Is there really a narrow nucleon resonance at $W=1700$ MeV?

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The 12th International Workshop on the Physics of Excited Nucleons
10 - 14 June 2019, Bonn
Outline

- Motivation
  V. Kuznetsov et al., JETP Letters 106 (2017) 693
  Anti-Decuplet N(1685)
- CB/TAPS Experiment @ ELSA
- Data analysis
  event selection
  comparison with published data
- Preliminary results
  invariant mass and angular distribution
  comparison with PWA MC
- Interpretation
- Summary and outlook
Observation of narrow $N(1685)$ resonances in $\gamma N \rightarrow \eta \pi N$ reactions

V. Kuznetsov et al., JETP Letters 106 (2017) 693

$E_\gamma = 1400 - 1500$ MeV

$\gamma N \rightarrow \pi \eta N$ - sum of all channels

$\Gamma \sim 10$ MeV

is the narrow structure in $M(\eta N)$ real?
Observation of narrow $N(1685)$ resonances in $\gamma N \rightarrow \eta \pi N$ reactions

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$E_\gamma = 1400 - 1500$ MeV

$\gamma N \rightarrow \pi \eta N$ - sum of all channels

is the narrow structure in $M(\eta N)$ real?

Anti-Decuplet of baryons in the Chiral Soliton Model


$Z^+(1530)$

$nK^+ \text{ or } pK^0$

$\Sigma^+(1890)$

$\Xi^{-}\pi^- \text{ or } \Sigma^-K^-$

$\Xi^0\pi^+ \text{ or } \Sigma^+K^0$

$\Xi^{-}\pi^- \text{ or } \Sigma^-K^-$

$\Xi^0\pi^+ \text{ or } \Sigma^+K^0$
Observation of narrow $N(1685)$ resonances in $\gamma N \rightarrow \eta \pi N$ reactions

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$E_\gamma = 1400 - 1500$ MeV

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$\Gamma \sim 10$ MeV

is the narrow structure in $M(\eta N)$ real?

Anti-Decuplet of baryons in the Chiral Soliton Model


new: pentaquark states in charm sector

LHCb Collaboration:

R. Aaij et al., PRL 115 (2015) 072001
Data taken in 2013

$E_\gamma = 0.7$ - $3.1$ GeV

**photon beam**

- **Crystal Barrel (CB)**: CsI
  - $11^\circ$ - $156^\circ$
  - $1^\circ$ - $11^\circ$

- **MiniTAPS (MT)**: BaF$_2$

**charged particle detection:**

- SciFi detector (CB)
- Plastic scintillators (FP and MT)

**target:** LH$_2$

**4$\pi$ photon detector:** ideally suited for identification of multi-photon final states

**identification of $\gamma p \rightarrow p\pi^0\eta \rightarrow p4\gamma$**

4 photons in the final state
Data analysis: event selection

- **identification of $\gamma\, p \rightarrow p\pi^0\eta$:**
  - decay channels: $\pi^0 \rightarrow \gamma\gamma$ and $\eta \rightarrow \gamma\gamma$
  - $E_\gamma = 1400-1600$ MeV

- **kinematic fit of all combinations**
  - hypothesis: $\gamma\, p \rightarrow p_{\text{miss}}\pi^0\eta$
  - constraints: $E$, $p$ conservation, $\pi^0$ and $\eta$ inv. mass
  - $p$ - missing particle, cut on missing mass using the experimental information on $\theta_p$ and $\Phi_p$

- **cuts:**
  - on $m(\gamma\gamma)$ to select $\pi^0$ and $\eta$
  - coplanarity $4\gamma$ - missing baryon $p$
  - $\theta_p(\text{meas}) - \theta_p(\text{miss})$
  - $\text{CL}_{\gamma\, p \rightarrow p\pi^0\eta} > 0.2$
  - anticut:
  - $\text{CL}_{\gamma\, p \rightarrow p\pi^0\pi^0} < 0.01$
  - (to suppress the dominant reaction!)

![Confidence level for hypothesis $\gamma\, p \rightarrow p_{\text{miss}}\pi^0\eta$](image1)

![Hypothesis $\gamma\, p \rightarrow p_{\text{miss}}\pi^0\eta\gamma$](image2)
Preliminary results compared to published data

invariant mass distributions

comparison with E. Gutz et al., EPJA 50 (2014) 74 (35 MeV binning)

angular distributions

acceptance corrected data
in comparison with
A2 data V. Sokhoyan et al.,
PRC 97 (2017) 055212

good agreement
with published data!!!
Comparison Kuznetsov et al.  CBELSA/TAPS

\[ E_\gamma = 1400 - 1500 \text{ MeV} \]

cut used by Kuznetsov: \( 1120 \text{ MeV} \leq m_{p\pi} \leq 1220 \text{ MeV} \)
to suppress \( \gamma p \rightarrow \Delta^* \rightarrow \eta \Delta(1232) \rightarrow p\pi\eta \)

Kuznetsov et al., JETP 106 (2017) 693

\( \gamma N \rightarrow \pi \eta N \) - sum of all channels

\[ \Gamma \sim 10 \text{ MeV} \]
Comparison Kuznetsov et al. ↔ CBELSA/TAPS

\[ E_\gamma = 1400 - 1500 \text{ MeV} \]

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to suppress \( \gamma p \rightarrow \Delta^* \rightarrow \eta \Delta(1232) \rightarrow p\pi\eta \)

Kuznetsov et al., JETP 106 (2017) 693

\[ \gamma N \rightarrow \pi \eta N \quad \text{sum of all channels} \]

\[ \gamma p \rightarrow p \pi^0\eta \]

\[ N(1685) \]

\[ \Gamma \sim 10 \text{ MeV} \]

\[ Z = \sqrt{2 \ln \left( \frac{L_{bg+s}}{L_{bg}} \right)} = 6 \sigma \]

cut applied to CBELSA/TAPS data: \( m_{p\pi} \leq 1190 \text{ MeV} \)
Preliminary results: structure at higher incident photon energies

\[ E_\gamma = 1400 - 1600 \text{ MeV} \]

comparison to event based PWA simulation

structure emerges at \( E_\gamma \approx 1400 \) MeV, gets broader with increasing incident photon energy, and disappears for \( E_\gamma > 1560 \) MeV
\[ \gamma \ p \rightarrow \ p \ \pi^0 \ \eta: \text{possible interpretation?} \]

cascade decay of primary resonance at \( \approx 1930 \text{ MeV} \) via \( N^*(1710) \ 1/2^+ \)

\[ \begin{array}{c}
N(1900)3/2^+ \\
N(1710)1/2^+ \\
N(938)1/2^+
\end{array} \]

\[ \begin{array}{c}
\pi^0 \\
\eta
\end{array} \]

\( \pi^0 \) decay of primary resonance near \( W = 1930 \text{ MeV} \) populates intermediate resonance \( (N^*(1710) \ ?) \) which decays into the \( p \ \eta \) channel
\( \gamma p \rightarrow p \pi^0 \eta: \) Dalitz plot

Comparison to event based PWA simulation

Structure is also seen in the Dalitz plot (linear presentation)

After subtraction of PWA simulation
angular distribution excess yield for different $\cos \theta_{\pi}$ bins in cm

$E_\gamma = 1480 - 1520$ MeV; $M_{p\pi^0} < 1190$ MeV

-1.0 < $\cos \theta_{\pi}$ < -0.8
-0.8 < $\cos \theta_{\pi}$ < -0.6
-0.6 < $\cos \theta_{\pi}$ < -0.4
-0.4 < $\cos \theta_{\pi}$ < -0.2
-0.2 < $\cos \theta_{\pi}$ < 0.0

0.0 < $\cos \theta_{\pi}$ < 0.2
0.2 < $\cos \theta_{\pi}$ < 0.4
0.4 < $\cos \theta_{\pi}$ < 0.6
0.6 < $\cos \theta_{\pi}$ < 0.8
0.8 < $\cos \theta_{\pi}$ < 1.0

data compared to event based PWA simulation
Preliminary results: angular distribution of excess yield in cm

\[ E_\gamma = 1480 - 1520 \text{ MeV}; \quad M_{p\pi^0} < 1190 \text{ MeV} \]

fit function: \( W(\cos(\theta_{\pi^0}) \propto 5 - 3 \cos^2(\theta_{\pi^0}) \)

- characteristic for the excitation of state with spin 3/2
angular distribution: excess yield for different $\cos \theta_p$ bins in cm

$E_\gamma = 1480 - 1520$ MeV; \quad $M_{p\pi 0} < 1190$ MeV

-1.0 < $\cos \theta_p$ < -0.8

-0.8 < $\cos \theta_p$ < -0.6

-0.6 < $\cos \theta_p$ < -0.4

-0.4 < $\cos \theta_p$ < -0.2

-0.2 < $\cos \theta_p$ < 0.0

0.0 < $\cos \theta_p$ < 0.2

0.2 < $\cos \theta_p$ < 0.4

0.4 < $\cos \theta_p$ < 0.6

0.6 < $\cos \theta_p$ < 0.8

0.8 < $\cos \theta_p$ < 1.0

data compared to event based PWA simulation
Preliminary results: angular distribution of excess yield in cm

\[ E_\gamma = 1480 - 1520 \text{ MeV}; \quad M_{p\pi^0} < 1190 \text{ MeV} \]

backward going proton

fit function: \[ W(\cos(\theta_{\pi^0}) \propto 5-3\cos^2(\theta_{\pi^0}) \]

- characteristic for the excitation of state with spin 3/2
angular distribution: excess yield for different cos $\theta_\eta$ bins in cm

$E_\gamma = 1480 - 1520$ MeV; $M_{p\pi^0} < 1190$ MeV

-1.0 < cos $\theta_\eta$ < -0.8

-0.8 < cos $\theta_\eta$ < -0.6

-0.6 < cos $\theta_\eta$ < -0.4

-0.4 < cos $\theta_\eta$ < -0.2

-0.2 < cos $\theta_\eta$ < 0.0

0.0 < cos $\theta_\eta$ < 0.2

0.2 < cos $\theta_\eta$ < 0.4

0.4 < cos $\theta_\eta$ < 0.6

0.6 < cos $\theta_\eta$ < 0.8

0.8 < cos $\theta_\eta$ < 1.0

data compared to event based PWA simulation
Preliminary results: angular distribution of excess yield in cm

\[ E_\gamma = 1480 - 1520 \text{ MeV}; \quad M_{p\pi^0} < 1190 \text{ MeV} \]

Fit function: \( W(\cos(\theta_{\pi^0}) \propto 5 - 3\cos^2(\theta_{\pi^0}) \)
- characteristic for the excitation of state with spin 3/2

forward going \( \eta \) in coincidence with backward going proton
Interpretation of results

\[ \pi^0 N^*(1900) \]

\[ \pi^0 N^*(1710) \]

\[ \beta_{\pi} = 0.754 \]

\[ \beta_{N^*(1710)} = 0.090 \]

\[ \gamma\text{-beam} \]

\[ \eta \]

\[ p \]
Interpretation of results

This data - momentum distribution
Event based PWA simulation
difference data - PWA
Interpretation of results

\[ \beta_\pi = 0.754 \]
\[ \beta_{N^*(1710)} = 0.090 \]

\[ \pi^0 \rightarrow \gamma \rightarrow N^*(1900) \rightarrow N^*(1710) \]

this data - momentum distribution

event based PWA simulation
difference data - PWA

difference data - PWA
Interpretation of results

η and p almost back-to-back in cm-system !!
characteristic for slowly moving heavy resonance like N(1710),
supporting decay chain $\gamma p \rightarrow N^*(1900) \rightarrow \pi^0 N^*(1710) \rightarrow \pi^0 \eta p$

this data - momentum distribution
event based PWA simulation
difference data - PWA
Conclusions and outlook

- For cuts suppressing the $\Delta(1232)$ contribution, there is some evidence for a structure at $M_{p\eta} \approx 1700$ MeV, as observed by Kuznetsov et al.

- This structure shows up as deviation from the $\gamma p \rightarrow p \pi^0 \eta$ PWA simulation. For higher incident photon energies a broader structure emerges at $1690 < M_{p\eta} < 1750$ MeV

- The structure is most pronounced for the incident photon energy range $1480 < E_\gamma < 1520$ MeV corresponding to $1910 < W < 1930$ MeV

- **Possible interpretation**: We are seeing the $N^*(1710)_{1/2}^+$ resonance with an $\eta p$ branching ratio of 10 - 50 % which is populated by $\pi^0$ decay from an $N^*$ or $\Delta^*$ resonance located around $1930$ MeV: candidate: $N^*(1900)_{3/2}^+$

- Interpretation supported by $p$-, $\eta$-, $\pi^0$- angular distributions in the cm system and by the measured reaction kinematics

- **Outlook**: implementation of claimed decay cascade in an improved PWA analysis
BACK UP
Preliminary results compared to published data

$\gamma p \rightarrow p \pi^0 \eta$: comparison with published data: **invariant mass distributions**

A2: V. Sokhoyan et al., PRC 97 (2017) 055212

![Graphs showing invariant mass distributions for $\pi^0$, $\eta$, and $p$](image.png)
E_{\gamma}=1400-1440 \text{ MeV}  
\sigma=7.3 \text{ MeV}  
\mu=1698 \text{ MeV}

E_{\gamma}=1440-1460 \text{ MeV}  
\sigma=15.5 \text{ MeV}  
\mu=1708 \text{ MeV}

E_{\gamma}=1460-1480 \text{ MeV}  
\sigma=14.2 \text{ MeV}  
\mu=1705 \text{ MeV}

E_{\gamma}=1480-1500 \text{ MeV}  
\sigma=25.8 \text{ MeV}  
\mu=1719 \text{ MeV}

E_{\gamma}=1500-1520 \text{ MeV}  
\sigma=25.7 \text{ MeV}  
\mu=1727 \text{ MeV}

E_{\gamma}=1520-1560 \text{ MeV}  
\sigma=34.1 \text{ MeV}  
\mu=1731 \text{ MeV}

structure most pronounced for 1480 < E_{\gamma} < 1520 \text{ MeV}

corresponding to 1910 < W < 1930 \text{ MeV}
$\gamma p \rightarrow \pi^0 N(1710) \rightarrow \pi^0 \eta p$; $E_\gamma = 1500$ MeV

**step 1: (overall cm-system)**

$\gamma$-beam

$\pi^0 \rightarrow N^*(1710)$

$N^*(1710)$

$N^*(1920)$

**step 2: (GJ-frame)**

$\eta$

$p$

$\pi^0 \rightarrow N^*(1710)$

$N^*(1920)$

$\beta_\gamma E_{\eta^*} = 62.0$ MeV

$\beta_\gamma E_{p^*} = 92.7$ MeV

$E_{p^*} = 413.4$ MeV

$p_{\pi} = 154.7$ MeV

$\eta$ and $p$ almost back-to-back in cm-system!!

characteristic for slowly moving heavy resonance like $N(1710)$, supporting decay chain

$\gamma p \rightarrow N^*(1920) \rightarrow \pi^0 N(1710) \rightarrow \pi^0 \eta p$
comparison $E_{\text{tot}}$ with event based PWA simulation

$E_\gamma = 1480 - 1520$ MeV; w/o cut on $M_{p\pi^0}$
comparison $E_{\text{tot}}$ with event based PWA simulation

$E_\gamma = 1480 - 1520$ MeV; w/o cut on $M_{p\pi^0}$

$M_{p\pi^0} < 1190$ MeV
$\gamma p \rightarrow \pi^0 \eta p$

$E_\gamma = 1480 - 1520$ MeV

data no cut

PWA rec no cut
$\gamma p \rightarrow \pi^0 \eta p$

$E_\gamma = 1480 - 1520$ MeV

data no cut

PWA rec no cut

$\theta_p = 180^0, 135^0, 90^0, 70^0, 45^0, 0^0$
$\gamma p \rightarrow \pi^0 \eta p$

$E_\gamma = 1480 - 1520$ MeV

data no cut

PWA rec no cut

$\theta_p = 180^0, 135^0, 110^0, 90^0, 45^0, 0^0$
cut used by Kuznetsov: \( 1120 \text{ MeV} \leq m_{p\pi} \leq 1220 \text{ MeV} \)

Kuznetsov et al., JETP 106 (2017) 693
including charged pion channels

\[ \gamma p \rightarrow p \pi^0 \eta \]

\( E_\gamma = 1400-1500 \text{ MeV} \)

- same structure with
- poorer resolution ??
The structure is also seen in the Dalitz plot (linear presentation) after subtraction of PWA simulation.
cut used by Kuznetsov: $1120 \text{ MeV} \leq m_{p\pi} \leq 1220 \text{ MeV}$

Kuznetsov et al., JETP 106 (2017) 693
including charged pion channels

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

$E_\gamma = 1400-1500 \text{ MeV}$

cut applied to CBELA/TAPS data: $1160 \text{ MeV} \leq m_{p\pi} \leq 1190 \text{ MeV}$
CL Antihypothese: $\gamma p \rightarrow p_{\text{miss}} \pi^0 \pi^0$
CL $\leq 0.01$ and factor $= 0.1$
CL Hypothese: $\gamma p \rightarrow p_{\text{miss}} \pi^0 \eta$
cut: $\text{CL} > 0.2$