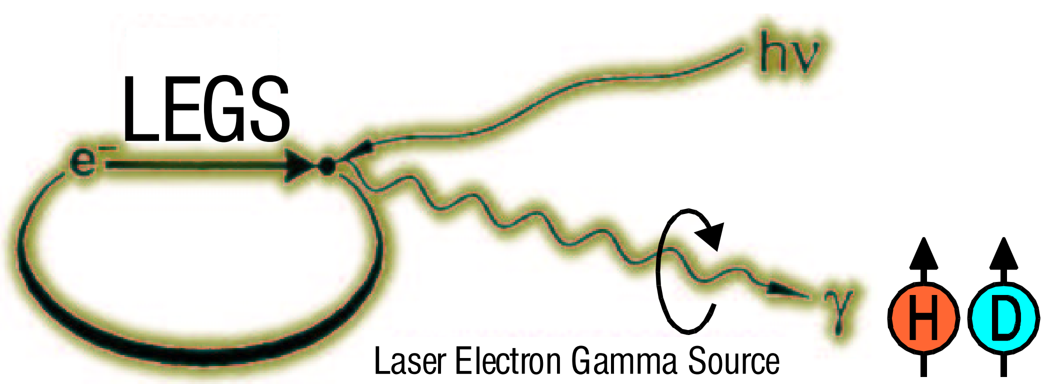
1st Pion Photoproduction Double-Polarization Results with Polarized $\vec{H}\vec{D}$ at LEGS

A. Lehmann (for the LEGS-Spin Collaboration)

NStar 2002



- Physics Motivation
- Experiment (SASY detector, HD target)
- Analysis and first results of polarized data
- Immediate and future plans

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*

What is LEGS ?

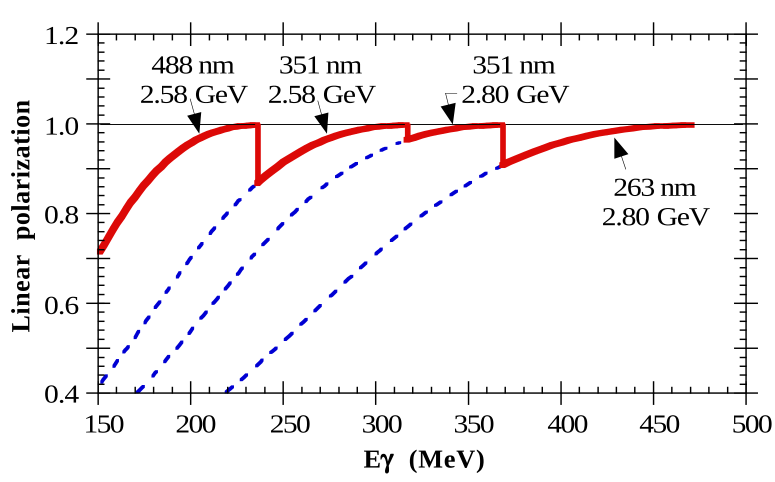
- Compton backscattering facility

$$E_\gamma = \frac{4 \in_l (E_e/m_e)^2}{1 + \frac{4 \in_l E_e}{m_e^2} + \theta^2 (E_e/m_e)^2}$$

  - Scattered laser photon ε_l gains energy from the moving electron E_e in a storage ring

- E_e = 2.8 GeV
  ε_l = 2.4 - 4.7 eV } **150 MeV < E_γ < 470 MeV**

- Polarization determined by laser
  - Linear and circular polarization states
  - By superposition of different lines always >80%



  - "Random" flipping through all linear and circular polarizations possible

Motivation for $\vec{N}(\vec{\gamma},\pi)$

Multipole Amplitudes

- Double polarization observables
  - Asymmetries E and G
  - Neutron channels $\pi^o n$ and $\pi^- p$

Nucleon Spin Sum Rules

- Gerasimov-Drell-Hearn

$$-\frac{\alpha}{2m^2}\kappa^2 = \frac{1}{4\pi^2}\int_{m_\pi}^{\infty}\frac{\sigma_{1/2}-\sigma_{3/2}}{E_\gamma}\,dE_\gamma$$

  - Nucleon spin structure at $Q^2=0$
  - LEGS covers ~65%
  - Measurement down to pion threshold is important

- Forward Spin-Polarizability

$$\gamma_0 = \frac{1}{4\pi^2}\int_{m_\pi}^{\infty}\frac{\sigma_{1/2}-\sigma_{3/2}}{E_\gamma^3}\,dE_\gamma$$

  - Test of chiral perturbation theory
  - LEGS covers ~90%
  - Measurement down to pion threshold is important

Other Physics Goals with polarized $\vec{p}$ and $\vec{D}$

Nucleon Spin-Polarizabilities

- Double polarized Compton scattering
  - $\vec{\gamma} + \vec{N} \rightarrow \gamma$ N
  - Forward and backward spin-polarizability
  - Multipole amplitudes

Nucleon-Delta Interaction

- Photo-disintegration
  - $\vec{\gamma} + \vec{D} \rightarrow$ p n
  - Multipole amplitudes

Current Status of GDH

(Only Q^2=0)

	Proton [μb]	Neutron [μb]
$-\frac{2\pi^2\alpha}{m^2}\kappa^2$	**-205**	**-233**
Experiment:		
$m_\pi < E_\gamma < 0.2$ GeV	---	---
MAMI / ELSA 0.2 GeV $< E_\gamma <$ 2.9 GeV	-255 ($\pm$5)	---
$E_\gamma >$ 2.9 GeV	---	---
Total (with extrapolations)	**-225 ($\pm$5)**	---
Multipoles:		
SAID multipoles $m_\pi < E_\gamma < 2.0$ GeV	-187	-137
MAID multipoles $m_\pi < E_\gamma < 1.8$ GeV	-178	-147
MAID multipoles (with extrapolations)	**-225**	**-200**

Experiment:

- Proton high
- Neutron no data

Multipole Calculations:

- Proton overestimated
- Neutron underestimated

Spin-ASYmmetry Array (SASY)

All four pion-photoproduction channels can be measured simultaneously (in principle):

$\gamma\, p \rightarrow \pi^+\, n$ $\qquad$ $\gamma\, n \rightarrow \pi^-\, p$

$\gamma\, p \rightarrow \pi^o\, p$ $\qquad$ $\gamma\, n \rightarrow \pi^o\, n$

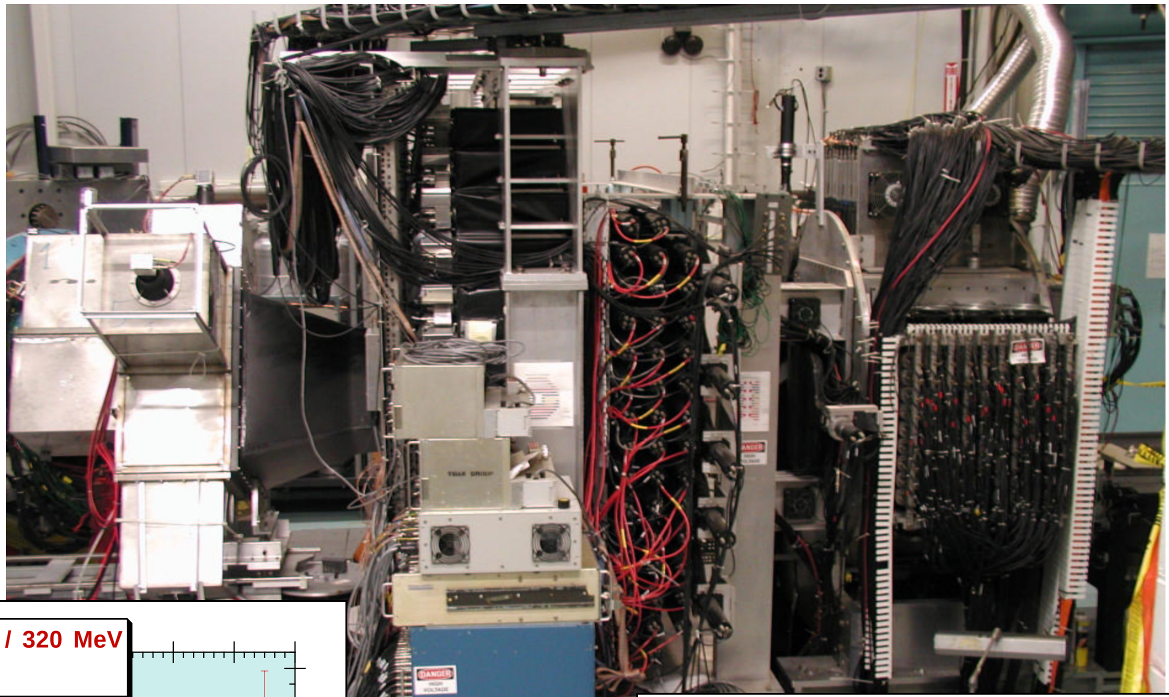
Phase I:

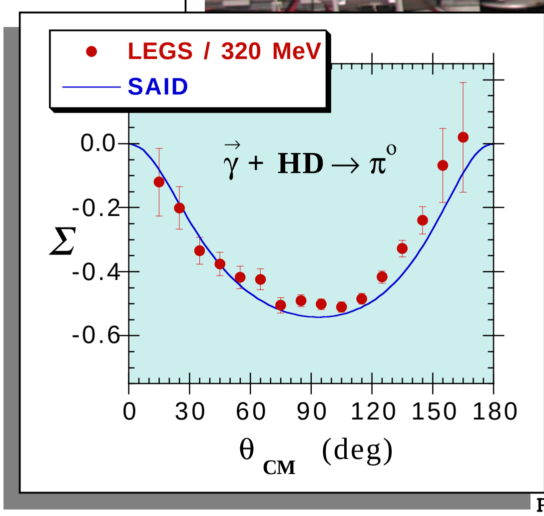
- Spin sum rules at the proton
  - Inclusive measurement of π^+n and $\pi^o p$
- Spin sum rules at the neutron
  - Upgrade with additional neutron detectors ("neutron barrel")
  - Exclusive measurement of $\pi^o n$

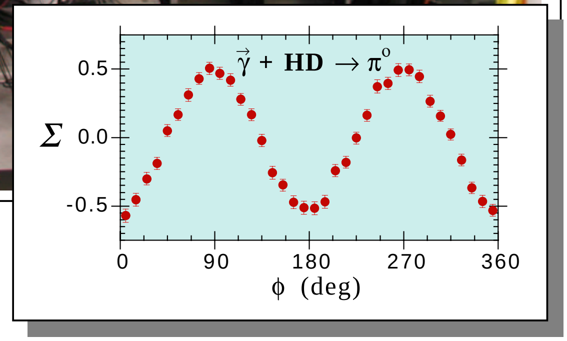
Phase II:

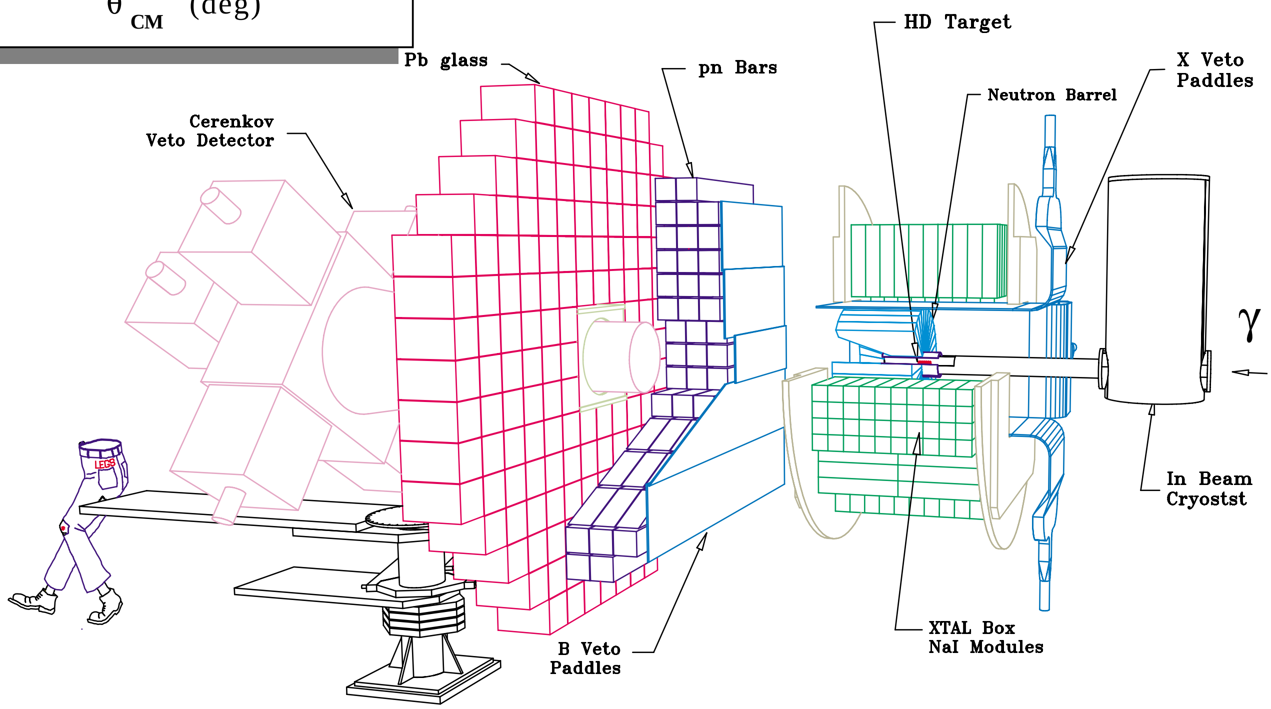
- Spin sum rules at the neutron
  - Upgrade with TPC $\Rightarrow$ magnetic analysis of π^+/π^-
  - Inclusive measurement of $\pi^- p$

SASY Current Setup









Strongly Polarized Hydrogen and Deuterium ICE Target (SPHICE)

- Frozen-spin hydrogen and deuterium target
  - HD molecules in solid phase
  - Simple: only two protons and one neutron

    $H(p_{free}) + D(p_{bound} + n_{bound})$

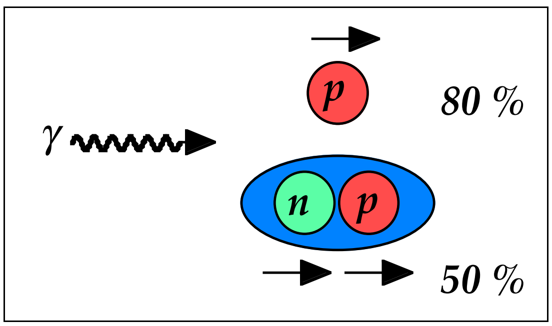
- High purity
  - Contains only 20% (weight) aluminium wires for cooling purposes

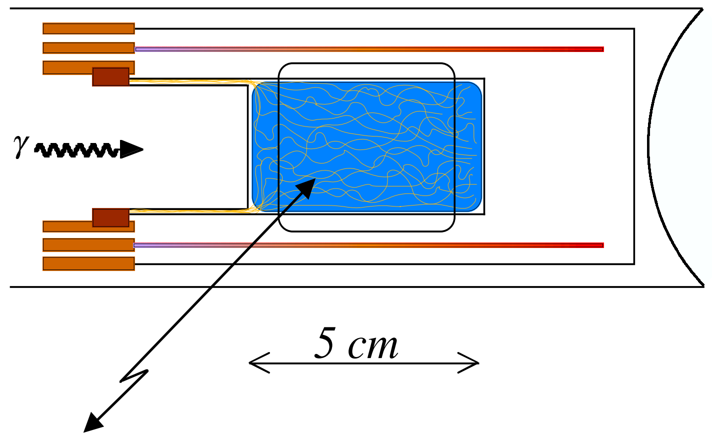
- Flexibility and high quality
  - Polarization of either H or D or both
  - Independent spin orientations
  - 80% proton and 50% deuteron polarization possible
  - Thickness up to ~1 g/cm^2
  - Relaxation times >10 days for H and >30 days for D

- Storable and transportable
  - Long relaxation times under storage

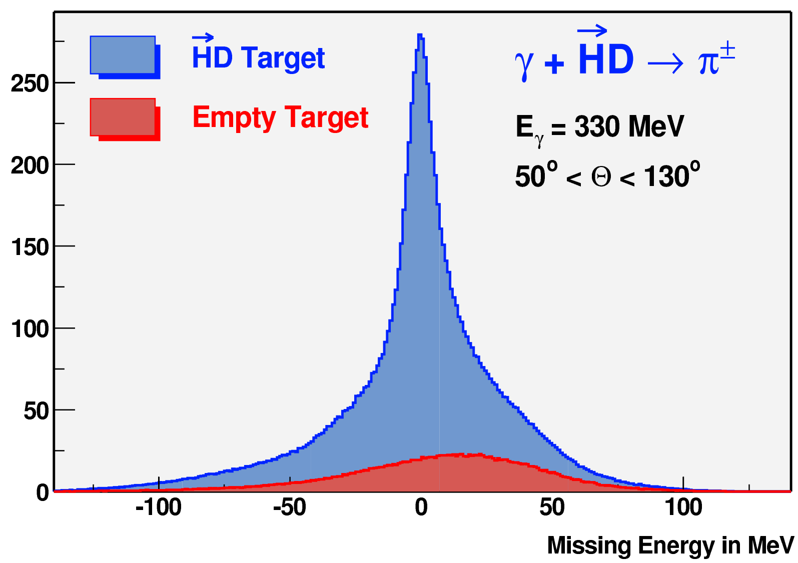
SPHICE -- Parameters

a new class of frozen-spin target for photonuclear experiments





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



Polarization

	P_H	P_D
Sept'01	70 %	17 %
Nov'01	30 %	6 %
goal	80 %	50 %

in-beam spin-relaxation

	T_1^H	T_1^D
Nov'01 (1.3°)	13 d	36 d
goal (0.2°)	>30 d	>100 d

Target Polarization History

- Initial $P_T = \begin{cases} 70\% \text{ for H} \\ 17\% \text{ for D} \end{cases}$

- Many tests to study target under various conditions (transfers, different holding fields and temperatures)

- Start conditions in-beam

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

  - Calibration of Polarization:
    - NMR line shift due to polarization decay (change in B field)
    - Low-B/high-T thermal equilibrium NMR signal (H_2 + HD)

- After 2 days magnet quench
  $\Rightarrow P_T$ dropped by about a factor of two

- After 1.5 days accelerator shutdown

$\Rightarrow$ 3.5 days of net data taking

$$\langle P_H \rangle = \int (P_H dt) / \int dt = 21.3\%$$

$$\langle P_D \rangle = \int (P_D dt) / \int dt = 5.0\%$$

$\vec{N}(\vec{\gamma},\pi)N$ Observables

$$\frac{d\sigma}{d\Omega}(\theta_\pi,\phi_\pi) = \frac{d\sigma}{d\Omega}(\theta_\pi)\cdot\{1 + \Sigma(\theta_\pi)\cdot 1\cdot\wp_L^\gamma\cos(2\phi_\pi)$$
$$- \mathbf{E}(\theta_\pi)\cdot \mathbf{P}_z\cdot\wp_C^\gamma$$
$$+ \mathbf{G}(\theta_\pi)\cdot \mathbf{P}_z\cdot\wp_L^\gamma\sin(2\phi_\pi)$$
$$- \mathbf{P}(\theta_\pi)\cdot \mathbf{P}_y\cdot\wp_L^\gamma\cos(2\phi_\pi)$$
$$+ \mathbf{T}(\theta_\pi)\cdot \mathbf{P}_y$$
$$+ \mathbf{F}(\theta_\pi)\cdot \mathbf{P}_x\cdot\wp_C^\gamma$$
$$- \mathbf{H}(\theta_\pi)\cdot \mathbf{P}_x\cdot\wp_L^\gamma\sin(2\phi_\pi)\}$$

- **(P_x,P_y,P_z)** target-; **($\wp^\gamma_L$, $\wp^\gamma_C$)** beam-polarizations
- Four of eight observables needed for a model independent multipole analysis are measured simultaneously
- E(θ) ⇒ GDH ; γ_0

Polarization Observables

- longitudinal target polarization $\boldsymbol{P_z}$
- flip between different γ-ray polarization states, at random intervals:

  left circular
  right circular
  0° linear
  90° linear
  +45° linear
  –45° linear
  bremsstrahlung

Klein-Nishina

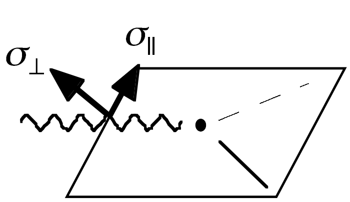
laser polarization

brem ≅ 0.99

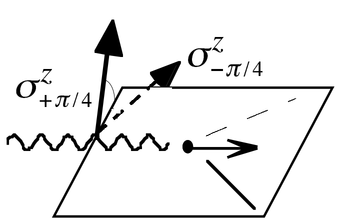
- γ polarization ⇔ *Stokes* vector:

$$\left\{\begin{aligned} Q_i(E_\gamma) &= Q_i^L \cdot \wp_{Linear}(E_\gamma)\cdot P_{brem}\ , \\ U_i(E_\gamma) &= U_i^L \cdot \wp_{Linear}(E_\gamma)\cdot P_{brem}\ , \\ V_i(E_\gamma) &= V_i^L \cdot \wp_{Circular}(E_\gamma)\cdot P_{brem}\ . \end{aligned}\right\}$$

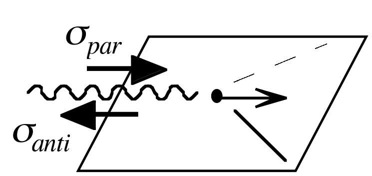
$$\frac{d\sigma_i}{d\Omega}(\theta,\phi;E_\gamma) = \frac{d\sigma}{d\Omega}(\theta;E_\gamma)\cdot\left\{\begin{aligned} &1+\left[Q_i(E_\gamma)\cdot\Sigma(\theta;E_\gamma) - P_z\cdot U_i(E_\gamma)\cdot G(\theta;E_\gamma)\right]\cdot\cos 2\phi \\ &+\left[P_z\cdot Q_i(E_\gamma)\cdot G(\theta;E_\gamma) + U_i(E_\gamma)\cdot\Sigma(\theta;E_\gamma)\right]\cdot\sin 2\phi \\ &- P_z\cdot V_i(E_\gamma)\cdot E(\theta;E_\gamma) \end{aligned}\right\}$$



Σ



G



E

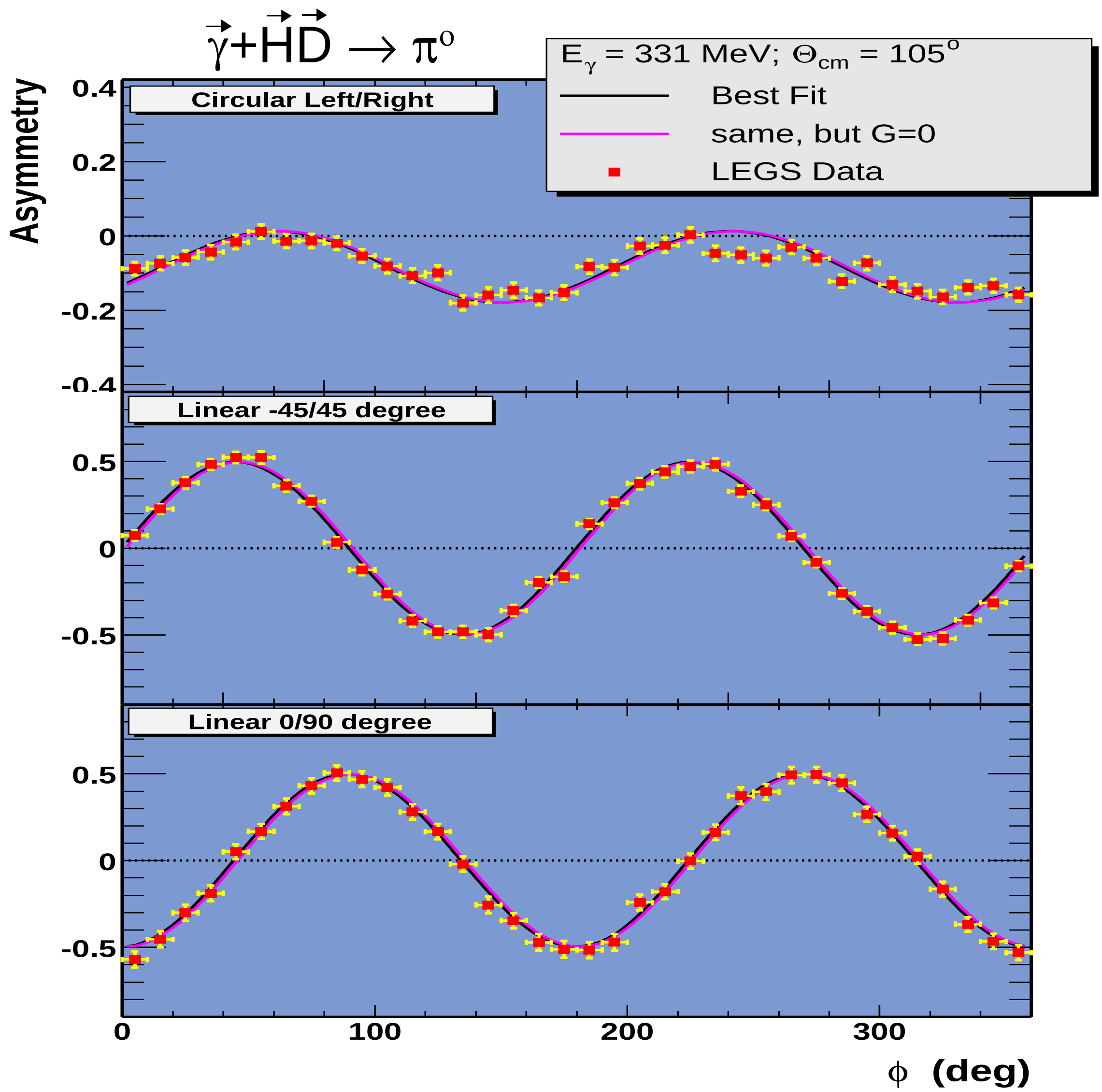
Extraction of Asymmetries

$$\frac{\frac{d\sigma_1}{d\Omega}-\frac{d\sigma_2}{d\Omega}}{\frac{d\sigma_1}{d\Omega}+\frac{d\sigma_2}{d\Omega}} = \frac{\wp_L P_{br}\{[(Q_1^L - Q_2^L)\Sigma - P_z(U_1^L - U_2^L)G]\cos(2\phi)}{2+\wp_L P_{br}\{[(Q_1^L + Q_2^L)\Sigma - P_z(U_1^L + U_2^L)G]\cos(2\phi)} \cdots$$

$$\frac{+[P_z(Q_1^L - Q_2^L)G - (U_1^L - U_2^L)\Sigma]\sin(2\phi)\}}{+[P_z(Q_1^L + Q_2^L)G - (U_1^L + U_2^L)\Sigma]\sin(2\phi)\}} \cdots$$

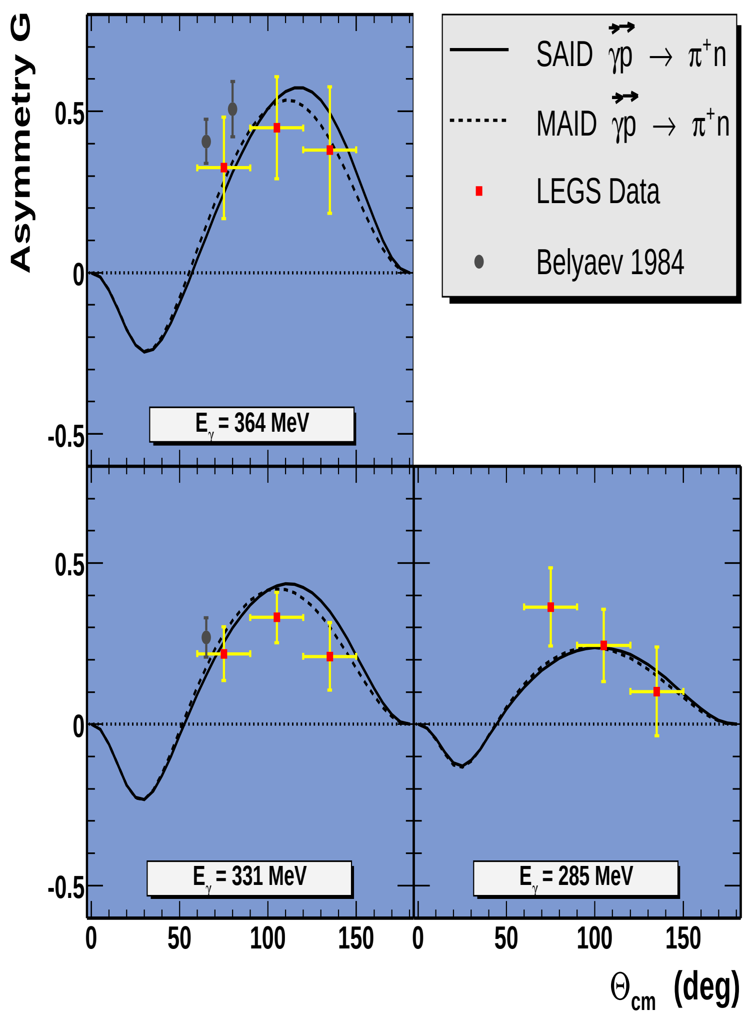
$$\frac{-\wp_C P_{br} P_z (V_1^L - V_2^L)E}{-\wp_C P_{br} P_z (V_1^L + V_2^L)E}$$

Fit ϕ-distributions with Σ, **G**, and **E** as the only free parameters !

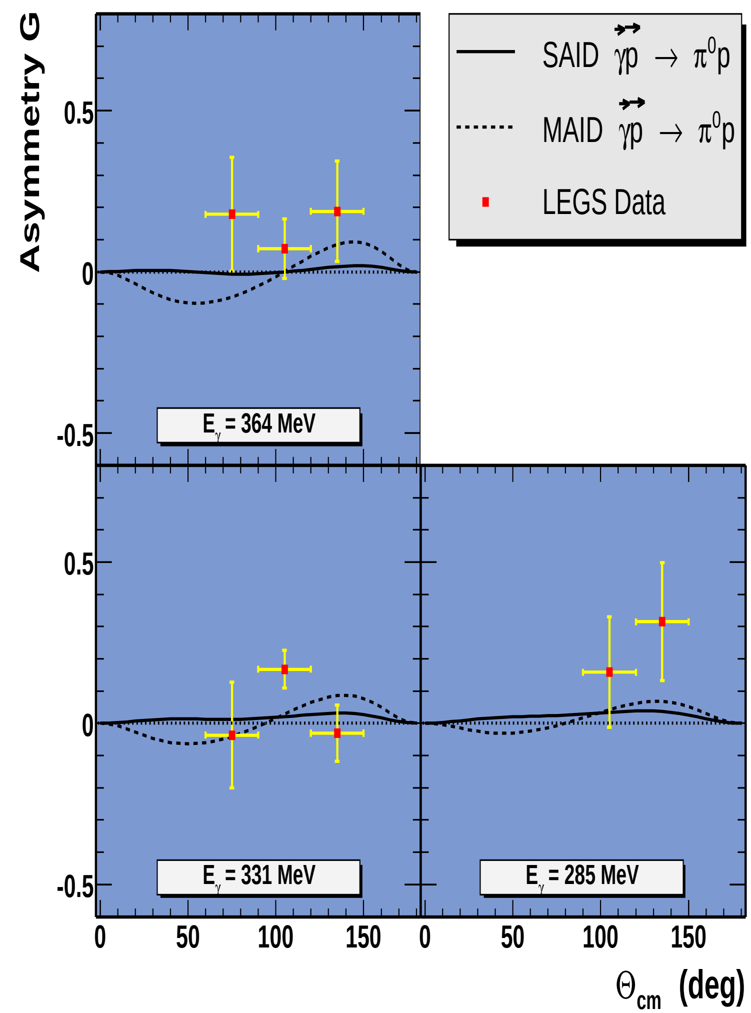


Proton G Asymmetries

$\vec{\gamma} + \vec{H}\vec{D} \rightarrow \pi^{+} n$



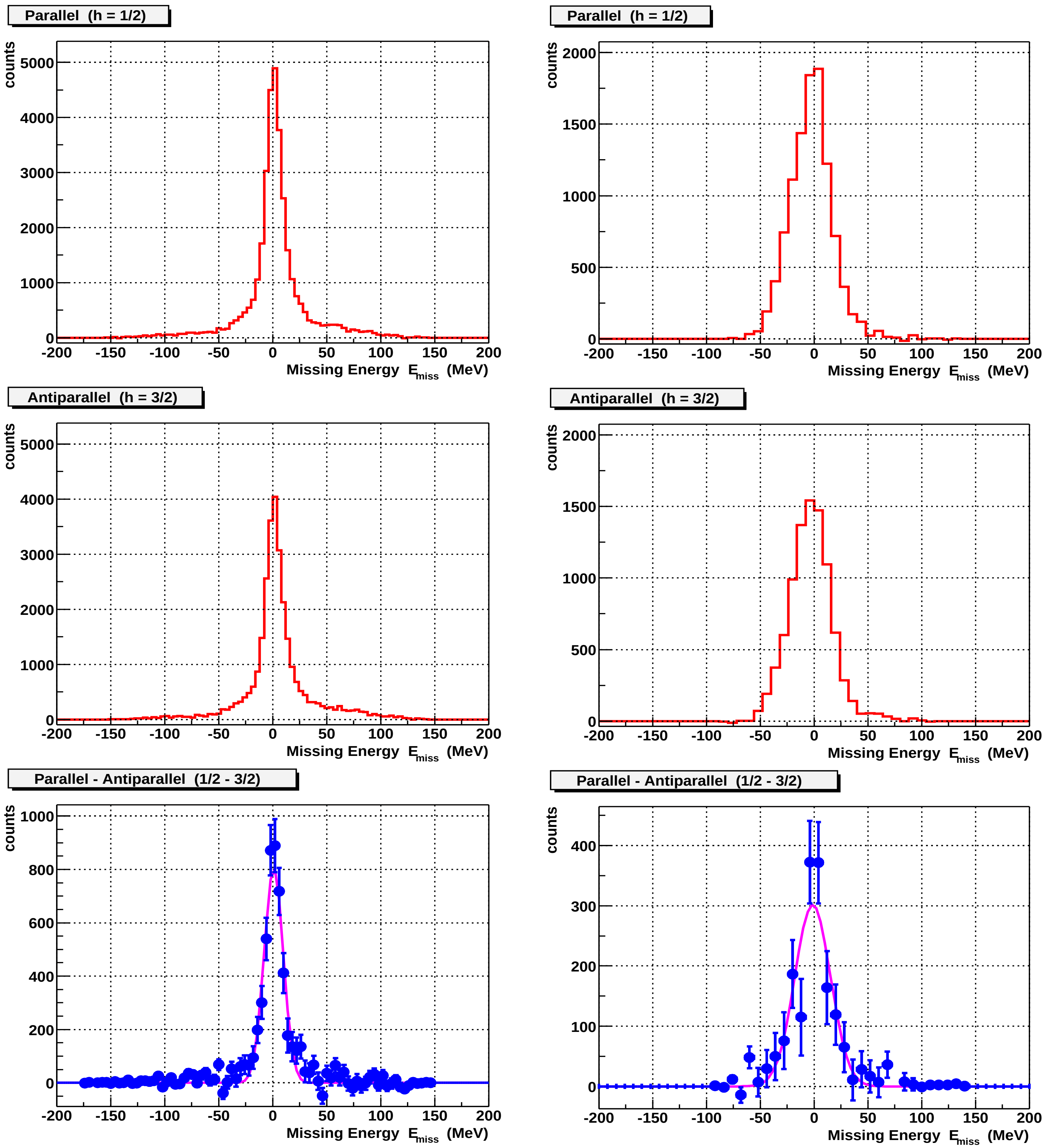
$\vec{\gamma} + \vec{H}\vec{D} \rightarrow \pi^{o} p$



Pion Missing Energy of $\vec{\gamma}+\vec{H}\vec{D}$

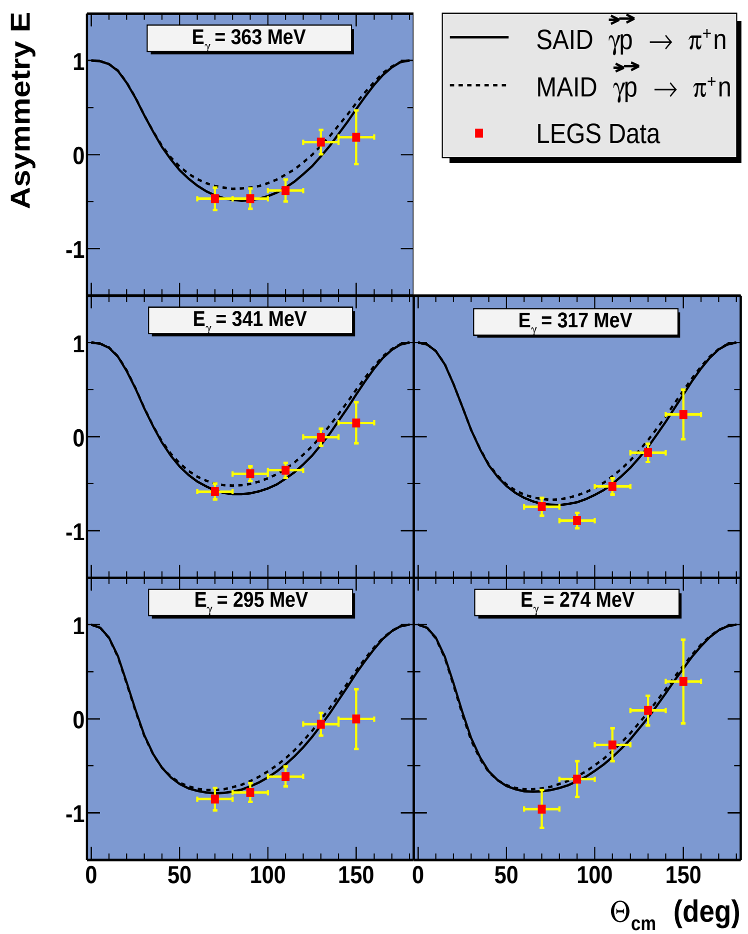
300 MeV < E_γ < 350 MeV
$75^o < \theta_{CM} < 105^o$

$\vec{H}\vec{D}(\vec{\gamma}, \pi^+ n)$ $\vec{D}(\vec{\gamma}, \pi^0 n)$

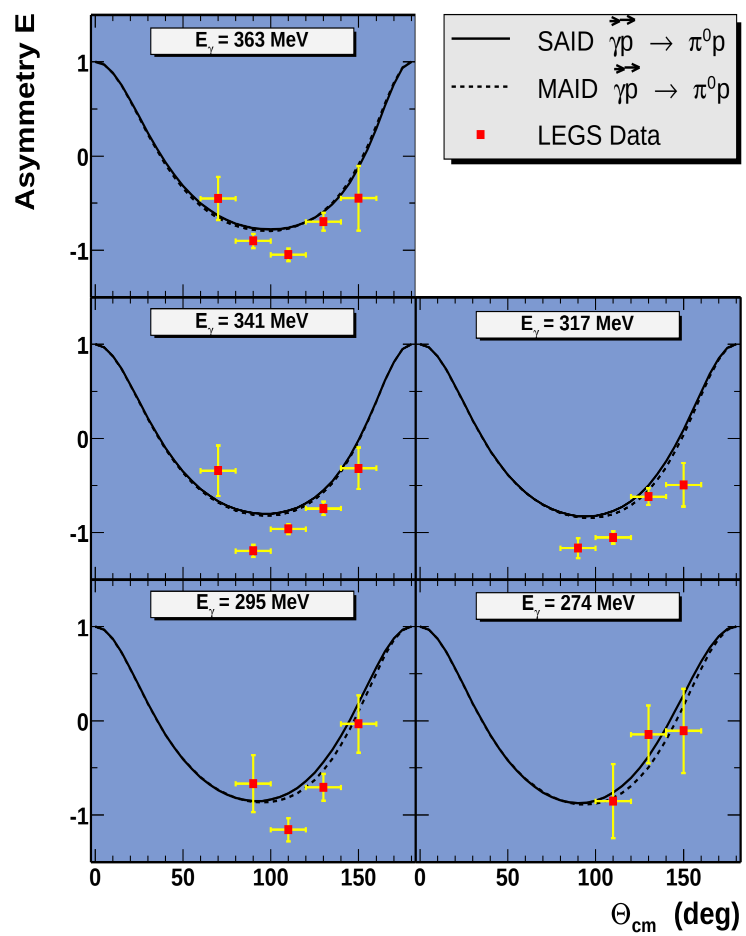


Proton E Asymmetries

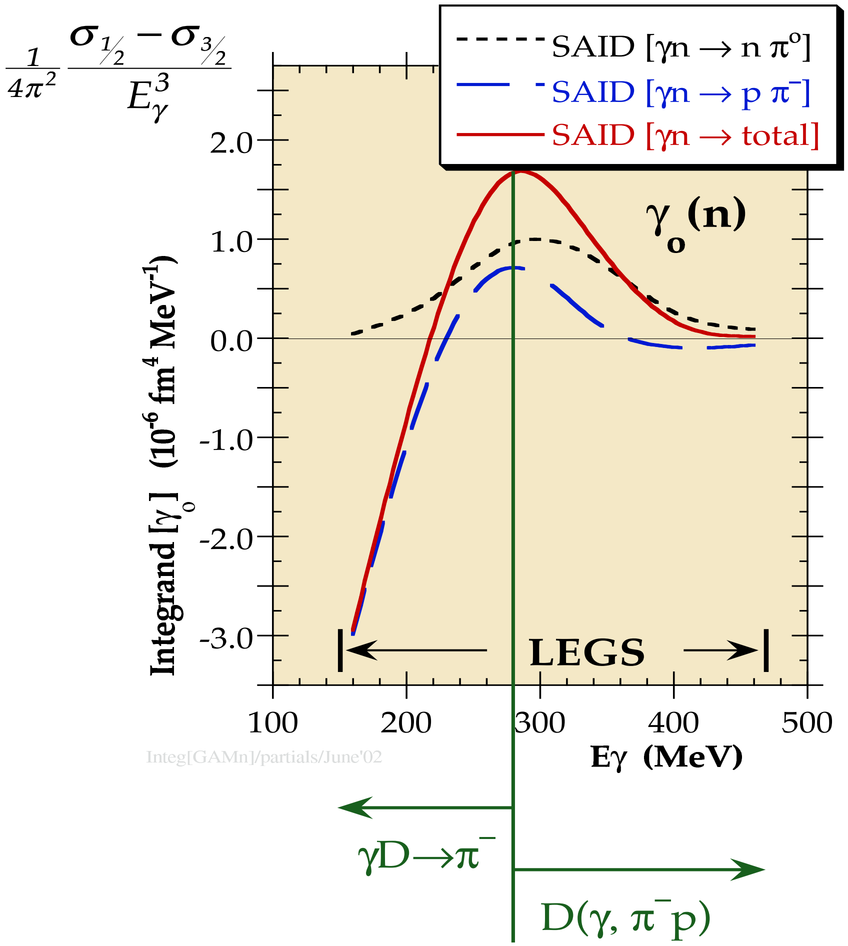
$\vec{\gamma} + \vec{H}\vec{D} \rightarrow \pi^+ n$

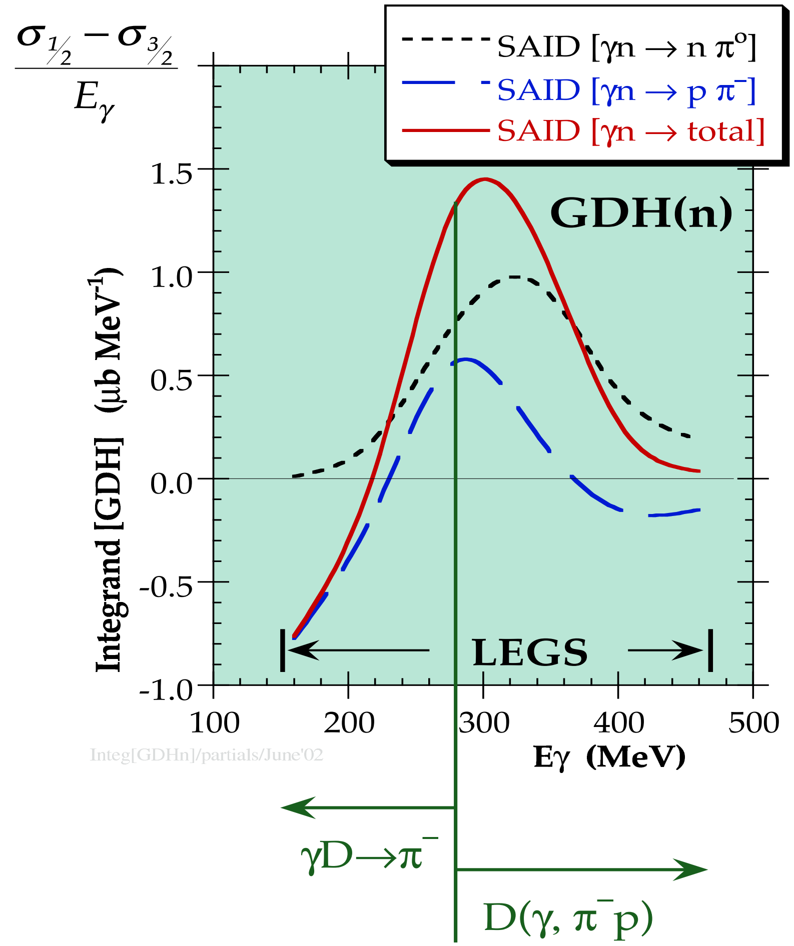


$\vec{\gamma} + \vec{H}\vec{D} \rightarrow \pi^o p$



Integrands of GDH and γ_0 at Neutron





to separate D(γ, π^-) p from D(γ, π^+)n

→ measure $\pi^\pm$ charge

Integ[SR]/partials/June'02

LEGS GDH Program

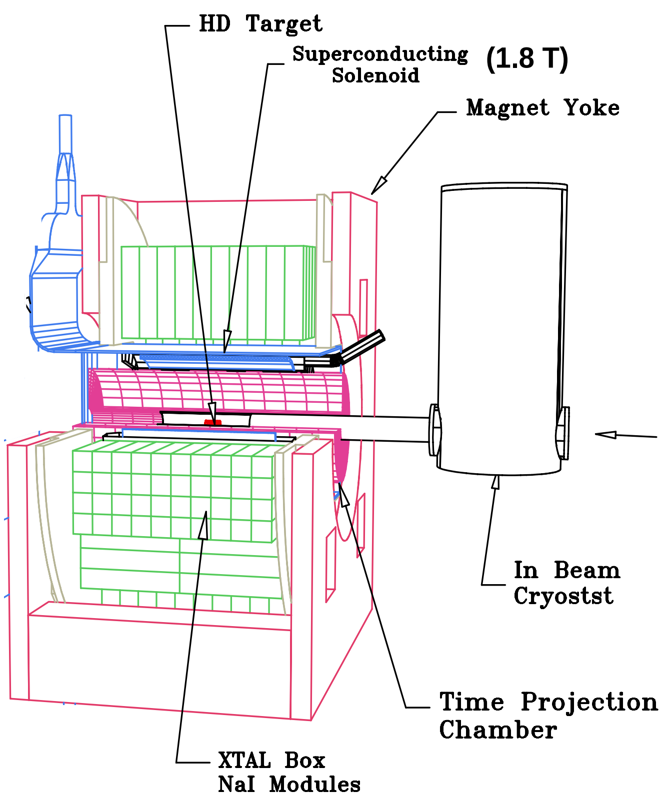
(~threshold < E_γ < 470 MeV)

near-term plans:

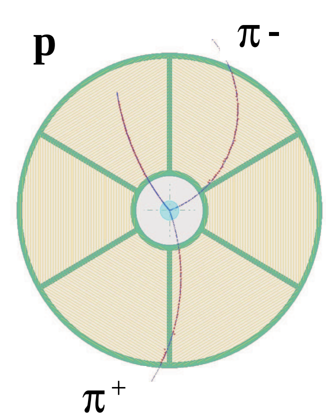
- **polarized-D** measurements, focusing on $\gamma + \mathbf{D} \rightarrow \pi^\circ \mathbf{n}$ – starting Feb'03
- **polarized-H** measurements – starting summer'03

longer-term plans:

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



TPC



- TPC experiments in 2005

Summary and Outlook

- First double-polarization data at the proton (π^+n, $\pi^o p$) and at the neutron ($\pi^- p$, $\pi^o n$) from a frozen-spin HD target
  - Large solid angle coverage (full ϕ)
  - H polarization 30%
  - D polarization 6%
  - Flipping through linear and circular beam polarizations
  - $\Sigma(\theta)$, $G(\theta)$, $E(\theta)$ and $\sigma(\theta)$ measured simultaneously
- Good quality results after only 3.5 days of running (even for GDH integrals)
- New sets of HD targets
  - D polarization ~20%
  - Double-polarization data on $\pi^o n$
  - H polarization >70%
  - Several weeks of running (in full energy range)
  - $\Rightarrow$ (GDH; $\gamma_0)_p$ down close to pion threshold
- Next phase
  - D polarization 50%
  - Detector upgrade with TPC $\Rightarrow$ magnetic analysis
  - Complete exclusive measurements of neutron observables $\Rightarrow$ (GDH; $\gamma_0)_n$ down close to pion threshold