4a. Charge exchange spectroscopy

- Interrogating state selective charge exchange cross-sections using ADAS301.
- Interrogating CXS effective emission coefficients using ADAS303.
- Calculating and examining effective emission coefficients using ADAS308.

Interrogating charge exchange cross-sections

- Datasets of class ADF01 contain state selective charge exchange xsect. (qcx) data as a function of energy.
- These data for bare nucleus light impurity receivers into nl-shells in general.
- The donors may be H, He or Li and can include donation from ground state and excited state. There are separate data sets for each excited donor state.
- Code ADAS301 interrogates ADF01 data sets and displays results at energies of your choice.

ADF01 charge exchange cross-sections

n,l

receiver

donor

Energies 1st block

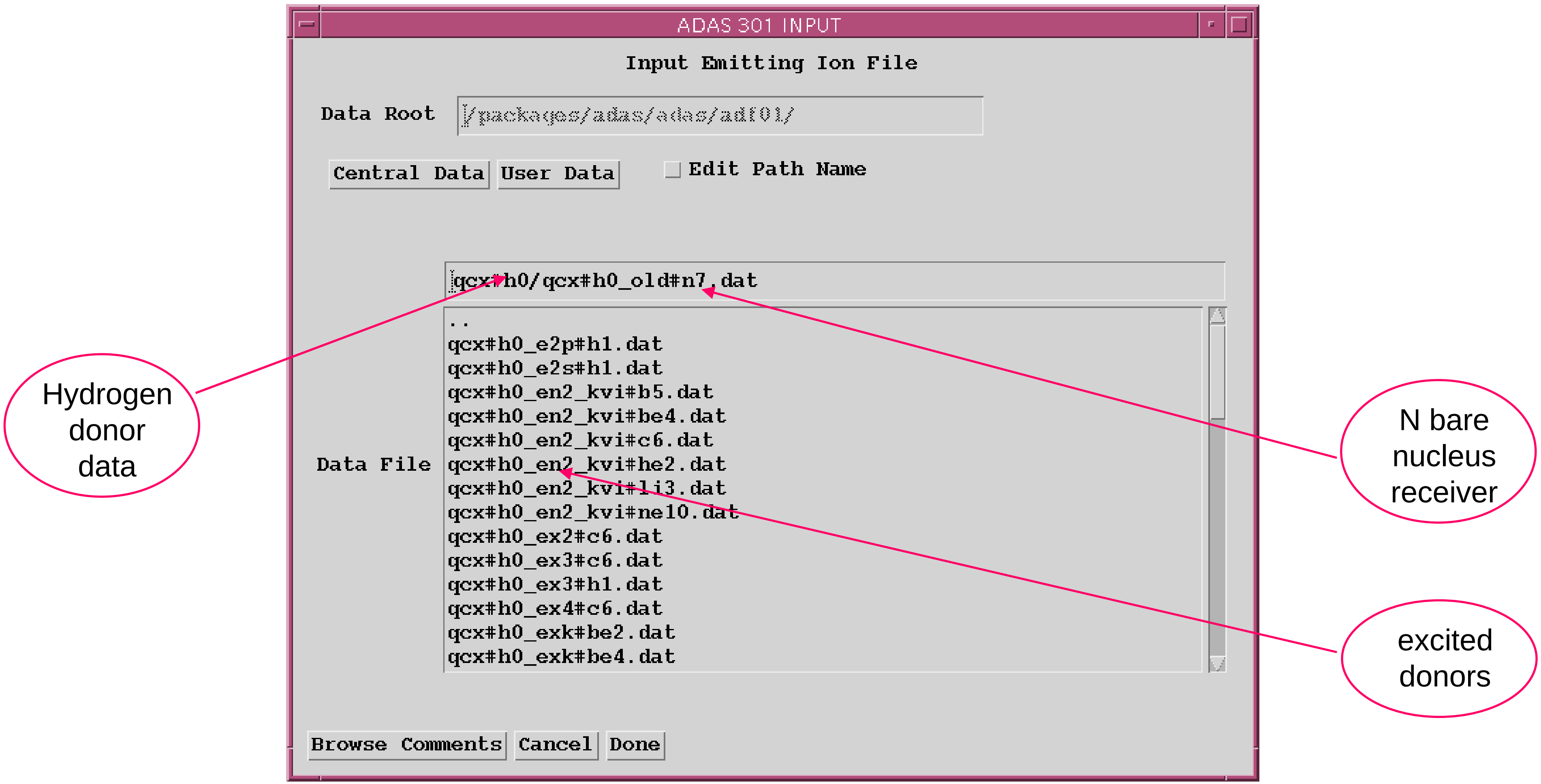
Total xsect.

n-extrapolation parameter

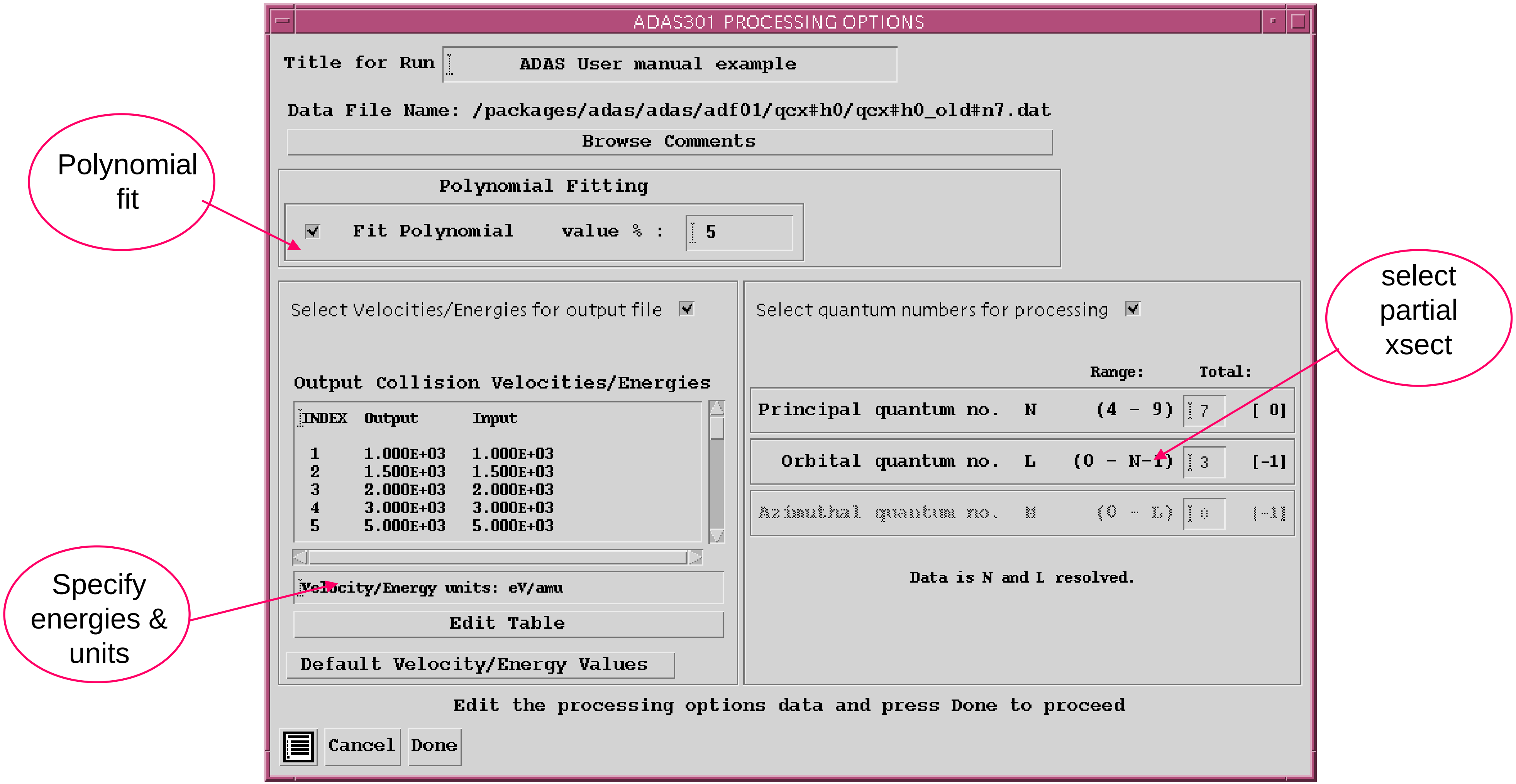
partial xsects

```
He+ 2      H + 0 (2) / receiver, donor (donor state n=2)       /        /
    9               / number of energies
    2               / nmin
    5               / nmax
              0.01     0.02     0.05     0.10     0.20     0.50     1.00     2.00     5.00 / energies        (keV/amu)
             17.00    16.20    15.00    13.86    12.68    11.00     9.65     8.30     5.85 / alpha
           1.11E-14 1.18E-14 1.18E-14 1.16E-14 1.16E-14 1.29E-14 1.30E-14 1.34E-14 1.34E-14 / total xsects.    (cm2)
  n   l  m                                                                               / partial xsects.  (cm2)
  2        0.00E+00 0.00E+00 0.00E+00 0.00E+00 2.75E-18 1.01E-17 1.77E-17 4.81E-17 9.32E-17
  2   0    0.00E+00 0.00E+00 0.00E+00 0.00E+00 2.20E-18 5.07E-18 7.60E-18 1.22E-17 3.09E-17
  2   1    0.00E+00 0.00E+00 0.00E+00 0.00E+00 5.50E-19 5.07E-18 1.01E-17 3.60E-17 6.23E-17

                        .        .        .

  5        1.50E-17 2.60E-17 5.30E-17 9.00E-17 1.60E-16 3.09E-16 5.50E-16 9.00E-16 1.55E-15
  5   0    0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
  5   1    0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
  5   2    0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
  5   3    0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
  5   4    0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
```

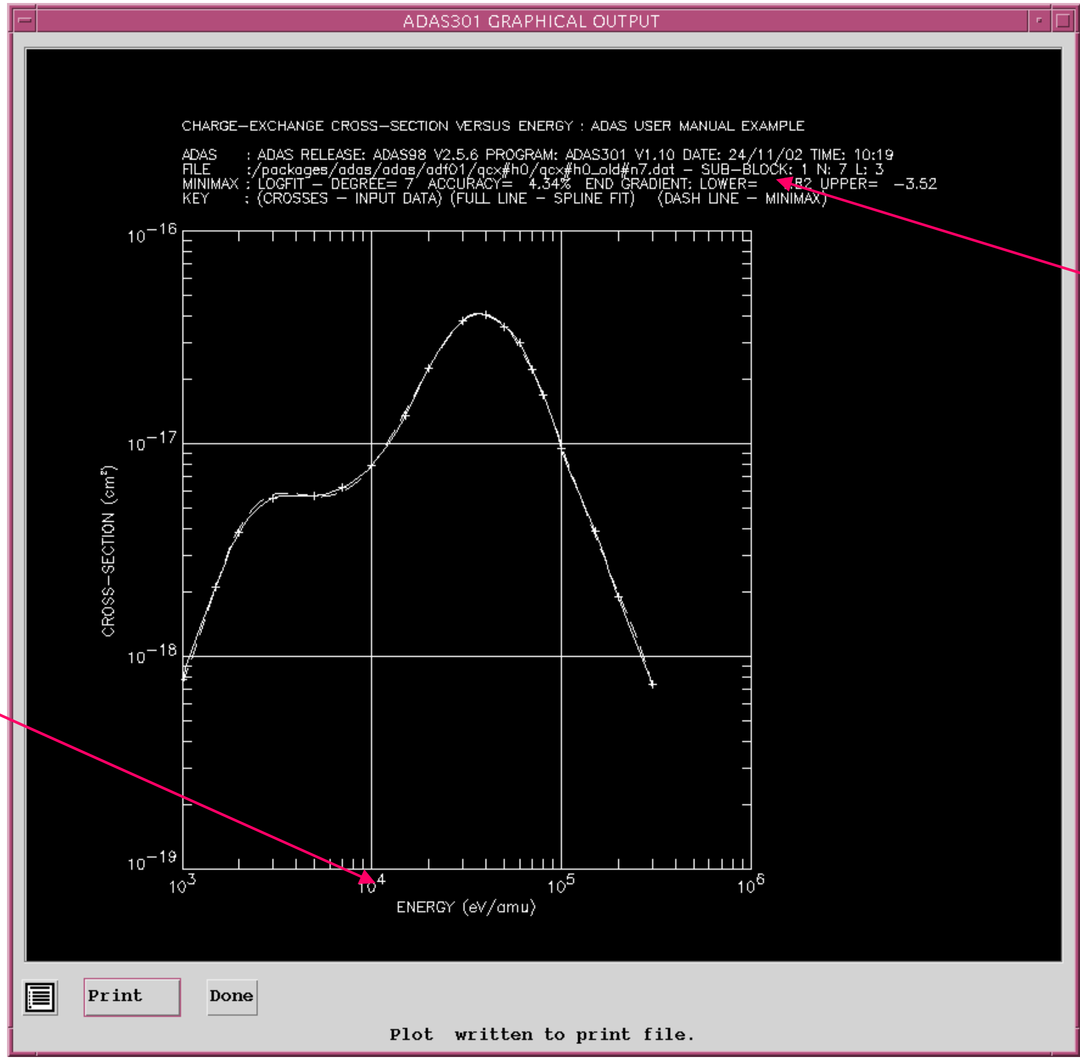
ADAS301 input



ADAS302 Processing



ADAS301 graph



specification of extracted xsect.

graph is a function of energy

Interrogating CXS effective emission coefficients

- Datasets of class ADF12 contain CXS effective emission (qef) data as a function of beam and plasma parameters.
- These coefficients include the effect of collisional redistribution of nl-substate populations of the receiver ion in the plasma.
- The individual components of the n->n' CX transition are not resolvable for bare nucleus receivers so only whole transition arrays are given.
- Code ADAS303 interrogates ADF12 data sets and displays results at beam and plasma conditions of your choice.

ADF12 charge exchange cross-sections

reference rate coefft

receiver

transition

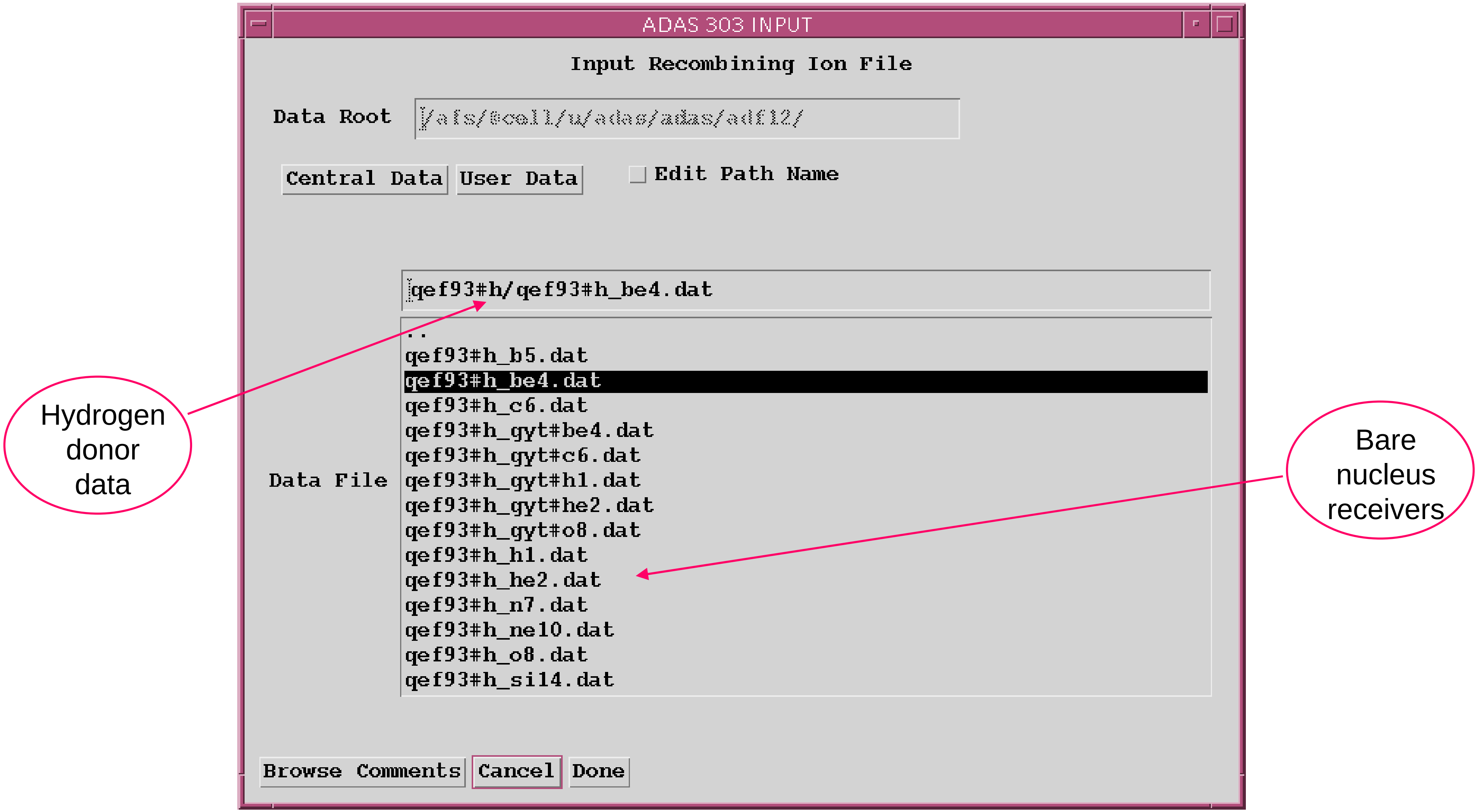
reference parameter values

1-D scans from ref.

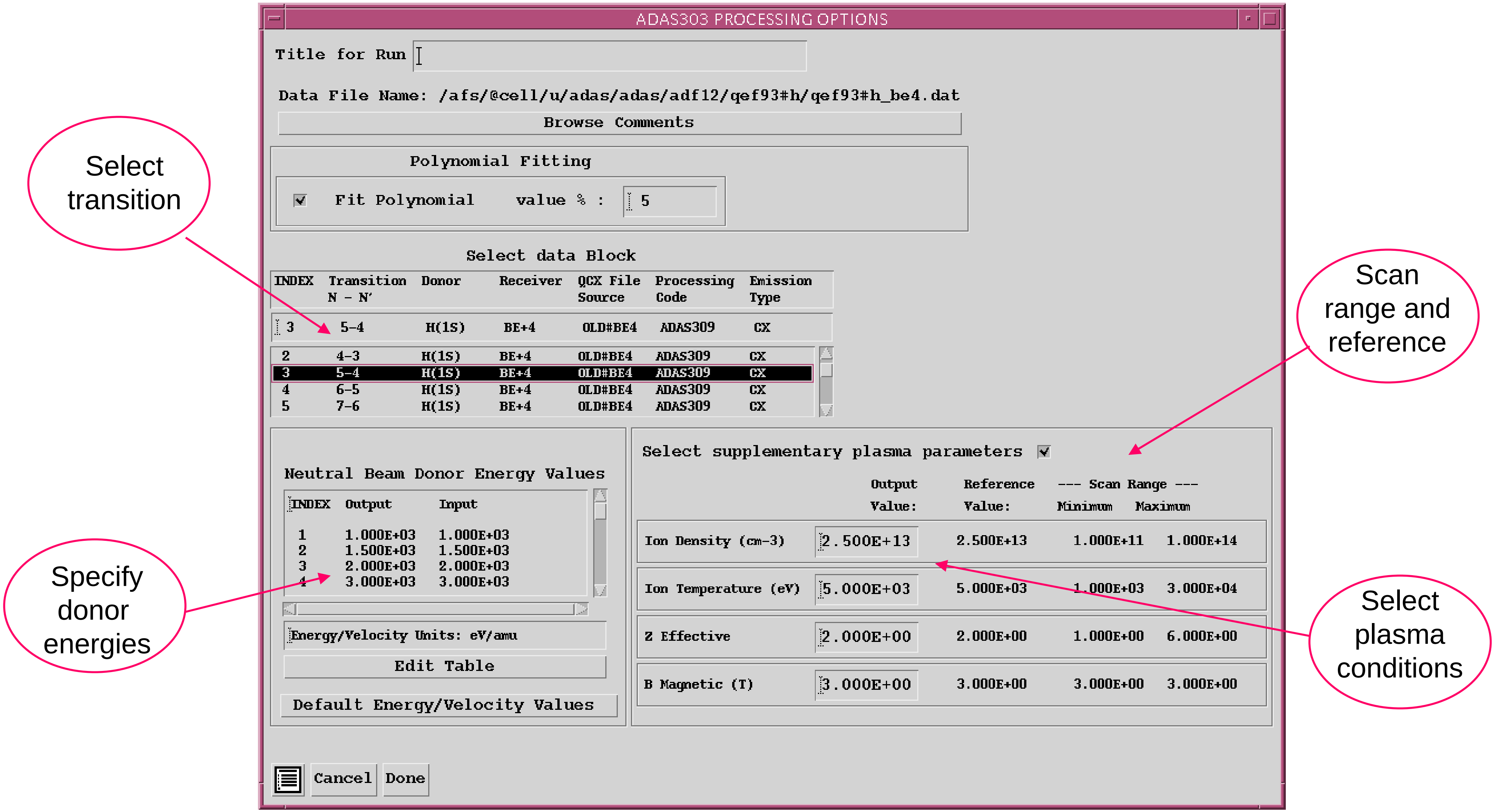
energy scan

```
33
SPSCLMS ON HE+2 6-4  H(1S) DONOR 10/7/90     HE2NEW1(4)  LMS    ISEL=8
  6.52D-10                                                      QEFREF
  4.00D+04  5.00D+03  2.50D+13  2.00D+00  3.00D+00              PARMREF
        19        12        17         6         1              NPARMSC
  1.00D+03  1.50D+03  2.00D+03  3.00D+03  5.50D+03  7.00D+03    ENER
  1.00D+04  1.50D+04  2.00D+04  3.00D+04  4.00D+04  5.00D+04
  6.00D+04  7.00D+04  8.00D+04  1.00D+05  1.50D+05  2.00D+05
  3.00D+05  0.00D+00  0.00D+00  0.00D+00  0.00D+00  0.00D+00
  1.67D-13  1.07D-12  2.51D-12  5.02D-12  1.07D-11  1.62D-11    QENER
  3.20D-11  7.65D-11  1.65D-10  5.06D-10  6.52D-10  5.82D-10
  4.65D-10  3.54D-10  2.58D-10  1.40D-10  3.78D-11  1.25D-11
  2.23D-12  0.00D+00  0.00D+00  0.00D+00  0.00D+00  0.00D+00
  1.00D+03  2.00D+03  3.00D+03  5.00D+03  7.00D+03  1.00D+04    TIEV
  1.30D+04  1.60D+04  1.90D+04  2.20D+04  2.50D+04  3.00D+04
  6.53D-10  6.53D-10  6.52D-10  6.52D-10  6.52D-10  6.52D-10    QTIEV
  6.51D-10  6.51D-10  6.51D-10  6.51D-10  6.51D-10  6.51D-10
    .      .        .
  3.00D+00  0.00D+00  0.00D+00  0.00D+00  0.00D+00  0.00D+00    BMAG
  0.00D+00  0.00D+00  0.00D+00  0.00D+00  0.00D+00  0.00D+00
  6.52D-10  0.00D+00  0.00D+00  0.00D+00  0.00D+00  0.00D+00    QBMAG
  0.00D+00  0.00D+00  0.00D+00  0.00D+00  0.00D+00  0.00D+00
C-----------------------------------------------------------------------
C   EFFECTIVE COEFFICIENT LIST:
C
C     ISEL     TYPE      ION       INFORMATION
C     ----     ----      ---       -----------
C       8.    CX.EMIS.  HE+ 1      N = 6 -  4   6559.4    10/7/90  J2460
C-----------------------------------------------------------------------
```

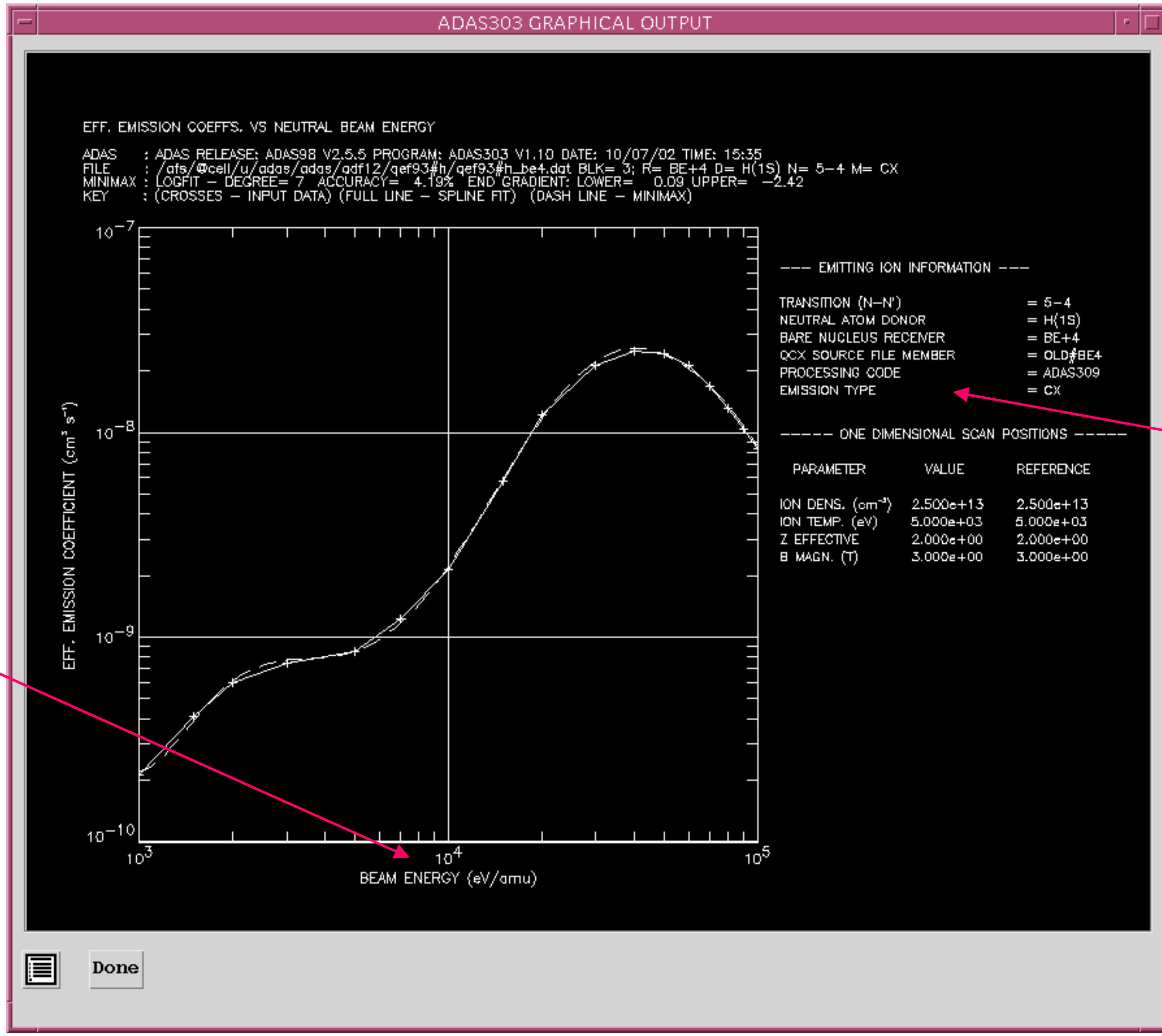
ADAS303 input



ADAS303 Processing



ADAS303 graph



graph is a function of beam energy

plasma and beam conditions for graph

Calculating CXS effective emission

- Datasets of class ADF01 state selective charge exchange cross-section data for capture by fully ionised ions.

- Code ADAS308 computes effective emission coefficients, predicts CXS line positions and profiles and deduces the beam plasma emission measure.

Calculating CXS effective emission (contd.)

- The driving reactions are

$$X^{+z_0} + D^0_{beam}(1s) \rightarrow X^{+z_0-1}(nl) + D^+_{beam}$$

- The effective emission coefficient for n-n' transition is

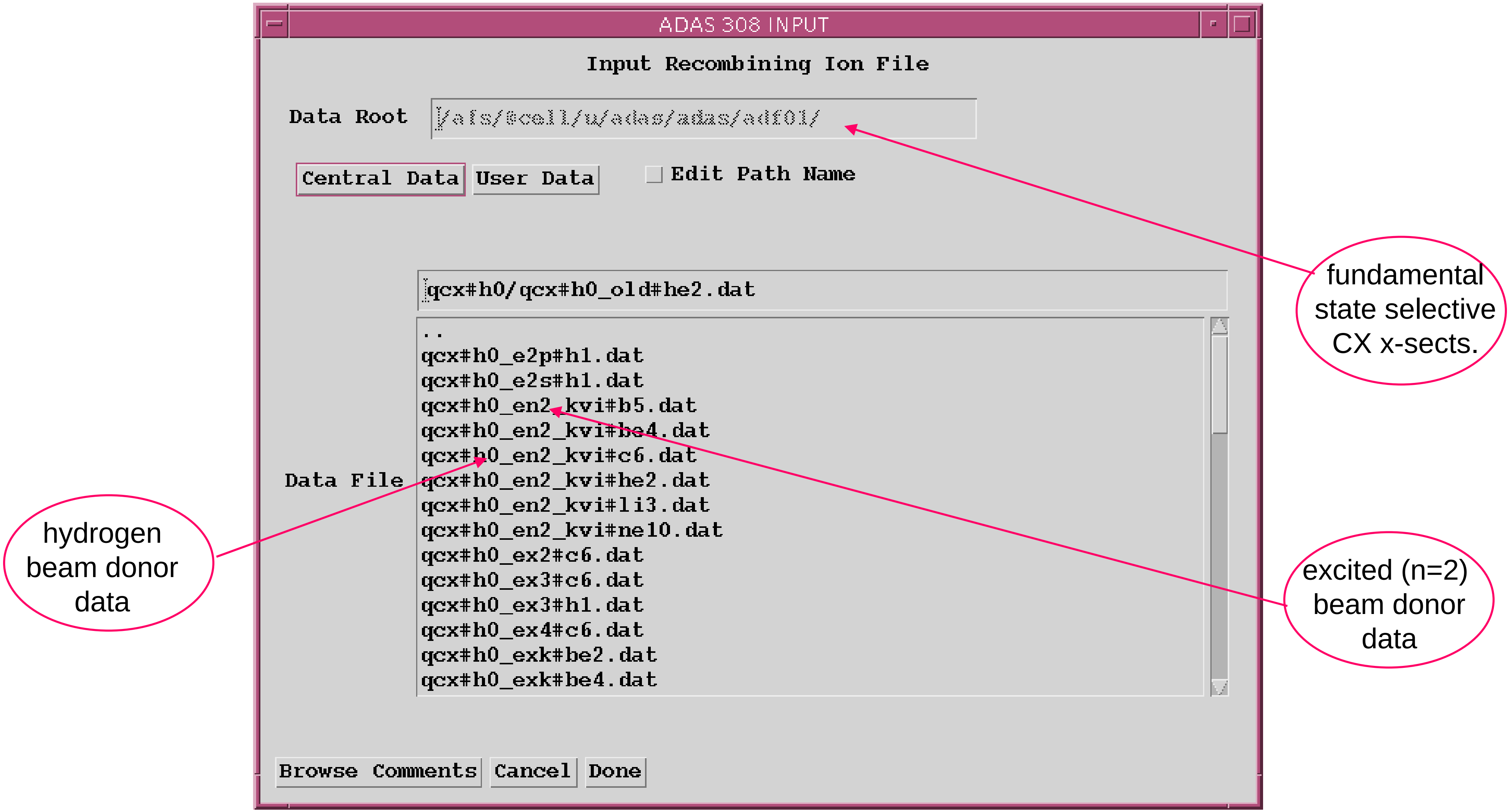
$$q^{(eff)}_{n\rightarrow n'} = \sum_{l,l'} A_{nl\rightarrow n'l'}\left(N^{(z_0-1)}_{nl} / N_D N^{(z_0)}\right)$$

- Thus a collisional-radiative, resolved-nl population calculation is required to determine the effective emission coefficients.

Calculating CXS effective emission (contd.)

- File selection
  - » The fundamental state selective charge exchange x-sect data is format ADF01. These data are resolved into the nl shells of the receiver.
  - » Note that there are sub-directories for different donors and separate data sets for ground and excited donor states.
- Processing options
  - » *Beam parameter, observed spectrum lines and required emssivity predictions must be entered using Table Editor.*
  - » *Then plasma conditions must be entered.*
  - » *Finally model for emission measure is chosen.*
- Output options
  - » Graphical display of the spectral position, intensity and shape of a designated n-n’ transition is given.
  - » Tabulations of predicted intensities of other lines are given together with the estimated emission measure.

ADAS308 Input



Calculating CXS effective emission (contd.)

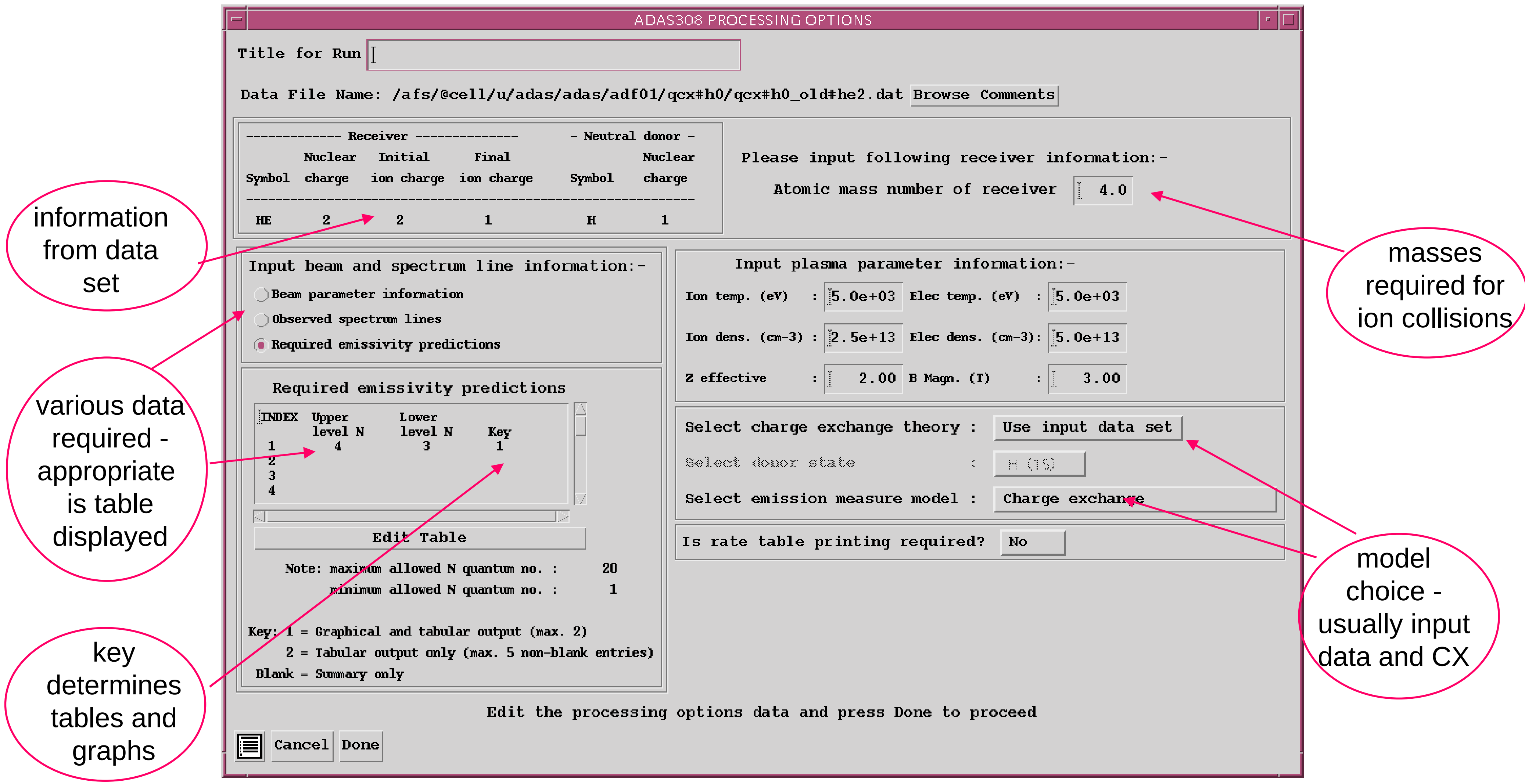
- ADAS308 is designed to do more than solve for the effective emission coefficients, qef.

- The program computes the qef and solves for the emission measure given the line of sight intensity in a charge exchange line as

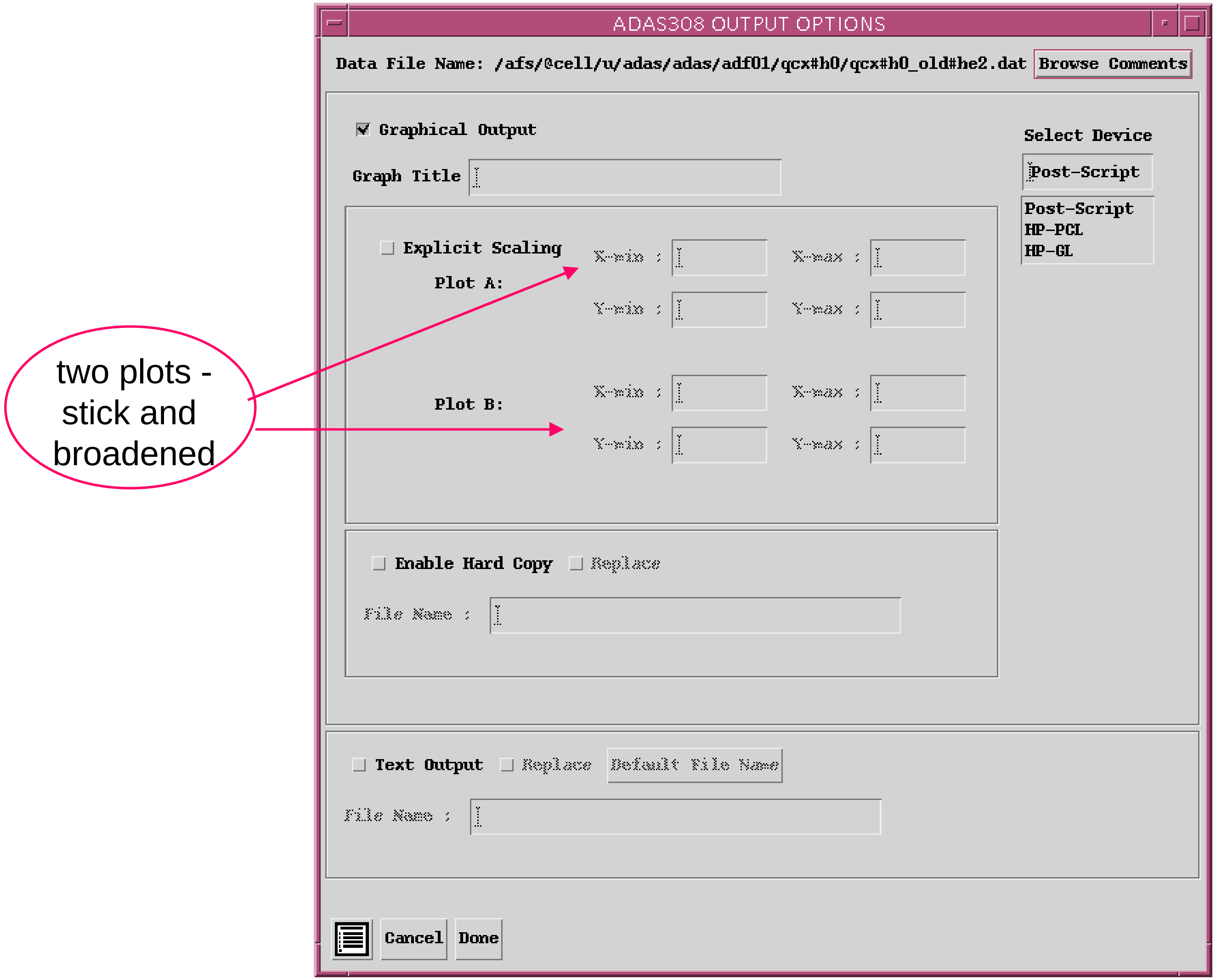
$$I_{n\to n'}^{(z_0-1)} \approx q_{n\to n'}^{(eff)} \int_s N_D N^{(z_0)} ds$$

- If more than one charge exchange line intensity, with different upper levels, the code can assess the consistency between experimental and theoretical data. ADAS308 casts this onto the consistency of the ADF01 total n-shell capture with observation.
- Most use of ADAS308 has been directed at qef and its components alone.

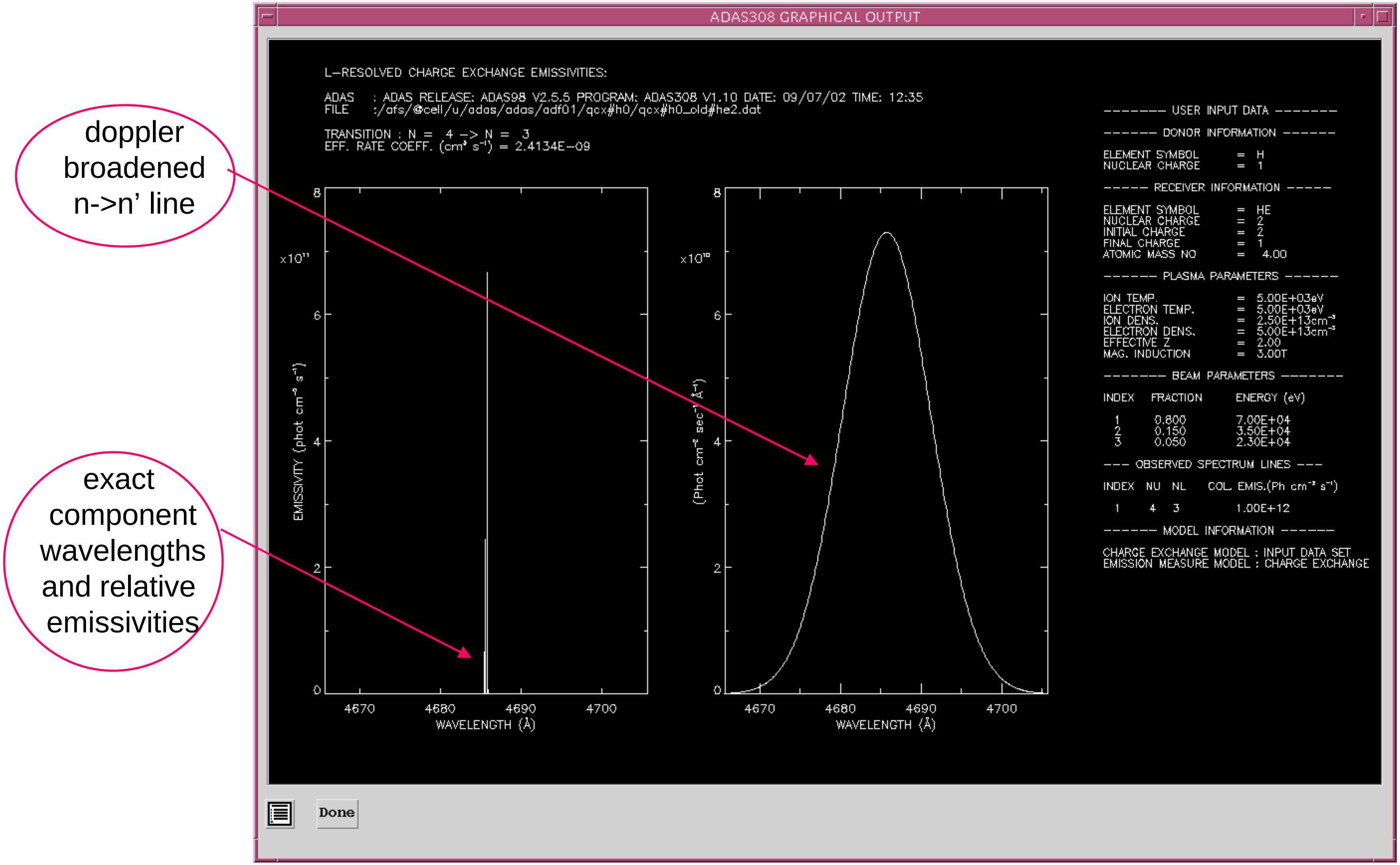
ADAS308 processing



ADAS308 output



ADAS308 graph



Mass production of CX effective emission coeffts.

- ADAS309 is the mass production code for the effective emission coefficients for charge exchange lines.
- The user input is similar to that for ADAS308 but there is no graphical output, nor does it attempt the inversion solution.
- Many transitions can be entered at the one time. An output file of effective emission coefficients is delivered fully formatted to the ADF12 specification.

Extension of the CXS capabilities to heavier species

- Motivated by the need to cope with heavier receiver ions beyond argon, which may be partially ionized.
- There are two new codes ADAS315 and ADAS316. ADAS315 works on a scaleable universal dataset of format ADF49 to produce an ADF01 data set.
- ADAS316 is a bundle-n population model. It requires a driver data set and, for bundle-n in ADAS, these have historically been archived in ADF25. A new sub-directory /a25_p316 has been assigned and a complete redesign of the driver has been carried out.
- Output ADF26 (the bundle-n population solution), ADF12 (charge exchange effective emission coefficients) and ADF40 (feature emissivity coefficients) may be produced.
- For heavy species CXS, because of the very large number of transitions between highly excited states, the ADF40 format becomes more useful that ADF12.