N* Physics with Meson Photoproduction at CLAS

D. G. Ireland

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BARYON SPECTROSCOPY

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In 1952 Fermi and coworkers (Andersen et al. [1952]) discovered the first baryon resonance – the $\Delta(1238)$. Since then, hundreds of resonances have been identified and nuclear democracy has given way to fundamental quarks. Baryon spectroscopy is now thirty years old and perhaps approaching a mid-life crisis. For it is inevitable in such a fast-moving field as high energy particle physics, that experiments have moved on beyond the resonance region to higher energies and different priorities. Thus it is probably no exaggeration to say that we now have essentially *all* the experimental data relevant to the low-energy baryon spectrum, that we are *ever* likely to obtain. It is therefore timely to review both the accumulated mass of resonance data, together with the techniques used in its analysis, and also our theoretical framework for understanding the results. The latter is inevitably based on quarks and, by and large, on a

Baryon Summary Table (PDG 2004)

p	P_{11}	****
n	P_{11}	****
$N(1440)$	P_{11}	****
$N(1520)$	D_{13}	****
$N(1535)$	S_{11}	****
$N(1650)$	S_{11}	****
$N(1675)$	D_{15}	****
$N(1680)$	F_{15}	****
$N(1700)$	D_{13}	***
$N(1710)$	P_{11}	***
$N(1720)$	P_{13}	****
$N(1900)$	P_{13}	**
$N(1990)$	F_{17}	**
$N(2000)$	F_{15}	**
$N(2080)$	D_{13}	**
$N(2090)$	S_{11}	*
$N(2100)$	P_{11}	*
$N(2190)$	G_{17}	****
$N(2200)$	D_{15}	**
$N(2220)$	H_{19}	****
$N(2250)$	G_{19}	****
$N(2600)$	$I_{1,11}$	***
$N(2700)$	$K_{1,13}$	**

$\Delta(1232)$	P_{33}	****
$\Delta(1600)$	P_{33}	***
$\Delta(1620)$	S_{31}	****
$\Delta(1700)$	D_{33}	****
$\Delta(1750)$	P_{31}	*
$\Delta(1900)$	S_{31}	**
$\Delta(1905)$	F_{35}	****
$\Delta(1910)$	P_{31}	****
$\Delta(1920)$	P_{33}	***
$\Delta(1930)$	D_{35}	***
$\Delta(1940)$	D_{33}	*
$\Delta(1950)$	F_{37}	****
$\Delta(2000)$	F_{35}	**
$\Delta(2150)$	S_{31}	*
$\Delta(2200)$	G_{37}	*
$\Delta(2300)$	H_{39}	**
$\Delta(2350)$	D_{35}	*
$\Delta(2390)$	F_{37}	*
$\Delta(2400)$	G_{39}	**
$\Delta(2420)$	$H_{3,11}$	****
$\Delta(2750)$	$I_{3,13}$	**
$\Delta(2950)$	$K_{3,15}$	**
$\Theta(1540)^+$		***
$\Phi(1860)$		*

Λ	P_{01}	****
$\Lambda(1405)$	S_{01}	****
$\Lambda(1520)$	D_{03}	****
$\Lambda(1600)$	P_{01}	***
$\Lambda(1670)$	S_{01}	****
$\Lambda(1690)$	D_{03}	****
$\Lambda(1800)$	S_{01}	***
$\Lambda(1810)$	P_{01}	***
$\Lambda(1820)$	F_{05}	****
$\Lambda(1830)$	D_{05}	****
$\Lambda(1890)$	P_{03}	****
$\Lambda(2000)$		*
$\Lambda(2020)$	F_{07}	*
$\Lambda(2100)$	G_{07}	****
$\Lambda(2110)$	F_{05}	***
$\Lambda(2325)$	D_{03}	*
$\Lambda(2350)$	H_{09}	***
$\Lambda(2585)$		**

Σ^+	P_{11}	****
Σ^0	P_{11}	****
Σ^-	P_{11}	****
$\Sigma(1385)$	P_{13}	****
$\Sigma(1480)$		*
$\Sigma(1560)$		**
$\Sigma(1580)$	D_{13}	**
$\Sigma(1620)$	S_{11}	**
$\Sigma(1660)$	P_{11}	***
$\Sigma(1670)$	D_{13}	****
$\Sigma(1690)$		**
$\Sigma(1750)$	S_{11}	***
$\Sigma(1770)$	P_{11}	*
$\Sigma(1775)$	D_{15}	****
$\Sigma(1840)$	P_{13}	*
$\Sigma(1880)$	P_{11}	**
$\Sigma(1915)$	F_{15}	****
$\Sigma(1940)$	D_{13}	***
$\Sigma(2000)$	S_{11}	*
$\Sigma(2030)$	F_{17}	****
$\Sigma(2070)$	F_{15}	*
$\Sigma(2080)$	P_{13}	**
$\Sigma(2100)$	G_{17}	*
$\Sigma(2250)$		***
$\Sigma(2455)$		**
$\Sigma(2620)$		**
$\Sigma(3000)$		*
$\Sigma(3170)$		*

Ξ^0	P_{11}	****
Ξ^-	P_{11}	****
$\Xi(1530)$	P_{13}	****
$\Xi(1620)$		*
$\Xi(1690)$		***
$\Xi(1820)$	D_{13}	***
$\Xi(1950)$		***
$\Xi(2030)$		***
$\Xi(2120)$		*
$\Xi(2250)$		**
$\Xi(2370)$		**
$\Xi(2500)$		*
Ω^-		****
$\Omega(2250)^-$		***
$\Omega(2380)^-$		**
$\Omega(2470)^-$		**
Λ_c^+		****
$\Lambda_c(2593)^+$		***
$\Lambda_c(2625)^+$		***
$\Lambda_c(2765)^+$		*
$\Lambda_c(2880)^+$		**
$\Sigma_c(2455)$		****
$\Sigma_c(2520)$		***
Ξ_c^+		***
Ξ_c^0		***
$\Xi_c'^+$		***
$\Xi_c'^0$		***
$\Xi_c(2645)$		***
$\Xi_c(2790)$		***
$\Xi_c(2815)$		***
Ω_c^0		***
Ξ_{cc}^+		*
Λ_b^0		***
Ξ_b^0, Ξ_b^-		*

Number of 3- and 4-star Resonances

Baryon	2004	
N*	15	
Δ	10	
Λ	14	
Σ	12	
Ξ	7	
Ω	2	
other	14	

Baryon Summary Table (PDG 2014)

p	$1/2^+$	****
n	$1/2^+$	****
$N(1440)$	$1/2^+$	****
$N(1520)$	$3/2^-$	****
$N(1535)$	$1/2^-$	****
$N(1650)$	$1/2^-$	****
$N(1675)$	$5/2^-$	****
$N(1680)$	$5/2^+$	****
$N(1685)$		*
$N(1700)$	$3/2^-$	***
$N(1710)$	$1/2^+$	***
$N(1720)$	$3/2^+$	****
$N(1860)$	$5/2^+$	**
$N(1875)$	$3/2^-$	***
$N(1880)$	$1/2^+$	**
$N(1895)$	$1/2^-$	**
$N(1900)$	$3/2^+$	***
$N(1990)$	$7/2^+$	**
$N(2000)$	$5/2^+$	**
$N(2040)$	$3/2^+$	*
$N(2060)$	$5/2^-$	**
$N(2100)$	$1/2^+$	*
$N(2120)$	$3/2^-$	**
$N(2190)$	$7/2^-$	****
$N(2220)$	$9/2^+$	****
$N(2250)$	$9/2^-$	****
$N(2300)$	$1/2^+$	**
$N(2570)$	$5/2^-$	**
$N(2600)$	$11/2^-$	***
$N(2700)$	$13/2^+$	**

$\Delta(1232)$	$3/2^+$	****
$\Delta(1600)$	$3/2^+$	***
$\Delta(1620)$	$1/2^-$	****
$\Delta(1700)$	$3/2^-$	****
$\Delta(1750)$	$1/2^+$	*
$\Delta(1900)$	$1/2^-$	**
$\Delta(1905)$	$5/2^+$	****
$\Delta(1910)$	$1/2^+$	****
$\Delta(1920)$	$3/2^+$	***
$\Delta(1930)$	$5/2^-$	***
$\Delta(1940)$	$3/2^-$	**
$\Delta(1950)$	$7/2^+$	****
$\Delta(2000)$	$5/2^+$	**
$\Delta(2150)$	$1/2^-$	*
$\Delta(2200)$	$7/2^-$	*
$\Delta(2300)$	$9/2^+$	**
$\Delta(2350)$	$5/2^-$	*
$\Delta(2390)$	$7/2^+$	*
$\Delta(2400)$	$9/2^-$	**
$\Delta(2420)$	$11/2^+$	****
$\Delta(2750)$	$13/2^-$	**
$\Delta(2950)$	$15/2^+$	**
Λ	$1/2^+$	****
$\Lambda(1405)$	$1/2^-$	****
$\Lambda(1520)$	$3/2^-$	****
$\Lambda(1600)$	$1/2^+$	***
$\Lambda(1670)$	$1/2^-$	****
$\Lambda(1690)$	$3/2^-$	****
$\Lambda(1710)$	$1/2^+$	*
$\Lambda(1800)$	$1/2^-$	***
$\Lambda(1810)$	$1/2^+$	***
$\Lambda(1820)$	$5/2^+$	****
$\Lambda(1830)$	$5/2^-$	****
$\Lambda(1890)$	$3/2^+$	****
$\Lambda(2000)$		*
$\Lambda(2020)$	$7/2^+$	*
$\Lambda(2050)$	$3/2^-$	*
$\Lambda(2100)$	$7/2^-$	****
$\Lambda(2110)$	$5/2^+$	***
$\Lambda(2325)$	$3/2^-$	*
$\Lambda(2350)$	$9/2^+$	***
$\Lambda(2585)$		**

Σ^+	$1/2^+$	****
Σ^0	$1/2^+$	****
Σ^-	$1/2^+$	****
$\Sigma(1385)$	$3/2^+$	****
$\Sigma(1480)$		*
$\Sigma(1560)$		**
$\Sigma(1580)$	$3/2^-$	*
$\Sigma(1620)$	$1/2^-$	*
$\Sigma(1660)$	$1/2^+$	***
$\Sigma(1670)$	$3/2^-$	****
$\Sigma(1690)$		**
$\Sigma(1730)$	$3/2^+$	*
$\Sigma(1750)$	$1/2^-$	***
$\Sigma(1770)$	$1/2^+$	*
$\Sigma(1775)$	$5/2^-$	****
$\Sigma(1840)$	$3/2^+$	*
$\Sigma(1880)$	$1/2^+$	**
$\Sigma(1900)$	$1/2^-$	*
$\Sigma(1915)$	$5/2^+$	****
$\Sigma(1940)$	$3/2^+$	*
$\Sigma(1940)$	$3/2^-$	***
$\Sigma(2000)$	$1/2^-$	*
$\Sigma(2030)$	$7/2^+$	****
$\Sigma(2070)$	$5/2^+$	*
$\Sigma(2080)$	$3/2^+$	**
$\Sigma(2100)$	$7/2^-$	*
$\Sigma(2250)$		***
$\Sigma(2455)$		**
$\Sigma(2620)$		**
$\Sigma(3000)$		*
$\Sigma(3170)$		*

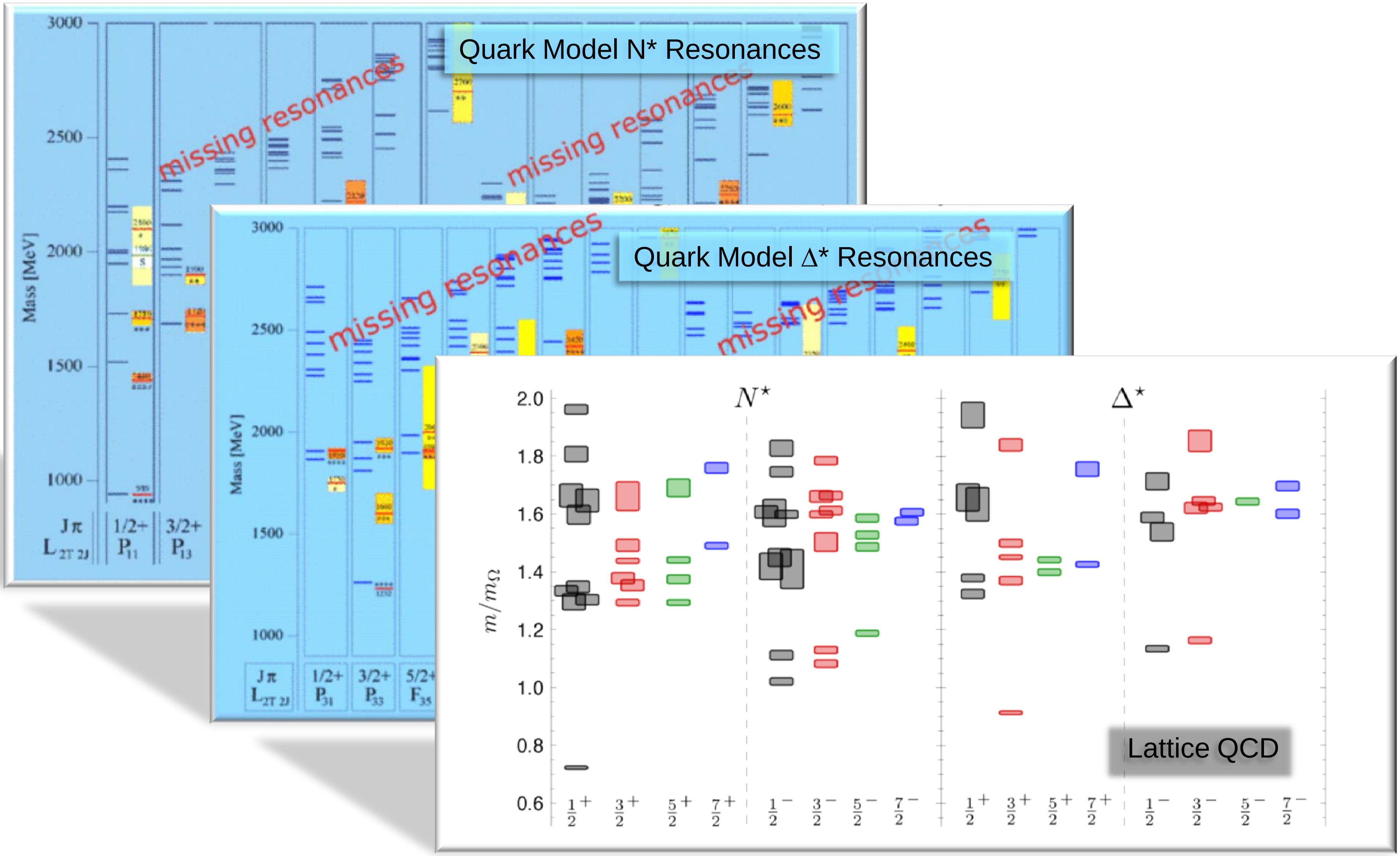
Ξ^0	$1/2^+$	****
Ξ^-	$1/2^+$	****
$\Xi(1530)$	$3/2^+$	****
$\Xi(1620)$		*
$\Xi(1690)$		***
$\Xi(1820)$	$3/2^-$	***
$\Xi(1950)$		***
$\Xi(2030)$	$\geq \frac{5}{2}?$	***
$\Xi(2120)$		*
$\Xi(2250)$		**
$\Xi(2370)$		**
$\Xi(2500)$		*
Ω^-	$3/2^+$	****
$\Omega(2250)^-$		***
$\Omega(2380)^-$		**
$\Omega(2470)^-$		**

Λ_c^+	$1/2^+$	****
$\Lambda_c(2595)^+$	$1/2^-$	***
$\Lambda_c(2625)^+$	$3/2^-$	***
$\Lambda_c(2765)^+$		*
$\Lambda_c(2880)^+$	$5/2^+$	***
$\Lambda_c(2940)^+$		***
$\Sigma_c(2455)$	$1/2^+$	****
$\Sigma_c(2520)$	$3/2^+$	***
$\Sigma_c(2800)$		***
Ξ_c^+	$1/2^+$	***
Ξ_c^0	$1/2^+$	***
$\Xi_c'^+$	$1/2^+$	***
$\Xi_c'^0$	$1/2^+$	***
$\Xi_c(2645)$	$3/2^+$	***
$\Xi_c(2790)$	$1/2^-$	***
$\Xi_c(2815)$	$3/2^-$	***
$\Xi_c(2930)$		*
$\Xi_c(2980)$		***
$\Xi_c(3055)$		**
$\Xi_c(3080)$		***
$\Xi_c(3123)$		*
Ω_c^0	$1/2^+$	***
$\Omega_c(2770)^0$	$3/2^+$	***
Ξ_{cc}^+		*
Λ_b^0	$1/2^+$	***
$\Lambda_b(5912)^0$	$1/2^-$	***
$\Lambda_b(5920)^0$	$3/2^-$	***
Σ_b	$1/2^+$	***
Σ_b^*	$3/2^+$	***
Ξ_b^0, Ξ_b^-	$1/2^+$	***
$\Xi_b(5945)^0$	$3/2^+$	***
Ω_b^-	$1/2^+$	***

Number of 3- and 4-star Resonances

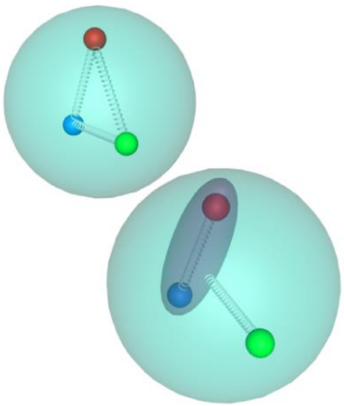
Baryon	2004	2014
N*	15	**17**
Δ	10	10
Λ	14	14
Σ	12	12
Ξ	7	**9**
Ω	2	2
other	14	**27**

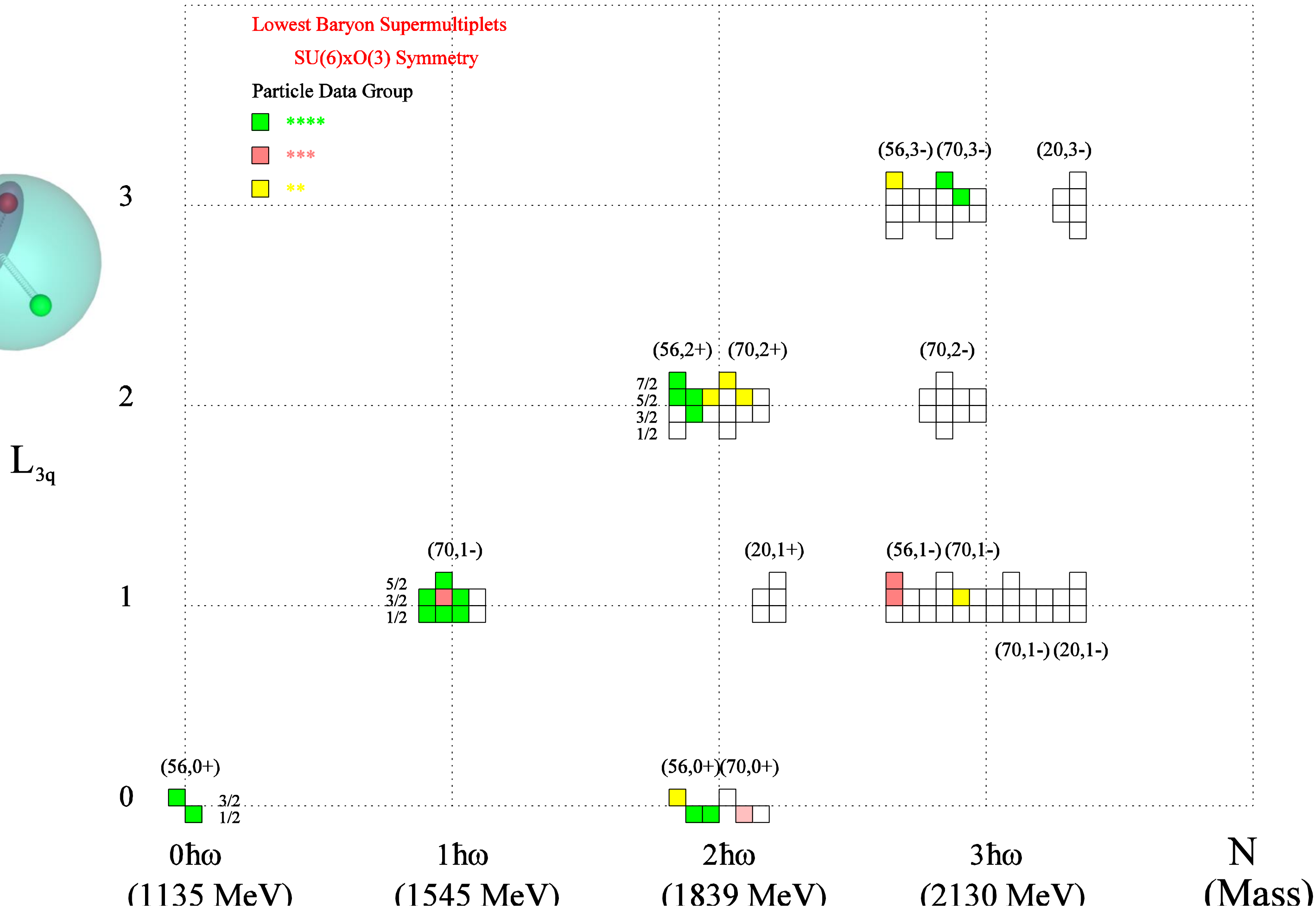
But...



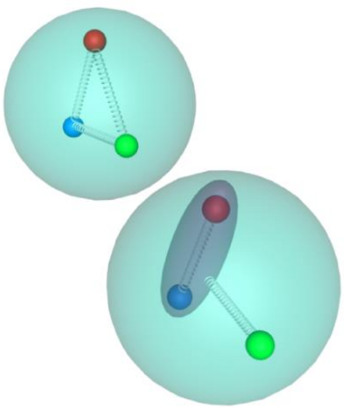
Quark Model N* Resonances
missing resonances
missing resonances
Quark Model Δ* Resonances
missing resonances
N*
Δ*
Lattice QCD

“Missing” Baryon Resonances



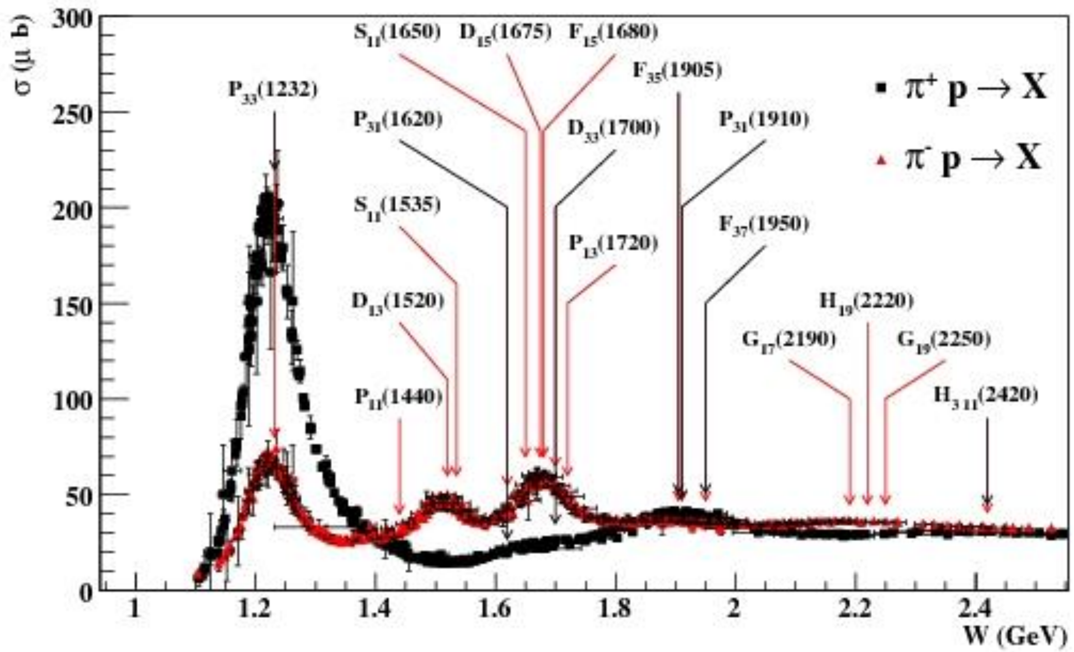


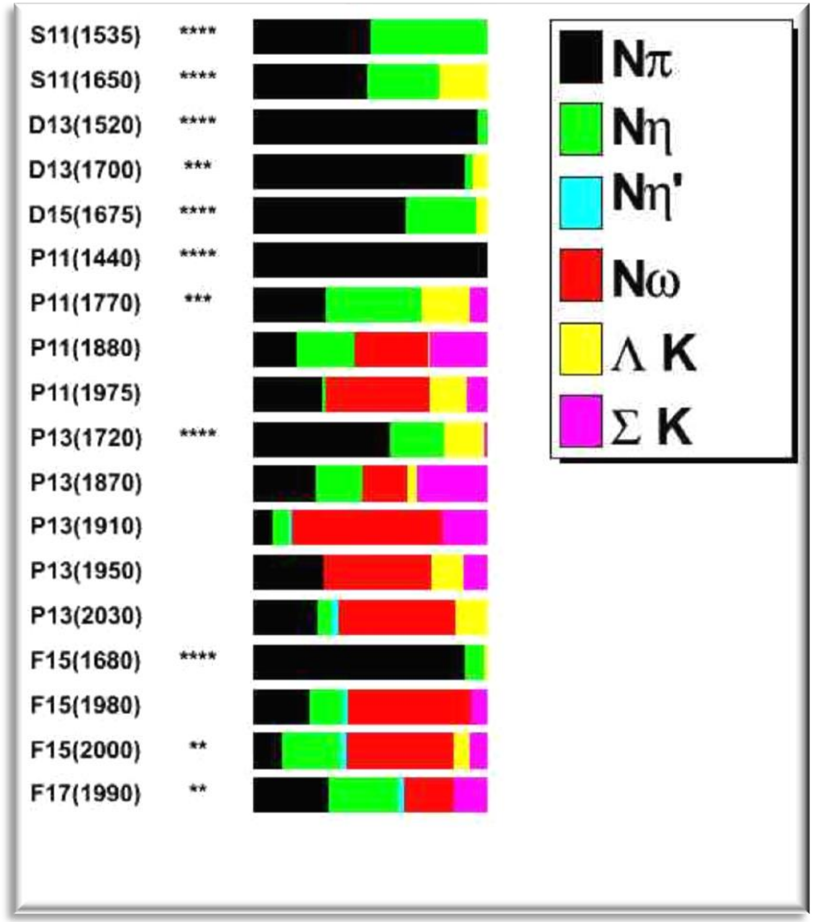
Resonances in Quark Models



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

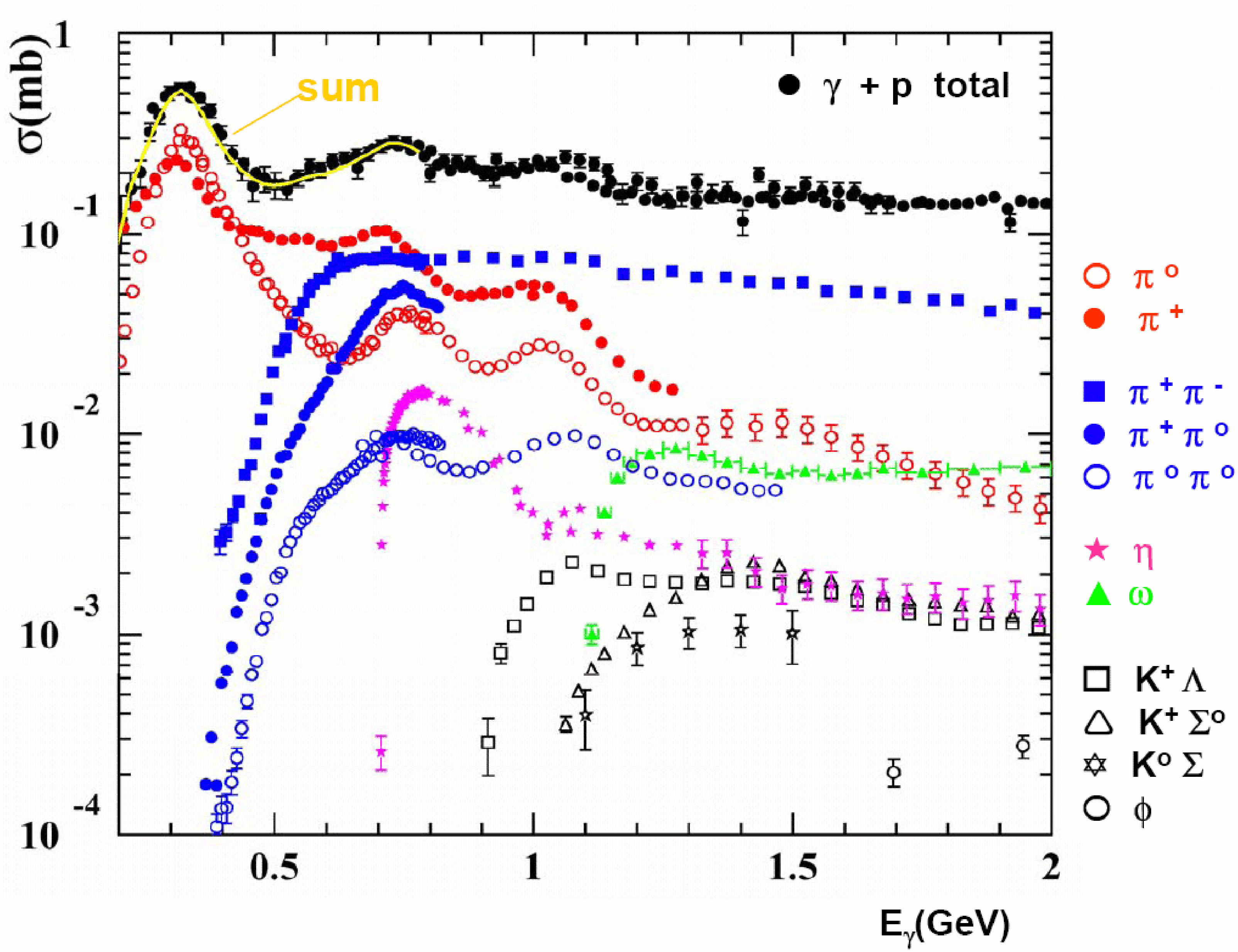
Total Cross-sections
+ differential cross-sections
+ Partial Wave Analysis + ...



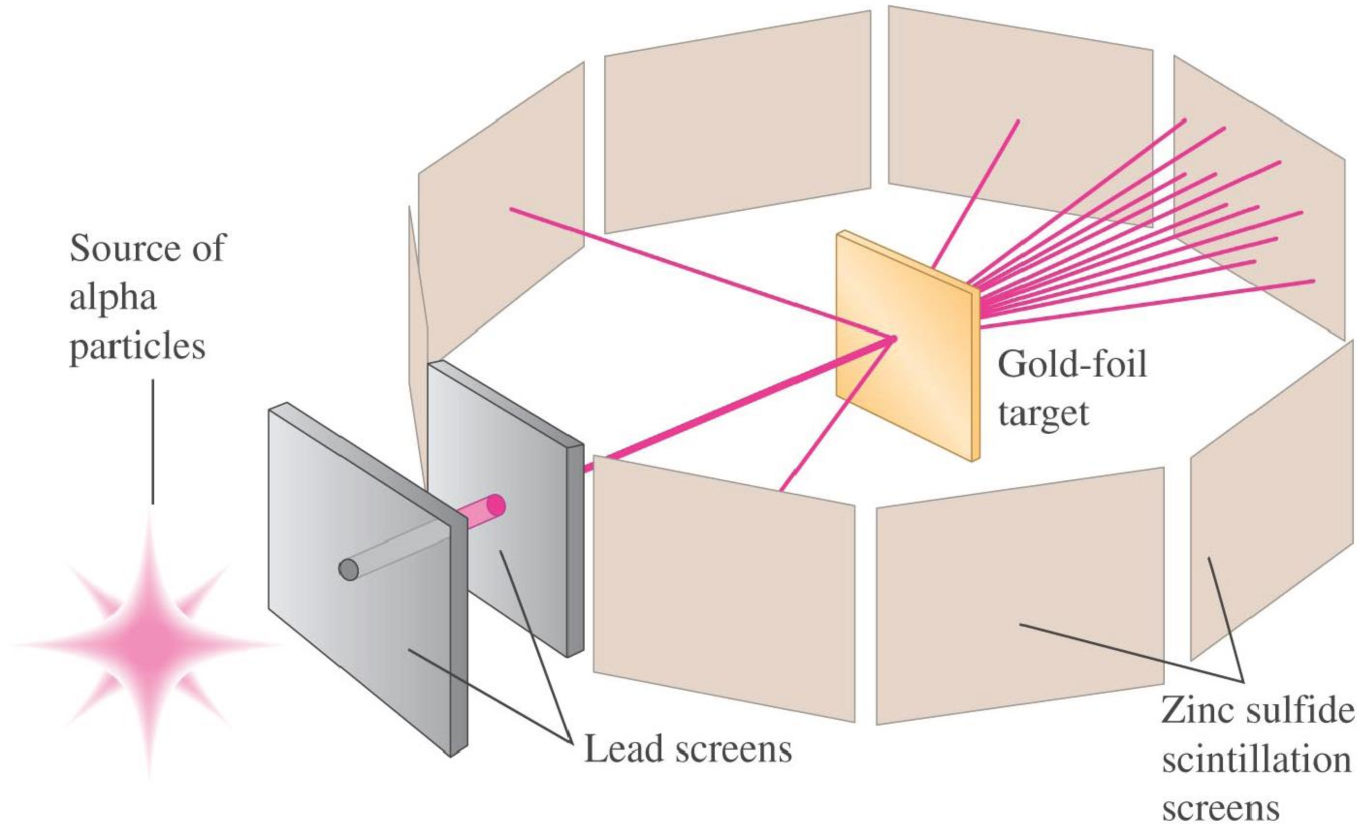


- Mostly done with πN scattering
- Missing resonances may decay through other channels

Meson Photoproduction Cross Sections

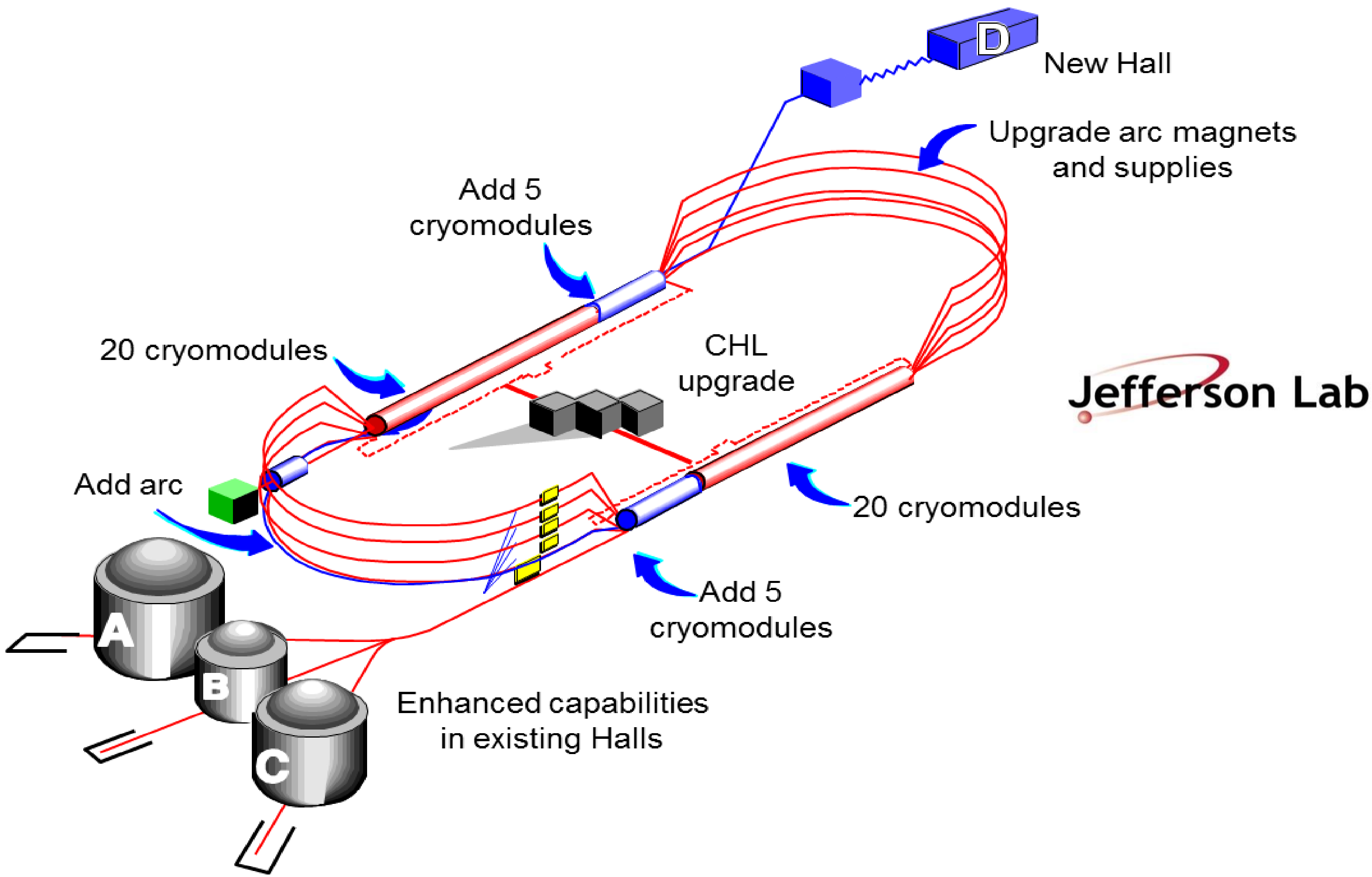


Scattering Experiments

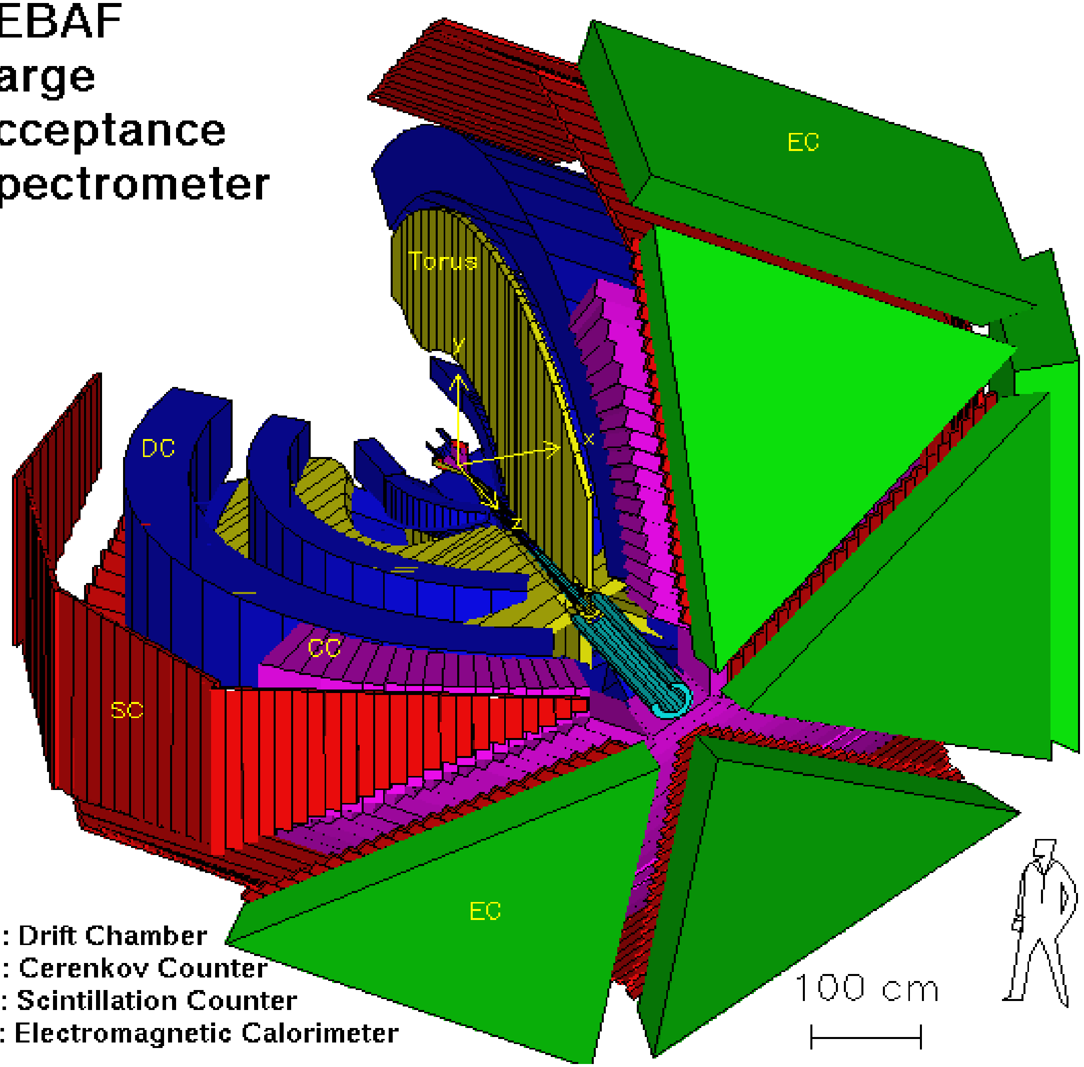


Jefferson Lab

JLab 12 GeV Upgrade

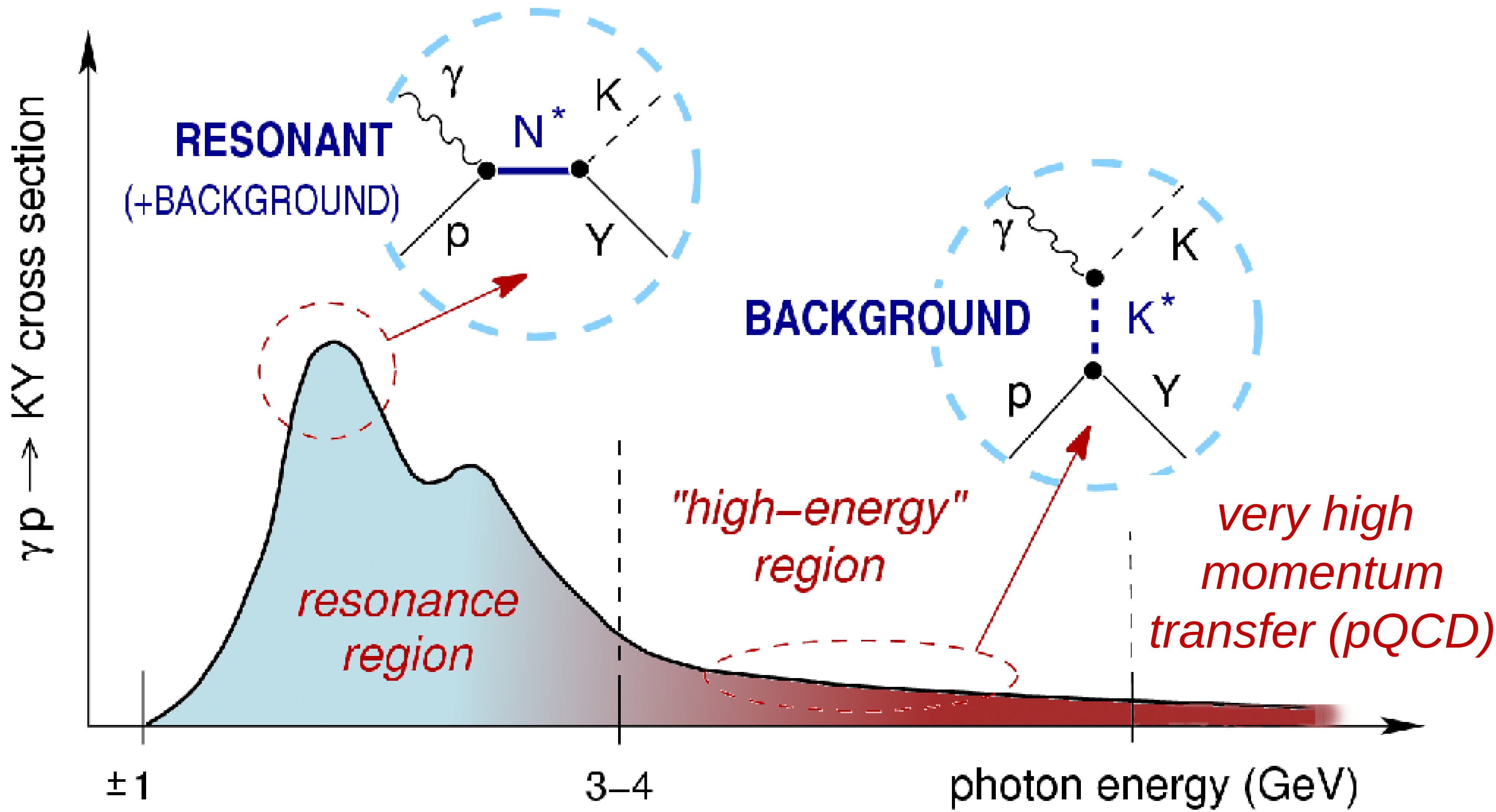


CEBAF
Large
Acceptance
Spectrometer



DC: Drift Chamber
CC: Cerenkov Counter
SC: Scintillation Counter
EC: Electromagnetic Calorimeter

Pseudoscalar Meson Photoproduction



N* photoproduction program at CLAS

Proton targets

Data taking completed May 18, 2012

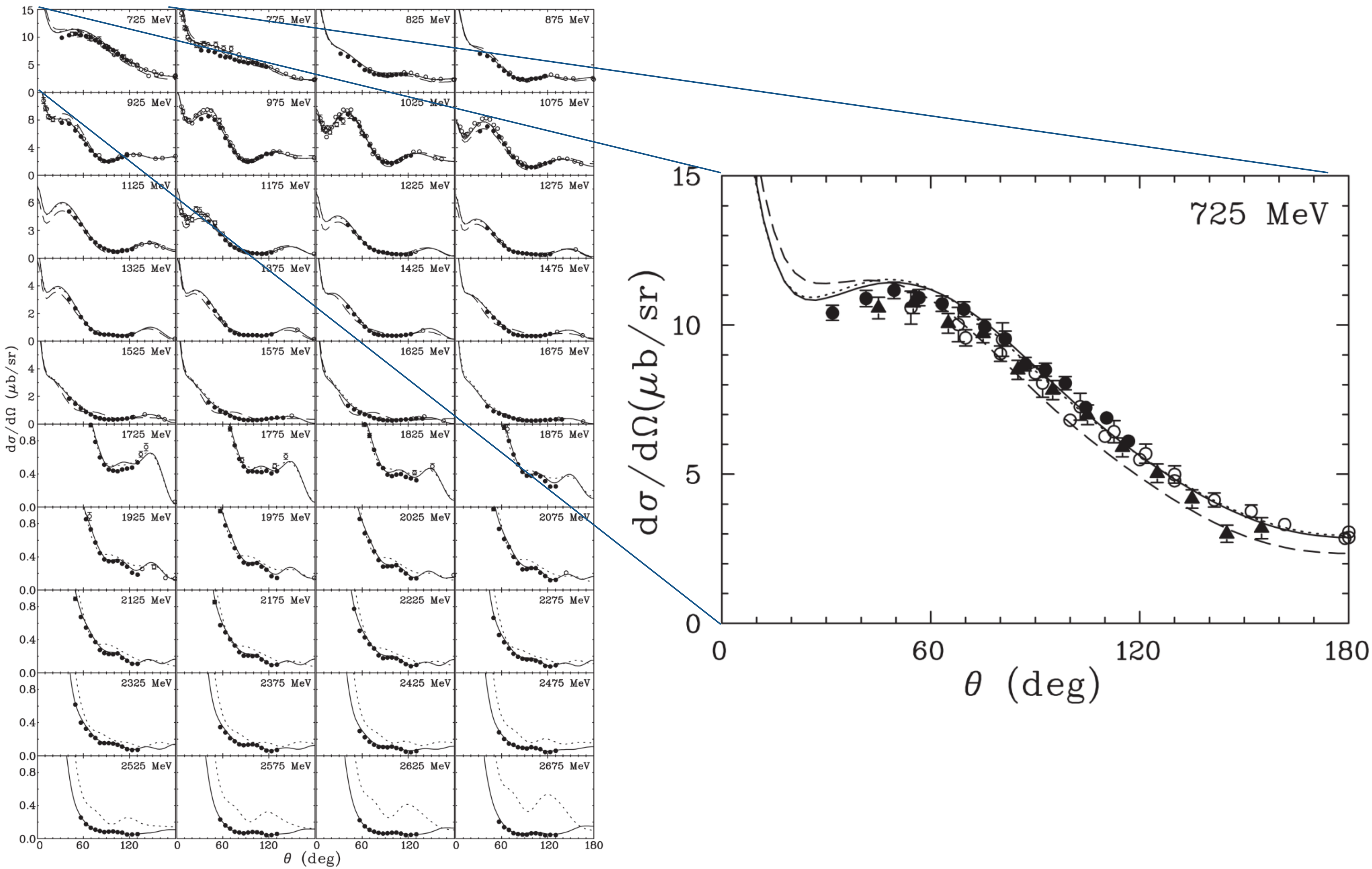
✔-published, ✓-acquired

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

Neutron targets

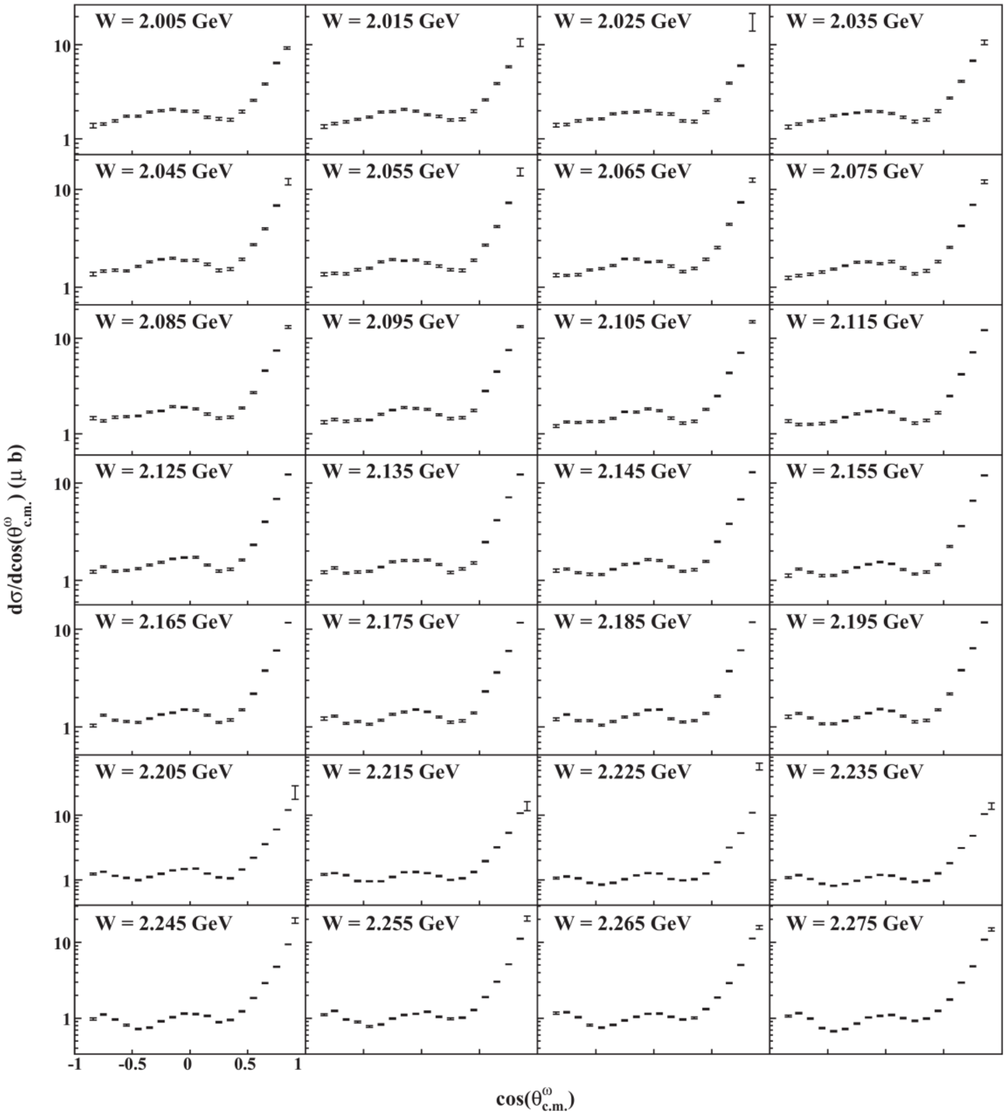
	σ	Σ	T	P	E	F	G	H	T_x	T_z	L_x	L_z	O_x	O_z	C_x	C_z
$p\pi^-$	✔	✓			✓	✓	✓									
$p\rho^-$	✓	✓			✓	✓	✓									
$K^-\Sigma^+$	✓	✓			✓	✓	✓									
$K^0\Lambda$	✓	✓		✓	✓	✓	✓				✓	✓	✓	✓	✓	✓
$K^0\Sigma^0$	✓	✓		✓	✓	✓	✓				✓	✓	✓	✓	✓	✓
$K^{0*}\Sigma^0$	✓	✓														

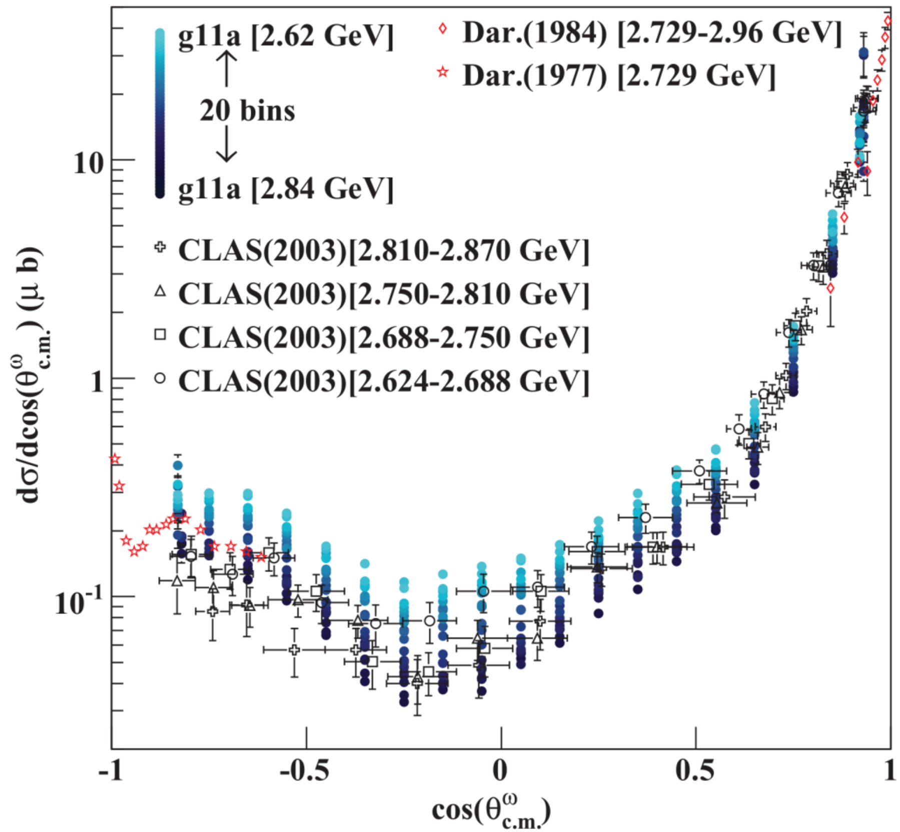
Channel: $\gamma + p \rightarrow \pi^+ + n$;Cross-section



M. Dugger et al. (CLAS), Phys. Rev. C 79, 065206, 2009

Channel: $\gamma + p \rightarrow \omega + p$;Cross-section



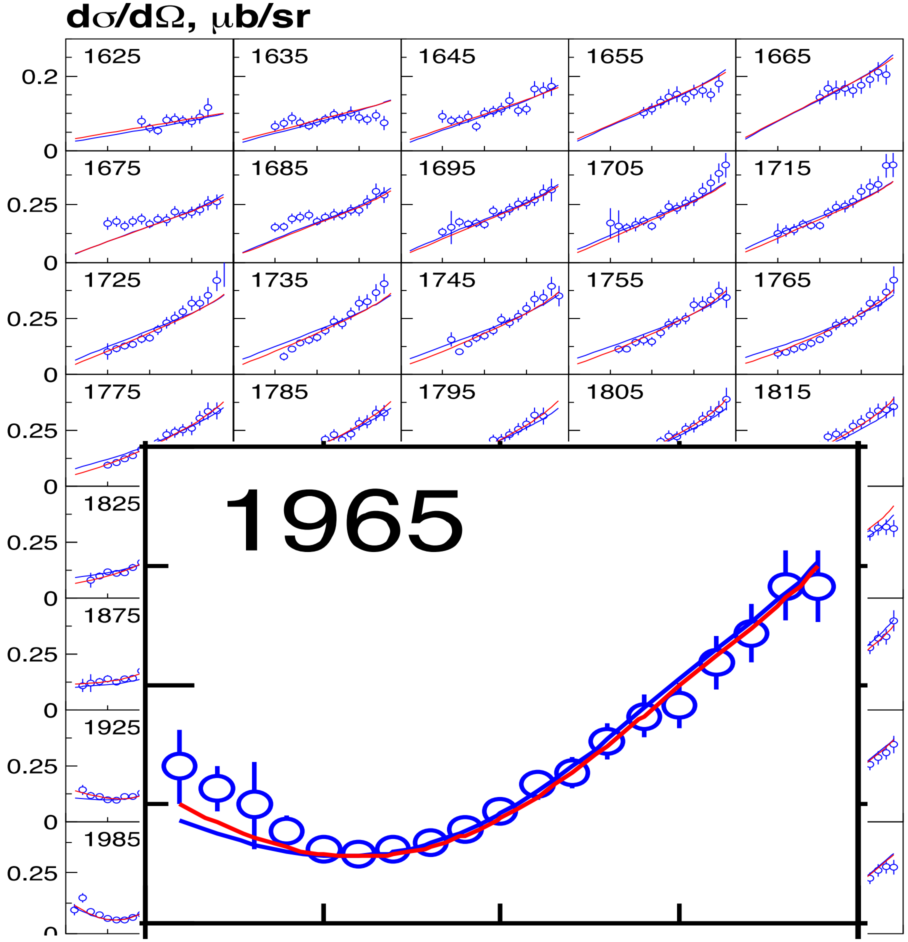


M. Williams et al. (CLAS), Phys. Rev. C 80, 065208, 2009

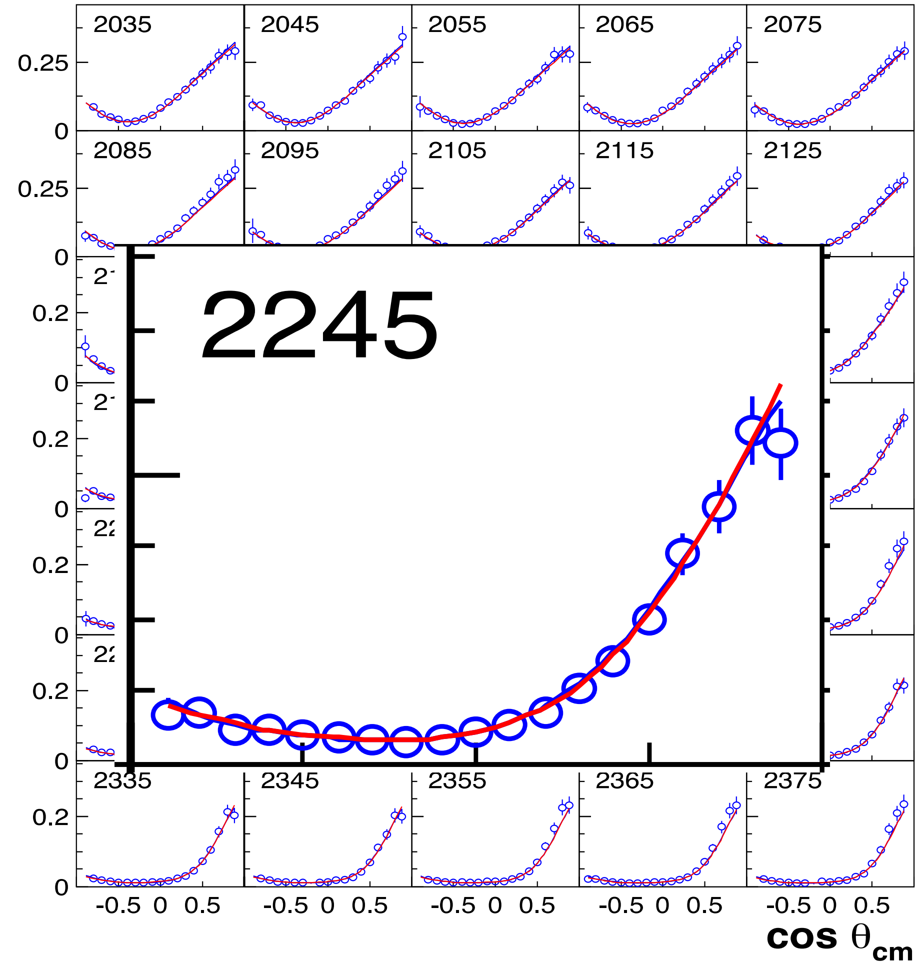
CLAS results $\gamma p \rightarrow K^+\Lambda \rightarrow K^+p\pi^-$

Bonn-Gatchina Coupled Channel Analysis, A.V. Anisovich et al, EPJ A48, 15 (2012)

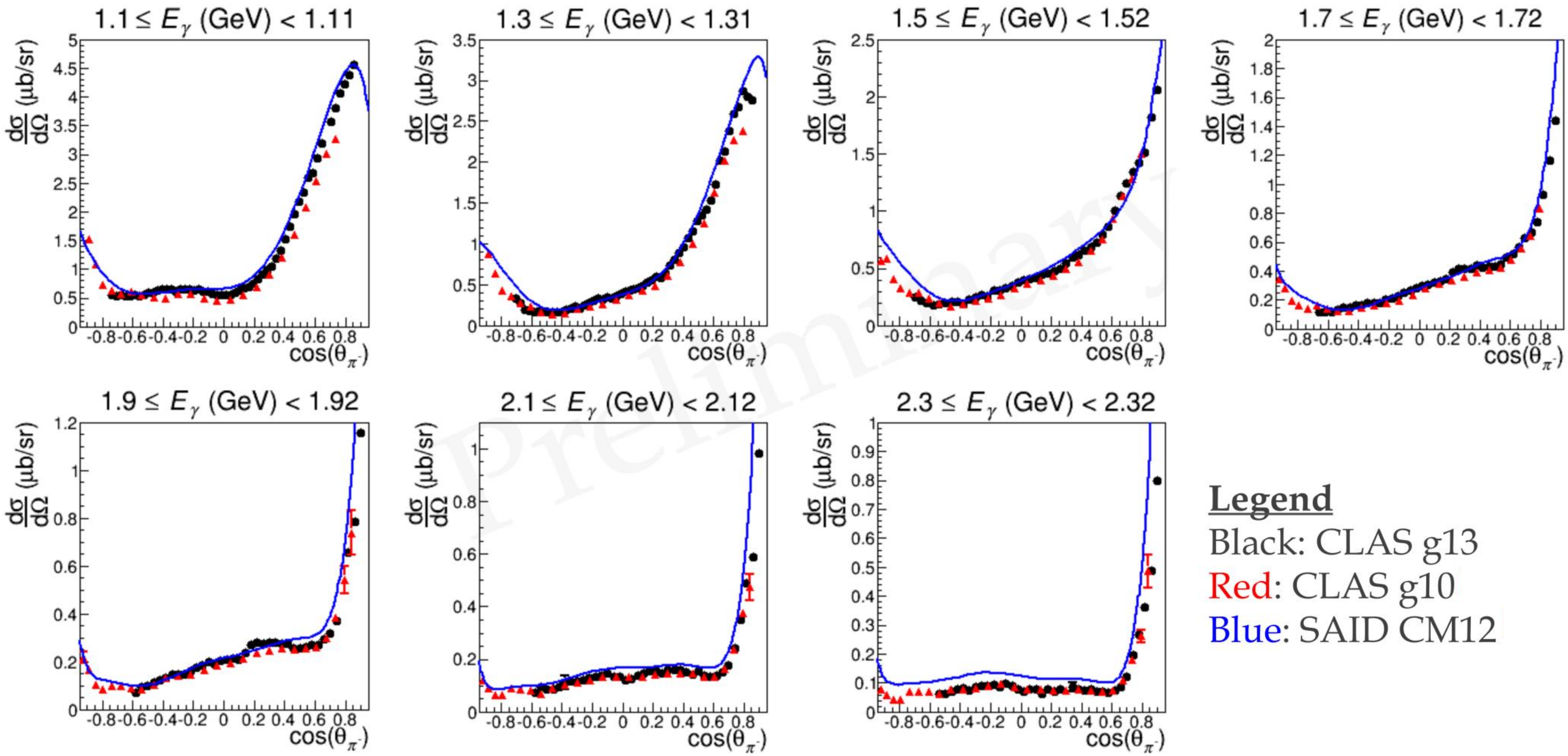
(Includes nearly all new photoproduction data)



M. McCracken et al. (CLAS), Phys. Rev. C 81, 025201, 2010



Channel: $\vec{\gamma} + d \rightarrow \pi^{-} + p\ (n)$;Cross-section



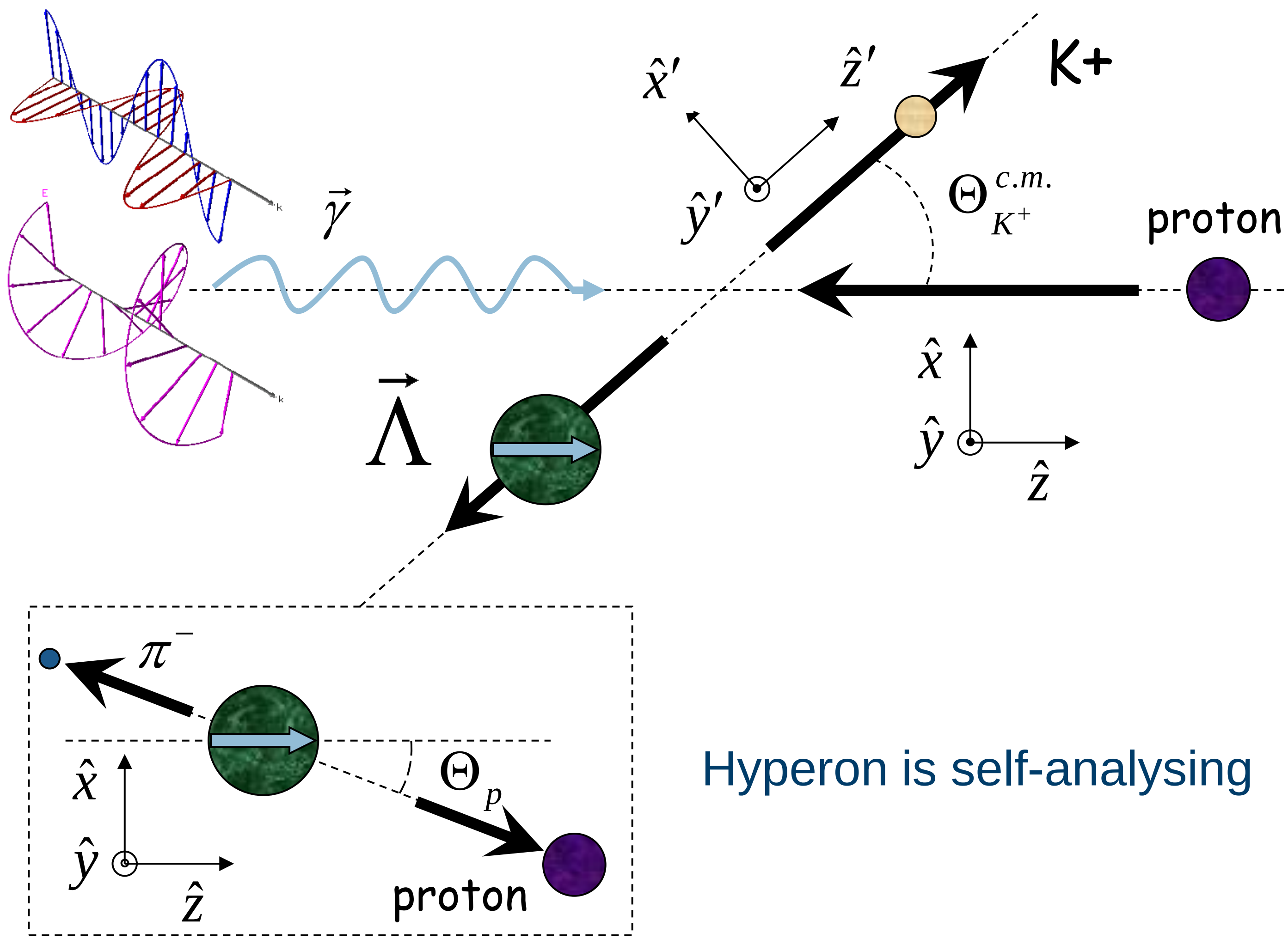
W. Chen et al. Phys. Rev. Lett. 103, 012301 (2009)
W. Chen et al, Phys Rev C **86**, 015206 (2012)
Black data points: ***Preliminary data (P. Mattione)***

In praise of polarisation...

Without Polarizer

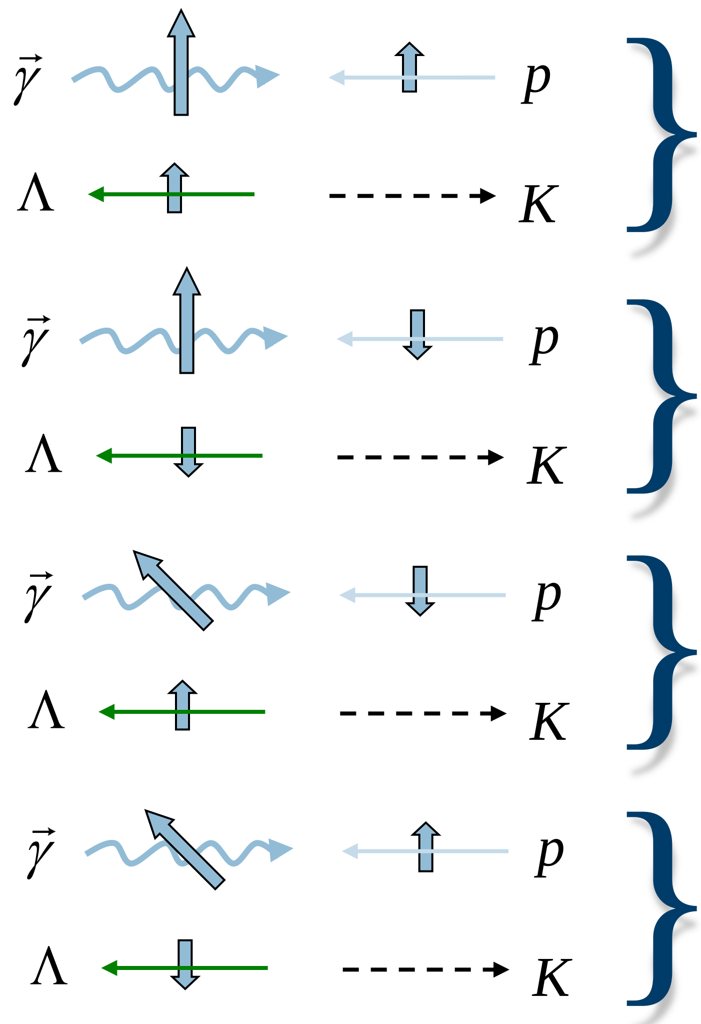
…you'll see more!

Example: Kaon Photoproduction



Hyperon is self-analysing

Transverity Amplitudes



$$b_1 = < + \,|\, M \,|\, + \perp >$$

$$b_2 = < - \,|\, M \,|\, - \perp >$$

$$b_3 = < + \,|\, M \,|\, - \parallel >$$

$$b_4 = < - \,|\, M \,|\, + \parallel >$$

Observables and Amplitudes

Type	Observable	Transversity representation	Helicity representation
S	σ	$\|a_1\|^2 + \|a_2\|^2 + \|a_3\|^2 + \|a_4\|^2$	$\|h_1\|^2 + \|h_2\|^2 + \|h_3\|^2 + \|h_4\|^2$
	Σ	$\|a_1\|^2 + \|a_2\|^2 - \|a_3\|^2 - \|a_4\|^2$	$2\Re(h_1 h_4^* - h_2 h_3^*)$
	P	$\|a_1\|^2 - \|a_2\|^2 + \|a_3\|^2 - \|a_4\|^2$	$2\Im(h_1 h_3^* + h_2 h_4^*)$
	T	$\|a_1\|^2 - \|a_2\|^2 - \|a_3\|^2 + \|a_4\|^2$	$2\Im(h_1 h_3^* + h_2 h_4^*)$
BT	E	$2\Re(a_1 a_3^* + a_2 a_4^*)$	$\|h_1\|^2 - \|h_2\|^2 + \|h_3\|^2 - \|h_4\|^2$
	F	$2\Im(a_1 a_3^* - a_2 a_4^*)$	$2\Re(h_1 h_2^* + h_3 h_4^*)$
	G	$2\Im(a_1 a_3^* + a_2 a_4^*)$	$-2\Im(h_1 h_4^* + h_2 h_3^*)$
	H	$-2\Re(a_1 a_3^* - a_2 a_4^*)$	$-2\Im(h_1 h_3^* - h_2 h_4^*)$
BR	C_x	$-2\Im(a_1 a_4^* - a_2 a_3^*)$	$2\Re(h_1 h_3^* + h_2 h_4^*)$
	C_z	$2\Re(a_1 a_4^* + a_2 a_3^*)$	$\|h_1\|^2 + \|h_2\|^2 - \|h_3\|^2 - \|h_4\|^2$
	O_x	$2\Re(a_1 a_4^* - a_2 a_3^*)$	$-2\Im(h_1 h_2^* - h_3 h_4^*)$
	O_z	$2\Im(a_1 a_4^* + a_2 a_3^*)$	$2\Im(h_1 h_4^* - h_2 h_3^*)$
TR	T_x	$2\Re(a_1 a_2^* - a_3 a_4^*)$	$-2\Re(h_1 h_4^* + h_2 h_3^*)$
	T_z	$2\Im(a_1 a_2^* - a_3 a_4^*)$	$-2\Re(h_1 h_2^* - h_3 h_4^*)$
	L_x	$-2\Im(a_1 a_2^* + a_3 a_4^*)$	$2\Re(h_1 h_3^* - h_2 h_4^*)$
	L_z	$2\Re(a_1 a_2^* + a_3 a_4^*)$	$\|h_1\|^2 - \|h_2\|^2 - \|h_3\|^2 + \|h_4\|^2$

Cross-section Formula

$$\begin{aligned}\sigma_{Total} = \sigma_0\{1 &- P_L^\gamma P_T^T P_y^R \sin(\phi)\cos(2\phi) + \Sigma(-P_L^\gamma \cos(2\phi) + P_T^T P_y^R \sin(\phi)) \\
&+ T(P_T^T \sin(\phi) - P_L^\gamma P_y^R \cos(2\phi)) + P(P_y^R - P_L^\gamma P_T^T \sin(\phi)\cos(2\phi)) \\
&+ E(-P_C^\gamma P_L^T + P_L^\gamma P_T^T P_y^R \cos(\phi)\sin(2\phi)) + F(P_C^\gamma P_T^T \cos(\phi) + P_L^\gamma P_L^T P_y^R \sin(2\phi)) \\
&- G(P_L^\gamma P_L^T \sin(2\phi) + P_C^\gamma P_T^T P_y^R \cos(\phi)) - H(P_L^\gamma P_T^T \cos(\phi)\sin(2\phi) - P_C^\gamma P_L^T P_y^R) \\
&- C_x(P_C^\gamma P_x^R - P_L^\gamma P_T^T P_z^R \sin(\phi)\sin(2\phi)) - C_z(P_C^\gamma P_z^R + P_L^\gamma P_T^T P_x^R \sin(\phi)\sin(2\phi)) \\
&- O_x(P_L^\gamma P_x^R \sin(2\phi) + P_C^\gamma P_T^T P_z^R \sin(\phi)) - O_z(P_L^\gamma P_z^R \sin(2\phi) - P_C^\gamma P_T^T P_x^R \sin(\phi)) \\
&+ L_x(P_L^T P_x^R + P_L^\gamma P_T^T P_z^R \cos(\phi)\cos(2\phi)) + L_z(P_L^T P_z^R - P_L^\gamma P_T^T P_x^R \cos(\phi)\cos(2\phi)) \\
&+ T_x(P_T^T P_x^R \cos(\phi) - P_L^\gamma P_L^T P_z^R \cos(2\phi)) + T_z(P_T^T P_z^R \cos(\phi) + P_L^\gamma P_L^T P_x^R \cos(2\phi))\}\end{aligned}$$

Experimental Configurations

Configuration	σ_{Red}/σ_0
$B_U\, T_U\, R_N$	$= 1$
$B_U\, T_U\, R_Y$	$= 1 + P\, P_y^R$
$B_U\, T_L\, R_N$	$= 1$
$B_U\, T_L\, R_Y$	$= 1 + P\, P_y^R + L_x\, P_x^R\, P_L^T$
$B_U\, T_T\, R_N$	$= 1 + T\, P_T^T \sin(\phi)$
$B_U\, T_T\, R_Y$	$= 1 + P\, P_y^R + (\Sigma\, P_y^R + T)\, P_T^T \sin(\phi) + (T_x\, P_x^R + T_z\, P_y^R)\, P_T^T \cos(\phi)$
$B_C\, T_U\, R_N$	$= 1$
$B_C\, T_U\, R_Y$	$= 1 + P\, P_y^R - C_x\, P_C^\gamma\, P_x^R - C_z\, P_C^\gamma\, P_z^R$
$B_C\, T_L\, R_N$	$= 1 - E\, P_C^\gamma\, P_L^T$
$B_C\, T_L\, R_Y$	$= 1 + P\, P_y^R - E\, P_C^\gamma\, P_L^T + H\, P_C^\gamma\, P_y^R\, P_L^T$
	$-C_x\, P_C^\gamma\, P_x^R - C_z\, P_C^\gamma\, P_z^R + L_x\, P_x^R\, P_L^T + L_z\, P_z^R\, P_L^T$
$B_C\, T_T\, R_N$	$= 1 + T\, P_T^T \sin(\phi) + F\, P_C^\gamma\, P_T^T \cos(\phi)$
$B_C\, T_T\, R_Y$	$= 1 + P\, P_y^R - C_x\, P_C^\gamma\, P_x^R - C_z\, P_C^\gamma\, P_z^R$
	$+(\Sigma\, P_y^R + T - O_x\, P_C^\gamma\, P_z^R + O_z\, P_C^\gamma\, P_x^R)\, P_T^T \sin(\phi)$
	$+(F\, P_C^\gamma\, P_y^R - G\, P_C^\gamma\, P_y^R + T_x\, P_x^R + T_z\, P_z^R)\, P_T^T \cos(\phi)$

Experimental Configurations

$B_L\, T_U\, R_N$	$= 1 - P_L^\gamma\, \Sigma\, \cos(2\phi)$
$B_L\, T_U\, R_Y$	$= 1 + P\, P_y^R - (\Sigma + T\, P_y^R)\, P_L^\gamma\, \cos(2\phi) - (O_x\, P_x^R + O_z\, P_z^R)\, P_L^\gamma\, \sin(2\phi)$
$B_L\, T_L\, R_N$	$= 1 - \Sigma\, P_L^\gamma\, \cos(2\phi) - G\, P_L^\gamma\, P_L^T \sin(2\phi)$
$B_L\, T_L\, R_Y$	$= 1 + P\, P_y^R + L_x\, P_x^R\, P_L^T + L_z\, P_z^R\, P_L^T$
	$-(\Sigma + T\, P_y^R + T_x\, P_z^R\, P_L^T - T_z\, P_x^R\, P_L^T)\, P_L^\gamma\, \cos(2\phi)$
	$+(F\, P_y^R\, P_L^T - G\, P_L^T - O_x\, P_x^R - O_z\, P_z^R)\, P_L^\gamma \sin(2\phi)$
$B_L\, T_T\, R_N$	$= 1 - \Sigma\, P_L^\gamma\, cos(2\phi) - P\, P_L^\gamma\, P_T^T \sin(\phi) \cos(2\phi)$
	$+T\, P_T^T \sin(\phi) - H\, P_L^\gamma\, P_T^T\, \cos(\phi) \sin(2\phi)$
$B_L\, T_T\, R_Y$	$= 1 - P_L^\gamma\, P_y^R\, P_T^T\, \sin(\phi) \cos(2\phi)\, + \Sigma(P_y^R\, P_T^T \sin(\phi) - P_L^\gamma\, \cos(2\phi))$
	$+P(P_y^R - P_L^\gamma\, P_T^T\, \sin(\phi) \cos(2\phi)\,) + T\,(P_T^T \sin(\phi) - P_L^\gamma\, P_y^R\, \cos(2\phi)\,)$
	$+(E\, P_y^R - H)\, P_L^\gamma\, P_T^T\, \cos(\phi) \sin(2\phi)$
	$+(C_x\, P_z^R - C_z\, P_x^R)\, P_L^\gamma\, P_T^T\, \sin(\phi) \sin(2\phi)$
	$-(O_x\, P_x^R\, \sin(2\phi) + O_z\, P_z^R)\, P_L^\gamma\, \sin(2\phi) + (T_x\, P_x^R + T_z\, P_z^R)\, P_T^T \cos(\phi)$
	$+(L_x P_z^R - L_z\, P_x^R)\, P_L^\gamma\, P_T^T\, \cos(\phi) \cos(2\phi)$

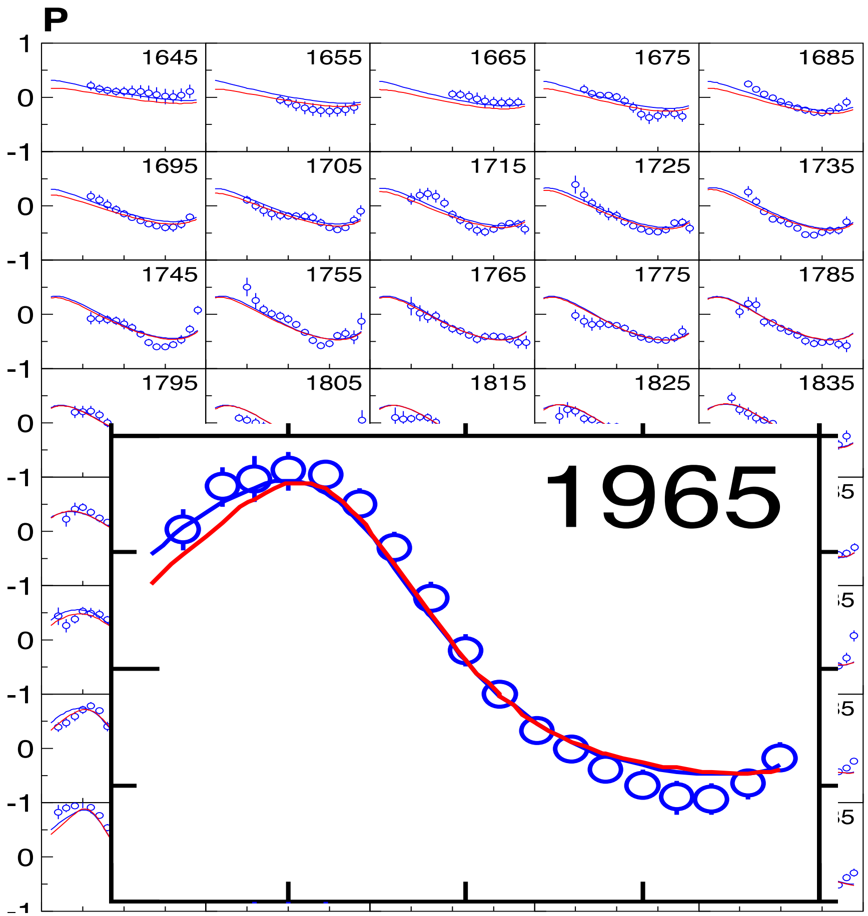
Recoil Polarization

Configuration	σ_{Red}/σ_0
$B_U\, T_U\, R_N$	$= 1$
$B_U\, T_U\, R_Y$	$= 1 + P\, P_y^R$
$B_U\, T_L\, R_N$	$= 1$
$B_U\, T_L\, R_Y$	$= 1 + P\, P_y^R + L_x\, P_x^R\, P_L^T$
$B_U\, T_T\, R_N$	$= 1 + T\, P_T^T \sin(\phi)$
$B_U\, T_T\, R_Y$	$= 1 + P\, P_y^R + (\Sigma\, P_y^R + T)\, P_T^T \sin(\phi) + (T_x\, P_x^R + T_z\, P_y^R)\, P_T^T \cos(\phi)$
$B_C\, T_U\, R_N$	$= 1$
$B_C\, T_U\, R_Y$	$= 1 + P\, P_y^R - C_x\, P_C^\gamma\, P_x^R - C_z\, P_C^\gamma\, P_z^R$
$B_C\, T_L\, R_N$	$= 1 - E\, P_C^\gamma\, P_L^T$
$B_C\, T_L\, R_Y$	$= 1 + P\, P_y^R - E\, P_C^\gamma\, P_L^T + H\, P_C^\gamma\, P_y^R\, P_L^T$ $-C_x\, P_C^\gamma\, P_x^R - C_z\, P_C^\gamma\, P_z^R + L_x\, P_x^R\, P_L^T + L_z\, P_z^R\, P_L^T$
$B_C\, T_T\, R_N$	$= 1 + T\, P_T^T \sin(\phi) + F\, P_C^\gamma\, P_T^T \cos(\phi)$
$B_C\, T_T\, R_Y$	$= 1 + P\, P_y^R - C_x\, P_C^\gamma\, P_x^R - C_z\, P_C^\gamma\, P_z^R$ $+(\Sigma\, P_y^R + T - O_x\, P_C^\gamma\, P_z^R + O_z\, P_C^\gamma\, P_x^R)\, P_T^T \sin(\phi)$ $+(F\, P_C^\gamma\, P_y^R - G\, P_C^\gamma\, P_y^R + T_x\, P_x^R + T_z\, P_z^R)\, P_T^T \cos(\phi)$

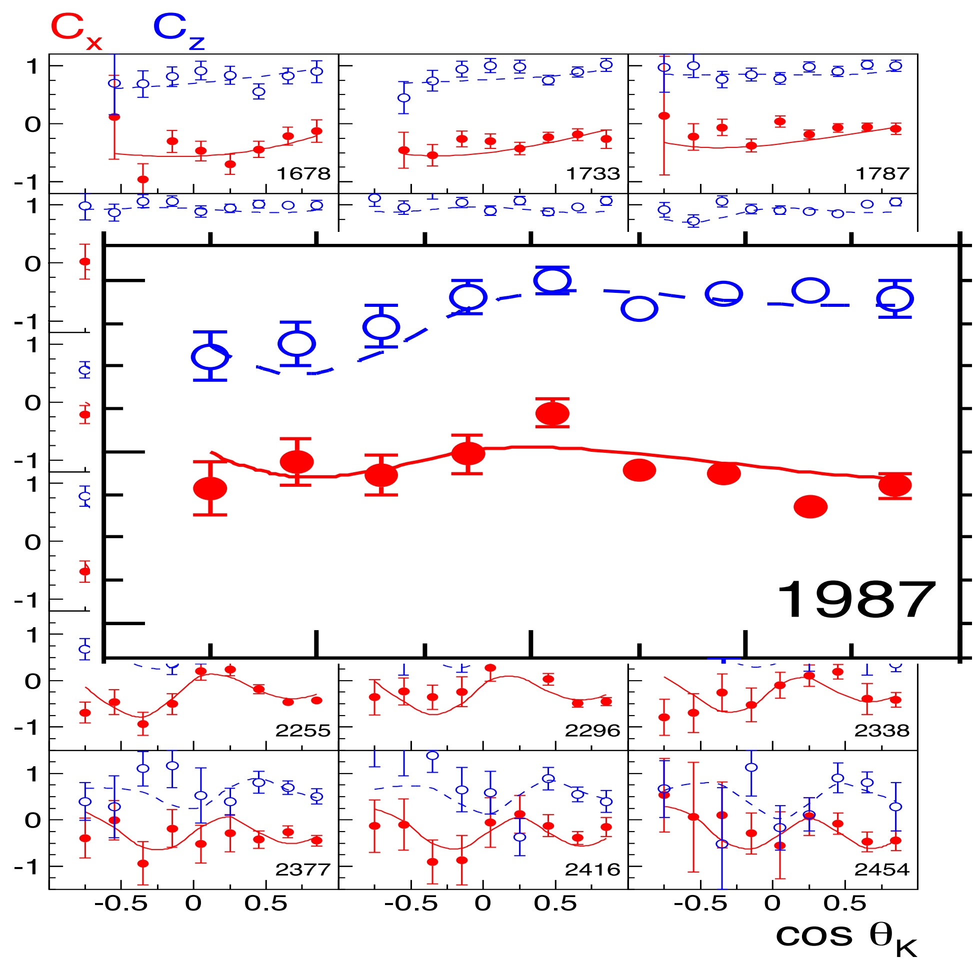
CLAS results $\gamma p \rightarrow K^+\Lambda \rightarrow K^+p\pi^-$

Bonn-Gatchina Coupled Channel Analysis, A.V. Anisovich et al, EPJ A48, 15 (2012)

(Includes nearly all new photoproduction data)



M. Mc Cracken et al. (CLAS), Phys. Rev. C 81, 025201, 2010



R. Bradford et al. (CLAS), Phys.Rev. C75, 035205, 2007

Evidence for new N* states and couplings

N^*	J^P $(L_{2I,2J})$	2010	2012	Δ	J^P $(L_{2I,2J})$	2010	2012
p	$1/2^+$ (P_{11})	****	****	$\Delta(1232)$	$3/2^+$ (P_{33})	****	****
n	$1/2^+$ (P_{11})	****	****	$\Delta(1600)$	$3/2^+$ (P_{33})	***	***
$N(1440)$	$1/2^+$ (P_{11})	****	****	$\Delta(1620)$	$1/2^-$ (S_{31})	****	****
$N(1520)$	$3/2^-$ (D_{13})	****	****	$\Delta(1700)$	$3/2^-$ (D_{33})	****	****
$N(1535)$	$1/2^-$ (S_{11})	****	****	$\Delta(1750)$	$1/2^+$ (P_{31})	*	*
$N(1650)$	$1/2^-$ (S_{11})	****	****	$\Delta(1900)$	$1/2^-$ (S_{31})	**	**
$N(1675)$	$5/2^-$ (D_{15})	****	****	$\Delta(1905)$	$5/2^+$ (F_{35})	****	****
$N(1680)$	$5/2^+$ (F_{15})	****	****	$\Delta(1910)$	$1/2^+$ (P_{31})	****	****
$N(1685)$			*				
$N(1700)$	$3/2^-$ (D_{13})	***	***	$\Delta(1920)$	$3/2^+$ (P_{33})	***	***
$N(1710)$	$1/2^+$ (P_{11})	***	***	$\Delta(1930)$	$5/2^-$ (D_{35})	***	***
$N(1720)$	$3/2^+$ (P_{13})	****	****	$\Delta(1940)$	$3/2^-$ (D_{33})	*	**
$N(1860)$	$5/2^+$		**				
$N(1875)$	$3/2^-$		***				
$N(1880)$	$1/2^+$		**				
$N(1895)$	$1/2^-$		**				
$N(1900)$	$3/2^+$ (P_{13})	**	***	$\Delta(1950)$	$7/2^+$ (F_{37})	****	****
$N(1990)$	$7/2^+$ (F_{17})	**	**	$\Delta(2000)$	$5/2^+$ (F_{35})	**	**
$N(2000)$	$5/2^+$ (F_{15})	**	**	$\Delta(2150)$	$1/2^-$ (S_{31})	*	*
~~$N(2080)$~~	D_{13}	**		$\Delta(2200)$	$7/2^-$ (G_{37})	*	*
~~$N(2090)$~~	S_{11}	*		$\Delta(2300)$	$9/2^+$ (H_{39})	**	**
$N(2040)$	$3/2^+$		*				
$N(2060)$	$5/2^-$		**				
$N(2100)$	$1/2^+$ (P_{11})	*	*	$\Delta(2350)$	$5/2^-$ (D_{35})	*	*
$N(2120)$	$3/2^-$		**				
$N(2190)$	$7/2^-$ (G_{17})	****	****	$\Delta(2390)$	$7/2^+$ (F_{37})	*	*
~~$N(2200)$~~	D_{15}	**		$\Delta(2400)$	$9/2^-$ (G_{39})	**	**
$N(2220)$	$9/2^+$ (H_{19})	****	****	$\Delta(2420)$	$11/2^+$ $(H_{3,11})$	****	****
$N(2250)$	$9/2^-$ (G_{19})	****	****	$\Delta(2750)$	$13/2^-$ $(I_{3,13})$	**	**
$N(2600)$	$11/2^-$ $(I_{1,11})$	***	***	$\Delta(2950)$	$15/2^+$ $(K_{3,15})$	**	**
$N(2700)$	$13/2^+$ $(K_{1,13})$	**	**				

Evidence for new N* states and couplings

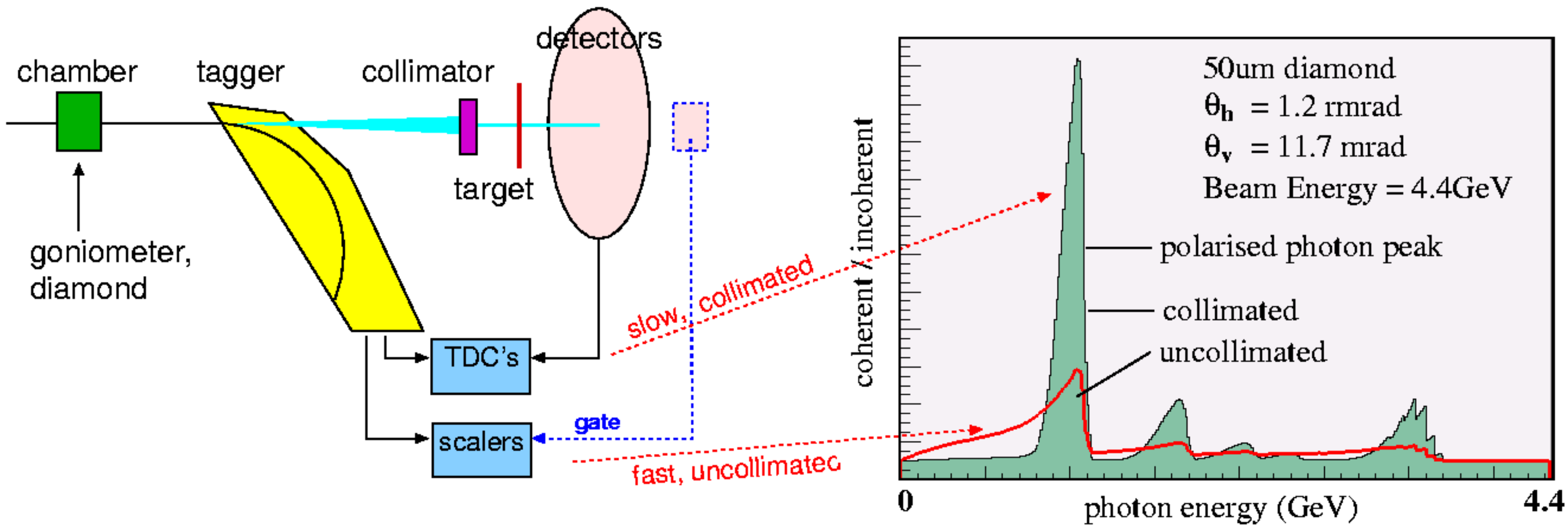
State N((mass)J^P	PDG 2010	PDG 2012	KΛ	KΣ	Nγ
N(1710)$1/2^+$	*** (not seen in GW analysis)	***	***	**	***
N(1880)$1/2^+$		**	**	*	**
N(1895)$1/2^-$		**	**	*	***
N(1900)$3/2^+$	**	***	***	**	***
N(1875)$3/2^-$		***	***	**	***
N(2150)$3/2^-$		**	**		**
N(2000)$5/2^+$	*	***	**	*	**
N(2060)$5/2^-$		***		**	***

Bonn-Gatchina Analysis – A.V. Anisovich et al., EPJ A48, 15 (2012)
(First coupled-channel analysis that includes nearly all new photoproduction data)

Tagged Photons at CLAS

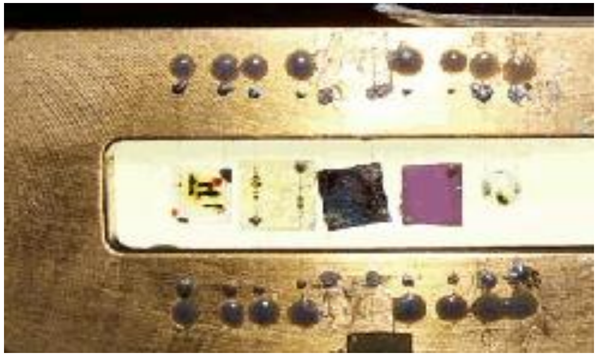
tagged photon facility

simulated coherent brem. spectrum

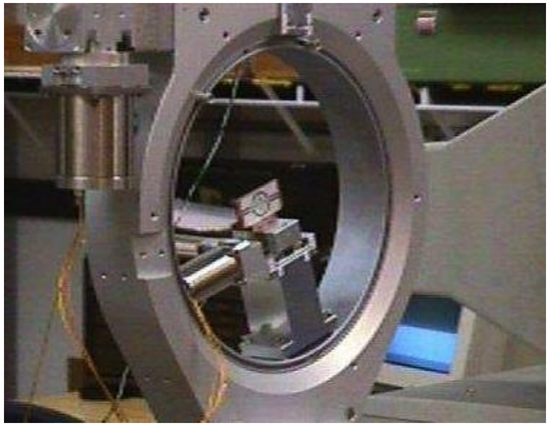


- $E_\gamma = E_0 - E'$
- Circular Polarisation: polarised electron beam, amorphous radiator
- Linear polarisation: Crystal (diamond) radiator

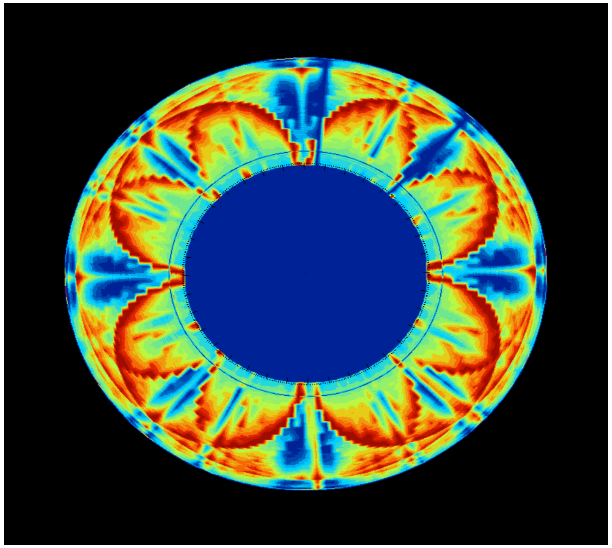
Linearly Polarized Photons



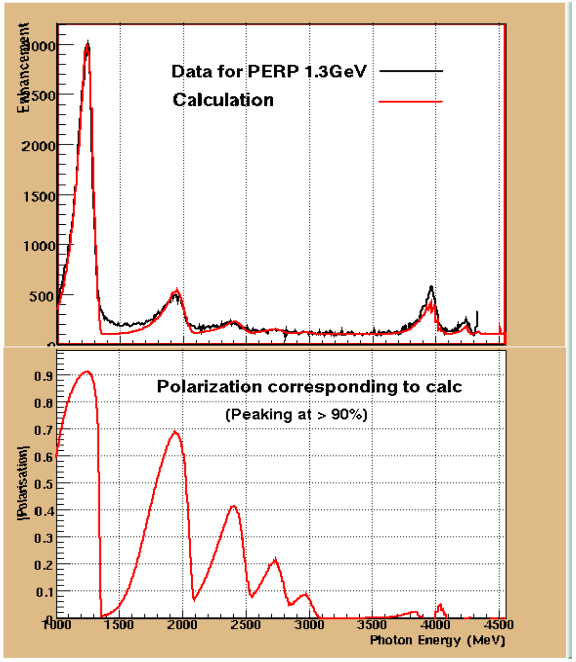
Diamond radiator mounted
on target ladder



Radiator in goniometer



Alignment checked by
observing symmetric
“Stonehenge Plot”



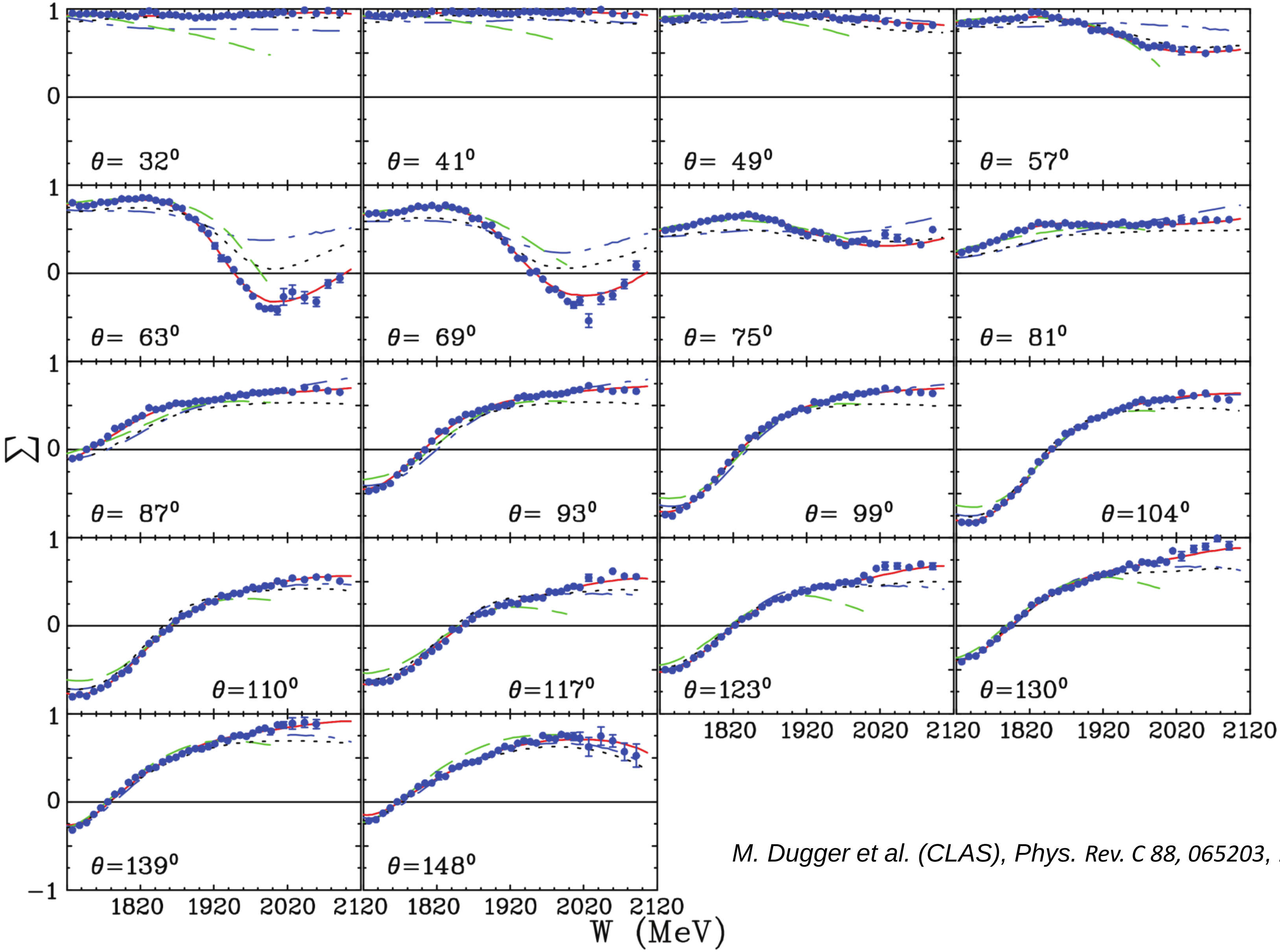
Polarization determined by fit
to coherent bremsstrahlung
spectrum

Technique will be used in JLab Hall D

Linearly Polarized Photons

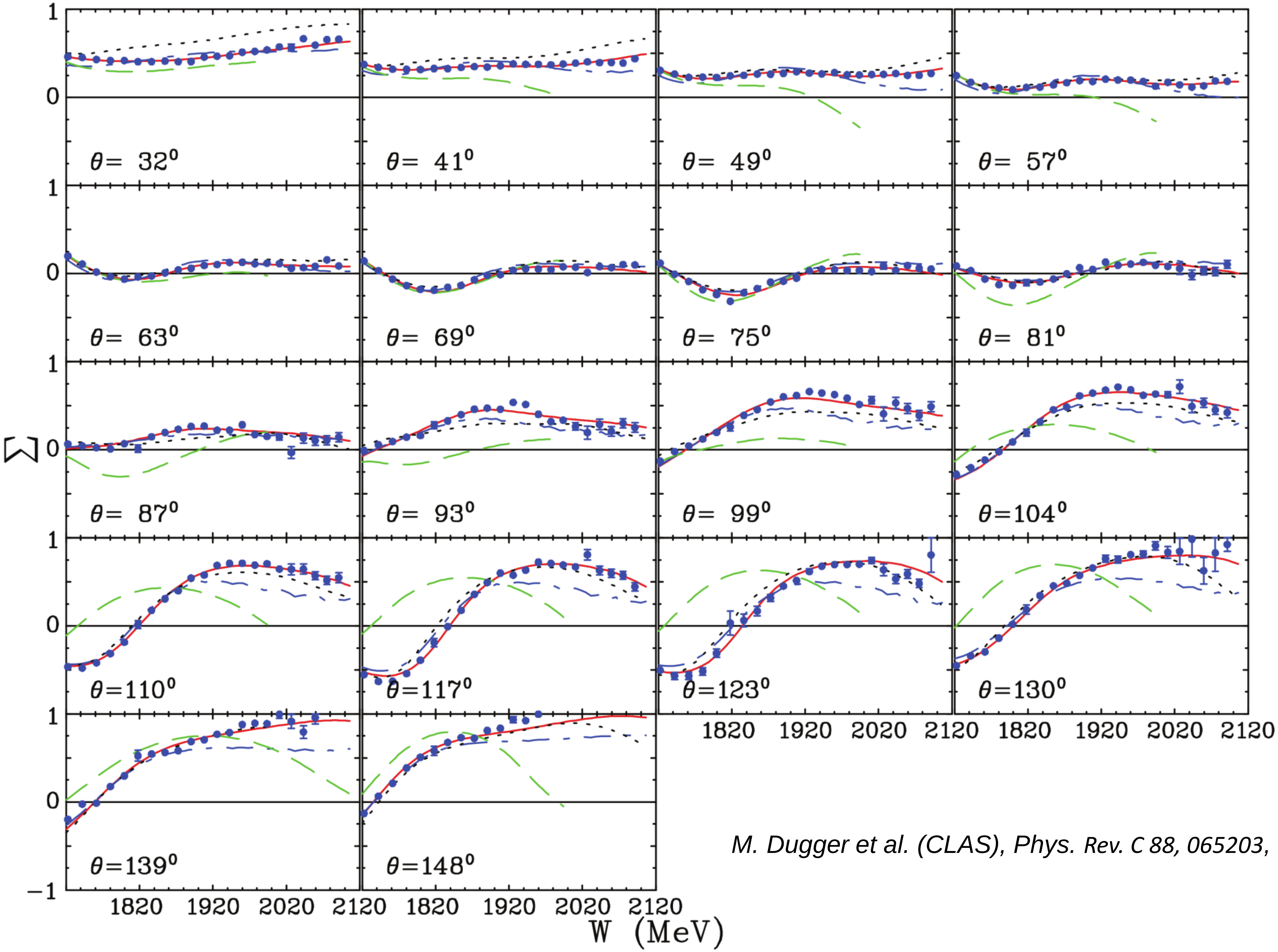
$B_L\,T_U\,R_N$	$= 1 - P_L^{\gamma}\,\Sigma\,\cos(2\phi)$
$B_L\,T_U\,R_Y$	$= 1 + P\,P_y^R - (\Sigma + T\,P_y^R)\,P_L^{\gamma}\,\cos(2\phi) - (O_x\,P_x^R + O_z\,P_z^R)\,P_L^{\gamma}\,\sin(2\phi)$
$B_L\,T_L\,R_N$	$= 1 - \Sigma\,P_L^{\gamma}\,\cos(2\phi) - G\,P_L^{\gamma}\,P_L^T\,\sin(2\phi)$
$B_L\,T_L\,R_Y$	$= 1 + P\,P_y^R + L_x\,P_x^R\,P_L^T + L_z\,P_z^R\,P_L^T$
	$-(\Sigma + T\,P_y^R + T_x\,P_z^R\,P_L^T - T_z\,P_x^R\,P_L^T)\,P_L^{\gamma}\,\cos(2\phi)$
	$+(F\,P_y^R\,P_L^T - G\,P_L^T - O_x\,P_x^R - O_z\,P_z^R)\,P_L^{\gamma}\,\sin(2\phi)$
$B_L\,T_T\,R_N$	$= 1 - \Sigma\,P_L^{\gamma}\,cos(2\phi) - P\,P_L^{\gamma}\,P_T^T\,\sin(\phi)\cos(2\phi)$
	$+T\,P_T^T\,\sin(\phi) - H\,P_L^{\gamma}\,P_T^T\,\cos(\phi)\sin(2\phi)$
$B_L\,T_T\,R_Y$	$= 1 - P_L^{\gamma}\,P_y^R\,P_T^T\,\sin(\phi)\cos(2\phi) + \Sigma(P_y^R\,P_T^T\,\sin(\phi) - P_L^{\gamma}\,\cos(2\phi))$
	$+P(P_y^R - P_L^{\gamma}\,P_T^T\,\sin(\phi)\cos(2\phi)) + T\,(P_T^T\,\sin(\phi) - P_L^{\gamma}\,P_y^R\,\cos(2\phi))$
	$+(E\,P_y^R - H)\,P_L^{\gamma}\,P_T^T\,\cos(\phi)\sin(2\phi)$
	$+(C_x\,P_z^R - C_z\,P_x^R)\,P_L^{\gamma}\,P_T^T\,\sin(\phi)\sin(2\phi)$
	$-(O_x\,P_x^R\,\sin(2\phi) + O_z\,P_z^R)\,P_L^{\gamma}\,\sin(2\phi) + (T_x\,P_x^R + T_z\,P_z^R)\,P_T^T\cos(\phi)$
	$+(L_x P_z^R - L_z\,P_x^R)\,P_L^{\gamma}\,P_T^T\,\cos(\phi)\cos(2\phi)$

CLAS Results: Channel: $\vec{\gamma} + p \rightarrow \pi^0 + p$;Observable: Σ



M. Dugger et al. (CLAS), Phys. Rev. C 88, 065203, 2013

CLAS Results: Channel: $\vec{\gamma} + p \rightarrow \pi^+ + n$;Observable: Σ

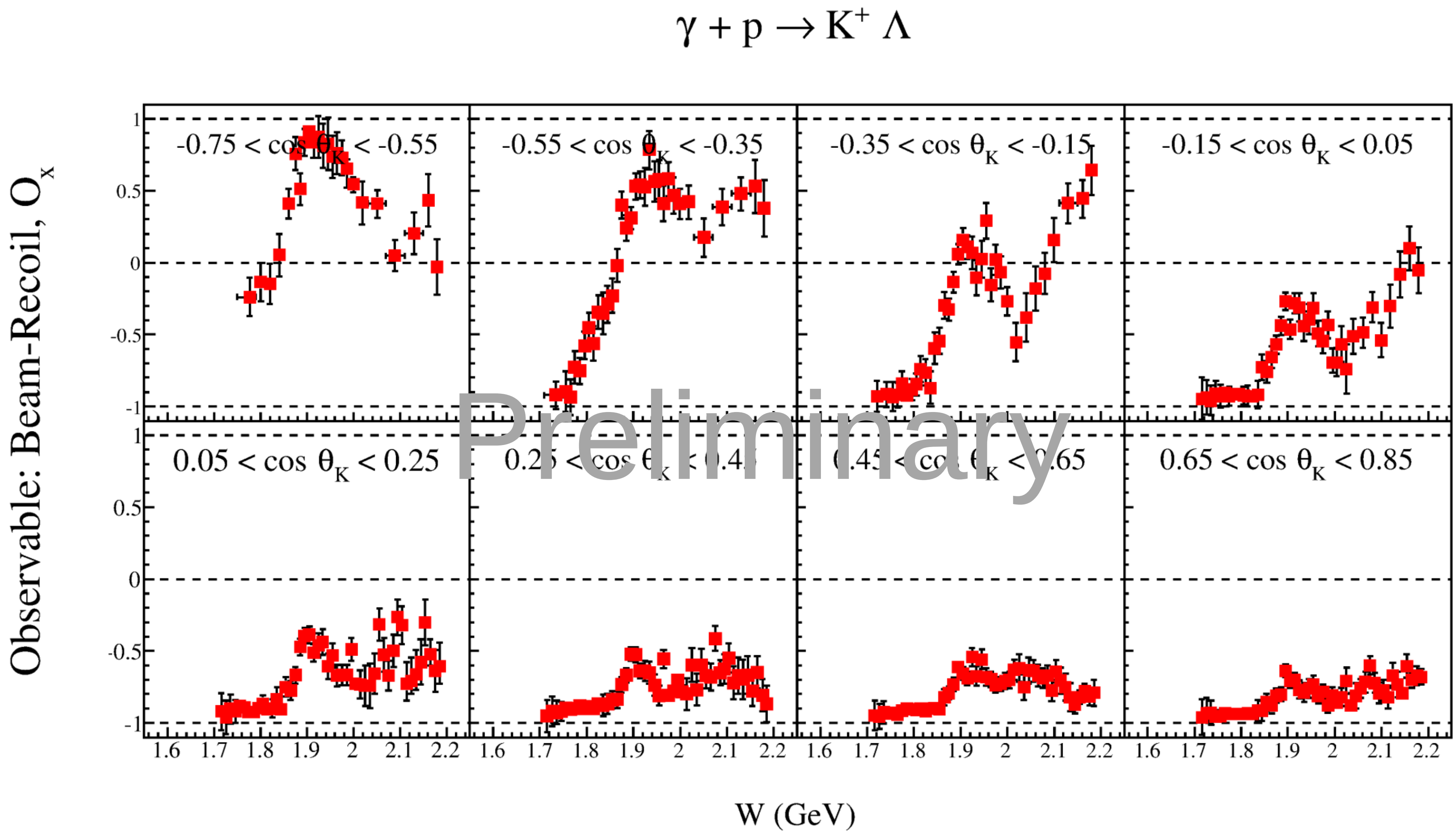


M. Dugger et al. (CLAS), Phys. Rev. C 88, 065203, 2013

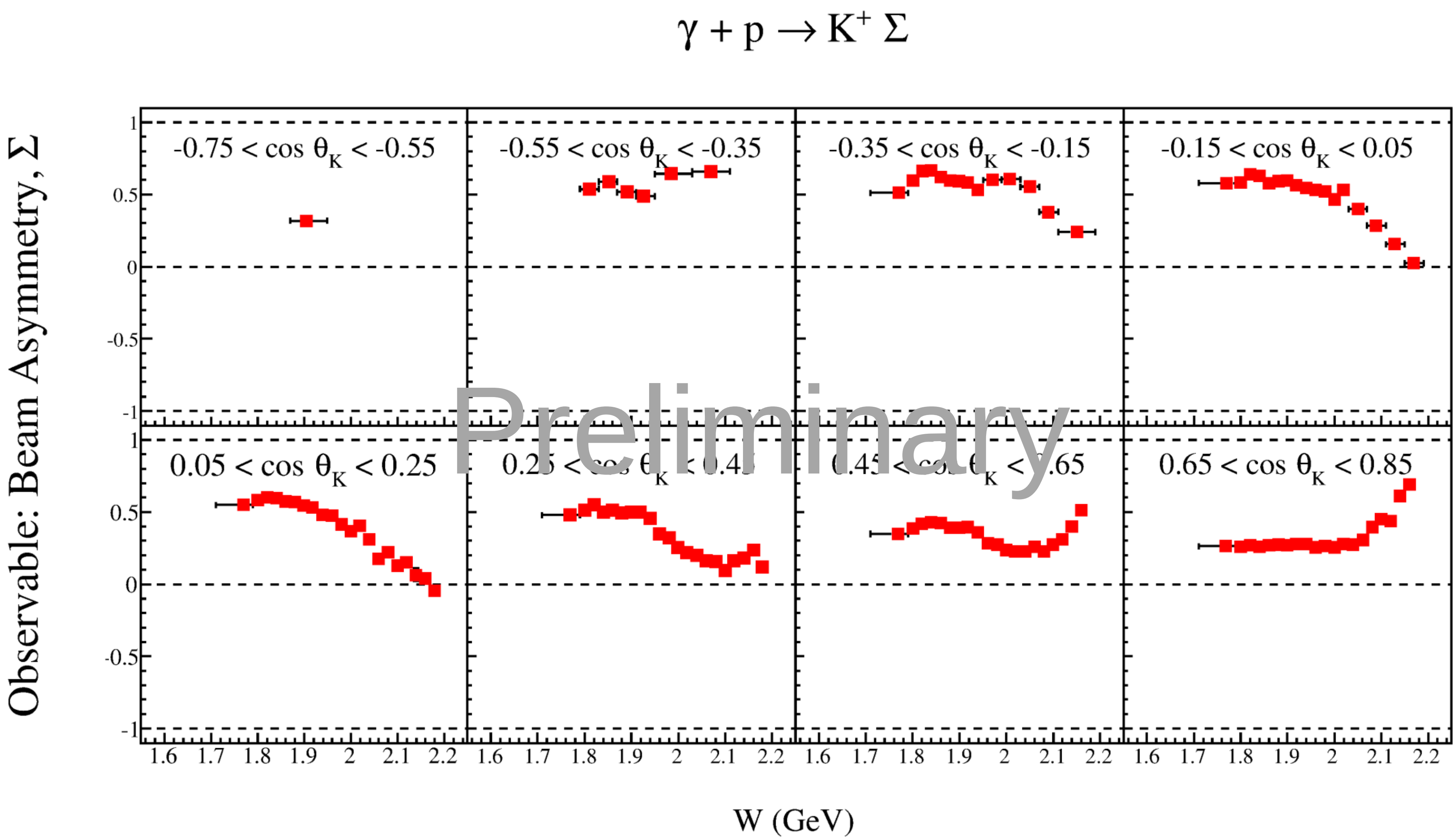
Beam-Recoil Polarization

$B_L\, T_U\, R_N$	$= 1 - P_L^\gamma\, \Sigma \cos(2\phi)$
$B_L\, T_U\, R_Y$	$= 1 + P\, P_y^R - (\Sigma + T\, P_y^R)\, P_L^\gamma \cos(2\phi) - (O_x\, P_x^R + O_z\, P_z^R)\, P_L^\gamma \sin(2\phi)$
$B_L\, T_L\, R_N$	$= 1 - \Sigma\, P_L^\gamma \cos(2\phi) - G\, P_L^\gamma\, P_L^T \sin(2\phi)$
$B_L\, T_L\, R_Y$	$= 1 + P\, P_y^R + L_x\, P_x^R\, P_L^T + L_z\, P_z^R\, P_L^T$
	$-(\Sigma + T\, P_y^R + T_x\, P_z^R\, P_L^T - T_z\, P_x^R\, P_L^T)\, P_L^\gamma \cos(2\phi)$
	$+(F\, P_y^R\, P_L^T - G\, P_L^T - O_x\, P_x^R - O_z\, P_z^R)\, P_L^\gamma \sin(2\phi)$
$B_L\, T_T\, R_N$	$= 1 - \Sigma\, P_L^\gamma\, cos(2\phi) - P\, P_L^\gamma\, P_T^T \sin(\phi) \cos(2\phi)$
	$+T\, P_T^T \sin(\phi) - H\, P_L^\gamma\, P_T^T \cos(\phi) \sin(2\phi)$
$B_L\, T_T\, R_Y$	$= 1 - P_L^\gamma\, P_y^R\, P_T^T \sin(\phi) \cos(2\phi) + \Sigma(P_y^R\, P_T^T \sin(\phi) - P_L^\gamma \cos(2\phi))$
	$+P(P_y^R - P_L^\gamma\, P_T^T \sin(\phi) \cos(2\phi)) + T\,(P_T^T \sin(\phi) - P_L^\gamma\, P_y^R \cos(2\phi))$
	$+(E\, P_y^R - H)\, P_L^\gamma\, P_T^T \cos(\phi) \sin(2\phi)$
	$+(C_x\, P_z^R - C_z\, P_x^R)\, P_L^\gamma\, P_T^T \sin(\phi) \sin(2\phi)$
	$-(O_x\, P_x^R \sin(2\phi) + O_z\, P_z^R)\, P_L^\gamma \sin(2\phi) + (T_x\, P_x^R + T_z\, P_z^R)\, P_T^T \cos(\phi)$
	$+(L_x P_z^R - L_z\, P_x^R)\, P_L^\gamma\, P_T^T \cos(\phi) \cos(2\phi)$

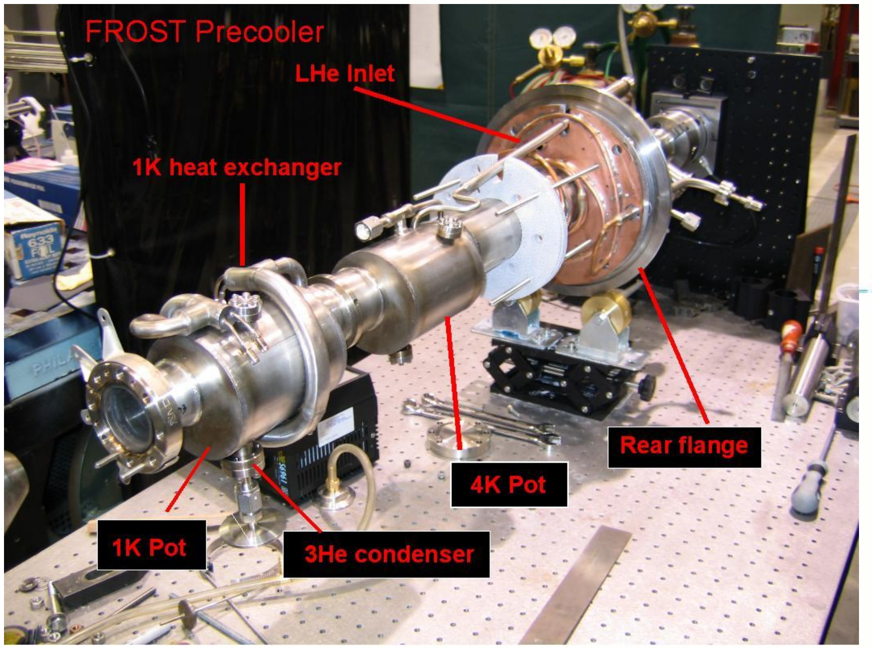
CLAS Results: Channel: $\vec{\gamma} + p \rightarrow K^+ + \Lambda$;Observable: Ox

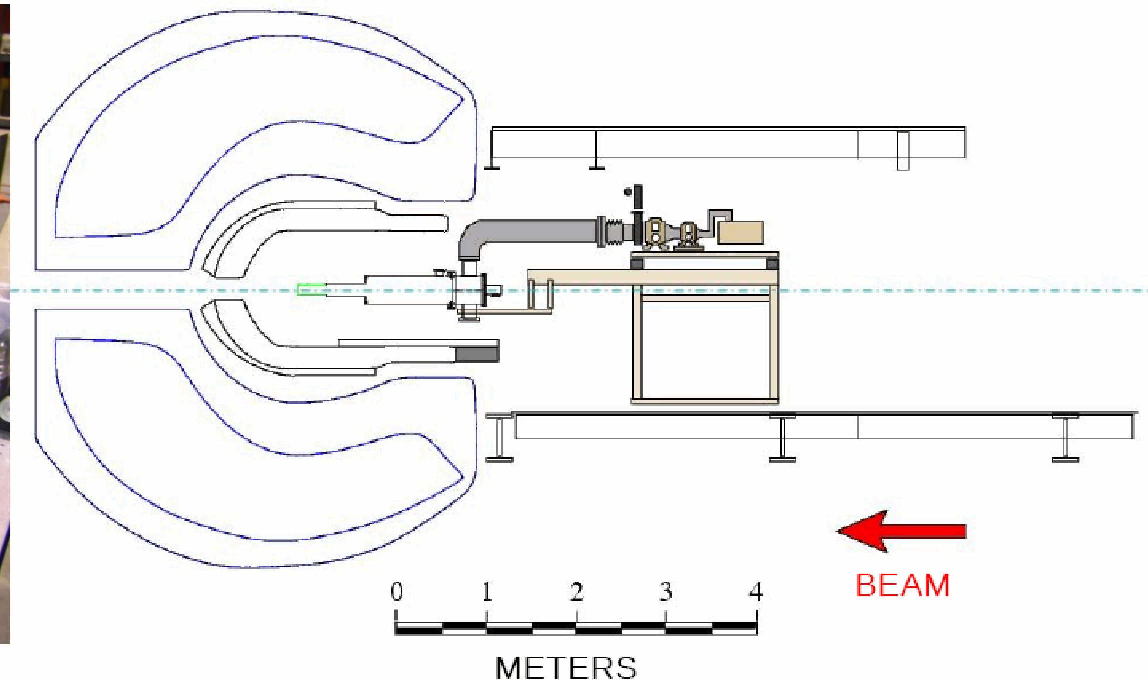


CLAS Results: Channel: $\vec{\gamma} + p \rightarrow K^+ + \Sigma^0$;Observable: Σ



FROzen Spin Target (FROST)



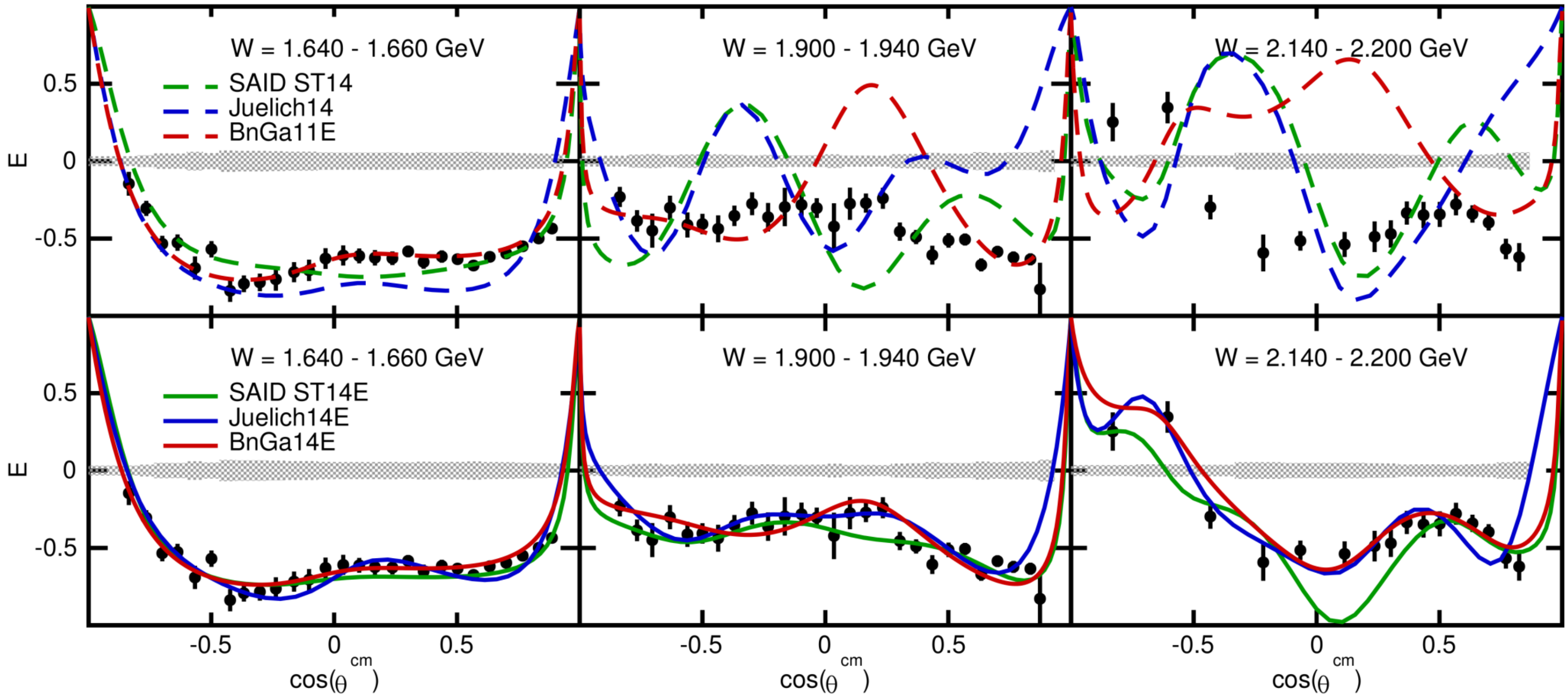


Target can be longitudinally or transversely polarised

Target Polarization

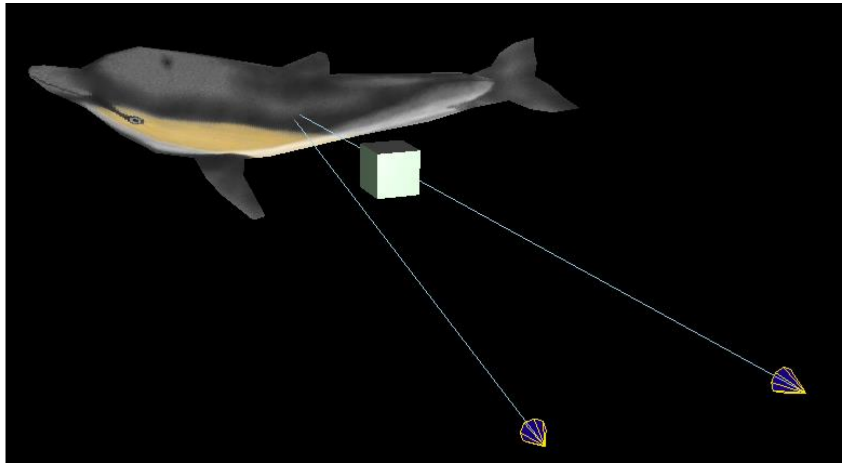
Configuration	σ_{Red}/σ_0
$B_U\,T_U\,R_N$	$= 1$
$B_U\,T_U\,R_Y$	$= 1 + P\,P_y^R$
$B_U\,T_L\,R_N$	$= 1$
$B_U\,T_L\,R_Y$	$= 1 + P\,P_y^R + L_x\,P_x^R\,P_L^T$
$B_U\,T_T\,R_N$	$= 1 + T\,P_T^T\sin(\phi)$
$B_U\,T_T\,R_Y$	$= 1 + P\,P_y^R + (\Sigma\,P_y^R + T)\,P_T^T\sin(\phi) + (T_x\,P_x^R + T_z\,P_y^R)\,P_T^T\cos(\phi)$
$B_C\,T_U\,R_N$	$= 1$
$B_C\,T_U\,R_Y$	$= 1 + P\,P_y^R - C_x\,P_C^\gamma\,P_x^R - C_z\,P_C^\gamma\,P_z^R$
$B_C\,T_L\,R_N$	$= 1 - E\,P_C^\gamma\,P_L^T$
$B_C\,T_L\,R_Y$	$= 1 + P\,P_y^R - E\,P_C^\gamma\,P_L^T + H\,P_C^\gamma\,P_y^R\,P_L^T$ $-C_x\,P_C^\gamma\,P_x^R - C_z\,P_C^\gamma\,P_z^R + L_x\,P_x^R\,P_L^T + L_z\,P_z^R\,P_L^T$
$B_C\,T_T\,R_N$	$= 1 + T\,P_T^T\sin(\phi) + F\,P_C^\gamma\,P_T^T\cos(\phi)$
$B_C\,T_T\,R_Y$	$= 1 + P\,P_y^R - C_x\,P_C^\gamma\,P_x^R - C_z\,P_C^\gamma\,P_z^R$ $+(\Sigma\,P_y^R + T - O_x\,P_C^\gamma\,P_z^R + O_z\,P_C^\gamma\,P_x^R)\,P_T^T\sin(\phi)$ $+(F\,P_C^\gamma\,P_y^R - G\,P_C^\gamma\,P_y^R + T_x\,P_x^R + T_z\,P_z^R)\,P_T^T\cos(\phi)$

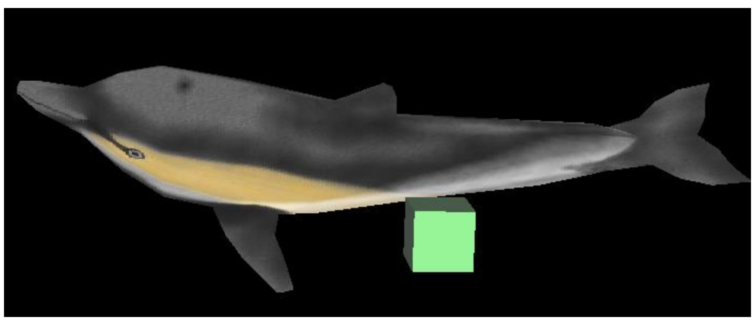
CLAS Results: Channel: $\vec{\gamma} + \vec{p} \rightarrow \pi^+ + n$;Observable: E

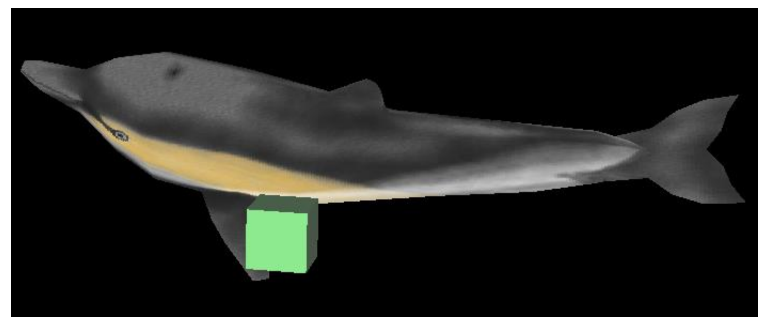


S. Strauch et al. (CLAS), http://arxiv.org/abs/1503.05163 , submitted to PRL

Imaging Multi-dimensional Objects



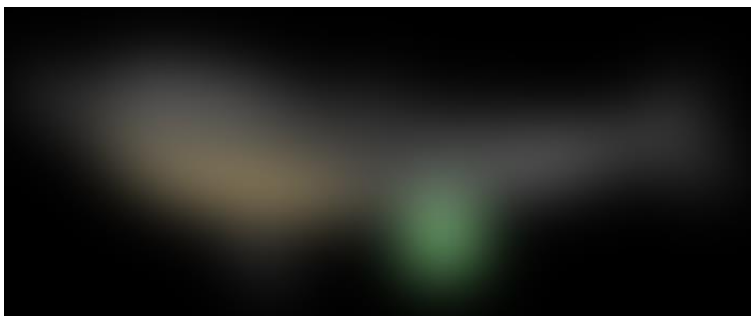


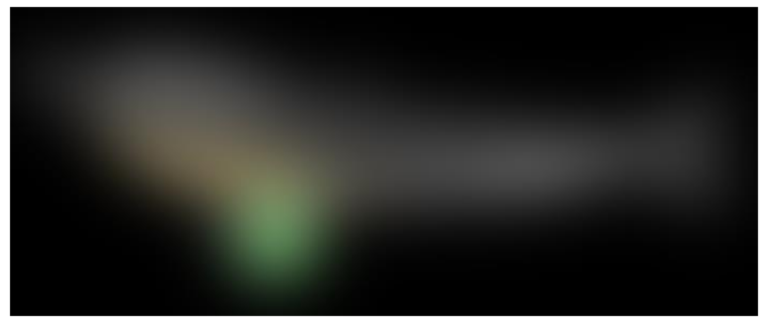


There is no such thing as a complete measurement!

Imaging Multi-dimensional Objects

?





Baryon Summary Table (PDG 2014)

p	$1/2^+$	****
n	$1/2^+$	****
$N(1440)$	$1/2^+$	****
$N(1520)$	$3/2^-$	****
$N(1535)$	$1/2^-$	****
$N(1650)$	$1/2^-$	****
$N(1675)$	$5/2^-$	****
$N(1680)$	$5/2^+$	****
$N(1685)$		*
$N(1700)$	$3/2^-$	***
$N(1710)$	$1/2^+$	***
$N(1720)$	$3/2^+$	****
$N(1860)$	$5/2^+$	**
$N(1875)$	$3/2^-$	***
$N(1880)$	$1/2^+$	**
$N(1895)$	$1/2^-$	**
$N(1900)$	$3/2^+$	***
$N(1990)$	$7/2^+$	**
$N(2000)$	$5/2^+$	**
$N(2040)$	$3/2^+$	*
$N(2060)$	$5/2^-$	**
$N(2100)$	$1/2^+$	*
$N(2120)$	$3/2^-$	**
$N(2190)$	$7/2^-$	****
$N(2220)$	$9/2^+$	****
$N(2250)$	$9/2^-$	****
$N(2300)$	$1/2^+$	**
$N(2570)$	$5/2^-$	**
$N(2600)$	$11/2^-$	***
$N(2700)$	$13/2^+$	**

$\Delta(1232)$	$3/2^+$	****
$\Delta(1600)$	$3/2^+$	***
$\Delta(1620)$	$1/2^-$	****
$\Delta(1700)$	$3/2^-$	****
$\Delta(1750)$	$1/2^+$	*
$\Delta(1900)$	$1/2^-$	**
$\Delta(1905)$	$5/2^+$	****
$\Delta(1910)$	$1/2^+$	****
$\Delta(1920)$	$3/2^+$	***
$\Delta(1930)$	$5/2^-$	***
$\Delta(1940)$	$3/2^-$	**
$\Delta(1950)$	$7/2^+$	****
$\Delta(2000)$	$5/2^+$	**
$\Delta(2150)$	$1/2^-$	*
$\Delta(2200)$	$7/2^-$	*
$\Delta(2300)$	$9/2^+$	**
$\Delta(2350)$	$5/2^-$	*
$\Delta(2390)$	$7/2^+$	*
$\Delta(2400)$	$9/2^-$	**
$\Delta(2420)$	$11/2^+$	****
$\Delta(2750)$	$13/2^-$	**
$\Delta(2950)$	$15/2^+$	**
Λ	$1/2^+$	****
$\Lambda(1405)$	$1/2^-$	****
$\Lambda(1520)$	$3/2^-$	****
$\Lambda(1600)$	$1/2^+$	***
$\Lambda(1670)$	$1/2^-$	****
$\Lambda(1690)$	$3/2^-$	****
$\Lambda(1710)$	$1/2^+$	*
$\Lambda(1800)$	$1/2^-$	***
$\Lambda(1810)$	$1/2^+$	***
$\Lambda(1820)$	$5/2^+$	****
$\Lambda(1830)$	$5/2^-$	****
$\Lambda(1890)$	$3/2^+$	****
$\Lambda(2000)$		*
$\Lambda(2020)$	$7/2^+$	*
$\Lambda(2050)$	$3/2^-$	*
$\Lambda(2100)$	$7/2^-$	****
$\Lambda(2110)$	$5/2^+$	***
$\Lambda(2325)$	$3/2^-$	*
$\Lambda(2350)$	$9/2^+$	***
$\Lambda(2585)$		**

Σ^+	$1/2^+$	****
Σ^0	$1/2^+$	****
Σ^-	$1/2^+$	****
$\Sigma(1385)$	$3/2^+$	****
$\Sigma(1480)$		*
$\Sigma(1560)$		**
$\Sigma(1580)$	$3/2^-$	*
$\Sigma(1620)$	$1/2^-$	*
$\Sigma(1660)$	$1/2^+$	***
$\Sigma(1670)$	$3/2^-$	****
$\Sigma(1690)$		**
$\Sigma(1730)$	$3/2^+$	*
$\Sigma(1750)$	$1/2^-$	***
$\Sigma(1770)$	$1/2^+$	*
$\Sigma(1775)$	$5/2^-$	****
$\Sigma(1840)$	$3/2^+$	*
$\Sigma(1880)$	$1/2^+$	**
$\Sigma(1900)$	$1/2^-$	*
$\Sigma(1915)$	$5/2^+$	****
$\Sigma(1940)$	$3/2^+$	*
$\Sigma(1940)$	$3/2^-$	***
$\Sigma(2000)$	$1/2^-$	*
$\Sigma(2030)$	$7/2^+$	****
$\Sigma(2070)$	$5/2^+$	*
$\Sigma(2080)$	$3/2^+$	**
$\Sigma(2100)$	$7/2^-$	*
$\Sigma(2250)$		***
$\Sigma(2455)$		**
$\Sigma(2620)$		**
$\Sigma(3000)$		*
$\Sigma(3170)$		*

Ξ^0	$1/2^+$	****
Ξ^-	$1/2^+$	****
$\Xi(1530)$	$3/2^+$	****
$\Xi(1620)$		*
$\Xi(1690)$		***
$\Xi(1820)$	$3/2^-$	***
$\Xi(1950)$		***
$\Xi(2030)$	$\geq \frac{5}{2}?$	***
$\Xi(2120)$		*
$\Xi(2250)$		**
$\Xi(2370)$		**
$\Xi(2500)$		*
Ω^-	$3/2^+$	****
$\Omega(2250)^-$		***
$\Omega(2380)^-$		**
$\Omega(2470)^-$		**

Λ_c^+	$1/2^+$	****
$\Lambda_c(2595)^+$	$1/2^-$	***
$\Lambda_c(2625)^+$	$3/2^-$	***
$\Lambda_c(2765)^+$		*
$\Lambda_c(2880)^+$	$5/2^+$	***
$\Lambda_c(2940)^+$		***
$\Sigma_c(2455)$	$1/2^+$	****
$\Sigma_c(2520)$	$3/2^+$	***
$\Sigma_c(2800)$		***
Ξ_c^+	$1/2^+$	***
Ξ_c^0	$1/2^+$	***
$\Xi_c'^+$	$1/2^+$	***
$\Xi_c'^0$	$1/2^+$	***
$\Xi_c(2645)$	$3/2^+$	***
$\Xi_c(2790)$	$1/2^-$	***
$\Xi_c(2815)$	$3/2^-$	***
$\Xi_c(2930)$		*
$\Xi_c(2980)$		***
$\Xi_c(3055)$		**
$\Xi_c(3080)$		***
$\Xi_c(3123)$		*
Ω_c^0	$1/2^+$	***
$\Omega_c(2770)^0$	$3/2^+$	***
Ξ_{cc}^+		*
Λ_b^0	$1/2^+$	***
$\Lambda_b(5912)^0$	$1/2^-$	***
$\Lambda_b(5920)^0$	$3/2^-$	***
Σ_b	$1/2^+$	***
Σ_b^*	$3/2^+$	***
Ξ_b^0, Ξ_b^-	$1/2^+$	***
$\Xi_b(5945)^0$	$3/2^+$	***
Ω_b^-	$1/2^+$	***

Number of 3- and 4-star Resonances

Baryon	2004	2014
N*	15	**17**
Δ	10	10
Λ	14	14
Σ	12	12
Ξ	7	**9**
Ω	2	2
other	14	**27**

N* photoproduction program at CLAS

Data taking completed May 18, 2012

✔-published, ✓-acquired

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

Summary and Outlook

- CLAS has measured many photoproduction channels in N* resonance region

- Much more still to come, including:
  - Two-pion photoproduction
  - Finalised results from linearly polarized photon beams
  - Results from deuterium target
  - More results from FROST
  - Results from HDIce

- Electroproduction also important (see Ralf Gothe's talk)

- Progress in N* physics needs:
  - Combined analyses of all relevant channels
  - Use of data from all sources (different labs)
  - Data consistency
  - More hard work!