Using AZURE (C++)

TALENT Course 6

Theory for exploring nuclear reaction experiments

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AZURE Credits

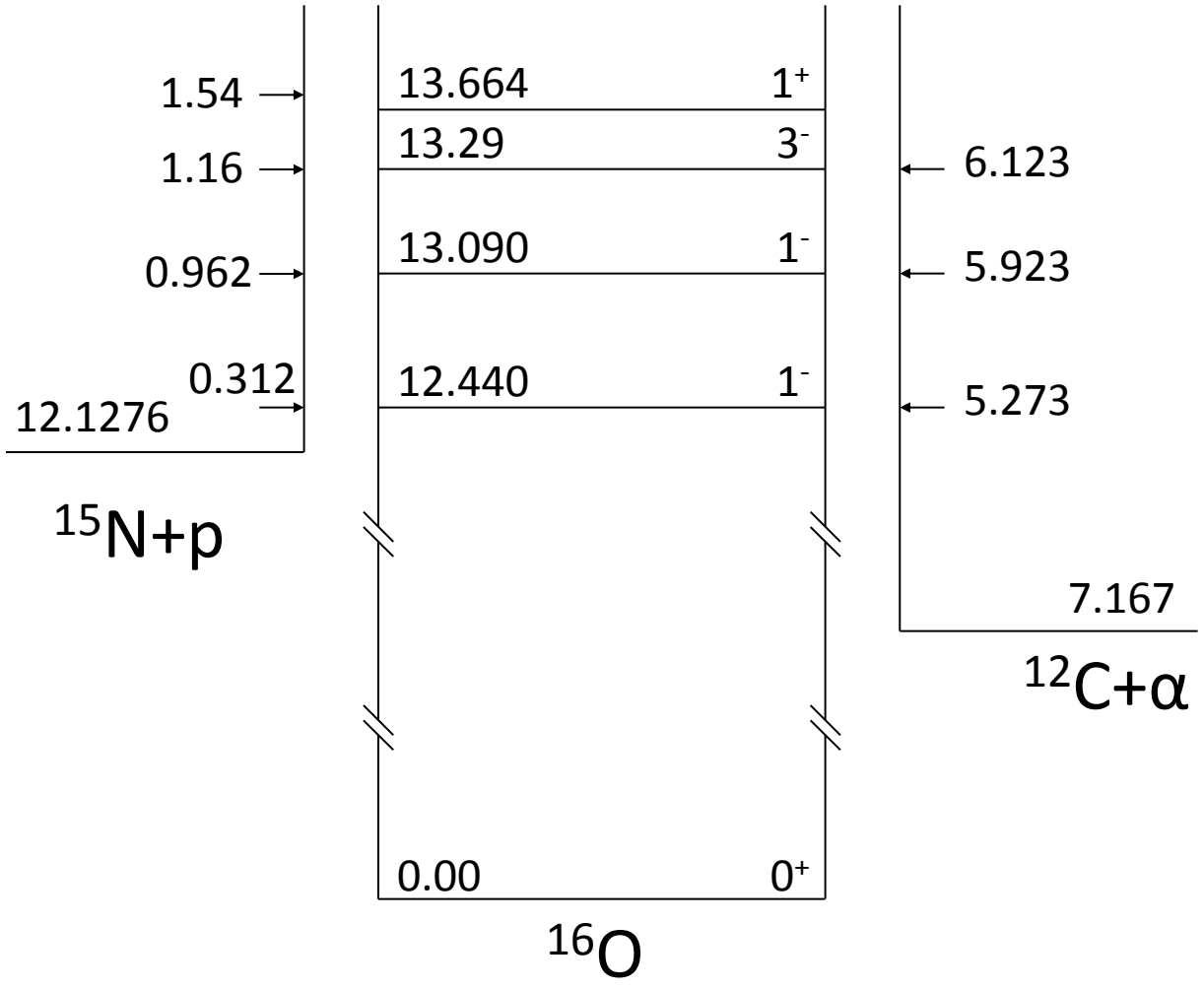
- Developed at the Joint Institute for Nuclear Astrophysics at University of Notre Dame
- FORTRAN 77 version (2002 ish – present)
  - R. E. Azuma, E. Uberseder, E. C. Simpson, C. R. Brune, H. Costantini, R. J. de Boer, J. Gorres, M. Heil, P. J. LeBlanc, C. Ugalde and M. Wiescher
- C++ version (in development)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

R. E. Azuma *et al.*, Phys. Rev. C 81, 041805 (2010)

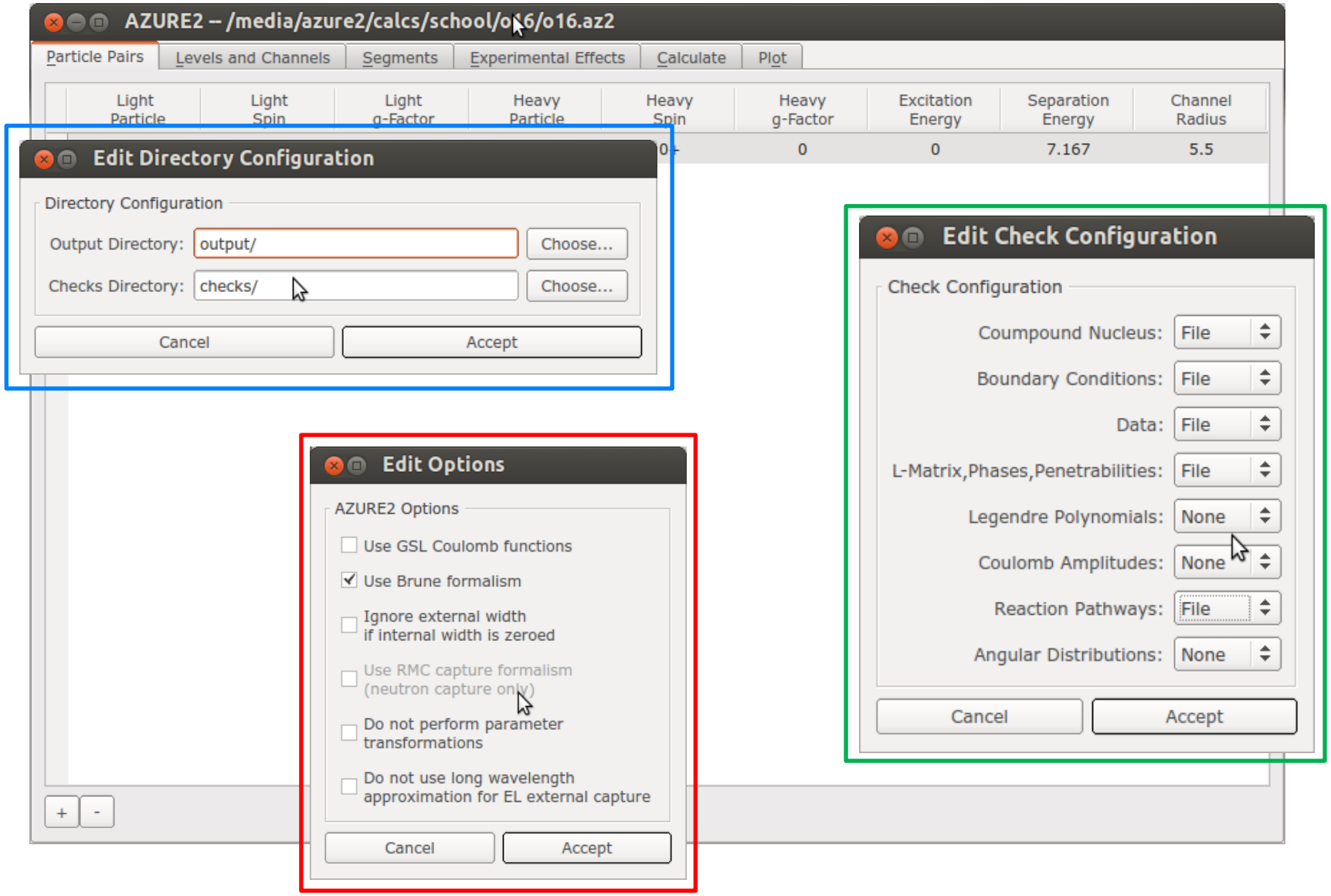
AZURE C++ code overview

- 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)

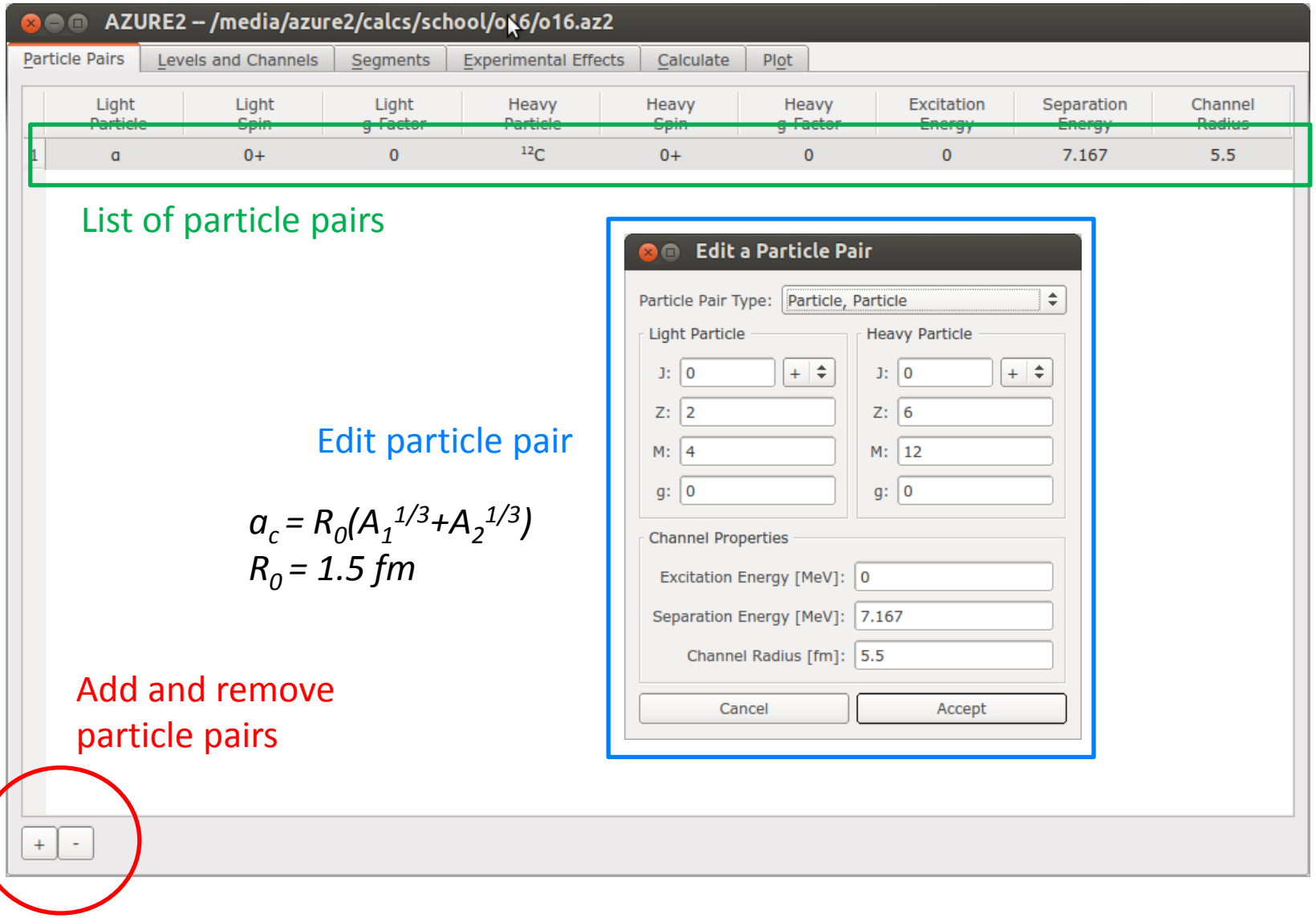
^{16}O thresholds: $^{12}C(\alpha,\alpha)^{12}C$, $^{15}N(p,\alpha)^{12}C$



AZURE setup and options



AZURE add particle pair



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

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

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

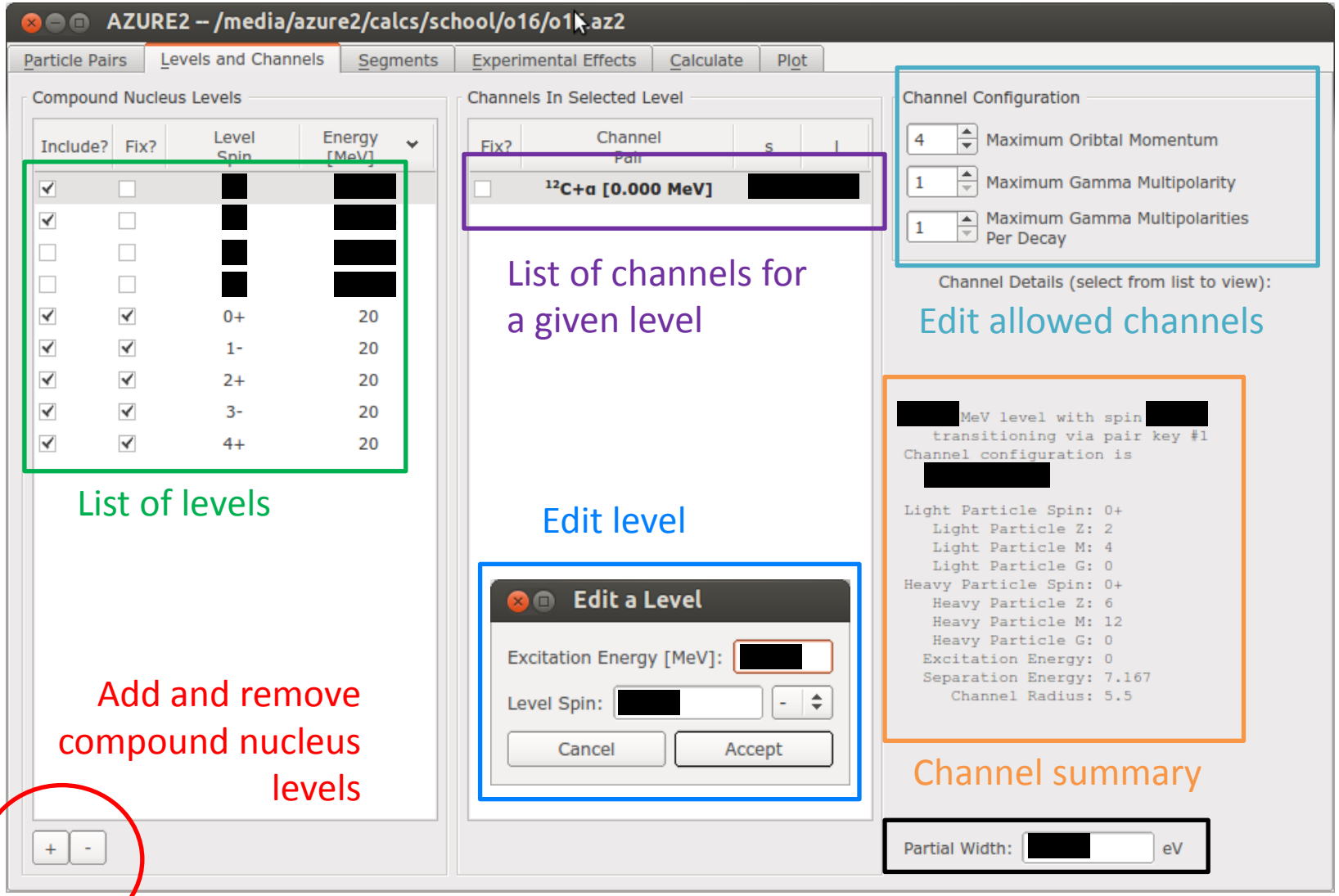
$$I_2 = 0 \qquad \pi_2 = 1$$

$$\therefore s = 0$$

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

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

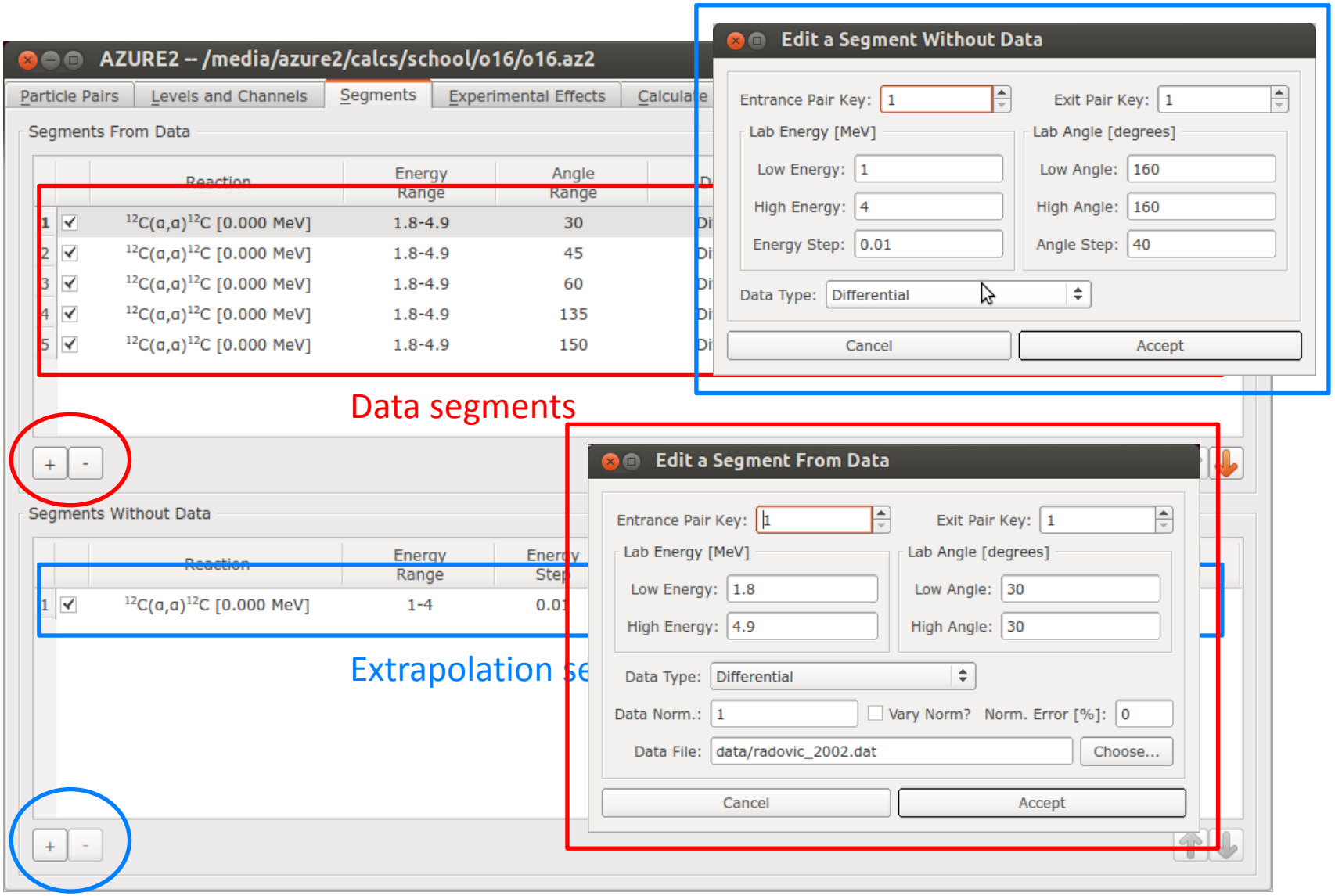
AZURE Levels and Channels



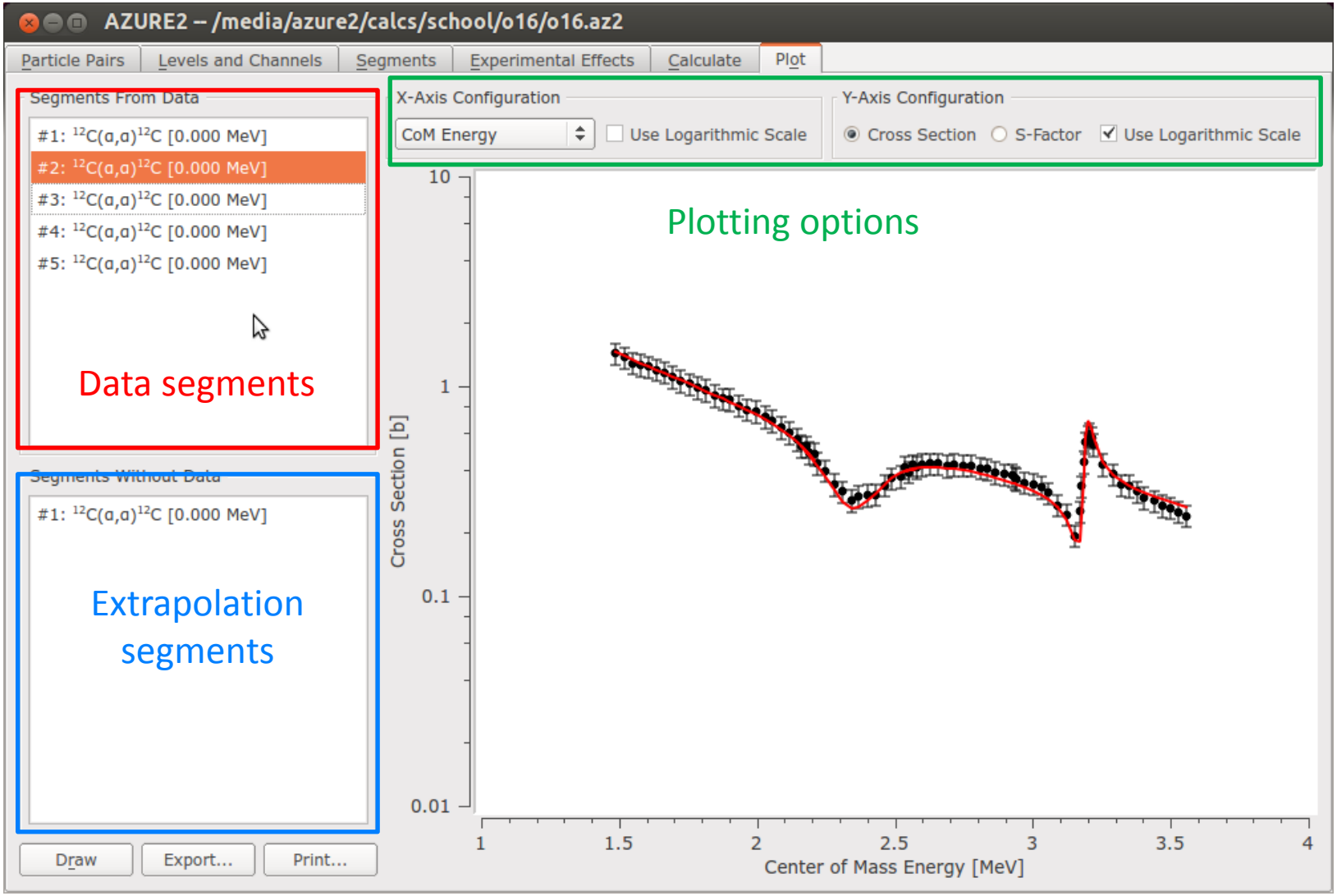
$^{12}C+\alpha$ Parameters

- For each resonance
  - Resonance energy $\mathbf{E_R}$
  - Width $\boldsymbol{\Gamma_\ell}$
- For each J^π, a background resonance
  - Resonance energy $\mathbf{E_R}$ (fixed, ~5 MeV above data)
  - Width $\boldsymbol{\Gamma_\ell}$ (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



Plotting


AZURE2 – /media/azure2/calcs/school/o16/o16.az2
Particle Pairs
Levels and Channels
Segments
Experimental Effects
Calculate
Plot
Segments From Data
#1: 12C(a,a)12C [0.000 MeV]
#2: 12C(a,a)12C [0.000 MeV]
#3: 12C(a,a)12C [0.000 MeV]
#4: 12C(a,a)12C [0.000 MeV]
#5: 12C(a,a)12C [0.000 MeV]
Data segments
Segments Without Data
#1: 12C(a,a)12C [0.000 MeV]
Extrapolation segments
Draw
Export...
Print...
X-Axis Configuration
CoM Energy
Use Logarithmic Scale
Y-Axis Configuration
Cross Section
S-Factor
Use Logarithmic Scale
Plotting options
Cross Section [b]
10
1
0.1
0.01
1
1.5
2
2.5
3
3.5
4
Center of Mass Energy [MeV]

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 $^{15}N(p,\alpha)^{16}O$?
- What are the spins and parities of states in ^{22}Mg?
- If you have completed $^{12}C(\alpha,\alpha)^{12}C$, 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...