Status of and Prospects for N^* Spectroscopy

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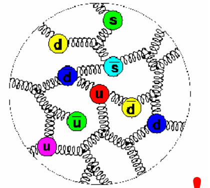
Lattice QCD and Experiment

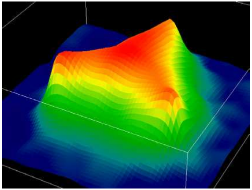
Jefferson Laboratory, 11/21/2008

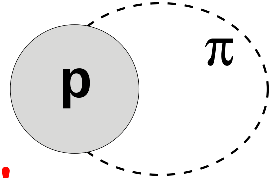
Outline

Outline

$\ll 0.1$ fm	$0.1 - 1.0$ fm	> 1.0 fm







pQCD	! ? ↔ ? !	Models	? ! ↔ ! ?	ChPT
q, g, $q\bar{q}$		Quarks and Gluons as Quasiparticles		Nucleon and Mesons

1. What are the relevant degrees of freedom?
2. What are the corresponding effective interactions responsible for hadronic phenomena?

The Excited Baryon Program

The excited baryon program has two main components:

- Establish the systematics of the spectrum
  - ➜ Provides information on the nature of effective degrees of freedom in strong QCD
- Probe resonance transitions at different distance scales (electron beams are ideal to measure transition form factors)
  - ➜ Provides information on the confining forces of the 3-quark system
  - ➜ Afternoon session on "Hadron Structure"

One of the Main Goals of the N^* Program ...

Search for *missing* or yet unobserved resonances

Quark models predict many more baryons than have been observed

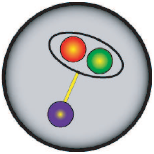
	****	***	**	*
N Spectrum	11	3	6	2
Δ Spectrum	7	3	6	6

$\Rightarrow$ according to PDG
Phys. Rev. **D66** (2002) 010001

$\Rightarrow$ little known
(many open questions left)

Possible solutions:

1. Quark-diquark structure



one of the internal degrees of freedom is frozen

2. Have not been observed, yet

Nearly all existing data result from πN scattering experiments

➜ If the missing resonances did not couple to Nπ, they would not have been discovered!!

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Phys. Lett. B **667**, 1 (2008)

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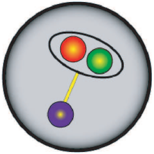

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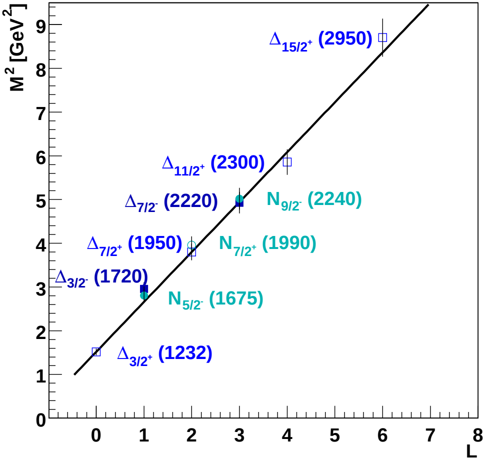
Possible Quark-Diquark Structure?



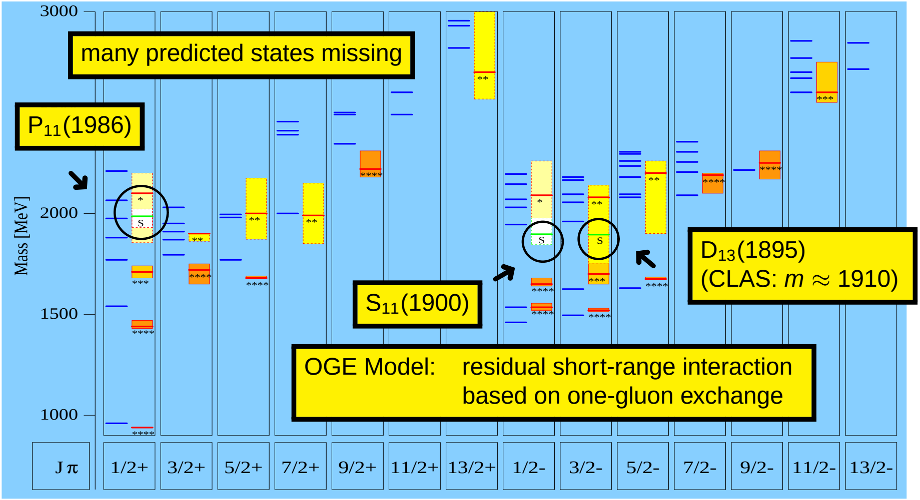
Regge trajectory for Δ^* states with intrinsic spin $S = 1/2$ and $S = 3/2$, and for N^* states with spin $S = 3/2$ (M^2 versus L, not J)

1. Common Regge trajectory for N/Δ states with $S = 3/2$
2. Not shown, but slope of the Regge trajectory for meson and Δ excitations is identical

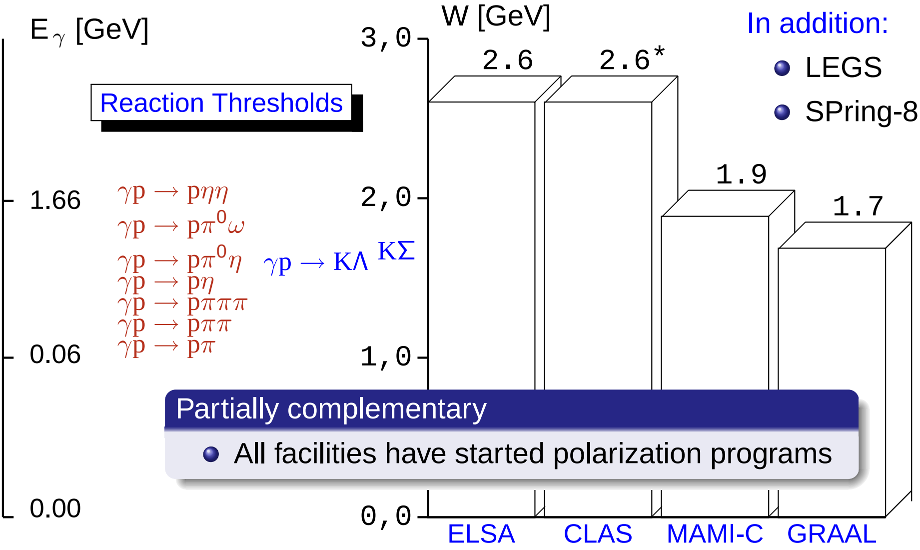
➜ Are baryons quark-diquark excitations?

Nucleon Resonances: Status – 2001

—— S. Capstick and N. Isgur, Phys. Rev. **D34** (1986) 2809



Outline



Partially complementary

- All facilities have started polarization programs

What is new?

Many excellent data have been accumulated over the last years

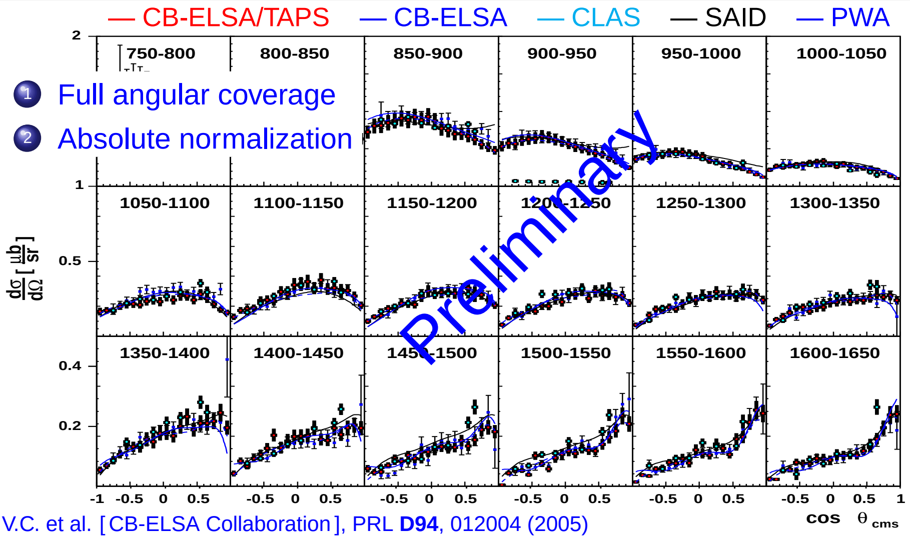
- High-statistics samples with excellent energy/angular coverage
- New resonances have been announced and formerly weakly established states have been verified, e.g.:
  $\Delta(1940)D_{33}$, $N(1900)P_{13}$, $N(2070)D_{15}$, $N(2200)P_{13}$, ...
- However, many of these candidates are not confirmed by other groups or disputed

Analysis techniques and models have been developed (improved):

- Coupled-channel (or combined) analyses
- Event-based likelihood fits
- ...

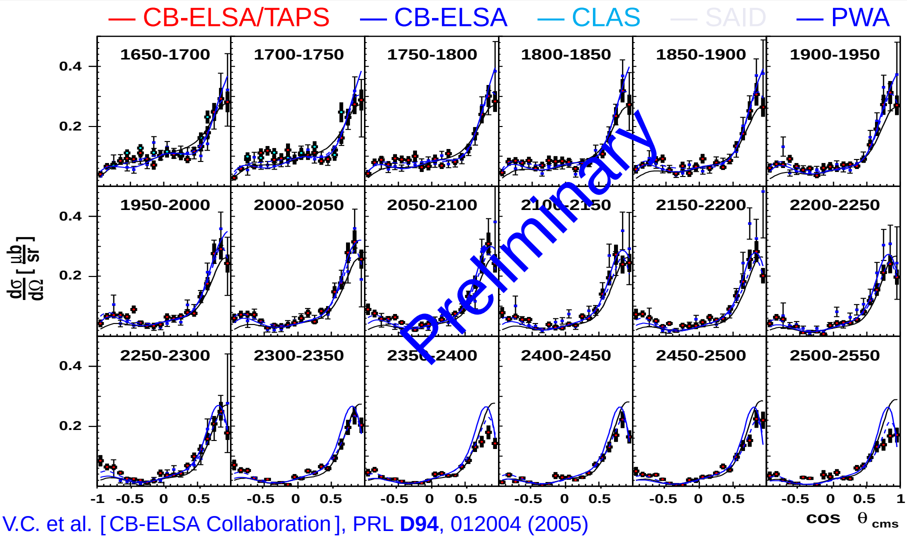
Study of $\gamma p \to p\,\eta$ (2008 Data from CB-ELSA/TAPS)

1. Full angular coverage
2. Absolute normalization



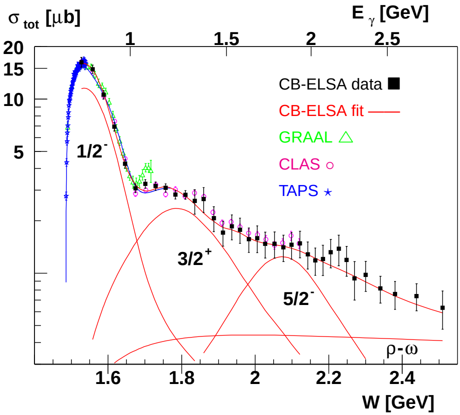
V.C. et al. [CB-ELSA Collaboration], PRL **D94**, 012004 (2005)

Study of $\gamma p \rightarrow p\,\eta$ (2008 Data from CB-ELSA/TAPS)



V.C. et al. [CB-ELSA Collaboration], PRL **D94**, 012004 (2005)

Analysis of $\gamma p \rightarrow p\,\eta$: Total Cross Section



Isospin Filter

➜ Only N^* resonances can contribute!

Bonn-Gatchina (PWA) group:
Hint for N^* resonance $N(2070)D_{15}$
(Phys. Rev. Lett. **D94**, 012004 (2005))

Three resonances are dominantly contributing!
$N(1535)S_{11}$, $N(1720)P_{13}$, $N(2070)D_{15}$

Partial Wave Analysis (PWA Center at ELSA)

PWA: Operator (Tensor) Formalism (Rarita–Schwinger)

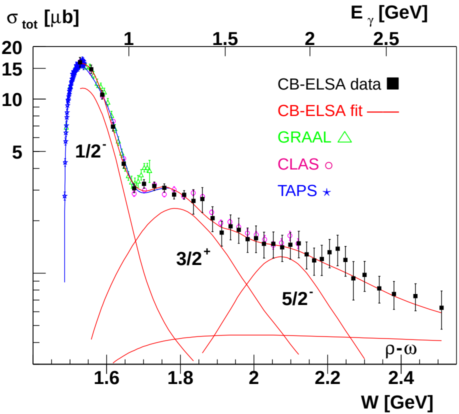
- Many data sets included
  - Cross section data and polarization observables
- Solutions not unique

Observables	Reference	N_{data}	χ^2/N
$\sigma(\gamma p \to p\eta)$	CB-ELSA	667	0.91
$\sigma(\gamma p \to p\eta)$	TAPS	100	1.6
$\Sigma(\gamma p \to p\eta)$	GRAAL 98	51	2.27
$\Sigma(\gamma p \to p\eta)$	GRAAL 04	100	1.75
$\sigma(\gamma p \to p\pi^0)$	CB-ELSA	1106	1.50
$\Sigma(\gamma p \to p\pi^0)$	GRAAL 04	469	3.43
$\Sigma(\gamma p \to p\pi^0)$	SAID	593	2.87
$\sigma(\gamma p \to n\pi^+)$	SAID	1583	2.86

Resonance	M (MeV)	Γ (MeV)	Fraction
$N(1520)D_{13}$	1523 ± 4	105^{+6}_{-18}	0.020
PDG	1520^{+10}_{-5}	120^{+15}_{-10}	
$N(1535)S_{11}$ *	1501 ± 5	215 ± 25	
PDG	1505 ± 10	170 ± 80	0.430
$N(1650)S_{11}$ *	1610 ± 10	190 ± 20	
PDG	1660 ± 20	160 ± 10	
$N(1675)D_{15}$	1690 ± 12	125 ± 20	0.001
PDG	1675^{+10}_{-5}	150^{+30}_{-10}	
$N(1680)F_{15}$	1669 ± 6	85 ± 10	0.005
PDG	1680^{+10}_{-5}	130 ± 10	
$N(1700)D_{13}$	1740 ± 12	84 ± 16	0.004
PDG	1700 ± 50	100 ± 50	
$N(1720)P_{13}$	1775 ± 18	325 ± 25	0.300
PDG	1720^{+30}_{-70}	250 ± 50	
$N(2000)F_{15}$	1950 ± 25	230 ± 45	0.007
$N(2070)D_{15}$	2068 ± 22	295 ± 40	0.171
$N(2080)D_{13}$	1943 ± 17	82 ± 20	0.011
$N(2200)P_{13}$	2214 ± 28	360 ± 55	0.051

* K-Matrix Fit,
Fraction for the total K-matrix contribution

Analysis of $\gamma p \to p\,\eta$: Total Cross Section



Isospin Filter

➜ Only N^* resonances can contribute!

Hint for N^* resonance $N(2070)D_{15}$

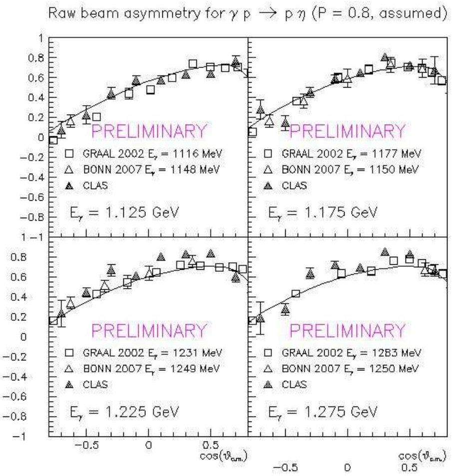
(Phys. Rev. Lett. **D94**, 012004 (2005))

1. Confirmed in 2008 analysis!
2. $N(1720)P_{13} \to \eta\, p$ unexpected
   ➜ η-MAID:
   $N(1710)P_{11} \to \eta$ p significant!

Three resonances are dominantly contributing!

$N(1535)S_{11}$, $N(1720)P_{13}$, $N(2070)D_{15}$

Linearly-Polarized Beam at JLab: $\Sigma(\gamma p \to p\,\eta)$



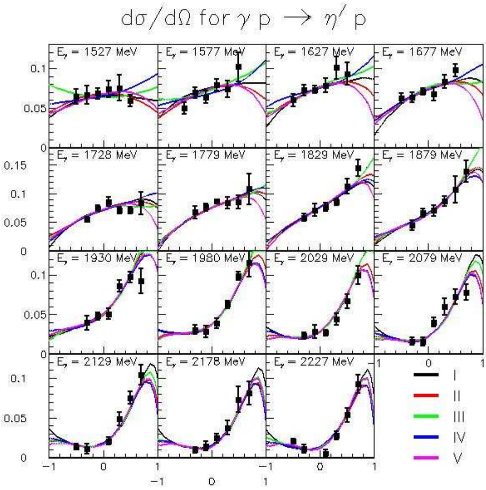
Good agreement with other data

- Interpretation of Bonn (PWA) and CLAS data (SAID) different: $P_{13}(1720) \Leftrightarrow P_{11}(1710)$

Preliminary analysis of $\gamma p \to p\,\eta$ (Mike Dugger, ASU)

- P_γ estimated at 0.8
- — SAID prediction
- Data with statistical errors (no systematic)

Study of $\gamma p \to p\ \eta'$ at JLab



Set IV

N(1535)S_{11}, N(2090)S_{11}

N(1710)P_{11}, N(2100)P_{11}

N(1700)D_{13}, N(2080)D_{13}

Similar to η analysis:

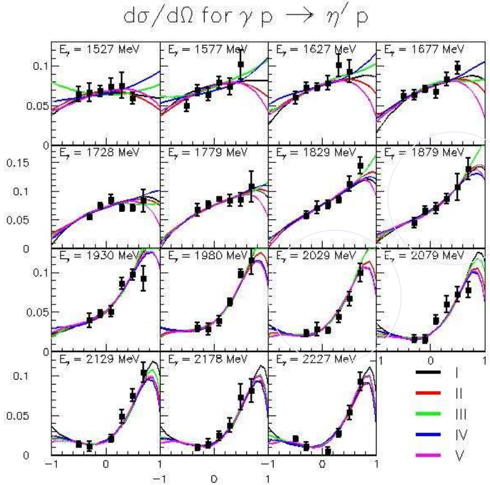
N(1535)S_{11} and N(1710)P_{11}

dominant (SAID, MAID)!

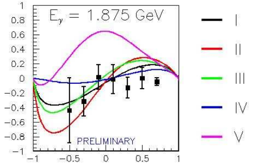
Analysis of $\gamma p \to p\eta'$

Phys. Rev. Lett. **96**, 062001 (2006)

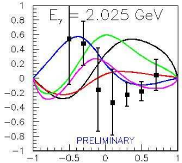
Linearly-Polarized Beam at JLab: g8b Run Group



Raw asymmetry for η' photoproduction (P = 0.8 assumed)



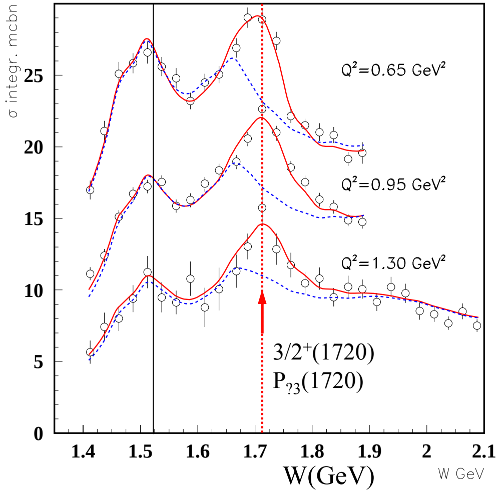
Set IV
$2\times$ S_{11}
$2\times$ P_{11}
$2\times$ D_{13}



Raw Asymmetries

Analysis of $\gamma p \rightarrow p\eta'$
Phys. Rev. Lett. **96**, 062001 (2006)

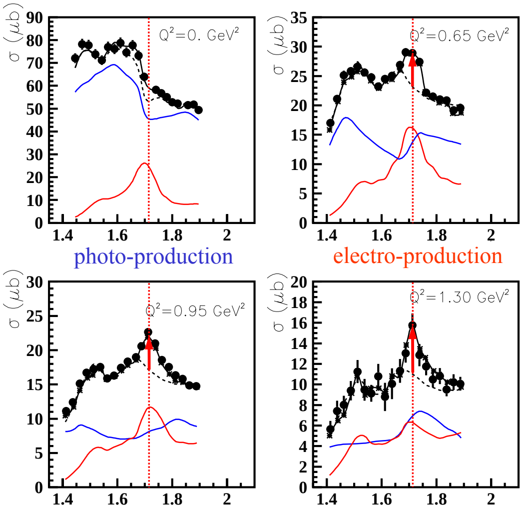
Resonances in $\gamma^{(*)}p \to p\,\pi^+\pi^-$



- 2π channel sensitive to N^*'s heavier than 1.4 GeV
- Provides complementary information to the 1π channel
- Many higher lying N^*'s decay preferably to $N\pi\pi$ final states via intermediate states

Solid curves are from fits using the recent JM06 model with and without a new ?(1720)$P_{?3}$ state

Resonances in $\gamma^{(*)}p \rightarrow p\pi^+\pi^-$

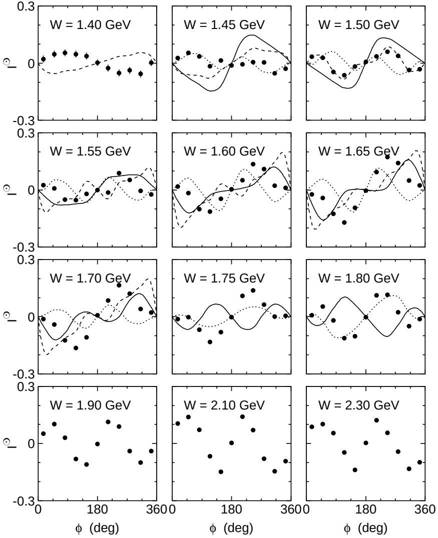


- Background
- Resonances

Combined analysis of preliminary real (M. Bellis) and also published virtual photon data (M. Ripani):

Fit needs both the candidate ?(1720)$P_{?3}$ and the $N(1720)P_{13}$ state.

Authors claim that combined fit of various single differential cross sections allowed to establish all significant mechanisms.



Beam-Helicity Asymmetry $I^{\odot}$ in the reaction $\vec{\gamma} p \to p \, \pi^+ \pi^-$

CLAS Measurements

(S. Strauch et al., PRL **95**, 162003 (2005))

and model calculations:

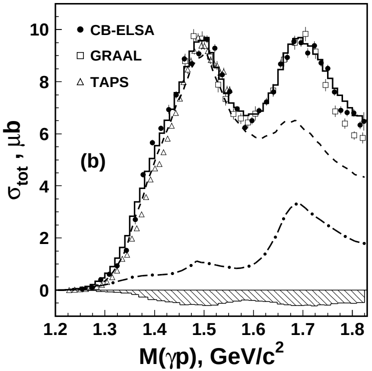
- Mokeev et al. (solid)
- Fix and Arenhövel (dashed)

Reasonable Description of $N\pi/N\pi\pi$ Electroproduction

The CLAS-Collaboration phenomenological models (UIM/DR/JM) reproduce reasonably well comprehensive CLAS/world data on all observables in $N\pi/N\pi\pi$ electroproduction:

- Isobar used in $N\pi\pi$ electroproduction
  1. All well-established $N^* \to \pi^-\Delta^{++}$ decays + $3/2^+(1720)$
  2. All well-established $N^* \to p\rho$ decays + $3/2^+(1720)$
  3. Observed for the first time in CLAS data: $\pi^+ D^0_{13}(1520)$, $\pi^+ F^0_{15}(1685)$, and $\pi^- P^{++}_{33}(1640)$
- Models can be used to evaluate N* electrocouplings
  - ➜ Information on contributing mechanisms will be used by EBAC for N* studies in advanced coupled channel analysis (Julia-Diaz, Lee, Phys. Rev. C**76**, 065201 (2007))

Analysis of $\gamma p \to p\pi^0\pi^0$ (CB-ELSA)



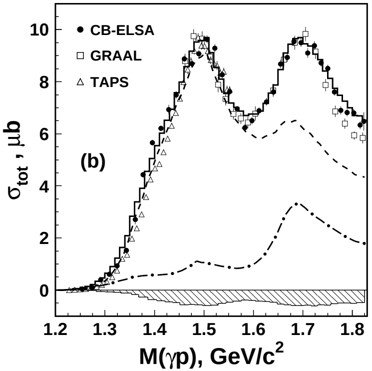
Event-based Maximum Likelihood Fit
(arXiv:0707.3592)

Further constraints

- $\gamma p \to p\pi^0$ (CB-ELSA, TAPS, GRAAL) beam and target asymmetries, recoil polarization, $d\sigma/d\Omega$,
- $\gamma p \to p\pi^0\pi^0$ (GRAAL, TAPS), $\pi^- p \to n\pi^0\pi^0$ (Crystal Ball)
- $\gamma p \to p\eta$ (CB-ELSA, GRAAL, TAPS)
- $\gamma p \to K\Lambda,\ K\Sigma$ (CLAS, SAPHIR)

- Mass region below 1.7 GeV/c^2 dominated by $\Delta^+\pi^0 \to p\,\pi^0\pi^0$ — — —
- Significant contributions from $N(\pi\pi)_S$-wave — · — · —

Analysis of $\gamma p \to p\pi^0\pi^0$ (CB-ELSA)



Main results

- Observation of decays into $\Delta\pi$, $N(\pi\pi)_S$, $N(1440)P_{11}\pi$, $N(1520)D_{13}\pi$
- $N(1900)P_{13}$ needed by CLAS spin-transfer data in hyperon photoproduction
- Properties of $N(1720)P_{13}$ disagree with PDG values (decay mode $\Delta\pi$ strong, Γ_{tot})
  ➜ Discrepancies interpreted as new P_{13} state by MSU-JLab group
- $N(1520)D_{13}$ decays into $(\Delta\pi)_{S-wave}$ as strong as decays into $(\Delta\pi)_{D-wave}$

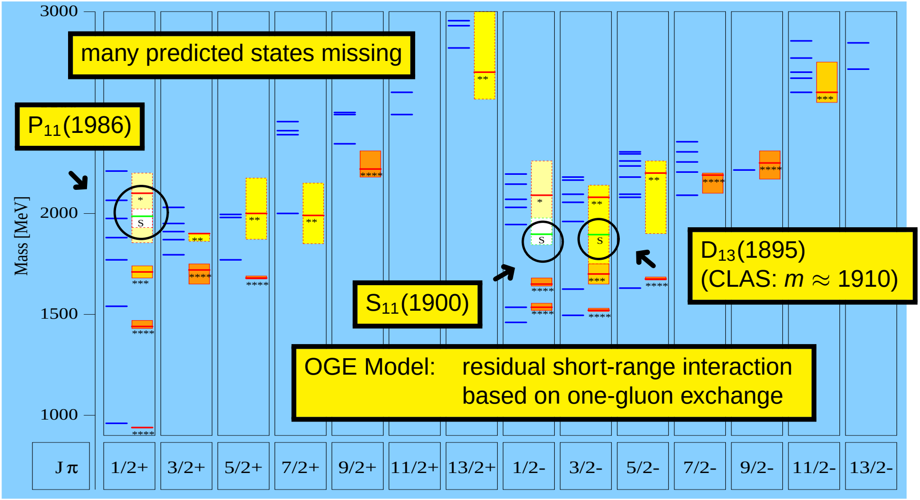
- Mass region below 1.7 GeV/c^2 dominated by $\Delta^+\pi^0 \to p\,\pi^0\pi^0$ — — —
- Significant contributions from $N(\pi\pi)_S$-wave — · — · —

Photoproduction of Strangeness

- Cross Sections for the $\gamma p \to K^{*0}\Sigma^+$ Reaction at E_γ = 1.7 – 3.0 GeV
  (PRC **75** 042201 (2007))
- First Measurement of the Beam-Recoil Observables C_x and C_z in Hyperon Photoproduction
  (PRC **75** 035205 (2007))
- Separated Structure Functions for the Exclusive Electroproduction of $K^+\Lambda$ and $K^+\Sigma^0$ Final States
  (PRC **75** 045203 (2007))
- Differential Cross Sections for $\gamma p \to K^+Y$ for Λ and Σ^0 Hyperons
  (PRC **73** 035202 (2006))

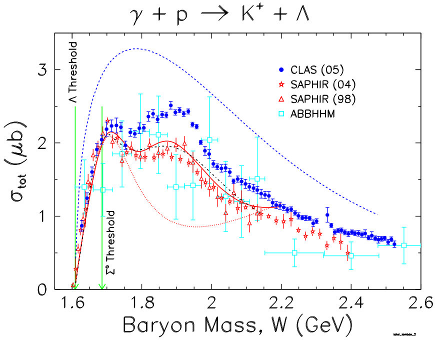
Nucleon Resonances: Status – 2001

—— S. Capstick and N. Isgur, Phys. Rev. **D34** (1986) 2809



Cross Section Measurements for $\gamma p \to K^+ Y$

Several existing theoretical models are compared to the data, but none provides a good representation of the data
➜ Further constraints needed!



SAPHIR data triggered discussion on *missing* $N(1950)D_{13}$ state:

1. Mart-Bennhold
   ➜ Evidence for $N(1890)D_{13}$
2. Saghai
   ➜ Bump due to u-channel and off-shell effects
3. no need, interference effect, strong evidence, etc.

Baryon Resonances in Hyperon Photoproduction

Mart & Bennhold:

—— including $N(1895)D_{13}$ $(*)$

$\cdots$ without $N(1895)D_{13}$

History of the $D_{13}(1895)$

2000 $D_{13}(1895)$

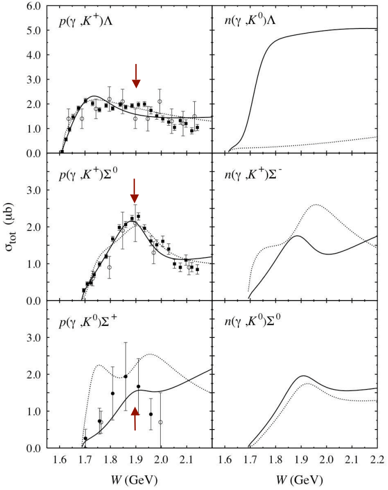
2000 $D_{13}(1895) + P_{13}(1720)$

2003 $D_{13}(1740)$

2005 $D_{13}(1870) = [\,D_{13}(1520)\,]$

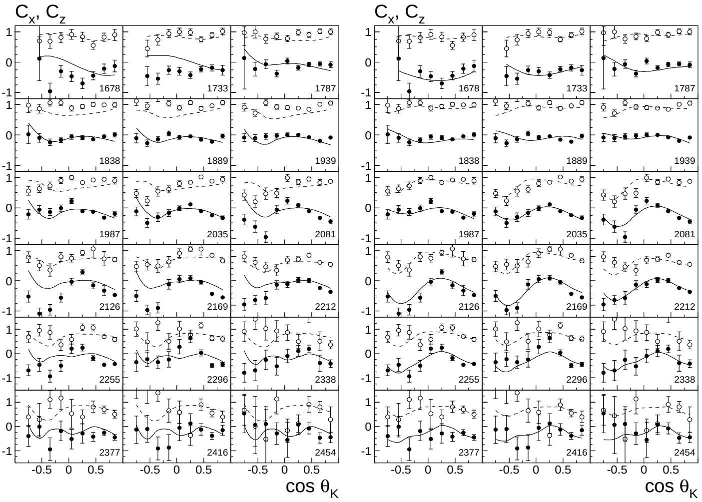
2006 $D_{13}(1912)$

➜ Problem: 20 % (energy-dependent) normalization discrepancy between SAPHIR and CLAS



p and n KY-Mart&Bennhold-hst06

Hyperon Production: Evidence for $N(1900)P_{13}$ **



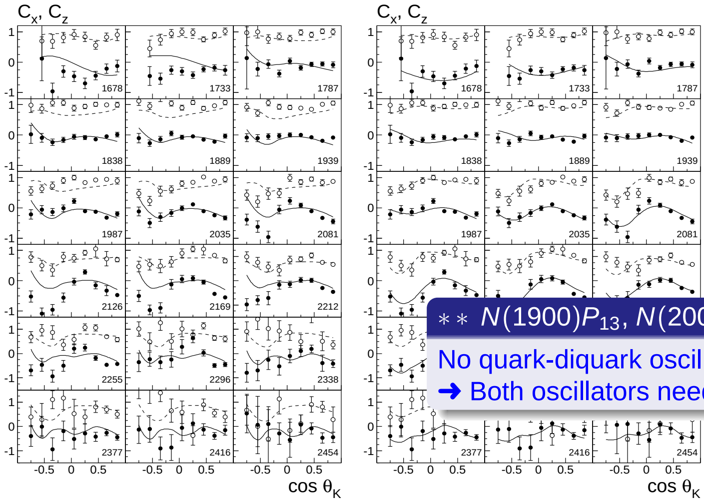
BoGa
(arXiv:0707.3600)

Left panel:
without $N(1900)P_{13}$

Right panel:
with $N(1900)P_{13}$

R. Bradford *et al.* [CLAS Collaboration], Phys. Rev. C**75** (2007) 035205

Hyperon Production: Evidence for $N(1900)P_{13}$ **



BoGa (arXiv:0707.3600)

Left panel: without $N(1900)P_{13}$

Right panel: with $N(1900)P_{13}$

** $N(1900)P_{13}$, $N(2000)F_{15}$, $N(1990)F_{17}$

No quark-diquark oscillations!
➜ Both oscillators need to be excited.

R. Bradford *et al.* [CLAS Collaboration], Phys. Rev. C**75** (2007) 035205

(New) Baryon Resonances in Photoproduction

Reaction	Resonances			
$\gamma p \to N\pi$	$\Delta(1232)P_{33}$	$N(1520)D_{13}$	$N(1680)F_{15}$	$S(1535)S_{11}$
$\gamma p \to p\eta$	$S(1535)S_{11}$	$N(1720)P_{13}$	$N(2070)D_{15}$	$N(1650)S_{11}$
$\gamma p \to p\pi^0\pi^0$	$\Delta(1700)D_{33}$	$N(1520)D_{13}$	$N(1680)F_{15}$	
$\gamma p \to p\pi^0\eta$	$\Delta(1940)D_{33}$	$\Delta(1920)P_{33}$	$N(2200)P_{13}$	$\Delta(1700)D_{33}$
$\gamma p \to \Lambda K^+$	S_{11}-wave	$N(1720)P_{13}$	$N(1900)P_{13}$	$N(1840)P_{11}$
$\gamma p \to \Sigma K$	S_{11}-wave	$N(1900)P_{13}$	$N(1840)P_{11}$	
$\pi^- p \to n\pi^0\pi^0$	$N(1440)P_{11}$	$N(1520)D_{13}$	S_{11}-wave	

The available data sets comprising various high-statistics differential cross sections, beam, target, recoil asymmetries, double polarization observables, and also data resolving isospin contributions are not yet sufficient to converge into a unique solution.

Outline

Ingredients

- Measurements off neutron and proton to resolve isospin contributions
  1. $\mathcal{A}(\gamma N \to \pi,\, \eta,\, K)^{I=3/2} \quad \Longleftrightarrow \quad \Delta^*$
  2. $\mathcal{A}(\gamma N \to \pi,\, \eta,\, K)^{I=1/2} \quad \Longleftrightarrow \quad N^*$
- Re-scattering effects: Large number of measurements (and also final states) needed to define the full scattering amplitude
- Double-polarization measurements

Chiang & Tabakin, Phys. Rev. C55, 2054 (1997)

In order to determine the full scattering amplitude without ambiguities, one has to carry out eight carefully selected measurements: four double-spin observables along with the four single-spin observables.

$\gamma p \to K^+\Lambda$ Series of JLab Experiments

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		$T_{z'}$		$L_{z'}$
linearly P_γ	Σ	H	P	G	$O_{x'}$	T	$O_{z'}$	$L_{z'}$	$C_{z'}$	$T_{z'}$	E		F	$L_{x'}$	$C_{x'}$	$T_{x'}$
circular P_γ		F		E	$C_{x'}$		$C_{z'}$		$O_{z'}$		G		H		$O_{x'}$	

status	*CLAS run period*	*beam*	*target*	***Full set of 16***
complete	*g1*	γ , $\vec{\gamma}_c$	LH_2	*Miskimen/Schumacher*
complete	*g8*	$\vec{\gamma}_L$	LH_2	*Cole*
complete	*g9a* - P^T_z	$\vec{\gamma}_L$, $\vec{\gamma}_c$	*FROST* - $C_4\vec{H}_9O\vec{H}$	*Klein, Pasyuk*
2010	*g9b* - P^T_x	$\vec{\gamma}_L$, $\vec{\gamma}_c$	*FROST* - $C_4\vec{H}_9O\vec{H}$	*Klein, Pasyuk*

Picture taken from A. Sandorfi

Beam-Target Polarization Observables

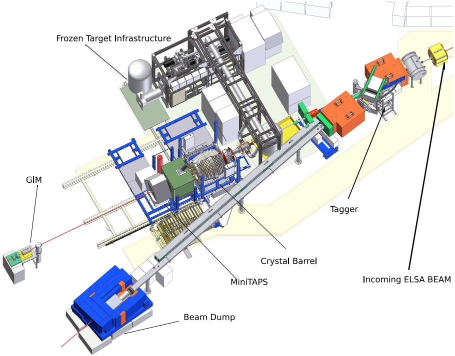
$$\frac{d\sigma}{d\Omega} = \sigma_0 \{ 1 - \delta_l \, \Sigma \cos 2\phi + \Lambda_x (-\delta_l \, \mathbf{H} \sin 2\phi + \delta_\odot \, \mathbf{F}) - \Lambda_y (-\mathbf{T} + \delta_l \, \mathbf{P} \cos 2\phi) - \Lambda_z (-\delta_l \, \mathbf{G} \sin 2\phi + \delta_\odot \, \mathbf{E}) \}$$

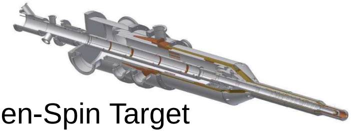
$\Leftarrow$ Single-Meson Final States (7 Observables)

$$I = I_0 \{ (1 + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}) + \delta_\odot (\mathbf{I}^\odot + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}^\odot) + \delta_l [\sin 2\beta (\mathbf{I}^s + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}^s) \cos 2\beta (\mathbf{I}^c + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}^c)] \}$$

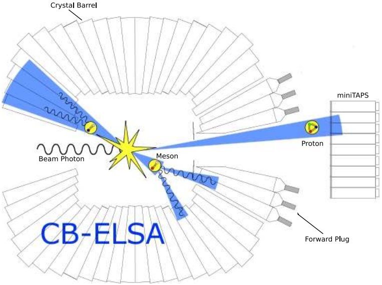
Two-Meson Final States $\Rightarrow$ (15 Observables)

Double-Polarization Measurements at ELSA



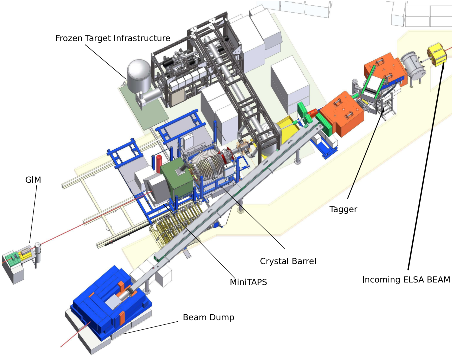


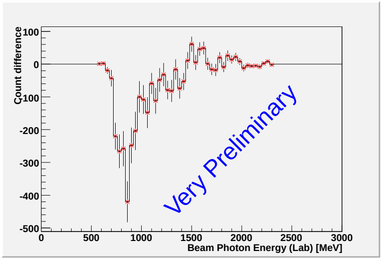
Frozen-Spin Target

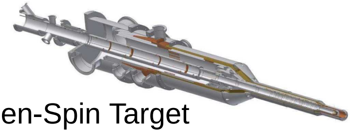


- Longitudinally-Polarized Target
- Polarized Photon Beams
- Excellent Photon Energy Detection
- Charged Particle Identification

Double-Polarization Measurements at ELSA







Frozen-Spin Target

Helicity Difference E for $\gamma p \to p\,\eta$

- Longitudinally-polarized target
- Circularly-polarized beam
- $\sim 40,000$ $p\eta$ events

The CLAS Polarization Program

The Double-Polarization Program (FROST) at JLab:

- E 02-112 $\Rightarrow$ *Photoproduction of Hyperons* $(K^+\Lambda\ (\Sigma^0),\ K^0\Sigma^+)$
- E 03-105 $\Rightarrow$ $\pi^0 p,\ \pi^+ n$ *Photoproduction*
  E 04-102
- E 05-012 $\Rightarrow$ η *Photoproduction*
- E 06-013 $\Rightarrow$ $\pi^+\pi^-$ *Photoproduction*

The Polarized Deuterium-Target Program (HD-Ice target from BNL):

- E 06-101 $\Rightarrow$ $\gamma n \to \pi^- p,\ \pi^+\pi^- n,\ K\,Y\ (K^0\Lambda,\ K^0\Sigma^0,\ K^+\Sigma^-)$

Polarized photon beams on unpolarized targets:

- g1, g8 $\Rightarrow$ Reactions on Hydrogen ($\checkmark$)
- g13 $\Rightarrow$ Reactions on Deuterium ($\checkmark$)

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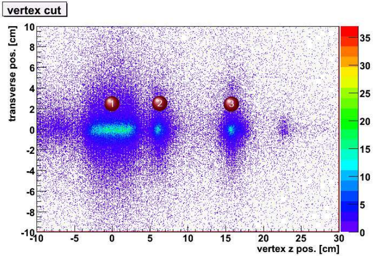
FROST Run Summary: Nov. 2007 - Feb. 2008



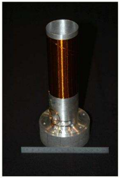
Production Data

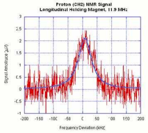
- Target (Butanol)

  Longitudinally-polarized target
  Average polarization $\sim 80\,\%$
  Additional targets: ^{12}C, CH_2

- PhotonBeam

  Circular and linear Polarization
  Excellent degrees of polarization



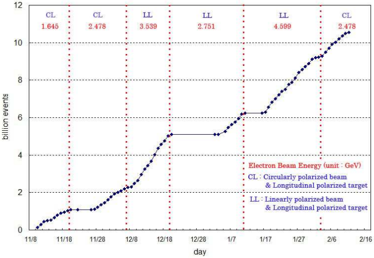


$\Delta B/B \approx 3 \cdot 10^{-3}$ at 0.5 T

$B \approx 0.5$ T

$T \approx 0.05$ K

10.5 Billion events



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g13

Summary

- Polarized photons
  - 1.1 - 2.3 GeV (linear)
  - 0.4 - 2.5 GeV (circular)
- Deuterium target
- $5 \cdot 10^{10}$ events

Status

- Data collected Nov 2006 – Jun 2007
- Calibration soon complete
- At least 7 PhD theses in progress

N^* Physics: $\gamma n \to N^* \to \dots$

$K^0 \Lambda$, $K^0 \Sigma^0$, $K^+ \Sigma^-$, $K^{0*} \Lambda$, $K^+ \Sigma(1385)^-$

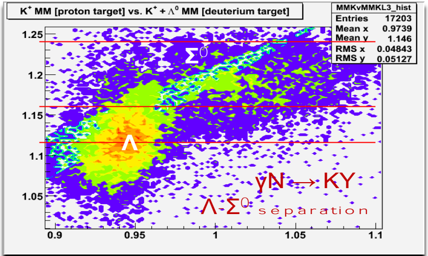
$\pi^- p$, $\pi^- \pi^0 p$, ωp

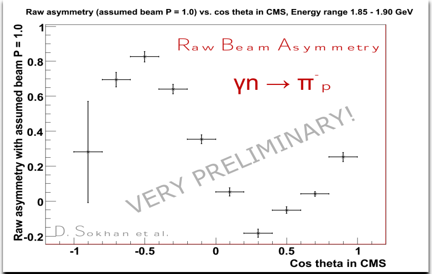
Nuclear effects, YN interactions, pQCD:

$\gamma d \to \dots$

$\pi^- p p$, $K^+ \Lambda p$, $K^0 \Lambda p$, $K^0 \Sigma^0 p$, Φn

$\pi^0 d$, ηd, ωd, ρd, $\eta' p n$, $p n$





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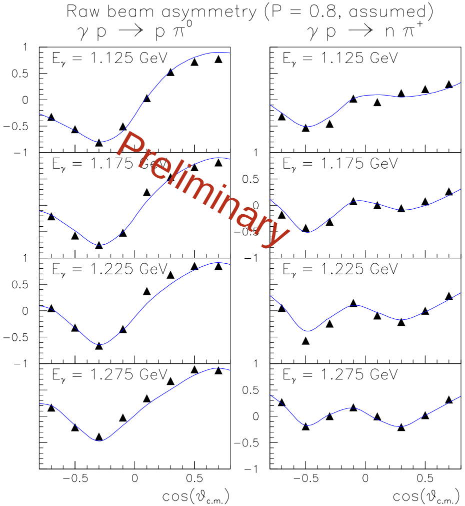
Polarized photon beams on unpolarized targets:

- g1, g8 $\Rightarrow$ Reactions on Hydrogen ($\checkmark$) “Linear Beam”
- g13 $\Rightarrow$ Reactions on Deuterium ($\checkmark$)

Linearly-Polarized Beam at JLab: g8b Run Group



- Many channels being analyzed:
- High statistics > 10 billion events
- High photon polarization from 1.3 – 2.1 GeV

$\Leftarrow$ Preliminary analysis of $\gamma p \to N\pi$ (Mike Dugger ASU)

- P_γ estimated at 0.8
- — SAID prediction
- Data with statistical errors (no systematic)

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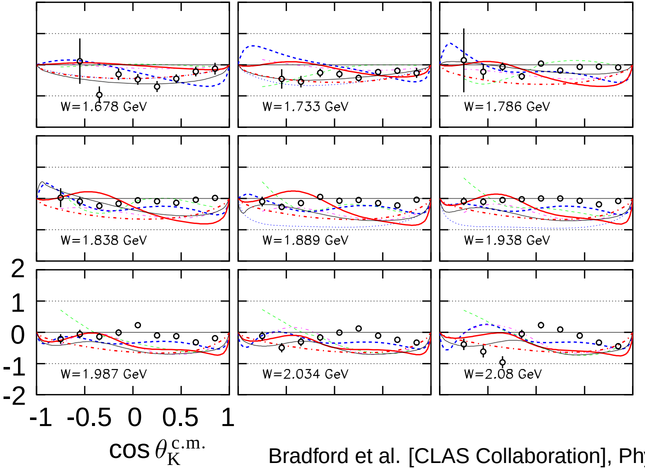
Polarized photon beams on unpolarized targets:

- g1, g8 $\Rightarrow$ Reactions on Hydrogen $(\checkmark)$ "Circular Beam"
- g13 $\Rightarrow$ Reactions on Deuterium $(\checkmark)$

C_x (and C_z) in Hyperon Photoproduction



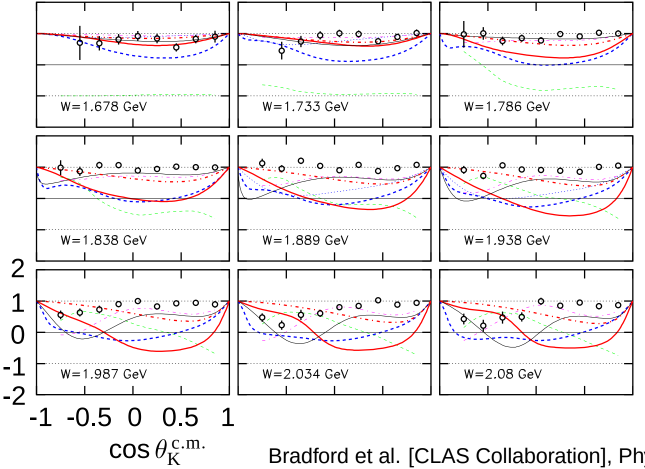
$\vec{\gamma} p \rightarrow K^+ + \vec{\Lambda}$

Circularly-polarized beam

C_x/C_z characterize polarization transfer from beam to recoiling hyperon

Bradford et al. [CLAS Collaboration], Phys. Rev. C **75**, 035205 (2007)

(C_x and) C_z in Hyperon Photoproduction



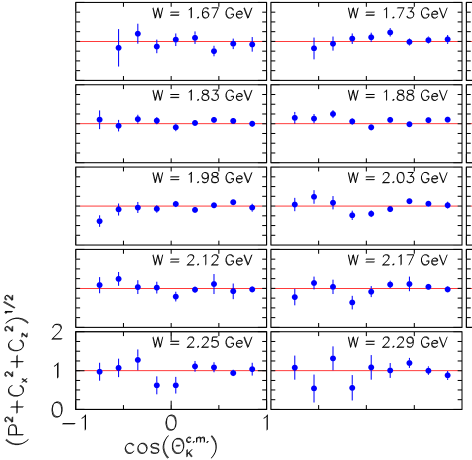
Circularly-polarized beam

Possible relation:

$C_z \approx C_x + 1$

Bradford et al. [CLAS Collaboration], Phys. Rev. C **75**, 035205 (2007)

C_x and C_z in Hyperon Photoproduction



Conclusion:
Λ hyperons appear 100 % spin polarized.

Kinematically not required, unknown origin!

Inequality:
$R^2 \equiv P^2 + C_x^2 + C_z^2 \leq 1$

Outline

Summary and Outlook

Many high-statistics data samples available with excellent energy and angular coverage:

- Several studies provide good description of η, $\pi\pi$, and hyperon photoproduction
  - New baryon resonances have been proposed
    ➜ Groups and studies do not always agree, ambiguities!
- Other reactions have been studied (not discussed here):
  - Latest GWU analysis of crucial πN channel suggests (ARNDT 06):
    $\ast\ast$ $N(2000)F_{15}$, $\Delta(2400)G_{39}$ and new $N(2245)H_{1,11}$
  - BES observes $N^*(2050)$ in $J/\psi \to p\pi^-\bar{n}$ and $J/\psi \to \bar{p}\pi^+ n$
- Essential polarization measurements have started at all facilities
  - Double-polarization data partly taken