Probing Chiral Dynamics @HIγS

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HIγS PROGRAM

JLAB August 9, 2007

***A wide variety of physical processes can be used to study Chiral Dynamics*, guided mainly by the results of ChPT, an expansion of the Lagrangian for low energy QCD about the chiral limit, m_q=0.**

I want to mention a few of these today.

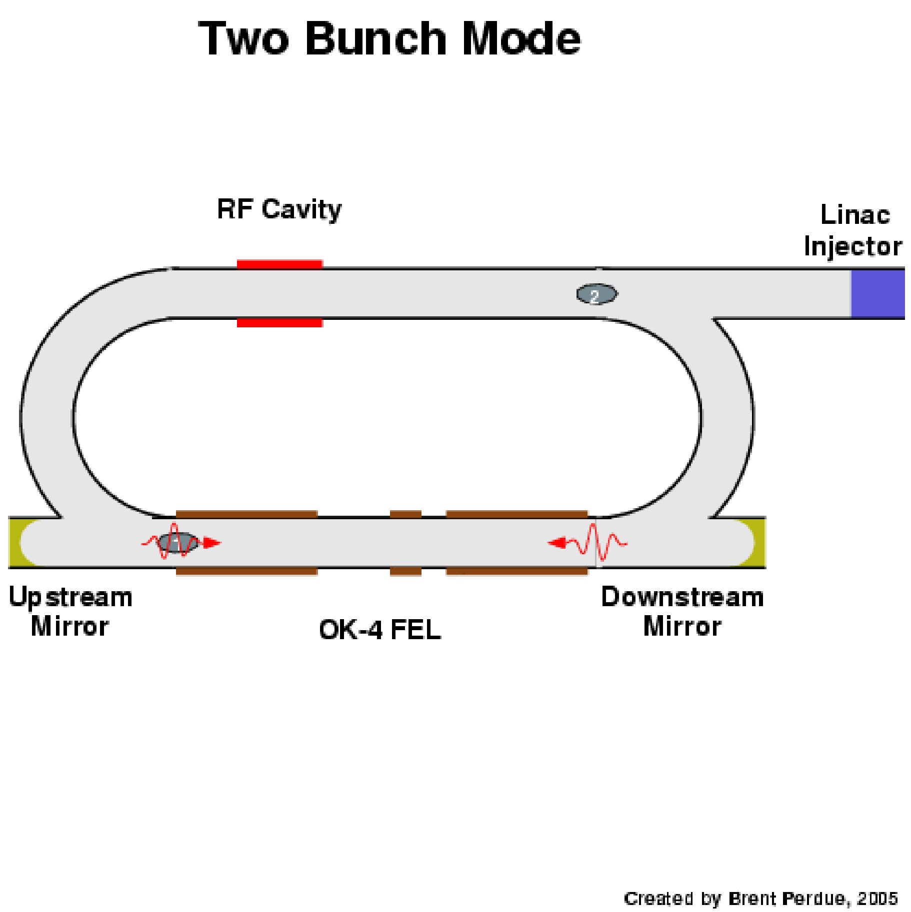
Reference:

International Workshop on Chiral Dynamics 2006

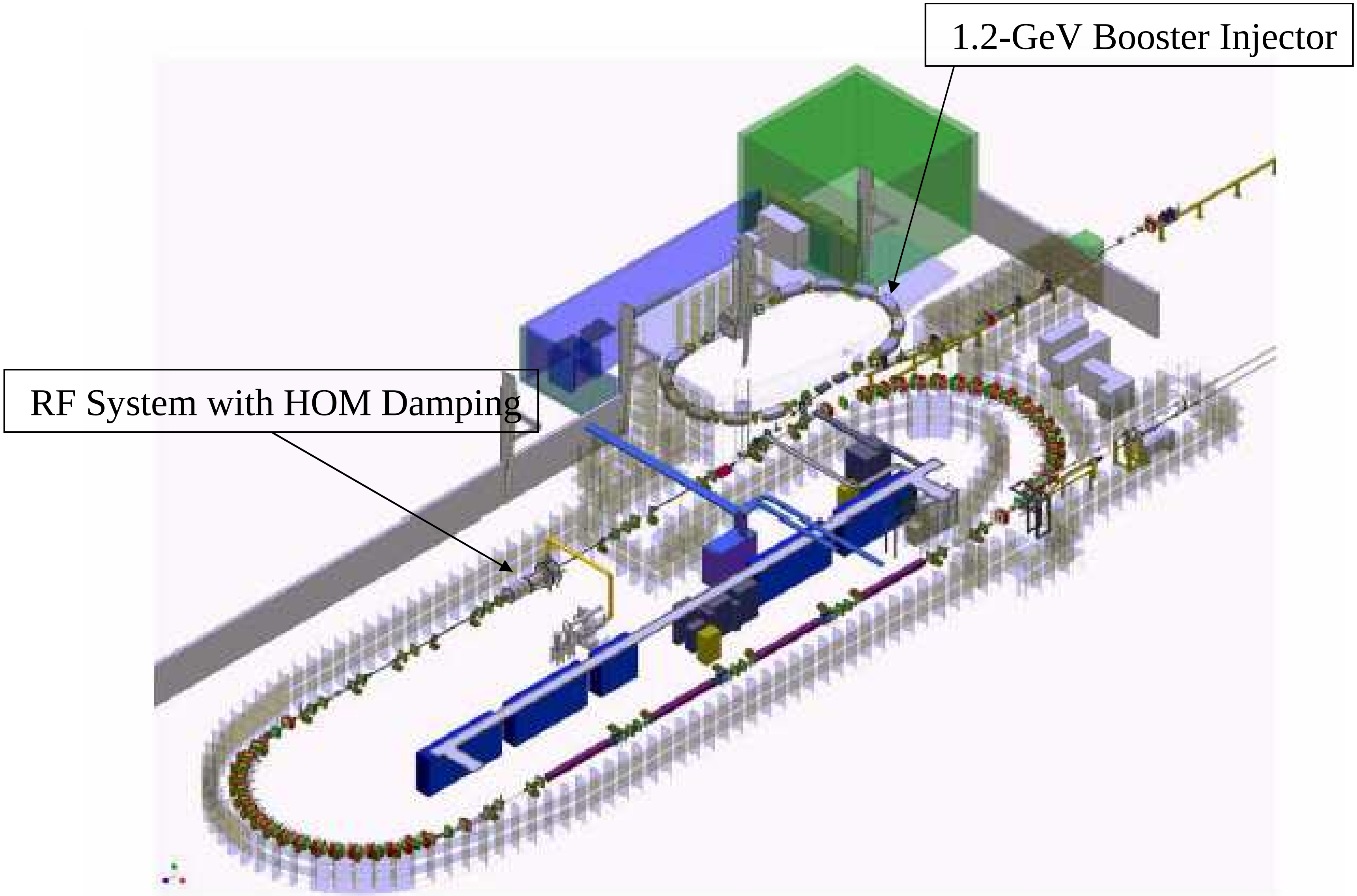
Organizers: H. Gao, B. Holstein, HRW

www.tunl.duke.edu/events/cd2006/proceeding.htm

HIγS –A free-electron laser generated γ-ray source



Upgraded Facility



Upgrade Schedule

Commissioning of Booster and Ring has been completed!

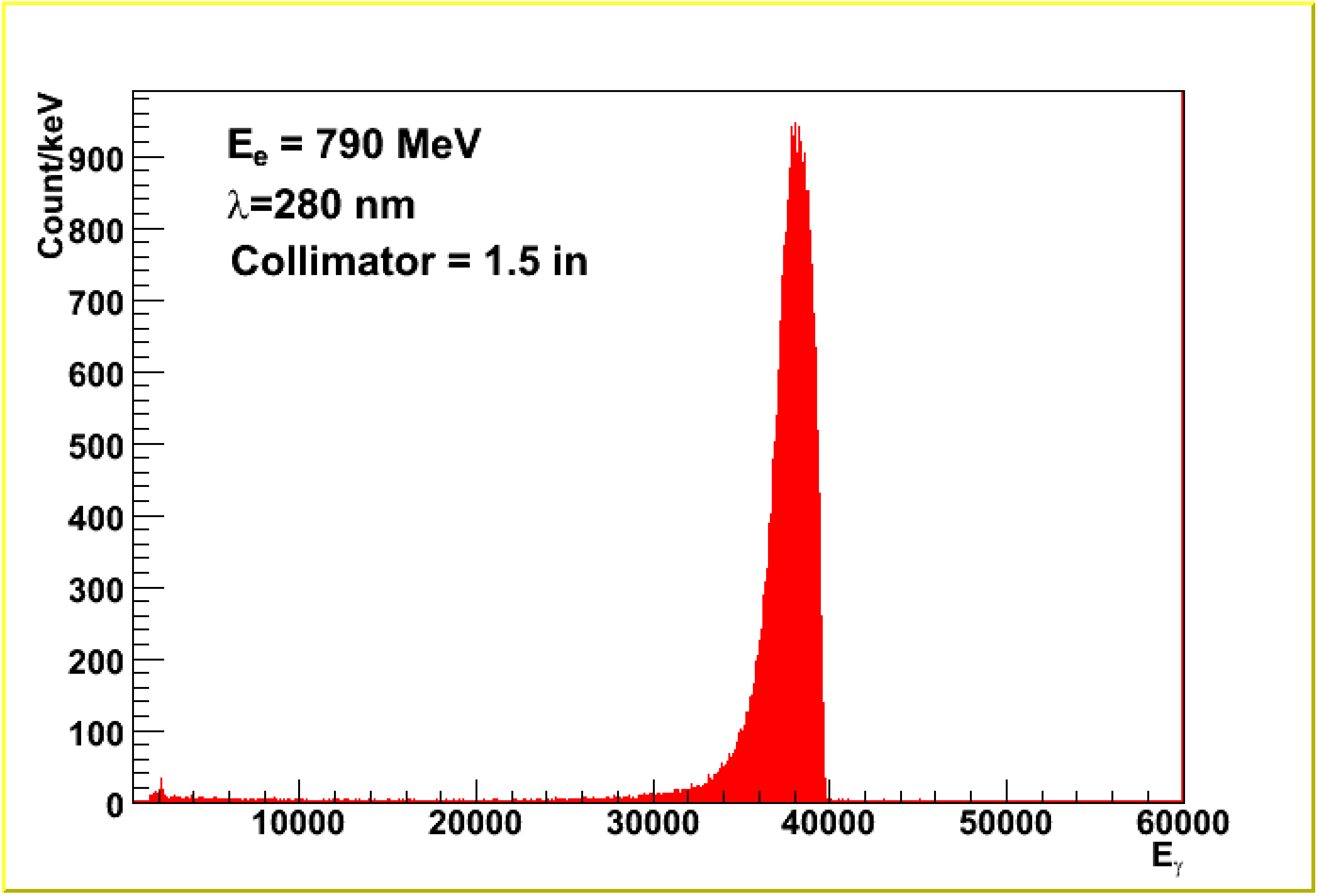
Nuclear Physics Program begins—August 21, 2007

August 07 → March 08 Linear and Circular Pol.- Below 65 MeV, >2x10^8 γ/s (4x10^9 at some energies)

June 08 → Linear and Circ. Pol. Up to 110 MeV, >10^8 γ/s

These are TOTAL intensities. Beam on target is ~ TOTAL x 1.5 x % resolution (ex. 5% res. at 100 MeV: 7.5 x 10^6 γ/s)

Expect to have energies up to 160 MeV by Spring 09



E_e = 790 MeV
λ=280 nm
Collimator = 1.5 in
Count/keV
0
100
200
300
400
500
600
700
800
900
10000
20000
30000
40000
50000
60000
E_γ

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GDH Sum Rule studies @ HIγS

GDH Collaboration spokespersons—H. Gao, B. Norum, HRW

Measure the GDH integrand on d and ^{3}He below pion threshold.

- ***Compare to theoretical predictions. Provides extremely sensitive test of spin dependent effects.***
- ***Combine with the global effort to measure this for n, p and d. Our piece is essential for a test of consistency and a search for new physics.***

•The Gerasimov-Drell-Hearn (GDH) Sum

•Rule for

The GDH Integral

$$I^{GDH} = \int_{2.2\ \mathrm{MeV}}^{\infty} (\sigma_P(E)-\sigma_A(E)) \frac{dE}{E} = 4\pi^2 \kappa^2 \frac{e^2}{M^2}$$

$$\vec{M} = (Q+\kappa)\frac{e}{M}\vec{S};$$

$\sigma_{P/A}(E)$ are the total cross sections for the absorption of circularly polarized photons on a target with spin Parallel/Antiparallel to the spin of the photon;

κ = anomalous magnetic moment (of the deuteron).

$\kappa_d = -0.143\ \mu_m$ ⟶ **•I^{GDH} Predicted = 0.65 μb**

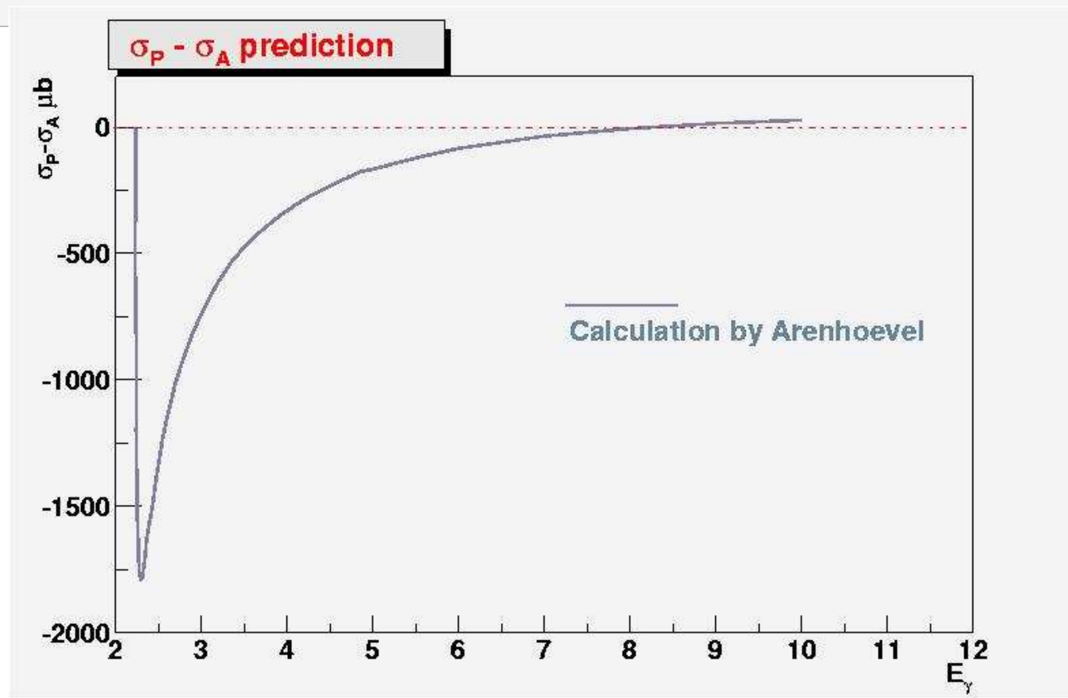
$$I^{GDH}_{total} = \int_{2.2\ \mathrm{MeV}}^{E_\pi} \cdots + \int_{E_\pi}^{\infty} \cdots$$

E_π = pion production threshold

$$\int_{E_\pi}^{\infty} = \int (\text{proton}) + \int (\text{neutron})$$

$$= 436\ \mu b$$

$$\int_{2.2\,\mathrm{MeV}}^{E_\pi} \ldots \approx -436\ \mu\mathrm{b}$$



•THE GDH INTEGRAND FOR THE DEUTERON NEAR PHOTODISINTEGRATION THRESHOLD

Contributions are expected from s-waves and p-waves (notation $^{2S+1}L_J$)

M1 terms: $^1S_0$ and $^3S_1$
Expect $^3S_1 \sim 0$.

E1 terms: $^1P_1$, $^3P_0$, $^3P_1$, and $^3P_2$
Expect the "spin-flip" E1 term $^1P_1 \sim 0$.

Then→ $\sigma_P - \sigma_A = \pi/2k^2 \{ - {^1S_0}^2 - {^3P_0}^2 – 3/2\ {^3P_1}^2 + 5/2\ {^3P_2}^2 \}$

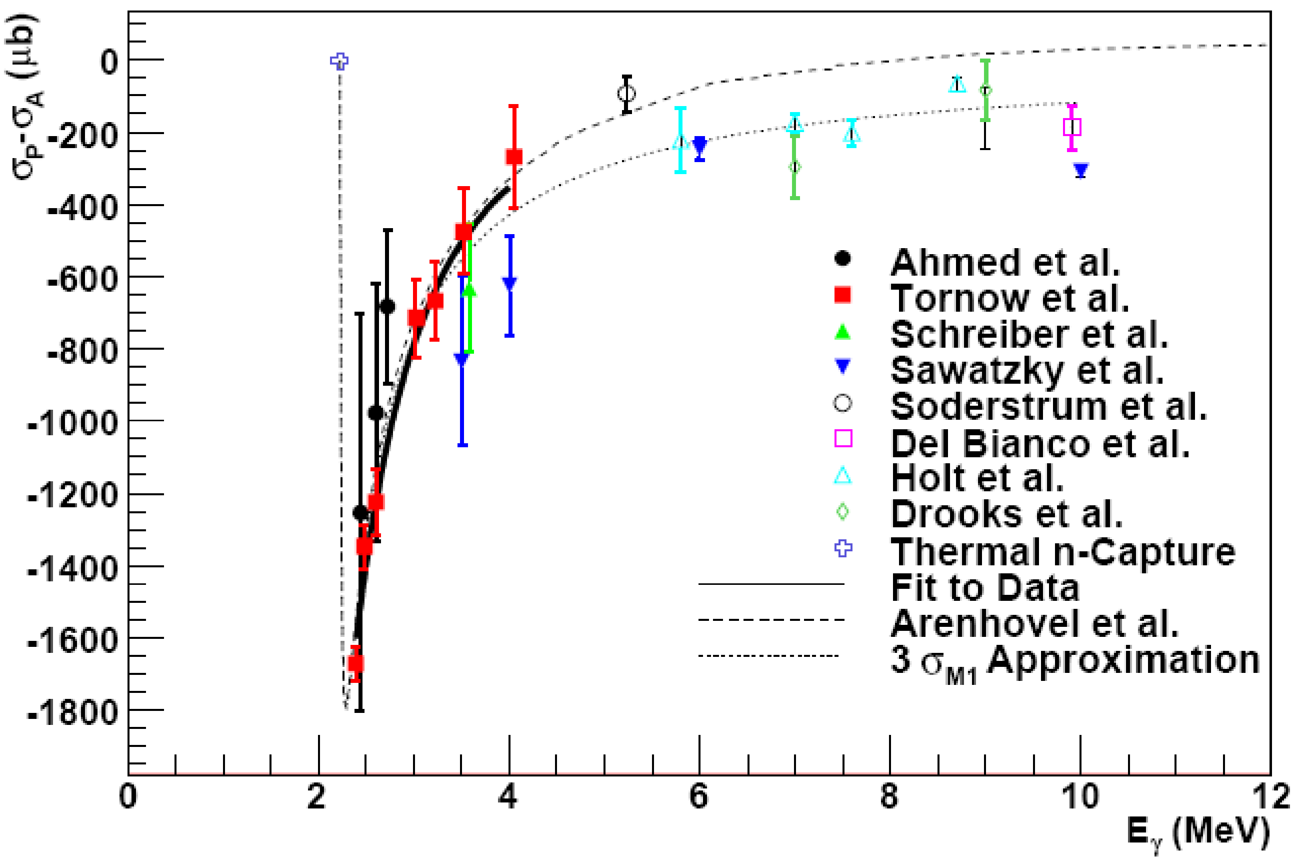
If $^3P_0 \sim {^3P_1} \sim {^3P_2}$

Then $\sigma_P - \sigma_A = \pi/2k^2 \{ - {^1S_0}^2 \}$

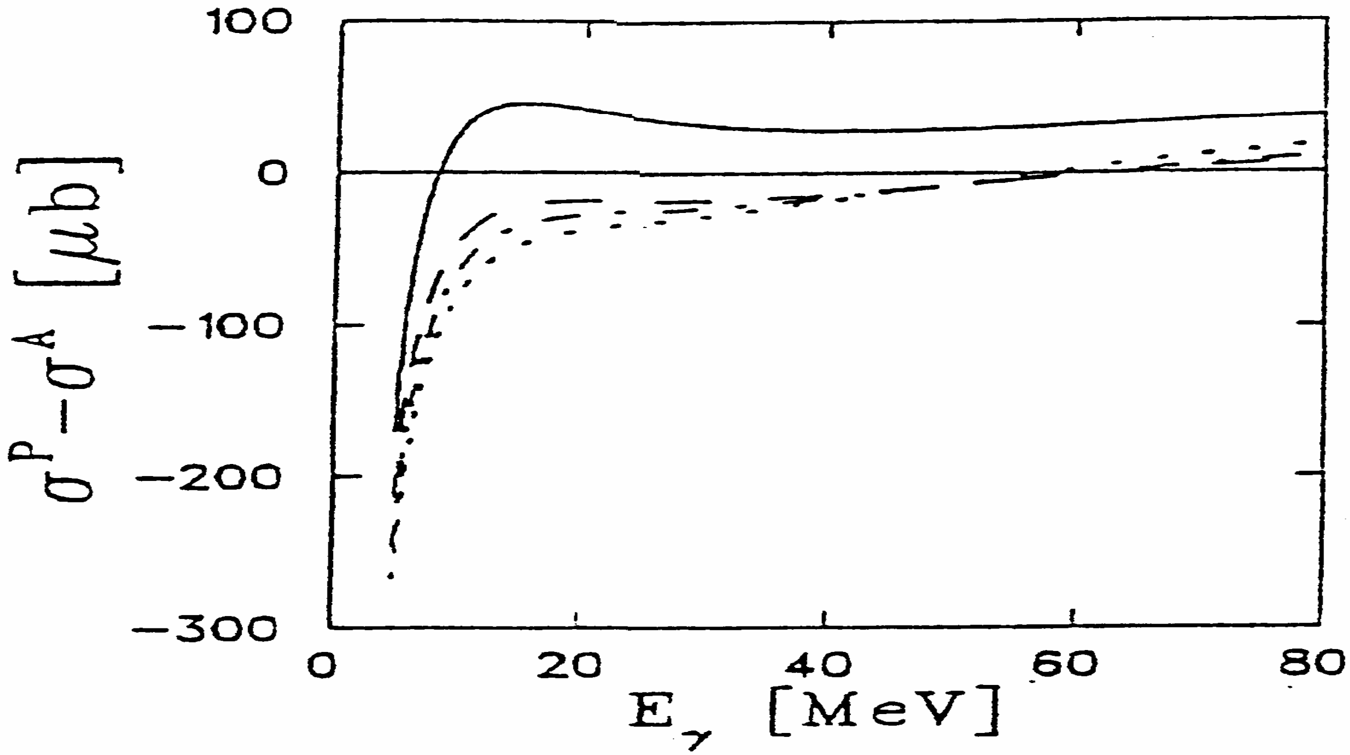
Which gives the result: σ_P **- σ_A = -3 σ(M1)**

Indirect determination of the GDH sum rule integrand below 10 MeV

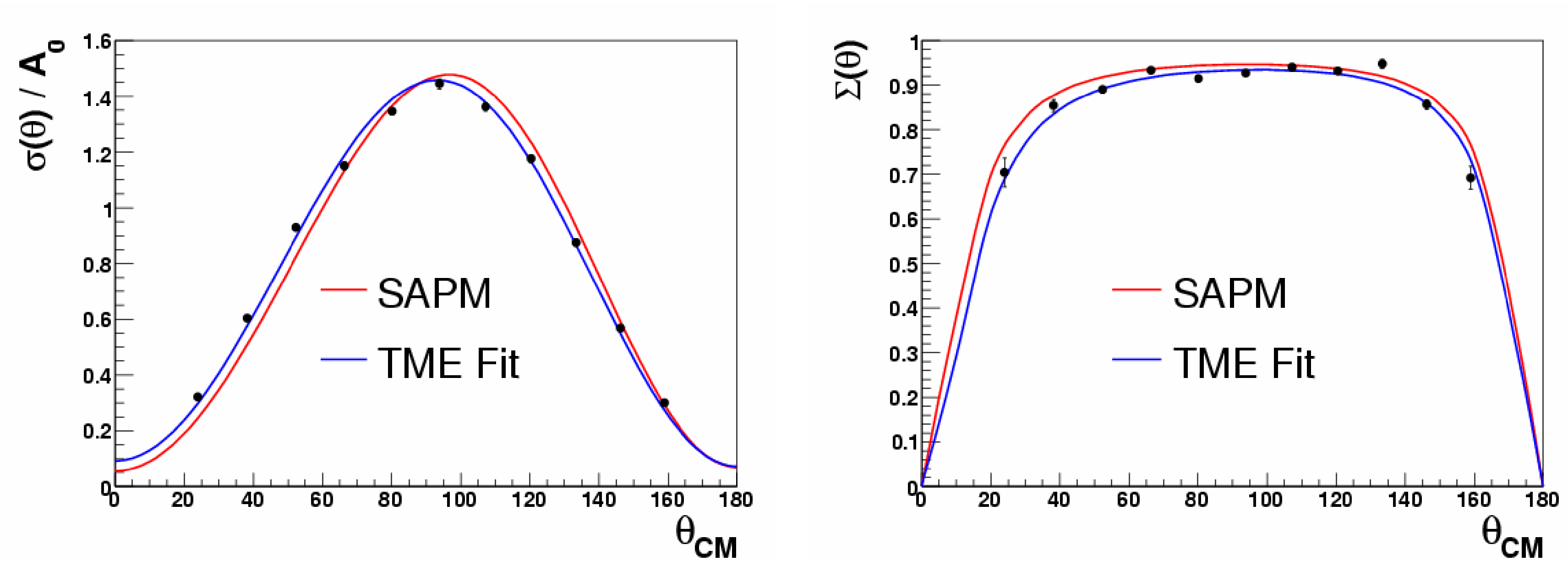
Theory (-------) predicts at value of **-634 μb** for the integral up to 10 MeV with positive contributions at higher energies arising from relativistic contributions.



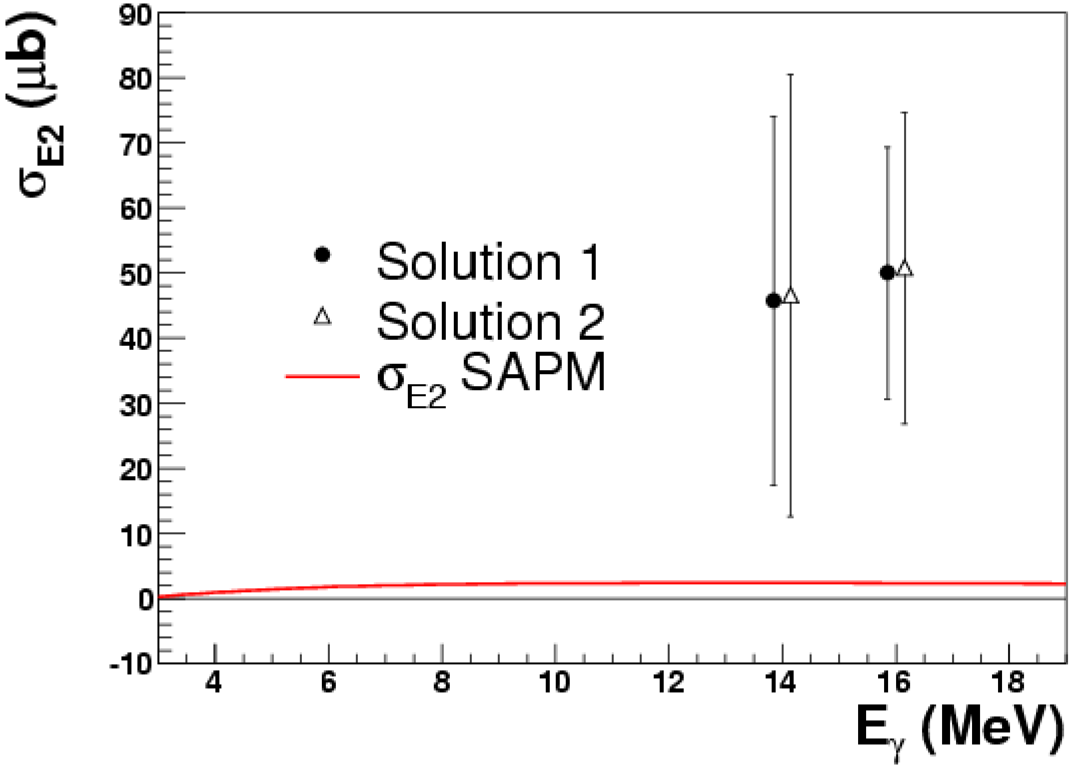
Predicted behavior (Ahrenhovel) of the GDH integrand. Solid line includes a *relativisitic* correction.



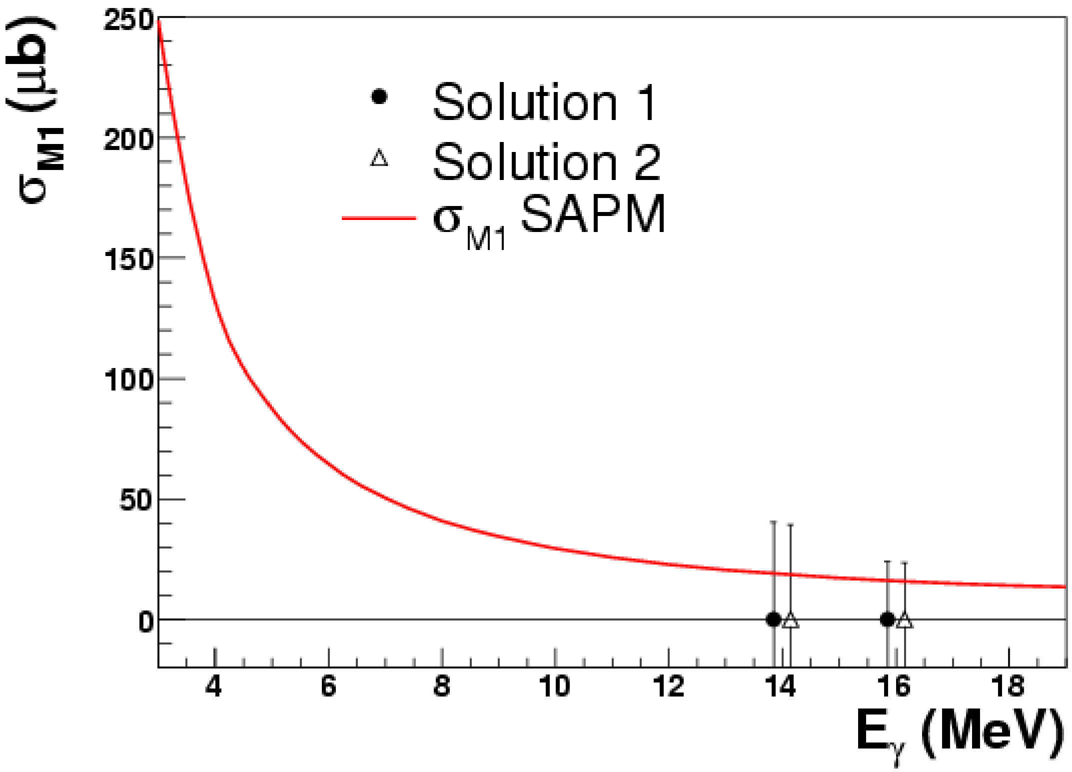
d(γ,n)p @ 14 MeV
red – theory results of Arenhovel;
blue – TME fit to data

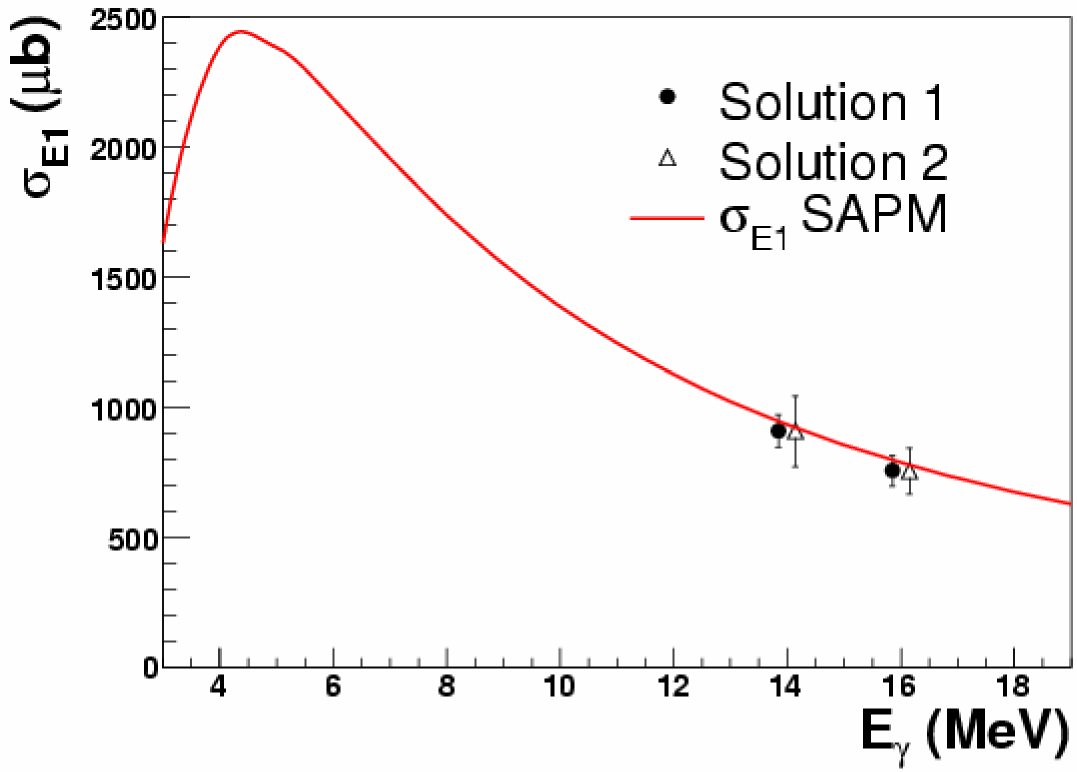


While theory predicts almost zero E2 strength, our results indicate around 5% E2.

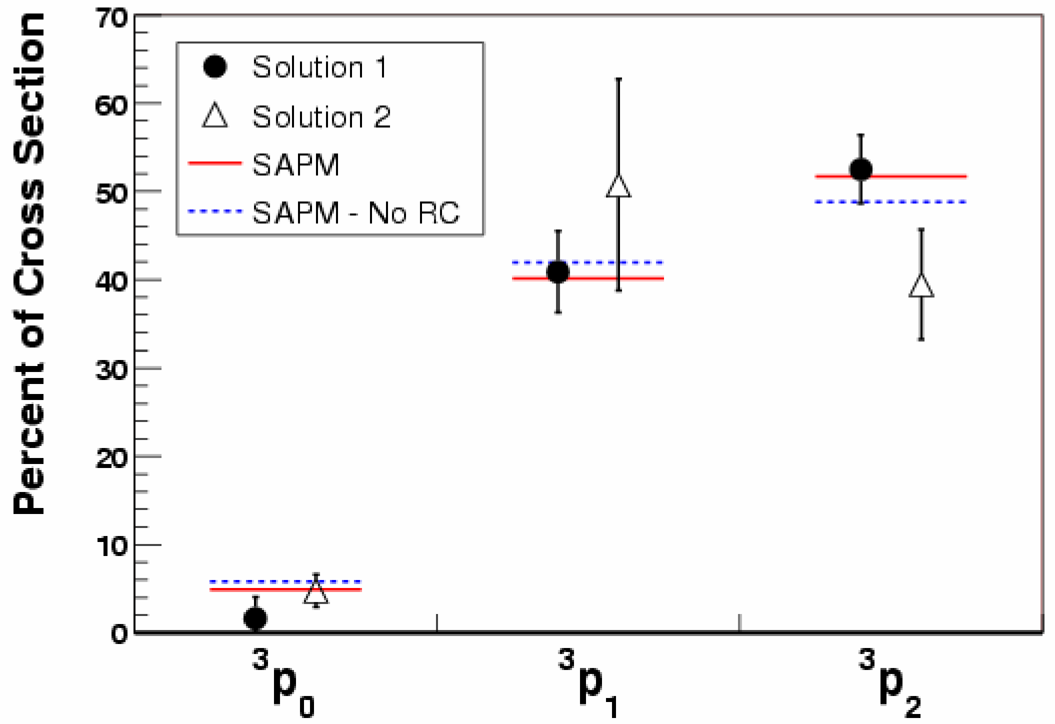


While theory predicts about 2% M1, our results are consistent with zero.





σ_{E1} (μb)
2500
2000
1500
1000
500
0
4
6
8
10
12
14
16
18
E_γ (MeV)
Solution 1
Solution 2
σ_{E1} SAPM



Percent of Cross Section
70
60
50
40
30
20
10
0
Solution 1
Solution 2
SAPM
SAPM - No RC
3p0
3p1
3p2

•THE GDH INTEGRAND FOR THE DEUTERON NEAR PHOTODISINTEGRATION THRESHOLD

Contributions are expected from s-waves and p-waves (notation $^{2S+1}L_J$)

M1 terms: $^1S_0$ and $^3S_1$
Expect $^3S_1 \sim 0$.

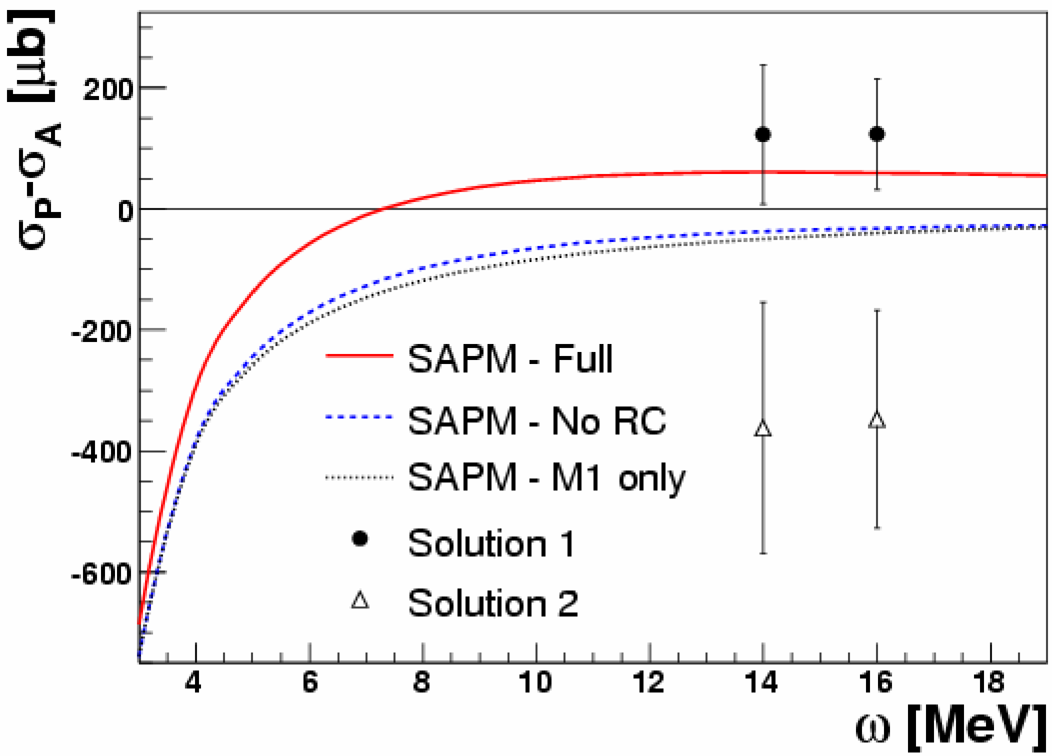
E1 terms: $^1P_1$, $^3P_0$, $^3P_1$, and $^3P_2$
Expect the “spin-flip” E1 term $^1P_1 \sim 0$.

Then→ $\sigma_P - \sigma_A = \pi/2k^2 \{ - {^1S_0}^2 - {^3P_0}^2 - 3/2\, {^3P_1}^2 + 5/2\, {^3P_2}^2 \}$

If $^3P_0 \sim {^3P_1} \sim {^3P_2}$

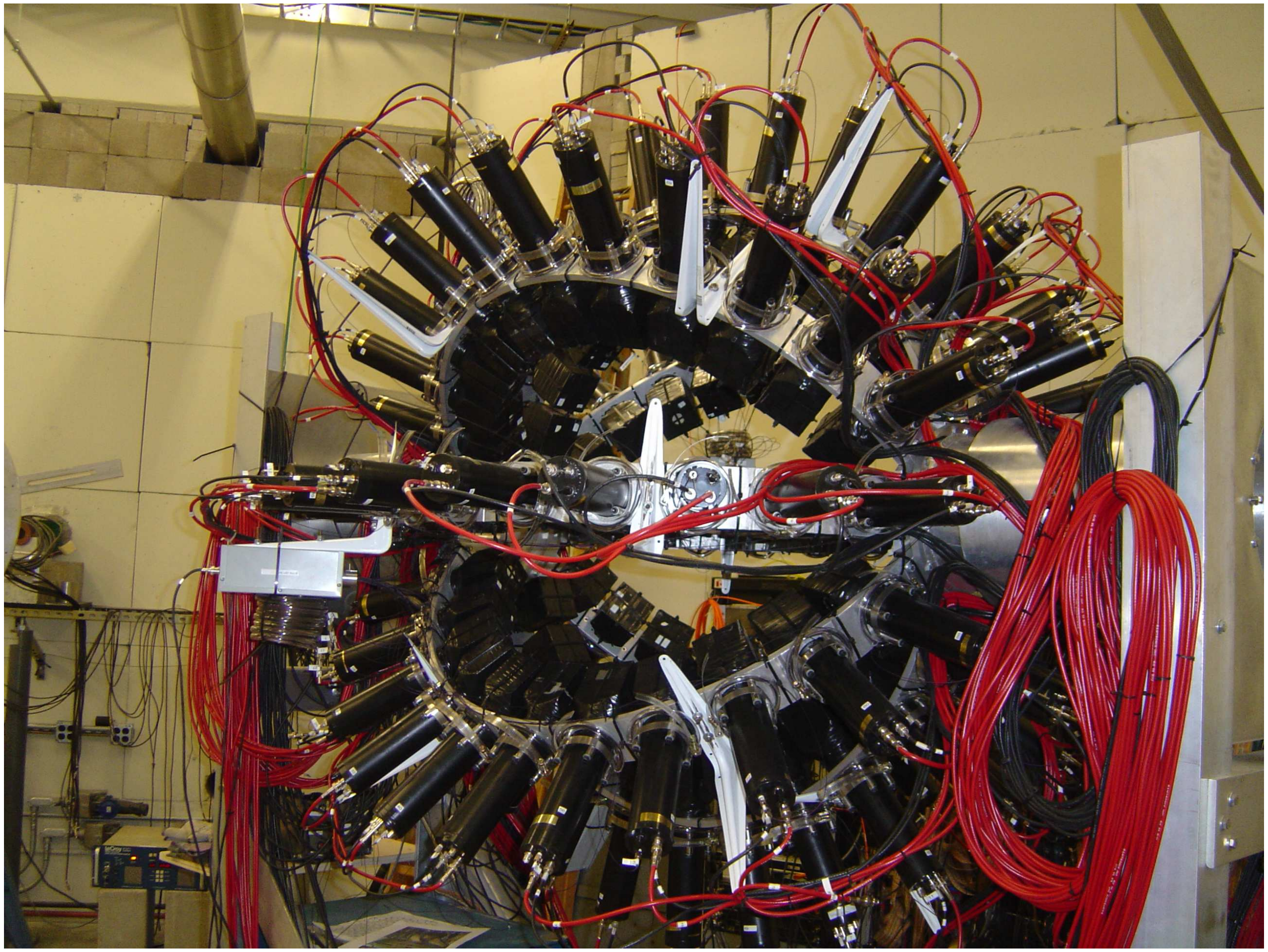
Then $\sigma_P - \sigma_A = \pi/2k^2 \{ - {^1S_0}^2 \}$

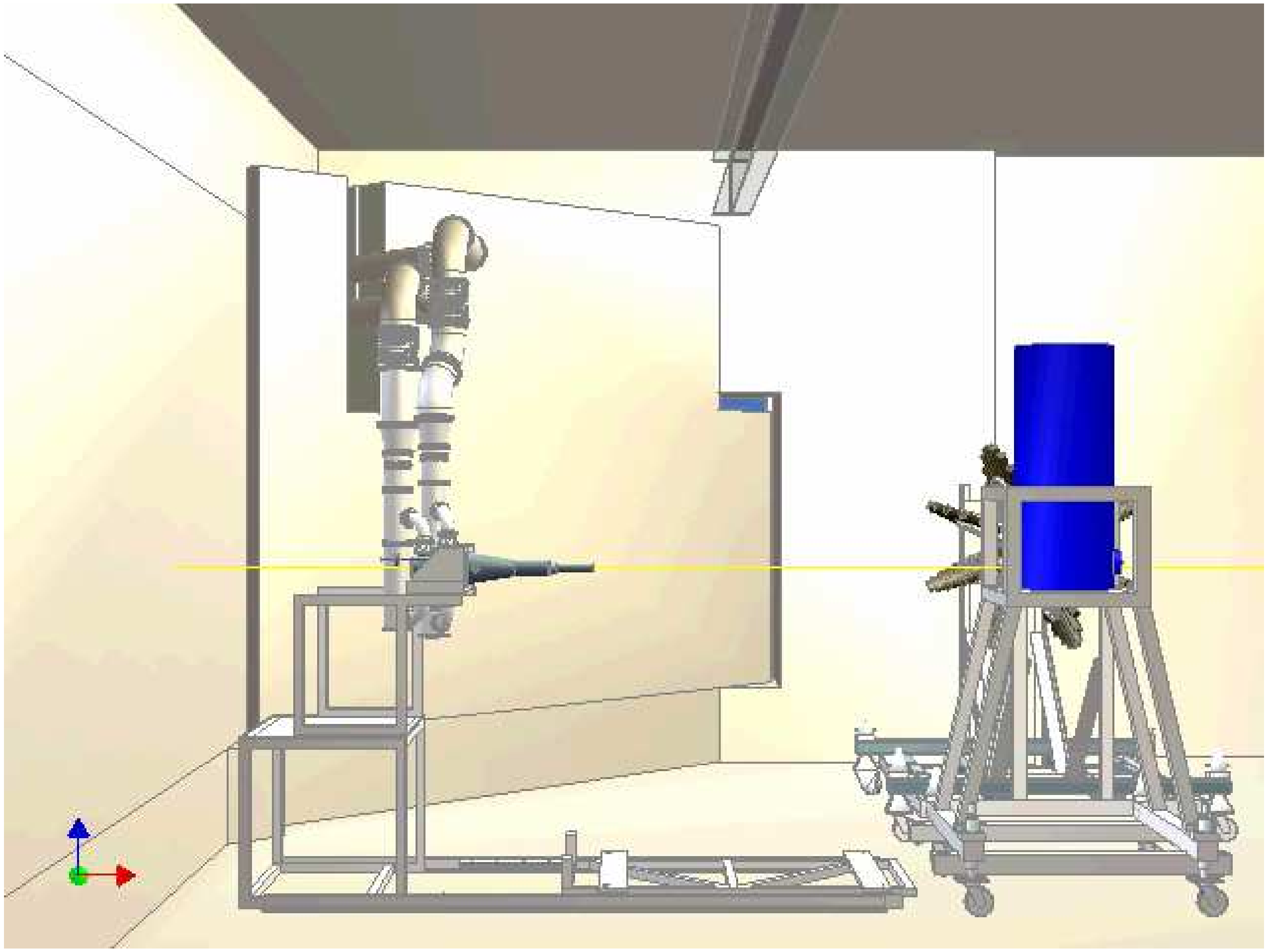
Which gives the result: $\sigma_P - \sigma_A$ **= -3 σ(M1)**



σP-σA [μb]
200
0
-200
-400
-600
4
6
8
10
12
14
16
18
ω [MeV]
SAPM - Full
SAPM - No RC
SAPM - M1 only
Solution 1
Solution 2

The upgraded *BLOWFISH array as of January, 2005.*





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The GDH integrand for deuterium below pion threshold @ HIγS

A 400 hour run will allow us to measure the GDH integrand between 5 and 100 MeV to an overall accuracy of about 3% or better, assuming a beam of 1 x 10^7 γ/s with ~5% energy spread.

An experiment to measure the GDH integrand for ^{3}He below pion threshold is also being developed by Haiyan Gao et al.

Compton@HIγS Collaboration

(see www.tunl.duke.edu/~mep/higs/compton.pdf)

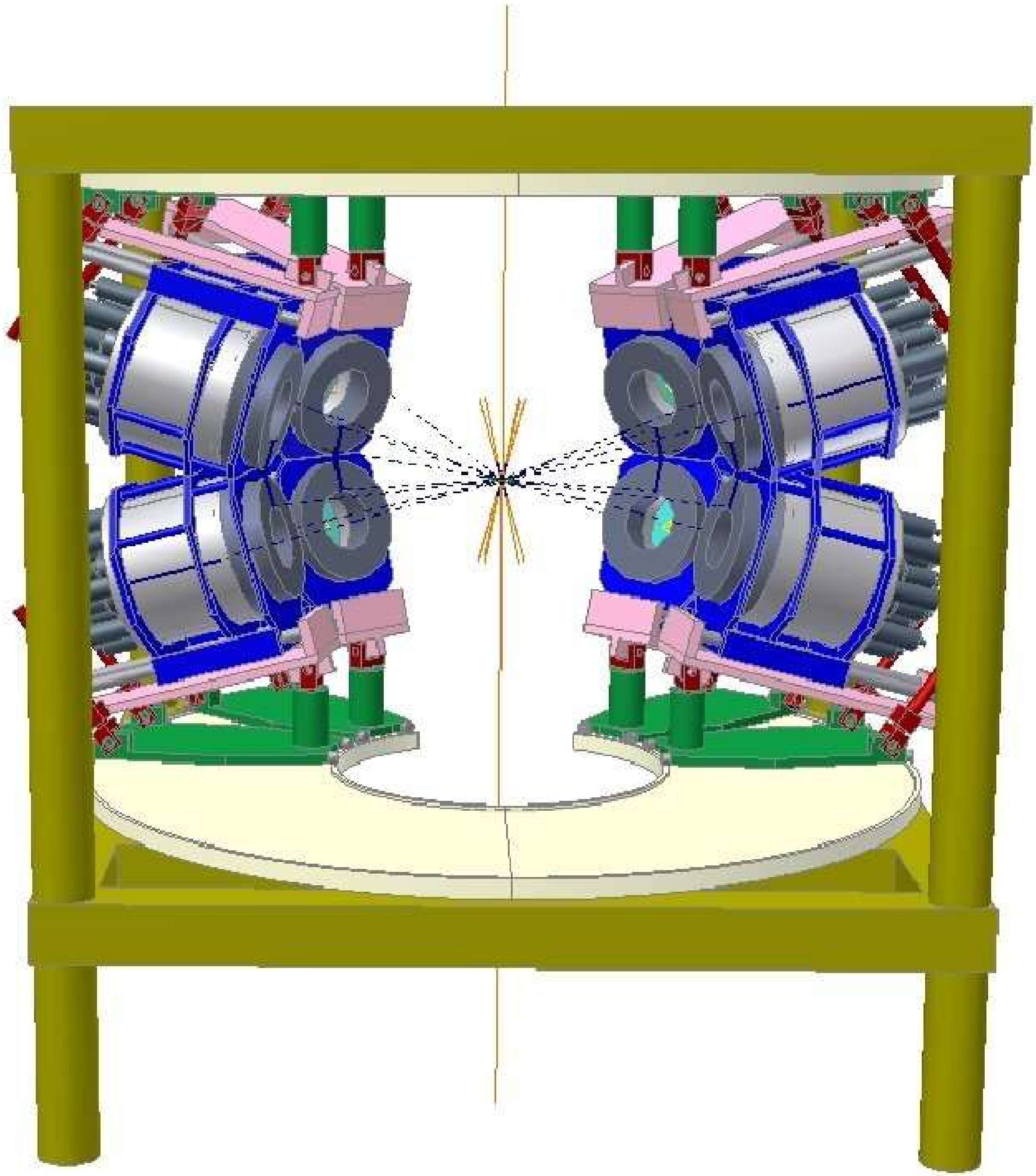
Use the intense polarized beams at HIγS to obtain very precise values of the electric and magnetic polarizabilities of the proton and the neutron.

Perform double polarization experiments to obtain precise values of the spin-polarizabilities of the proton and the neutron.

The HINDA Array
(HIγS **N**aI **D**etector **A**rray)

Recently NSF/MRI funded project—a high resolution-high acceptance gamma-ray spectrometer consisting of eight 10”x12” NaI detectors in 3” thick segmented NaI shields.

The Compton@HIγS Collaboration



Electric and Magnetic Polarizability of the proton

- Recent results (B. Pasquini) of a free fit to data yield:

$\alpha = 11.52 \pm 2.4 \times 10^{-4}\ fm^3$

$\beta = 3.42 \pm 1.70 \times 10^{-4}\ fm^3$

(with Baldin sum rule value of 13.82→

α=11.0 +/- 1.4 ; β= 2.8 +/-1.4)

A ~50% error in β – which will impact future measurements.

100% Linearly polarized beams at HIγS can improve this

$$\left[\frac{d\sigma_\perp}{d\Omega} - \frac{d\sigma_\perp^{pt}}{d\Omega}\right]^{\frac{1}{2}} - \cos\theta\left[\frac{d\sigma_{||}}{d\Omega} - \frac{d\sigma_{||}^{pt}}{d\Omega}\right]^{\frac{1}{2}} = +\bar{\alpha}\sin^2\theta\left(\frac{E_\gamma}{hc}\right)^2,$$

$$\cos\theta\left[\frac{d\sigma_\perp}{d\Omega} - \frac{d\sigma_\perp^{pt}}{d\Omega}\right]^{\frac{1}{2}} - \left[\frac{d\sigma_{||}}{d\Omega} - \frac{d\sigma_{||}^{pt}}{d\Omega}\right]^{\frac{1}{2}} = -\bar{\beta}\sin^2\theta\left(\frac{E_\gamma}{hc}\right)^2,$$

Simulation (Blaine Norum) assumed:

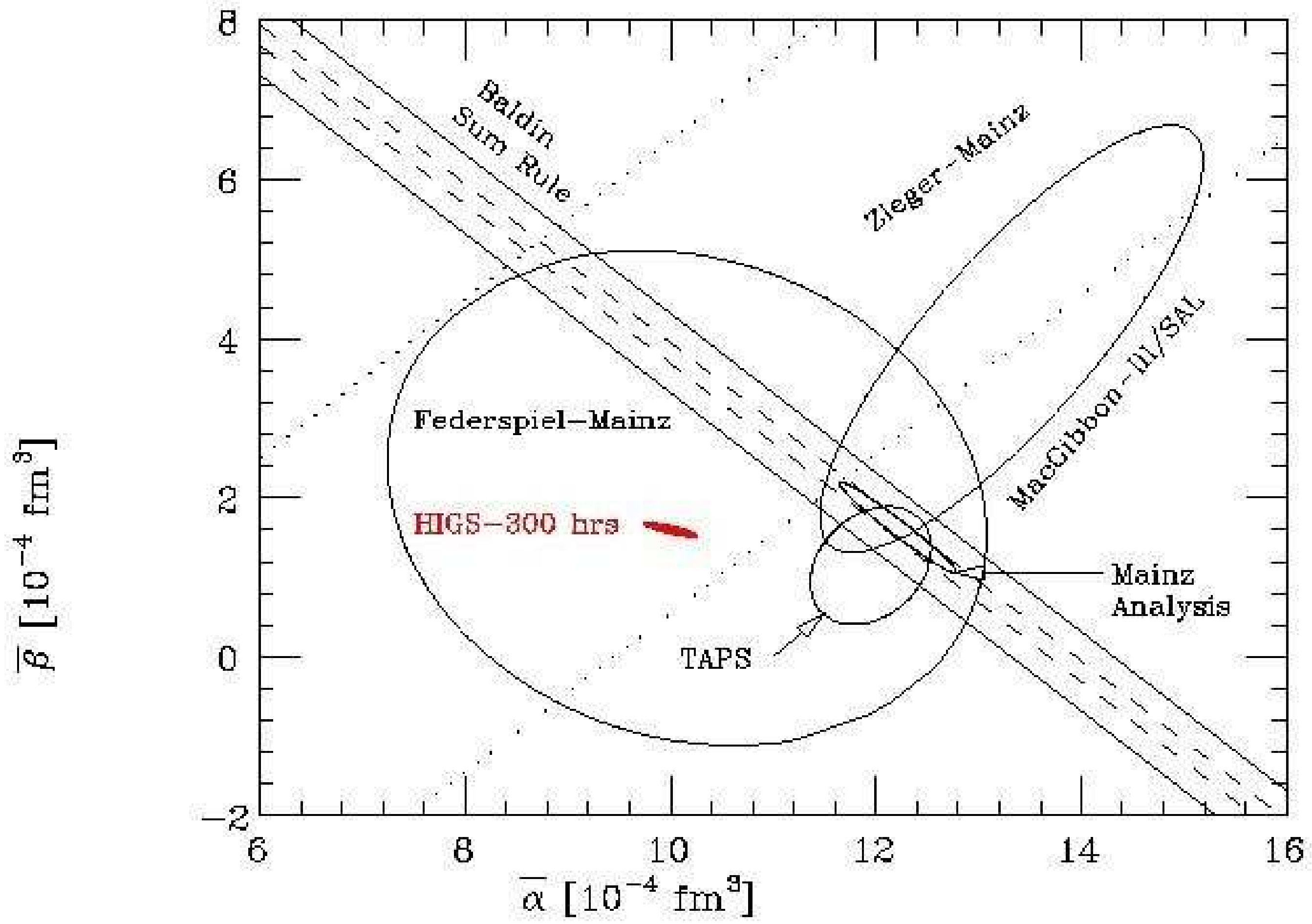
E_γ = 120 MeV

Target: 80 mg/cm^2

10^7 γ/s

280 hours

Determination of the electric and magnetic polarizabilities of the proton using 100% linearly polarized gammas@HIγS –a ~300 hr experiment ***will yield ~5% errors on both α (now~20%) and β (now~50%).***



Compton Scattering from the deuteron below 100 MeV Measurements yield the isoscalar polarizabilities:
$\alpha_E^s = ½(\alpha_E^p + \alpha_E^n)$ *and* $\beta_M^s = ½(\beta_M^p + \beta_M^n)$

Hildebrandt, Griesshammer and Hemmert have used *Chiral Effective Field Theory with explict Δ(1232) degrees of freedom* within the Small Scale Expansion up to leading-one loop order and calculated this process up to 100 MeV.

(nucl-th/0512063)

Their results have resolved a “long standing” problem with obtaining consistent fits to the data, especially the 94.2 MeV data.

Results from 55 and 66 MeV disagreed with those obtained from 94 MeV data. eg. **94 MeV (SAL) data yielded $\alpha_N - \beta_N$ ~ 2.5 while we expect a value of ~10 if the proton and neutron have the same values for this difference** (as expected from Chiral Symmetry).

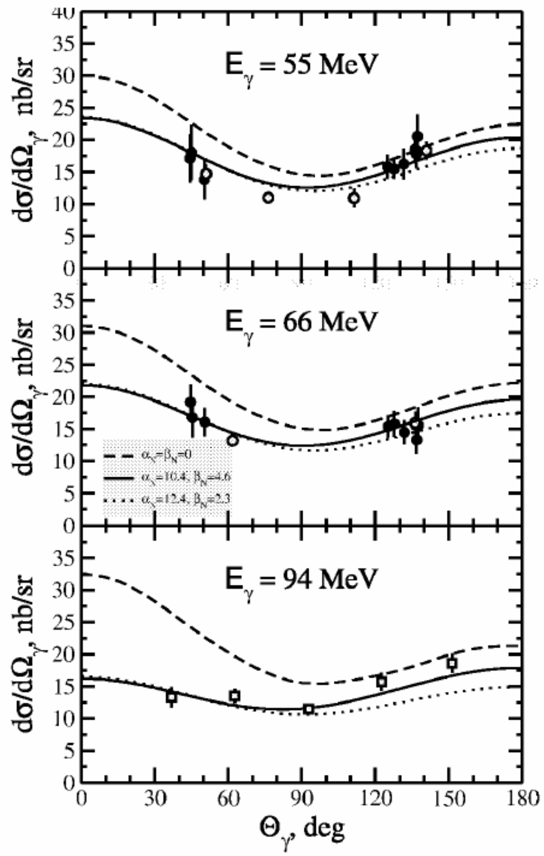


Figure 4. The present γd data set. Solid circles: Lund[30]; Open circles: extrapolated Illinois results[31]; Open squares: SAL results[32].

A global fit to all existing γd data using the Baldin sum rule. The results are

α_E^s = (11.3 +/- 0.7 (stat) +/- 0.6 (Baldin)) x 10^{-4} fm^3

β_M^s = (3.2 -/+ 0.7 (stat) +/- 0.6 (Baldin)) x 10^{-4} fm^3

which indicates, by comparing to the proton values, that ***the n and p polarizabilities are essentially the same.***

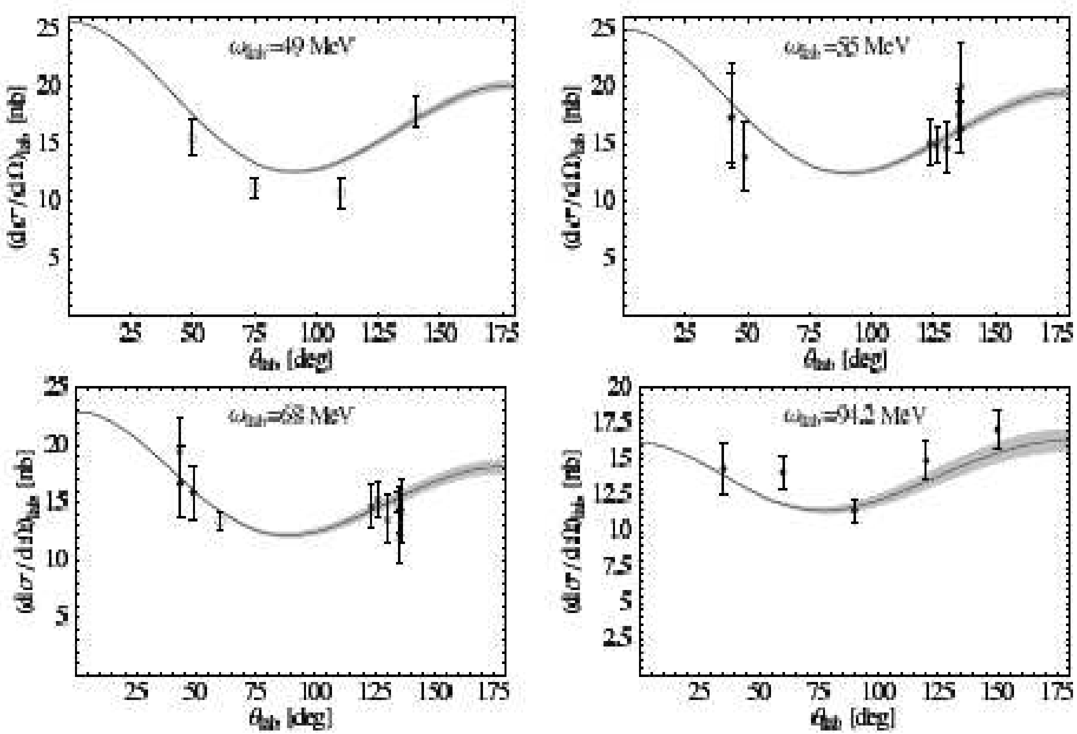


Figure 18: Results from a global fit of α_E^s to all existing elastic γd data, using the chiral wave function [36]. β_M^s is fixed via the Baldin sum rule, Eq. (4.3). The grey bands are derived from our statistical errors.

Spin polarizabilities.

Measuring these requires polarized beams and polarized targets. They are predicted (ChPT) to be different for the n and the p.

There are four "dipole" spin polarizabilities: $\gamma_{1,2,3,4}$ which can be written in terms of $\gamma_{E1E1,\ E1M2,\ M1E2,\ M1M1}$.

γ_1 ($\sim\gamma_{E1E1}$) and γ_4($=\gamma_{M1M1}$) are the largest.

HIγS Proposal for measuring the proton spin-polarizabilities

Spokesperson – Rory Miskimen

A 200 hr. run at 120 MeV will give helicity dependent cross sections at the 3% level, which translates into ~10% measurments of spin-polarizabilities using the HINDA array.

Sensitivity estimates for all four spin-polarizabilities are based upon calculations of ***Hildebrandt, Griesshammer and Hemmert.***

Conceptual designs for a scintillating frozen-spin polarized target

Rory Miskimen et al., U. Mass.

Simulations have been performed for both designs. A working prototype for

Concept II is under construction.

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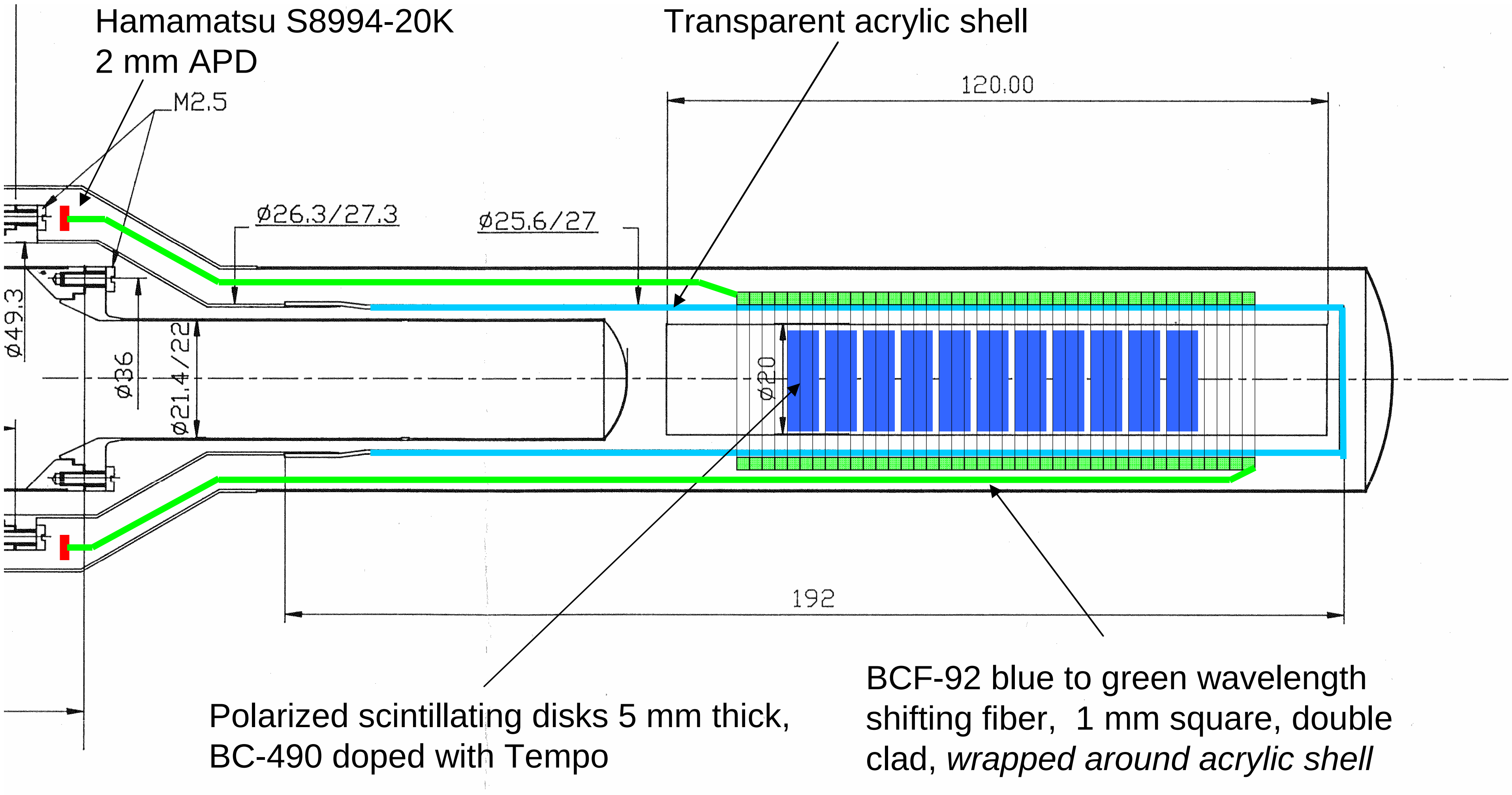
Concept II: Light capture with wavelength shifting fibers

Hamamatsu S8994-20K
2 mm APD

Transparent acrylic shell



Polarized scintillating disks 5 mm thick,
BC-490 doped with Tempo

BCF-92 blue to green wavelength
shifting fiber, 1 mm square, double
clad, *wrapped around acrylic shell*

Overall light transport efficiency ≈ 4%

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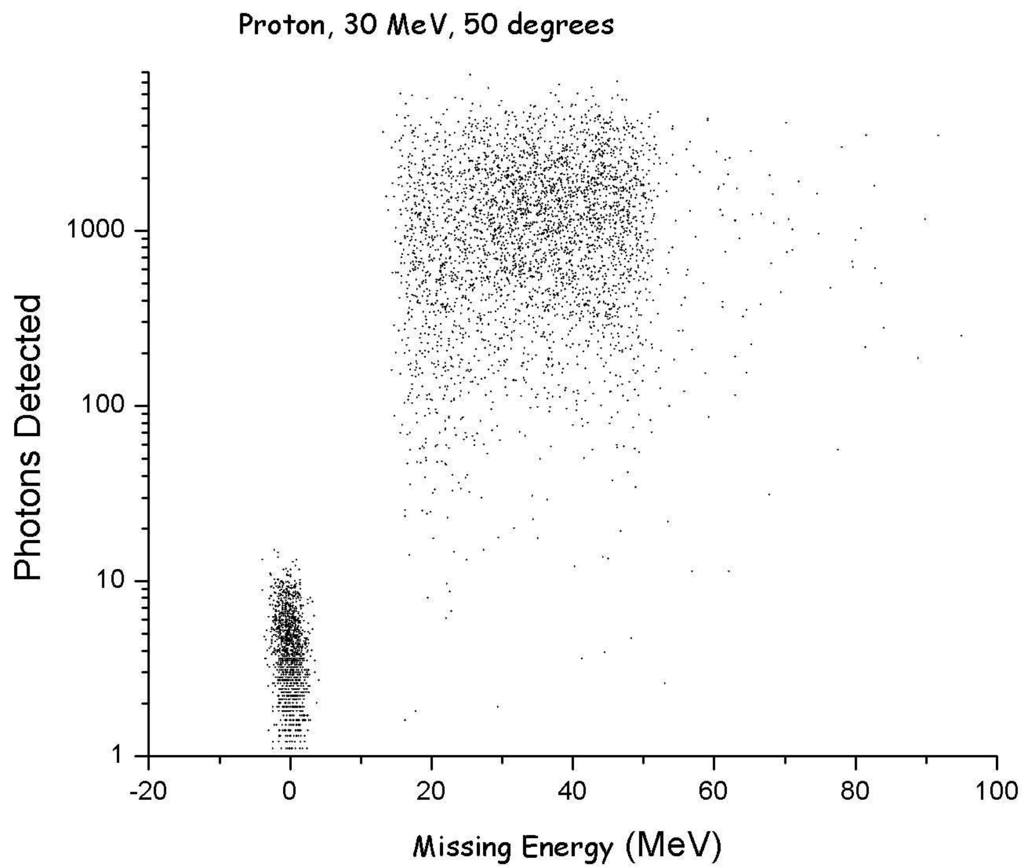
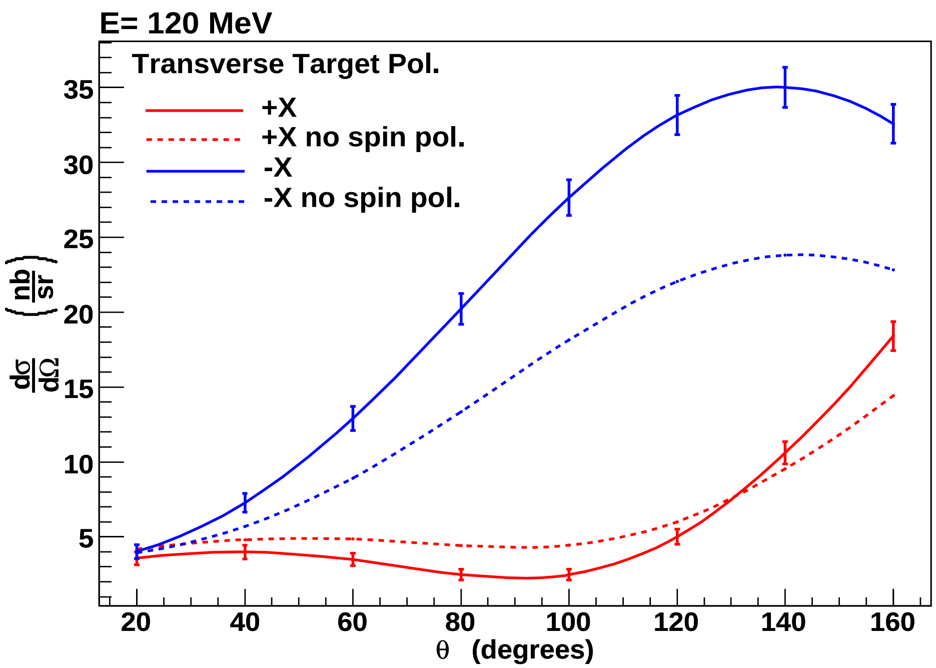
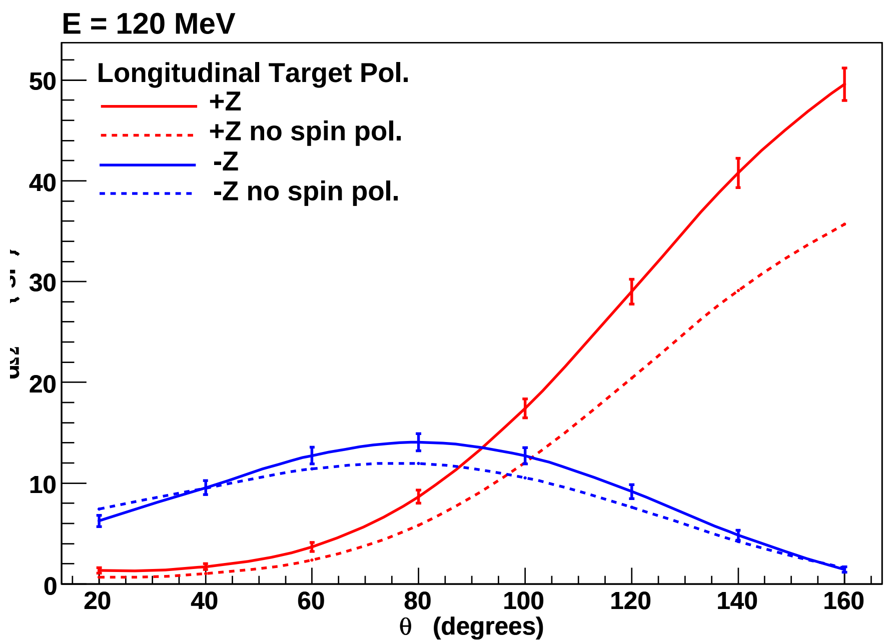

Proton, 30 MeV, 50 degrees
Photons Detected
1000
100
10
1
-20
0
20
40
60
80
100
Missing Energy (MeV)

Projection for double-polarized Compton scattering from proton





Total beam time for proton measurement: 450 hrs

100 hrs for each target spin orientation

R. Miskimen, theory curves: Hildebrandt, Griesshammer, Hemmert, Nucl-th/0308054

Experiments are being developed by Dr. Haiyan Gao at Duke/HIγS to measure the spin-polarizabilities of the neutron.

Haiyan Gao has built a high pressure spin-polarized ^{3}He target. Target thickness will be about 10^{22} atoms/cm^{2} with a length of 40 cm. Polarizations of ~40% have been achieved.

- *Effect of the reduced target thickness is offset by the increased sensitivity in the observables.*

Present proposed experiments

- New theoretical calculations by Choudhury, Nogga and Phillips make extraction of spin-polarizabilities possible from elastic scattering data from ^3He.

- With a gamma intensity of 2×10^7/sec and the target and detector system just described, a **350 hour** experiment will give neutron spin polarizabilities with errors of about **$\pm$/- 0.5 x 10^{-4}** fm^4.

Estimate of the experimental uncertainties in the individual spin polarizabilities

For example, at 90^o, the longitudinal cross section difference is sensitive to γ_1, while the transverse polarization cross section difference is sensitive to γ_4.

The value of γ_0 for the proton was fixed from the Mainz experiment with an error of +/- 13%.

(Could improve the results by considering additional constraints (B. Pasquini)).

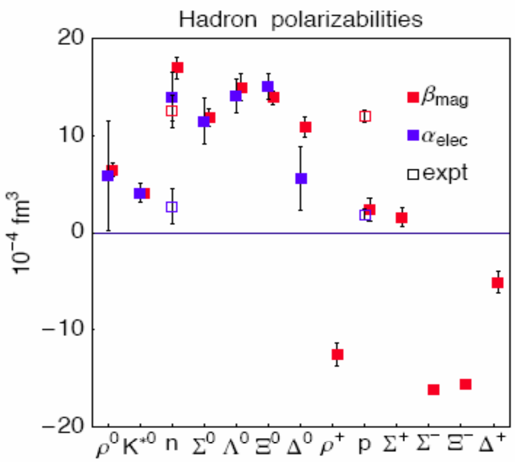
•Projected HIγS measurement on Nucleon Spin

•Polarizabilities (quasifree) (all in 10^{-4} fm^4)

•Proton HIγS projected uncertainties		•Neutron HIγS projected uncertainties	
$\gamma^p_1 \sim \gamma_{E1} = 1.1$	± 0.05	•$\gamma^n_1 = 3.7$	± 0.40
$\gamma^p_2 = -1.5$	± 0.36	•$\gamma^n_2 = -0.1$	± 0.50
$\gamma^p_3 = 0.2$	± 0.24	•$\gamma^n_3 = 0.4$	± 0.50
$\gamma^p_4 = \gamma_{M1} = 3.3$	± 0.17	•$\gamma^n_4 = 2.3$	± 0.35

•McGovern et al. NLO heavy baryon Chiral Perturbation Theory

Spin Polarizabilities from Lattice QCD



Quenched Lattice QCD results — J.Christensen *et.al.*

$(m_\pi \simeq 500\,\mathrm{MeV})$ α_{elec} — PRD73 (2006) 100 configurations

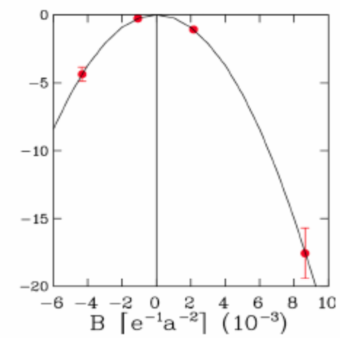
β_{mag} — PRD72 (2005) 150 configurations

(see also E.Shintani *et.al.* hep-lat/0611032)

Measure mass shift in background field:

eg: magnetic polarizability

$$\delta m = m(B) - m(0) = -\vec{\mu}\cdot\vec{B} - \frac{1}{2}\beta_{mag}\vec{B}^2 + \ldots$$



Can also determine neutron (and proton) spin polarizabilites from lattice QCD with varying external field — W.Detmold, B.C.Tiburzi, A.Walker-Loud — PRD73 (2006)

- Exploratory, *quenched* calculation at $m_\pi \simeq 500$ MeV possible today. Precision similar to that of electromagnetic polarizabilities, α_{elec} , β_{mag}
- First full QCD calculation of all isovector electromagnetic and spin polarizabilities possible with moderate computational resources: 1-2 year time frame.
- Complete calculation will require significant computational investment:
  - Need studies on multiple volumes and lattice spacings
  - For isoscalar polarizabilities, need new gauge configurations with EM fields (expensive but also useful for other EM lattice studies)

Threshold pion-photoproduction from the proton @ HIγS
$p(\gamma,\pi^0)p$

Co-spokesperson: Aron Bernstein

The first experiment:

A measurement of the Target analyzing power at $E_\gamma = 158$ MeV.

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These experiments will provide stringent tests of

- The predictions of Chiral Perturbation Theory
- Predictions of isospin breaking due to the mass differences of the up and down quarks.

<u>Motivation</u>

<u>Isospin Symmetry Breaking</u>

A measurement of the imaginary part of the s-wave production amplitude (E_{0}^{+}) provides a determination of the charge exchange scattering length $a_{cex}(\pi^{+}n \rightarrow \pi^{0}p)$.

Requires measurement of the polarized target analyzing power $T(\theta)$.

Simulations

(Bernstein et al.)

The results indicate that ***we can measure ImE_{0+} with a statistical uncertainty of 3.7% in 200 hours of actual data taking at 158 MeV.***

This gives us the value of $\mathbf{a_{cex}\,(\pi^+ n \to \pi^0 p)}$**.**

Isospin conservation implies

$$\mathbf{a_{cex}\,(\pi^+ n \to \pi^0 p) = -a_{cex}\,(\pi^- p \to \pi^0 n).}$$

The latter is well known from the width of pionic hydrogen (0.1301 +/- 0.0059) after a decade of work. Our result will give a comparable accuracy for $\mathbf{a_{cex}\,(\pi^+ n \to \pi^0 p)}$**.**

Our measurement will determine β to +/- 0.10, where

$$\boldsymbol{Im}[E_{0+}(\gamma p \rightarrow \pi^0 p)] = \beta\, p_{\pi+}/m_\pi$$

and $\beta = \mathrm{Re}[E_{0+}(\gamma p \rightarrow \pi^+ n)]\, a_{cex}(\pi^+ n \rightarrow \pi^0 p)$

$\mathrm{Re}[E_{0+}(\gamma p \rightarrow \pi^+ n)]$ is well measured (=28.06 +/- 0.27 +/- 0.45), giving us $a_{cex}(\pi^+ n \rightarrow \pi^0 p)$.

Isospin conservation implies $a_{cex}(\pi^+ n \rightarrow \pi^0 p) = -a_{cex}(\pi^- p \rightarrow \pi^0 n)$.

The latter is well known from the width of pionic hydrogen (-0.1301 +/- 0.0059) after a decade of work. Our measurement will give a comparable accuracy for $a_{cex}(\pi^+ n \rightarrow \pi^0 p)$.

Resources at HIγS

Mirror development is the key to pion threshold Physics at HIγS.

Present mirrrors take us up to 110 MeV.

Although a development plan is in place for 165 nm mirrors (140 MeV), **additional resources are needed to assure that 160 MeV is reached** (150 nm mirrors) with full flux in a timely manner.

Funding presently limits operations to 1000 hrs/yr. In order to execute this program we would like ***to increase this to 1500 hours per year. This requires additional $upport.***