SCALING AND INTERFERENCE IN BREAKUP

Mahir S. Hussein
São Paulo

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With:
R. Lichtenthaler (São Paulo),
F. M. Nunes (NSCL-MSU) and
I. J. Thompson (Surrey/LLNL)

- **Couolmb Dissociation of Halo Nuclei.**
- **Continuum Discretized Coupled Channels Theory.**
- **Nuclear Breakup and the Scaling Law.**
- **Coulomb – Nuclear Interference.**
- **Extracted B(EL).**
- **Conclusions.**

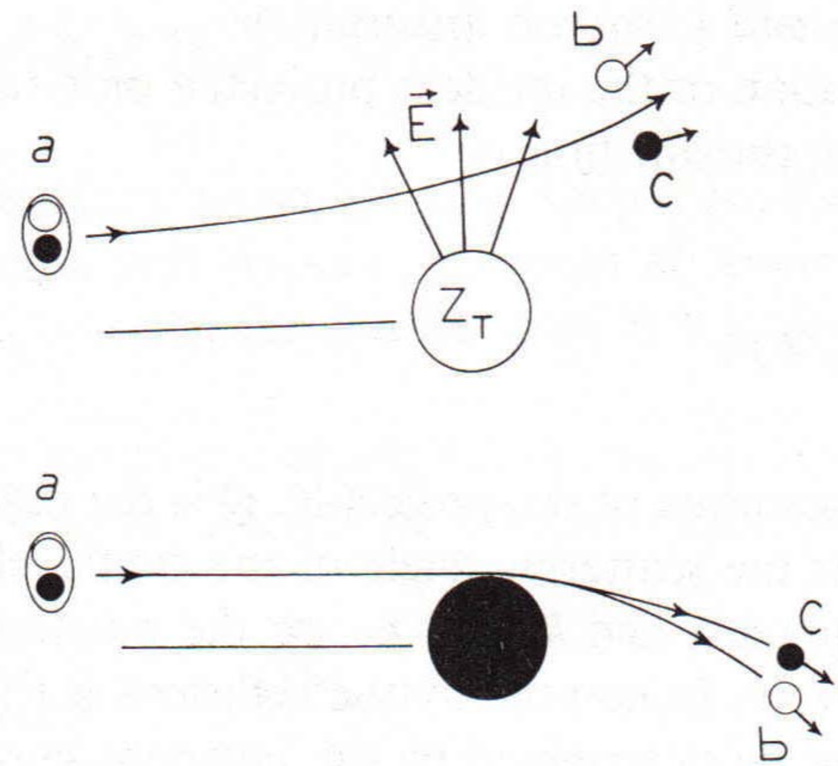
Coulmb Dissociation of Halo Nuclei

The Coulomb dissociation of halo nuclei is an important tool to understand their structure. The CD cross section is directly related to the EM response of these exotic systems [1].

$$\frac{d\sigma_{\mathrm{CD}}}{dE_{\mathrm{rel}}} = \frac{16\pi^3}{9\hbar c} N_{E1}(E_{\mathrm{x}}) \frac{dB(E1)}{dE_{\mathrm{rel}}}$$

Where $N_{E1}(E_x)$ is the number of virtual photons.

The picture below, based on the FWW method of virtual photons undelines the methods used for the analysis of the data.



Upper figure, pure Coulomb dissociation.
Lower figure, pure nuclear dissociation.

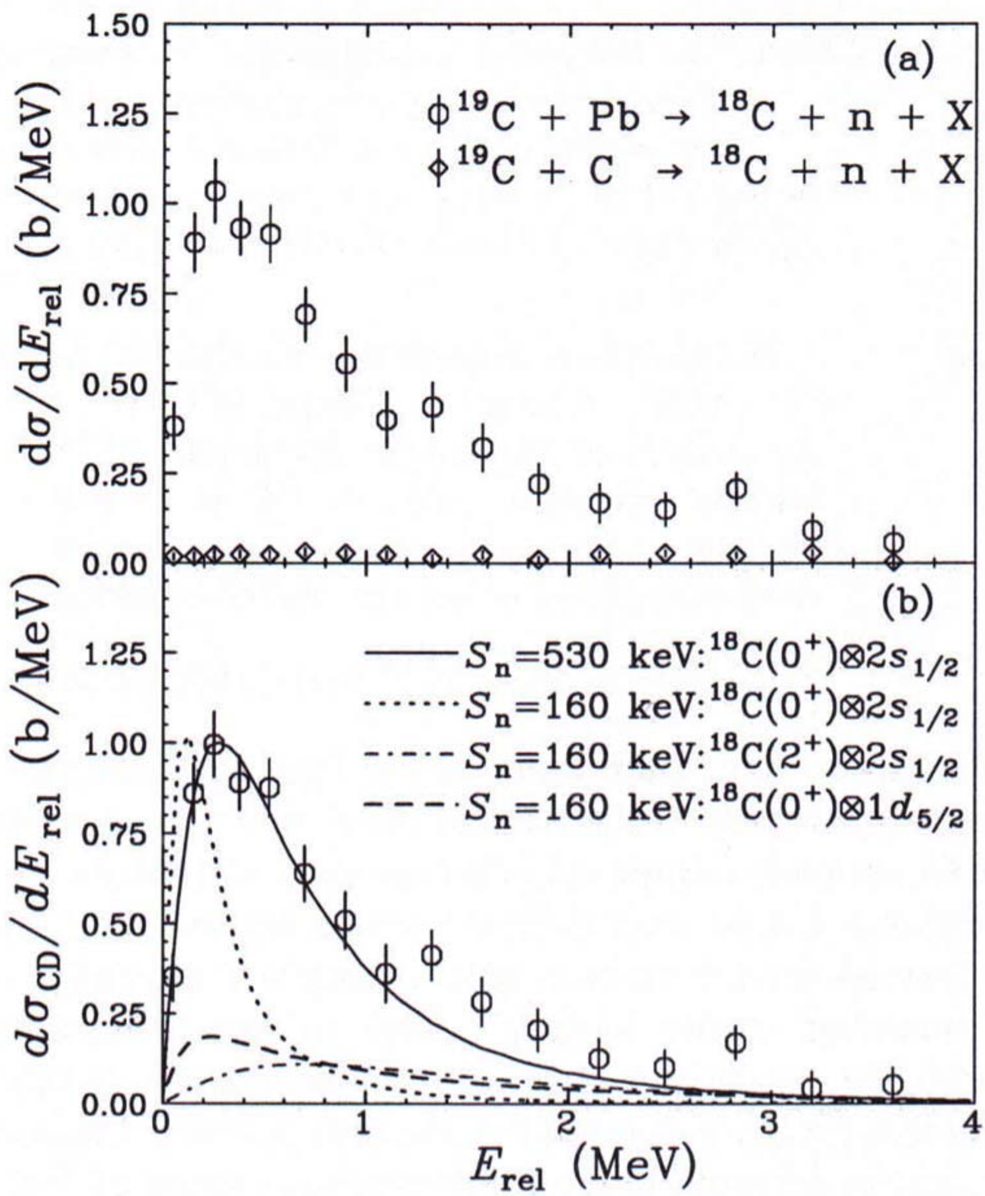
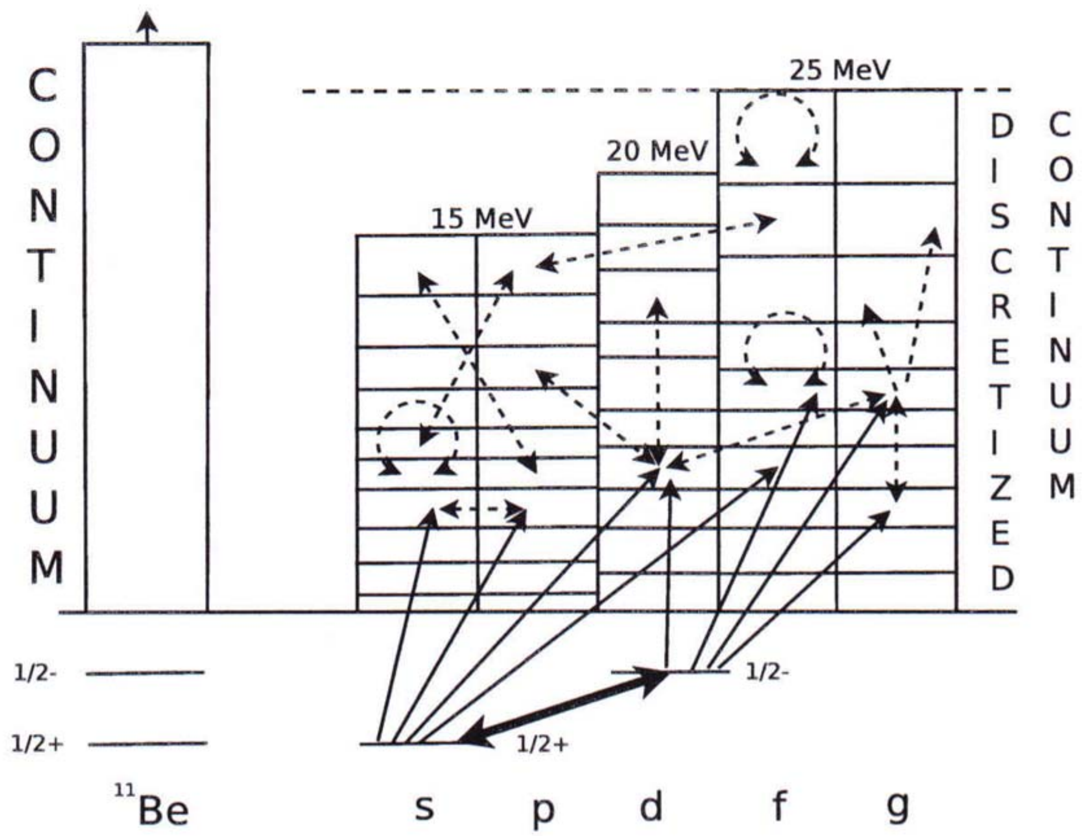


FIG. 1. (a) Dissociation cross sections as a function of relative energy E_{rel} for Pb (circles) and C (diamonds) targets. (b) Coulomb dissociation cross section for the Pb target, obtained by subtracting the nuclear contribution scaled from the C target spectrum in (a). The spectrum is compared with the calculations for the possible single-particle configurations described in the text.

From Ref. [2] : use of FWW plus scaling.

Continuum Discretized Coupled Channels Theory

Use a coupled bound and continuum channels to perform calculation of breakup cross section and other observables. The continuum channels are discretized as in the figure



Nuclear Breakup and the Scaling Law

To extract the Coulomb disscoiation cross section one has to remove the contribution of the short range nuclear field (lower figure above). It is assumed that the nuclear cross section behaves as

$$\sigma_D \approx 2\pi a(R_1 + R_2)$$

(This is the Serber Model !)

Thus it goes as the cubic root of the target mass. By measuring the dissociation on a light target, as 12C, (where little Coulomb effect is present), one scales the nuclear cross section to heavier targets. This is the scaling law. Subract this from the measurement, get the CD cross section [2, 3].

HOW ACCURATE IS THIS PROCEDURE (SCALING AND SUBTRACTION) IN THE CASE OF HALO NUCLEI?

The Nuclear Breakup Cross Section

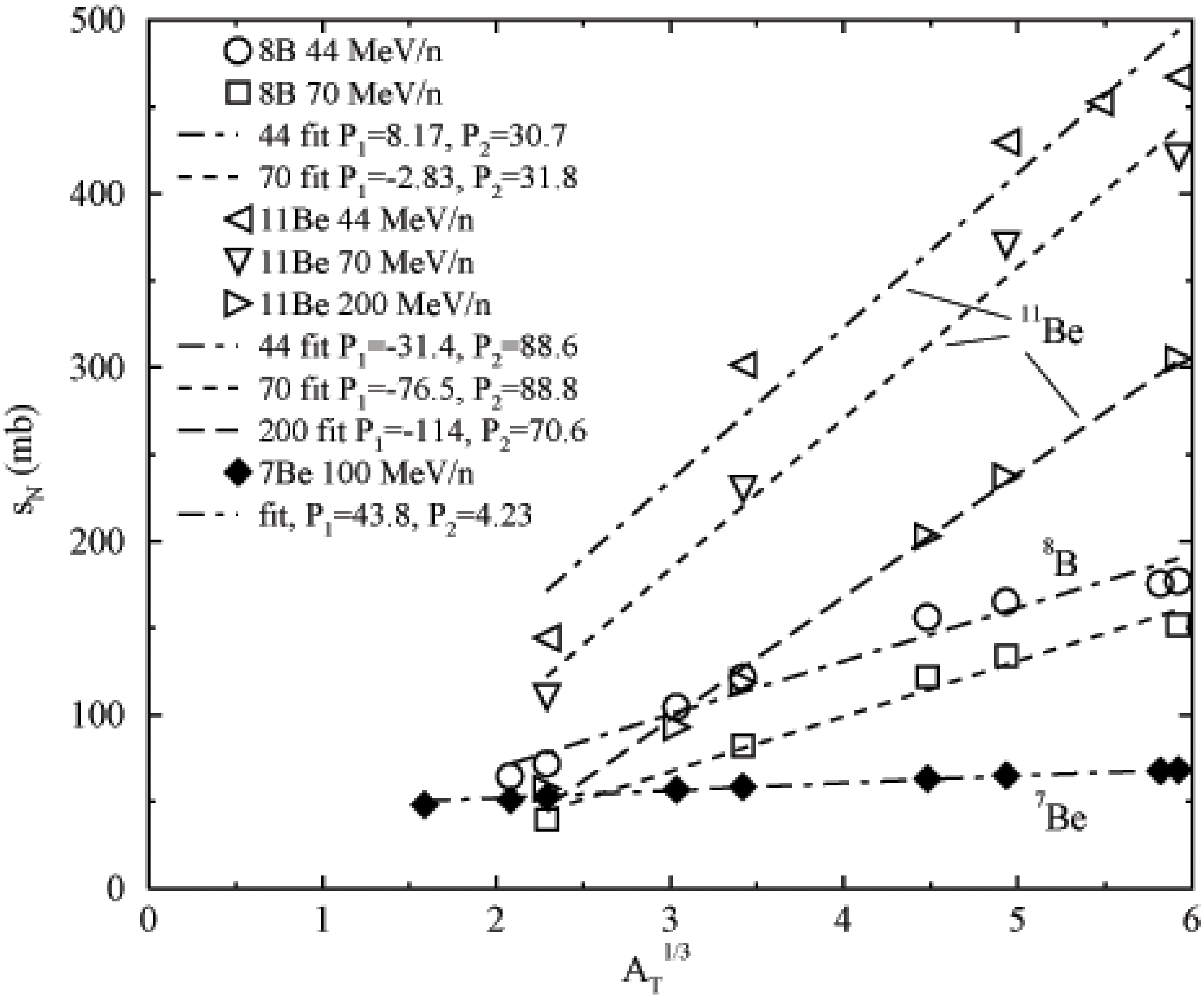
The elastic breakup cross section and its dependence on the target mass can be most easily analysed within the Distorted Wave Born Approximation (DWBA) within the adiabatic theory of Austern and Blair [4, 5] If we treat the breakup as an inelastic multipole process and ignore the Q-value, in line with the adiabatic/sudden limit, one can show that the breakup cross section containing both dipole and quadrupole excitations [6] would basically depend on $\delta^{(N)}_1$ and $\delta^{(N)}_2$; the nuclear dipole and quadrupole deformation lengths given by $\delta^{(N)}_L = \beta^{(N)}_L R_P$ with $\beta^{(N)}_L$ being the nuclear L- multipole deformation parameter and Rp is the radius of the projectile.

The inegrated pure nuclear breakup cross section then becomes the following [6]

$$\sigma = c \quad [\, (\delta^{(N)}{}_1)^2 \; (3/2\; \Delta R/R_P)^2 + (\delta^{(N)}{}_2)^2 \,] \quad l_g$$

Where ΔR is the difference between the neutron and proton distribution radii in the projectile, l_g is the grazing angular momentum given by [k ($R_P + R_T$)] and c is a constant numerical factor. It is clear that σ depends linearly on the radius of the target and thus on the cubic root of its mass (scaling) and, more importantly on the nuclear dipole and quadrupole deformation lengths, squared.The above formula is consistent with the geometrical, Serber, model.
To check the above formula and the validity of the Serber scaling law for the nuclear breakup cross section , we have performed a CDCC calculation for the elastic breakup of the one-neutron halo nucleus, ^{11}Be; The one-proton halo nucleus ^{8}B and the non-halo nucleus ^{7}Be, on several targets and at different E_{lab}/n.

The nuclear breakup cross sections for these system are shown in the figure below:



CAPTION

Elastic nuclear breakup cross-section for ^{8}B, ^{11}Be and ^{7}Be projectiles at indicated energies, as a function of target mass number A_T, along with linear fits.

Guided by the Serber formula above, we fit the cross section dependence on the mass of the target with $A_T^{1/3}$

$$\sigma_N = P_1(E) + P_2(E)\, A_T^{1/3}$$

The parameters $P_1(E)$ and $P_2(E)$ are in millibarns. It is clear that the fit to the CDCC calculation is reasonable.

The nuclear breakup cross section calculated with CDCC for ^8B and ^{11}Be do show approximately the $A_T^{1/3}$ dependence as seen above. By comparison, scaling holds for ^7Be, a normal non-halo nucleus and the geometrical Serber formula is fully satisfied (both P_1 and P_2 are positive).

The different behaviour in the nuclear scaling of ^8B and ^{11}Be is a clear manifestation of their halo nature

Our result above should be contrasted with those of Nagarajan et al. (PLB, 503 (2001) 65) where it is claimed that the breakup cross section scales with A_T , rather than $A_T^{1/3}$. We consider this finding totally unacceptable since the cross section we are considering is that corresponding to the action of a strong force and thus the total reaction cross section goes as $A_T^{2/3}$ while the direct, breakup one scales like the area of an annular disc, namely as R_T or $A_T^{1/3}$ as our CDCC calculation clearly indicates. An A_T - dependence (or target volume-dependence) of a cross section reflects the action of a weak force, such as the EM one. which is not the case here.

We believe that the results of Nagarajan et al. is in error owing to the use of a wrong nuclear coupling form factor that extends unrealistically too far.

Coulomb-Nuclear Interference

It is clear that the total dissociation amplitude is a coherent sum of the Coulomb and the nuclear ones. Accordingly the cross section is

$$\sigma_{bup}^{NC} = |A_c + A_n|^2$$

or

$$\sigma_{bup}^{NC} = \sigma_{bup}^{C} + \sigma_{bup}^{N} + \sigma_{bup}^{I}$$

If one uses scaling for the nuclear cross section and subtract from the total dissociation cross section one gets for σ_{CN} - σ_{C} = "σ_{bup}^{C}" ,

$$\text{“}\sigma^{C}_{bup}\text{“} = \sigma^{C}_{bup} + \sigma^{I}_{bup}$$

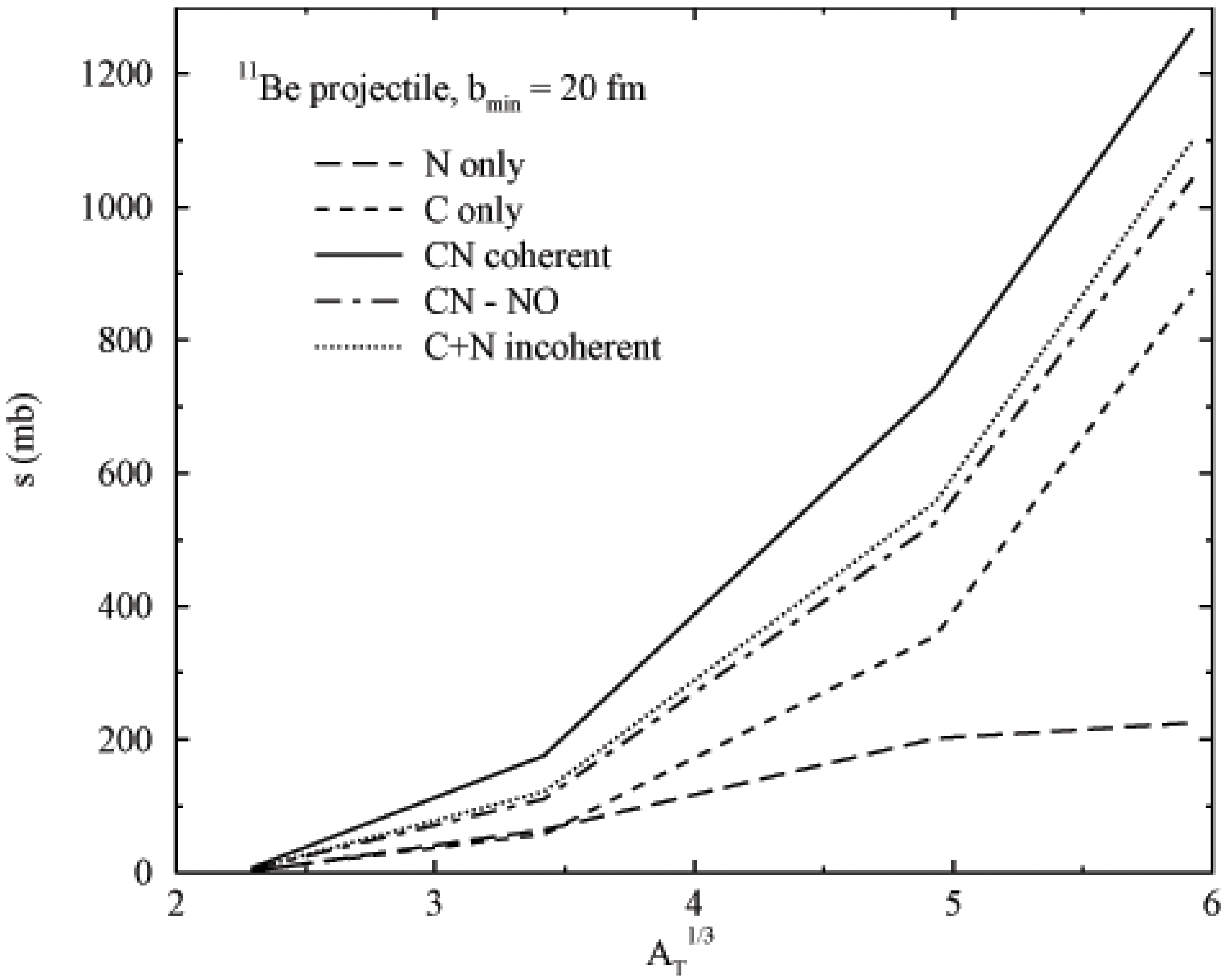
which contains the Coulomb AND the interference terms. When used to extract the dipole or higher multipole responses of halo nuclei one gets an “error” which depends on energy and the target mass. Thus BEWARE about the values of the extracted B(EL)!

The analysis of experimental data proceeds through the expression:

$$d\sigma/dE^{*} = S\, d\sigma_C/dE^{*} + L(A_T)\, d\sigma\, (^{12}C)/dE^{*}$$

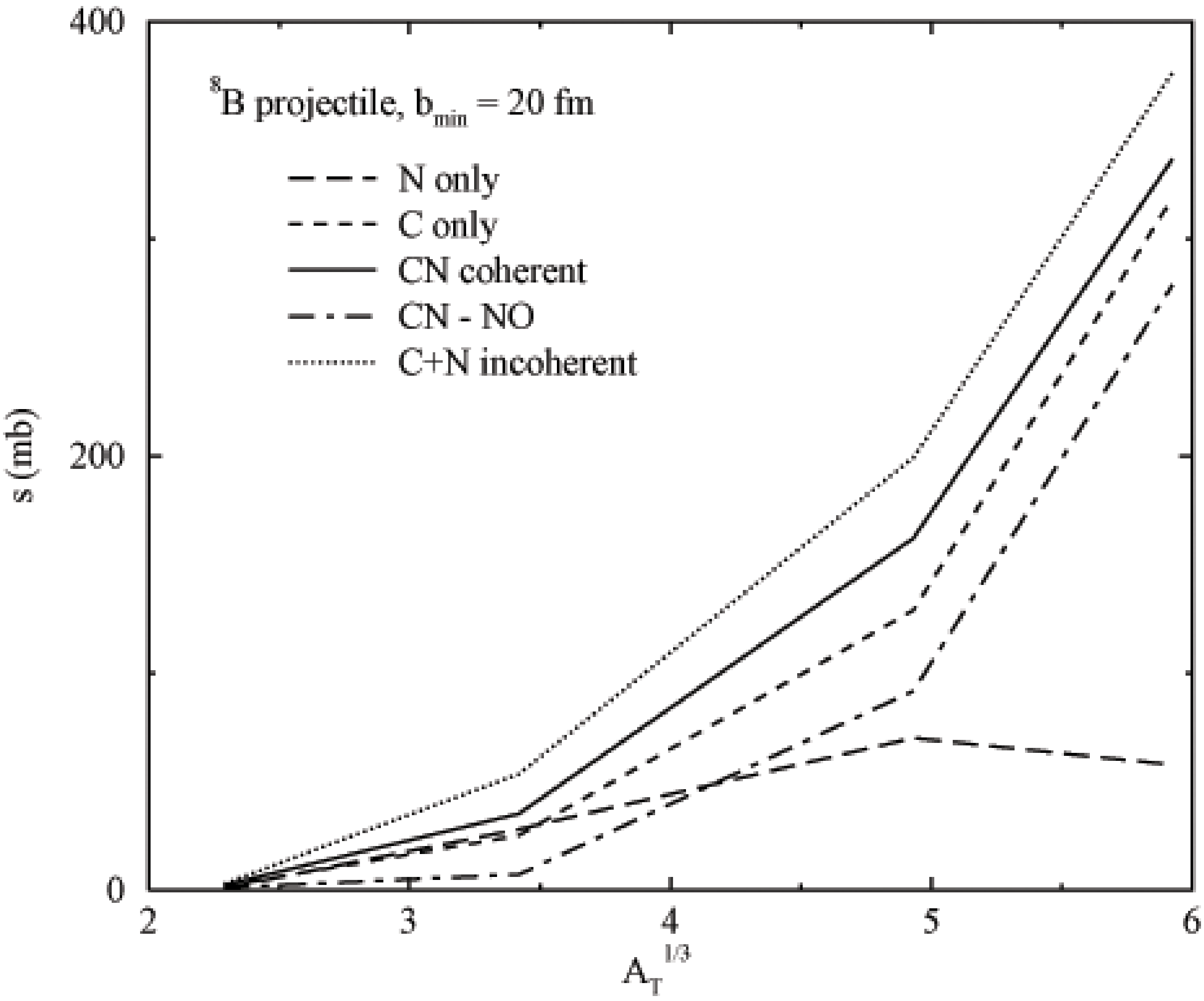
NO INTERFERENCE TERM!

We have analysed the interference term as shown in the figures below. We designate “N only” as the nuclear breakup cross section with no Coulomb coupling effects; “C only”, to Coulomb breakup, with no nuclear coupling. In both cases, conventional optical potentials are emplyed (monopole Coulomb + Complex nuclear). “CN coherent”, corresponds to the total Coulomb + nuclear + interference breakup cross section; “CN-NO”, is the “ CN coherent” – “N only” and “C+N incoherent” is “N only” + “C only”. The value of b_{min} was set equal to 20 fm in all three cases: ^{11}Be, ^{8}B and ^{7}Be.



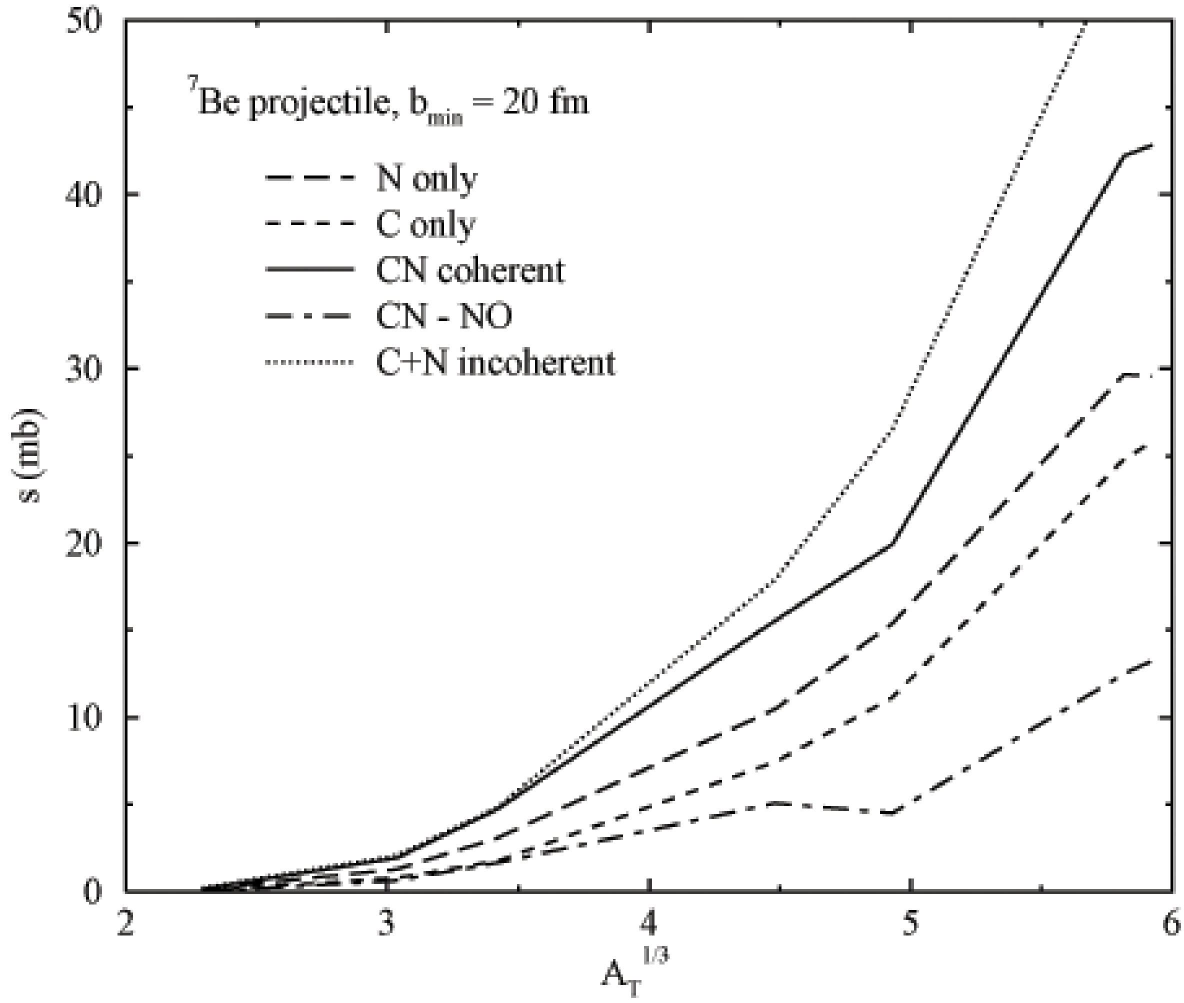
CAPTION

Total breakup, Coulomb only, and nuclear only contributions for ^{11}Be at 44 MeV/n, as a funtion of $A_T^{1/3}$. All results use scattering angle limit θ_{max} corresponding semiclassically (through the Rutherford relation) to b_{min} = 20 fm.



CAPTION

Total breakup, Coulomb only, and nuclear only contributions for ^{8}B at 44 MeV/n, as a funtion of $A_T^{1/3}$. All results use scattering angle limit θ_{max} corresponding semiclassically (through the Rutherford relation) to b_{min} = 20 fm.

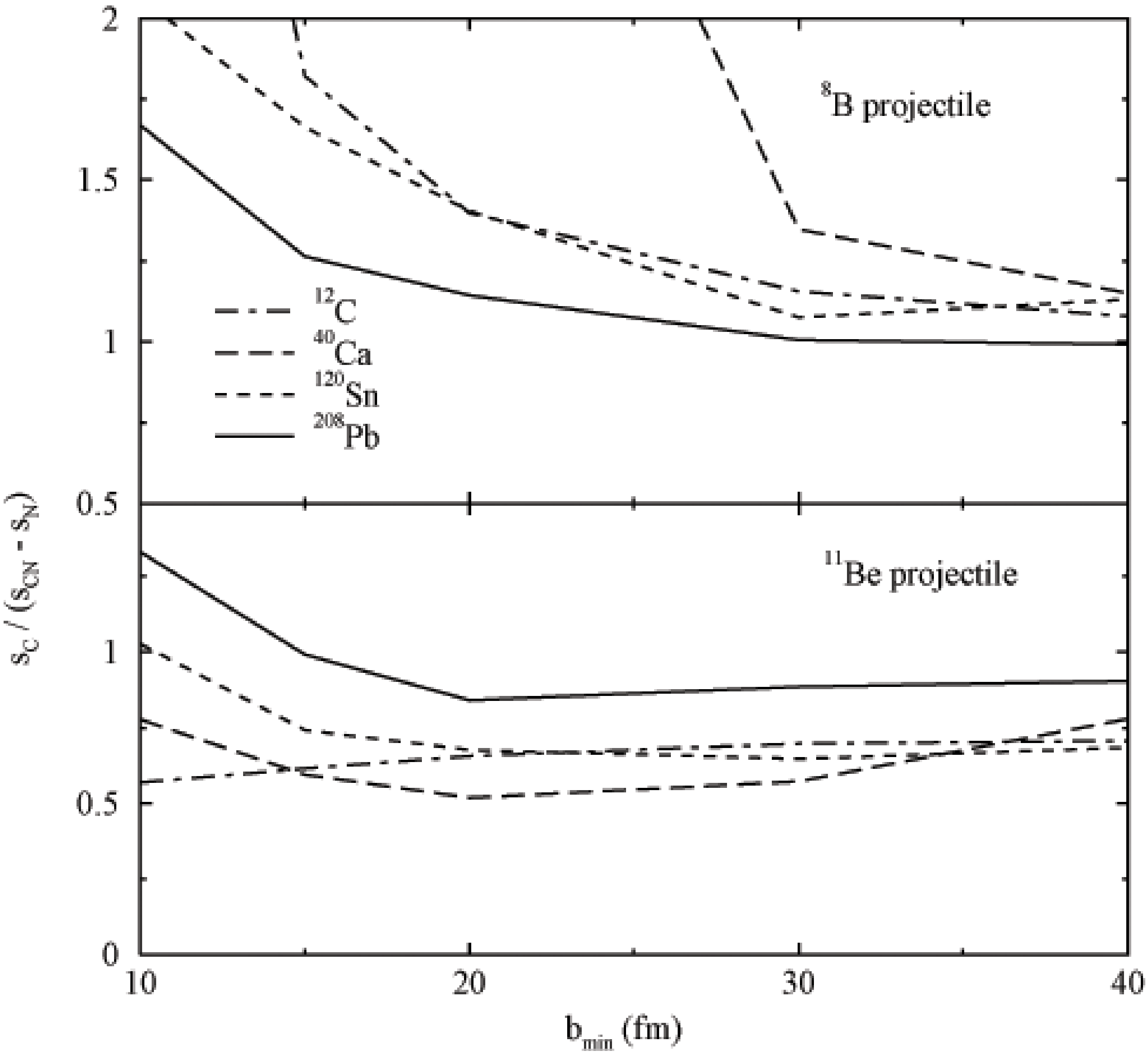


CAPTION

Total breakup, Coulomb only, and nuclear only contributions for ^{7}Be at 100 MeV/n, as a funtion of $A_T^{1/3}$. All results use scattering angle limit θ_{max} corresponding semiclassically (through the Rutherford relation) to b_{min} = 20 fm.

It is clear that the Coulomb-Nuclear interference term can be constructive (^{11}Be) or destructive (^{8}B). We have no clue why this is so, except for the obvious difference of their being a one-neutron halo and a one-proton halo systems, respectively.

The quantity σ_C/ ("$\sigma_{bup}{}^{C}$ ") alluded to above as a function of low cutoff impact parameter b_{min}, for ^{8}B and ^{11}Be nuclear breakup on several targets is shown below



CAPTION

Ratio of the true to the contaminated Coulomb breakup cross sections σ_C / "σ_C " = σ_C/ (σ_{CN}-σ_N) as a function of the lower radial cutoff b_{min}, for four different targets. Results for ^{8}B are shown in the upper panel, and for ^{11}Be in the lower panel.

The “error” due to the nuclear-Coulomb interference in the calculated B(E1) distribution measured by $\sigma_C/(\sigma_{CN}-\sigma_N)$, if the above formula is employed in conjuction with the virtual photon method, could be large.

For ^{11}Be we expect a smaller B(E1) than already reported.

For ^{8}B we expect a larger B(E1) than already reported.

Conclusions

- **The scaling of the nuclear cross section works for non-halo nuclei, but only approximately for halo ones.**

- **The Coulomb-Nuclear interference term could be significant and if proparly considered, may lead to a smaller values of the extracted B(E1) for ^{11}Be (one –neutron halo) and larger values for ^{8}B (one-proton halo)**

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