GDH sum rule experiments at $Q^2 = 0$ GeV^2/c^2

@ Spin discussion

July 30, 2002

Tsuneo KAGEYA

LEGS at BNL and Virginia Polytechnic Institute and State University

GDH sum rule ☆

* Forward Compton scattering amplitude of GGT

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

$$g(\omega) = g(0) + g'(0)\, \omega^2 + O(\omega^4)$$

* GGT dispersion relation

$$g(0) - g(\infty) = 1/4\pi^2 \int_{\omega_0}^{\infty} (\sigma_{1/2} - \sigma_{3/2})/\omega\, d\omega$$

* Low energy theorem of LGG

$$g(0) = -\,\alpha\kappa^2/2m^2$$

* An assumption

$$g(\infty) = 0$$

* GDH $= \int_{\omega_0}^{\infty} (\sigma_{1/2} - \sigma_{3/2})/\omega\, d\omega$

$$= -\,2\pi^2\alpha\kappa^2/m^2 - 4\pi^2 g(\infty)$$

(GGT: Gell–Mann, Goldberger & Thirring
Phy. Rev. 95, 1612 (1954)
LLG: Low, Gell–Mann & Goldberger
Phy. Rev. 96, 1428 (1954), 1433 (1954))

☆ S. D. Drell & A. C. Hearn, PRL. 16 (1966) 908
S. B. Gerasimov, Yad. Fiz. 2 (1965) 598,
Sov. J. NP. 2 (1966) 430

Multipole predictions
for the forward spin-polarizability and the GDH sum rules

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

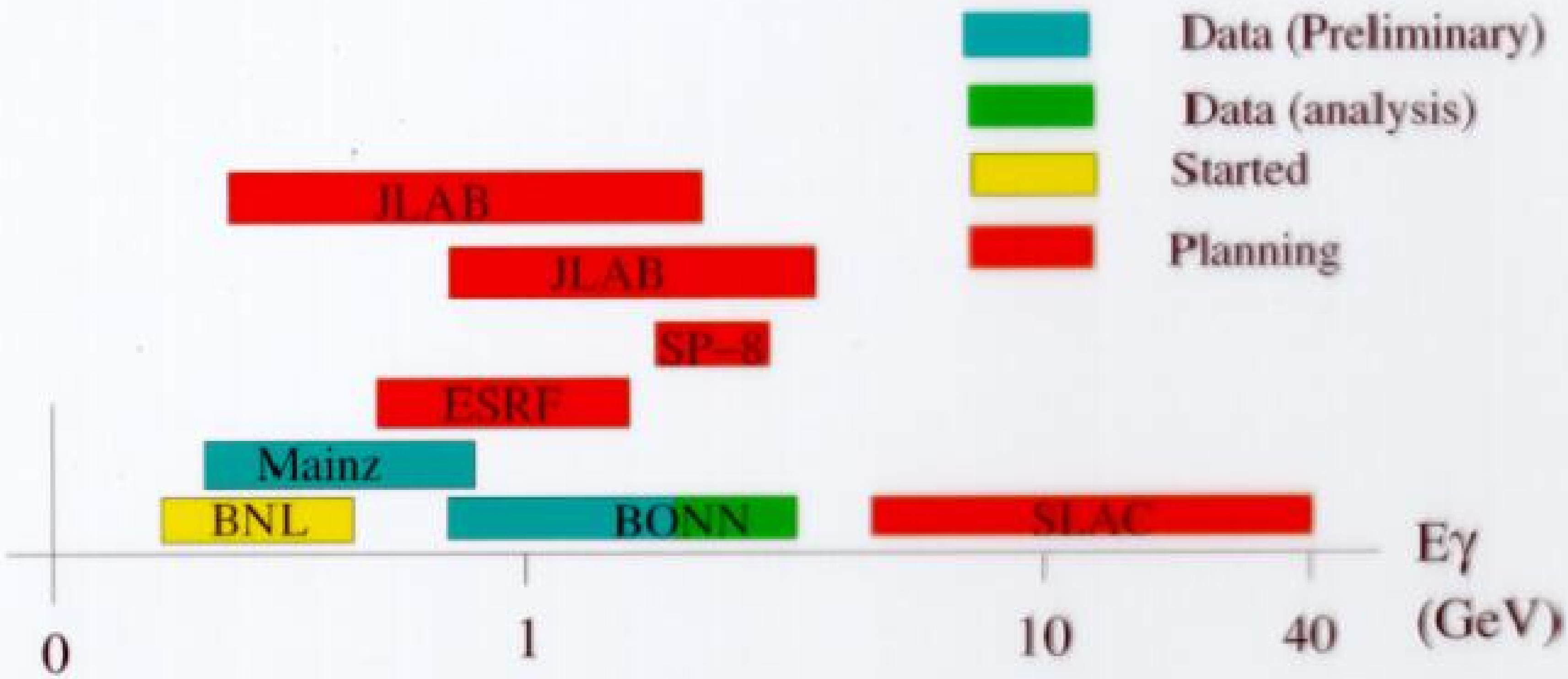
Before the polarized data from Mainz

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

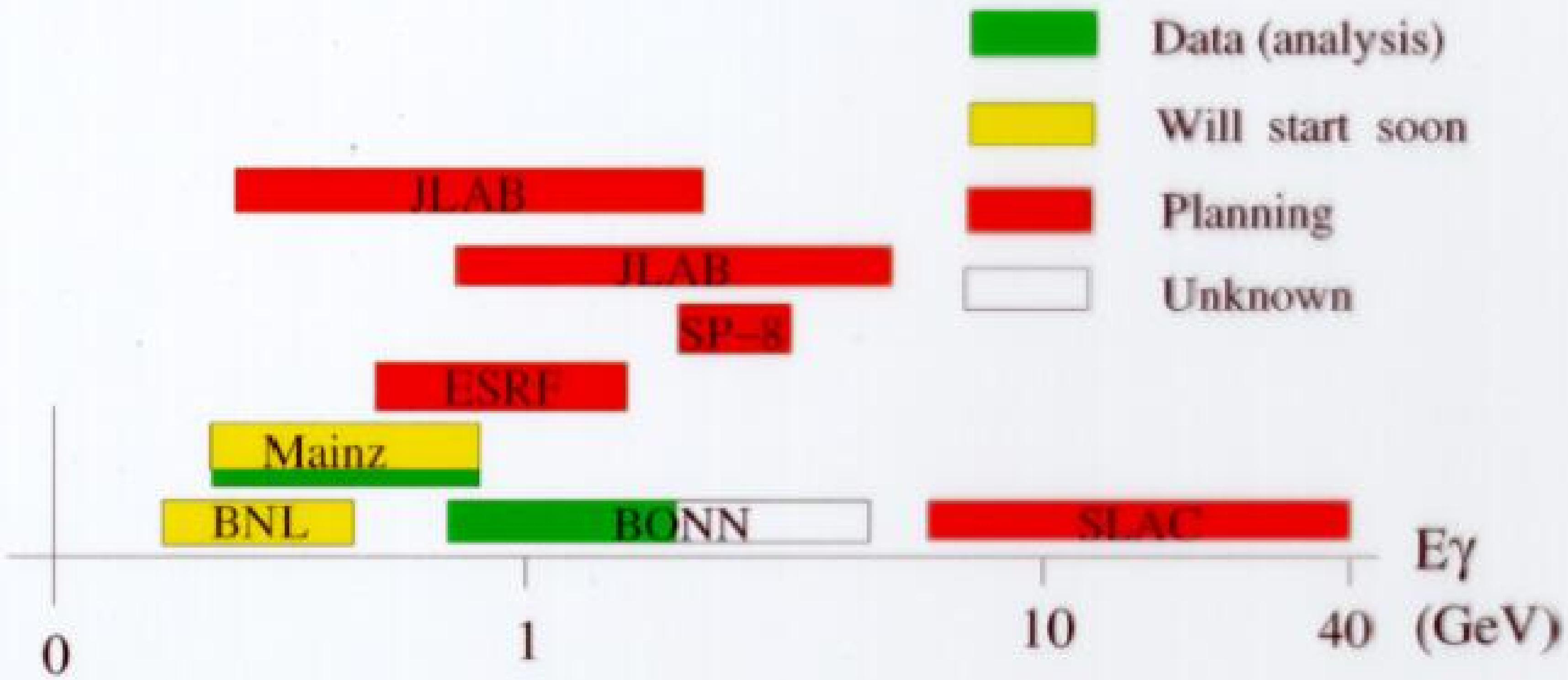
(b) neutron:	χPT rel $O(p^3)$	*HBχPT* $O(p^4)$	*π-multipoles (SAID)*	GDH $-(\kappa_n^2)\frac{2\pi^2\alpha}{m^2}$
$\gamma_o(n)$ $(10^{-6}\,fm^4)$:	−46	+120	−38 (± ~20)	
GDH_n $(10^{-4}\,fm^2)$:			−160 (± ~16)	−234

note: – multipole uncertainties reflect propagation of errors on existing data,
– appropriate for interpolation,
– may not be good for *extrapolation* to $\sigma_{1/2}$ and $\sigma_{3/2}$.

Proton GDH experiments at $Q^2 = 0$



Neutron GDH experiments at $Q^2 = 0$



Mainz e Bonn

[illegible]

J. Ahrens[1], S. Altieri[13], J.R.M. Annand[6], G. Anton[4], H.-J. Arends[1], G. Audit[15], R. Beck[1], C. Bradtke[3], A. Braghieri[13], N. d'Hose[15], D. Drechsel[1], H. Dutz[2], B. Fürst[1], S. Goertz[3], P. Grabmayr[16], S.J. Hall[6], K. Hansen[8], J. Harmsen[3], D. v.Harrach[1], S. Hasegawa[12], T. Hasegawa[10], T. Hehl[16], E. Heid[1], W. Heil[9], K. Helbing[4], H. Holvoet[5], L. van Hoorebeke[5], N. Horikawa[12], T. Iwata[12], P. Jennewein[1], T. Kageya[12], B. Kiel[4], F. Klein[2], R. Kondratjev[11], K. Kossert[7], J. Krimmer[16], M. Lang[1], B. Lannoy[5], R. Leukel[1], V. Lisin[11], T. Matsuda[10], J.C. McGeorge[6], A. Meier[3], D. Menze[2], W. Meyer[3], T. Michel[4], J. Naumann[4], R.O. Owens[6], A. Panzeri[13,14], P. Pedroni[13], T. Pinelli[13,14], I. Preobrajenski[1], S. Proff[7], E. Radtke[3], T. Reichelt[2], E. Reichert[9], G. Reicherz[3], Ch. Rohlof[2], D. Ryckbosch[5], F. Sadiq[6], M. Sauer[16], B. Schoch[2], B. Schröder[8], M. Schumacher[7], B. Seitz[7], F. Smend[7], T. Speckner[4], N. Takabayashi[12], G. Tamas[1], A. Thomas[1], R. van de Vyver[5], A. Wakai[12], R. Weigelt[4], W. Weihofen[7], B. Wiegers[2], F. Wissmann[7], F. Zapadtka[7], and G. Zeitler[4].

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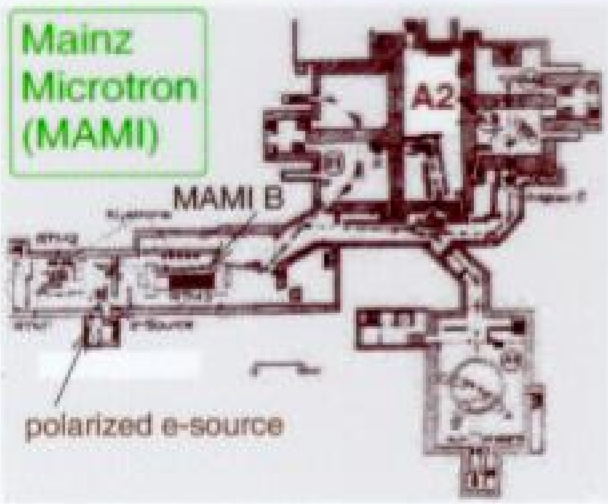
[16] Physikalisches Institut, Universität Tübingen, Germany

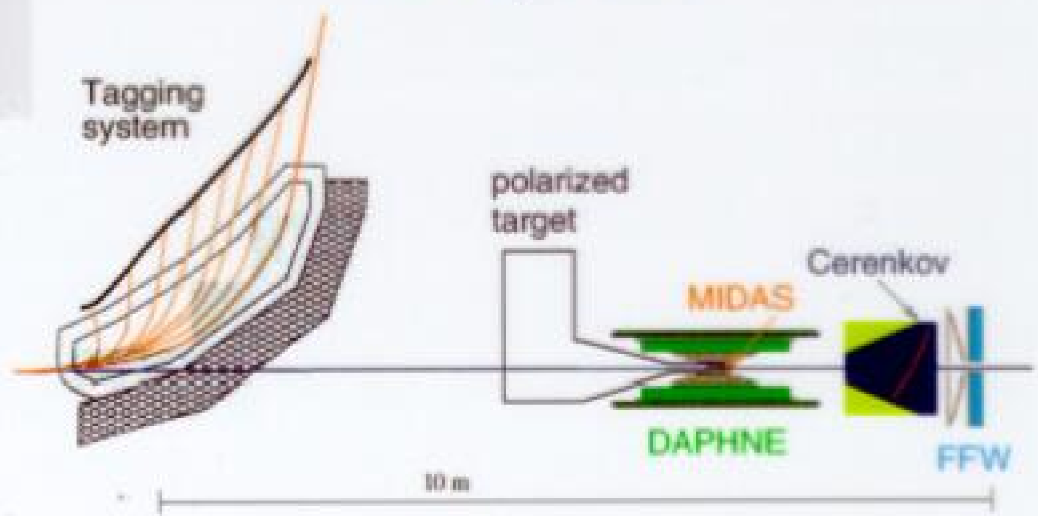
8 countries 16 institutes

GDH Facility at MAMI



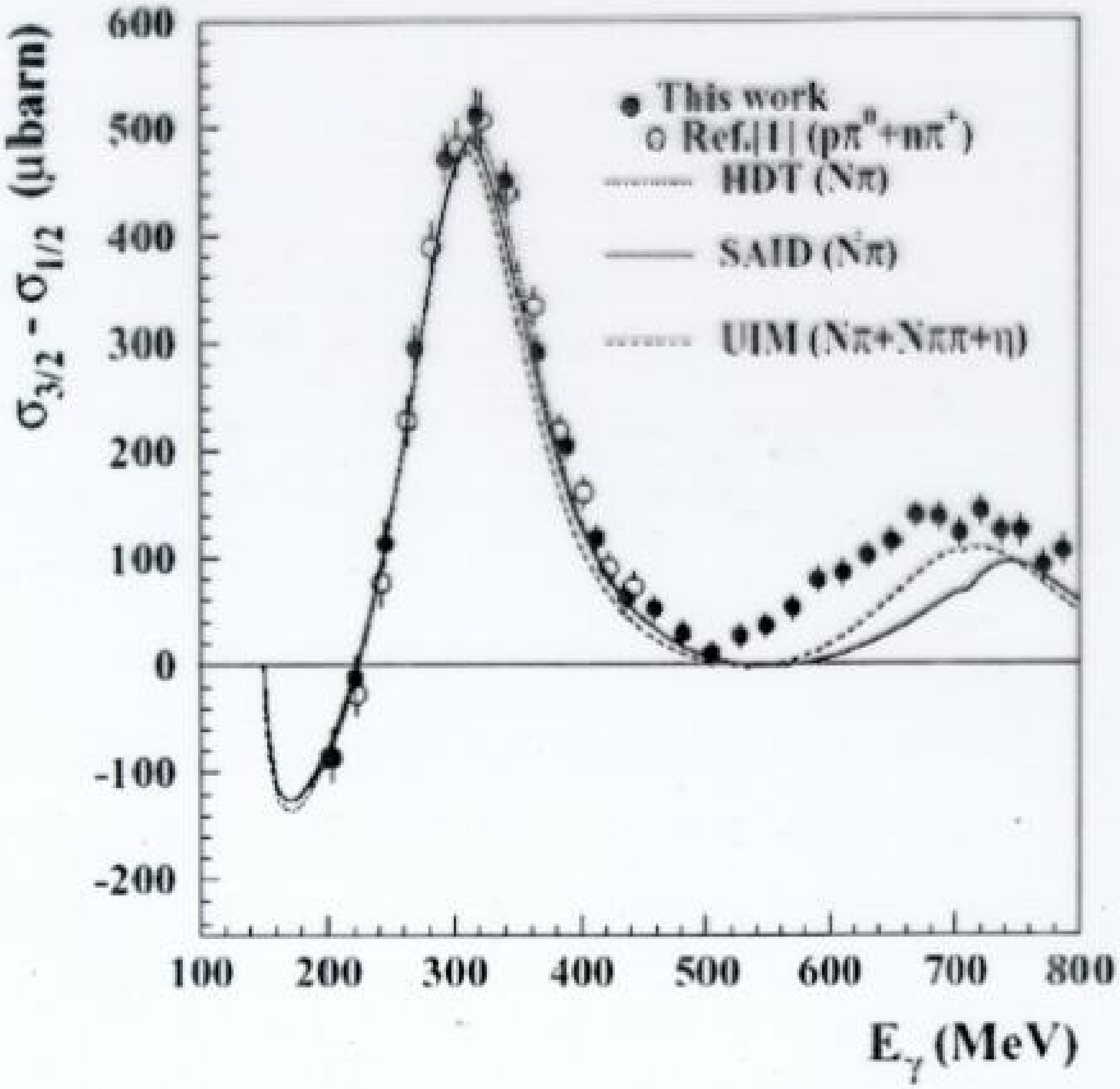
- Existing tagging facility A2
- Photon energy range
  0.14 - 0.8 GeV

GDH setup at MAMI



Mainz GDH result2

Difference of the helicity dependent
cross sections for proton

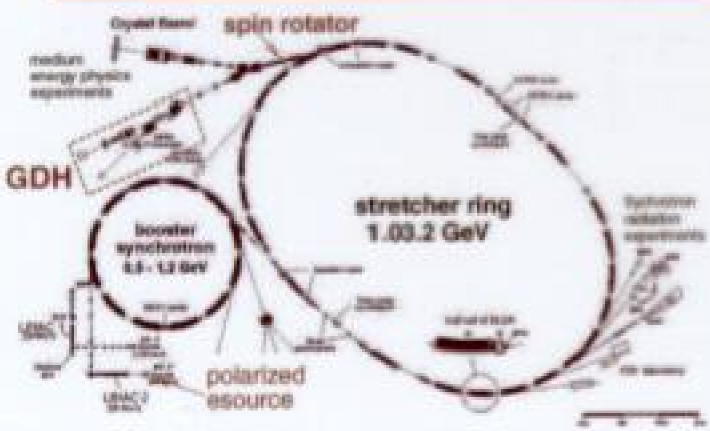


(PRLv87(2001)022003)

HDT: dispersion theory,Hanstein,Drechsel,Tiator,NPA 632(99),521
SAID: phenomenological multipole analysis, solution SM99k
UIM: unitary Isobar model,Drechsel,Kamalov,Krein,Tiator,PRD 59(99)

GDH Facility at ELSA

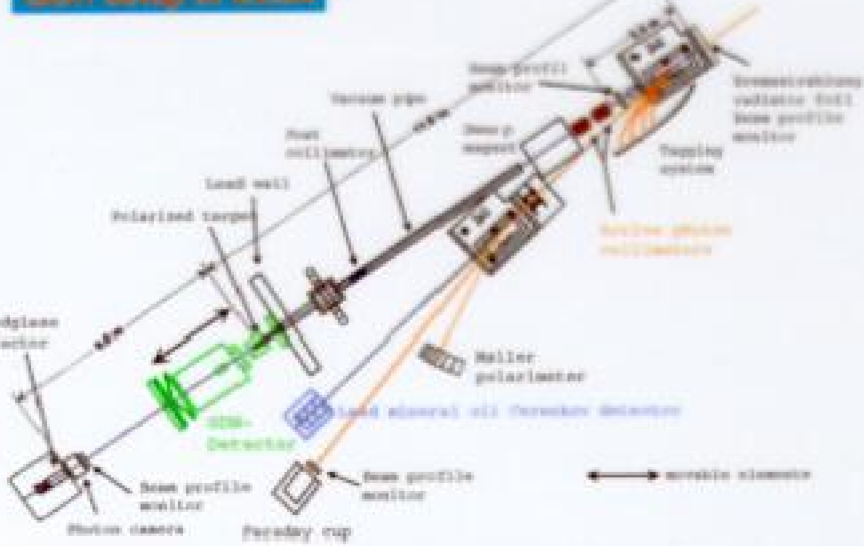
Electron Stretcher Accelerator (ELSA)



Grabmayr
Thursday 14:20

- New experimental area setup for GDH.
- Photon energy range 0.7 - 3.0 GeV.

GDH setup at ELSA

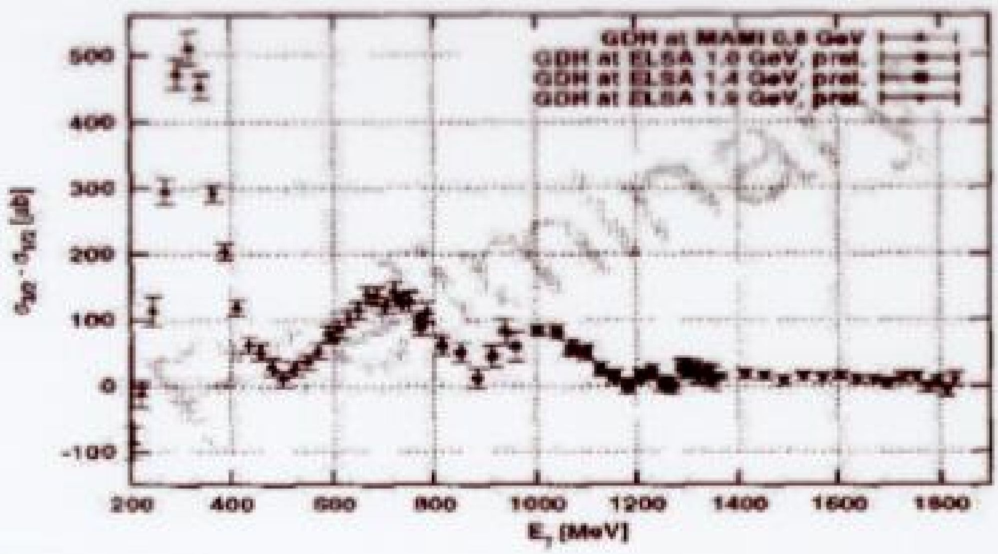


MAMI/ELSA GDH Results at the Proton

Taken from K. Helbing, NPB 105 (2002) 113

MAMI: E_γ = 200 – 800 MeV

ELSA: E_γ = 700 – 1850 MeV

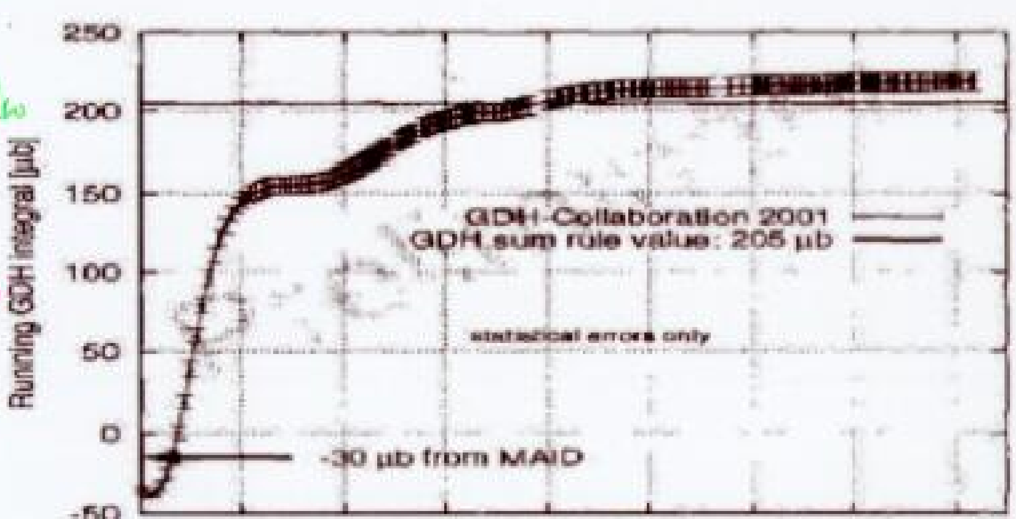


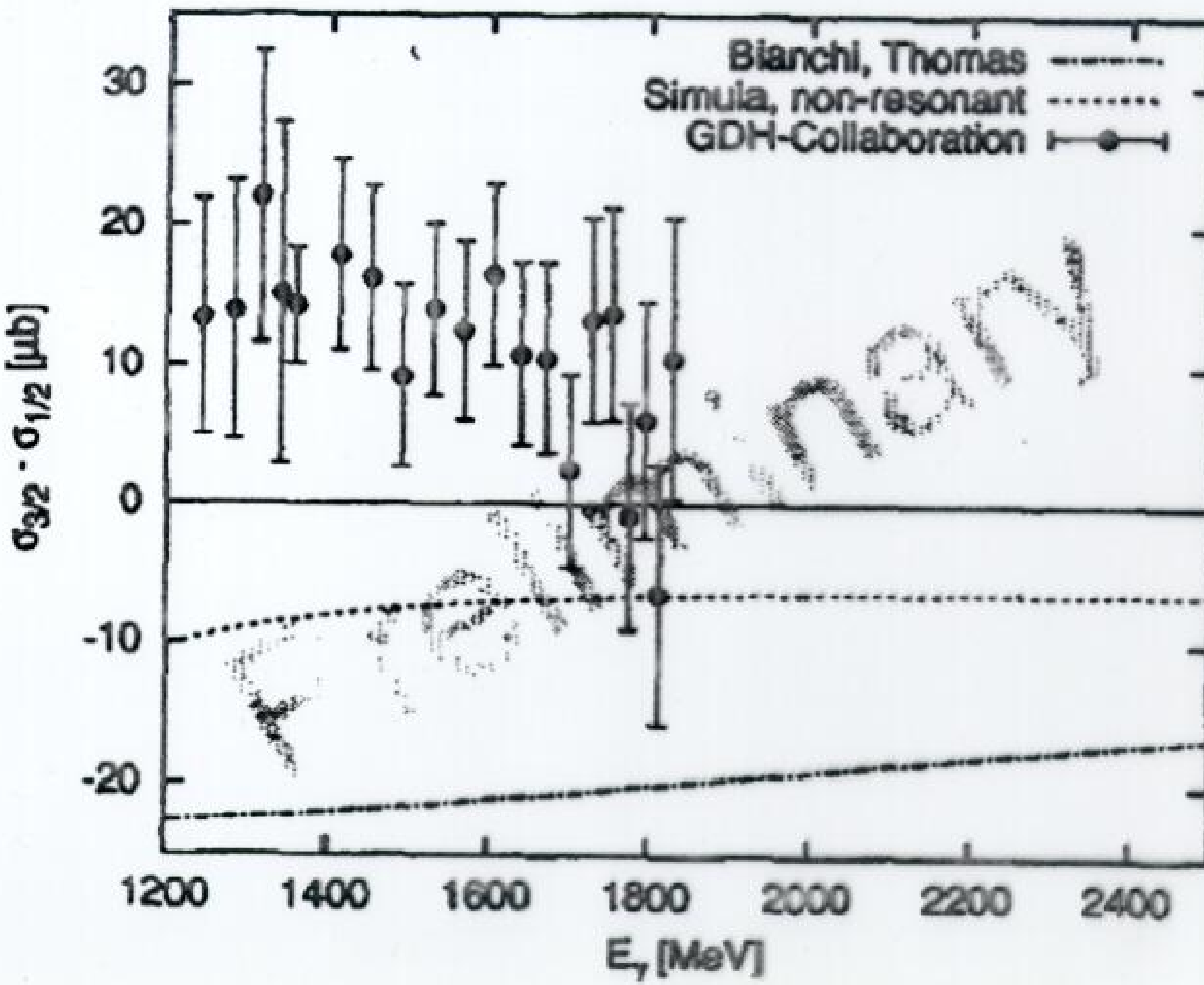
Calculation

$$\int_{\omega_0}^{200\,\mathrm{MeV}} \frac{\sigma_{3/2} - \sigma_{1/2}}{\omega}\, d\omega$$

$$+ \int_{200\,\mathrm{MeV}}^{E_\gamma} \frac{\sigma_{3/2} - \sigma_{1/2}}{\omega}\, d\omega$$

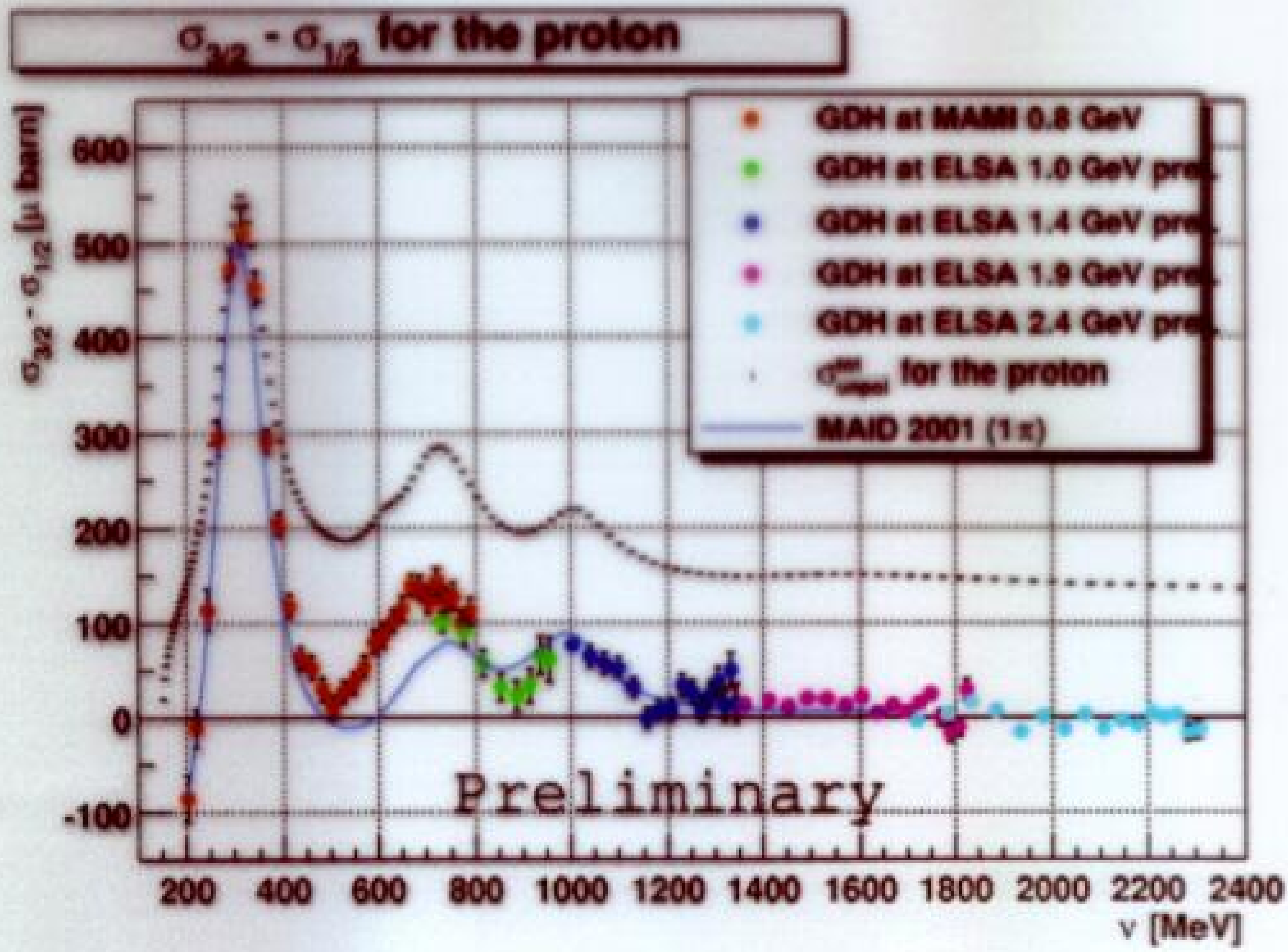
Experiments




Bianchi, Thomas
Simula, non-resonant
GDH-Collaboration
30
20
10
0
-10
-20
σ3/2 - σ1/2 [μb]
1200
1400
1600
1800
2000
2200
2400
Eγ [MeV]
Preliminary

Results for the proton

0.8 – 2.4 GeV



Comparison of σ_{tot} and $\Delta\sigma$

have structures at similar energies
"pure" Δ resomance (M1)
zero $\Delta\sigma$ between 2[nd] and 3[rd]
for E_γ >600 MeV: σ_{tot}=150mb + $\Delta\sigma$

MAID – Mainz Unitary Isobar Model (Drechsel, Kamalov, Tiator)

– Tiator, GDH'2000

resonance-region ν = thr - 1.7 GeV (W<2 GeV)

$$\textbf{GDH:}\ I = \int_{thr}^{1.7GeV} \frac{\sigma_{1/2} - \sigma_{3/2}}{\nu}\, d\nu$$

	proton	neutron
sum rule:	-204 μb	-234 μb
Mainz exp. (200-800 MeV)	-218±6	-
MAID γ,π^0	-150	-154
MAID $\gamma,\pi^\pm$	-21	+30
Mainz γ,η	+15	+10
Born $\gamma,\pi\pi$ [1]	-30	-35
D13 $\gamma,\pi\pi$ [1]	-15	-15
sum	-201	-164
high energy γ,π [2]	-4	-4
γ, K [3]	+4	-2
total	-201 μb	-170 μb

!

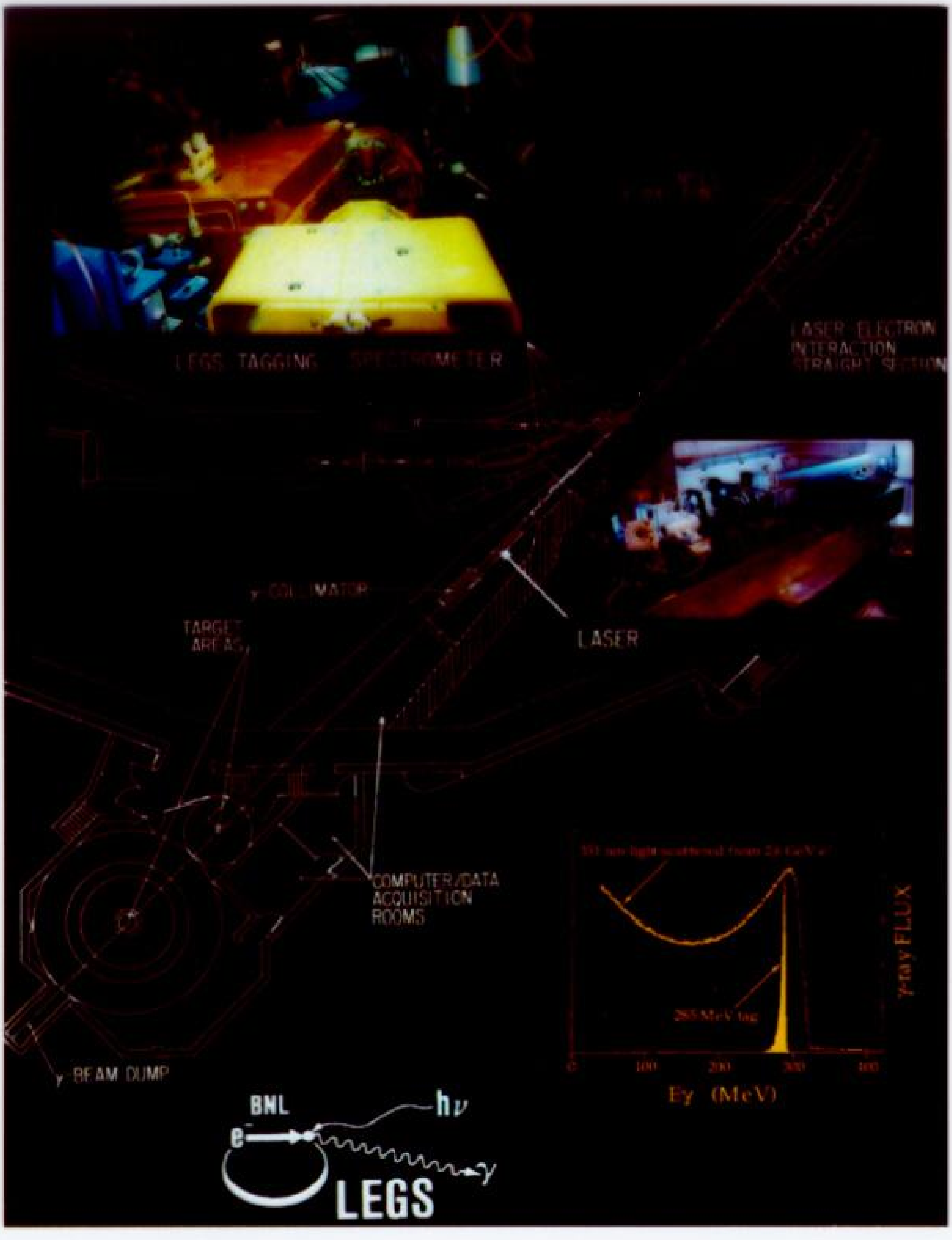
Calculation $thr \le E_\gamma \le 1.7$ GeV

Calc. $1.7 \le E_\gamma$ GeV

[1] H. Holvoet and M. Vanderhaeghen in progress
[2] M. Guidal, J.M. Laget and M. Vanderhaeghen, Nucl. Phys. A **627** (1997) 645
[3] S. Sumowidago and T. Mart, Phys. Rev. C **60**, 028201 (1999)

" where are the missing <u>–64 μb</u> of the neutron? "

– Tiator, GDH'2000


LEGS TAGGING SPECTROMETER
LASER ELECTRON
INTERACTION
STRAIGHT SECTION
γ COLLIMATOR
TARGET
AREAS
LASER
COMPUTER/DATA
ACQUISITION
ROOMS
γ BEAM DUMP
γ-ray FLUX
0
100
200
300
400
Eγ (MeV)
BNL
e⁻
hν
γ
LEGS

LEGS–Spin Collaboration

- Brookhaven National Laboratory
  - *C. Cacace, A. Caracappa, S. Hoblit, O.C. Kistner, A. Kuczewski, F. Lincoln, M. Lowry, L. Miceli, A.M. Sandorfi, C. Thorn, X. Wei*
- James Madison University
  - *A. Lehmann, C.S. Whisnant*
- Norfolk State University
  - *M. Khandakar*
- Ohio University
  - *K. Ardashev, C. Bade, R. Deininger, K. Hicks, M. Lucas, J. Mahon*
- Syracuse University
  - *A. Honig*
- Universita di Roma II – Tor Vergata
  - *A. D'Angelo, A. d'Angelo, R. Di Salvo, D. Moricciani, C. Schaerf*
- Universitè de Paris – Sud, ORSAY
  - *C. Commeaux, J.–P. Didelez*
- University of South Carolina
  - *I. Danchev, C. Gibson, B.M. Preedom*
- University of Virginia
  - *A. Cichocki, B. Norum, K. Wang*
- Virginia Polytechnic Institute & State University
  - *M. Blecher, T. Kageya, H. Meyer, T. Saitoh*

3 countries, 10 institutes

LEGS (Laser Electron Gamma Source) GDH experiments

1. Compton backscattered polarzied γ beam

   $0.15 < E\gamma < 0.47$ GeV

   $P\gamma \sim 90$ %

2. Polarized HD solid target

   Good dilution factor

   $\vec{H}\vec{D}$, $\vec{H}D$ and $H\vec{D}$

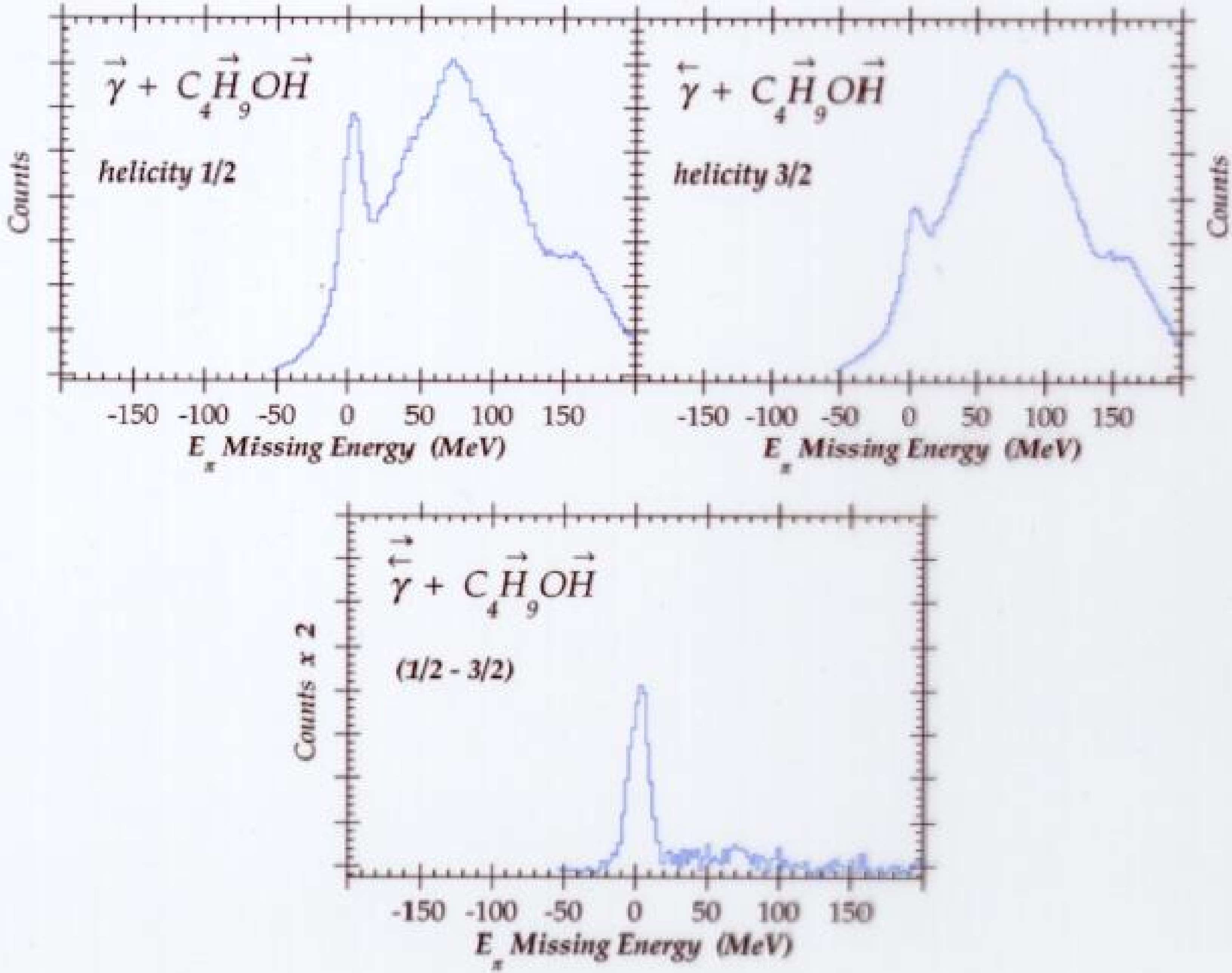
   $P_H \sim 80$ %, $P_D \sim 50$ %

3. 4π detector

   $(\sigma_{1/2} - \sigma_{3/2}) / E\gamma$;

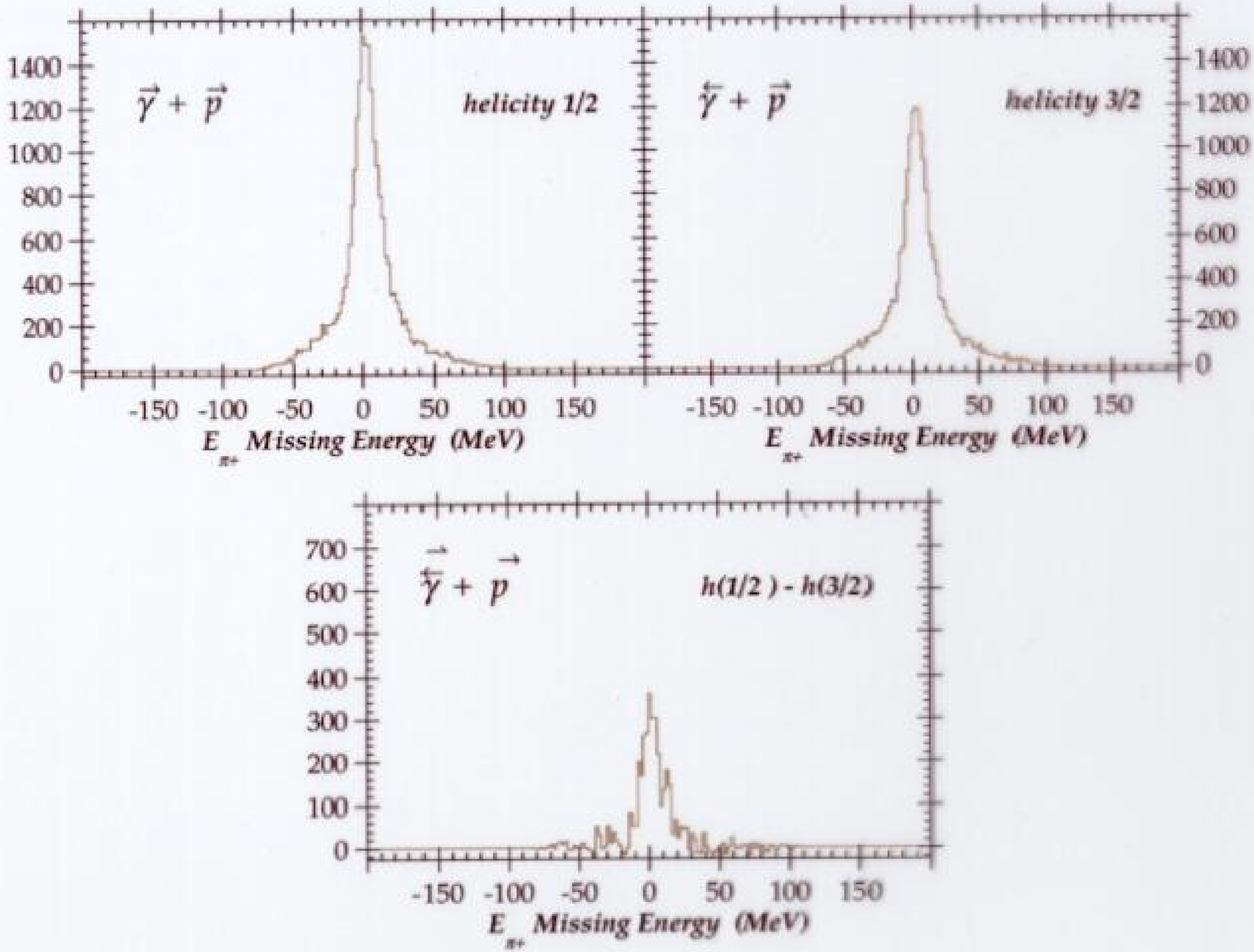
   Total cross sections

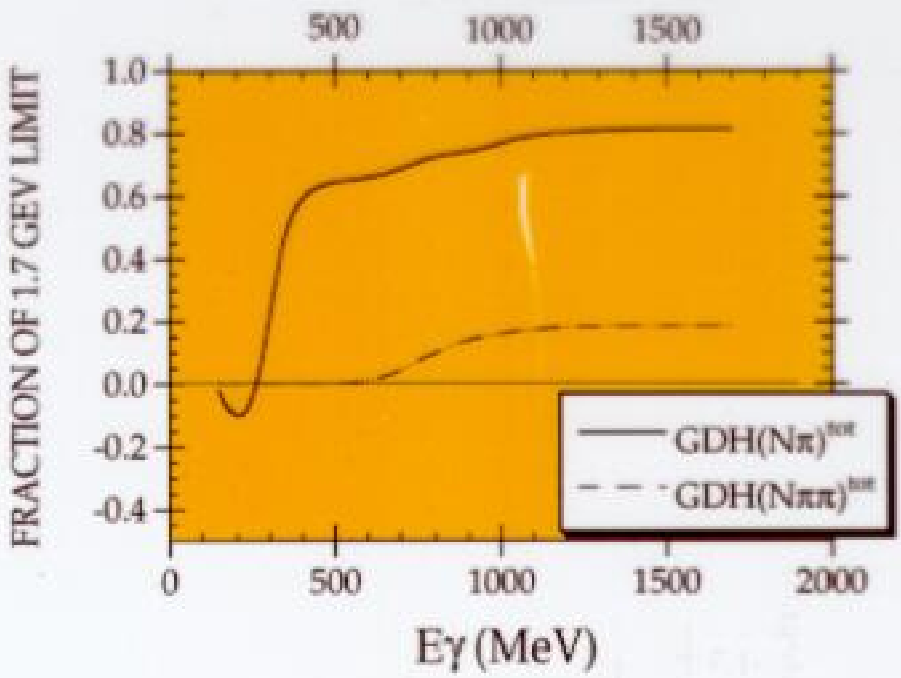
Mainz: $\gamma + C_4H_9OH \rightarrow p$ $E_\gamma \sim \Delta$ region *PRL 84(2000)5950*



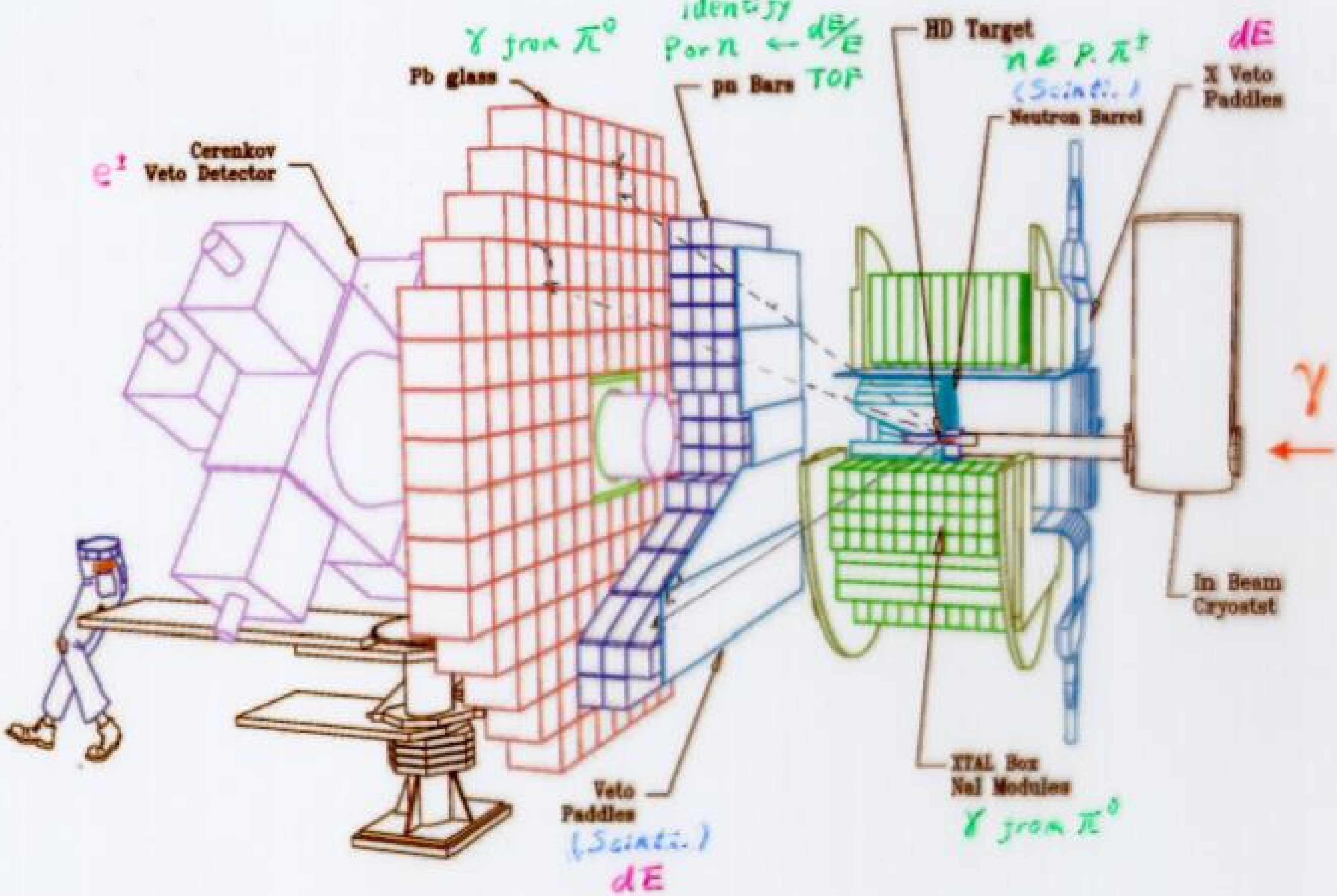
1st double-polarization data with HD - LEGS/Nov17'01

$E_\gamma = 300$ MeV $\theta_{\pi+} = 80°$ c.m.

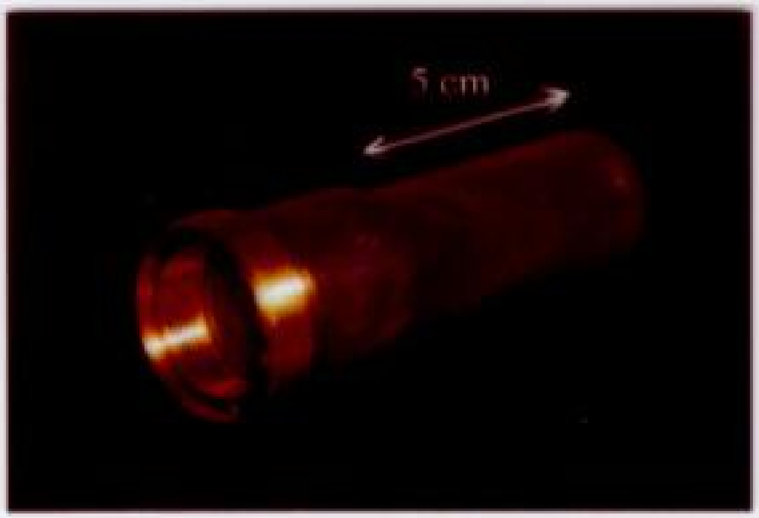



500
1000
1500
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
FRACTION OF 1.7 GEV LIMIT
GDH(Nπ)^tot
GDH(Nππ)^tot
0
500
1000
1500
2000
Eγ (MeV)

SASY Current Setup

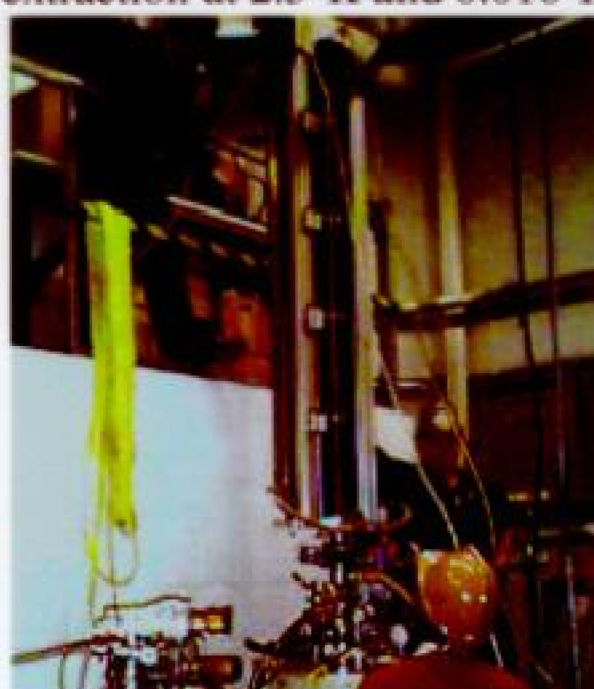


HD target cycle:



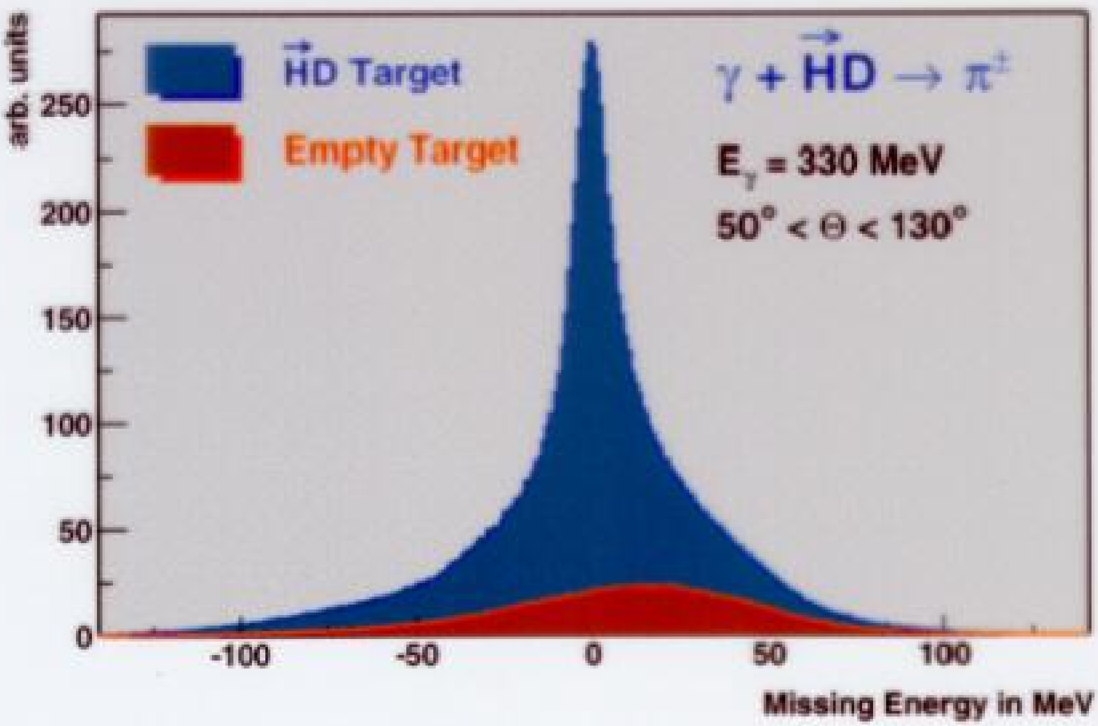
target injection into dilution fridge;
~50 to 100 days at 15 Tesla / 18 mK

extraction at 2.5°K and 0.016 T



loading in-beam cryostat
(1.25°K and 0.7 Tesla)

Empty Target Contribution



area in red is 20% of blue

as expected

Target Polarization History

- Initial $P_T = \begin{cases} 71\% \text{ for H} \\ 16\% \text{ for D} \end{cases}$
- Many tests to study target under various conditions (transfers, different holding fields and temperatures)
- Start conditions in-beam

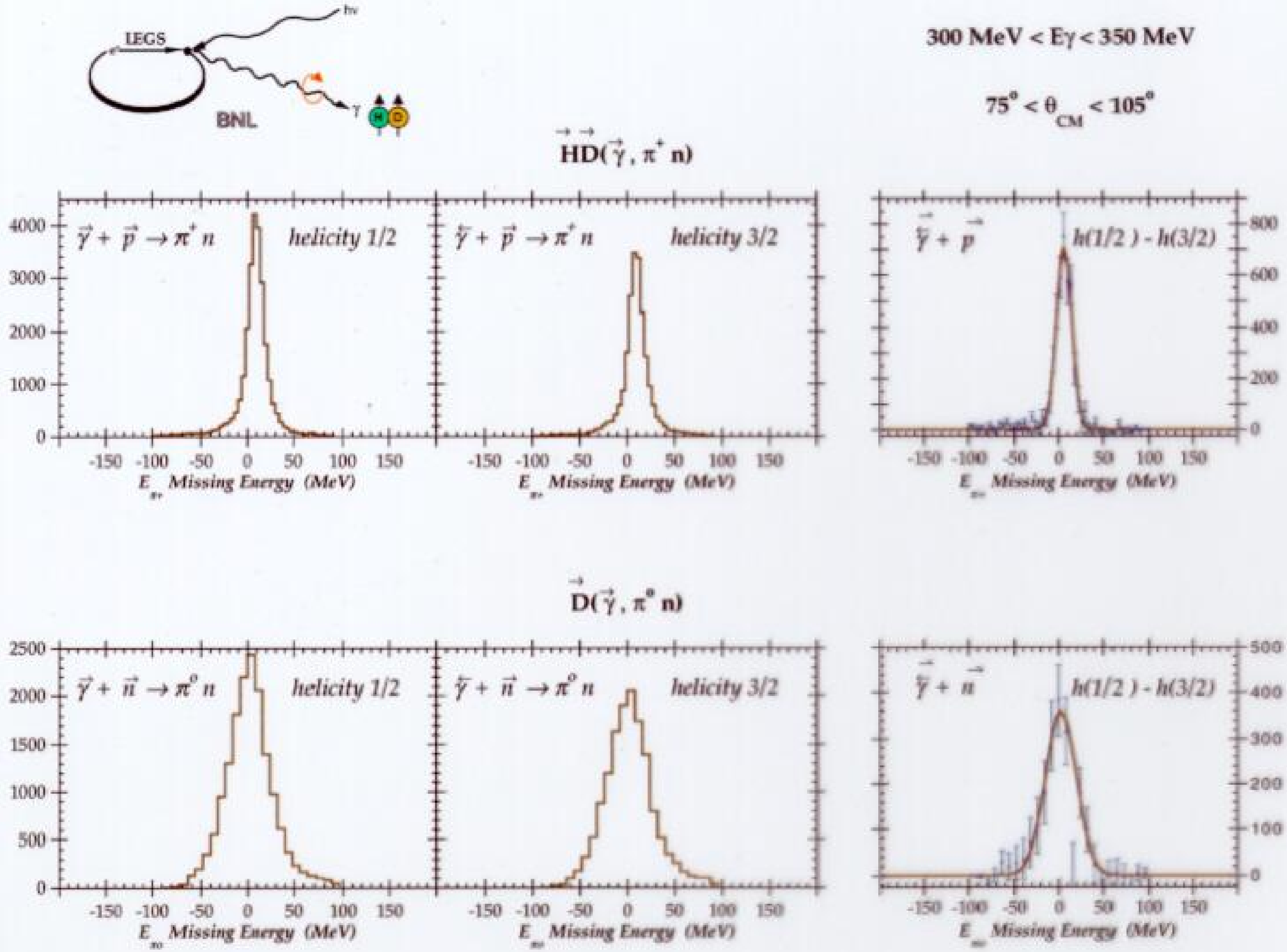
$$P_T = \begin{cases} 30 \pm 3\% \text{ for H} & (T_1 = 13\text{d}) \\ 6 \pm 1\% \text{ for D} & (T_1 = 36\text{d}) \end{cases}$$

  - Calibration of Polarization:
    - NMR line shift due to polarization decay (change in B field)
    - { low-B/hi-T thermal equilibrium NMR signal (H_2 + HD) }
- After 2 days magnet quench
  ⇒ P_T dropped by about a factor of two
- After 1.5 days accelerator shutdown

⇒ 3.5 days of net data taking

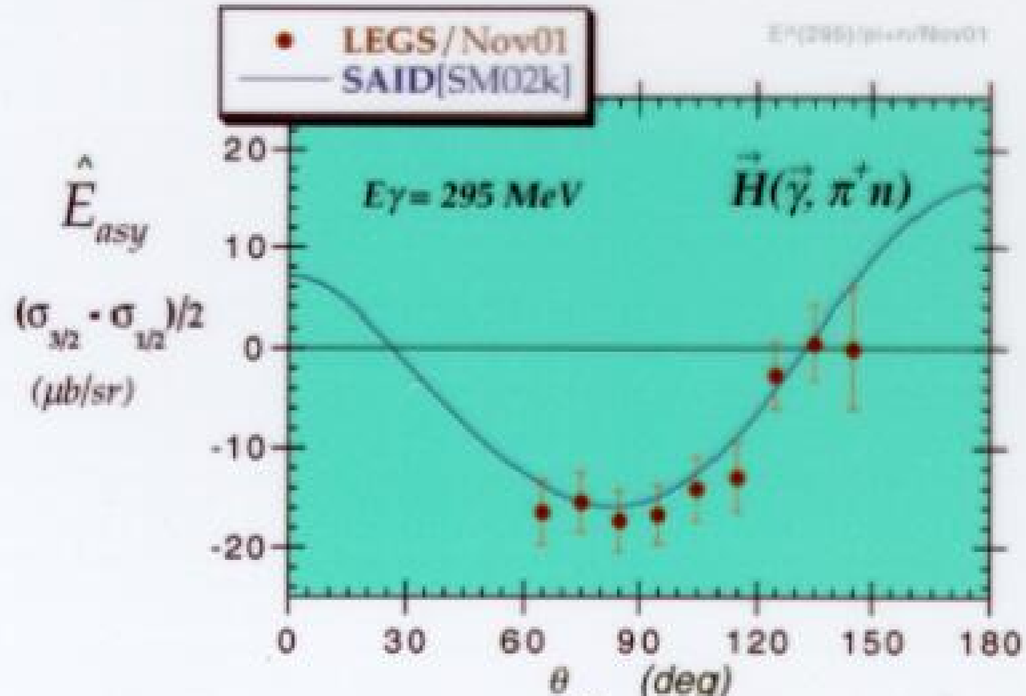
$\overline{P}_H = \int(P_H dt)/\int dt = 21.3\%$

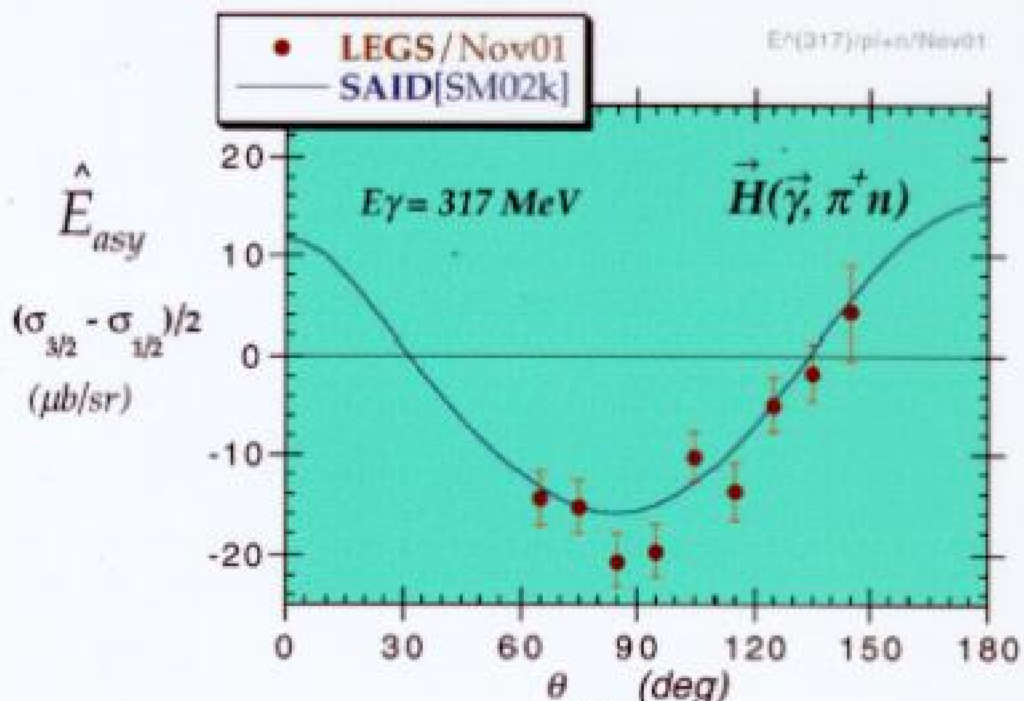
$\overline{P}_D = \int(P_D dt)/\int dt = 5.0\%$



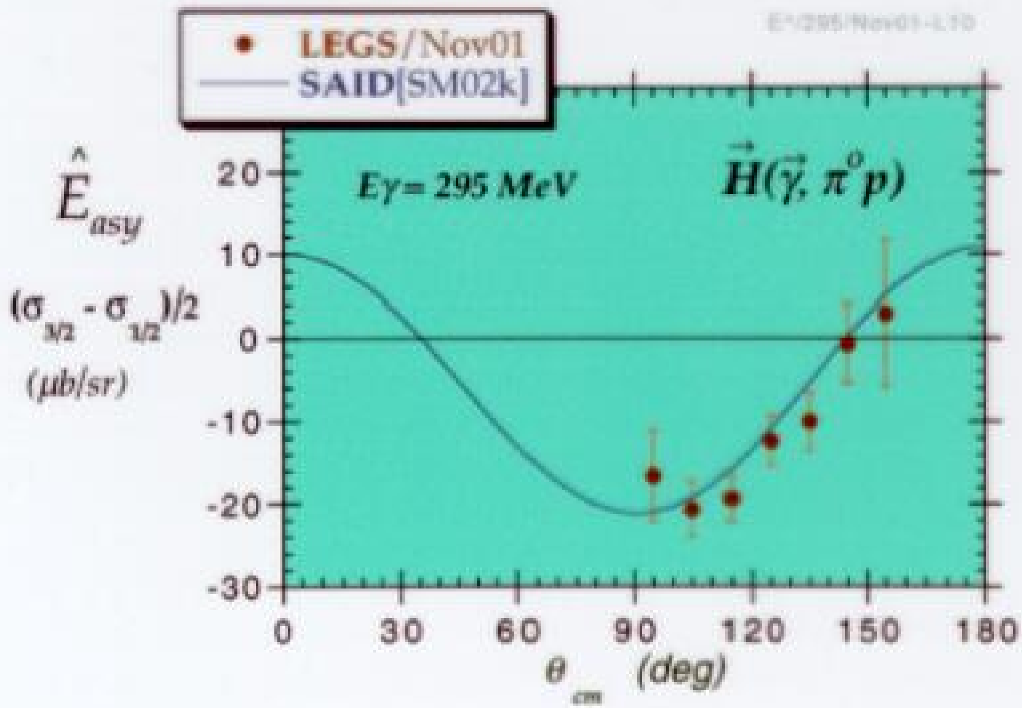
LEGS
BNL
hν
γ
300 MeV < Eγ < 350 MeV
75° < θ_CM < 105°
HD(γ, π⁺ n)
γ + p → π⁺ n
helicity 1/2
helicity 3/2
γ + p
h(1/2) - h(3/2)
E_π+ Missing Energy (MeV)
D(γ, π⁰ n)
γ + n → π⁰ n
helicity 1/2
helicity 3/2
γ + n
h(1/2) - h(3/2)
E_π0 Missing Energy (MeV)

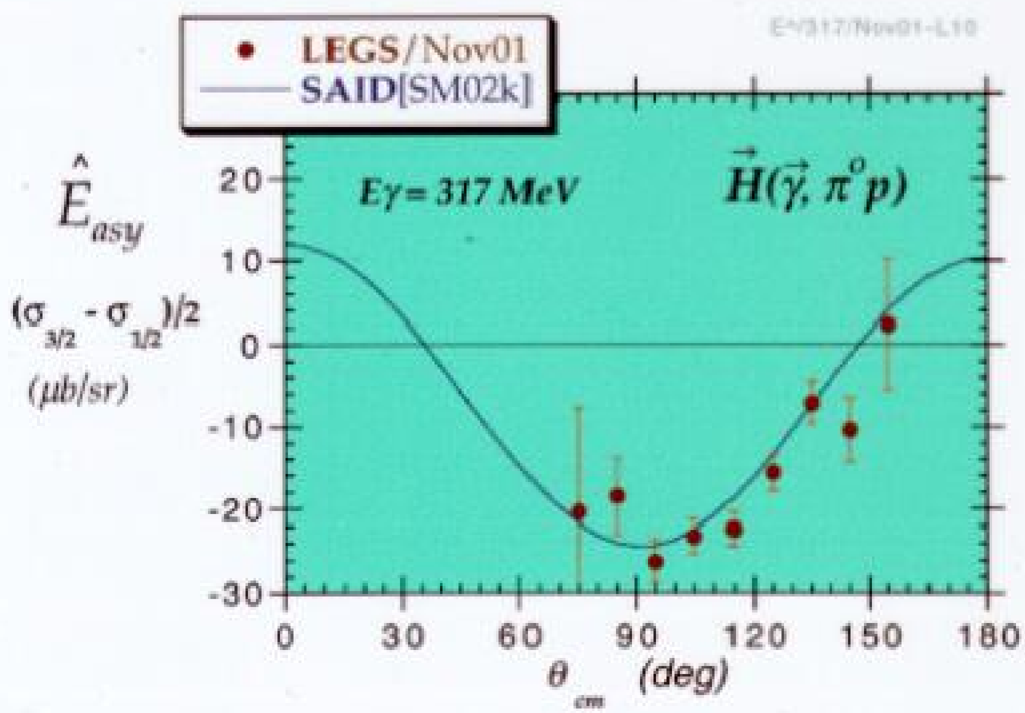
$$\hat{E}_{asy} = \tfrac{1}{2}\left(\sigma_{3/2} - \sigma_{1/2}\right)$$





$$\hat{E}_{asy} = \tfrac{1}{2}\left(\sigma_{3/2} - \sigma_{1/2}\right)$$





GDH Program at LEGS

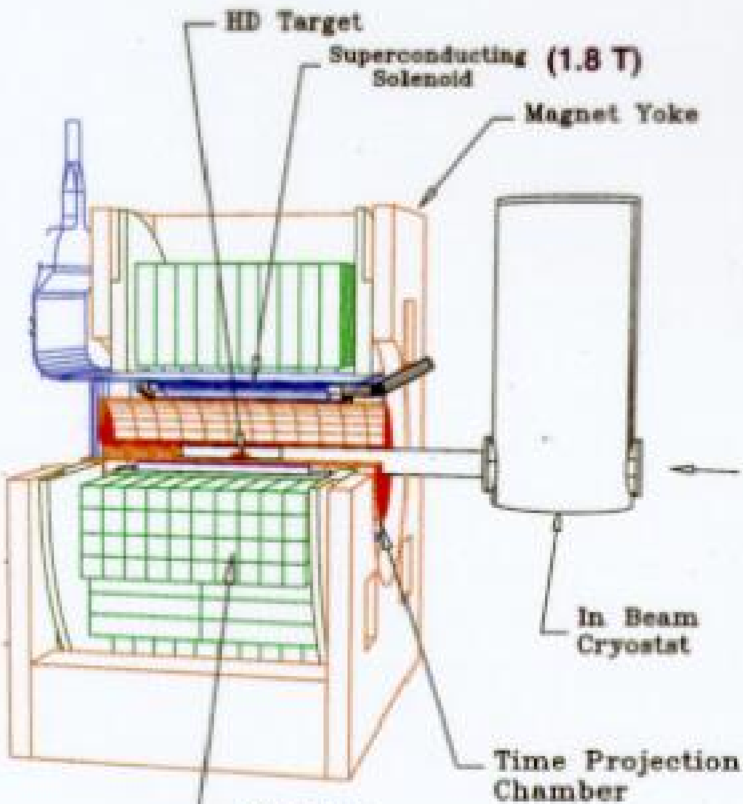
~ threshold < E_γ < 470 MeV

near-term plans:

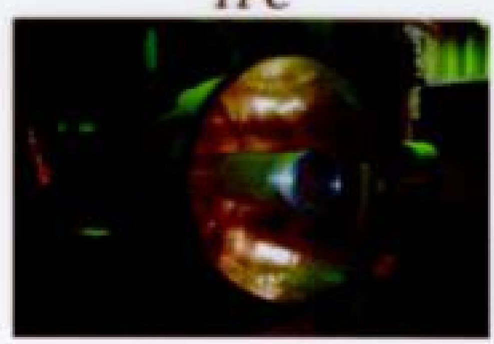
- **polarized-D** measurements, focusing on $\gamma + D \rightarrow \pi^0 n$
  – starting fall'02
- **polarized-H** measurements
  – starting summer'03

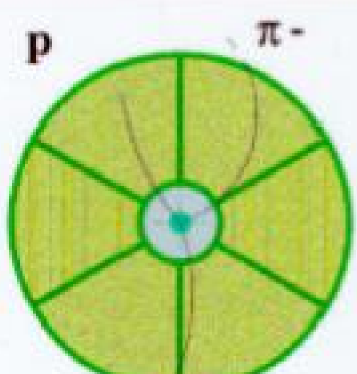
longer-term plans:

- separate **D(γ, π⁻ p)** from **D(γ, π⁺ n)** :
  isolate $\gamma + n \rightarrow \pi^- p$ at low energies ⇔ **measuring the π^± charge**
  ⇒ magnetic analysis in a ***Time-Projection Chamber*** (***TPC***)



TPC





- TPC experiments in 2005

GDH Program at LEGS

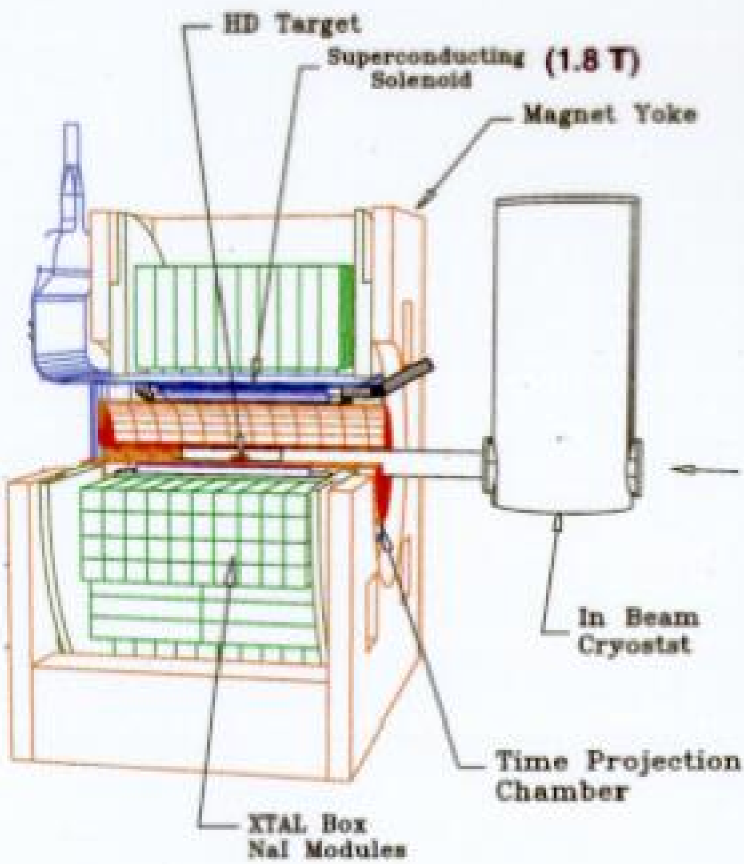
~ threshold < E_γ < 470 MeV

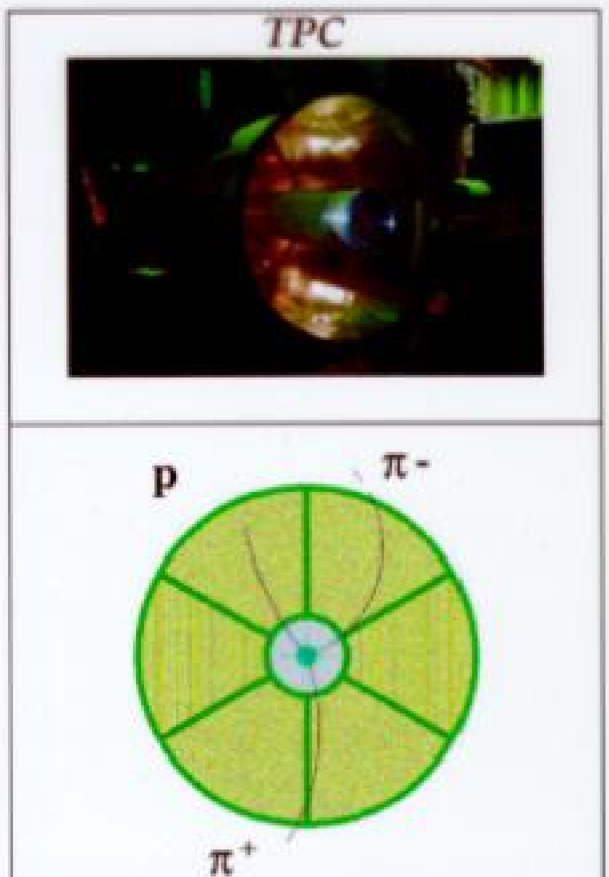
near-term plans:

- **polarized-D** measurements, focusing on $\gamma + \mathbf{D} \rightarrow \pi^\circ \mathbf{n}$
  – starting fall'02
- **polarized-H** measurements
  – starting summer'03

longer-term plans:

- separate **D(γ, π^- p)** from **D(γ, π^+ n)** :
  isolate γ + **n** → π^- **p** at low energies ⇔ **measuring the** $\pi^\pm$ **charge**
  ⇒ magnetic analysis in a *Time-Projection Chamber* (*TPC*)





- TPC experiments in 2005

Future Plans

(1) Improve DF performance at High Field

Vibration isolation from pumping line

– reduce eddy current heating

D polarization -> 22 %

(2) Foridden Adiabatic Fast Transition at DF

Install resonace coils in DF

D polarization 22 % -> Higher

(3) IBC (Orsay) --> New IBC (Quantum tech.)

1.3 K	0.2 K
0.65 Tesla	1 Tesla

(4) TC (Orsay) --> New TC (BNL/Juelich)

0.016 Tesla	0.16 Tesla

(5) Construction of Time Projection Chamber

Identify $\pi+/\pi-$

Summary

1. Recently GDH data started to be taken at $Q^2 = 0$ and small Q^2

2. Data with high quality and high statistics are required to be taken from pion threshold to higher energy for proton and neutron

3. Results are required to be confirmed by other experiments independently

4. Mainz and Bonn have been taking, will continue to take data and the analyses are going on.

5. LEGS started taking data in November 2001 and plan to run for deuteron for a couple of months in 2002, 2003

6. LEGS will improve the target system and design, construct and install TPC

Generalized GDH sum rule

* At $Q^2 = 0$

$$I_{GDH}(0) \equiv \int_{\omega_0}^{\infty} (\sigma_{1/2} - \sigma_{3/2})/\omega \, d\omega = -2\pi^2\alpha\kappa^2/m^2$$

* $I_{GDH}(Q^2) = 16\pi^2\alpha/Q^2 \int_0^1 dx \, g_1(x,Q^2)$

(M. Anselmino et al., Sov J. Nuc Phys. 49(1989) 136)

Relation to $Q^2>0$

- From *N. Bianchi* and *E. Thomas*, hep–ph/9902266

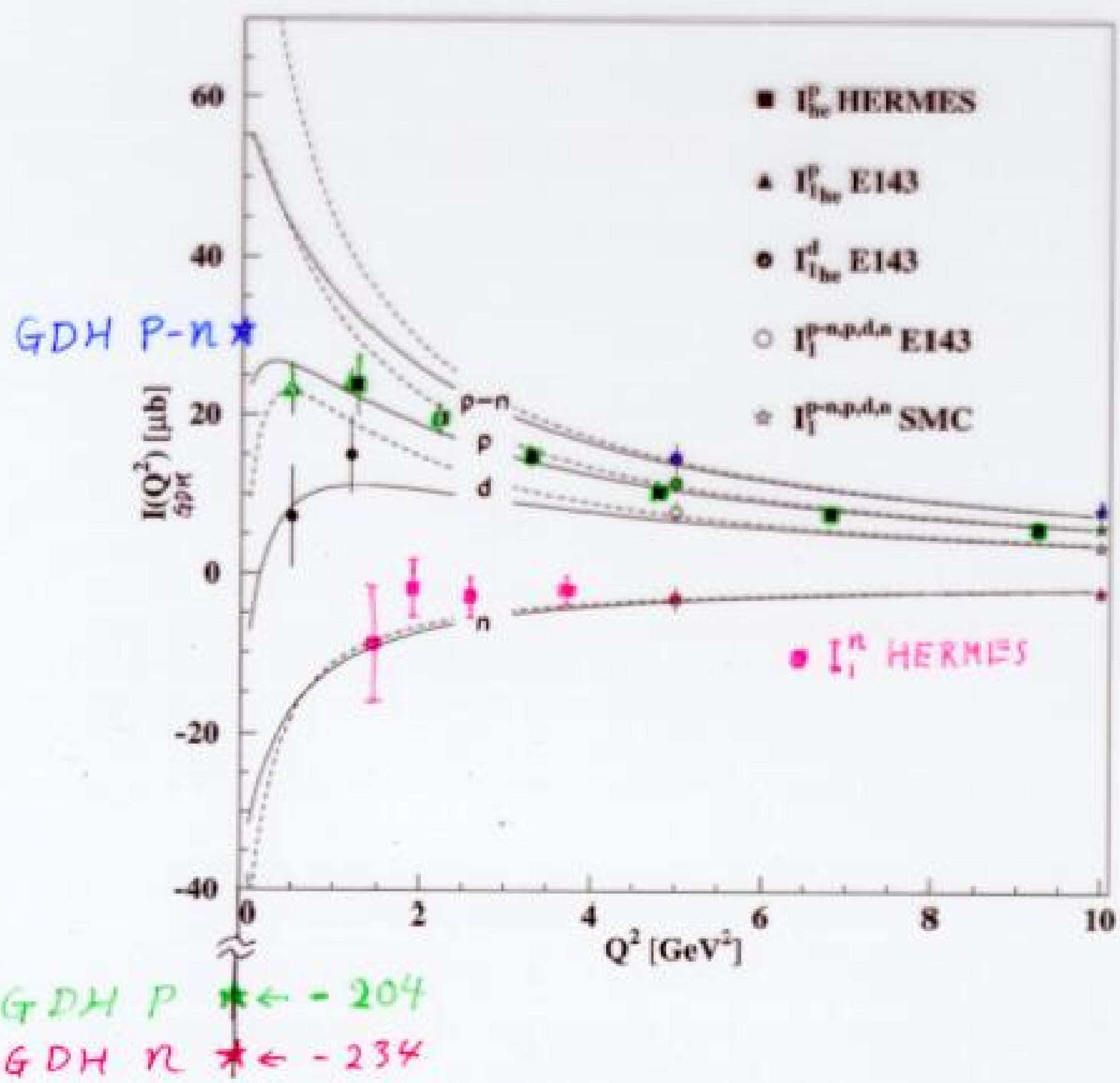


Figure 4: Q^2-evolution of $I_{he}(Q^2)$ (solid curves) and of $I(Q^2)$ (dashed curves) evaluated with Model II for (p-n), p, d and n. The Model predictions are compared with experimental results. The error bars show the quadratic combination of the statistical and the systematic uncertainties.

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our measured points by interpolation , or for a few points, extrapolation. The results are plotted in Fig. 2 as a function of ν. The prominent peak in the cross section is the

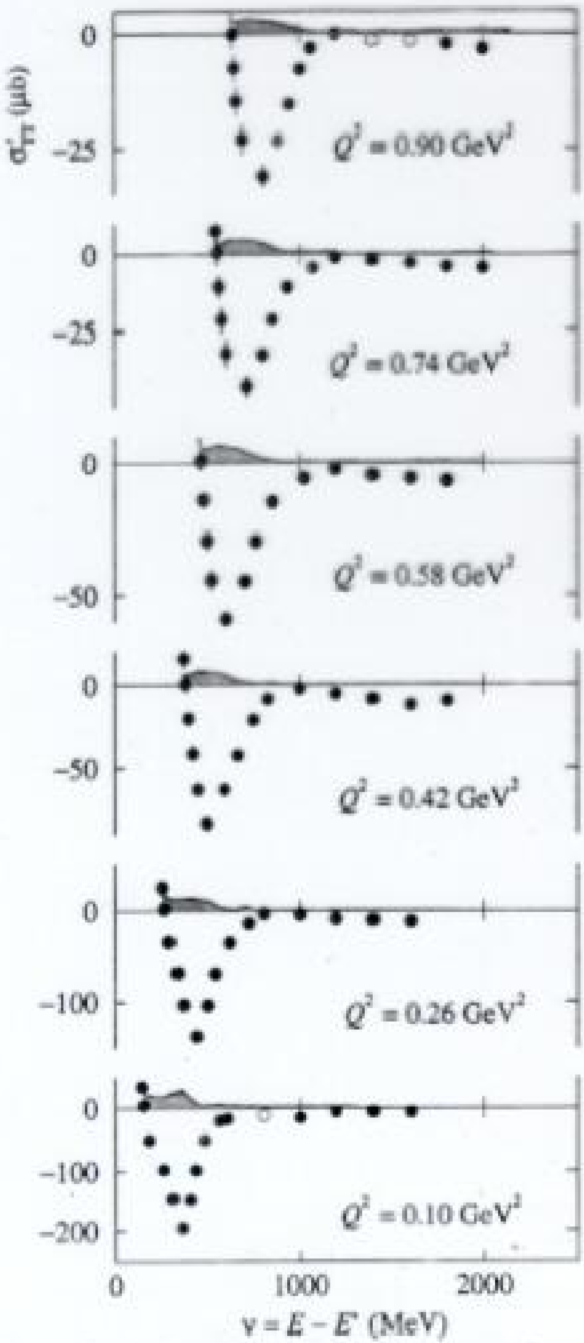

FIG. 2. σ'_{TT} is plotted as a function of energy loss ν for each of six values of constant Q^2. The points shown with solid (open) circles were determined by interpolation (extrapolation).

Δ_{1232} resonance, which decreases in magnitude with increasing Q^2. The error bars represent the uncertainty due to statistics, and the grey bands indicate the uncertainty due to systematic errors, which in addition to those shown in Fig. 1, include a contribution from interpolation and extrapolation.

The extended GDH integral was computed for each value of Q^2 according to eq. 1 using limits of integration extending from the nucleon pion threshold to a value of ν corresponding to $W = 2.0$ GeV. The results are given in Table I. Before plotting our results, we have applied a correction to account for the fact that our neutron was embedded in a ^{3}He nucleus using a calculation due to Ciofi degli Atti and Scopetta [27]. This procedure introduces an additional 5% systematic uncertaintly in our result. Our results for $I(Q^2)$ for the neutron, with the integration covering roughly the resonance region, are shown in Fig. 3 using open circles. The error bars, when visible, represent statistical uncertainties only, and the systematic effects are shown with the grey band. We have made an estimate of the unmeasured strength in $I(Q^2)$ for the region 4 GeV^2 < W^2 < 1000 GeV^2 using the parameterization of Thomas and Bianchi [29] (1000 GeV^2 was the highest value considered in their paper). The solid squares have this estimate included, and an estimate of the theoretical uncertainty has already been included in the systematic error shown.

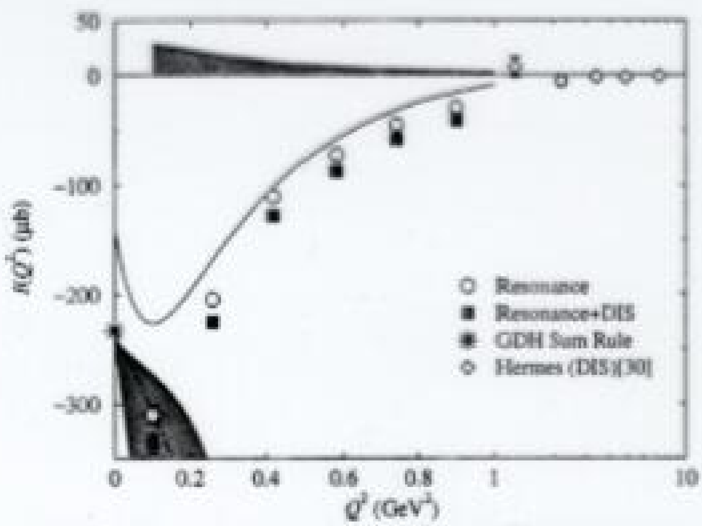

FIG. 3. Our measurements for $I(Q^2)$ vs. Q^2, both with and without an estimate of the DIS contribution. Also shown with a dotted (dot-dashed) line are the χPT calculations of ref. [12] (refs. [13] and [14]). The calculation of ref. [11], based largely on the MAID model, is shown with a solid line. We have included data from HERMES [30], and to avoid compressing our horizontal scale, we have adopted a semi-log scale for 1 GeV^2 < Q^2.

Q^2 (GeV^2)	I_{GDH} (μb)	Statistical (μb)	Systematic (μb)
0.10	-223.76	6.18	23.68
0.26	-156.52	3.01	13.58
0.42	-88.73	2.10	7.46
0.58	-59.56	1.51	4.56
0.74	-37.96	1.43	3.14
0.90	-23.63	1.00	2.09

TABLE I. Measured values for $I(Q^2)$ prior to nuclear corrections together with statistical and systematic errors.