Spectroscopy of Baryon Resonances at ELSA

Volker Credé

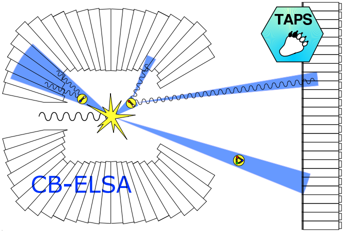
Florida State University
Tallahassee, FL

MESON 2010

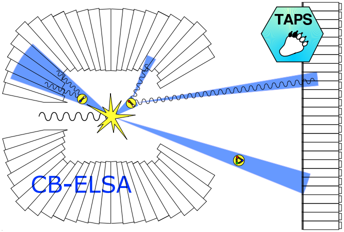
Krakow, Poland
June 14, 2010

Outline

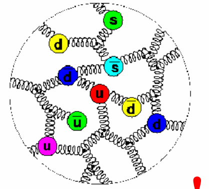
1. Introduction
2. Photoproduction of a Single Pseudoscalar Meson
   - η Photoproduction off the Proton
   - π^0 Photoproduction off the Proton
3. Double-Meson Final States
   - Observables in $\gamma p \rightarrow p\,\pi^0\eta$
4. Summary and Outlook



Outline



$\ll 0.1$fm

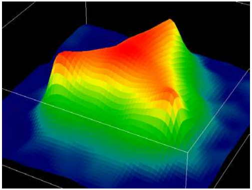


pQCD

q, g, $q\bar{q}$

! ? ↔ ? !

0.1 – 1.0 fm

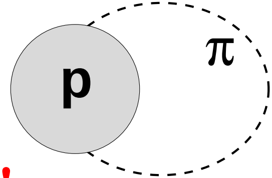


Models

Quarks and Gluons as Quasiparticles

? ! ↔ ! ?

> 1.0 fm



ChPT

Nucleon and Mesons

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

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

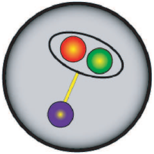
	****	***	**	*
N Spectrum	11	3	6	2
Δ Spectrum	7	3	6	6

$\Rightarrow$ according to PDG
(Phys. Lett. B **667**, 1 (2008))

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

Possible solutions:

1. Quark-diquark structure



one of the internal degrees of freedom is frozen

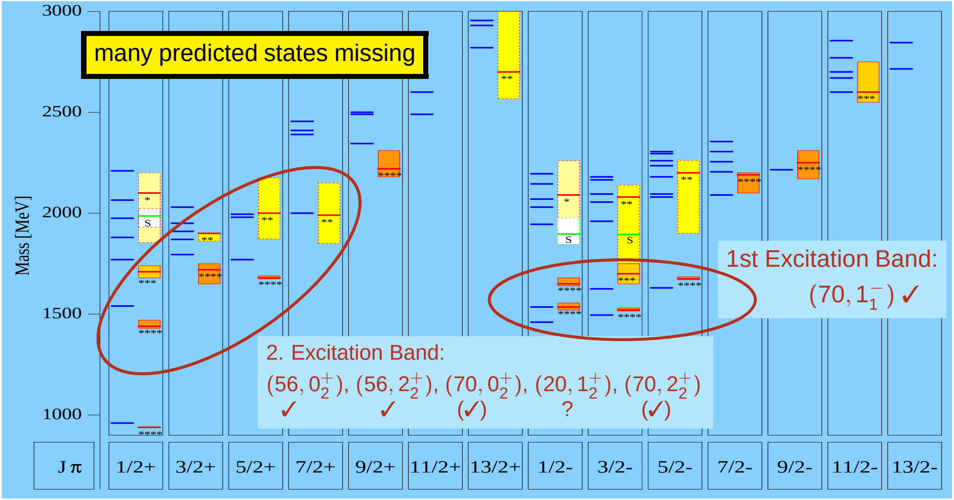
2. Have not been observed, yet

Nearly all existing data result from πN scattering experiments

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

Nucleon Resonances: Status of 2001

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

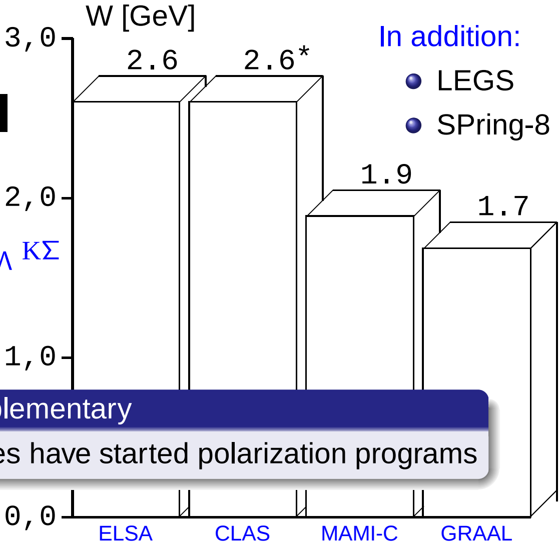


E_γ [GeV]

Reaction Thresholds

1.66
$\gamma p \to p\eta\eta$
$\gamma p \to p\pi^0\omega$
$\gamma p \to p\pi^0\eta$ $\quad \gamma p \to K\Lambda$ $K\Sigma$
$\gamma p \to p\eta$
$\gamma p \to p\pi\pi\pi$
$\gamma p \to p\pi\pi$
$\gamma p \to p\pi$
0.06

0.00



In addition:

- LEGS
- SPring-8

Partially complementary

- All facilities have started polarization programs

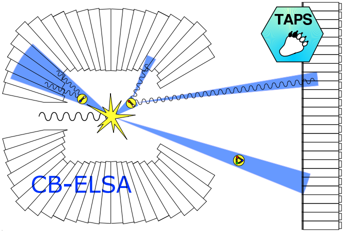
Ingredients in the Study of Excited Baryons

- Measurements off neutron and proton to resolve isospin contributions
  1. $\mathcal{A}(\gamma N \rightarrow \pi,\ \eta,\ K)^{I=3/2} \quad \Longleftrightarrow \quad \Delta^*$
  2. $\mathcal{A}(\gamma N \rightarrow \pi,\ \eta,\ K)^{I=1/2} \quad \Longleftrightarrow \quad N^*$
- 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)

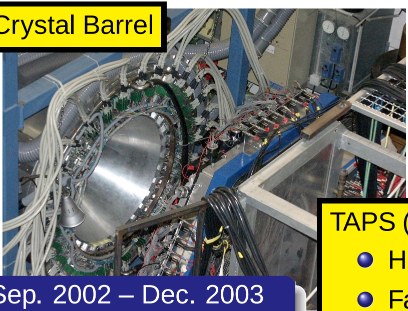
In order to determine the full scattering amplitude without ambiguities, one has to carry out eight carefully selected measurements: four double-spin observables along with the four single-spin observables.

Outline



The CBELSA/TAPS Experiment

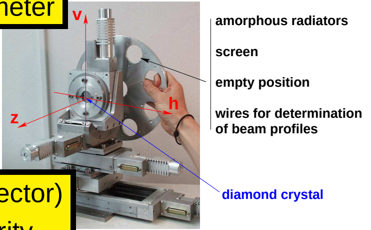
Crystal Barrel



Sep. 2002 – Dec. 2003

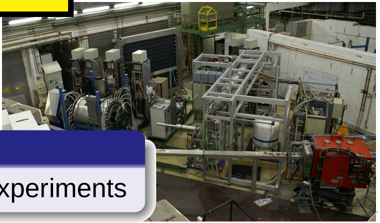
- (un)polarized beam
- liquid H_2, deuterium

Goniometer



TAPS (forward detector)

- High Granularity
- Fast Trigger

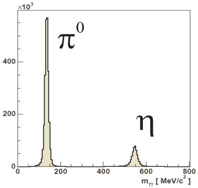


2007 -

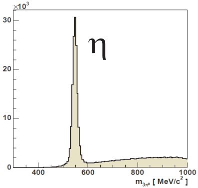
Double-Polarization Experiments

Isospin Filter: $\gamma p \to N^* \ (I = 1/2) \ \to p\,\eta$

$\eta \to \gamma\gamma$



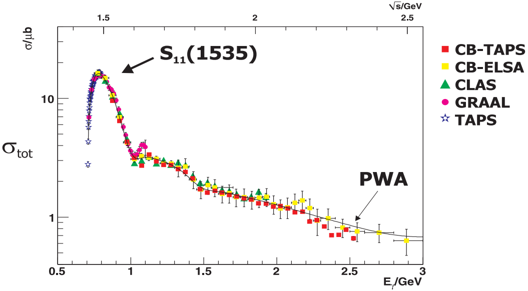
$\eta \to 3\pi^0$



$d\sigma/d\Omega$

PWA

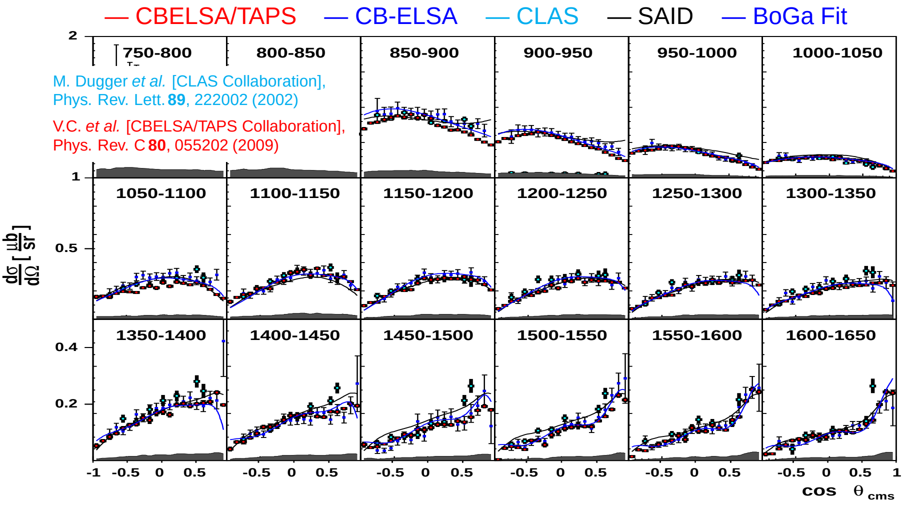
σ_{tot}



Only nucleon resonances can contribute

- $N(1535)S_{11},\ N(1520)D_{13},\ N(1650)S_{11},\ N(1680)F_{15},\ N(1720)P_{13},\ \dots,\ \rho$- and ω-t-channel exchange
- New resonance $N(2070)D_{15}$: $m = (2068 \pm 22)$ MeV/c^2
  $\Gamma = (295 \pm 40)$ MeV/c^2
  (needs confirmation in polarization experiments)

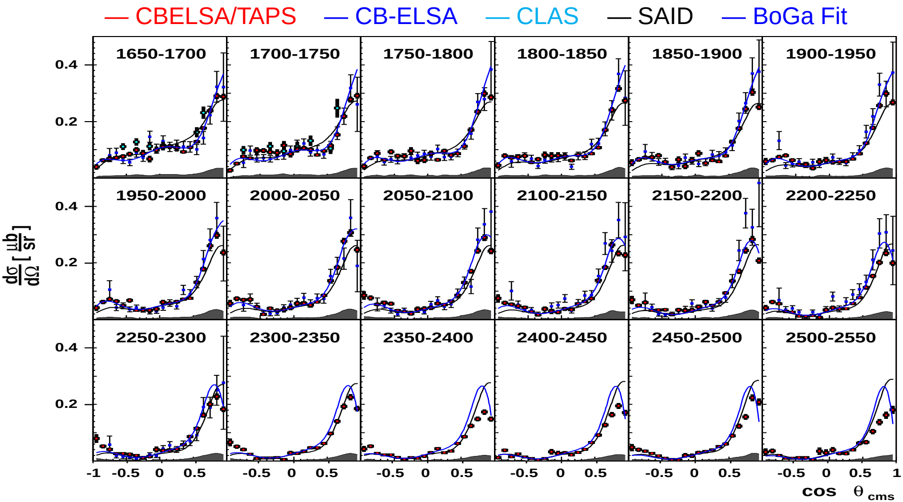
Photoproduction of η Mesons off the Proton



M. Dugger *et al.* [CLAS Collaboration], Phys. Rev. Lett. **89**, 222002 (2002)

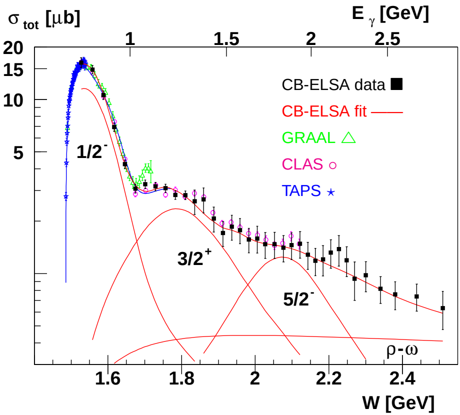
V.C. *et al.* [CBELSA/TAPS Collaboration], Phys. Rev. C **80**, 055202 (2009)

Photoproduction of η Mesons off the Proton



V.C. *et al.* [CBELSA/TAPS Collaboration], Phys. Rev. C **80**, 055202 (2009)

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



Isopsin Filter

➜ Only N^* resonances can contribute!

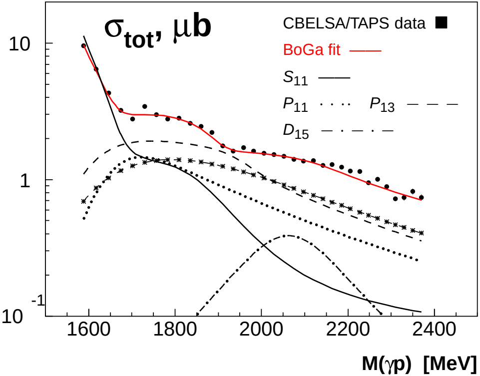
Bonn-Gatchina (PWA) group:
Hint for N^* resonance $(2070)D_{15}$

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

Three resonances are dominantly contributing:

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

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



Isospin Filter

➜ Only N^* resonances can contribute!

Bonn-Gatchina (PWA) group: Hint for N* resonance (2070)D_{15}

(Phys. Rev. Lett. **94**, 012004 (2005))

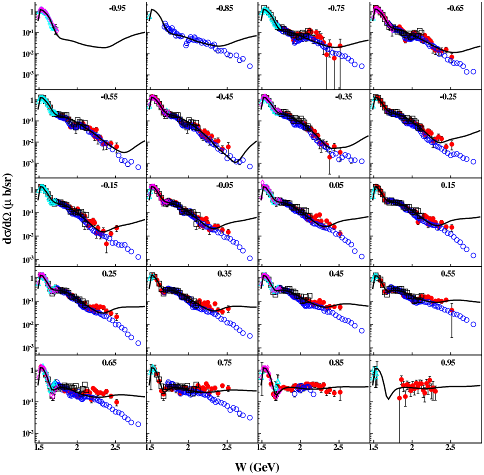
1. Confirmed in 2009 analysis!
2. $N(1720)P_{13} \to p\,\eta$?
   ➜ η-MAID: $N(1710)P_{11} \to p\,\eta$ significant!

Resonances dominantly contributing:

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

Photoproduction of η Mesons at CLAS (Jefferson Lab)

○ g11a ● CB-ELSA ('05) □ CLAS ('02) △ GRAAL ('02) ◇ LNS ('06) — SAID



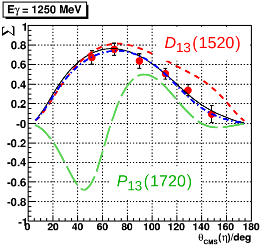
Big discrepancies at high energies and in the forward direction

➜ CLAS PWA in the works

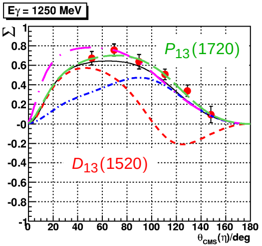
V.C. *et al.* [CB-ELSA Collaboration], Phys. Rev. Lett. **94**, 012004 (2005)

M. Williams *et al.* [CLAS Collaboration], Phys. Rev. C **80**, 045213 (2009)

Beam Asymmetry Σ in the Reaction $\vec{\gamma} p \to p\,\eta$



BoGa-PWA



η-MAID

[CBELSA/TAPS Collaboration], EPJ A **80**, 055202 (2009)

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

Further spin observables available

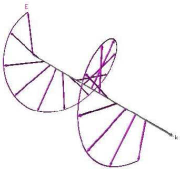
G and E from 2007-2009 experiments with longitudinal target polarization

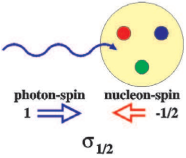
H, F, T, and P from future experiments with transverse target polarization (2011-)

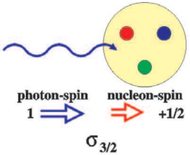
Predictions for E “Helicity Difference”

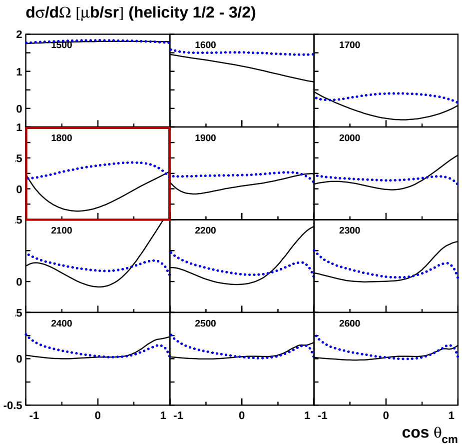
η-MAID / BoGa-PWA

$$\frac{d\sigma_{(3/2-1/2)}}{d\Omega} = \frac{d\sigma_{3/2}}{d\Omega} - \frac{d\sigma_{1/2}}{d\Omega}$$

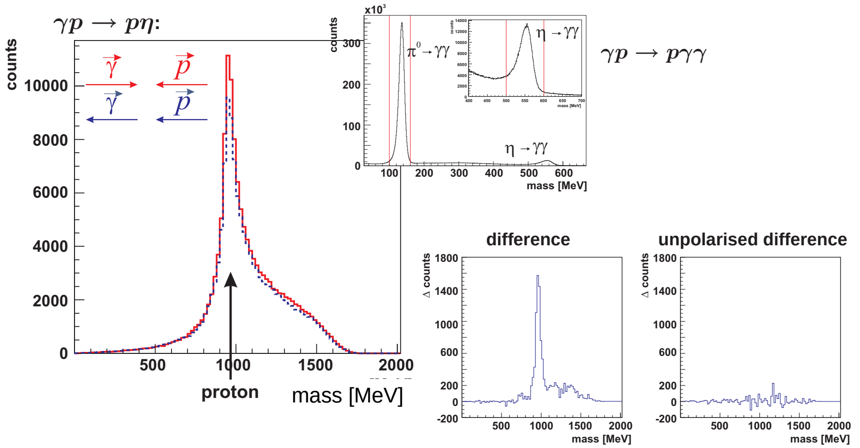








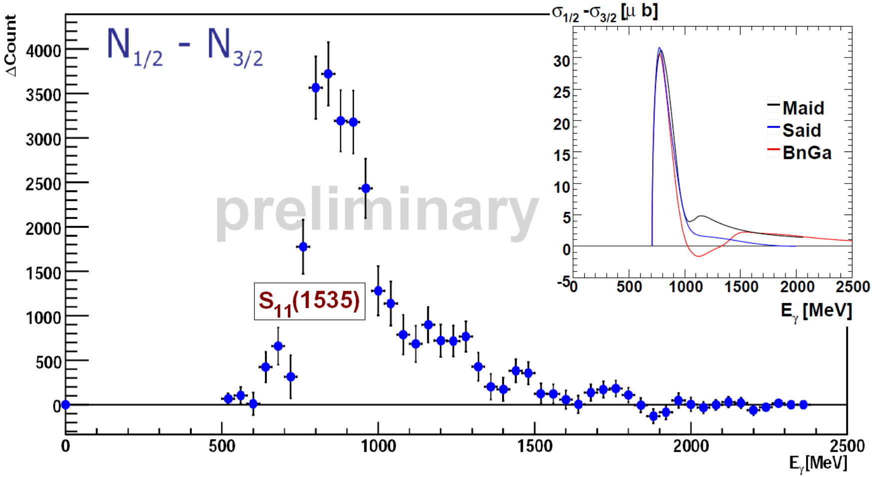
First Asymmetries Observed at ELSA



$\Rightarrow$ **First asymmetries observed**

U. Thoma, HADRON 2009

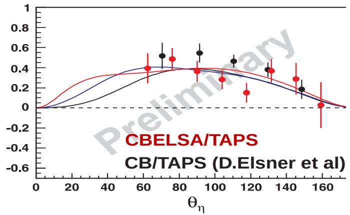
Clear Asymmetries Observed in $\gamma p \to p\,\eta$



U. Thoma, HADRON 2009

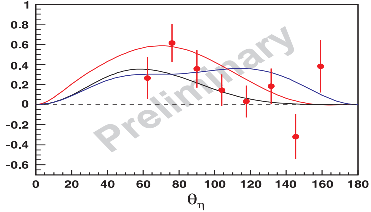
E_γ=950$\pm$50 MeV

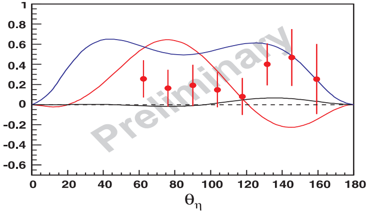
Σ:



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

G:

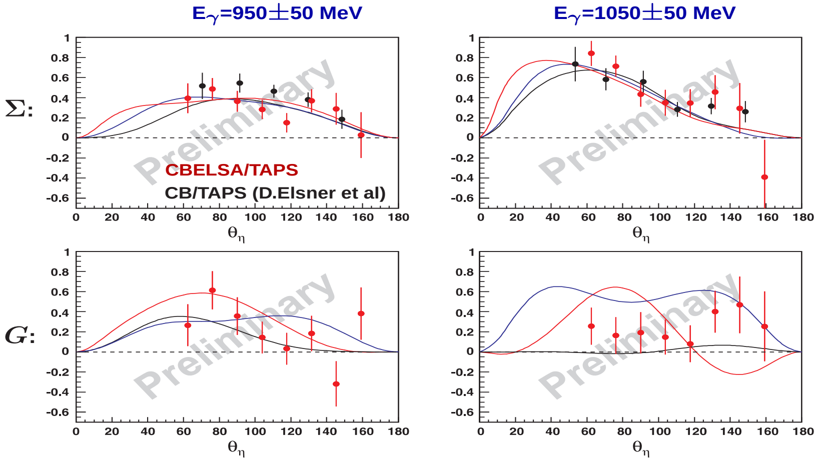




– MAID – BoGa – SAID

$\leftrightarrow$ **preliminary dilution factor included**

A. Thiel, Bonn



– MAID – BoGa – SAID

↔ **preliminary dilution factor included**

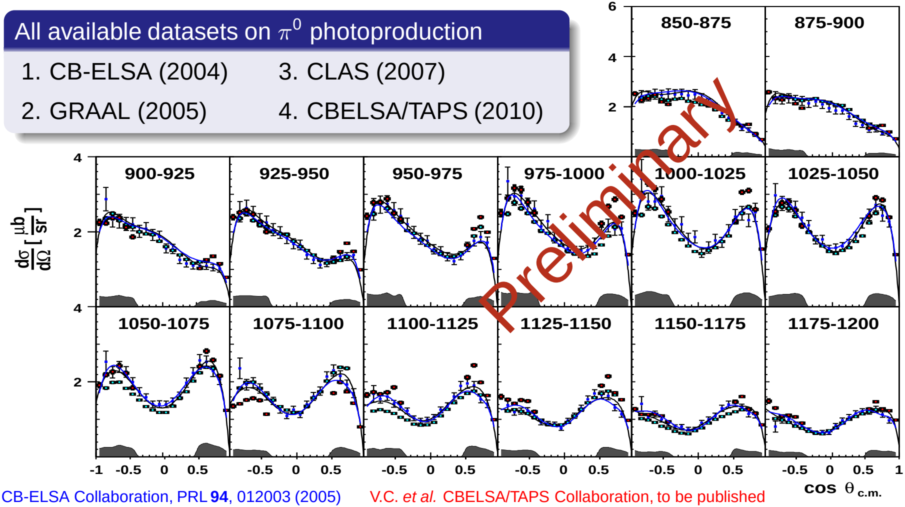
A. Thiel, Bonn

Differential Cross Sections for $\gamma p \rightarrow p\,\pi^0$

— CBELSA/TAPS — CB-ELSA — CLAS — SAID — BoGa

All available datasets on π^0 photoproduction

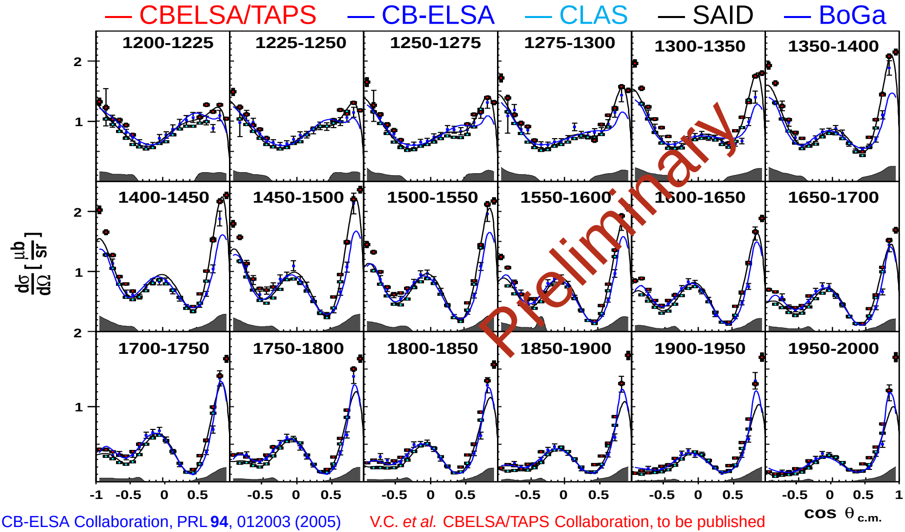
1. CB-ELSA (2004)
2. GRAAL (2005)
3. CLAS (2007)
4. CBELSA/TAPS (2010)



CB-ELSA Collaboration, PRL **94**, 012003 (2005)

V.C. *et al.* CBELSA/TAPS Collaboration, to be published

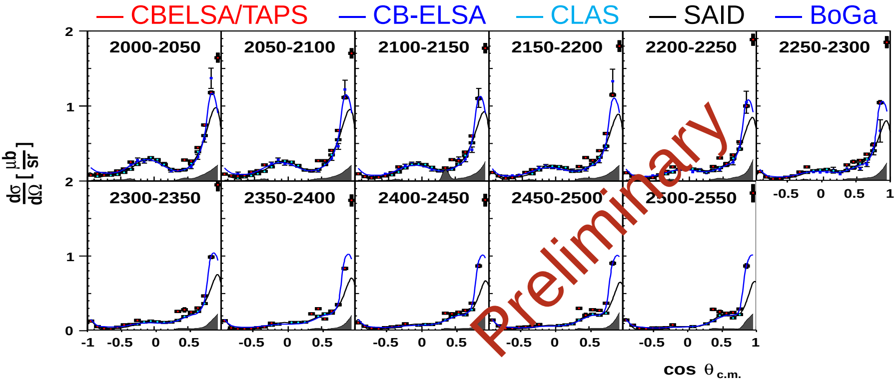
Differential Cross Sections for $\gamma p \to p\pi^0$



CB-ELSA Collaboration, PRL **94**, 012003 (2005)

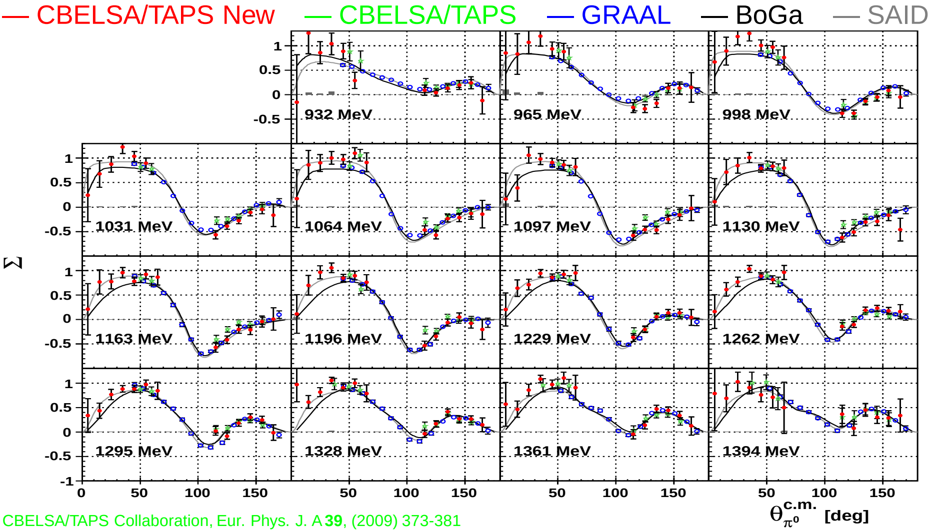
V.C. *et al.* CBELSA/TAPS Collaboration, to be published

Differential Cross Sections for $\gamma p \to p\pi^0$



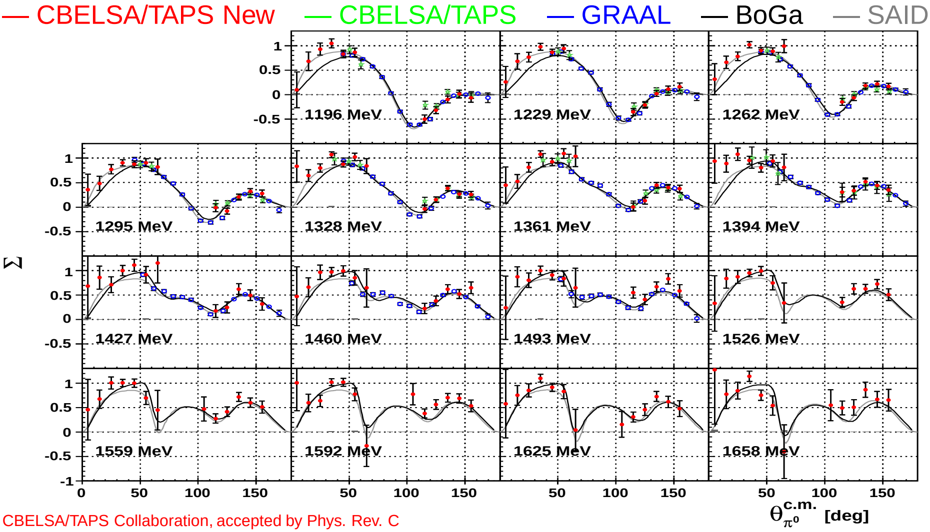
CB-ELSA Collaboration, PRL **D94**, 012003 (2005)   V.C. *et al.* CBELSA/TAPS Collaboration, to be published

Beam Asymmetries for $\gamma p \rightarrow p\pi^0$



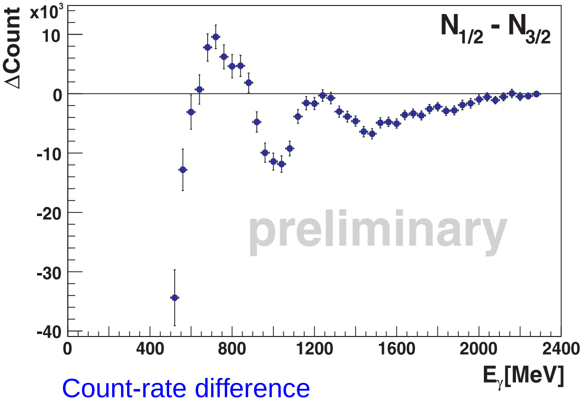
CBELSA/TAPS Collaboration, Eur. Phys. J. A **39**, (2009) 373-381

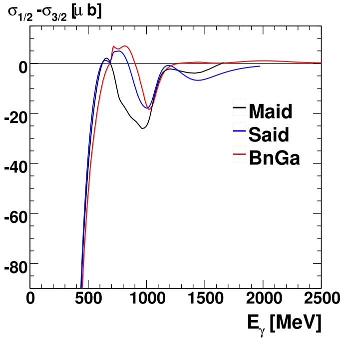
Beam Asymmetries for $\gamma p \rightarrow p\pi^0$



CBELSA/TAPS Collaboration, accepted by Phys. Rev. C

Helicity Difference E

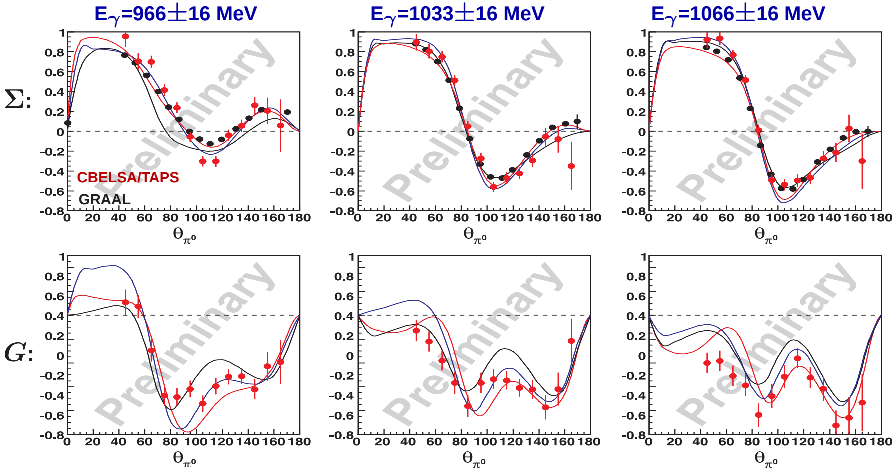




Count-rate difference

- Preliminary acceptance correction
- Important information for PWA

Observable G

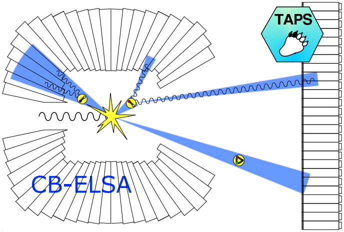


– MAID – BoGa – SAID

↔ **preliminary dilution factor included**

A. Thiel, Bonn

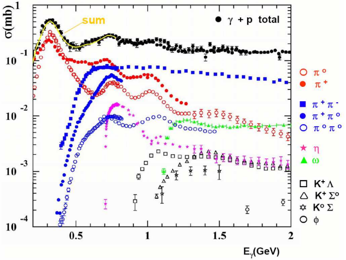
Outline



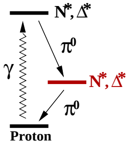
Beam-Target Polarization Observables

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

⇐ Single-Meson Final States (7 Observables)



At higher excitation energies:
Multi-meson final states play an increasingly important role

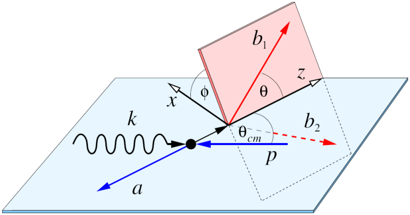


➜ Search for states in cascades!

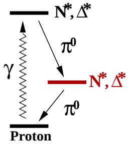
Beam-Target Polarization Observables

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

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



At higher excitation energies:
Multi-meson final states play an increasingly important role



➜ Search for states in cascades!

Beam-Target Polarization Observables

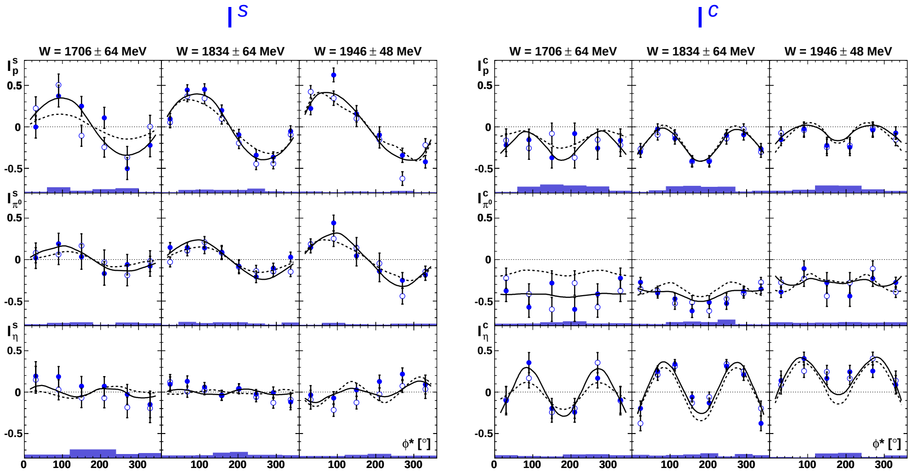
$$\frac{d\sigma}{d\Omega} = \sigma_0\,\{\,1 - \delta_l\,\Sigma\cos 2\phi$$
$$+\,\Lambda_x\,(\,-\delta_l\,\mathbf{H}\sin 2\phi + \delta_\odot\,\mathbf{F}\,)$$
$$-\,\Lambda_y\,(\,-\mathbf{T} + \delta_l\,\mathbf{P}\cos 2\phi)$$
$$-\,\Lambda_z\,(\,-\,\delta_l\,\mathbf{G}\sin 2\phi + \delta_\odot\,\mathbf{E})\}$$

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

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

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

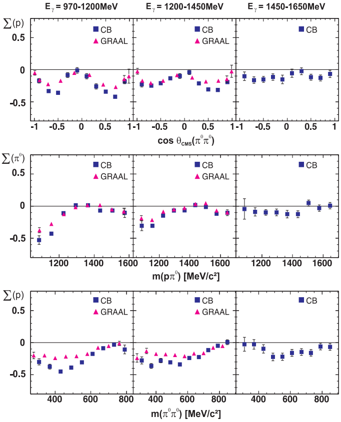
Beam Asymmetries in $\gamma p \rightarrow p\,\pi^0\eta$



CBELSA/TAPS Collaboration, Phys. Lett. B **687**, 11 (2010)

Observables in $\gamma p \longrightarrow p\,\pi^0\pi^0$

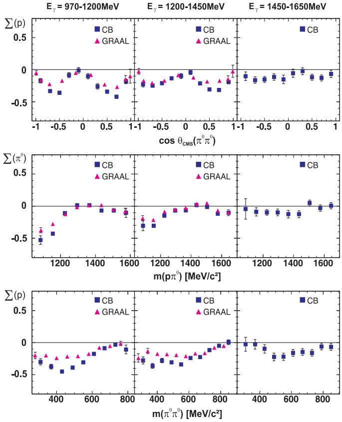
$$I = I_0\,(1 + \delta_l\,[\,\mathbf{I}^{s}\sin 2\beta + \mathbf{I}^{c}\cos 2\beta\,]\,)$$

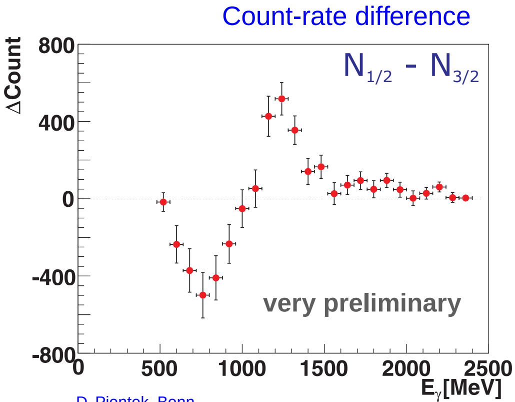


Vahe Sokhoyan, to be published

Observables in $\gamma p \to p\,\pi^0\pi^0$

$$I = I_0\,(\,1 + \delta_l\,[\,\mathbf{I}^{s}\sin 2\beta + \mathbf{I}^{c}\cos 2\beta\,]\,)$$



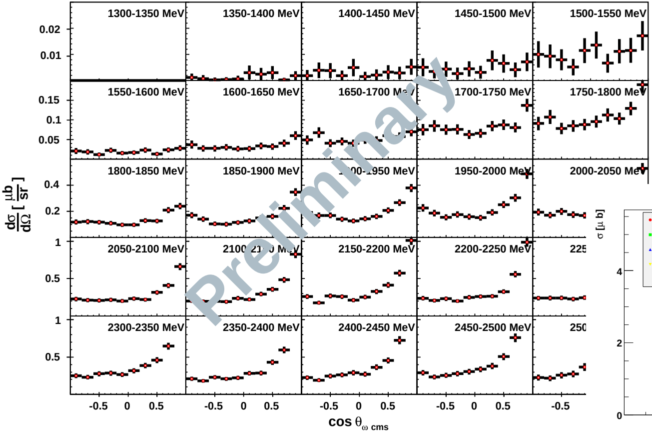


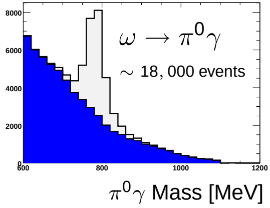
D. Piontek, Bonn

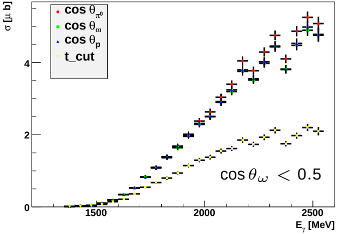
Vahe Sokhoyan, to be published

Isospin Filter: $\gamma p \to \Delta^* \; (I = 3/2) \; \to \Delta\, \omega \to p\, \pi^0 \omega$

Preliminary Differential Cross Sections for $\gamma p \to p\, \pi^0 \omega$



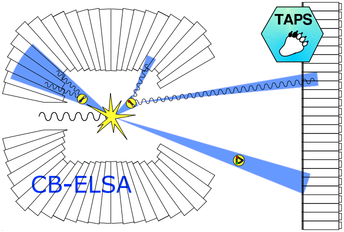




A. Wilson, Florida State University

Outline

1. Introduction
2. Photoproduction of a Single Pseudoscalar Meson
   - η Photoproduction off the Proton
   - π^0 Photoproduction off the Proton
3. Double-Meson Final States
   - Observables in $\gamma p \rightarrow p\,\pi^0\eta$
4. Summary and Outlook



Summary and Outlook

High-quality data recorded and published: $\gamma p\ (\vec{\gamma} p) \rightarrow p\,\eta,\ p\,\pi^0,\ p\,\omega,\ p\,\pi^0\eta,\ ...$

- Excellent angular coverage: e.g. full range for $\eta,\ \eta'$ photoproduction
  ➜ Important for resonance extraction
- Observation of higher-mass resonances in sequential decays leading to double-meson final states like $\pi^0\pi^0$, $\pi^0\eta$, etc.
  ➜ $\Delta(1232)\pi^0$, $N(1520)D_{15}\pi^0$, $N(1535)S_{11}\pi^0$, ...

First double-polarization observables observed (longitudinally-pol. target)

- Important milestone toward complete experiments
- Program using transverse target polarization from 2011 -

➜ Better understanding of the baryon spectrum!