Nuclei at the Limits
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IN-BEAM GAMMA-RAY SPECTROSCOPY OF TARGET FRAGMENTATION

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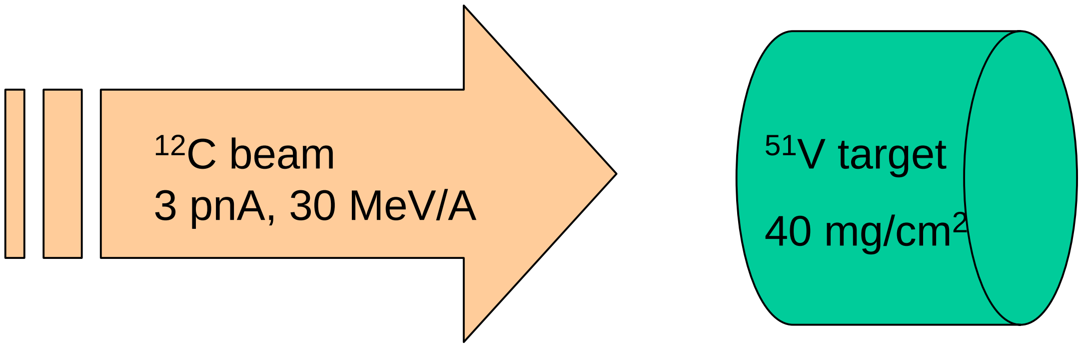
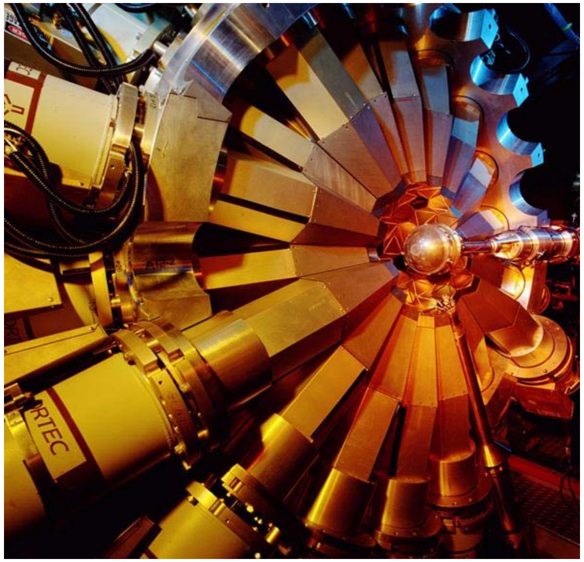
Motivation

- Fragmentation reactions (usually E/A > 50 MeV) produce neutron-rich nuclei but at relatively low angular momentum.
- In this work we use a target fragmentation reaction (E/A = 30 MeV) to study the feasibility of producing neutron-rich nuclei at higher spins.

Experimental set-up

Target fragmentation experiment with Gammasphere

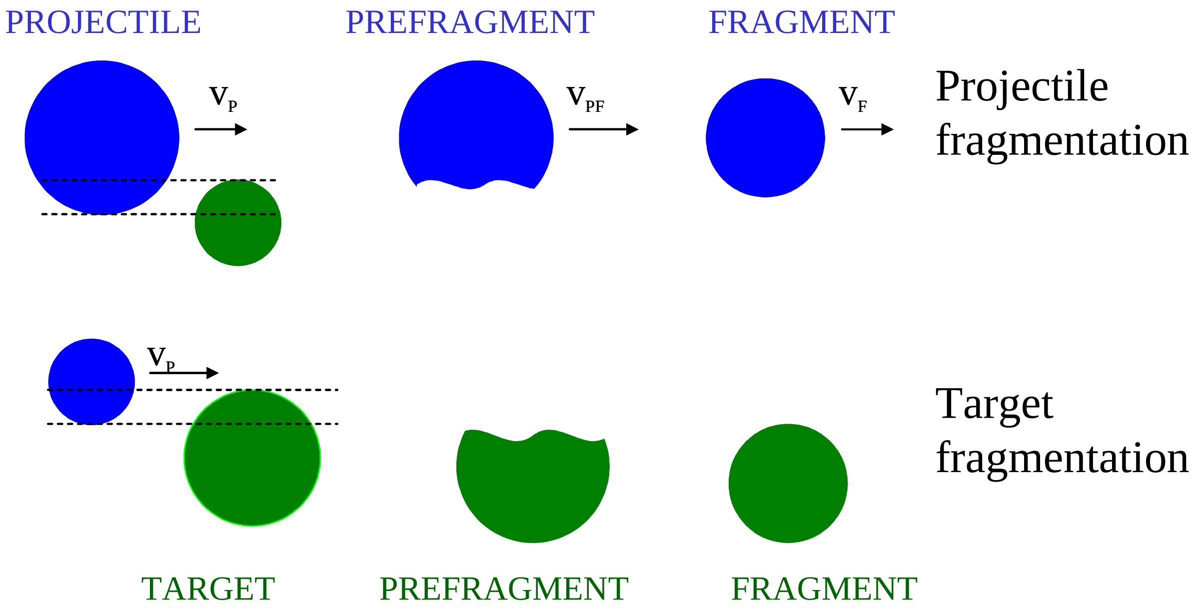




Gammasphere array

The experiment was performed with the Gammasphere array and the beam delivered by the 88-inch cyclotron at LBNL.

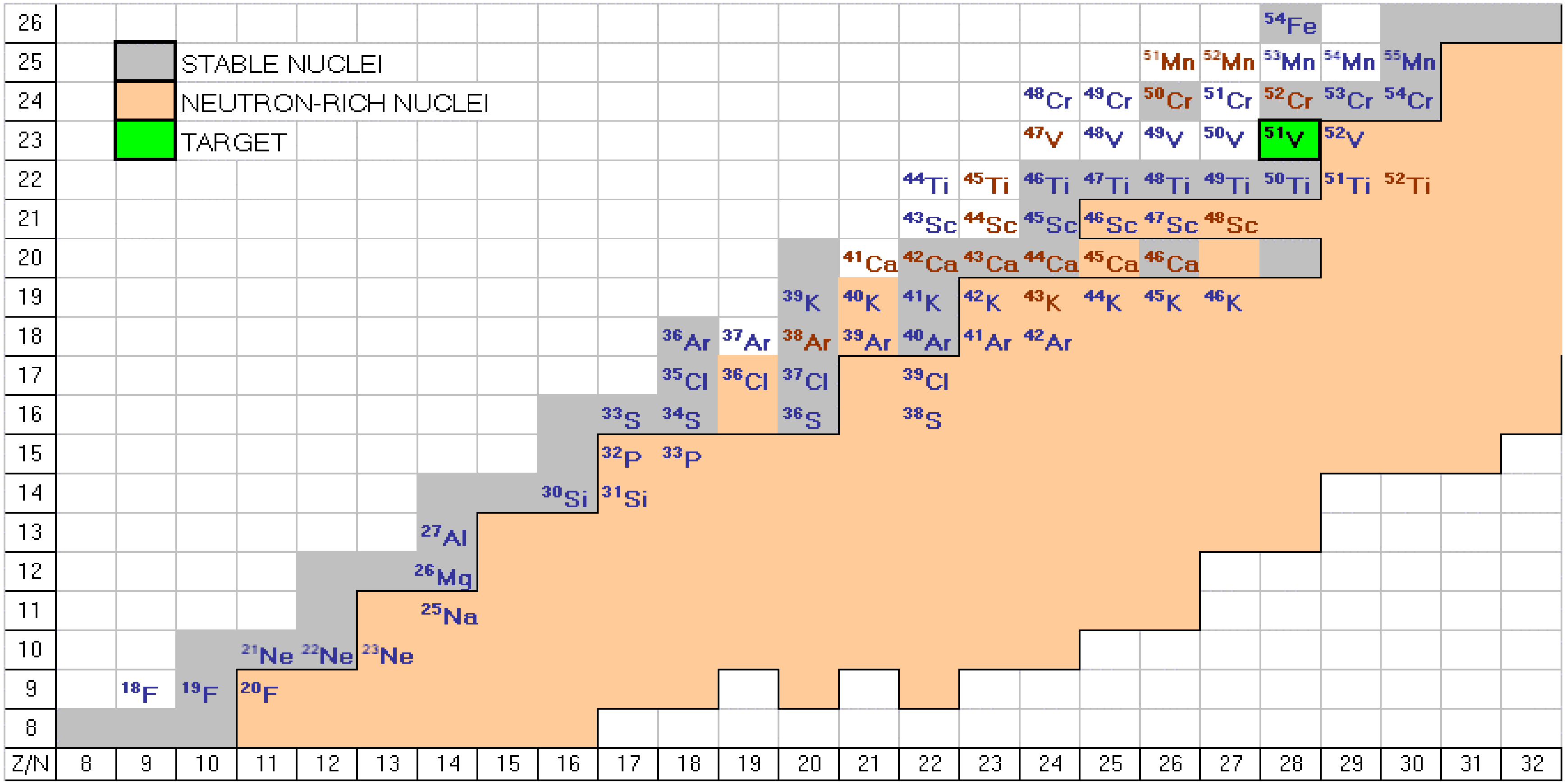
Target vs. projectile fragmentation



	Advantages	Disadvantages
Projectile fragmentation	Fragment separation is possible	Doppler broadening due to free flight of fragments, but correctable with the gamma array
Target fragmentation	No Doppler broadening when lifetimes are longer than the stopping time (1 ps)→ sharp gamma lines	Fragment separation not possible but fragments identified by the gamma spectrum

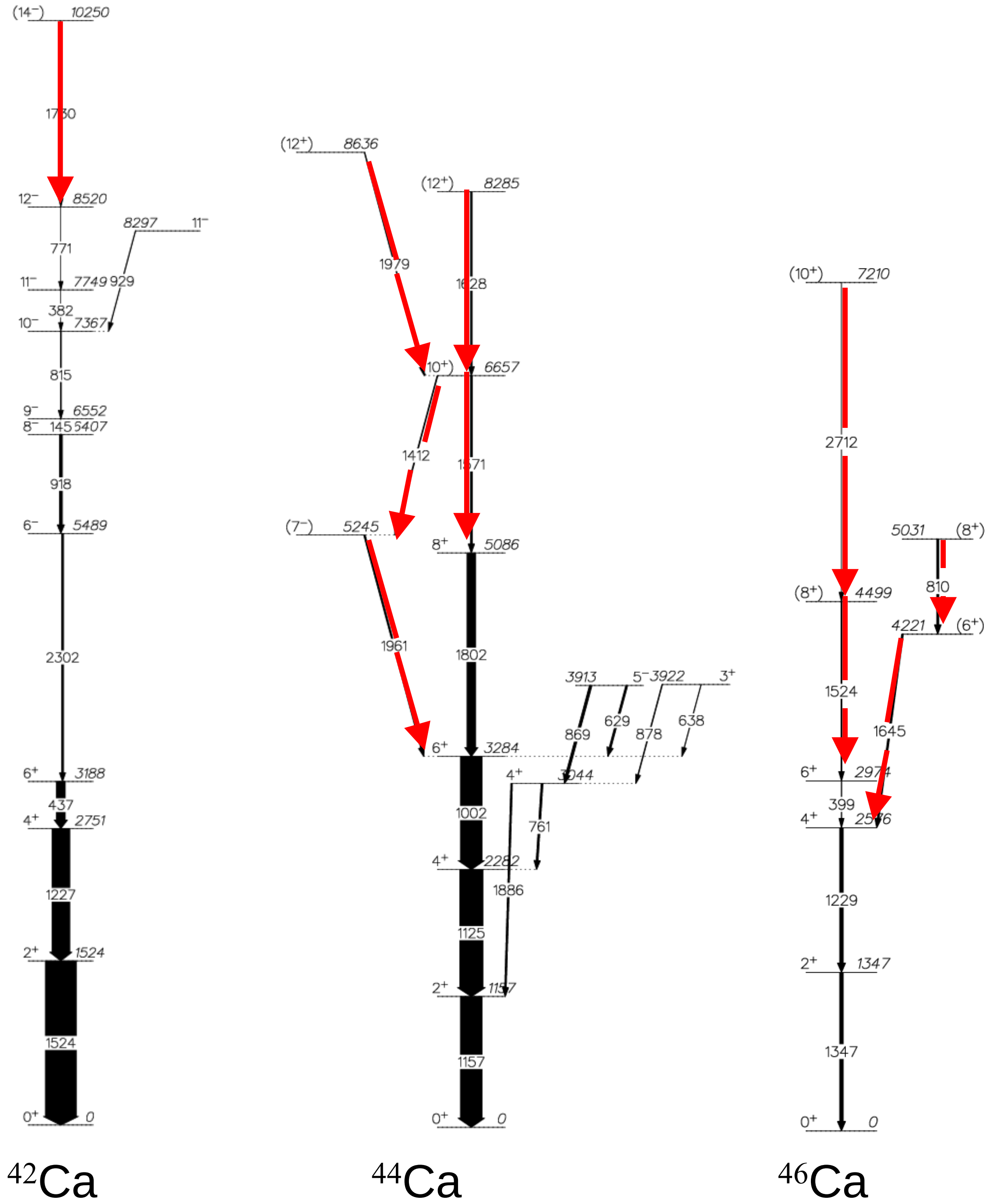
- Fragmentation at low energies [G. A. Souliotis *et al.*, "Enhanced production of neutron-rich rare isotopes in peripheral collisions at Fermi energies", PRL, 11 July 2003, 022701-1]
- Fragmentation of ^{86}Kr at 25 MeV/A on targets of neutron-rich ^{124}Sn and ^{64}Ni

Experimental product distribution



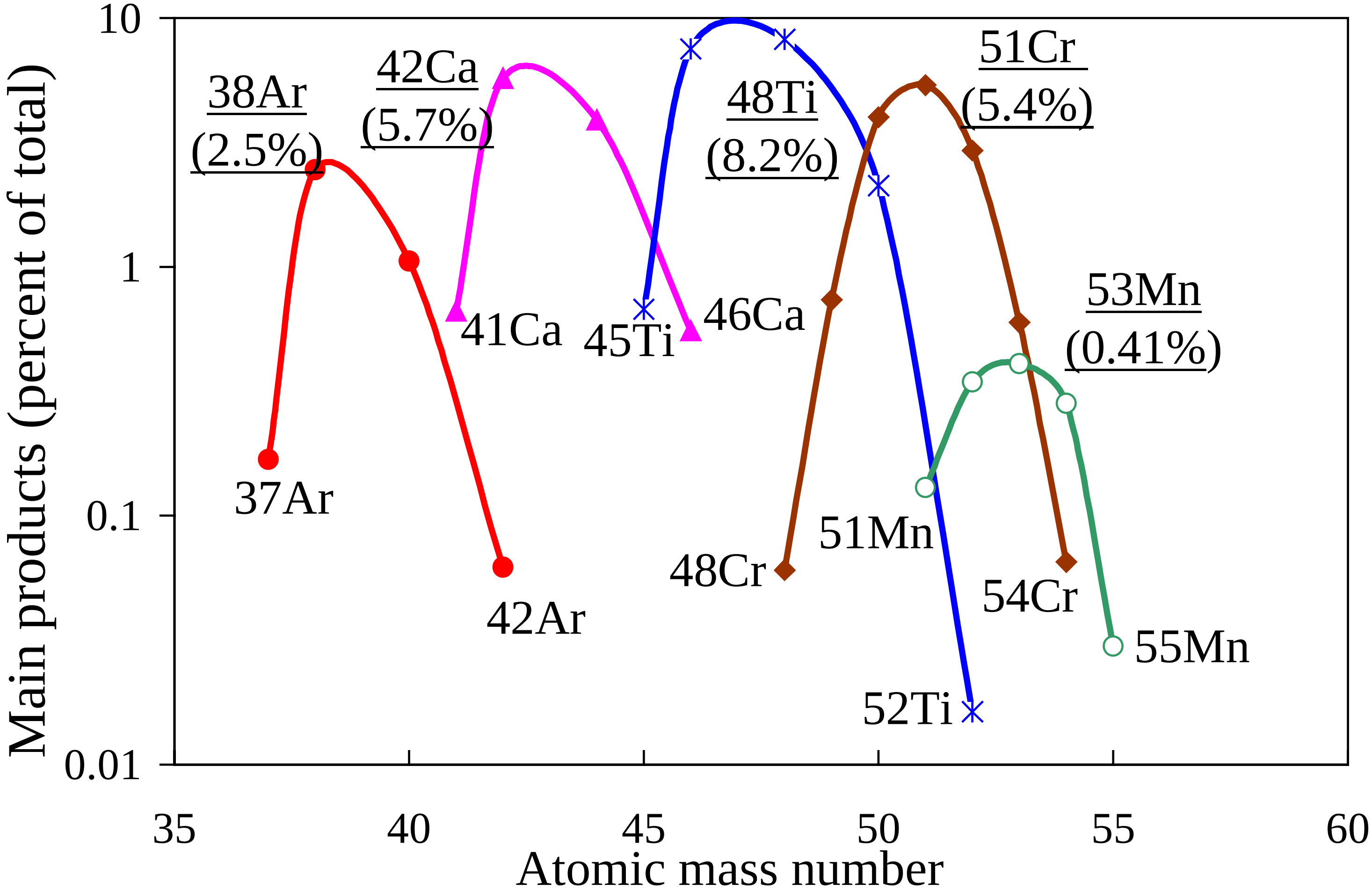
New gamma-ray transitions found in:
^{38}Ar, ^{41,42,43,44,45,46}Ca, ^{45,52}Ti, ^{50,52}Cr,
^{43}K, ^{44,48}Sc, ^{47}V, ^{51,52}Mn

Gamma-ray spectroscopy analysis



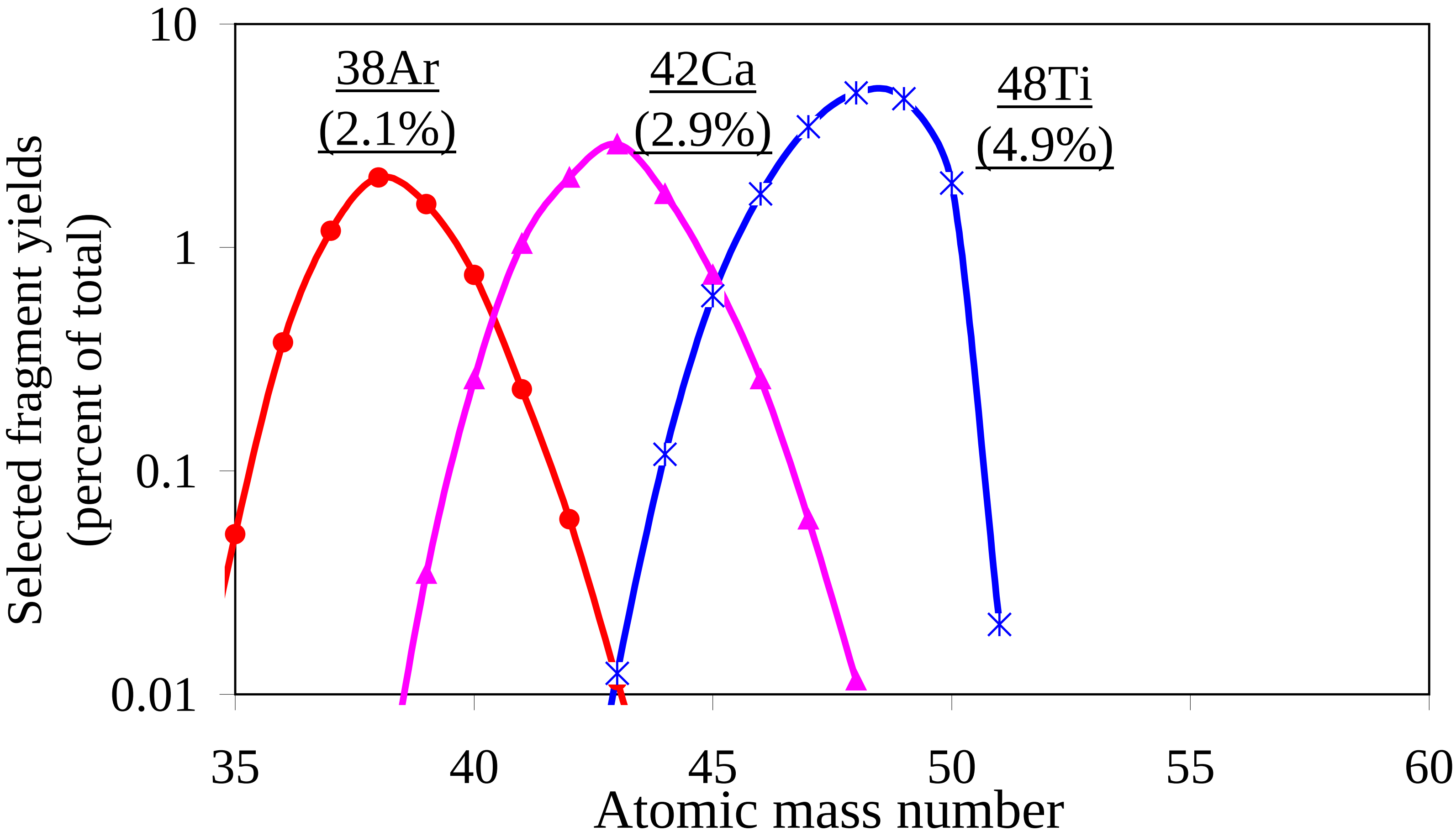
The spectrum of <3 MeV gamma rays emitted within ~100 ns of the beam burst was analyzed using double and triple gamma-ray coincidences to identify the product nucleus from which they were emitted. The intensity of these coincidences provides the basis for determining the yields of different product nuclei.

Experimental product yields



Product yield predictions from the LISE code

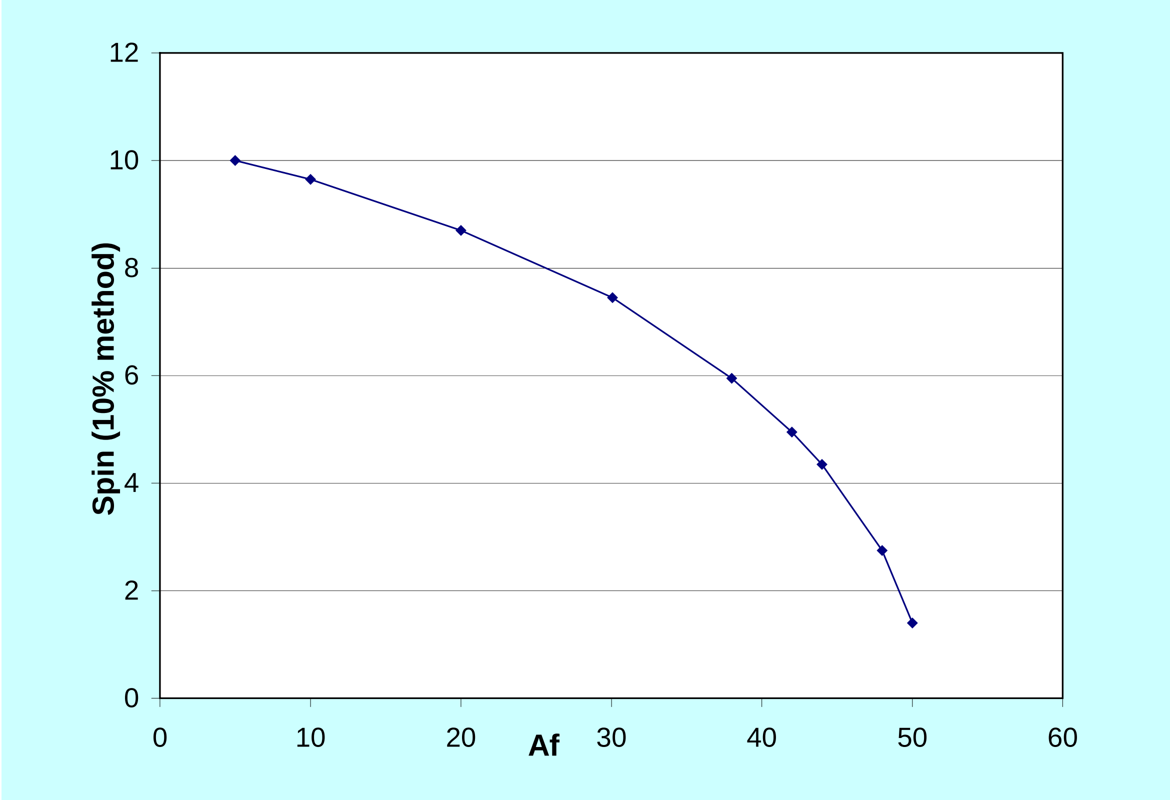
(based on abrasion-ablation model of pure fragmentation)



LISE code [Bazin *et al.*, NIMA 482, 307-327 (2002)]

Predicted spin of ^{51}V target fragments
(model based on pure fragmentation)

• In [Pfützner et al., PRC 65, 064604, 2002] an analytical model to predict spin of fragments is presented. The probability of populating a given spin J (P_J) is given as a function of A of the fragment, projectile and target (A_f, A_p, A_t, respectively).



$$P_J = \frac{2J+1}{2\sigma_f^2}\exp\left[-\frac{J(J+1)}{2\sigma_f^2}\right]$$

$$\sigma_f = \left\langle j_z^2 \right\rangle \frac{(A_p - A_f)(\nu A_p + A_f)}{(\nu+1)^2 (A_p - 1)}$$

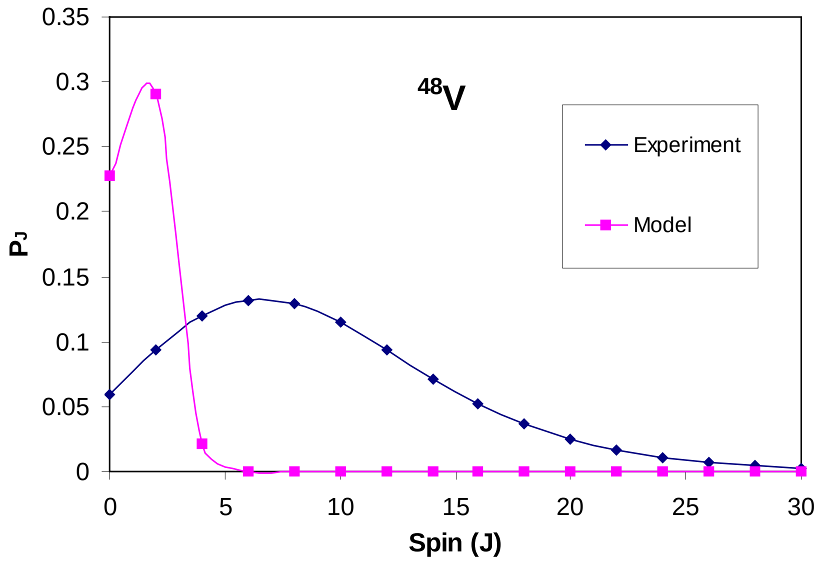
$$\left\langle j_z^2 \right\rangle = 0.16\, A_p^{2/3}\left(1 - \frac{2}{3}\beta\right)$$

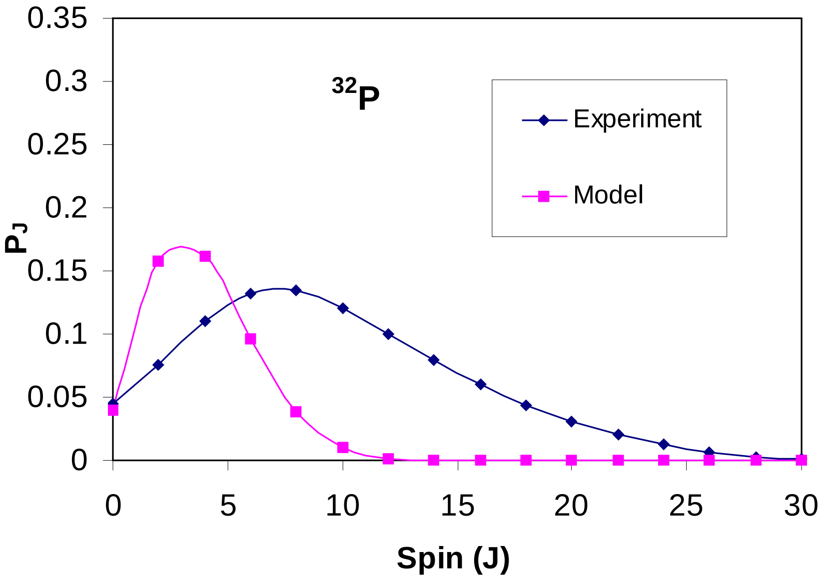
• This figure represents the maximum spin of each fragment depending on its mass number A_f

• Smaller fragments achieve higher spins

Experimental and model spin distributions

- The experimental data on spin populations do not match the pure fragmentation model [Pfützner]
- Discrepancies are larger for the higher mass fragments.





Response functions

Distribution M → N(K)

I = 2 * (M-4) + 1 * 4

I = 2M-4

Conclusions

When experimental results are compared to predictions from pure fragmentation:

- Product distribution:
  - LISE code predicts same N/Z of isotopic yield peaks as experiment
- Yields:
  - LISE code predicts slower rate of increase of yields with increasing A of fragment.
- Spin:
  - As with yields, discrepancies are larger for higher mass fragments

Neither spins nor yields can be modeled by pure fragmentation → other reaction mechanisms taking place at 30 MeV/A

Future work

- Complete gamma-ray spectroscopy analysis
- Experimental product yields are being compared with more comprehensive reaction models: AMD model by A. Ono [Ono et al., PRL 68(19), 2898 (1992)]
- Complete analysis of product spin population