THE GLUON SPIN STRUCTURE FUNCTION FROM SLAC E161 and HERMES

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REPRESENTING THE REAL PHOTON COLLABORATION

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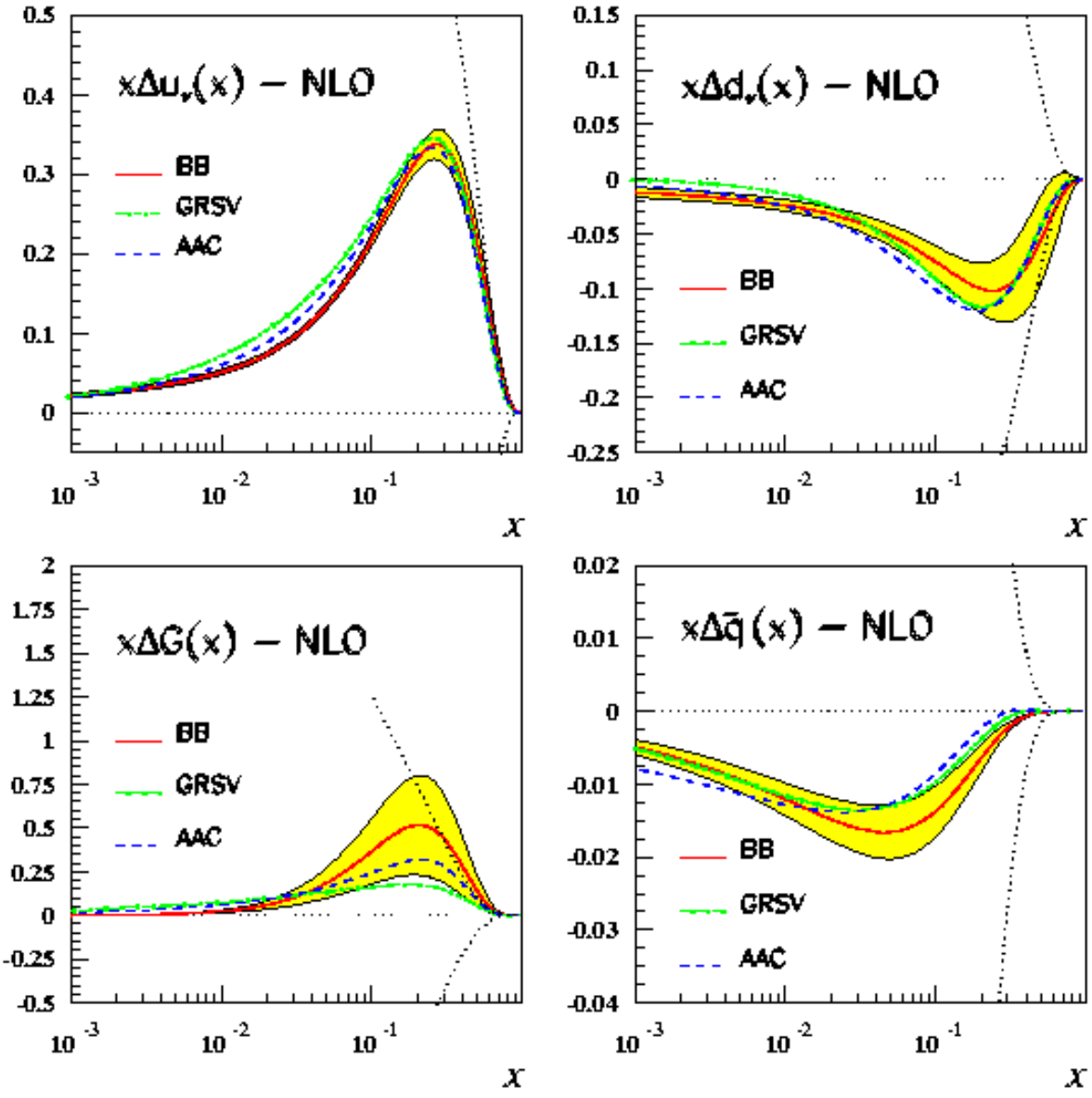
- SOME THEORY
  - POLARIZED GLUON DISTRIBUTION POORLY KNOWN
  - DIS MEASUREMENTS OF g_1 PUT WEAK LIMITS
- E161 EXPERIMENTAL METHOD
  - PHOTON-GLUON FUSION $\Rightarrow$ CHARM
  - POLARIZED PHOTON BEAM
  - POLARIZED TARGET
  - MUON DETECTION
  - EXPECTED ACCURACY
- HERMES PLANS

NLO pQCD FIT TO g_1 DATA

BLUMLEIN and Bottcher (2001)



POLARIZED GLUON DISTRIBUTIONS FROM pQCD EVOLUTION EQUATIONS.

VARIOUS FITS

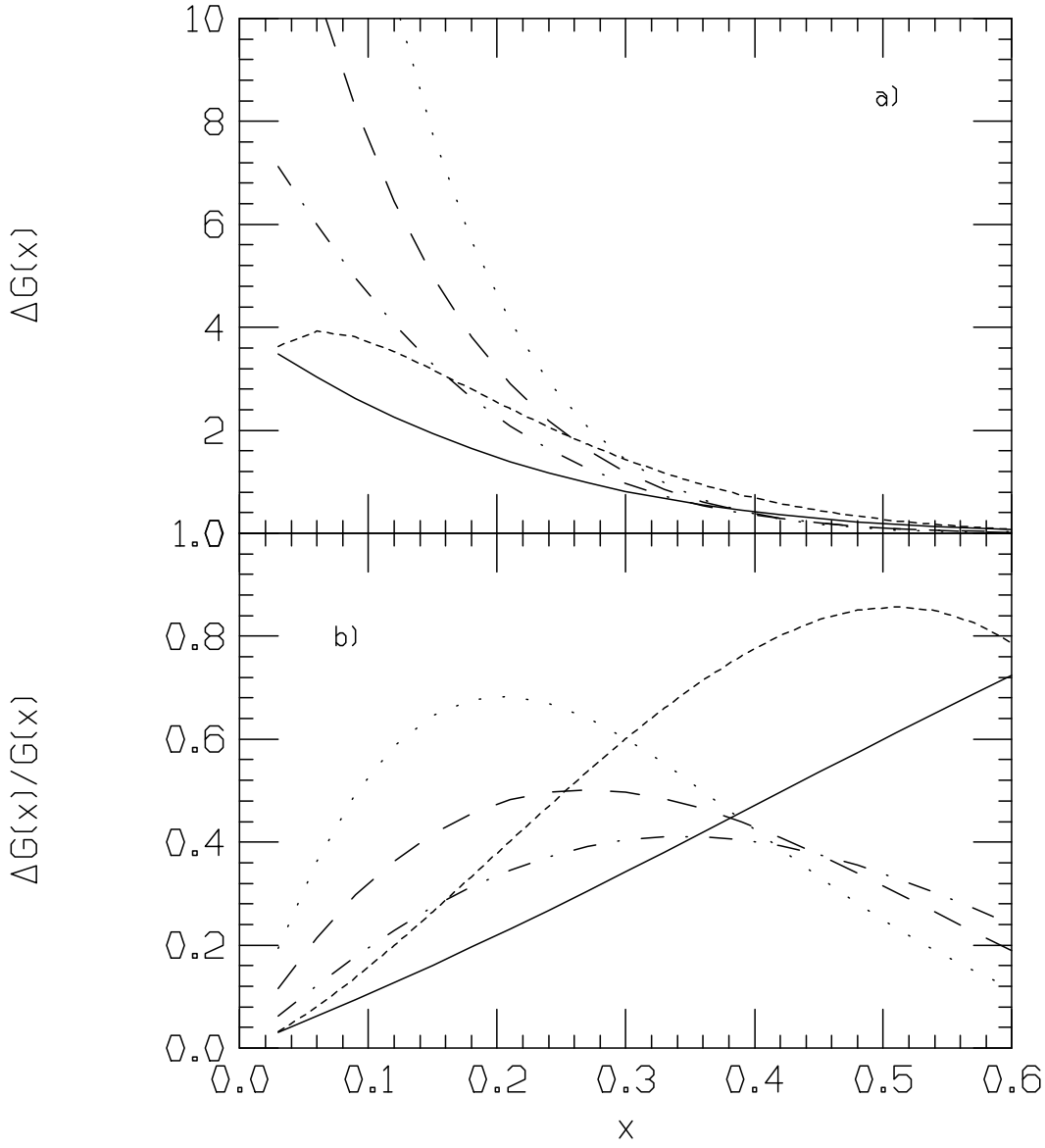
——— Brodsky (1995) $\Delta G = 0.7$

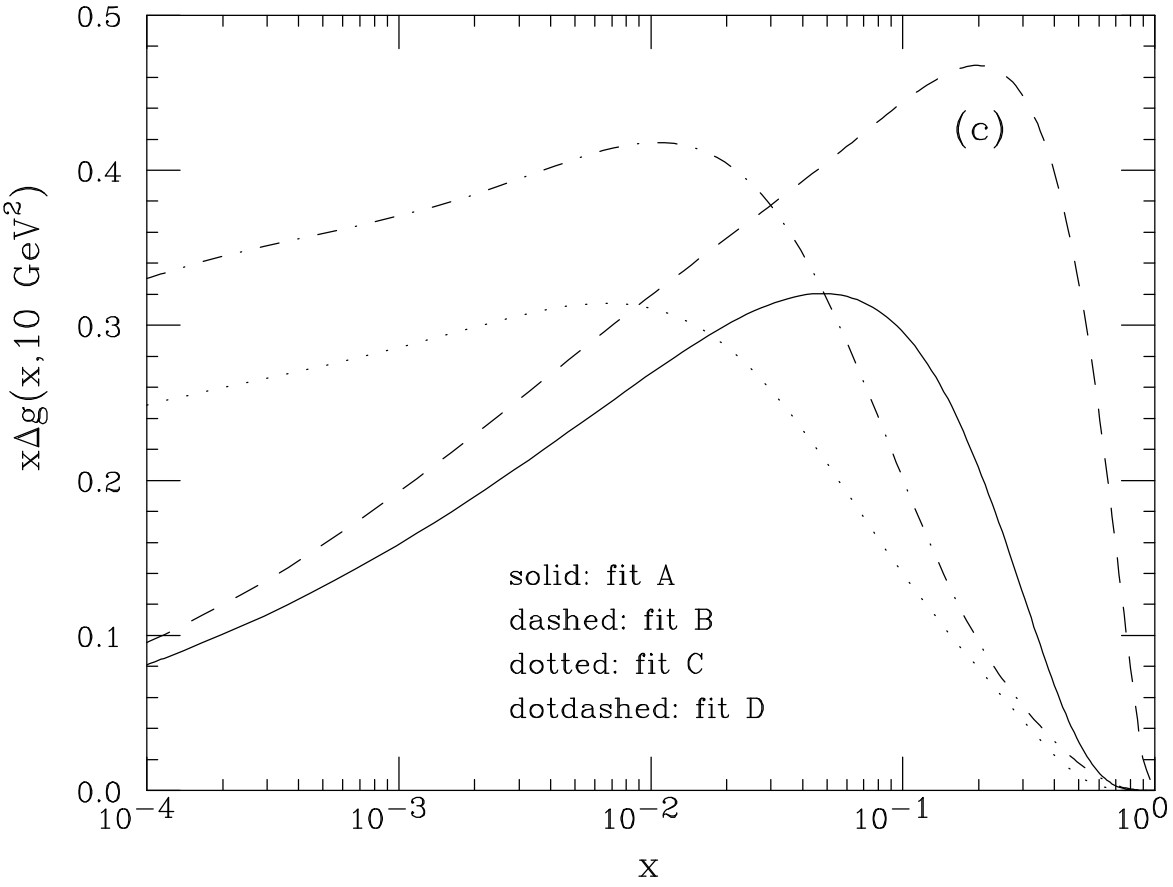
– – – Sterling (1996) $\Delta G = 1.7$

. . . . . GRSV (1996) $\Delta G = 2.3$

– · – Ball AR Model (1996) $\Delta G = 1.1$

- - - - Ball OS Model (1996) $\Delta G = 1.0$



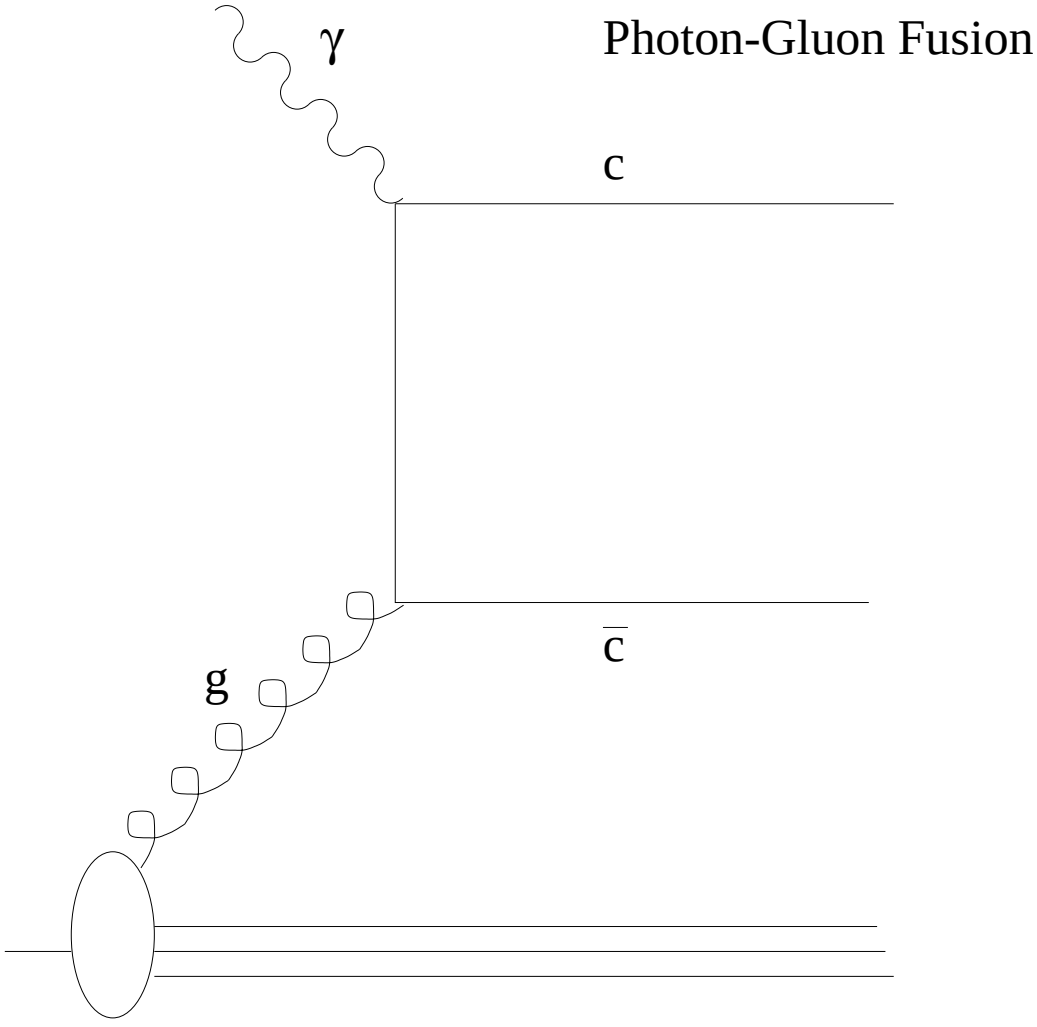

0.5
0.4
0.3
0.2
0.1
0.0
$x\Delta g(x,10\ GeV^2)$
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
x
(c)
solid: fit A
dashed: fit B
dotted: fit C
dotdashed: fit D

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

POLARIZED PHOTON BEAM

POLARIZED LiD TARGET

PHOTON-GLUON FUSION



TOTAL CHARM PHOTOPRODUCTION σ

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

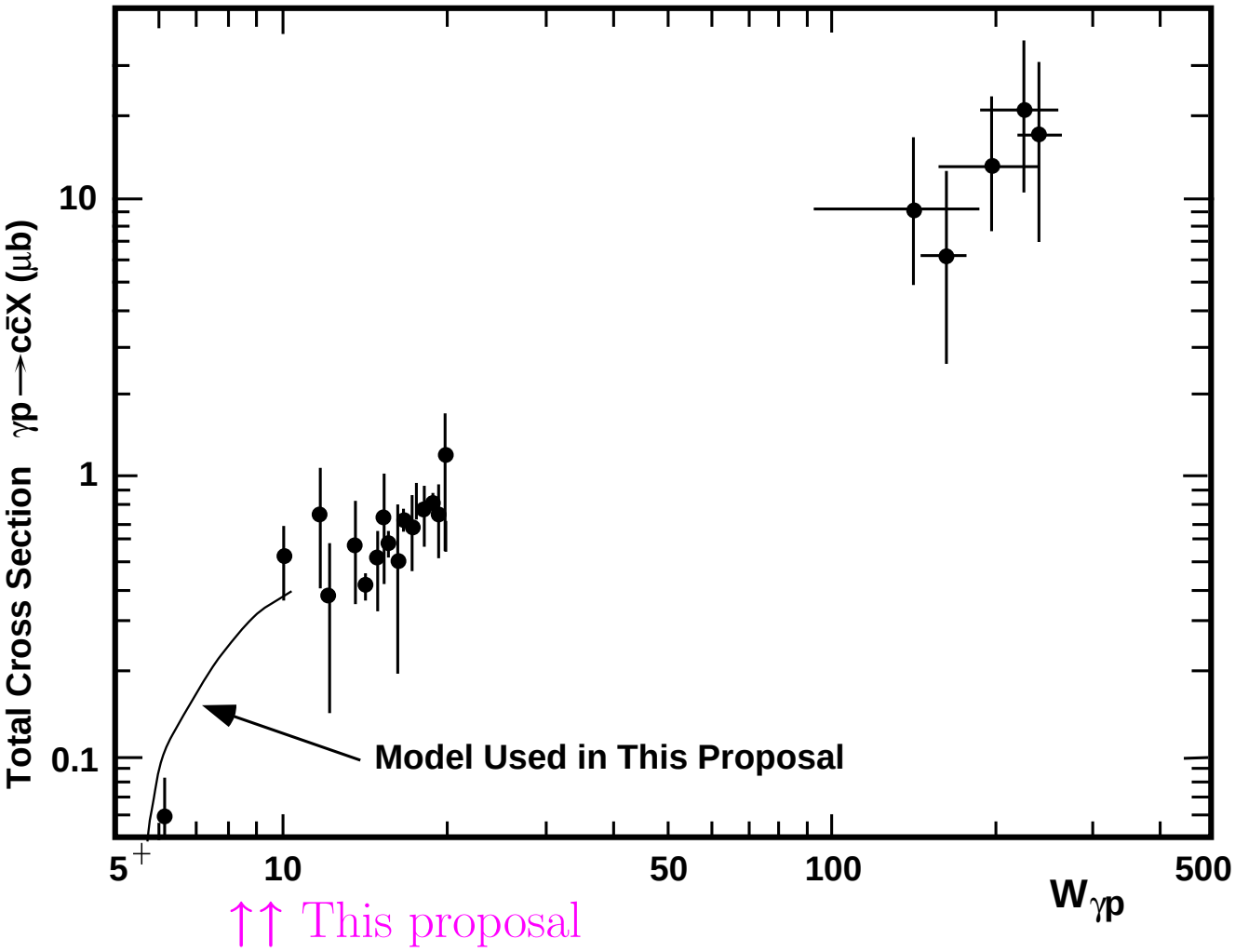
$\mathbf{x_{min}} = \mathbf{4m_c^2/2Mk}$

$s = 2Mk + M^2 = W_{\gamma p}^2$

$\beta = \sqrt{1 - 4m_c^2/\hat{s}}$ is the c.m. velocity of $\mathbf{c, \bar{c}}$

$\hat{\mathbf{s}} = \mathbf{xs}$ is the energy of the photon-gluon system squared

$\sigma(\hat{s}, \cos(\theta^*))$ is for the hard scattering



↑↑ This proposal

POLARIZED $c\bar{c}$ CROSS SECTION

$$\boldsymbol{\Delta\sigma = \sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}$$

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

where

$$\Delta\sigma(\hat{s}, \cos(\theta^*)) = \frac{4}{9}\frac{2\pi\alpha\alpha_s(\hat{s})}{\hat{s}}\left[\frac{4m_c^4(\hat{t}^3+\hat{u}^3)}{\hat{t}^2\hat{u}^2} + 2\frac{\hat{t}^2+\hat{u}^2-2m_c^2\hat{s}}{\hat{t}\hat{u}}\right].$$

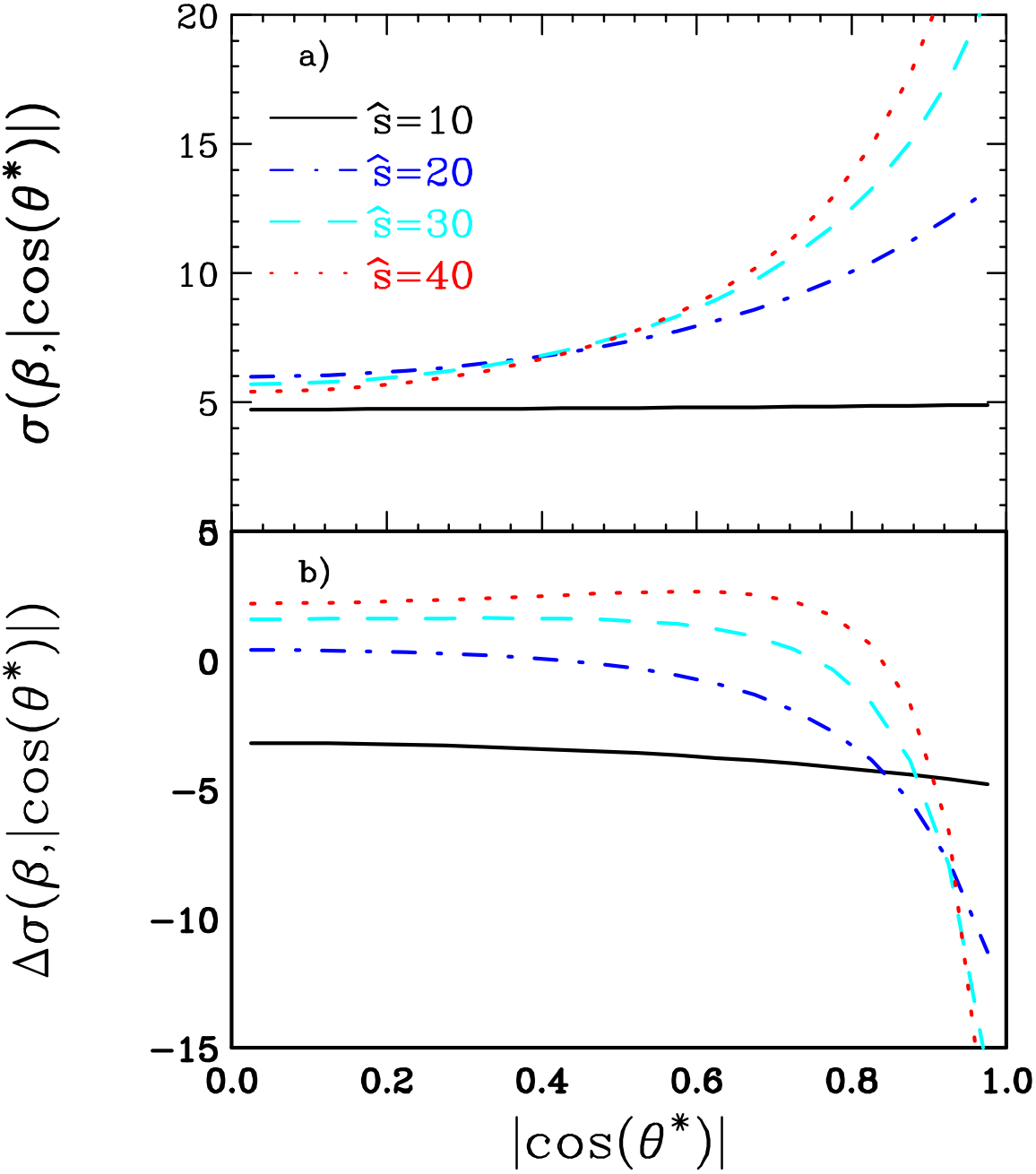
Integrated over $\cos(\theta^*)$, this becomes

$$\Delta\sigma(\hat{s}) = \frac{4}{9}\frac{2\pi\alpha\alpha_s(\hat{s})}{\hat{s}}\left[-3\beta + \ln\frac{1+\beta}{1-\beta}\right].$$

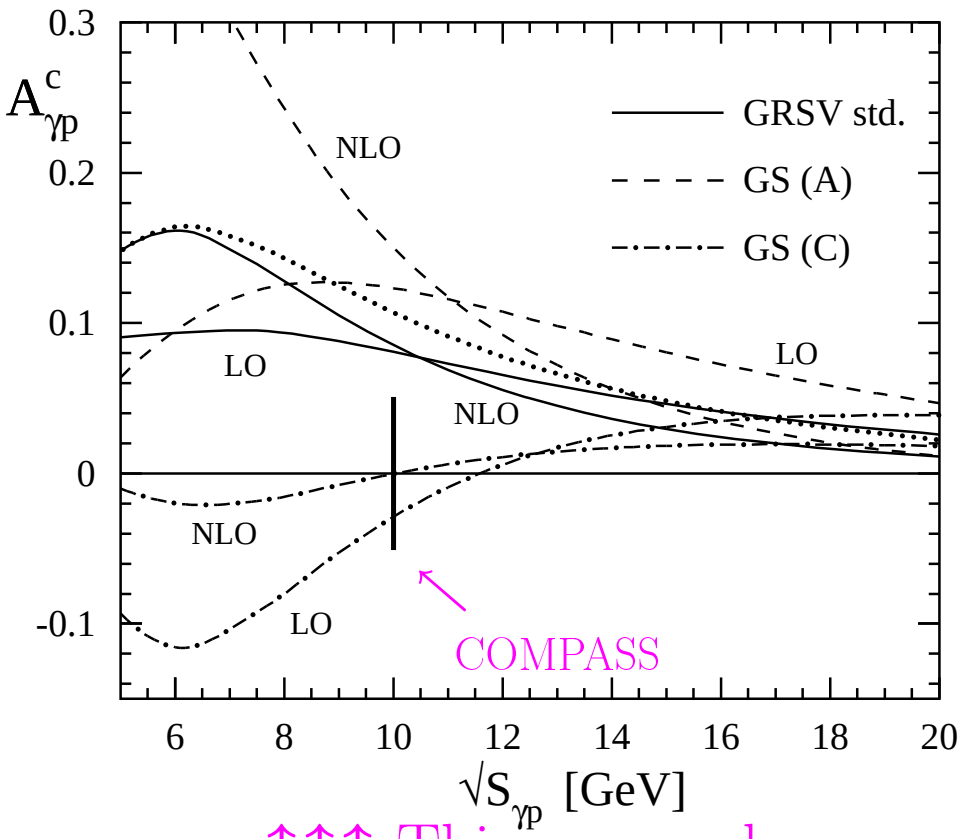
$$\boldsymbol{A_{cc}(k) = \Delta\sigma_{\gamma p}(k)/\sigma_{\gamma p}(k) = \frac{1}{P_t P_b f}\frac{N^{\uparrow\uparrow} - N^{\downarrow\uparrow}}{N^{\uparrow\uparrow} + N^{\downarrow\uparrow}}}$$

CROSS SECTION and $\Delta\sigma$

DEPENDENCY ON CENTER OF MASS ANGLE



NLO pQCD



↑↑↑ This proposal

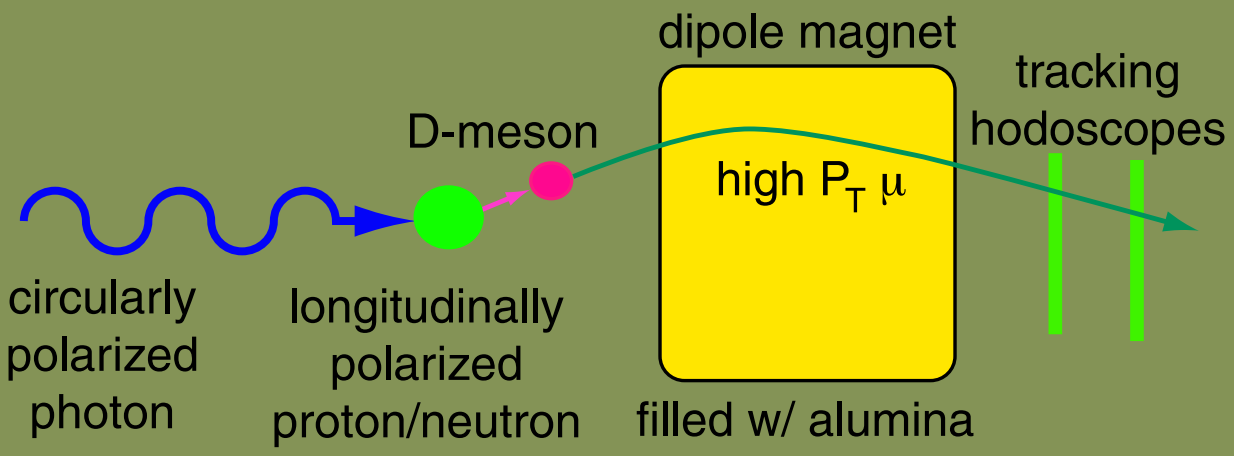
(I. Bojak and M. Stratmann)
also calculated by Z. Merebashvili et al.

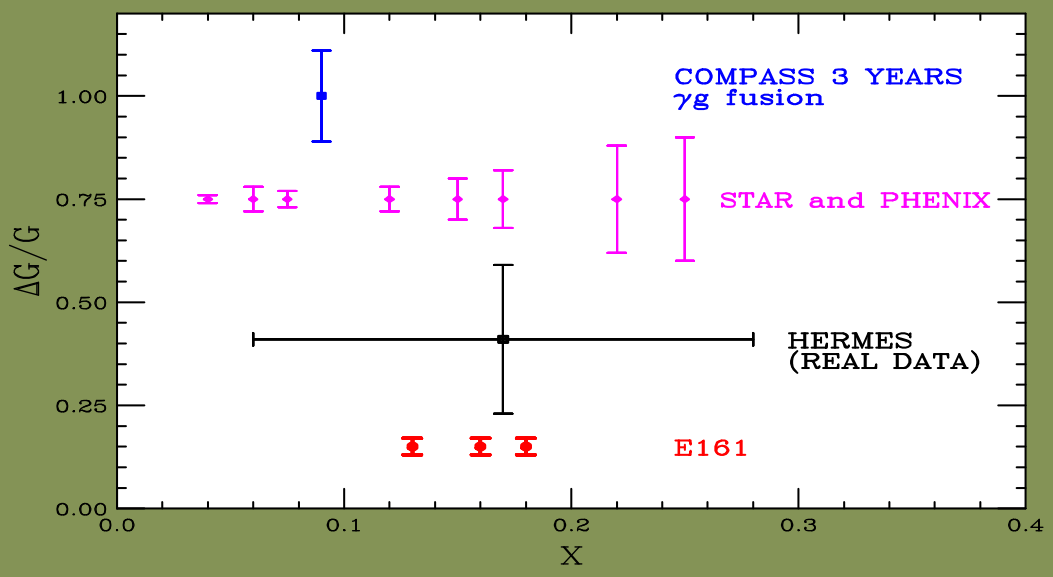
E161

Gluon Spin in Nucleons Using Polarized Open Charm Photoproduction

Goal

Find gluon contribution to the nucleon "Spin Puzzle" using photoproduction of open charm (dominated by photon-gluon fusion diagram). Complementary to measurements at RHIC-Spin and COMPASS.





Projected Errors

EXPERIMENTAL STRATEGY

TAG CHARM WITH SINGLE DECAY μ

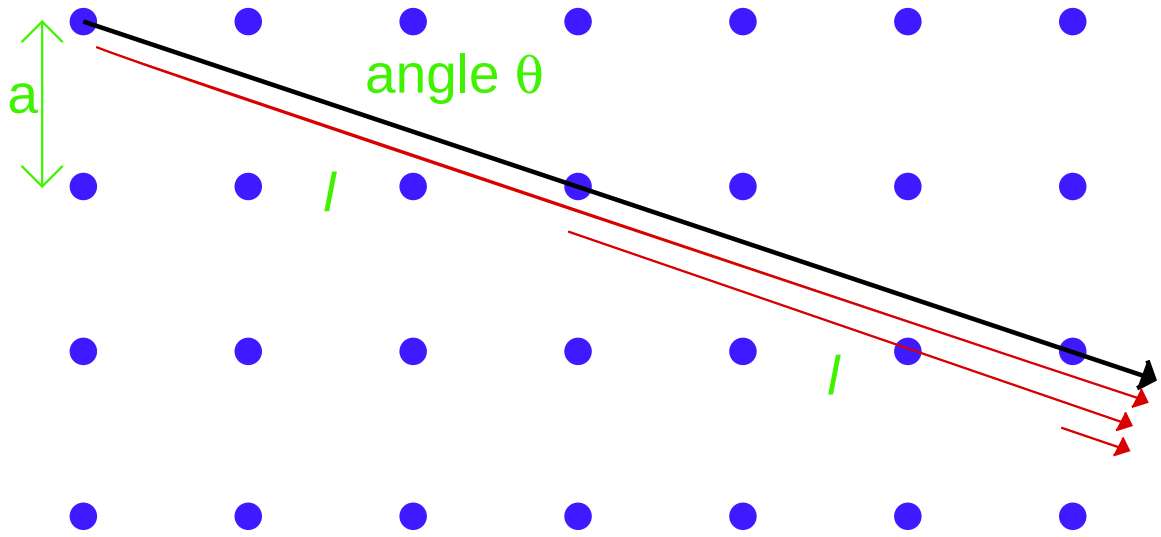
VERY SHORT LIFETIME

	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

Fraction of different charmed particles produced with k=40 GeV photons and a deuterium target with $p_T > 0.5$ GeV generated using PYTHIA 5.7. Also shown is the percent of muons of each charge which ORIGINATED from the parent charmed particle. (Similar results with HERWIG)

COHERENT PHOTON BEAM

- SLAC POLARIZED HIGH INTENSITY ELECTRON BEAM PASSES THRU THIN CRYSTAL
- CONSTRUCTIVE INTERFERENCE OF PHOTONS AT CERTAIN ORIENTATIONS OF CRYSTAL
- DIAMOND THE BEST
- ENHANCEMENT OF BREMSTULUNG SPECTRUM AT SELECTED PHOTON ENERGY
- MORE FORWARD THAN ORDINARY BREM.
- PHOTONS KEEP MOST OF ELECTRON POLARIZATION (AT HIGH PHOTON ENERGY)



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

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

OVERVIEW OF COHERENT BREMSSTRAHLUNG

- Momentum transfer q very small. Minimum momentum transfer given by:

$$\delta = y/2E(1-y)$$

where $y = k/E$, k is photon energy, E is electron energy (in electron mass units).

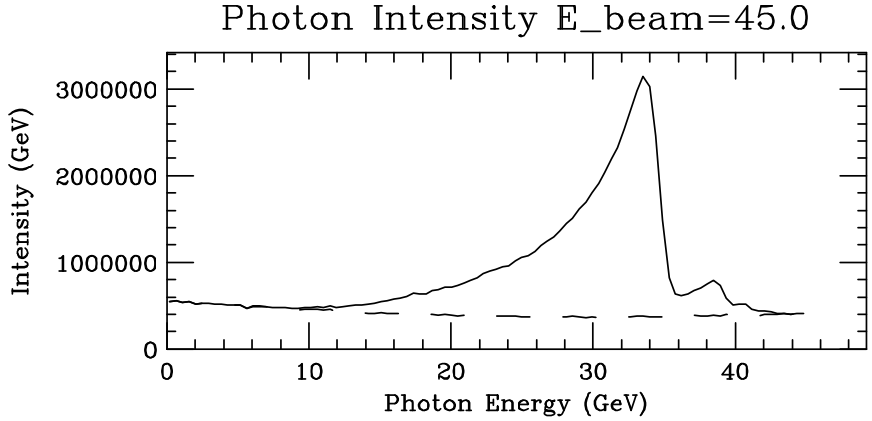
- Classical argument based on electron traveling slightly slower than photon. $\Delta l = l(1-\beta)/\beta$, where $l = a/\theta$ is distance between two lattice rows with spacing a and an electron angle θ.

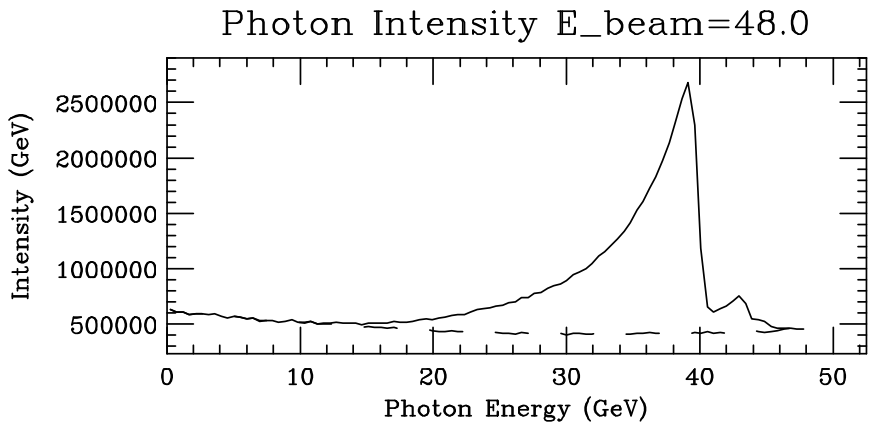
- For coherence, want $\Delta l = n\lambda$, where $\lambda = 2\pi/k$ is wavelength of photon. Combining, we find

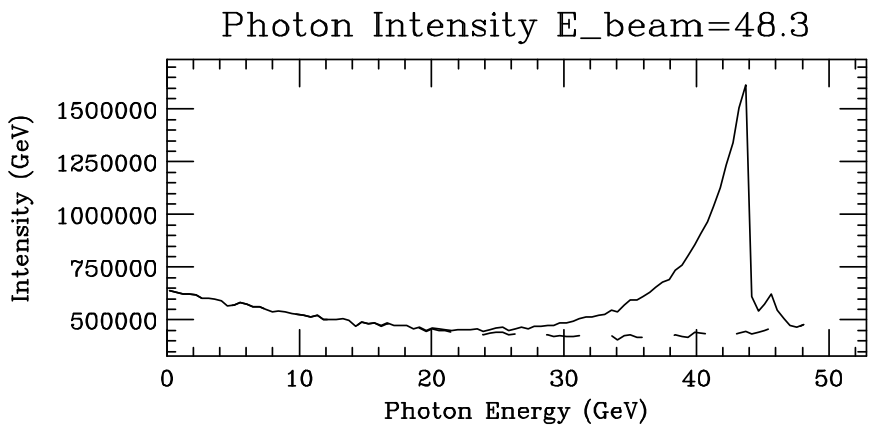
$$n(2\pi/a) = \delta/\theta$$

$$\theta = \frac{y}{2E(1-y)}\frac{a}{n2\pi}$$

INTENSITY SPECTRA FOR E161





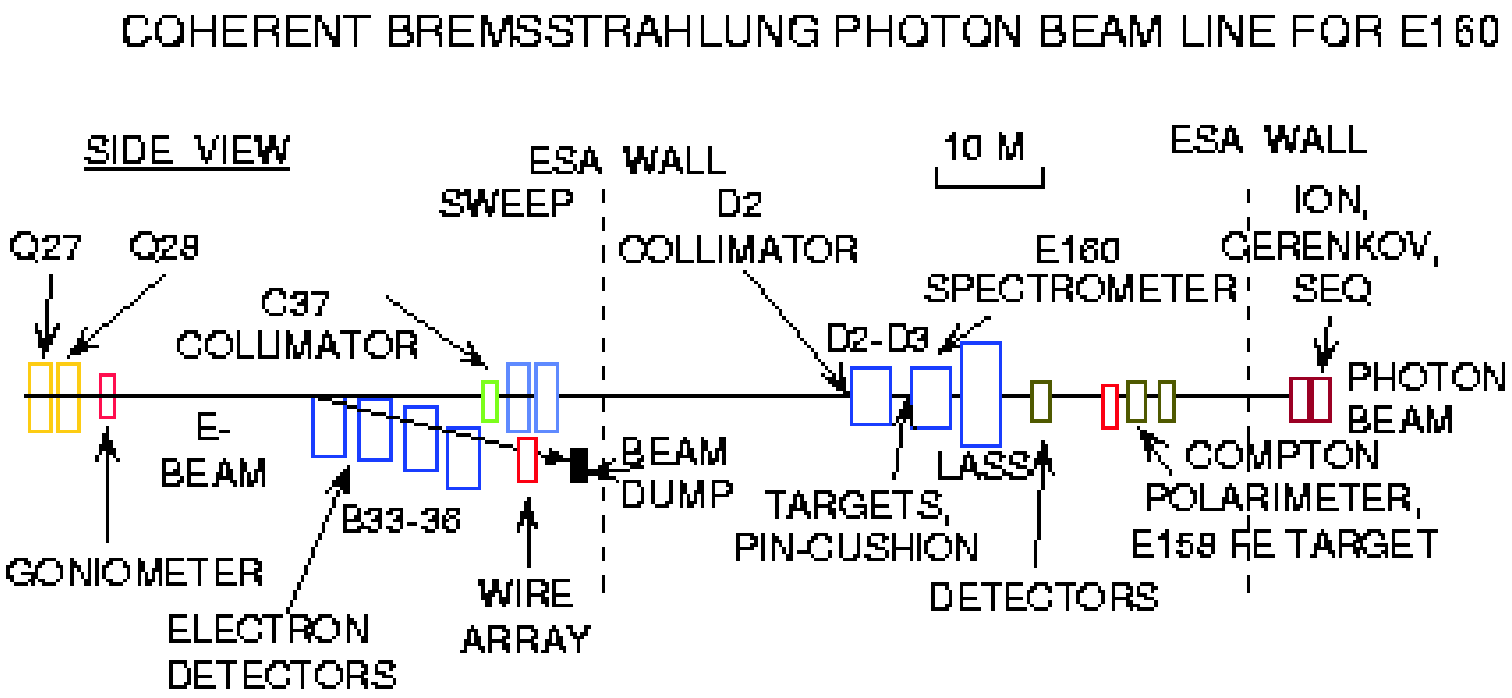


BEAM PARAMETERS

Electron Energy (GeV)	45.1	48.3	48.3
Electron Current (10^{10}/spill)	2.0	2.0	2.0
Peak Photon Energy (GeV)	35.0	40.0	44.0
Photons (10^7/spill)	2	1.5	1.1
Circular Polarization	0.75	0.80	0.84
x_{min}	.10	.12	.13
High p_t Muons/day	160,000	140,000	120,000
days (at 120 Hz, 100% efficiency)	9	10	11

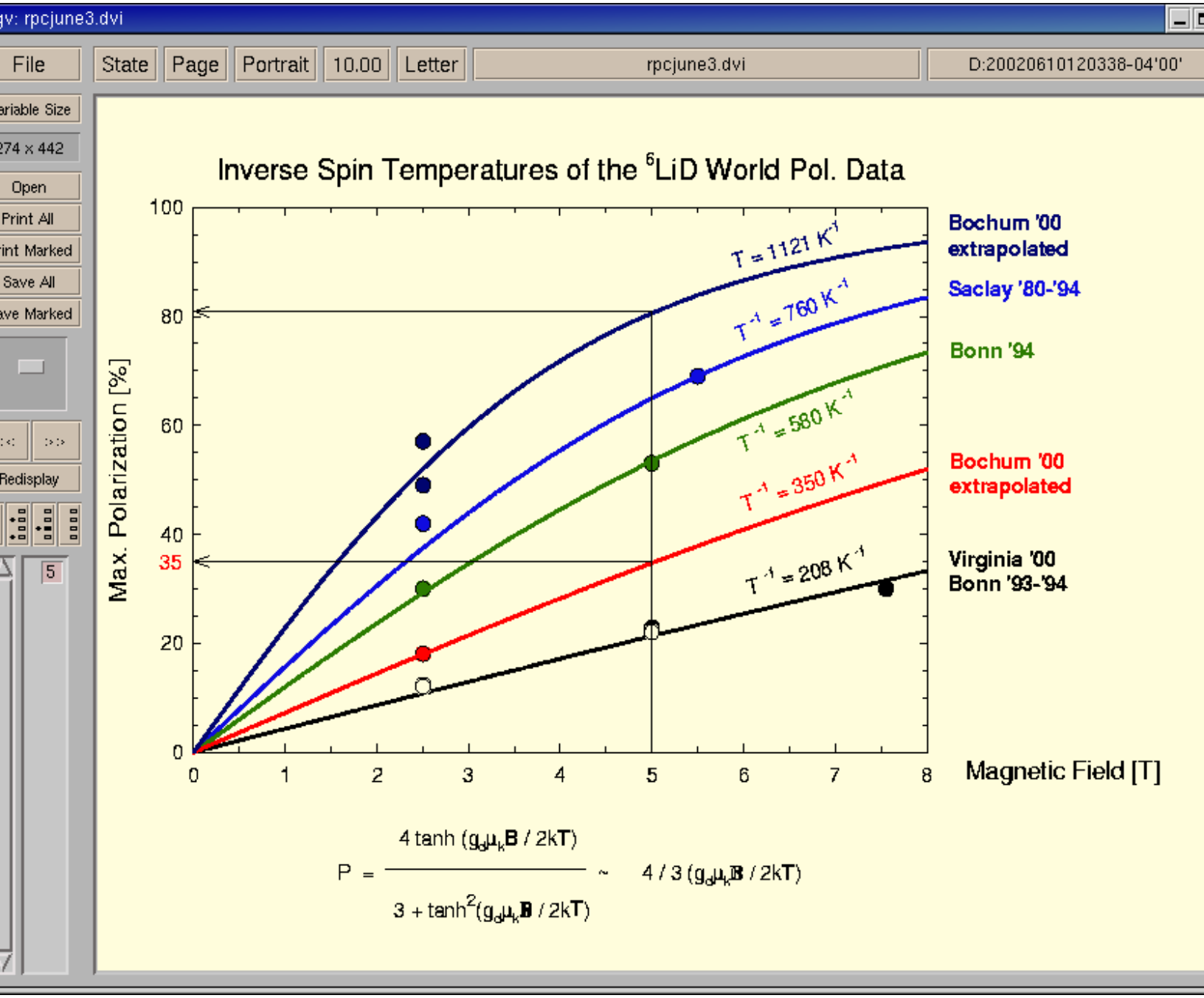
POLARIZED QUASI-MONOENERGIC PHOTON BEAM

Electron Beam ⇒



POLARIZED LiD TARGET

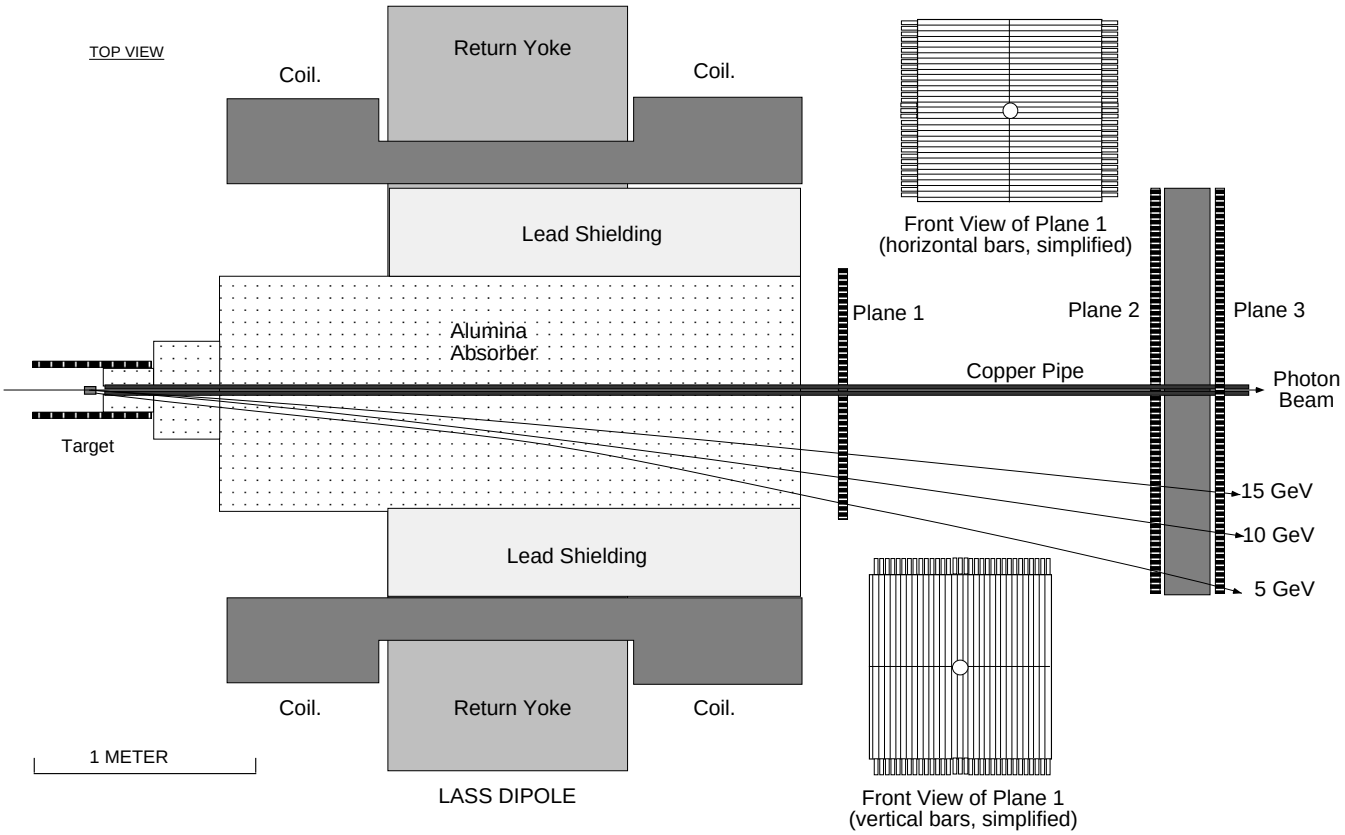
- Photon Beam Allows Low Temperature
- New 7 T magnet
- LiD for Lowest Z (B-H Pairs)
- 70% POLARIZATION



DETECTOR FOR OPEN CHARM

- **PHOTON GLUON FUSION $\rightarrow$ OPEN CHARM**
- **CHARMED MESONS (and Baryons) DECAY TO μ**
- **DETECT μ**
- **DO NOT DETECT OTHER HADRONIC CRAP**

DETECTOR FOR OPEN CHARM



Overall plan view of the main components of the spectrometer. The absorber fills most of the gap of the LASS dipole, and also extends into the warm bore of the target magnet. A thick evacuated copper beam pipe contains the photon beam. The three detector planes are made from scintillator hodoscopes. Two simplified front views of the front plane are shown. The dashed curves are typical trajectories for muons with $p_t = 0.7$ and $P = 5$, 10, and 15 GeV.

BACKGROUNDS

OTHER SOURCES OF μ

- μ FROM K and π DECAY (Long Lifetime)
- Bethe-Heitler μ PAIRS
- J/ψ DECAY (Small)
- VECTOR MESON DECAYS (Small)

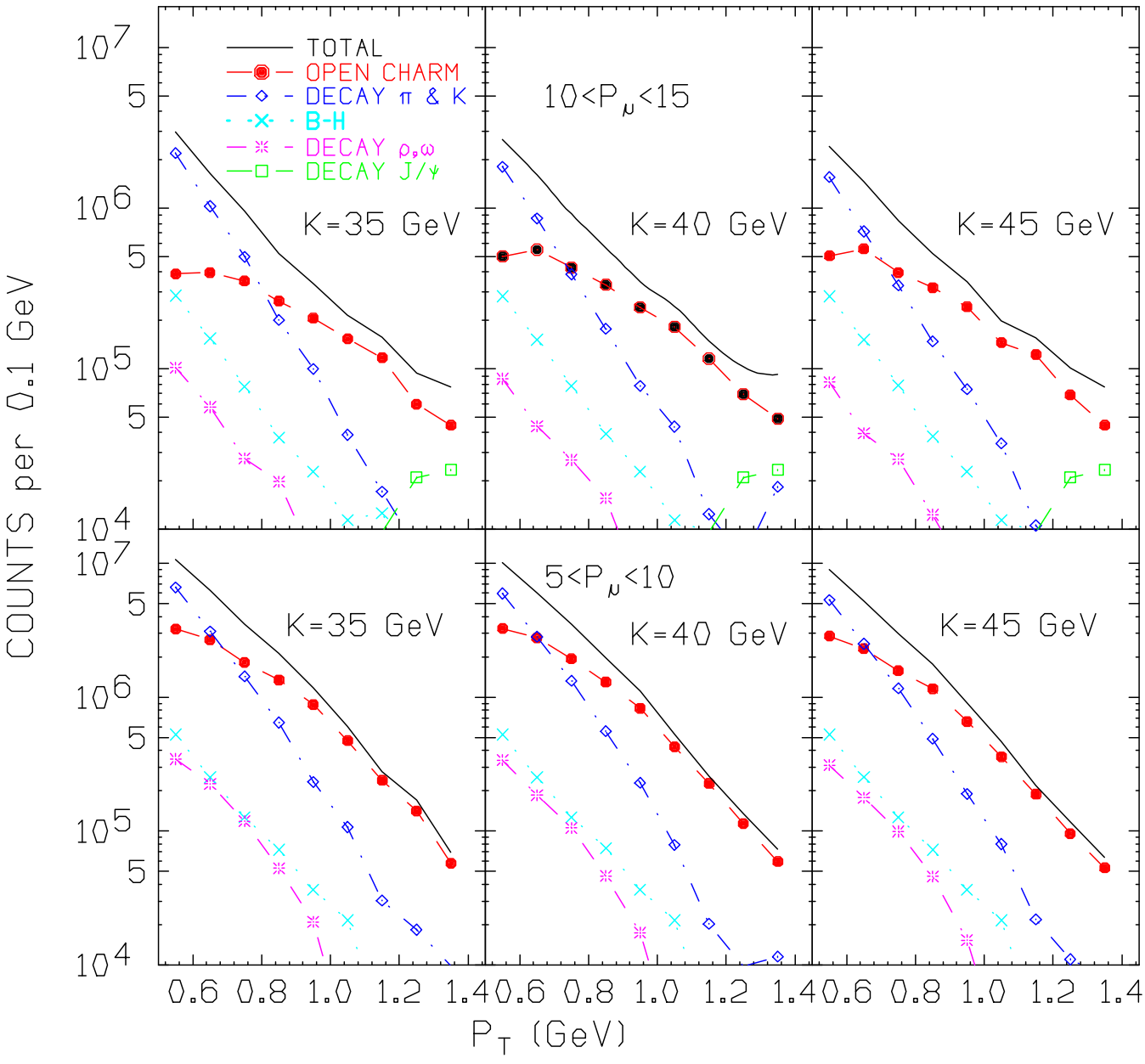
PHYSICS BACKGROUND

- ASSOCIATED PRODUCTION (Small)
- FINAL STATE INTERACTIONS (Small)
- DIFFRACTIVE PRODUCTION (Small)

NUMBER OF EXPECTED SINGLE μ

SIGNAL and BACKGROUNDS

BEFORE BACKGROUND SUBTRACTION

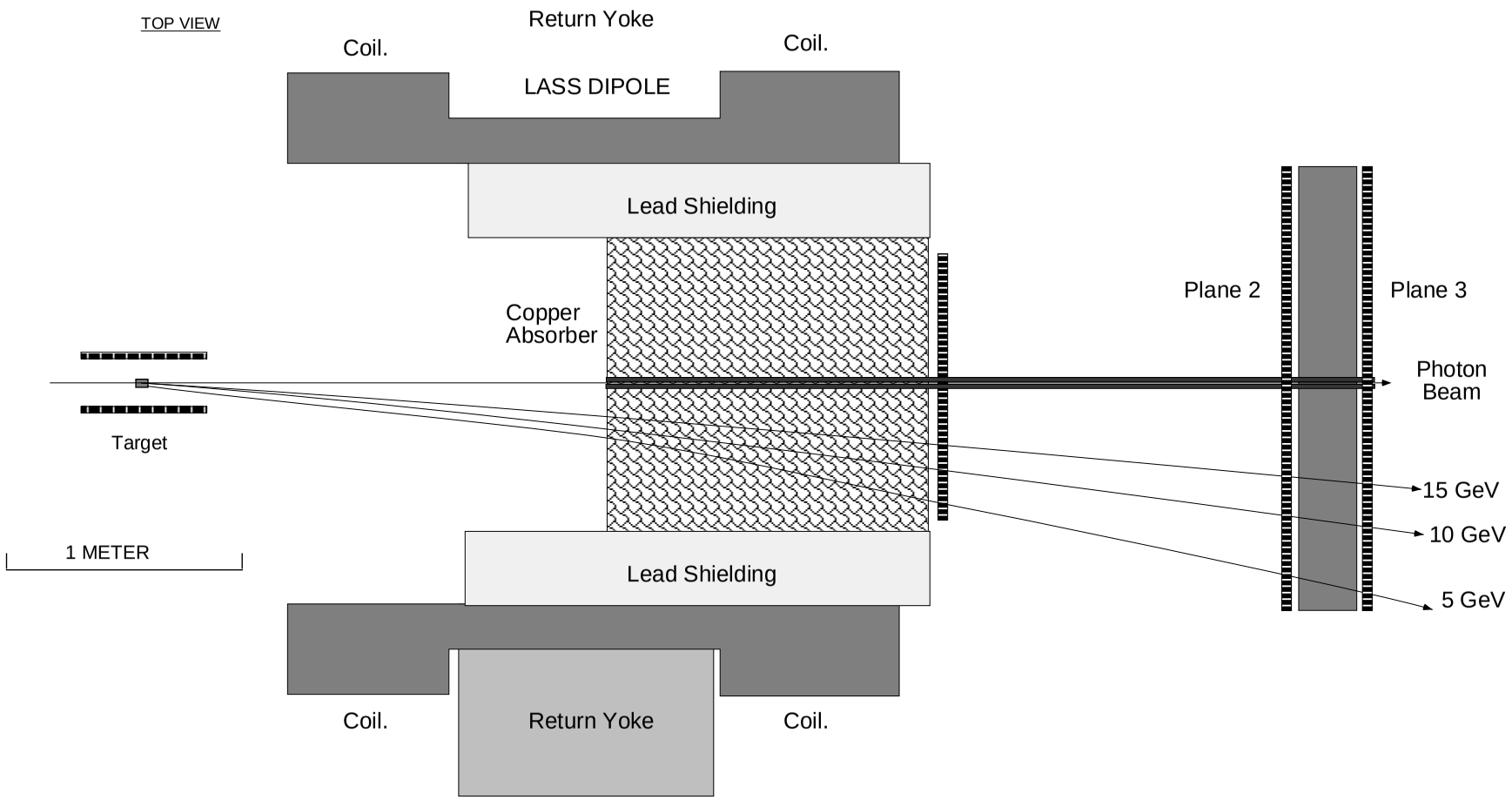


EXPERIMENTAL STRATEGY

- **HIGH POLARIZATION TARGET**
- **HIGH POLARIZATION BEAM**
- **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**

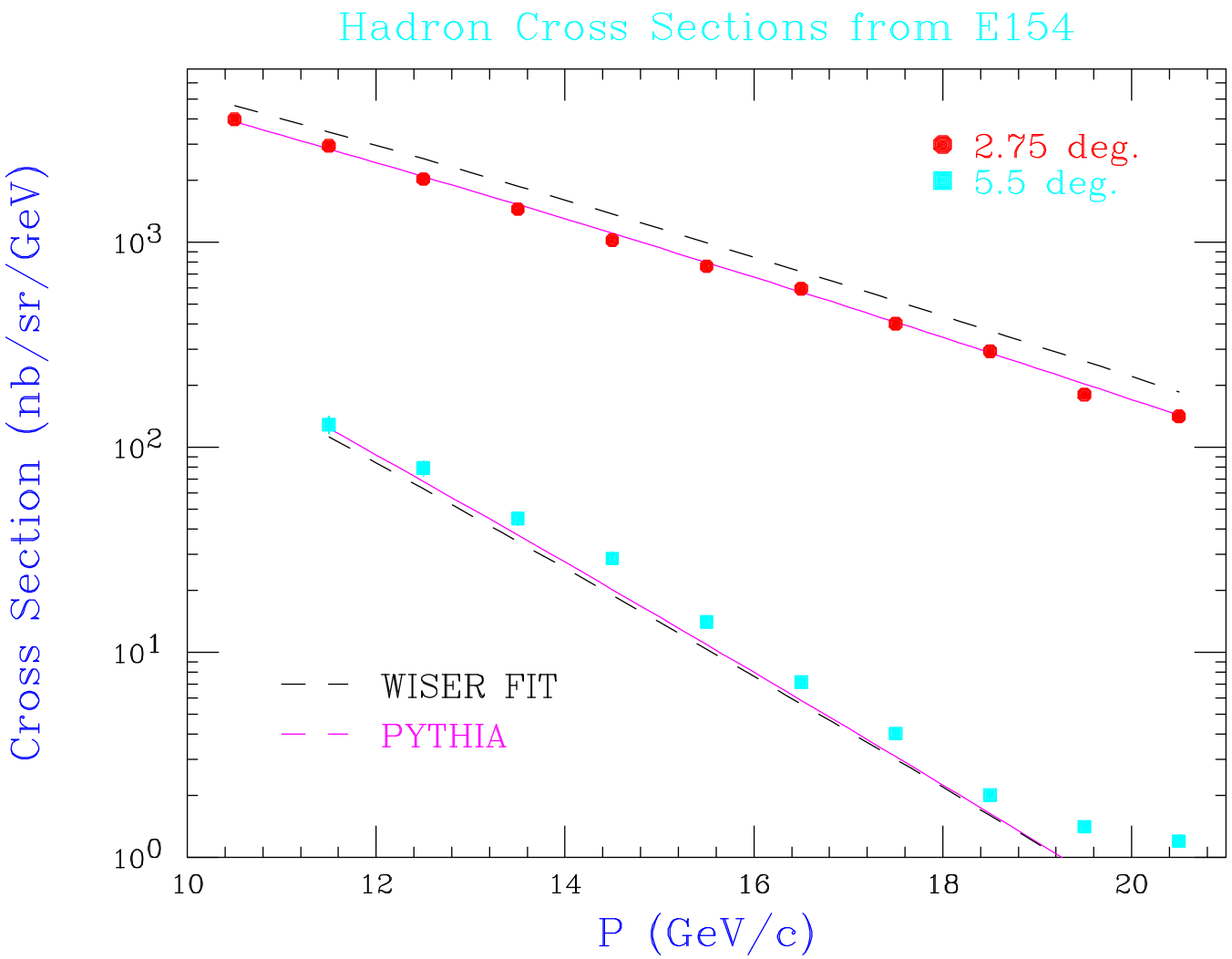
μ SPECTROMETER

BACKGROUND MODE



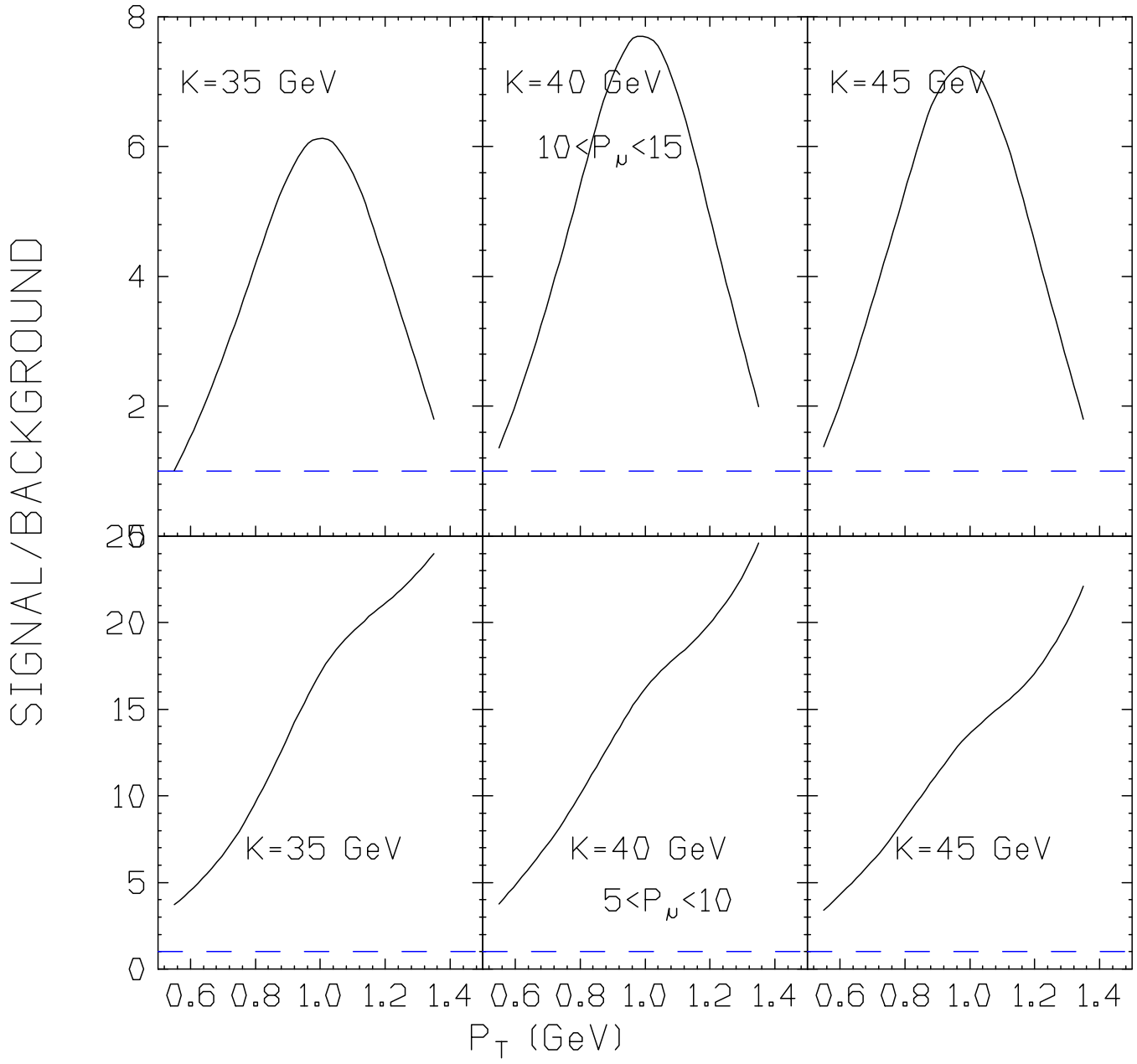
BACKGROUND: π, K DECAY

HOW WELL DO WE KNOW CROSS SECTION



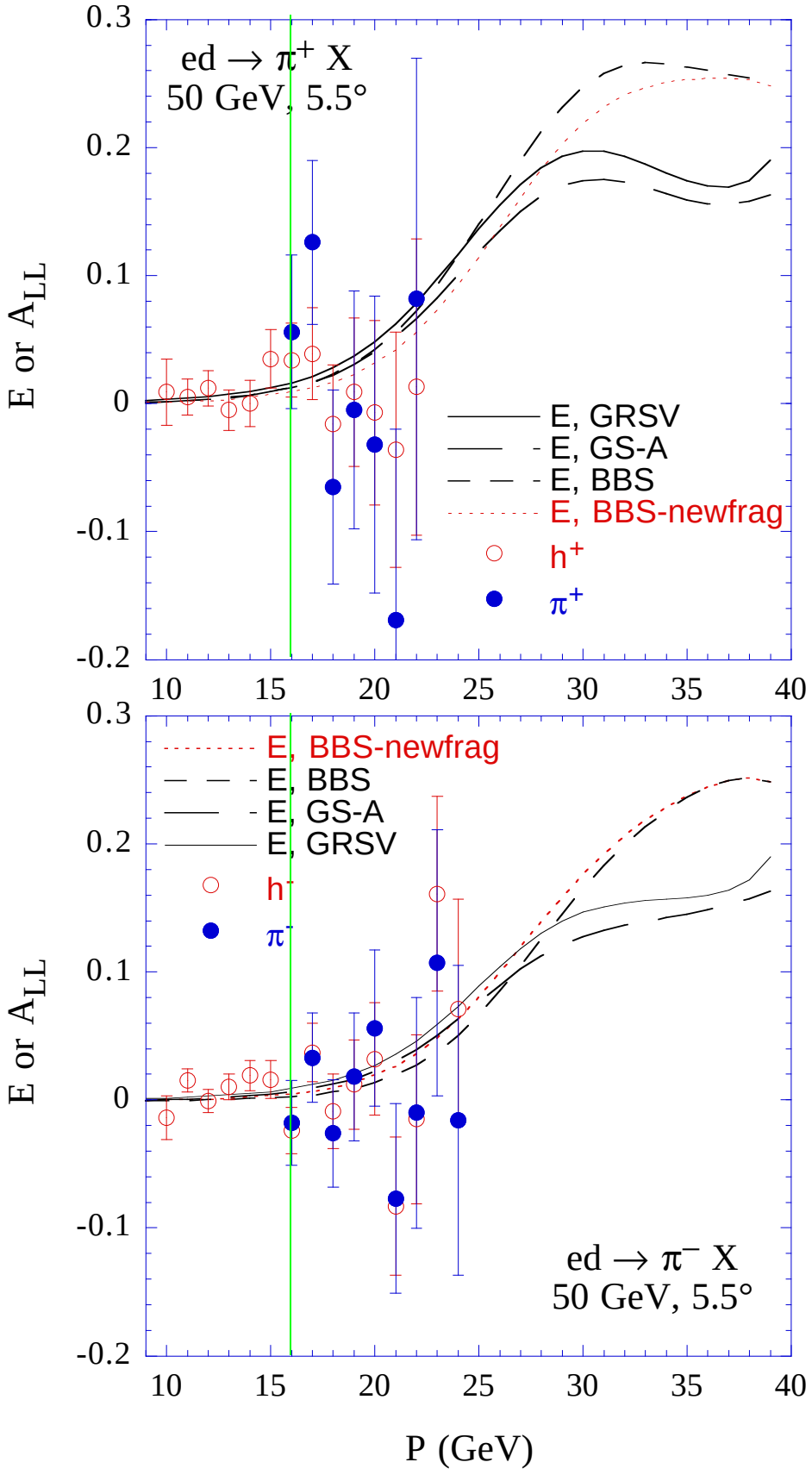
SIGNAL/BACKGROUNDS

DECAY SUBTRACTED



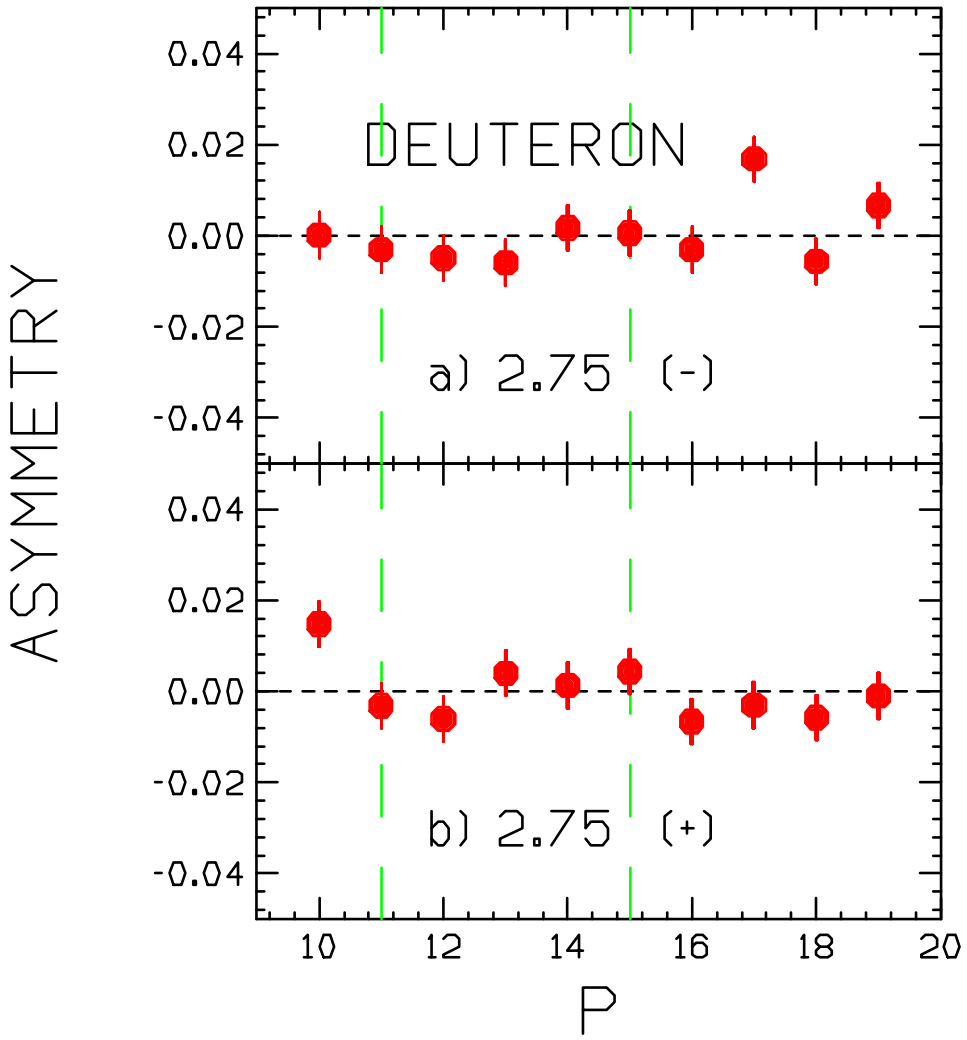
BACKGROUND: π, K DECAY

E155 HADRON ASYMMETRY 5.5°

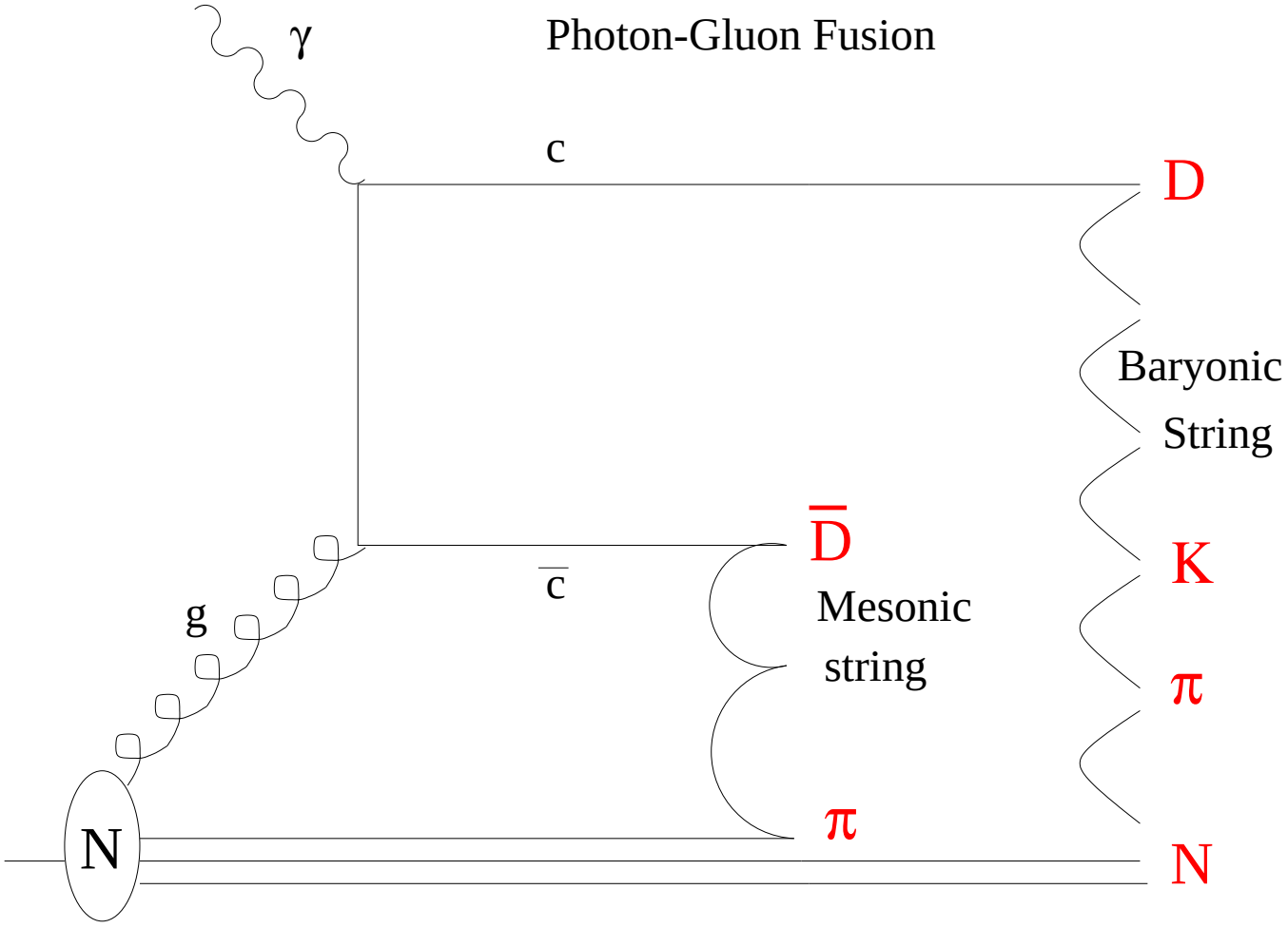


BACKGROUND: π, K DECAY

E155 HADRON ASYMMETRY 2.75°



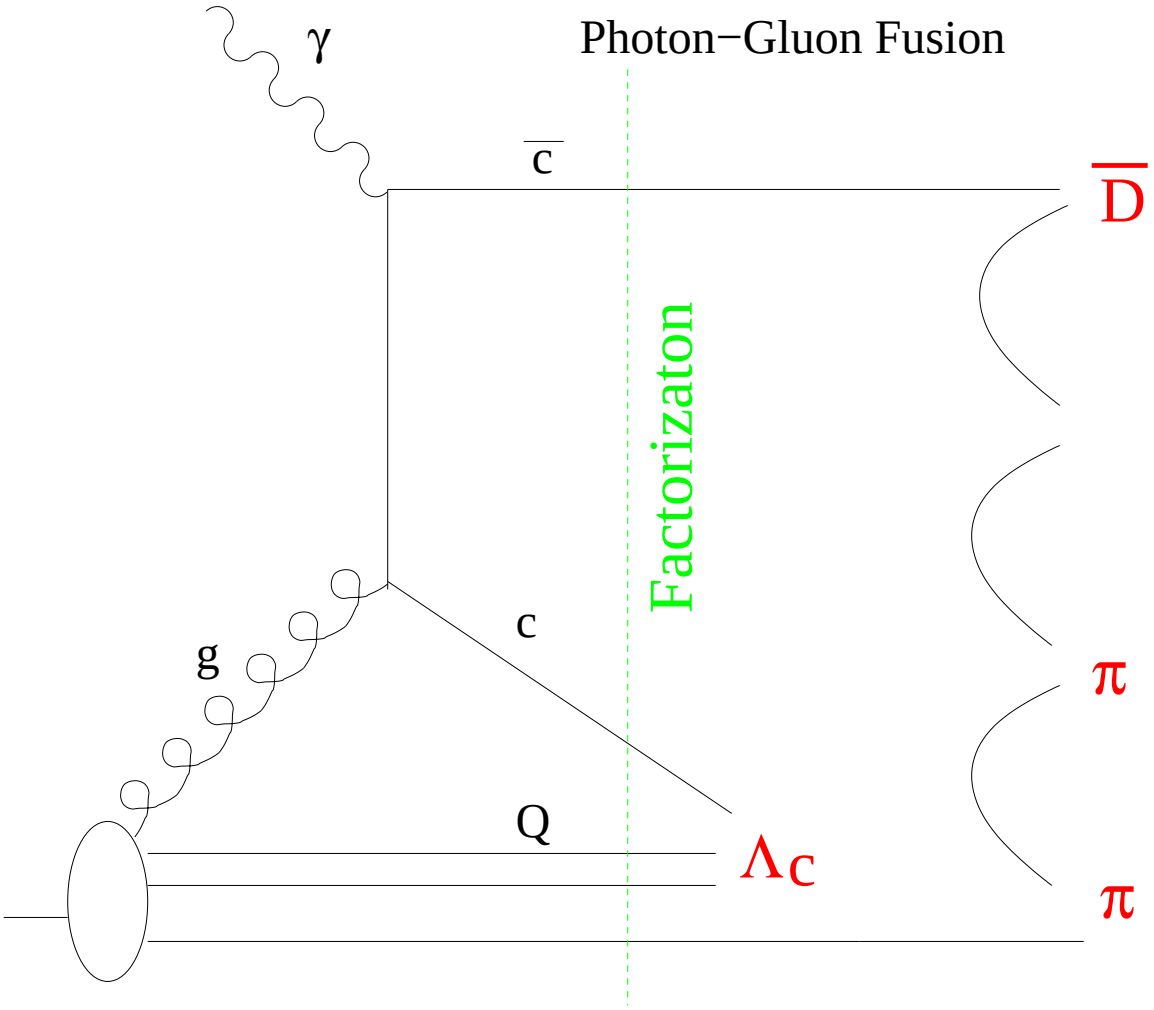
PHYSICS BACKGROUND
NORMAL HADRONIZATION



PHYSICS BACKGROUND

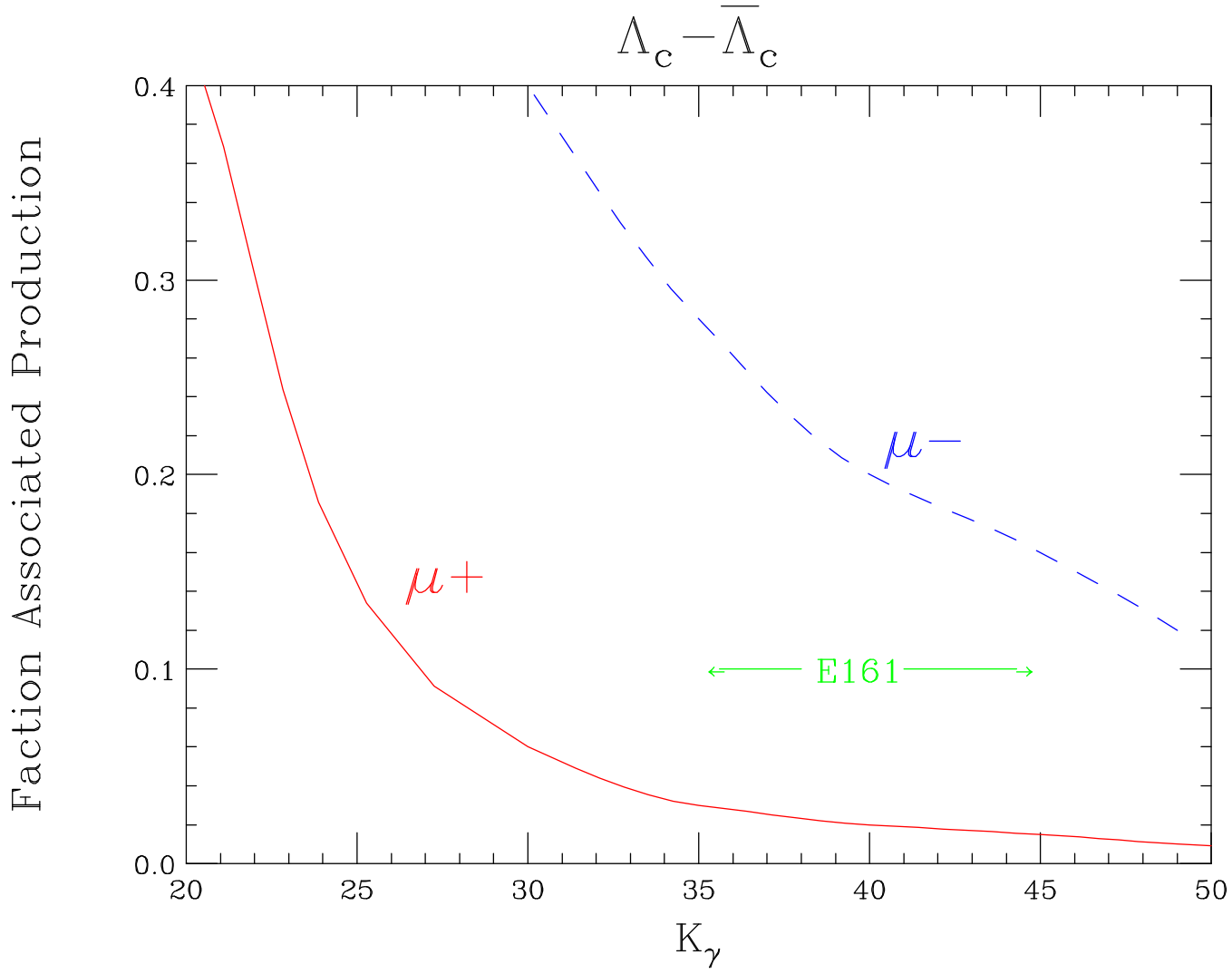
ASSOCIATED PRODUCTION

POLARIZED FRAGMENTATION?



- **FACTORIZATION**
- **RELATIVE DETECTED CROSS SECTION (Few Percent)**
- **HOW DOES c INTERACT WITH POLARIZED TARGET FRAGMENTS?**

PHYSICS BACKGROUND
ASSOCIATED PRODUCTION
PRODUCTION RATE LOW



μ^+ Mostly from D (c quark) $\Rightarrow$ No Λ_c^+

μ^- Mostly from $\bar{D}$ ($\bar{c}$ quark) $\Rightarrow$
c quark can form Λ_c^+

PHYSICS BACKGROUND
ASSOCIATED PRODUCTION
INTERACTION MECHANISM

Λ_c^+ PRODUCTION INDEPENDENT OF TARGET FRAGMENT POLARIZATION

- Λ_c^+ = cud with ud in Spin=0 State
- Production does NOT Depend on Polarization of c Quark.
- Production Does NOT Depend on Polarization of Target Fragments.
- Decay of Polarized Λ_c^+: small correction

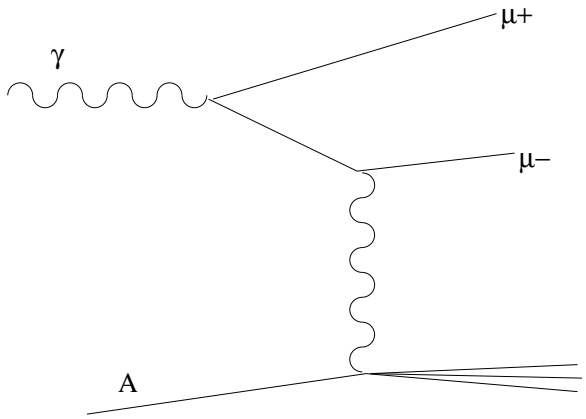
DIFFERENCE BETWEEN μ^+ and μ^-

- Checks These Ideas
- Can Extrapolate to Zero Associated Production

BEAM POLARIZATION MEASUREMENT

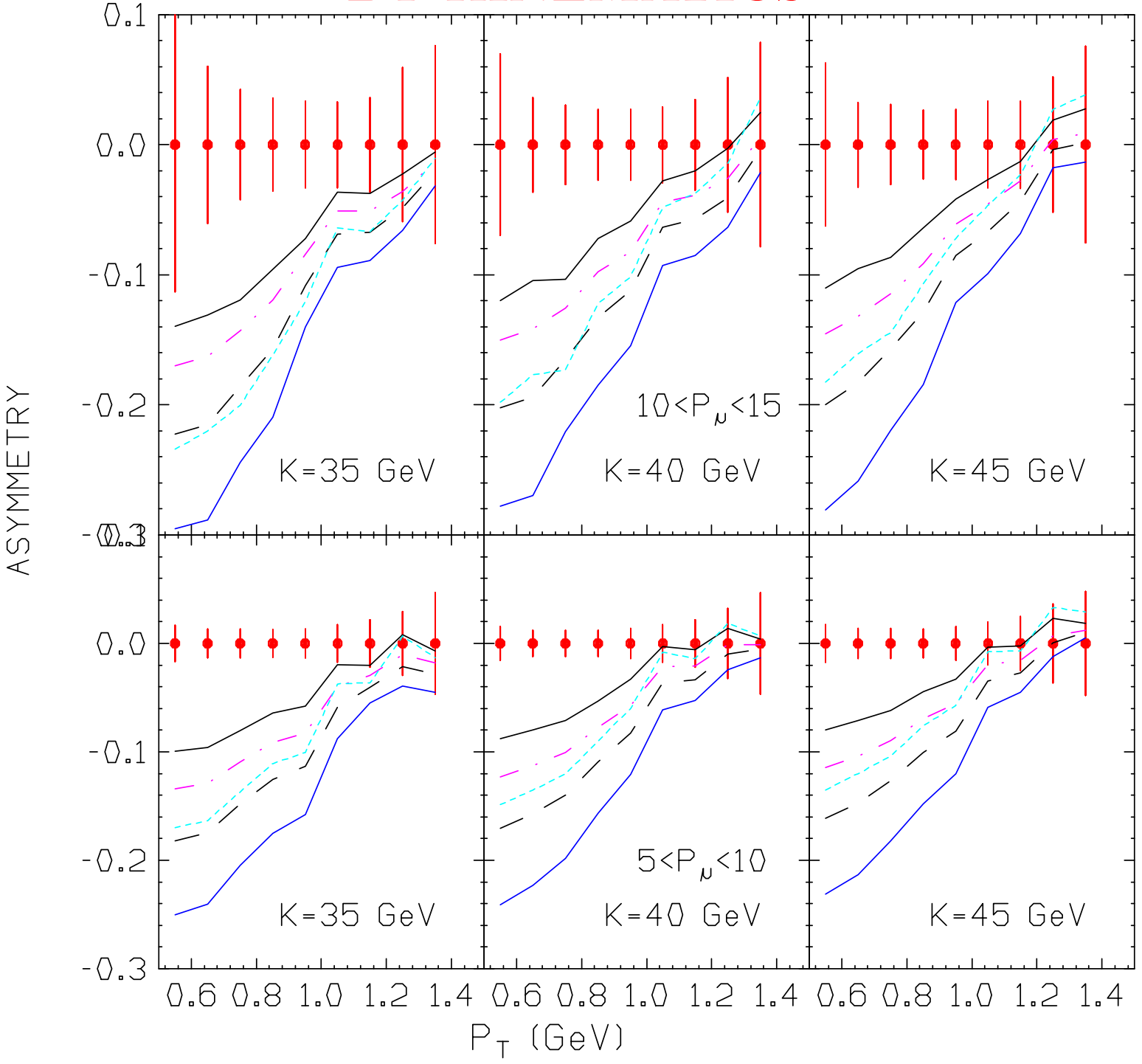
Use Bethe-Heitler Muon Pairs

Calculated by Gehrmann and Stratmann

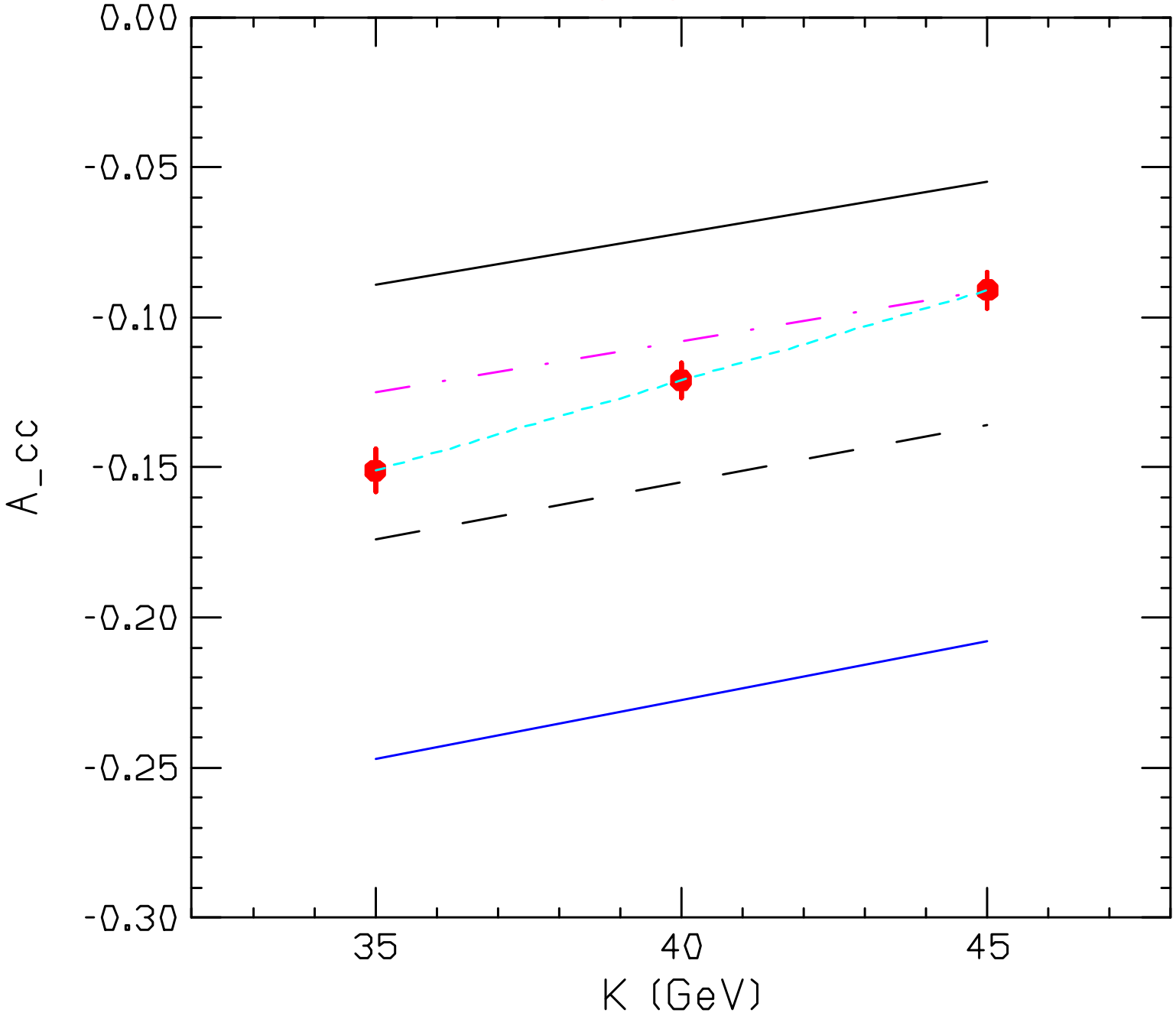


- **Polarization Data taken Simultaneously with PGF**
- **Pairs with $1.2 < M_{\mu\mu} < 2.8$ GeV.**
- **Pair Rate Greater Than the PGF rate.**
- **Elastic (from ^{6}Li), Quasi Elastic and Inelastic Contributions.**
- **Relative importance depends on kinematics.**
- **Depends on Nuclear and Nucleon Form Factors and Polarized Structure Functions.**
- **Asymmetry about 3% depending on Kinematics.**

EXPECTED RESULTS BY KINEMATICS

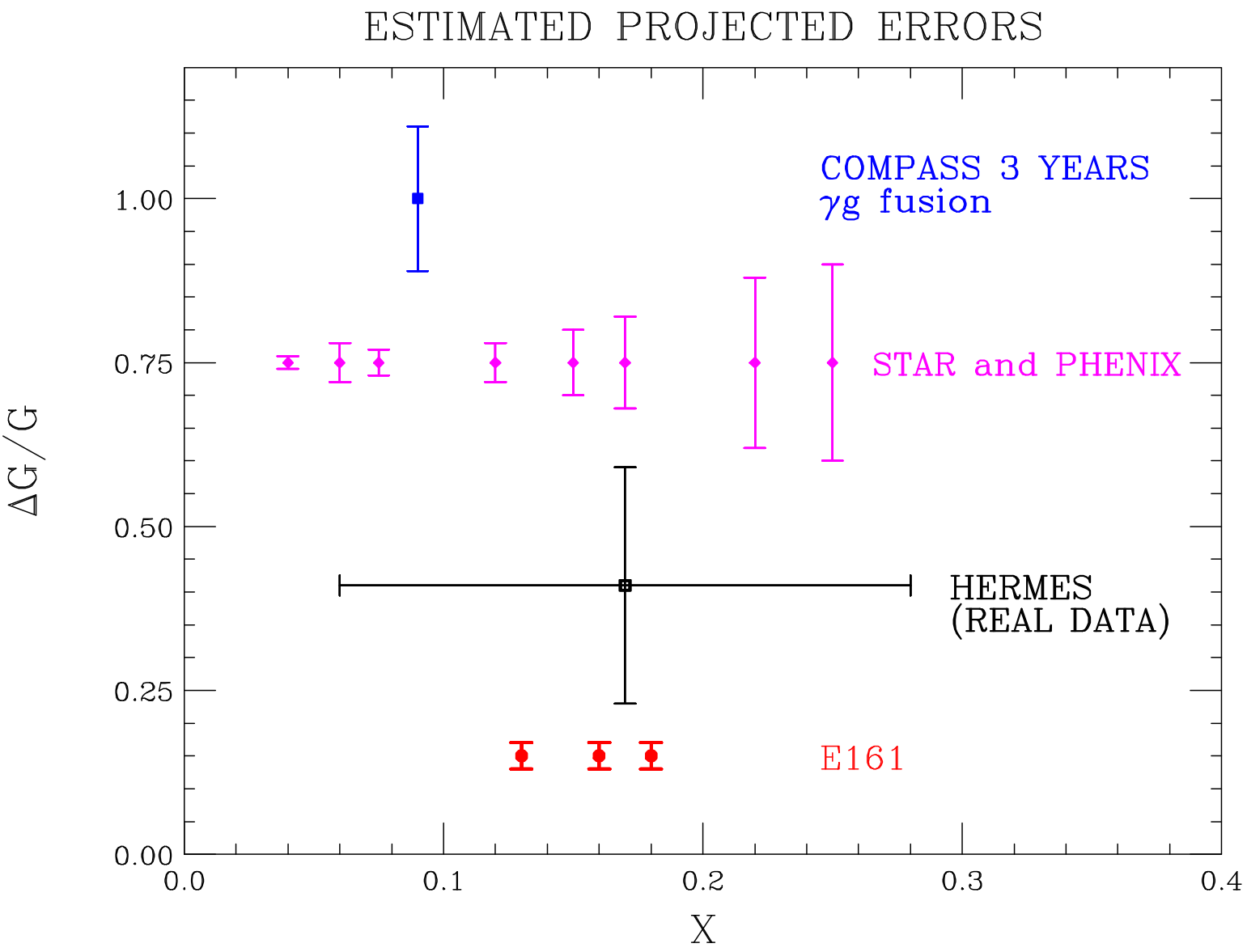


EXPECTED RESULTS
AVERAGE



SYSTEMATIC ERRORS $\sim$ 8%

COMPARISON OF EXPERIMENTS



SCHEDULE

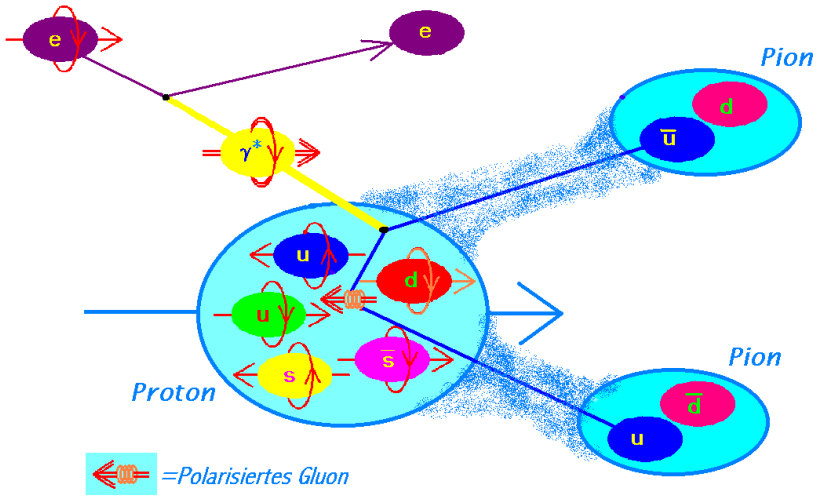
- SLIPPING ALL THE TIME
- MUST WAIT FOR SLAC E158 (POLARIZED MOLLER SCATTERING) TO FINISH
- THEN E161 FOR J/ψ CROSS SECTION IN NUCLEAR MATTER
- BABAR IS EATING UP ALMOST ALL THE MONEY TO BEAT BELLE
- MAYBE 2005?

ALTERNATE METHODS

- HIGHER INTENSITY PHOTON BEAM ($\times 50$)
- DETECT J/ψ (Some Theory Problems)
- DETECT μ^+ and μ^- FROM c and $\bar{c}$ IN COINCIDENCE
  - LOWER BACKGROUNDS OF SOME KINDS.
  - HIGHER BACKGROUNDS OF OTHER KINDS.

Direct Measurements of ΔG

Isolate the photon-gluon fusion process (PGF)

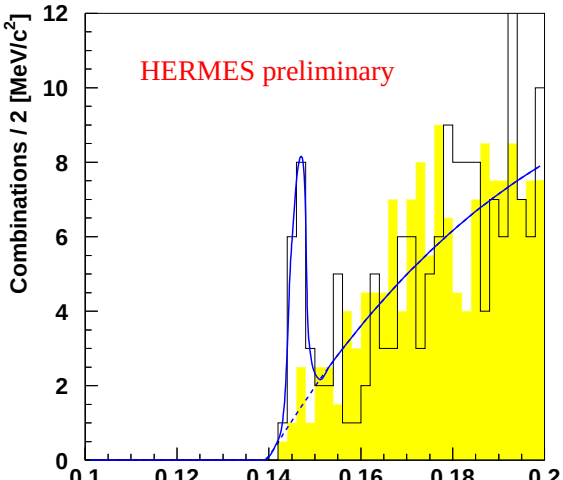


OPEN CHARM

reconstruct D^*, D^0

$$A_{||} = \frac{N^{\rightarrow}_{c\bar{c}}(\overleftarrow{\Leftarrow}) - N^{\rightarrow}_{c\bar{c}}(\overrightarrow{\Rightarrow})}{N^{\rightarrow}_{c\bar{c}}(\overleftarrow{\Leftarrow}) + N^{\rightarrow}_{c\bar{c}}(\overrightarrow{\Rightarrow})}$$

$$A^{\gamma p \to c\bar{c}} \sim \Delta G/G$$



HIGH-P_T

pairs of high-P_T hadrons

$$A_{||} = \frac{N^{\rightarrow}_{h^\pm}(\overleftarrow{\Leftarrow}) - N^{\rightarrow}_{h^\pm}(\overrightarrow{\Rightarrow})}{N^{\rightarrow}_{h^\pm}(\overleftarrow{\Leftarrow}) + N^{\rightarrow}_{h^\pm}(\overrightarrow{\Rightarrow})}$$

$$A^{\gamma p \to h^+ h^-} \sim \Delta G/G$$

additionally:

use identified hadrons

pairs of high-P_T Pions

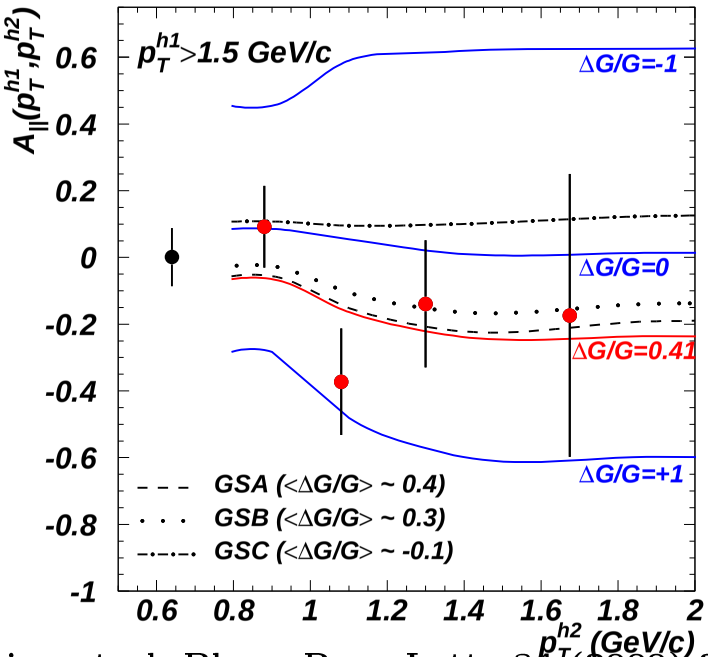
pairs of high-P_T Kaons

Pairs of high-P_T Hadrons

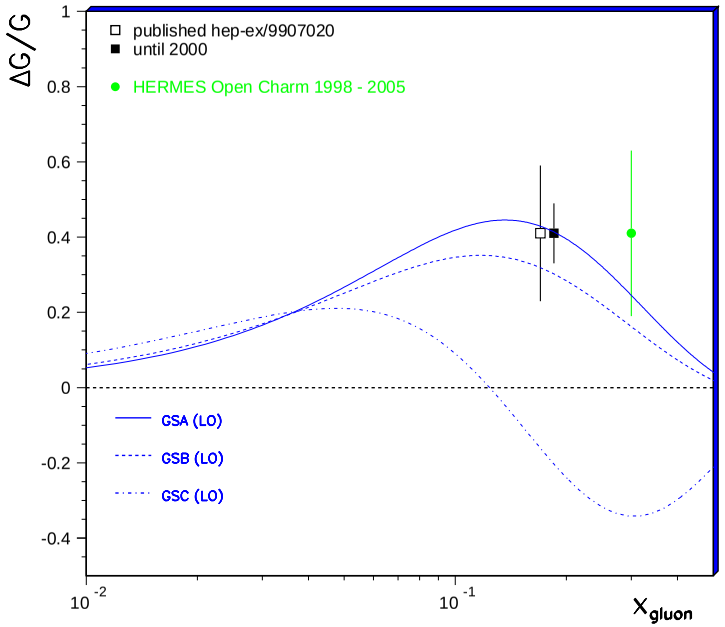
within LO pQCD and PYTHIA5 MC model

$$\Delta G/G = 0.41 \pm 0.18\ (\text{stat.}) \pm 0.03\ (\text{exp.syst.})$$

at $\langle x_G \rangle = 0.17$ **and** $\langle \hat{p}_T^2 \rangle = 2.1\ \mathbf{GeV}^2$



petian et al, Phys. Rev. Lett. 84 (2000) 2584



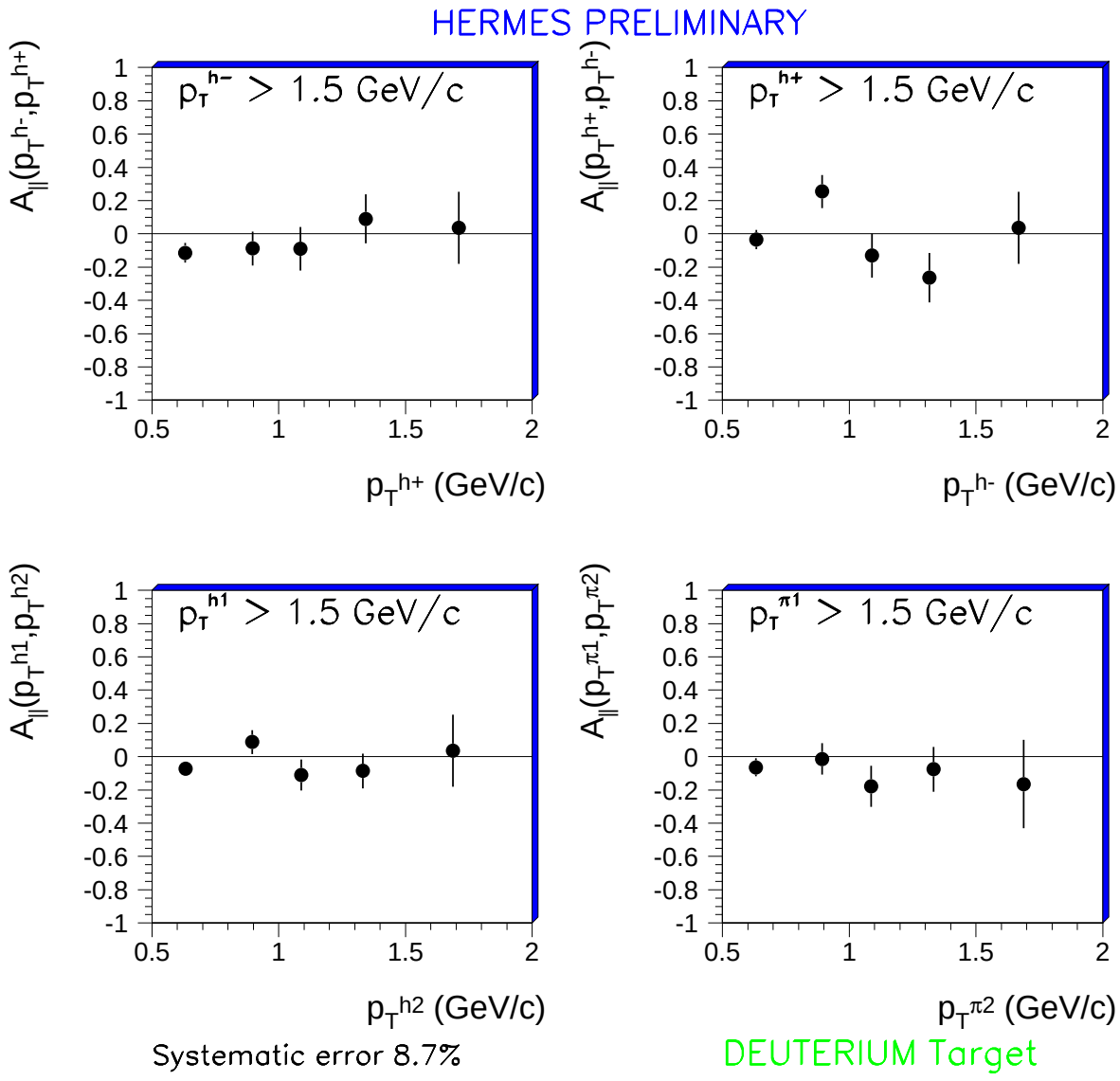
2 x smaller errors with 1998-2000 data

Target: Hydrogen

ction strongly Model dependent

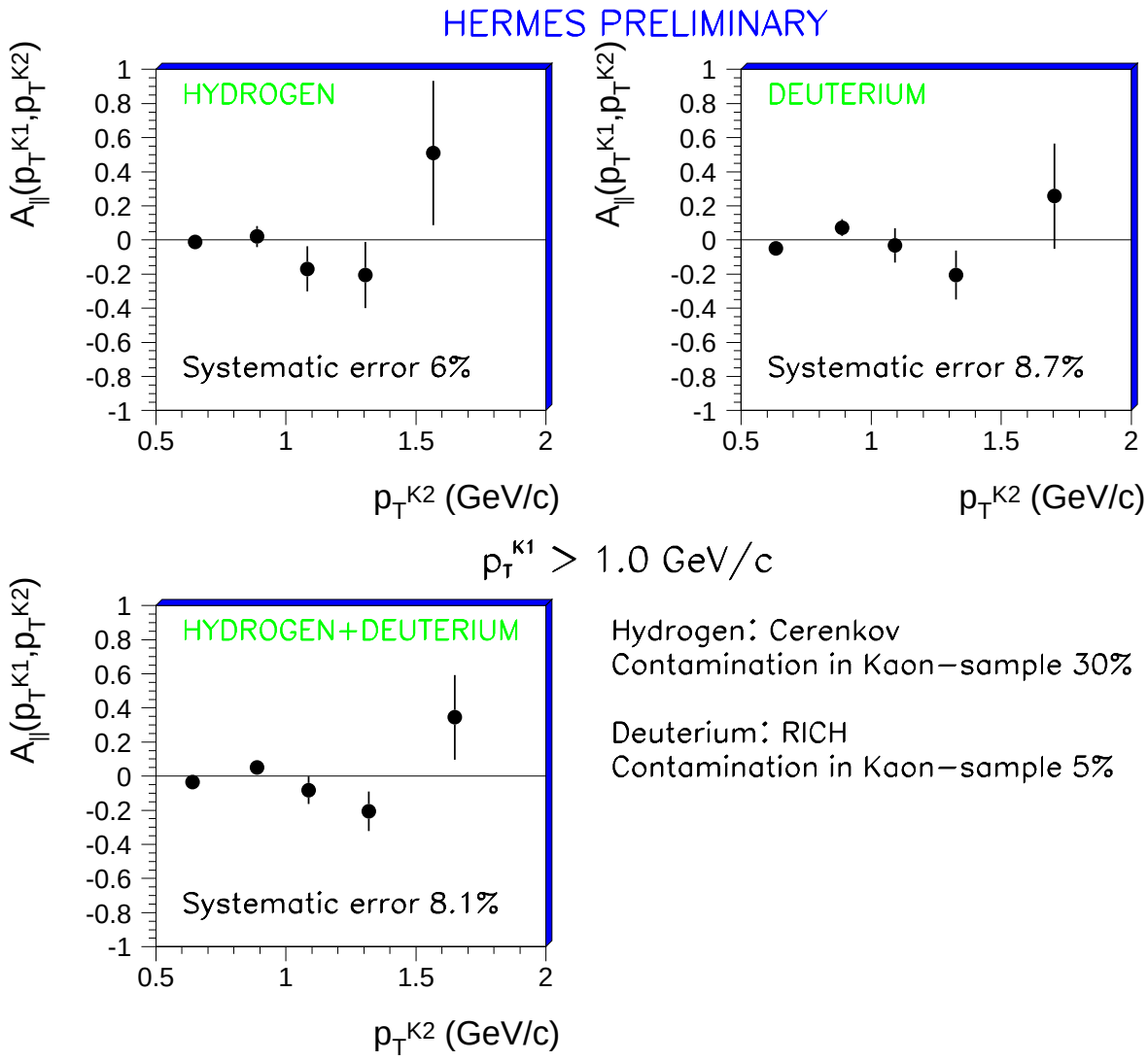
Deuterium Results

Statistics: $\sim$ 3 x hydrogen statistics



$\Delta G/G$ Extraction still under way

Pairs of high-P_T Kaons



- **Advantage:**
  Production of strange hadrons in fragmentation is suppressed compared to non-strange hadrons
  $\longrightarrow$ **cleaner sample**

- **reduced p_T(h1) > 1.5GeV to p_T(K1) > 1.0GeV**
  $\longrightarrow$ **more statistics**

Perspectives

- more longitudinal polarized Hydrogen data
- Ongoing investigations of different charm channels
  - partially reconstructed D^*
  - semileptonic D^0 decays

strong model dependence in all channels

SUMMARY

- MOTIVATION
  - POLARIZED GLUON DISTRIBUTION POORLY KNOWN
  - DIS MEASUREMENTS OF g_1 PUT WEAK LIMITS
- APPROVED SLAC E161
  - PHOTON-GLUON FUSION $\Rightarrow$ CHARM
  - POLARIZED PHOTON BEAM
  - POLARIZED TARGET
  - MUON DETECTION
  - EXPECT HIGH PRECISION
  - NEED MONEY
  - WILLING TO BEG
- HERMES RUNNING NOW
  - HIGH P_T LIGHT QUARKS
  - GETTING RESULTS