The $N \rightarrow \Delta$ Program at Bates

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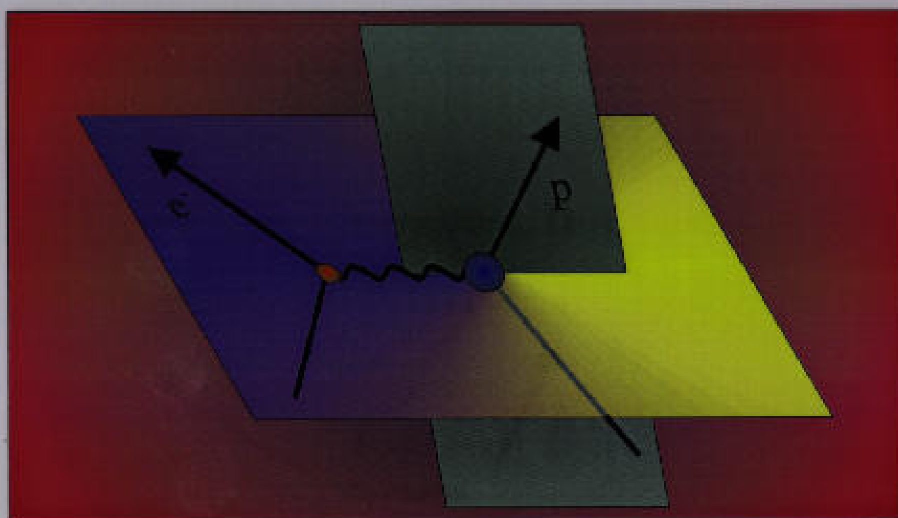
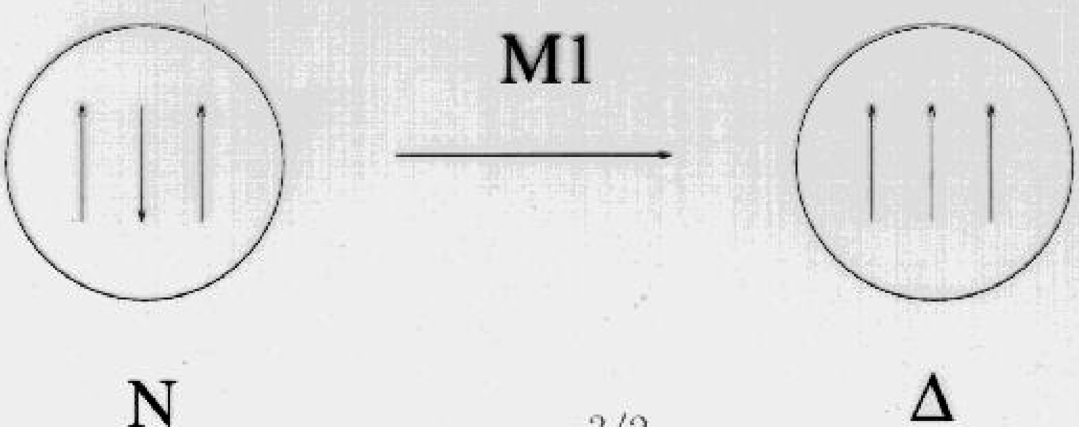
MIT/Bates



LowQ Workshop

Halifax, August 2001

The $N \to \Delta$ Transition

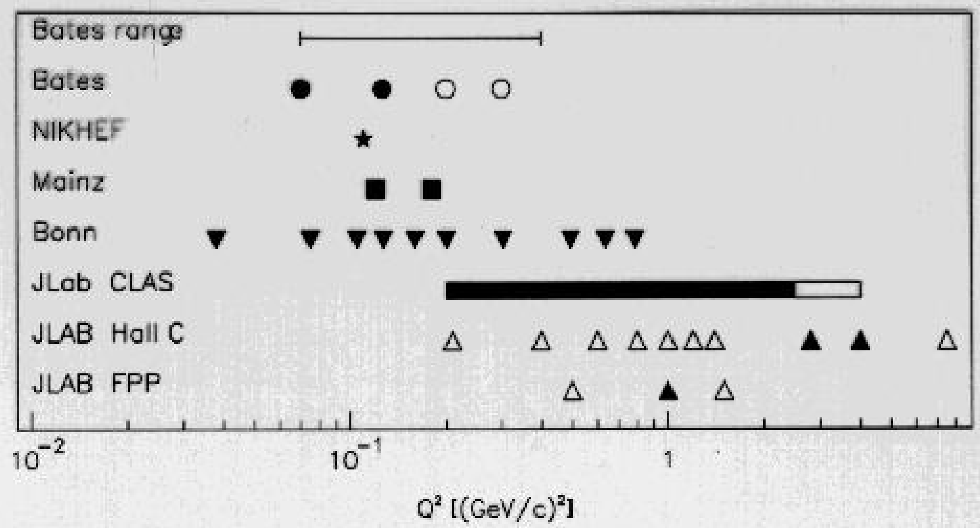


$$\text{E2} \to (E_{1+}^{3/2})$$

$$\text{C2} \to (S_{1+}^{3/2})$$

Recent / Future Experiments

(1990's)

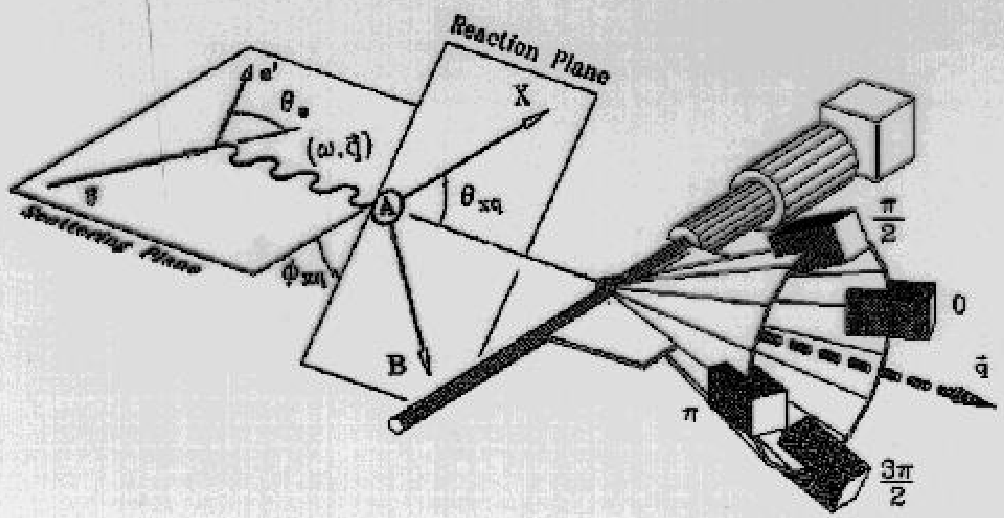


The Bates $N \rightarrow \Delta$ Program

Approach

- Measure all $N \rightarrow \Delta$ channels: $p\pi^0$, $p\gamma$ and $\pi^+ n$
- Scan invariant mass (W), momentum transfer (Q^2), polar angle (θ)
- Measure cross section simultaneously at multiple ϕ angles, in/out of the scattering plane
- Extract response functions L+T, TT, LT, LT′
- Form asymmetries $\Rightarrow$ control the systematic error

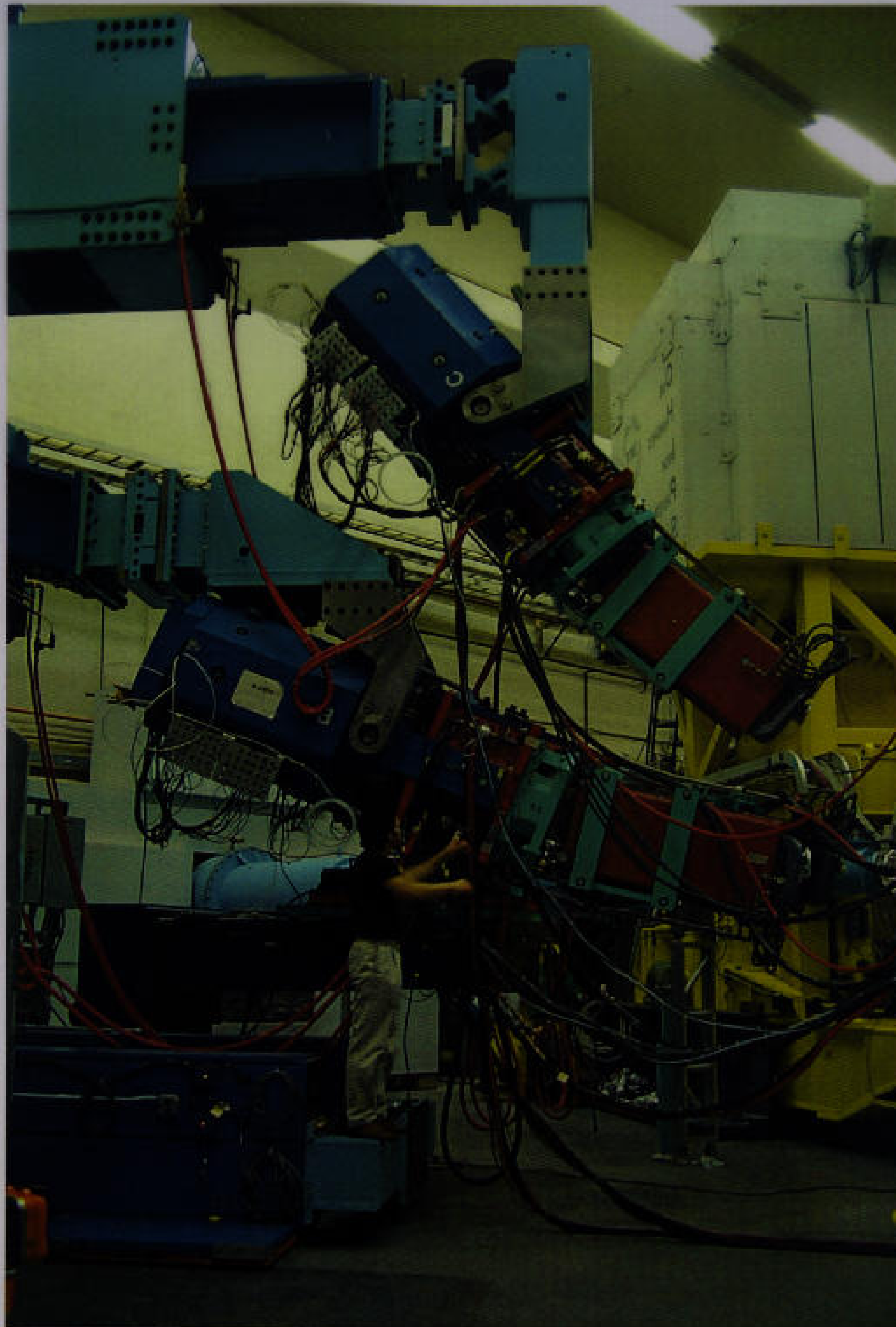
Experimental method

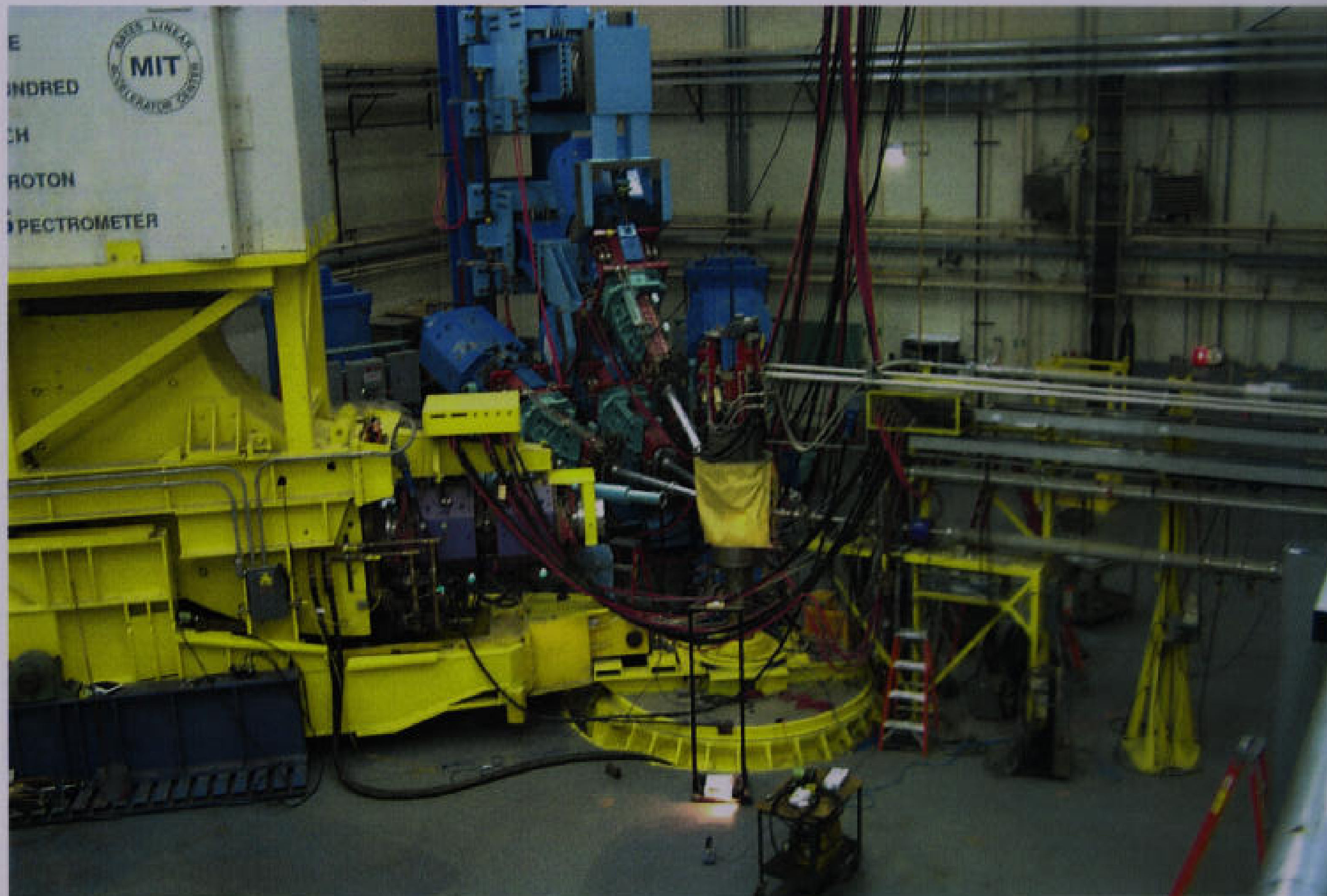


e N $\rightarrow$ e' N x cross section

$$\sigma = \frac{\mathrm{d}^5\sigma}{\mathrm{d}\omega \mathrm{d}\Omega_\mathrm{e} \mathrm{d}\Omega_\mathrm{xq}} = \mathrm{J}\,\Gamma_\mathrm{v}\,\frac{\mathrm{d}^2\sigma}{\mathrm{d}\Omega^\mathrm{cm}_\mathrm{xq}}$$

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}\Omega^\mathrm{cm}_\mathrm{xq}} = \mathrm{v_L R_L} + \mathrm{v_T R_T} + \mathrm{v_{LT} R_{LT}} \cos\phi_\mathrm{xq} + \mathrm{v_{TT} R_{TT}} \cos 2\phi_\mathrm{xq} + \mathrm{h v'_{LT} R'_{LT}} \sin\phi_\mathrm{xq}$$




E
NDRED
CH
ROTON
PECTROMETER
MIT
BATES LINEAR ACCELERATOR CENTER

Unpolarized $N \to \Delta$ in FY 2000

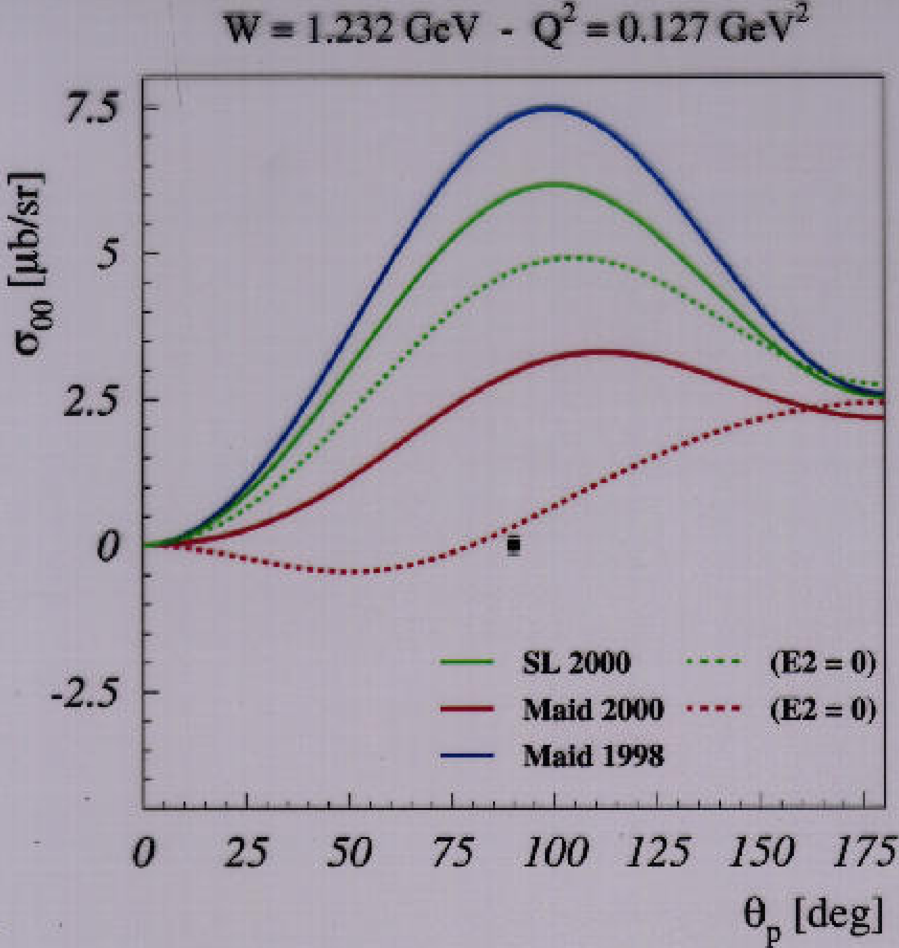
A High sensitivity to the E2/M1 ratio.

B The interesting case at $W = 1292$ MeV.

C Isospin decomposition (π^+ channel).

Three Very Urgent Issues

Sensitivity to E2/M1

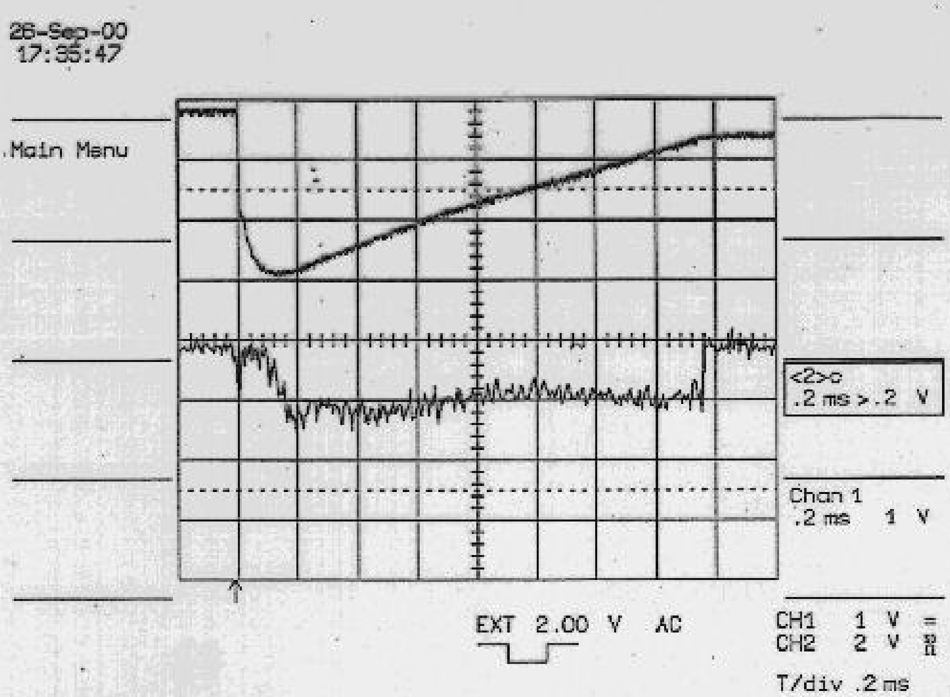


$$\sigma_{00} = R_T(\theta_{pq}) + R_{TT}(\theta_{pq}) - R_T(0) =$$

$$\propto 12 \cdot \mathrm{Re}(E^*_{1+} M_{1+}) + \text{non res.}$$

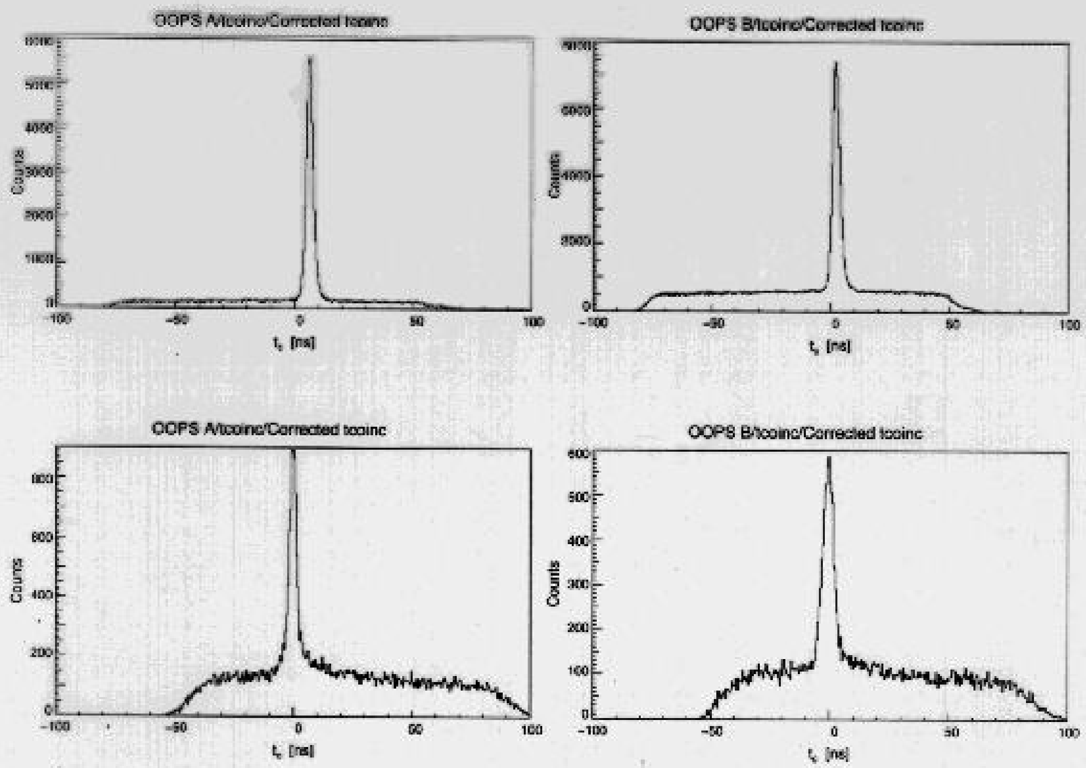
OOPS "firsts" 2000/2001

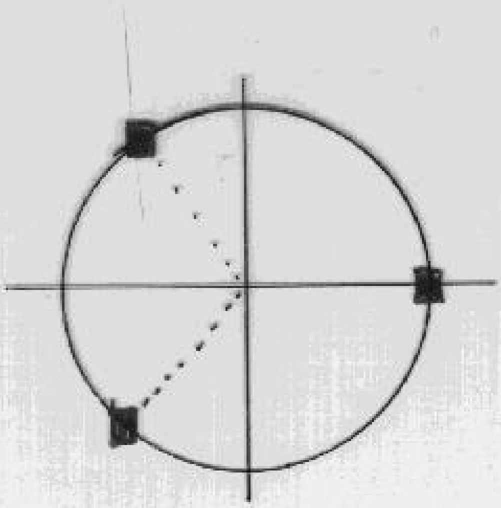
- 8 uA CW extracted beam
- Full 4-spectrometer set-up
  including Gantry
- Upgraded OHIPS spectrometer
  (13 % momentum bite)
- First low-momentum measuraments
  (Pmin < 230 MeV/c)
- Highest experiment beam energy
  (950 MeV)
- Data taken at 1.4 and 2.5 m
  drift-distance

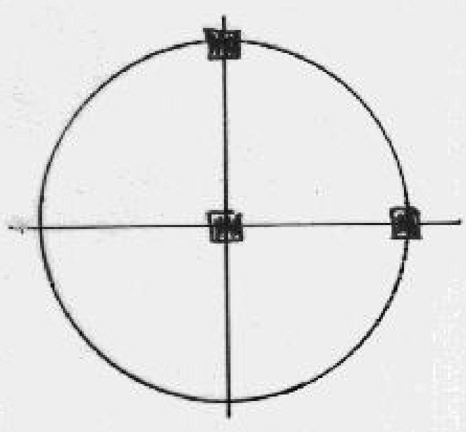


26-Sep-00
17:35:47
Main Menu
<2>c
.2 ms >.2 V
Chan 1
.2 ms 1 V
EXT 2.00 V AC
CH1 1 V =
CH2 2 V
T/div .2 ms

$N \to \Delta$ 2001 run





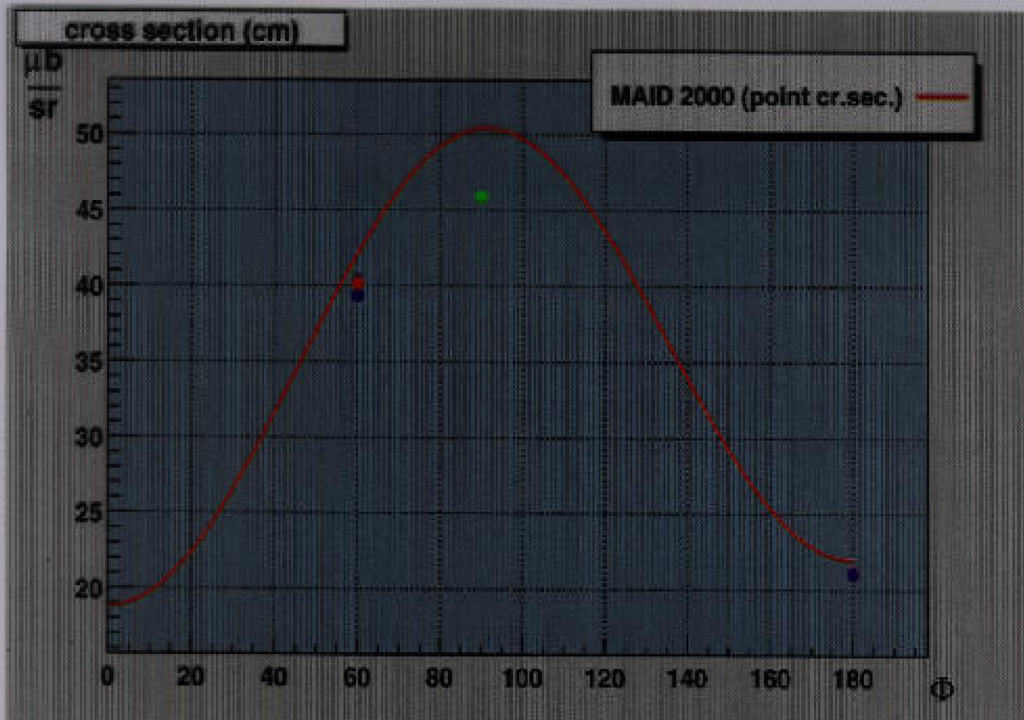


$N \rightarrow \Delta$ 2001 run

spectrometer average cross sections

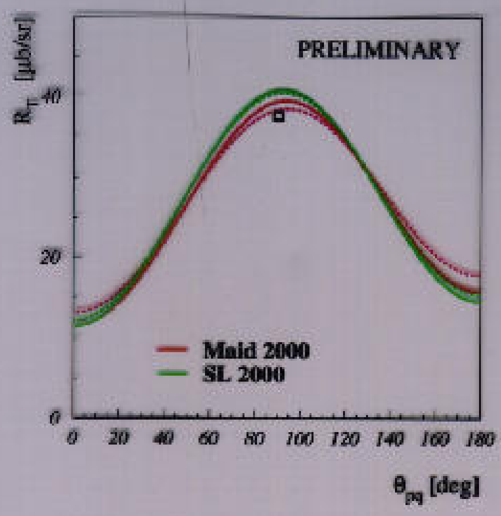
W = 1232 MeV
Q2 = 0.127 GeV2/c2

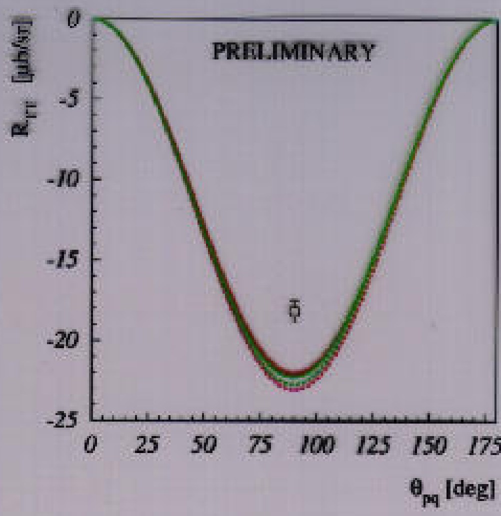
$\Theta^*_{pq} = 90°$

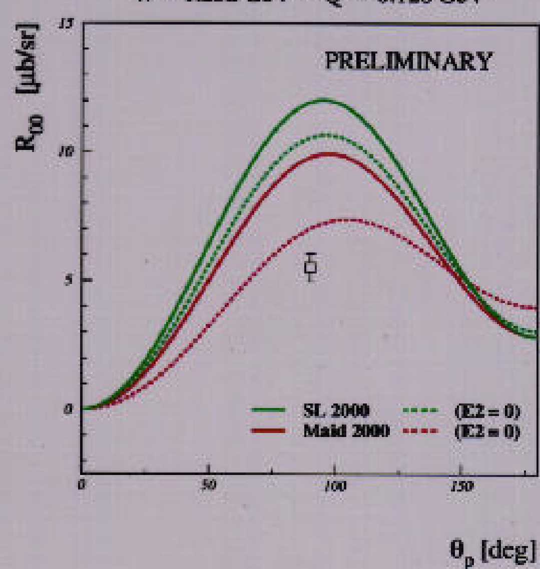


spectrometer average cross sections

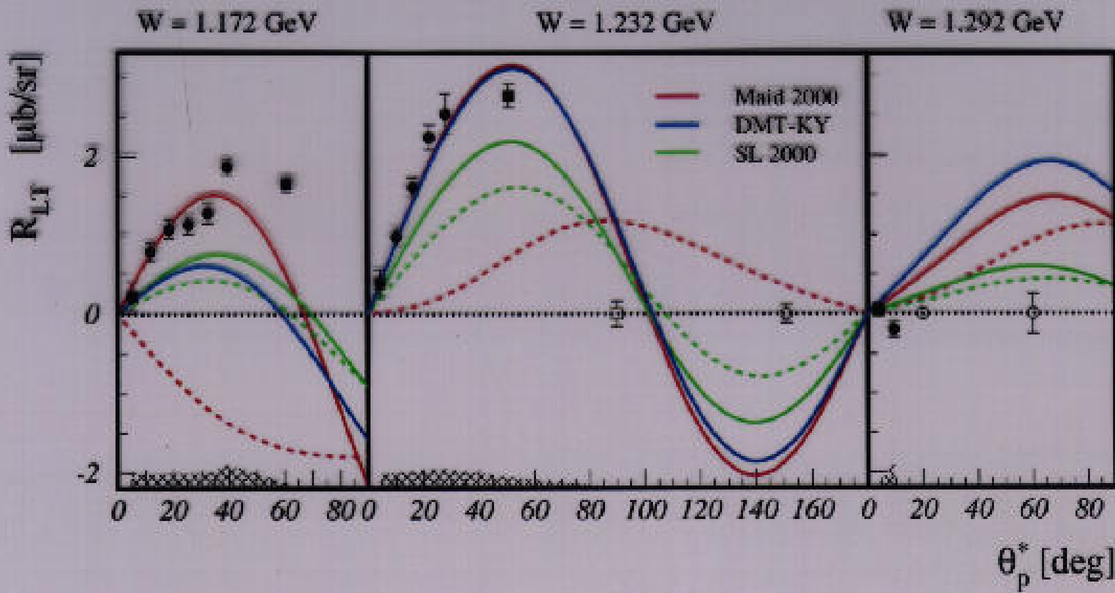
Preliminary data 2001







$H(e,e'p)\pi^0$ LT Response



$$\frac{Coulomb\ Quadrupole}{Dipole} = -6.5 \pm 0.2 \pm 2.5\ \%$$
$$\frac{Electric\ Quadrupole}{Dipole} = -2.1 \pm 0.2 \pm 2.0\ \%$$

No model consistently describes all data

- Need to expand θ_{pq} lever arm
- Need to measure above the resonance

Summary

- High-precision data across the $\Delta(1232)$ resonance
  - ⋆ cross section, isolated responses
  - ⋆ polarization observables

  ⇒ Inconsistencies between models

  ⇒ Evidence for strong contributions from background multipoles

$$\Downarrow$$

Model–dependent EMR, CMR extraction

- Planned experiments at Bates will measure

$$H(\vec{e}, e'p)\pi^0, \qquad H(\vec{e}, e'\vec{p})\pi^0$$
$$H(\vec{e}, e'\pi^+)n,$$
$$H(\vec{e}, e'p)\gamma$$

- Other exciting experiments planned at JLab and Mainz

Physics potential of $d(\vec{e}, e'p)$ with OOPS
$d(\vec{e}, e'd)\pi^0$, ...

(Present and future)

L	$\rightarrow$	charge distribution
T	$\rightarrow$	initial IC (?)
LT	$\rightarrow$	relativity — high p_m
TT	$\rightarrow$	MEC, IC — Δ-region
LT′	$\rightarrow$	FSI — Δ-N interactions

OOPS (structure of EM currents) vs.
BLAST ("spin structure")

⇕

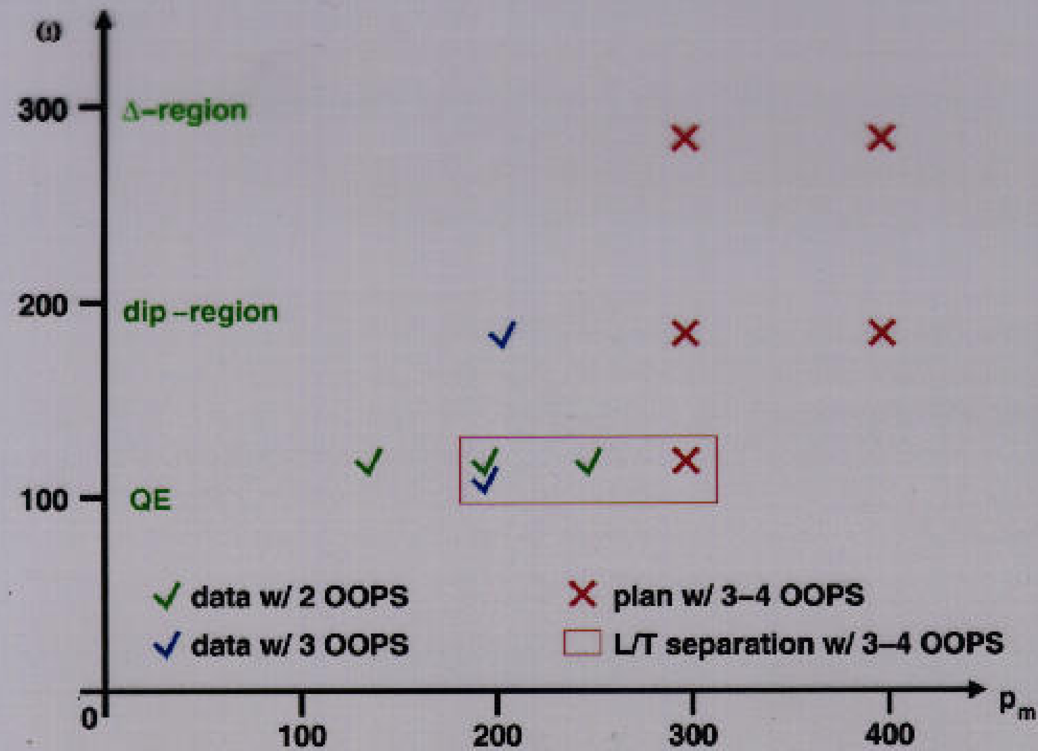
unique contributions, benchmark test of
"Standard Model" of Few-Body Theory

⇕

NN-potentials
access to neutron amplitudes

$d(\vec{e}, e'p)$ program with OOPS

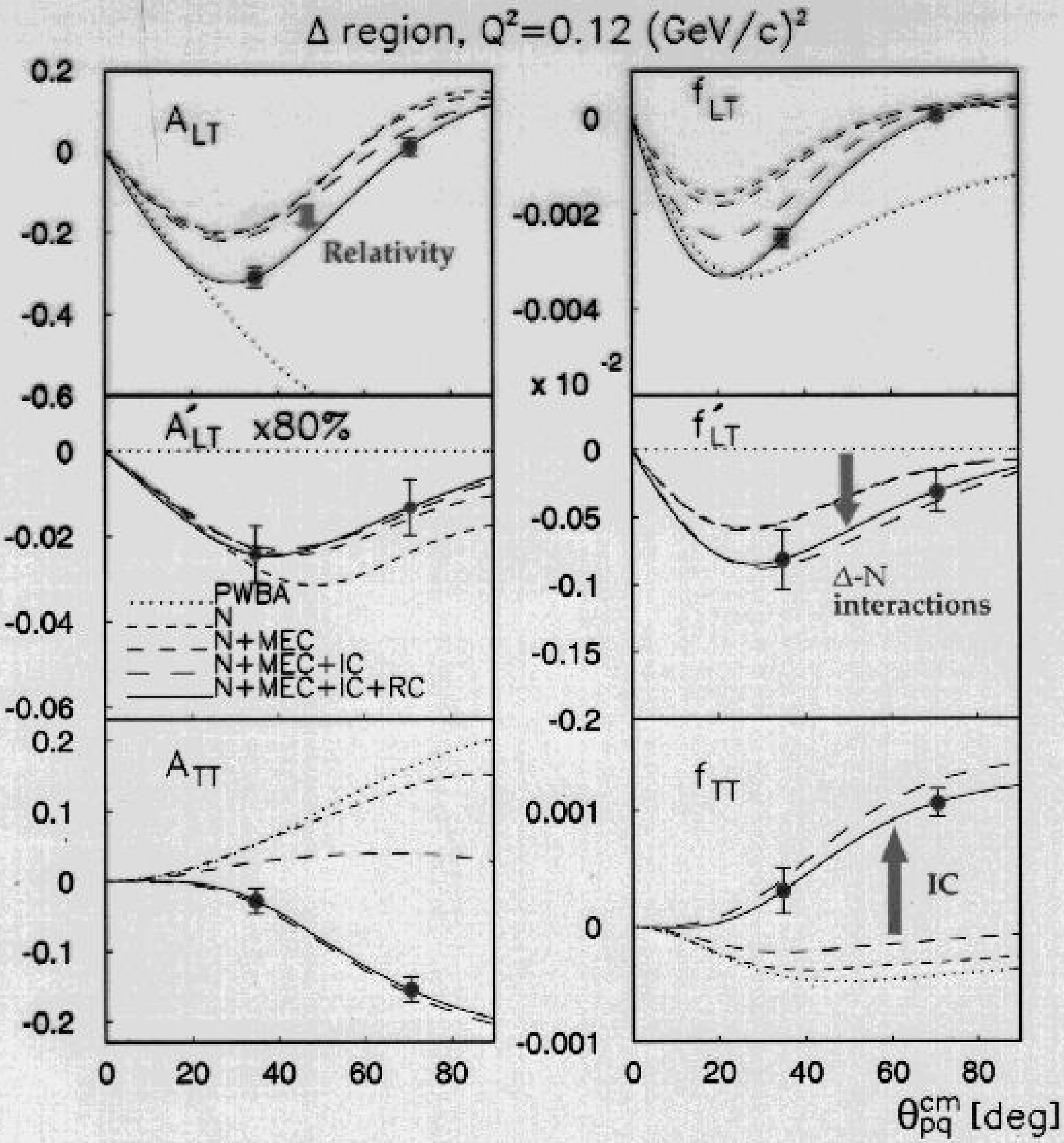
Kinematics map



- ▹ "ω/p_m-structure" of deuteron
- ▹ role of relativity (high p_m)
- ▹ (initial) isobar configurations (high ω)
- ▹ excellent for L/T in $\perp$ kinematics

⇒ Selectively probe competing effects in different kinematical regimes

Projected $d(\vec{e}, e'p)$ responses in Δ-region



E_{np} = 220 MeV, 250 hrs of 10 μA CW beam

Out of plane Recoil Polarimetry

13 "new" structure functions

$$\sigma_0 \mathcal{P}_t / K_{Mott} = [v_{LT} R^t_{LT} \sin\phi + v_{TT} R^t_{TT} \sin 2\phi] + \text{h} \, [v_{LT'} R^t_{LT'} \cos\phi + v_{T'} R^t_{TT'}]$$

$$\sigma_0 \mathcal{P}_n / K_{Mott} = [v_L R^n_L + v_T R^n_T + v_{LT} R^n_{LT} \cos\phi + v_{TT} R^n_{TT} \cos 2\phi] + \text{h} \, [v_{LT'} R^n_{LT'} \sin\phi]$$

$$\sigma_0 \mathcal{P}_l / K_{Mott} = [v_{LT} R^l_{LT} \sin\phi + v_{TT} R^l_{TT} \sin 2\phi] + \text{h} \, [v_{LT'} R^l_{LT'} \cos\phi + v_{T'} R^l_{TT'}]$$

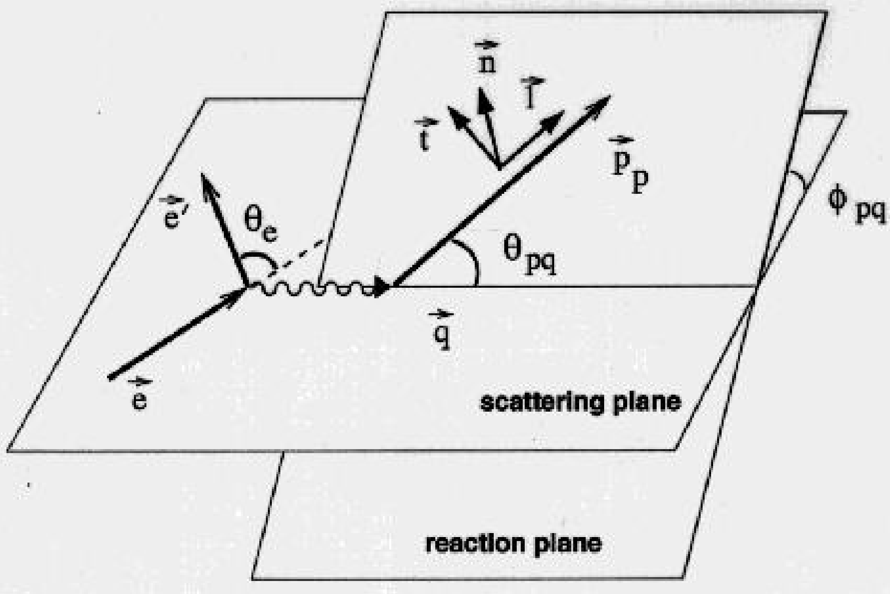
- Many of these terms can only be accessed in out of plane measuraments and with polarized beams.
- Best done with simultaneous measurements at different out-of-plane angles ϕ for a given kinematics.
- Requires a recoil polarimeter in each spectrometers.

Formalism for $A(\vec{e}, e'\vec{p})B$ reactions

$$\sigma(\vec{S}) = \frac{1}{2}\sigma_0(1 + \vec{P} \cdot \vec{S}) \qquad (1)$$

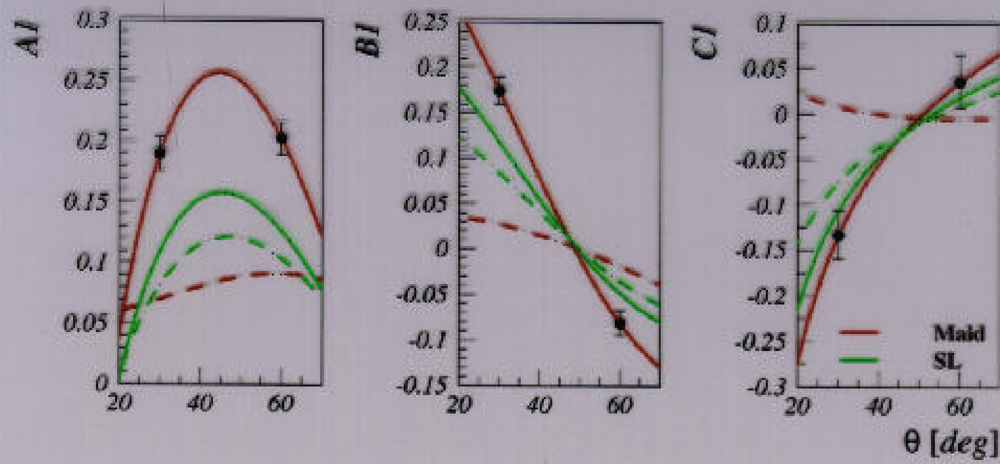
$\sigma_0 = \sigma(\vec{S}) + \sigma(-\vec{S})$ $\quad$ $\vec{S}$ = *Nucleon spin*

$\vec{P}$ = *Recoil Polarization*



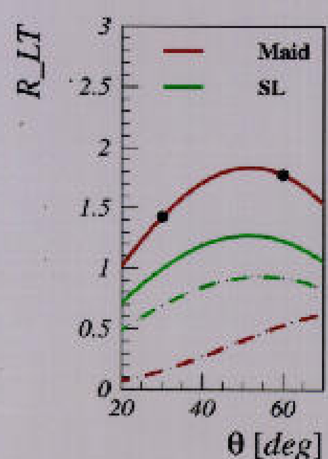
$$\hat{\mathbf{l}} \,||\, \vec{\mathbf{P}}_{\mathbf{p}} \quad \hat{\mathbf{n}} = \hat{\mathbf{q}} \times \hat{\mathbf{l}} / \sin\theta_{pq} \quad \hat{\mathbf{t}} = \hat{\mathbf{n}} \times \hat{\mathbf{l}}$$

Sensitivity of CMR observables



$$A1 = \frac{\Pi_x^1(\phi = 0) + \Pi_x^1(\phi = \pi)}{\Pi_x^1(\phi = 0) - \Pi_x^1(\phi = \pi)} \qquad B1 = \frac{\Pi_y^1(\phi = 0) - \Pi_y^1(\phi = \pi)}{\Pi_x^1(\phi = 0) - \Pi_x^1(\phi = \pi)}$$

$$C1 = \frac{\Pi_x^1(\phi = \pi/2) + \Pi_x^1(\phi = 3\pi/2)}{\Pi_y^1(\phi = \pi/2) - \Pi_y^1(\phi = 3\pi/2)}$$



Comparable deformation signal