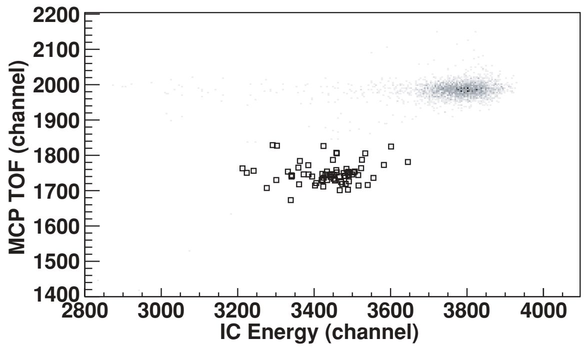

FIG. 7. Local time-of-flight vs. total detected energy for singles recoil events at $E_{\mathrm{beam,lab}} = 502A$ keV and $P_{\mathrm{targ}} = 3.55$ mbar, with the gray density plot indicating all particles detected and the empty squares showing $A = 24$ recoils.

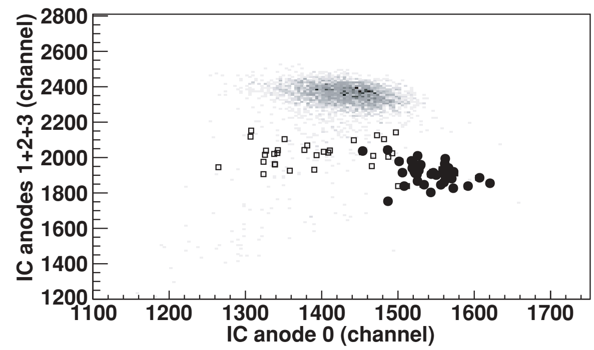

FIG. 9. E vs. ΔE in the ionization chamber for singles events at $E_{\mathrm{beam,lab}} = 502A$ keV and $P_{\mathrm{targ}} = 3.55$ mbar, with the gray density plot indicating all events, the empty squares showing events identified as $A = 24$, and the filled circles being ^{24}Al.

spectrum in the ionization chamber where the $A = 24$ recoils clearly separate into two groups. The empty squares indicate those events satisfying "$A = 24$" mass cuts and the filled circles indicate the subset of events passing the "^{24}Al" PID cuts.

Figure 10 shows coincidence data for these runs with the detected γ energy (Q-value cut) as an additional criterion, illustrating the superior ^{24}Mg background rejection and leaving the ^{24}Al coincidence recoil group. For comparison, data from a pure ^{23}Na beam from the off-line ion source can be seen in Fig. 11 showing the grouping of ^{24}Mg recoils. As mentioned the ^{23}Na content of the mass-23 ion beam varied over nearly two orders of magnitude during this experiment. The selected low ^{23}Na content runs shown here were used to prepare the stringent cuts (applied to the local MCP time-of-flight, the individual five segments of the ionization chamber and the BGO array) for identification of ^{24}Al and ^{24}Mg recoils that were then used in the analysis of the higher ^{23}Na content runs.

The final results of the coincidence identification are presented in Table III. This information is further used in Sec. IV D. Independently, an analysis of the recoil singles relying solely on the MCP time-of-flight and ionization chamber particle identification was performed and our discussion of this is continued in Sec. IV B.

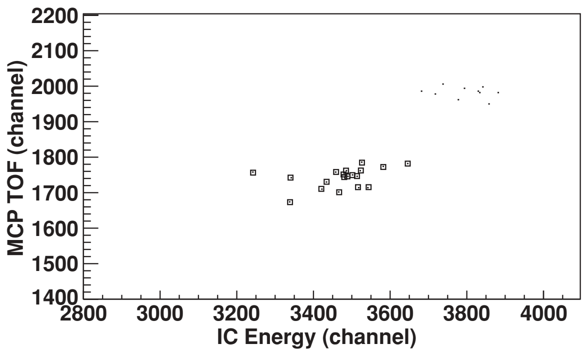

FIG. 8. Local time-of-flight vs. total detected energy for coincidence recoil events at $E_{\mathrm{beam,lab}} = 502A$ keV and $P_{\mathrm{targ}} = 3.55$ mbar, with the black dots indicating all particles detected, and the empty squares showing $A = 24$ recoils.

In addition to the number of detected ^{24}Al recoils, the number of detected ^{24}Mg recoils is also extracted from the analysis. Because the ^{23}Na$(p,\gamma)^{24}$Mg reaction has a large Q value, and therefore a maximum recoil cone angle that is larger than the acceptance of DRAGON, it is difficult to estimate the normalized yield of the reaction without considerable simulation. Since the ^{23}Na$(p,\gamma)^{24}$Mg reaction was not the focus of this experiment, we have not attempted to derive yields but have instead looked at the geometric position of the reaction in the gas target (using the BGO array hit-pattern) in order to determine resonance energies of the ^{23}Na$(p,\gamma)^{24}$Mg and ^{23}Mg$(p,\gamma)^{24}$Al reactions. Table IV shows the extracted BGO z-coordinate centroids for a selection of runs at different beam energies and target pressures. It can be seen that with the lower target pressure the ^{23}Na$(p,\gamma)^{24}$Mg reaction moves to positive (downstream) values. The uncertainties are large because of low statistics, but an estimate of the resonance energy of the ^{23}Na$(p,\gamma)^{24}$Mg reaction gives $E_R \approx 475$ keV, which would correspond to an excitation energy of 12.168 MeV (the uncertainty on this value could be as large as 10 keV). No such proton resonance in ^{24}Mg has been reported previously, although the 1990 evaluation of ^{24}Mg energy levels [23] lists a candidate excited state at $E_x = 12.161$ MeV with total width of 0.9 keV observed in the ^{20}Ne$(\alpha,\gamma)^{24}$Mg reaction. Our data indicate this resonance has a strength on the order of 100 μeV, using a rough estimation. A possible explanation for its previous nonobservation by proton capture is that the presence of the strong resonance at 490 keV removed the incentive for carrying out a high-sensitivity experiment at

TABLE III. Summary of coincidence recoil identification among four periods of the experiment.

Group	$E_{\mathrm{beam,lab}}$	P_{targ} (mbar)	Coinc. events	$A = 24$ Recoils	^{24}Al coinc.
1	497A keV	10.39	24	2	0
2	502A keV	9.87	26	11	7
3	502A keV	9.87	1065	54	14
4	502A keV	3.55	29	19	12