Search for new Baryon States at ELSA

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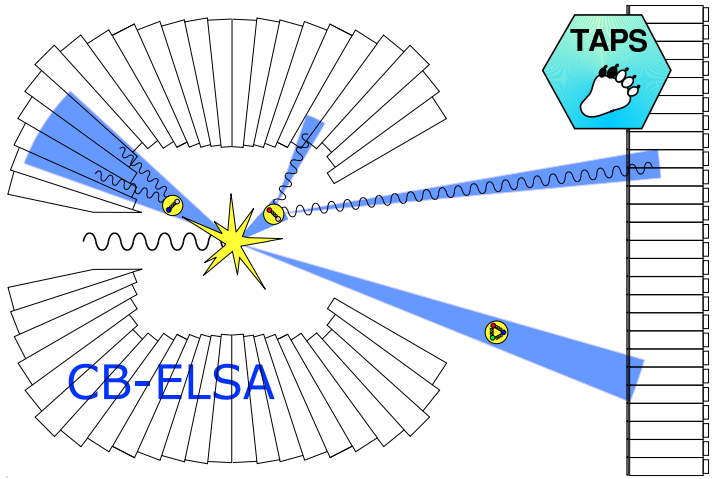
Tallahassee, FL

Narrow Nucleon Resonances:
Predictions, Evidences, Perspectives

Edinburgh, June 9th, 2009

Outline



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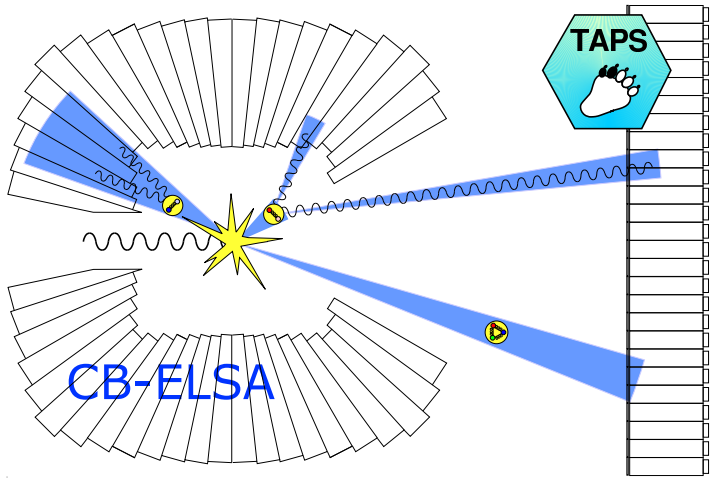


One of the Main Goals of the N^* Program ...

Search for *missing* or yet unobserved resonances

Quark models predict many more baryons than have been observed

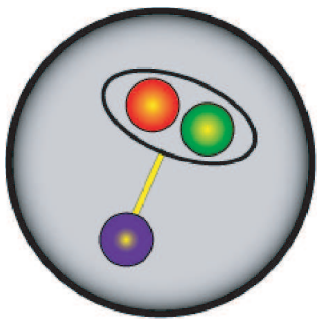
	****	***	**	*
N Spectrum	11	3	6	2
Δ Spectrum	7	3	6	6

$\Rightarrow$ 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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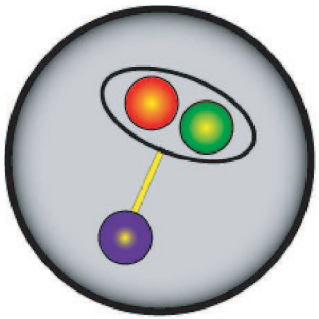

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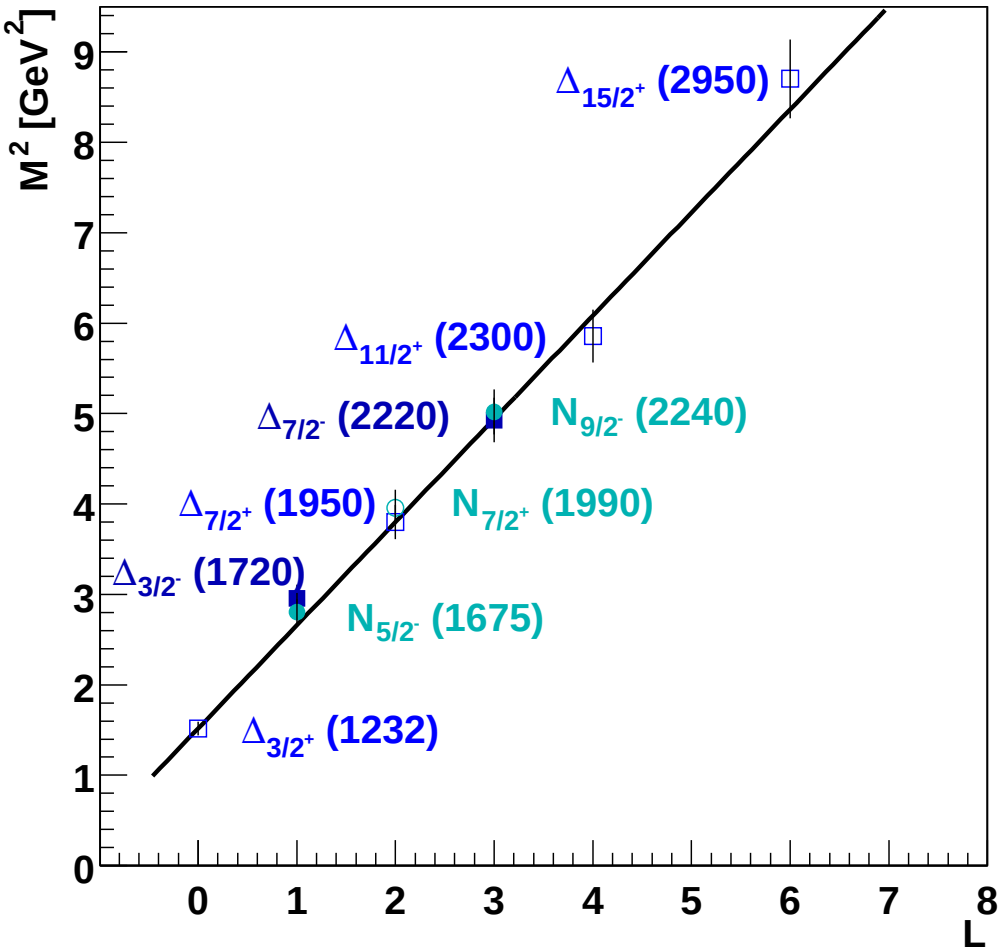
Possible Quark-Diquark Structure?



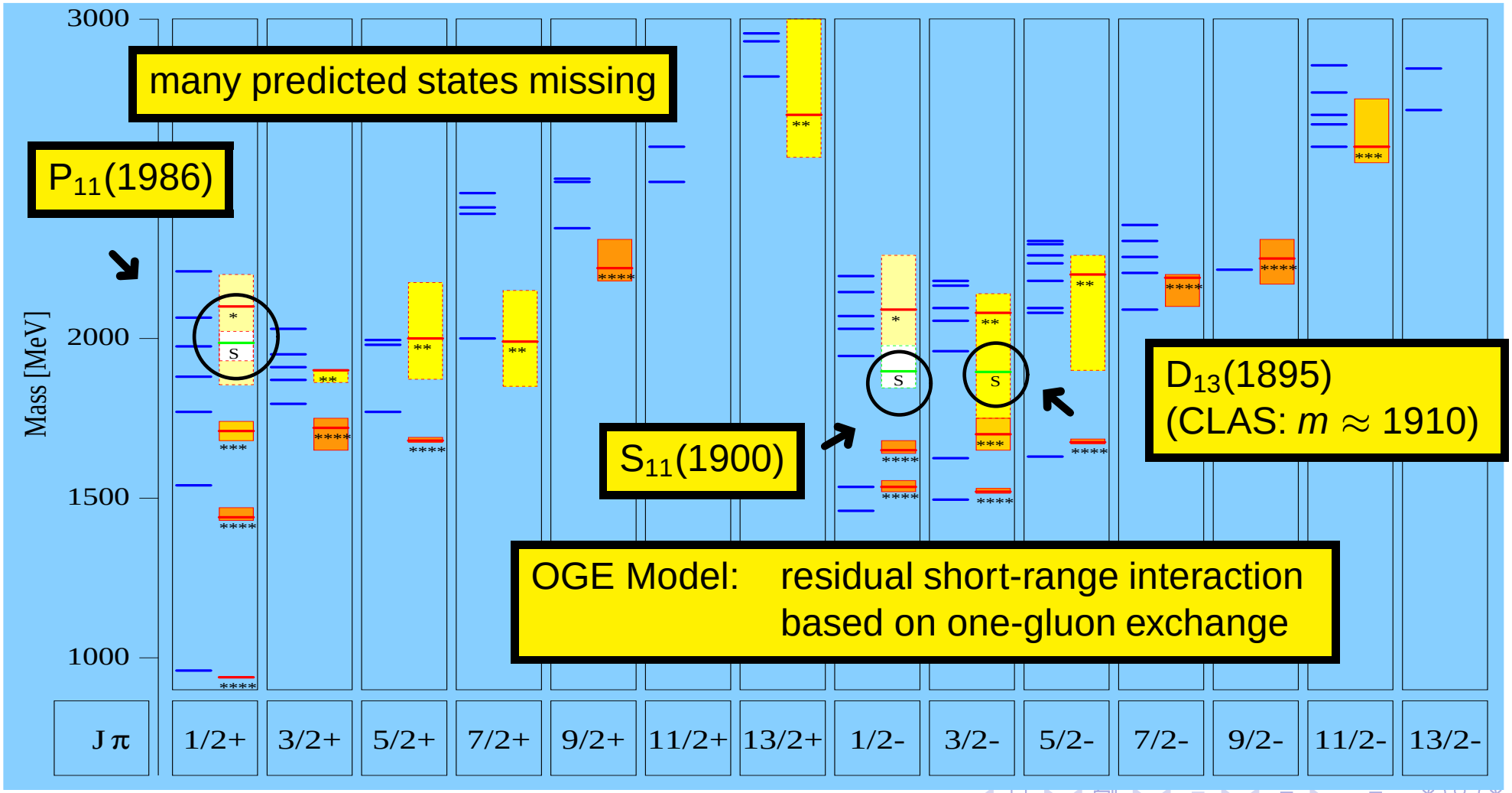
Regge trajectory for Δ^* states with intrinsic spin $S = 1/2$ and $S = 3/2$, and for N^* states with spin $S = 3/2$ (M^2 versus L, not J)

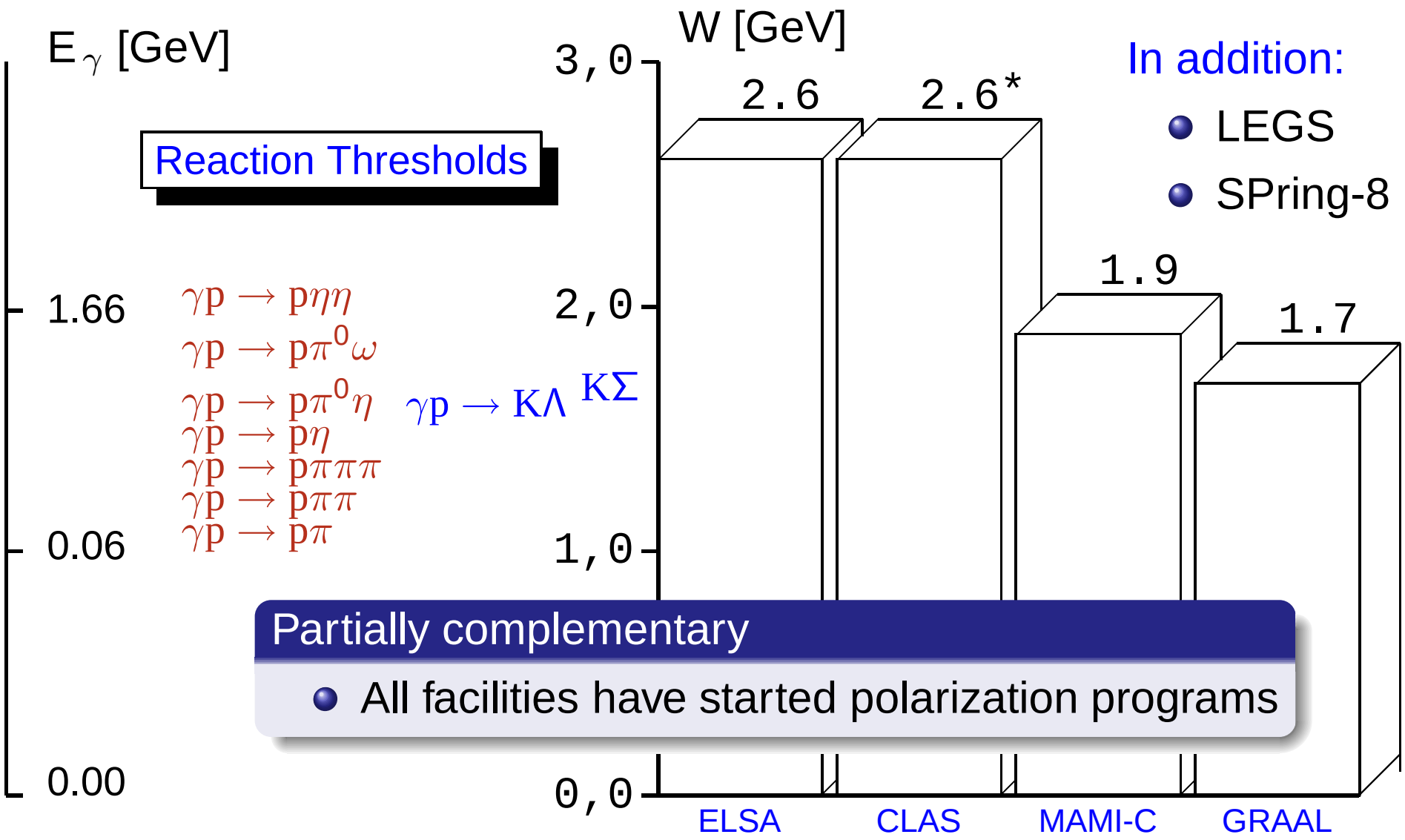
1. Common Regge trajectory for N/Δ states with $S = 3/2$
2. Not shown, but slope of the Regge trajectory for meson and Δ excitations is identical

➜ Are baryons quark-diquark excitations?

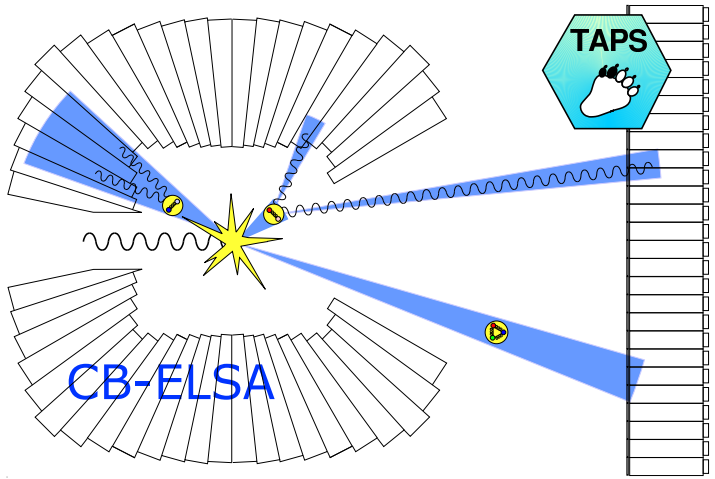
Nucleon Resonances: Status of 2001

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

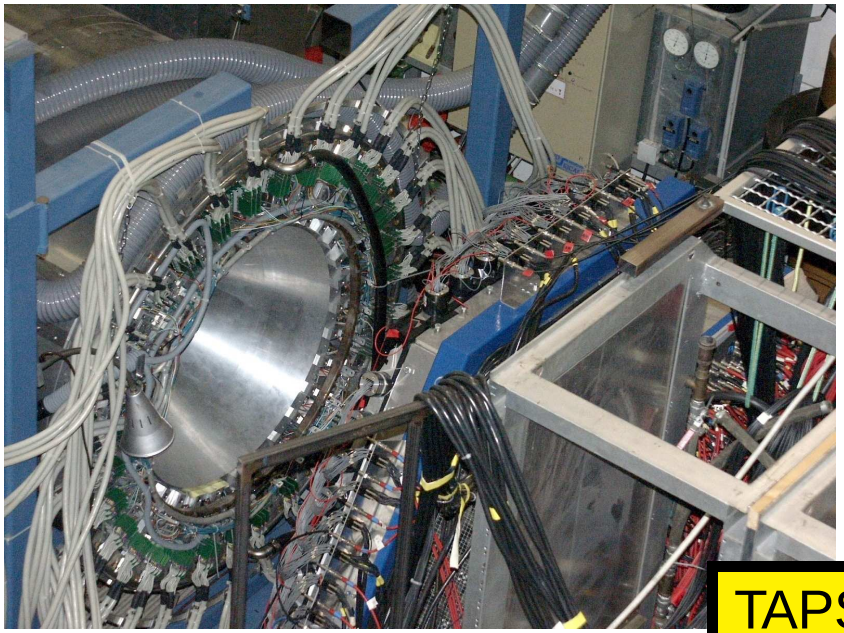



E$_\gamma$ [GeV]
W [GeV]
Reaction Thresholds
1.66
0.06
0.00
$\gamma p \to p\eta\eta$
$\gamma p \to p\pi^0\omega$
$\gamma p \to p\pi^0\eta$
$\gamma p \to p\eta$
$\gamma p \to p\pi\pi\pi$
$\gamma p \to p\pi\pi$
$\gamma p \to p\pi$
$\gamma p \to K\Lambda$
$K\Sigma$
3,0
2,0
1,0
0,0
2.6
2.6*
1.9
1.7
ELSA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

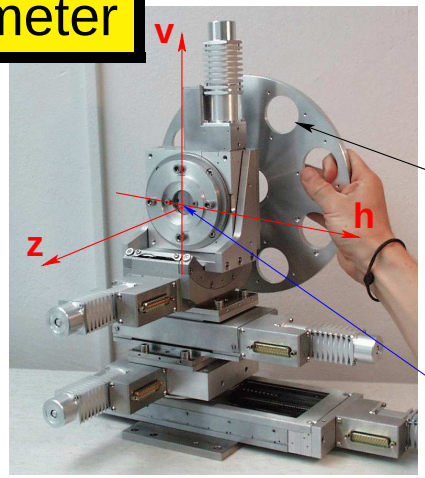
Outline



The CB-ELSA/TAPS Experiment



Goniometer



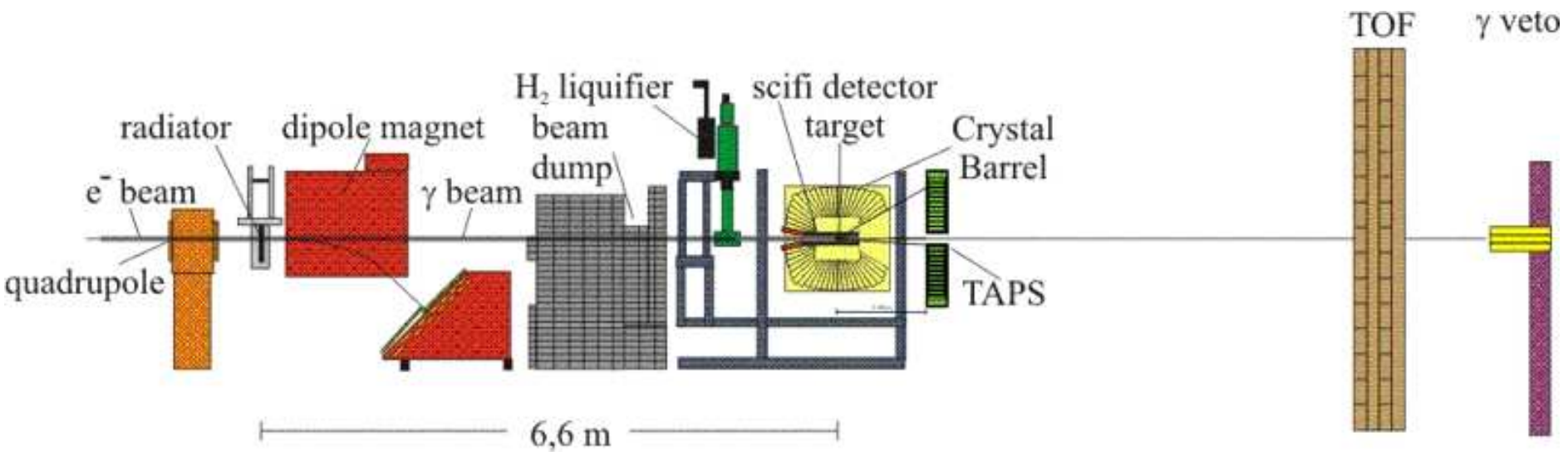
Sep. 2002 – Dec. 2003

- (un)polarized beam
- liquid H_2, deuterium
- solid targets

TAPS

- 512 BaF Crystals
- Forward detector
  - High Granularity
  - Fast Trigger

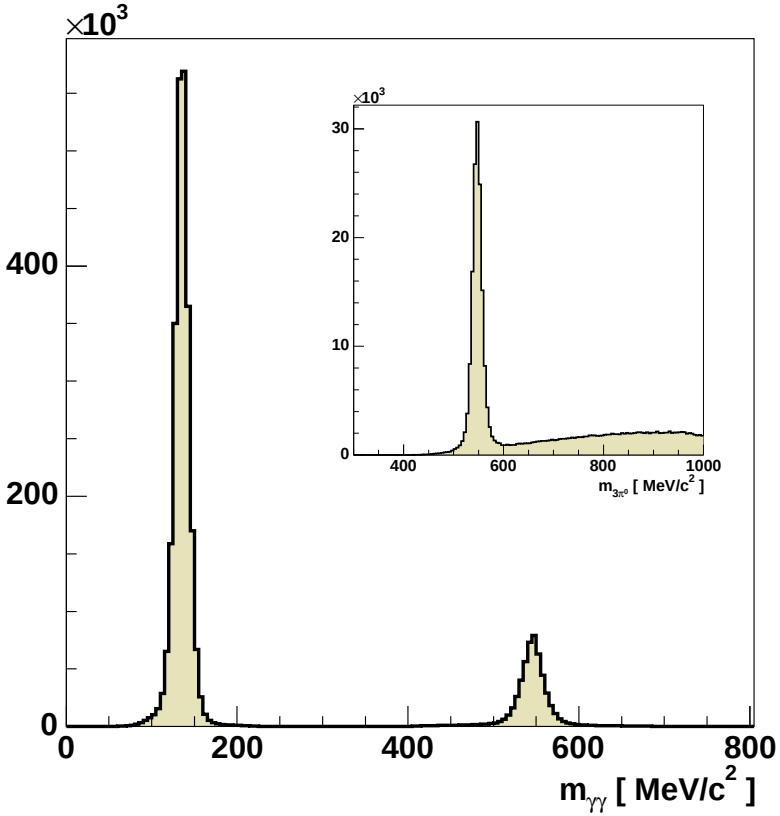
CB-ELSA/TAPS Experimental Setup of 2002/2003



Tagged Photons (E_{e^-} = 3.2 GeV)

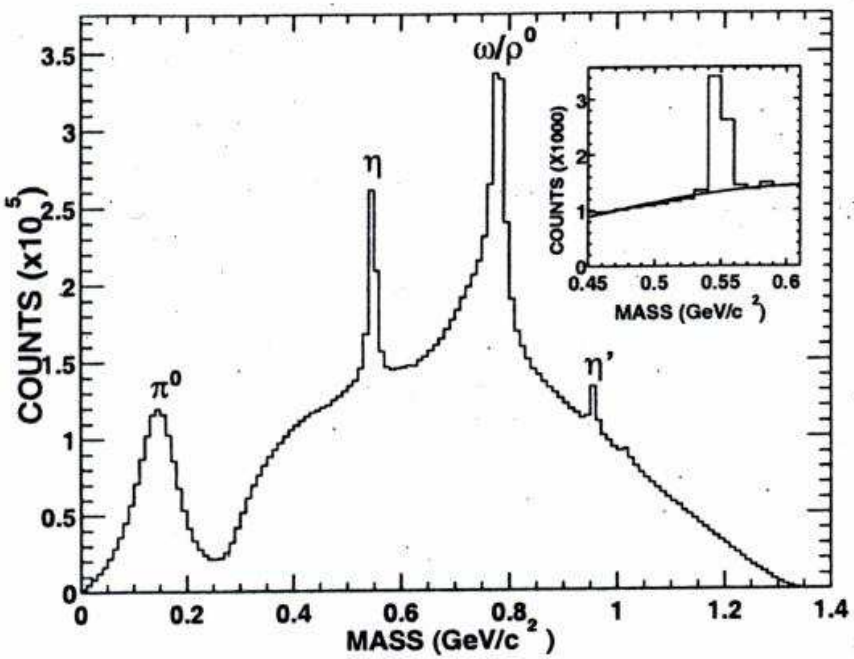
- 14 counters + 2 wire chambers
- $0.25 \cdot E_{e^-} \leq E_\gamma \leq 0.95 \cdot E_{e^-}$
  $800\ \text{MeV} \leq E_\gamma \leq 3000\ \text{MeV}$

Study of $\gamma p \rightarrow p\eta$ with CB-ELSA/TAPS



$$\left\{ \begin{array}{l} \eta \rightarrow 3\pi^0, \gamma\gamma \\ \text{(CB-ELSA/TAPS)} \end{array} \right.$$

M. Dugger et al., PRL **89**, 222002 (2002)



$$\left\{ \begin{array}{l} \gamma\, \mathrm{p} \rightarrow \mathrm{p\, X\ (missing\ mass)} \\ \text{(CLAS)} \end{array} \right.$$

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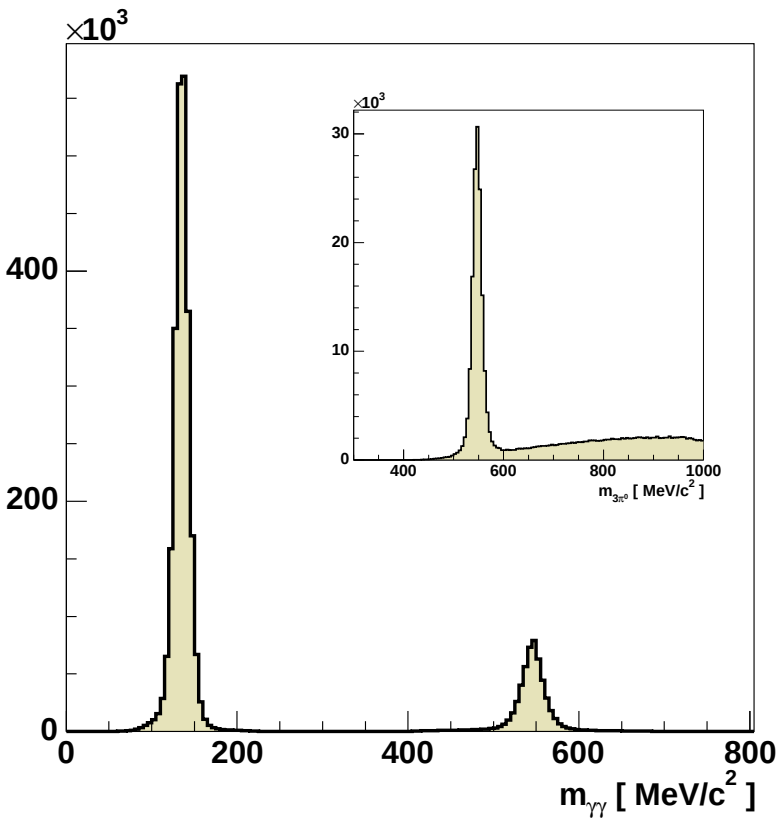


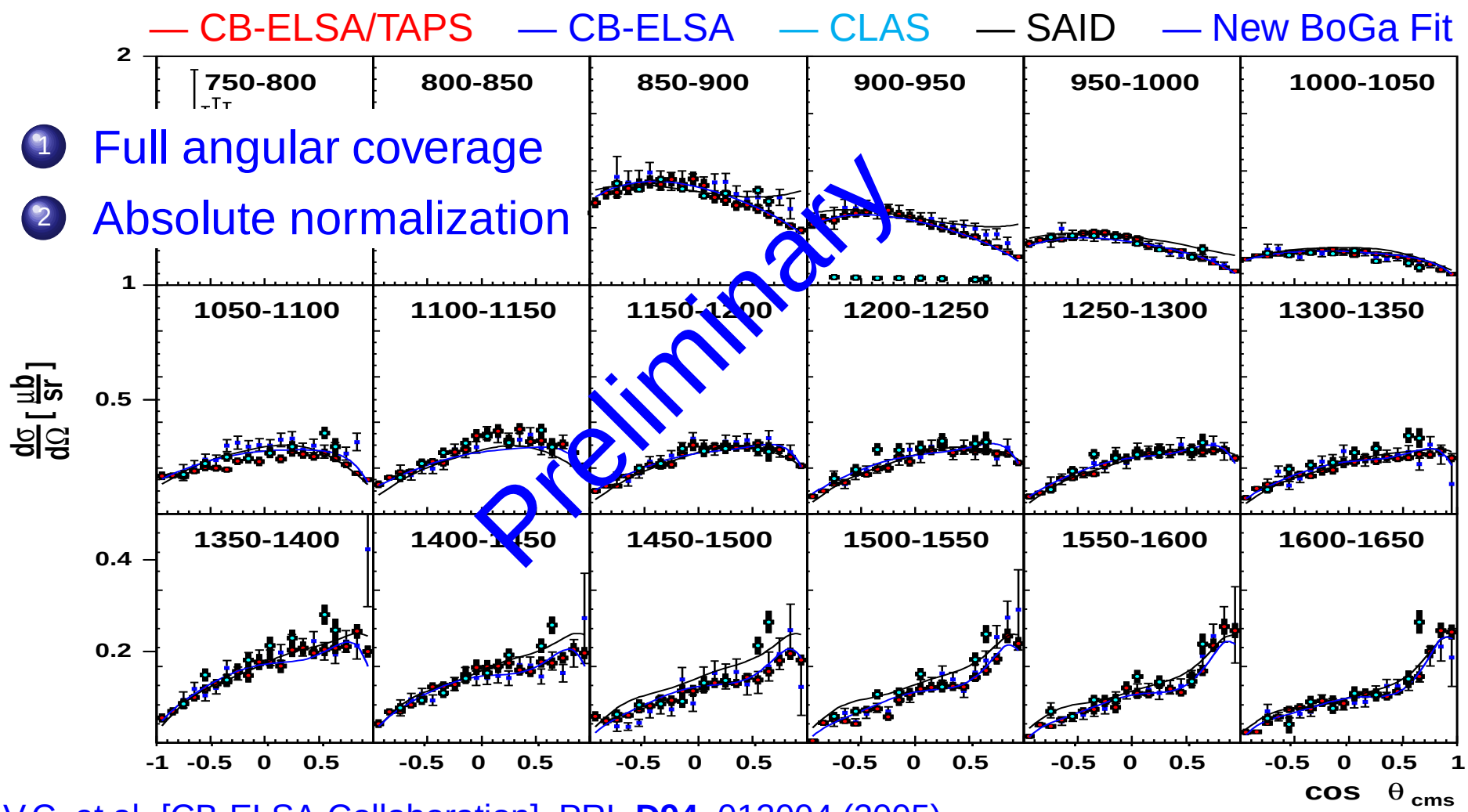
$\leftarrow \begin{cases} \eta \to 3\pi^0, \gamma\gamma \\ \text{(CB-ELSA/TAPS)} \end{cases}$

Reconstruction

- Number of photons: $N_\gamma = 2,\ 6$
- Proton identification: TAPS and inner scintillating fibre detector
  ➜ Missing proton kinematic fit
- Data quality
  - 422,300 events for $\eta \to \gamma\gamma$: $\sigma \approx 13$ MeV
  - 126,300 events for $\eta \to 3\pi^0$: $\sigma \approx 10$ MeV

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)

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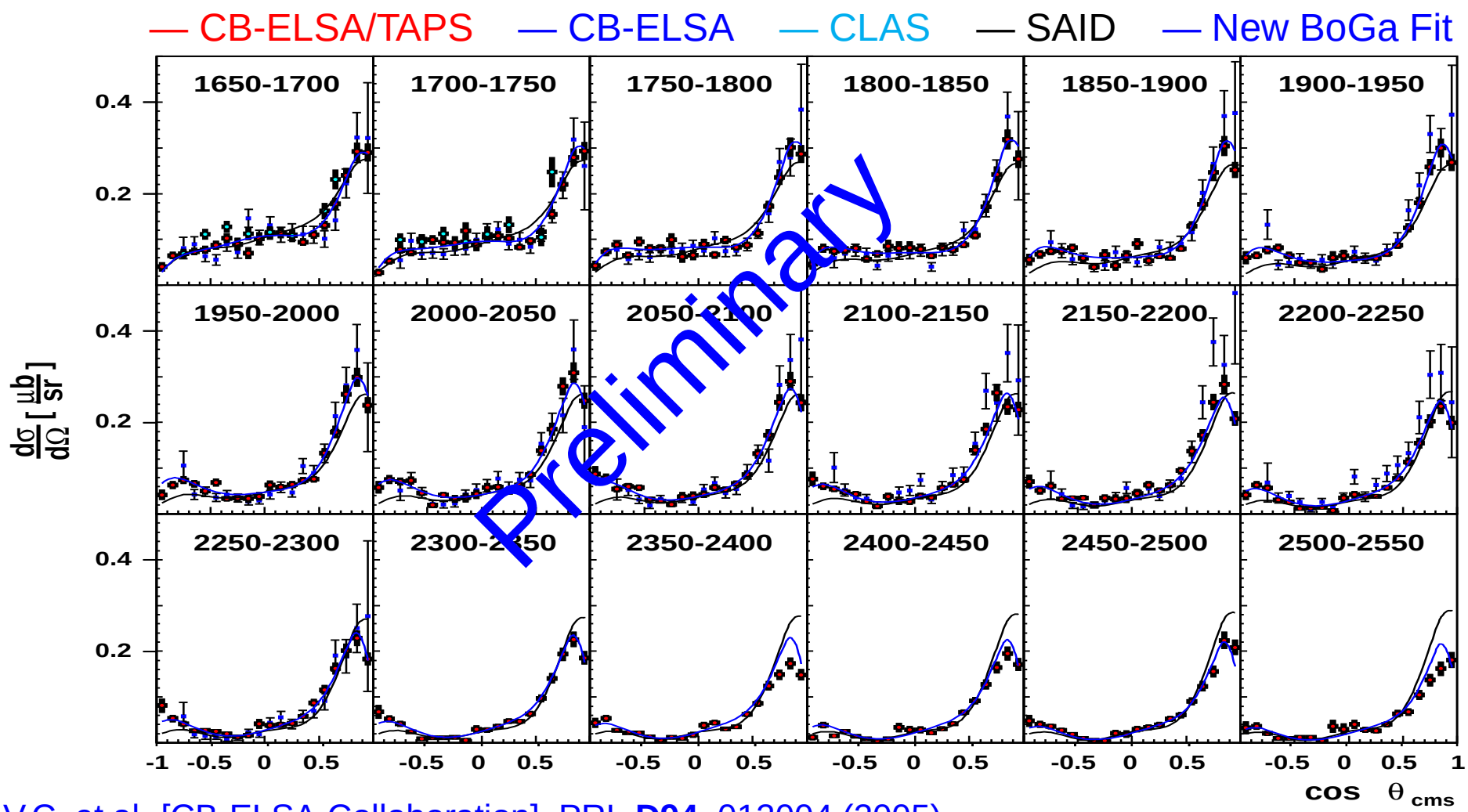

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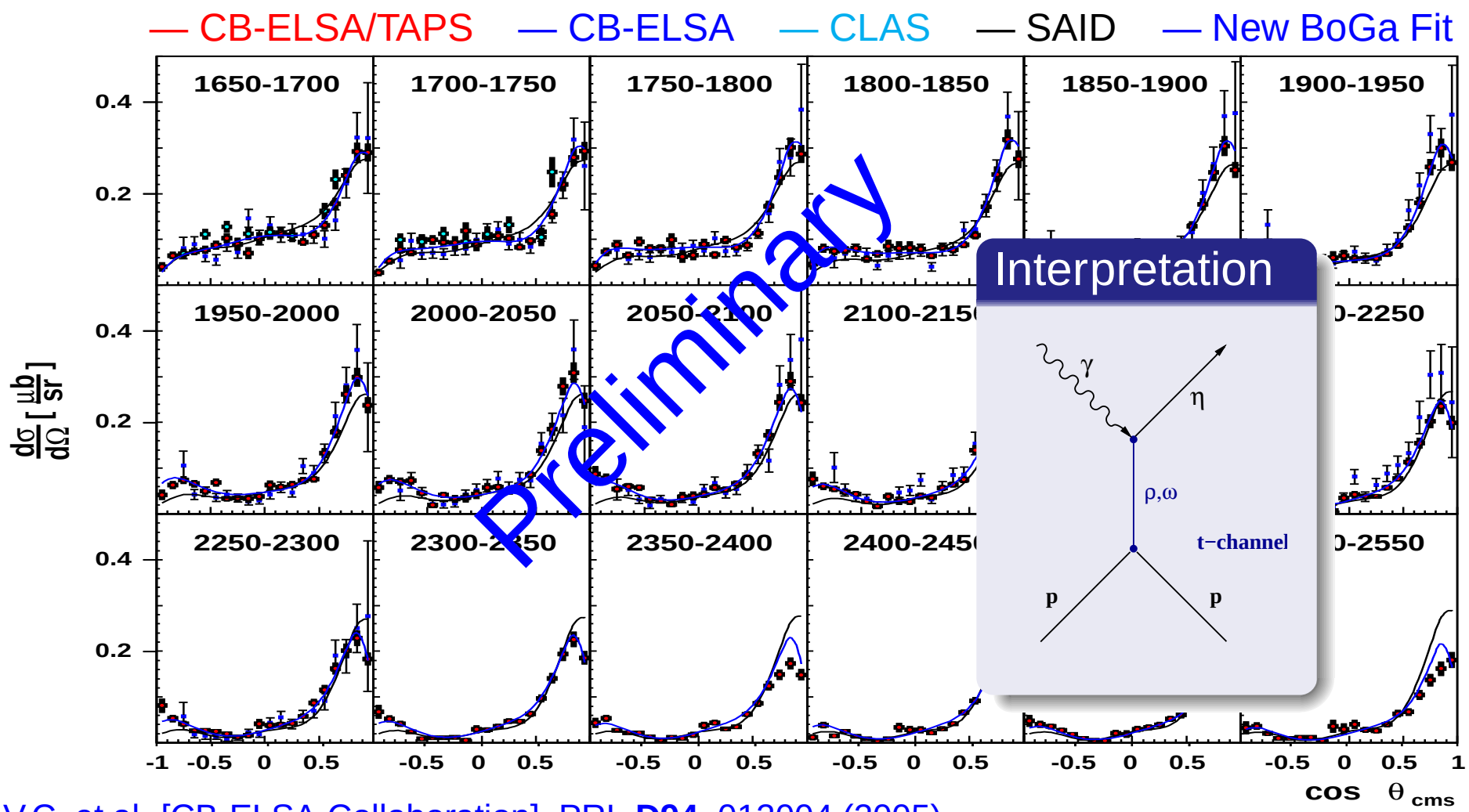

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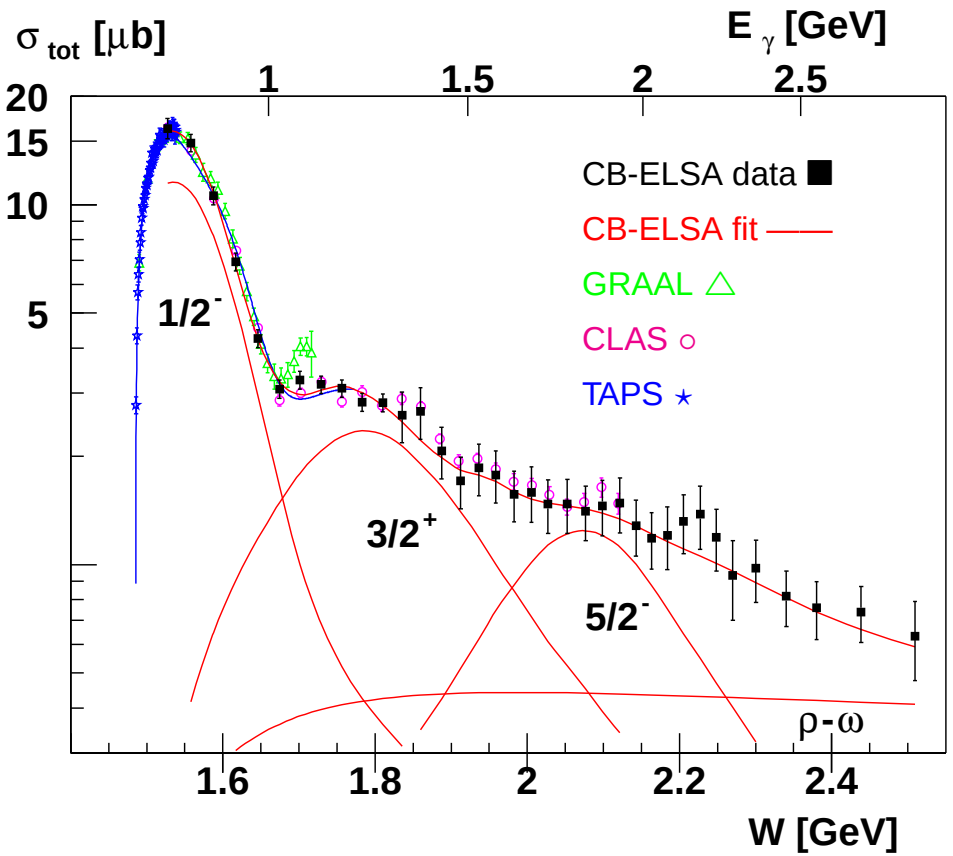
Analysis of $\gamma p \to p\eta$: Total Cross Section



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:

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

Partial Wave Analysis: $\gamma p \to p\eta$

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

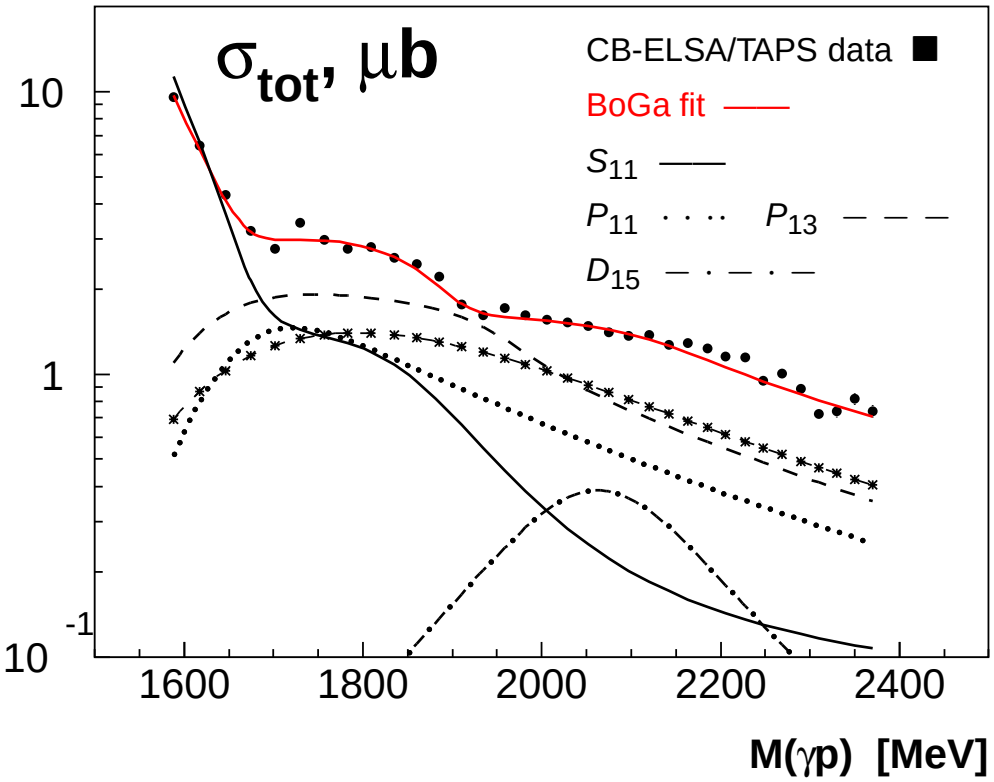
- Many data sets included
  - Cross section data and polarization observables
- Solutions not unique

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	0.430
PDG	1505 ± 10	170 ± 80	
$N(1650)S_{11}$ *	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 $\gamma p \rightarrow p\eta$: Total Cross Section



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

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

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

Resonances dominantly contributing:

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

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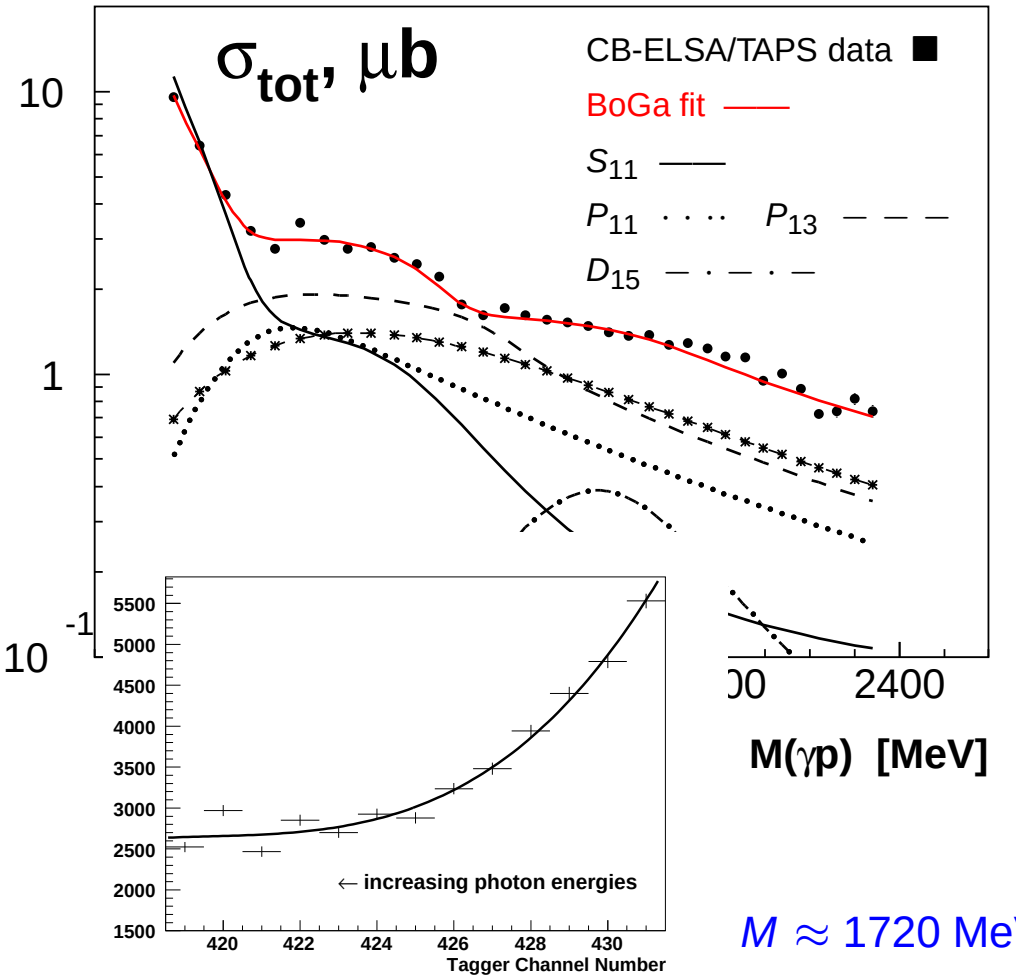

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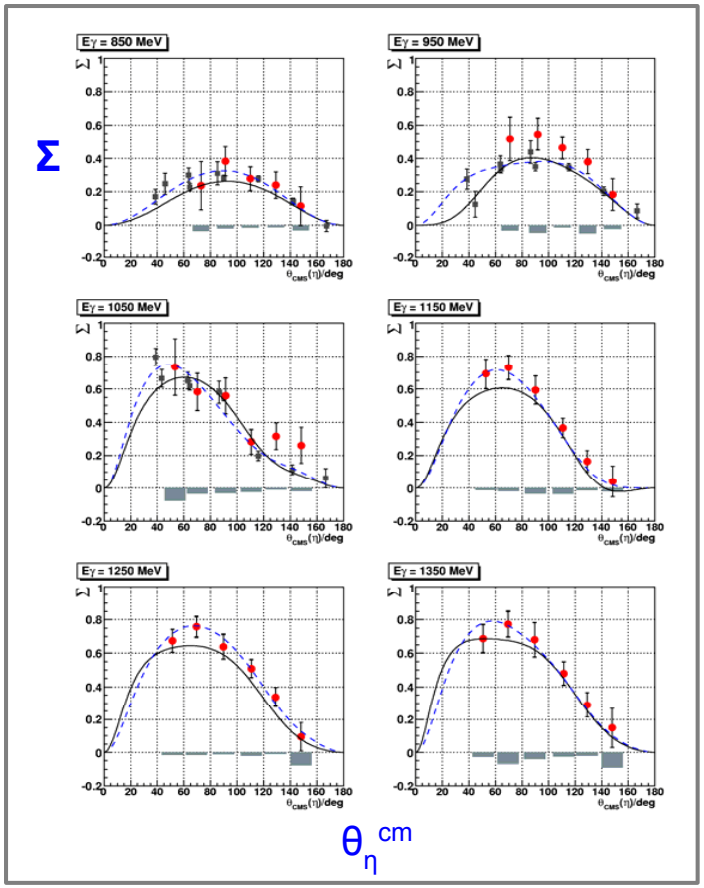
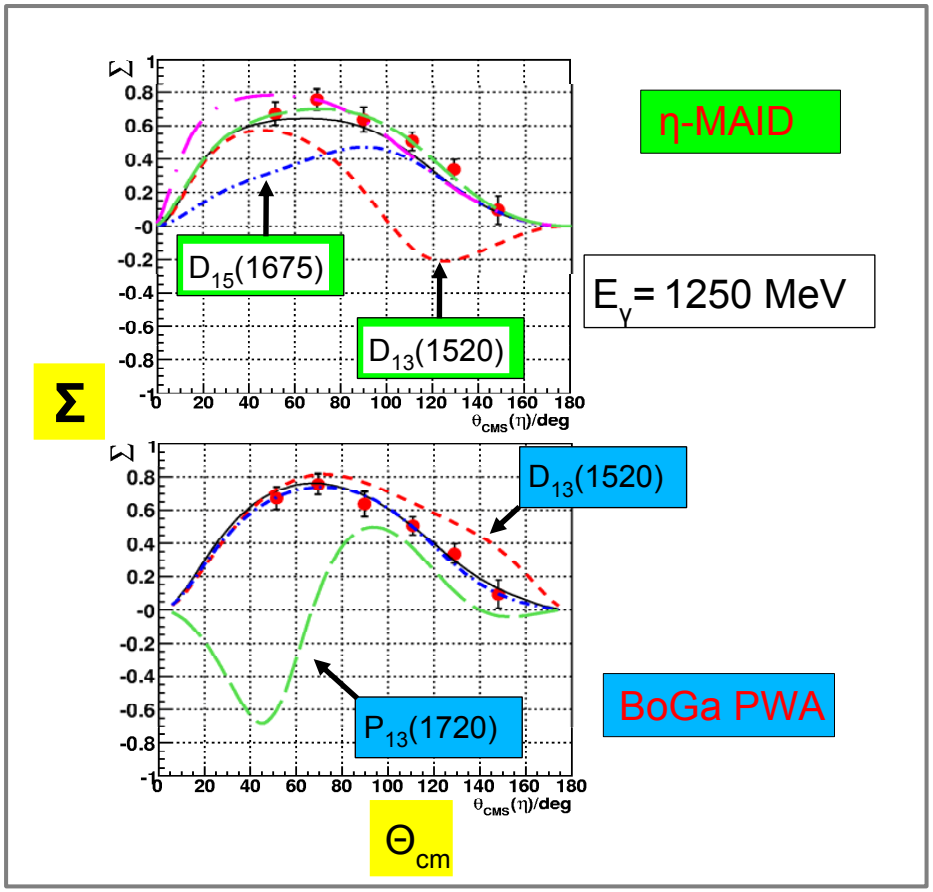
$M \approx 1720$ MeV/c^2

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

Higher sensitivity due to interference effects: $\Sigma \sim A_{1/2}(S_{11}) * A_{1/2}(P_{13}) + \ldots$



D. Elsner et al., EPJ A33 (2007) 147



R. Beck, Talk at N* 2009

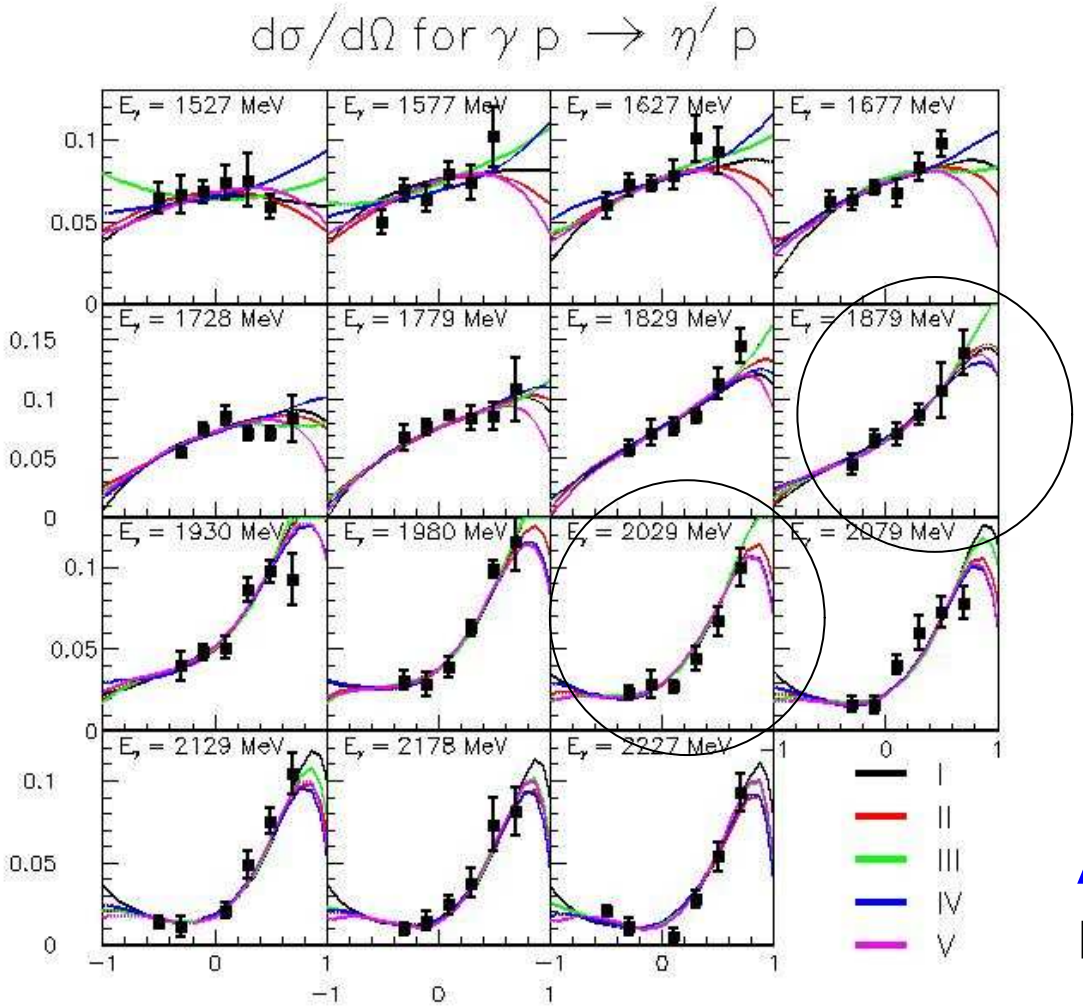
Study of $\gamma p \to p\eta'$ with CB-ELSA/TAPS

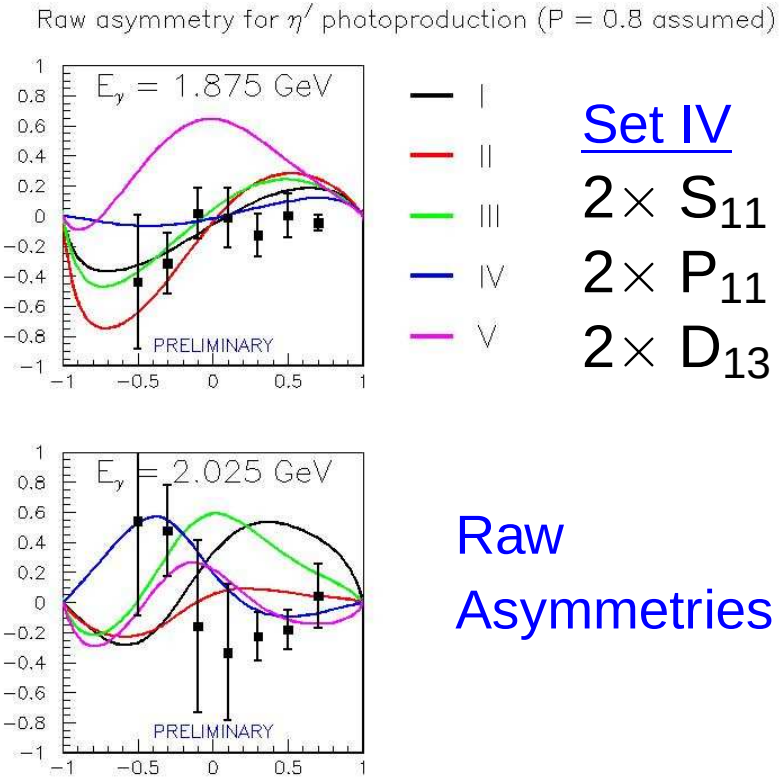
Isospin Filter: only N* resonances can contribute

- 1968: 11 events from the ABBHHM bubble chamber experiment
- 1976: 7 events from the AHHM streamer chamber experiment
- 1998: 250 events from SAPHIR collaboration
  ➜ First differential cross sections
- 2006: over $2 \cdot 10^5$ events from CLAS
  (Contributions from N(1535)S_{11}, N(1710)P_{11}, $J = 3/2$ states)
- 2008: New data from CBELSA/TAPS over the full angular range

No published asymmetry data for η'...
(Data available from CLAS and ELSA)

Linearly-Polarized Beam at JLab: g8b Run Group



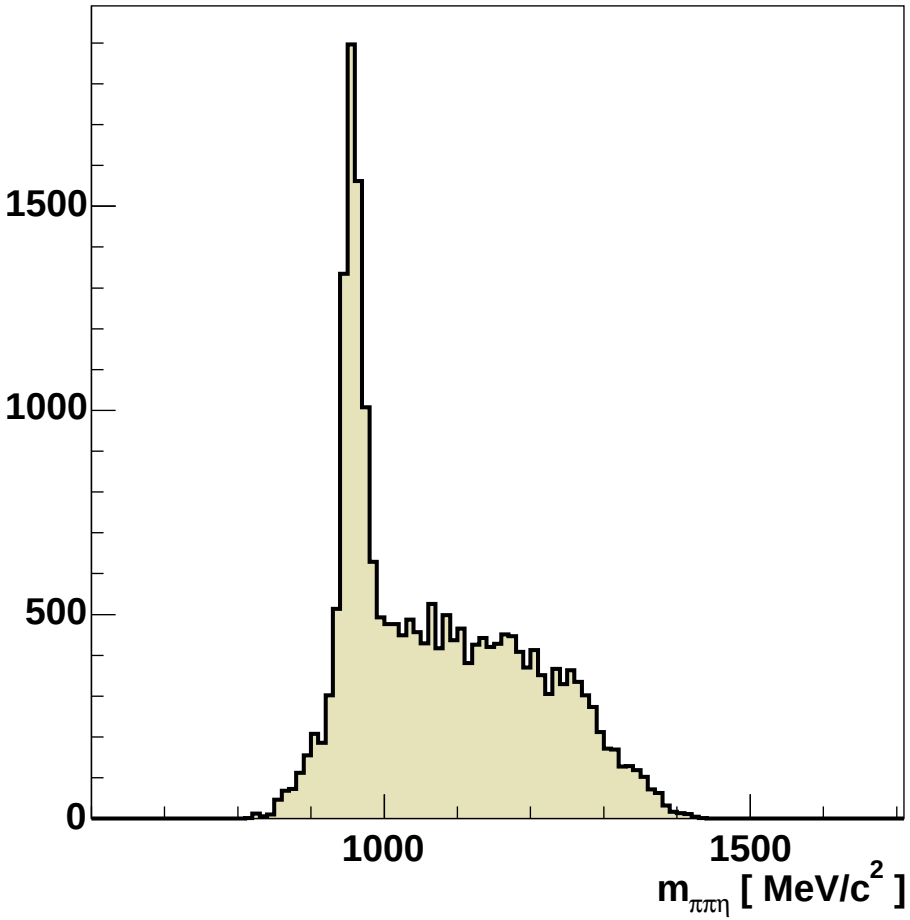


Set IV
$2\times S_{11}$
$2\times P_{11}$
$2\times D_{13}$

Raw Asymmetries

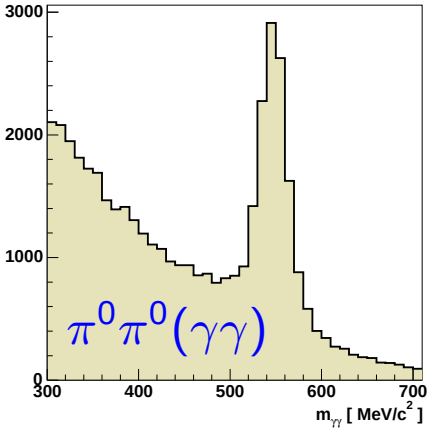
Analysis of $\gamma p \rightarrow p\eta'$
Phys. Rev. Lett. **96**, 062001 (2006)

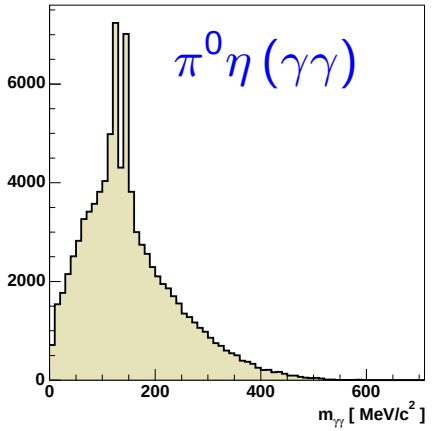
Study of $\gamma p \to p\eta'$ with CB-ELSA/TAPS



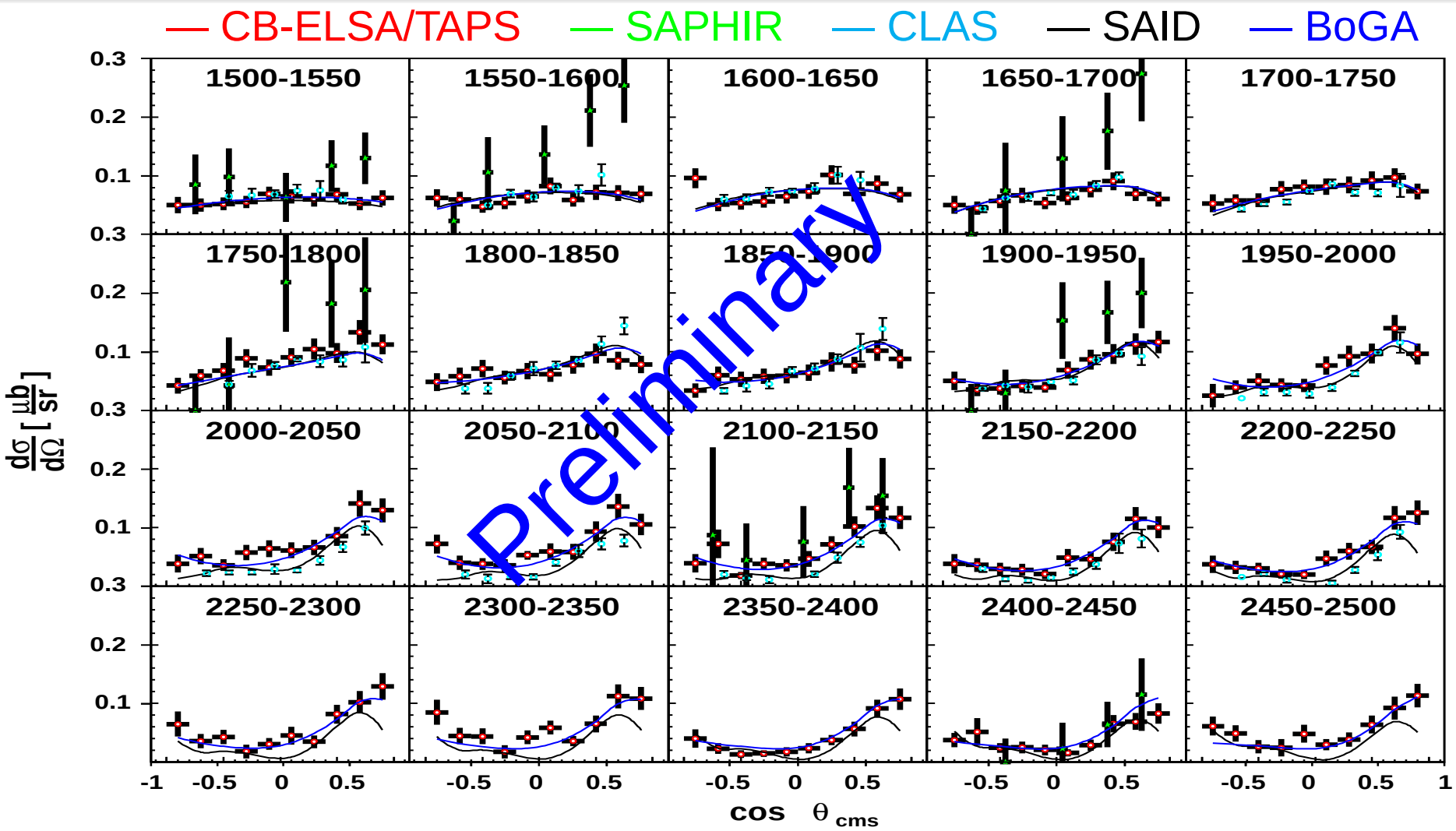
Reconstruction of η':

- Kinematic Fitting to $\gamma p \to p\pi^0\eta\gamma\gamma$
- Mass window for remaining π^0:
  $110 < m_{\gamma\gamma} < 160$ MeV
- Mass window for η':
  $910 < m_{\pi^0\pi^0\eta} < 1010$ MeV

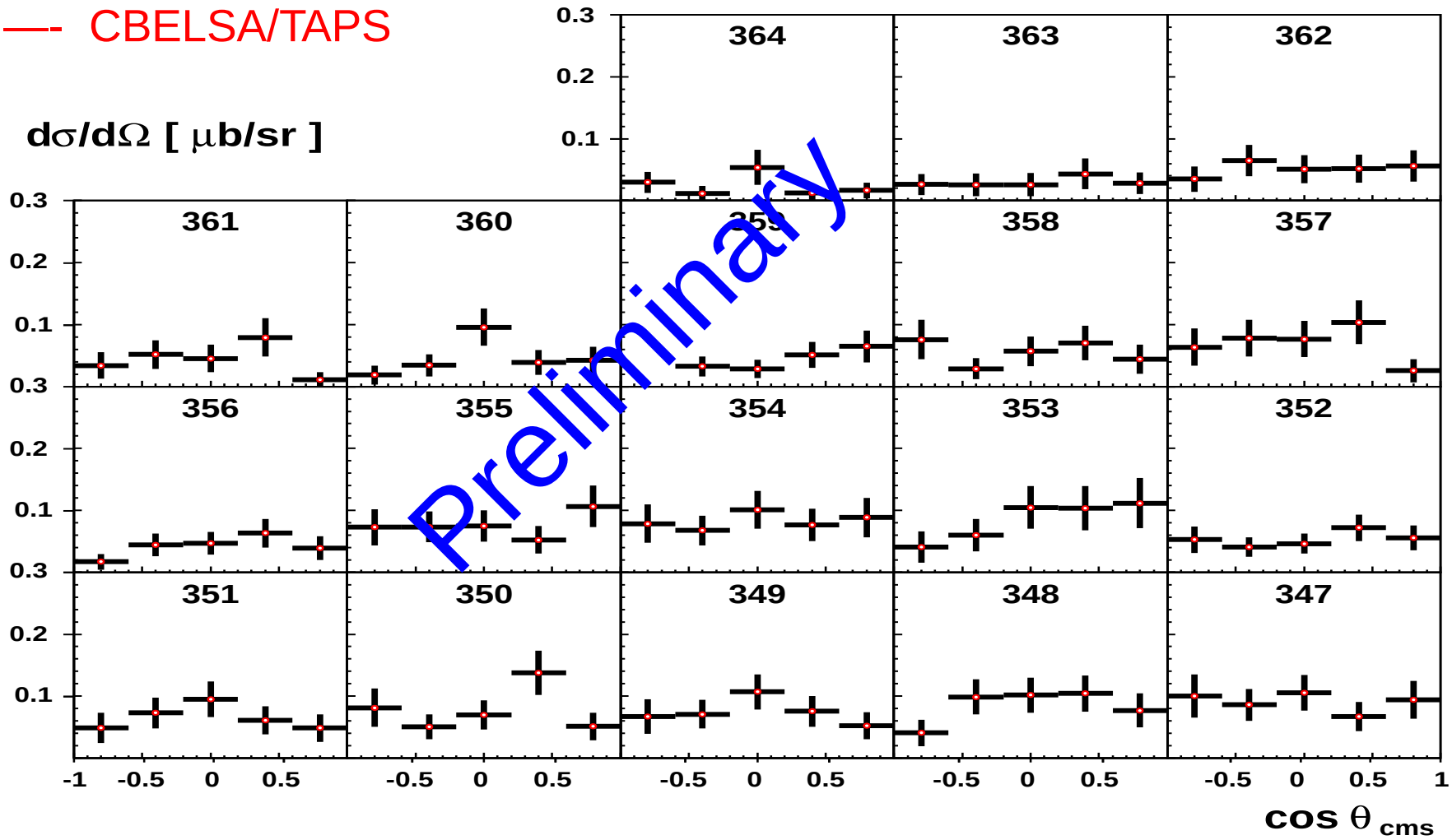




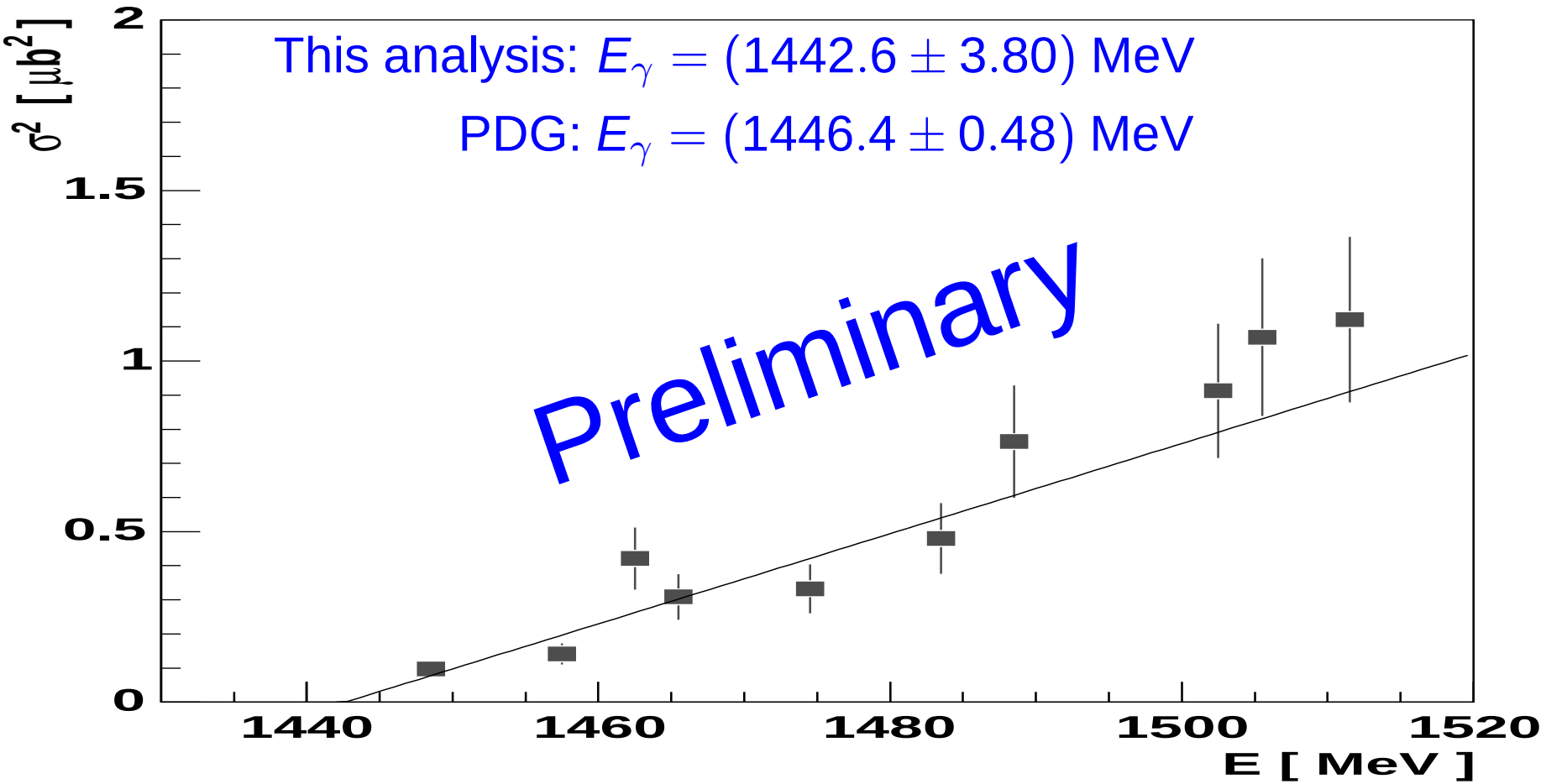
Differential Cross Sections for $\gamma p \longrightarrow p\eta'$



Study of $\gamma p \longrightarrow p\eta'$ Threshold



Threshold Behavior of $\gamma p \rightarrow p\eta'$



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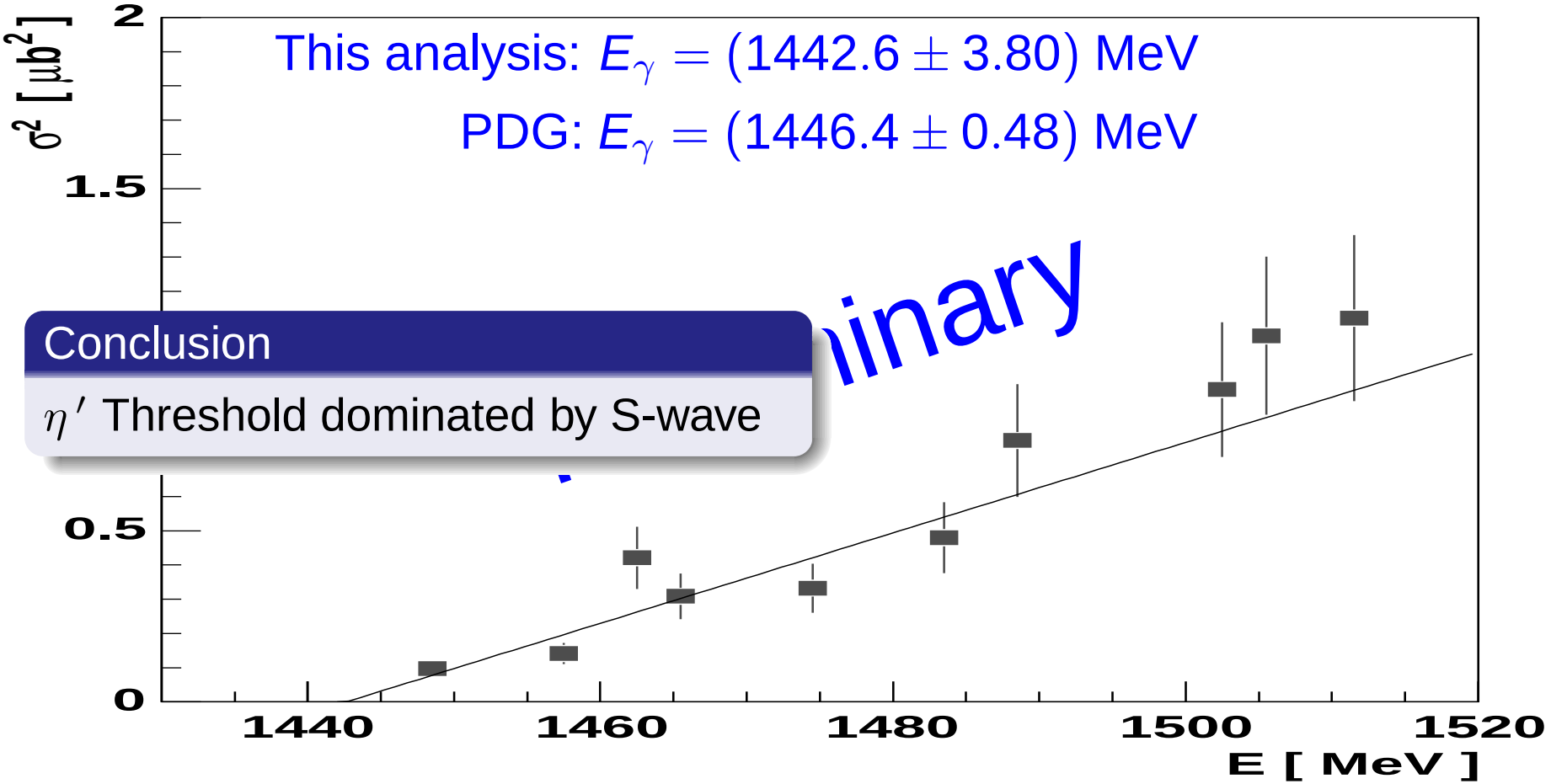
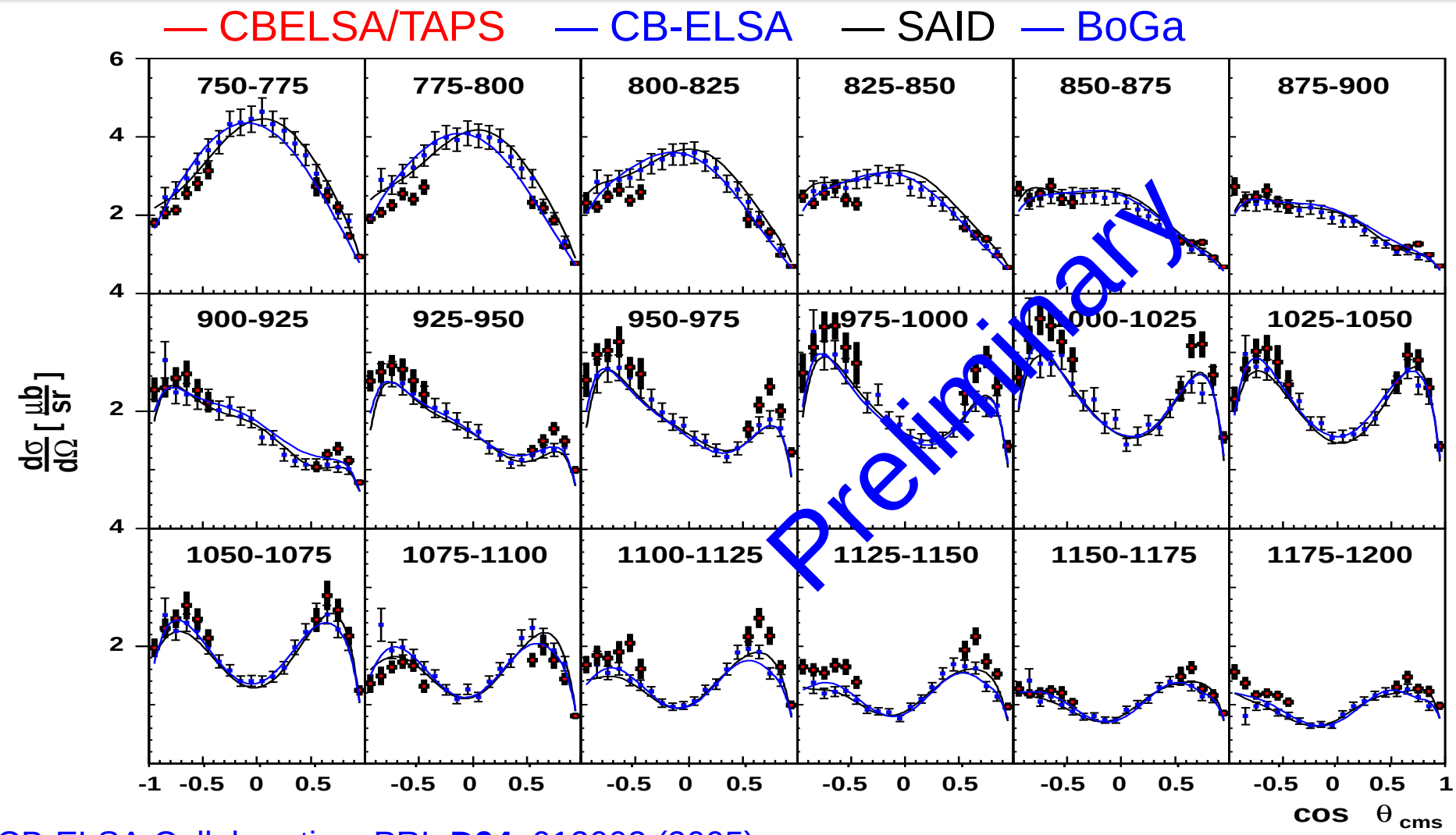


Conclusion

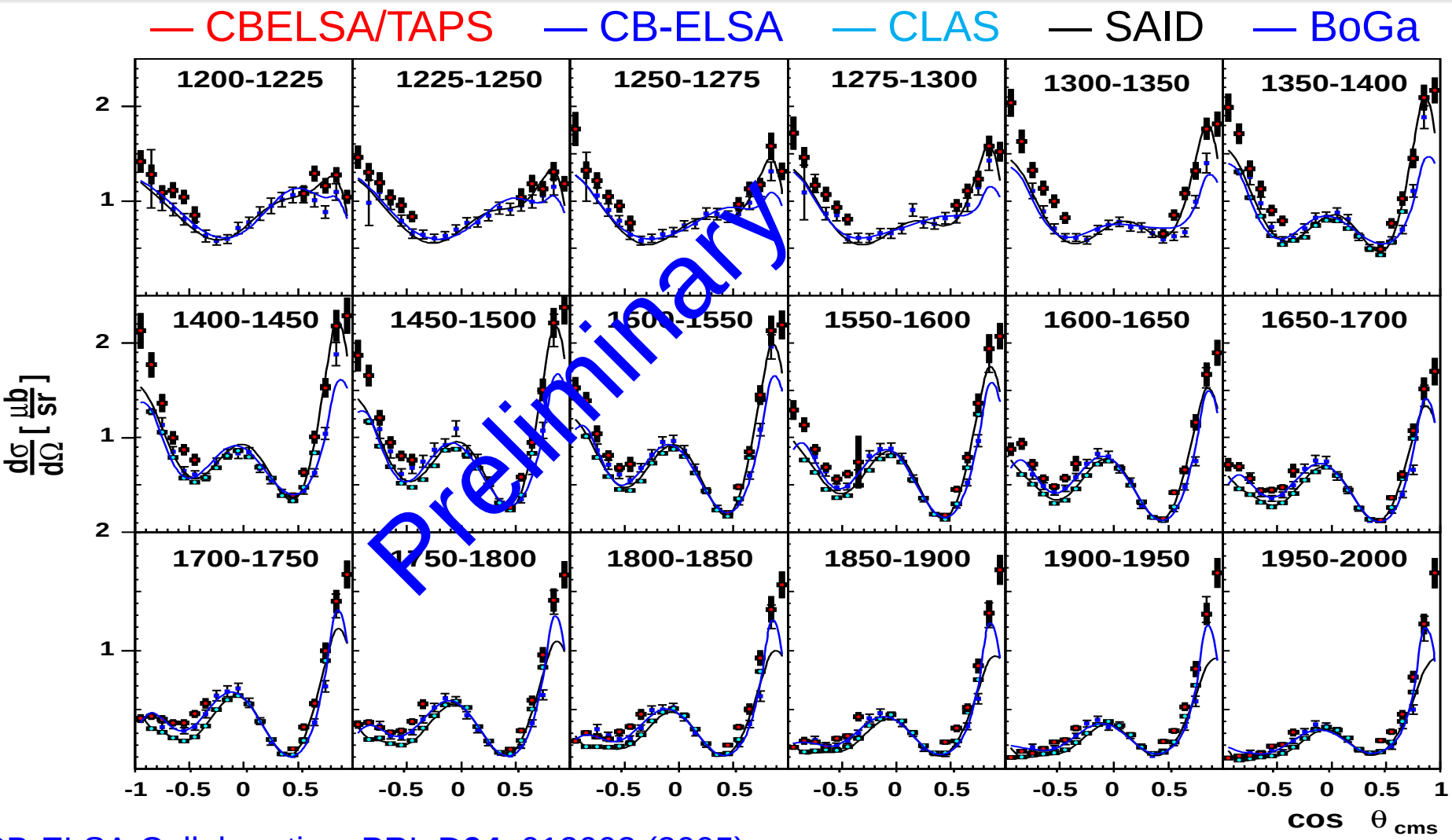
η' Threshold dominated by S-wave

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



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

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



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

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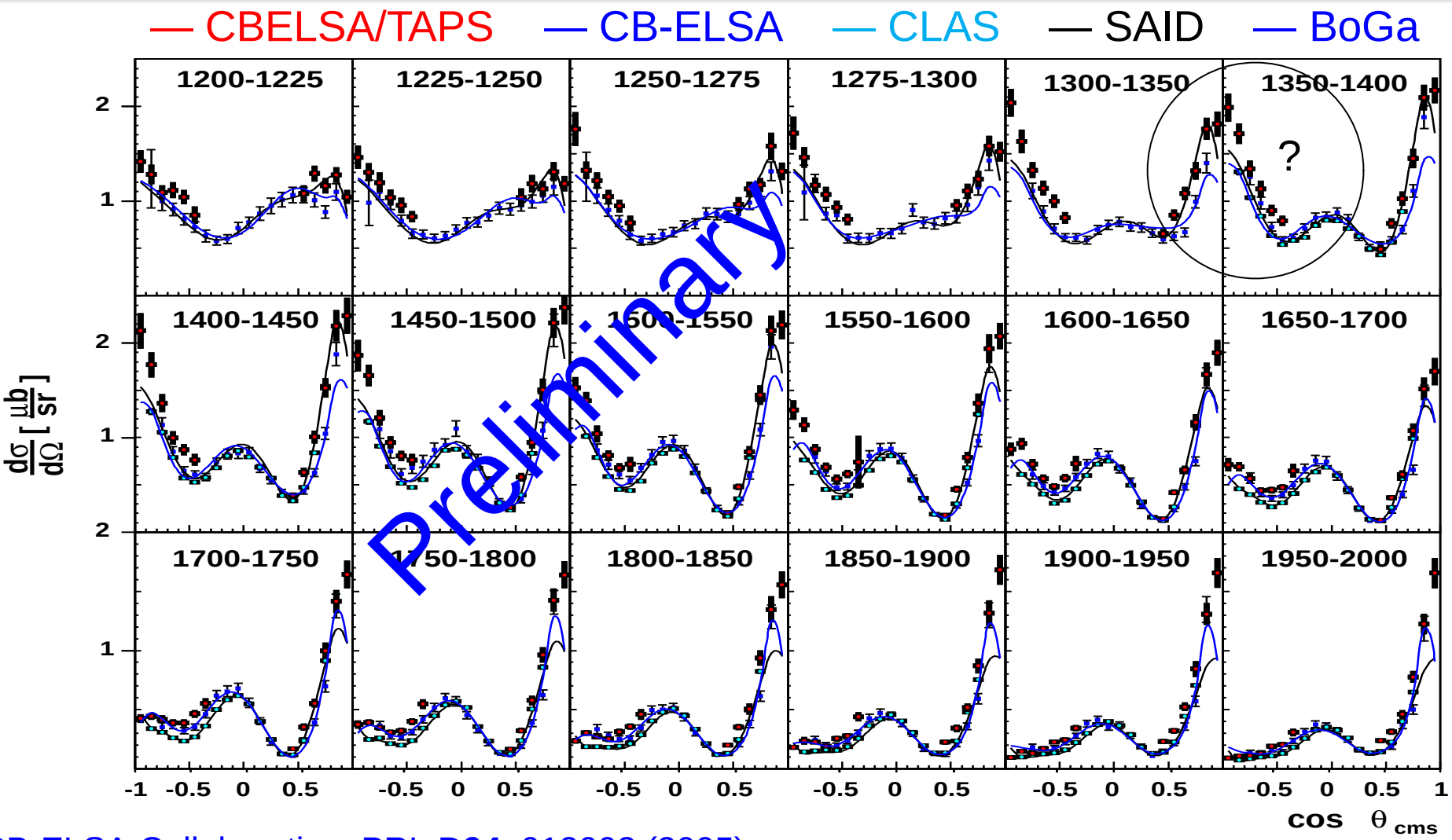

CB-ELSA Collaboration, PRL **D94**, 012003 (2005)

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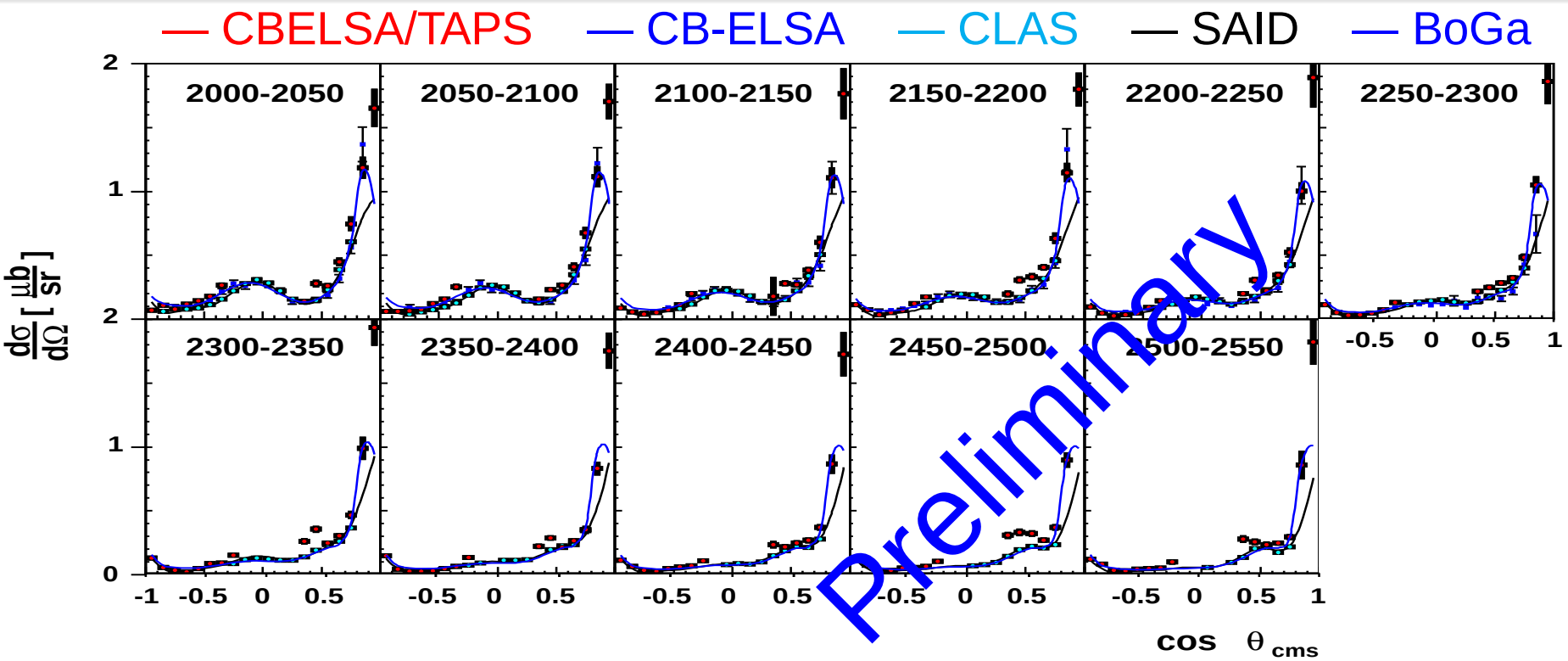
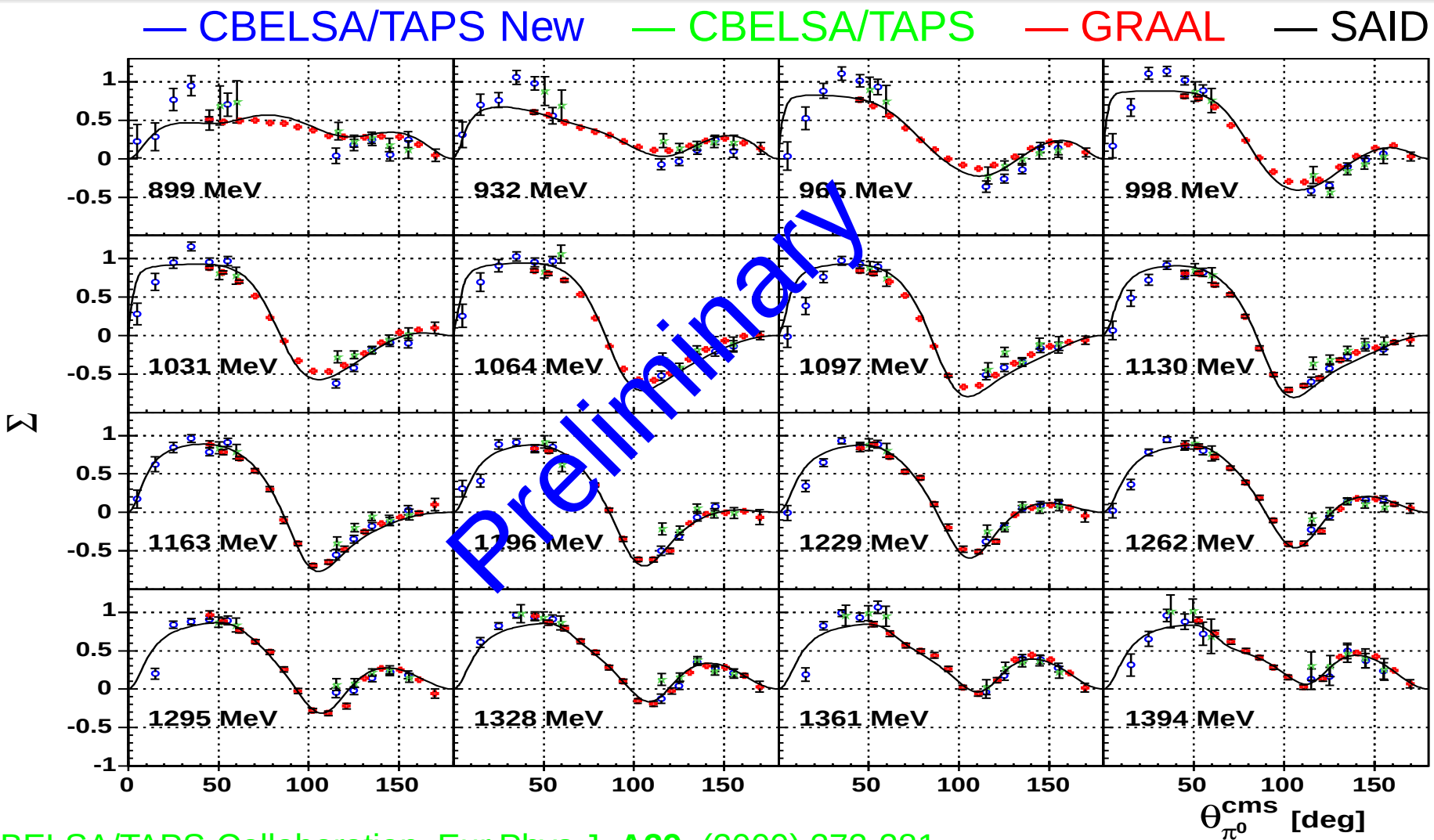


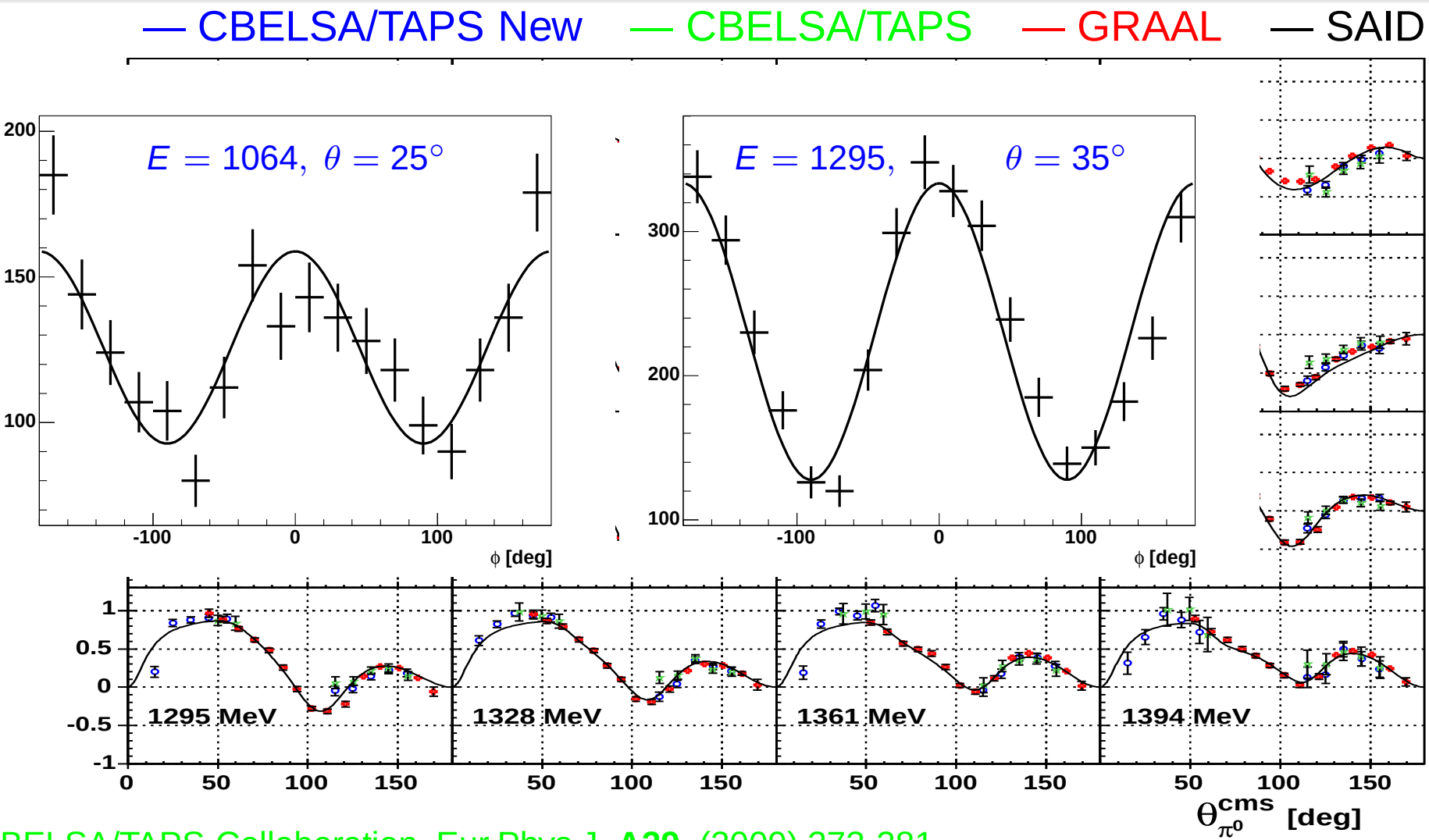
CB-ELSA Collaboration, PRL **D94**, 012003 (2005)

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



CBELSA/TAPS Collaboration, Eur.Phys.J. **A39**, (2009) 373-381

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



CBELSA/TAPS Collaboration, Eur.Phys.J. **A39**, (2009) 373-381

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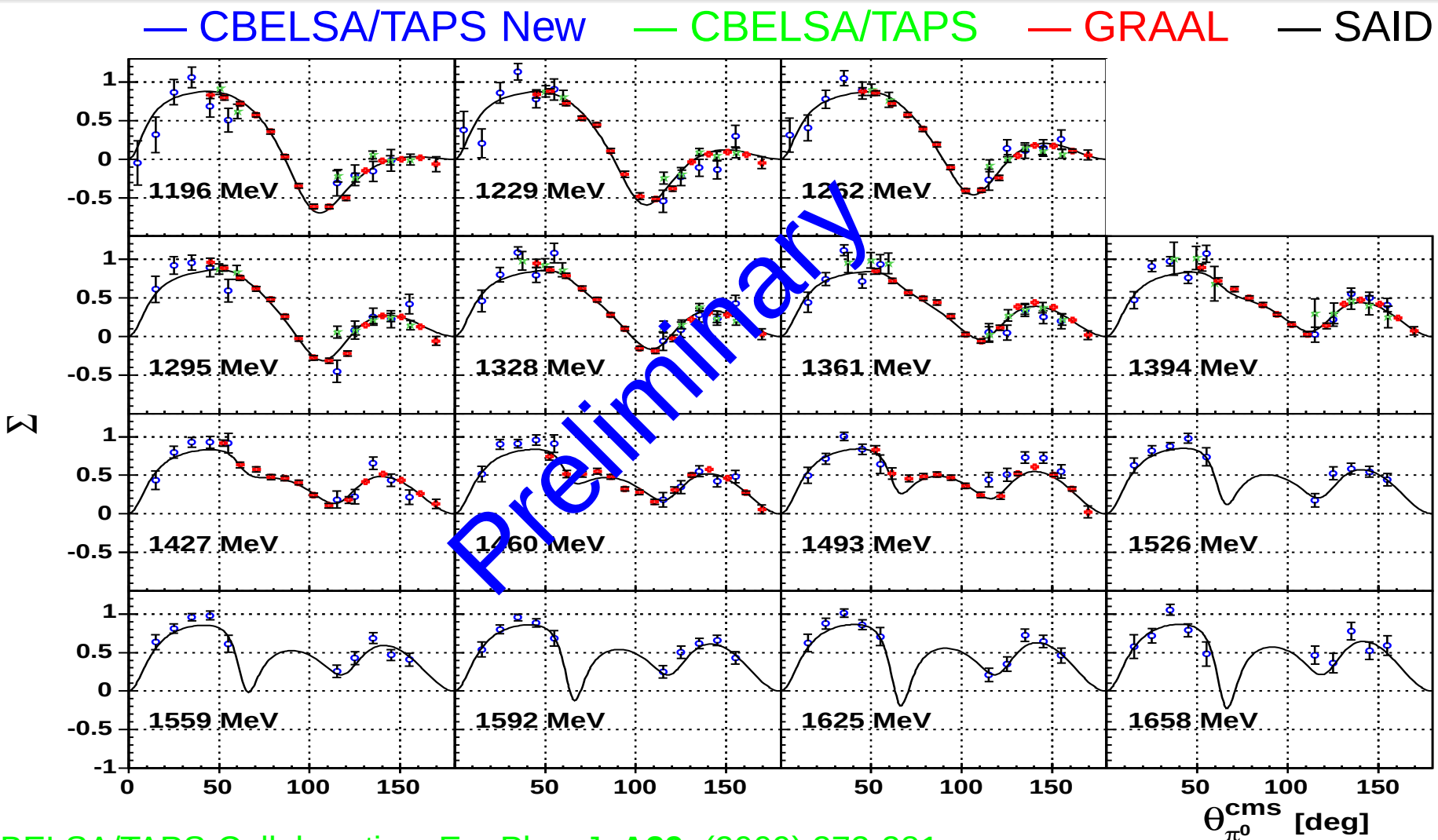

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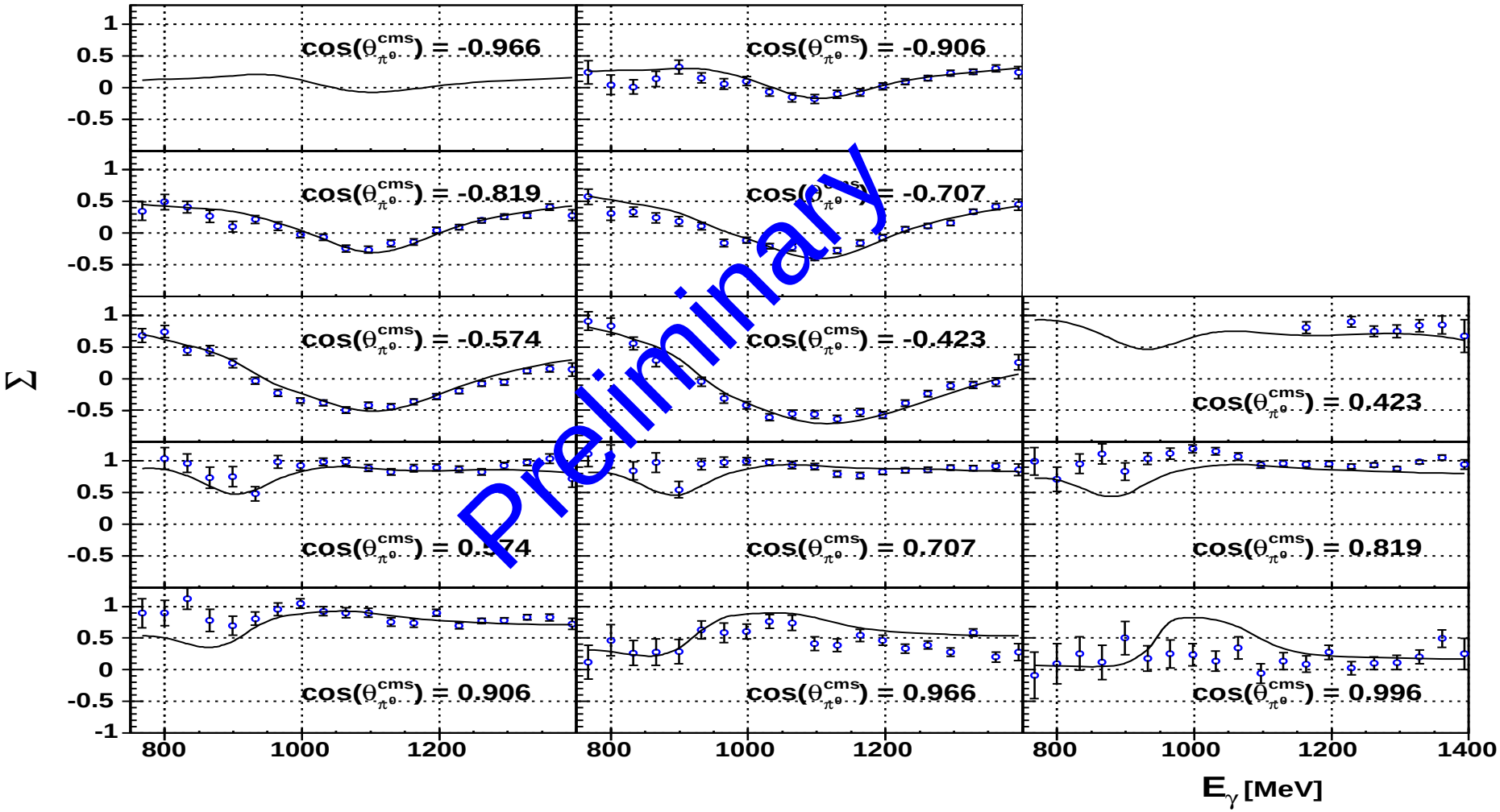
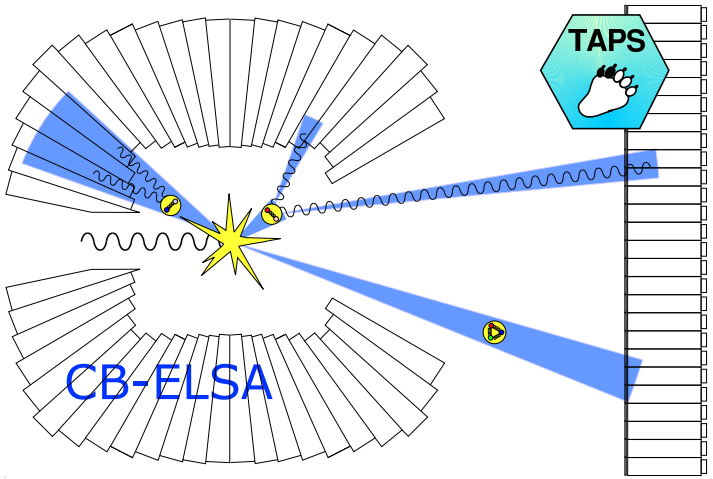


Outline



(New) Baryon Resonances: Bonn-Gatchina PWA

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

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.

Ingredients

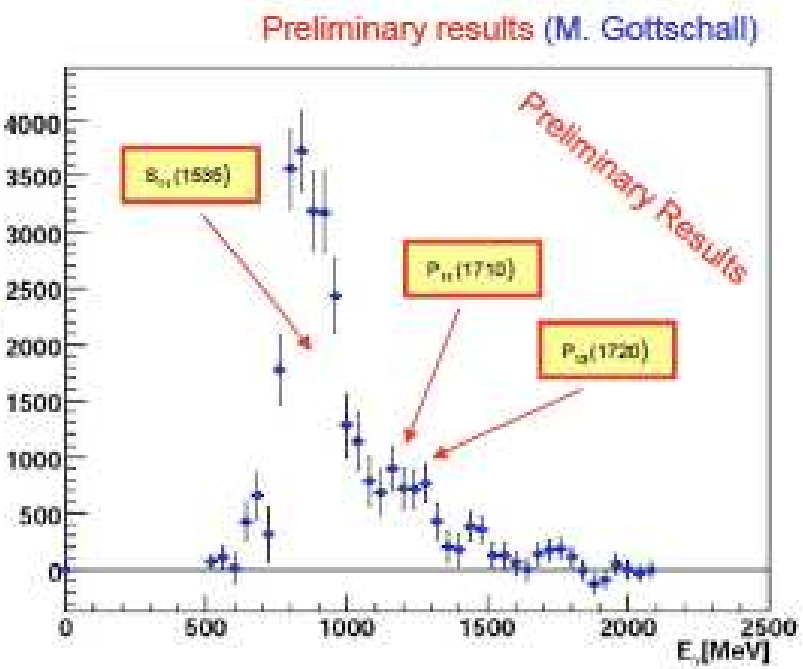
- Measurements off neutron and proton to resolve isospin contributions
  1. $\mathcal{A}(\gamma N \rightarrow \pi,\ \eta,\ K)^{I=3/2} \quad \Longleftrightarrow \quad \Delta^*$
  2. $\mathcal{A}(\gamma N \rightarrow \pi,\ \eta,\ K)^{I=1/2} \quad \Longleftrightarrow \quad N^*$
- Re-scattering effects: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

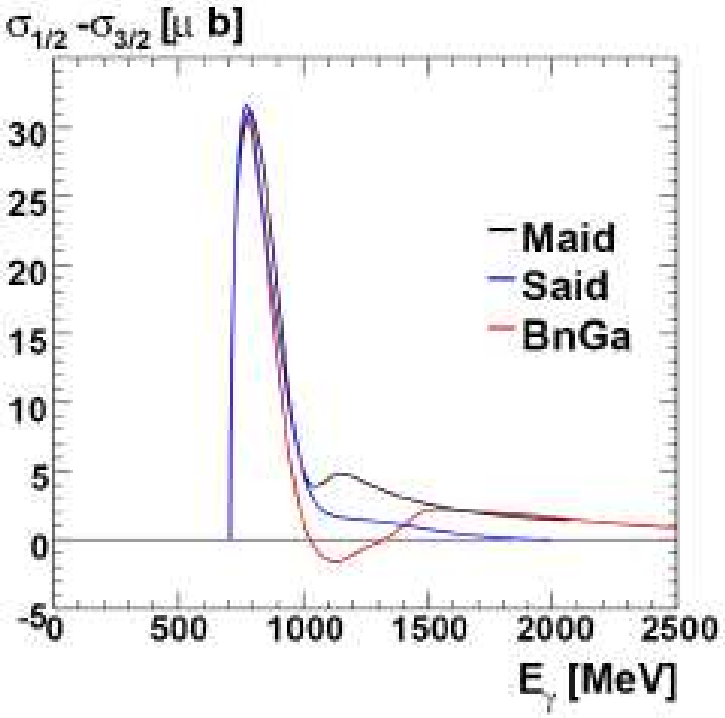
Chiang & Tabakin, Phys. Rev. C55, 2054 (1997)

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.

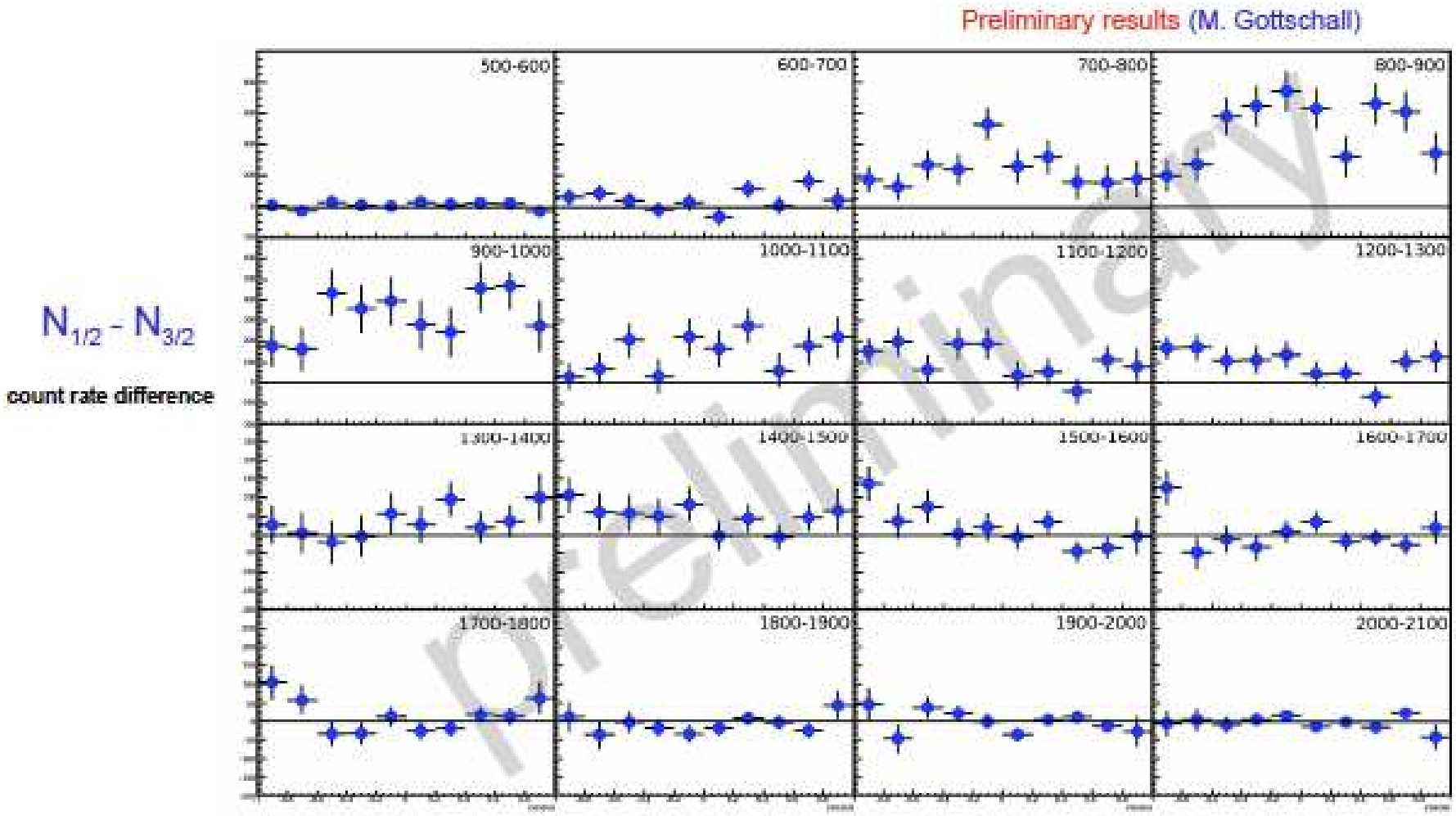
Helicity-Dependent Cross Section: $\vec{\gamma}\vec{p} \rightarrow p\eta$

$N_{1/2} - N_{3/2}$

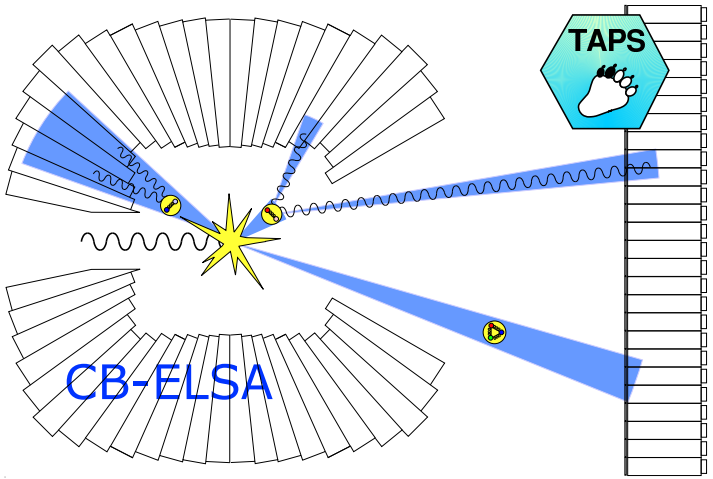




Helicity-Dependent Cross Section: $\vec{\gamma}\vec{p} \longrightarrow p\eta$



Outline



Summary and Outlook

Photoproduction of neutral mesons with the CBELSA/TAPS detector

- Full angular coverage for η and η' production
  ➜ Confirmation of $D_{15}(2070) \rightarrow p\eta$
- No evidence for narrow state at $M \approx 1685$ MeV/c^2
- Excellent coverage for the π^0 in the very forward direction
- Contributions for new results from
  Aaron McVeigh, Nathan Sparks, Anna Woodard

Summary and Outlook

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