

Spin Polarisabilities and Compton Scattering from χ EFT: Bridging Between QCD and Data



THE GEORGE
WASHINGTON
UNIVERSITY
WASHINGTON DC

H. W. Grießhammer

Institute for Nuclear Studies
The George Washington University, DC, USA



- ① Two-Photon Response Explores System Dynamics
- ② Polarisabilities from Compton Scattering
- ③ Spin Polarisabilities and Nucleon Spin Structure
- ④ Concluding Questions



How do constituents of the nucleon react to external fields?

How to reliably extract proton, neutron, spin polarisabilities?

How to bridge between QCD and Nuclear Physics?



Comprehensive Theory Effort:

hg, J. A. McGovern (Manchester), D. R. Phillips (Ohio U): *Eur. Phys. J.* **A49** (2013) 12 (proton)

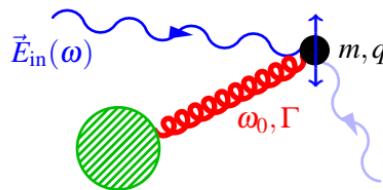
hg/JMcG/DRP/G. Feldman: *Prog. Part. Nucl. Phys.* **67** (2012) 841; as COMPTON@MAX-lab: *Phys. Rev. Lett.* **113** (2014) 262506

hg: *Eur. Phys. J.* **A49** (2013) 100 [arXiv:1304.6594 [nucl-th]]; hg/Hemmert/Hildebrandt: *Eur. J. Phys.* **A20** (2003), 329 [nucl-th/0308054]

1. Two-Photon Response Explores System Dynamics

(a) Polarisabilities: Stiffness of Charged Constituents in El.- Mag. Fields

Example: induced electric dipole radiation from harmonically bound charge, damping Γ Lorentz/Drude 1900/1905



$$\vec{d}_{\text{ind}}(\omega) = \frac{q^2}{m} \underbrace{\frac{1}{\omega_0^2 - \omega^2 - i\Gamma\omega}}_{=: 4\pi \alpha_{E1}(\omega)} \vec{E}_{\text{in}}(\omega)$$

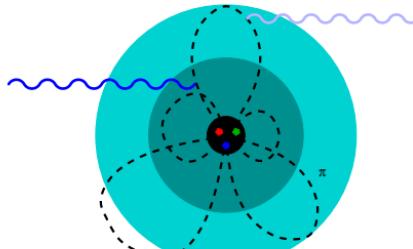
$$\mathcal{L}_{\text{pol}} = 2\pi \left[\underbrace{\alpha_{E1}(\omega) \vec{E}^2 + \beta_{M1}(\omega) \vec{B}^2}_{\text{electric, magnetic scalar dipole}} + \dots \right]$$

“displaced volume” [10⁻³ fm³]



Energy- (ω)-dep. multipoles for interaction scales, symmetries & mechanisms with & among constituents.

⇒ Clean, perturbative probe of $\Delta(1232)$ properties, nucleon spin-constituents,
chiral symmetry of pion-cloud & its breaking (proton-neutron difference).

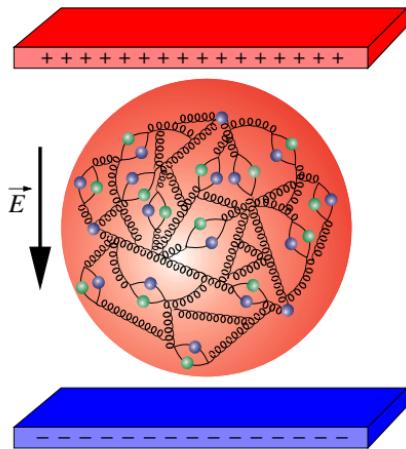


- Fundamental hadron property
- **Contributes to Nucleon Self Energy:**
 $\beta_{M1}^p - \beta_{M1}^n$ in elmag. p-n mass split $M_\gamma^p - M_\gamma^n \approx [1.1 \pm 0.5]$ MeV
Gasser/Leutwyler+Hoferichter/Rusetsky 1975/2015; Walker-Loud/Miller/Carlson 2012
- **Contributes to 2γ :** Lamb shift in muonic H (β_{M1}), proton radius

(b) En Route to Static Polarisabilities from Lattice QCD: Chiral Extrapolations

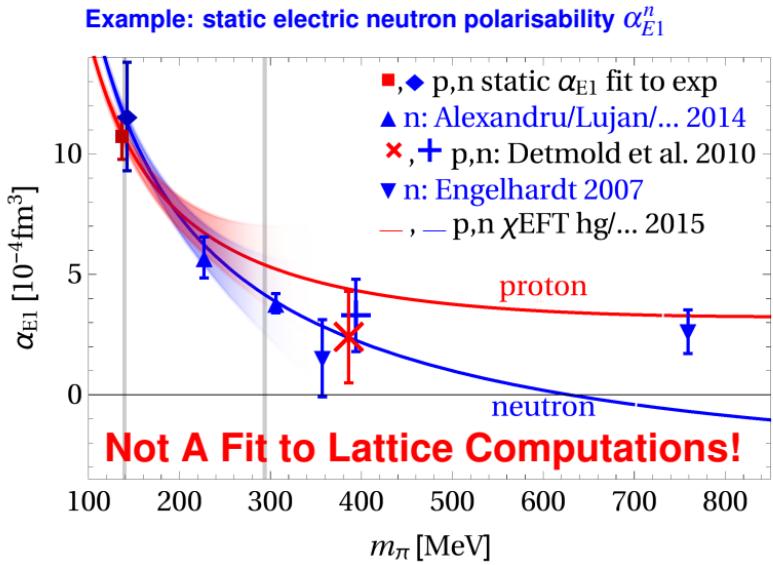
Towards comparable uncertainties in experiment, χ EFT and lattice QCD:

χ EFT at $\mathcal{O}(e^2 \delta^4)$ provides reliable error estimate for $\frac{m_\pi}{\Lambda_\chi}$ extrapolation.



Active lattice groups:

Alexandru/Lee/... 2005-;
Engelhardt/LHPC 2006-;
EMC/NPLQCD 2006-, 2015;
Leinweber/Primer/Hall/... 2013-



(c) There Is Money In It...

2015 LRP: Great progress has been made in determining the electric and magnetic polarizabilities. Within the next few years, data are expected from [HI γ S] that will allow accurate extraction of proton-neutron differences and spin polarizabilities....

2015 QCD White Paper: "Synergistic Blend of Theory and Experiment"

Lattice QCD: relate to fundamental interactions

→ polarQCD (Alexandru/Lee) 2005-; NPLQCD 2006-; LHPC (Engelhardt) 2007-; Leinweber/... (Adelaide) 2013

Experiment: Significant investments; data taken/scheduled/approved:

HI γ S (DOE): a central goal; > 3000 hrs committed at 60 – 100 MeV

proton doubly & beam pol. (E-06-09/10)

deuteron beam pol. (E-18-09, running)

^3He unpol & doubly pol. (E-07-10, E-08-16)

^4He unpol

^6Li unpol. (E-15-11, first!)

A2 @ MAMI (DFG: 5-year SFB): running, data cooking and planned

proton 100 – 400 MeV: beam & target pol.

deuteron, ^3He , ^4He unpol., beam & target pol.

MAXlab: data cooking

deuteron 100 – 160 MeV: unpol.

Chiral EFT: data consistency, binding effects, analysis, extraction

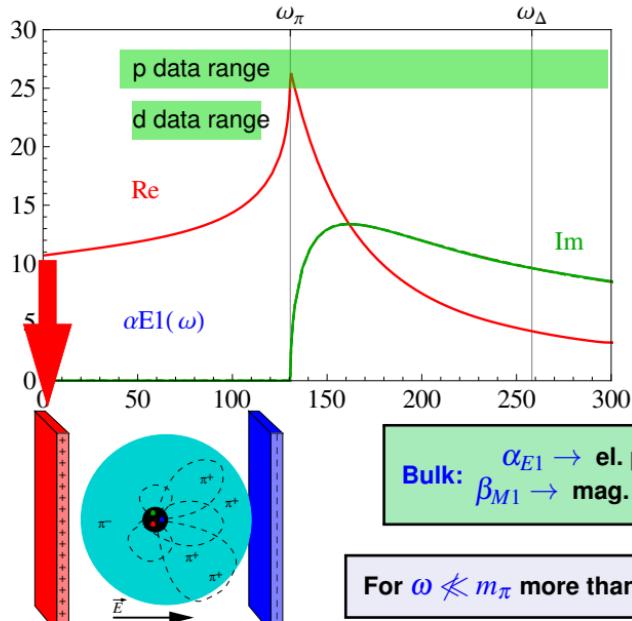
**Goal: Unified framework with reliable error bars for
proton, deuteron, ^3He (elastic & inelastic) into $\Delta(1232)$ region.**

Polarisabilities: *Energy-dependent* Multipoles of real Compton scattering.

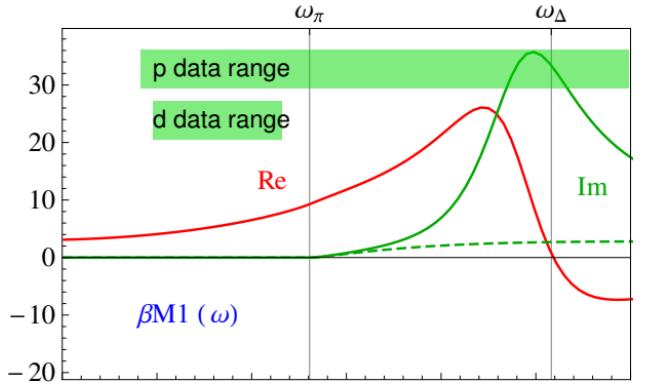
$$2\pi \left[\alpha_{E1}(\omega) \vec{E}^2 + \beta_{M1}(\omega) \vec{B}^2 + \gamma_{E1E1}(\omega) \vec{\sigma} \cdot (\vec{E} \times \dot{\vec{E}}) + \gamma_{M1M1}(\omega) \vec{\sigma} \cdot (\vec{B} \times \dot{\vec{B}}) + \dots \right]$$

Neither more nor less information about *two-photon response* of constituents, but **more readily accessible**.

$\alpha_{E1}(\omega)$: Pion cusp well captured by single- $N\pi$.



$\beta_{M1}(\omega)$: para-magnetic N -to- Δ M1-transition.



Bulk: $\alpha_{E1} \rightarrow$ el. permittivity $\epsilon(\omega)$
 $\beta_{M1} \rightarrow$ mag. permeability $\mu(\omega)$ Re: refraction; Im: absorption

For $\omega \ll m_\pi$ more than “static+slope”! \Rightarrow Need to understand **dynamics!**

2. Polarisabilities from Compton Scattering

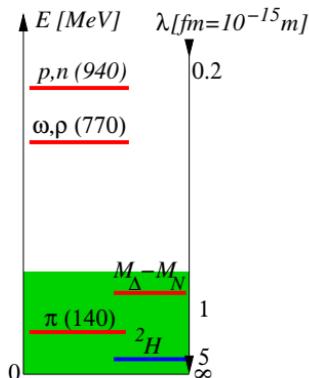
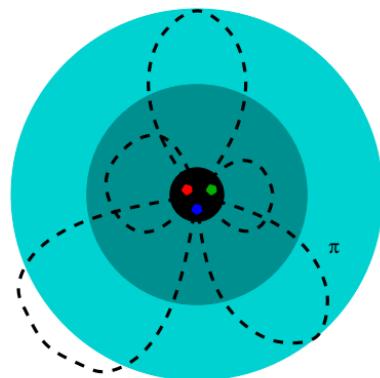
(a) The Method: Chiral Effective Field Theory

Degrees of freedom $\pi, N, \Delta(1232)$ + all interactions allowed by symmetries: Chiral SSB, gauge, iso-spin, ...

⇒ Chiral Effective Field Theory $\chi\text{EFT} \equiv$ low-energy QCD

$$\mathcal{L}_{\chi\text{EFT}} = (D_\mu \pi^a)(D^\mu \pi^a) - m_\pi^2 \pi^a \pi^a + \dots + N^\dagger [i D_0 + \frac{\vec{D}^2}{2M} + \frac{g_A}{2f_\pi} \vec{\sigma} \cdot \vec{D} \pi + \dots] N + C_0 (N^\dagger N)^2 + \dots$$

Controlled approximation ⇒ Model-independent, error-estimate.



Expand in $\delta = \frac{M_\Delta - M_N}{\Lambda_\chi} \approx 1 \text{ GeV}$ $\approx \sqrt{\frac{m_\pi}{\Lambda_\chi}} = \frac{p_{\text{typ}}}{\Lambda_\chi} \ll 1$ (numerical fact) Pascalutsa/Phillips 2002.

(b) All 1N Contributions to N⁴LO

Bernard/Kaiser/Meißner 1992-4, Butler/Savage/Springer 1992-3, Hemmert... 1998
 McGovern 2001, hg/Hemmert/Hildebrandt/Pasquini 2003
 McGovern/Phillips/hg 2013

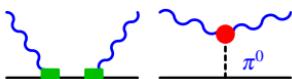
Unified Amplitude: gauge & RG invariant set of all contributions which are

in low régime $\omega \lesssim m_\pi$ at least N⁴LO ($e^2 \delta^4$): accuracy $\delta^5 \lesssim 2\%$;
 or in high régime $\omega \sim M_\Delta - M_N$ at least NLO ($e^2 \delta^0$): accuracy $\delta^2 \lesssim 20\%$.

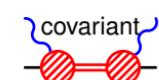
$$\omega \lesssim m_\pi \quad \approx M_\Delta - M_N \\ \approx 300 \text{ MeV}$$



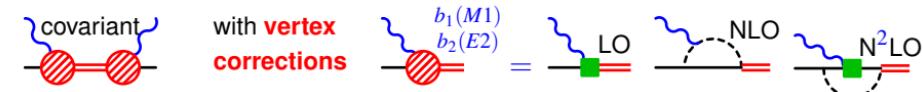
$e^2 \delta^0$ LO $e^2 \delta^0 \searrow$ NLO



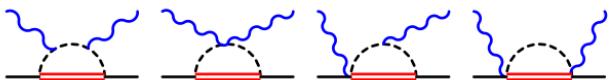
$e^2 \delta^2$ N²LO $e^2 \delta^1$ N²LO



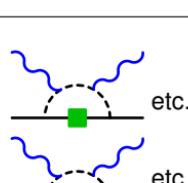
with vertex corrections



$e^2 \delta^3$ N³LO $e^2 \delta^{-1}$ ↗ LO

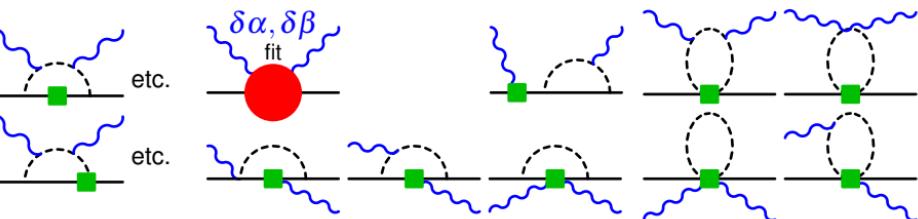


$e^2 \delta^3$ N³LO $e^2 \delta^1$ N²LO



$\delta\alpha, \delta\beta$
fit

etc.



$e^2 \delta^4$ N⁴LO $e^2 \delta^2$ N³LO

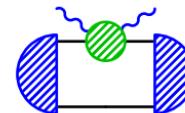
Unknowns: short-distance $\delta\alpha, \delta\beta \iff$ static α_{E1}, β_{M1}

(c) Neutron Polarisabilities and Nuclear Binding

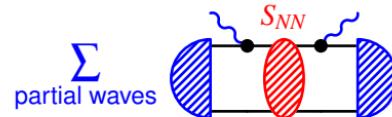
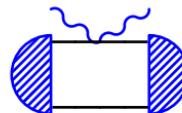
hg/...+Phillips/+McGovern 2004-2014
MECs: Beane/... 1999-2005

- Nucleon structure: average of neutron & proton polarisabilities:

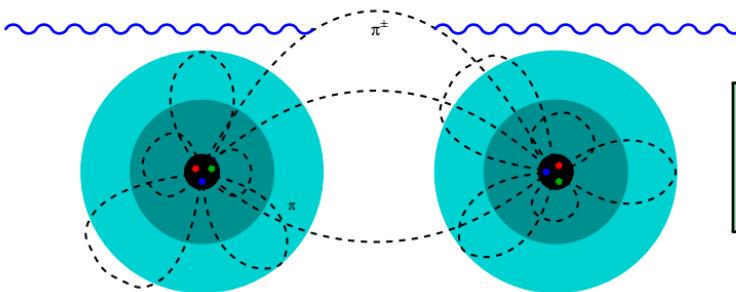
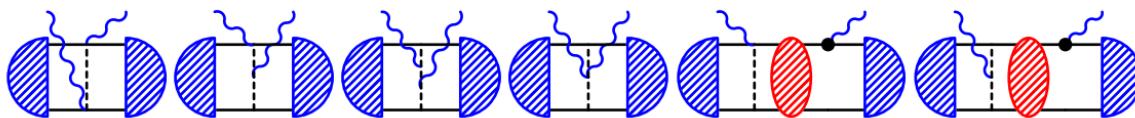
χ EFT, Disp. Rel.: p-n difference is small hg/Pasquini/... 2005



- Parameter-free one-nucleon contributions:

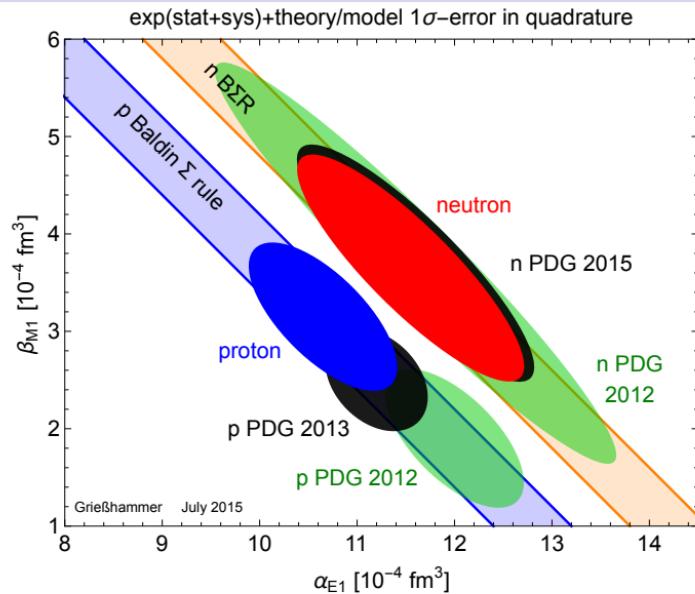
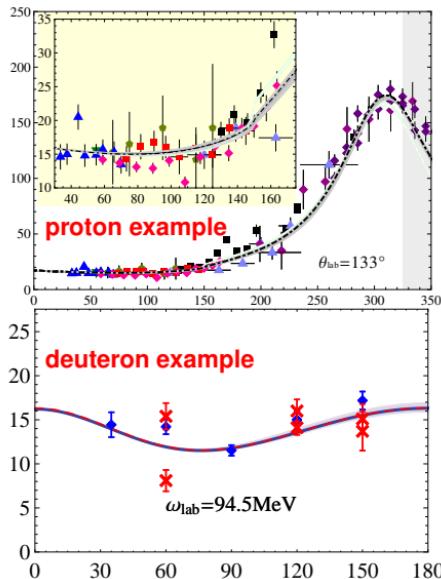


- Parameter-free charged meson-exchange currents dictated in χ EFT by gauge & chiral symmetry:



Model-independently subtract binding
 $\Rightarrow \chi$ EFT: reliable uncertainties.
Test charged-pion component of NN force.

(d) Scalar Dipole Polarisabilities: Values, Data and Theory Errors in χ EFT



proton (Baldin, N²LO)
McGovern/Phillips/hg EPJA 2013
neutron, new data from
Compton@MAXlab
COMPTON@MAX-lab PRL 2014

$$\alpha_{E1} [10^{-4} \text{ fm}^3]$$

$$10.65 \pm 0.35_{\text{stat}} \pm 0.2_{\Sigma} \pm 0.3_{\text{theory}}$$

$$\beta_{M1} [10^{-4} \text{ fm}^3]$$

$$3.15 \pm 0.35_{\text{stat}} \pm 0.2_{\Sigma} \pm 0.3_{\text{theory}}$$

$$\chi^2/\text{d.o.f.}$$

$$113.2/135$$

$$11.55 \pm 1.25_{\text{stat}} \pm 0.2_{\Sigma} \pm 0.8_{\text{theory}}$$

$$3.65 \pm 1.25_{\text{stat}} \pm 0.2_{\Sigma} \pm 0.8_{\text{theory}}$$

$$45.2/44$$

→ neutron \approx proton polarisabilities; exp. error dominates.

(e) Targeting & Switching Off Polarisabilities

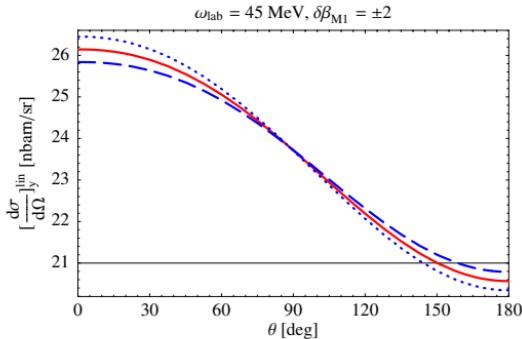
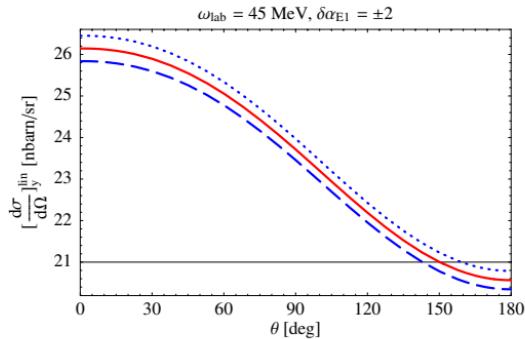
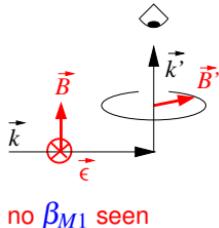
Maximon 1994 (proton)

p: hg/Hildebrandt 2003-5; d: hg/Shukla 2010, hg 2013;

hg/McGovern/Phillips 2015

$$\mathcal{L}_{\text{pol}} = 4\pi N^\dagger \left\{ \frac{1}{2} \left[\alpha_{E1}(\omega) \left(\omega^2 (\vec{\epsilon} \cdot \vec{\epsilon}'^\dagger) \right) + \beta_{M1}(\omega) \left((\vec{k} \times \vec{\epsilon}) \cdot (\vec{k}' \times \vec{\epsilon}'^\dagger) \right) \right] + \dots \right\} N$$

Example: photon linearly polarised perp. to scatt. plane, $\omega = 45$ MeV, $\theta = 90^\circ$, deuteron unpolarised



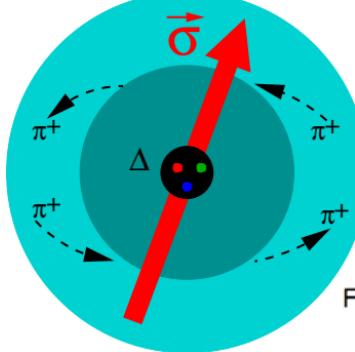
Unaffected by orbital ang. momentum in deuteron; Weller H1γS approved for $\omega = 65$ MeV circpol.

Only in cross-sections of special configurations; not for asymmetries!

3. Spin Polarisabilities and Nucleon Spin Structure

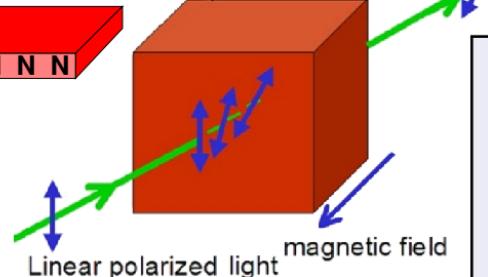
(a) Spin Polarisabilities: Nucleonic Bi-Refringence and Faraday Effect

Optical Activity: Response of spin-degrees of freedom, experimental frontier.



Faraday active crystal

$$\begin{aligned} \mathcal{L}_{\text{pol}} = 4\pi N^\dagger \times & \left\{ \frac{1}{2} \left[\alpha_{E1} \vec{E}^2 + \beta_{M1} \vec{B}^2 \right] \right. & \text{scalar dipole} \\ & + \frac{1}{2} \left[\gamma_{E1E1} \vec{\sigma} \cdot (\vec{E} \times \dot{\vec{E}}) + \gamma_{M1M1} \vec{\sigma} \cdot (\vec{B} \times \dot{\vec{B}}) \right. & \text{"pure" spin-dependent dipole} \\ & \left. - 2 \gamma_{M1E2} \sigma_i B_j E_{ij} + 2 \gamma_{E1M2} \sigma_i E_j B_{ij} \right] + \dots \left. \right\} N \\ & \left. \text{"mixed" spin-dependent dipole} \right. \\ & \left. + \text{quadrupole etc.} \right. \\ E_{ij} := & \frac{1}{2} (\partial_i E_j + \partial_j E_i) \text{ etc.} \end{aligned}$$

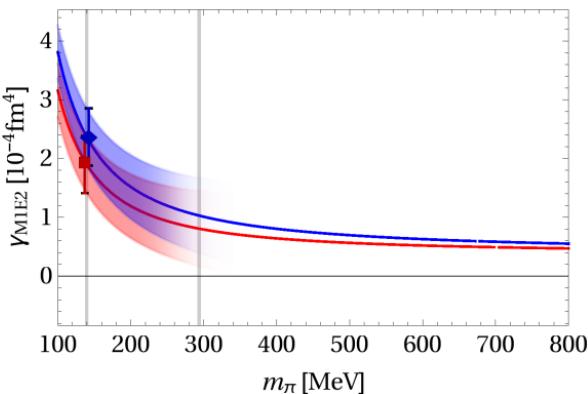
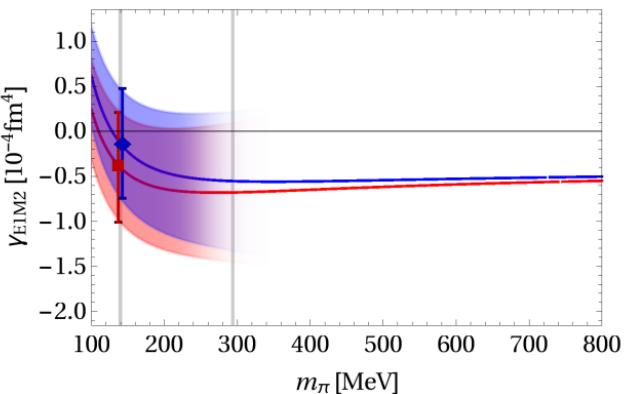
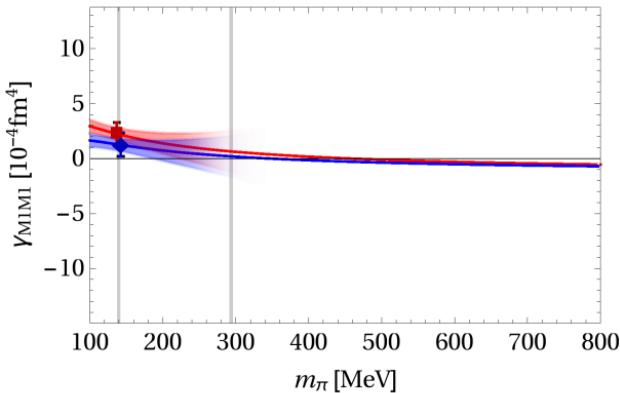
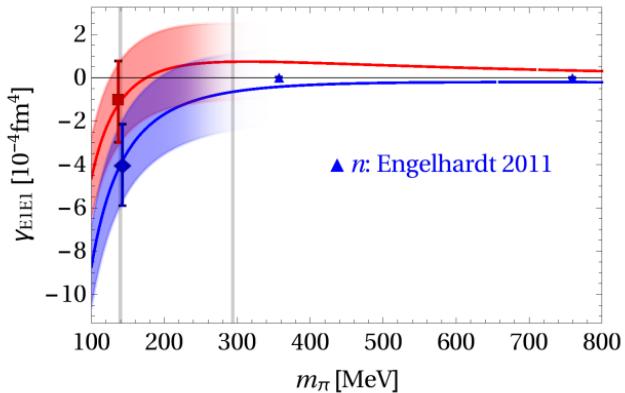


$\pi N \gamma: -\frac{g_A}{2f_\pi} \vec{\sigma} \cdot (\vec{q} + e\vec{\epsilon}) + \dots$
⇒ π emission/absorption
depends on N spin
⇒ **Test chiral Symmetry!**



(b) Spin Polarisabilities: Theory Speaks

χ EFT: Parameter-free predictions; lattice-QCD: Ramping up.

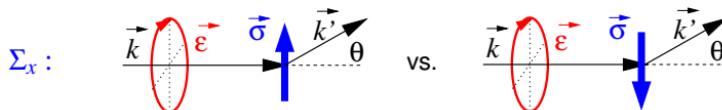


(c) Spin Polarisabilities from Polarised Photons

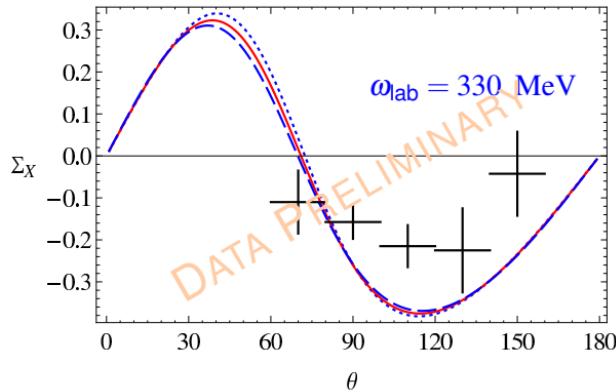
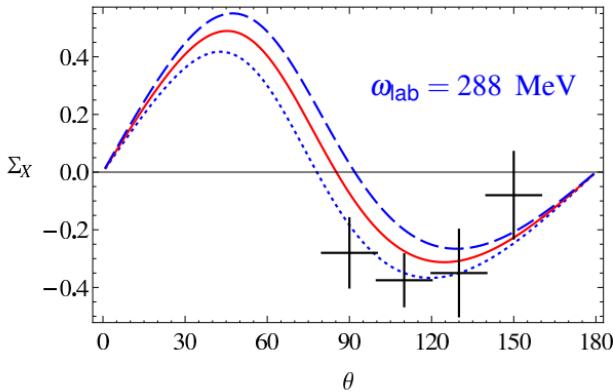
$\mathcal{O}(e^2 \delta^3)$: hg/Hildebrandt/... 2003

$\mathcal{O}(e^2 \delta^4)$: hg/McGovern/Phillips 1511.0952 & in prep.
exp MAMI: Martel/... PRL 2014; Collicott/... t.b.a.

Proton best: Incoming γ circularly polarised, sum over final states. N -spin in (\vec{k}, \vec{k}') -plane, perpendicular to \vec{k} :



$$\gamma_{E1E1} = \text{---} -1.1: \chi_{\text{EFT}} \text{ prediction; } \text{---} -1.1 + 2; \text{ } -1.1 - 2 = -3.1 \leftrightarrow \text{Martel fit: } -3.5 \pm 1.2$$



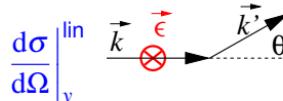
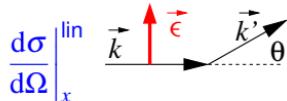
$\mathcal{O}(e^2 \delta^4)$ χ_{EFT} hg/McGovern/Phillips 2014 vs. MAMI extraction Martel/... 2014

static [10^{-4} fm 4]	γ_{E1E1}	γ_{M1M1}	γ_{E1M2}	γ_{M1E2}
MAMI 2014 proton	-3.5 ± 1.2	3.2 ± 0.9	-0.7 ± 1.2	2.0 ± 0.3
χ_{EFT} proton predicted	$-1.1 \pm 1.9_{\text{th}}$	$2.2 \pm 0.5_{\text{stat}} \pm 0.6_{\text{th}}$ fit to unpol.	$-0.4 \pm 0.6_{\text{th}}$	$1.9 \pm 0.5_{\text{th}}$
χ_{EFT} neutron predicted	$-4.0 \pm 1.9_{\text{th}}$	$1.3 \pm 0.5_{\text{stat}} \pm 0.6_{\text{th}}$	$-0.1 \pm 0.6_{\text{th}}$	$2.4 \pm 0.5_{\text{th}}$

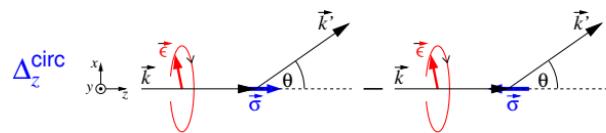
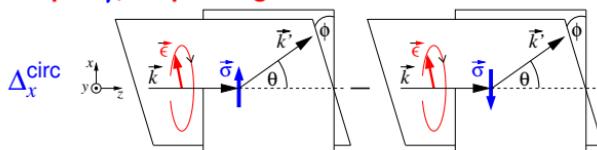
(d) Plethora of Polarised Compton Observables: Proton/Spin- $\frac{1}{2}$

Babusci/... 1998

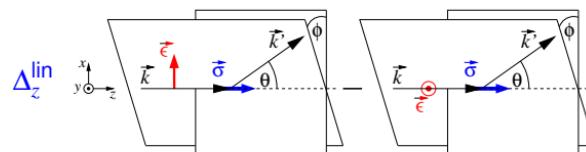
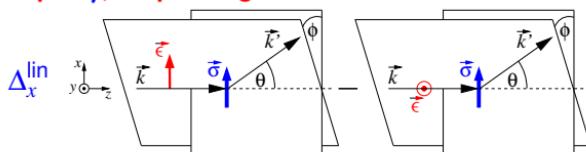
linpol. γ , unpol. target:



circpol. γ , vecpol. target:



linpol. γ , vecpol. target:



$$\text{Differences } \Delta \text{ and asymmetries } \Sigma = \frac{\Delta}{\text{sum}}$$

2×6 observables, 6 polarisabilities, 3 kinemat. variables ω, θ, ϕ + additional constraints:

– scalar polarisabilities α_{E1}, β_{M1}

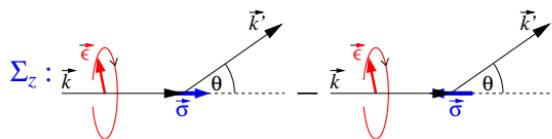
– γ_0, γ_π (???)

– experiment: detector settings,...

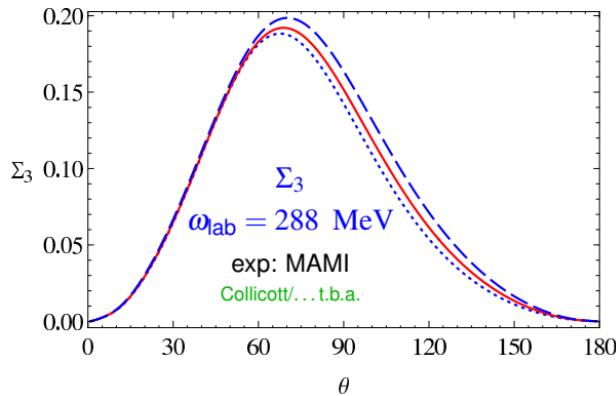
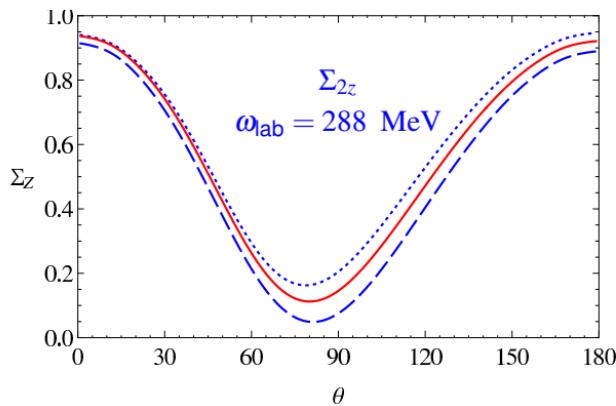
⇒ Interactive mathematica notebooks. hg/...2010-

(e) Spin Polarisabilities from Polarised Photons

$\mathcal{O}(e^2\delta^3)$: hg/Hildebrandt/... 2003
 $\mathcal{O}(e^2\delta^4)$: hg/McGovern/Phillips 1511.0952 & in prep.
 exp MAMI: Martel/... PRL 2014; Collicott/... t.b.a.



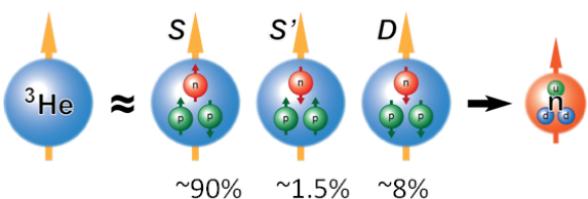
$$\gamma_{E1E1} = \text{---} -1.1; \text{---} -1.1 + 2; \cdots -1.1 - 2$$



Polarisabilities beyond dipoles negligible – ω -dependence important.
 Also good signal for linear polarisations.

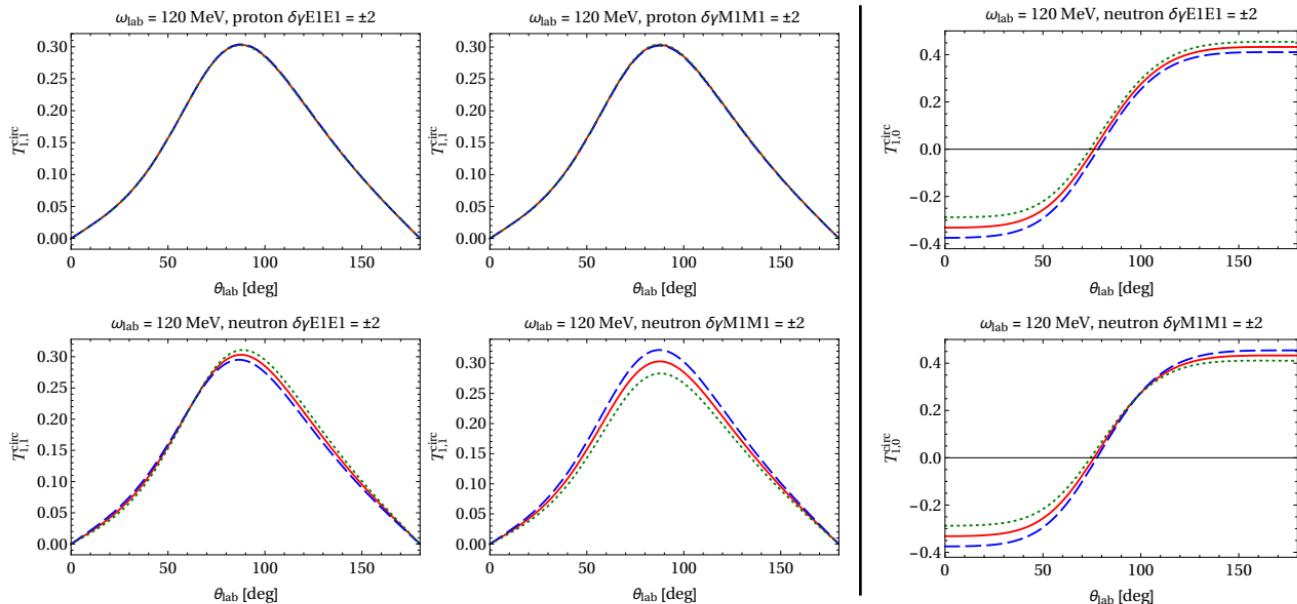
(f) Double-Polarised on ^3He : Effective n Spin Target

Choudhury/Shukla/Phillips/Nogga 2006-09
hg/Phillips/Sandberg/Margaryan 2015-



Example polarised:

Sensitivity on γ^n 's at $\omega_{\text{lab}} = 120$ MeV



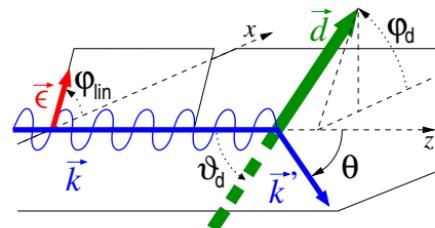
⇒ Polarised- ^3He target with 10^{23} cm^{-2} ?

(g) Plethora of Polarised Compton Observables: Deuteron/Spin-1

hg 2013

Parametrise $d\gamma \rightarrow X$: unpol./linear/circular beam on scalar/vector/tensor target.

$$\frac{d\sigma}{d\Omega} \Big|_{\text{unpol}} \times \left[\begin{array}{l} 1 + \Sigma^{\text{lin}}(\omega, \theta) P_{\text{lin}}^{(\gamma)} \cos 2\phi_{\text{lin}} \\ \quad \text{1 beam asymmetry} \\ + \sum_{\substack{l=1,2 \\ 0 \leq M \leq l}} T_{IM}(\omega, \theta) P_I^{(d)} d_{M0}^l(\theta_d) \cos[M\phi_d - \frac{\pi}{2}\delta_{l1}] \\ \quad \text{4 target asymmetries} \\ + \sum_{\substack{l=1,2 \\ 0 \leq M \leq l}} T_{IM}^{\text{circ}}(\omega, \theta) P_{\text{circ}}^{(\gamma)} P_I^{(d)} d_{M0}^l(\theta_d) \sin[M\phi_d + \frac{\pi}{2}\delta_{l1}] \\ \quad \text{4 circpol. double asymmetries} \\ \quad \text{8 linpol.} \\ + \sum_{\substack{l=1,2 \\ -l \leq M \leq l}} T_{IM}^{\text{lin}}(\omega, \theta) P_{\text{lin}}^{(\gamma)} P_I^{(d)} d_{M0}^l(\theta_d) \cos[M\phi_d - 2\phi_{\text{lin}} - \frac{\pi}{2}\delta_{l1}] \end{array} \right]$$



Differences Δ and asymmetries $\frac{\Delta}{\text{sum}}$

2×18 observables, 6 polarisabilities, 2 kinemat. variables ω, θ + additional constraints:

– scalar polarisabilities α_{E1}, β_{M1} – γ_0, γ_π (???)

Experiment: $P_1 \gtrsim 90\%, P_2 \lesssim 75\% \Rightarrow 100\%!!$, detector settings,...

Excellent vector & tensor targets available. Crabb/Norium/...

(h) Guide, Support, Analyse, Predict Polarised Experiments

hg 2010-13
hg/McGovern/Phillips 2012-

→ Interactive *mathematica* notebooks from hgrie@gwu.edu

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

Reference frame cm lab

Deuteron vector polarisation $P_1^{(d)} = 1.1^\circ$

Deuteron tensor polarisation $P_2^{(d)} = 0.53^\circ$

Photon right-circular polarisation $P_{\text{rc}}^{(r)} = 0^\circ$

Photon linear polarisation $P_{\text{lin}}^{(l)} = 1.1^\circ$

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 $\phi_{\text{lin}2} = 90^\circ$

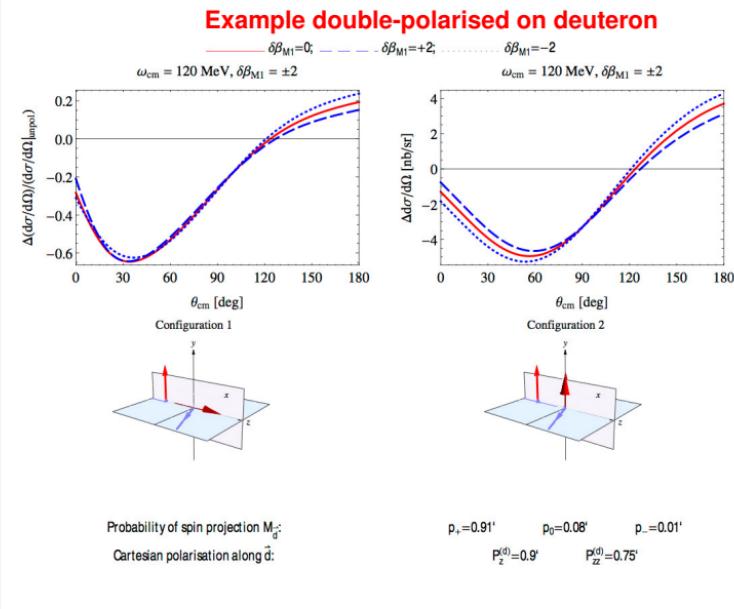
Variation by ± 2 of $\delta\beta_{M1}$

χ^{EFT} order $e^2\delta^2 = e^3$: with $\Delta(123)$ $e^2\delta^2 = Q^3$: no $\Delta(123)$

Deuteron wave function NNLO Epelbaum 650MeV AV18

NN potential AV1.8

Range on y-axis All



Goal: guide & analyse polarised experiments

extend deuteron analysis to 300 MeV

Compton@Web on DAC/SAID website

In progress.

When all in place.

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

(i) Spin Polarisabilities at $\omega_{\text{lab}} = 100$ MeV: Vector & Tensor Deuteron

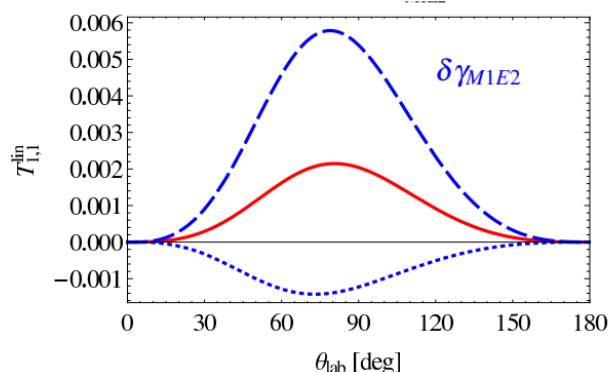
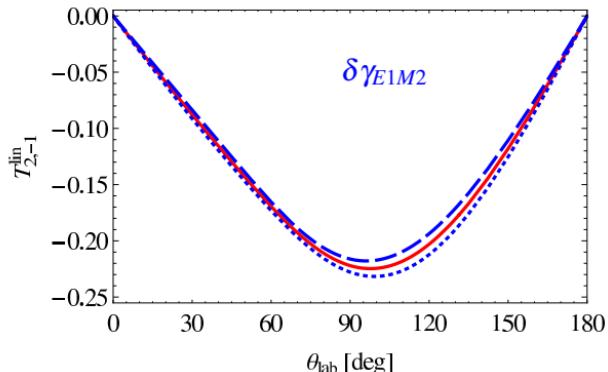
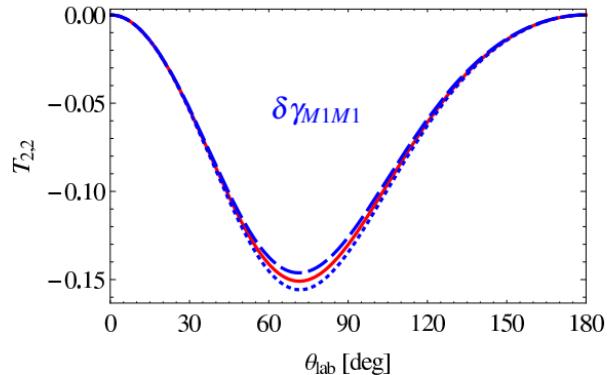
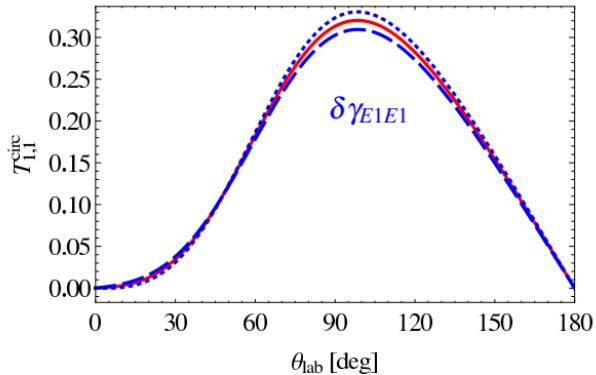
hg 2013

Want very clean observables: Large rates, insensitive to other pols, deuteron wave fu,...

— central;

--- $\delta\gamma_i = +2$;

..... $\delta\gamma_i = -2$

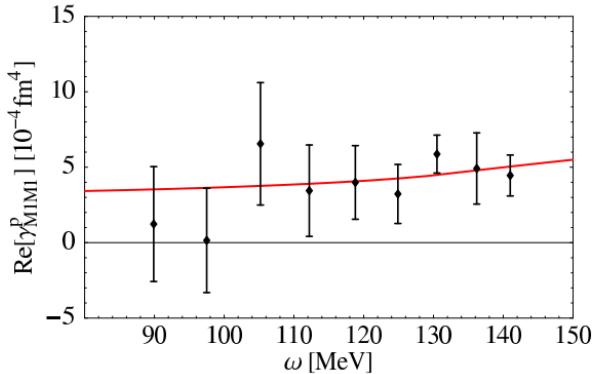
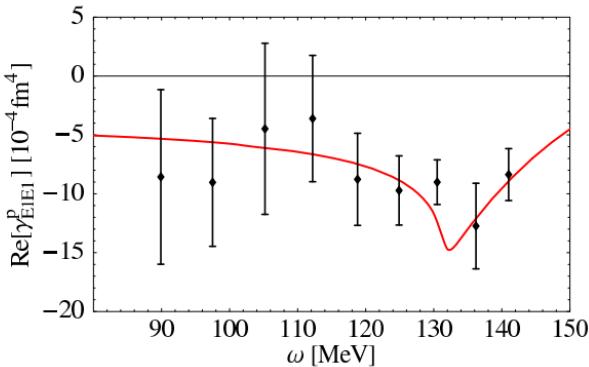


Do not reduce richness of information to just static values!

Multipole Analysis of two-photon response in infancy: Need asymmetry data!

$$4\pi N^\dagger \left\{ \begin{array}{l} \frac{1}{2} \left[\alpha_{E1}(\omega) \vec{E}^2 + \beta_{M1}(\omega) \vec{B}^2 \right] \\ + \frac{1}{2} \left[\gamma_{E1E1}(\omega) \vec{\sigma} \cdot (\vec{E} \times \dot{\vec{E}}) + \gamma_{M1M1}(\omega) \vec{\sigma} \cdot (\vec{B} \times \dot{\vec{B}}) \right. \\ \left. - 2 \gamma_{M1E2}(\omega) \sigma_i B_j E_{ij} + 2 \gamma_{E1M2}(\omega) \sigma_i E_j B_{ij} \right] + \dots \end{array} \right\} N$$

spin-indep. dipole "pure" spin-dep. dipole "mixed" spin-dep. dipole



Assume $\alpha_{E1}(\omega)$, $\beta_{M1}(\omega)$ well captured, only $\gamma_{E1E1}(\omega)$, $\gamma_{M1M1}(\omega)$ large \implies superficial fit to data.

4. Concluding Questions

Polarisabilities: clean probes to relate lattice-QCD to low-energy phenomena.

scales, symmetries & mechanisms of interactions with & among constituents:

Chiral symmetry of pion-cloud, iso-spin breaking, $\Delta(1232)$ properties, nucleon spin-constituents.

Huge synergies between Experiment, Low-Energy Theory χ EFT, Lattice QCD.

Goals: Guide, support, analyse, predict experiments. hg, J. McGovern (U. Manchester), D.R. Phillips (Ohio U.)

Compton amplitude to 350 MeV – Scalar Dipole Polarisabilities from all Compton data below 200 MeV:

proton N²LO $\alpha^p = 10.65 \pm 0.35_{\text{stat}} \pm 0.2_{\Sigma} \pm 0.3_{\text{theory}}$ $\beta^p = 3.15 \pm 0.35_{\text{stat}} \pm 0.2_{\Sigma} \pm 0.3_{\text{theory}}$

neutron NLO $\alpha^n = 11.55 \pm 1.25_{\text{stat}} \pm 0.2_{\Sigma} \pm 0.8_{\text{theory}}$ $\beta^n = 3.65 \pm 1.25_{\text{stat}} \pm 0.2_{\Sigma} \pm 0.8_{\text{theory}}$

Spin Polarisabilities: Stiffness of Spin Constituents; Nuclear Faraday Effect.

χ EFT: parameter-free predictions for all proton & neutron scalar & spin polarisabilities.

Opportunities for high intensities, polarised beam and/or target: p, d, ³He, ⁴He?, ⁶Li?

We Need Data: elastic & inelastic cross-sections & asymmetries – reliable systematics!

Only combination of dedicated experiments meaningful! (Not “one datum for one answer”.)

Sweet-spot $\omega \in [80; 180]$ MeV: Single- & double-polarisation observables, elastic & inelastic:

increased count-rates \iff accurate theory; proton–neutron differences; cross-checks.

\implies Experiment, χ EFT, lattice with competitive uncertainties!



The efficient person gets the job
done right. The effective person
gets the right job done.

