Projectile Fragmentation at the Fragment Separator

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for the **CHARMS** Collaboration

Symposium on *30 Years of Projectile Fragmentation*, ACS meeting, San Francisco, September 10-11, 2006

CHARMS

Collaboration for High-Accuracy Experiments on Nuclear Reaction Mechanisms with Magnetic Spectrometers

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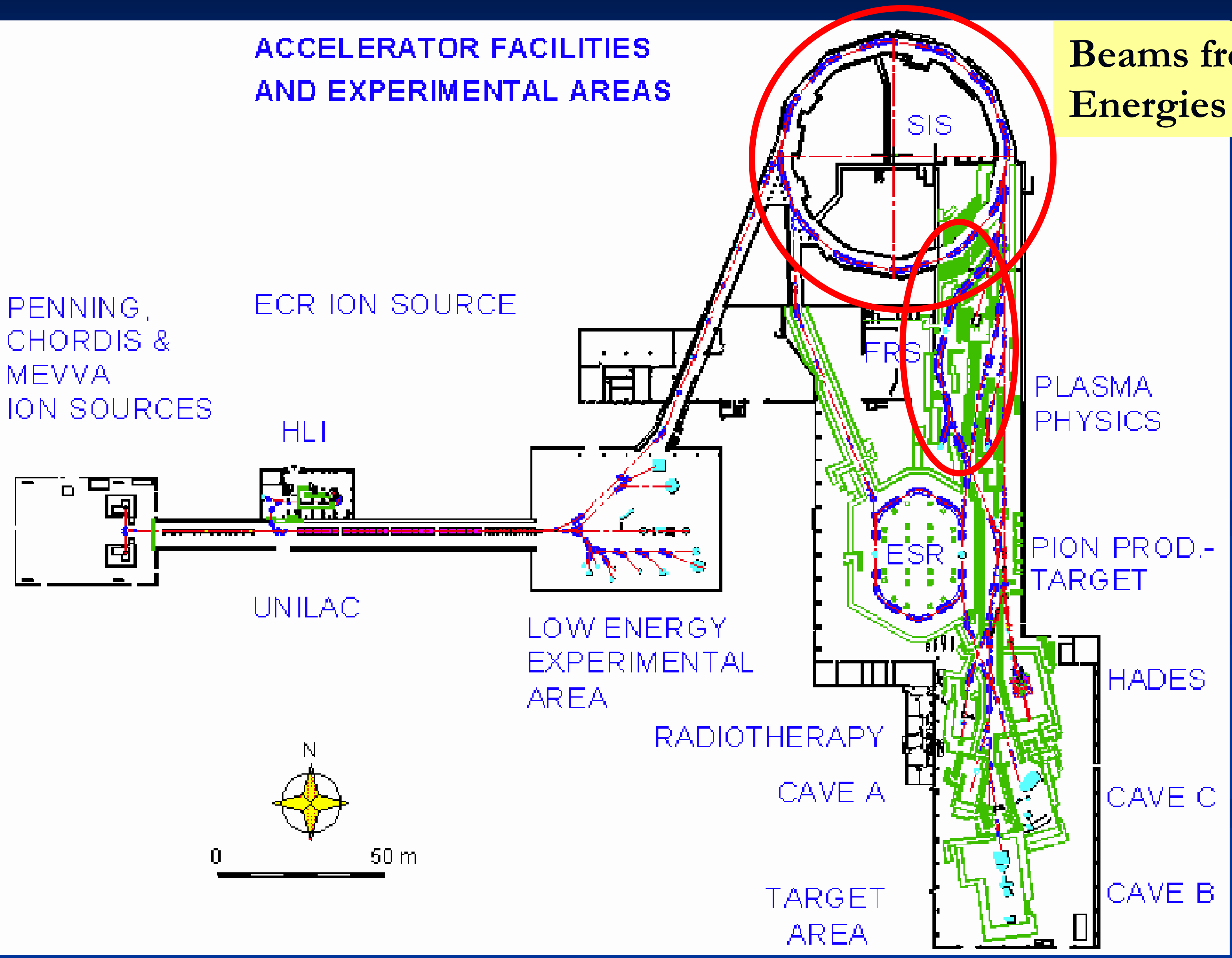
Topics

- Basic research:
  - Momentum dependence of the nuclear mean field (Talk of V. Henzl)
  - Thermal instabilities of nuclear matter (Talk of D. Henzlova)
  - Dissipation in Nuclear Matter
  - Very asymmetric fission
  - Structure effects in fission and fragmentation
  - Nuclide production in fragmentation and fission (Talk of J. Benlliure)

- Applications:
  - Nuclear astrophysics
  - Spin, alignment and polarisation in fragmentation
  - Transmutation of nuclear waste
  - Nuclear safety
  - Production of secondary beams (RIA, FAIR)

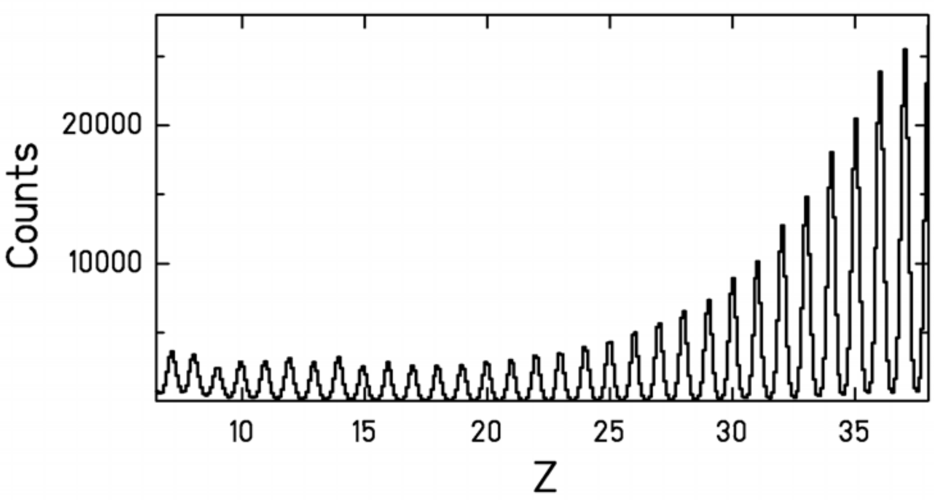
The Heavy-Ion Synchrotron at GSI

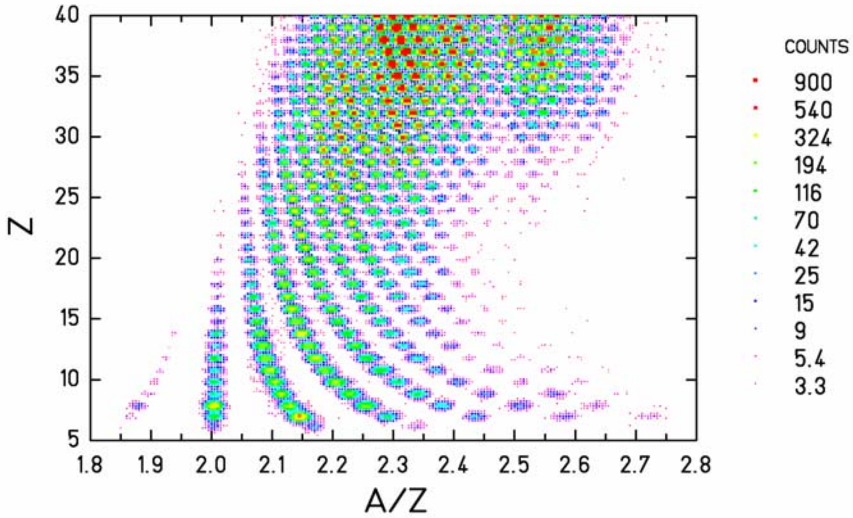


Beams from p to ^{238}U
Energies of 1-2 A GeV

The FRagment Separator FRS

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





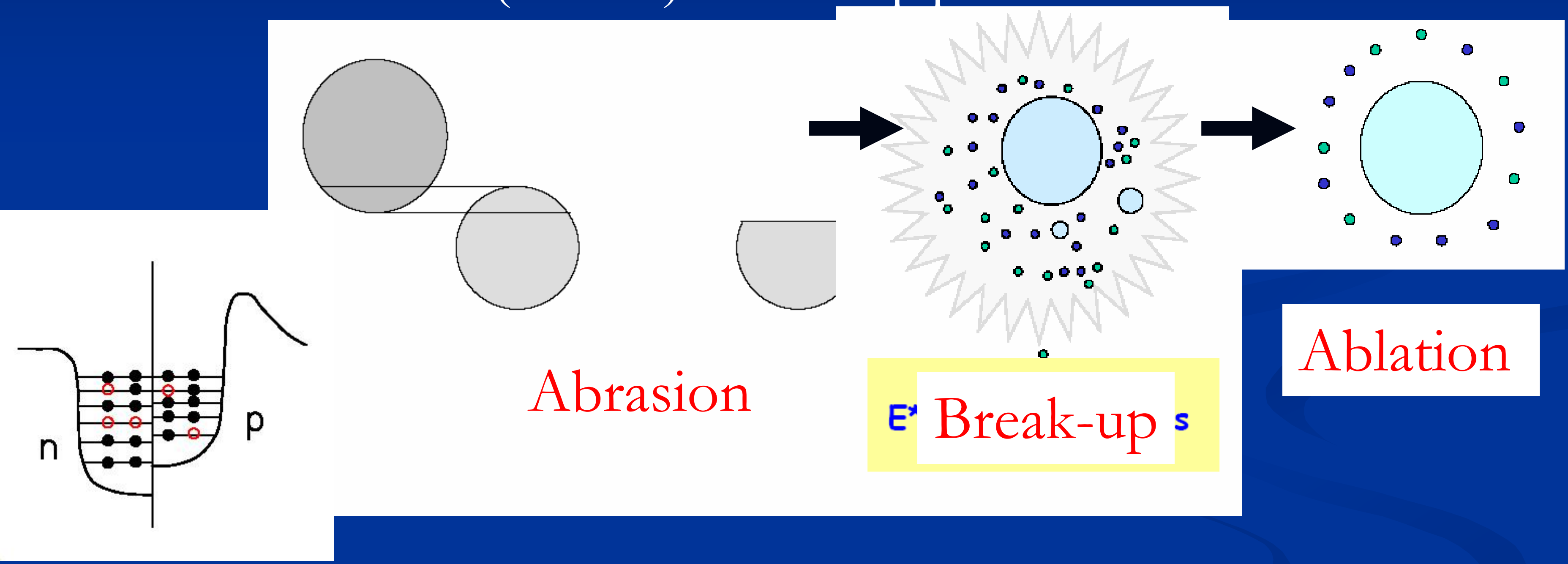
M.V. Ricciardi, PhD thesis

Two "natural" observables:

- **Momentum distributions**
- **Cross sections**

Projectile Fragmentation

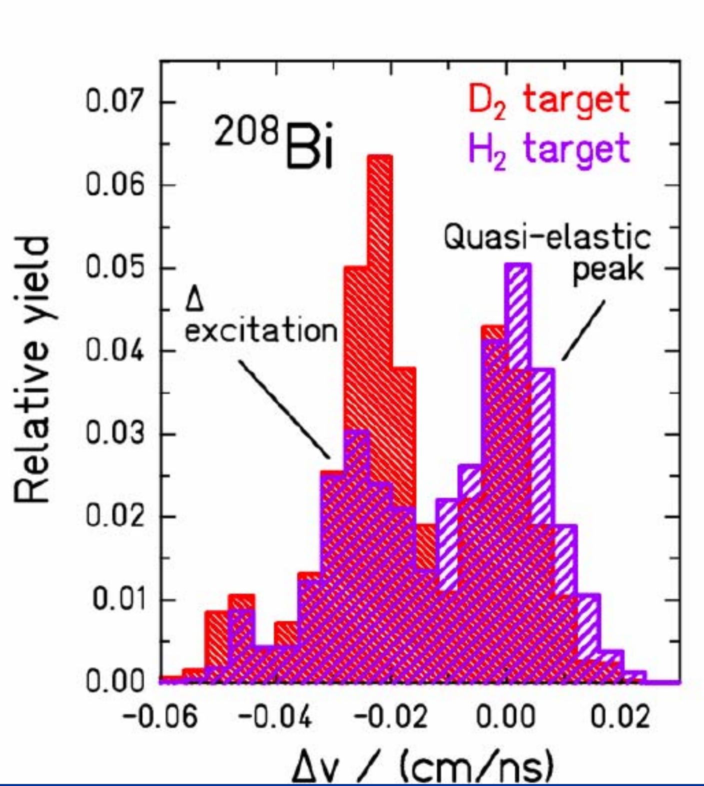
Two different time scales for abrasion and ablation →
(at least) a two-step process!



- Abrasion of nucleons in a peripheral collision produces excited CN (prefragment).
  - high <E*> ≈ 27 MeV per abraded nucleon
- De-excitation through particle evaporation (n,p,α) or fission
- (relatively) low angular momenta (listen tomorrow to Z. Podolyak)

$^{193-208}_{83}$Bi

Momentum Distributions



Nucleon excitation in projectile fragmentation

^{1}H(^{208}Pb,^{208}Bi)x at 1 A GeV

^{2}H(^{208}Pb,^{208}Bi)x at 1 A GeV

Velocity of ^{208}Bi in the frame of the ^{208}Pb projectile.

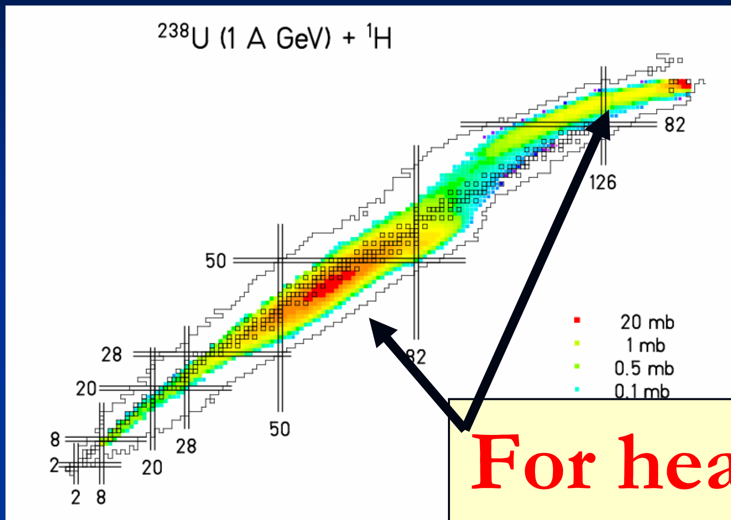
A. Kelić et al., PRC 70, 064608 (2004)

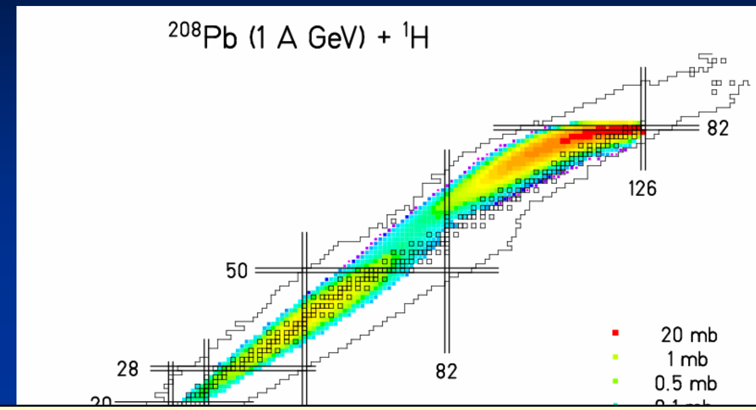
Two components can be distinguished:

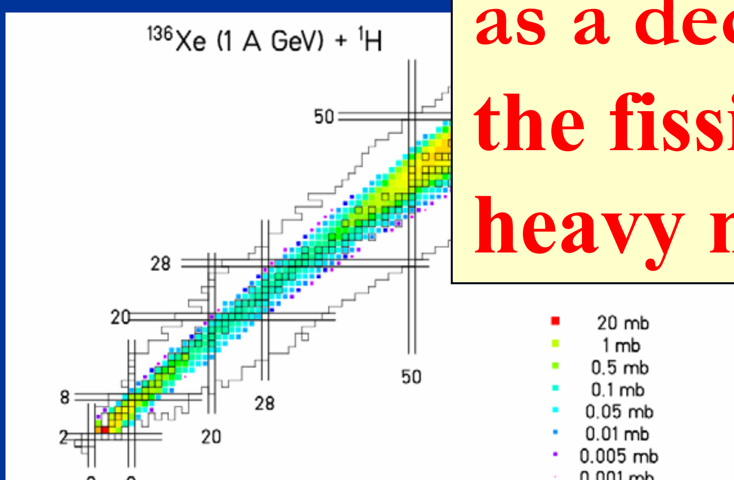
- Quasi-elastic scattering (p replaces n in ^{208}Pb)
- Δ(1232) excitation (e.g. $n \rightarrow \Delta^0 \rightarrow p + \pi^-$)

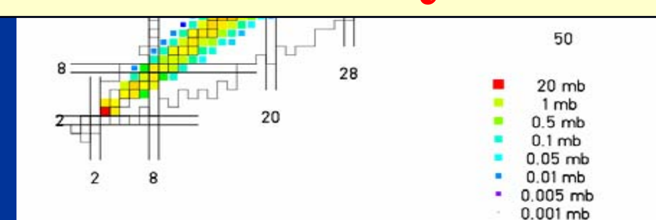
Probability for Δ excitation and energy in the nuclear medium can be deduced.

Measured Nuclide Production in Fragmentation and In-flight Fission







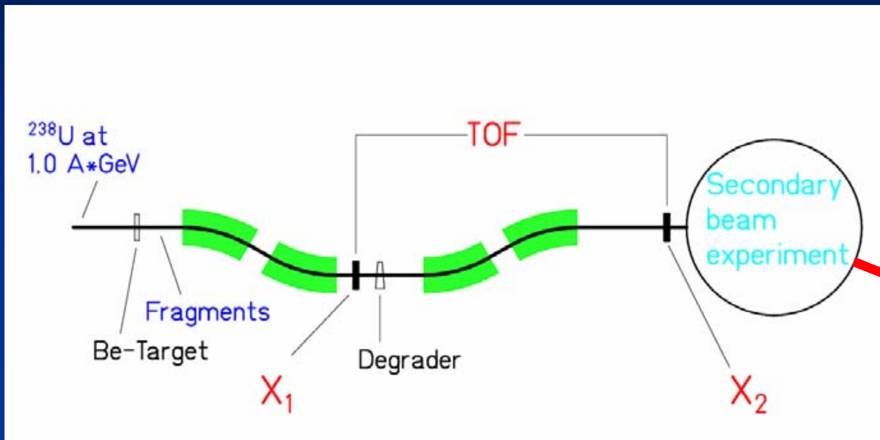


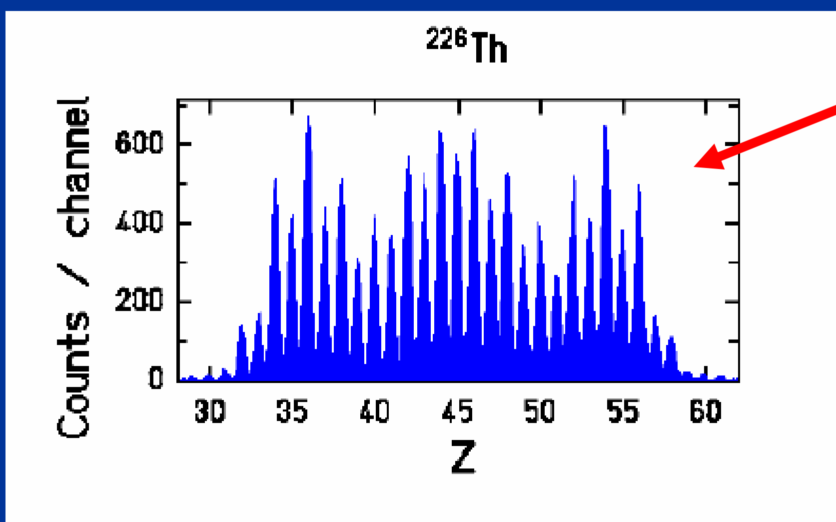
For heavy projectile fission opens up as a decay channel → knowledge of the fission properties of unstable heavy nuclei is necessary

Excellent basis for model development

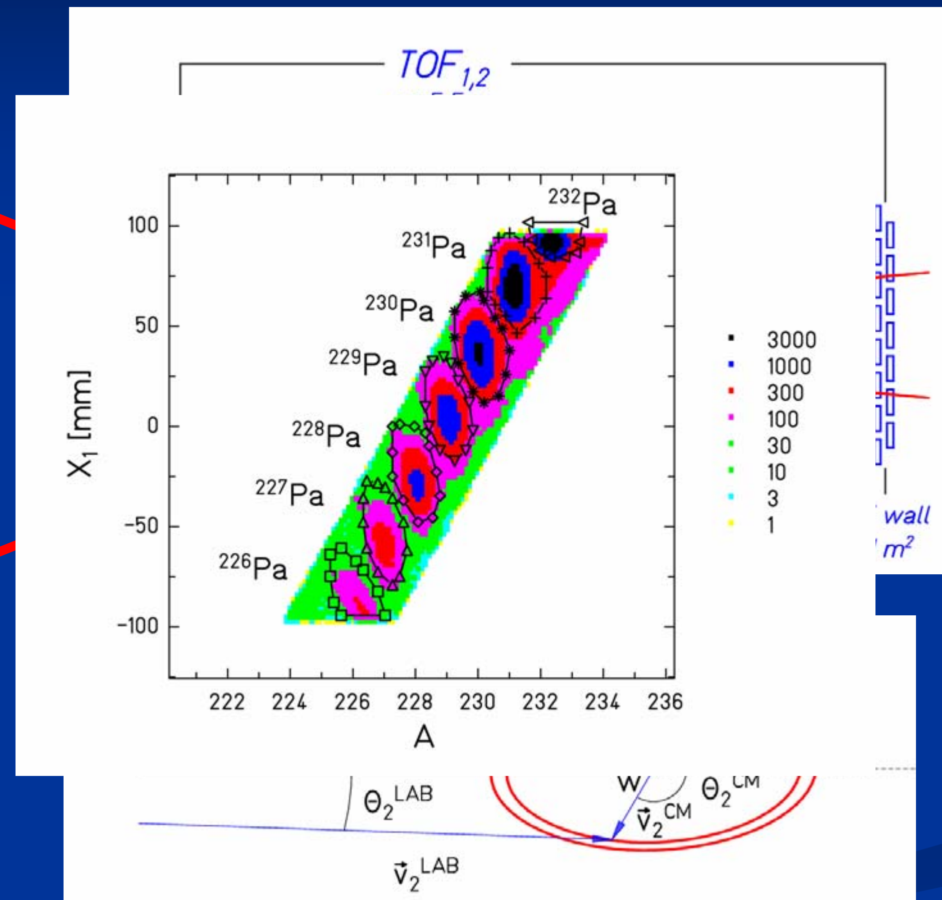
Data available at: http://www-w2k.gsi.de/charms/data.htm

Experiment



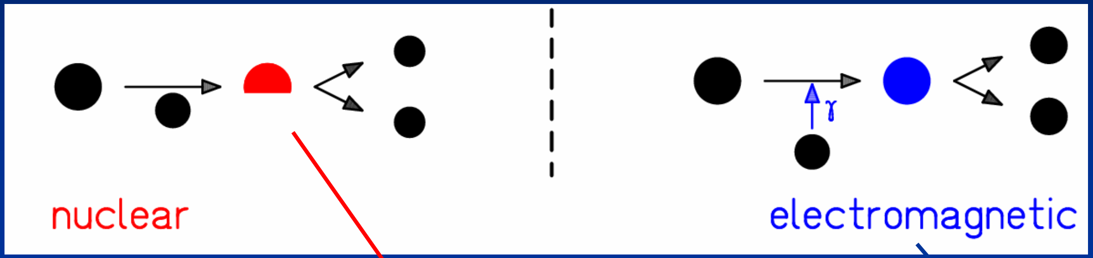


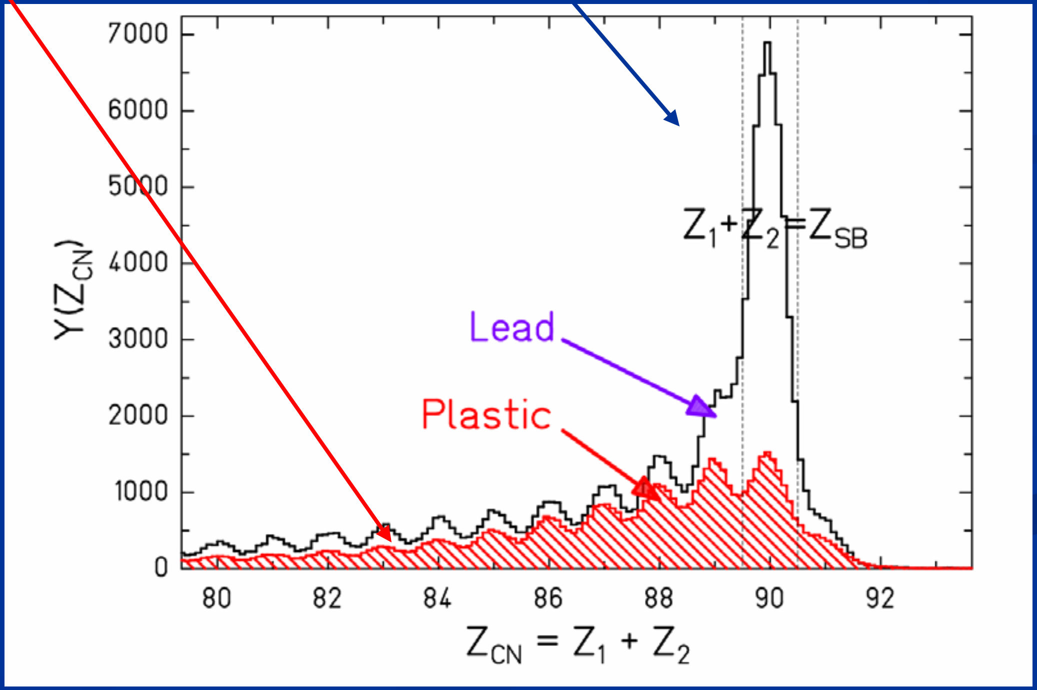
Charge distribution



Total Kinetic Energy (TKE) distribution

Two Reaction Mechanisms





Plastic: only nuclear-induced fission

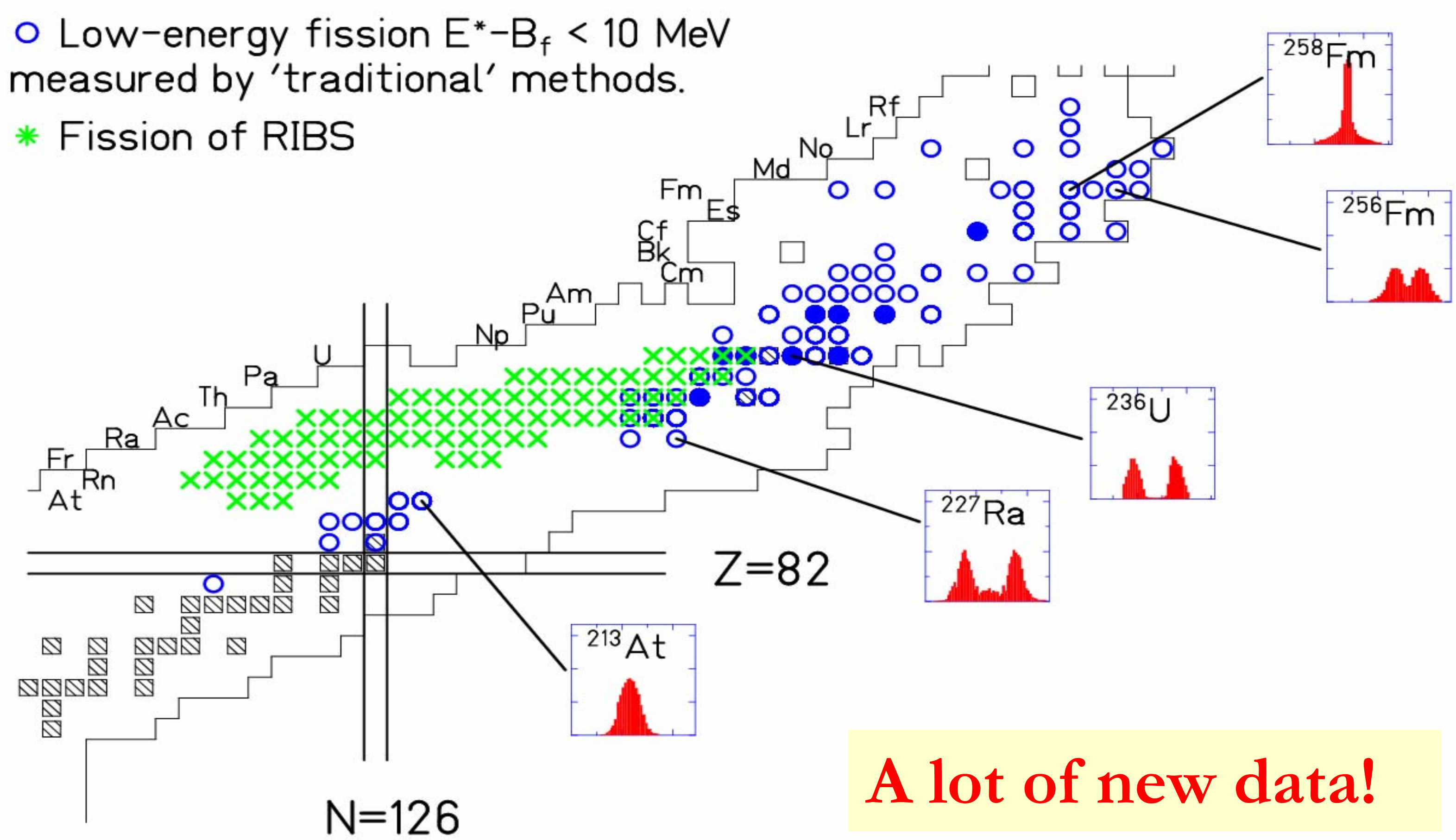
Pb: nuclear and electromagnetic-induced fission

Nuclear: $Z_{CN} = Z_1 + Z_2$

Electromagnetic: $Z_{CN} = Z_1 + Z_2$

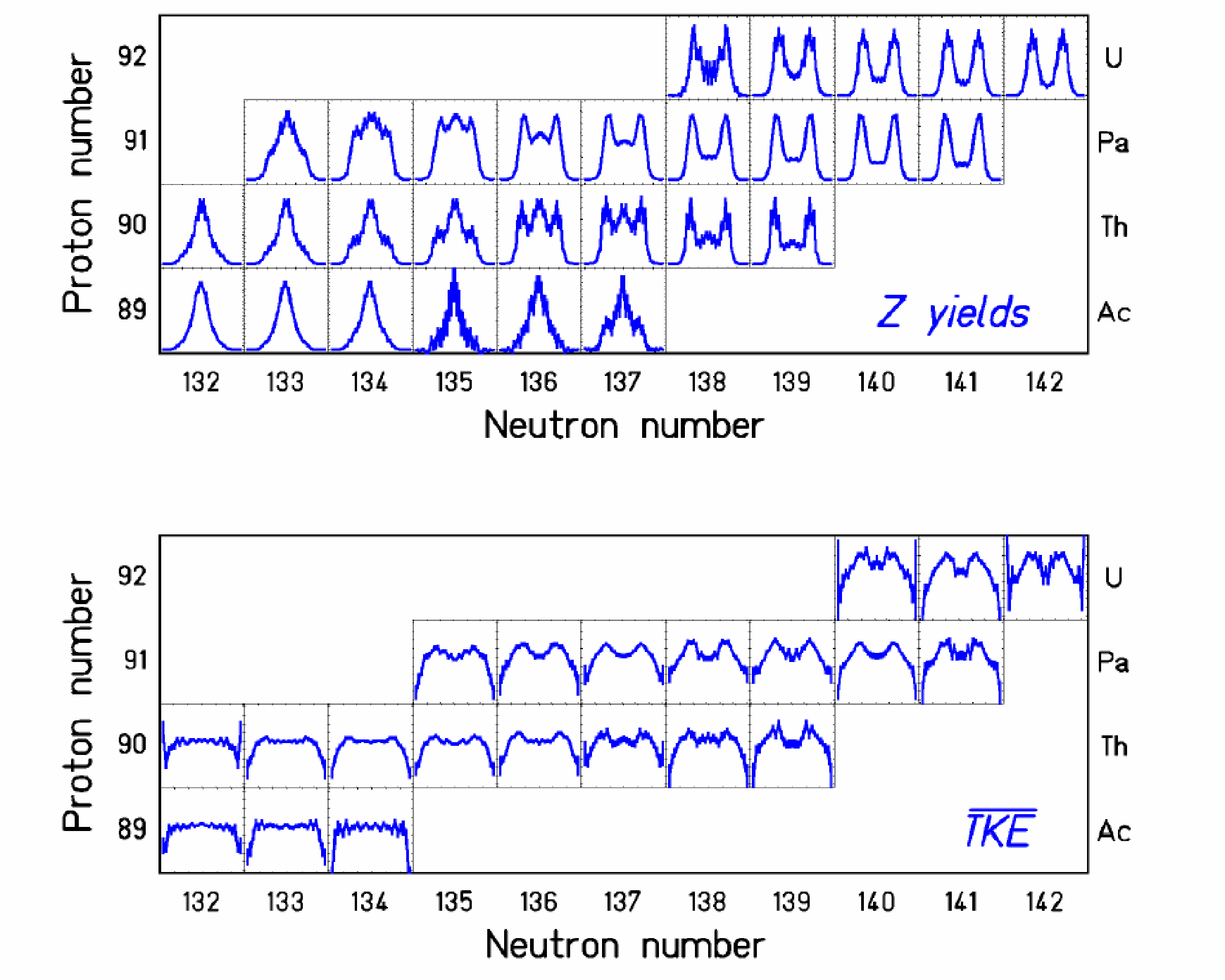
→ trigger for low excitation energies!

Experimental Information on Fission at low E*



A lot of new data!

Transition from Symmetric to Asymmetric Fission



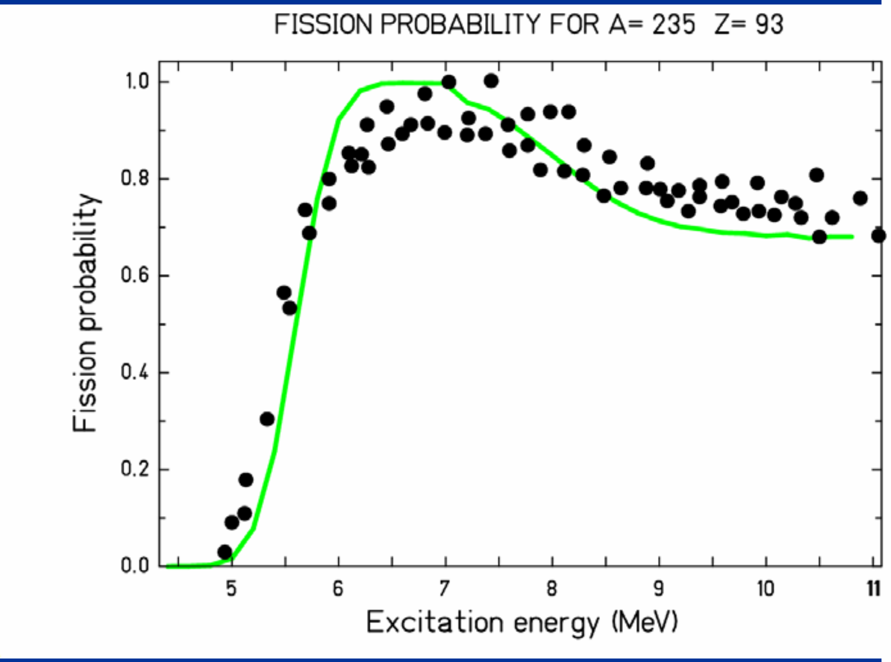
Data resulted in:

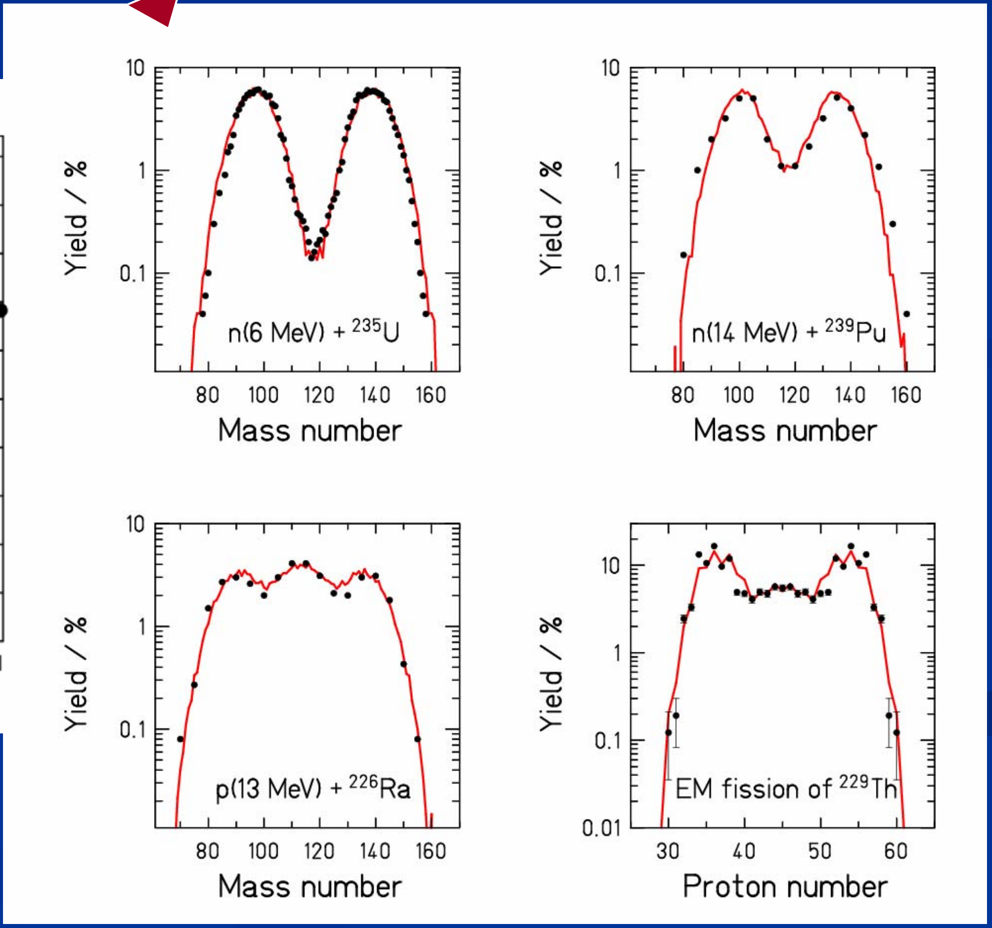
o improved models for yield calculations

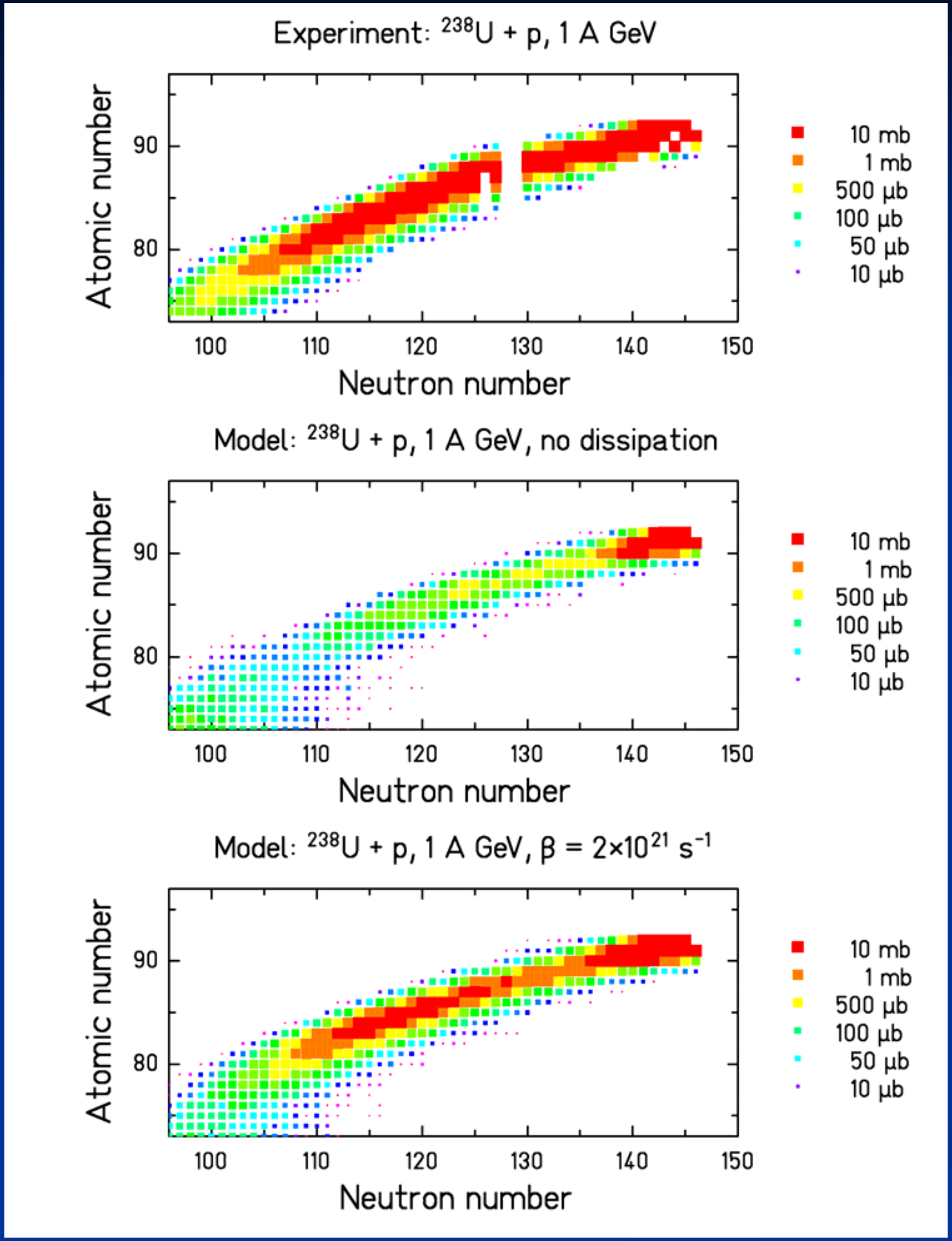
o better understanding of low-energy fission: evolution of fission channels, influence of pairing, …

GSI code ABLA - Examples low-energy reactions

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







Dissipation and Nuclide Production

J. Taïeb et al.

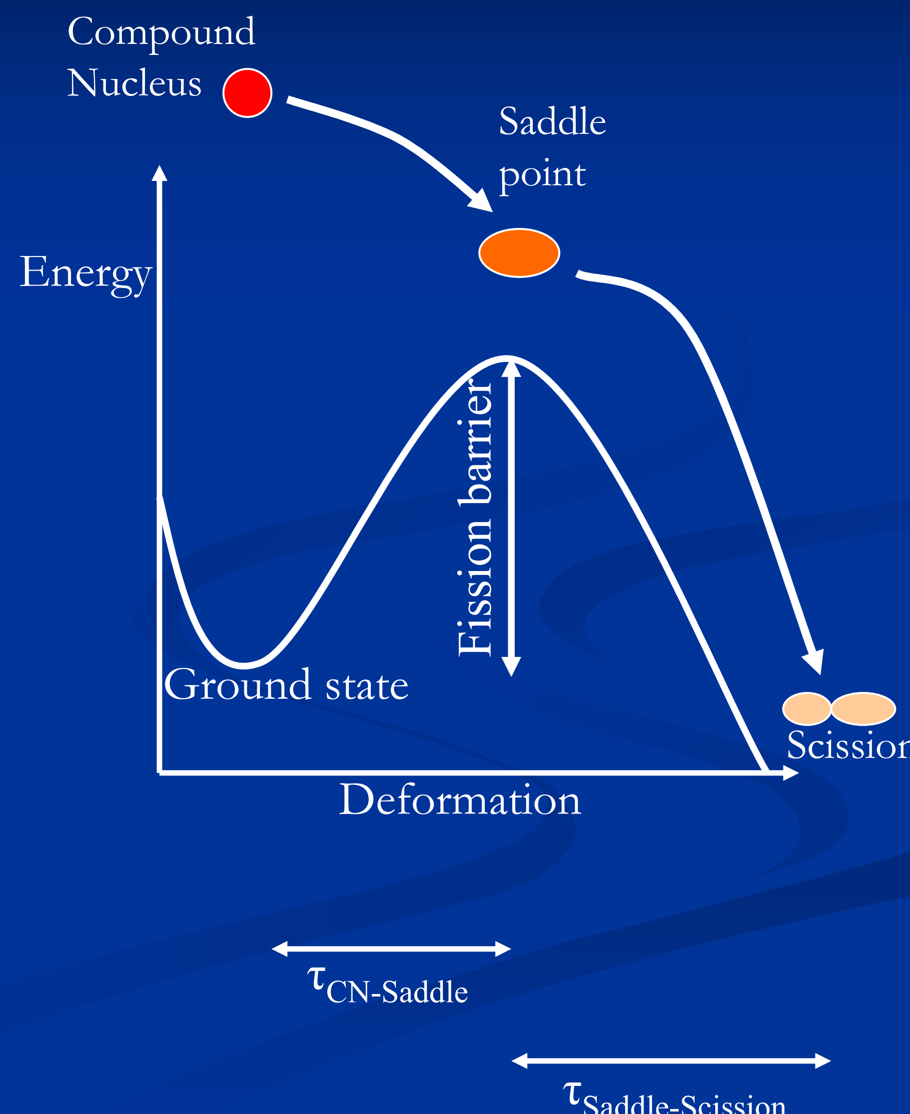
Dissipation and Nuclear Fission

Collective motion

Junior researcher

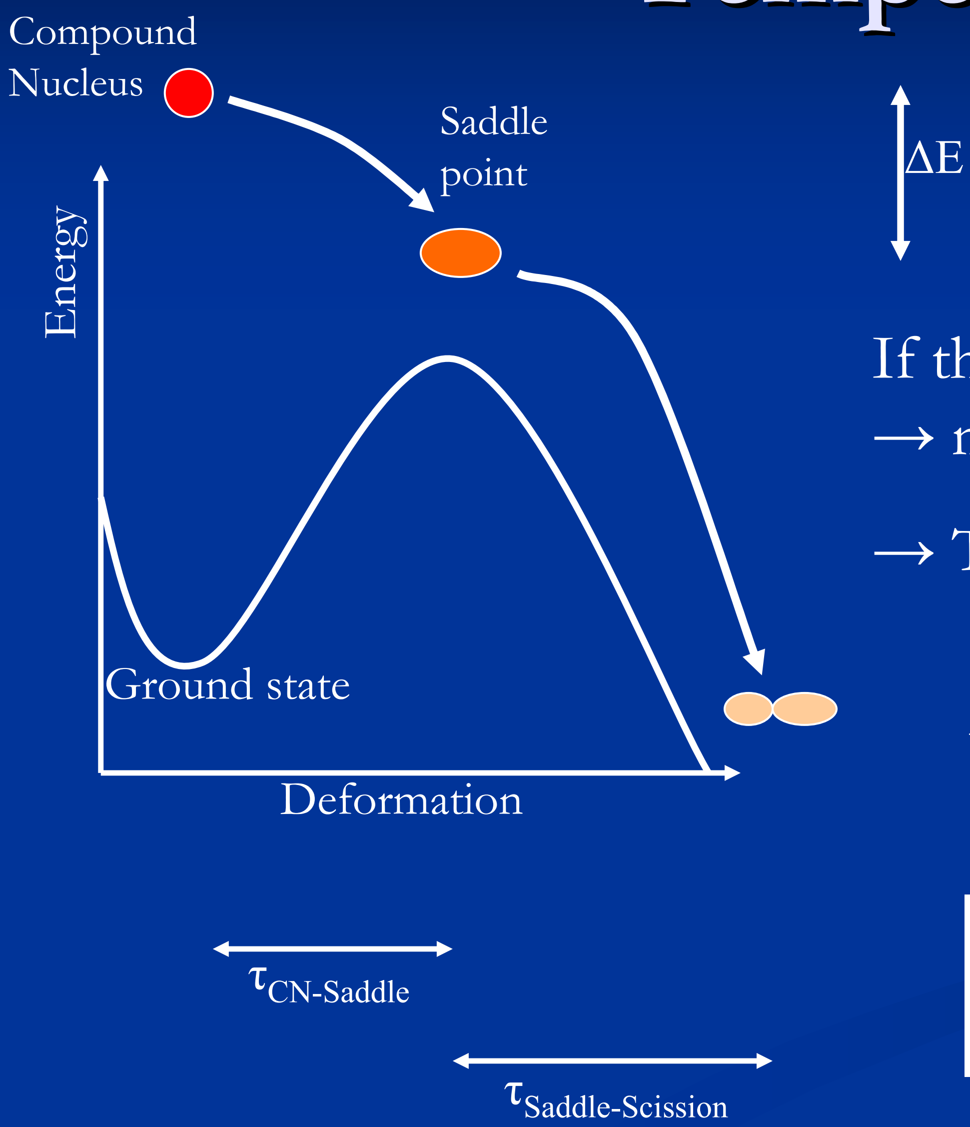
Potential difference

Collective motion converts into "heat" due to friction



What does this have to do with nuclear fission?

Dissipation and the Saddle Point Temperature



If there is any dissipation $\tau_{neutron} < \tau_{fission}$

→ $m_{neutron}$ and ΔE get larger

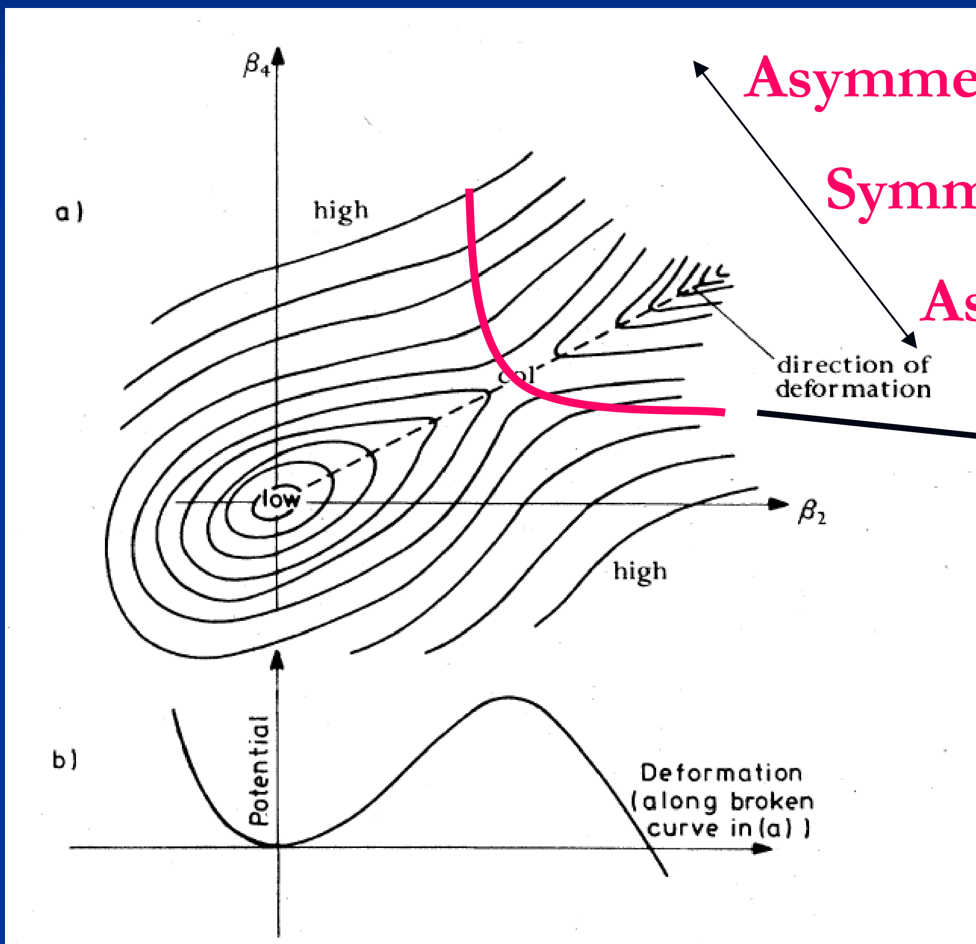
→ T_{saddle} is smaller

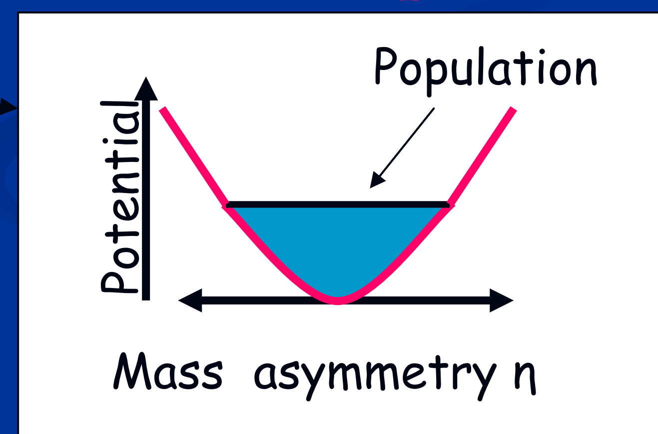
Reminder: the connection between temperature and excitation energy

$$T_{nuc} = \sqrt{\frac{E^*}{a}}$$

Level density parameter

Charge Width as a Thermometer



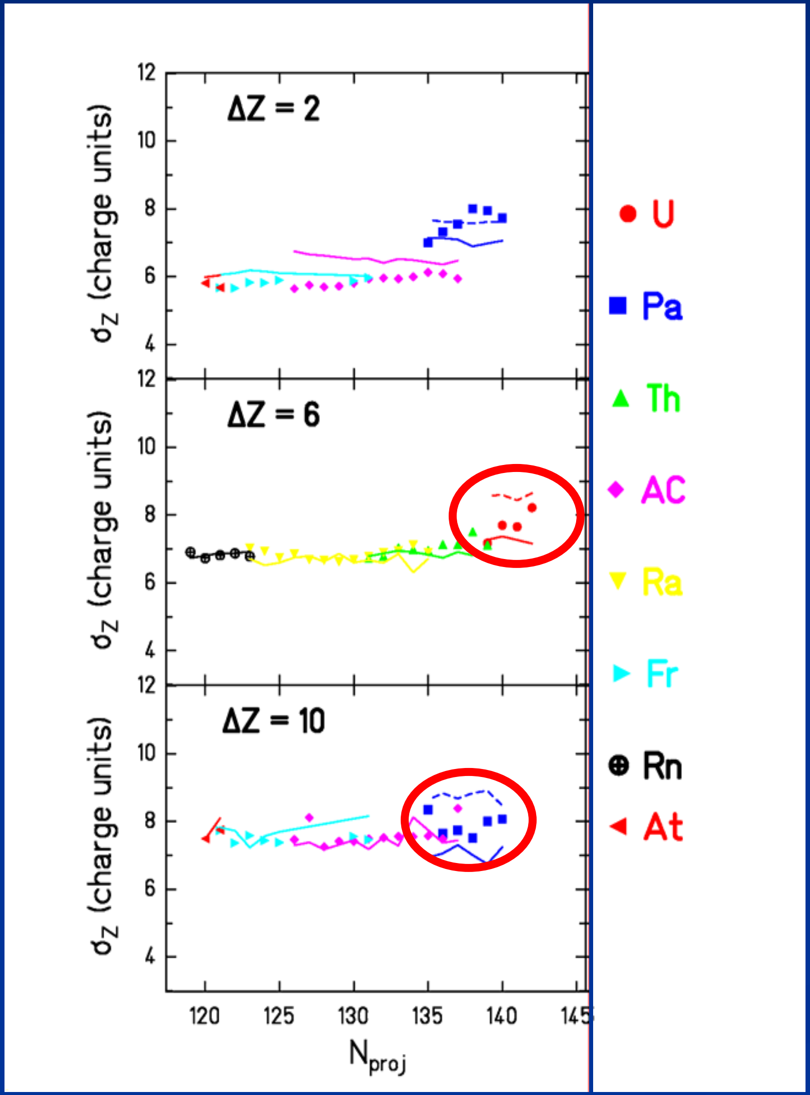


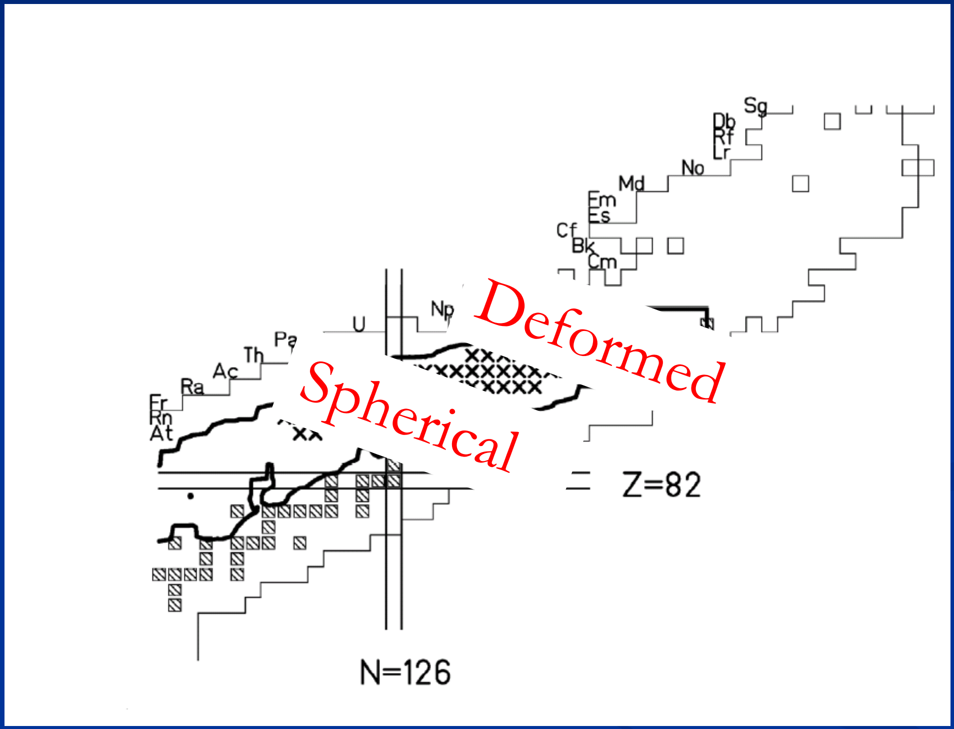
$$\sigma_Z^2 = \left(\frac{Z_{fiss}}{A_{fiss}}\right)^2 \frac{T_{saddle}}{\left.\frac{d^2V}{d\eta^2}\right|_{\frac{A_{fiss}}{2}}}$$

From: Bjornholm, Lynn; Rev. Mod. Phys. 52, 725 (1980)

First Results

^{238}U @ 1 A GeV on ^{9}Be

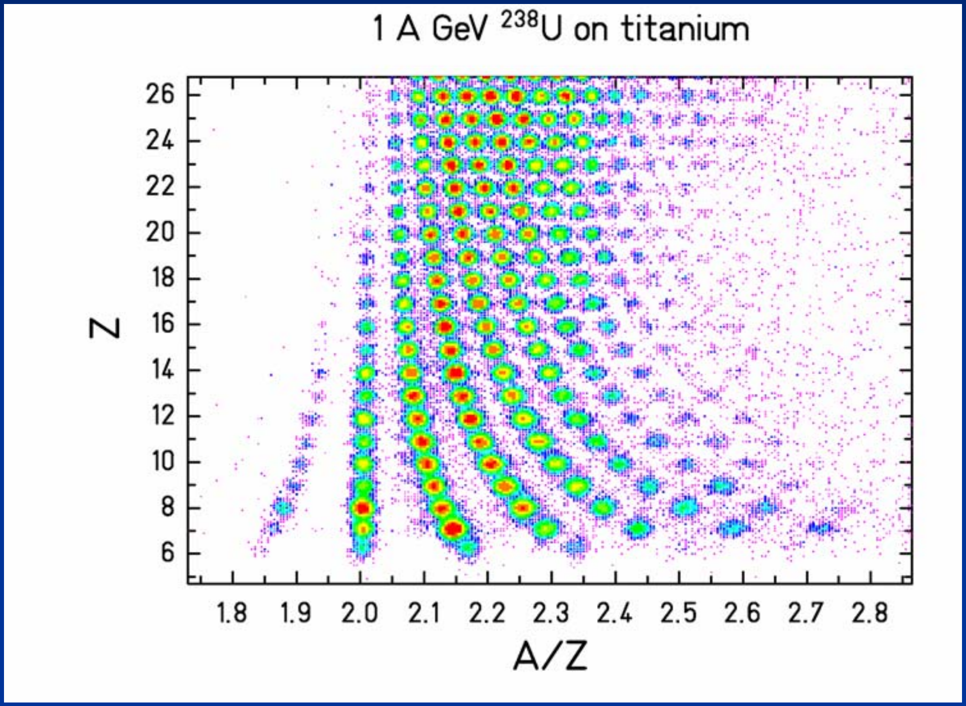


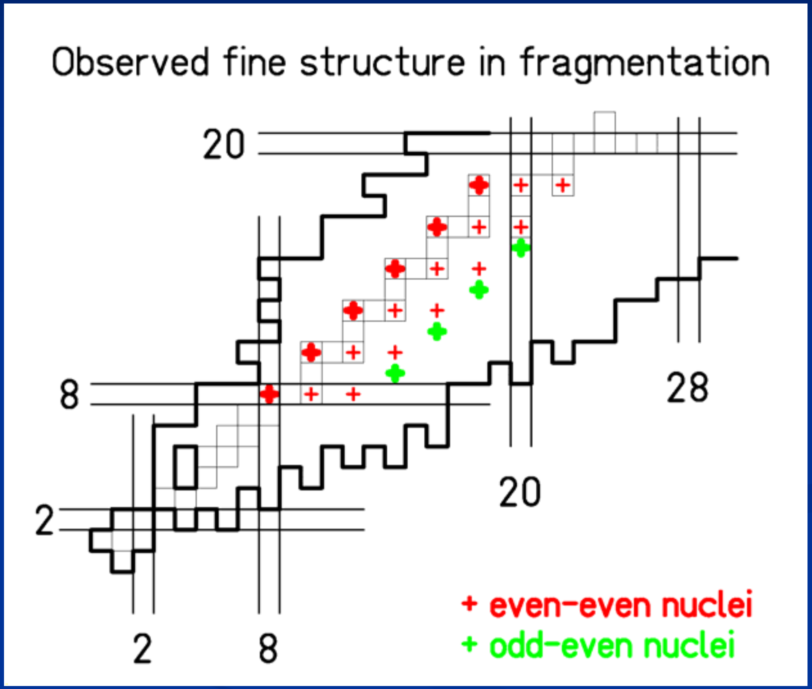


Model description fails for deformed projectiles

→ influence of “initial” deformation on dissipation in nuclear fission

Fine structure in residue yields after violent nuclear collisions

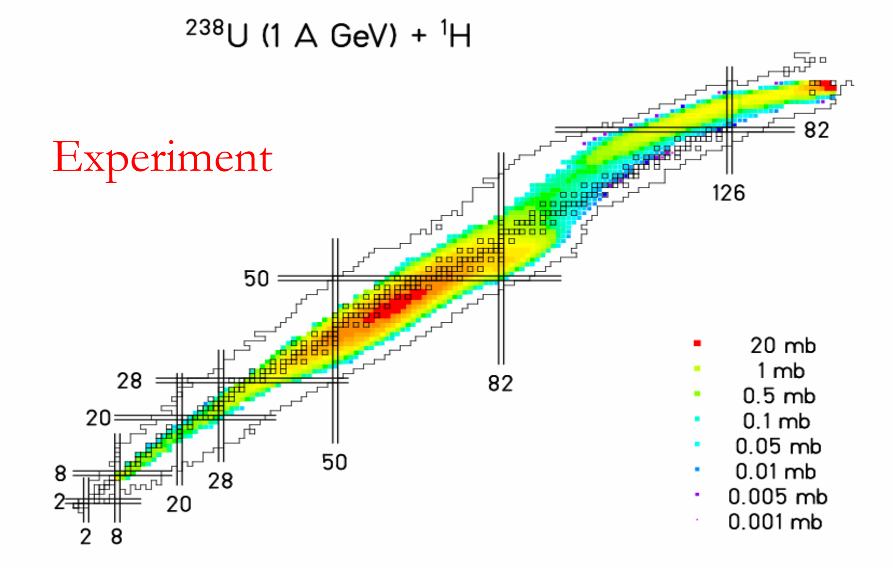


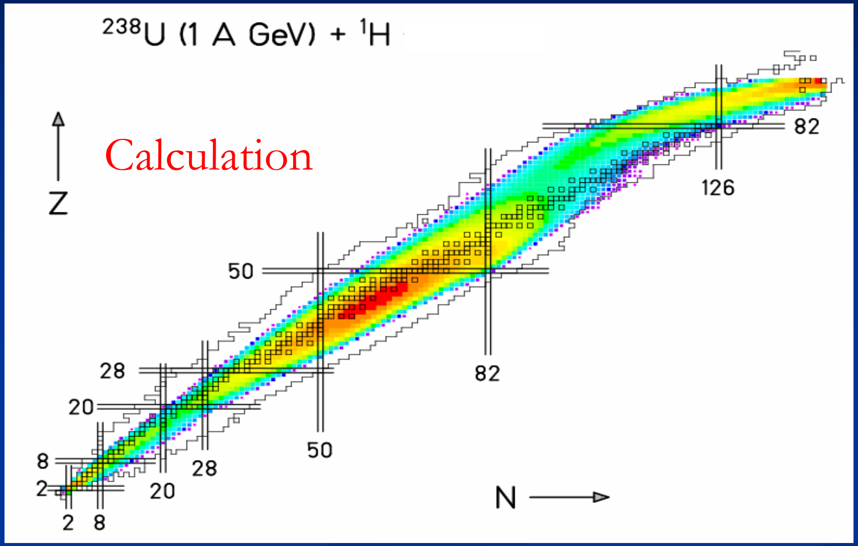


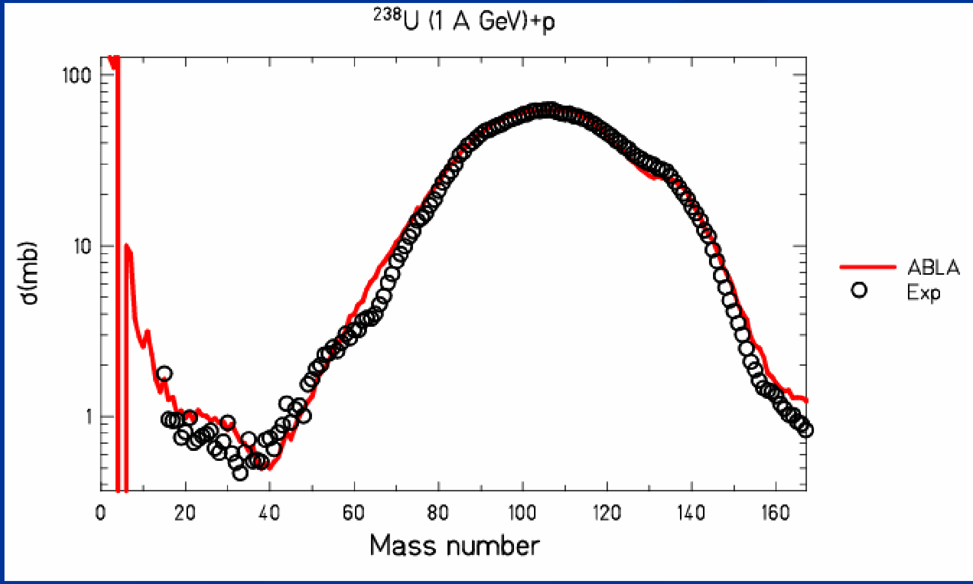
Caution when interpreting nuclide yields with thermodynamic approaches without nuclear structure!

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

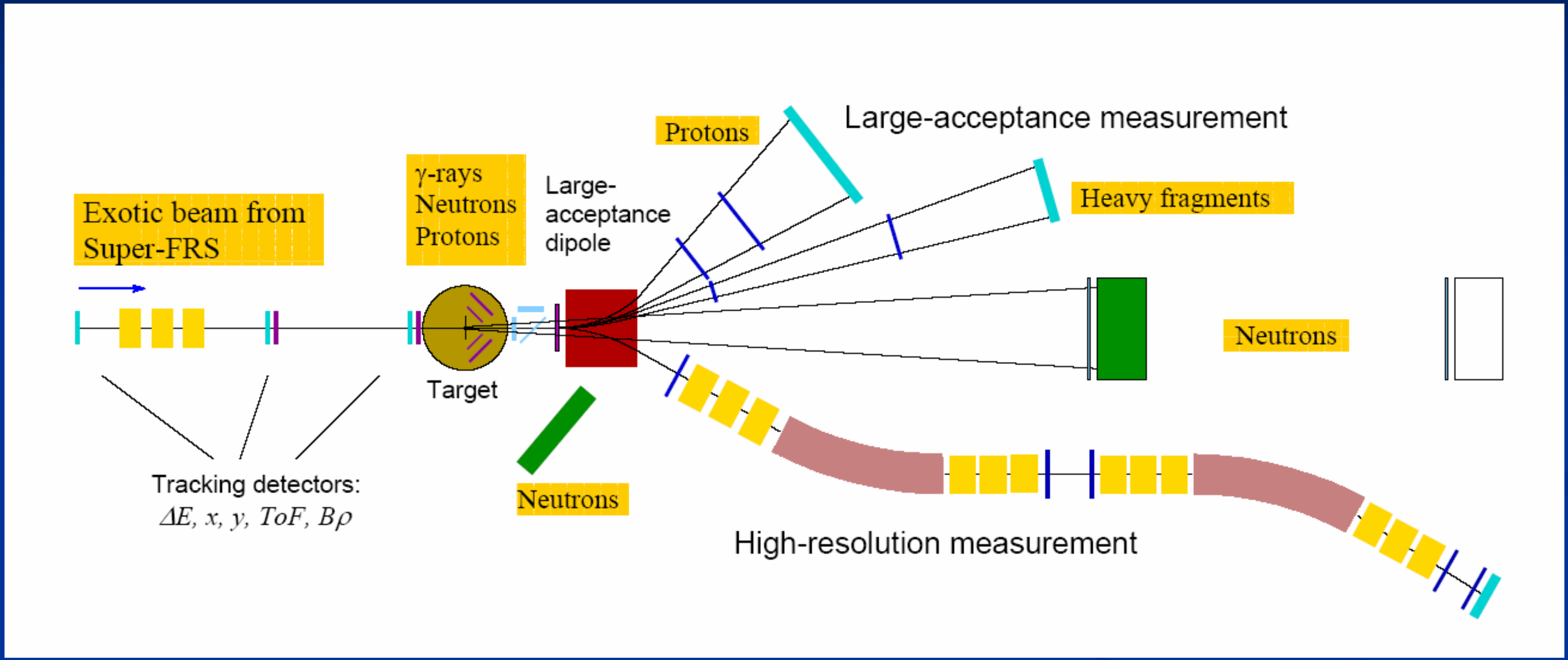
GSI code ABLA – Examples for high-energy reactions







The Future: R^3B

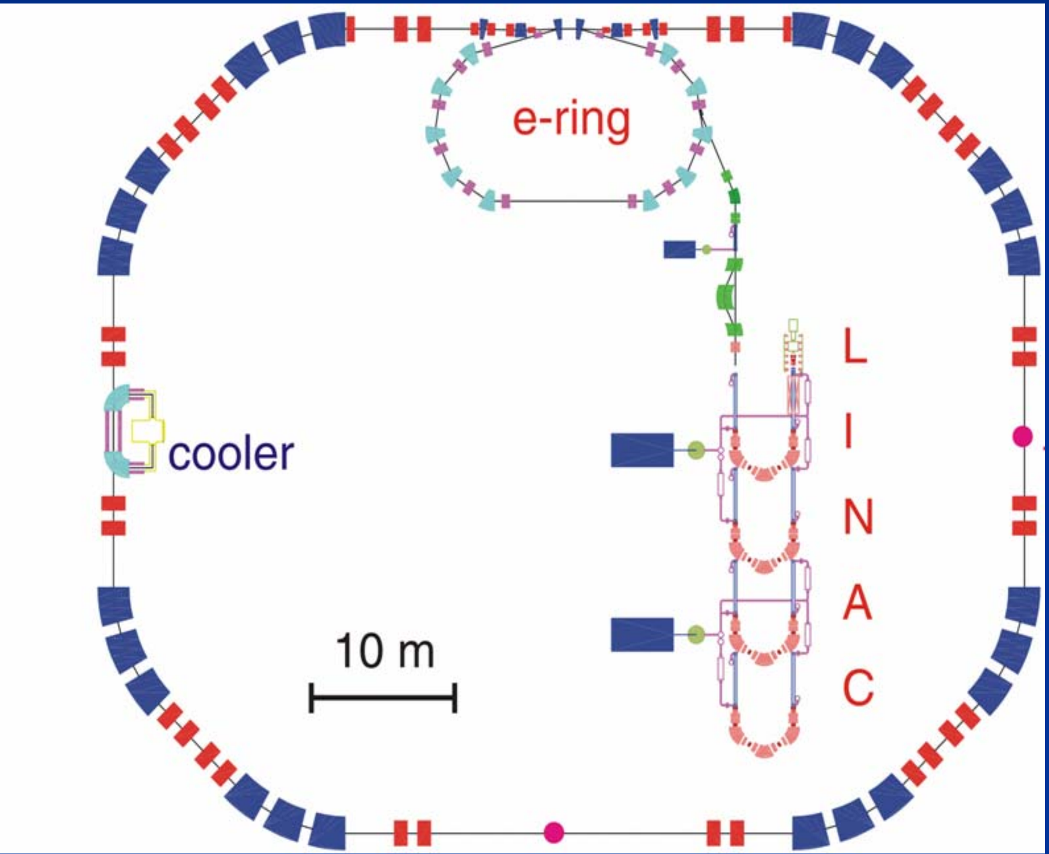


Measure:

- Charge **AND** Mass of projectile and fission fragments
- Neutrons
- Gammas
- Cross sections

Exclusive experiments AND high resolution

Future (Part II): Electron-Ion scattering in a Storage Ring (eA Collider) ELISe



- 125-500 MeV electrons
- 200-740 MeV/u RIBs

- achievable luminosity: 10^{25}-10^{29} $cm^{-2}s^{-1}$ depending on ion species

- spectrometer setup at the interaction zone

- detection system for RI in the arcs of the NESR (see EXL)

Conclusions

- A lot of progress in the understanding of projectile fragmentation.
- Heavy beams and high resolution spectrometers are excellent tools.
- Don't forget the influence of nuclear structure and nucleonic exciations.
- A wealth of new data from projectile fragmentation, spallation, in-flight fission and fission of secondary beams allowed for the development of realistic models with predictive power.
- Applications in accelerator driven systems, nuclear astrophysics, ...
- The future looks bright!