FRIBS: Radioactive Ion Beams at LNS by Projectile Fragmentation

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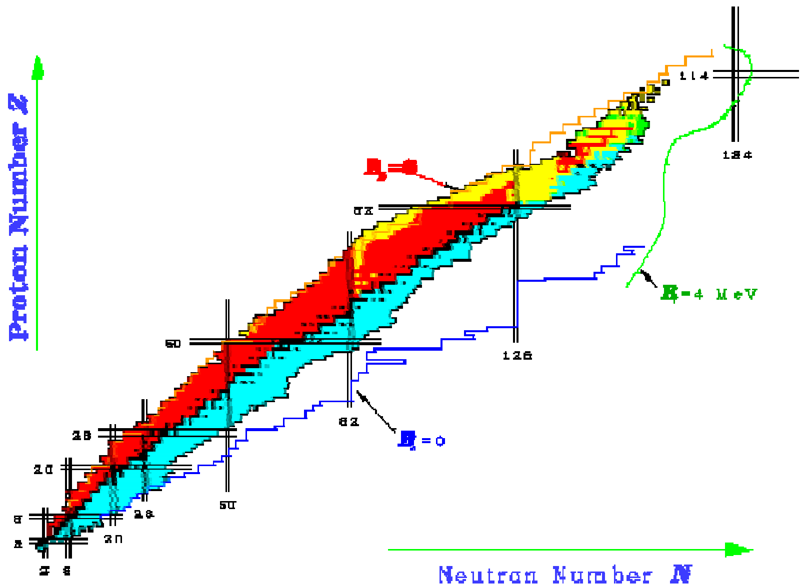
Abstract

Preliminary results on radioactive ion beams produced by means of projectile fragmentation at intermediate energy at the LNS are presented. ^{12}C + ^{9}Be (500 μm) at 62 A MeV and ^{40}Ar + ^{9}Be (500 μm) and ^{58}Ni + ^{27}Al (100 μm) both at 40 A MeV reactions were studied. Two similar detector arrays were placed at the final focus of the magnetic fragment separator and at the entrance of the Ciclope scattering chamber to measure production and transmission yields. Several isotopes were identified and their rates were measured and compared with the LISE predictions. The clean ion identification and their rates open the possibility of using such ions as tagged beams for nuclear reactions and/or spectroscopy studies at the LNS.

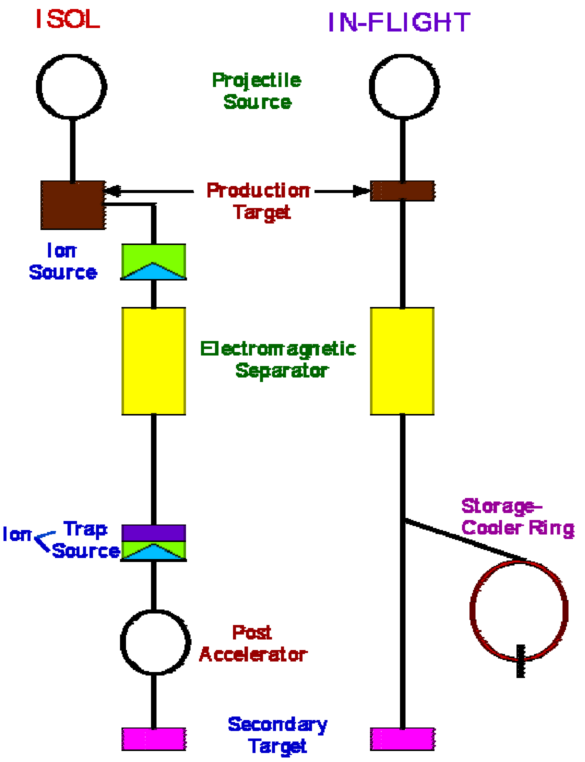
1 INTRODUCTION

The study of exotic nuclei, far from the valley of beta stability, represents an important challenge for nuclear physics.



Nuclear models must be improved in order to accommodate the new phenomena that have been unveiled by the recent experimental work. Prominent milestones are: the discovery of the heaviest chemical elements and the discovery of nuclear halos in the lightest neutron-rich nuclei. The consequent theoretical effort to describe these experimental results has considerably advanced our understanding of this phenomena. The experimental mapping of the nuclear shell structure far from stability, reaching in some cases the neutron or proton drip lines is one of the future research line. Although we are still far from having a unified theoretical description valid far from stability, important progress has been made.

Today, our knowledge about nuclei, is restricted to about 2500 of the potentially existing 6000 combinations of protons and neutrons (see Figure 1).



Moreover the possibility to explore the isospin degree of freedom dependence both of reaction dynamics (neck formation, isospin diffusion) and of nuclear calorimetry (nuclear caloric curve, specific heat, latent heat, limiting temperature) to better determine the I3 term in the nuclear equation of state, claims for intermediate energy RIBs. The two basic ways of making radioactive beams (see figure 2), offer unique research opportunities in nuclear physics and nuclear astrophysics. It is important to note that the two techniques address two different energy regimes with a very small overlap around 25 AMeV. They thus are complementary. The ISOL method, which was the first to be developed, uses the radioactive ions produced by the beams of a primary accelerator or by the neutrons from a nuclear reactor. The target/catcher arrangement stops the recoils and the activity is transported from there into an ion-source (diffusion, jet transport...). After the extraction of the desired charge-state from the ion-source, and mass-separation, the radioactive species can be used for experiments at low energy (a few tens to a few hundreds of keV) or may be *re-accelerated* by a *second* accelerator.

Radioactive beams of energies above 20 AMeV have so far been made at heavy-ion accelerators using in-flight separation of the recoils; a technique which relies on the forward focusing present in peripheral nuclear reactions at intermediate energies.

The possibility of producing radioactive ion beams (RIB) has become nowadays a reality in several laboratories [1]: GSI, GANIL, NSCL-MSU, RIKEN, and JINR Dubna produce relativistic and intermediate energy RIB by projectile fragmentation (IN-FLIGHT method), Louvain-le Neuve, SPIRAL-GANIL, ISOLDE-CERN, TRIUMF-Vancouver, ORNL Oak Ridge and ANL Argonne, low energy RIB by the ISOL method. New projects are at present under development: RIA (USA), ARENAS(Japan), EURISOL(Europe) based on both techniques. At the LNS the EXCYT [2] (ISOL based) project will be commissioned in 2004 but the ETNA [3] (IN-FLIGHT) one was left for technical reasons. However, since the present extraction line of the Superconducting Cyclotron was configured as a fragment separator ,we have tested, recently, the possibility of using it to produce tagged radioactive beams at intensities useful for experiments.

2 THE FRAGMENT SEPARATOR

Fig.1 shows a drawing of the Fragment Separator and Table 1 summarizes a comparison with presently operating similar devices. It consists of two 45^{o} bending magnets D1 and D2, three quadrupole triplets Q1-Q3, Q4-Q6 and Q7-Q9, two sextupole correctors S4, S9 near quadrupoles Q4, Q9. There are two slits at the intermediate and achromatic foci, and a beam stopper after the bend D1. A degrader foil could be installed at the intermediate focus, however was not used in the present experiment. Larger solid angle and momentum acceptance will be achieved by replacing the present quadrupoles with larger ones (FRIBs in Table1).

The production targets were set in a rotating holder and, self supported ^{9}Be and ^{27}Al 500 and 100 μm tick respectively, were used. The dipoles current was scaled accordingly to the Bρ values calculated by the code LISE [4] self-consistently with respect to the values measured for the transmission of the primary fully stripped beam.

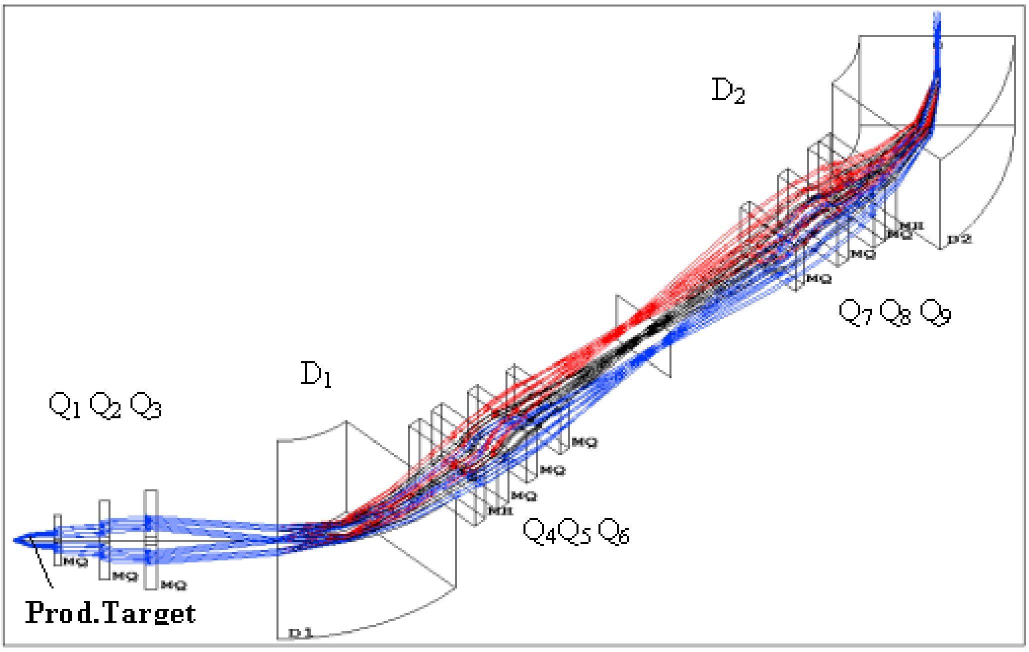


Fig.1:LNS Fragment Separator layout

Table 1: Fragment Separators Main Parameters.

	ΔΩ (msr)	ΔP/P (%)	R_p	MaxB**ρ** (Tm)	Length (m)
FRIBs	4.0	+/- 1.1	800-1500	4.0	23
Present	1.1	+/-0.65	1000	2.7	23
GANIL	1.0	+/-2.5	800	3.2	18
GSI	0.7-2.5	+/-1	240-1500	9-18	74
RIKEN	5.0	+/-3	1500	5.76	21
NSCL	0.8- 8	+/-1.5	700-1500	5.4	22
JINR	6.4	+/-1	4360	4.5	14.5

3 THE DETECTOR ARRAY

Two similar detector arrays were installed: one at the final focus of the fragment separator and the other at the entrance of the LNS Ciclope scattering chamber (see fig.2 and 3). They consist of:

- PPAC (4x 4 cm^2 active area, 40x40 wires , operated at 500 Volts and at 4 mbar of pentane between windows of Mylar 0.8 mg/cm^2 thick)
- Silicon detector 300 μm thick and 3×3cm^2 active area.(5x5 cm^2 in the Ciclope setup)
- Plastic scintillator 0.5 mm thick and 2.5×2.5 cm^2 active area.(CsI scintillator 6 cm long, 5x5 cm^2 in the Ciclope setup)

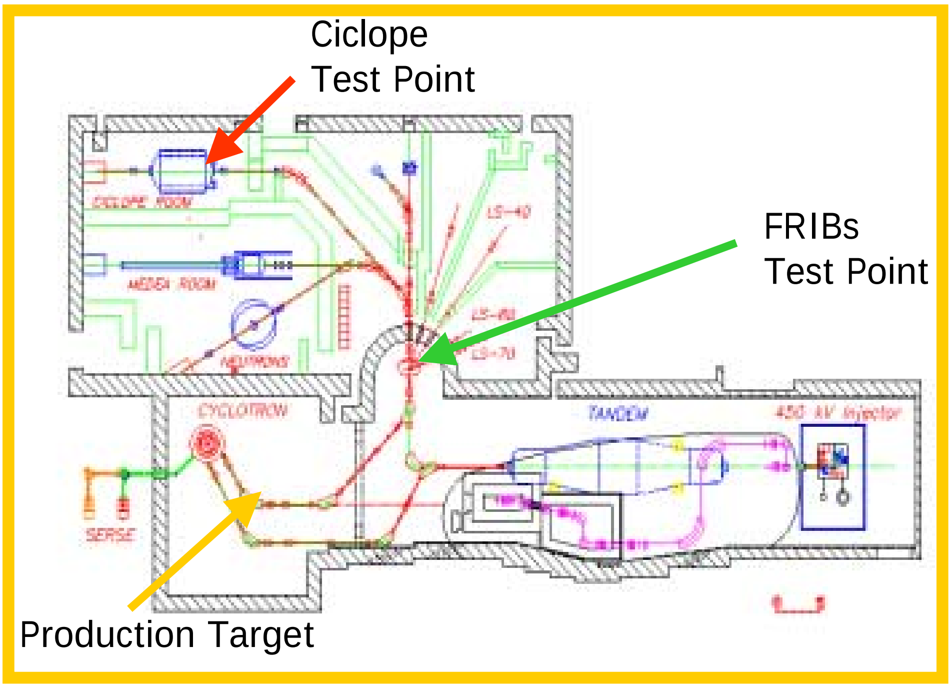


Fig.2: Location of the detectors.

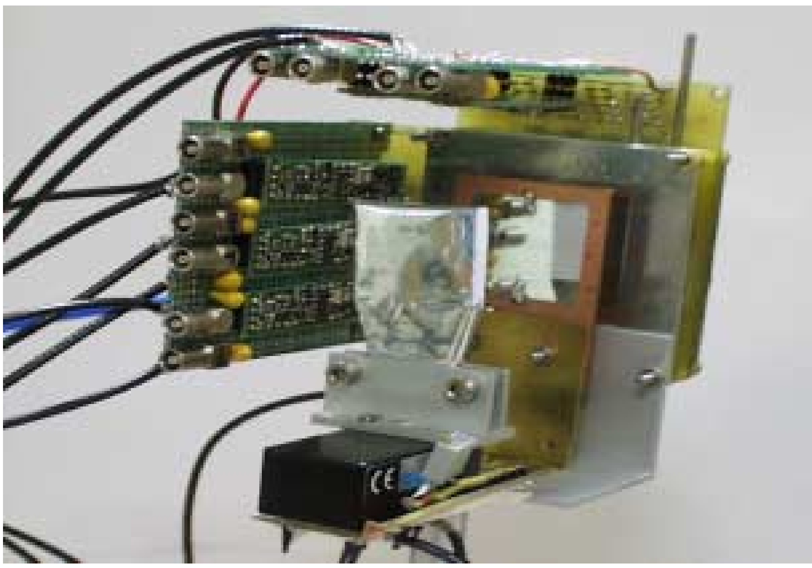


Fig. 3: Detectors array at the final focus of the fragment separator.

The silicon detectors were calibrated in energy both with a three peak alpha source and with O^{16} beams delivered by the Tandem at 50 and 113 MeV energies and by the energy loss of the primary beams as shown in fig.4.Scintillator detectors were calibrated through residual energy estimated from the energy loss in the silicon ones.

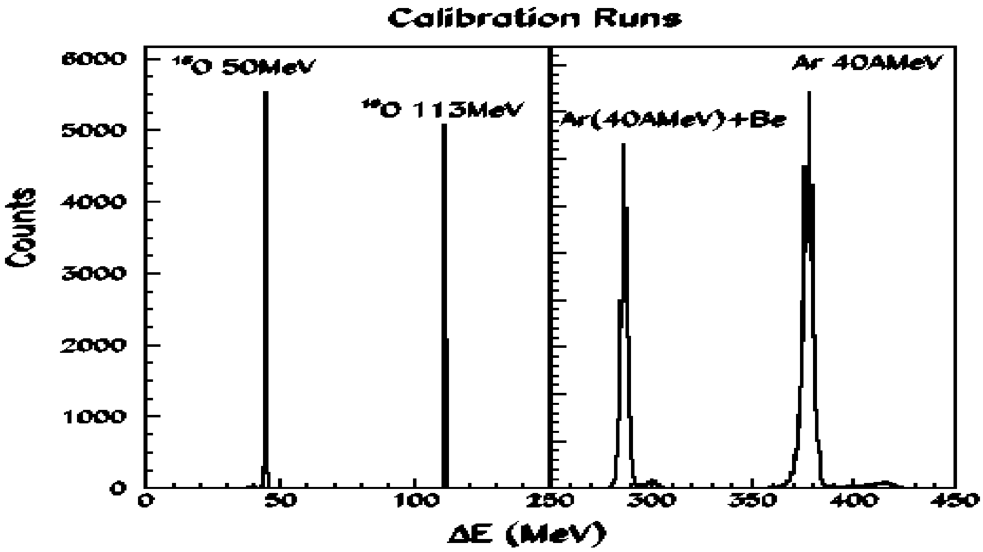


Fig.4: Silicon Detector Calibration by O^{16} Tandem beams and primary ^{40}Ar beam.

This detectors combination allows to measure energy, charge and positions of all the products, however, since we want to tag the ions without stopping them, only thin detectors must be used. Therefore we checked the possibility of identifying the products, event by event, by coupling the ΔE information from the silicon detector with the time of flight of the ion measured by the same detector with respect to the RF signal from the accelerator. Time resolution was in the order of 1.2 nsec.

4. RESULTS

Three different combinations of projectile and target were used: ^{12}C + ^{9}Be (500 μm) at 62 A MeV and ^{40}Ar + 9Be (500 μm) and ^{58}Ni + ^{27}Al (100 μm) both at 40 AMeV. Current intensities were typically set in the 100 epA range.

Fig.5 shows the energy loss in the silicon detector versus the time of flight of the products detected in the three reactions.Fig.6 shows energy loss versus residual energy in the thick detector for the ^{40}Ar and ^{58}Ni reactions. Several isotopes were well identified both in the ΔE-E plot and in the ΔE-ToF allowing an event-by-event tagging of the produced ion. Position diagnostic was achieved by the PPAC information. Beam spots of 9x21 mm^2 were measured at the Ciclope scattering chamber entrance, but no focusing was attempted (Fig 7).

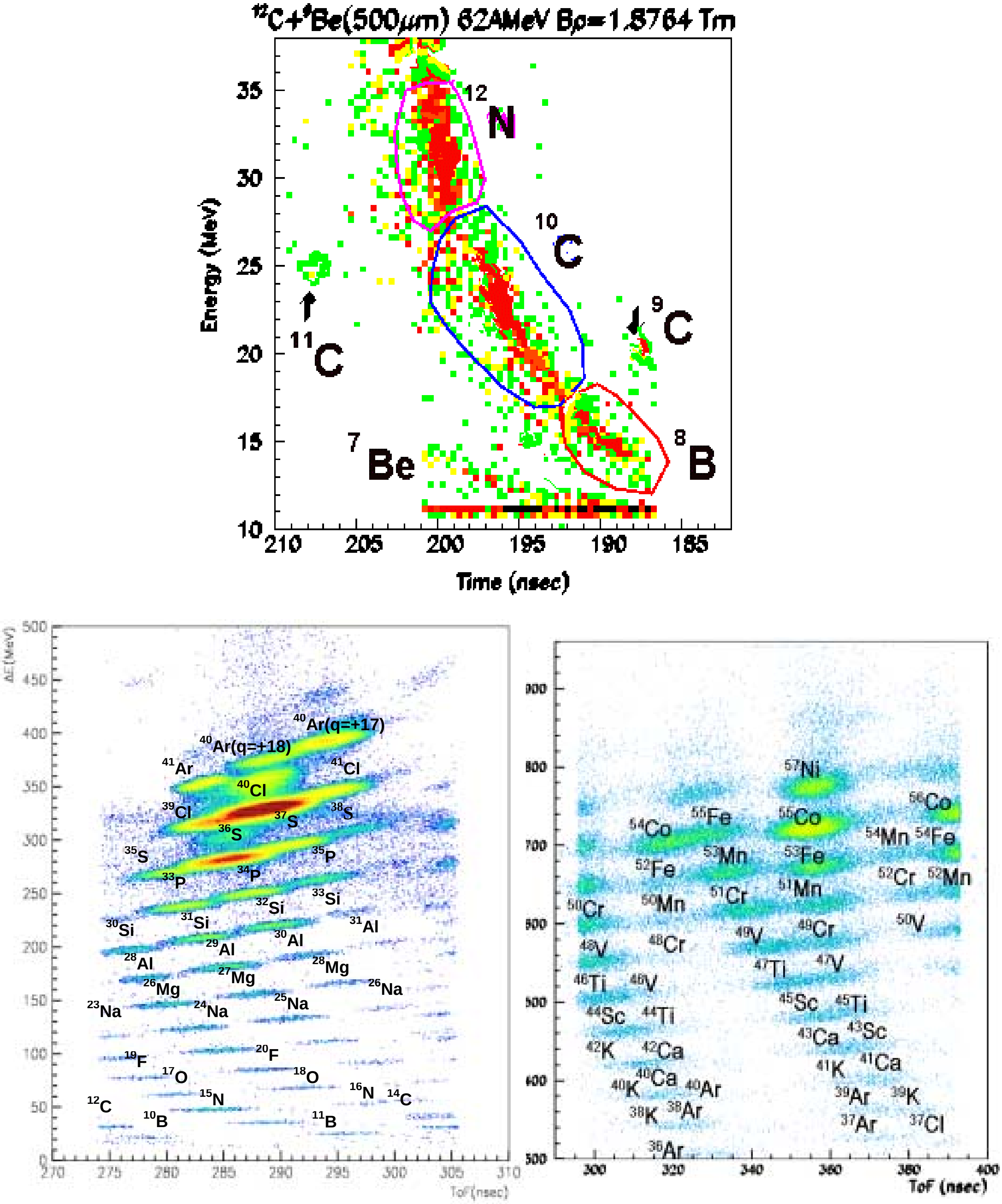


Fig.5: Energy loss in the silicon detector versus ToF for the three investigated reactions.

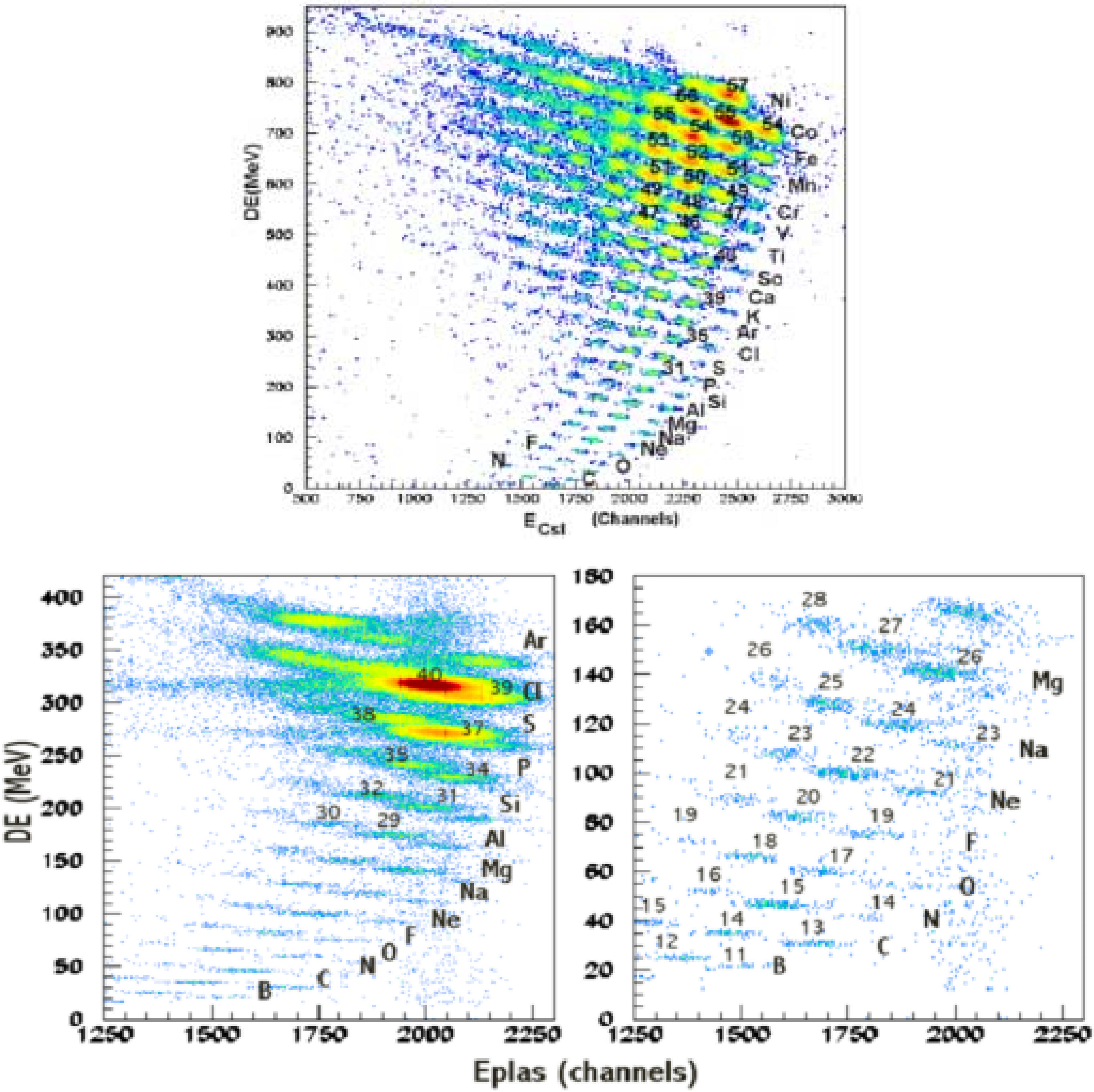


Fig.6: Energy loss versus residual energy in the ^{40}Ar and ^{58}Ni induced reactions

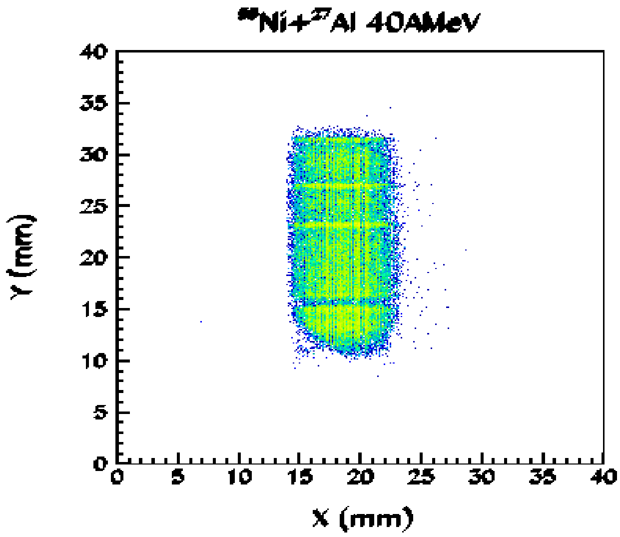


Fig.7: PPAC X-Y positions in ^{58}Ni+ ^{27}Al reaction measured in Ciclope.

Measured yields were in good agreement with LISE calculations (fig 8) and they are reported ,for the most populated isotopes, in Table 2.

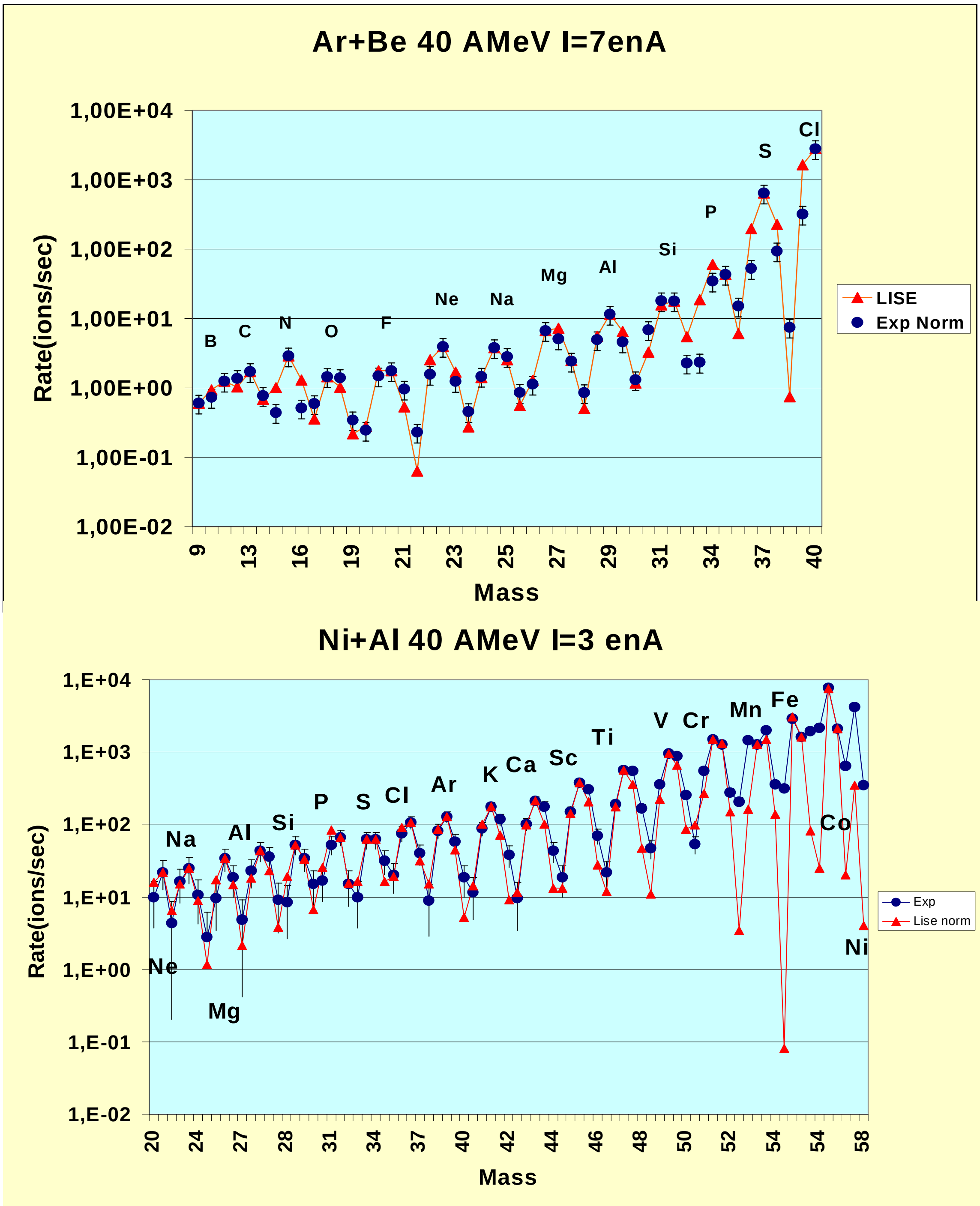


Fig.8: Experimental Yields of RIBs produced in the studied reactions, normalized to LISE calculations.

Table 2: Rates of the most abundant produced Isotopes for I_{Beam}=100 epA.

C+Be	**Ions/sec**	**Ar+Be**	**Ions/sec**	**Ni+Al**	**Ions/sec**
N^{12}	61.2	**Cl^{40}**	9.3	**Co^{55}**	1.6
C^{10}	29.0	**S^{37}**	5.8	**Fe^{54}**	0.9
B^{8}	8.8	**P^{35}**	3.1	**Mn^{52}**	0.5

Moreover the knowledge of the transmission along the beam pipe up to the Ciclope scattering chamber is needed to test the possible use of RIBs for secondary reactions. Using the second detector array at the entrance of the scattering chamber, a transmission (fig.8) between 20% and 90% was measasured without any optical optimization.

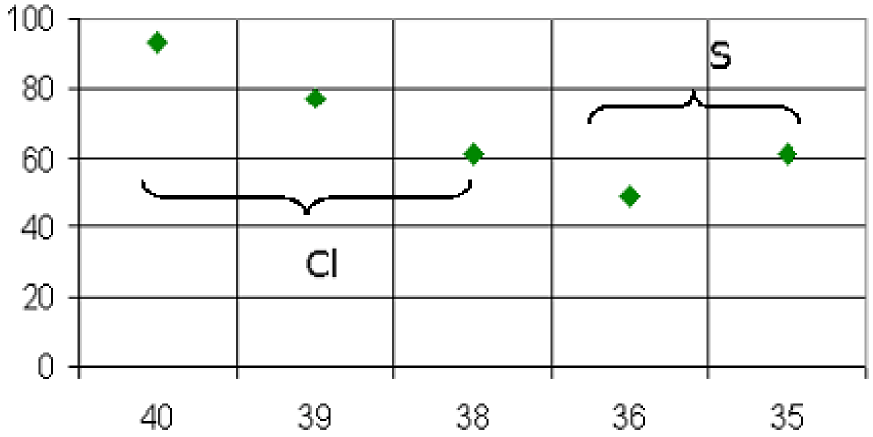


Fig.8: Transmission values for some isotopes produced in $^{40}Ar+^{9}Be$ reaction.

Rates between 10 and 100 ions/sec have been measured for the most produced ions at 100 epA of primary beam current. Therefore, increasing the beam currents up to 100 enA and with the new quadrupoles in the fragment separator which will increase the total acceptance by a factor 10, rates of the order of $10^5 – 10^6$ ions/sec can be achieved

Due to the reaction mechanism and to the energy straggling in the production target, ions are not produced with fixed energy. The energy spread measured is about 3-10%, and it depends on the ion considered.

In fig.9 the energy spectra of different isotopes are reported.

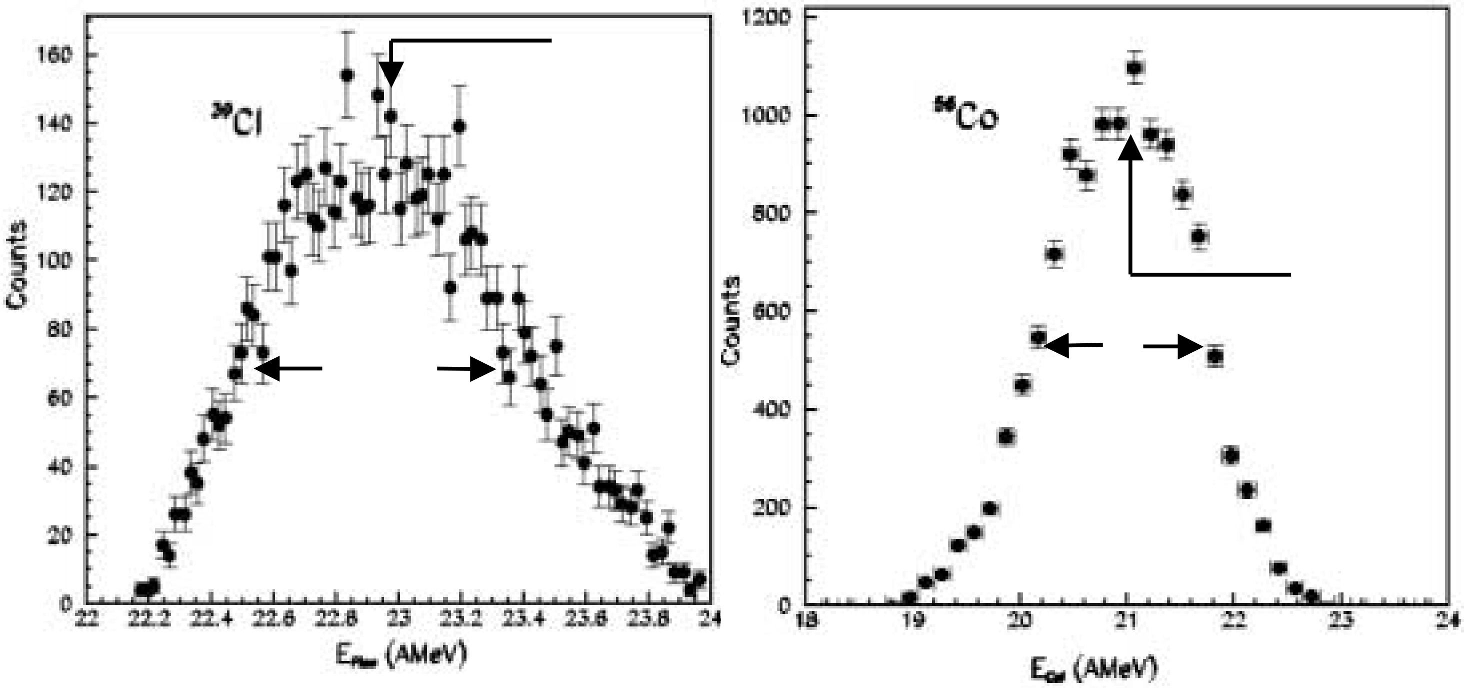


Fig.9: Residual energy in thick detector of ^{39}Cl and ^{54}Co, produced, respectively, in $^{40}Ar+^{9}Be$ and $^{58}Ni+^{27}Al$ reactions.

5. CONCLUDING REMARKS

The preliminary results here presented refer to an experiment intended to identify event-by-event radioactive ions produced in the projectile fragmentation. ^{12}C, ^{40}Ar and ^{58}Ni beams were used on light targets. Very good identification of the products was achieved and production rates were in good agreement with the LISE code estimates. Transmission through the beam line was ranging between 90 and 60%. The present results show the possibility of producing Radioactive Ion Beams, at the LNS, at rates of $10^5 – 10^6$ ions/sec that can be used as tagged beams for nuclear reactions or spectroscopy studies.

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6 REFERENCES

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