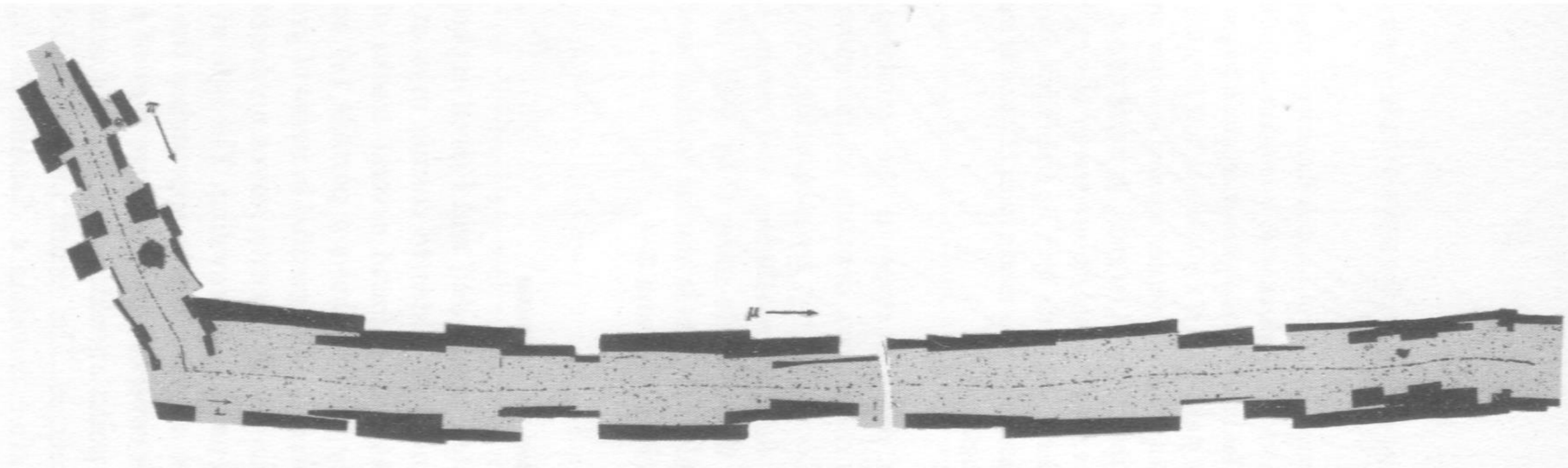
Impact of CLAS meson photoproduction experiments on N* spectroscopy

Eugene Pasyuk
Jefferson Lab

Outline

- History
- Some formalism
- Experimental tools
- What we have measured with CLAS
- Selected results
- Summary

1947: Discovery of pion



Photomicrograph showing a π meson (π) coming to rest in a nuclear emulsion and a μ meson (μ) arising from the end of the π-meson track. (From C. M. G. Lattes, H. Muirhead, G. Occhialini, and C. F. Powell, *Nature*, vol. 160, p. 453, 1947.)

1949: First pion photoproduction experiment

December 2, 1949, Vol. 110 SCIENCE

Production of Mesons by X-Rays

Edwin M. McMillan, Jack M. Peterson, and R. Stephen White[1]

Radiation Laboratory, Department of Physics, University of California, Berkeley

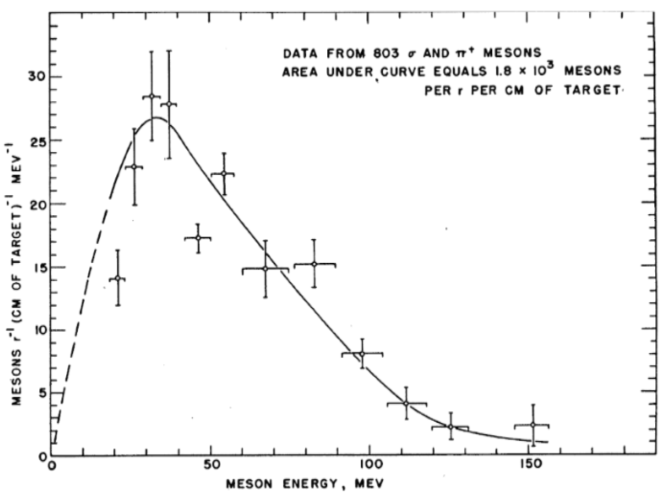


FIG. 4. Distribution of meson energies from x-ray energy of 335 Mev. The apparent lower limit on the energy is caused by the fact that the energies are computed as if the mesons originated in the center of the carbon block. The dotted line is simply a guess as to the trend of the distribution at low energies, which was used in the integration leading to the total cross section.

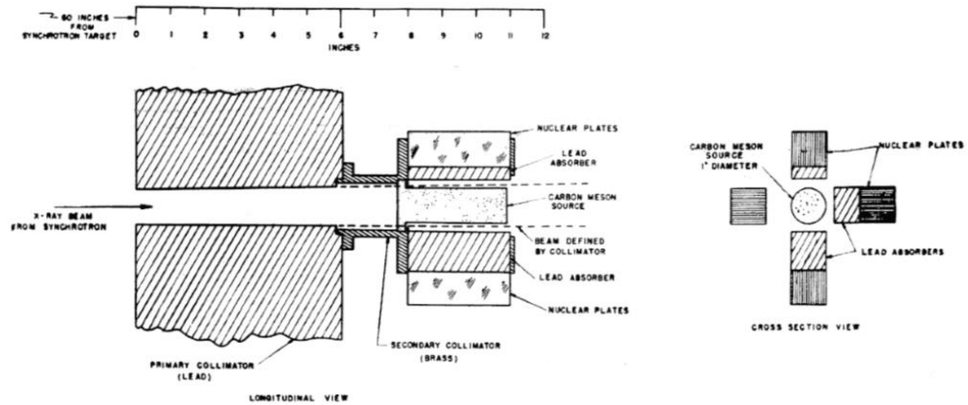


FIG. 1. Drawing of experimental arrangement (Geometry 4).

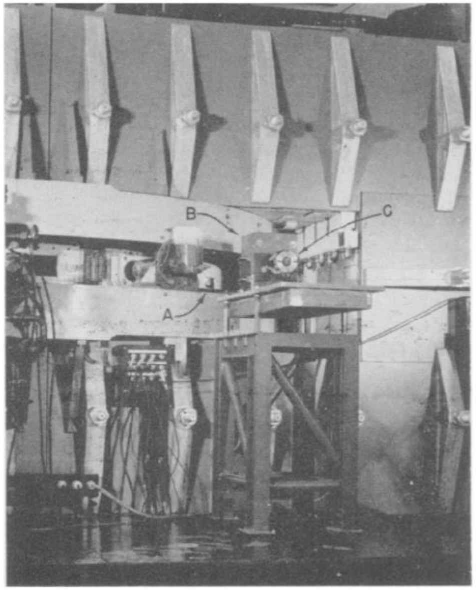


FIG. 2. Photograph of experimental arrangement (Geometry 4). The x-ray beam emerges from the synchrotron through the rectangular hole (A). The 6-inch-thick lead collimator is at B. C is the plate holder.

1952: Discovery of Δ resonance

Physical Review **85,** 936 (1952)

produced in pairs by the decay of the neutral pions, the cross sections for the processes (1) and (2) would be $(10\pm4)\times10^{-27}$ and $(20\pm5)\times10^{-27}$ cm². The cross section obtained for the charge exchange process is not very sensitive to the angular distribution adopted. It would be $(29\pm7)\times10^{-27}$ cm² for a $\cos^2\theta$-distribution and $(18\pm4)\times10^{-27}$ cm² for a $\sin^2\theta$-distribution.

* Research sponsored by the ONR and AEC.

Total Cross Sections of Positive Pions in Hydrogen*

H. L. Anderson, E. Fermi, E. A. Long,† and D. E. Nagle
Institute for Nuclear Studies, University of Chicago, Chicago, Illinois

(Received January 21, 1952)

In a previous letter,[1] measurements of the total cross sections of negative pions in hydrogen were reported. In the present letter, we report on similar experiments with positive pions.

The experimental method and the equipment used in this

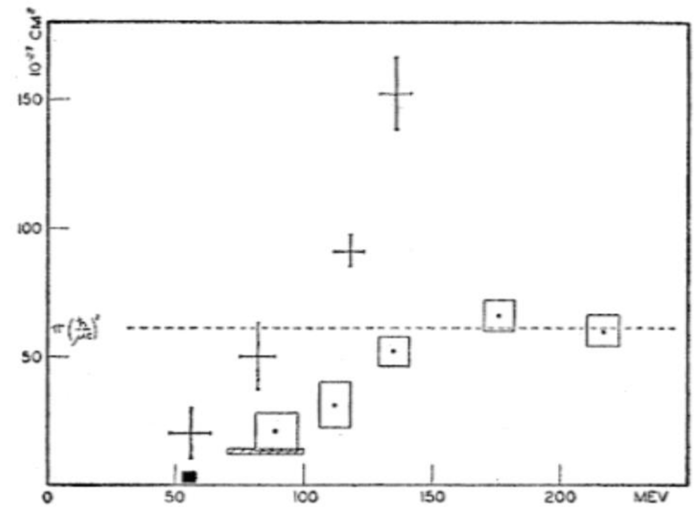


Fig. 1. Total cross sections of negative pions in hydrogen (sides of the rectangle represent the error) and positive pions in hydrogen (arms of the cross represent the error). The cross-hatched rectangle is the Columbia result. The black square is the Brookhaven result and does not include the charge exchange contribution.

processes should be (9:2:1), a set of values which is compatible with the experimental observations. It is more difficult, at present,

This event marks the beginning of baryon resonance era

1982: Baryon spectroscopy is 30 years old

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

BARYON SPECTROSCOPY

Anthony J.G. HEY*

California Institute of Technology, Pasadena, California 91125, U.S.A.
and Physics Department, University of Southampton, SO9 5NH, England

and

Robert L. KELLY**

Arete Associates, P.O. Box 350, Encino, California 91316†, U.S.A.
and Lawrence Berkeley Laboratory, Berkeley, California 94720, U.S.A.

Received 29 September 1982

Preface

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 very simple, phenomenological, nonrelativistic potential model. Nonetheless, the advent of Quantum-Chromo-Dynamics (QCD) has inspired some rethinking of the original quark model, as originated and developed by Zweig, Greenberg, Dalitz and others, and now appears to culminate in a very successful variant due to Isgur, Karl and co-workers. Needless to say, the phenomenal phenomenological success of this model does not mean that all is understood!

1996: known nucleon resonances

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

R.M. Barnett *et al.*, Physical Review **D54**, 1 (1996) and 1997 off-year partial update for the 1998 edition
December 18, 1997 15:23

Particle	$L_{2I \cdot 2J}$	Overall status	Status as seen in — $N\pi$	$N\eta$	ΛK	ΣK	$\Delta\pi$	$N\rho$	$N\gamma$
$N(939)$	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}	****	****	*					
$N(2600)$	$I_{1\,11}$	***	***						
$N(2700)$	$K_{1\,13}$	**	**						

Particle	$L_{2I \cdot 2J}$	Overall status	Status as seen in — $N\pi$	$N\eta$	ΛK	ΣK	$\Delta\pi$	$N\rho$	$N\gamma$
$\Delta(1232)$	P_{33}	****	****	F					****
$\Delta(1600)$	P_{33}	***	***	o			***	*	**
$\Delta(1620)$	S_{31}	****	****	r			****	****	***
$\Delta(1700)$	D_{33}	****	****	b		*	***	**	***
$\Delta(1750)$	P_{31}	*	*	i					
$\Delta(1900)$	S_{31}	**	**	d		*	*	**	*
$\Delta(1905)$	F_{35}	****	****	d		*	**	**	***
$\Delta(1910)$	P_{31}	****	****	e		*	*	*	*
$\Delta(1920)$	P_{33}	***	***	n		*	**		*
$\Delta(1930)$	D_{35}	***	***			*			**
$\Delta(1940)$	D_{33}	*	*	F					
$\Delta(1950)$	F_{37}	****	****	o		*	****	*	****
$\Delta(2000)$	F_{35}	**		r				**	
$\Delta(2150)$	S_{31}	*	*	b					
$\Delta(2200)$	G_{37}	*	*	i					
$\Delta(2300)$	H_{39}	**	**	d					
$\Delta(2350)$	D_{35}	*	*	d					
$\Delta(2390)$	F_{37}	*	*	e					
$\Delta(2400)$	G_{39}	**	**	n					
$\Delta(2420)$	$H_{3\,11}$	****	****						*
$\Delta(2750)$	$I_{3\,13}$	**	**						
$\Delta(2950)$	$K_{3\,15}$	**	**						

**** Existence is certain, and properties are at least fairly well explored.
*** Existence ranges from very likely to certain, but further confirmation is desirable and/or quantum numbers, branching fractions, *etc.* are not well determined.
** Evidence of existence is only fair.
* Evidence of existence is poor.

22 N* + 22 Δ

General spin dependent cross section

$$
\begin{aligned}
d\sigma^{B,T,R}(\vec{P}^{\gamma},\vec{P}^{T},\vec{P}^{R}) = \frac{1}{2}\{ & d\sigma_0[1 - P_L^{\gamma} P_y^{T} P_{y'}^{R} \cos(2\phi_{\gamma})] \\
& + \Sigma[-P_L^{\gamma}\cos(2\phi_{\gamma}) + P_y^{T} P_{y'}^{R}] \\
& + T[P_y^{T} - P_L^{\gamma} P^{R}_{y'} \cos(2\phi_{\gamma})] \\
& + P[P^{R}_{y'} - P_L^{\gamma} P_y^{T} \cos(2\phi_{\gamma})] \\
& + E[-P_c^{\gamma} P_z^{T} + P_L^{\gamma} P_x^{T} P_{y'}^{R} \sin(2\phi_{\gamma})] \\
& + G[P_L^{\gamma} P_z^{T} \sin(2\phi_{\gamma}) + P_c^{\gamma} P_x^{T} P_{y'}^{R}] \\
& + F[P_c^{\gamma} P_x^{T} + P_L^{\gamma} P_z^{T} P_{y'}^{R} \sin(2\phi_{\gamma})] \\
& + H[P_L^{\gamma} P_x^{T} \sin(2\phi_{\gamma}) - P_c^{\gamma} P_x^{T} P_{y'}^{R}] \\
& + C_{x'}[P_c^{\gamma} P_{x'}^{R} - P_L^{\gamma} P_y^{T} P_{z'}^{R} \sin(2\phi_{\gamma})] \\
& + C_{z'}[P_c^{\gamma} P_{z'}^{R} - P_L^{\gamma} P_y^{T} P_{x'}^{R} \sin(2\phi_{\gamma})] \\
& + O_{x'}[P_L^{\gamma} P_{x'}^{R} \sin(2\phi_{\gamma}) + P_L^{\gamma} P_y^{T} P_{z'}^{R}] \\
& + O_{z'}[P_L^{\gamma} P_{z'}^{R} \sin(2\phi_{\gamma}) - P_c^{\gamma} P_y^{T} P_{x'}^{R}] \\
& + L_{x'}[P_z^{T} P_{x'}^{R} + P_L^{\gamma} P_x^{T} P_{x'}^{R} \cos(2\phi_{\gamma})] \\
& + L_{z'}[P_z^{T} P_{z'}^{R} - P_L^{\gamma} P_x^{T} P_{z'}^{R} \cos(2\phi_{\gamma})] \\
& + T_{x'}[P_x^{T} P_{x'}^{R} + P_L^{\gamma} P_z^{T} P_{z'}^{R} \cos(2\phi_{\gamma})] \\
& + T_{z'}[P_z^{T} P_{z'}^{R} - P_L^{\gamma} P_z^{T} P_{x'}^{R} \cos(2\phi_{\gamma})]\}
\end{aligned}
$$

Single spin

Beam-Target

Beam-Recoil

Target-Recoil

- Pseudo scalar photoproduction is described by 4 complex amplitudes.
- Mathematically speaking in order to reconstruct amplitude one needs to measure 8 carefully chosen observables.
- In real life it is not enough. There are no measurements without uncertainties. We need more than 8 and is not redundancy. Precision is important!
- Every observable can be measured in at least two different experiments.

A. M. Sandorfi, S. Hoblit, H. Kamano, T.-S. H. Lee J.Phys.G38:053001,2011

Measurements

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	$d\sigma_0$		T			P		$T_{x'}$		$L_{x'}$		Σ		$T_{z'}$		$L_{z'}$
$P_L^\gamma \sin(2\varphi_\gamma)$		H		G	$O_{x'}$		$O_{z'}$		$C_{z'}$		E		F		$-C_{x'}$	
$P_L^\gamma \cos(2\varphi_\gamma)$	Σ		$-P$			$-T$		$-L_{x'}$		$T_{z'}$		$-d\sigma_0$		$L_{x'}$		$-T_{x'}$
circular P_c^γ	$d\sigma_0$	F		$-E$	$C_{x'}$		$C_{z'}$		$-O_{z'}$		G		$-H$		$O_{x'}$	

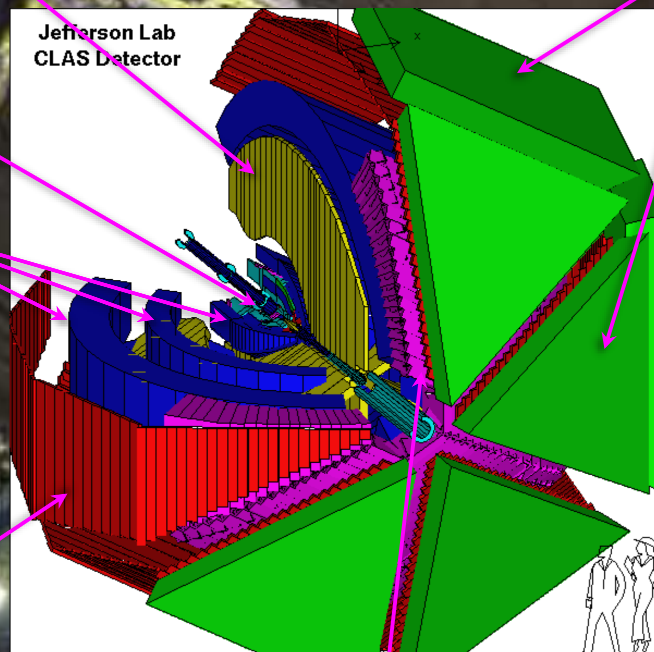
- Every observable can be measured in at least two different experiments configurations.
- **η, η′** and **ω** are isospin filtered channels, not coupled directly to **Δ**
- It is important to measure both **$K^+\Lambda$** and **$K^+\Sigma^0$**: isospin filter
- It is also important to do measurement on both proton and neutron target
- **There is no such things as redundant data!**

CEBAF Large Acceptance Spectrometer 1997-2012

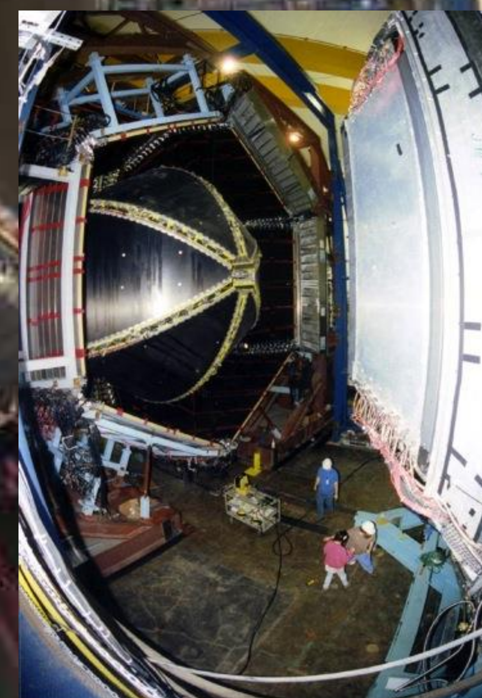
Torus magnet
6 superconducting coils

Electromagnetic calorimeters
Lead/scintillator, 1296 photomultipliers

target + start counter



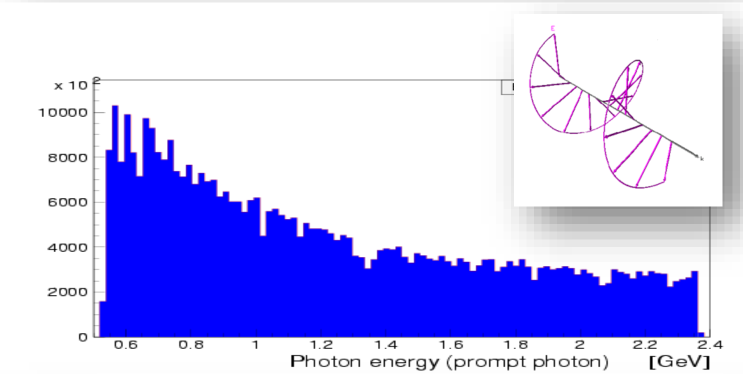
Drift chambers
35,000 cells



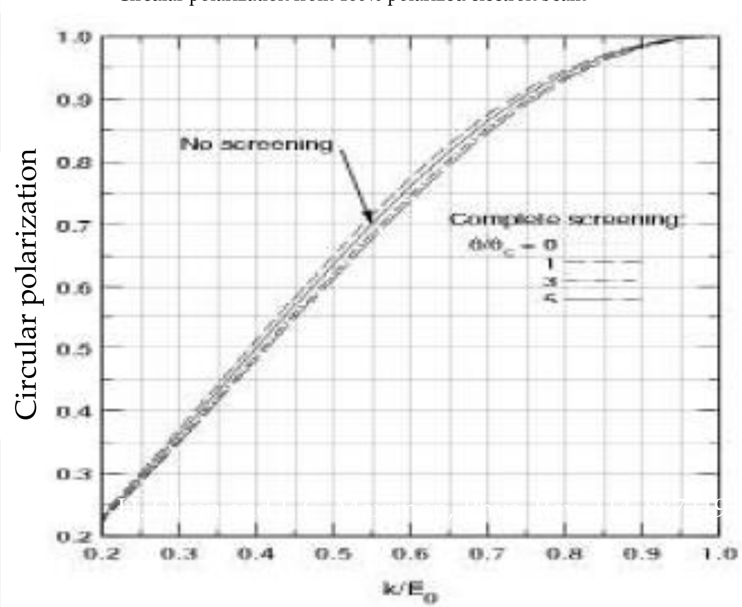
Time-of-flight counters
plastic scintillators, 684 photomultipliers

Gas Cherenkov counters
e/π separation, 256 PMTs

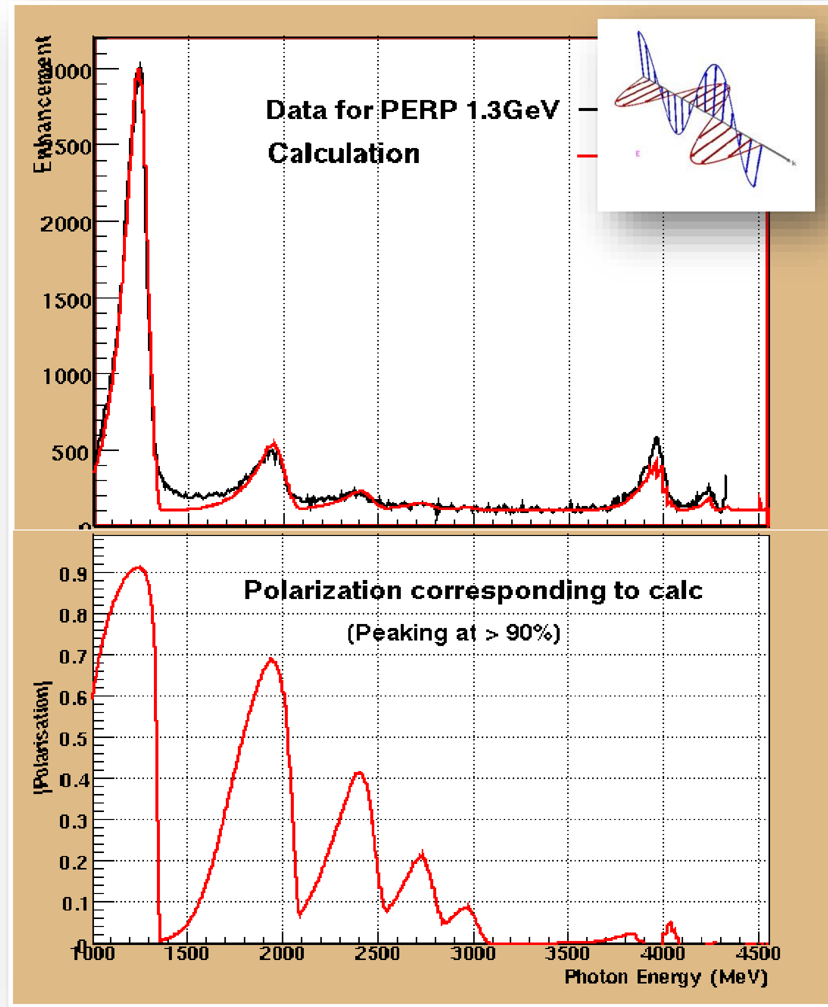
Polarized photon beams



Circular polarization from 100% polarized electron beam

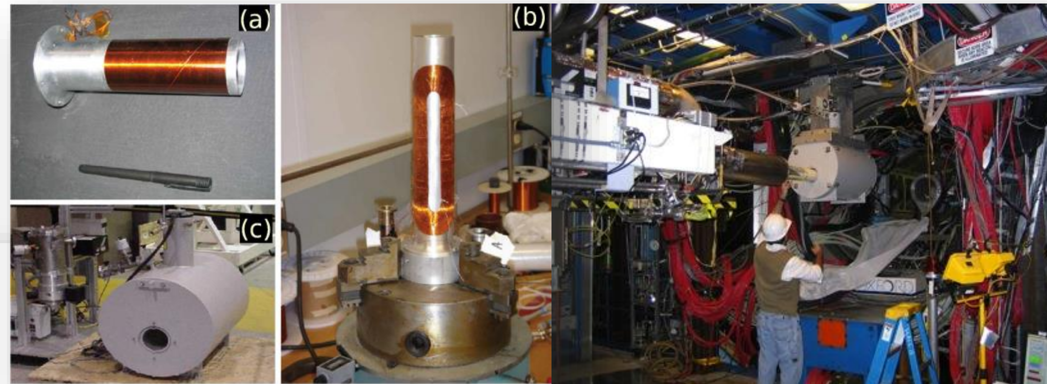


Circularly polarized beam produced by longitudinally polarized electrons



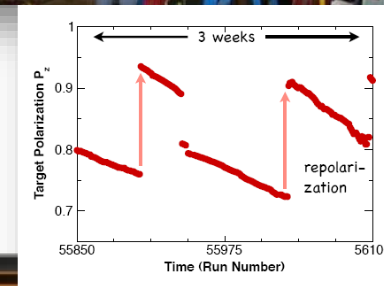
Linearly polarized photons: coherent bremsstrahlung on oriented diamond crystal

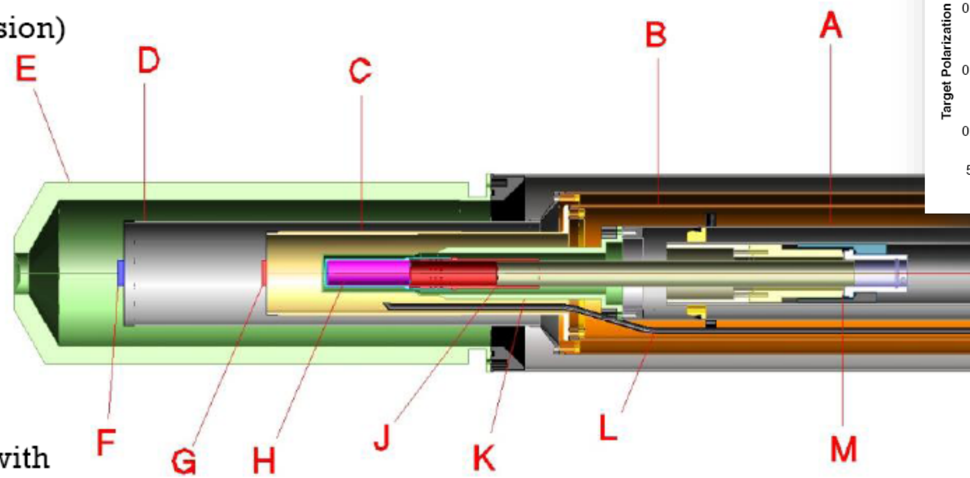
FROST



The FroST target and its components:

A: Primary heat exchanger
B: 1 K heat shield
C: Holding coil
D: 20 K heat shield
E: Outer vacuum can (Rohacell extension)
F: CH2 target
G: Carbon target
H: Butanol target
J: Target insert
K: Mixing chamber
L: Microwave waveguide
M: Kapton coldseal



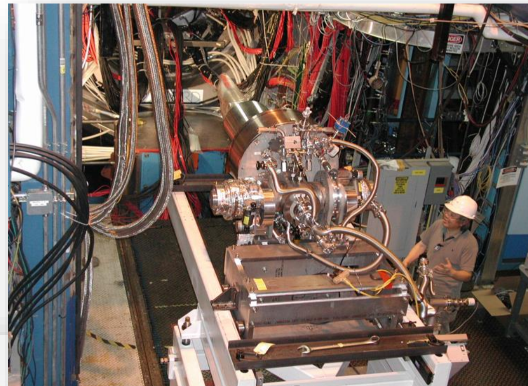


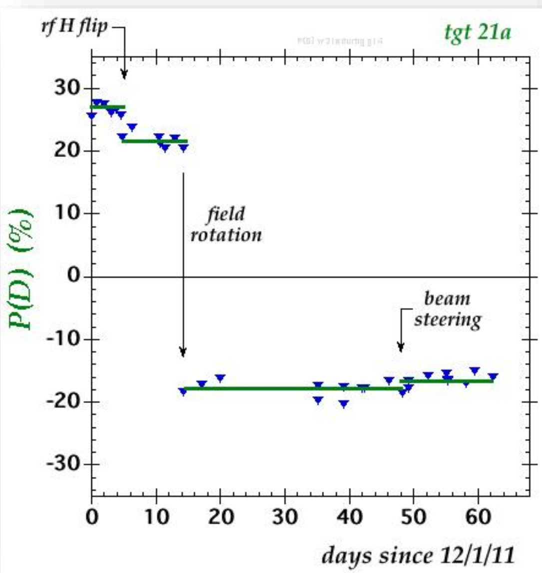
Performance Specs:

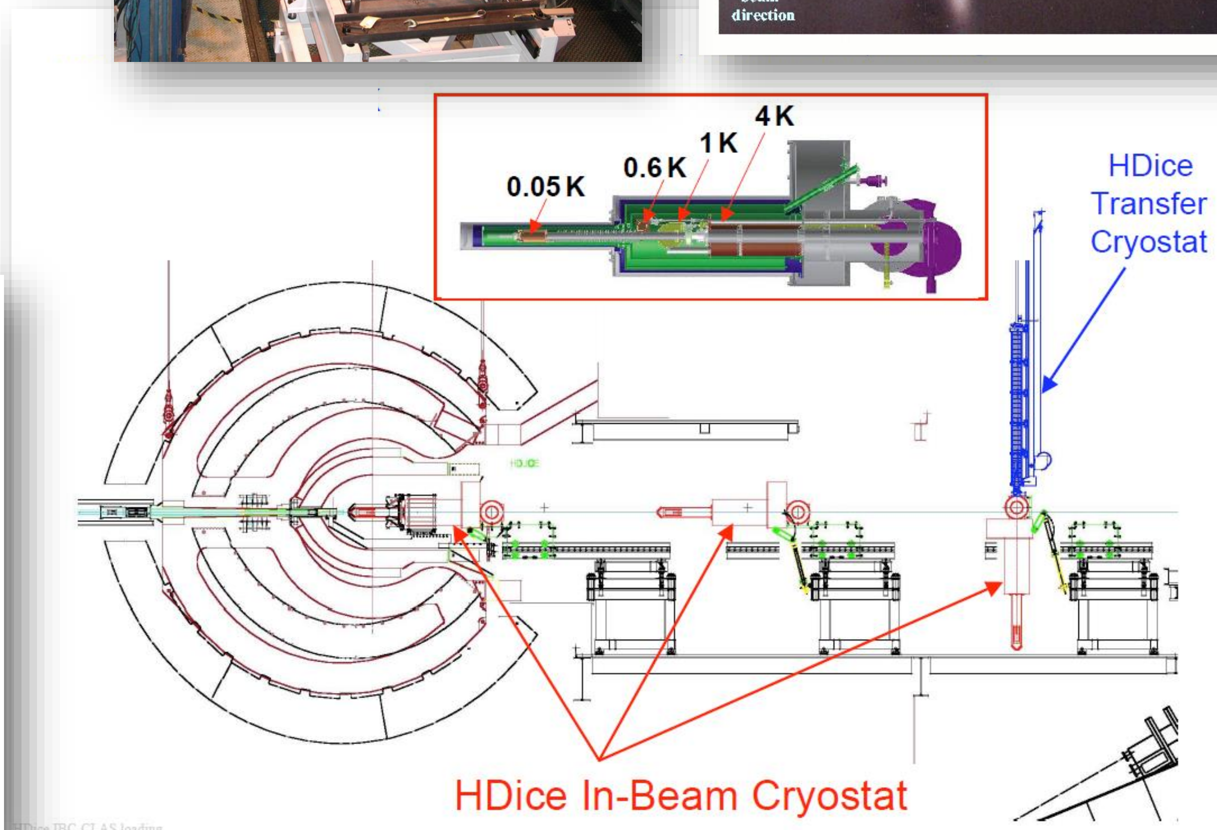
Base Temp: 28 mK w/o beam, 30 mK with
Cooling Power: 800 μW @ 50 mK, 10 mW @ 100 mK, and 60 mW @ 300 mK
Polarization: +82%, -90%
1/e Relaxation Time: 2800 hours (+Pol), 1600 hours (-Pol)
Roughly 1% polarization loss per day.

HDIce polarized target

- Polarized at very high magnetic field and very low temperature
- Transferred to in-beam cryostat
- Spin can be moved between H and D with RF transitions
- All material can be polarized with small background







Final states and observables measured in 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 target: $\gamma p \to X$																
$p\pi^0$	✓ red	✓ red	✓ blue	✓ blue	✓ red	✓ blue	✓ blue	✓ blue								
$n\pi^+$	✓ red	✓ red	✓ blue	✓ blue	✓ red	✓ blue	✓ blue	✓ blue								
$p\eta$	✓ red	✓ red	✓ green	✓ blue	✓ red	✓ green	✓ blue	✓ blue								
$p\eta'$	✓ red	✓ red	✓ blue	✓ blue	✓ blue	✓ blue	✓ blue	✓ blue								
$p\pi^+\pi^-$	✓ red	✓ green			✓ green		✓ green	✓ green + 8 more ππ observables ✓ green								
$p\omega$	✓ red	✓ red	✓ red	✓ green	✓ red	✓ green	✓ green	✓ green	SDME							
$K^+\Lambda$	✓ red	✓ red	✓ red	✓ red	✓ blue	✓ blue	✓ blue	✓ blue	✓ blue	✓ blue	✓ blue	✓ blue	✓ red	✓ red	✓ red	✓ red
$K^+\Sigma^0$	✓ red	✓ red	✓ red	✓ red	✓ blue	✓ blue	✓ blue	✓ blue	✓ blue	✓ blue	✓ blue	✓ blue	✓ red	✓ red	✓ red	✓ red
$K^{0*}\Sigma^+$	✓ red															
$K^0\Sigma^+$	✓ red	✓ blue	✓ blue	✓ blue	✓ blue	✓ blue	✓ blue	✓ blue								
"Neutron" target: $\gamma n \to X$																
$p\pi^-$	✓ red	✓ blue			✓ red		✓ green									
$n\pi^+\pi^-$	✓ blue	✓ blue			✓ blue		✓ blue	✓ blue + 4 more ππ observables ✓ blue ✓ blue								
$K^+\Sigma^-$	✓ red	✓ blue			✓ blue		✓ blue									
$K^0\Lambda$	✓ blue	✓ blue	✓ blue	✓ blue	✓ red								✓ blue	✓ blue	✓ blue	✓ blue
$K^0\Sigma^0$	✓ blue	✓ blue	✓ blue	✓ blue	✓ red								✓ blue	✓ blue	✓ blue	✓ blue

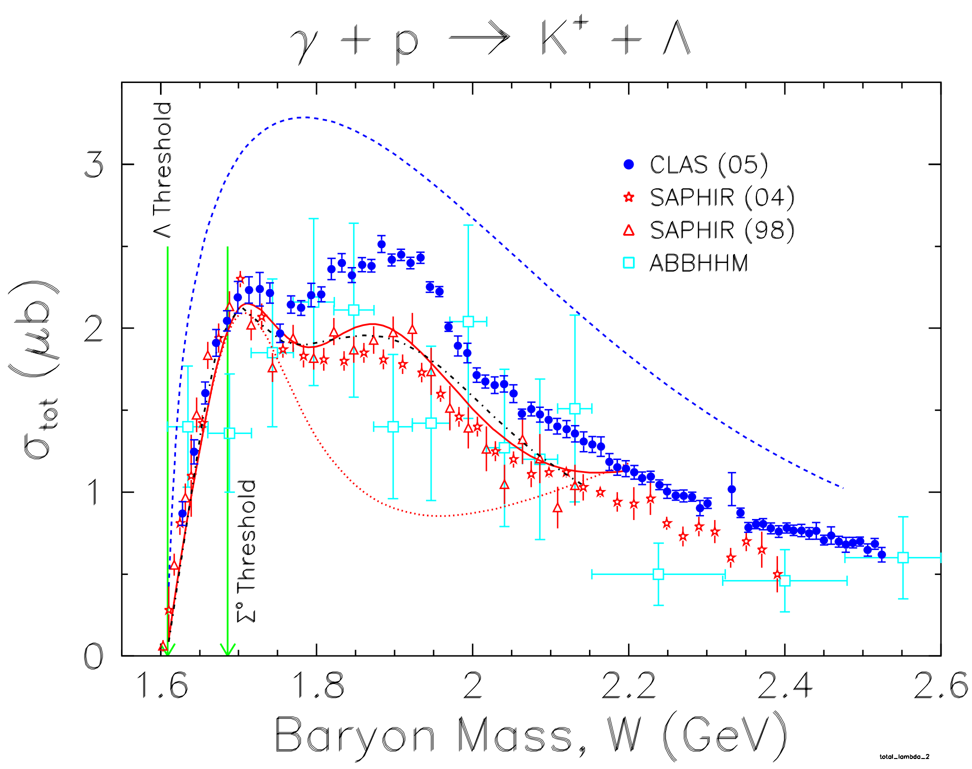
✓ red *Published* ✓ green *Analysis complete* ✓ blue *Acquired*

Data summary (CALS vs world)

reaction	Cross section	polarization
$\gamma p \to p\pi^0$	1200 (21002)	700 (1341)
$\gamma p \to n\pi^+$	618 (7731)	1286 (4539)
$\gamma n \to p\pi^-$	9127 (11411)	266 (805)
$\gamma p \to p\eta$	1202 (12293)	270 (821)
$\gamma p \to p\eta'$	635 (989)	62 (76)
$\gamma p \to p\omega$	1470 (3015)	5257 (5925)
$\gamma p \to K^+\Lambda$	3971 (6338)	3590 (4070)
$\gamma p \to K^+\Sigma^0$	3633 (6204)	1341 (1467)
$\gamma n \to K^+\Sigma^-$	285 (354)	0 (36)

CLAS share is significant
However quality of the data is even more important than quantity

Bump?



SAPHIR data (1998) triggered discussion of "missing" resonances.

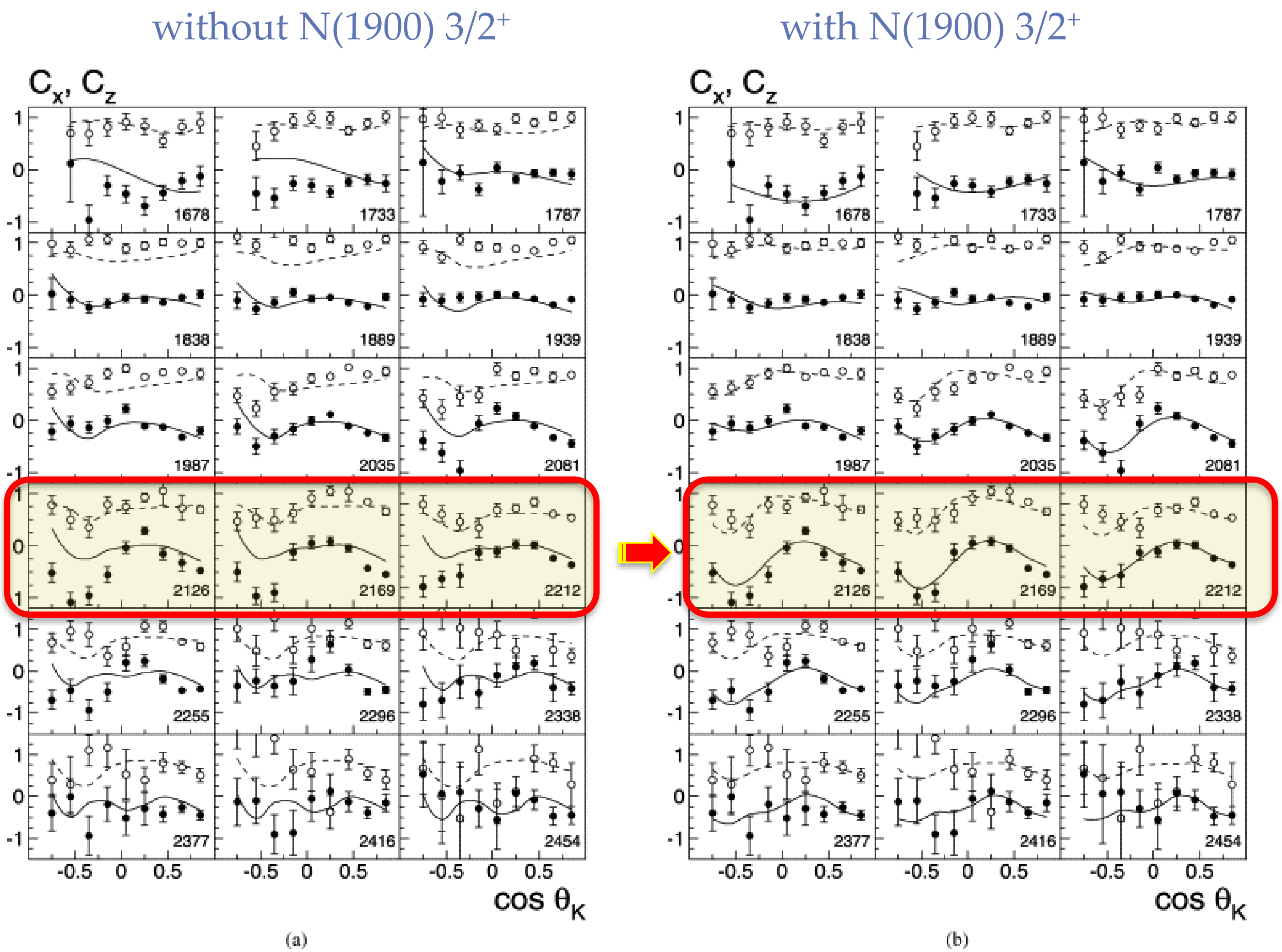
D_{13}(1890)?, P_{11}(1840)? D_{13}(1900)?... lots of other interpretations

CLAS got into the game

First CLAS measurements (g1c): ***dσ/dΩ, P, Cx, Cz***

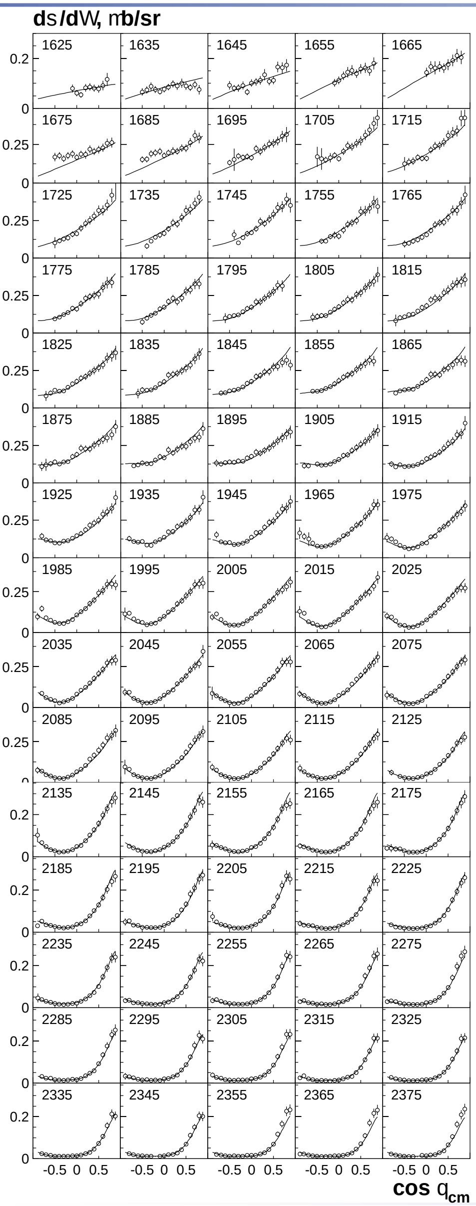
Confirmed bump around 1.9 GeV

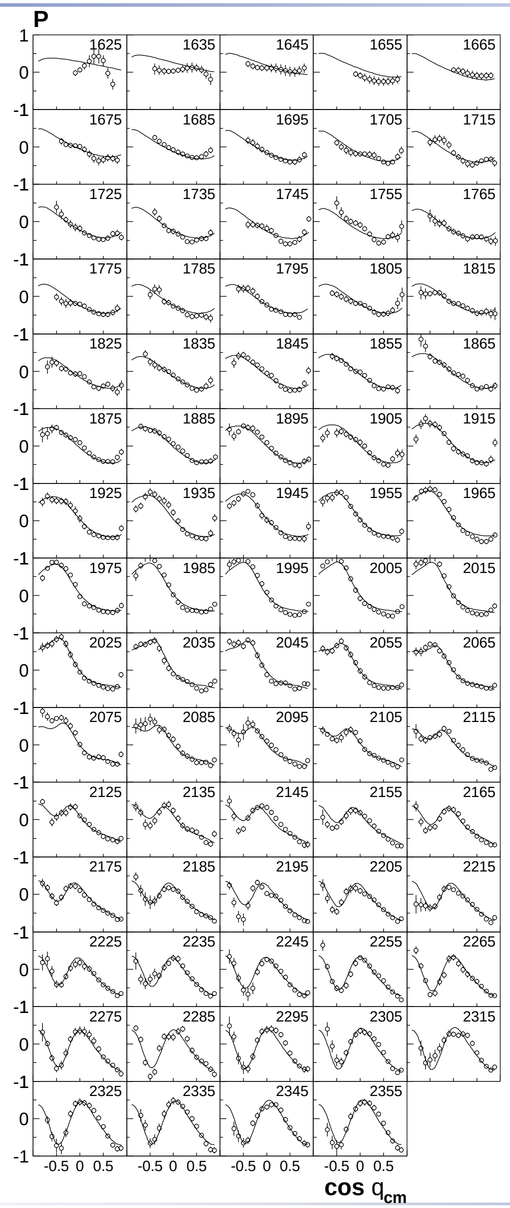
Polarization transfer C_x and C_z

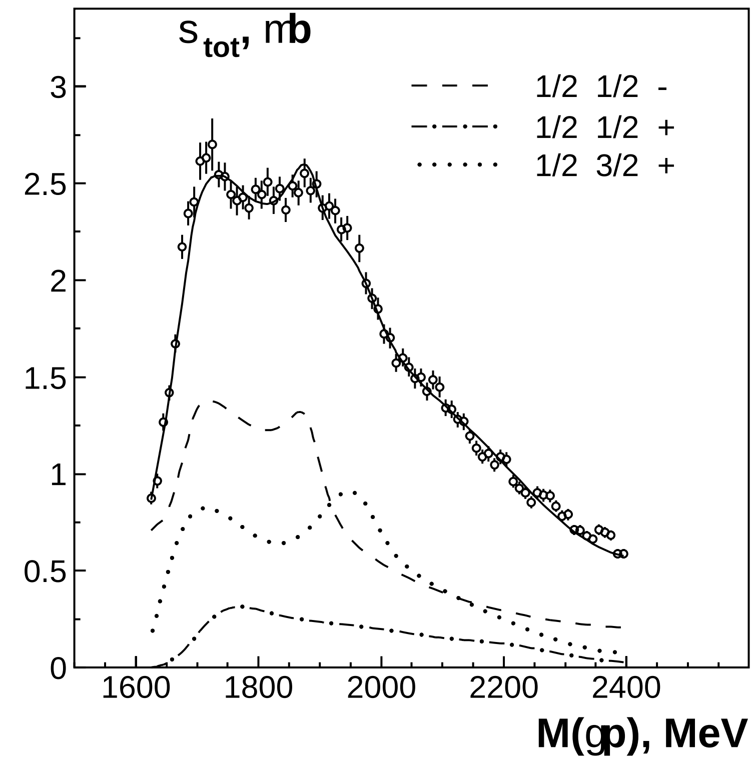


Fits: BnGa-Model, V. A. Nikonov et al., Phys. Lett. B 662, 245 (2008)

cross sections and *P*



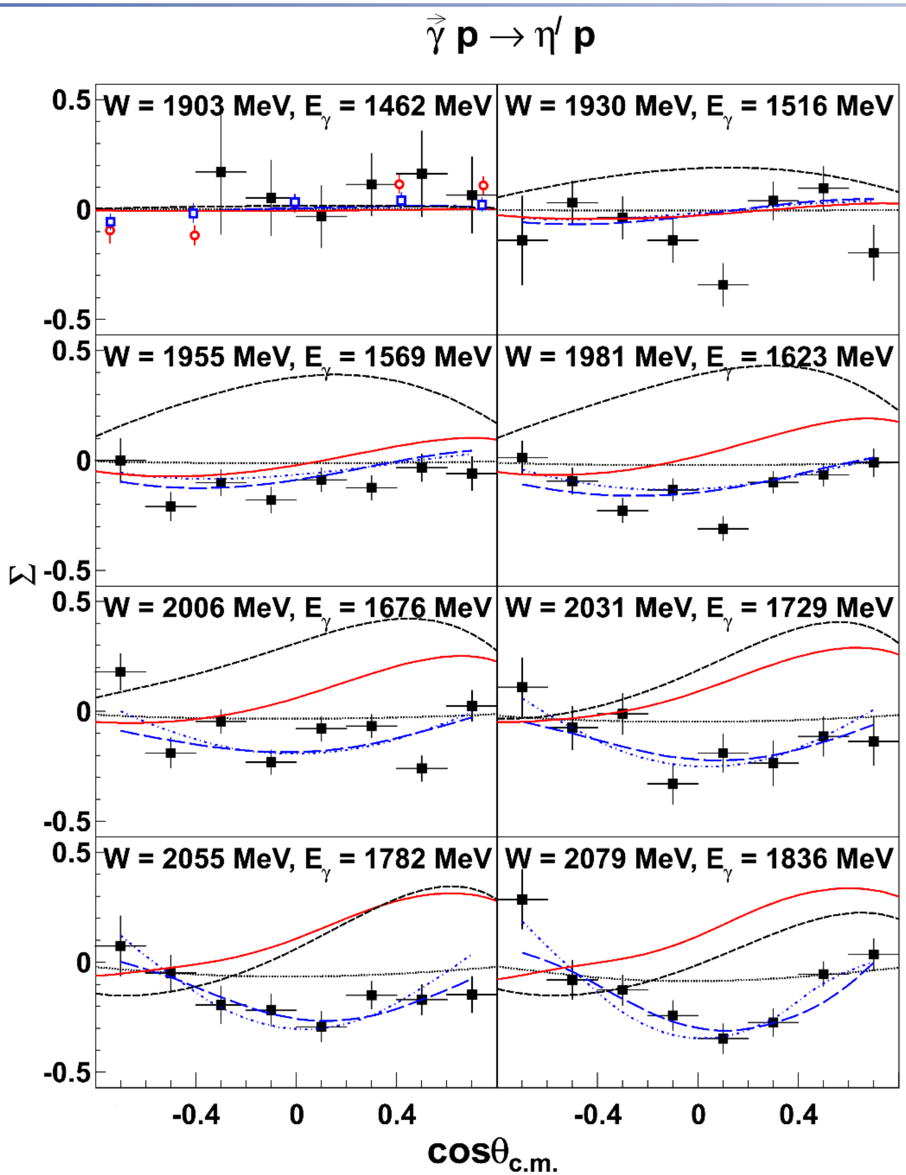




A.V. Anisovich *et al.* EPJ. A (2011) 47: 27

***N(1880)* 1/2+**
***N(1895)* 1/2-**
***N(1900)* 3/2+**

Latest η' photoproduction results

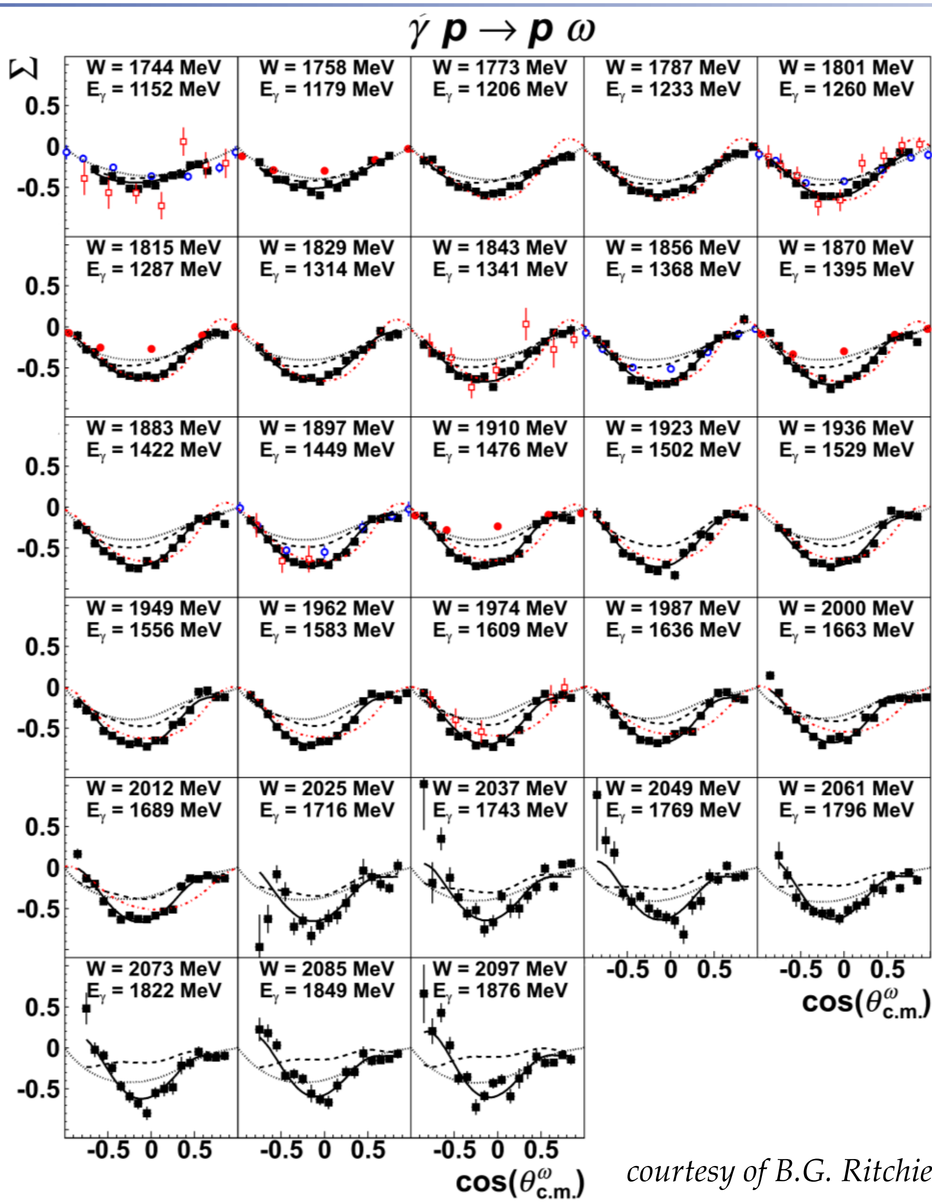


- ■ CLAS P. Collins *et al.*, Phys Lett B **771**, 213 (2017)
  - 62 points distributed over 8 *W* bins
- ○ GRAAL, 1.461 GeV
- □ GRAAL, 1.480 GeV

- Asymmetry is small
- SAID (black dotted line), ETA-MAID (red solid line), and NH (black dashed line) don't work so well.
- New fits with BnGa model work well
  - *N*(1900)3/2+ is important!
  - Statistically significant η' branches for *N*(1895)1/2$^-$, *N*(1900)3/2$^+$, *N*(2100)1/2$^+$, and *N*(2120)3/2$^-$

courtesy of B.G. Ritchie, ASU

Latest ω photoproduction results



courtesy of B.G. Ritchie, ASU

- ■ CLAS P. Collins *et al.*, just have been accepted to PLB **773**, 112 (2017)https://doi.org/10.1016/j.physletb.2017.08.015
  - 547 data points distributed over 28 *W* bins
- ○ GRAAL (2006)
- ● GRAAL (2015)
- □ CB-ELSA/TAPS (2015)

- BnGa fit with (black solid line) and without (black dashed line) incorporating these new data
- Close to threshold the process is dominated by $3/2^+$ and $5/2^+$ partial waves associated with $N(1720)3/2^+$ and $N(1680)5/2^+$

$\gamma d \rightarrow \pi^- p(p)$ cross sections

Need measurements for both proton and neutron targets to disentangle different isospin contributions
(neutron measurements sorely lacking)

CLAS "g13" experiment: $\gamma d \rightarrow \pi^- p(p)$

<u>8400 bins</u> *g13 triples world data base!*

$E\gamma$: [0.445 – 2.510 GeV]

$\cos\theta_\pi^{cm}$: [-0.72 – 0.92]

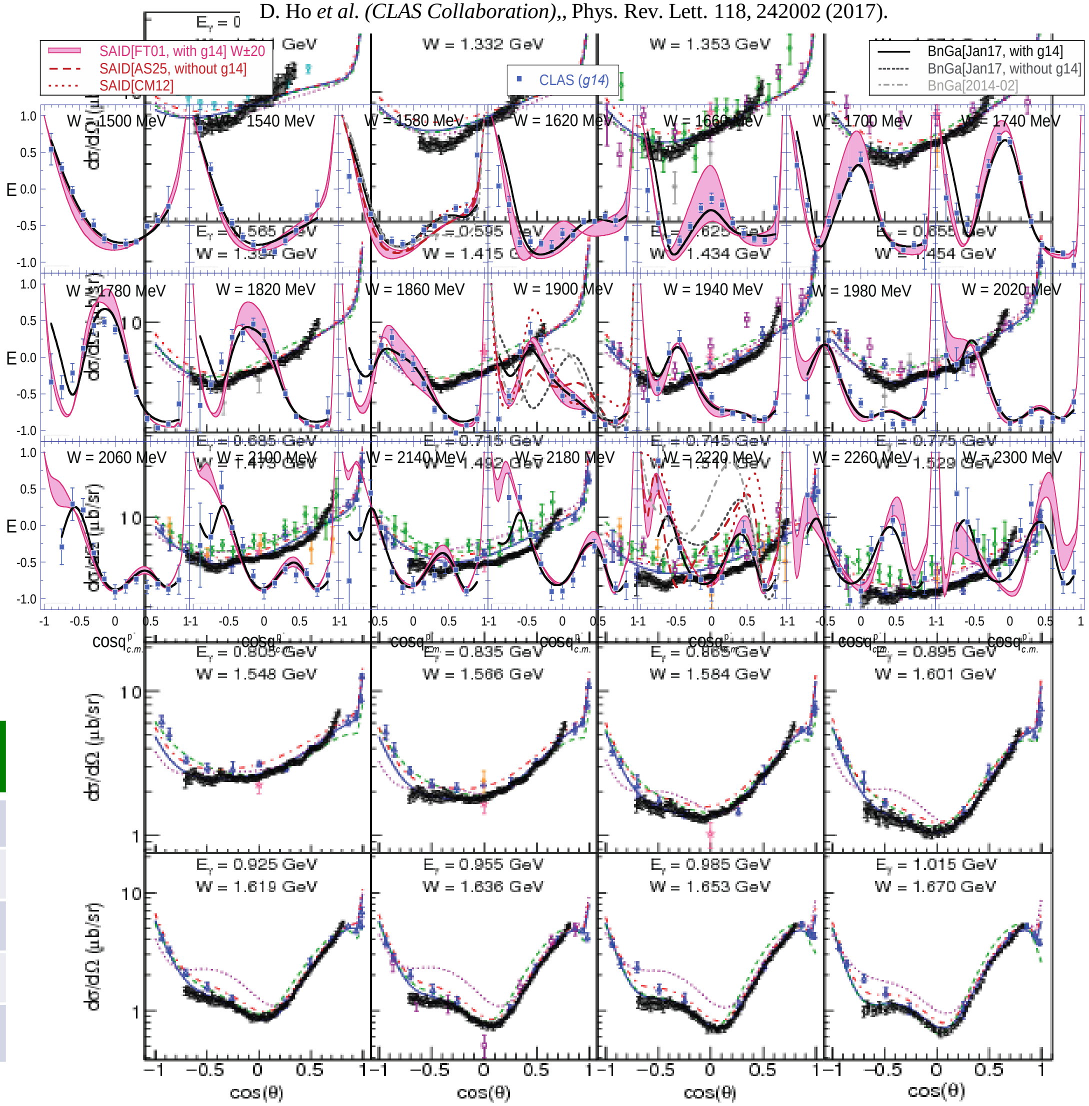
FSI corrections applied to extract γn from γd

This first determination of neutron couplings at the pole positions significantly improves the world data

amplitudes [GeV$^{-1/2}$]

Resonance	Coupling	SAID Fits Modulus, phase	PDG 2016 BW
N(1440)1/2$^+$	$A_{1/2}(n)$	0.065±0.005, 5º±3º	0.040±0.010
N(1535)1/2$^-$	$A_{1/2}(n)$	-0.055±0.005, 5º±2º	-0.075±0.020
N(1650)1/2$^-$	$A_{1/2}(n)$	0.014±0.002, -30º±10º	-0.050±0.020
N(1720)3/2$^+$	$A_{1/2}(n)$	-0.016±0.006, 10º±5º	-0.080±0.050
N(1720)3/2$^+$	$A_{3/2}(n)$	0.017±0.005, 90º±10º	-0.140±0.065

D. Ho *et al. (CLAS Collaboration)*,, Phys. Rev. Lett. 118, 242002 (2017).



P.T. Mattione et al. (CLAS Collaboration), arXiv:1706:01963, (2017) submitted to PRC

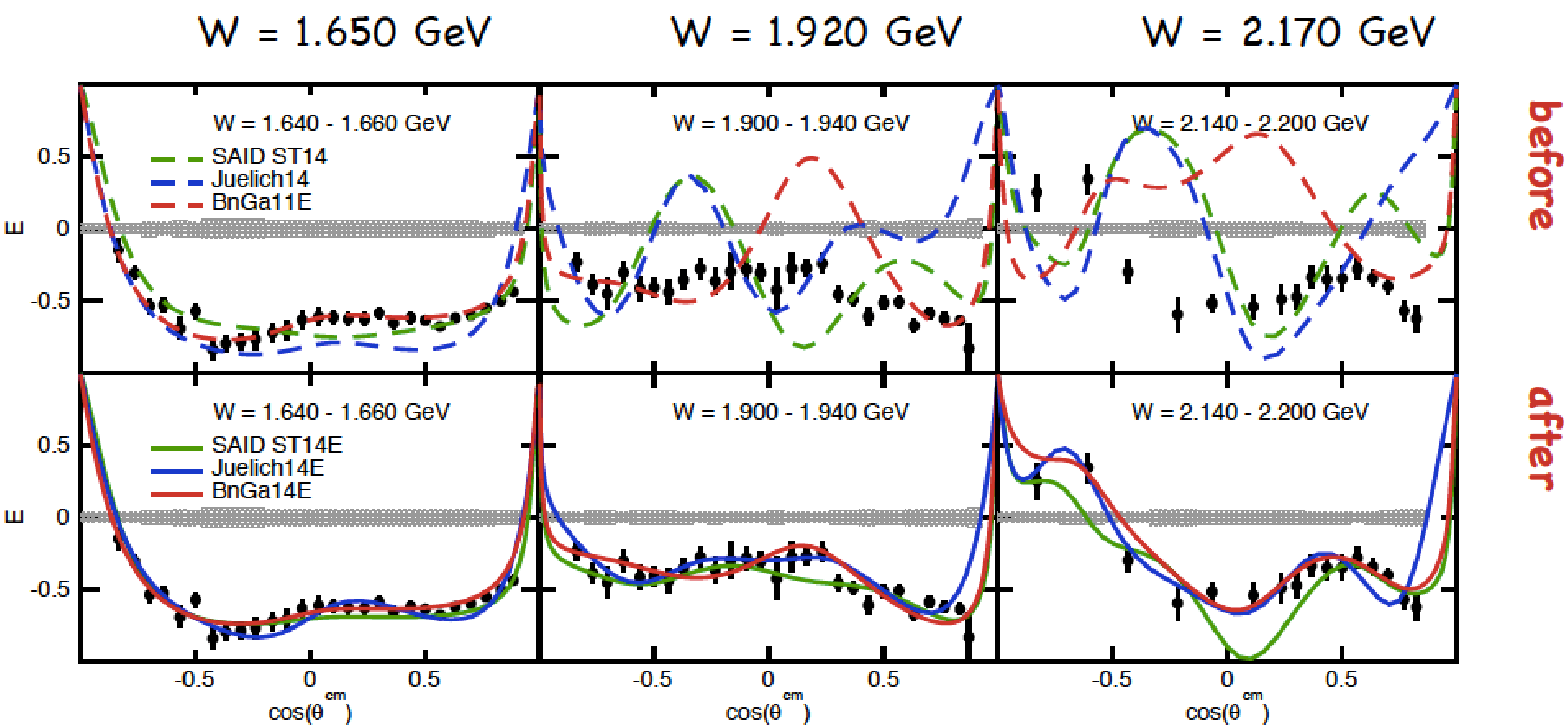
E asymmetry for $\gamma p \to n\pi^+$

$$\left(\frac{d\sigma}{d\Omega}\right) = \left(\frac{d\sigma}{d\Omega}\right)_0 \left(1 - P_z P_{\odot} E\right)$$

$W = 1240 - 2260$ MeV

$-0.9 \le \cos(\theta_\pi^{cm}) \le +0.9$

$$\vec{\gamma}\vec{p} \to \pi^+ n$$

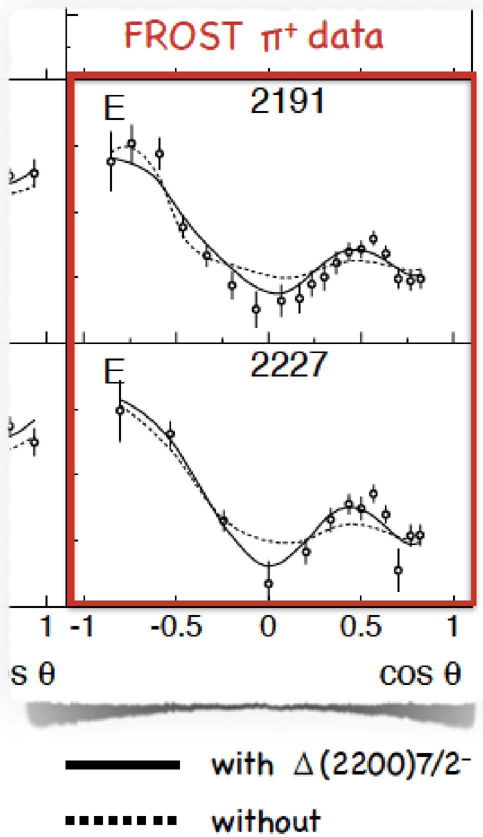


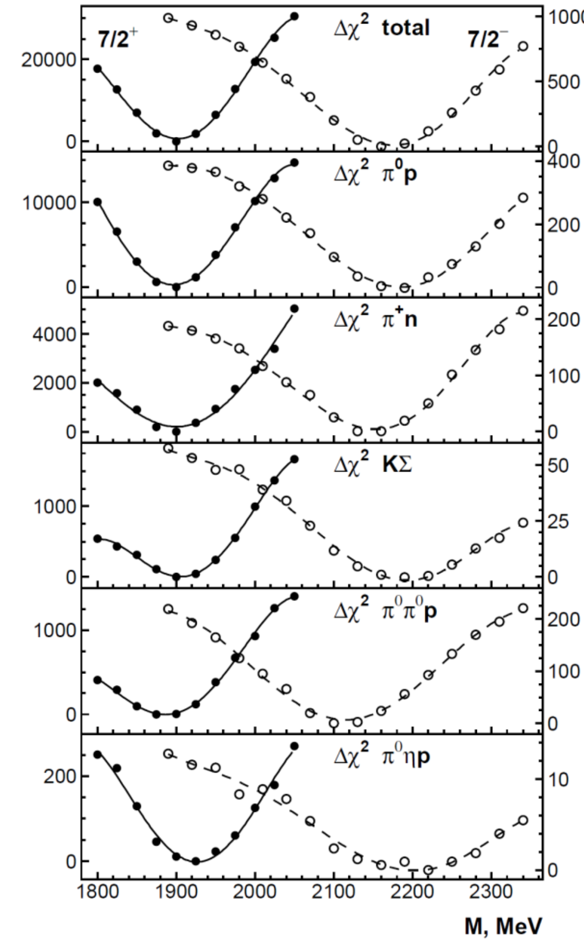
S. Strauch, et al., PLB 750 (2015) 53.

Δ(2200)7/2⁻

Parity partner of Δ(1950)7/2⁺ is poorly known

Δ(1950)7/2⁺ *****
Δ(2200)7/2⁻ *





Particle	J^P	year	Overall status	$N\gamma$	$N\pi$	$\Delta\pi$	ΣK	$N\rho$	$\Delta\eta$
Δ(2200)	$7/2^-$	1996	*		*				—
		2018	***	***	**	***	**		

Pre-Summary I
N* PDG 2018 vs 1996

clas

Particle	J^P	year	Overall status	Status as seen in									
				$N\gamma$	$N\pi$	$\Delta\pi$	$N\sigma$	$N\eta$	ΛK	ΣK	$N\rho$	$N\omega$	$N\eta'$
N	$1/2^+$	1996	****										
		2018	****										
$N(1440)$	$1/2^+$	1996	****	***	***	***	—	*			*	—	—
		2018	****	****	****	****							
$N(1520)$	$3/2^-$	1996	****	****	****	****	—	*			****	—	—
		2018	****	****	****	****	**	****					
$N(1535)$	$1/2^-$	1996	****	***	****	*	—	****			**	—	—
		2018	****	****	****	***	*	****					
$N(1650)$	$1/2^-$	1996	****	***	****	***	—	*	***	**	**	—	—
		2018	****	****	****	***	*	****	*				
$N(1675)$	$5/2^-$	1996	****	***	****	****	—	*	*		*	—	—
		2018	****	****	****	****	***	****	*	*			
$N(1680)$	$5/2^+$	1996	****	****	****	****	—				****	—	—
		2018	****	****	****	****	***	****	*	*			
$N(1700)$	$3/2^-$	1996	***	**	***	**	—	*	**	*	*	—	—
		2018	***	**	***	***	*	*			*		
$N(1710)$	$1/2^+$	1996	***	***	***	**	—	**	**	*	*	—	—
		2018	****	****	****	*		***	**	*	*	*	
$N(1720)$	$3/2^+$	1996	****	**	****	*	—	*	**	*	**	—	—
		2018	****	****	****	***	*	*	****	*	*	*	
$N(1860)$	$5/2^+$	1996	—	—	—	—	—	—	—	—	—	—	—
		2018	**	*	**		*	*					
$N(1875)$	$3/2^-$	1996	—	—	—	—	—	—	—	—	—	—	—
		2018	***	**	**	*	**	*	*	*	*	*	
$N(1880)$	$1/2^+$	1996	—	—	—	—	—	—	—	—	—	—	—
		2018	***	**	*	**	**	*	**	**		**	
$N(1895)$	$1/2^-$	1996	—	—	—	—	—	—	—	—	—	—	—
		2018	****	****	*	*	*	****	**	**	*	**	****
$N(1900)$	$3/2^+$	1996	**		**		—				**	—	—
		2018	****	****	**	**	*	*	**	**		*	**
$N(1900)$	$7/2^+$	1996	**	*	**		—	*	*	*		—	—
		2018	**	**	**			*	*	*			
$N(2000)$	$5/2^+$	1996	**		**	*	—	*	*	*	**	—	—
		2018	**	**	*	**	*	*				*	
$N(2040)$	$3/2^+$	1996	—	—	—	—	—	—	—	—	—	—	—
		2018	*	*									
$N(2060)$	$5/2^+$	1996	—	—	—	—	—	—	—	—	—	—	—
		2018	***	***	**	*	*	*	*	*	*	*	
$N(2080)$	$3/2^-$	1996	**	*	**		—	*	*			—	—
		2018	—	—	—	—	—	—	—	—	—	—	—
$N(2090)$	$1/2^-$	1996	*		*		—					—	—
		2018	—	—	—	—	—	—	—	—	—	—	—

Particle	J^P	year	Overall status	Status as seen in									
				$N\gamma$	$N\pi$	$\Delta\pi$	$N\sigma$	$N\eta$	ΛK	ΣK	$N\rho$	$N\omega$	$N\eta'$
$N(2100)$	$1/2^+$	1996	**		**	*	—	*	*	*	**	—	—
		2018	**	**	*	**	*	*				*	
$N(2120)$	$3/2^-$	1996	—	—	—	—	—	—	—	—	—	—	—
		2018	***	***	**	**	**		**	*		*	*
$N(2190)$	$7/2^-$	1996	****	*	****		—	*	*	*	**	—	—
		2018	****	****	****	****	**	*	**	*	*	*	
$N(2200)$	$5/2^-$	1996	**		**		—	*	*			—	—
		2018	—	—	—	—	—	—	—	—	—	—	—
$N(2220)$	$9/2^+$	1996	****		****		—	*				—	—
		2018	****	**	****			*	*	*			
$N(2250)$	$9/2^-$	1996	****		****		—	*				—	—
		2018	****	**	****			*	*	*			
$N(2300)$	$1/2^+$	1996	—	—	—	—	—	—	—	—	—	—	—
		2018	**		**								
$N(2570)$	$5/2^-$	1996	—	—	—	—	—	—	—	—	—	—	—
		2018	**		**								
$N(2600)$	$11/2^-$	1996	***		***		—					—	—
		2018	***		***		—					—	—
$N(2700)$	$13/2^+$	1996	**		**		—					—	—
		2018	**		**							—	—

- Only 3 states remained untouched. On of them is nucleon itself.
- 9 new states added
- 3 taken out
- 3 new decay modes added

N* 22-3+9=28

Pre-Summary II
Δ PDG 2018 vs 1996

No new Δ states have been added but quite a few of them has changed their status.

Particle	J^P	year	Overall status	Status as seen in $N\gamma$	$N\pi$	$\Delta\pi$	ΣK	$N\rho$	$\Delta\eta$
Δ(1232)	$3/2^+$	1996	****	****	****				—
		2018	****	****	****				
Δ(1600)	$3/2^+$	1996	***	**	***	***		*	—
		2018	****	****	***	****			
Δ(1620)	$1/2^-$	1996	****	***	****	****		****	—
		2018	****	****	****	****			
Δ(1700)	$3/2^-$	1996	****	***	****	***	*	**	—
		2018	****	****	****	****	*	*	
Δ(1750)	$1/2^+$	1996	*		*				—
		2018	*	*	*		*		
Δ(1900)	$1/2^-$	1996	***	*	***	*	*	**	—
		2018	***	***	***	*	**	*	
Δ(1905)	$5/2^+$	1996	****	***	****	**	*	**	—
		2018	****	****	****	**	*	*	**
Δ(1910)	$1/2^+$	1996	****	*	****	*	*	*	—
		2018	****	***	****	**	**		*
Δ(1920)	$3/2^+$	1996	***	*	***	**	*		—
		2018	***	***	***	***	**		**
Δ(1930)	$5/2^-$	1996	***	**	***		*		—
		2018	***	***	***	*	*		
Δ(1940)	$3/2^-$	1996	*		*				—
		2018	**	*	**	*			*
Δ(1950)	$7/2^+$	1996	****	****	****	****	*	*	—
		2018	**	****	****	**	***		
Δ(2000)	$5/2^+$	1996	**					**	—
		2018	**	*	**	*		*	
Δ(2150)	$1/2^-$	1996	*		*				—
		2018	*		*				
Δ(2200)	$7/2^-$	1996	*		*				—
		2018	***	***	**	***	**		
Δ(2300)	$9/2^+$	1996	**		**				—
		2018	**		**				
Δ(2350)	$5/2^-$	1996	*		*				—
		2018	*		*				
Δ(2390)	$7/2^+$	1996	*		*				—
		2018	*		*				
Δ(2400)	$9/2^-$	1996	**		**				—
		2018	**	**	**				
Δ(2420)	$11/2^+$	1996	****		****				—
		2018	****	*	****				
Δ(2750)	$13/2^-$	1996	**		**				—
		2018	**		**				
Δ(2950)	$15/2^+$	1996	**		**				—
		2018	**		**				

Summary

"…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" (1982)

- The field of the N* physics is still very much alive!
- There is significant progress in N* physics over the last two decades.
- CLAS photoproduction experiments played major role in it.
- There is no redundant data. Any data are useful.
- Precision and consistency of the experimental data is of critical importance.
- More interesting data are on the way for strange and non-strange meson production both on proton and deuteron targets.