Nucleon Polarizabilities and Sum Rules

Transient dipole moments induced by the photons'
EM fields probed through photon scattering

Induced electric dipole moment:

$$\vec{D} = \alpha\vec{E} + \left\{\alpha_1\nabla(\vec{\sigma}\cdot\vec{B}) + \alpha_2\vec{\sigma}\times(\nabla\times\vec{B})\right\}$$

rearrangement of charge distribution

Induced magnetic dipole moment:

$$\vec{M} = \beta\vec{B} + \left\{\beta_1\nabla(\vec{\sigma}\cdot\vec{E}) + \beta_2\vec{\sigma}\times(\nabla\times\vec{E})\right\}$$

rearrangement of magnetic moments

γ, π channels have a common S-matrix

$$S = \begin{pmatrix} A_{\gamma\gamma} & A_{\gamma\pi} \\ A_{\pi\gamma} & A_{\pi\pi} \end{pmatrix}$$

From the Optical Theorem:

$$\mathrm{Im} A_{\gamma\gamma} = A_{\gamma\pi} A^*_{\gamma\pi}$$

And Dispersion Relations:

$$\mathrm{Re} A_{\gamma\gamma} = \mathrm{Born}_{\gamma\gamma} + \int \frac{\mathrm{Im} A_{\gamma\gamma}}{\omega'^2 - \omega^2} \omega' d\omega + \mathrm{asym}$$

Compton Helicity Amplitudes A_i

$$A_{\gamma,\gamma} = \sum_1^6 A_i$$

$$\Re e A_i(\nu,t) = A_i^B(\nu,t) + \frac{2}{\pi} P \int_{\nu_0}^{\nu^{max}} \frac{\nu' \, \Im m A_i(\nu',t)}{\nu'^2 - \nu^2} \, d\nu' + A_i^{as}(t)$$

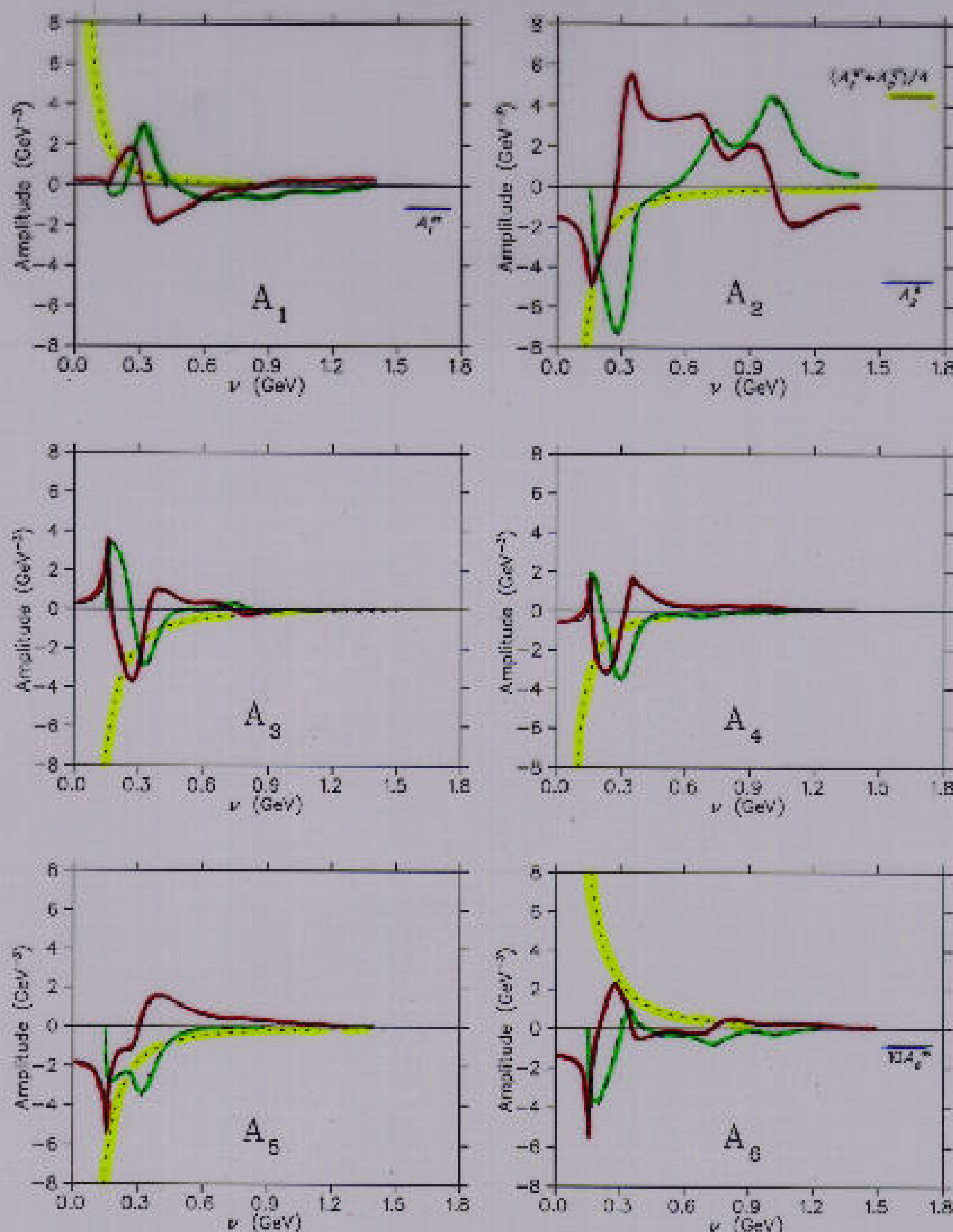


Figure 47 *t = 0*

Special Case for $t = 0$

$$\frac{1}{8\pi\sqrt{s}} A_{\gamma\gamma}(0) = \frac{E_\gamma^2 M}{2\pi\sqrt{s}} \left\{ -(A_3 + A_6)\epsilon' \cdot \epsilon + i\frac{E_\gamma}{M} A_4 \sigma \cdot (\epsilon' \times \epsilon) \right\}$$

$$= f(E_\gamma^2)\epsilon' \cdot \epsilon + iE_\gamma g(E_\gamma^2)\sigma \cdot (\epsilon' \times \epsilon) \text{ (GGT)}$$

Thomson

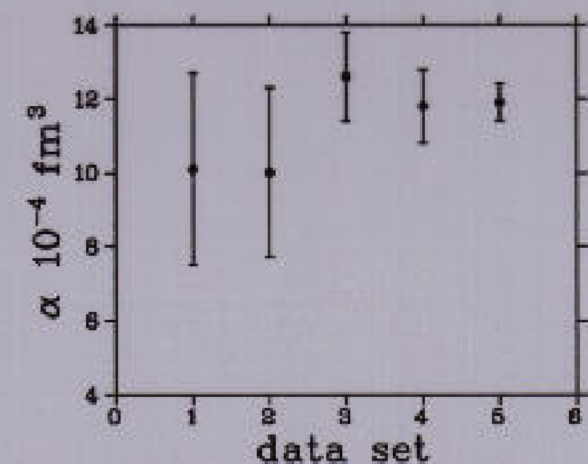
$$4\pi f(\nu^2) = -\frac{e^2}{m} + 4\pi(\alpha + \beta)\nu^2 + [\nu^4]$$

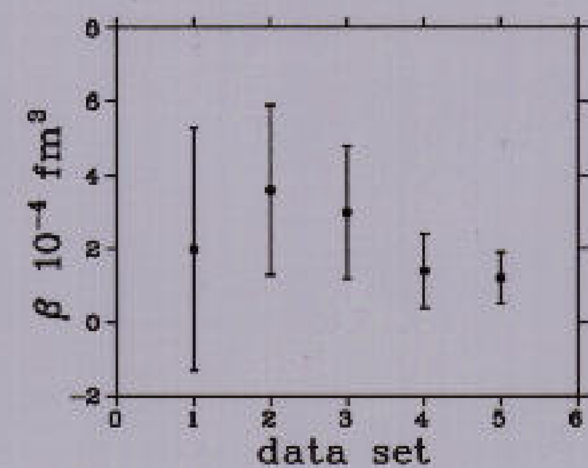
$$4\pi g(\nu^2) = -\frac{e^2\kappa^2}{2m^2} + 4\pi\gamma_0\nu^2 + [\nu^4]$$

Low

Summary of measurements of $\bar{\alpha}$ and $\bar{\beta}$ (proton)

Data set	$\bar{\alpha}$	$\bar{\beta}$
Federspiel '91	$10.1 \pm 2.6 \mp 2.0$	$2.0 \pm 3.3 \pm 0.3$
Zieger '92	$10.0 \pm 2.3 \pm 1.9$	$3.6 \pm 2.3 \pm 1.9$
MacGibbon '95	$12.6 \pm 1.2 \mp 1.3$	$3.0 \pm 1.8 \pm 0.1$
LEGS '98	$11.8 \pm 1.0 \mp 0.8$	$1.4 \pm 1.0 \pm 0.8$
TAPS '01	$11.9 \pm 0.5 \mp 1.3$	$1.2 \pm 0.7 \pm 0.3$





Spin Sum Rules

$$
\begin{aligned}
4\pi f(\nu^2) &= -\frac{e^2}{m} + 4\pi(\alpha+\beta)\nu^2 + [\nu^4] \\
4\pi g(\nu^2) &= -\frac{e^2\kappa^2}{2m^2} + 4\pi\gamma_0\nu^2 + [\nu^4]
\end{aligned}
$$

The Baldwin sum rule:

$$f'(0) = \frac{1}{2\pi^2}\int_{\nu_0}^{\infty}\frac{\sigma_{tot}(\nu)}{\nu^2}d\nu = \alpha+\beta$$

The forward spin-polarizability sum rule:

$$g'(0) = \frac{1}{4\pi^2}\int_{\nu_0}^{\infty}\frac{\sigma_{1/2}(\nu)-\sigma_{3/2}(\nu)}{\nu^3}d\nu = \gamma_0$$

The Gerasimov-Drell-Hearn sum rule:

$$g(0) - g(\infty) = \int_{\nu_0}^{\infty}\frac{\sigma_{1/2}(\nu)-\sigma_{3/2}(\nu)}{\nu}d\nu = -\frac{e^2\kappa^2}{2m^2}$$

Induced Dipole Moments:

$$\vec{D} = \alpha\vec{E} + \left\{\alpha_1 \nabla(\vec{\sigma}\cdot\vec{B}) + \alpha_2\vec{\sigma}\times(\nabla\times\vec{B})\right\}$$

$$\vec{M} = \beta\vec{B} + \left\{\beta_1 \nabla(\vec{\sigma}\cdot\vec{E}) + \beta_2\vec{\sigma}\times(\nabla\times\vec{E})\right\}$$

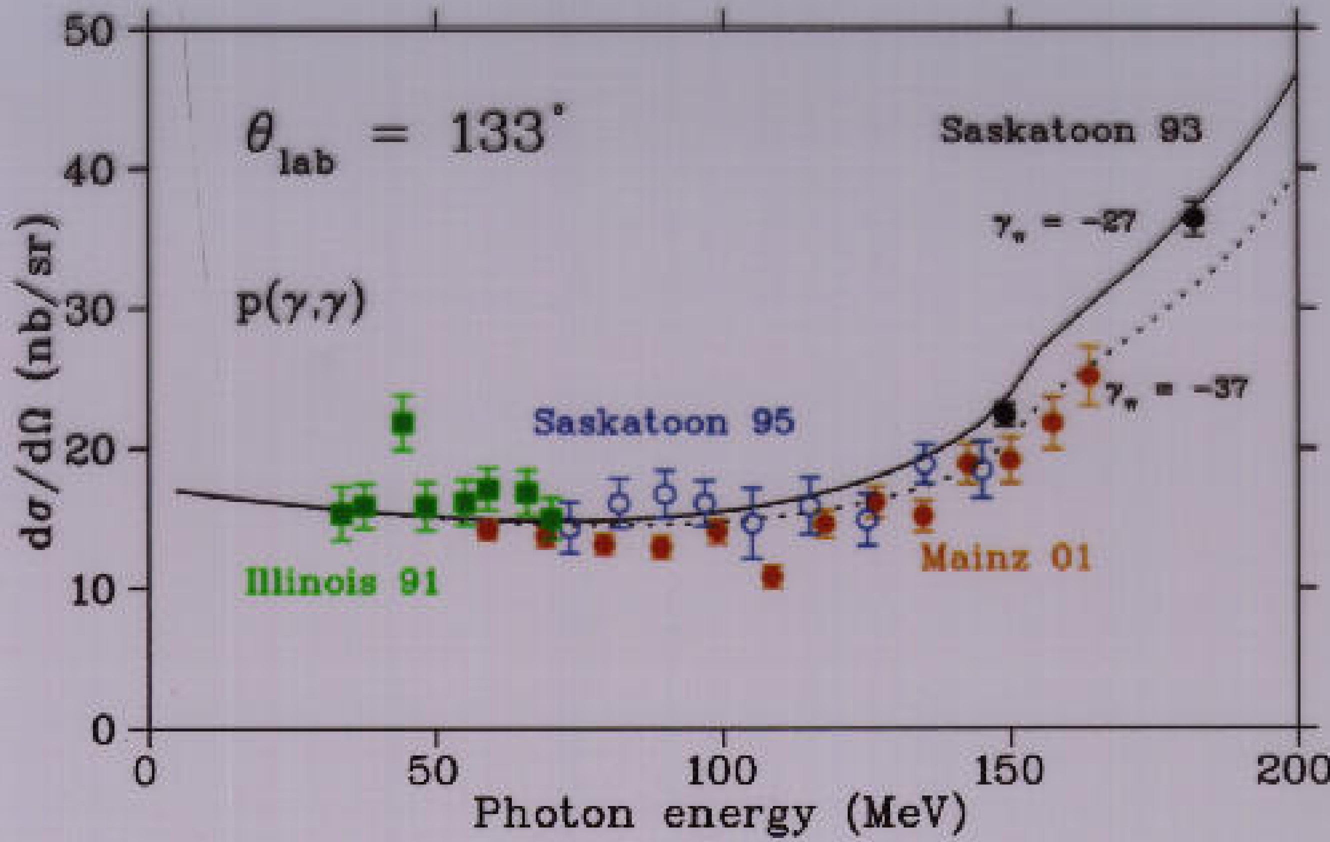
Various definitions of the spin polarizabilities:

$$\begin{aligned}
\bar{\alpha}_1 &= 4\gamma_3 &&= -\gamma_0 - \gamma_\pi + 2\gamma_{13} &&= 4\gamma_{M2} \\
\bar{\beta}_1 &= -4(\gamma_2 + \gamma_4) &&= 3\gamma_0 - \gamma_\pi - 2\gamma_{14} &&= -4\gamma_{E2} \\
\bar{\alpha}_2 &= 2\gamma_1 &&= \gamma_0 + \gamma_\pi &&= -2(\gamma_{E1} + \gamma_{M2}) \\
\bar{\beta}_2 &= 2(\gamma_2 + 2\gamma_4) &&= \gamma_0 + \gamma_\pi &&= 2(\gamma_{M1} + \gamma_{E2})
\end{aligned}$$

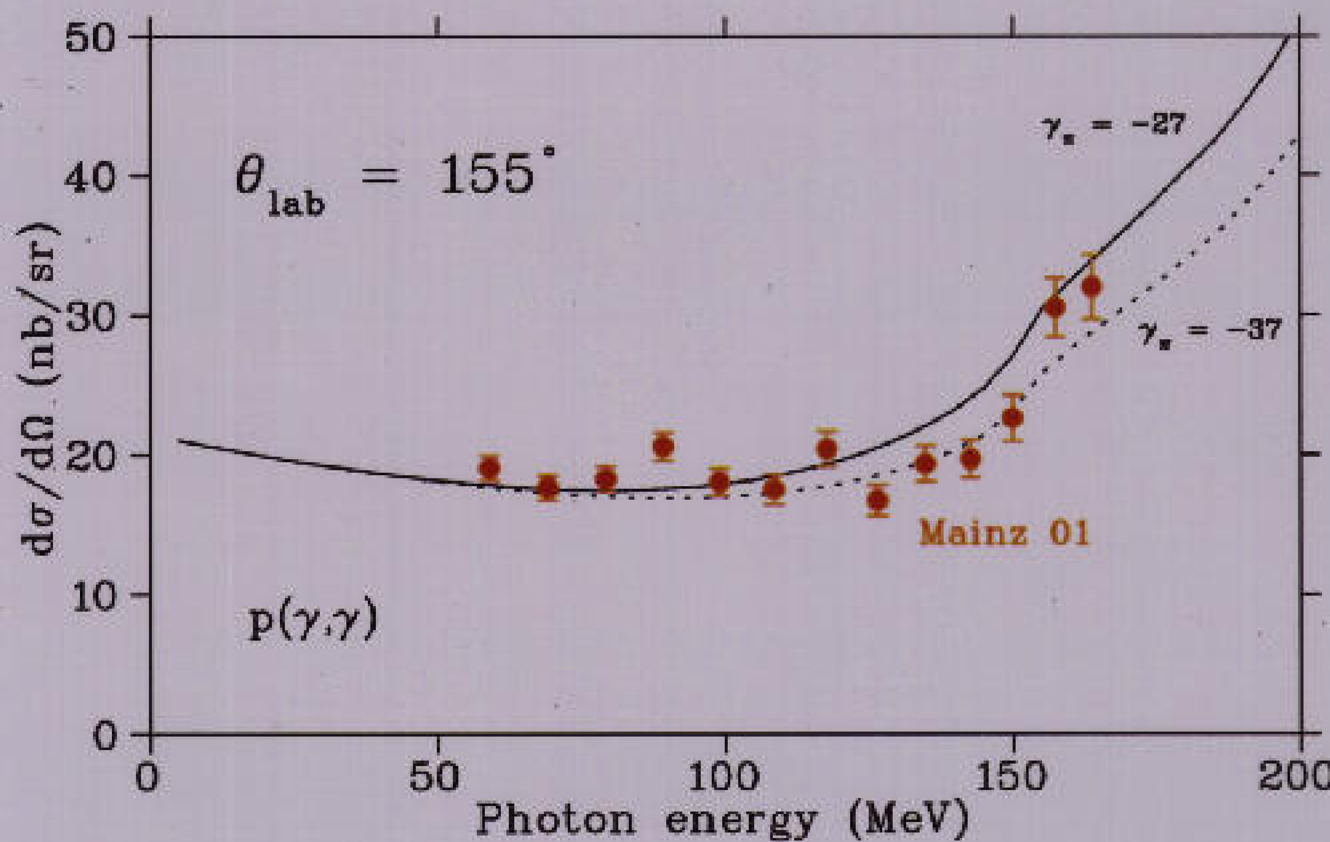
Babusci	Ragusa	Drechsel	L'Vov
lab	Breit	cm	multipoles

↑

A_2 only in γ_π

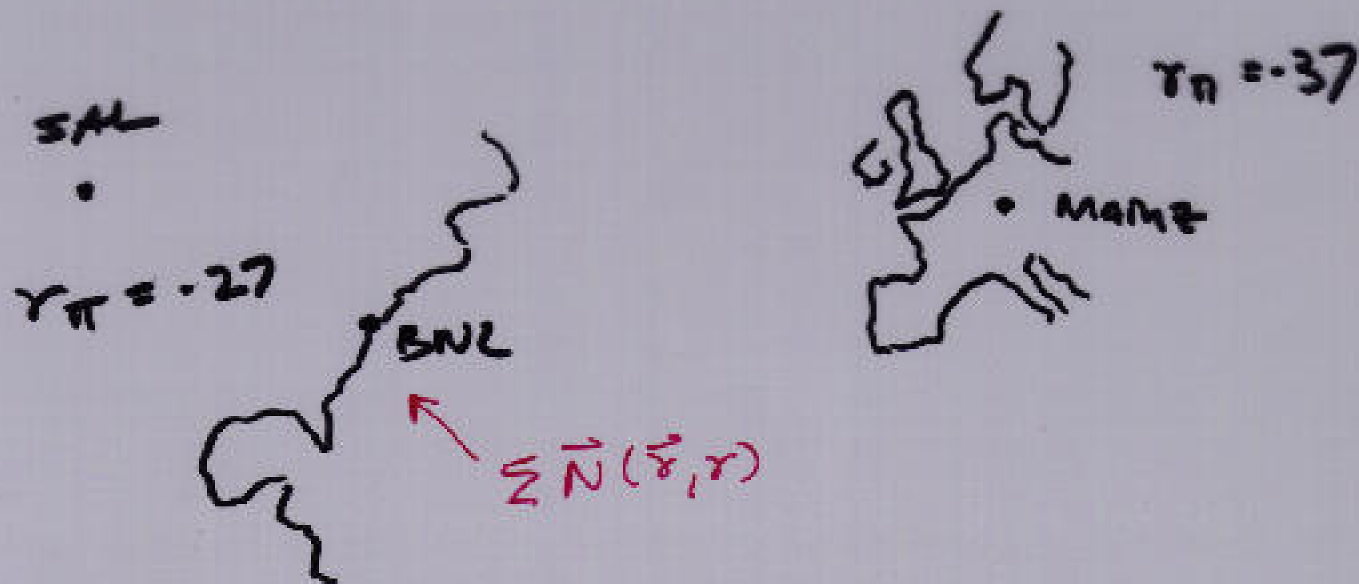


θ_{lab} = 133°
Saskatoon 93
γ_π = -27
p(γ,γ)
Saskatoon 95
γ_π = -37
Illinois 91
Mainz 01
dσ/dΩ (nb/sr)
Photon energy (MeV)

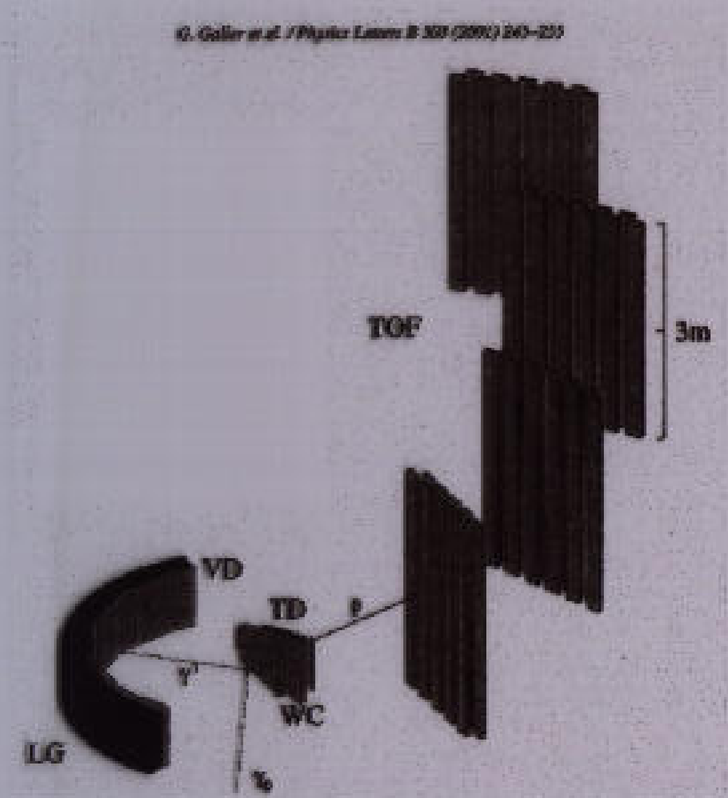


θ_{lab} = 155°
γ_π = -27
γ_π = -37
Mainz 01
p(γ,γ)
dσ/dΩ (nb/sr)
Photon energy (MeV)

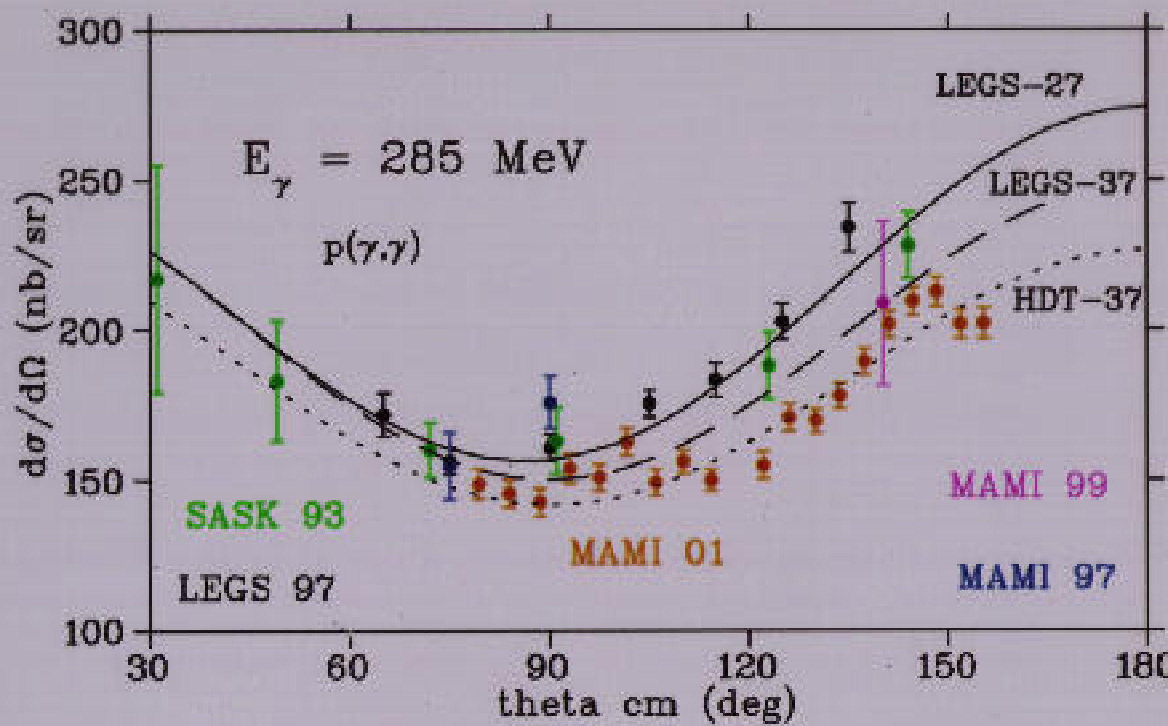
Spin Polarizability Puzzle



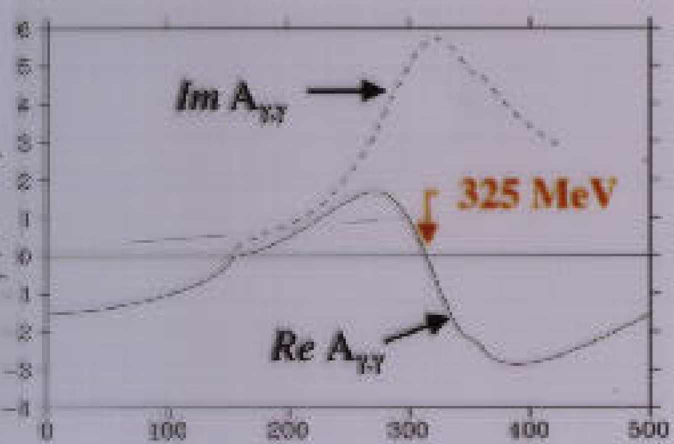
Spin Sum Rules for Neutron??



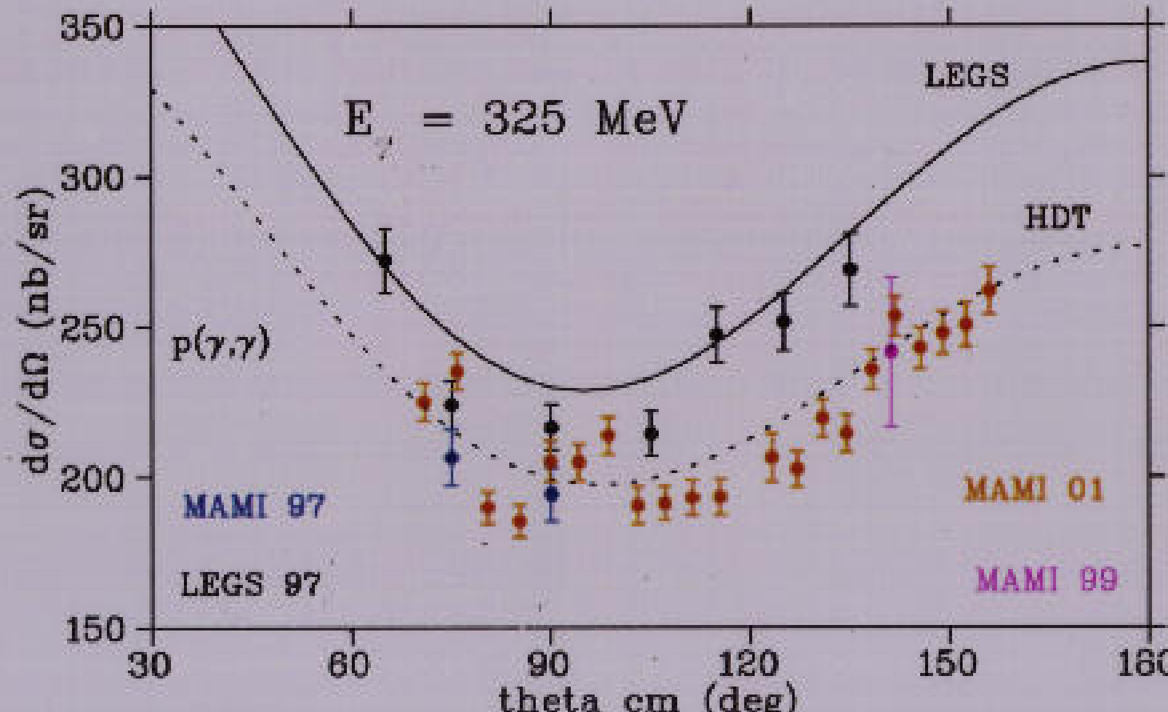
TOF
3m
VD
TD
p
γ'
WC
LG



E_γ = 285 MeV
p(γ,γ)
LEGS-27
LEGS-37
HDT-37
SASK 93
LEGS 97
MAMI 01
MAMI 99
MAMI 97
dσ/dΩ (nb/sr)
theta cm (deg)



Im A_γγ
Re A_γγ
325 MeV

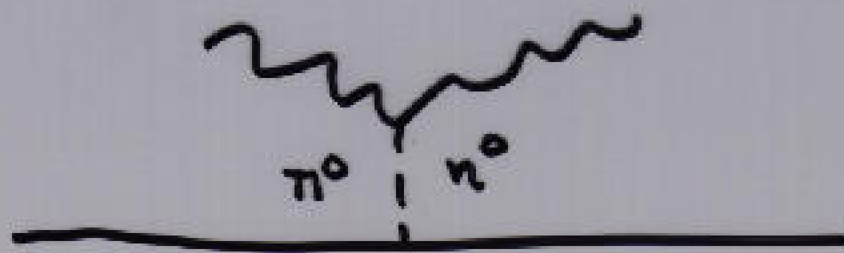


E_γ = 325 MeV
p(γ,γ)
LEGS
HDT
MAMI 97
LEGS 97
MAMI 01
MAMI 99
dσ/dΩ (nb/sr)
theta cm (deg)

Predictions & measurements : (in units 10^{-4} fm^4)

$$\gamma_\pi = \mathrm{Born}_{t(\pi^0,\eta^0)} + \bar{\gamma}_\pi$$

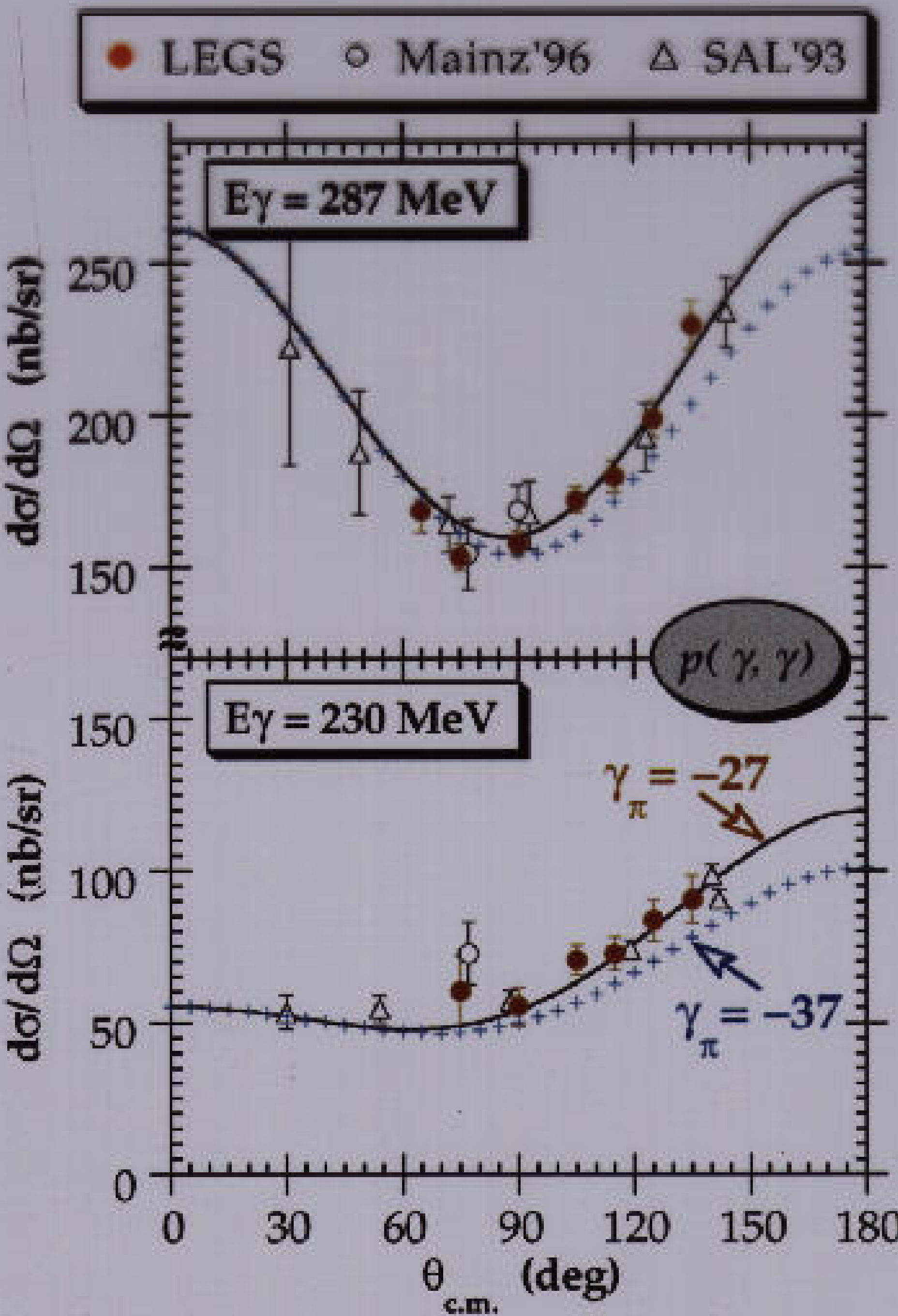
$$= \quad -45.6 \quad + \bar{\gamma}_\pi$$



	HBχPT		Subt. Disp. Rel.	Disp. Rel.
	$O(p^3)$	$O(p^4) + O(p^3)$[1]	HDT[2](π) + multi-π	LEGS[3]
$\bar{\gamma}_\pi$	+4.6	+3.4	+9.5	+18.4
γ_0	+4.6	-1.0	-0.8	-1.6
γ_{13}	+6.8	2.6	+4.3	+3.9
γ_{14}	+6.8	+0.4	-1.5	-2.2

[1] PRL **85**, 14
[2] PRC **61**, 015204
[3] PRC **64**, 025203

large $O(p^5)$ corrections expected from Δ

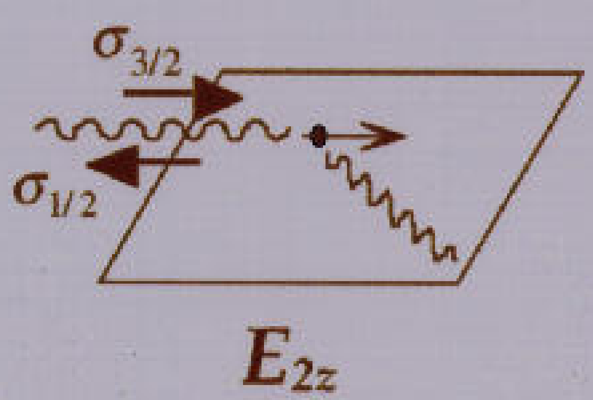


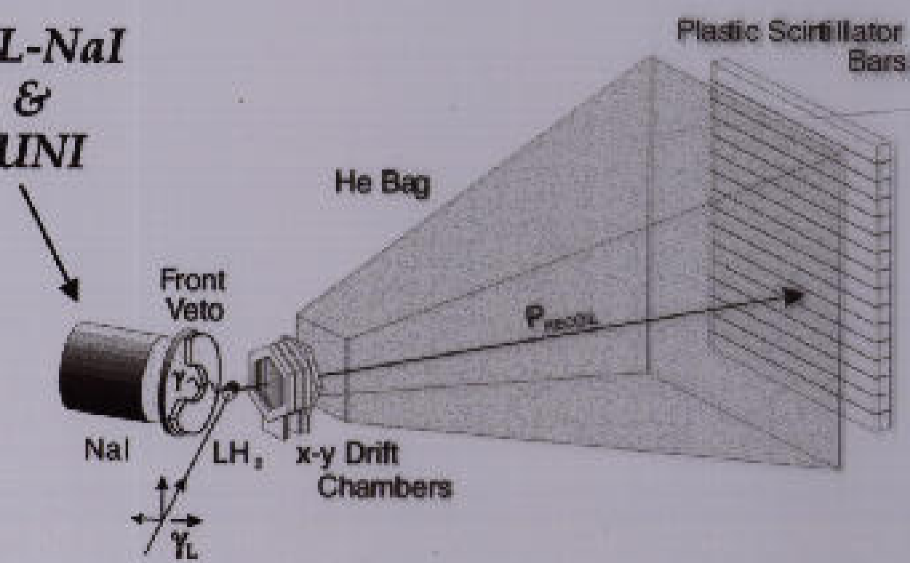
J. Tonnison, A.M. Sandorfi, S. Hoblit and A.M. Nathan,
Phys. Rev. Lett. **80**, 4382 (1998).

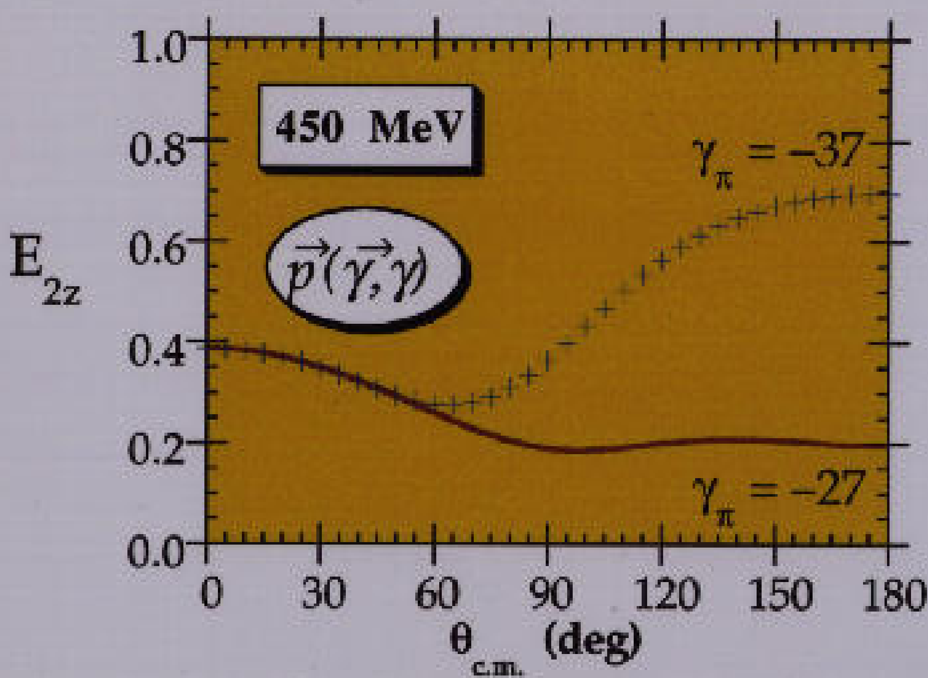
LEGS Collaboration, G. Blanpied *et al.*,
Phys. Rev. **C64**, 025203 (2001).

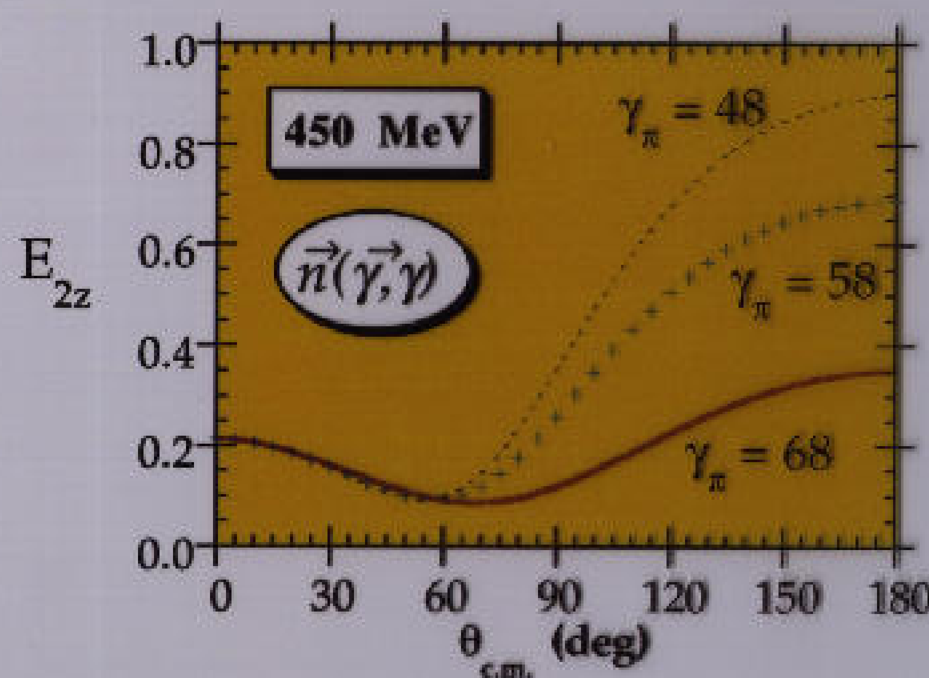
p(g,g)/PRC64,Gg00/Aug01

Backward Spin-Polarizabilities from double-polarized Compton Scattering









7/ n(g,g) /SC magnet

Multipole predictions for the forward spin-polarizability and the Gerasimov-Drell-Hearn sum rules

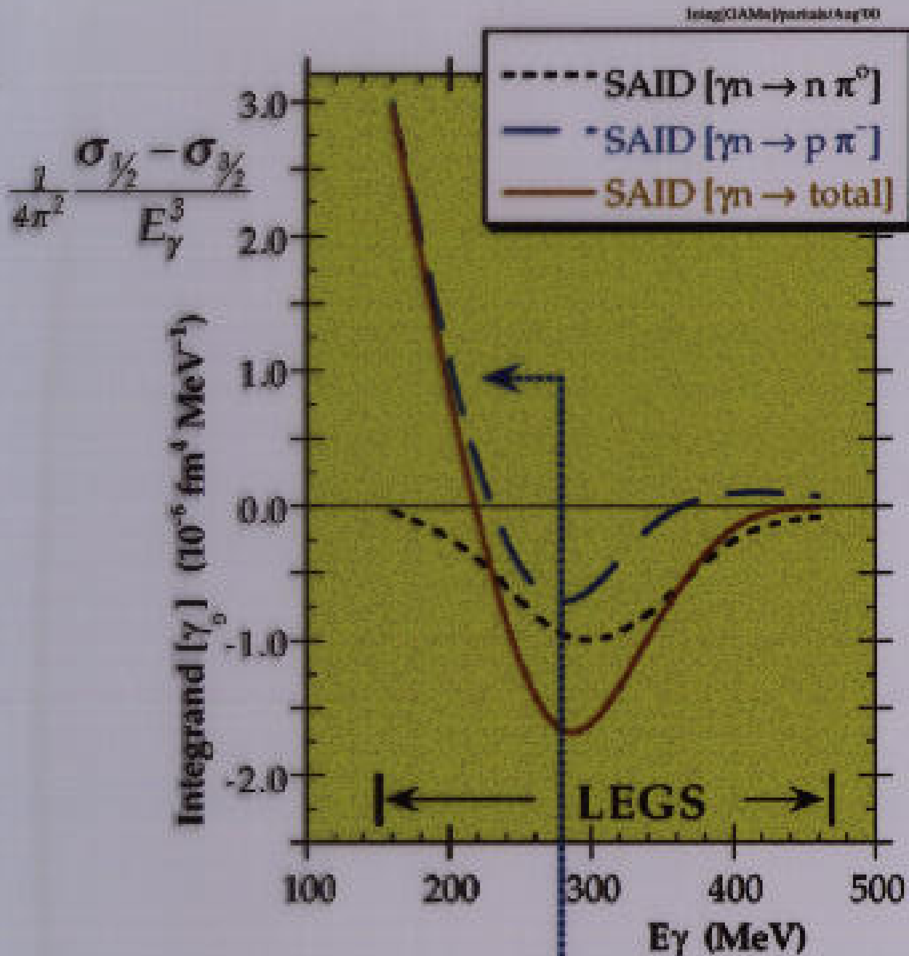
$$\gamma_o = \int \frac{1}{4\pi^2} \frac{\sigma_{1/2} - \sigma_{3/2}}{E_\gamma^3} \, dE_\gamma \qquad GDH = \int \frac{\sigma_{1/2} - \sigma_{3/2}}{E_\gamma} \, dE_\gamma$$

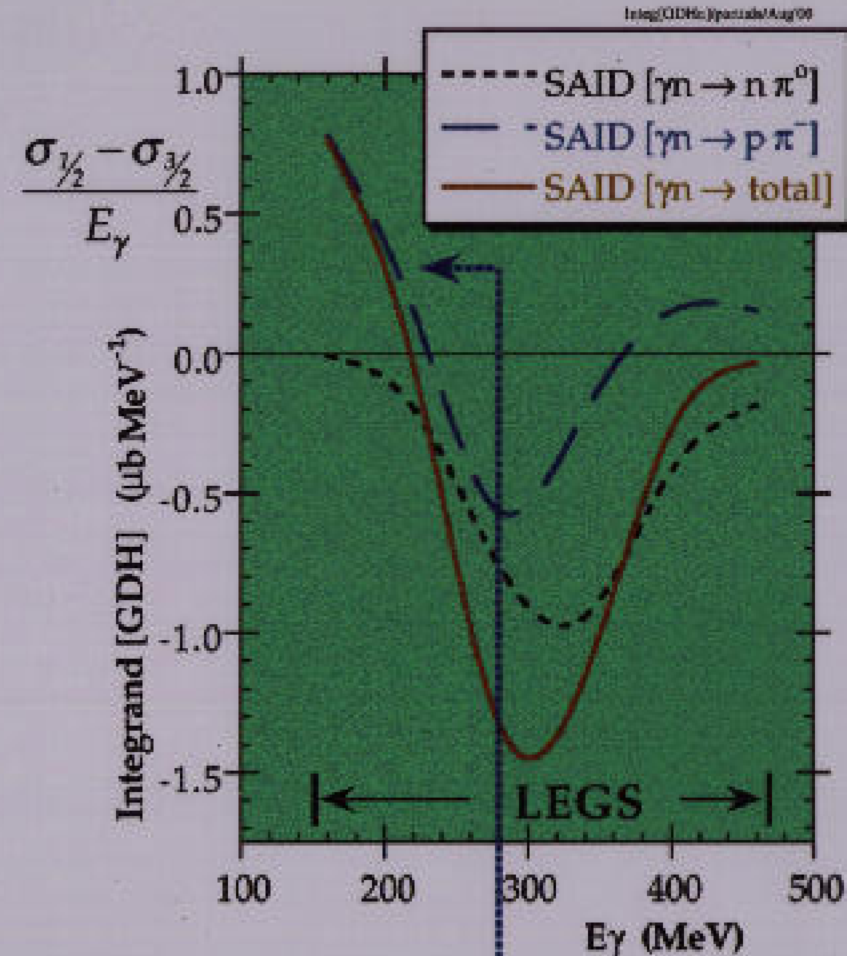
(a) proton:	*χPT rel $O(p^3)$*	*HBχPT $O(p^4)$*	*π-multipoles (LEGS+SAID)*	*π-multipoles* (MAID)*	$-(\kappa_p^2)\frac{2\pi^2\alpha}{m^2}$
$\gamma_o(p)$ $(10^{-6}\, fm^4)$:	**−150**	**−100**	**−155 (± 15)**	**−68**	
GDH_p $(10^{-4}\, fm^2)$:			**−290 (± ~12)**	**−209**	**−204**

(b) neutron:	*χPT rel $O(p^3)$*	*HBχPT $O(p^4)$*	*π-multipoles (SAID)*	*π-multipoles* (MAID)*	$-(\kappa_n^2)\frac{2\pi^2\alpha}{m^2}$
$\gamma_o(n)$ $(10^{-6}\, fm^4)$:	**−46**	**+120**	**−38 (± ~20)**	**+15**	
GDH_n $(10^{-4}\, fm^2)$:			**−160 (± ~16)**	**−170**	**−234**

* includes fits to Mainz 200–800 MeV $\vec{\gamma}+\vec{p}$ data

(Tiator, GDH'2000)





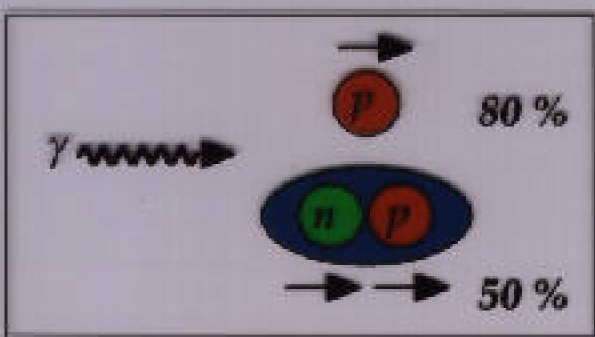
$$\gamma + D = \gamma + n\,(p_s) \rightarrow \pi^- \,p\,(p_s)$$

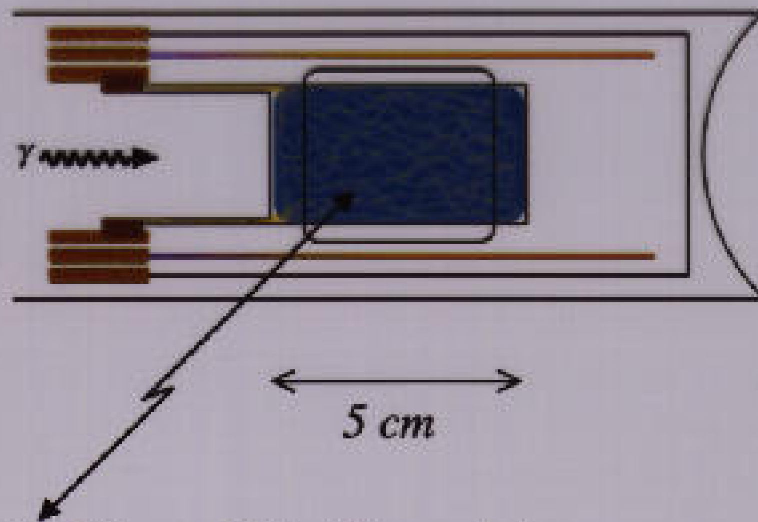
$$\gamma + D = \gamma + p\,(n_s) \rightarrow \pi^+ \,n\,(n_s)$$

large low energy contributions
channels can only be distinguished by the pion charge
→ requires magnetic analysis

Strongly Polarized Hydrogen-deuteride ICE (SPHICE)

an entirely new class of frozen-spin target for photonuclear physics





4 gm solid HD + 20% Al by weight
(2050 × 50 μm wires)

Features

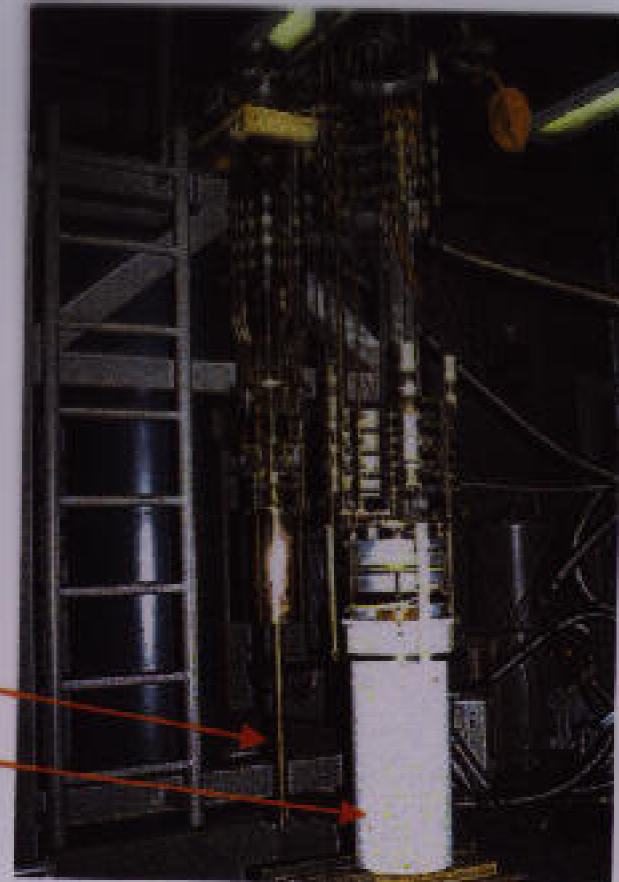
- 80% H-polarization
- 50% D-polarization
- high polarization accuracy, particularly for D
- exceptionally good dilution
- long relaxation times

	$\vec{H}$	$\vec{D}$
Storage:	90 days	240 days
in-beam:	10 days	30 days

SPHICE-1b

HD target cycle:

target injection into dilution fridge;
~1 month at 17 Tesla / 20 mK



extraction at 2.5°K and 0.016 T

loading in-beam cryostat
(1.5°K and 0.7 Tesla)

π-production from polarized targets