First experiments with the heavy-ion magnetic spectrometer PRISMA

A.M.Stefanini[1], L.Corradi[1], B.R.Behera[1], G.De Angelis[1], E.Fioretto[1], A.Gadea[1], A.Latina[1], D.R.Napoli[1], S.Szilner[1], M.Trotta[1,3], Y.W.Wu[1], L.Costa[1], L.Doná[1], D.Conventi[1], M.Gulmini[1], G.Maron[1], A.Pisent[1], N.Toniolo[1], S.Beghini[2], G.Montagnoli[2], F.Scarlassara[2], R.Menegazzo[2], S.Marchini[2], V.Schiavon[2], P.G.Zatti[2], A.De Rosa[3], G.Inglima[3], M.La Commara[3], D.Pierroutsakou[3], M.Romoli[3], M.Sandoli[3], A.De Francesco[3], M.Di Pietro[3], G.Pollarolo[4], D.Ackermann[5]

1 INFN, Laboratori Nazionali di Legnaro 2 Dipartimento di Fisica and INFN-Sez. di Padova 3 Dipartimento di Fisica and INFN-Sez. di Napoli 4 Dipartimento di Fisica and INFN-Sez. di Torino 5 Univ. of Mainz and GSI, Darmstadt (Germany)

PRISMA is the magnetic spectrometer [1] designed for the A=100-200, E = 5-10 MeV×A heavy-ion beams of the XTU Tandem-ALPI-PIAVE accelerator complex and for the possibile use with the proposed radioactive beam facility SPES. Its main features are large solid angle 80 msr ($\pm 6^0$ for θ and $\pm 11^0$ for ϕ), wide momentum acceptance±10%, mass resolution 1/300 via time-of-flight, energy resolution up to 1/1000 and rotation in a large angular range -20^0 - $+130^0$. The final tests of the overall performance of the complete set-up of the spectrometer have taken place between end of 2002 and Summer 2003, by using various heavy-ion reactions.

Figs.1 and 2 show two examples of spectra taken with PRISMA using ^{32}S beams on a ^{64}Ni target, around the grazing angle (the beam energy is slightly above the barrier). The mass resolution is quite good. In the same tests we measured ΔE-E spectra using the ionization chamber, with good Z resolution. For each Z value, different ion charge states q are clearly distinguishable.

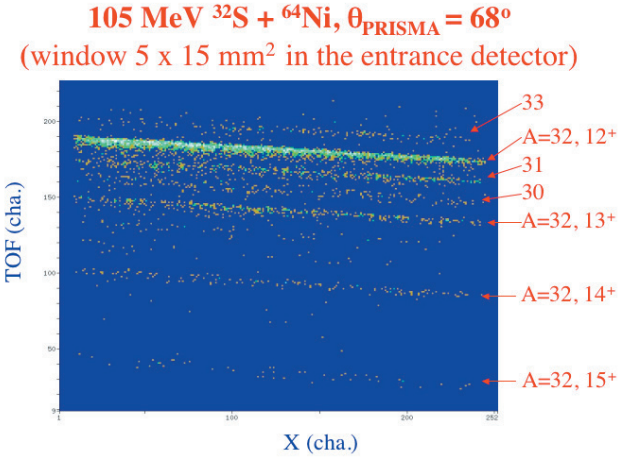

FIG. 1: *Two-dimensional spectrum of time-of-flight TOF vs. position along the focal plane X, for the indicated reaction, from one of the ten sections of the focal plane.*

Further commissioning tests were performed during March-April 2003 with ^{58}Ni and ^{40}Ca beams. The reaction ^{40}Ca + ^{208}Pb was used to check the energy (momentum) resolution of PRISMA in an interesting case. We used a thin ^{208}Pb target (50μg/cm^2) and a ^{40}Ca beam at

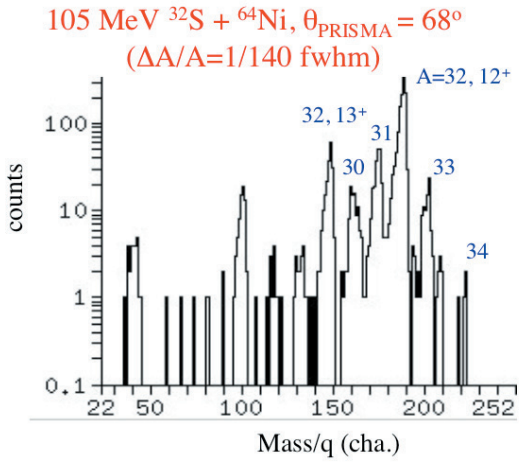

FIG. 2: *Projection onto the TOF axis from the previous matrix.*

235 MeV (see Fig.3). Elastically and inelastically scattered ^{40}Ca particles were identified on the focal plane by the TOF, position and IC signals. Fig.3 shows the X position spectrum along the focal plane for one of the three ^{40}Ca ion charge states which were clearly visible. Elastic and inelatic scattering are very nicely separated, and the deduced energy resolution is roughly 700 keV, or 1/300, mainly depending on the target thickness, on the reaction kinematics, and on the TOF measurement accuracy.

A significant test of the mass resolution was performed in the multinucleon transfer reactions from ^{58}Ni + ^{124}Sn at E_{lab}=263 MeV, θ_{lab}=70^o (near the grazing angle), where many mass spectra were measured, corresponding to various Z cuts in the ΔE vs. E spectra of the IC, where mainly few- and multi-proton stripping channels were observed besides strong neutron pickups, as expected from the systematics of the Q-values for the various reactions. A very good A/q resolution was obtained, up to ΔA/A=1/280. Here and in the other test experiments the unique identification of the ion charge states needs still to be done, since it requires a more detailed analysis of the data. It is anyway not necessary for characterizing the performance of PRISMA.

The first real experiments on grazing collisions between

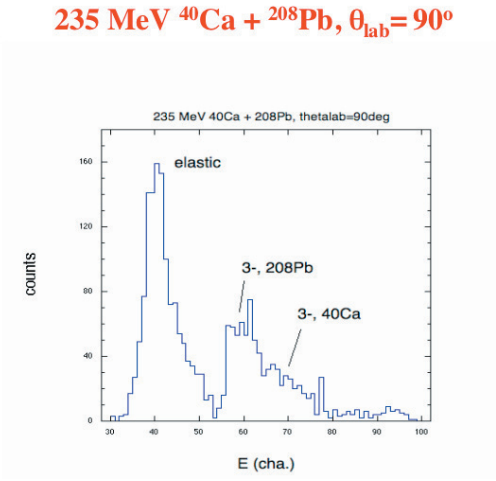

FIG. 3: *Position (energy) spectrum measured with PRISMA for the indicated reaction. The arrows indicate the locations where inelatic excitations of octupole vibrations of both ^{40}Ca and ^{208}Pb are expected from the kinematics (see also text).*

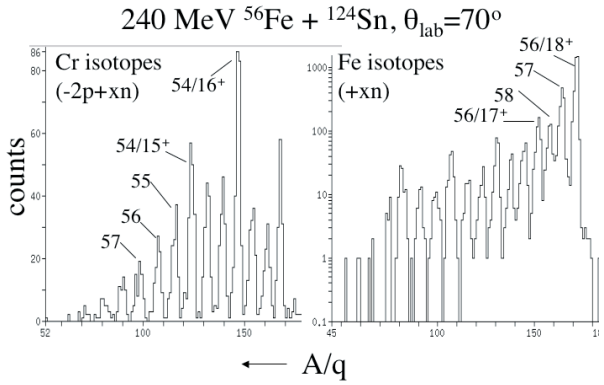

FIG. 4: *A/q spectra measured with PRISMA during one of the recent runs.*

heavy ions were performed with PRISMA recently. The goal of the experiments was to investigate the population of neutron-rich nuclei in the A=50-60 mass region by means of multinucleon transfer reactions. We used ^{54}Cr, ^{56}Fe and ^{64}Ni projectiles on a heavier and more neutron-rich target like ^{124}Sn (a 300μg/cm^2 strip metallic evaporation on a thin carbon backing), at incident energies corresponding to E/V$_b$=1.07-1.10 depending on the system. The beams were produced by the XTU Tandem accelerator of LNL at intensities in the range 2-10 pnA. A small silicon detector in the rotating scattering chamber was used for beam monitoring and for normalization between the different runs. Angular distributions of the transfer reactions and of quasi-elastic scattering were measured in the range θ_{lab}= 65^o-105^o, and longer runs were taken around the grazing angle, in order to identify weak multinucleon transfer channels.

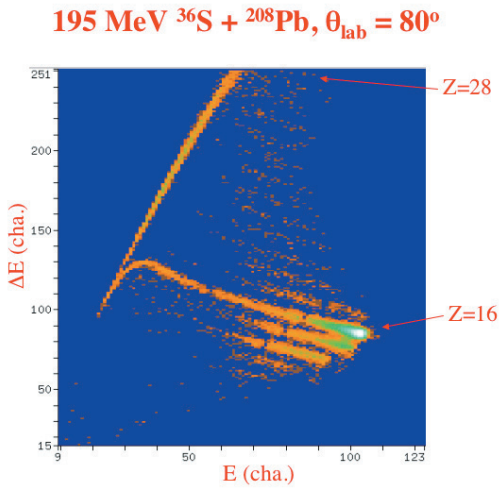

FIG. 5: *ΔE vs. E matrix obtained from the indicated reaction; in addition to strong proton stripping channels, pick-up reactions are identified, merging with deep inelastic events and with the tail (probably) of target fission.*

Examples of mass spectra showing particular nuclei populated in the region of interest are reported in Fig.4. Very good mass and Z resolutions were reached (ΔA/A=1/280 routinely). The left spectrum is obtained by selecting Z=24 events in the IC (i.e. -2p+xn reactions); the right panel is the A/q distribution of the (+xn) neutron pick-up channels. Six-proton stripping and six-neutron pick-up channels were clearly observed.

The complete data sets from these experiments are being analyzed, and mass- and Z-distributions will be extracted for a number of cases. This will help understanding the dynamics of few- and multi-nucleon transfer reactions, with the high efficiency and resolutions allowed by PRISMA. Moreover we will extract cross sections for the population of selected nuclei, where experiments with PRISMA-CLARA coincidences will be very interesting for nuclear structure studies.

The latest experiment was an exploratory run with a ^{36}S beam (from the XTU Tandem) on a ^{208}Pb target, where the main goal was to identify exotic nuclei produced by proton stripping and/or neutron pickup at an energy ≈10% higher than the Coulomb barrier. Very good resolutions were obtained also in this case, and the data analysis is underway. From the on-line spectra, anyway, it seems that the reaction is very prolific, as we expected, and a multitude of neutron-rich nuclei with A=30-40 is produced (Fig.5). In this case a single run was performed at the (calculated) grazing angle.

[1] A.M.Stefanini et al., LNL Annual Report 2002, pp. 147,148,150,152