LISE++ Tutorial++

- 1. Start the program and configure LISE++ by loading the desired .lcn or .lpp file, $File \rightarrow Configuration \rightarrow Load$.
 - a. For the example in this tutorial, "A1900_2015.lcn" is used and can be found in the NSCL directory.
- 2. Choose a primary beam to best produce the isotope of interest. A list of available NSCL beams can be found at: <u>http://nscl.msu.edu/users/beams.html</u>.
 - a. In the menu bar, select the primary beam, or projectile, Settings \rightarrow Projectile.
 - b. Select desired nuclear fragment, Settings \rightarrow Setting Fragment.
 - c. Calculate optimum target thickness, *Calculations* \rightarrow *Optimum Target*.
 - d. Redo steps 2a-2c for other primary beams to find best yield for the chosen fragment. Example, for fragment ²²Al:
 - i. ⁴⁰Ar: 7.75
 - ii. ⁴⁰Ca: 6.0
 - iii. ³⁶Ar: 16.4, thickness 1070.7 mg/cm²
 - iv. ²⁴Mg: 87.6, thickness 1100.0 mg/cm²



Fig. 1: Event rate plotted against target thickness. Outlined in orange are the events, yield in particles per second, and the optimum thickness for the target material, beryllium in this case. The green line indicates the thickness at the maximum yield.

- 3. Set target thickness for optimal beam found in step 2, Settings \rightarrow Target
 - a. Calculate fragment separator settings by clicking the button shown in Fig. 2 to "Tune spectrometer for setting fragment on beam a."

File	Settings	Options	Calculations	Utilities	1D-Plot	2D-Plot	Databases	Help
*	b	Set-Up	66 👳 👳	\		sŗ	9 8 <u></u>	<u> </u>

Fig. 2: Menu and toolbar. Click the icon circled in orange to calculate the fragment separator settings.

b. Calculate the fragment's yield by double-right-clicking on its corresponding isotope in table of nuclei.



Fig. 3: Circled in black is the selected isotope, where the top yellow number is yield in particles per second, which should match the yield calculated in step 2. The bottom number is the transmission efficiency.

4. If the experiment requires the fragment stops within some range of the detector material, constrain the momentum width of the secondary beam.



Fig. 4: The full momentum acceptance is indicated by the percentage below the dp/p sign in the bottom left-hand corner of the screen.

- a. Find the average range of fragments, *Calculations* \rightarrow *Goodies*.
- b. In the "AFTER" pane, choose "after D4" to select energy after the last dipole.
- c. Select the desired material in which the range is to be calculated with the "Range to" button. Note the magnitude of the range.

Goodies	6 M S	
A Element Z 22 AI 13 Beta+ decay Table of Nuclides Charge states Set 13+ D1	AFTER Energy 102.477 MeV/u sig.(Energy) 0.495 MeV/u Brho 2.5348 Tm Energy Stragging 0 MeV/u Angular Stragging 0 mrad Velocity 13.0124 cm/ns Beta 0.434 Rest after reactions 100 % after D4 Range to Si 1336.27 mg/cm2	INTO Energy Loss MeV sig.[Energy Loss] MeV Energy Straggling MeV/u Angular Straggling mrad Loss due to reactions in this material [2] Time of Flight Start of TOF Target Stop of TOF FP_PIN
Print ? Help	Energy Loss to Si 100 micron 22.605 MeV	Time of Flight 273.917 ns sig(TDF) 0.734 ns Length 35.643 m

Fig. 5: Goodies window.

d. Set the thickness of the "FP_PIN" detector to a value greater than the average range calculated in step 4c.



Fig. 6: FP_PIN icon in left list pane of main window.

e. Plot the range distribution in the detector, 1D-Plot \rightarrow Range distributions. Choose the FP_PIN option.



Fig. 7: Range distribution of ²²Al fragments in FP_PIN. To calculate the full width half maximum (FWHM) of the distribution, select the icon circled in red on the right side of the window.

🖶 Statistics		100	4-1				
Range distribution in FP_PIN 36År (150.0 MeV/u) + Be (1070.7 mg/cm2); Settings on 22Ål; Config: DSDSWDDMMSMM dp/p=1.00%; Wedges: 0; Brho(Tm): 2.5350, 2.5350, 2.5350, 2.5350 Material: Si (2000 mg/cm2) Strag.Method: 1 (% stopped in detector [100% incomed into it]) Plot 1							
N distribution	x-mean	x-max	y-max deviatio	n FWHM	area	SumOfCounts	LeftPsigma RightPsigma
01 22Ål: 100.0%	+1.3328e+03	+1.3267e+03	2.654e-01 1.820e+0	1 6.196e+01	1.6286e+01	1.275e+01	2.111e+01 3.151e+01

Fig. 8: Statistics calculated for distribution. FWHM circled in red. Units are given in µm.

5. Reduce the momentum acceptance of the fragment separator until it satisfies the constraint, namely that the FWHM is less than or equal to the required penetration depth. Adjust the horizontal slits at the dispersive focal plane, or "I2_slits," in the list pane.



Fig. 8: I2_slits window. Select the display outlined in red to open the I2_slits window. Adjust the horizontal aperture width using the sliding tool to select the width. Notice that the momentum acceptance value dp/p is automatically recalculated. Also, both the fragment yield and transmission decrease with narrowing momentum acceptance.

- 6. If the rate of fragments is not above the desired threshold, compromise between minimum acceptable intensity and implantation width. Then, calculate fragment transmissions.
 - a. Reset the thickness of the FP_PIN to a low enough value such that fragments do not stop in it.
 - b. Calculate transmitted fragments, *Calculations* \rightarrow *Transmission and rate* \rightarrow *All nuclei*.



Fig. 9: Table of nuclei. The event rates and transmission efficiencies for all nuclear fragments created in the collisions are calculated. To interrupt, press the "ESC" key.

- c. Set up the parameters for generating plots, 2D-*Plot* \rightarrow *Plot Options*. For example:
 - i. Default Dispersive Block for 'Brho'-plot (Tm): D1
 - ii. Default Dispersive Block for 'Wedge'-plot (mm): I2_slits
 - iii. dE-detector: FP_PIN
 - iv. Stop of TOF calculated: FP_PIN
 - v. Leave the other options at their default options.
- d. Generate a ΔE -TOF identification plot, 2D-*Plot* $\rightarrow dE$ -TOF. Each transmitted nucleus is represented by an ellipsis, as shown in Fig. 10.
- e. Run a live simulation of the spectrum by clicking the button labeled "Monte Carlo" to show the relative intensities of transmitted nuclei. Click "Stop" to interrupt the simulation and "Continue" to resume.



Fig. 10: A two-dimensional plot of nuclear fragments, comparing energy loss and time of flight. Color is an indication of relative intensity. Select the button circled in red to label each nuclei. To run a simulation, select the Monte Carlo button outlined in black.

- f. To compare calculations to online spectra, calibrate the plot. Select two nuclei in the plotted spectrum, and hover over them with the cursor. The x- and y-coordinates of these points will appear in a yellow box in the upper right corner of the plot window.
 - i. Record these values for both nuclei as well as the x- and y-coordinates in the box below labelled "Channels." Open the calibration window by clicking the button shown in Fig. 11.



Fig. 11: Calibration window. Select the button on the left side of the 2D plot window, which is shown here circled in red. Click the "Y calibration" button outlined in black to calibrate energy loss shown on the y-axis. Do the same for the "X calibration" using time of flight values.

ii. Click the calibrate button for each axis and then "Input experimental points." Enter the energy loss and corresponding channel of both nuclei for the Y calibration and the time of flight with its corresponding channel for both nuclei in the X calibration window.



Fig. 12: More calibrating windows. To enter the data points chosen from the 2D plot, click the "Input experimental points" button circled in red. Enter the energy values for both points along with their corresponding channels. Repeat for the X calibration with time values.

- g. To save the plot for later, simply minimize the window.
- 7. Apply an achromatic wedge to remove contaminants from the beam; the thicker the wedge, the greater the fragment separation but also the greater the angular and energy stragglings.
 - a. Set the wedge thickness to about 20 percent of the total range. Then, calculate the fragment separator settings after the wedge.

Stro Stripper	I2_wedge		×
D1 Brho 2.5350 Tm S I1_slits -100 B +100	Al Density 2.702	State Dimension Thickness defect (!!) Calculate the W	edge thickness Next optical etting fragment
D2 Brho 2.5350 Tm	Z Element Mass	Set the spect	rometer after ng changes
S 12_sits slits	Image: Market And Imarket And Image: Market And Imarket And Image: Market And Image:	Thickness at 0 degrees Position - thickness • 1000 micron • 29 coordinate, mm +29 1017.07 thickness, micron 982.93 Atom	/R = 0.196 s/cm2 = 6.03e+21
D3 Brho 2.5350 Tm	□ 14	Degrader profile	
D4 Brho 2.5350 Tm	□ 14	C Wedge profile Angle (mrad) -0.5886 🥳 Calculate angl	le
FP_PPAC0 AI 2 mg/cm2	Compound dictionary	C Homogeneous	
M FP_PPAC1 AI 2 mg/cm2	General setting of block	Curved profile	alog
FP_sits slits -25 H +25 -25 V +25	✓ OK X Cancel	C Custom shape no current profile!	alog

Fig. 13: I2_wedge options window. Select the I2_wedge icon on the left side of the screen, shown here circled in red. Change the thickness of the wedge in the box outlined in black. Click the button "Set the spectrometer after this block using changes."

b. Calculate the wedge angle by selecting "Wedge profile" in the "Degrader profile pane." This will pull up another window. Select the calculated achromatic value.

this block usin	ng changes	
Thickness at 0 degrees Position : thickness • 1000 • 270.2 • mg/cm2 Position : thickness, micron • 29 1015.65 thickness, micron 984.35 Atoms Degrader profile • Wedge profile • 0.5337 • Homogeneous • 0.5397 • Calculate angle • Curved profile • internal profile • ge Curved profile • Custom shape • no current profile • ge Custom shape dia	d / R = 0.196 s/cm2 = 6.03e+21	Wedge degrader in dispersive focal plane - □ × Dispersion Plane - □ × Image: Second
		C Achromatic -0.57 Fix C Monochromatic -2.83 Fix Energy after the degrader 90.39 MeV/u
2	²² Si ²³ Si	C Fixed in the code 0.5397 Dimension of wedge angle
30	07e-8 2.23e-1 0% 1.379%	To plot a dependence from angle
_	²² AI	V Ok X Quit ? Help Achromatic -0.54 Fix atic -2.85 Fix
	1.576+1	

Fig. 14: Wedge degrader window. By selecting the wedge profile outlined in red and clicking "Calculate angle," the "Wedge degrader in dispersive focal plane" window appears. Select the achromatic value by clicking "Fix" in the "Wedge angle calculations from formulae (mrad)" pane.

c. Calculate the new settings of the fragment separator. Then, recalculate all transmitted fragments.



Fig. 15: Nuclear fragments with some contaminants removed. By applying the wedge, many contaminants have been removed from the beam. Clicking "All nuclei" button in the menu bar at the top of the page calculates the transmitted fragments.

d. Generate another ΔE -TOF identification plot. Identify the individual nuclei by comparing the results of the LISE++ calculations with the wedge in place to the channels on the spectrum.



Fig. 16: ΔE -TOF identification plot after removing contaminants.

8. While applying the wedge has improved the quality of the beam, the purity is still too low to be experimentally useful. Continue to modify the wedge parameters to clean the beam.



a. Calculate the wedge selection plot.

Fig. 17: Plot of yield over horizontal distance. A wedge plot can be generated by clicking the "Wedge selection plot" button in the toolbar. Each fragment's yield is plotted as a function of position. In the test case, the nuclei of interest, ²²Al, displayed in red, is barely visible amid the remaining contaminants. The current setting of the focal plane slits are shown in green.

- b. Close the slits around the image of the fragments of interest to eliminate the contaminants on the far sides of the focal plane without cutting into the yield of the desired nuclei. To do this, open the display shown in Fig. 18, and adjust the horizontal width of the aperture using the sliding tool. Then, recalculated the transmitted fragments.
- To further separate contaminants, try increasing the thickness of the wedge, first с. by a factor of two. Then, recalculate the settings after the edge as well as the achromatic wedge angle.
- d. Generate another wedge plot to compare to the previous yield distribution. By increasing the thickness of the wedge and narrowing the focal plane slits, the yield of the desired isotope is reduced.
- e. Repeat steps 8b-8d by varying the wedge thickness and slit width until a maximum purity is reached without reducing the yield below the necessary experimental threshold.



Fig. 18: Focal point slits window. Select the display below the "FP_slits" icon on the left side of the home screen to open the window.

- 9. Since the various nuclei have very different times of flight, use a velocity, or Wien, filter to further purify the beam.
 - a. Modify the spectrometer design by opening the setup window. Select the "FP_PIN" material block. Make sure Insert Mode is set to "before." Then, add a Wien velocity filter. The nuclear fragments are velocity dispersed at the exit of the Wien filter, so add a Compensating Dipole following the filter, which acts to refocus the fragments.

Set-Up 661	9 🖳 🍾	🕂 T 🖻		88	R		\$ <mark>5</mark> P\$ 🗶 🔣 🕅 🕅 🕅 🕅
meter	designing	-	-		1		2
BI	Given Name	ZQ	Length,m	Enable	*	- Insert Mode	Insert block
Wedge	12_wedge			+		before	T 🔘 Target
Material	I2_PPAC1			NO		C	Stroper after Target
Material	I2_SCI			NO		C after	
Dipole	D3	0	8.767	+			Wedge
S 🔲 Drift	13_slits		0	NO		- Move element	Material(Detector)
🖤 🔻 Wedge	13_wedge			NO			
Dipole Dipole	D4	0	9.39	+		<u>T</u> Ob	Haraday cup
Material	FP_PPAC0			+		👃 Down	Discussion (Maticala)
Material	FP_PPAC1			+			Dispersive (M-dipole)
S 🔲 Drift	FP_slits		0	+			Wien velocity filter
Material	XF_SCI			NO		🚯 Edit	Drift (multipole.slits)
Material	FP_PIN			+	Ξ	¥ Delete	
Material	FP_Stack0			NO			K > Beam Rotation
Material	FP_Stack1			NO			H↔ Shift of Optical Axis
Material	FP_Stack2			NO		🖌 ок	E Electrostatio dinole
Material	FP_Stack3			NO			
Material	FP_Stack4			NO		7 Help	Gas-filled separator
Material	FP_SCI			+	-		Compensating Dipole
Selected block						Total	K 📫 RF separator
Enable 🔽		Material(Detector)			Number of Blocks	B RF buncher	
Let call automatically		Block Ler	ngth (m)	0		26	
Block name = FP_PIN		- Len this b	gth after block [m]	35.643		Length [m]	Solenoid
		Sequence	number [20		35.643	Z Delay (efficiency) block

Fig. 19: Spectrometer designing window. Click the "Set-Up" button in the toolbar to open the window. Choose "before" in the "Insert Mode" pane. Add desired elements from the "Insert

block" pane. Elements in the block chain can be deleted and moved up or down in their order using the respective commands.

b. If the Wien filter has been added to the beam line, it should appear on the left side of the home screen. Select the icon to set the electric field. In this example, the field chosen is 3000 kV/m.

D3 Brho 2.3734 Tm	Wien 1 ? X
2.2724 Im P 04 Bitho 2.2724 Im M FP_PPACO AI 2.11 2.11 2.11 M FP_PPAC1 AI 2.11 2.11 2.11 S FP_PPAC1 Sills -8 1.28 Sills	Wien Velocity Filter settings Select constant field © Electric field E = 0.01 + KV/m © Magnetic field B = 0.01 + Gauss Dispersion Calculate the Values using the Setting fragment from the Setting f
Ween 1 E 0 KV/m 1 8 0.01 G 1 9 0 0.01 G 1 9 0 0.01 G 1 20 0 0.01 G 1 20 0 0.01 G 1 20 0.01 G 0.01 G -20 1.40 G 0.01 G 0.01 G	Outor mint/∞ Filter settings correspond to a Bhrov-value for the setting fragment 6% Qptical matrix € CompDip 1 ✓ Vertical (USE3) 0.1756 Tm ✓ Calculate other Calculate other
M FP_PIN Si 300 m etcn M FP_SCI C9H10 100 mm Config. 41800 (2015 eption: 41800 (2015 version: 51.9.4 Epce	Filter constants Dispersion coefficient 4.8139e.4 Liegths (m) Wien filter Electric & magnetic effective 1 Block (total) 10 VOK X Cancel Y Help

Fig. 20: Wien velocity filter options. Select the Wien filter icon and adjust the field values outlined in red in the "Wien 1" window.

c. Recalculate all the transmissions. Generate all plots at the compensating dipole, 1D-Plot \rightarrow Block selection distributions \rightarrow CompDip1.



Fig. 21: All compensating dipole plots. To generate these plots, click the button plot button in the toolbar and select "CompDip 1."



Fig. 22: Yield for each fragment as a function of vertical position at the compensating dipole. The different fragments travel various velocities over some distance. Thus, they accrue different phases. These phase differences can be spatially resolved such that by narrowing the slits at the compensating dipole, only the desired fragment is preserved.

d. While the contaminants remain with the same intensities, the Wien filter spatially separates the different radioactive species as seen in the y-space plot of Fig. 22. Close the slits around the desired fragment by narrowing the vertical plane.



Fig. 23: Compensating dipole options window. Like previously, the window can be opened by selecting the display, and the slits narrowed by adjusting the sliding ruler. The vertical pane is outline in red.



Fig. 24: Upon applying the latest selection criterion, namely the discrimination in y-space, all of the ²⁰Na contaminants have been removed from the example beam. However, the ²²Al yield has been reduced to 60 percent, and other contaminants, such as ²¹Mg, remain.

e. Recalculate all transmissions, and generate new plots for the compensation dipole. Repeat any of the previous steps as necessary until beam is sufficiently pure and intense.

The content of this tutorial is by no means exhaustive of the many functions in the LISE++ program. For more information, visit: <u>http://lise.nscl.msu.edu/documentation.html</u>.