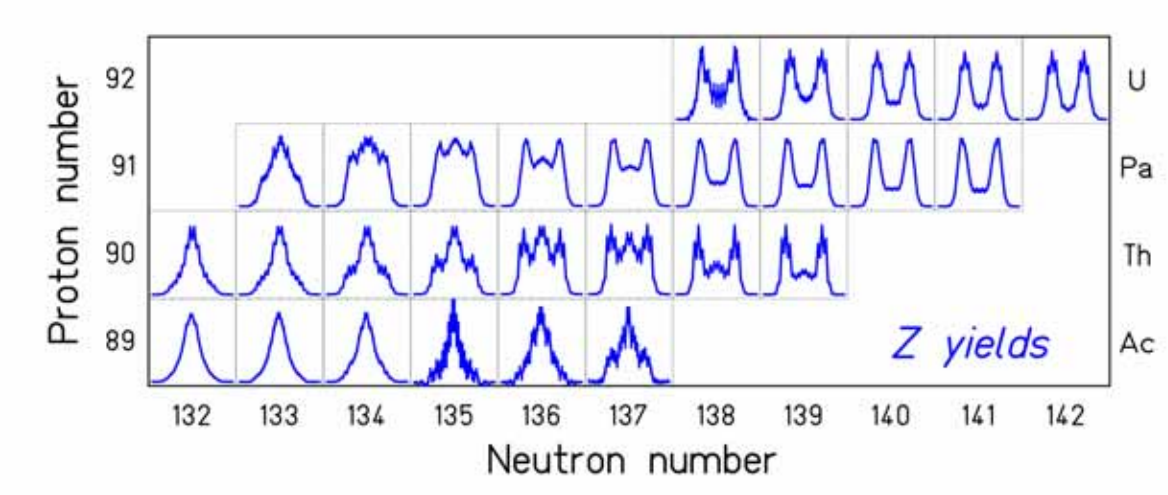
Nuclear Charge-Exchange Reaction



- Charge-exchange reactions: ^{1}H(^{208}Pb,^{208}Bi)x, ^{2}H(^{208}Pb, ^{208}Bi)x at 1 A GeV
- Quasielastic scattering and excitation of the Δ(1232) resonance
- Excitation of the nucleon in the nuclear medium

A. Kelic, Phys. Rev. C, submitted

Fission channels



- Z-distributions from e.m.-induced fission of 70 secondary beams (E* ~ 11 MeV).
- Transition from asymmetric to symmetric fission mapped.

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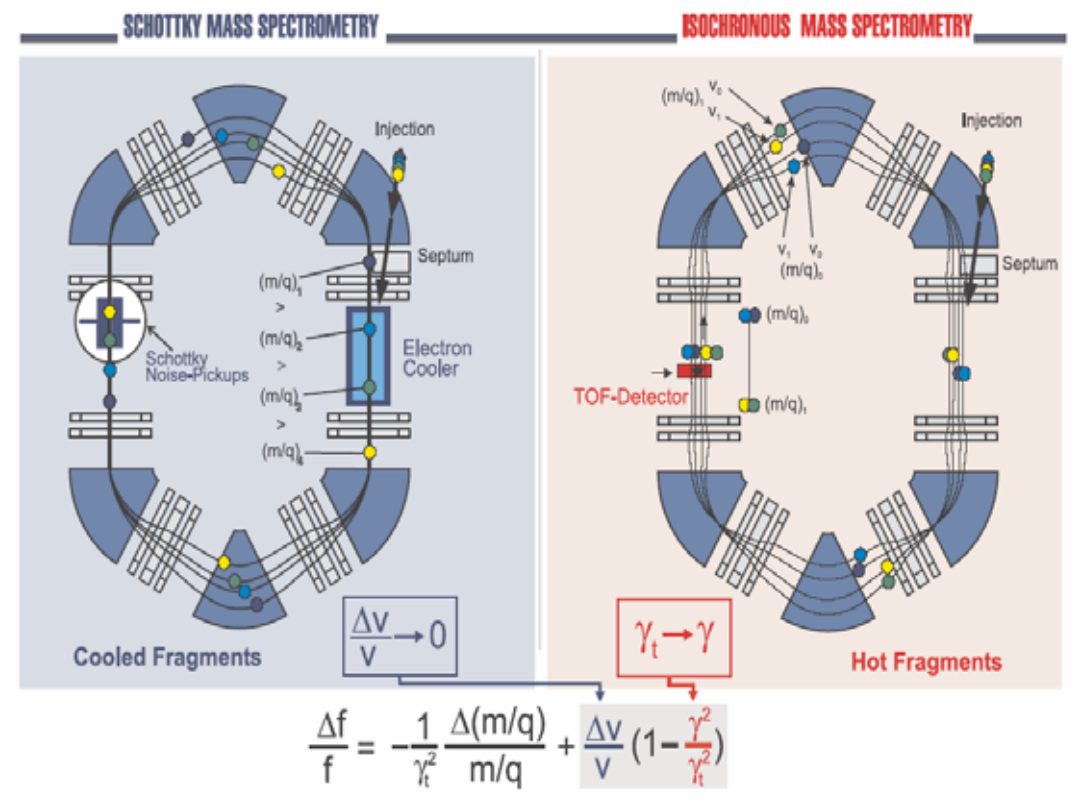
K.-H. Schmidt et al., Nucl. Phys. A 665 (2000) 221

The Experimental Storage Ring (ESR)



Schottky mass spectrometry

Fourier analysis of the circulation frequency

- Needs cooling ($t_{1/2}$ > 30 s)
- Uncertainty ~ 30 keV

Time-of-flight spectroscopy

Timing detectors measure revolution time

- $t_{1/2}$ > 10 µs
- Uncertainty ~ 100 keV

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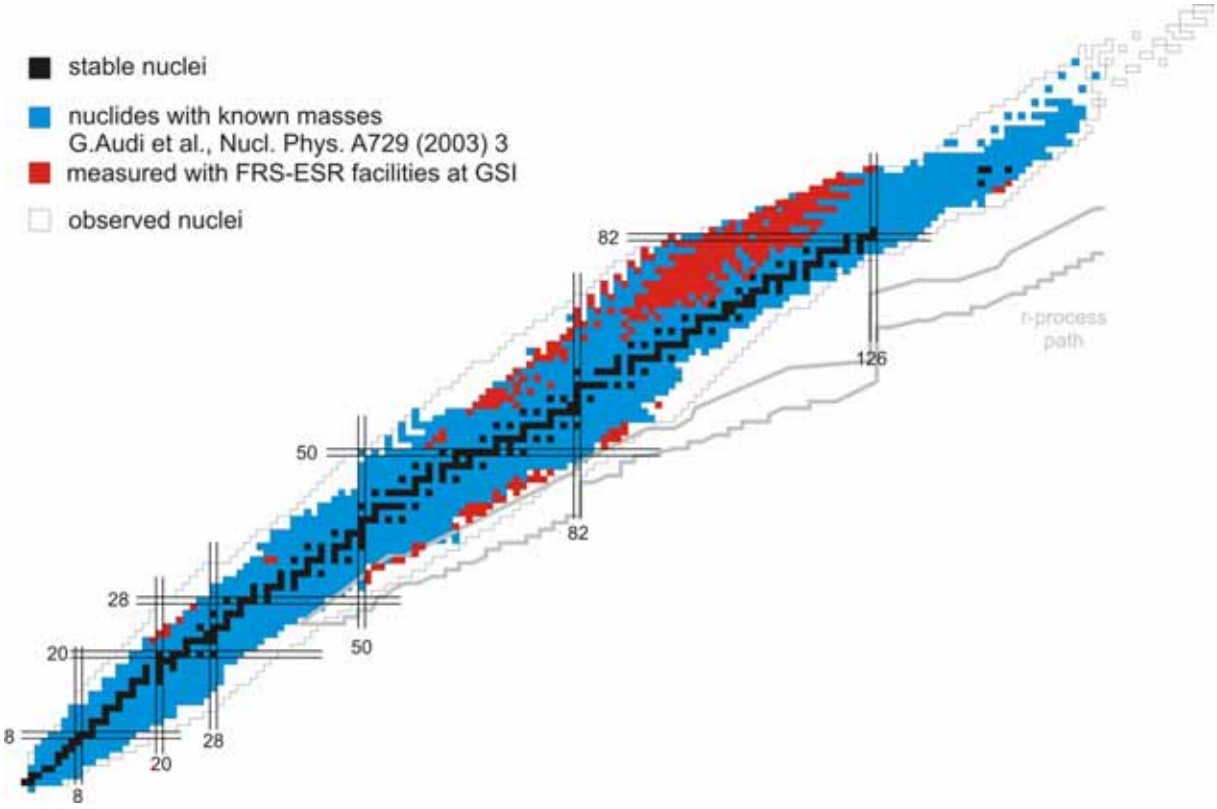
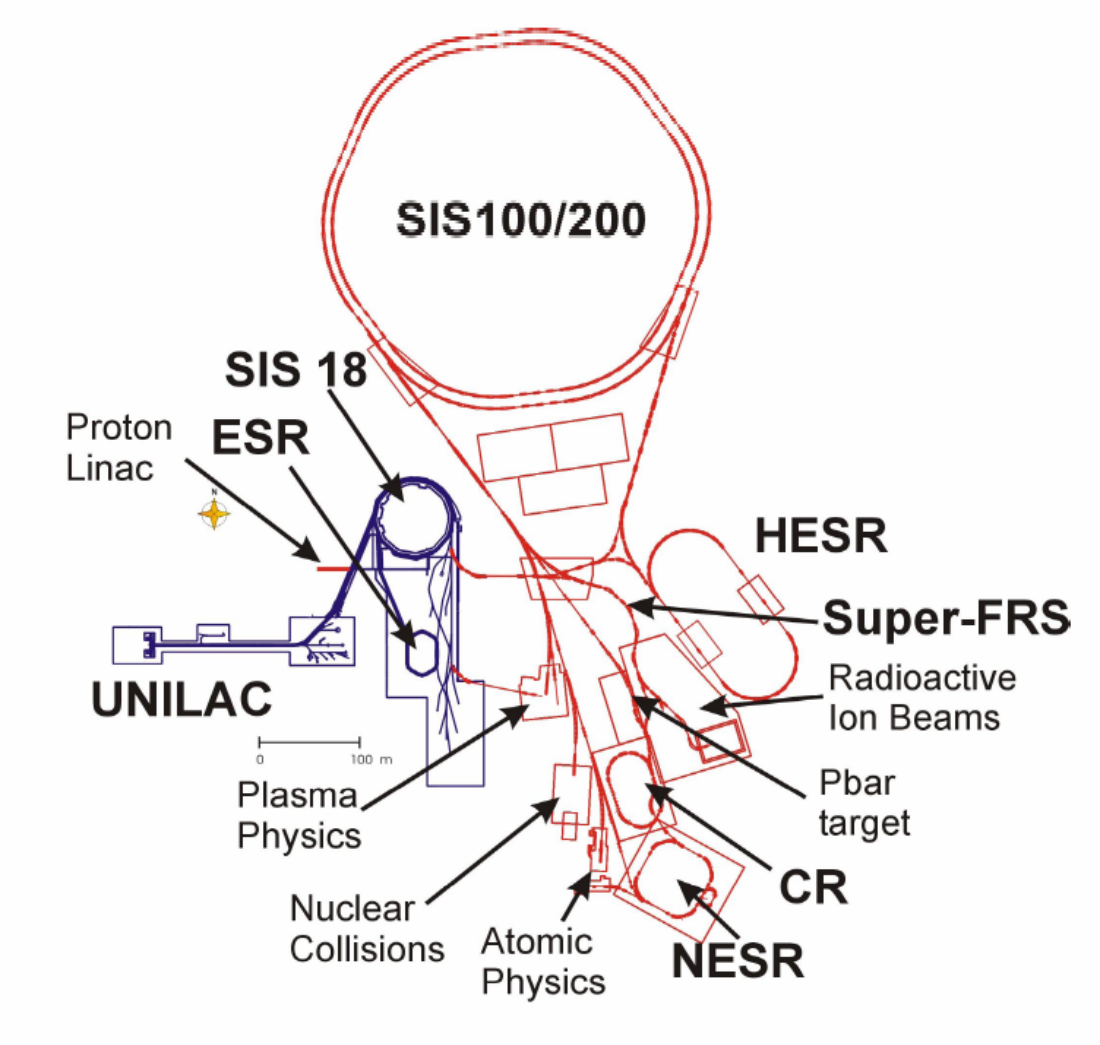
Mass Measurements



- Mapping of large areas on the chart of the nuclides.
- Ground-state masses of 332 nuclei measured for the first time.

Yu. A. Litvinov et al., Nucl. Phys. A 734 (2004) 473c
T. Radon et al., Nucl. Phys. A 677 (2000) 75
Y. Novikov et al., Nucl. Phys. A 697 (2002) 92
Y. Litvinov, PhD thesis, Univ. Giessen, 2003
E. Kaza, PhD thesis, Univ. Giessen, 2004
M. Hausmann et al., Hyp. Inter. 132 (2001) 291
J. Stadlmann et al., Phys. Lett. B 586 (2004) 27
M. Matos, PhD thesis, Univ. Giessen , 2004

The FAIR Project



Improved experimental possibilities for nuclear-data experiments by

- Higher beam intensities
- Higher beam energies
- New spectrometers and rings

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Summary

- **In-flight investigations** of projectile-like reaction products at the GSI heavy-ion facility.
- Mapping of nuclide **production cross sections**.
- Indications for a **break-up phase** from *N*/*Z* ratios.
- **Acceleration** of projectile fragments (**EoS**).
- **Excitation of the nucleon** in peripheral collisions.
- Mapping of the **fission channels**.
- Mapping of nuclear **ground-state masses**.
- ... and many more observations
  (see also http://www-w2k.gsi.de/kschmidt)

Mass Measurements

F. Attallah, K. Beckert, P. Beller, F. Bosch, D. Boutin, T. Buervenich, H. Eickhoff, T. Faestermann, M. Falch, B. Franczak, B. Franzke, H. Geissel, M. Hausmann, M. Hellström, E. Kaza, Th. Kerscher, O. Klepper, H.-J. Kluge, R. Koyama, C. Kozhuharov, K.-L. Kratz, K.E.G. Löbner, S.A. Litvinov, Yu.A. Litvinov, M. Matoš, L. Maier, G. Münzenberg, F. Nolden, Yu.N. Novikov, T. Ohtsubo, A.Ostrowski, A. Ozawa, Z. Patyk, B. Pfeiffer, M. Portillo, B.W. Quint, T. Radon, C. Scheidenberger, V. Shishkin, C.J. Stadlmann, M. Steck, K. Sümmerer, T. Suzuki, M.B. Trzhakovskaya, S. Typel, D.J. Vieira, S. Watanabe, P. Walker, H. Weick, M. Winkler, H. Wollnik, T. Yamaguchi

Measurements on Nuclear Reactions

P. Armbruster, L. Audouin, C.-O. Bacri, J. Benlliure, M. Bernas, B. Berthier, A. Boudard, E. Casarejos, J. J. Connell, S. Czajkowski, P. Danielewicz, J.-E. Ducret, T. Enqvist, B. Fernandez, J. S. George, A. Heinz, K. Helariutta, V. Henzl, D. Henzlova, A. R. Junghans, B. Jurado, A. Kelić, A. Krasa, R. Legrain, S. Leray, B. Mustapha, P. Napolitani, M. F. Ordonez, J. Pereira, M. Pfützner, R. Pleskac, M. Pravikoff, B. Ranjan Behera, F. Rejmund, M. V. Ricciardi, K.-H. Schmidt, C. Schmitt, S. Steinhäuser, C. Stéphan, J. Taïeb, L. Tassan-Got, C. Villagrasa, F. Vivès, C. Volant, B. Voss, A. Wagner, W. Wlazlo, O. Yordanov