INT Workshop INT-16-62W

Spectrum and Structure of Excited Nucleons from Exclusive Electroproduction

November 14 - 18, 2016

Nucleon Resonance Spectrum from exclusive meson photo-electroproduction

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Outline:

- Why study spectroscopy
- Establishing N* states
- Identifying the effective degrees of freedom
- Outlook & conclusions

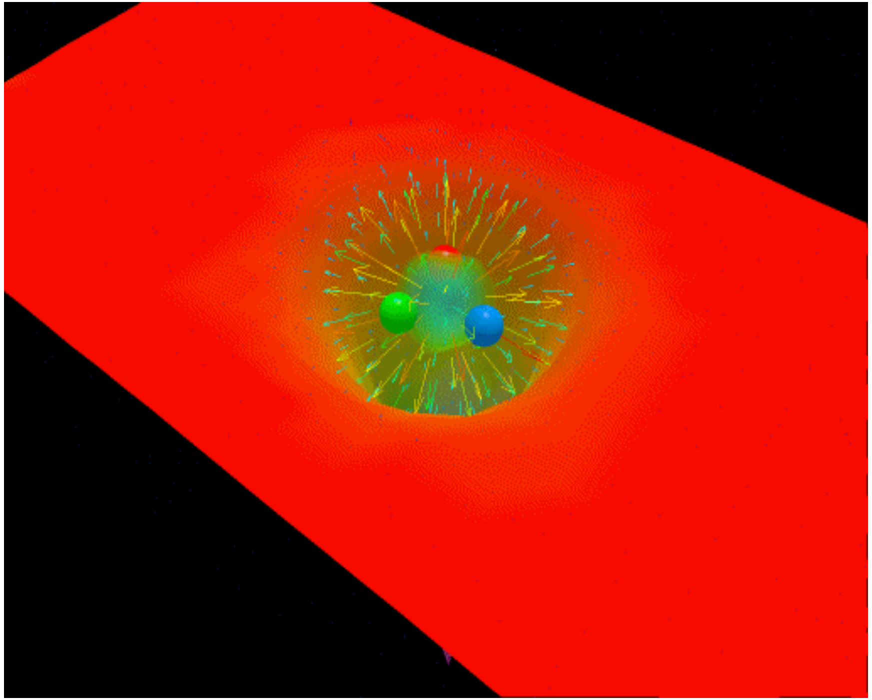
Why N* ?

Baryon Spectroscopy Reveals the Workings of QCD

"Nucleons are the stuff of which our world is made.

As such they must be at the center of any discussion of why the world we actually experience has the character it does."

Nathan Isgur, NStar2000, Newport News, Virginia

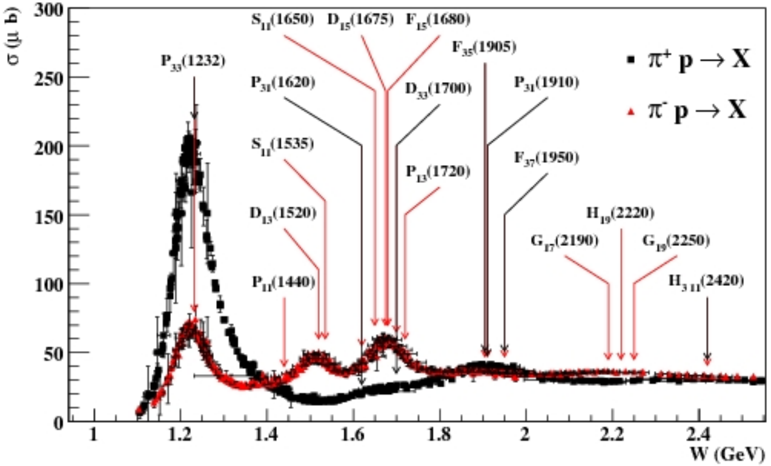


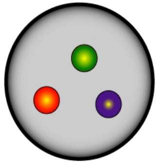
Derek B. Leinweber – University of Adelaide

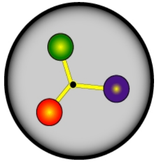
Why N* ? From the N* Spectrum to QCD

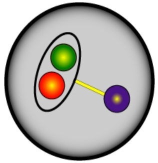
- Understanding the proton's ground state requires understanding its excitation spectrum.

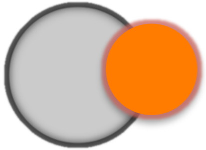
- The N* spectrum reflects the effective degrees of freedom and the forces.




CQM

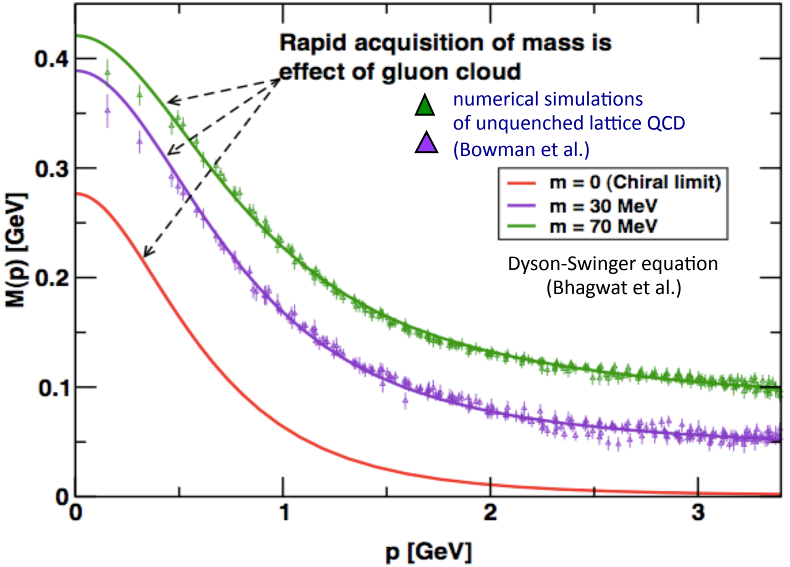

CQM+flux tubes


Quark–diquark clustering

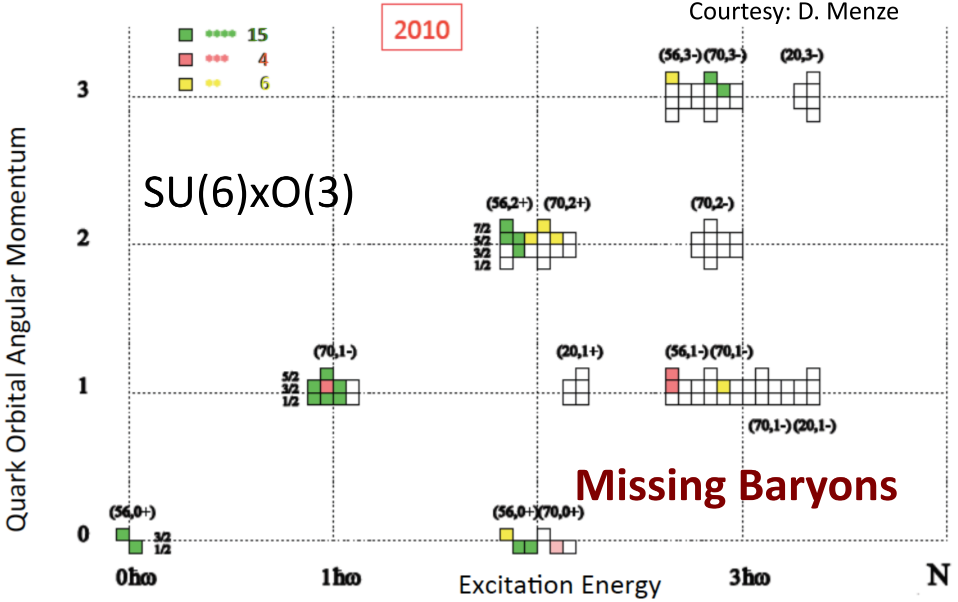

Baryon-meson system

→ From the Constituent Quark model to QCD.

Constituent quark models and SU(6)xO(3)



Courtesy: D. Menze



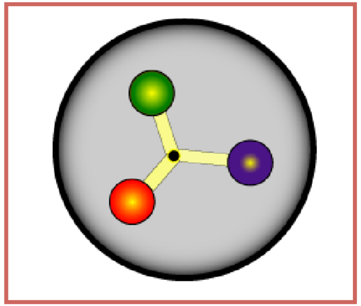
Missing Baryons

- Current-quarks of perturbative QCD evolve into constituent quarks at low momentum.

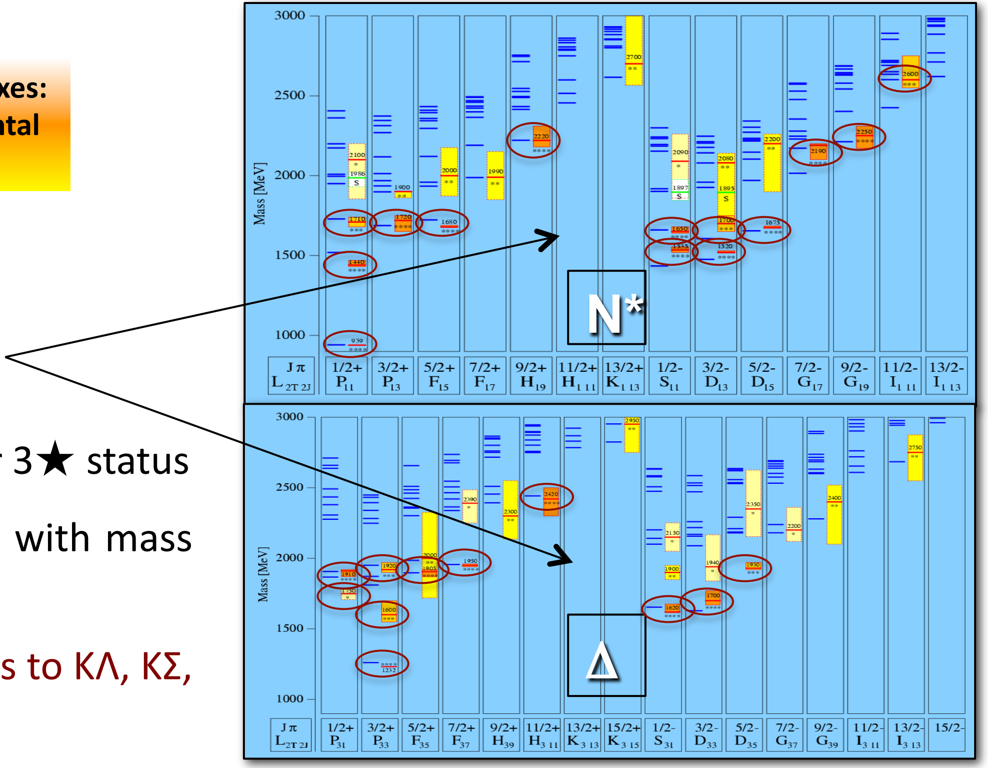
→ Connection between constituent and current quarks.

- QCD-inspired Constituent Quark models: states classified by isospin, parity and spin within each oscillator band. Many projected q^3 states are still missing or uncertain.

Constituent quark models and SU(6)xO(3)



Thick segments: theoretical predictions	Shaded boxes: experimental results

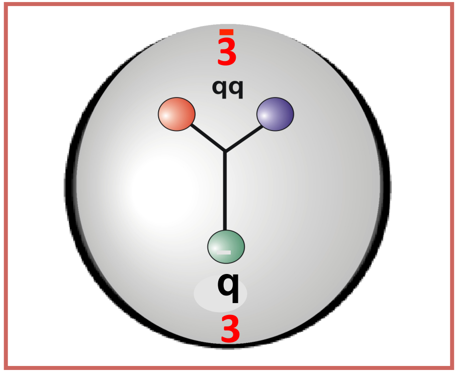


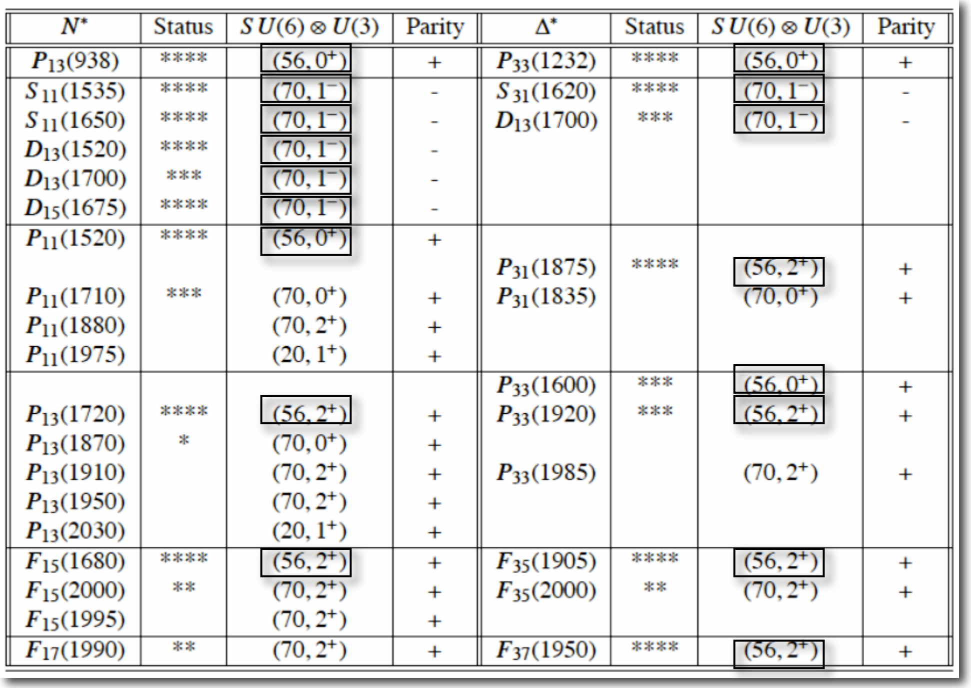
U. L¨oring, B. Metsch, H. Petry, Eur. Phys. J. A 10, 395 (2001).

Findings:

- Linear Regge trajectories
- Only lowest few in each band seen with 4★ or 3★ status
- g(πN) couplings predicted to decrease rapidly with mass in each oscillator band
- Higher levels predicted to have larger couplings to KΛ, KΣ, ππN, …

QCD-inspired di-Quark Models



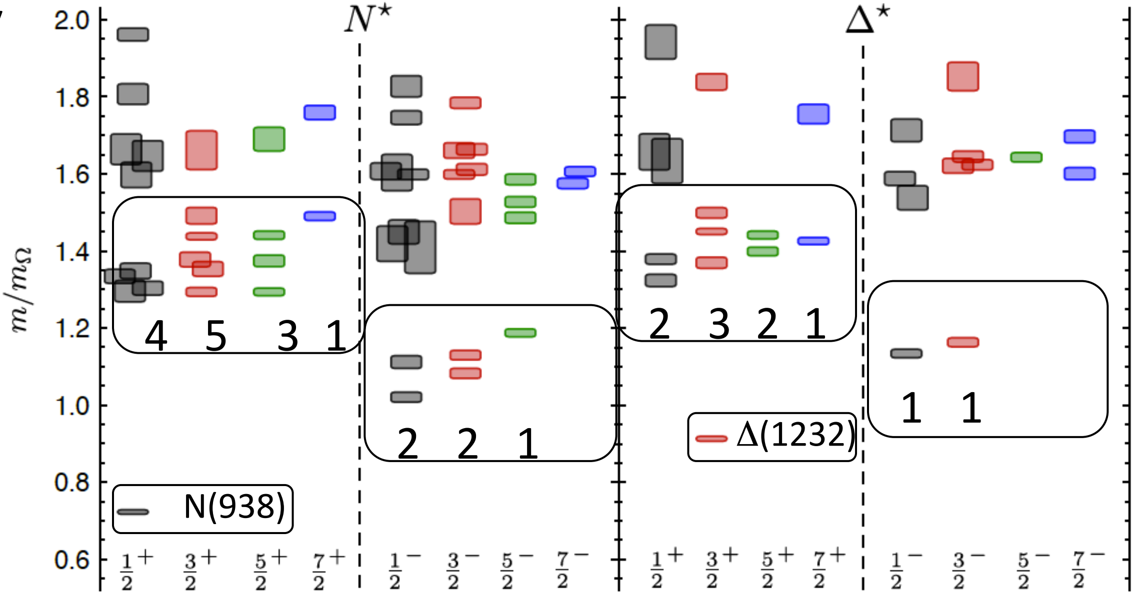


N^*	Status	$SU(6)\otimes U(3)$	Parity	Δ^*	Status	$SU(6)\otimes U(3)$	Parity
$P_{13}(938)$	****	$\boxed{(56,0^+)}$	+	$P_{33}(1232)$	****	$\boxed{(56,0^+)}$	+
$S_{11}(1535)$	****	$\boxed{(70,1^-)}$	-	$S_{31}(1620)$	****	$\boxed{(70,1^-)}$	-
$S_{11}(1650)$	****	$\boxed{(70,1^-)}$	-	$D_{13}(1700)$	***	$\boxed{(70,1^-)}$	-
$D_{13}(1520)$	****	$\boxed{(70,1^-)}$	-				
$D_{13}(1700)$	***	$\boxed{(70,1^-)}$	-				
$D_{15}(1675)$	****	$\boxed{(70,1^-)}$	-				
$P_{11}(1520)$	****	$\boxed{(56,0^+)}$	+				
				$P_{31}(1875)$	****	$\boxed{(56,2^+)}$	+
$P_{11}(1710)$	***	$(70,0^+)$	+	$P_{31}(1835)$		$(70,0^+)$	+
$P_{11}(1880)$		$(70,2^+)$	+				
$P_{11}(1975)$		$(20,1^+)$	+				
				$P_{33}(1600)$	***	$\boxed{(56,0^+)}$	+
$P_{13}(1720)$	****	$\boxed{(56,2^+)}$	+	$P_{33}(1920)$	***	$\boxed{(56,2^+)}$	+
$P_{13}(1870)$	*	$(70,0^+)$	+				
$P_{13}(1910)$		$(70,2^+)$	+	$P_{33}(1985)$		$(70,2^+)$	+
$P_{13}(1950)$		$(70,2^+)$	+				
$P_{13}(2030)$		$(20,1^+)$	+				
$F_{15}(1680)$	****	$\boxed{(56,2^+)}$	+	$F_{35}(1905)$	****	$\boxed{(56,2^+)}$	+
$F_{15}(2000)$	**	$(70,2^+)$	+	$F_{35}(2000)$	**	$(70,2^+)$	+
$F_{15}(1995)$		$(70,2^+)$	+				
$F_{17}(1990)$	**	$(70,2^+)$	+	$F_{37}(1950)$	****	$\boxed{(56,2^+)}$	+

- 2 quarks in nucleon assumed to be quasi-bound in a color isotriplet; diquark-quark is a net color isosinglet.
- All possible internal di-quark excitations ⇔ full spectrum of CQM.
- Internal di-quark excitations are frozen out (spin 0; isospin 0) ⇔ large reduction in the number of degrees of freedom ⇔ may predict less N* states than seen in πN.

LQCD N* & Δ Spectra

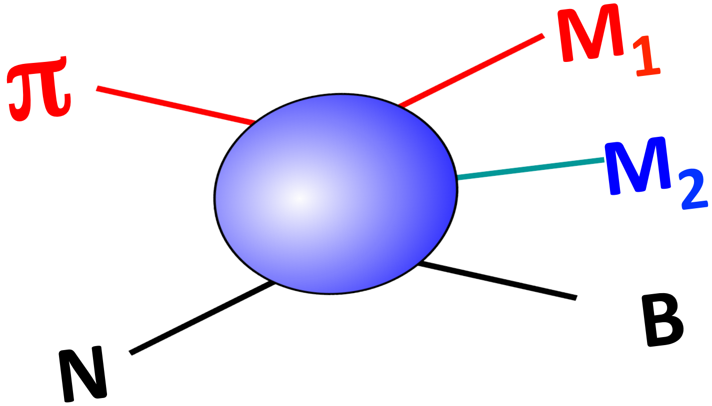
- Exhibit the SU(6)×O(3)-symmetry features
- Counting of levels consistent with non-rel. quark model
- Striking similarity with quark model
- No parity doubling

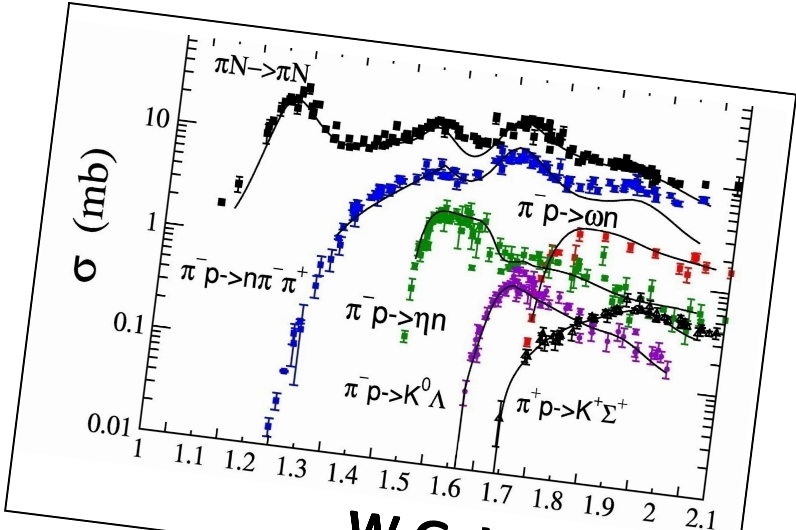


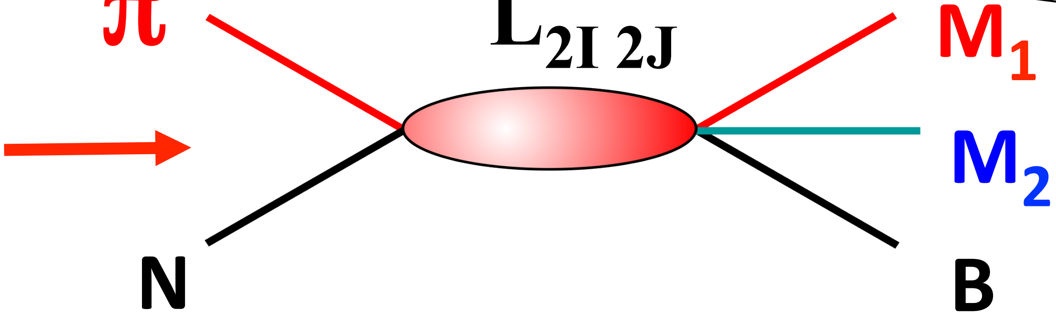
Robert G. Edwards, Jozef J. Dudek, David G. Richards, Stephen J. Wallace
Phys.Rev. D84 (2011) 074508

Problems are not solved!

Establishing the N* and Δ Spectrum: πN scattering



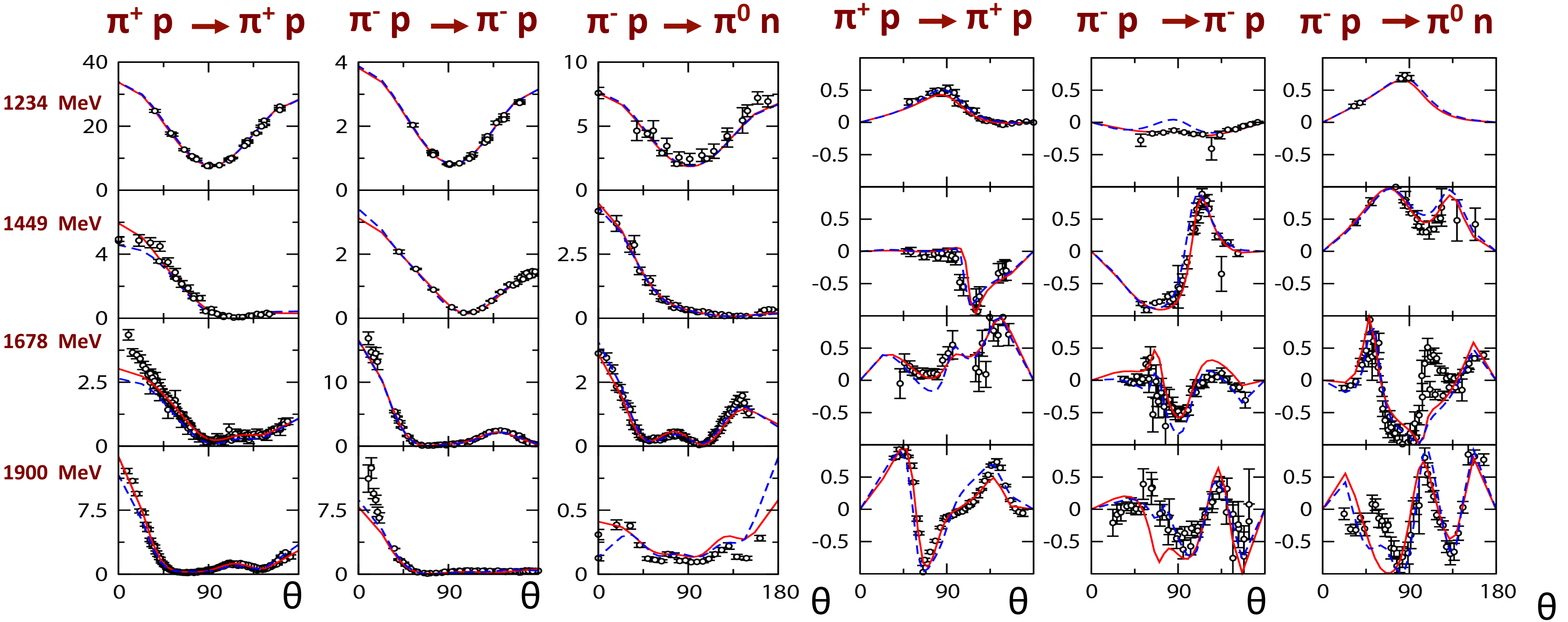




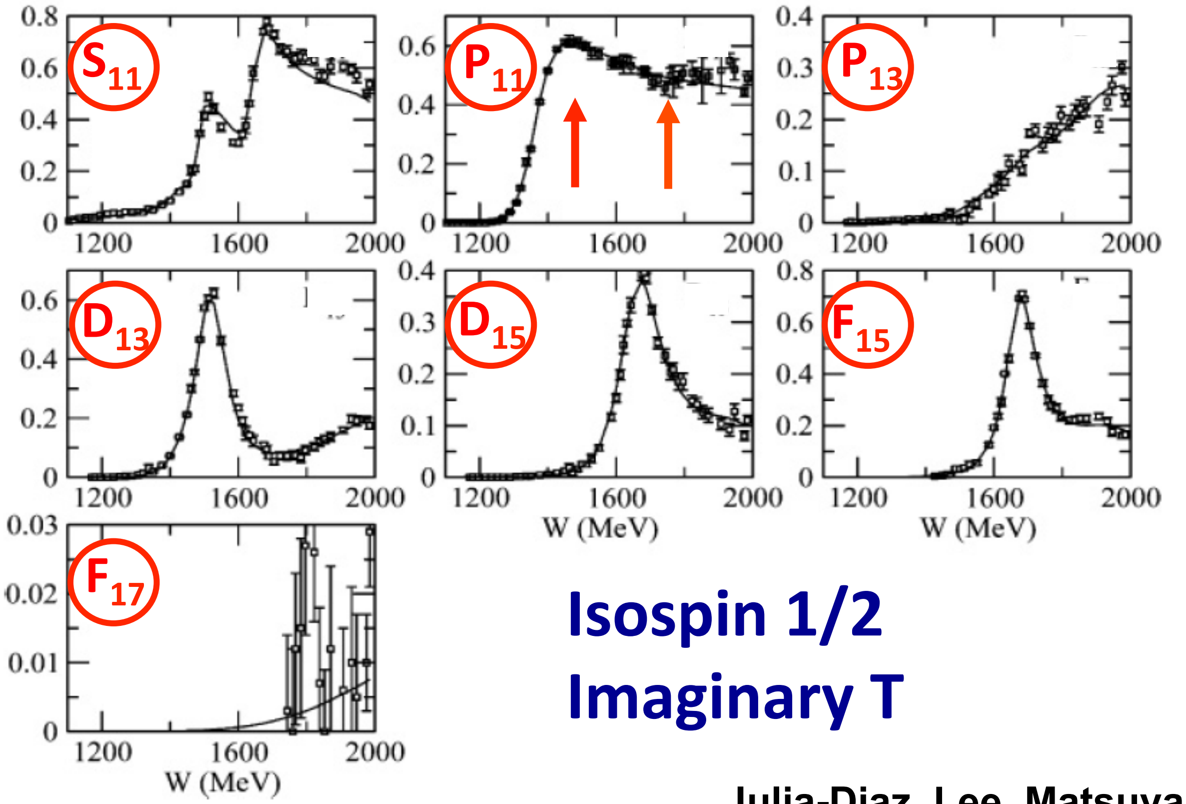
Establishing the N* and Δ Spectrum: πN Scattering

dσ/dΩ

P Julia-Diaz, Lee, Matsuyama, Sato



Establishing the N* and Δ Spectrum: πN Amplitudes



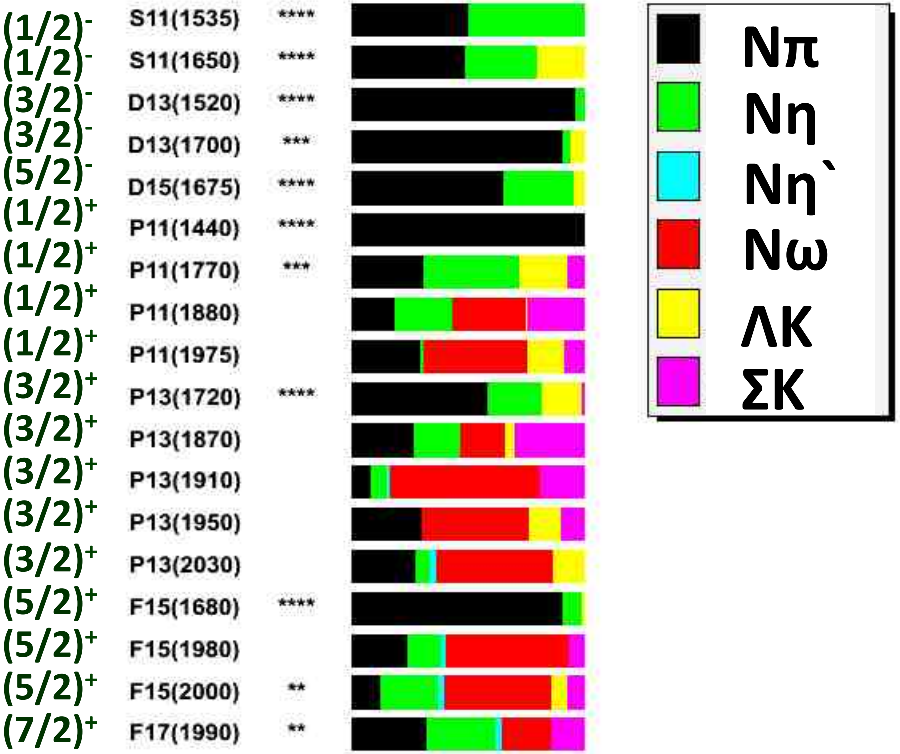
Isospin 1/2

Imaginary T

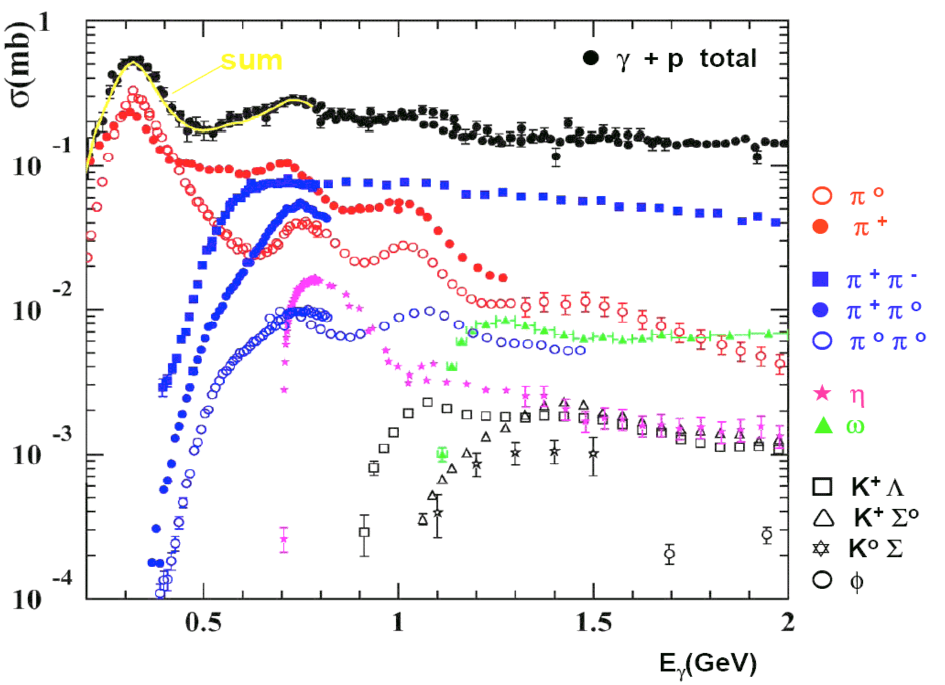
Julia-Diaz, Lee, Matsuyama, Sato

Establishing the N* and Δ Spectrum

Search all channels: not just πN



Photonuclear cross sections



From Experiment to Theory

Experiment
cross section,
spin observables

σ, dσ/dΩ, Σ, P, T
(beam-target) E,F,G,H,
(beam-recoil) C_x,C_z,O_x,O_z,
(target-recoil) L_x,L_z, T_x,T_z,

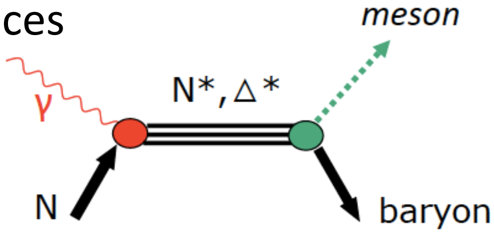
Amplitude analysis
→multipole amplitudes
→phase shifts

Reaction Theory
dynamical frameworks

Theory
LQCD,
quark models,
QCD sum rules, …

Coupled channels:
resonance parameter
extraction

Extract s-channel
resonances



From Experiment to Theory

Idealized path to search for N*, Δ* states via meson photo-production:

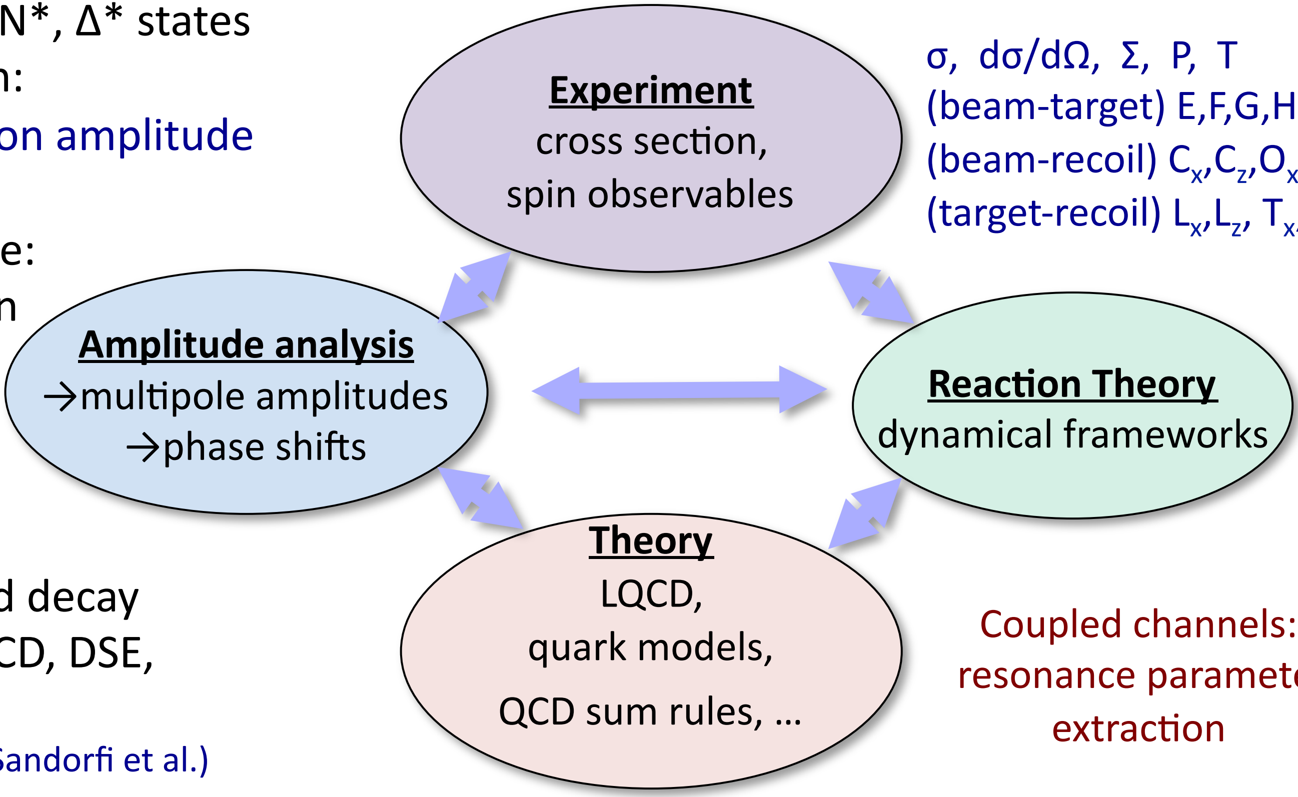
1. determine the production amplitude from experiment

search for resonant structure: Argand circles, phase motion speed plots, etc.

2. separate resonance and background components

determine resonant γN* and decay couplings;   contact with LQCD, DSE, Hadron models

(A. Sandorfi et al.)



Experiment
cross section,
spin observables

σ, dσ/dΩ, Σ, P, T
(beam-target) E,F,G,H,
(beam-recoil) C_x,C_z,O_x,O_z,
(target-recoil) L_x,L_z, T_x,T_z,

Amplitude analysis
→multipole amplitudes
→phase shifts

Reaction Theory
dynamical frameworks

Theory
LQCD,
quark models,
QCD sum rules, …

Coupled channels:
resonance parameter
extraction

From Experiment to Theory

Idealized path to search for N*, Δ* states via meson photo-production:

1. determine the production amplitude from experiment

search for resonant structure: Argand circles, phase motion speed plots, etc.

Never been done after 50 years of experiments

2. separate resonance and background components

determine resonant γN* and decay couplings; contact with LQCD, DSE, Hadron models

(A. Sandorfi et al.)

Without exp Amplitudes models have conjectured resonances and adjusted couplings to compare with limited data

Polarization Observables: Complete Experiment

Pseudoscalar Meson Photoproduction

	γ	+	N	$\rightarrow$	m	+	N
Spin states	± 1		$\pm\frac{1}{2}$		0		$\pm\frac{1}{2}$
	2	x	2			x	2

8 possible spin states → 4 independent complex amplitudes describe the transition matrix

$$F_\lambda = \vec{J}\cdot\varepsilon_\lambda = iF_1\vec{\sigma}\cdot\hat{\varepsilon}_\lambda + F_2(\hat{\sigma}\cdot\hat{q})\hat{\sigma}\cdot(\hat{k}\times\hat{\varepsilon}_\lambda) + iF_3(\hat{\sigma}\cdot\hat{k})(\hat{q}\cdot\hat{\varepsilon}_\lambda) + iF_4(\hat{\sigma}\cdot\hat{q})(\hat{q}\cdot\hat{\varepsilon}_\lambda)$$

CGLN amplitudes in terms of Pauli matrixes: are conveniently expanded into multipoles →

$$F_1 = \sum_{l=0}^{l_{max}}[P'_{l+1}(x)E_{l+} + P'_{l-1}(x)E_{l-} + lP'_{l+1}(x)M_{l+} + (l+1)P'_{l-1}(x)M_{l-}]$$

$$F_2 = \sum_{l=0}^{l_{max}}[(l+1)P'_l(x)M_{l+} + lP'_l(x)M_{l-}],$$

$$F_3 = \sum_{l=0}^{l_{max}}[P''_{l+1}(x)E_{l+} + P''_{l-1}(x)E_{l-} - P''_{l+1}(x)M_{l+} + P''_{l-1}(x)M_{l-}],$$

$$F_4 = \sum_{l=0}^{l_{max}}[-P''_l(x)E_{l+} - P''_l(x)E_{l-} + P''_l(x)M_{l+} - P''_l(x)M_{l-}].$$

Polarization Observables: Complete Experiment

Pseudoscalar Meson Photoproduction

Spin states

$$\begin{array}{ccccccc} \gamma & + & N & \rightarrow & m & + & N \\ \pm 1 & & \pm\frac{1}{2} & & 0 & & \pm\frac{1}{2} \\ 2 & \mathrm{x} & 2 & & & \mathrm{x} & 2 \end{array}$$

8 possible spin states → 4 independent complex amplitudes describe the transition matrix

Helicity amplitudes: amplitudes are expressed in terms of all independent photon and nucleons helicity states

$$H_1(\theta) \equiv \langle +1 | J_{11} | -1 \rangle$$
$$H_2(\theta) \equiv \langle +1 | J_{11} | +1 \rangle$$
$$H_3(\theta) \equiv \langle -1 | J_{11} | -1 \rangle$$
$$H_4(\theta) \equiv \langle -1 | J_{11} | +1 \rangle$$

$$\longrightarrow$$

$$H_1(\theta) \equiv \frac{i}{\sqrt{2}} \sin\theta \sin\left(\frac{\theta}{2}\right)\left[F_3 - F_4\right]$$
$$H_2(\theta) \equiv -\frac{i}{\sqrt{2}} \sin\left(\frac{\theta}{2}\right)\left[F_1 + F_2 + \left(F_4 + F_3\right)\cos^2\left(\frac{\theta}{2}\right)\right]$$
$$H_3(\theta) \equiv +\frac{i}{\sqrt{2}} \sin\theta \cos\left(\frac{\theta}{2}\right)\left[F_3 + F_4\right]$$
$$H_4(\theta) \equiv -i\sqrt{2} \cos\left(\frac{\theta}{2}\right)\left[F_1 - F_2 + \left(F_4 - F_3\right)\sin^2\left(\frac{\theta}{2}\right)\right]$$

Polarization Observables: Complete Experiment

Pseudoscalar Meson Photoproduction $\gamma \quad + \quad N \quad \longrightarrow \quad m \quad + \quad N$

Spin states $\pm 1 \quad \pm\frac{1}{2} \qquad 0 \qquad \pm\frac{1}{2}$

2 x 2 x 2

8 possible spin states → 4 independent complex amplitudes describe the transition matrix

Helicity amplitudes: amplitudes are expressed in terms of all independent photon and nucleons helicity states

$$H_1(\theta) = \sum_J (2J+1)\ H_1^J\ d^J_{-\frac{1}{2}\frac{3}{2}}(\theta),$$

$$H_2(\theta) = \sum_J (2J+1)\ H_2^J\ d^J_{-\frac{1}{2}\frac{1}{2}}(\theta),$$

$$H_3(\theta) = \sum_J (2J+1)\ H_3^J\ d^J_{\frac{1}{2}\frac{3}{2}}(\theta),$$

$$H_4(\theta) = \sum_J (2J+1)\ H_4^J\ d^J_{\frac{1}{2}\frac{1}{2}}(\theta)\ .$$

From decomposition into partial waves:

$$d^J{}_{\Lambda_f - \Lambda_i}(\theta) \qquad \Lambda_i = \lambda - \lambda_1 \qquad \Lambda_f = -\lambda_2$$

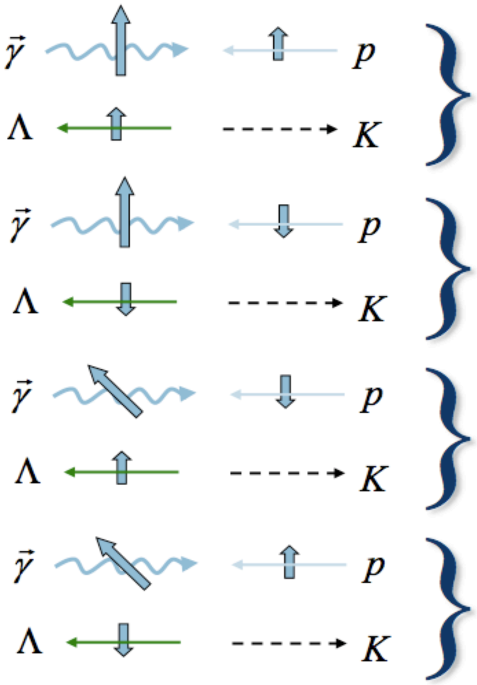
$H_4 = N$ no helicity flip

$H_2, H_3 = S_1, S_2$ single helicity flip

$H_1 = D$ double helicity flip

Pseudoscalar Meson Photoproduction: Complete Experiment

Transversity amplitudes: are expressed in terms of linearly polarized photons and transversely polarized nucleons. They are linear combinations of helicity amplitudes.



$$b_1 = {}^1/_2[(S_1 + S_2) + i(N - D)]$$

$$b_2 = {}^1/_2[(S_1 + S_2) - i(N - D)]$$

$$b_3 = {}^1/_2[(S_1 - S_2) - i(N + D)]$$

$$b_4 = {}^1/_2[(S_1 - S_2) + i(N + D)]$$

Pseudoscalar Meson Photoproduction: Complete Experiment

4 complex amplitudes

↓

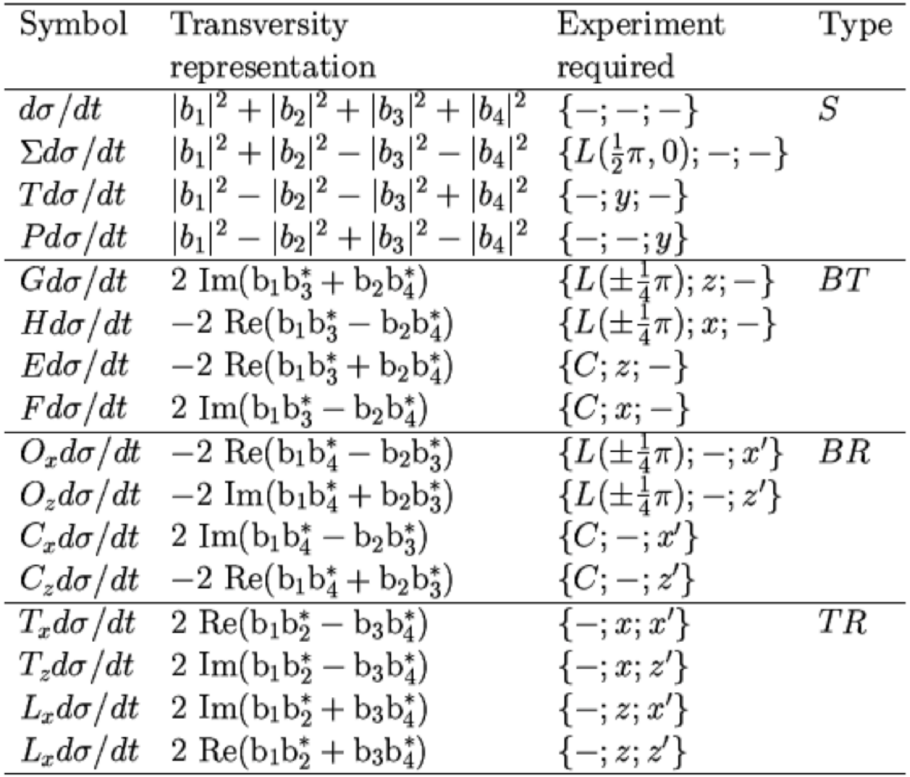
16 bilinear combinations

↓

16 observables

Complete experiment:

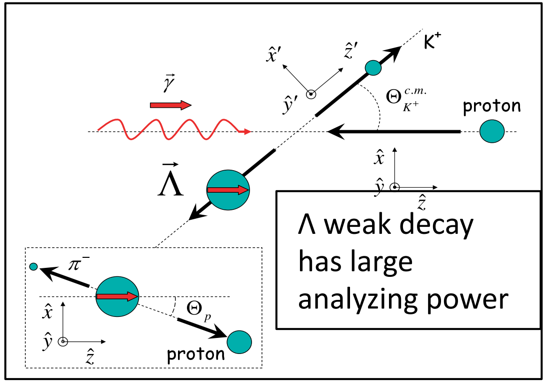
at least 8 carefully chosen observables are needed to extract the amplitudes



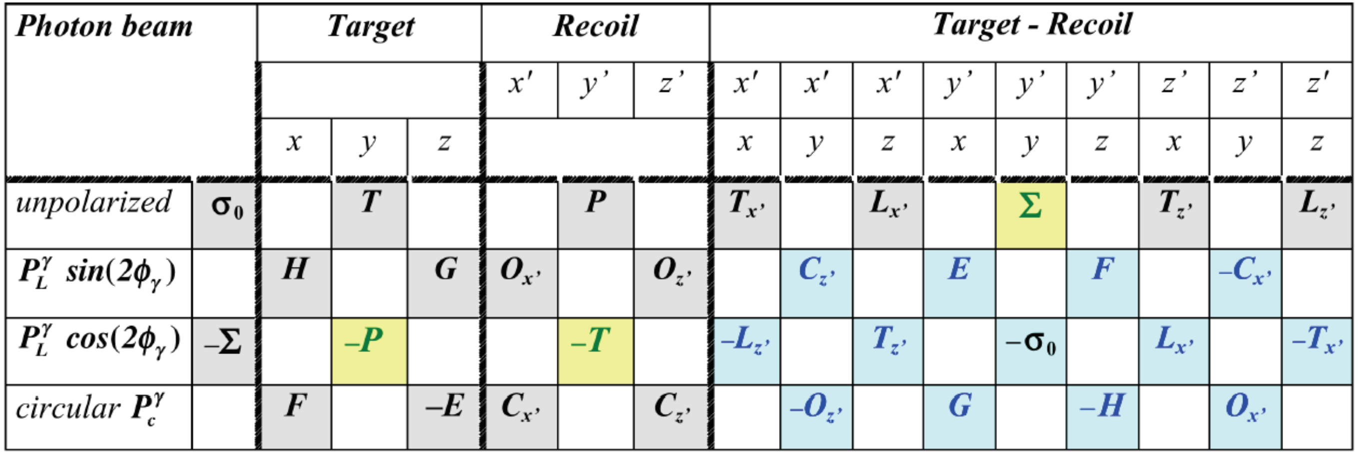
Symbol	Transversity representation	Experiment required	Type
$d\sigma/dt$	$\lvert b_1\rvert^2+\lvert b_2\rvert^2+\lvert b_3\rvert^2+\lvert b_4\rvert^2$	$\{-;-;-\}$	S
$\Sigma d\sigma/dt$	$\lvert b_1\rvert^2+\lvert b_2\rvert^2-\lvert b_3\rvert^2-\lvert b_4\rvert^2$	$\{L(\frac{1}{2}\pi,0);-;-\}$	
$Td\sigma/dt$	$\lvert b_1\rvert^2-\lvert b_2\rvert^2-\lvert b_3\rvert^2+\lvert b_4\rvert^2$	$\{-;y;-\}$	
$Pd\sigma/dt$	$\lvert b_1\rvert^2-\lvert b_2\rvert^2+\lvert b_3\rvert^2-\lvert b_4\rvert^2$	$\{-;-;y\}$	
$Gd\sigma/dt$	$2\ \mathrm{Im}(b_1b_3^*+b_2b_4^*)$	$\{L(\pm\frac{1}{4}\pi);z;-\}$	BT
$Hd\sigma/dt$	$-2\ \mathrm{Re}(b_1b_3^*-b_2b_4^*)$	$\{L(\pm\frac{1}{4}\pi);x;-\}$	
$Ed\sigma/dt$	$-2\ \mathrm{Re}(b_1b_3^*+b_2b_4^*)$	$\{C;z;-\}$	
$Fd\sigma/dt$	$2\ \mathrm{Im}(b_1b_3^*-b_2b_4^*)$	$\{C;x;-\}$	
$O_xd\sigma/dt$	$-2\ \mathrm{Re}(b_1b_4^*-b_2b_3^*)$	$\{L(\pm\frac{1}{4}\pi);-;x'\}$	BR
$O_zd\sigma/dt$	$-2\ \mathrm{Im}(b_1b_4^*+b_2b_3^*)$	$\{L(\pm\frac{1}{4}\pi);-;z'\}$	
$C_xd\sigma/dt$	$2\ \mathrm{Im}(b_1b_4^*-b_2b_3^*)$	$\{C;-;x'\}$	
$C_zd\sigma/dt$	$-2\ \mathrm{Re}(b_1b_4^*+b_2b_3^*)$	$\{C;-;z'\}$	
$T_xd\sigma/dt$	$2\ \mathrm{Re}(b_1b_2^*-b_3b_4^*)$	$\{-;x;x'\}$	TR
$T_zd\sigma/dt$	$2\ \mathrm{Im}(b_1b_2^*-b_3b_4^*)$	$\{-;x;z'\}$	
$L_xd\sigma/dt$	$2\ \mathrm{Im}(b_1b_2^*+b_3b_4^*)$	$\{-;z;x'\}$	
$L_zd\sigma/dt$	$2\ \mathrm{Re}(b_1b_2^*+b_3b_4^*)$	$\{-;z;z'\}$	

I. S. Barker, A. Donnachie, J. K. Storrow, Nucl. Phys. B95, 347 (1975).

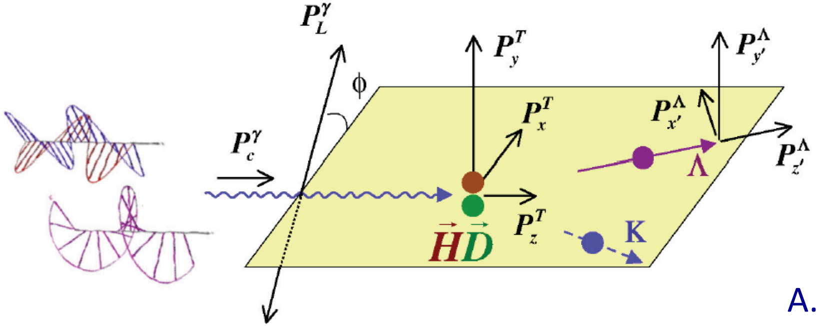
Pseudoscalar Meson Photoproduction: Complete Experiment



Λ weak decay has large analyzing power



Photon beam		Target			Recoil			Target - Recoil								
					x'	y'	z'	x'	x'	x'	y'	y'	y'	z'	z'	z'
		x	y	z				x	y	z	x	y	z	x	y	z
unpolarized	σ_0		T			P		$T_{x'}$		$L_{x'}$		Σ		$T_{z'}$		$L_{z'}$
$P_L^\gamma \sin(2\phi_\gamma)$		H		G	$O_{x'}$		$O_{z'}$		$C_{z'}$		E		F		$-C_{x'}$	
$P_L^\gamma \cos(2\phi_\gamma)$	$-\Sigma$		$-P$			$-T$		$-L_{z'}$		$T_{z'}$		$-\sigma_0$		$L_{x'}$		$-T_{x'}$
circular P_c^γ		F		$-E$	$C_{x'}$		$C_{z'}$		$-O_{z'}$		G		$-H$		$O_{x'}$	



16 different observables, each appearing twice:

- Single-pol observables can be measured from double-pol asymmetry
- Double-pol observables can be measured from triple-pol asymmetry

A. Sandorfi, S. Hoblit, H. Kamano, T.-S.H. Lee, J.Phys. 38 (2011) 053001

Pseudoscalar Meson Photoproduction: Isospin dependence

A^0 and A^1 are the components results from coupling of I=1/2 with isoscalar and isovector components of the photon.

Their contributions appear in linear combinations that may be disentangled only by measurements on both the neutron and the proton.

$$A_{\gamma n \to \binom{\pi^0 n}{K^0\Sigma^0}} = \pm\left[\frac{1}{\sqrt{3}}A^{(0)}_{\binom{\pi N}{K\Sigma}} + \frac{1}{3}A^{(1)}_{\binom{\pi N}{K\Sigma}}\right]^{(I=1/2)} + \frac{2}{3}A^{(I=3/2)}_{\binom{\pi N}{K\Sigma}}$$

$$A_{\gamma n \to \binom{\pi^- p}{K^+\Sigma^-}} = \mp\sqrt{2}\left[\frac{1}{\sqrt{3}}A^{(0)}_{\binom{\pi N}{K\Sigma}} + \frac{1}{3}A^{(1)}_{\binom{\pi N}{K\Sigma}}\right]^{(I=1/2)} + \frac{\sqrt{2}}{3}A^{(I=3/2)}_{\binom{\pi N}{K\Sigma}}$$

$$A_{\gamma n \to \binom{\eta n}{K^0\Lambda}} = +\left[A^{(0)}_{\binom{\eta N}{K\Lambda}} + \frac{1}{\sqrt{3}}A^{(1)}_{\binom{\eta N}{K\Lambda}}\right]^{(I=1/2)} .$$

$$A_{\gamma p \to \binom{\pi^0 p}{K^+\Sigma^0}} = \mp\left[\frac{1}{\sqrt{3}}A^{(0)}_{\binom{\pi N}{K\Sigma}} - \frac{1}{3}A^{(1)}_{\binom{\pi N}{K\Sigma}}\right]^{(I=1/2)} + \frac{2}{3}A^{(I=3/2)}_{\binom{\pi N}{K\Sigma}}$$

$$A_{\gamma p \to \binom{\pi^+ n}{K^0\Sigma^+}} = \pm\sqrt{2}\left[\frac{1}{\sqrt{3}}A^{(0)}_{\binom{\pi N}{K\Sigma}} - \frac{1}{3}A^{(1)}_{\binom{\pi N}{K\Sigma}}\right]^{(I=1/2)} + \frac{\sqrt{2}}{3}A^{(I=3/2)}_{\binom{\pi N}{K\Sigma}}$$

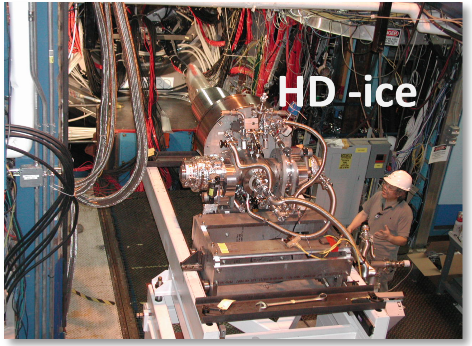
$$A_{\gamma p \to \binom{\eta p}{K^+\Lambda}} = +\left[A^{(0)}_{\binom{\eta N}{K\Lambda}} - \frac{1}{\sqrt{3}}A^{(1)}_{\binom{\eta N}{K\Lambda}}\right]^{(I=1/2)} .$$

I. S. Barker, A. Donnachie, J. K. Storrow, Nucl. Phys. B95, 347 (1975).

Experimental set-up

Polarized Frozen-spin Targets & CEBAF Large Acceptance Spectrometer

or



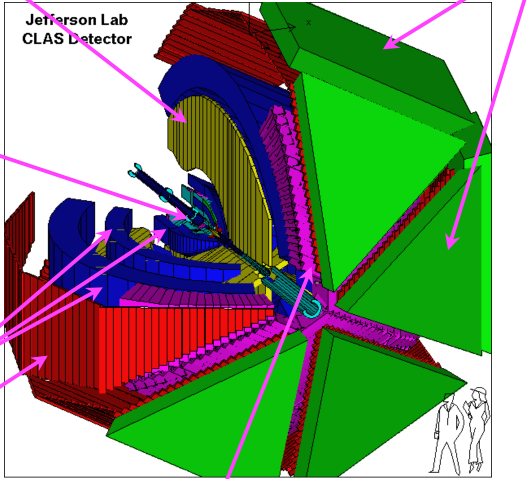
+

start counter

Drift chambers
35,000 cells

Time-of-flight counters
plastic scintillators,
684 photomultipliers

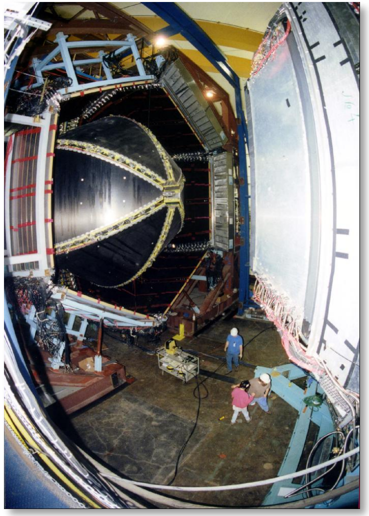
Torus magnet
6 superconducting coils



Electromagnetic calorimeters
Lead/scintillator, 1296 photomultipliers

Gas Cherenkov counters
e/π separation, 256 PMTs

Open CLAS detector



CLAS N* Experimental Program

	σ	Σ	T	P	E	F	G	H	T_x	T_z	L_x	L_z	O_x	O_z	C_x	C_z
$p\pi^0$	✔	✔	✓		✓	✓	✓	✓								
$n\pi^+$	✔	✔	✓		✔	✓	✓	✓								
$p\eta$	✔	✓	✓		✔	✓	✓	✓								
$p\eta'$	✔	✓	✓		✓	✓	✓	✓								
$p\omega/\phi$	✔	✓	✓		✓	✓	✓	✓								
$N\pi\pi$	✓	✓														
$K^+\Lambda$	✔	✔	✔	✔	✓	✓	✓	✓	✓	✓	✓	✓	✔	✔	✔	✔
$K^+\Sigma^0$	✔	✔	✔	✔	✓	✓	✓	✓	✓	✓	✓	✓	✔	✔	✔	✔
$K^{0*}\Sigma^+$	✔	✓									✓	✓				
$K^{+*}\Sigma^0$	✔	✓														
$p\pi^-$	✔	✓			✓	✓	✓									
$p\rho^-$	✓	✓			✓	✓	✓									
$K^-\Sigma^+$	✓	✓			✓	✓	✓									
$K^0\Lambda$	✓	✓		✓	✓	✓	✓				✓	✓	✓	✓	✓	✓
$K^0\Sigma^0$	✓	✓		✓	✓	✓	✓				✓	✓	✓	✓	✓	✓
$K^{0*}\Sigma^0$	✓	✓														

Proton targets

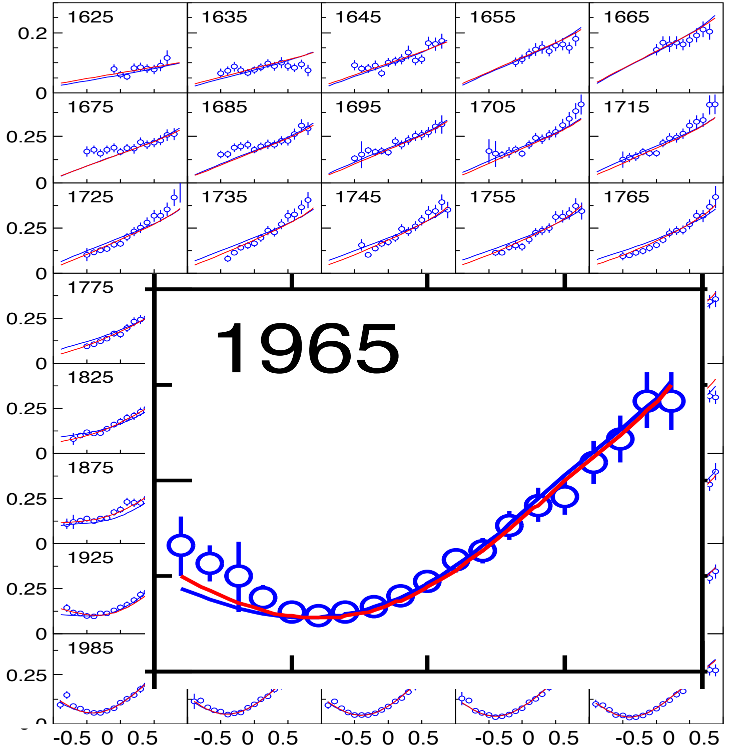
Data taking completed May 18, 2012

✔-published, ✓-acquired

Neutron targets

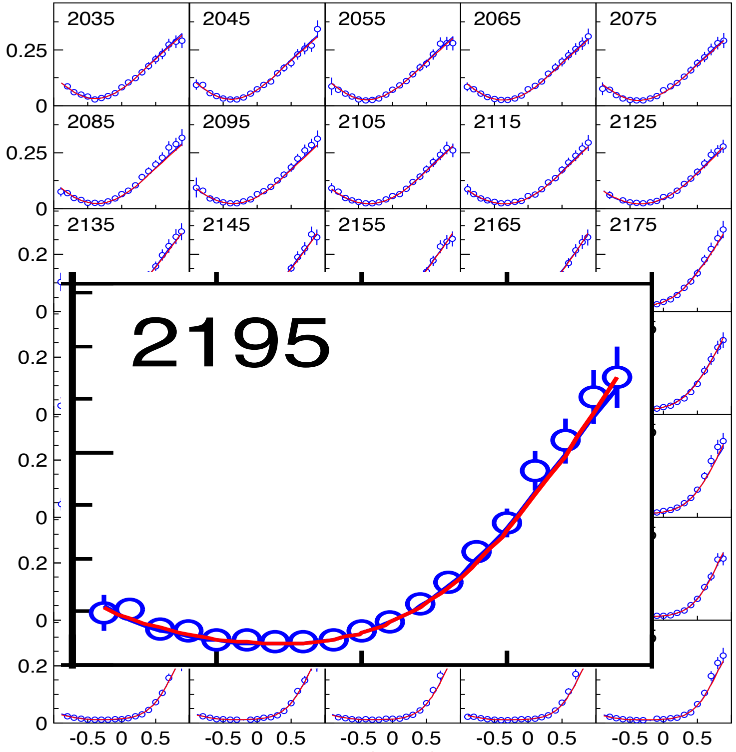
Strangeness production: $\vec{\gamma} + \vec{p} \rightarrow K^+ + \vec{\Lambda} \rightarrow K^+ + p + \pi^-$

Differential cross section



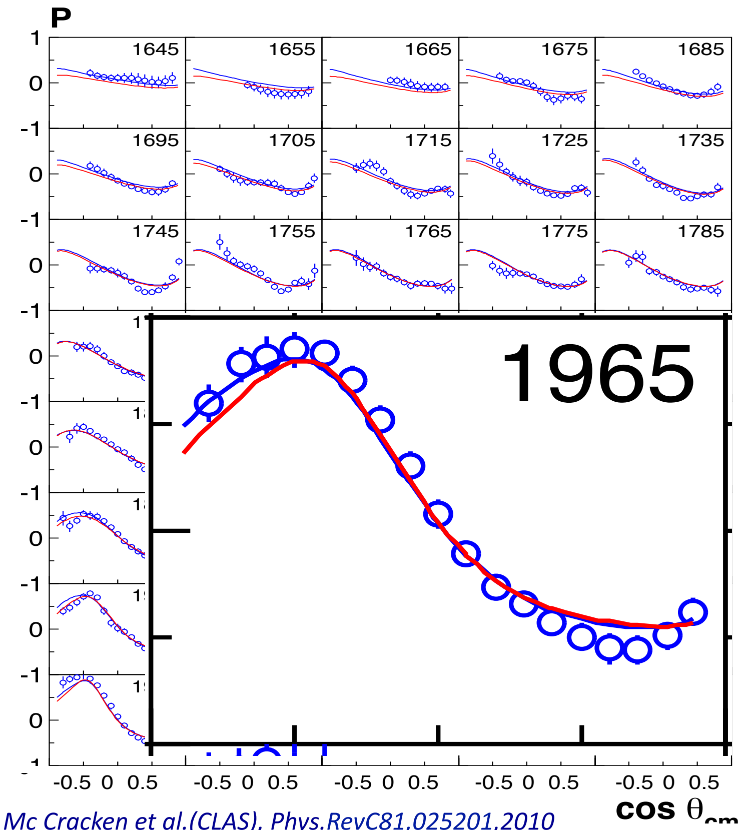
M. Mc Cracken et al.(CLAS), Phys.RevC81,025201,2010

Σ Beam Asymmetry

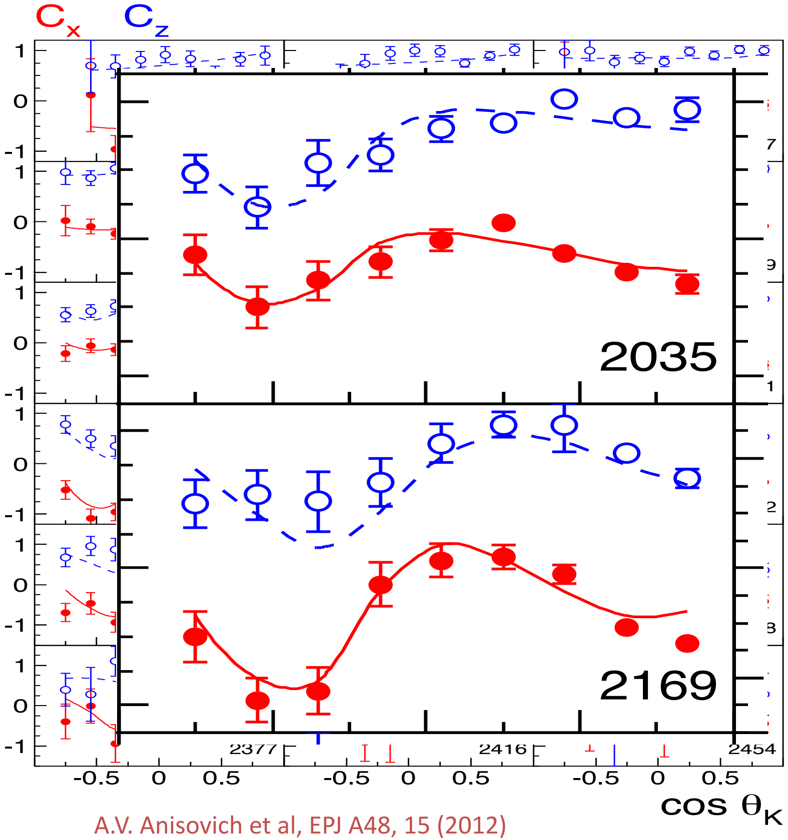


A.V. Anisovich et al, EPJ A48, 15 (2012)

Strangeness production: $\vec{\gamma} + \vec{p} \rightarrow K^+ + \vec{\Lambda} \rightarrow K^+ + p + \pi^-$



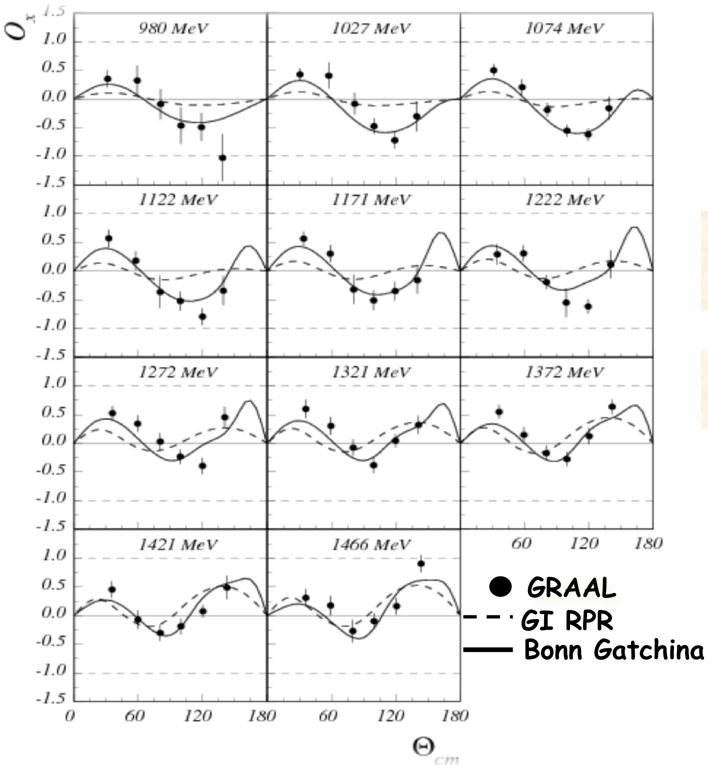
M. Mc Cracken et al.(CLAS), Phys.RevC81,025201,2010



A.V. Anisovich et al, EPJ A48, 15 (2012)

Strangeness production: $\vec{\gamma} + \vec{p} \rightarrow K^+ + \vec{\Lambda} \rightarrow K^+ + p + \pi^-$

A.Lleres et al., EPJ A **39**, 149-161 (2009)

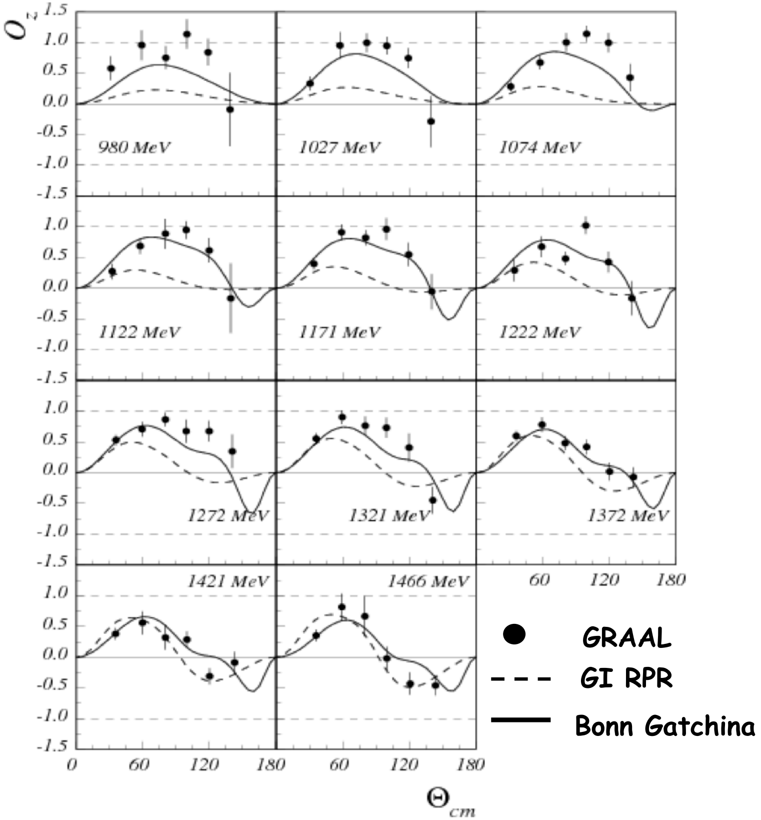


O_x, O_z Double Polarization Asymmetries

$$\frac{2N_+^{x'}}{N_+^{x'}+N_-^{x'}} = \left(1+\alpha\frac{2P_\gamma O_x}{\pi}\cos\theta_p^{x'}\right)$$

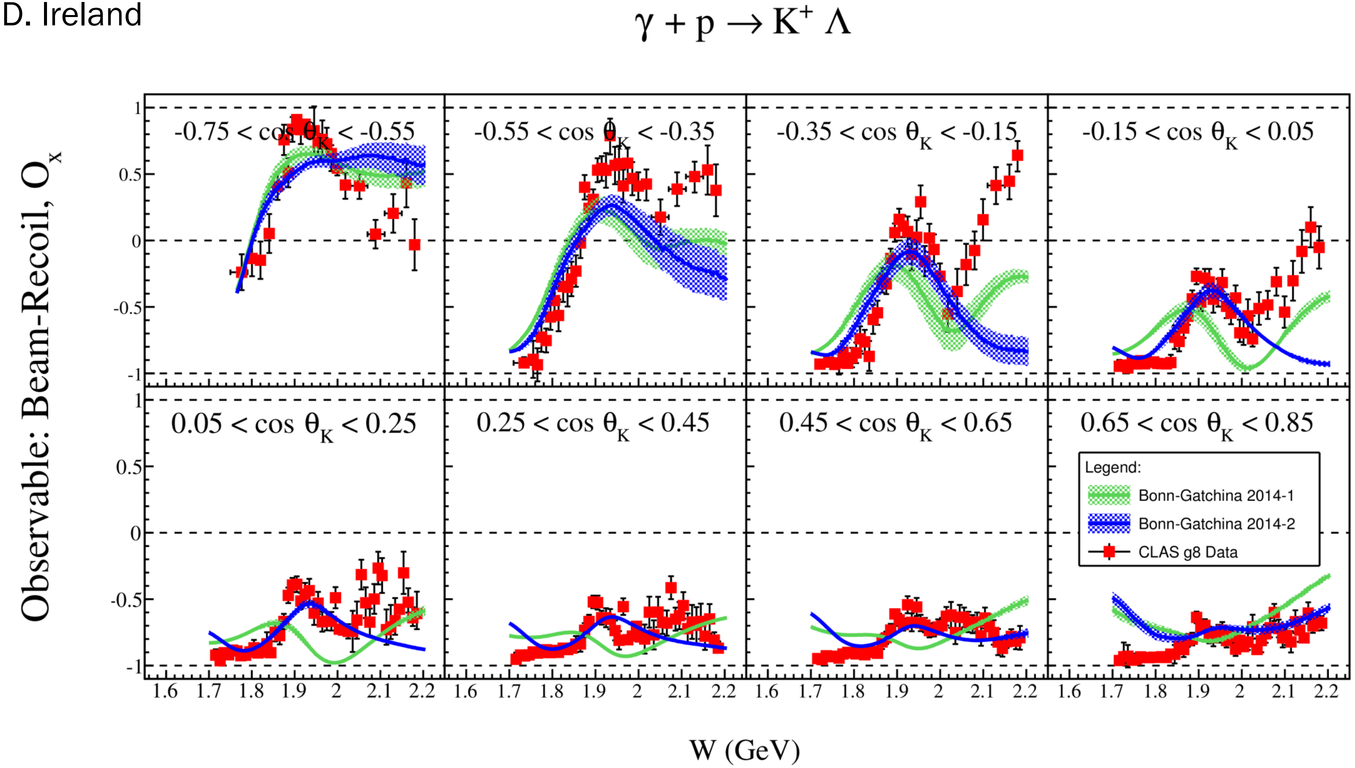
$$\frac{2N_+^{z'}}{N_+^{z'}+N^{z'}} = \left(1+\alpha\frac{2P_\gamma O_z}{\pi}\cos\theta_p^{z'}\right)$$

GRAAL Experiment



Strangeness production: $\vec{\gamma} + \vec{p} \rightarrow K^+ + \vec{\Lambda} \rightarrow K^+ + p + \pi^-$

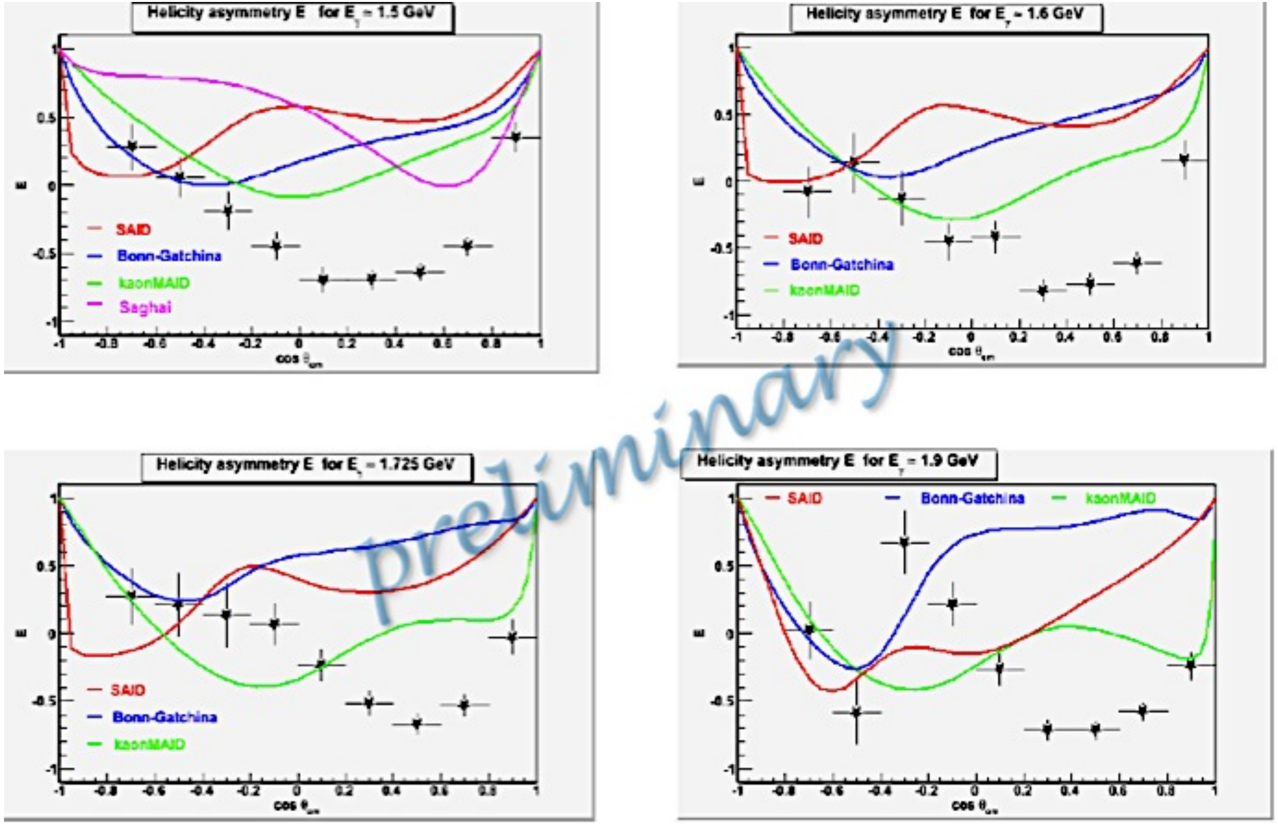
D. Ireland



O_x Double Polarization Asymmetry

CLAS Experiment

Strangeness production: $\vec{\gamma} + \vec{p} \rightarrow K^+ + \vec{\Lambda} \rightarrow K^+ + p + \pi^-$

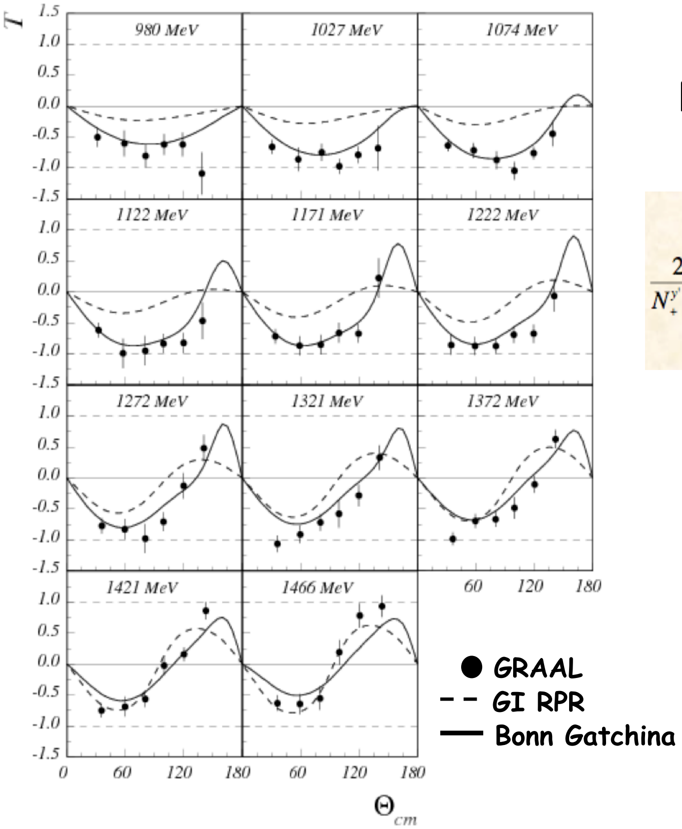


E Polarization Asymmetry

CLAS Experiment

L. Casey, Catholic Univ.

Strangeness production: $\vec{\gamma} + \vec{p} \rightarrow K^+ + \vec{\Lambda} \rightarrow K^+ + p + \pi^-$



T asymmetry from P_γ and Σ polarization observables

$$\frac{2N_+^{y'}}{N_+^{y'}+N_-^{y'}} = \left(1+\frac{2P_\gamma\Sigma}{\pi}\right)\left(\frac{1+\alpha\frac{P\pi+2P_\gamma T}{\pi+2P_\gamma\Sigma}\cos\theta_p^{y'}}{1+\alpha P\cos\theta_p^{y'}}\right)$$

GRAAL Experiment

A.Lleres et al., EPJ A **39**, 149-161 (2009)

From O_x, O_z and T results:

- Ghent Isobar RPR Model:

$S_{11}(1650)$ $P_{11}(1710)$ $P_{13}(1720)$

$\boxed{P_{13}(1900)}$ $\boxed{D_{13}(1900)}$

- Bonn Gatchina Model:

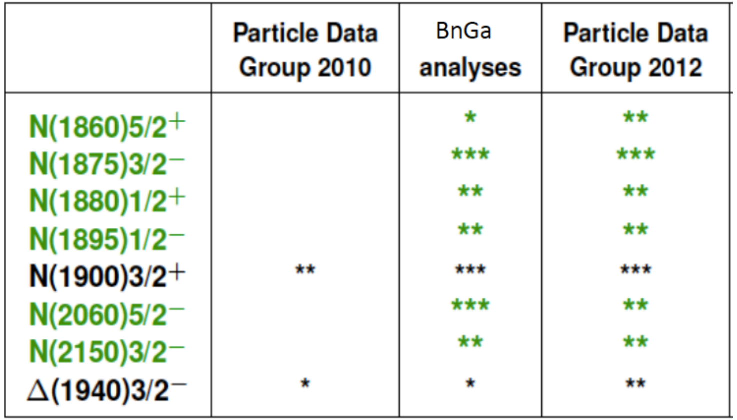
$S_{11}(1535)$ $S_{11}(1650)$ $P_{11}(1840)$

$\boxed{P_{13}(1900)}$

Jefferson Lab

Updated Spectrum of Baryon Resonances

- From 2000 to 2010 no new Baryon resonances were considered by the PDG.
  - Used πN- scattering data and some π-photoproduction only.
- Mature multi-channel models now include many photoproduction data.
- E.g. Bonn-Gatchina PWA analysis, A. Anisovich et al. EPJ A 48, 15 (2012).



	Particle Data Group 2010	BnGa analyses	Particle Data Group 2012
$N(1860)5/2^+$		*	**
$N(1875)3/2^-$		***	***
$N(1880)1/2^+$		**	**
$N(1895)1/2^-$		**	**
$N(1900)3/2^+$	**	***	***
$N(2060)5/2^-$		***	**
$N(2150)3/2^-$		**	**
$\Delta(1940)3/2^-$	*	*	**

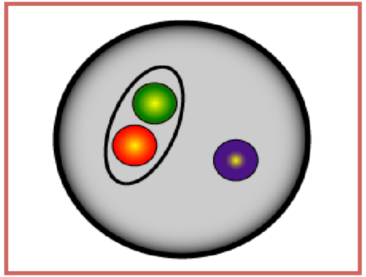
Naming scheme has changed:

$L_{2I\ 2J}(E) \longrightarrow J^P(E)$

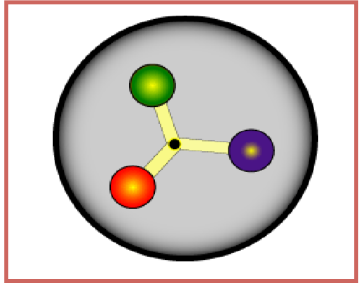
- Results from photoproduction now add to the PDG tables and determine properties of baryon resonances

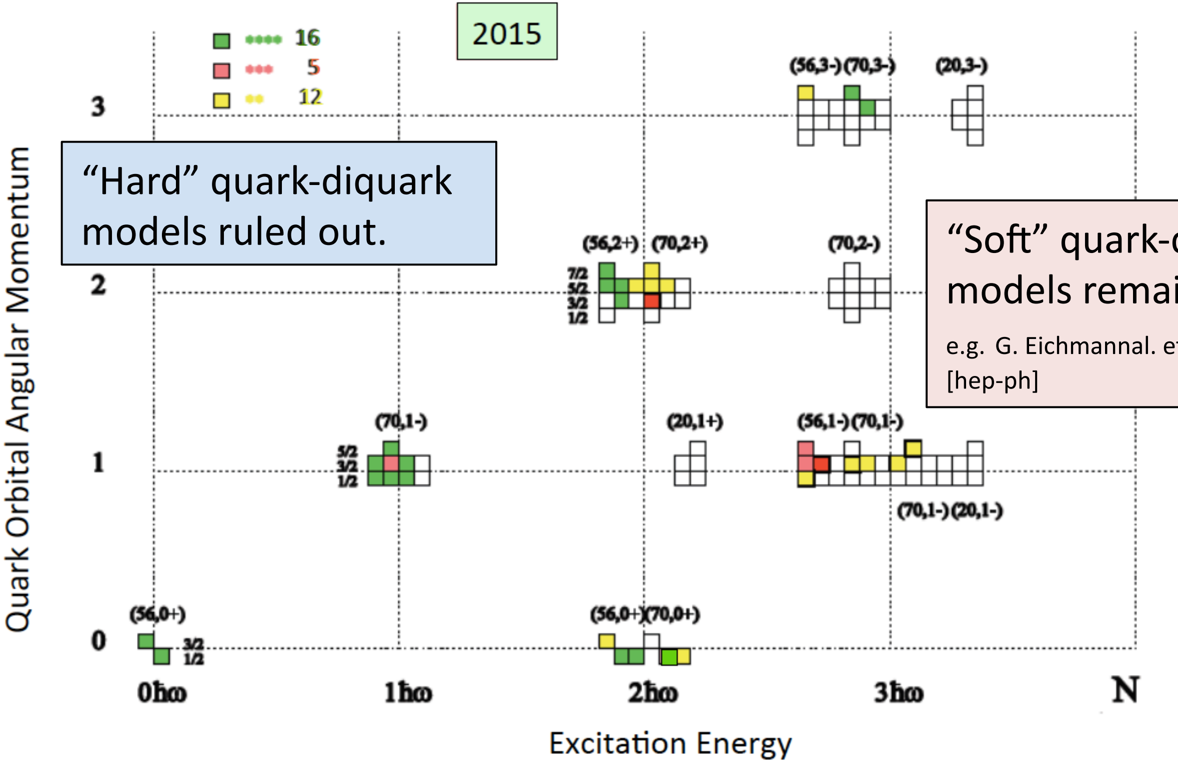
Do New States Fit into Q^3 QM ?

SU(6)xO(3)



vs





"Hard" quark-diquark models ruled out.

"Soft" quark-diquark models remain viable.

e.g. G. Eichmannal. et arXiv:1607.05748 [hep-ph]

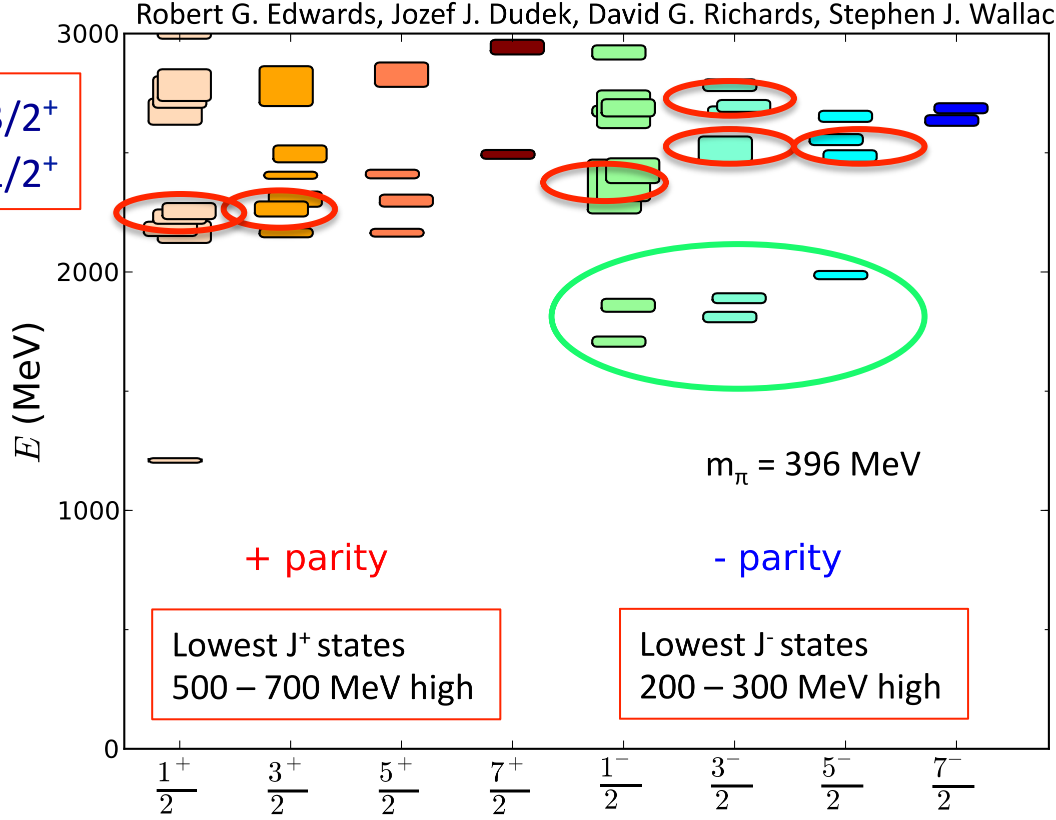
Do New States Fit into LQCD Projections ?

Robert G. Edwards, Jozef J. Dudek, David G. Richards, Stephen J. Wallace **Phys.Rev. D84 (2011) 074508**

N(1900)3/2$^+$
N(1880)1/2$^+$

Ignoring the mass scale, new candidates fit the J^P values predicted from LQCD.

The field would really benefit from more realistic Lattice masses for N* states.



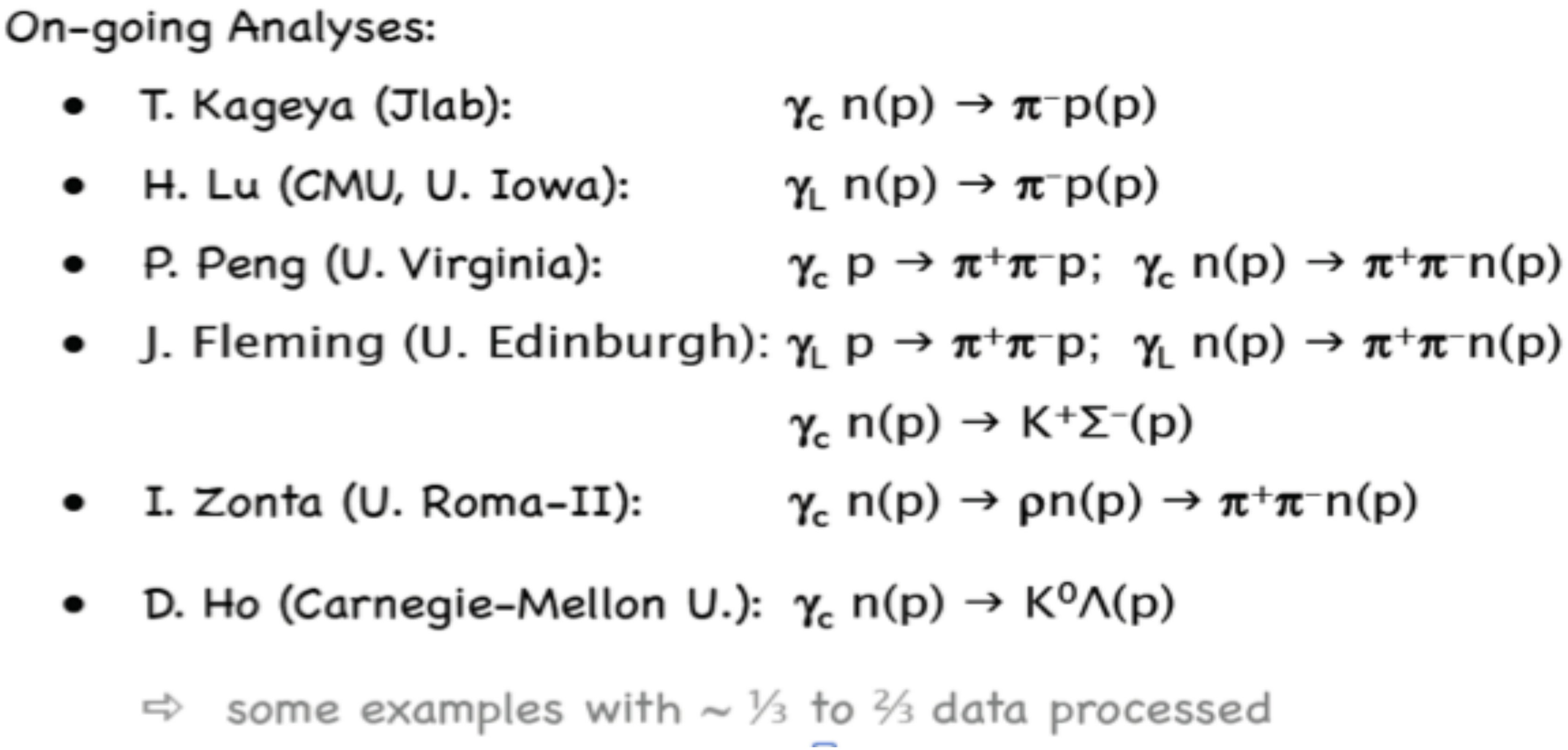
Lowest J$^+$ states
500 – 700 MeV high

Lowest J$^-$ states
200 – 300 MeV high

N(2060)5/2$^-$
N(2120)3/2$^-$
N(1875)3/2$^-$
N(1895)1/2$^-$

Known states:
N(1675)5/2$^-$
N(1700)3/2$^-$
N(1520)3/2$^-$
N(1650)1/2$^-$
N(1535)1/2$^-$

Results on Polarized Neutron Target

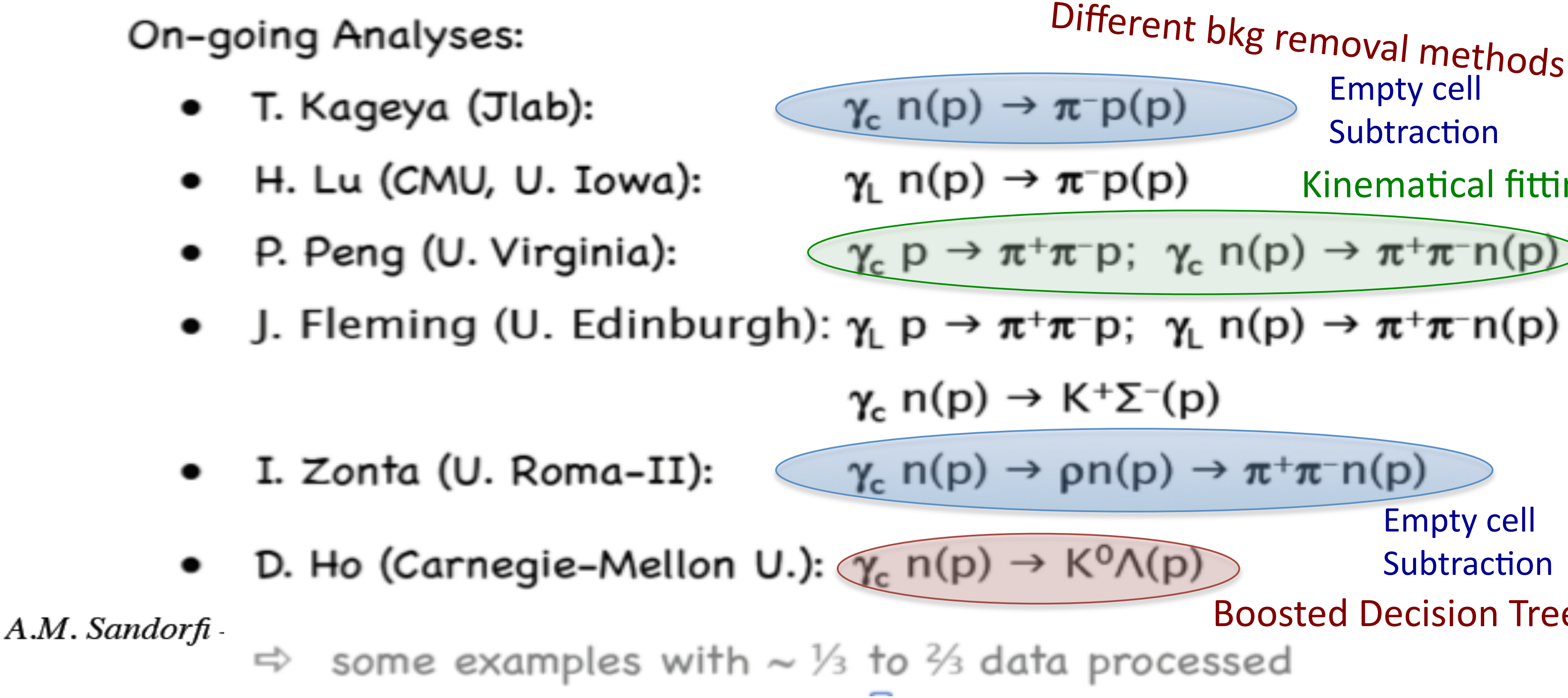


On-going Analyses:

- T. Kageya (Jlab): $\gamma_c\ n(p) \rightarrow \pi^- p(p)$
- H. Lu (CMU, U. Iowa): $\gamma_L\ n(p) \rightarrow \pi^- p(p)$
- P. Peng (U. Virginia): $\gamma_c\ p \rightarrow \pi^+\pi^- p$; $\gamma_c\ n(p) \rightarrow \pi^+\pi^- n(p)$
- J. Fleming (U. Edinburgh): $\gamma_L\ p \rightarrow \pi^+\pi^- p$; $\gamma_L\ n(p) \rightarrow \pi^+\pi^- n(p)$
  $\gamma_c\ n(p) \rightarrow K^+\Sigma^-(p)$
- I. Zonta (U. Roma-II): $\gamma_c\ n(p) \rightarrow \rho n(p) \rightarrow \pi^+\pi^- n(p)$
- D. Ho (Carnegie-Mellon U.): $\gamma_c\ n(p) \rightarrow K^0\Lambda(p)$

⇨ some examples with ~ ⅓ to ⅔ data processed

Results on Polarized Neutron Target



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A.M. Sandorfi -

⇨ some examples with ~ ⅓ to ⅔ data processed

Different bkg removal methods

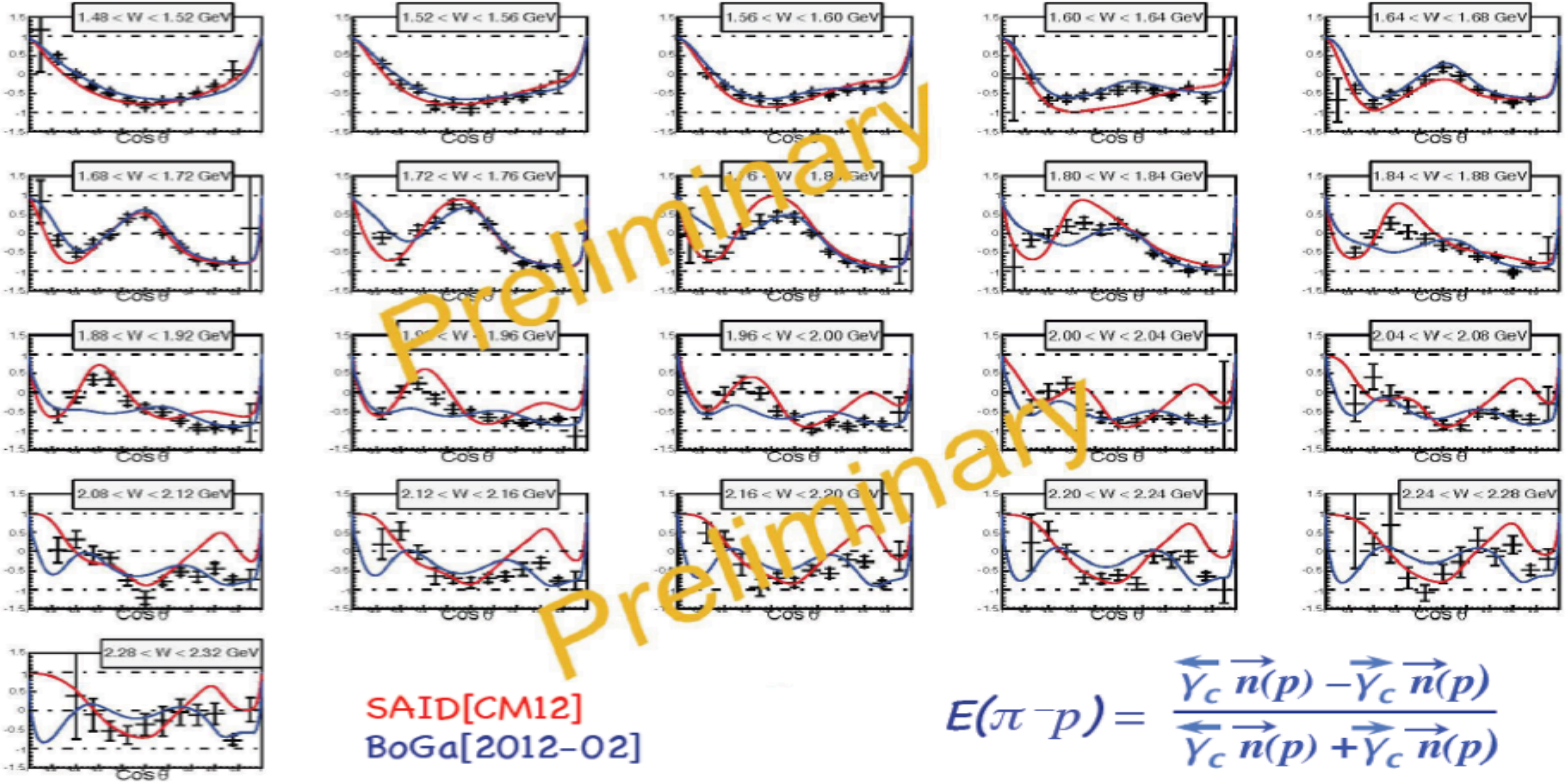
Empty cell Subtraction

Kinematical fitting

Empty cell Subtraction

Boosted Decision Trees

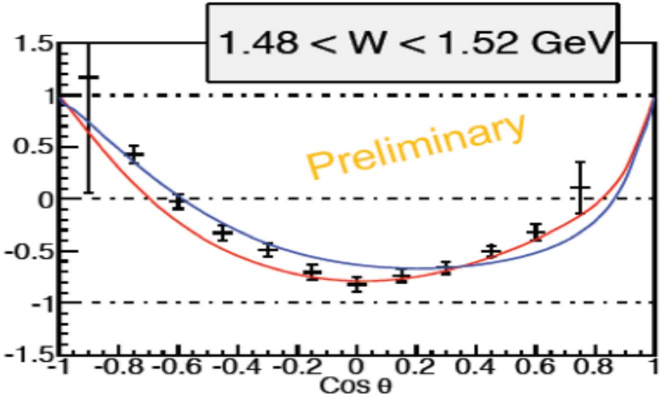
γd→π⁻p(p) Helicity Asymmetry E

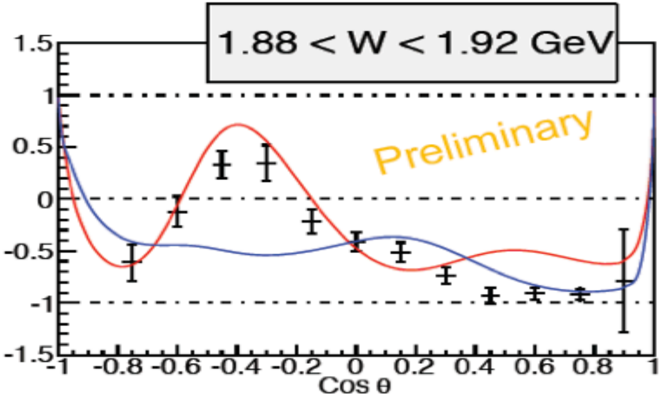


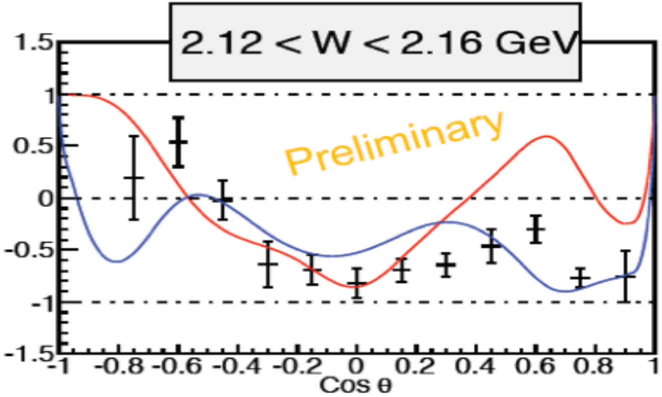
SAID[CM12]
BoGa[2012-02]

$$E(\pi^-p) = \frac{\overleftarrow{Y_c}\,\overrightarrow{n(p)} - \overrightarrow{Y_c}\,\overrightarrow{n(p)}}{\overleftarrow{Y_c}\,\overrightarrow{n(p)} + \overrightarrow{Y_c}\,\overrightarrow{n(p)}}$$

$\gamma d \to \pi^- p(p)$ Helicity Asymmetry E







$$E(\pi^- p) = \frac{\overleftarrow{\gamma_c}\,\overrightarrow{n}(p) - \overrightarrow{\gamma_c}\,\overrightarrow{n}(p)}{\overleftarrow{\gamma_c}\,\overrightarrow{n}(p) + \overrightarrow{\gamma_c}\,\overrightarrow{n}(p)}$$

T. Kageya

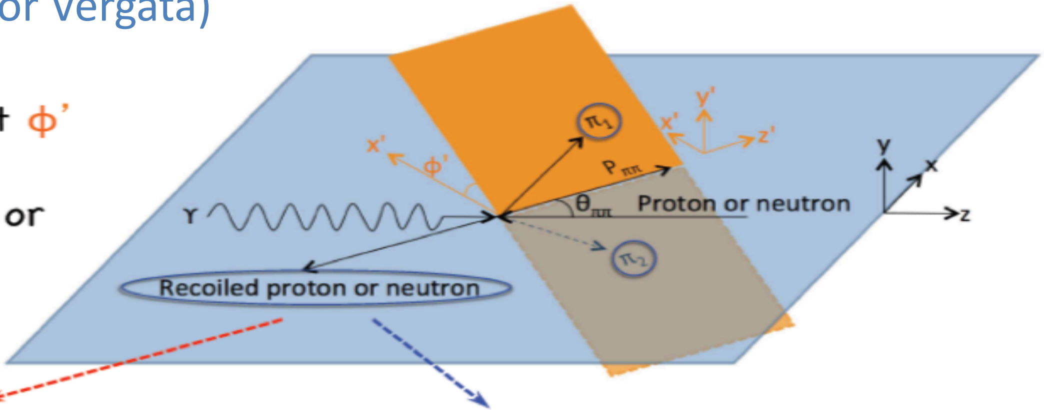
A.M. Sandorfi

PWA:
SAID[CM12]
BoGa[2012-02]

$\gamma p \rightarrow \pi^+\pi^- p$ and $\gamma d \rightarrow \pi^+\pi^- n(p)$

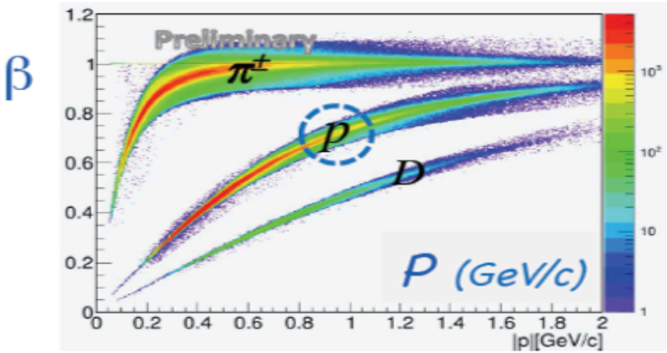
P. Peng(UVa), I. Zonta (U. Roma Tor Vergata)

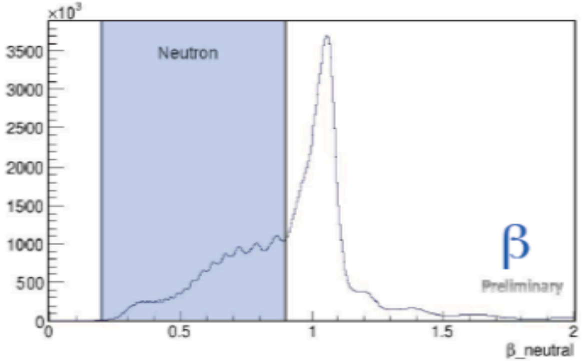
- elementary $d^5\sigma$
- $\pi^+ \pi^-$ define a plane at ϕ' *wrt reaction plane*
- observables are even or odd *wrt* ϕ'
- $P_{\pi\pi}(\theta_{\pi\pi}) = P_{\pi+} + P_{\pi-}$



protons in drift chambers

neutrons in forward calorimeter





$\gamma p \rightarrow \pi^+\pi^- p$ and $\gamma d \rightarrow \pi^+\pi^- n(p)$

- in the notation of Roberts and Oed, PR C71 (05) 055201
- 64 possible polarization observables; ≥ 15 needed to determine amplitude

$$\frac{d\sigma^{BT}}{d\Omega} = d\sigma_0 \left\{ \begin{aligned} &\left(1+\vec{\Lambda}\cdot\vec{P}\right)+\delta_{\odot}\left(I^{\odot}+\vec{\Lambda}\cdot\vec{P}^{\odot}\right) \\ &+\delta_L\left[\sin(2\varphi_\gamma)\left(I^S+\vec{\Lambda}\cdot\vec{P}^S\right)+\cos(2\varphi_\gamma)\left(I^C+\vec{\Lambda}\cdot\vec{P}^C\right)\right] \end{aligned} \right\}$$

- $\delta_{\odot}, \delta_L$: beam polarization ;
- $\vec{\Lambda}$: target polarization

$$\frac{d\sigma}{dx_i} = \sigma_0\{(1+\Lambda_z\cdot\mathbf{P_z})+\delta_{\odot}(\mathbf{I}^{\odot}+\Lambda_z\cdot\mathbf{P}_z^{\odot})\}$$

helicity difference beam-helicity beam-target

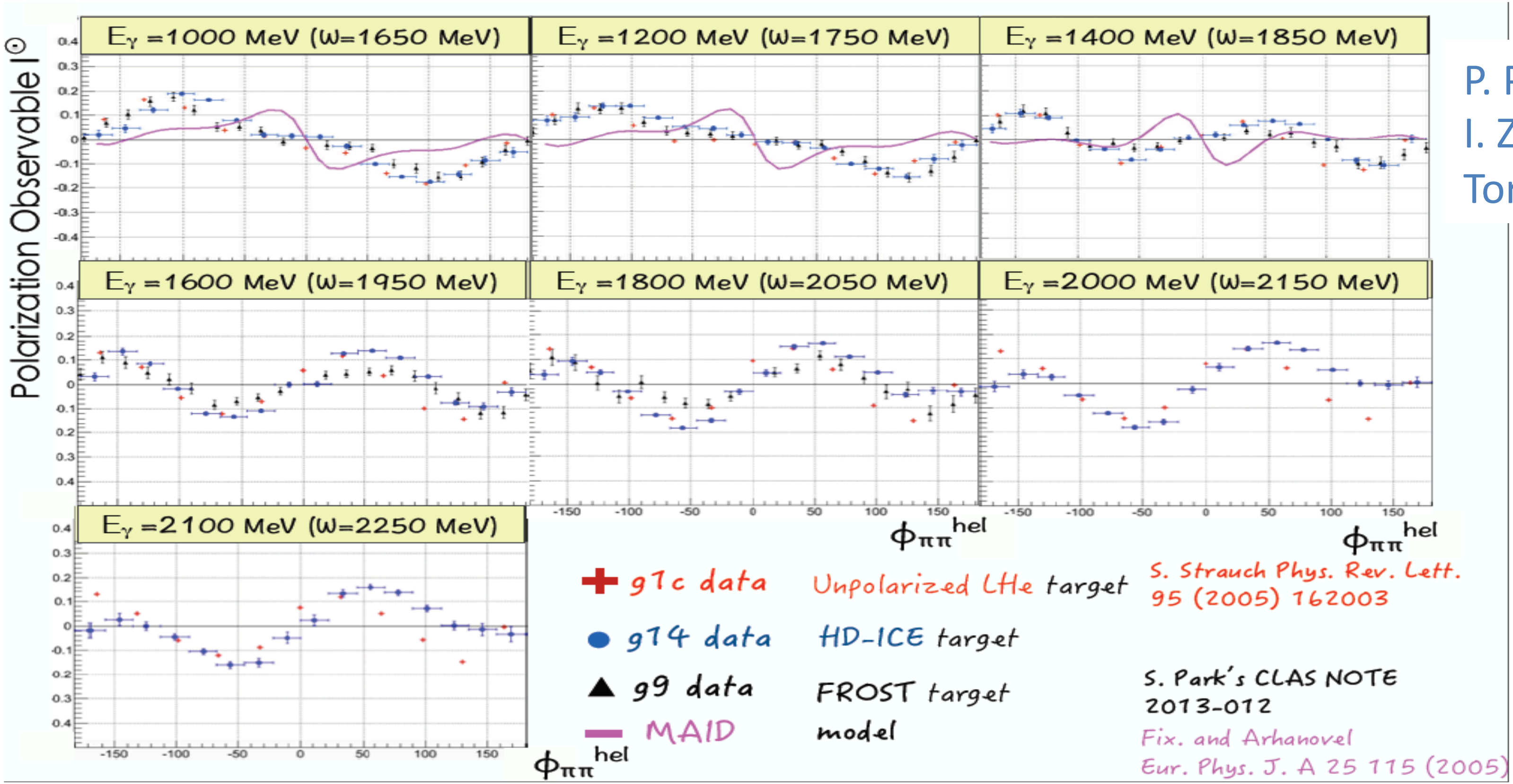
P_z and $I^{\odot}$ are odd functions of ϕ'

$$P_z = \frac{1}{\Lambda_z}\frac{[N(\rightarrow\Rightarrow)+N(\leftarrow\Rightarrow)]-[N(\rightarrow\Leftarrow)+N(\leftarrow\Leftarrow)]}{[N(\rightarrow\Rightarrow)+N(\leftarrow\Rightarrow)]-[N(\rightarrow\Leftarrow)+N(\leftarrow\Leftarrow)]}$$

$$I^{\odot} = \frac{1}{\delta_{\odot}}\frac{[N(\rightarrow\Rightarrow)+N(\rightarrow\Leftarrow)]-[N(\leftarrow\Rightarrow)+N(\leftarrow\Leftarrow)]}{[N(\rightarrow\Rightarrow)+N(\rightarrow\Leftarrow)]+[N(\leftarrow\Rightarrow)+N(\leftarrow\Leftarrow)]}$$

$$P_z^{\odot} = \frac{1}{\Lambda_z\delta_{\odot}}\frac{[N(\rightarrow\Rightarrow)+N(\leftarrow\Leftarrow)]-[N(\rightarrow\Leftarrow)+N(\leftarrow\Rightarrow)]}{[N(\rightarrow\Rightarrow)+N(\leftarrow\Leftarrow)]+[N(\rightarrow\Leftarrow)+N(\leftarrow\Rightarrow)]}$$

$I^{\odot}$ $\gamma p \rightarrow \pi^+\pi^- p$ and $\gamma d \rightarrow \pi^+\pi^- n(p)$



S. Strauch Phys. Rev. Lett. 95 (2005) 162003

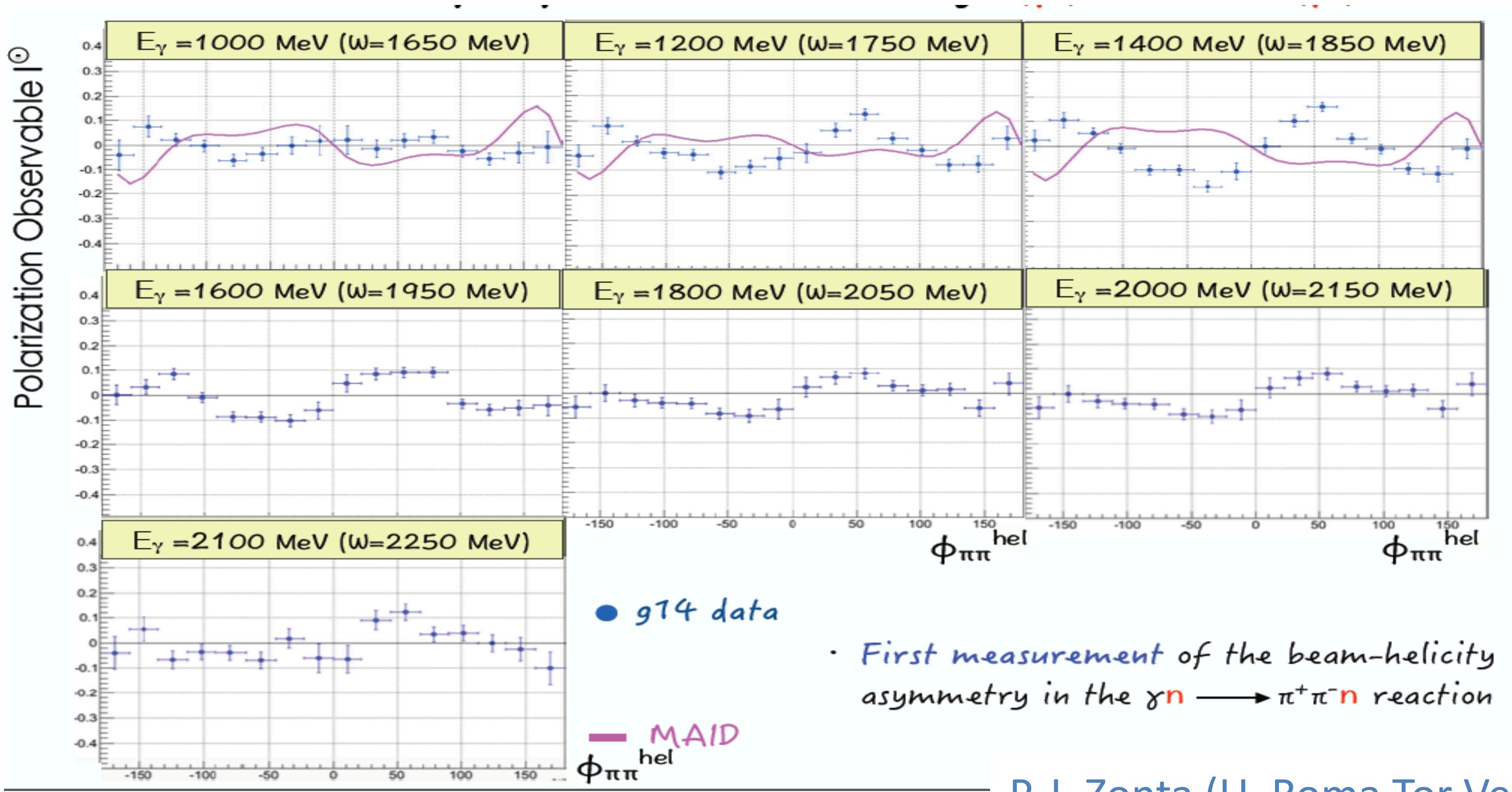
S. Park's CLAS NOTE 2013-012

Fix. and Arhanovel Eur. Phys. J. A 25 115 (2005)

P. Peng(UVa),
I. Zonta (U. Roma Tor Vergata)

$P_{33}(1232)$
$P_{11}(1440)$
$D_{13}(1520)$
$S_{11}(1535)$
$S_{11}(1620)$
$D_{15}(1675)$
$F_{15}(1680)$
$D_{33}(1700)$
$P_{13}(1720)$

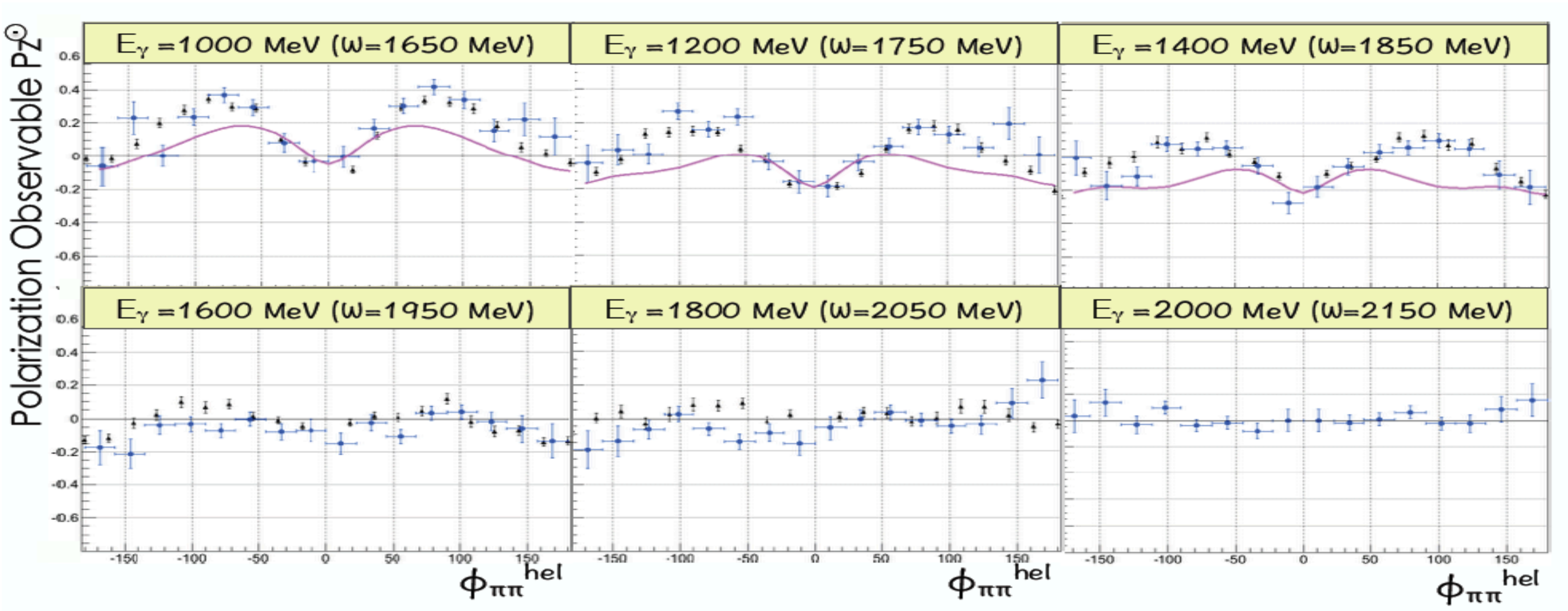
$I^{\odot}$ for $\gamma d \rightarrow \pi^{+}\pi^{-}n(p)$



- *First measurement* of the beam-helicity asymmetry in the $\gamma n \longrightarrow \pi^{+}\pi^{-}n$ reaction

P. I. Zonta (U. Roma Tor Vergata)

$P_z^{\odot}$ for $\gamma p \rightarrow \pi^+\pi^- p$ and $\gamma d \rightarrow \pi^+\pi^- p(n)$



● g14 data HD-ICE target

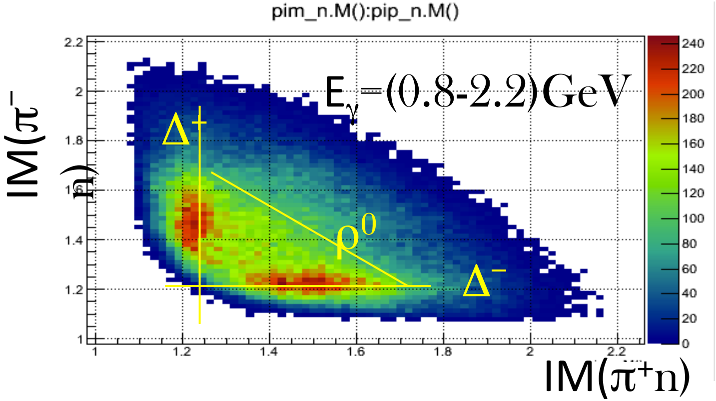
▲ g9 data FROST target

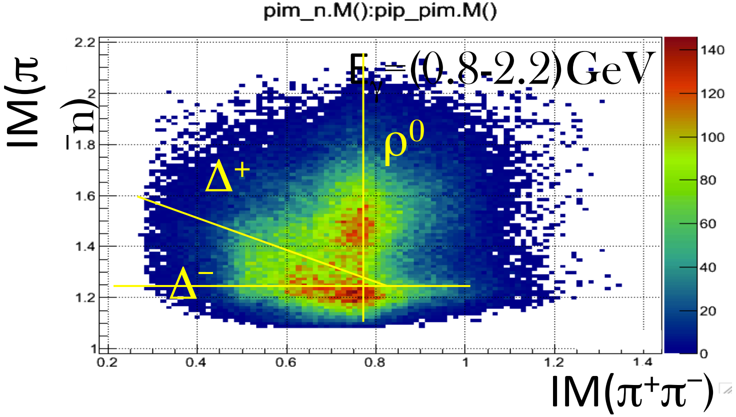
▬ MAID model

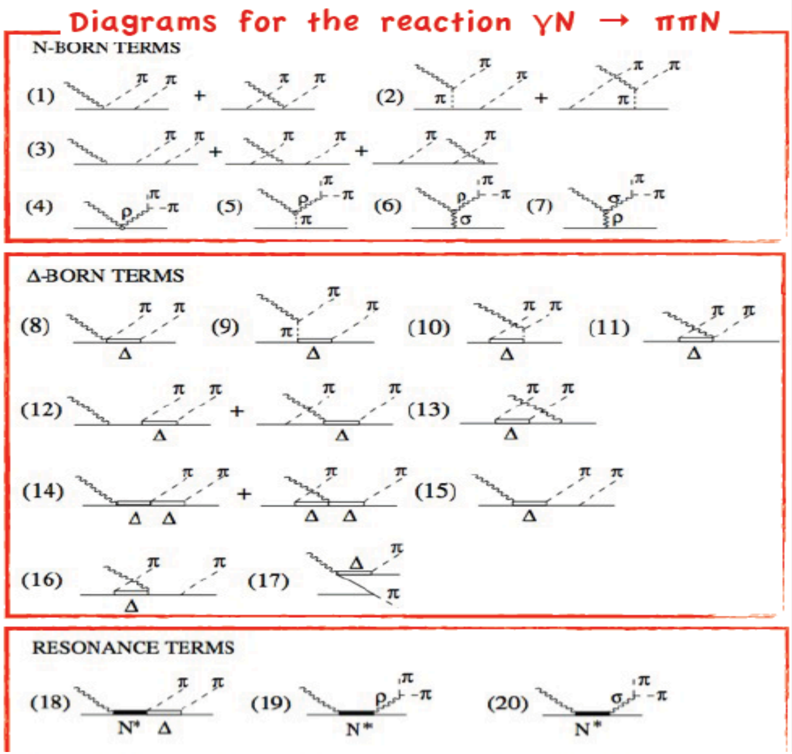
P. I. Zonta (U. Roma Tor Vergata)

$\gamma p \rightarrow \rho p \rightarrow \pi^+\pi^- p$ $\gamma d \rightarrow \rho n(p) \rightarrow \pi^+\pi^- n(p)$

P. I. Zonta (U. Roma Tor Vergata)





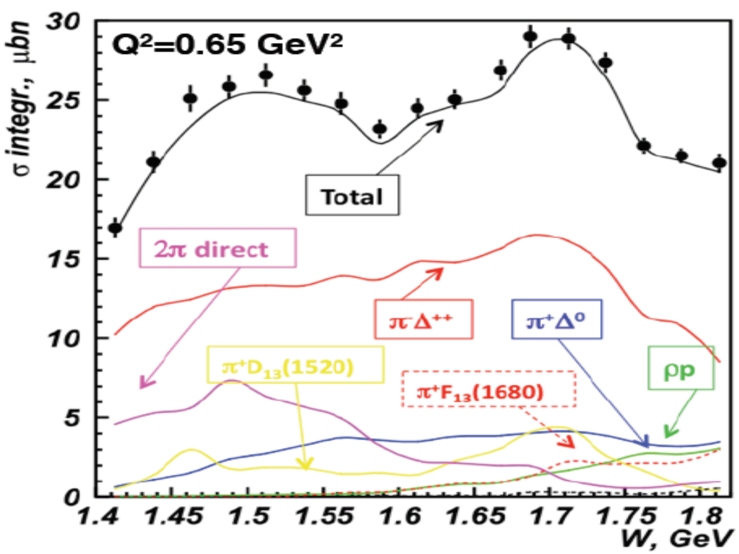


A. Fix and H. Arenhovel, Eur.Phys.J. **A25** (2005) 115, nucl-th/0503042.

$\gamma p \to \rho p \to \pi^+ \pi^- p$

P. I. Zonta (U. Roma Tor Vergata)

$$\gamma^* + N \to \pi^+ + \pi^- + N$$



by V. Mokeev (JLab-Moscow model)

it's the final states of several possible reactions

disentangled for electroproduction by V. MokeeV

$\gamma p \rightarrow \rho p \rightarrow \pi^+\pi^- p$

P. I. Zonta (U. Roma Tor Vergata)

1) SELECTION: $IM(\pi^+ p) > 1.3$ GeV and $IM(\pi^- p) > 1.3$ GeV

Goal → disentangle the reaction:

$\gamma p \longrightarrow \rho^0 p \longrightarrow \pi^+\pi^- p$

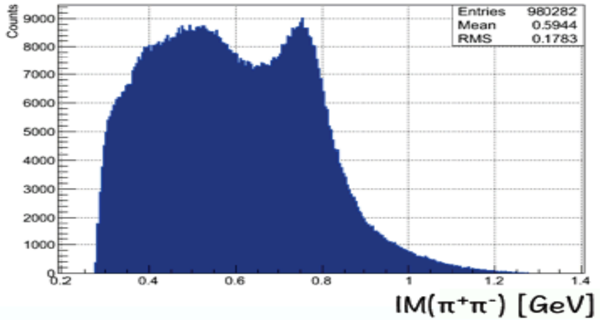
From the three concurrent reactions:

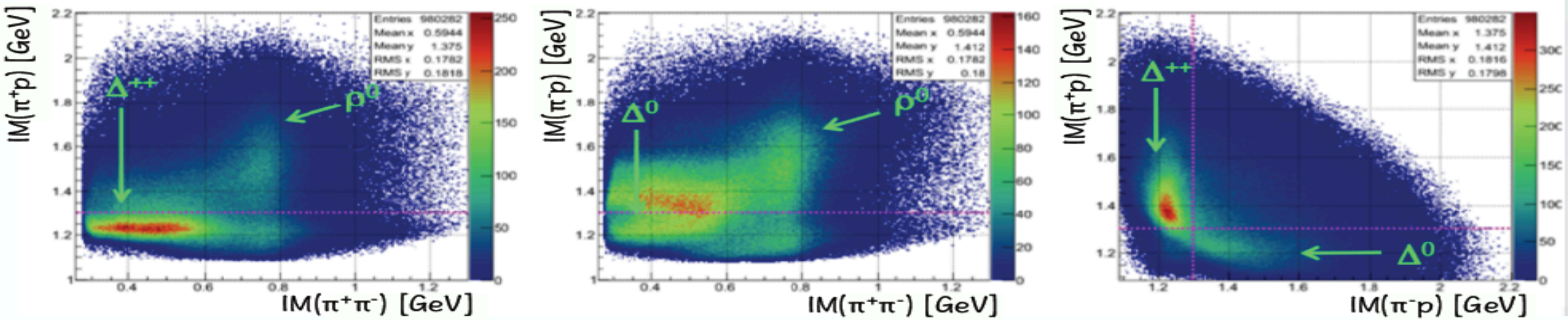
$\gamma p \longrightarrow \pi^-\Delta^{++} \longrightarrow \pi^+\pi^- p$

$\gamma p \longrightarrow \pi^+\Delta^0 \longrightarrow \pi^+\pi^- p$

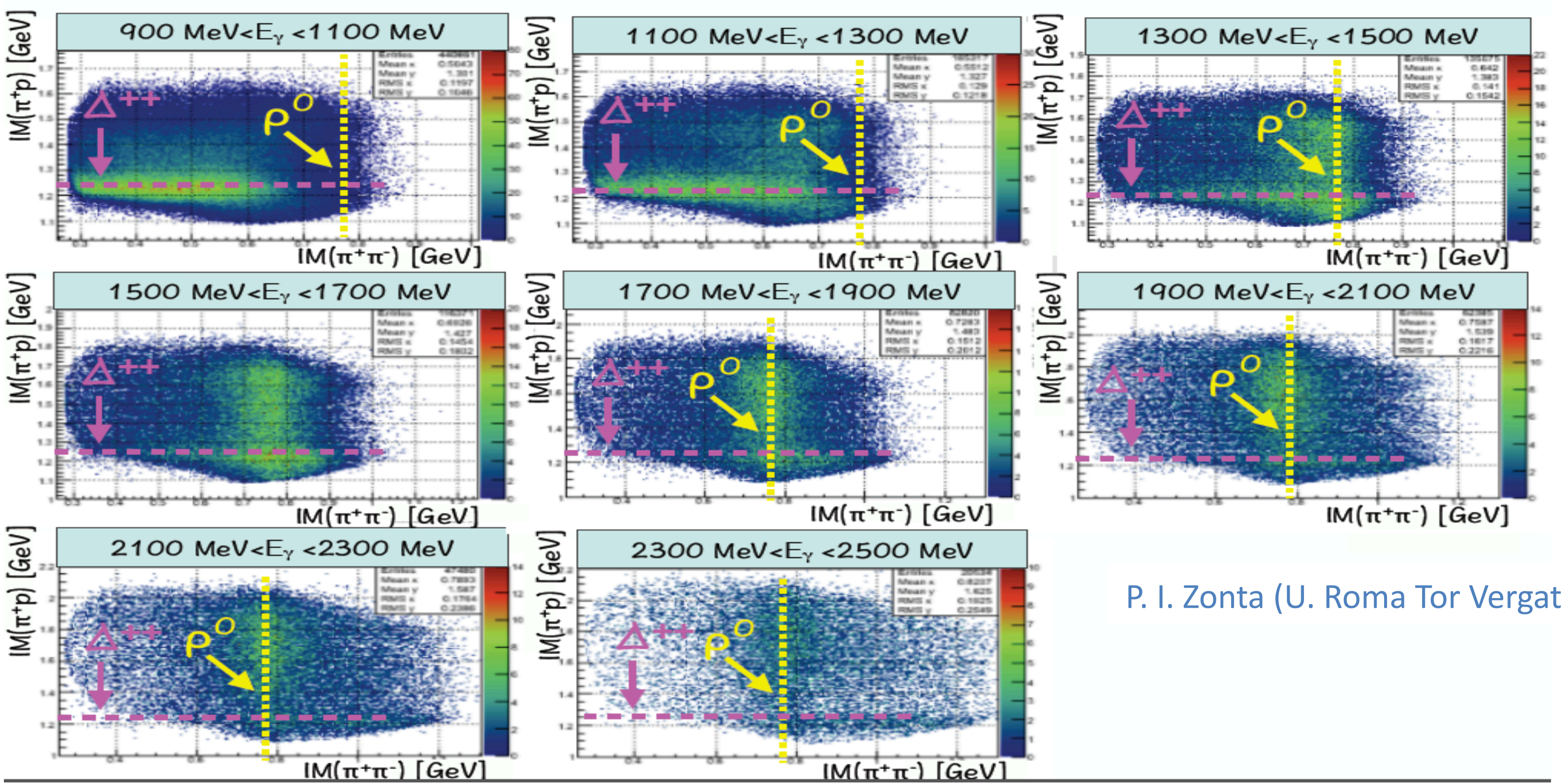
$\gamma p \longrightarrow \pi^+\pi^- p$

$IM(\pi^+\pi^-)$ spectrum



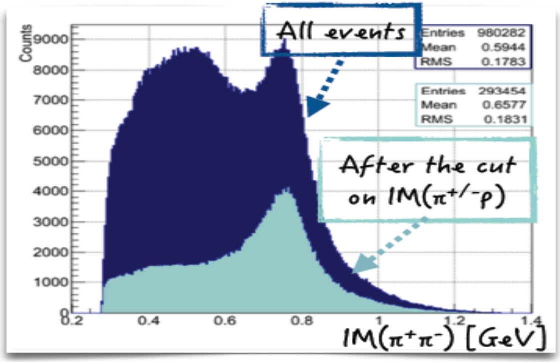


$\gamma p \rightarrow \rho p \rightarrow \pi^+\pi^- p$

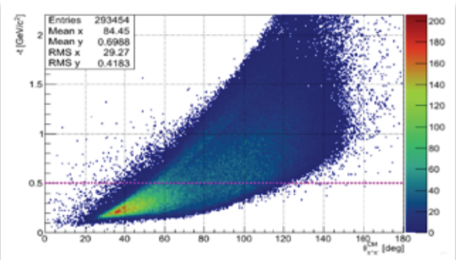


P. I. Zonta (U. Roma Tor Vergata)

$\gamma p \rightarrow \rho p \rightarrow \pi^+\pi^- p$

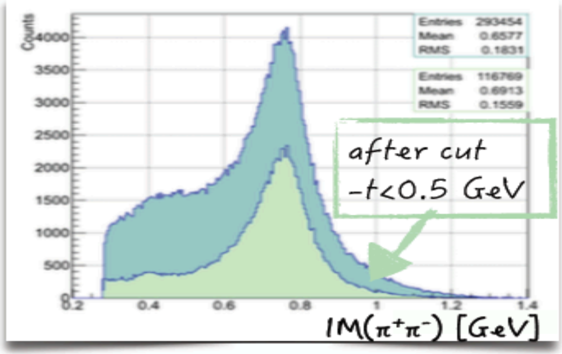


2) SELECTION: cut on $-t<0.5$ GeV

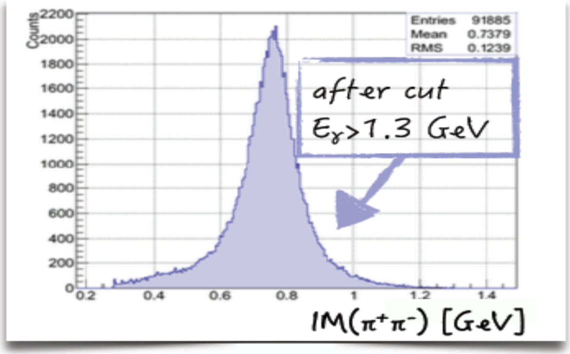


$-t$ vs. $\theta(\pi^+\pi^-)^{CM}$

3) SELECTION: cut on $E_\gamma>1.3$ GeV



Final $IM(\pi^+\pi^-)$ spectrum

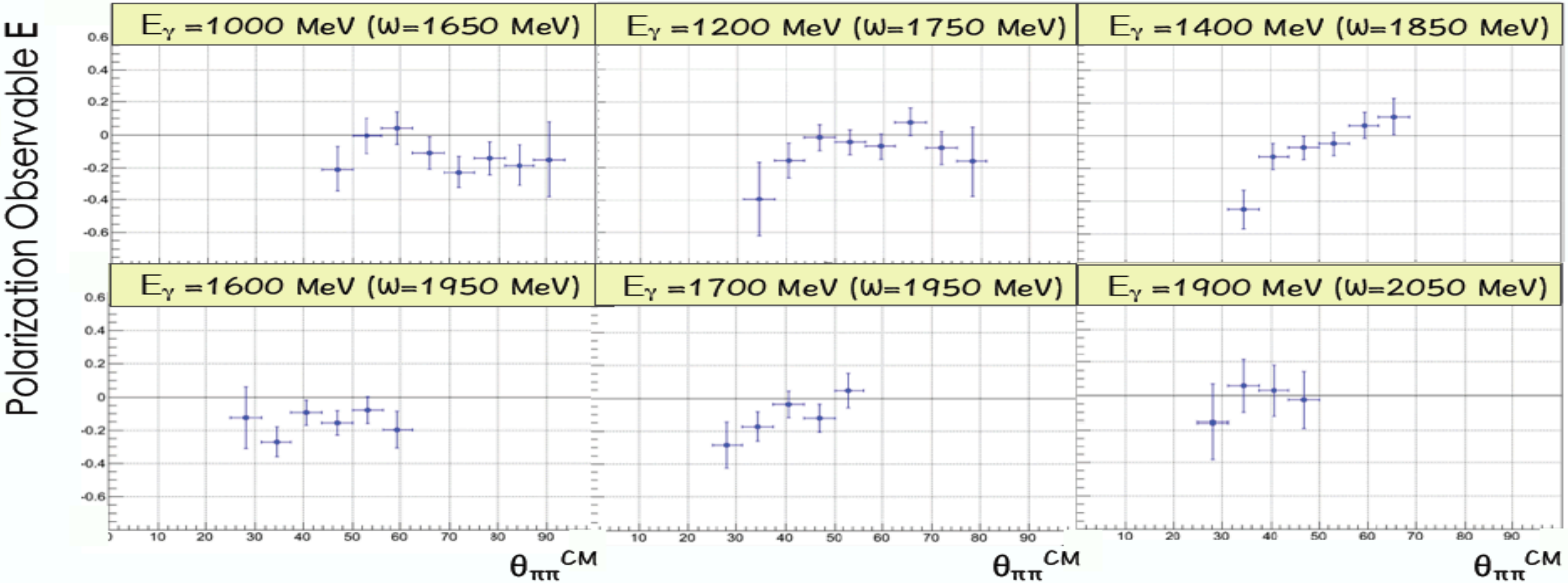


Events selection:

- $Im(p\pi^+)>1.3$ GeV
- $Im(p\pi^-)>1.3$ GeV
- $t<0.5$ GeV
- $E_\gamma>1.3$ GeV

P. I. Zonta (U. Roma Tor Vergata)

$\gamma p \rightarrow \rho p \rightarrow \pi^+\pi^- p$



- g14 data HD-ICE target

- First measurement of the beam-target asymmetry

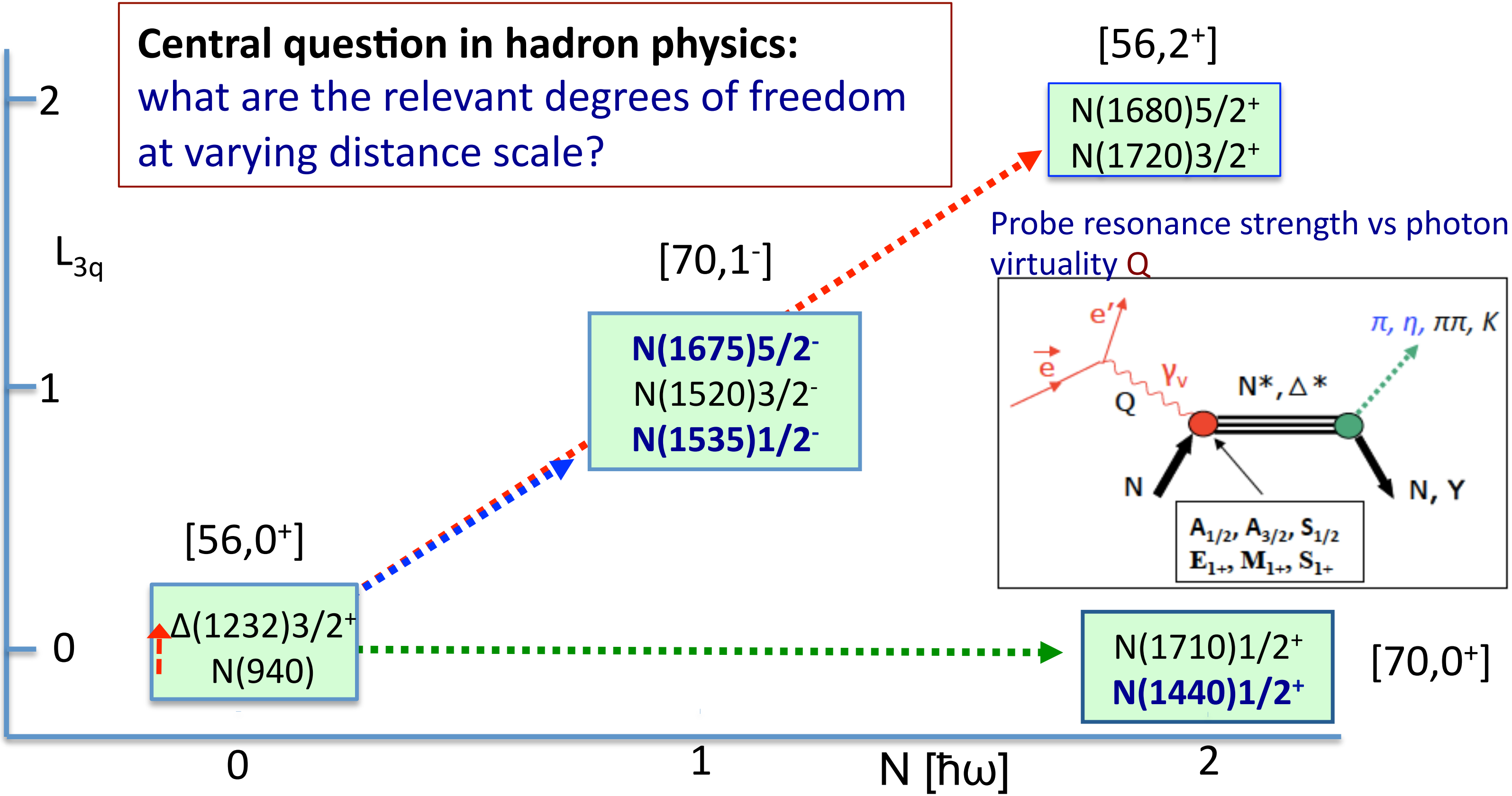
Very preliminary

P. I. Zonta (U. Roma Tor Vergata)

Electroexcitation of N*/Δ resonances

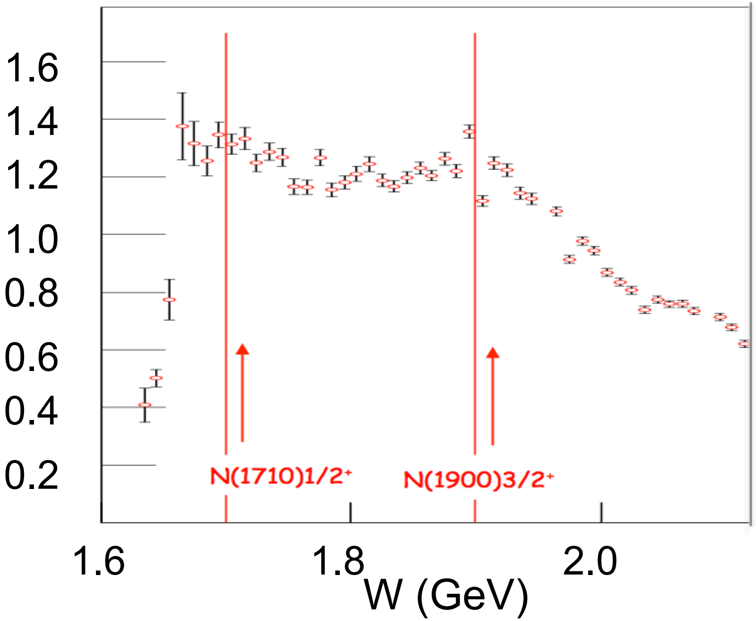
Central question in hadron physics:
what are the relevant degrees of freedom at varying distance scale?

Probe resonance strength vs photon virtuality Q

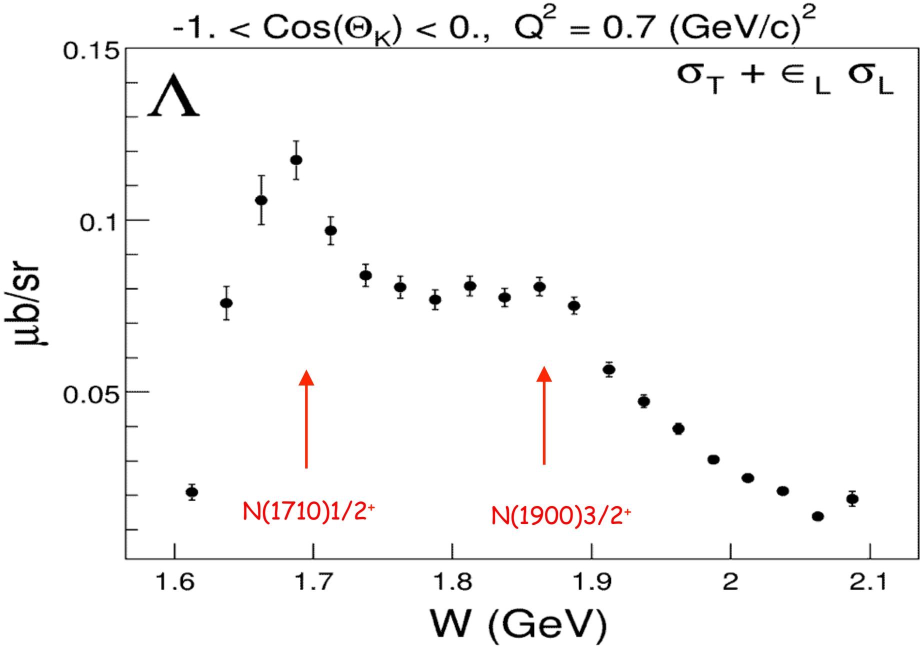


Studying Baryons in γ*p → KΛ/Σ ?

Photoproduction

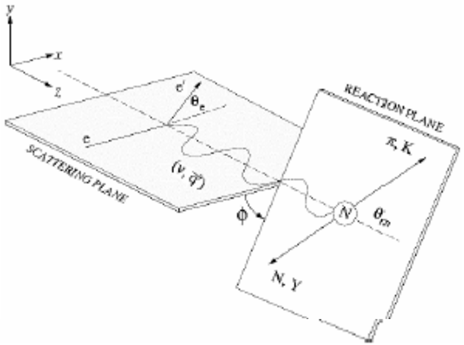


Electroproduction



Strangeness electroproduction is a fertile ground in studying S=0 baryon states with masses above 1.6 GeV.

Electroexcitation kinematics



$$\frac{d^4\sigma}{dQ^2dW\,d\Omega_K} = \Gamma(Q^2,W)\times\frac{d\sigma}{d\Omega_K}\left(Q^2,W,\Theta_K,\varepsilon,\phi\right)$$

Virtual photon flux

Electroproduction cross section

Transverse

Transverse-tra e interference

Helicity structure

$$\frac{d\sigma}{d\Omega_K} = \sigma_T + \varepsilon_L\sigma_L + \varepsilon\sigma_{TT}\cos(2\phi) + \sqrt{2\varepsilon_L(\varepsilon+1)}\sigma_{LT}\cos(\phi) + h\sqrt{2\varepsilon_L(1-\varepsilon)}\sigma_{LT'}$$

σ_u "Unseparated"

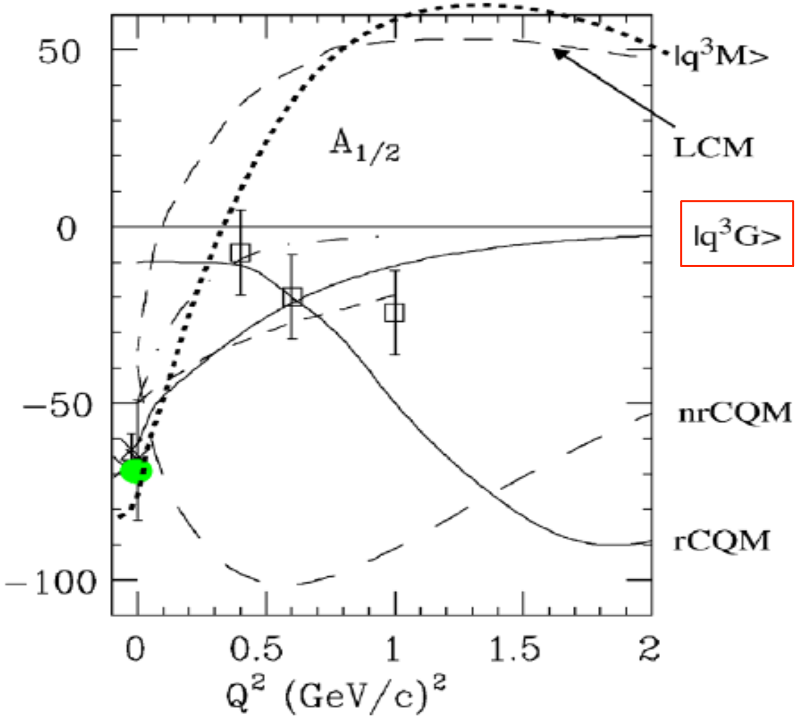
Longitudinal (sensitive to J=0± exchange in t-channel: mesons, diquarks)

Transverse-longitudinal interference

Measured σ are decomposed using UIM or fixed-t DR to extract N* & Δ helicity amplitudes.

Electrocouplings of the ‘Roper’ in 2002

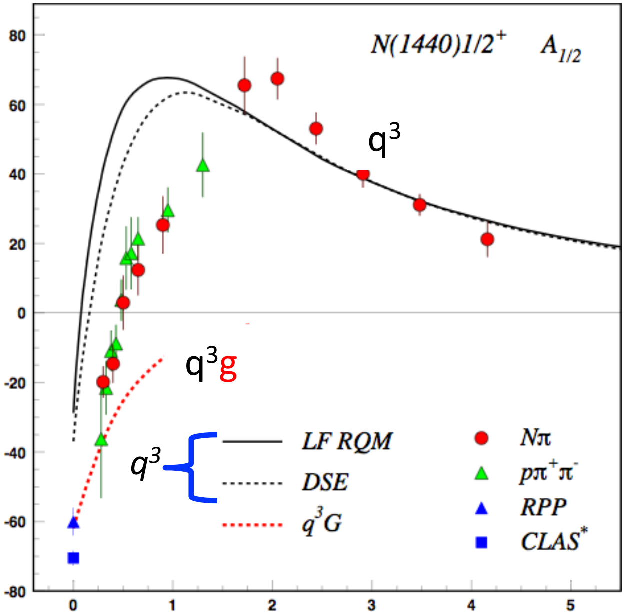
N(1440)1/2$^+$

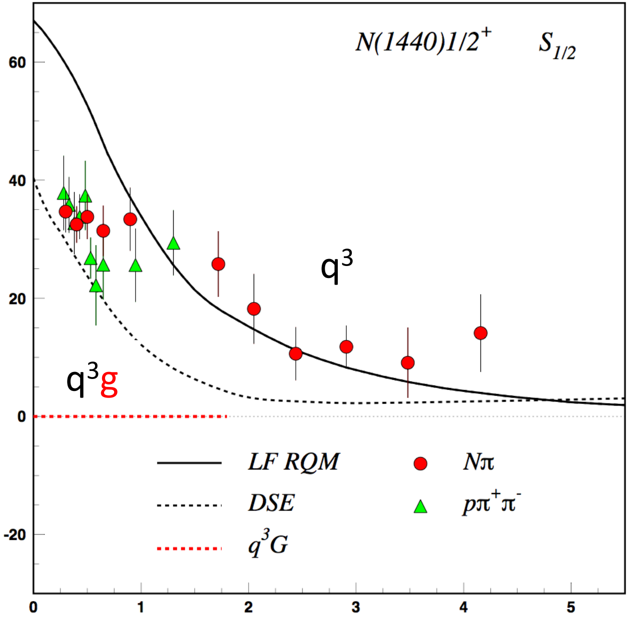


In 2002 Roper amplitude $A_{1/2}$ measurements were more consistent with hybrid state but data were limited with large uncertainties.

Separating q^3g from q^3 states ?

CLAS results on electrocouplings clarified nature of the Roper: the structure is driven by the interplay of the core of three dressed quarks and the 1st radial excitation of the external meson-baryon cloud





Will CLAS12 data be able to identify gluonic contributions ?

For hybrid "Roper", $A_{1/2}(Q^2)$ drops off faster with Q^2 and $S_{1/2}(Q^2)$ ~ 0.

Hybrid Baryons: Baryons with Explicit Gluonic Degrees of Freedom

Hybrid hadrons with dominant gluonic contributions are predicted to exist by QCD.

Experimentally:

- **Hybrid mesons** |qqg> states may have exotic quantum numbers J^{PC} not available to pure |qq> states GlueX, MesonEx, COMPASS, PANDA ….

- **Hybrid baryons** |qqqg> have the same quantum numbers J^P as |qqq> electroproduction with CLAS12 (Hall B).

Theoretical predictions:

✧ MIT bag model - T. Barnes and F. Close, Phys. Lett. 123B, 89 (1983).

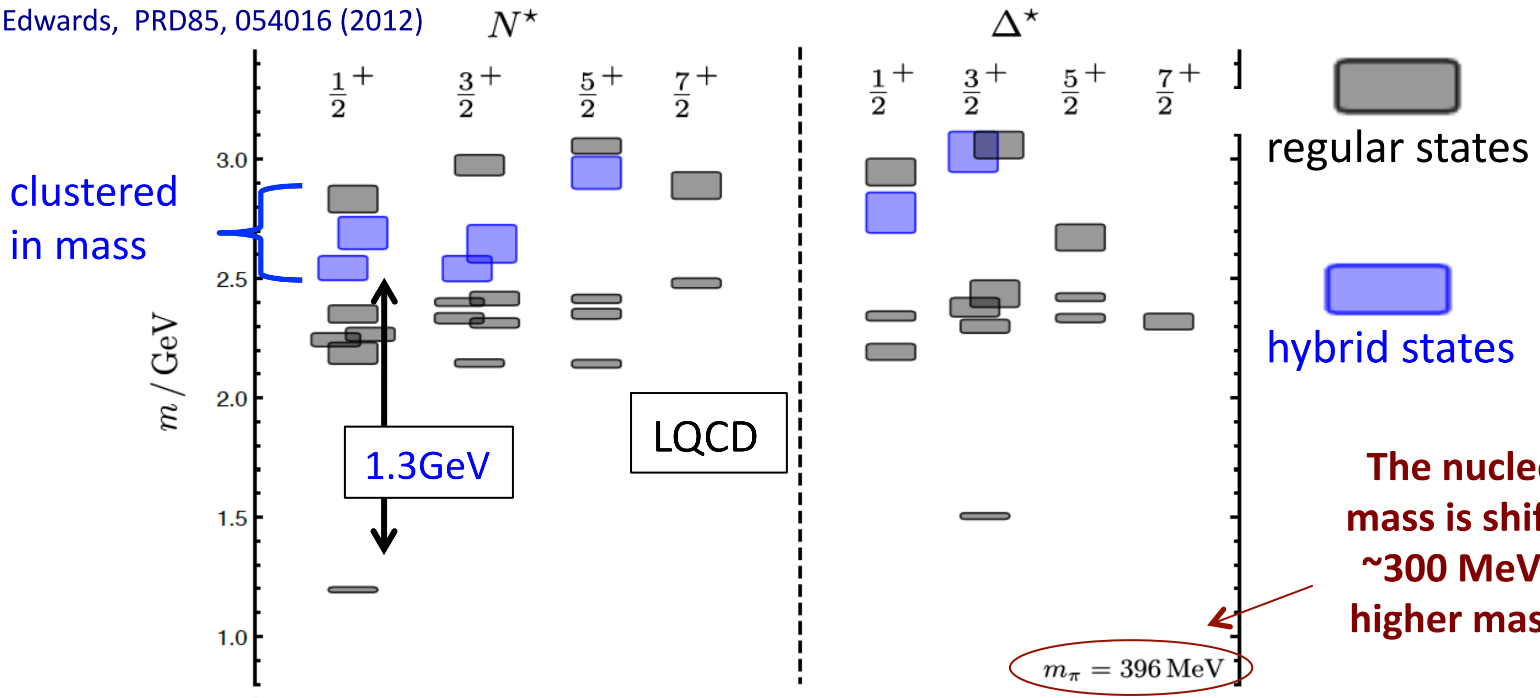
✧ QCD Sum Rule - L. Kisslinger and Z. Li, Phys. Rev. D 51, R5986 (1995).

✧ Flux Tube model - S. Capstick and P. R. Page, Phys. Rev. C 66, 065204 (2002).

✧ LQCD - J.J. Dudek and R.G. Edwards, PRD85, 054016 (2012).

Hybrid Baryons in LQCD

J.J. Dudek and R.G. Edwards, PRD85, 054016 (2012)



The nucleon mass is shifted ~300 MeV to higher masses

Hybrid states have same J^P values as qqq baryons. How to identify them?

- Overpopulation of N $1/2^+$ and N $3/2^+$ states compared to QM projections.
- **$A_{1/2}$ ($A_{3/2}$) and $S_{1/2}$ show different Q^2 evolution.**

Hybrid Baryon Signatures

Based on available knowledge, the ***signatures*** for hybrid baryons consist of***:***

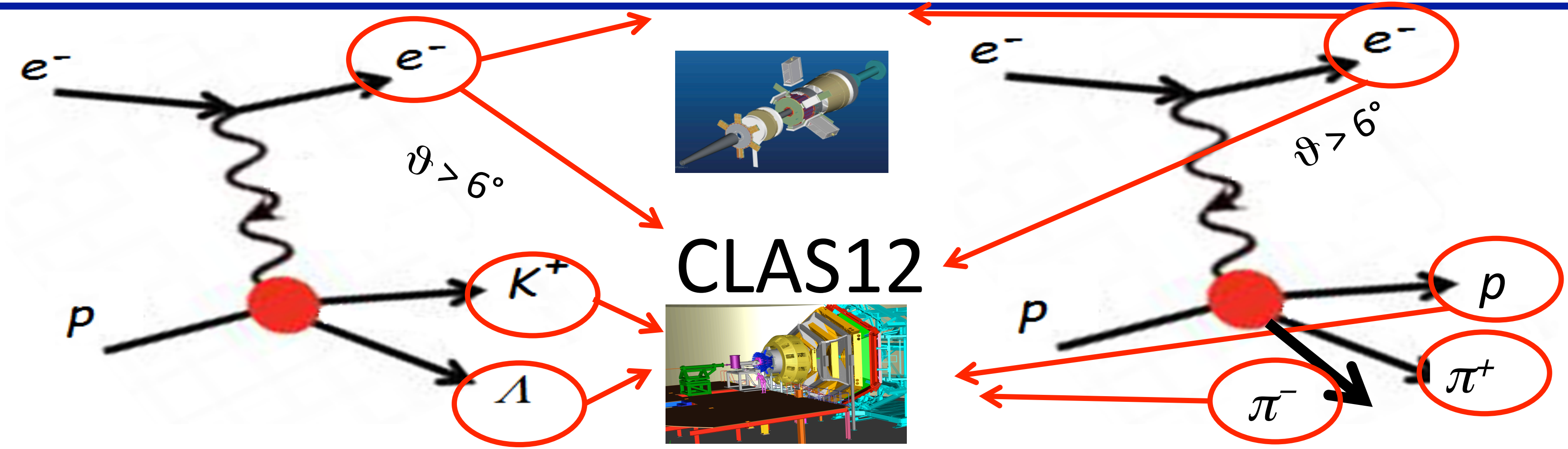
- **Extra resonances** with $J^p=1/2^+$ and $J^p=3/2^+$, with masses > 1.8 GeV and decays into $N\pi\pi$ or KY final states.
- A **drop** of the transverse helicity amplitudes $A_{1/2}(Q^2)$ and $A_{3/2}(Q^2)$ faster than for ordinary three quark states, because of extra glue-component in valence structure.
- A **suppressed** longitudinal amplitude $S_{1/2}(Q^2)$ in comparison with transverse electro-excitation amplitude ($J^P=1/2^+$).

We focused on:

$$e\,p \longrightarrow e\,p\,\pi^+\pi^-$$

$$e\,p \longrightarrow e\,K^+\Lambda,\ e\,K^+\Sigma^0$$

The Experiment



Scattered electrons will be detected:

- in the Forward Tagger for angles from 2.5° to 4.5°
- in the Forward Detector of CLAS12 for scattering angles greater than about 6°

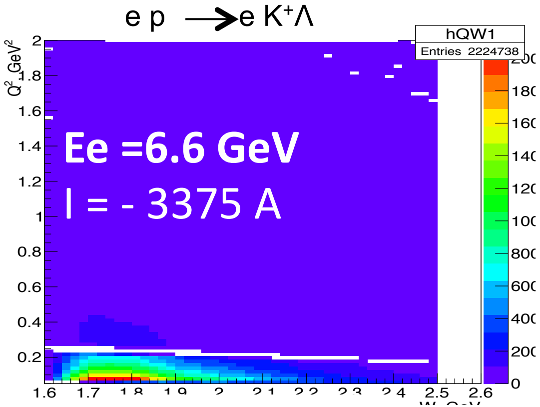
Charged hadrons will be measured in the full range from 6° to 130°

$$Q^2 = 4E_{Beam}E_{e'}\sin^2\frac{\vartheta}{2} \quad \Rightarrow \quad \vartheta < 5°$$

W < 3 GeV Q^2 range of interest: **0.05 - 2 GeV²**

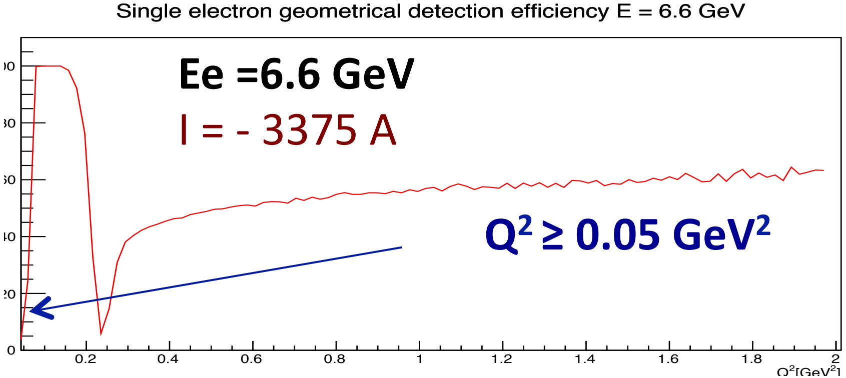
FT allows to probe the **crucial Q^2 range** where hybrid baryons may be identified due to their fast dropping $A_{1/2}(Q^2)$ amplitude and the suppression of the scalar $S_{1/2}(Q^2)$ amplitude.

Kinematical Coverage: Full Q^2 Range



Ee =6.6 GeV

I = - 3375 A



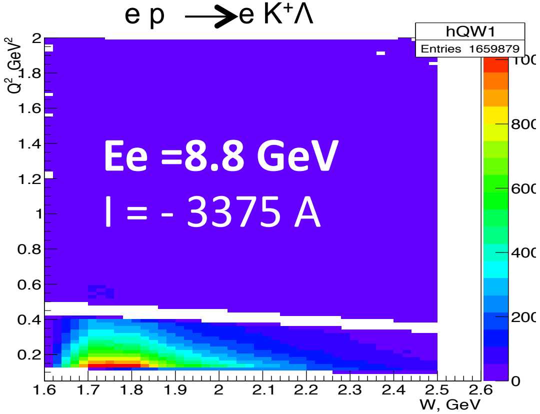
Single electron geometrical detection efficiency E = 6.6 GeV

Ee =6.6 GeV

I = - 3375 A

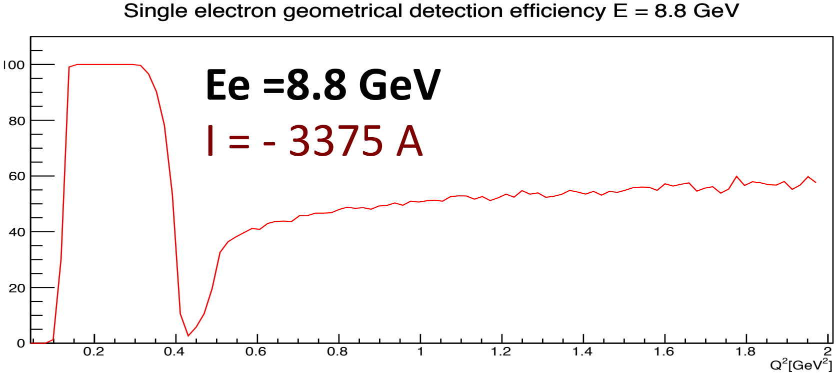
$Q^2 \geq 0.05$ GeV^2

^{2} as low as 0.05 GeV^2 may be reached



Ee =8.8 GeV

I = - 3375 A



Single electron geometrical detection efficiency E = 8.8 GeV

Ee =8.8 GeV

I = - 3375 A

Quasi – Data Analysis

A hypothetical hybrid baryon contribution added at the amplitude level to the best presently available model RPR-2011:
M_R = 2.2 GeV Γ_R=0.25 GeV $J^P = 1/2^+$ ($J^P = 3/2^+$)

The reaction cross section has been calculated with and without the hybrid baryon resonance contribution to determine:

1. Minimum beam time needed to obtain statistical uncertainty for cross sections comparable with CLAS photoproduction data.
   → 100 days of beam time (50 days at 6.6 GeV & 50 days at 8.8 GeV)
2. The Legendre moments of the unseparated and polarization interference components of the cross section.
   → Search for distinctive structures due to the added resonance.
3. The statistical sensitivity to hybrid baryons electrocouplings.
   → Minimum electrocoupling values with 100 days of beam time.

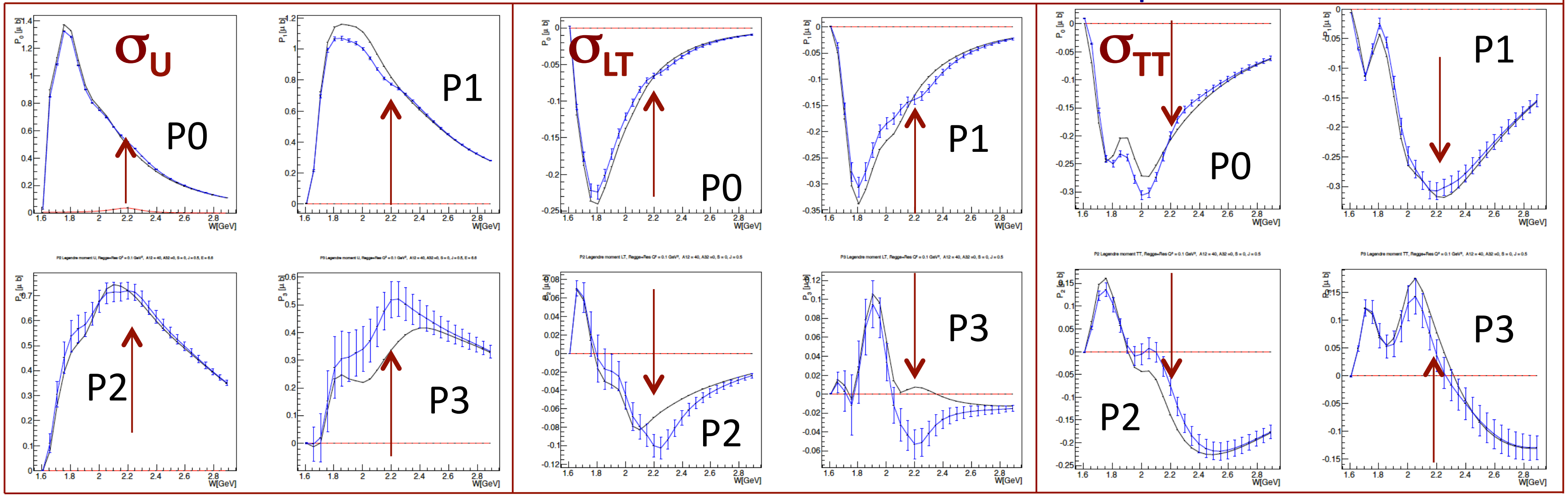
4. The capability of extracting the added resonance parameters from expected data.
   → Blind analysis of quasi-data.

Extraction of Legendre Moments

$e\,p \rightarrow e\,K^+\Lambda$ First Legendre Moments

Black curves RPR 2011 model

Blue points RPR 2011 + Resonance



- J = ½ Regge + Res. $Q^2 = 1\ \mathrm{GeV}^2$ $M_{res} = 2.2\ \mathrm{GeV}$ $A_{1/2} = 0.04\ \mathrm{GeV}^{-1/2}$ $S_{1/2} = 0$

Significant structures appear in most of the Legendre moments at the value of W = 2.2 GeV, corresponding to the mass of the added hybrid baryon

Statistical Sensitivity of Resonance Electrocouplings

$e\,p \longrightarrow e\,K^+Y$

Regge + Resonance (RPR-2011) Gent model

Fixing the resonance parameters: M_{res} = 2.2 GeV, Γ_{res} = 0.25 GeV, $S_{1/2}$ = 0
and varying $A_{1/2,\,3/2}$ $\longrightarrow$ **Minimum values for hybrid baryons electrocouplings**

$$\chi^2/d.p. = \frac{1}{N_{d.p.}} \sum_{W,\cos\theta^*\phi} \frac{(d\sigma_{\text{mod}} - d\sigma_{\text{mod+}res})^2}{(d\sigma_{\text{mod}} + d\sigma_{\text{mod+}res})/N_{ev}}$$

Q^2 (GeV^2)	$J_R = 1/2$		$J_R = 3/2$		
X 10^{-3} (GeV$^{-1/2}$)	$A_{1/2}$	$S_{1/2}$	$A_{1/2}$	$A_{3/2}$	$S_{1/2}$
0.1	9.5	9.5	13	8.5	8.5
0.5	14	16	15	15	10
1.0	13	19	14	14	7.5

To be compared with N(1440)1/2$^+$

Q^2 (GeV^2)	0.	0.65	1.3
$A_{1/3}$ x 10^{-3}(GeV$^{-1/2}$)	-70	10	30

Blind Extraction: $J^P=1/2^+ + J^P=3/2^+$

Two hybrid baryon resonances with $J^p = 1/2^+$ and $J^p = 3/2^+$ were inserted in the ep → e $K^+\Lambda$ Gent RPR2011 reaction amplitude and **quasi-data** were generated → $d\sigma_{q.d.}$

A blind analysis has been then attempted trying to extract the resonances J^P spin-parities and

7 unknown parameters: M_{res}^1 Γ_{res}^1 $A_{1/2}^1$
M_{res}^2 Γ_{res}^2 $A_{1/2}^2$ $A_{3/2}^2$

Searching the minimum of the quantity:

$$\chi^2 / d.p. = \frac{1}{N_{d.p.}} \sum_{W,\cos\theta^*,\phi} \frac{(d\sigma_{th} - d\sigma_{q.d.})^2}{(d\sigma_{q.d.})/N_{ev}}$$

$d\sigma_{th}$ were calculated using the **Gent RPR2011** amplitudes including two resonances $J^p = 1/2^+$ and $J^p = 3/2^+$, whose parameters values were scanned in the range:

$2.0 < W < 2.5$ GeV	$-0.05 < A_{1/2} < +0.05$ GeV$^{-1/2}$
$0.1 < \Gamma < 0.4$ GeV	$-0.05 < A_{3/2} < +0.05$ GeV$^{-1/2}$

at a fixed $Q^2 = 0.5$ GeV^2

$S_{1/2} = 0$

Blind Extraction: $J^P=1/2^+$ + $J^P=3/2^+$

Two hybrid baryon resonances with $J^p = 1/2^+$ and $J^p = 3/2^+$ were inserted in the $ep \longrightarrow e K^+\Lambda$ Gent RPR2011 reaction amplitude and **quasi-data** were generated $\longrightarrow$ **$d\sigma_{q.d.}$**

A blind analysis has been then attempted trying to extract the resonances J^P spin-parities and

7 unknown parameters: M_{res}^1 Γ_{res}^1 $A_{1/2}^1$
M_{res}^2 Γ_{res}^2 $A_{1/2}^2$ $A_{3/2}^2$

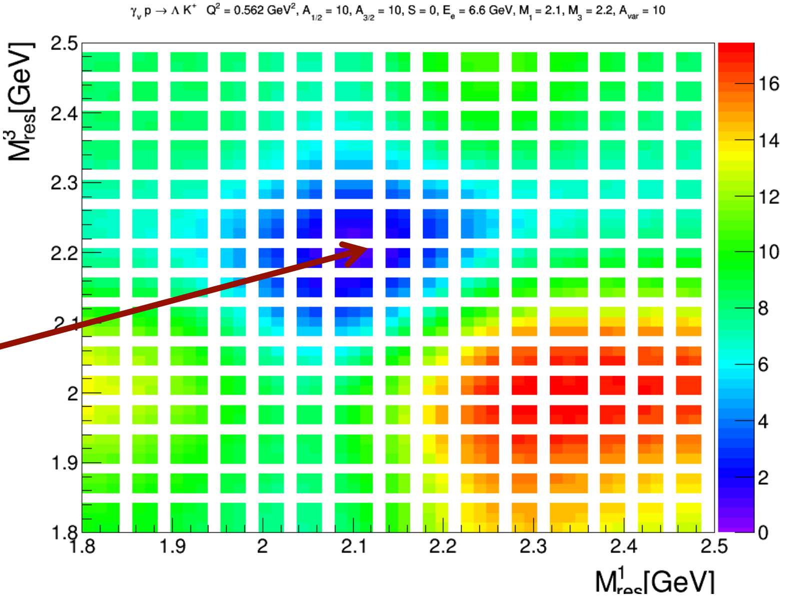
Iterative procedure:

- The algorithm calculates the χ^2 value over a 7-dim parameters coarse grid, covering the full range
- The combination of parameters corresponding to the minimum χ^2 value is found
- χ^2 value is calculated over a finer 7-dim parameters grid, around the minimum
- The procedure is repeated three times.

Blind Extraction: $J^P=1/2^+ + J^P=3/2^+$

Two hybrid baryon resonances with $J^p = 1/2^+$ and $J^p = 3/2^+$ were inserted in the ep $\longrightarrow$ e $K^+\Lambda$ Gent RPR2011 reaction amplitude and **quasi-data** were generated $\longrightarrow$ **$d\sigma_{q.d.}$**

Typical 3-dim map of χ^2 as a function of the two resonance masses, evolving in time for increasing $A_{1/2}$ ($A_{3/2}$) strength.



χ^2 minimum

Blind Extraction: $J^P=1/2^+ + J^P=3/2^+$

Two hybrid baryon resonances with $J^p = 1/2^+$ and $J^p = 3/2^+$ were inserted in the $ep \longrightarrow e K^+\Lambda$ Gent RPR2011 reaction amplitude and **quasi-data** were generated $\longrightarrow$ $d\sigma_{q.d.}$

A blind analysis has been then attempted trying to extract the resonances J^P spin-parities and 7 unknown parameters: M_{res}^1 Γ_{res}^1 $A_{1/2}^1$ M_{res}^2 Γ_{res}^2 $A_{1/2}^2$ $A_{3/2}^2$

Hybrid Baryons parameters are well reconstructed.

Blind Resonance Parameters	Extracted Resonance Parameters
M_{res}^1 = 2.30 GeV	M_{res}^1 = 2.32 GeV
Γ_{res}^1 = 0.30 GeV	Γ_{res}^1 = 0.30 GeV
$A_{1/2}^1$ = 0.020 $GeV^{-1/2}$	$A_{1/2}^1$ = 0.019 $GeV^{-1/2}$
M_{res}^2 = 2.45 GeV	M_{res}^2 = 2.45 GeV
Γ_{res}^2 = 0.35 GeV	Γ_{res}^2 = 0.31 GeV
$A_{1/2}^2$ = - 0.015 $GeV^{-1/2}$	$A_{1/2}^2$ = - 0.014 $GeV^{-1/2}$
$A_{3/2}^2$ = 0.04 $GeV^{-1/2}$	$A_{3/2}^2$ = 0.038 $GeV^{-1/2}$

Baryon Spectroscopy Status Today

- Major progress made in the last ~ 5 years in the search for N* and Δ states.
  All states can be accommodated in CQM and LQCD schemes.
    - Non-dynamical di-quark models are ruled out.

- Knowledge of Q^2-dependence of electrocouplings is absolutely necessary to understand the nature (the internal structure) of the excited states.
    - Roper IS the first radial excitation of the q^3 core, obscured at large distances by meson-cloud effects.
- Leading electrocoupling amplitudes of prominent low-mass states (e.g. N(1535)1/2^-) is well modeled by DSE/QCD, LC SR and LF RQM for Q^2> 2 GeV.

- Search for hybrid baryons with explicit gluonic degrees of freedom would be possible investigating the low Q^2 evolution of high-mass resonance (2-3 GeV) electrocoupligs:
    - Looking for suppressed $A^{1/2}$, $A^{3/2}$, $S^{1/2}$ at low $Q^{2.}$