Electroweak Processes in Few-Nucleon Systems

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Electron Nucleon Scattering XI, June 25-29, 2012, Marciana Marina, Isola d'Elba

Outline

1. EFT approach
2. EM Processes
3. Compton scattering
4. Weak interactions
5. Outlook

Collaborators

- F. Spadoni Graduate student, Pisa
- R. Schiavilla *Jefferson Lab. & ODU, Norfolk (VA, USA)*
- S. Pastore *ANL (USA)*
- L. Girlanda *University of Salento & INFN-Lecce, Lecce (Italy)*
- A. Kievsky & L.E. Marcucci - *INFN-Pisa & Pisa University, Pisa (Italy)*

Chiral symmetry - QCD with u and d quarks only

$$q = \begin{pmatrix} u \\ d \end{pmatrix} \qquad q_{R/L} = \frac{(1 \pm \gamma^5)}{2} q = \begin{pmatrix} u_{R/L} \\ d_{R/L} \end{pmatrix} \qquad \begin{aligned} q'_R &= R q_R = \exp\left(-i\vec{\theta}_R \cdot \vec{\tau}/2\right) q_R \\ q'_L &= L q_L = \exp\left(-i\vec{\theta}_L \cdot \vec{\tau}/2\right) q_L \end{aligned}$$

$\vec{\theta}_R = \vec{\theta}_L = \vec{\theta}_V$: isospin transformation $\quad \vec{\theta}_R = -\vec{\theta}_L = \vec{\theta}_A$: axial transformation

- $\mathcal{L}_{QCD}$ (almost) invariant under the L, R transformations since m_u, m_d “small”
- also for *locals* transformations introducing external currents

$$\begin{aligned} \mathcal{L} \;=\; & \mathcal{L}^0_{\rm QCD} + \overline{q}_L \gamma^\mu \big(l_\mu(x) + \frac{1}{3} v^{(s)}{}_\mu(x)\big) q_L + \overline{q}_R \gamma^\mu \big(r_\mu(x) + \frac{1}{3} v^{(s)}{}_\mu(x)\big) q_R \\ & - \overline{q}_R(x)\big(s(x) + i p(x)\big) q_L(x) - \overline{q}_L(x)\big(s(x) - i p(x)\big) q_R(x) \end{aligned}$$

- $r_\mu(x) \rightarrow r'_\mu(x) = R(x) r_\mu(x) R^\dagger(x) + i R(x) \partial_\mu R^\dagger(x)$, etc

- The external current are related to $A_\mu(x)$ and $W^\pm_\mu(x)$ to reproduce the EM and weak interactions of the quarks
- Example

$$\begin{aligned} r_\mu(x) &= l_\mu(x) = -e \frac{\tau_z}{2} \mathcal{A}_\mu(x) \qquad v^{(s)}_\mu(x) = -\frac{e}{2} \mathcal{A}_\mu(x) \\ \mathcal{L}_{em} &= -e \mathcal{A}_\mu \left(\frac{2}{3} \overline{u} \gamma^\mu u - \frac{1}{3} \overline{d} \gamma^\mu d \right) \end{aligned}$$

Non-linear realization of the chiral symmetry for hadrons

[Weinberg, 1968, 1990],[CCWZ, 1969],[Gasser & Leutwyler, 1984], . . .

"Compensator field" h

- $u = \exp(i\vec{\pi}\cdot\vec{\tau}/2f_\pi)$
- $u' = Luh^\dagger = huR^\dagger$
- $h \equiv h(L, R, \pi)$

Nucleons

- $N' = hN$
- However $(\partial_\mu N)$ does not transform "covariantly"

$$u_\mu = i[u^\dagger(\partial_\mu - ir_\mu)u - u(\partial_\mu - il_\mu)u^\dagger] \qquad D_\mu = \partial_\mu + \frac{1}{2}[u^\dagger(\partial_\mu - ir_\mu)u + u(\partial_\mu - il_\mu)u^\dagger] - iv_\mu^{(s)}$$

- Transformations: $u'_\mu = hu_\mu h^\dagger \qquad (D_\mu N)' = hD_\mu N$
- Lagrangian $\mathcal{L}_{\pi N} = \overline{N}\left(i\gamma^\mu D_\mu - m_N + \frac{g_A}{2}\gamma^\mu\gamma^5 u_\mu\right)N + \cdots + C_S\overline{N}N\overline{N}N + \cdots$
- it contains an infinite number of LECs
- Contributions organized as an expansion over $(Q/\Lambda_\chi)^\nu \quad [\Lambda_\chi \approx 1 \text{ GeV}]$

NN, $3N$, ..., potentials from the EFT

NN Potential V

- Two methods:
  - S-matrix: for a given process $NN \to NN$ define V so that (on-shell) $\langle NN|T_{\rm EFT}|NN\rangle \equiv \langle NN|T_V|NN\rangle$
  - Unitary transformation: find U in order to decouple $|NN\rangle$ Hilbert space from $|NN\pi\rangle$, etc.
- Realization thanks to the chiral counting: all terms can be organized as powers of Q/Λ_χ, $Q \sim$ small momenta or the pion mass
- Alternatively: Lattice χEFT [Lee *et al.*, 2010]

Example

- $T_{\rm EFT} = T_V \equiv V + VG_0V + \cdots \qquad G_0 = (E - H_0 + i\epsilon)^{-1}$
- $T_{\rm EFT} \equiv T^{(0)}_{\rm EFT} + T^{(1)}_{\rm EFT} + T^{(2)}_{\rm EFT} \ldots \qquad V \equiv V^{(0)} + V^{(1)} + V^{(2)} \ldots \qquad T^{(n)}_{\rm EFT},\, V^{(n)} \sim Q^n$

$$\langle \mathbf{p}'_1\mathbf{p}'_2|\, V^{(n')}G_0V^{(n)}\,|\mathbf{p}_1\mathbf{p}_2\rangle = \sum_{\mathbf{p}''_1\mathbf{p}''_2} \frac{\langle \mathbf{p}'_1\mathbf{p}'_2|\, V^{(n')}\,|\mathbf{p}''_1\mathbf{p}''_2\rangle\langle \mathbf{p}''_1\mathbf{p}''_2|\, V^{(n)}\,|\mathbf{p}_1\mathbf{p}_2\rangle}{E_{\mathbf{p}_1}+E_{\mathbf{p}_2}-E''_{\mathbf{p}_1}-E''_{\mathbf{p}_2}+i\epsilon} \sim Q^{n+n'+1}$$

- Then $V^{(0)} = T^{(0)}_{\rm EFT} \qquad V^{(1)} = T^{(1)}_{\rm EFT} - V^{(0)}G_0V^{(0)}$, etc

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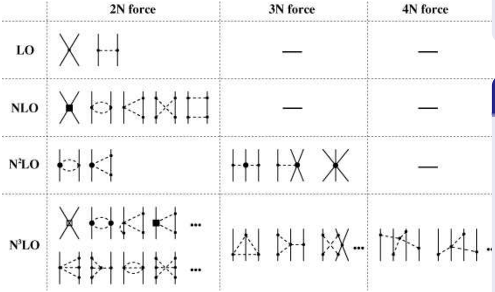
$$\langle \boldsymbol{p}'_1\boldsymbol{p}'_2|\,V^{(n')}G_0V^{(n)}\,|\boldsymbol{p}_1\boldsymbol{p}_2\rangle = \sum_{\boldsymbol{p}''_1\boldsymbol{p}''_2} \frac{\langle \boldsymbol{p}'_1\boldsymbol{p}'_2|\,V^{(n')}\,|\boldsymbol{p}''_1\boldsymbol{p}''_2\rangle\,\langle \boldsymbol{p}''_1\boldsymbol{p}''_2|\,V^{(n)}\,|\boldsymbol{p}_1\boldsymbol{p}_2\rangle}{E_{\boldsymbol{p}_1} + E_{\boldsymbol{p}_2} - E''_{\boldsymbol{p}_1} - E''_{\boldsymbol{p}_2} + i\epsilon} \sim Q^{n+n'+1}$$

- Then $V^{(0)} = T^{(0)}_{\rm EFT} \qquad V^{(1)} = T^{(1)}_{\rm EFT} - V^{(0)}G_0V^{(0)}$, etc

NN & 3N interaction

For more information see for example
[Epelbaum *et al*., NPA **714**, 535 (2003)]



NN interaction

- J-N3LO [Epelbaum and Coll, 1998-2006]
- I-N3LO [Entem & Machleidt, 2003]

Part of the LEC's fitted to the NN database or πN database

3N interaction

- J-N2LO [Epelbaum *et al*, 2002]
- N-N2LO [Navratil, 2007]
- 3N force at N3LO [see Kreb's talk]

– At N2LO there are two LECS c_D and c_E: fitted to some 3N data (see later)
– At N3LO no new parameters
– At N4LO 10 new LECs [Girlanda *et al., 2011*]

EM current

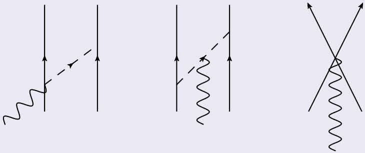
Basic problem: transition $|\alpha\rangle + \gamma \longrightarrow |\beta\rangle$

$$\langle\beta|H_{e.m.}|\alpha;\boldsymbol{q}\lambda\rangle = \langle\Psi_\beta|\mathcal{K}_1|\Psi_\alpha\rangle \qquad \mathcal{K}_1 = \frac{-e}{\sqrt{2\omega\Omega}}\int d\boldsymbol{x}\; e^{i\boldsymbol{q}\cdot\boldsymbol{x}}\;\widehat{\epsilon}_{\boldsymbol{q}\lambda}\cdot\hat{\boldsymbol{J}}(\boldsymbol{x})$$

- $\mathcal{K}_1$ acts only on the nucleons' d.o.f.
- $|\alpha\rangle$, $|\beta\rangle$ initial & final nuclear states, Ψ_α, Ψ_β corresponding w.f.
- $\boldsymbol{q}$, ω, $\hat{\epsilon}_{\boldsymbol{q}\lambda}$ = momentum, energy, polarization of the emitted photon
- for virtual photons, one needs also the m.e. of $\hat{\boldsymbol{q}}\cdot\widehat{\boldsymbol{J}}$ and ρ

$$J^\mu(\boldsymbol{q}) = \int d\boldsymbol{x}\; e^{i\boldsymbol{q}\cdot\boldsymbol{x}}\;\widehat{J}^\mu(\boldsymbol{x}) \qquad \mu = 0, 1, 2, 3$$

Meson exchange currents



$$\widehat{\boldsymbol{J}}(\boldsymbol{x}) = \sum_i \widehat{\boldsymbol{j}}_i(\boldsymbol{x}) + 2B + 3B + \ldots$$

Current conservation $\nabla \cdot \widehat{\boldsymbol{J}}(\boldsymbol{x}) = -i[H, \rho(\boldsymbol{x})]$

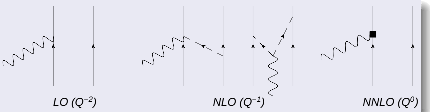
- Strict interplay between H, $\widehat{\boldsymbol{J}}$ and $\widehat{\rho}$

$$\widehat{\rho}(\boldsymbol{x}) = \sum_{i=1}^{A} \frac{1+\tau_z(i)}{2} \delta(\boldsymbol{r}_i - \boldsymbol{x})$$

  - [Buchmann *et al*, 1985]
  - [Riska, 1989], [Schiavilla *et al*, 1990]
- EFT approach: H and J^μ derived from the same Lagrangian.

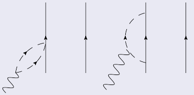
Current at N3LO

[Park *et al*, 1993], [Kolling *et al*, 2009], [Pastore *et al*, 2009]

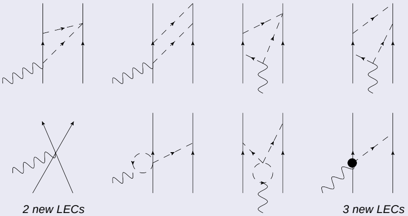


black square= $(Q/M_N)^2$ relativistic correction to the $NN\gamma$ vertex

Note: $NN\gamma$ vertex
$= (e_N/2M_N)(\boldsymbol{p}+\boldsymbol{p}') + i(e_N+\kappa_N)\mu_N(\boldsymbol{\sigma}\times\boldsymbol{q})$
it takes into account the Pauli term + pion loop corrections



N3LO (Q^1) terms



black dot= three $(Q/\Lambda_\chi)^2$ vertices

Most of the LECs enter also the NN potential. There are 5 uncostrained LECs ($\rightarrow \mu_d$, $\mu_{^3\mathrm{H}}$, $\mu_{^3\mathrm{He}}$, etc.)

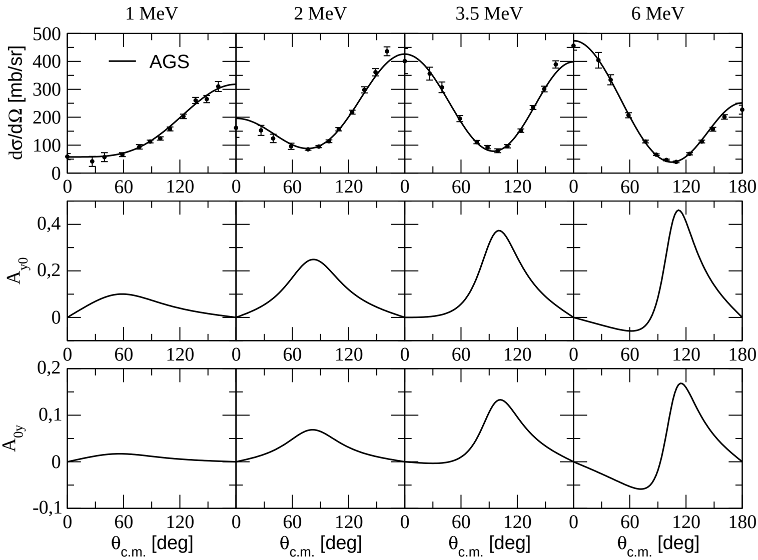
Wave functions

HH variational method: A. Kievsky, S. Rosati, MV, L.E. Marcucci, and L. Girlanda J. Phys. G, **35**, 063101 (2008)

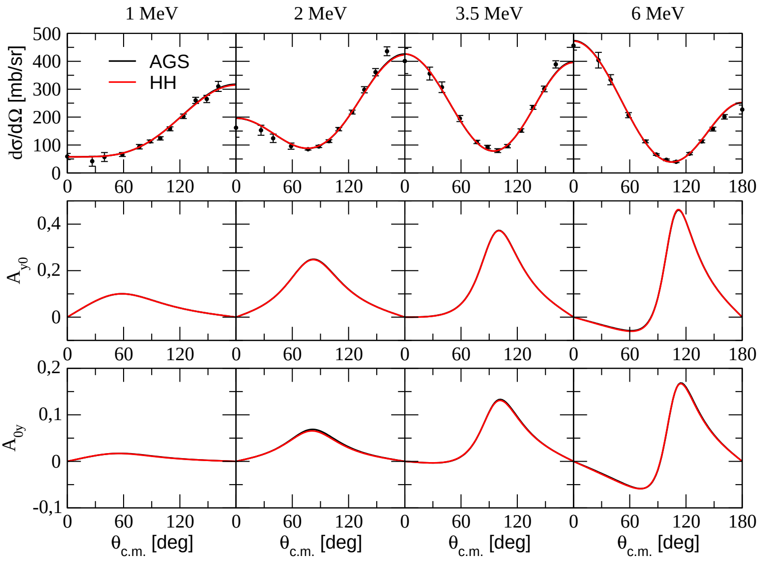
A benchmark for $A = 4$

- AGS: Deltuva & Fonseca, PRL **98** 162502 (2007)
- FY: Lazauskas & Carbonell, PRC **70**, 044002 (2004)
- $n - {}^3\mathrm{H}$ & $p - {}^3\mathrm{He}$ elastic scattering $0 \leq E_{c.m.} \leq B_3 - B_2 \approx 5.5$ MeV
- NN interaction models:
  - AV18 [Wiringa, Stoks & Schiavilla (1995)]
  - I-N3LO [Entem & Machleidt (2003)]
  - V_{low-q} [Bogner, Kuo & Schwenk, (2003)] (derived from the CD-Bonn potential [Machleidt (2001)])
- Results reported in [MV *et al.*, 2011]

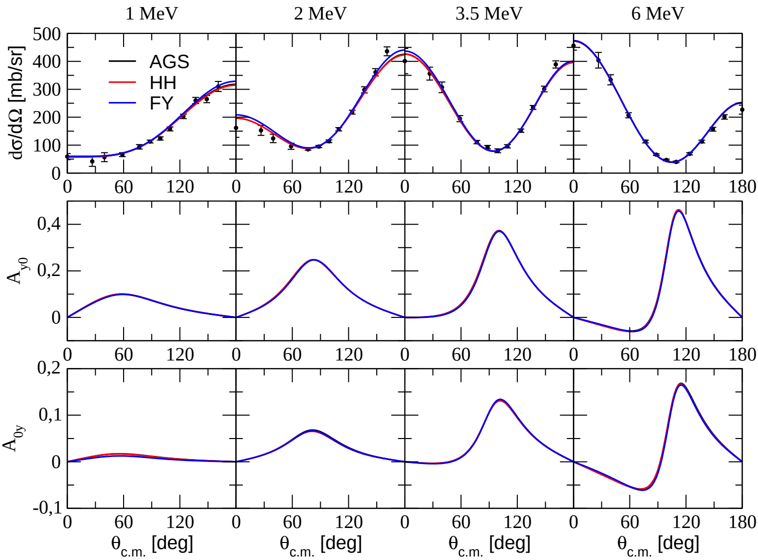
$n - {}^3\mathrm{H}$ scattering (I-N3LO pot.)



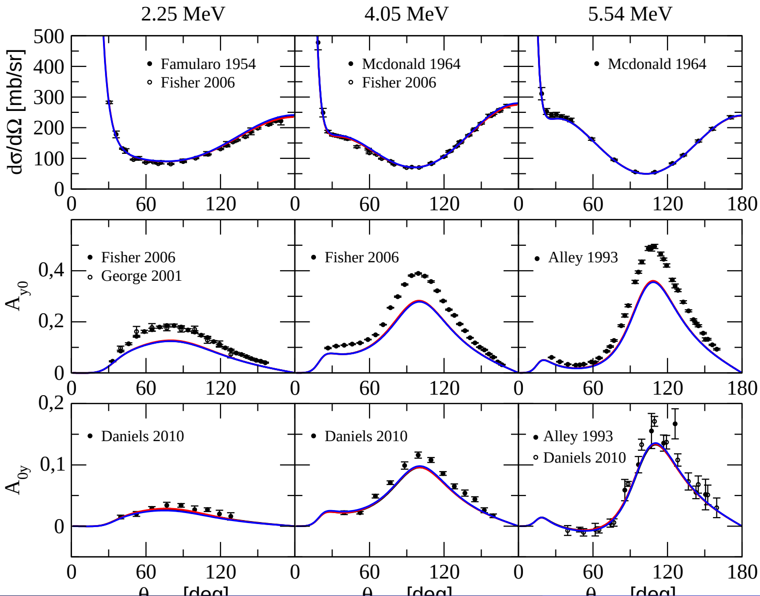
$n - {}^3\mathrm{H}$ scattering (I-N3LO pot.)



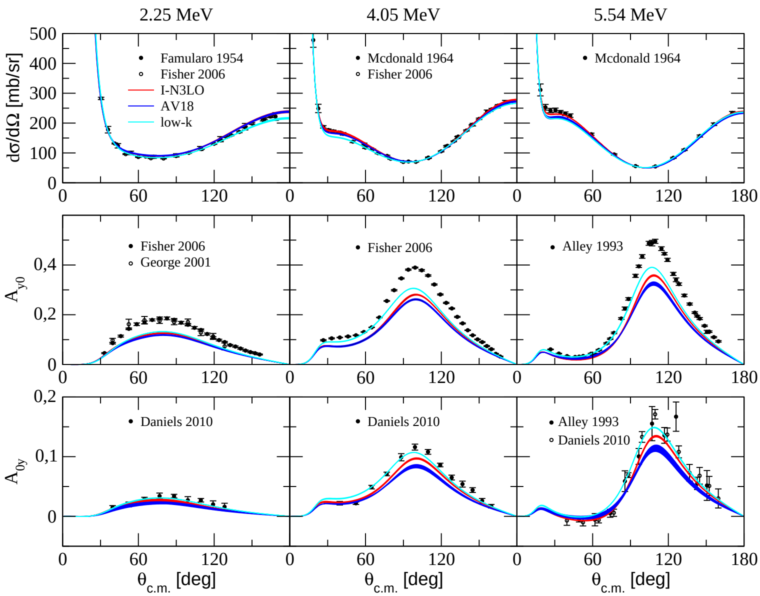
$n - {}^3\mathrm{H}$ scattering (I-N3LO pot.)

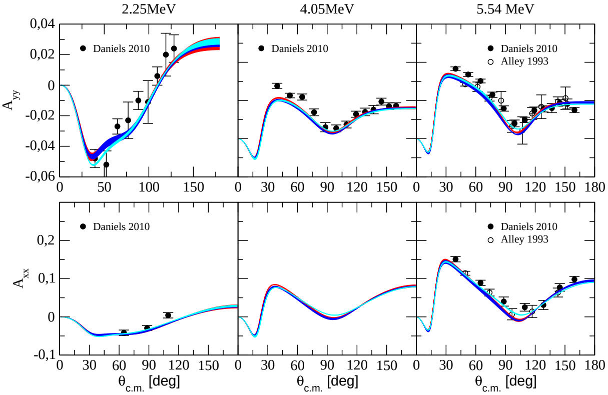


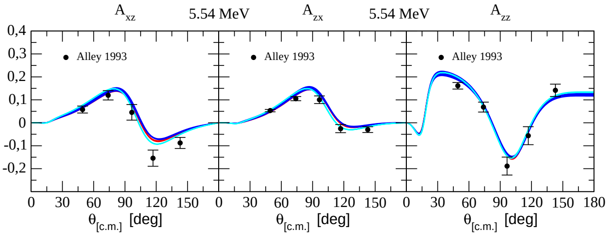
$p - {}^3$He scattering (I-N3LO pot.)



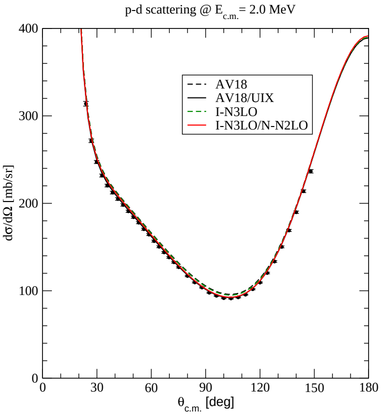
Predictions by different potentials

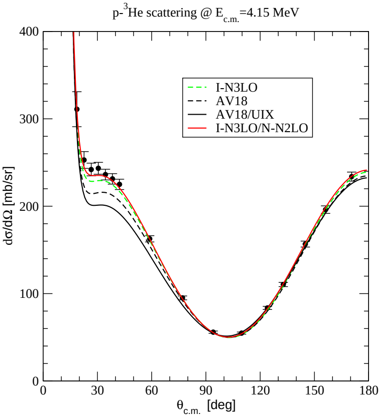



2.25MeV
4.05MeV
5.54 MeV
A_yy
A_xx
Daniels 2010
Alley 1993
θ_c.m. [deg]

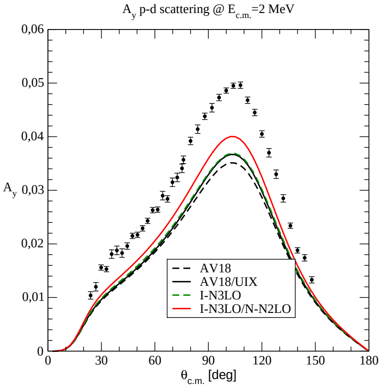

A_xz
5.54 MeV
A_zx
5.54 MeV
A_zz
Alley 1993
θ_[c.m.] [deg]

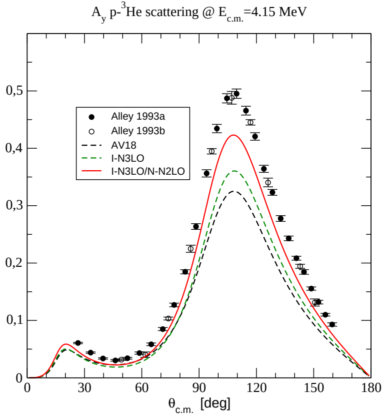
Results for $A = 3, 4$ (1)





Results for $A = 3, 4$ (2)





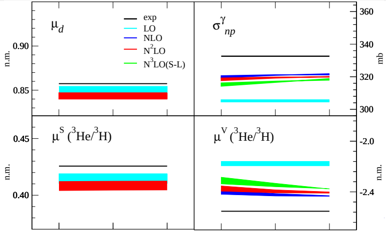
Study of the 3N force in $A = 4$ scattering in progress

Current at N3LO ($\mathcal{O}(Q)$) $\leftrightarrow$ NN potential at NLO ($\mathcal{O}(Q^2)$)

$$\boldsymbol{q} \cdot \widehat{\boldsymbol{J}}(\boldsymbol{q}) = -[H, \rho(\boldsymbol{q})]$$

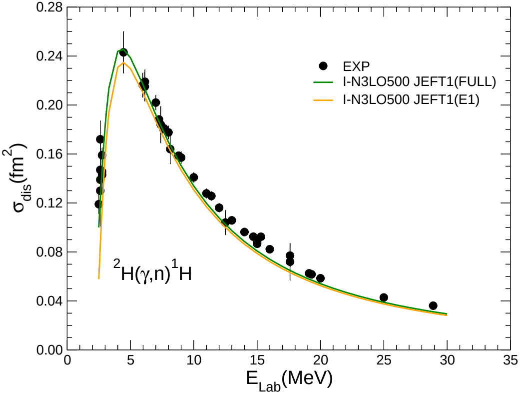
Fit of the LECs

- We have constructed a NN potential at NLO and fitted the corresponding LECs to the NN database: [Pastore *et al.*, 2009]
- In $\boldsymbol{J}$ there are 5 additional LECs: fitted to the $A = 2, 3$ magnetic moments & $n - p$ capture cross section at thermal energies using the I-N3LO NN potential
- The model depends on a cutoff Λ ($\Lambda = 500 - 600$ MeV)
  - the dependence on Λ is used to test the convergence
  - [Girlanda *et al.*, 2010]



Deuteron-photodisintegration

- Wave functions calculated using I-N3LO for $\Lambda = 500$ & 600 MeV
- Observable dominated by the E1 transitions



$n-d$ & $n-{}^3\mathrm{He}$ radiative captures at thermal energies

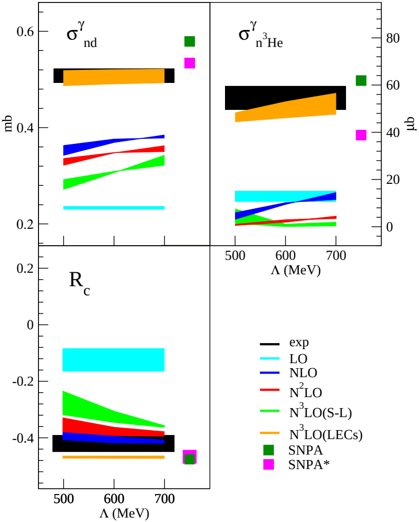
- $n-d$ capture from the $^2S_{1/2}$ & $^4S_{3/2}$ waves
- $n-{}^3\mathrm{He}$ capture from the $^3S_1$ wave

Scattering lenghts

Case	I-N3LO/N-N2LO	Expt.
a_{nd} doublet	0.675	0.645(10)
a_{nd} quartet	6.342	6.35(2)
$a_{n^3\mathrm{He}}$ doublet	3.37	3.278(53)

$n-d$ & $n-{}^3\mathrm{He}$ capture cross sections

Order	σ_{n-d} [mb]	$\sigma_{n-{}^3\mathrm{He}}$ [μb]
LO	0.235	10.6
+NLO	0.361	5.9
+N2LO	0.334	0.9
+N3LO (loops)	0.276	1.4
+N3LO (LECs)	0.478	48.4
Expt	0.508(15)	52(4)



Compton scattering (1)

Nucleon Polarizabilities

- Induced dipoles by an EM field: $\mathbf{d} = \alpha \mathbf{E} \quad \boldsymbol{\mu} = \beta \mathbf{B}$

$$H_{eff} = -2\pi \left[\alpha \mathbf{E}^2 + \beta \mathbf{B}^2 + \gamma_{E1E1} \boldsymbol{\sigma} \cdot \left(\mathbf{E} \times \frac{\partial \mathbf{E}}{\partial t} \right) + \cdots \right]$$

Experimental status [Griesshammer *et al.*, 2012]

- proton: from $\gamma p \to \gamma p$ experiments (MAMI [de Lèon *et al.*, 2001], ...)
  - $\alpha_p = (10.7 \pm 0.3(\text{stat}) \pm 0.2(\text{Baldin}) \pm 0.8(\text{theory}))\ 10^{-4}\text{fm}^3$
  - $\beta_p = (3.1 \pm 0.3(\text{stat}) \pm 0.2(\text{Baldin}) \pm 0.8(\text{theory}))\ 10^{-4}\text{fm}^3$
- neutron: from $\gamma d \to \gamma d$ experiments or with other methods
  - Data sparse and not accurate [Illinois (1994), SAL (2000), Lund (2003)]
  - $\alpha_n = (11.1 \pm 1.8(\text{stat}) \pm 0.4(\text{Baldin}) \pm 0.8(\text{theory}))\ 10^{-4}\text{fm}^3$
  - $\beta_n = (4.1 \mp 1.8(\text{stat}) \pm 0.4(\text{Baldin}) \pm 0.8(\text{theory}))\ 10^{-4}\text{fm}^3$
  - Theory input needed to separate: 1) structure effects 2) MEC effects
- New experiments on d, ^3He, ^6Li planned/in progress at TUNL/HγGS, MaxLab (Lund), S-DALINAC (Darmstaad)

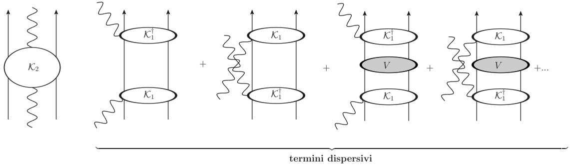
Compton scattering (2)

Status of the calculations

- First applications to γN: [Bernard *et al*, 1992]
- Recent applications to γd:
  - [Beane *et al*, 2004]: NNLO, no rescattering
  - [Griesshammer & Shukla, 2009]: NLO, rescattering calculated with AV18
  - Review: [Griesshammer *et al.*, 2012]
- Only a few applications to $\gamma^3\mathrm{He}$

Aims of the new calculation

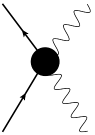
- $NN\gamma \rightarrow NN$ transition operators derived from the EFT at N3LO [Pastore *et al.*, 2009]
- *NN* interaction derived from the same EFT (at present we have used the I-N3LO potential by Entem & Machleidt)
- Future: applications to $^3\mathrm{He}$ and ^{6}Li

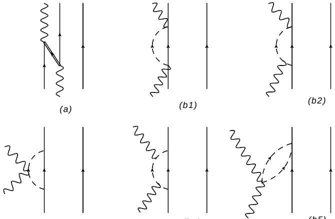


$$\langle d_f \gamma_f | \mathcal{T} | d_i \gamma_i \rangle = \langle \Psi_f^d | \mathcal{K}_2 + \underbrace{\mathcal{K}_1^\dagger G \mathcal{K}_1 + \mathcal{K}_1 G \mathcal{K}_1^\dagger}_{\text{Dispersive part}} | \Psi_i^d \rangle$$

- The Green function $G = (E - H + i\epsilon)^{-1}$ describes the rescattering of the *NN* pair between the two EM vertices
  - *NN* interaction from [Entem & Machleidt, 2003]
- The irriducible "kernel" $\mathcal{K}_2$ derived from the EFT at NLO ($\sim Q^{-2}$) (PRELIMNARY)
  - In literature $\mathcal{K}_2$ is derived up to NNLO [Griesshammer *et al*, 2012]
  - inclusion of Δ d.o.f. $\rightarrow$ [Hildebrandt Ph.D. Thesis, München, 2005]

Diagrams (1)





- Diagrams (a): contribution to $\mathcal{K}_2$ "seagull" (SG) & "spin-orbit" (SO)

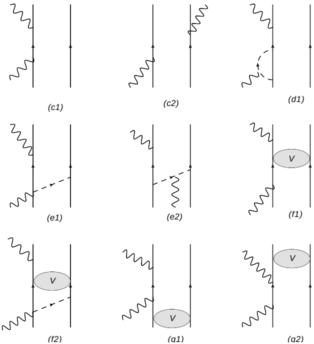
$$\mathcal{K}_2^{(SG)} = \sum_j \frac{e_j}{2M} \boldsymbol{\epsilon}_i \cdot \boldsymbol{\epsilon}_f^* e^{i(\boldsymbol{q}-\boldsymbol{q}')\cdot \boldsymbol{r}_j} \;, \quad e_j = \frac{1+\tau_z^j}{2}$$

  - Note: the SG can be derived from $H_{NR} = (1/2M)(\boldsymbol{p} - e\boldsymbol{A})^2$
  - SG: order $\sim Q^{-3}$, SO=corrections to the SG $\sim Q^{-2}$

- Diagrams (b): contribution to $\mathcal{K}_2$ from the "polarization" of the nucleon
  - They can be used to estimate α and β [Bernard *et al*, 1992]
  - We'll consider α and β as free parameters $(\alpha_j = \alpha_p(1+\tau_z^j)/2 + \alpha_n(1-\tau_z^j)/2)$

$$\mathcal{K}_2^{(\alpha\beta)} = \sum_j \Big[-2\pi\alpha_j \boldsymbol{\epsilon}_i \cdot \boldsymbol{\epsilon}_f^* q q' - 2\pi\beta_j (\boldsymbol{q} \times \boldsymbol{\epsilon}_i) \cdot (\boldsymbol{q}' \times \boldsymbol{\epsilon}_f^*) \Big] e^{i(\boldsymbol{q}-\boldsymbol{q}')\cdot \boldsymbol{r}_j}$$

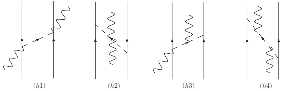
Diagrams (2)



- Diagrams (c-f): Contributions taken into account by the "dispersive" part

$$\langle \Phi_d^f | \mathcal{K}_1^\dagger G \mathcal{K}_1 + \mathcal{K}_1 G \mathcal{K}_1^\dagger | \Phi_d^i \rangle$$

  - (c1), (f1) $\sim Q^{-3}$, (e1), (f2) $\sim Q^{-4}$
  - Exact resummation [Ishikawa *et al.*, 1998]
  - $|\Psi_1\rangle = G\mathcal{K}_1 |\Phi_d^i\rangle$
  - $|\Psi_2\rangle = G\mathcal{K}_1^\dagger |\Phi_d^i\rangle$
  - $(E - H + i\epsilon)|\Psi_1\rangle = \mathcal{K}_1 |\Phi_d^i\rangle$ $(E = q - B_d > 0)$
  - $(E - H + i\epsilon)|\Psi_2\rangle = \mathcal{K}_1^\dagger |\Phi_d^i\rangle$
    $(E = -q' - B_d < 0)$
- Diagrams (g): contribution taken into account by the fact that $|\Phi_d\rangle$ are solution of the Schroedinger equation



- Diagrams (h): Contribution to $\mathcal{K}_2$

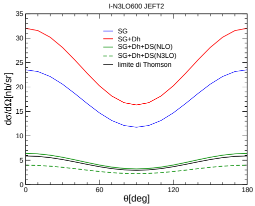
Test

Photodisintegration

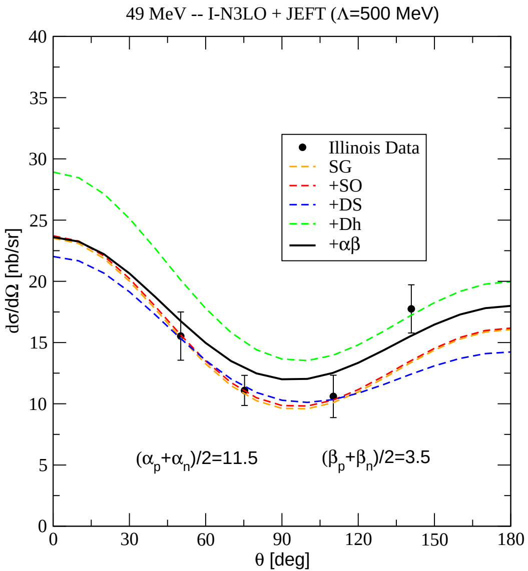
- $\Im[\langle\Phi_d^f|\mathcal{K}_1^\dagger G\mathcal{K}_1|\Phi_d^i\rangle \sim \sigma_{\gamma+d\to n+p}$
- In our calculation $[\langle\Phi_d^f|\mathcal{K}_1^\dagger G\mathcal{K}_1|\Phi_d^i\rangle = \langle\Phi_d^f|\mathcal{K}_1^\dagger|\Psi_1\rangle$
- At $E_\gamma = 20$ MeV $\sigma_{\gamma+d\to n+p} = 540.7\ \mu$b: we find 541.1 μb (I-N3LO + JEFT $\Lambda = 500$ MeV)

Thomson limit

- For $E_\gamma \to 0$, the calculation should reproduce the Thomson limit
- Compton amplitude $\mathcal{M}^{(TL)} = e^2/M_d$ (note: $\mathcal{M}^{(SG)} = e^2/M \approx 2\mathcal{M}^{(TL)}$)
- True if V, $\mathcal{K}_1$, and $\mathcal{K}_2$ are consistent (current conservation)

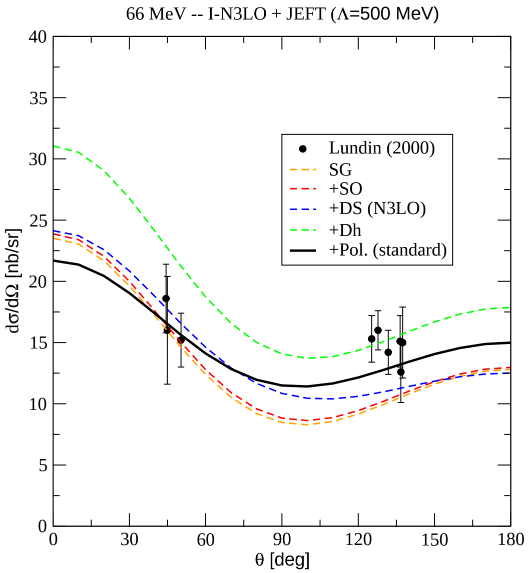


Results (1)



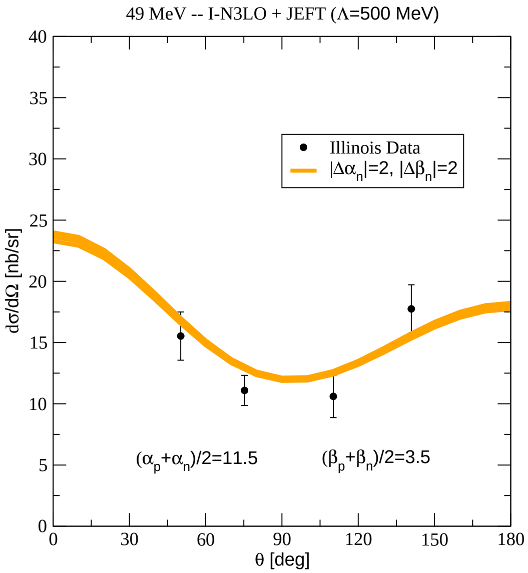
49 MeV -- I-N3LO + JEFT (Λ=500 MeV)
dσ/dΩ [nb/sr]
θ [deg]
0
5
10
15
20
25
30
35
40
0
30
60
90
120
150
180
Illinois Data
SG
+SO
+DS
+Dh
+αβ
(α_p+α_n)/2=11.5
(β_p+β_n)/2=3.5

Results (2)

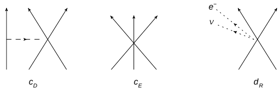


66 MeV -- I-N3LO + JEFT (Λ=500 MeV)
Lundin (2000)
SG
+SO
+DS (N3LO)
+Dh
+Pol. (standard)
dσ/dΩ [nb/sr]
θ [deg]
0
5
10
15
20
25
30
35
40
0
30
60
90
120
150
180

Sensitivity to α_n & β_n



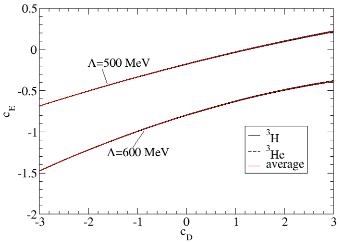
β-decay and the 3N force

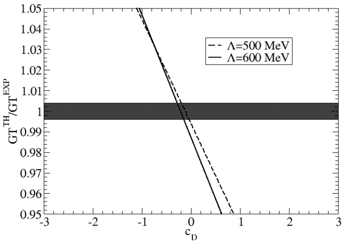


[Gardestig & Phillips, 2006], [Gazit *et al.*, 2009]

$$d_R = \frac{M_n}{\Lambda_\chi g_A} c_D + \frac{1}{3} M_N (c_3 + 2c_4)$$

New fit of c_D and c_E
using ^{3}H binding energy and tritium β-decay lifetime





New versions of the 3N at N2LO: first application for μ-capture on d and ^{3}He [Marcucci *et al.*, 2012]

pp capture at astrophysical energies

Aim: new calculation of the astrophysical factor S_{11} of the $p + p \rightarrow {}^2H + e^- + \bar{\nu}_e$ reaction

$$S_{11}(E) = S_{11} + S'_{11}E + \frac{1}{2}S''_{11}E^2 + \cdots$$

Preliminary Results – units 10^{-25} MeV b
I-N3LO NN interaction + weak transition operator derived from EFT

	S_{11}	S'_{11}/S_{11} [MeV^{-1}]	S''_{11}/S_{11} [MeV^{-2}]
LO $\Lambda = 500$	3.98	11.7	270
LO $\Lambda = 600$	3.96	11.7	270
Full $\Lambda = 500$	4.05	11.7	270
Full $\Lambda = 600$	4.03	11.7	270

Outlook

Motivations of this work

- consistent calculations for a variety of processes using potential/current/wave functions derived from the same EFT

Applications

- Main interest: test of 3N interaction in $A = 3, 4$ systems, study of reactions of astrophysical interest
  - $p - d$ & $d - d$ captures, form factors of light nuclei, *ldots*)
  - Compton scattering on $^3\mathrm{He}$ & ^{6}Li (in the near future new data at HIγS & Lund)
  - weak transitions (*pp* capture, μ-capture, parity-violation in nuclei, ...)