Report on NSTAR 2005 Workshop

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Tallahassee, FL

Cascade Workshop at JLab, 12/03/2005

Outline

1. Introduction

2. N^*/Δ^* Spectroscopy
   - What are the problems?
   - The NSTAR 2005 Workshop

3. Experimental Status
   - Recent Results (reported at workshop)
   - New Experimental Approaches

4. Summary and Outlook

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⇒ Search for *missing* resonances

Quark models predict many more baryons than have been observed

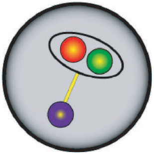
	****	***	**	*
N spectrum	11	3	6	2
Δ spectrum	7	3	6	6

⇒ according to PDG
(Phys. Rev. **D66** (2002) 010001)

⇒ little known
(many open questions left)

Possible solutions:

a) Quark-Diquark Structure

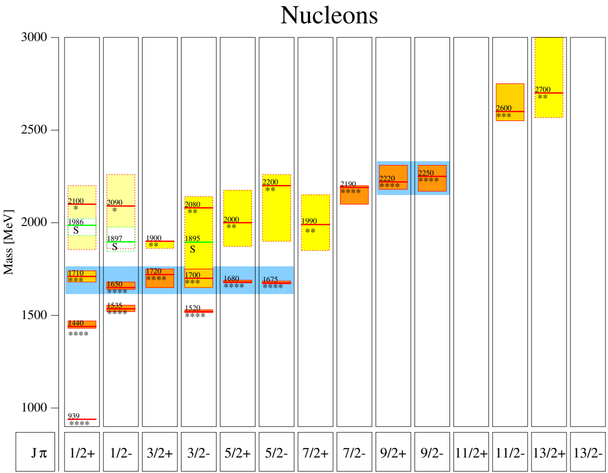


b) They have not been observed, yet

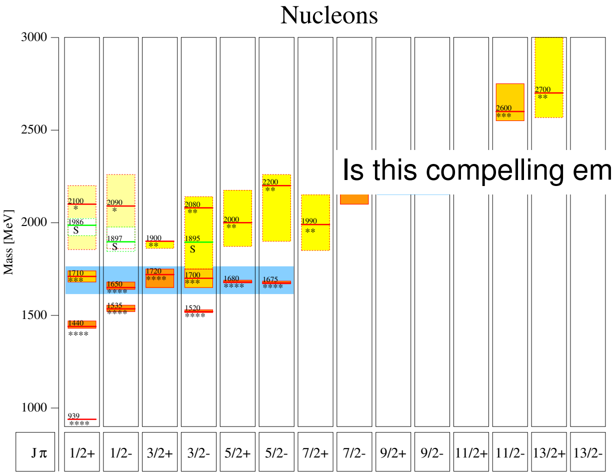
Nearly all existing data result from πN scattering experiments

⇒ If the missing states did not couple to Nπ, they would not have been discovered!!

Parity Doublets

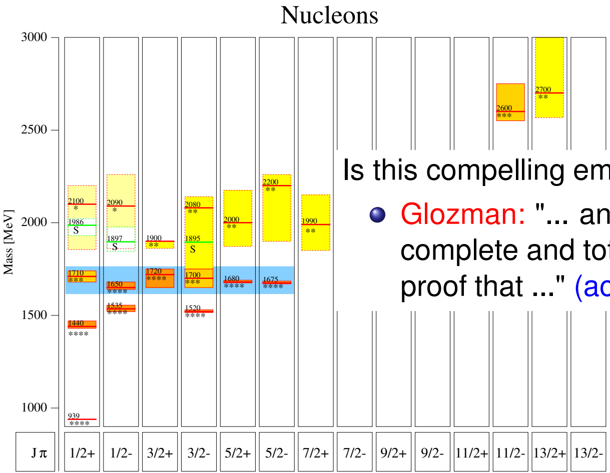


Parity Doublets



Is this compelling empirical data?

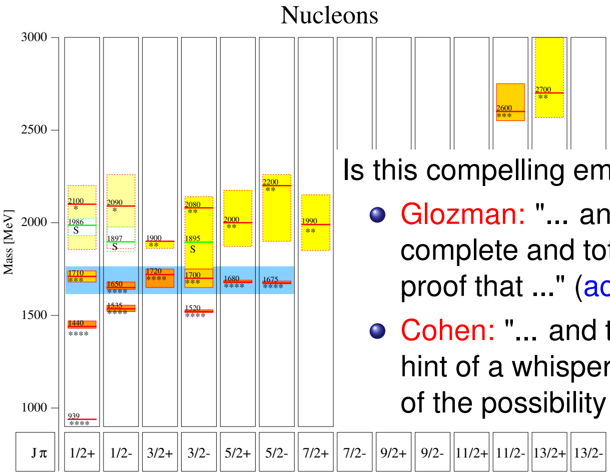
Parity Doublets



Is this compelling empirical data?

- Glozman: "... and thus we have a complete and total, 100 % ironclad proof that ..." (according to T. Cohen)

Parity Doublets

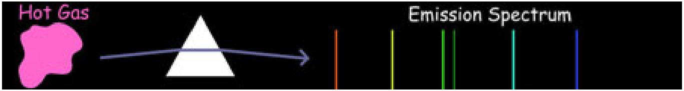


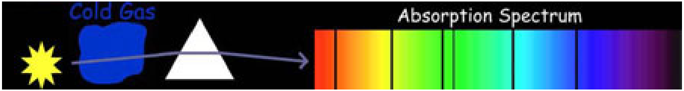
Is this compelling empirical data?

- Glozman: "... and thus we have a complete and total, 100 % ironclad proof that ..." (according to T. Cohen)
- Cohen: "... and thus we have a faint hint of a whisper of the suggestion of the possibility that perhaps ..."

Let's look for them ...

Atomic Spectra



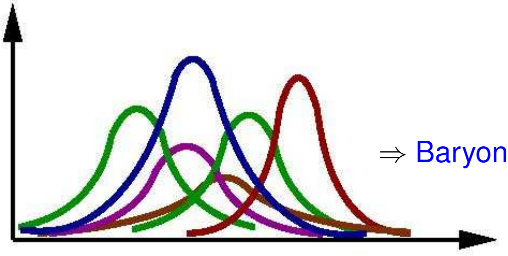


- Discrete spectrum of absorption and emission lines

⇒ Excitation spectrum of nucleon offers access to QCD

However, ...

N^* spectral lines look more like



$\Rightarrow$ Baryons are broad and overlapping

- Rescattering
  $\Rightarrow$ Coupled-channel effects
- Polarization (need complete experiment)

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IVN-1
Tallahasse, Florida
NASA - Weatherstock News

Program of the Workshop

- Focus session on coupled-channel analysis
- Recent experimental results, including Pentaquarks, and strangeness production
- Cascades
- Focus session on polarization
- Focus session on developments in theoretical description of baryon spectrum, including lattice QCD and coupled-channel unitarised chiral models

Coupled-Channel Analyses

Important in 2nd and 3rd resonance region

↓

Amplitude analysis of data

↓

Extract N^* parameters

↓

Interpretations in terms of QCD

Coupled-Channel Analyses

- Unitary Isobar Models
  - MAID
  - JLab/Yerevan UIM
- Multi-Channel K-Matrix Models
  - SAID
  - Giessen Model, KVI Model
  - Kent State University (KSU)
- Carnegie-Mellon-Berkeley (CMB) Model
  Recent applications:
  - Zagreb, PITT-ANL, FSU-PITT
- Dynamical Reaction Models
  - Jülich, SL, DMT, Ohio-Utrecht, ...

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Coordinating efforts by

BRAG
(Baryon Resonance Analysis Group)

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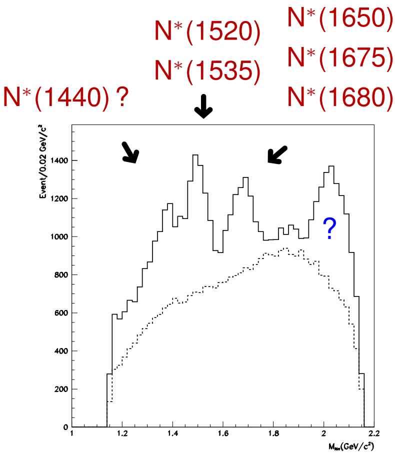
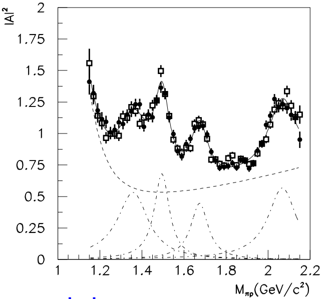
Baryon Spectroscopy at BES: $J/\psi \to p\pi^- \bar{n}\ \ (\bar{p}\pi^+ n)$



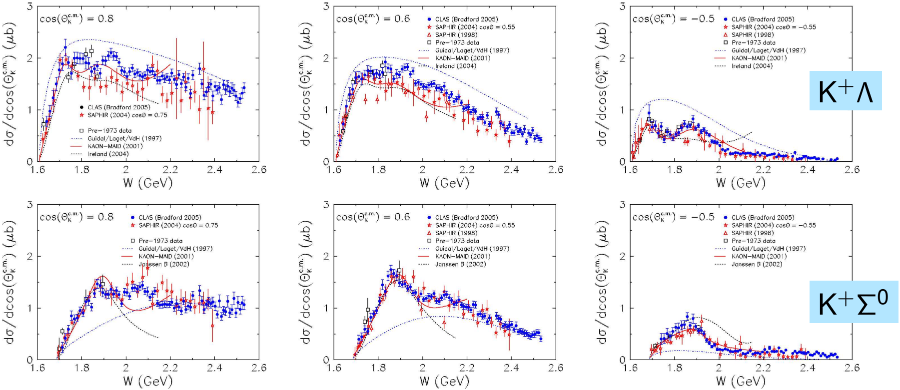


Possible new state

- $M = 2065 \pm 3^{+15}_{-30}$ MeV/c^2
- $\Gamma = 175 \pm 12 \pm 40$ MeV/c^2

$\Rightarrow$ Prel. PWA favors $\frac{3}{2}^+$ (hep-ex/0405030)

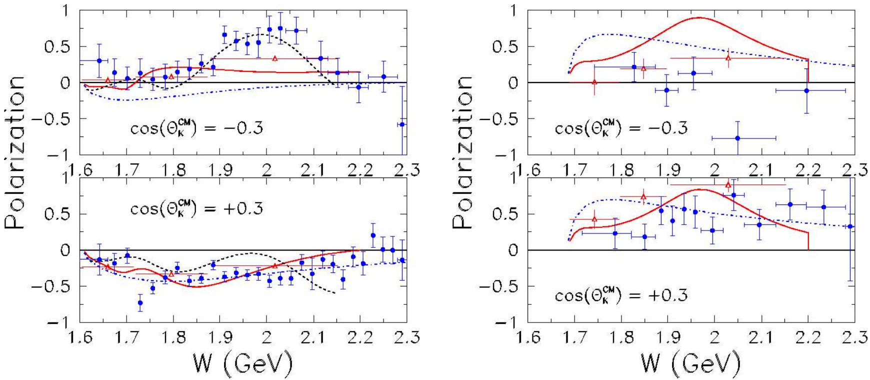
Strangeness Production



Models developed from fits to Bonn data (SAPHIR)

⇒ Only reproduce the threshold region

Induced Polarization of the Λ and Σ^0 Hyperon



CLAS results consistent with some older data from Bonn

Strangeness Production

⇒ Neither hadrodynamic nor Regge calculations reproduce the magnitudes or the trends seen in the hyperon polarization data

Data included in recent coupled-channel analysis (Sarantsev et al.):

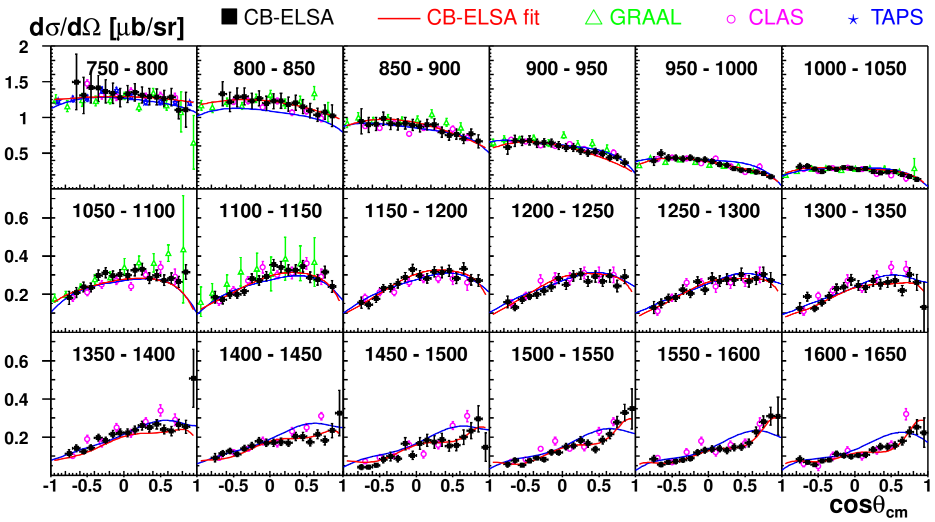
- SAPHIR and CLAS
- Beam asymmetry data from SPring-8/LEPS for $K^+\Lambda$
- Recent π^0/η data from CB-ELSA

⇒ New P_{11} at 1840 MeV

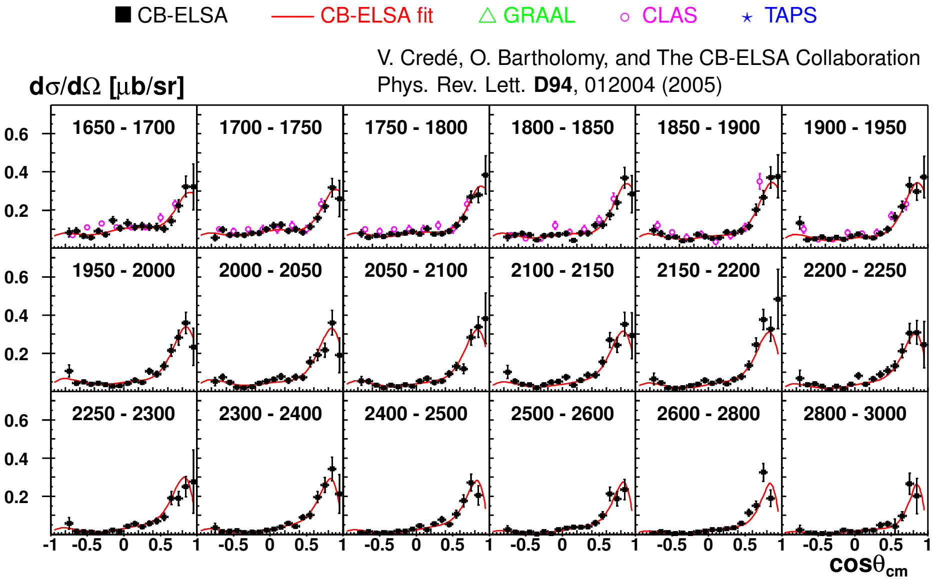
⇒ Two D_{13}: at 1870 MeV and 2130 MeV

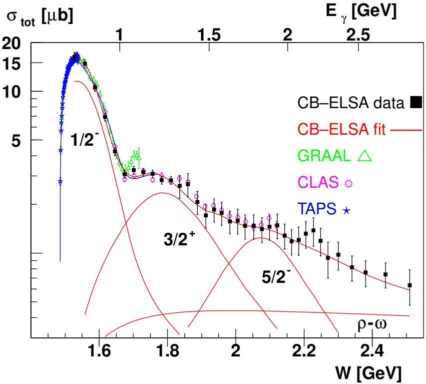
⇒ $\Delta(1940)D_{33}$ only Δ^* contributing to $K^+\Sigma^0$

Recent Results from the CB-ELSA Experiment



V. Credé, O. Bartholomy, and The CB-ELSA Collaboration
Phys. Rev. Lett. **D94**, 012004 (2005)





← The angular coverage of new data allows determination of the total cross section

Hint for N^* resonance (2070)D_{15}
(Phys. Rev. Lett. **D94**, 012004 (2005))
⇒ Needs confirmation !
⇒ No need for third S_{11}

CB-ELSA Isobar-Model Fit:
(Data included)

- $\gamma p \to p\eta$, $\gamma p \to p\pi^0$ (CB-ELSA)
- $\gamma p \to p\eta$ (TAPS, low energies)
- $\Sigma\,(\vec{\gamma}p \to p\eta)$, $\Sigma\,(\vec{\gamma}p \to p\pi^0)$ (GRAAL)
- $\Sigma\,(\vec{\gamma}p \to p\pi^0)$, $\sigma\,(\gamma p \to n\pi^+)$ (SAID)

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Polarization: Single-Meson Production

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

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

- δ_l, $\delta_\odot$: Beam Polarization
- Λ_x, Λ_y, Λ_z: Target Polarization

Polarization: 2-Meson Production ($\pi^+\pi^-$, $\pi^0\pi^0$, $\pi^0\eta$, ...)

$$\gamma N \rightarrow N\pi\pi \ = \\ \gamma N \rightarrow \Delta\pi \rightarrow N\pi\pi \ + \\ \gamma N \rightarrow N\rho \rightarrow N\pi\pi, \ \text{etc.}$$

- Many possibilities to be included
- Polarization treated in terms of density matrix for each quasi two-body (QTB) state
- C'est pas très efficace! (W. Roberts)

In addition:

- QTB treatment neglects contributions that are not QTB
- Interferences may be (largely) ignored
- Treating process as Nρ, for example, will lead to results *(of some kind)* $\Rightarrow$ Interpretation may not be convincing

Polarization: 2-Meson Production ($\pi^+\pi^-$, $\pi^0\pi^0$, $\pi^0\eta$, ...)

$$\gamma N \to N\pi\pi \; = \; \gamma N \to \Delta\pi \to N\pi\pi \; + \; \gamma N \to N\rho \to N\pi\pi, \; \text{etc.}$$

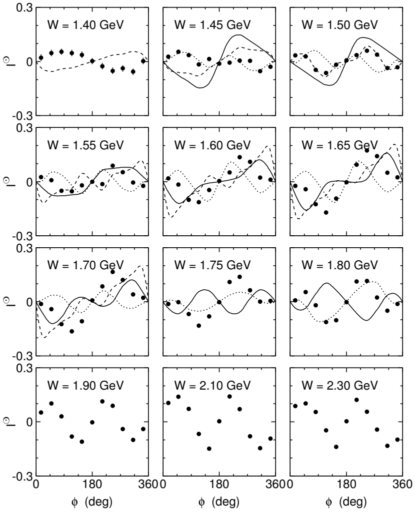
- Many possibilities to be included
- Polarization treated in terms of density matrix for each quasi two-body (QTB) state
- C'est pas très efficace! (W. Roberts)

Direct Calculation (W. Roberts and T. Oed, Phys. Rev. C71, 055201 (2005)):

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

$\Leftarrow$ Double-Meson Final States (15 Observables)

Measurement of $I^{\odot}$ at CLAS



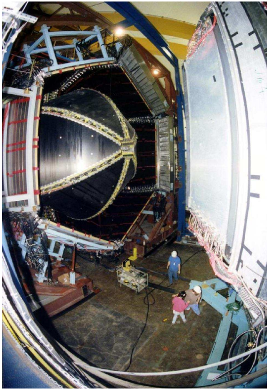
- Only one observable in $\pi\pi$, $I^{\odot}$, measured and published

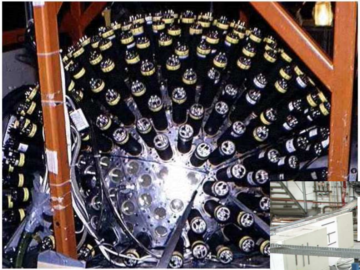
  (S. Strauch et. al., PRL **95**, 162003 (2005))

  $\Rightarrow$ Circularly-polarized beam on unpolarized target
- Mokeev et al. (solid, dotted)
- Fix and Arenhövel (dashed)

Polarization Experiments in 2006

CLAS, JLab

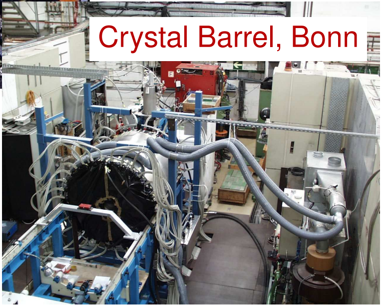




Crystal Ball, Mainz

GRAAL

Crystal Barrel, Bonn

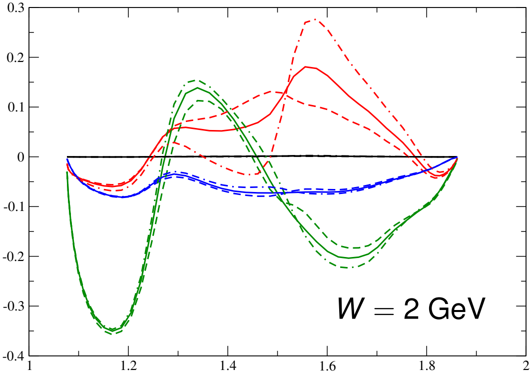


The FROST Program at CLAS

- Search for Missing Nucleon Resonances in the Photoproduction of Hyperons using Polarized Photon Beam and Polarized Target
- Pion Production From a Polarized Target
- Helicity Structure of Pion Photoproduction
- Measurement of Polarization Observables in η Photoproduction
- \+ Measurement of $\pi^+\pi^-$ Photoproduction in Double-Polarization Experiments (to be submitted to PAC 29 next Monday)

Model Calculations of $P_y^{\odot}$ (new) by W. Roberts

$\phi \approx 0$, $\phi = 0.56$ rad, $\phi = 2.09$ rad, $\phi \approx \pi$



Invariant $p\pi^+$ mass [GeV/c^2]

$\gamma p \rightarrow p \pi^+ \pi^-$

Circ. Beam → Trans. Target (target pol. ⊥ reaction plane)

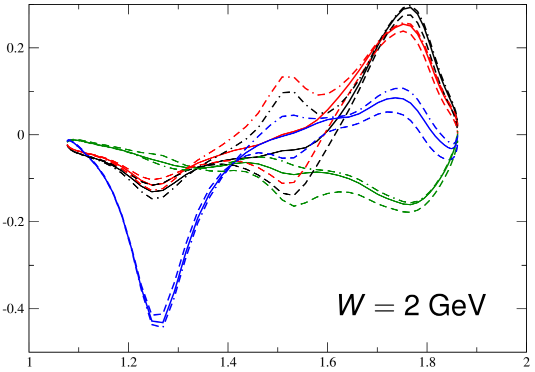
$D_{13}(1520) \rightarrow \Delta\pi$

- $g_1 = -0.4698$ (solid) $g_2 = -3.336$
- $g_1 = 0$ (dot-dashed)
- $g_2 = 0$ (dashed)

Model Calculations of P_z^s (known as G) by W. Roberts

$\phi \approx 0$, $\phi = 0.56$ rad, $\phi = 2.09$ rad, $\phi \approx \pi$

$\gamma p \rightarrow p \pi^+ \pi^-$



Invariant $p\pi^+$ mass [GeV/c^2]

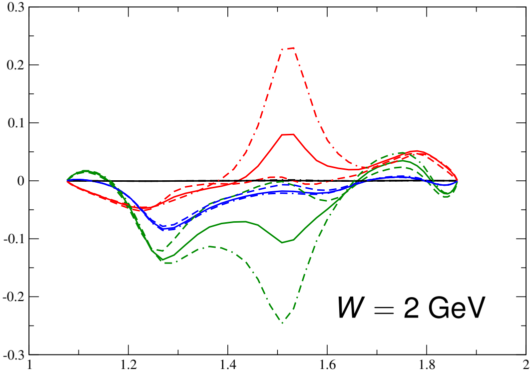
Lin. Beam → Long. Target

$D_{13}(1520) \rightarrow \Delta\pi$

- $g_1 = -0.4698$ (solid)
  $g_2 = -3.336$
- $g_1 = 0$ (dot-dashed)
- $g_2 = 0$ (dashed)

Model Calculations of P_z^c (new) by W. Roberts

$\phi \approx 0$, $\phi = 0.56$ rad, $\phi = 2.09$ rad, $\phi \approx \pi$



Invariant $p\pi^+$ mass [GeV/c^2]

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Lin. Beam $\rightarrow$ Long. Target

$D_{13}(1520) \rightarrow \Delta\pi$

- $g_1 = -0.4698$ (solid)
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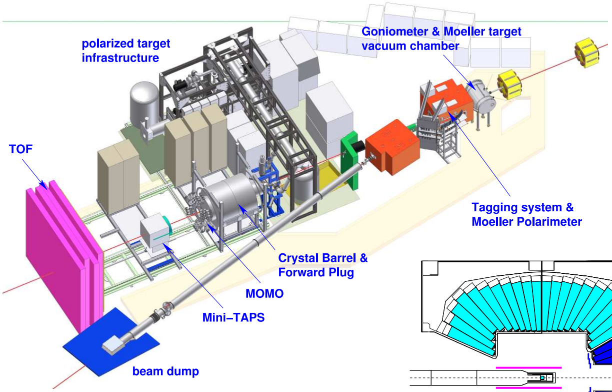
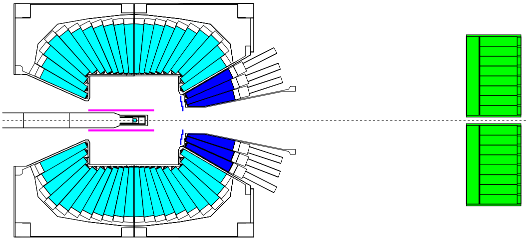
The CB-ELSA Polarization Program





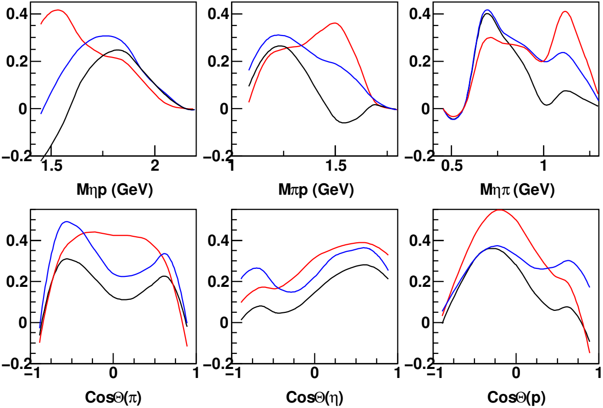
The CB-ELSA Polarization Program ($E_\gamma \leq 3.0$ GeV)

Advantage: Very good Neutral-Particle Detection

Proposals submitted to ELSA/MAMI PAC-05/September 2005

- 1. ELSA/1-2005 — G in single π^0 and η production
- 2. ELSA/2-2005 — Helicity Dependence in Single π^0/η Production
- 3. ELSA/3-2005 — Σ and G in η photoproduction off Neutron
- 4. ELSA/4-2005 — Beam-Target Asymmetries in ω Photoproduction
- 5. ELSA/5-2005 — Meson-Nucleus Bound States
- 6. ELSA/6-2005 — Double Polarization in $2\pi^0$ Photoproduction
- 7. ELSA/7-2005 — Helicity Difference in $\pi^0\eta$ Photoproduction

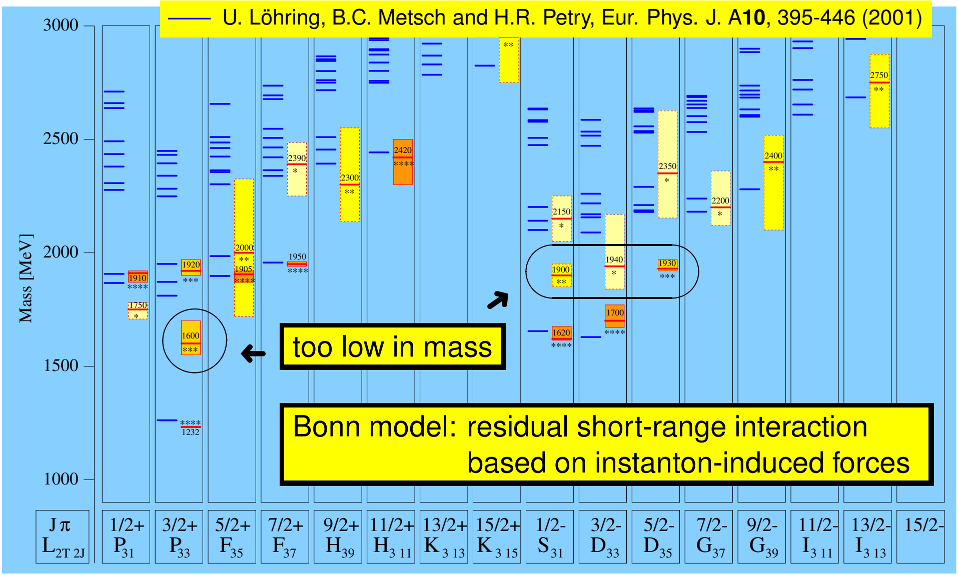
Sensitivity of Observable $P_z^{\odot}$ (or E) to Resonances



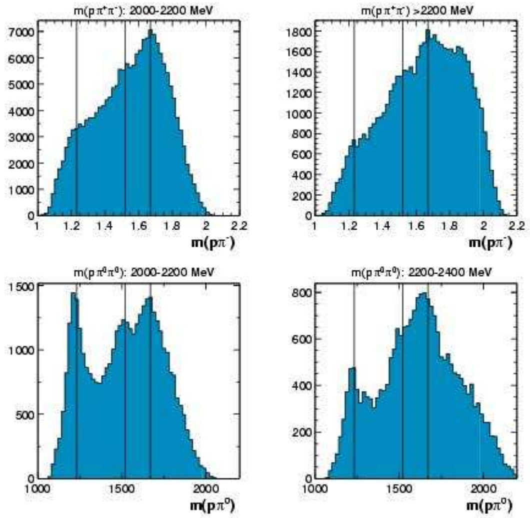
- — Best Solution
- — No $N(2100)P_{11}$
- — No $\Delta(1940)D_{33}$

Mass Region:
2000-2200 MeV/c^2

$\Rightarrow$ Effects are big ...


U. Löhring, B.C. Metsch and H.R. Petry, Eur. Phys. J. A10, 395-446 (2001)
Mass [MeV]
3000
2500
2000
1500
1000
too low in mass
Bonn model: residual short-range interaction based on instanton-induced forces
J π
L2T 2J
1/2+ P31
3/2+ P33
5/2+ F35
7/2+ F37
9/2+ H39
11/2+ H3 11
13/2+ K3 13
15/2+ K3 15
1/2- S31
3/2- D33
5/2- D35
7/2- G37
9/2- G39
11/2- I3 11
13/2- I3 13
15/2-

Combined Analysis: CLAS and Crystal Barrel



For example:

$\gamma p \rightarrow p\pi^+\pi^-$ at CLAS

Not Competitors
$\Rightarrow$ Complementary

$\gamma p \rightarrow p\pi^0\pi^0$ at CB-ELSA

Summary and Outlook

Fruitful Discussions at NSTAR 2005 in Tallahassee !

Summary and Outlook

Next NSTAR Workshop: Bonn, Germany in 2007 !