Model Independent Analysis of the $\gamma^* p \rightarrow \Delta$ Transition with Polarized Electron Scattering Data

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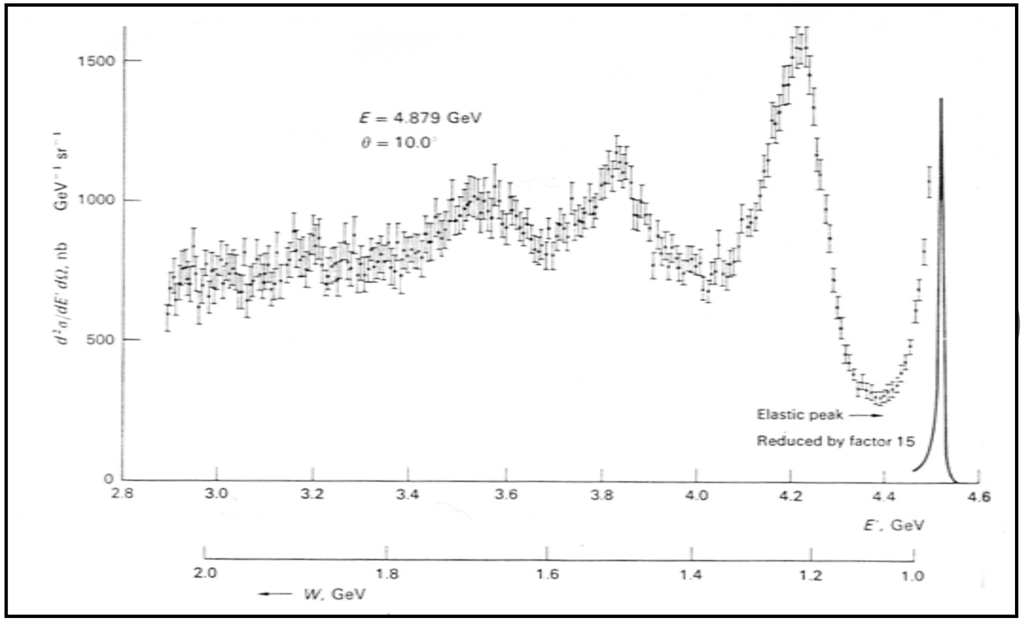
The signal for deformation in the $\gamma^* N \rightarrow \Delta$ transition

p(qqq)

$I = \frac{1}{2} \quad J = \frac{1}{2}$

938 MeV



Δ(qqq)

$I = \frac{3}{2} \quad J = \frac{3}{2}$

1232 MeV

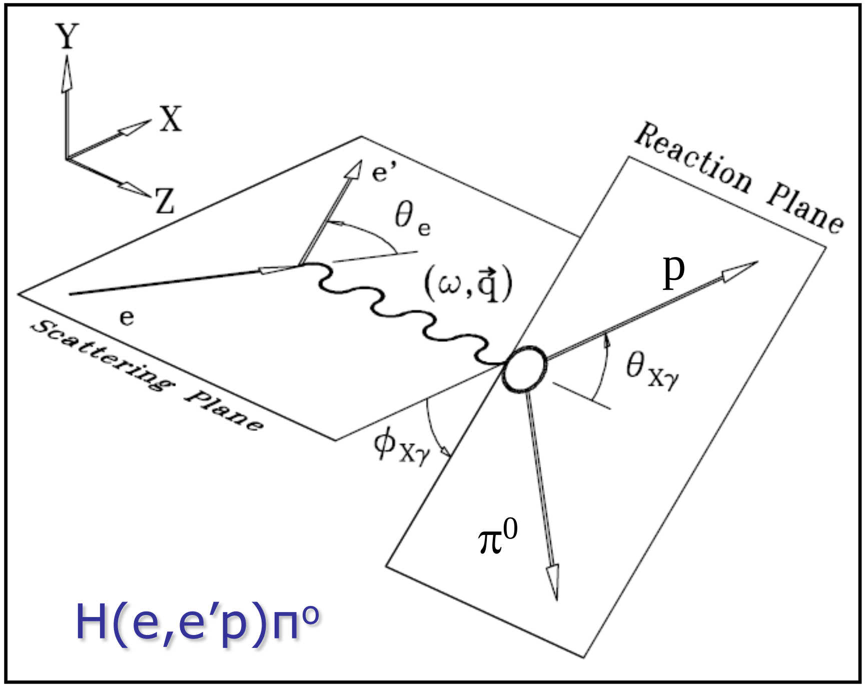
Spherical $\Rightarrow$ M1

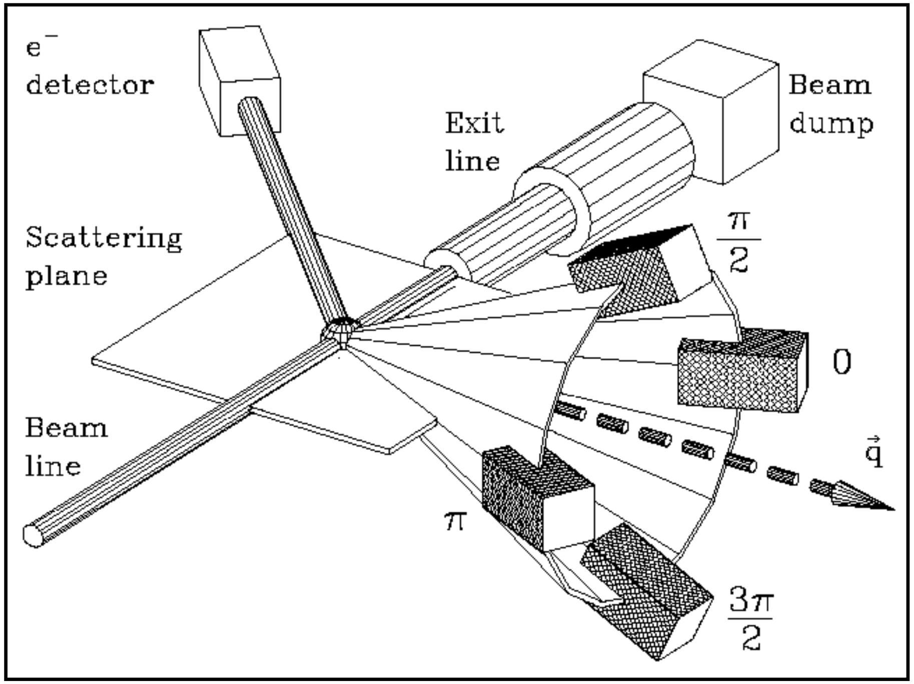
Deformed $\Rightarrow$ M1 , E2 , C2

Deformation signal

$$\begin{cases} \text{CMR} = \text{Re}\left(\dfrac{S_{1+}^{3/2}}{M_{1+}^{3/2}}\right) \\ \text{EMR} = \text{Re}\left(\dfrac{E_{1+}^{3/2}}{M_{1+}^{3/2}}\right) \end{cases}$$

Out of Plane Spectroscopy





$$R_T + \epsilon_L R_L = \frac{\sigma_0 + \sigma_{\pi/2} + \sigma_\pi + \sigma_{3\pi/2}}{4K}$$

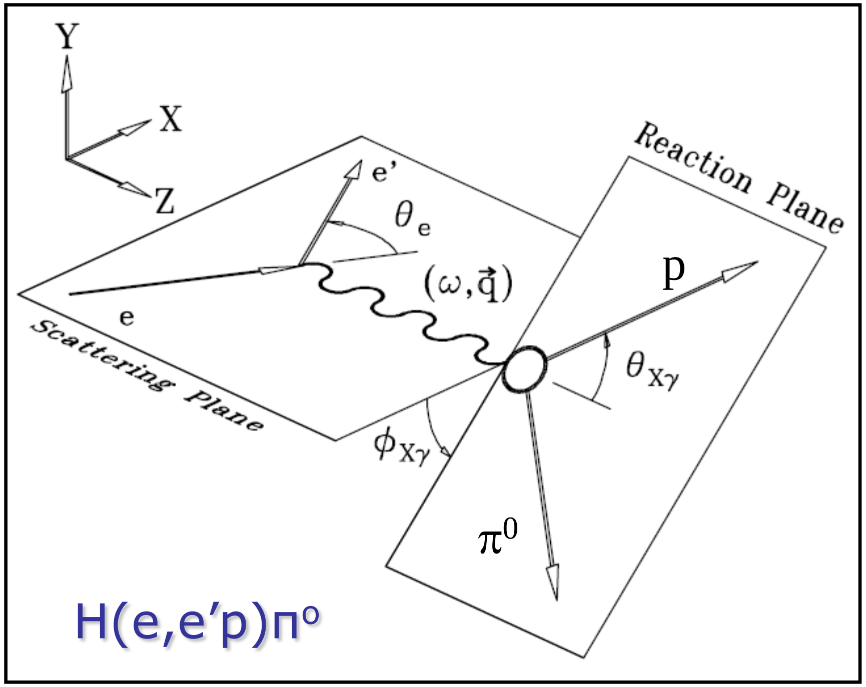
$$\sigma = J_\Omega \Gamma_v \frac{p_{cm}}{k_{cm}} \left(R_T + \epsilon_L R_L + \epsilon R_{TT} \cos 2\phi_{X\gamma} - v_{LT} R_{LT} \cos\phi_{X\gamma} - h\, v'_{LT} R'_{LT} \sin\phi_{X\gamma} \right)$$

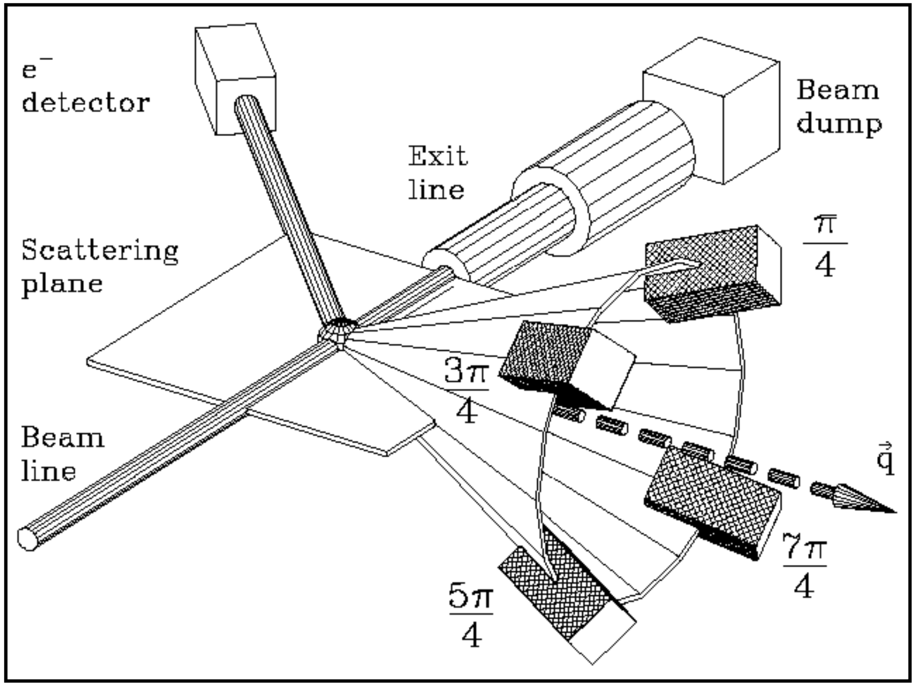
$$R_{TT} = \frac{\sigma_0 - \sigma_{\pi/2} + \sigma_\pi - \sigma_{3\pi/2}}{4K\epsilon}$$

$$R_{LT} = \frac{\sigma_\pi - \sigma_0}{2K v_{LT}}$$

$$R'_{LT} = \frac{\sigma_{3\pi/2} - \sigma_{\pi/2}}{2K h v'_{LT}}$$

Out of Plane Spectroscopy





$$\sigma = J_\Omega \Gamma_v \frac{p_{cm}}{k_{cm}} \left(R_T + \epsilon_L R_L + \epsilon R_{TT} \cos 2\phi_{X\gamma} - v_{LT} R_{LT} \cos\phi_{X\gamma} - h\, v'_{LT} R'_{LT} \sin\phi_{X\gamma} \right)$$

$$R_T + \epsilon_L R_L = \frac{\sigma_{\pi/4} + \sigma_{5\pi/4}}{2K}$$

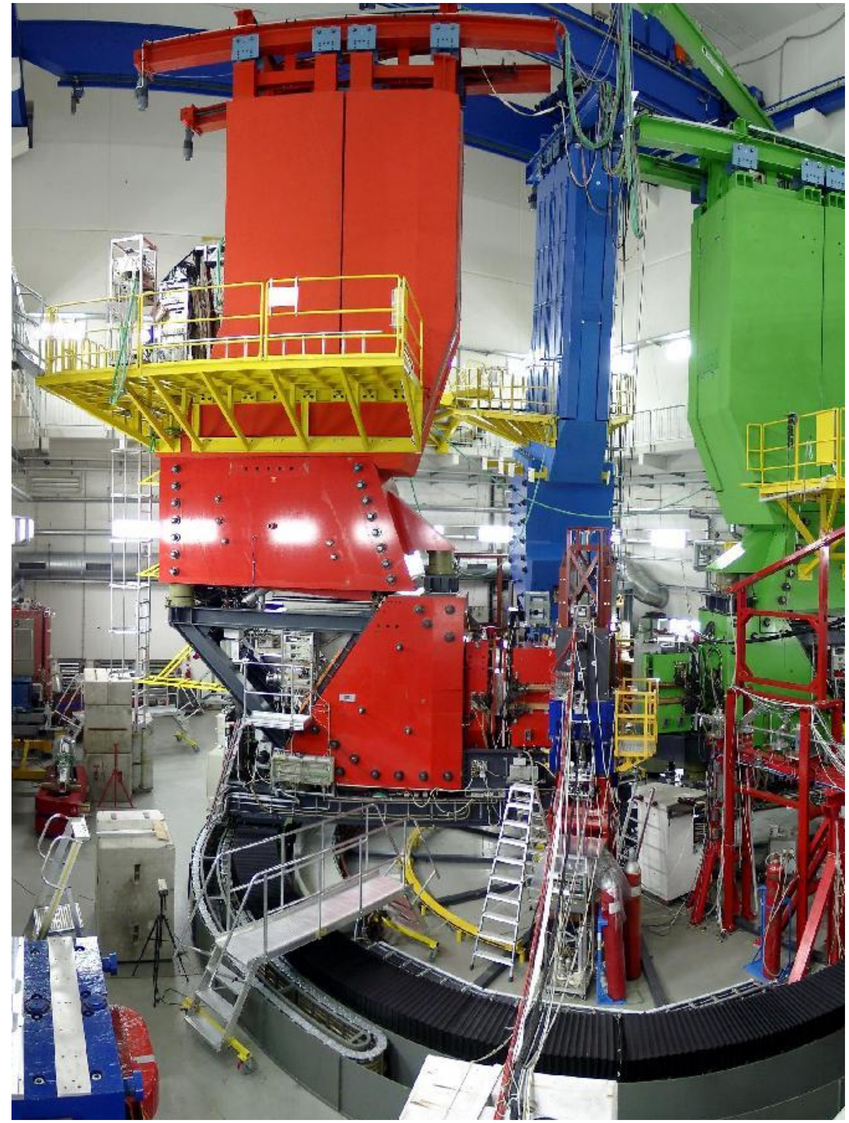
$$R_{LT} = \frac{\sigma_{3\pi/4} - \sigma_{\pi/4}}{\sqrt{2} K v_{LT}}$$

$$R'_{LT} = \frac{\sigma_{5\pi/4} - \sigma_{3\pi/4}}{\sqrt{2} K h v'_{LT}}$$

OOPS Spectrometer
MIT-Bates Linear Accelerator

Proposed and designed by C.N. Papanicolas

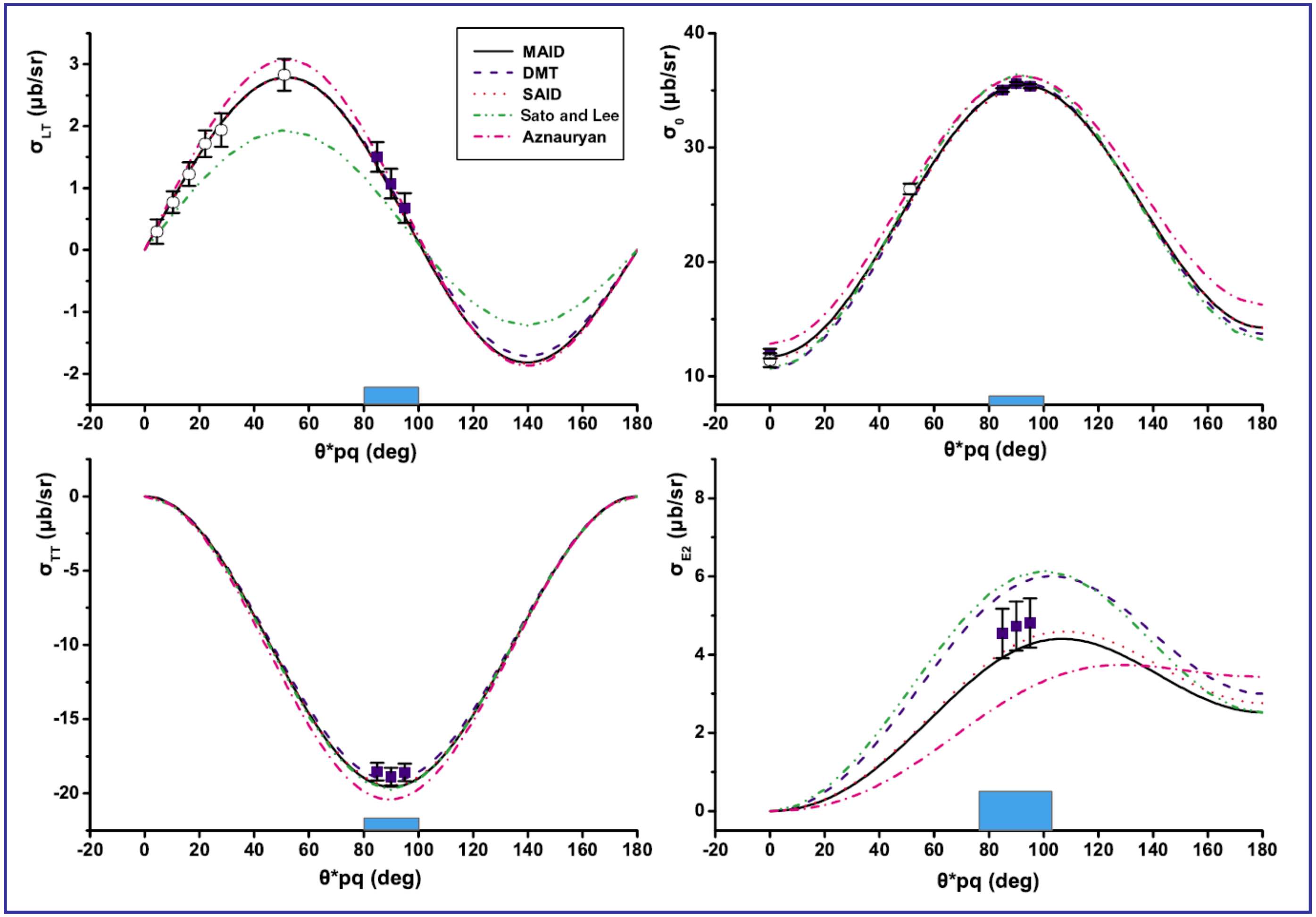
A1 Spectrometer
MAMI – Mainz, Germany



alignment precision: 1 mm , 1 mrad

H(e,e'p)π^0 Measurements at the Δ(1232) Resonance

OOPS Collaboration, Q^2=0.127 (GeV/c)^2



N.F. Sparveris *et al.* PRL 94 (2005) 022003

H(e,e'p)π^0 Measurements at the Δ(1232) Resonance

A1 Collaboration, Q^2=0.200 $(GeV/c)^2$

Δεν είναι δυνατή η εμφάνιση της εικόνας. Ίσως να μην επαρκεί η μνήμη του υπολογιστή για το άνοιγμα της εικόνας ή ίσως η εικόνα να έχει καταστραφεί. Επανεκκινήστε τον υπολογιστή και ανοίξτε ξανά το αρχείο. Αν εμφανίζεται ακόμα το κόκκινο x, ίσως να πρέπει να διαγράψετε την εικόνα και να την εισαγάγετε ξανά.

N.F. Sparveris *et al.* Phys. Lett. B 651 (2007) 102

Model Errors

- Extracted amplitudes and their ratios (EMR, CMR) are characterized by statistical, systematic and model error.

- Model error often dominates.

- So far we have only guestimates, at best!

A Model Independent Analysis Scheme

AMIAS

Based on statistical concepts and Monte Carlo techniques

- E. Stiliaris and C.N. Papanicolas: *"Multipole Extraction: A Novel, Model Independent Method"*, AIP Vol. **904** (2007) 257-268.
- C.N. Papanicolas and E. Stiliaris: *"A Novel Method of Data Analysis for Hadronic Physics"*, http://arxiv.org/abs/1205.6505v1, submitted for publication.

Multipole Expansion

$$F_1(W, z) = \sum_0^\infty l \left\{ \left[l M_{l+}(W) + E_{l+}(W) \right] P'_{l+1}(z) + \left[(l+1) M_{l-}(W) + E_{l-}(W) \right] P'_{l-1}(z) \right\}$$

$$F_2(W, z) = \sum_1^\infty l \left[(l+1) M_{l+}(W) + l M_{l-}(W) \right] P'_l(z),$$

$$F_3(W, z) = \sum_1^\infty l \left\{ \left[(E_{l+}(W) - M_{l+}(W) \right] P''_{l+1}(z) + \left[E_{l-}(W) + M_{l-}(W) \right] P''_{l-1}(z) \right\},$$

$$F_4(W, z) = \sum_2^\infty l \left[M_{l+}(W) - E_{l+}(W) - M_{l-}(W) - E_{l-}(W) \right] P''_l(z), \qquad (C.7)$$

$$F_5(W, z) = \sum_0^\infty l \left[(l+1) L_{l+}(W) P'_{l+1}(z) - l L_{l-}(W) P'_{l-1}(z) \right]$$

$$F_6(W, z) = \sum_1^\infty l \left[l L_{l-}(W) - (l+1) L_{l+}(W) \right] P'_l(z).$$

Chew-Goldberger-Low-Nambu (CGLN) Amplitudes

E. Amaldi, S. Fubini and G. Furlan: *Pion-Electroproduction* (1979) Springer Verlag

E_{L+} , E_{L-} , M_{L+} , M_{L-} , L_{L+} , L_{L-} $0 \leq L \leq Lcut$

↓

F1, F2, F3, F4, F5, F6   (CGLN)

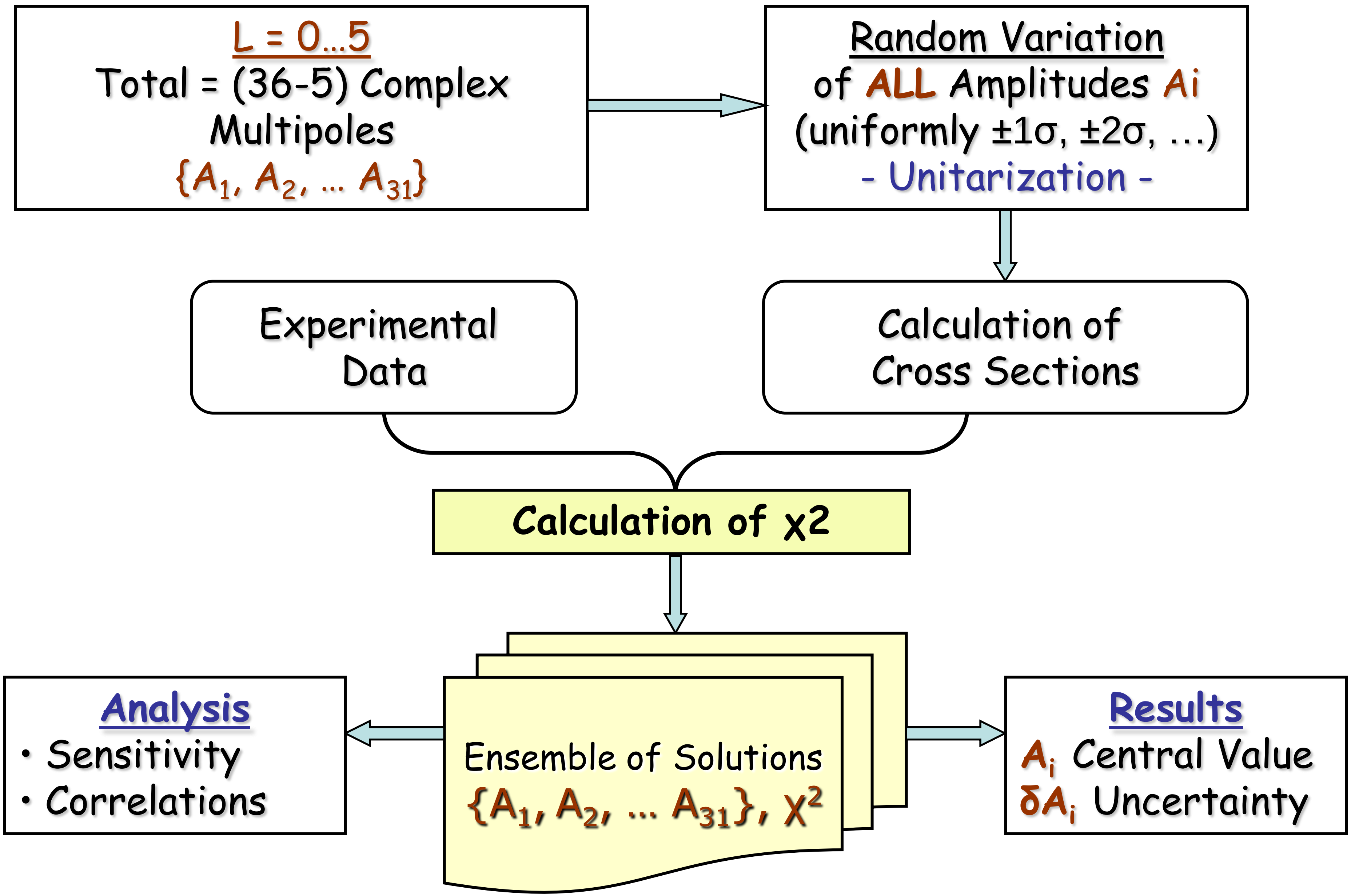
↓

Response Functions: R_T, R_L, R_{TT}, R_{LT}, ...

↓

OBSERVABLES

AMIAS Flowchart (Multipole Extraction)



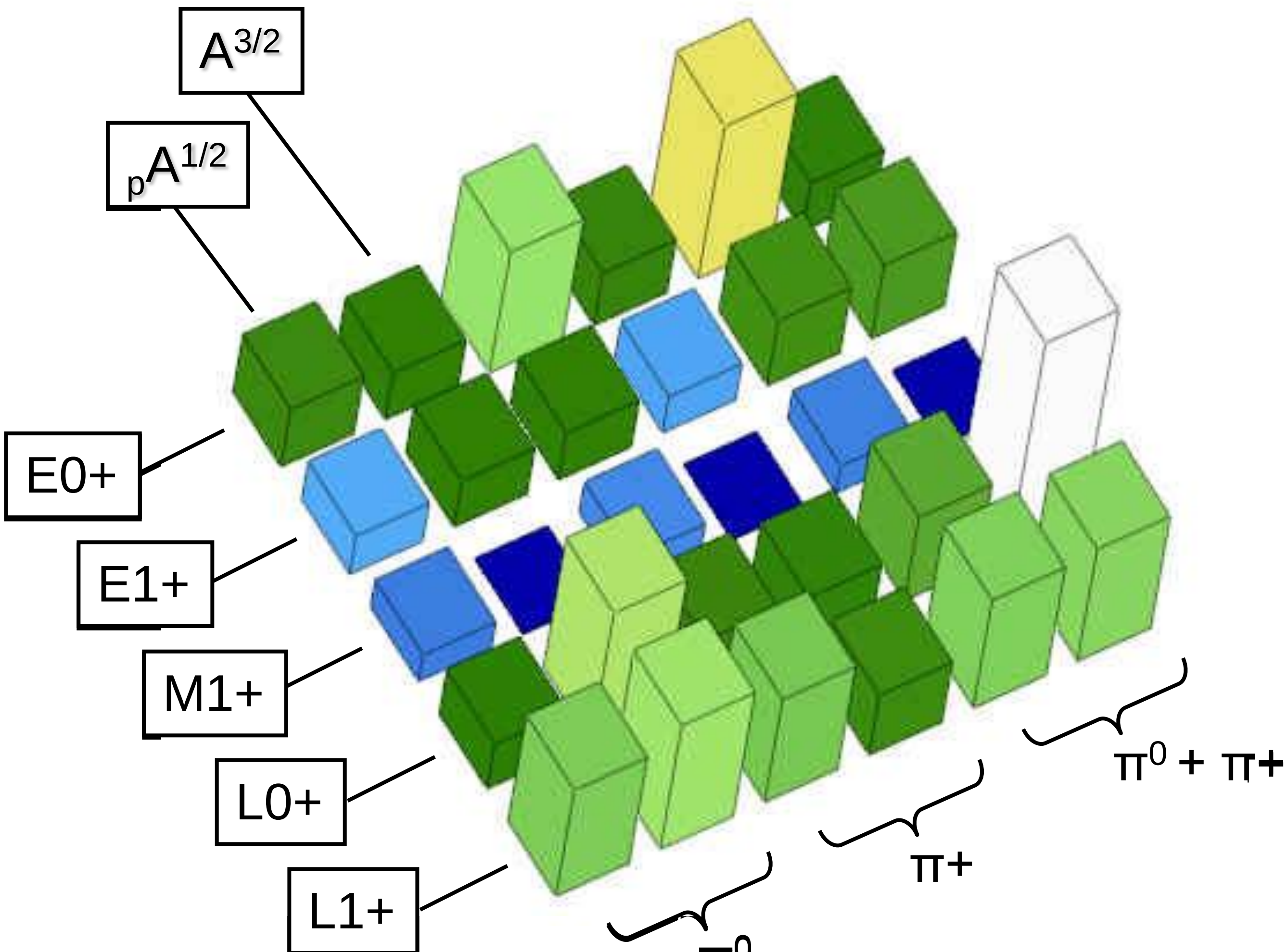
E0+	E0-	M0+	M0-	L0+	L0-
E1+	E1-	M1+	M1-	L1+	L1-
E2+	E2-	M2+	M2-	L2+	L2-
E3+	E3-	M3+	M3-	L3+	L3-
E4+	E4-	M4+	M4-	L4+	L4-
E5+	E5-	M5+	M5-	L5+	L5-

N FREE PARAMETER
m: fitted
n: fixed
N-m-n: randomly varying

MODEL DEPENDENT FIT
m=3
n=N-3
0 randomly varying

MODEL INDEPENDENT ANALYSIS
m=0
n=0
N: randomly varying

AMIAS: Sensitivity Analysis

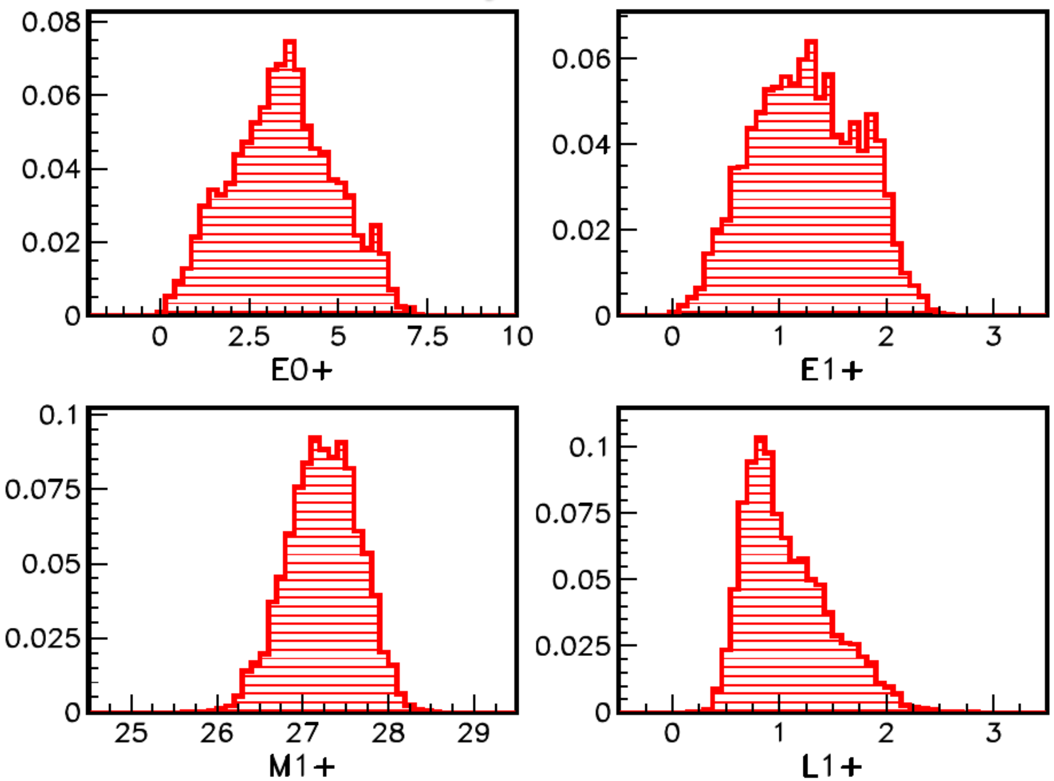


Bates-Mainz Data (Q^2=0.127 (GeV/c)^2 , W=1232 MeV)

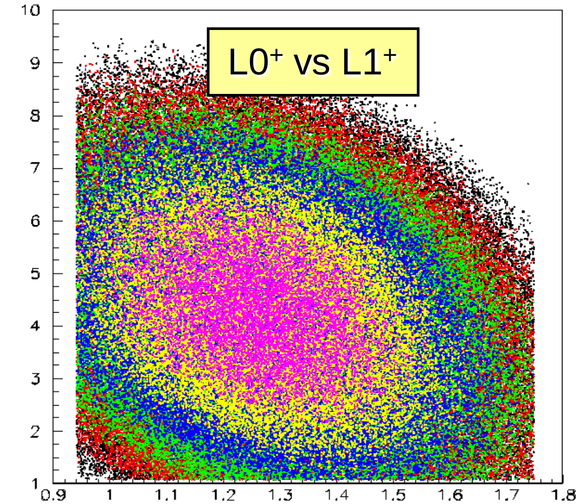
Extracted Values

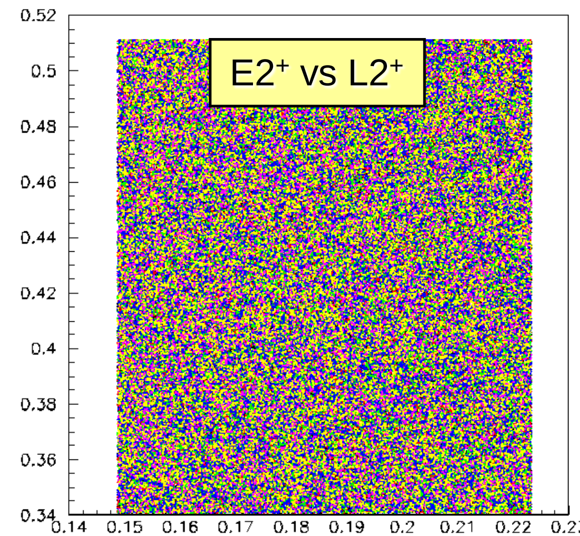
Multipole	Extracted Value	Relative Error	MAID-2003	Sato & Lee	DMT
M_{1+}	27.24 ± 0.20	0.73 %	27.464	27.661	27.489
L_{1+}	$0.82\,^{+0.20}_{-0.09}$	17.7 %	1.000	0.672	0.986
L_{0+}	2.23 ± 0.41	18.4 %	2.345	1.008	1.994
E_{0+}	3.44 ± 0.70	20.3 %	2.873	2.213	3.206
E_{1+}	$1.16\,^{+0.32}_{-0.24}$	24.1 %	1.294	1.288	1.401

Probability Distributions

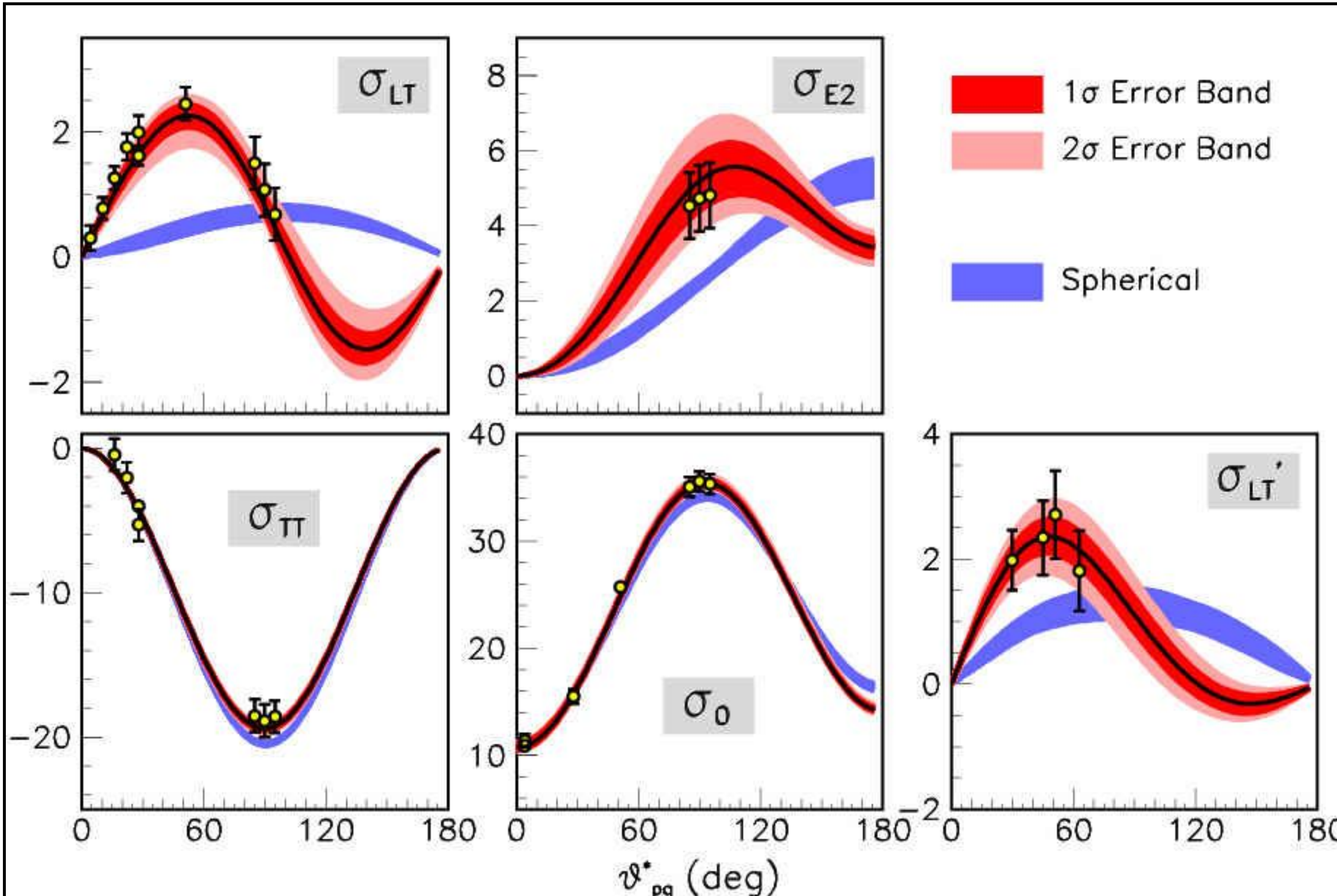


Correlations



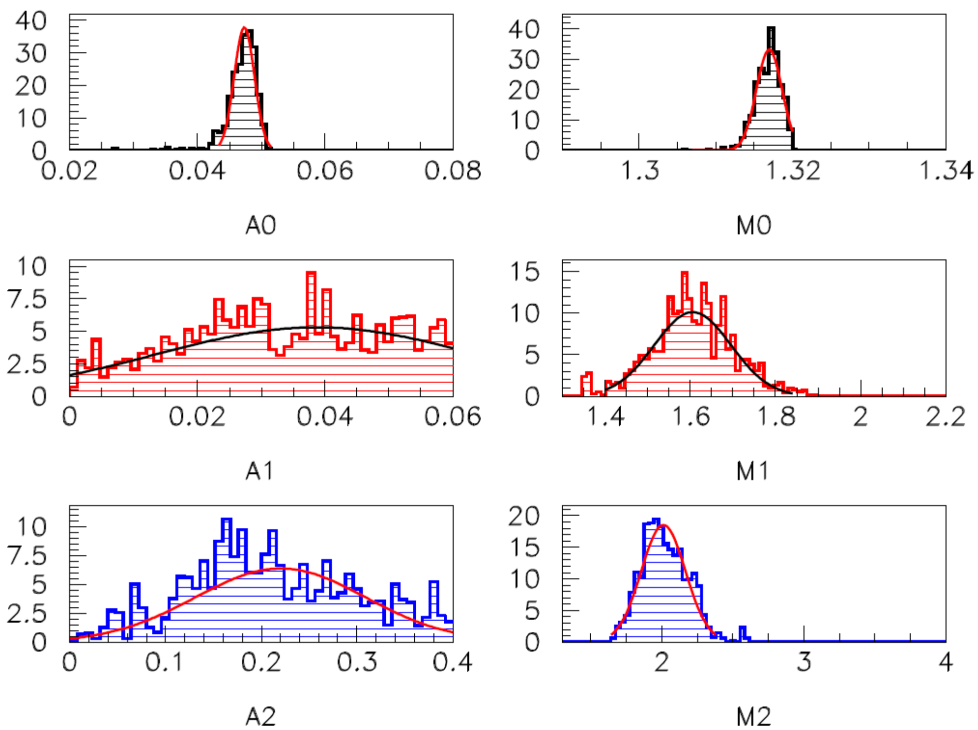


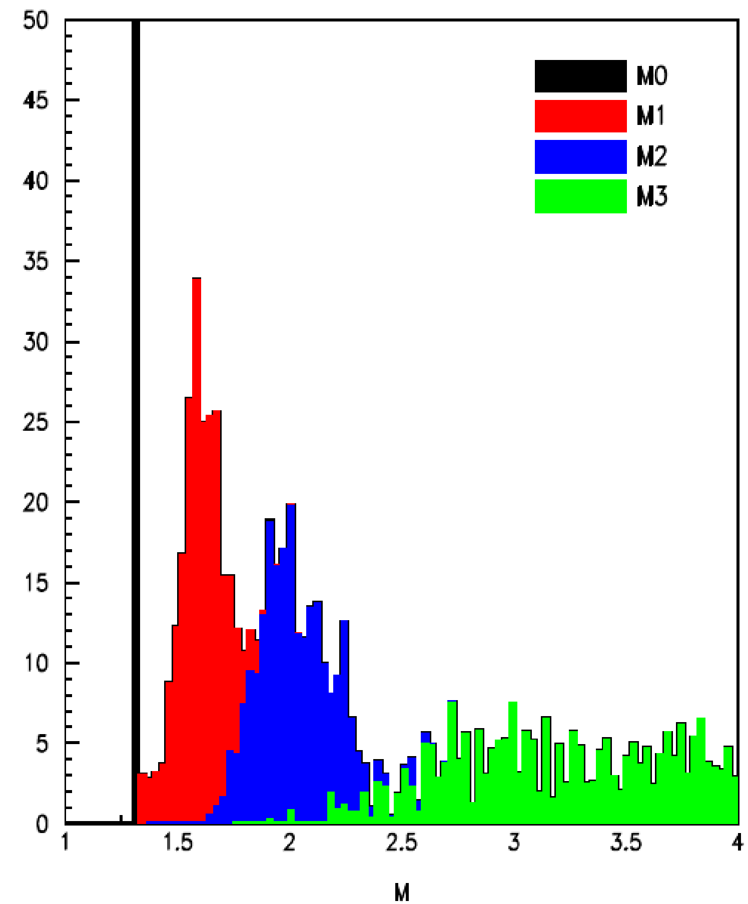
Bates-Mainz Data (Q^2=0.127 (GeV/c)^2 , W=1232 MeV)



AMIAS and Lattice QCD

AMIAS has been successfully tested in the determination of hadron excited states in Lattice QCD applied to the nucleon.



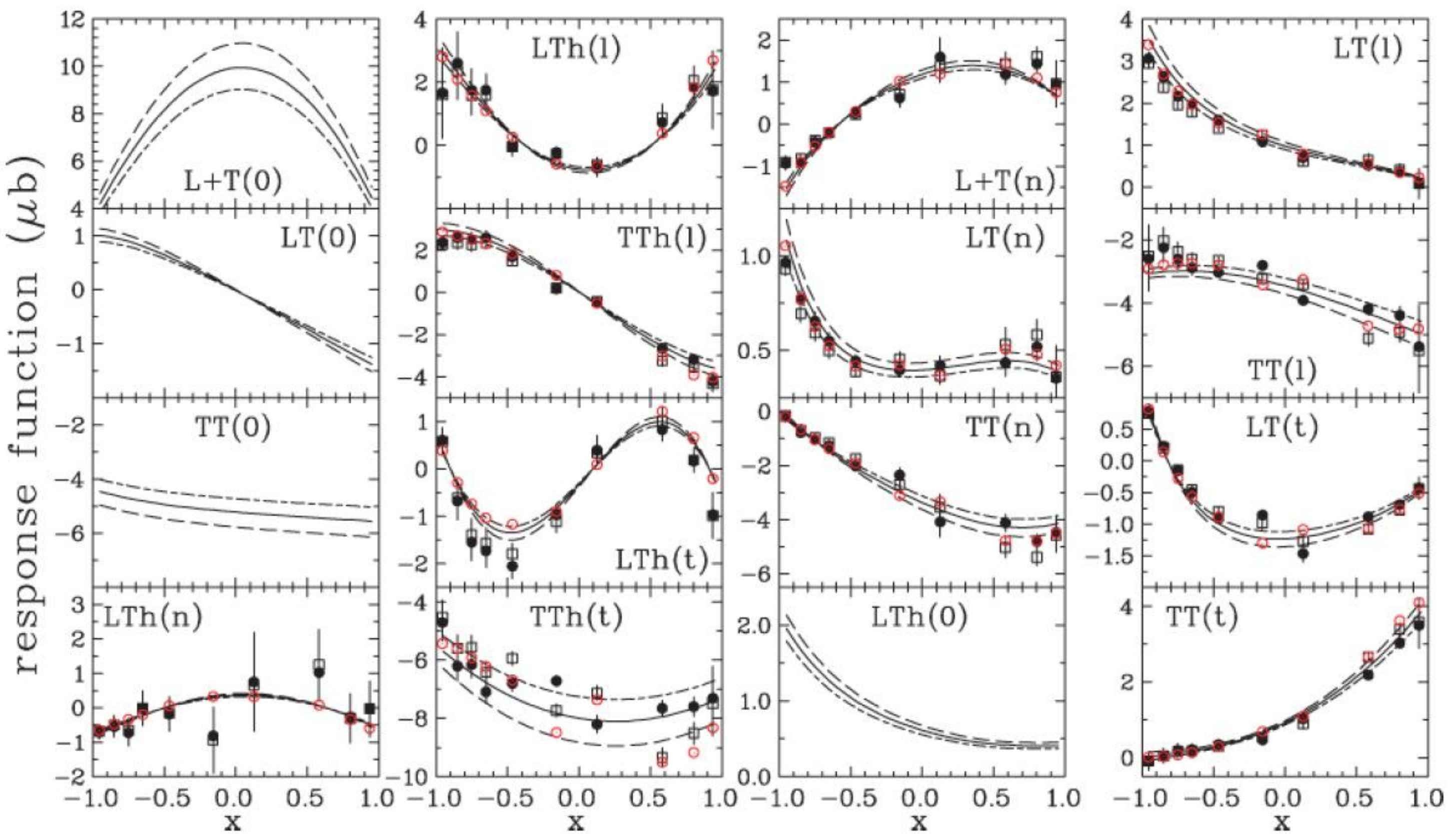


C. Alexandrou, C.N. Papanicolas and E. Stiliaris:
A novel fitting scheme – Nucleon excited states
PoS (Lattice 2008) 099

Future Plans: Model Independent Analysis of JLab Data

PHYSICAL REVIEW C **75**, 025201 (2007)

Recoil polarization measurements for neutral pion electroproduction at $Q^2 = 1\ (\mathrm{GeV}/c)^2$ near the Δ resonance



Thank You!