

Using AZURE (C++)

TALENT Course 6

Theory for exploring nuclear reaction experiments

GANIL 1st-19th July

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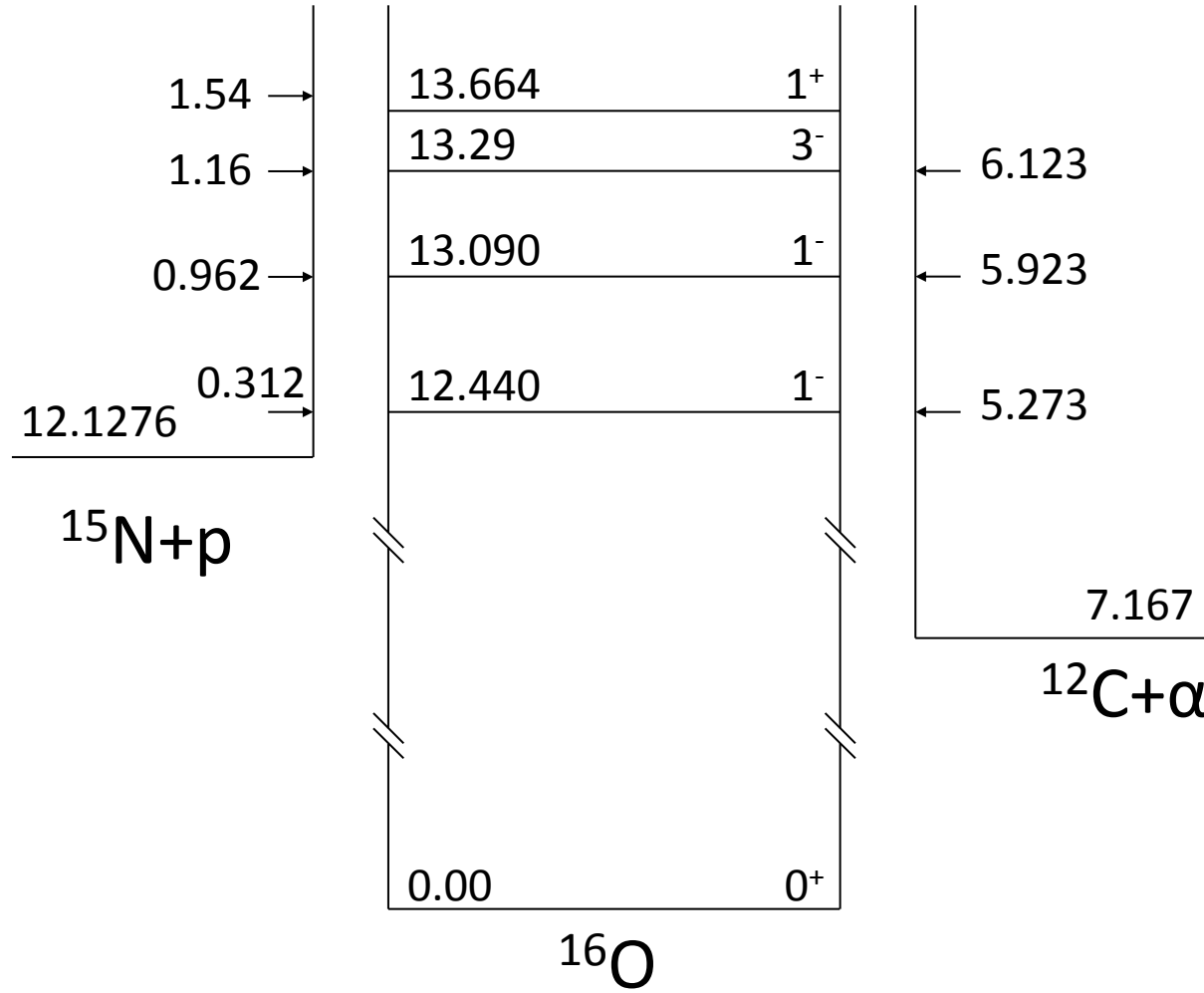
AZURE Credits

- Developed at the Joint Institute for Nuclear Astrophysics at University of Notre Dame
- FORTRAN 77 version (2002 ish – present)
 - R. E. Azuma, E. Uberseder, E. C. Simpson, C. R. Brune, H. Costantini, R. J. de Boer, J. Gorres, M. Heil, P. J. LeBlanc, C. Ugalde and M. Wiescher
- C++ version (in development) AZURE
 - Ethan Uberseder, Dick Azuma, James deBoer

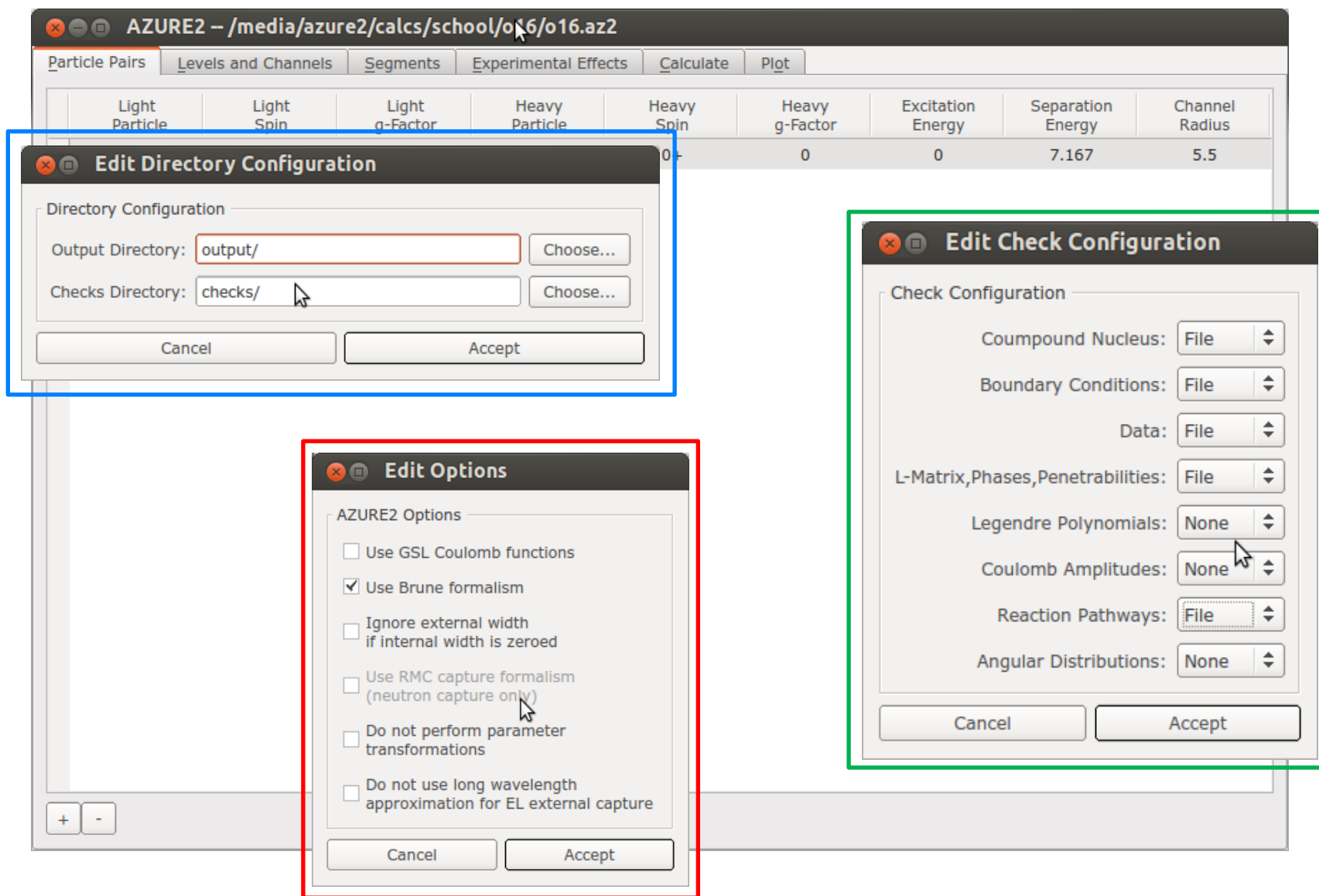
AZURE C++ code overview

- Written exclusively in C++
- Uses GNU Scientific Library and Minuit2
- Parallel using OpenMP (single node)
- All capture and reaction channels simultaneously
- Make extrapolations based on fitted resonance parameters
- Graphical user interface built using Qt and QWT (for plotting)

^{16}O thresholds: $^{12}\text{C}(\alpha,\alpha)^{12}\text{C}$, $^{15}\text{N}(\text{p},\alpha)^{12}\text{C}$



AZURE setup and options



AZURE add particle pair

AZURE2 -- /media/azure2/calcs/school/o16/o16.az2

Particle Pairs Levels and Channels Segments Experimental Effects Calculate Plot

	Light Particle	Light Spin	Light g Factor	Heavy Particle	Heavy Spin	Heavy g Factor	Excitation Energy	Separation Energy	Channel Radius
1	α	0+	0	^{12}C	0+	0	0	7.167	5.5

List of particle pairs

Edit particle pair

$a_c = R_0(A_1^{1/3} + A_2^{1/3})$
 $R_0 = 1.5 \text{ fm}$

Add and remove particle pairs

Particle Pair Type: Particle, Particle

Light Particle

J: 0 + -

Z: 2

M: 4

g: 0

Heavy Particle

J: 0 + -

Z: 6

M: 12

g: 0

Channel Properties

Excitation Energy [MeV]: 0

Separation Energy [MeV]: 7.167

Channel Radius [fm]: 5.5

Cancel Accept

Channels for $^{12}\text{C}+\alpha$

- Calculated automatically by AZURE2
- For $^{12}\text{C}+\alpha$ things are simple:

$$I_1 = 0 \qquad \pi_1 = 1$$

$$I_2 = 0 \qquad \pi_2 = 1$$

$$\therefore s = 0$$

$$\text{and } J = \ell \qquad \pi = \pi_1 \pi_2 (-1)^\ell = (-1)^\ell$$

- One channel per J , only natural parity states allowed $\pi = (-1)^J$
- In general, many channels allowed per resonance

AZURE Levels and Channels

AZURE2 -- /media/azure2/calcs/school/o16/o16.azure2

Particle Pairs | **Levels and Channels** | Segments | Experimental Effects | Calculate | Plot

Compound Nucleus Levels

Include?	Fix?	Level Spin	Energy [MeV]
☒	☐		
☒	☐		
☐	☐		
☐	☐		
☒	☒	0+	20
☒	☒	1-	20
☒	☒	2+	20
☒	☒	3-	20
☒	☒	4+	20

List of levels

Add and remove compound nucleus levels

Channels In Selected Level

Fix?	Channel Pair	s	l
☐	$^{12}\text{C} + \alpha$ [0.000 MeV]		

List of channels for a given level

Edit level

Channel Configuration

4 Maximum Orbital Momentum
1 Maximum Gamma Multipolarity
1 Maximum Gamma Multipolarities Per Decay

Channel Details (select from list to view):
Edit allowed channels

Channel summary

MeV level with spin
transitioning via pair key #1
Channel configuration is

Light Particle Spin: 0+
Light Particle Z: 2
Light Particle M: 4
Light Particle G: 0
Heavy Particle Spin: 0+
Heavy Particle Z: 6
Heavy Particle M: 12
Heavy Particle G: 0
Excitation Energy: 0
Separation Energy: 7.167
Channel Radius: 5.5

Edit a Level

Excitation Energy [MeV]:
Level Spin: - +

Cancel Accept

Partial Width: eV

Edit channel width

$^{12}\text{C}+\alpha$ Parameters

- For each resonance
 - Resonance energy E_R
 - Width Γ_ℓ
- For each J^π , a background resonance
 - Resonance energy E_R (fixed, ~ 5 MeV above data)
 - Width Γ_ℓ (variable, a few MeV)
- R-matrix radius
 - $a \approx 1.5(A_1^{1/3} + A_2^{1/3}) = 4.5 - 5.5$ fm
 - Sensitivity to R-matrix radius should be checked

Data and extrapolation segments

The screenshot displays the AZURE2 software interface with the 'Segments' tab selected. The main window is divided into two sections: 'Segments From Data' and 'Segments Without Data'.

Segments From Data: This section contains a table with 5 rows of data segments. A red box highlights this table, with the text 'Data segments' written in red below it.

	Reaction	Energy Range	Angle Range
1	☒ $^{12}\text{C}(\alpha, \alpha)^{12}\text{C}$ [0.000 MeV]	1.8-4.9	30
2	☒ $^{12}\text{C}(\alpha, \alpha)^{12}\text{C}$ [0.000 MeV]	1.8-4.9	45
3	☒ $^{12}\text{C}(\alpha, \alpha)^{12}\text{C}$ [0.000 MeV]	1.8-4.9	60
4	☒ $^{12}\text{C}(\alpha, \alpha)^{12}\text{C}$ [0.000 MeV]	1.8-4.9	135
5	☒ $^{12}\text{C}(\alpha, \alpha)^{12}\text{C}$ [0.000 MeV]	1.8-4.9	150

Segments Without Data: This section contains a table with 1 row of data segments. A blue box highlights this table, with the text 'Extrapolation segments' written in blue below it.

	Reaction	Energy Range	Energy Step
1	☒ $^{12}\text{C}(\alpha, \alpha)^{12}\text{C}$ [0.000 MeV]	1-4	0.01

Edit a Segment Without Data Dialog: This dialog box is overlaid on the top right. It contains the following fields:

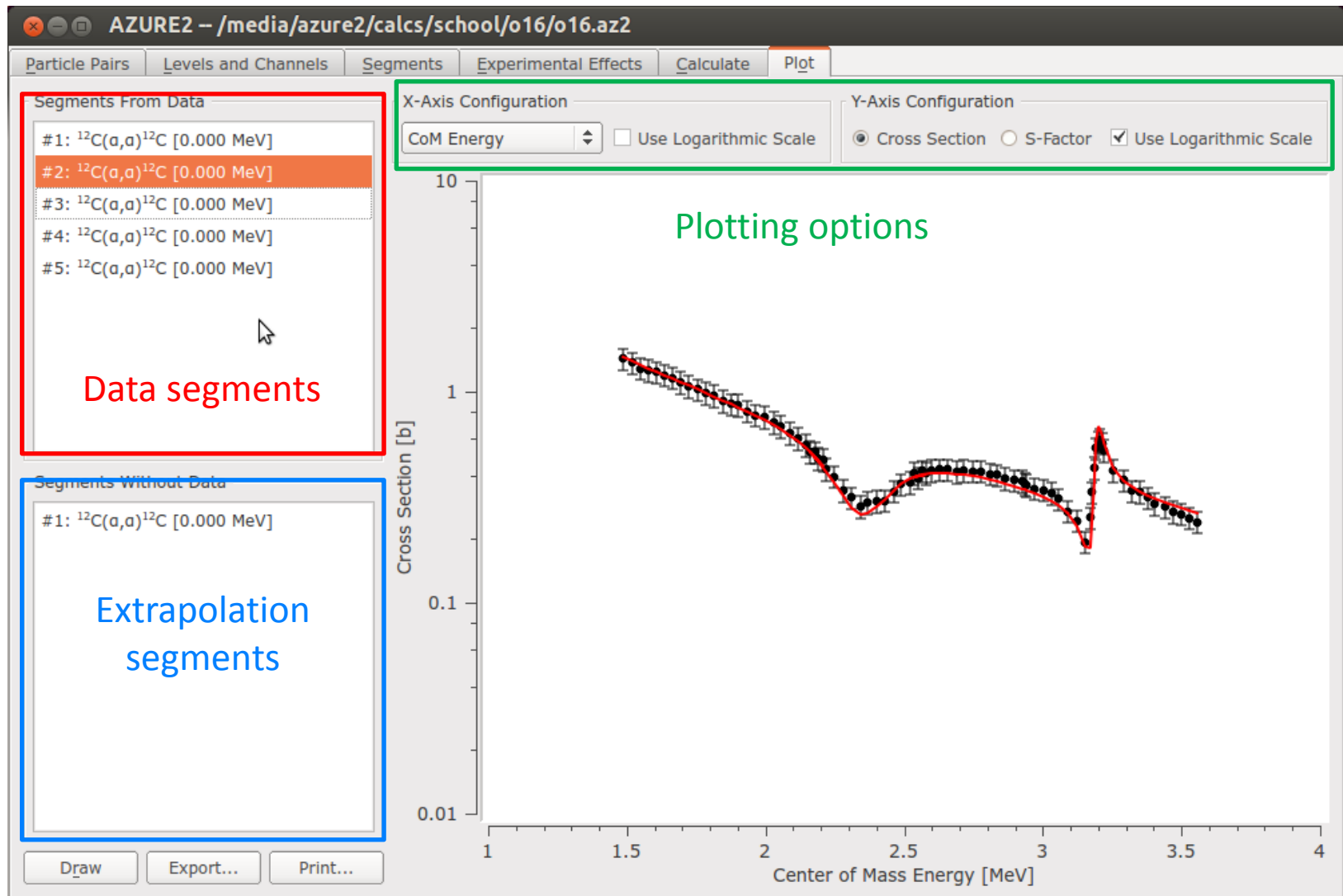
- Entrance Pair Key: 1
- Exit Pair Key: 1
- Lab Energy [MeV]: Low Energy: 1, High Energy: 4, Energy Step: 0.01
- Lab Angle [degrees]: Low Angle: 160, High Angle: 160, Angle Step: 40
- Data Type: Differential
- Buttons: Cancel, Accept

Edit a Segment From Data Dialog: This dialog box is overlaid on the bottom right. It contains the following fields:

- Entrance Pair Key: 1
- Exit Pair Key: 1
- Lab Energy [MeV]: Low Energy: 1.8, High Energy: 4.9
- Lab Angle [degrees]: Low Angle: 30, High Angle: 30
- Data Type: Differential
- Data Norm.: 1, Vary Norm? (unchecked), Norm. Error [%]: 0
- Data File: data/radovic_2002.dat
- Buttons: Cancel, Accept

Additional UI elements include '+' and '-' buttons in the left margin of both segment lists, which are circled in red and blue respectively.

Plotting



Nuclear data resources

Masses and structure

- [US National Nuclear Data Centre](#)
 - Resonance energies, J^π and widths/branches
 - [Q-value calculator](#)
- [TUNL Nuclear Data Project](#)
 - Energy level of light nuclei ($A < 20$)
 - Energies, widths, reaction specific
- [Berkeley Table of Atomic Masses](#)
- [Atomic Mass Data Centre](#)
- [Chart of the Nuclides](#)

Reactions resources

- [EXFOR: Experimental Nuclear Reaction Data](#)
 - Varying format (CM/LAB etc.) - MUST check against original paper
- [IBANDL: Ion Beam Analysis Nuclear Data Library](#)
 - IBANDL and EXFOR not always perfectly consistent...
- [NACRE: Nuclear Astrophysics Compilation of REaction Rates](#)
- [AZURE](#) website

Summary

Tutorial Session

- Analysis of α -scattering on ^{12}C
- Identify the spins and parities of two resonances from angular distributions
- Fit to optimize resonance parameters
- What is the S-factor at 30 keV for $^{15}\text{N}(p,\alpha)^{16}\text{O}$?
- What are the spins and parities of states in ^{22}Mg ?
- If you have completed $^{12}\text{C}(\alpha,\alpha)^{12}\text{C}$, feel free to try any example you like (data from EXFOR, IBANDL etc.)

If things go wrong

- Code still in development; you could encounter problems...
- If so let me know – these can be very useful for debugging
- But may occur in very particular circumstances

Tutorial files

- Tutorial is on the TALENT website
- Connect to the TALENT server
- Copy tutorial files:

```
cp -R /home/commun/azure .
```

- You only need to do this once...