Baryon Resonances in Two Pion Electroproduction with the CLAS Detector at Jefferson LAB

M. Ripani − INFN
Genova − Italy
for the CLAS collaboration

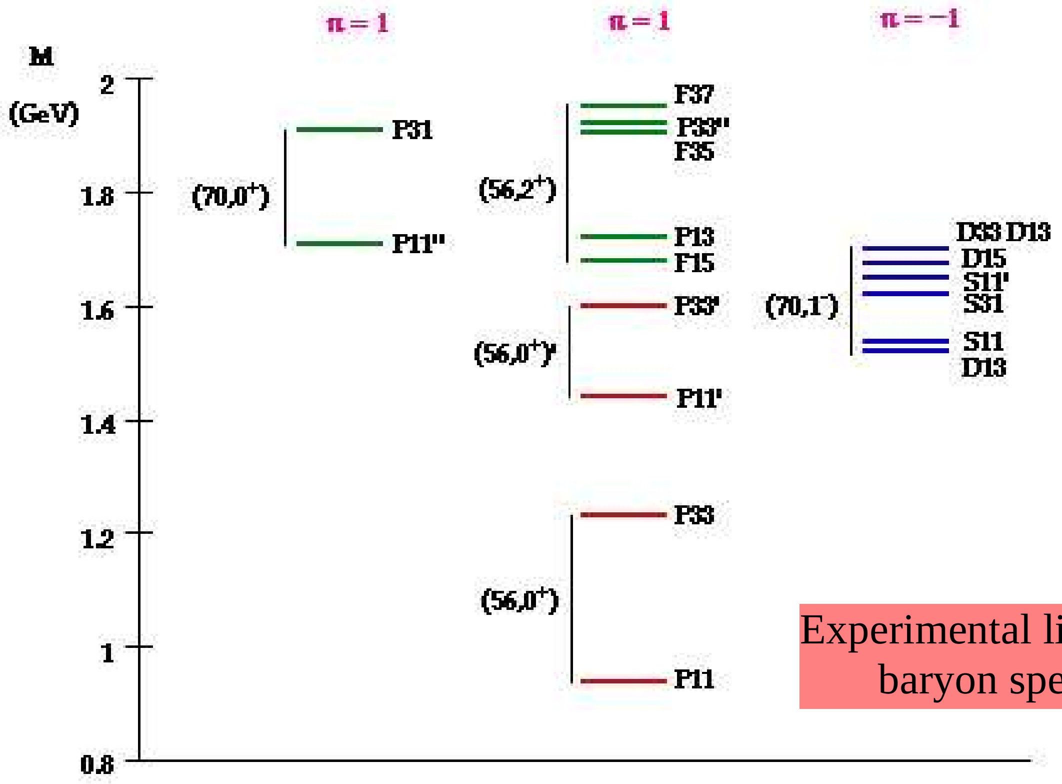
i) Physics motivation: baryon spectrum

ii) Two pion electroproduction: features, phenomenology, theory, exptl aspects

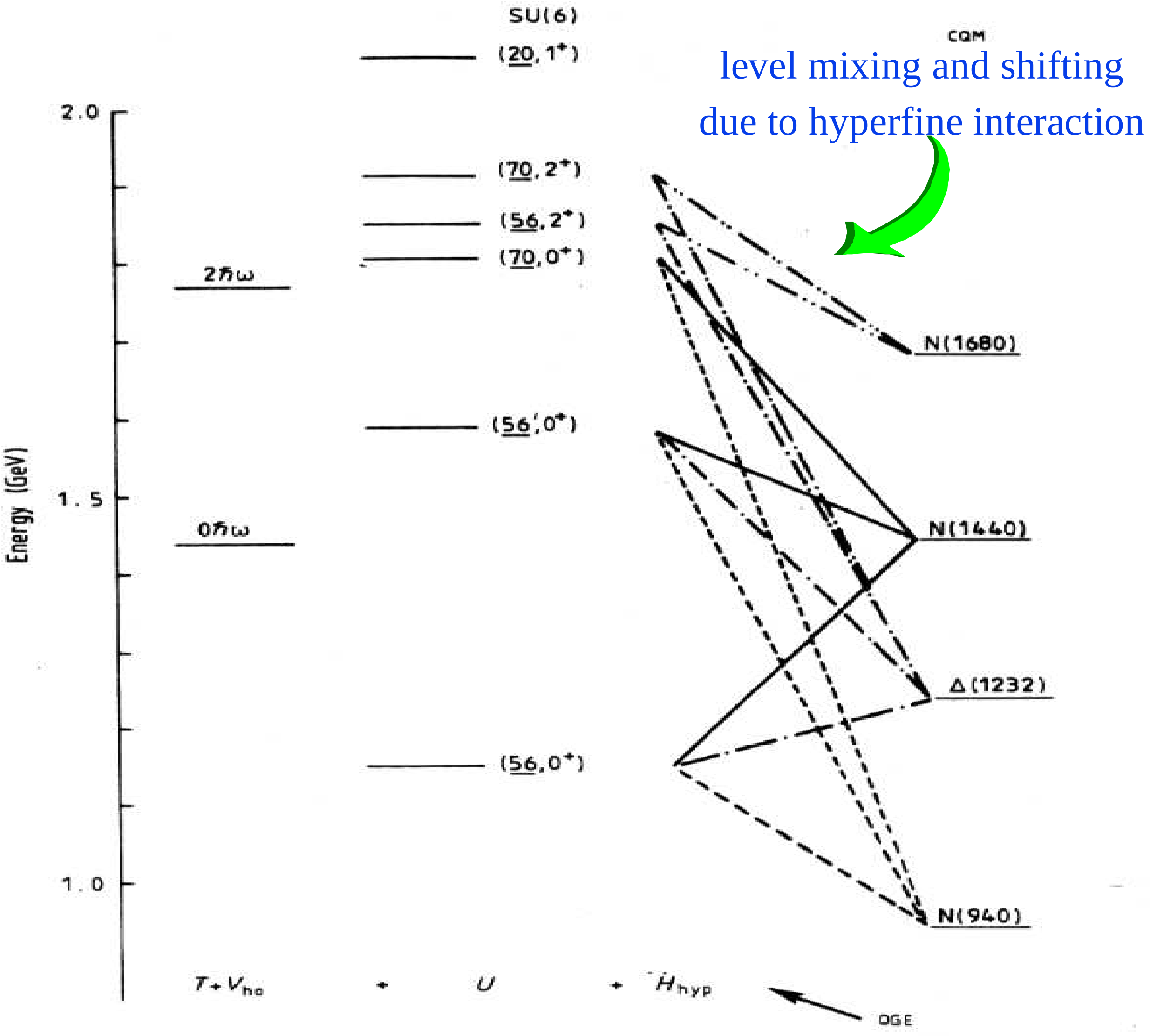
iii) Preliminary results from CLAS
a) Data taking
b) Event reconstruction and selection

iv) Preliminary total and differential cross sections and first attempt at physical interpretation

NSTAR 2002,
Pittsburgh, PA, October 8−12, 2002



Experimental light−quark baryon spectrum



level mixing and shifting due to hyperfine interaction

Recent theoretical schemes:

- “string” linear confinement + Coulomb
- hyperfine interaction as SU(6) breaking

Isgur−Karl, Isgur−Capstick and collaborators

  - Coulomb potential + linear confinement
  - hyperspherical coordinates incorporate 3−body forces (expected based on QCD)

Giannini −Santopinto and collaborators

- linear confinement
- SU(6) breaking by spin−flavor−dependent interaction (GBE)

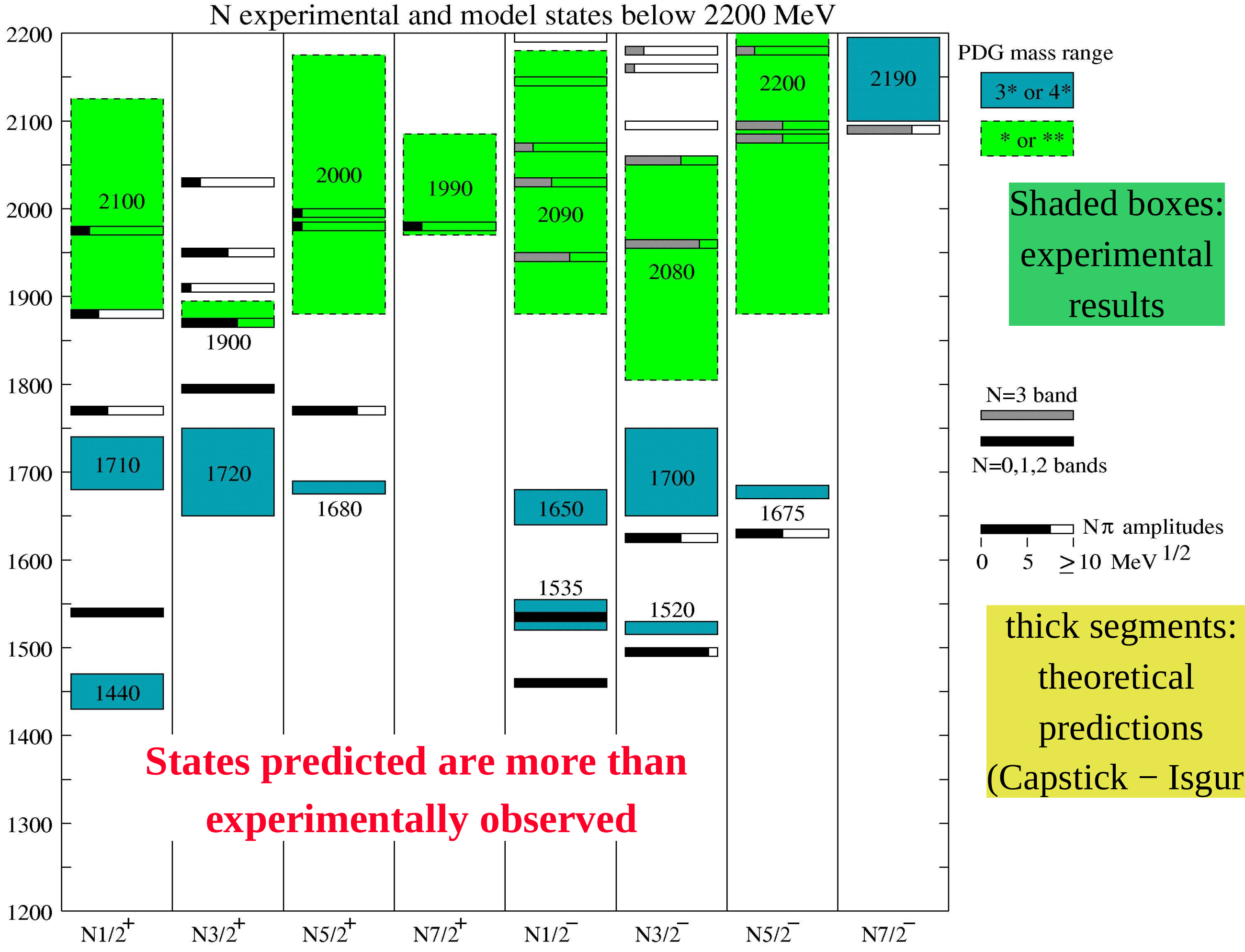
Glozman−Riska; Graz group

  - algebraic models **U(7) (Bijker − Iachello − Leviatan)**

- The diquark model predicts fewer states

K.F. Liu and C.W. Wong Phys. Rev. D28, 170 (1983)

Different schemes produce changes in state position, ordering, amount of splitting, etc.



Shaded boxes: experimental results

thick segments: theoretical predictions (Capstick − Isgur)

States predicted are more than experimentally observed

Baryon properties are not limited to the spectrum

Experimental sources of information:

reactions induced by pions:

$\pi N \rightarrow X$ $\pi N \rightarrow \pi N$ $\pi N \rightarrow \pi\pi N$ **etc.**

OR

pion photo− and electroproduction:

$\gamma N \rightarrow N \pi$ $e N \rightarrow e' \pi N$

Suggestion from phenomenology:
increased multihadron coupling
with increasing resonance mass

Looking at Particle Data from 1996

several N* resonances have strong B(N* → N π π)

Res. L 2I 2J P	Mass (MeV)	Γ (MeV)	B(Δπ) (%)	B(Nρ) (%)
P_{11}(1440) +	1430−1470	250 − 450	20 − 30	< 8
S_{31}(1620) −	1615−1675	120 − 180	30 − 60	7 − 25
D_{15}(1675) −	1670−1685	140 − 180	50 − 60	< 1− 3
D_{33}(1700) −	1670−1770	200 − 400	30 − 60	30 − 55
P_{13}(1720) +	1650 − 1750	100 − 200	−	70 − 85
F_{35}(1905) +	1870−1920	280 − 440	< 25	> 60

Several models of baryon decays have been developed

R. Koniuk and N. Isgur,
(pointlike coupling)

Graz group,
(Modified $^3P_0$ model)

S. Capstick and W. Roberts,
(Relativized $^3P_0$ model)

Stancu and Stassart,
(flux tube breaking)

Missing states :

Quark models predict decoupling from N π channel

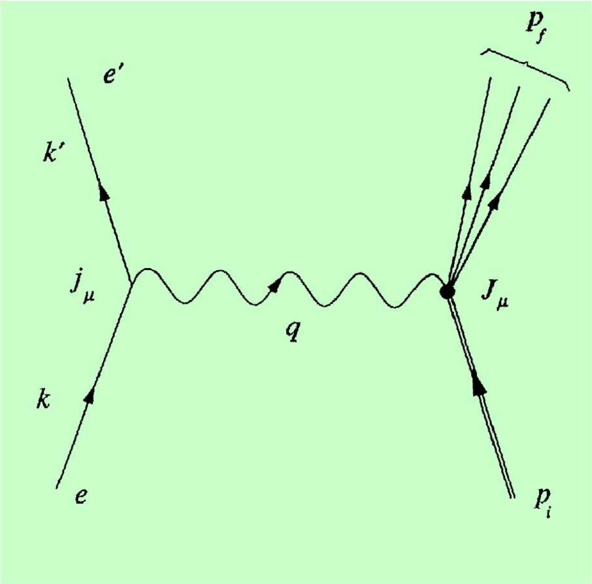
and coupling to N $\pi\pi$, N ω

From
S. Capstick and W. Roberts,
Phys. Rev. D49, (1994) 4570
(Relativized $^3P_0$ model)

Res. **N_{2J} (mass) P**	$\Gamma(\Delta\pi)$ **(MeV)**	$\Gamma(\rho N)$ **(MeV)**	$\Gamma(\omega N)$ **(MeV)**
N_1(1880) +	**80**	**5**	**25**
N_3(1910) +	**300**	**10**	**70**
N_3(1950) +	**60**	**15**	**40**
N_1(1975) +	**20**	**6**	**10**
N_5(1980) +	**240**	**5**	**8**
N_3(2030) +	**50**	**8**	**10**

Therefore,
it is important to investigate multihadron production channels,
like for instance the double pion production
<u>BUT</u> the probe cannot be a pion beam, as the coupling is
expected to be very weak → electromagnetic probe

- What about dynamical properties like transition probabilities ?
- Can we investigate properties like space distributions of charge and spin ?



The electromagnetic interaction has the advantage of being

- weaker than strong interactions
- therefore calculable perturbatively
- based on the well- known QED

The scattering is normally analysed in term of the
One- Photon- Exchange approximation (OPE)

In this picture, the virtual photon acts as the light
in a microscope, with tunable wavelength such to allow
investigation of a broad range of phenomena,
from nuclear charge distributions to deep inelastic scattering

see: D. Drechsel, M.M. Giannini, Rep. Prog. Phys., 52, 1083(1989)
S. Boffi et al., Physics Reports, 226 (vol. 1 & 2), 1(1993)

General aspects and issues in 2π calculations or fits

Unitarity:
in principle, only way is multichannel analysis
in practice, wide use of theoretical or phenomenol. models
where multichannel coupling is effective or missing

eff. Lagrangians vs Regge:
former is better suited for low energy
latter is very powerful and economical for high energy
In practice (our case) Regge not so bad even at low energy
Maybe:
physics foundation not solid but parametrisation good enough

Regge is supposed to effectively include s−channel
but this is true only for a full theory with all trajectories
and presumably at W above 5−6 GeV
In our case: Regge gives strength at forward angles,
N* at all angles → visible at medium−large angles

Regarding PWA, one thing to bear in mind is that multiple
pion production (Δπ, ρ, ω) is generally producing
VERY HIGH PARTIAL WAVES
(think about diffractive vector meson production)
traditionally, “standard” PWA effective with few PW
→ models absolutely needed to guide analysis

TJNAF Experiments:
93−006 (M. Ripani−V.Burkert) $e\,N \rightarrow e'\,N\,\pi\,\pi$

93−033 (J.Napolitano et al.) $\gamma\,p \rightarrow p\,\pi^{+}\,\pi^{-}$

94−109 (P. Cole et al.) $\vec{\gamma}\,p \rightarrow p\,\rho^{0}$

Possible contributing channels on proton are

$$\gamma_V\,p \rightarrow p\,\pi^{+}\,\pi^{-}$$
$$n\,\pi^{+}\,\pi^{0}$$
$$p\,\pi^{0}\,\pi^{0}$$

on neutron

$$\gamma_V\,n \rightarrow n\,\pi^{+}\,\pi^{-}$$
$$p\,\pi^{-}\,\pi^{0}$$
$$n\,\pi^{0}\pi^{0}$$

Each reaction can take place through different intermediate processes

e.g.

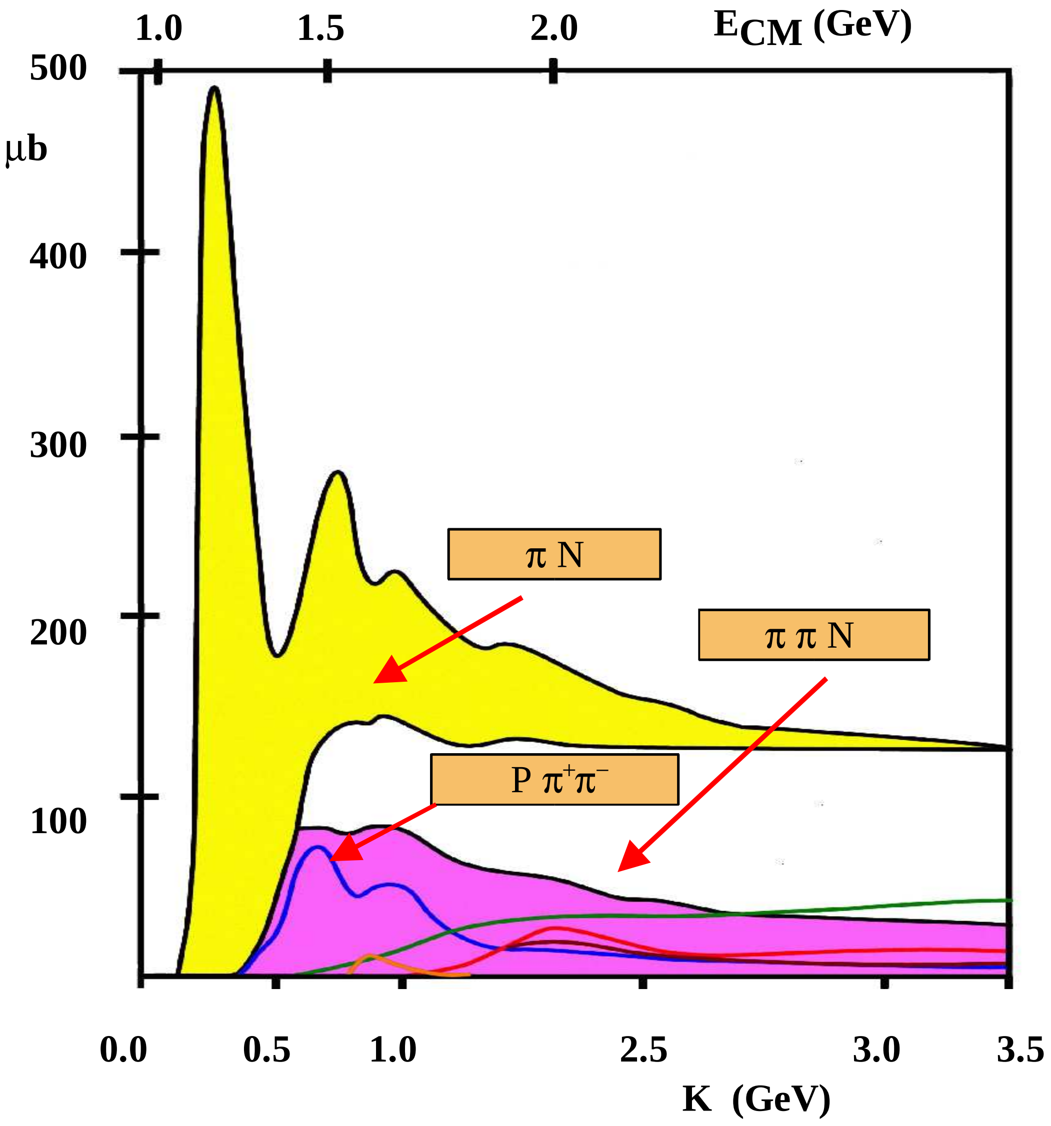
$$\gamma_V\,p \rightarrow p\,\pi^{+}\,\pi^{-}$$

$$\gamma_V\,p \rightarrow \Delta^{++}\,\pi^{-} \rightarrow (p\,\pi^{+})\,\pi^{-}$$
$$\gamma_V\,p \rightarrow \Delta^{0}\,\pi^{+} \rightarrow (p\,\pi^{-})\,\pi^{+}$$
$$\gamma_V\,p \rightarrow \rho^{0}\,p \rightarrow (\pi^{+}\,\pi^{-})\,p$$
$$\gamma_V\,p \rightarrow p\,\pi^{+}\,\pi^{-}\ \text{(“phase space”)}$$

Focus concentrated on resonant contributions like

$$\boxed{\gamma_V\ p \rightarrow N^{*} \rightarrow \Delta^{++}\,\pi^{-} \rightarrow p\ \pi^{+}\,\pi^{-}}$$

Total photo−absorption Cross Section on proton



Data for photoproduction

- ✔ From ABBHHM bubble chamber in wide energy range
- ✔ Lots of data at W<1.5 GeV from DAPHNE and TAPS

**electroproduction
data in the literature
are very limited**

Preliminary results from CLAS

Typical electron luminosity for first half of 1998 was a few 10^{33}
DAQ rate was about 500 events/sec

In 1999 data taking was improved to about 10^{34} luminosity and
DAQ rate 1500 events/sec

Overall data collection in 1999:

Electron scattering on Hydrogen target with polarised beam

Beam energies:
1.5, 2.5, 4.0, 4.2, 4.5, 5.5 GeV

3.6 billion triggers - half a billion electrons !!!

Event reconstruction completed for all data sets

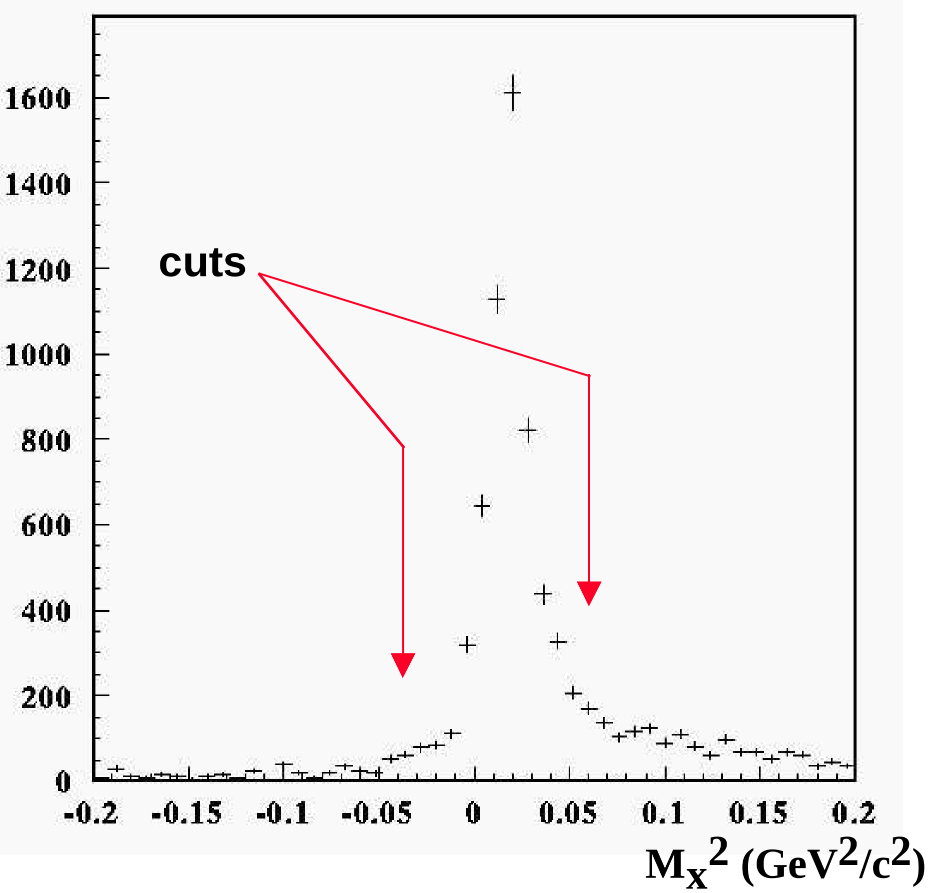
For two pion production, we will present data
from 1999 (higher statistics)

Hadronic variables (our choice):
- direction Θ and Φ for one particle
- invariant masses $M(p\,\pi^+)$, $M(\pi^+\pi^-)$
- azimuthal angle ψ of decay products

10 bins for $s(p\,\pi^+)$, $s(\pi^+\pi^-)$ and Θ, 5 for the others
→ total of about 25,000 hadronic bins
(plus binning in W, Q^2, while electron φ is obviously integrated)

Data have been corrected in particular for:
- detector kinematic acceptance
- reconstruction efficiency
- electron radiation

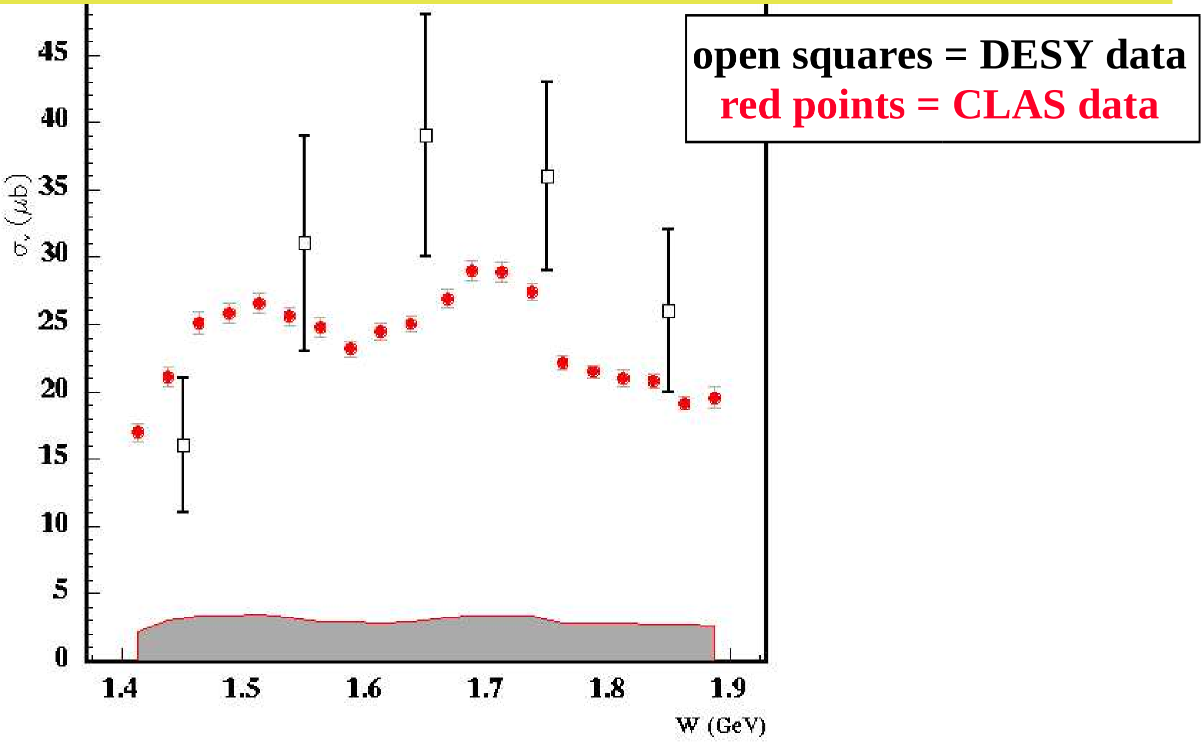
Reaction identification: missing mass for e p → e p π^+ (π^-)

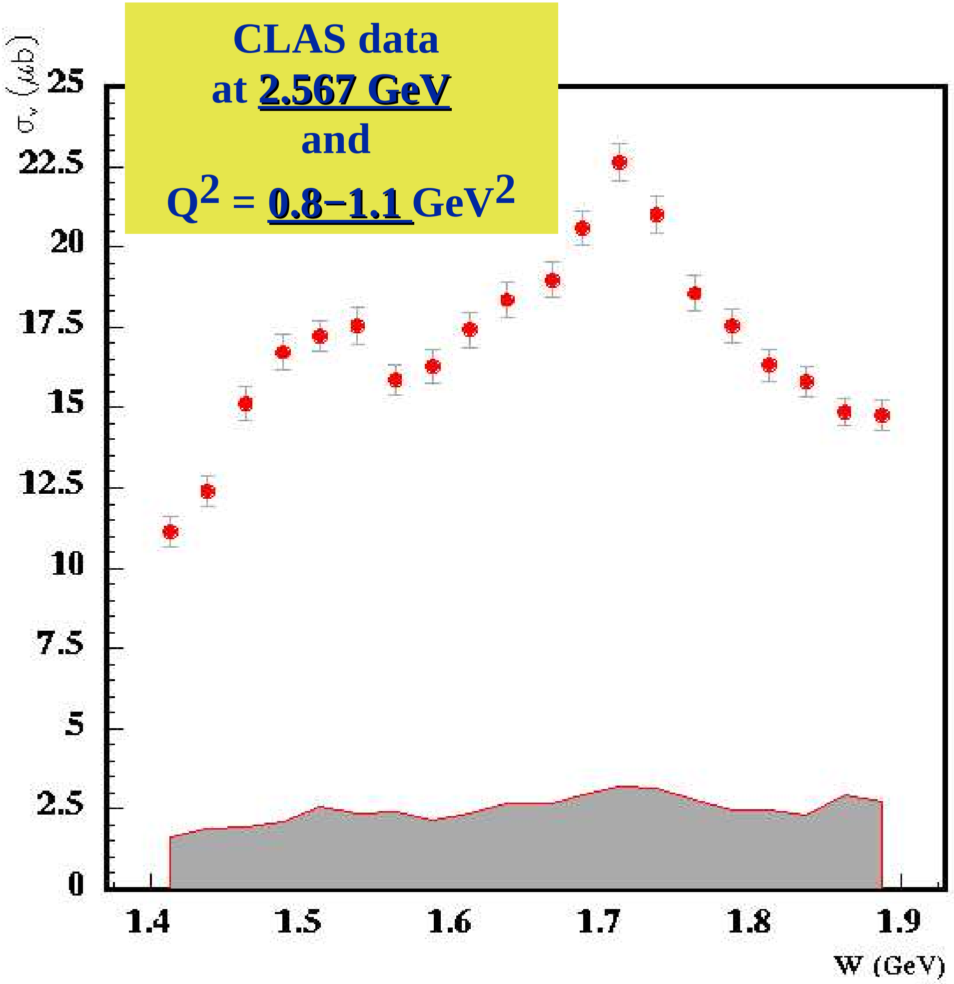


Absolute virtual photon cross section $\sigma_V(W,Q^2)$ for e' p π^+ π^-

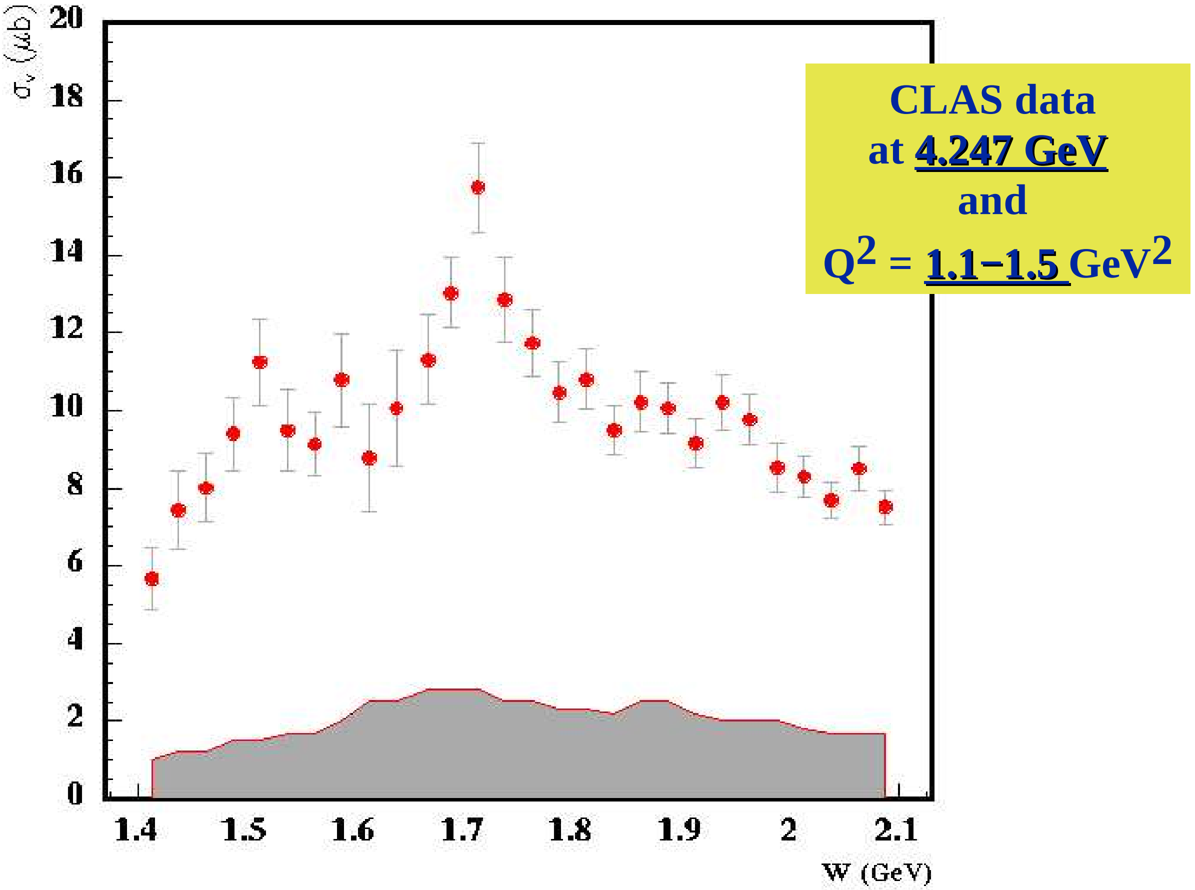
CLAS data at 2.567 GeV and Q^2 = 0.5−0.8 GeV^2

DESY data from Eckart et. al NP B55 (1973)45





CLAS data
at **2.567 GeV**
and
Q^2 = **0.8−1.1** GeV^2



CLAS data
at **4.247 GeV**
and
Q^2 = **1.1−1.5** GeV^2

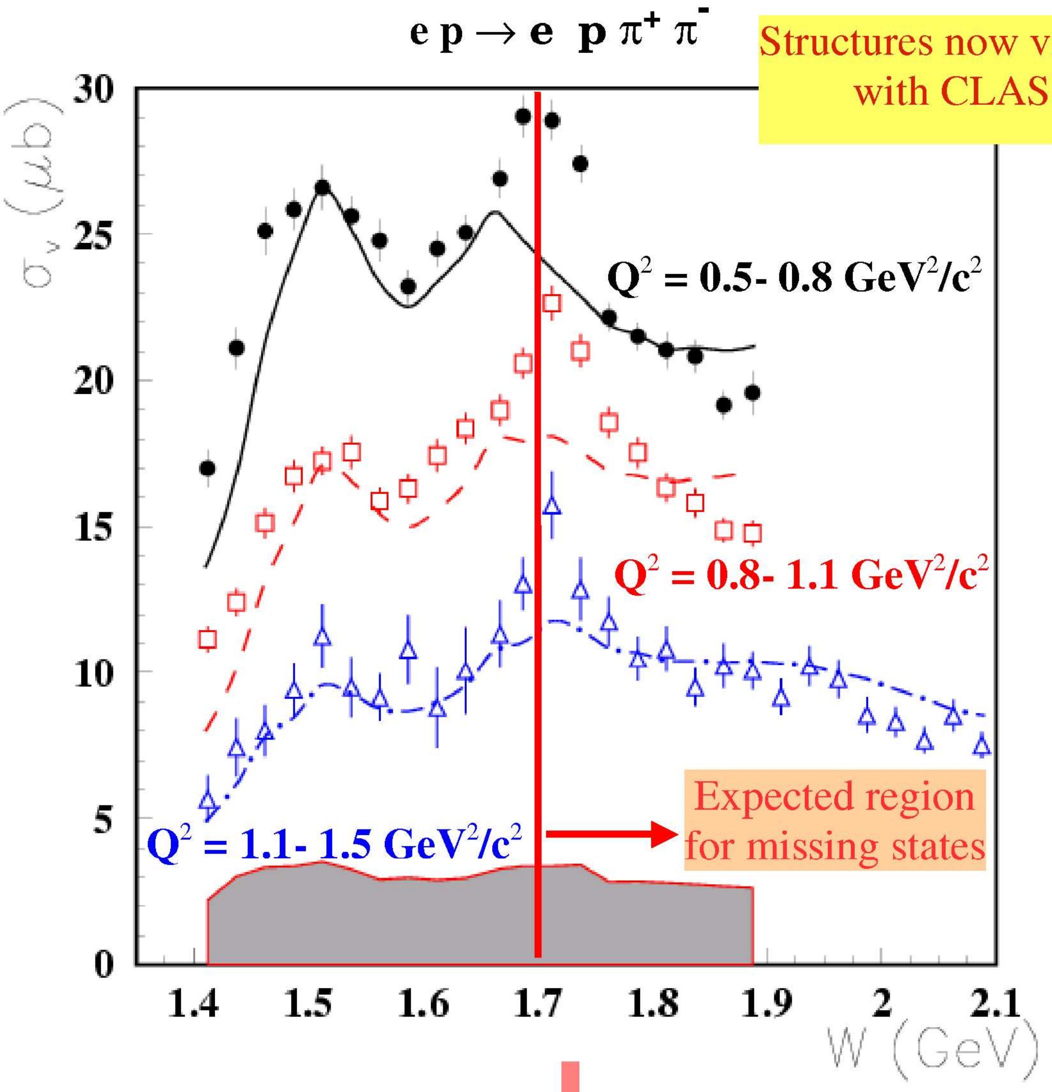
Virtual photon cross section

$\sigma_V(W,Q^2)$ for $e\,p \rightarrow e\,p\,\pi^+\pi^-$

CLAS data at 2 .6 GeV and 4.2 GeV (1999)

Preliminary comparison with Genova- Moscow phenomenological model for two pion electroproduction

Input for resonance photocouplings $A_{1/2}$, $A_{3/2}$ coming from
V. Burkert fit based on experimental data +
Single Quark Transition Model assumptions
Strong decay couplings from M. Manley hadronic analysis



Structures now visible with CLAS

Expected region for missing states

Data seems to indicate relevant missing strength in the region around 1.7 GeV

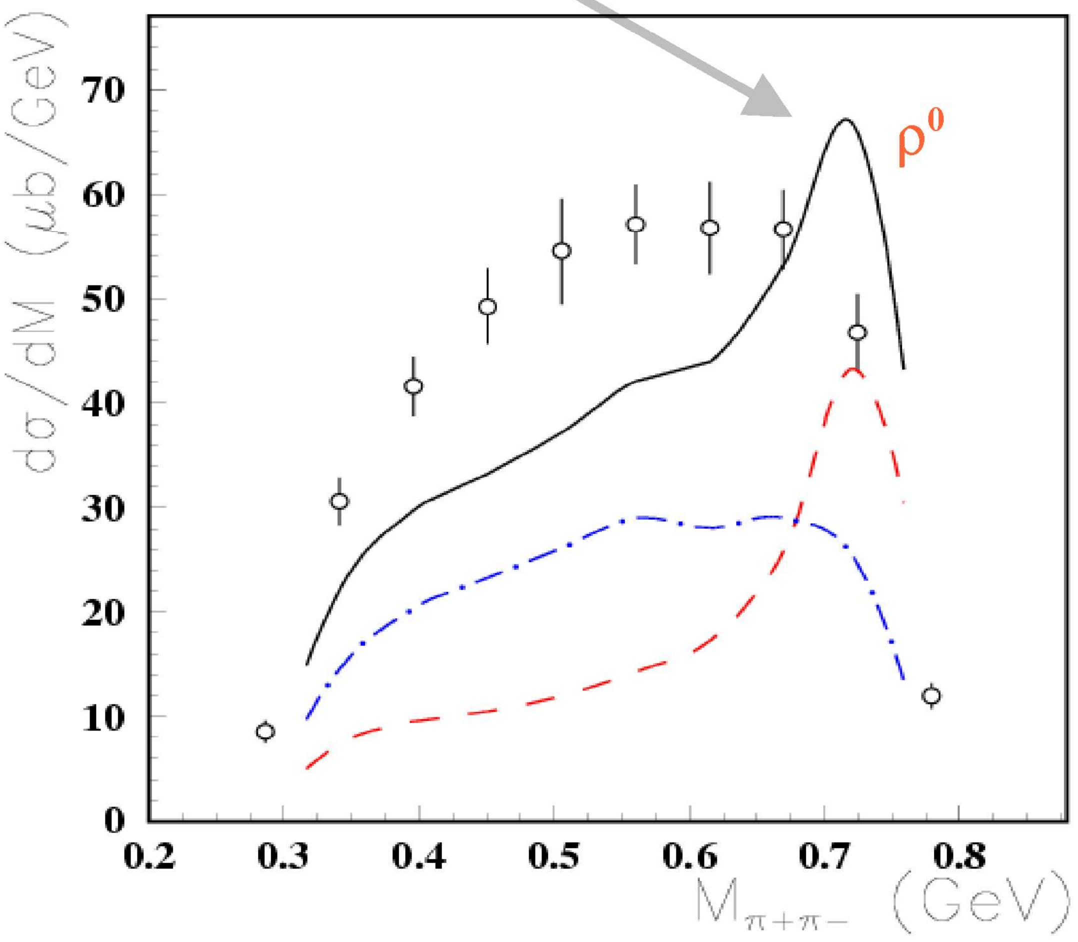
Virtual photon cross section $\sigma_V(W,Q^2)$ for $e\,p \rightarrow e\,p\,\pi^+\,\pi^-$

CLAS data at 2 .6 GeV , Q^2 = 0.8 - 1.1 GeV^2

Analysis of mass and angular distributions

Deviations indicate decay couplings or photocouplings different from expected, as well as possible new states

W=1.71 GeV
Q^2 = 0.8- 1.1 GeV^2/c^2

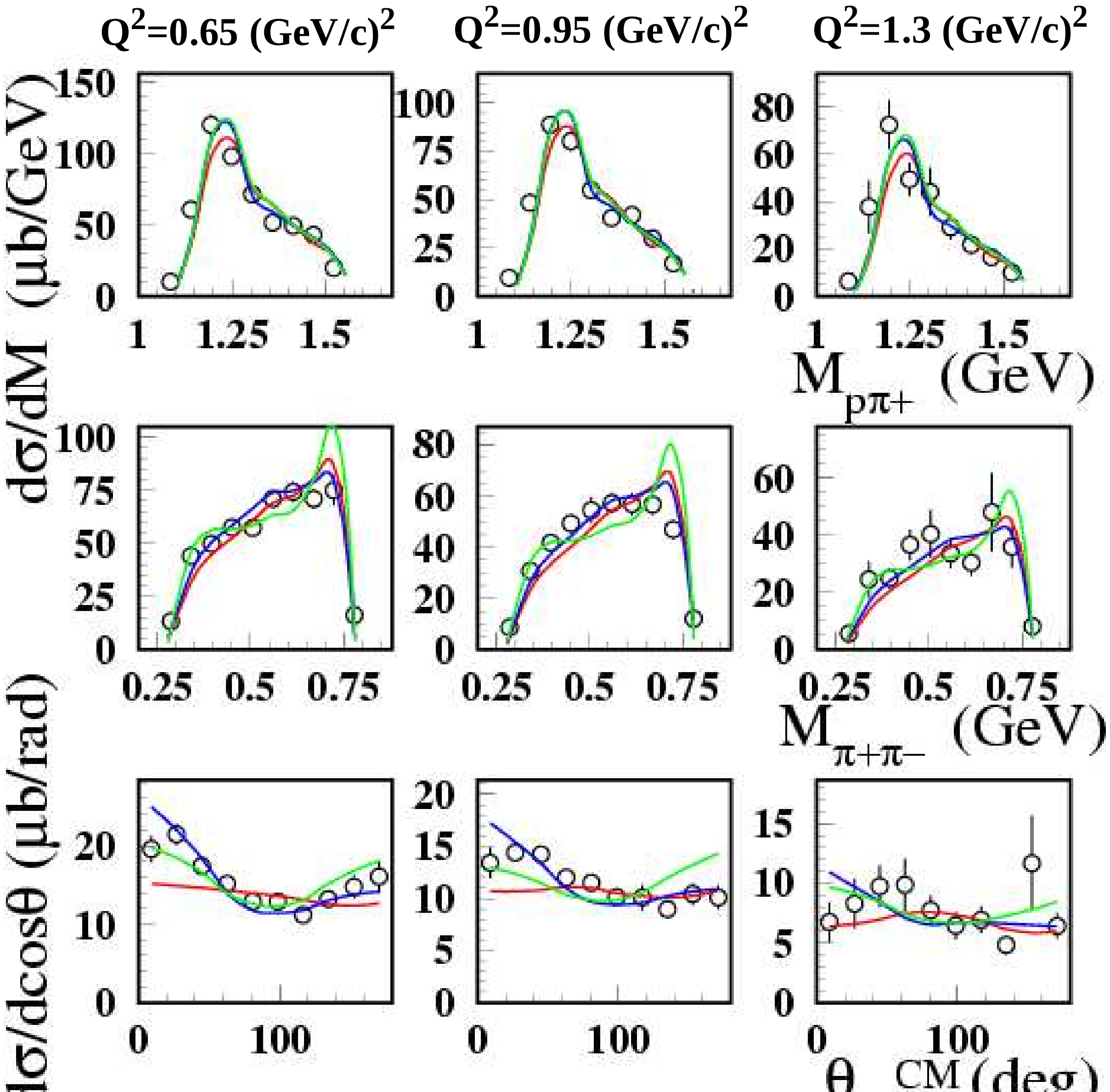


- **blue curve: non- resonant part**
- **red curve: resonant part**
- **black curve: full calculation**

Virtual photon cross section $\sigma_V(W,Q^2)$ for e p → e′ p π+ π−

CLAS data at 2 .6 GeV , W= 1.7 GeV

Analysis of mass and angular distributions



Possible candidates for the bump:

D33(1700) → too wide

D15(1675) → too low mass

F15(1680) → too low mass

The 1.7 GeV bump was fitted in five different ways:

1) increasing the conventional D_{13}(1700) (red line)

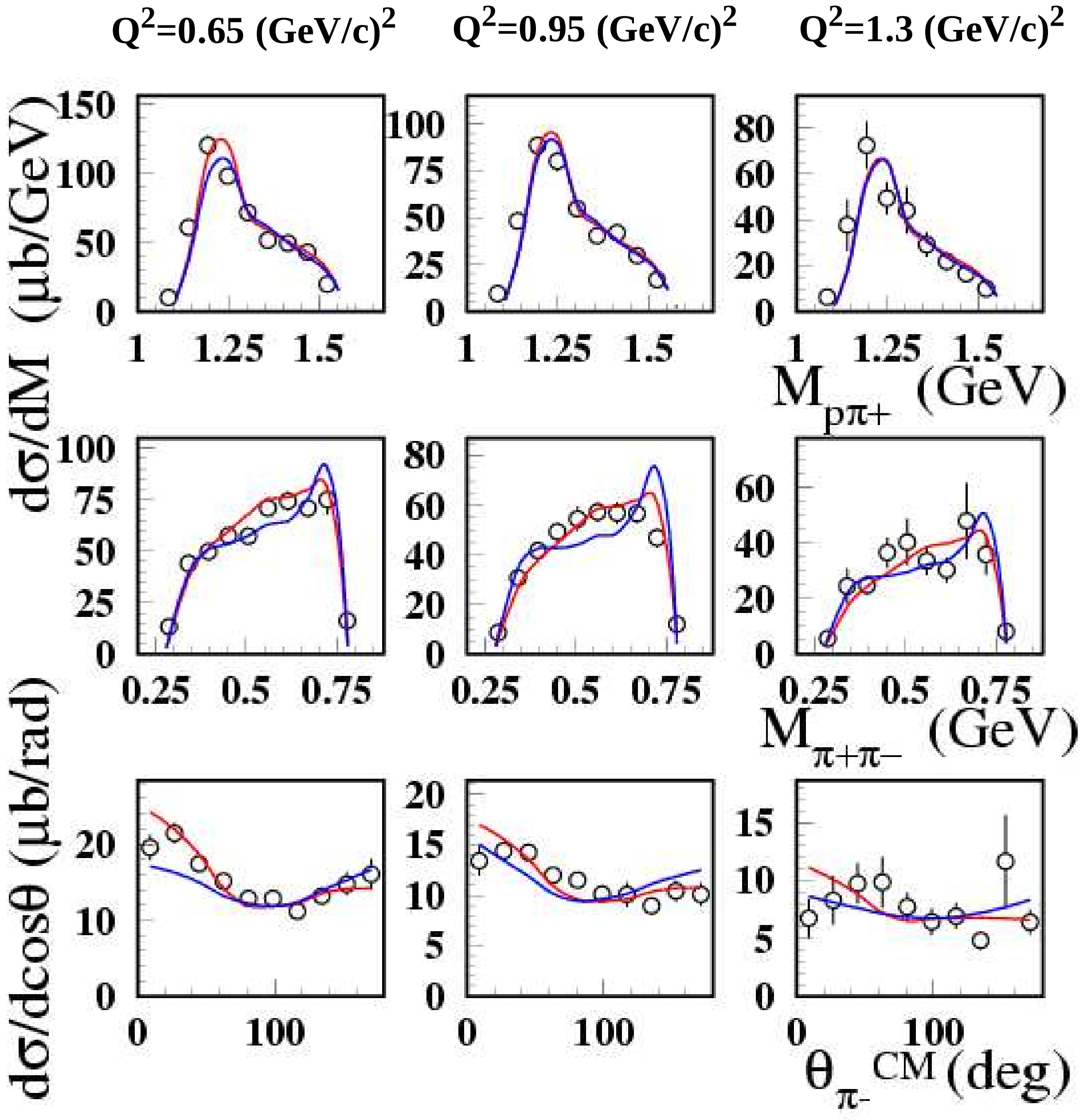
2) increasing the conventional P11(1710) (green line)

3) modifying the conventional P_{13}(1720) (blue line)

Virtual photon cross section $\sigma_V(W,Q^2)$ for e p → e′ p $\pi^+ \pi^-$

CLAS data at 2 .6 GeV , W= 1.7 GeV

Analysis of mass and angular distributions



The 1.7 GeV bump was fitted in three different ways:

4) fit $A_{1/2-3/2}$ for all 3 conventional states (blue line)

5) introducing a new state: best fit by P_{I3} (red line) among many quantum numbers we tried

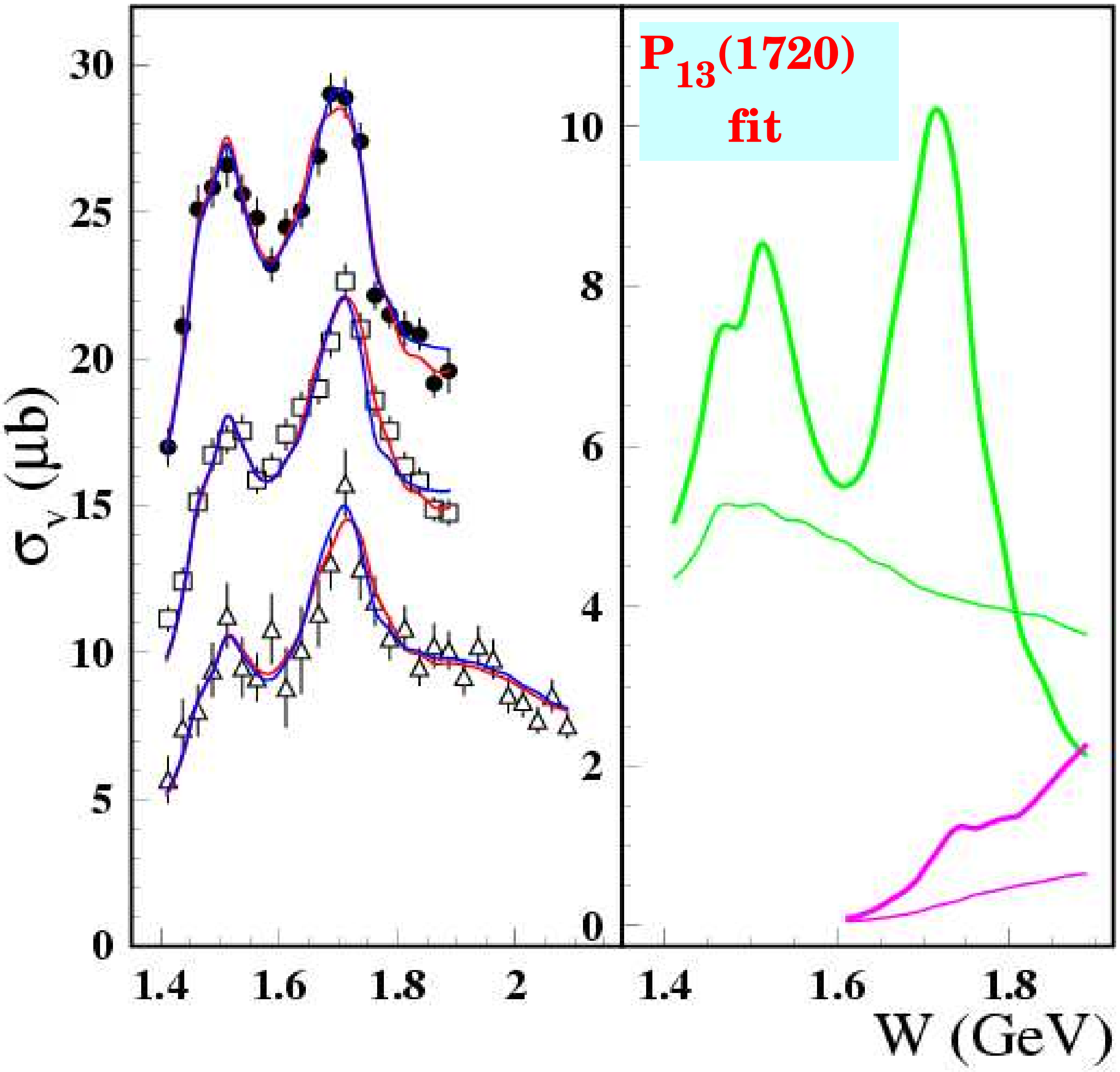
Virtual photon cross section $\sigma_V(W,Q^2)$ **for** $e\,p \rightarrow e'\,p\,\pi^+\,\pi^-$

CLAS data at 2 .6 GeV and 4.2 GeV (1999)

The 1.7 GeV bump was fitted in various ways:

3) **increasing the conventional** P_{13}**(1720) (red line)**

4) **fit** $A_{1/2-3/2}$ **for all 3 conventional states (blue line)**



- **right plot: black thick curve is** Δ^{++} **resonant part**
- **black thin curve is** Δ^{++} **non−resonant part**
- **magenta thick curve is** ρ^0 **resonant part**
- magenta thin curve is ρ^0 non−resonant part

Results of our resonance analysis of the 1.7 GeV bump are:

1) the PDG $D_{13}(1700)$ does not provid a good fit

2) the PDG $P_{11}(1710)$ does not provid a good fit

3) the PDG $P_{13}(1720)$ provides a good fit but with strong couplings substiantially different from PDG and recent literature (KSU, Pittsburgh multichannel fits)

4) fitting the photocouplings of all 3 states does not work, either

5) introducing a new P_{13} allows to keep the PDG $P_{13}(1720)$ strong couplings at published values and provides a good fit

	Mass (MeV)	Γ (MeV)	B(Δπ) (%)	B(Nρ) (%)
our fit of PDG P_{13}	1725 ± 20	114 ± 19 ± 29	63 ± 12 ± 17	19 ± 9 ± 14
PDG values	1650−1750	100 − 200	absent	70 − 85
new P_{13}	1720 ± 20	88 ± 17 ± 25	41 ± 13 ± 20	17 ± 10 ± 17

	Q^2 $(GeV/c)^2$	$\sqrt{A_{1/2}^2 + A_{3/2}^2}$ $(10^{-3}\ GeV^{-1/2})$
our fit of PDG P_{13}	0.65	83 ± 5
	0.95	63 ± 8
	1.3	45 ± 27
new P_{13}	0.65	76 ± 9
	0.95	54 ± 7
	1.3	41 ±18

Conclusions and outlook

- Two pion electroproduction is connected to basic properties of the baryon spectrum: it allows to investigate poorly known states and search for “missing” (an hybrid) ones

structures in W now appearing in two pion channel,
not visible in previous experiments

- Resonance analysis performed using the Genova−Moscow isobar model that containes resonances and background: first attempt to extract N* contribution !!

- The bump at 1.7 GeV was reproduced in two different hypotheses:

I) Ordinary P_{13}(1720) from PDG can fit the data but with significant strong parameters changes

II) A new P_{13} can equally well fit the data : is it a missing state ? A hybrid ?