**Development of a new MARS simulation in LISE++**

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LISE++ [1] is a program that has been developed since the 1980s to simulate the operation of fragment separators used to produce radioactive beams with various reaction mechanisms. While it was initially developed to simulate the LISE spectrometer [2] at GANIL, it has since been expanded and now contains configuration files for existing fragment and recoil separators such as the A1900 and the S800 at the NSCL-MSU, LISE3 at GANIL, FRS and SuperFRS at GSI, BigRIPS and RIPS at RIKEN. Given the versatility of this program, it seemed reasonable to develop a configuration file for the Momentum Achromat Recoil Separator, or MARS [3], that has been in operation here at the Cyclotron Institute at Texas A&M University, and producing radioactive beams, since 1991.

Previously, one of the problems with the LISE++ program was that it did not support individual quadrupole and sextupole elements in the spectrometer configuration. This prevented a straightforward simulation of the MARS spectrometer because it was not possible to compare old spectrometer calculations made with the TRANSPORT program [4] directly with the predictions of LISE++. Beginning with LISE++ version 9.5 (available in 2013), "extended" configurations which allowed the inclusion and calculation of matrices for quadrupoles and sextupoles in the spectrometer became available in the program. The ability to include quadrupoles and sextupoles, as well as an improvement to the calculation of the optical matrix of the compensating dipole in LISE++, has led to the new MARS configuration in LISE++.

In addition to the new configuration file, some measurements of the magnetic fields of the MARS quadrupoles were also conducted. In these measurements, four of the five MARS quadrupoles were measured for electric current vs. magnetic field with existing NMR probes. It is assumed that these NMR probes measured the magnetic fields at the pole tip of the quadrupoles, which is what is required for the quadrupole optical matrix calculation in both LISE++ and TRANSPORT. The results of these measurements for MARS quadrupoles Q1-Q4 and an estimation of the field vs. current for Q5, have been included in the new LISE++ configuration file for MARS. In this way, a direct comparison between the LISE++ simulation and the optimized settings for the dipoles and quadrupoles for a given radioactive beam in MARS can be made. Measurements of the field vs. current of quadrupole Q5 and the sextupole magnets are planned for later this year, provided the equipment needed to make these measurements is available.

The new "extended" MARS configuration in LISE++, including the quadrupoles, sextupoles, velocity filter, compensating dipole and slits, is shown in Fig. 1. This new configuration has been available for the user of LISE++ beginning with version 9.8.56 of the code. An example file with the new configuration can be found in the included files of the program in the directory "*LISE/files/examples/TAMU/TAMU-MARS_extended_35K.lpp*". This file gives a simulation of the p($^{36}$Ar,$^{35}$K)2n reaction in MARS, which was recently produced in MARS and is reported this year as one of the new beams produced with MARS [5]. A comparison between the simulated ΔE vs. Y-position

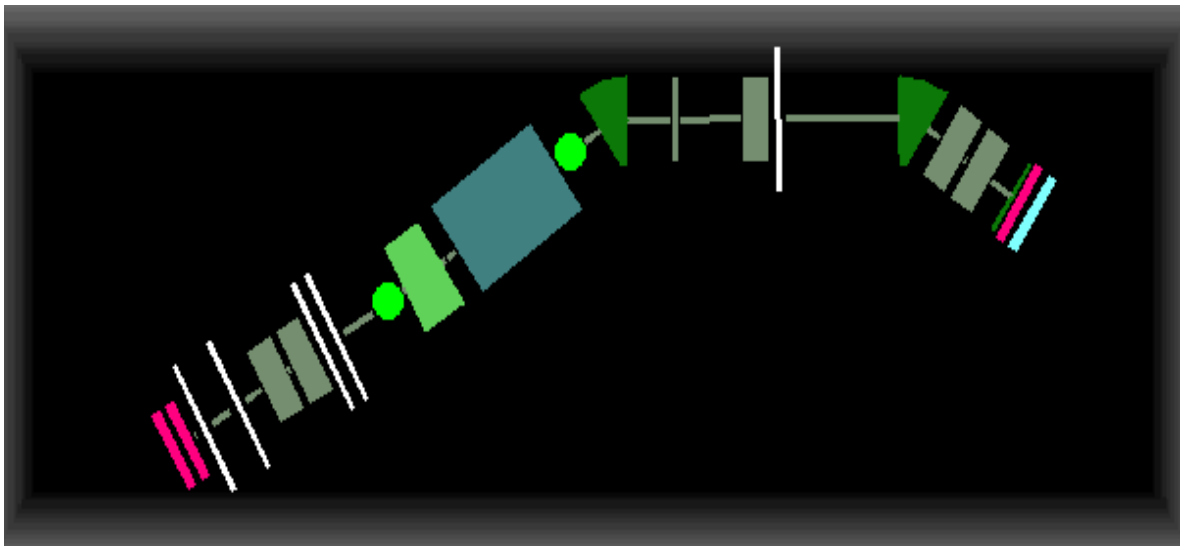

**FIG. 1.** A diagram of the new "TAMU-MARS_extended" configuration in the LISE++ simulation program.

spectrum obtained with this file and the actual ΔE vs. Y-position spectrum from the p($^{36}$Ar,$^{35}$K)2n test experiment is shown in Fig. 2. The simulation predicts much more $^{34}$Ar relative to the $^{32}$Cl and $^{35}$K than was seen in the experiment, but the simulated beam spot sizes on the detector and the mass dispersion are similar to what was obtained in the experiment.

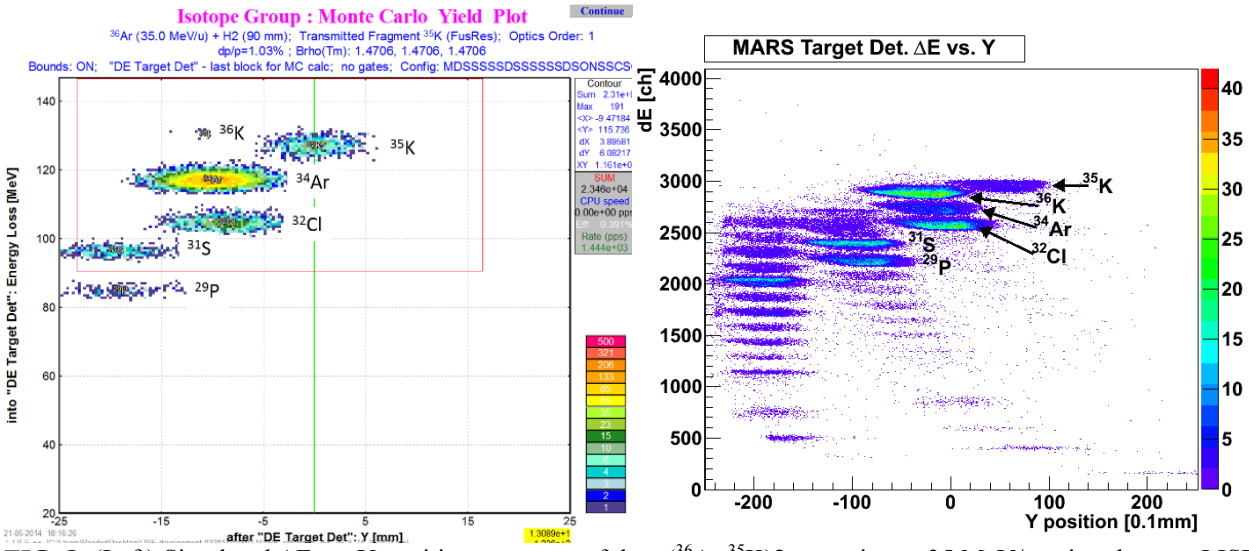


**FIG. 2.** (Left) Simulated ΔE vs. Y-position spectrum of the p($^{36}$Ar,$^{35}$K)2n reaction at 35 MeV/u using the new LISE++ "TAMU-MARS_extended" configuration. (Right) MARS target detector spectrum for the ΔE vs. Y-position recorded during the production test experiment for the p($^{36}$Ar,$^{35}$K)2n reaction at 35 MeV/u.

With this simulation of MARS in the LISE++ program, new experiments can be planned in advance as the user will have a better idea about the production rate and purity of their radioactive beam prior to their experiment. In addition, new methods of tuning the MARS optics can be studied in an effort

to improve the transmission. Finally, some possible future upgrades to the MARS beamline can be investigated.

[1] O.B. Tarasov and D. Bazin, Nucl. Instrum. Methods Phys. Res. **B266,** 4657 (2008).
[2] R. Anne *et al.*, Nucl. Instrum. Methods Phys. Res. **A257**, 215 (1987).
[3] R.E. Tribble, R.H. Burch, and C.A. Gagliardi, Nucl. Instrum. Methods Phys. Res. **A285**, 441 (1989).
[4] K.L. Brown, The ion optical program TRANSPORT, Technical Report 91, SLAC, (1979).
[5] B.T. Roeder *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2013-2014), p. I-48.