Electron Scattering on the Hoyle State and Carbon Production in Stars*

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Motivation: Nuclear Structure

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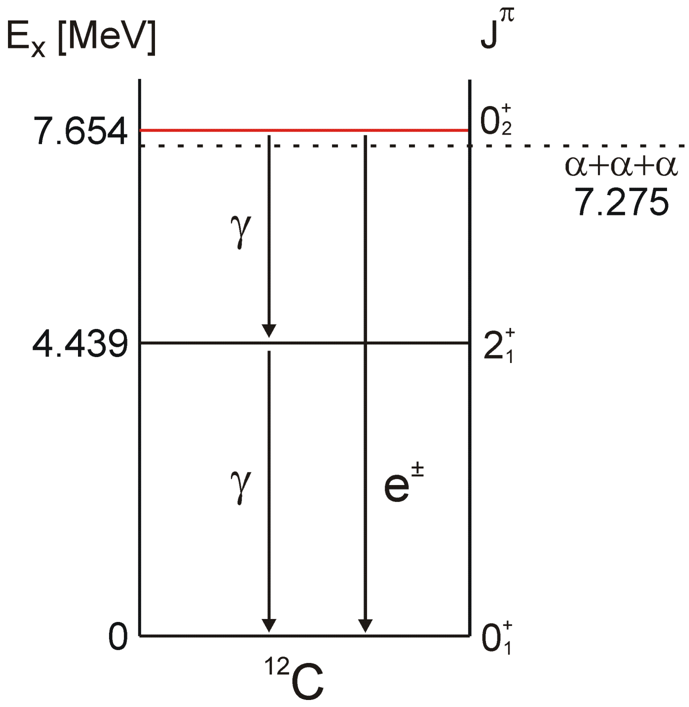
- The Hoyle state is a prototype of α-cluster states in light nuclei
- Some α-cluster models predict the Hoyle state to consist of a dilute gas of weakly interacting α particles with properties of a Bose-Einstein Condensate (BEC)



- Comparison of high-precision electron scattering data with predictions of FMD and α-cluster models

→ Hoyle state cannot be understood as a true BEC

M. Chernykh et al., PRL 98 (2007) 032501

Motivation: Astrophysics

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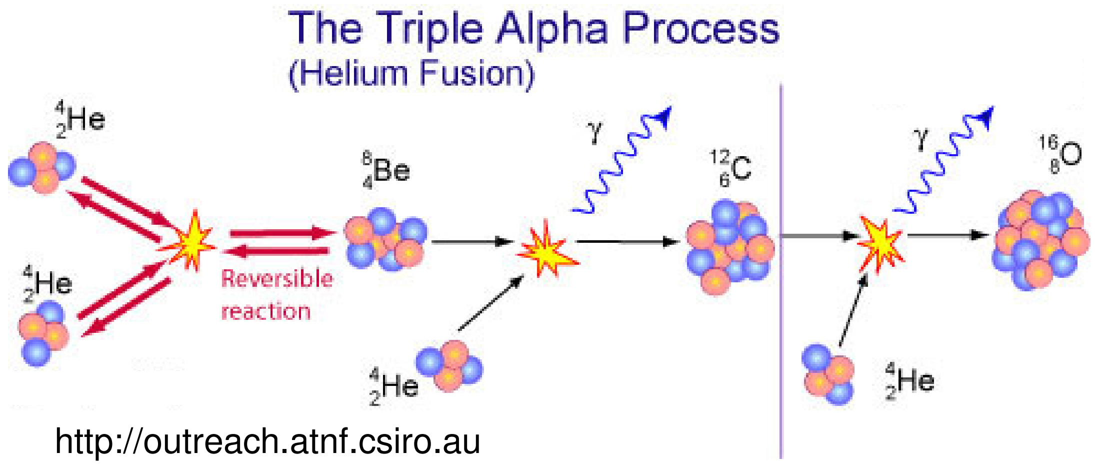
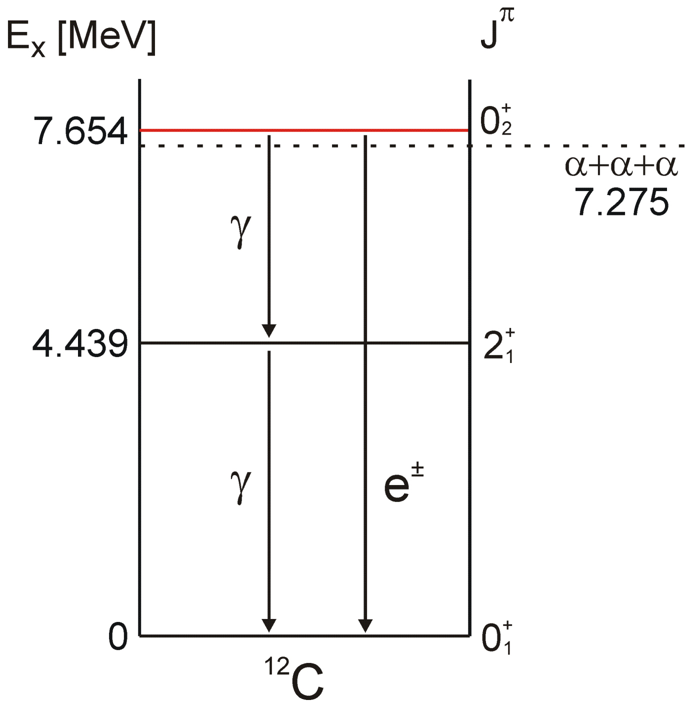


http://outreach.atnf.csiro.au



- Triple alpha reaction rate

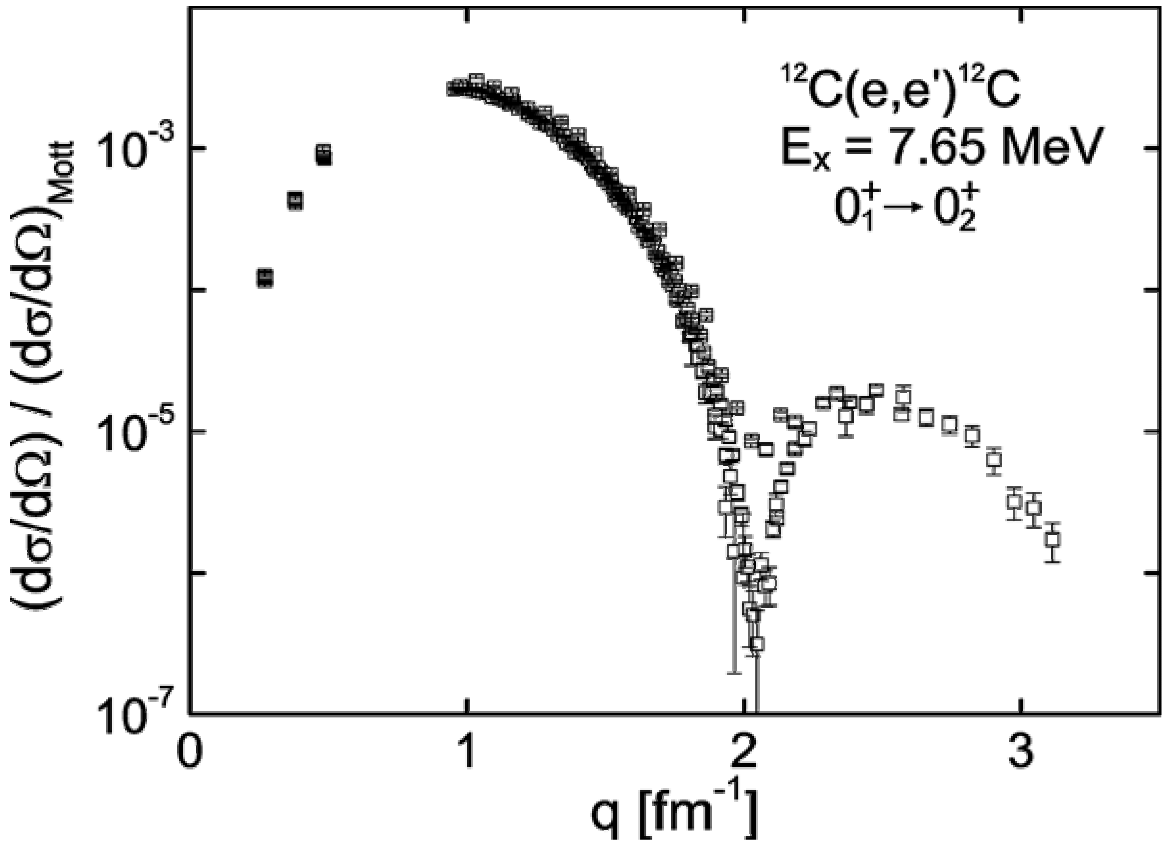
$$r_{3\alpha} \propto \Gamma_{rad} \exp\left(-\frac{Q_{3\alpha}}{kT}\right)$$

$$\Gamma_{rad} = \Gamma_\gamma + \Gamma_\pi = \frac{\Gamma_\gamma + \Gamma_\pi}{\Gamma} \cdot \frac{\Gamma}{\Gamma_\pi} \cdot \Gamma_\pi$$

- Reaction rate with accuracy $\pm 6\%$ needed
- Total uncertainty $\Delta r_{3\alpha}/r_{3\alpha} = \pm 12\%$ presently

S.M. Austin, NPA 758 (2005) 375c

Transition Form Factor to the Hoyle State



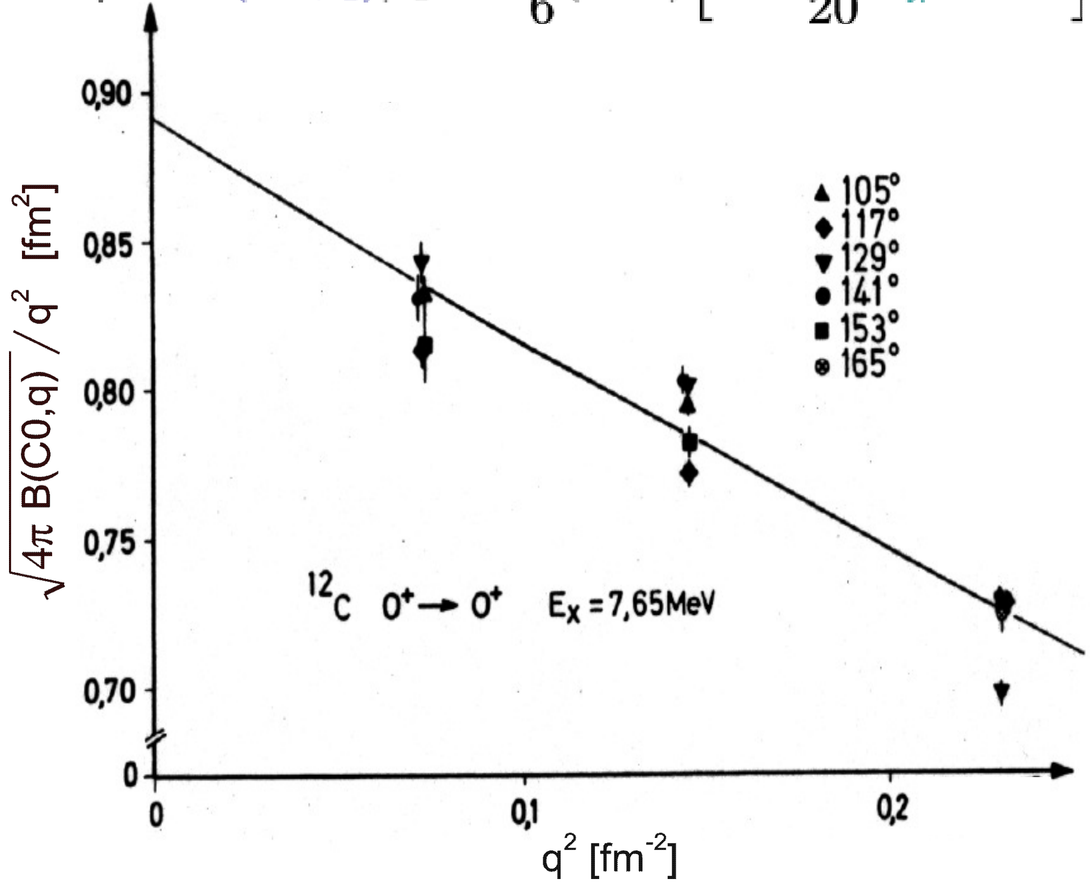
- Extrapolation to zero momentum transfer
- Fourier-Bessel analysis

} Low-q data needed !

H. Crannell, data compilation (2005)

Low-q Extrapolation

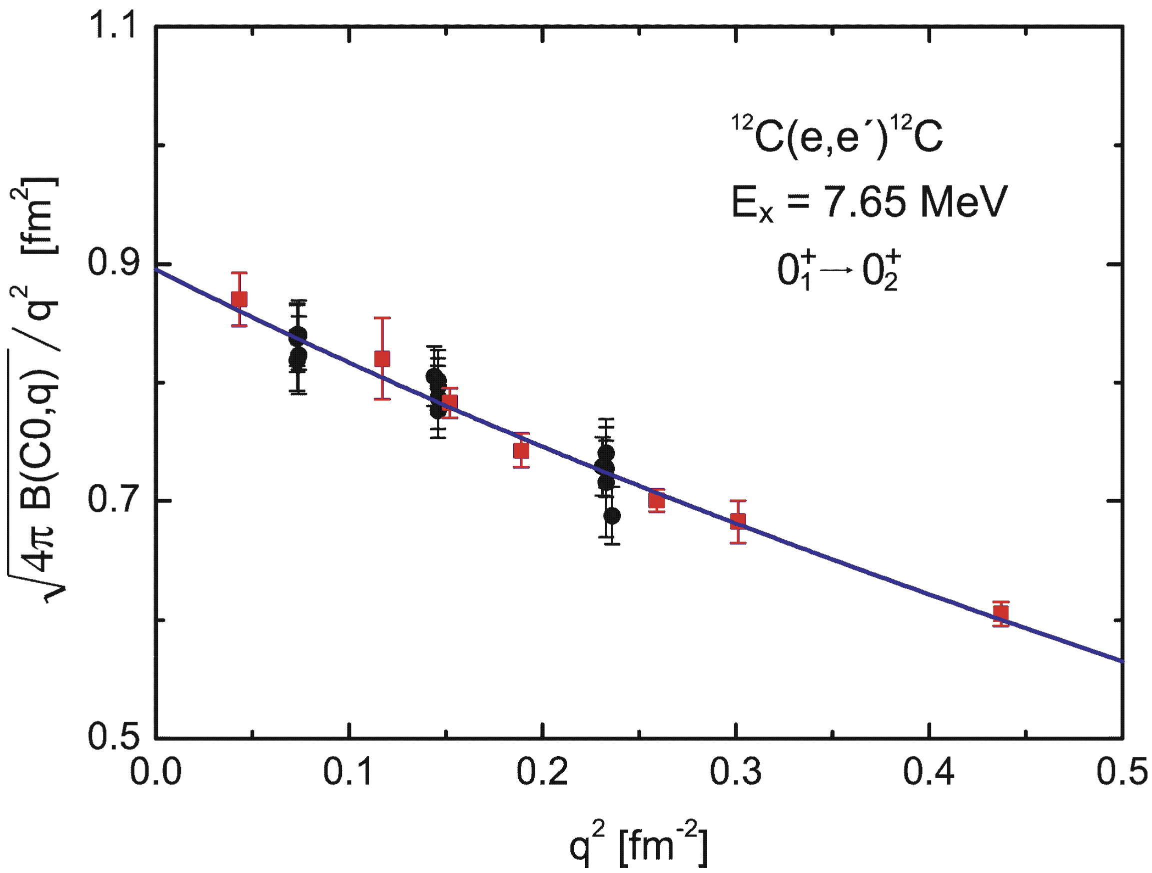
$$\sqrt{4\pi B(C0,q)}/q^2 = \frac{1}{6}(ME)\left[1 - \frac{q^2}{20}R_{tr}^2 + \dots\right]$$



- ME = 5.37(22) fm^2, R_{tr} = 4.24(30) fm
- Large uncertainty because of narrow momentum transfer region

P. Strehl, Z. Phys. 234 (1970) 416

Low-q Extrapolation



- $ME = 5.37(7)\ \mathrm{fm}^2$, $R_{tr} = 4.30(12)\ \mathrm{fm}$

Fourier-Bessel Analysis

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- Transition form factor is the Fourier-Bessel transform of the transition charge density

$$F(q) = 4\pi \int_0^\infty \rho_{tr}(r)\, j_0(qr)\, r^2\, dr$$

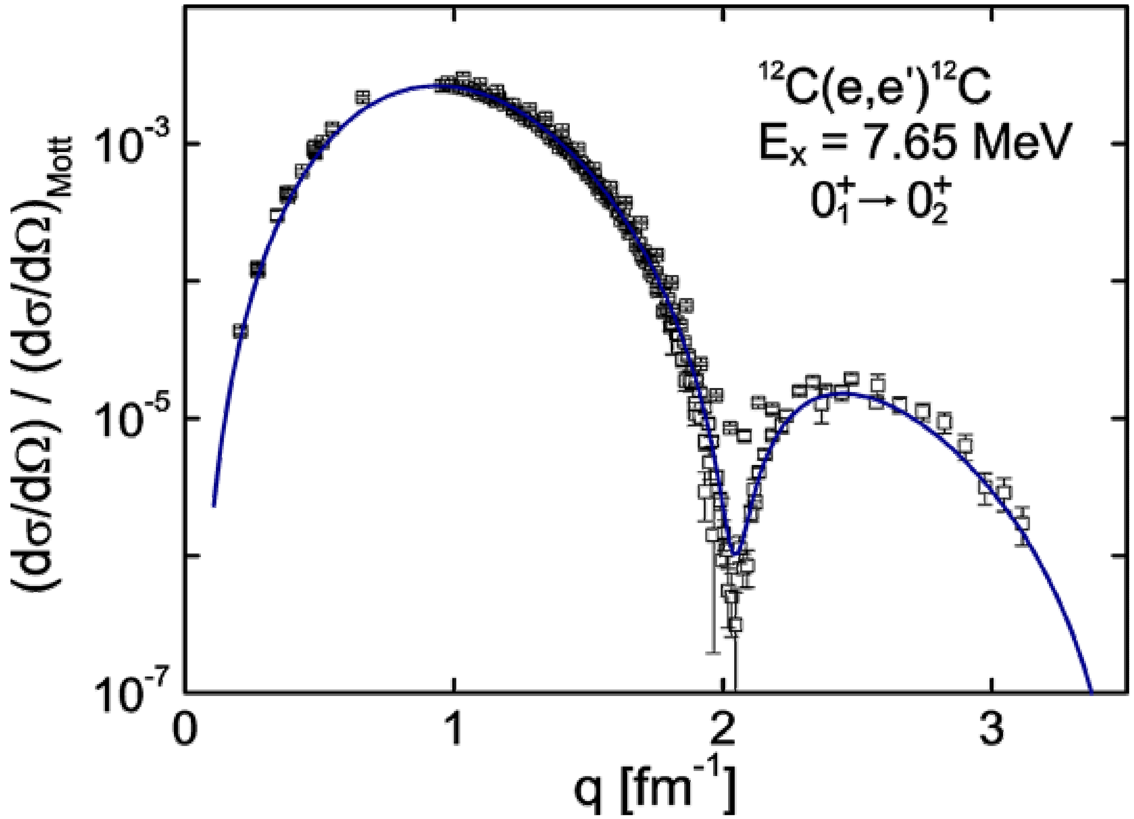
$$\rho_{tr}(r) = \begin{cases} \sum_{\mu=1}^{\infty} a_\mu\, j_0(q_\mu r) & \text{for} \quad r < R_c \\ 0 & \text{for} \quad r \geq R_c \end{cases}$$

with

$$q_\mu = \frac{\mu\pi}{R_c}$$

- Data should be measured over a broad momentum transfer range

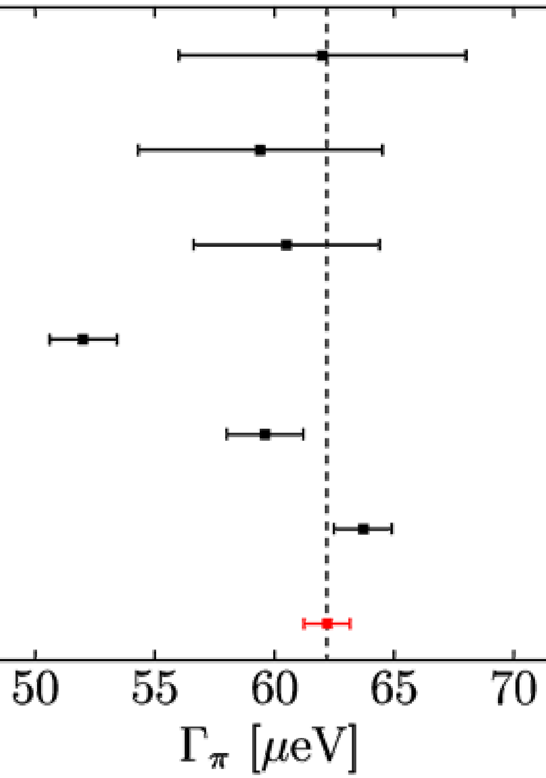
Fourier-Bessel Analysis



- q = 0.2 – 3.1 fm^{-1}
- *ME* = 5.55(5) fm^2

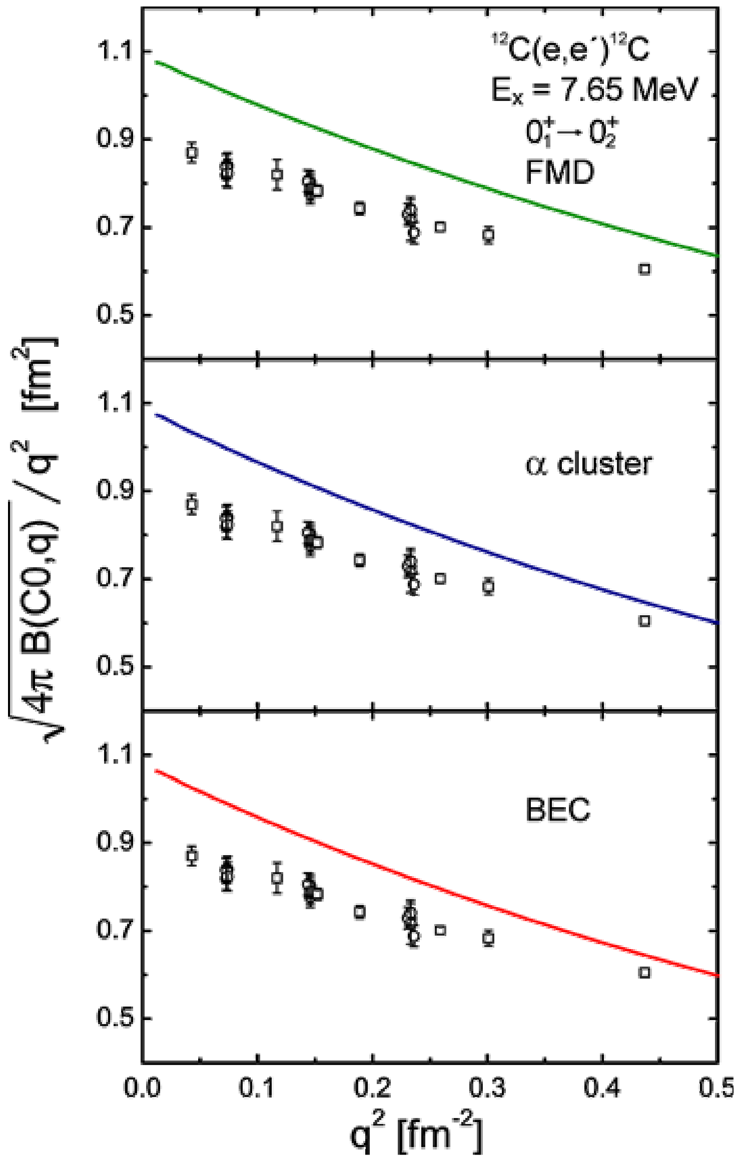
Results

Year	Analysis	Pair width	Ref.
1967	PWBA		Crannell *et al.*
1970	PWBA		Strehl
1970	Old average		Ajzenberg-Selove
2005	Fourier-Bessel		Crannell *et al.*
2008	PWBA		Present work
2008	Fourier-Bessel		Present work
2008	New average		Present work

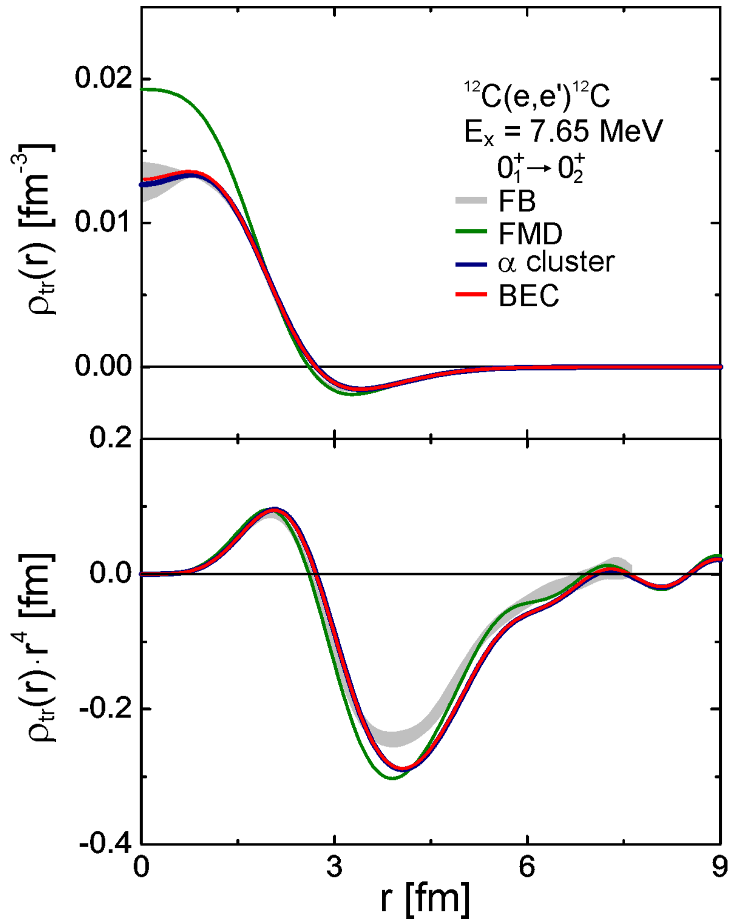


- $\Gamma_\pi = 62.2(10)\ \mu\text{eV}$
- Total uncertainty $\Delta r_{3\alpha}/r_{3\alpha} = \pm 10\%$
- Only Γ_π/Γ needs still to be improved now

Outlook



- Theory systematically overpredicts experiment



Outlook

- ^{12}C: 0_3^+ and 2_2^+ states
- ^{16}O: 6th excited 0^+ state at 15.1 MeV is the “Hoyle” state ? → ^{16}O(e,e´α)