The GDH sum rule using nearly real photons

Measuring the spin structure of the Helium-3 nucleus & Neutron at low Q^2

Jaideep Singh (for the JLab Hall A Collaboration)

Department of Physics, University of Virginia, Charlottesville, VA 22904

The GDH sum rule for using real photons

First derived in the mid-1960's by Gerasimov and Drell & Hearn, the sum rule for spin-I particles is based on the following *modest yet robust arguments:*

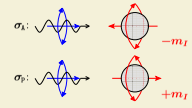
Cause precedes Effect
analyticity ⇒ *dispersion relations*

Special Relativity
Conservation of Charge
Lorentz & gauge invariance ⇒ *Low Energy Theorem*

Conservation of Probability
unitarity ⇒ *Optical Theorem*

$$\int_{\nu_{th}}^{\infty} \sigma_A(\nu) - \sigma_P(\nu) \frac{d\nu}{\nu} = -2\pi^2 \alpha_{em} (2m_I) \left(\frac{\kappa}{M}\right)^2$$

The ***differential*** response of a particle to a beam of ***circularly polarized*** light summed over ***all*** wavelengths:



The ***anomalous*** magnetic moment κ of a particle is a measure of its ***deviation*** from point-like behaviour:

$$\frac{\kappa}{M} = \frac{\mu/e\hbar}{I} - \frac{Z}{M}$$

(total particle m.m. / point-like m.m. is the charge-to-mass ratio)

The anomalous magnetic moment κ is a ***coarse global*** property of the particle. It contains ***little information*** about the particle's ***detailed local*** substructure.

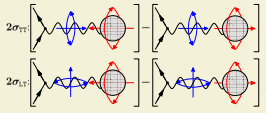
Generalized GDH sum rule for spin-1/2 particles

An ***electron*** interacts with a particle via a ***virtual photon*** with a ***tunable*** "spacetime" resolving power $\sqrt{Q^2}$.

	real photon	virtual photon
beam	photons	electrons
ν	wavelength	energy lost by electron
Q^2	0	$4E(E-\nu)\sin^2(\theta/2) > 0$
length scale	∞	$0.2\ \text{fm} \cdot \text{GeV}/\sqrt{Q^2}$
resolution	**fixed & coarse**	**chosen by E & θ**

Consequently, the response of a particle to a beam of polarized electrons is sensitive to its ***detailed substructure***. If we carefully choose the appropriate response to sum over, we can obtain a ***generalized sum rule for $Q^2 > 0$:***

$$\int_{\nu_{th}}^{\infty} \frac{K'(\nu,Q^2)}{K'(\nu,0)} \left[2\sigma_{TT} + \left(\frac{Q}{\nu}\right) 2\sigma_{LT}\right] \frac{d\nu}{\nu} = -2\pi^2 \alpha_{em} \mathcal{M}(Q^2)$$



Low Q^2 expansion of the Compton amplitude:

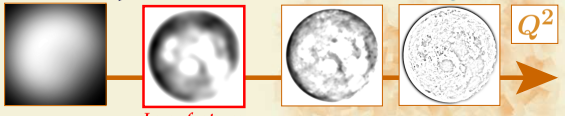
$$\mathcal{M}(Q^2) = \left(\frac{\kappa}{M}\right)^2 + Q^2 \left.\frac{d\mathcal{M}}{dQ^2}\right|_{Q^2=0} + \cdots$$

$\mathcal{M}(Q^2)$ is a quantity that is, in principle, *calculable from theory for any Q^2!*

A tool for studying the Strong interaction

Much like this image of the Moon, the neutron can be "decomposed" into features of different sizes.

At very low resolution ($Q^2 = 0$), the Neutron is just a chargeless spherical blob with a completely anomalous magnetic moment.

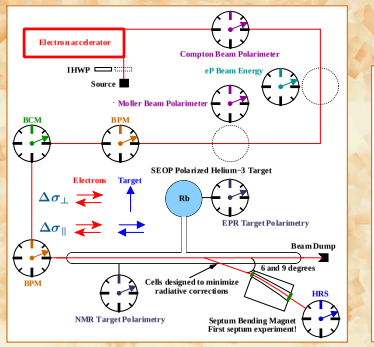


Large features
Hadronic degrees of freedom
"Effective" interactions
Chiral Perturbation Theory

Very difficult... full QCD, solve numerically on a spacetime lattice?

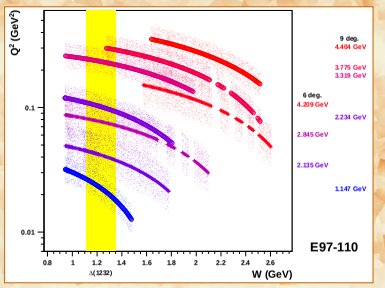
Small features
Partonic d.o.f.
Fundamental int.
perturbative QCD

Experimental layout



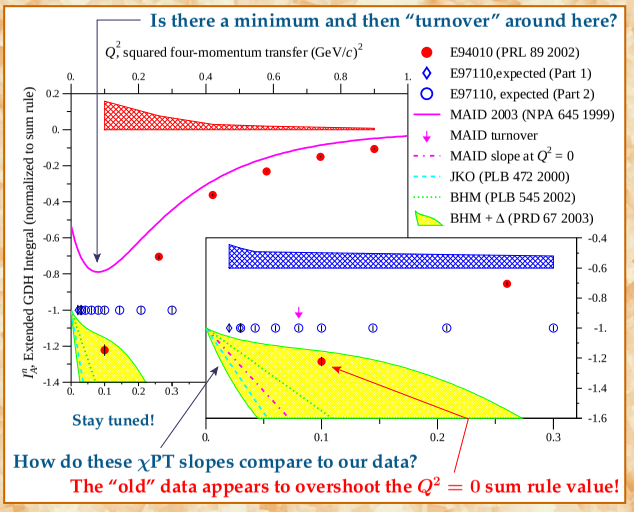
The Experiment 97-110

Kinematic coverage



Expected results compared to "old" data

Is there a minimum and then "turnover" around here?

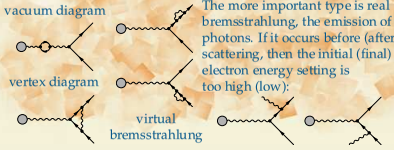


How do these χPT slopes compare to our data?

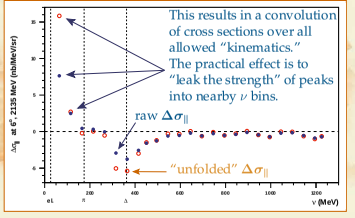
The "old" data appears to overshoot the $Q^2 = 0$ sum rule value!

Radiative corrections

The first type of radiative corrections are higher order diagrams. They contribute a weakly Q^2 dependant multiplicative factor:

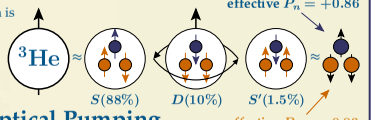


The more important type is real bremsstrahlung, the emission of photons. If it occurs before (after) scattering, then the initial (final) electron energy setting is too high (low):



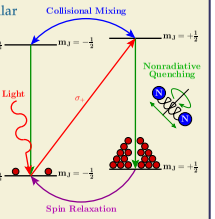
The ^{3}He nucleus as an effective polarized Neutron

The ^{3}He nuclear wave function is dominated by two groups of states with no orbital angular momentum S & S' and one group of D states ($L = 2$):



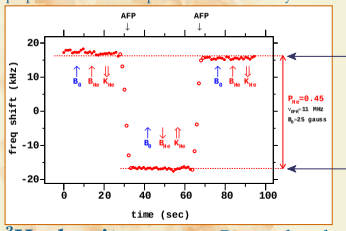
Spin-Exchange Optical Pumping

Rb atoms are illuminated by photons with $+1$ unit of angular momentum. Due to the ***conservation of energy and angular momentum***, only Rb atoms in the $m_J = -1/2$ ground state undergo transitions to the excited state. These atoms decay back into either m_J ground state with equal probability without reemitting a photon. These "non-radiative" decays occur due to collisions with N_2. On average a reemitted photon would limit the optical pumping efficiency. Since the $m_J = +1/2$ ground state is "transparent" to the laser light, most of the Rb atoms eventually end up there. Finally these polarized Rb atoms undergo spin-exchange collisions with the ^{3}He atoms, and the cycle repeats itself.



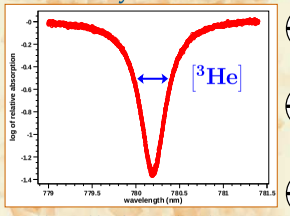
EPR frequency shift polarimetry

The polarized ^{3}He nuclei produce an ***effective magnetic field*** of about 30 milligauss. This field causes an additional ***Zeeman splitting*** of the Rb atomic energy levels. The ***frequency shift*** associated with the small splitting due to the ^{3}He can be ***isolated*** by flipping the ^{3}He spins by an "**AFP**." The subsequent change in the Rb EPR transition frequency is proportional to the ^{3}He polarization and density:

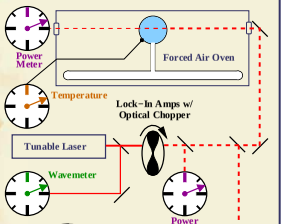


$$\Delta\nu \propto P_{He} \cdot [^3He]$$

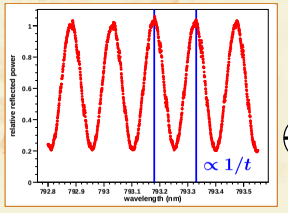
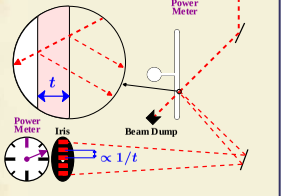
^{3}He density



Pressure broadened absorption spectroscopy



Cell wall glass thickness



Thin film laser interferometry