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LISE^{++}: Exotic beam production with fragment separators and their design

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ABSTRACT

Since the LISE^{++} code presentation at the EMIS 2007 conference (Tarasov and Bazin, 2008), important improvements have been made in the analytical and Monte Carlo calculations of transmission, and accuracy of reaction product distributions. In this paper new features of the code in ion-beam optics, creation of new LISE^{++} blocks, and development of some reaction models will be discussed. Large progress has been done in ion-beam optics with the introduction of "elemental" blocks, that allows optical matrices calculation within LISE^{++}. New type of configurations based on these blocks allow a detailed analysis of the transmission, useful for fragment separator design, and can be used for optics optimization based on user constraints.

1. Introduction

The LISE^{++} program [1] is designed to predict intensities and purities for the planning of future experiments with in-flight separators, but is also essential for radioactive beam tuning where its results can be quickly compared to on-line data. This is achieved via the simulation of fragment separators through the use of different sections called "blocks" (magnetic and electric multipoles, solenoid, velocity filter, RF deflector and buncher, material in beam, drift, rotation element, and others). The code is built around a user-friendly interface that helps to seamlessly construct any fragment separator from the different blocks. The LISE^{++} package includes configurations of existing separators at NSCL/MSU, RIKEN, GANIL, GSI, FLNR/JINR, TAMU and others. Projectile Fragmentation, Fusion–Evaporation, Fusion–Fission, Coulomb Fission, and Abrasion–Fission models are used in the program to simulate experiments at beam energies above the Coulomb barrier. The LISE^{++} package includes also the PACE4, Global, Charge, Spectroscopic calculator codes and is available online [2]. The LISE^{++} code development is based on user requests, and will soon be converted to a modern graphics framework using new compilers to improve its performance and sustainability, as well as cross-platform compatibility and the ability to take advantage of computational tools such as parallel computing. For more details see the corresponding contribution in these proceedings [3].

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2. Block types development

The "Beam rotation", "Shift of Optical Axis", "Solenoid", "RF buncher", "Fitting constraints", and "Delay (efficiency)" blocks were created recently (see Fig. 1). Although LISE^{++} is intended for direct in-flight production and separation, a new "Delay (efficiency)" block, that denotes time delay and mass dependent efficiency, has been implemented to calculate intensities of stopped and reaccelerated beams. Large developments took place for the "Drift", "Electrostatic Dipole" and "Compensating Dipole" blocks. The "Compensating Dipole" inclination angle and optic matrix calculations are now available depending on its geometry and compensation property as defined by user. The "Drift" block has now the option to contain a magnetic quadrupole and sextupole, or electrostatic quadrupole. The gas-filled optical block will be developed soon in LISE^{++} to perform analysis of beam dynamics in low-energy recoil separators using the Monte Carlo calculation mode.

3. Progress in ion beam optics

New capabilities in ion-beam optics calculations come from the introduction of elemental blocks that enable a new type of configuration, named "extended (or elemental)" in addition to the classic "sector (or segmented)" configuration [4]. "S" and "E" optical blocks properties are given in Table 1. Optical matrices can be entered by the user directly or linked to COSY maps (up to fifth order) [5] for both optics block types, but they can now be calculated within LISE^{++} (up to second order) in the case of "E" block. The introduction of "E" optical blocks enables a detailed analysis

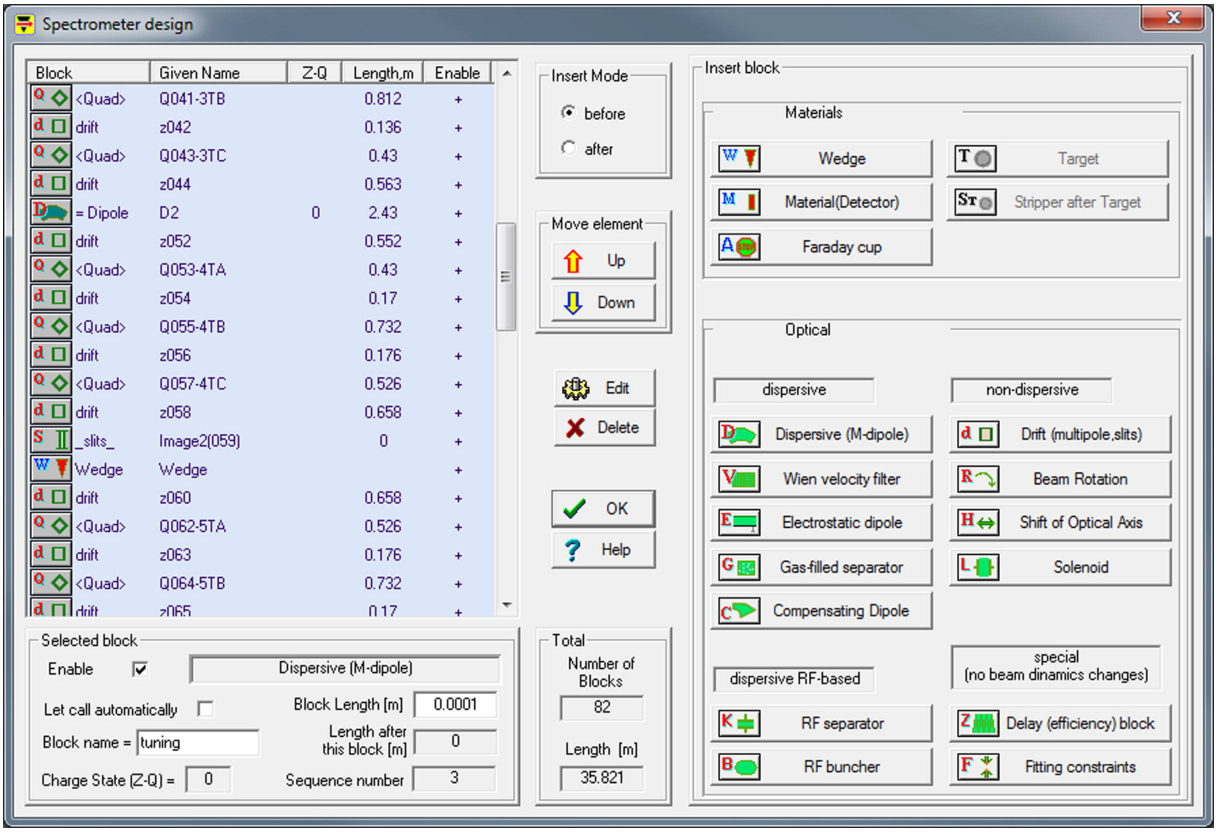

Fig. 1. Updated view of the "Spectrometer Design" dialog window.

Table 1
LISE^{++} optical blocks properties.

Property	S-block (sector)	E-block (element)
Optical matrix calculation within the code	No	Yes
Length of block	Manually	Calculated
Optional drawing of quadrupoles in scheme	Allowed	No
Aperture property	No	Yes
Slits after block	Yes	Yes
Angular acceptance	Yes	Yes
Block use in the segmentation process (G-block in future)	No	Yes
Export/import separator configuration between LISE^{++} and other beam transport codes	No	Yes
User level	Regular	Expert
Efficient to calculation model	Analytical convolution	Monte Carlo
Principal use	Experiment planning	Benchmarking, separator design

of the transmission, useful for fragment separator design, provides a powerful tool to calculate angular acceptances, and allows to display ion-beam optics characteristics (see for example Fig. 2).

Sector (segmented) configurations are dispersive blocks that contain at least one dispersive optical element (M-dipole, E-dipole, velocity filter, ...) and other optical non-dispersive components (multipoles, drifts, ...) combined. Their features are:

- Fast transmission calculations.
- Simple and compact description of optical system.
- Effective with analytical convolution technique for experiment planning.

Features of extended (elemental) configurations – all elements are separated:

- Allows detailed transmission analysis
- Matrices can be calculated by LISE^{++}
- Tools to obtain angular acceptances
- Tools for displaying beam envelopes and optics coefficients along the beam line
- Useful with Monte Carlo calculations to observe correlations between parameters in different blocks. Includes gating on all correlations

Others new features in ion beam optics with elemental blocks:

- Quadrupole and sextupole fields superposition
- Multipole effective length calculation
- Quadrupole magnetic field vs. current calibration B(I)
- Possibilities to Import/Export from/to TRANSPORT code files [6]
- Optics conditions can be adjusted with multipole fields variation by a fitting algorithm

4. Optics optimization

The first stage of optics conditions fitting procedure was introduced, based on the levmar package by M.I.A. Lourakis using the Levenberg–Marquardt nonlinear least square algorithm [7]. At this stage magnetic fields (and/or electric voltages) of E-blocks can be varied in the distribution mode to minimize user constraints for 1st and 2nd order matrix and beam ellipse elements. The "Fit constraint" dialog is shown in Fig. 3.

In the future this minimization procedure will be used to define the curved profile of the degrader shape, the fragment spatial

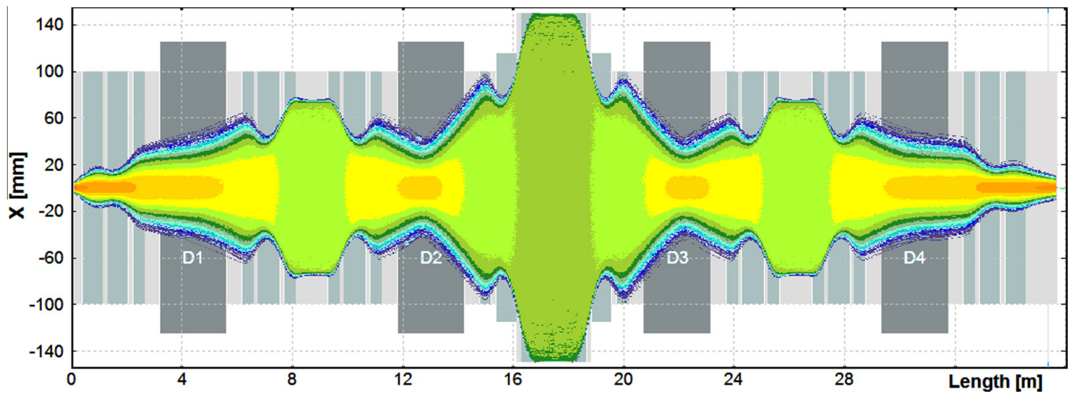

Fig. 2. A1900 separator horizontal envelope calculated by LISE^{++} for ±2.5% momentum spread.

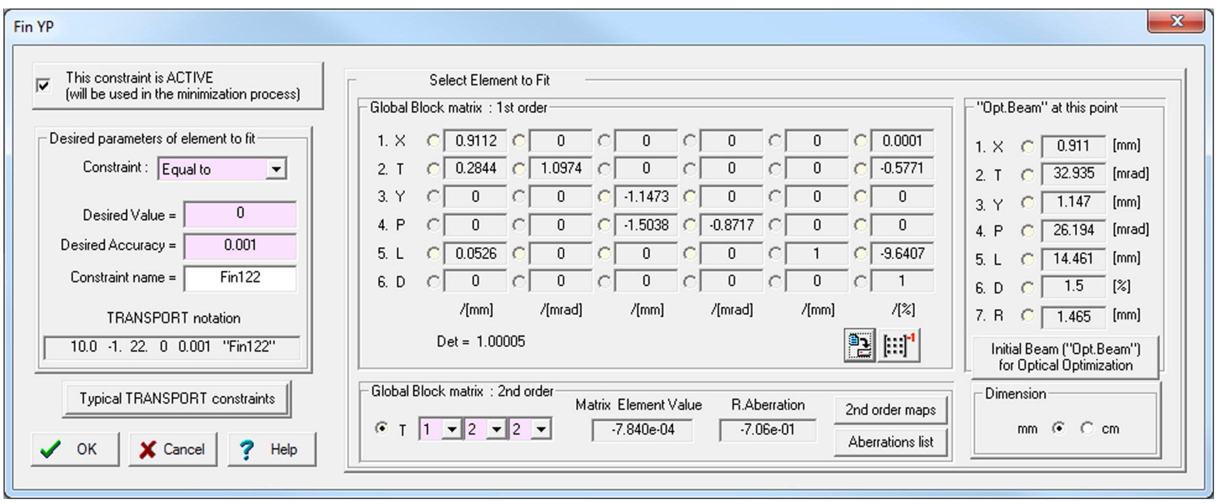

Fig. 3. The "Fit constraint" dialog. For a constraint the user selects an element from first- or second-order optical matrices, or beam sigma vector, and set its desired value and precision.

distributions in Monte Carlo mode, and to optimize intensity/purity combination. Higher-order minimization for distribution in Monte Carlo mode will also be developed.

5. Low-energy reaction mechanism update

The creation of built-in reactions models and implementation of modern powerful algorithms in the code remains an important priority for the LISE^{++} development. A recent update of low-energy reaction mechanisms was performed to simulate the dependence of different reaction channels from angular momentum and qualitatively estimate production cross sections in the case of Fusion–Fission and Fusion–Residue reactions [8].

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