

3 - 24 Research Progress of RIB Physics Laboratory

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The Rare-Isotope Beam (RIB) Physics Laboratory at IMP has made steady progress in 2022 in the following five aspects.

1. **Nuclear structure and reaction studies with intermediate- and low-energy RI beams.** Measurements of charge-changing cross-sections (CCCS) of $^{30-36}\text{P}$ on a ^{nat}C target were successfully performed at beam energies around 200~300 MeV/nucleon at the External Target Facility (ETF) of HIRFL to investigate the effect of the $N = 20$ shell closure. Theoretical analysis using the Glauber model is in progress. Systematic study of production cross sections for several boron, carbon and nitrogen elemental fragment from a 260-MeV/nucleon ^{18}O beam incident on a carbon target has also been performed. The results for boron and nitrogen isotopes are consistent with the existing data at higher beam energies, while discrepancies are observed between those of carbon isotopes measured at three different beam energies^[1]. On the low-energy side, measurements of elastic scattering and breakup reaction of the weakly bound ^{11}Be , ^{13}B and ^{13}O nuclei on a ^{208}Pb target were performed at intermediate incident energies several times above their Coulomb barriers^[2,3]. The suppression of the Coulomb nuclear interference peak reported for the quasielastic scattering angular distribution of ^{11}Be at energy around the Coulomb barrier persists even at higher energy. Alpha-elastic and -inelastic scattering measurements on $^{11,12}\text{C}$ were successfully performed at HIRFL-RIBLL1 using the active-target time-projection-chamber at IMP – MATE (Multi-purpose Active target Time projection chamber for nuclear astrophysical and the exotic beam Experiments)^[4]. The successful application of MATE will opened up opportunities for various experiments with radioactive-isotope beams.

2. **Nuclear structure at high spin and nuclear astrophysics.** Measurements of angular correlation and linear polarization for several electromagnetic transitions were performed at the University of Jyväskylä, Finland. The results are in good agreement with quasiparticle-plus-triaxial-rotor model calculations, and do not support the wobbling nature of low-spin bands in ^{135}Pr ^[5]. In two other separate measurements, transverse wobbling bands in ^{136}Nd ^[6] and detailed investigation of positive-parity bands in ^{120}Ba ^[7] were reported. In a study of weak r-process network calculations, the sensitivity of magnetohydrodynamically driven supernovae towards several nuclear reactions was investigated, and the results suggest the (α, n) reactions as the most active reactions^[8].

3. **Design of the CSR External-target Experiment (CEE) spectrometer and status of space detectors.** The CSR External-target Experiment (CEE) spectrometer was proposed to study the bulk properties of nuclear matter including the nuclear equation of state at high baryon density with large isospin asymmetry, and to understand the Quantum Chromo Dynamics (QCD) phase diagram. The spectrometer and dedicated detectors such as time-projection chamber (TPC) and multi-wire drift chambers (MWDCs) are currently being constructed. The Mars Energetic Particle Analyzer (MEPA), which was onboard the Tianwen-1 satellite launched in 2020, has been operating stably and steadily collecting background radiation data. The first paper reporting the observation of solar energetic particle events was published recently^[9].

4. **Instrumentation development.** The development and upgrade of radiation detectors and other instruments for use at RIBLL1, ETF and RIBLL2 are ongoing. Substantial progress has been achieved in 2022. We have tested an upgraded parallel-plate avalanche counter (PPAC), and achieved stable operation for more than 120 hours; the first beam tests were performed for the diamond and GAGG scintillation detectors; the readout system of the neutron wall, conducted in-beam test experiments to develop pulse-shape analysis algorithm for CsI(Tl) detector array at ETF. Development of a liquid-nitrogen-cooled low-temperature gas target and a cryogenic solid-hydrogen target systems are also in progress to perform experiments at RIBLL1 and RIBLL2. At RIBLL1, a prototype wedge aluminum degrader was successfully used in the alpha-scattering experiment with MATE.

5. **Design of prototype production target system and detectors for HIAF-HFRS.** Performance test of a prototype production target system for the heavy-ion fragment separator (HFRS) at HIAF is ongoing. We are also testing various prototypes of diamond detector, multi-readout plastic scintillation detectors, PPAC, low-pressure multi-wire drift chambers and GEM time-projection-chamber for use at the High-energy Fragment Separator (HFRS).

References

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3 - 25 The Introduction of Tianwen-1 Mars Energetic Particle Analyzer and Its First Scientific Result

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Mars is the fourth planet in the solar system and could become a destination for human existence. The radiation environment of Mars is much more severe than that of Earth due to the lack of a global magnetic in future field and a thick enough atmosphere. Once leaving the near-Earth environment and going into space, astronauts and spacecraft without the protection of the geomagnetic field are inevitably exposed to intense high energy particle radiation. Thus it is necessary to measure the background radiation environment both in the Martian atmosphere and the transfer orbit from Earth to Mars.

Mars Energetic Particle Analyzer (MEPA), jointly being designed and developed by scientists and engineers from Institute of Modern Physics and the Lanzhou Institute of Physics, is an important scientific payload aimed at studying the interplanetary and near-Mars space radiation environment onboard the orbiter of Tianwen-1. MEPA consists of two parts: sensor head and electronics system. The MEPA sensor head adopts $\Delta E-E$ method to identify

Table 1 The detection performance of MEPA instrument.

Radiation dose	LET in silicon	Particle species
Indirect measurement	0.2~1 200 KeV/ μm	1~100 MeV/nuc proton/alpha
below 400 MeV		20~20 000 MeV B C N O Ne Mg Si

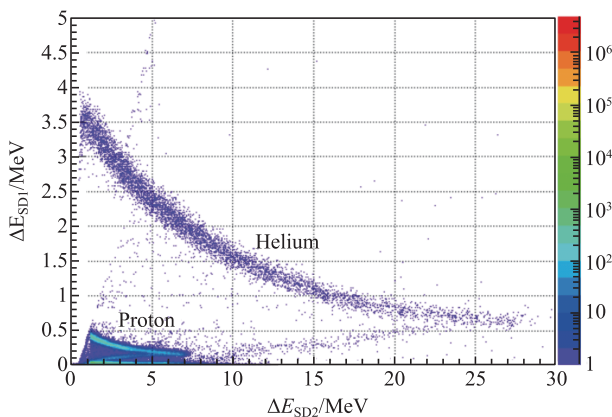


Fig. 1 (color online) The scattering plot of SEP events observed by MEPA.

the diverse species of charged particles in a wide energy range, the specific detection parameters of MEPA is listed in Table 1. In $\Delta E-E$ telescope system, SSD1 ($\phi 8$ mm with $15 \mu\text{m}$ thick) and SSD2 ($\phi 26$ mm with $300 \mu\text{m}$ thick) acts as $\Delta E1$ and $\Delta E2$ detectors respectively to identify charged particles with low energy. The CsI, acting as E detector with 32.5 mm thick, could stop and measure most of the energy of charged particles with relative high energy. Meanwhile the combination of SSD2 and CsI forms $\Delta E-E$ telescope to discriminate those faster charged particles. In order to ensure head sensor accept charged particles in the 60° field of view (FOV), the $\Delta E-E$ telescope is surrounded by two plastic scintillator detectors to eliminate particles coming from outside of the FOV. In-orbit data transferred back to ground indicates MEPA is in good work conditions and has an excellent particle identification as shown in Fig. 1.

MEPA was launched with the TW-1 spacecraft in July, 2020 to start exploration of space radiation environment. Unlike galactic cosmic rays whose flux is stable for a long time, SEP (solar energetic particle) events are sporadic and unpredictable during any Solar cycle. Their flux is several orders of magnitude higher than the background cosmic rays, which not only has a great impact on the interplanetary and near-earth space radiation environment, but will