Drip-line Studies with Past and Present NSCL Fragment Separators

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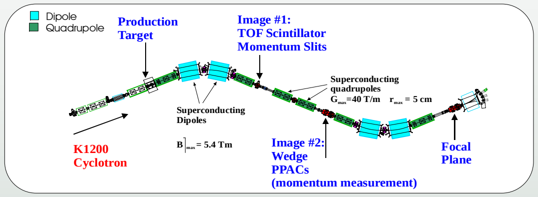
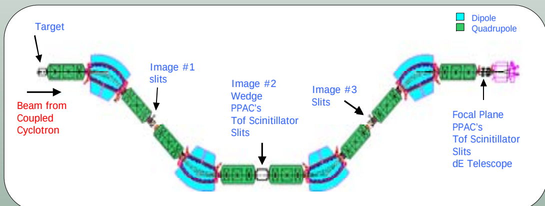
A1200
Operation dates: 1990-1999



A schematic layout of the A1200, the first projectile fragment separator constructed with super-conducting magnets. The A1200 was placed immediately after the K1200 cyclotron and was able to deliver rare-ion beams to all of the experimental vaults.

A1900
Operation dates:2001-Present



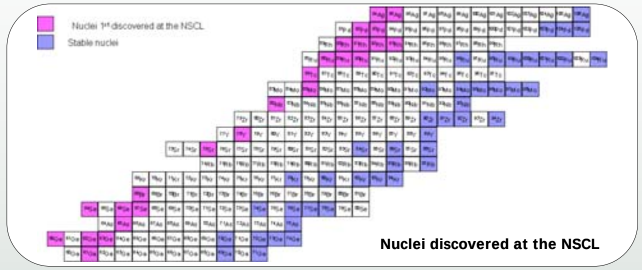
The schematic layout of the A1900. The device has three dispersive images compared to two in the A1200 which allows for more flexibility in fragment selection. The device features sixteen sets of super-conducing sextupole and octupole magnets for aberration corrections.

The NSCL produces rare-ion beams by fragmentation of relativistic heavy-ion beams followed by rapid separation of the products. The first separator called the A1200 was matched to the magnetic rigidity of the cyclotron facility and was the backbone of the experimental program during the 1990's. In 1999, the A1200 was replaced with a redesigned separator, the A1900. This new separator had increased resolving power and momentum acceptance. This was made possible in part by the replacement of the 22.5º dipoles with 45º dipoles. The optical parameters of the A1200, A1900 and next generation fragment separator for RIA are listed below.

Ion-optical parameters

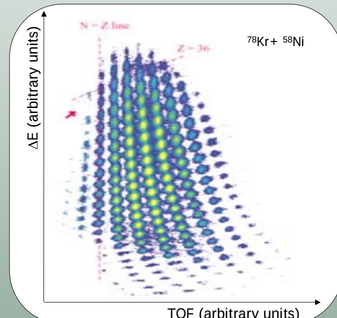
Parameter	A1200	A1900	RIA* (high resolution)
dΩ (msr)	0.8-4.3	8.0	8-10
dp/p (%)	3.0	5.5	6
Resolving power	2400	2915	3000
Magnification (M_x) at image 2	0.7	2.04	
Magnification (M_y) at image 2	3.0	0.75	
Dispersion (cm/%) at image 2	1.67	5.95	
Total length (m)	22.0	35.0	
Quadrupole gradient (kG/cm)	3.5	2.3	
Quadrupole inner diameter (cm)	10	20 40**	
Dipole full vertical gap (cm)	5	9	
Maximum Rigidity (Tm)	5.4	6	10

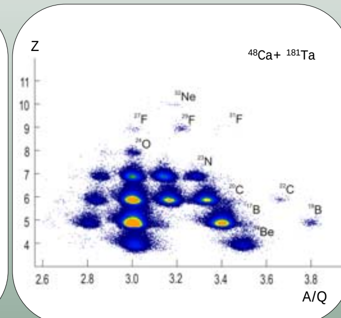
* Preliminary design specifications ** The two quadrupoles nearest to image 2



An important feature of the rapid separation of projectile fragments at the NSCL is the production and identification of nuclei near the limits of nuclear stability. The neutron-deficient nuclei discovered at the NSCl through fragmentation are shown in magenta.

Particle Identification

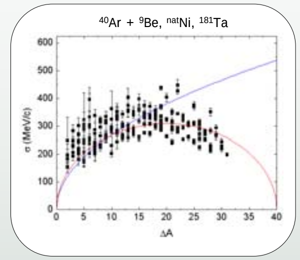




Fragmentation products can be identified from simultaneous measurements of the time of flight (TOF) and the energy loss (ΔE) in a detector. The energy at which these products leave a target and enter the separator determines the TOF to the focal plane telescope. The figure on the left displays a ΔE vs. TOF distribution for a few hundred products from the reaction of 75MeV/u ^{78}Kr beam on a ^{58}Ni target. The red arrow indicates the absence of ^{69}Br. The figure on the right shows the calculated values of atomic number (Z) vs. mass to charge (A/Q) for neutron-rich nuclei produced from the reaction of 140MeV/u ^{48}Ca beam with ^{181}Ta. The A/Q ratios are calculated based on the magnetic rigidities and TOF of the fragments, while Z is calculated from the TOF and $\Delta E^{1/2}$.

Systematic Observables:

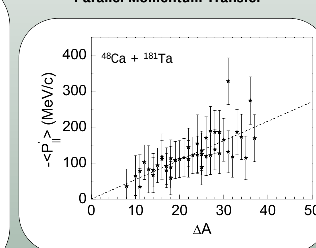
Parallel Momentum Width



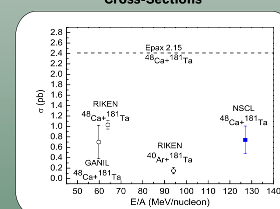
Fragments that have less than ½ the projectile mass provide insight into the reaction mechanism. Goldhaber predicted that nucleons are removed from the nucleus simultaneously during the projectile-target interaction leading to the observed momentum distributions, while Morrissey suggested that the nucleons are removed at random intervals during interaction. Shown in red and blue in the figure to the left are the predicted widths (σ's) of the momentum distribution by Goldhaber and Morrissey, respectively, from the reaction of ^{40}Ar in ^{9}Be, ^{nat}Ni, and ^{181}Ta plotted as a function of mass loss (ΔA). The figure suggests that the nucleons in the projectile are removed instantaneously during the interaction and that the widths of the distributions are independent of the target.

Parallel Momentum Transfer

Momentum is transferred to colliding nucleons as the projectile and target interact. These nucleons may gain enough energy to break free of the nucleus and escape. The average value of the transverse momenta of a set of fragments measured one at a time is zero by symmetry. The parallel momentum transfer was found to be proportional to the number of removed nucleons. The figure on the right shows the linear trend in the parallel momentum transfer from the projectile in its rest frame with a slope of approximately 6 MeV/c/u.

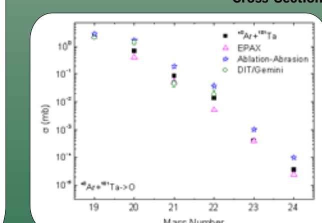


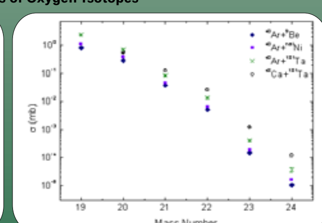
Cross-Sections



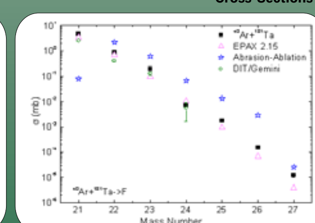
The location of the neutron drip-line of fluorine is unknown. The most neutron rich isotope, ^{31}F, was observed at RIKEN, GANIL and the NSCL. Shown in the figure to the left are the measured cross-sections of ^{31}F produced from the reaction of ^{48}Ca in ^{181}Ta plotted as a function of projectile energy compared to the predicted value by EPAX 2.15 (dash line). The figure shows that in the range of 60-130 MeV/u, the cross-section to produce ^{31}F is independent of the projectile's energy.

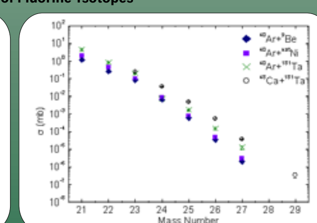
Cross-Sections of Oxygen Isotopes





Cross-Sections of Fluorine Isotopes





The separators can be used in stand alone mode to measure various properties of the fragments at the focal plane, or as is more common, the products can be sent to any of the adjoining vaults. Shown above are comparisons of cross-sections of the oxygen and fluorine isotopes produced by 140MeV/u ^{40}Ar and ^{48}Ca beams in ^{9}Be, ^{Nat}Ni, and ^{181}Ta targets. The results obtained using the A1900 are compared to three theoretical models: Ablation-Abrasion, Epax 2.15 and a Deep Inelastic Transfer code coupled to Gemini (DIT/Gemini). The left and middle right figures shows an agreement to within a factor of three between the measured cross-sections of neutron-rich oxygen and fluorine produced from the reaction of ^{40}Ar+^{181}Ta with DIT/Gemini and EPAX 2.15.

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