Electroproduction of N* resonances at Jefferson Lab

K. Hicks, Ohio University

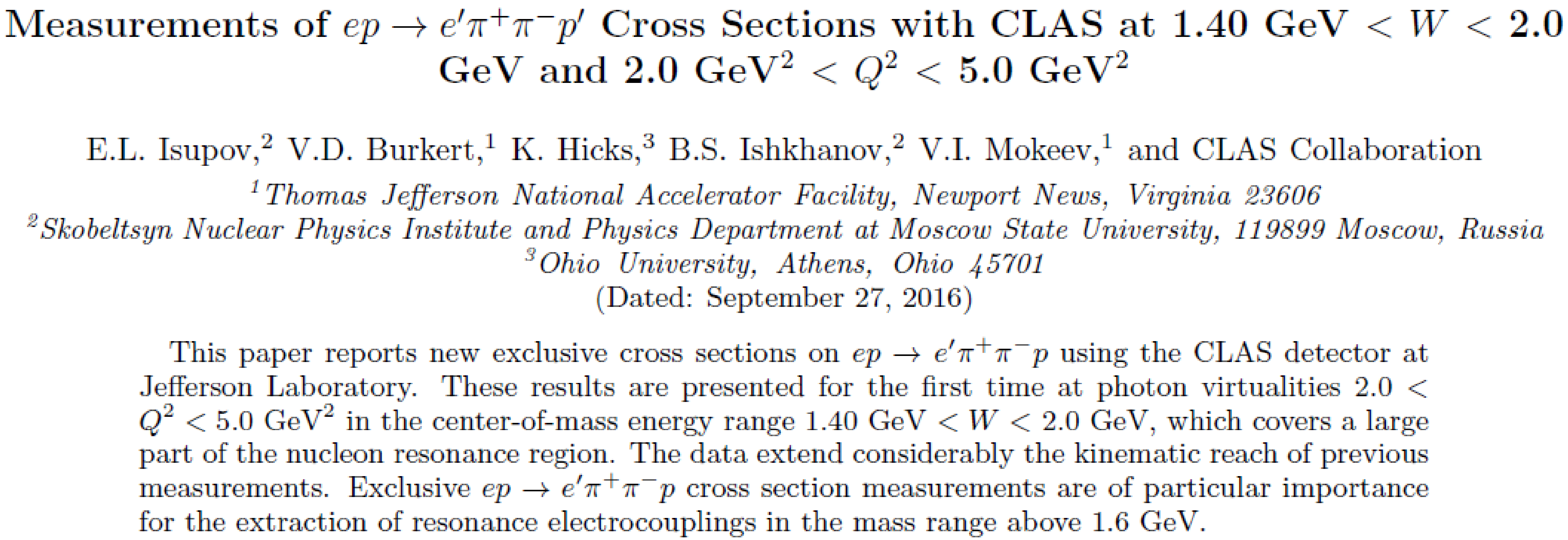
INT Workshop on N*'s from Exclusive Electroproduction

November 15, 2016

Overview of N* electroproduction at JLab

- Single-pion electroproduction (K. Park, M. Ungaro, N. Markov)
  - Talks to be presented tomorrow
- Rho electroproduction (S. Morrow, et al.) 2009
- Phi electroproduction (J. Santoro, et al.) 2008
- Eta electroproduction (H. Denezil, et al.) 2007
- $\pi^+\pi^-$ electroprod. (E. Isupov, et al.; G. Fedotov, et al.) ← This Talk
- KY electroproduction (D. Carman, B. Raue, et al.) 2014, 2013, 2007
  - If time allows, some of the newer (2014) data will be shown

Paper under internal review at CLAS



Measurements of $ep \to e'\pi^+\pi^-p'$ Cross Sections with CLAS at $1.40\ \mathrm{GeV} < W < 2.0\ \mathrm{GeV}$ and $2.0\ \mathrm{GeV}^2 < Q^2 < 5.0\ \mathrm{GeV}^2$

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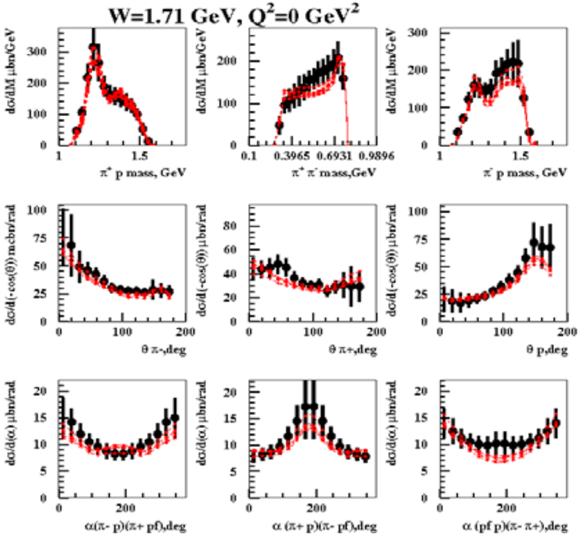
(Dated: September 27, 2016)

This paper reports new exclusive cross sections on $ep \to e'\pi^+\pi^-p$ using the CLAS detector at Jefferson Laboratory. These results are presented for the first time at photon virtualities $2.0 < Q^2 < 5.0\ \mathrm{GeV}^2$ in the center-of-mass energy range $1.40\ \mathrm{GeV} < W < 2.0\ \mathrm{GeV}$, which covers a large part of the nucleon resonance region. The data extend considerably the kinematic reach of previous measurements. Exclusive $ep \to e'\pi^+\pi^-p$ cross section measurements are of particular importance for the extraction of resonance electrocouplings in the mass range above 1.6 GeV.

Goals of the CLAS two-pion analysis

- Compare electrocouplings of N*'s extracted from 1- and 2-pion data
  - Tests our understanding of reaction mechanisms in π+π- electroproduction.
  - Validate N* electrocouplings determined in Nπ data.
- Look for signature of "missing N*" at higher mass (M > 1.6 GeV)
  - Missing resonances are predicted to have small B.R. to single-pion final state, but substantial B.R. to the N$\pi\pi$
  - Hybrid baryons are predicted at higher mass—can we find these states?
- Explore the quark mass function and dressed quark-gluon vertex
  - Electrocouplings at Q^2>3.0 GeV^2 offer access to the momentum dependence of dressed quark mass function (J.Segovia, V.Mokeev talks)

Further Evidence for the Existence of the New State N'(1720)3/2$^+$ from Combined $\pi^+\pi^-p$ Analyses in both Photo- and Electroproduction



Almost the same quality of the photoproduction data fit at 1.66 GeV <W<1.76 GeV and Q^2=0, 0,65, 0.95, 1.30 GeV^2 was achieved with and without N'(1720)3/2$^+$ new states

N(1720)3/2$^+$ hadronic decays from the CLAS data fit with conventional resonances only

	BF($\pi\Delta$), %	BF(ρp), %
electroproduction	64-100	<5
photoproduction	14-60	19-69

The contradictory BF values for N(1720)3/2$^+$ decays to the $\pi\Delta$ and ρp final states deduced from photo- and electroproduction data make it impossible to describe the data with conventional states only.

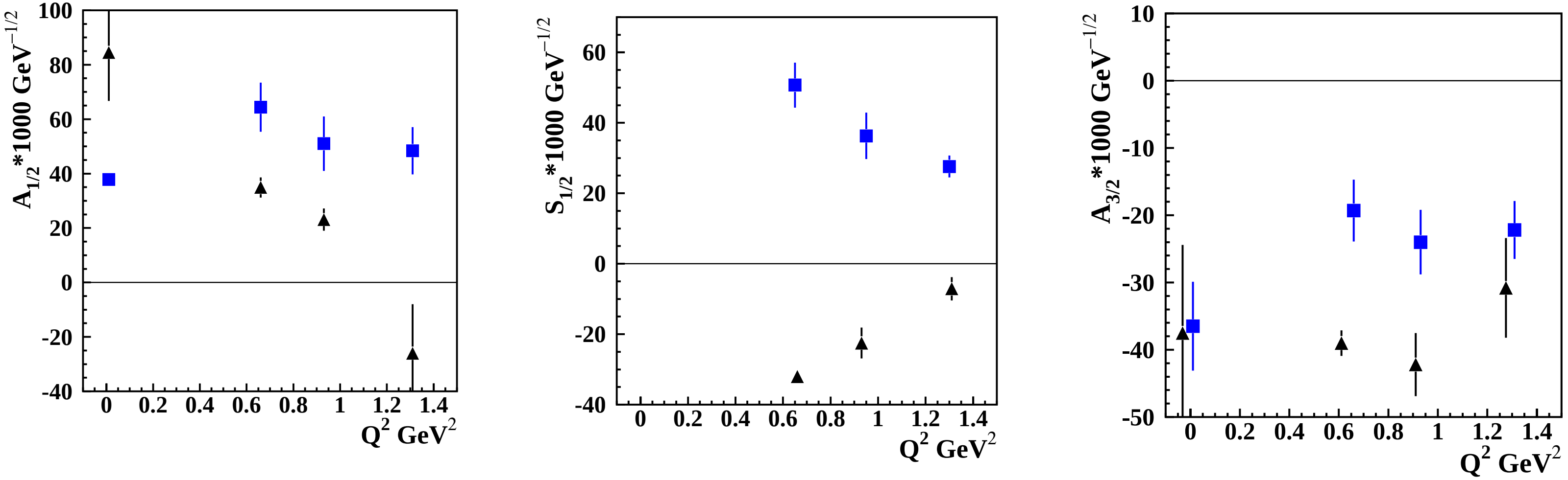
N* hadronic decays from the data fit that incorporates the new N'(1720)3/2$^+$ state

Resonance	BF($\pi\Delta$), %	BF(ρp), %
N'(1720)3/2$^+$ electroproduction photoproduction	47-64 46-62	3-10 4-13
N(1720)3/2$^+$ electroproduction photoproduction	39-55 38-53	23-49 31-46
Δ(1700)3/2$^-$ electroproduction photoproduction	77-95 78-93	3-5 3-6

Successful description of $\pi^+\pi^-p$ photo- and electroproduction data achieved by implementing new N'(1720)3/2$^+$ state with Q^2-independent hadronic decay widths of all resonances contributing at W~1.7 GeV provides strong evidence for the existence of new N'(1720)3/2$^+$ state.

The Parameters of N’(1720)3/2$^+$ New State from the CLAS Data Fit

The photo-/electrocouplings of N’(1720)3/2$^+$ and conventional N(1720)3/2$^+$ states:

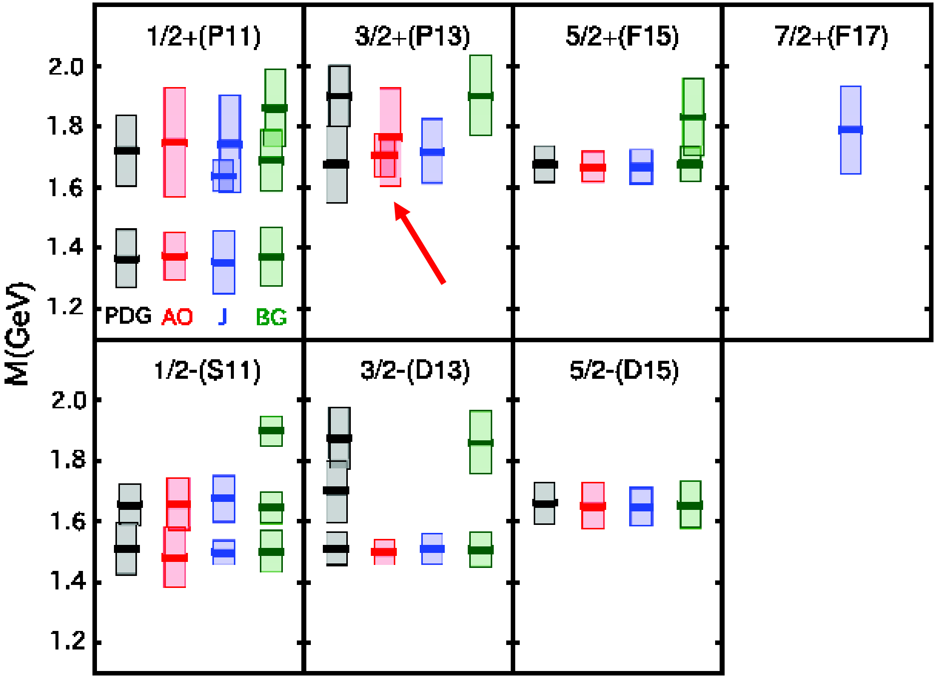


■ N’(1720)3/2$^+$

▲ N(1720)3/2$^+$

Resonance	Mass, GeV	Total width, MeV
N’(1720)3/2$^+$	1.715-1.735	120±6
N (1720)3/2$^+$	1.743-1.753	112±8

Support for the N'(1720)3/2⁺ from the Coupled Channel Analysis



H. Kamano et al., Phys. Rev. C88, 035209 (2013)

N* masses (bars) and widths (boxes) from the coupled channel analyses:
AO – Argonne-Osaka;
J – Julich;
BG- Bonn-Gatchina.

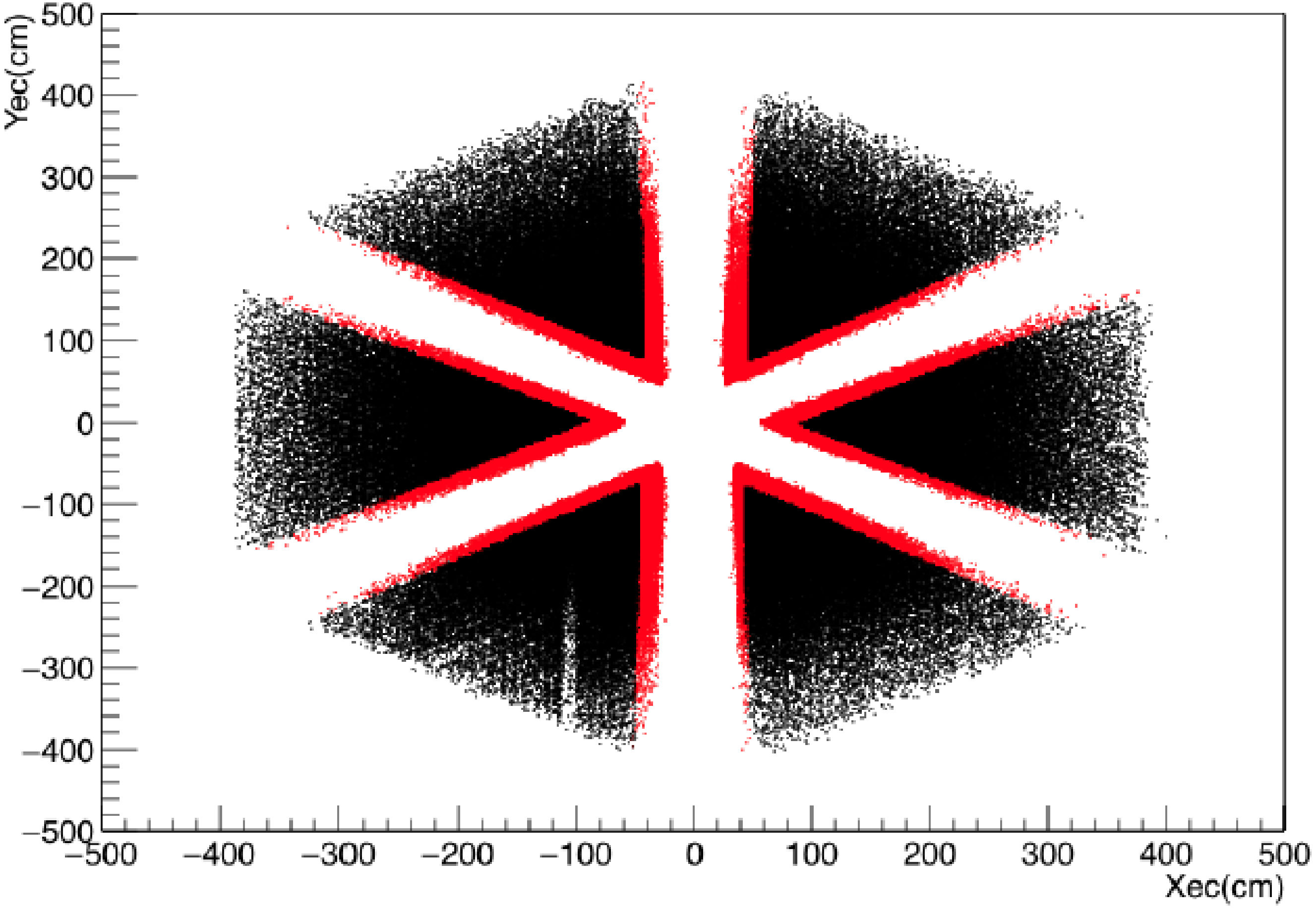
The coupled channel approach with 8 channels included :
$\gamma N \leftrightarrow \pi N, \eta N, K\Lambda, K\Sigma, \pi\Delta, \rho N, \sigma N$

Observation of N'(1720)3/2⁺ state in the CLAS $\pi^+\pi^-p$ photo-/electroproduction data is also seen in the global multi-channel photo-/hadroproduction data analysis by the Agronne-Osaka group.

CLAS experimental parameters

- Run period e1-6: beam energy 5.75 GeV
- Liquid hydrogen target (5 cm long)
- To identify pions cleanly:
  - Electromagnetic Calorimeter (EC)
  - Cerenkov Counter (CC)
  - Time-of-flight Scintillators (SC)
  - Tracking by Drift Chambers (DC)
- Open trigger: above-threshold signal in CC + signal in EC

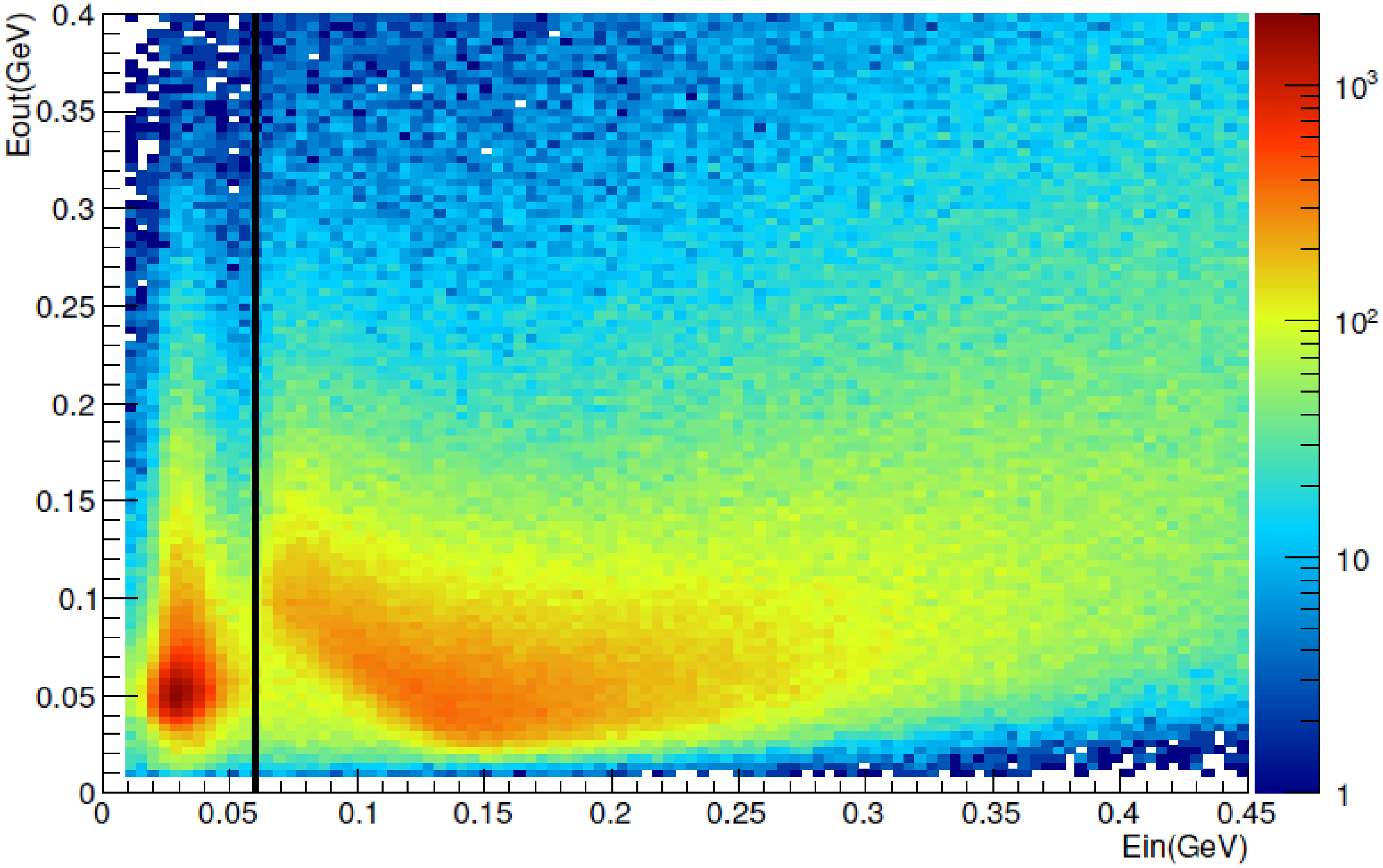
Electron events in the EC



Red: all events

Black: events after fiducial cut

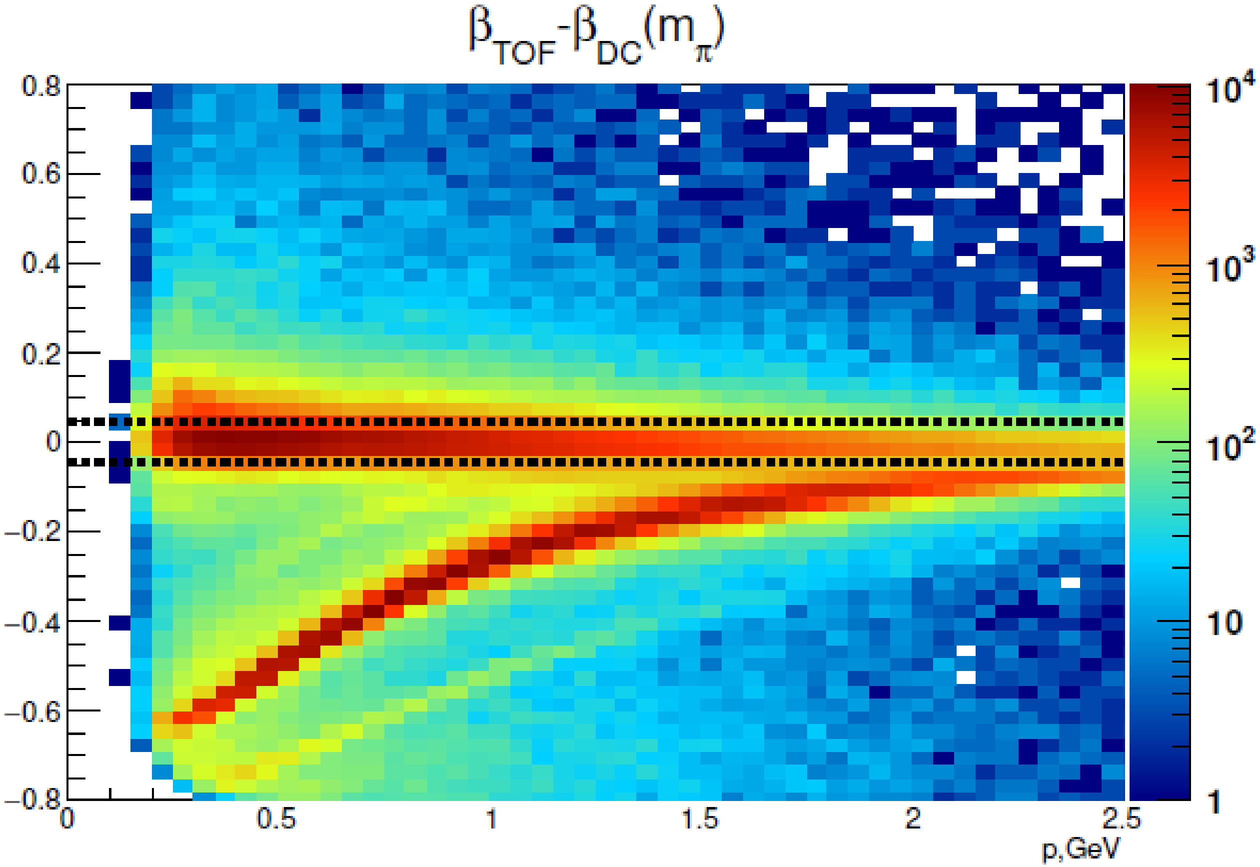
Energy Deposit in the EC



Left of cut: electrons

Right of cut: pions

Particle identification (pions)

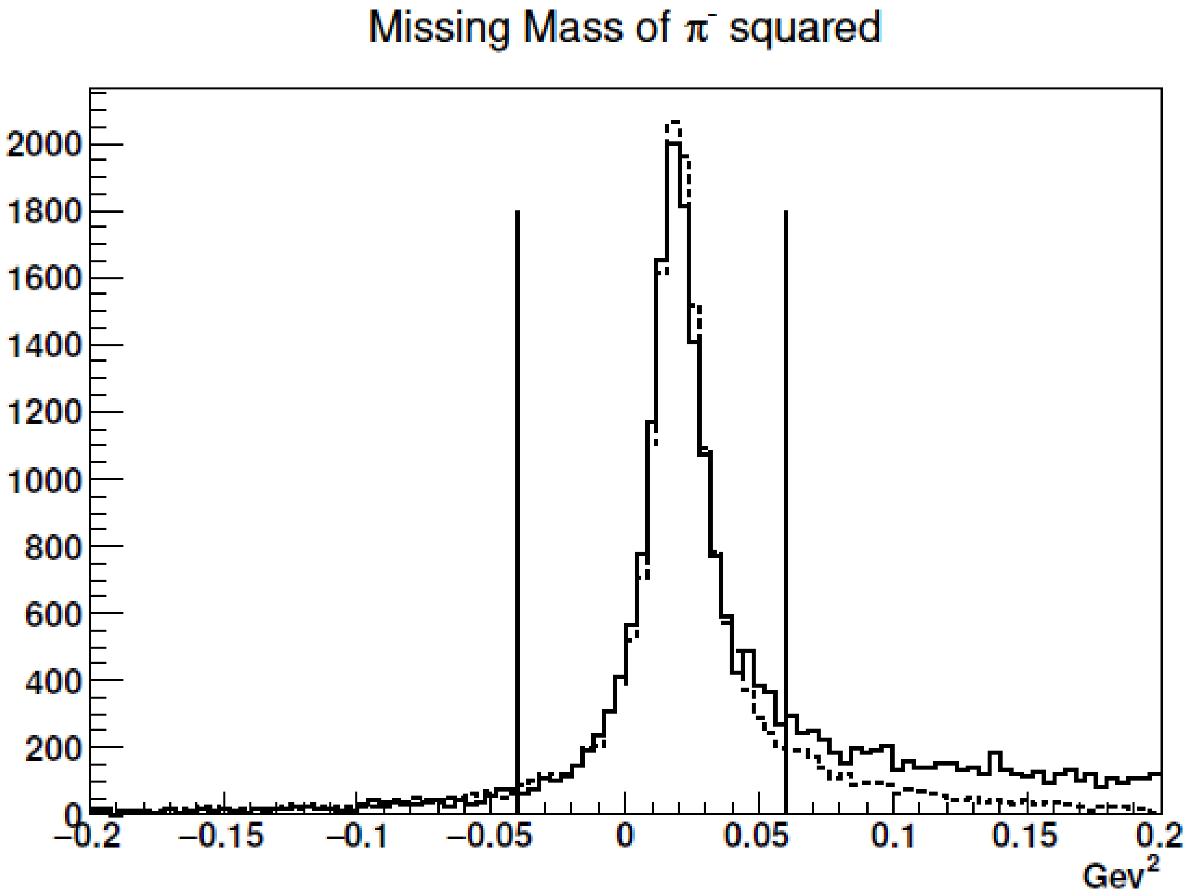


Centered on zero: pions

Band below: protons

<u>Note</u>: MC looks very similar

Exclusive Final State: missing mass

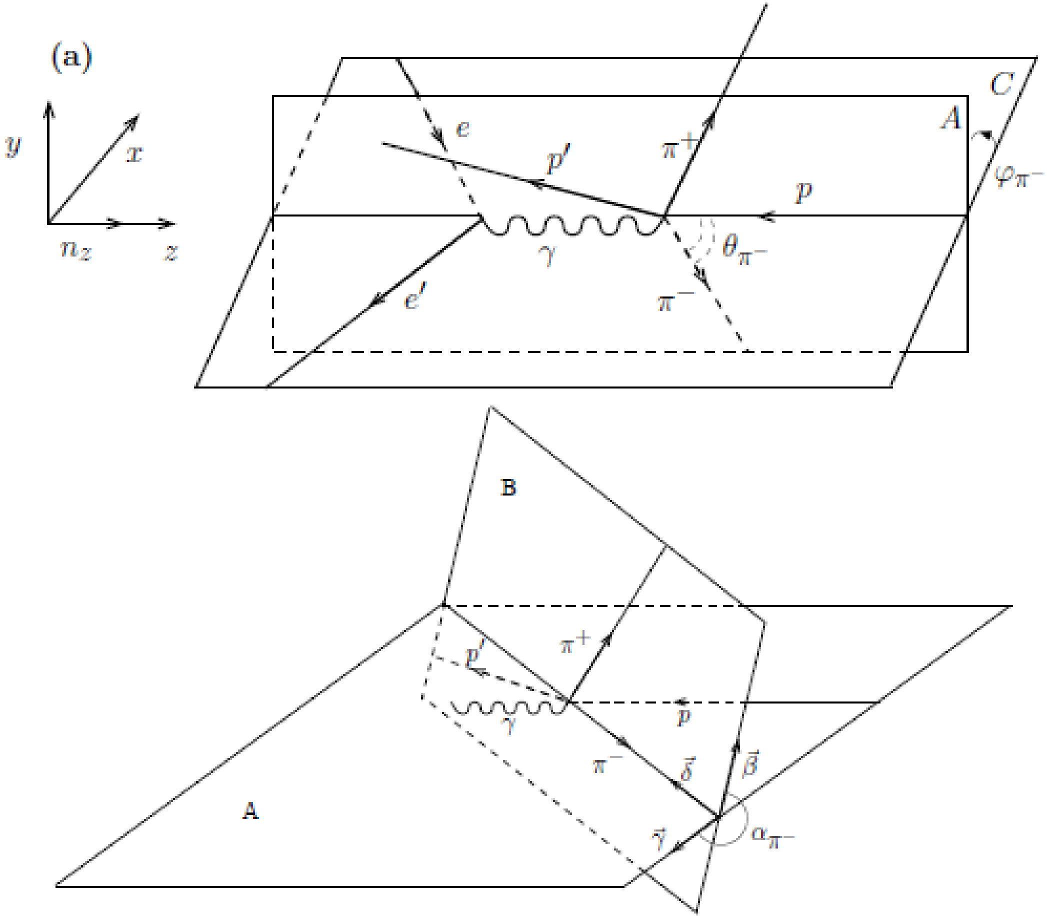


Peak: missing pion at $m^2 = (0.14)^2$.

Dashed: same, but for MC

Vertical lines: event selection cut

Kinematics



z-axis defined by Q-vector
x-z plane (C) defined by electron scattering
y-z plane (A) defined by p and π- plane
Angle $\theta_{\pi-}$: from vector p to vector π-
Angle $\phi_{\pi-}$: from plane C to plane A

Plane (B) defined by final-state p’ and π+
Angle α: from plane B to plane A
Unit vectors: β, γ, δ as shown

Need 5 variables: 3 angles, $M_{\pi\pi}$, $M_{\pi+p}$

Cross sections: 5-fold differential & integrated

$$\frac{d\sigma}{dM_{p\pi^+}dM_{\pi^+\pi^-}d\Omega_{\pi^-}d\alpha_{p\pi^+}} = \frac{1}{\Gamma_v}\frac{d\sigma}{dW\,dQ^2dM_{p\pi^+}dM_{\pi^+\pi^-}d\Omega_{\pi^-}d\alpha_{p\pi^+}}$$

where Γ_v is the virtual photon flux, given by

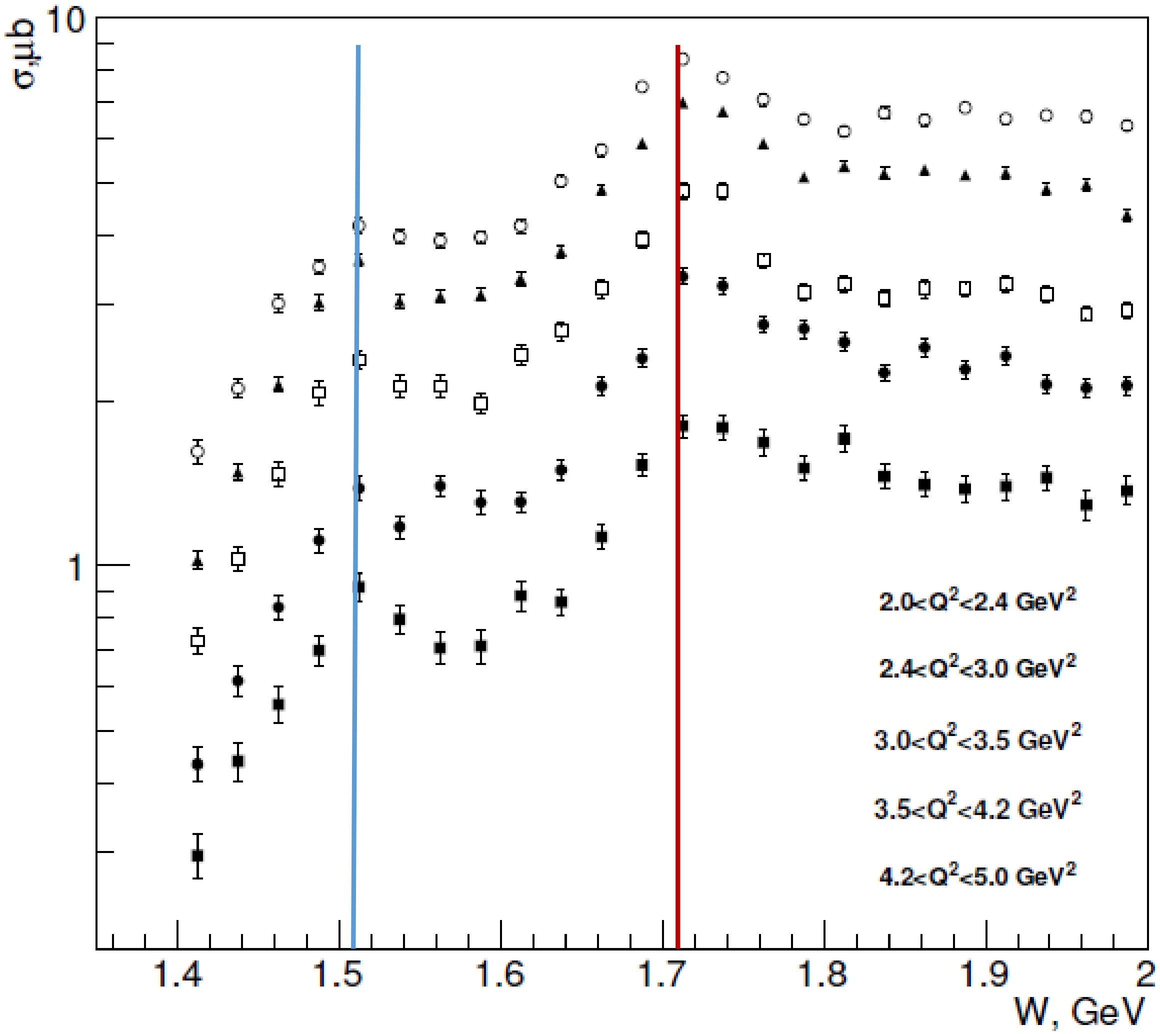
$$\Gamma_v = \frac{\alpha}{4\pi}\frac{1}{E_{beam}^2M_p^2}\frac{W(W^2-M_p^2)}{(1-\varepsilon)Q^2}$$

Each bin in W and Q2 has a unique 5-D representation. The complete cross sections are 7-fold.

There is not enough data to fully populate all 5-D bins, nor could we plot all of these in a paper. We integrate to get 1-D projections:

$$\begin{aligned}
\frac{d\sigma}{dM_{\pi^+\pi^-}} &= \int \frac{d^5\sigma}{d^5\tau_{\pi^-}}dM_{\pi^+p}d\Omega_{\pi^-}d\alpha_{[p'\pi^+][p\pi^-]} \\
\frac{d\sigma}{dM_{\pi^+p}} &= \int \frac{d^5\sigma}{d^5\tau_{\pi^-}}dM_{\pi^+\pi^-}d\Omega_{\pi^-}d\alpha_{[p'\pi^+][p\pi^-]} \qquad (17) \\
\frac{d\sigma}{d(-cos(\theta_{\pi^-}))} &= 2\pi\int \frac{d^5\sigma}{d^5\tau_{\pi^-}}dM_{\pi^+\pi^-}dM_{\pi^+p}d\alpha_{[p'\pi^+][p\pi^-]} \\
\frac{d\sigma}{d\alpha_{[p'\pi^+][p\pi^-]}} &= \int \frac{d^5\sigma}{d^5\tau_{\pi^-}}dM_{\pi^+\pi^-}dM_{\pi^+p}d\Omega_{\pi^-} \ .
\end{aligned}$$

Fully integrated (total) cross sections vs. W

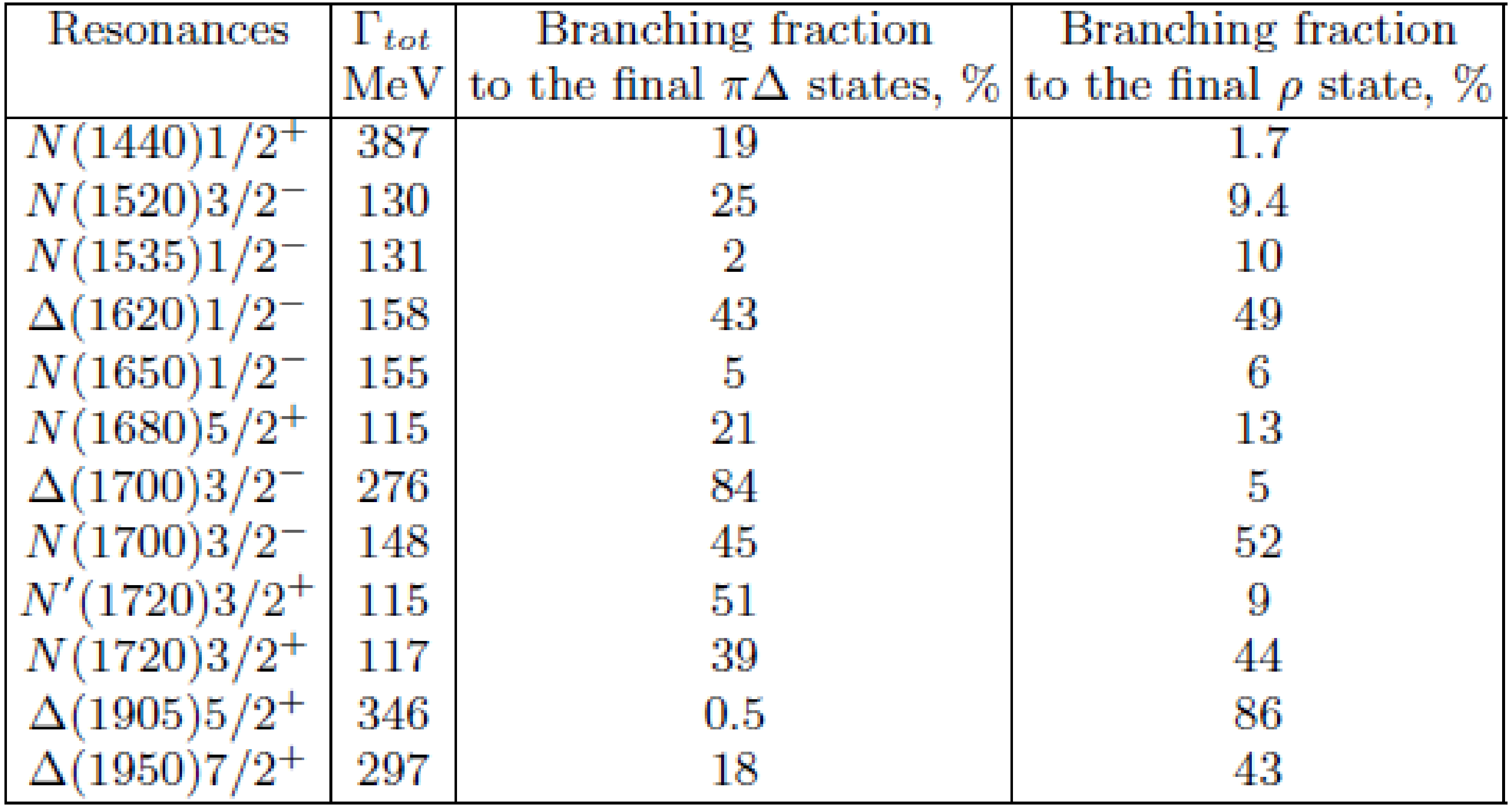


In general, the cross sections fall off as a function of Q^2.

Also, bumps for the 1st resonance and the 2nd resonance regions are seen at all values of Q^2.

We expect the resonance portion of the cross section to increase with Q^2.

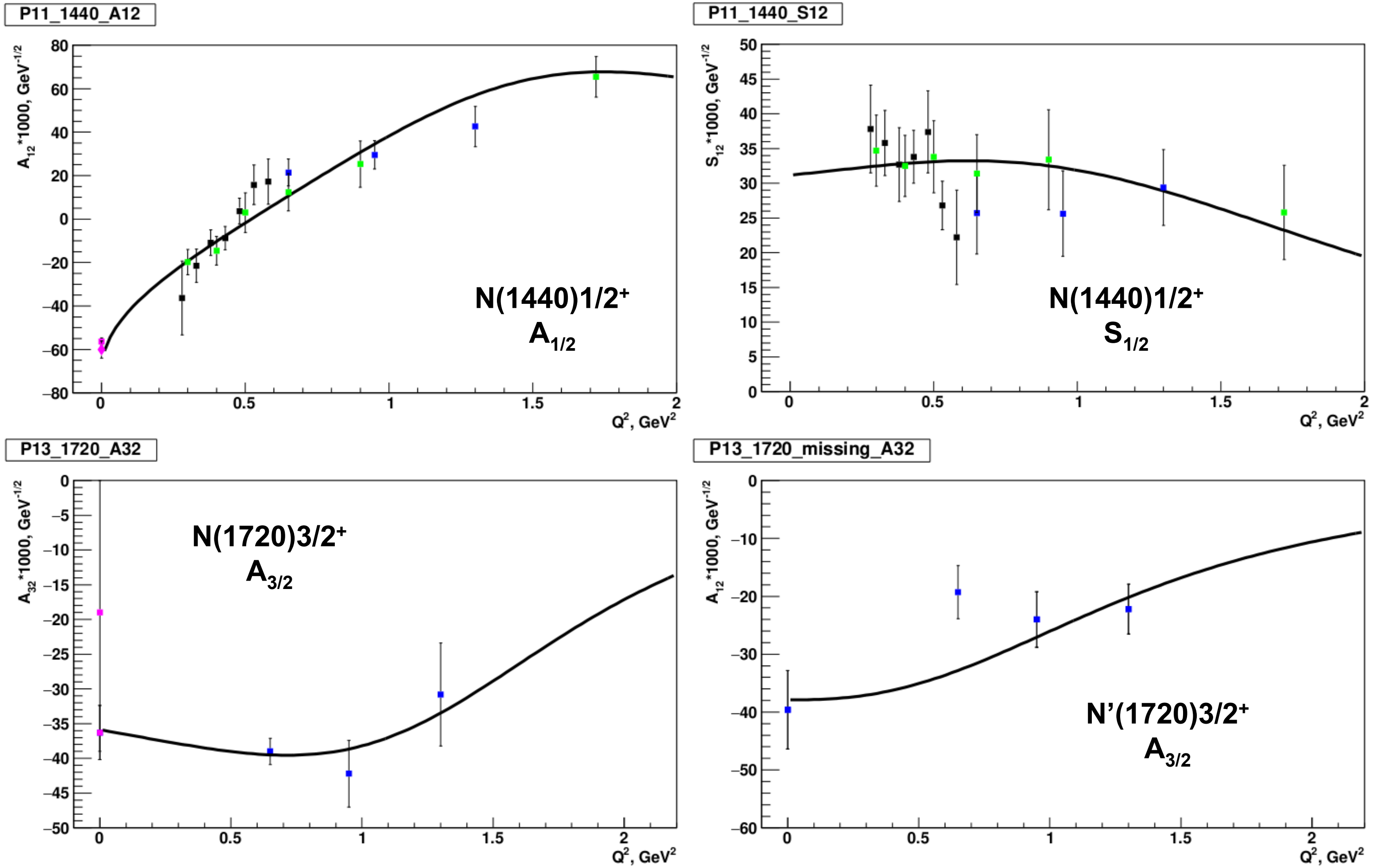
N*'s and %B.F. used in the JM model



Resonances	Γ_{tot} MeV	Branching fraction to the final $\pi\Delta$ states, %	Branching fraction to the final ρ state, %
$N(1440)1/2^+$	387	19	1.7
$N(1520)3/2^-$	130	25	9.4
$N(1535)1/2^-$	131	2	10
$\Delta(1620)1/2^-$	158	43	49
$N(1650)1/2^-$	155	5	6
$N(1680)5/2^+$	115	21	13
$\Delta(1700)3/2^-$	276	84	5
$N(1700)3/2^-$	148	45	52
$N'(1720)3/2^+$	115	51	9
$N(1720)3/2^+$	117	39	44
$\Delta(1905)5/2^+$	346	0.5	86
$\Delta(1950)7/2^+$	297	18	43

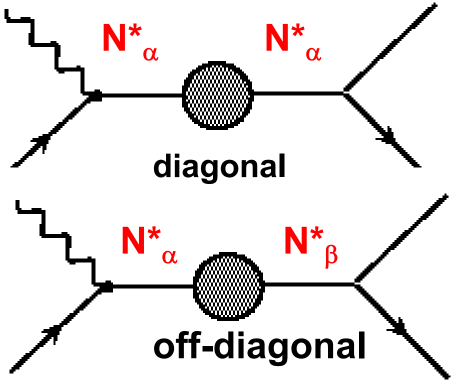
The JM model is described elsewhere: See V. Mokeev et al., PRC 86, 055203 (2012).

Interpolation/Extrapolation of the CLAS Results on $\gamma_v pN^*$ electrocpouplings



Electrocouplings from the CLAS data employed for evaluation of the resonant contributions within the framework of unitarized Breit-Wigner ansatz

Unitarized Breit-Wigner anstaz for resonant amplitudes



Inverse of the JM unitarized N* propagator:

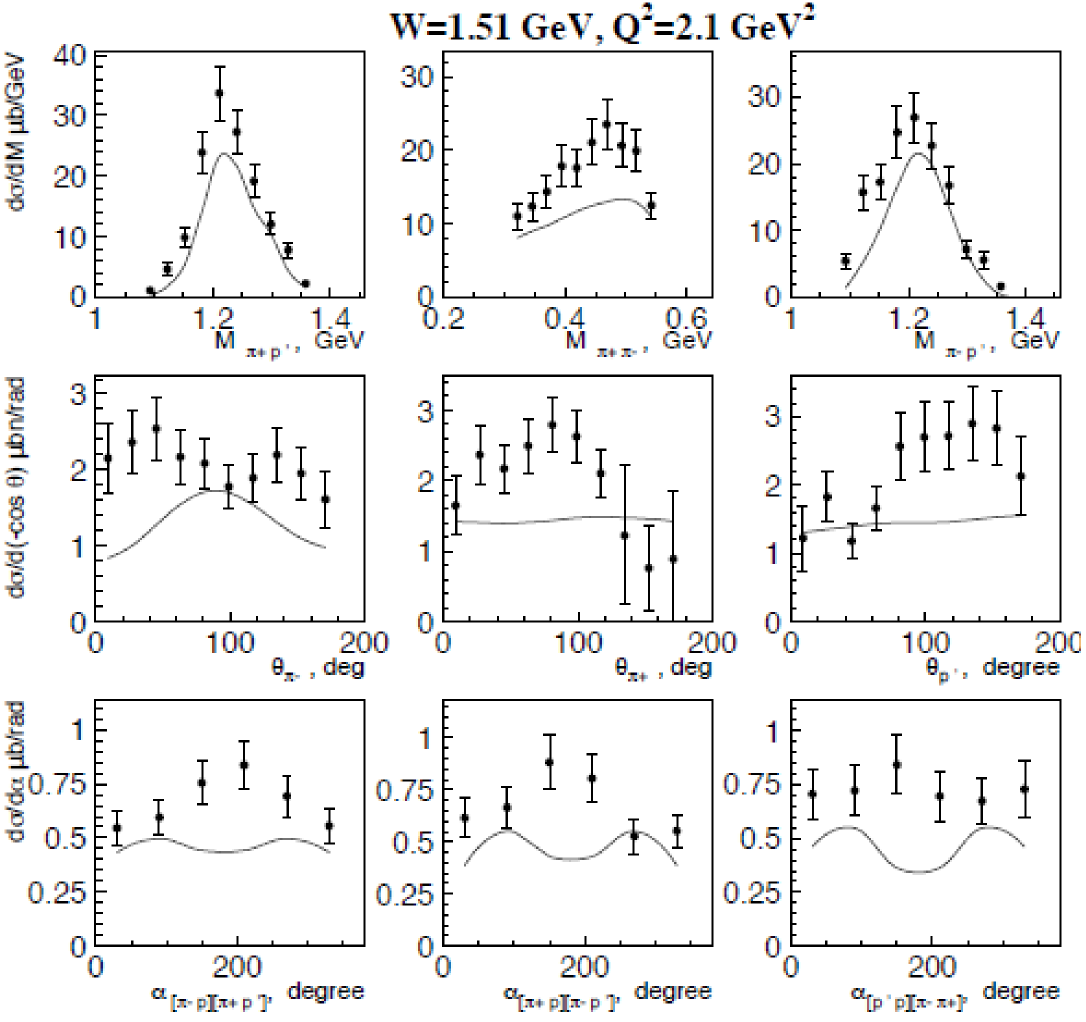
$$S^{-1}_{\alpha\beta} = M^2_{N^*}\delta_{\alpha\beta} - i\left(\sum_i \sqrt{\Gamma_{\alpha i}}\sqrt{\Gamma_{\beta i}}\right)\sqrt{M_{N^*\alpha}}\sqrt{M_{N^*\beta}} - W^2\delta_{\alpha\beta}$$

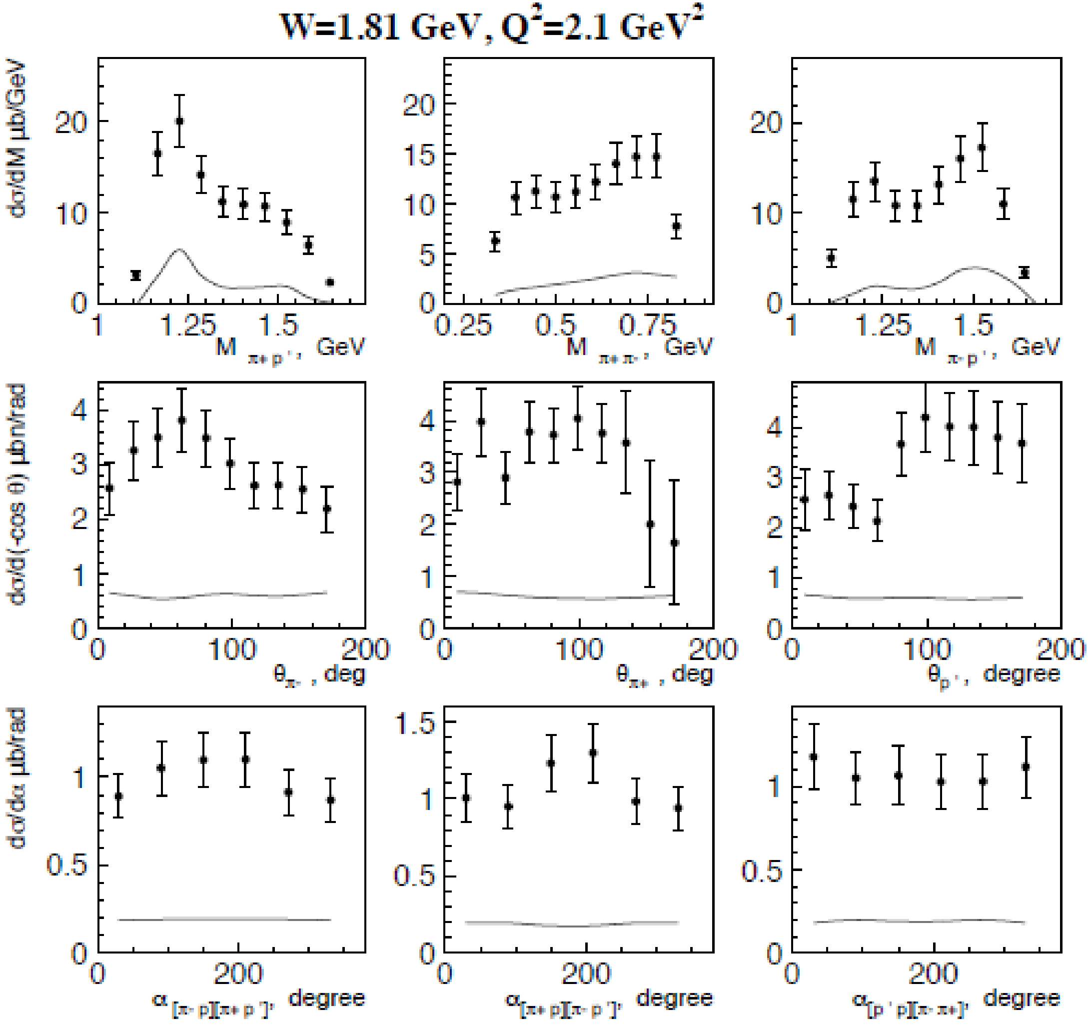
Off-diagonal transitions incorporated into the full resonant amplitudes of the JM model:

S_{11}(1535) ↔ S_{11}(1650)
D_{13}(1520) ↔ D_{13}(1700)
$3/2^+$(1720) ↔ P_{13}(1700)

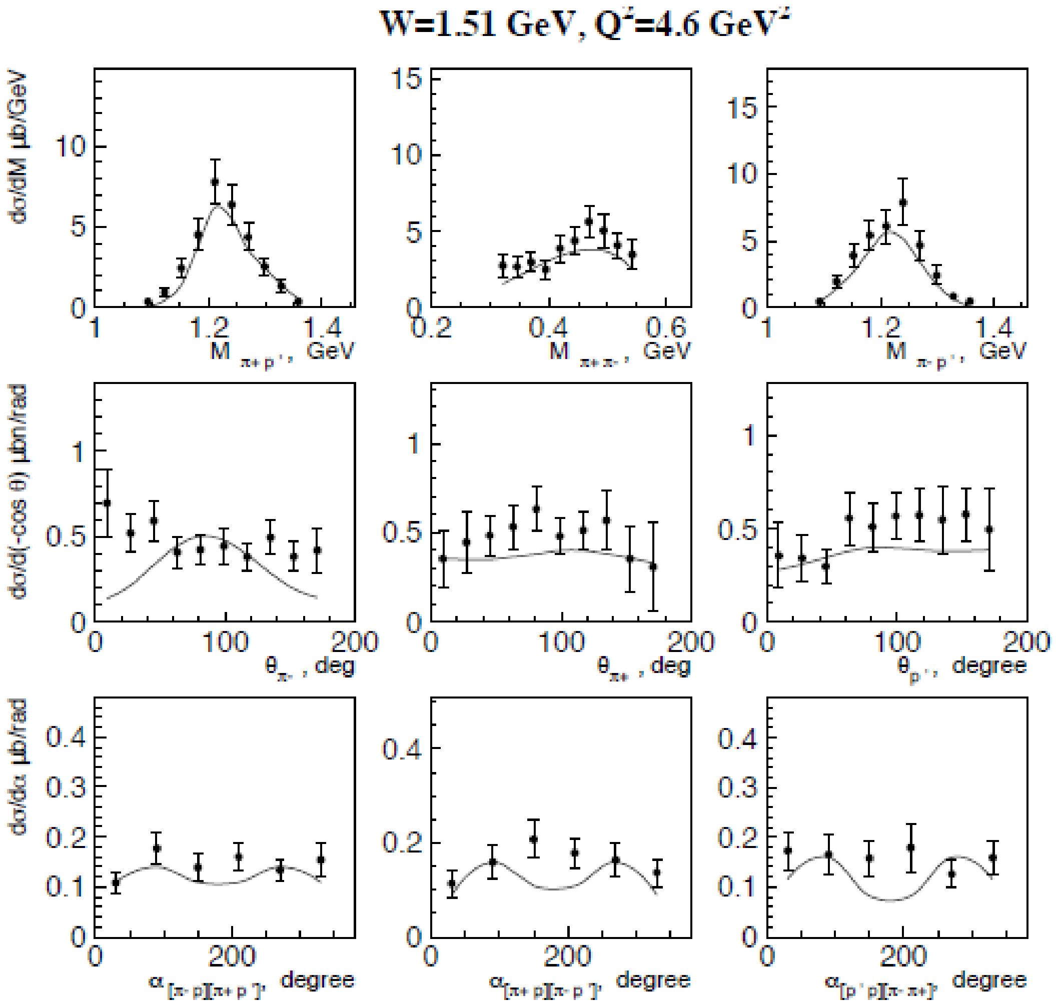
Full resonant amplitude of unitarized Breit-Wigner ansatz is consistent with restrictions imposed by a general unitarity condition.

Resonant contribution from JM model at $Q^2 = 2.1$ GeV^2.

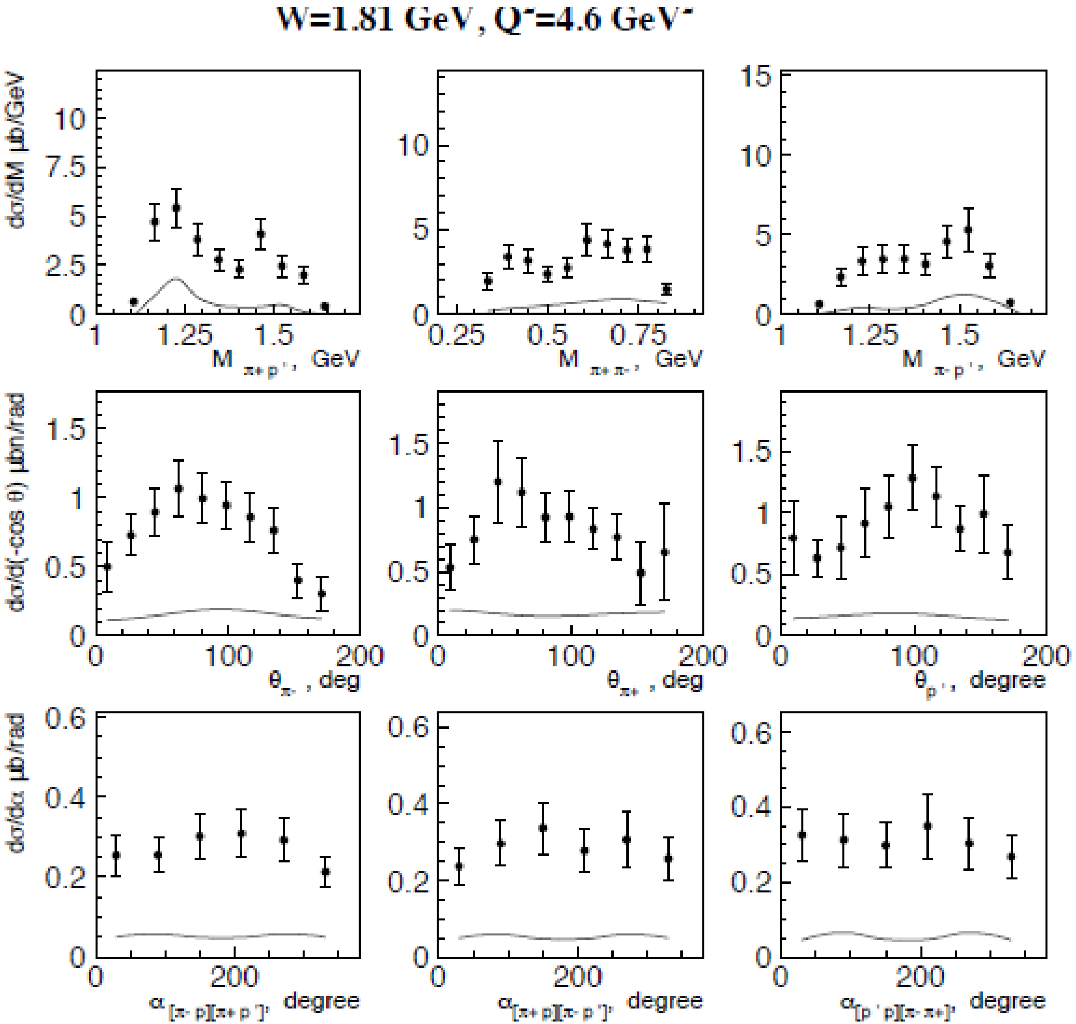




Resonant contributiond at Q^2 = 4.6 GeV^2 from JM model

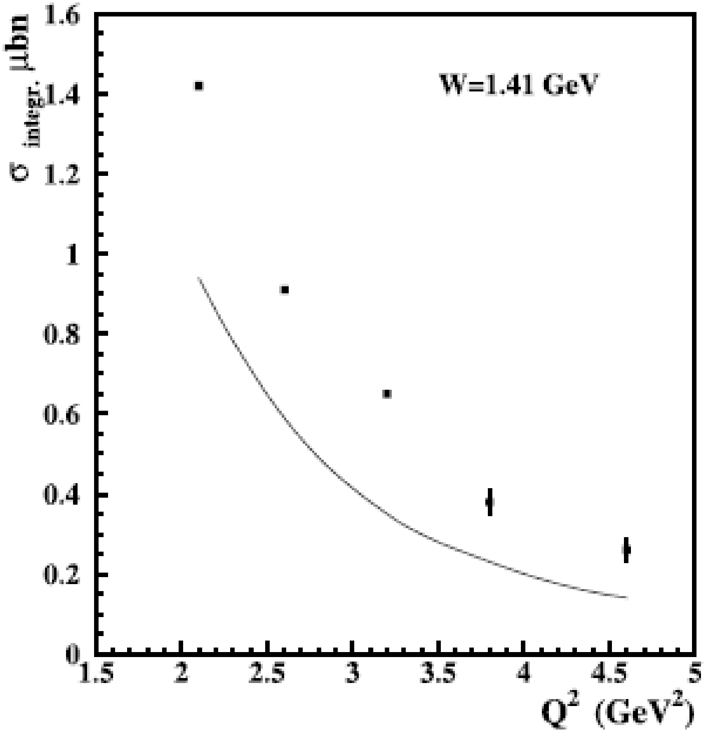


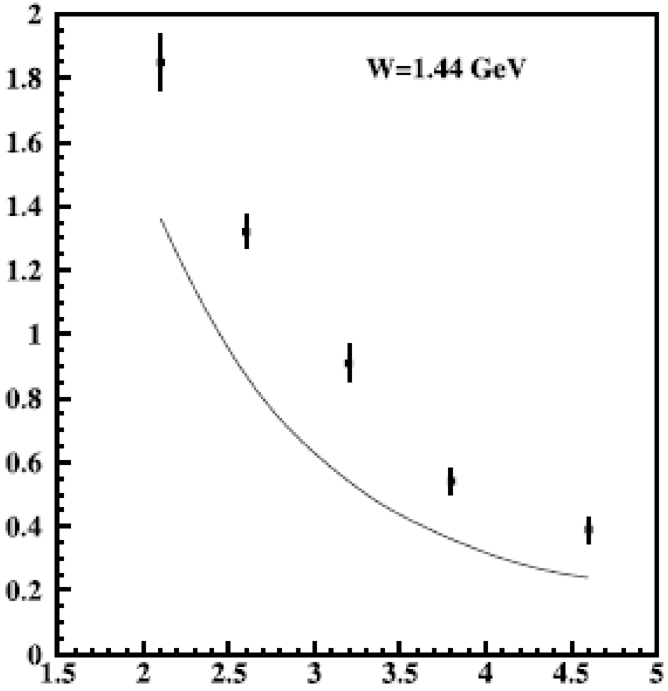
W=1.51 GeV, Q^2=4.6 GeV^2

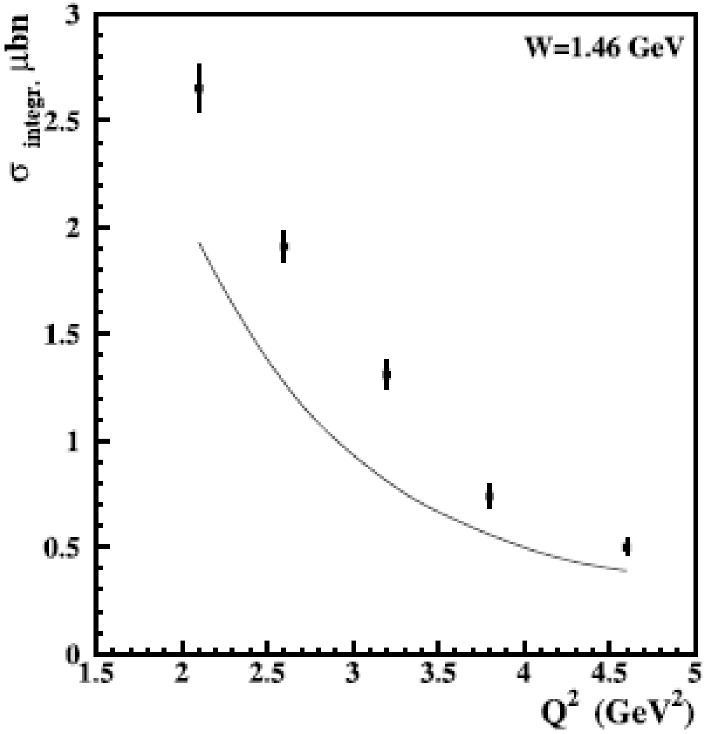


W=1.81 GeV, Q^2=4.6 GeV^2

Resonant contributions near the N(1440)1/2+

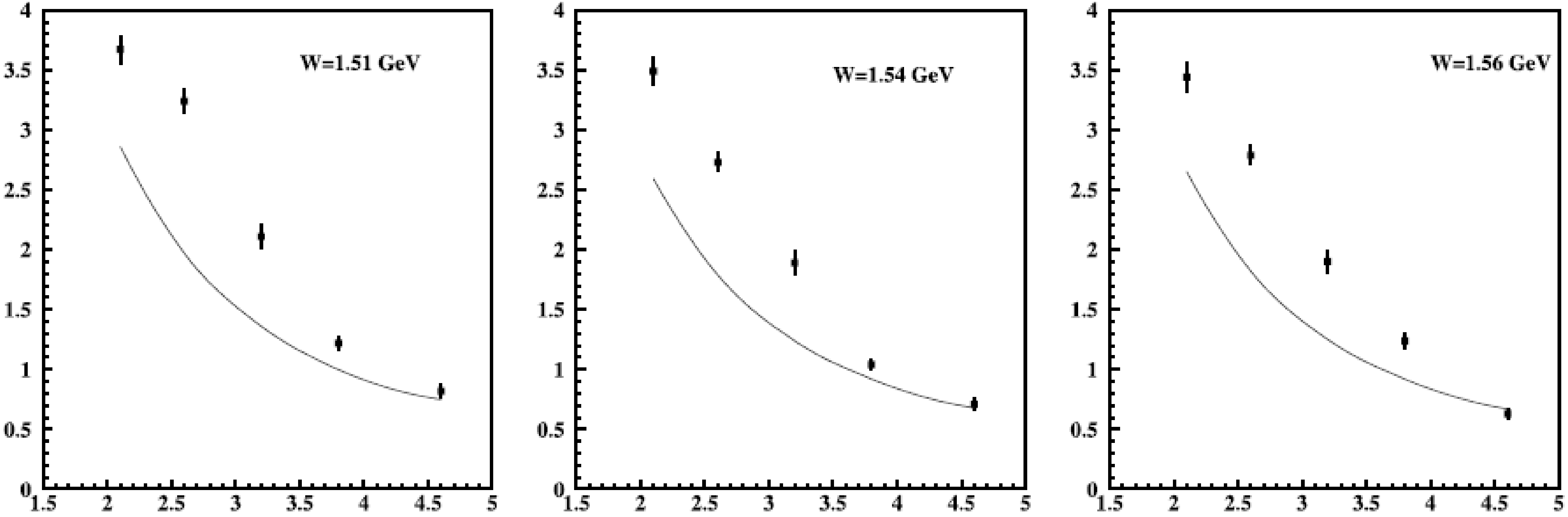






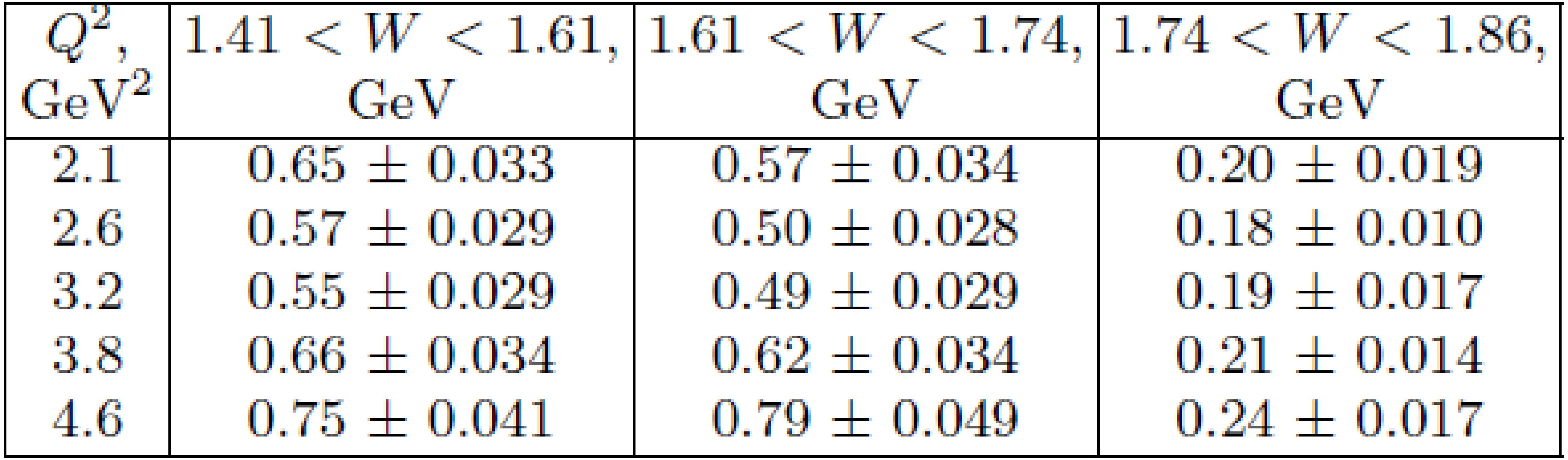
The percentage of calculated resonant contribution increases as Q^2 gets bigger.

Resonant contributions near the N(1530)3/2-



The increase of calculated resonance contribution appears even larger here for $Q^2 > 4$ GeV^2.

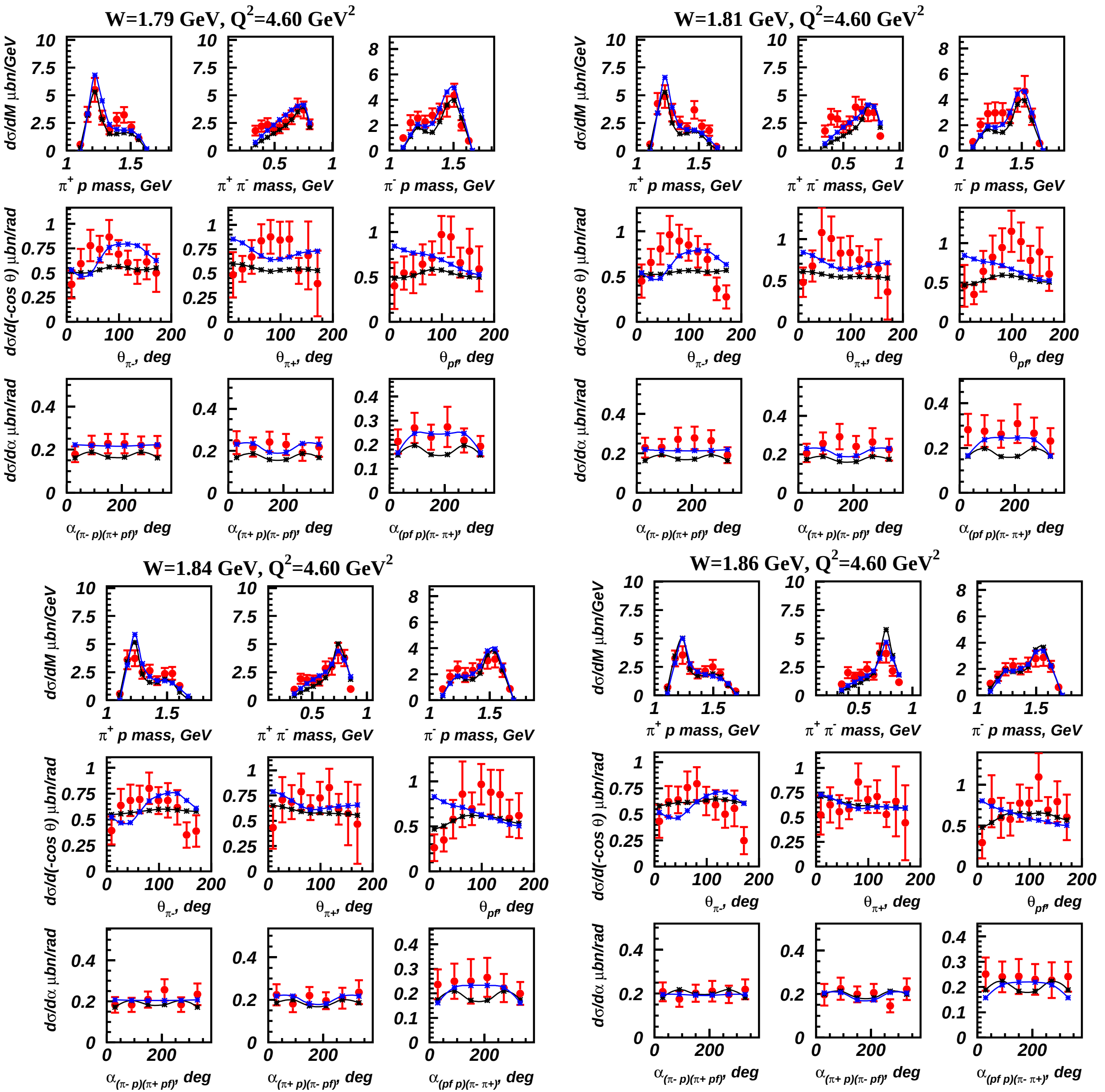
Ratios of resonant contributions at various W



Q^2, GeV^2	$1.41 < W < 1.61$, GeV	$1.61 < W < 1.74$, GeV	$1.74 < W < 1.86$, GeV
2.1	0.65 ± 0.033	0.57 ± 0.034	0.20 ± 0.019
2.6	0.57 ± 0.029	0.50 ± 0.028	0.18 ± 0.010
3.2	0.55 ± 0.029	0.49 ± 0.029	0.19 ± 0.017
3.8	0.66 ± 0.034	0.62 ± 0.034	0.21 ± 0.014
4.6	0.75 ± 0.041	0.79 ± 0.049	0.24 ± 0.017

Notes about JM model predictions

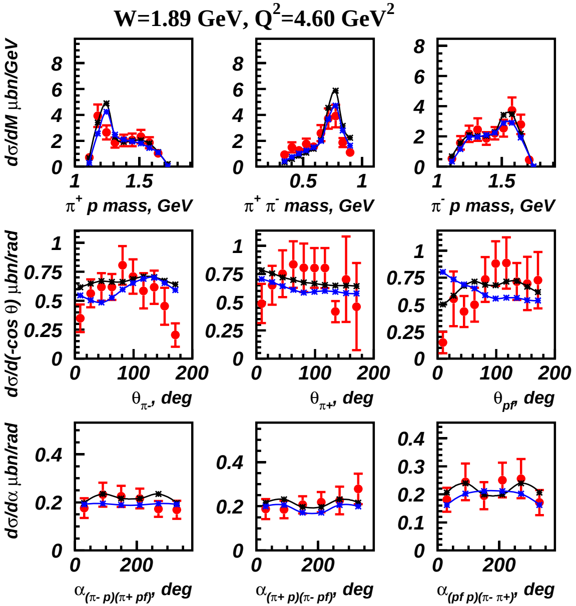
- The JM16 model only computes the resonance part
    - Non-resonance background is necessary to include before any conclusions.
    - A complete calculation (including non-resonant background) is in progress.
    - The calculations are only intended for comparison to show what may be missing in the resonant-only calculations.
- Clearly, more work needs to be done, especially at higher W, to explain the new CLAS data on ep → e' p' $\pi^+ \pi^-$.
    - Is this evidence for needing more resonances at higher W?
    - Examples (from BoGa PWA): N(1895)1/2^-, N(1875)3/2^- and N(1900)3/2^+.

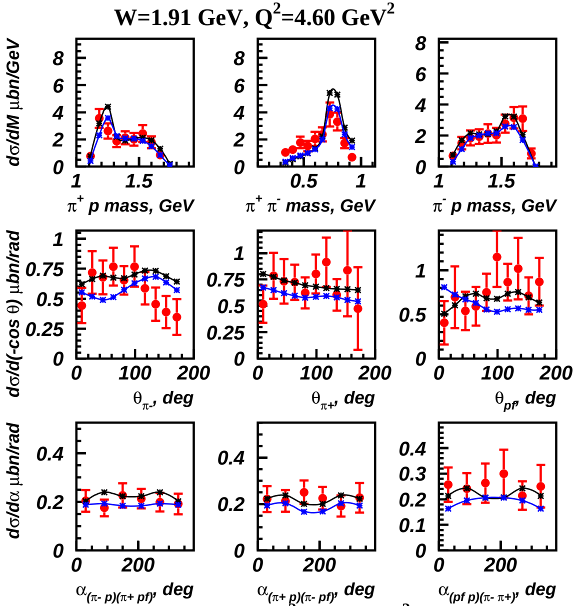


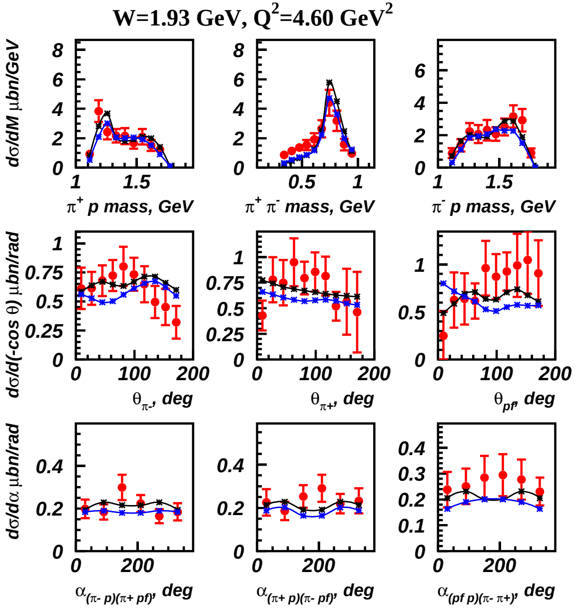
W = 1.79-1.86 GeV
Q2 = 4.6 GeV^2.

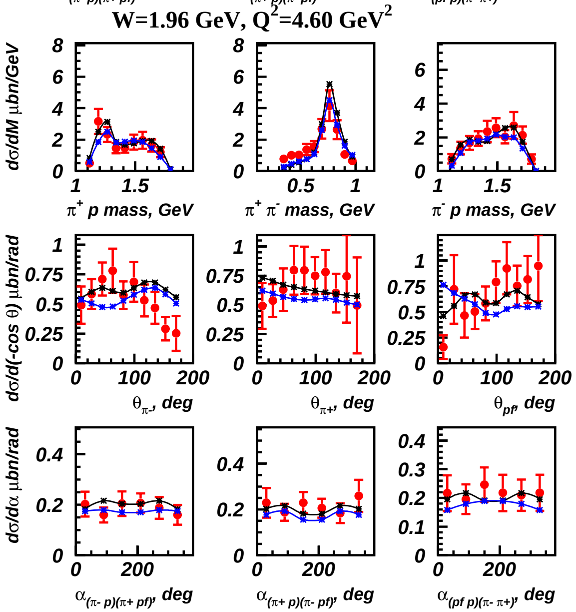
Description with N(1875) 3/2⁻ M=1.805 GeV

N(1900)3/2+ M=1.86GeV









W = 1.89-1.96 GeV
Q2 = 4.6 GeV^2.

Description
with N(1875) 3/2$^-$
M=1.805 GeV

N(1900)3/2+
M=1.86 GeV

Studies at Q^2=4.6 GeV^2 implementing N(1875)3/2$^-$ and N(1900)3/2+ states

(reduced χ^2 are evaluated at 1.76< W < 1.94 GeV)

N(1875)3/2$^-$	M=1.875 GeV	M=1.86 GeV (BG left edge)	M=1.805 GeV (ours)
χ^2/d.p.=	2.17	2.14	1.45

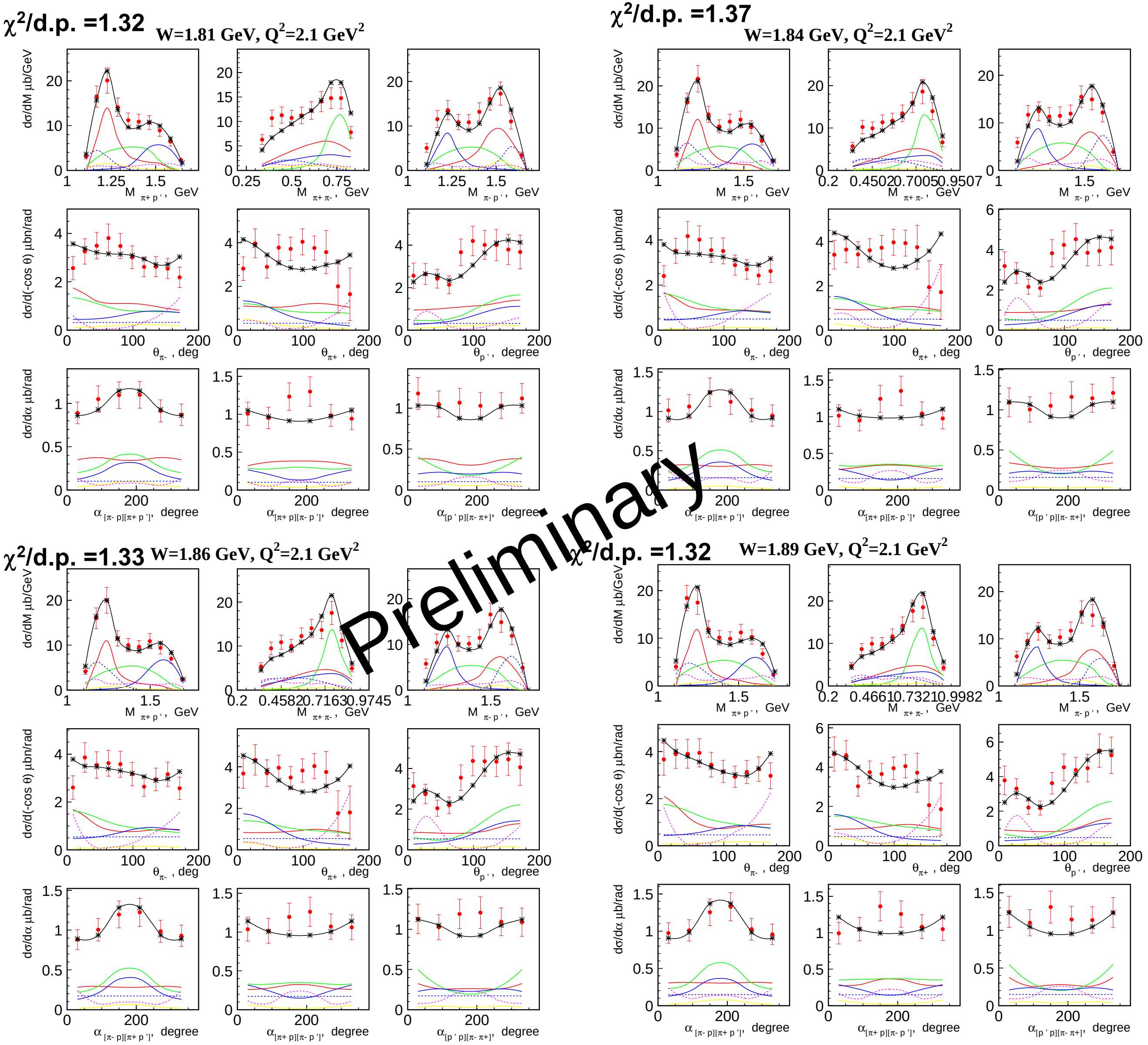
Inconsistent resonance mass values from independent analyses of photo- and electroproduction. The hypotheses is rejected

N(1900)3/2$^+$	M=1.900 GeV	M=1.875 GeV(BG left edge)	M=1.85 GeV (ours)
χ^2/d.p.=	1.69	1.50	1.39

Almost the same χ^2/d.p. with mass taken from the photoproduction studies and from our fit. $\pi^+\pi^-p$ electroproducttion data can be described with resonance mass taken from the photoproduction analysis.

Hypothesis on N(1900)3/2$^+$ contribution is accepted

W = 1.81-1.89 GeV
Q2 = 2.1 GeV^2.



— **full**

— $\pi^-\Delta^{++}$

— $\pi^+\Delta^0$

— 2π direct

— $\pi^+D_{13}(1520)$

- - - π^+F_{15}

— ρp

Data fit will provide electrocouplings πΔ, ρp decay widths of most N* in mass range M_{N^*}<2.0 GeV and 2.0<Q^2<5.0 GeV^2.

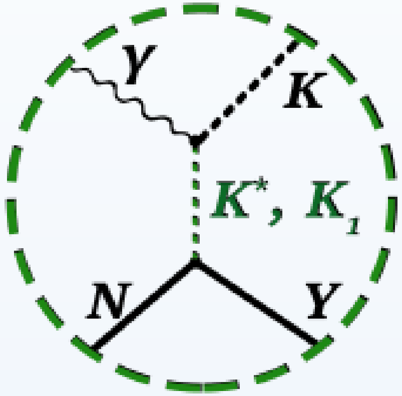
Summary of $e\ p \rightarrow e'\ p'\ \pi^+\ \pi^-$ CLAS data

- Data analysis has a very clean signal
  - Paper is under internal review at CLAS; to be submitted soon
- 7-dimensional binning splits data many times
  - Limited statistics, but most bins have reasonable error bars
- Model fits using conventional resonances fail at higher W.
  - Suggests the need for new higher-mass resonances.
  - A second N'(1720)$3/2^+$ resolves difference of photo- and electroproduction.
  - Preliminary calculations suggest addition of N(1900)$3/2^+$ helps.
- A second paper is in preparation using the full JM16 model calc.

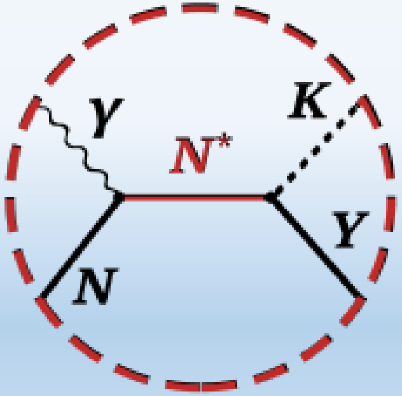
$\gamma d \to K^0\Lambda(p)$

Nick Compton thesis

- Deuteron target is used to access neutron reactions
- Momentum is not zero
- Neutron (udd) goes to $K^0(d\bar{s})$ Λ (uds)
- T-Channel diagrams suppressed
- Complimentary reaction to $\gamma p \to K^+\Lambda$
  - N(1900) was found through $K^+\Lambda$
  - Access to resonances with weak pion coupling



- PWA
  - Extract resonance parameters
  - Incorporated coupled channel
    - Decay amplitudes
    - Neutron coupling

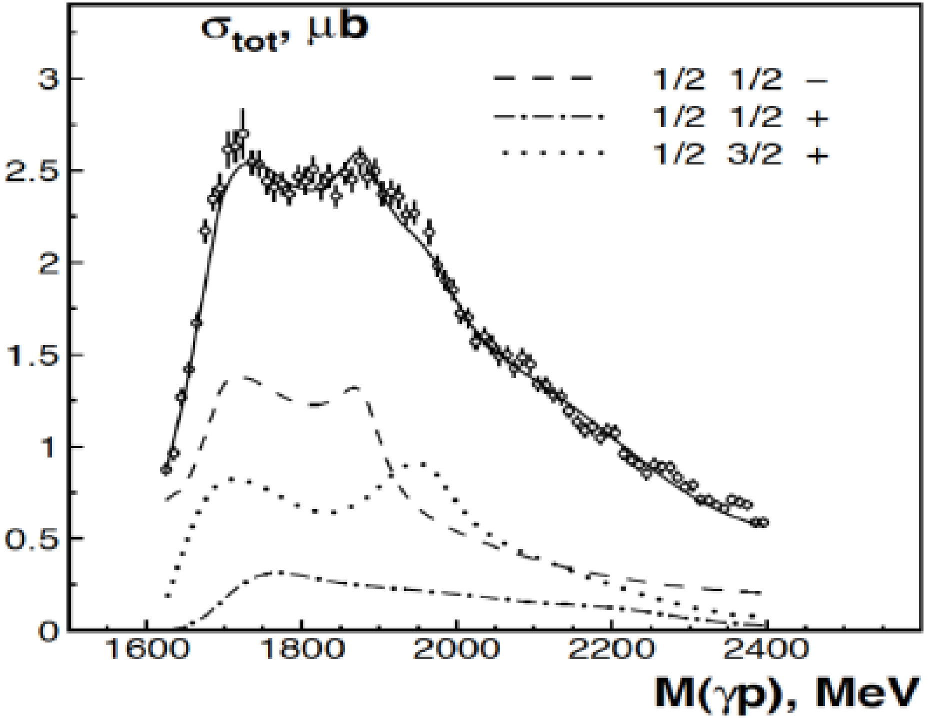


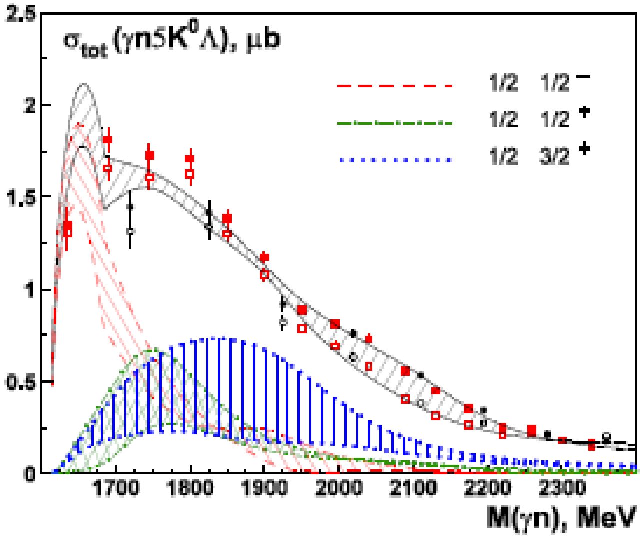
Total Cross Section

Nick Compton thesis

BoGa Estimation and Fit Compared to K+Lambda

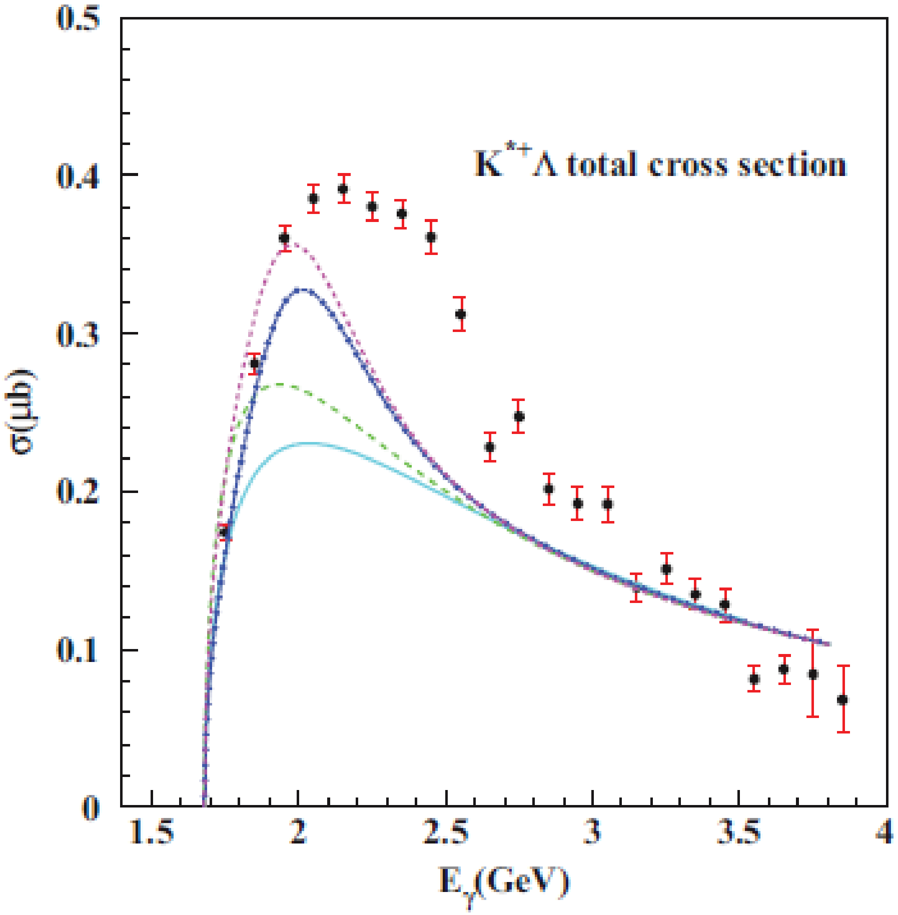
- Estimated with BoGa Model
- S and P wave contribution shown





Wei Tang thesis

CLAS photoproduction of $K^{*+}\ \Lambda$ data



Cyan: Oh and Kim
Isobar Model

Blue: Kim, Nam, Oh, Kim
Regge Model

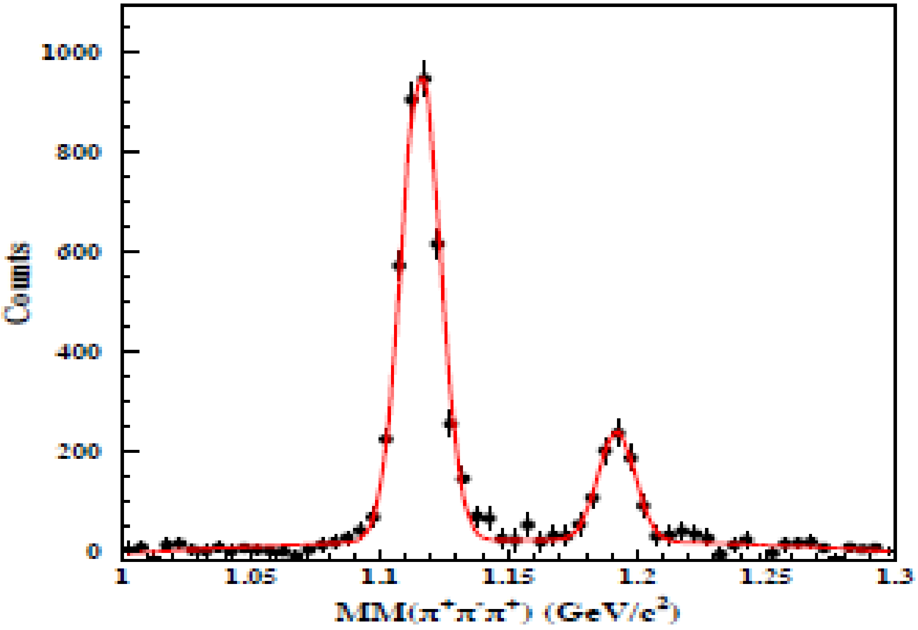
Dotted curves include additional s-channel N* with M<2.2 GeV and L<3.

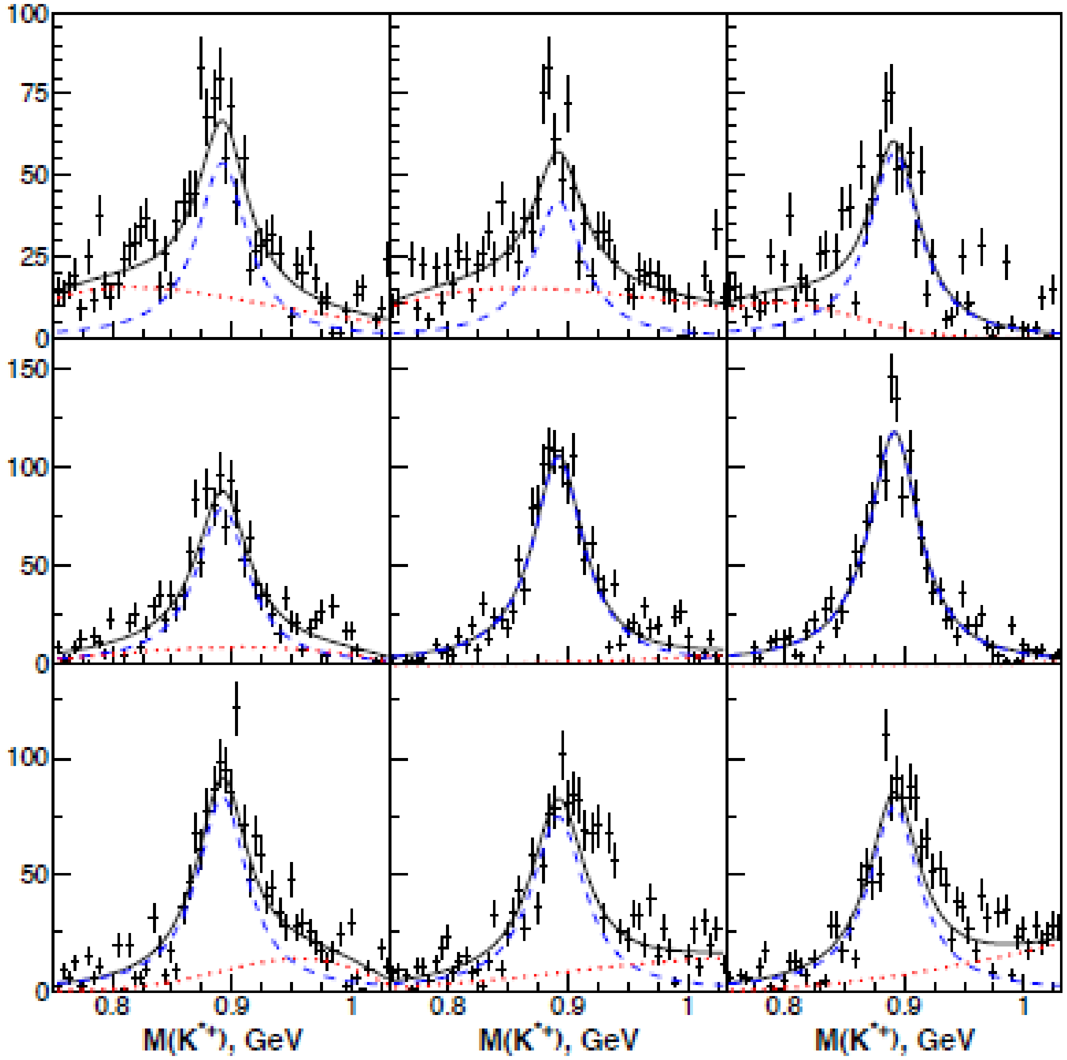
Clearly, the currently available theoretical models cannot reproduce the data. This suggests that higher-mass and higher-L resonances are needed.

New analysis of K* Λ by the Bonn group

- Used the CLAS K* skim of g11 done by Wei Tang
  - Measured $K^{*+} \rightarrow K^0 \pi^+ \rightarrow \pi^+ \pi^+ \pi^-$ final state
  - Λ identified using missing mass
- Analyzed angular distribution in the K* rest system
  - Extracted density matrix elements: ρ_{00}, ρ_{10}, ρ_{11} using Log Likelihood method
  - Fit using the BoGa PWA to search for new N* resonances

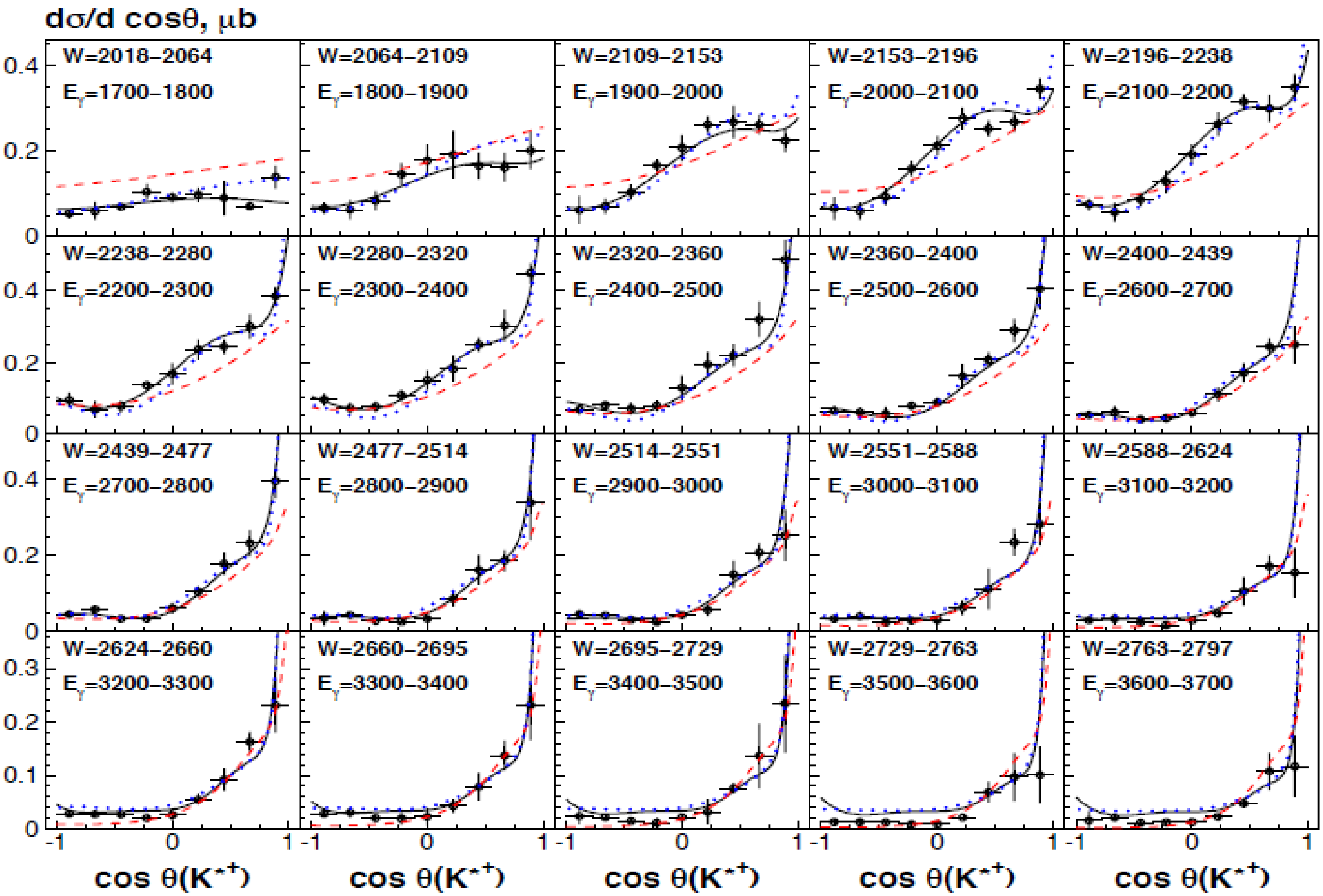
Λ and K* yield extraction

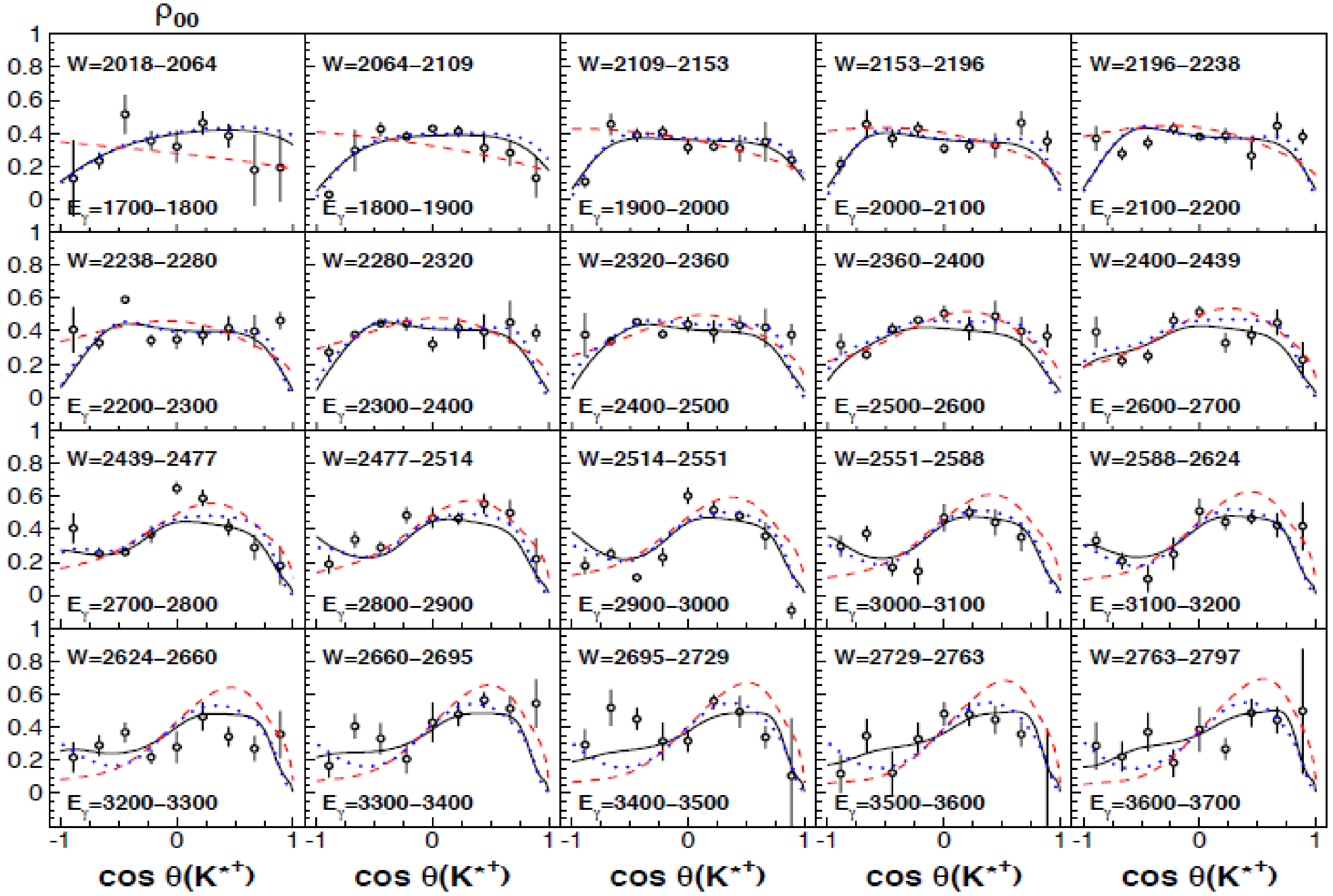


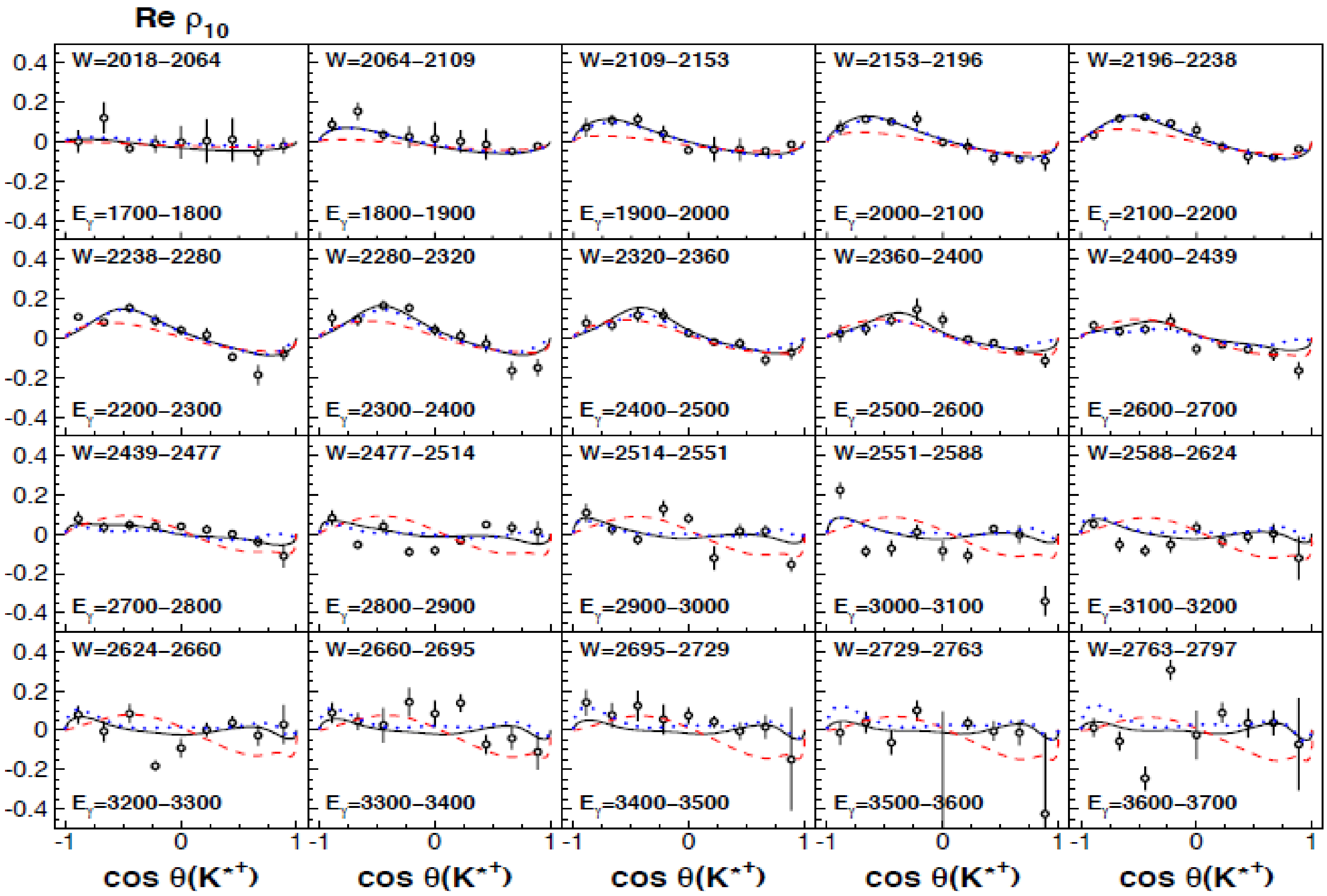


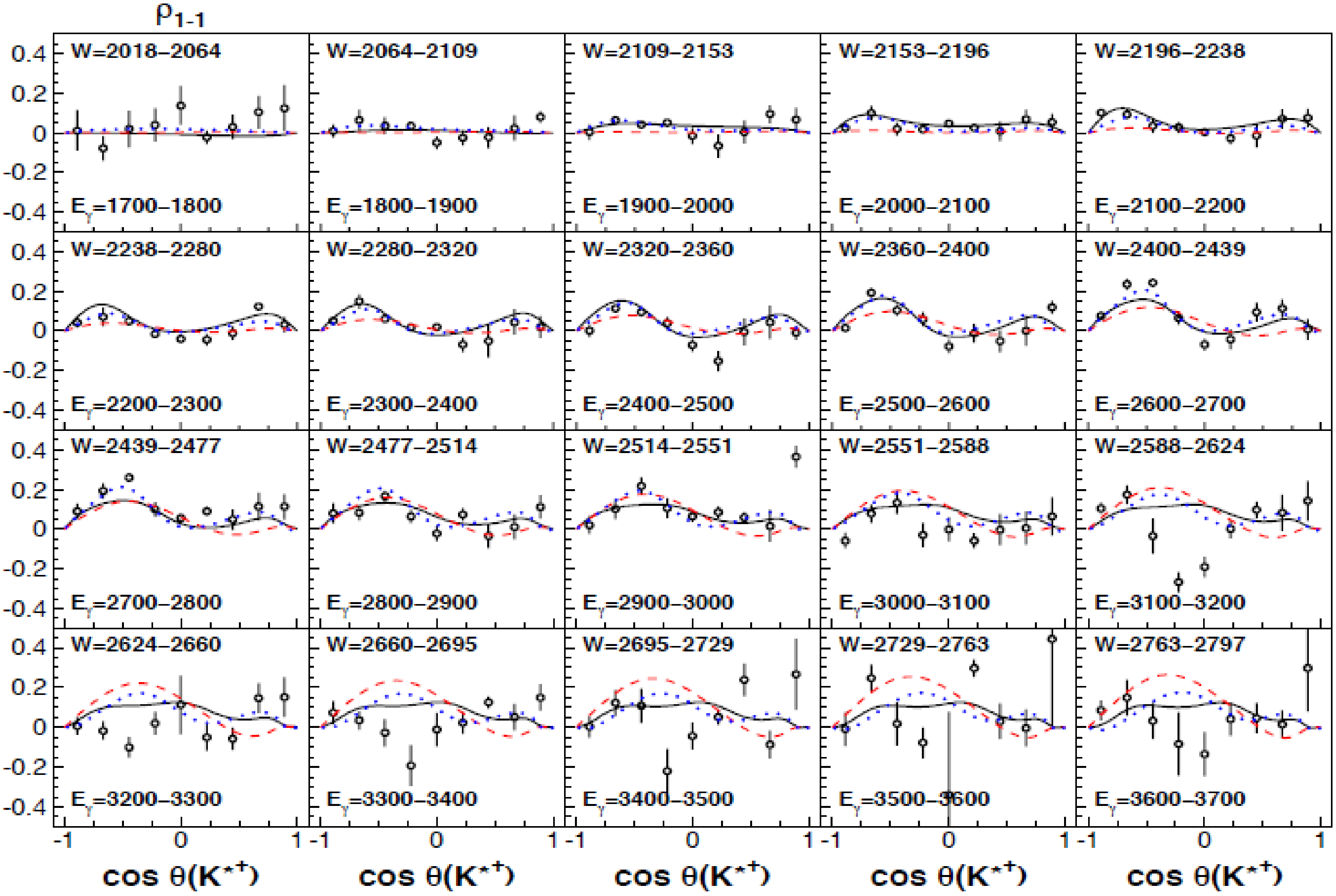
In the following plots:

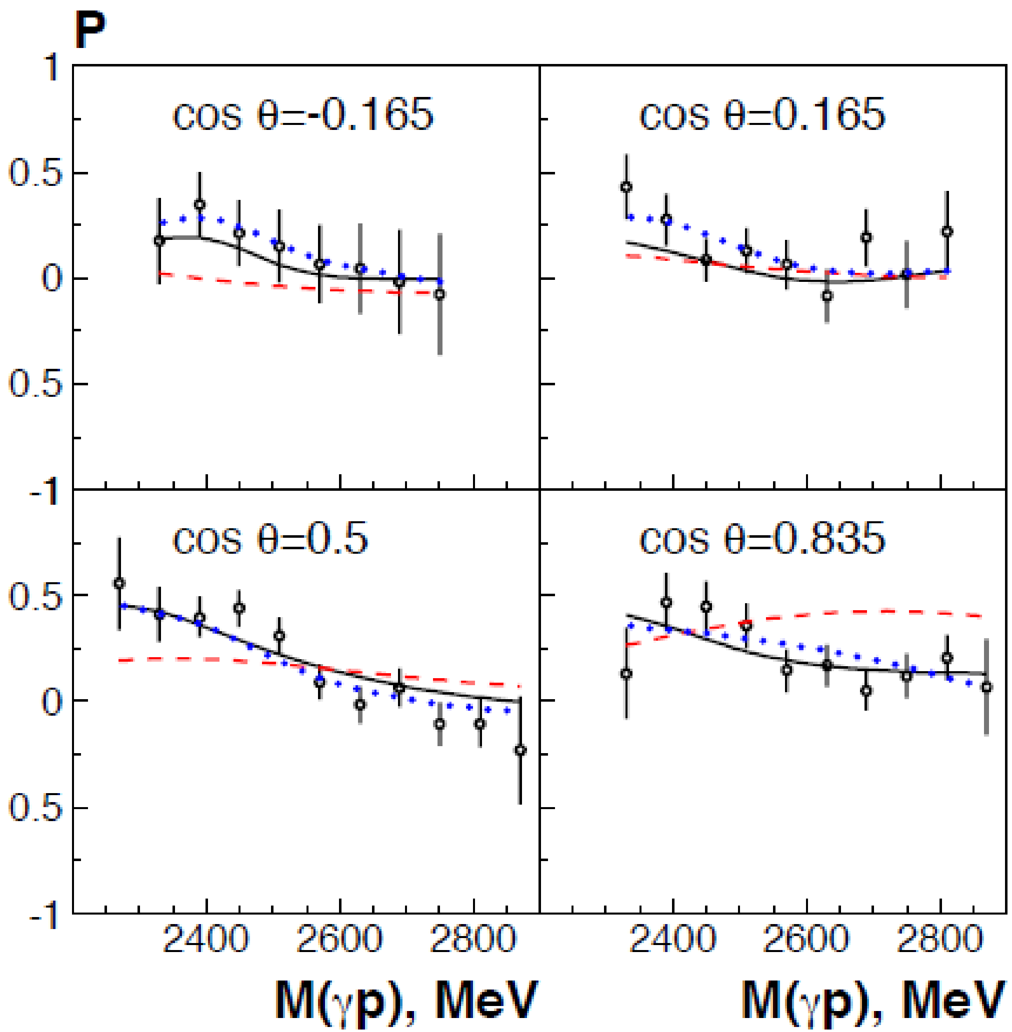
- Solid curves: final PWA fit (including possible new N* states)
  - Reduced χ^2: 0.84, 1.84, 0.76 for diff. x-sec, spin-density matrix, recoil pol.
- Blue dotted curves: PWA fit without the new high-mass N*’s
  - Noticeable (but small) effect in the mass regions 2200-2350
  - Reduced χ^2: 1.92, 1.84, 0.61
- Red dashed curves: t-channel contributions only
  - At higher photon energies, we expect t-channel to dominate

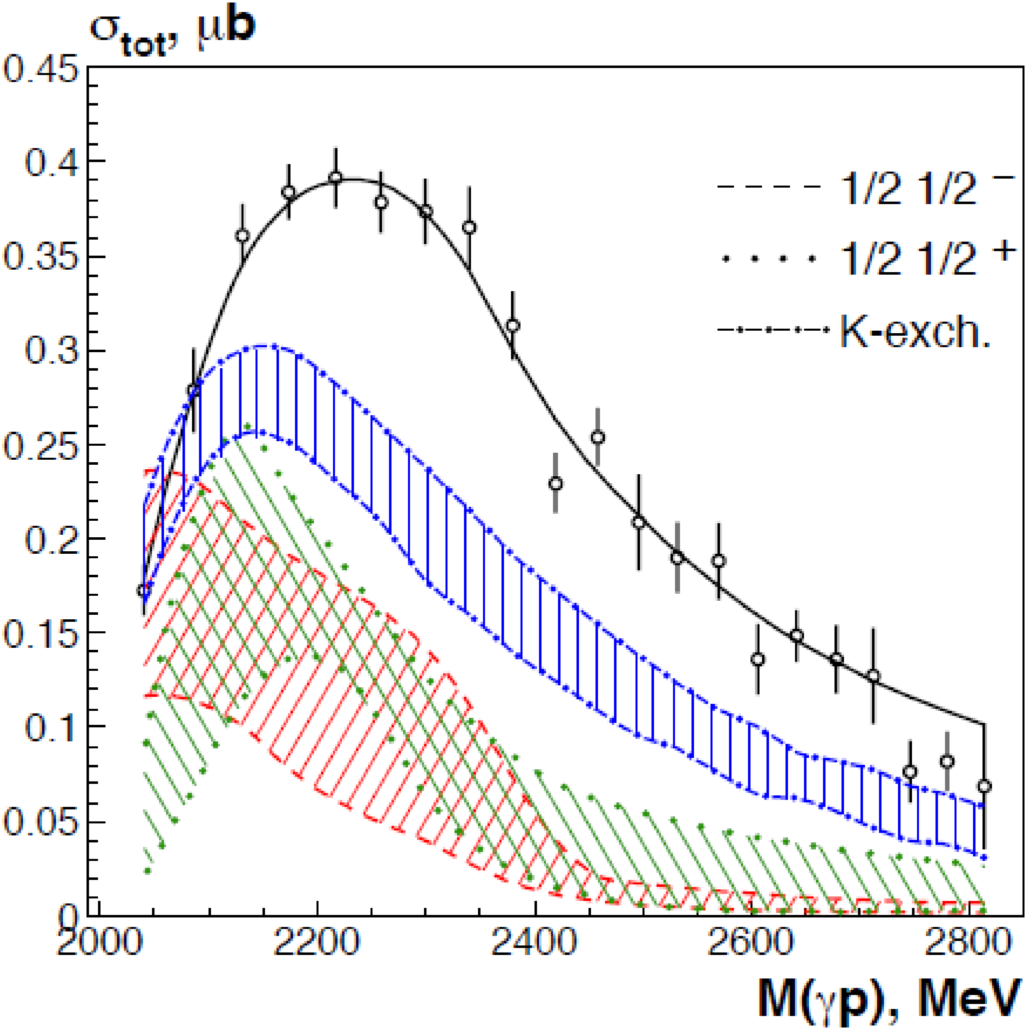

dσ/d cosθ, μb
W=2018–2064
E$_\gamma$=1700–1800
W=2064–2109
E$_\gamma$=1800–1900
W=2109–2153
E$_\gamma$=1900–2000
W=2153–2196
E$_\gamma$=2000–2100
W=2196–2238
E$_\gamma$=2100–2200
W=2238–2280
E$_\gamma$=2200–2300
W=2280–2320
E$_\gamma$=2300–2400
W=2320–2360
E$_\gamma$=2400–2500
W=2360–2400
E$_\gamma$=2500–2600
W=2400–2439
E$_\gamma$=2600–2700
W=2439–2477
E$_\gamma$=2700–2800
W=2477–2514
E$_\gamma$=2800–2900
W=2514–2551
E$_\gamma$=2900–3000
W=2551–2588
E$_\gamma$=3000–3100
W=2588–2624
E$_\gamma$=3100–3200
W=2624–2660
E$_\gamma$=3200–3300
W=2660–2695
E$_\gamma$=3300–3400
W=2695–2729
E$_\gamma$=3400–3500
W=2729–2763
E$_\gamma$=3500–3600
W=2763–2797
E$_\gamma$=3600–3700
0.4
0.2
0
0.3
0.1
-1
0
1
cos θ(K^{*+})


ρ_{00}
W=2018–2064
E$_\gamma$=1700–1800
W=2064–2109
E$_\gamma$=1800–1900
W=2109–2153
E$_\gamma$=1900–2000
W=2153–2196
E$_\gamma$=2000–2100
W=2196–2238
E$_\gamma$=2100–2200
W=2238–2280
E$_\gamma$=2200–2300
W=2280–2320
E$_\gamma$=2300–2400
W=2320–2360
E$_\gamma$=2400–2500
W=2360–2400
E$_\gamma$=2500–2600
W=2400–2439
E$_\gamma$=2600–2700
W=2439–2477
E$_\gamma$=2700–2800
W=2477–2514
E$_\gamma$=2800–2900
W=2514–2551
E$_\gamma$=2900–3000
W=2551–2588
E$_\gamma$=3000–3100
W=2588–2624
E$_\gamma$=3100–3200
W=2624–2660
E$_\gamma$=3200–3300
W=2660–2695
E$_\gamma$=3300–3400
W=2695–2729
E$_\gamma$=3400–3500
W=2729–2763
E$_\gamma$=3500–3600
W=2763–2797
E$_\gamma$=3600–3700
1
0.8
0.6
0.4
0.2
0
-1
0
1
cos θ(K^{*+})


Re ρ_{10}
W=2018–2064
E$_\gamma$=1700–1800
W=2064–2109
E$_\gamma$=1800–1900
W=2109–2153
E$_\gamma$=1900–2000
W=2153–2196
E$_\gamma$=2000–2100
W=2196–2238
E$_\gamma$=2100–2200
W=2238–2280
E$_\gamma$=2200–2300
W=2280–2320
E$_\gamma$=2300–2400
W=2320–2360
E$_\gamma$=2400–2500
W=2360–2400
E$_\gamma$=2500–2600
W=2400–2439
E$_\gamma$=2600–2700
W=2439–2477
E$_\gamma$=2700–2800
W=2477–2514
E$_\gamma$=2800–2900
W=2514–2551
E$_\gamma$=2900–3000
W=2551–2588
E$_\gamma$=3000–3100
W=2588–2624
E$_\gamma$=3100–3200
W=2624–2660
E$_\gamma$=3200–3300
W=2660–2695
E$_\gamma$=3300–3400
W=2695–2729
E$_\gamma$=3400–3500
W=2729–2763
E$_\gamma$=3500–3600
W=2763–2797
E$_\gamma$=3600–3700
0.4
0.2
0
-0.2
-0.4
-1
0
1
cos θ(K^{*+})


ρ1-1
W=2018–2064
E_γ=1700–1800
W=2064–2109
E_γ=1800–1900
W=2109–2153
E_γ=1900–2000
W=2153–2196
E_γ=2000–2100
W=2196–2238
E_γ=2100–2200
W=2238–2280
E_γ=2200–2300
W=2280–2320
E_γ=2300–2400
W=2320–2360
E_γ=2400–2500
W=2360–2400
E_γ=2500–2600
W=2400–2439
E_γ=2600–2700
W=2439–2477
E_γ=2700–2800
W=2477–2514
E_γ=2800–2900
W=2514–2551
E_γ=2900–3000
W=2551–2588
E_γ=3000–3100
W=2588–2624
E_γ=3100–3200
W=2624–2660
E_γ=3200–3300
W=2660–2695
E_γ=3300–3400
W=2695–2729
E_γ=3400–3500
W=2729–2763
E_γ=3500–3600
W=2763–2797
E_γ=3600–3700
0.4
0.2
0
-0.2
-0.4
-1
0
1
cos θ(K*+)


P
1
0.5
0
0.5
-1
cos θ=-0.165
cos θ=0.165
cos θ=0.5
cos θ=0.835
2400
2600
2800
M(γp), MeV
M(γp), MeV


σ_tot, μb
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
2000
2200
2400
2600
2800
M(γp), MeV
1/2 1/2 −
1/2 1/2 +
K-exch.

PDG: listed high-mass N* states plus new N*’s

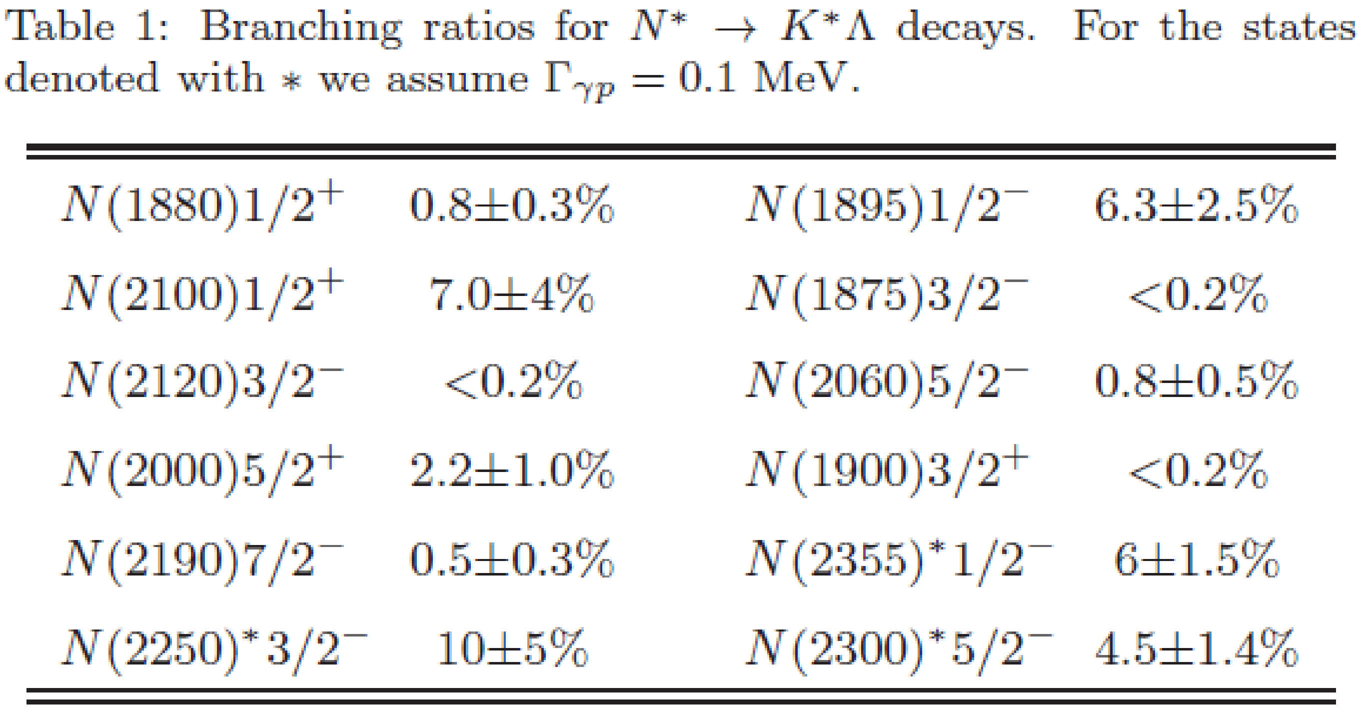


Table 1: Branching ratios for $N^* \to K^*\Lambda$ decays. For the states denoted with $*$ we assume $\Gamma_{\gamma p} = 0.1$ MeV.

$N(1880)1/2^+$	$0.8\pm0.3\%$	$N(1895)1/2^-$	$6.3\pm2.5\%$
$N(2100)1/2^+$	$7.0\pm4\%$	$N(1875)3/2^-$	$<0.2\%$
$N(2120)3/2^-$	$<0.2\%$	$N(2060)5/2^-$	$0.8\pm0.5\%$
$N(2000)5/2^+$	$2.2\pm1.0\%$	$N(1900)3/2^+$	$<0.2\%$
$N(2190)7/2^-$	$0.5\pm0.3\%$	$N(2355)^*1/2^-$	$6\pm1.5\%$
$N(2250)^*3/2^-$	$10\pm5\%$	$N(2300)^*5/2^-$	$4.5\pm1.4\%$

Notes: 1) the photocoupling to the new N*’s (marked with *) are not known.
2) The N*(1880) and N*(1895) are very close to threshold—handled carefully.

Possible new high-mass resonances

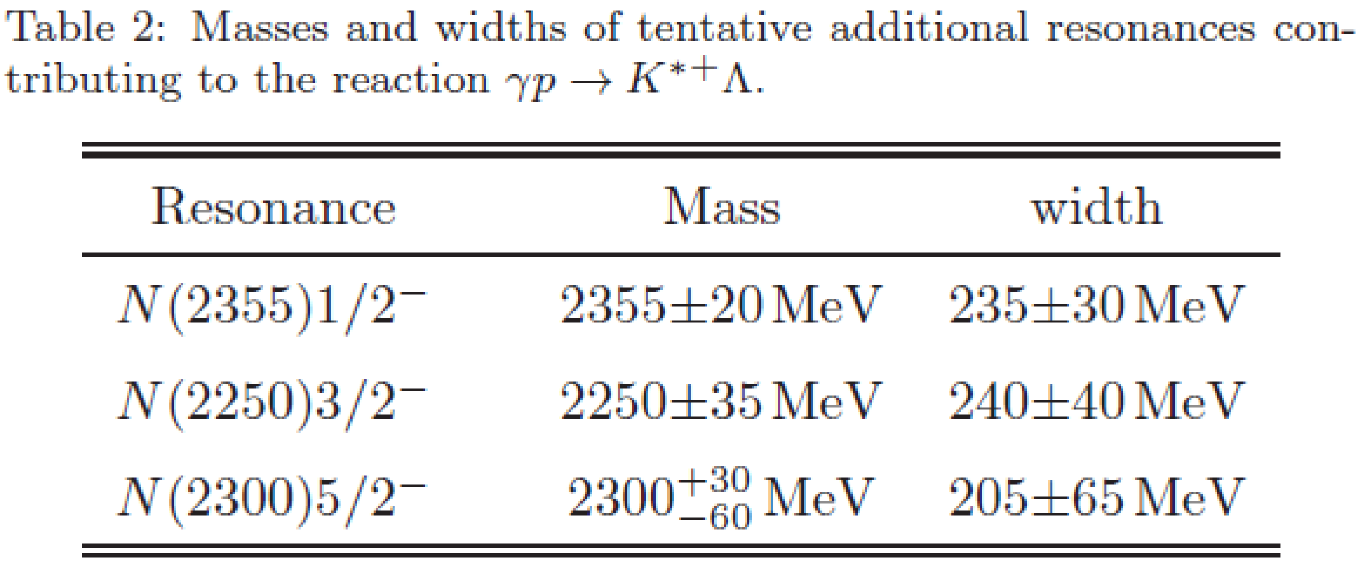


Table 2: Masses and widths of tentative additional resonances contributing to the reaction $\gamma p \rightarrow K^{*+}\Lambda$.

Resonance	Mass	width
$N(2355)1/2^-$	2355 ± 20 MeV	235 ± 30 MeV
$N(2250)3/2^-$	2250 ± 35 MeV	240 ± 40 MeV
$N(2300)5/2^-$	2300^{+30}_{-60} MeV	205 ± 65 MeV

Comments:

1) masses and widths in the fits are fairly stable.
2) These N*’s have significant B.R. to the K* final state
3) Reasonable PWA fits even with any two of the three states

Caveat Emptor

- The new N* states are seen only in this reaction
  - We need other final states at higher masses to confirm
  - It is likely that there is substantial coupling to two-pion decay
  - We need hadronic-beam data to separate photocouplings.
- The spin-density matrix elements are useful to constrain PWA fits
  - There is significant interference in the N* amplitudes
  - Too much uncertainty in the PWA fits without the spin-density m.e.
- More polarization data would be nice
  - This is, in fact, possible using g12 data

Summary of γ p → K^{*+} Λ CLAS data

- It is likely that the “missing” N* resonances are there, and just need to be “found”.
  - Reactions with high-mass thresholds are useful to explore high-mass N*’s
  - A wide variety of final states can be explored by CLAS
  - Polarization observables are helpful to constrain the PWA
- We have 2-3 possible new high-mass N*’s here (need confirmation)