Internal Target Experiments

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03/17/2017

Workshop on Science at JLab's LERF

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Nucleosynthesis: $\alpha + {}^{12}C \longrightarrow \gamma + {}^{16}O$

- ${}^{12}C/{}^{16}O$ ratio → affects nucleosynthesis of heavier elements and stellar evolution

  → massive stars: carbon, oxygen, neon burning

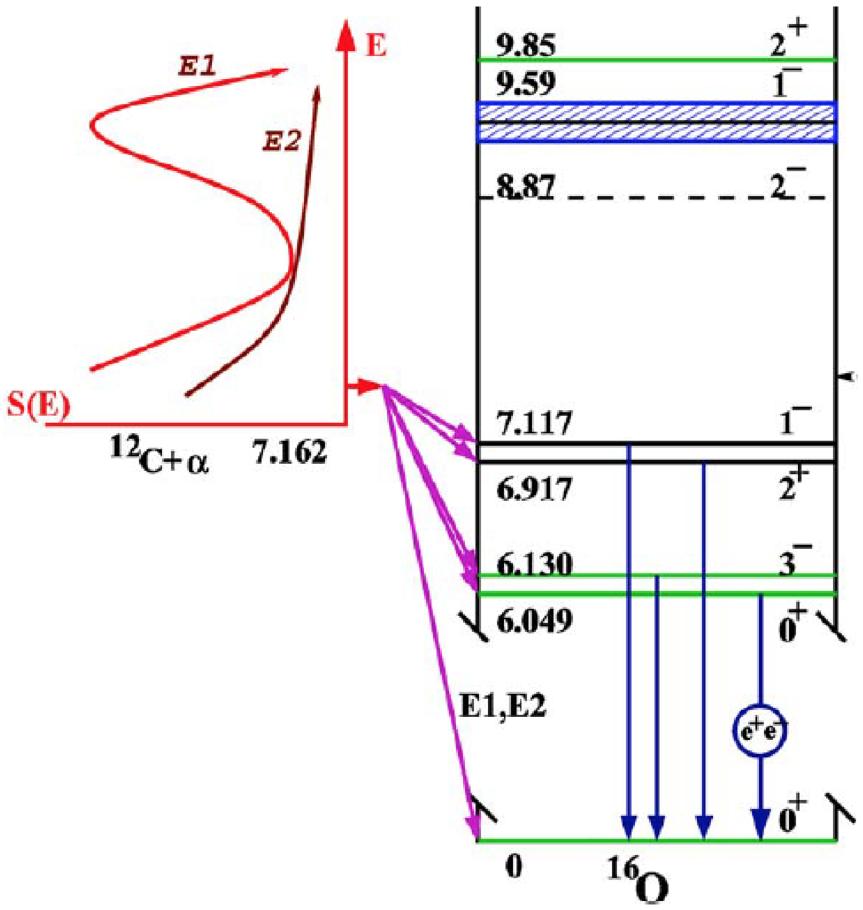
  → white dwarfs: super nova type Ia

  → end of stars: ${}^{16}O$ rich star - black hole, ${}^{12}C$ rich star – neutron star

  T. A. Weawer and S. E. Woosley, Phys. Rep. 227 (1993) 335.

- For $\alpha + {}^{12}C$ at $T \sim 2 \cdot 10^8$ K, Gamow window ~ 300 keV
- Due to Coulomb barrier $\sigma \sim 10^{-5}$ pb (direct measurement is not possible)

Nucleosynthesis: $\alpha + {}^{12}C \longrightarrow \gamma + {}^{16}O$



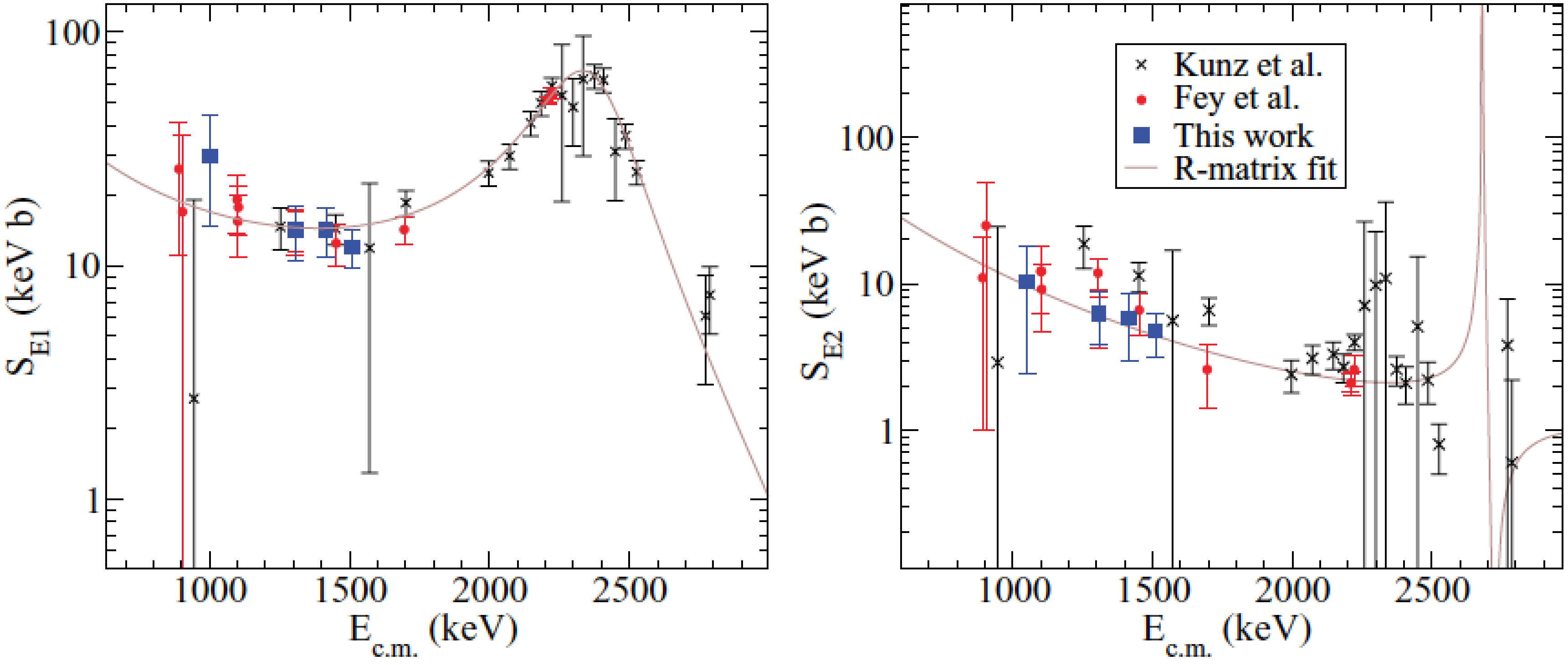
- Contribution to the cross section at Gamow window is complicated:

→ E1 component, 1^-: subthreshold state at 7.117 MeV and broad resonance at 9.59 MeV

→ E2 component, 2^+: subthreshold state at 6.917 MeV and narrow resonance at 9.85 MeV

L.R. Buchmann, C.A. Barnes, Nucl. Phys. A 777 (2006)

Nucleosynthesis: $\alpha + {}^{12}C \longrightarrow \gamma + {}^{16}O$



R. Plag et al, Phys. Rev. C 86 (2012)

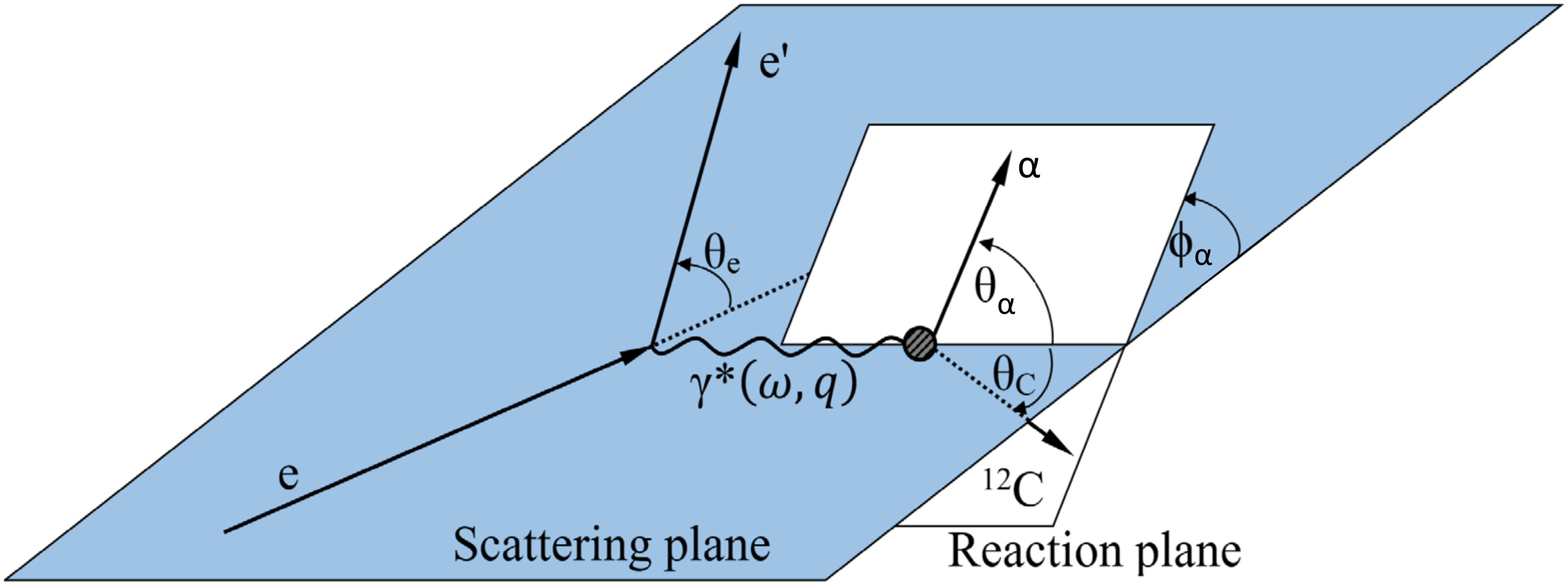
$$\sigma(E) = \frac{S(E)}{E} e^{-2\pi\eta}$$

$$\eta = \frac{2\pi Z_1 Z_2 e^2}{hv}$$

Cross section measurements

- Direct measurements by using:
  - a) α beam: detection of gammas $\rightarrow S_{E1}$ and S_{E2}
  - b) ^{12}C beam (inverse kinematic): detection of ^{16}O recoils $\rightarrow S_{tot}$
- Indirect measurements:
  - a) β decay of ^{16}N: $^{16}O^{*} \rightarrow \alpha + {}^{12}C$ (S_{E1} can be obtained)
  - b) inverse reaction, $\frac{\sigma(\gamma + {}^{16}O)}{\sigma(\alpha + {}^{12}C)} = \frac{\mu c^2 E_\alpha}{E_\gamma^2} \approx 42$ (for $E_\alpha = 1$ MeV)
    - – photo-disintegration of ^{16}O: $\gamma + {}^{16}O \rightarrow \alpha + {}^{12}C$
    - – electro-disintegration of ^{16}O: $^{16}O(e, e' \alpha)^{12}C$

Electro-disintegration of ^{16}O



Electro-disintegration of ^{16}O

- Advantage:
  - a) inverse reaction: larger cross section than direct reaction
  - b) JLab's Low Energy Recirculator Facility (LERF) e^- beam
  - c) Internal windowless gas target – Jet target
- Disadvantage: cross section has more complicated structure

$$\frac{d\sigma}{d\omega d\Omega_e d\Omega_\alpha} = \frac{M_\alpha M_{12C}}{8\pi^3 W} \frac{p_\alpha^{cm} f_{rec}^{-1}}{(\hbar c)^3} \sigma_{Mott}(v_L R_L + v_T R_T + v_{LT} R_{LT} + v_{TT} R_{TT})$$

A. S. Raskin and T. W. Donnelly, Ann. of Phys. 191 (1989)

Electro-disintegration of ^{16}O

$$R_T = P_0(cos\theta_\alpha)[|t_{E1}|^2 + |t_{E2}|^2] +$$

$$+ P_1(cos\theta_\alpha)\frac{6}{\sqrt{5}}\cos(\varphi_{E2} - \varphi_{E1})\,|t_{E1}||t_{E2}| +$$

$$+P_2(cos\theta_\alpha)\left[-|t_{E1}|^2 + \frac{5}{7}|t_{E2}|^2\right] -$$

$$- P_3(cos\theta_\alpha)\frac{6}{\sqrt{5}}\cos(\varphi_{E2} - \varphi_{E1})\,|t_{E1}||t_{E2}| -$$

$$-P_4(cos\theta_\alpha)\frac{12}{7}|t_{E2}|^2$$

- Multipole matrix elements (q_0 = 1.2 fm^{-1}):

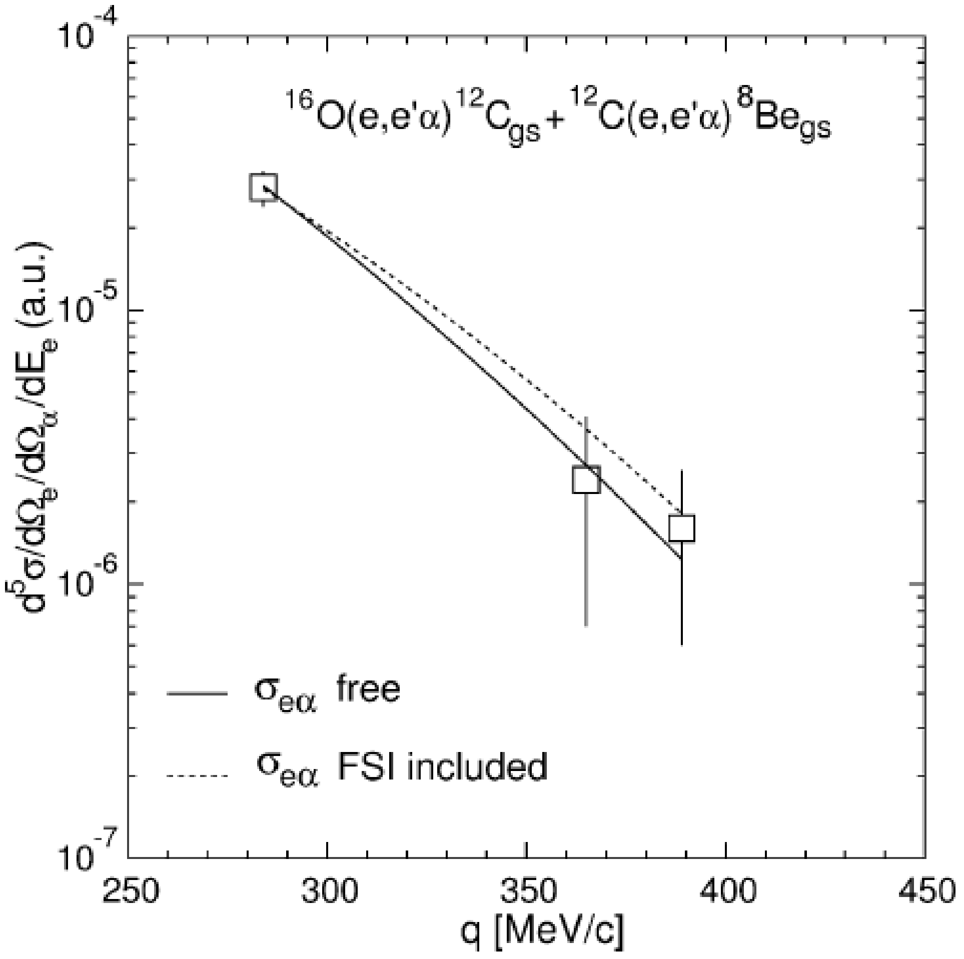
$$t_{EJ} = \frac{\omega}{q}\left(\frac{q}{q_0}\right)^J\left[a'_{EJ} + \left(\frac{q}{q_0}\right)^2 b'_{EJ}(q)\right]e^{-\left(\frac{q}{q_0}\right)^2}$$

$$t_{CJ} = \left(\frac{q}{q_0}\right)^J\left[a'_{CJ} + \left(\frac{q}{q_0}\right)^2 b'_{CJ}(q)\right]e^{-\left(\frac{q}{q_0}\right)^2}$$

- Long wavelength limit (q→0) and continuity:

$$t_{EJ} \to -\sqrt{\frac{J+1}{J}}\left(\frac{\omega}{q}\right)t_{CJ} \qquad a'_{EJ} = -\sqrt{\frac{J+1}{J}}\left(\frac{\omega}{q}\right)a'_{CJ}$$

Electro-disintegration of ^{16}O



- α-knockout experiment at NIKHEF
- 3μA e^- beam at 639 MeV and 615 MeV
- Energy of α-particles: from 20 to 35 MeV
- Target: CO_2 at 1.6 bar and 300 K
- Luminosity: $1.46 \cdot 10^{34}$ ($cm^{-2}s^{-1}$)

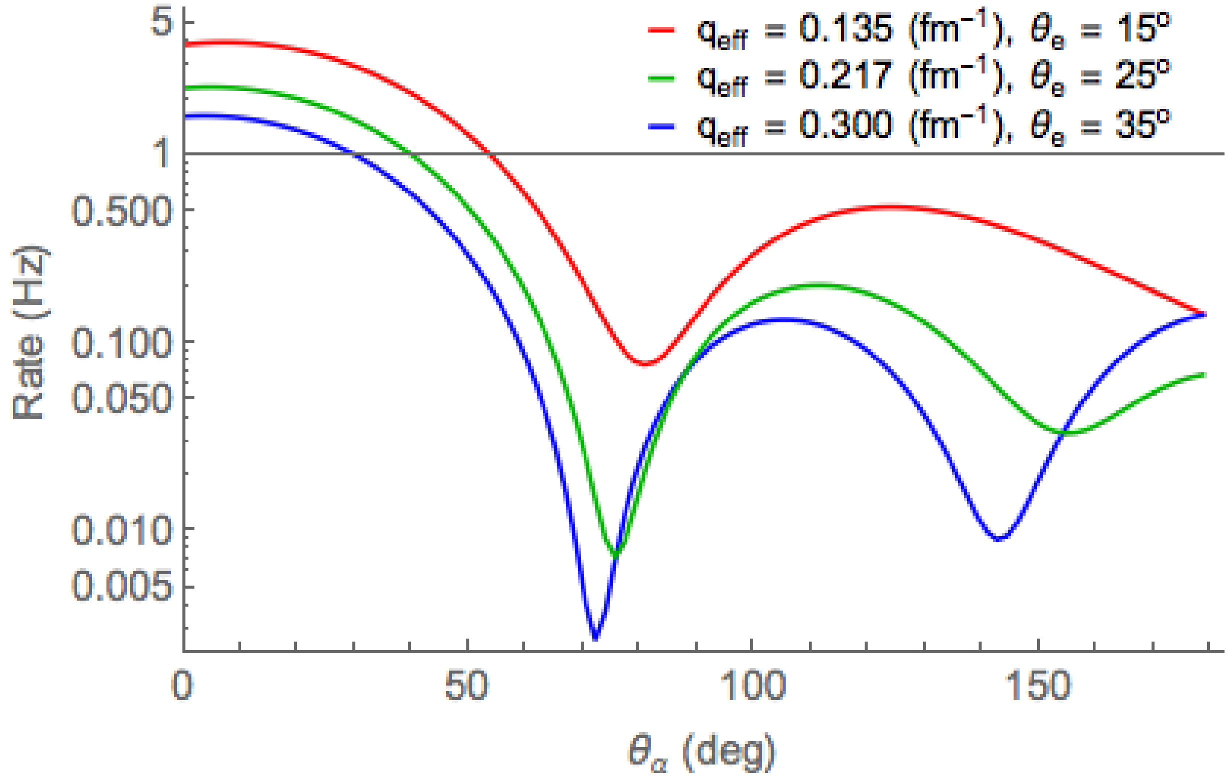
G. De Meyer et al., Phys. Lett. B 513 (2001)

Electro-disintegration of ^{16}O

- e^- 5 mA at 100 MeV at LERF
- Mainz jet target: $132 \cdot 10^{-6}$ g/cm^2

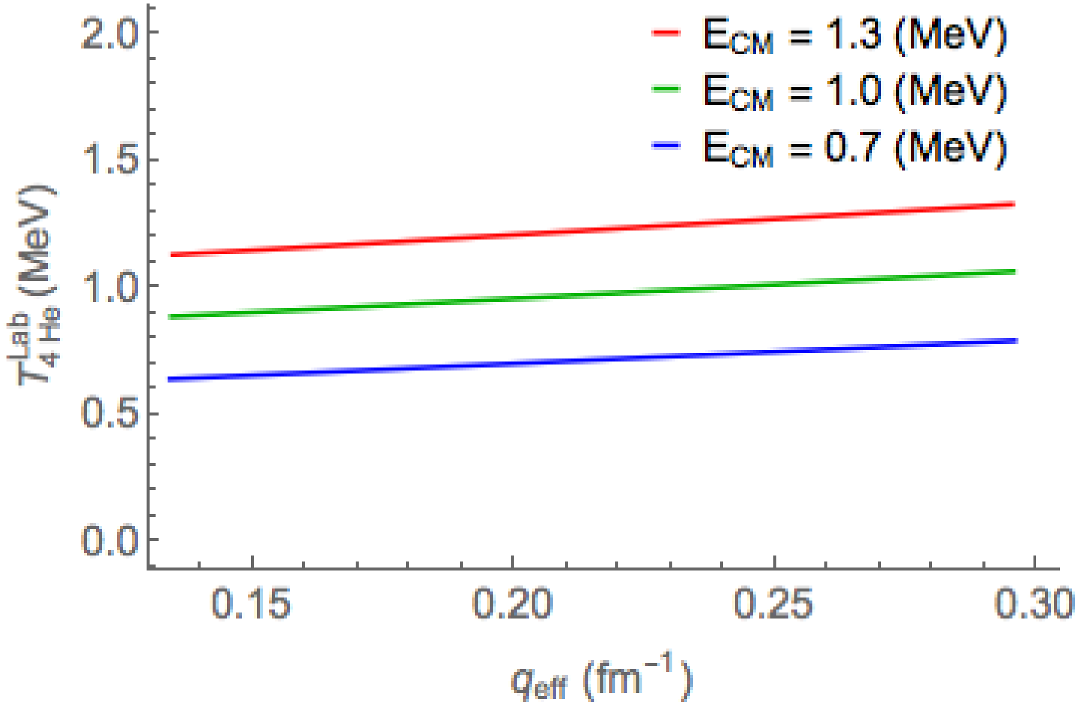
(S. Aulenbacher, DarkLight meeting June 2016)

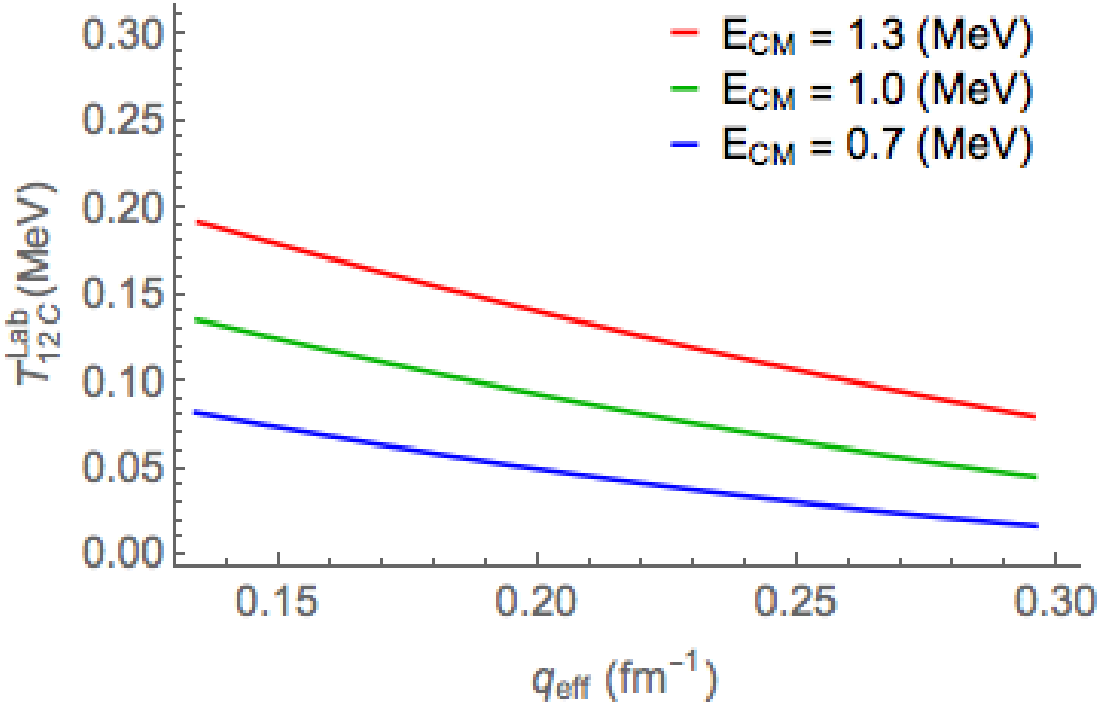
- Luminosity: $2.45 \cdot 10^{36}$ (cm^{-2}s^{-1})
- Solid angle: 5 msr for e^-, 25 msr for α
- Data from M. Assunção et al. Phys. Rev. C 73 (2006) to estimate a'_{EJ}, a'_{CJ} and $\varphi_{E2} - \varphi_{E1}$
- $E_{CM} = 0.7$ MeV



Electro-disintegration of ^{16}O

- $\theta_\alpha = 0$ deg.





Outlook

- Perform the error analysis to estimate acceptable uncertainties
- Selection of detector set-up
- Build a simulation to study the background
- Optimize the rate

Backup

Electro-disintegration of ^{16}O

- $\theta_\alpha = 0$ deg.