Contributions to the Proton GDH Sum Rule above 2.5 GeV

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and the CLAS Collaboration at Jefferson Lab

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Outline

The GDH Sum Rule (for real photons)

Experimental status of the GDH sum rule (Mainz, Bonn)

What does it have to do with this conference?

The Jefferson Lab Hall B experiment

The future

The Gerasimov-Drell-Hearn (GDH) Sum Rule on the proton

S.B.Gerasimov, Sov. J. Nucl. Phys.**2**, 430 (1966)
S.D. Drell and A.C. Hearn, Phys. Rev.Lett. **16**, 908 (1966)

$$I_{GDH} = \int_{k_{thresh}}^{\infty} \frac{\sigma_{1/2} - \sigma_{3/2}}{k} dk = \frac{2\pi^2 \alpha \kappa_p^2}{m_p^2} = -204.8 \mu b$$

where

$\sigma_{1/2}$ ($\sigma_{1/2}$)	=	total cross section for $\gamma p \rightarrow$ hadrons in the helicity-1/2 (helicity-3/2) state
k	=	photon energy
k_{thresh}	=	threshold energy for $\gamma p \rightarrow \pi p \approx 150$ MeV
α	=	fine structure constant
m_p	=	proton mass
κ_p	=	proton anomalous magnetic moment

The sum rule follows from

Dispersion relation for forward Compton scattering
Low-energy theorem for Compton scattering

Convergence?

Regge theory predicts $\lim_{k \rightarrow \infty} \left(\sigma_{1/2} - \sigma_{3/2}\right) = 0$

Motivation of the Hall B Experiment

Testing the GDH sum rule requires measurements at all energies:

0.15-0.20 GeV	theory and fits (MAID, SAID) to threshold data
0.20-0.80 GeV	**Mainz measurement** (published) } P. Pedroni (Wed)
0.80-2.9 GeV	**Bonn measurement** (analysis in progress)
≳ 3 GeV	Bianchi-Thomas Regge parameterization
5-40 GeV	**Planned SLAC measurement** (E-159, P. Bosted and D. Crabb)

Other planned experiments:

< 0.47 GeV	LEGS A. Lehmann (Saturday)
<1.55 GeV	GRAAL
1.8–2.8 GeV	Spring-8

Would like an experimental test of the 3 - 5 GeV region.

For the high-energy region:

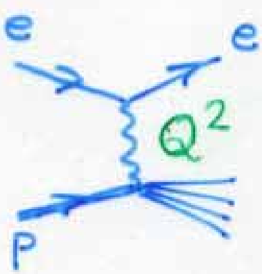
Parameterization of Bianchi and Thomas

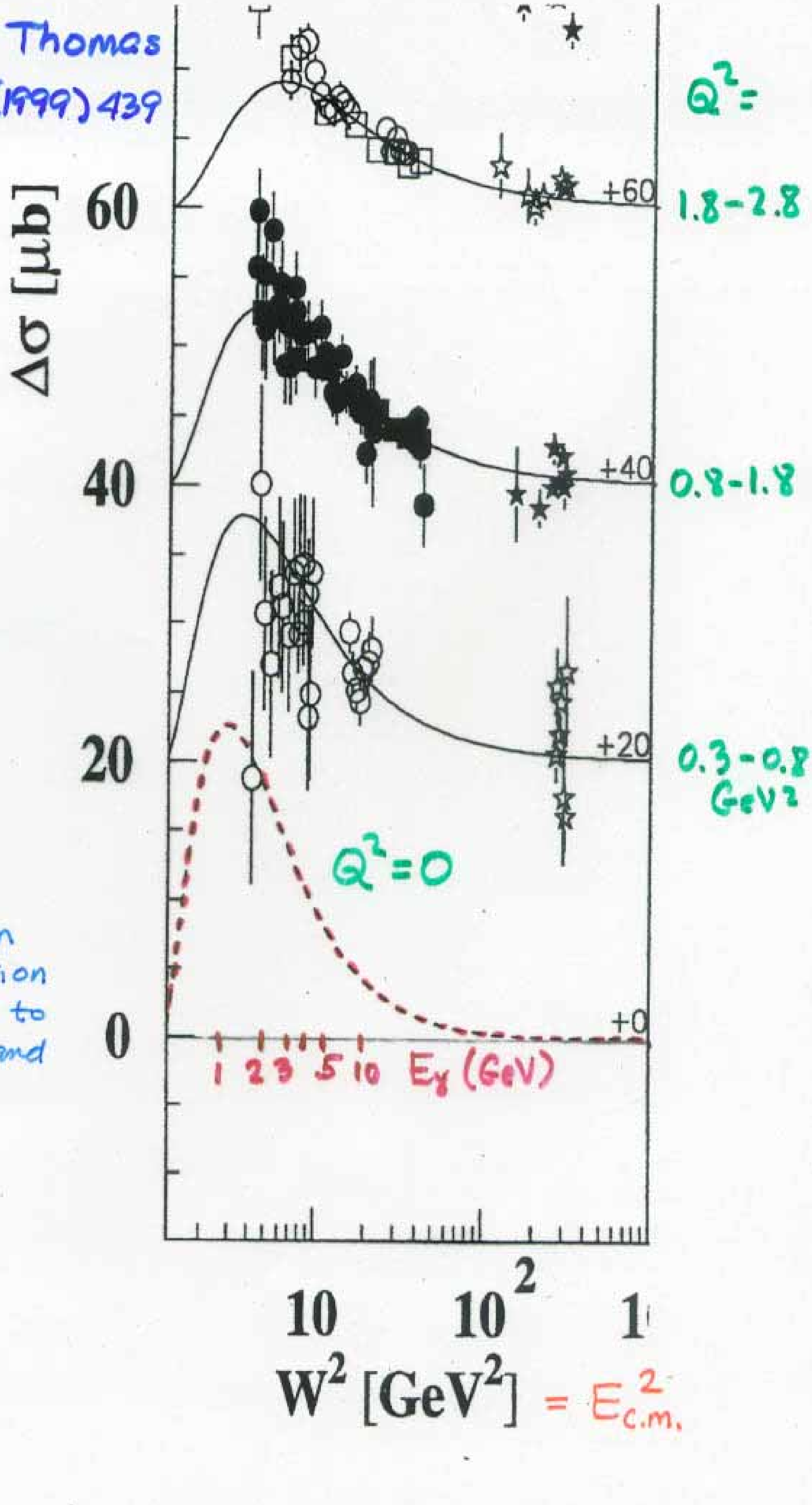
N. Bianchi and E. Thomas, Phys. Lett. **B 450**, 439 (1999).

Regge model, fit to polarized electron scattering data, extrapolated to $Q^2 = 0$.

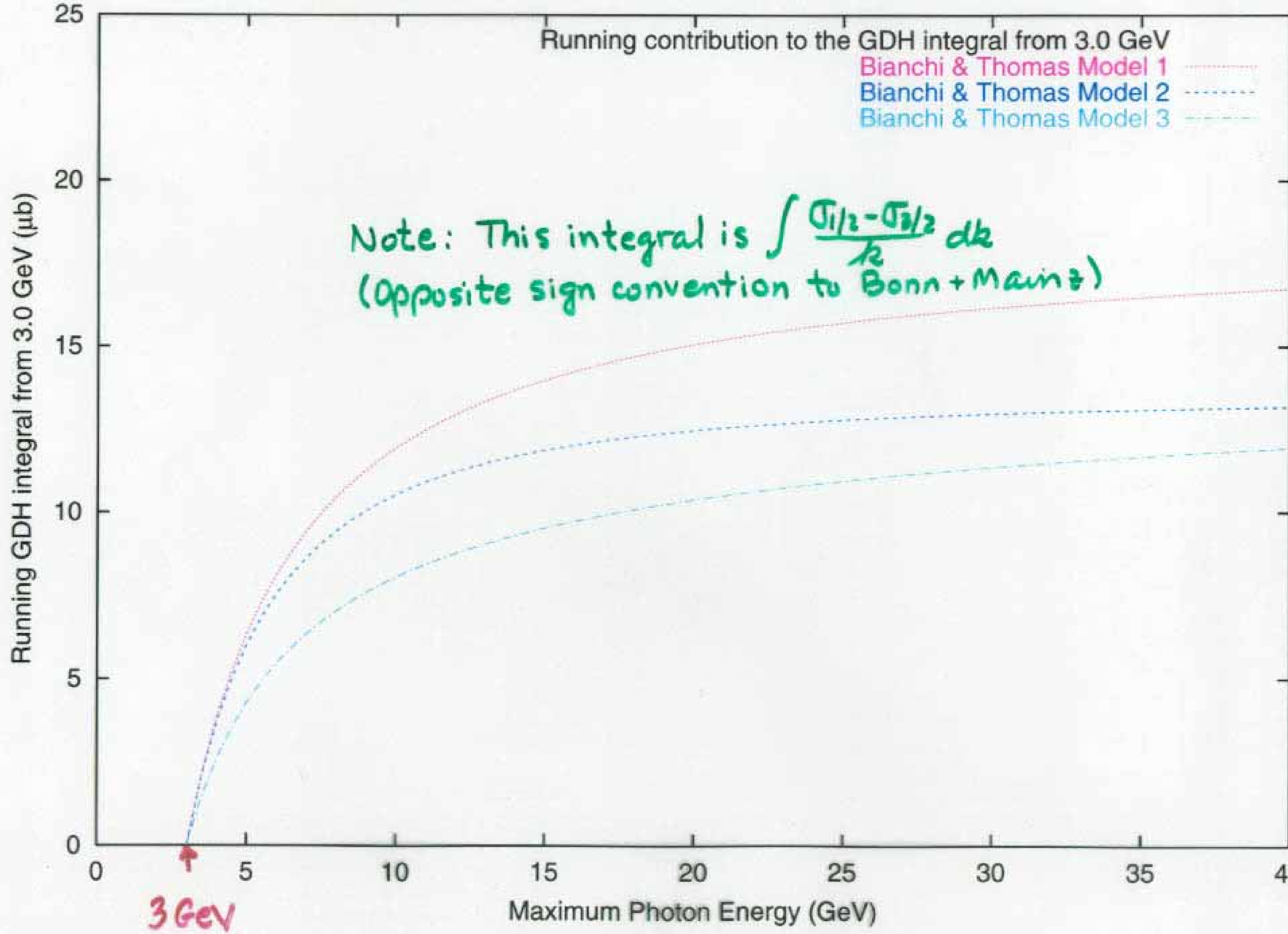
Figure: $\Delta\sigma$ vs. W
Figure: Running sums, 3 models

Bianchi + Thomas
PL B 450 (1999) 439





Note: Sign convention opposite to Mainz and Bonn.


Running contribution to the GDH integral from 3.0 GeV
Bianchi & Thomas Model 1
Bianchi & Thomas Model 2
Bianchi & Thomas Model 3
Note: This integral is $\int \frac{\sigma_{1/2}-\sigma_{3/2}}{k}\,dk$
(Opposite sign convention to Bonn + Mainz)
3 GeV
Running GDH integral from 3.0 GeV (μb)
Maximum Photon Energy (GeV)
0
5
10
15
20
25
30
35
40

What does the GDH sum rule have to do with this conference (NStar2002)?

The GDH sum rule integrates over the entire excitation spectrum of the proton. The measured part of the integral is dominated by resonances at low energies.

At present, the main open question is how much of the GDH integral is due to the unmeasured region (photon energies above ≈3 GeV.)

The Bianchi-Thomas model is a non-resonant parameterization which is not valid in the "resonance region" below ≈2 GeV.

What do we need to know about the resonant contributions in the energy region above the measurements?

A first look at the 3 – 5 GeV region:

The "Real Photon GDH test run"

3 days of run time during "EG2000" electron run period (Y. Prok talk)

Limitations:

- Particle detection only between 8° (limit of CLAS) and 50° (limit of polarized target magnet)

  (Estimated acceptance ~75–85% of total cross section)

- No downstream photon beam monitoring
- Very wide (80 ns) time coincidence between tagger and CLAS

...

EG2000 Experimental Overview

$\vec{e} + \vec{p} \rightarrow \ldots$
$\vec{e} + \vec{d} \rightarrow \ldots$

CEBAF electron beam

- Laser driven photoemission source
- Strained GaAs cathode
- Polarization measured by the Moller polarimeter
- Typical beam polarization $\sim 75\%$
- Beam current 1-10 nA

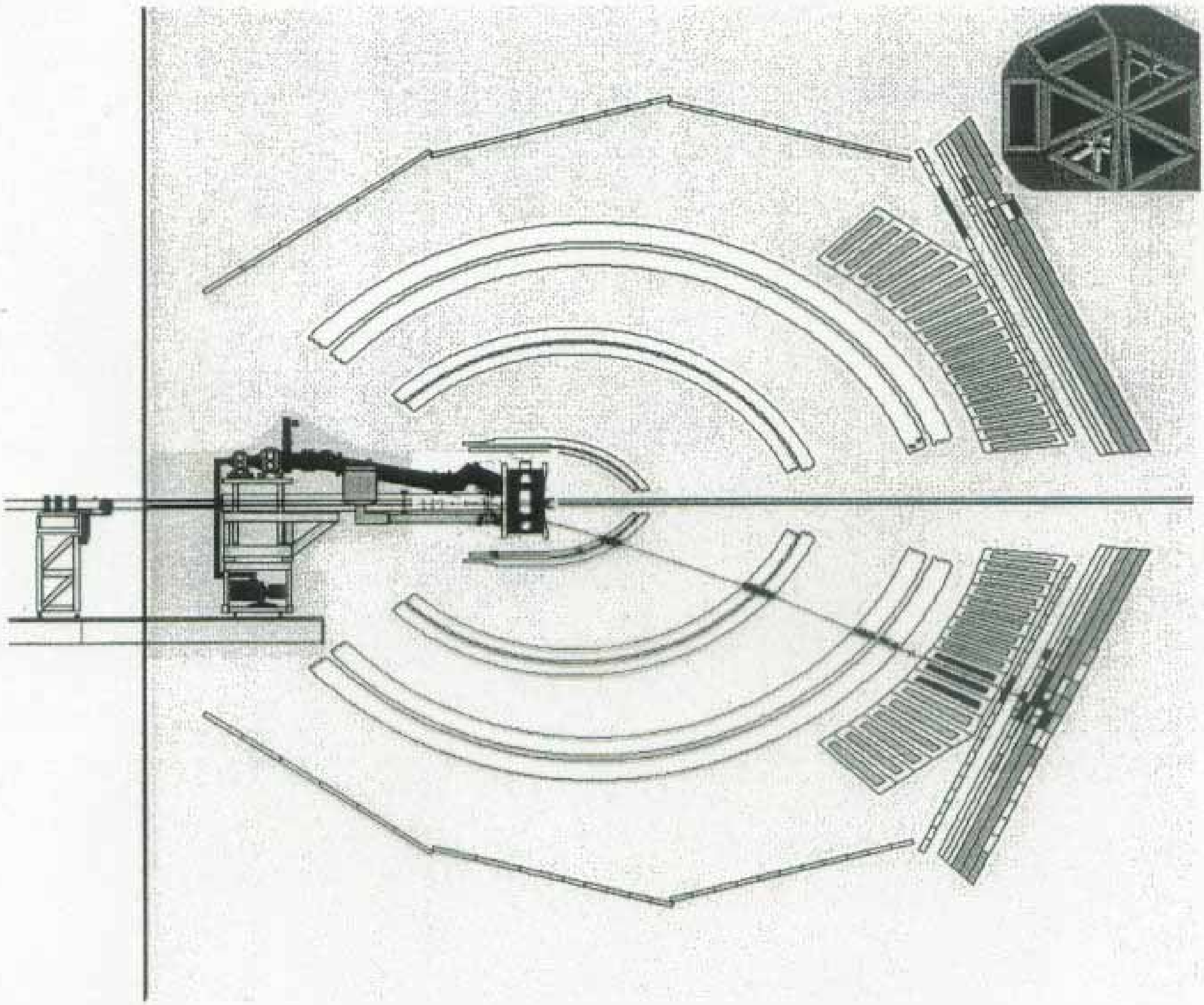
Longitudinally Polarized Targets

- Dynamic Nuclear Polarization
- 5T, 1K, microwave radiation
- Frozen NH_3 and ND_3 granules
- Polarization is monitored by the NMR system

CEBAF Large Acceptance Spectrometer

- Magnetic Toroidal Spectrometer
- "Nearly 4π" acceptance
- Multi-particle final states

CLAS Detector



- Drift chambers
- Cerenkov counters
- Scintillation counters
- Electromagnetic calorimeter

Modifications for photon run : $E_0 = 5.63$ GeV

Turn on tagger magnet + electronics

Insert radiator foil + collimator

Trigger = Tagger + Calorimeter (low threshold)

(2.5 – 5.3 GeV)

$P_{circ} = (.55 - .98) P_e$

Data

123 M	triggers	with	P_{target} : −70%
94 M	"	"	" +79%
15 M	"	"	empty (He-filled) target

Analysis (by Luminita Todor, CMU)

Time calibration of calorimeter and scintillation counters relative to tagger

Select events with at least 1 charged particle
(neutral trigger analysis is in progress.)

Vertex cuts on target region

Figure

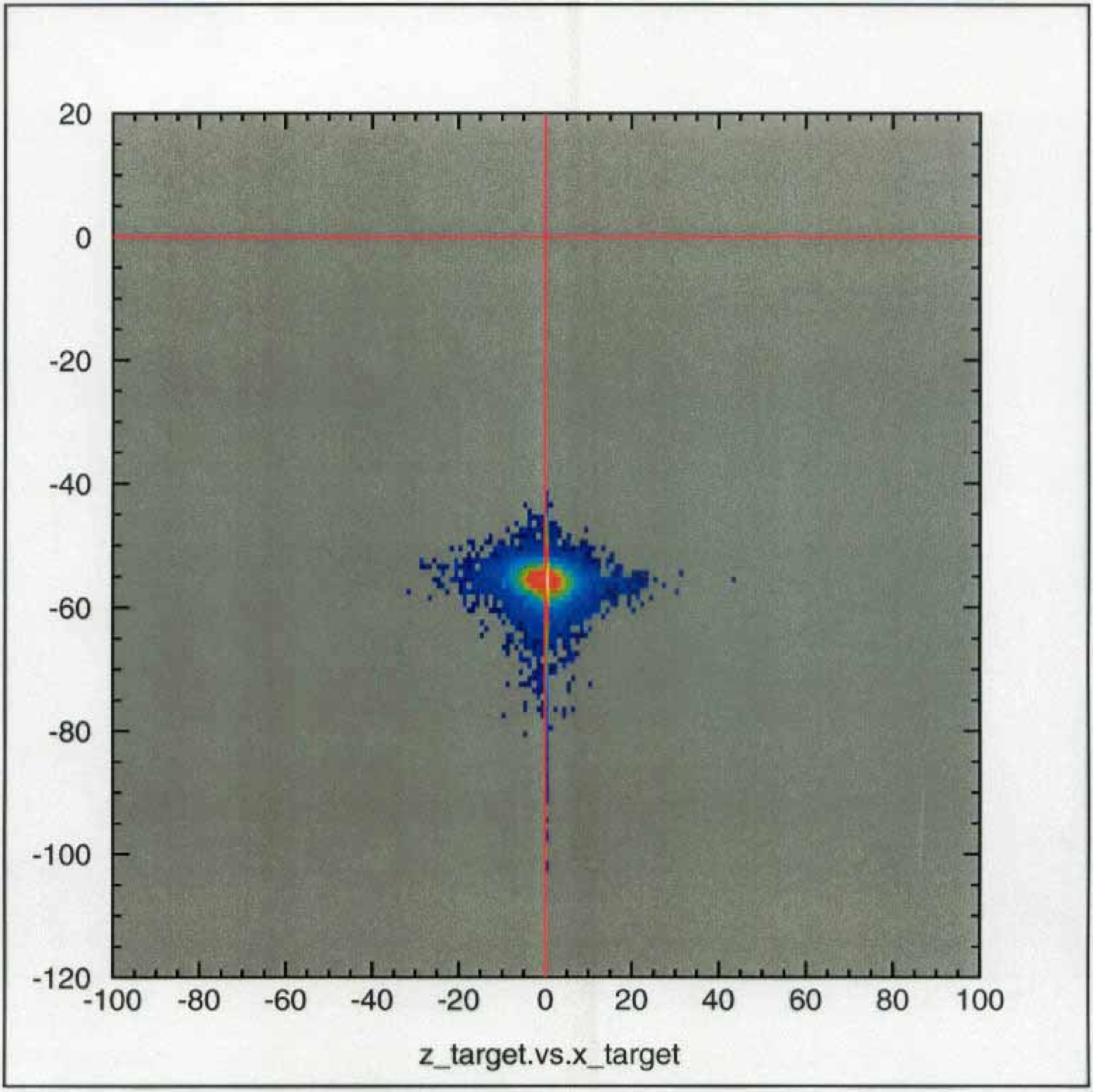
Time cuts: 2, 6 or 10 ns (1, 3 or 5 RF buckets)
~1.9% of triggers survive

Figure

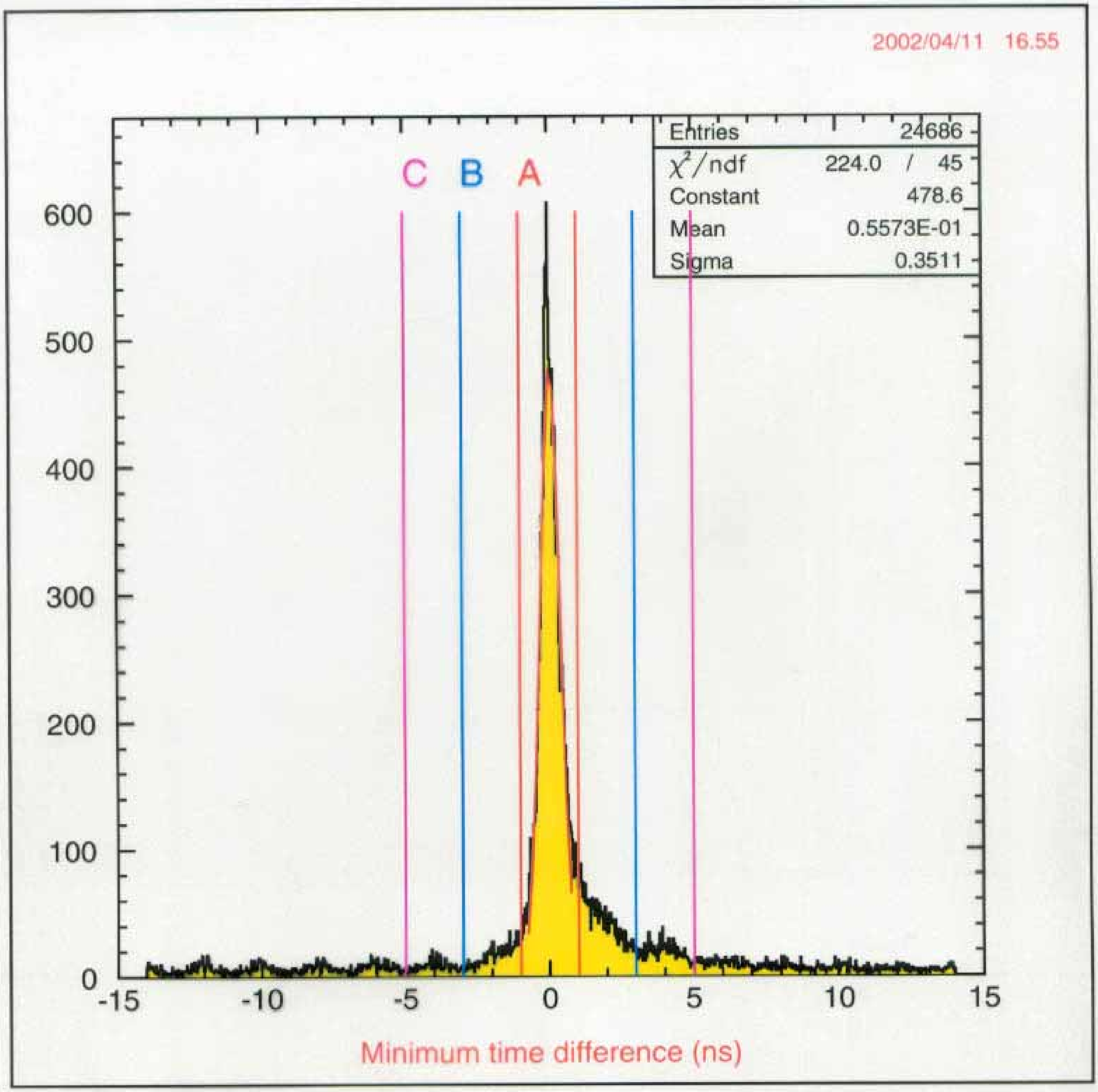
Consistency checks:

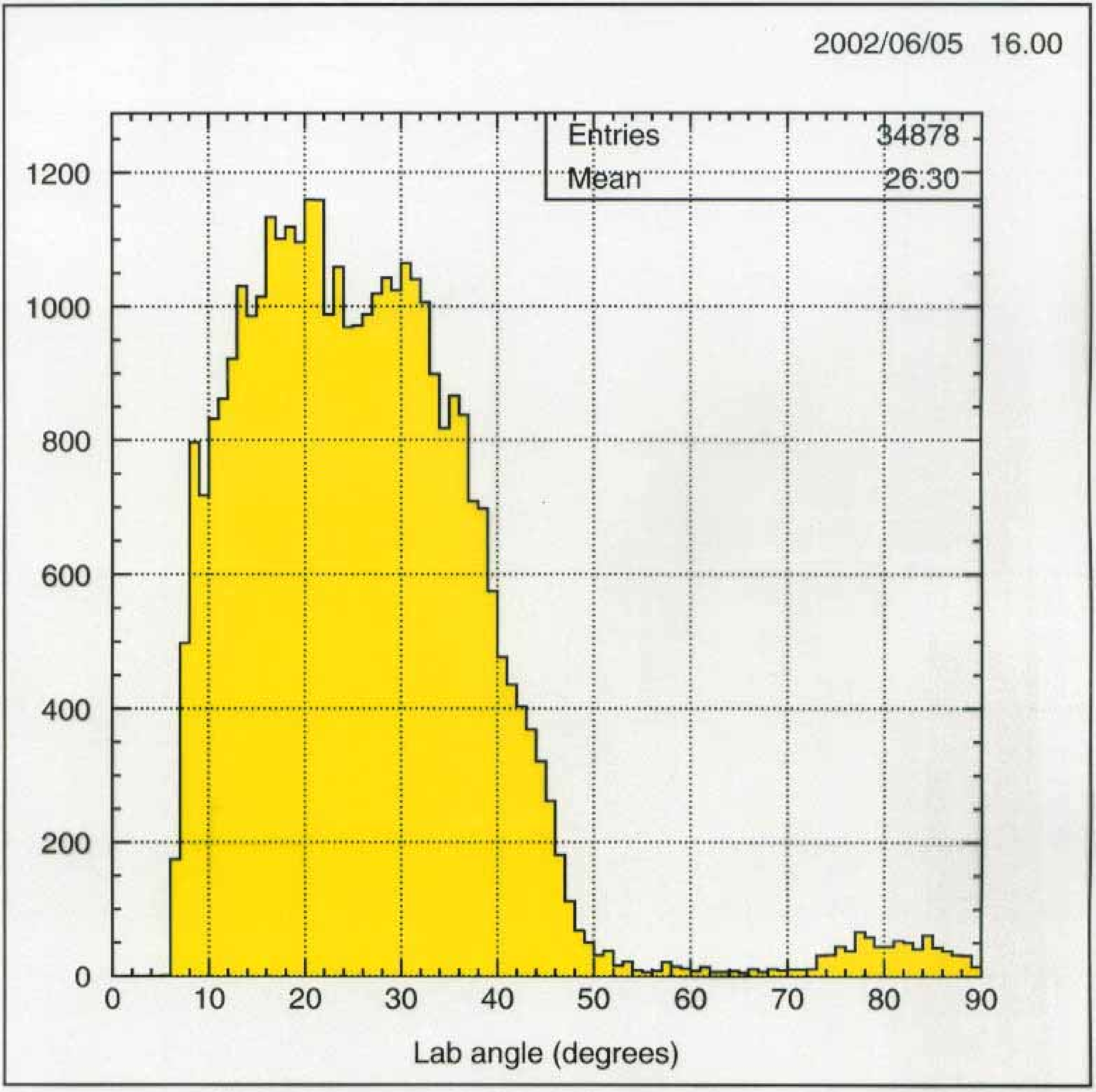
137 data files with negative target polarization
105 data files with positive target polarization

Events/flux per data file and asymmetry per data file are consistent for runs in each group.



20
0
-20
-40
-60
-80
-100
-120
-100
-80
-60
-40
-20
0
20
40
60
80
100
z_target.vs.x_target


2002/04/11 16.55
Entries 24686
χ^2/ndf 224.0 / 45
Constant 478.6
Mean 0.5573E-01
Sigma 0.3511
C
B
A
600
500
400
300
200
100
0
-15
-10
-5
0
5
10
15
Minimum time difference (ns)



2002/06/05 16.00
Entries 34878
Mean 26.30
1200
1000
800
600
400
200
0
0 10 20 30 40 50 60 70 80 90
Lab angle (degrees)

Calculation of asymmetry

Raw asymmetry without using empty-target data

$$A_{raw} = \frac{N_+/f_+ - N_-/f_-}{N_+/f_+ - N_-/f_-}$$ where $f_\pm$ = livetime-corrected flux

(+ and − refer to beam helicity states)

Raw asymmetry using empty-target subtraction

$$A_{raw}^{empty} = \frac{N_+/f_+ - N_-/f_-}{(N_+/f_+ - N_{empty}/f_{empty}) + (N_-/f_- - N_{empty}/f_{empty})}$$

where N_{empty} / f_{empty} = empty-target (He-filled) contribution per helicity state, divided by livetime-corrected flux.

Advantage of empty-target subtraction method:

Windows and foils subtract out.

Dilution factor depends only on ratio of NH_3 and He densities, which are better known than the thicknesses.

In each case, the physics asymmetry is calculated using

$$A = A_{raw} \frac{F_{dilution}}{P_{target} P_{electron} (P_{circ}/P_{electron})}$$

where

P_{target} = target polarization (measured by NMR probe for each run)

$P_{electron}$ = electron beam polarization (measured by Møller polarimeter several times during run period)

$P_{circ}/P_{electron}$ = polarization transfer to Bremsstrahlung photons, calculated using formulas of Olsen and Maximon, Phys. Rev. 144, 887 (1959).

$F_{dilution}$ = dilution factor
= (contribution of all nucleons)/(contribution of free protons)
≈ 7.94 without empty-target subtraction
≈ 4.0 using empty-target (He) subtraction

The product $P_{target} P_{electron}$ was checked using *ep* elastic scattering in the immediately preceding runs.

Systematic uncertainties:		
	$P_{target} P_{electron}$	±10%
	Dilution factor	±10%

Compare asymmetries obtained for each target polarization in 6 energy bins.

6 calculations of each asymmetry:

3 time windows (2 ns, 6 ns, 10 ns)
With and without empty-target subtraction

All 6 calculations are fully consistent.

Will show only results for 10 ns time window, with empty-target subtraction

What have we measured?

The helicity asymmetry for ***some fraction*** of the total cross section.

Trigger: charged or neutral particles, ≈8° to 45°

Analyzed (so far): at least one charged particle *Figure*

What fraction of the γp total cross section is measured?

Using best estimates of target thickness, photon tagging efficiency and bound nucleon contributions, calculate measured cross section per proton: (±20% systematic uncertainty):

Photon energy (GeV)	$\sigma_{measured}$ (μb)	Fraction of σ_{total} (PDG)
2.75	70	52%
3.25	68	52%
3.75	64	50%
4.25	61	48%
4.75	61	49%
5.17	59	47%

Preliminary

Note: The analysis to date includes only events with charged particles.

There is no way to correct the asymmetry for the missing part of the cross section. All we can do is **assume** that the measured asymmetry is the same as the asymmetry in the total cross section.

For comparison, convert Bianchi & Thomas $\Delta\sigma \equiv \sigma_{1/2} - \sigma_{3/2}$ to asymmetry *A* using the Particle Data Group's Regge fit to the γp total cross section.

Results (using 10 ns time window and empty-target subtraction):

Two target polarizations separately *Figure*

and combined *Figure*

(Error bars statistical only)

together with predictions of Bianchi & Thomas.

χ^2 of agreement of the two target polarization values at each energy: 10.7/6 D.of F. *Table*

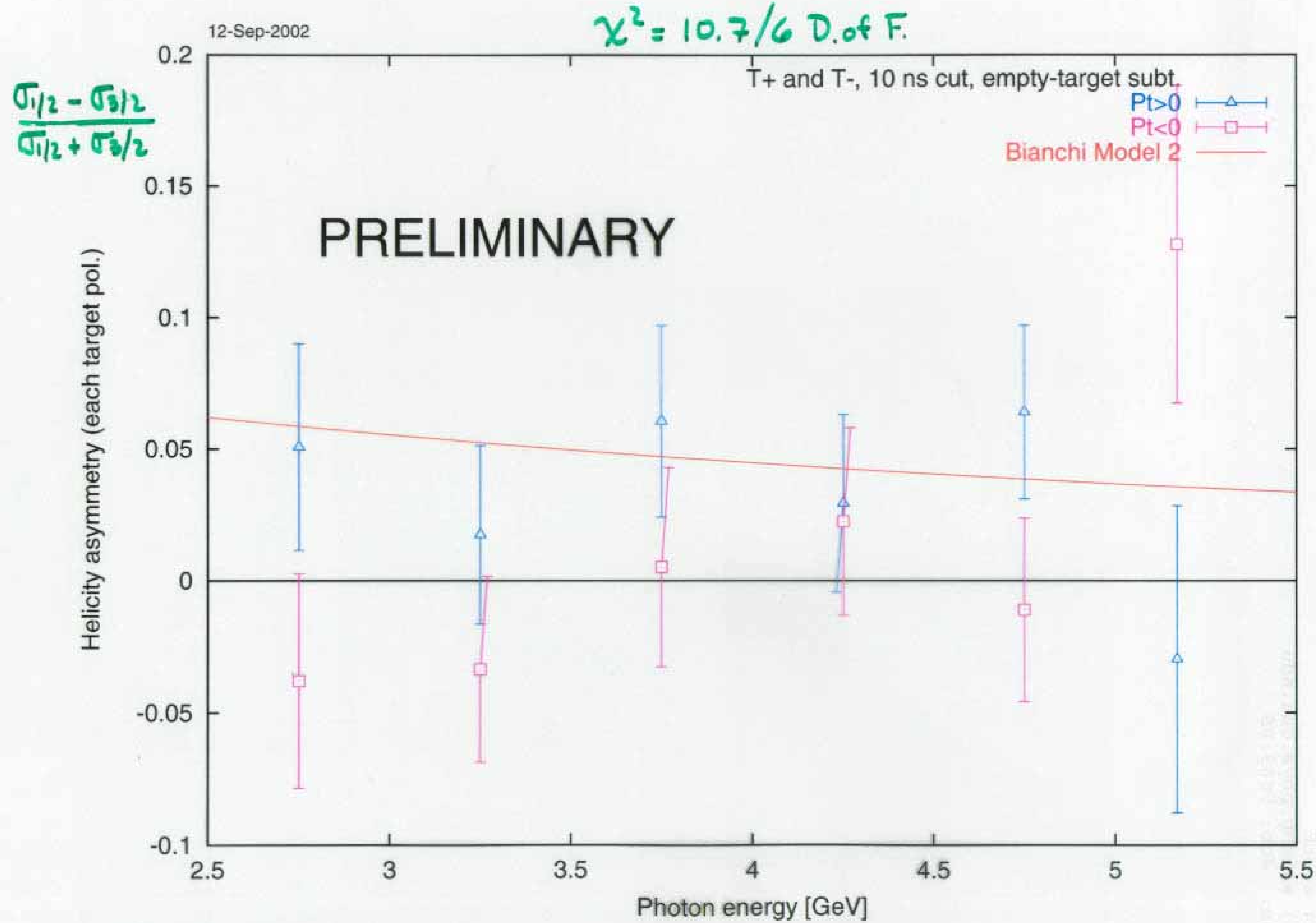
Features:

In each of 6 energy bins there are 2 independent measurements (runs with $P_T < 0$ and $P_T > 0$.

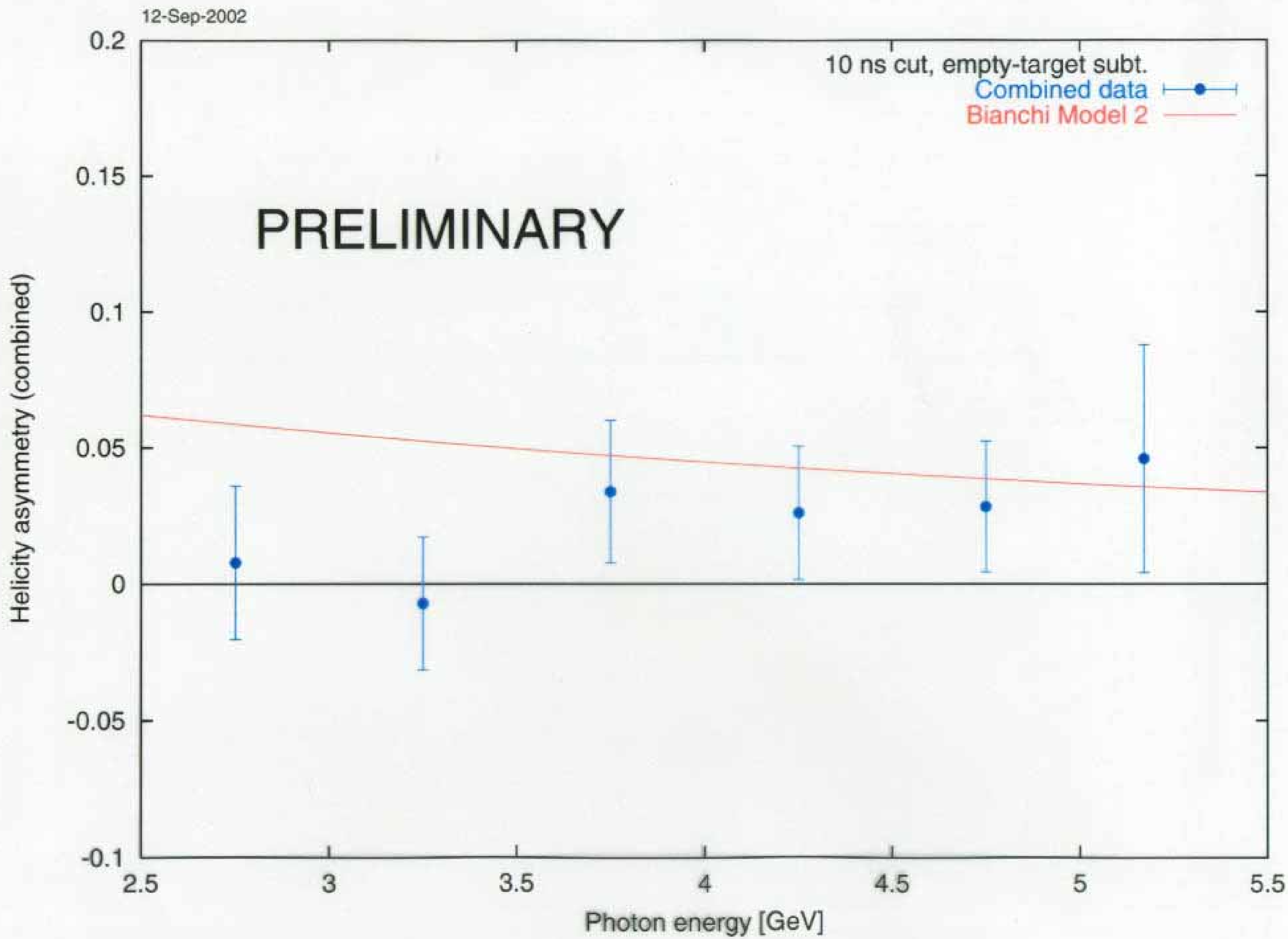
8 of the 12 independent values are within one standard deviation of zero.

2 of the 6 combined values are within one standard deviation of zero. (All 6 are within 1.3 standard deviation of zero)

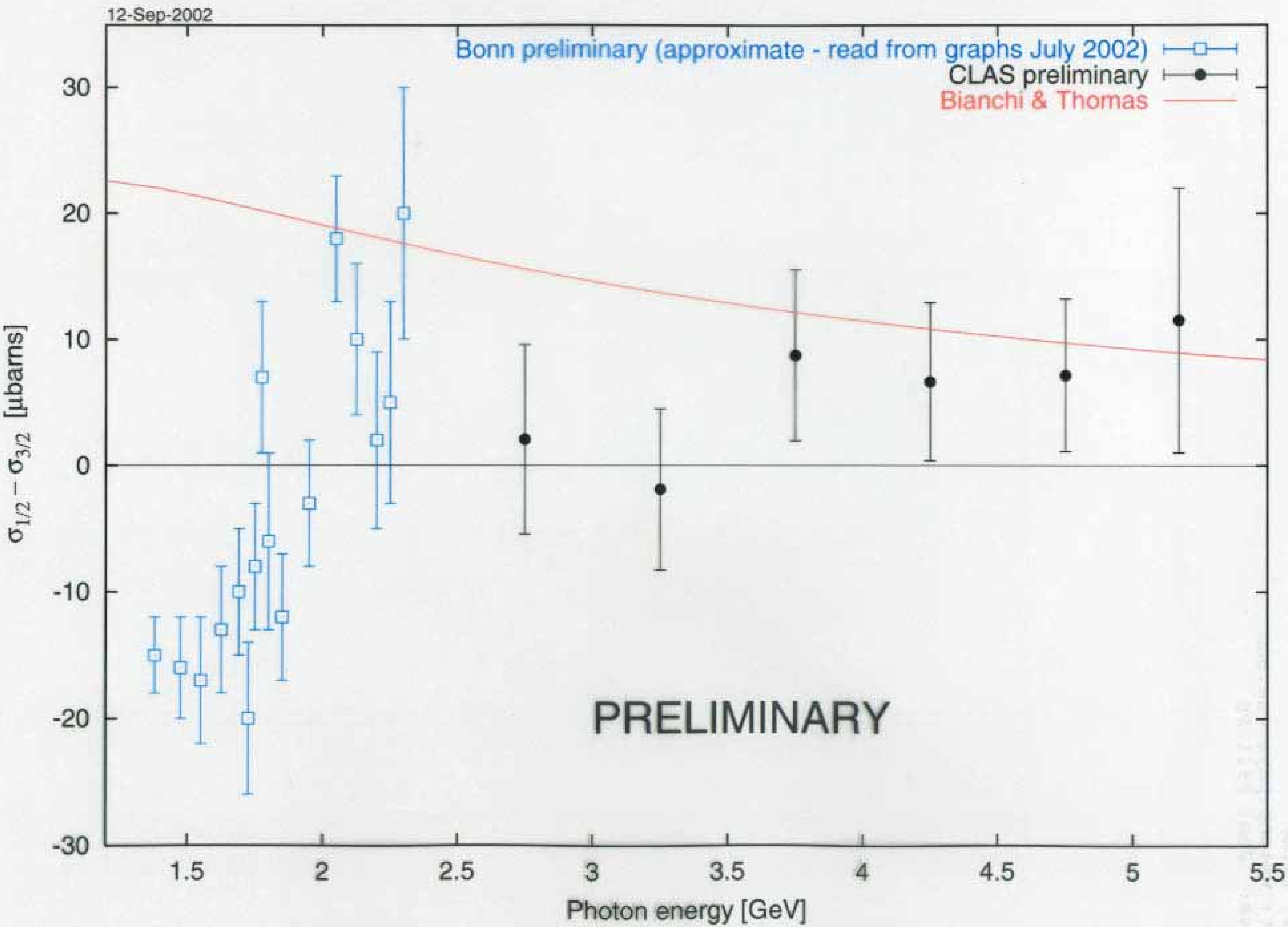
Sign and general trend are consistent with the preliminary data from Bonn *Figure*

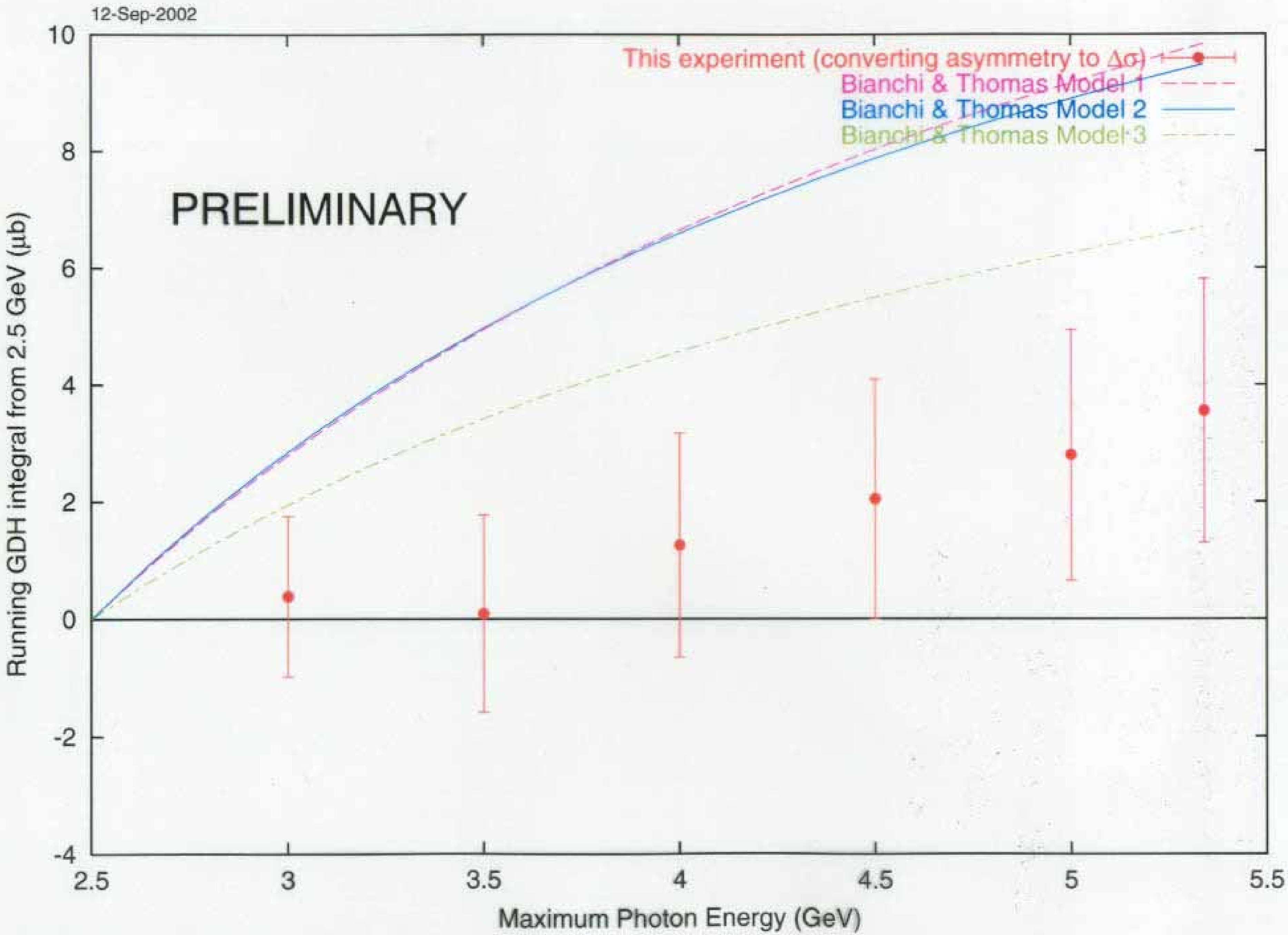


12-Sep-2002
$\chi^2 = 10.7/6$ D. of F.
$\frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$
T+ and T-, 10 ns cut, empty-target subt.
Pt>0
Pt<0
Bianchi Model 2
PRELIMINARY
Helicity asymmetry (each target pol.)
Photon energy [GeV]
0.2
0.15
0.1
0.05
0
-0.05
-0.1
2.5
3
3.5
4
4.5
5
5.5



12-Sep-2002
10 ns cut, empty-target subt.
Combined data
Bianchi Model 2
PRELIMINARY
Helicity asymmetry (combined)
Photon energy [GeV]
0.2
0.15
0.1
0.05
0
-0.05
-0.1
2.5
3
3.5
4
4.5
5
5.5


12-Sep-2002
Bonn preliminary (approximate - read from graphs July 2002)
CLAS preliminary
Bianchi & Thomas
PRELIMINARY
$\sigma_{1/2} - \sigma_{3/2}$ [μbarns]
30
20
10
0
-10
-20
-30
1.5
2
2.5
3
3.5
4
4.5
5
5.5
Photon energy [GeV]

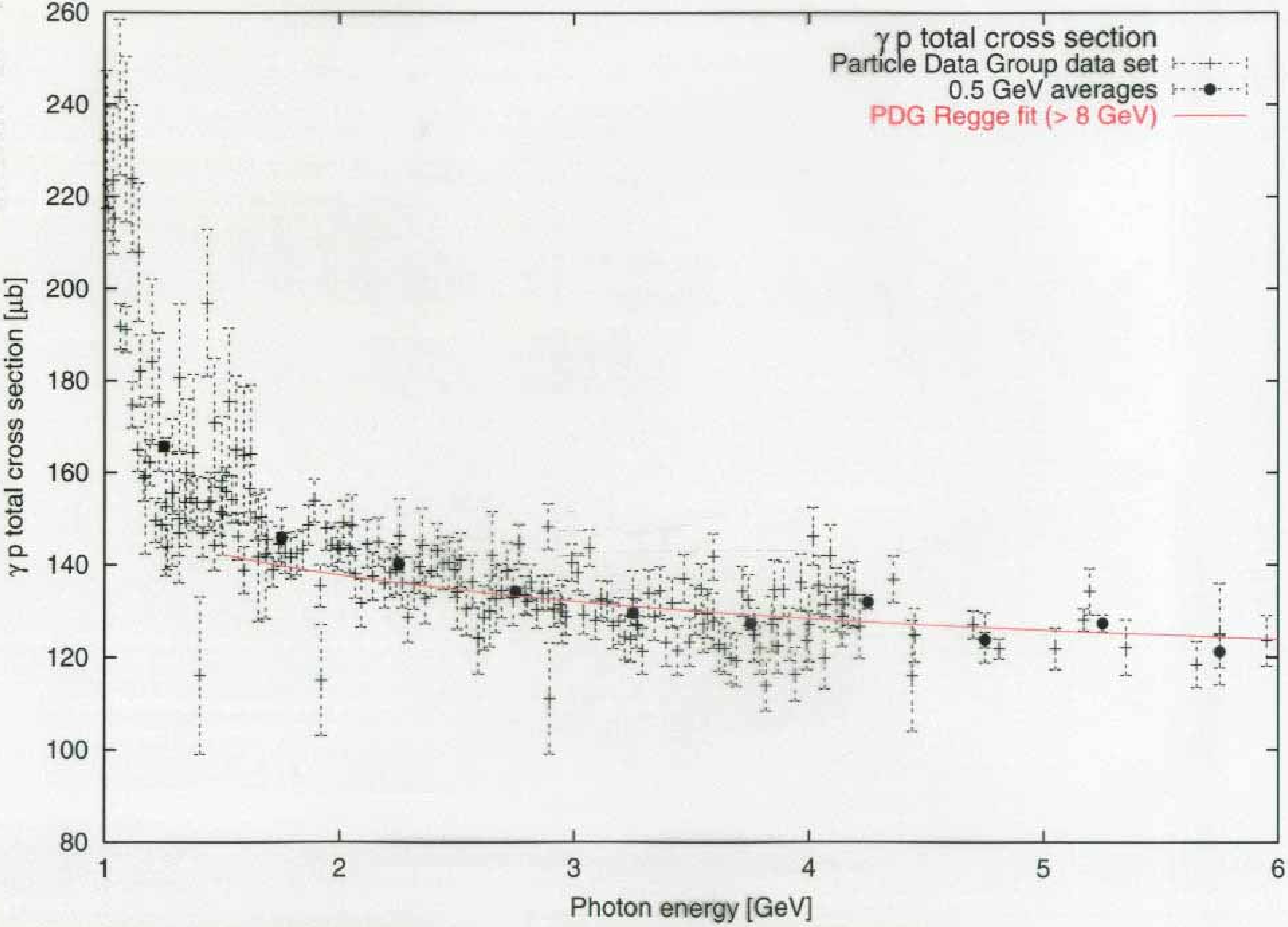

12-Sep-2002
PRELIMINARY
This experiment (converting asymmetry to Δσ)
Bianchi & Thomas Model 1
Bianchi & Thomas Model 2
Bianchi & Thomas Model 3
Running GDH integral from 2.5 GeV (μb)
Maximum Photon Energy (GeV)
10
8
6
4
2
0
-2
-4
2.5
3
3.5
4
4.5
5
5.5

As a set, our asymmetries are more consistent with 0 ($\chi^2 = 5.6/6$ D.F.) than with Bianchi + Thomas ($\chi^2 = 10.1/6$)

But there is hint of a trend:

$E_\gamma < 3.5$ GeV ($W < 2.7$ GeV) $A \approx 0$

$E_\gamma > 3.5$ GeV ($W > 2.7$ GeV) $A \approx B+T$


γ p total cross section
Particle Data Group data set
0.5 GeV averages
PDG Regge fit (> 8 GeV)
γ p total cross section [μb]
260
240
220
200
180
160
140
120
100
80
1
2
3
4
5
6
Photon energy [GeV]

Some conclusions about the Hall B measurement:

1. It is hard to get a definitive result from a 3-day experiment.

And – assuming that the measured asymmetry represents the asymmetry in the total cross section –

2. The **sign** of the γp helicity asymmetry in the region 2.5–5.3 GeV is consistent with the preliminary data from Bonn and with the nonresonant Regge parameterization of Bianchi and Thomas.

3. The γp helicity asymmetry in the region 2.5–5.3 GeV is **on average** smaller than the parameterization of Bianchi and Thomas.

4. Within their large uncertainties, the data are not inconsistent with a transition from 0 asymmetry at ≈ 3 GeV to the Bianchi-Thomas values at ≈ 5 GeV.

But ...

5. Reliance on the extrapolations from electron scattering experiments is not a satisfactory solution to the high-energy convergence of the GDH sum rule for real photons – **MORE DATA ARE NEEDED.**

Plans for the future:

- Proposal E-159 at SLAC
  (P. Bosted, D.Crabb, spokesmen) *Figures* (3)

- Plans for a new proposal in Hall B at Jefferson Lab
  (L. Todor *et al.*)

  CLAS
  + frozen spin target → access to large angles
  + forward calorimeter
  (being built for DVCS experiment) *Figure*
  → access to angles < 8° (neutral and charged)

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 or 2006

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