# Cross Section of the (n, 2n) Reaction in 12C in the Energy Interval 20-30 MeV

Stephen Padalino, Danae Polsin, Megan Russ, Michael Krieger, Collin Stillman, Angela Simone, Mollie Bienstock, Drew Ellison- SUNY Geneseo
Mark Yuly, Keith Mann, Tyler Reynolds- Houghton College,
Craig Sangster- Laboratory for Laser Energetics

## Abstract

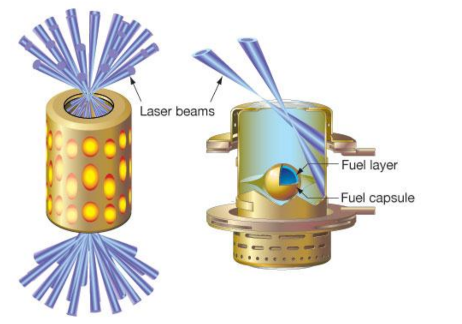
The behavior of the (n, 2n) reaction in 12C and other light nuclei is known with much less certainty than for heavy nuclei. The published cross section data for the 12C(n, 2n)11C reaction is bifurcated in the energy range of 20-30 MeV. An experiment to measure the 12 C(n,2n)11C cross section for these neutron energies has been performed using the Ohio University Tandem Accelerator. Deuterons from the accelerator struck a tritium foil releasing neutrons via the T(d, n)4He reaction. Deuteron bombarding energies between 3.3-8.7 MeV resulted in neutrons with energies between 20-26 MeV. The geometry of the experiment was chosen so that the incident neutron energy would not vary by more than 0.5 MeV across the graphite target. After neutron bombardment, the decay of the 11C nuclei by positron emission was measured with an array of NaI detectors to determine the activity of the carbon sample. The neutron fluence through the carbon was measured using a particle telescope to detect protons from the 1H(n, p) reaction in a polyethylene target, allowing the absolute cross section for the 12C(n, 2n)11C reaction to be determined. Funded in part by a grant from the DOE through the Laboratory for Laser Energetics.

## Motivation

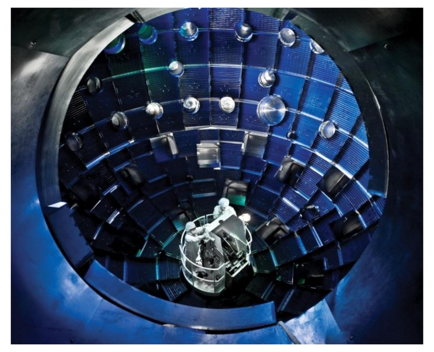
National Ignition Facility

The tertiary neutron yield is a good indicator of the success of an ICF burn. The yield can be determined by the neutron activation of graphite through the 12C(n,2n)11C reaction. Unfortunately, published cross sections for this reaction are bifurcated in the energy range of interest.

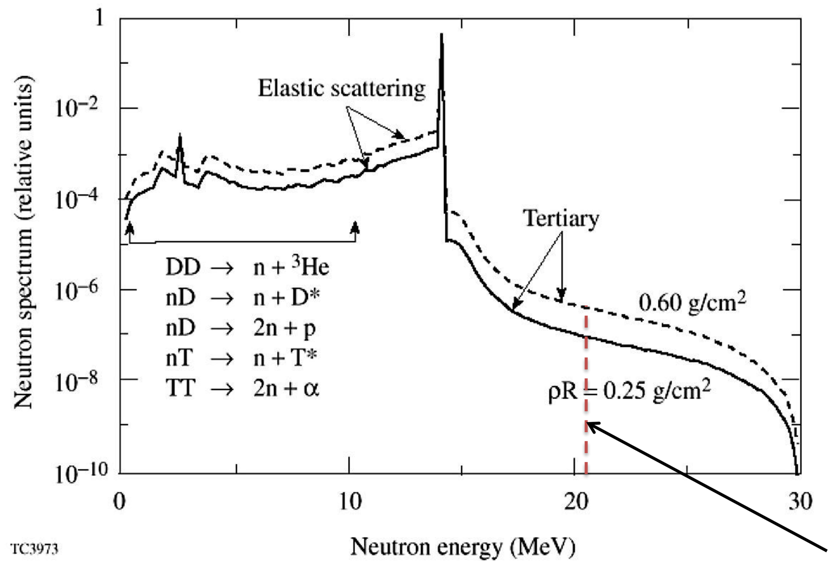
NIF Laser and Target Area Building



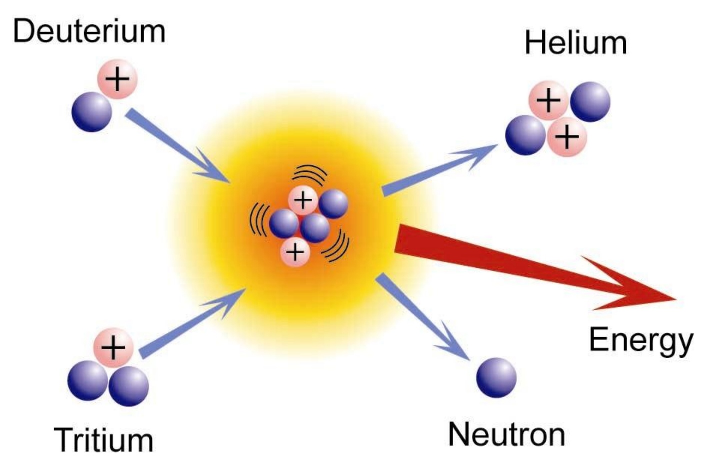
A 1200 micron diameter capsule containing deuterium and tritium is housed in a gold hohlraum.



10 meter diameter NIF Target Chamber




Threshold for Carbon Activation



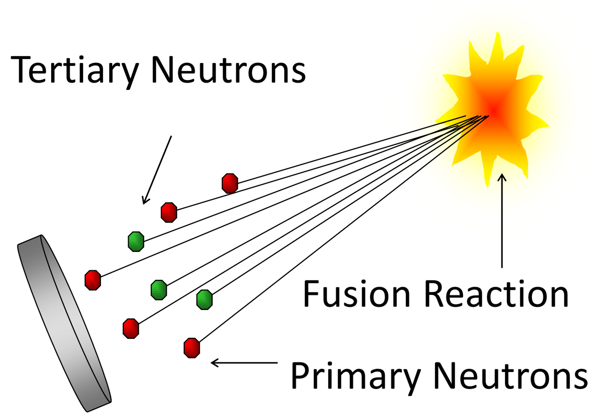

## ICF, Graphite Activation, and Positron Annihilation

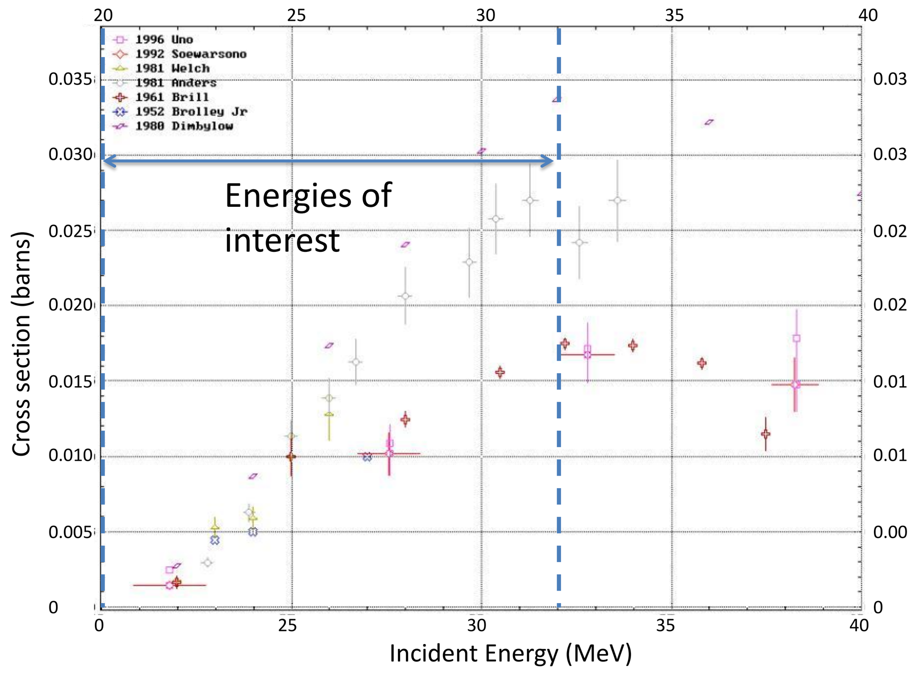
$D_{fuel} + T_{fuel} \rightarrow \alpha + n$ Primary neutrons are roughly 14.1 MeV

$n + D_{fuel} \rightarrow n' + D_{ko}$ Producing 0 – 12.5 MeV knock-ons

$D_{ko} + T_{fuel} \rightarrow \alpha + n^{**}$ Producing 12 - 30 MeV tertiary neutrons

The number of tertiary neutrons is related to $(\rho r)^2$ or $\rho r$ parameter




The experimental cross sections follow two separate curves, differing by as much as a factor of two.

Due to the 20.3 MeV threshold, only tertiary neutrons from the burn contribute to the 12C(n,2n)11C reaction (insensitive to primary & scattered neutrons)

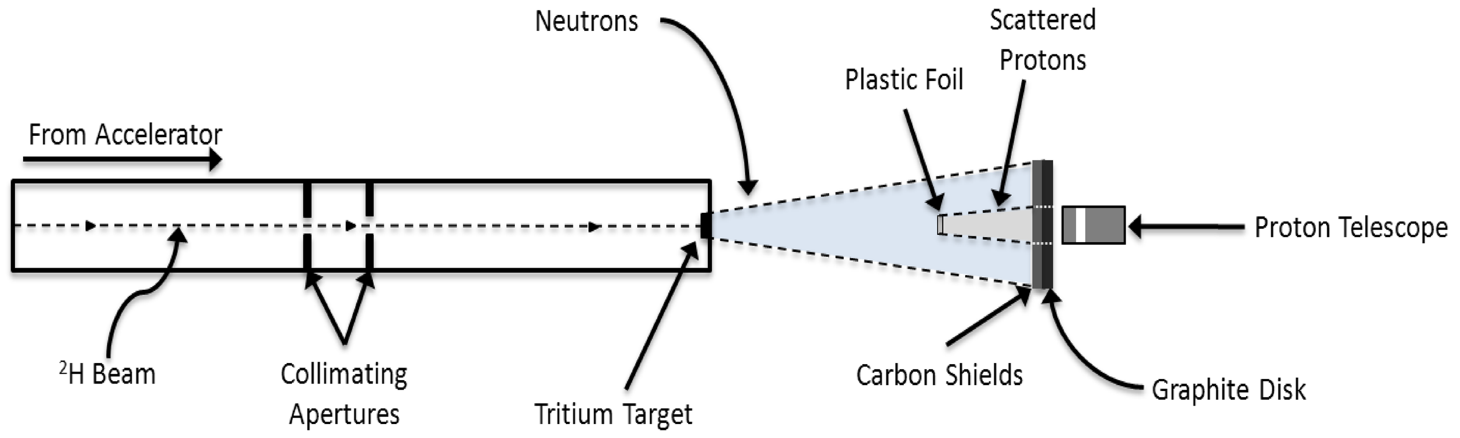
$D_{ko} + T_{fuel} \rightarrow \alpha + n^{**}$

$n^{**} + {}^{12}C \rightarrow 2n + {}^{11}C$

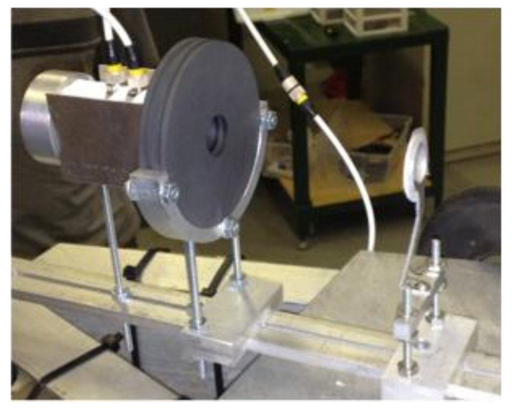
${}^{11}C \rightarrow {}^{11}B + e^+$

$e^+ + e^- \rightarrow 2\,\gamma_{511KeV}$

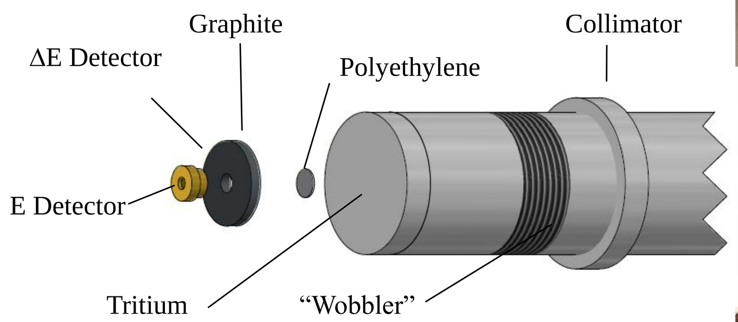
## Experimental Setup at the Ohio University Accelerator Lab



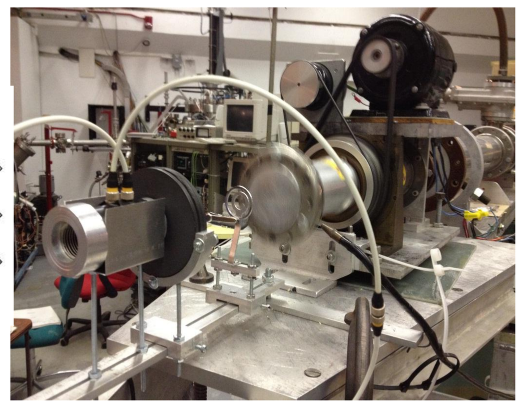

Deuterons were accelerated to energies between 3.5 and 8.285 MeV and allowed to strike a titanium tritide foil. Beam currents were typically between 0.5 and 1.0 μA. Before striking the target, the deuteron beam was defocused by a pair of quadrupole magnets and allowed to pass through a collimator, reducing the risk of creating a hot spot on the target.



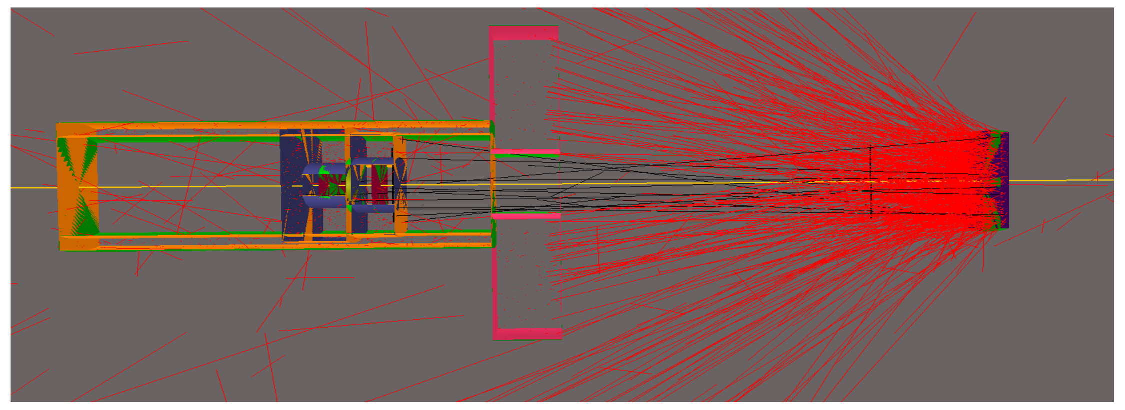
The activation setup



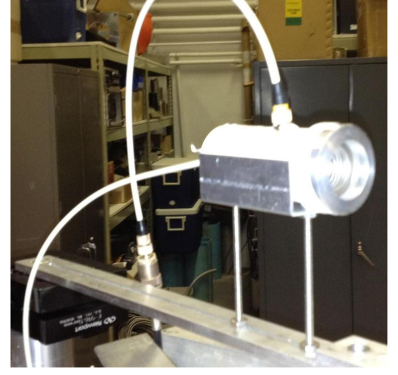

Protons produced in the polyethylene target via the p(n,p) reaction passed through a cylindrical hole in the graphite target where they were detected by the telescope.

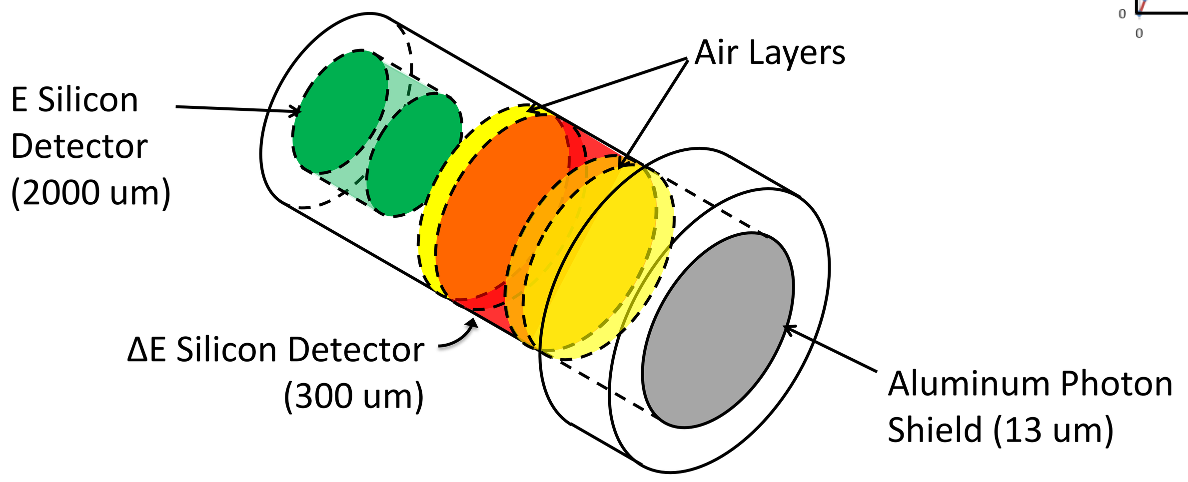


The target was moved in a circular path about the beam axis to prevent it from overheating and releasing tritium.

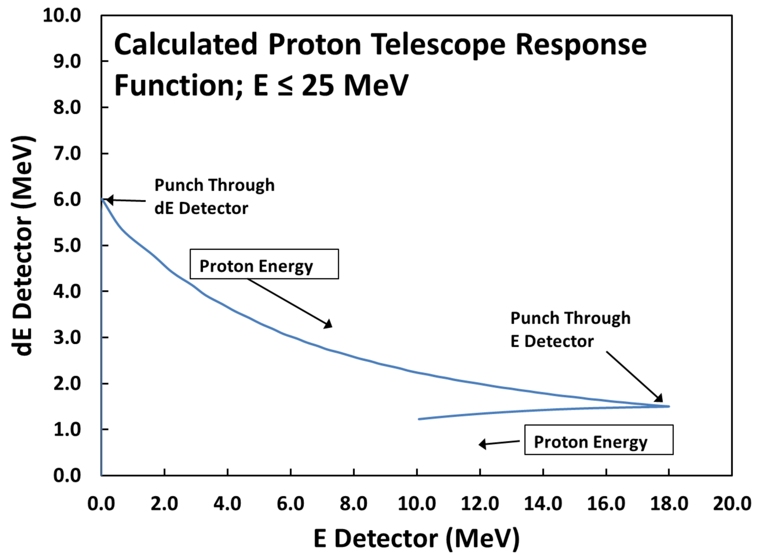


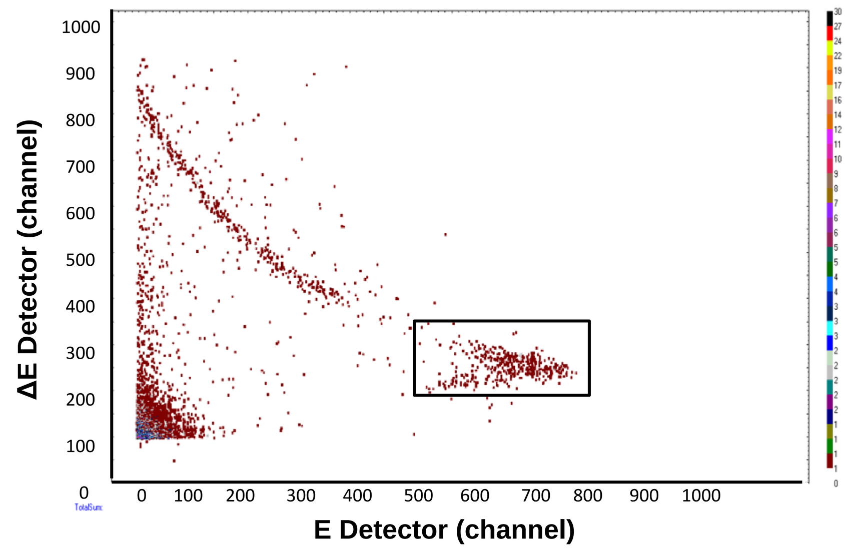
A visualization of an MCNPX simulation of the experiment. Proton tracks (indicated in red), emitted from the polyethylene target (in purple), strike the graphite target (in pink). Some protons (indicated in black) pass through the hole in the graphite target where they are detected by the proton telescope (in blue).






In order to determine the neutron flux, protons from neutron-proton elastic scattering were counted in a ΔE-E detector telescope



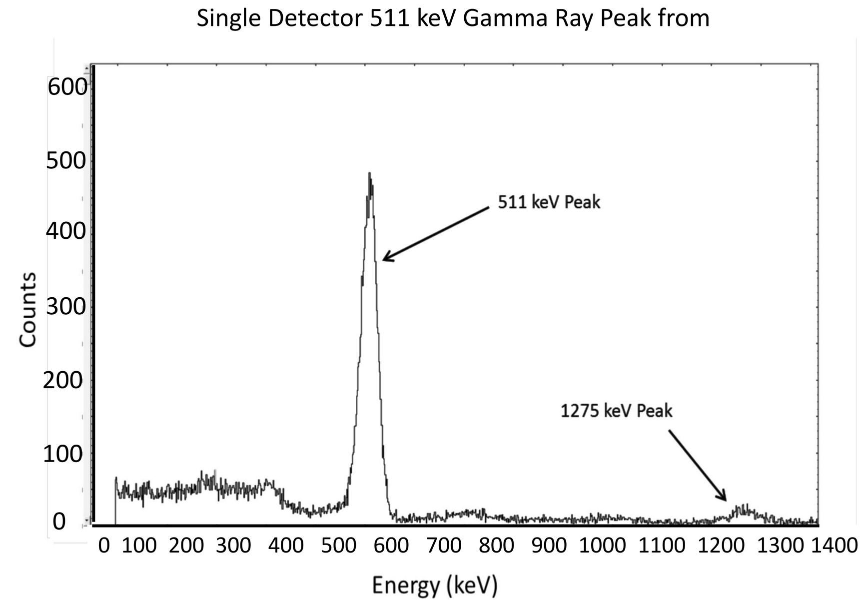

The marked region-of-interest indicates the counted protons elastically scattered by neutrons.

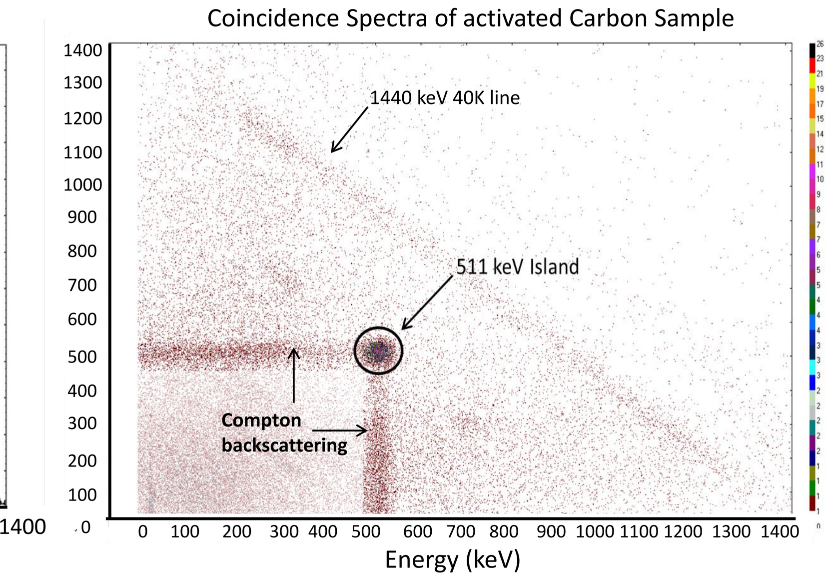
## Counting Station

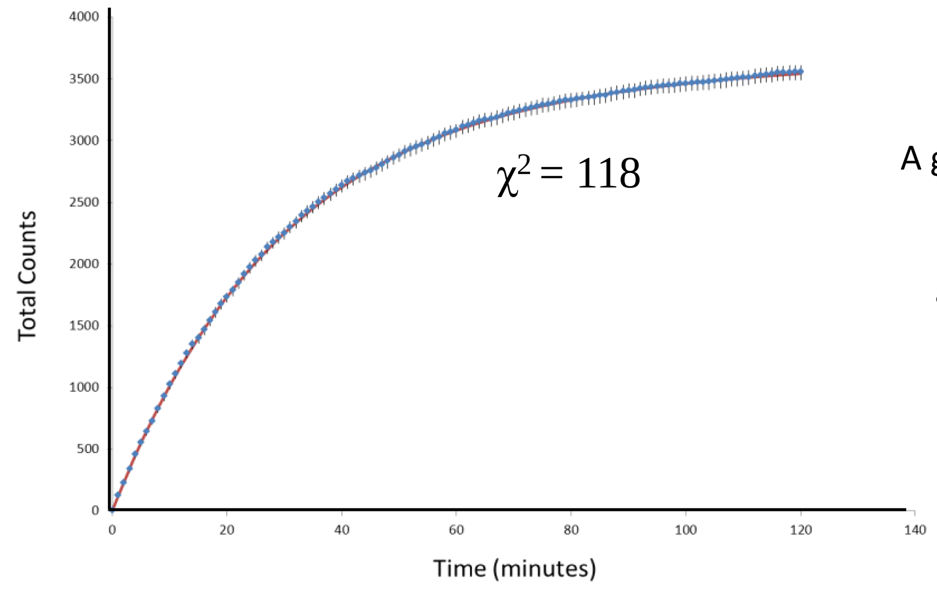
After an activation period of approximately 6 half lives, the targets were removed to a counting station. The rate of back-to-back gamma rays resulting from positron annihilation was used to determine the number of $^{11}C$ nuclei present.

${}^{11}C \rightarrow {}^{11}B + e^+ \qquad e^+ \rightarrow 2\,\gamma_{511KeV}$

Two pairs of 3 inch by 3 inch NaI detectors were used for coincidence counting

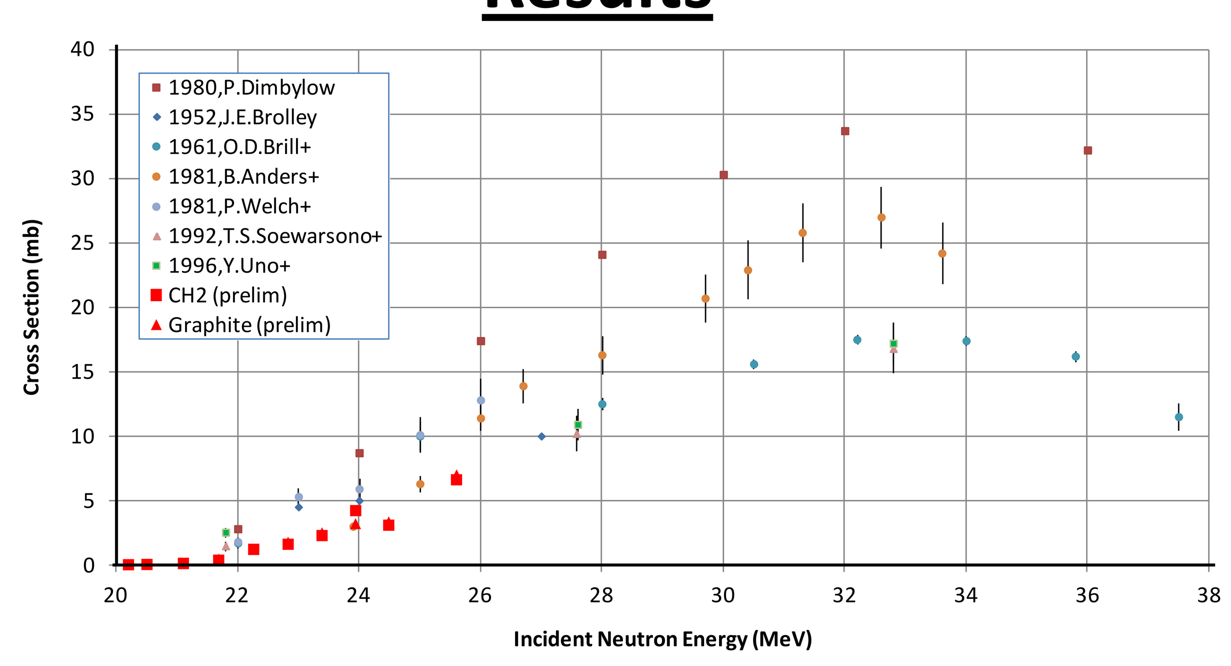



A growth curve with a linear background produced the initial number of measured $^{11}C$ decays. Transport time and detector efficiency were accounted for, resulting in the total number of original carbon activations.

## Results




The measured cross sections are shown above (in red, as squares and triangles). However, efficiency calibrations of the detector pairs need to be confirmed.