EXPERIMENTS WITH A POLARIZED COHERENT BREMSSTRAHLUNG BEAM AT SLAC

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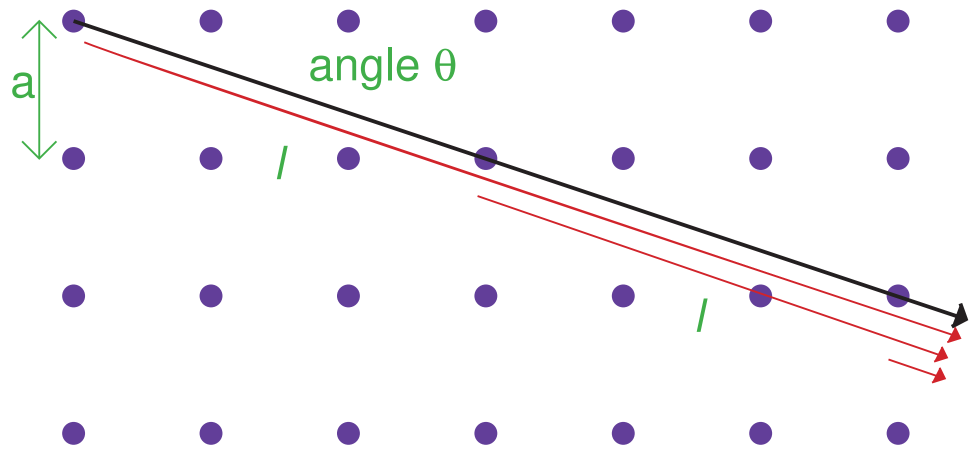
CEBAF/INT workshop on Correlations in Nucleons and Nuclei
16 March 2001

- Coherent Bremsstrahlung beam
- E160: J/ψ Photoproduction (1/2003)
- E161: ΔG (1/2004)
- E159: GDH Sum Rule (1/2005)

E159/E160/E161 Collaboration

University of California Los Angeles, Frascati, Jefferson Lab, University of Massachusetts, Saclay, Institut für Kernphysik Mainz, University of Liverpool, Los Alamos National Laboratory, Mississippi State University, Old Dominion University, Ruhr-Universität Bochum, Smith College, Stanford Linear Accelerator Center, University of Virginia, College of William and Mary, Yerevan Physics Institute

Coherent Bremsstrahlung

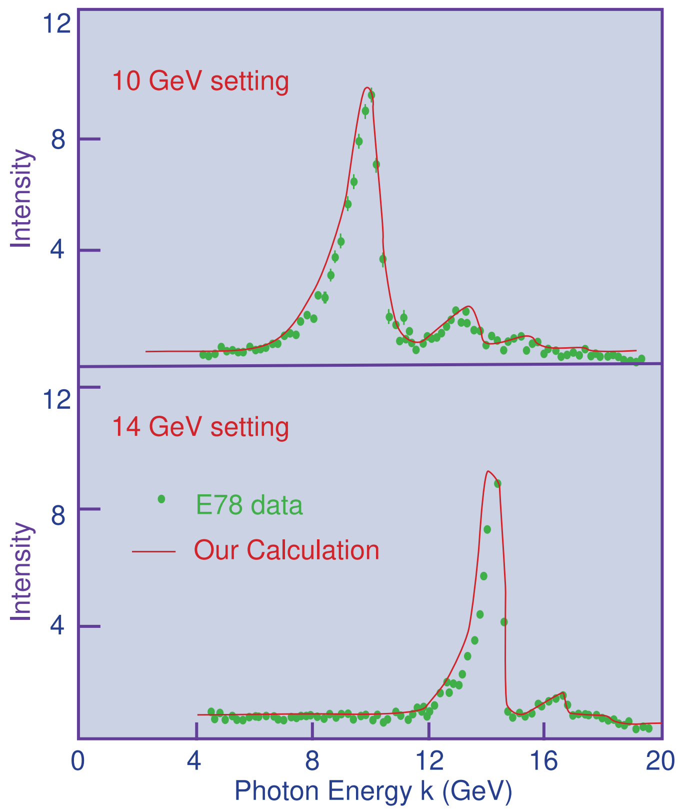


photon waves, velocity=1.
Want to be in phase.

electron, velocity=β.
Lag by one photon wavelength over distance a/θ

- High flux quasi-monoenergetic circularly polarized real photon beam.
- Thin diamond crystal radiators: low mosaic spread, low Z, small lattice spacing.
- Outperforms laser backscattering (emittance growth limits intensity) and tagging (rates are too low with 10^{-4} duty cycle).

Coherent Bremsstrahlung Spectra



- Calculations using formulas from Diambrini Palazzi, Rev. Mod. Phys. 40, 611 (1968).
- Data from SLAC E78, W. Kaune et al., Phys. Rev. D11, 478 (1975)
- Calculations are shown to be reliable for 19.7 GeV electron beams. Plotted is intensity—photon flux times energy.

Beam Parameters

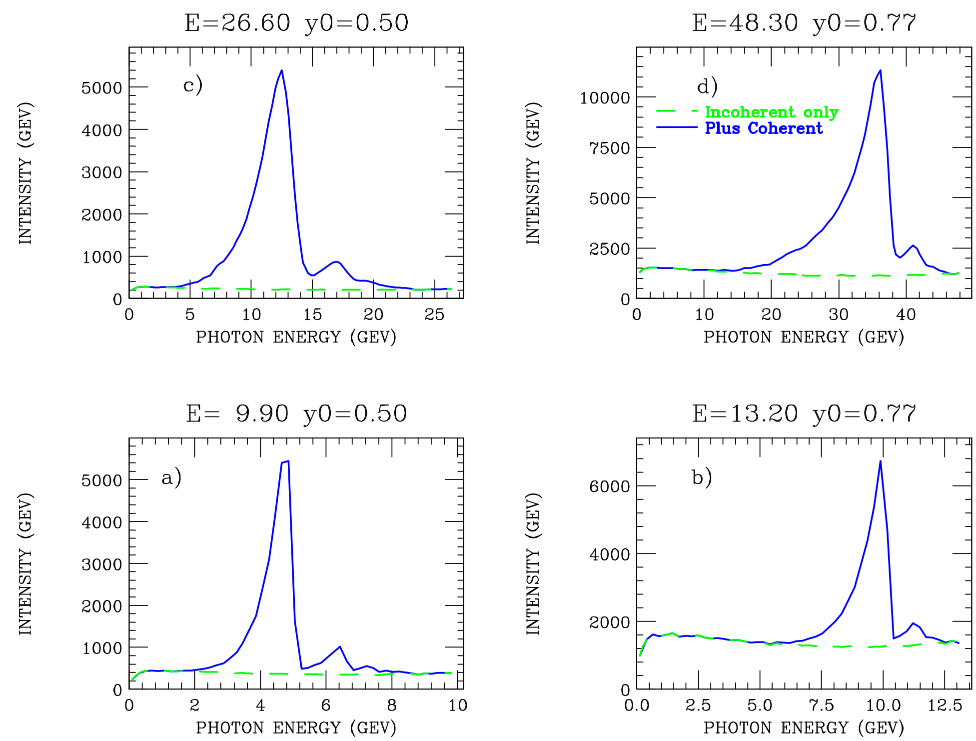
Experiment	Photon Energies	Photons/Spill	Polarization
E159	4 to 40 GeV	10^5 to 10^7	yes
E160	15, 25, 35 GeV	$< 10^7$	no
E161	35, 40, 45 GeV	$< 10^7$	yes

- Limit current to about 3×10^{10} e^- per 500 ns spill. At 120 spills/s, this avoids breaking diamonds and limits radiation damage.
- Tight collimation and thin diamond enhances coherent peak when high flux is not needed.
- Lower $y = k/E$ gives better coherent/incoherent ratio for given k, but also lower polarization.
- Higher k/E reduces effect of higher energy spikes.
- Linear polarization $\approx (1 - y)$
- Circular polarization

$$P_\gamma = \frac{P_e 1 - (1-y)^2 - \frac{2}{3}y(1-y)}{1 + (1-y)^2 - \frac{2}{3}y(1-y)}$$

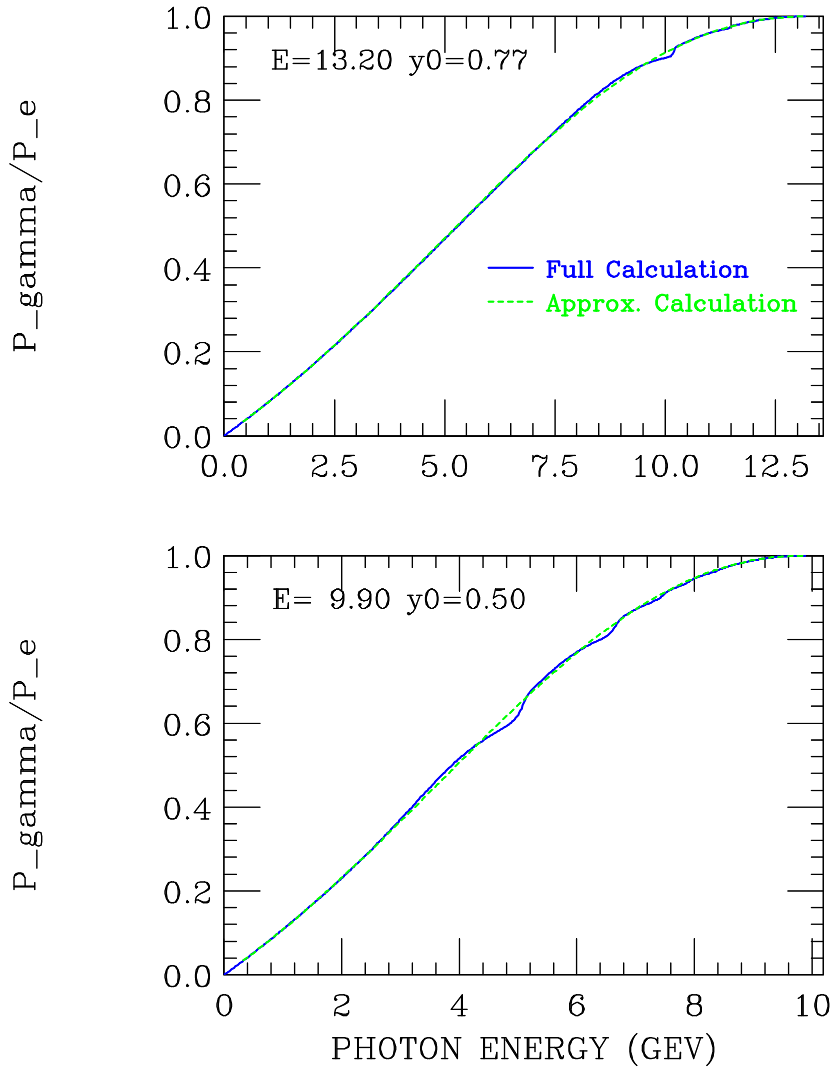
is nearly the same for coherent and incoherent.
I.M. Nadzhafov, Bull. Acad. Sci. USSR, Phys. Ser. Vol. 14, No. 10, p. 2248 (1976).

Representative Photon Intensities

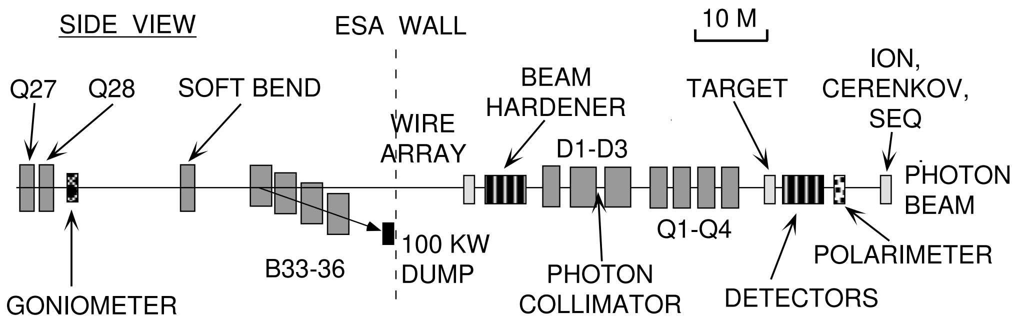


- Coherent contribution (blue lines)
- Incoherent contribution (green dashed lines)
- $y_0 = k/E$

Circular Polarization

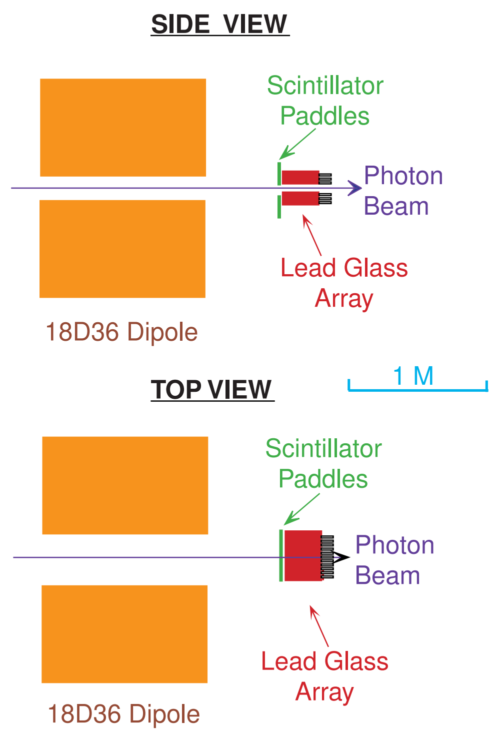


Beamline Overview



- Goniometer
- Sweeping magnets to dump electron beam
- Beam dump
- Hardener
- Collimator and position monitors
- Polarimeter
- Flux and intensity measuring devices

Compton Polarimeter



- Designed to measure flux, energy distribution, and circular polarization of beam photons.
- Helicity-dependent $\gamma e \to \gamma e$ cross section:

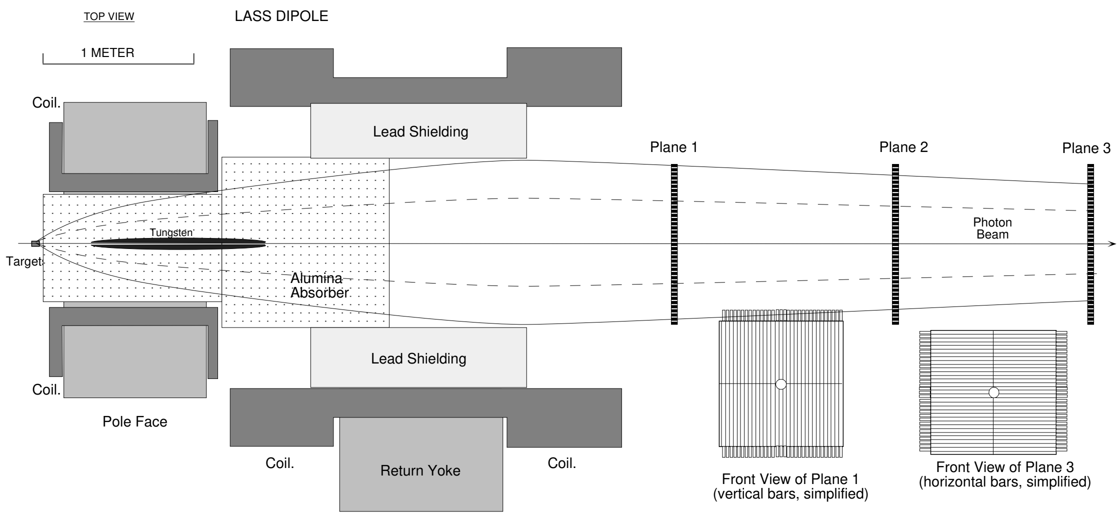
$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{2m_e^2}\left(\frac{k}{k_0}\right)^2\left[\frac{k}{k_0}+\frac{k_0}{k}-\sin^2\theta-P_\gamma P_e(1-\cos\theta)\cos\theta\frac{(k+k_0)}{m_e}\right]$$

- Iron target with $P_e \approx 0.08$.
- Photon energy measurement to 3%-5%.
- Polarization measurement to 3% in about 1 hour.

E160: Measurement of the A-dependence of J/ψ and ψ' photoproduction

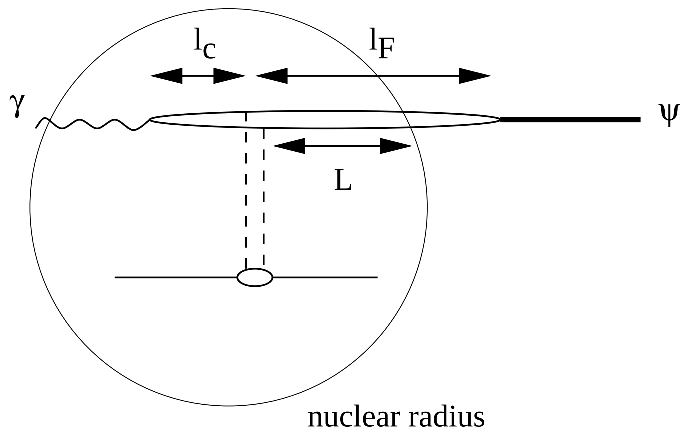
- Goals:
  - Understand interplay of pQCD and color transparency in creation and interaction of J/ψ and ψ' in nuclei.
  - Understand why VMD and geometrical expectations for $\sigma_{\rm tot}^{\psi N}$ are at odds.
  - Constrain causes for J/ψ suppression in relativistic heavy-ion collisions.
- Measurement:
  - Reconstruct J/ψ from $\mu^+\mu^-$ pairs.
  - Be, Al, Cu, Pb targets
  - 15, 25, 35 GeV photons
- Results:
  - t-distributions
  - α from $\sigma_A \propto A^\alpha$
  - ψ-nucleon cross section $\sigma_{\rm tot}^{\psi N}$
- http:www.slac.stanford.edu/exp/e160/

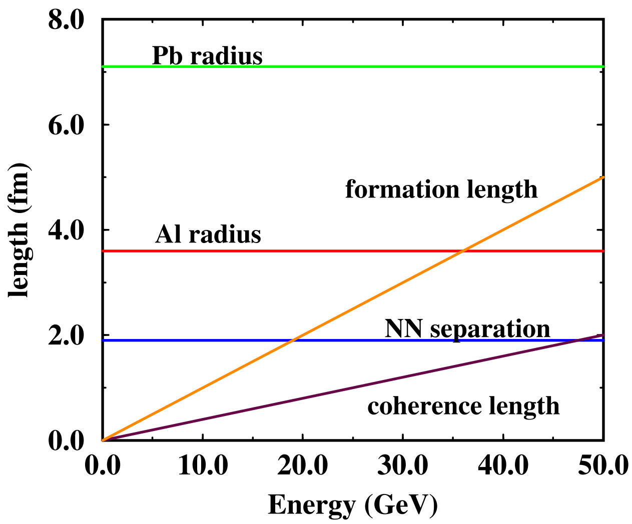
E160 Spectrometer



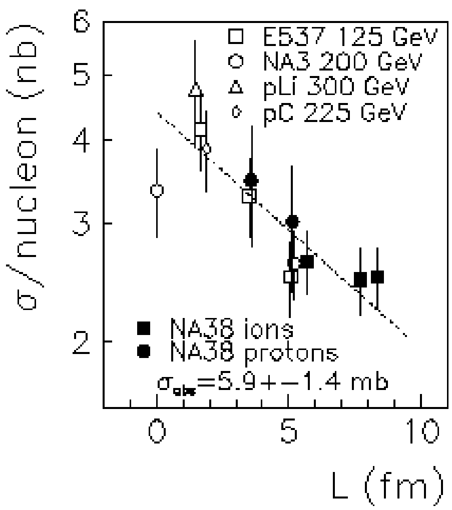
- 29D32 Dipole Magnet
  - 25.4 cm gap; $\pm$36 cm width; $\approx$ 1 m length.
  - $\int \mathbf{B} \cdot \mathbf{d}\ell = 22$ kG-m.
- 70D43 LASS Dipole Magnet
  - 102 cm gap; $\pm$45 cm width; 109 cm length.
  - $\int \mathbf{B} \cdot \mathbf{d}\ell = 25$ kG-m.
  - 4000 A from 2 existing 1.6 MW power supplies.
  - mirror plates removed.
- 2.2 m alumina (Al_2O_3) absorber with tungsten core.
- 3 planes of scintillator hodoscopes.

Length Scales



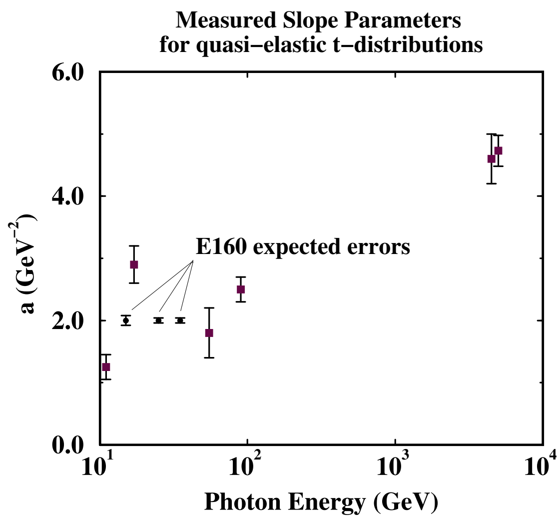


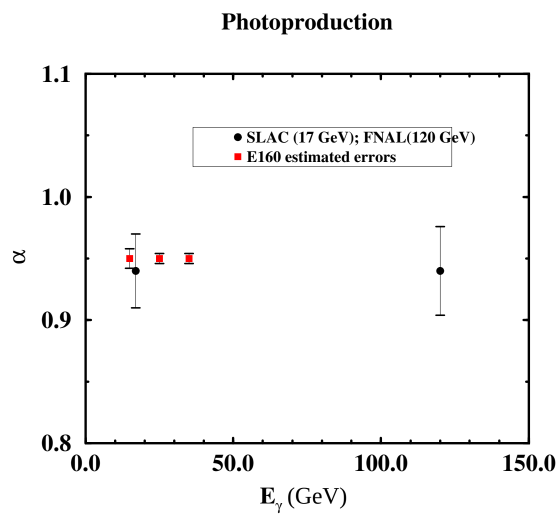
$\psi - N$ Cross Sections



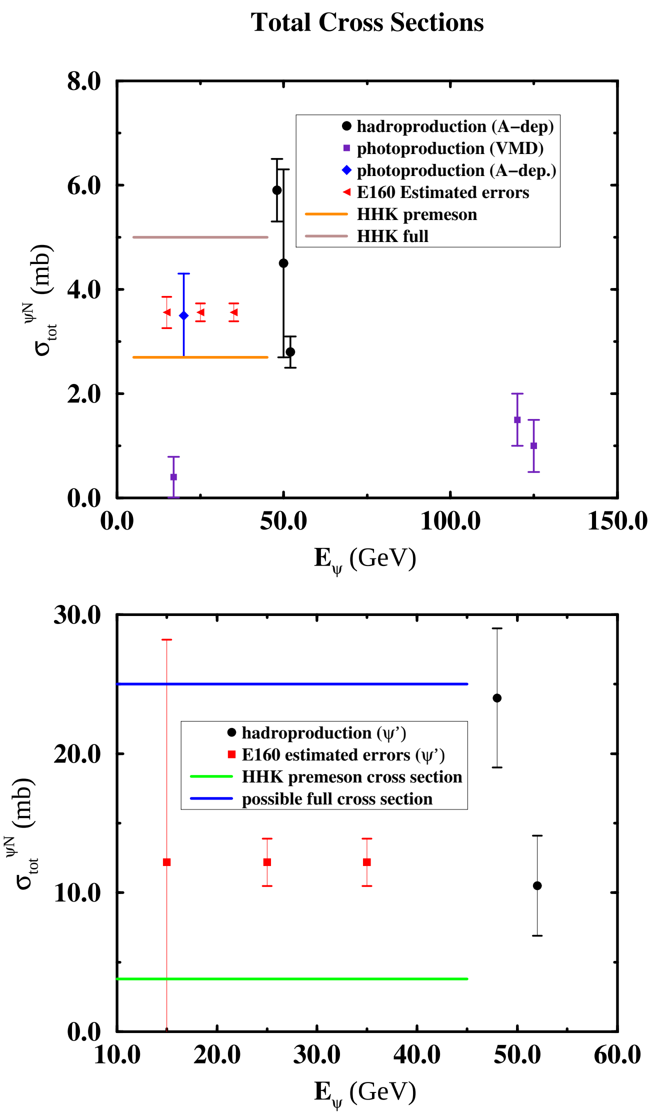
- Data: nucl-th/9806023 review
- Glauber:
$$\frac{\sigma^{pA\to\psi}}{A\sigma^{pN\to\psi}} = e^{-L\rho_0\sigma_{\rm tot}^{\psi N}}.$$
in which L is the length of absorption trajectory, ρ_0 is nuclear density. If $L \propto A^{\frac{1}{3}}$ then $\sigma_{\rm tot}^{\psi N} \propto A^{\alpha}$. $\sigma_{\rm tot}^{\psi N} \approx 6$ mb, $\alpha \approx 0.92$.
- Vector Meson Dominance: $\sigma_{\rm tot}^{\psi N} \propto \frac{d\sigma}{dt}(\gamma N \to \psi N)|_{t=0}$ by the optical theorem. $\sigma_{\rm tot}^{\psi N} \leq 1$ mb.
- Geometry: $\sigma_{\rm tot}^{\psi N}$ is proportional to the square radius. $\sigma_{\rm tot}^{\psi N} = 2 - 5$ mb.

Projected Results





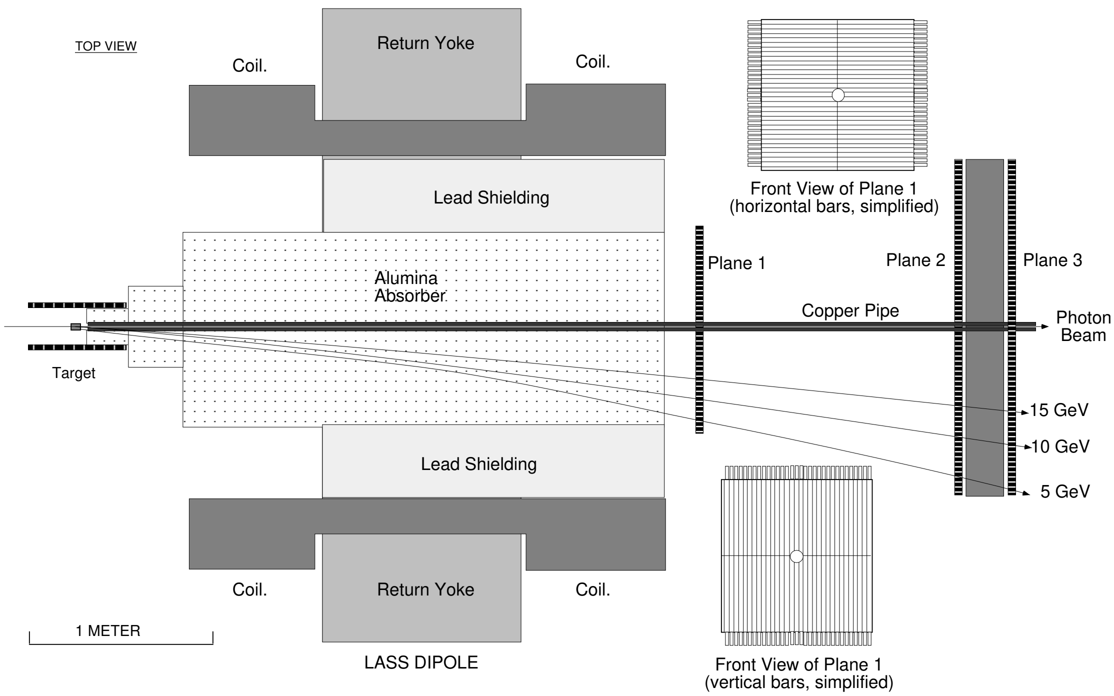
Error Estimates on $\sigma_{\rm tot}^{\psi N}$



E161: Measurement of the Gluon Spin Distribution using Polarized Open Charm Photoproduction

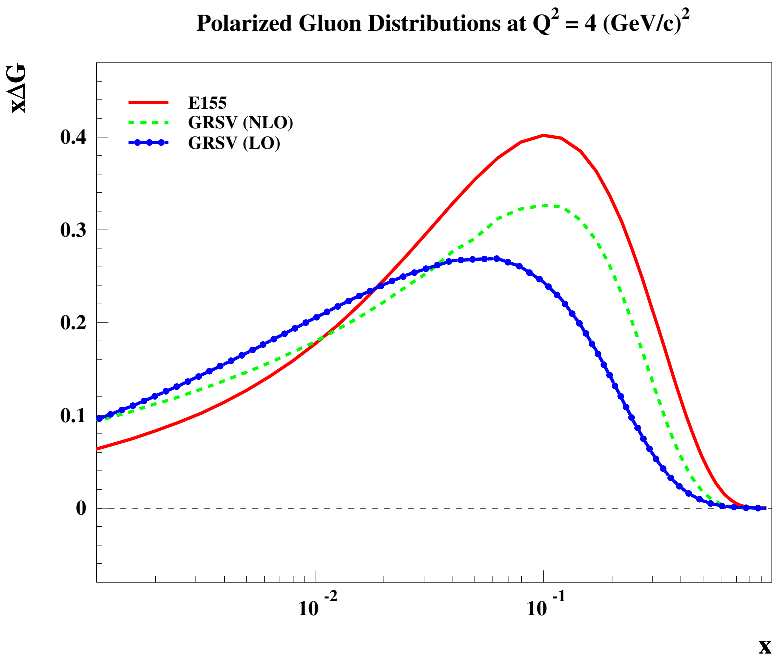
- Goals:
  - Determine the polarized gluon distribution of the nucleon.
  - Discriminate between models of $\Delta G(x)$.
  - Make precise measurements complementary to COMPASS, HERMES, STAR and PHENIX.
- Measurement:
  - Detection of a single μ (veto μ pairs).
  - Polarized LiD target
  - 35, 40 and 45 GeV circularly polarized photons
- Results:
  - Asymmetries for longitudinal beam and target polarizations.
  - Momentum distributions p_μ and $p_{T\mu}$.
  - $\Delta G(x)$ for $0.1 < x < 0.2$.
- http:www.slac.stanford.edu/exp/e161/

E161 Spectrometer



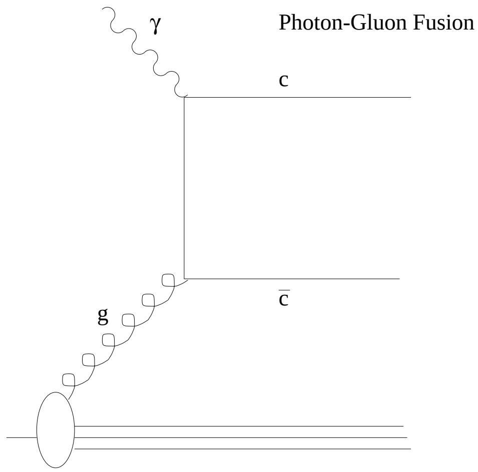
- 70D43 LASS Dipole Magnet
  - 102 cm gap; ±45 cm width; 109 cm length.
  - $\int \mathbf{B} \cdot \mathbf{d}\ell = 25$ kG-m.
  - 4000 A from 2 existing 1.6 MW power supplies.
- alumina (Al_2O_3) absorber.
- 3 planes of scintillator hodoscopes, last behind extra shielding.

ΔG



- $\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z$
- $\Delta\Sigma = 0.23 \pm 0.07$ from NLO fit of E155.
- $\Delta G = 1.6 \pm 0.8 \pm 1.1$ from NLO fit of E155.
- Large uncertainty remains in ΔG (0.5–2.5).

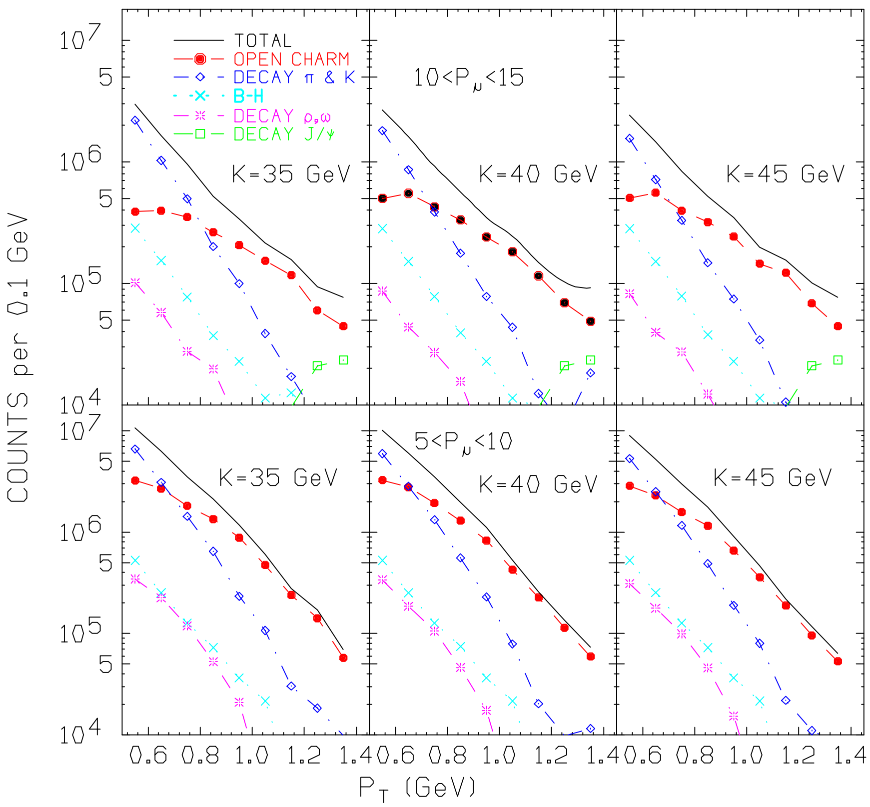
Photon Gluon Fusion



- $\sigma_{\gamma p}(k) = \int_{x_{min}}^{1} g(x, Q^2)dx \int_{-1}^{1} \sigma(\hat{s}, \cos(\theta^*))\beta \, d\cos(\theta^*)$
  - $x_{min} = 4m_c^2/2Mk$
  - $s = 2Mk + M^2$
  - $\beta = \sqrt{1 - 4m_c^2/\hat{s}}$ is the c.m. velocity of $c\bar{c}$
  - $\hat{\mathbf{s}} = \mathbf{xs}$ is the energy of the photon-gluon system squared
  - $\sigma(\hat{s}, \cos(\theta^*))$ is hard scattering cross section
- $\Delta\sigma = \sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}$

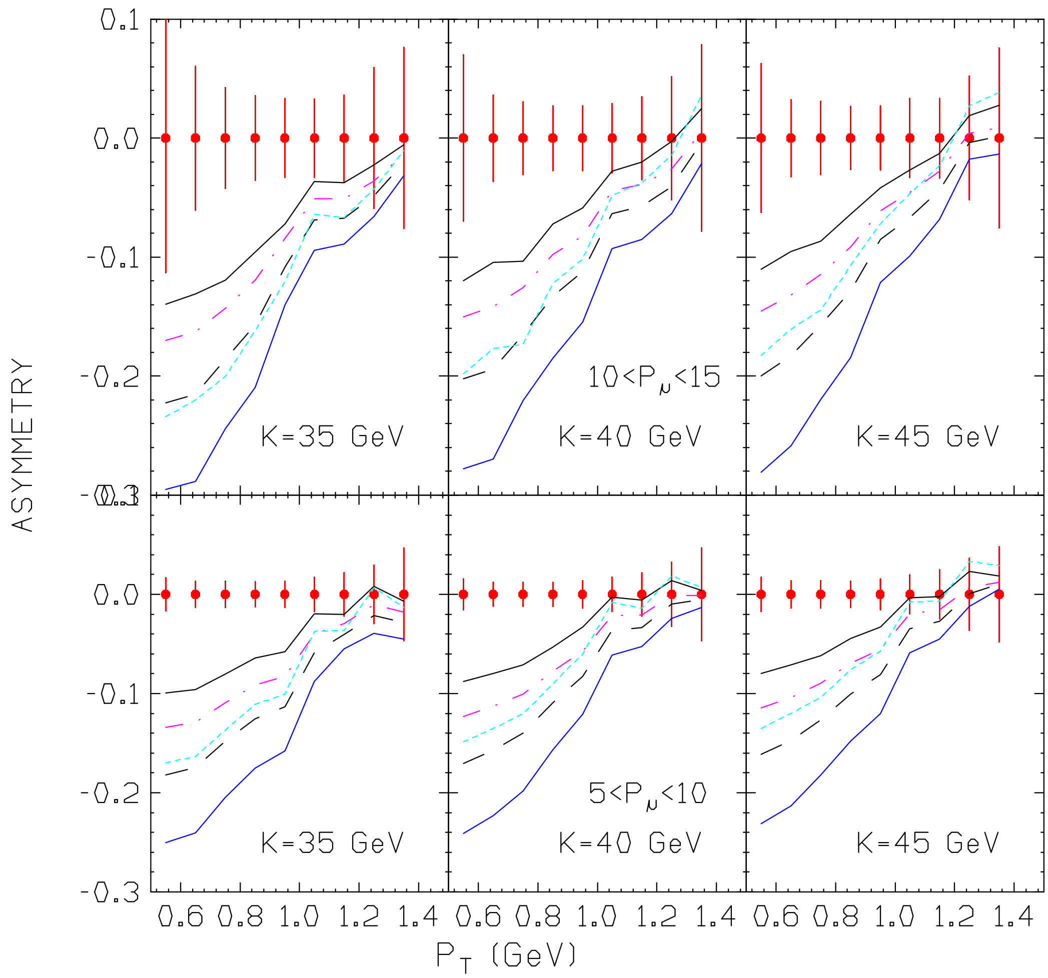
$$\Delta\sigma_{\gamma p}(k) = \int_{x_{min}}^{1} \Delta g(x, Q^2)dx \int_{-1}^{1} \Delta\sigma(\hat{s}, \cos(\theta^*))\beta d\cos(\theta^*)$$

Tag Charm with Single Muon



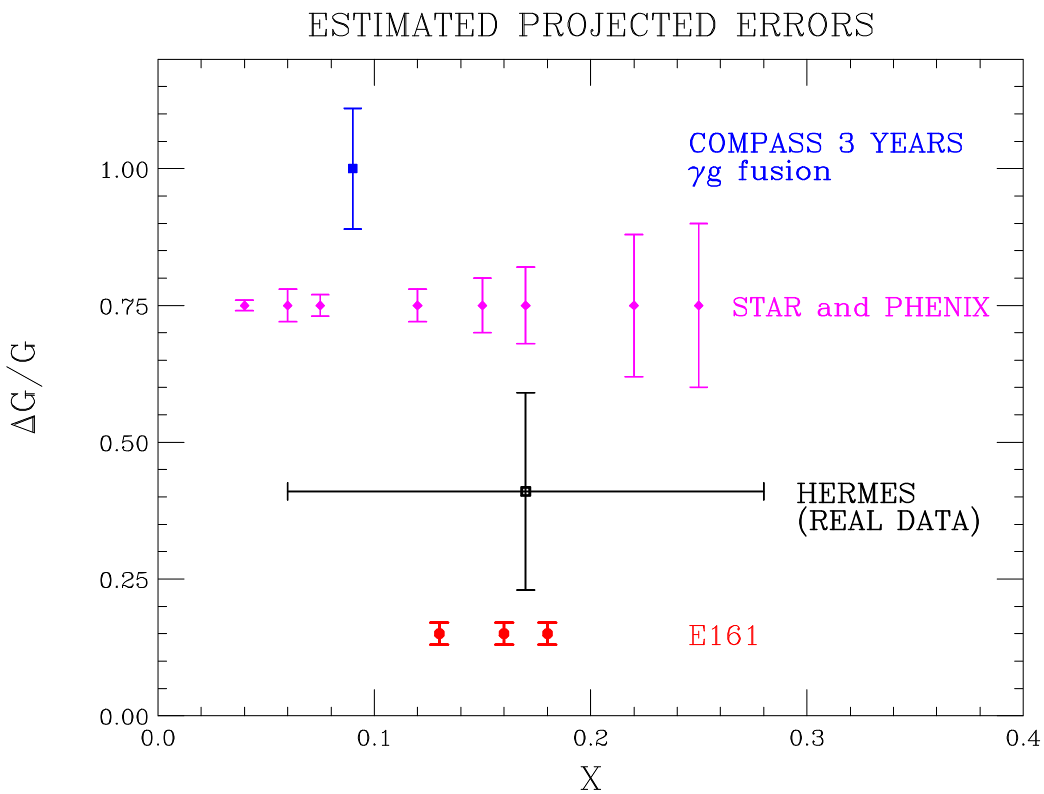
	D^+	D^0	D_s^+	Λ_c^+
produced(%)	19	63	8	8
Branching Ratio(%)	17	7	8	4
decay to μ^+(%)	37	47	8	4
	D^-	$\bar{D}^0$	D_s^-	Λ_c^-
produced(%)	21	71	6	2
decay to μ^-(%)	40	53	5	1

Expected Asymmetries



- Curves use various models for ΔG
- Data points show expected errors; central position arbitrarily set to zero.

Expected Errors on ΔG

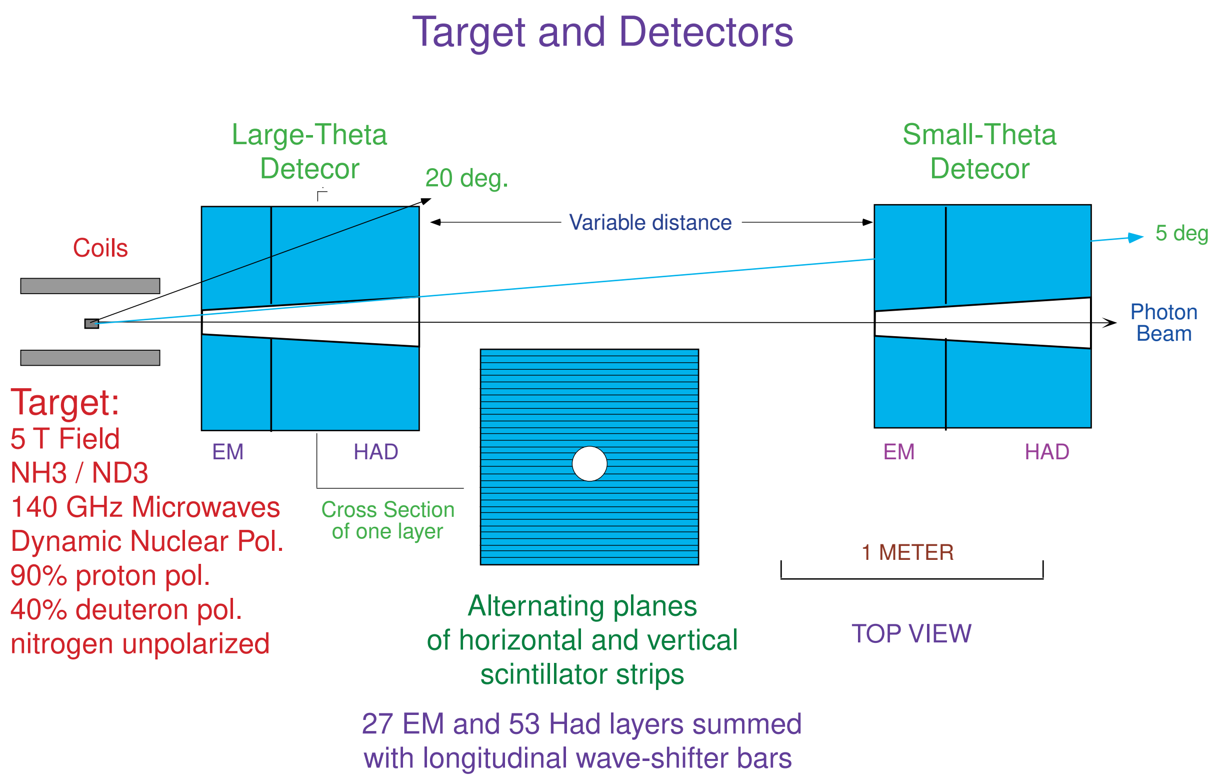


- Points are arbitrarily shifted on the vertical scale for comparison.

E159: Measurement of $\Delta^{\gamma N}(k)$ and the High Energy Contribution to the Gerasimov-Drell-Hearn Sum Rule

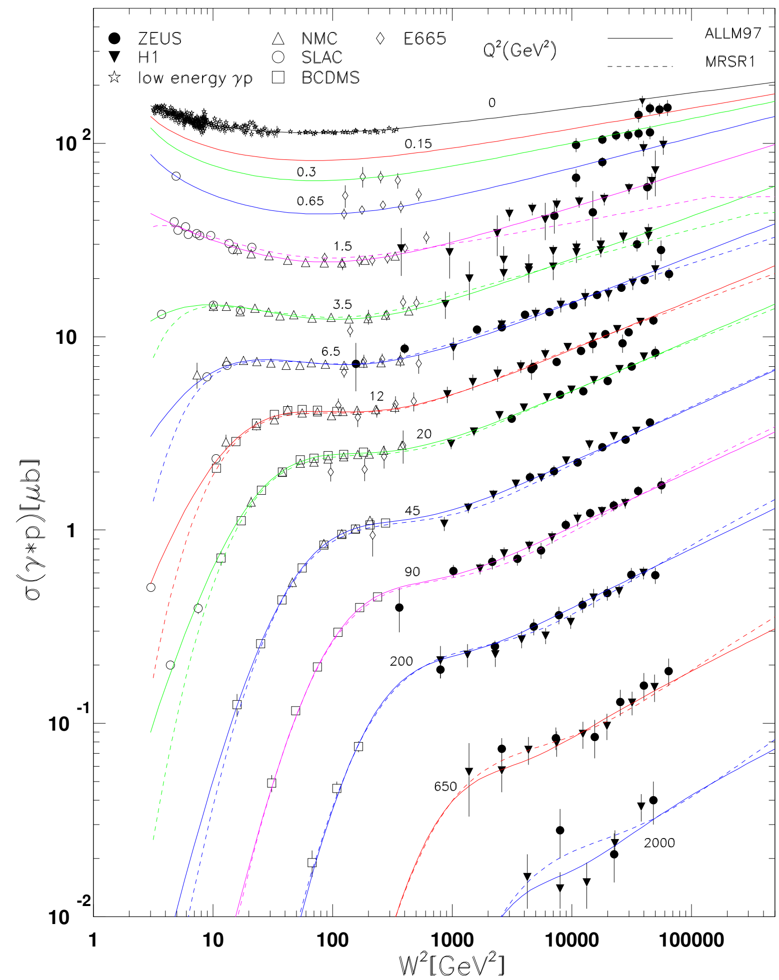
- Goals:
  - Determine for the first time the difference between right- and left-handed polarized photoabsorption above the resonance region.
  - Compare to models that predict the cross section difference changes sign at high energies.
  - Experimentally constrain the GDH sum.
- Measurement:
  - Identification of at least one hadron.
  - Polarized $^{15}NH_3$ and $^{15}ND_3$ targets
  - 4–40 GeV circularly polarized photons
- Results:
  - Cross section differences for longitudinal beam and target polarizations.
  - $4 < k < 40$ GeV for the proton and deuteron.
  - Experimental integrals of the GDH sum.
- http:www.slac.stanford.edu/exp/e159/

E159 Spectrometer



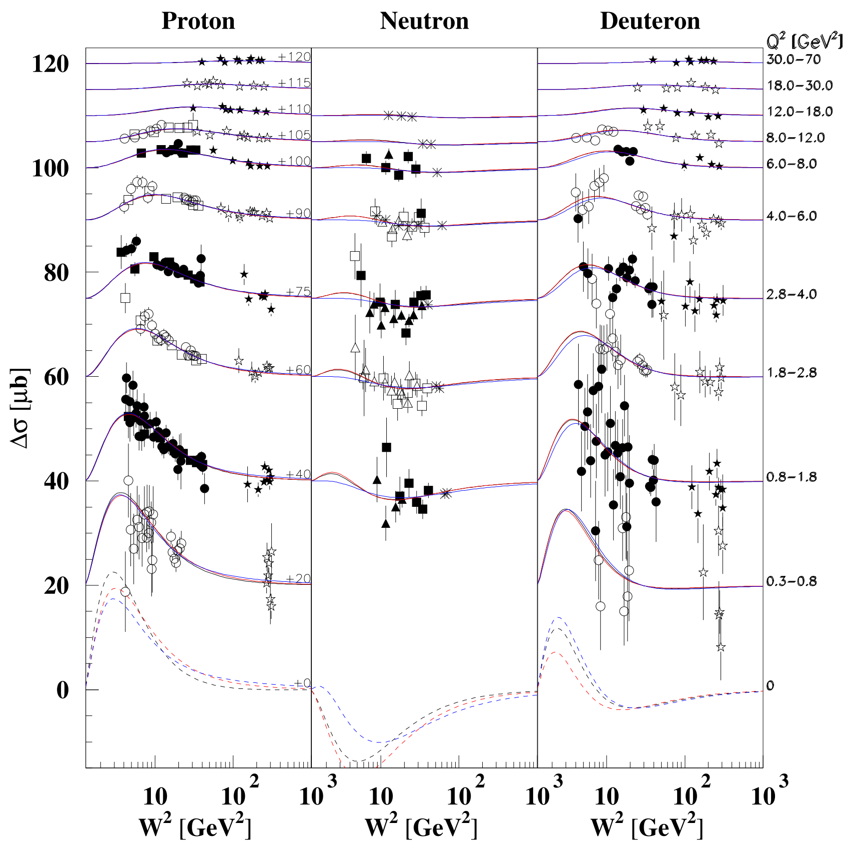
- Two identical calorimeters, 0.5–5° movable and 5–20° fixed.
- Sampling calorimetry with alternating hodoscope fingers and lead layers for measuring x and y. Separate readouts for first 27 rl (E.M.) and subsequent 53 rl (hadrons)
- Single event counting and flux integration mode.

Unpolarized Photoproduction



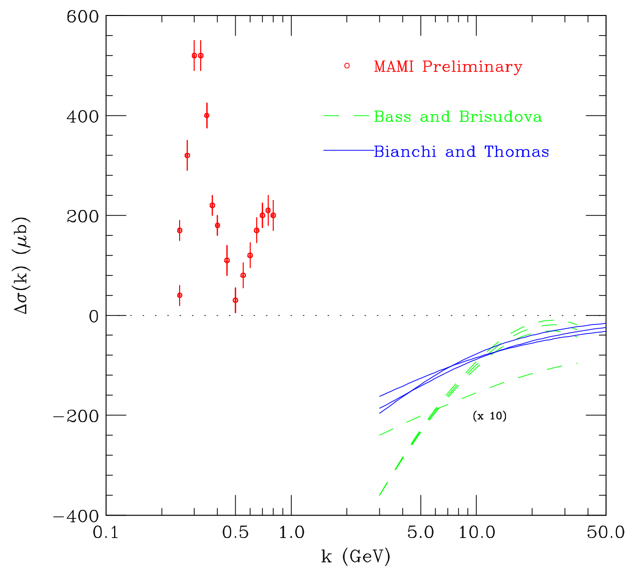
- $\sigma^{\gamma N}(k, Q^2) = (\sigma_{1/2} + (\sigma_{3/2})/2$
- Real photon absorption depends only on photon energy k and is roughly constant at 120μ b.

Polarized Photoproduction



- $\Delta\sigma^{\gamma N}(k, Q^2) = \sigma_{3/2} - \sigma_{1/2}$
- Regge theory fits of Bianchi and Thomas describe virtual photon data well.

$$\Delta\sigma(k)$$



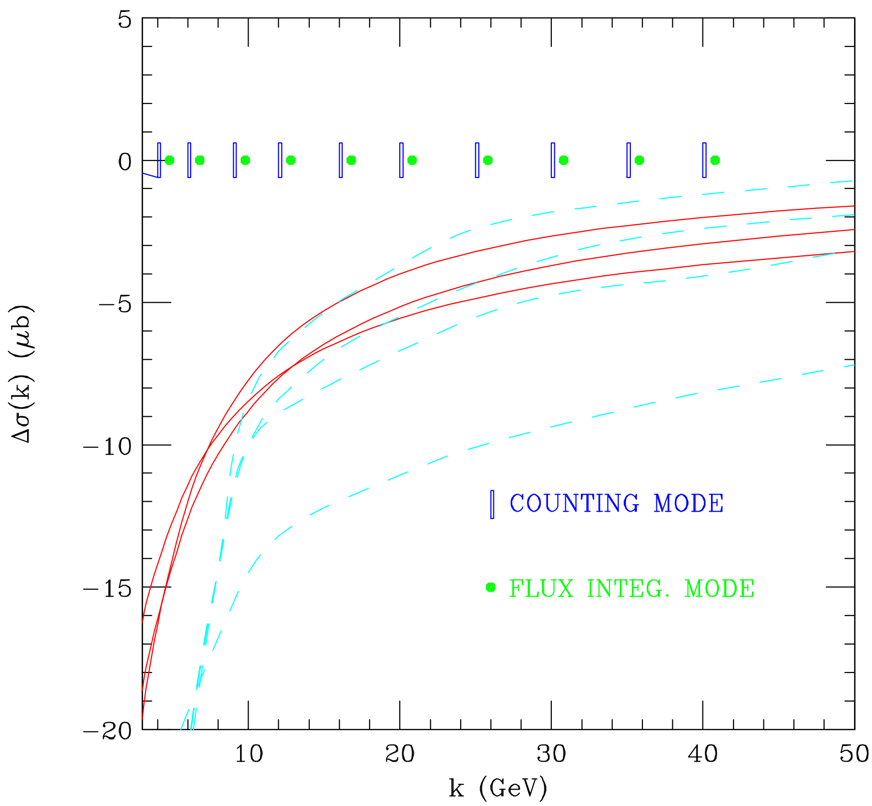
- GDH Sum Rule relates integral of $\Delta\sigma(k)$ to the anomalous magnetic moment of the nucleon:

$$\int_{k_\pi}^{\infty} \frac{dk}{k} \Delta\sigma^{\gamma N}(k) = \frac{2\pi^2 \alpha \kappa^2}{M^2}$$

- Worldwide program at Mainz, Bonn, GRAAL, SPIN8, LEGS, Jlab, TUNL, etc. is limited to $k = 5$ GeV.

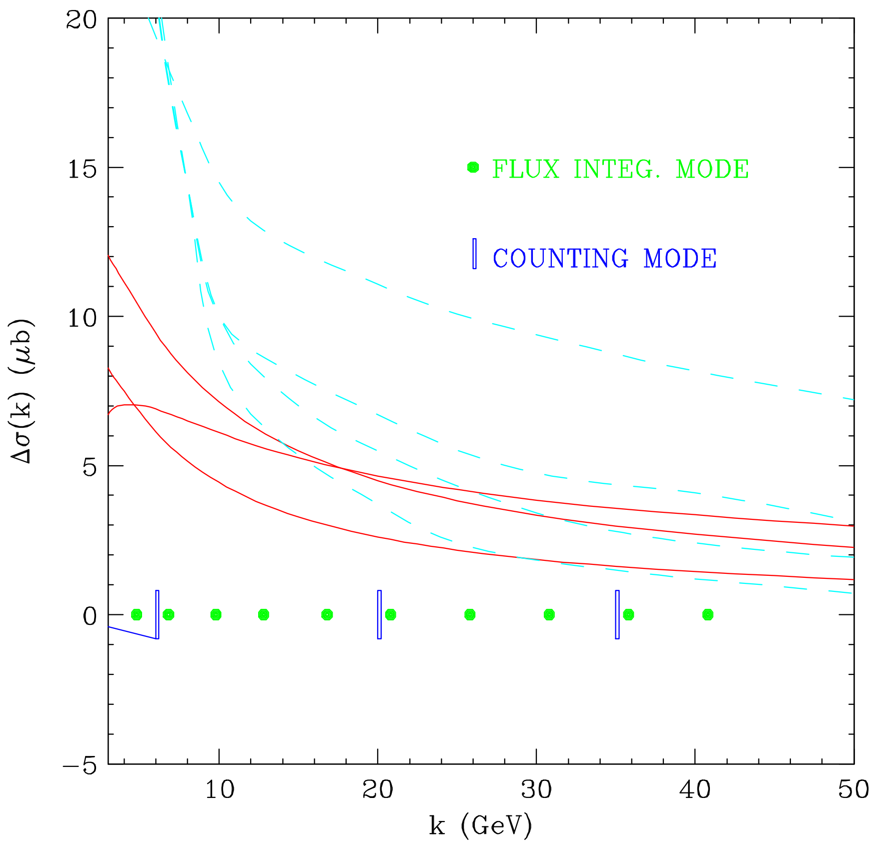
target	$2\pi^2\alpha\kappa^2/M^2$	Analyses
proton	204 μb	257 to 289 μb
neutron	232 μb	169 to 189 μb
isoscalar (p+n)/2	219 μb	213 to 239 μb
isovector (p-n)/2	-15 μb	34 to 65 μb

$\Delta\sigma(k)$ for the Proton



- Estimated E159 errors

$\Delta\sigma(k)$ for the Neutron



- Estimated E159 errors

target	$2\pi^2\alpha\kappa^2/M^2$	$4 < k < 40$ GeV
proton	204 μb	$-14 \pm 0.5 \pm 1.0$ μb
neutron	232 μb	$14 \pm 0.8 \pm 1.0$ μb
isoscalar (p+n)/2	219 μb	$0 \pm 0.4 \pm 0.7$ μb
isovector (p-n)/2	-15 μb	$-28 \pm 0.4 \pm 0.7$ μb

Conclusion

- End Station A at SLAC has new life over the next 5-10 years generated by the upcoming polarized coherent bremsstrahluhng beam.
- Experiments on J/ψ photoproduction (E160), open charm photoproduction (E161), and polarized photoabsorption cross sections (E159) are approved.
- Tentative schedule calls for one experiment per year starting in January 2003, each running 2 calendar months.