The Joint Institute for Nuclear Astrophysics

r-process experimental campaign at NSCL

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Astrophysical context

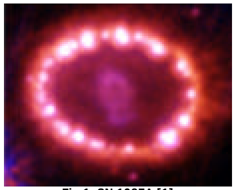


Fig.1: SN 1987A [1]

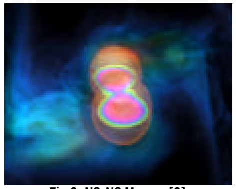


Fig.2: NS-NS Merger [2]

The rapid neutron capture process (r-process) synthesizes roughly 50% of all heavy elements past the Fe-peak and all of the actinides observed in the solar system. While the site of the r-process remains unknown – the high entropy shell surrounding a proto-neutron star left behind a core collapse supernova (Fig.1) and, to a lesser degree, neutron star mergers (Fig.2) being currently the most promising ones – there is hope that more detailed knowledge of the properties of nuclei far from stability can help us to constrain the astrophysical scenario in the future.

Experiments aimed to study the nuclear structure of neutron-rich nuclei far from stability are crucial for understanding the r-process, as well as for identifying its sites.

Motivation

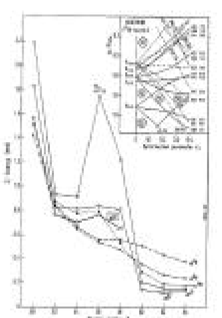


Fig.3: Systematics of the E(2+) of heavy $_{36}$Kr to $_{46}$Pd isotopes [3]. The inset shows the Nilsson single particle levels of $_{40}$Br as a function of quadrupole deformation.

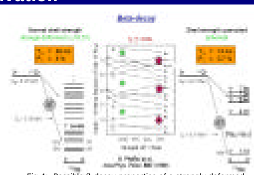


Fig.4: Possible β-decay properties of a strongly deformed ^{110}Zr (left) and a spherical, double semi-magic ^{110}Zr with "quenched" shells (right).

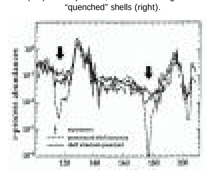


Fig.5: Global r-process abundance fits for the ETFS-I [4] and EFTS-Q (shell quenching) mass models [5].

In this context, a JINA/VISTARS r-process campaign was launched at the NSCL of MSU in the 2005 fall. The purpose of the campaign was to measure the β-decay half-lives and P_n-values of different neutron-rich nuclei in order to investigate –first– the region between the N=56 sub-shell closure and the "sudden onset of deformation" at N=60 around the A=100 region (Fig.3), and –second– the "new shell structures" around the possible local, spherical double sub-shell closure at Z=40, N=70 (Fig.4), which may help clarify the origin of the calculated r-process abundance deficiencies around A=110 (Fig.5). Moreover, the two regions explored in these experiments included some important r-process "waiting-point" nuclei.

Performance

The neutron-rich nuclei to be investigated were produced at the NSCL with the Fragmentation reaction ^{136}Xe @ 120Mev/u + Be in inverse kinematics.

The forward emitted fragments, including the species to be measured, were separated and identified with the zero-degree in-flight separator A1900 [6] (Fig.6)

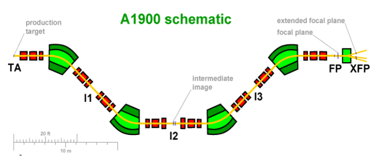
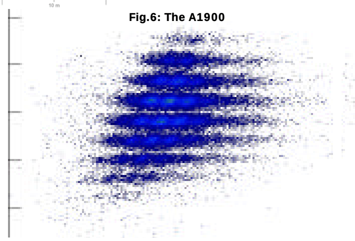


Fig.6: The A1900

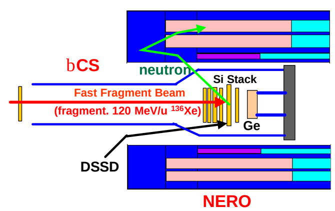


A1900:

(Dp=±2.5%; dW=8 msrd; Br_{max}=6Tm)

- Separation of nuclei by measuring ToF *vs.* DE (Fig.7).
  - *ToF: plastic scintillators at I2 and FP.*
  - *Energy-loss (DE) signal: Silicon PIN detector at experimental vault.*
- Identification of nuclei done by measuring gammas emitted by ms-isomers.
- Transversal positions were measured with a plastic scintillator at I2 in order to correct position-dependence of ToF.
- The DE signals were corrected from ToF-dependence.
- Primary-beam charge state contaminants were blocked with slits and a new blocking finger at I1

The nuclei transmitted through the A1900 were transported into the implantation setup (Fig.8) allocated in the N3 vault.

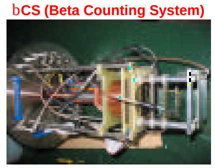


Measure:
- b-decay half-lives
- Branching for b-delayed neutron emission

Detect:
- Implantation time and location (DSSD)
- b emission time and location (DSSD)
- b-delayed neutron coincidences (NERO)

Fig.8: Implantation setup: bCS [7] + NERO [8]

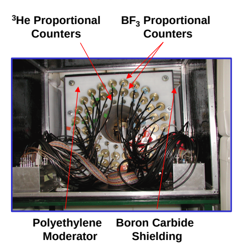
bCS (Beta Counting System)



4 Si PIN: Energy-loss
1 DSSD: Trigger, implantations, b-decays
- 4 cm x 4 cm active area
- 1 mm thick
- 40-strips in x and y → 1600 pixels

1 SSSD: Veto
1 Ge: spectroscopy

NERO (Neutron Emission Ratio Observer)



Preliminary results

Several μsec-isomers for particle identification were observed:

^{121}Pd (135keV), ^{123}Ag (714keV), ^{124}Ag (156keV), ^{125}Ag (685keV), ^{125}Cd (720keV, 743keV), ^{98}Y (120.9keV, 170.3keV)

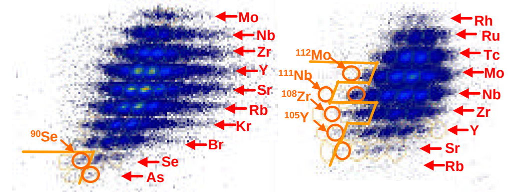


Fig.9: Nuclei measured in the r-process experimental campaign at NSCL. Nuclei with unknown half-lives are on the left of the orange line; r-process waiting-point nuclei are surrounded by circles

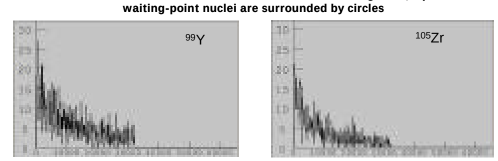


Fig.10: Two examples of b-decay curves measured for ^{99}Y (left) and ^{105}Zr (right).

New nuclei are shown below (r-process waiting points in red color).

^{88}Ar, ^{90}Se, ^{91}Se ^{105}Y, ^{106}Zr, ^{107}Zr, ^{108}Zr, ^{111}Mo, ^{112}Mo

Analysis in progress:

- Extract half-lives: decay-curve fit, MLH (poor statistics)
- Extract P_n values for b-delayed n-emission
- Analyze possible gamma-decay lines

Conclusions and future perspectives

- Investigation of the nuclear structure of neutron-rich nuclei helps understand the r-process and determine its site(s).
- An r-process experimental campaign was performed at the NSCL in order to investigate nuclear structure of neutron-rich nuclei by measuring β-decay half-lives and P_n-values.
- New primary-beam charge-state blocking system at A1900 has been successfully tested.
- Nine neutron-rich nuclei around ^{90}Se and ^{107}Zr with unknown half-lives were measured, including four waiting-points.
- Half-lives and P_n-values of these nuclei are presently being analyzed.
- Results from the present experiments will provide information about the sudden onset of deformation at N=60, A=100, and the possible new spherical sub-shell closure at Z=40, N=70.

References

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[8]: G.Lorusso et al., this poster session (NERO)

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