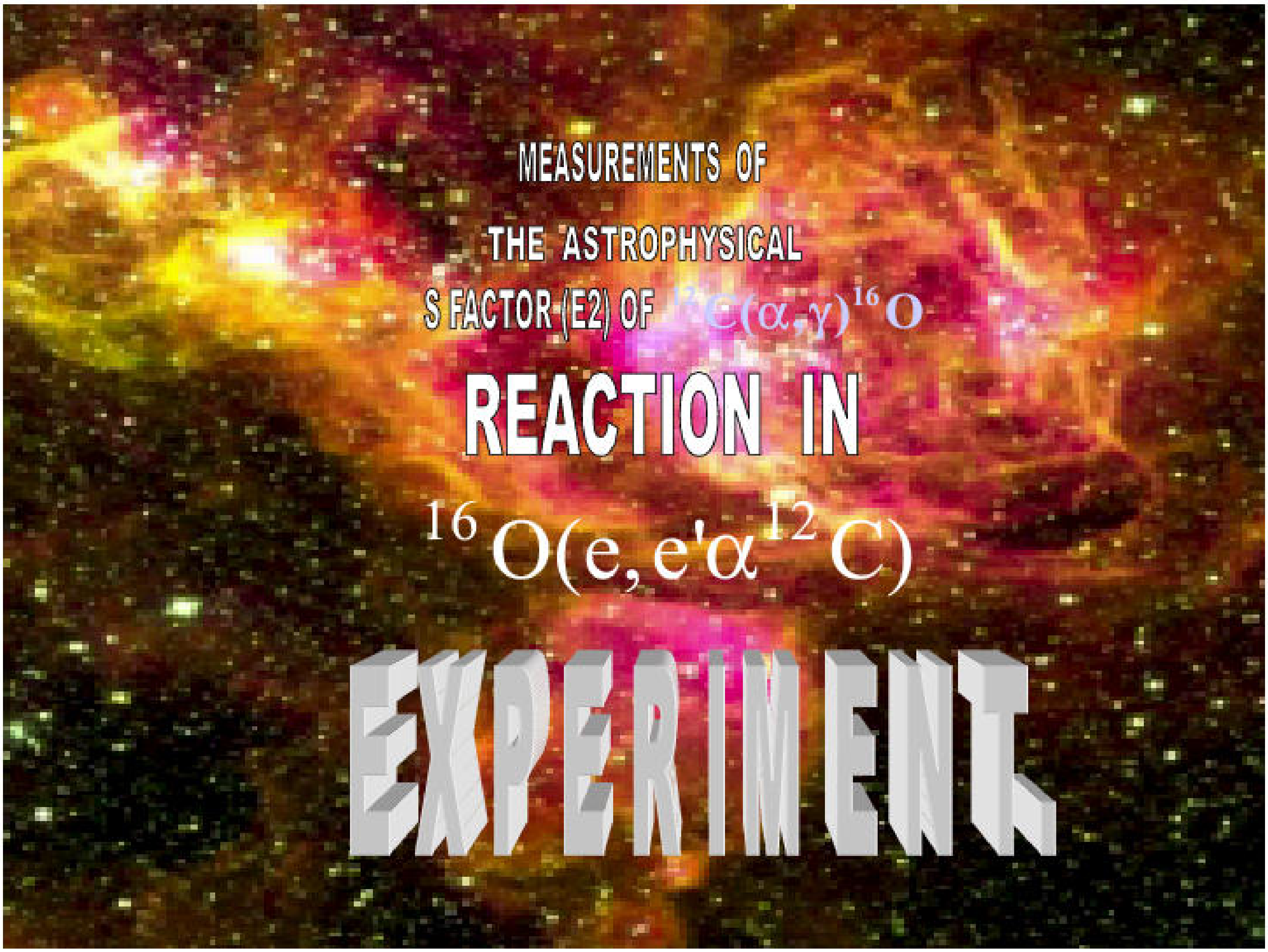
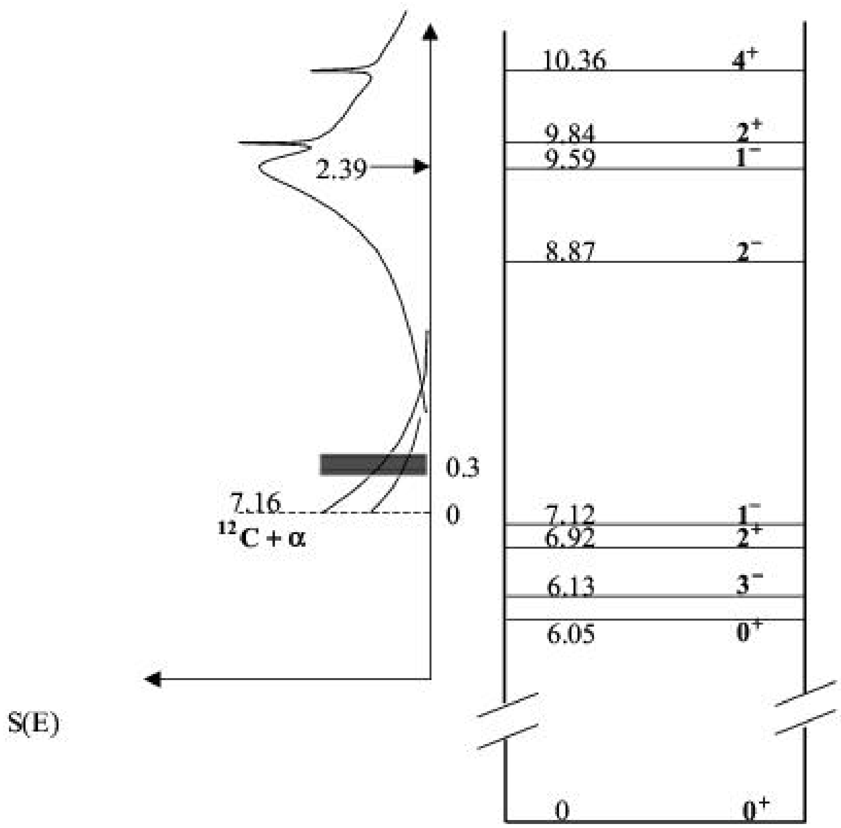
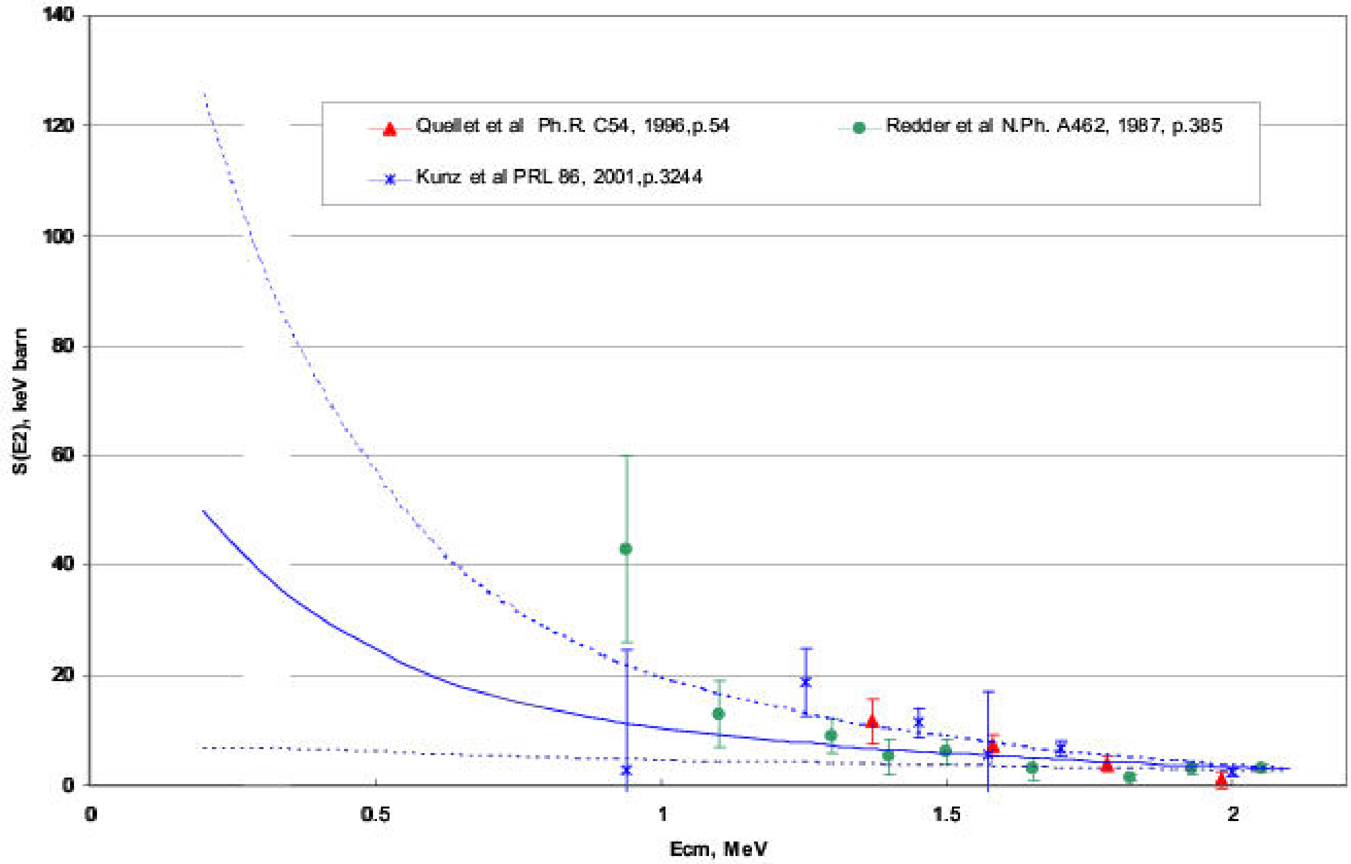

MEASUREMENTS OF
THE ASTROPHYSICAL
S FACTOR (E2) OF $^{12}C(\alpha,\gamma)^{16}O$
REACTION IN
$^{16}O(e,e'\alpha^{12}C)$
EXPERIMENT

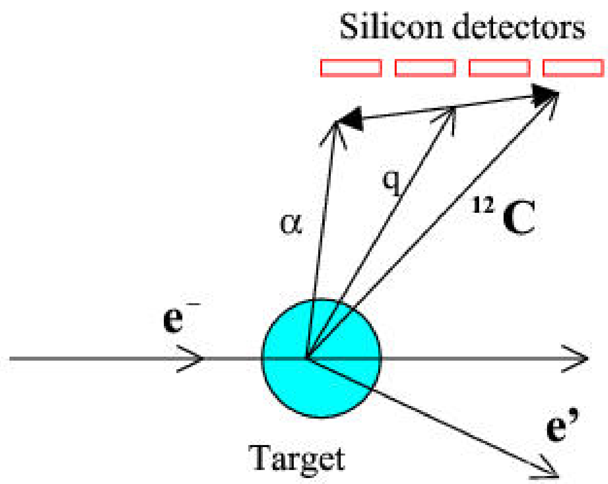
Level scheme of ^{16}**O** near and above the α threshold.





S(E2), keV barn
140
120
100
80
60
40
20
0
0
0.5
1
1.5
2
Ecm, MeV
Quellet et al Ph.R. C54, 1996,p.54
Redder et al N.Ph. A462, 1987, p.385
Kunz et al PRL 86, 2001,p.3244

^{16}O(e, e'α ^{12}C)



Advantages:

- Enhanced cross-section (phase space & formfactors q-dependence)
- High luminosity with very thin target (internal target in the electron storage ring)
- Momentum boost and concentration around q vector
- Clean identification, no major physical background
- Detector calibration and luminosity monitor via elastic scattering
- Multipole analysis via angular distributions

Problems

- High luminosity results in high detector's counting rates
- Non-zero momentum transfer

$$^{12}C(\alpha,\gamma)^{16}O$$

$$\Updownarrow$$

$$^{16}O(\gamma,\alpha)^{12}C$$

$$\Updownarrow \quad (E2)$$

$$^{16}O(e,e'\alpha)^{12}C$$

Cross-section of $^{16}O(\gamma,\alpha)\,^{12}C$ reaction via $^{12}C(\alpha,\gamma)\,^{16}O$.

$$\sigma_{\gamma,\alpha} = \mathbf{R} * \sigma_{\alpha,\gamma}$$

$$\mathbf{R} = \frac{\mathbf{g}_{\alpha} \cdot \mathbf{g}_{\mathbf{C12}}}{\mathbf{g}_{\gamma} \cdot \mathbf{g}_{\mathbf{O16}}} \cdot \frac{(\mathbf{k}_{\alpha+\mathbf{C12}})^2}{(\mathbf{k}_{\gamma+\mathbf{O16}})^2},$$

$E_{c.m}$, MeV	0.6	1.0	1.6
ω, MeV	7.762	8.162	8.762
R	49.5	74.6	104
$\sigma_{\alpha,\gamma}$(E2), cm^2	$9.47\cdot10^{-38}$	$1.15\cdot10^{-35}$	$2.70\cdot10^{-34}$
$\sigma_{\gamma,\alpha}$ (E2), cm^2	$4.69\cdot10^{-36}$	$8.60\cdot10^{-34}$	$2.80\cdot10^{-32}$

$$\frac{d\sigma}{d\omega d\Omega_e d\Omega_x} = \sigma_{Mott} * \{v_L R_L + v_T R_T + v_{TL} R_{TL} + v_{TT} R_{TT}\}$$

$$v_L = \rho^2, \qquad v_T = \frac{1}{2}\rho + \tan^2 \theta_e/2,$$

$$\rho = 1 - (\omega/q)^2,$$

$$v_{TL} = -\frac{1}{\sqrt{2}}\rho\sqrt{\rho + \tan^2 \theta_e/2}, \qquad V_{TT} = -\frac{1}{2}\rho,$$

$$E_i \approx \frac{\omega}{q} C_i$$

$$R_L = |C_0|^2 + 3|C_1|^2 \cos^2\theta_x + \frac{5}{16}|C_2|^2(1 + 3\cos 2\theta_x)^2 + \ldots(C_0C_{1,}\ldots)$$

$$R_T = \frac{3}{2}|E_1|^2 \sin^2\theta_x + \frac{15}{8}|E_2|^2 \sin^2 2\theta_x + \ldots(E_1E_2)$$

$$R_{TT} = -R_T \cos 2\varphi_x$$

$$\begin{aligned} R_{TL} = \cos\varphi_x \{ & -2\sqrt{3}|C_0||E_1|\cos\delta_1 \sin\theta_x - \sqrt{15}|C_0||E_2|\cos\delta_2 \sin 2\theta_x \\ & - 3|C_1||E_1|\cos\delta_3 \sin 2\theta_x - 3\sqrt{5}|C_1||E_2|\cos\delta_4 \cos\theta_x \sin 2\theta_x \\ & + \frac{\sqrt{15}}{4}|C_2||E_1|\cos\delta_5(\sin\theta_x - 3\sin 3\theta_x) \\ & - \frac{5\sqrt{3}}{4}|C_2||E_2|\cos\delta_6(\sin 2\theta_x + \frac{3}{2}\sin 4\theta_x)\} \end{aligned}$$

$$C_J = \left(q/q_0\right)^J * \left[a_{CJ} + \left(q/q_0\right)^2 b_{CJ}(q)\right] * \exp\left(-\left(q/q_0\right)^2\right)$$

$$E_J = \left(\omega/q\right)\left(q/q_0\right)^J * \left[a_{EJ} + \left(q/q_0\right)^2 b_{EJ}(q)\right] * \exp\left(-\left(q/q_0\right)^2\right)$$

$$q_0 \cong 1.2f^{-1}$$

$$\text{at } q \to 0$$

$$E_J \to -\sqrt{\frac{J+1}{J}} * \left(\frac{\omega}{q}\right) * C_J \Rightarrow \quad a_{EJ} = -\sqrt{\frac{J+1}{J}} * a_{CJ}$$

But! For *pure* isoscalar transitions

$$a_{C1} \equiv a_{E1} \equiv 0$$

And only isospin mixing makes these coefficients nonzero.

$$a_{C1} \approx a_{E1} \approx \left(q/q_0\right)^2 b_{C1} \approx \left(q/q_0\right)^2 b_{E1} << 1$$

$$\left[\frac{d\sigma}{d\omega d\Omega_e d\Omega_\alpha^{c.m.}}\right]_{(e,e'\alpha)} = \frac{M_T}{8\pi^3}\frac{p_\alpha^{c.m.}}{(\hbar c)^3}\sigma_M\left(1-\frac{\omega^2}{q^2}\right)^2 * R_L$$

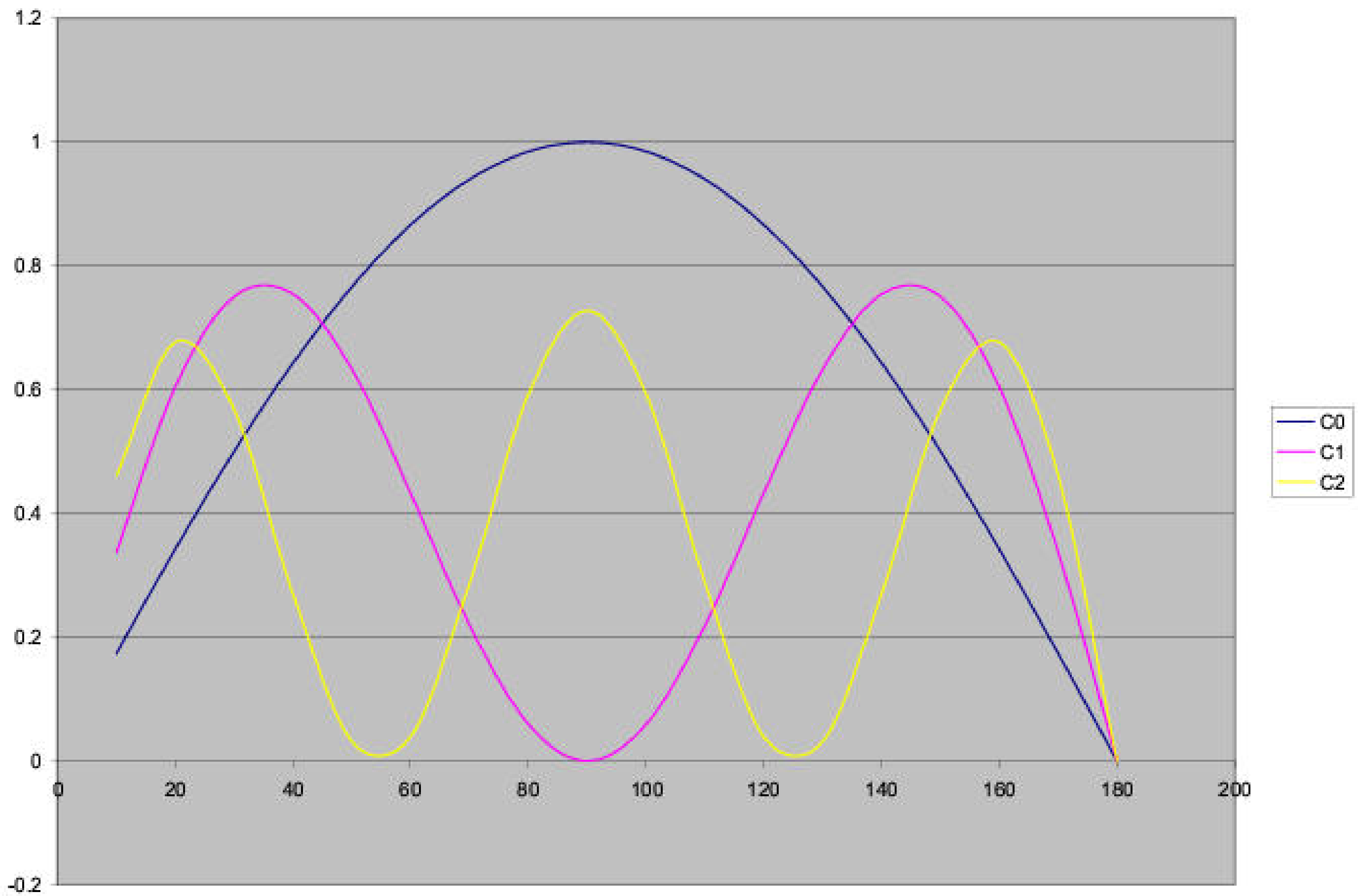
$$R_L = |C_0|^2 + 3|C_1|^2\cos^2(\theta_\alpha) +$$

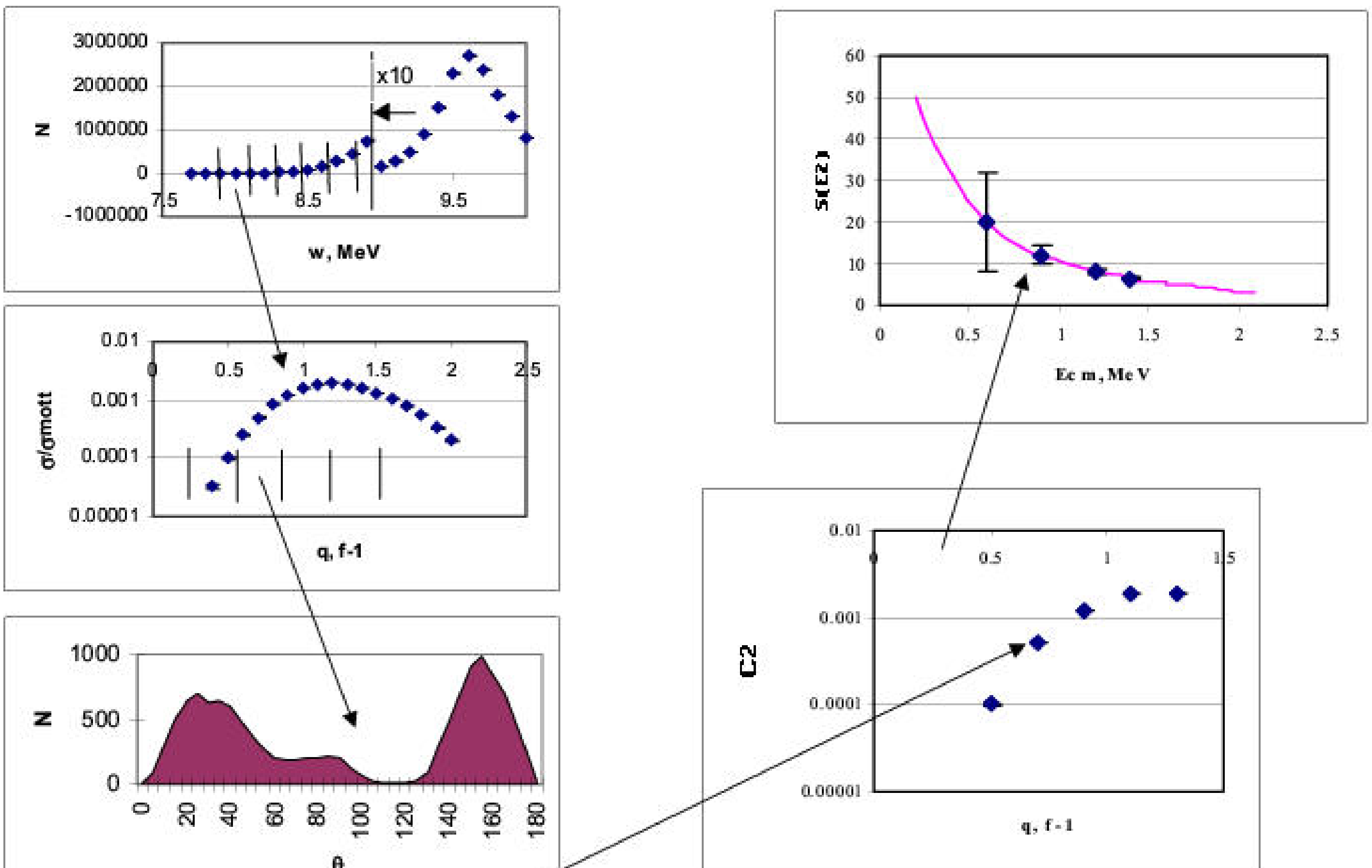
$$+\frac{5}{16}|C_2|^2[1+3\cos(2\theta_\alpha)]^2 +$$

$$+2\sqrt{3}|C_0||C_1|\cos(\delta_1)\cos(\theta_\alpha) +$$

$$+\frac{\sqrt{5}}{2}|C_0||C_2|\cos(\delta_2)[1+3\cos(2\theta_\alpha)] +$$

$$+\frac{\sqrt{15}}{4}|C_1||C_2|\cos(\delta_1-\delta_2)[5\cos(\theta_\alpha)+3\cos(3\theta_\alpha)]$$


1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
20
40
60
80
100
120
140
160
180
200
C0
C1
C2

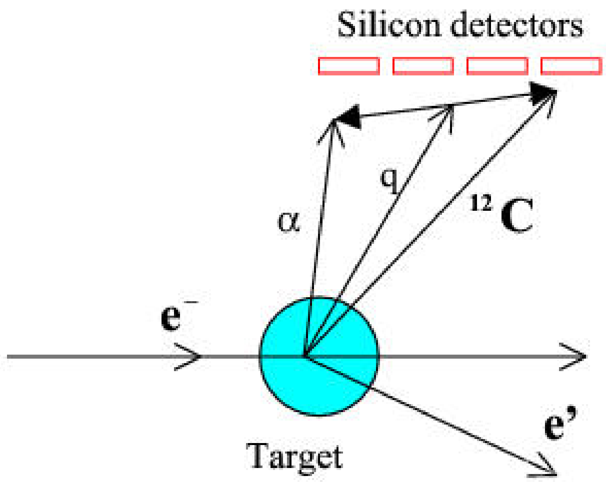


Multipole analysis produces C0, C1, ***C2*** .

$$C2=(q/q_0)^2*\exp(-q/q_0)*(a_{C2}+(q/q_0)^2*b_{C2}+\ldots)$$

$$\text{at}\quad q\to\omega\quad E2=-\sqrt{3/2}*C2$$

$^{16}O(e,e'\alpha\ \ ^{12}C)$

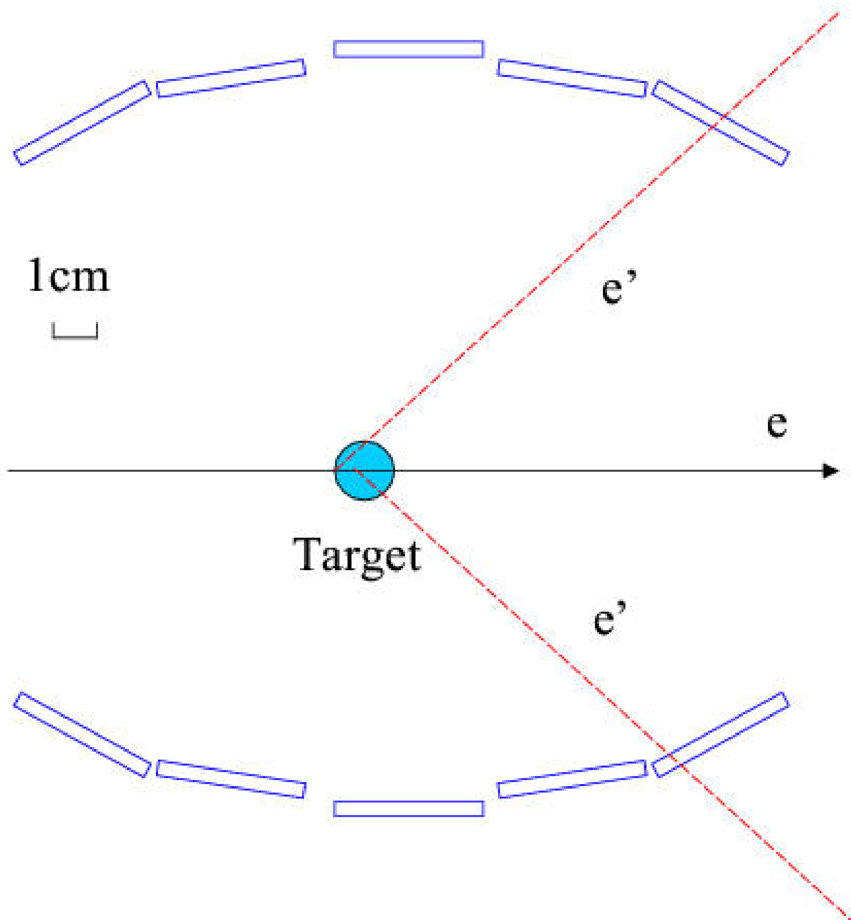


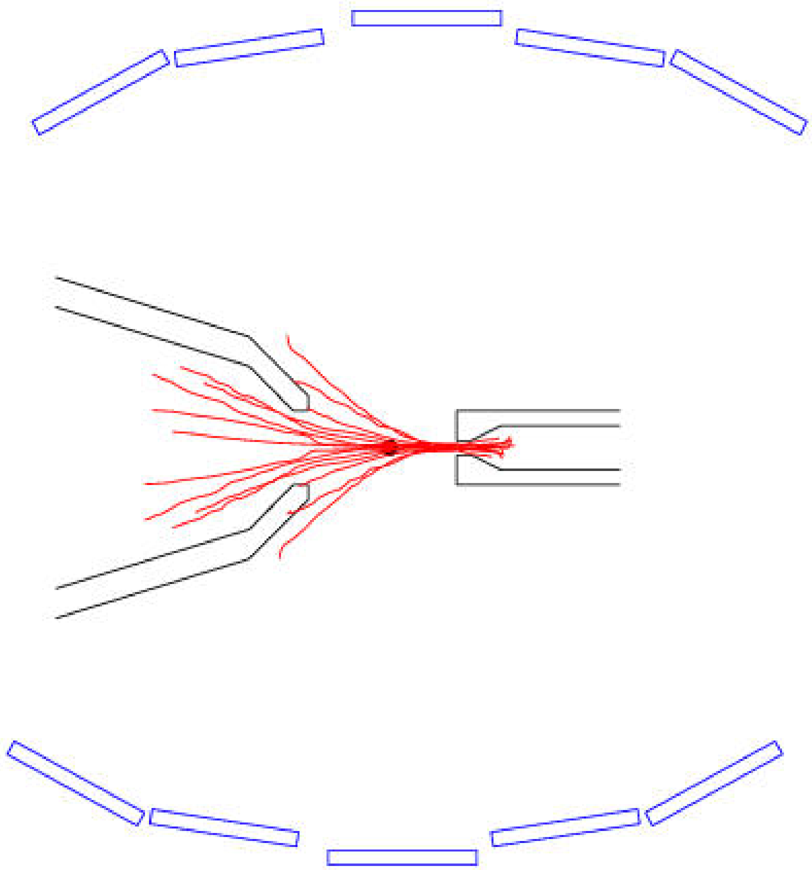
Electron beam: $E_0 = 400$ **MeV,** $I = 100$ **mA.**

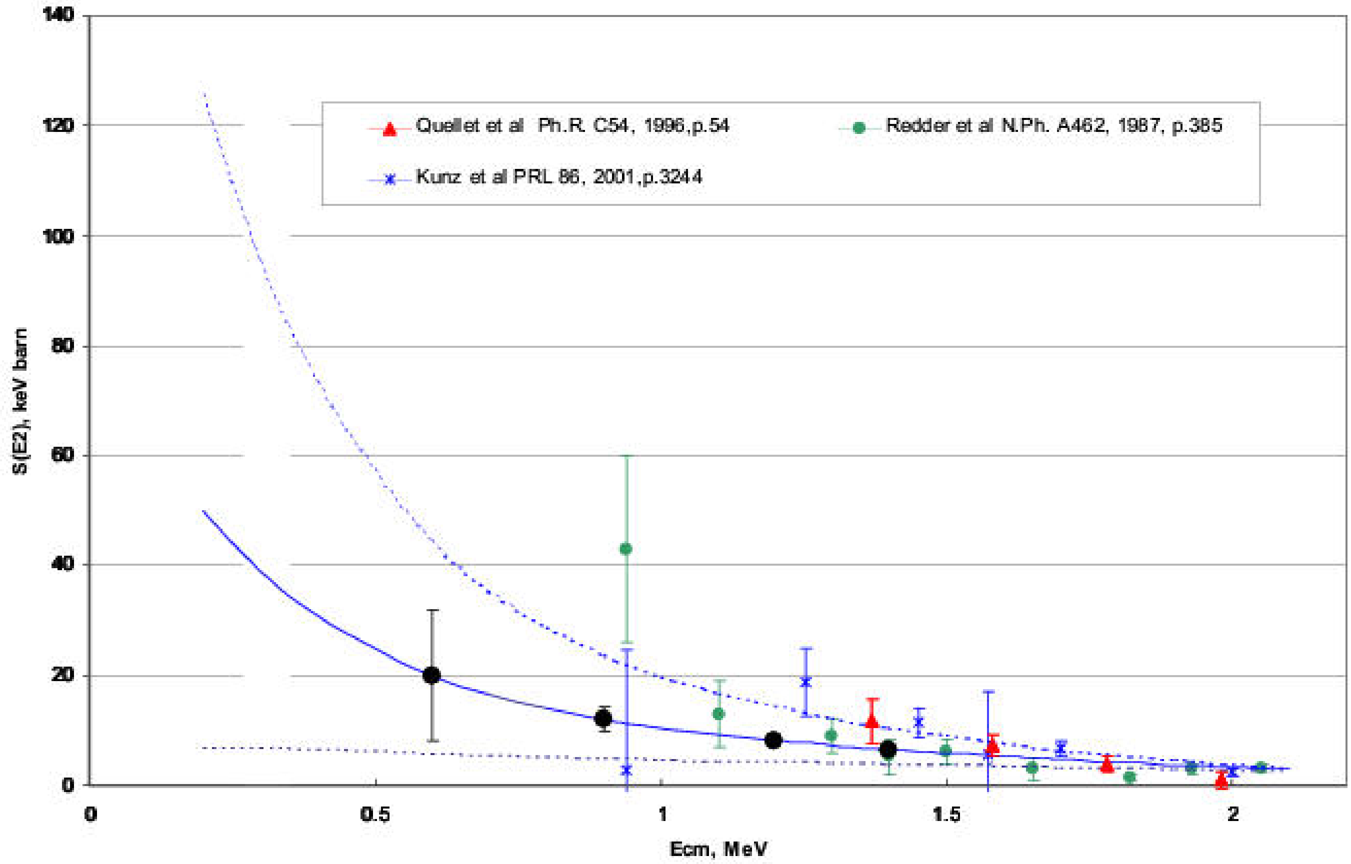
Target: H_2O, $2\cdot10^{15}$ at/cm$^2 \approx 0.06\ \mu g/cm^2$.

Luminosity $L = 10^{33}\ cm^{-2}\ sec^{-1}$.

$\theta_e = 15° - 40° \Rightarrow q \approx 1\ f^{-1}$.


1cm
e'
e
Target
e'





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