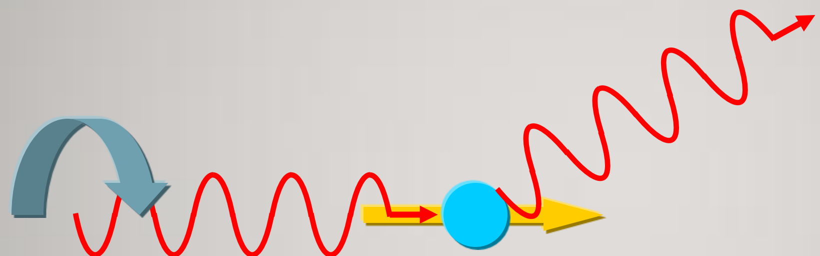
Measuring the Proton Spin-Polarizabilities at HIγS



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NNPSS '08 - GWU

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Nuclear Compton Scattering

Compton scattering refers to scattering a photon off of a bound electron (atomic) or off of a nucleon (nuclear). Below about 20 MeV, this process is described by the Hamiltonian:*

$$H = \frac{\left(\vec{p} - e\vec{A}\right)^2}{2m} + e\phi$$

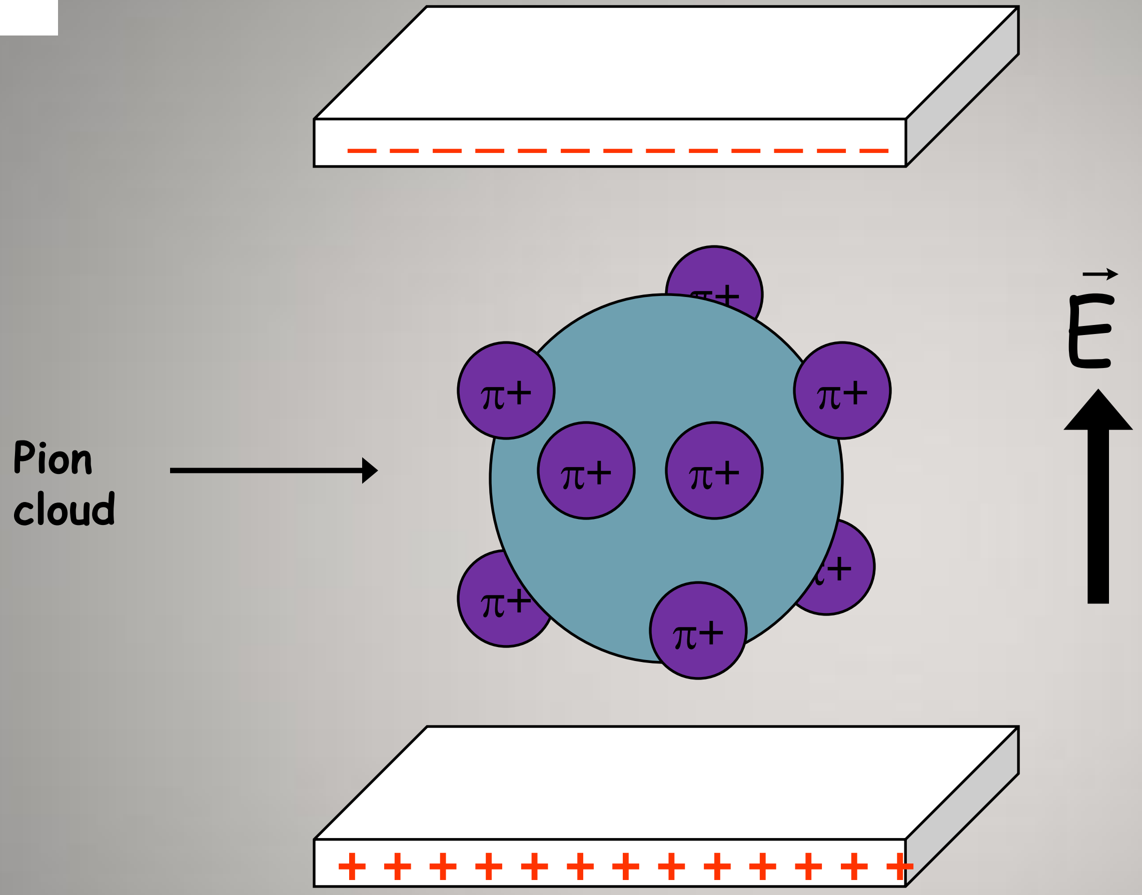
Above 20 MeV, the photon begins to probe the nucleon structure. To second order, an effective Hamiltonian can be written:

$$H_{eff}^{(2)} = -4\pi\left[\tfrac{1}{2}\alpha_{E1}\vec{E}^{\,2} + \tfrac{1}{2}\beta_{M1}\vec{H}^{\,2}\right]$$

Here, α_{E1} represents the electric, and β_{M1} the magnetic, dipole (scalar) polarizabilities.*

*B. Holstein, GDH Convenor's Report: Spin polarizabilities (2000)

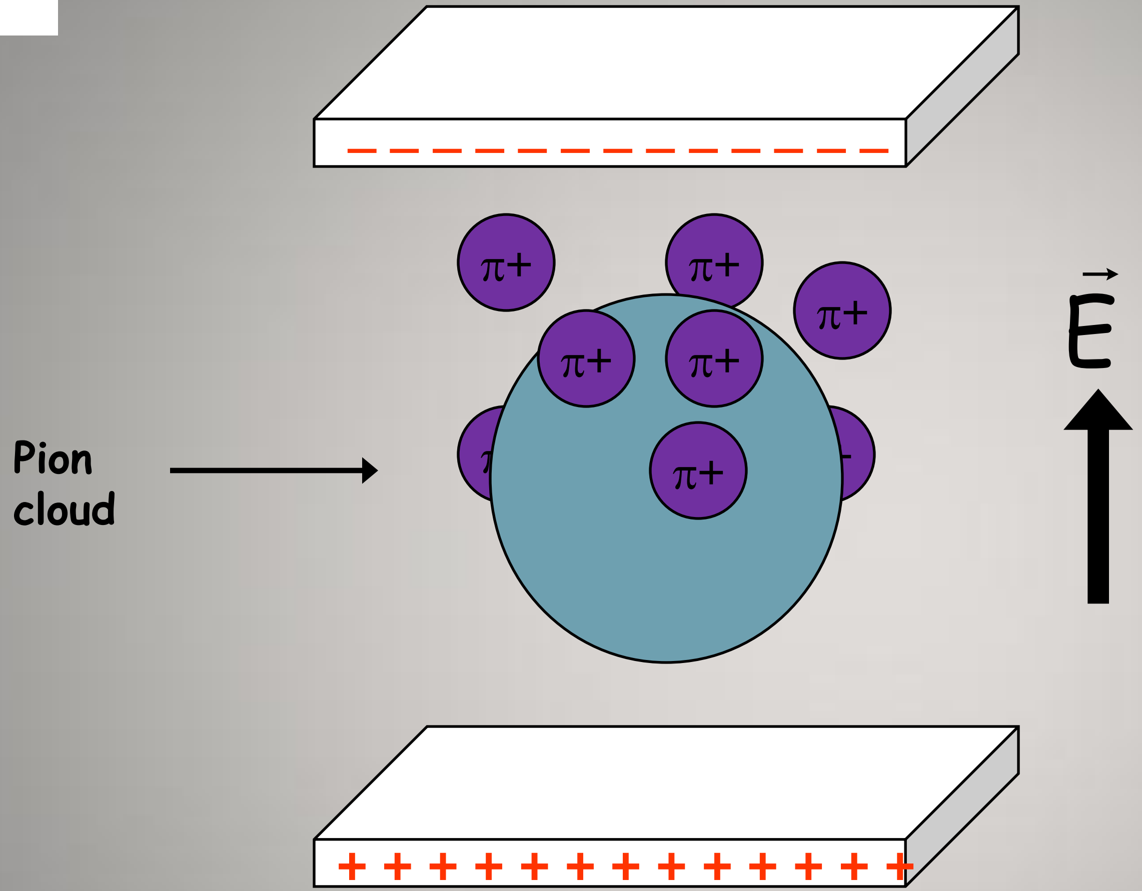
Proton electric polarizability



Electric polarizability: proton between charged parallel plates

Courtesy of R. Miskimen - UMass

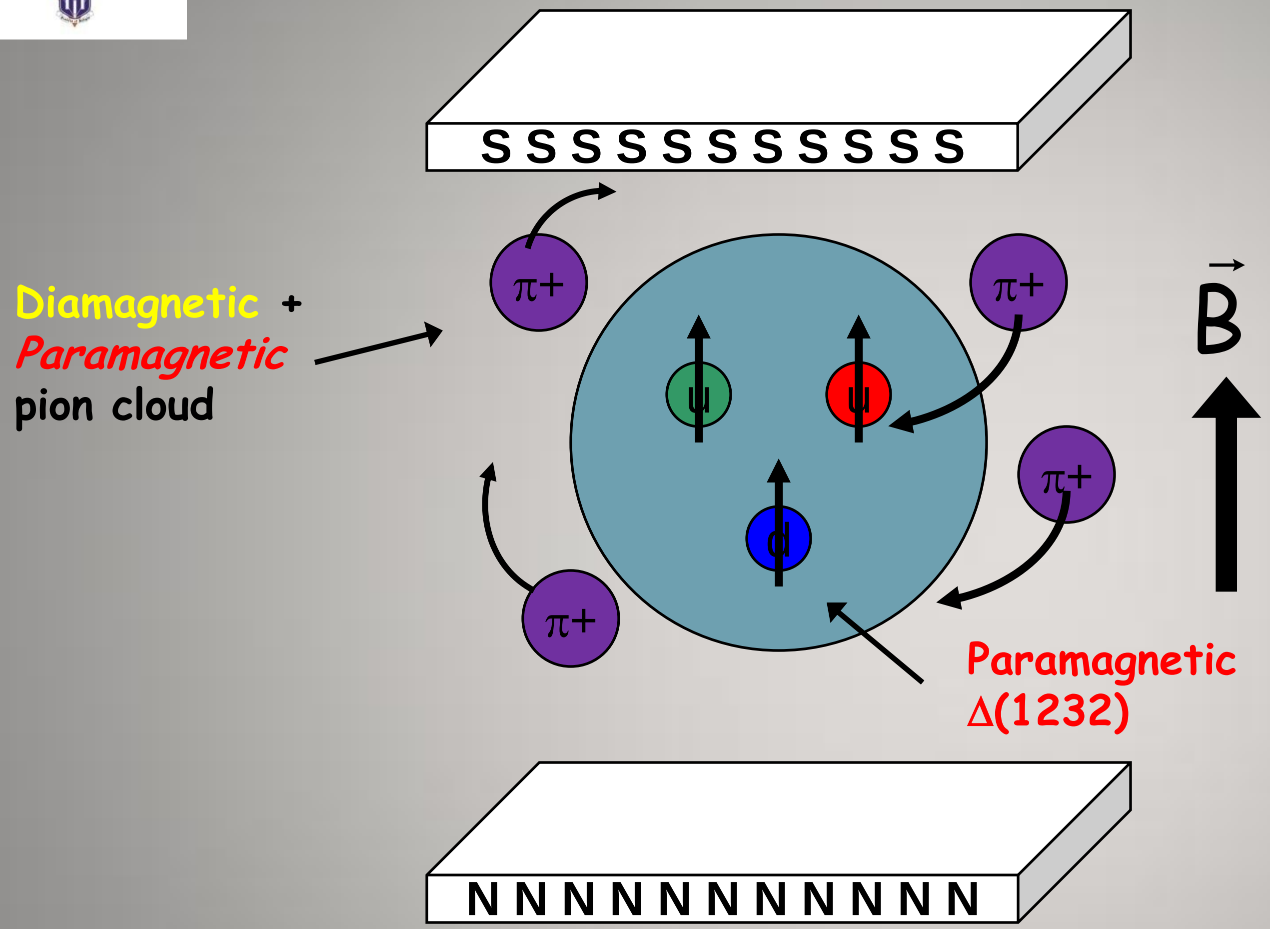
Proton electric polarizability



Electric polarizability: proton between charged parallel plates

Courtesy of R. Miskimen - UMass

Proton magnetic polarizability



Magnetic polarizability: proton between poles of a magnetic

Courtesy of R. Miskimen - UMass

Spin Polarizabilities

These scalar polarizabilities have been measured for the proton through real Compton scattering experiments.*

$$\alpha^{p}_{E1} = (12.0 \pm 0.6) \times 10^{-4}\,\mathrm{fm}^3$$
$$\beta^{p}_{M1} = (1.9 \mp 0.6) \times 10^{-4}\,\mathrm{fm}^3$$

Advancing to third order, four new terms arise in the effective Hamiltonian:*

$$H^{(3)}_{eff} = -4\pi\left[\tfrac{1}{2}\gamma_{E1E1}\vec{\sigma}\cdot\left(\vec{E}\times\dot{\vec{E}}\right) + \tfrac{1}{2}\gamma_{M1M1}\vec{\sigma}\cdot\left(\vec{H}\times\dot{\vec{H}}\right) - \gamma_{M1E2}E_{ij}\sigma_i H_j - \gamma_{E1M2}H_{ij}\sigma_i E_j\right]$$

These γ terms are the spin (vector) polarizabilities. The subscript notation denotes their relation to a multipole expansion.

*R.P. Hildebrandt, Elastic Compton Scattering from the Nucleon and Deuteron (2005) - Dissertation thesis

S.P. Measurements

The GDH experiments at Mainz and ELSA used the Gell-Mann, Goldberger, and Thirring sum rule to evaluate the forward S.P. γ_0:

$$\gamma_0 = -\gamma_{E1E1} - \gamma_{E1M2} - \gamma_{M1M1} - \gamma_{M1E2}$$

$$\gamma_0 = \frac{1}{4\pi^2} \int_{m_\pi}^{\infty} \frac{\sigma_{1/2} - \sigma_{3/2}}{\omega^3} d\omega$$

$$\gamma_0 = (-1.00 \pm 0.08 \pm 0.10) \times 10^{-4}\,\mathrm{fm}^4$$

The Backward S.P. was determined from dispersive analysis of backward angle Compton scattering:

$$\gamma_\pi = -\gamma_{E1E1} - \gamma_{E1M2} + \gamma_{M1M1} + \gamma_{M1E2}$$

$$\gamma_\pi = (-38.7 \pm 1.8) \times 10^{-4}\,\mathrm{fm}^4$$

*B. Pasquini *et al.*, Proton Spin Polarizabilities from Polarized Compton Scattering (2007)

S.P. Theoretical Values

	HBχPT			Fixed-t dispersion analyses		
	$O(p^3)$	$O(p^4)$	SSE	HDPV	BGLMN	DPV
γ_{E1E1}	-5.7	-1.8	-5.7	-4.3	-3.4	-5.0
γ_{M1M1}	-1.1	2.9	3.1	2.9	2.7	3.4
γ_{E1M2}	1.1	.7	.98	-0.01	0.3	-1.8
γ_{M1E2}	1.1	1.8	.98	2.1	1.9	1.1

Lattice calculations are in progress

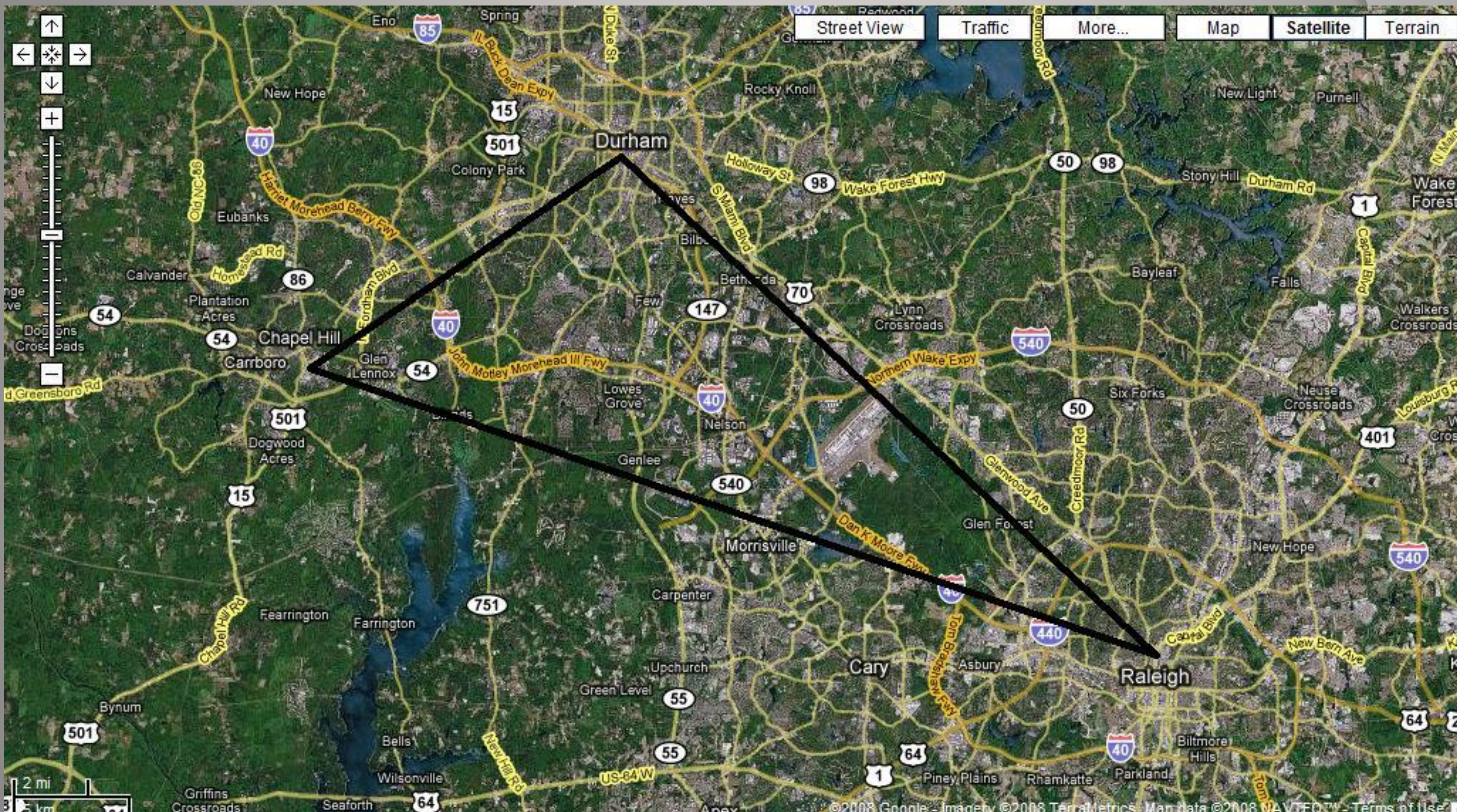
Experimental Concept

We will measure the absolute cross section of the $\gamma p \rightarrow \gamma p$ reaction. By using a circularly polarized gamma-ray beam and a polarized target (either longitudinally or transversely), the S.P.s can be extracted due to energy shifts in the particle from a rotating electric (or magnetic) field.

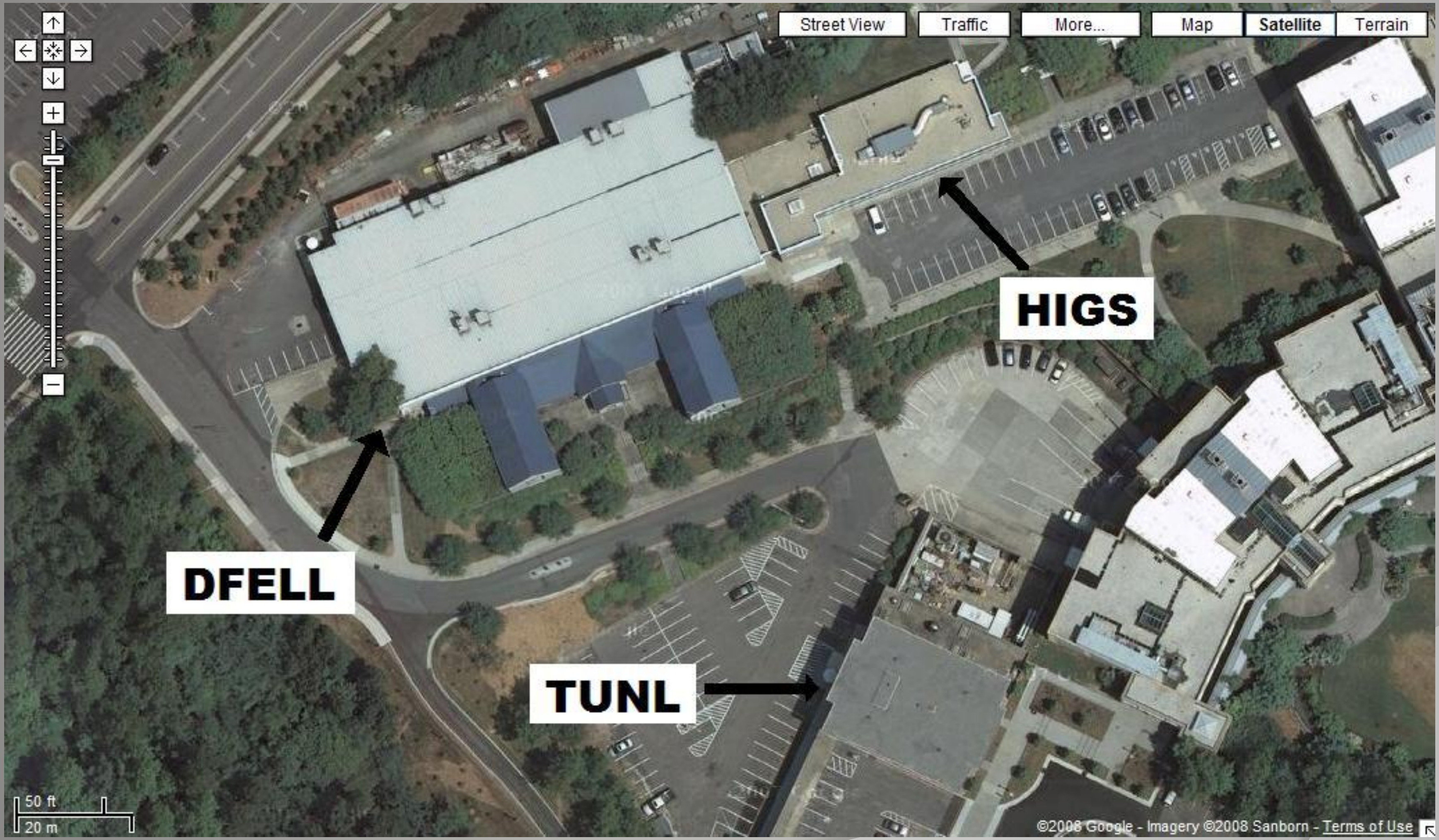
Requirements:

- Circularly polarized gamma-ray beam
- Polarized target
- Detector for scattered gamma
- Minimization of background

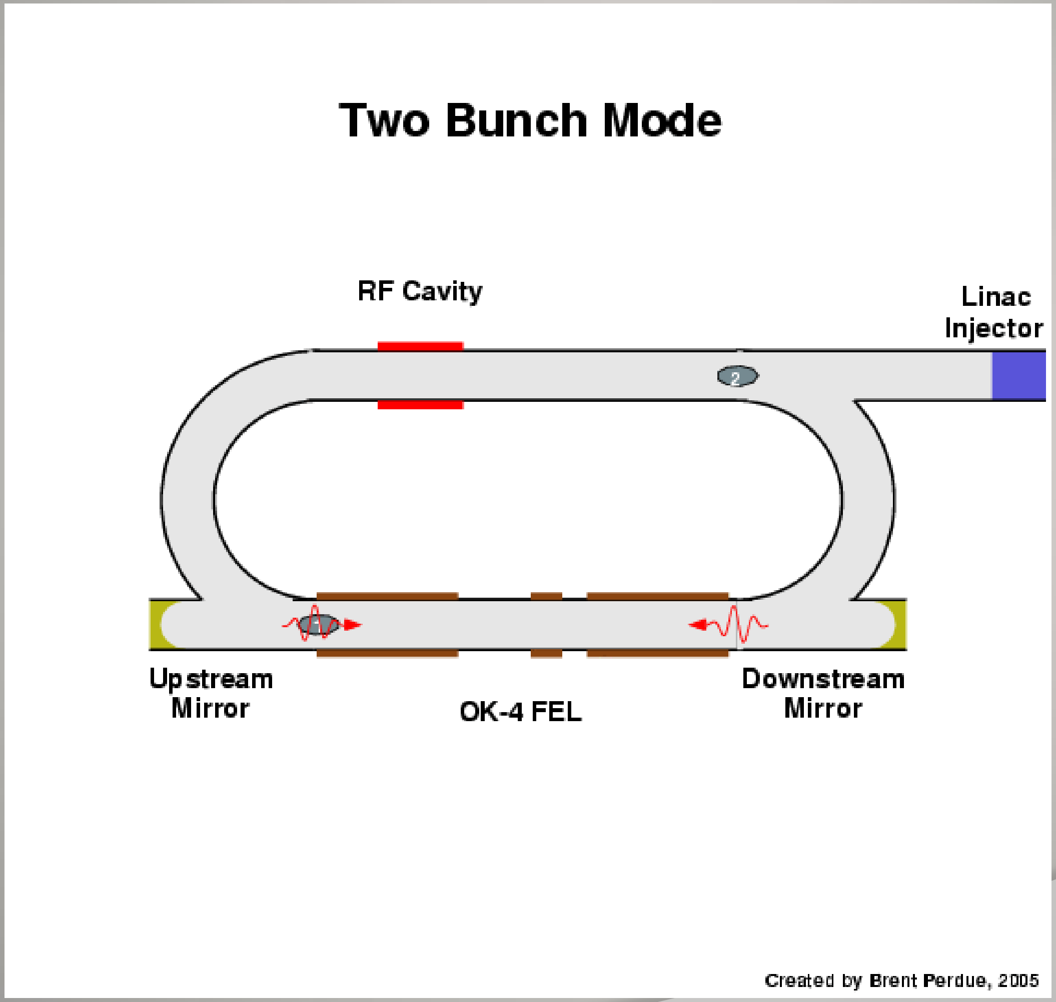
First You Need Some Space



Next You Need a Lab



High Intensity Gamma-ray Source ($HI\gamma S$)

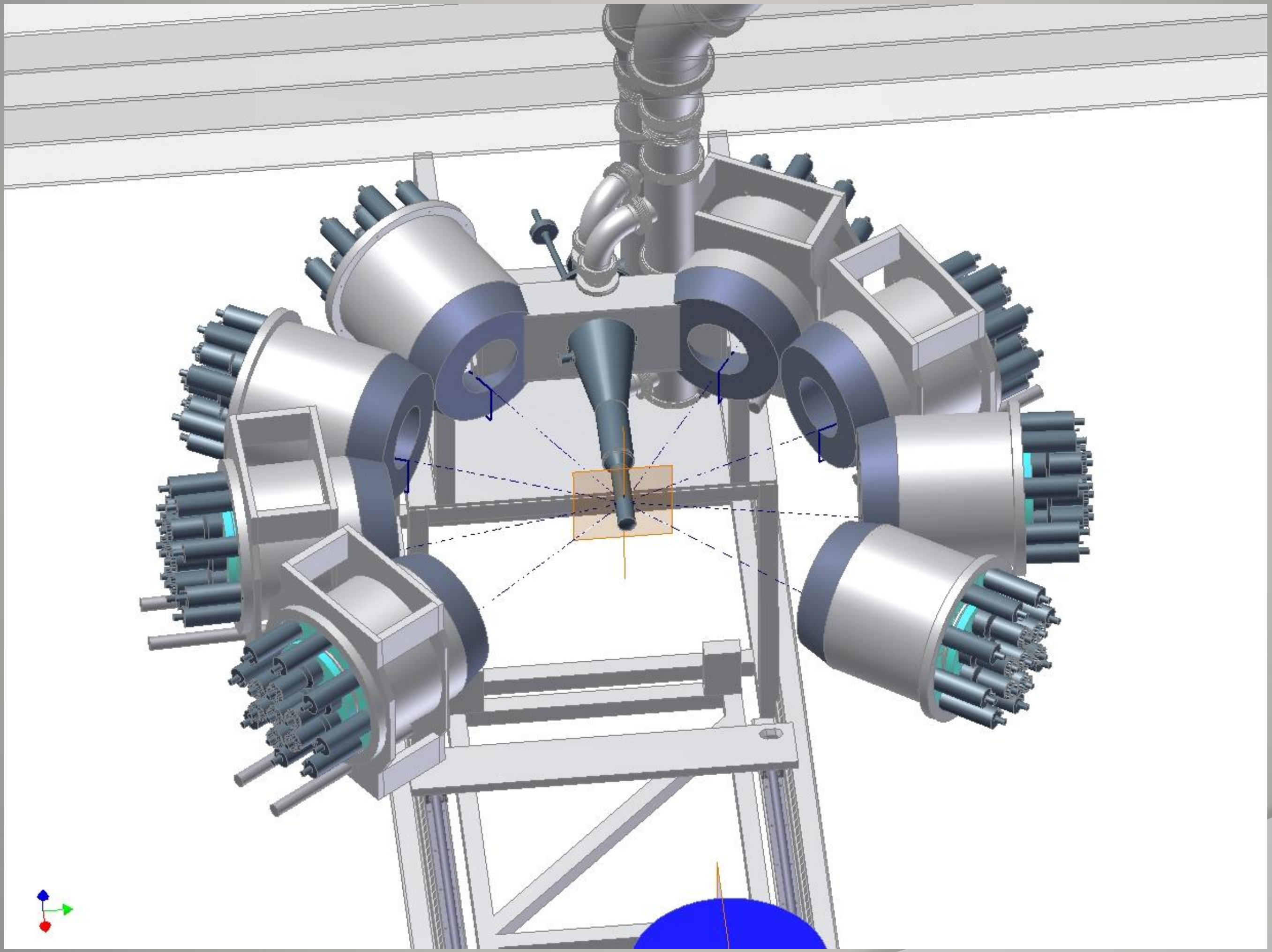


HIγS Frozen Spin Target (HIFROST)

This experiment will make use of a process called Dynamic Nuclear Polarization in order to polarize the target. The steps are:

1. Place target (while at about 0.3 K) in large (2.5 T) magnetic field to polarize free electrons
2. Apply a microwave signal to the target, which transfers the spin state from the electron to the proton, until satisfied
3. Cool target to about 50 mK temperature to 'freeze' the spin in, then remove magnetic field
4. Apply a weaker 'holding' field to help maintain the polarization

HIγS NaI Detector Array (HINDA)



Courtesy of M. Busch - TUNL

What's the Best Target?

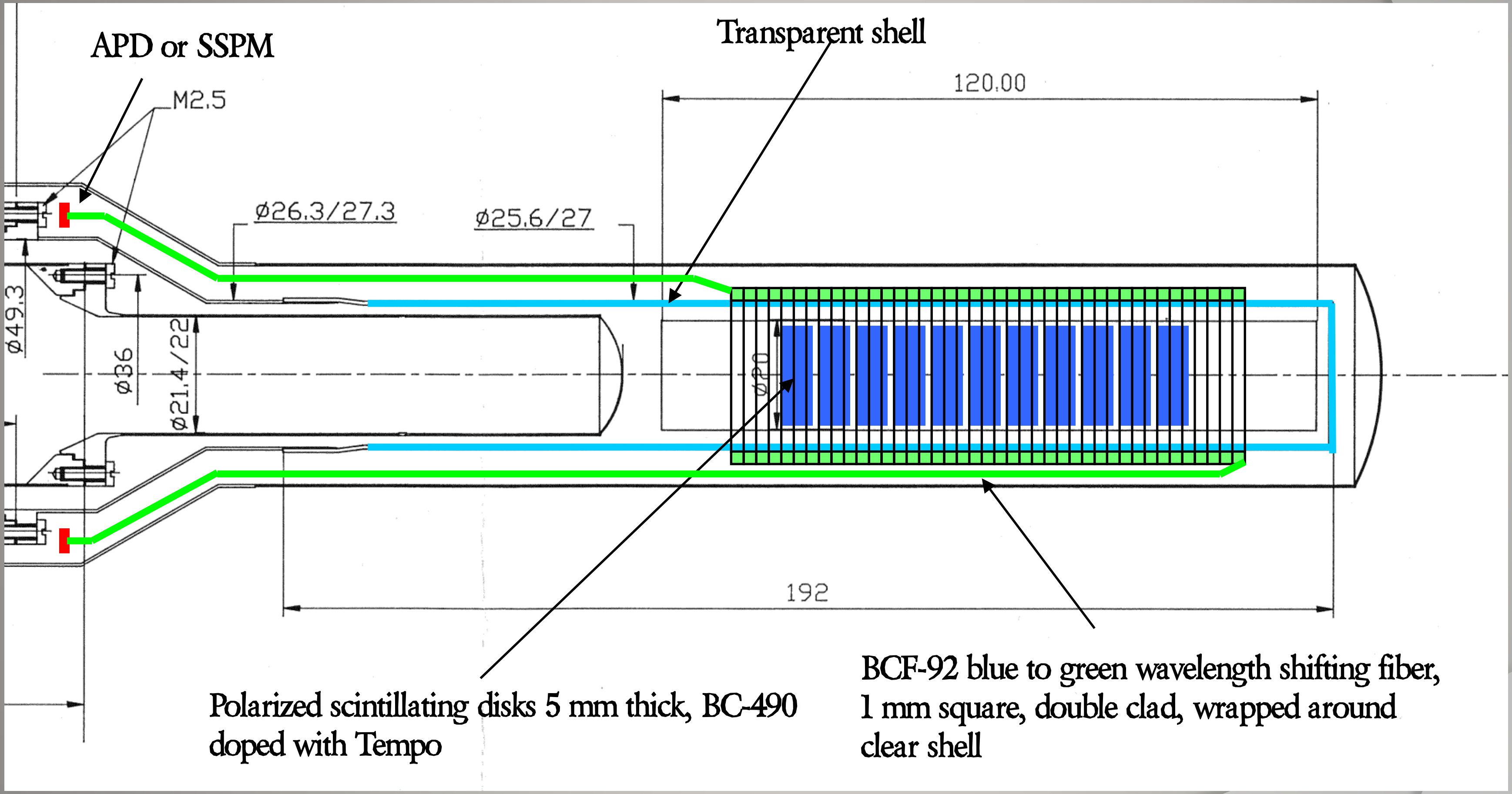
• Pure hydrogen target would be ideal, but is extremely expensive, and difficult to work with

• A butanol ($C_4H_{10}O$) target doped with TEMPO (a source of free radicals for the DNP process), could be used, but nuclear Compton cross section is much larger for carbon and oxygen than for protons

• By using a typical scintillator material (BC-490), doped with TEMPO, the proton recoil can be detected, effectively tagging the scattering event

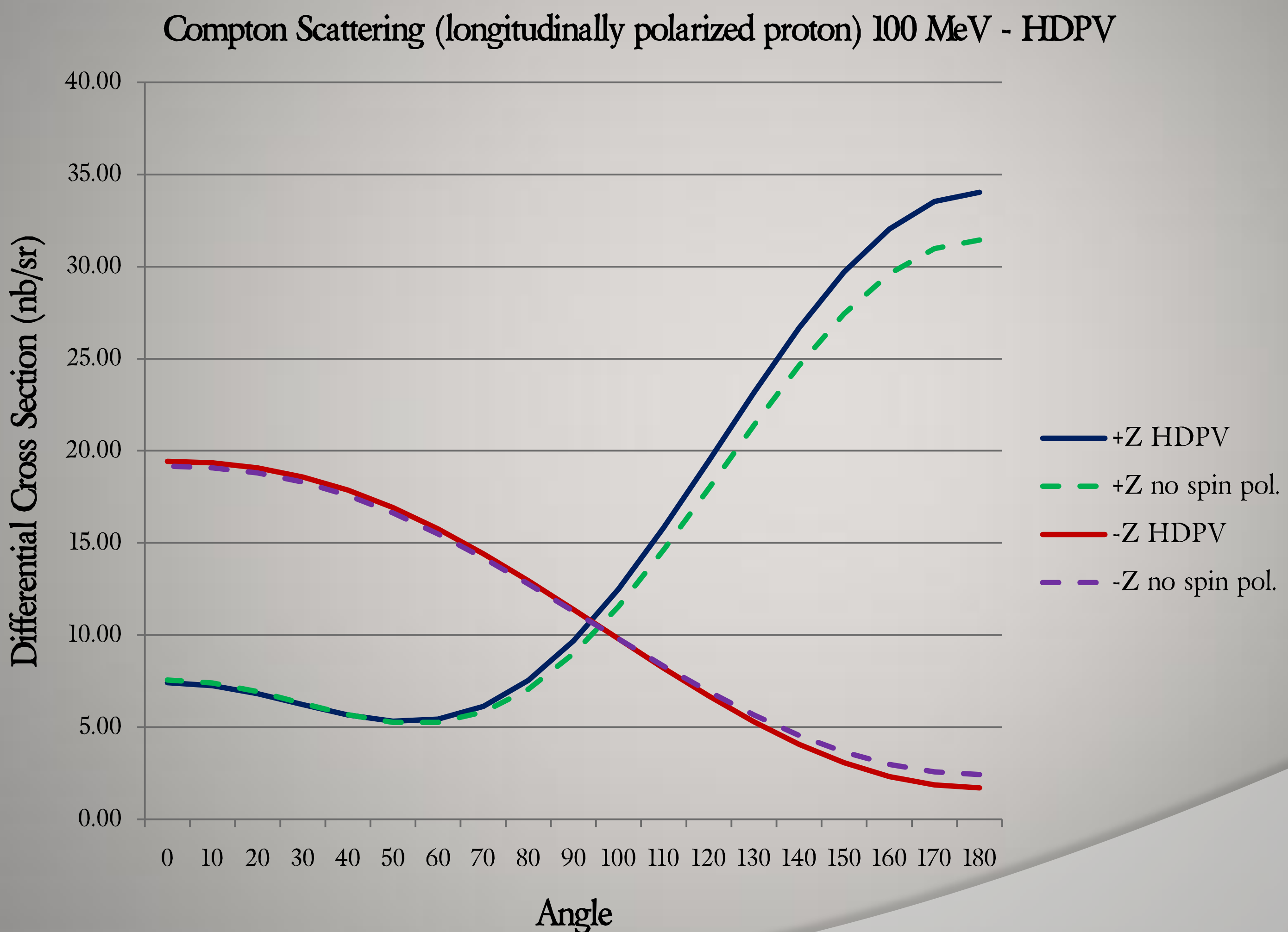
• How can this target design be coupled to an existing dilution refrigerator unit?

Scintillation Light Readout

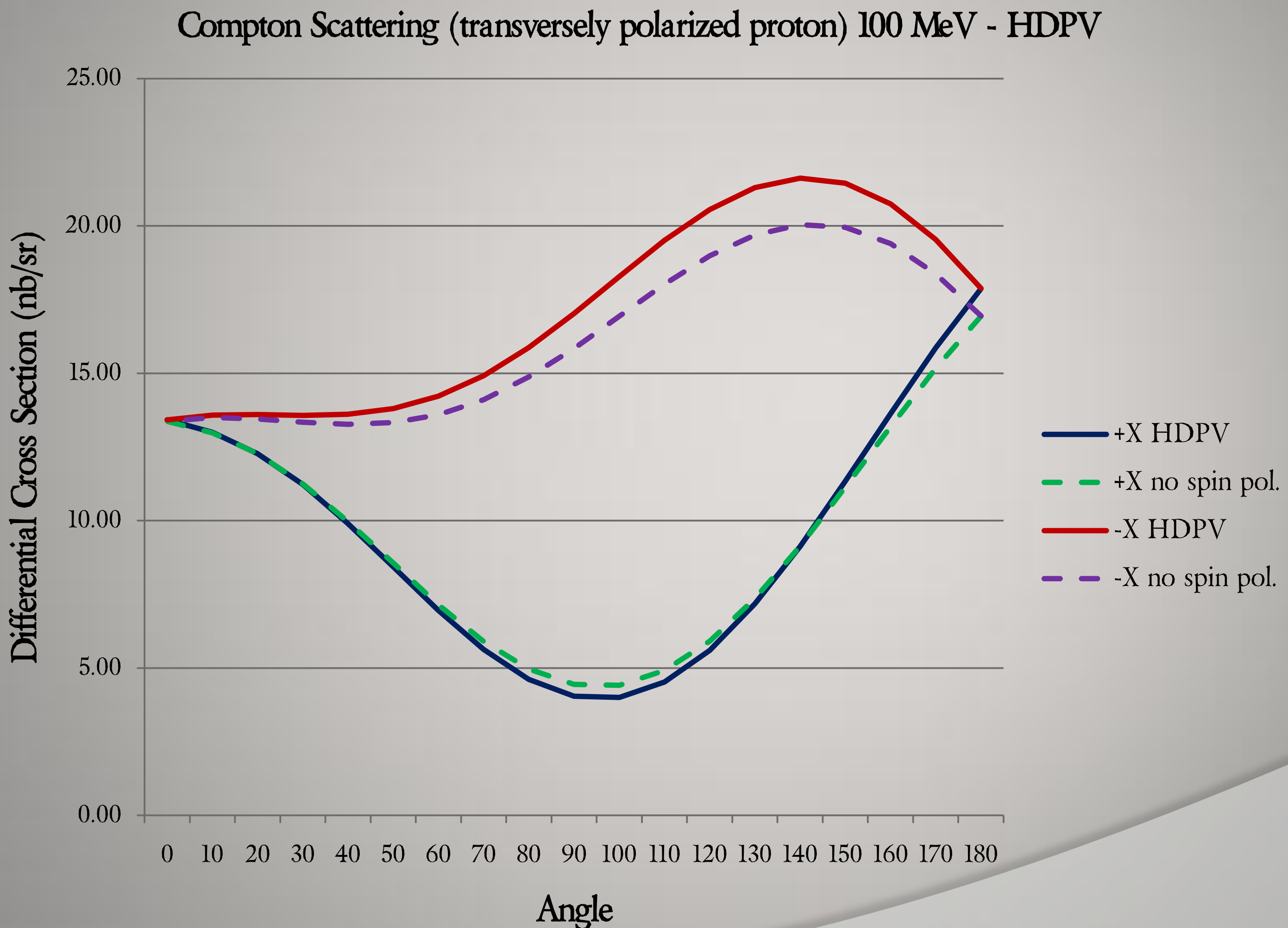


Initial tests demonstrate a 2% light transmission with fibers

Longitudinal Cross Sections



Transverse Cross Sections



Projected S.P. Errors

A dispersion code provided by Barbara Pasquini computed cross sections while varying the HDPV values for the S.P.s by ±1e-4 fm^4. Pseudo-data points were calculated for the angles of interest, and a minimization function fit these points, providing the errors. Using detectors doubled up at angles 42, 78, 114, and 150 deg:

- $\gamma_{E1E1} \rightarrow \pm 2.06e\text{-}5 \rightarrow 4.8\%$
- $\gamma_{E1M2} \rightarrow \pm 2.51e\text{-}5$
- $\gamma_{M1E2} \rightarrow \pm 2.45e\text{-}5 \rightarrow 11.7\%$
- $\gamma_{M1M1} \rightarrow \pm 1.58e\text{-}5 \rightarrow 5.4\%$

Based on 800 hours of running time, 200 for each of 4 helicity+pol states.

S.P. Theoretical Values

	HBχPT			Fixed-t dispersion analyses			
	$O(p^3)$	$O(p^4)$	SSE	HDPV	BGLMN	DPV	±Err
γ_{E1E1}	-5.7	-1.8	-5.7	-4.3	-3.4	-5.0	.21
γ_{M1M1}	-1.1	2.9	3.1	2.9	2.7	3.4	.16
γ_{E1M2}	1.1	.7	.98	-0.01	0.3	-1.8	.25
γ_{M1E2}	1.1	1.8	.98	2.1	1.9	1.1	.25

Conclusions

- The HIγS facility can provide a 100% circularly polarized beam on the order of 1e7 gammas/s, and theoretically up to 100 MeV (higher?)
- UVa is continuing work on the dilution refrigerator, and aiming for an install this fall
- TEMPO doped scintillator targets are presently being worked on at JMU and UMass
- Full scale prototype of fiber readout system is being designed
- Analysis of cross sections, using the dispersion code provided by Barbara Pasquini, has helped to verify run parameters (detector angles, running time, etc.)

Acknowledgements

- Umass – Rory Miskimen, John Barrett, and Keith Landry
- Duke/TUNL – Henry Weller, Mohammad Ahmed, Matthew Busch, Eric Clinton, Seth Henshaw, Brent Perdue, Pil-Neyo Seo, Sean Stave, and Aram Teymurazyan
- UVa – Don Crabb and company, Blaine Norum
- JMU – Steve Whisnant and company
- MIT – Aron Bernstein
- INFN (Instituto Nazionale di Fisica Nucleare) – Barbara Pasquini