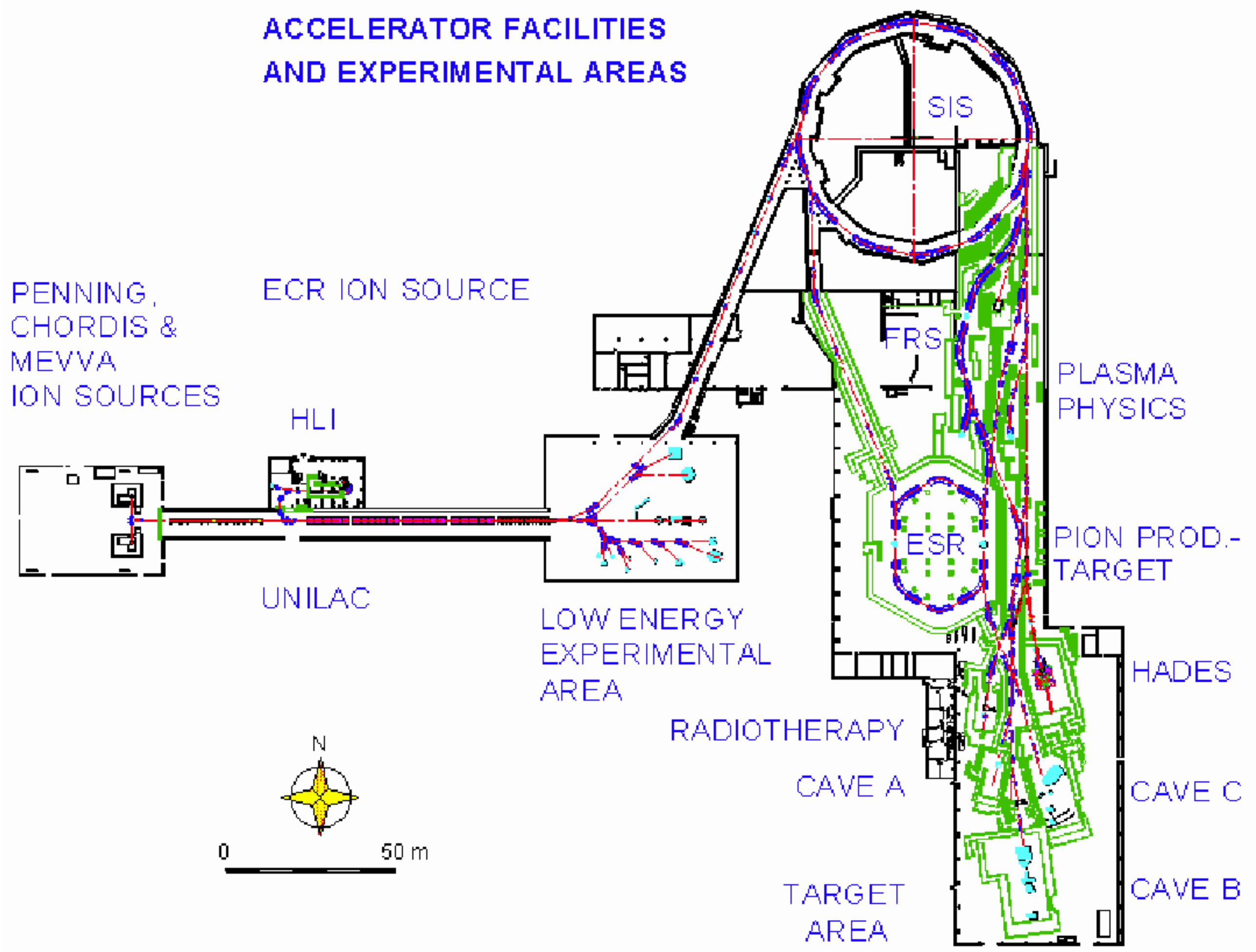
High-resolution experiments on nuclear reactions and their implications for astrophysics and nuclear technology

Karl-Heinz Schmidt for CHARMS

SIS + FRS ⇨ Unique combination world-wide

Availability of relativistic HI beams and high-resolution magnetic spectrometer

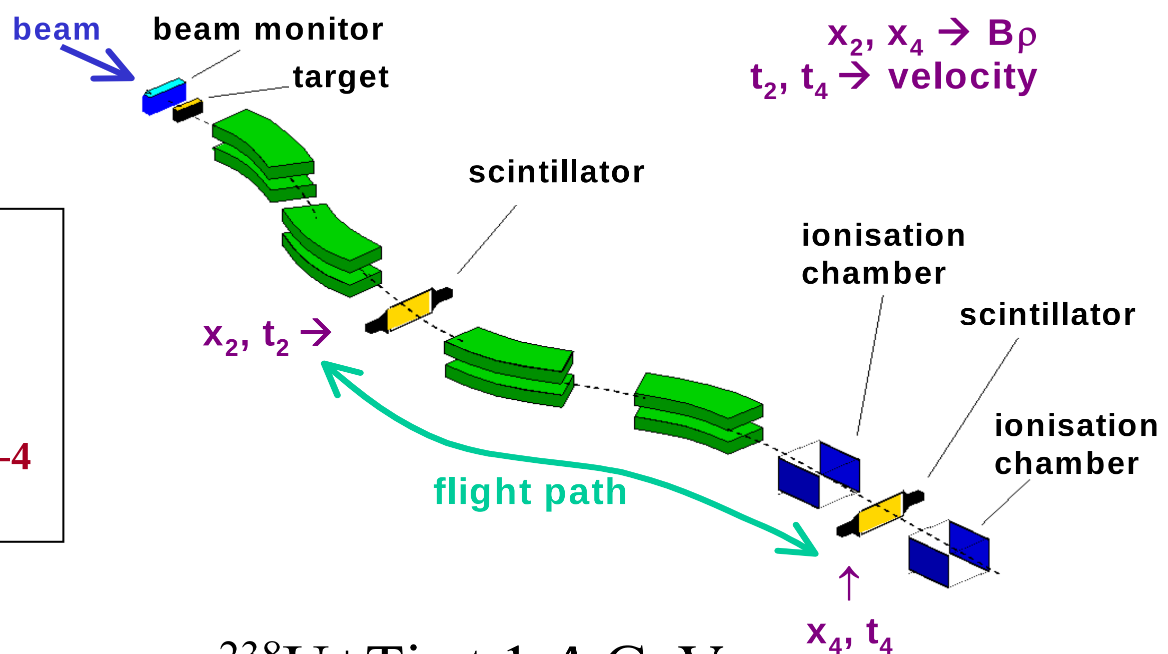


High-resolution magnetic spectrometer FRS

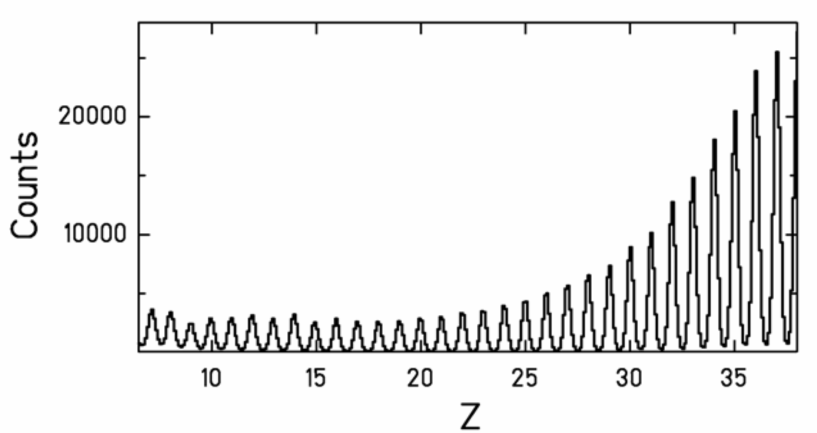
$A / \Delta A \approx 400$

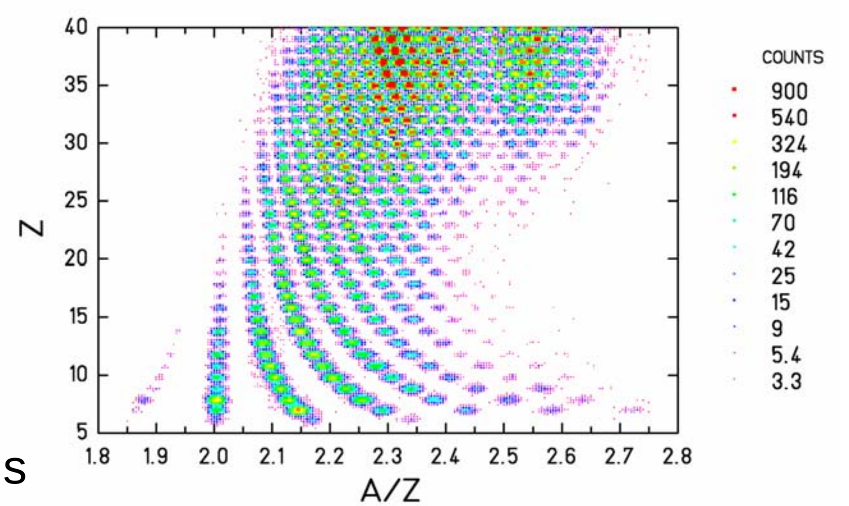
$Z / \Delta Z \approx 200$

$\Delta(\beta\gamma)/\beta\gamma \approx 5 \cdot 10^{-4}$



^{238}U+Ti at 1 *A* GeV





M.V. Ricciardi, PhD thesis

Engagement of the CHARMS group

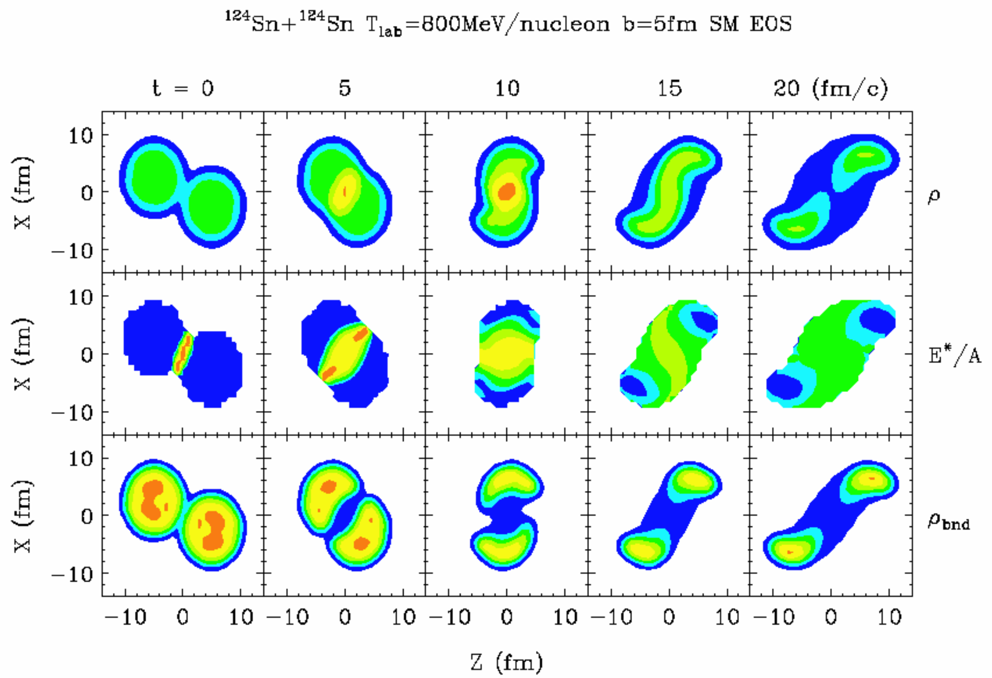
Status on May 2005

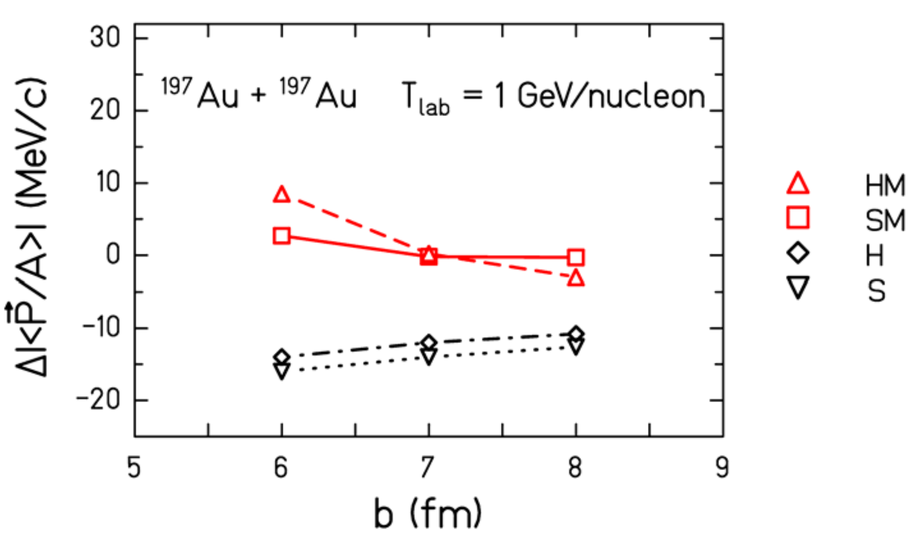
- 10 scientists (1 Senior scientist, 6 Postdocs, 3 PhD)
- Basic research:
  - Momentum dependence of nuclear mean field
  - Thermal instabilities of nuclear matter
  - Nuclear dissipation
  - Very asymmetric fission
  - Structure effects in fission and fragmentation
  - Nuclide production in fragmentation and fission
- Applications:
  - Nuclear astrophysics
  - Spin, alignment and polarisation in fragmentation
  - Transmutation of nuclear waste
  - Nuclear safety
  - Production of secondary beams

Momentum dependence of nuclear mean field

Spectator response to the participant blast - A measure of the momentum dependence of the nuclear mean field

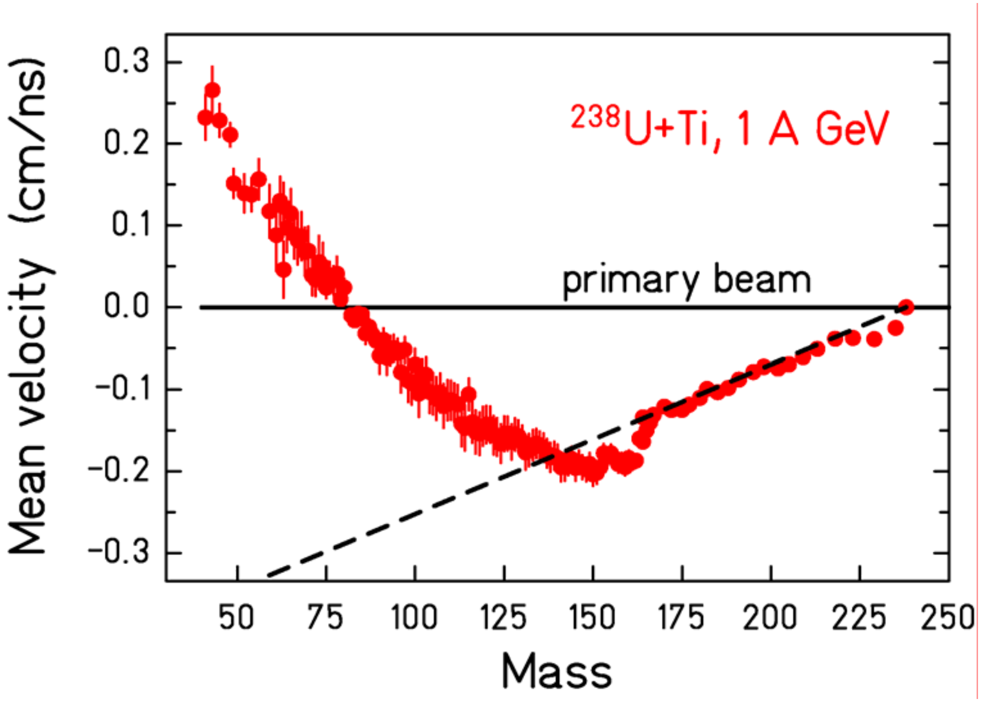
Shi, Danielewicz and Lacey, Phys. Rev. C 64 (2001) 034601





Momentum dependence of nuclear mean field

New FRS results



M.V. Ricciardi et al., PRL 90 (2003) 212302

- The data give an <u>early signature</u> (the acceleration of the spectator is acquired during contact with the fireball).

- Valuable basis for general verification of transport calculations.

Major difficulties

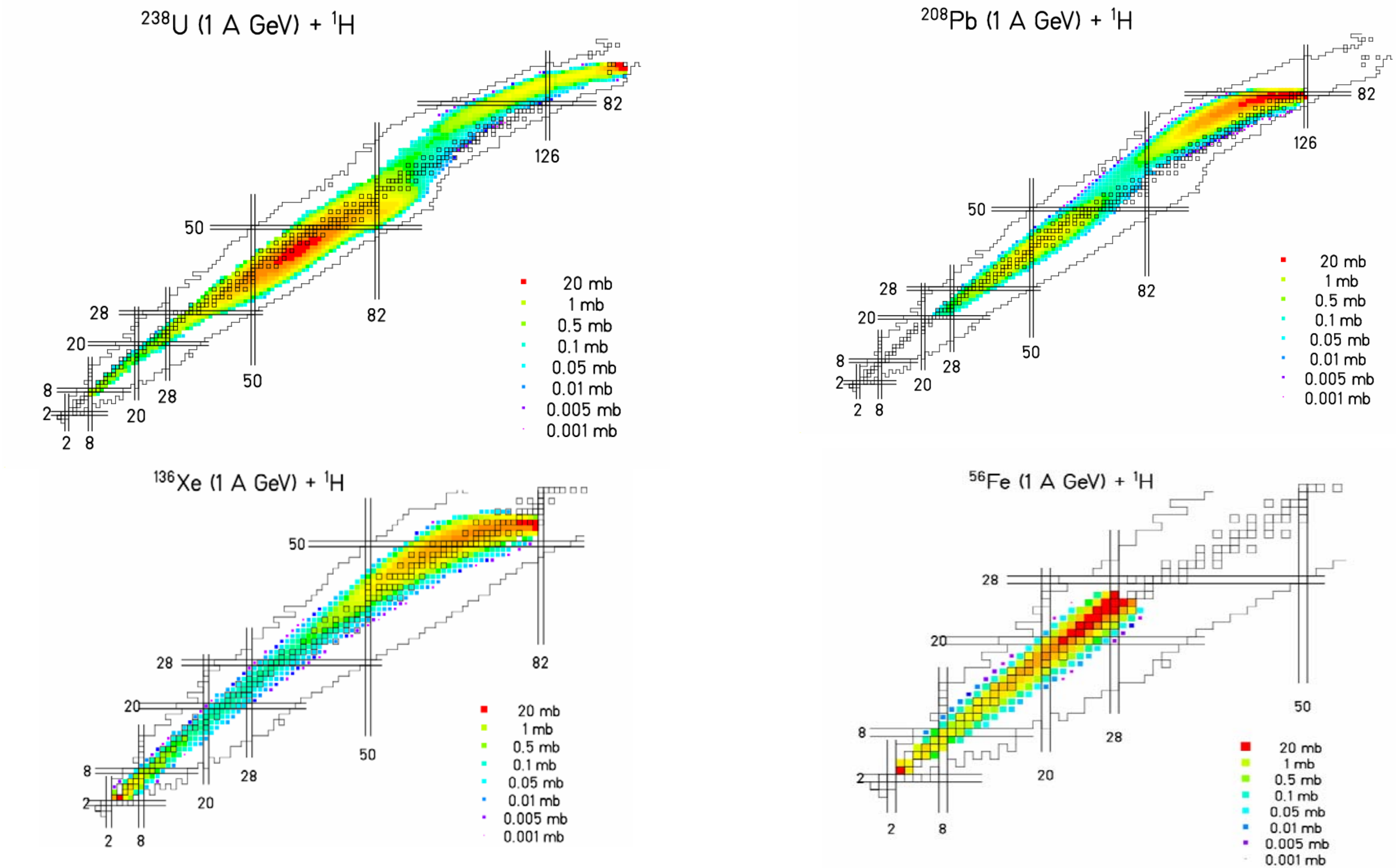
- Not many data available on nuclide distributions (radiochemical methods).
  Difficulties in obtaining information on the dynamics of the reaction.

- Theoretical models facing problems in reproducing measured data

  IAEA - CRP F4.10.16 (1997-2003) - Importance of calculating fission-fragment yields recognised but severe difficulties in modelling nuclide-distribution.

- Models should have predictive power (physics basis required).

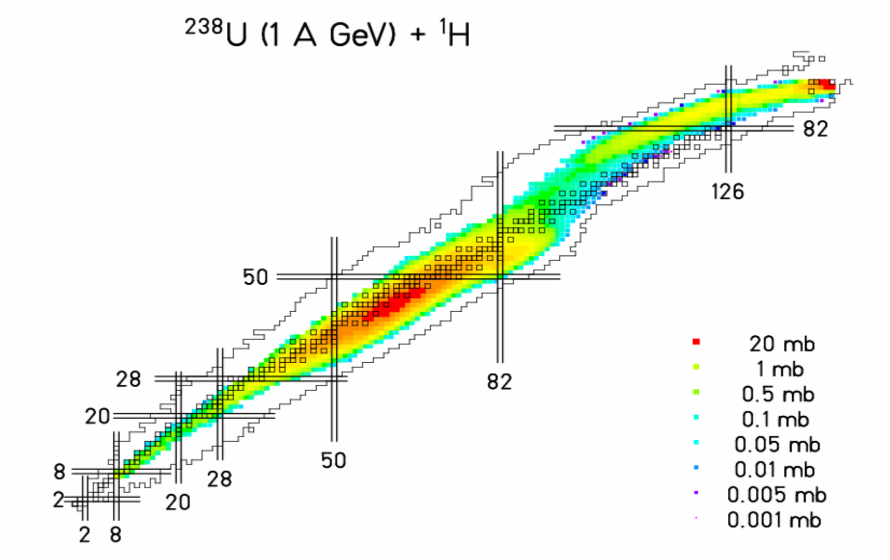
Measured nuclide production in fragmentation and fission

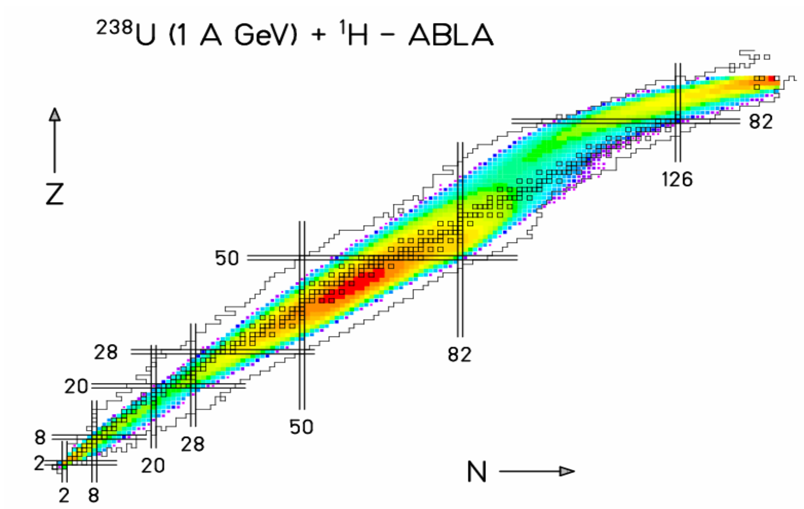


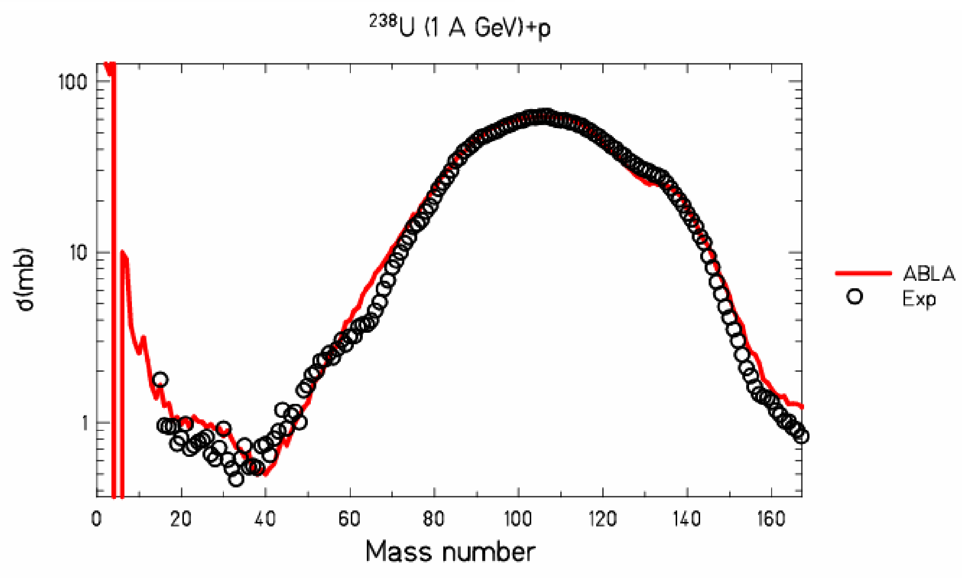
Excellent basis for model development ⇨ GSI code ABLA

Data available at: http://www-w2k.gsi.de/charms/data.htm

GSI code ABLA - Examples high-energy reactions

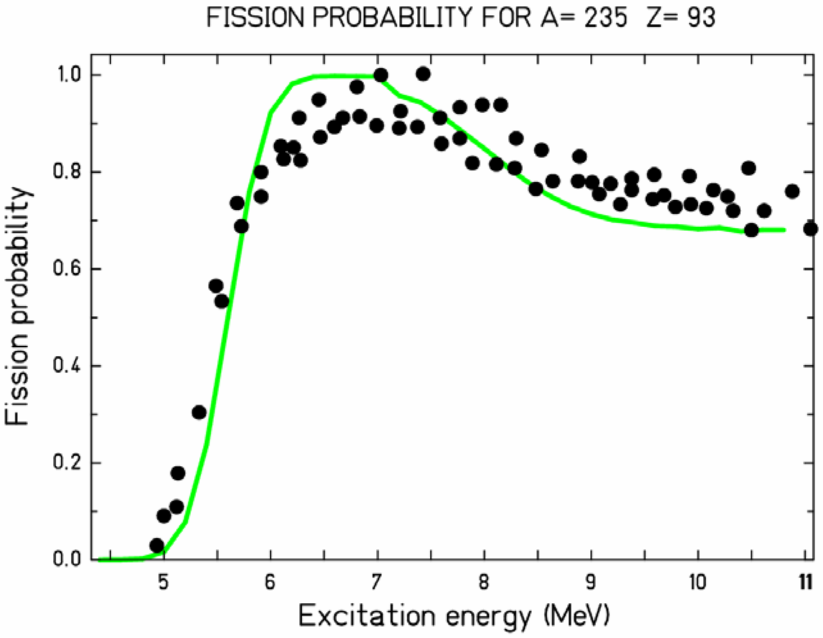


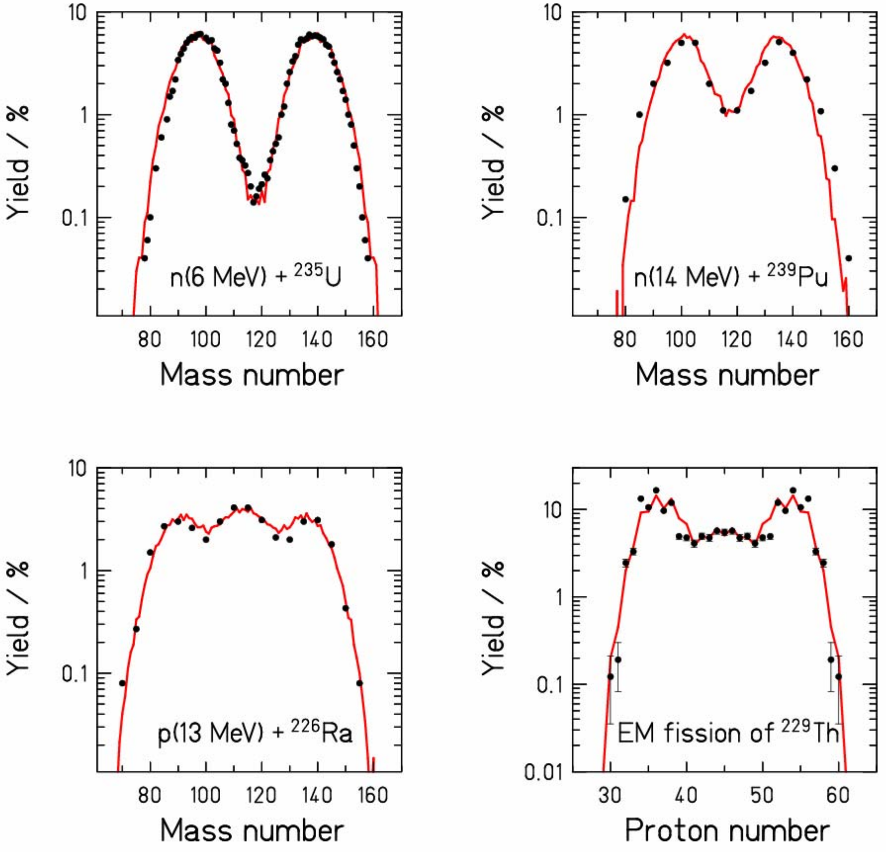




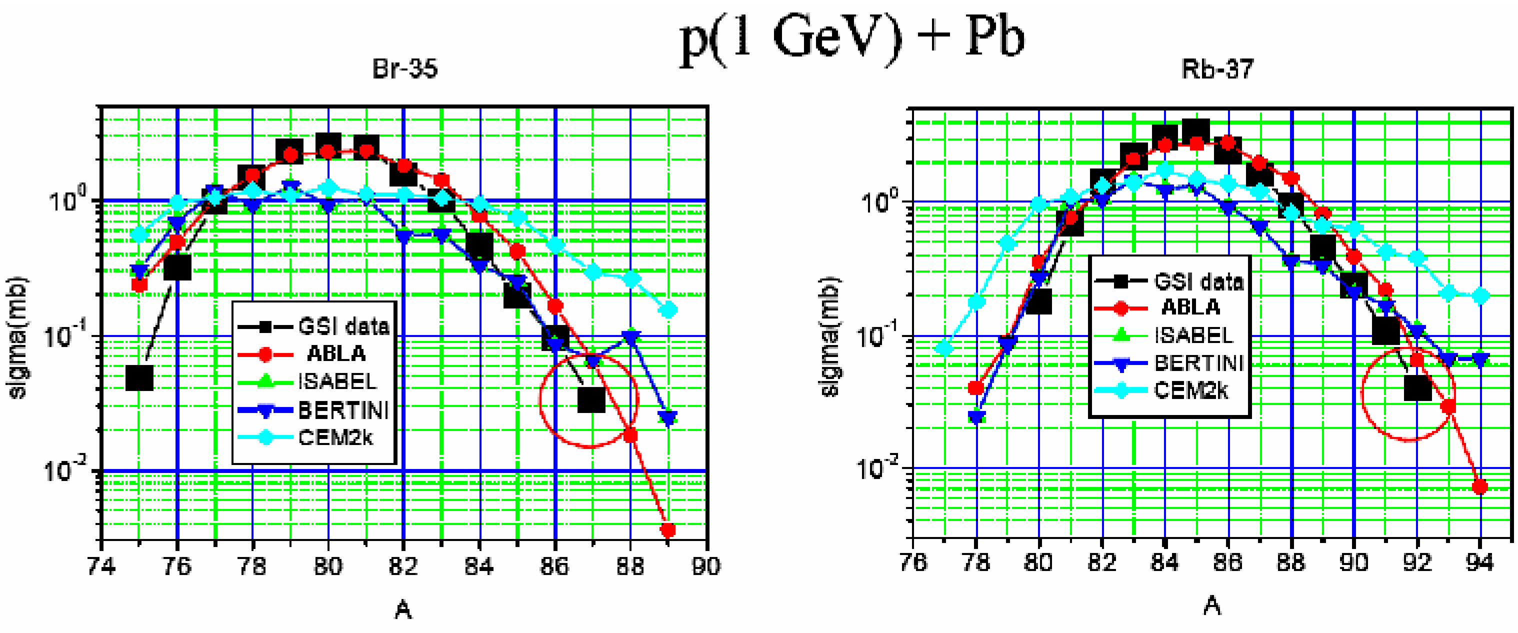
GSI code ABLA - Examples low-energy reactions

Excitation function and *A*- and *Z*- distributions:





Comparison between experimental data and different model calculations

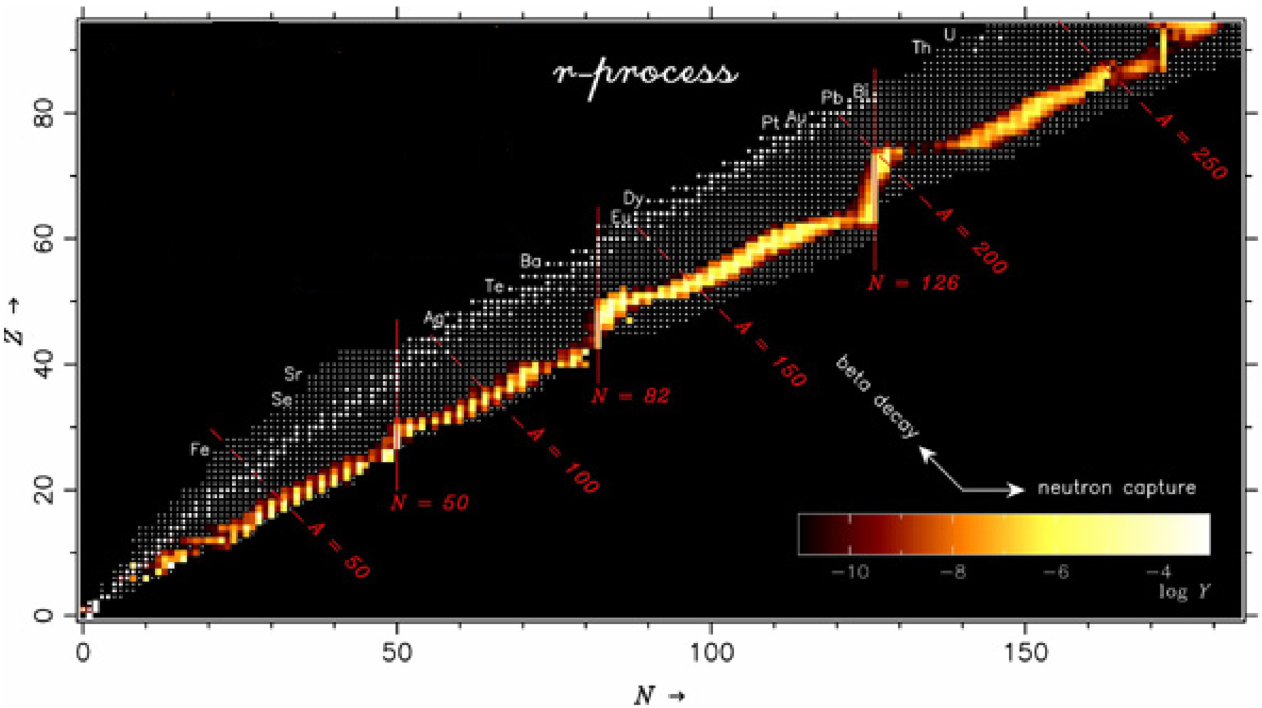


Best results ⇨ GSI code ABLA!

D. Ridikas, Fission05, Cadarache, 2005

Application I - Nuclear astrophysics

r-process nucleosynthesis and fission



Fission plays an important role in the r-process which is responsible not only for the yields of transuranium isotopes, but may have a strong influence on the formation of the majority of heavy nuclei due to fission recycling.

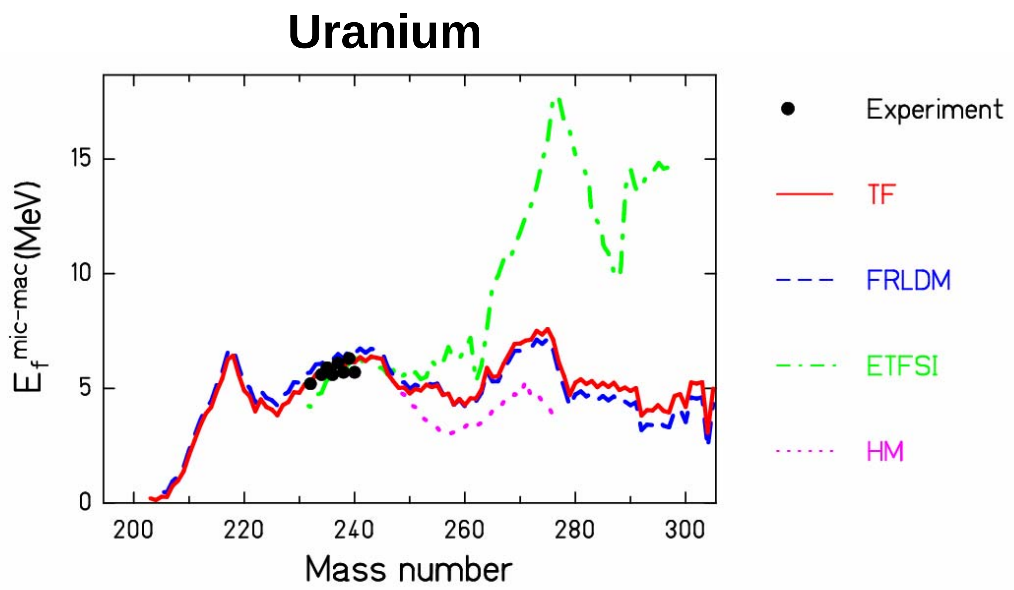
Application I - Nuclear astrophysics

r-process nucleosynthesis and fission

- Previous status:

• Large uncertainties on fission barriers ⇨

• No calculations on nuclide distribution (only symmetric fission assumed)



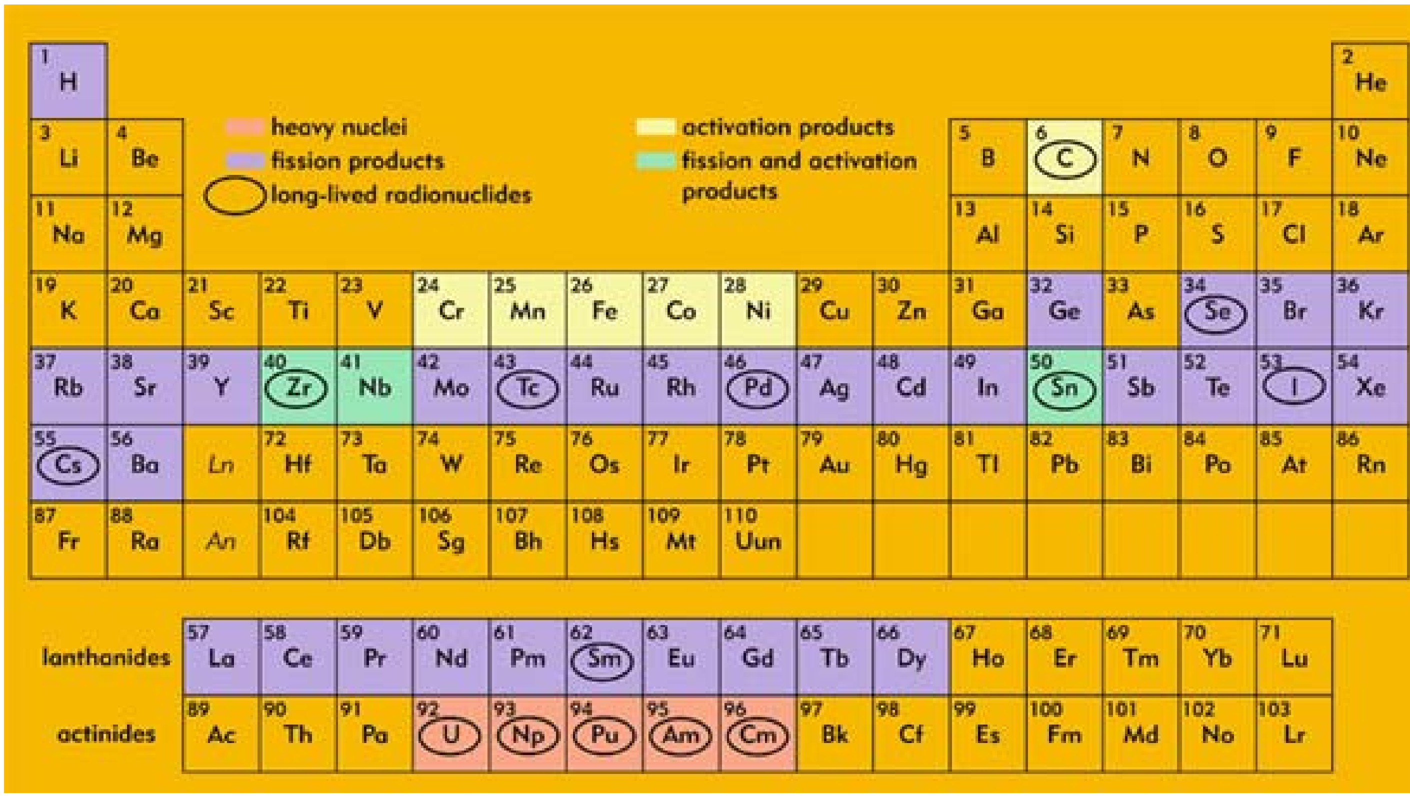
- Our contribution:

• Careful analysis of macroscopic fission barriers (A. Kelić and K.-H. Schmidt, proceedings of Fission05, Cadarache, 2005)

•Modelling of nuclide distribution in fission (A. Kelić, N. Zinner, E. Kolbe, K. Langanke and K.-H. Schmidt, accepted in PLB)

Application II - Nuclear-waste transmutation

Nuclear Waste



<u>Fission products:</u>

^{129}I (15.7 $\cdot 10^6$ y), ^{107}Pd (6.5$\cdot 10^6$ y),

^{135}Cs (2$\cdot 10^6$ y), ^{93}Zr (1.5$\cdot 10^6$ y) ...

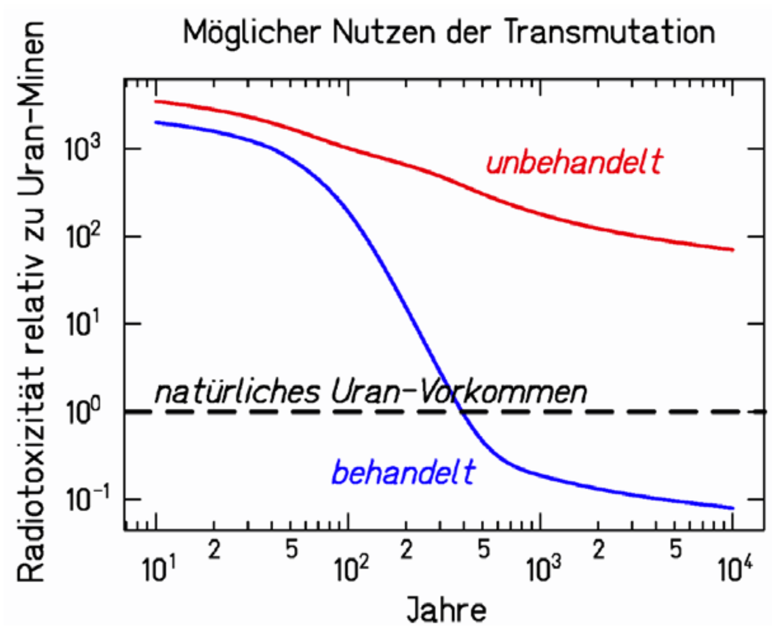
<u>Heavy nuclei:</u>

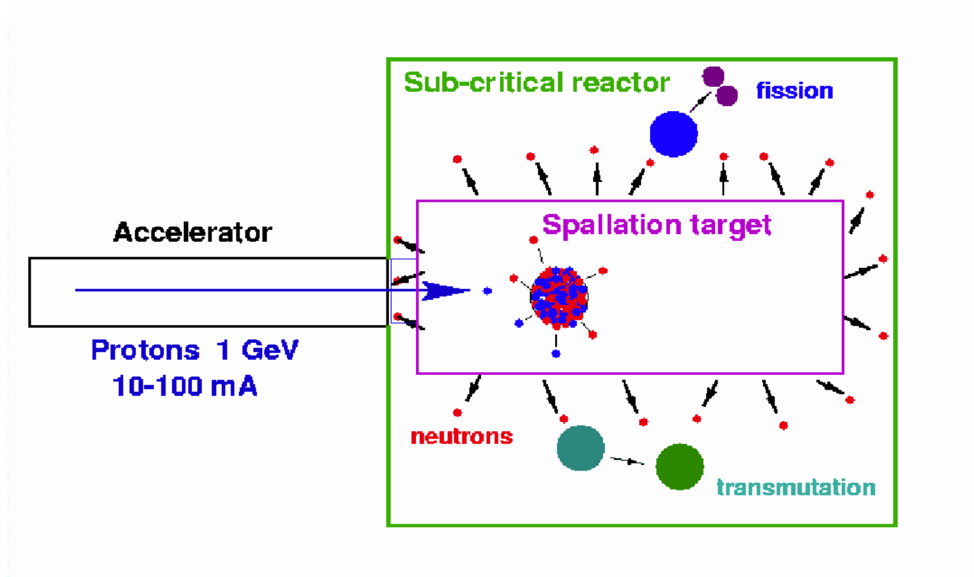
^{239}Pu (2.4 $\cdot 10^4$ y), ^{237}Np (2.1$\cdot 10^6$ y),

^{241}Am (432.6 y), ^{242}Am (141 y) ...

Application II - Nuclear-waste transmutation

Accelerator-driven systems



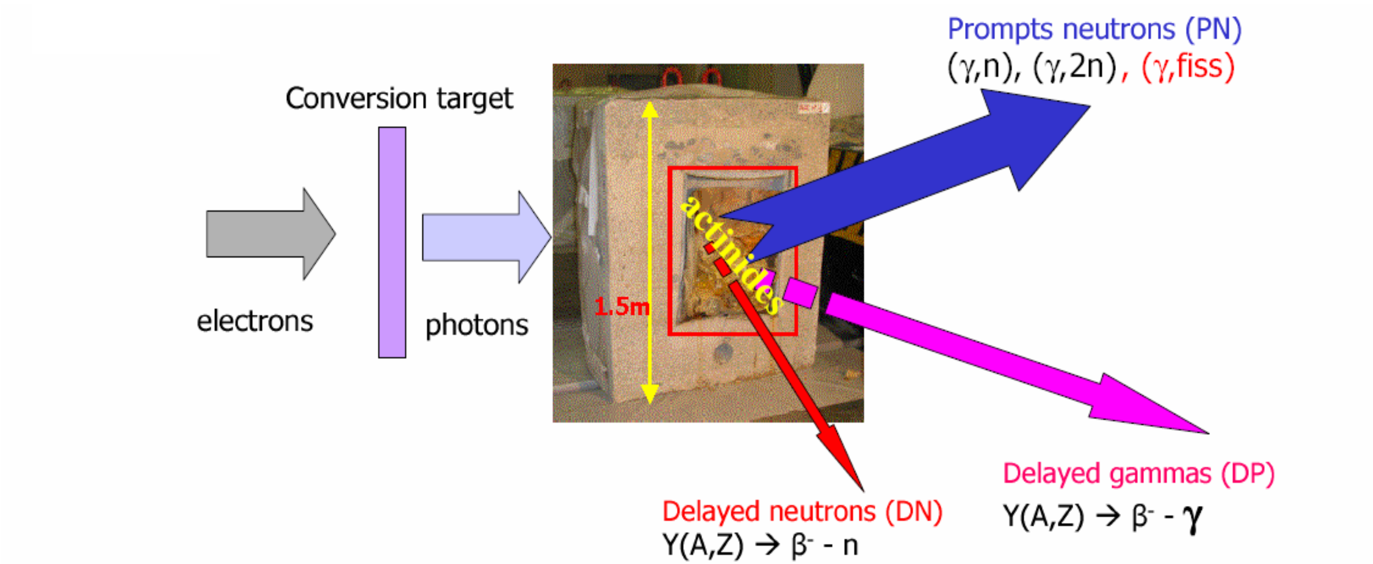


Needed: High-energy data and models of proton-induced reactions.

Damage to window and construction materials due to irradiation, yields of spallation neutrons, production of radioactive nuclei...

Application III - Nuclear safety

Non-destructive characterisation of weapon grade materials or nuclear waste



D. Ridikas et al. 2004

Detection sensitivity. 0.1 g of nuclear material per ton of container

Needed: delayed-neutron yields, fission fragments *A* and *Z* distributions.

Projects with external financing

From 2004:

- **Humboldt foundation** ⇨ Fundamental research; 1 fellowship on nuclear dissipation.
- **IP_EUROTRANS** ⇨ EU-FP6 Technical application - Transmutation of nuclear waste; 32 research institutes + 17 universities; 2 EURATOM fellowship + 1 financed by the project.
- **EURISOL_DS** ⇨ EU-FP6 Technical application - Production of secondary beams; 20 participants + 20 contributors; 1 fellowship; task leader - Calculations of Beam Intensities.
- **NUMADE** ⇨ EU-FP6 Technical application - Nuclear safety; 14 partners (research centers, universities, industry); 1 fellowship; task leader - Basic Physics Experiments on Photofission.

1998 - 2004:

- FP4 – Mobility fellows (3 fellowships);
- FP5 - HINDAS (4 fellowships), EURISOL_R&D (1 fellowship);
- Humboldt foundation (1 fellowship)

In total: 15 fellowships with external financing.

Collaboration

- GSI: Antoine Bacquias, Lydie Giot, Vladimir Henzl, Daniela Henzlova, Aleksandra Kelić, Strahinja Lukić, Pavel Nadtochy, Radek Pleskač, Maria Valentina Ricciardi, Karl-Heinz Schmidt, Orlin Yordanov / Peter Armbruster, Karlheinz Langanke
- Univ. Santiago de Compostela, Spain: Jose Benlliure, Jorge Pereira, Enrique Casarejos, Manuel Fernandez, Teresa Kurtukian
- IPN Orsay, France: Charles-Olivier Bacri, Monique Bernas, Laurent Tassan-Got, Laurent Audouin, Claude Stéphan
- DAPNIA/SPhN, CEA Saclay, France: Alain Boudard, Sylvie Leray, Claude Volant, Carmen Villagrasa, Beatriz Fernandez, Jean-Eric Ducret
- DEN/DM2S/SERMA/LENR, CEA Saclay, France: Julien Taïeb
- IPNL, France: Christelle Schmitt
- CENBG, France: Beatriz Jurado
- GANIL, France: Fanny Rejmund, Paolo Napolitani, David Boilley
- FZ Rossendorf, Germany: Arnd Junghans, Andreas Wagner
- Nuclear Physics Institute, Czech Republic: Andrej Kugler, Vladimir Wagner, Antonin Krasa
- Yale University, USA: Andreas Heinz
- MSU, USA: Pawel Danielewicz, L. Shi
- CUPP Project, Finland: Timo Enqvist
- University of Helsinki, Finland: Kerttuli Helariutta
- IPPE-Obninsk, Russia: Anatoly Ignatyuk
- Institute for Nuclear Research, Russia: Alexandre Botvina

etc.