Detection of Beta-Delayed Neutrons

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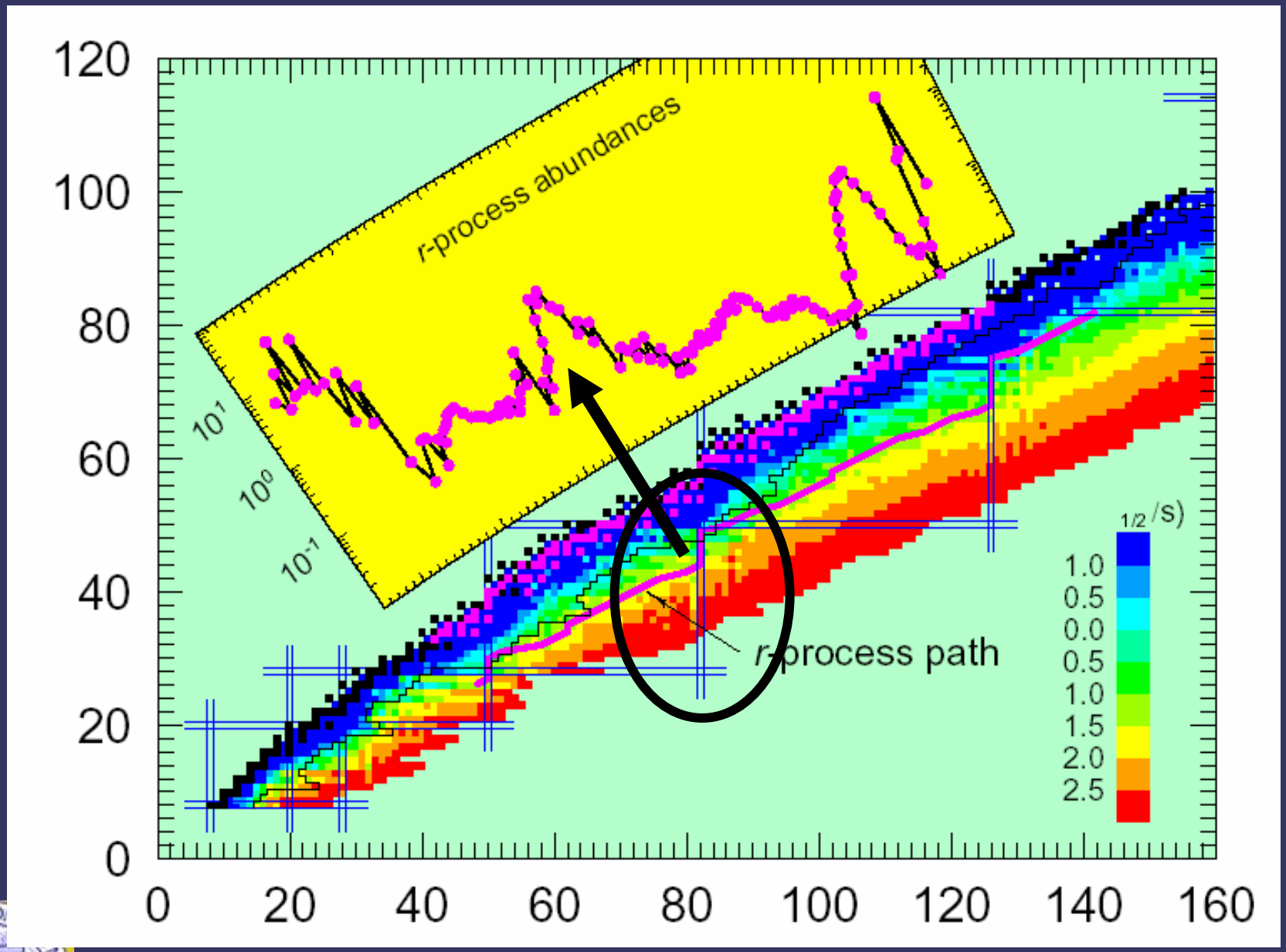

Proton Number Z
Neutron Number N
r-process abundances
r-process path
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
1.0
0.5
0.0
0.5
1.0
1.5
2.0
2.5

^{130}Cd is the most important nuclus bevor the break-out of the magic N=82 Shell

⇨ Generation of the solar r-process abundance peaks arround ^{130}Te

r-process in the A ≈ 130 region

Proton Number Z

N=82

^{130}Te								
	^{130}Sb							
		^{130}Sn	^{131}Sn	^{132}Sn	^{133}Sn	^{134}Sn	^{135}Sn	^{136}Sn
			^{130}In	^{131}In	^{132}In	^{133}In		
			^{129}Cd	^{130}Cd			^{133}Cd	
		^{127}Ag	^{128}Ag	^{129}Ag				
	^{123}Pd		^{127}Pd	^{128}Pd				
^{121}Rh		^{125}Rh	^{126}Rh	^{127}Rh				

⇨(n,γ)⇨

⇨(n,γ)⇨

n,γ β⁻

r-prozess Boulevard for T_9=1.35 and $n_n=10^{24}$ cm^{-3}

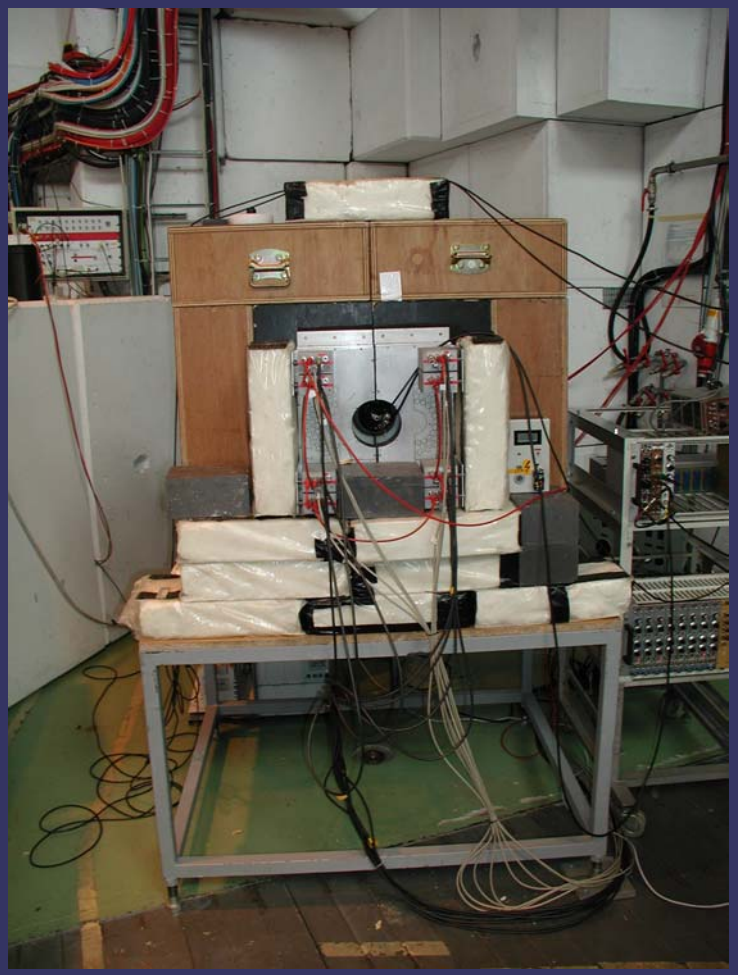
Neutron Number N

SELECTIVITY

- Production
  - specific reaction A(x,y)B
  - thermal fission
- Target temperature
  - $\tau_{relase}=f(T_{target})$
  - $T_{target} = T_{desoprt} = f(\Delta H_{adsorpt.}) = f(Z)$
- Duty-cycle
  - optimize with respect to beam structure,
  - τ_{relase}, $T_{1/2}$, $T_{1/2}$(isobars)
- Ionization
  - positve/negative surface ionization
  - laser ionization
- Separation
  - TOF-ΔE/E
  - high resolution mass separation
  - chemistry before or after mass separation
  - isomers (μs, laser-frequency)
- Detection
  - shielding against background , specific decay mode βdn, e.g. multi-fold coincidences

Neutron Detectors

- Low energy threshold (25 meV)
- High detection efficiency (ca. 33%)
- Two detectors are existing:
  - The Mainz detector by (K.-L. Kratz et al.)
  - NERO at the NSCL at MSU (Schatz et al.)



Neutron Detection (^{3}He-proportional counters)

- ^{3}He-proportional counters based on $^3He(n,p)^3H$ + 765 keV reaction
  - **Advantage:**
    - has high cross-section for thermal neutrons.
    - pulses caused by gamma- and beta- radiation can be easily discriminated.
  - **Disadvantage:**
    - neutrons have to be thermalized. The moderation time is ca. 80 μs. However the bulk of neutrons is moderated within 30 μs.
    - can be used for counting only, no real energy resolution.
    - The detectors are “electronically” very slow.

Neutron Detection (^{3}He-ionization chamber)

- This detector is based on the same reaction. It is built as an ionization chamber with a Frisch-grid.
  - Advantages:
    - good energy resolution over a wide energy range
    - Software to correct for efficiency exists (K.-L. Kratz)
  - Disadvantages:
    - very noise sensitive
    - low detection efficiency
    - high cost and special (custom-made) electronics is required.

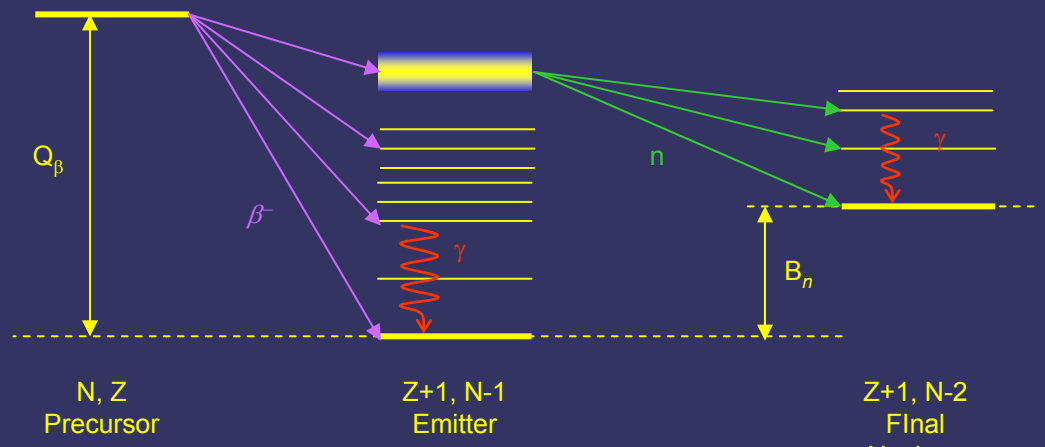
Neutron Detection (NE213 liquid scintillators)

- Good neutron detectors for “higher-energy” neutrons (> 1MeV). Frequently used in TOF spectroscopy and in in-beam spectroscopy (e.g. Gamma-Sphere)
  - **Advantage:**
    - extremely good timing
    - well suited for coincidence measurements.
    - work very well also in high gamma-radiation backgrounds.
  - **Disadvantage:**
    - efficiency curve has an extreme slope for low energy neutrons.
    - neutron-gamma discrimination is required.
    - Energy spectra can be obtained by time of flight measurements or by unfolding procedures
    - TOF has low solid angle and thus low efficiency.

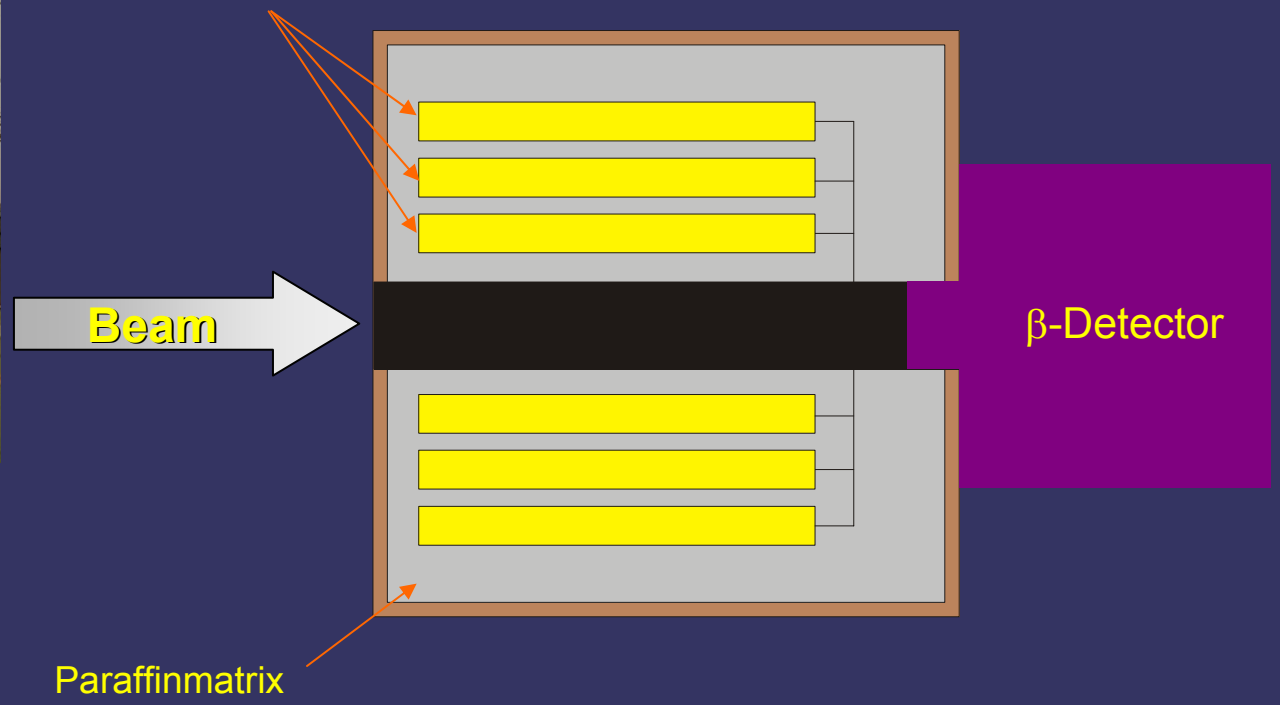
Summary on neutron detectors

- Over the years I have worked with may different neutron detectors and I come to the following conclusions:
  - For the identification and half-life measurements of extreme neutron-rich nuclei (N/Z = 1.6) a long counter consisting of ^{3}He-porotional counters is the best solution.
  - For coincidence spectroscopy NE213-liquid scintillators are the best choice. However, they are not suited for low neutron energies.
  - Neutron-gamma coincidences with a long-counter have been done (H. Gabelmann et. al.). The method is working and requires due to the long moderation time also very long beam-times.

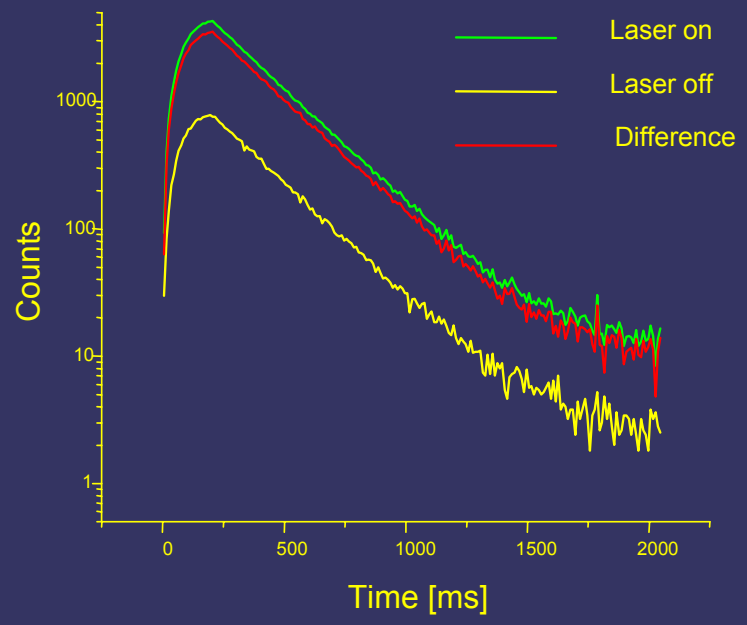
β-Delayed Neutrons (Mainz-detector)



^{3}He-Proportinal Counters

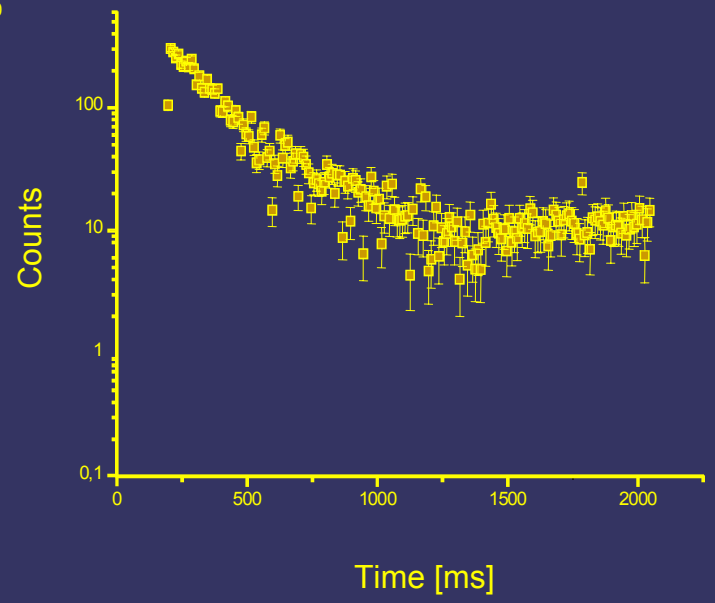


Detector in combination with RILIS



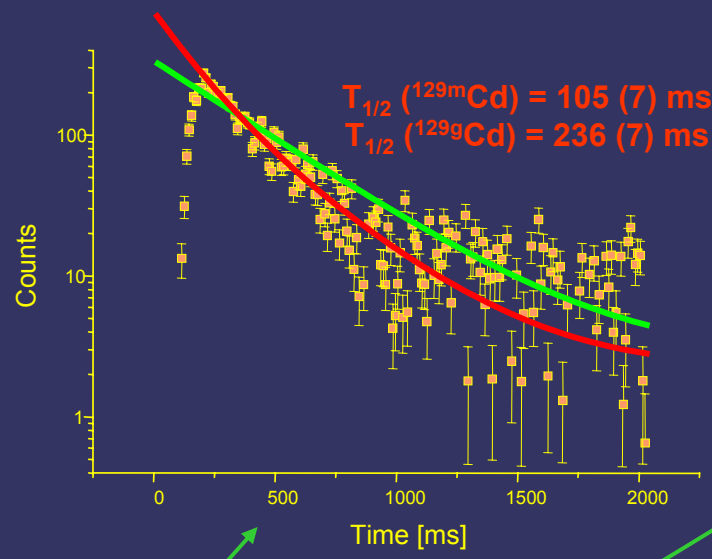
„Raw“ Spectrum

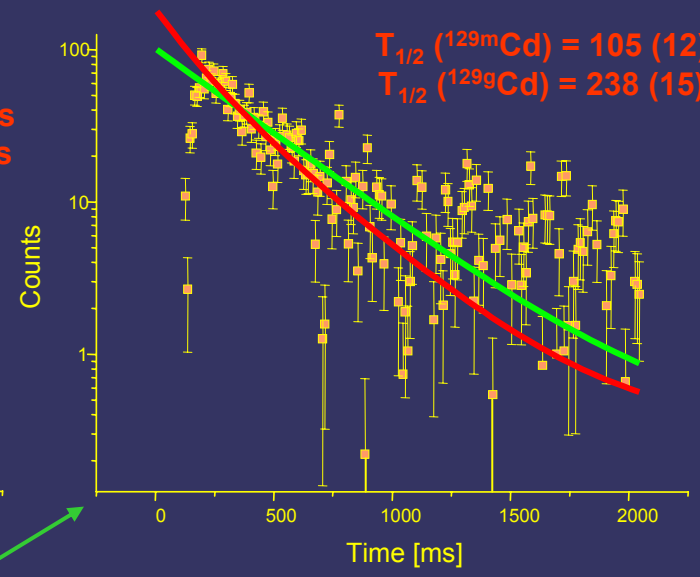
Normalizaton from „Laser off“ to „Laser on“ and subsequnt subtraction

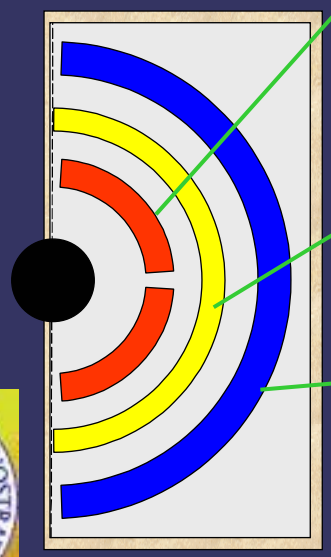


Difference

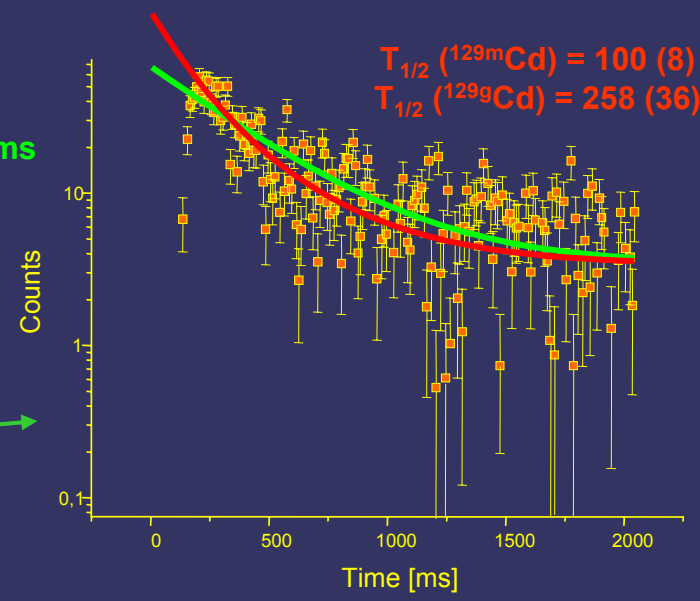
Energy discrimination





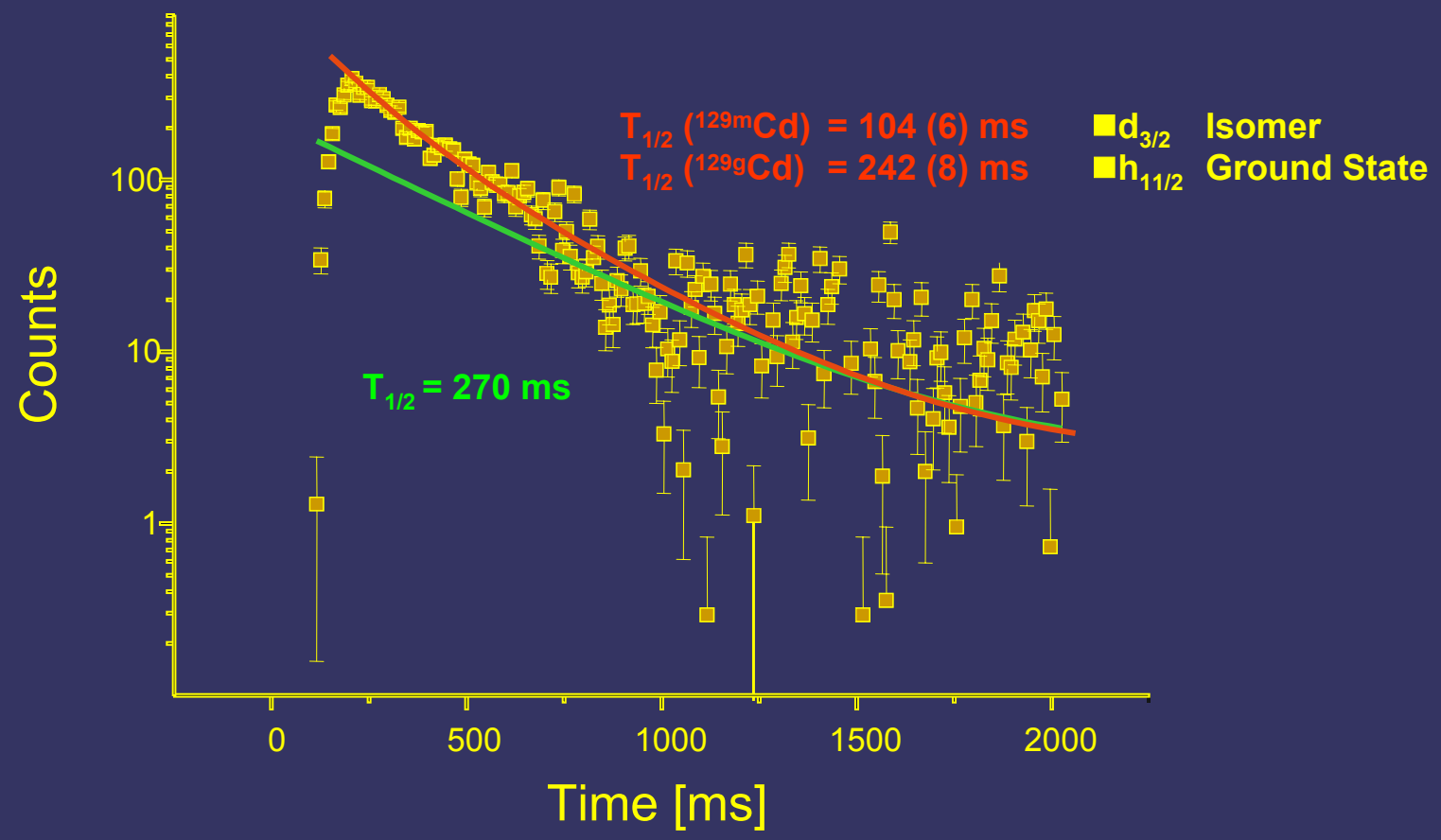


$T_{1/2}$ = 270 ms



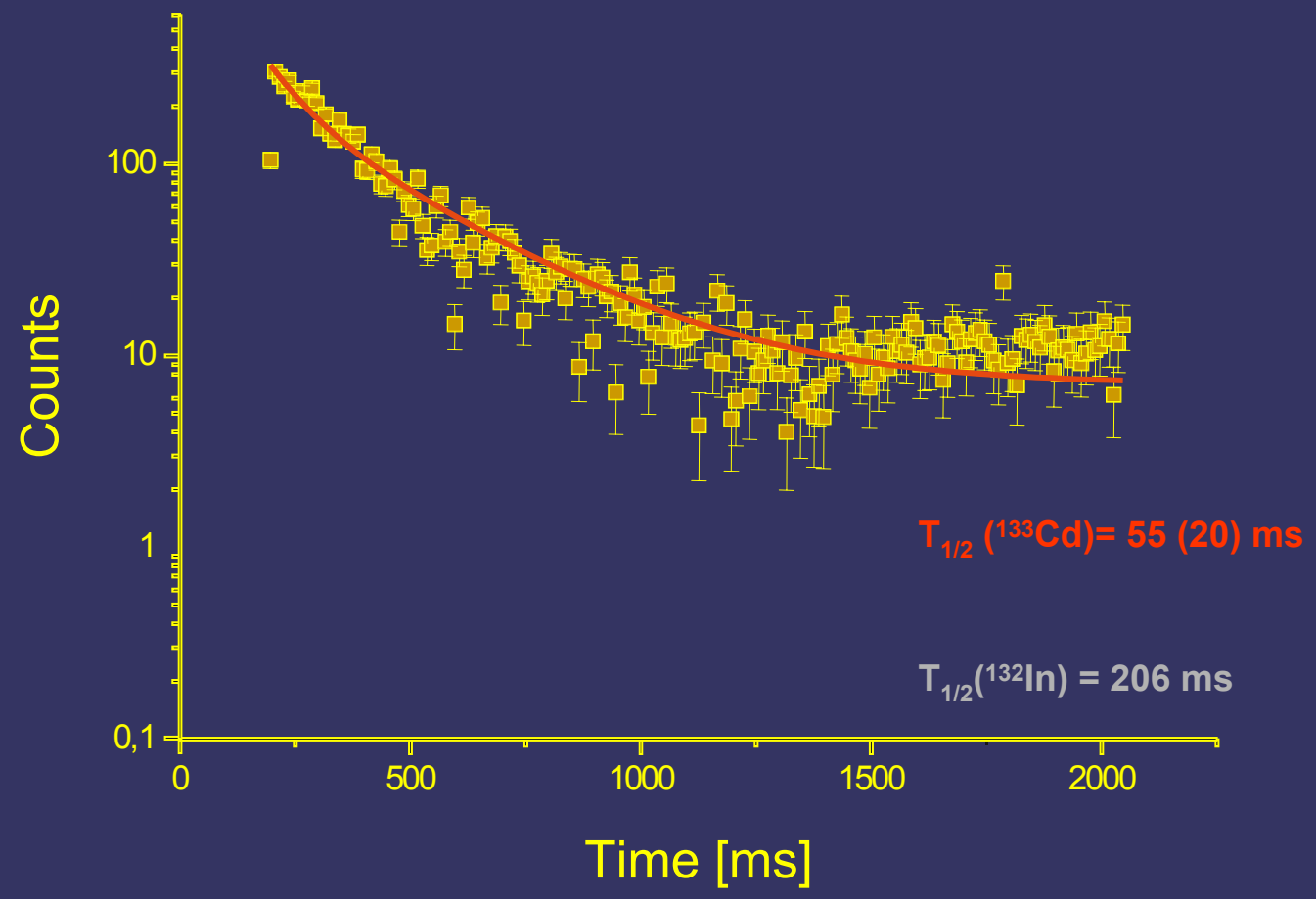
Some Results

^{129}Cd

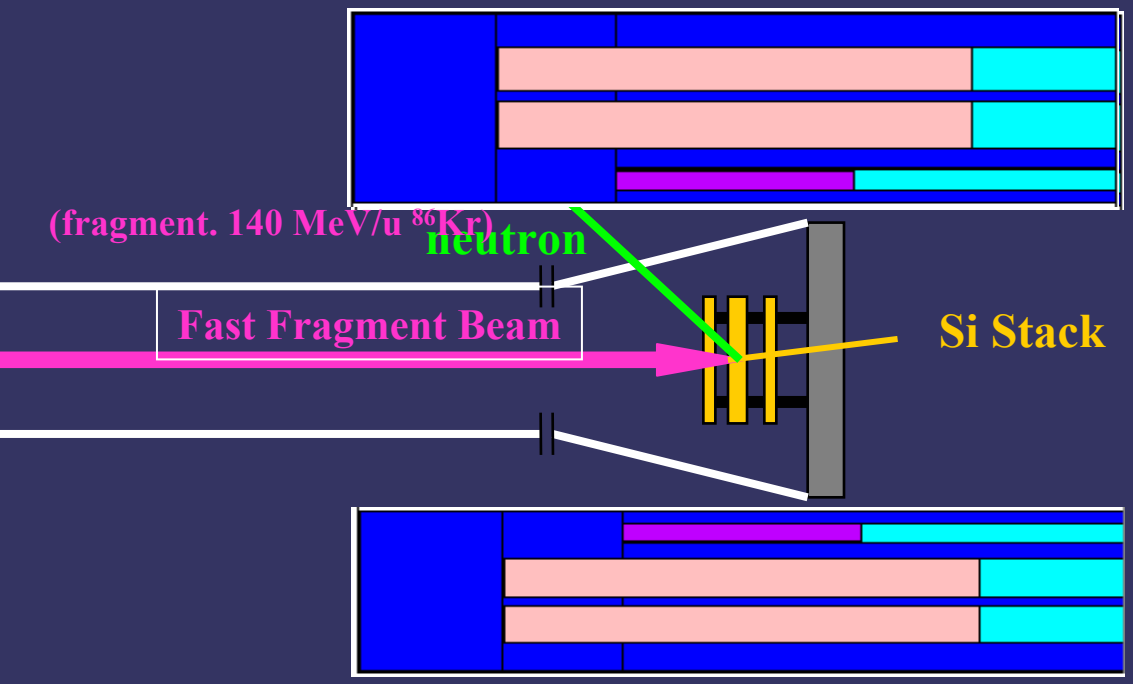


Some Results

^{133}Cd

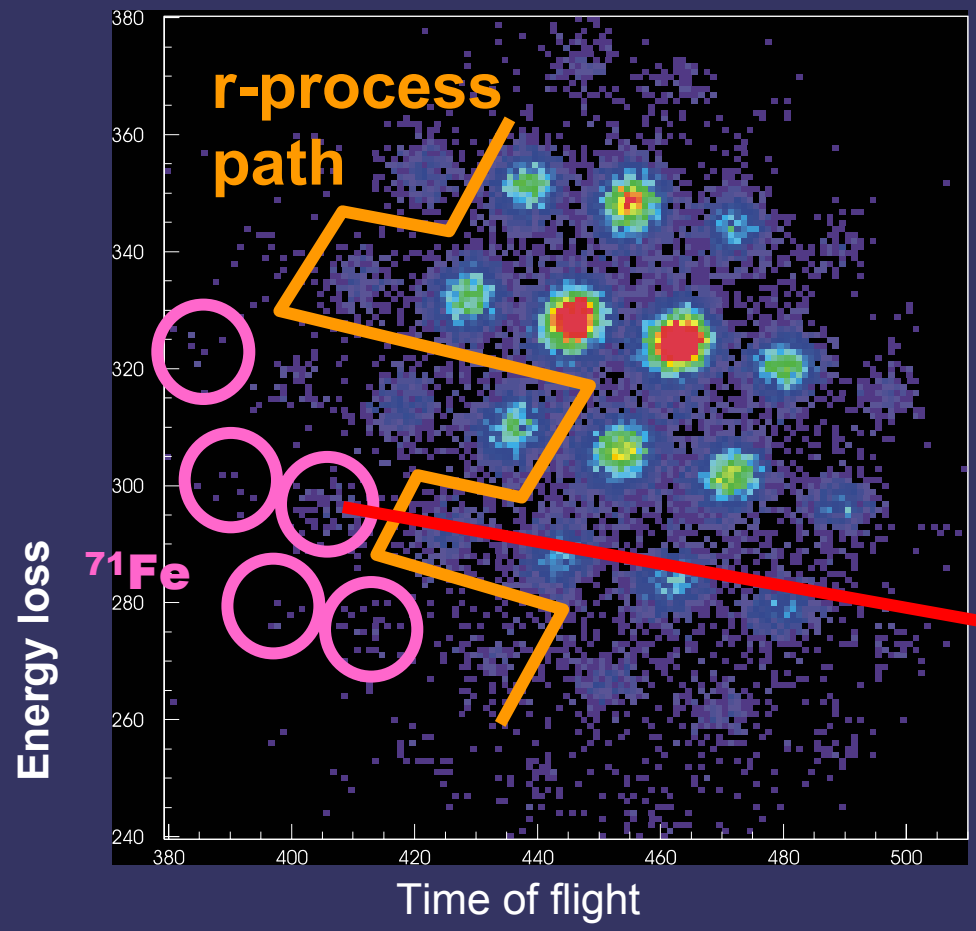


The NERO – detector at NSCL/ MSU

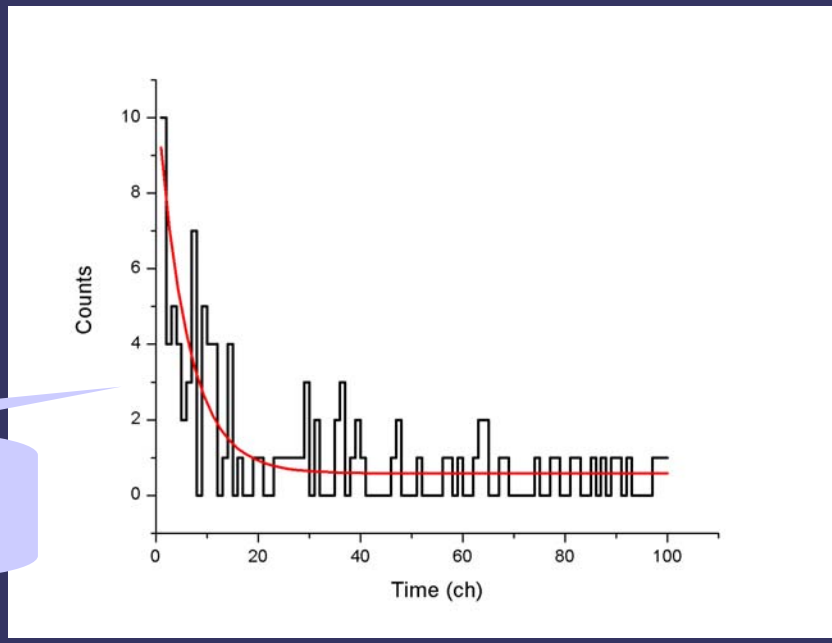


Mainz: K.-L. Kratz, B. Pfeifer
PNNL: P. Reeder
Maryland/ANL: W.B. Walters, A. Woehr
Notre Dame: J. Goerres, M. Wiescher
NSCL: **P. Hosmer**, R. Clement, A. Estrade, P.F. Mantica, F. Montes, C. Morton, M. Ouellette, P. Santi, A. Stolz

Some Results with NERO



- Fast RIB's:
  - no in-flight decay losses
  - cocktail beams
  - measure with low rates (>1/day)



Gated β-decay time curve (implant-decay time differences)

If I have a dream

- Build a neutron new long-counter with ca. 60 ^{3}He-poportional counters. (ca. 200 k $)
  - different matrices for neutron gamma-coincidences.
  - individual preamplifiers (could be home built), (ca. 10 k $)
  - digitalization with XIA-**d**igital-**G**amma-**F**inder modules (priceless).
- The use of DGF for the experiment would enable to measure neutron-gamma coincidences.
  - special sorting software was to be developed.