

Chiral Dynamics: 2 Photons and Few Nucleons

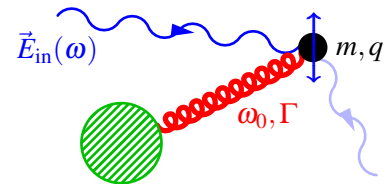
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Compton Scattering $\gamma X \rightarrow \gamma X$ Tests Low-Energy QCD

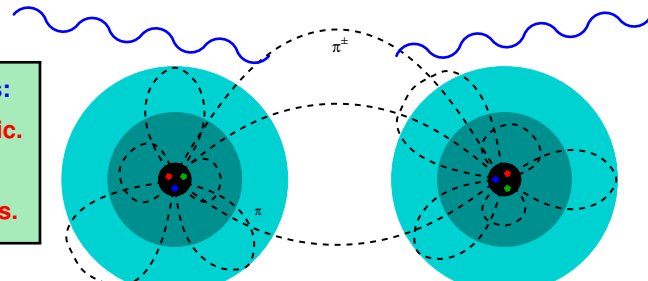
cf. Phillips, Howell, Ahmed, Tiburzi, ...

Phillips, Howell: **Polarisabilities: scales, symmetries & mechanisms** of interactions with & among constituents:
 Clean, perturbative probe of χ iral symmetry of pion-cloud
 iso-spin breaking, $\Delta(1232)$ properties,
 spin-constituents: nucleonic bi-refringence (Faraday effect).
 Lattice-QCD gears up for results.



$$\mathcal{L}_{\text{pol}} = 2\pi \left[\underbrace{\alpha_{E1}(\omega)\vec{E}^2 + \beta_{M1}(\omega)\vec{B}^2}_{\text{electric, magnetic scalar dipole}} + \underbrace{\gamma_{E1E1}(\omega)\vec{\sigma} \cdot (\vec{E} \times \dot{\vec{E}}) + \gamma_{M1M1}(\omega)\vec{\sigma} \cdot (\vec{B} \times \dot{\vec{B}}) + \dots}_{\text{spin-dependent dipole}} \right]$$

Neutron polarisabilities from few-nucleon targets:
 Subtract binding model-independently, systematic.
 + Understanding of charged-pion NN force.
 $\Rightarrow \chi$ EFT for $A = 0 - 6$ for reliable uncertainties.



Guide, Support, Analyse, Predict Polarised Experiments

Unpol./linear/circular beam on scalar/vector/tensor target \Rightarrow 23 indep. deuteron observables

Constraints: rates, detector settings, partial beam/target polarisations, Sum rules, . .

HI γ S, MAMI: Exp. & theory collaborate on *observables with biggest impact* using *mathematica notebooks*.

Photon energy $\omega = 120 \text{ MeV}$

Reference frame cm lab

Deuteron vec or polarisation $P_1^{(0)} = 1.1'$

Deuteron tensor polarisation $P_2^{(0)} = 0.53'$

Photon right-circular polarisation $P_{\text{rc}}^{(2)} = 0.1'$

Photon linear polarisation $P_{\text{lin}}^{(2)} = 1.1'$

Configuration 1

Deuteron polarisation quantisation axis $\theta_{d1} = 0^\circ$

$\phi_{d1} = 0^\circ$

Photon linear polarisation angle $\phi_{\text{lin}1} = 90^\circ$

Configuration 2

Deuteron polarisation quantisation axis $\theta_{d2} = 90^\circ$

$\phi_{d2} = 90^\circ$

Photon linear polarisation angle $\phi_{\text{lin}2} = 90^\circ$

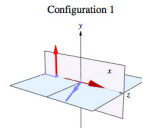
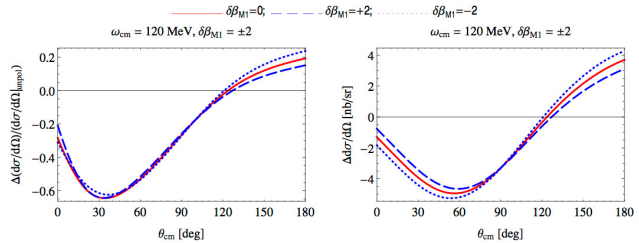
Variation by ± 2 of $\delta\beta_{M1}$

χ^2 EFT order $e^2\delta^3 = e^3$, with $\Delta(1232)$ $e^2\delta^2 = Q^2$, no $\Delta(1232)$

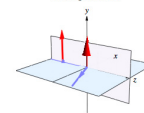
Deuteron wave function NNLO Epelbaum 650MeV AV18

NN potential AV18

Range on y-axis All



Probability of spin projection M_d^z :
Cartesian polarisation along \hat{d} :



$p_x = 0.91'$ $p_y = 0.08'$ $p_z = 0.01'$
 $P_2^{(0)} = 0.9'$ $P_2^{(2)} = 0.75'$

Example double-polarised on deuteron hg EPJA49 (2013) 100

$$\Delta \frac{d\sigma}{d\Omega} - \frac{d\sigma}{d\Omega}_{\text{unpol}} \times [0 + 0.78 T_{1,-1}^{(0)} - 0.78 T_{1,1}^{(0)} + 0.78 T_{1,-1}^{(2)} - 0.32 T_{1,-2}^{(2)} + 0.8 T_{2,0}^{(0)} - 0.8 T_{2,0}^{(2)} + 0.32 T_{2,2}^{(0)} - 0.32 T_{2,2}^{(2)}]$$

Spin-polarisabilities to 20%: 80 to 200 MeV, 100% polarised: $\lesssim 10^7 \frac{\text{photons}}{\text{s MeV}} \times 1000 \text{ hrs}$ per observable.

χ EFT Goals for Compton/Polarisabilities:

- **Comprehensive, unified picture into resonance region:**
p: done; deuteron: done for $\omega \lesssim m_\pi$; ^3He : only $\omega \sim [80 - 120]$ MeV
- **Connect lattice-QCD and experiment with competitive errors.**
- **Continue close collaboration with US experimenters at HI γ S, MAMI.**

Compton@ χ EFT Collaboration: hg, McGovern (U. Manchester), Phillips (Ohio U.), ...

Deliverables: Extractions with Reproducible Error Estimates

- **Identify proton-neutron difference: isospin breaking of pion cloud, μH ,...**
- **Extract spin-polarisabilities to $\lesssim 20\%$ accuracy.**

Intensity & Precision Frontier: *“At present, single and double polarised data is sorely missing.”* Theory letter [arXiv:1409.1512]

Experiment: $\frac{d\sigma}{d\Omega} \propto (\text{target-charge})^{2 \text{ to } 1} \implies$ more & easier targets, better signals

Theory: Reliable extraction needs accurate description of binding & levels: **computational resources for $A \geq 3$.**

Find sweet-spot between competing forces: ^3He , ^4He , ^6Li (HI γ S data!): Find Most Cost-Effective!

χ EFT for few- N systems provides important answers with quantifiable errors (Compton is one example).