Recent Polarization experiments and the GDH sum rule

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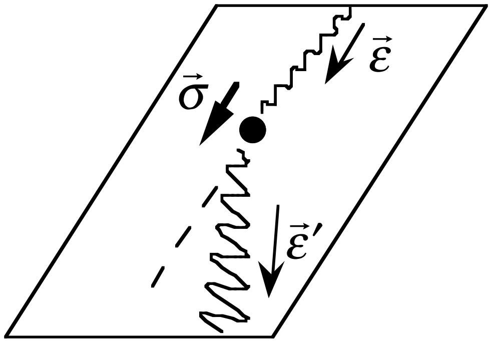
- the Gerisamov, Drell-Hearn, Hosoda-Yamamoto sum rule
- measurements of GDH(p) at Mainz-Bonn and at LEGS
- the GDH(D) sum rule for the deuteron
- what do we learn from all this !?!

Forward elastic (Compton) photon scattering



as energy $\omega \to 0$, angle $\theta \to 0$

$$A(\omega) = f(\omega^2)\,\vec{\varepsilon}' \cdot \vec{\varepsilon} + i\omega\, g(\omega^2)\,\vec{\sigma} \cdot (\vec{\varepsilon}' \times \vec{\varepsilon})$$

Gell-Mann, Goldberger, Thirring, PR95(54)

Thompson $= -\alpha / m$

$$f(\omega^2) = f(0) + f'(0)\ \omega^2 + \mathrm{O}(\omega^4)$$

charge polarizability

magnetic $= -\alpha\,\kappa^2 / 2m^2$

$$g(\omega^2) = g(0) + g'(0)\ \omega^2 + \mathrm{O}(\omega^4)$$

spin polarizability

GGT: σ(reaction)

$\Downarrow$

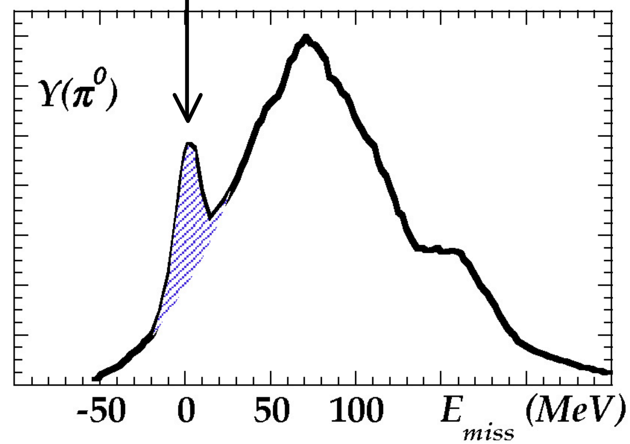
$A(\gamma,\gamma)$

$$\boxed{\frac{1}{4\pi^2}\int_{\omega_o}^{\infty} \frac{\sigma_A - \sigma_P}{\omega}\, d\omega = g(0) - g(\infty)}$$

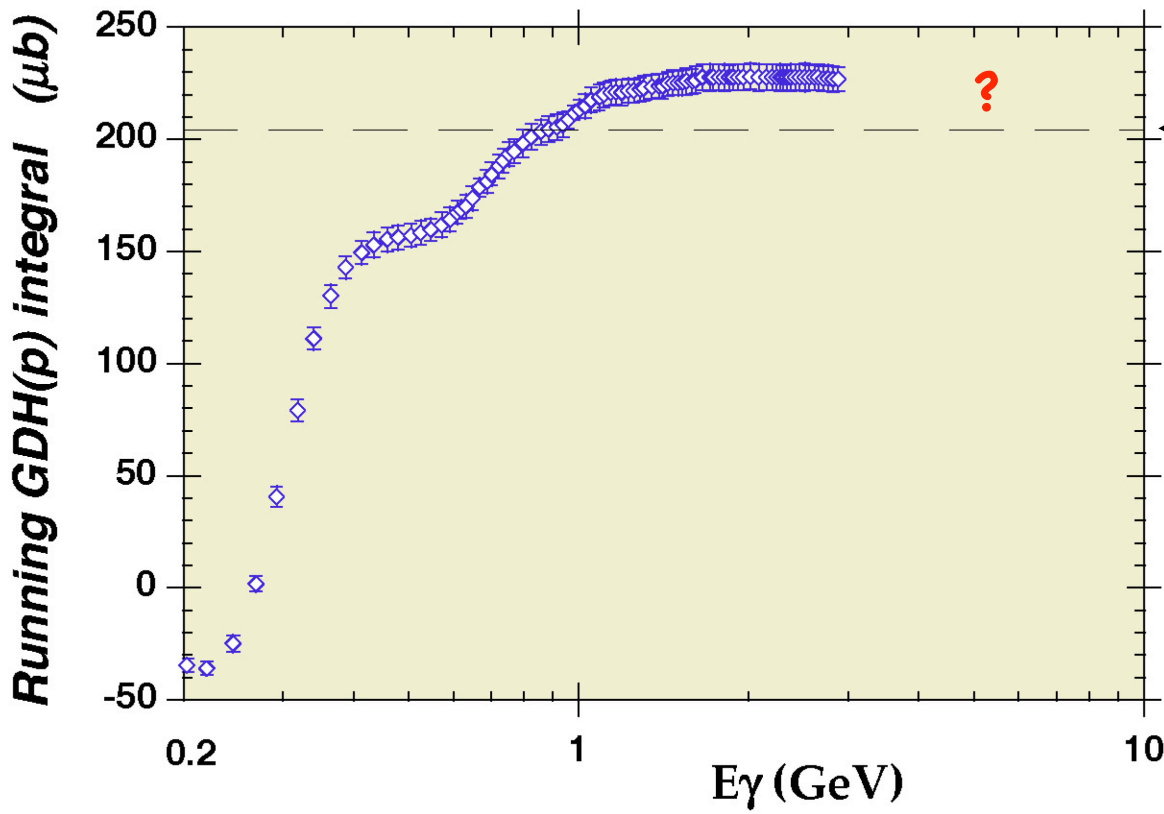
Gerisamov, Drell-Hearn,
Hosoda-Yamamoto ('66): ***maybe*** $g(\infty) = 0$ ***?***

Mainz+Bonn measurements on polarized protons in C_4H_9OH

if $g(\omega) \to 0$ *faster than* $1/\ln\omega$



$$\Rightarrow GDH \equiv \int_{\omega_o}^{E_\gamma} \frac{\sigma_P - \sigma_A}{\omega}\, d\omega = S\frac{4\pi^2\alpha}{m^2}\kappa^2$$



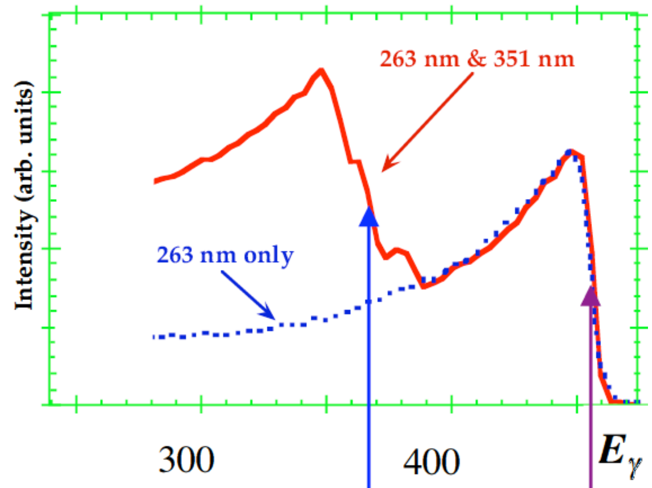
GDH(p) = 204 μb

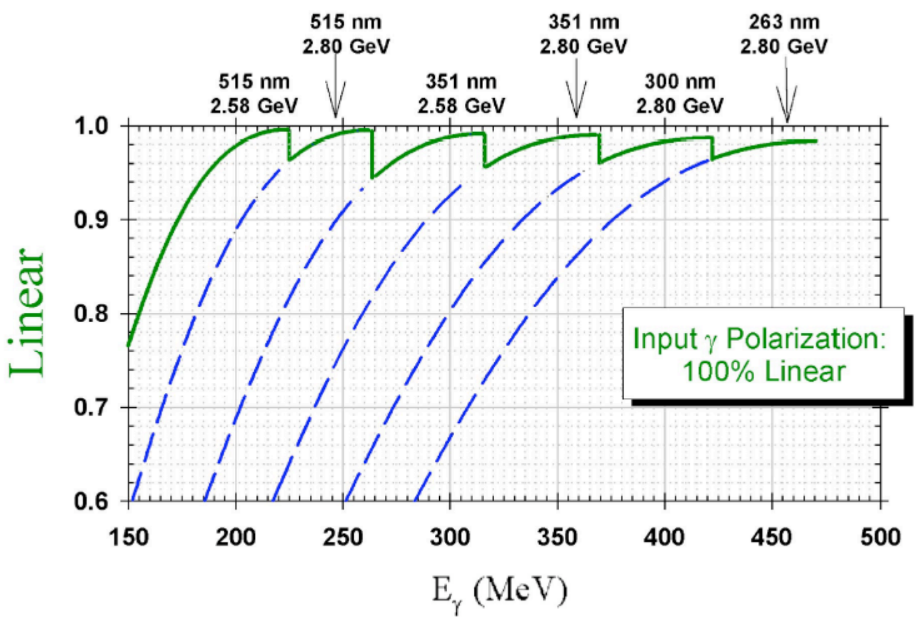
PRL 93, 32003 (2004)

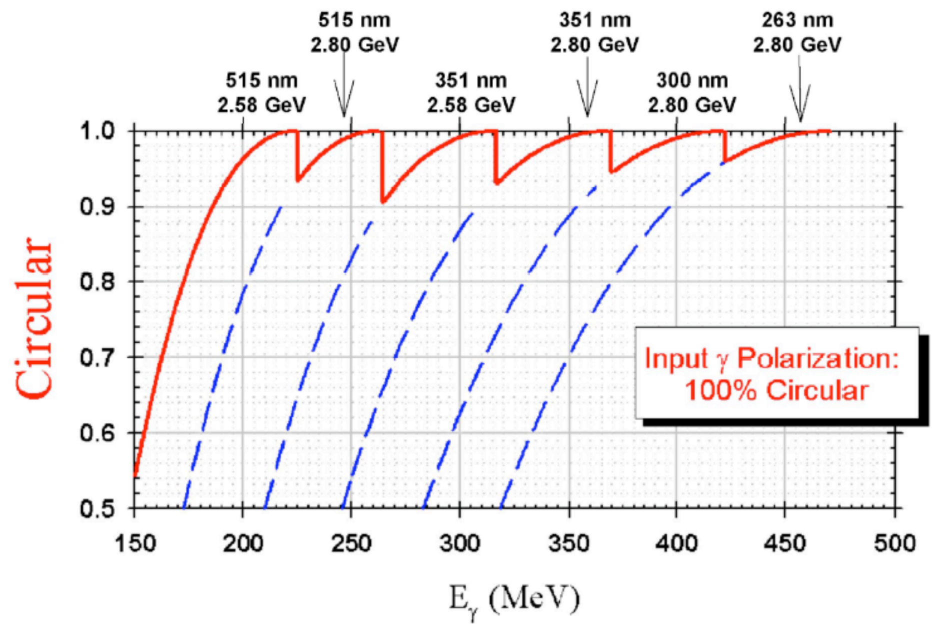
- **new measurements of** $\vec{\gamma}_{L,C} + \vec{H}\vec{D} \rightarrow \pi^0, \pi^\pm$

  from LEGS (Laser-Electron-Gamma-Source) at BNL

	4ω Nd-YLF ring laser	Ar-Ion laser			
λ(nm)	263	300	351	488	515
E_γ (max)	*471 MeV*	*421 MeV*	*368 MeV*	*275 MeV*	*262 MeV*



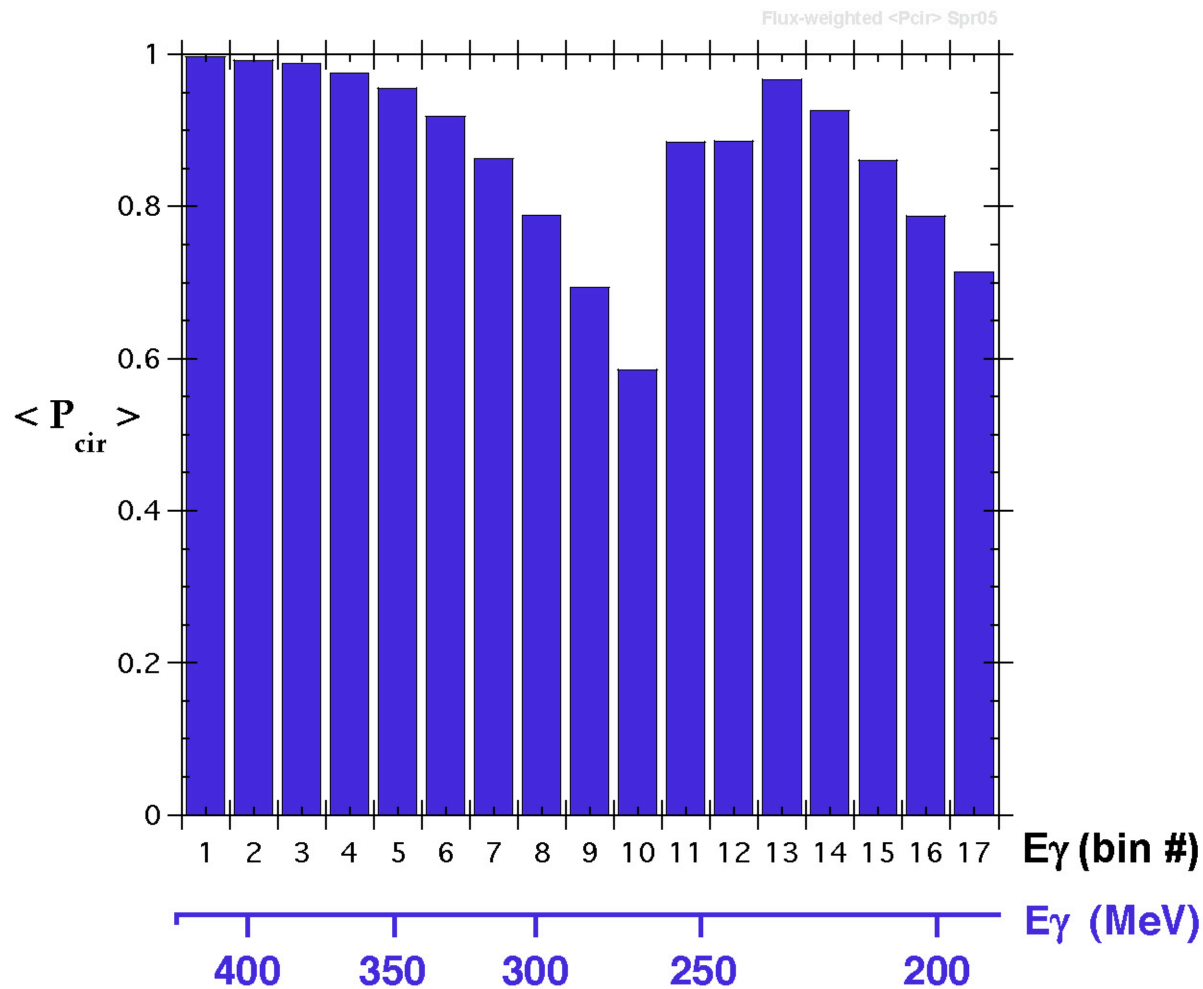




eg. Spring'05 data set:

laser wavelength	E_γ(max)
300-333 nm	421 MeV
351-363 nm	368 MeV
515 nm	262 MeV

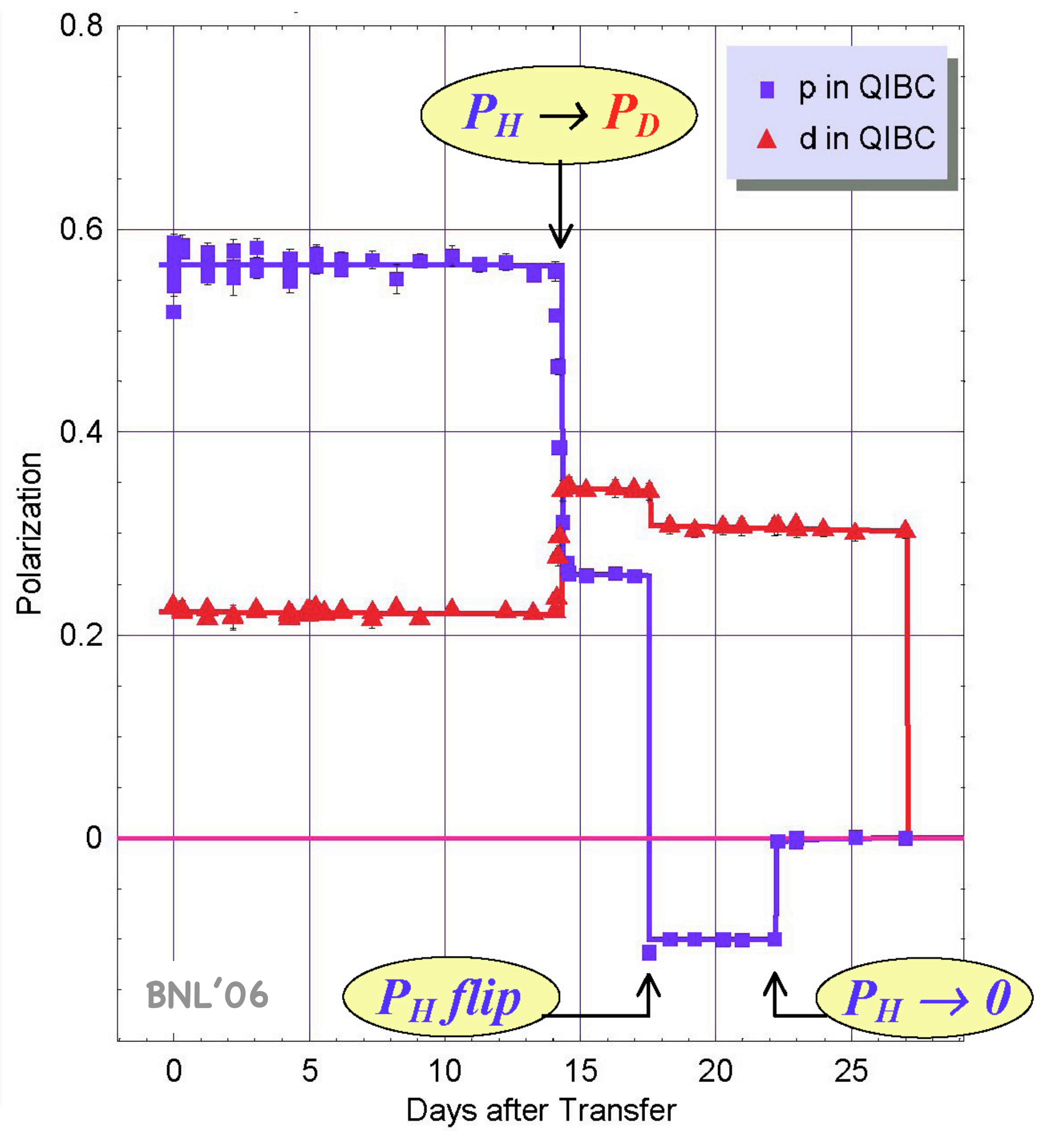
<average circular Pol>



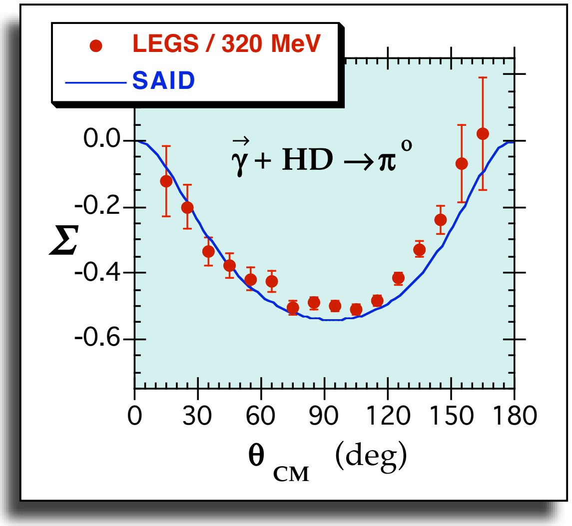
Flux-weighted Pcir-Sp05

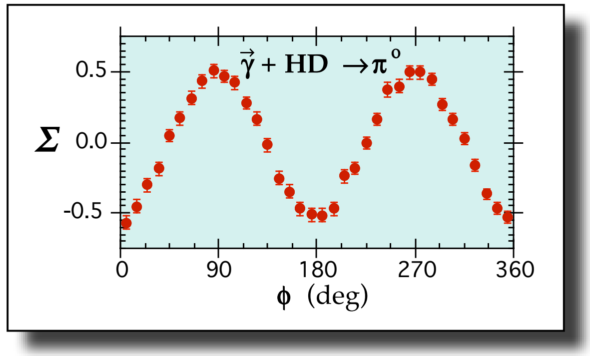
HDice Frozen-Spin Target

- target: ∅ 25 mm × 50 mm
- material: solid HD
- dilution factors: 1/2 for $\vec{p}$
  1/1 for $\vec{n}$
- P(H) = 60%; P(D) = 35%
- T_1 (1/e relaxation) ~ year
- RF forbidden (mol-mol)
  $\vec{H} \Rightarrow \vec{D}$ transfer
- RF allowed (intra-mol)
  $\vec{H}$ flip

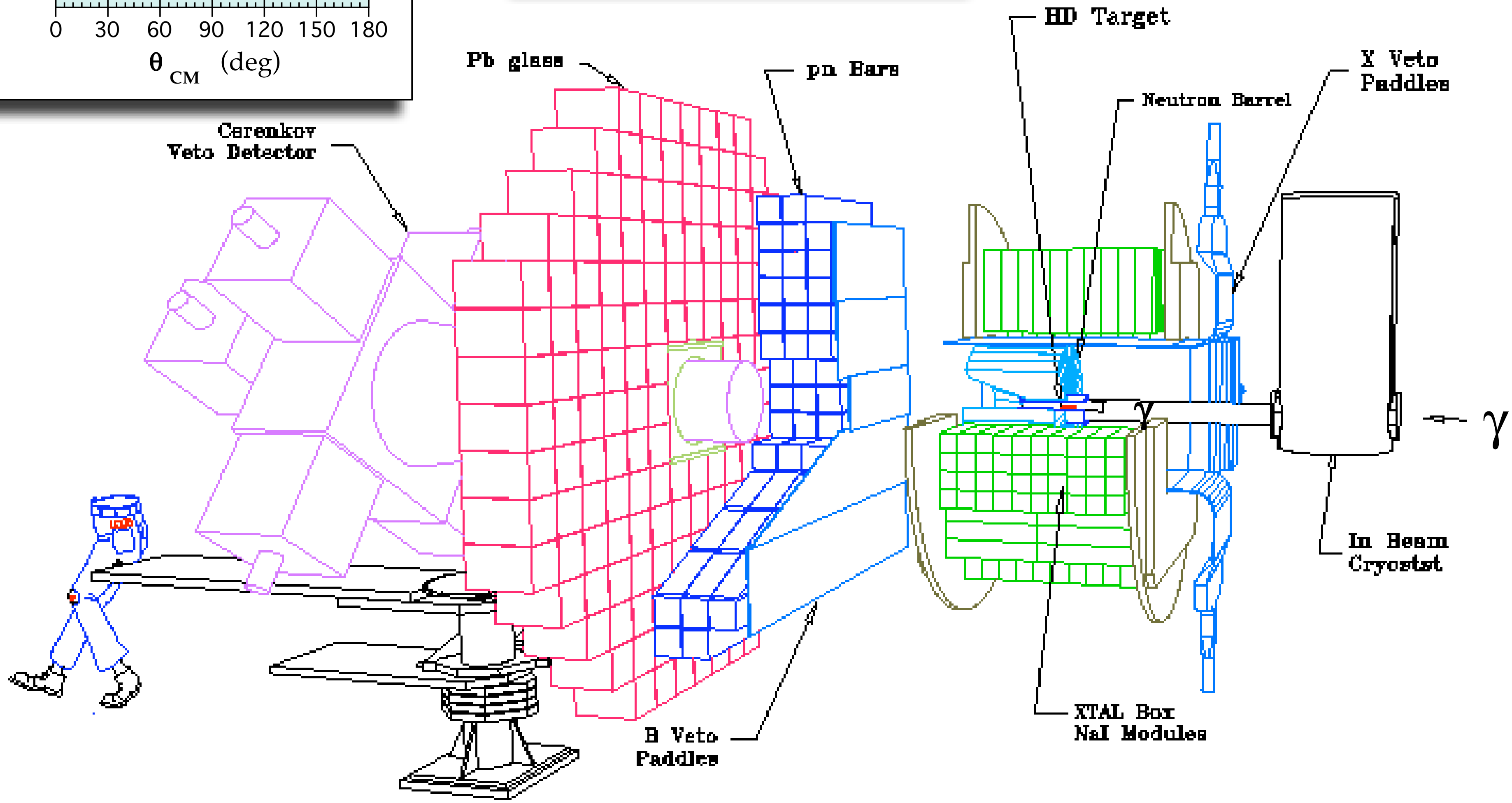


LEGS *S*pin *ASY*mmetry array (*SASY*)





~ 4π acceptance for π^0

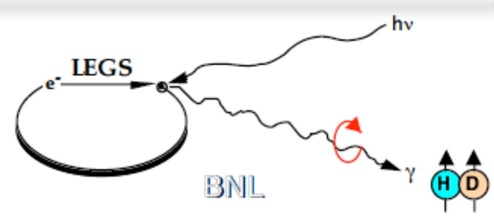


The LEGS-Spin Collaboration

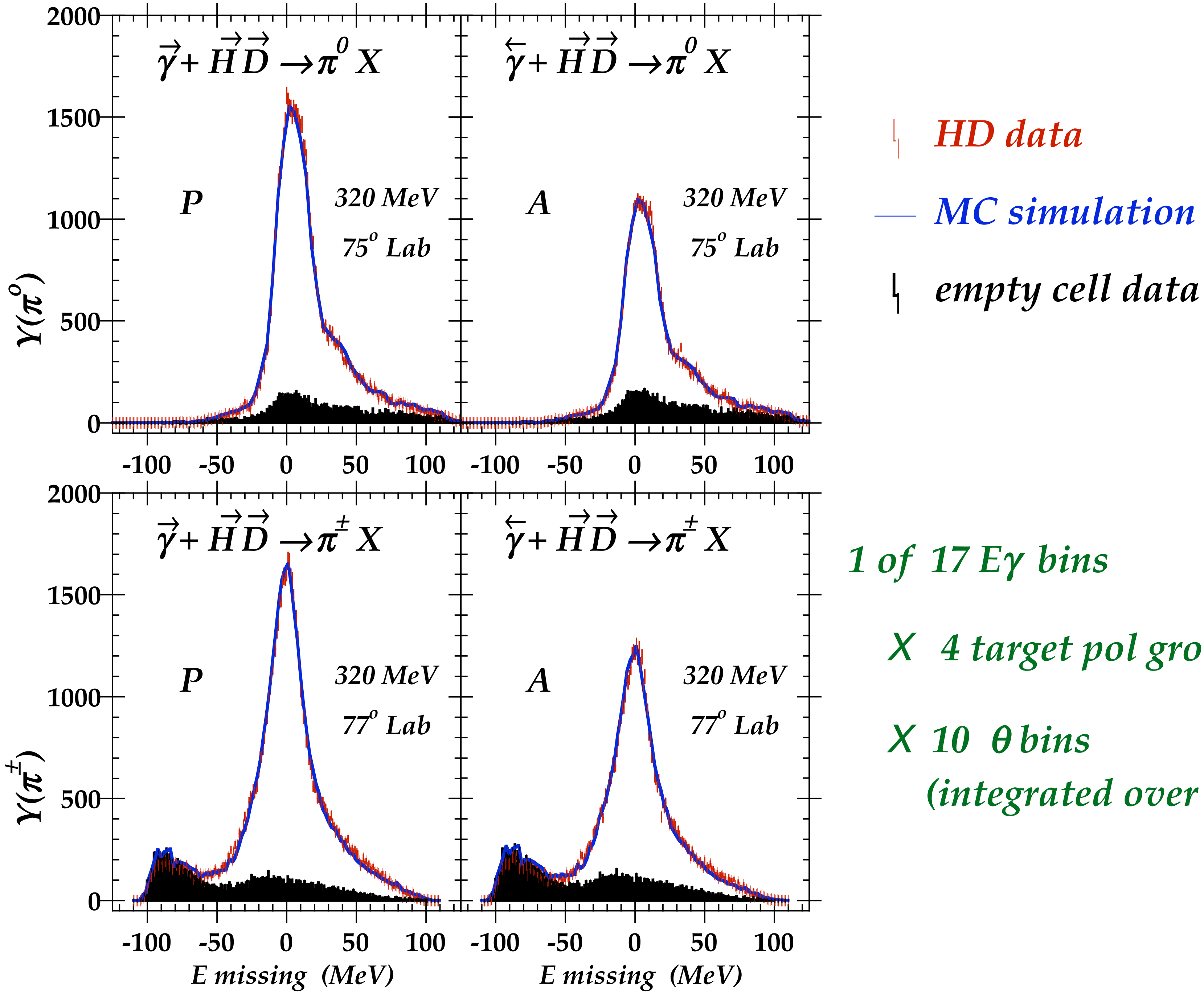
- Brookhaven National Laboratory
  A. Caracappa, S. Hoblit, O. Kistner, F. Lincoln, L. Miceli, M. Lowry, **A.M. Sandorfi ***, C. Thorn, X. Wei
- Forschungszentrum Jülich GmbH
  M. Pap, H. Glückler, H. Seyfarth, H. Ströher
- James Madison University
  C. S. Whisnant
- Norfolk State University
  M. Khandakar
- Ohio University
  C. Bade, **K. Hicks ***, M. Lucas, J. Mahon, S. Kizigul
- Syracuse University
  A. Honig
- University di Roma - Tor Vergata
  A. D'Angelo *, A. d'Angelo, D. Moricciani, C. Schaerf, R. Di Salvo, A. Fantini
- University of South Carolina
  K. Ardashev, C. Gibson, **B. M. Preedom ***, A. Lehmann
- University of Virginia
  S. Kucuker, R. Lindgren, B. Norum, K. Wang
- Virginia Polytechnic Institute & State University
  M. Blecher, T. Kageya

- ~ 40 people
- 10 institutions
- 3 countries

Post-Docs (NSF)
Grad Students
* LSC Executive com



LSC Fa04+Sp05 list



1 of 17 Eγ bins

X 4 target pol groups

X 10 θ bins

(integrated over φ)

γ+HD Polarized cross sections and asymmetries:

- *γ-beam polarization states:* $P_\gamma^c = +1$ for $h = +1$, *R-circular* with spin along beam axis $+\hat{z}$
  $P_\gamma^L = +1$ for *0° Linear,* with *Electric* vector along $+\hat{x}$

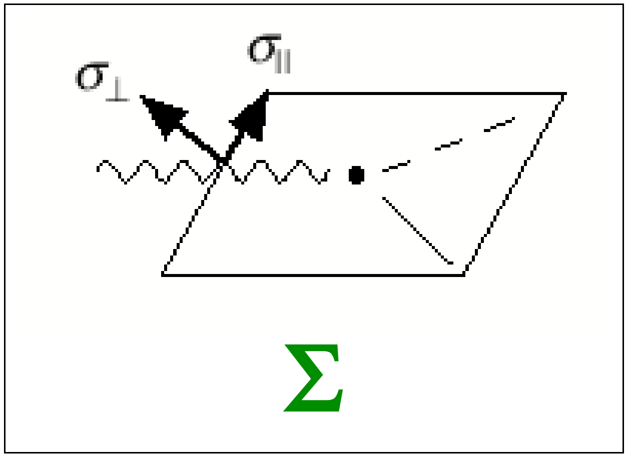
(H) For **Hydrogen** polarization $P_z = P^V$ defined as +1 when spin is along $+\hat{z}$,
- there are three asymmetries: **Σ** , ***G*** **and** ***E*** :

- $$\frac{d\sigma}{d\Omega}(\theta,\phi;E_\gamma) = \frac{d\sigma_o}{d\Omega}(\theta;E_\gamma)\cdot\left\{\begin{array}{l} 1 + P_\gamma^L \cdot \left[\ \Sigma(\theta;E_\gamma)\ \right]\cdot \cos 2\phi \\ + P_\gamma^L \cdot P_H^V \cdot G(\theta;E_\gamma)\cdot \sin 2\phi \\ -\ P_\gamma^C \cdot P_H^V \cdot E(\theta;E_\gamma) \end{array}\right\}$$

(D) For **Deuterium** with vector polarization $P^V{}_D$ along γ-beam, and tensor polarization $P^V{}_T$,
- there are three vector asymmetries: $\tilde{\Sigma}$, $\tilde{G}$ **and** $\tilde{E}$;
- and there are 2 tensor asymmetries: $T^L{}_{20}$ and $T^0{}_{20}$:

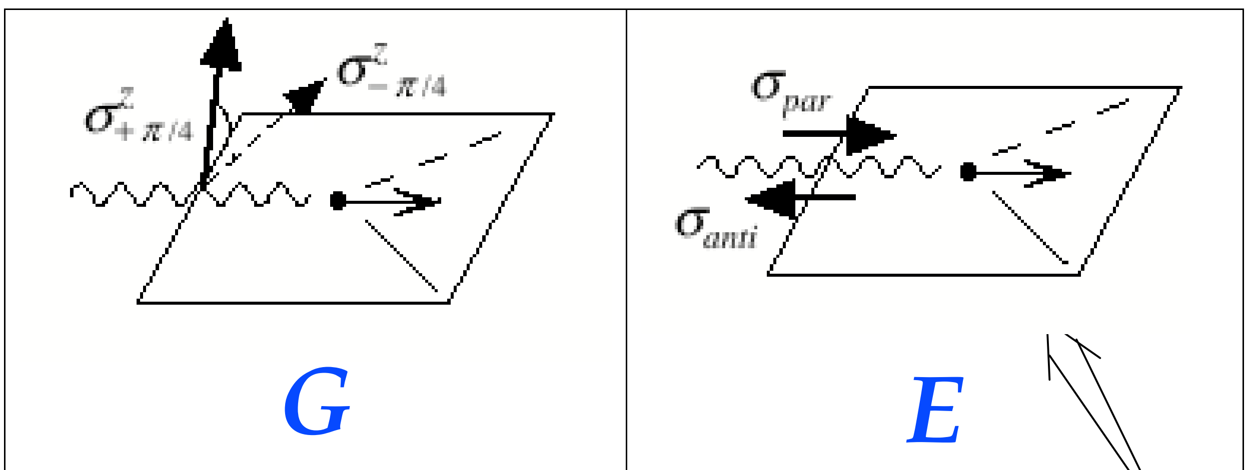
- $$\frac{d\sigma}{d\Omega}(\theta,\phi;E_\gamma) = \frac{d\sigma_o}{d\Omega}(\theta;E_\gamma)\cdot\left\{\begin{array}{l} 1 + P_\gamma^L \cdot \left[\tilde{\Sigma}(\theta;E_\gamma) + \tfrac{1}{\sqrt{2}} P_D^T \cdot T_{20}^L(\theta;E_\gamma)\right]\cdot \cos 2\phi \\ + P_\gamma^L \cdot P_D^V \cdot \tilde{G}(\theta;E_\gamma)\cdot \sin 2\phi \\ -\ P_\gamma^C \cdot P_D^V \cdot \tilde{E}(\theta;E_\gamma)\ + \tfrac{1}{\sqrt{2}} P_D^T \cdot T_{20}^0(\theta;E_\gamma) \end{array}\right\}$$

Single-spin (beam) asymmetry



$$\hat{\Sigma} = \sigma_o \times \Sigma$$

double-spin (beam-target) asymmetries



$$\hat{G} = \sigma_o \times G$$

$$\hat{E} = \sigma_o \times E$$

GDH

$$\int \frac{d\sigma}{d\Omega}\, d\phi :$$

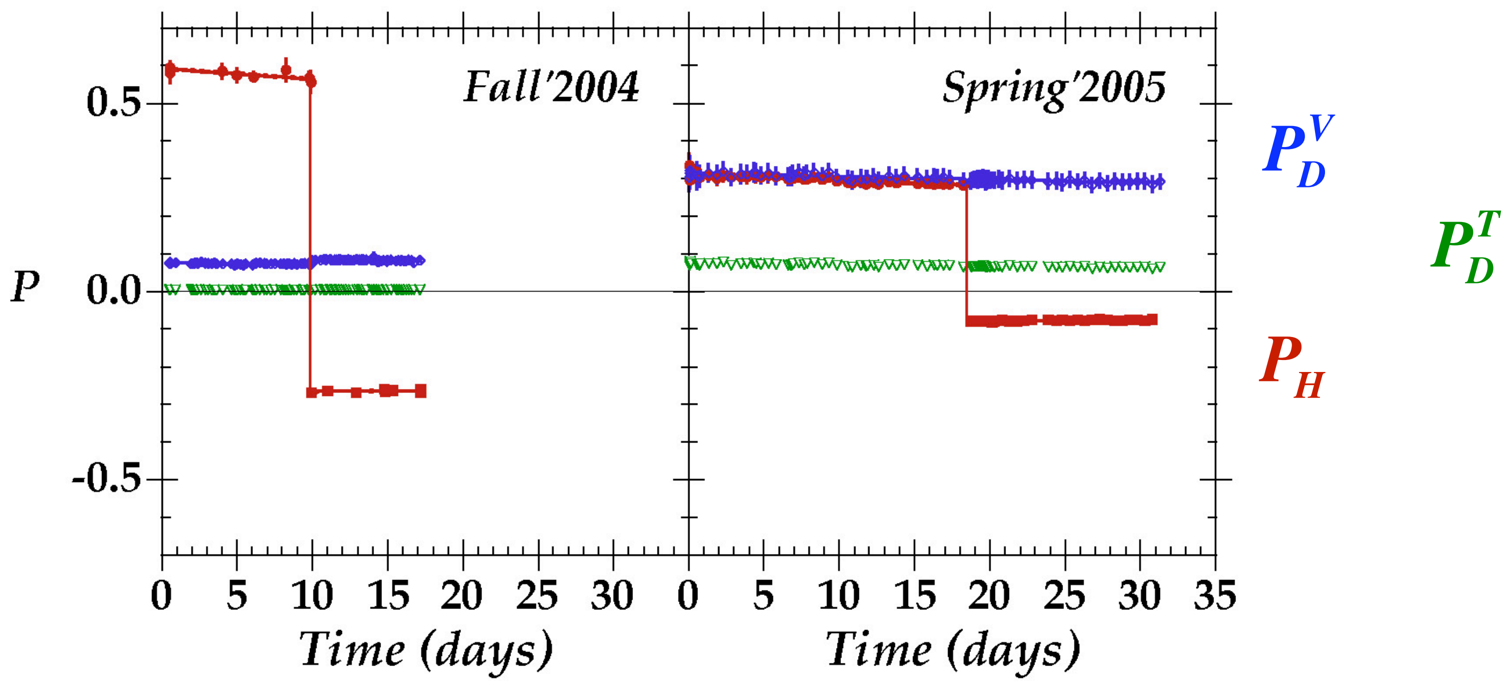
GDH spin sum-rule

$$\hat{E}_{H,D} = \tfrac{1}{2}\left[d\sigma^{H,D}(A) - d\sigma^{H,D}(P)\right]$$

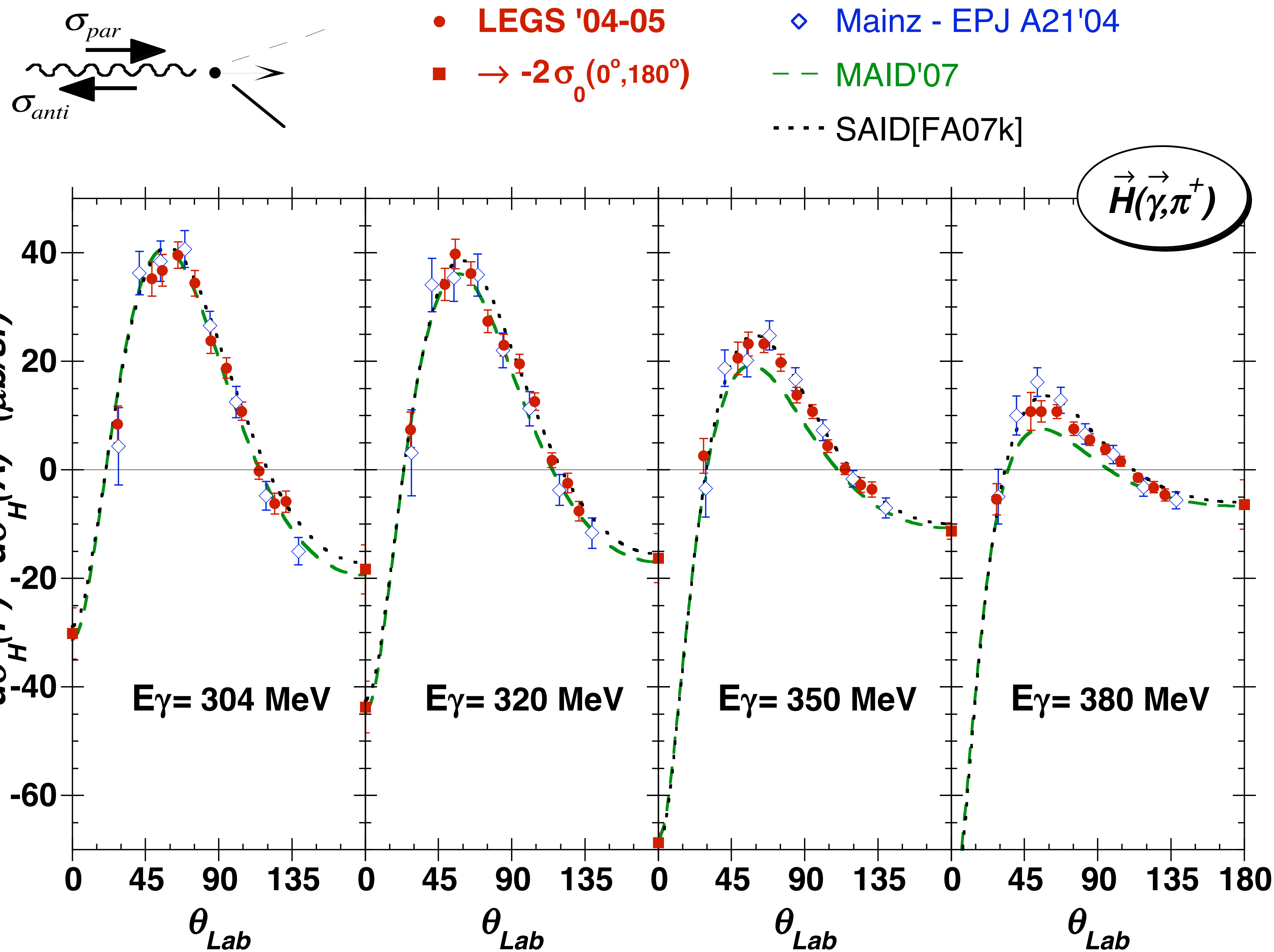
$$d\sigma(\theta, E_\gamma) = \boxed{d\sigma_0^{HD}} - P_\gamma^c P_H \boxed{\hat{E}_H} - P_\gamma^c P_D^V \boxed{\hat{E}_D} + \sqrt{1/2}\; P_D^T \boxed{\hat{T}_{20}^0}$$

$$\sqrt{1/2}\; \boxed{\hat{T}_{20}^0} = \tfrac{1}{2}\left[d\sigma^D(A) + d\sigma^D(P) - 2 d\sigma_0^D\right]$$

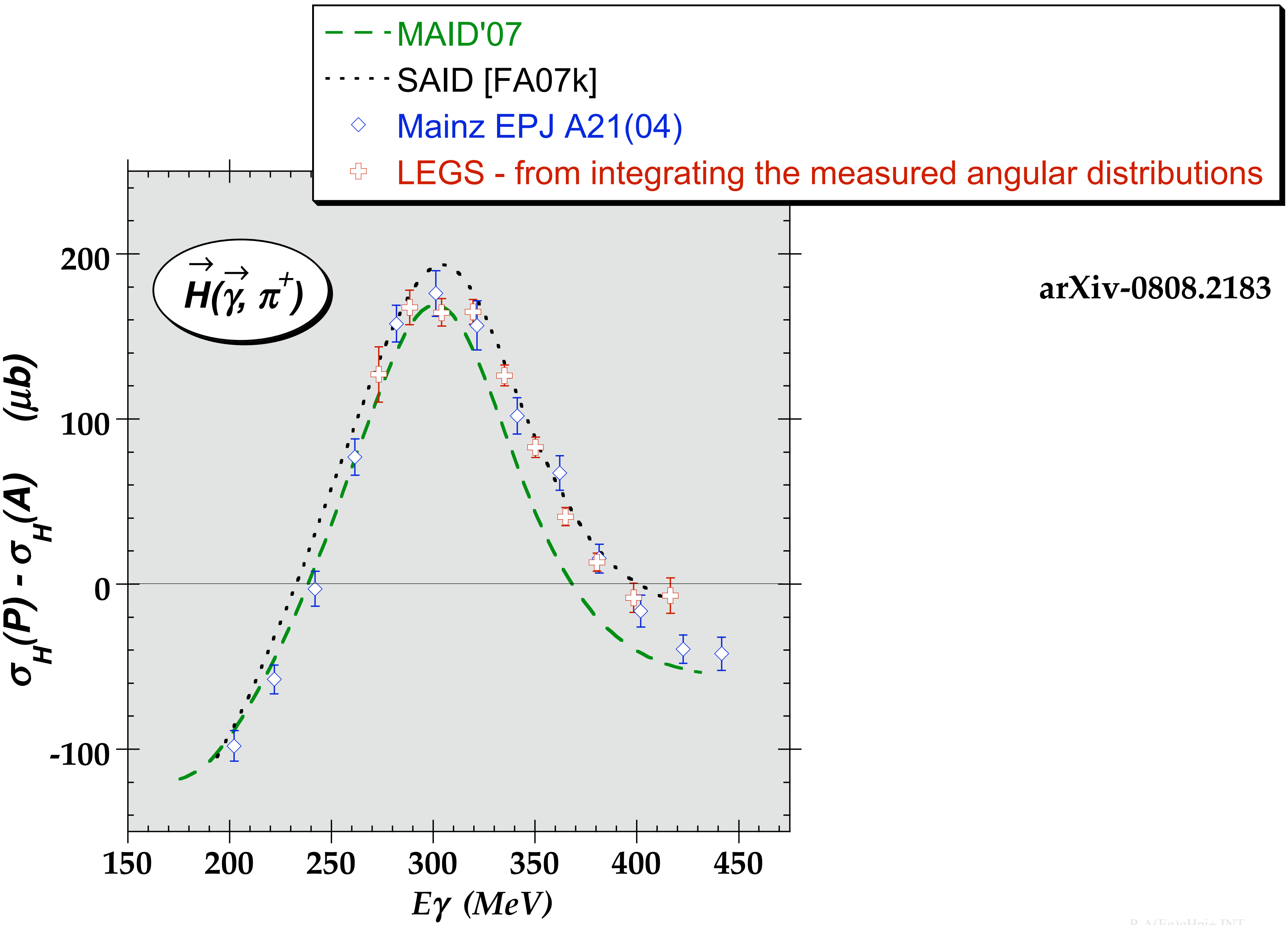
$\vec{\gamma} + \vec{H}\ \vec{D}$



phi-int pol-crs T3/T4 in-beam -GDH

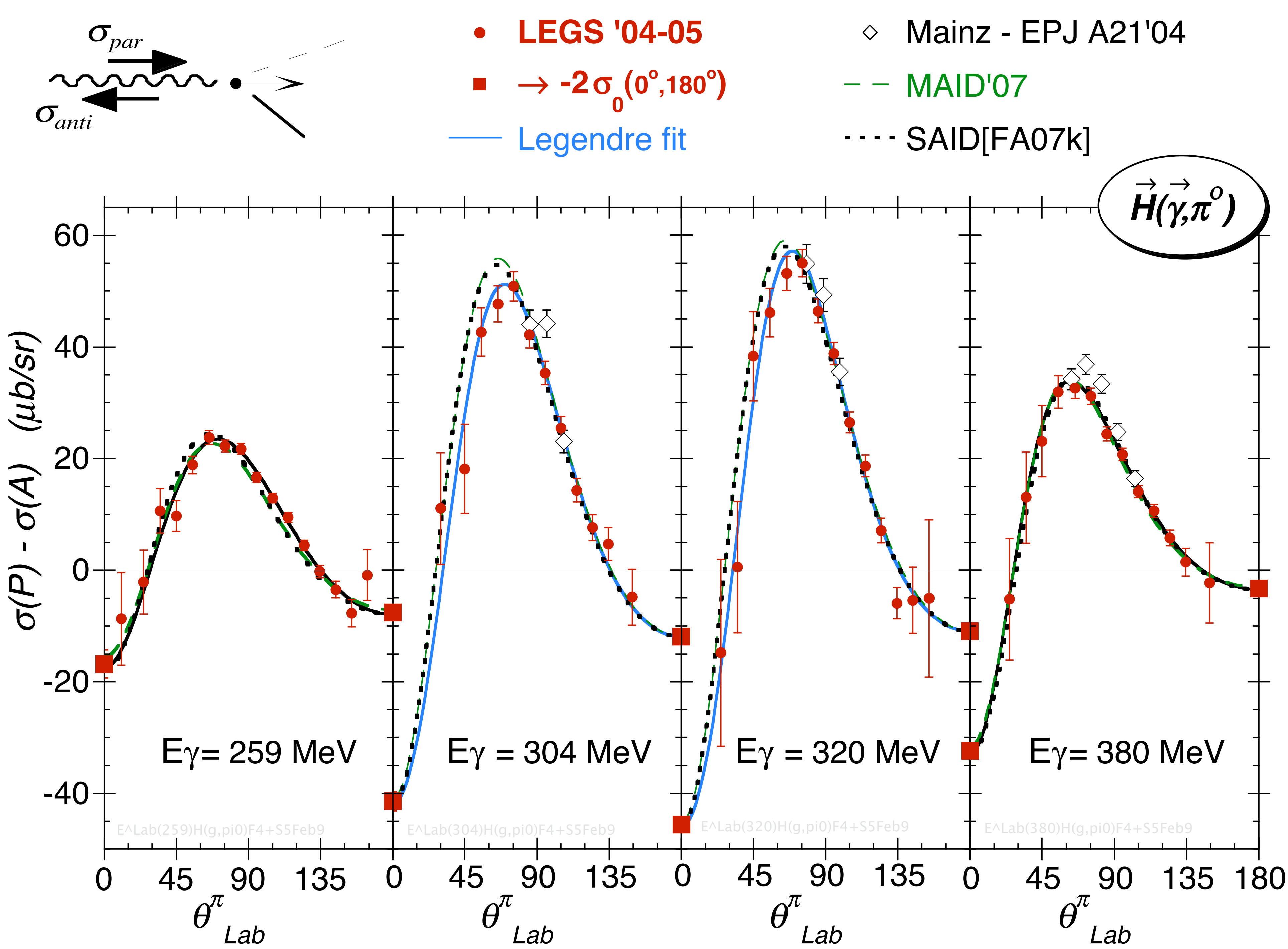


σpar
σanti
LEGS '04-05
→ -2σ0(0°,180°)
Mainz - EPJ A21'04
MAID'07
SAID[FA07k]
H(γ,π+)
dσH(P) - dσH(A) (μb/sr)
40
20
0
-20
-40
-60
Eγ= 304 MeV
Eγ= 320 MeV
Eγ= 350 MeV
Eγ= 380 MeV
0 45 90 135 180
θLab

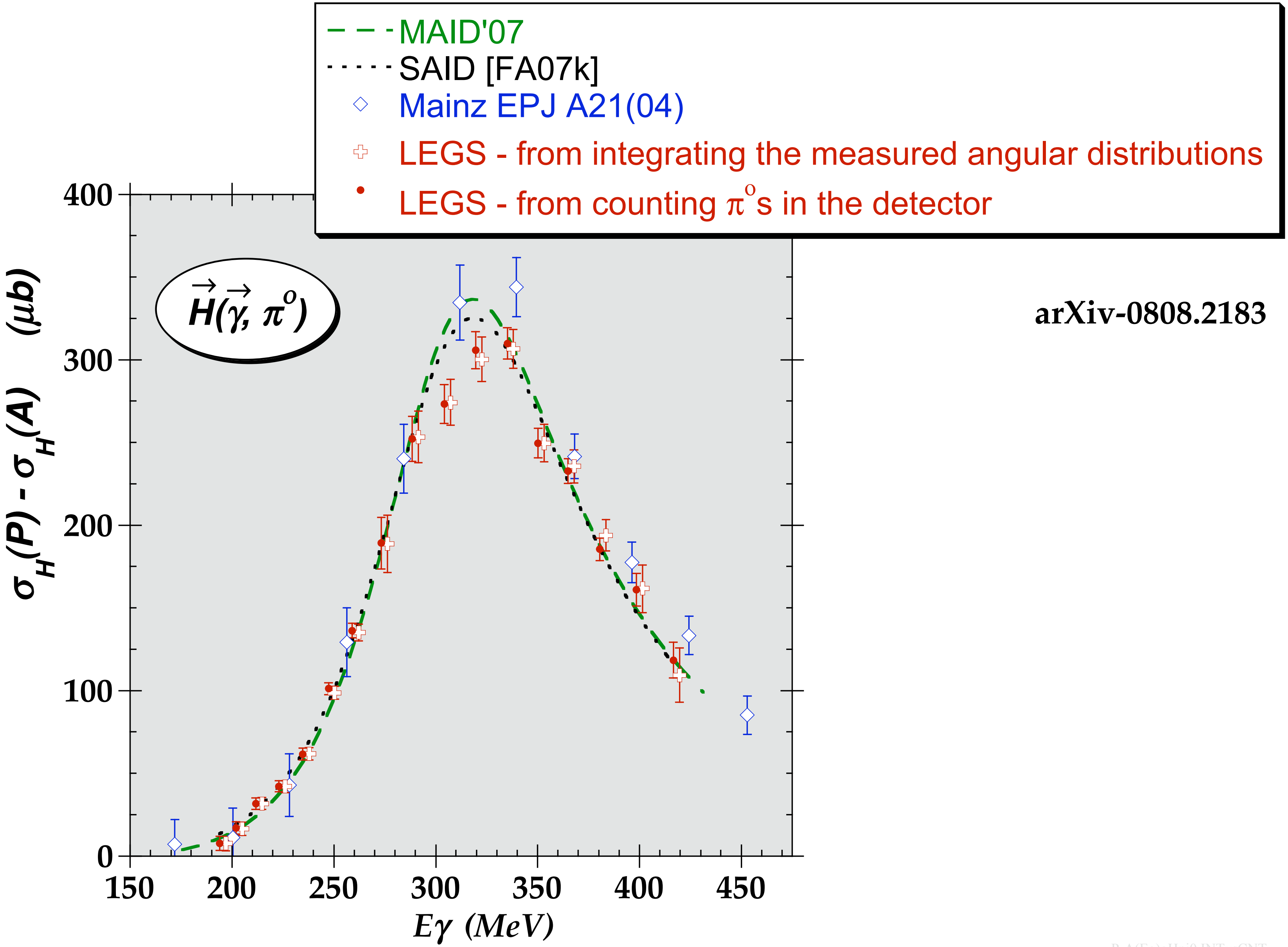


arXiv-0808.2183

P-A(Eg)gHpi+ INT



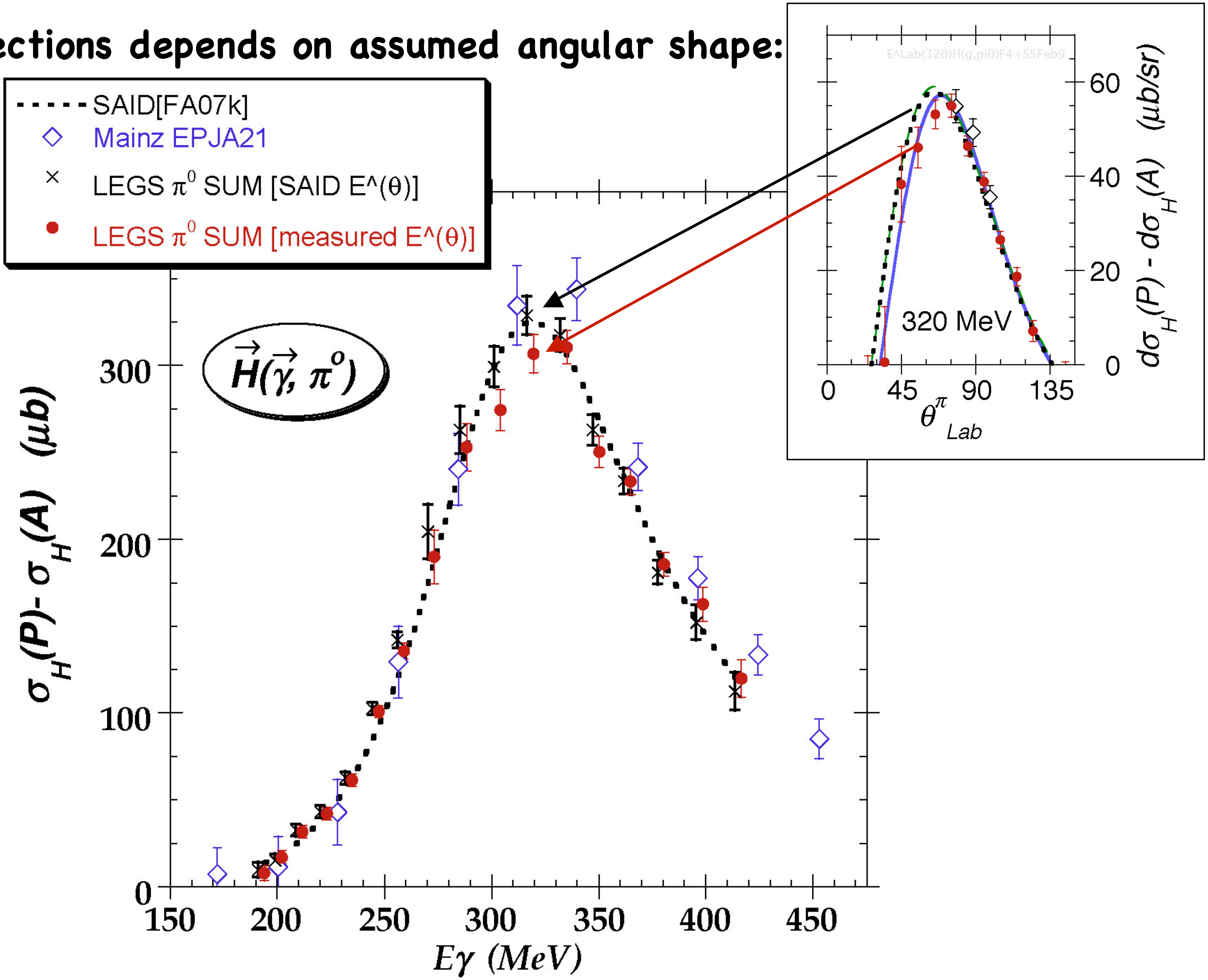
σ_{par}
σ_{anti}
LEGS '04-05
$\rightarrow -2\sigma_0(0^o,180^o)$
Legendre fit
Mainz - EPJ A21'04
MAID'07
SAID[FA07k]
$\vec{H}(\vec{\gamma},\pi^o)$
$\sigma(P) - \sigma(A)$ ($\mu b/sr$)
Eγ= 259 MeV
Eγ = 304 MeV
Eγ = 320 MeV
Eγ= 380 MeV
θ^{π}_{Lab}



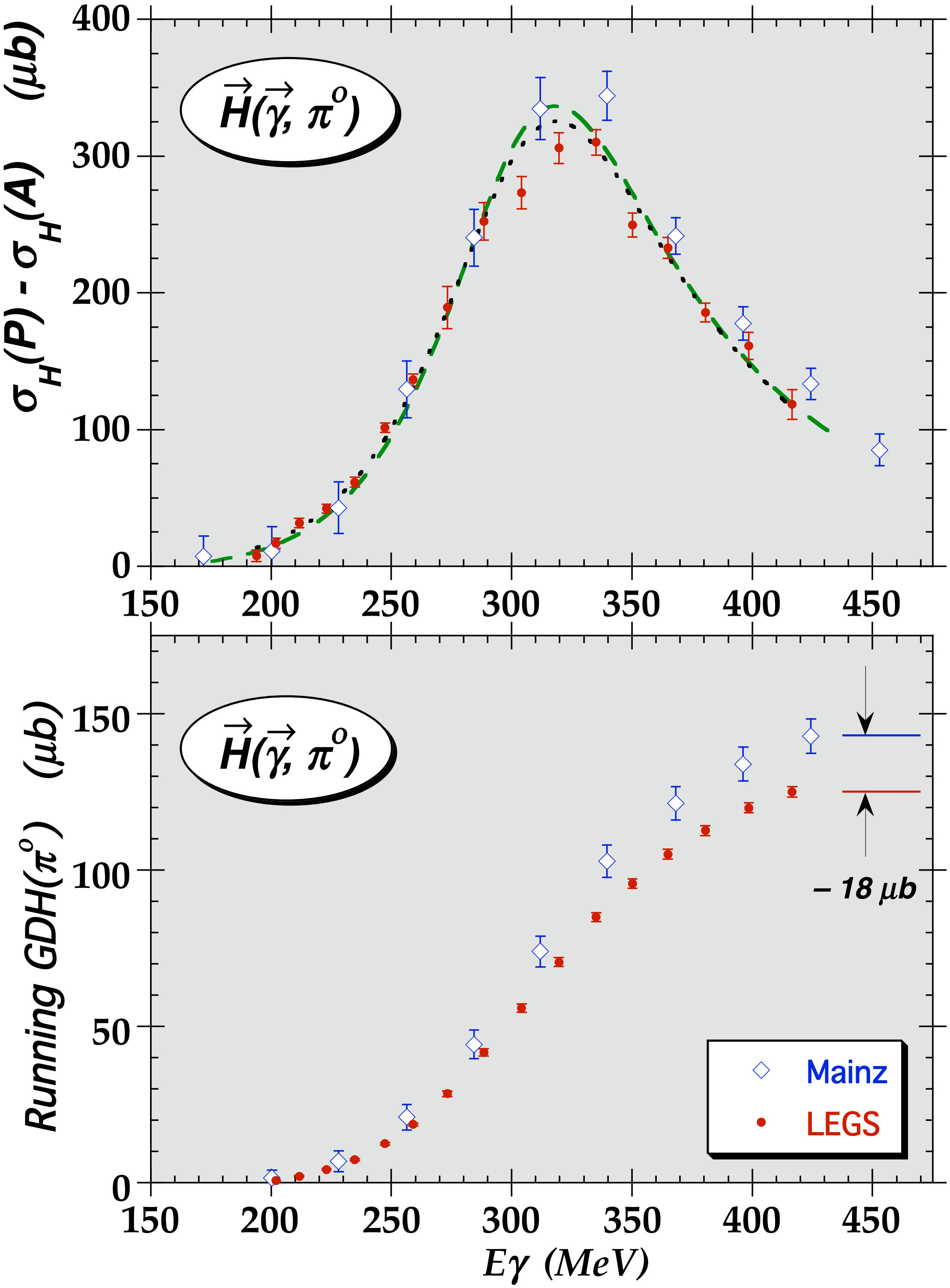
MAID'07
SAID [FA07k]
Mainz EPJ A21(04)
LEGS - from integrating the measured angular distributions
LEGS - from counting π°s in the detector
$\vec{H}(\vec{\gamma}, \pi^o)$
$\sigma_H(P) - \sigma_H(A)$ (μb)
$E\gamma$ (MeV)
0
100
200
300
400
150
200
250
300
350
400
450
arXiv-0808.2183
P-A(Eg)gHpi0 INTvsCNT

Total spin difference from counting π°s in the detector

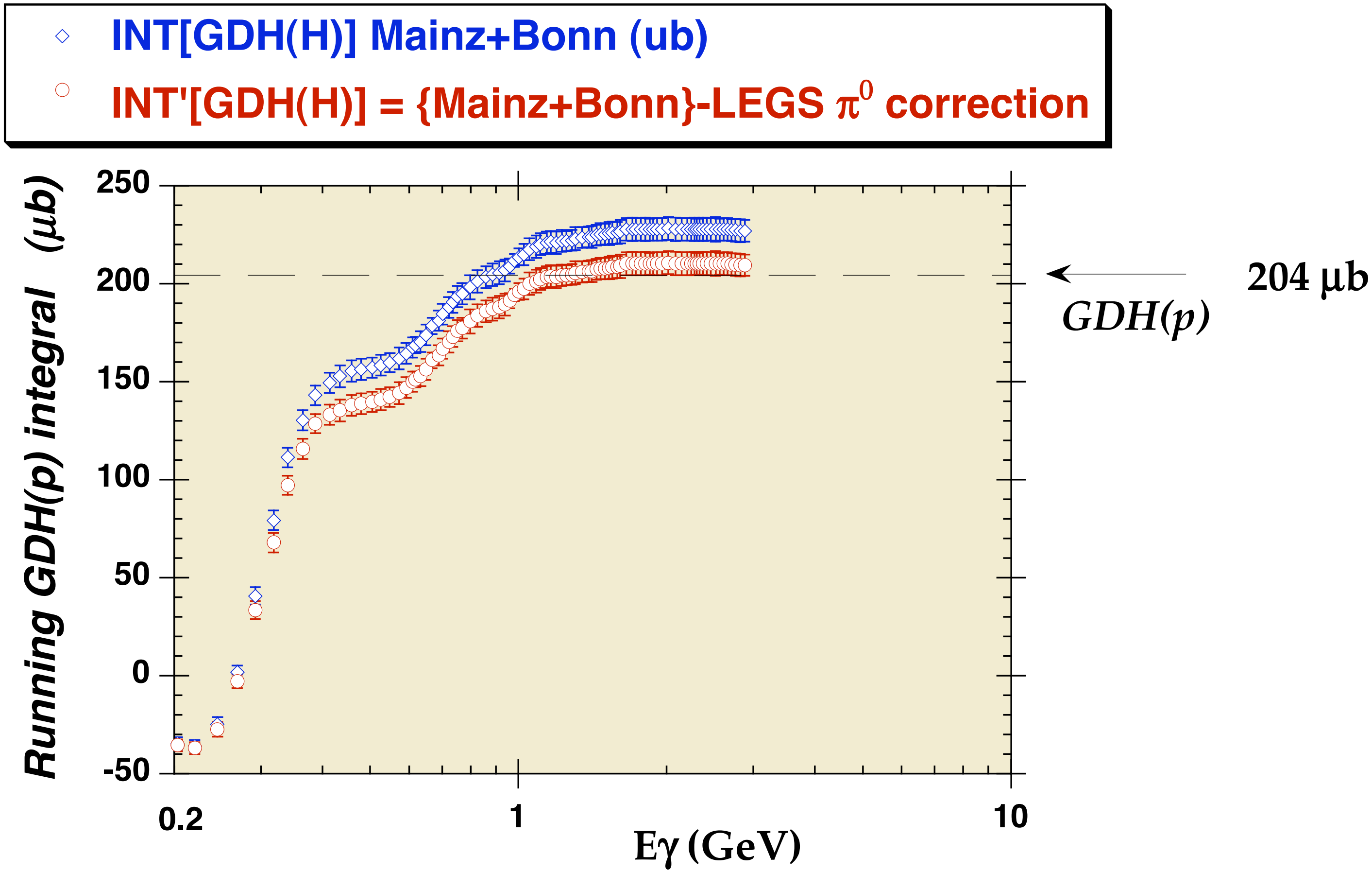
- eff corrections depends on assumed angular shape:



arXiv-0808.2183



$$Running\ INT_{GDH}(E_\gamma) = \int^{E_\gamma} \frac{\sigma(P) - \sigma(A)}{E}\, dE$$



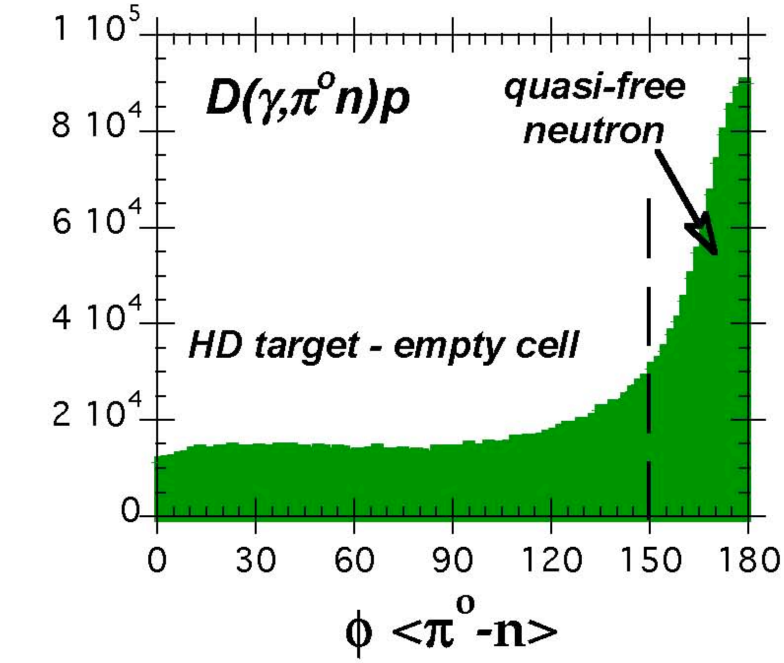
GDHp [combined Mainz+Bonn+LEGS]
= 208 ±6(stat) ± 14(sys) μb

indicates $g_p(\omega) \rightarrow 0$ rapidly

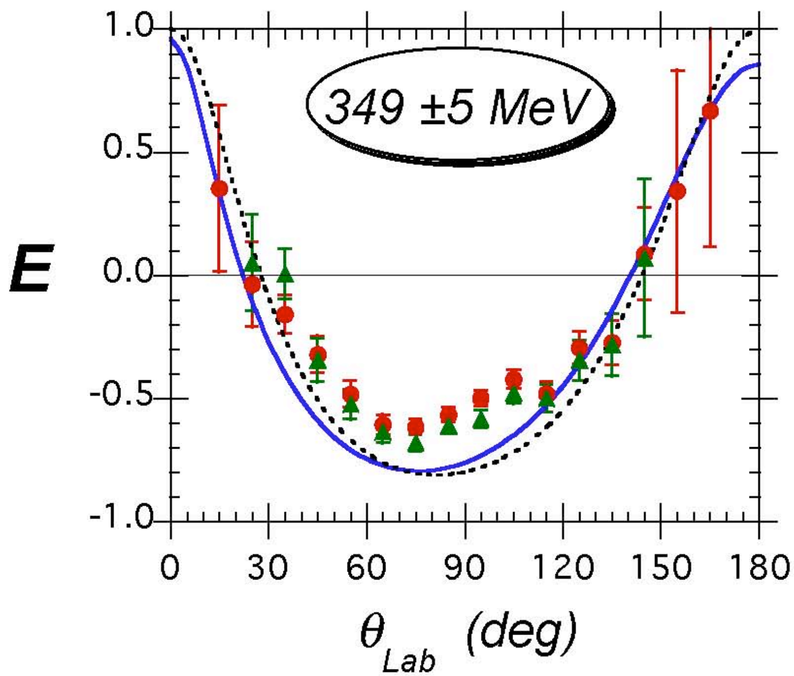
LEGS(pi0)corr to INTGDH(p)

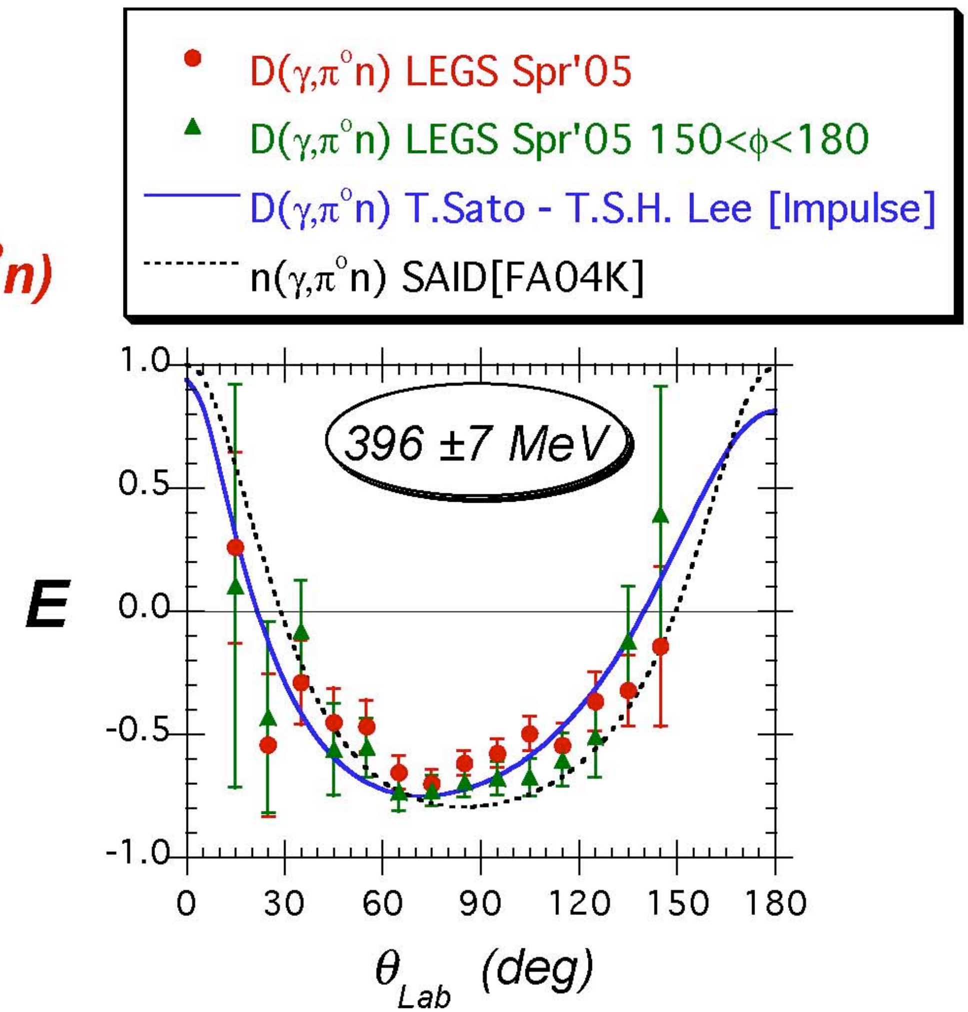
GDH(n) from D(γ,πN) at LEGS

- preliminary
- more to come !



$\vec{D}(\vec{\gamma},\pi^o n)$





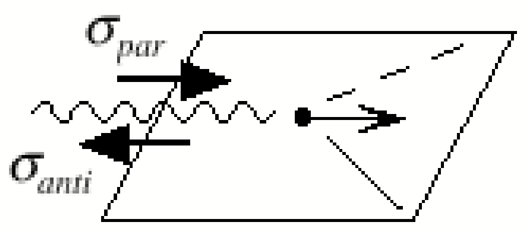
- the GDH sum rule should hold for any spin system:

$$\int_{E_0}^{\infty} \frac{\sigma(P)-\sigma(A)}{E_\gamma}\, dE_\gamma \quad = \quad S\frac{4\pi^2\alpha}{m^2}K \quad + g_{\gamma,\gamma}(\infty)$$

$$\Uparrow$$

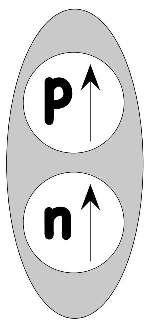
provided $g_{\gamma,\gamma} \to 0$

faster than *1/ln(E_γ)*



$$-2\cdot\hat{E} = \left[d\sigma(P) - d\sigma(A)\right]$$

GDH for γ + Deuteron



$K(p) = +1.79\ m_N$

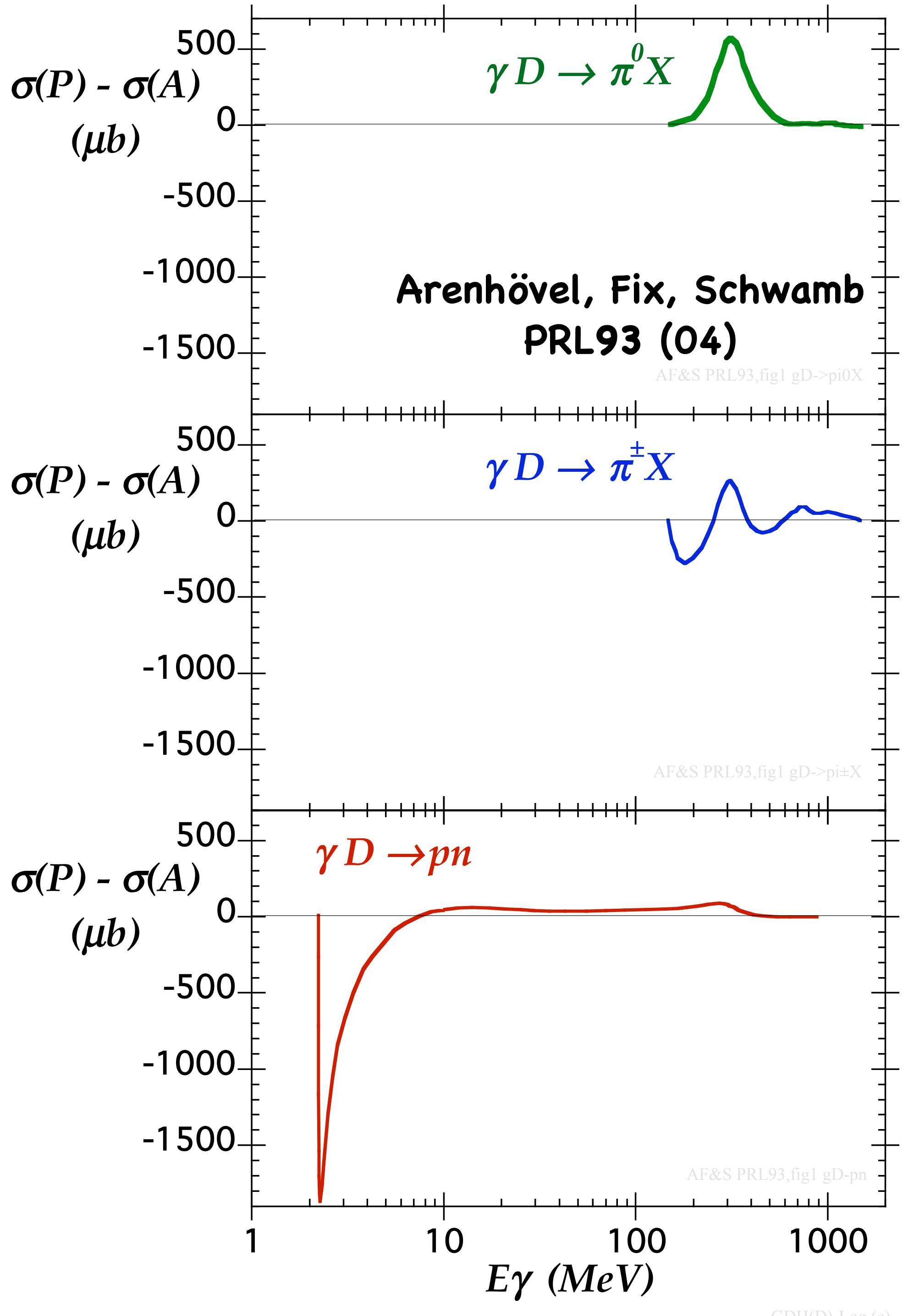
$K(n) = -\ 1.91\ m_N$

$S = 1$ $\qquad$ $K(D) = -\ 0.14\ m_N$

$$\int_{E_0}^{\infty} \frac{\sigma(P) - \sigma(A)}{E_\gamma}\, dE_\gamma$$

$$= (S=1)\frac{4\pi^2\alpha}{m_D^2}K^2(D)$$

$$\rightarrow\ 0.65\ \mu b$$



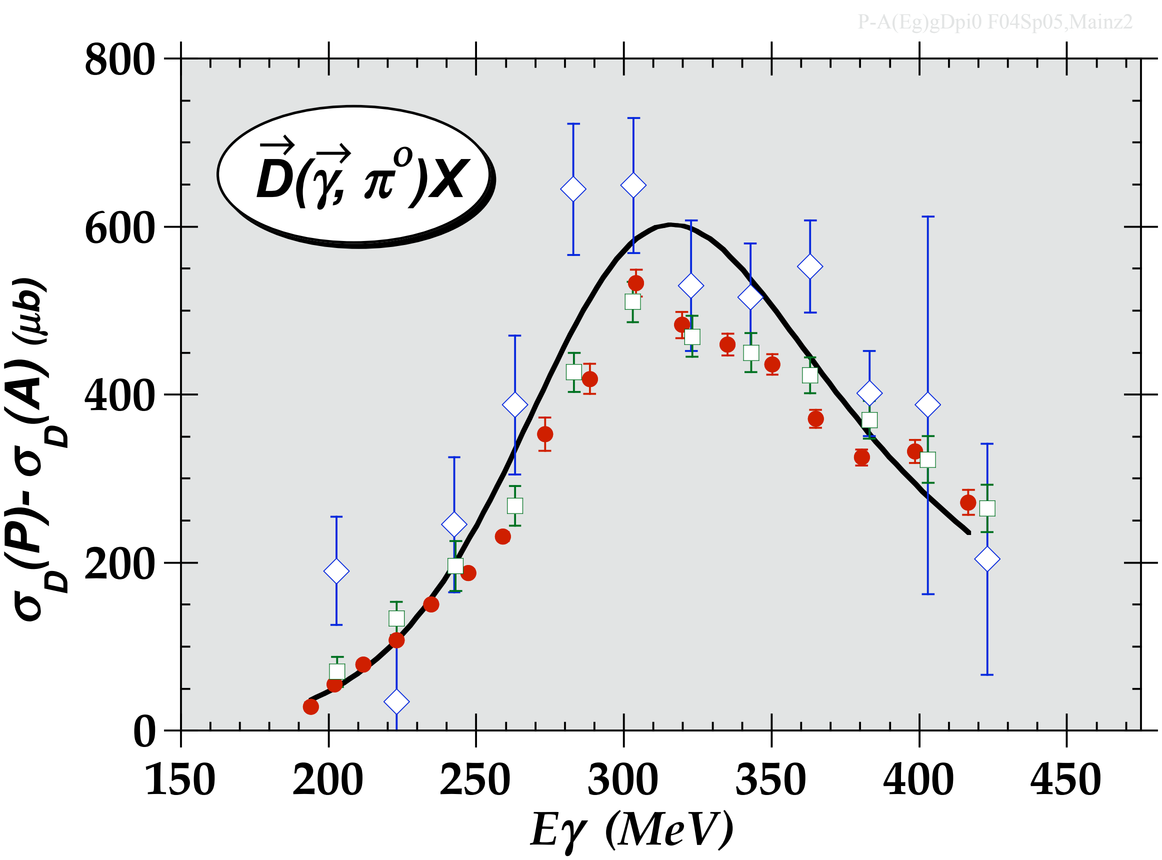
γ + D expectation:

Arenhövel, Fix, Schwamb PRL93 (04)

◇ Mainz, PRL97 (06)

• LEGS, arXiv-0808.2183 [PRL-*in press*]

□ Mainz, PL B672 (09)



γ + D expectation:

Arenhövel, Fix, Schwamb PRL93 (04)

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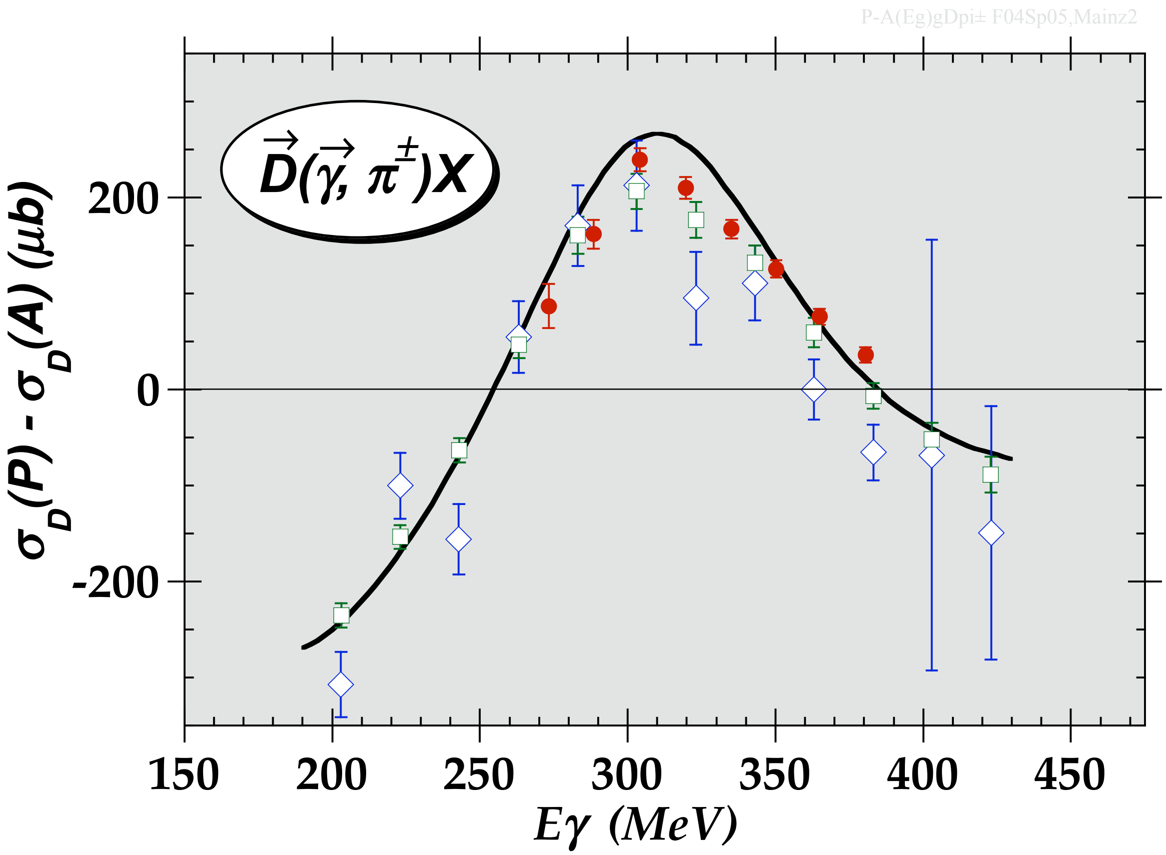
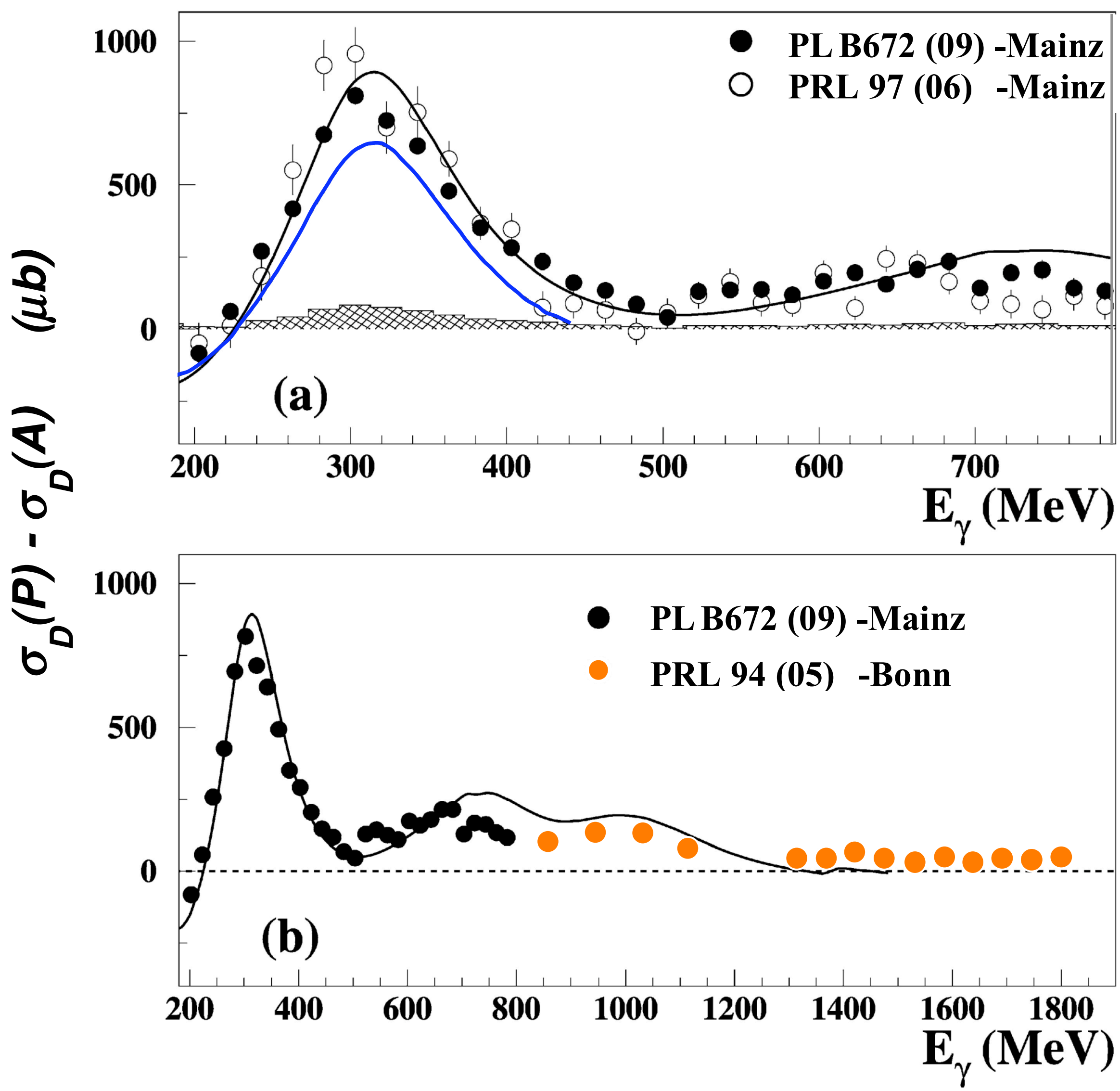
□ Mainz, PL B672 (09)



$\vec{\gamma}+\vec{D}$: Phys. Lett. B672, 328(2009) $\Leftrightarrow \int_{0.2}^{\sim 2\,GeV} \frac{\sigma_P - \sigma_A}{\omega} d\omega = 452 \pm 9 \pm 24\ \mu b$



Arenhövel, Fix, Schwamb
PRL 93, 202301(04)

- pn, π^0D :
  parametrized currents, MEC, retarded pot, NN-ΔN cc
- πNN, ππNN, ηNN :
  leading diagrams with A(γN) from MAID and NN rescat

$$\Rightarrow \int_{E\pi}^{\sim 2\,GeV} \frac{\sigma_P - \sigma_A}{\omega} d\omega = 488\ \mu b$$

Schwamb. Phys. Rep. (in press)
- consistent retarded NN-ΔN cc for all channels

P-A(gD) fig1 PLB672(09)

GDH(D) contribution above π-threshold:

$$\text{Mainz+Bonn} \Rightarrow \int_{0.2}^{\sim 2\ GeV} \frac{\sigma_P - \sigma_A}{\omega} d\omega = 452 \ \pm 9 \pm 24 \ \mu b$$

$$\text{Arenhövel/Fix/Schwamb} \Rightarrow \int_{E\pi}^{\sim 2\ GeV} \frac{\sigma_P - \sigma_A}{\omega} d\omega = 488 \ \mu b$$

But !

- how well do the calculations reproduce other non-GDH spin observables ?

$\Rightarrow$ Σ(D) and G(D) extracted from ϕ-dependent fits at LEGS

Extracting ϕ-dependent quantities:

from Fall'04 data, where P_D^T =0

$\Downarrow$

$$d\sigma = d\sigma_o(HD) + P_\gamma^L \cdot \left[\hat{\Sigma}(HD) + \tfrac{1}{\sqrt{2}} P_D^T \cdot T_{20}^L(D) \right] \cdot \cos 2\phi$$

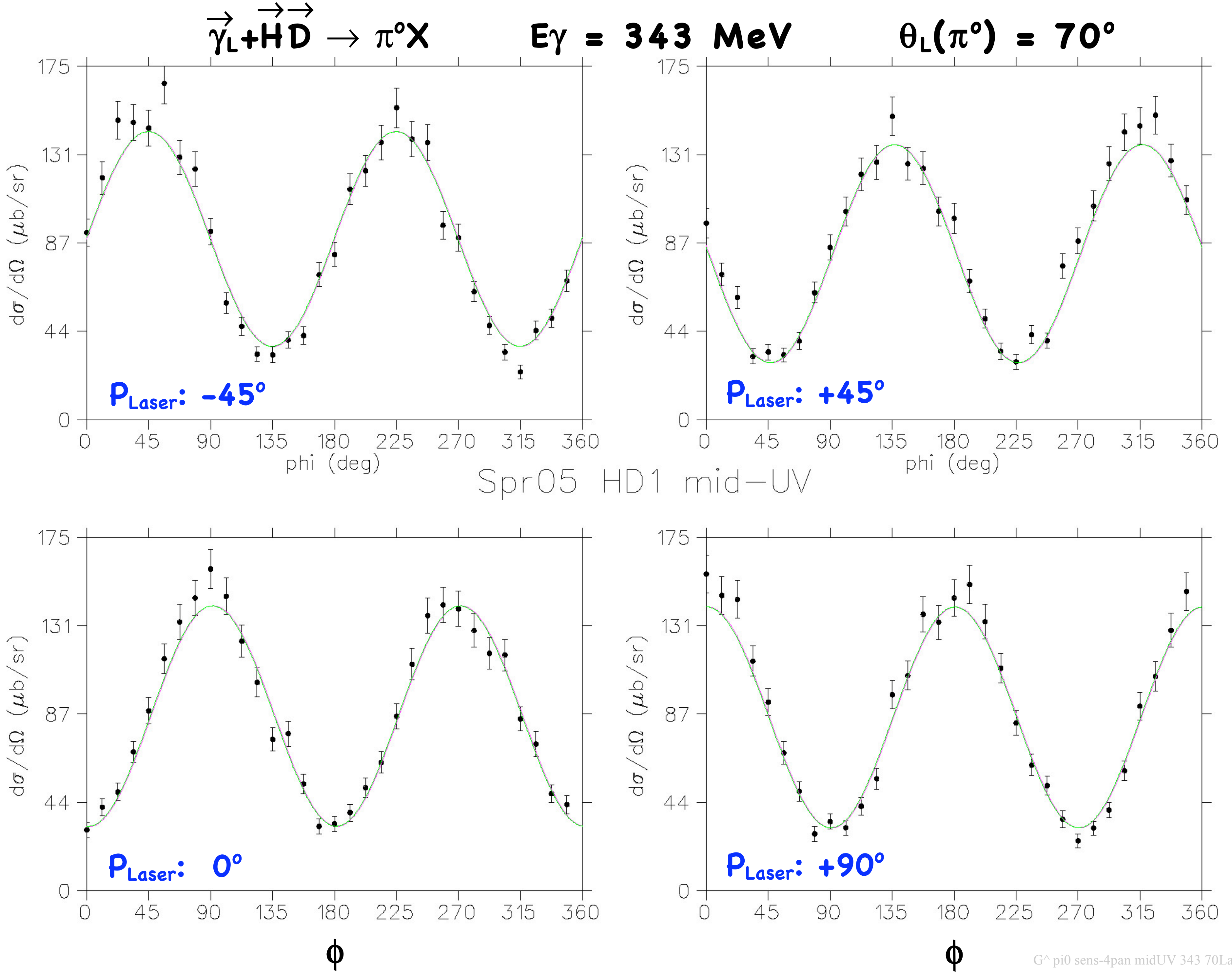
$$+ P_\gamma^L \cdot \left[P_H \cdot \hat{G}(H) + P_D^V \cdot \hat{G}(D) \right] \cdot \sin 2\phi$$

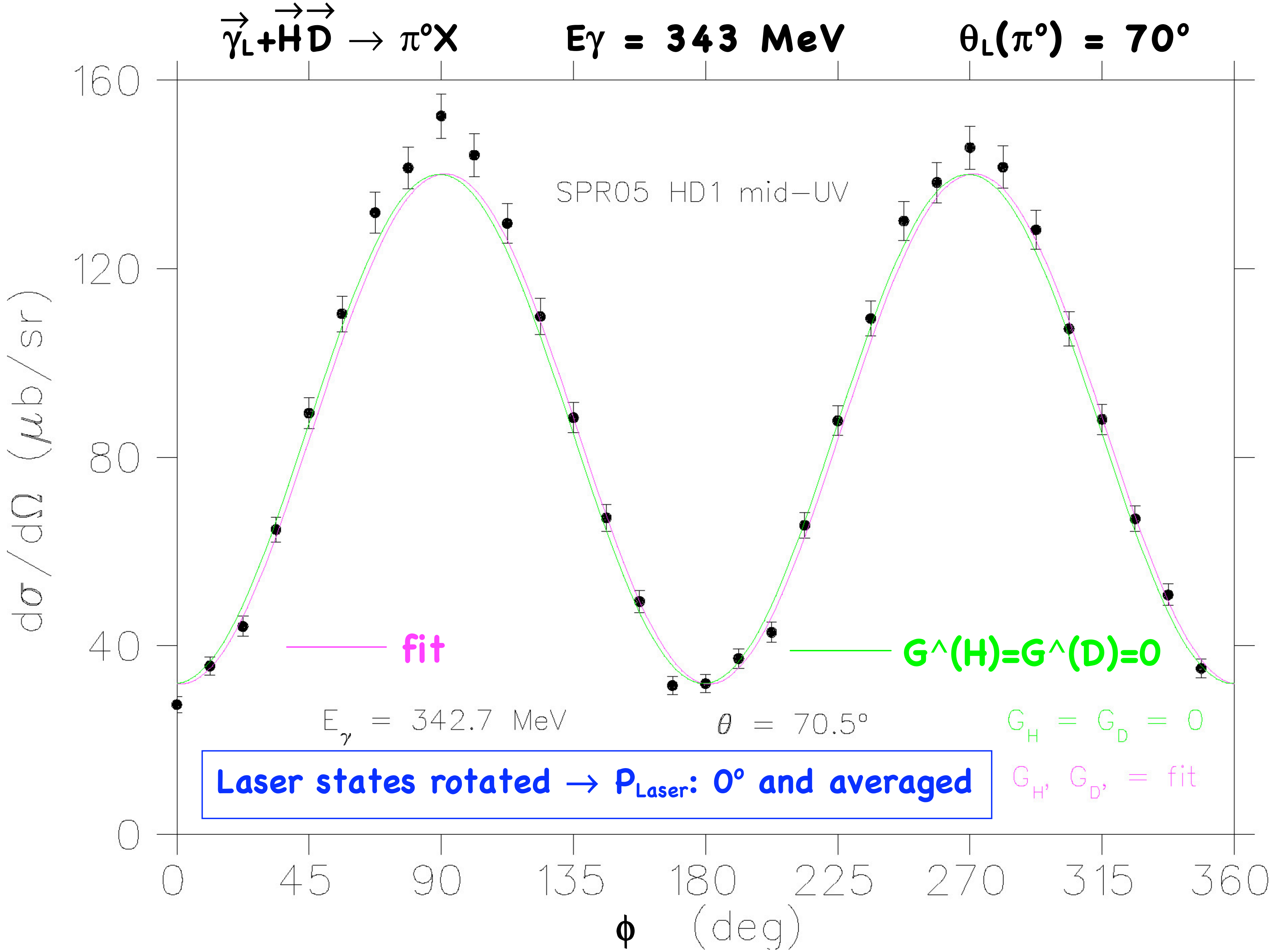
$$- P_\gamma^C \cdot \left[P_H \cdot \hat{E}(H) + P_D^V \cdot \hat{E}(D) \right] + \tfrac{1}{\sqrt{2}} P_D^T \cdot T_{20}^0(D)$$

ϕ-fits

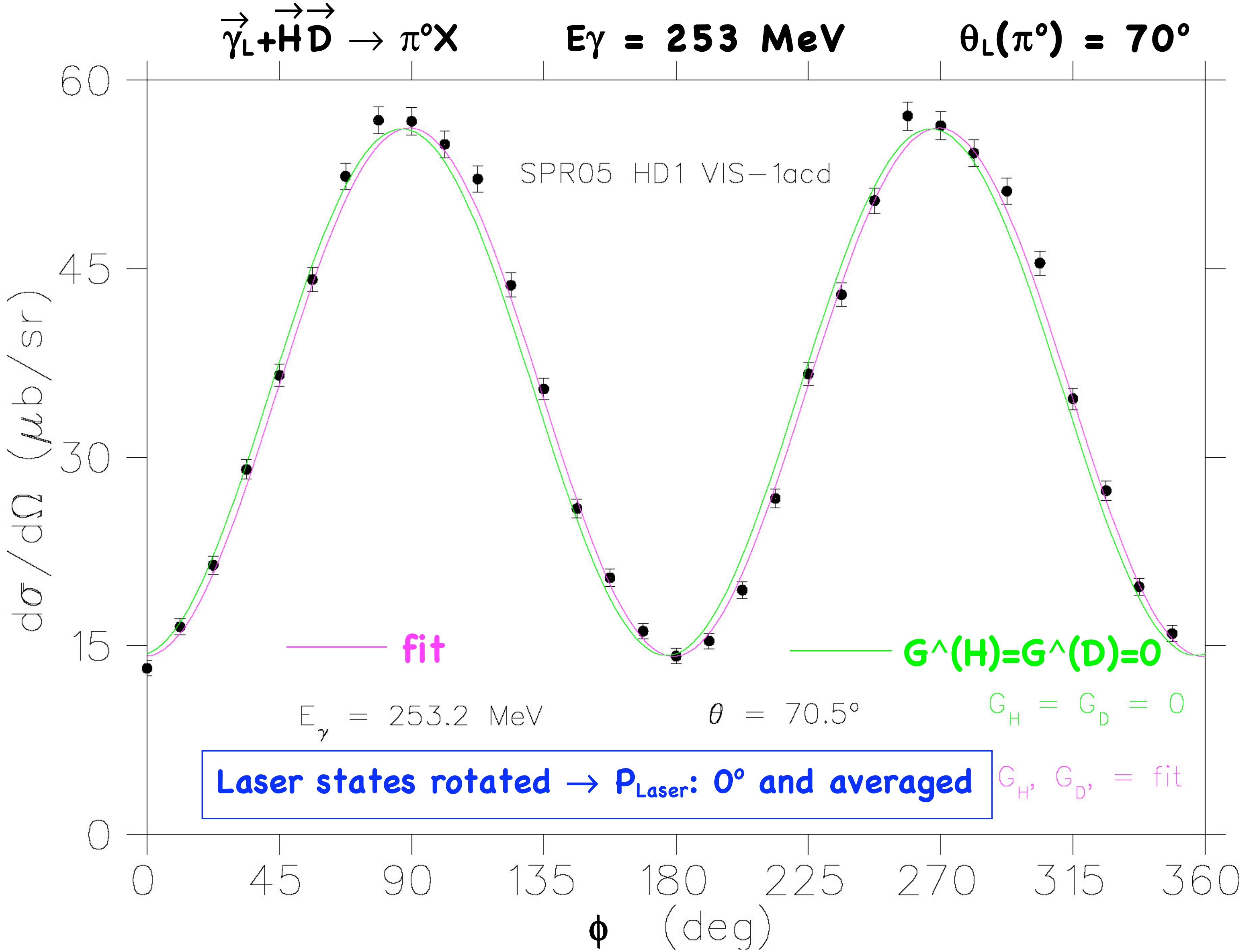
from $\int d\phi$ fits

General eqn phi-fits


$\vec{\gamma}_L + \vec{\vec{HD}} \rightarrow \pi^o X$
$E\gamma$ = 343 MeV
$\theta_L(\pi^o)$ = 70°
$d\sigma/d\Omega$ (μb/sr)
phi (deg)
P_{Laser}: -45°
P_{Laser}: +45°
Spr05 HD1 mid-UV
P_{Laser}: 0°
P_{Laser}: +90°
ϕ
G^ pi0 sens-4pan midUV 343 70Lab



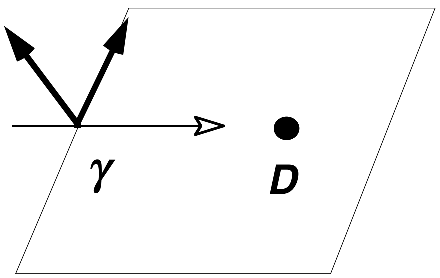
G^ pi0 rot-sum midUV 343 70Lab

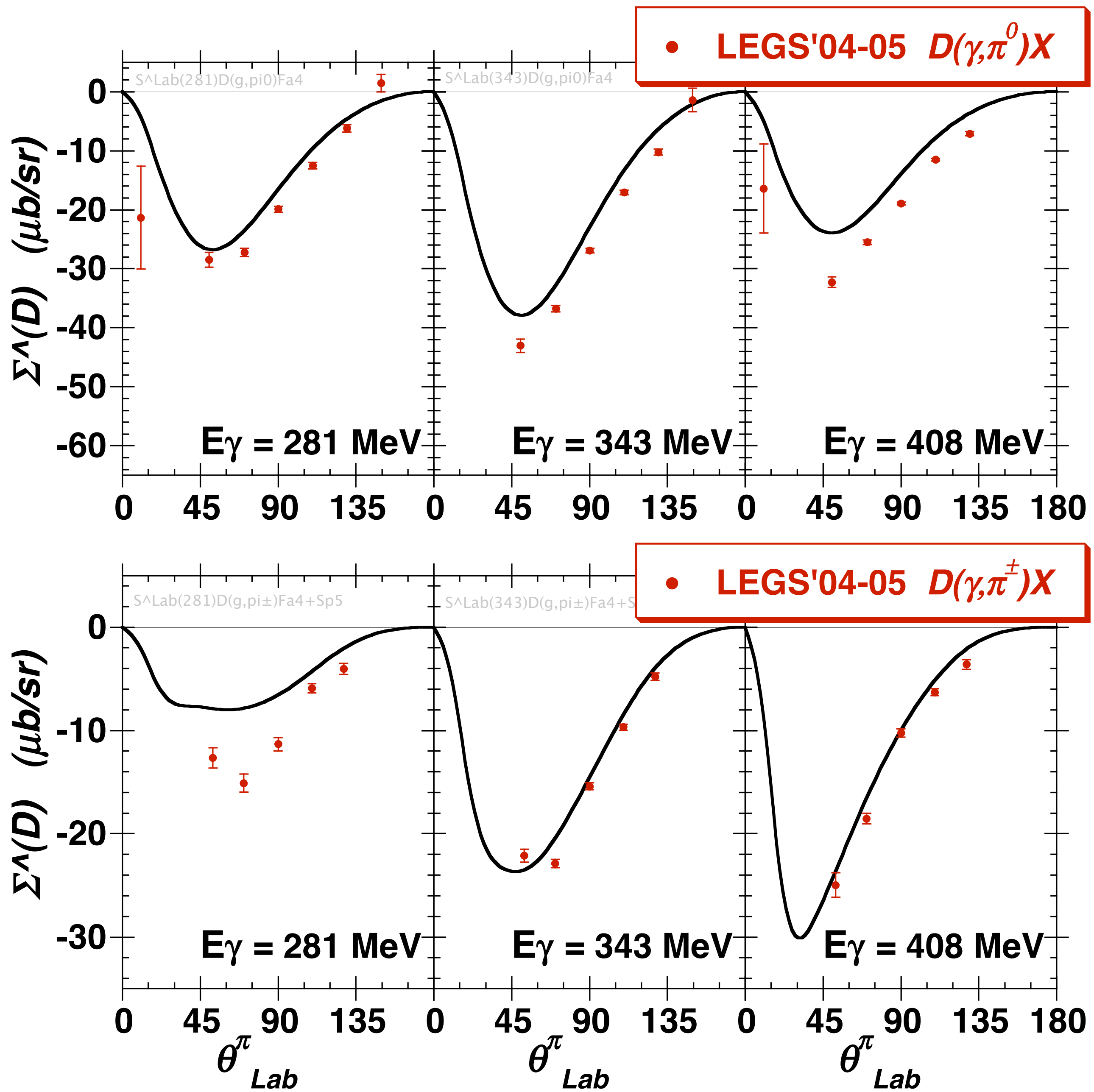


G^ pi0 rot-sum SpVIS1 253 70Lab

• Σ^(D) = Σ^(HD) - Σ^(H_{SAID})

Fix & Arenhövel, PRC 72 (2005)

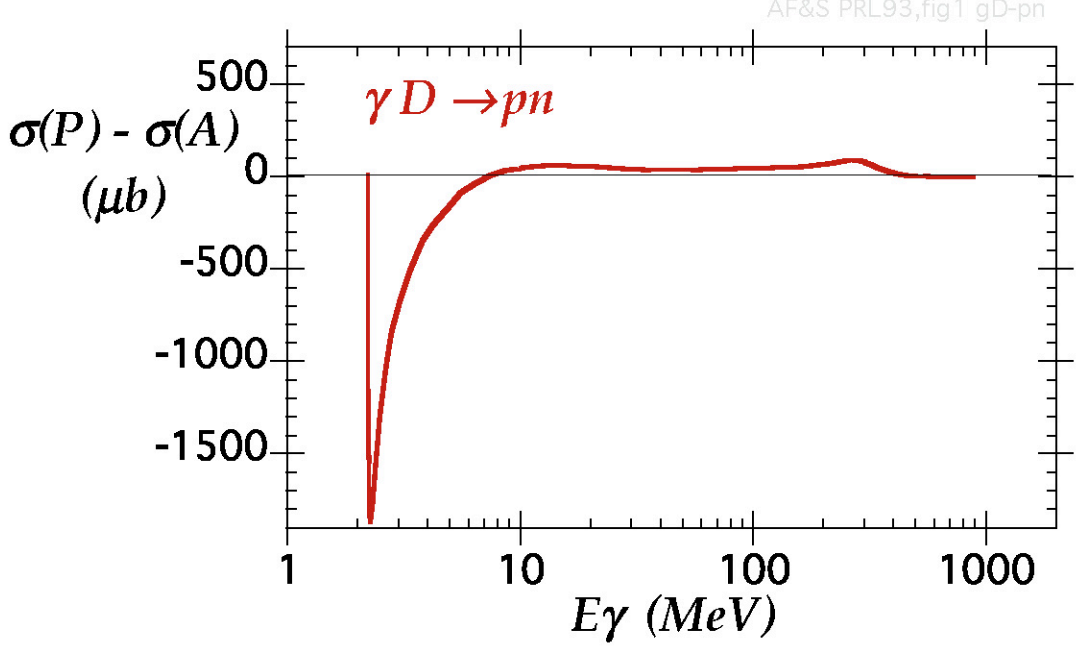




S^(D) pi0X,pi±X

GDH(D) below π-threshold:

$$(S=1)\frac{4\pi^2\alpha}{m_D^2}K_D^2 = 0.65\ \mu b$$



- ∫dω [π, ππ, η] ~ +450 μb
- large negative contribution needed in γD → pn
- $\vec{\gamma}+\vec{D}$ experiments planned for HIGS at Duke (2010 ?)
- indirect info is possible at low energies where there are few partial waves
- at threshold γD → pn is pure E1, but quickly (+200 Kev) switches to mostly M1
- $\sigma(P)-\sigma(A)=\frac{\pi\lambda^2}{2}\left[-\ \left|M1\left({}^1S_0\right)\right|^2\right]$

↑

| γ-multipole $({}^{2S+1}L_J)_{np}$ | ⇔ γ(M1) flips a N spin in D

→ s-wave pn pair with spins opposed

more generally,

- $$\sigma(P)-\sigma(A)=\tfrac{\pi\lambda^2}{2}\left[-\left|M1\left({}^1S_0\right)\right|^2-\left|E1\left({}^3P_0\right)\right|^2-\tfrac{3}{2}\left|E1\left({}^3P_1\right)\right|^2+\tfrac{5}{2}\left|E1\left({}^3P_2\right)\right|^2 -\tfrac{3}{2}\left|E2\left({}^3D_1\right)\right|^2-\tfrac{5}{6}\left|E2\left({}^3D_2\right)\right|^2+\tfrac{7}{3}\left|E2\left({}^3D_3\right)\right|^2\right]$$

$$\Rightarrow \tfrac{\pi\lambda^2}{2}\left[-\left|M1\left({}^1S_0\right)\right|^2\right]$$, if P and D wave splittings are small

- if only E1 and M1 radiation contribute, components are easily separated in single-spin measurements of beam-asymmetry (Σ) or recoil polarization.

$\Rightarrow$ indirect determination of double-pole spin-difference $\sigma_D(P) - \sigma_D(A)$

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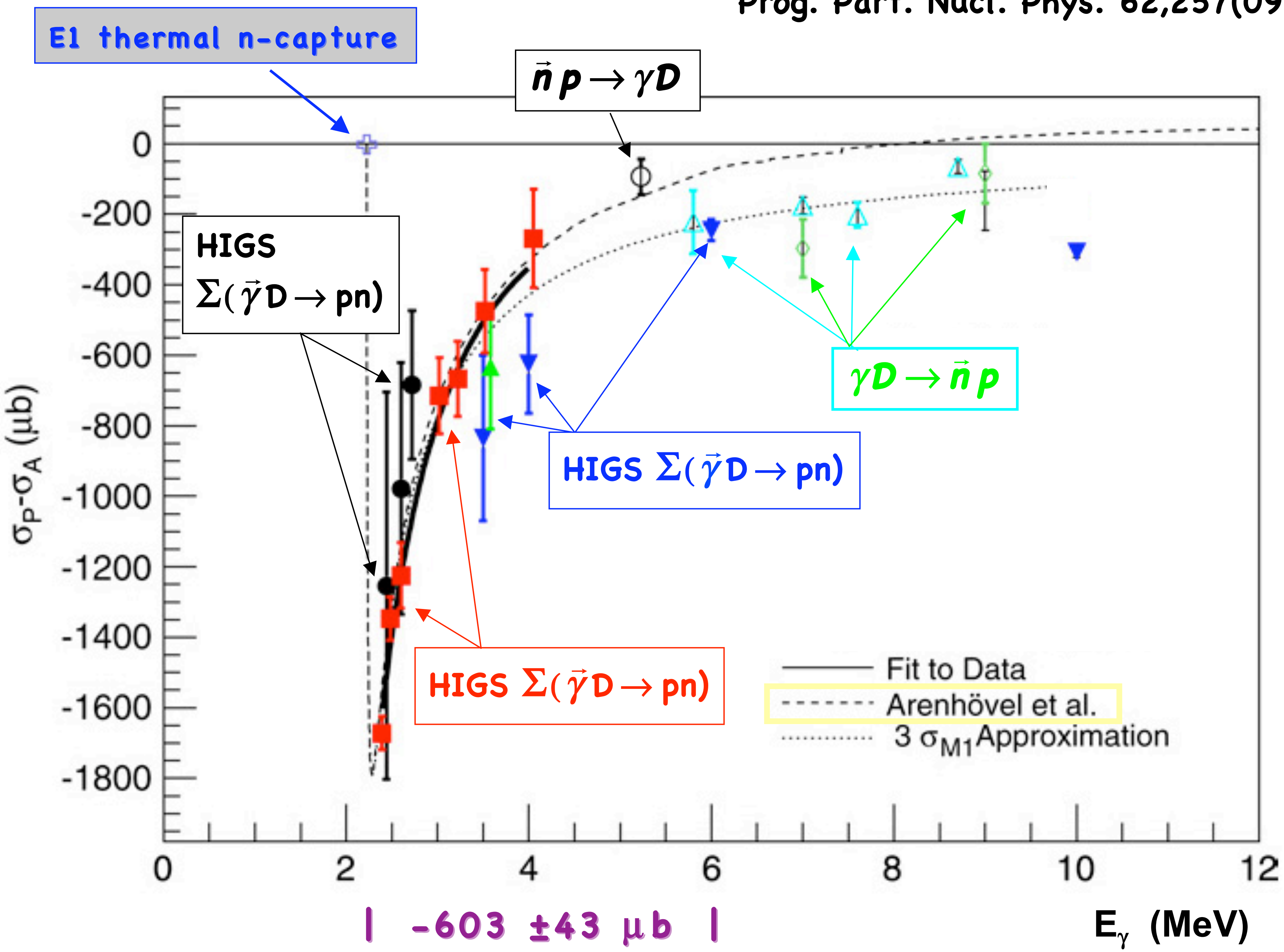
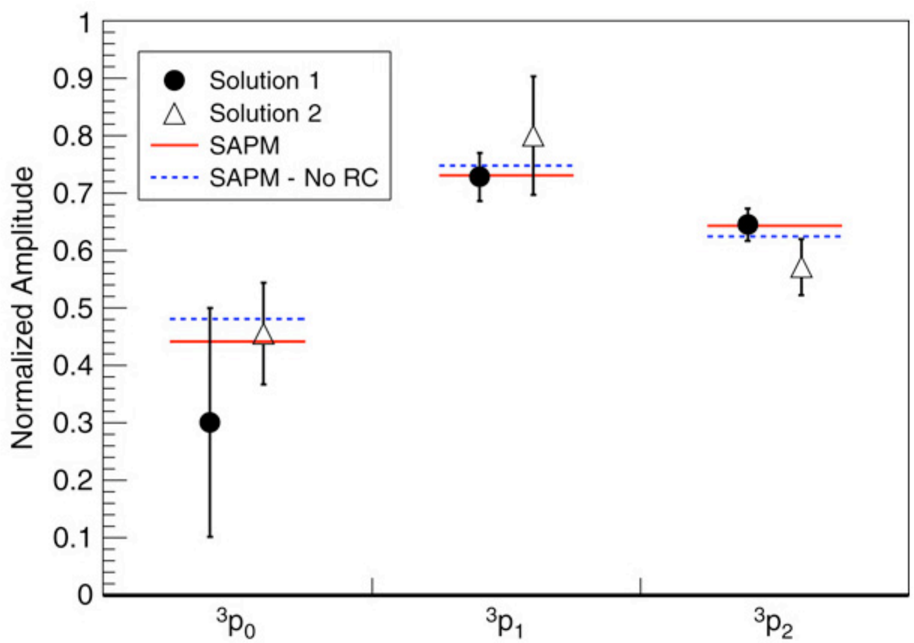


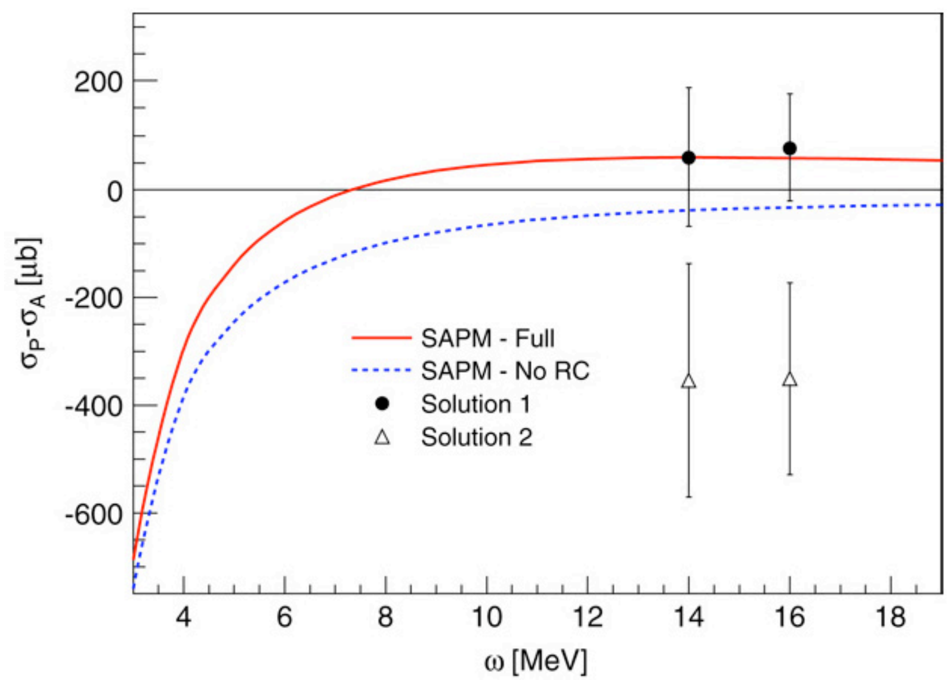
GDH(D) from lowE gDpn

HIGS: $\Sigma(\vec{\gamma} D \rightarrow pn)$ above 10 MeV:

Arenhövel/Fix/Schwamb - full

Arenhövel/Fix/Schwamb - without relativistic corr





- GDH(D) $= \int_{.002}^{.01} d\omega \frac{\sigma_P - \sigma_A}{\omega} + \int_{.01}^{.20} d\omega \frac{\sigma_P - \sigma_A}{\omega} + \int_{.20}^{\sim 2} d\omega \frac{\sigma_P - \sigma_A}{\omega}$

$\approx$ -600 +AFS +450

w relativistic (S•L)

What do we learn from all this !?!

- GDH(p):

  - combined measurements up to 2.9 GeV now agrees very well with the SR expectation

  $\Rightarrow$ $g_p(\infty)$ is certainly quite small

- GDH(n):

  - quasi-free πN coincidence data under analysis, at least over LEGS energy range

- GDH(D):

  - understanding the convergence of the GDH integral will ultimately teach us a lot about NN interaction and dynamics

  - a lot more work will be necessary before an experimental statement can be made about the GDH sum rule for light nuclei