Beam Normal Spin Asymmetries: Experimental Data

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Precision Electroweak Interactions – W&M

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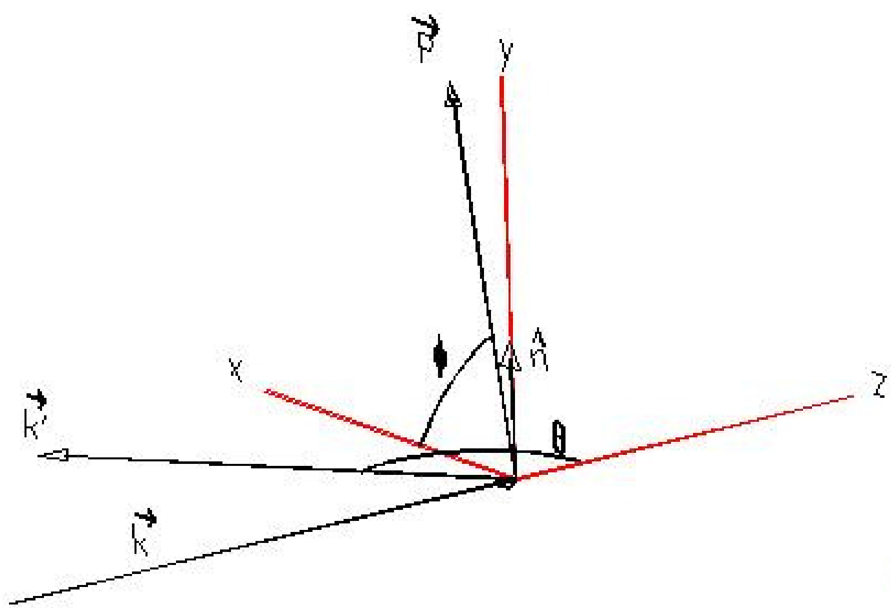
Terminology

A_n *(Vector Analyzing Power)*

= *TBSSA (Transverse Beam Single Spin Asymmetry)*

= B_n *(Beam Normal Spin Asymmetry)*

What is A_n ?



$$\sigma(\theta) = \sigma_0(\theta)[1 + A_n \vec{P} \bullet \hat{n}]$$

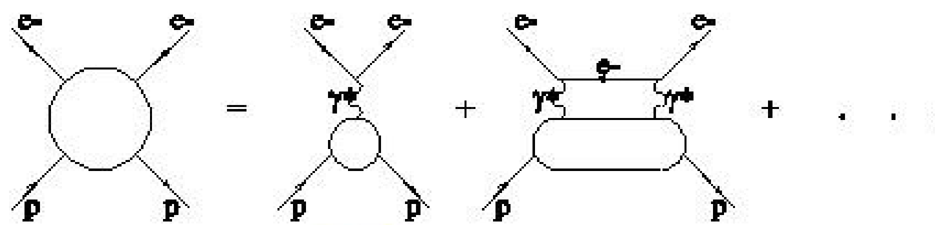
$$A_n = \frac{1}{P_n} \frac{\sigma_\uparrow(\theta) - \sigma_\downarrow(\theta)}{\sigma_\uparrow(\theta) + \sigma_\downarrow(\theta)}$$

For axially symmetric detectors: $A_{meas} = A_n \sin(\varphi + \delta)$

How is A_n related to $M_{2\gamma}$?

$$A_n = \frac{Tr\{M\Sigma_n M^\dagger\}}{Tr\{MM^\dagger\}}$$

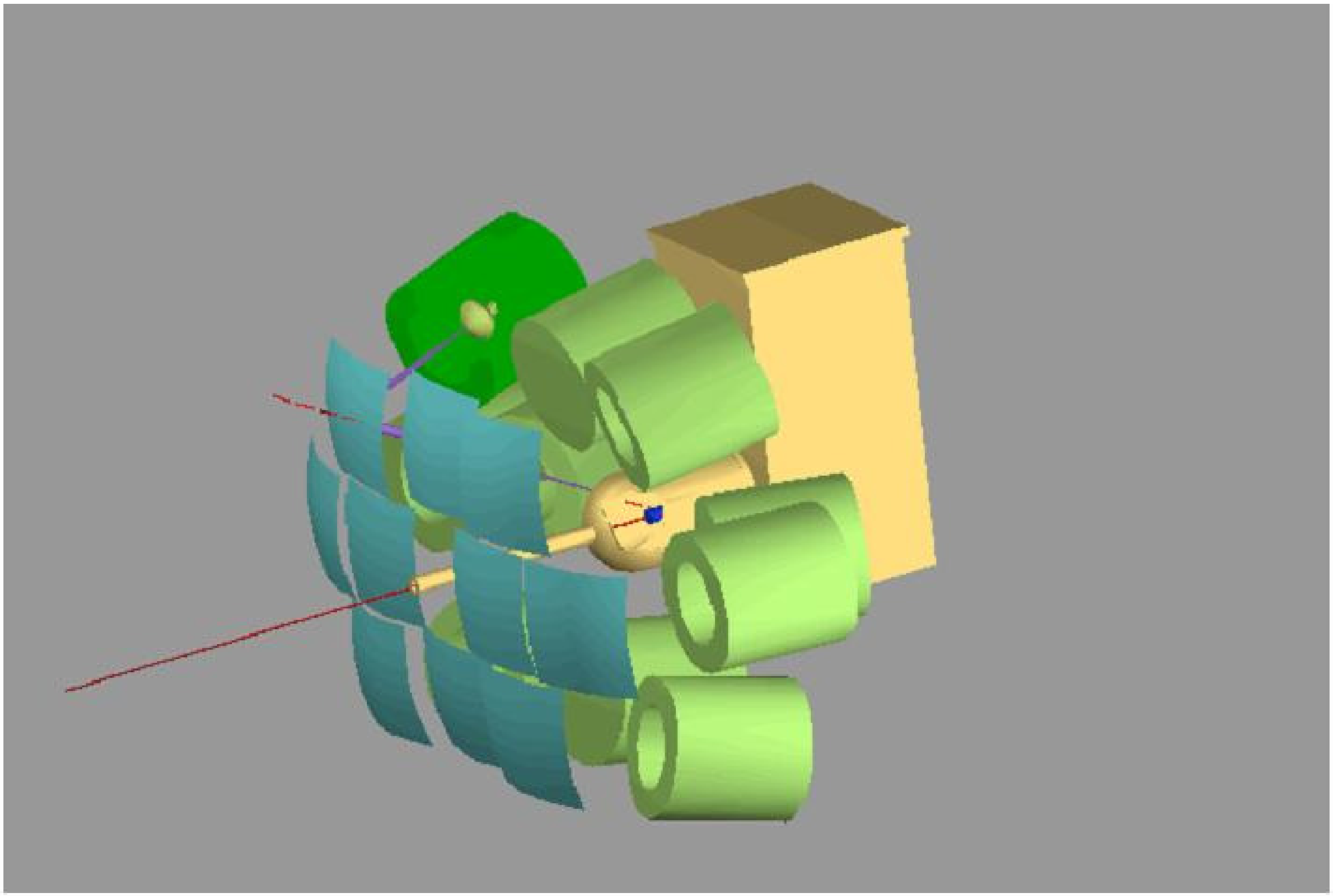
$$M = M_{Born} + M_{2\gamma} + \bullet \quad \bullet \quad \bullet$$



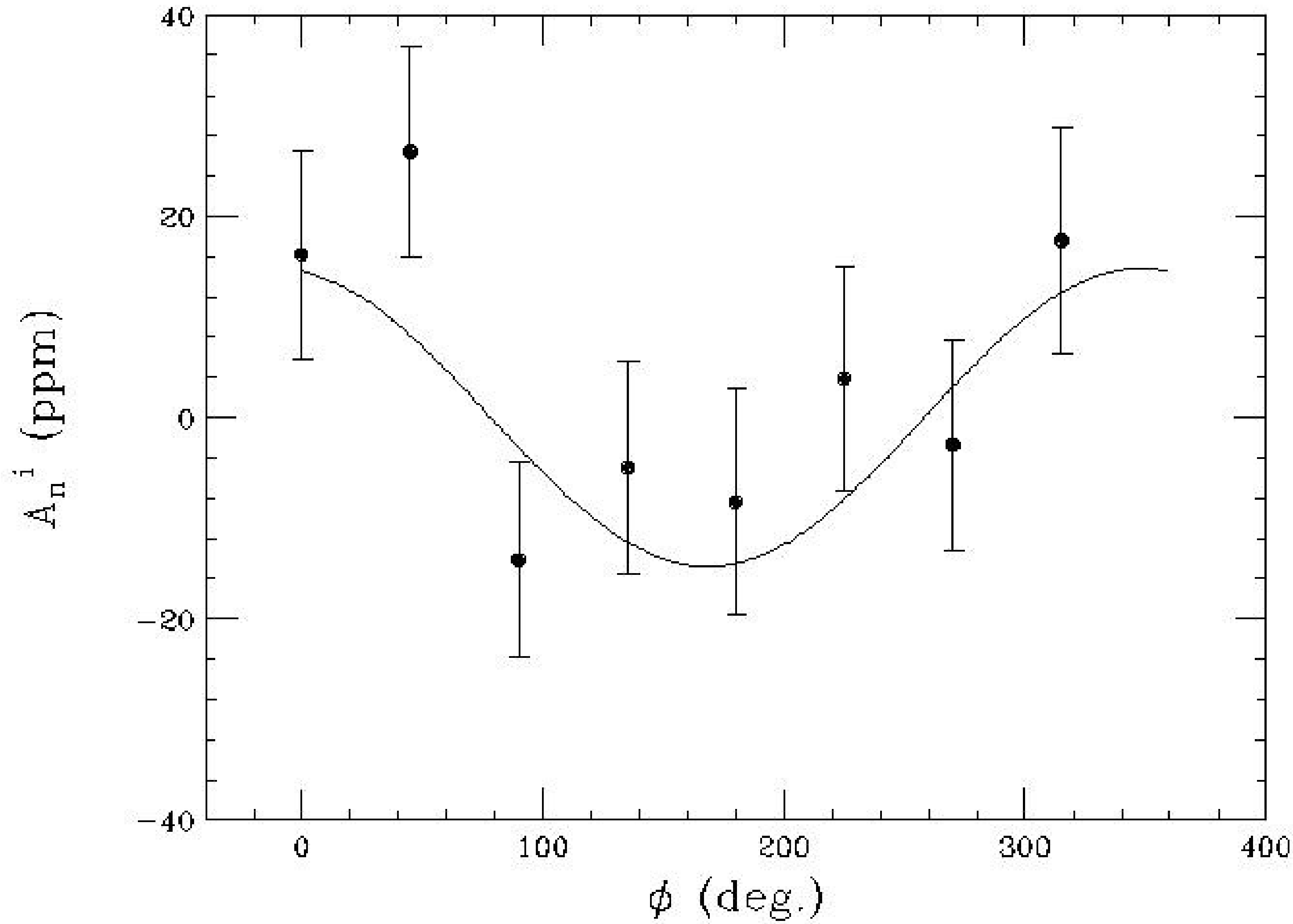
Real!

$$A_n = \frac{2M_{Born}\Im\{M_{2\gamma}\}}{M_{Born}^2}$$

SAMPLE Apparatus (E=192 MeV, θ_e=146°)



SAMPLE Result
(Phys.Rev.C63:064001,2001)



$A_n = -16.4 \pm 5.9$ ppm

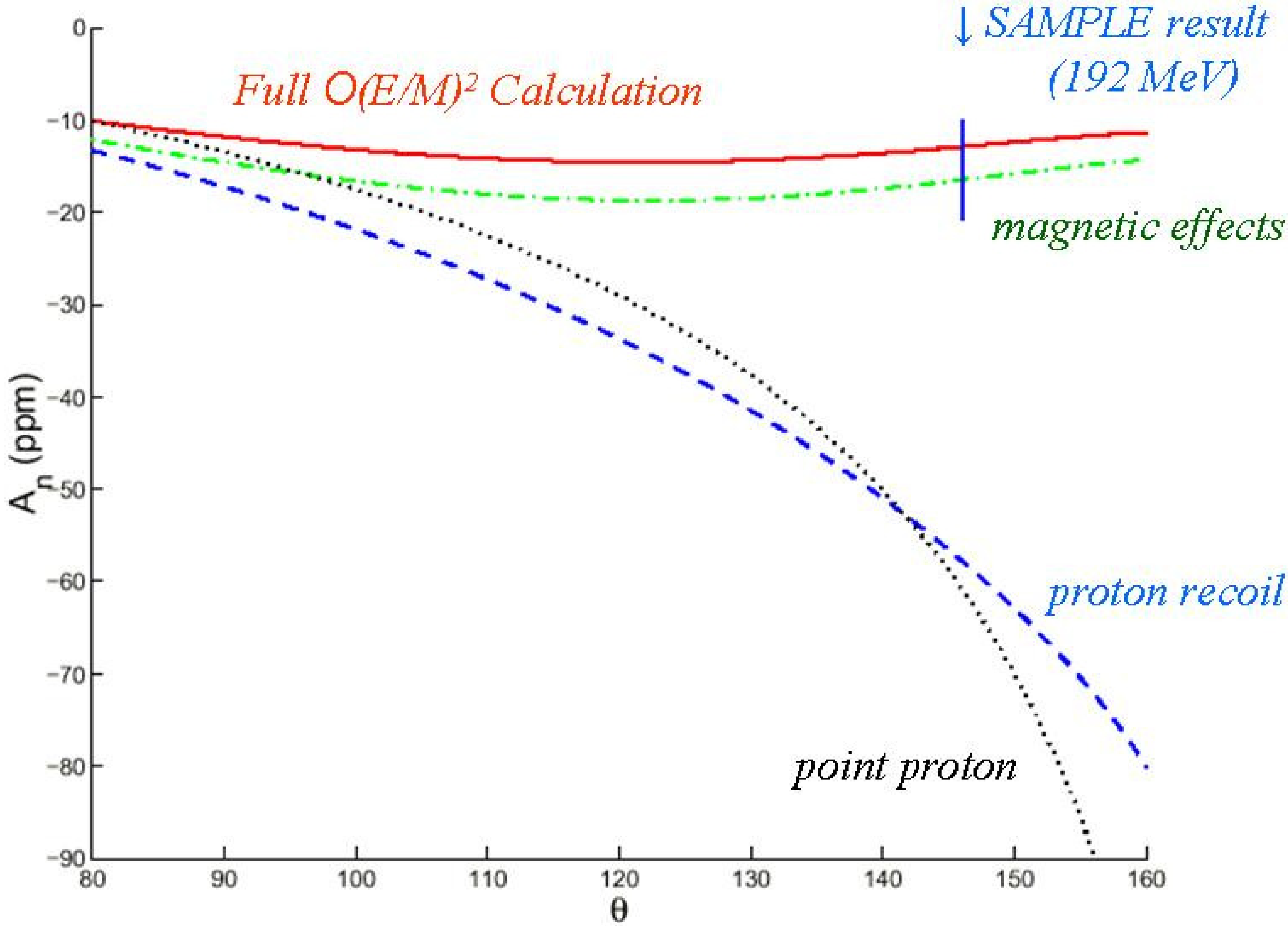
What is $M_{2\gamma}$? (*HBχPT*)
(Phys.Rev.C70:054003,2004)

* *Effective field theory with e^-, γ, N d.o.f.*
* *Expansion in powers of E/M*

  → *Valid for low E beams, $E \lesssim m_\pi$*

$$L_{N\gamma} = \overline{B_v} i v \bullet D B_v + \frac{1}{2M} \overline{B_v} \left[(v \bullet D)^2 - D^2 \right] B_v$$
$$+ \frac{e\mu}{2M} \varepsilon_{\mu\nu\alpha\beta} F^{\mu\nu} v^\alpha \overline{B_v} S^\beta B_v - \frac{eC_r}{M^2} \overline{B_v} v_\mu B_v \partial_\lambda F^{\mu\lambda}$$

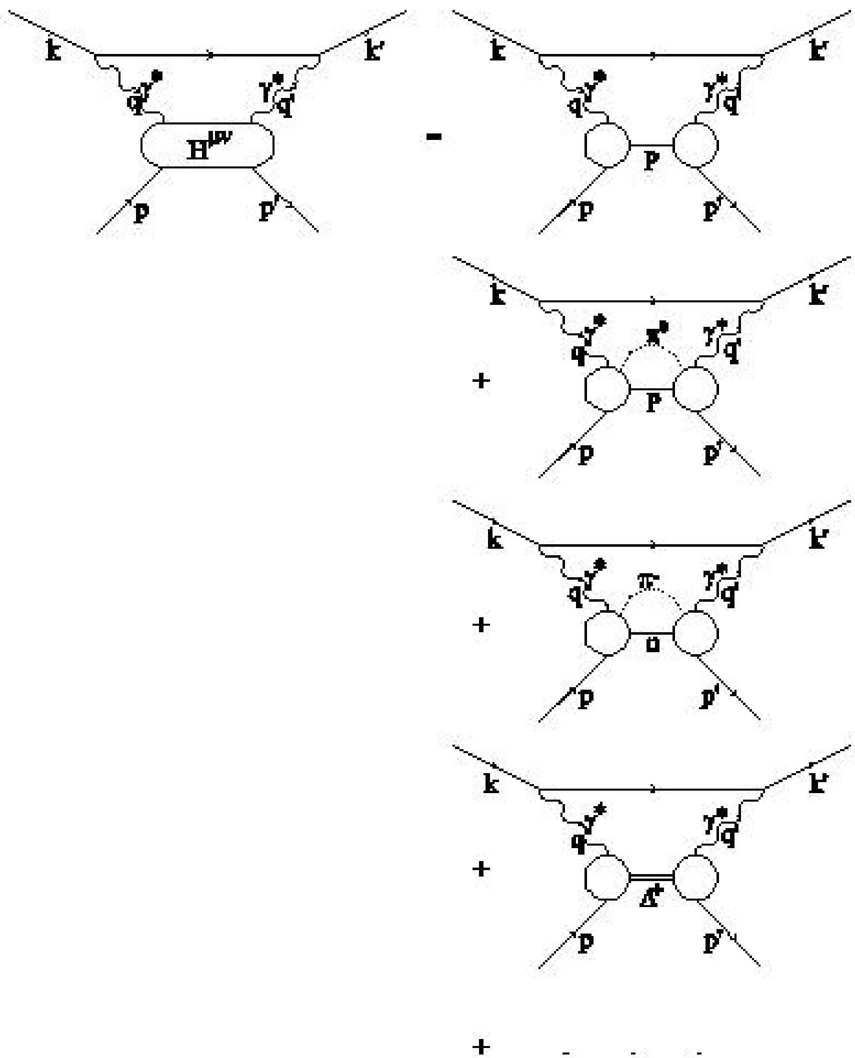
$$\mu = 2.793 n.m. \quad , \quad C_r = \frac{M^2}{6} \left\langle r^2 \right\rangle_E$$



↓ SAMPLE result
(192 MeV)
Full O(E/M)² Calculation
magnetic effects
proton recoil
point proton
A_n (ppm)
θ
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
80
90
100
110
120
130
140
150
160

What is $M_{2\gamma}$? (Resonance region treatment)

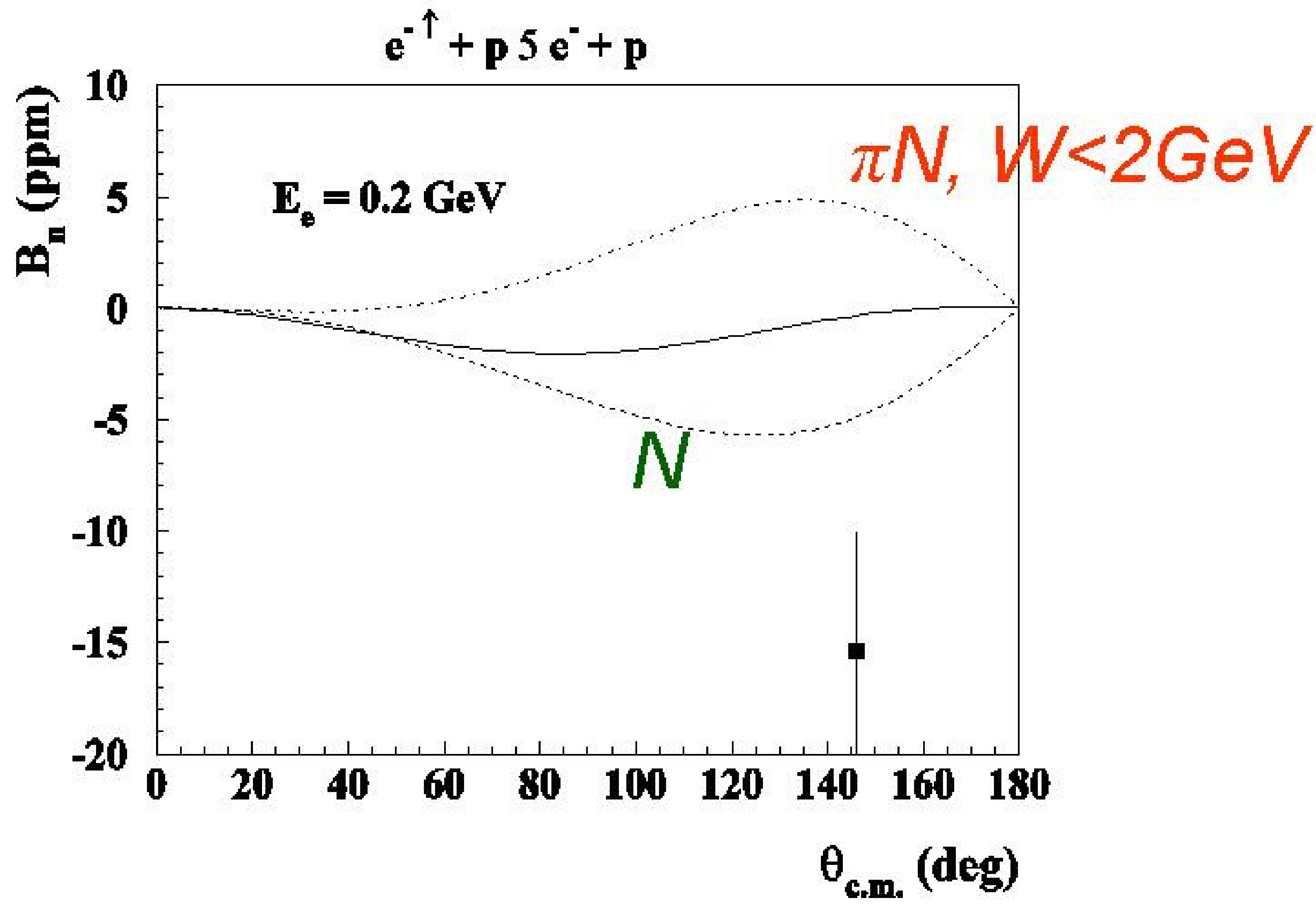
(Phys.Rev.C70:045206,2004)



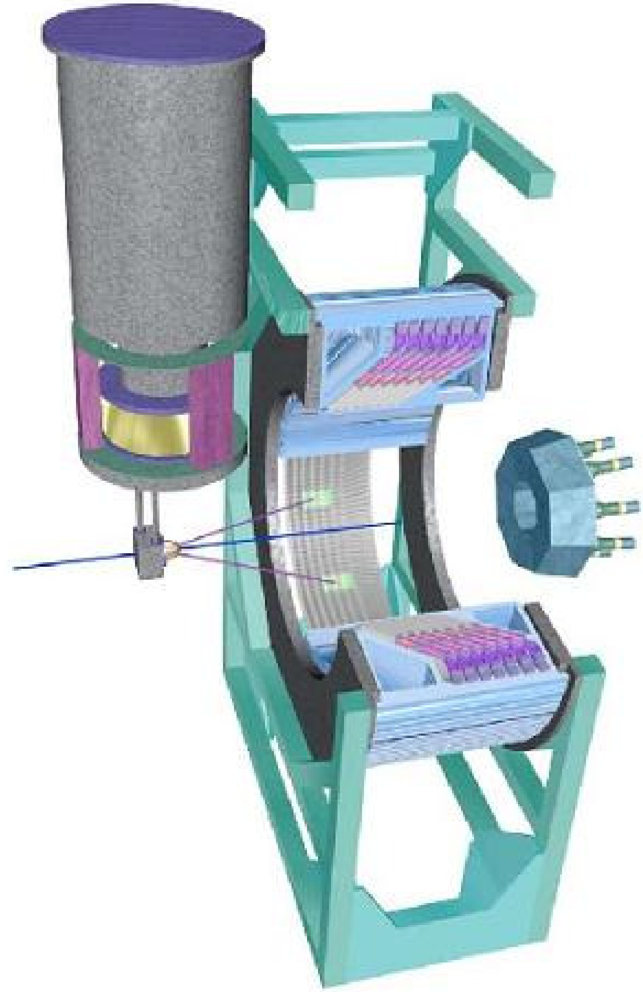
- Free P FF's
- Free P propagator

- $s > M_p + M_\pi$
- $\gamma N \pi$ couplings
- π and N propagators

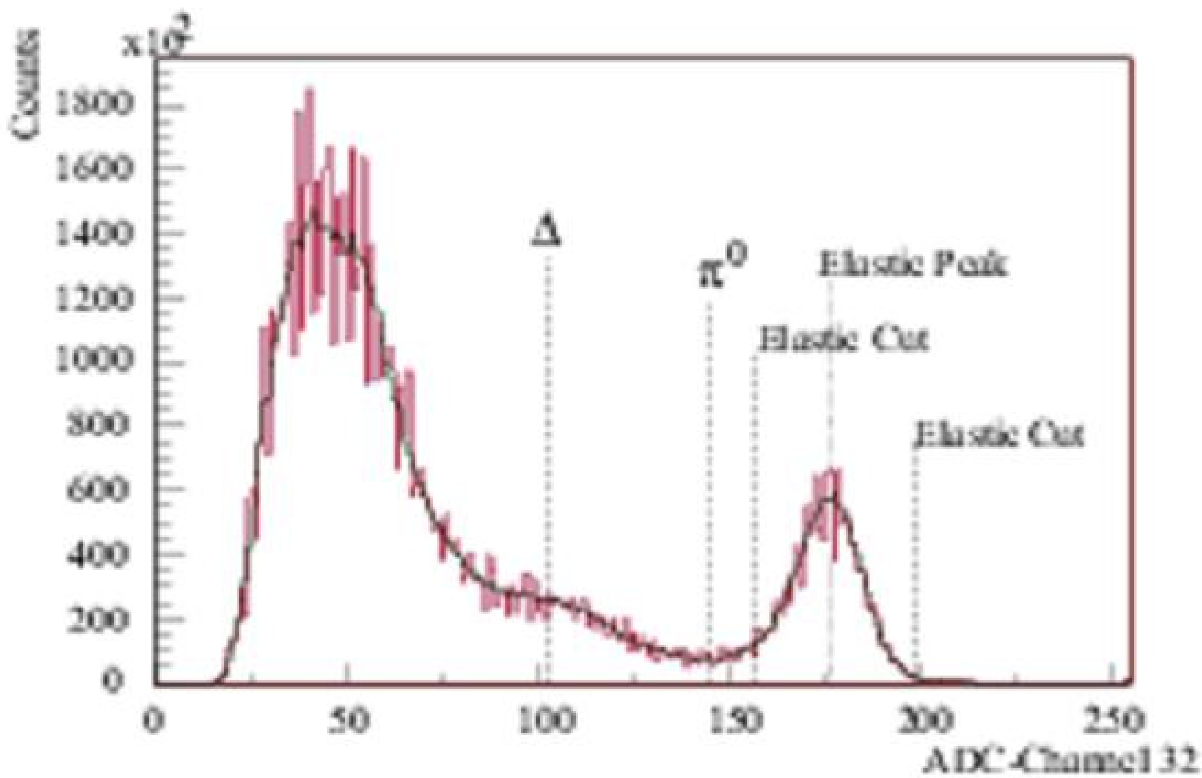
- $s > M_p + M_\Delta$
- $\gamma N \Delta$ couplings
- N and Δ propagators

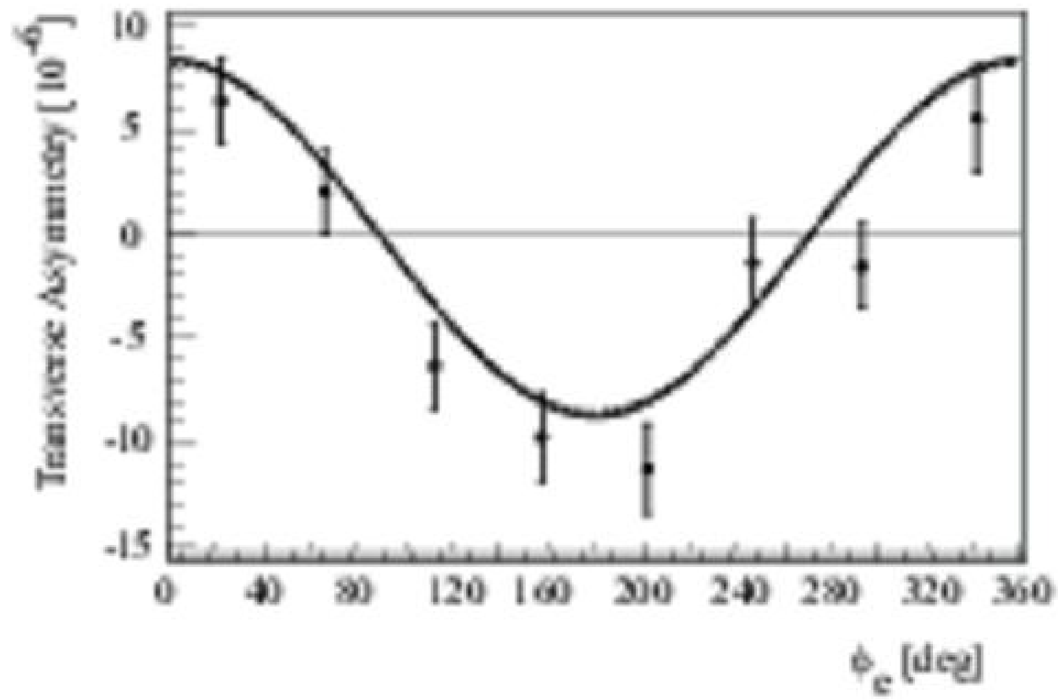

e-↑ + p 5 e- + p
Bn (ppm)
Ee = 0.2 GeV
πN, W<2GeV
N
10
5
0
-5
-10
-15
-20
0
20
40
60
80
100
120
140
160
180
θc.m. (deg)

A4 Mainz Apparatus

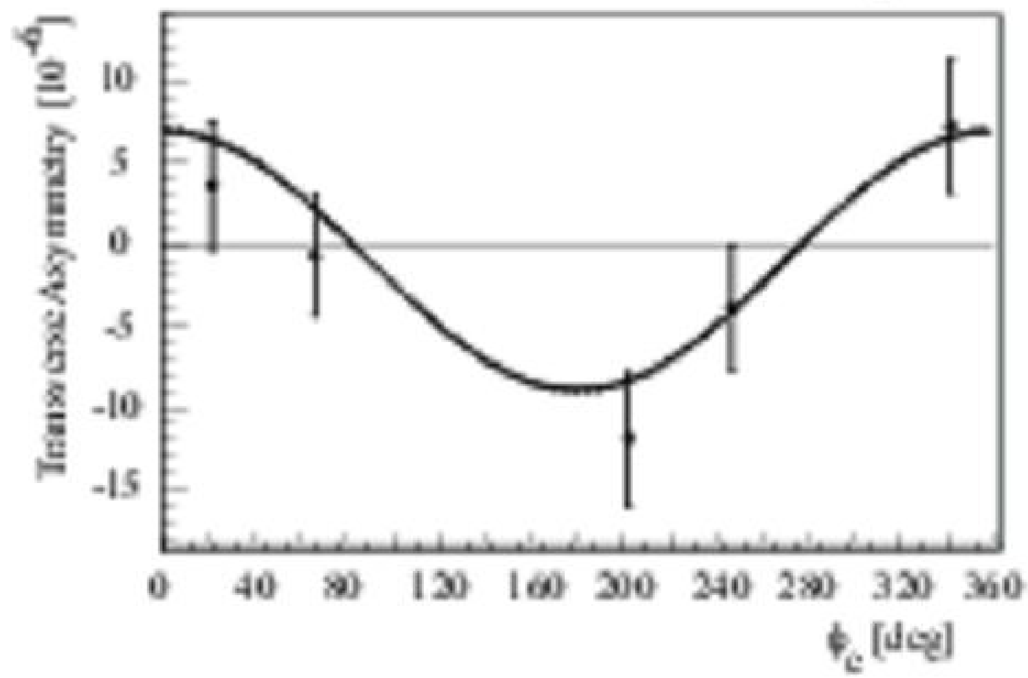


Energy Spectrum from A4 Experiment

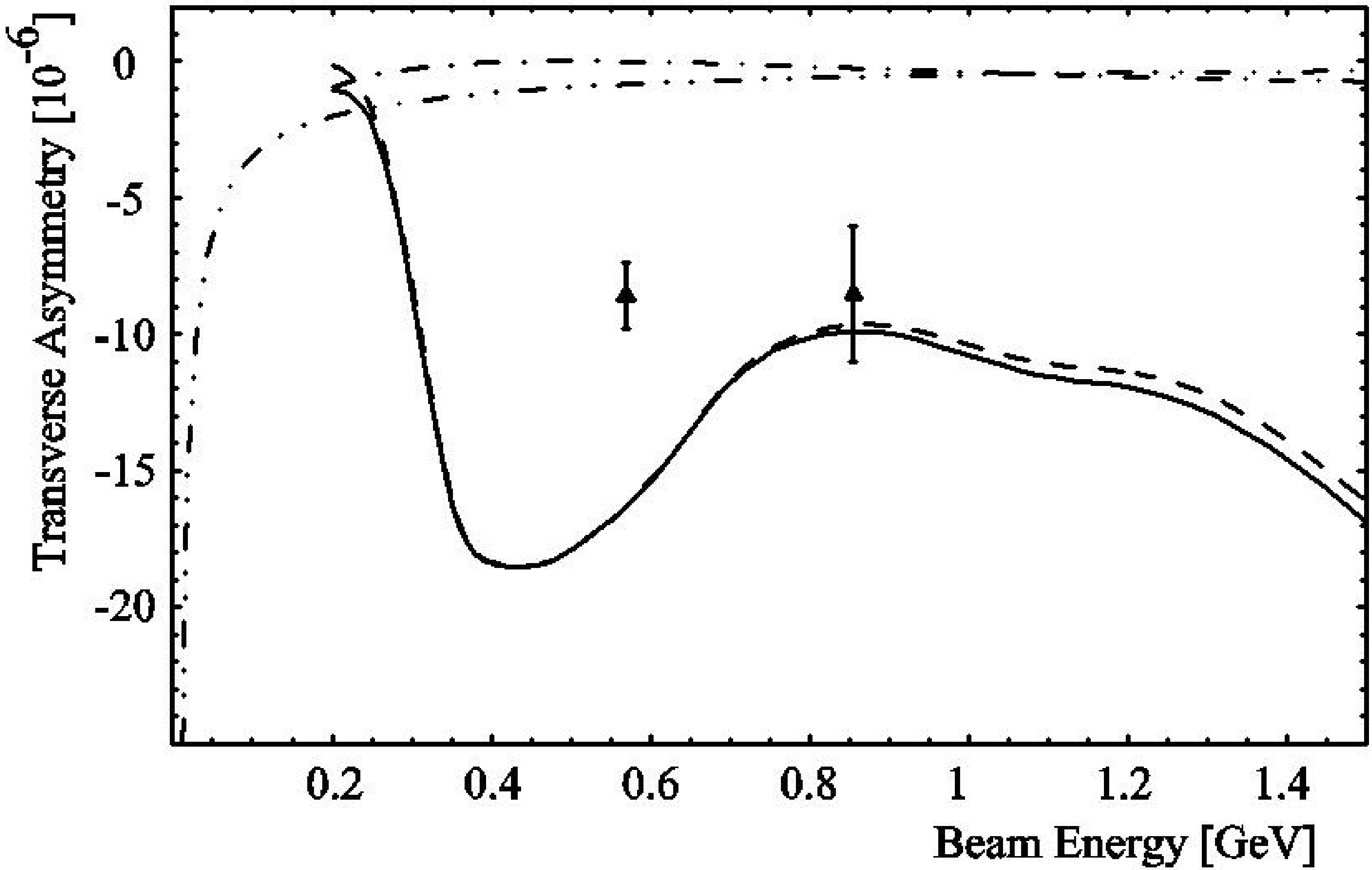




E=570 MeV



E=855 MeV

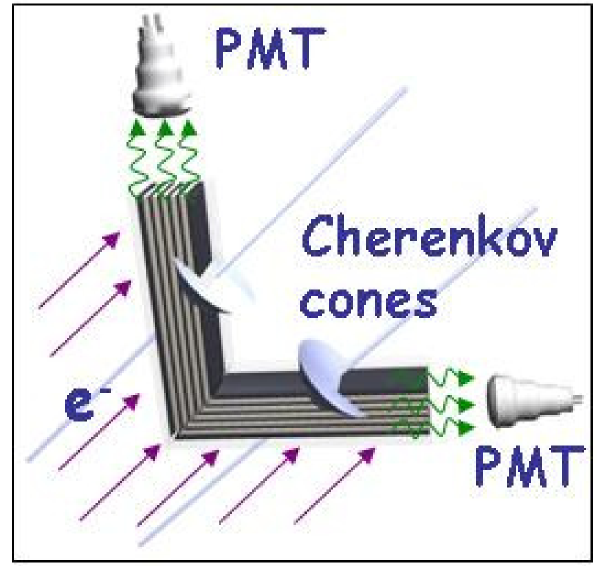


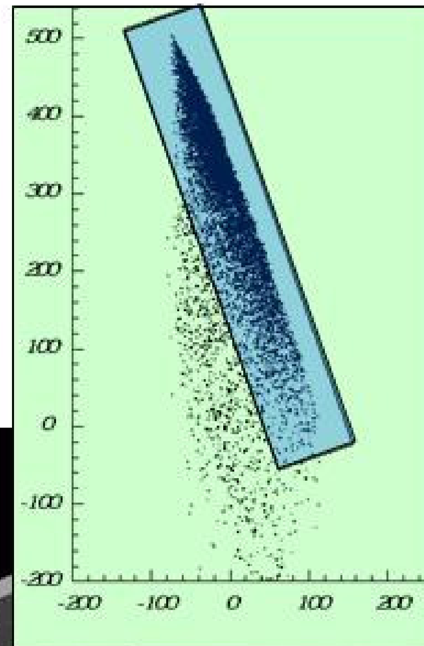
Thanks to Frank Maas, Phys.Rev.Lett. **94**:082001, 2005

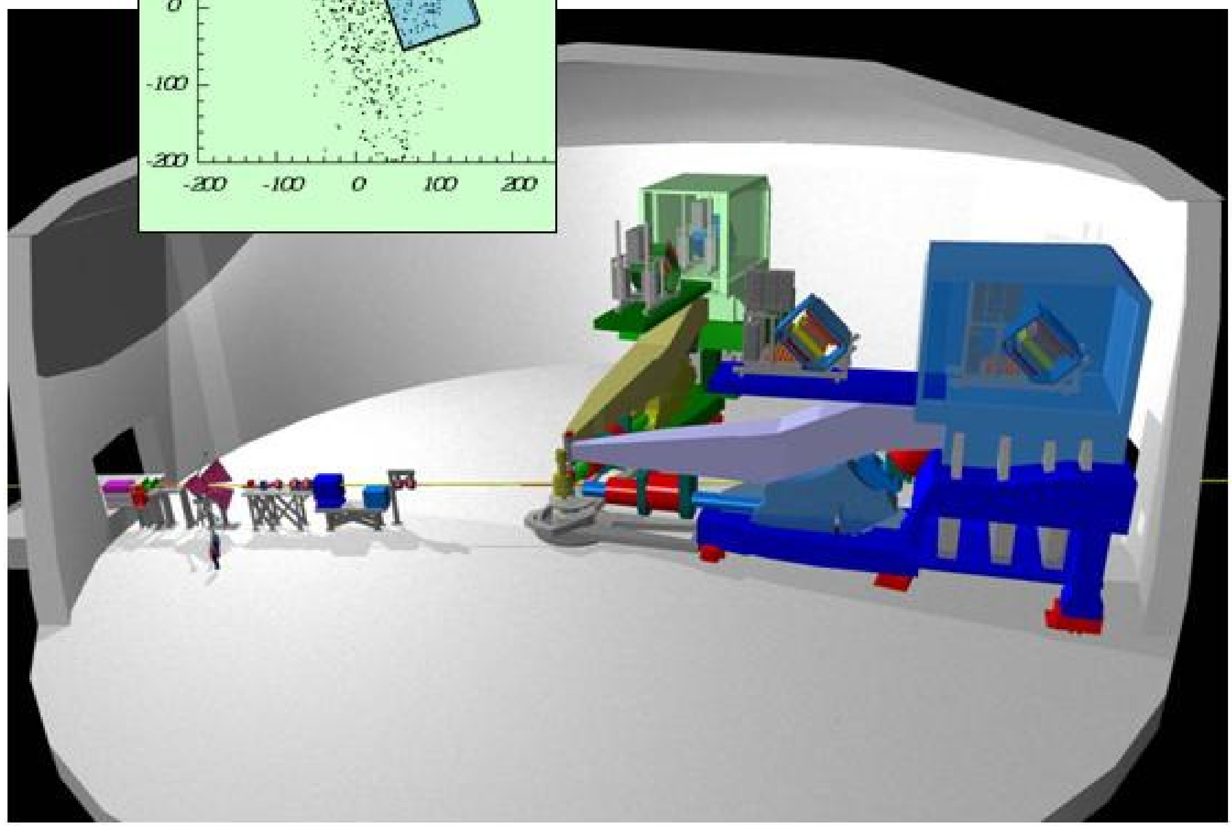
HAPPEX

Two high resolution spectrometers
- acceptance approximately in horizontal plane
- left-right symmetric spectrometers

Vertical Polarization:
- *Created in injector* using solenoid to rotate polarization
- *Measured in injector* with *Mott*, not expected to change
- *Measured (roughly) in* Hall *A* using tilted *Moller* foil







HAPPEX 2004 Result

E_e = 3 GeV, θ_{CM} ~16°

A_T = -6.6 ppm ± 1.5 ppm (stat) ± 0.2 ppm (syst)

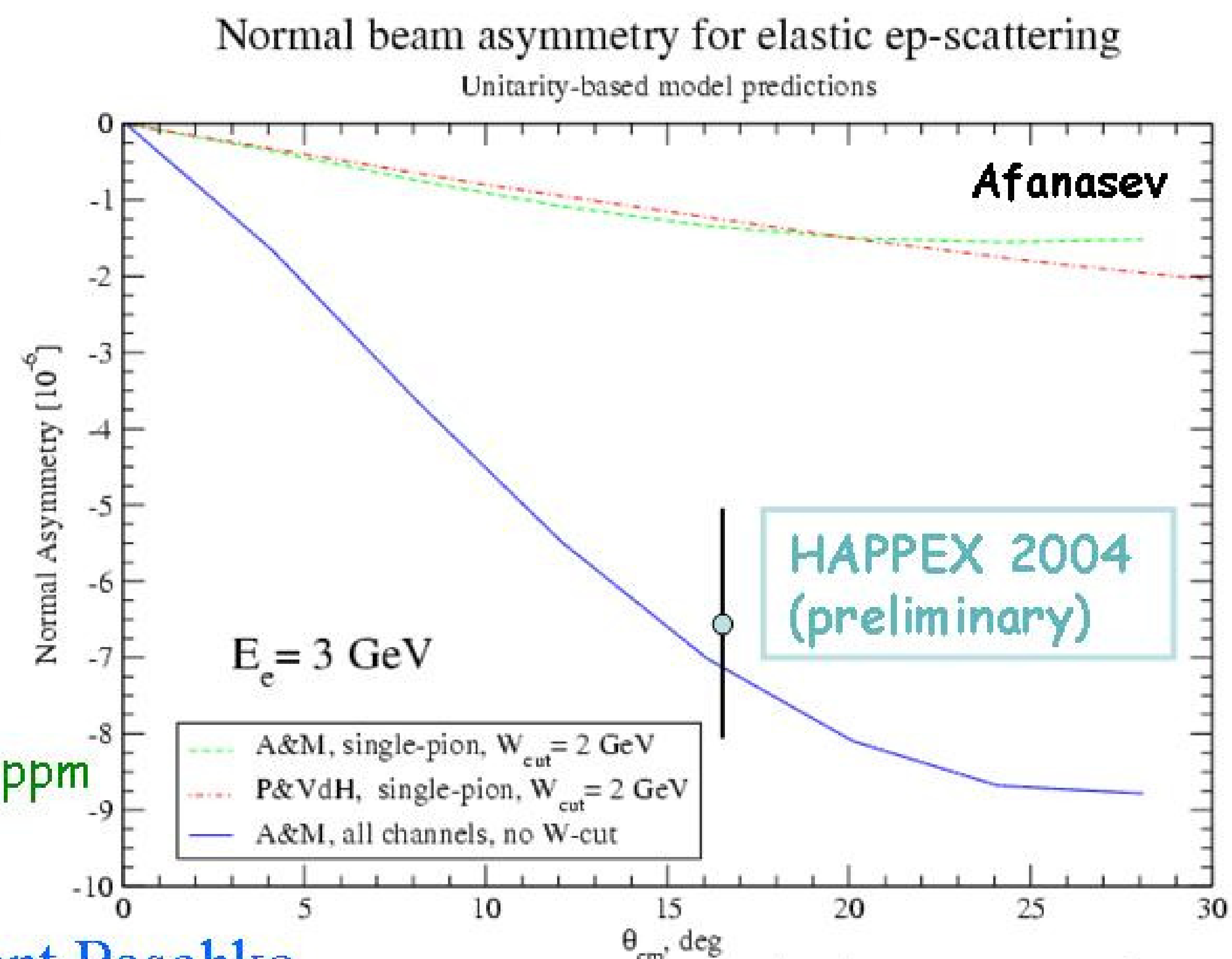
Total corrections ~200 ppb

Dominant systematic errors:

- Polarimetry (190 ppb)
- Beam asymmetry (100 ppb)
- Al background dilution (70 ppb, assumed $A_T^{Al} = 0$)

Compare to A4:
(same Q^2, E_e = .85 GeV)
$A_T = -8.59 \pm 0.89_{stat} \pm 0.75_{sys}$ ppm

Coming Soon: much from G0

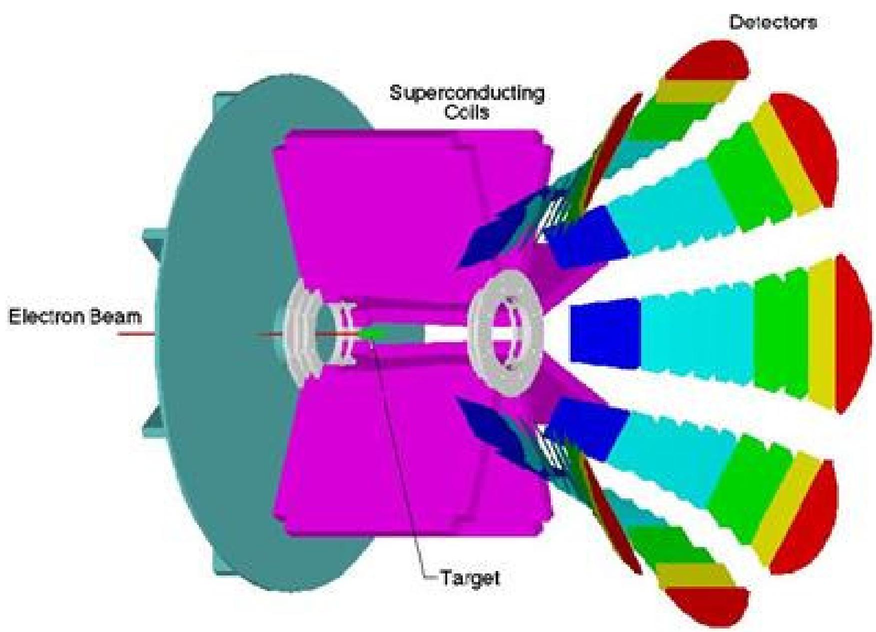


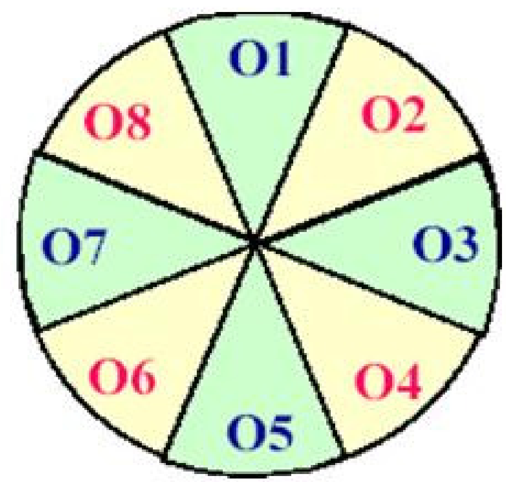
Thanks to Kent Paschke

Thanks to Lisa Kaufman

The G^0 forward angle measurement

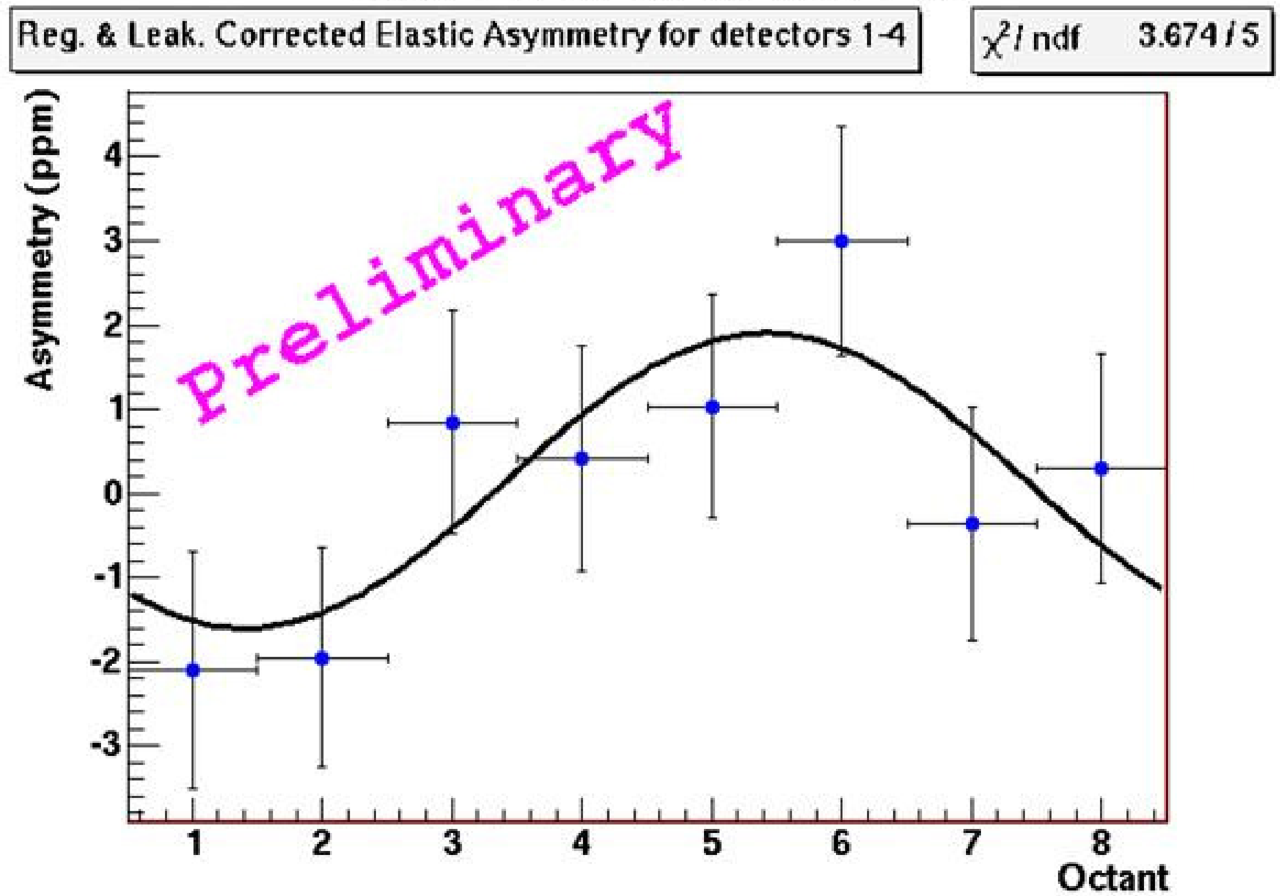
- Recoil protons are focused in a superconducting magnet, and detected in 8 azimuthally symmetric detector packages with 16 detectors in each octant.
- Runs in Hall C at JLab: 3 GeV longitudinally polarized electrons scatter from a 20 cm LH2 target
- Parity violating asymmetries of 2-20 ppm are measured.
- A_n is a physics background to G^0; 5% of the G^0 data was taken with transverse polarization to minimize systematic uncertainties





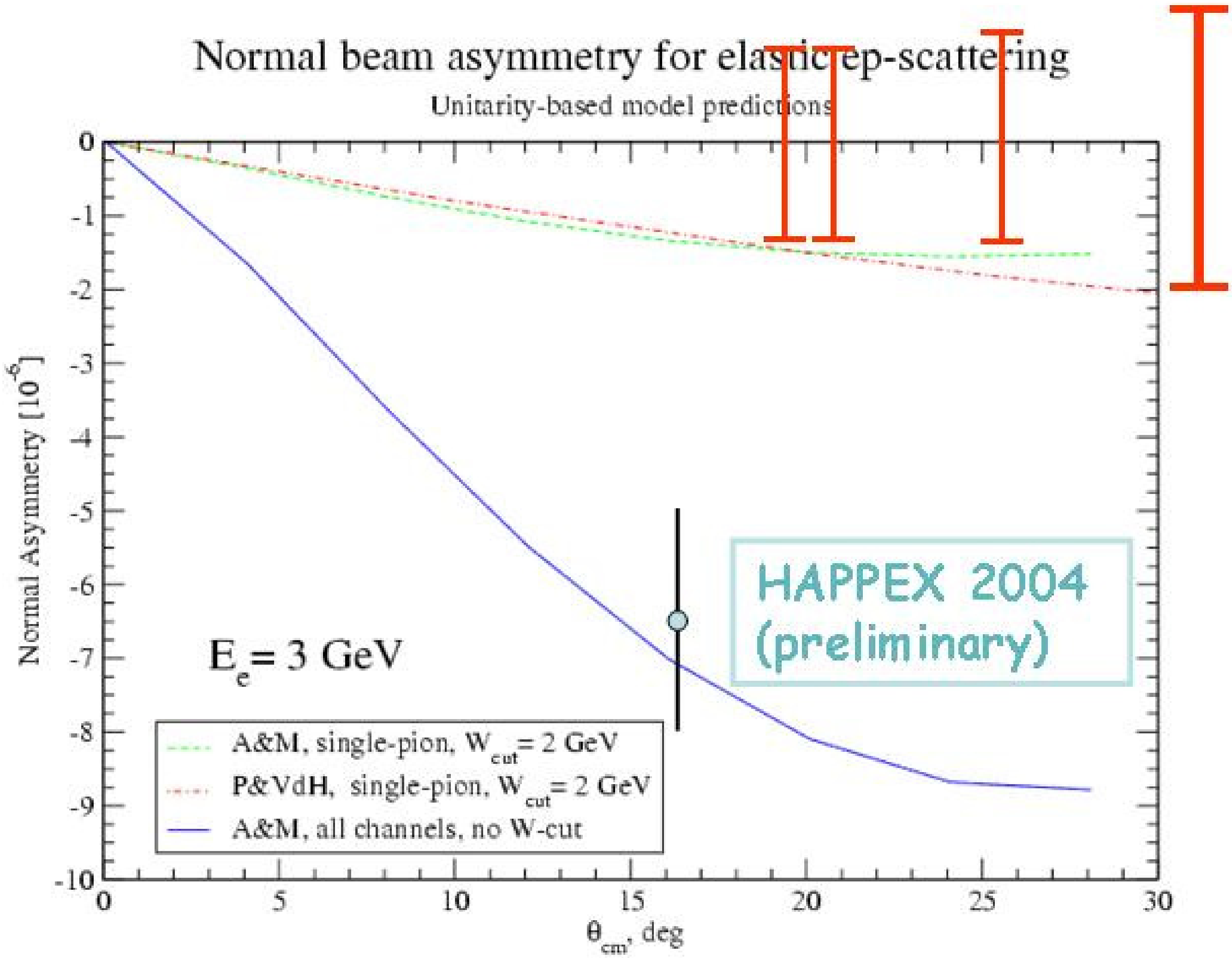
Octant Layout (looking DS)

Asymmetries & required corrections



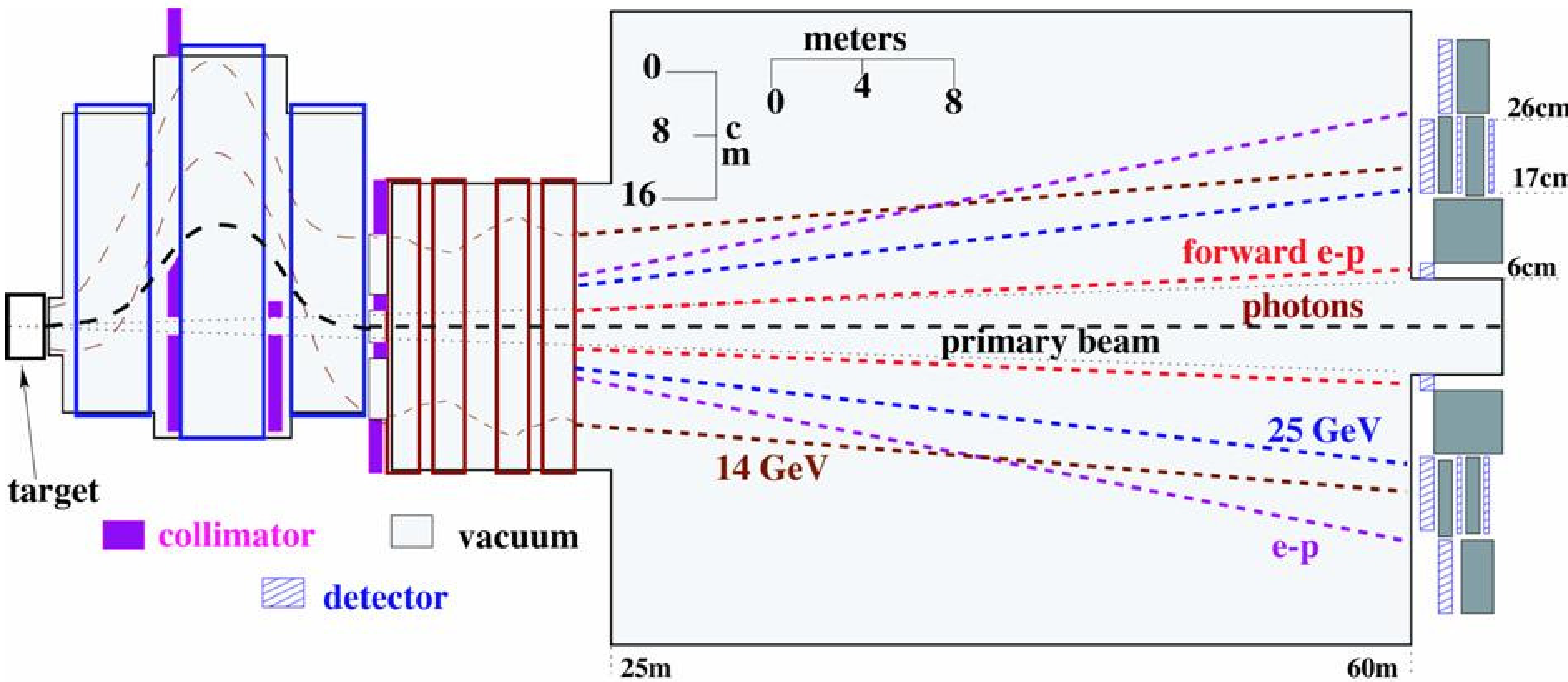
- LH2 data with leakage correction and beam parameter regression only.
- Does not include background corrections, target wall subtraction, beam polarization, detector alignment corrections.
- Multiplied by a blinding factor in the range of 0.75-1.25.

G0 Forward Angle Expected Errors



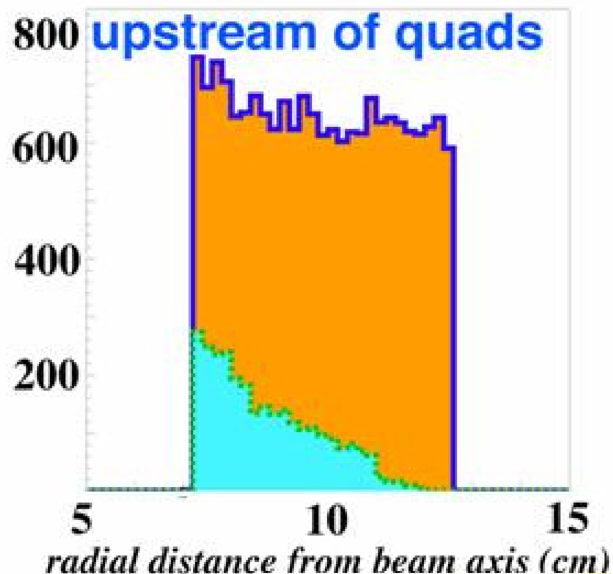
E-158 Apparatus

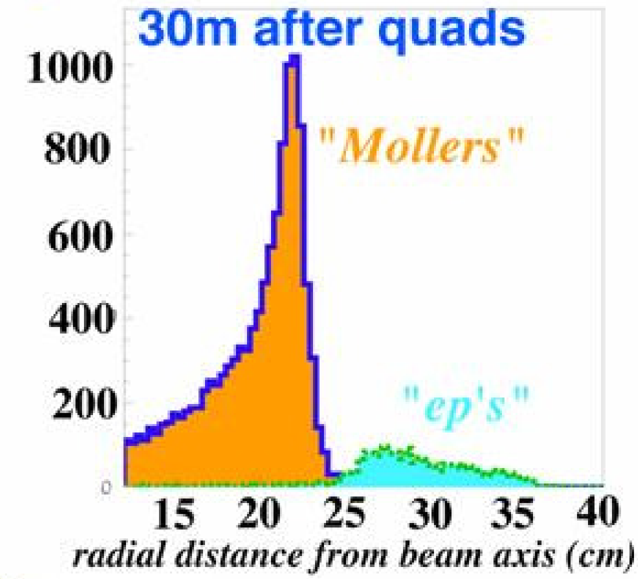
- Magnetic spectrometer focuses signal, removes background
- Analog integration of calorimeter signal
  - Very forward angle, azimuthal acceptance
  - Line-of-sight shielding requires a "dogleg" or "chicane"

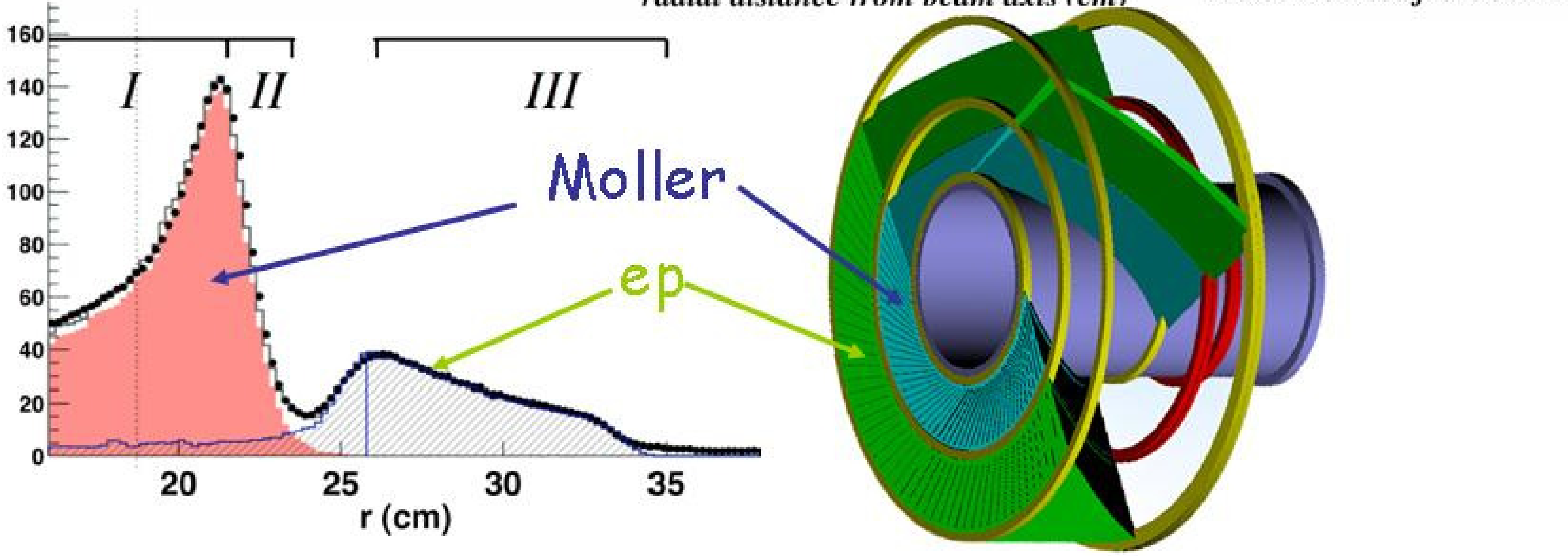


Quadrupole Quadruplet

- primary & scattered electrons enclosed in quadrupoles
- Mollers (e-e) focused, Motts (e-p) defocused
- full range of azimuth





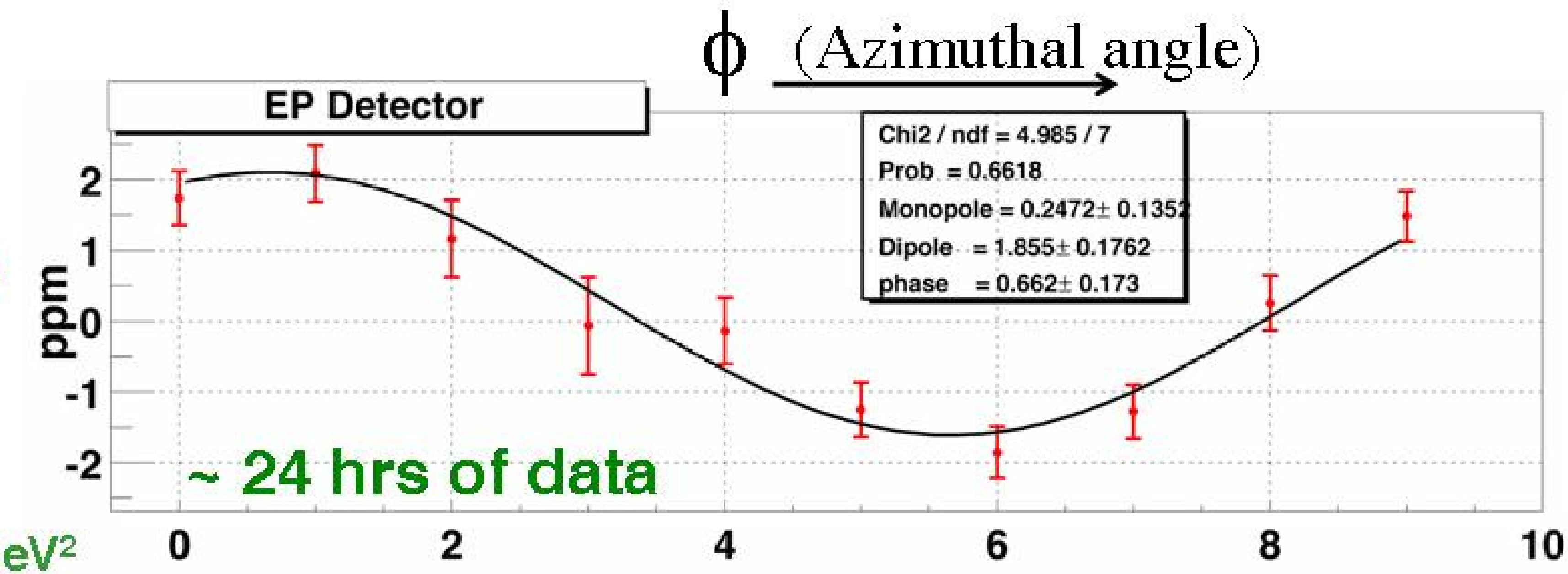


A_T^{ep} from E-158

46 GeV

$ep \rightarrow ep$

$Q^2 \sim 0.06\ GeV^2$



Sign: $A_T < 0$ Magnitude: ~2.5 ppm

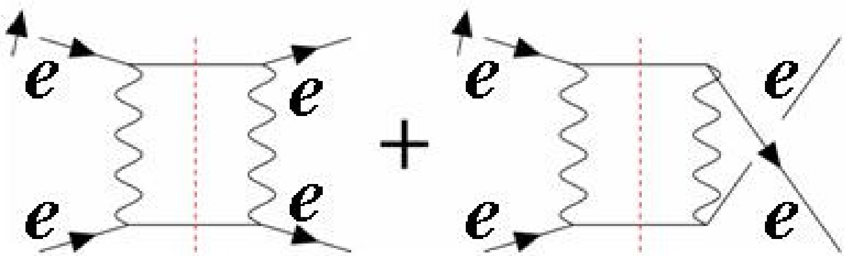
Without enhancement by inelastic states, $A_T \sim 10^{-10}$

Final Precision will approach 3% (stat) and 7% (syst)

Corrections to be made:
- Polarization
- Background corrections
  - ~25% inelastic ep ($A_T=0$)
  - Pions ~0.5% and $A_T < 10$ ppm

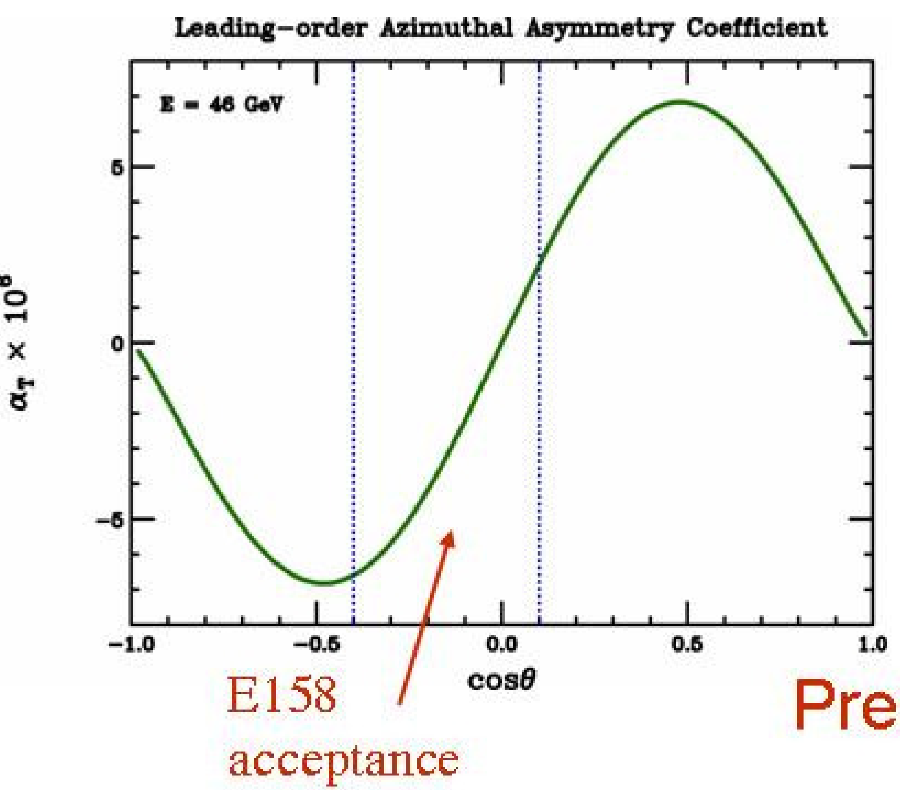
Dominant Systematic Errors:
- Polarization
- Background
- Spectrometer Acceptance (kinematics)

A_T in Møller Scattering



A_T goes to zero for 90° in COM

$\sqrt{s} \approx 200\, MeV$



E158 acceptance is mostly in the backward direction

Theory References:

1. **A. O. Barut and C. Fronsdal, (1960)**
2. **L. L. DeRaad, Jr. and Y. J. Ng (1975)**
3. **Lance Dixon and Marc Schreiber:hep/ph-0402221**
   (Included bremsstrahlung corrections: few percent)

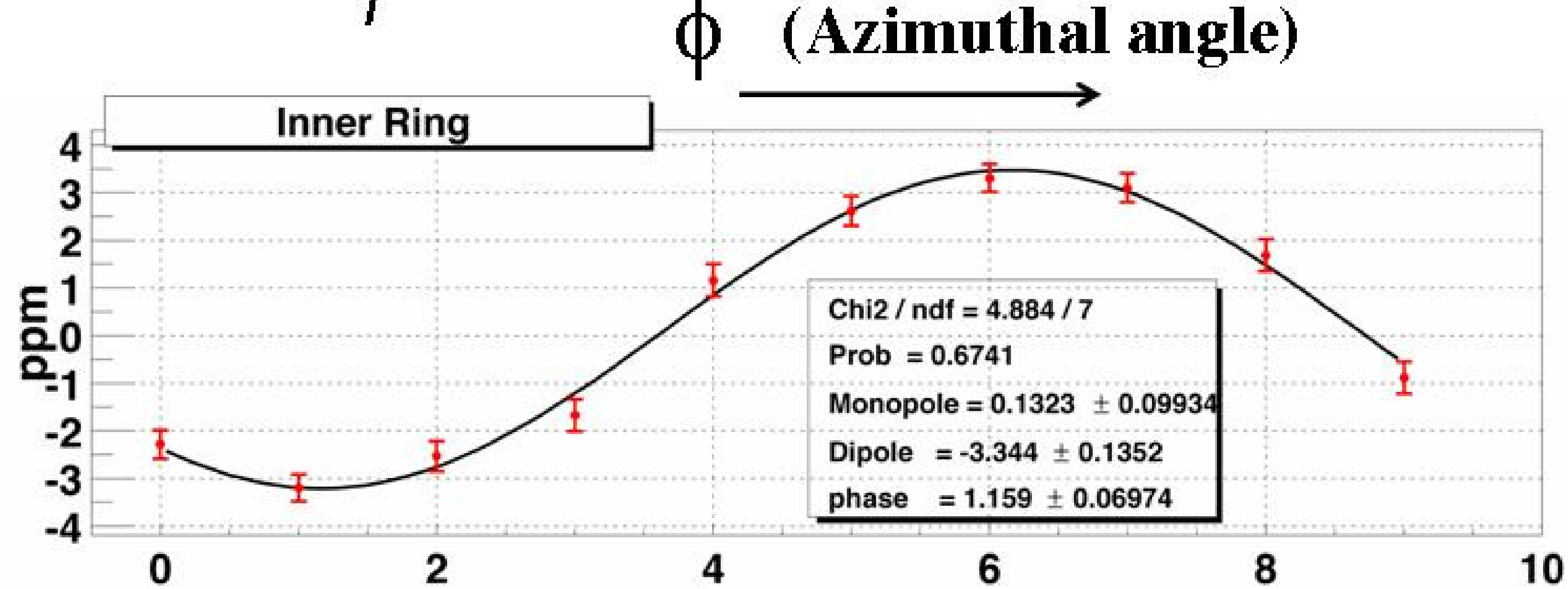
Prediction for 46 GeV: ~ -3.5 ppm

A_T^{ee} at E158

46 GeV

$ee \rightarrow ee$

backward angle



Sign: opposite A_T^{ep}?

Magnitude: ~3.5 ppm

If confirmed, sign would disagree with published predictions, BUT

- experimental cross-checks are not complete
- some authors now wonder about the sign...

Final Precision will approach 3% (stat) and 10% (syst)

Corrections to be made:

- Polarization
- Background corrections
  - ~9% ep

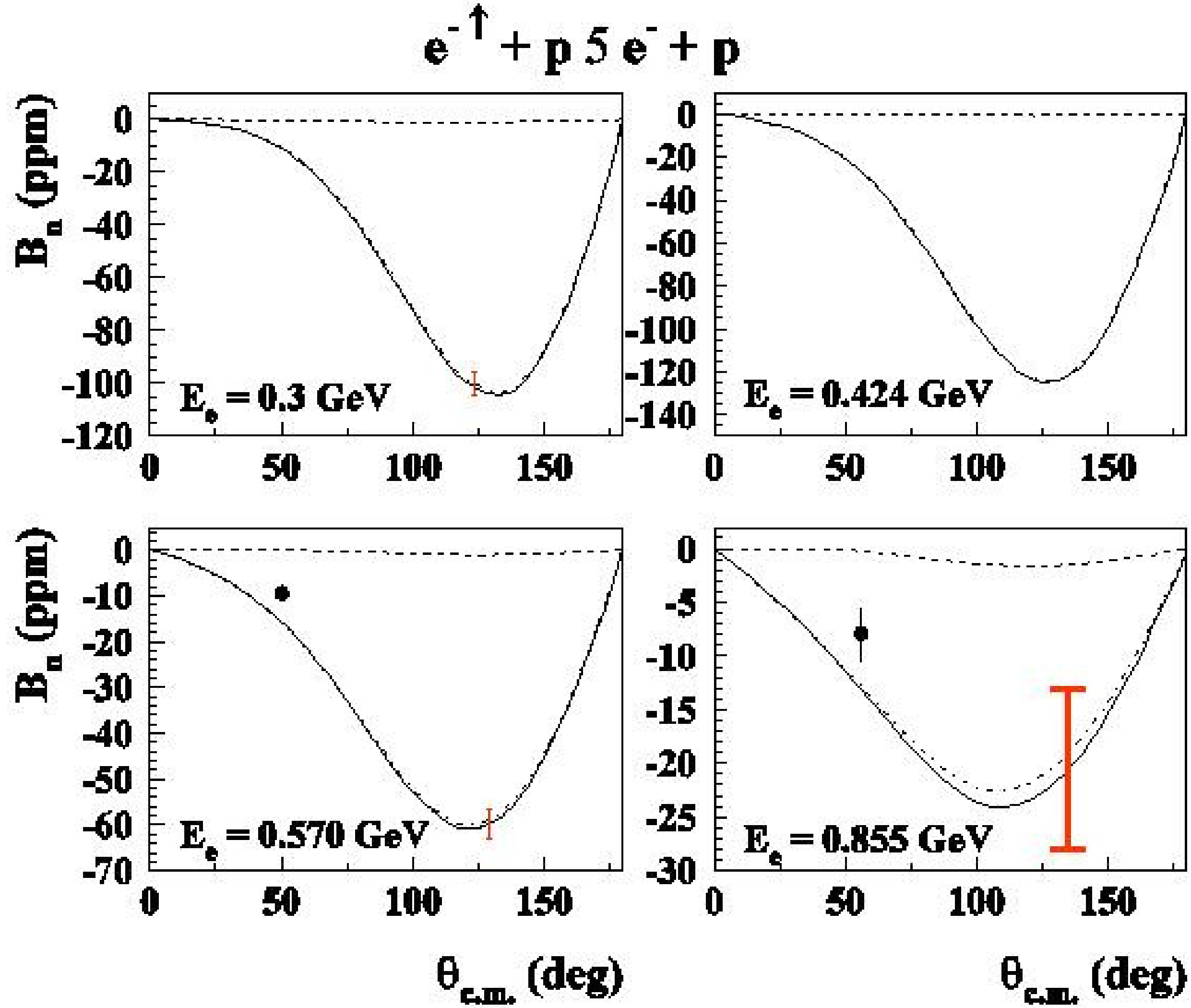
Dominant Systematic Errors:

- Polarization
- Background
- Spectrometer Acceptance (kinematics)

Expt.	$E(GeV)$	θ_e	$Q^2\ GeV^2$	$A_n(ppm)$
SAMPLE	0.192	146	0.10	-16.4±5.9
A4	0.570	35	0.11	-8.59±0.89
A4	0.855	35	0.23	-8.52±2.31
HAPPEX	3.0	16	0.11	-6.6±1.5
G0	3.0	19 - 37	0.13 – 0.6	??±1.3-3.0
E-158(ep)	46.0	~3.0	0.06	~-2.5±??
E-158(ee)	46.0	~100	0.03	~±3.5±0.4

Kinematics and Expected Errors for Future G0 Backward Angle Measurements

Beam Energy (GeV)	Q^2 $(GeV/c)^2$ (Elastic)	θ_{CM} (°)	$\delta A_n (ppm)$
0.799	0.8	133.9	8.0
0.585	0.5	129.9	3.0
0.360	0.23	118.1	2.0



e-↑ + p 5 e- + p
Bn (ppm)
Ee = 0.3 GeV
Ee = 0.424 GeV
Ee = 0.570 GeV
Ee = 0.855 GeV
θc.m. (deg)

Projected Future Mainz A4 Measurements

$Energy (GeV)$	$\theta_{lab}\,(^{o})$	$\delta A_n (ppm)$
0.300	35	0.5
0.420	35	0.5
0.570	35	0.5
0.854	35	0.5
1.20	35	1.0
1.50	35	2.0
0.300	145	3.0
0.420	145	3.0
0.570	145	4.0
0.854	145	8.0

Summary

* A_n – Direct Measure of $Im\{M_{2\gamma}\}$
* SAMPLE, A4, G0, E-158

  $\rightarrow$ All yield $A_n \neq 0$
* Different Kinematics $\rightarrow$ Different Theoretical Models of $M_{2\gamma}$

  (varying degrees of success)
* More $Im\{M_{2\gamma}\}$ Measurements to Come: A_n , A_y , P_n
* Impetus for more theoretical work on $Im\{M_{2\gamma}\}$

  ? Dispersion Analyses: $Im\{M_{2\gamma}\} \rightarrow Re\{M_{2\gamma}\} \rightarrow G_E^p / G_M^p$?