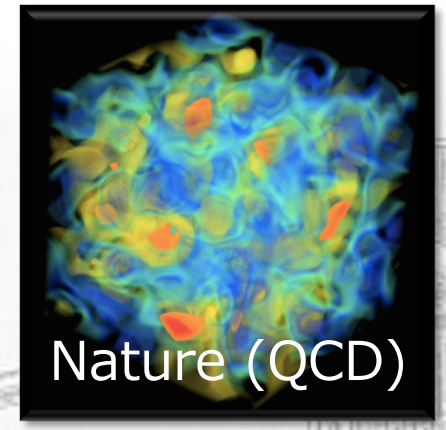
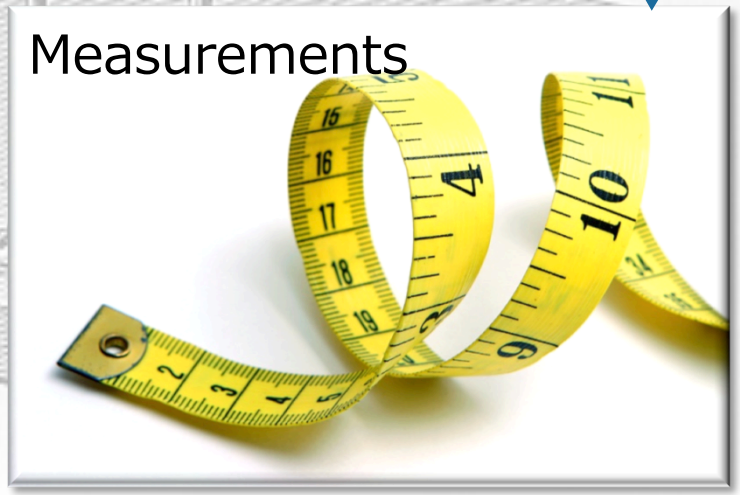
Our Task

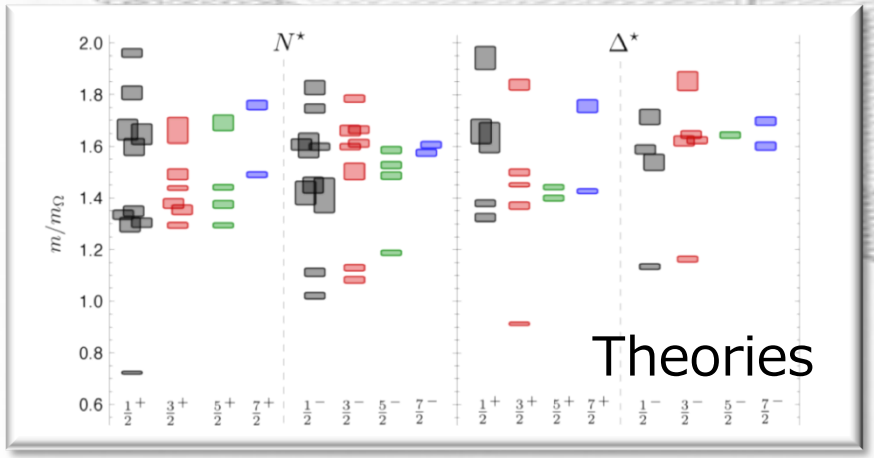


manifests itself in

are accessible to



inspire



help us understand

Measurement

"When you can measure what you are speaking about, and express it in numbers, you know something about it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts advanced to the stage of science."

— William Thomson, 1st Baron Kelvin

PHYSICS REPORTS (Review Section of Physics Letters) 96, Nos. 2 & 3 (1983) 71–204. North-Holland Publishing Company

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

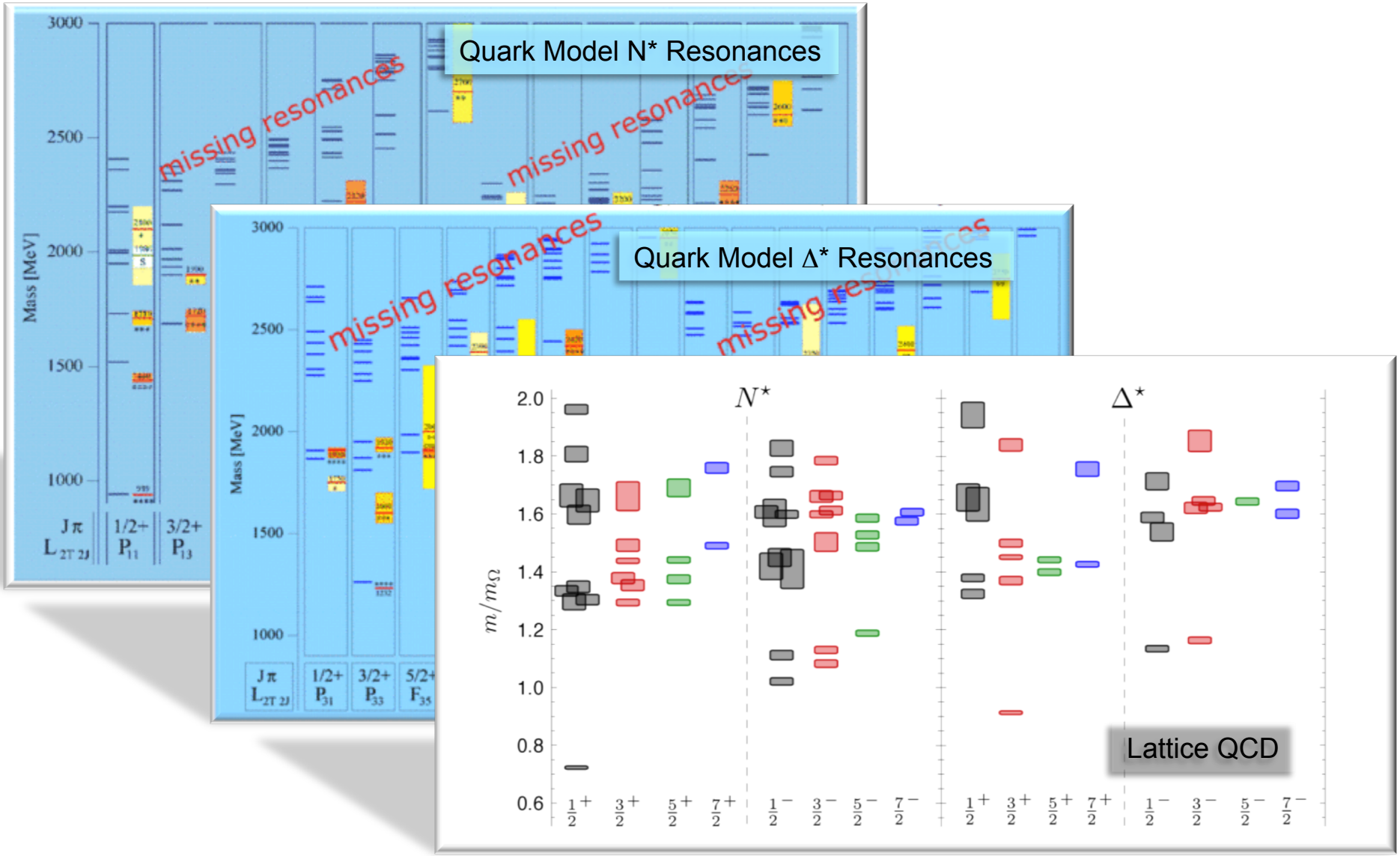
Ξ^0	$1/2^+$	****
Ξ^-	$1/2^+$	****
$\Xi(1530)$	$3/2^+$	****
$\Xi(1620)$		*
$\Xi(1690)$		***
$\Xi(1820)$	$3/2^-$	***
$\Xi(1950)$		***
$\Xi(2030)$	$\geq \frac{5}{2}?$	***
$\Xi(2120)$		*
$\Xi(2250)$		**
$\Xi(2370)$		**
$\Xi(2500)$		*
Ω^-	$3/2^+$	****
$\Omega(2250)^-$		***
$\Omega(2380)^-$		**
$\Omega(2470)^-$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

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	$1/2^+$	***
$\Xi_c^{\prime +}$	$1/2^+$	***
$\Xi_c^{\prime 0}$	$1/2^+$	***
$\Xi_c(2645)$	$3/2^+$	***
$\Xi_c(2790)$	$1/2^-$	***
$\Xi_c(2815)$	$3/2^-$	***
$\Xi_c(2930)$		*
$\Xi_c(2980)$		***
$\Xi_c(3055)$		**
$\Xi_c(3080)$		***
$\Xi_c(3123)$		*
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^-	$1/2^+$	***

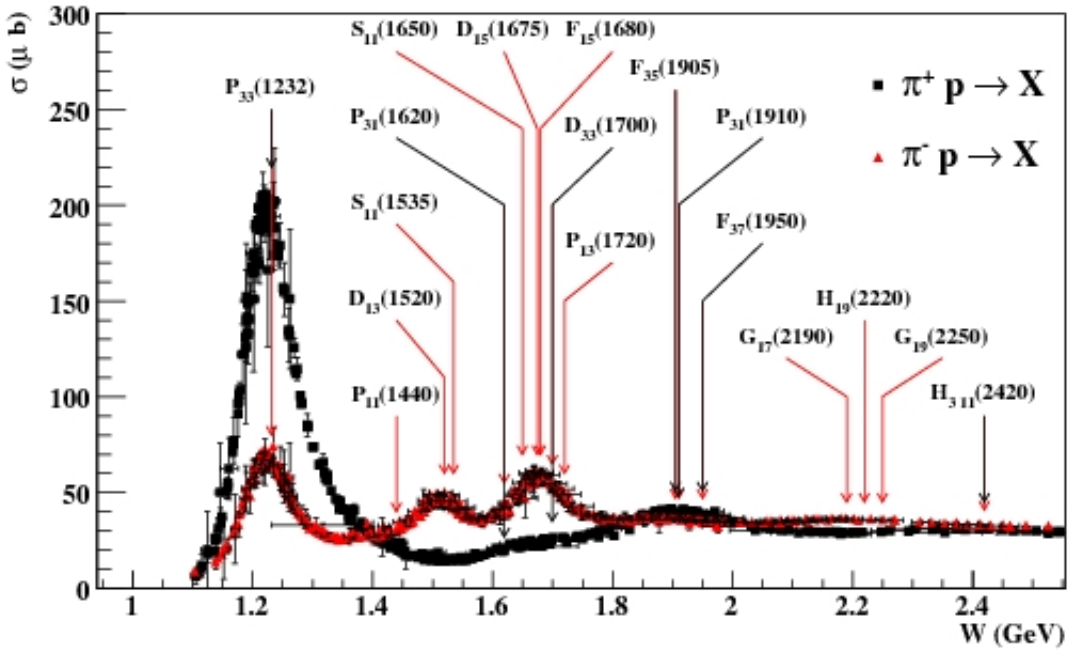
Number of 3- and 4-star Resonances

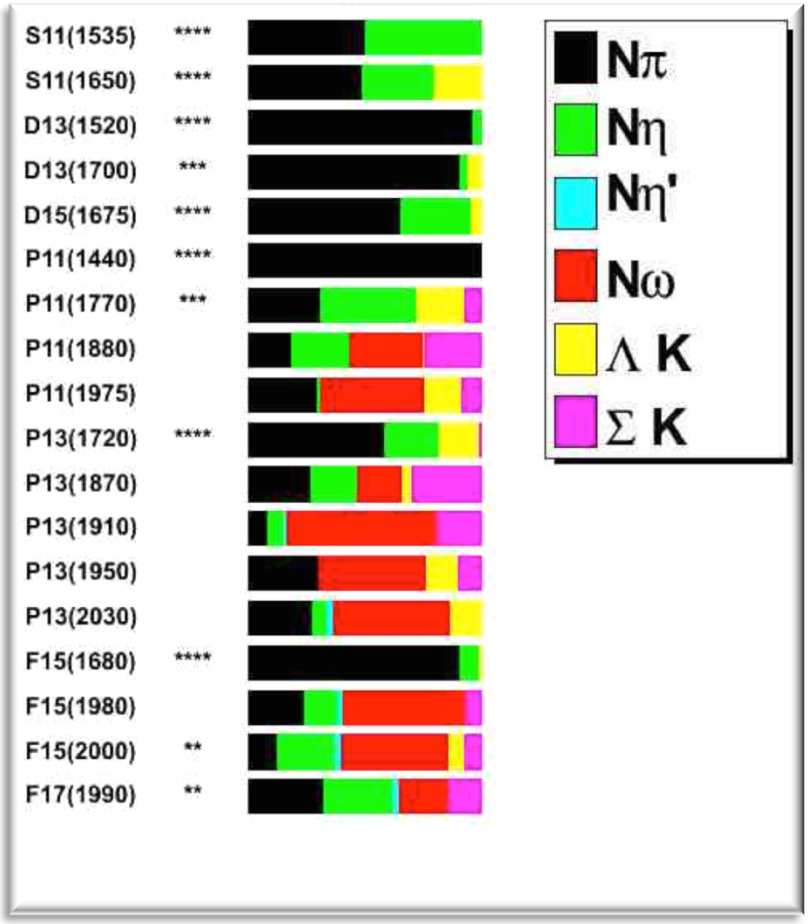
Baryon	2004	2014
N*	15	17
Δ	10	10
Λ	14	14
Σ	12	12
Ξ	7	9
Ω	2	2
other	14	27

But...


Quark Model N* Resonances
missing resonances
missing resonances
Mass [MeV]
3000
2500
2000
1500
1000
Jπ
L 2T 2J
1/2+
P11
3/2+
P13
Quark Model Δ* Resonances
missing resonances
missing resonances
Mass [MeV]
3000
2500
2000
1500
1000
Jπ
L 2T 2J
1/2+
P31
3/2+
P33
5/2+
F35
N*
Δ*
m/mΩ
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
1/2+ 3/2+ 5/2+ 7/2+ 1/2− 3/2− 5/2− 7/2−
1/2+ 3/2+ 5/2+ 7/2+ 1/2− 3/2− 5/2− 7/2−
Lattice QCD

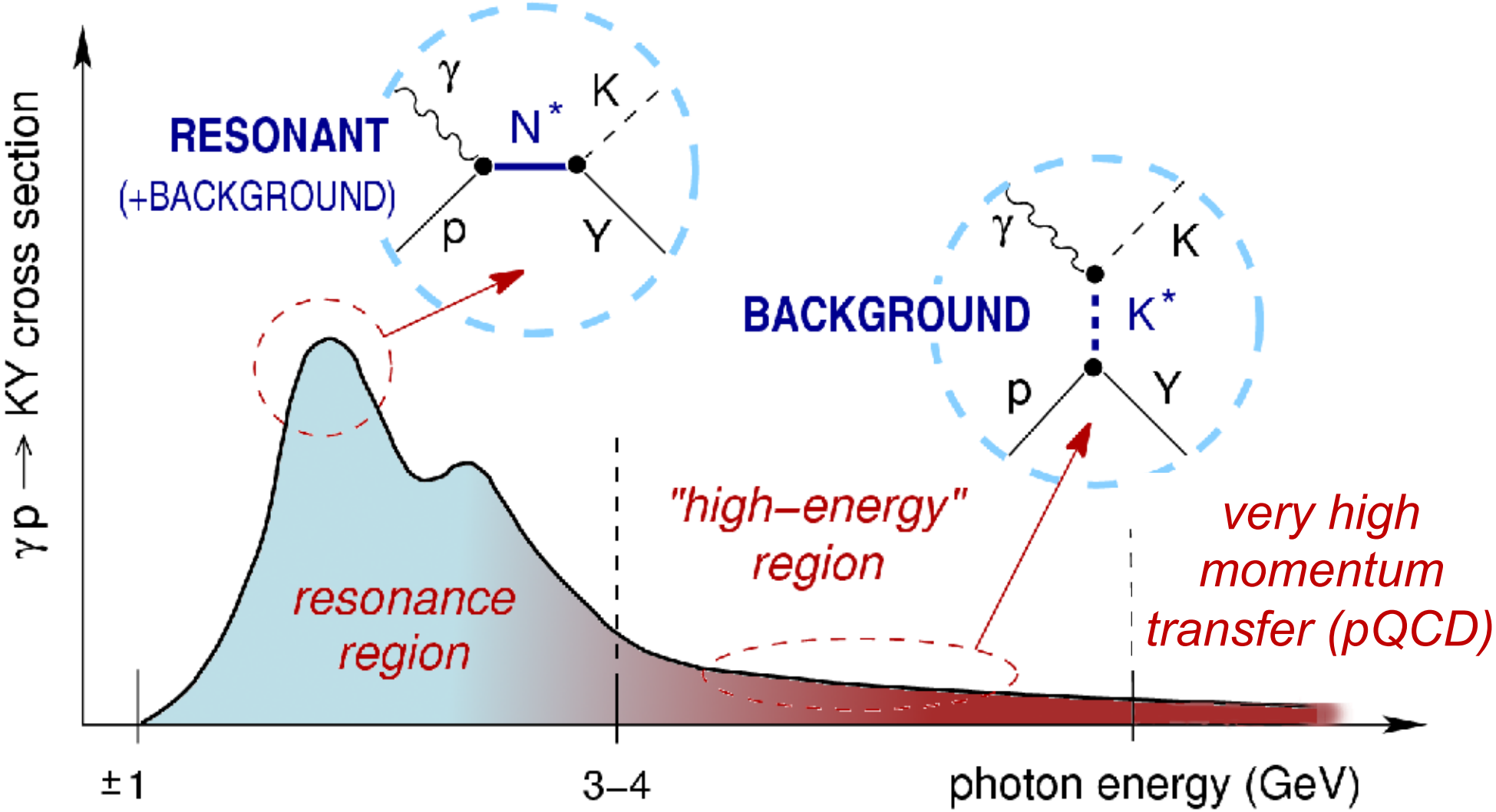
Total Cross-sections
+ differential cross-sections
+ Partial Wave Analysis + ...



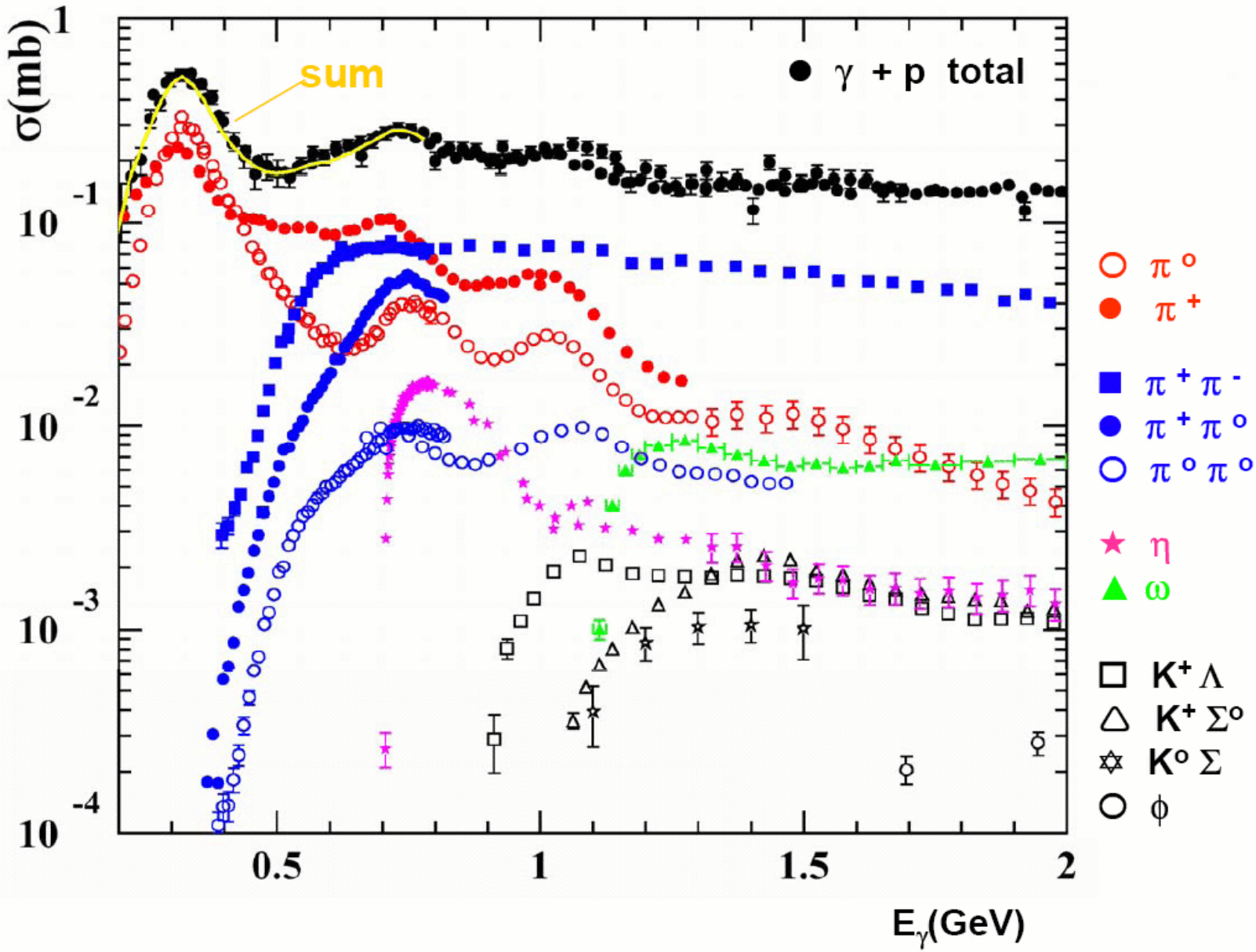


- Mostly done with πN scattering
- Missing resonances may decay through other channels

Pseudoscalar Meson Photoproduction

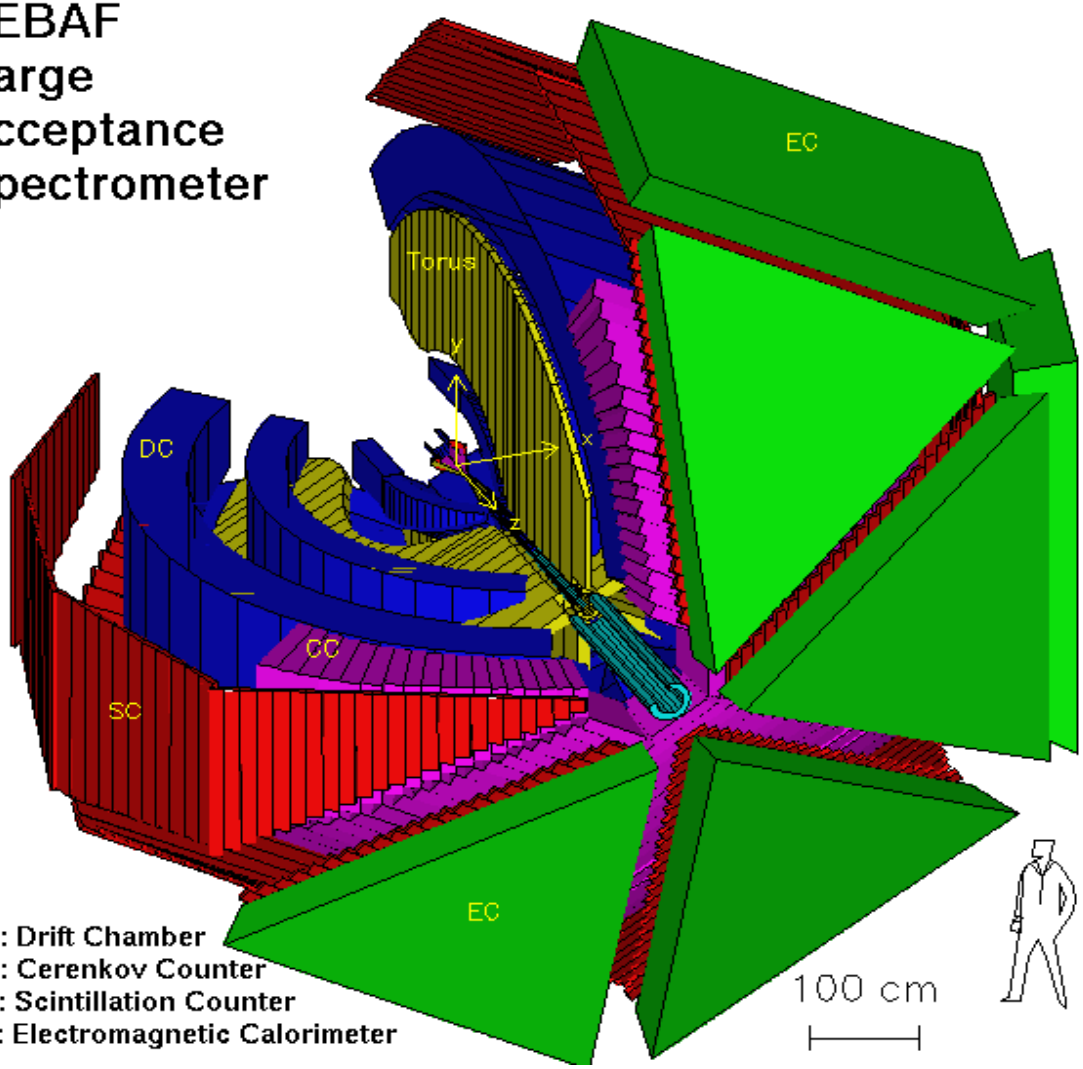


Meson Photoproduction Cross Sections



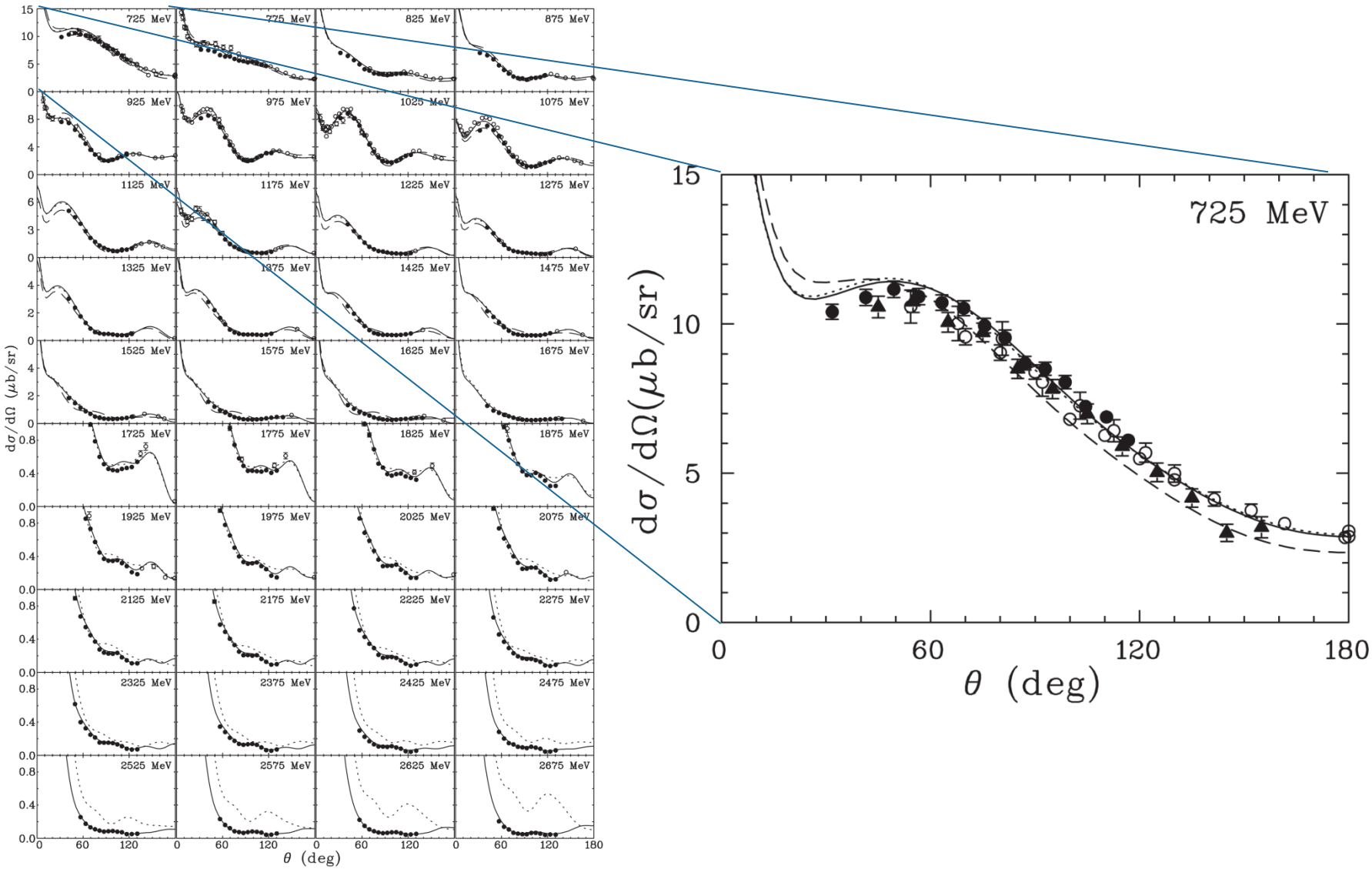
Jefferson Lab

CEBAF
Large
Acceptance
Spectrometer



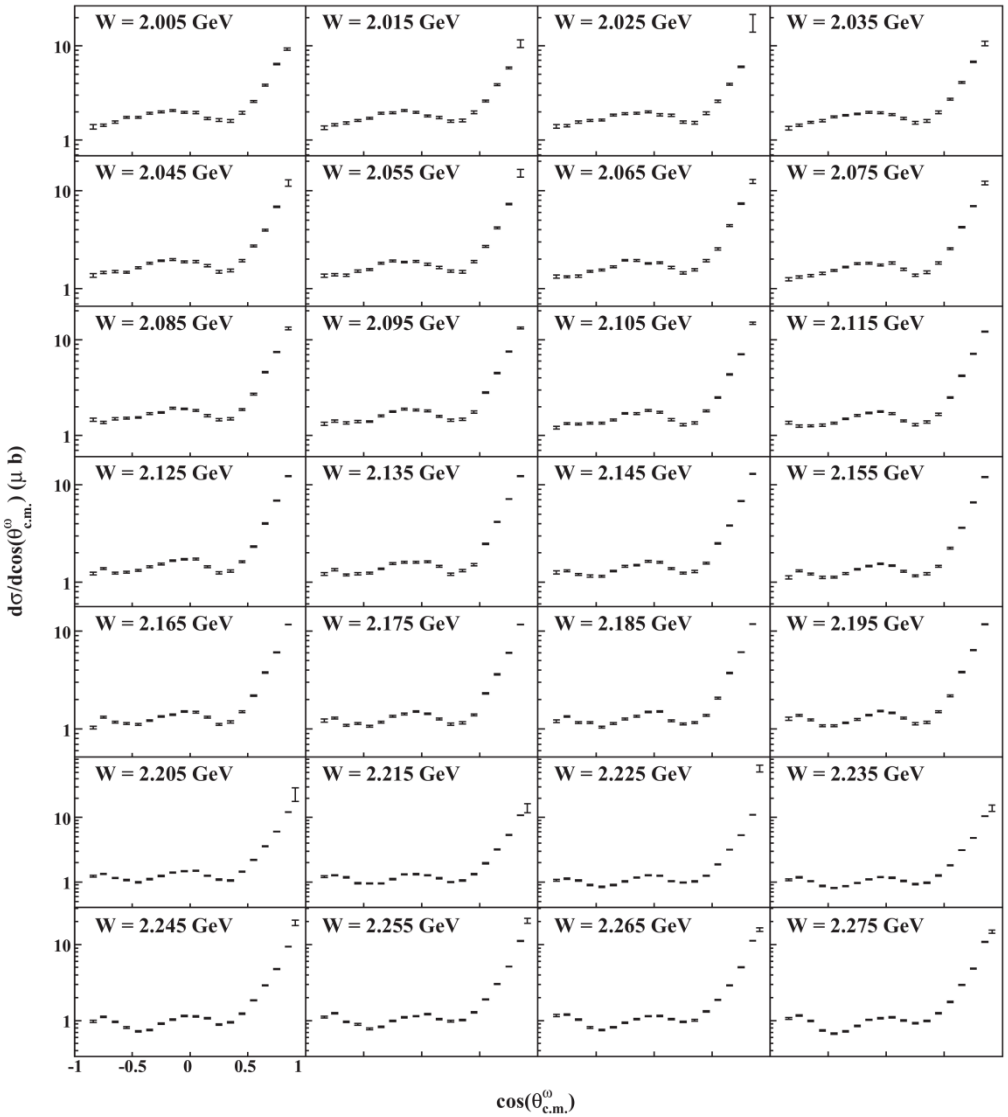
DC: Drift Chamber
CC: Cerenkov Counter
SC: Scintillation Counter
EC: Electromagnetic Calorimeter

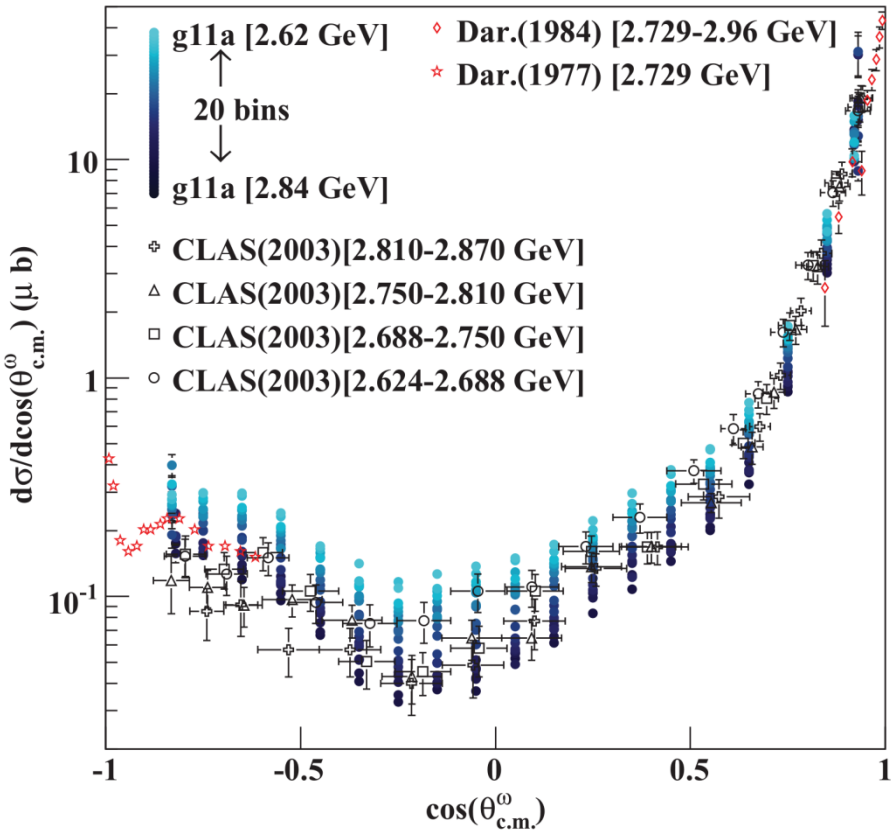
Channel: $\gamma + p \rightarrow \pi^{+} + n$; Cross-section



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

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



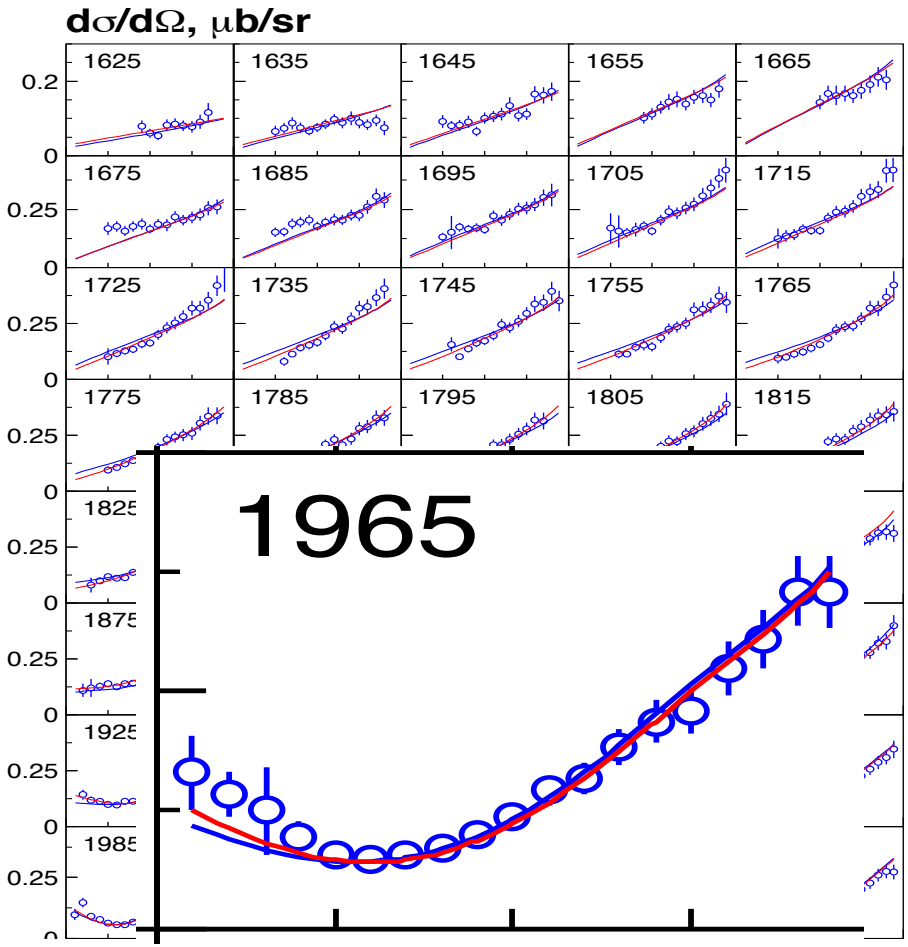


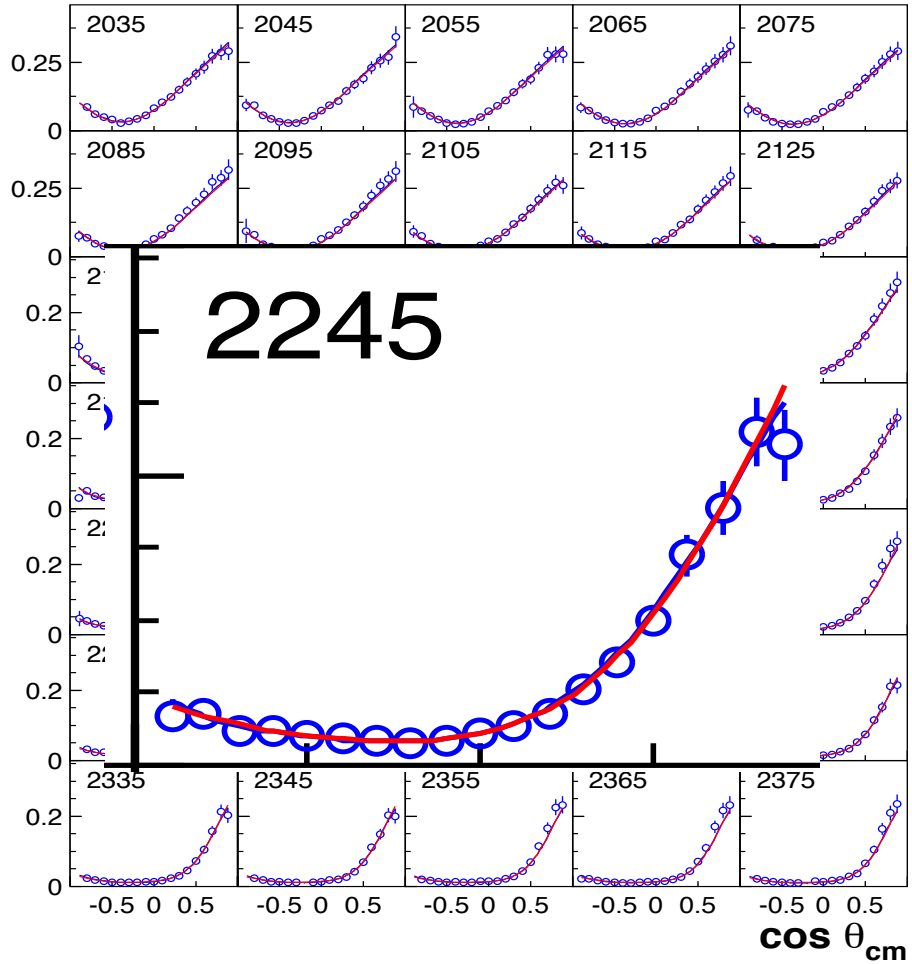
M. Williams et al. (CLAS), Phys. Rev. C 80, 065208, 2009

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)

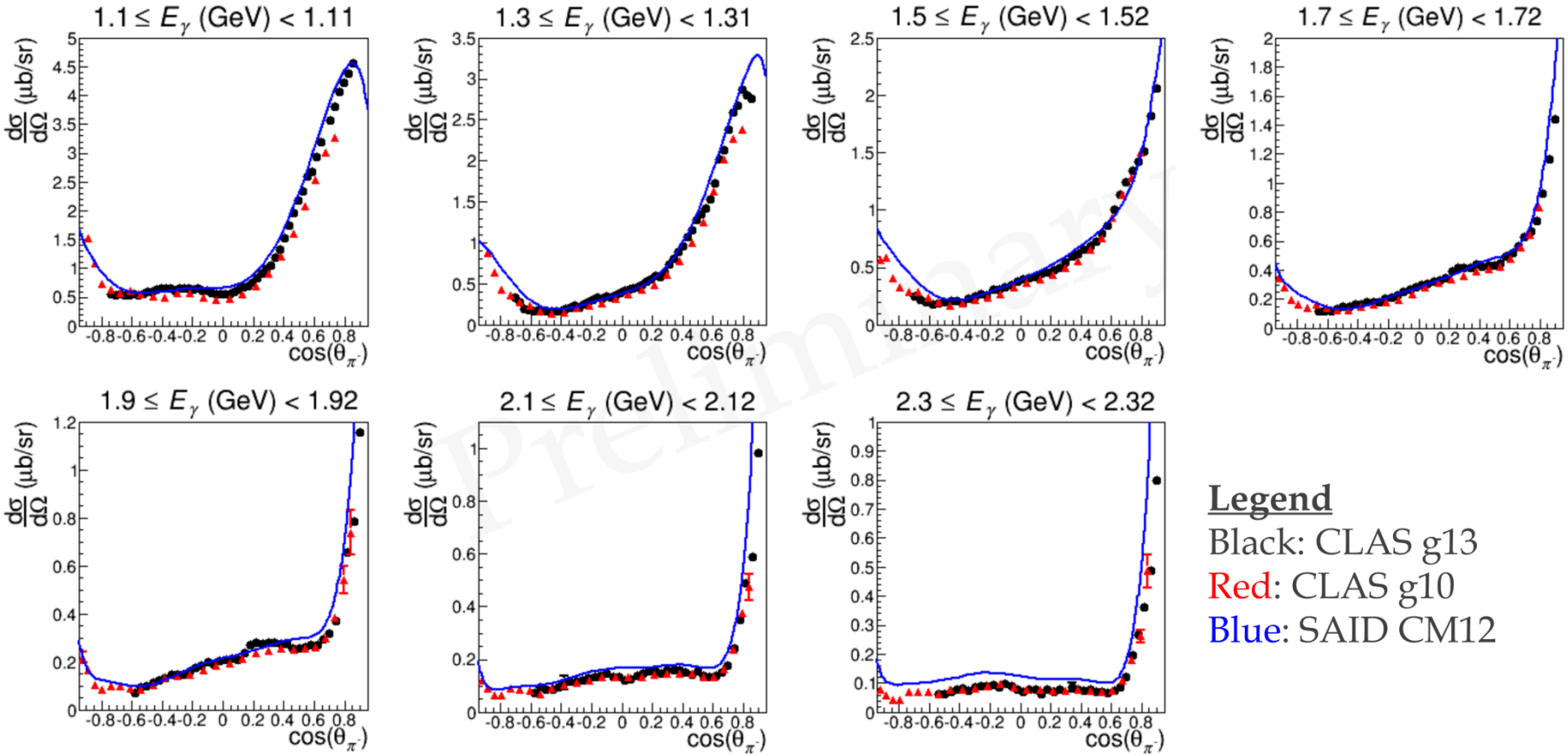
(Includes nearly all new photoproduction data)





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

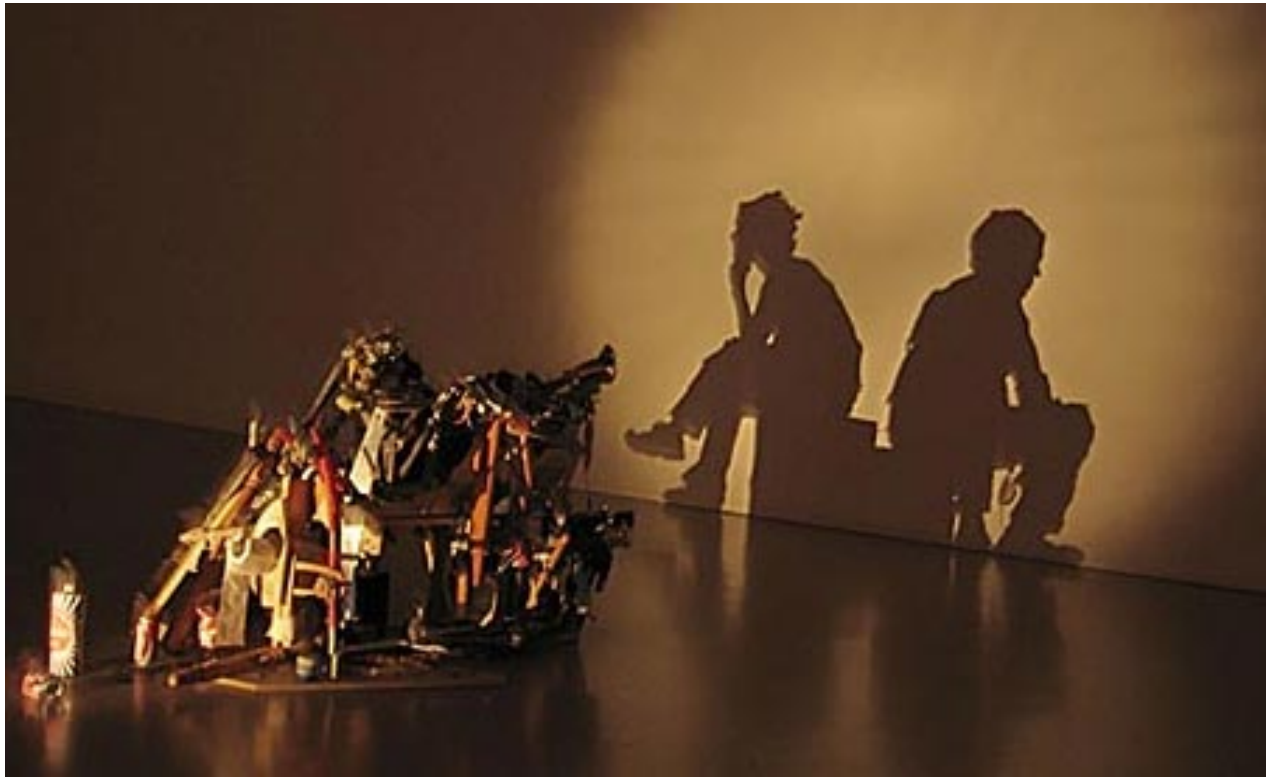
Channel: $\gamma + d \rightarrow \pi^{-} + p\,(n)$;Cross-section



Legend
Black: CLAS g13
Red: CLAS g10
Blue: SAID CM12

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)***

Interpreting results from one point of view

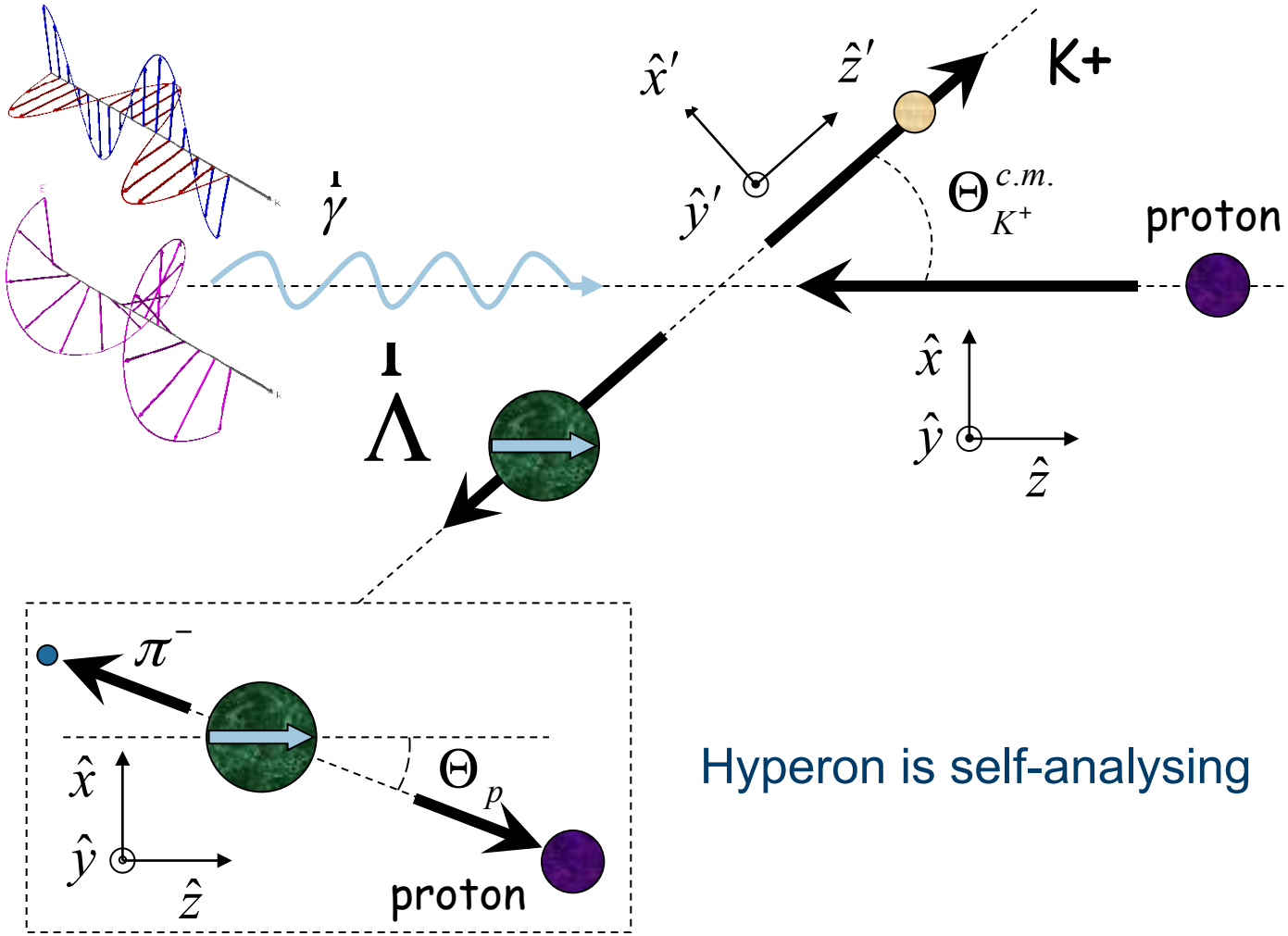


In praise of polarization...

Without Polarizer

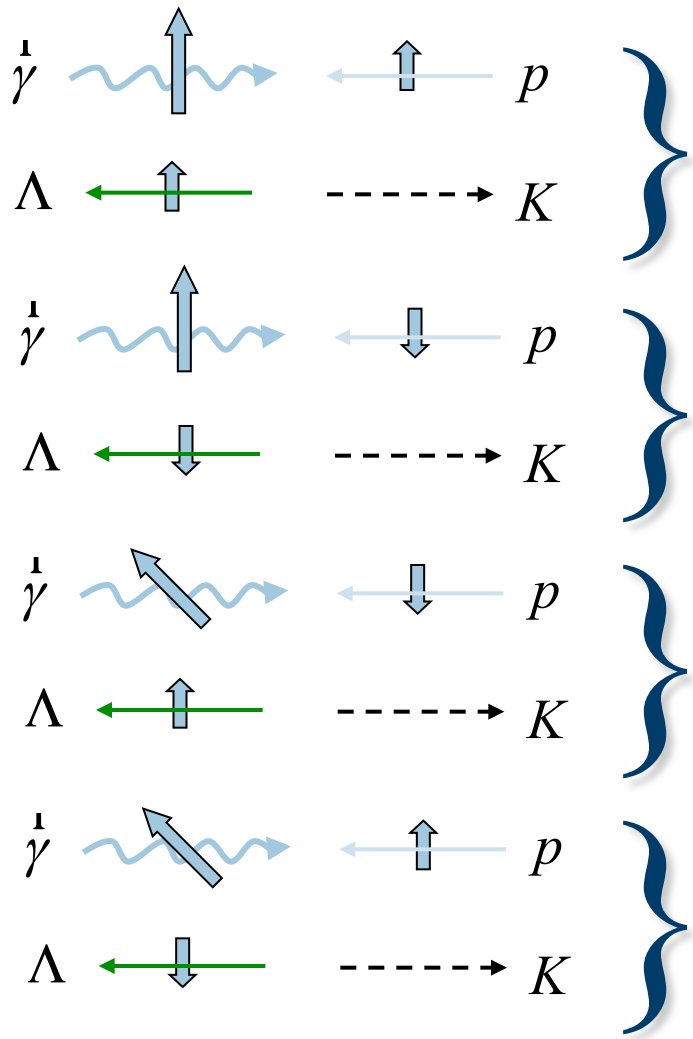
…you'll see more!

Example: Kaon Photoproduction



Hyperon is self-analysing

Transversity Amplitudes



$$b_1 = \langle + | M | + \perp \rangle$$

$$b_2 = \langle - | M | - \perp \rangle$$

$$b_3 = \langle + | M | - \parallel \rangle$$

$$b_4 = \langle - | M | + \parallel \rangle$$

Observables and Amplitudes

Type	Observable	Transversity representation	Helicity representation
S	σ	$\lvert a_1\rvert^2 + \lvert a_2\rvert^2 + \lvert a_3\rvert^2 + \lvert a_4\rvert^2$	$\lvert h_1\rvert^2 + \lvert h_2\rvert^2 + \lvert h_3\rvert^2 + \lvert h_4\rvert^2$
	Σ	$\lvert a_1\rvert^2 + \lvert a_2\rvert^2 - \lvert a_3\rvert^2 - \lvert a_4\rvert^2$	$2\Re(h_1 h_4^* - h_2 h_3^*)$
	P	$\lvert a_1\rvert^2 - \lvert a_2\rvert^2 + \lvert a_3\rvert^2 - \lvert a_4\rvert^2$	$2\Im(h_1 h_3^* + h_2 h_4^*)$
	T	$\lvert a_1\rvert^2 - \lvert a_2\rvert^2 - \lvert a_3\rvert^2 + \lvert a_4\rvert^2$	$2\Im(h_1 h_3^* + h_2 h_4^*)$
BT	E	$2\Re(a_1 a_3^* + a_2 a_4^*)$	$\lvert h_1\rvert^2 - \lvert h_2\rvert^2 + \lvert h_3\rvert^2 - \lvert h_4\rvert^2$
	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	$2\Re(a_1 a_4^* + a_2 a_3^*)$	$\lvert h_1\rvert^2 + \lvert h_2\rvert^2 - \lvert h_3\rvert^2 - \lvert h_4\rvert^2$
	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	$2\Re(a_1 a_2^* + a_3 a_4^*)$	$\lvert h_1\rvert^2 - \lvert h_2\rvert^2 - \lvert h_3\rvert^2 + \lvert h_4\rvert^2$

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

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

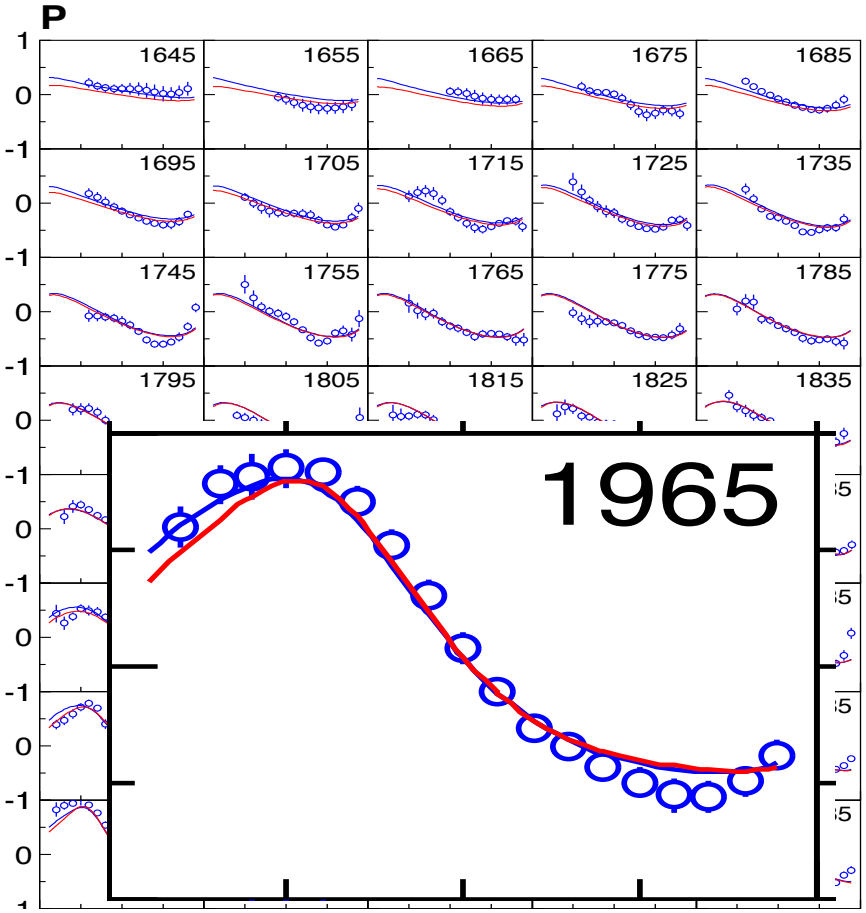
Recoil Polarization

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

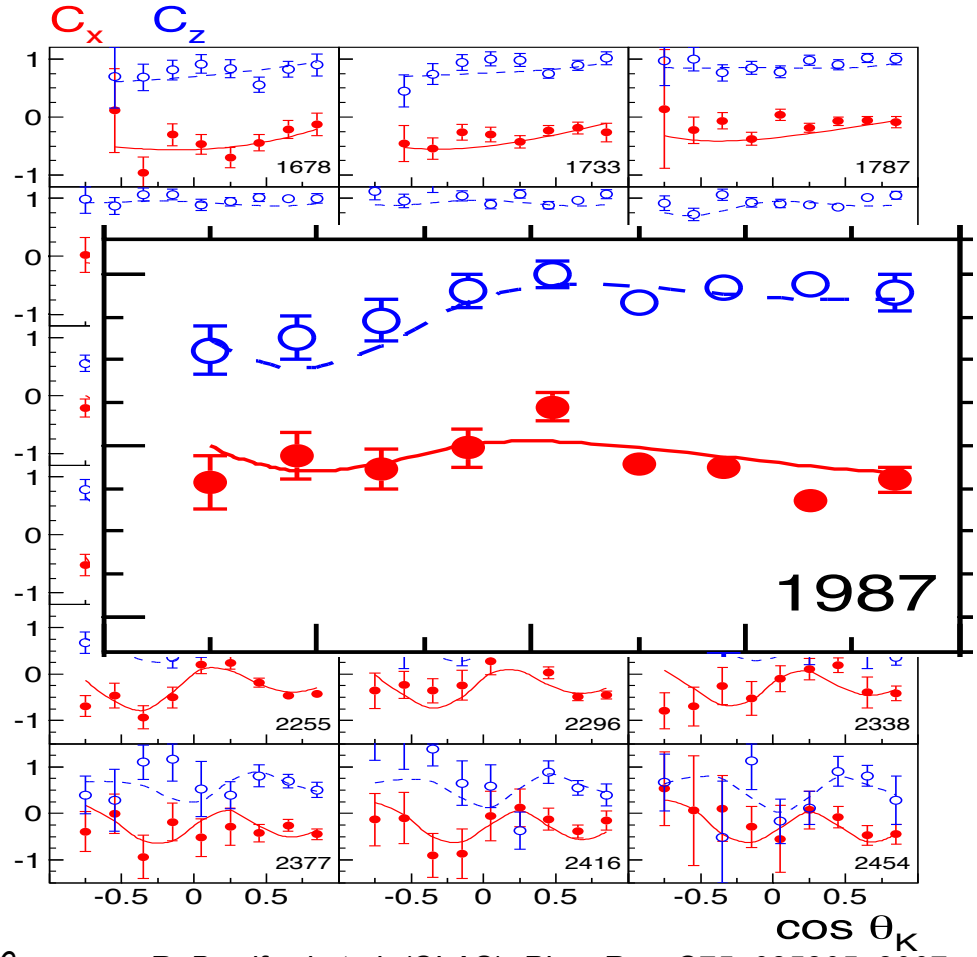
CLAS results $\gamma p \rightarrow K^+\Lambda \rightarrow K^+p\pi^-$

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



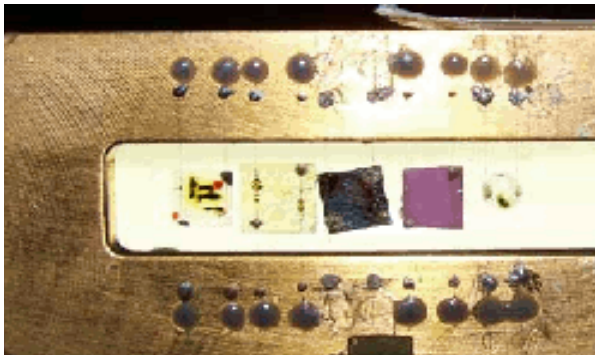
R. Bradford et al. (CLAS), Phys.Rev. C75, 035205, 2007

Evidence for new N* states and couplings

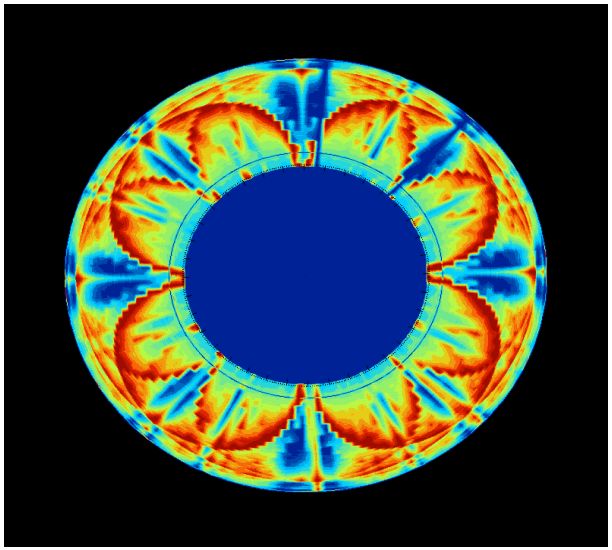
State N((mass)J^P	PDG 2010	PDG 2012	KΛ	KΣ	Nγ
N(1710)$1/2^+$	*** (not seen in GW analysis)	***	***	**	***
N(1880)$1/2^+$		**	**	*	**
N(1895)$1/2^-$		**	**	*	***
N(1900)$3/2^+$	**	***	***	**	***
N(1875)$3/2^-$		***	***	**	***
N(2150)$3/2^-$		**	**		**
N(2000)$5/2^+$	*	***	**	*	**
N(2060)$5/2^-$		***		**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

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

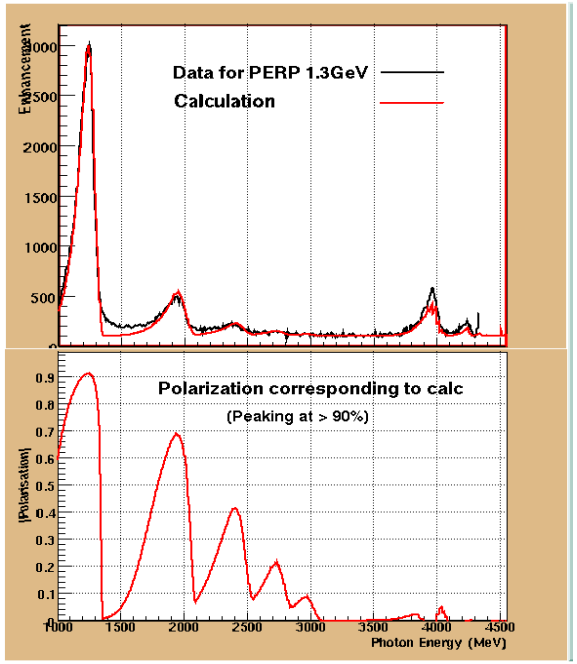
Linearly Polarized Photons



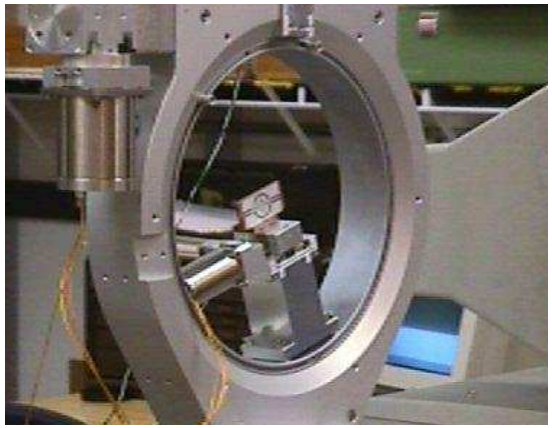
Diamond radiator mounted on target ladder



Alignment checked by observing symmetric "Stonehenge Plot"



Polarization determined by fit to coherent bremsstrahlung spectrum



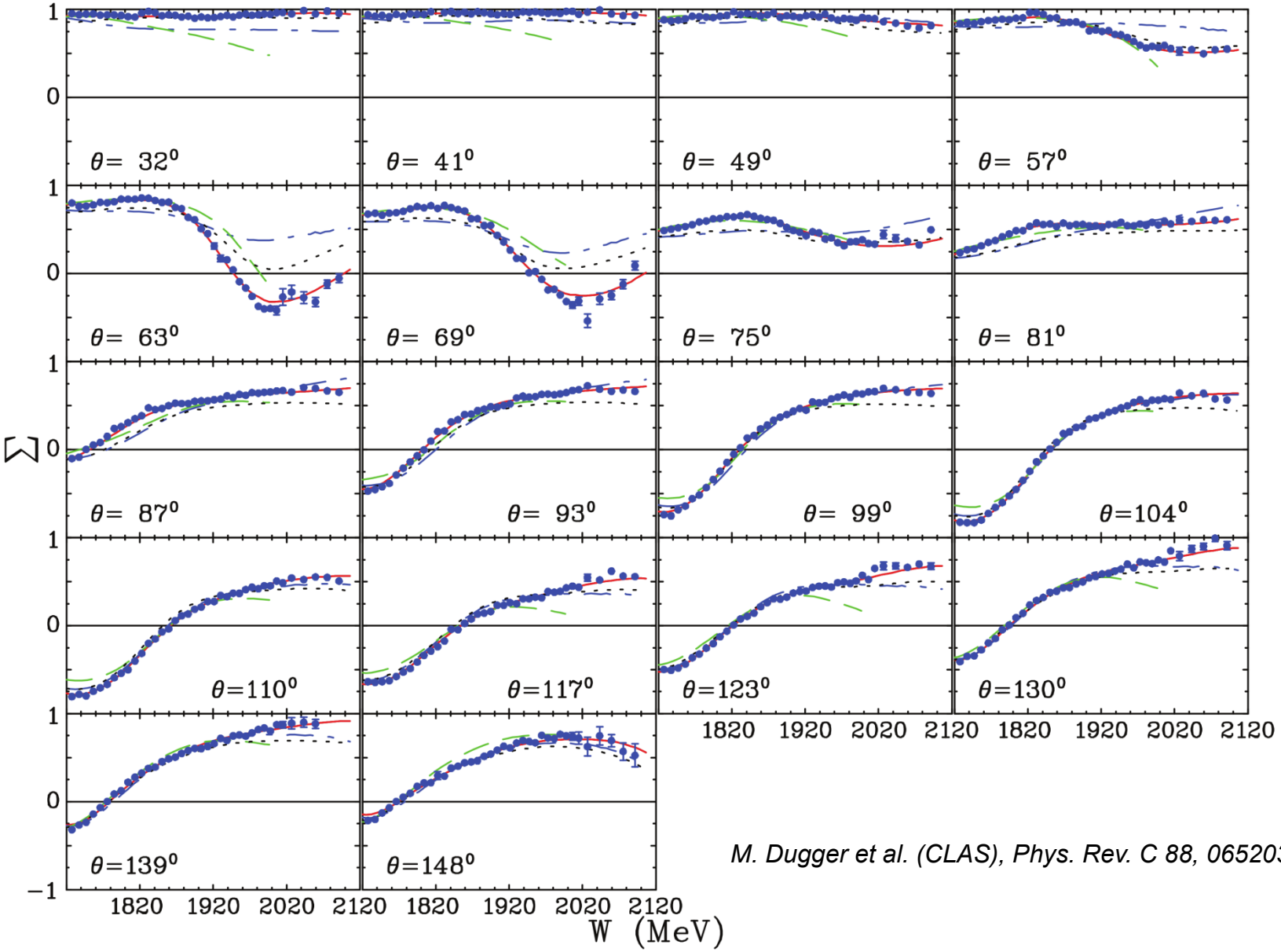
Radiator in goniometer

Technique also used in JLab Hall D

Linearly Polarized Photons

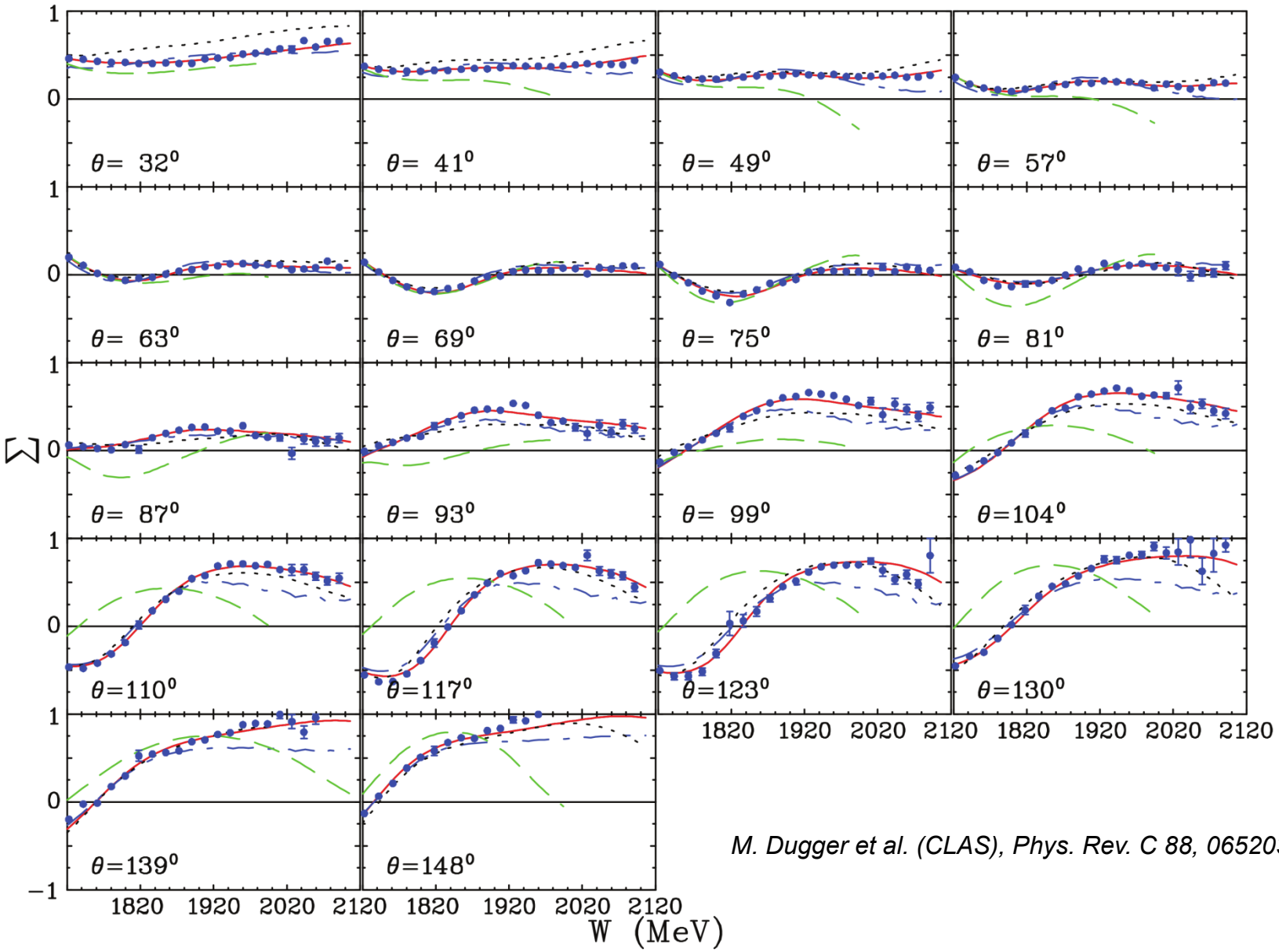
$B_L\, T_U\, R_N$	$= 1 - P_L^\gamma\, \Sigma \cos(2\phi)$
$B_L\, T_U\, R_Y$	$= 1 + P\, P_y^R - (\Sigma + T\, P_y^R)\, P_L^\gamma \cos(2\phi) - (O_x\, P_x^R + O_z\, P_z^R)\, P_L^\gamma \sin(2\phi)$
$B_L\, T_L\, R_N$	$= 1 - \Sigma\, P_L^\gamma \cos(2\phi) - G\, P_L^\gamma\, P_L^T \sin(2\phi)$
$B_L\, T_L\,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

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



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

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



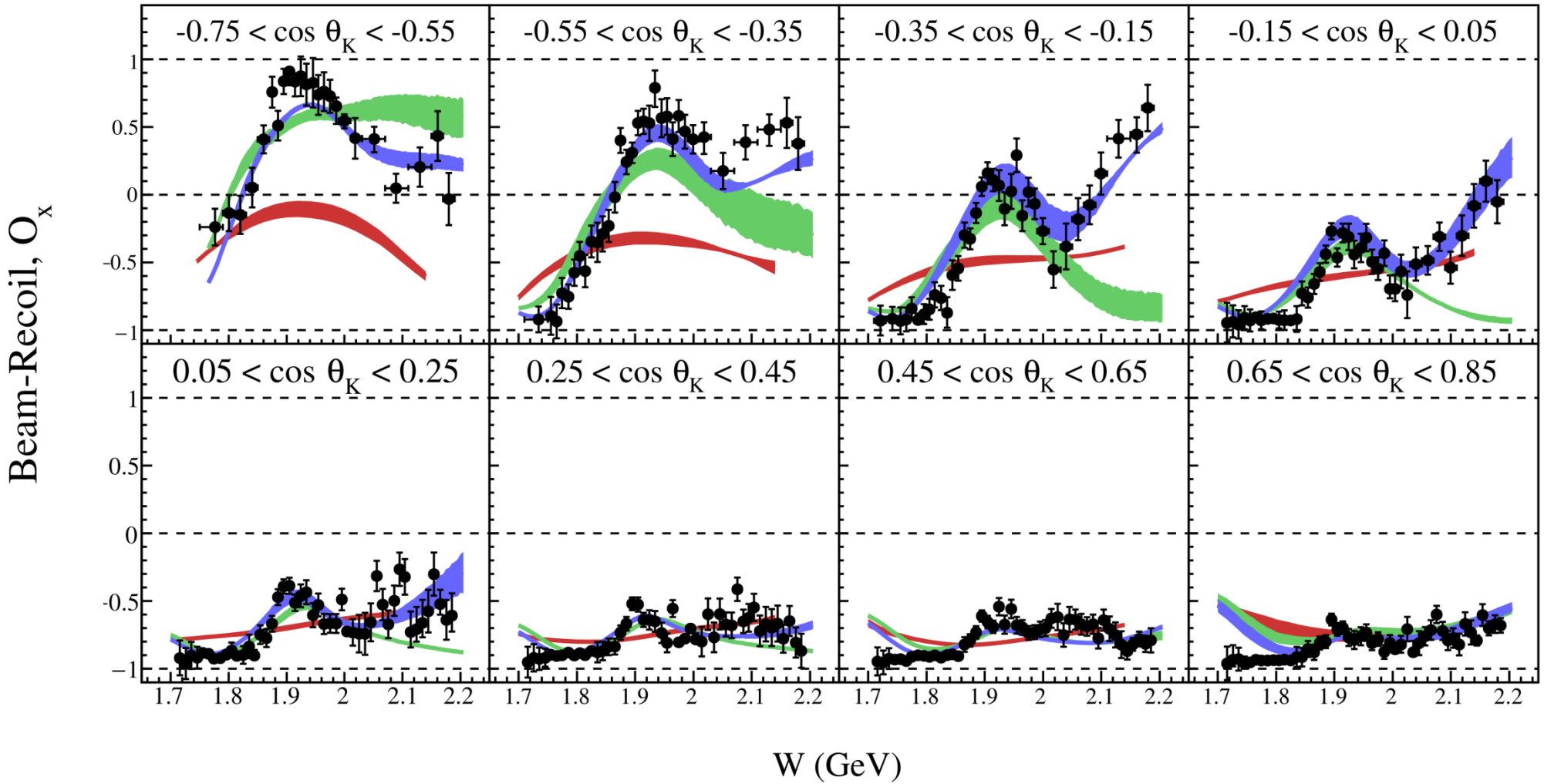
M. Dugger et al. (CLAS), Phys. Rev. C 88, 065203, 2013

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: $\gamma + p \rightarrow K^{+} + \Lambda$;Observable: O_x

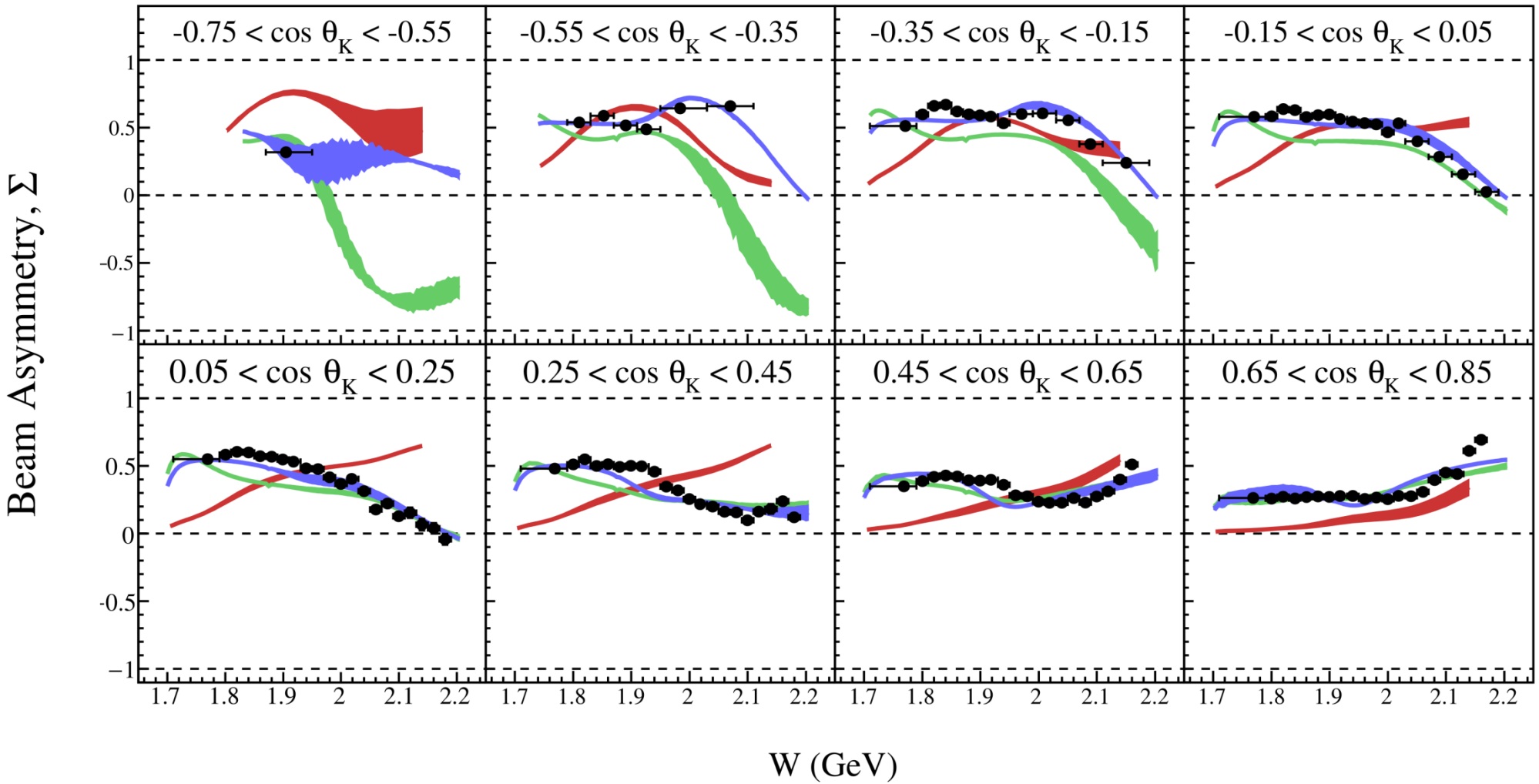
C. A. Paterson et al. (CLAS), Phys. Rev. C 93, 065201 (2016)



ANL-Osaka Bonn-Gatchina 2014(prediction) Bonn-Gatchina (new fit)

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

C. A. Paterson et al. (CLAS), Phys. Rev. C 93, 065201 (2016)



Bonn-Gatchina fits

1 Initial fit

We start from the solution BG2014-02. The first fit produced a rather bad description of the new data. Then the rather large weight was introduced for these data and all channels with 2 body final states were refitted. The couplings to the three body final states were fixed while all other parameters were optimized free. In this case we can get a rather good description of the new data except O_z for $\gamma p \to k\Sigma$ (see Fig. 10). The total χ^2 was found to be 55370 (33988 points). However the description of some observables (especially for the $\gamma p \to \pi^+ n$ channel) is notably deteriorated. Then we added one resonance in the region 2.1-2.3 GeV.

	Total	cl09	3200	P	T	Cx	Oz
			$\gamma p \to \pi^+ n$			$\gamma p \to K\Sigma$	
BG2014		1.36	1.30	1.84	3.01	2.58	
Fit	55370	1.78	1.71	2.36	3.78	3.32	2.56
S_{11}	55050	1.92	1.75	2.43	3.79	3.35	2.55
D_{15}	54596	1.58	1.56	2.30	3.61	3.37	2.49
G_{17}	55084	1.90	1.77	2.53	3.76	3.42	2.69
G_{19}	55308	1.78	1.71	2.38	3.78	3.32	2.52
S_{31}	55284	1.82	1.72	2.40	3.81	3.27	2.44
D_{33}	54888	1.66	1.81	2.53	3.76	3.12	2.20
D_{35}	54958	1.85	1.79	2.52	3.73	3.32	2.05
G_{37}	55267	1.72	1.71	2.39	3.80	3.29	2.52
G_{39}	54966	1.57	1.75	2.42	3.58	3.31	2.53
P_{11}	55107	1.63	1.83	2.52	3.62	3.28	2.53
F_{15}	54903	1.80	1.84	2.49	3.73	3.52	2.61
P_{31}	55406	1.77	1.70	2.37	3.75	3.34	2.63
P_{33}	55278	1.72	1.71	2.37	3.81	3.28	2.47
F_{35}	55114	1.81	1.78	2.39	3.76	3.33	2.69
F_{37}	55233	1.75	1.73	2.34	3.66	3.27	2.53
H_{39}	55309	1.78	1.73	2.39	3.75	3.30	2.52
$S_{11}+$							
D_{13}	54821	1.78	1.77	2.46	3.77	3.26	2.39
D_{15}	54539	1.67	1.65	2.34	3.66	3.48	2.59
G_{17}	54953	1.77	1.75	2.40	3.83	3.40	2.51
D_{35}	54732	1.99	1.73	2.53	3.77	3.17	2.26
G_{37}	54852	1.81	1.71	2.51	3.86	3.59	2.45
P_{11}	54933	1.79	1.84	2.52	3.73	3.40	2.52
F_{15}	54760	1.98	1.84	2.42	3.72	3.59	2.64
P_{33}	54865	1.87	1.70	2.55	3.68	3.22	2.51
F_{35}	54526	1.74	1.84	2.63	3.66	3.60	2.65
F_{37}	55049	1.78	1.74	2.24	3.74	3.31	2.47
$D_{13}+$							
D_{15}	54340	1.39	1.59	2.29	3.75	3.34	2.37
S_{31}	54924	1.61	1.74	2.59	3.73	3.40	2.42
D_{35}	54585	1.93	1.88	2.51	3.69	3.15	2.19
G_{37}	54524	1.95	1.82	2.60	3.69	3.24	2.30
P_{11}	54765	1.69	2.06	2.71	3.66	3.19	2.33
F_{15}	54664	1.78	1.78	2.61	3.89	3.29	2.36

	Total	cl09	3200	P	T	Cx	Oz
			$\gamma p \to \pi^+ n$			$\gamma p \to K\Sigma$	
BG2014		1.36	1.30	1.84	3.01	2.58	
Fit	55370	1.78	1.71	2.36	3.78	3.32	2.56
$D_{15}+$							
G_{17}	54441	1.38	1.52	2.37	3.87	3.38	2.57
G_{19}	54436	1.45	1.58	2.37	3.68	3.35	2.54
D_{33}	54285	1.52	1.64	2.55	3.48	3.21	2.22
D_{35}	54190	1.53	1.65	2.39	3.70	3.31	2.16
G_{37}	54224	1.48	1.62	2.39	3.56	3.45	2.51
G_{39}	54304	1.73	1.72	2.52	3.27	3.36	2.56
P_{11}	54427	1.45	1.77	2.59	3.74	3.22	2.41
F_{15}	54056	1.71	1.65	2.45	3.68	3.43	2.57
H_{19}	54505	1.45	1.55	2.29	3.58	3.29	2.49
P_{33}	54493	1.28	1.62	2.31	3.68	3.32	2.55
F_{35}	54144	1.41	1.61	2.21	3.82	3.25	2.42
F_{37}	54365	1.49	1.62	2.27	3.65	3.23	2.47
$G_{17}+$							
G_{19}	54784	1.74	1.75	2.54	3.88	3.41	2.72
S_{31}	55163	1.81	1.72	2.38	3.77	3.27	2.44
D_{33}	54464	1.74	1.86	2.54	3.64	3.07	2.20
D_{35}	54760	2.00	1.77	2.59	3.78	3.08	2.59
G_{37}	54782	1.84	1.71	2.50	3.79	3.50	2.55
G_{39}	54618	1.63	1.78	2.50	3.49	3.43	2.67
P_{11}	54847	1.65	1.87	2.50	3.59	3.29	2.54
F_{15}	54521	1.91	1.69	2.41	3.90	3.45	2.61
H_{19}	54822	1.85	1.73	2.56	3.62	3.27	2.49
P_{33}	54891	1.80	1.75	2.41	3.79	3.27	2.49
F_{35}	54645	1.88	1.79	2.48	3.69	3.44	2.68
F_{37}	54525	1.55	1.84	2.57	3.77	3.33	2.76
H_{39}	54733	1.47	1.79	2.57	3.84	3.39	2.73
$G_{19}+$							
S_{31}	54985	1.84	1.77	2.54	3.84	3.34	2.60
D_{33}	54576	1.67	1.80	2.60	3.56	3.07	2.28
D_{35}	54964	1.83	1.69	2.54	3.68	3.20	2.65
G_{39}	54795	1.55	1.75	2.43	3.48	3.37	2.55
P_{11}	55189	1.66	1.81	2.46	3.73	3.32	2.49
F_{15}	54789	1.91	1.79	2.51	3.86	3.49	2.66
H_{19}	54963	1.90	1.75	2.49	3.56	3.33	2.52
P_{33}	54968	1.51	1.73	2.47	3.86	3.38	2.62
F_{35}	54859	1.74	1.71	2.39	3.78	3.47	2.65
F_{37}	54934	1.76	1.71	2.42	3.67	3.12	2.15
H_{39}	55274	1.83	1.72	2.38	3.71	3.30	2.55
$S_{31}+$							
D_{33}	54870	1.68	1.85	2.54	3.72	3.16	2.25
D_{35}	54957	1.99	1.74	2.53	3.83	3.02	2.44
P_{11}	55047	1.69	1.90	2.51	3.62	3.19	2.42
$D_{33}+$							
D_{35}	54681	1.69	1.72	2.57	3.82	3.07	2.17
G_{37}	54453	1.83	1.83	2.54	3.69	3.03	2.09
G_{39}	54633	1.64	1.79	2.47	3.69	3.20	2.32
P_{11}	54684	1.63	1.97	2.64	3.49	3.09	2.26
F_{15}	54478	1.77	1.91	2.66	3.70	3.31	2.34
H_{19}	54679	1.76	1.81	2.71	3.74	3.14	2.22
P_{33}	54815	1.51	1.85	2.55	3.85	3.09	2.25
F_{35}	54760	1.65	1.81	2.43	3.58	3.15	2.31
F_{37}	54732	1.54	1.86	2.48	3.54	2.99	2.14
H_{39}	54875	1.66	1.80	2.53	3.78	3.12	2.18

	Total	cl09	3200	P	T	Cx	Oz
			$\gamma p \to \pi^+ n$			$\gamma p \to K\Sigma$	
BG2014		1.36	1.30	1.84	3.01	2.58	
Fit	55370	1.78	1.71	2.36	3.78	3.32	2.56
$D_{35}+$							
G_{37}	54476	2.25	1.75	2.70	3.67	2.88	2.16
G_{39}	54352	1.60	1.70	2.56	3.47	2.98	2.53
P_{11}	54398	1.42	1.57	2.20	3.55	3.21	2.49
F_{15}	54525	2.09	1.85	2.59	3.85	2.94	2.40
H_{19}	54682	1.98	1.71	2.73	3.87	2.99	2.47
P_{33}	54398	1.42	1.57	2.20	3.55	3.21	2.49
F_{35}	54543	2.07	1.80	2.54	3.70	3.02	2.47
F_{37}	54685	1.86	1.89	2.48	3.44	2.88	2.53
H_{39}	54790	2.00	1.77	2.54	3.65	3.01	2.47
$P_{11}+$							
H_{19}	54489	1.42	1.82	2.94	3.84	3.23	2.48
P_{31}	54999	1.74	1.91	2.54	3.61	3.21	2.48
P_{33}	54795	1.63	1.97	2.69	3.66	3.22	2.42
F_{35}	54734	1.61	1.93	2.60	3.56	3.19	2.38
$F_{15}+$							
P_{33}	54398	1.42	1.57	2.20	3.55	3.21	2.49
F_{35}	54568	1.75	1.80	2.36	3.85	3.35	2.63
F_{37}	54725	1.75	1.92	2.59	3.51	3.36	2.59
$P_{33}+$							
F_{35}	54588	1.57	1.89	2.48	3.95	3.46	2.66
F_{37}	54985	1.58	1.82	2.43	3.72	3.33	2.63

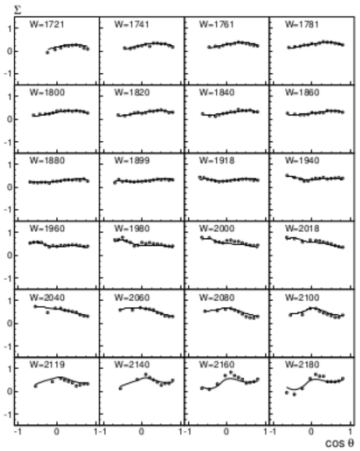


Fig. 1. Description of the beam asymmetry on $\gamma p \to K\Lambda$.

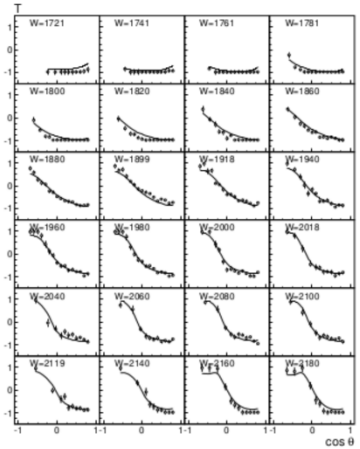


Fig. 2. Description of the target asymmetry on $\gamma p \to K\Lambda$.

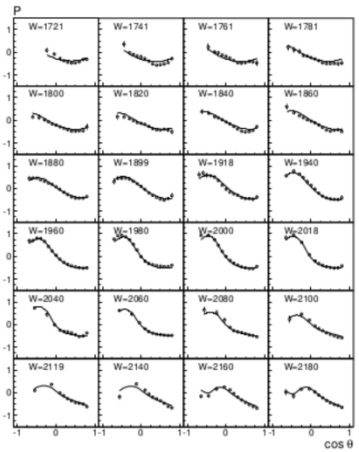
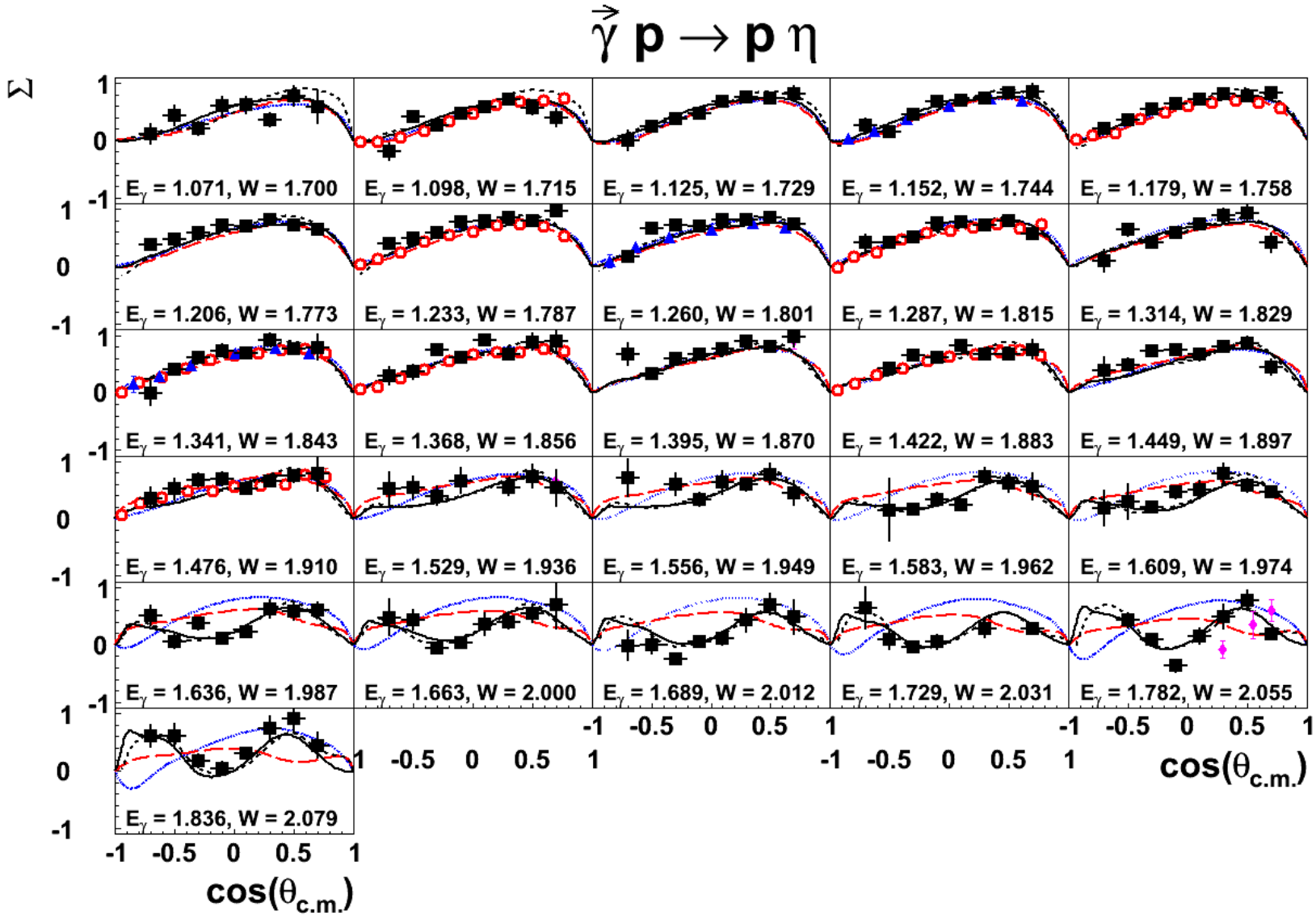


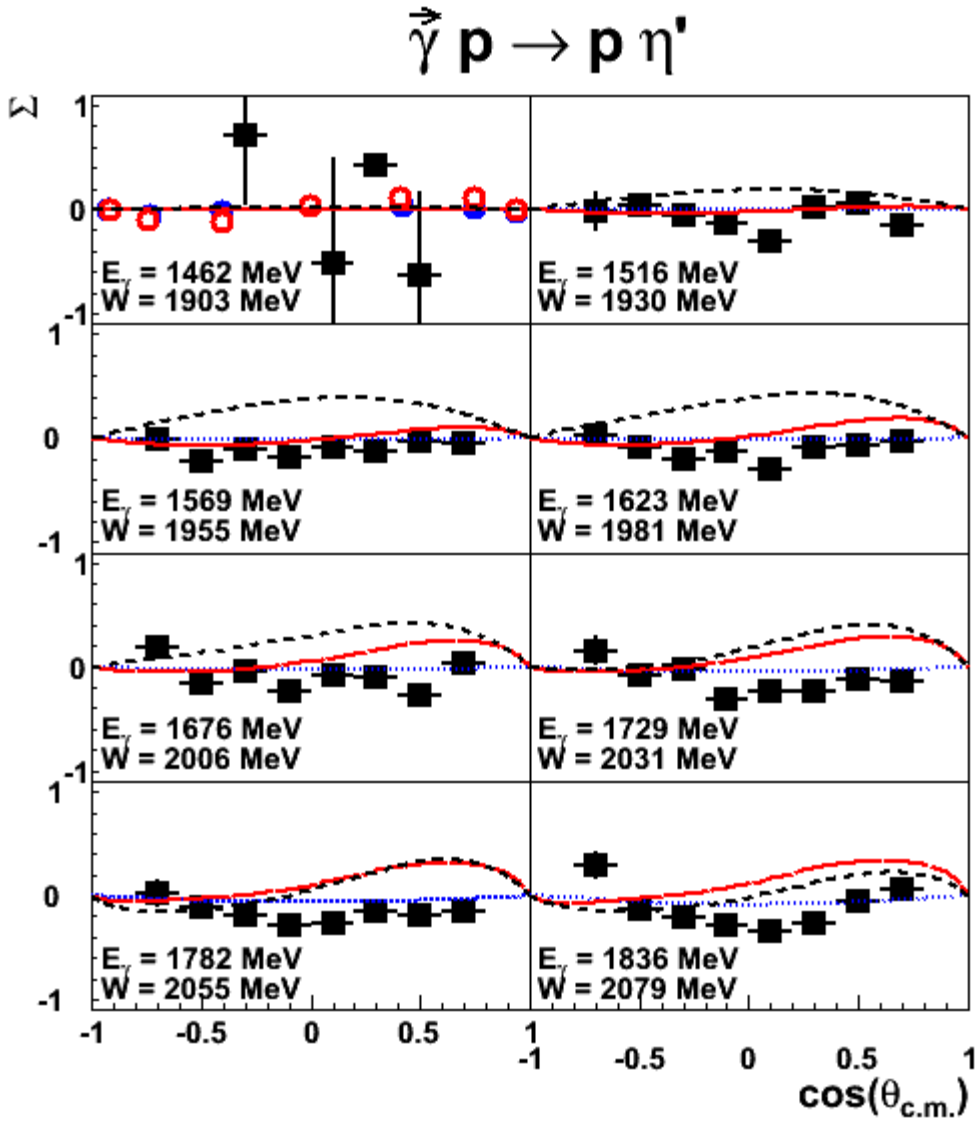
Fig. 3. Description of the recoil asymmetry on $\gamma p \to K\Lambda$.

CLAS Results: Channel: $\gamma + p \rightarrow p + \eta$;Observable: Σ



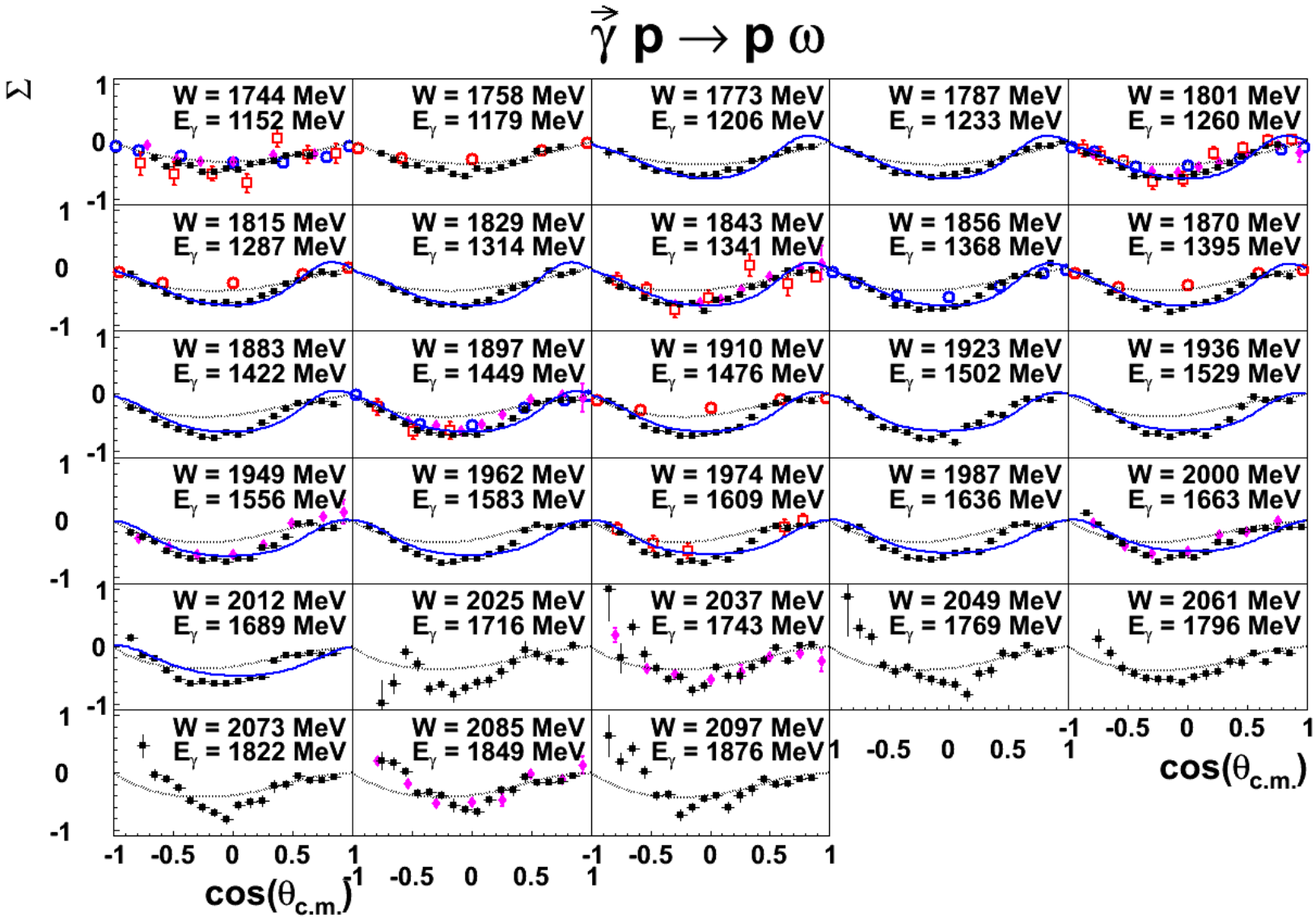
Arizona State University and CLAS, to be submitted.

CLAS Results: Channel: $\gamma + p \rightarrow p + \eta'$;Observable: Σ



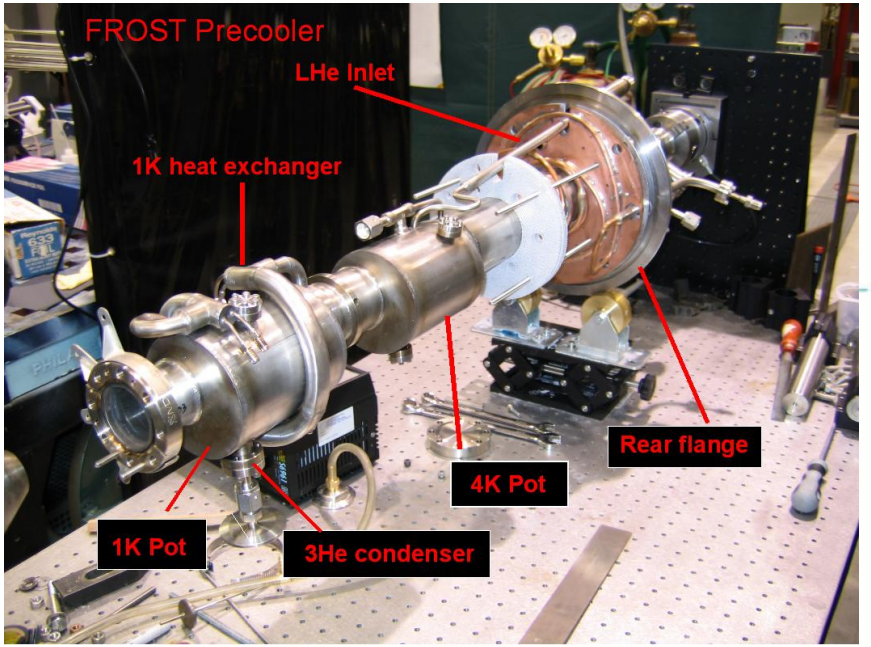
Arizona State University and CLAS, to be submitted.

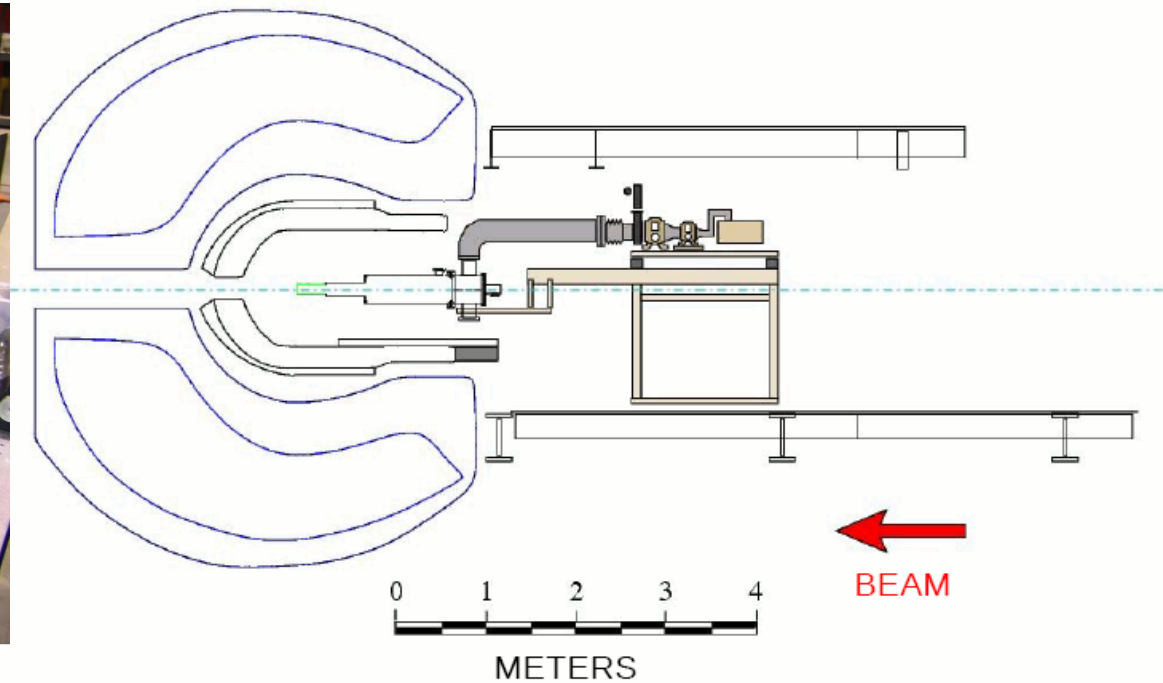
CLAS Results: Channel: $\gamma + p \rightarrow p + \omega$;Observable: Σ



Arizona State University and CLAS, to be submitted.

FROzen Spin Target (FROST)



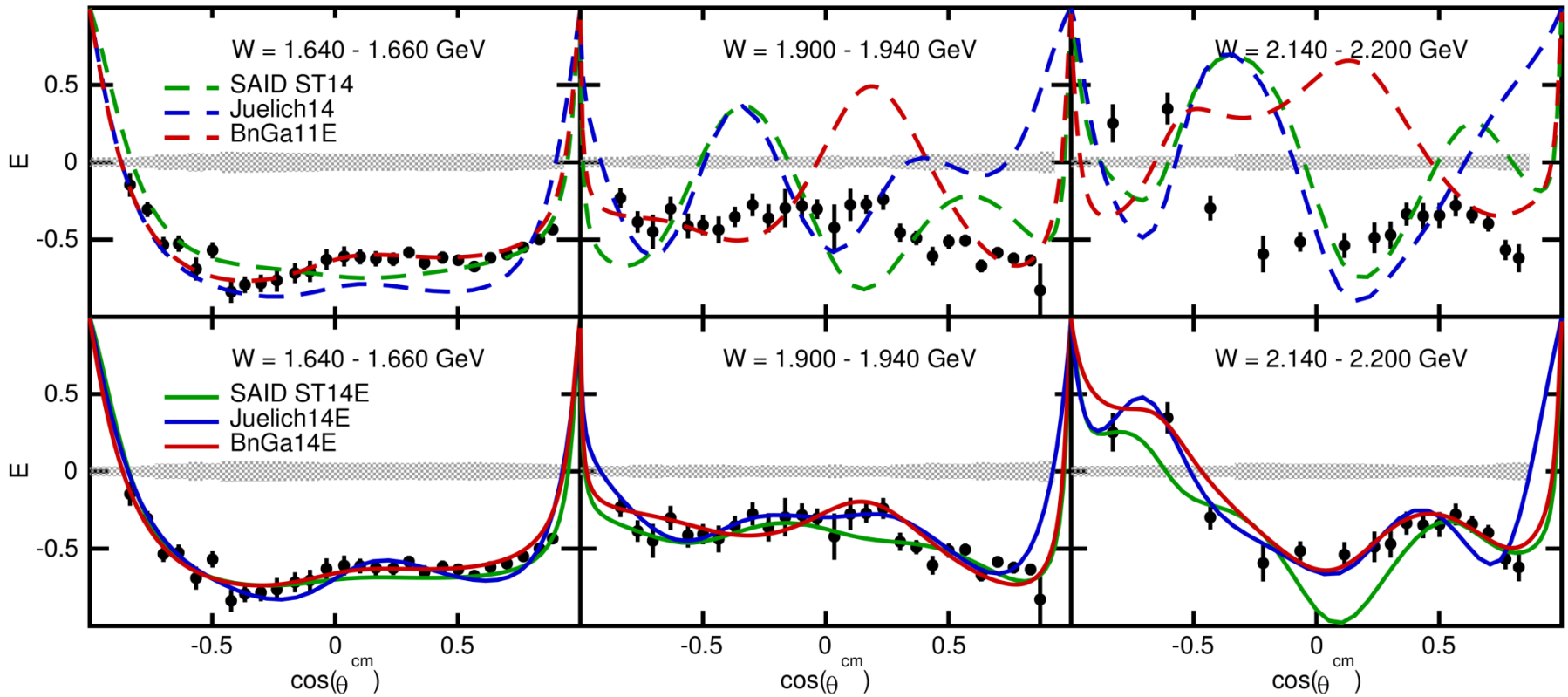


Target can be longitudinally or transversely polarized

Target Polarization

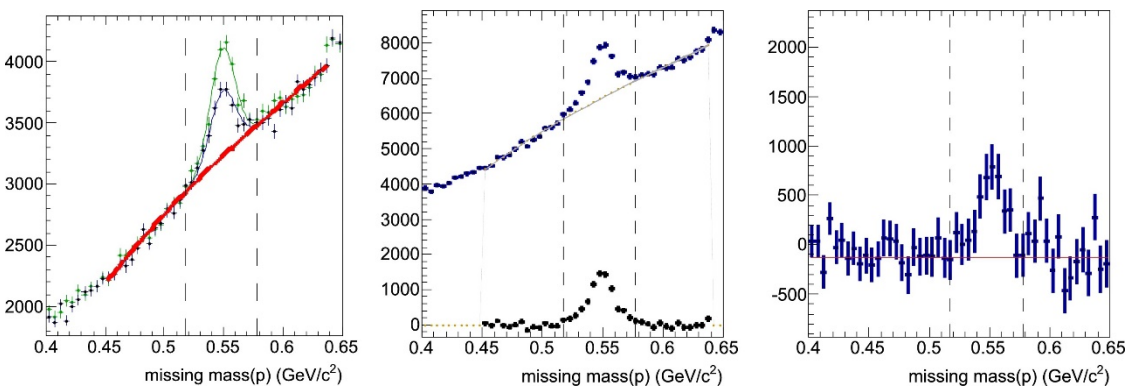
Configuration	σ_{Red}/σ_0
$B_U\, T_U\, R_N$	$= 1$
$B_U\, T_U\, R_Y$	$= 1 + P\, P_y^R$
$B_U\, T_L\, R_N$	$= 1$
$B_U\, T_L\, R_Y$	$= 1 + P\, P_y^R + L_x\, P_x^R\, P_L^T$
$B_U\, T_T\, R_N$	$= 1 + T\, P_T^T \sin(\phi)$
$B_U\, T_T\, R_Y$	$= 1 + P\, P_y^R + (\Sigma\, P_y^R + T)\, P_T^T \sin(\phi) + (T_x\,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

CLAS Results: Channel: $\gamma + p \rightarrow \pi\uparrow + + n$;Observable: E

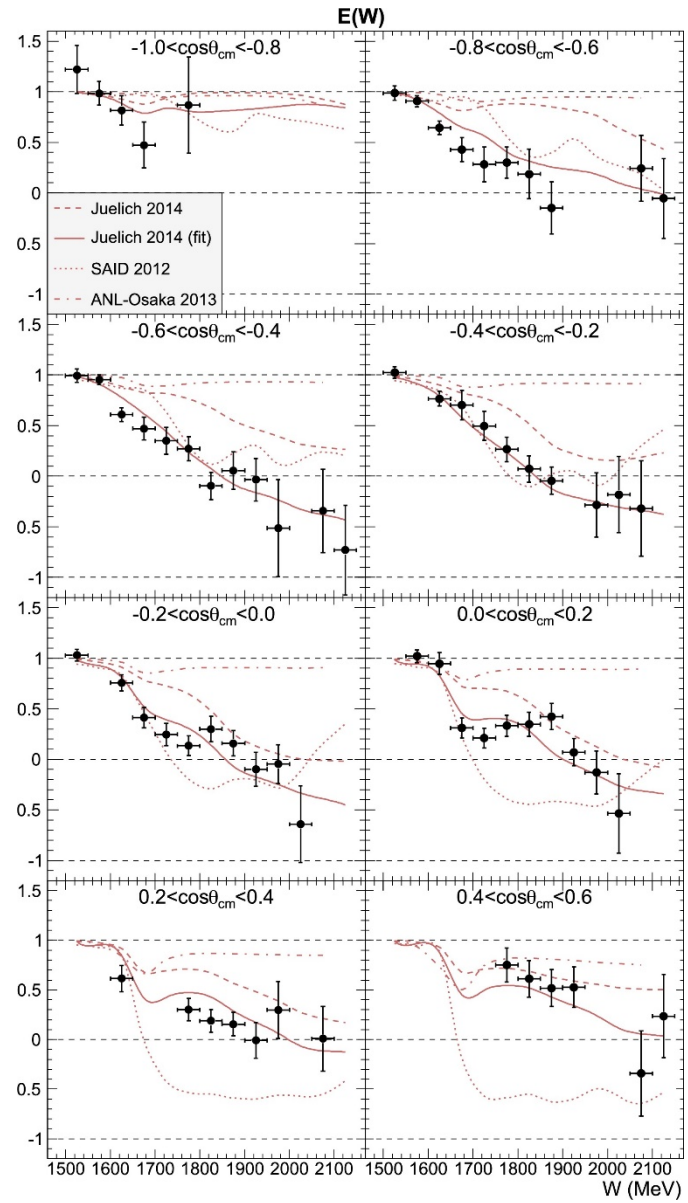


S. Strauch et al. (CLAS), http://arxiv.org/abs/1503.05163 , Phys. Lett. B 750, 53 (2015).

CLAS Results: Channel: $\gamma + p \rightarrow$ [W] $+ p$;Observable: E



I. Senderovitch et al. (CLAS), Physics Letters B Volume 755, 10 April 2016, Pages 64–69



N* photoproduction program at CLAS

	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																
$p\pi^-$	✔	✓			✓	✓	✓									
$p\rho^-$	✓	✓			✓	✓	✓									
$K^-\Sigma^+$	✓	✓			✓	✓	✓									
$K^0\Lambda$	✓	✓		✓	✓	✓	✓				✓	✓	✓	✓	✓	✓
$K^0\Sigma^0$	✓	✓		✓	✓	✓	✓				✓	✓	✓	✓	✓	✓
$K^{0*}\Sigma^0$	✓	✓														

Data taking completed May 18, 2012

✔-published, ✓-acquired

PDG Summary of Evidence

Table 1. The status of the N resonances. Only those with an overall status of *** or **** are included in the main Baryon Summary Table.

Particle	J^P	overall	Status as seen in								
			$N\gamma$	$N\pi$	$N\eta$	$N\sigma$	$N\omega$	ΛK	ΣK	$N\rho$	$\Delta\pi$
N	$1/2^+$	****									
$N(1440)$	$1/2^+$	****	****	****		***				*	***
$N(1520)$	$3/2^-$	****	****	****	***					***	***
$N(1535)$	$1/2^-$	****	****	****	****					**	*
$N(1650)$	$1/2^-$	****	****	****	***			***	**	**	***
$N(1675)$	$5/2^-$	****	****	****	*			*		*	***
$N(1680)$	$5/2^+$	****	****	****	*	**				***	***
$N(1700)$	$3/2^-$	***	**	***	*			*	*	*	***
$N(1710)$	$1/2^+$	****	****	****	***		**	****	**	*	**
$N(1720)$	$3/2^+$	****	****	****	***			**	**	**	*
$N(1860)$	$5/2^+$	**		**						*	*
$N(1875)$	$3/2^-$	***	***	*			**	***	**		***
$N(1880)$	$1/2^+$	**	*	*		**		*			
$N(1895)$	$1/2^-$	**	**	*	**			**	*		
$N(1900)$	$3/2^+$	***	***	**	**		**	***	**	*	**
$N(1990)$	$7/2^+$	**	**	**					*		
$N(2000)$	$5/2^+$	**	**	*	**			**	*	**	
$N(2040)$	$3/2^+$	*		*							
$N(2060)$	$5/2^-$	**	**	**	*				**		
$N(2100)$	$1/2^+$	*		*							
$N(2120)$	$3/2^-$	**	**	**				*	*		
$N(2190)$	$7/2^-$	****	***	****			*	**		*	
$N(2220)$	$9/2^+$	****		****							
$N(2250)$	$9/2^-$	****		****							
$N(2300)$	$1/2^+$	**		**							
$N(2570)$	$5/2^-$	**		**							
$N(2600)$	$11/2^-$	***		***							
$N(2700)$	$13/2^+$	**		**							

**** Existence is certain, and properties are at least fairly well explored.
*** Existence is very likely but further confirmation of decay modes is required.

Table 2. The status of the Δ resonances. Only those with an overall status of *** or **** are included in the main Baryon Summary Table.

Particle	J^P	overall	Status as seen in								
			$N\gamma$	$N\pi$	$N\eta$	$N\sigma$	$N\omega$	ΛK	ΣK	$N\rho$	$\Delta\pi$
$\Delta(1232)$	$3/2^+$	****	****	****	F						
$\Delta(1600)$	$3/2^+$	***	***	***	o					*	***
$\Delta(1620)$	$1/2^-$	****	***	****		r				***	***
$\Delta(1700)$	$3/2^-$	****	****	****		b				**	***
$\Delta(1750)$	$1/2^+$	*		*			i				
$\Delta(1900)$	$1/2^-$	**	**	**			d		**	**	**
$\Delta(1905)$	$5/2^+$	****	****	****				d	***	**	**
$\Delta(1910)$	$1/2^+$	****	**	****				e	*	*	**
$\Delta(1920)$	$3/2^+$	***	**	***				n	***		**
$\Delta(1930)$	$5/2^-$	***		***							
$\Delta(1940)$	$3/2^-$	**	**	*	F						
$\Delta(1950)$	$7/2^+$	****	****	****	o				***	*	***
$\Delta(2000)$	$5/2^+$	**				r					**
$\Delta(2150)$	$1/2^-$	*		*		b					
$\Delta(2200)$	$7/2^-$	*		*			i				
$\Delta(2300)$	$9/2^+$	**		**			d				
$\Delta(2350)$	$5/2^-$	*		*				d			
$\Delta(2390)$	$7/2^+$	*		*				e			
$\Delta(2400)$	$9/2^-$	**		**				n			
$\Delta(2420)$	$11/2^+$	****	*	****							
$\Delta(2750)$	$13/2^-$	**		**							
$\Delta(2950)$	$15/2^+$	**		**							

**** Existence is certain, and properties are at least fairly well explored.
*** Existence is very likely but further confirmation of decay modes is required.
** Evidence of existence is only fair.
* Evidence of existence is poor.

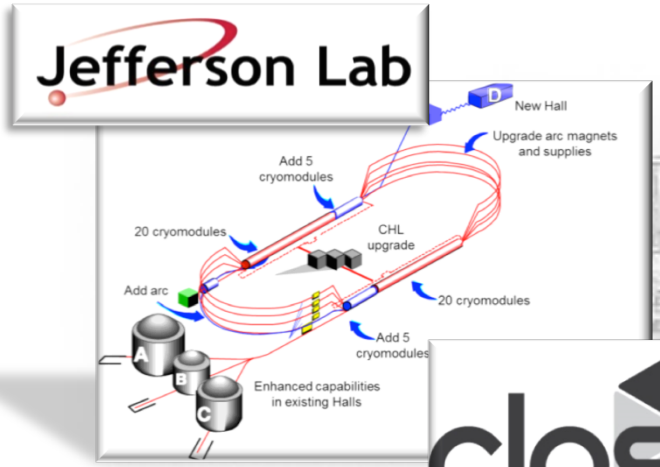
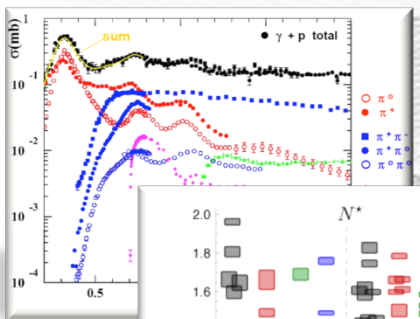
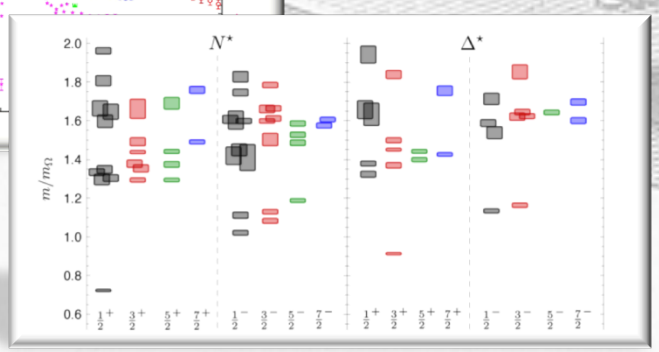
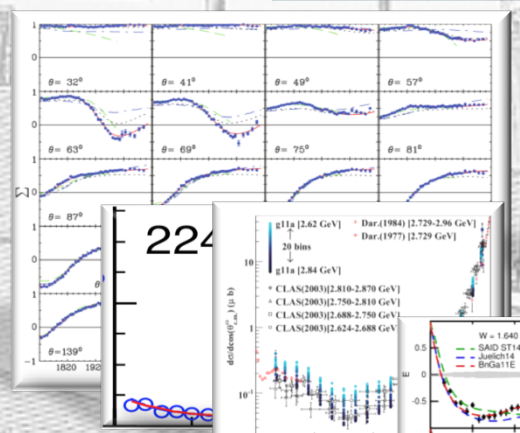
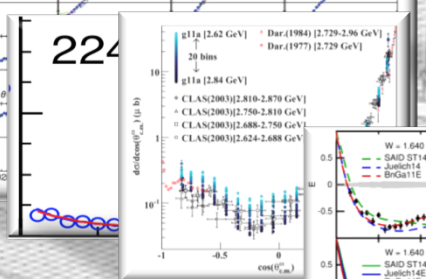
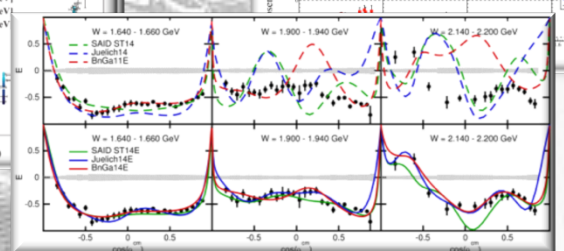
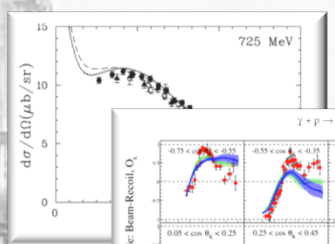
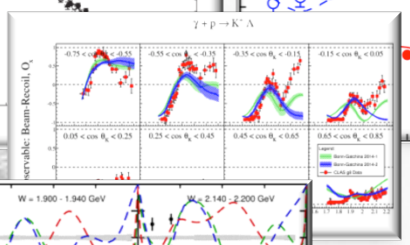
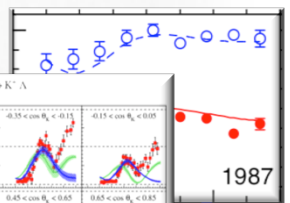
Summary and Outlook

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

- **Much more still to come, including:**
  - **Two-pion photoproduction**
  - **Results from deuterium target**
  - **More results from FROST**
  - **Results from HDIce**

- **Progress in N* physics needs:**
  - **Combined analyses of all relevant channels**
  - **Use of data from all sources (different labs)**
  - **Analysis of experimental and theoretical uncertainty**
  - **More hard work!**

Conclusions



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