AMIAS: A Model Independent Analysis Scheme

From Hadronics to Medical Imaging

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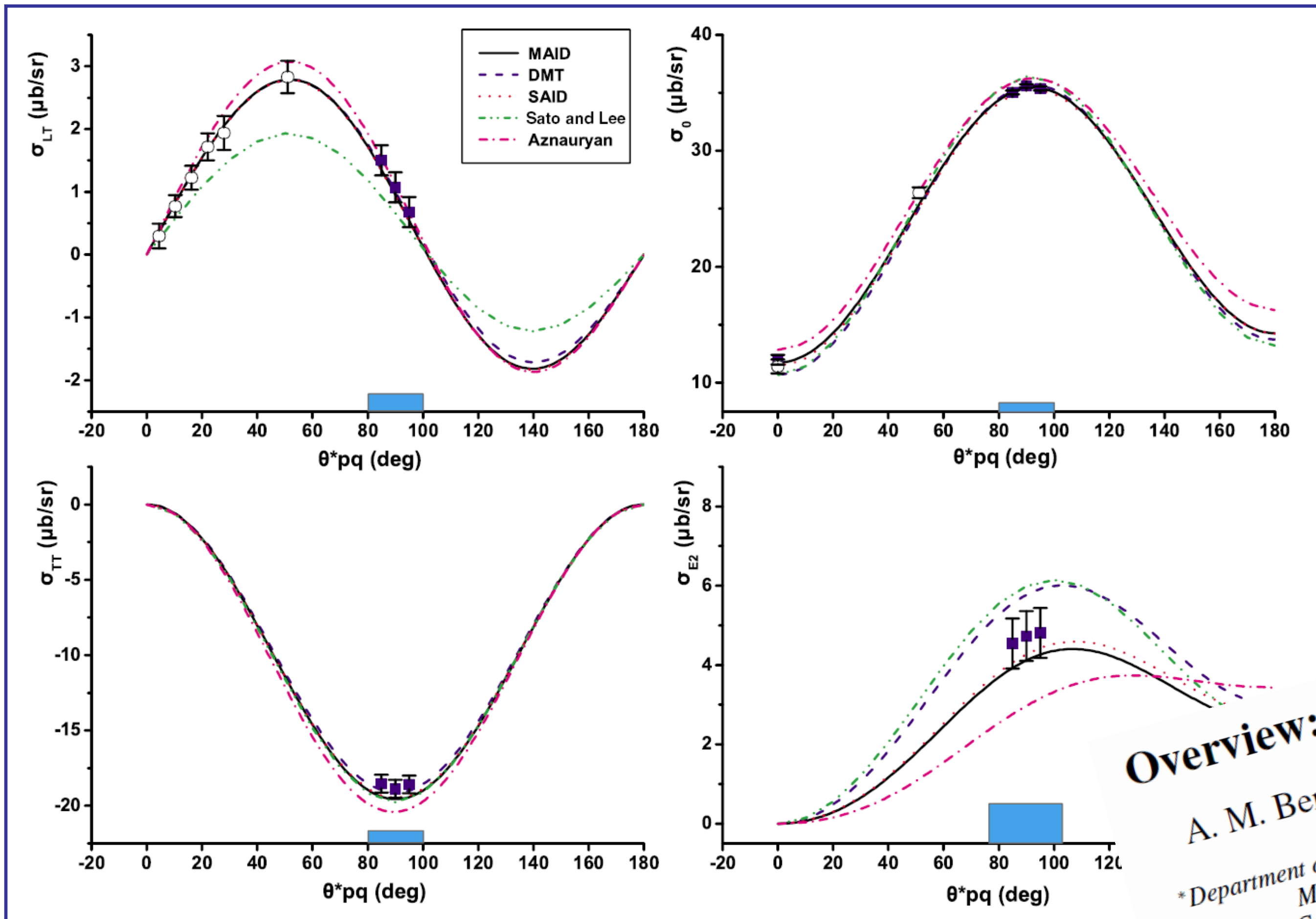
Karolos Papoulias Conference Center, University of Ioannina, Greece

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

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



Begin of the story

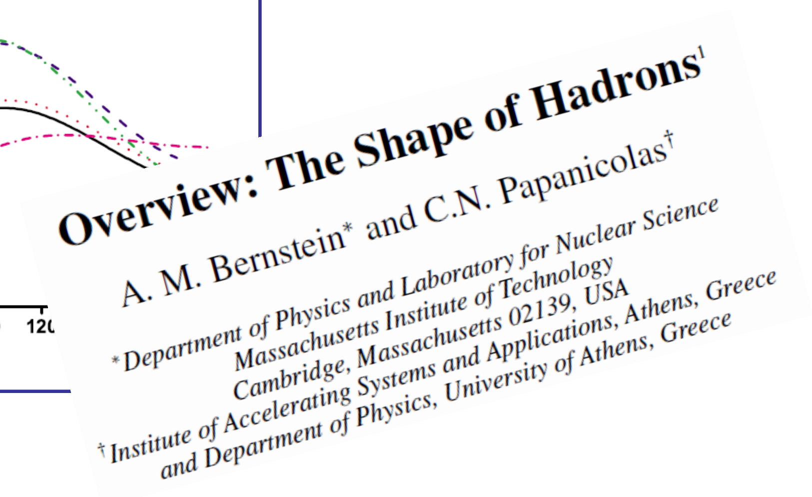
MIT 2004

Workshop on

The Shape of Hadrons

2004 MIT, USA

2006 Athens, GR



Overview: The Shape of Hadrons[1]

A. M. Bernstein* and C.N. Papanicolas†

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Massachusetts Institute of Technology
Cambridge, Massachusetts 02139, USA

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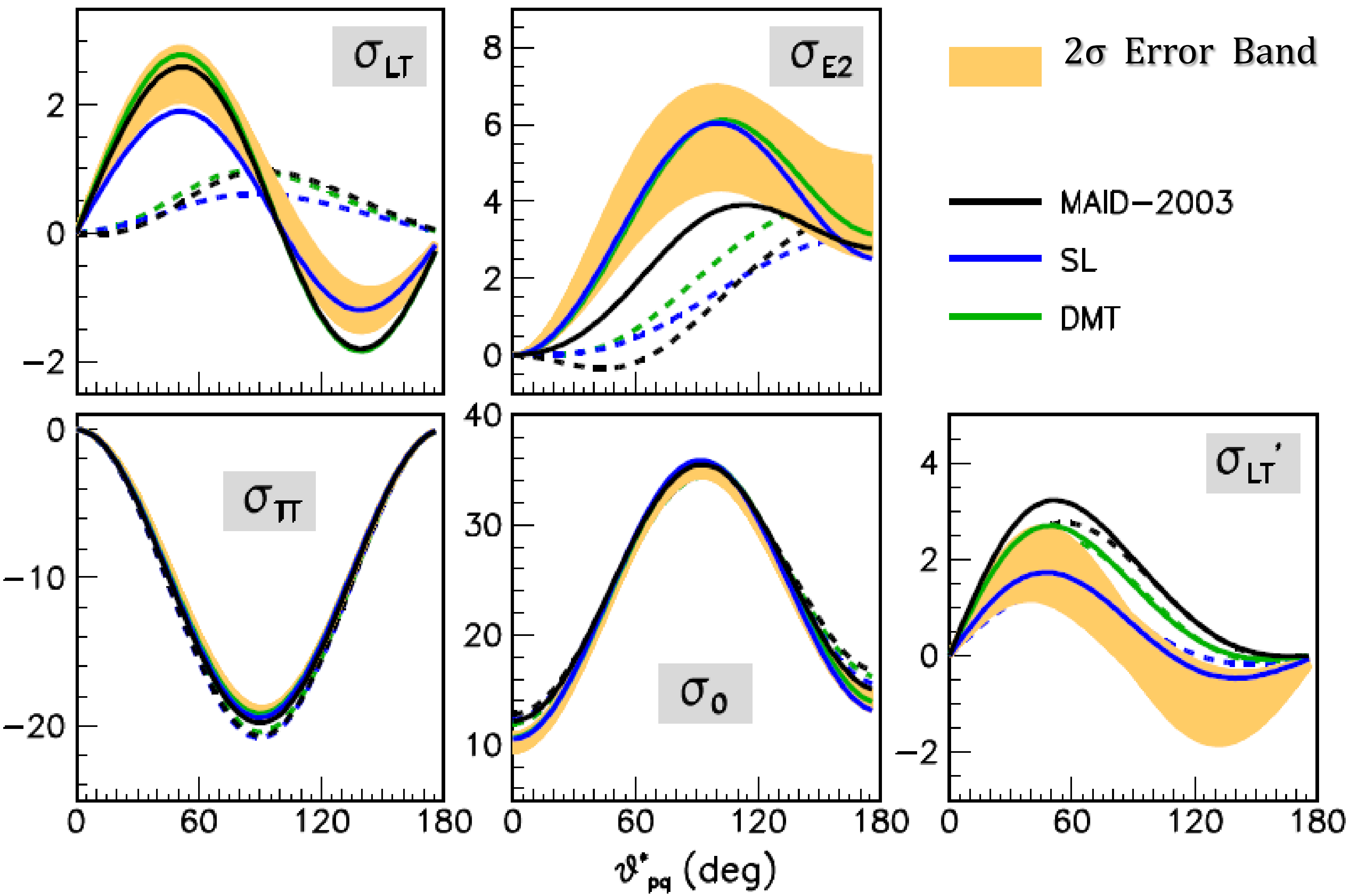
and Department of Physics, University of Athens, Greece

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

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

How to extract model independent amplitudes from experimental data?

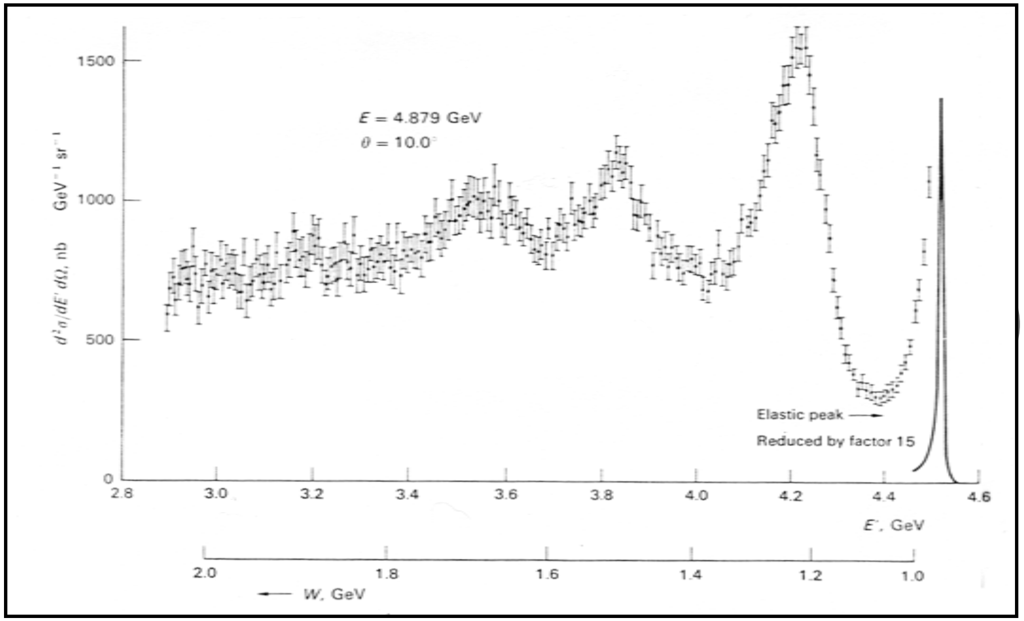


The signal for deformation in the $\gamma^* N \rightarrow \Delta$ transition

p(qqq)

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

938 MeV



Δ(qqq)

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

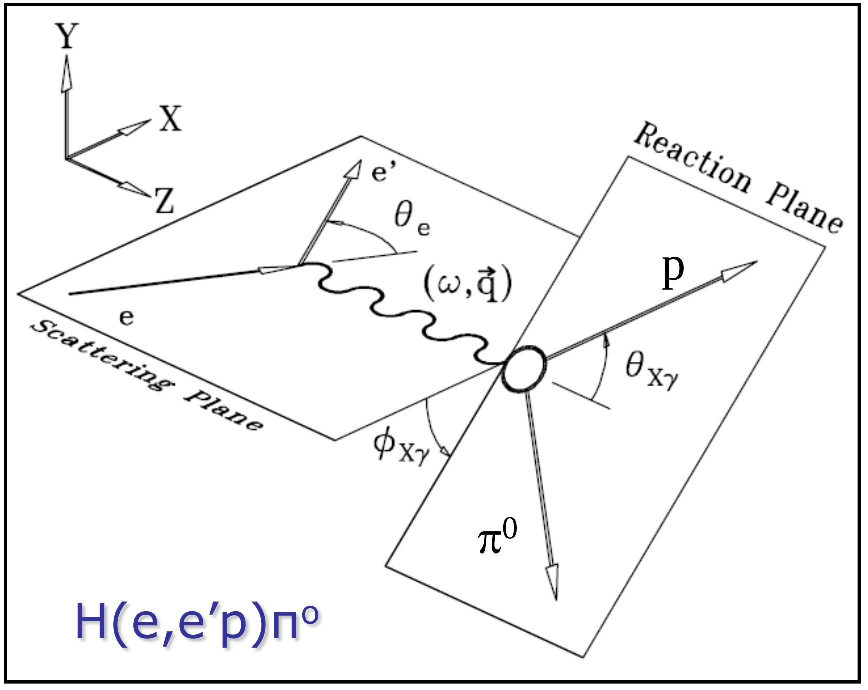
1232 MeV

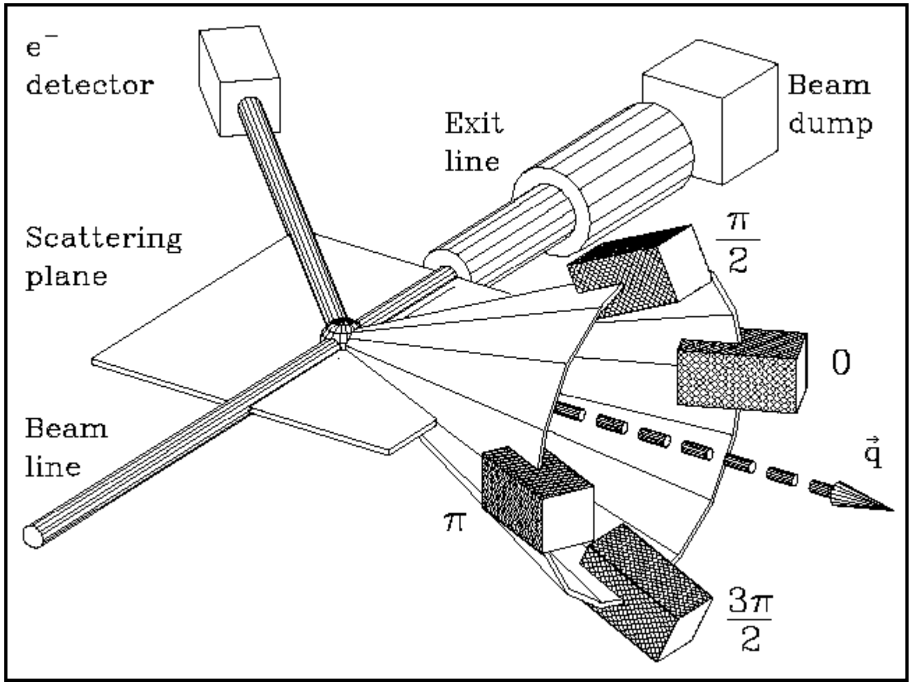
Spherical $\Rightarrow$ M1

Deformed $\Rightarrow$ M1 , E2 , C2 Deformation signal

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

Out of Plane Spectroscopy





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

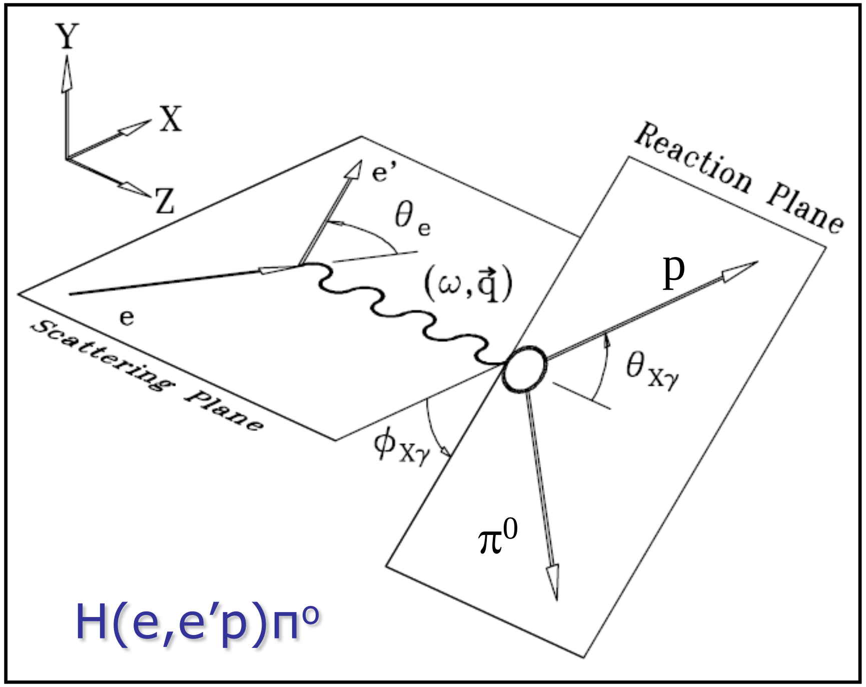
$$\sigma = J_\Omega \Gamma_v \frac{p_{cm}}{k_{cm}} \left(R_T + \epsilon_L R_L + \epsilon R_{TT} \cos 2\phi_{X\gamma} \right.$$
$$\left. - v_{LT} R_{LT} \cos\phi_{X\gamma} - h\, v'_{LT} R'_{LT} \sin\phi_{X\gamma} \right)$$

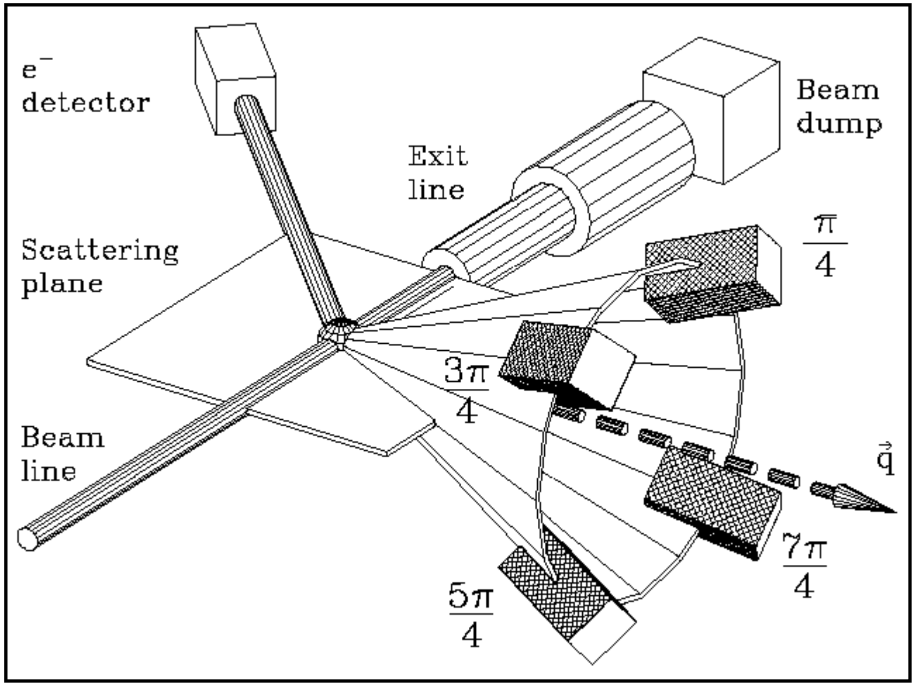
$$R_{TT} = \frac{\sigma_0 - \sigma_{\pi/2} + \sigma_\pi - \sigma_{3\pi/2}}{4K\epsilon}$$

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

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

Out of Plane Spectroscopy





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

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

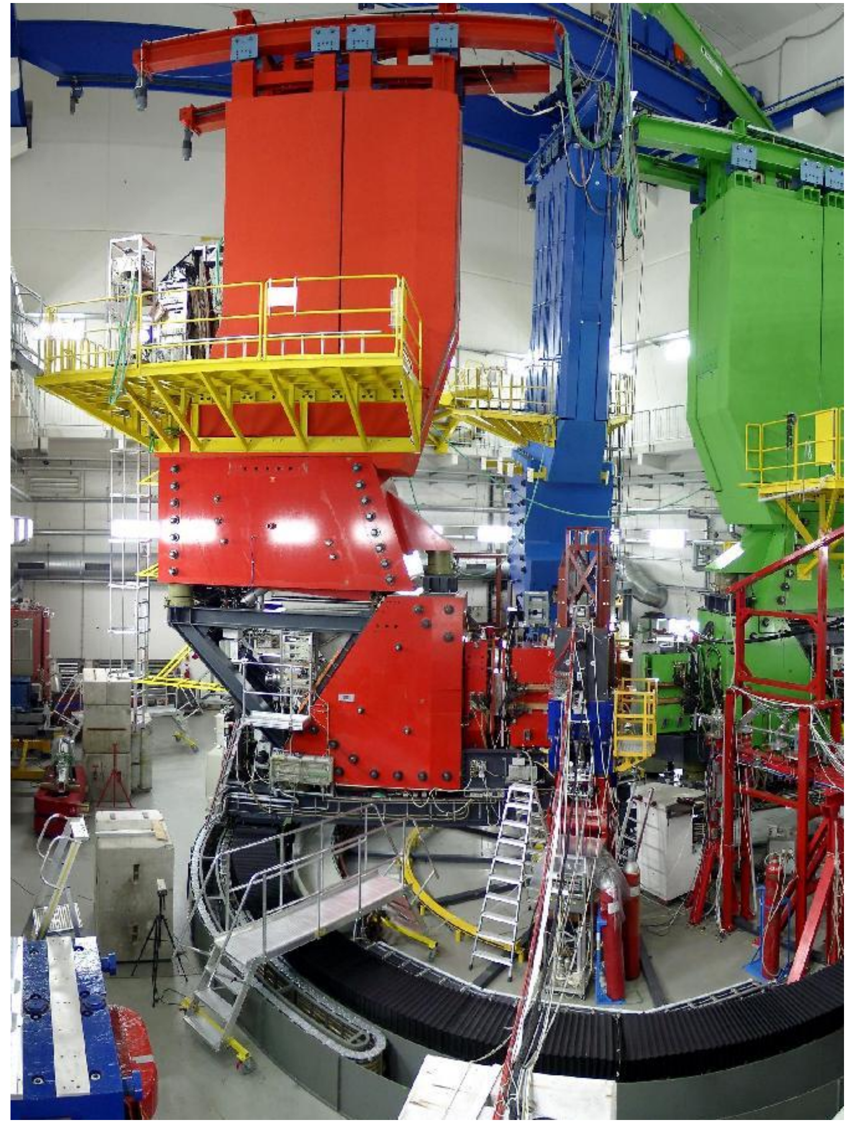
$$R_{LT} = \frac{\sigma_{3\pi/4} - \sigma_{\pi/4}}{\sqrt{2} K v_{LT}}$$

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

OOPS Spectrometer
MIT-Bates Linear Accelerator

Proposed and designed by C.N. Papanicolas

A1 Spectrometer
MAMI – Mainz, Germany



alignment precision: 1 mm , 1 mrad

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.

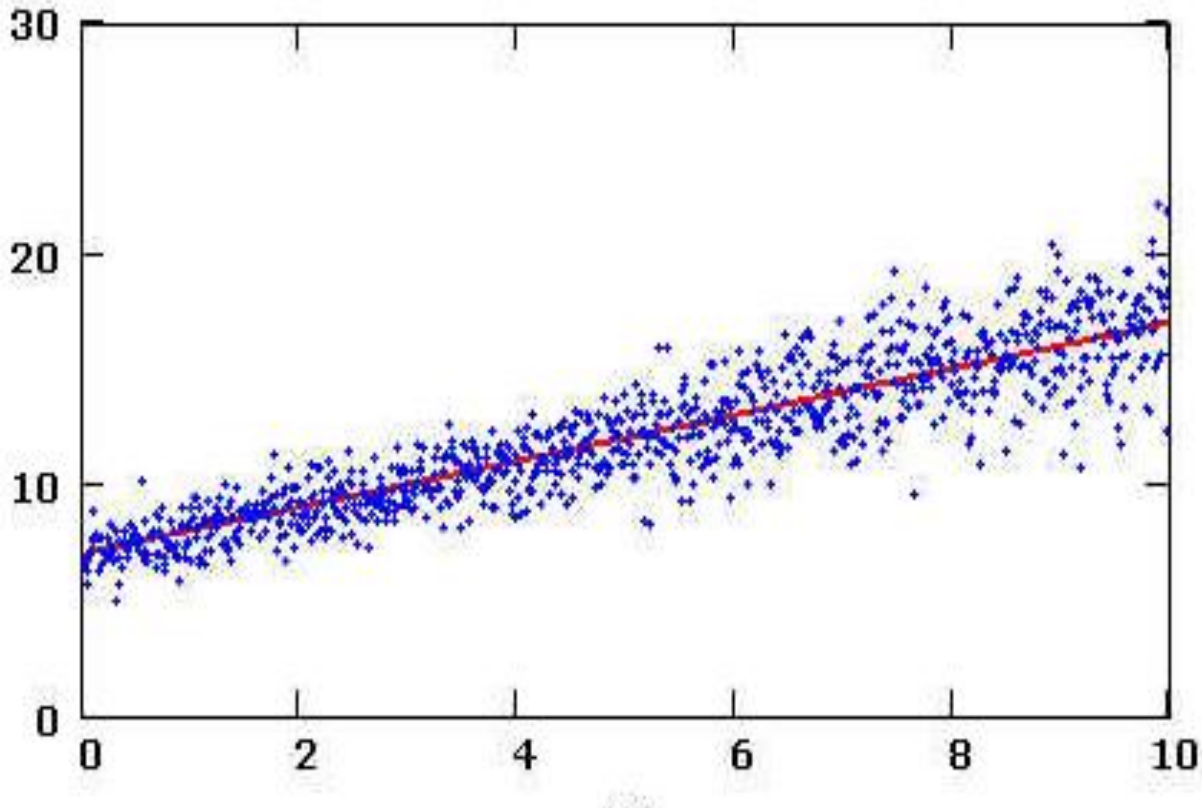
A Simple AMIAS Example: Fitting a Straight Line

- Theory: $y = A_0 + A_1 x$ $\{A_\mu\} = (A_0, A_1)$

- Pseudodata

Generated with:

$A_0 = 7.0 \pm 0.8$
$A_1 = 1.0 \pm 0.2$

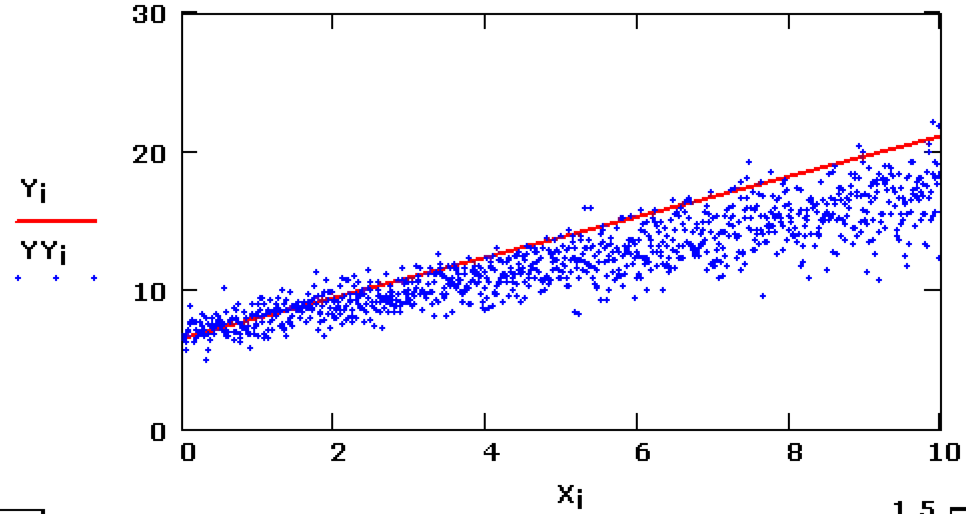


How to analyze them with AMIAS ?

A Simple AMIAS Example: Fitting a Straight Line

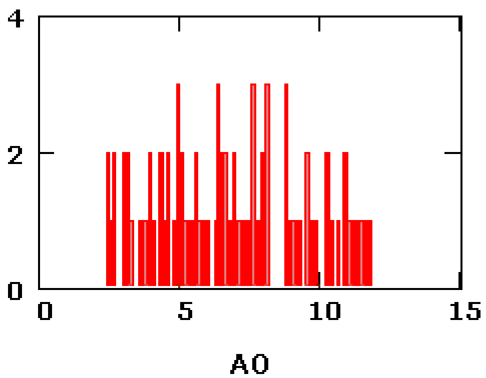
Chi2 = 2783

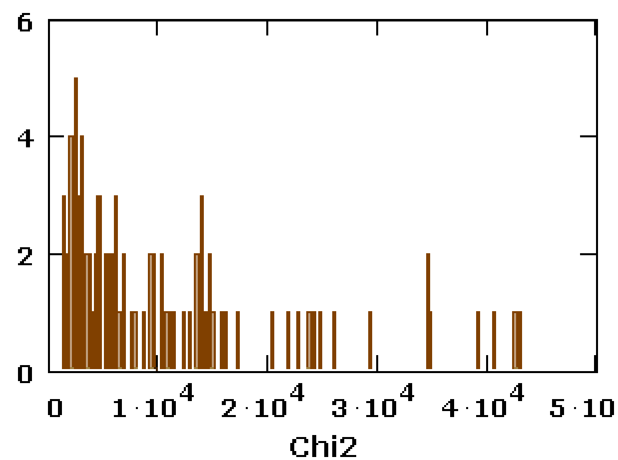
χ^2

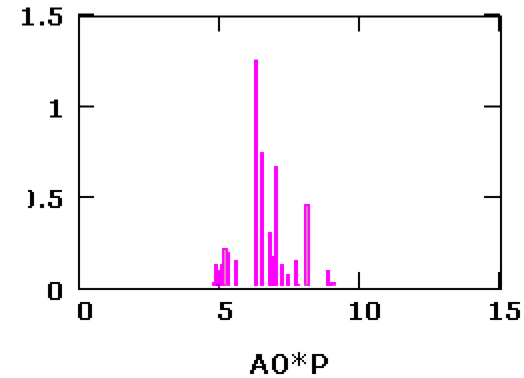


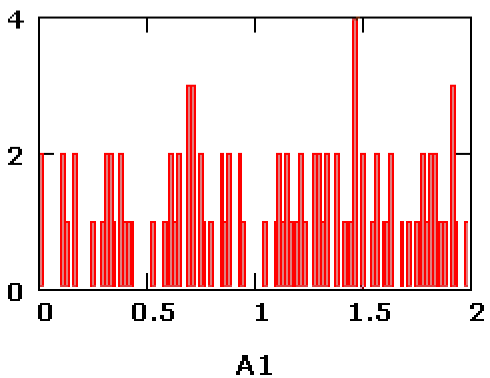
P = 0.00780880

$\exp\{-\chi^2/2\}$

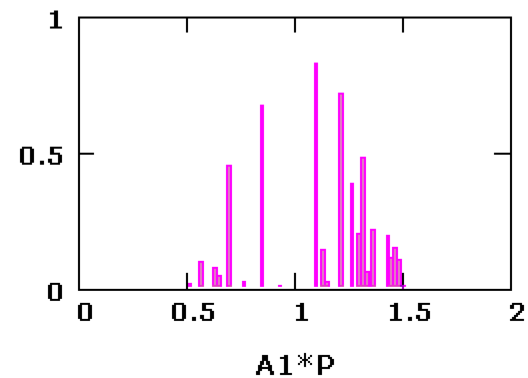








N = 100



Multipole Expansion

$$F_1(W,z) = \sum_{0}^{\infty} l \left\{ \left[lM_{l+}(W) + E_{l+}(W) \right] P'_{l+1}(z) + \left[(l+1)\, M_{l-}(W) + E_{l-}(W) \right] P'_{l-1}(z) \right\}$$

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

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

$$F_4(W,z) = \sum_{2}^{\infty} l \left[M_{l+}(W) - E_{l+}(W) - M_{l-}(W) - E_{l-}(W) \right] P''_{l}(z), \qquad (C.7)$$

$$F_5(W,z) = \sum_{0}^{\infty} l \left[(l+1)\, L_{l+}(W)\, P'_{l+1}(z) - lL_{l-}(W)\, P'_{l-1}(z) \right]$$

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

Chew-Goldberger-Low-Nambu (CGLN) Amplitudes

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

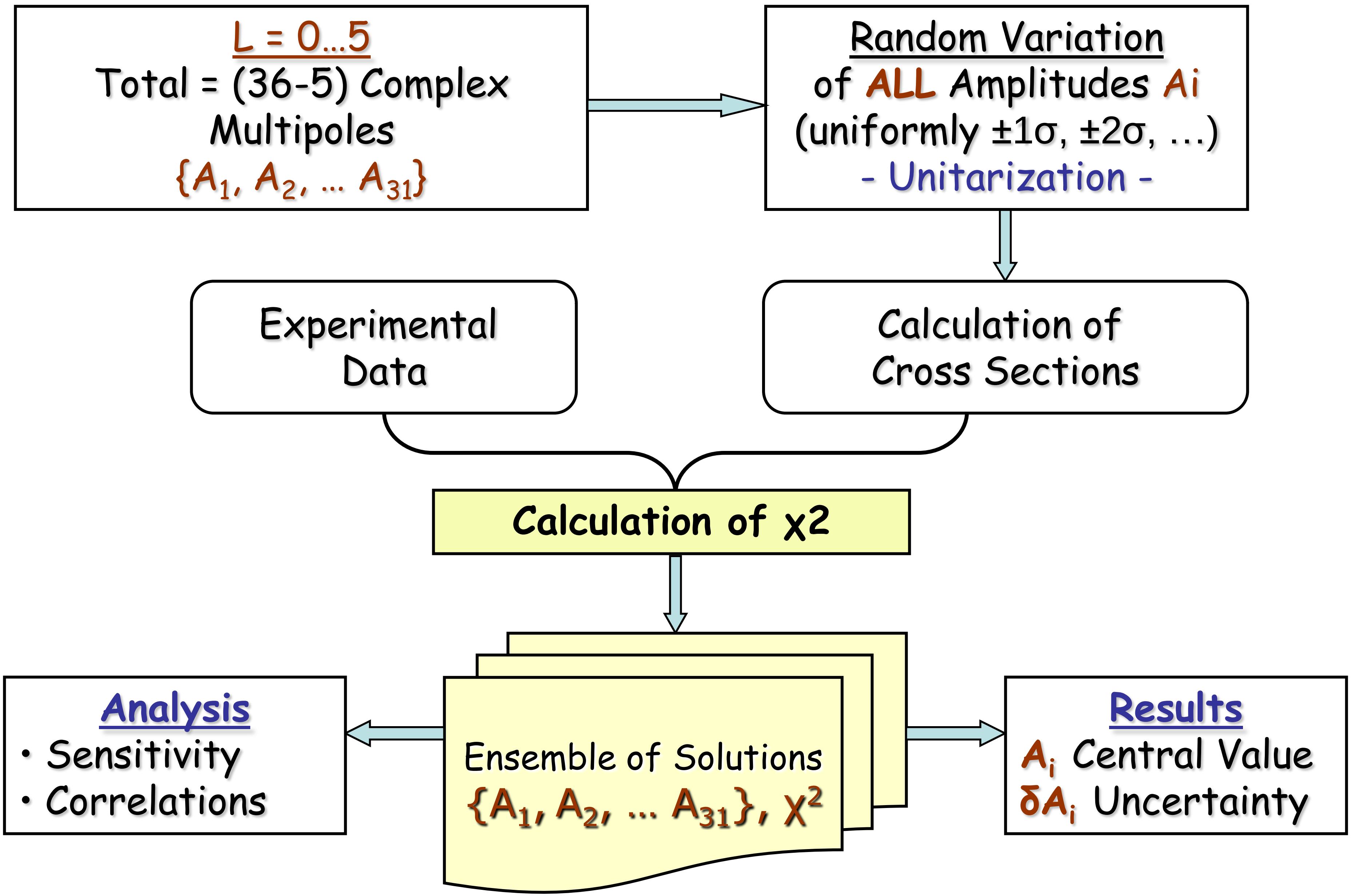
E_L+ , E_L- , M_L+ , M_L- , L_L+ , L_L- $\quad 0 \leq L \leq Lcut$

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

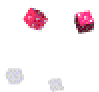
Response Functions: R_T, R_L, R_{TT}, R_{LT}, ...

OBSERVABLES

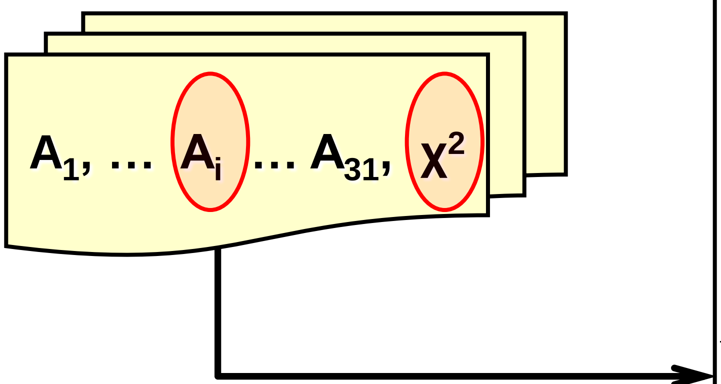
AMIAS Flowchart (Multipole Extraction)

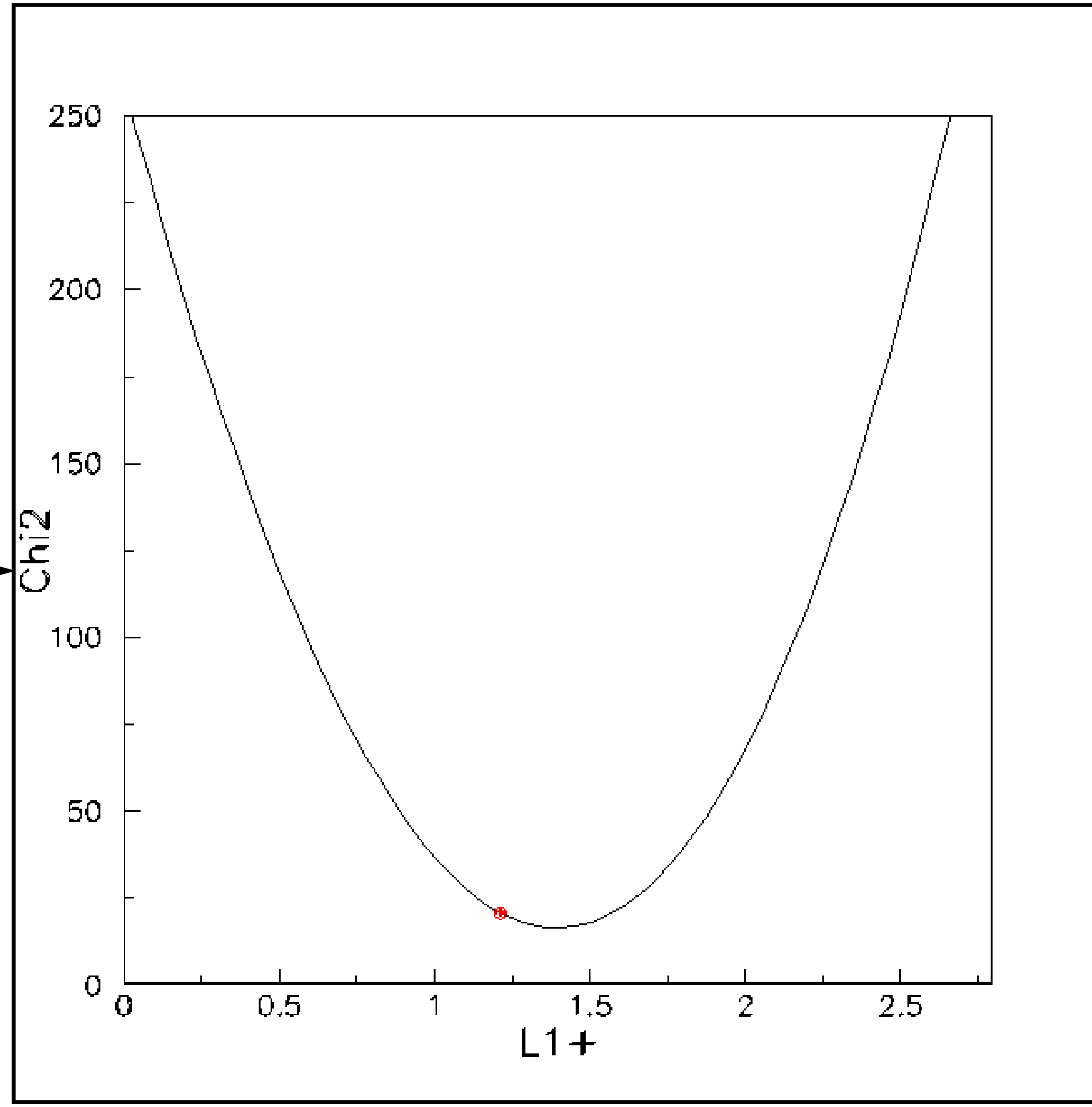


Sensitivity on Amplitude A_i



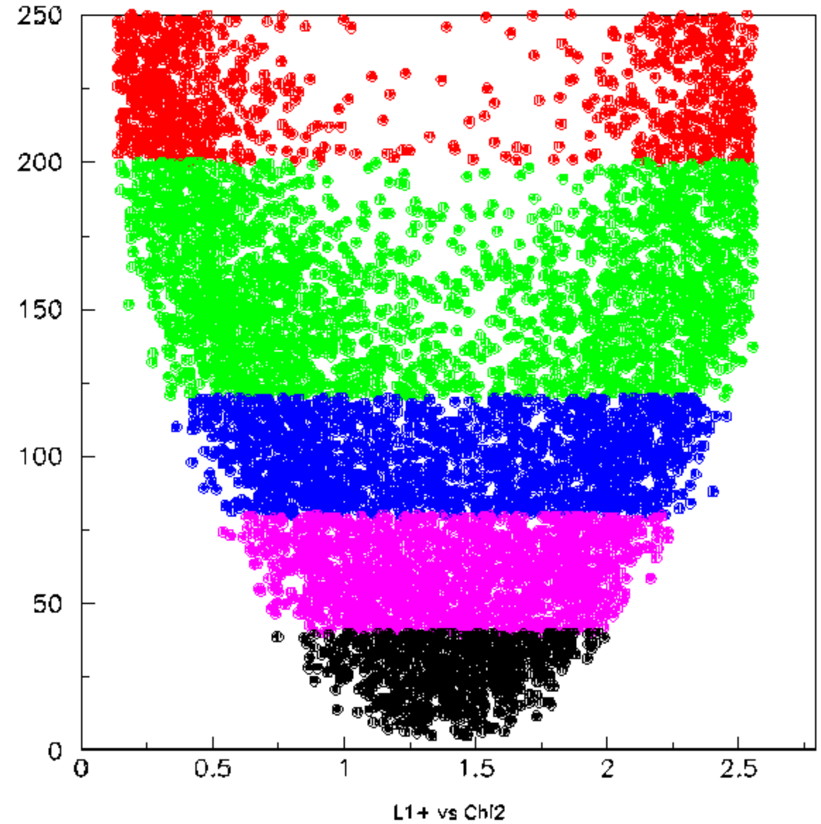
χ^2 versus A_i Plot



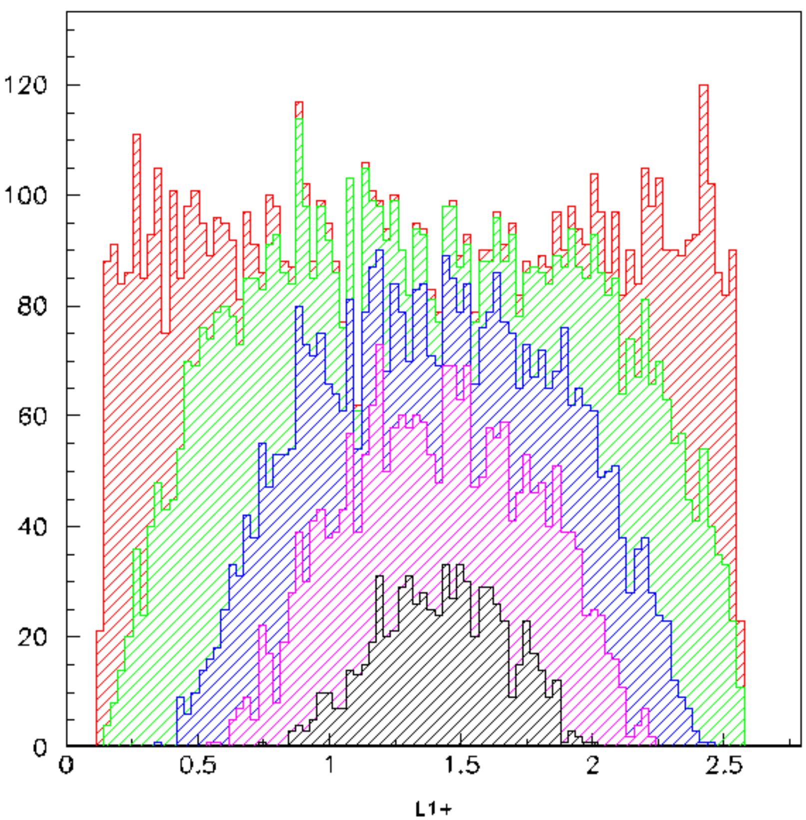


A_i is uniformly distributed

Applying χ^2 Cut on **SENSITIVE** Amplitude A_i



A_i Distribution



PROJECTION

ALL VALUES

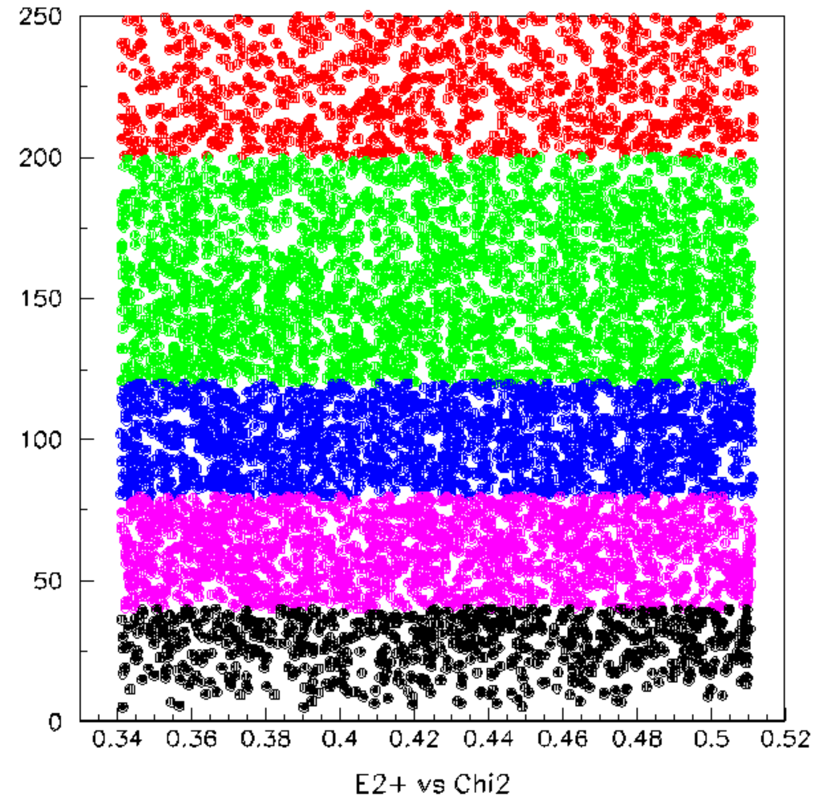
$\chi^2 < 200$

$\chi^2 < 120$

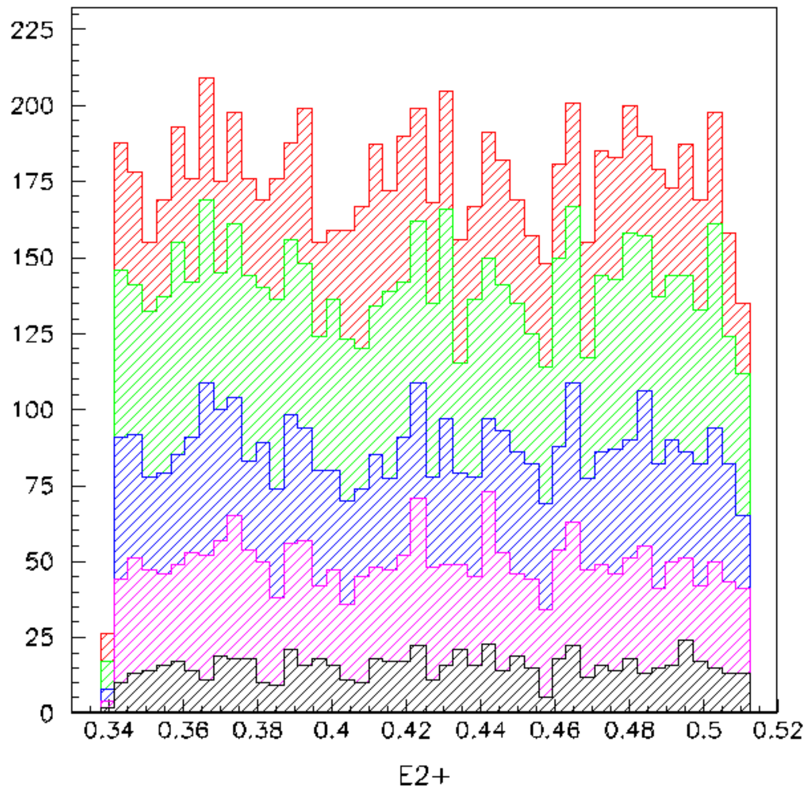
$\chi^2 < 80$

$\chi^2 < 40$

Applying χ^2 Cut on **NON SENSITIVE** Amplitude A_i



A_i Distribution



PROJECTION

ALL VALUES

$\chi^2 < 200$

$\chi^2 < 120$

$\chi^2 < 80$

$\chi^2 < 40$

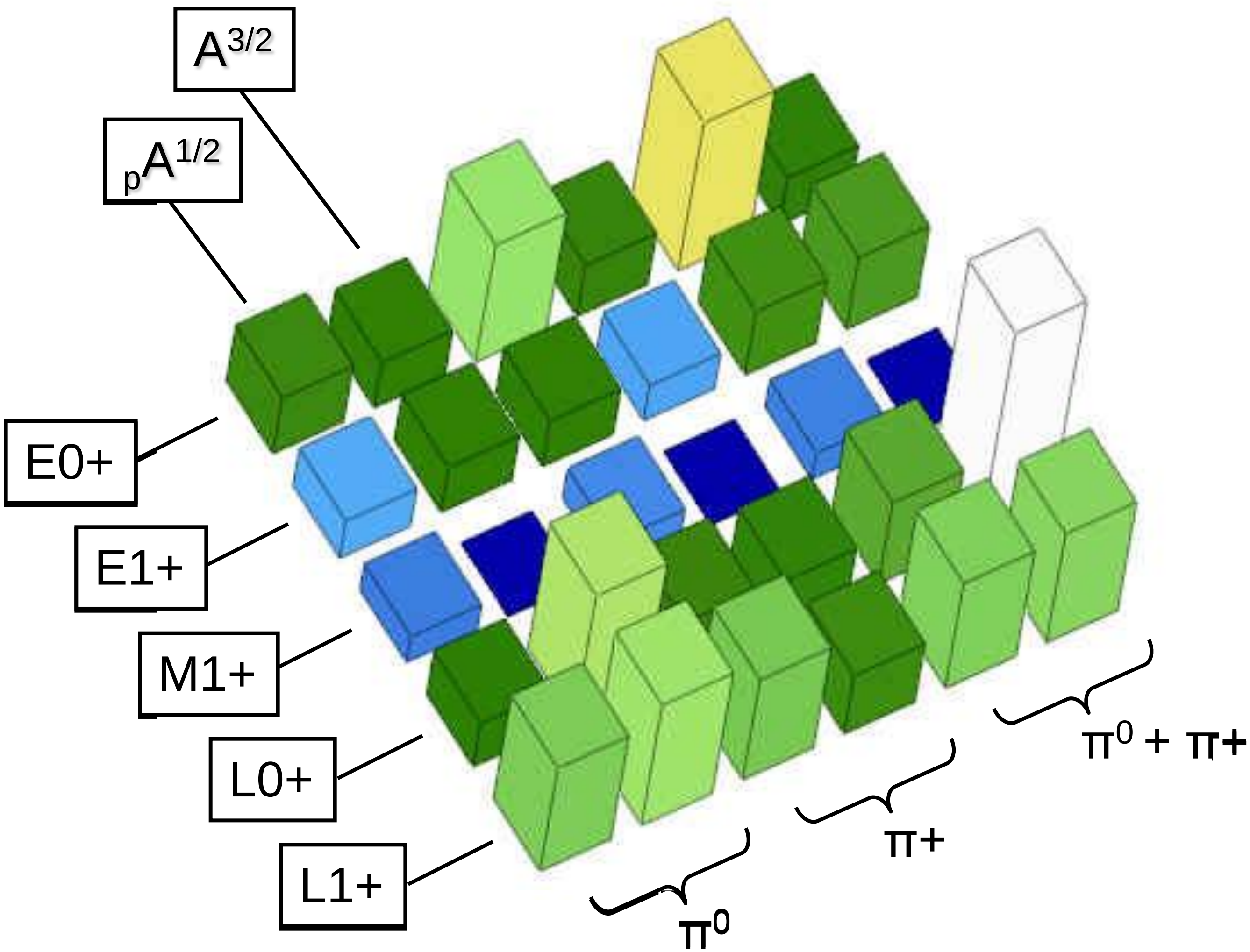
E0+	E0-	M0+	M0-	L0+	L0-
E1+	E1-	M1+	M1-	L1+	L1-
E2+	E2-	M2+	M2-	L2+	L2-
E3+	E3-	M3+	M3-	L3+	L3-
E4+	E4-	M4+	M4-	L4+	L4-
E5+	E5-	M5+	M5-	L5+	L5-

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

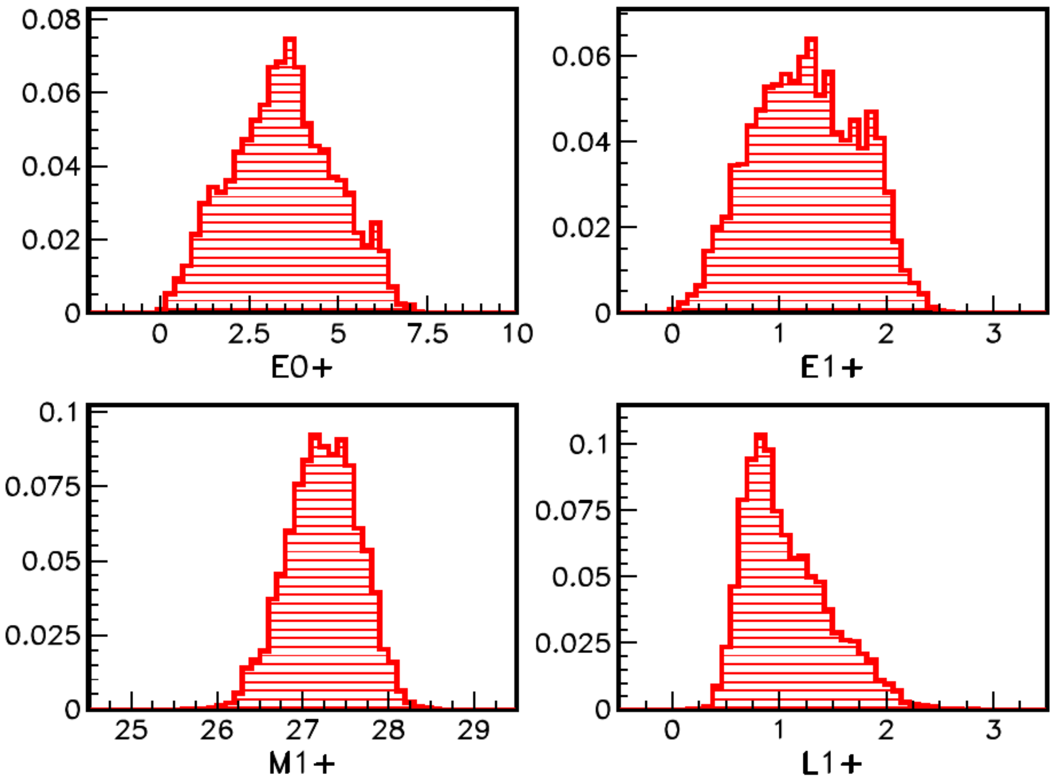


Bates-Mainz Data (Q^2=0.127 (GeV/c)^2 , W=1232 MeV)

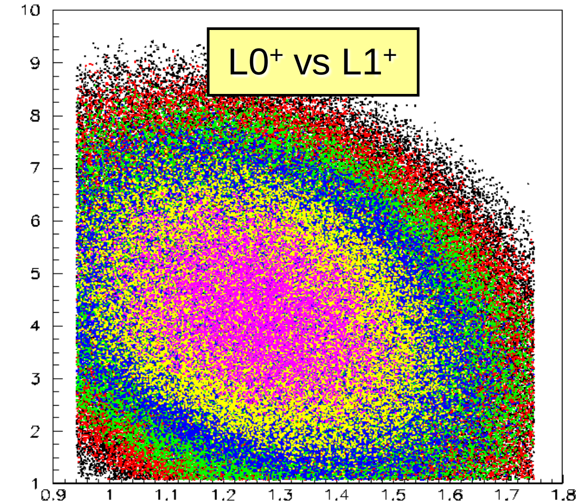
Extracted Values

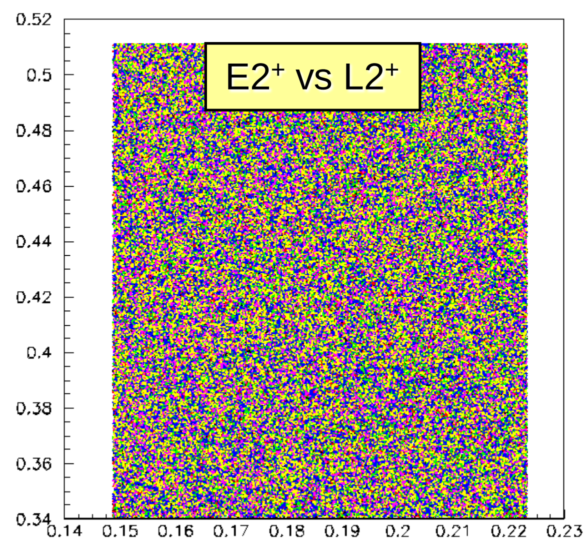
Multipole	Extracted Value	Relative Error	MAID-2003	Sato & Lee	DMT
M_{1+}	27.24 ± 0.20	0.73 %	27.464	27.661	27.489
L_{1+}	$0.82^{+0.20}_{-0.09}$	17.7 %	1.000	0.672	0.986
L_{0+}	2.23 ± 0.41	18.4 %	2.345	1.008	1.994
E_{0+}	3.44 ± 0.70	20.3 %	2.873	2.213	3.206
E_{1+}	$1.16^{+0.32}_{-0.24}$	24.1 %	1.294	1.288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

Probability Distributions



Correlations





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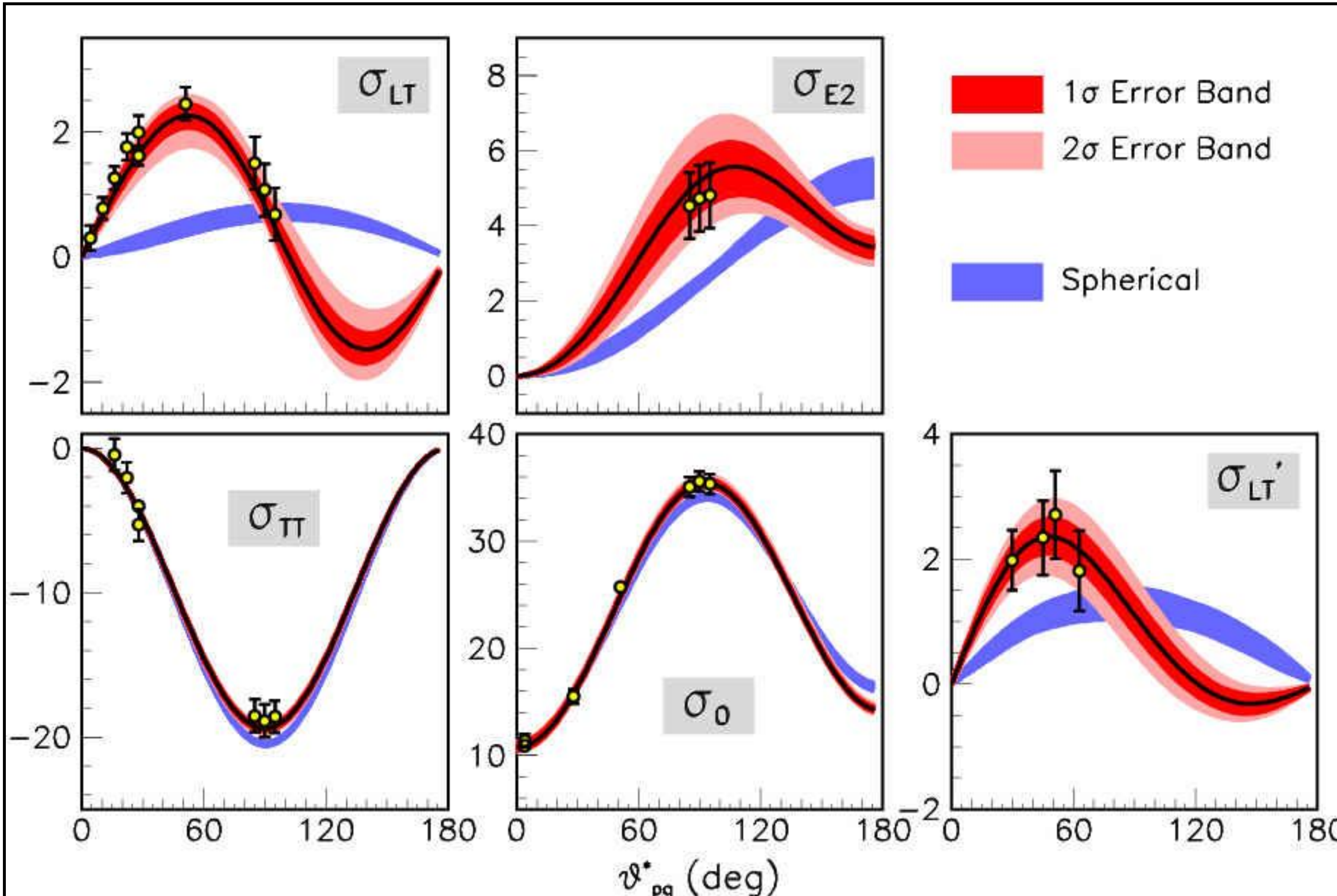
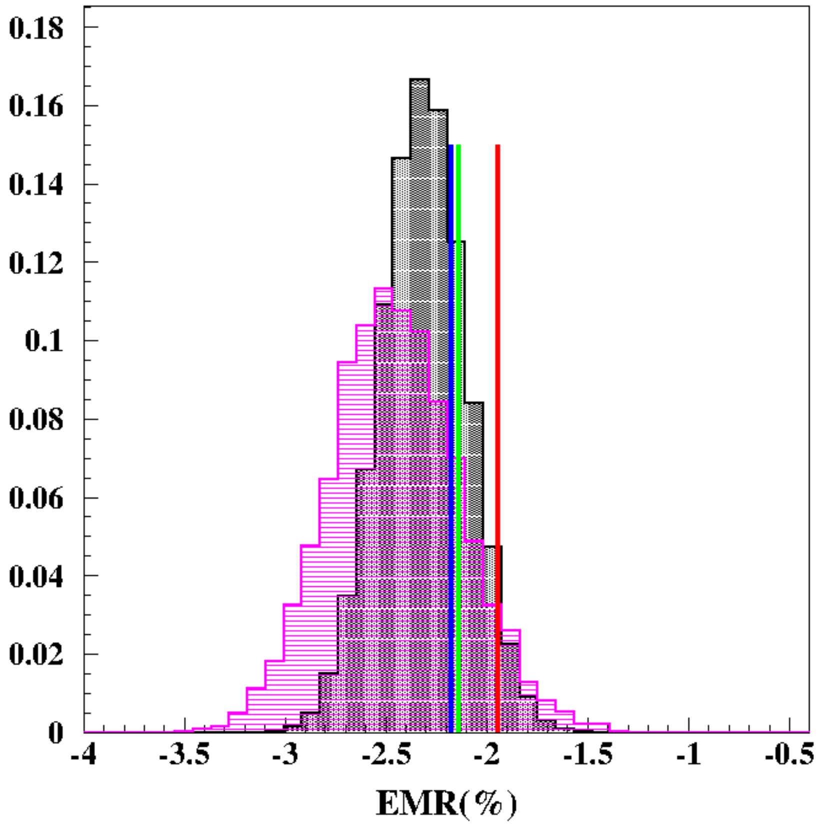


Mainz W=1232 Photoproduction Data



Model Independent Analysis

Lefteris Markou (CyI)

Model Predictions:

- **SAID (PR15): -2.2**
- **SAID (CM12): -1.9**
- **MAID07: -2.1**

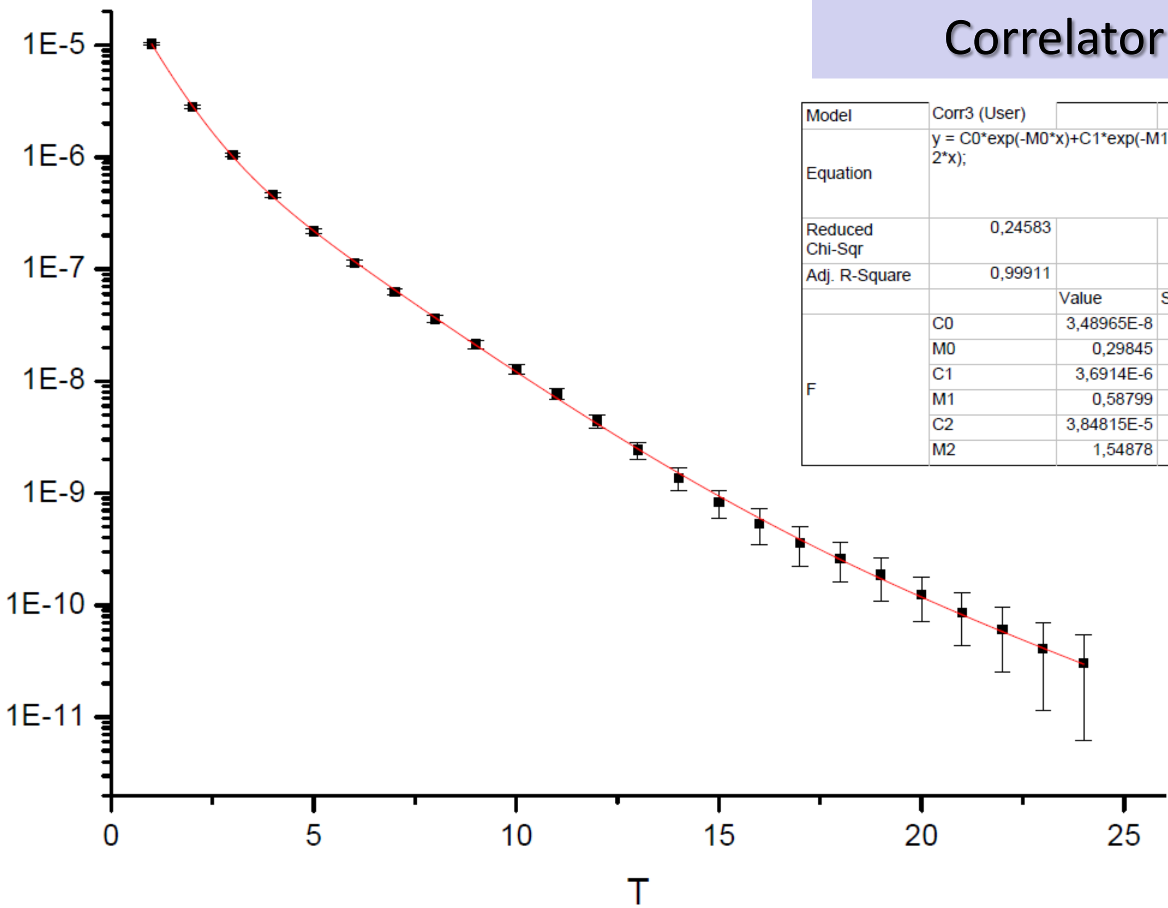
PHYSICAL REVIEW C **75**, 025201 (2007)

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

Jlab Hall A Data ⟹ Vasileios Hantzikos (UoA)

AMIAS and Lattice QCD

Spectral decomposition of the hadron propagator → QCD Correlators



Correlator

Model	Corr3 (User)		
Equation	y = C0*exp(-M0*x)+C1*exp(-M1*x)+C2*exp(-M2*x);		
Reduced Chi-Sqr	0,24583		
Adj. R-Square	0,99911		
		Value	Standard Error
F	C0	3,48965E-8	4,62628E-8
	M0	0,29845	0,06231
	C1	3,6914E-6	3,91195E-7
	M1	0,58799	0,0234
	C2	3,84815E-5	1,23951E-6
	M2	1,54878	0,04394

$$\bar{C}(t_j) = \sum_{n=0}^{\infty} A_n e^{-E_n t_j}$$

Conventional Fit

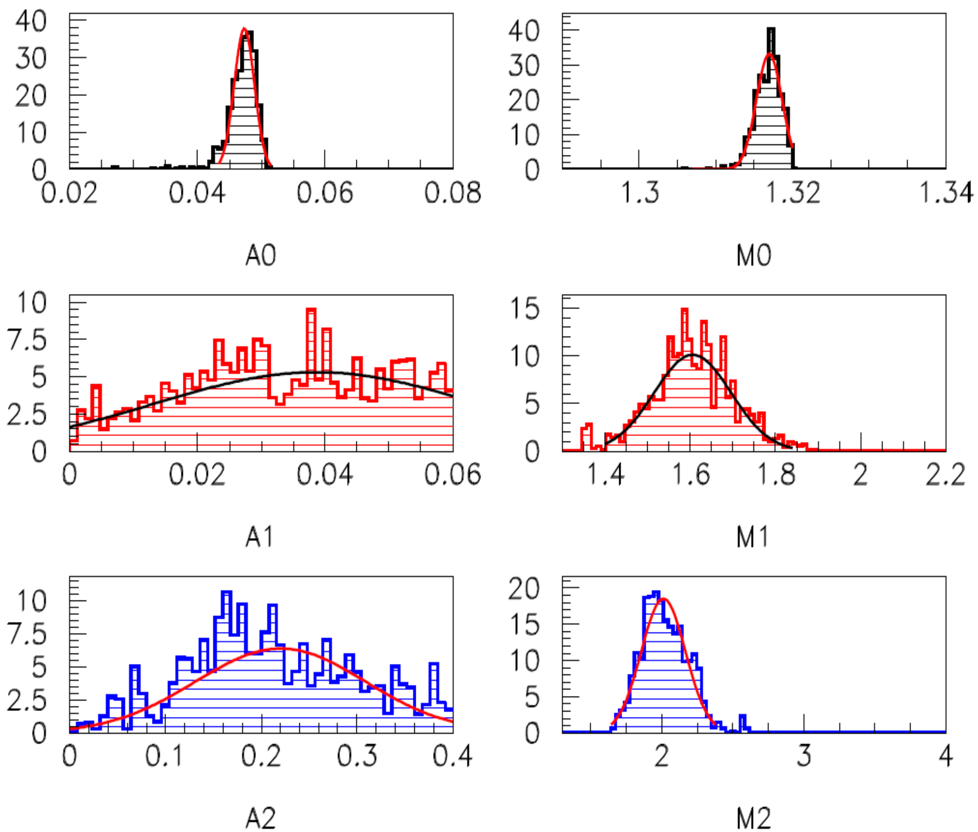
How many terms?

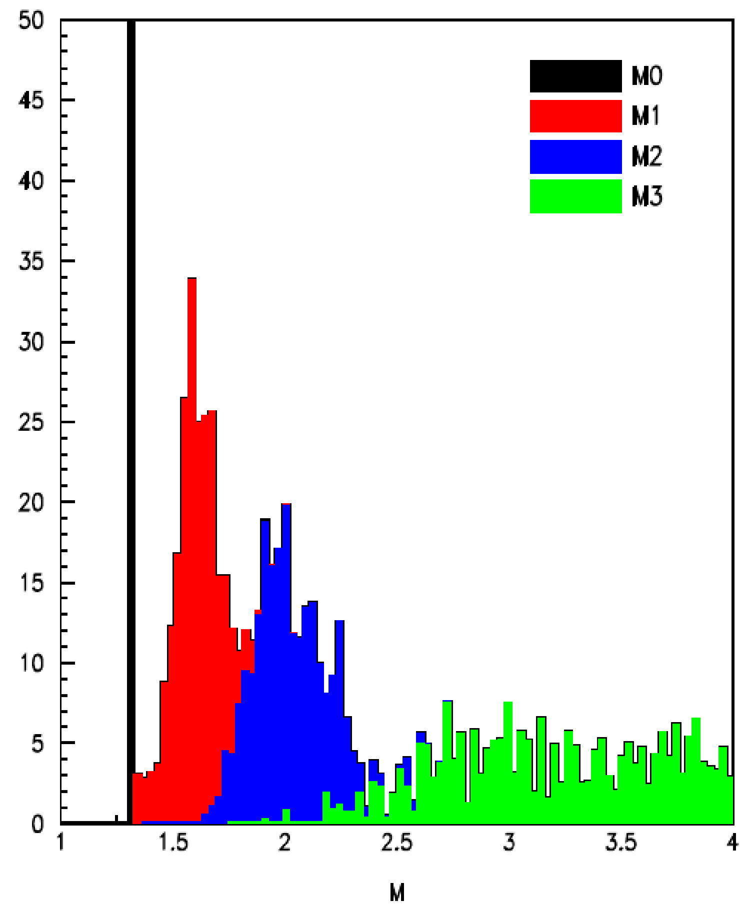
Correlations?

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

AMIAS and Lattice QCD

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





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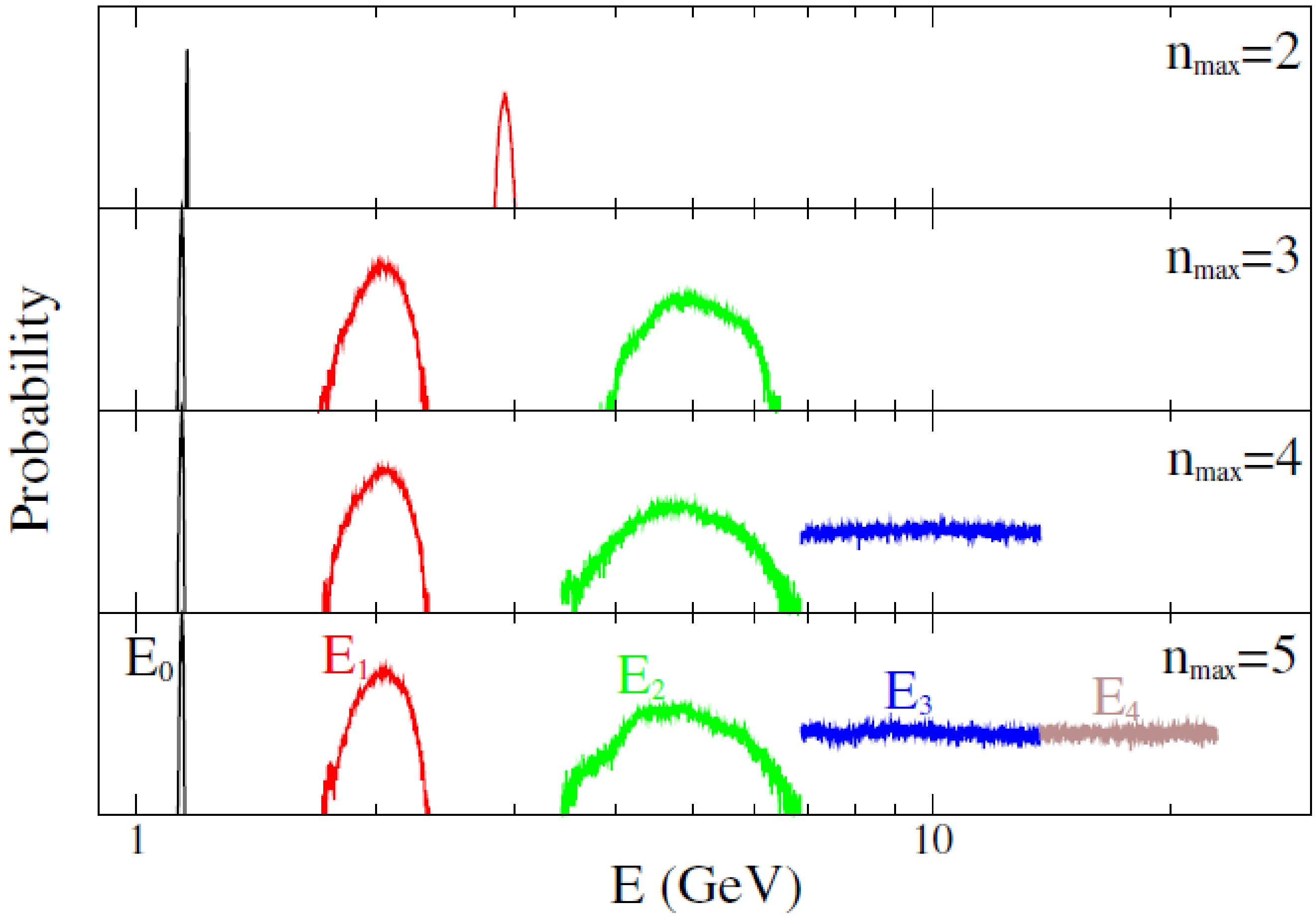
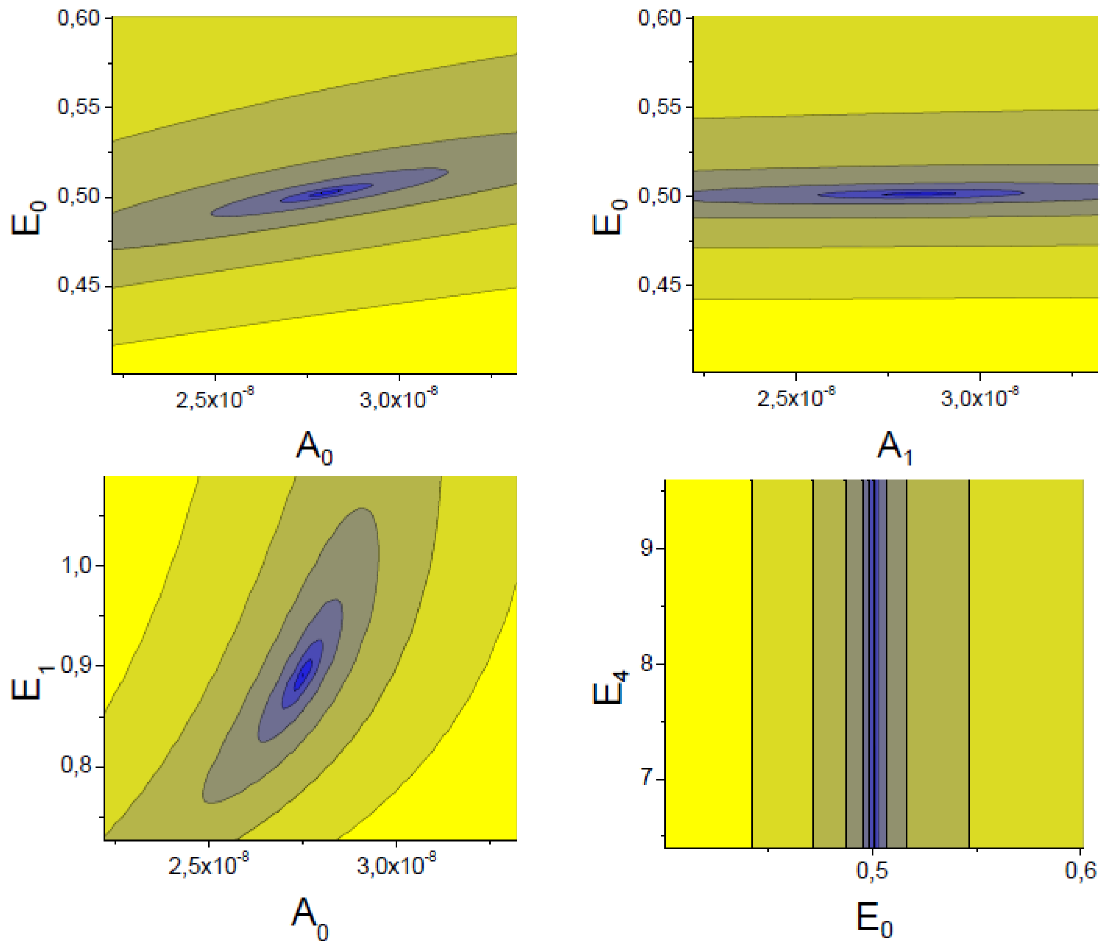


C. Alexandrou, T. Leontiou, C.N. Papanicolas and E. Stiliaris: *A Novel Analysis for Excited States in Lattice QCD – The Nucleon Case,* Phys. Rev. **D91** (2015) 014506

AMIAS and Lattice QCD

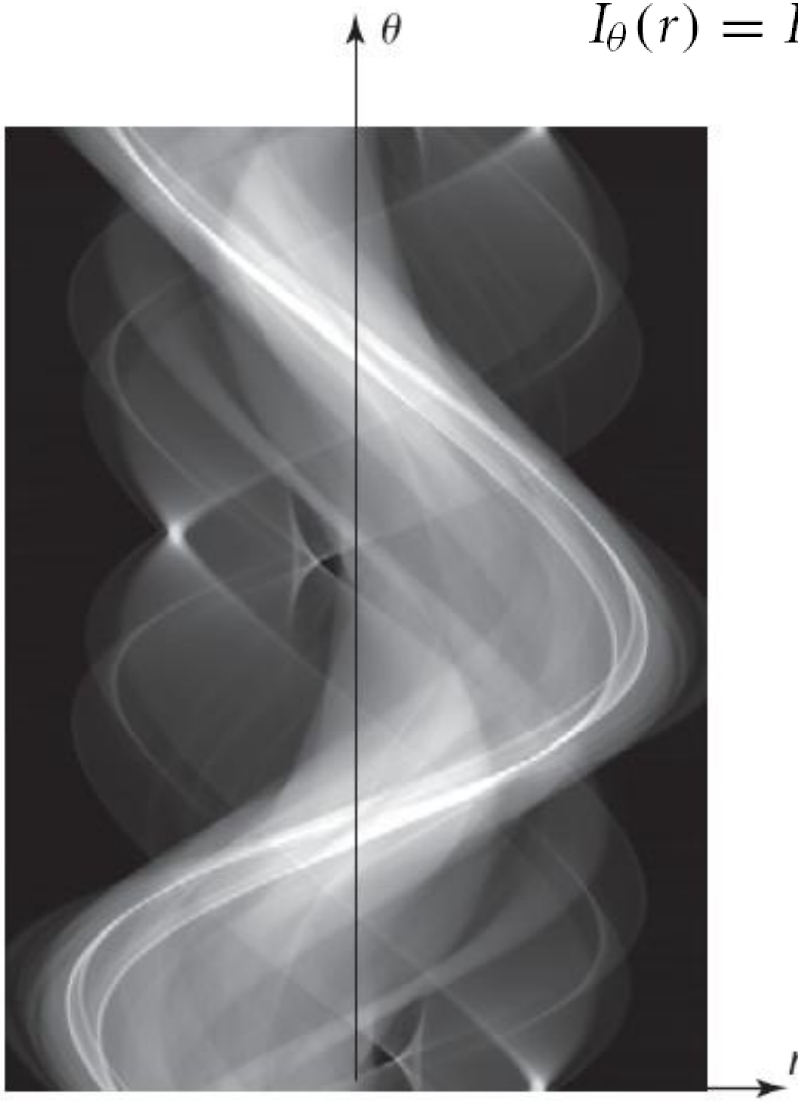
AMIAS Correlations



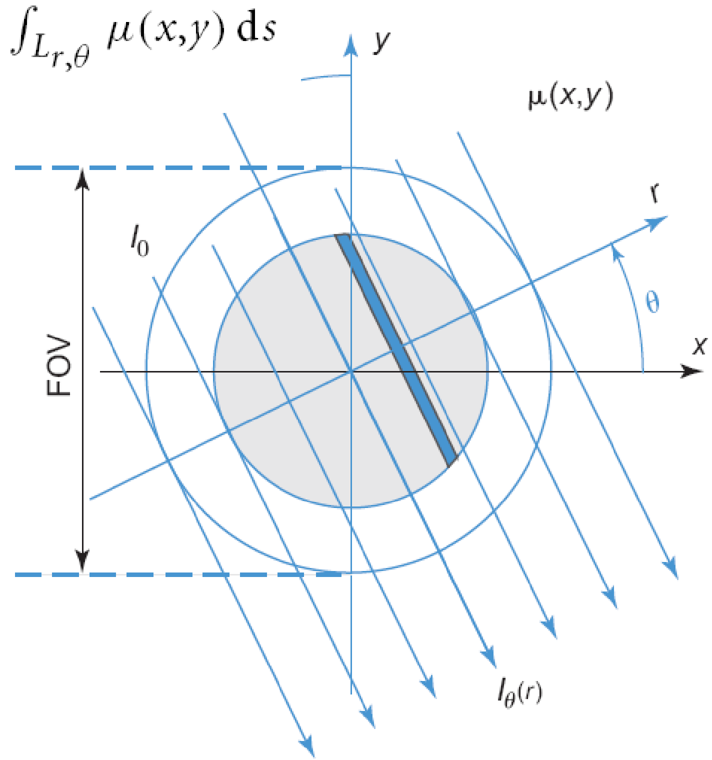
C. Alexandrou, T. Leontiou, C.N. Papanicolas and E. Stiliaris: *A Novel Analysis for Excited States in Lattice QCD – The Nucleon Case,* Phys. Rev. **D91** (2015) 014506

AMIAS in the Emission Tomography

$$I_\theta(r) = I_0 \cdot \mathrm{e}^{-\int_{L_{r,\theta}} \mu(x,y)\,\mathrm{d}s}$$



Sinogram



The usual solution: Radon Transform

$$p(r,\theta) = \mathcal{R}\{f(x,y)\}$$

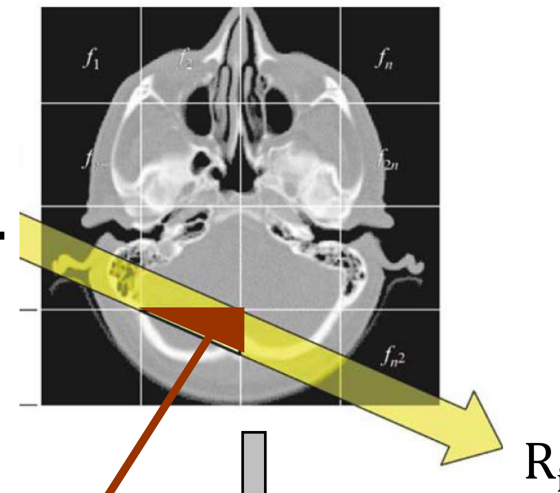
$$\int_{-\infty}^{\infty} f(r \cdot \cos\theta - s \cdot \sin\theta, r \cdot \sin\theta + s \cdot \cos\theta)\,\mathrm{d}s.$$

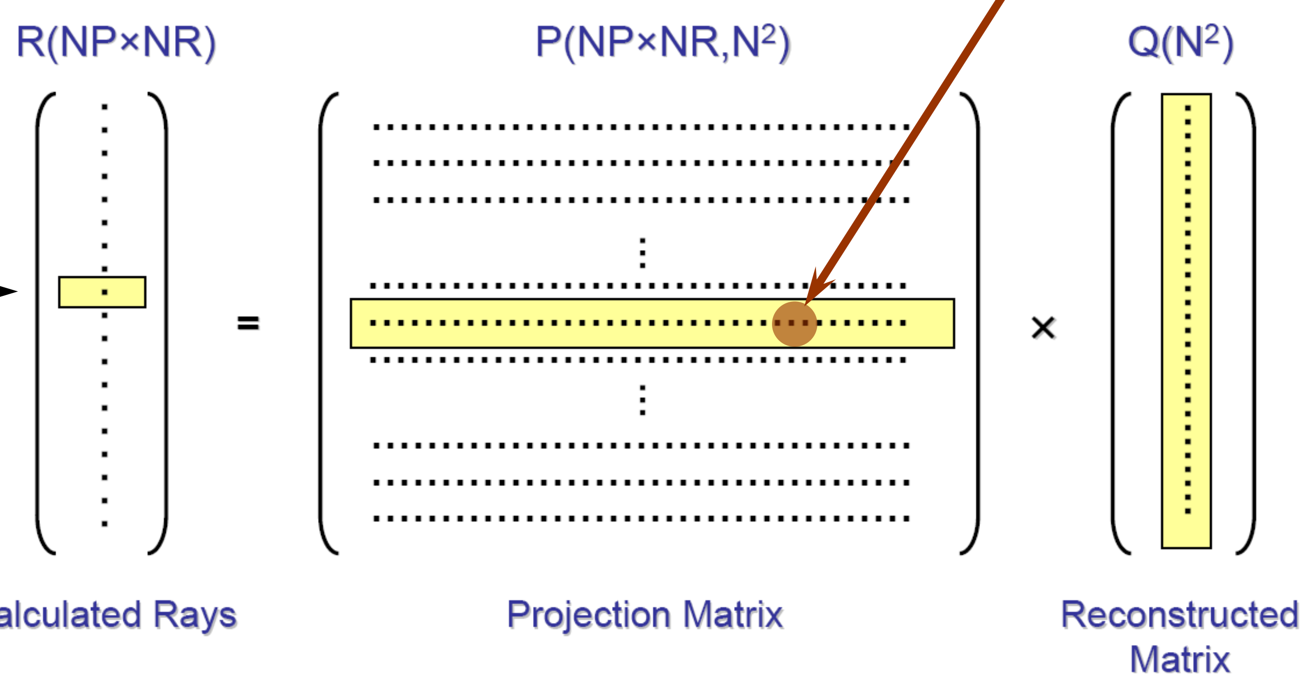
Tomographic Reconstruction

Algebraic Reconstruction Methods

$$R_i = \sum_{j=1}^{N^2} P_{ij} \times Q_j$$

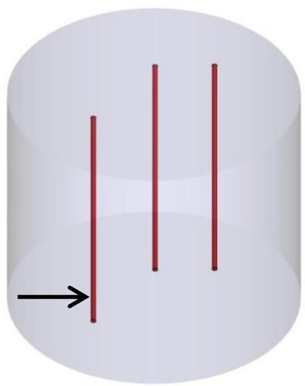
NP: Number of Projections (Angles)
NR: Number of Rays

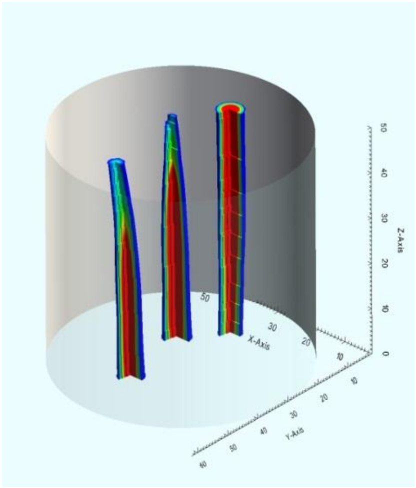


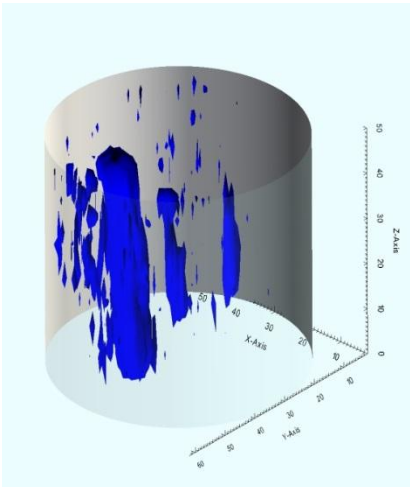


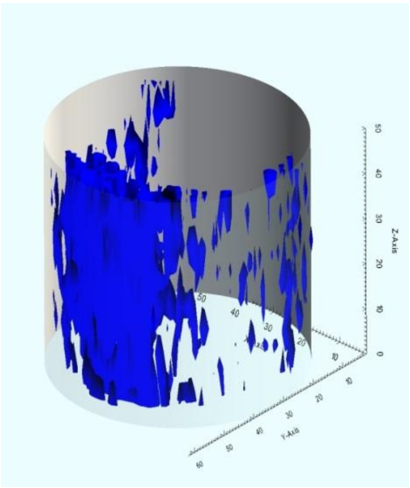
AMIAS in the Emission Tomography

PHANTOM	AMIAS	ART	MLEM

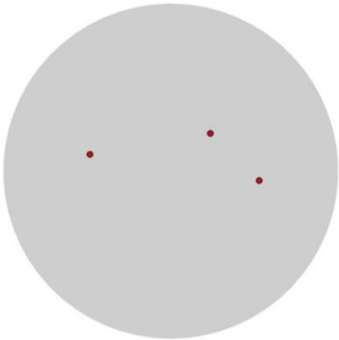


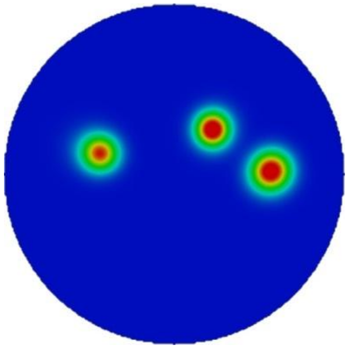


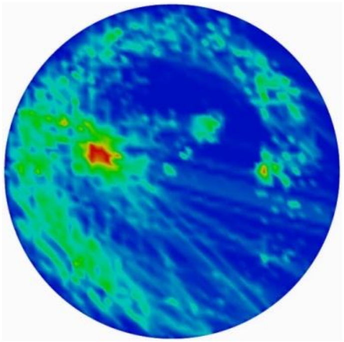


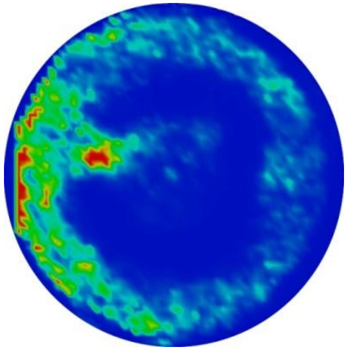


Background = 0.5 %

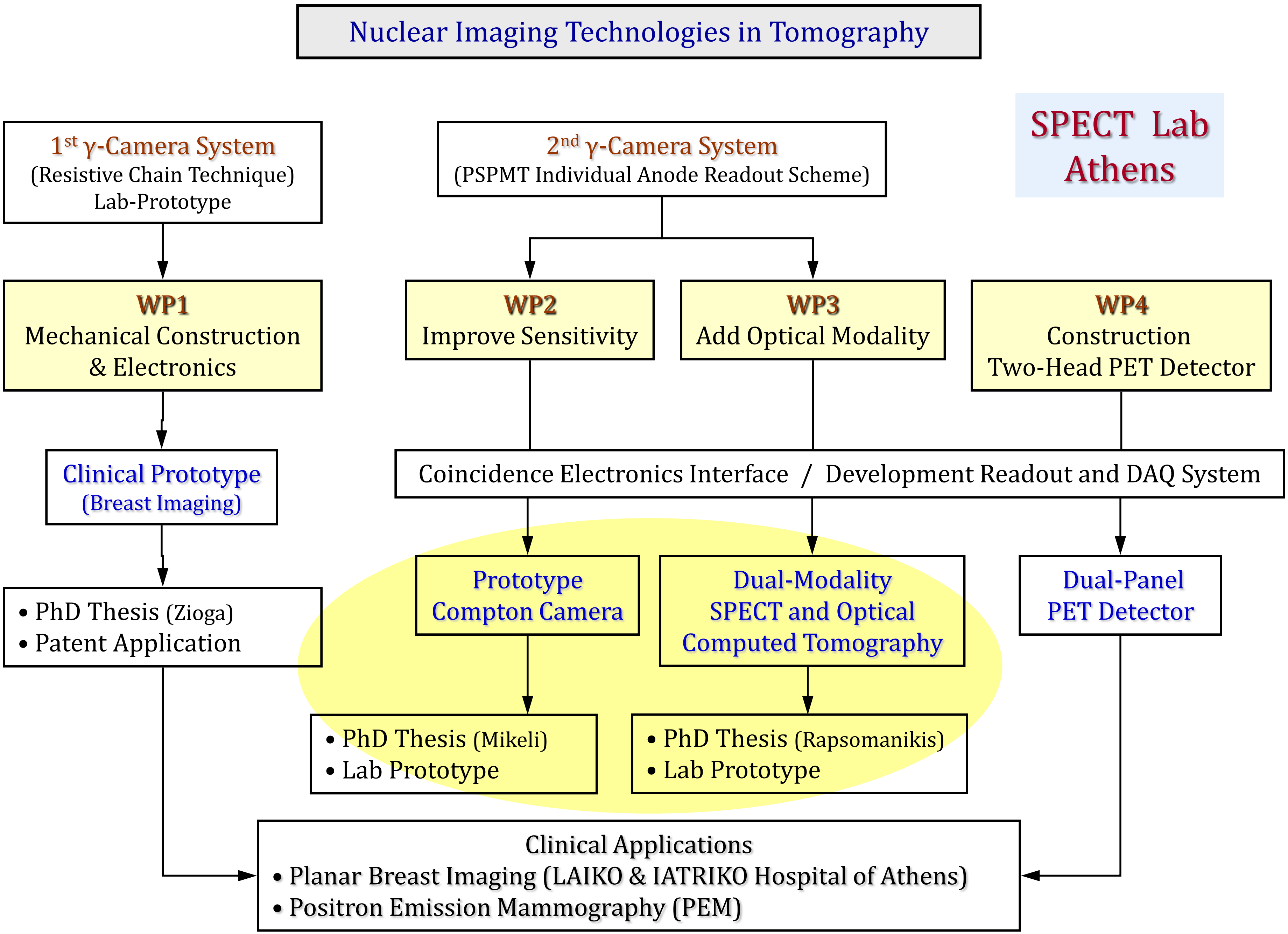








⟹ Loizos Koutsantonis (CyI)


Nuclear Imaging Technologies in Tomography
SPECT Lab Athens
1st γ-Camera System
(Resistive Chain Technique)
Lab-Prototype
2nd γ-Camera System
(PSPMT Individual Anode Readout Scheme)
WP1
Mechanical Construction & Electronics
WP2
Improve Sensitivity
WP3
Add Optical Modality
WP4
Construction Two-Head PET Detector
Clinical Prototype
(Breast Imaging)
Coincidence Electronics Interface / Development Readout and DAQ System
Prototype Compton Camera
Dual-Modality SPECT and Optical Computed Tomography
Dual-Panel PET Detector
• PhD Thesis (Zioga)
• Patent Application
• PhD Thesis (Mikeli)
• Lab Prototype
• PhD Thesis (Rapsomanikis)
• Lab Prototype
Clinical Applications
• Planar Breast Imaging (LAIKO & IATRIKO Hospital of Athens)
• Positron Emission Mammography (PEM)

Conclusions

The AMIAS Method is demonstrated to:

- Be model independent.

- Extract maximum information for all available Multipoles, without any bias; it is capable of ranking them in order of significance.

- Account for the correlations amongst the contributing Multipoles, and to provide an easy visualization of them.

- Yield uncertainties which have a precise meaning, in terms of confidence levels.

- Be numerically robust, regardless of the data base.

Thank You!

One-Day Workshop on New Aspects and Perspectives in Nuclear Physics
September 8, 2012
University of Ioannina, Greece