Recent Results from the CBELSA/TAPS Experiment off the Proton

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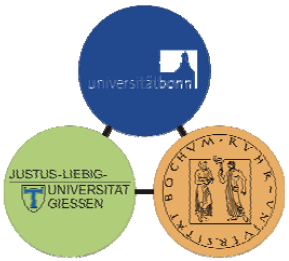
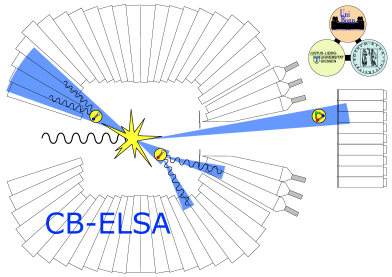
Universtät Bonn, Bonn, Germany

29 September - 1 October 2014
MesonNet 2014 Meeting (Frascati, Italy)



Supported by the DFG
within the SFB/TR16



Light Quark Baryon Spectroscopy

Pattern of Excited Baryons

- $\rightarrow$ the effective degrees of freedom of the nucleon
- $\rightarrow$ non-perturbative regime of QCD, bound states of QCD

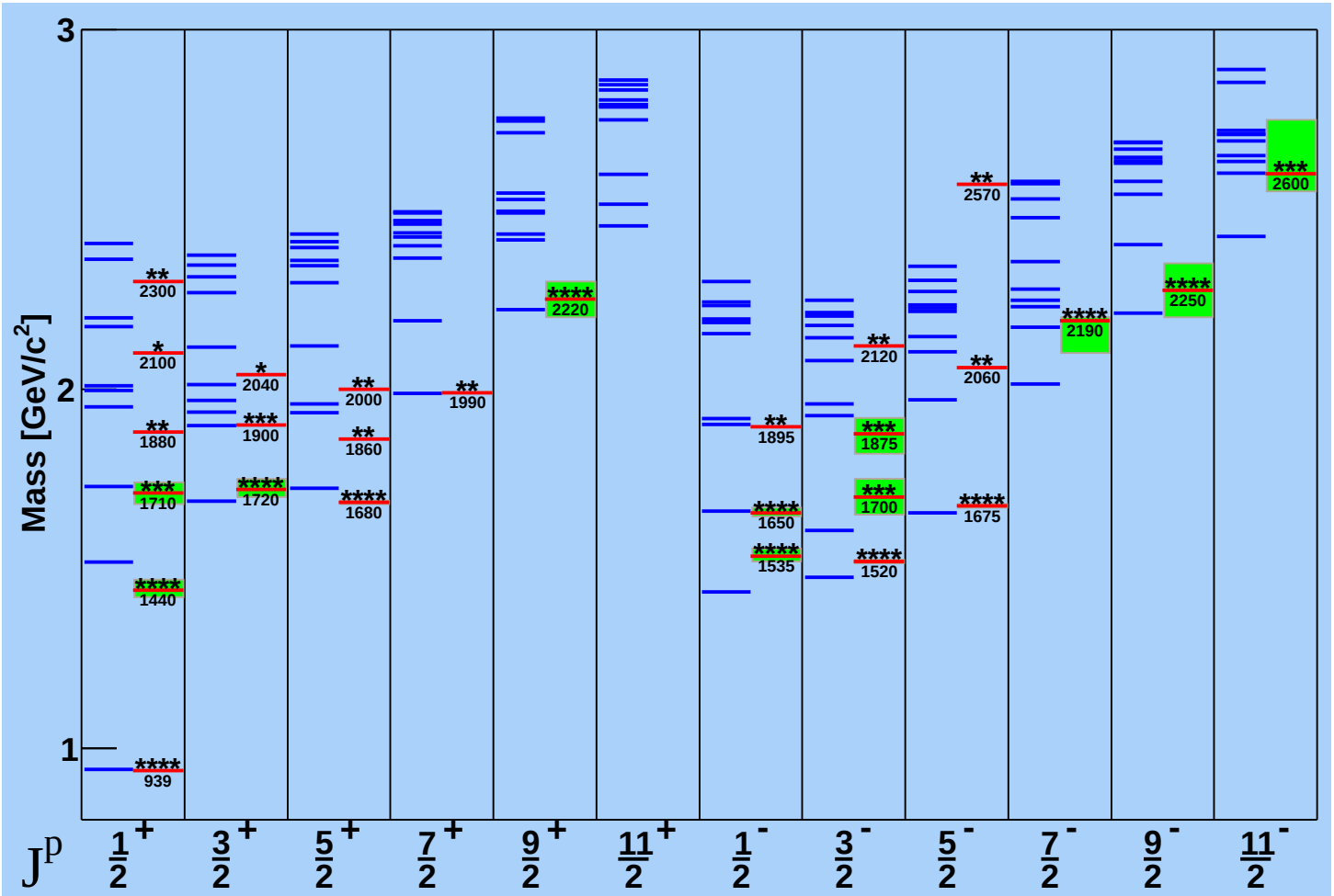
Theoretical Candidates

Solve the QCD Lagrangian? ... not yet $\rightarrow$ Lattice QCD

Must turn to models:
$\rightarrow$ Constituent Quark Models

Symmetric Constituent Quark Model

N^* Spectrum (Isospin=$\frac{1}{2}$, Strangeness = 0)



U. Loring, B. C. Metsch and H. R. Petry, Eur. Phys. J. A **10** (2001) 395.

Constituent Quarks + Confining Potential + residual interaction

Experimentally known states are those known as of 2013.

**** well-established resonance

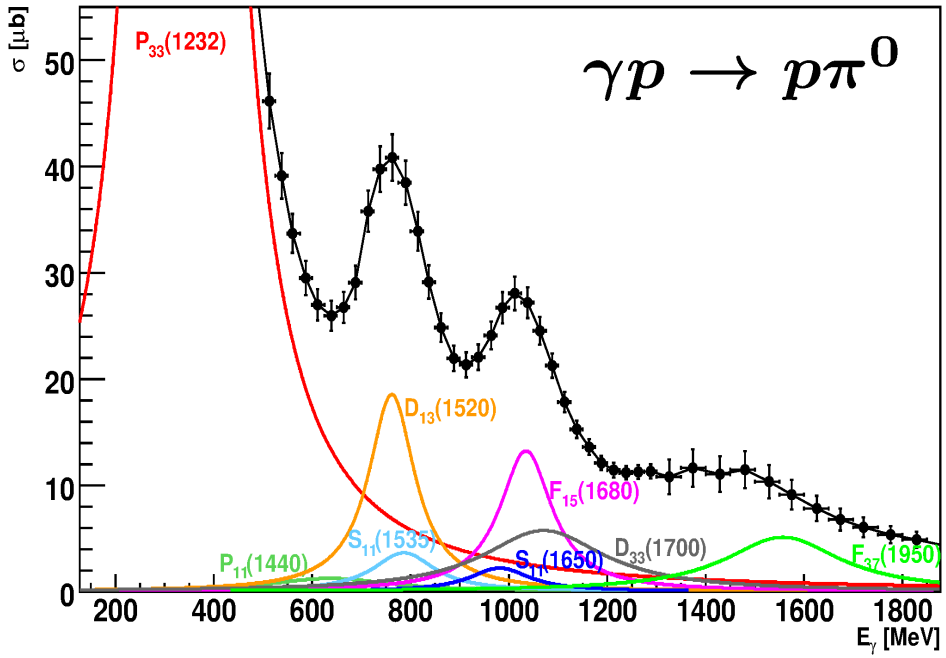
Similar Counting to Lattice QCD

R. G. Edwards, Phys. Rev. D **84** (2011) 074508.

Where are the high mass resonances?

How do we identify these resonances?

- Most known resonances from πN scattering
- Resonances do not couple to πN?
  $\rightarrow$ Photoproduction and a multitude of final states
- Broad and Overlapping Resonances
  - Differential Cross Sections with high resolution and full kinematic coverage
  - Polarization Observables $\rightarrow$ "complete" experiment



Polarization Observables

"Complete" Experiment

The spin-dependent amplitudes measured independently in all kinematic variables. (Up to a common phase)

Two-body Final State Polarization Observables

Pseudoscalar Meson and Nucleon in Final State

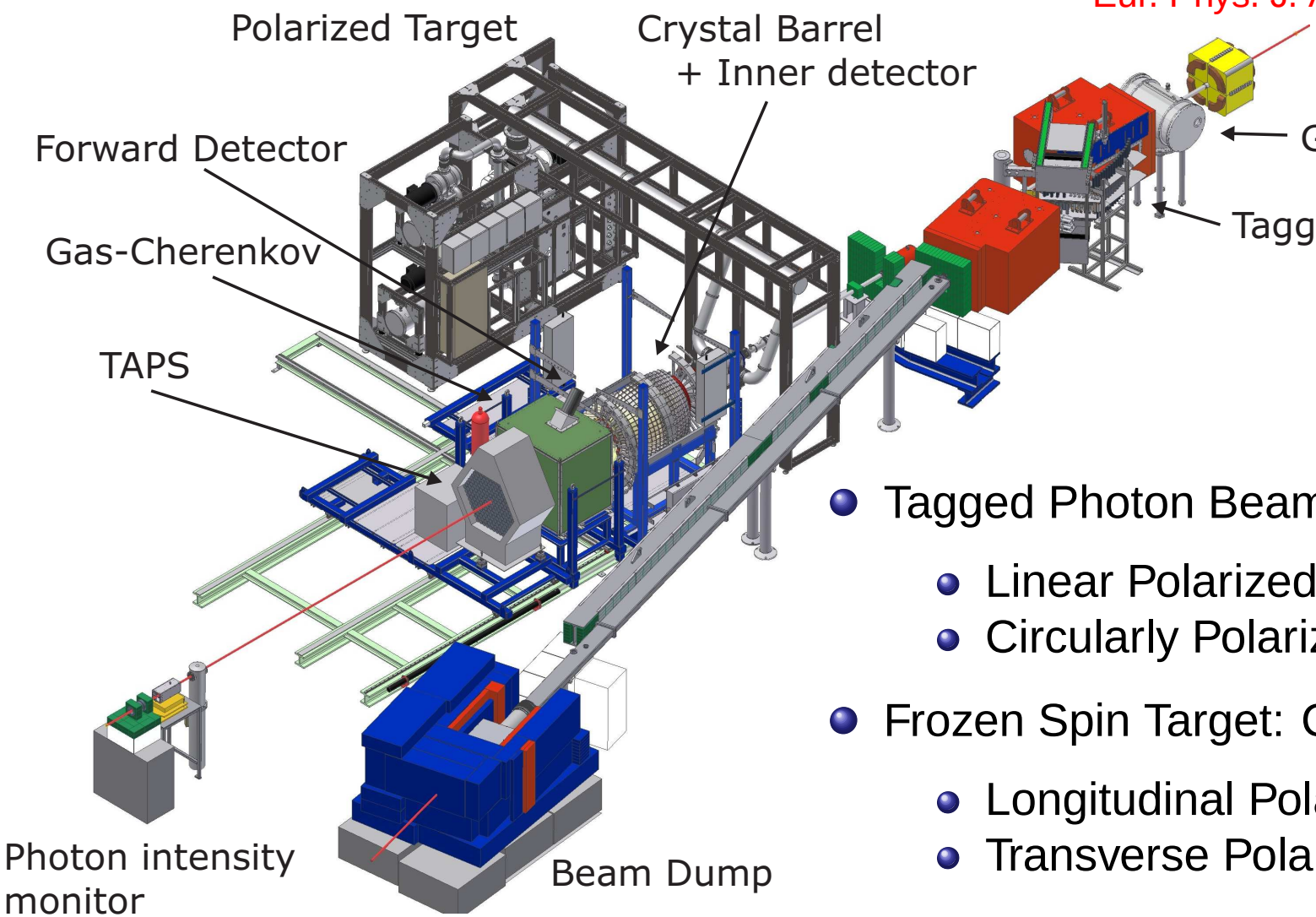
Photon Polarization		Target Polarization			Recoil Nucleon Polarization			Target and Recoil Polarization			
		X	Y	Z	X'	Y'	Z'	X X'	X Z'	Z X'	Z Z'
	σ	-	T	-	-	P	-	T_x	T_z	L_x	L_z
linear	Σ	H	$(-P)$	G	O_x	(-T)	O_z	$(-L_z)$	$(-L_x)$	$(-T_z)$	$(-T_x)$
circular	-	F	-	E	C_x	-	C_z	-	-	-	-

Single Polarization Observables Double Polarization Observables

CBELSA/TAPS Experiment at ELSA (Bonn)

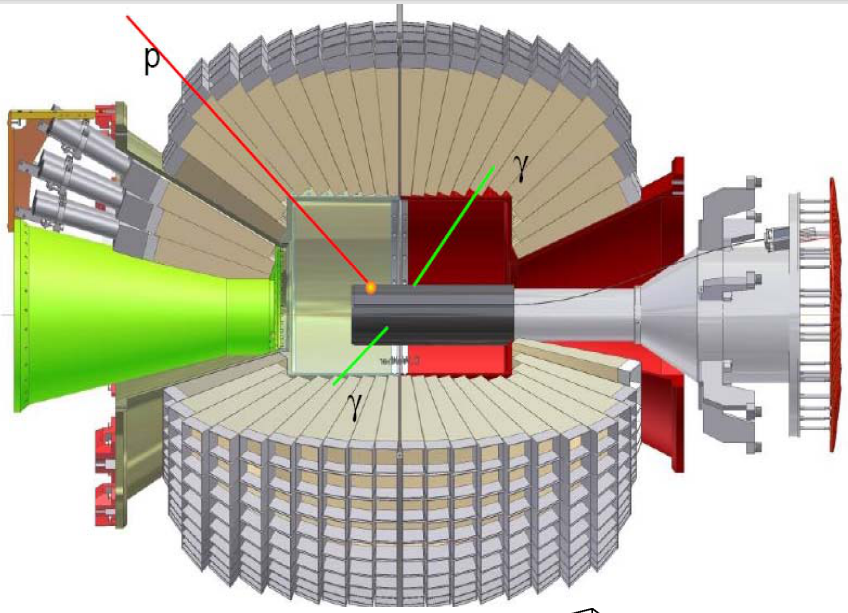
ELSA : W. Hillert,

Eur. Phys. J. A **28S1** (2006) 139.

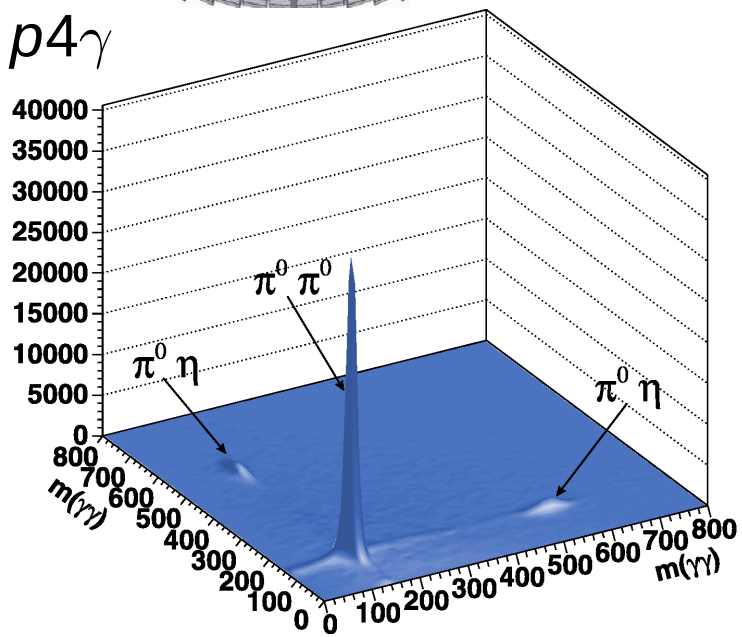


- Tagged Photon Beam($\leq$ 3.2 GeV)
  - Linear Polarized
  - Circularly Polarized
- Frozen Spin Target: C_4H_9OH Butanol
  - Longitudinal Polarization
  - Transverse Polarization

Detector Setup



$\gamma p \rightarrow p4\gamma$



Calorimeter Detectors

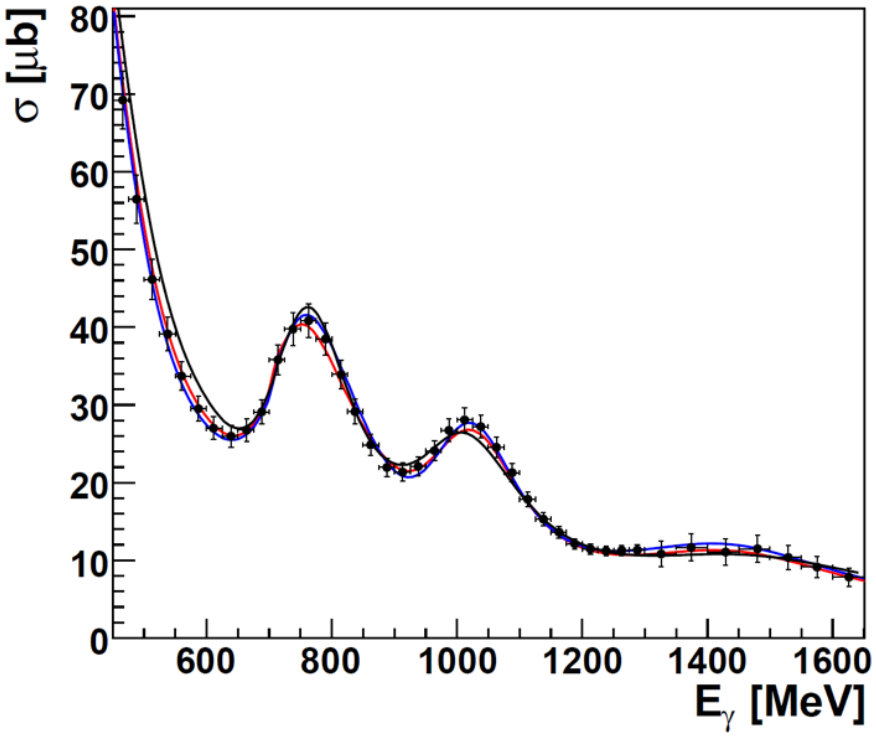
- Crystal Barrel
  (1230 CsI crystals) $30° - 157°$
- Forward Plug
  (90 CsI crystals) $12° - 30°$
- Mini-TAPS Detector
  (216 BaF_2 crystals) $1° - 12°$

Nearly 4π coverage

Optimized for detecting mesons decaying to photons.

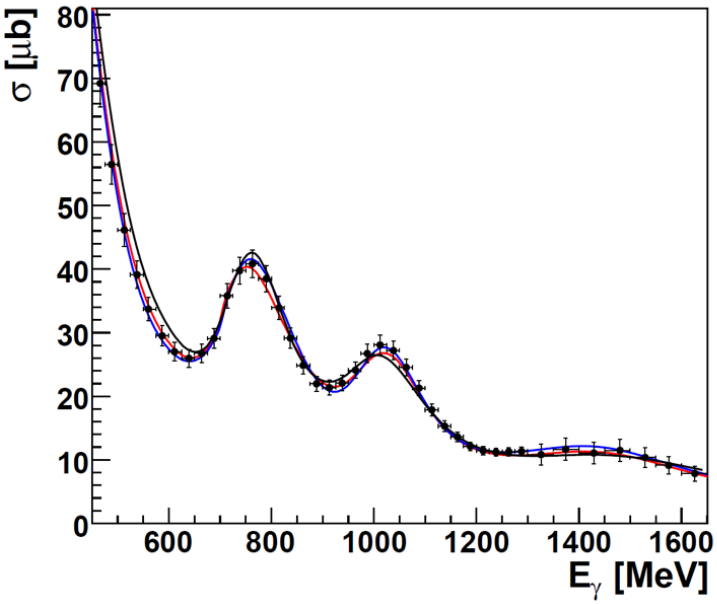
$\gamma p \rightarrow p\pi^0$

- π^0 - pseudoscalar meson (0^{-+})
- $M_{\pi^0} \approx 135$ MeV/c^2, $\pi^0 \rightarrow \gamma\gamma \approx 98\%$
- Differential Cross Sections well measured
- Contains πN coupling $\rightarrow$ should be understood through πN scattering.



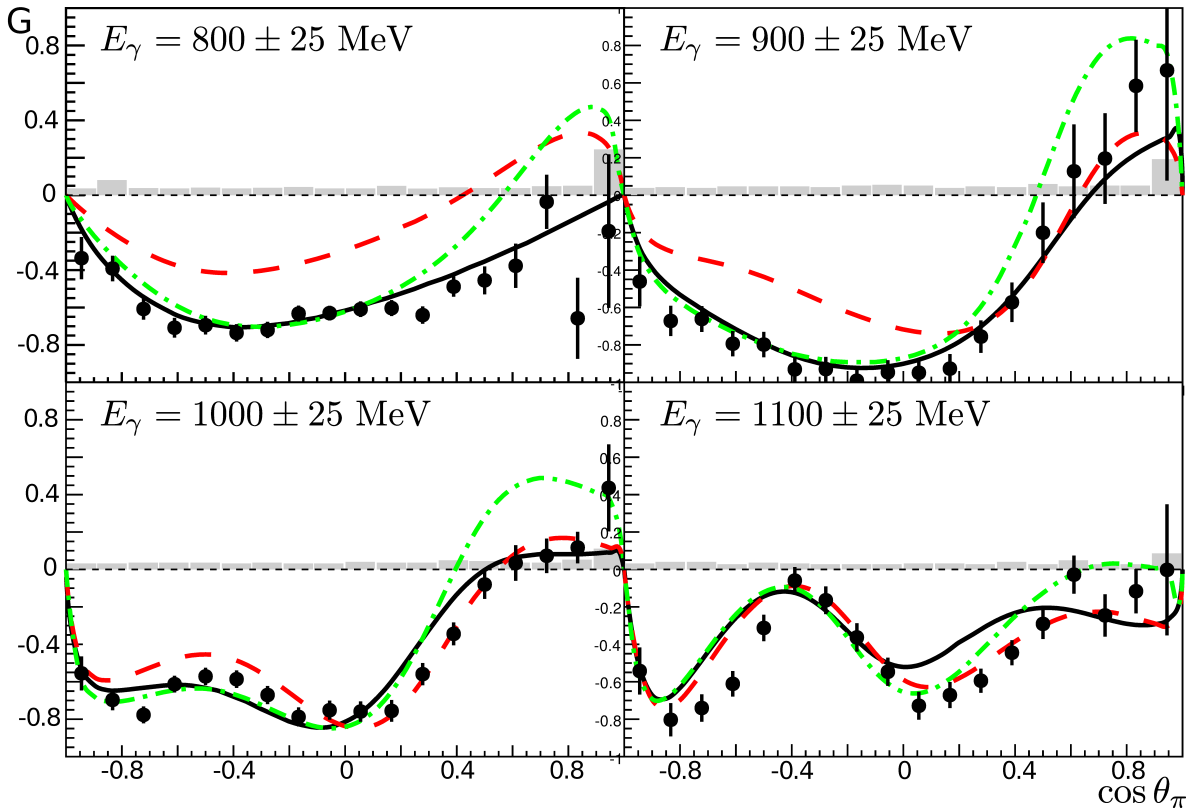
$\gamma p \rightarrow p\pi^0$: G

G - Linearly Polarized Photons, Longitudinally Polarized Protons



$$\frac{d\sigma}{d\Omega}(\Phi) = \left(\frac{d\sigma}{d\Omega}\right)_0 (1 - P_\gamma^{lin}\Sigma\cos(2\phi) + P_\gamma^{lin}P_z^{tar}G\sin(2\phi))$$

Bonn-Gatchina SAID(SN11, CM12)

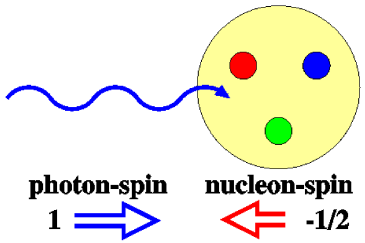


E_{0+} and E_{2-} Multipoles

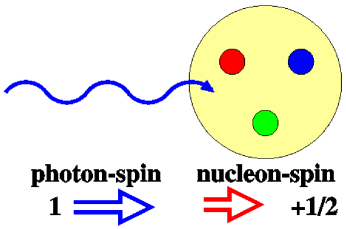
$\frac{1}{2}^-$, $\frac{3}{2}^-$ Partial Waves

A. Thiel, Phys. Rev. Lett. **109** (2012) 102001.

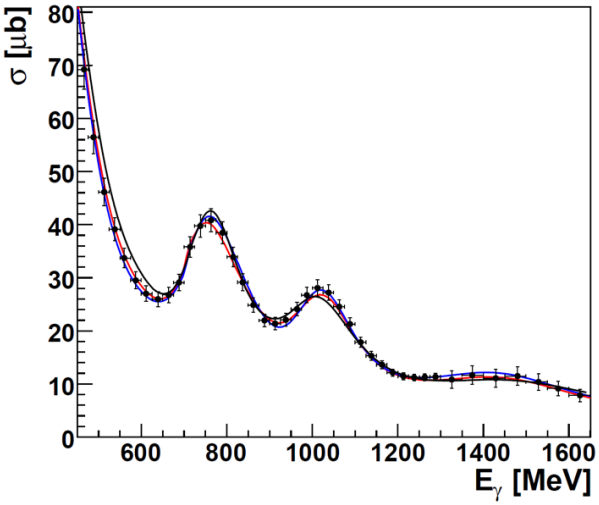
$\gamma p \rightarrow p\pi^0$: Helicity Asymmetry E



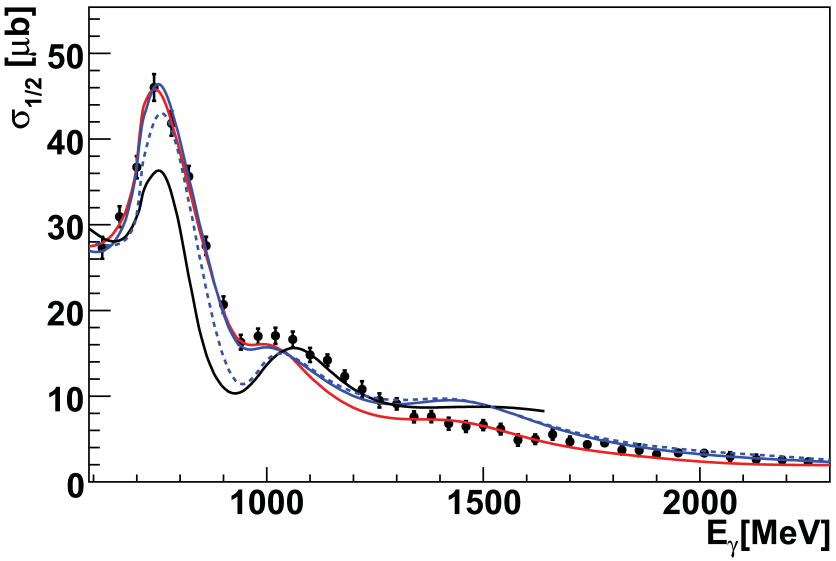
$\sigma_{1/2}$

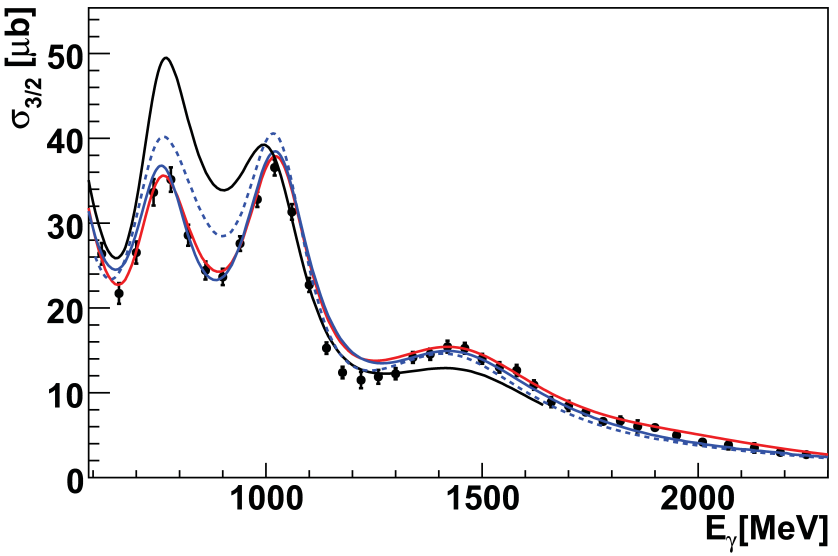


$\sigma_{3/2}$



BnGa(2011-02) SAID(CM12) MAID



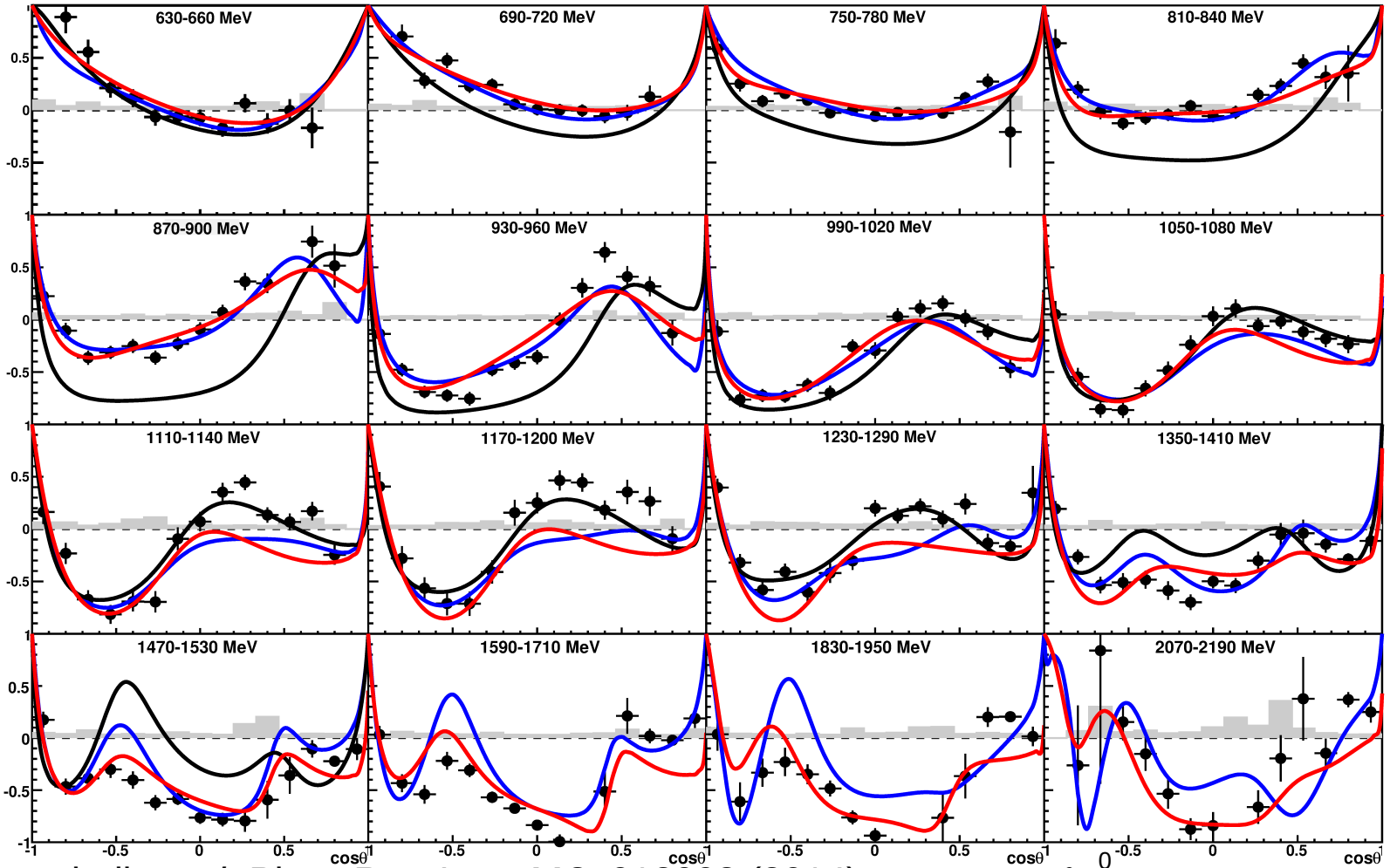


M. Gottschall, *et al.* Phys. Rev. Lett. **112**, 012003 (2014).

$\gamma p \to p\pi^0$: Helicity Asymmetry E

$$E = \frac{\left(\frac{d\sigma}{d\Omega}\right)_{1/2} - \left(\frac{d\sigma}{d\Omega}\right)_{3/2}}{\left(\frac{d\sigma}{d\Omega}\right)_{1/2} + \left(\frac{d\sigma}{d\Omega}\right)_{3/2}}$$

BnGa(2011-02) SAID(CM12) MAID



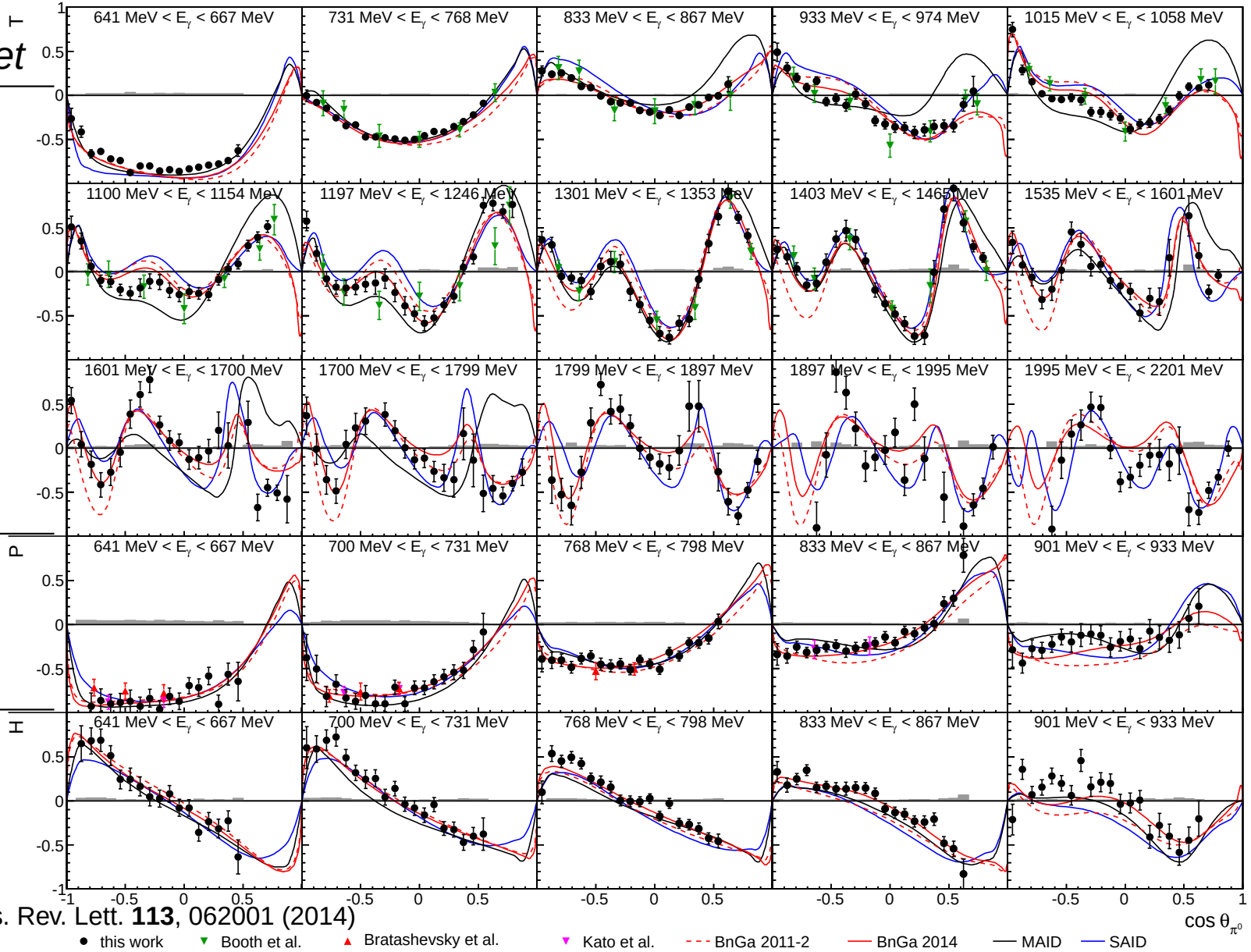
M. Gottschall, *et al.* Phys. Rev. Lett. **112**, 012003 (2014).

$\cos\theta^{\pi^0}_{c.m.}$

$\gamma p \to p\pi^0$: T, P, H

Polarization

Photon	*Target*
-	y
linear	x
linear	y

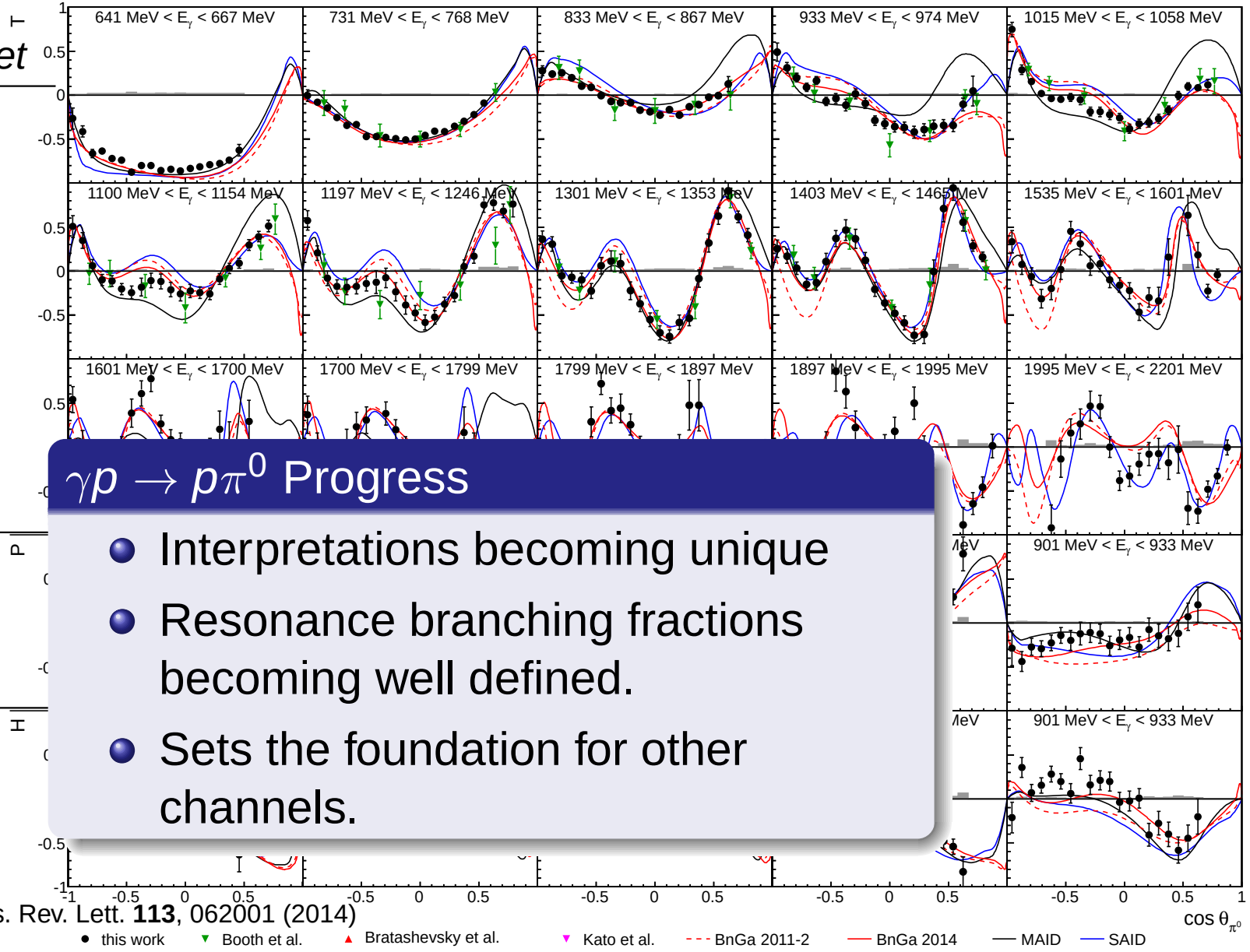


J. Hartmann *et al.*, Phys. Rev. Lett. **113**, 062001 (2014)

$\gamma p \rightarrow p\pi^0$: T, P, H

Polarization

Photon	*Target*
-	y
linear	x
linear	y



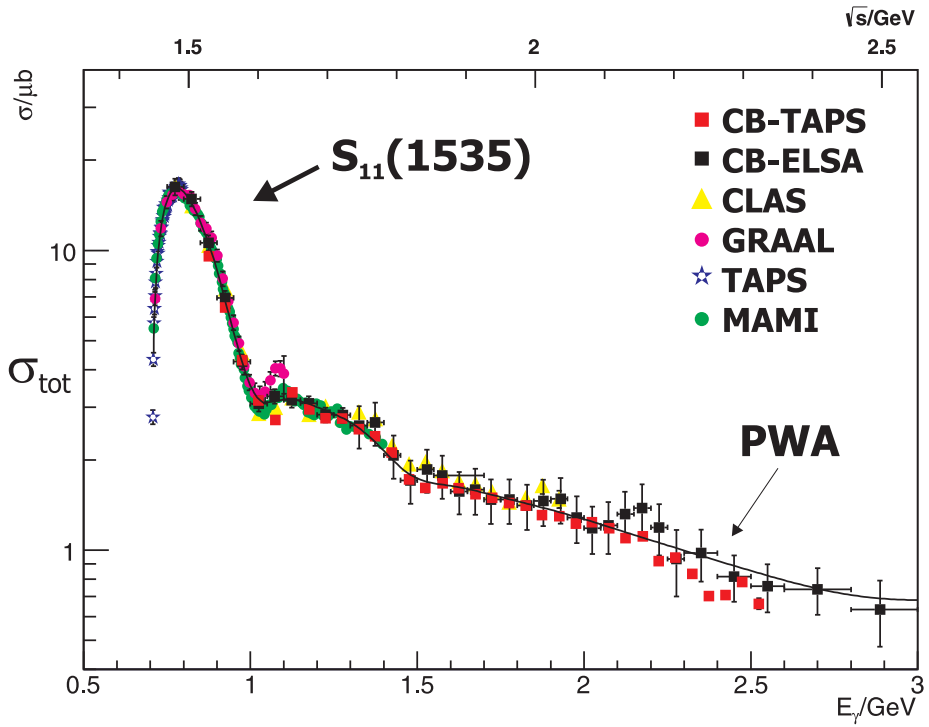
$\gamma p \rightarrow p\pi^0$ Progress

- Interpretations becoming unique
- Resonance branching fractions becoming well defined.
- Sets the foundation for other channels.

J. Hartmann *et al.*, Phys. Rev. Lett. **113**, 062001 (2014)

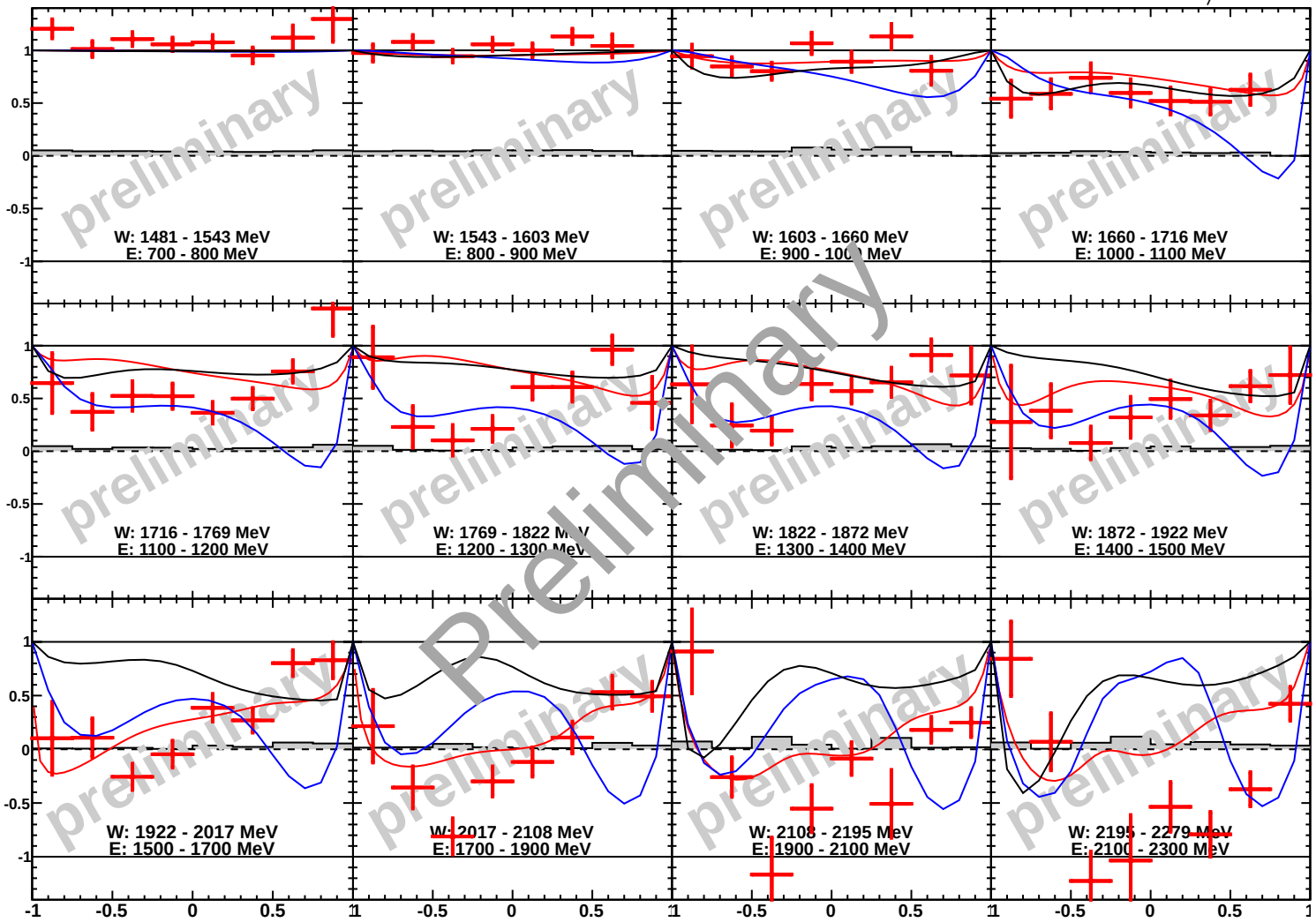
$\gamma p \rightarrow p\eta$

- η - pseudoscalar meson (0^{-+}), Isospin 0, Only N^*'s
- $M_\eta \approx 547.8$ MeV/c^2
- $\eta \rightarrow \gamma\gamma \approx 39.4\%$, $\eta \rightarrow 3\pi^0 \rightarrow 6\gamma \approx 32\%$
- Differential Cross Sections well measured.
- Resonances with large ηN coupling and very small πN coupling would not be seen in πN scattering.



$\gamma p \to p\eta$: Helicity Asymmetry E

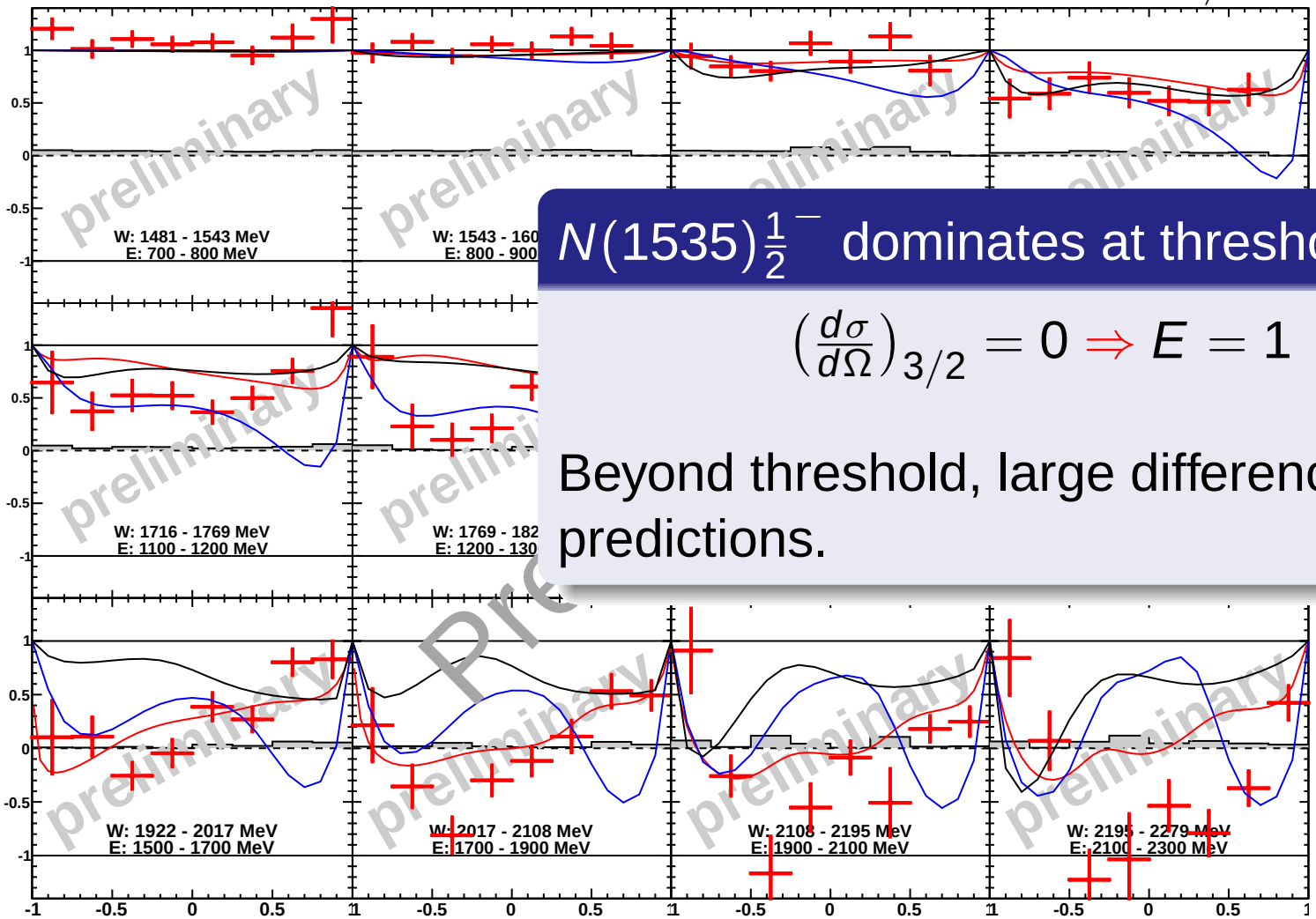
BnGa(2011-02) SAID(09) MAID $E = \frac{\left(\frac{d\sigma}{d\Omega}\right)_{1/2} - \left(\frac{d\sigma}{d\Omega}\right)_{3/2}}{\left(\frac{d\sigma}{d\Omega}\right)_{1/2} + \left(\frac{d\sigma}{d\Omega}\right)_{3/2}}$



Jonas Müller, *et al.* [CBELSA/TAPS] to be published.

$\gamma p \to p\eta$: Helicity Asymmetry E

BnGa(2011-02) SAID(09) MAID $E = \frac{\left(\frac{d\sigma}{d\Omega}\right)_{1/2} - \left(\frac{d\sigma}{d\Omega}\right)_{3/2}}{\left(\frac{d\sigma}{d\Omega}\right)_{1/2} + \left(\frac{d\sigma}{d\Omega}\right)_{3/2}}$



$N(1535)\frac{1}{2}^-$ dominates at threshold

$$\left(\frac{d\sigma}{d\Omega}\right)_{3/2} = 0 \Rightarrow E = 1$$

Beyond threshold, large differences from predictions.

Jonas Müller, *et al.* [CBELSA/TAPS] to be published.

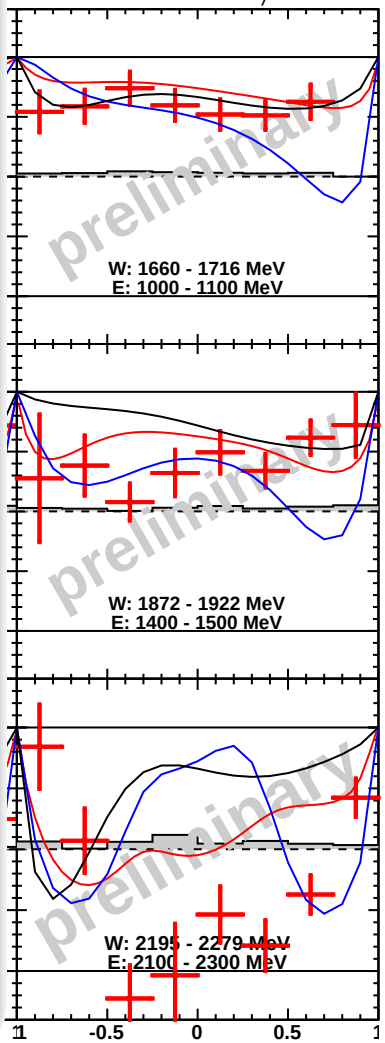
$\gamma p \to p\eta$: Helicity Asymmetry E

Single Psuedoscalar Meson Photoproduction

Polarization Observables currently being analyzed for:

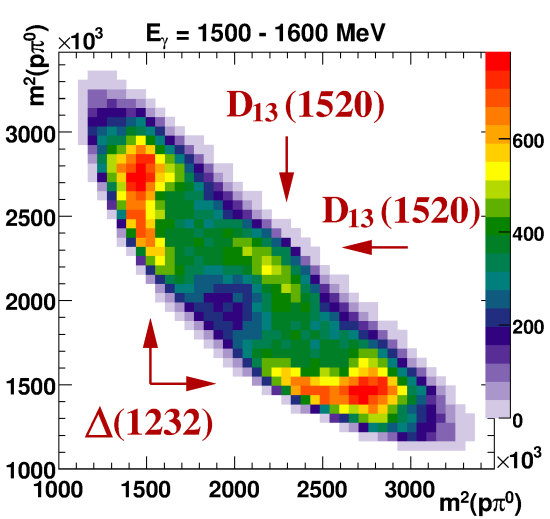
- $\gamma p \to p\pi^0$
  - Approaching Complete Experiment: PWA solutions becoming unique
- $\gamma p \to p\eta$
  - Others Close to Publish: T, P, H, G, Σ
  - Starting to see evidence of new higher mass states.
- $\gamma p \to p\eta'$
  - See Farah Noreen Afzal's Talk: Σ

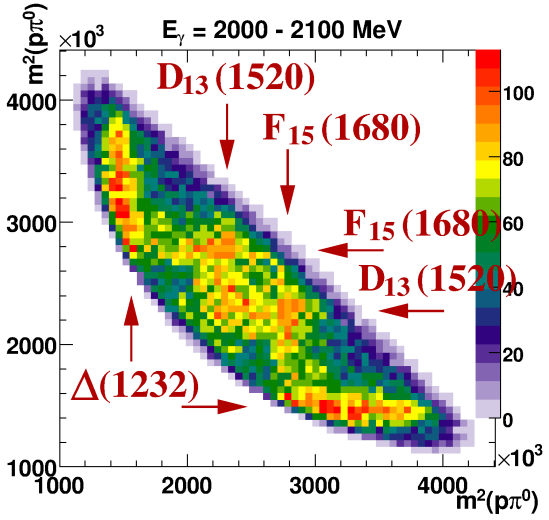
$$E = \frac{\left(\frac{d\sigma}{d\Omega}\right)_{1/2} - \left(\frac{d\sigma}{d\Omega}\right)_{3/2}}{\left(\frac{d\sigma}{d\Omega}\right)_{1/2} + \left(\frac{d\sigma}{d\Omega}\right)_{3/2}}$$

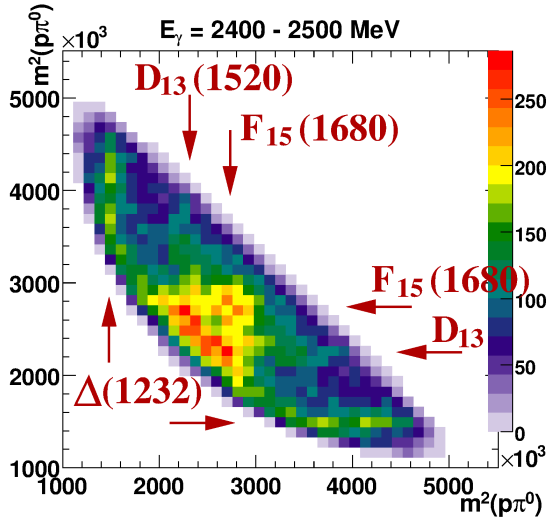


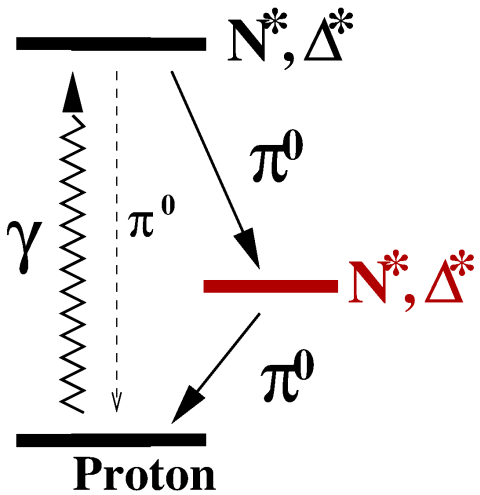
Jonas Müller, *et al.* [CBELSA/TAPS] to be published.

$\gamma p \rightarrow p\pi^0\pi^0$





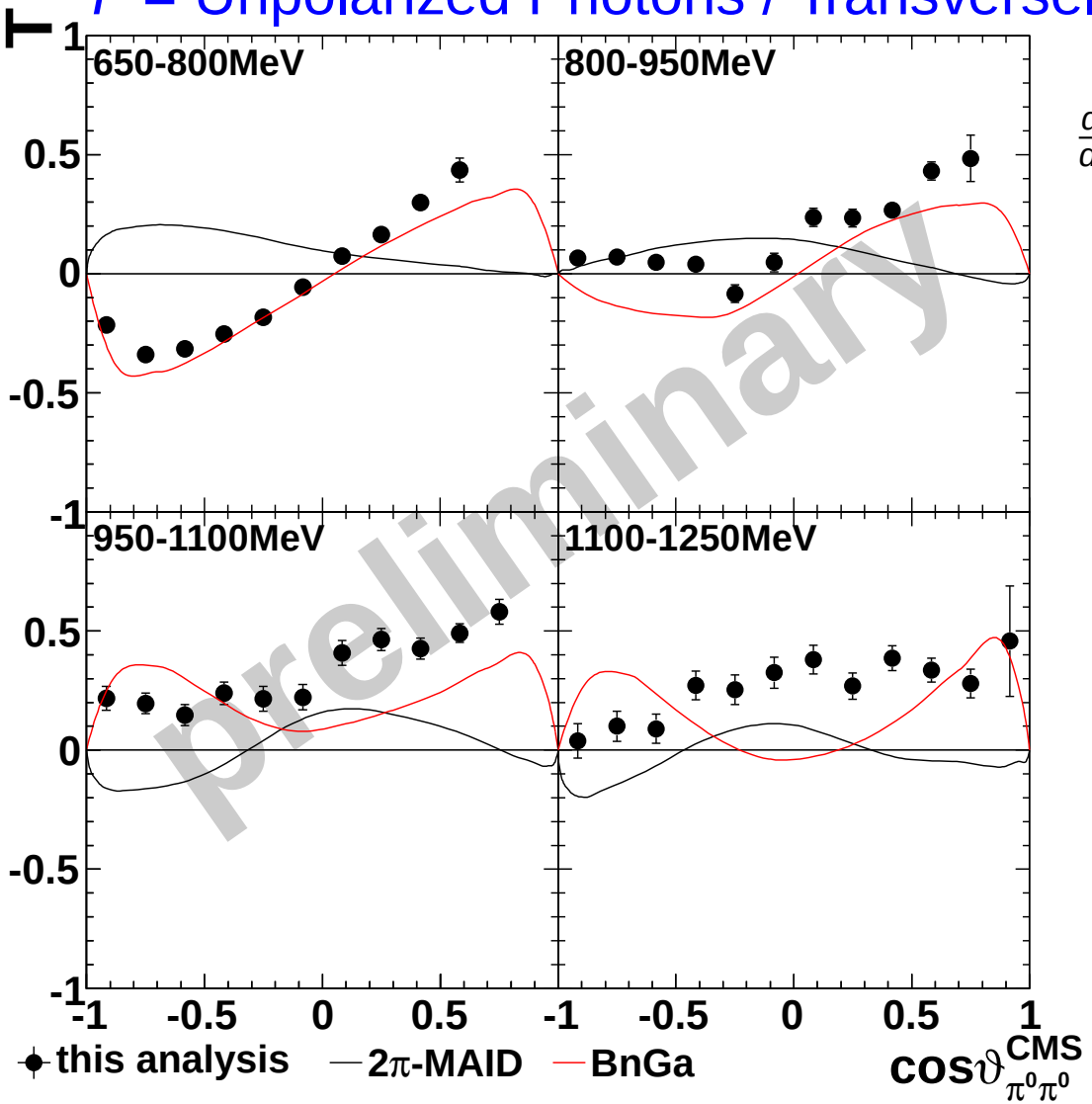




- Resonances can decay into $\Delta^*\pi^0$, $N^*\pi^0$, or $N\sigma$
- Rich environment to find resonances.
- Differential Cross Sections measured.

$\pi^0\pi^0$ Meson Photoproduction: T

T = Unpolarized Photons / Transversely Polarized Proton



$$\frac{d\sigma}{dX_i}(\Phi) = \left(\frac{d\sigma}{dX_i}\right)_0 (1 - P_y^{targ} T(\theta))$$

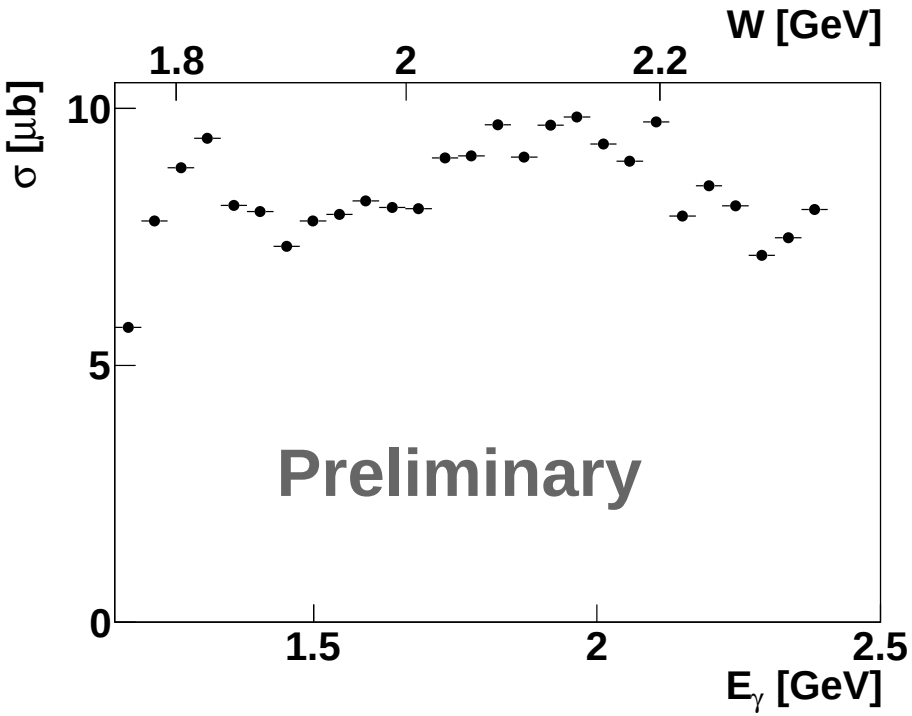
- Low Energy, Quasi two-body treatment
- Predictions do not match data
- Significant resolving power even at low E
- See:
  Karsten Spieker's Talk:
  Σ, G

Tobias Seifen, *et al.* [CBELSA/TAPS] to be published.

$\gamma p \rightarrow p\omega$

- ω - pseudo-vector meson (1^{--}), Isospin 0, Only N^*'s
- $M_\omega \approx 783$ MeV/c^2
- $\omega \rightarrow \pi^0\gamma \rightarrow 3\gamma \approx 8\%$
- Large contribution from non-resonant processes
- Predicted to be good final state for baryon resonances

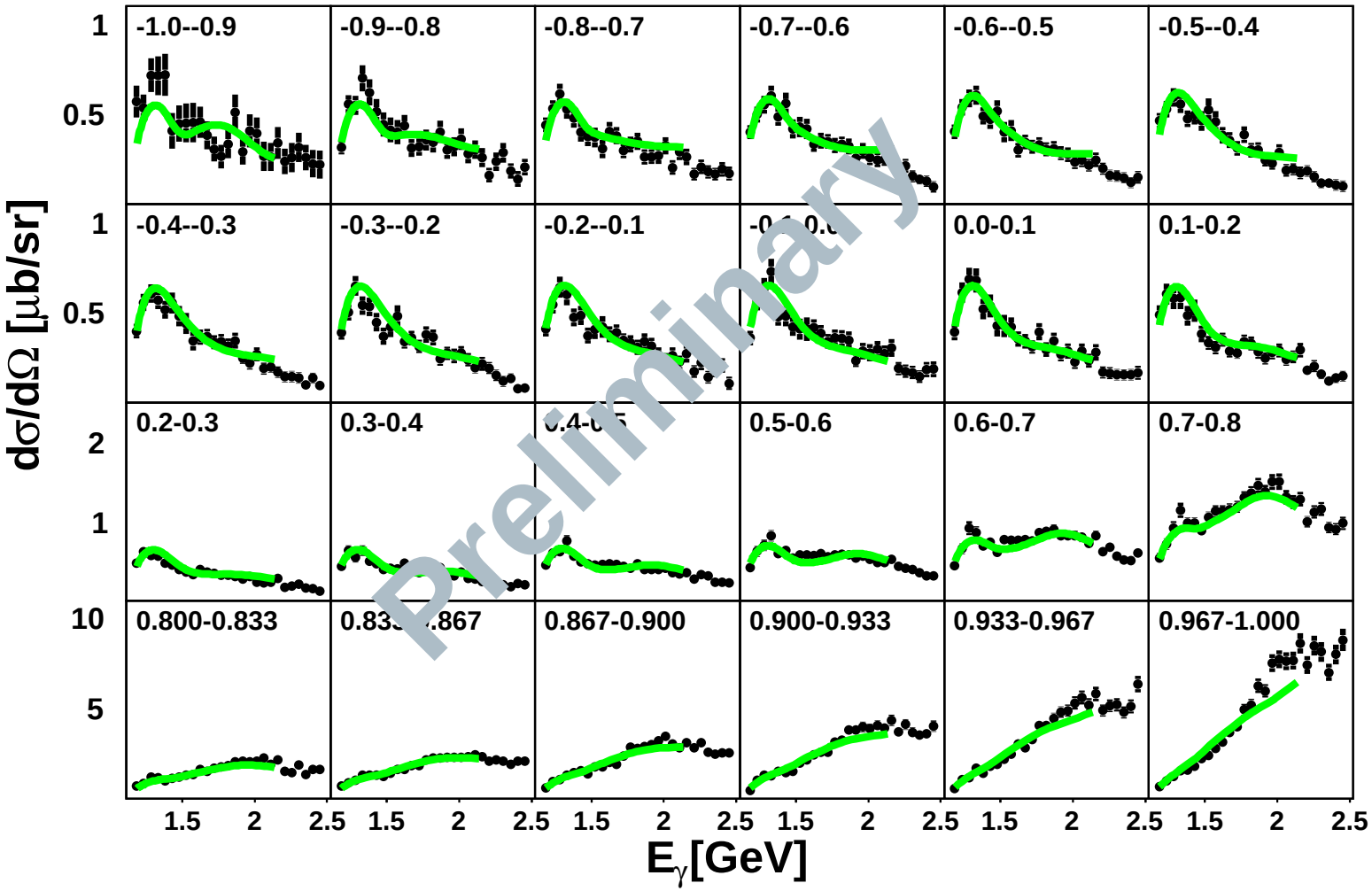
S. Capstick and W. Roberts, Phys. Rev. D **49** (1994) 4570.



A. Wilson, to be published soon.

Resonance peak at threshold

$\gamma p \rightarrow p\omega$ Differential Cross Sections



A. Wilson, *et al.* [CBELSA/TAPS] to be published

Slightly different experimental setup

$\gamma p \rightarrow p\omega$ Spin Density Matrix Elements

ω polarization $\rightarrow \pi^0\gamma$ angular distributions

Polarization Observables

Spin Density Matrix Elements

superscript: γ_i polarization type

subscript: ω polarization

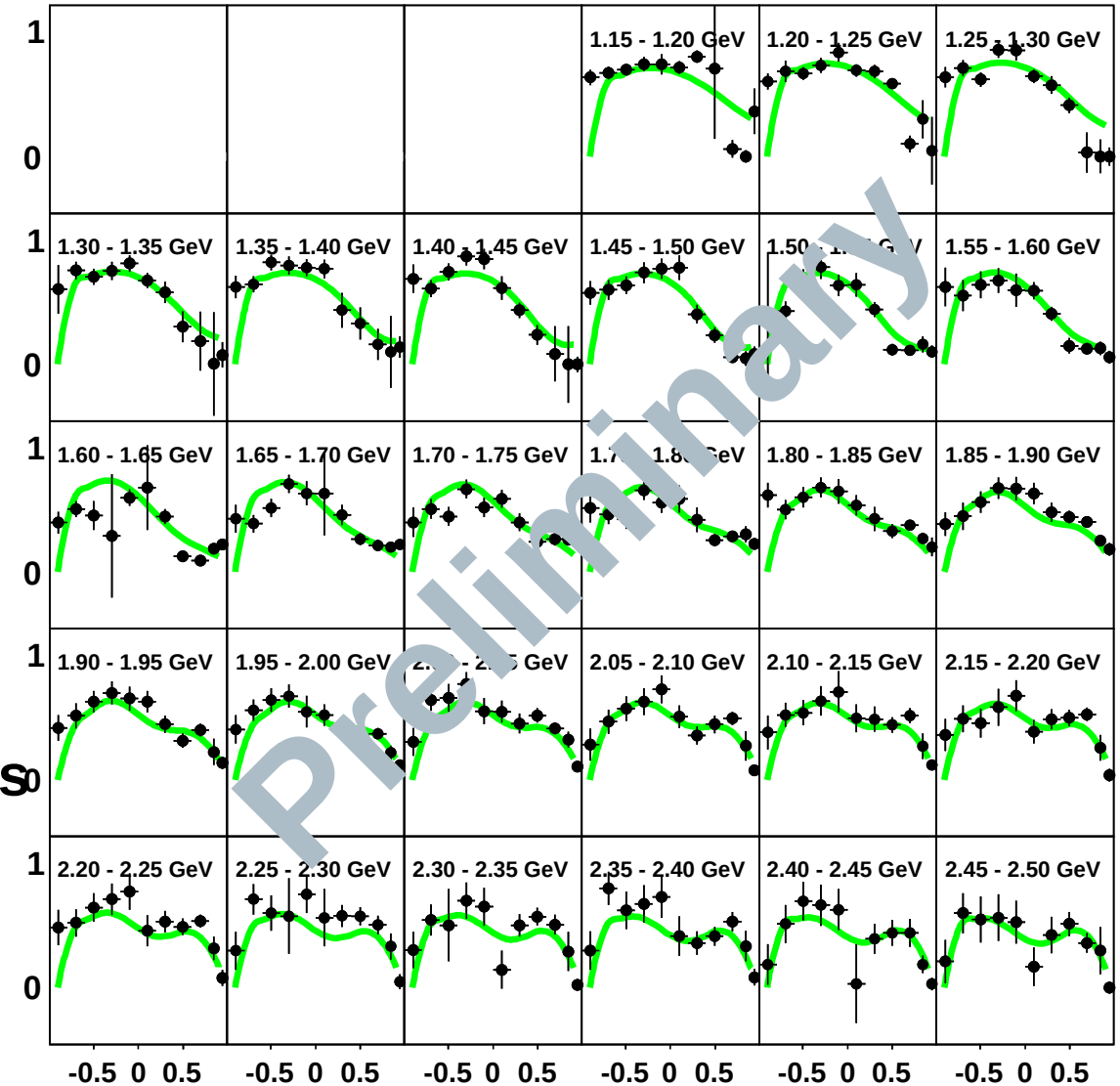
Unpolarized

$\rho^0_{00}, \rho^0_{1\,-1}, Re\rho^0_{10}$

Linearly Polarized Photons

$\rho^1_{00}, \rho^1_{11}, \rho^1_{1\,-1}, Re\rho^1_{10}$

$Im\rho^2_{10}, Im\rho^2_{1\,-1}$



A. Wilson, *et al.* [CBELSA/TAPS] to be published

Adair Frame

$\gamma p \rightarrow p\omega$ Spin Density Matrix Elements

ω polarization $\rightarrow \pi^0\gamma$ angular distributions

Polarization Observables

Spin Density Matrix Elements

superscript: γ_i polarization type

subscript: ω polarization

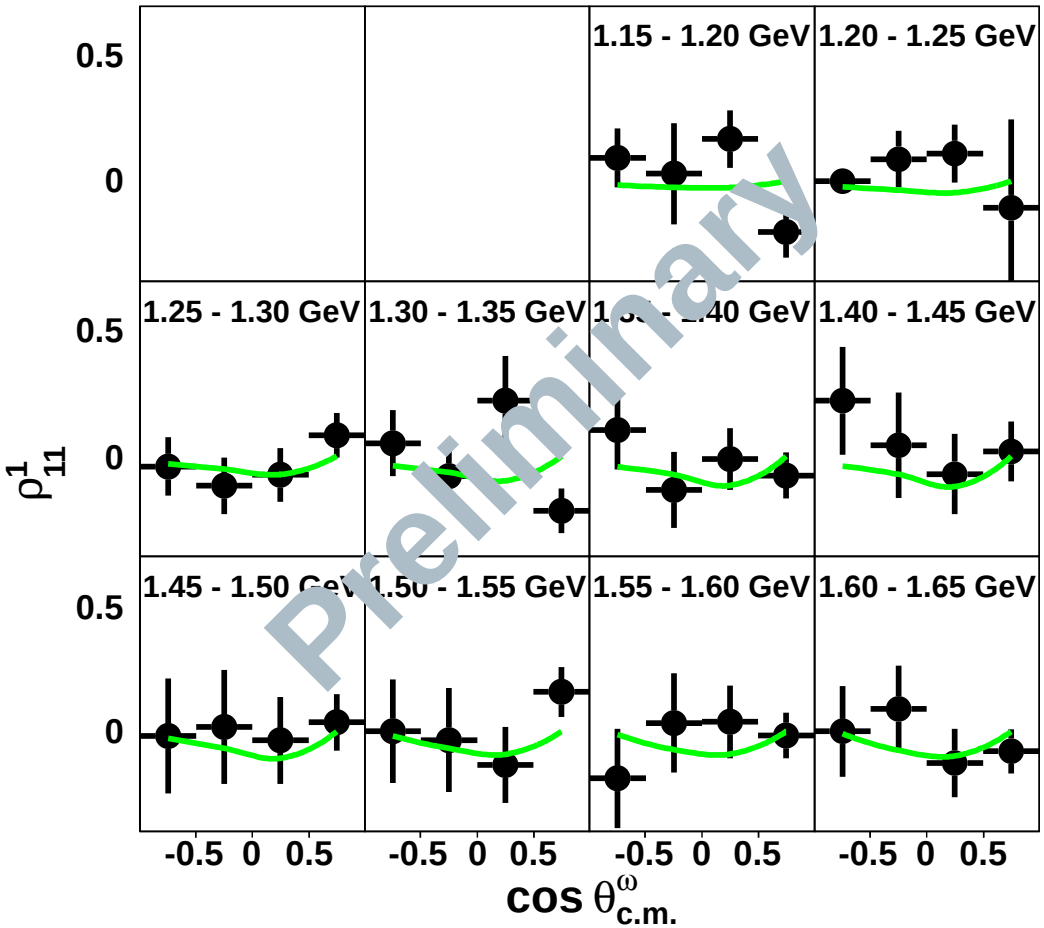
Unpolarized

$\rho^0_{00}, \rho^0_{1\,-1}, Re\rho^0_{10}$

Linearly Polarized Photons

$\rho^1_{00}, \rho^1_{11}, \rho^1_{1\,-1}, Re\rho^1_{10}$

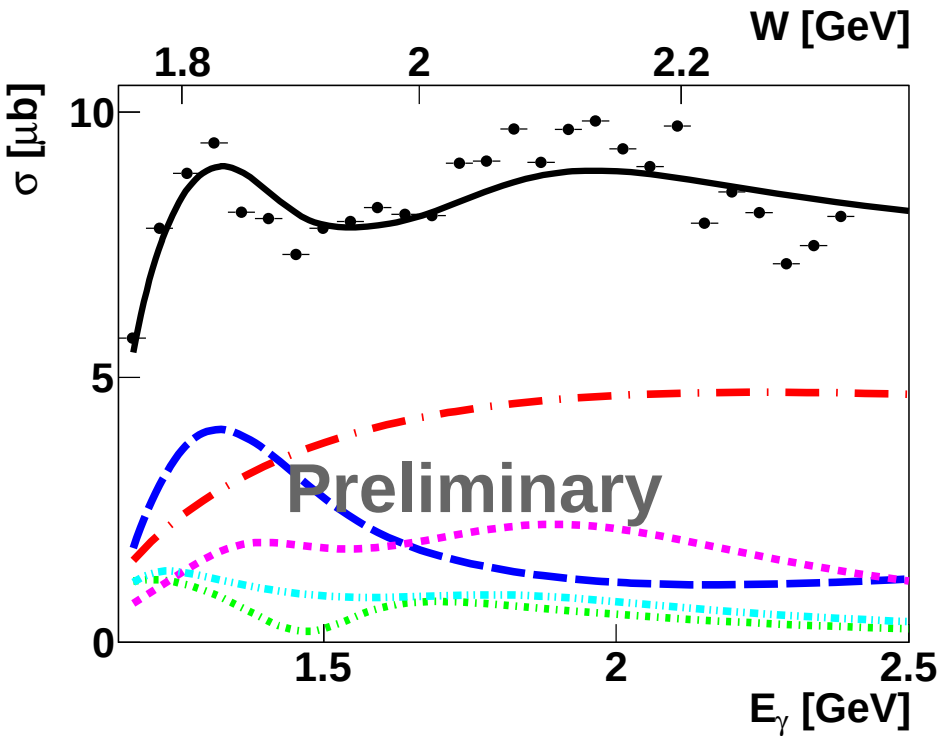
$Im\rho^2_{10}, Im\rho^2_{1\,-1}$



A. Wilson, *et al.* [CBELSA/TAPS] to be published

Adair Frame

$\gamma p \to p\omega$ PWA fit



Full Solution

pomeron-exchange

$\frac{1}{2}^-$

$\frac{3}{2}^-$

$\frac{3}{2}^+$

$\frac{5}{2}^+$

Bonn-Gatchina PWA (2014-02)

Includes

- Helicity Asymmetry E
  (Holger Eberhardt CBELSA/TAPS)
- All other data already included in
  A. V. Anisovich, *et. al.*, Eur. Phys. J. A **48**, 15 (2012).

π^0-exchange < pomeron-exchange

threshold: $N(1700)\frac{3}{2}^{-}{}^{***}$

$N(1895)\frac{1}{2}^{-}{}^{**}$, $N(1875)\frac{3}{2}^{-}{}^{***}$,

$N(2120)\frac{3}{2}^{-}{}^{**}$, $N(2000)\frac{5}{2}^{+}{}^{**}$

Baryon Resonances - recent PDG Additions

Progress Made!

Newest Baryon Resonance Updates to the PDG

A. V. Anisovich, *et al.*, Eur. Phys. J. A **48** (2012) 15.

	PDG 2010	BnGa-PWA	PDG 2012	GWU'06
N(1860)5/2$^+$		*	**	
N(1875)3/2$^-$		***	***	
N(1880)1/2$^+$		**	**	
N(1895)1/2$^-$		**	**	
N(1900)3/2$^+$	**	***	***	no evidence
N(2060)5/2$^-$		***	**	
N(2150)3/2$^-$		**	**	
Δ(1940)3/2$^-$	*	*	**	no evidence

- before 2010: All resonances almost exclusively from πN scattering + a couple resonances from $\gamma p \rightarrow p\pi^0$
- New Baryons come from including more photoproduction data on final states which do not include the πN coupling.

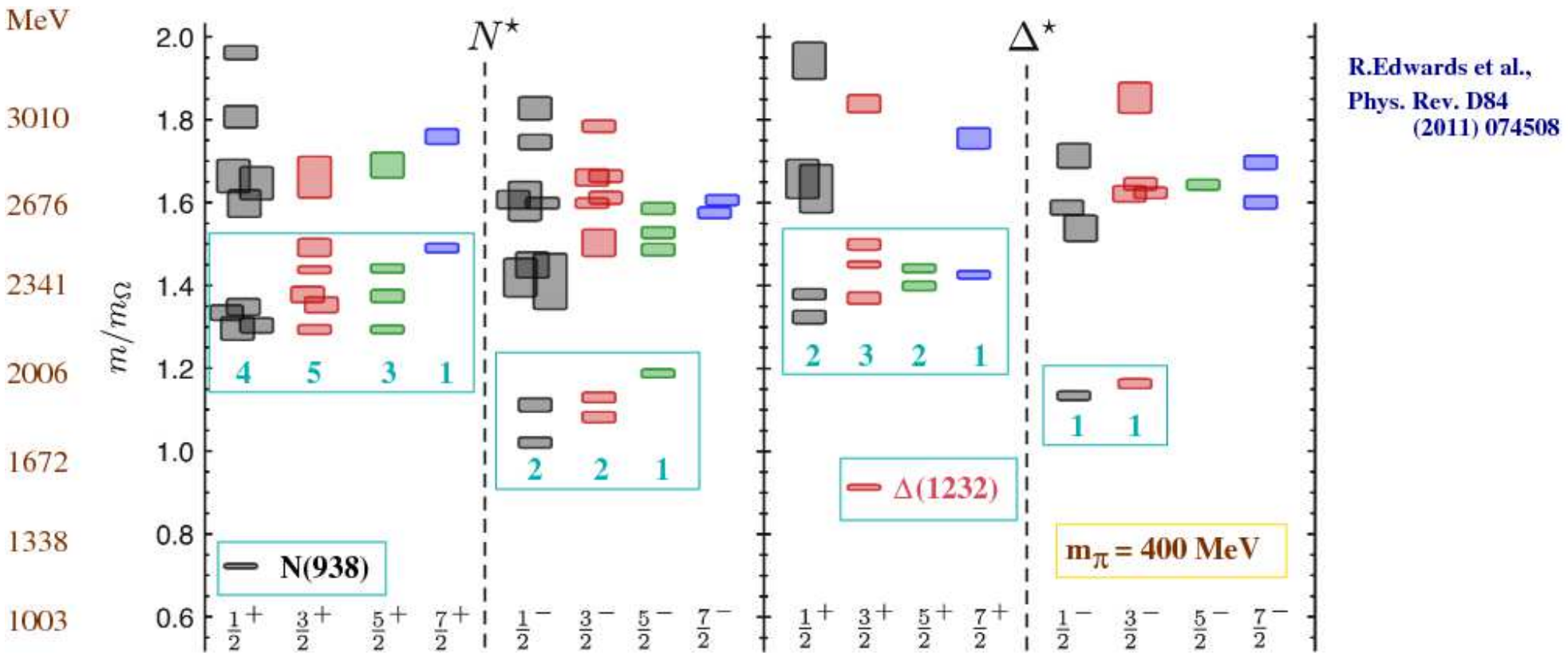
Summary

- Polarization Observables for:
  - $\gamma p \rightarrow p\pi^0$, $p\eta$,$p\omega$, $p\pi^0\pi^0$
- Differential Cross Sections for $\gamma p \rightarrow p\omega$
- Bonn-Gatchina PWA fit to $\gamma p \rightarrow p\omega$
- Recent additions to the PDG due to photoproduction results

Future

- Just the tip of the Iceberg
  - Many more polarization observables under analysis
  - $\gamma p \rightarrow p\pi^0$, $p\eta$, $p\eta'$, $p\omega$, $p\pi^0\pi^0$
- All data shown are close to publication
  - Help shed light on nucleon spectrum
- CBELSA/TAPS detector upgrade
  - Increase triggering rate
  - Access to more final states including off the neutron

Solving QCD Lagrangian on the Lattice

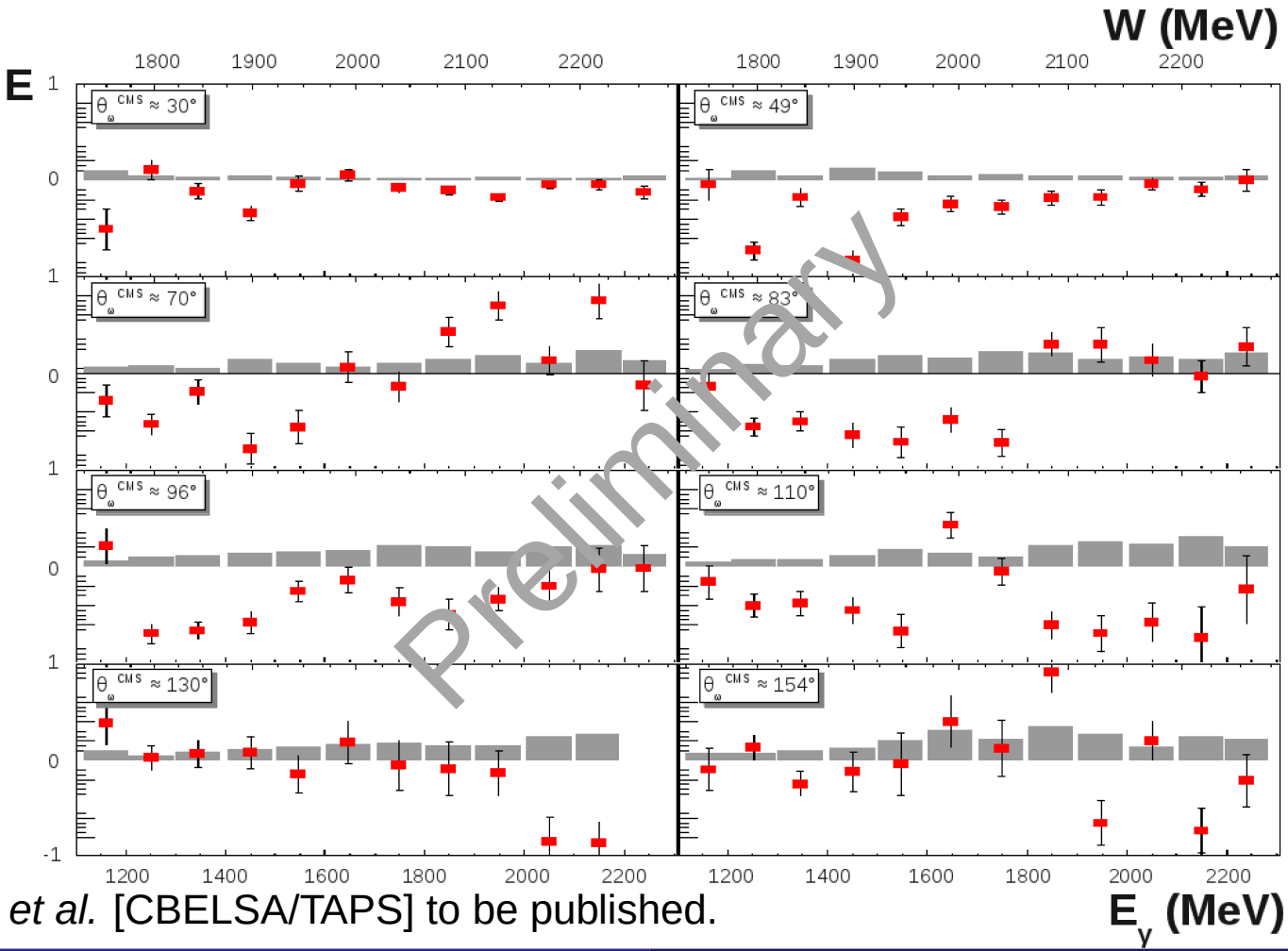


- Lattice Results similar counting to Symmetric Constituent Quark Models.
- No Parity Doubling & N^* Lowest Lying $\frac{1}{2}^+$ > N^* Lowest Lying $\frac{1}{2}^-$
- High Mass Resonances still expected.

$\gamma p \to p\omega$: Helicity Asymmetry E

Circularly Polarized Photons / Longitudinally Polarized Protons

$$E = \frac{\left(\frac{d\sigma}{d\Omega}\right)_{1/2} - \left(\frac{d\sigma}{d\Omega}\right)_{3/2}}{\left(\frac{d\sigma}{d\Omega}\right)_{1/2} + \left(\frac{d\sigma}{d\Omega}\right)_{3/2}}$$



H. Eberhardt, *et al.* [CBELSA/TAPS] to be published.