Deuteron Electro-Disintegration at Low Energies ◇

S. Christlmeier [a] and H.W. Grießhammer [a,b]

[a] Institut für Theoretische Physik (T39), TU München, Garching

[b] Centre for Nuclear Studies, The George Washington University, Washington DC, USA

An experiment of deuteron electro-disintegration $d(e,n)pe'$ at S-DALINAC [1] examined the decomposition of the triple-differential cross section at low momentum transfer (< 60 MeV) and energies close to the breakup threshold into the contributions of different structure functions:

$$\frac{\mathrm{d}^3\sigma}{\mathrm{d}E_e\ \mathrm{d}\Omega_e\ \mathrm{d}\Omega_p} = (\sigma_L + \sigma_T) + \sigma_{LT}\ \cos\phi_p + \sigma_{TT}\ \cos 2\phi_p$$

It reported a discrepancy of the longitudinal-transverse interference cross section σ_{LT} to theoretical predictions by about 30 %. In contradistinction, all other experiments are in good agreement with potential-model calculations, but were performed at relatively high energy transfers.

We studied this process within the "Pion-less" Effective Field Theory, EFT(π), of few-nucleon systems at energies below the pion mass [2]. This extension of Effective Range Theory starts from the most general Lagrangean of local interactions between the nucleons as the only effective low-energy degrees of freedom, and respects all symmetries of QCD. It does not suffer from ambiguities in the treatment of exchange-currents, is manifestly gauge-invariant, and renders analytic, simple answers which include an estimate of the theoretical uncertainties by expanding in a dimension-less, small parameter.

We calculated up to next-to-next-to-leading order (NNLO) for electric transitions and up to NLO for magnetic ones. EFT(π) contains at this order no unknowns, and predicts the cross-section to suffer at this order from a theoretical uncertainty of less that 1%. As the deuteron is mostly an S-wave state, σ_{LT} is predominantly sensitive to final-state interactions. The leading-order (LO) electric transitions from minimal coupling largely dominate. Their strengthes are fixed by the scattering lengths and effective ranges of NN-scattering in the $^1S_0$- and $^3S_1$-channels. The first corrections arise from SD-mixing and enter at NNLO. They are fixed by the deuteron quadrupole moment, but even smaller than estimated by power counting. The magnetic transitions are determined by the anomalous nucleon magnetic moments and the cross section for thermal radiative capture $np \to d\gamma$. They are however near-negligible in our energy-régime and become important only with decreasing momentum transfer. We found rapid convergence from order to order and showed that various effects from even higher orders do not influence the result, e.g. P-wave and magnetic 2-photon final-state interactions.

Our result is in excellent agreement with a potential-model calculation by Arenhövel et al. [3]. The full triple-differential cross section measured at S-DALINAC is also reproduced. However, σ_{LT}, when normalised to $\sigma_L + \sigma_T$ at $\theta = 0$, shows a strong discrepancy to the S-DALINAC data, see Fig. 1 for examples. Unfolding the data, we see a strong hint that this might come from a dis-advantageous experimental normalisation. An earlier experiment [4] at a slightly higher momentum transfer agrees also with our predictions. In addition, we took some issues with the kinematical set-up of the experiment. Our findings triggered an ongoing data re-analysis of the S-DALINAC group and a proposal at FZ Rossendorf.

We also predicted the cross-section for a proposed S-DALINAC experiment directly above the breakup threshold, where magnetic transitions are dominant. It allows for an indirect measurement of deuteron radiative capture at energies relevant for big-bang nucleo-synthesis.

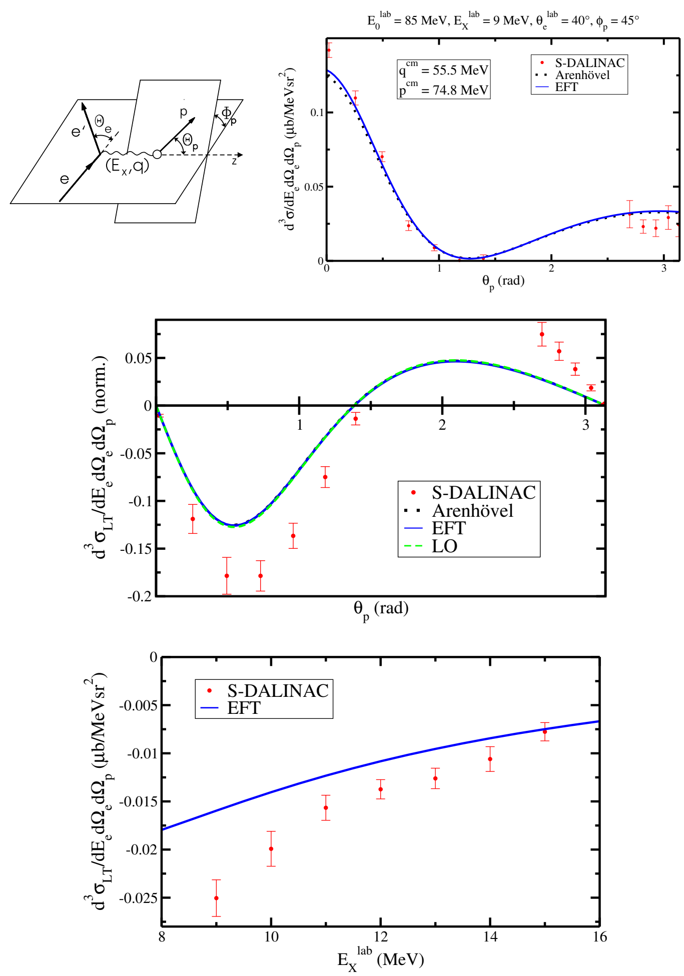

Fig. 1: Top left: Lab-frame kinematics of [1]. Incident electron energy $E_0 = \{50; 85\}$ MeV, outgoing proton energy $E_p \lesssim 16$ MeV. Rest: Exemplary comparisons of data from [1] with predictions in EFT(π) [2] and a potential model [1,3] for full triple-diff. cross-section (Top Right) and σ_{LT} (Mid: normalised as in experiment to $\sigma_L + \sigma_T$ at $\theta = 0$. Bottom: absolute value at minima of σ_{LT}).

References

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