^{7}Be(p, γ)^{8}B and the High-Energy Solar Neutrino Flux *

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* Work performed under the auspices of the U.S. Department of Energy

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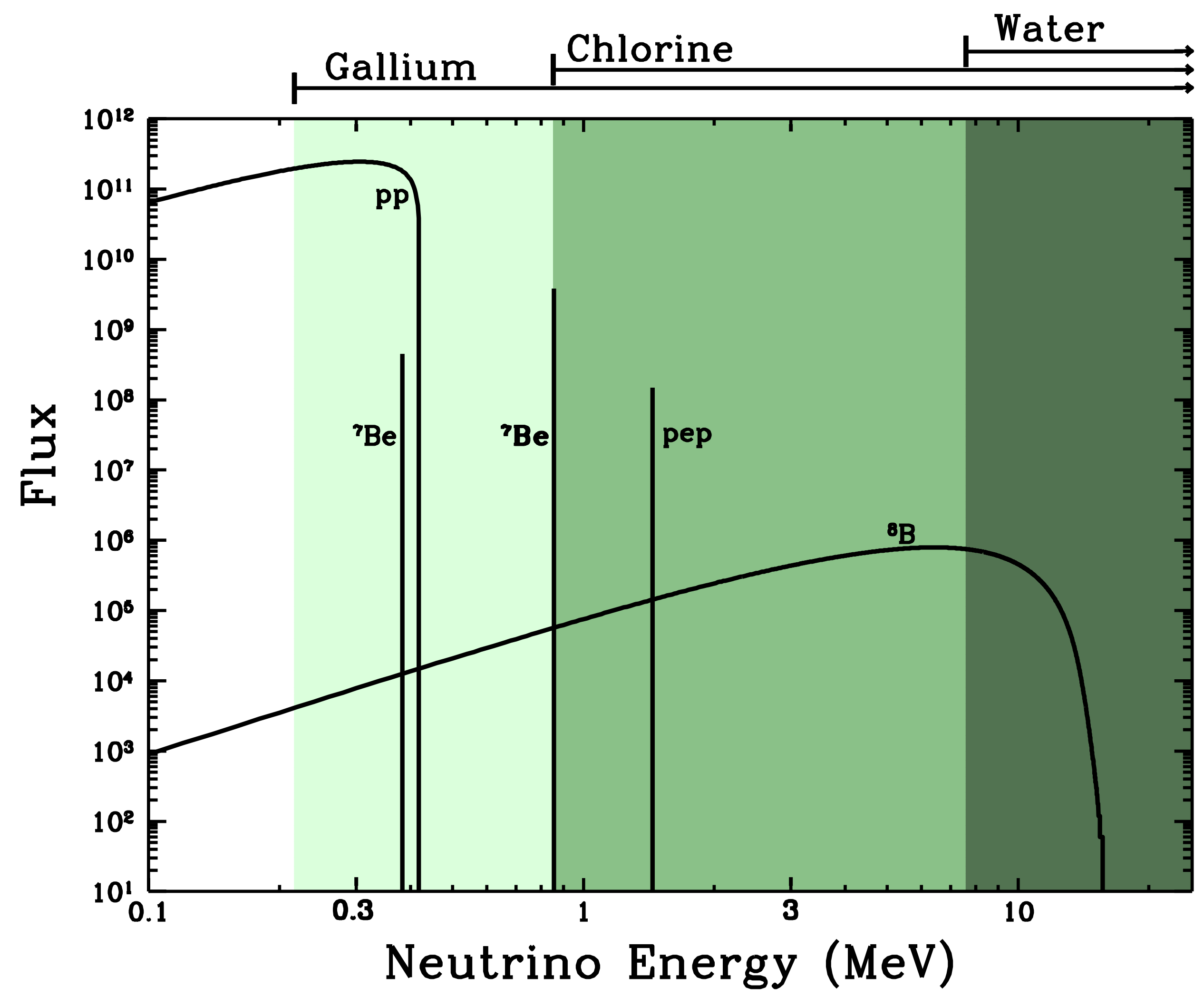


Gallium
Chlorine
Water
Flux
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
pp
^{7}Be
^{7}Be
pep
^{8}B
0.1
0.3
1
3
10
Neutrino Energy (MeV)

The combined results of the Homestake, Kamiokande, and Gallium experiments are barely consistent with the following pattern of suppression of the neutrino fluxes (only if the uncertainties are pushed to their very limits and the CNO neutrinos are neglected):

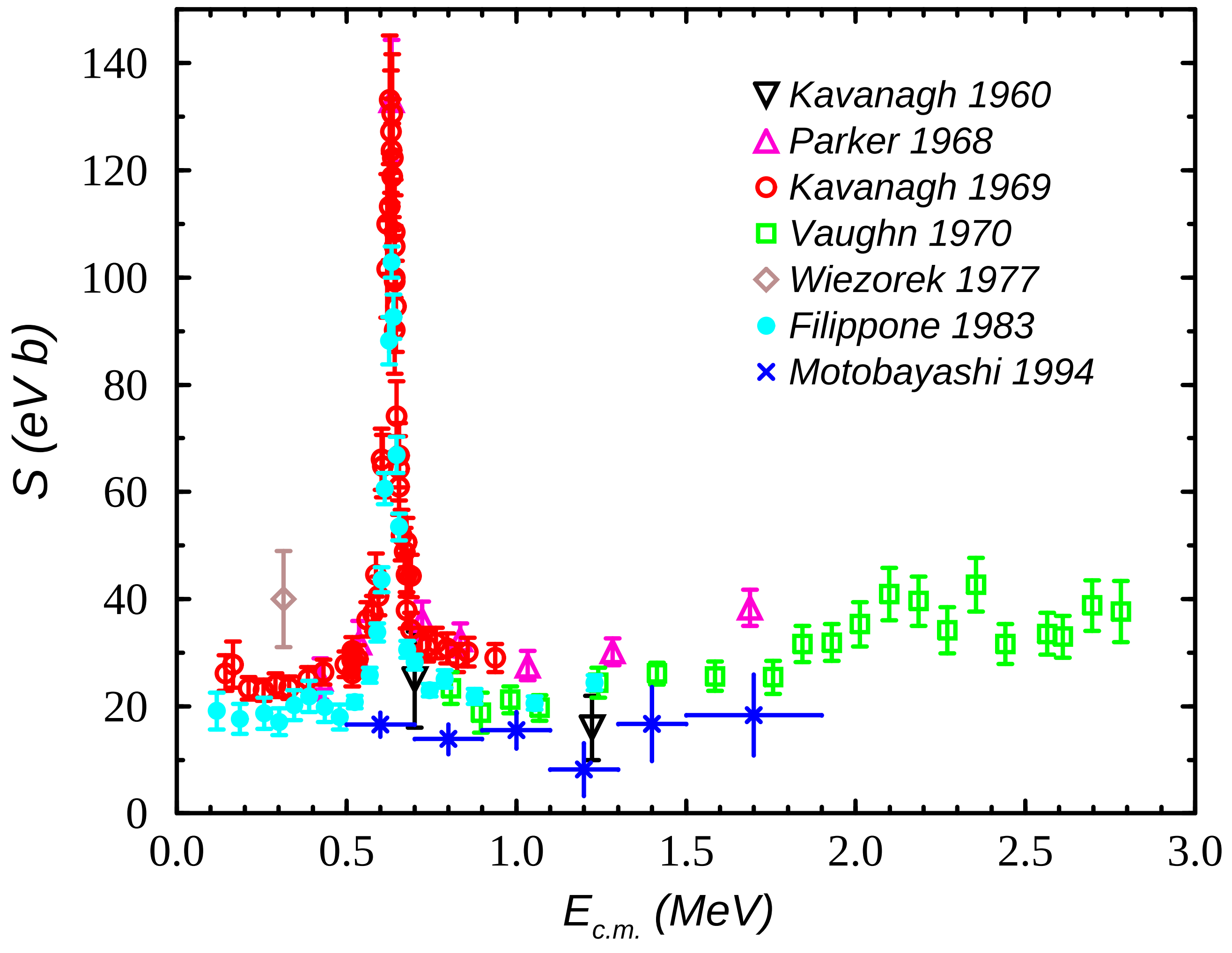
$$\begin{aligned} \phi(pp) &\sim 0.95\phi^{SSM}(pp) \\ \phi(^7\mathrm{Be}) &\sim 0 \\ \phi(^8\mathrm{B}) &\sim 0.4\phi^{SSM}(^8\mathrm{B}) \end{aligned}$$

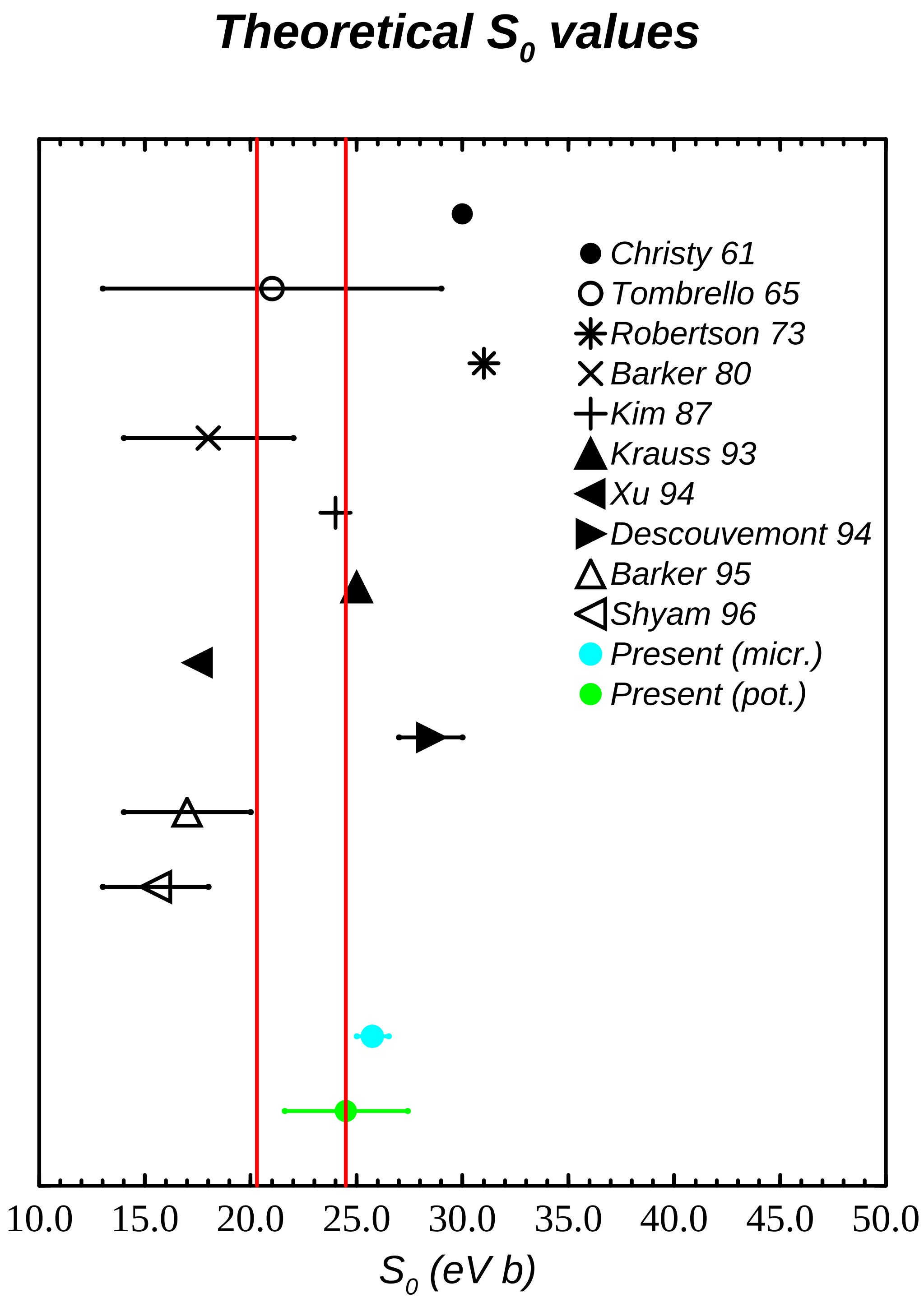
SSM: Standard Solar Model

This strongly suggests physics effects beyond the standard model.

The precise determination of SSM input parameters is very important. The most uncertain nuclear input parameter is the $^7\mathrm{Be}(p,\gamma)^8\mathrm{B}$ cross section.

World data for the $^{7}Be(p,\gamma)^{8}B$ S-factors





Theoretical S0 values
Christy 61
Tombrello 65
Robertson 73
Barker 80
Kim 87
Krauss 93
Xu 94
Descouvement 94
Barker 95
Shyam 96
Present (micr.)
Present (pot.)
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
S0 (eV b)

Microscopic 8-body model (Phys. Rev. C**52**, 1130 (1995))

$$\Psi = \sum_{I_7,I,l_2} \sum_{i=1}^{N_7} \mathcal{A}\Big\{\Big[[\Phi_s^p \Phi_{I_7}^{^7\mathrm{Be},i}]_I \chi_{l_2}^i(\boldsymbol{\rho}_2)\Big]_{JM}\Big\} + \Psi^{^5\mathrm{Li}+h} + \Psi^{^4\mathrm{Li}+\alpha}$$

$\mathcal{A}$ is the intercluster antisymmetrizer, $\boldsymbol{\rho}_2$ and l_2 are the relative coordinate and relative angular momentum between ^{7}Be and p, s and I_7 are the spin of the proton and ^{7}Be, I is the channel spin, and [...] denotes angular momentum coupling.

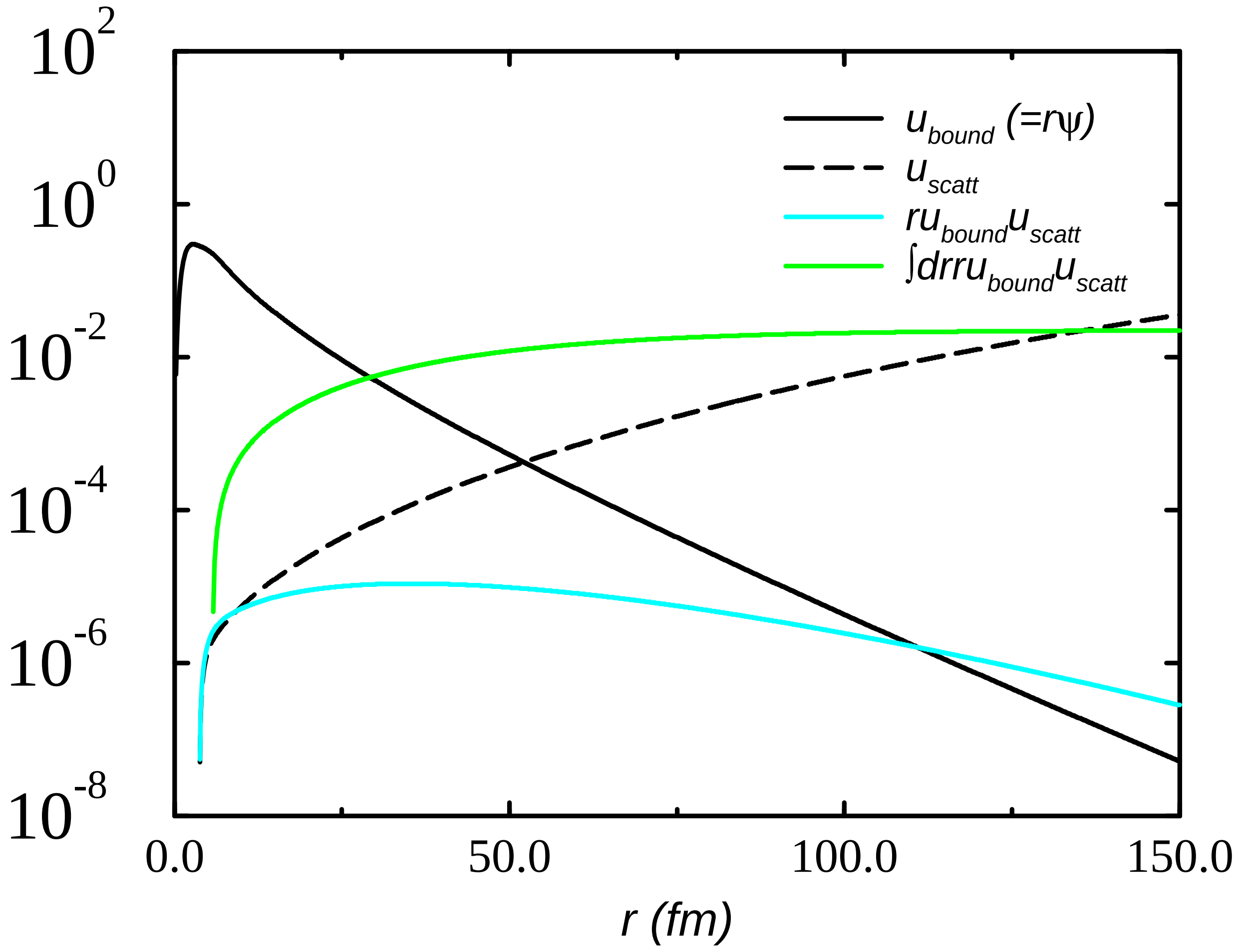
$$\Phi_{I_7}^{^7\mathrm{Be},i} = \sum_{j=1}^{N_7} c_{ij} \sum_{l_1} \mathcal{A}\left\{\left[\left[\Phi^\alpha \Phi^h\right]_{\frac{1}{2}} \Gamma_{l_1}^j(\boldsymbol{\rho}_1)\right]_{I_7 M_7}\right\}$$

$\mathcal{A}$ is the intercluster antisymmetrizer between α and h, Φ^α and Φ^h are translationally invariant harmonic oscillator shell model states (α=^{4}He, h=^{3}He), $\boldsymbol{\rho}_1$ is the relative coordinate between α and h, l_1 is the $\alpha - h$ relative angular momentum, and $\Gamma_{l_1}^j(\boldsymbol{\rho}_1)$ is a Gaussian function with a width of γ_j. The c_{ij} parameters are determined from a variational principle for the ^{7}Be energy.

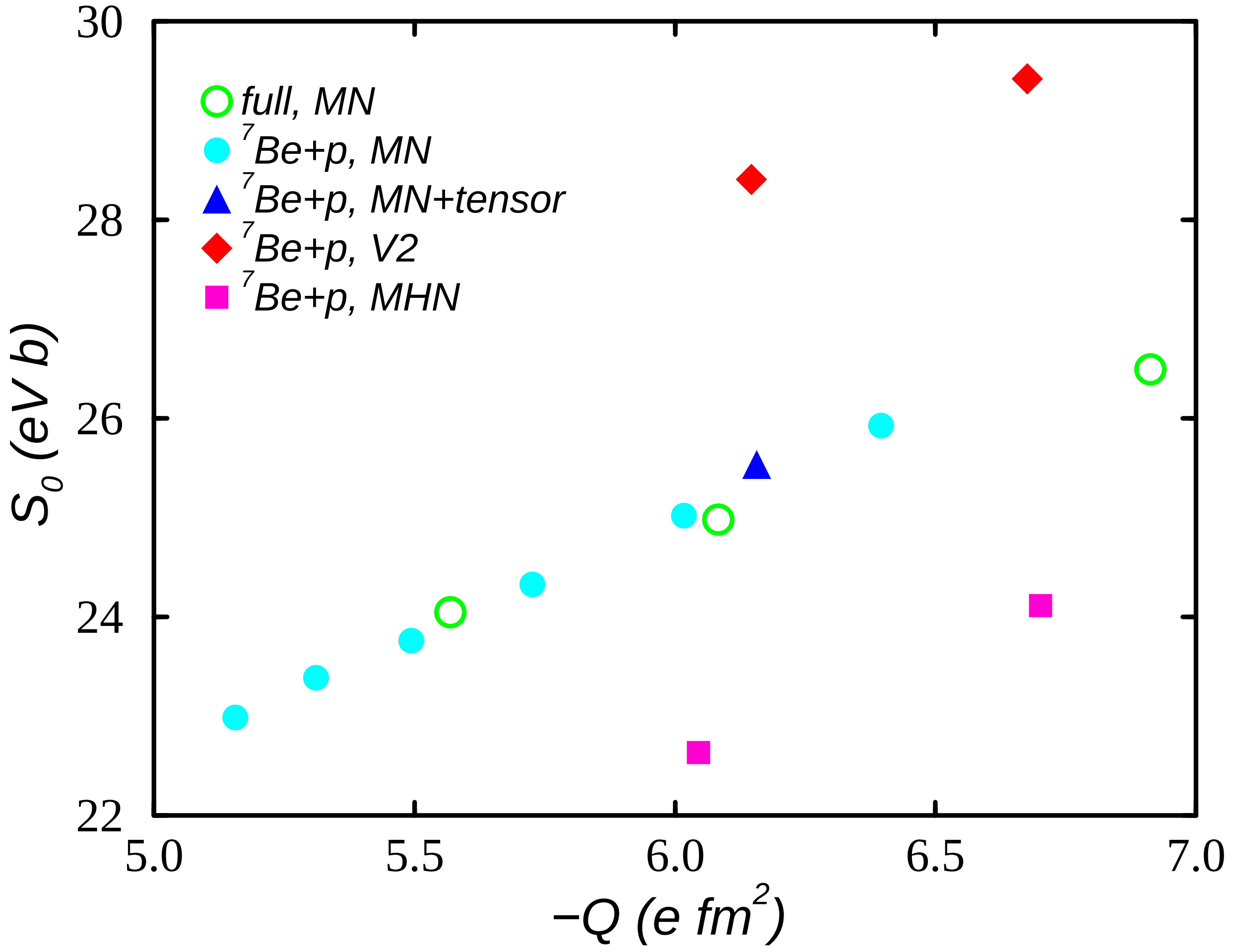
N_7=6, l_1=1, I_7=3/2,1/2, I=1,2, and l_2=0,1,2 are used for the bound and scattering states.

$$\begin{aligned}\sigma(E_{cm}) &= \sum_{J_i} \frac{1}{(2I_7+1)(2s+1)} \frac{16\pi}{3\hbar}\left(\frac{E_\gamma}{\hbar c}\right)^3 \\ &\times \sum_{l_\omega, I_\omega} (2l_\omega+1)^{-1} |\langle \Psi^{J_f} || \mathcal{M}_1^E || \Psi_{l_\omega, I_\omega}^{J_i} \rangle|^2\end{aligned}$$

E1 matrix element at E_{cm}=20 keV



$S_0(Q_7)$ correlation in the microscopic model



Potential model (Nucl. Phys. A**597**, 66 (1996))

Connection between Δ and $r_{\rm valence}$: larger $r_{\rm valence}$ $\Longrightarrow$ smaller Δ.

^{8}B : ^{8}Be + proton-particle + neutron-hole

^{8}Li: ^{8}Be + proton-hole + neutron-particle

$$\Delta_8 = \Delta_{\rm hole} + \Delta_{\rm part}$$

Δ_8: $\Delta(^8{\rm Li} - {}^8{\rm B})$ $2^+, T = 1$

$\Delta_{\rm hole} = \Delta_7$: $\Delta(^7{\rm Li} - {}^7{\rm Be})$ $3/2^-, T = 1/2$

$\Delta_{\rm part} = \Delta_9$: $\Delta(^9{\rm Be} - {}^9{\rm B})$ $3/2^-, T = 1/2$

Experiment: $\Delta_7 = 1.645$ MeV, $\Delta_9 = 1.851$ Mev, $\Delta_8 = 3.540$ MeV

$$\begin{aligned}
\Delta_8 &= \Delta_{\rm hole} + \Delta^{'}_{\rm part} + \Delta_{\rm SM} \\
\Delta^{'}_{\rm part} &= \Delta_0 + \Delta_{\rm ex} + \Delta_{\rm SO} + \Delta_{\rm vp} + \Delta_{\rm np} + \Delta_{\rm NS}
\end{aligned}$$

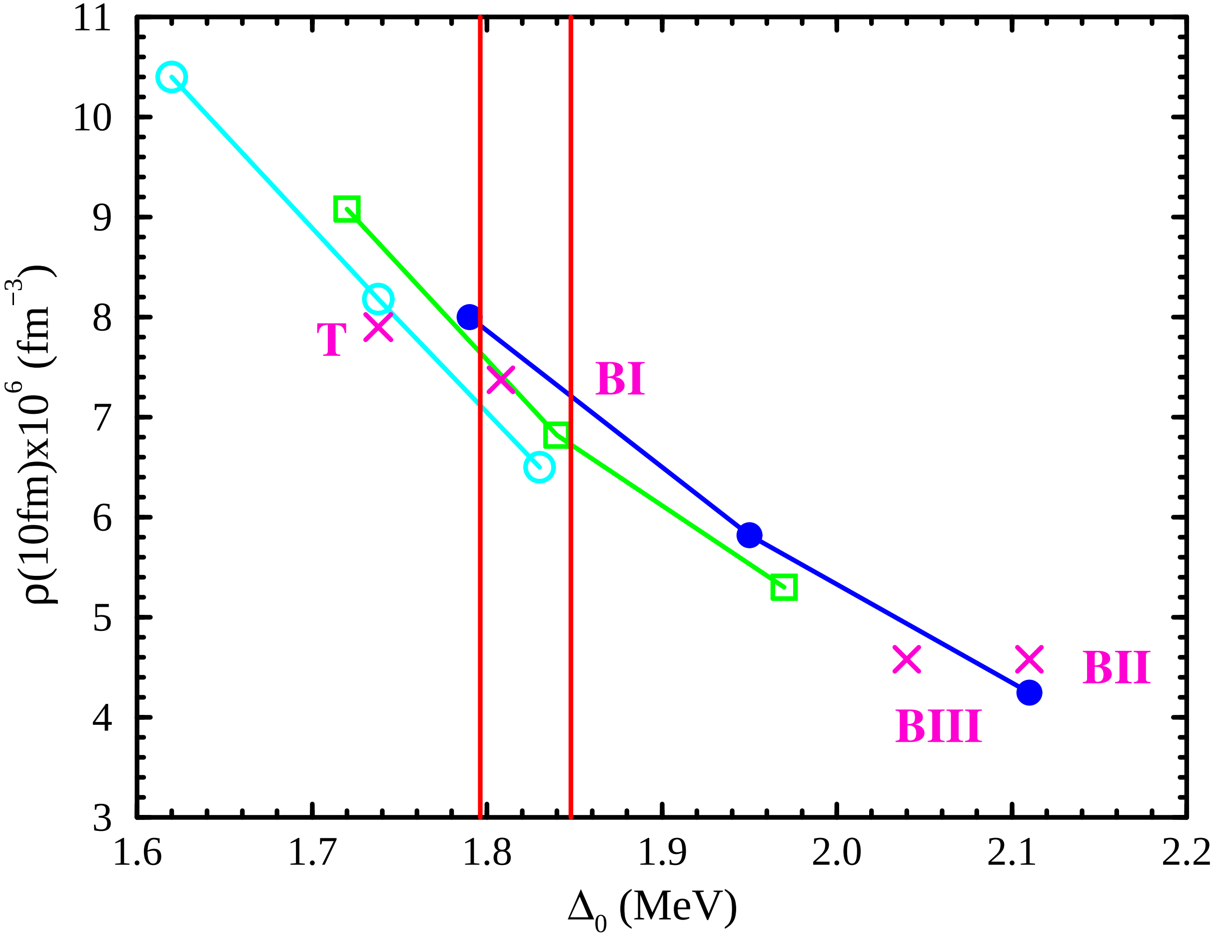
$$\begin{aligned}
\Delta_{\rm SM} &= 64{\rm keV},\ \text{shell} - \text{model structure beyond 1p} - \text{1h} \\
\Delta_{\rm ex} &= -125{\rm keV},\ \text{exchange correction} \\
\Delta_{\rm SO} &= -20{\rm keV},\ \text{rel. spin} - \text{orbit correction} \\
\Delta_{\rm vp} &= 12{\rm keV},\ \text{vacuum polarization correction} \\
\Delta_{\rm np} &= 14{\rm keV},\ \text{n} - \text{p mass difference correction} \\
\Delta_{\rm NS} &= 128{\rm keV},\ \text{Nolen} - \text{Schiffer correction}
\end{aligned}$$

$$\Delta_0 \ \ \text{direct Coulomb displacement}$$

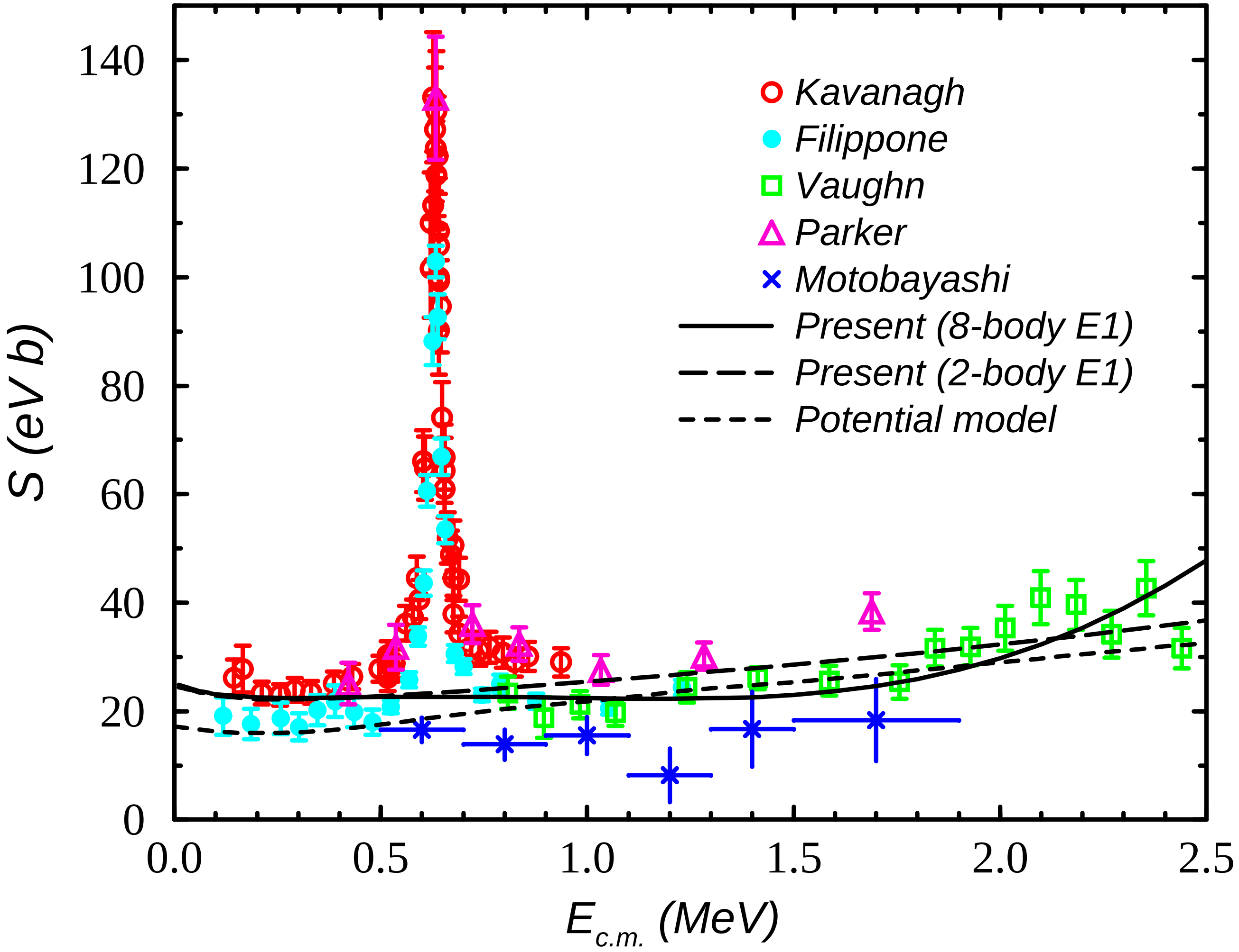
$$\Delta_0(\text{empirical}) = 1.822 \pm 0.026 \text{ MeV}$$

The $A = 8$ Coulomb displacement is calculated using Woods-Saxon potentials with various sets of parameters.

$\rho(\Delta_0)$ *correlation in the potential model*



Off-shell effects in $^7Be(p,\gamma)^8B$



Summary

- Renewed experimental efforts using radioactive nuclear beams
  - New radiative capture experiments (Orsay-Bordeaux)
  - ^{8}B Coulomb dissociation experiments to map out the various electromagnetic multipole components (MSU, GSI, RIKEN)
  - ^{7}Be+p elastic scattering data for optical potential parameters (TRIUMF?)
  - The "Ultimate Experiment": Radiative capture using ^{7}Be beam in inverse kinematics (TRIUMF?, ORNL)
- Improved theoretical calculations are necessary
  - Role of core deformation in potential models (Surrey)
  - Microscopic calculations with new N-N interactions, larger model spaces, etc. (ULB Brussels)
  - The "Ultimate Calculation": Full solution of the 8-body problem with modern 2N and 3N interactions and EM currents (Argonne-Urbana-Los Alamos Quantum Monte Carlo group)