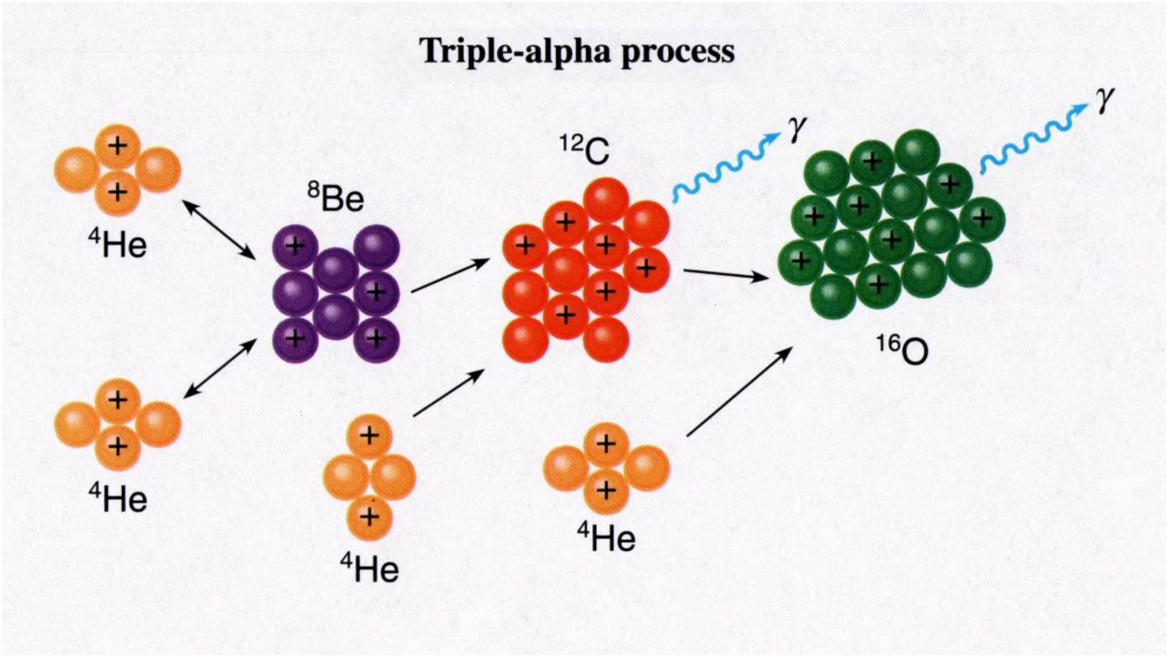
Bubble Chamber

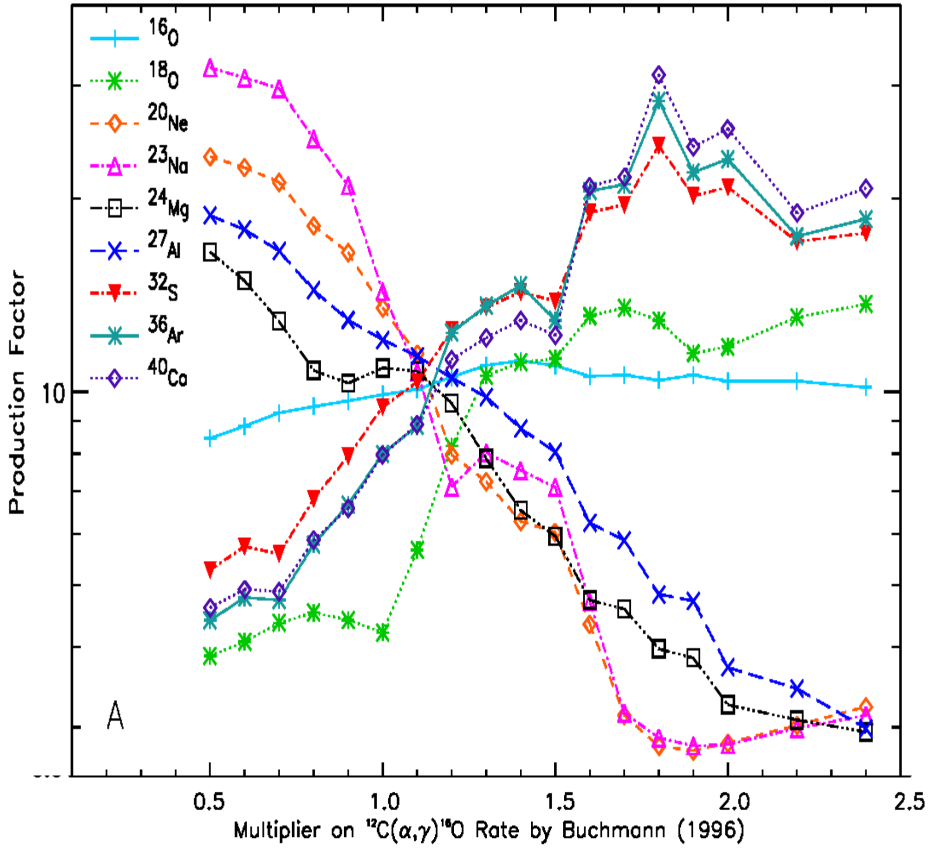
A novel technique towards understanding the $^{12}C(\alpha,\gamma)^{16}O$ reaction

Rashi Talwar

Astrophysical Motivation

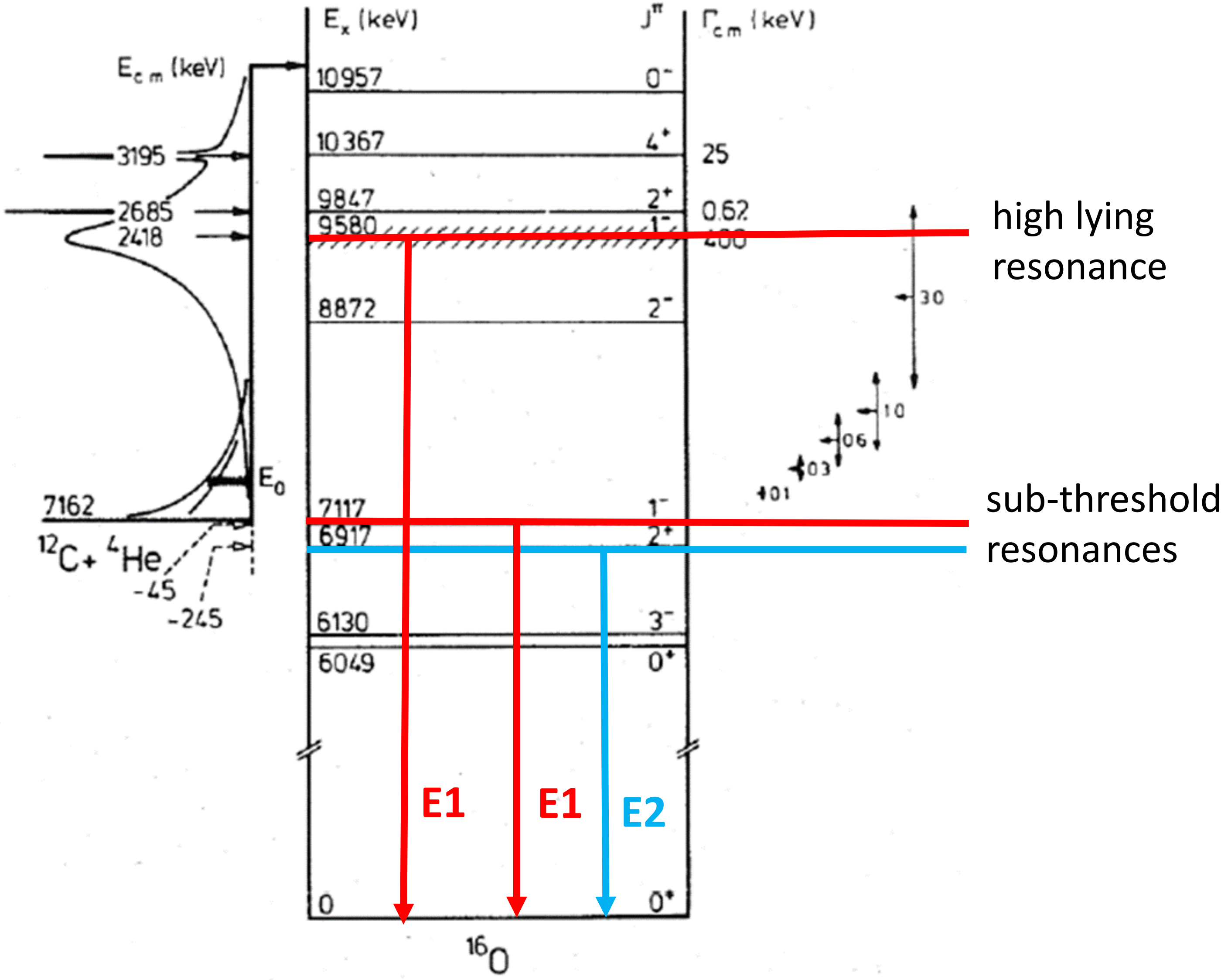
Role of $^{12}C(\alpha,\gamma)^{16}O$ reaction in Stellar Helium Burning

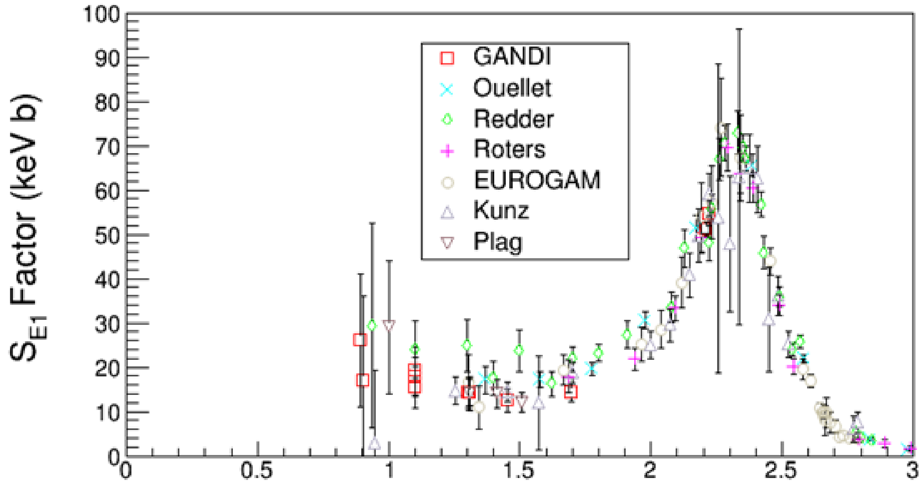


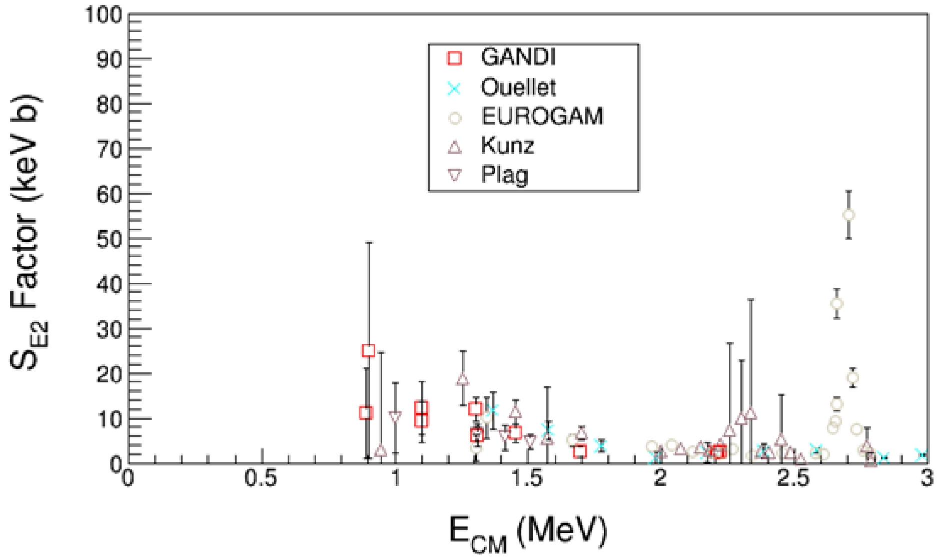


- It defines the ratio of carbon to oxygen in stellar cores and, as a result, in the universe
- It affects the synthesis of most of the elements of the periodic table
- Determines the minimum mass required by a star to become a supernova

Challenges associated with the measurement of $^{12}C(\alpha,\gamma)^{16}O$





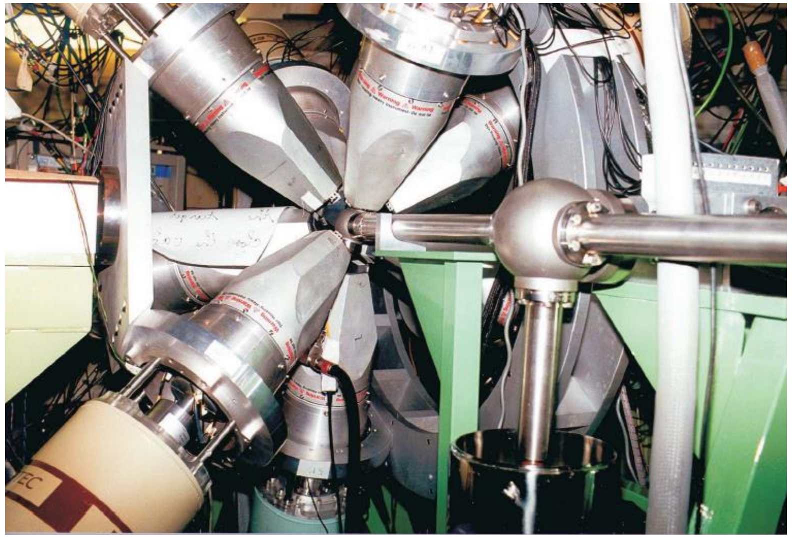


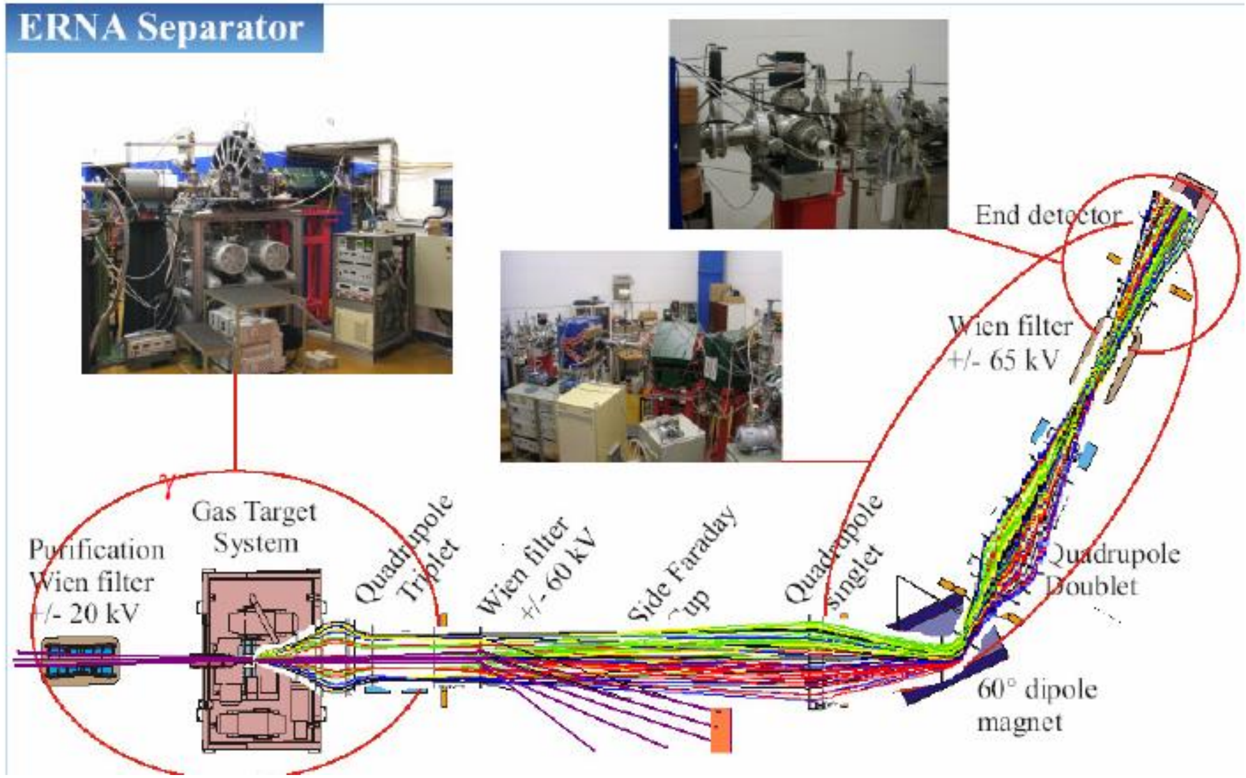
Time Reversal + The Bubble Chamber

Traditional Techniques

Assuncao et al., PRC73, 055801 (2006)

9 EUROGAM detectors





Count rate estimate for:

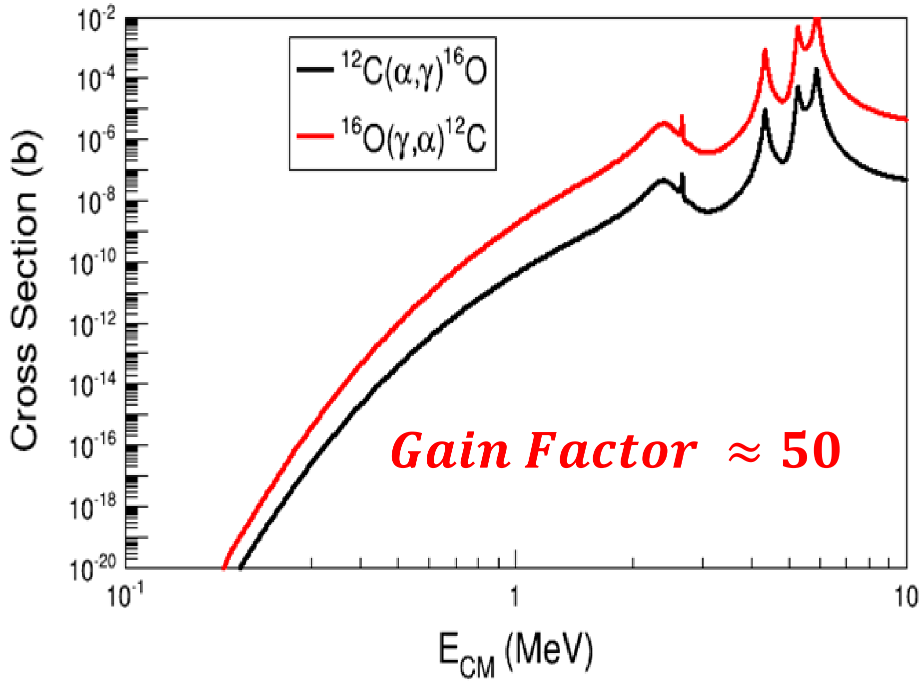
σ=1 pb, I=100 pμA, T_{target}=12 μg/cm^2

$$\frac{dN}{dt} = \sigma.I.T \cong 1\, count/day$$

Time Reversal Technique

- 0(1,2)3 vs 3(2,1)0 : $\dfrac{\sigma_{23\to01}}{\sigma_{01\to23}} = \dfrac{(2j_o+1)(2j_1+1)}{(2j_2+1)(2j_3+1)}\dfrac{k_{01}^2}{k_{23}^2}$

$^{12}C(\alpha,\gamma)^{16}O$ vs $^{16}O(\gamma,\alpha)^{12}C$: $\dfrac{\sigma_{\gamma,\alpha}}{\sigma_{\alpha,\gamma}} = \dfrac{2\mu_{\alpha,\gamma}c^2E_{\alpha,\gamma}}{2E_\gamma^2}$

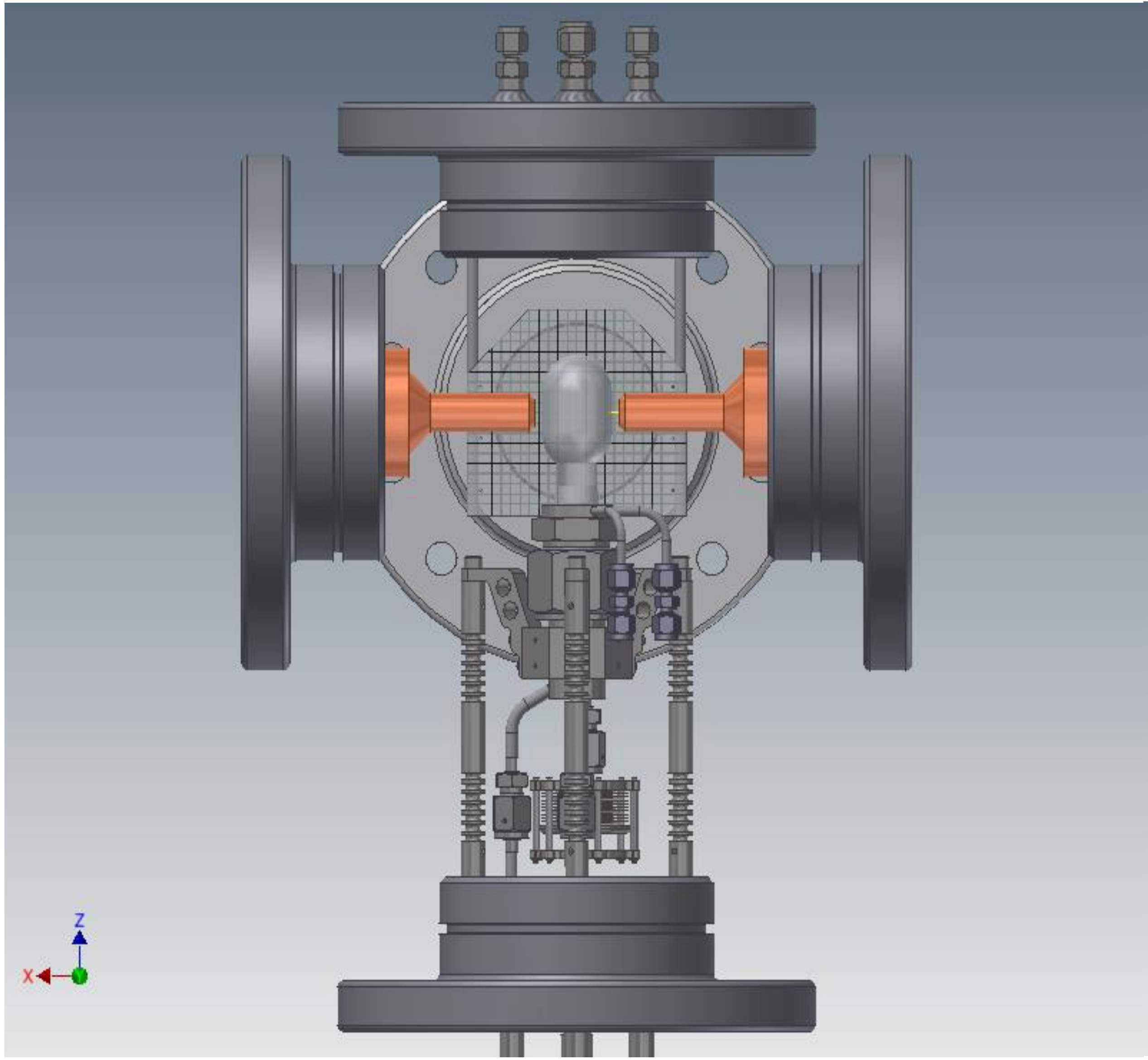


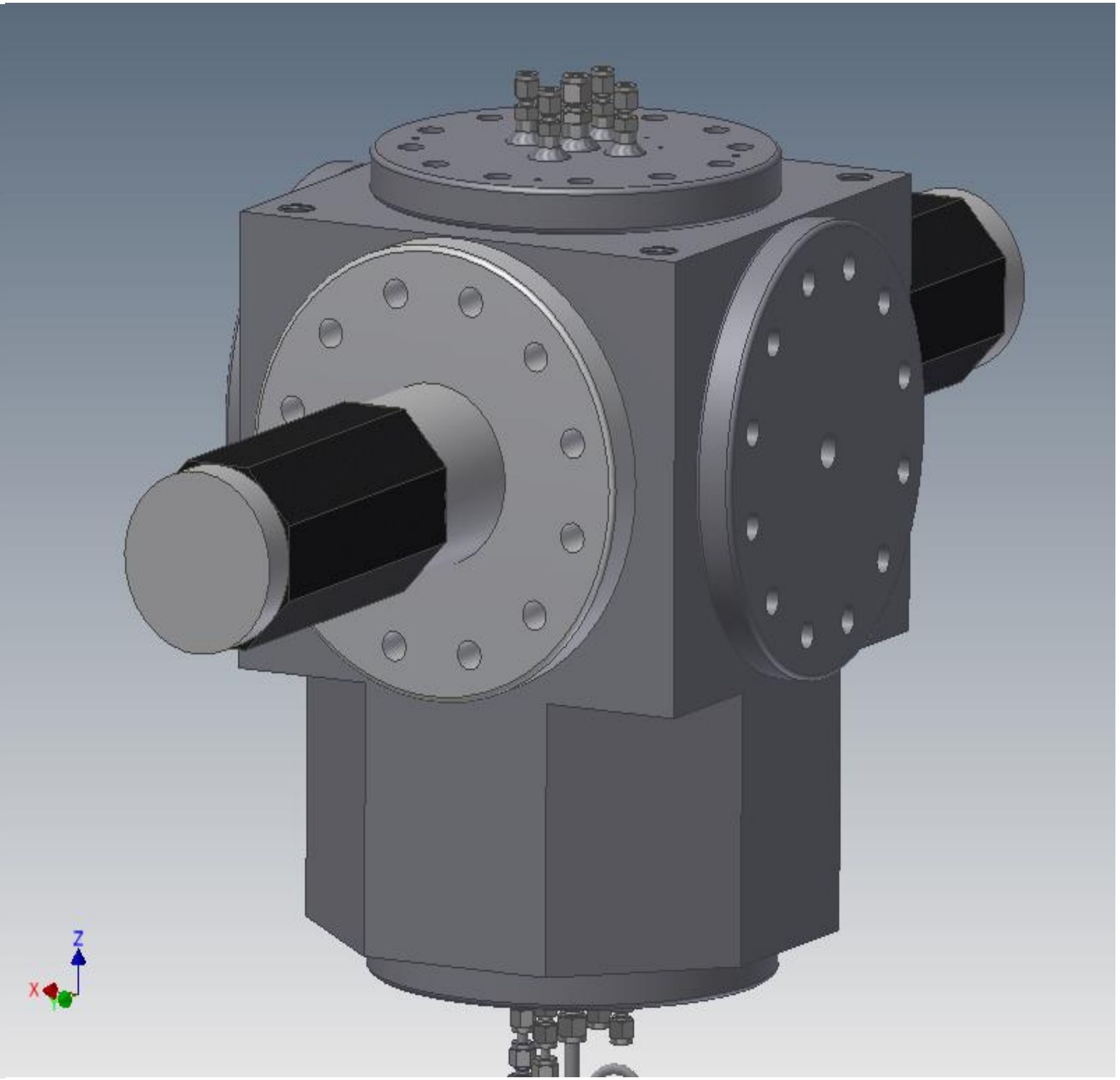
- The large range of incident γ-rays allows us to use targets with thickness of ~ 1-10 g/cm^2

$L = I.T.\varepsilon \cong 8.4\ X\ 10^{32}$

$R = L.\sigma \cong 70\ counts/day/pb$

Bubble Chamber : For Nuclear Astrophysics





Work At HlγS

Proof of Principle Experiment at HIγS

Case Study : $^{15}N(\alpha,\gamma)^{19}F$ via the time inverse $^{19}F(\gamma,\alpha)^{15}N$ process

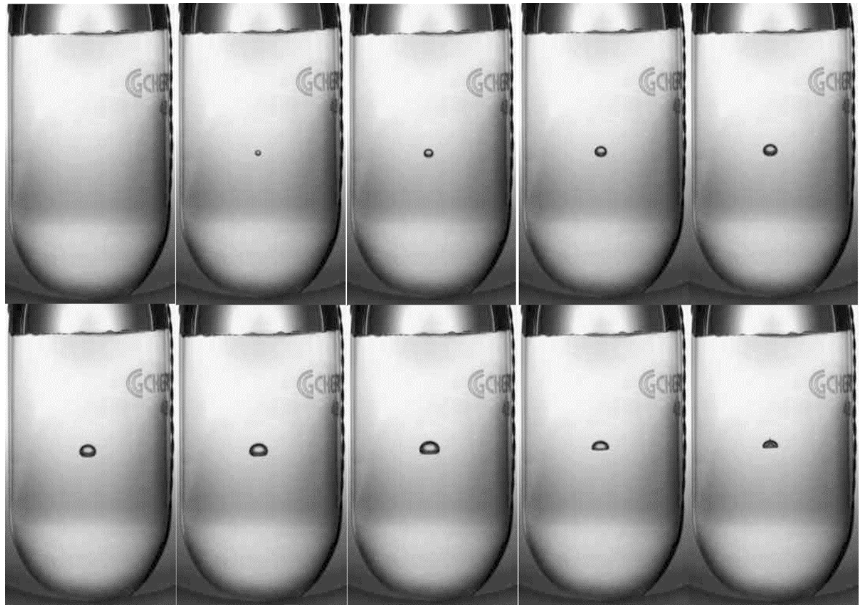
Astrophysical Motivation : This reaction is the last link in the thermonuclear reaction chain leading to formation of fluorine in AGB stars

Resonance under study : E_x = 5.337 MeV, $J^\pi = ½^+$

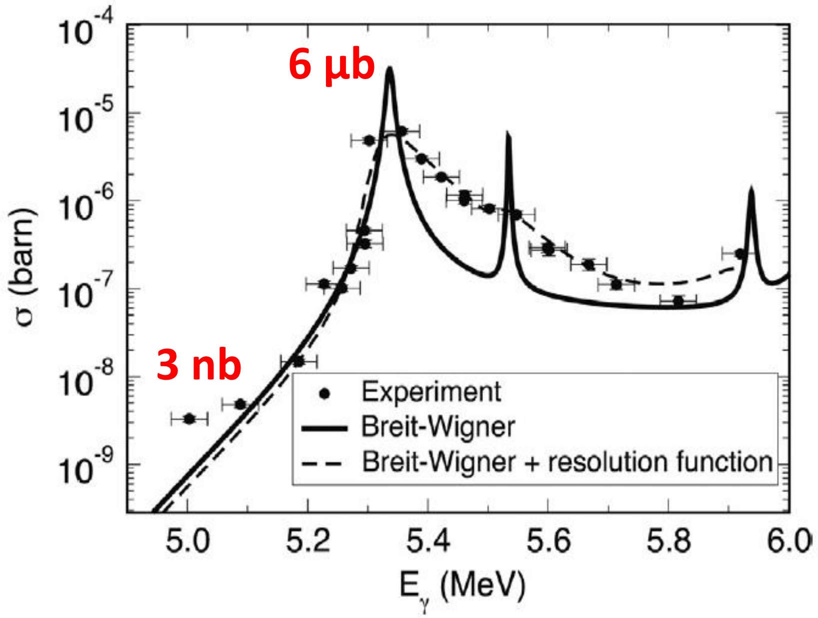
Target + Buffer Fluid : $C_4F_{10} + H_2O$

Superheat conditions : T = 30°C, P = 3 atm

100 Hz Digital Camera Δt = 10 ms



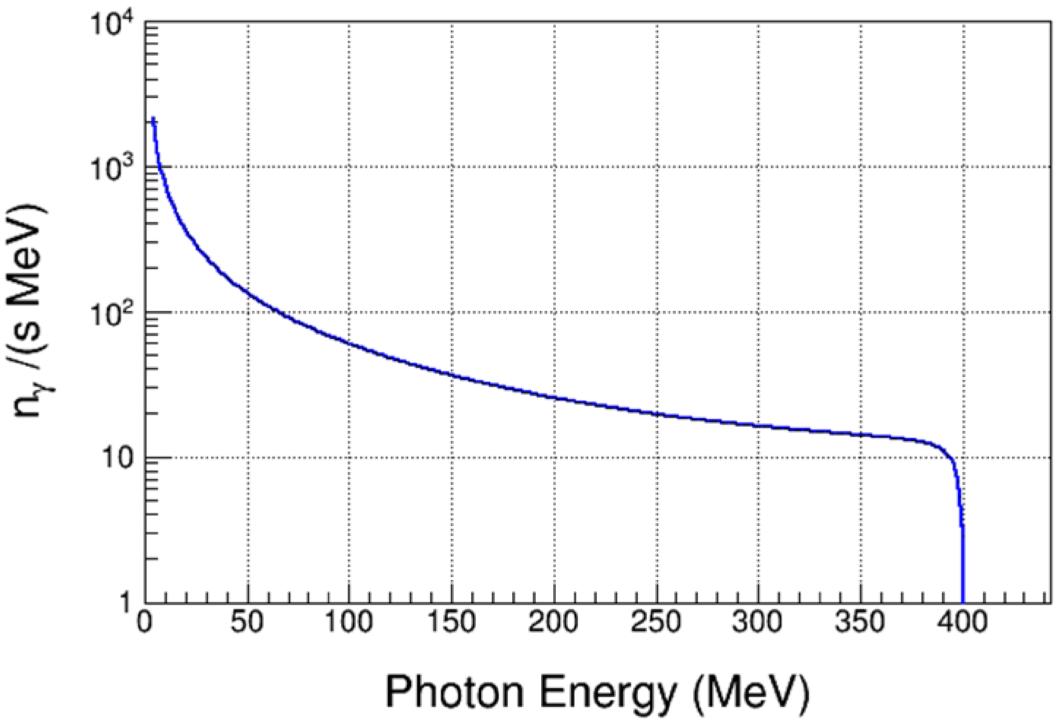
$N_\gamma = 2 \times 10^3 – 3 \times 10^6$ γ/sec

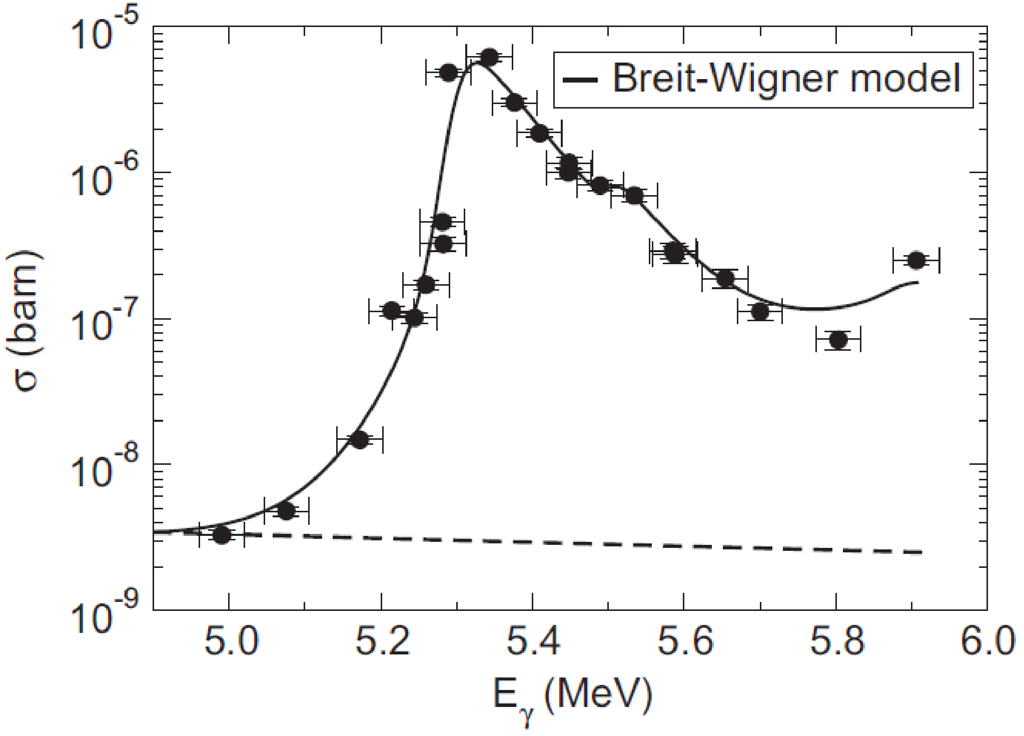


Lower Limit of HIγS Measurement

Electron Beam Energy : 400 MeV
Electron Beam Current : 41 mA
Interaction Length: 35m

Strong Bremsstrahlung background when coupled with large cross-sections at high energies





Work At JLab

Goal of the Experiment

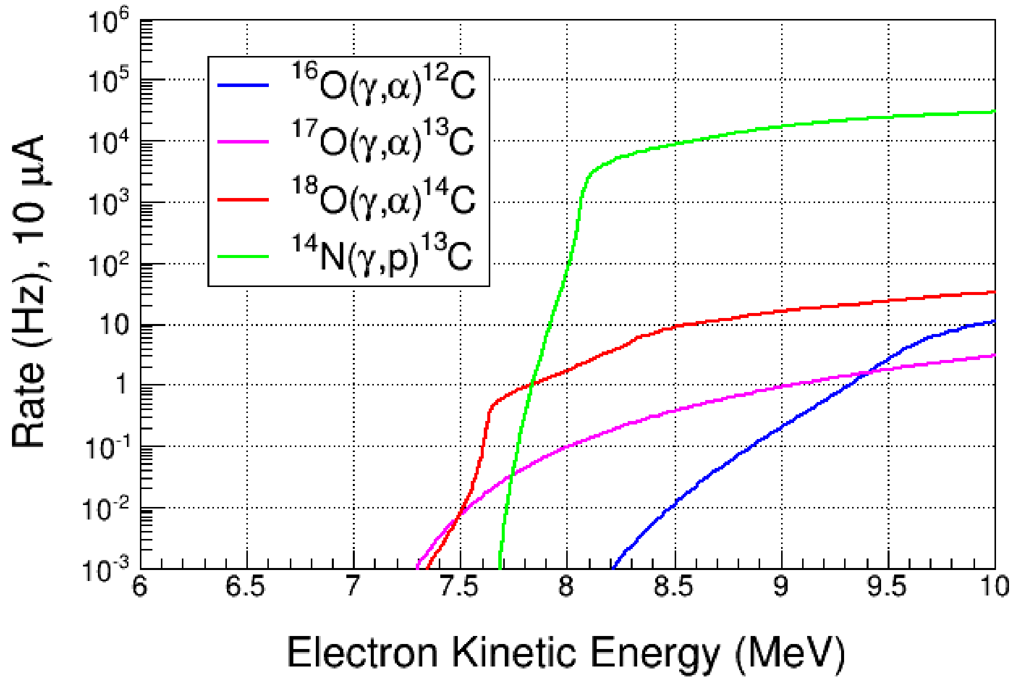
- First test of the bubble chamber with a Bremsstrahlung beam
- Study the cosmic background level
- Study the background contributions from photodisintegration of nuclei in the superheated N_2O liquid

Background from oxygen isotopes and nitrogen in N_2O

a) $^{18}O(\gamma,\alpha)^{14}C$ (Q-value = -6.23 MeV)

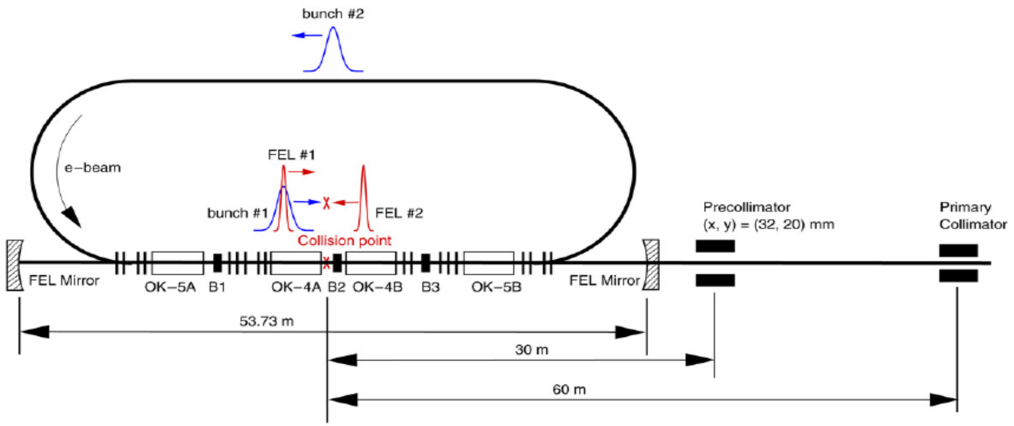
b) $^{17}O(\gamma,\alpha)^{13}C$ (Q-value = -6.36 MeV)

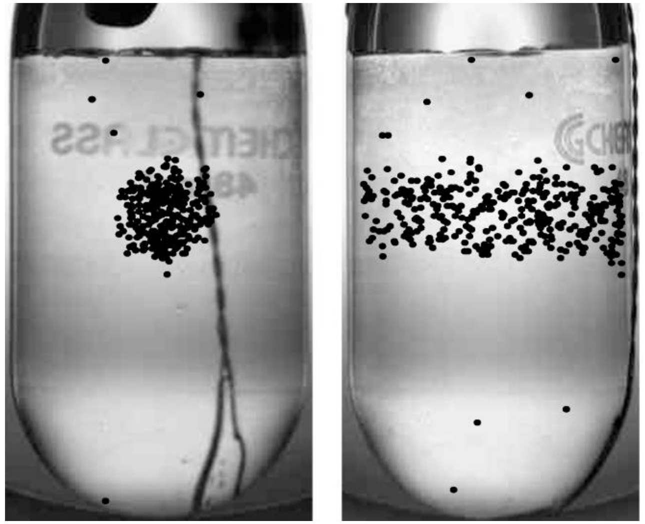
c) $^{14}N(\gamma,p)^{13}C$ (Q-value = -7.55 MeV)



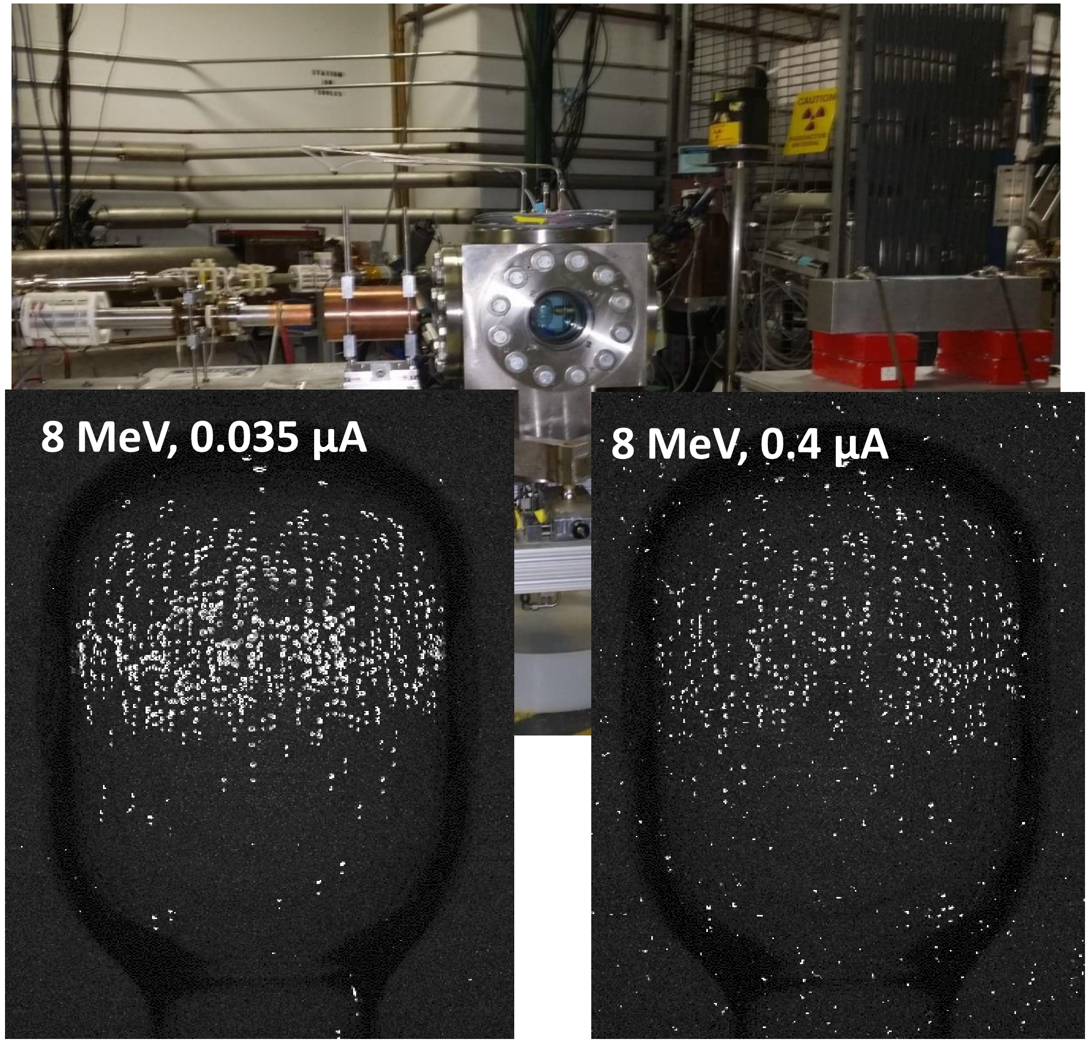
Bubble Distribution

HIγS Data

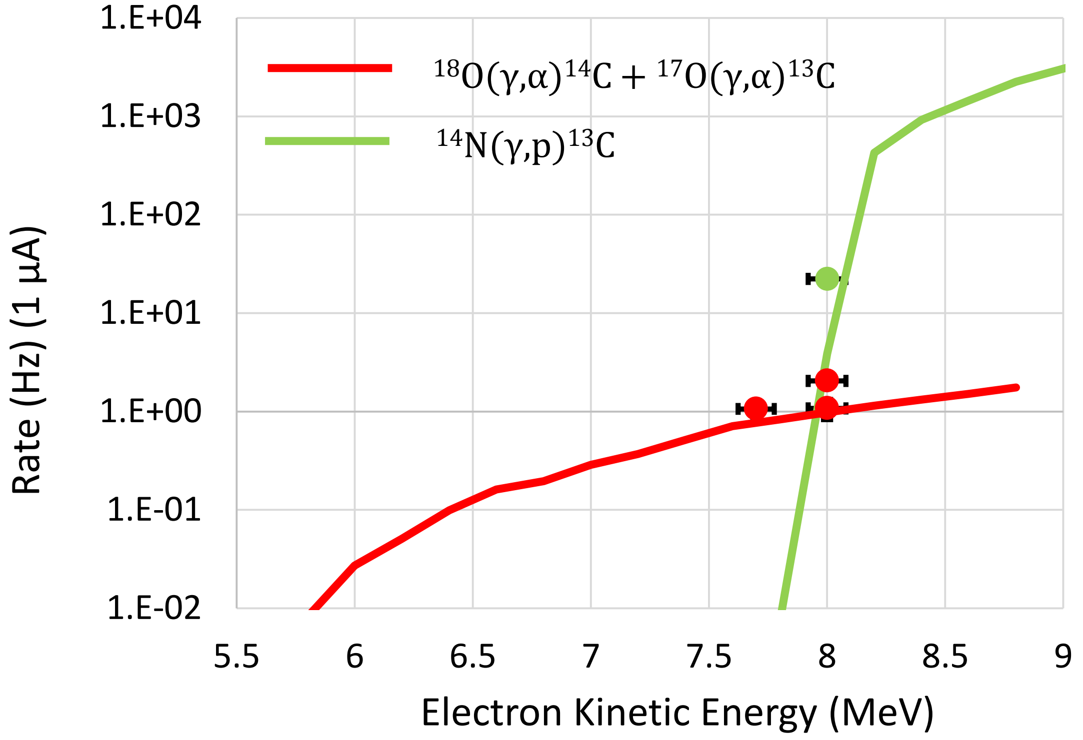


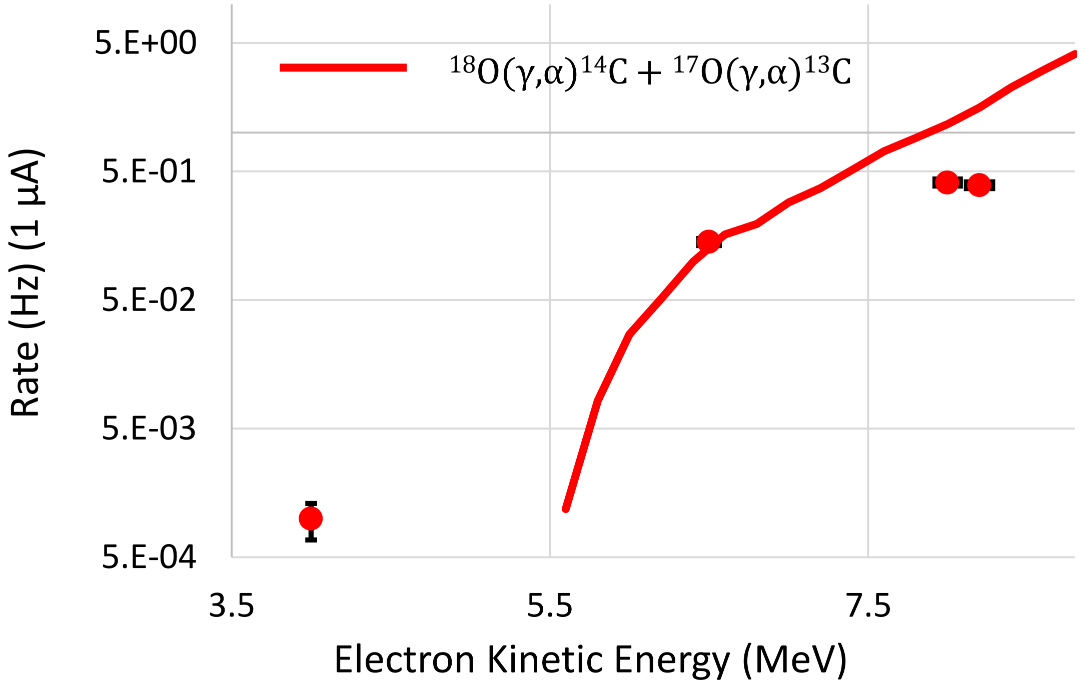


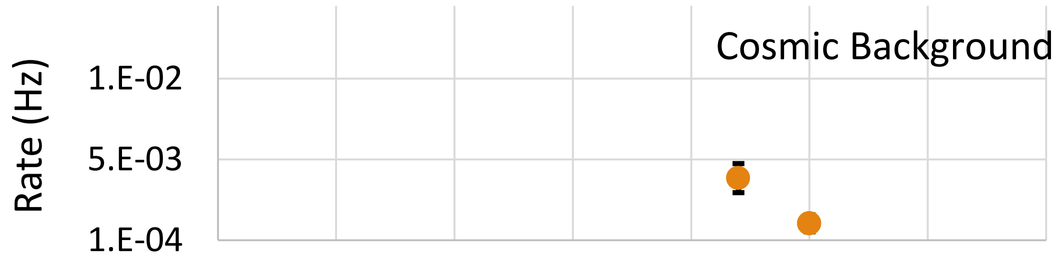
Jlab Data

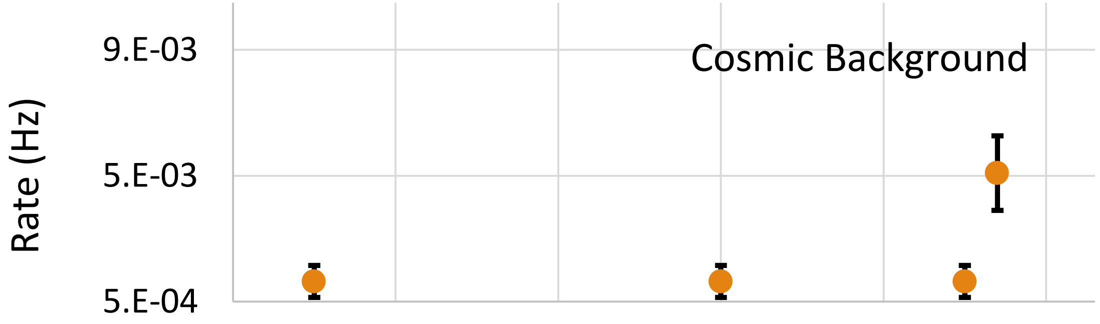


Results from the Experiment









Conclusions And Future Plans

Conclusions

- ✓ New limit of γ-ray insensitivity of the bubble chamber : 1 in 10^{12} (1 in 10^{9})
- ✓ Cosmic background rate : JLab = 1 in 17 minutes, HIγS = 1 in 2 minutes
- ✓ Rate limit of the bubble chamber is 10^{-3} counts/s at 4 MeV beam energy

If we consider a 3 cm long glass vessel filled with C_4F_{10} (1.5 g/cm^3) bombarded by 10^{11} γ/s, out of which 1% are "good" γs, we get :

$$\frac{N_R}{t} = \sigma I N_T = 10^{-1} \text{ counts/s/nb}$$

Since our rate limit is 10^{-3}, we reach this limit at a cross-section of 10 pb !

Future Plans

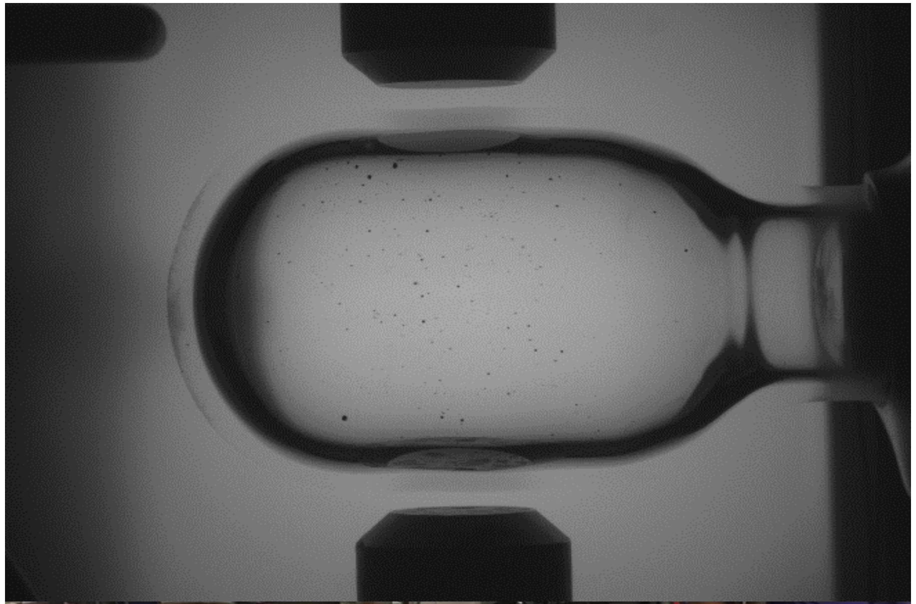
- ✓ Study $^{19}\mathrm{F}(\gamma,\alpha)^{15}\mathrm{N}$ at cross-sections below 3 nb (beam time approved at JLab from May 31 – June15, 2016)

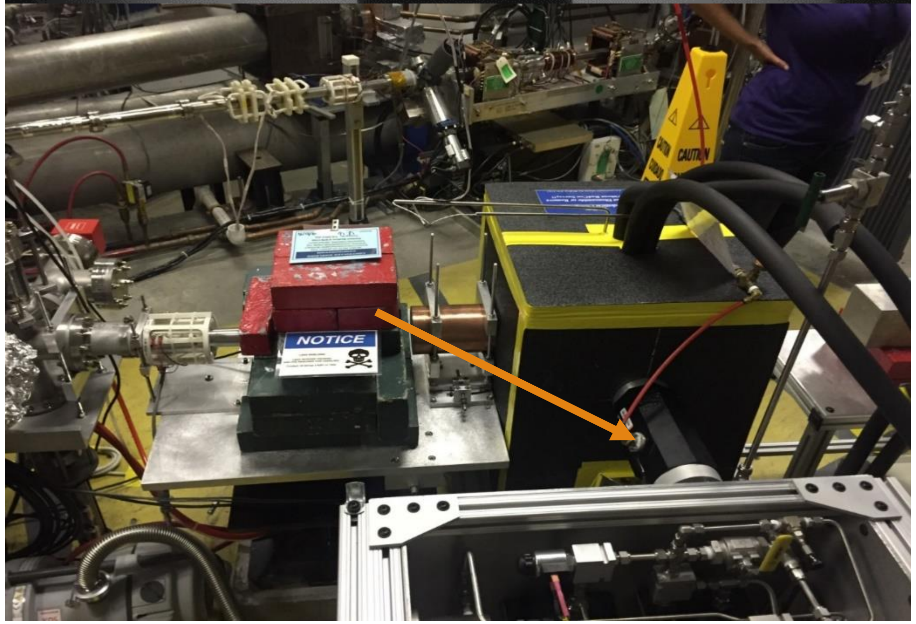
- ✓ Design a single fluid bubble chamber

- ✓ Place scanners in the beam line to get a more accurate estimate of the beam position

- ✓ Move the camera further back which will allow to put more shielding around the camera as well as lower the number of scintillations at higher beam currents

- ✓ Study of ^{16}O enrichment : $^{17,18}\mathrm{O} < 10^{-6}$





Collaboration

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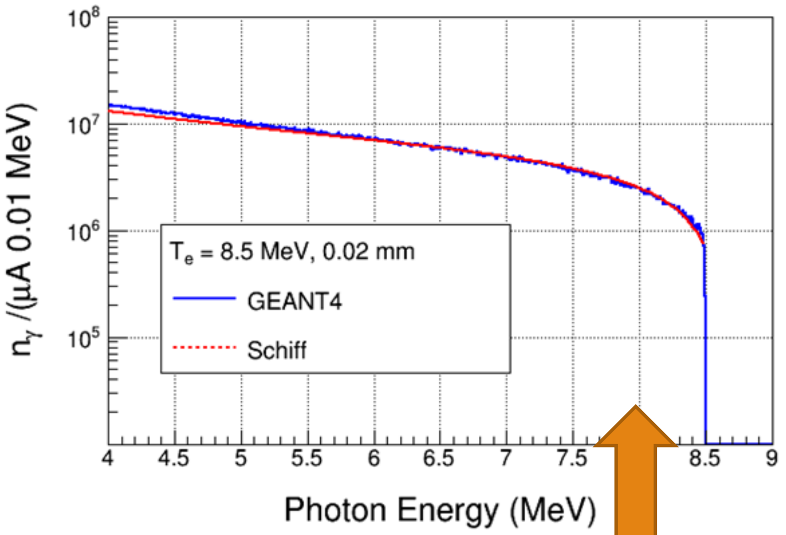
THANK YOU

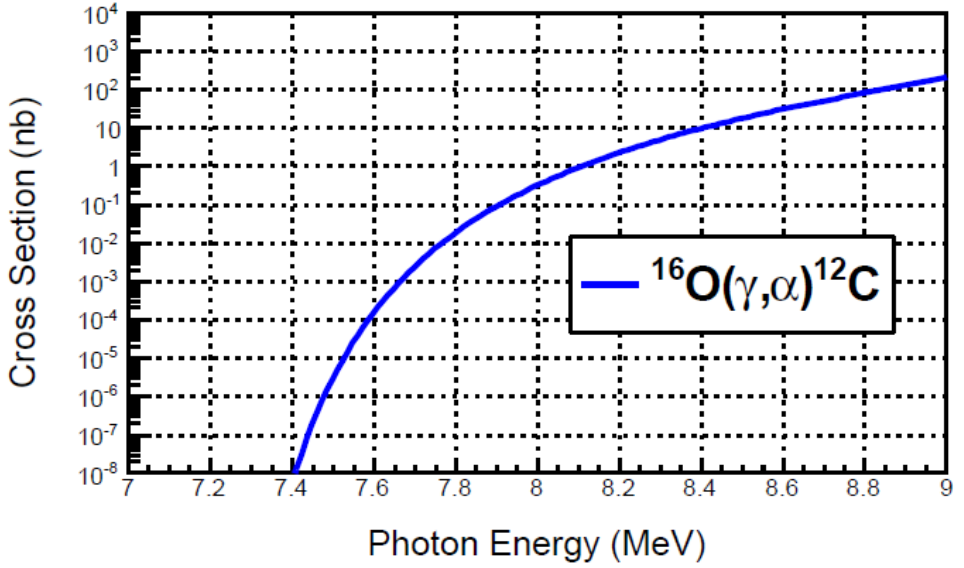
Back - Up

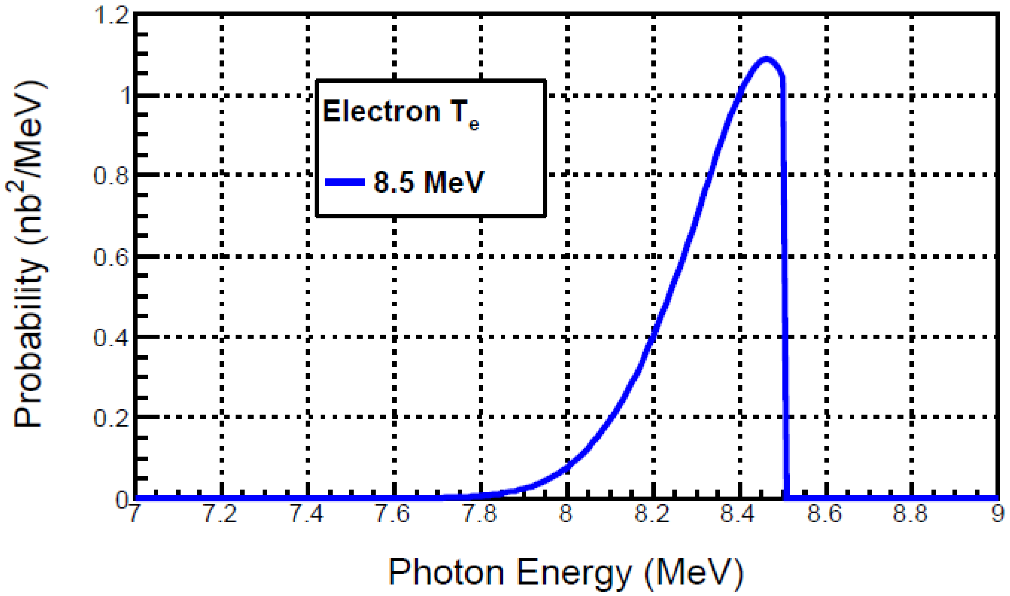
Bremsstrahlung Beam

$^{16}O(\gamma,\alpha)^{12}C$ is an ideal case for a Bremsstrahlung beam :

- Very steep cross-section, only photons near the endpoint contribute to the yield
- No structure (resonances)







Bremsstrahlung spectra calculated using GEANT4 and FLUKA

Penfold-Leiss Cross-section Unfolding

- Measure yields at electron beam kinetic energy E = E_1, E_2 …… E_n
- Yield can be expressed as the convolution of the cross-section with the Bremsstrahlung spectrum :

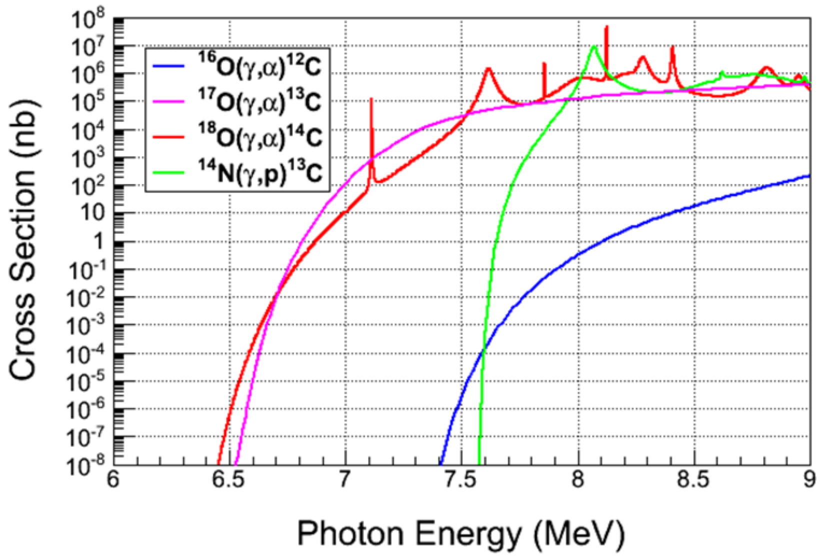
$$y(E_i) = \int_{threshold}^{Ei} N_\gamma(E_i, k)\sigma(k)dk \approx \sum_{j=1}^{i} N_\gamma(E_i, \Delta, k_j)\sigma(k_j)$$

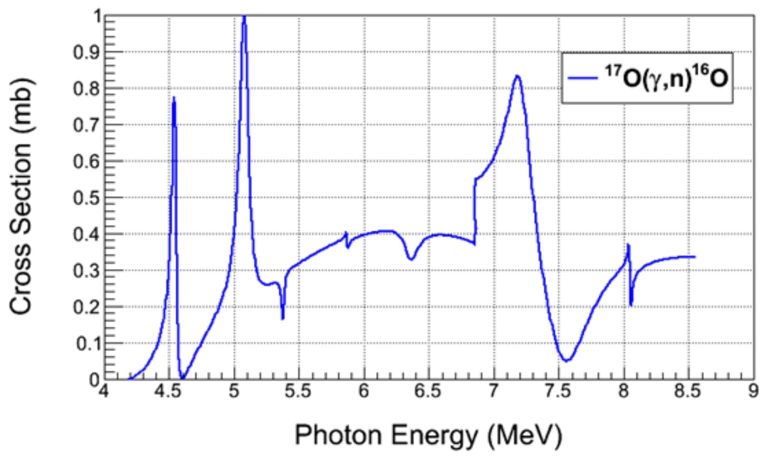
Where $N_\gamma(E_i, \Delta, k_j)$ is the number of gammas in the energy bin of width $\Delta = E_i - E_{i-1}$

- The solution to the above equation gives the cross-section and the corresponding error as follows :

$$\sigma_i = \frac{1}{N_{ii}}\left[y_i - \sum_{j=1}^{i-1}(N_{ij}\sigma_j)\right]$$

$$\left(\frac{d\sigma_i}{\sigma_i}\right)^2 = \frac{\left[(dyi)^2 + \sum_{j=1}^{i-1}(N_{ij}d\sigma_j)^2\right]}{\left[y_i - \sum_{j=1}^{i-1}(N_{ij}\sigma_j)\right]^2}$$


$^{16}O(\gamma,\alpha)^{12}C$
$^{17}O(\gamma,\alpha)^{13}C$
$^{18}O(\gamma,\alpha)^{14}C$
$^{14}N(\gamma,p)^{13}C$
Cross Section (nb)
Photon Energy (MeV)


$^{17}O(\gamma,n)^{16}O$
Cross Section (mb)
Photon Energy (MeV)

Suppression of neutron events by a factor of 100 using acoustic signals