LISE++ Tutorial++

1. Start the program and configure LISE++ by loading the desired .lcn or .lpp file, *File* → *Configuration* → *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: http://nscl.msu.edu/users/beams.html.
    a. In the menu bar, select the primary beam, or projectile, *Settings* → *Projectile.*
    b. Select desired nuclear fragment, *Settings* → *Setting Fragment.*
    c. Calculate optimum target thickness, *Calculations* → *Optimum Target.*
    d. Redo steps 2a-2c for other primary beams to find best yield for the chosen fragment. Example, for fragment ^{22}Al:
        i. ^{40}Ar: 7.75
        ii. ^{40}Ca: 6.0
        iii. ^{36}Ar: 16.4, thickness 1070.7 mg/cm^2
        iv. ^{24}Mg: 87.6, thickness 1100.0 mg/cm^2

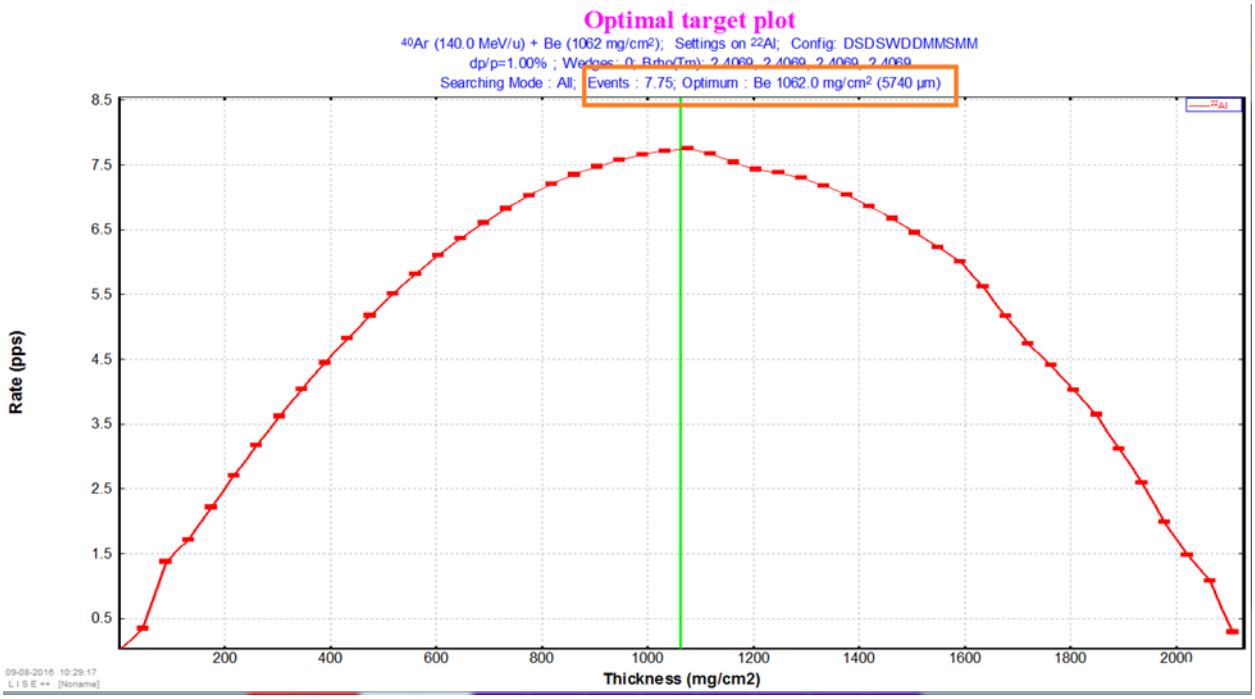

Fig. 1: Event rate plotted against target thickness. Outlined in orange are the events, yield in particles per second, and the optimum thickness for the target material, beryllium in this case. The green line indicates the thickness at the maximum yield.

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

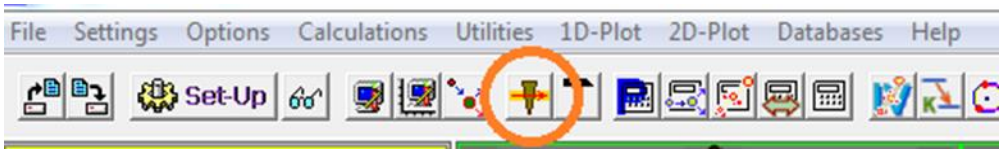

Fig. 2: Menu and toolbar. Click the icon circled in orange to calculate the fragment separator settings.

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

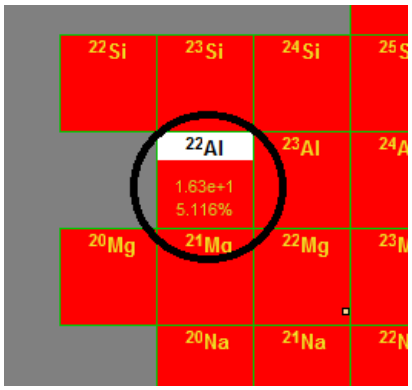

Fig. 3: Circled in black is the selected isotope, where the top yellow number is yield in particles per second, which should match the yield calculated in step 2. The bottom number is the transmission efficiency.

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 → 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.

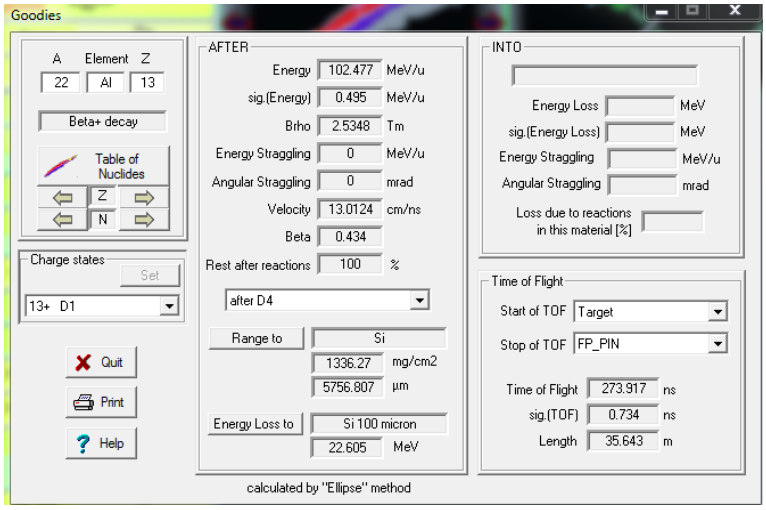

Fig. 5: Goodies window.

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 → Range distributions.* Choose the FP_PIN option.

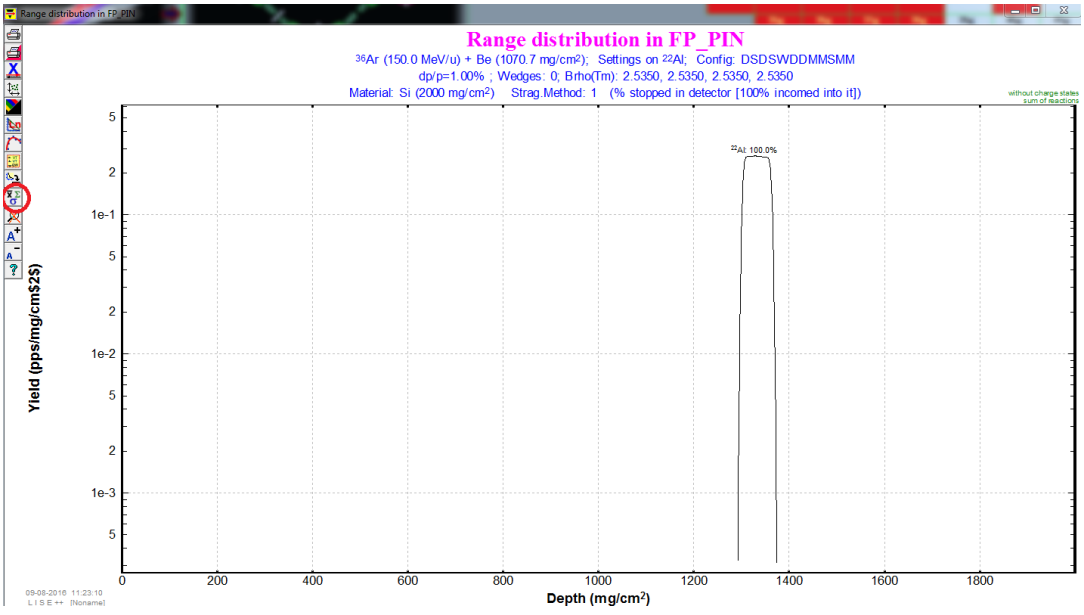

Fig. 7: Range distribution of ^{22}Al fragments in FP_PIN. To calculate the full width half maximum (FWHM) of the distribution, select the icon circled in red on the right side of the window.

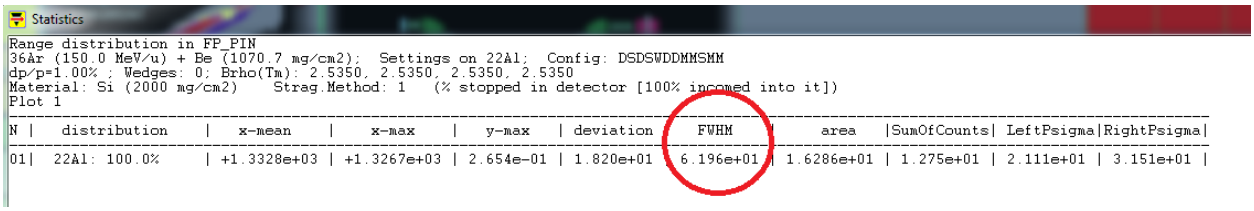

Fig. 8: Statistics calculated for distribution. FWHM circled in red. Units are given in μm.

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.

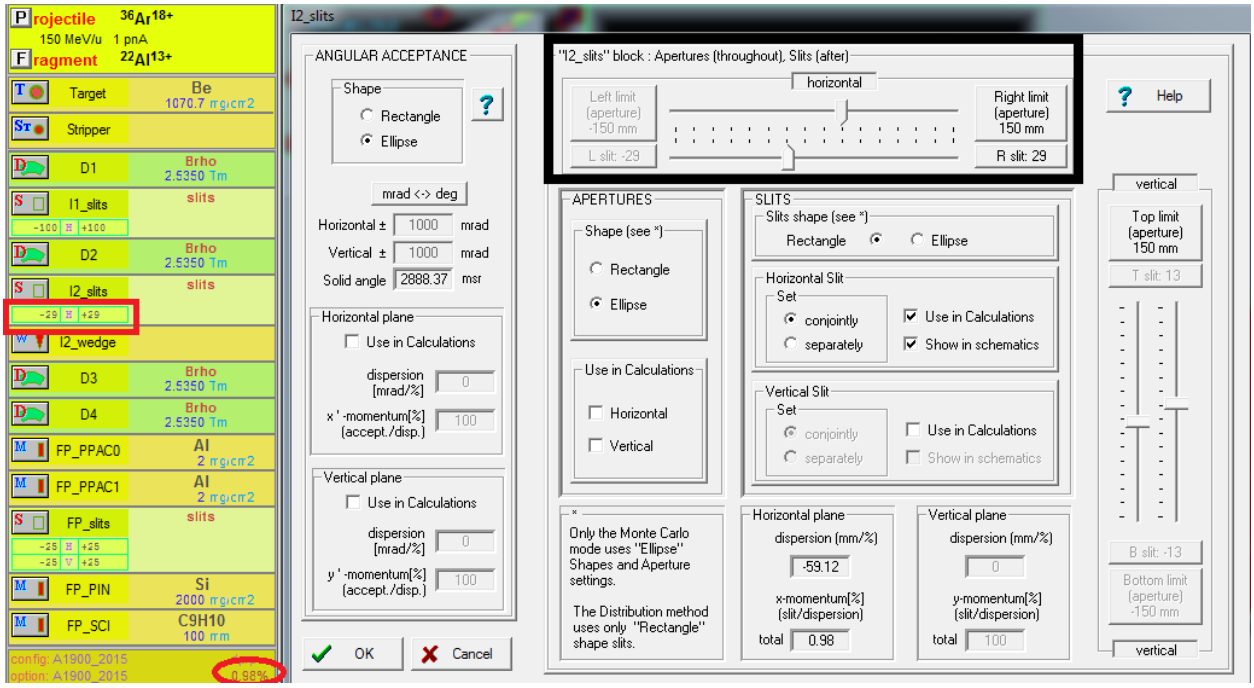

Fig. 8: I2_slits window. Select the display outlined in red to open the I2_slits window. Adjust the horizontal aperture width using the sliding tool to select the width. Notice that the momentum acceptance value dp/p is automatically recalculated. Also, both the fragment yield and transmission decrease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

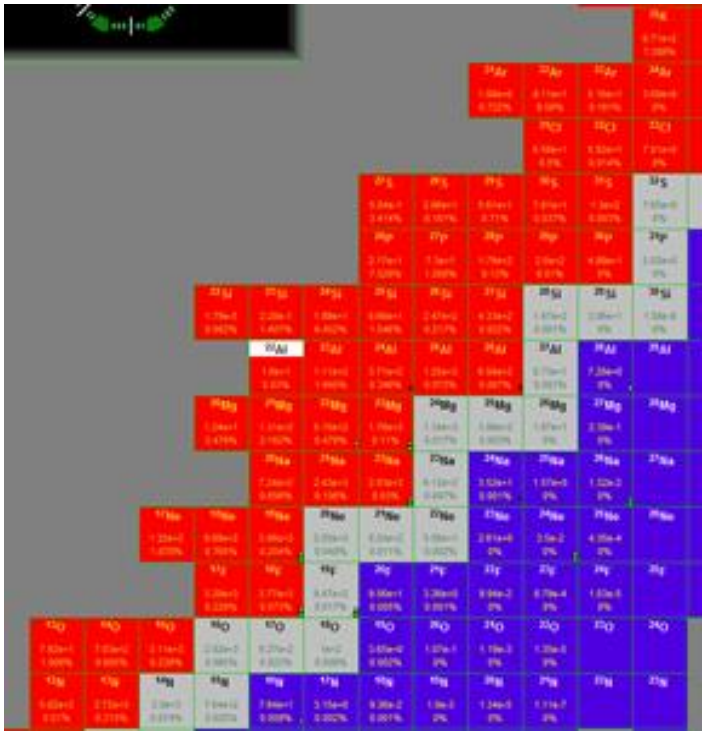

Fig. 9: Table of nuclei. The event rates and transmission efficiencies for all nuclear fragments created in the collisions are calculated. To interrupt, press the "ESC" key.

c. Set up the parameters for generating plots, *2D-Plot → 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 → 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.

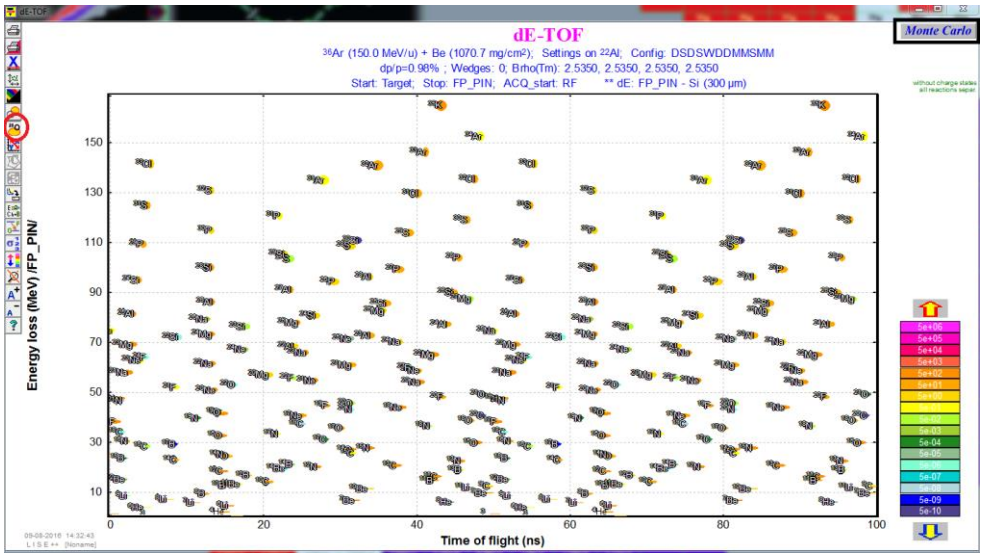

Fig. 10: A two-dimensional plot of nuclear fragments, comparing energy loss and time of flight. Color is an indication of relative intensity. Select the button circled in red to label each nuclei. To run a simulation, select the Monte Carlo button outlined in black.

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.

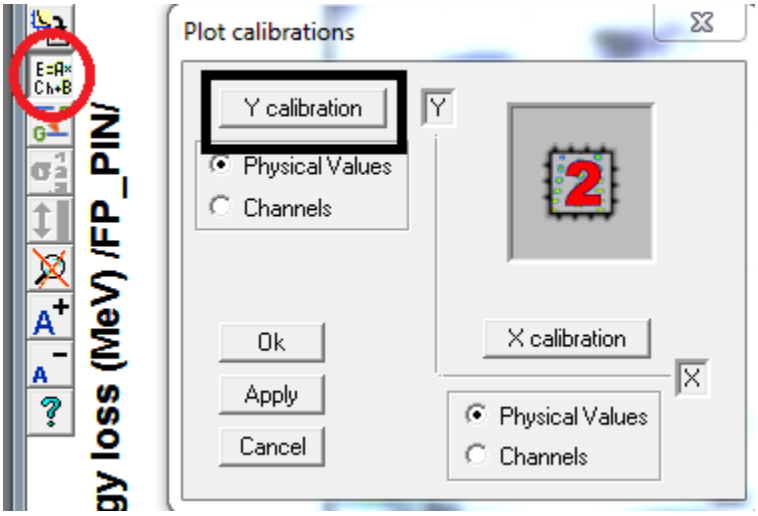

Fig. 11: Calibration window. Select the button on the left side of the 2D plot window, which is shown here circled in red. Click the "Y calibration" button outlined in black to calibrate energy loss shown on the y-axis. Do the same for the "X calibration" using time of flight values.

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.

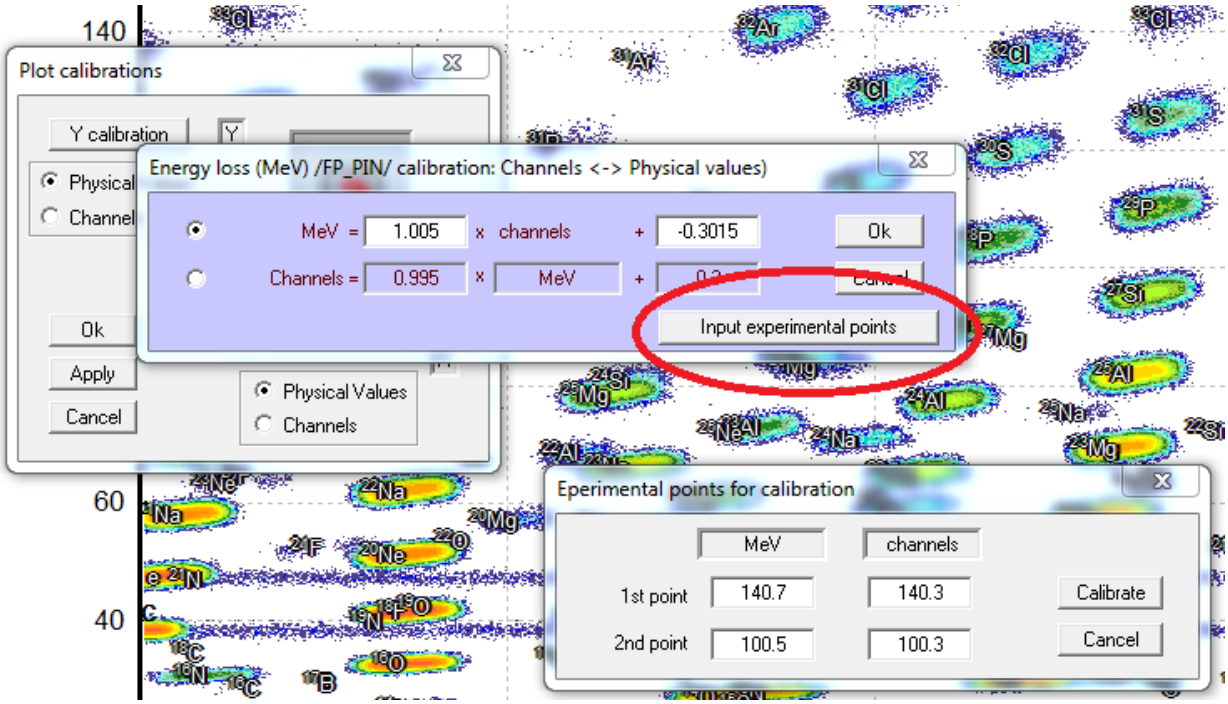

Fig. 12: More calibrating windows. To enter the data points chosen from the 2D plot, click the "Input experimental points" button circled in red. Enter the energy values for both points along with their corresponding channels. Repeat for the X calibration with time values.

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.

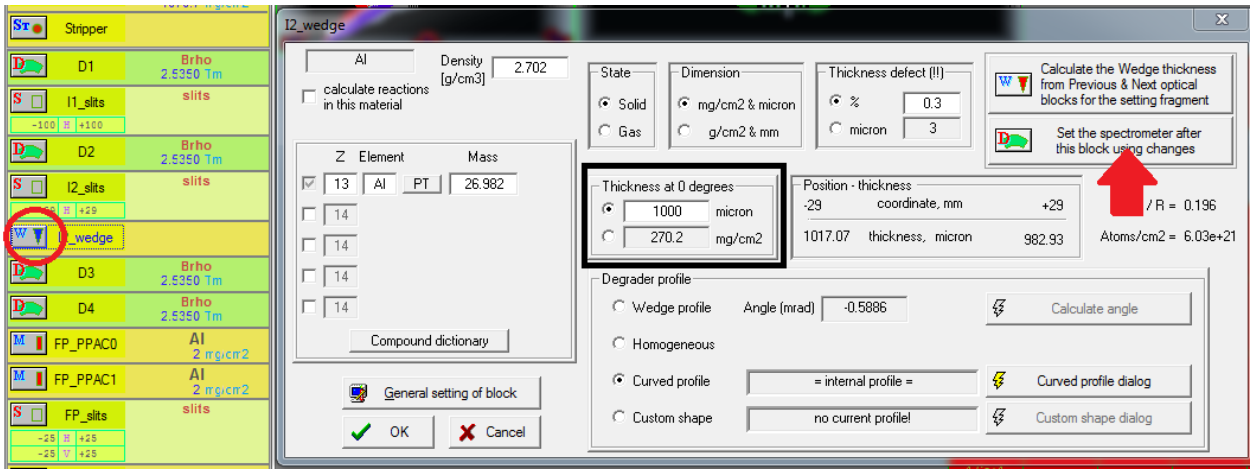

Fig. 13: I2_wedge options window. Select the I2_wedge icon on the left side of the screen, shown here circled in red. Change the thickness of the wedge in the box outlined in black. Click the button "Set the spectrometer after this block using changes."

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.

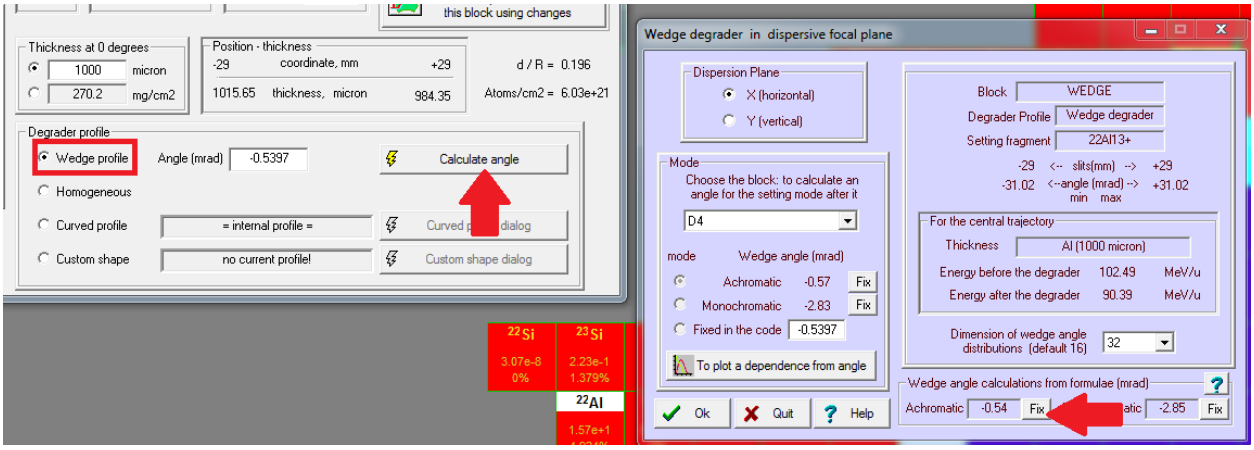

Fig. 14: Wedge degrader window. By selecting the wedge profile outlined in red and clicking "Calculate angle," the "Wedge degrader in dispersive focal plane" window appears. Select the achromatic value by clicking "Fix" in the "Wedge angle calculations from formulae (mrad)" pane.

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

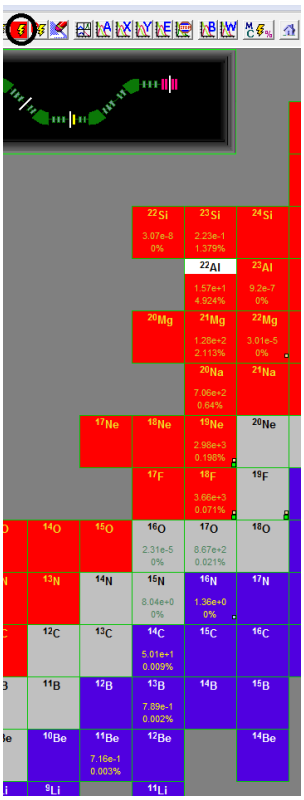

Fig. 15: Nuclear fragments with some contaminants removed. By applying the wedge, many contaminants have been removed from the beam. Clicking "All nuclei" button in the menu bar at the top of the page calculates the transmitted fragments.

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.

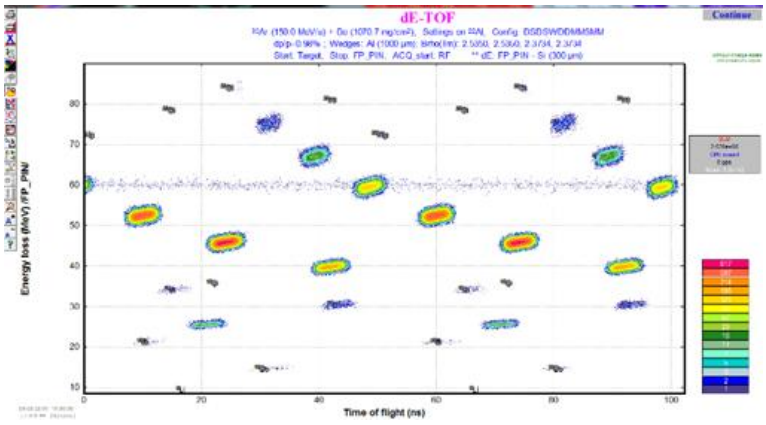

Fig. 16: ΔE-TOF identification plot after removing contaminants.

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.

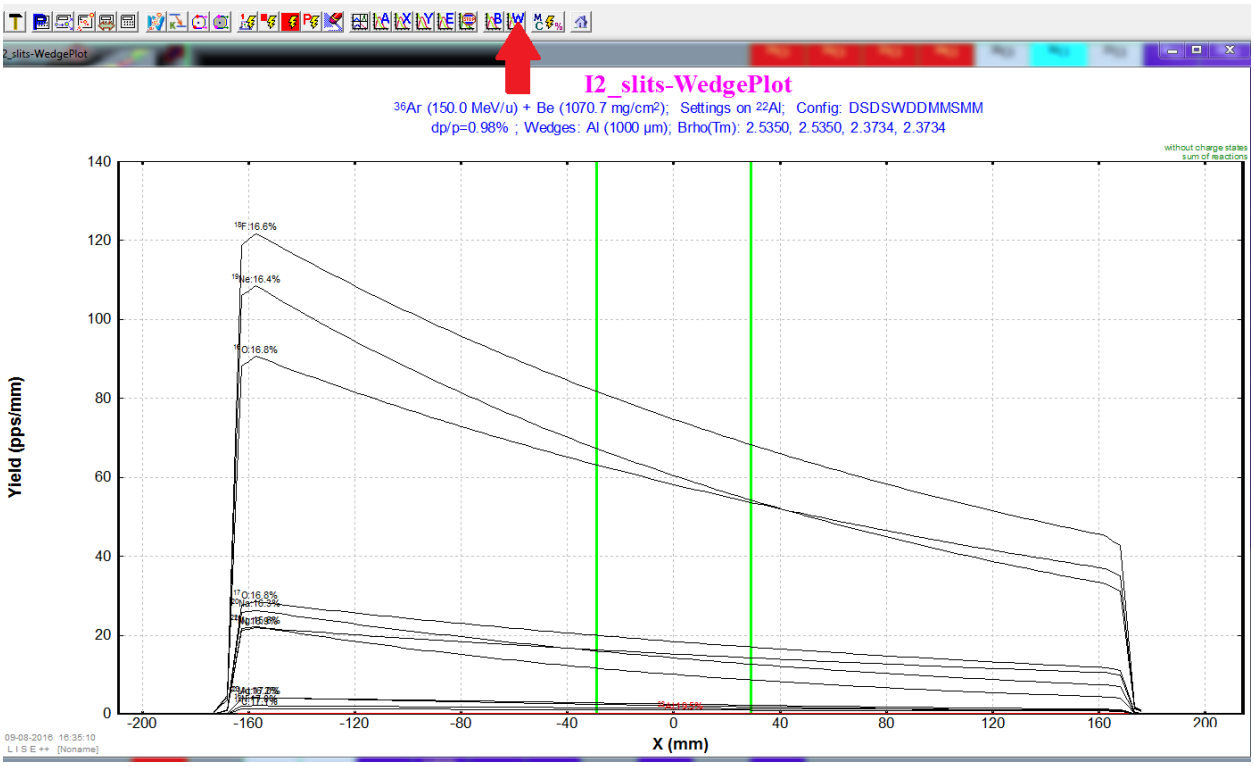

Fig. 17: Plot of yield over horizontal distance. A wedge plot can be generated by clicking the "Wedge selection plot" button in the toolbar. Each fragment's yield is plotted as a function of position. In the test case, the nuclei of interest, ^{22}Al, displayed in red, is barely visible amid the remaining 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.
    c. To further separate contaminants, try increasing the thickness of the wedge, first 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.

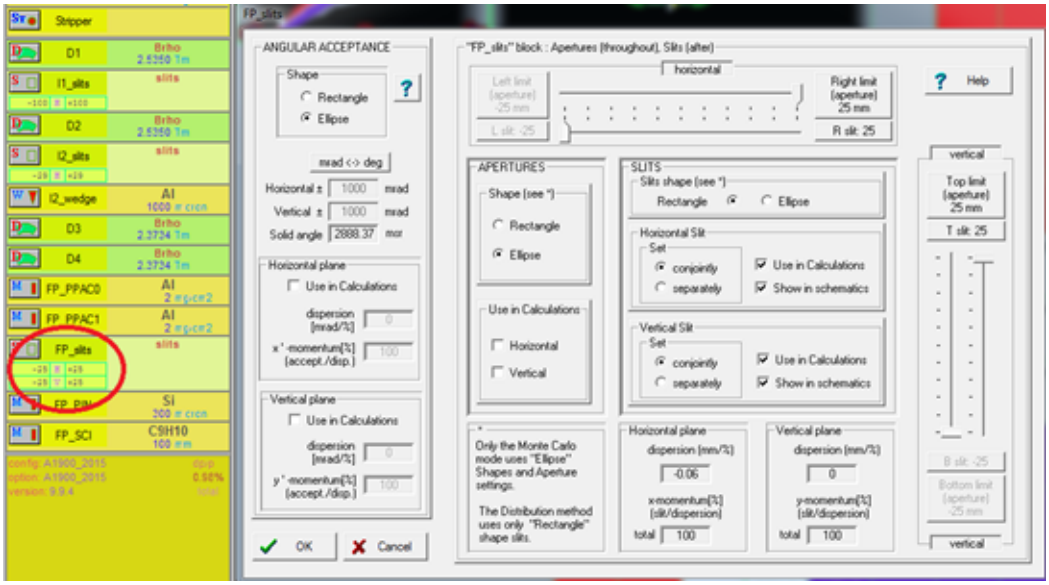

Fig. 18: Focal point slits window. Select the display below the "FP_slits" icon on the left side of the home screen to open the window.

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.

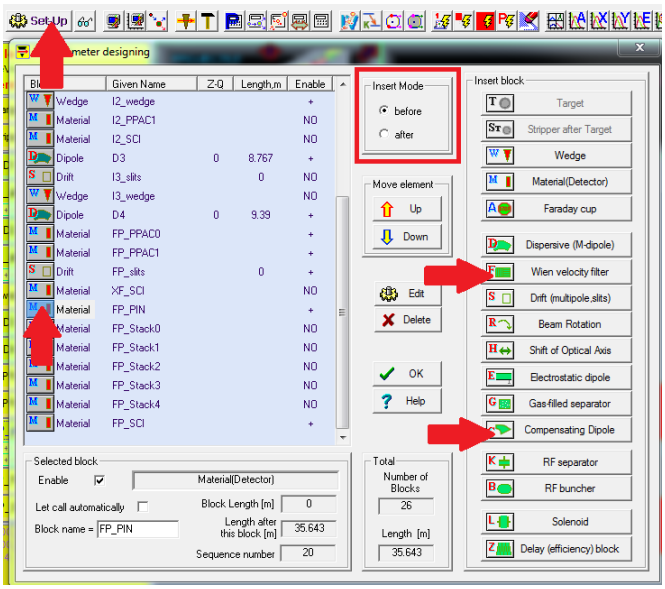

Fig. 19: Spectrometer designing window. Click the "Set-Up" button in the toolbar to open the window. Choose "before" in the "Insert Mode" pane. Add desired elements from the "Insert

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.

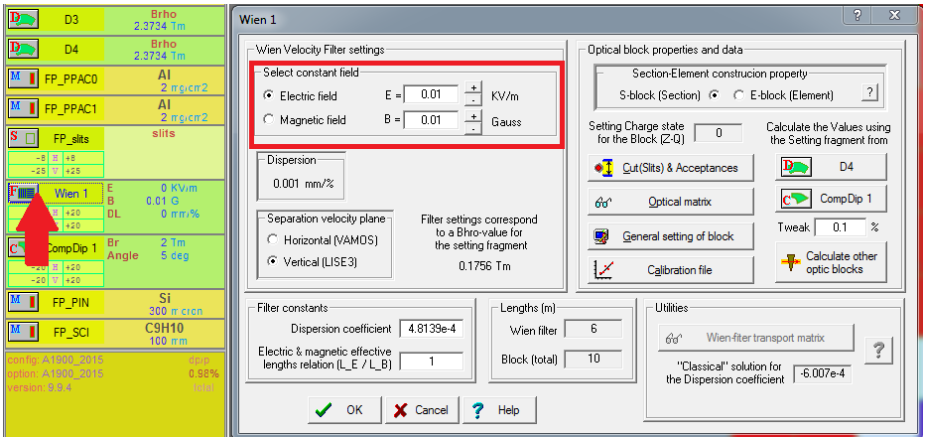

Fig. 20: Wien velocity filter options. Select the Wien filter icon and adjust the field values outlined in red in the "Wien 1" window.

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

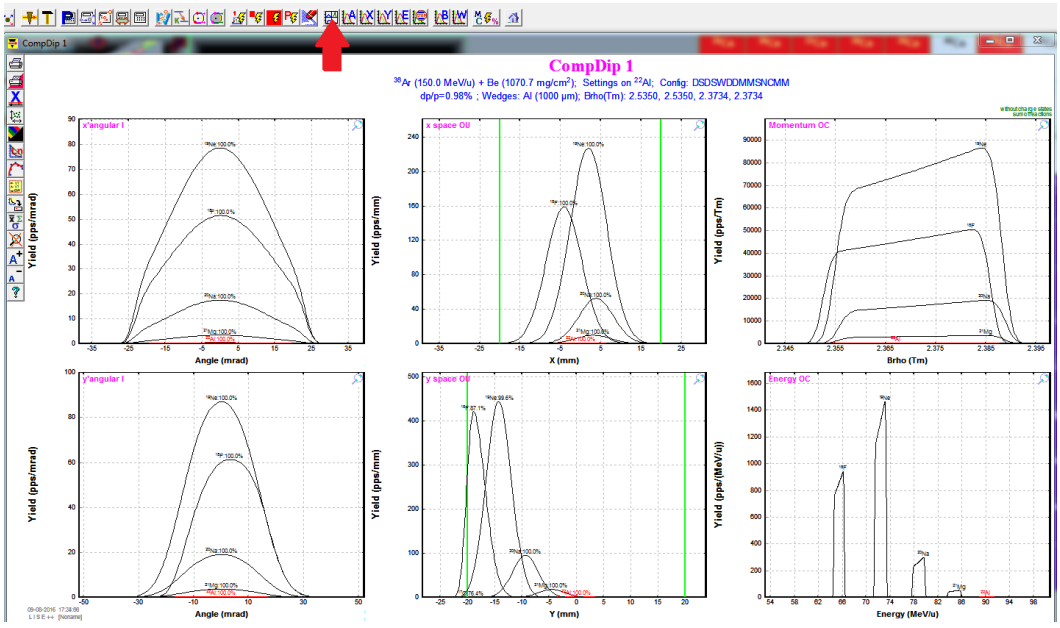

Fig. 21: All compensating dipole plots. To generate these plots, click the button plot button in the toolbar and select "CompDip 1."

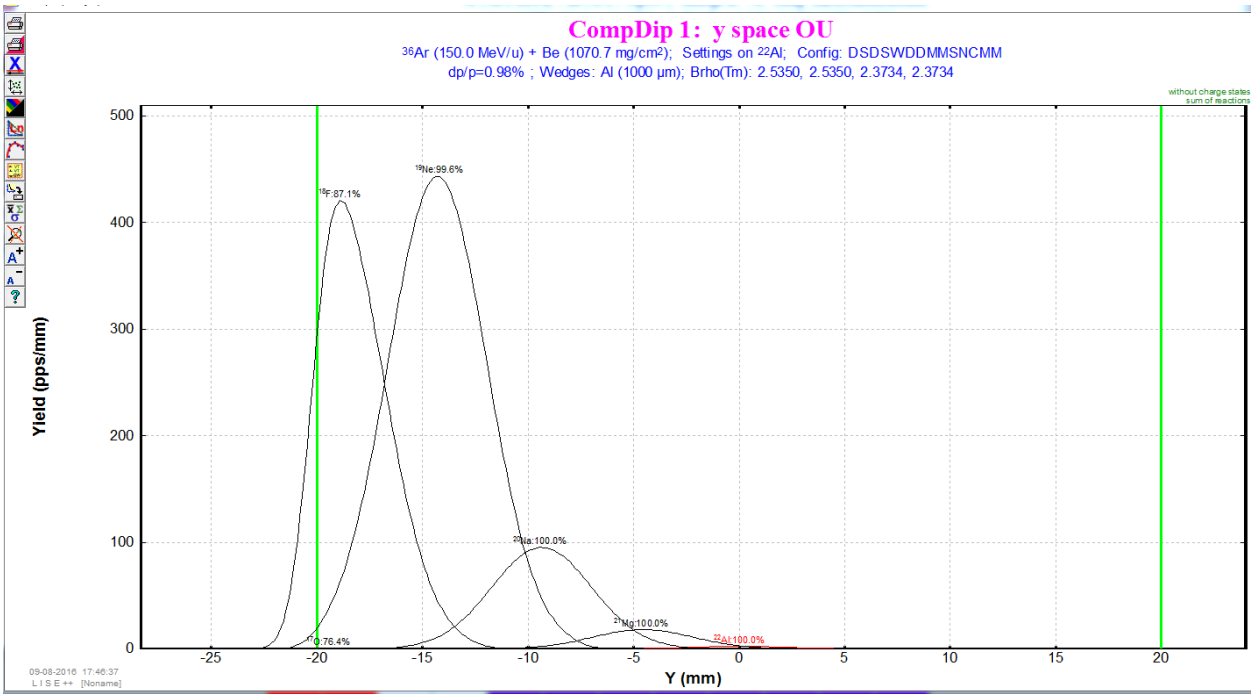

Fig. 22: Yield for each fragment as a function of vertical position at the compensating dipole. The different fragments travel various velocities over some distance. Thus, they accrue different phases. These phase differences can be spatially resolved such that by narrowing the slits at the compensating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

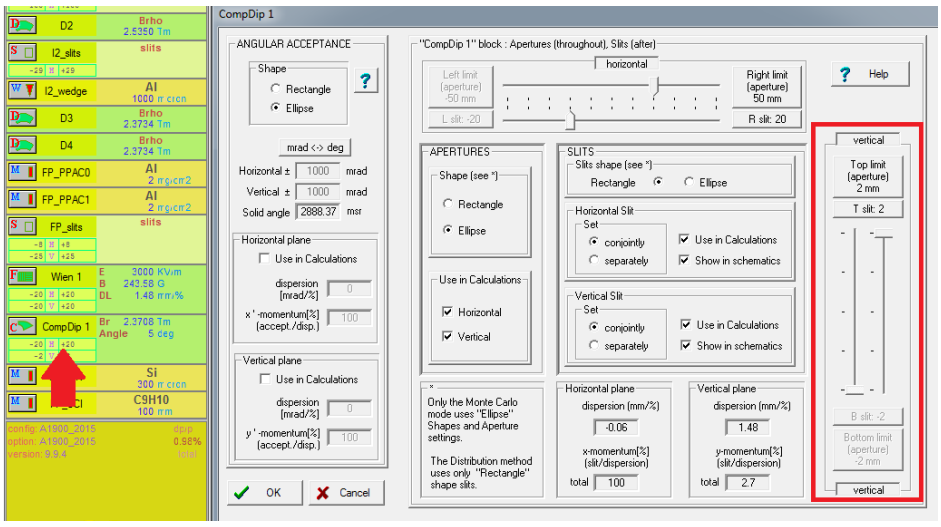

Fig. 23: Compensating dipole options window. Like previously, the window can be opened by selecting the display, and the slits narrowed by adjusting the sliding ruler. The vertical pane is outline in red.

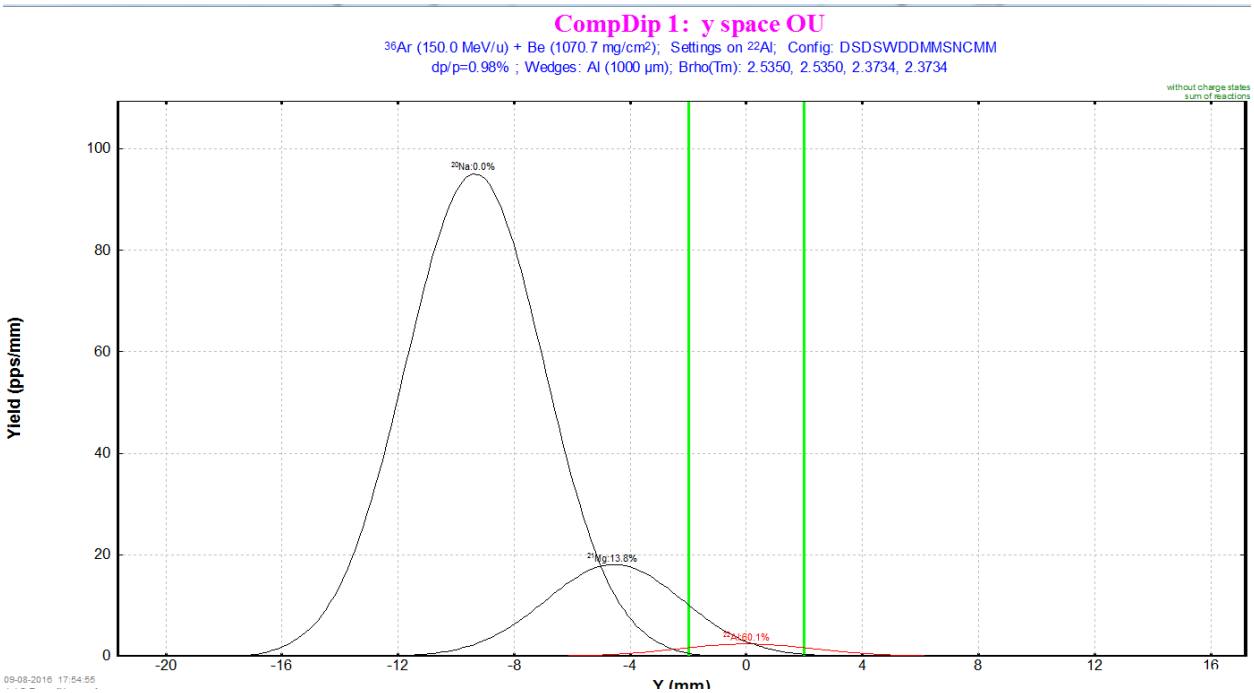

Fig. 24: Upon applying the latest selection criterion, namely the discrimination in y-space, all of the ^{20}Na contaminants have been removed from the example beam. However, the ^{22}Al yield has been reduced to 60 percent, and other contaminants, such as ^{21}Mg, remain.

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