Spectroscopy of Baryon Resonances at ELSA

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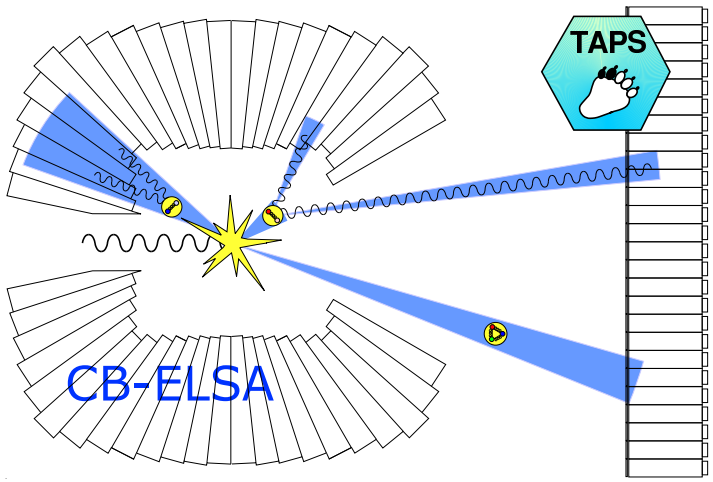
Tallahassee, FL

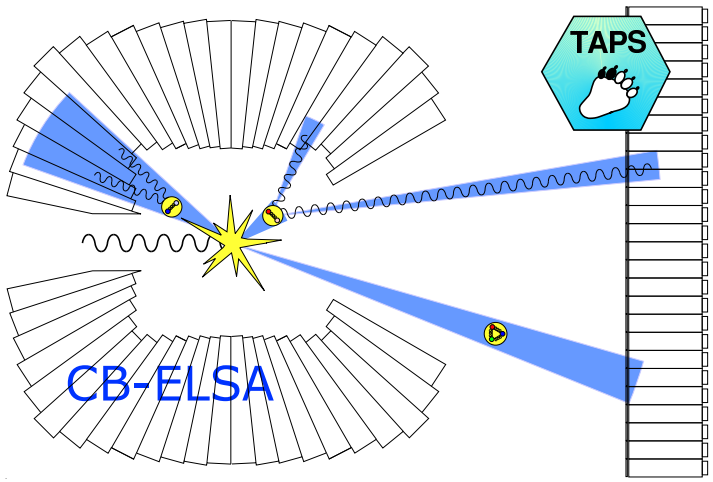
MESON 2010

Krakow, Poland
June 14, 2010

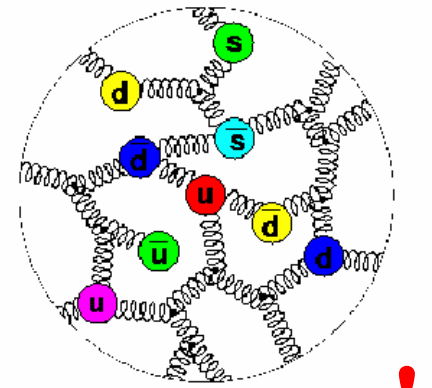
Outline

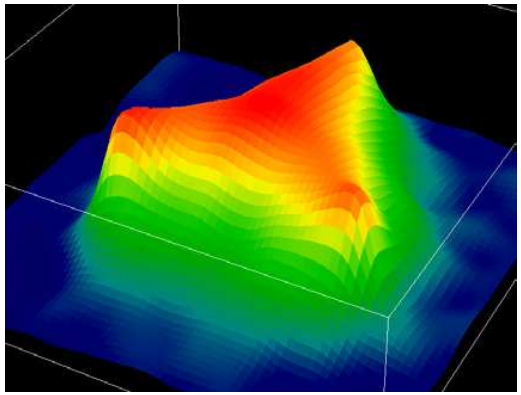


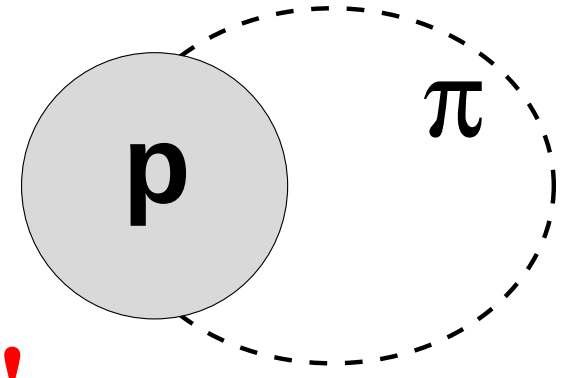
Outline



$\ll 0.1\,\mathrm{fm}$ | $0.1 - 1.0\,\mathrm{fm}$ | $> 1.0\,\mathrm{fm}$







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

? ! ↔ ? !

Models
Quarks and Gluons
as Quasiparticles

? ! ↔ ! ?

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

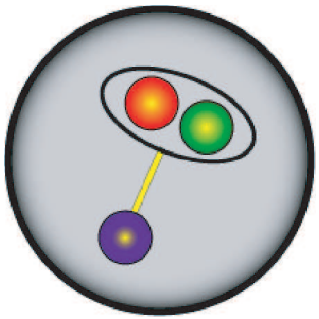
	****	***	**	*
N Spectrum	11	3	6	2
Δ Spectrum	7	3	6	6

$\Rightarrow$ 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

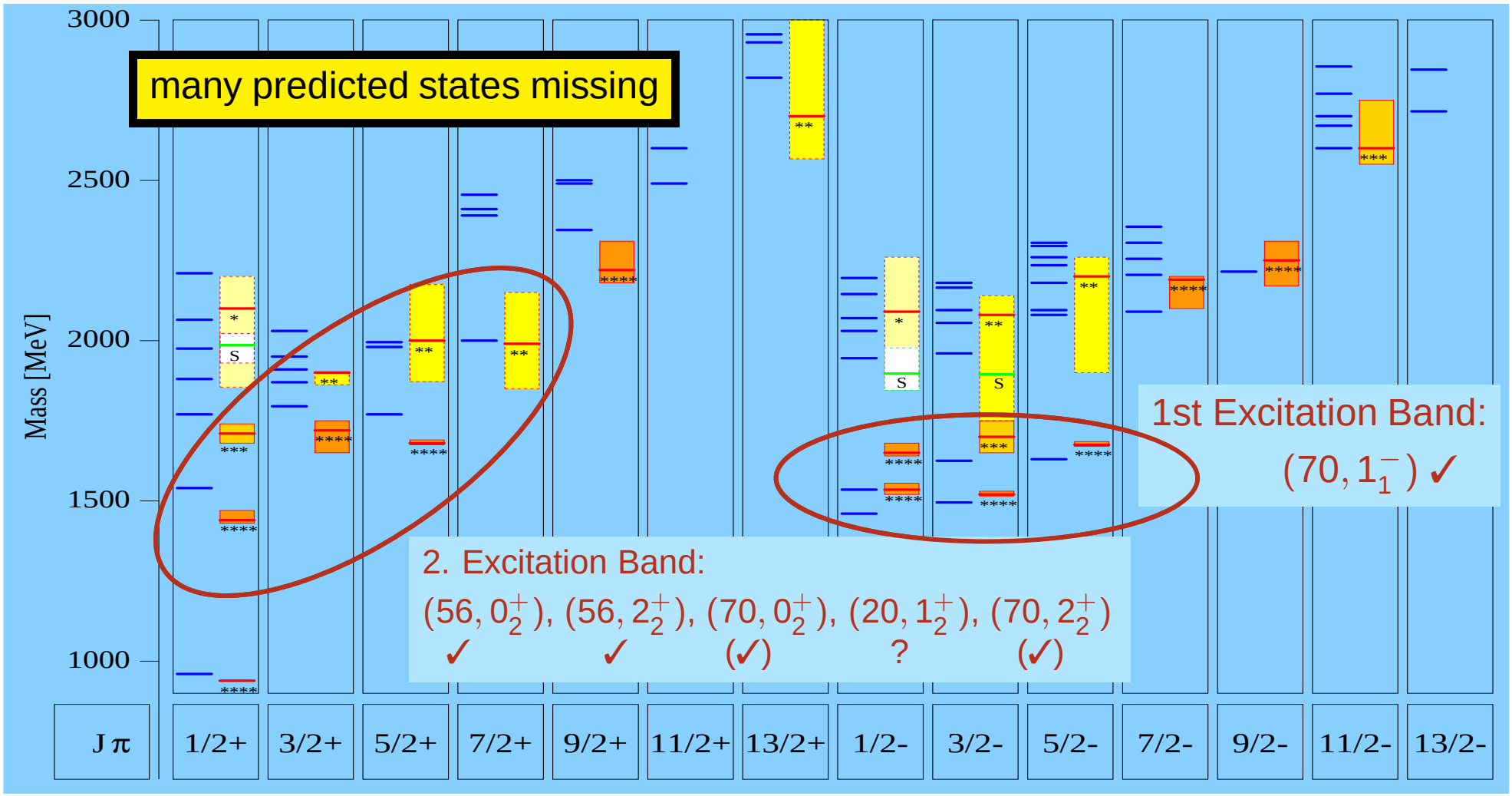
2. Have not been observed, yet

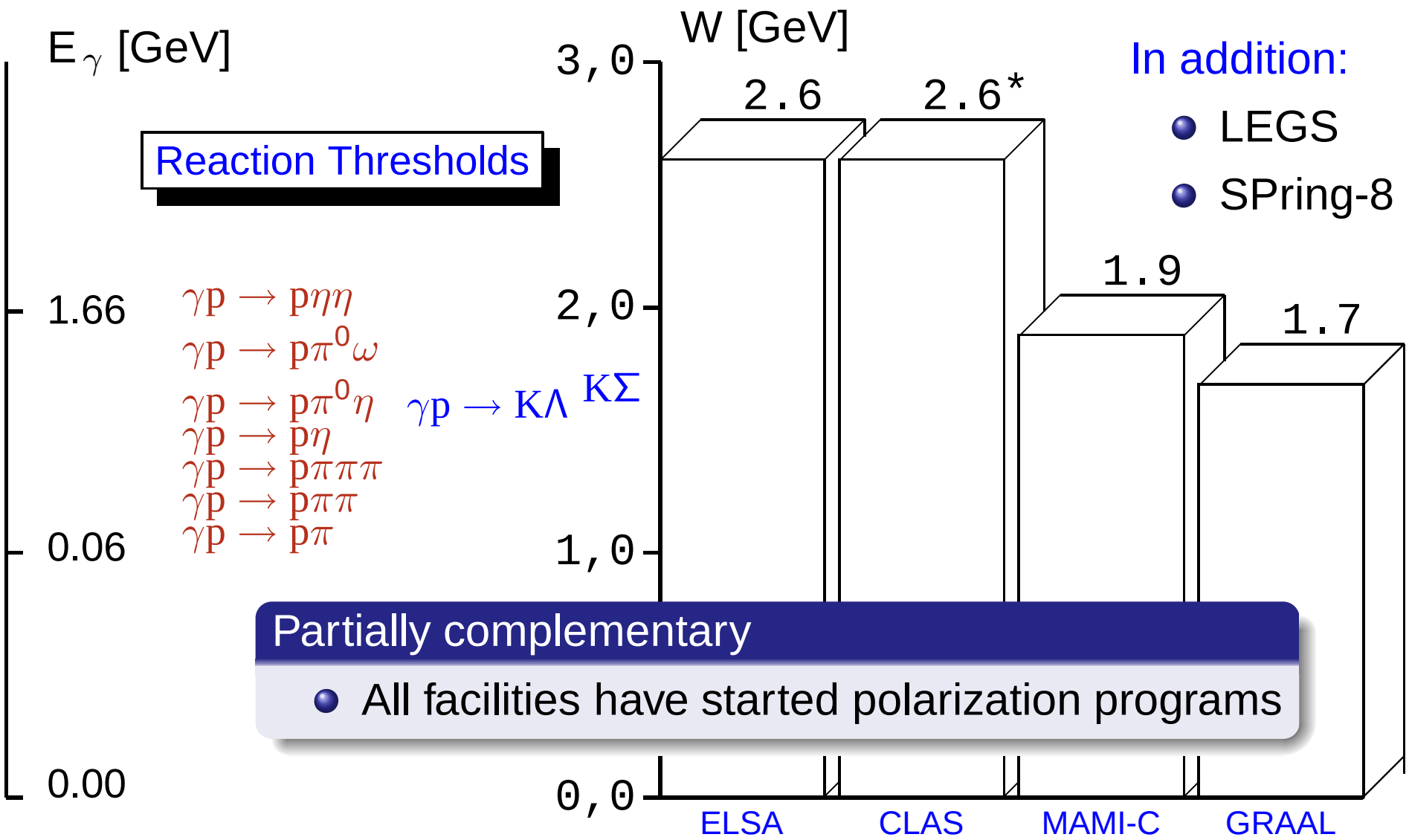
Nearly all existing data result from πN scattering experiments

➜ 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$_\gamma$ [GeV]
W [GeV]
Reaction Thresholds
1.66
0.06
0.00
$\gamma p \to p\eta\eta$
$\gamma p \to p\pi^0\omega$
$\gamma p \to p\pi^0\eta$
$\gamma p \to p\eta$
$\gamma p \to p\pi\pi\pi$
$\gamma p \to p\pi\pi$
$\gamma p \to p\pi$
$\gamma p \to K\Lambda$
$K\Sigma$
3,0
2,0
1,0
0,0
2.6
2.6*
1.9
1.7
ELSA
CLAS
MAMI-C
GRAAL
In addition:
LEGS
SPring-8
Partially complementary
All facilities have started polarization programs

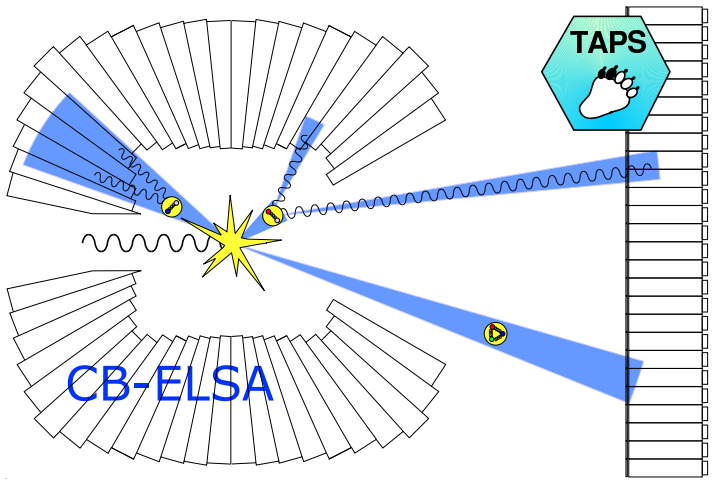
Ingredients in the Study of Excited Baryons

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

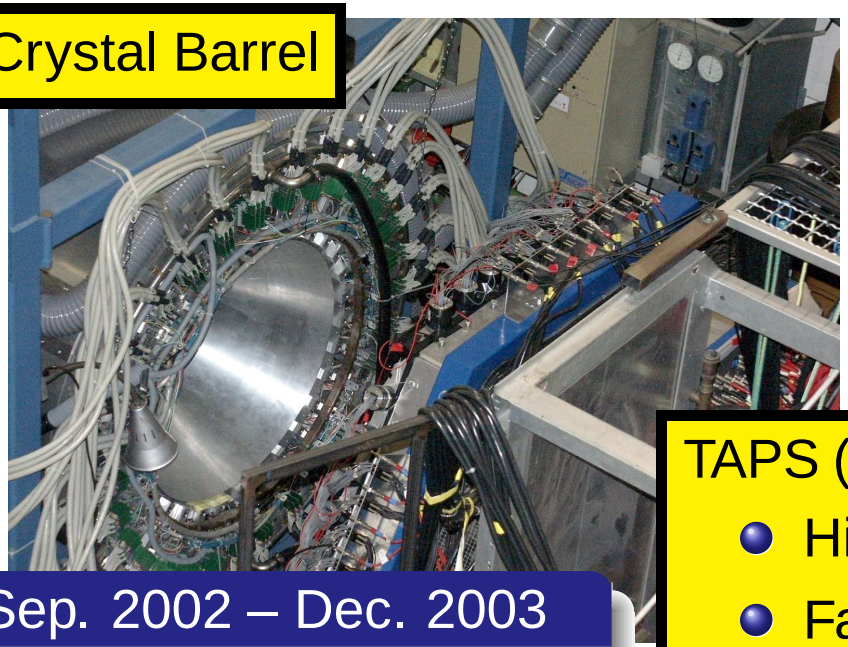
In order to determine the full scattering amplitude without ambiguities, one has to carry out eight carefully selected measurements: four double-spin observables along with the four single-spin observables.

Outline

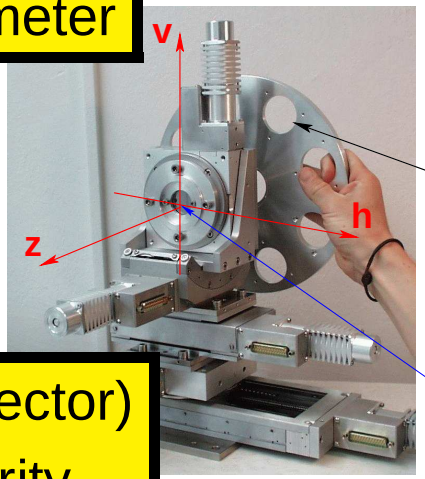


The CBELSA/TAPS Experiment

Crystal Barrel



Goniometer

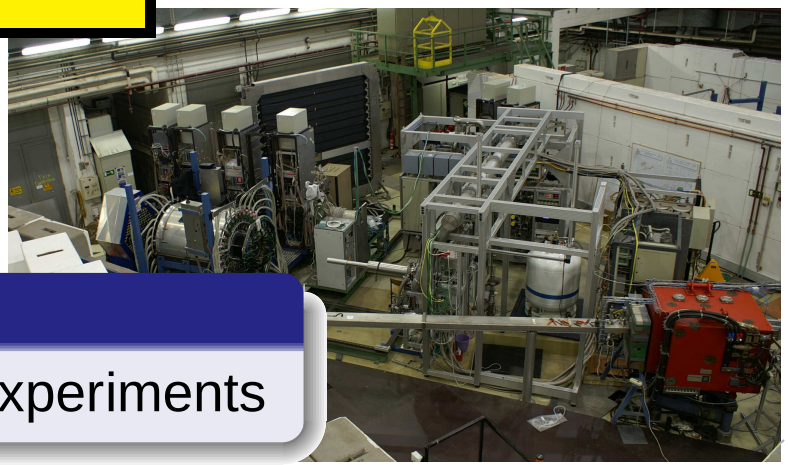


TAPS (forward detector)

- High Granularity
- Fast Trigger

Sep. 2002 – Dec. 2003

- (un)polarized beam
- liquid H_2, deuterium

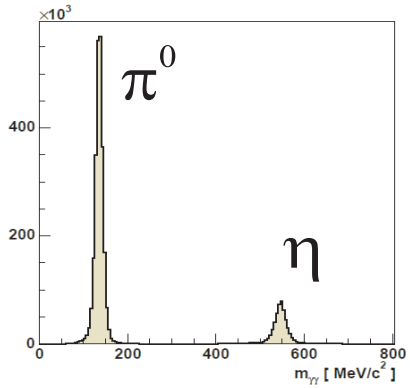


2007 -

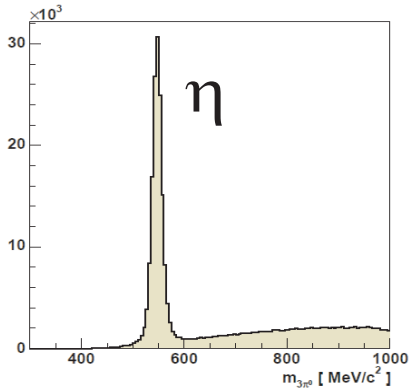
Double-Polarization Experiments

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

$\eta \to \gamma\gamma$



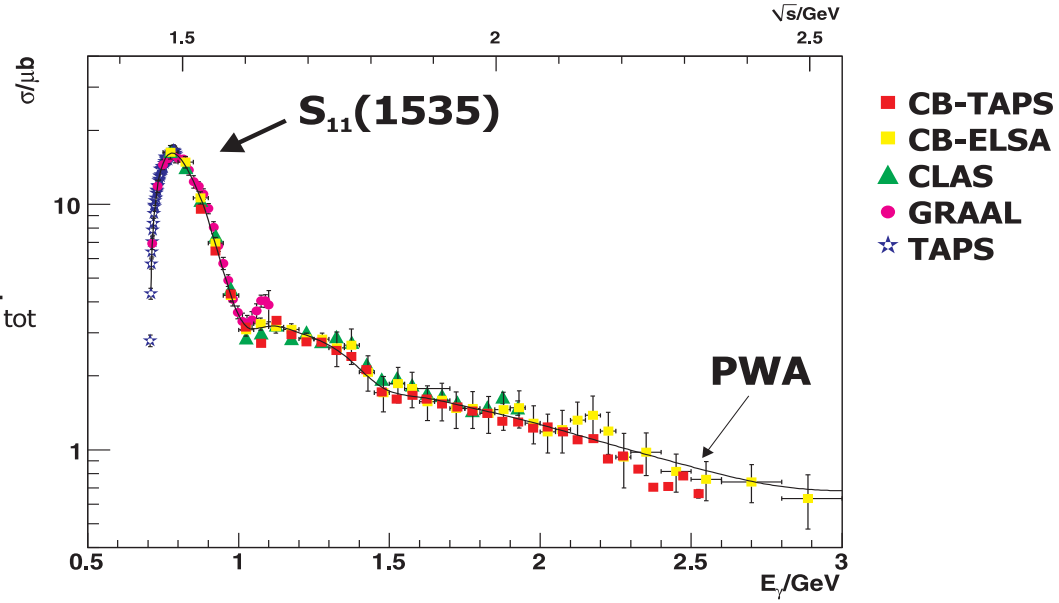
$\eta \to 3\pi^0$



$d\sigma/d\Omega$

PWA

σ_{tot}

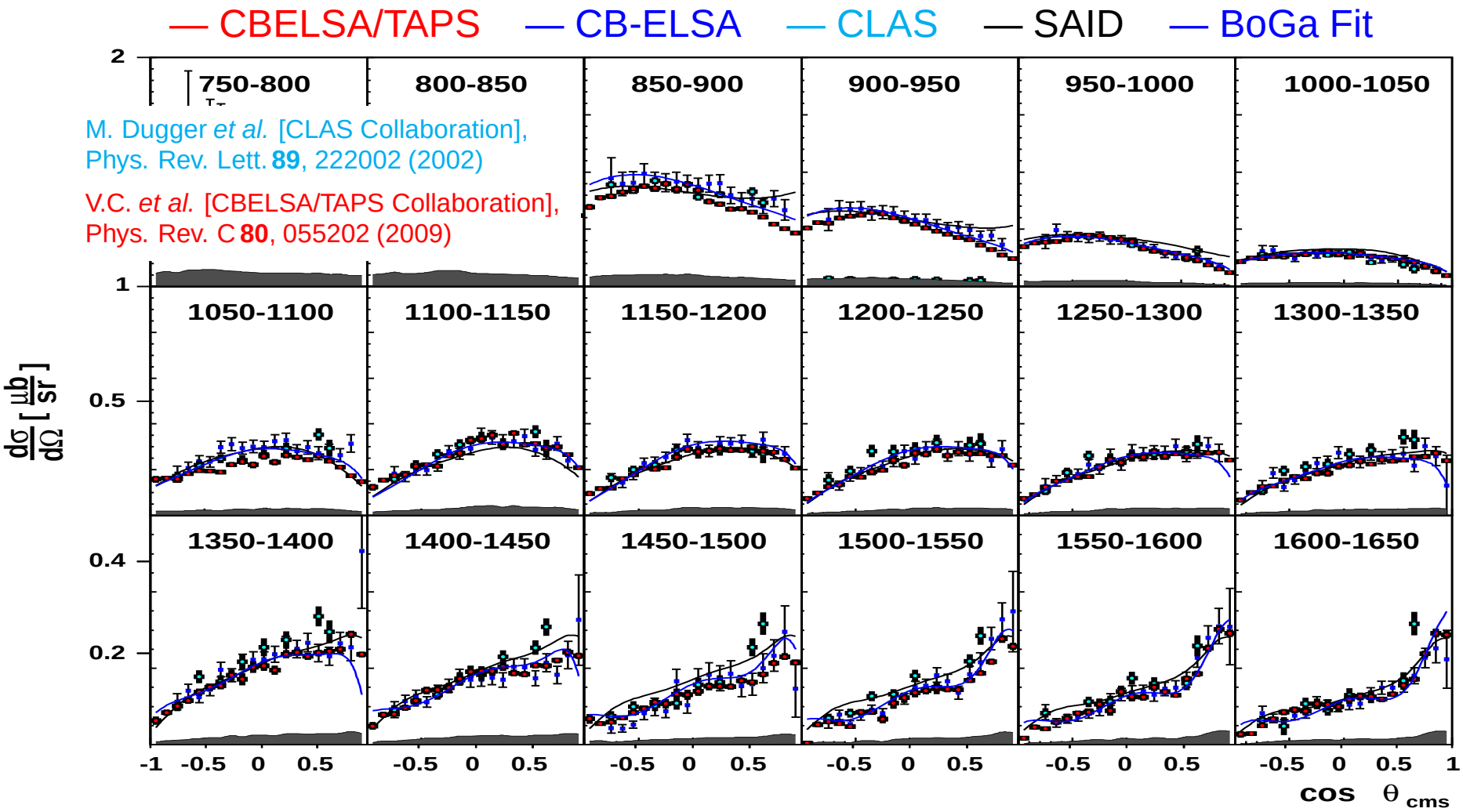


Only nucleon resonances can contribute

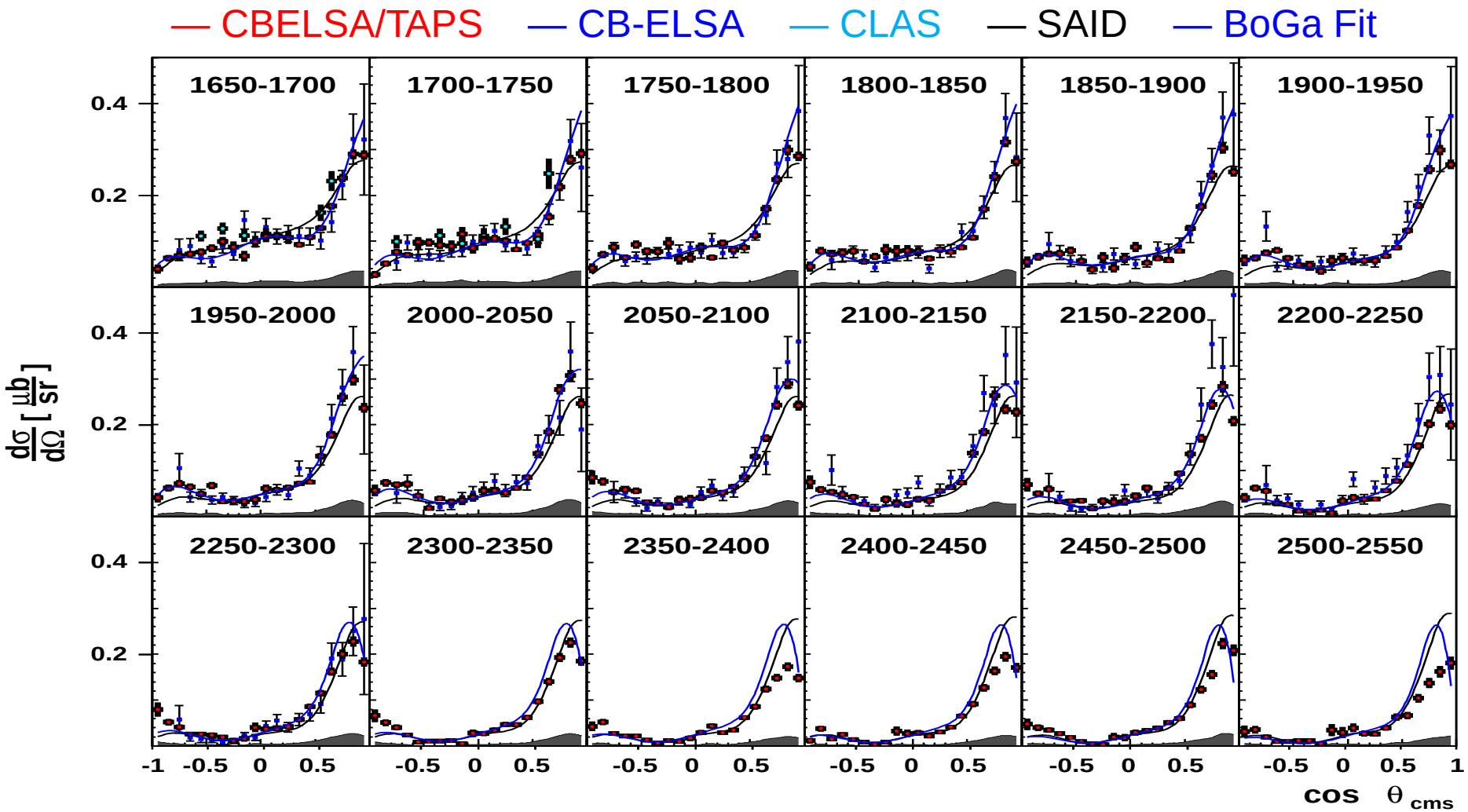
- $N(1535)S_{11}$, $N(1520)D_{13}$, $N(1650)S_{11}$, $N(1680)F_{15}$, $N(1720)P_{13}$, ..., ρ- and ω-t-channel exchange
- New resonance $N(2070)D_{15}$: $m = (2068 \pm 22)$ MeV/c^2
  $\Gamma = (295 \pm 40)$ MeV/c^2

  (needs confirmation in polarization experiments)

Photoproduction of η Mesons off the Proton

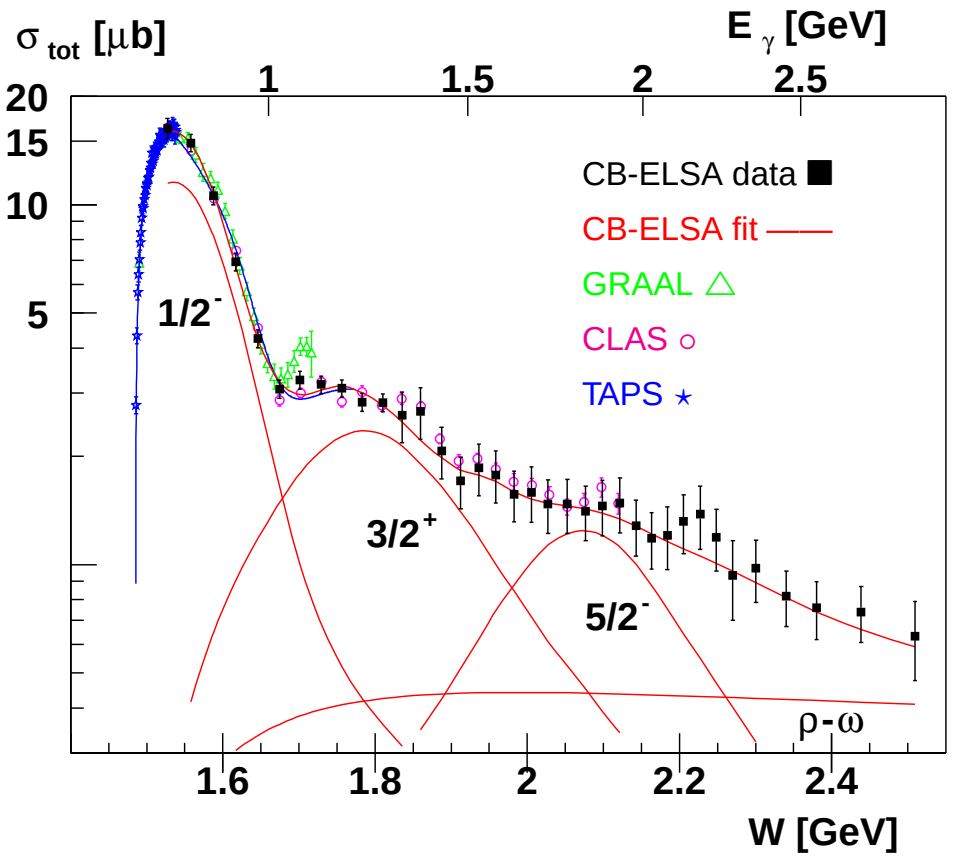


Photoproduction of η Mesons off the Proton



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!

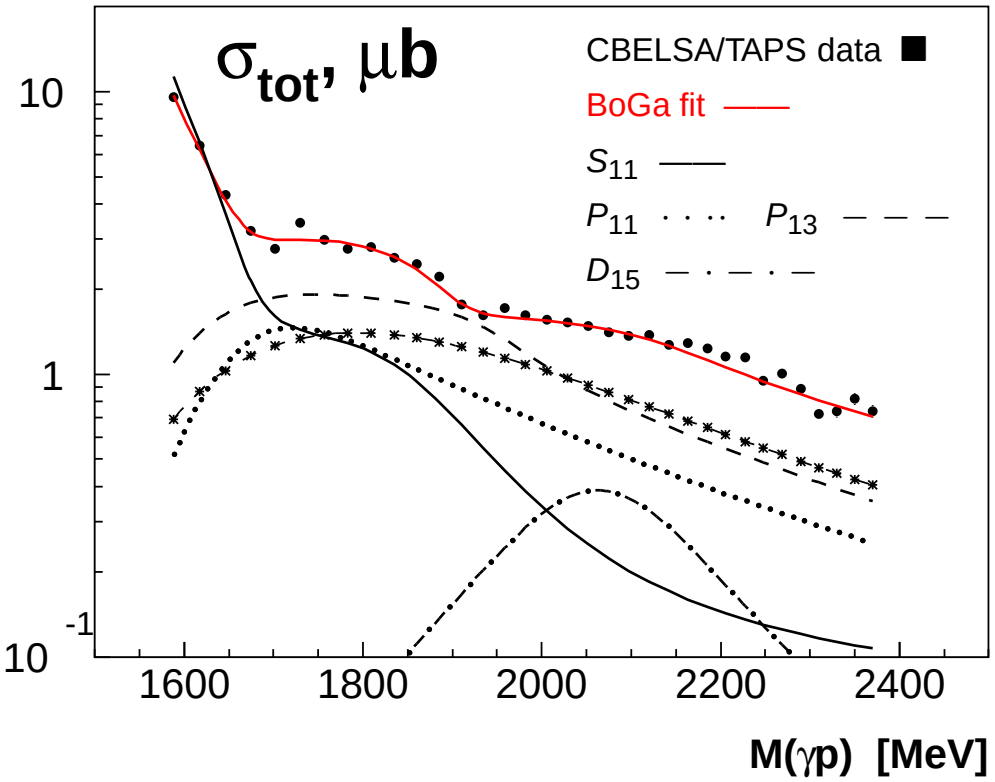
Bonn-Gatchina (PWA) group: Hint for N^* resonance $(2070)D_{15}$

(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))

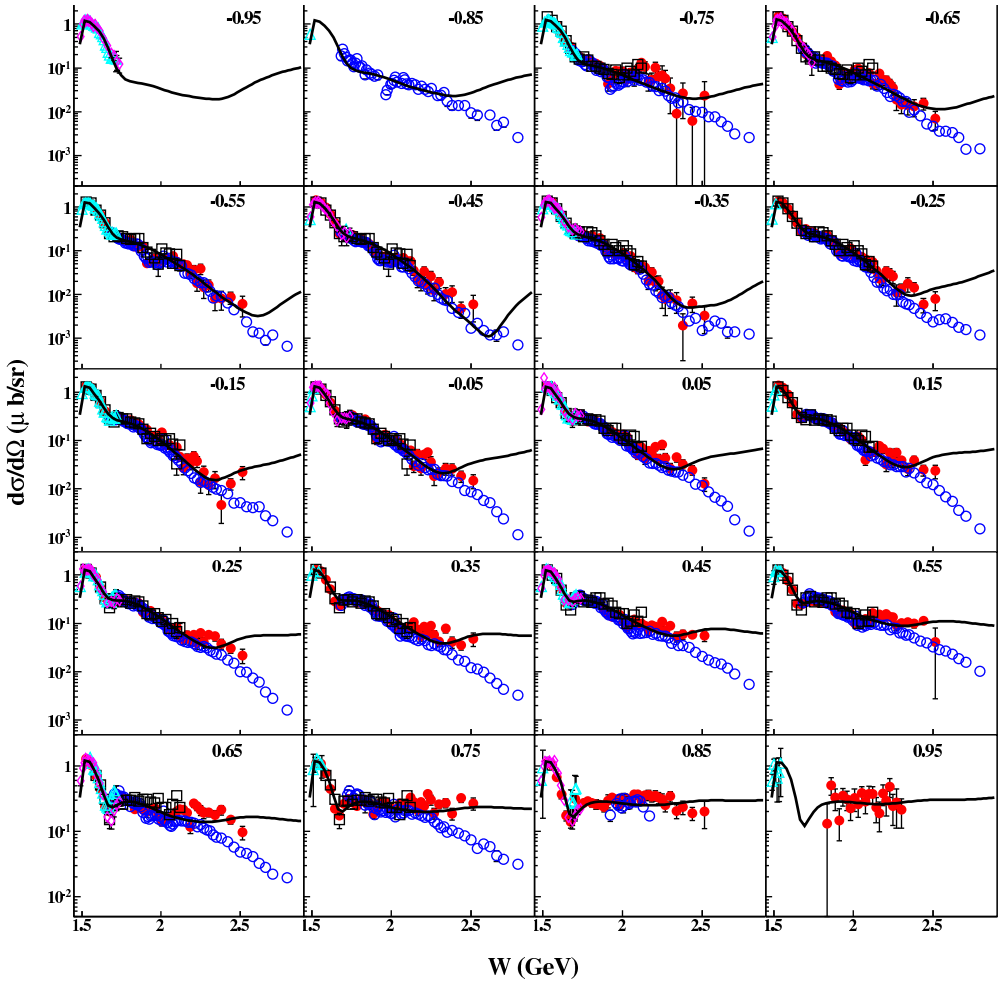
1. Confirmed in 2009 analysis!
2. $N(1720)P_{13} \to p\,\eta$?
   ➜ η-MAID:
   $N(1710)P_{11} \to p\,\eta$ significant!

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



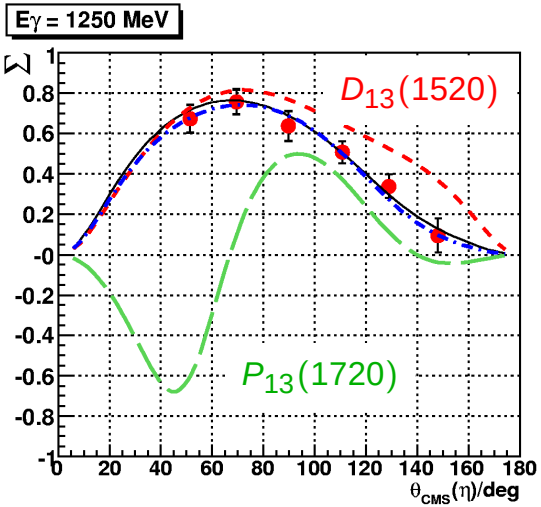
Big discrepancies at high energies and in the forward direction

➜ CLAS PWA in the works

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

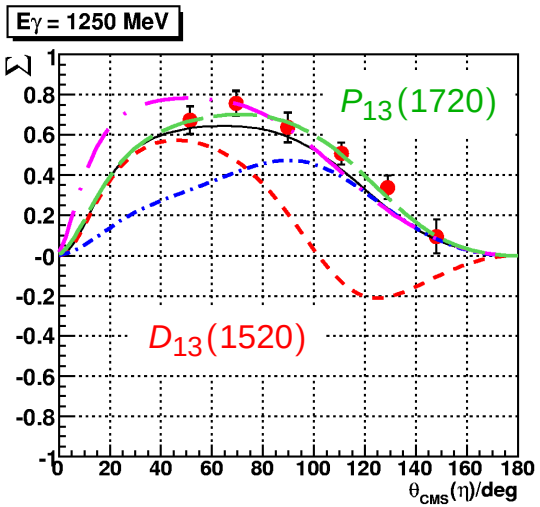
M. Williams *et al.* [CLAS Collaboration], Phys. Rev. C **80**, 045213 (2009)

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



BoGa-PWA

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



η-MAID

Further spin observables available

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

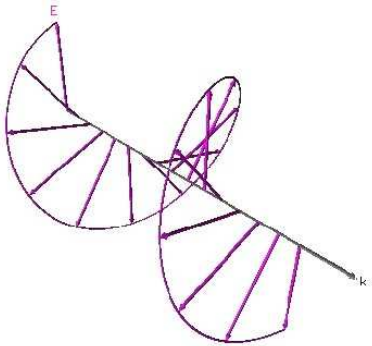
H, F, T, and P from future experiments with transverse target polarization (2011-)

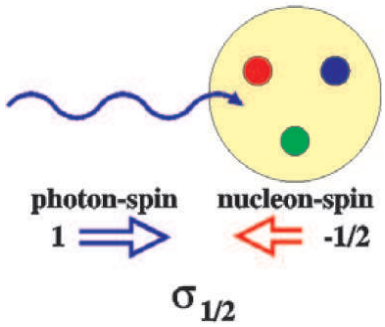
[CBELSA/TAPS Collaboration], EPJ A **80**, 055202 (2009)

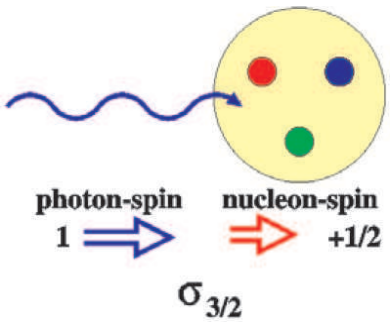
Predictions for E "Helicity Difference"

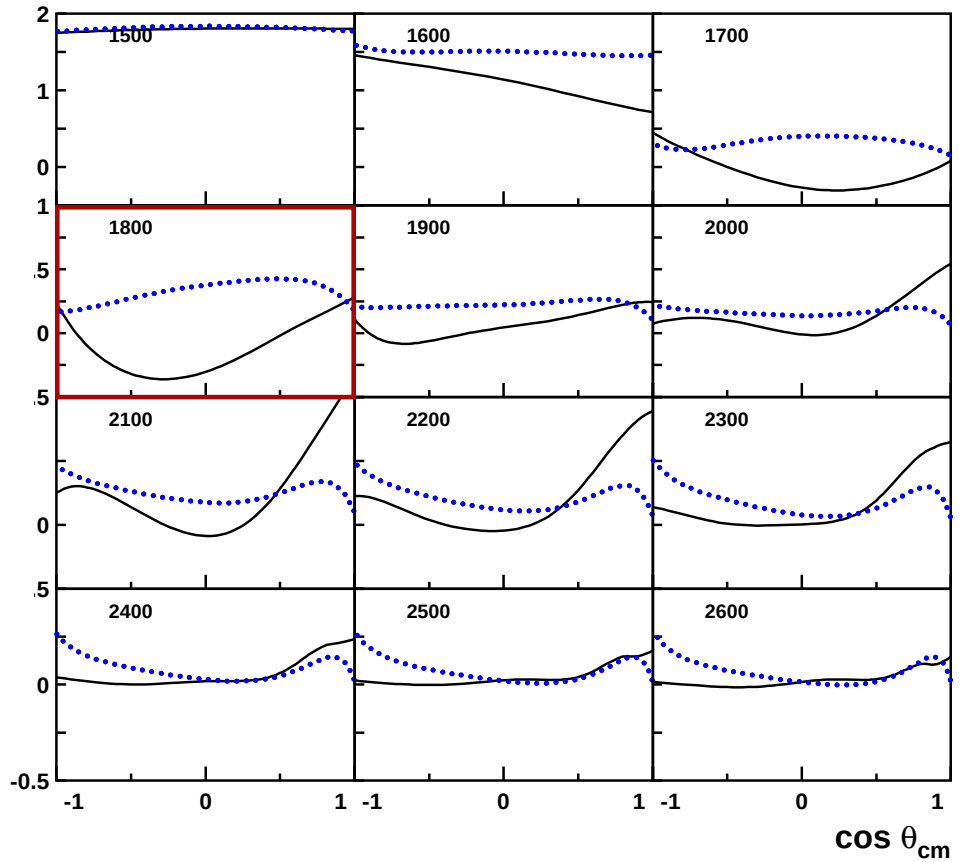
η-MAID / BoGa-PWA

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

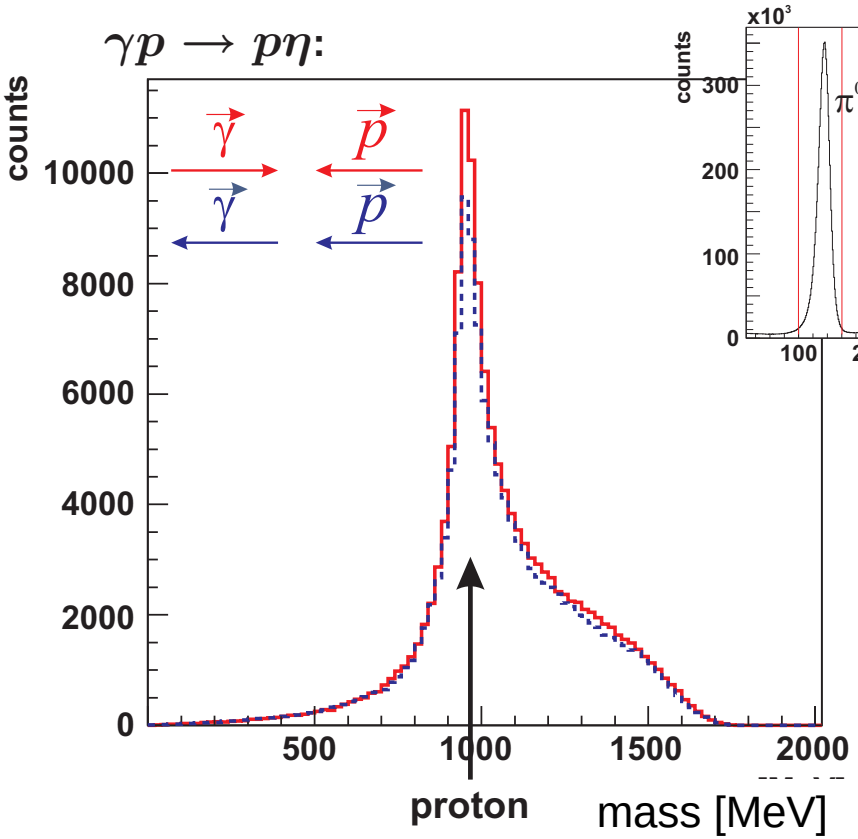


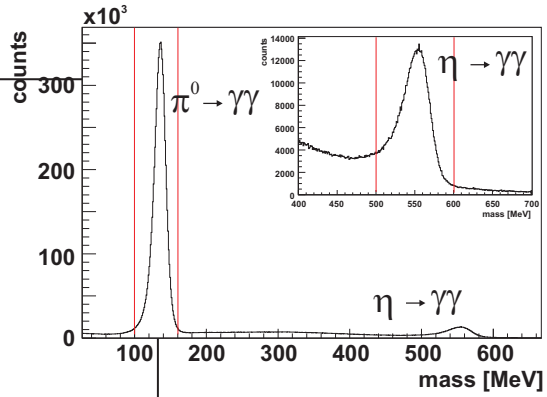




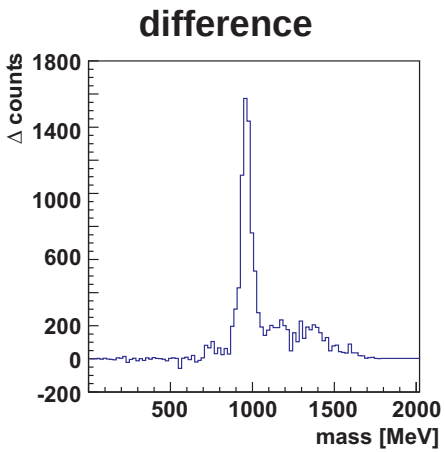


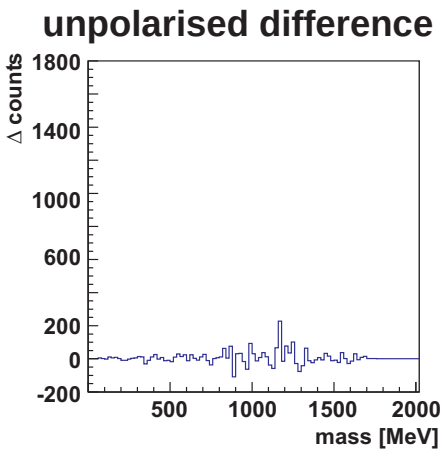
First Asymmetries Observed at ELSA





$\gamma p \rightarrow p\gamma\gamma$

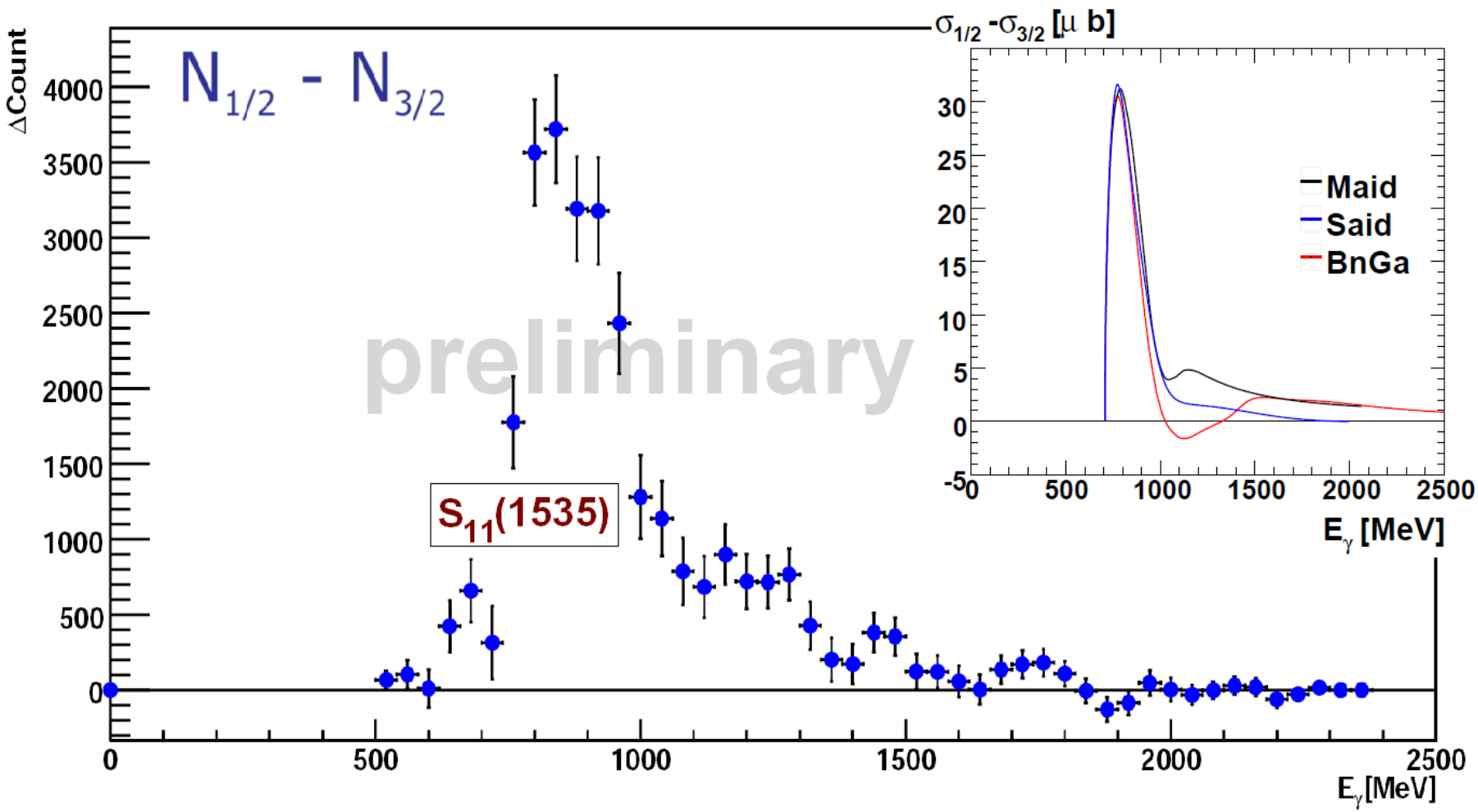




$\Rightarrow$ **First asymmetries observed**

U. Thoma, HADRON 2009

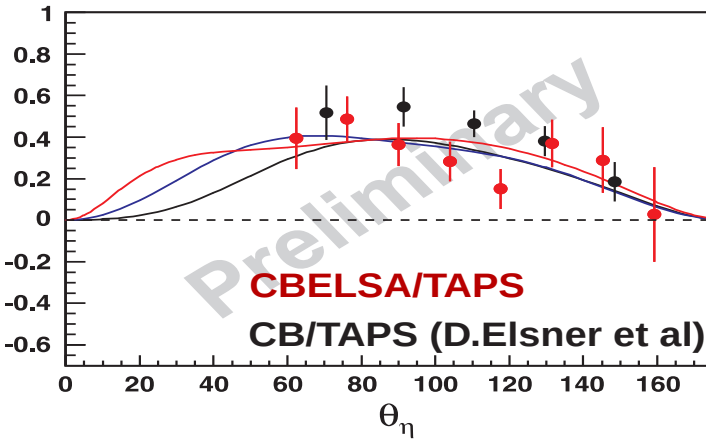
Clear Asymmetries Observed in $\gamma p \longrightarrow p\,\eta$



U. Thoma, HADRON 2009

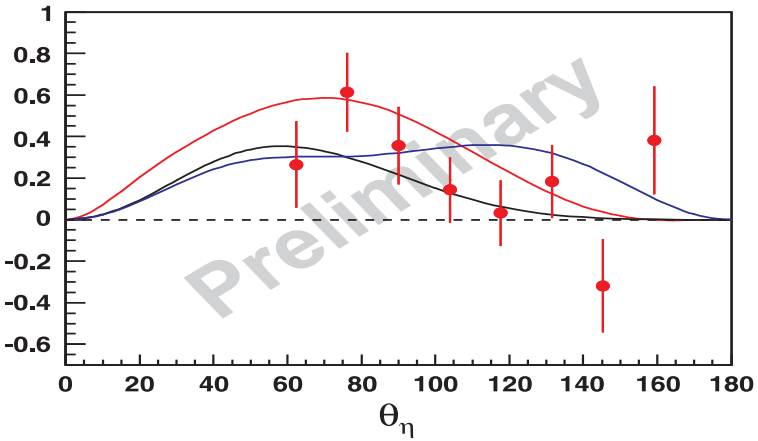
E_γ=950±50 MeV

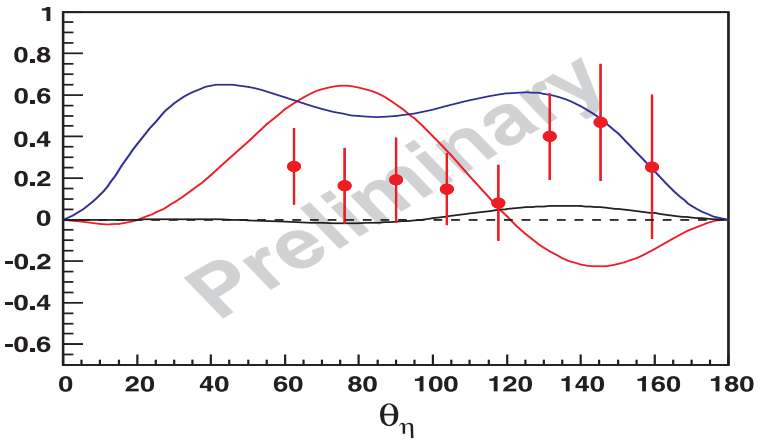
Σ:



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

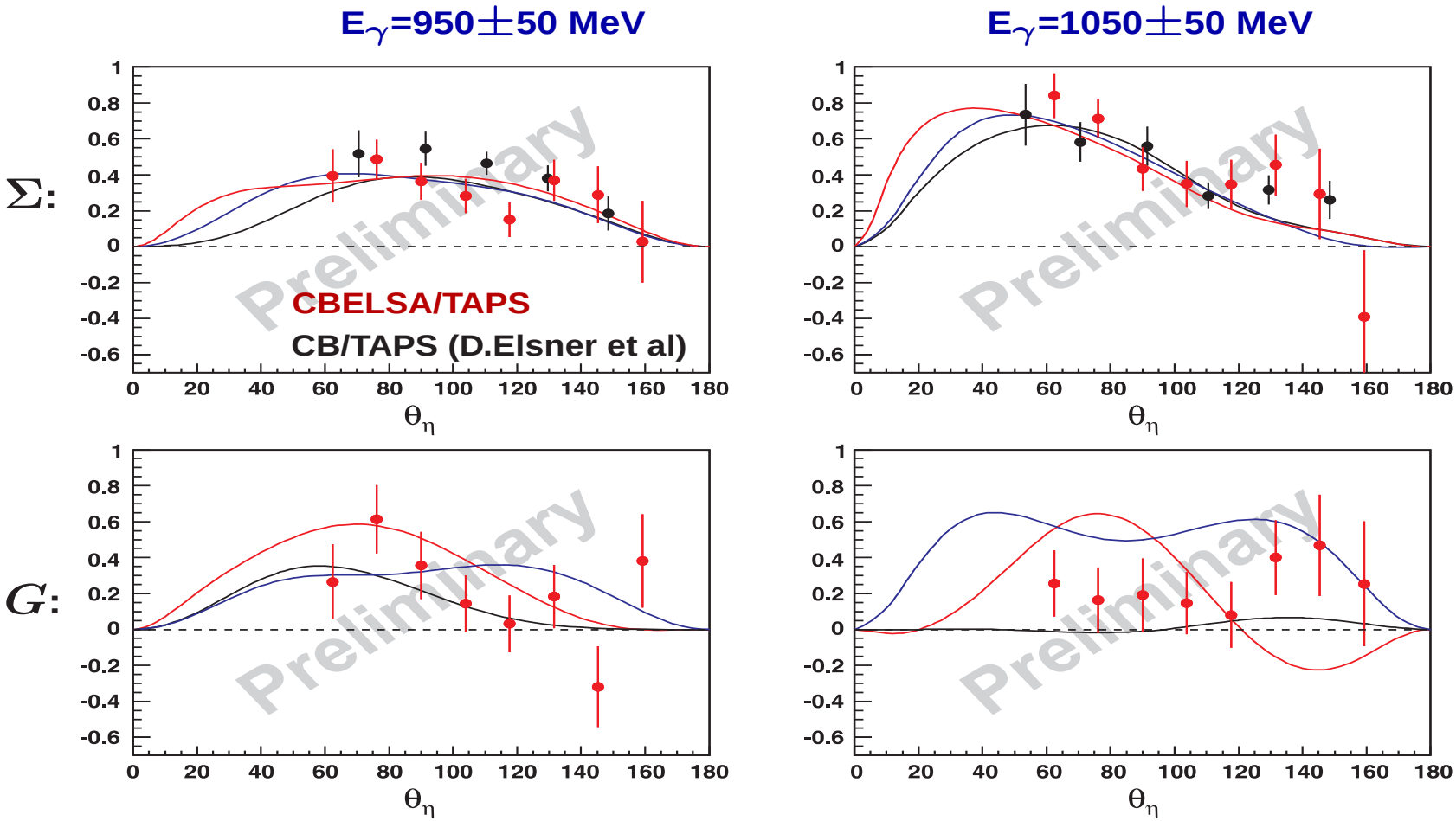
G:





– MAID – BoGa – SAID

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



↔ **preliminary dilution factor included**

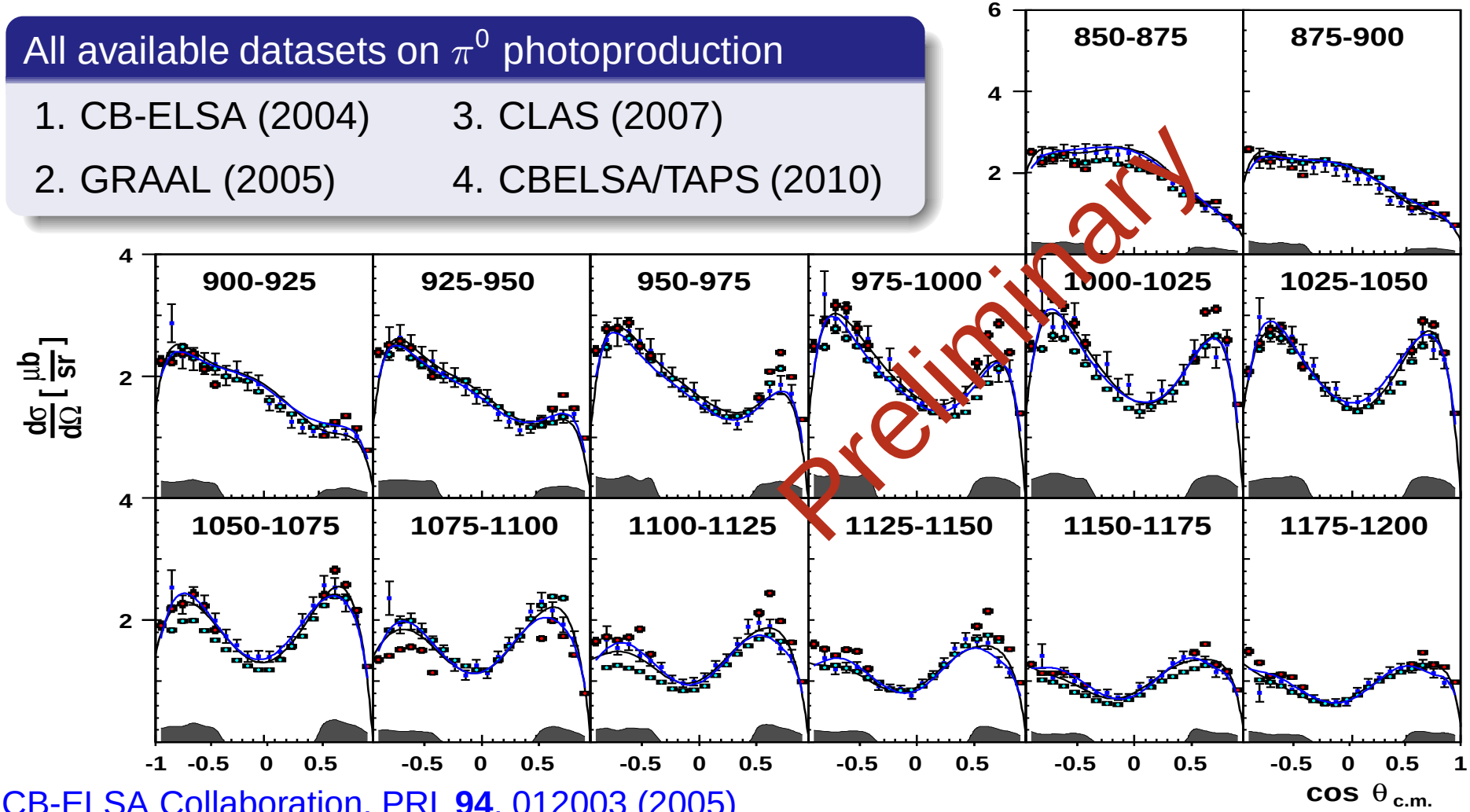
– MAID – BoGa – SAID

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

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

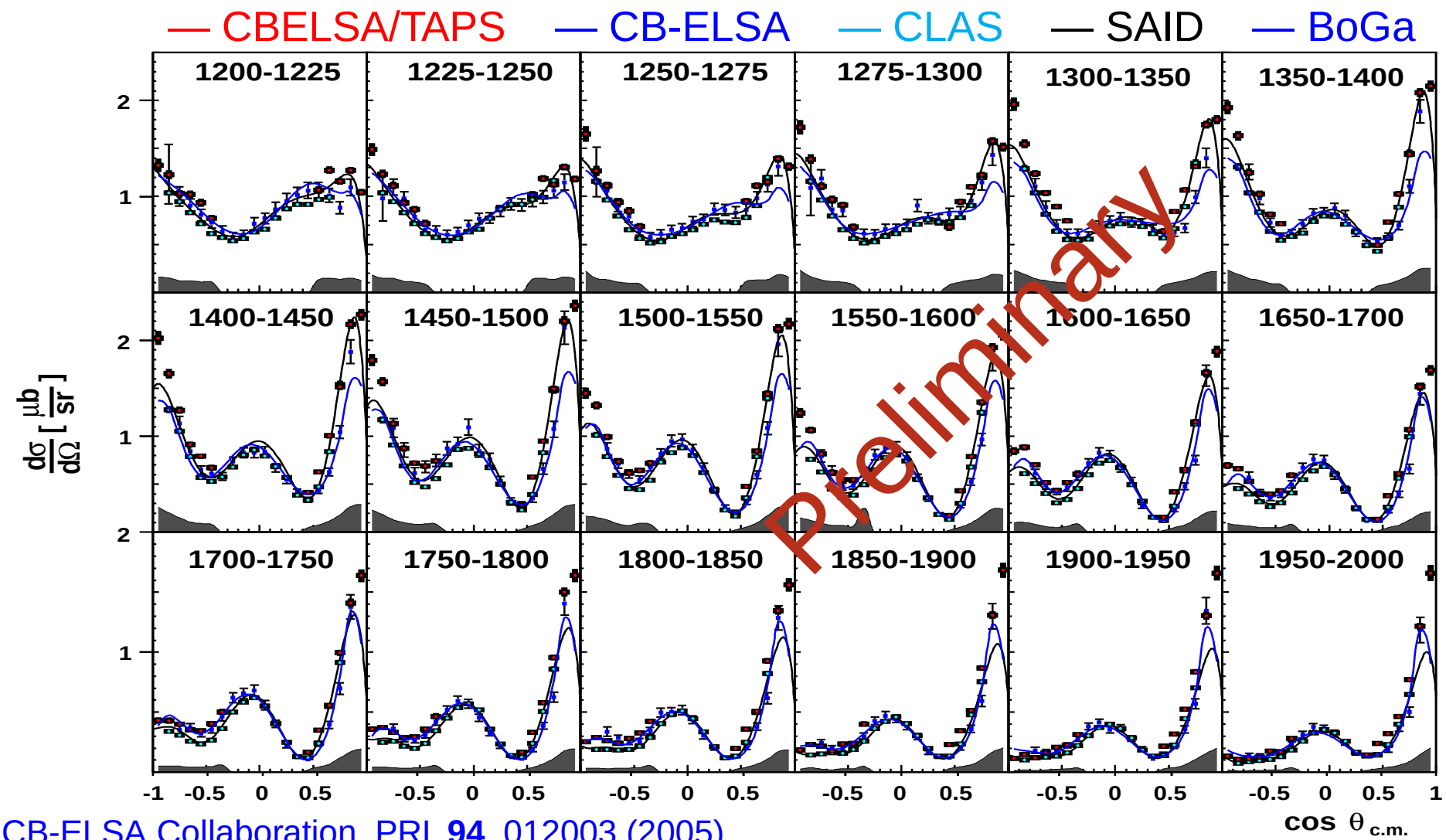
All available datasets on π^0 photoproduction

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



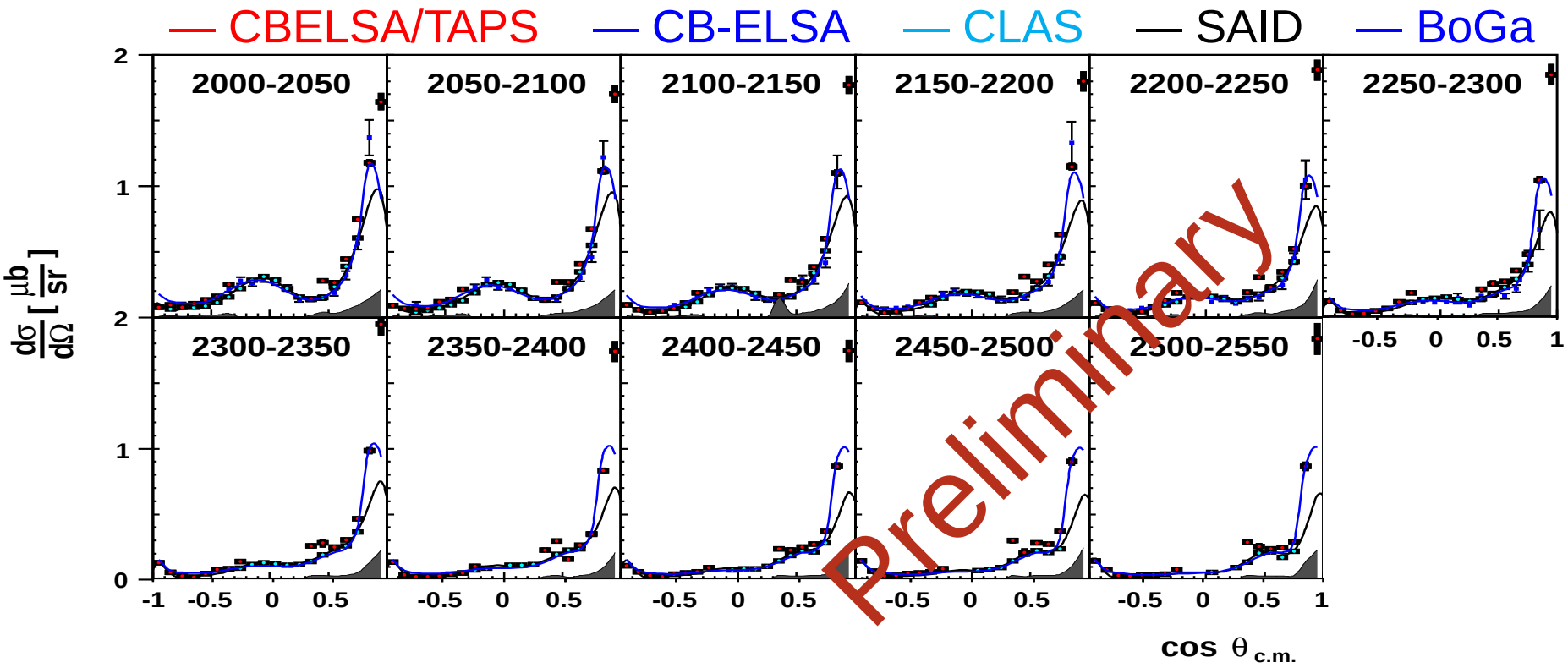
CB-ELSA Collaboration, PRL **94**, 012003 (2005)

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



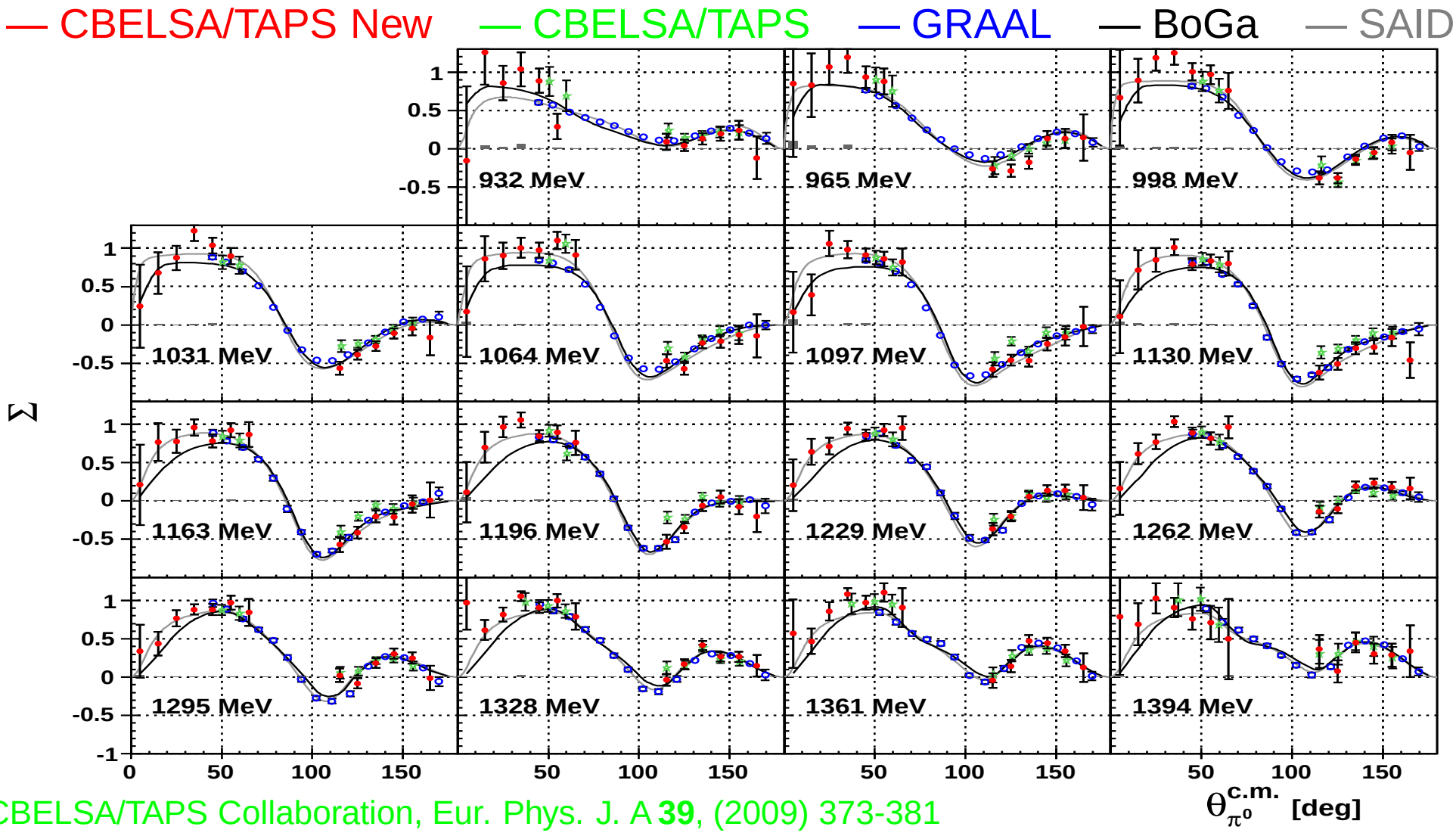
CB-ELSA Collaboration, PRL **94**, 012003 (2005)

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



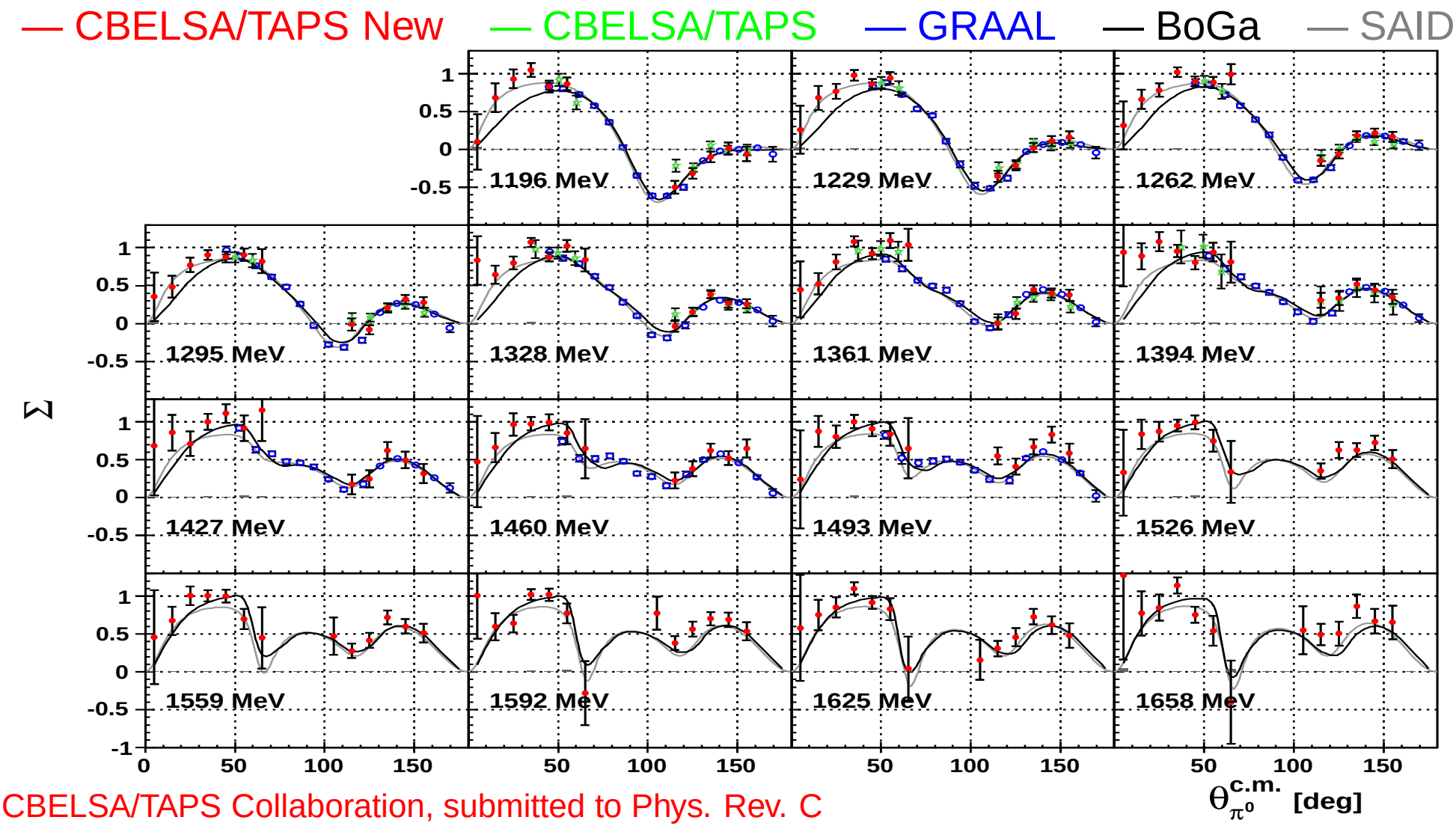
CB-ELSA Collaboration, PRL **D94**, 012003 (2005)

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



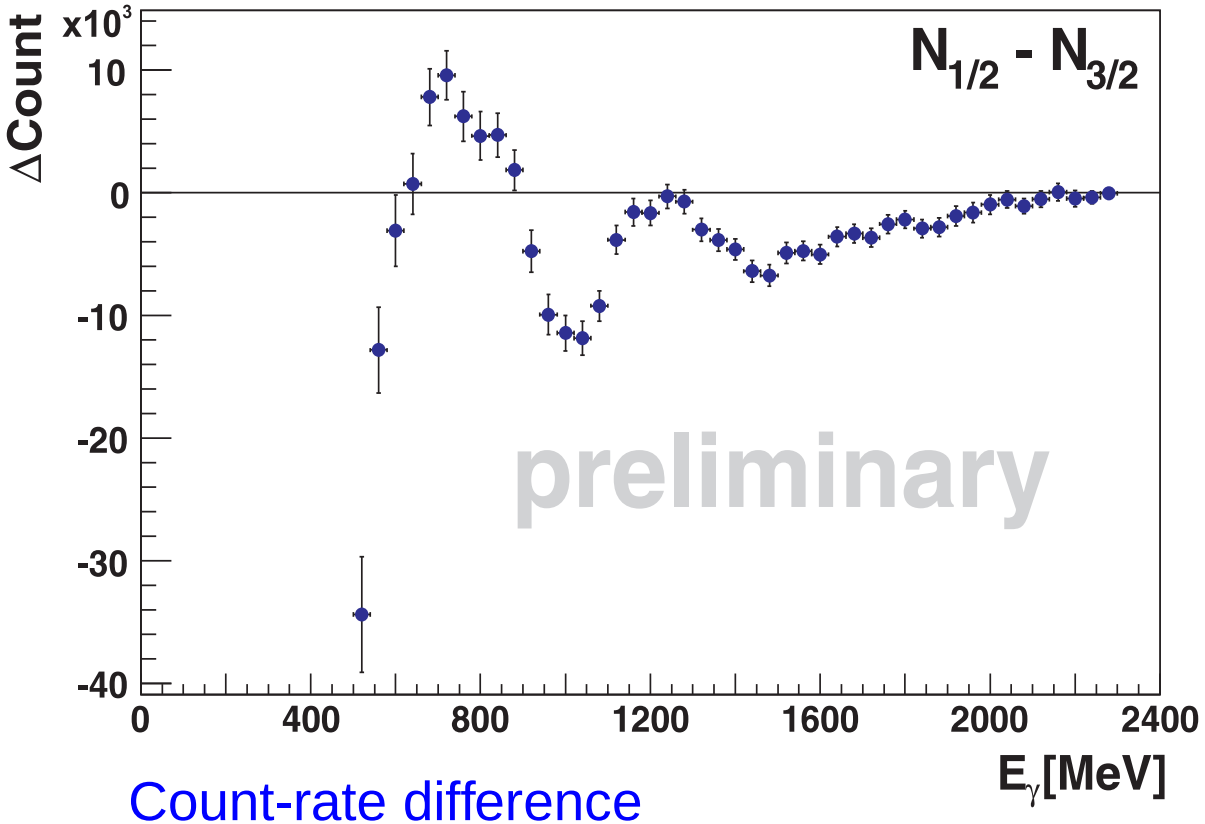
CBELSA/TAPS Collaboration, Eur. Phys. J. A **39**, (2009) 373-381

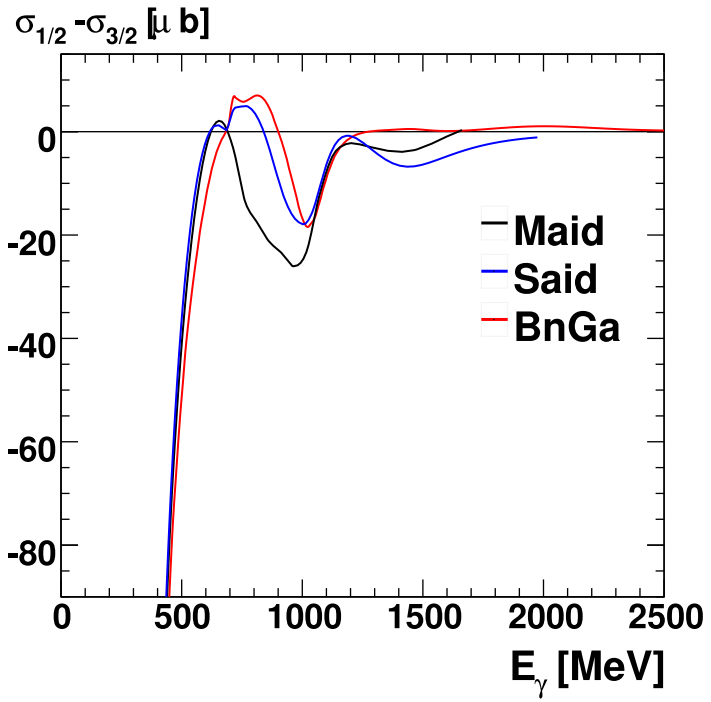
Beam Asymmetries for $\gamma p \rightarrow p\pi^0$



CBELSA/TAPS Collaboration, submitted to Phys. Rev. C

Helicity Difference E

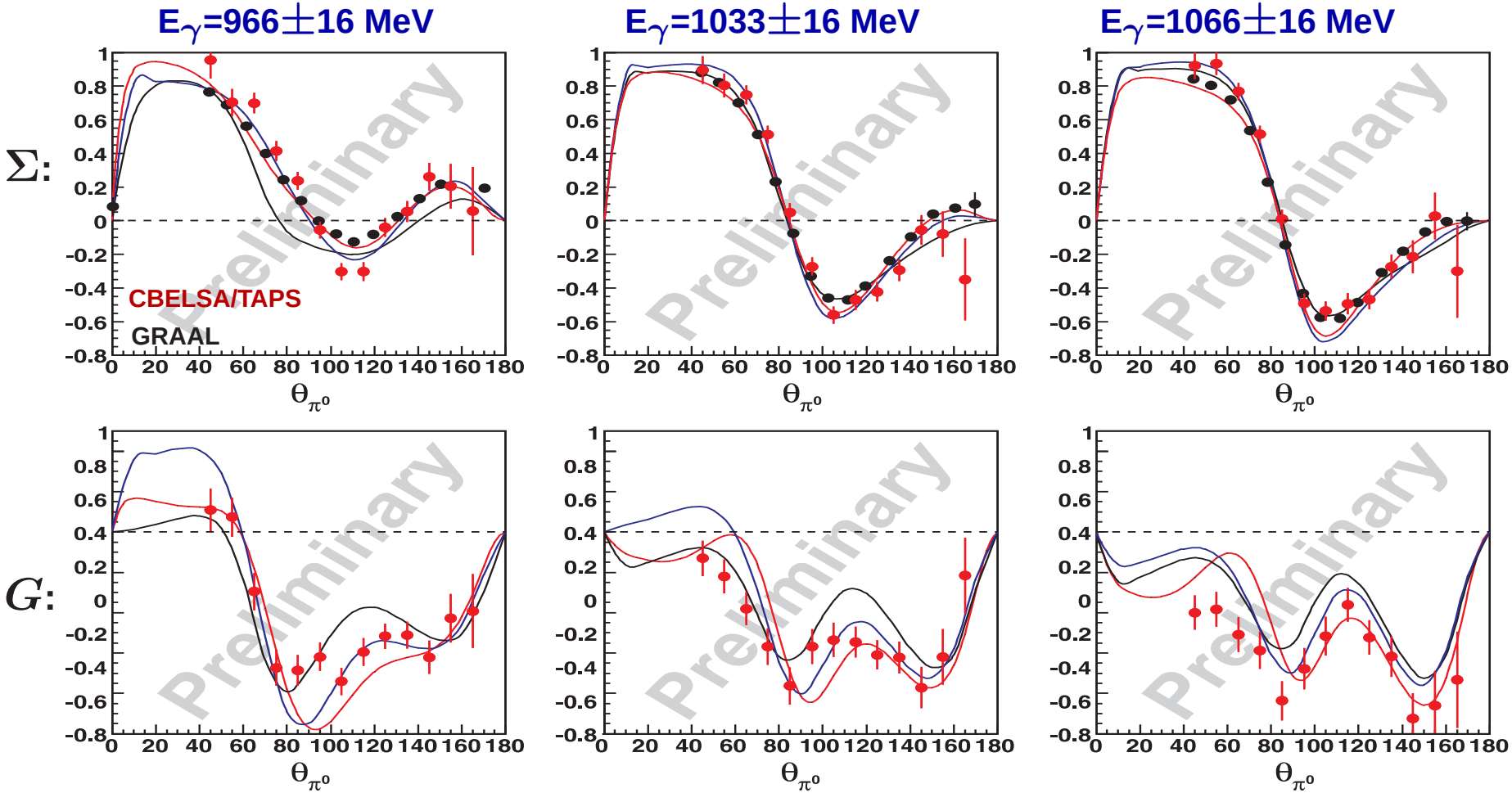




Count-rate difference

- Preliminary acceptance correction
- Important information for PWA

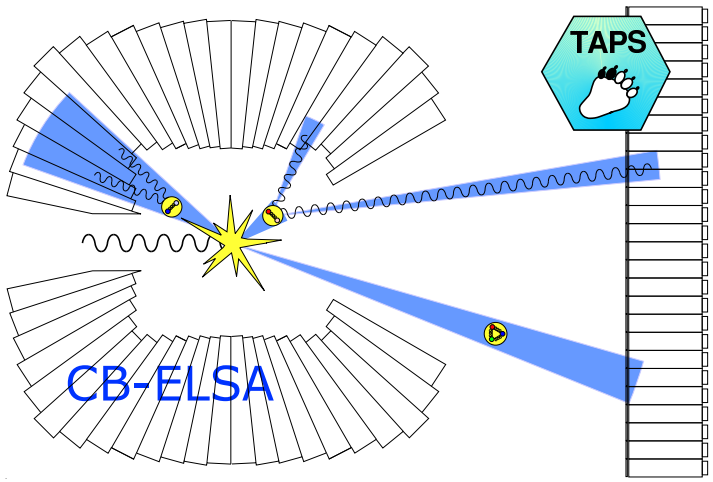
Observable G



– MAID – BoGa – SAID

↔ **preliminary dilution factor included**

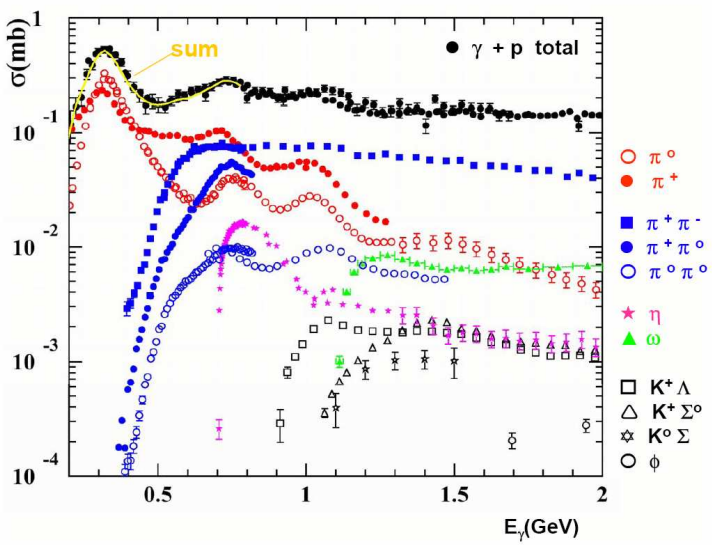
Outline



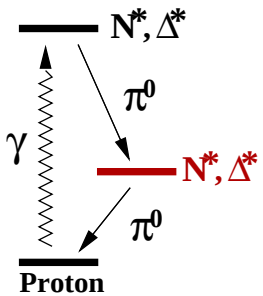
Beam-Target Polarization Observables

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

$\Leftarrow$ 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

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

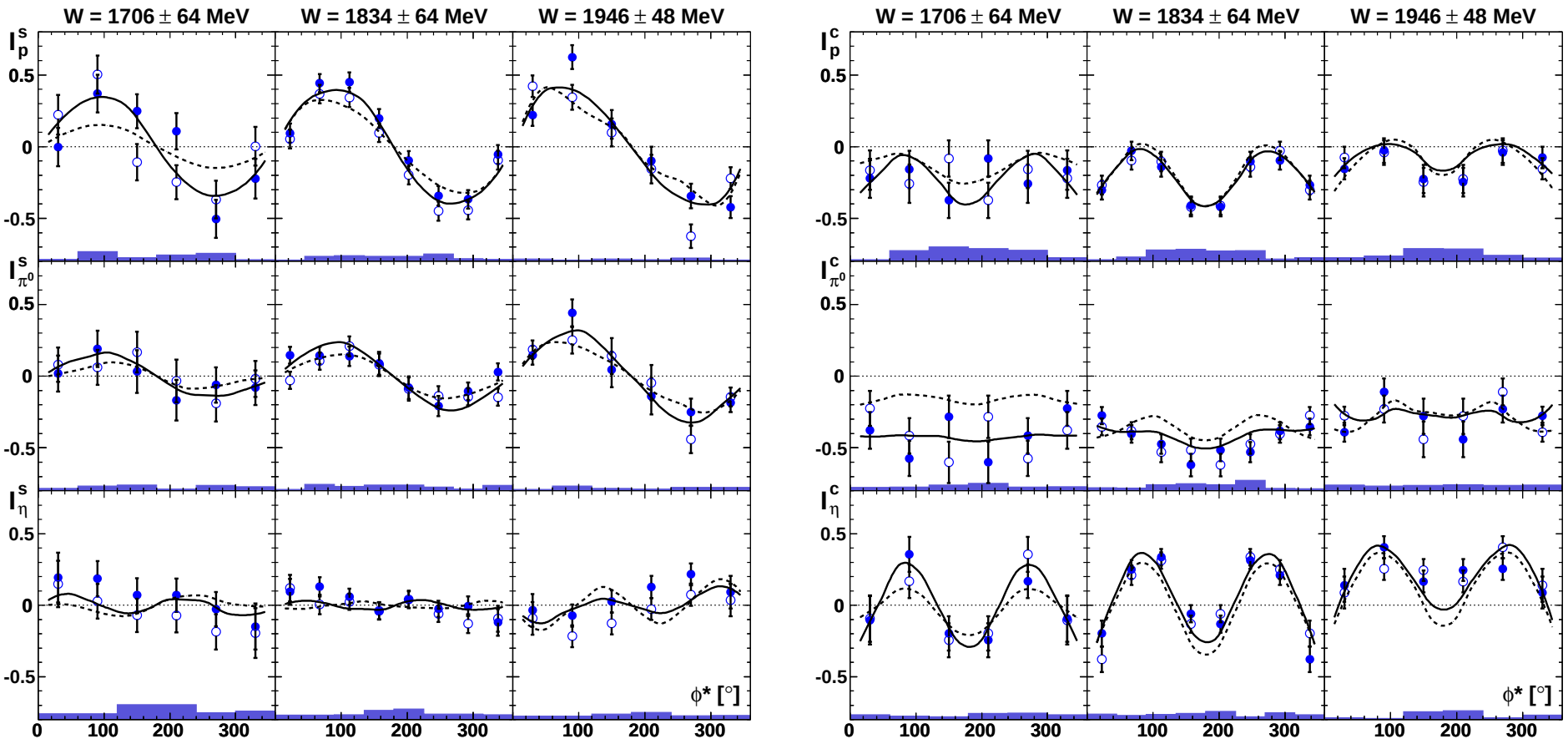
$\Leftarrow$ Single-Meson Final States (7 Observables)

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

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

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

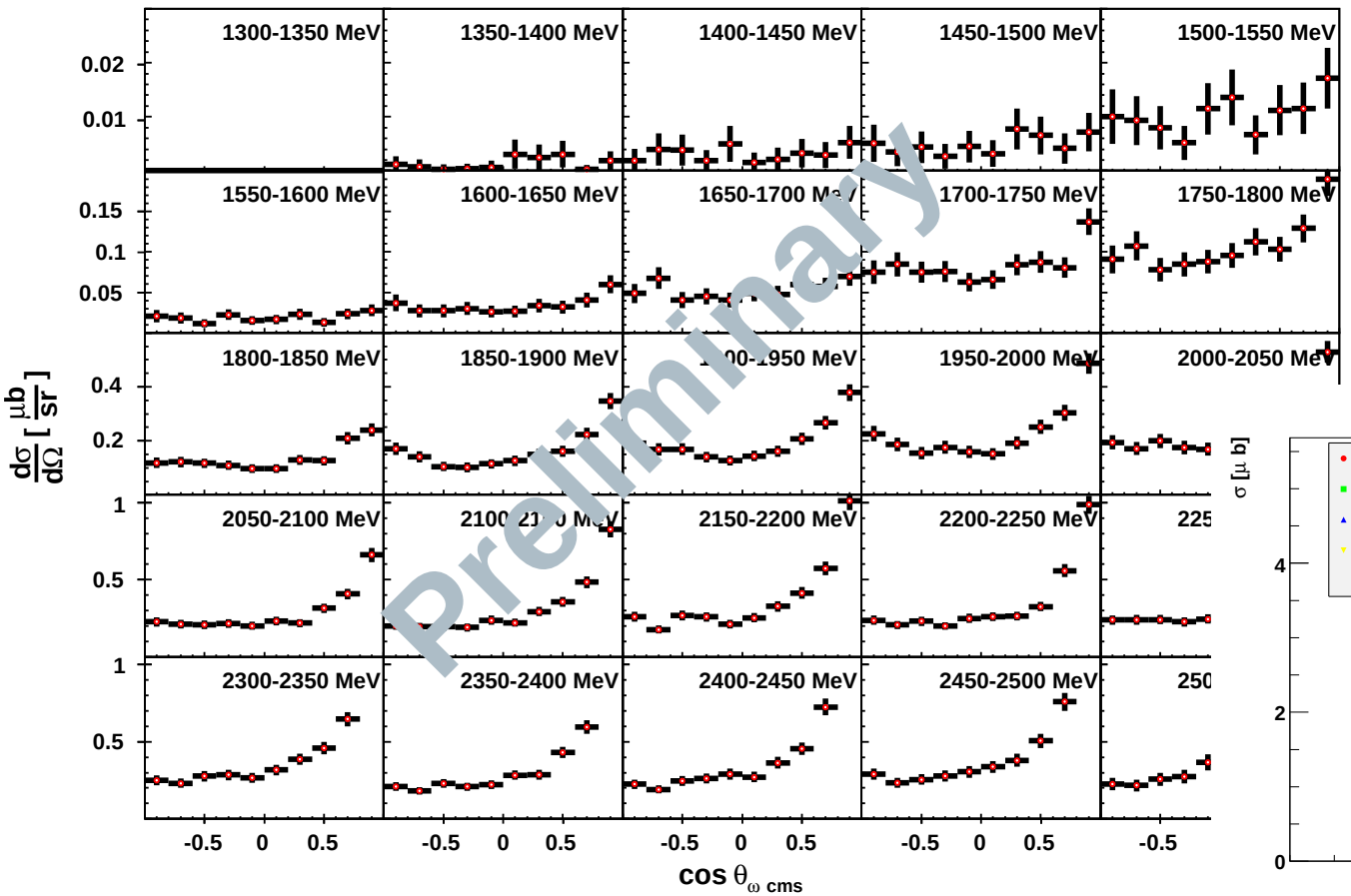
I^S I^C

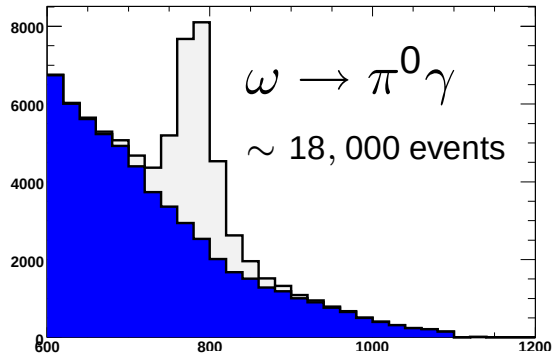


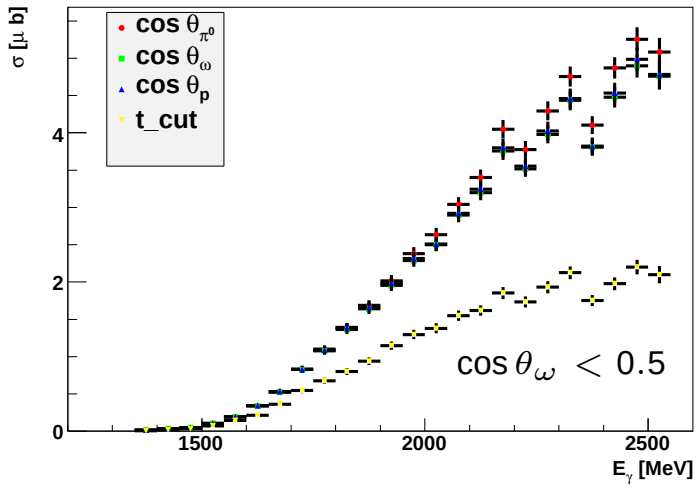
CBELSA/TAPS Collaboration, Phys. Lett. B **687**, 11 (2010)

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

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

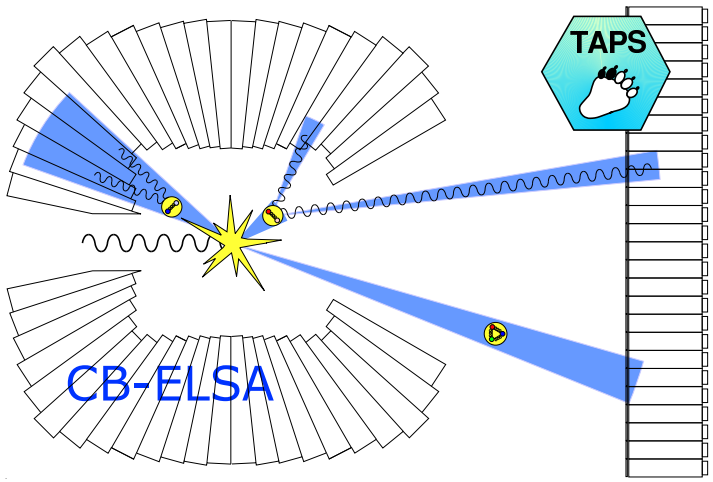






A. Wilson, Florida State University

Outline



Summary and Outlook

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

- 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!