FRIB

$LISE^{++}_{cute}$,

Reaction Mechanisms for Exotic Nuclei Production

Oleg Tarasov

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8th International Expert Meeting on challenging issues of next-generation high-intensity in-flight separators

January 14–16, 2025; RIKEN Nishina Center, Saitama, Japan

U.S. DEPARTMENT OF ENERGY | Office of Science

MICHIGAN STATE UNIVERSITY

National Science Foundation

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Content

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  - **Abrasion-Ablation**
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- **LISE site statistics**
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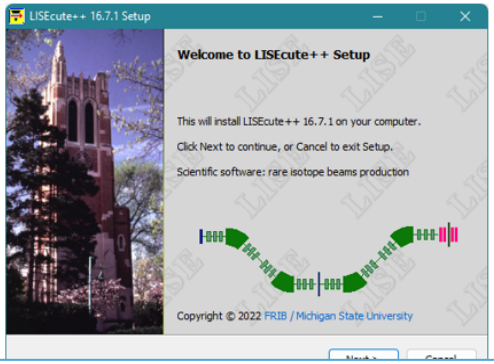
- **Acknowledgements**

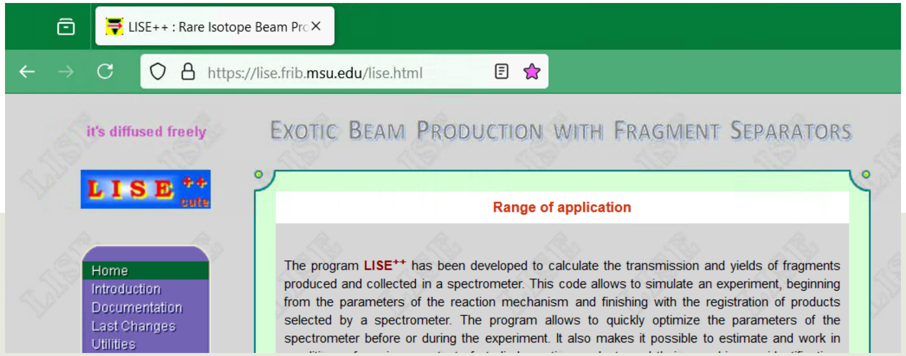
Introduction

Introduction

LISE^{++} : 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
- Many “satellite” tools have been incorporated into the LISE^{++} framework
- It can be freely downloaded from the following internet addresses: http://lise.nscl.msu.edu





Squeezed for the experts meeting

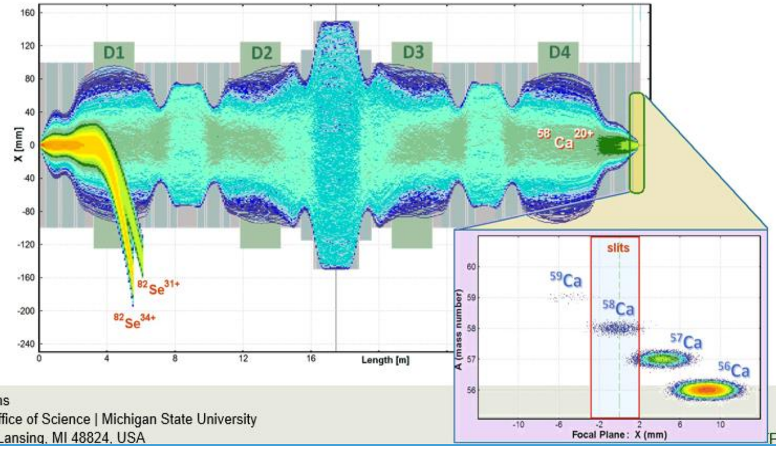
Main LISE^{++} Functions

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



X-envelope
^{82}Se → ^{58}Ca @ A1900

“wedge” selection

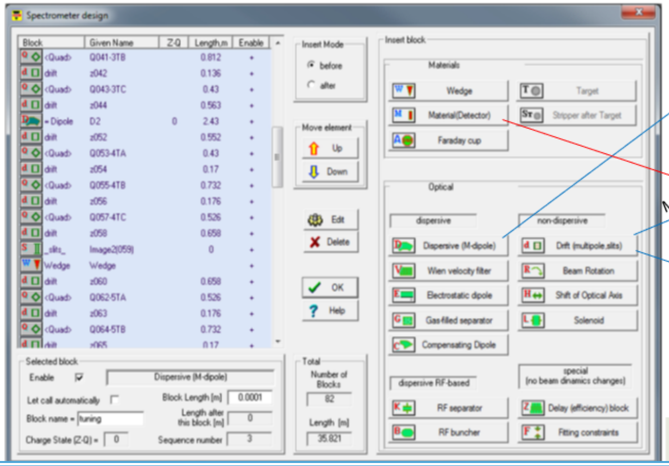
Facility for Rare Isotope Beams
U.S. Department of Energy Office of Science | Michigan State University
640 South Shaw Lane • East Lansing, MI 48824, USA

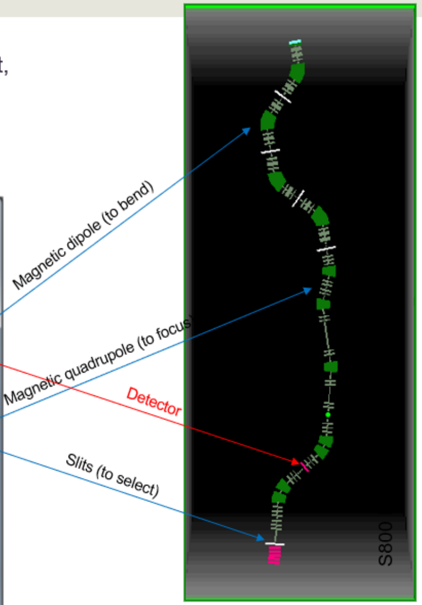
EN.JP, 16 January 2025, Slide 2

FRIB

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.

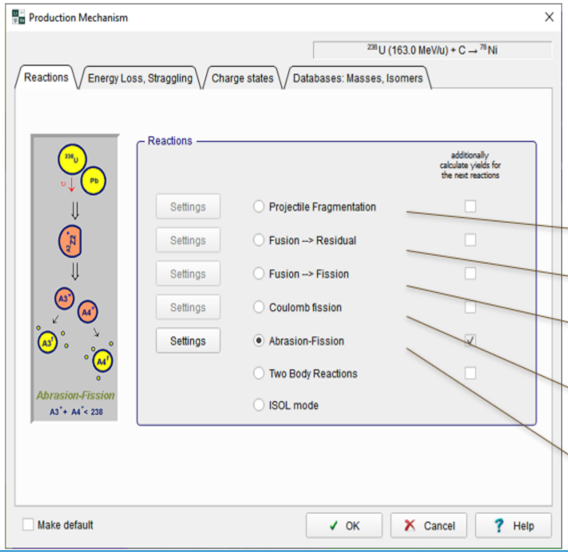




Configuration: A1900_S800BL (2nd order) 164 blocks

Reaction Mechanisms

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



O.B.Tarasov	Analysis of momentum distributions of projectile fragmentation products	NPA 734 (2004) 536-540
O.B.Tarasov, D.Bazin	Development of the program LISE: application to fusion–evaporation	NIM B204 (2003) 174-178
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
O.B.Tarasov	LISE++ development: application to low-energy fission of projectiles at realtivistic energies	ENAM2004: EPJ A25 (2005) 751
O.B.Tarasov	LISE++ development: Abrasion-Fission	Preprint NSCL MSU, MSUCL-1300, 09.2005

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:

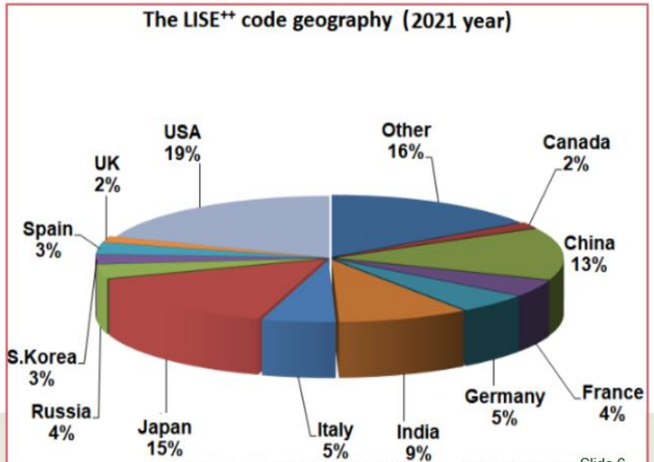
- «PACE4» (fusion-evaporation code),
- «MOTER» (raytracing-type program for magnetic optic system design)
- «ETACHA4» (charge-state distribution code) *(new)*,
- «Global» (charge-state distribution code),
- «Charge» (charge-state distribution code),
- «Spectroscopic Calculator" (of J.Kantele»)

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:

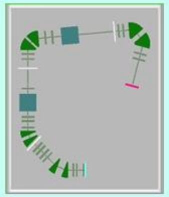
- Nuclide and Isomeric State databases with utilities,
- Large Set of Calculated Mass Tables (includes FRIB mass tables),
- Ionization Energy database (used with the Ion Mass calculator),
- Decay Branching Ratio database (used with the Radiation Residue calculator)



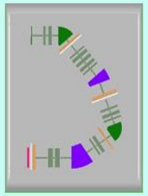
Application : Energy region and Facilities

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

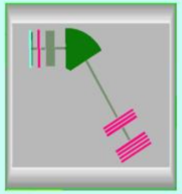
The LISE++ package includes configuration files for most of the existing fragment and recoil separators



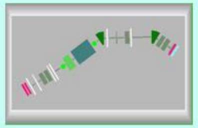
SECAR, *MSU*



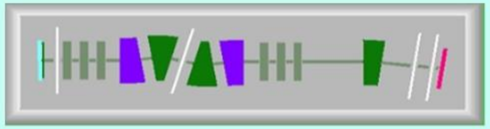
DRAGON, *Canada*



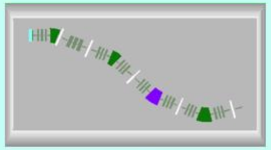
PRISMA, *Italy*



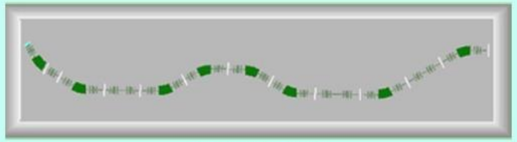
MARS, *TAMU, USA*



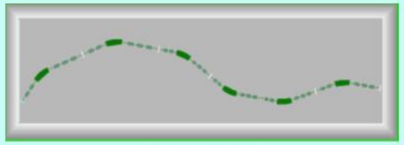
SHELS, *Russia*



S3, *France*



BigRIPS+ZeroDegree, *Japan*



SuperFRS_HEB, *Germany*

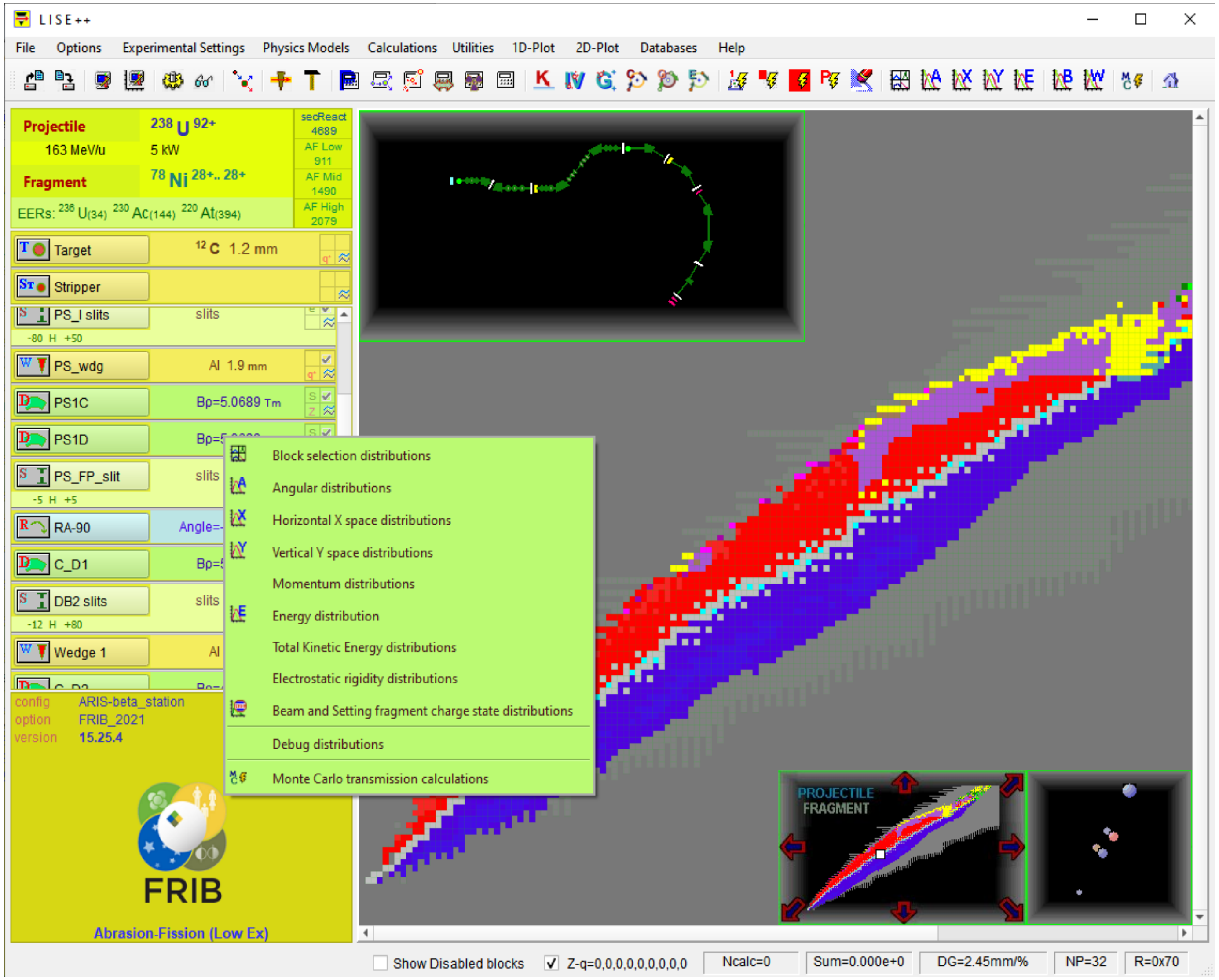
LISE^{++} porting

This time is better known as the time of Covid…

LISE^{++} transportation → LISE$^{++}_{cute}$

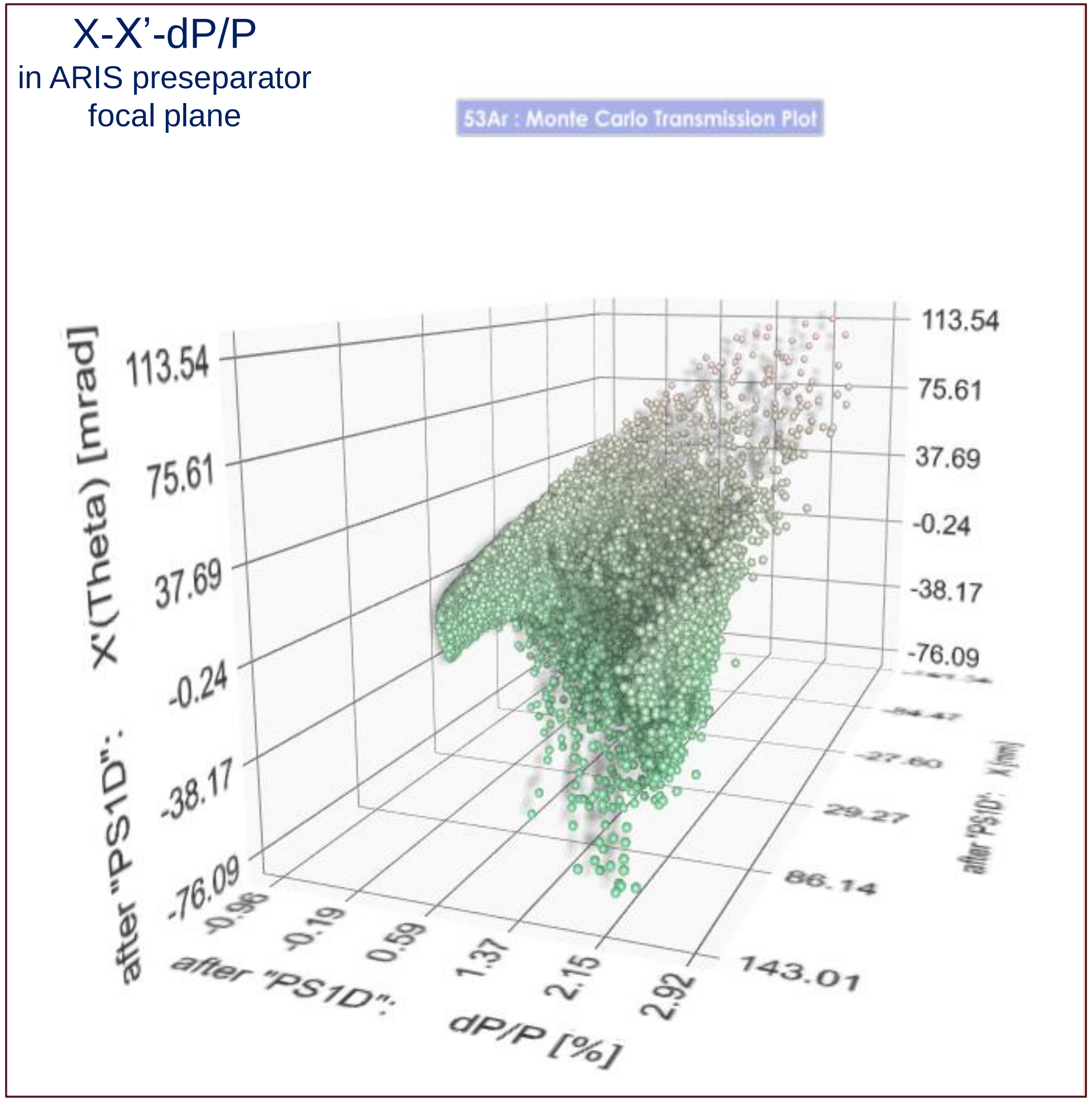
- The LISE^{++} code (v.6-13) was developing at Borland C++ 5.02 IDE (integrating development environment), which is not compatible with the next Borland (Builder, Embarcadero C++) generations
- The LISE^{++} software suite was ported to Qt-framework in order to
  - Aid in sustainability of the code
  - Support modern compilers and computing methods:
    - ✓ 64-bit operation
    - ✓ Cross-platform compatibility (Windows, Mac, and Linux versions)
    - ✓ The ability to take advantage of computational progress (for example parallel computing methods)
    - ✓ Integration with control systems

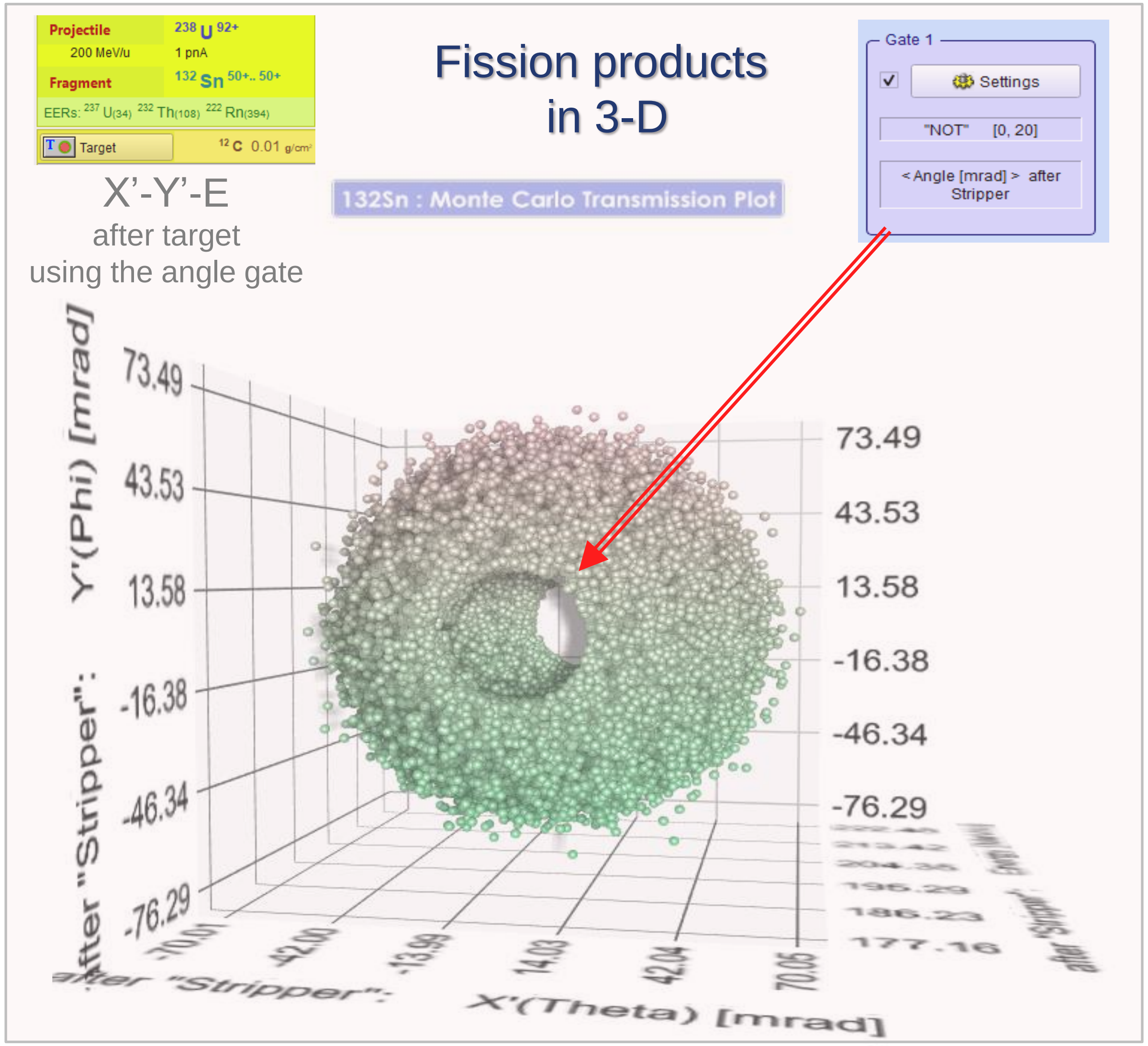
1998:	Currently:
MS-DOS version	811 cpp-files
14 cpp-files	565 h-files
	262 dialogs



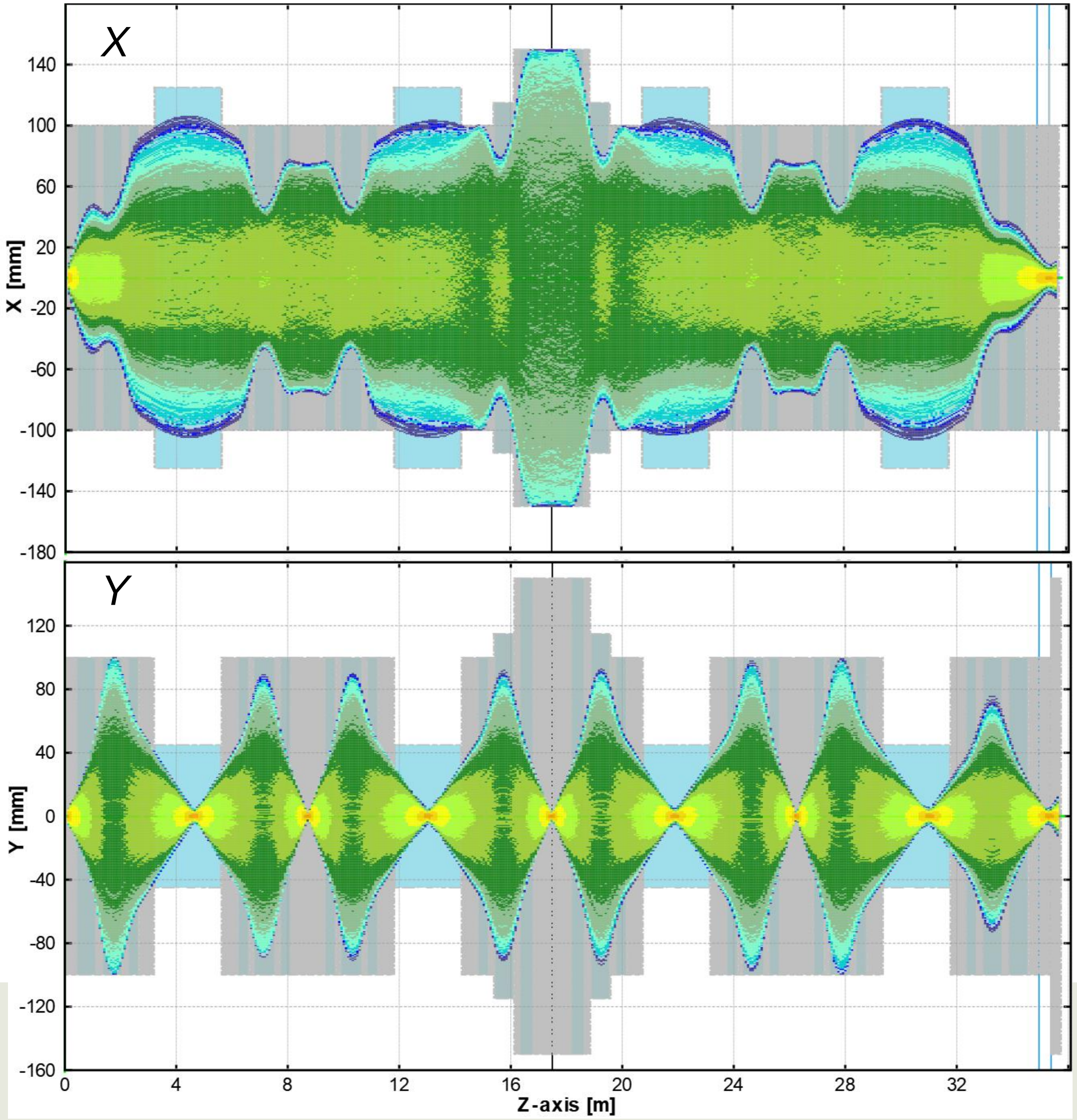
LISE^{++}, created using the Qt framework, is named LISE$_{cute}$ to indicate a new generation different from the previous Borland-based versions.

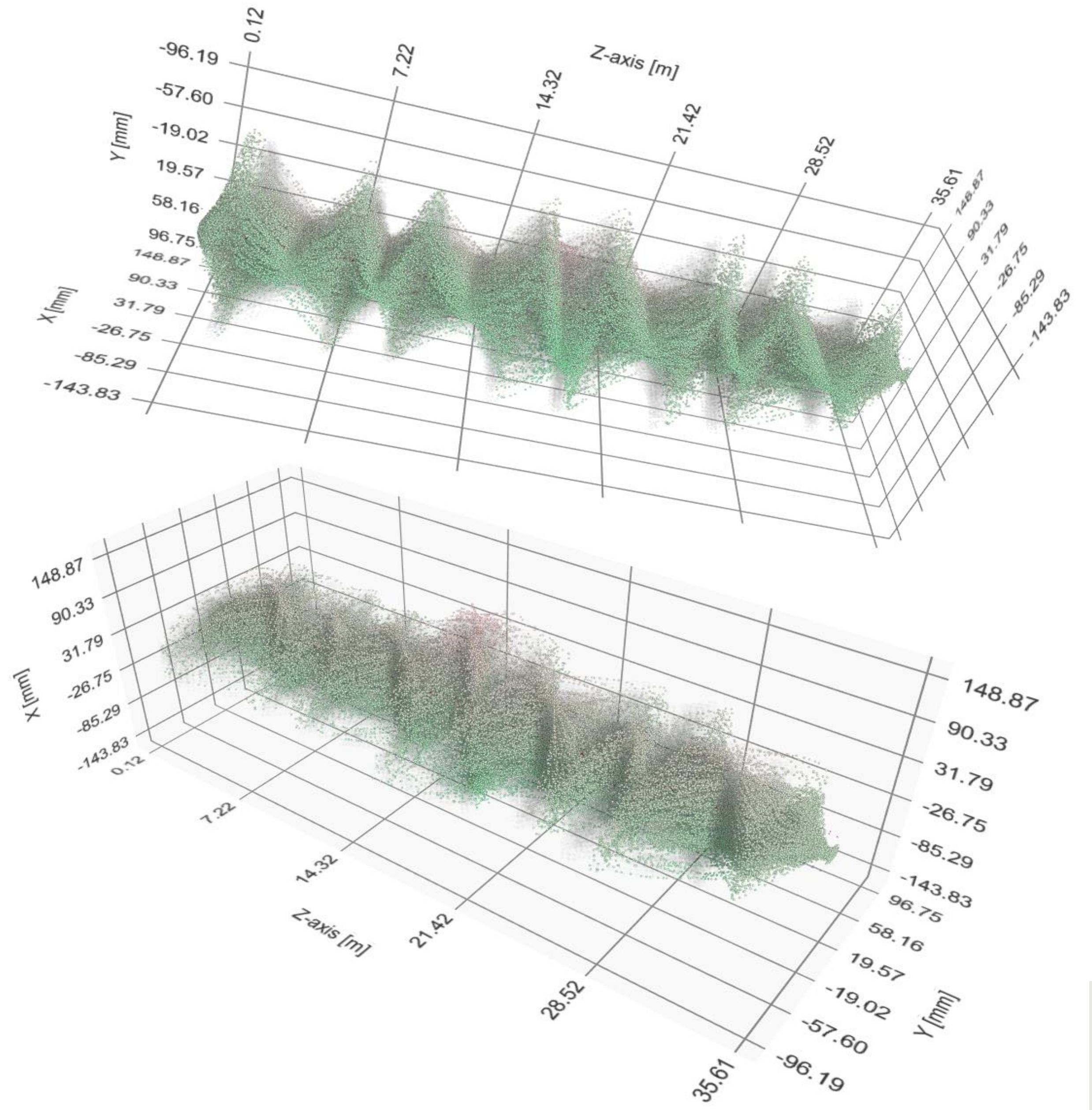
New Feature: 3-D Monte Carlo Transmission Plots



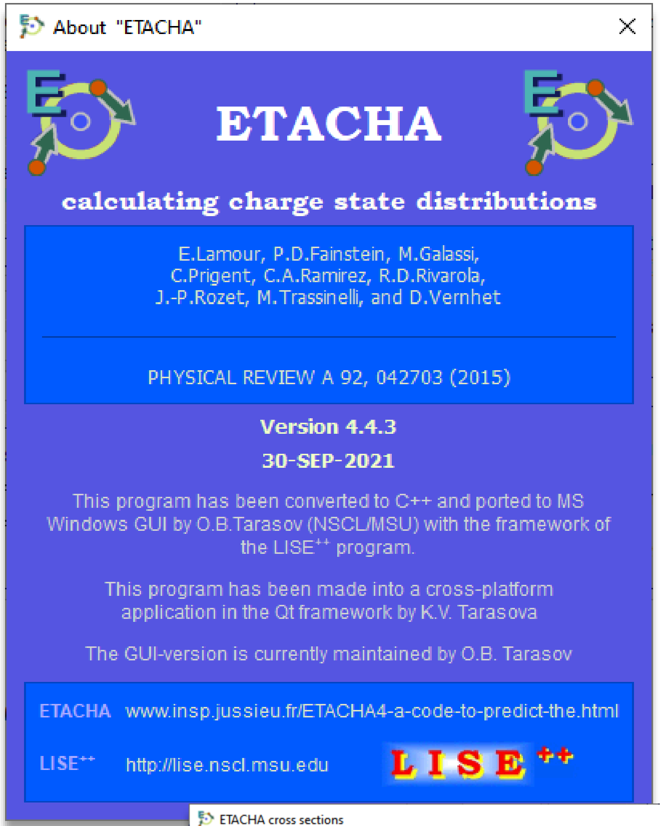


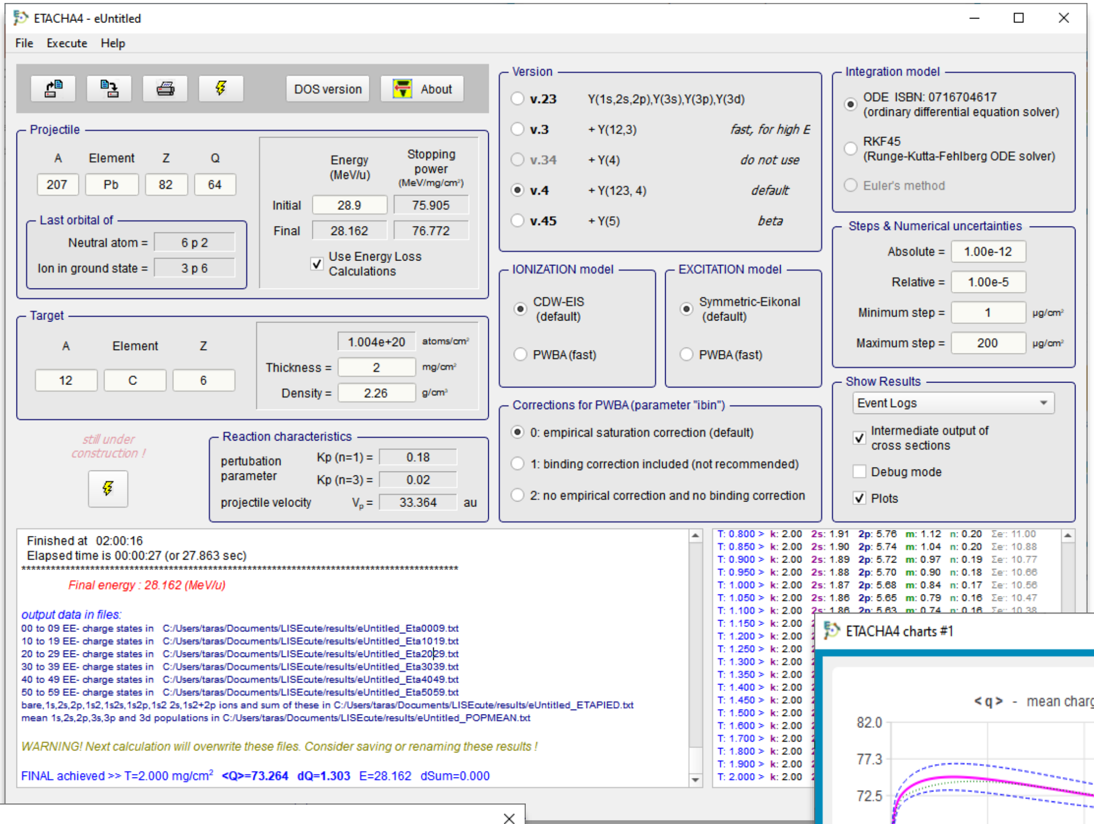
3-D Monte Carlo Envelope Plots



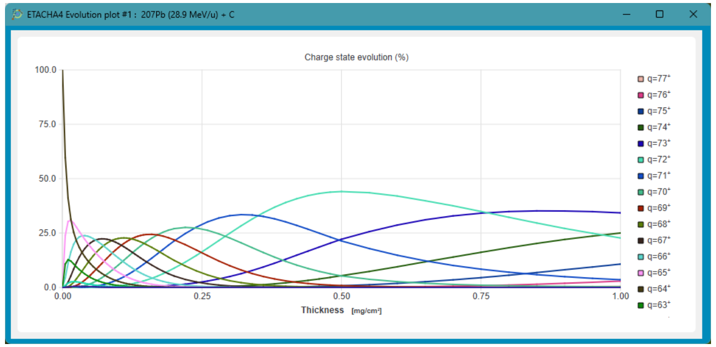


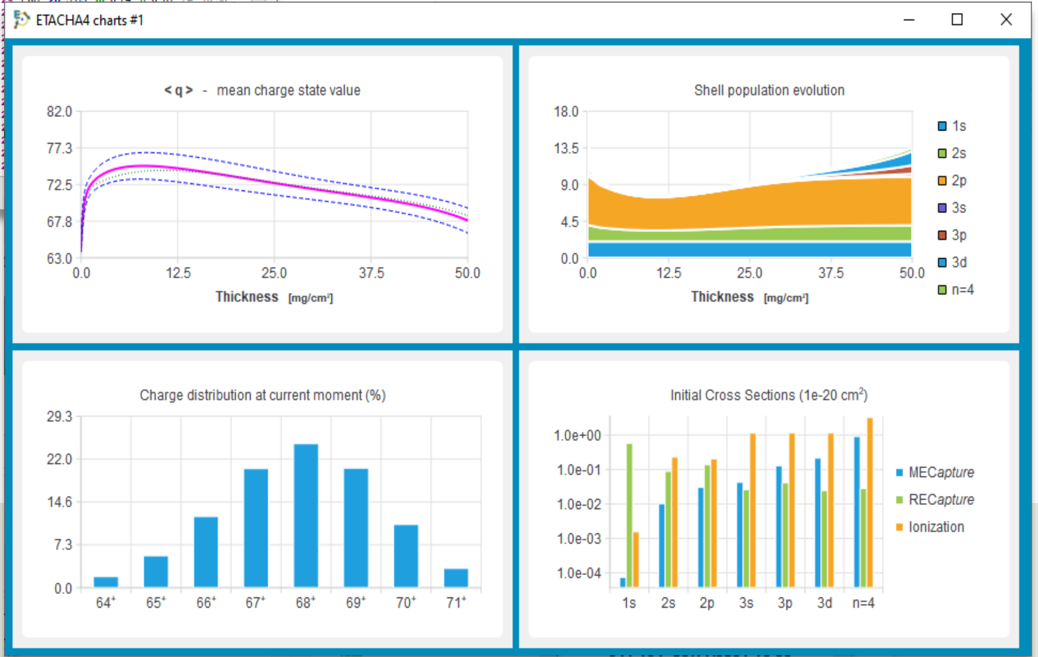
ETACHA4 porting and development: evolution plots and corrections

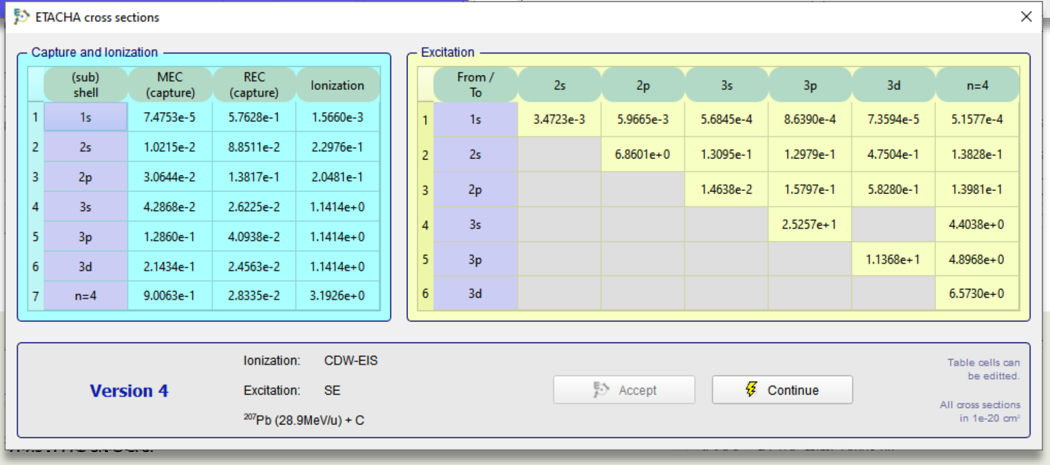




We are very grateful to Dr. Toshiyuki Sumikama (RIKEN) for the fast and quality analysis of bug locations during the porting process







Capture and Ionization

	(sub) shell	MEC (capture)	REC (capture)	Ionization
1	1s	7.4753e-5	5.7628e-1	1.5660e-3
2	2s	1.0215e-2	8.8511e-2	2.2976e-1
3	2p	3.0644e-2	1.3817e-1	2.0481e-1
4	3s	4.2868e-2	2.6225e-2	1.1414e+0
5	3p	1.2860e-1	4.0938e-2	1.1414e+0
6	3d	2.1434e-1	2.4563e-2	1.1414e+0
7	n=4	9.0063e-1	2.8335e-2	3.1926e+0

Excitation

	From / To	2s	2p	3s	3p	3d	n=4
1	1s	3.4723e-3	5.9665e-3	5.6845e-4	8.6390e-4	7.3594e-5	5.1577e-4
2	2s		6.8601e+0	1.3095e-1	1.2979e-1	4.7504e-1	1.3828e-1
3	2p			1.4638e-2	1.5797e-1	5.8280e-1	1.3981e-1
4	3s				2.5257e+1		4.4038e+0
5	3p					1.1368e+1	4.8968e+0
6	3d						6.5730e+0

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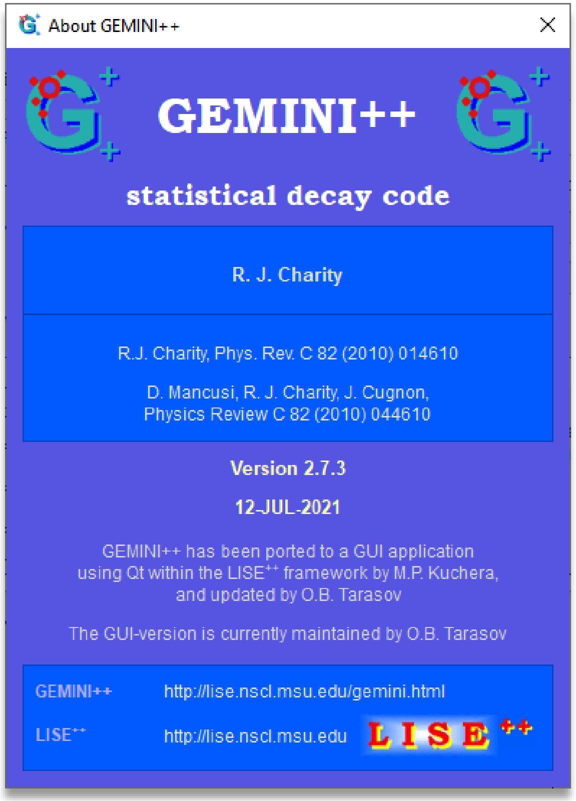
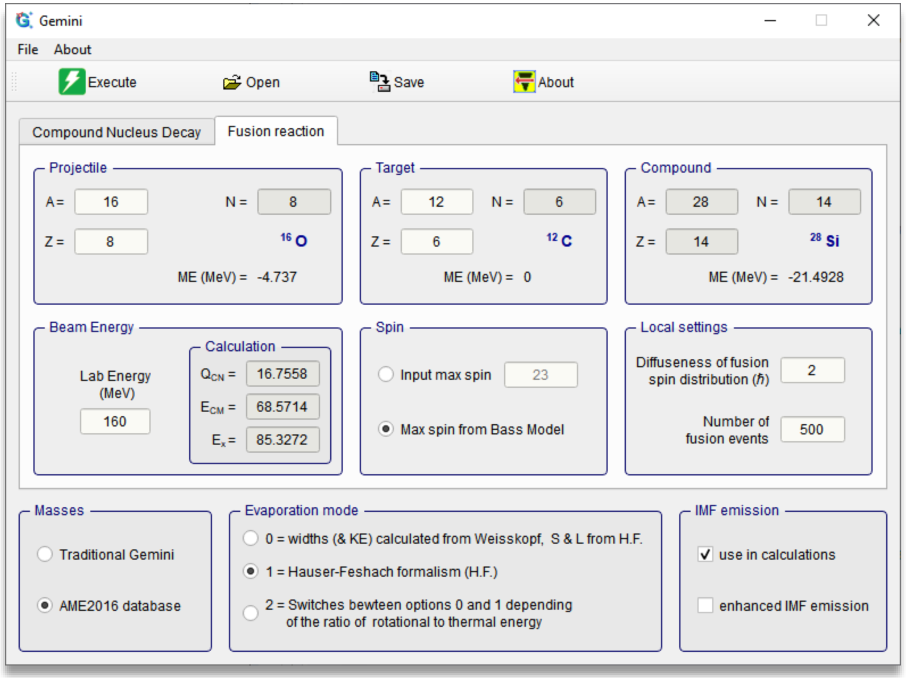
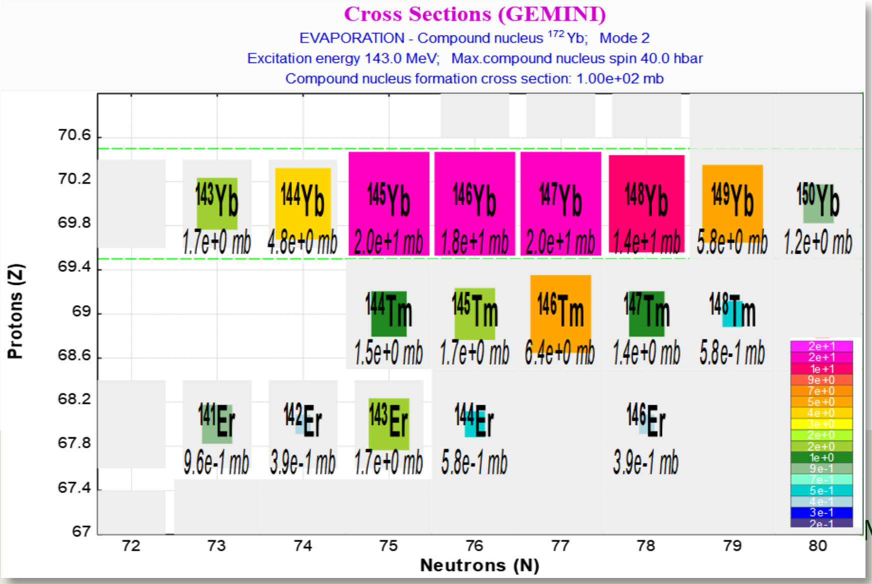
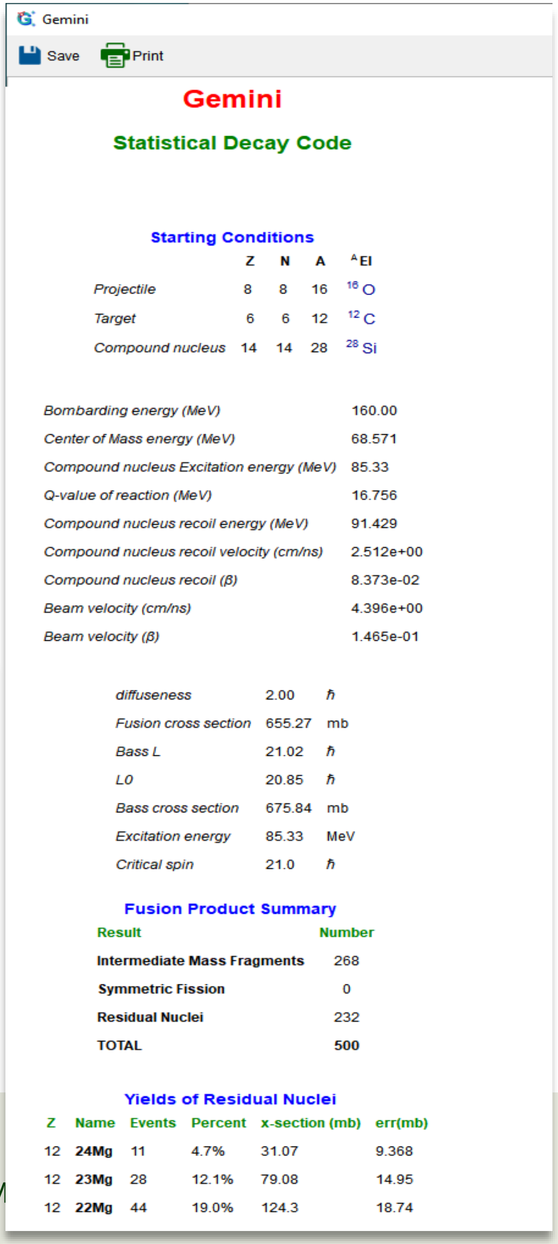
GEMINI++ : GUI application









The Gemini++ code was implemented to the LISE++ package after porting to a GUI application using the Qt graphics framework.

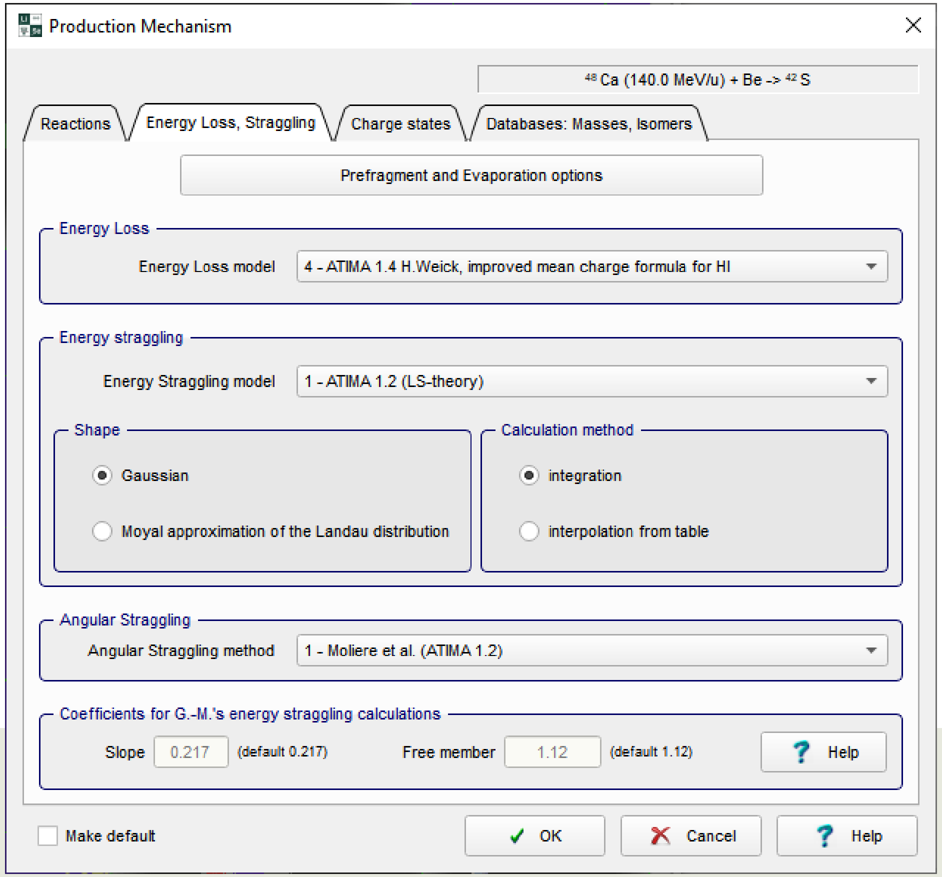
The code was updated to use the AME2016 database and to plot calculation results with the LISE++ code.

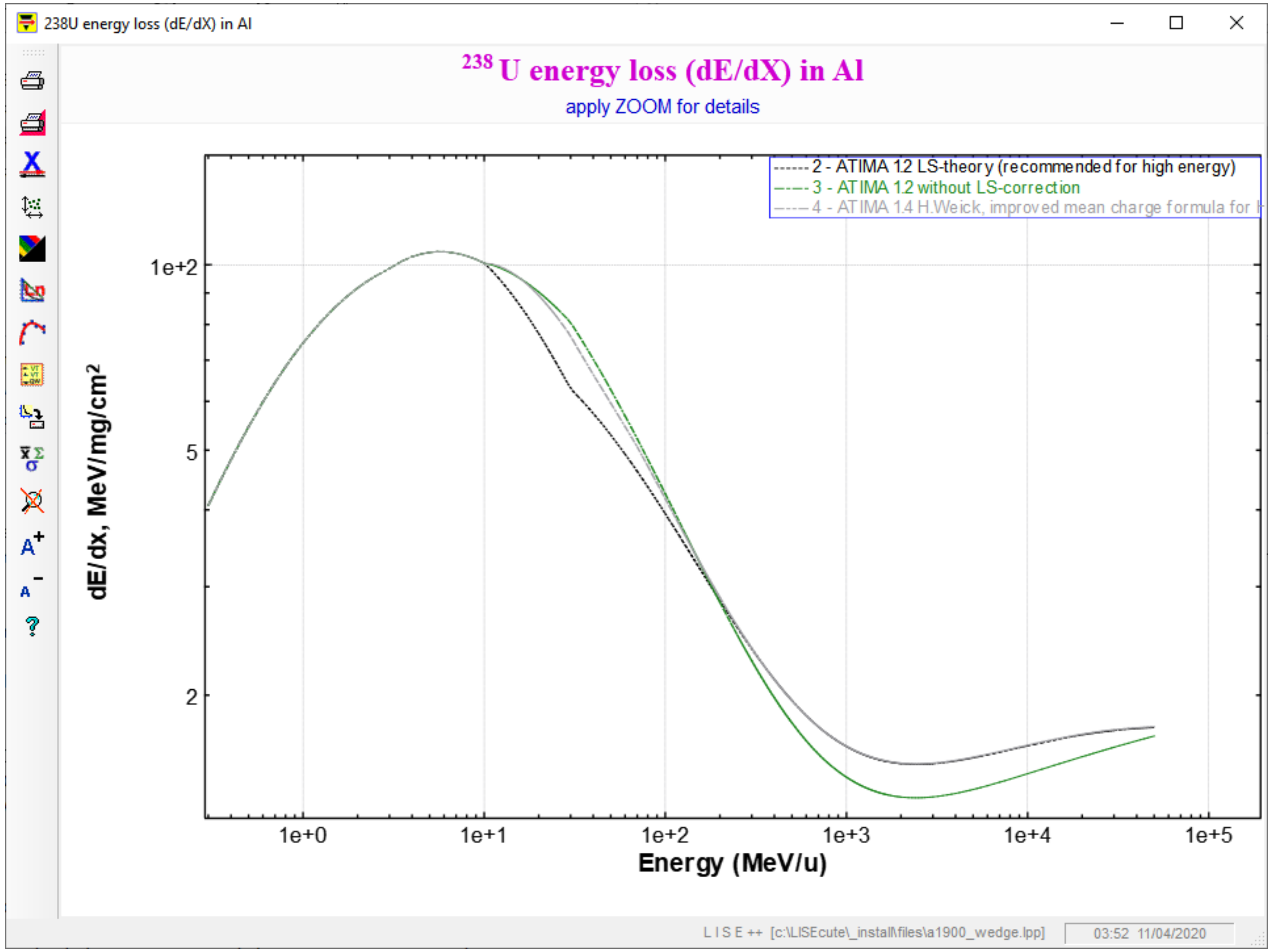
http://lise.nscl.msu.edu/gemini.html

Implementation of ATIMA1.4 (catima1.5)

Complete agreement with site results were obtained

ATIMA 1.4 is set as default Energy loss model in version 15





Acknowledgements to Drs. H.Weick and A.Prochazka

ATIMA website: http://web-docs.gsi.de/~weick/atima/

LISE^{++} development chart

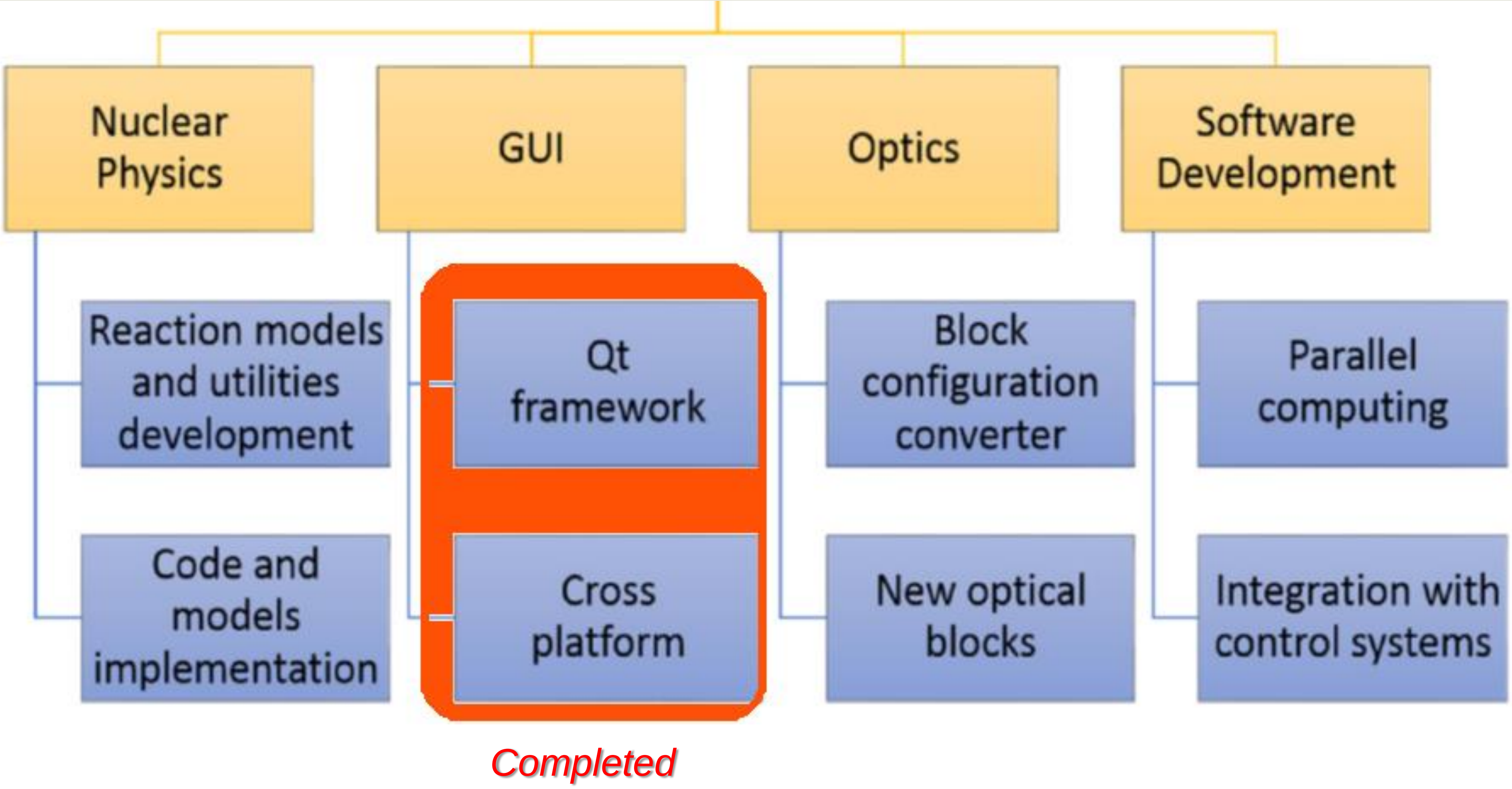


Fig. A schematic diagram of the LISE^{++} development plans.

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

Enhancing LISE^{++}

Through Student Research Contributions

Research group

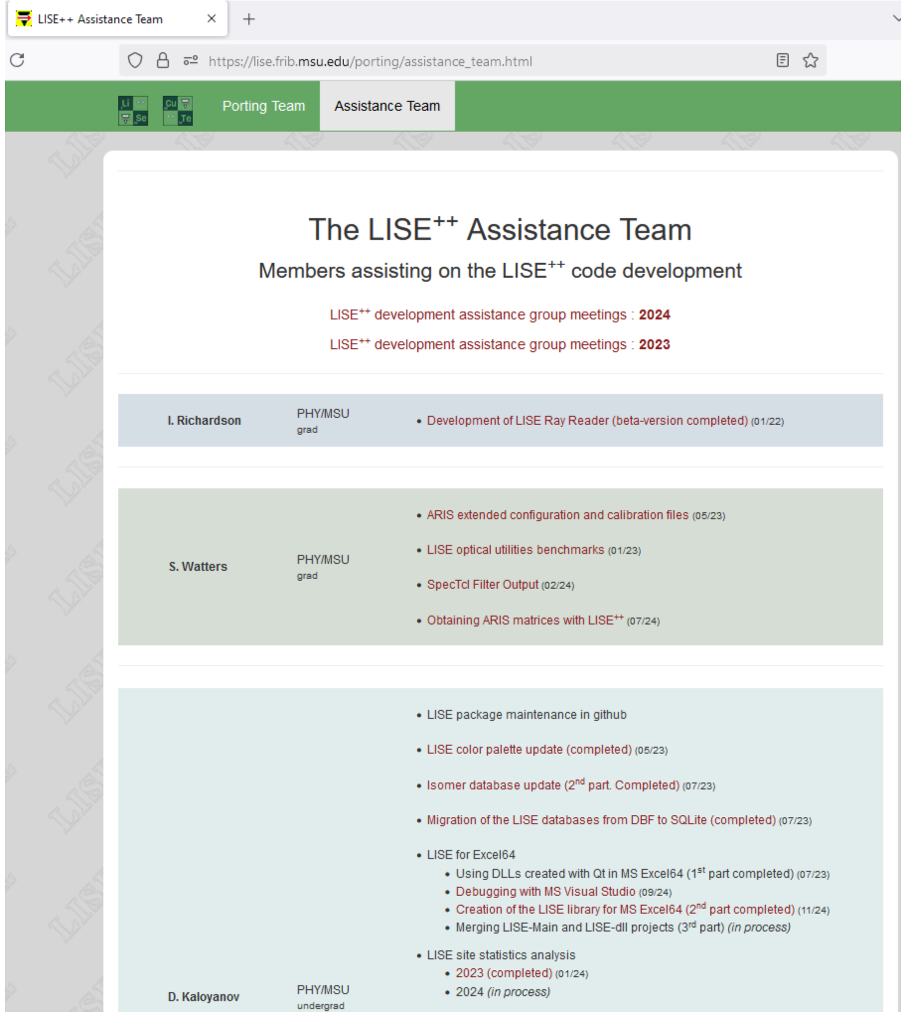
LISE++ Assistance Team

https://lise.frib.msu.edu/porting/assistance_team.html

Research - Sherrill - Group

Name	Title
Sherrill, Bradley (M)	University Distinguished Professor
Tarasov, Oleg (M)	Senior Research Physicist
Ray, Arjun	Student Research Assistant I
Kaloyanov, Daniel	Student Research Assistant II
Matthews, Holly	Graduate Assistant
Watters, Shane	Graduate Assistant
Richardson, Isaiah	Graduate Assistant
Tarasova, Sasha	Student Research Assistant II

6 from 8-person list @ this workshop
with 4 talks and 4 posters



The LISE^{++} Assistance Team : Daniel

Daniel Kaloyanov (joined in 2023)

- LISE^{++} package maintenance in github
- LISE^{++} color palette update
- LISE^{++} Isomer database update
- Migration of the LISE^{++} databases from DBF to SQLite
- LISE^{++} for Excel:
  Using DLLs created with Qt in MS Excel64,
  Creation of libraries in the LISE^{++} package
- LISE^{++} site statistics analysis
- SpecTk: Improvement and maintenance

see Daniel's poster for **LISE for Excel** and **SpecTk**,

see LISE website statistics at the end of this presentation

https://lise.frib.msu.edu/16/16_Databases.pdf

DBF → SQLite

Problem

- in the old system we stored data in dbf-format what are essentially text files (Excel: only read).
- While this works there are many issues with this primarily Scalability, Security, and Usability.

Solutions

- Using a library like libxl to read from an excel file
- The better choice: using SQL to read from a database file
- We Initially chose to use Access .accdb files as our databases, but ran into some issues and decided to switch.
- We then began to use SQLite because it was light weight, high performance, and had cross platform support.
- SQLIte files are also significantly smaller than Access files.

Post-Implementation

- There is now more versatility thanks to SQL queries
- Each query takes significantly less time to search for data than the old dbf code
- GEMINI++ reads in the data about 5x faster than before
- PACE4 reads data in about 2x quicker
- LISE^{++} : the start is faster, the performance is slightly better
- Overall, there were slight performance improvements, but the databases in LISE and other codes overall is now more future proof, safe, and easier to work with

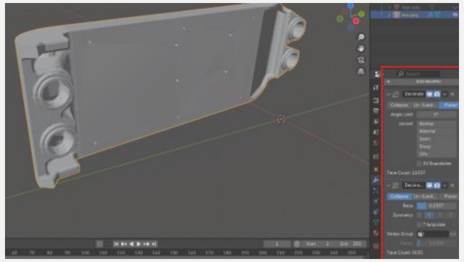
Hope, that Daniel joins our graduation program

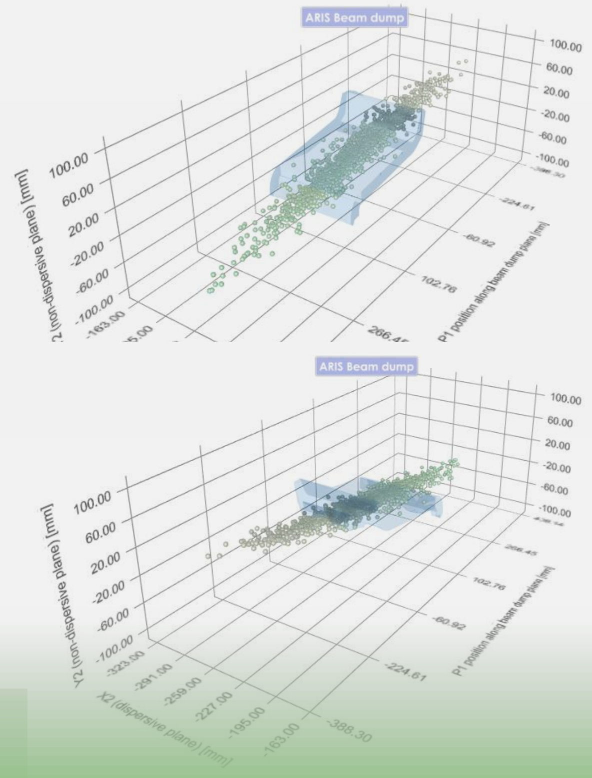
The LISE^{++} Assistance Team : Sasha

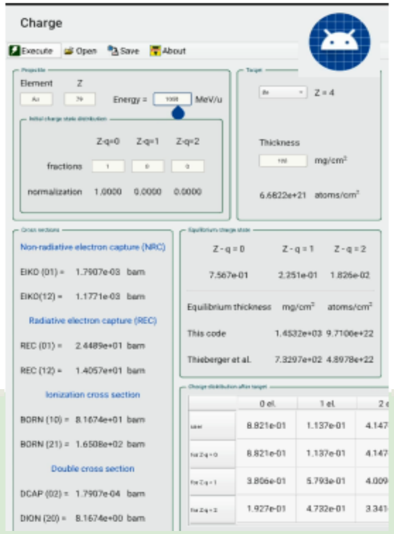
Alexandra Tarasova (joined in 2023)

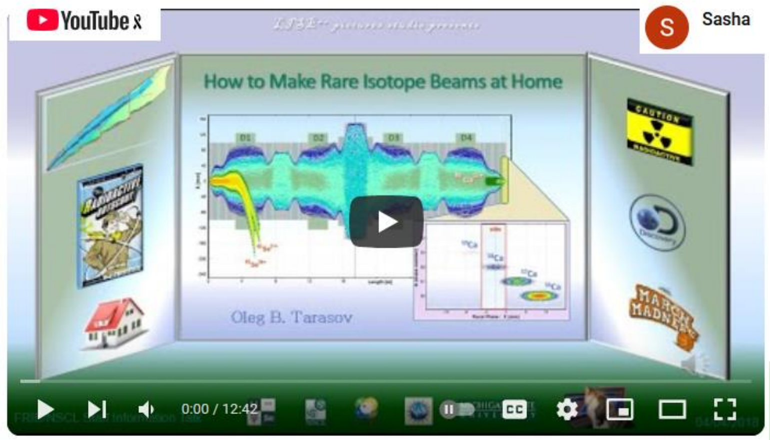
- Package benchmarks & optimization (profiler, memory check)
- Adaptation of the LISE^{++} "new version" utility to SSL connection
- FRIB logo application using Qt Design studio
- Creation of a LISE^{++} video tutorial,
  "How to Make Rare Isotope Beams at Home",
  to be used on YouTube
- Sound support for LISE^{++} code
- Porting the LISE^{++} package to Android Operating System
- Development of the ARIS Beam dump utility [3D-graphics]

3D ARIS BeamDump







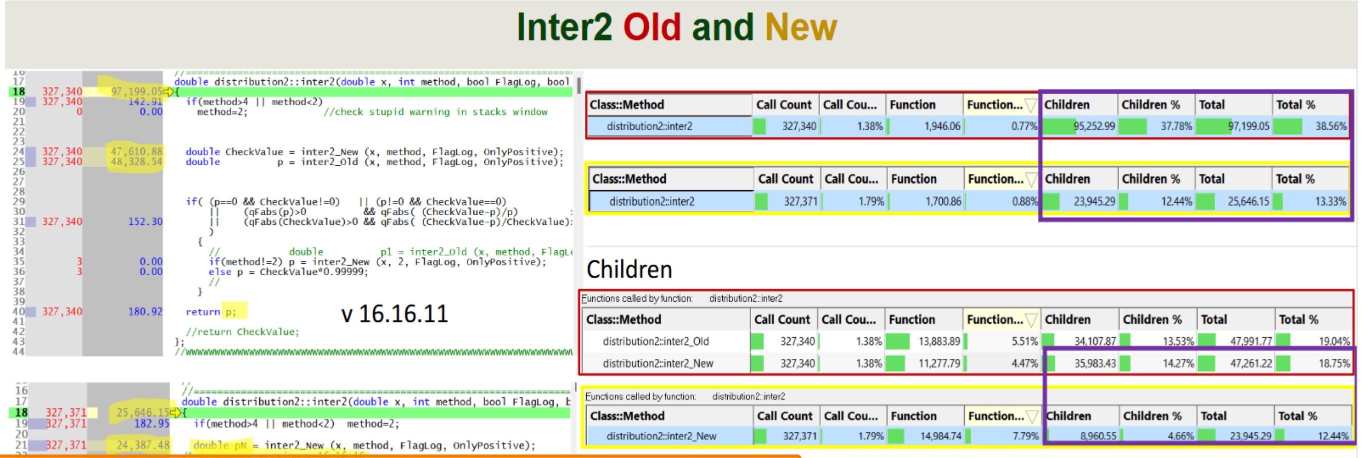


How to Make Rare Isotope Beams at Home (LISE Package Video Tutorial v.2)

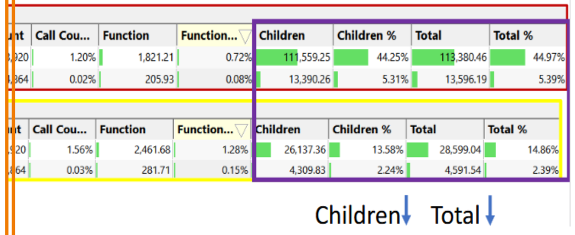
Sasha's project : LISE^{++} performance optimization

Profiler (links)	Latest Release	OS	Languages	Integration	Setup	Overhead	Tools	Licensing	Support
Intel VTune	Intel 2023	Windows Mac OS Linux	C/C++ Python Java .NET	Standalone Visual Studio	Easy	Low	Performance CPU/GPU MemoryEvent-based sampling Call graph analysis Threading analysis	Free	Documentation Community Forum
MS Visual Studio	Microsoft 2023	Windows	C/C++ Python Java .NET	Visual Studio	Easy	Low	Performance CPU/GPU Memory Concurrency Visualizer Threading analysis	Free	Documentation Community Forum
Very Sleepy	Richard Mitton 2021	Windows	C/C++	Standalone	Easy	Low	CPU Call graph analysis	Free	Documentation
Relyze	Relyze 2022	Windows	C/C++ Delphi	Standalone Visual Studio	Easy	Moderate	Memory Resource allocation Extensive graphs/ representations	Free	Documentation
AQTime Pro	SmartBear Software 2023	Windows	C/C++ Java .NET Delphi	Standalone Visual Studio RAD Studio	Moderate		Performance CPU/GPU		Documentation
Deleaker	Softanics 2023	Windows	C#/C++ .NET Delphi	Standalone Visual Studio RAD Studio QT Creator	Easy				
Performance Validator	Software Verify 2023	Windows	C/C++ .NET Delphi	Standalone	Easy				

Profiler Comparison Cha



version	compiler	release date	time elapsed (sec) 124Xe, EPAX, charge states	time elapsed (sec) 198Pt, Abrasion-Ablation charge states	Average factor
13.4	Borland(32)	5/5/2020	206	685	12.40
16.3.1	MinGW	4/6/2022	99	290	5.60
16.14.20	MinGW	4/26/2023	50	187	3.20
16.16.14	MinGW	7/25/2023	48	167	2.96
16.16.34	MinGW	8/12/2023	35	90	1.86
16.17.2	MinGW	8/18/2023	28	87	1.63
16.17.2	**MSVC**	8/18/2023	17	54	1.00



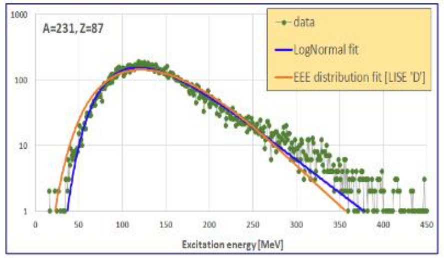
An example of identifying bottlenecks and performing subsequent optimization

Applying Graduate Research in the LISE development

Excitation energy distribution study with BeAGLE

Isaiah Richardson

Analysis of events generated by BeAGLE for ^{238}U, ^{208}Pb, ^{136}Xe, ^{124}Xe, ^{90}Zr, ^{64}Ni, ^{58}Ni projectiles to deduce an excitation energy model to be used in LISE^{++}



results wiht the LogNormal distribution fit: Mode/dA

Z/N	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147
93						26.43	22.86	24.42	21.83	23.17	23.86	23.58	23.58	23.86	23.97	24.23	23.37	22.80	4.04		
92				21.23	22.60	22.90	21.62	22.45	22.21	21.53	21.47	21.35	20.95	20.59	19.97	19.14	17.63	15.33	8.33	3.07	
91			20.53	21.90	21.36	21.22	21.58	21.48	21.04	20.99	20.65	20.52	19.97	19.56	18.96	18.25	17.18	15.87	13.44	8.17	3.96
90			19.55	19.56	21.95	21.02	20.67	20.84	20.71	20.33	20.12	20.00	19.65	19.39	18.75	18.26	17.36	16.46	14.79	12.63	15.23
89	21.20	21.96	20.93	19.99	19.82	21.11	20.49	20.47	20.13	20.18	19.89	19.62	19.29	19.00	18.54	18.06	17.34	16.55	15.32	14.20	16.95
88		19.98	20.68	20.75	20.48	20.52	20.62	20.37	20.12	19.86	19.76	19.55	19.17	18.96	18.57	18.10	17.52	16.95	16.07	15.77	17.95
87	19.09	19.93	21.17	19.85	20.13	20.22	20.02	19.81	20.03	19.82	19.48	19.16	19.02	18.80	18.29	18.09	17.52	17.01	16.44	16.20	17.39
86	20.85	19.23	19.39	20.32	21.07	19.70	19.73	19.96	19.80	19.47	19.26	19.26	18.89	18.73	18.22	17.94	17.44	17.18	16.72	16.52	18.86
85		19.85	19.89	20.27	20.11	19.67	19.54	19.89	19.59	19.25	19.17	18.97	18.46	18.53	18.20	17.89	17.48	17.19	17.14	16.57	17.91
84	20.23	19.96	19.58	19.27	20.39	19.41	19.37	19.72	19.34	19.45	19.16	18.89	18.51	18.44	18.11	17.97	17.43	17.35	17.23	18.01	18.73
83			17.86	19.03	18.70	19.83	19.17	19.45	19.43	19.25	18.81	18.58	18.70	18.16	17.99	17.96	17.64	17.26	16.73	16.33	
82			18.06	18.66	18.93	20.06	19.76	19.93	19.22	19.41	18.89	18.89	18.41	18.27	18.06	17.27	18.16	17.18	16.18	18.89	
81				20.04	17.35	18.66	19.11	18.68	19.11	19.26	19.55	18.31	18.67	18.31	17.28	16.77	16.21	16.56	17.79		
80					17.33	18.63	18.11	18.53	17.78	18.68	19.34	17.99	18.36	17.83	18.36	17.16	18.17	16.82			
79							17.78	17.29	17.88	17.78	18.68	19.56	18.02	17.99	15.99	17.50					
78									17.41		20.02	17.84	18.69								
77											17.92										

dA = 11

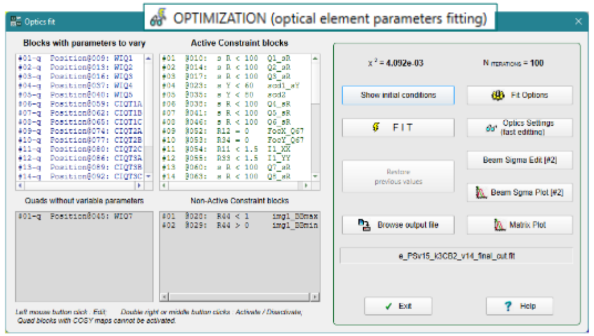
dA = 16

Our first outlines from BeAGLE results
- No events in 0-20 MeV range (dA=7)
- LogNormal distribution, not Gaussian
- N/Z dependence of modes (statistics)

see Isaiah's poster

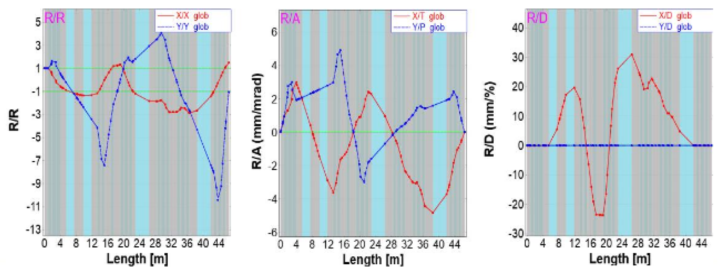
Optics calculations for PID reconstruction

Shane Watters



- Trajectory reconstruction required for PID analysis
- Fast updates of optics settings to analysis
- Creation of reliable configurations for transport calculations of the 2nd order
- It can be used to study ARIS optics

LISE minimization results (Dipoles: COSY maps, Quads: effective lengths from calibration)



see Shane's poster

New Shane's project:
Reverse trajectory reconstruction with fragment-separators

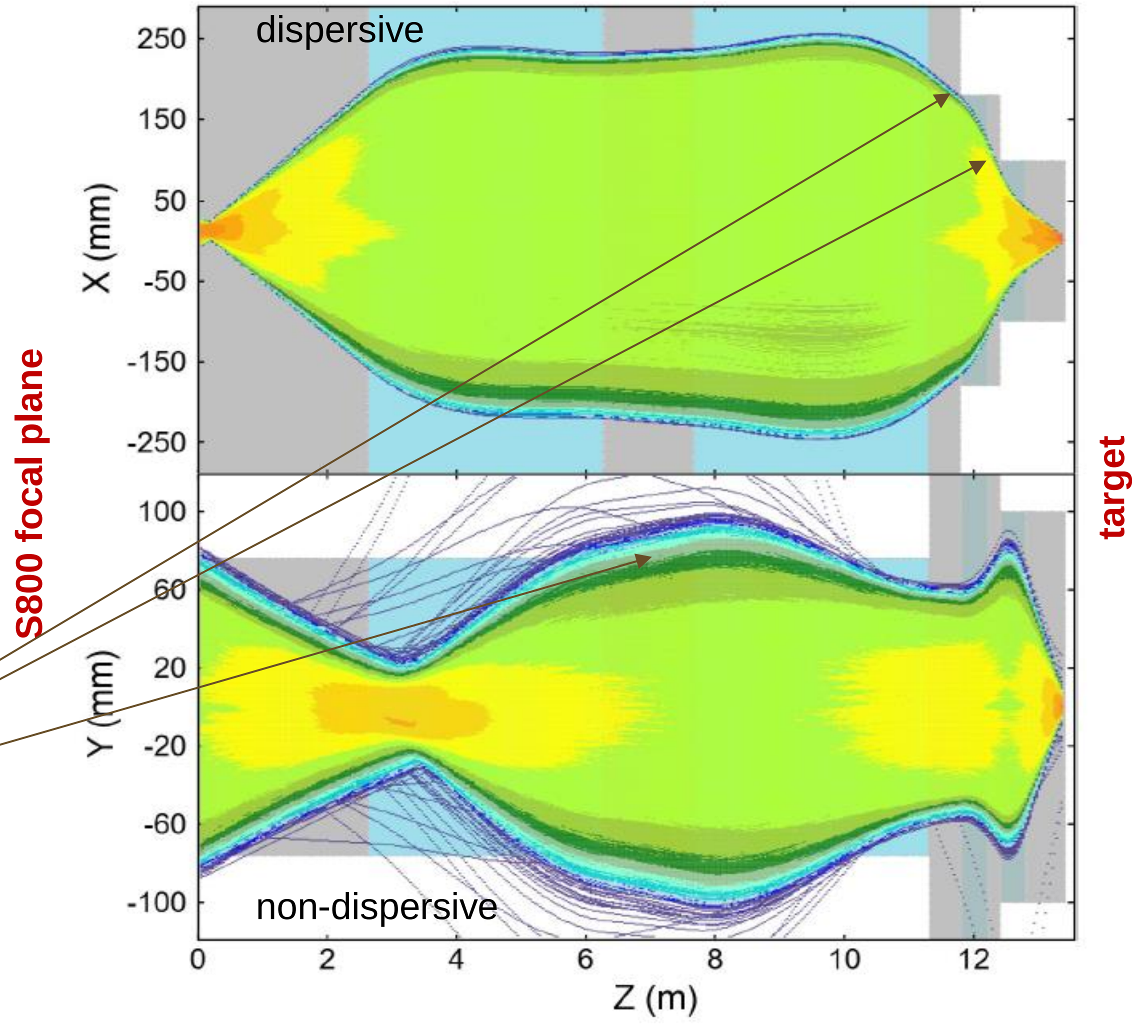
Trajectory reconstruction

Using trajectory reconstruction to benchmark

- The reverse ray-tracing technique provides valuable benchmarks of the analysis providing the beam-optics constraints of fragments passing through a spectrometer.
- Reverse rays should be inside of beam optics element, that can be seen from reverse envelopes in dispersive and non-dispersive planes plotted

https://lise.nscl.msu.edu/9_10/ReverseConfiguration.pdf

- Blue and grey shadow areas demonstrate aperture sizes of multpipole and drift elements correspondingly.
- These envelopes demonstrates how well rays fit in apertures of two quadrupole located after a target



Reconstruction of fission fragment trajectory at S800

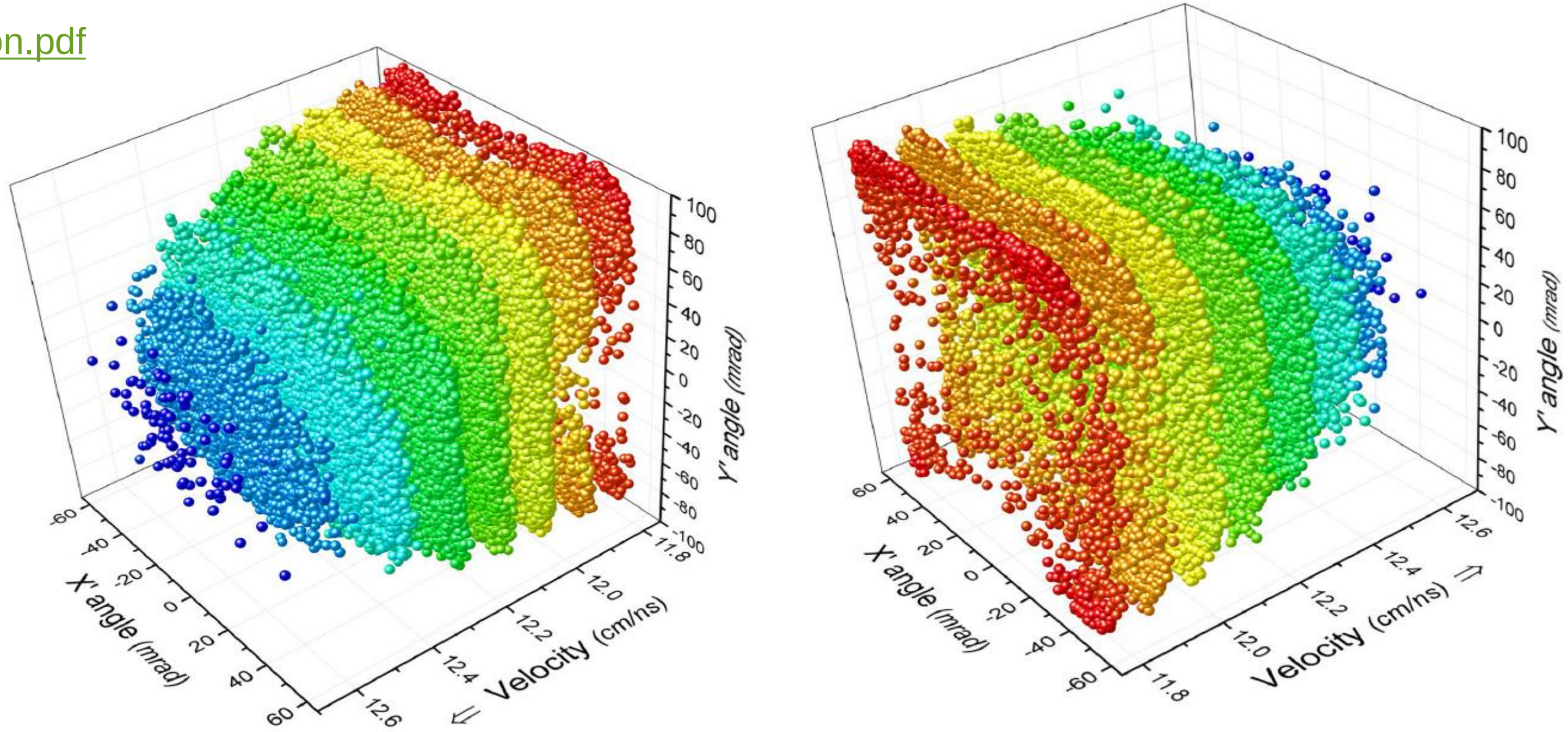
- LISE^{++} now supports reverse mode, allowing experimental data to be input for simulation, with reaction product properties extrapolated **back to the target**

https://lise.nscl.msu.edu/9_10/ReverseConfiguration.pdf

M. Bowry, O.T. et al., PRC 108, 034604 (2023)

- Data extracted from a ROOT tree (or SpecTcl) are converted to text and processed in LISE^{++}, using 5th-order COSY maps for ion-optical transformations.

^{238}U (80 MeV/u) + C → $^{83-90}$Kr



Experimental momentum space of krypton isotopes at the target position (A = 83[blue]–90[red]) reconstructed from experimental data using the LISE^{++} software package

- This reverse ray-tracing technique provides valuable benchmarks for beam optics as fragments traverse the **fragment separator**

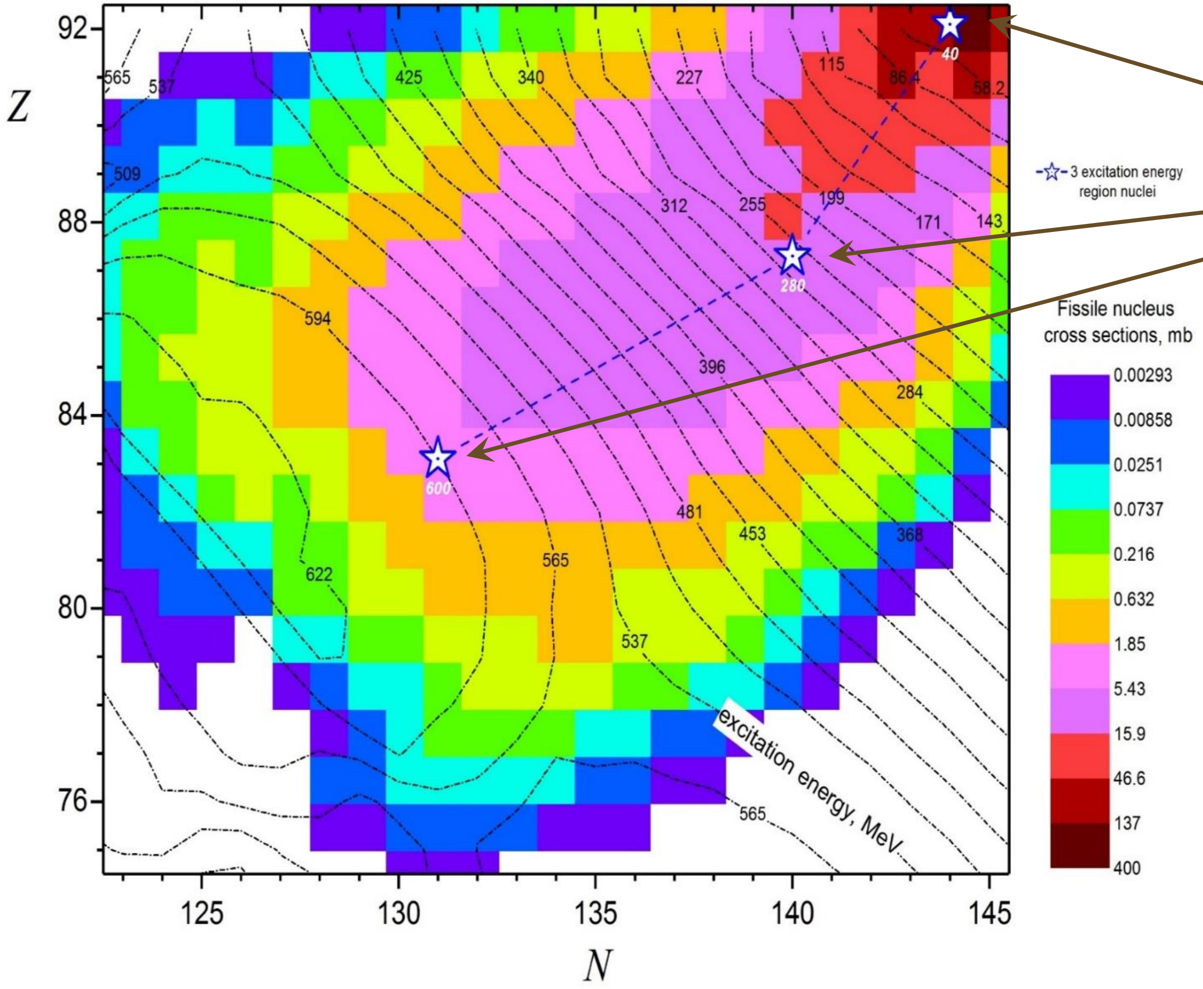
Reaction mechanism:

Abrasion-Fission

LISE^{++} 3 Excitation-Energy Regions (3EER) model

Fissioning nuclei map (CS, E*)
calculated by the LISE^{++} AA model

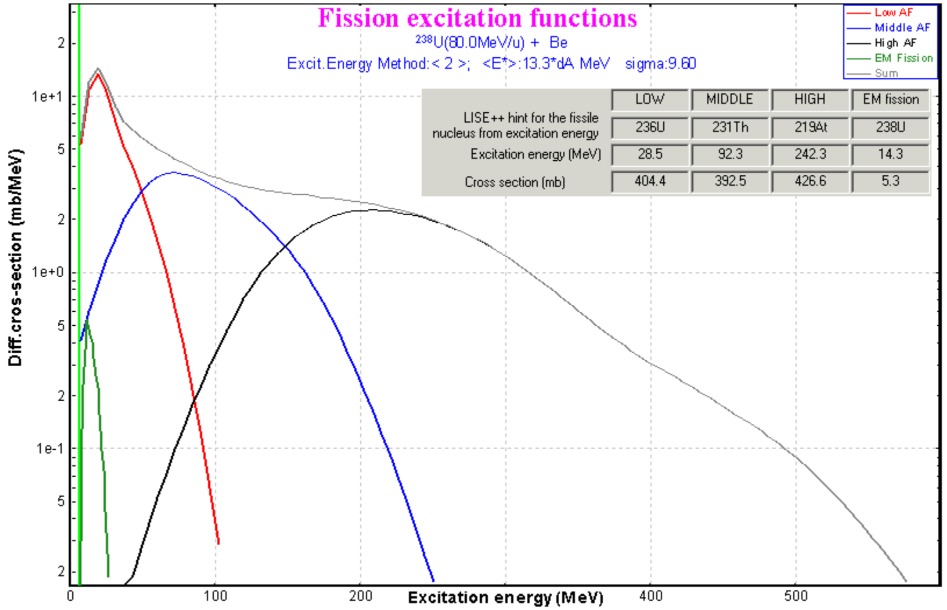
M.Bowry, O.T., et al. PRC 108, 034604 (2023)



Abrasion - Fission

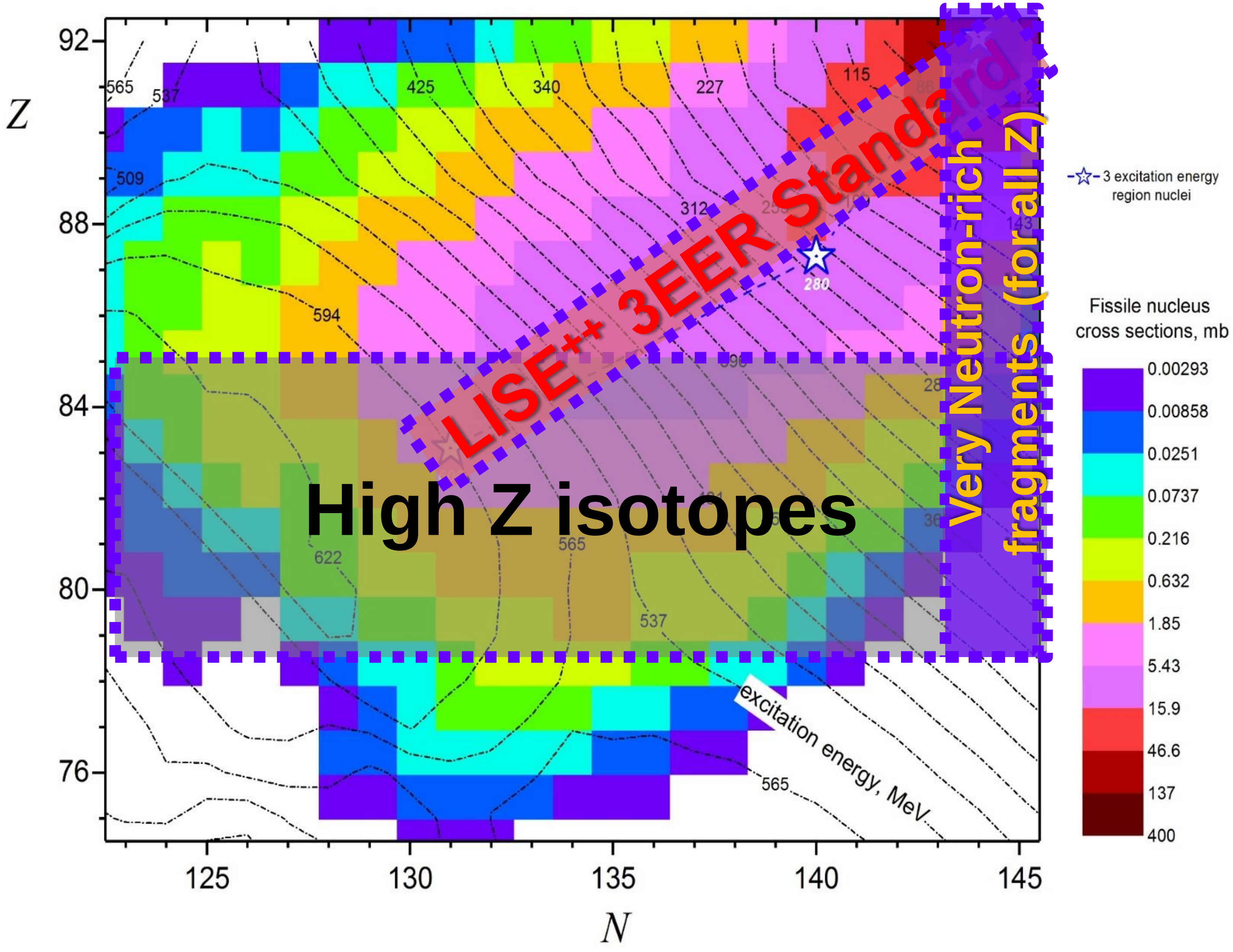
LISE^{++} 3EERs (excitation energy region) model:

Simple approximation to substitute about 400 fissioning nuclei by 3 nuclei based on excitation energy



http://lise.nscl.msu.edu/7_5/lise++_7_5.pdf

Disadvantages of LISE++ AF 3EER model : high Z settings

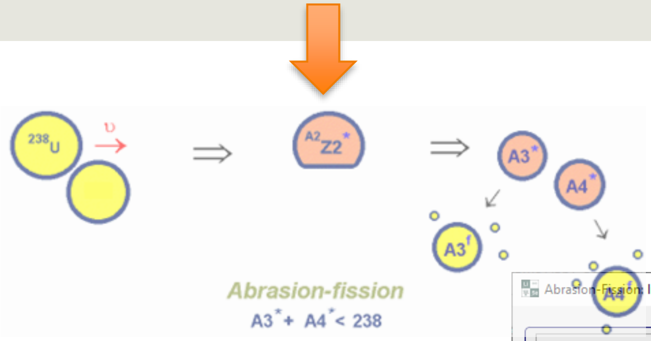


https://lise.nscl.msu.edu/10_1/10_1_127_highZ_AF.pdf

Limitations of the 3EER model due to averaging on more probable fragments

- Use manual cross sections as BigRIPS CS table
- New model development to use pre-calculated tables
  (in process, see IFN analyzer slides)

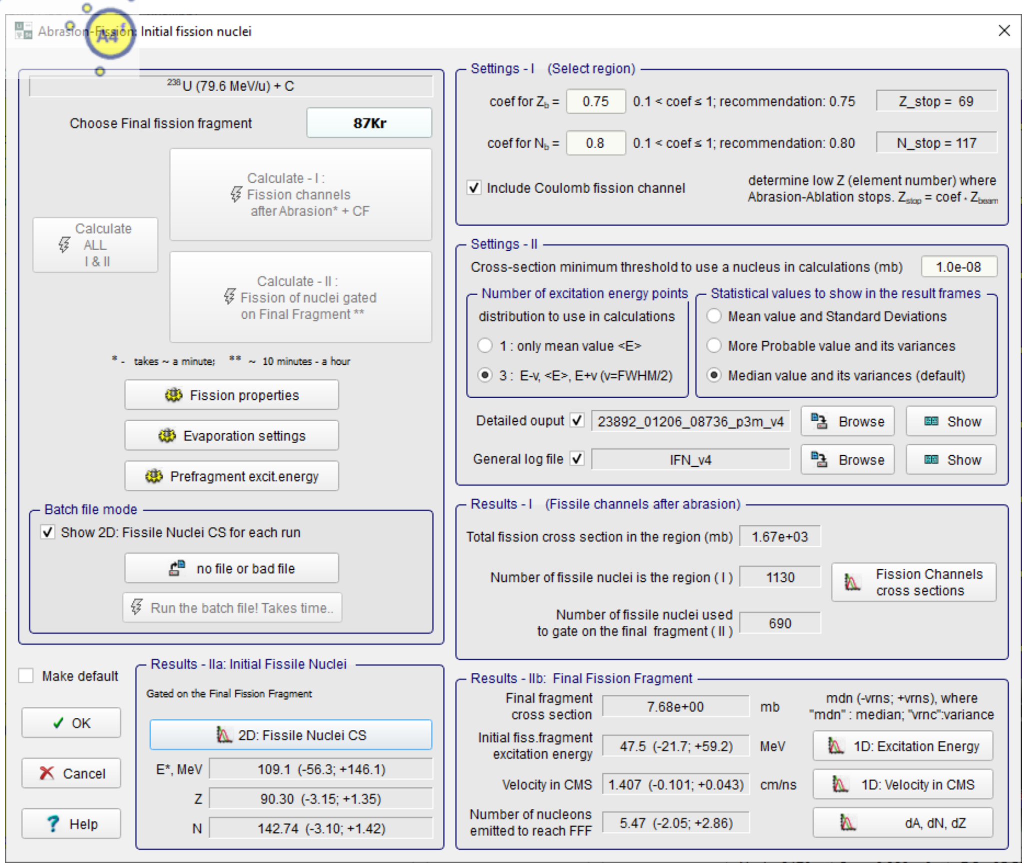
Initial Fissioning Nuclei (IFN) Analyzer



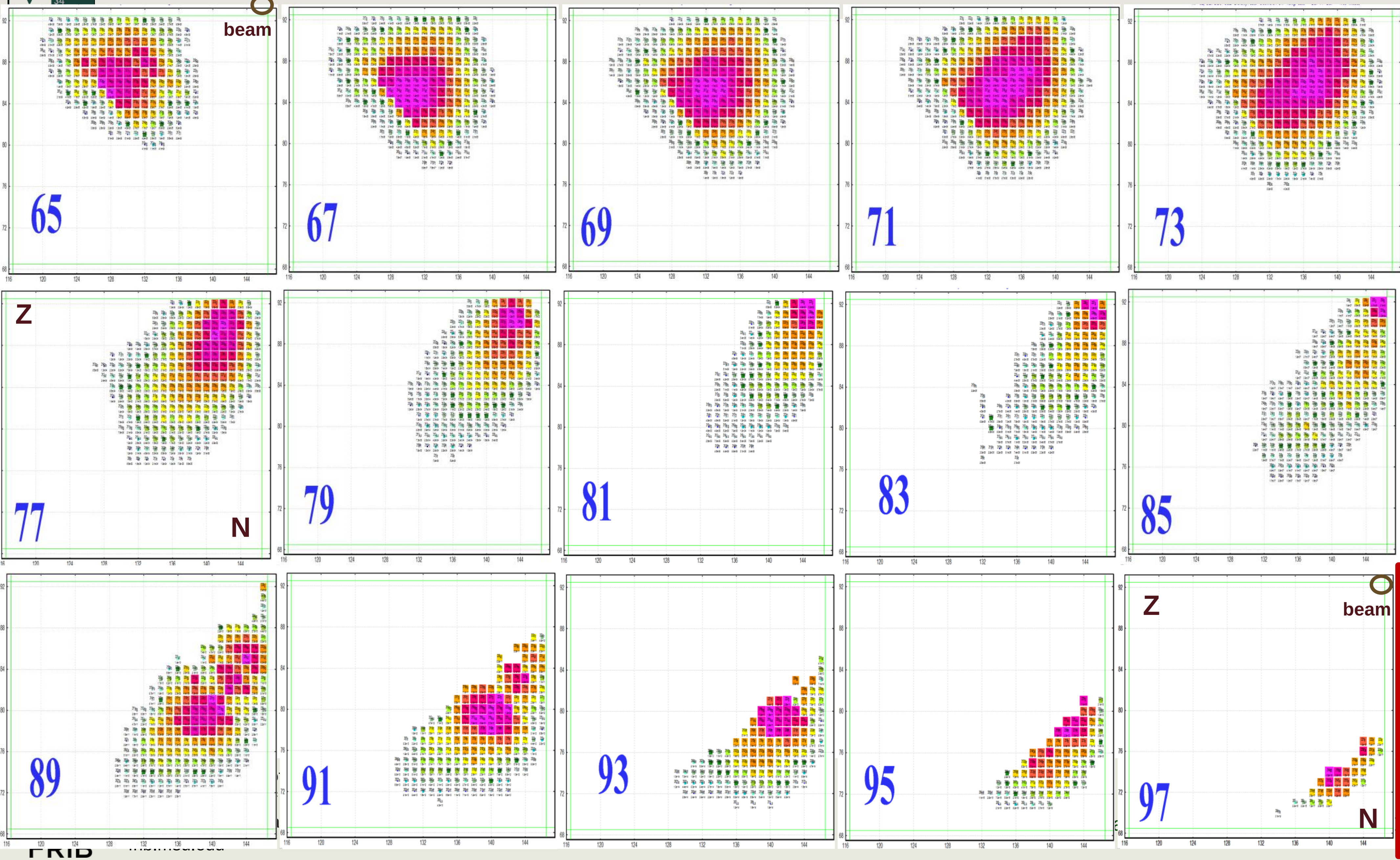
http://lise.nscl.msu.edu/10_1/11_0_28_IFN_search.pdf

- The utility, Initial Fissioning Nuclei (IFN) Analyzer, calculates the contribution **from all possible** parent Fissioning nuclei to the final fission fragment, which allows to calculate
  - fission fragment production cross section as contribution of all Fissioning parents,
  - more probable parent Fissioning nuclei,
  - fragment velocity in CMS (provide kinematics),
  - excitation energy of the initial fission fragment,
  - number of nucleons released to reach the final fission fragment.

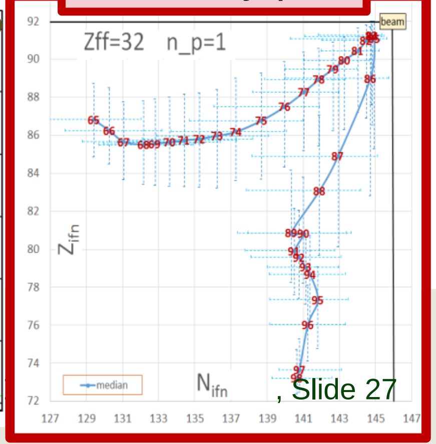
- Still under development:
  - Overprediction reported by BigRIPS requires the Global revision of the de-excitation process (mathematics & physics, constructed in 2003)
  - creation of pre-calculated tables to use in production rate calculations (CS value and velocity$_{CMS}$ array)



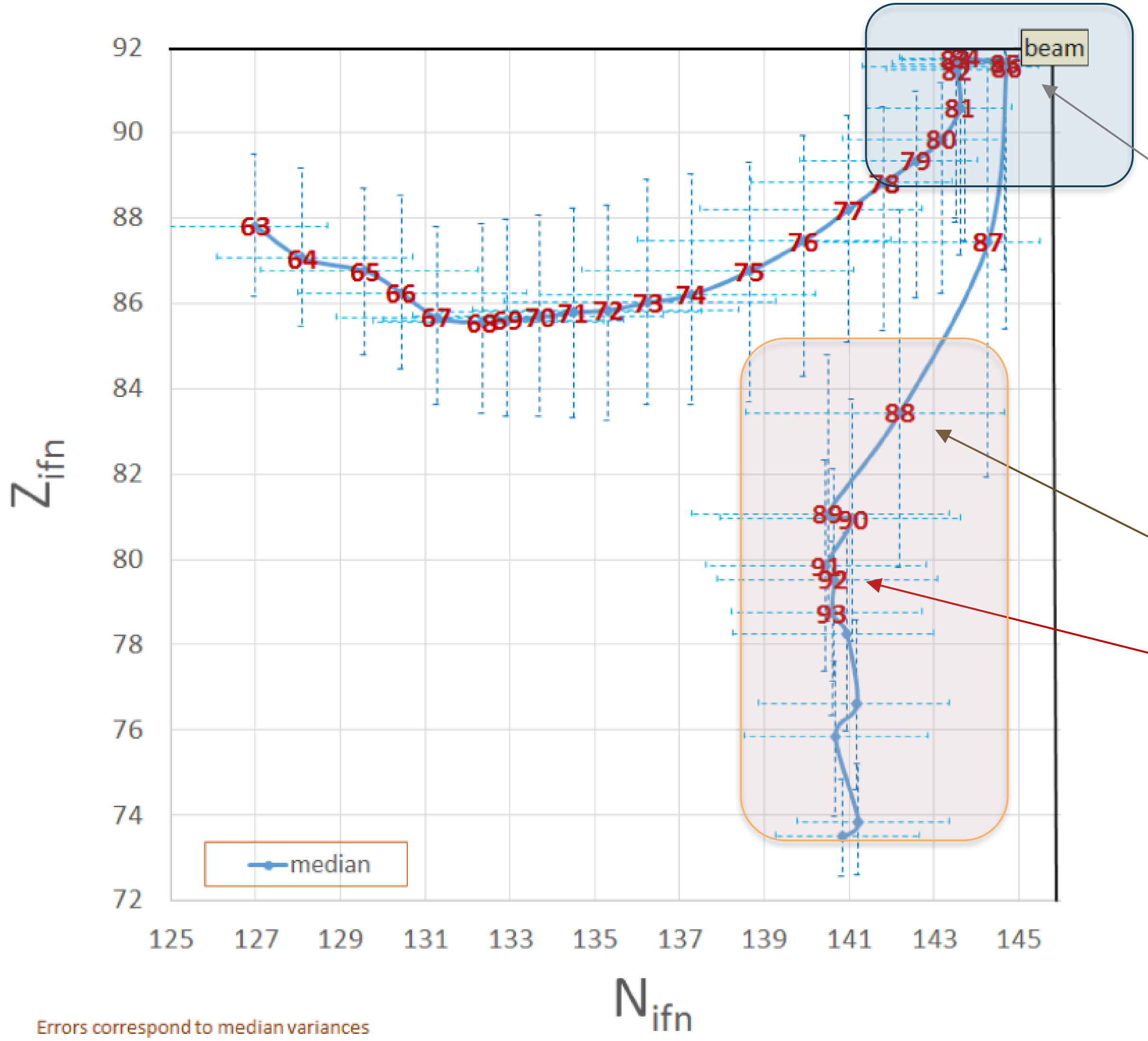
Initial Fissioning Nuclei (IFN) for final Ge-isotopes (Z=32)



Summary plot



IFN-analysis for final Ge-isotopes (Z=32) : summary plot



Corresponds to Low excitation fission. Isotopes are well produced in Coulomb fission with a heavy target.

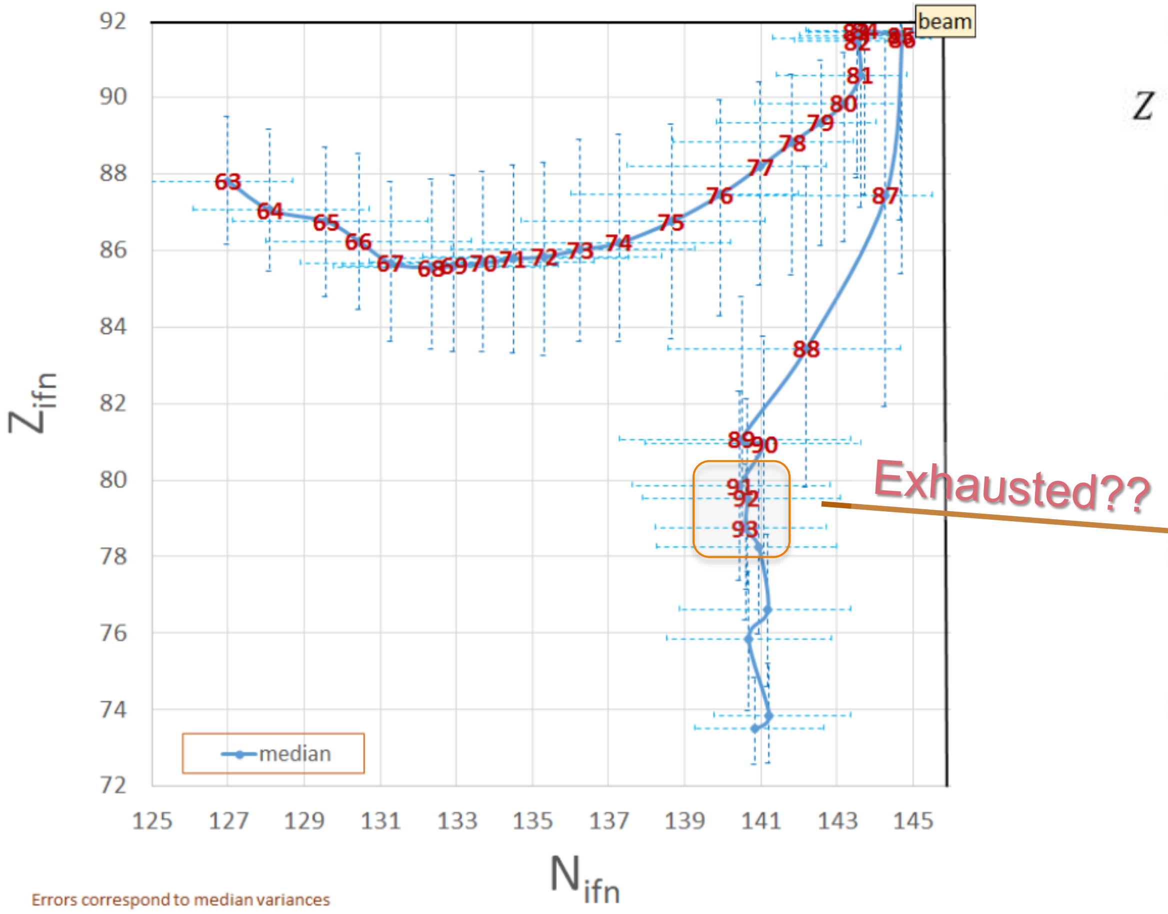
86 @ GSI (1994) Pb-target

Corresponds to High excitation fission. Isotopes are produced in Abrasion-Fission. Preferably to have a light target.

88 @ GSI (1997) Be-target (high E*)
90 @ RIKEN (2010) Be-target (high E*)
92 @ RIKEN (2024) Be-target (high E*)
last observed isotope

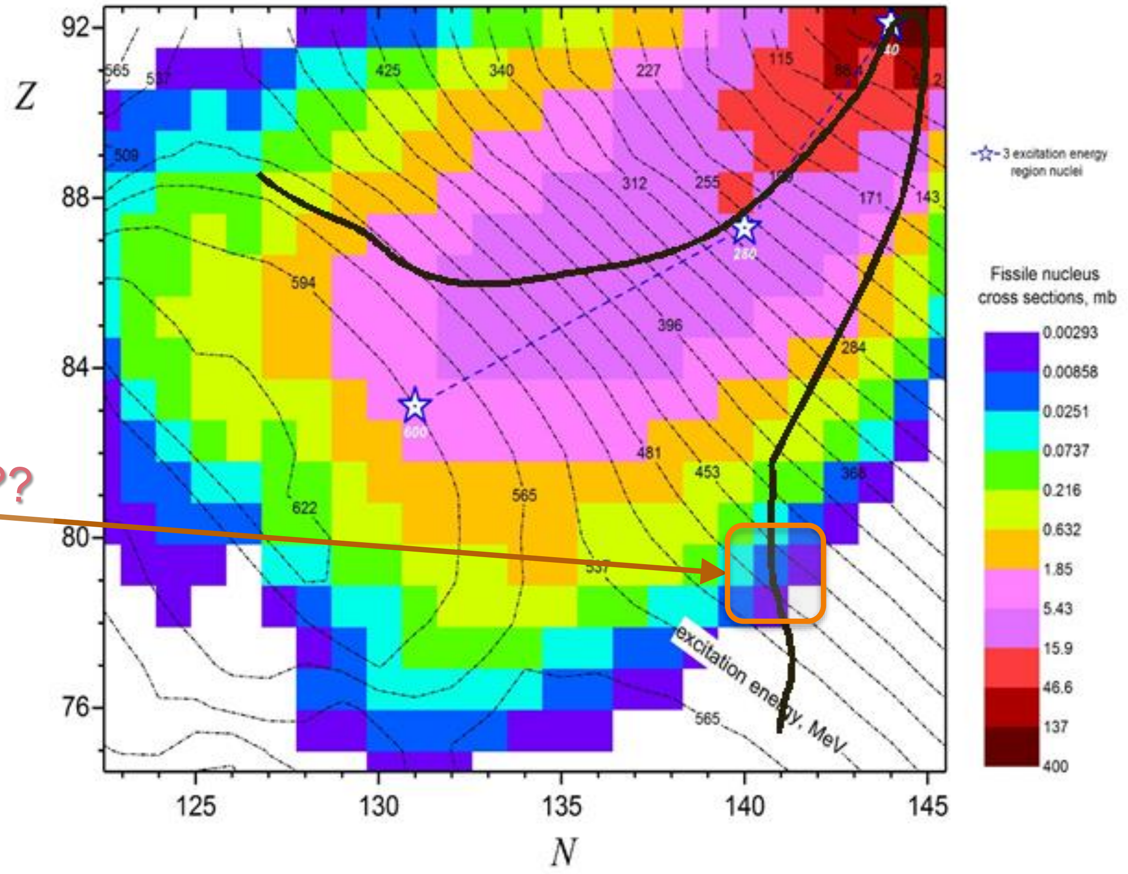
Light target should be used to get far

Reaching limit with one-step fission reactions



Errors correspond to median variances

LISE++ 3EER model: Fissioning channel map after abrasion



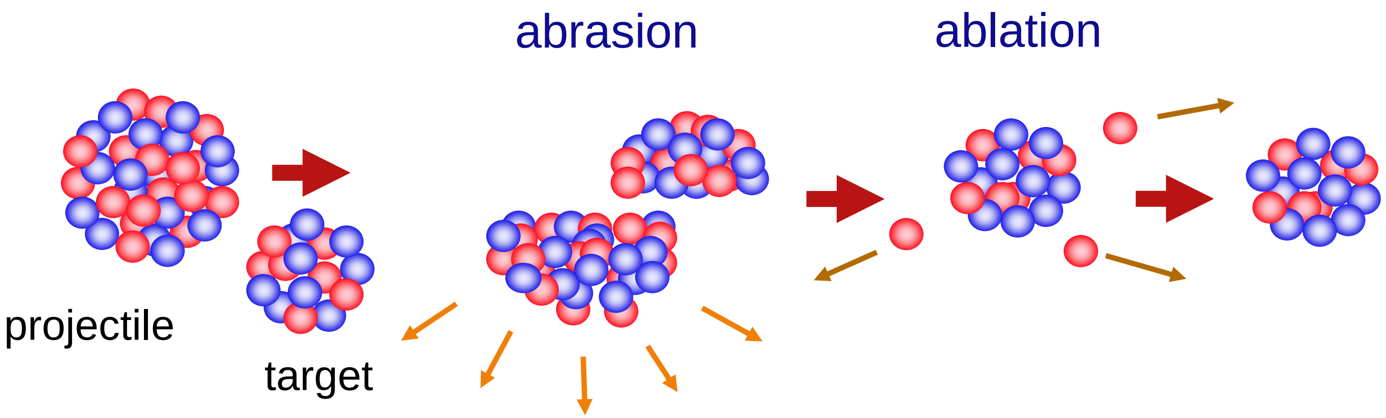
Time to think about the multi-step reactions?

Facility for Rare Isotope Beams
U.S. Department of Energy Office of Science | Michigan State University
640 South Shaw Lane • East Lansing, MI 48824, USA
frib.msu.edu

Reaction mechanism:

Abrasion-Ablation

Abrasion-Ablation model

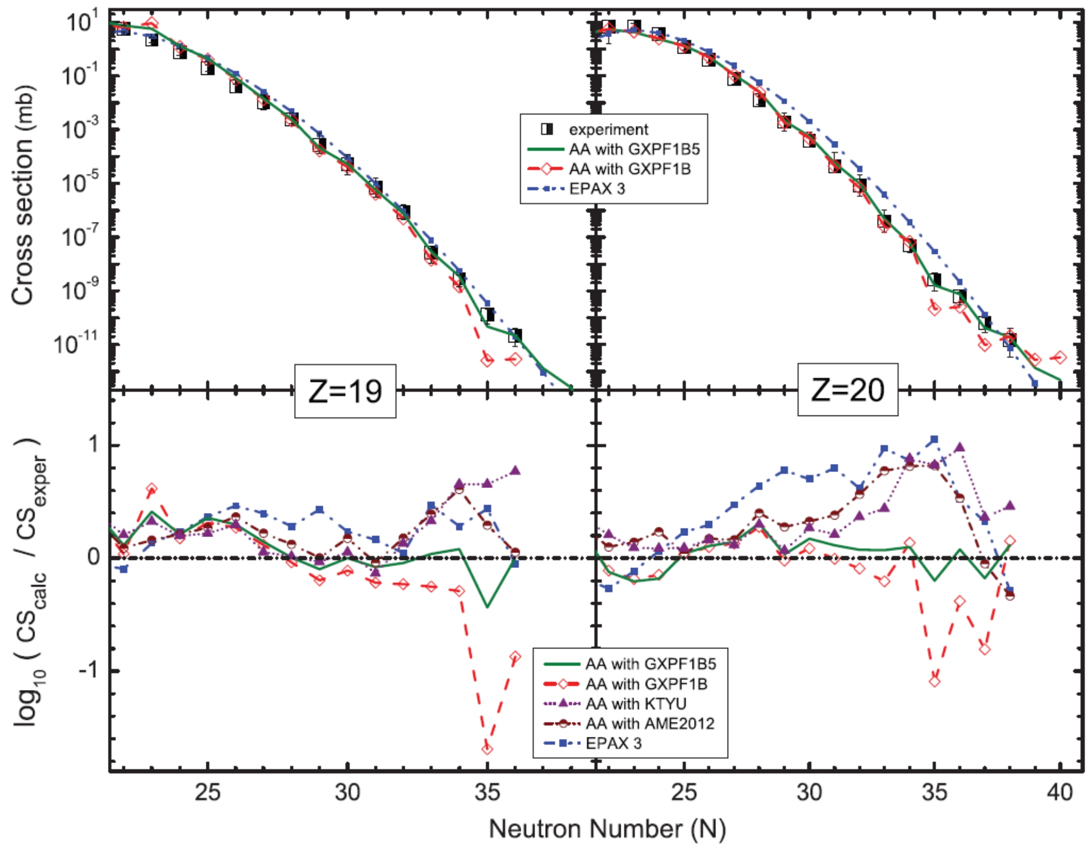


- AA is the most advanced method, modeling final fragment production in two steps.
- Its applicability is limited by the extensive input requirements and insufficient data on prefragment excitation functions.
- The excitation function is critical for setting energetics in the ablation step.
- Abrasion-Ablation calculations are highly sensitive to mass model input. Considered as mass model benchmarking.

Obtaining excitation energies from experimental cross-sections with mass model variation

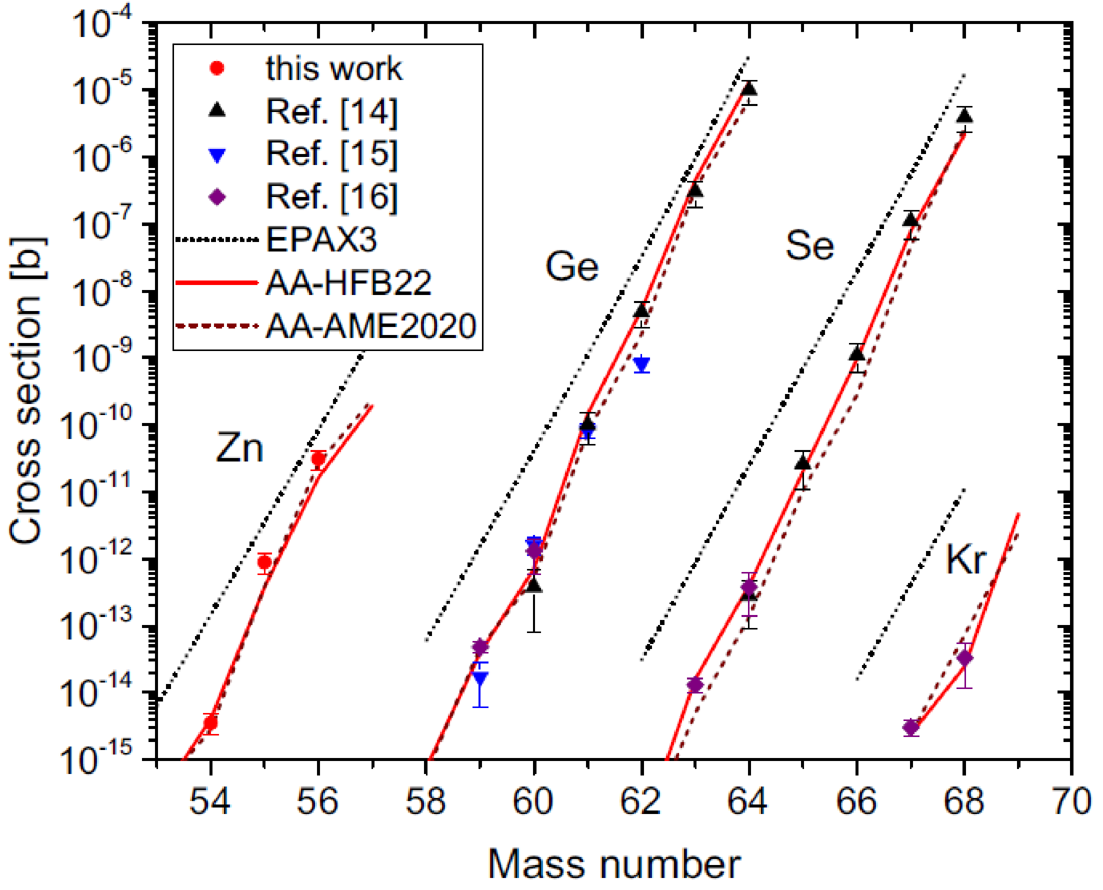
O. B. T. et al., PHYSICAL REVIEW C **87**, 054612 (2013)

^{82}Se + Be E* = 15 MeV/dA



A.Kubiela et al., PHYSICAL REVIEW C **104**, 064610 (2021)

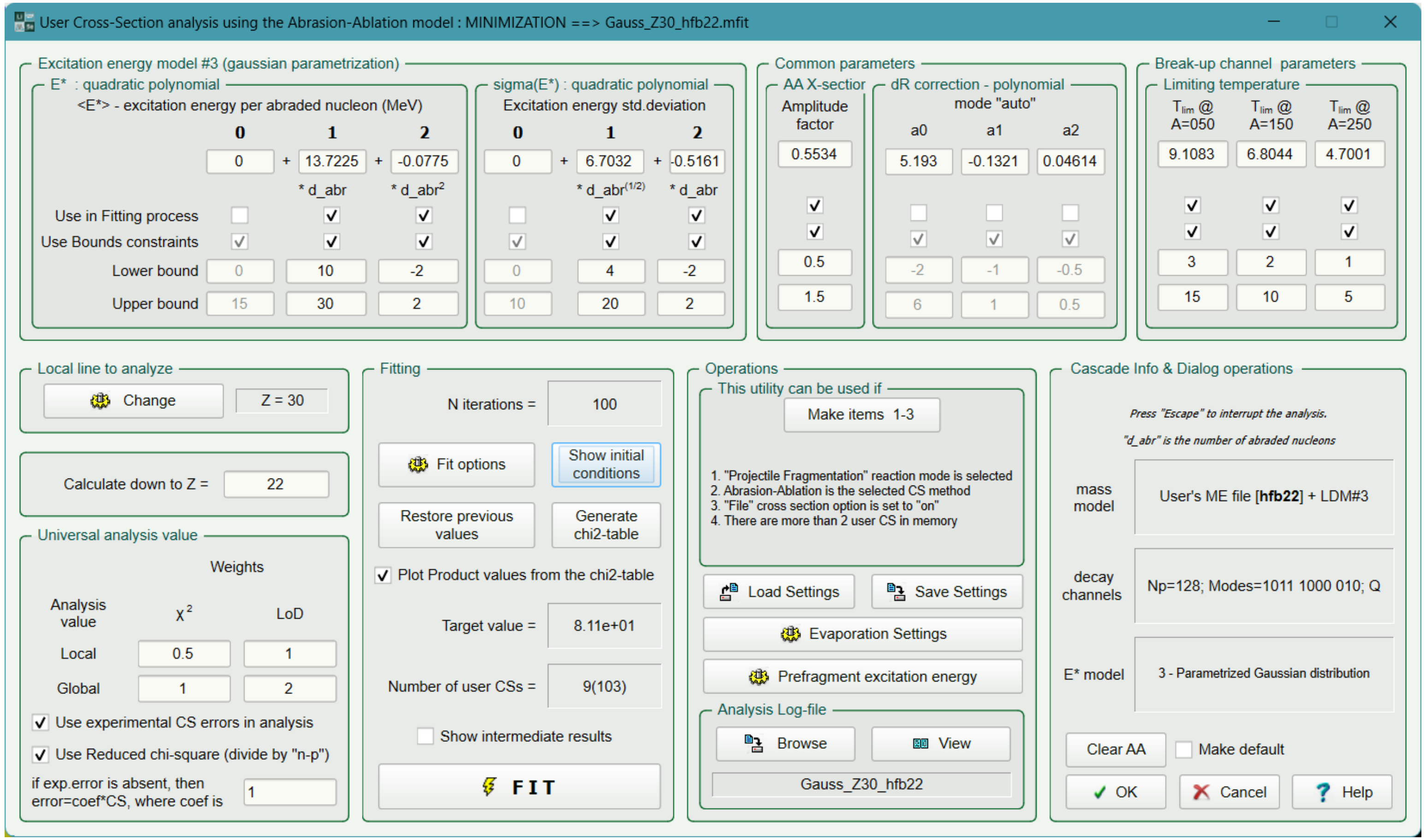
^{78}Kr + Be E* = 13.3 MeV/dA



LISE^{++} Abrasion-Ablation minimization utility

The new minimization utility allows to deduce Abrasion-Ablation model parameters from comparison of AA-calculation results with experimental cross-sections with selection one from 28 mass models distributed with the LISE^{++} suite. The utility is based on the levmar package using the Levenberg-Marquardt nonlinear least square algorithm.

https://lise.frib.msu.edu/AA.html



^{78}Kr + Be

H.Suzuki et al., submitted to PTEP

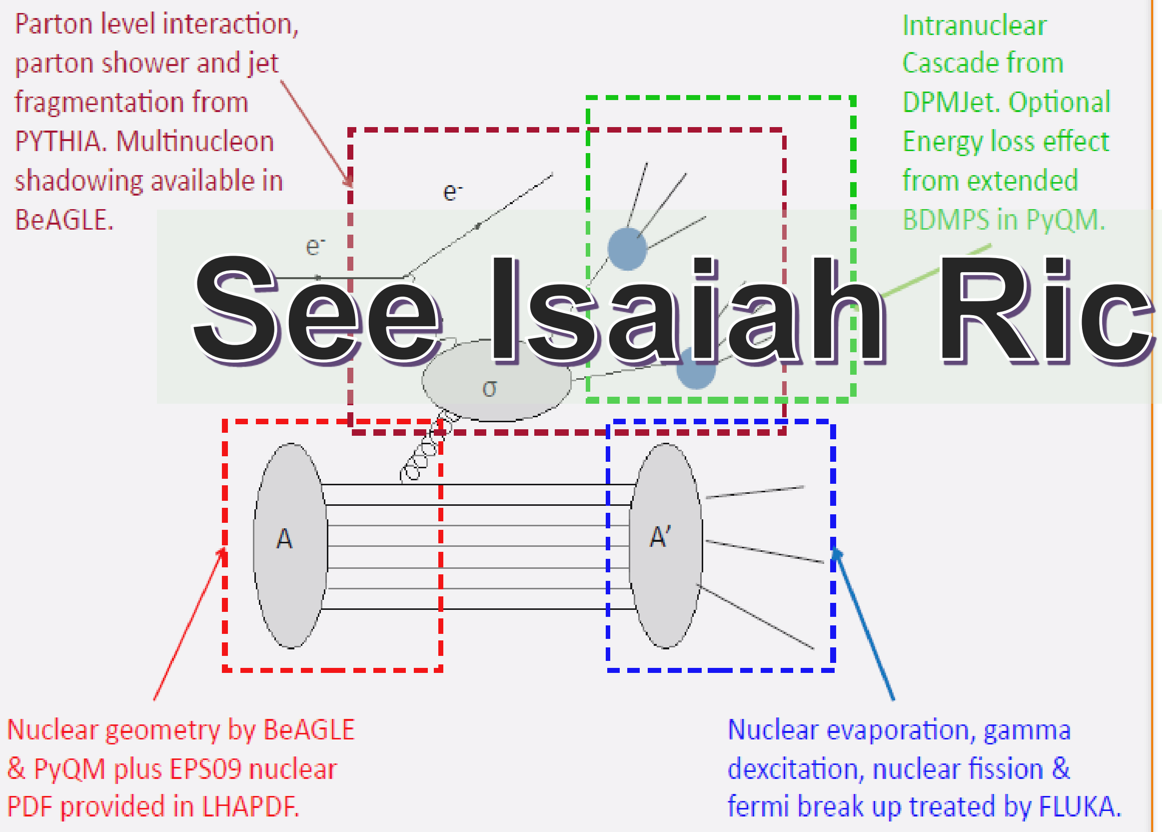
mass table	chi2
ws4_rbf	1.60
hfb22	1.91
ktuy	1.91
frdm12	2.02
ws4	2.49
tuyy	2.85
ame2016	2.95
ame2020	3.22
hfb27	3.87
unedf1	4.81
unedf0	13.88

Excitation Energy (theory) : "Exotic nuclei" collaboration BNL-FRIB

BeAGLE: Monte Carlo *eA* Generator

Courtesy of Barak Schmookler

W. Chang et al., Phys. Rev. D 106, (2022), 012007



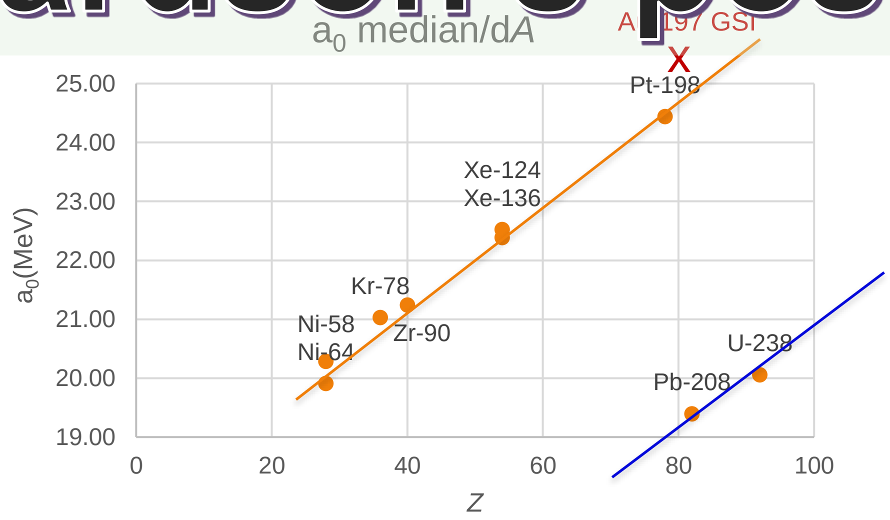
See Isaiah Richardson's poster

Parametrization of E* using BeAGLE

Courtesy of I.Richardson

^{238}U

MedianLogN/dA (dZ \ dN)	19	18	17	16	15	14	13	12	11	dN		8	7	6	5	4	3	2	1	0
0						23.63	23.12	23.66	23.51	23.09	23.30	23.30	23.01	23.02	22.71	22.39	21.76	21.11		
1					22.40	22.29	22.60	22.63	22.28	22.38	22.19	22.16	21.79	21.62	21.29	20.96	20.43	19.97	19.13	
2				20.62	22.73	22.24	21.90	22.00	21.86	21.58	21.57	21.56	21.31	21.23	20.83	20.63	20.14	19.77	19.01	18.33
3				21.17	20.64	21.82	21.41	21.56	21.32	21.34	21.23	21.04	20.87	20.67	20.39	20.16	19.75	19.43	18.90	18.90
4			21.33	22.28	21.26	21.21	21.50	21.48	21.21	21.03	20.94	20.86	20.62	20.55	20.25	20.06	19.72	19.48	19.20	19.92
5			21.75	20.59	21.07	21.07	21.04	20.92	21.03	20.97	20.67	20.43	20.38	20.35	19.94	19.81	19.57	19.35	19.31	19.81
6			20.79	21.03	21.63	20.60	20.82	20.92	20.82	20.65	20.40	20.43	20.22	20.07	19.73	19.66	19.38	19.48	19.31	20.23
7			20.47	21.54	20.76	20.69	20.58	20.66	20.54	20.22	20.18	20.07	19.78	19.97	19.72	19.47	19.39	19.33	19.41	19.76
8			21.29	20.89	20.96	20.88	20.36	20.63	20.23	20.31	20.30	19.99	19.65	19.61	19.74	19.59	19.22	18.93	19.33	20.95
9				20.32	19.96	20.56	20.23	20.29	20.08	20.36	19.96	19.55	19.95	19.43	19.53	19.37	19.28	19.29	18.92	19.90
10					20.34	20.37	20.51	20.81	19.87	20.42	19.53	19.85	19.50	19.46	19.26	18.58	20.04	19.22		
11						19.63	20.11	19.45	19.75	20.35	20.70	19.24	19.79	19.38	18.32	18.16	17.64			
12									18.97	[illegible]	20.11	18.81	19.43	20.16						



- E* distribution: LogNormal shape
- Slopes E/dA kN != kZ
- The "isospin" factor has been observed in the ^{78}Kr analysis
- Two regions, where Z=82 boundary
- ^{198}Pt NSCL data: E_x from the AA minimization agrees with BeAGLE results

Excitation Energy (theory) : INCL Liege

PHYSICAL REVIEW C **96**, 054602 (2017)

Courtesy of I.Richardson

Improvement of one-nucleon removal and total reaction cross sections in the Liège intranuclear-cascade model using Hartree-Fock-Bogoliubov calculations

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(Received 20 July 2017; revised manuscript received 16 October 2017; published 20 November 2017)

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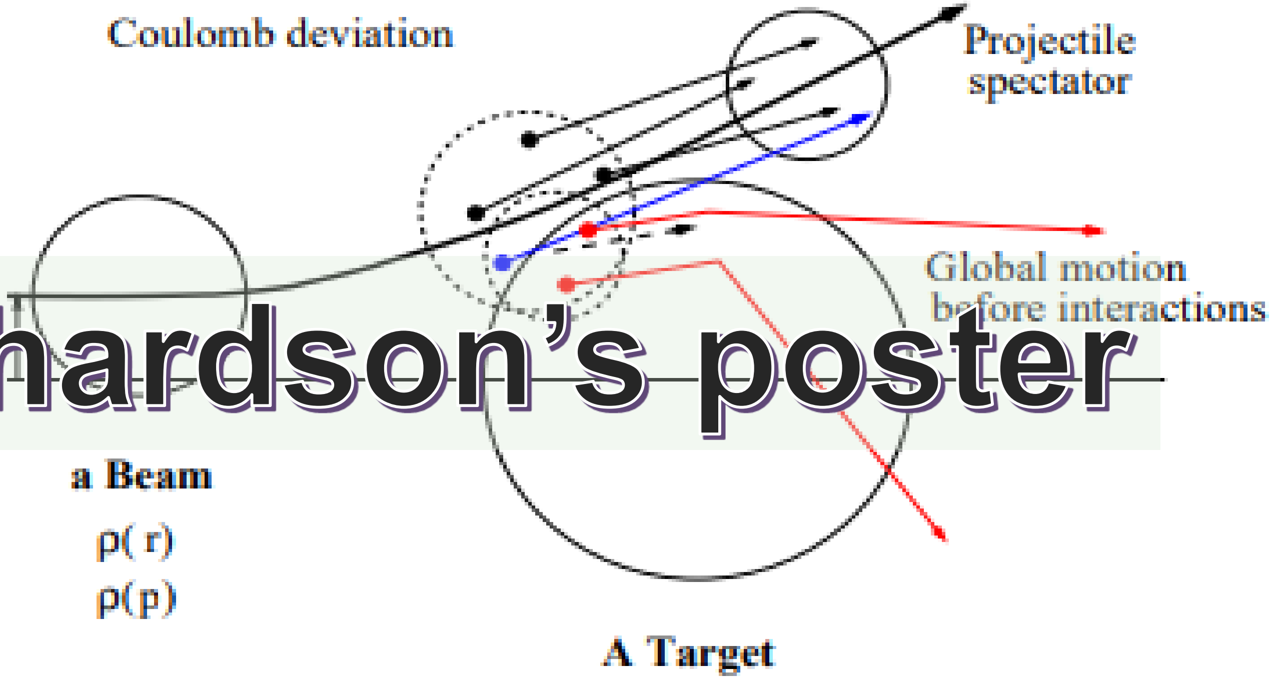
See Isaiah Richardson's poster



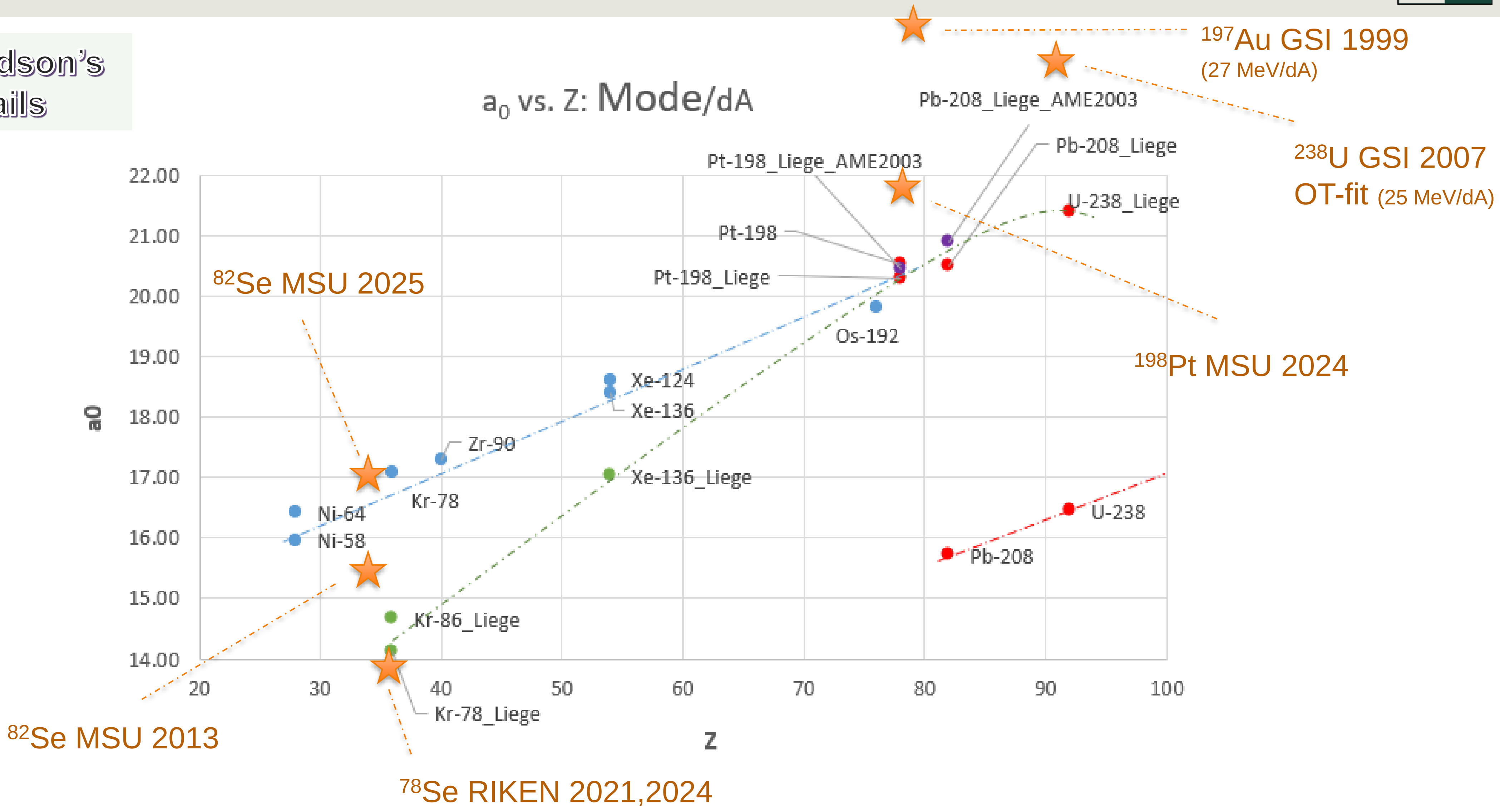
Liège : ^{78}Kr+p

Mo/dA dZ \ dN	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0					17.62	17.48	19.18	19.18	18.88	18.37	13.84	9.34		
1				8.74	18.60	19.12	19.29	19.16	18.09	17.66	14.97	12.00	7.79	
2			15.74	17.51	18.21	18.05	18.12	18.23	17.88	17.34	15.73	14.01	11.12	8.45
3			15.44	16.75	16.91	17.57	17.52	17.82	17.08	17.24	16.03	15.26	13.66	12.37
4		15.04	16.90	16.26	16.84	16.95	16.76	17.09	17.01	16.91	16.42	16.39	15.34	14.61
5		14.12	15.91	16.19	15.91	16.44	16.27	16.37	16.52	16.59	16.43	16.82	15.76	16.55
6		15.04	15.81	15.59	15.92	16.06	16.29	16.34	16.25	16.78	16.04	16.42	16.86	18.02
7	14.77	15.50	14.96	15.03	15.72	15.67	15.63	16.28	15.87	16.07	15.93	16.82	16.03	17.17
8	13.21	15.46	14.54	15.22	15.09	15.45	15.79	16.16	15.34	15.67	15.41	16.45	18.84	
9	14.80	14.16	14.27	15.00	14.67	14.50	15.14	14.86	14.30	15.57	15.07	15.01		
10		13.39	14.53	14.51	14.22	15.38	14.56	15.74	14.26	12.51				
11					14.03	12.77	10.31	15.45						

This schematic depicts the Liège event process. The interacting particles are composed of spherical nucleons which interacts via a peripheral collision and cascades through the nucleus resulting in an excited prefragment.

Excitation Energy: Theory vs. Experiment

See Isaiah Richardson's poster for details

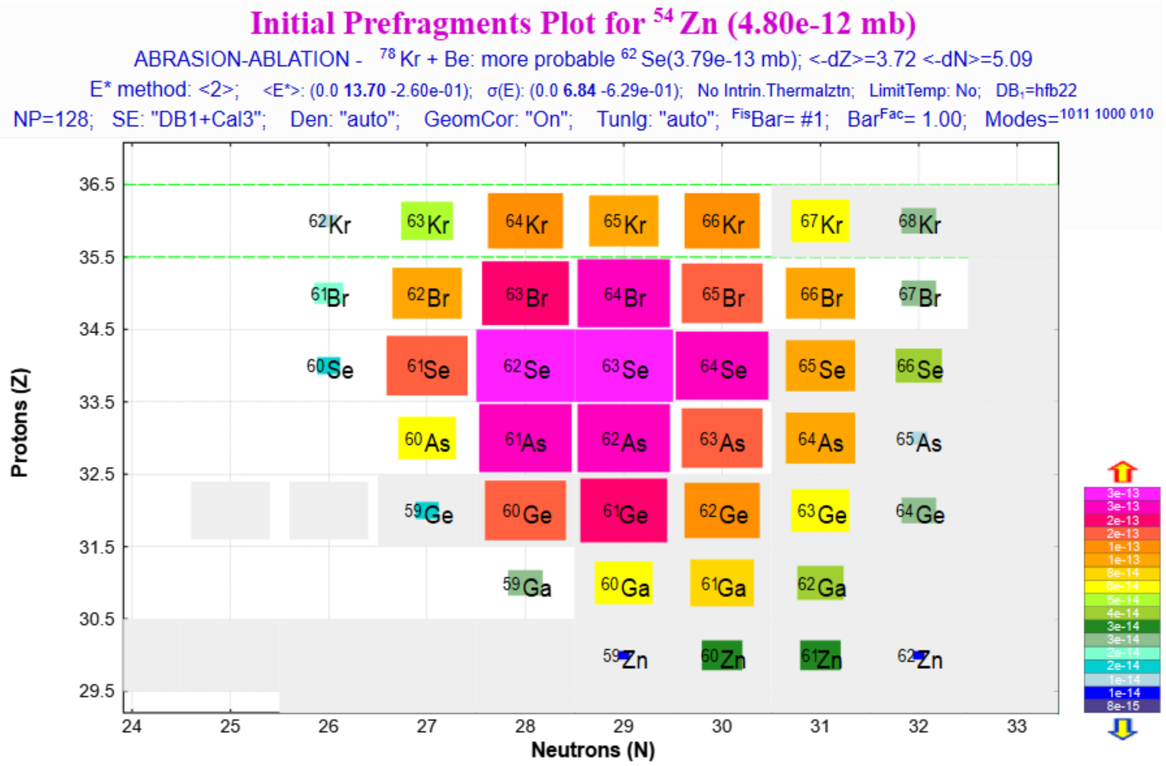


^{78}Kr + Be : Momentum distributions

- Velocity distribution modes (peak location) of Prefragment* & Final Fragment are the same.
  (* before de-excitation)

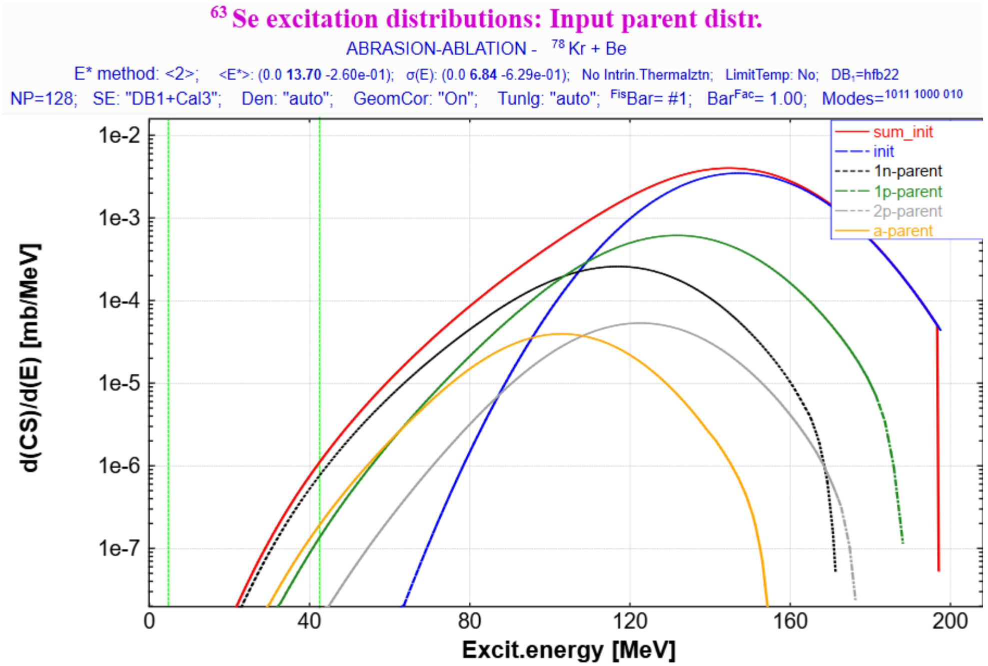
- Probably for systematics:
  ΔA should be equal to
  A_{beam} - $A_{prefragment}$

^{63}Se is most probable initial prefragment for ^{54}Zn



^{78}Kr + Be : Momentum distributions vs. *E* *

Prefragment velocity @ corresponding E* should be considered
$v(A_{PF}) = f(E^*)$ (Convolution model mechanism)



If E* / dA = const , dv / dA = const
but according to INC results E* / dA != const

BeAGLE: ^{78}Kr+e

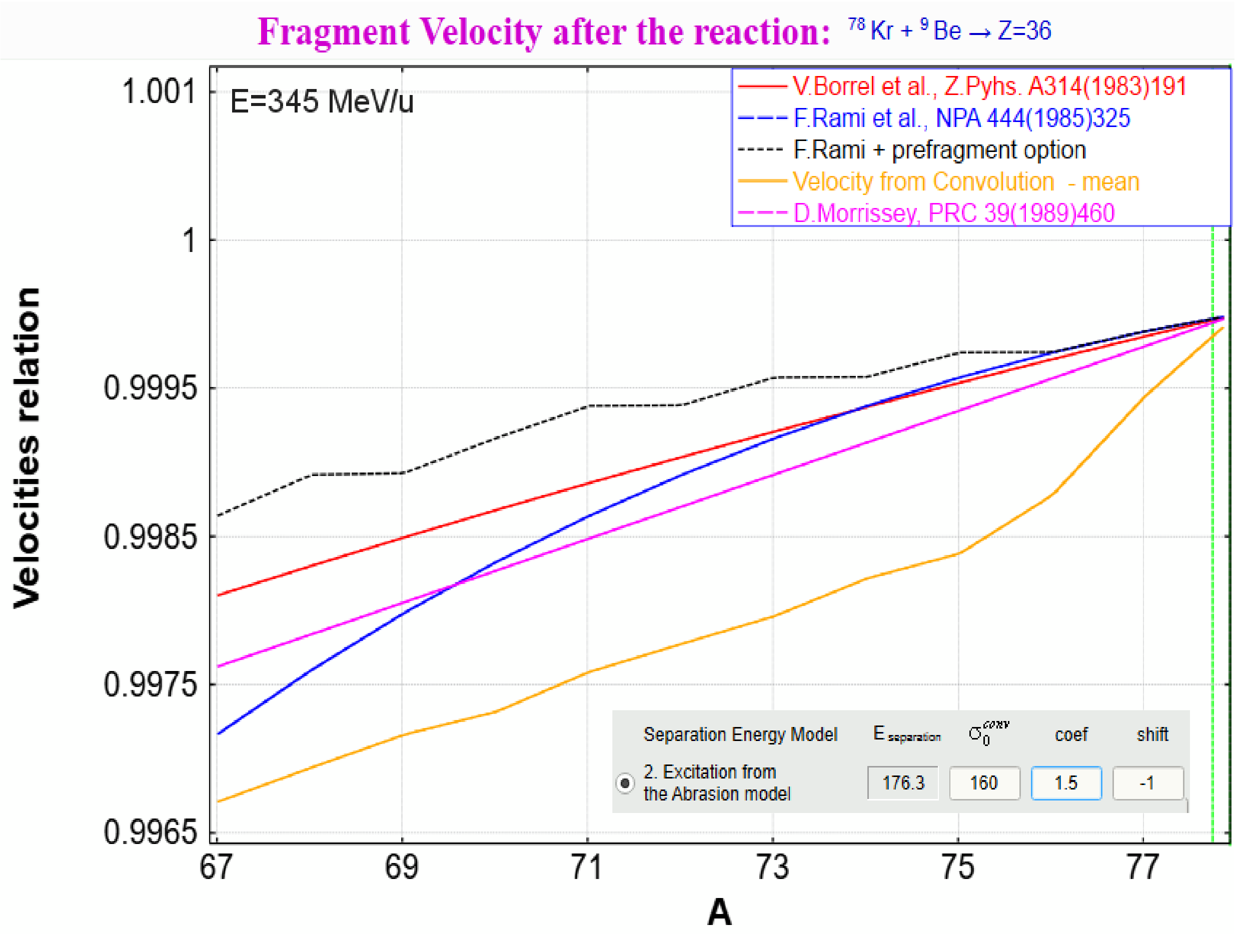
Mo/dA dZ \ dN	9	8	7	6	5	4	3	2	1	0
0		20.25	20.84	21.54	20.09	19.64	18.14	17.23		
1		20.34	20.00	20.61	19.51	19.63	18.54	18.09	16.34	
2	19.86	21.43	20.69	20.12	20.08	20.50	19.69	19.56	18.09	17.46
3	20.09	20.69	21.92	20.95	20.71	20.53	19.83	19.68	18.21	17.67
4	19.32	22.26	21.74	21.59	21.12	21.45	20.03	19.97	18.66	19.24
5		20.24	20.66	21.36	21.30	20.03	19.66	19.63	18.81	18.52
6			20.29	21.08	21.36	20.93	20.63	20.06	19.08	18.07
7			21.42	19.95	20.14	19.33	20.17	20.24	17.31	19.87
8				22.10	20.13	19.82	19.21	18.01		

Liège : ^{78}Kr+Be

Mo/dA dZ \ dN	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0																		22.10	19.54	18.37	18.53	16.50	16.35	15.21	12.39	8.62	6.23		
1																	18.22	17.77	17.60	16.82	19.71	17.26	16.37	14.87	13.48	11.28	8.77	6.45	
2															15.37	11.61	21.12	17.75	20.29	18.89	18.50	17.23	16.49	15.24	14.88	13.03	11.63	9.15	8.34
3														20.37	19.48	20.31	20.91	19.67	19.54	18.33	18.33	17.21	16.71	15.57	15.54	14.09	13.36	11.72	10.72
4													17.89	19.95	20.75	20.37	19.56	19.62	19.21	18.76	18.15	17.64	17.29	16.24	15.98	15.25	15.26	13.69	14.06
5											19.51	21.17	17.50	19.91	20.43	20.31	19.51	19.86	19.03	18.50	18.23	17.42	17.27	16.78	16.40	15.88	15.87	15.00	14.21
6										21.39	18.66	21.35	21.10	20.81	20.42	19.09	19.56	19.11	19.20	18.47	18.60	17.84	17.81	17.23	17.59	16.55	16.70	16.06	17.22
7									20.81	19.07	20.17	19.93	20.75	20.29	20.27	19.49	19.52	19.41	19.37	18.70	18.76	18.40	18.05	17.84	17.95	17.34	17.57	17.34	20.51
8								20.22	20.84	19.90	20.19	19.73	20.00	20.14	20.20	19.49	19.54	19.09	19.18	19.17	18.60	18.52	18.75	18.49	18.62	18.24	17.83	17.62	17.84
9							18.77	18.82	19.95	19.70	20.39	20.13	20.45	19.88	19.50	19.66	19.64	19.20	19.05	19.01	19.22	18.87	18.76	18.65	19.33	19.21	18.15	19.25	20.81
10						19.72	20.01	20.94	19.87	20.31	20.72	20.41	19.87	20.03	20.13	19.49	19.67	19.16	19.35	19.46	19.57	19.36	19.67	19.67	18.78	19.64	19.37	19.31	
11					19.77	19.34	19.39	19.87	20.06	20.25	20.16	20.21	19.67	19.85	19.76	19.78	19.97	19.62	19.29	19.31	19.16	19.20	19.40	19.58	19.66	20.54	21.21		
12					19.79	20.06	20.06	19.35	20.24	20.22	19.92	19.87	20.18	19.79	20.13	19.80	19.86	19.96	19.86	19.61	19.68	20.29	19.71	20.23	20.23	19.73	22.31		
13				19.32	19.91	20.02	19.93	20.13	19.70	19.79	20.02	19.82	19.81	19.80	19.80	19.71	19.77	19.95	19.53	19.73	19.94	20.01	20.50	19.83	19.91	17.86			
14			18.56	19.20	19.67	20.00	19.75	19.75	19.54	19.64	19.97	19.71	19.89	19.83	19.82	19.71	19.84	19.68	19.87	19.47	19.98	20.59	19.26	20.86	18.53				
15			18.55	19.12	19.63	19.36	19.87	19.46	19.68	19.49	19.92	19.59	19.90	19.68	19.64	19.53	20.01	19.86	19.49	20.25	20.53	20.26	21.73	19.64					
16		18.79	18.82	18.71	19.50	19.79	19.11	19.42	19.47	19.48	19.48	19.51	19.90	20.13	19.82	20.01	19.60	19.73	20.29	20.66	21.10	20.36	19.23	18.85					
17		18.24	18.69	19.20	18.67	18.77	19.07	19.04	19.17	19.29	19.29	19.41	19.69	19.76	19.85	20.03	19.76	20.42	19.66	20.14	22.08	20.38							
18	19.41	17.82	19.63	18.69	18.72	18.63	19.08	18.94	19.46	19.06	19.46	19.47	19.75	19.36	19.95	19.52	20.46	20.65	20.17	20.29	9.10								
19	16.95	17.75	19.03	18.47	18.57	19.06	18.92	18.79	18.76	19.17	19.11	19.35	19.59	19.81	19.51	19.76	20.00	18.90	18.91	18.56									
20	15.51	18.38	18.29	18.27	18.24	18.73	18.98	19.02	19.07	19.05	19.27	19.60	19.62	19.97	19.64	20.52	19.91	19.67	22.39										
21	17.53	18.17	18.13	18.65	18.29	18.99	18.55	18.70	18.77	19.08	18.80	18.77	20.15	19.43	18.41	19.01	20.52												
22	16.02	17.77	18.33	17.82	18.54	18.65	18.46	18.51	18.83	19.01	19.16	19.16	19.00	18.33	14.55	18.23	18.59												
23		17.35	17.23	17.47	18.72	18.57	18.55	18.78	18.75	18.08	18.16	17.89	17.07	17.97															
24		15.99	17.52	17.15	17.24	18.38	17.57	18.57	18.32	17.94	18.54	18.36																	
25					17.26	17.99	18.03	17.13	18.61																				

Courtesy of I.Richardson

Momentum distribution “shift” – Dissipation contribution?



- This shift can be attributed to an intermediate step—Dissipation (Friction)—between the Abrasion and Ablation processes, which contributes to the appearance of the low-energy exponential tail.
- Discrepancy in results: Is the measurement reflecting the mean value or the mode (peak location)?
- Further investigation is needed on the neutron-rich side.

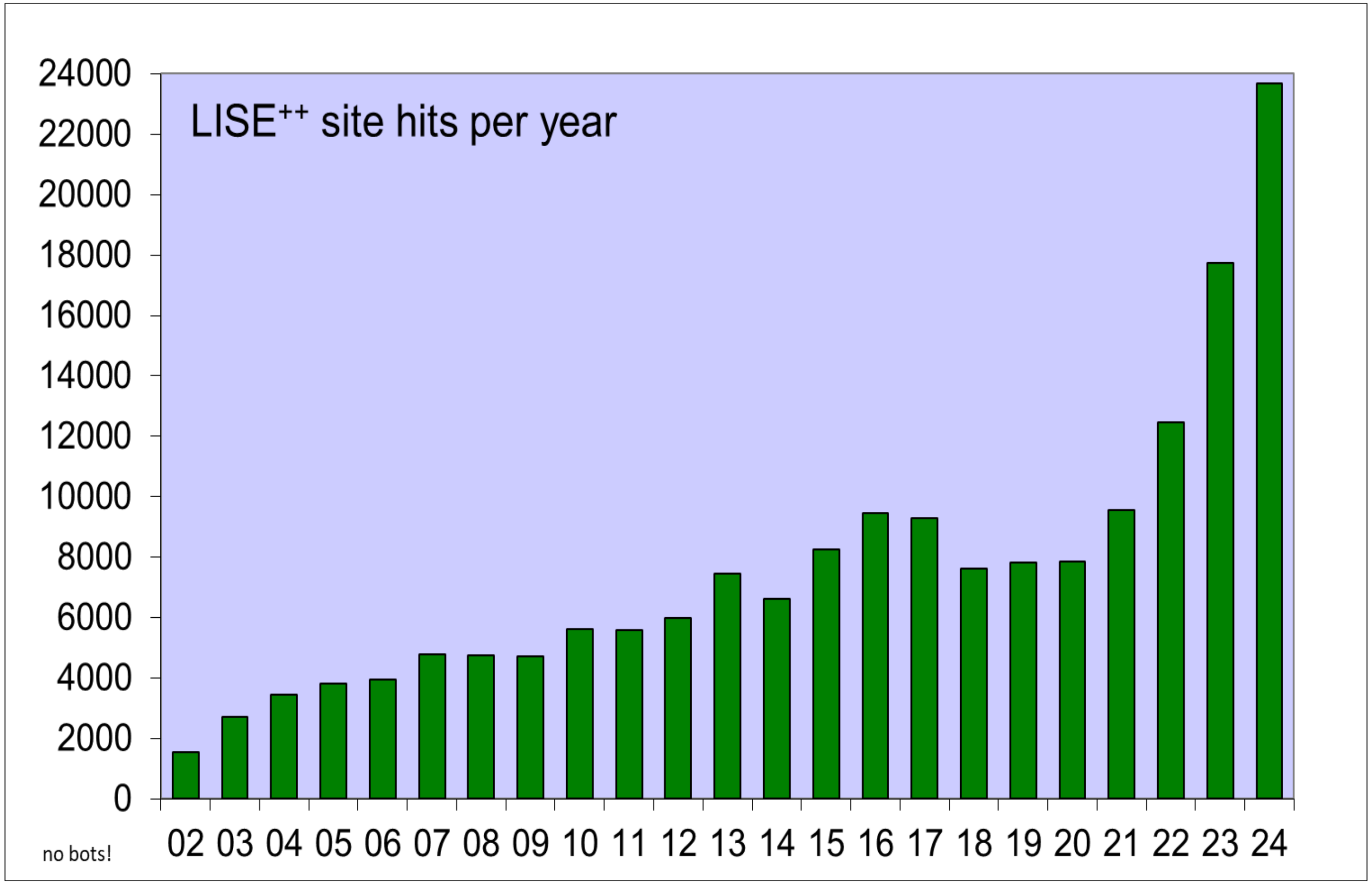
Multistep reactions

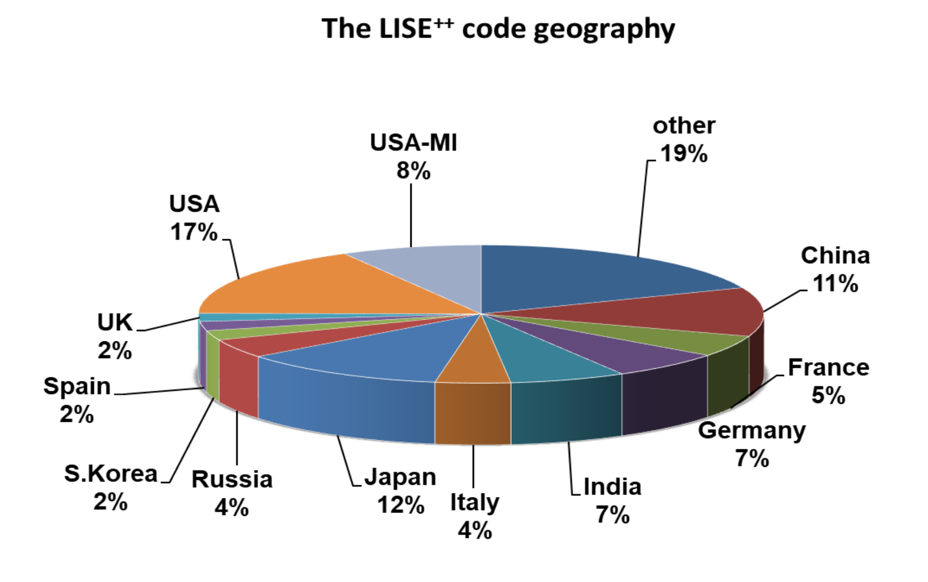
(see NI presentation)

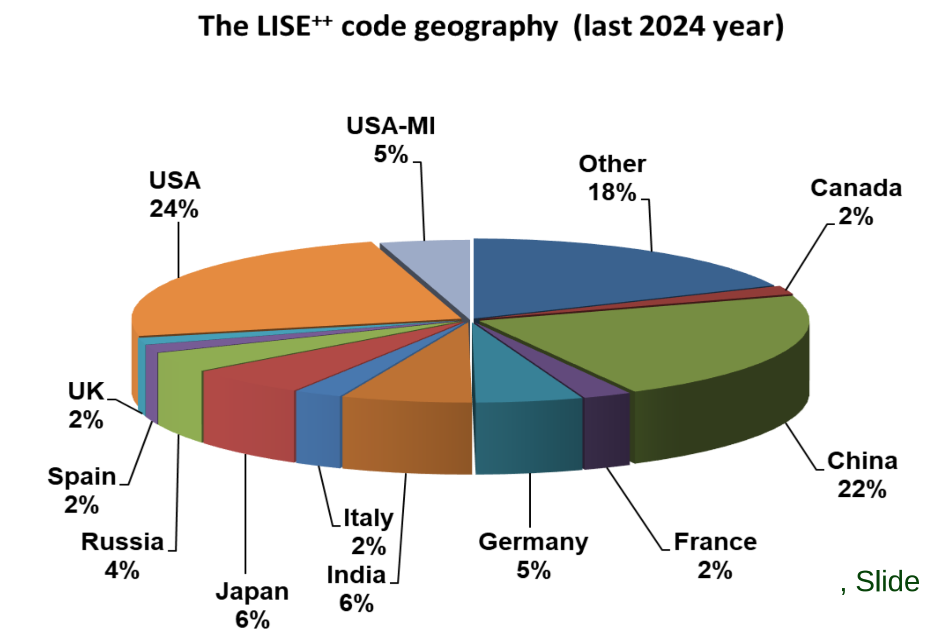
LISE site statistics

2024 LISE^{++} site statistics

The LISE site log-file was sorted by Daniel Kaloyanov (P&A, MSU)



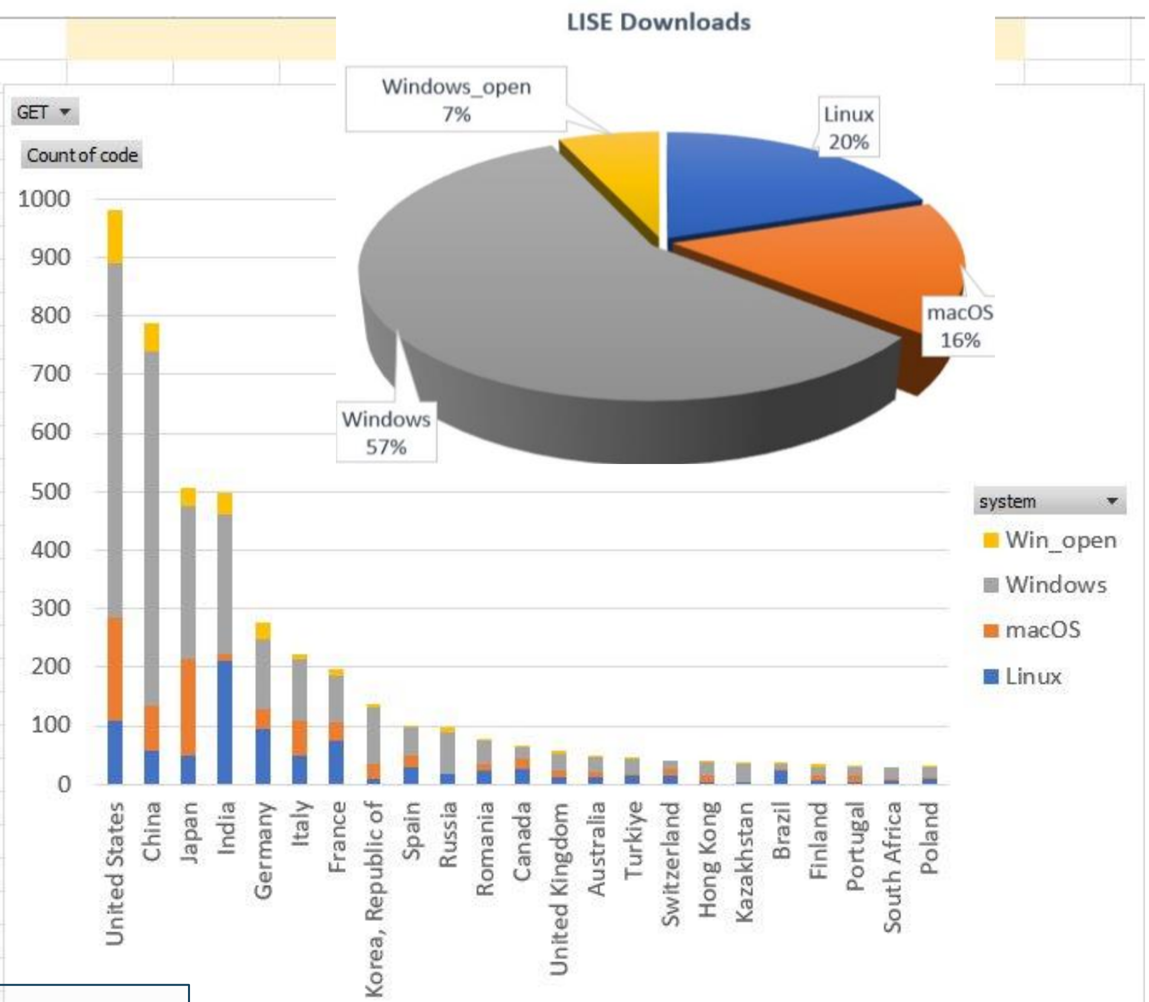




2023: Downloading the LISE package: Countries

GET (All)

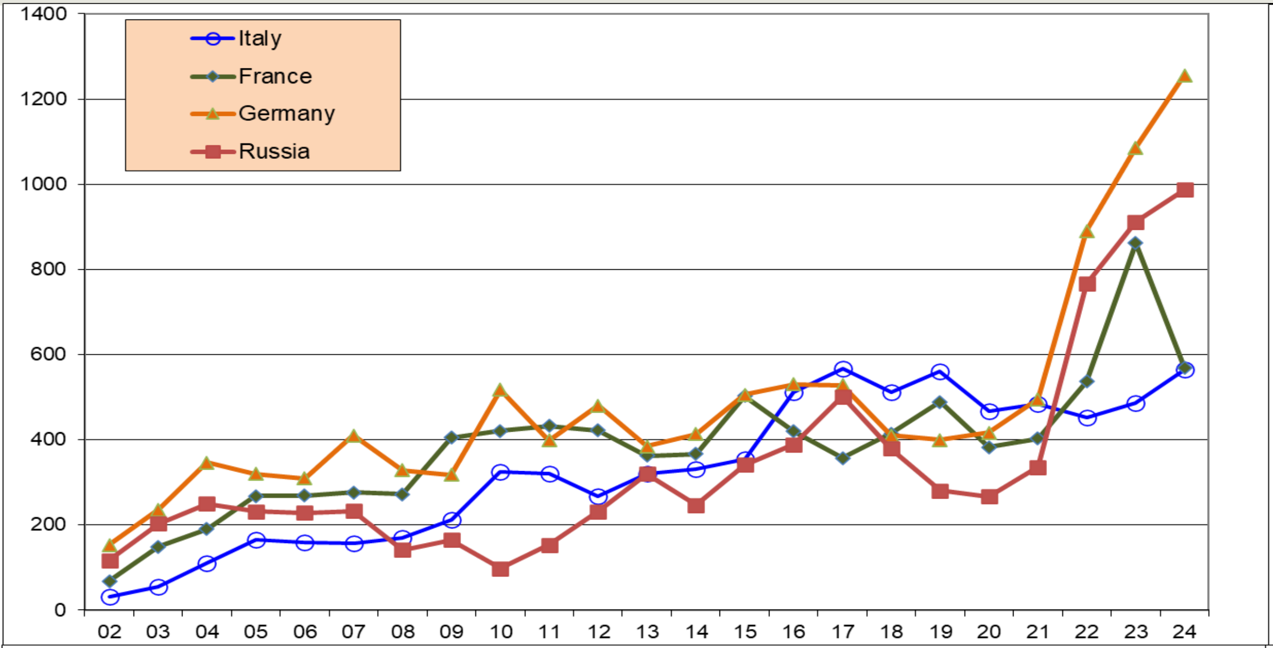
Count of code / Row Labels	Linux	macOS	Windows	Win_open	Grand Total	Windows	Linux	macOS
United States	109	175	605	91	980	71%	11%	18%
China	57	76	607	47	787	83%	7%	10%
Japan	48	165	261	32	506	58%	9%	33%
India	211	11	240	35	497	55%	42%	2%
Germany	96	32	119	29	276	54%	35%	12%
Italy	50	58	107	7	222	51%	23%	26%
France	74	32	80	10	196	46%	38%	16%
Korea, Republic of	10	24	97	7	138	75%	7%	17%
Spain	28	20	50	3	101	52%	28%	20%
Russia	18	1	70	9	98	81%	18%	1%
Romania	23	12	40	2	77	55%	30%	16%
Canada	26	18	19	2	65	32%	40%	28%
United Kingdom	11	12	30	4	57	60%	19%	21%
Australia	13	9	24	3	49	55%	27%	18%
Turkiye	14	3	26	1	44	61%	32%	7%
Switzerland	14	13	15		42	36%	33%	31%
Hong Kong	3	12	23	2	40	63%	8%	30%
Kazakhstan	4	1	29	4	38	87%	11%	3%
Brazil	23	4	8	1	36	25%	64%	11%
Finland	6	10	14	4	34	53%	18%	29%
Portugal	4	10	16	1	31	55%	13%	32%
South Africa	7	3	20		30	67%	23%	10%
Poland	8	3	17	1	29	62%	28%	10%
Grand Total	**857**	**704**	**2517**	**295**	**4373**	64%	20%	16%

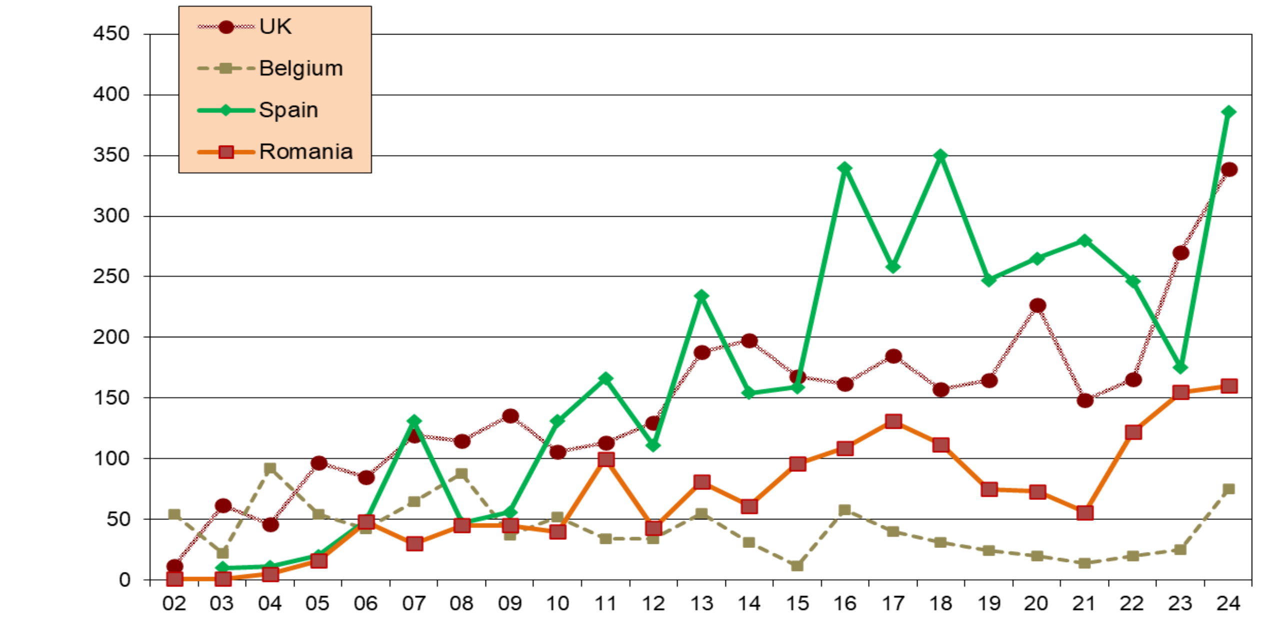


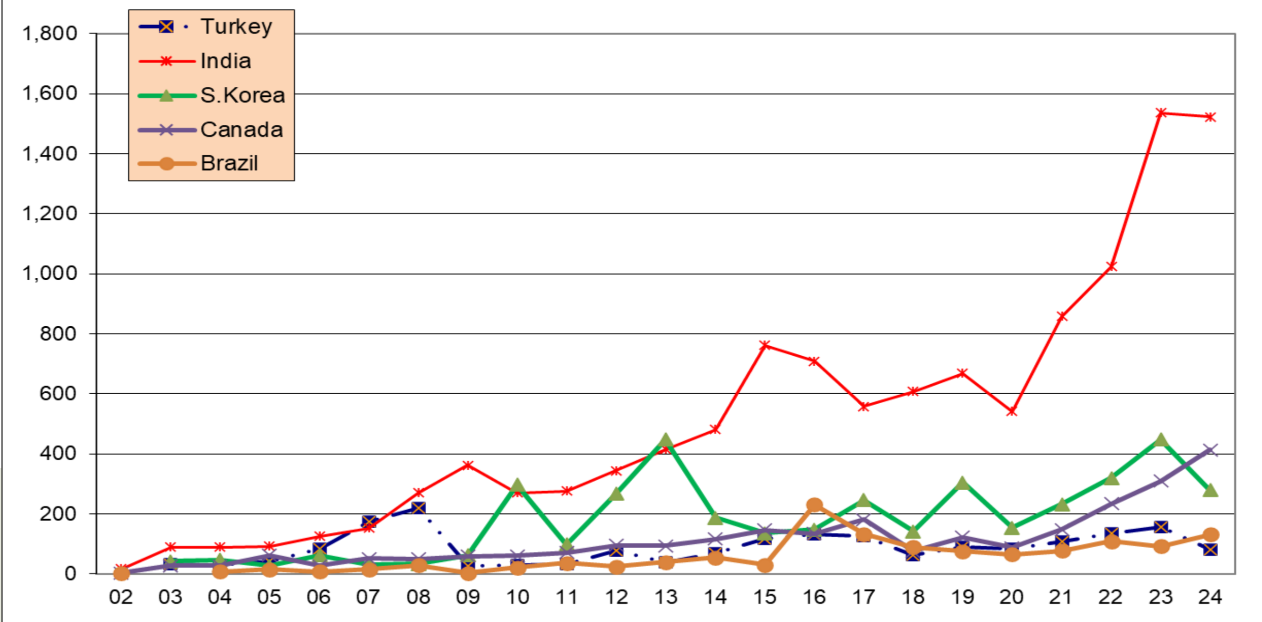
1 download per ~4 hits

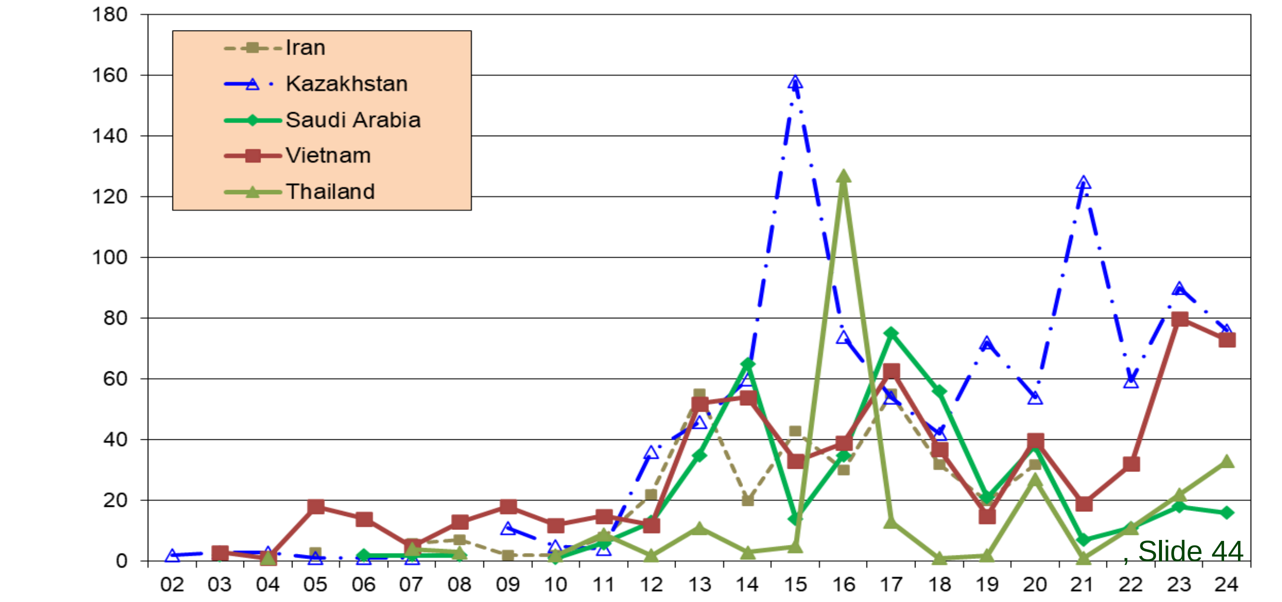
Windows: China, Kazakhstan, Russia, Korea, US
Linux: Brazil, India, Canada
macOS: Japan, Portugal, Switzerland

By countries per year (1)

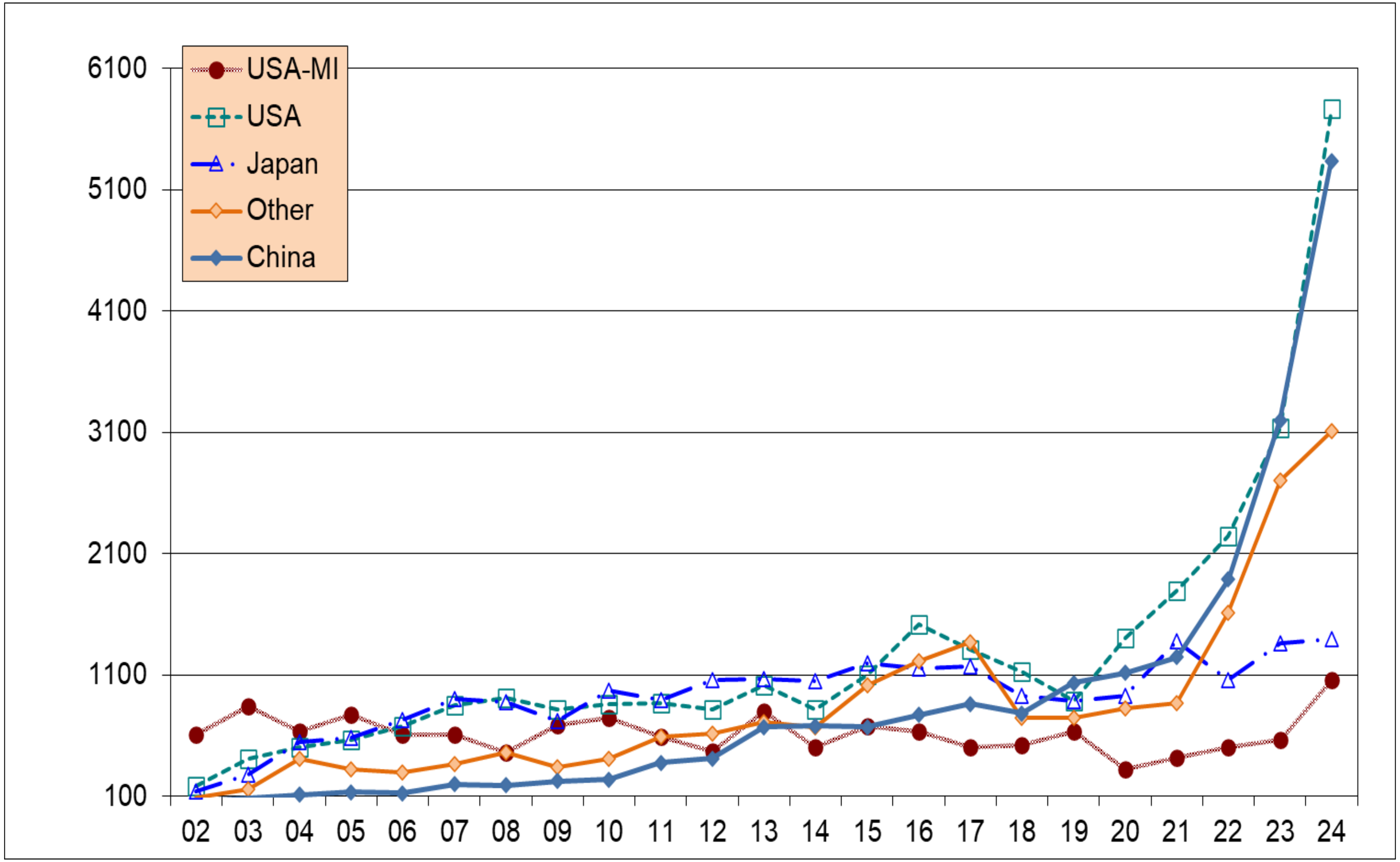








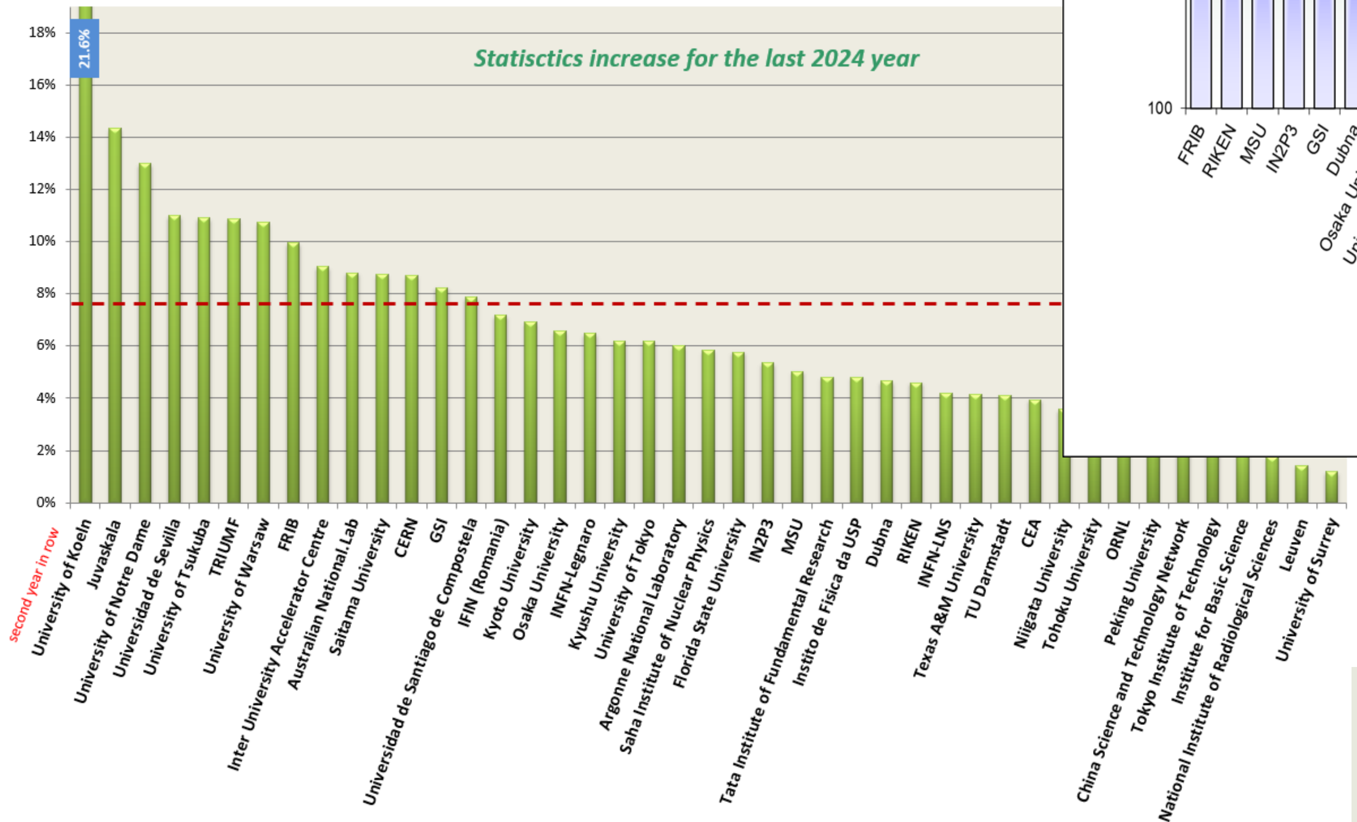
By countries per year (2)

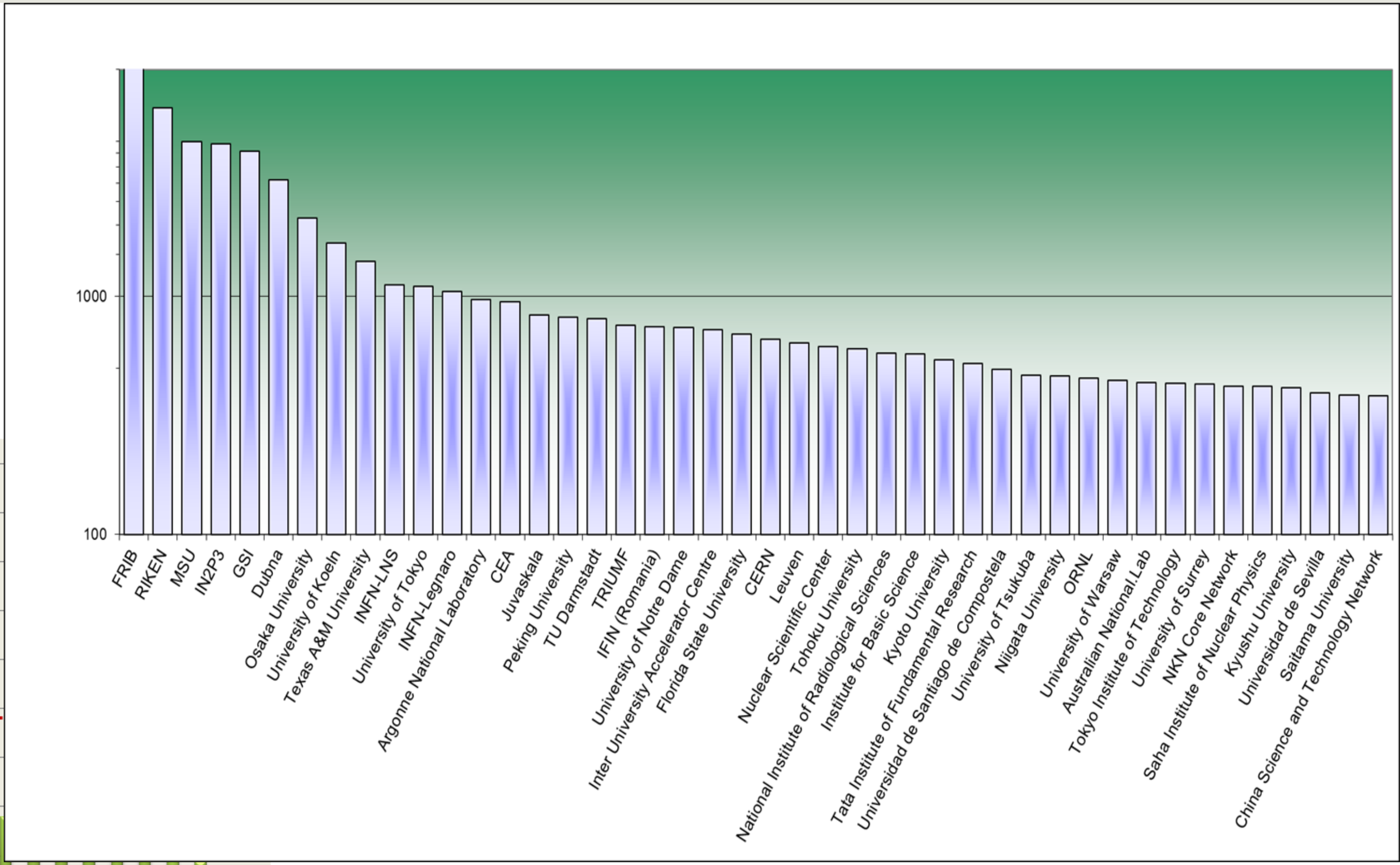


country	difference <22,23>-21	country	difference 24-23
China	1296	USA	2631
other	1088	China	2141
USA	895	USA-MI	490
Russia	503	Other	408
Germany	493	Spain	211
India	421	Germany	170
France	296	Canada	105
S.Korea	152	Italy	78
Canada	124	Russia	75
USA-MI	118	UK	69
Romania	83	Belgium	50
UK	70	Brazil	39
Turkey	39	Japan	34
Vietnam	37	Thailand	11
Brazil	23	Iran	10
Thailand	16	Romania	5
Belgium	8	Saudi Arabia	-2
Saudi Arabia	8	Vietnam	-7
Italy	-16	India	-14
Iran	-21	Kazakhstan	-14
Kazakhstan	-50	Turkey	-78
Spain	-69	S.Korea	-168
Japan	-168	France	-293
bot	-21	bot	92
Total no bots	5547	Total no bots	5951
Total w ith botl	5525	Total with botl	5475

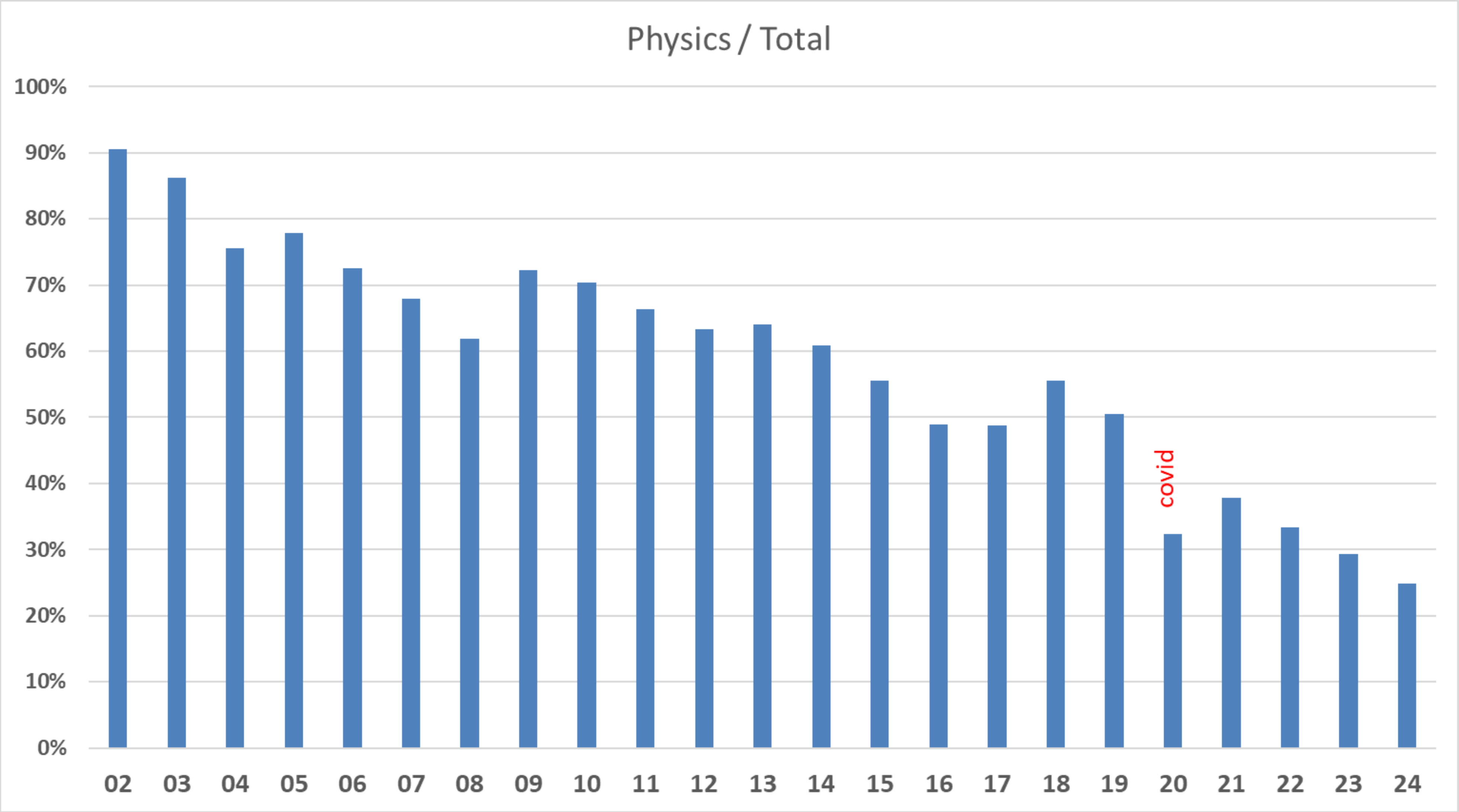
Facility for Rare Isotope Beams
U.S. Department of Energy Office of Science | Michigan State University
640 South Shaw Lane • East Lansing, MI 48824, USA
frib.msu.edu

Laboratories (absolute values) : 2024

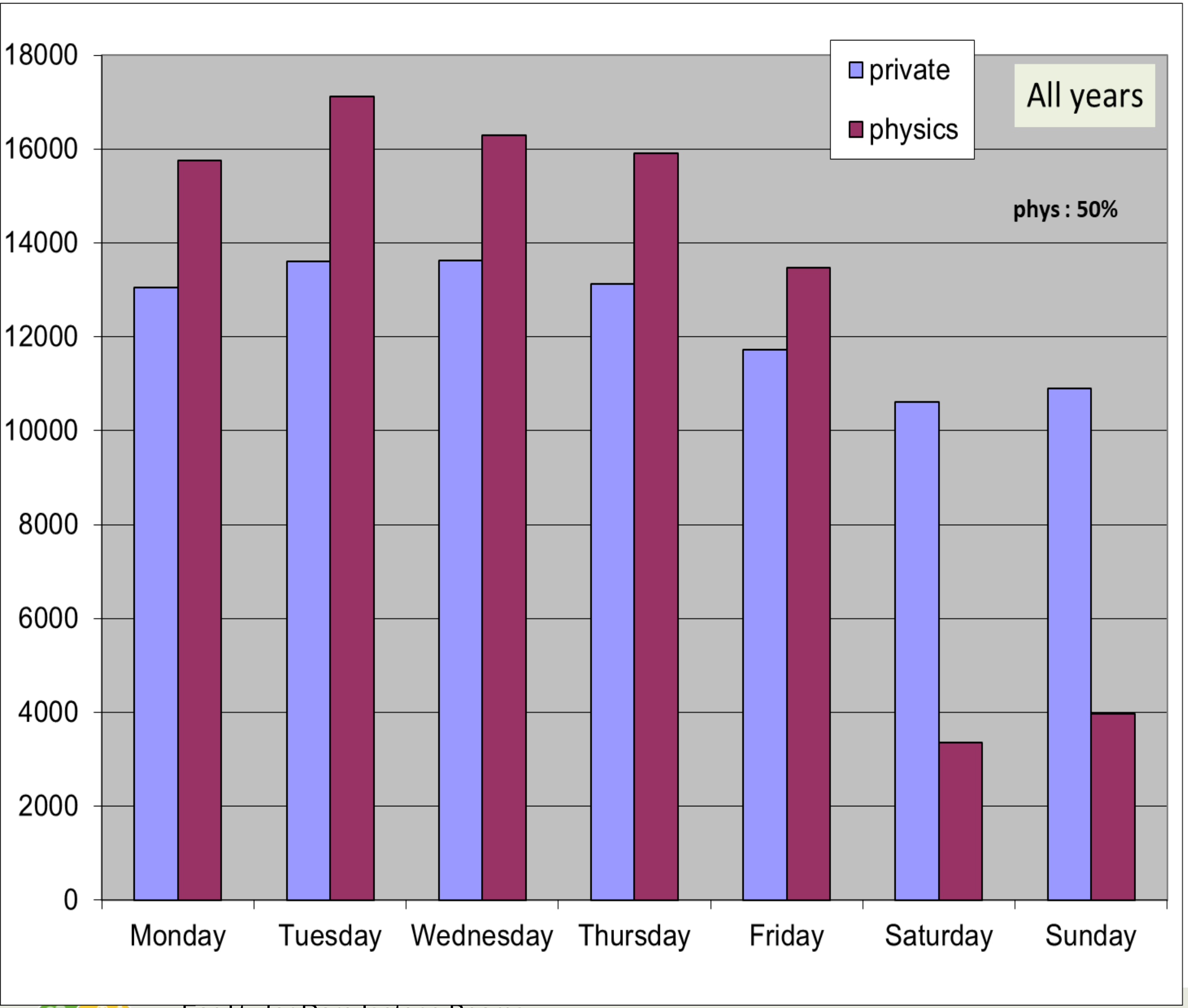


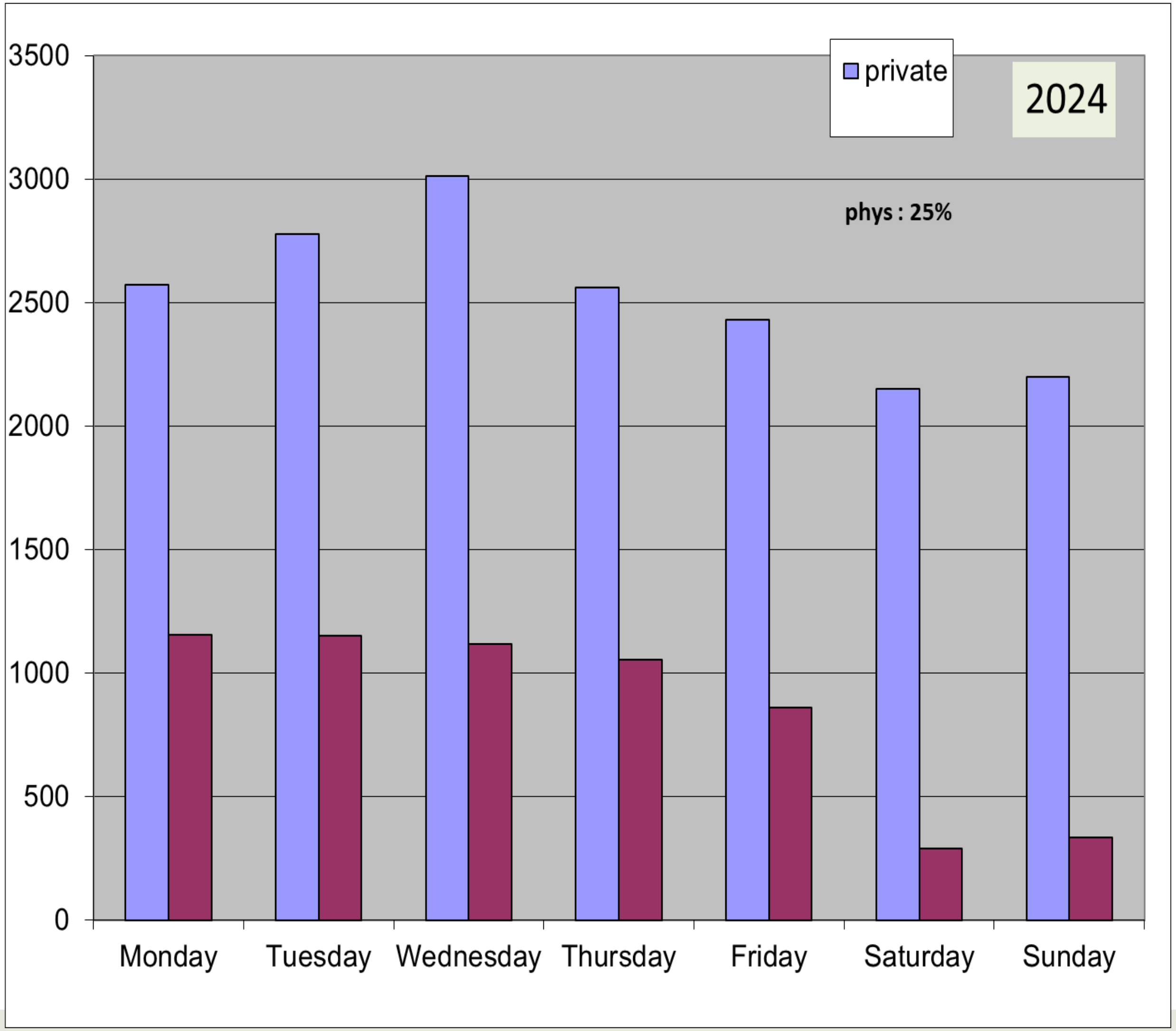


Private/Phys IPs by years



Weekday

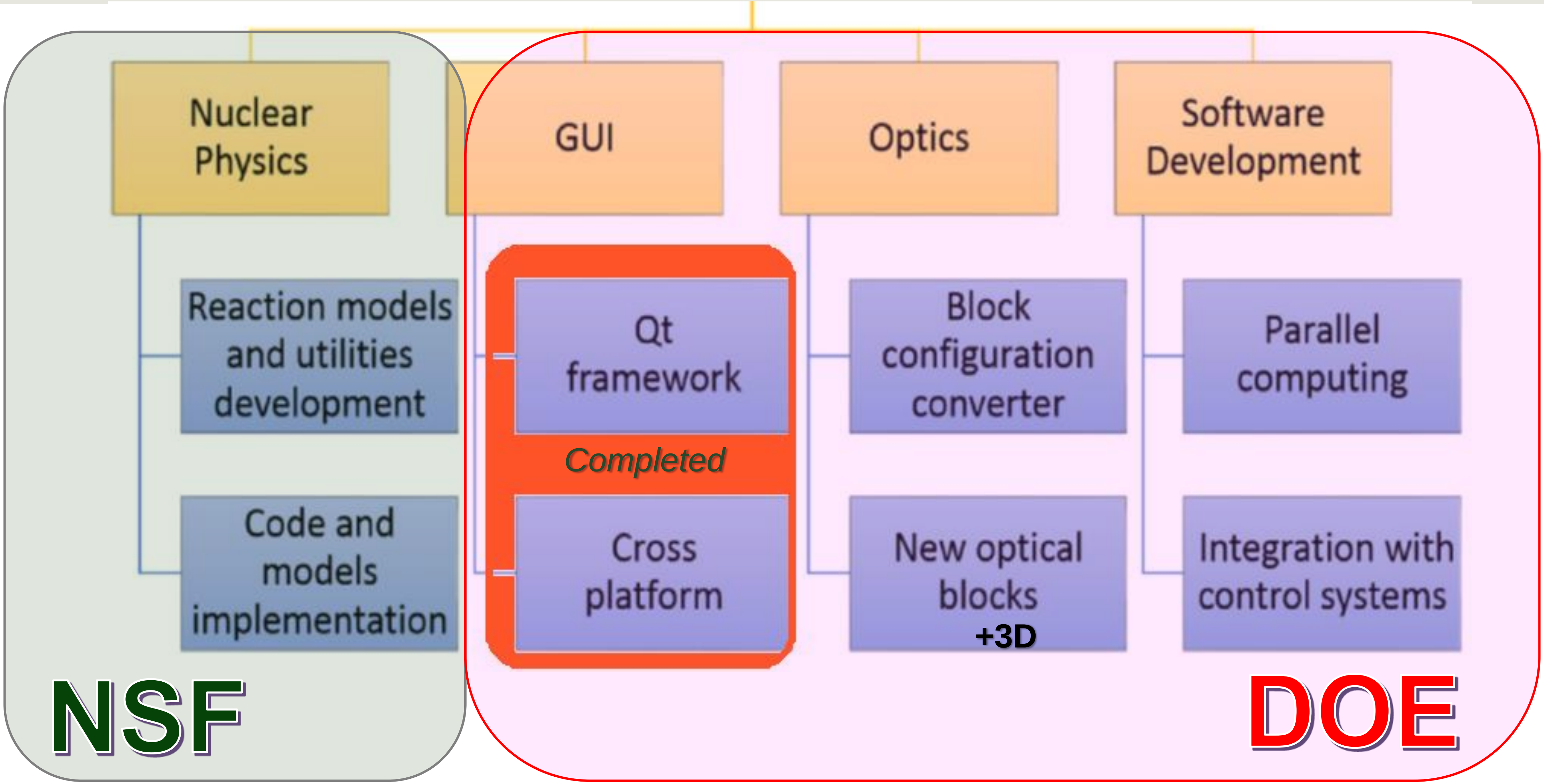

18000
16000
14000
12000
10000
8000
6000
4000
2000
0
private
physics
All years
phys : 50%
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday


3500
3000
2500
2000
1500
1000
500
0
private
2024
phys : 25%
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday

LISE++ Development Plans

LISE++ Development Plans

LISE++ development chart



LISE $^{++}_{cute}$ software development

In the near future:

- The creation of a LISE $^{++}_{core}$ library

  ❖ This library will allow to integrate LISE^{++} calculations within control systems, in order to directly assist the tuning of fragment separators.

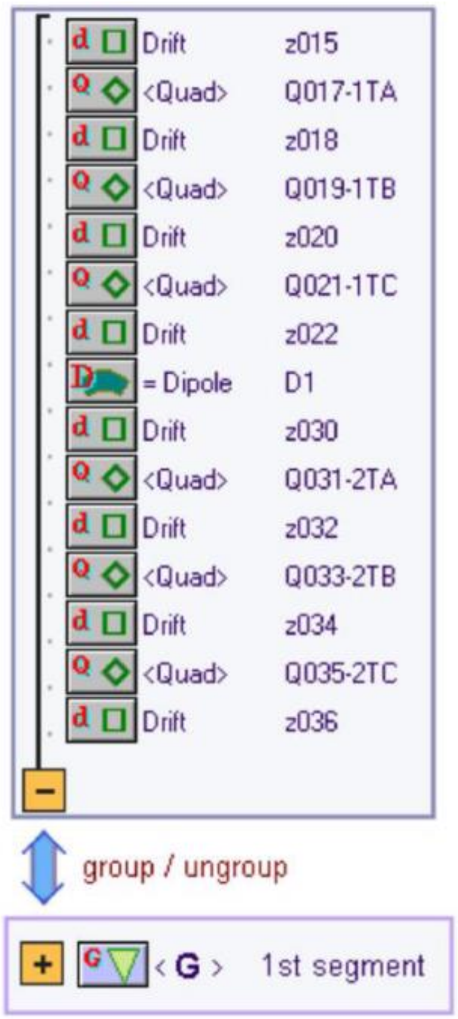
  ❖ LISE for Excel-64 (just completed)

- The code parallelization will be undertaken (project of A.Ray)

  ❖ To take advantage of modern computing architecture, parallel computing methods are essential in achieving faster computation. As a first step, the LISE^{++} code parallelization process will be implemented on the Monte Carlo and “Distribution” analytical methods for fragment transmission calculation.

- Block configuration converter

  ❖ This new tool will be built around a new type of block, labeled G (Group), which allows the grouping and ungrouping of E blocks. The tool can be applied to create sector configurations for fast analytical calculations.



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

LISE $^{++}_{cute}$ Reaction Models Development Plans

- Creation of fast and accurate Abrasion-Fission model based on the IFN Analyzer tables
- Abrasion-Ablation:
  - Global revision of the de-excitation process (mathematics & physics, constructed in 2003)
  - Improvement of the fast model for multi-step reactions (implementation of the AA for second step)
  - Intermediate Dissipation step in the Abrasion-Ablation model
  - Theoretical investigation of prefragment excitation energy with BeAGLE and INC-Liege models, incorporating in-house developments
- Direct 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
- Creation of Monte Carlo de-excitation cascade utility to benchmark the analytical LISE^{++} cascade subroutine and to create condition (gating) options
- Systematization of experimental production cross-sections (ΔBE, ..)
- Investigate charge-exchange and pick-up reactions in RIB production

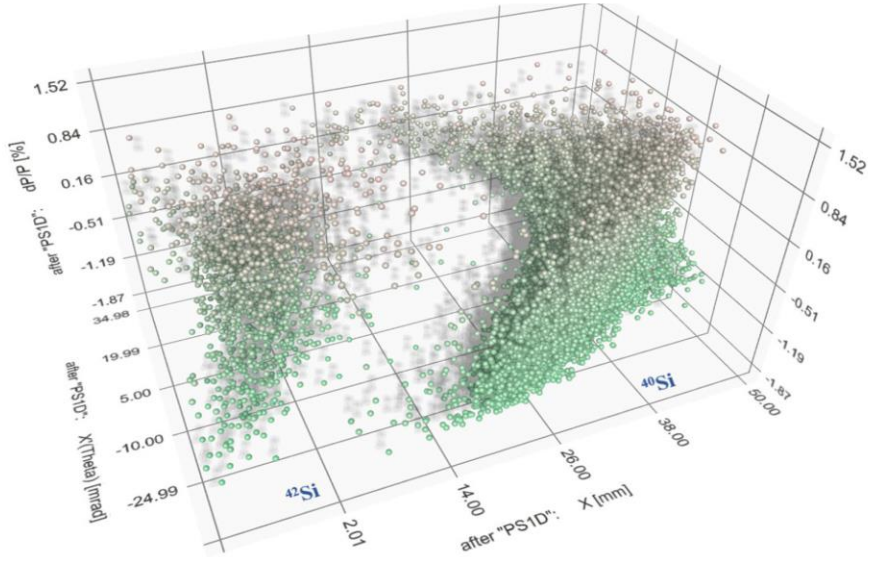
Summary

LISE$^{++}_{cute}$: Powerful tool of the FRIB scientific program

16
10-11-21

The LISE^{++} package has been ported to Qt-framework for compatibility with multiple operating systems. The benefits include **64**-bit operation, cross-platform compatibility (**Windows, macOS, Linux**), and the ability to take advantage of future computational improvements.

The new version is named LISE$^{++}_{cute}$ to indicate a new generation different from the previous LISE^{++} Borland-based versions.



- The latest official version 17.11 has been released 01/06/2025

Nuclear Instruments and Methods in Physics Research B 541 (2023) 4–7

LISE$^{++}_{cute}$, the latest generation of the LISE^{++} package, to simulate rare isotope production with fragment-separators

O.B. Tarasov [a,*], D. Bazin [a,b], M. Hausmann [a], M.P. Kuchera [c], P.N. Ostroumov [a,b], M. Portillo [a], B.M. Sherrill [a,b], K.V. Tarasova [a], T. Zhang [a]

[a] Facility for Rare Isotope Beams, Michigan State University, East Lansing, MI 48824, USA
[b] Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA
[c] Department of Mathematics and Computer Science, Davidson College, NC 28035, USA

03/17/23 openAI: Write an essay about LISE++ code

LISE++ is a computer code designed for the simulation of nuclear reactions and the calculation of ion beam transport.

…..

Overall, the LISE++ code is a powerful tool for the simulation of nuclear reactions and ion beam transport. Its ability to accurately model these processes has made it an essential tool for researchers in a range of fields, from nuclear physics to medical imaging. **As the field of nuclear science continues to evolve, it is likely that the LISE++ code will continue to play a critical role in advancing our understanding of the underlying physics.**

Team & Acknowledgements

The LISE^{++} Transportation Team

Members working on the transportation of the LISE^{++} software suite to Qt

D. Bazin	physics & ion optics consulting, benchmarks, adaptation to macOS
M. Hausmann	physics & ion optics consulting, benchmarks
M. Kuchera	source porting, development of porting process base
P. Ostroumov	supervision, funding acquisition
M. Portillo	physics & ion optics consulting, benchmarks
B. Sherrill	supervision, funding acquisition
O.B. Tarasov	leading porting process worker
K.V. Tarasova	source porting, benchmarks
T. Zhang	process administration, IT consulting, adaptation to Linux

The LISE^{++} Assistance Team

Members assisting on the LISE^{++} code development

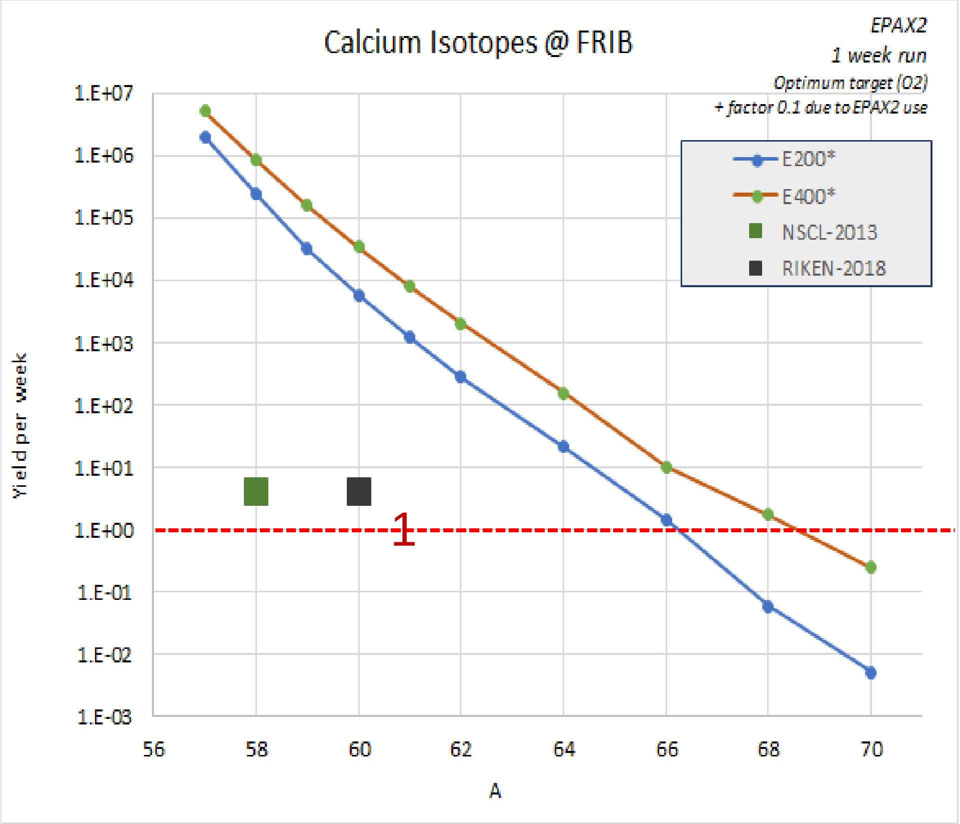
I. Richardson	grad
S. Watters	grad
D. Kaloyanov	undergrad (senior)
A.O. Tarasova	undergrad (senior)
A. Ray	undergrad (sophomore)

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics and used resources of the Facility for Rare Isotope Beams (FRIB), which is a DOE Office of Science User Facility, operated by Michigan State University, under Award Number DE-SC0000661. This work was supported by the US National Science Foundation under Grant No. PHY-20-12040, 23-10078.

Upgrading to 400 MeV/u

Impact of Facility Upgrades and Target Design on Multistep Reactions

- **Upgrading FRIB to 400 MeV/u** will significantly increase the production probability of neutron-rich isotopes in multistep reactions by an order of magnitude
- **Target Production Research:** Utilizing a liquid lithium target can further enhance the multistep factor, improving isotope production efficiency



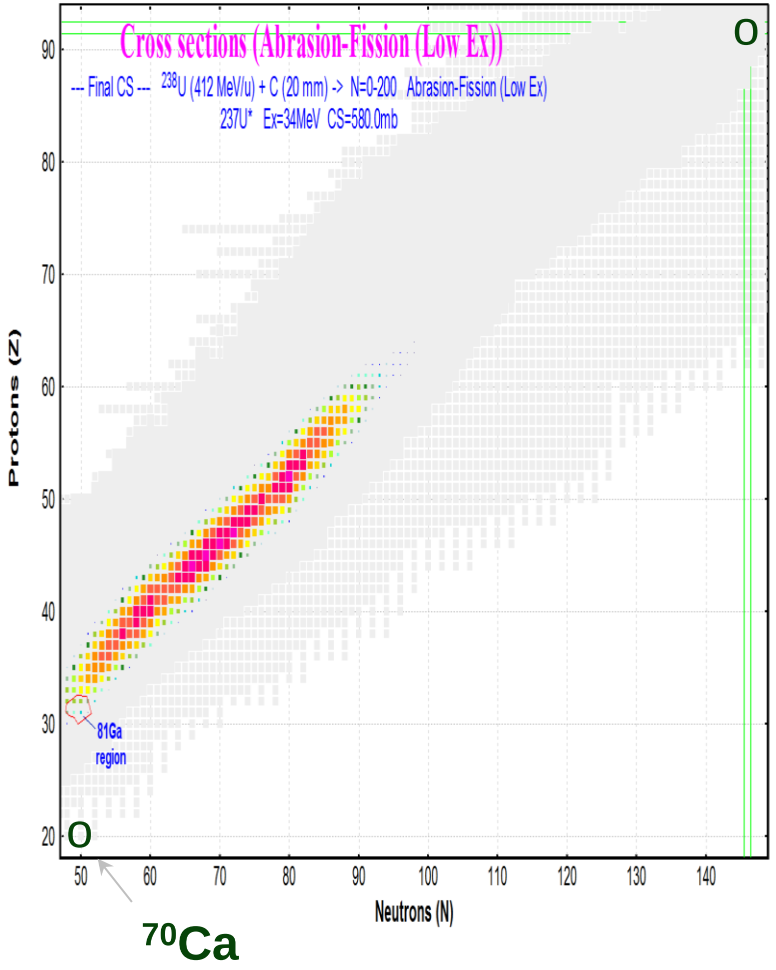
1 week run

^{66}Ca @ E200 ~ 1 event: C-target
^{68}Ca @ E400 ~ 1 event: C-target
^{70}Ca @ E400 ~ 1 event: Li-target

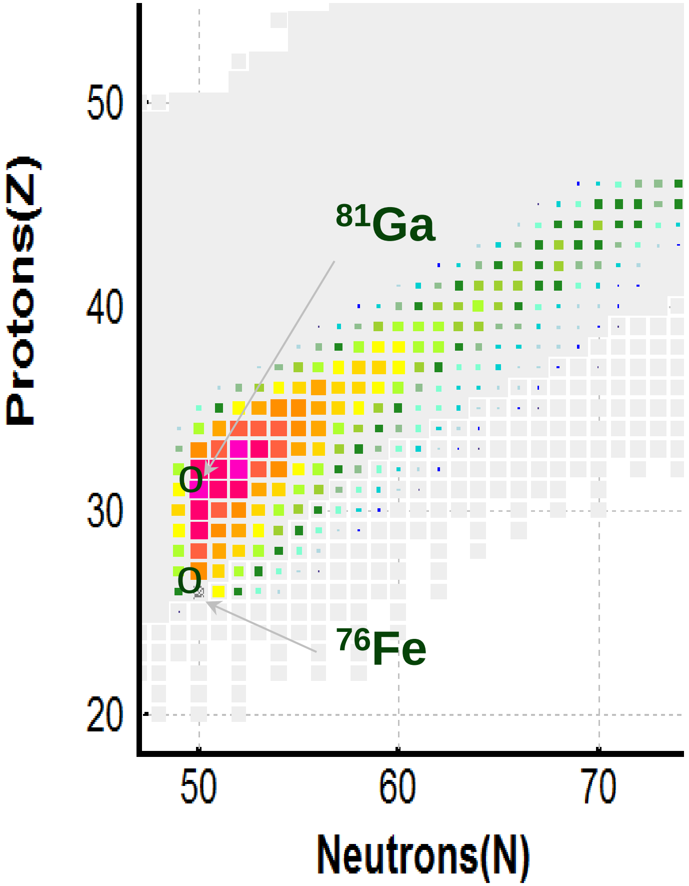
1 – FRIB 2024 (20 kW, 1 day, dP/P=4%, FOI as 50%)
a 1/700 factor compared to E200

^{70}Ca production in 3-steps reaction: $^{238}U \rightarrow {}^{237}U^* \rightarrow {}^{81}Ga \rightarrow {}^{76}Fe \rightarrow {}^{70}Ca$

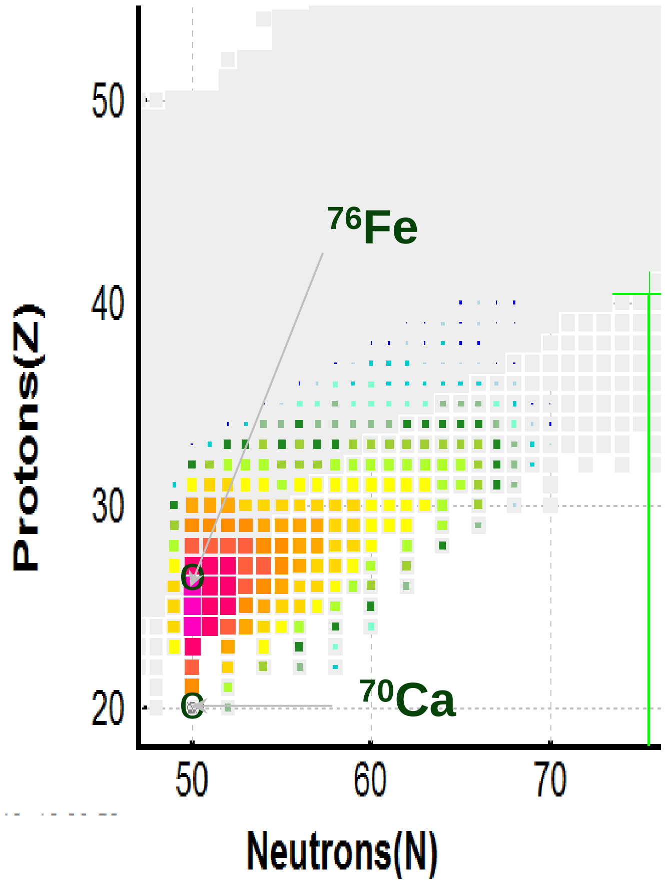
^{237}U (E*=34 MeV)
Fissioning nucleus



More probable parents of ^{76}Fe



More probable parents of ^{70}Ca



A lot of uncertainties, where main one is PF production cross sections in exotic regions