



LISE⁺⁺

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MICHIGAN STATE

UNIVERSITY

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- Application
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- Reaction Mechanism models development
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Overview and Goals

- The proposed research on rare isotope production will be incorporated into the LISE⁺⁺ program
- A** ▪ The underlying physics of LISE⁺⁺, i.e., cross sections and momentum distribution of fragments, is central to accurate simulation of experiments; this is the subject of our grant proposal
- B** ▪ The broader impact of this work is significant. All rare isotope facilities, and many low-energy laboratories use LISE⁺⁺ for spectrometer design, experiment planning, and data analysis
- C** ▪ The PIs are uniquely qualified to do this work

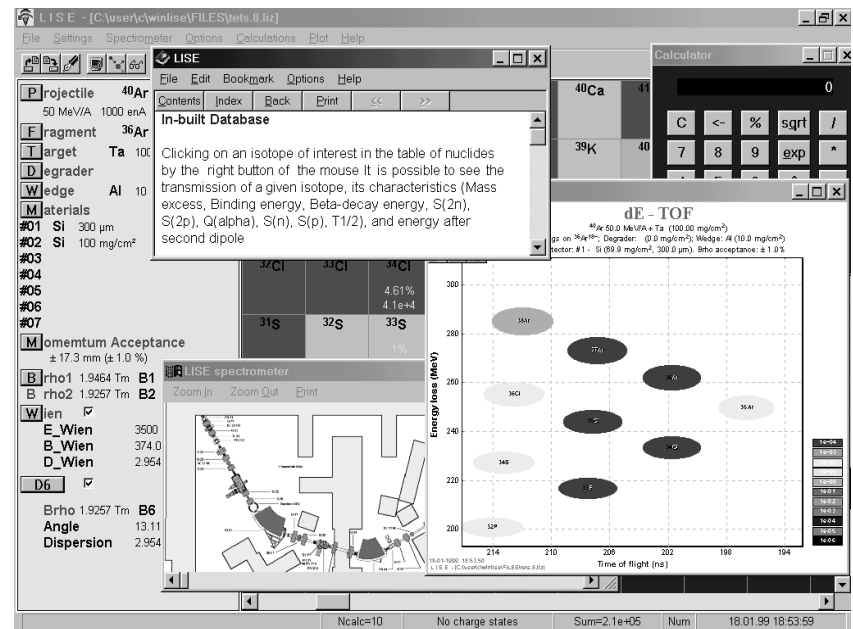
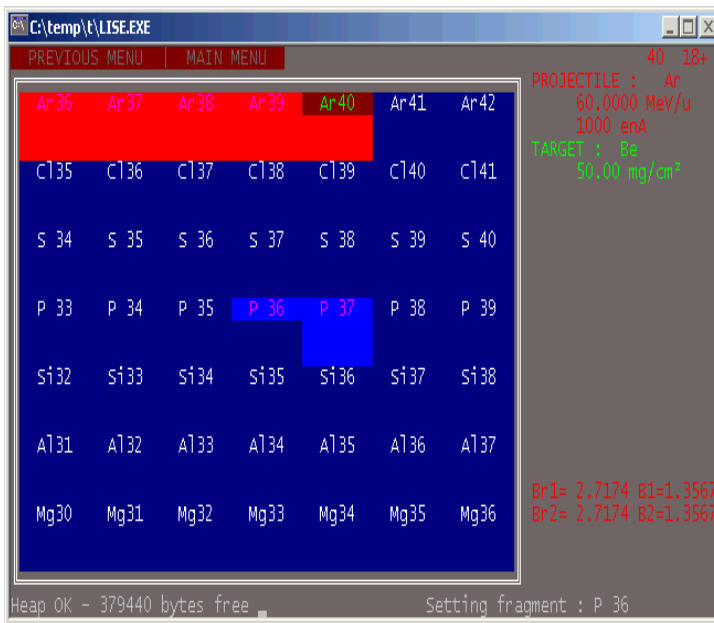
History: France

- GANIL - The program LISE was designed to predict intensities and purities for the planning of experiments at the LISE fragment-separator as well as for tuning experiments where its results can be quickly compared to on-line data.

1986-1993
D.Bazin, O.Sorlin
v.1.0-2.2

1994-2000
O.Tarasov
v.2.3 – 4.9

- 1998: LISE operates under MS Windows



History: USA

■ NSCL / MSU

- Active development of the LISE code stimulated by B. Sherrill at MSU by the hire of O. Tarasov
- LISE⁺⁺ is the new generation of the LISE code, which allows the creation of any spectrometer through the use of different “blocks”
- Fusion – Residues, Coulomb Fission, Abrasion – Fission, Fusion – Fission
- Monte Carlo calculation of fragment transmission
- Optics calculation up to 2nd order (5th order use)
- Optics minimization
- v.12 was recently released

2001
NSCL / MSU
v.4.10 –5.12

2003
NSCL / MSU
v.6

20...
NSCL / MSU
v.7-9.10

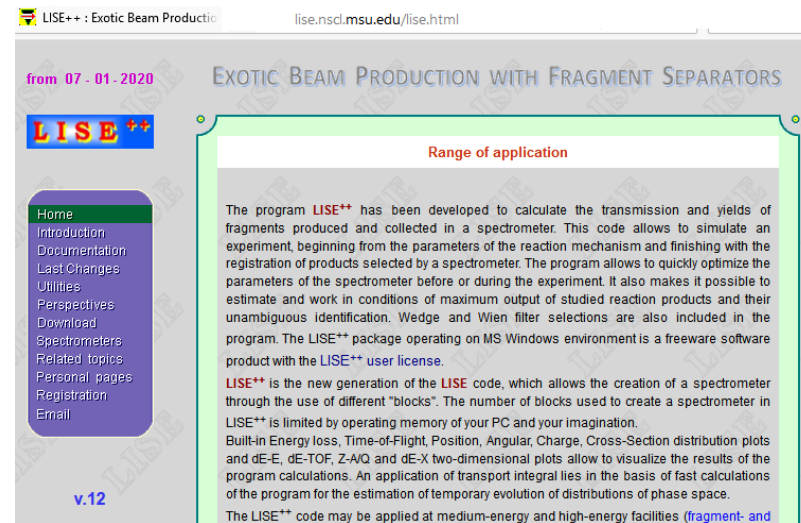
2020
NSCL / MSU
v.12

Authors	Name	Journal	citations
O.B.Tarasov, D.Bazin	LISE ⁺⁺ : Exotic beam production with fragment separators ..	NIM B 376 (2016) 185	16
M.P.Kuchera, O.B.Tarasov et al	LISE ⁺⁺ Software Updates and Future Plans	NIM B 376 (2016) 168	1
O.B.Tarasov, D.Bazin	LISE ⁺⁺ : Radioactive beam production with in-flight separators	NIM B 266 (2008) 4657-4664	231
O.B.Tarasov, D.Bazin	LISE ⁺⁺ : design your own spectrometer	Nuclear Physics A746 (2004) 411-414	49
O.B.Tarasov, D.Bazin et al.	The code LISE: The code LISE: a new version for 'Windows'	Nuclear Physics A701 (2002) 661-665	15
D.Bazin, O.B.Tarasov et al.	The program LISE: a simulation of fragment separators	NIM A482 (2002) 307-327	87

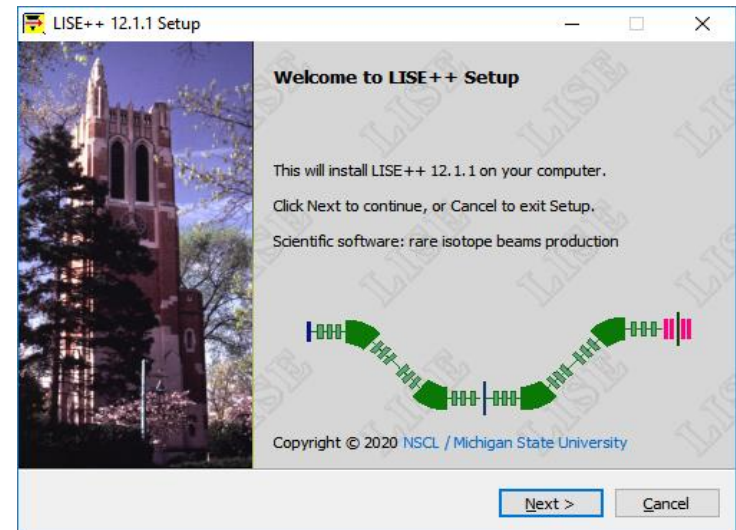


Rare Isotope Beam Production with Fragment Separators

- The program LISE++ is designed to predict the intensity and purity of rare isotope beams (RIB) produced by In-flight separators
- The program is constantly expanding and evolving from the feedback of its users around the world
- The LISE++ package includes configuration files for most of the existing fragment and recoil separators found in the world
- Many “satellite” tools have been incorporated into the LISE++ framework
- The code operates under MS Windows environment and provides a highly user-friendly interface
- It can be freely downloaded from the following internet addresses: <http://lise.nslc.msu.edu>



The screenshot shows the LISE++ website homepage. The browser address bar displays "lise.nslc.msu.edu/lise.html". The page title is "EXOTIC BEAM PRODUCTION WITH FRAGMENT SEPARATORS". A navigation menu on the left includes: Home, Introduction, Documentation, Last Changes, Utilities, Perspectives, Download, Spectrometers, Related topics, Personal pages, Registration, and Email. The main content area features a "Range of application" section with text describing the program's capabilities, such as calculating transmission and yields of fragments, and simulating experiments. A version number "v.12" is visible at the bottom left of the page.

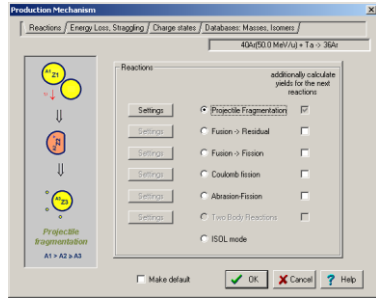


The screenshot shows the "LISE++ 12.1.1 Setup" window. The window title is "LISE++ 12.1.1 Setup". The main text reads: "Welcome to LISE++ Setup", "This will install LISE++ 12.1.1 on your computer.", "Click Next to continue, or Cancel to exit Setup.", and "Scientific software: rare isotope beams production". Below the text is a diagram of a fragment separator, showing a series of magnets and a particle path. At the bottom, there are "Next >" and "Cancel" buttons. The copyright notice at the bottom reads "Copyright © 2020 NSCL / Michigan State University".

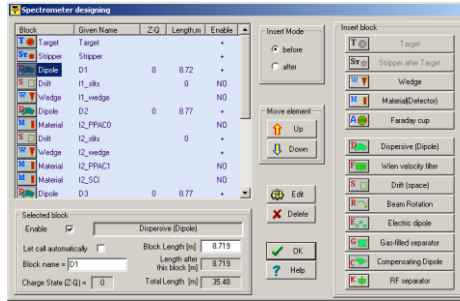
Main LISE++ Functions

- predict the fragment separator settings necessary to obtain a specific RIB
- predict the intensity and purity of the chosen RIB
- simulate identification plots for on-line comparison
- provide a highly user-friendly graphical environment
- allow configuration for different fragment separators

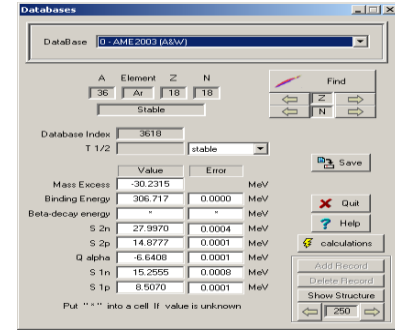
LISE++ physics:
Production mechanisms,
energy loss etc



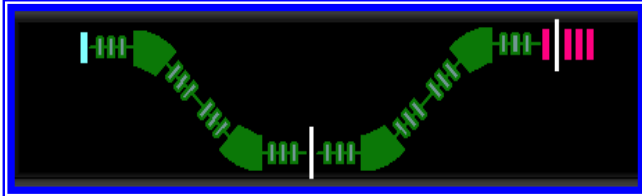
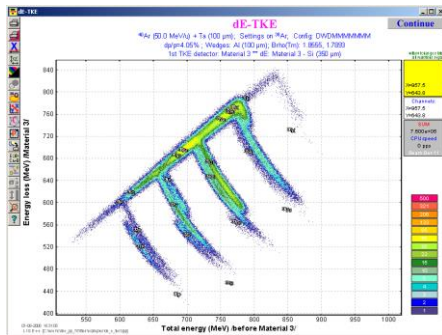
Shell to construct a spectrometer



LISE++ databases

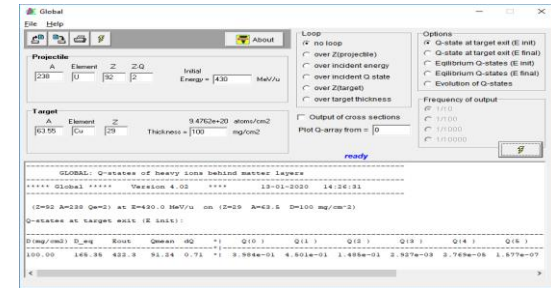


LISE++ graphics



Beam Optics calculation and optimization

LISE++ utilities and satellites



LISE++ in Action

LISE++ [C:\Program Files\LISE\files\examples\de_e_test.lpp]

File Settings Options Calculations Utilities 1D-Plot 2D-Plot Databases Help

Projectile 40Ar¹⁸⁺
50 MeV/u 1000 enA

Fragment 36Ar¹⁸⁺

Target Ta
100 micron

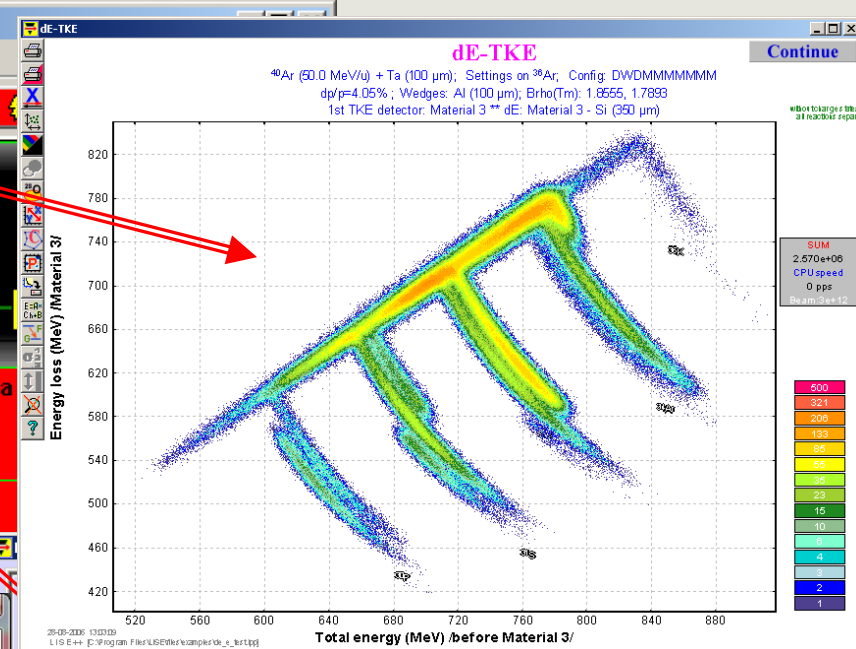
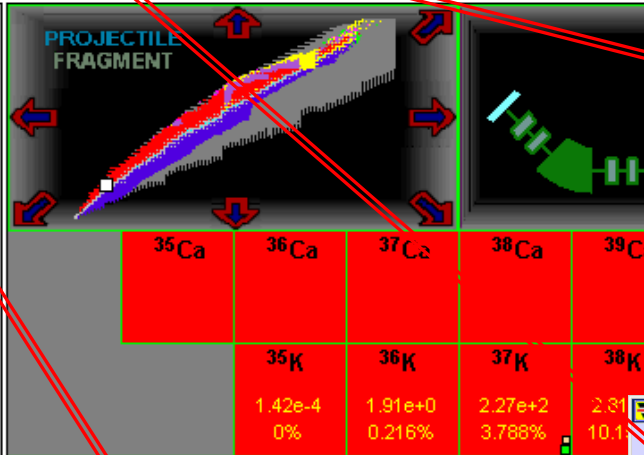
Stripper

Dipole 1 Brho 1.8555 Tm
-35 H +35
-20 V +20

Wedge Al
100 micron

Dipole 2 Brho 1.7893 Tm

Material 1 Si



Spectrometer designing

Block	Given Name	Z-Q	Length,m	Enable
Target	Target			+
Stripper	Stripper			+
Dipole	D1	0	8.72	+
Drift	I1_slits	0	NO	NO
Wedge	I1_wedge			NO
Dipole	D2	0	8.77	+
Material	I2_PPAC0			NO
Drift	I2_slits	0	+	
Wedge	I2_wedge			NO
Material	I2_PPAC1			NO
Material	I2_SCI			NO
Dipole	D3	0	8.77	+
Drift	I3_slits	0	NO	NO
Wedge	I3_wedge			NO
Dipole	D4	0	9.39	+

Insert Mode
 before
 after

Move element
Up
Down

Edit
Delete
OK
Help

Selected block: Dispersive (Dipole)

Enable

Let call automatically

Block name = D1

Charge State (Z-Q) = 0

Dispersive (Dipole)
Block Length [m] 8.719
Length after this block [m] 8.719
Sequence number 3

Total
Number of Blocks 26
Length [m] 35.643

Insert block:
Target
Stripper after Target
Wedge
Material (Detector)
Faraday cup
Dispersive (Dipole)
Wien velocity filter
Drift (space)
Beam Rotation
Electric dipole
Gas-filled separator
Compensating Dipole
RF separator
Solenoid
Delay (efficiency) block

Energy 12.0051 MeV/u Energy 11.9943 AMeV

Brho 1.0000 Tm TKE 431.793 MeV

Erho 47.7368 MJ/C Velocity 4.76718 cm/ns

P 5396.27 MeV/c Beta 0.159016

ptmstpt 0.299793 GeV/c Gamma 1.012888

After

Block	Z \ Thickness	MeV/u	MeV	MeV	<Q>
Material 1	Si 300 micron	0	0	431.79	0.00
Material 2	Si 250 micron	0	0	0	
Material 3	Si 350 micron	0	0	0	
Material 4	Si 500 micron	0	0	0	
Material 5					
Material 6					
Material 7					

Energy Strag.(sigma) 0.008037 MeV/u

Angular Strag.(sigma) 8.2974 mrad (plane)

Lateral spread (sigma) 0.29013 microns

Brho (for Q=Z) 0 Tm

Equilibrium values for material "Si"

Charge State <Q> 17.29

dQ (sigma) 0.66

Thickness *** mg/cm2

Range and Energy Loss to Si

Range dRange (sigma)

34.3447 0.07774 mg/cm2

147.402 0.33365 micron

Energy Remain. 0.000 MeV/u

Material thickness 34.345 mg/cm2

for energy rest 147.4 micron

Calculation method of

Energy Losses 2 Energy straggling 1

Charge States 3 Angular straggling 1

Print ? Help X Quit

Fragment Separator Construction

- With different sections called "blocks" (magnetic and electric multipoles, solenoid, velocity filter, RF deflector and buncher, material in beam, drift, rotation element, and others).
- A user-friendly interface that helps to seamlessly construct a fragment separator from the different blocks.

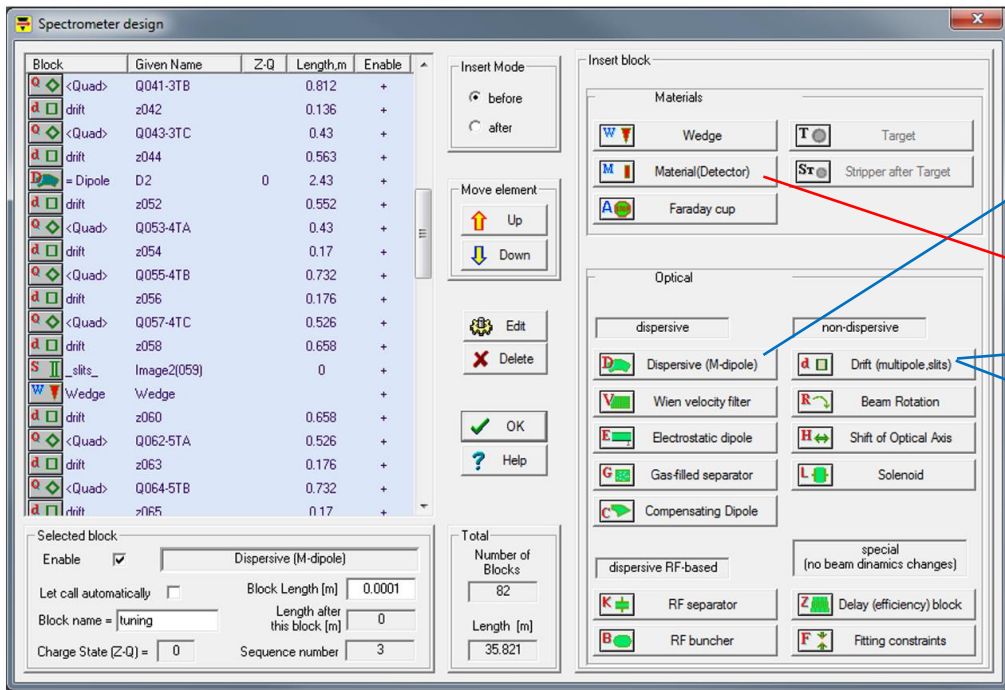
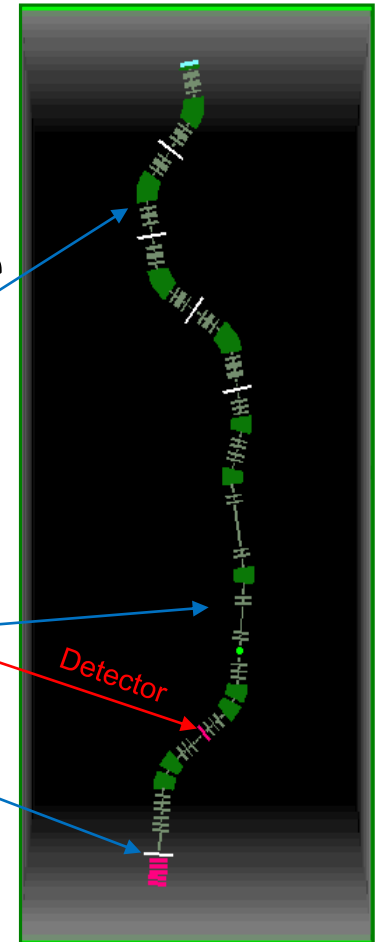
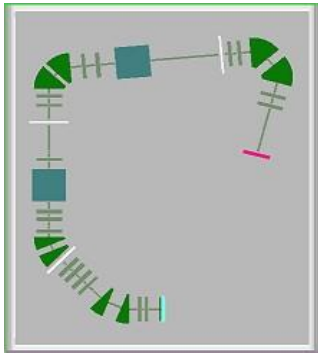


Fig. 1. Updated view of the "Spectrometer Design" dialog window.

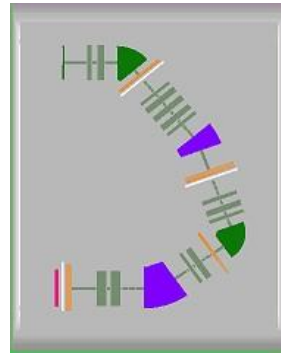


Configuration: A1900_S800BL
(2nd order) 164 blocks

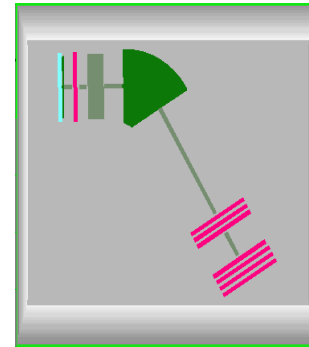
Examples of LISE++ Use



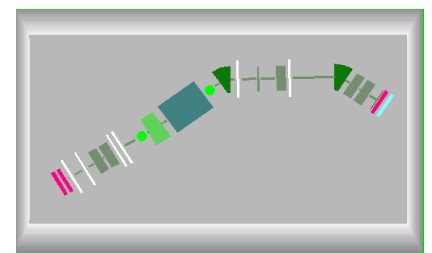
SECAR, MSU



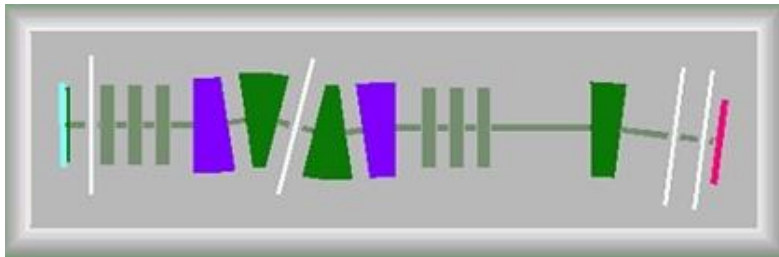
DRAGON, Canada



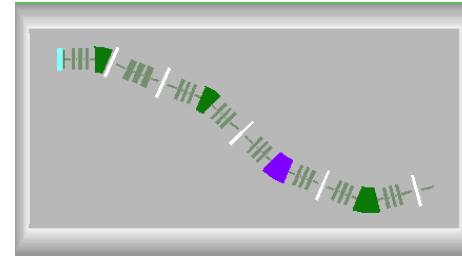
PRISMA, Italy



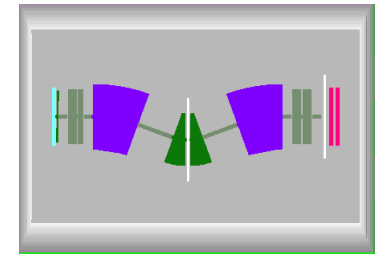
MARS,
Texas A&M U



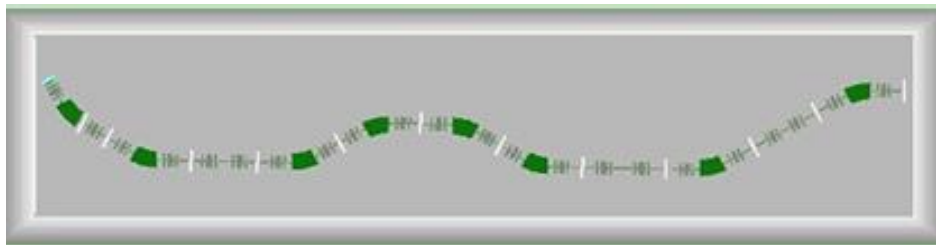
SHELS, Russia



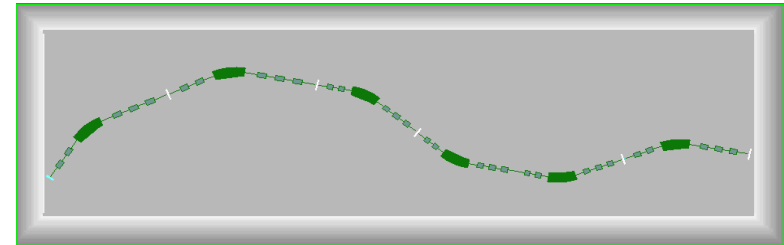
S³, France



FMA, ANL



BigRIPS+ZeroDegree, Japan



SuperFRS_HEB, Germany

World Wide Use: PAC requirements

- Some laboratory PACs require to attach RIB estimations done with the LISE++ code

A1900 @ NSCL

<http://www.nscl.msu.edu/exp/propexp/procedure>



National Superconducting Cyclotron Laboratory
Call for Proposals—PAC 37

February 2, 2012

Dear NSCL User:

We invite proposals for beam time to be considered at the next meeting of the NSCL Program

(C) An electronic copy of the LISE++ files used to obtain rare isotope intensity estimates with the official version of LISE++ (referenced in item 3 of the “Notes for PAC37” below). The LISE files can be e-mailed to the [A1900 Device Contact](#) at the time of submission of the proposal.

BigRIPS @ RIBF

<http://www.nishina.riken.jp/RIBF/BigRIPS/intensity.html>

RIBF



RIKEN Nishina Center for Accelerator-Based Science

Introduction to RI Beam Factory and Users' Information

[Nishina Center Top](#) [RIBF Top](#)

Facility Information

Accelerator

Intensity

BigRIPS

Intensity

RIPS

GARIS

SAMURAI

SHARAQ(CNS)

SR2

Biology Beamline

Material Beamline

CRIB(CNS)

KISS(KEK)

DAQ

User Guide

Access to RIBF

User Procedures

FAQ

For new visitors

[HOME](#) > [BigRIPS](#) > [Technical Information](#) > Secondary beam intensity expected

BigRIPS

[Overview](#) [Concept](#) [Configuration](#) [Technical Information](#) [Publication list /Link](#)

[Device Information \(password protected\)](#) [Secondary beam intensity expected](#) [BigRIPS optics](#) [ZeroDearee optics](#)

Technical Information - Secondary beam intensity expected

- [The LISE++ input file for BigRIPS is ready for use](#)
- [Production cross section for the \$^{48}\text{Ca}+\text{Be}\$ reaction at 345A MeV.](#)
- [Production cross section for the in-flight-fission \$^{238}\text{U}\$ \(345 A MeV\)+Be](#)
- [Production cross section for the in-flight-fission \$^{238}\text{U}\$ \(345 A MeV\)+Pb](#)
- [Estimated RI beam intensities \(for the first two years\)](#)
- [Estimated RI beam intensities \(nominal operating value\)](#)

The LISE++ input file for BigRIPS is ready for use

You can make detailed calculation using the LISE++ code [1] based on the standard configuration and ion optics of BigRIPS and ZeroDearee, and the experimental cross sections that we measured for in-flight fission of ^{238}U (345 A MeV) + Be in 2007 and 2008 [2]



National Science Foundation
Michigan State University



World Wide Use: configuration development inside laboratories

- The LISE++ code can be used at low-energy, medium-energy and high-energy facilities (fragment- and recoil-separators with electrostatic and/or magnetic selections)

LISE separator @ GANIL (France)

<http://pro.ganil-spiral2.eu/laboratory/experimental-areas/lise/technical-informations/lise-configuration/lise/>

The screenshot shows the LISE++ website interface. At the top, there's a banner for GANIL spiral2 and LISE. Below it, a navigation menu includes HOME, LABORATORY, USER'S GUIDE, SPIRAL2, EURISOL, SAFETY AND SECURITY, INDUSTRY, and SCIENTIFIC EVENTS. A search bar is also present. The main content area is titled 'LISE++' and contains text about the program's purpose: 'The program LIS++ is dedicated to calculate the transmission and yields of fragments produced and collected in a spectrometer LISE. Here are the different configurations Lise++ used for the tuning:'. It lists two modes: 'LISE 3 mode' and 'LISE 2K mode', each with specific configuration files and their parameters (angular acceptance and X_{foc}).

FRS @ GSI (Germany)

<http://web-docs.gsi.de/~weick/frs/frs-steps.html>

How to set up the FRS – From SIS extraction of primary beam to isotope identification

Tests

The FRS will be controlled and monitored from the console in the FRS Messhalle. T

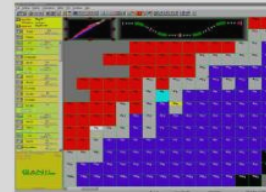


Operating console in Messhalle.

Before first Beam

Calculation of settings

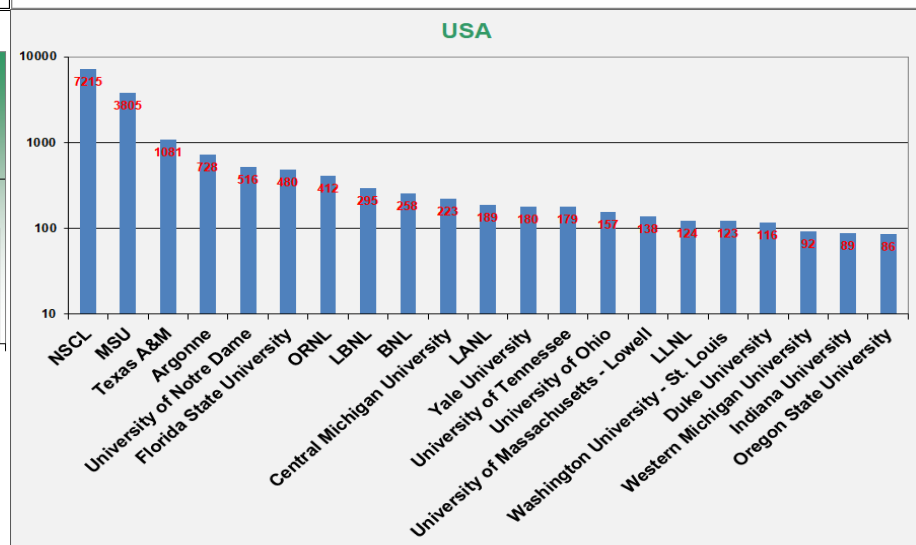
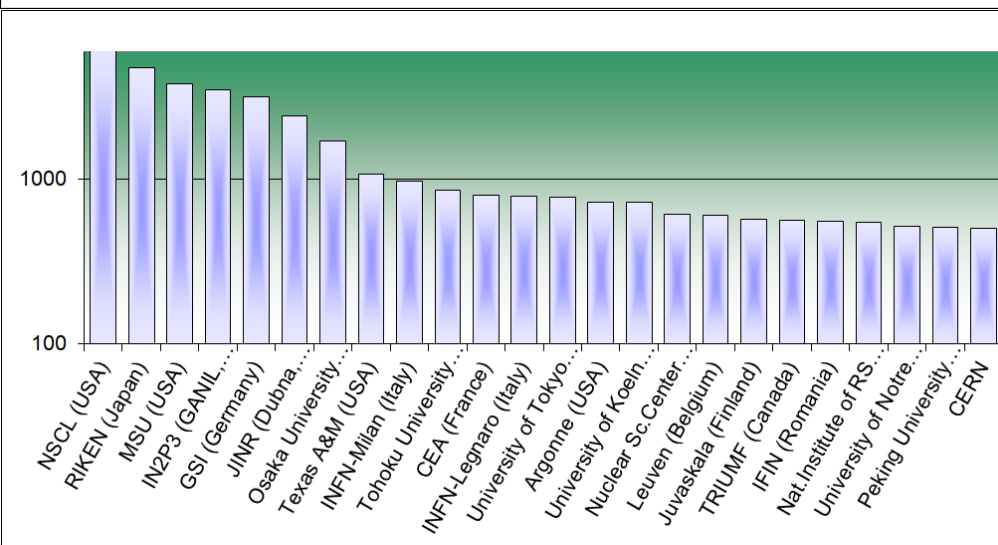
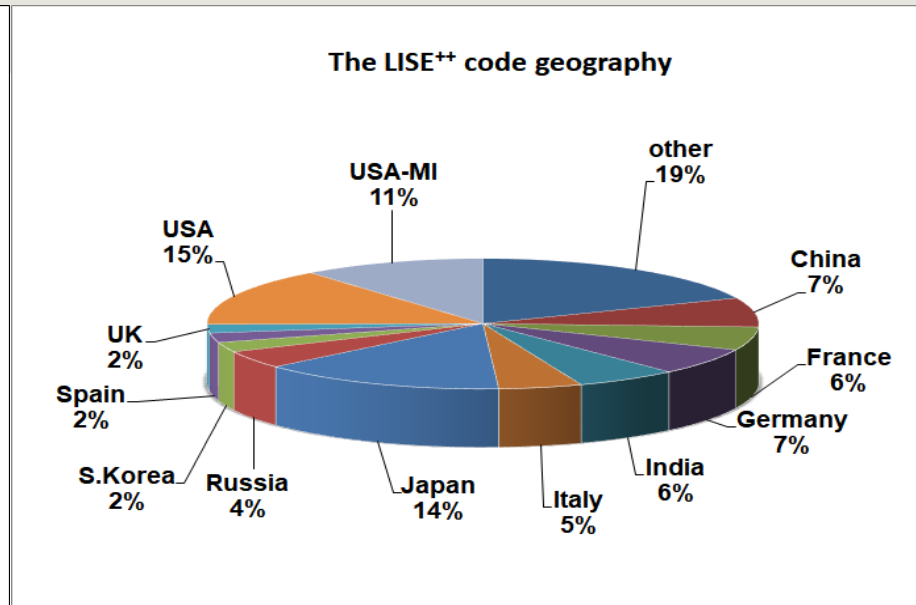
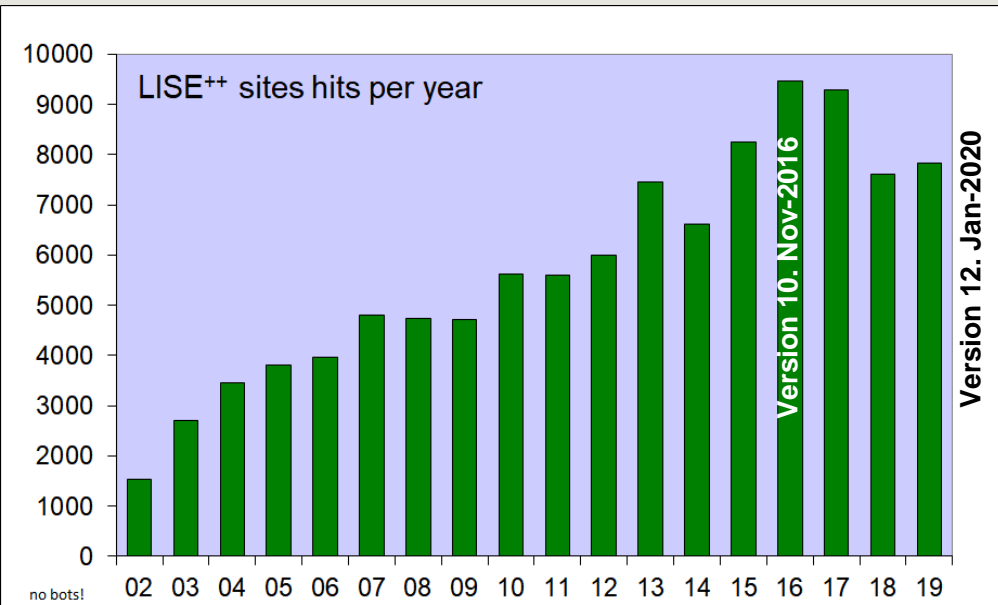
Prepare a data set in ATIMA, MOCADI or LISE with layers of matter (targets, dete For the primary beam ATIMA alone is enough (on LINUX 'u/weick/JavaAtima). For



Online Analysis

Name	Ext
[.]	
FRS - TA2 - CaveC (2012)	lcn
FRS - TA1-S4 std (2012)	lcn
FRS - TA2-S4 std (2012)	lcn
Super-FRS_LEB2008	lcn
Super-FRS_HEB2008	lcn
Super-FRS_RB2008	lcn
FRS - TA-ESR	lcn
FRS - TA-Cave C	lcn
FRS - FB07E to S8	lcn
FRS - ESR	lcn

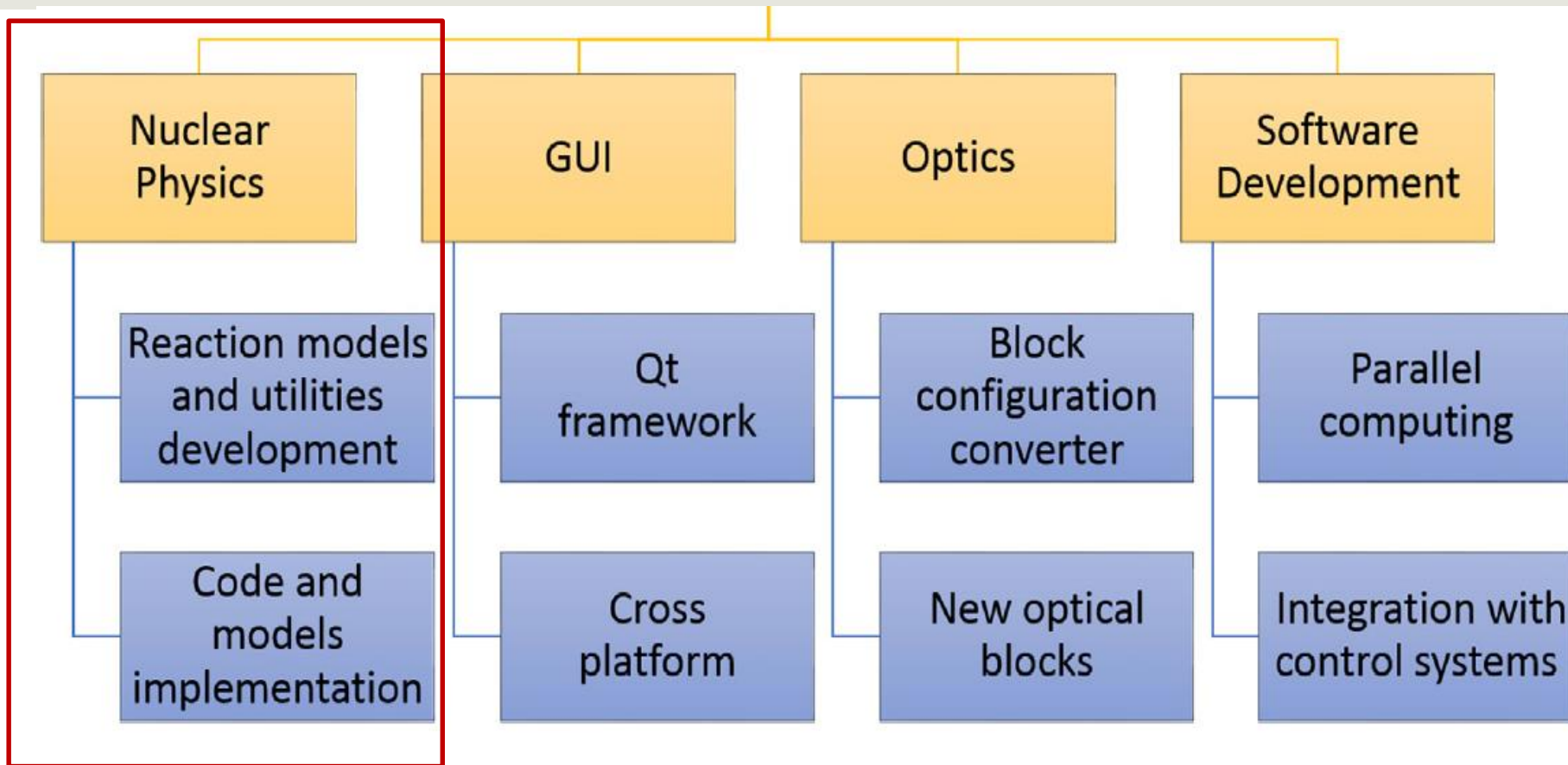
Statistics – LISE++ is Widely Used



National Science Foundation
Michigan State University



LISE++ development



This Proposal

Fig. A schematic diagram of the LISE++ development plans.

M.P. Kuchera et al./Nuclear Instruments and Methods in Physics Research B 376 (2016) 168–170

Reaction Mechanisms

- Not only using classical reaction mechanism models, but actively developing fast and accurate in-house models
- Includes fragment production in materials (wedges, detectors)

			cit-ns
O.B.Tarasov	Analysis of momentum distributions of projectile fragmentation products	NPA 734 (2004) 536-540	35
O.B.Tarasov, D.Bazin	Development of the program LISE: application to fusion–evaporation	NIM B204 (2003) 174-178	92
O.B.Tarasov, A.C.C.Villari	Fusion–fission is a new reaction mechanism to produce exotic radioactive beams	NIM B 266 (2008) 4670-4673	5
O.B.Tarasov	LISE ⁺⁺ development: application to low-energy fission of projectiles at relativistic energies	ENAM2004: EPJ A25 (2005) 751	3
O.B.Tarasov	LISE ⁺⁺ development: Abrasion-Fission	Preprint NSCL MSU, MSUCL-1300, 09.2005	

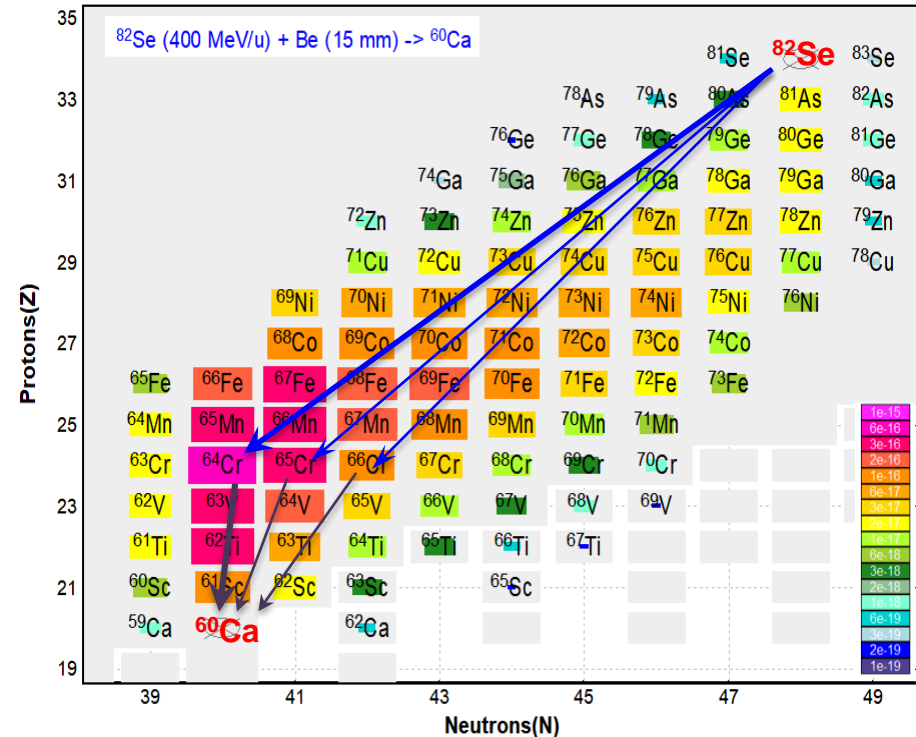
Reaction Models Development

- Development and improvement of fast model for multi-step reactions
- Investigate charge-exchange and pick-up reactions in RIB production
- Creation of Fast and accurate Abrasion-Fission model based on the Initial Fissile Nuclei Analyzer tables
- Intermediate Dissipation step in the Abrasion-Ablation model
- Implementation in LISE⁺⁺ code for transmission and cross section calculations
 - ETACHA4: Low-energy non-equilibrium charge state evolution
 - PACE4: Projection Angular-momentum coupled evaporation
 - INC: intranuclear cascade model to use at higher energies with light targets
- Theoretical study of prefragment excitation energy
- Systematization of experimental production cross-sections
- Creation of Monte Carlo de-excitation cascade utility to benchmark the analytical LISE⁺⁺ cascade subroutine and to create condition (gating) options

Multi-Step Reactions

- Multi-step reactions in thick targets is process then the projectile undergoes a series of successive reactions until the fragment of interest is produced
- For the second and next reactions we assume always a projectile fragmentation mechanism and uses the EPAX parameterization to speed up calculations

Parent nuclei: multistep production probability



LISE++ \rightarrow ^{64}Cr is more probable second-step projectile to produce ^{60}Ca with a ^{82}Se beam (400 MeV/u) on Be (15 mm).
 Total Multi-step reaction factor is equal to 10.1

Multi-Step Reactions Study

- The study (experimental and theoretical) of the multi-step reactions:
 - the development of a fast model for multistep reactions
 - the measurement of experimental secondary cross sections
- Important to approach the nucleon drip-lines
 - So, more probable path for ^{70}Ca production at FRIB is a three-step process:
 1. Abrasion of ^{238}U to low-excited ^{237}U ($E^* \sim 32$ MeV) with sequential fission to ^{81}Ga ($2e-2$ mb)
 2. First projectile fragmentation step : $^{81}\text{Ga} \rightarrow ^{76}\text{Fe}$ (-5p, $\sim 1e-5$ mb)
 3. Second projectile fragmentation step : $^{76}\text{Fe} \rightarrow ^{70}\text{Ca}$ (-6p, $\sim 1e-6$ mb)
- MSU-RIKEN collaboration recent experiments with multi-step reactions analysis in process:
 - Production of neutron-rich isotopes around ^{60}Ca by projectile fragmentation of a beam of ^{70}Zn at 345 MeV/u (*O.Tarasov et al., PRL 121 (2018) 022501*)
 - Production of very neutron-rich Pd isotopes around $N = 82$ by projectile fragmentation of a RI beam of ^{132}Sn at 280 MeV/u (*H.Suzuki et al.*)

Charge-Exchange Reactions (1)

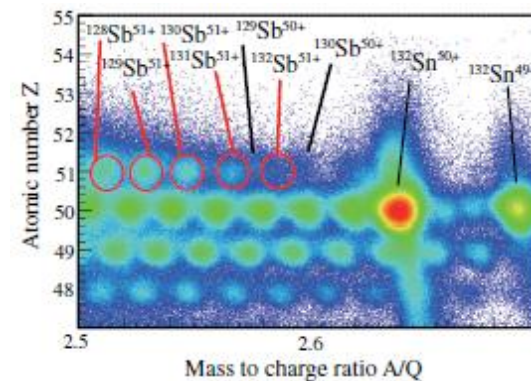
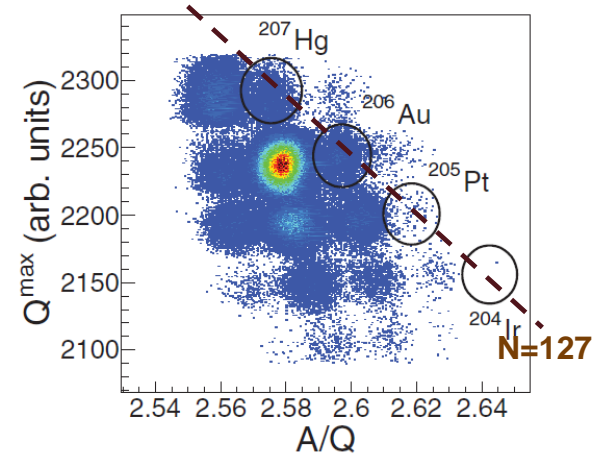
- The study (experimental and theoretical) of the charge-exchange mechanism as a **step for rare isotope production**

- (p,n)

- A. I. Morales, J. Benlliure et al.,
PRC84, 011601(R) (2011)
 $^{208}\text{Pb}_{126}$ (1 AGeV) + Be

- (n,p)

- J. Yasuda, M. Sasano, et al.,
PRL 121, 132501 (2018)
 ^{132}Sn (200 MeV/u) + H \rightarrow $^{**}\text{Sb}$
 - D. Kostyleva, I. Mukha et al.,
PRL 123, 092502 (2019)
 ^{31}Ar (620 MeV/u) + Be \rightarrow ^{31}K

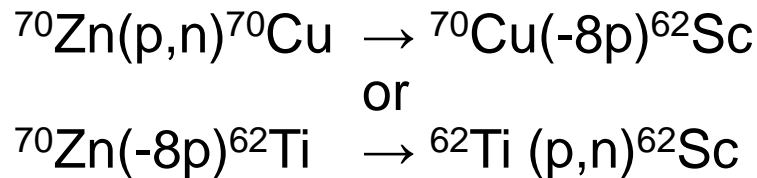


Charge-Exchange Reactions (2)

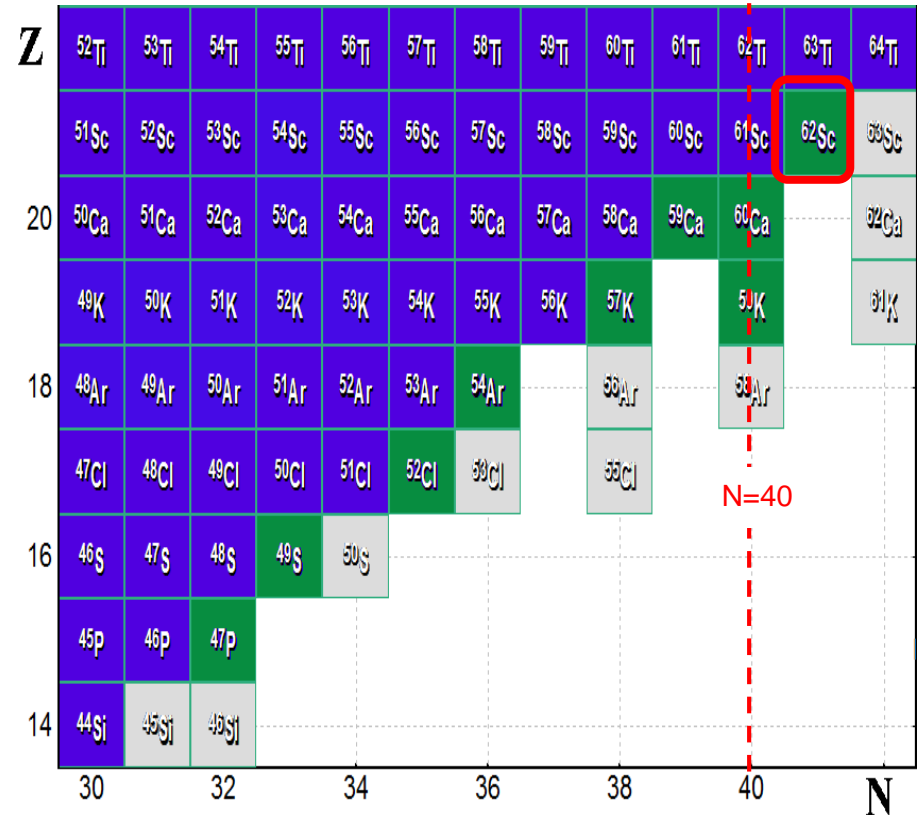
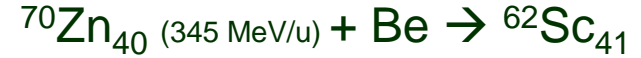
Recent “ ^{60}Ca ” experiment at RIKEN

O.Tarasov et al., PRL 121 (2018) 022501

- Production of ^{62}Sc is $-9p,+1n$
- Pickup is suppressed at these energies
- Two-step reactions through a charge-exchange channel?



- Cross sections are under analysis
- Charge-exchange reactions become an important mechanism for the Rare Isotopes production



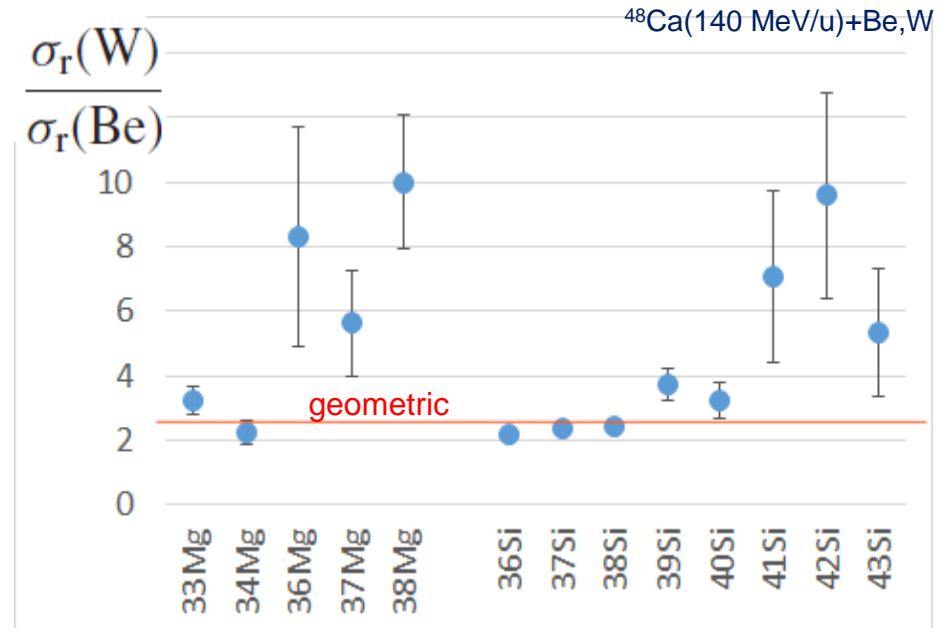
Target factor

- The study of the target factor in rare isotope yields for energies 50–150 MeV/u

- $^{48}\text{Ca}(140 \text{ MeV/u}) + \text{Be}, \text{W}$

- ^{40}Mg , $^{42,43}\text{Al}$:
T. Baumann, et al.,
Nature 449 (2007) 1022
- ^{44}Si :
O.B.Tarasov, et al.,
PRC75 (2007) 064613

- $^{198}\text{Pt}(85 \text{ MeV/u}) + \text{Be}, \text{Ni}$
NCSL/MSU, 2019
O.Tarasov et al, under analysis



The cross sections for reaction with the tungsten target are larger than those with beryllium by factors that range from approximately 2.5 at $A = 36$ ($Z=14$) to about 10 at $A = 42$, values that become significantly larger than the ratio of the geo-metric reaction cross sections equal to 2.66






LISE++ porting

- The LISE++ code is developing at Borland C++ 5.02 IDE (integrating development environment), which is not compatible with the next Borland (Builder, Embarcadero C++) generations
- The LISE++ software suite is undergoing a major transportation to a new graphics framework (Qt) in order to
 - Aid in sustainability of the code
 - Support modern compilers and computing methods:
 - ✓ 64-bit operation
 - ✓ cross-platform compatibility (Windows, Mac, and Linux versions)
 - ✓ the ability to take advantage of computational advances (for example parallel computing methods)
 - ✓ Integration with control systems

Summary

- The program LISE⁺⁺ is designed to predict the intensity and purity of rare isotope beams (RIB) is widely used at heavy ion collision facilities
- A**
B ■ The program is constantly expanding and evolving from the feedback of its users around the world
- A**
C ■ Fast and accurate models of rare isotope production mechanism are being developed in the LISE⁺⁺ framework
- B** ■ Work is underway to update the LISE⁺⁺ software suite by transferring to a new graphics framework, Qt, to use with modern compilers
- B** ■ New code capabilities such as parallel computing, cross-platform functionality, and integration with control systems are planned
- B** ■ Computational speedup is requested from users at many facilities, and becomes more crucial with the new large-scale nuclear physics facilities under construction, such as FRIB and FAIR, that have keen interest in integrating the LISE⁺⁺ software with their control systems

Site visit charge - symbols

-  Intellectual Merit
-  Broader Impacts
-  Synergy Between PIs
-  Budget Analysis
-  Broader Impacts out of this proposal

Reaction Mechanisms

- In recent years, the LISE⁺⁺ group has been the leader in the development of rare isotope production mechanism models

12.1.1
07-01-20

- Universal parameterization ('Convolution' method) revision
- AA model minimization to describe user cross sections
- Initial Fissile Nuclei Analyzer (IFN)
- AF 3EER: High Z isotopes production
- Plotting and passing both two fission fragments
- Two Fission Fragments registration efficiency BATCH

Projectile fragmentation

Abrasion-Fission

In-flight Fission
products registration

10.0
18-11-16

- Update of Fusion reaction mechanism
- FRIB Theory Alliance mass predictions

Fusion-Fission
Fusion-Residual

Applied for excited
prefragment reactions

LISE++ Powerful Tools

Besides analytical calculation of the transmission and yields of fragments

- Monte Carlo simulation of fragment transmission,
- Monte Carlo simulation of fission fragment kinematics,
- Ion Optics calculation and Optimization ,
- LISE for Excel (MS Windows, Mac OS - download)

LISE++ calculators:

- "Physical Calculator",
- "Relativistic Kinematics Calculator",
- "Evaporation Calculator",
- "Radiation Residue Calculator" (new),
- "Ion Mass calculator" (new),
- "Matrix calculator"
- "Initial Fissile Nuclei analyzer" (new)

Implemented codes:

- «PACE4» (fusion-evaporation code),
- «MOTER» (raytracing-type program for magnetic optic system design)
- «ETACHA4» (charge-state distribution code) (new),
- «Global» (charge-state distribution code),
- «Charge» (charge-state distribution code),
- «Spectroscopic Calculator» (of J.Kantele«)

LISE++ Utilities:

- Stripper Foil Lifetime Utility,
- Brho Analyzer,
- Twinsol (solenoid) utility,
- Units Converter,
- ISOL Catcher,
- Decay Analysis (includes Proton, Alpha, Cluster, Sp.Fission half-lives calculation),
- Reaction Utilities (Characteristics, Converters, Plots),
- «BI»- the automatized search of two-dimensional peaks in spectra

Databases:

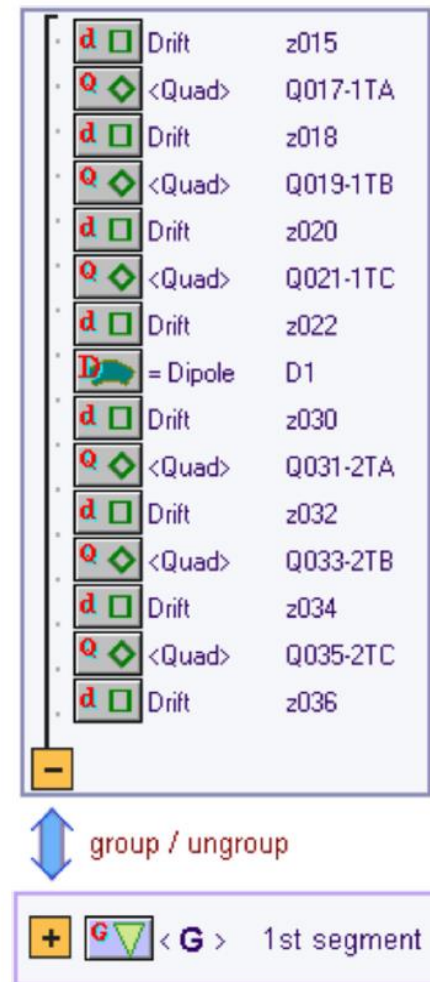
- Nuclide and Isomeric State databases with utilities,
- Large Set of Calculated Mass Tables (includes FRIB mass tables),
- Ionization Energy database (used with the Ion Mass calculator),
- Decay Branching Ratio database (used with the Radiation Residue calculator)



Ion Optics: Block Configuration Converter

■ Configurations

- **S**egmented: comprised of Sector (S) blocks, which are dispersive blocks that can contain quadrupole and dipole magnets, drift elements, along with other optical components – *fast analytical calculations for planning experiments*
- **E**xtended: all elements are separated into their own blocks and their matrices can be calculated and used in minimization by the LISE⁺⁺ code – *Monte Carlo high-order optics transmission calculations*
- **C**onverter: This new tool will be built around a new type of block, labeled **G** (Group), which allows the grouping E blocks to S block, and reverse ungrouping.



The new LISE⁺⁺ feature for converting a series of extended blocks to a single segmented block.