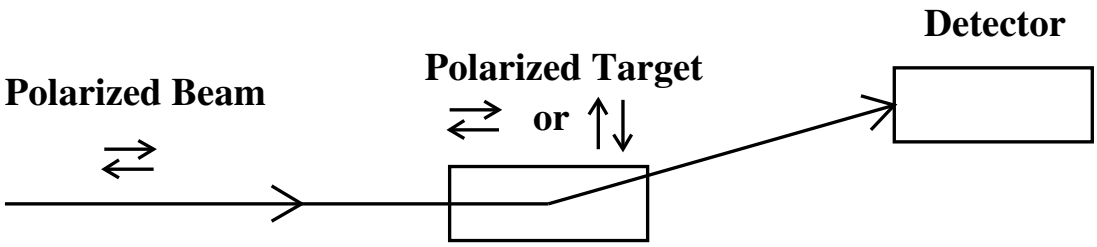
SPIN STRUCTURE OF THE NUCLEON AT SLAC

Latest Results and Future Perspectives

P. Bosted, July 2002

- Final Results on g_1
- Final Results for g_2
- *Future:* Open Charm Photoproduction and $\Delta G(x)$.
- *Future:* GDH Sum Rule

POLARIZED DEEP INELASTIC SCATTERING



$$A_{\parallel} = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} = f_k\Big[g_1(x,Q^2)[E + E'\cos(\theta)] - \frac{Q^2}{\nu}g_2(x,Q$$

$$A_{\perp} = \frac{\sigma^{\downarrow\leftarrow} - \sigma^{\uparrow\leftarrow}}{\sigma^{\downarrow\leftarrow} + \sigma^{\uparrow\leftarrow}} = f_k E'\sin(\theta)\Big[g_1(x,Q^2) + \frac{2E}{\nu}g_2(x,Q^2)\Big]$$

g_1 and g_2 are the polarized structure functions.

→ $A_{\parallel}$ is primarily sensitive to g_1

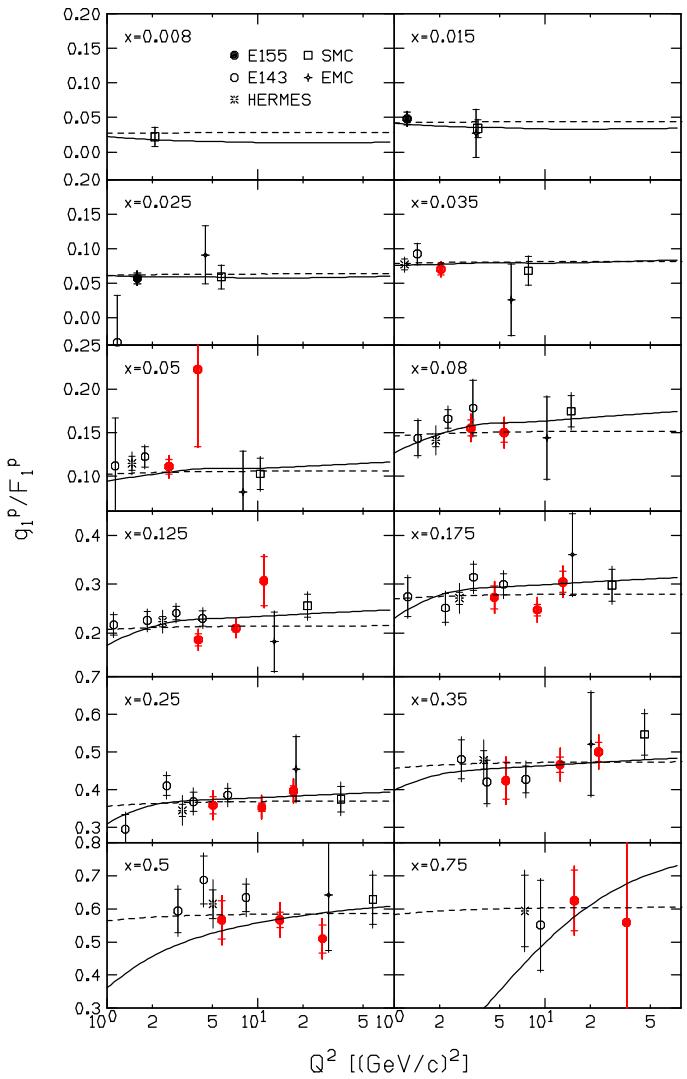
→ $A_{\perp}$ is more sensitive to g_2

→ f_k includes contribution from kinematics and unpolarized structure functions

E155 MEASUREMENTS OF g_1^p and g_1^n

- Measured in 1997: published 2000.
- Electron beam 48 GeV, polarization $P_b = 0.83$
- NH_3 target for protons, polarization $P_t = 0.8$, dilution factor $f = 0.16$
- LiD target for deuterons, $P_t = 0.25$, $f = 0.22$. ^{6}Li treated like unpolarized α plus polarized d.
- Neutron results from proton and deuteron.
- Spectrometers at 2.75, 5.5 and 10.5 degrees.
- Kinematics: $0.014 < x < 0.9$, $1 < Q^2 < 40$ GeV^2.

RESULTS FOR g_1 PROTON VRS Q^2



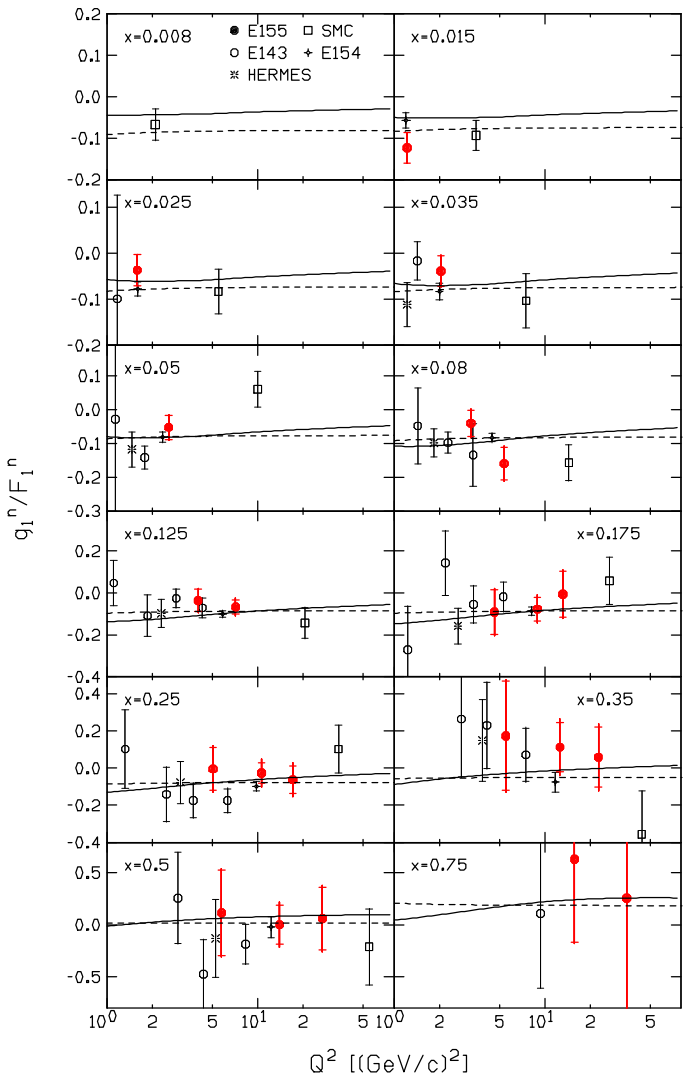
g1 for Proton

Dashed curve: Empirical Fit

Solid curve: pQCD fit

g1/F1 consistent with slight Q^2 dependence

RESULTS FOR g_1 NEUTRON VRS Q^2



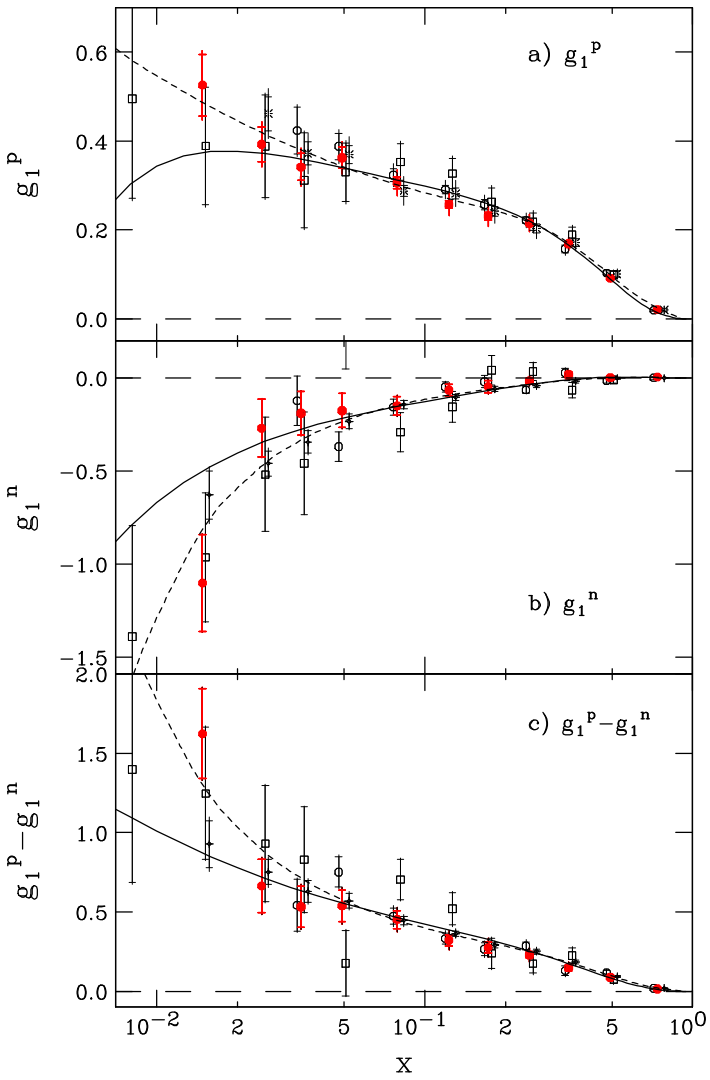
g1 for Neutron

Dashed curve:
Empirical Fit

Solid curve:
pQCD fit

g1/F1 consistent with slight Q^2 dependence (also no Q^2) dependence

RESULTS FOR g_1 VRS x



g1 at Q^2=5 GeV^2

Proton well-determined for x>0.02

Neutron has larger errors

Low-x extrapolation uncertain (less so for p−n)

GLOBAL PQCD FIT TO g_1

- At $Q^2 = 5$ GeV^2 find quark singlet contribution:

$$\Delta\Sigma = 0.23 \pm 0.04(stat) \pm 0.06(syst)$$

(low compared to Ellis-Jaffe prediction of 0.58).

- Proton first moment:

$$\Gamma_1^p = 0.118 \pm 0.004 \pm 0.007$$

- Neutron first moment:

$$\Gamma_1^n = -0.058 \pm 0.005 \pm 0.008$$

- Bjorken Sum Rule:

$$\Gamma_1^p - \Gamma_1^n = 0.176 \pm 0.003 \pm 0.007$$

(in agreement prediction 0.182 ± 0.005).

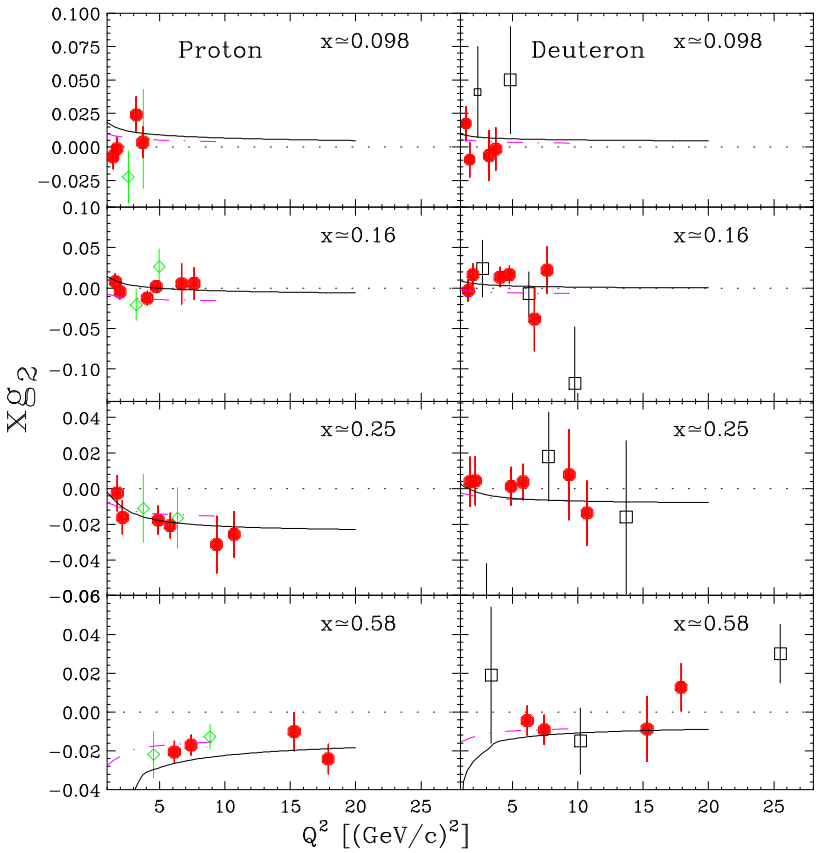
published: Phys. Rev. Lett. B463 (1999) 339; B493 (2000) 19.

E155x MEASUREMENTS OF g_2^p and g_2^d

- Measured in 1999: on web as hep-ex/0204028, submitted to PRL.
- Electron beam 29 GeV and 32 GeV, polarization $P_b = 0.83$
- NH_3 and LiD targets as in E155.
- Spectrometers at 2.75, 5.5 and 10.5 degrees.
- Kinematics: $0.02 < x < 0.8$, $1 < Q^2 < 30$ GeV^2.
- Compare to Twist-2 Wandzura-Wilczek:

$$g_2^{WW}(x, Q^2) = -g_1(x, Q^2) + \int_x^1 \frac{dy}{y} g_1(y, Q^2)$$

RESULTS FOR g_2 VRS Q^2



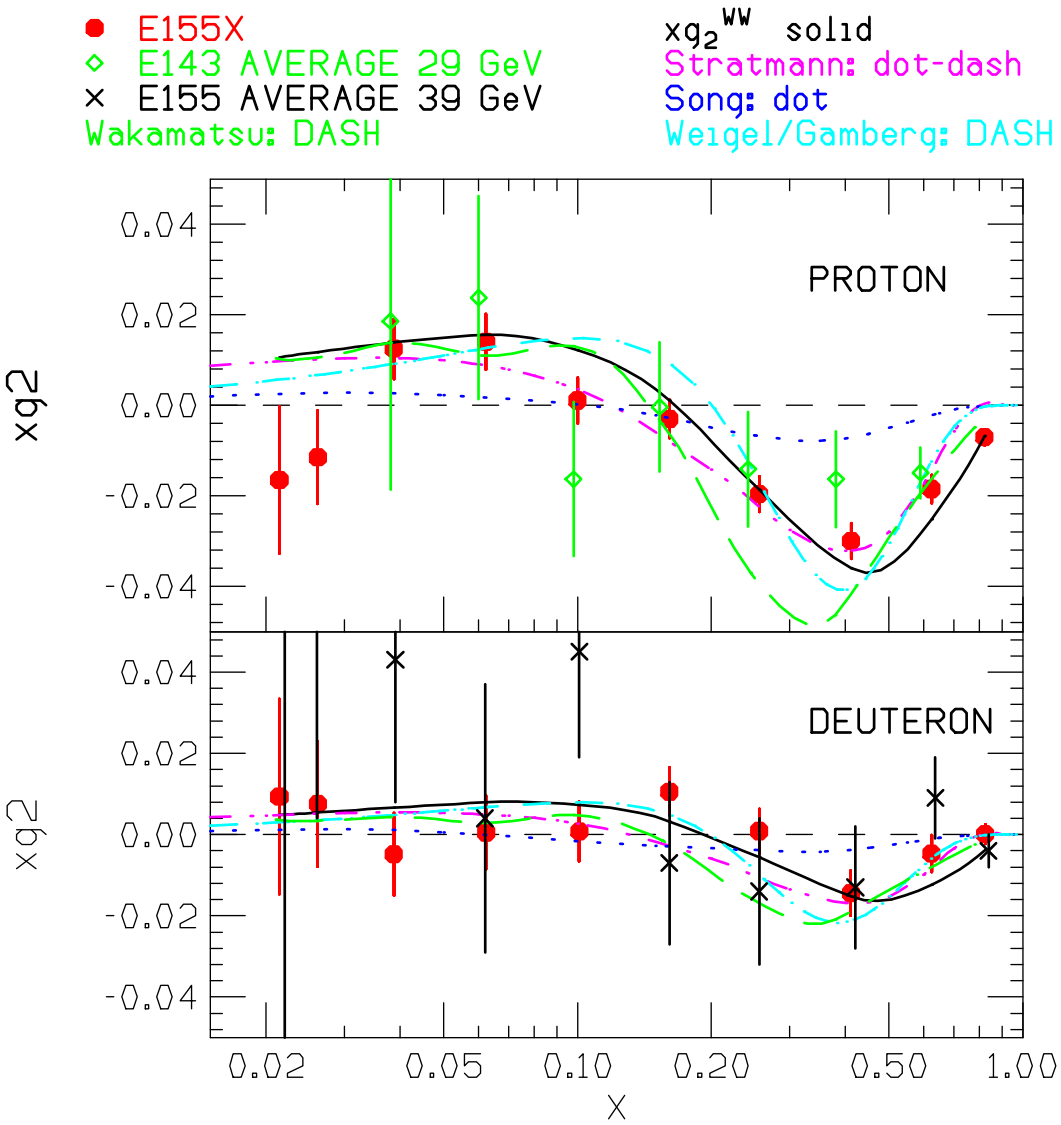
solid curve:
twist−2 g2ww

Q^2 dependence
is weak: agrees
with g2ww

Deuteron errors
larger: consistent
no Q^2 dependence

proton negative
at high x

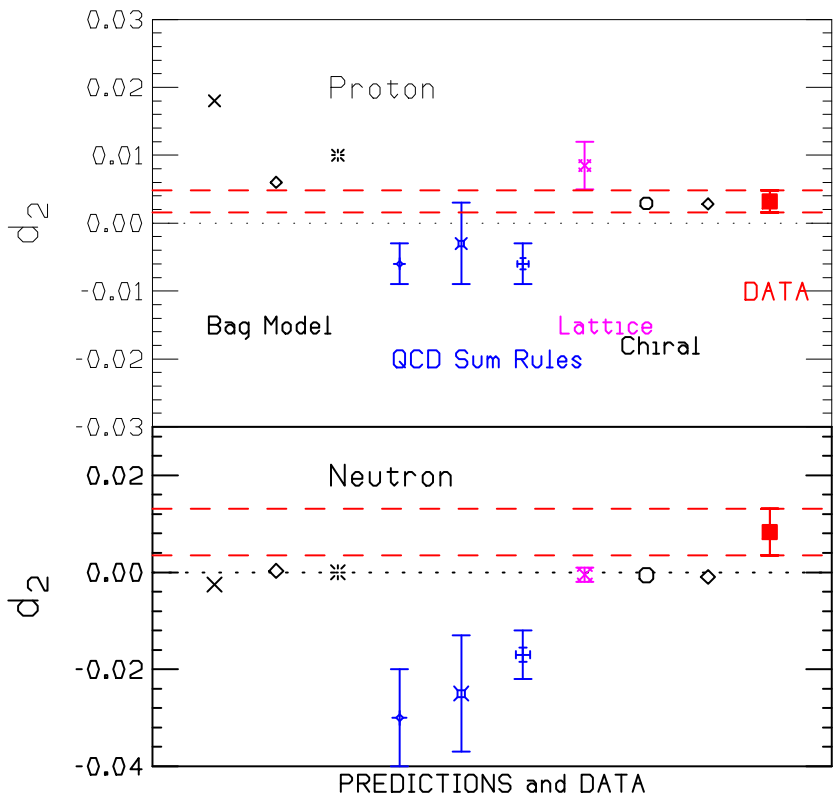
RESULTS FOR g_2 VRS x



THE TWIST-3 d_2 MATRIX ELEMENT

$$d_2 = 3\int_0^1 x^2[g_2(x,Q^2) - g_2^{WW}(x,Q^2)]dx$$

is a measure of twist-3 quark-gluon correlations (if $m_q h_T/M_n$ neglected).



BURKHARDT-COTTINGHAM SUM RULE

- The Burkhardt-Cottingham sum rule predicts:

$$\int_0^1 g_2(x)dx = 0,$$

- For $0.02 \leq x \leq 0.8$ at $Q^2 = 5$ $(\mathrm{GeV/c})^2$. we find -0.042 ± 0.008 for proton and -0.006 ± 0.011 for deuteron.

- Disagreement for proton could be due to low-x. If assume g_2^{WW} for $x < 0.02$, and negligible contribution from $x > 0.8$, obtain -0.022 ± 0.008 for proton and -0.002 ± 0.011 for deuteron. Still 2.8 σ discrepancy for proton. Note, only need to know g_2^{WW} at $x = 0.02$, since

$$\int_0^x g_2^{WW}(y)dy = x\left[g_2^{WW}(x) + g_1(x)\right]$$

ELT SUM RULE

- **Efremov-Leader-Teryaev Sum Rule (assuming isospin symmetry):**

  $$\int_0^1 x[g_1^p(x) + 2g_2^p(x) - g_1^n(x) - 2g_2^n(x)]dx = 0.$$

- **We find** -0.009 ± 0.008 **at** $Q^2 - 2.5$ **GeV**^{2}**, consistent with prediction.**

- **Low-**x **region suppressed by** x**-weighing in integral, test more conclusive than for B.C. Sum Rule.**

E155x MEASUREMENTS OF A_2^p and A_2^d

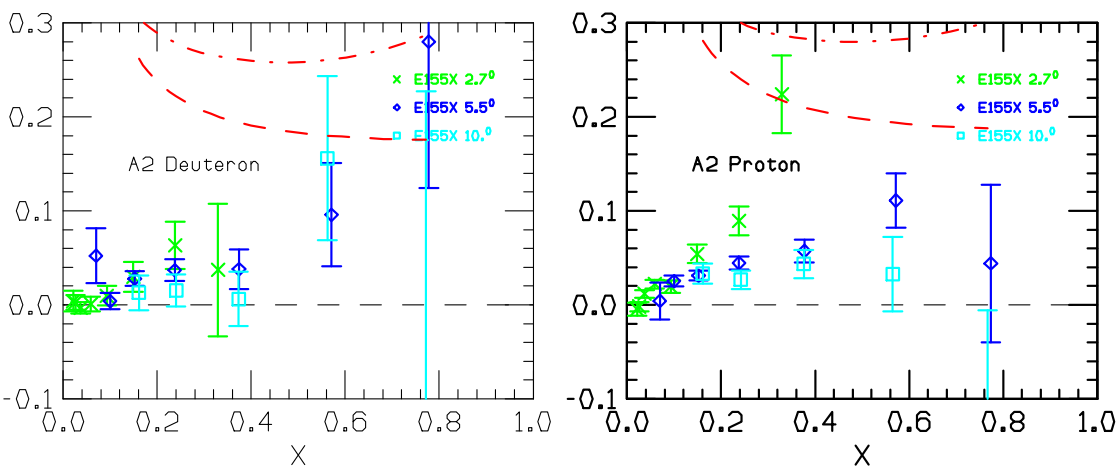
$$A_2(x,Q^2) = \frac{2\sigma_{TL}}{\sigma_T^{1/2} + \sigma_T^{3/2}} = \gamma \frac{g_1(x,Q^2) + g_2(x,Q^2)}{F_1(x,Q^2)}$$

Compare to positivity limit

$$A_2 < \sqrt{R(x,Q^2)}$$

and Soffer limit

$$A_2 < \sqrt{R(x,Q^2)(1 + A_1(x,Q^2))/2}$$



E161

MEASUREMENT OF

GLUON SPIN DISTRIBUTION IN NUCLEONS USING POLARIZED OPEN CHARM PHOTOPRODUCTION

Gluon Spin Distribution in Nucleons using Polarized Open Charm Photoproduction

S. Rock, D. Crabb, P. Bosted co-spokespersons

Planned to run in 2005

http:www.slac.stanford.edu/exp/e161/

WHY MEASURE THE GLUON POLARIZATION?

1. FUNDAMENTAL SUM RULE
   $1/2 = 1/2 \cdot \Delta\Sigma + \Delta G + L_z$
   - $\Delta\Sigma \sim 0.23 \pm 0.07$ (from quarks)
   - ΔG (from Gluons)
   - L_z includes quarks and gluons. Possible to measure it.

2. pQCD CONSISTENCY FOR ALL REACTIONS
   - g_1 FROM DIS (SLAC,SMC,EMC,HERMES)
   - PHOTOPRODUCTION (COMPASS, HERMES, SLAC)
   - P-P at RHIC

3. FUNDAMENTAL PROPERTY OF NUCLEON
   - 30 YEARS ON UNPOLARIZED PARTON DISTRIBUTIONS
   - 10 YEARS ON POLARIZED QUARKS

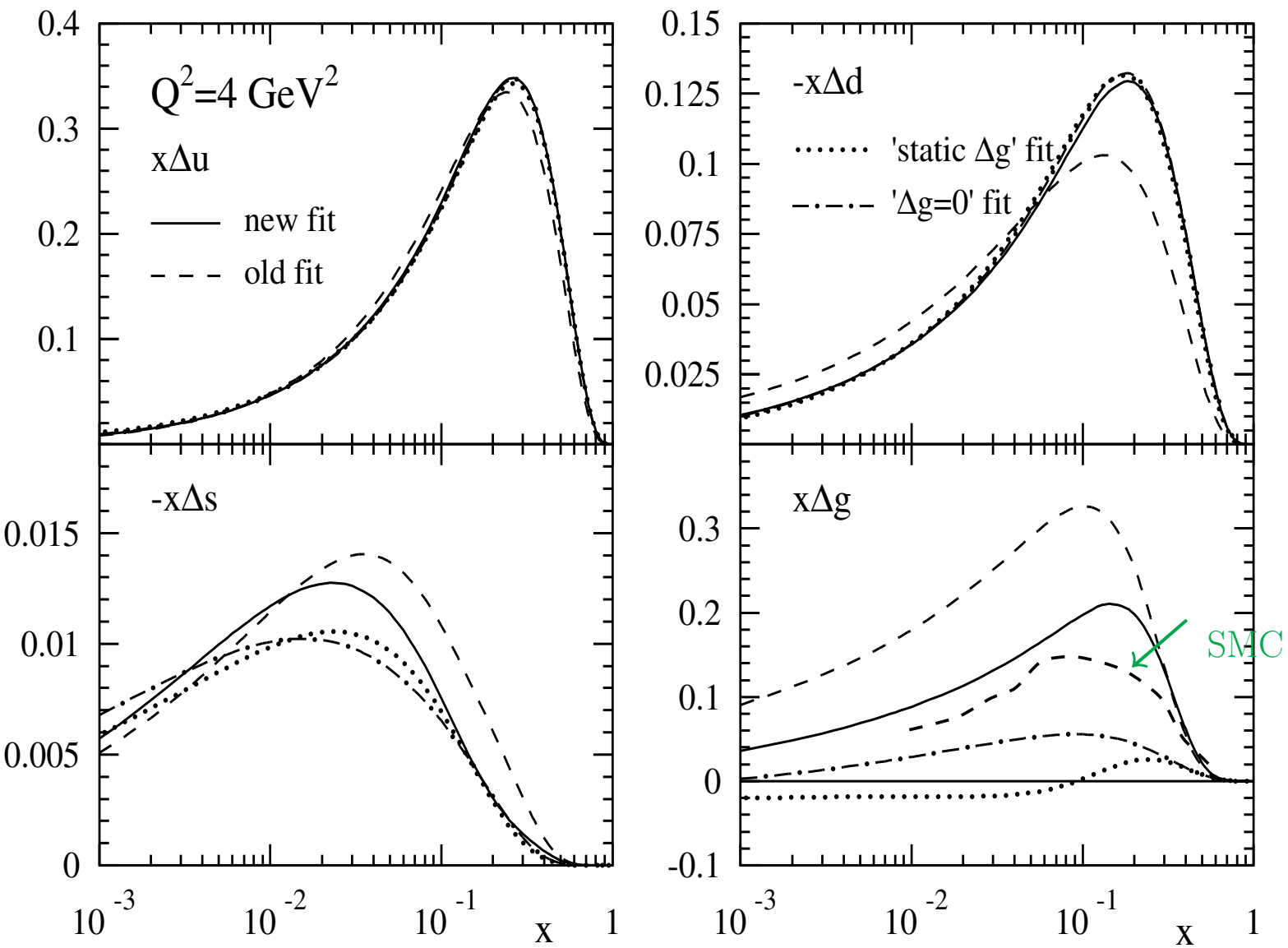
WHAT WE KNOW

POLARIZED PARTON DISTRIBUTIONS FROM pQCD EVOLUTION EQUATIONS. THE FIT OF

Gluck, Reya, Stratmann and Vogelsang (1999)

$$\Delta q(x,Q^2) = q_i^{\uparrow}(x,Q^2) - q_i^{\downarrow}(x,Q^2)$$

Δg ONLY APPEARS in NLO

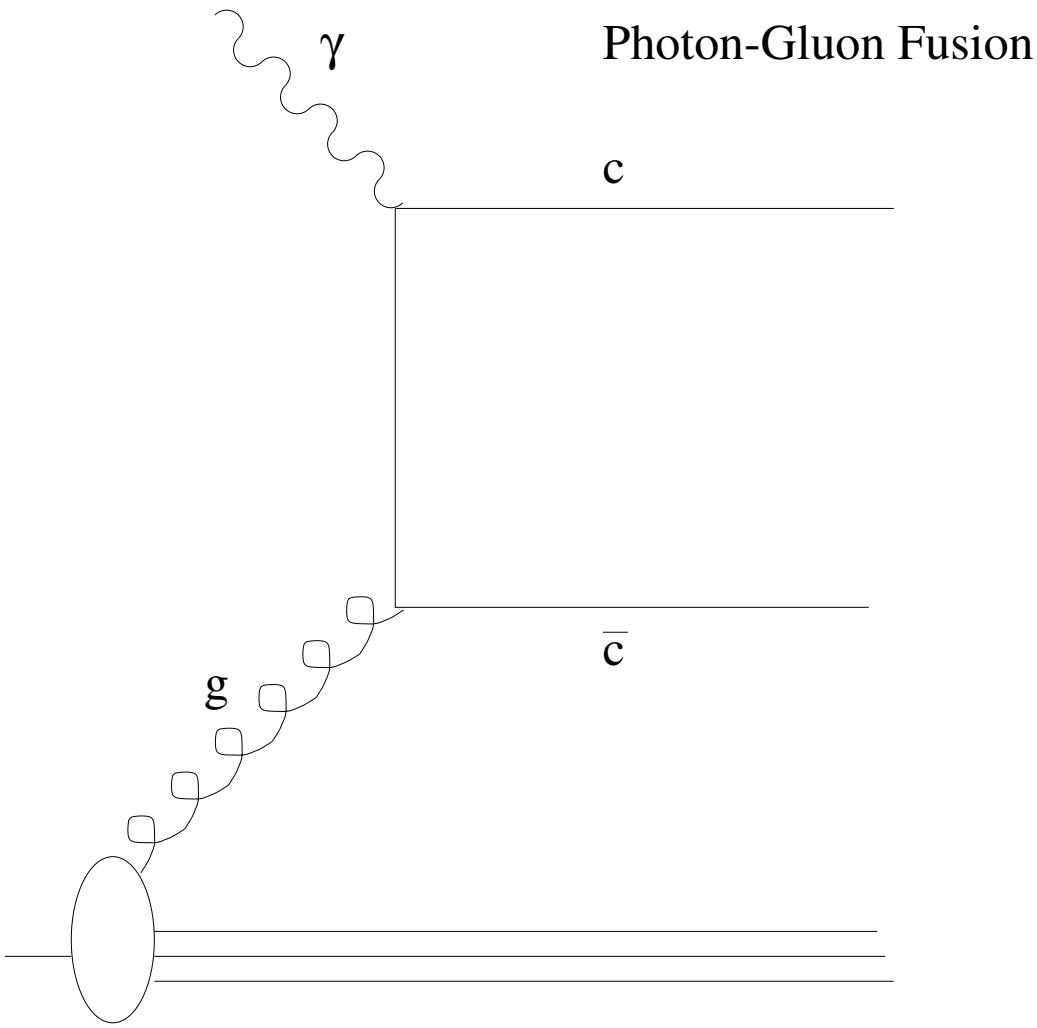


HOW TO MEASURE $\Delta g(x, Q^2)$ DIRECTLY

ZED COHERENT BREMSSTRAHLUNG PHOTO

POLARIZED LiD TARGET

PHOTON-GLUON FUSION



EXPERIMENTAL STRATEGY

Tag Charm With Single Decay μ

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

BACKGROUNDS

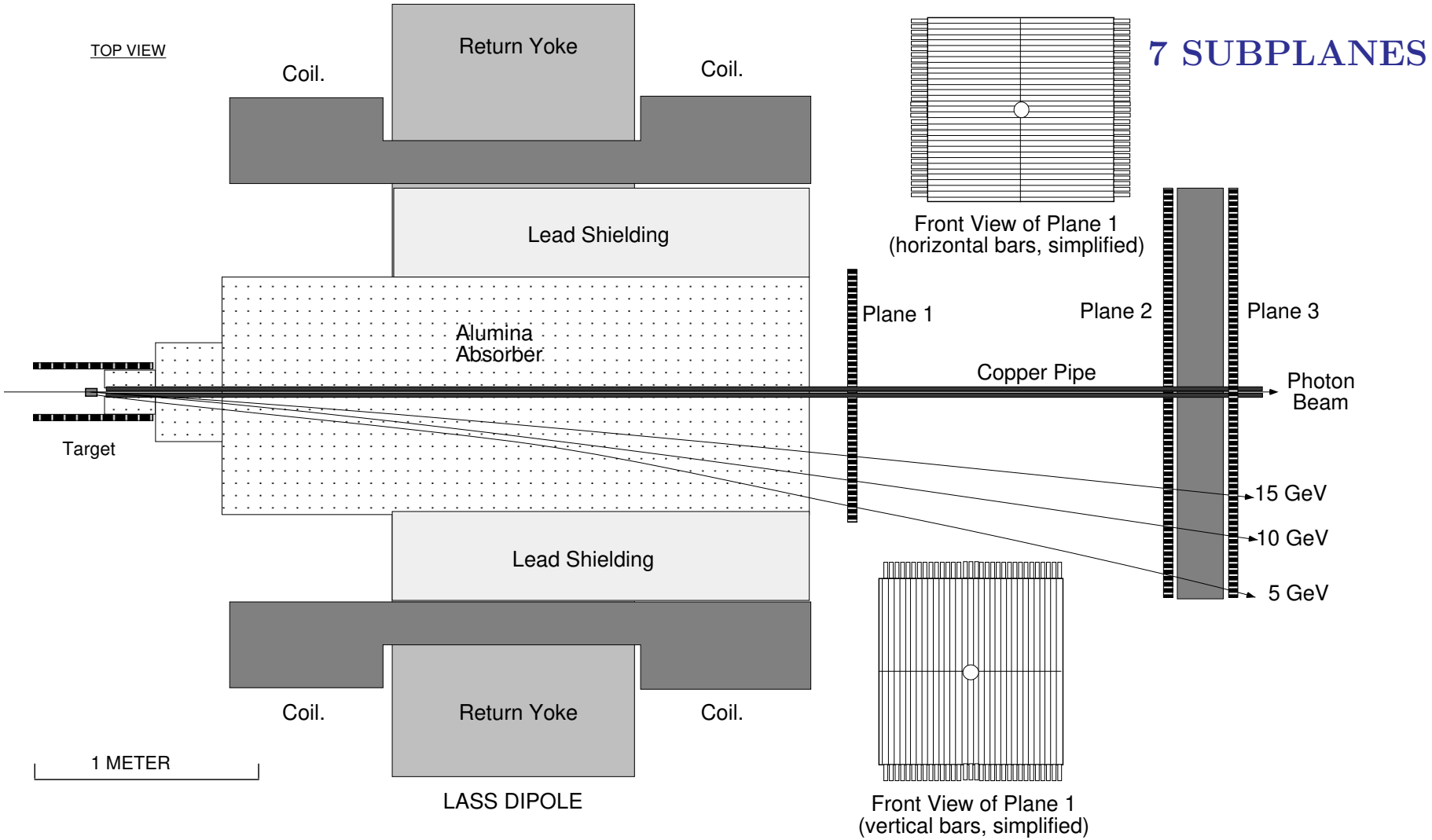
- μ FROM K and π DECAY (Long Lifetime)
- Bethe-Heitler μ PAIRS
- J/ψ DECAY (Small)
- VECTOR MESON DECAYS (Small)
- ASSOCIATED PRODUCTION (Small)
- FINAL STATE INTERACTIONS (Small)
- DIFFRACTIVE PRODUCTION (Small)

EXPERIMENTAL STRATEGY

- **HIGH POLARIZATION TARGET ($> 60\%$)**
- **HIGH POLARIZATION BEAM (80%)**
- **MEASURE MOMENTUM of μ**
  - High Field Magnet
  - Fine Grain Hodoscopes
  - Good Time Resolution
- **ABSORB K and π BEFORE DECAY**
  - $\sim$ 10 Interaction Lengths (38 R.L.)
  - Monte Carlo Predicts Rates
  - Asymmetry Very Small (E155)
  - Two Absorber Setups
    75% and 25% of Time
  - Multiple Scattering of μ Almost the Same
- **VETO $\mu^+\mu^-$ PAIRS**
  (B-H, J/ψ, VECTOR MESONS)
  - Some Singles Remain (Acceptance)
  - Calculate Based on Pairs and Known σ

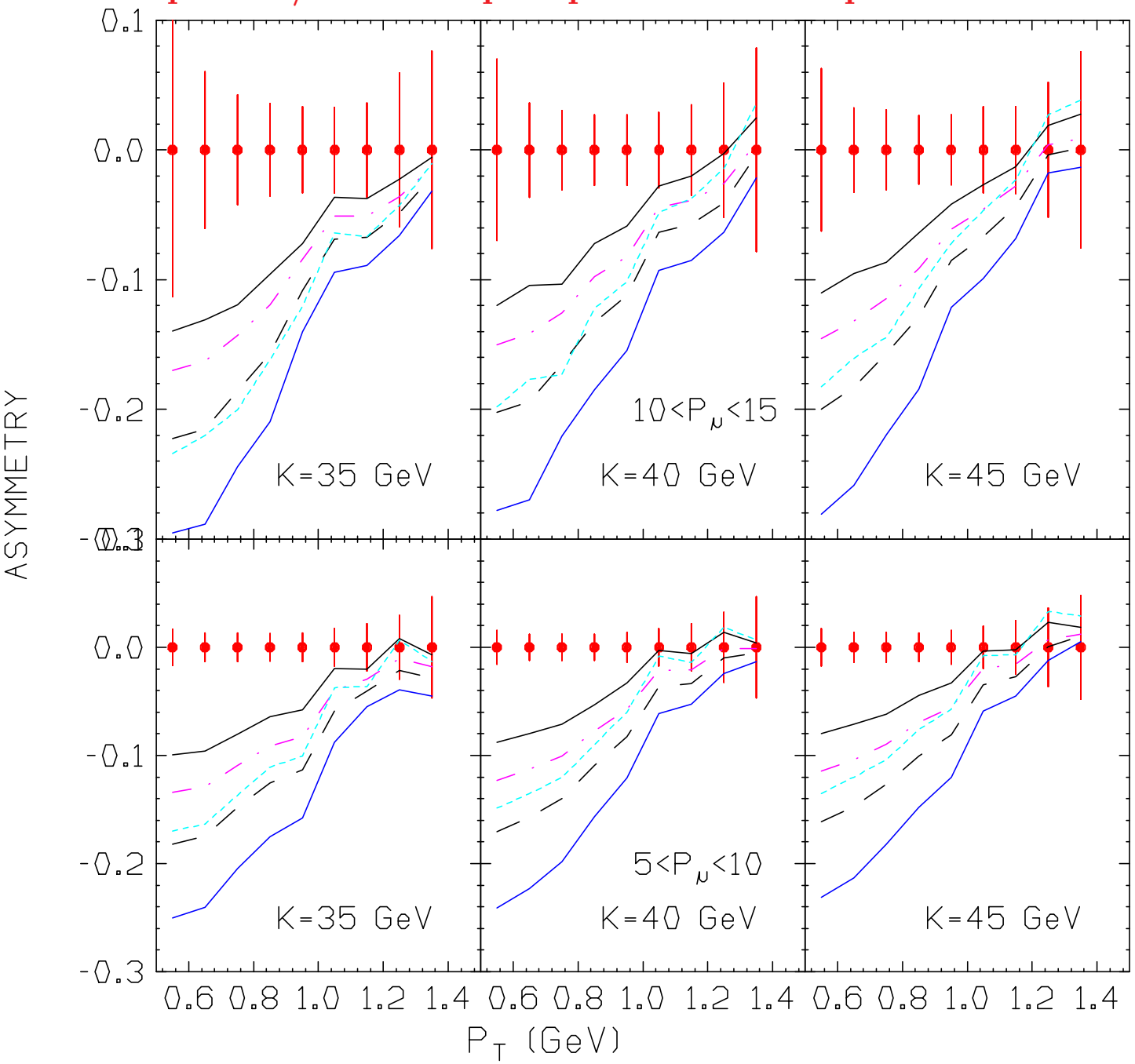
μ SPECTROMETER

NORMAL MODE

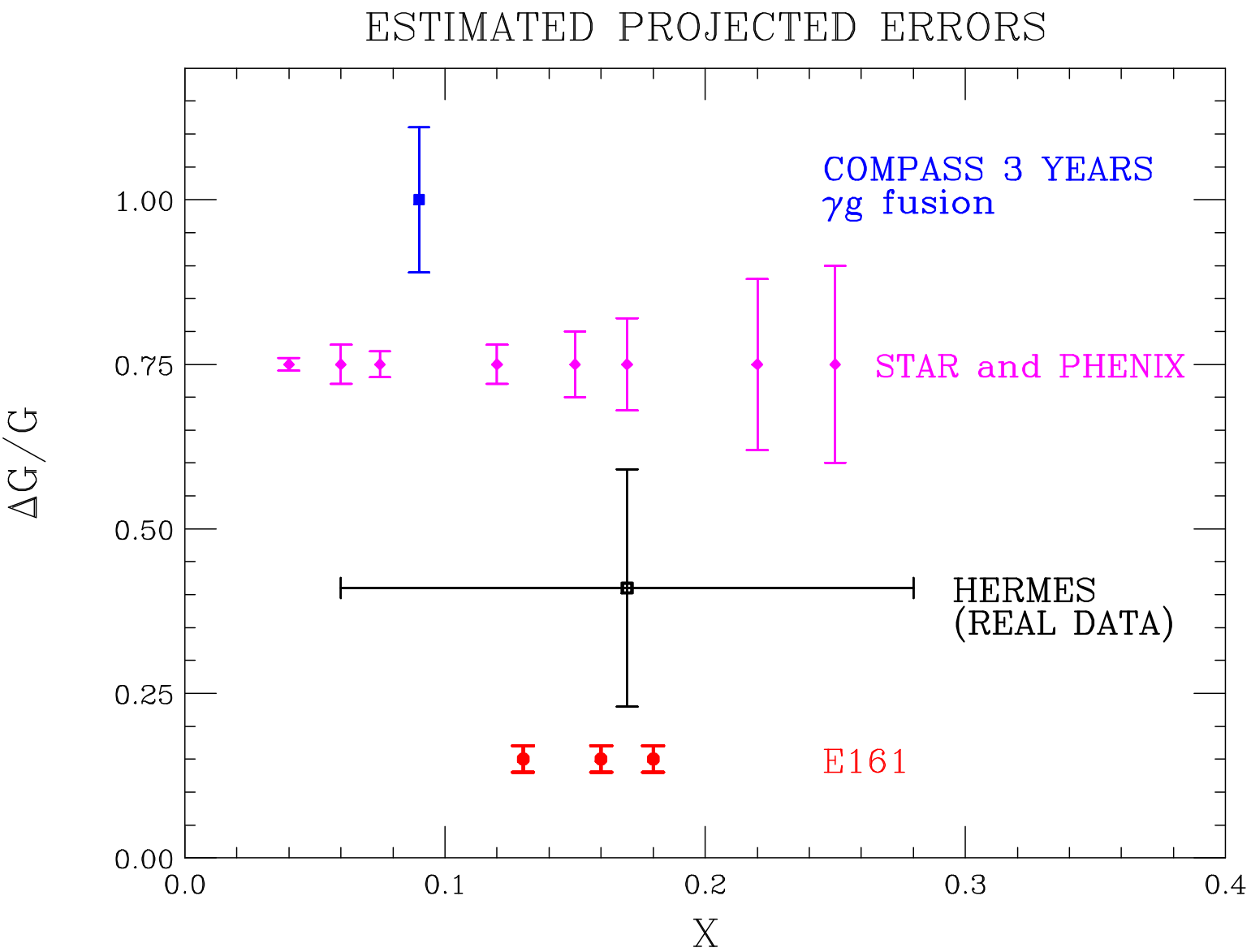


EXPECTED RESULTS

for Asymmetry in Cross Sections with photon/nucleon Spins parallel or anti-parallel



COMPARISON OF EXPERIMENTS



SLAC-PROPOSAL-E159

Proposal to Measure $\Delta\sigma^{\gamma N}(k)$ and the High Energy Contribution to the Gerasimov-Drell-Hearn Sum Rule

P. Bosted, D. Crabb co-spokespersons

Planned to run in 2005/6

http:www.slac.stanford.edu/exp/e159/

INTRODUCTION

- Total photoabsoption cross section $\sigma^{\gamma N}(k)$ depends only on photon energy k for real photons.
- Can be decomposed into spin 1/2 and 3/2 final states $\sigma_{3/2}$ and $\sigma_{1/2}$, corresponding to helicity of photon aligned or anti-aligned with spin of nucleon.
- Spin-averaged $\sigma^{\gamma N}(k) = (\sigma_{1/2} + \sigma_{3/2})/2$ well-measured (including SLAC early 1970's). Roughly constant at 120 μb.
- We propose to measure

$$\Delta\sigma^{\gamma N}(k) = \sigma_{3/2} - \sigma_{1/2}$$

using circularly polarized photons and longitudinally polarized nucleons.

The GDH SUM RULE

- Relates integral over $\Delta\sigma(k)$ to anomalous magnetic moment κ of target with spin S (composite or elementary).

$$\int_{k_\pi}^{\infty} \frac{dk}{k} \Delta\sigma^{\gamma N}(k) = \frac{2\pi^2 \alpha \kappa^2}{M^2} \qquad (1)$$

- Follows from general principles of causality, universality, Lorentz and electromagnetic gauge invariance.
- One assumption: that unsubtracted dispersion relation can be used for $f_2(\nu)$.
- Scale of convergence gives scale of highest spin-flip excitations of target.
- $\Delta\sigma^{\gamma N}(k)$ must decrease with k at high k for integral to converge. Contrast to $\sigma^{\gamma N}(k)$, known to increase with k at high energies.

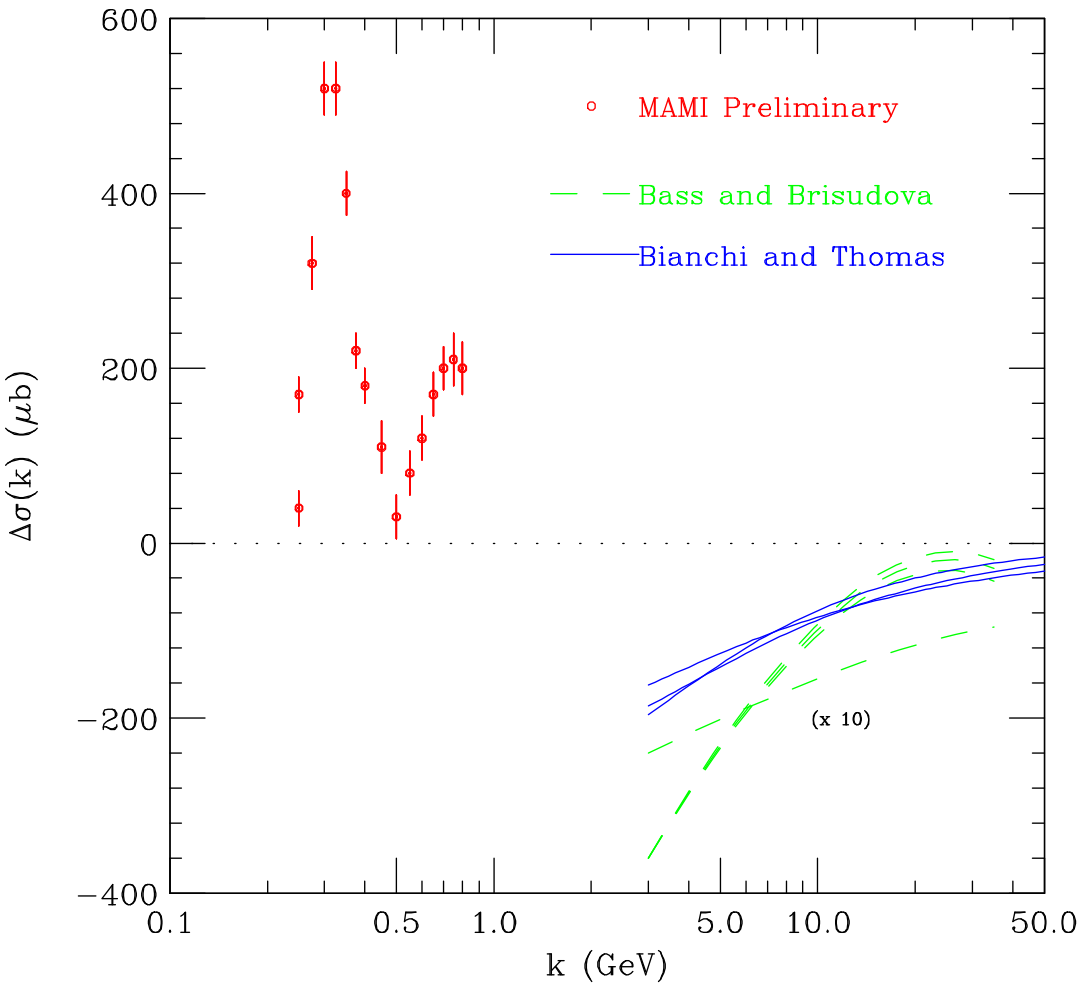
- Various resonance region multi-pole analyses have made estimates of integrals.

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

- Large discrepancy, especially isovector case.
- Non-resonant contribution important?
- High energy contributions important?
- Need data on both proton and neutron to find out.
- Worldwide program at Mainz, Bonn, GRAAL, SPIN8, LEGS, Jefferson Lab, TUNL, other, but limited to about 5 GeV.

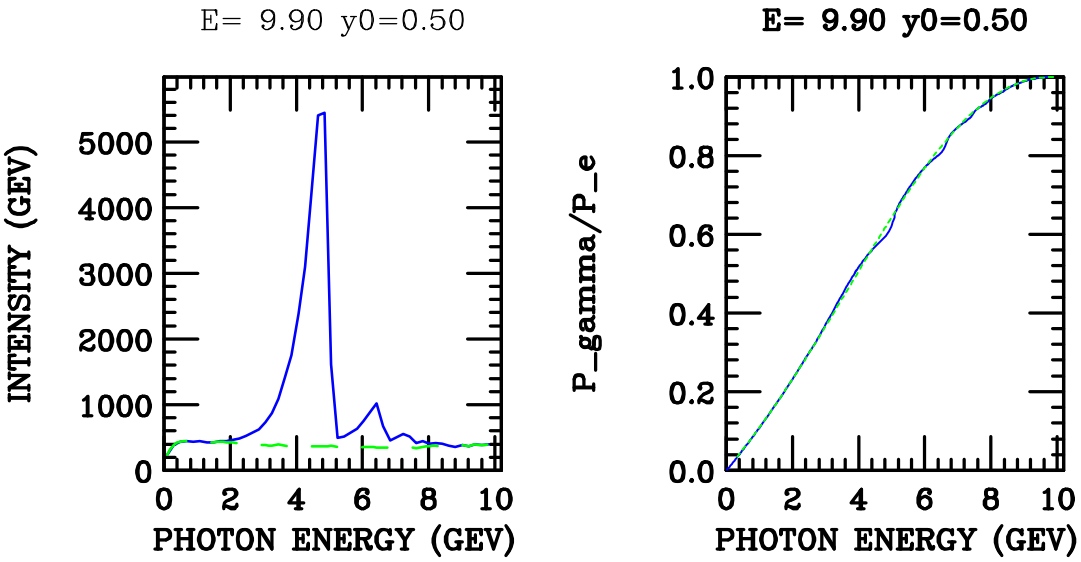
LOW ENERGY BEHAVIOR OF $\Delta\sigma(k)$

Preliminary data from Mainz on proton. Resonant excitations are evident (especially $\Delta(1232)$).



EXPERIMENTAL OVERVIEW

- **Coherent bremsstrahlung** provides circularly polarized photons $4 < k < 40$ GeV (actually elliptical).



- **Atomic Compton scattering from polarized Fe planned to check polarization calculations (predict similar to ordinary bremsstrahlung).**

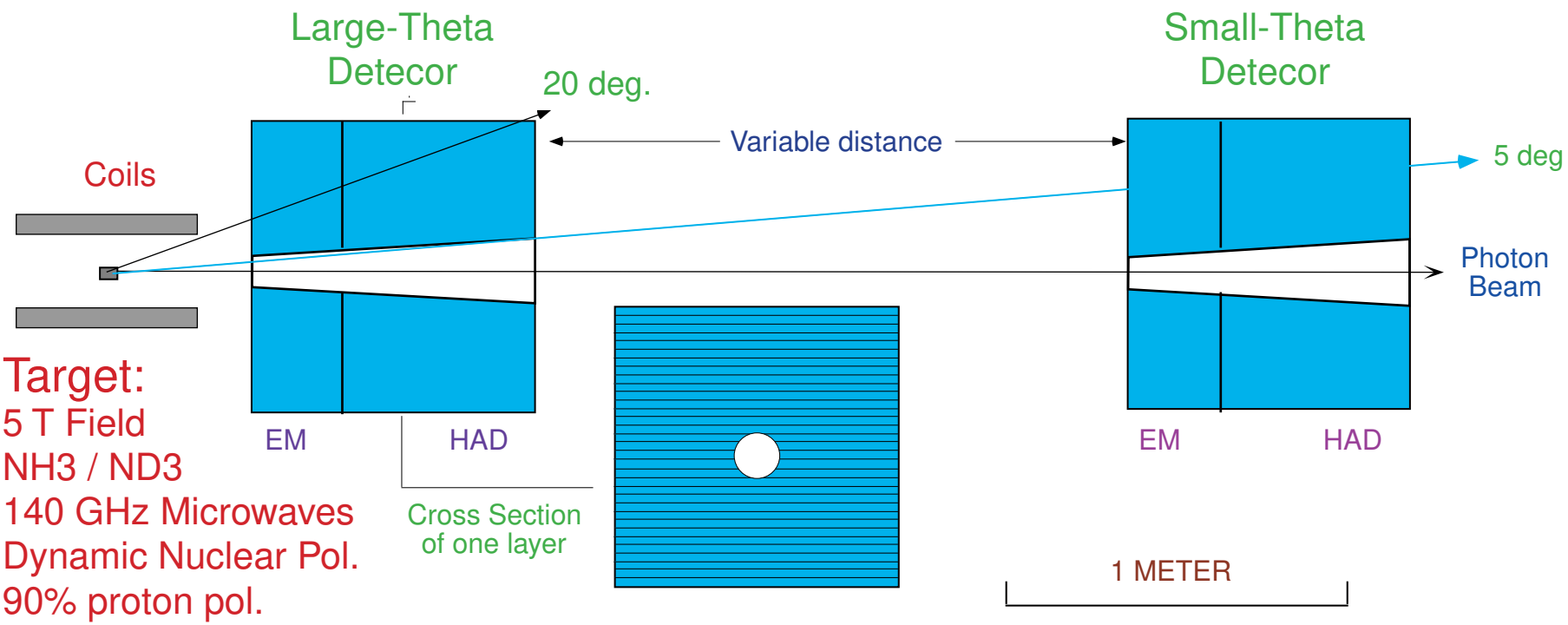
$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{2m_e^2}\left(\frac{k}{k_0}\right)^2\left[\frac{k}{k_0}+\frac{k_0}{k}-\sin^2\theta - P_\gamma P_e(1-\cos\theta)\cos\theta\frac{(k+k_0)}{m_e}\right],$$

- Subtract incoherent contributions to obtain $\Delta\sigma(k)$ at discrete values of k.

EXPERIMENTAL OVERVIEW (cont).

- Longitudinally polarized NH_3 (90%) and ND_3 ($> 30\%$) targets (same as used in E155 and E155x)
- Split solenoid target magnet allows θ up to 45 degrees ($> 99\%$ of total cross section for $k > 5$ GeV).
- Measure total cross section asymmetry with large calorimeters.
- Reject E.M. backgrounds with cuts, longitudinal segmentation of detector, and/or calculations
- Measure in Counting Mode for lower systematic error (each hadronic interaction is individually counted)
- Use Flux Integration Mode for smaller statistical errors (total hadronic energy summed over many interactions).

Target and Detectors



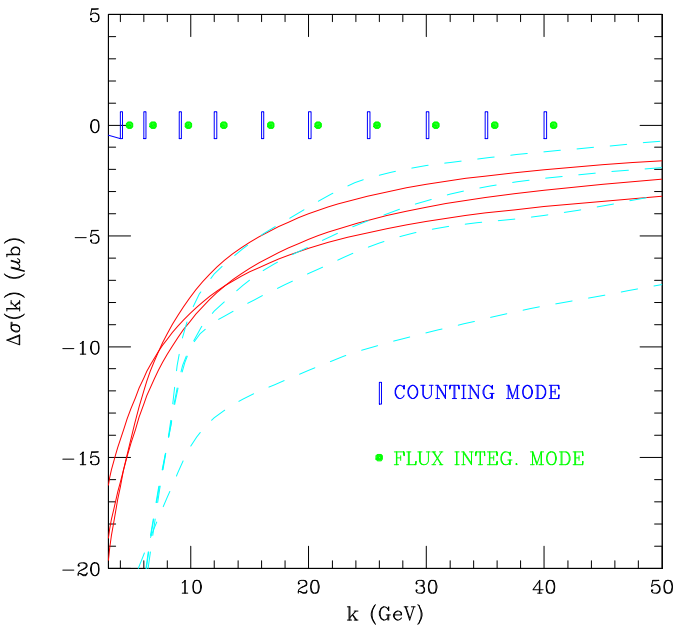
Target:
5 T Field
NH3 / ND3
140 GHz Microwaves
Dynamic Nuclear Pol.
90% proton pol.
40% deuteron pol.
nitrogen unpolarized

Alternating planes
of horizontal and vertical
scintillator strips

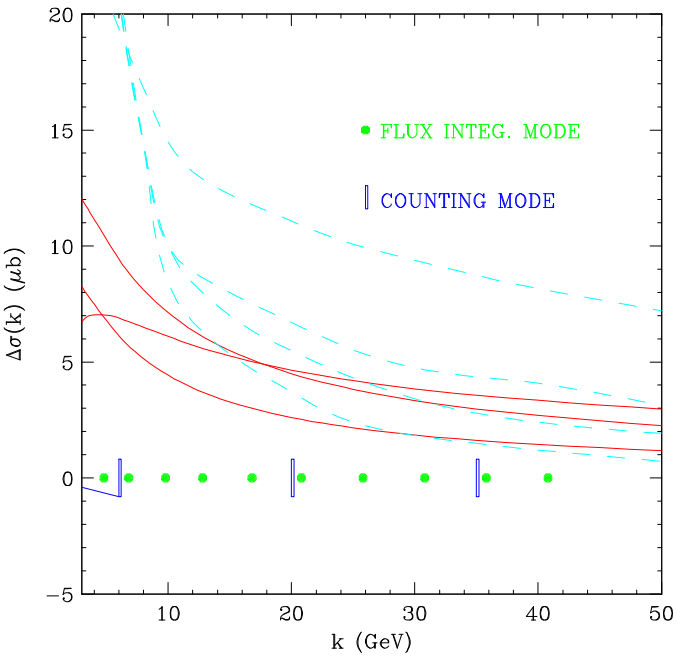
27 EM and 53 Had layers summed
with longitudinal wave-shifter bars

EXPECTED ERRORS FOR PROTON

Systematic errors (not shown) expected to be 6% to 8% (relative).



EXPECTED ERRORS FOR NEUTRON



SUMMARY

- Final SLAC results on g_1, g_2 available
- Bjorken, ELT sum rules look ok.
- Need large g_2^p at low x for BC sum rule.
- Future holds competitive measurements of $\Delta G(x)$
- and only data for GDH sum rule at high energy