Nucleon Excited States

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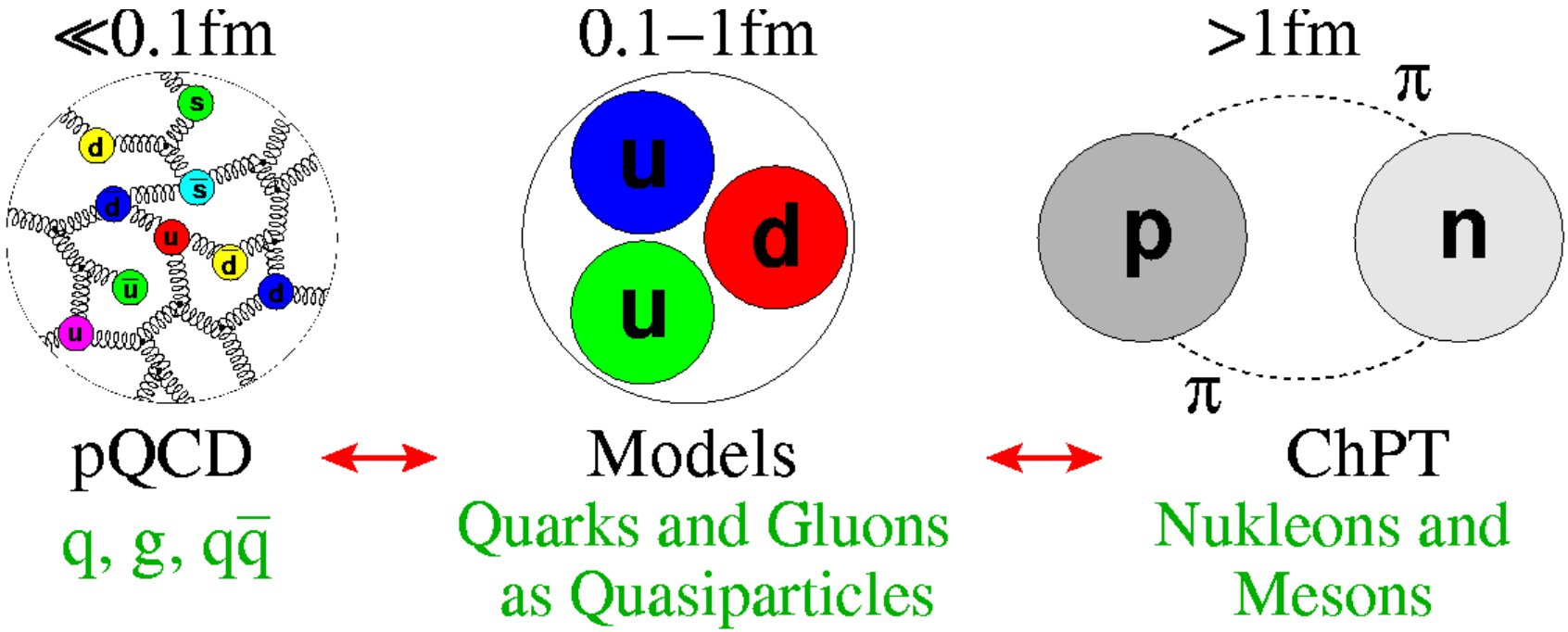
Mini-Workshop on Nucleon Excited States
PAC25
January 17, 2004

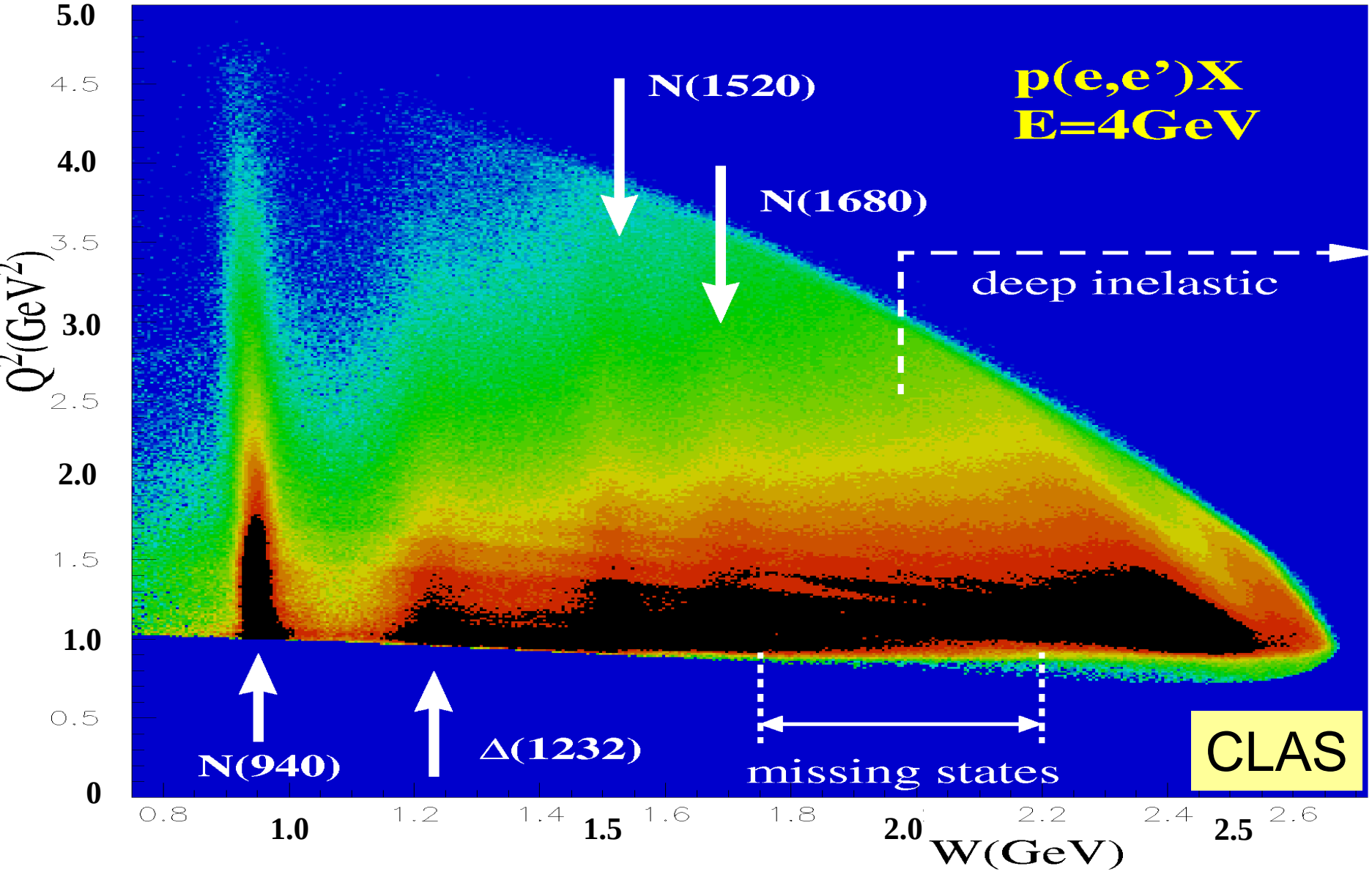
Introduction
$N \rightarrow \Delta$ transition
“Missing” Resonances, Strange Resonances and Two Pion Production
Pentaquark States
Outlook

Physics Goals



- Understand QCD in the full strong coupling regime
  - transition form factors
  - mass spectrum, quantum numbers of nucleon excited states
  - relevant degrees-of-freedom
  - wave function and interaction of the constituents

CLAS Coverage for ep → e'X at 4 GeV



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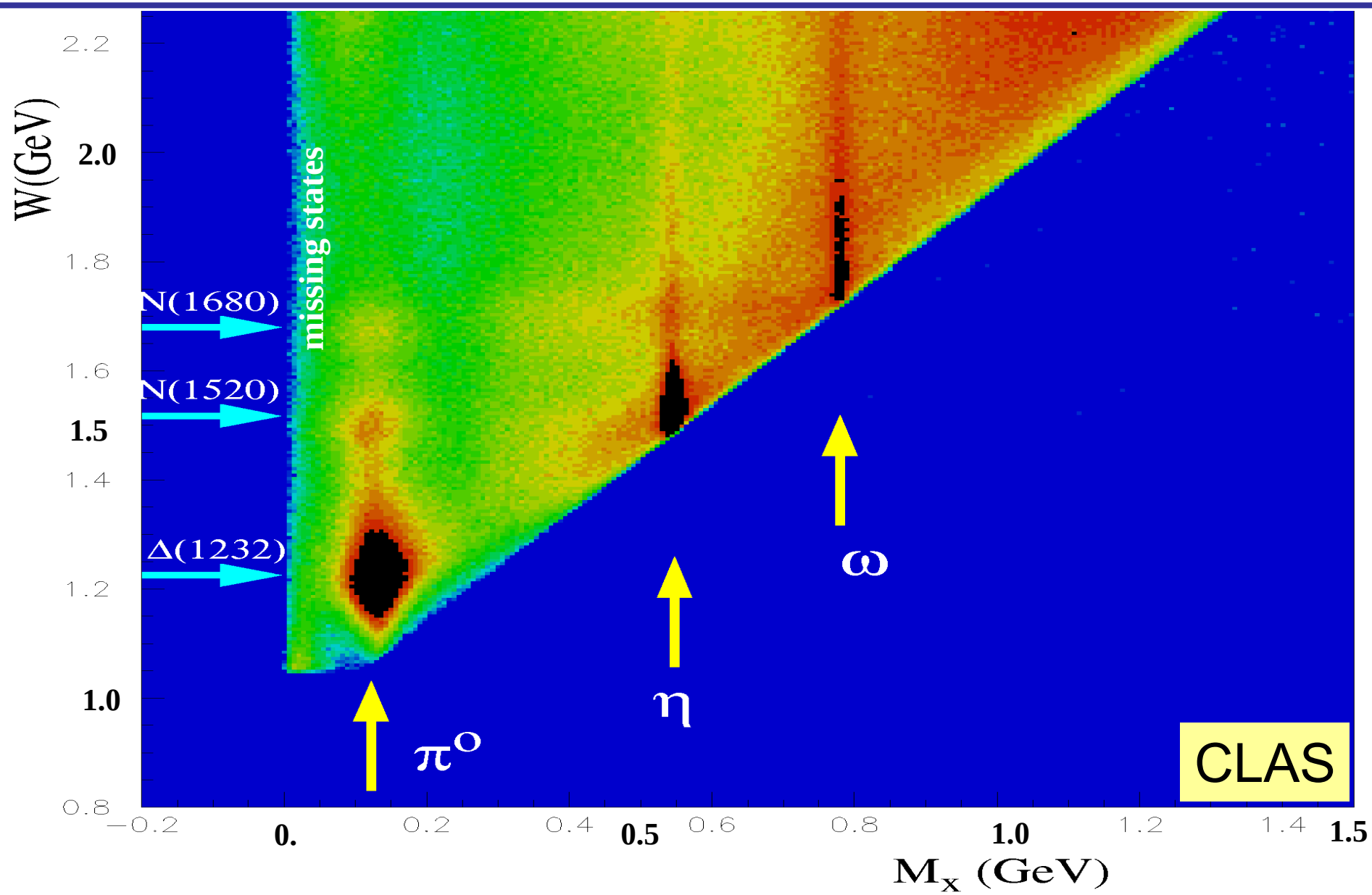
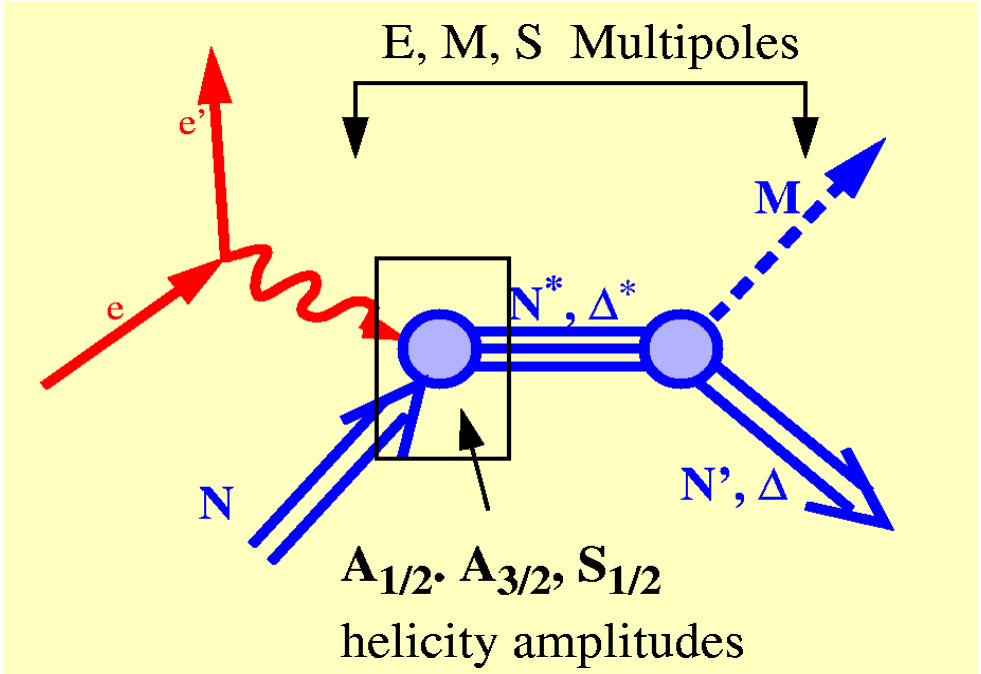


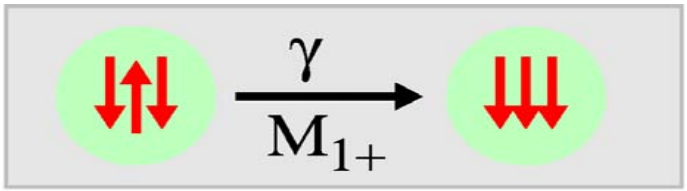
Electromagnetic Probe

- helicity amplitudes are sensitive to the difference in wave functions of N and N*
- can separate electric and magnetic parts of the transition amplitude
- is linearly polarized

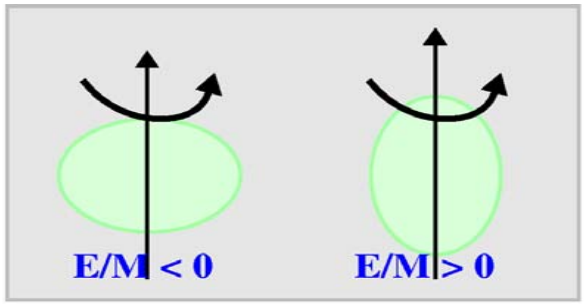


- varying Q^2 allows to change the spatial resolution and enhances different multipoles
- sensitive to missing resonance states

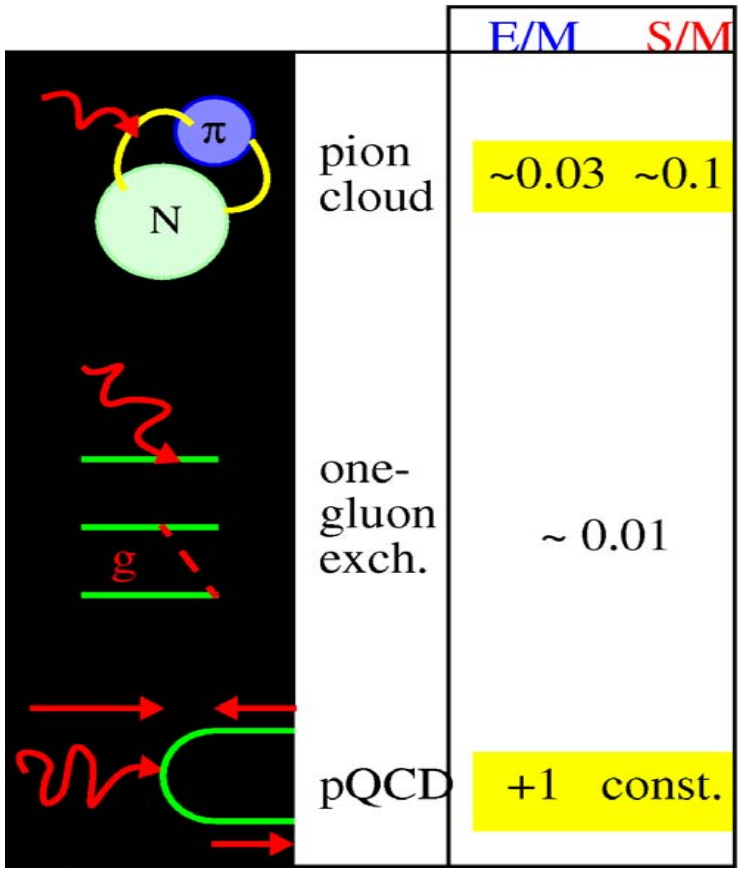
N→Δ(1232) Transition Form Factors

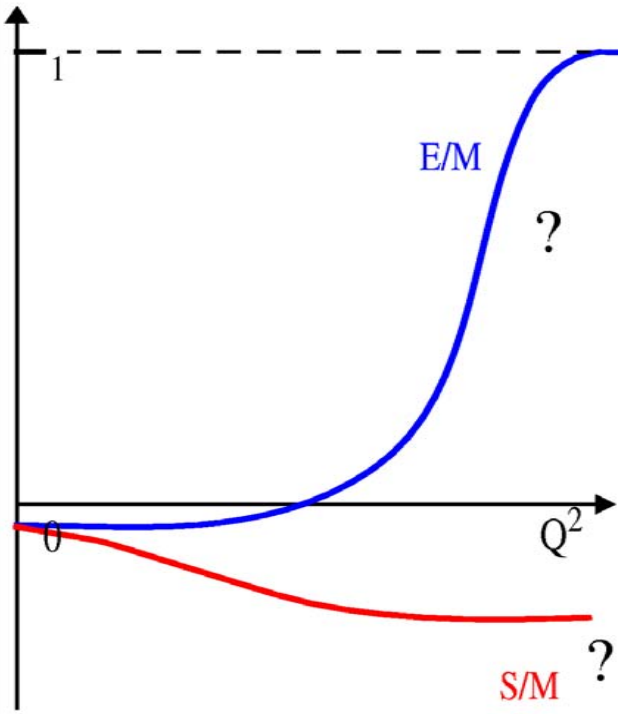


SU(6): $E_{1+}=S_{1+}=0$



(A. Buchmann, E. Henley, 2000)

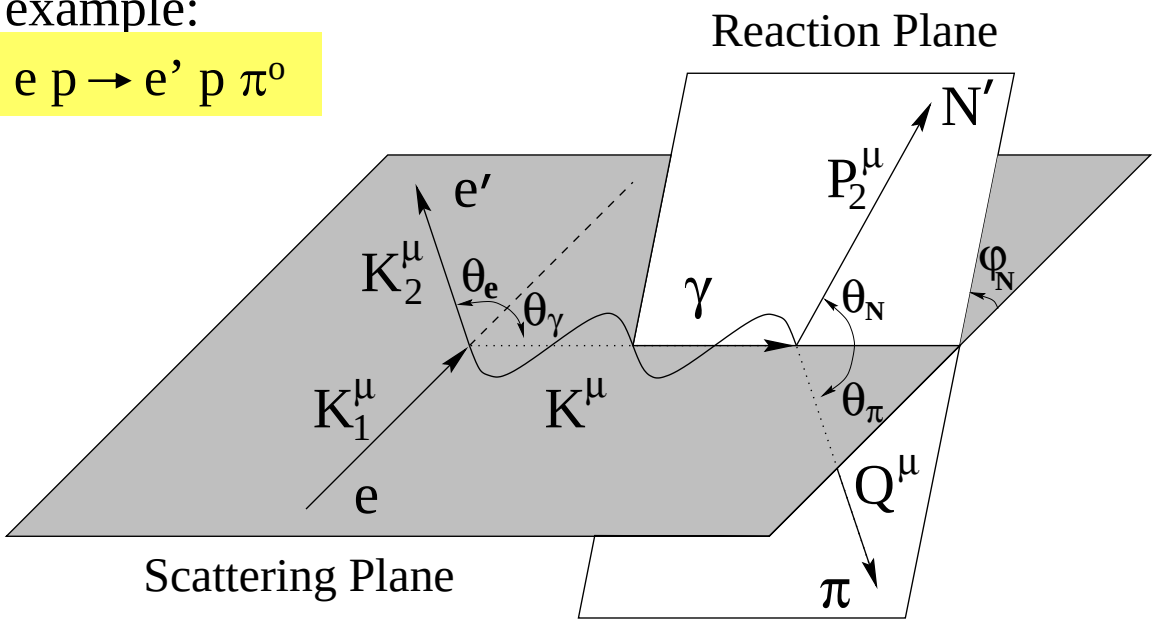




Cross Section Decomposition

example:

e p → e' p π^o



virtual photon flux

$$\frac{d^5\sigma_v}{d\Omega_e dE'_e d\Omega^*} = \Gamma_v \frac{d^2\sigma_v}{d\Omega^*}$$

hadronic cross section

linearly polarized photons

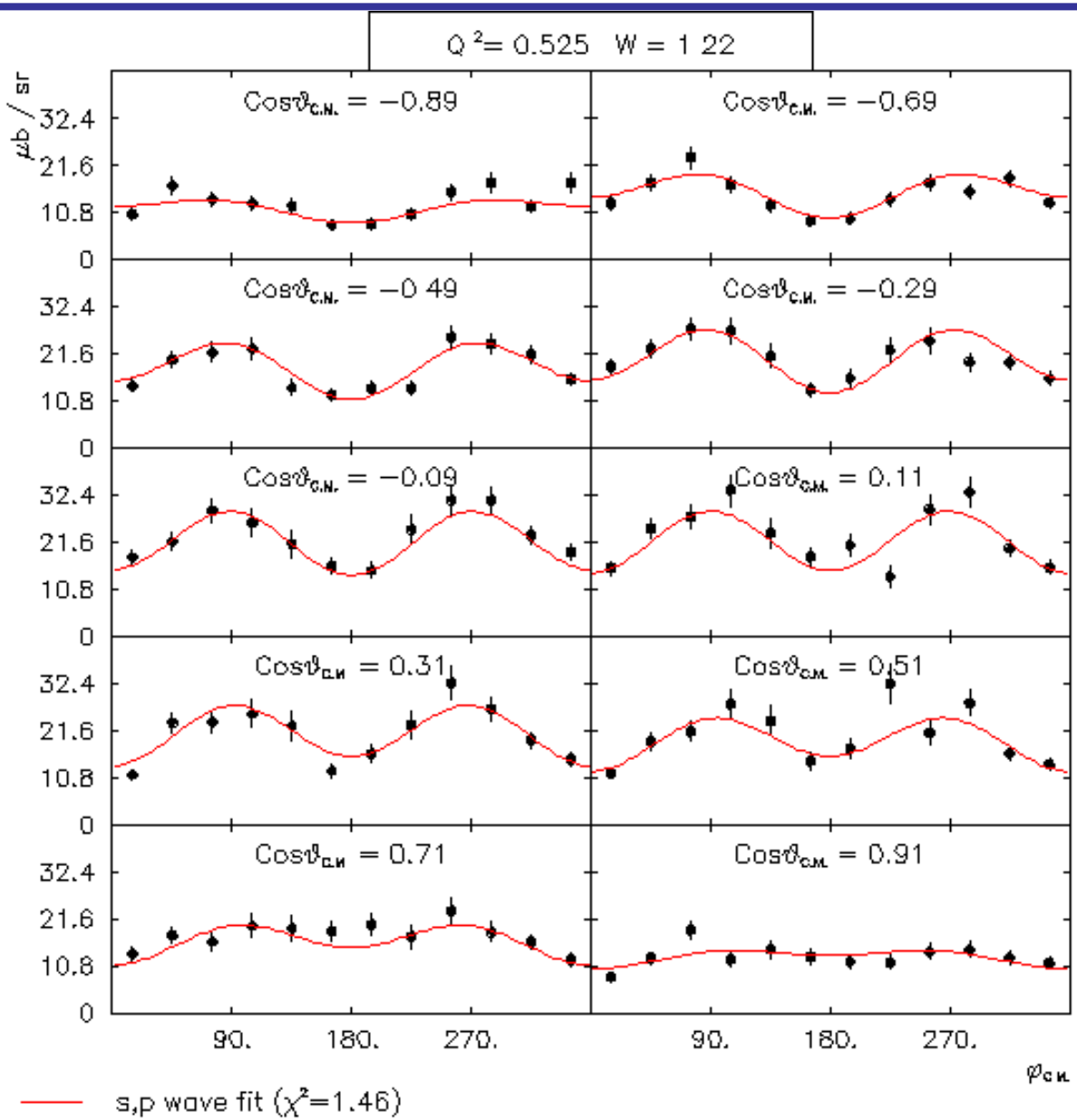
$$\frac{d^2\sigma_v}{d\Omega^*} = \frac{|\vec{q}^{\,*}|}{k^*_\gamma}\left(R_T + \epsilon R_L + \sqrt{2\epsilon(1+\epsilon)}\, R_{LT}\cos\varphi + \epsilon R_{TT}\cos 2\varphi\right)$$

θ−dependence

E_{1+}, M_{1+} $\quad$ S_{1+} $\quad$ M_{1+}

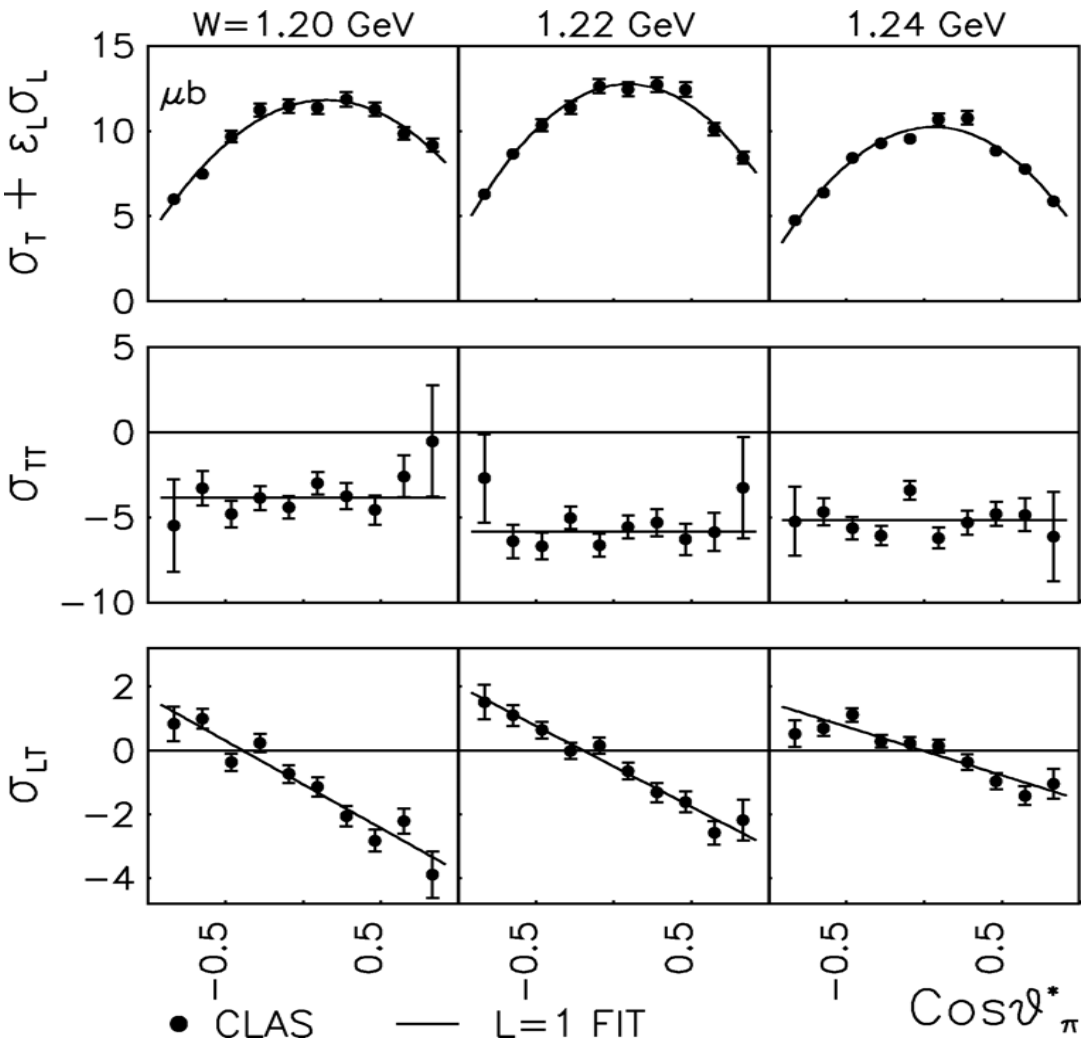
$\gamma^* p \rightarrow p\pi^o$ – Response Functions

CLAS



Multipole Analysis for $\gamma^* p \rightarrow p\pi^o$

CLAS



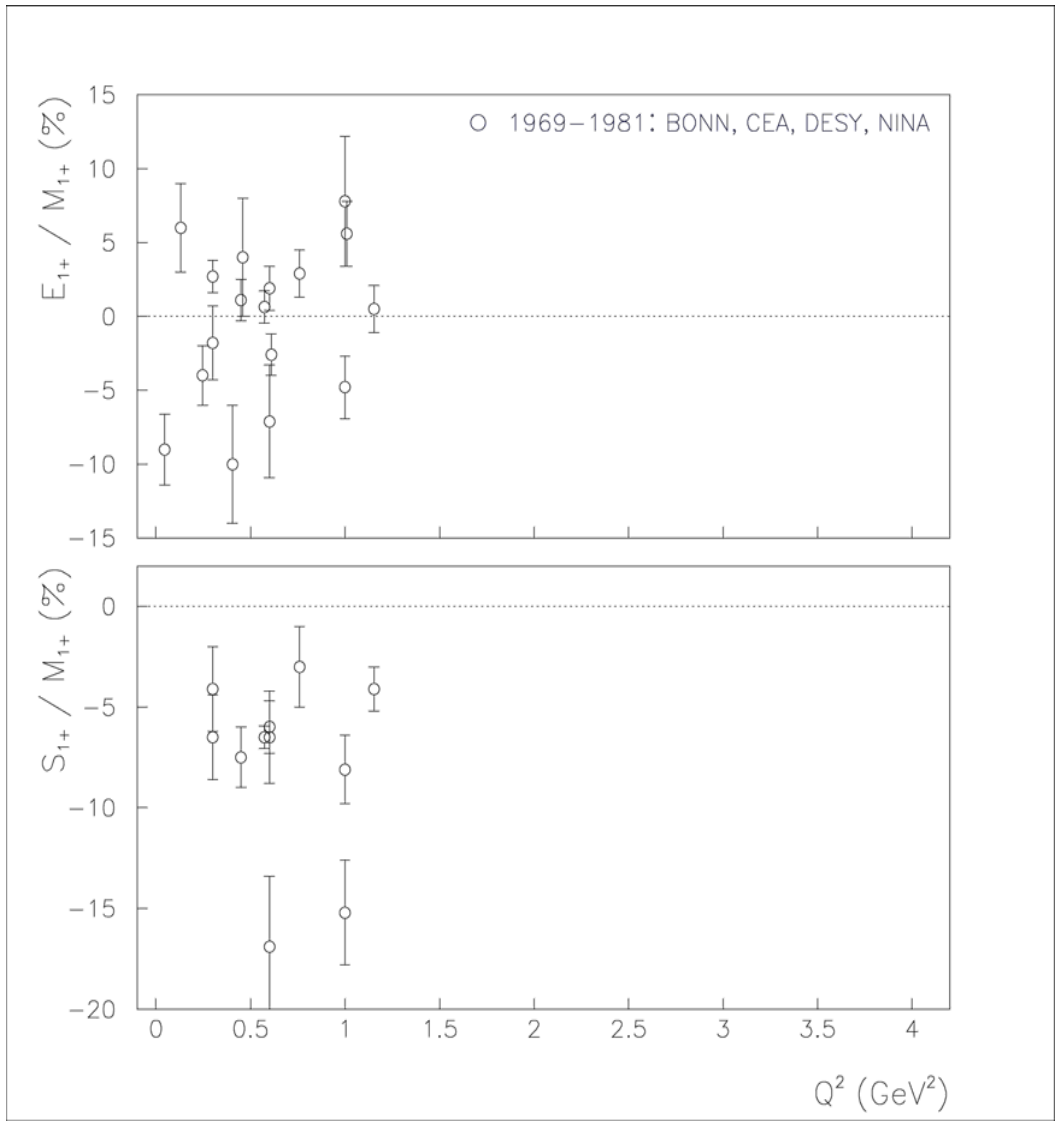
$Q^2 = 0.9\ \mathrm{GeV}^2$

$|M_{1+}|^2$

$\mathrm{Re}(E_{1+}M_{1+}^*)$
$|M_{1+}|^2$

$\mathrm{Re}(S_{1+}M_{1+}^*)$

Multipole Ratios R_{EM}, R_{SM} before 1999

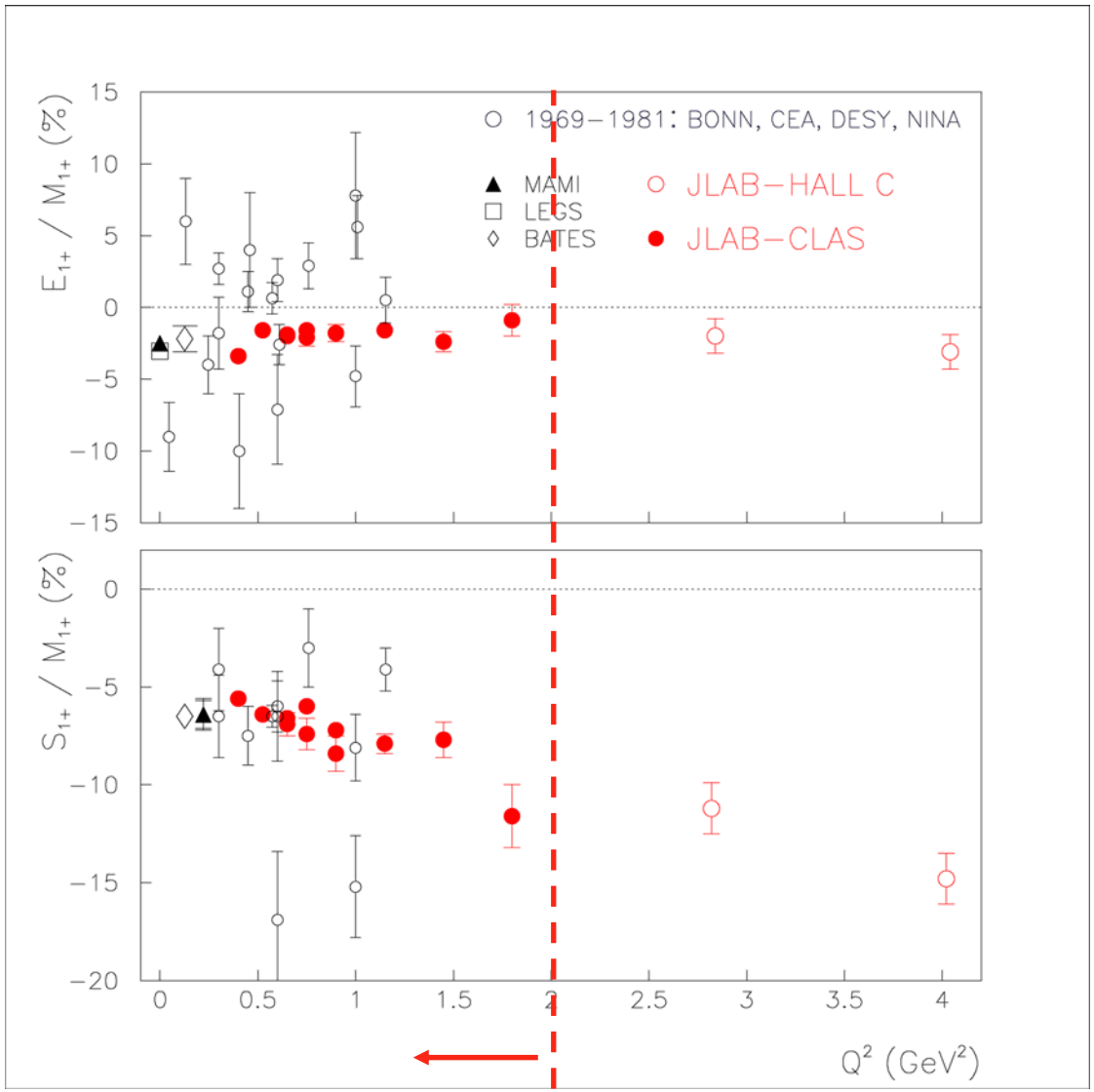


⟸ Sign?

⟸ Q^2 dependence?

➢ Data could not determine sign or Q^2 dependence

Multipole Ratios R_{EM}, R_{SM} in 2002



Sign?

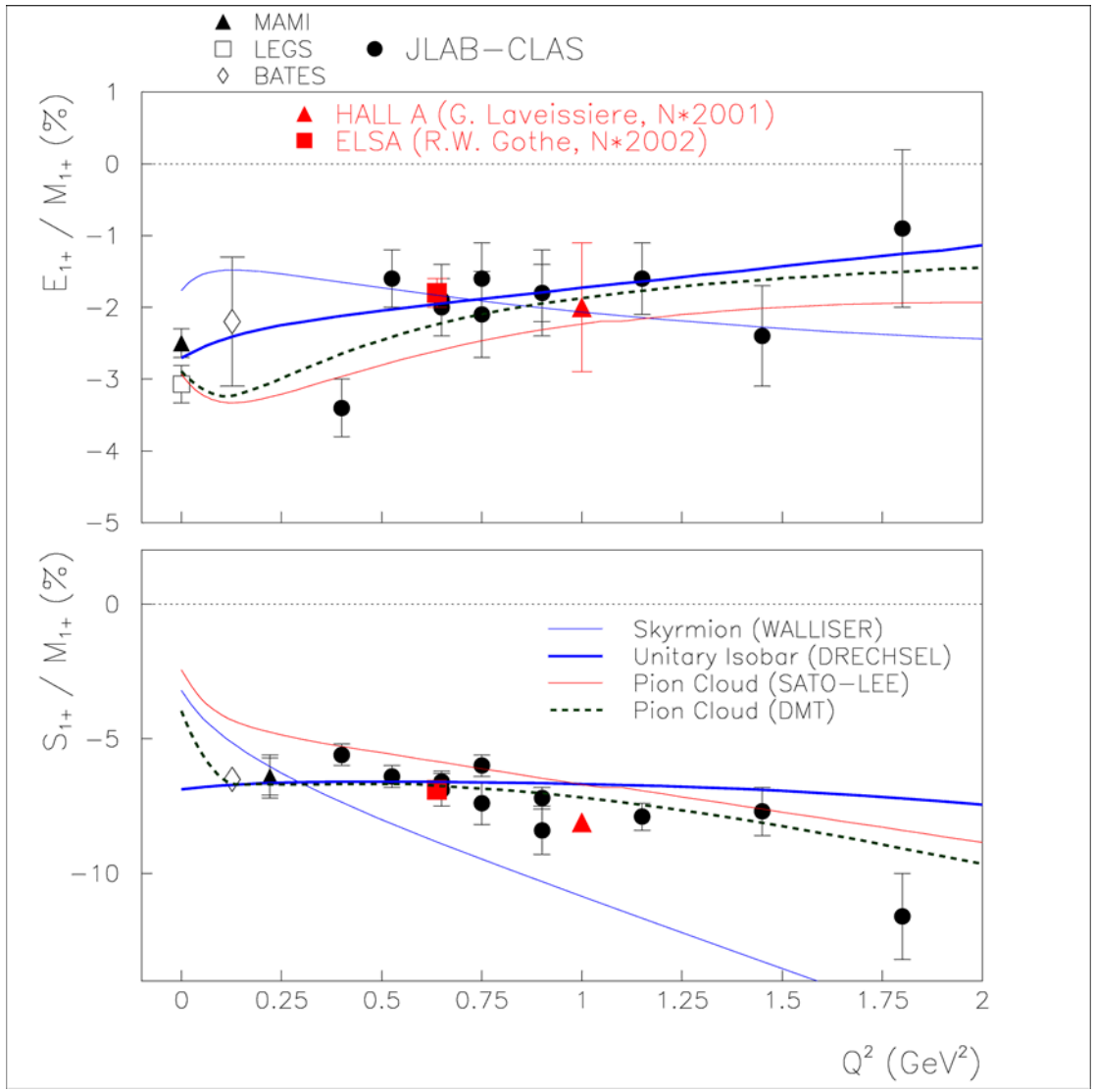
< 0 !

Q^2 dependence !

Slope < 0

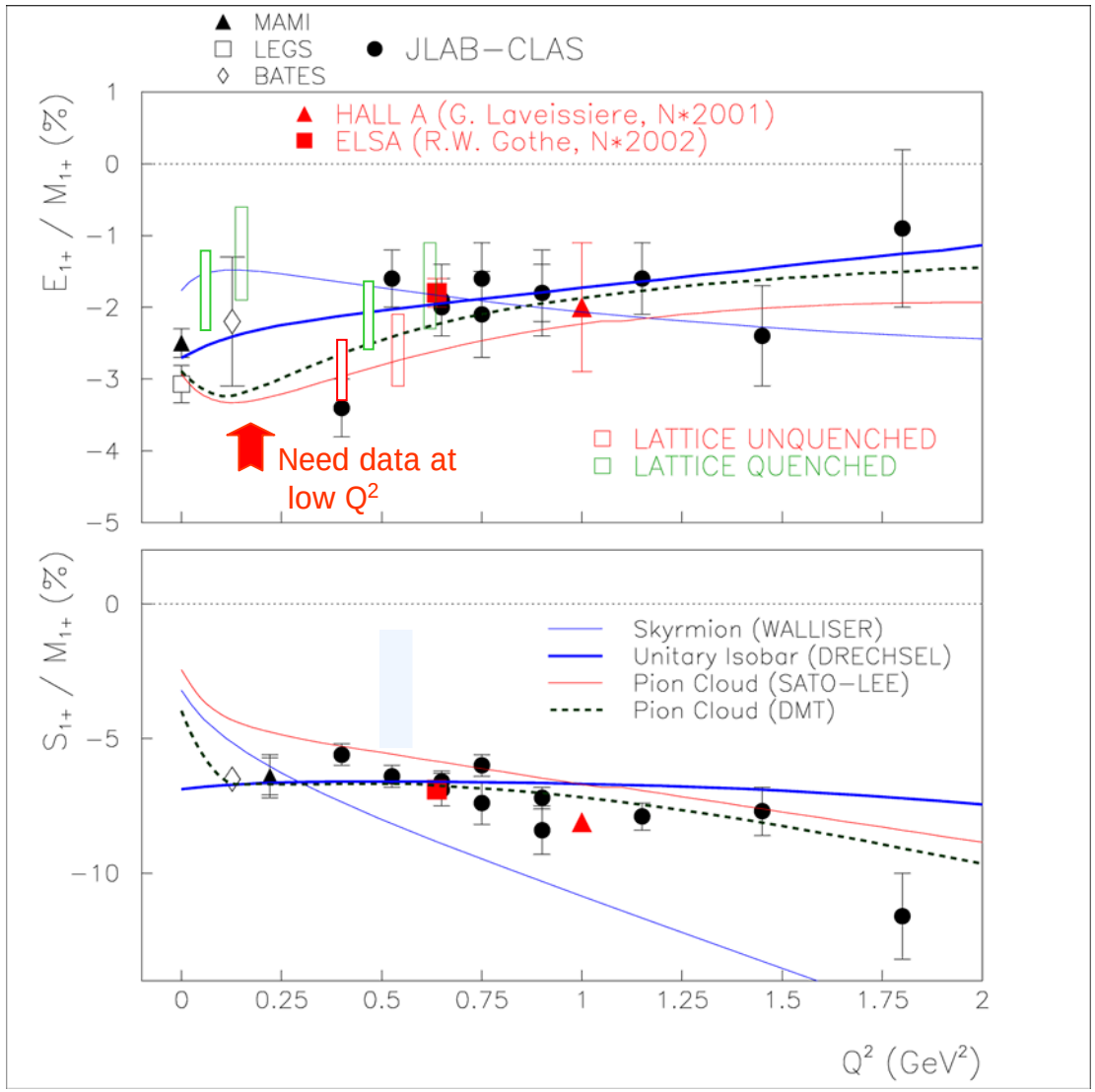
- No trend towards pQCD behavior is observed for Q^2 up to 4 GeV^2.

N→Δ(1232) Transition Form Factors



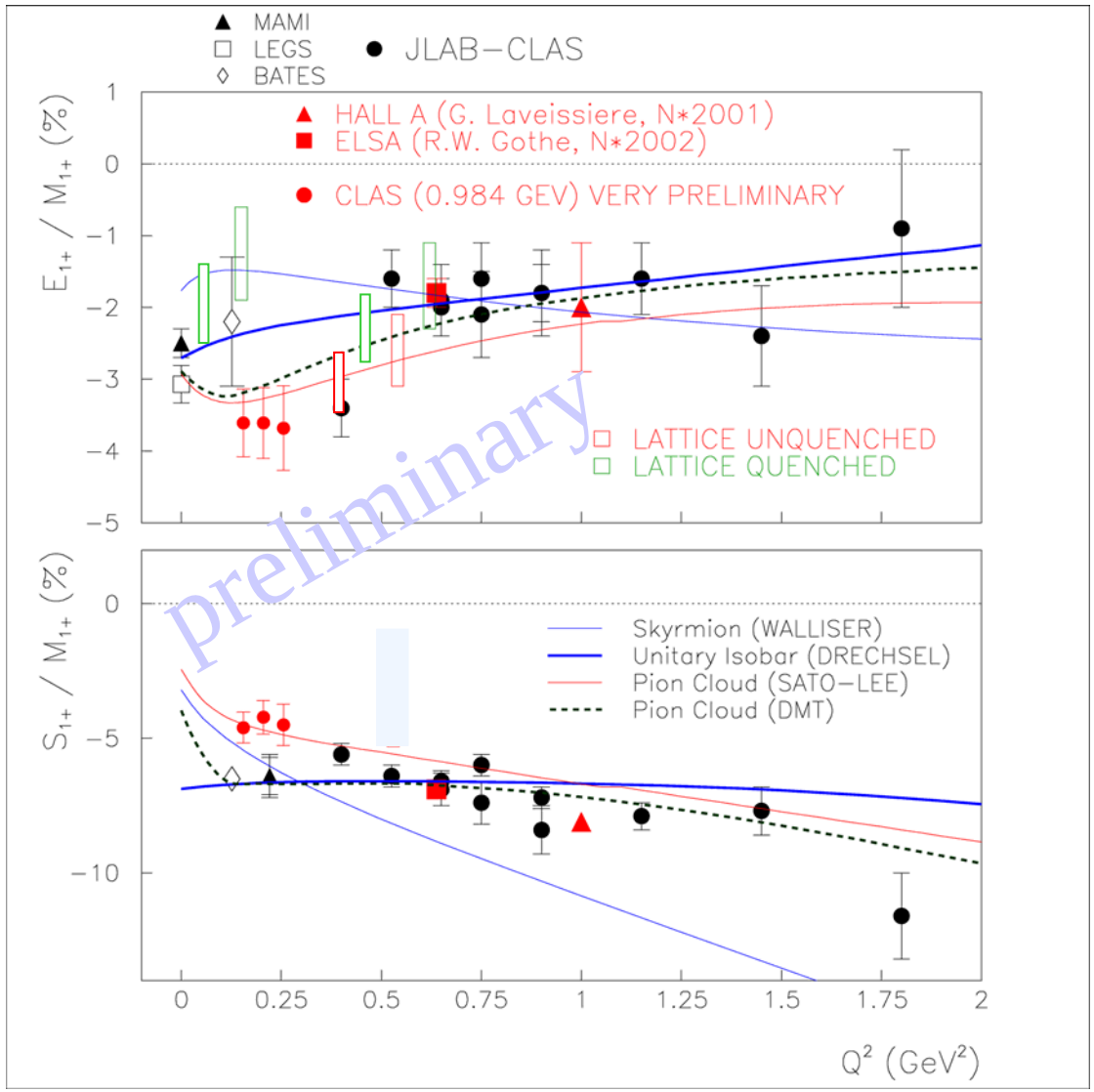
➢Preliminary results from ELSA and Hall A using different techniques confirm CLAS data.

N→Δ(1232) Transition Form Factors



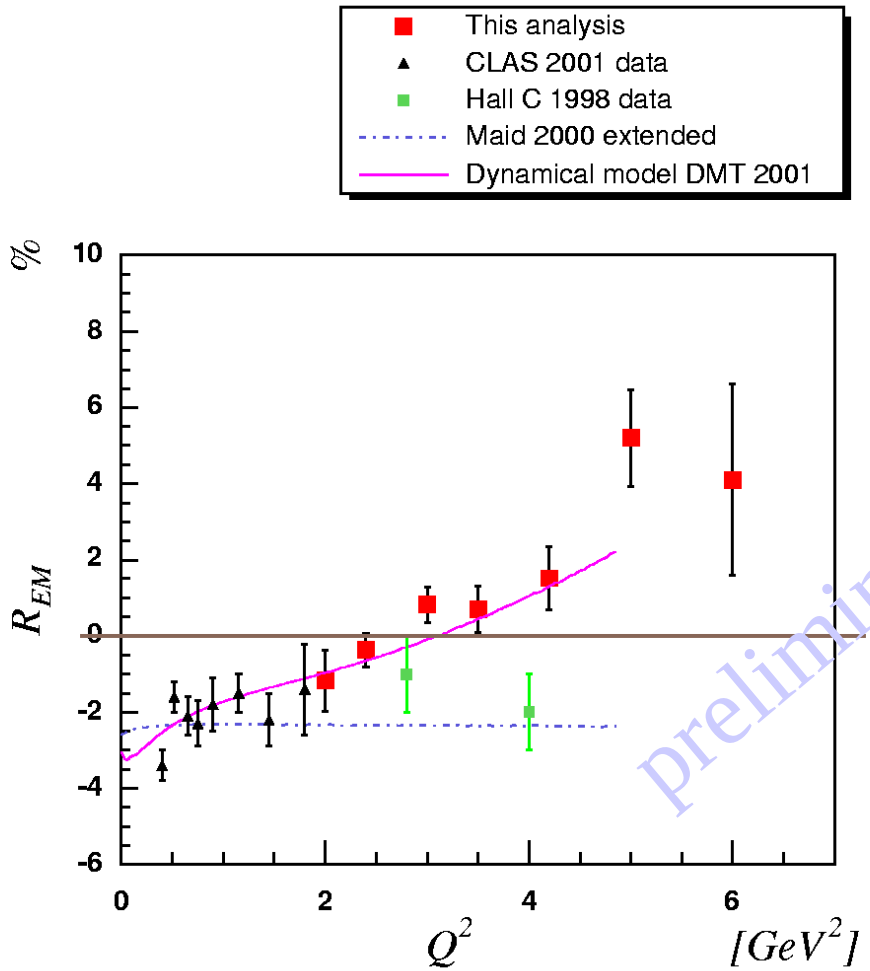
- Lattice QCD indicates that the pion cloud makes E_{1+}/M_{1+} more negative at small Q^2.
- Data at low Q^2 needed to study effects of the pion cloud.

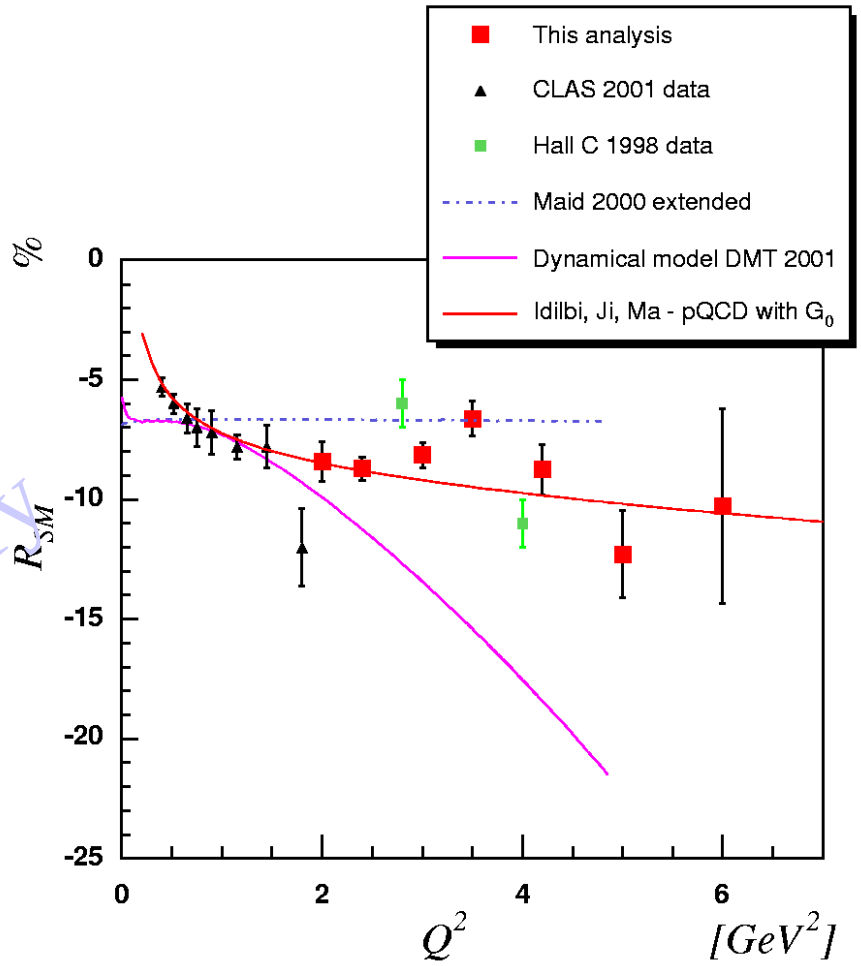
Preliminary Multipole Ratios R_{EM}, R_{SM}



- Dynamical models and full LQCD calculations indicate the importance of the pion cloud at low Q^2 consistent with the trend of data.
- Full LQCD results indicate a small oblate deformation of the $\Delta(1232)$.
- Data at high Q^2 needed to study the transition to pQCD.

Very Preliminary Multipole Ratios R_{EM} , R_{SM}





- New trend towards pQCD behavior may or may not show up.
- Experiment E-01-002 in Hall C will reach Q^2~8 GeV² and after the energy upgrade R_{EM} and R_{SM} can be measured up to Q^2~12 GeV².

N→Δ Transition and Background Terms

- systematic uncertainties in extraction of E_{1+}/M_{1+} from $ep \to e'p\,\pi^o$ around 0.5%
  - differences in treatment of background terms (models not constrained)
  - will become more severe for higher Q^2 (Δ dropping faster)

- more experimental information on hand (polarization and isospin)
  - single-spin asymmetry $\sigma_{TL'}$ for $\vec{e}\,p \to e'p\,(\pi^o)$ and $\vec{e}\,p \to e'\pi^+\,(n)$ — CLAS
  - polarization transfer in $\vec{e}\,p \to \vec{e}'p\,(\pi^o)$ — Hall A
  - differential cross sections for $e\,p \to e'\pi^+\,n$ (Δ less important) — CLAS

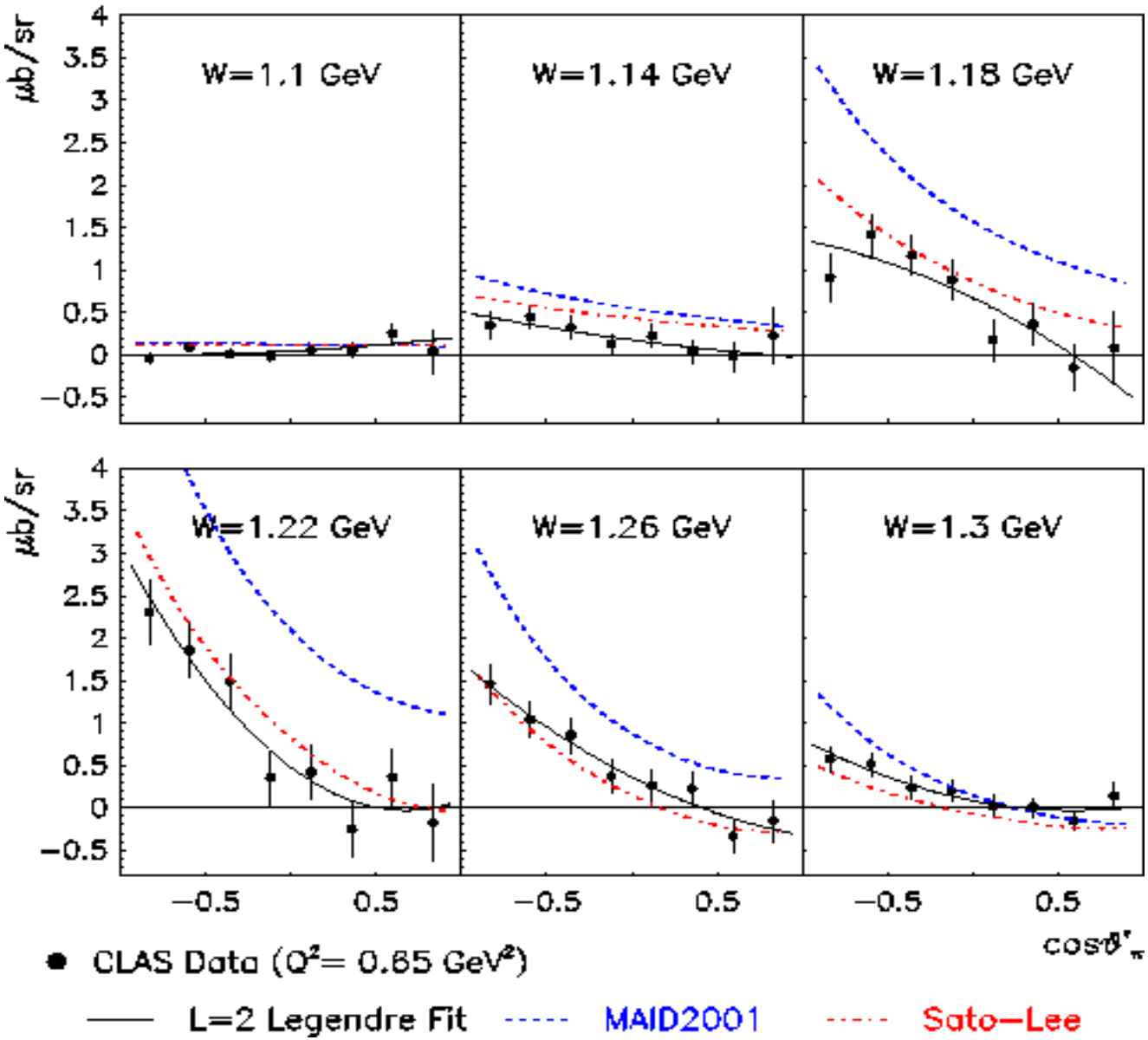
Polarized Beam Observables

CLAS

$\sigma_{LT'}$ response function for

$$\vec{e}\, p \rightarrow e\, p\, \pi^o$$

$\sigma_{LT'} = 0$ if only a single diagram contributes (sensitive to the interference between Δ and background)



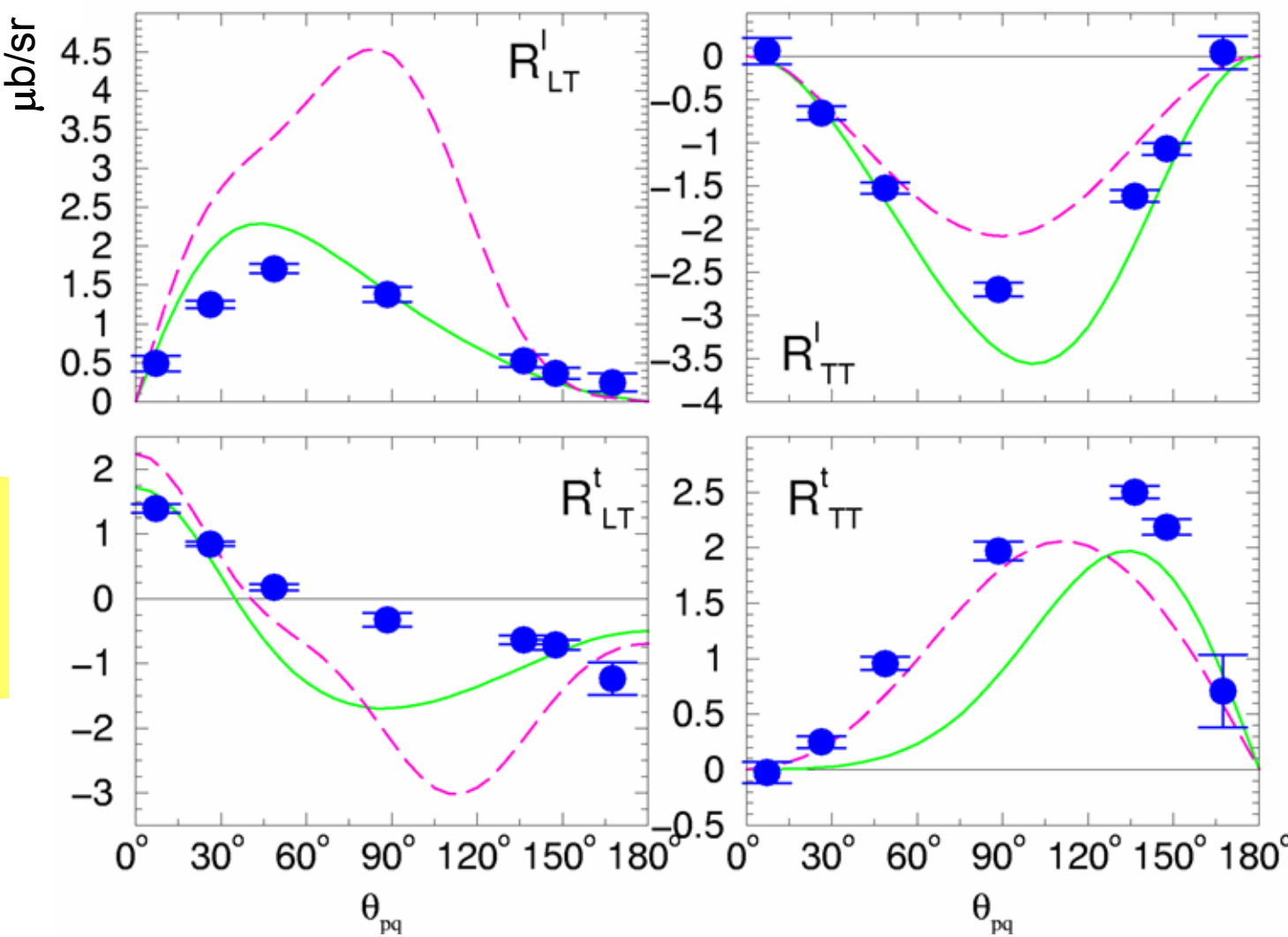
Polarization Measurement in $\vec{e}\,p \rightarrow e'\,\vec{p}\,(\pi^0)$

Hall A

$Q^2 = 1\ GeV^2$

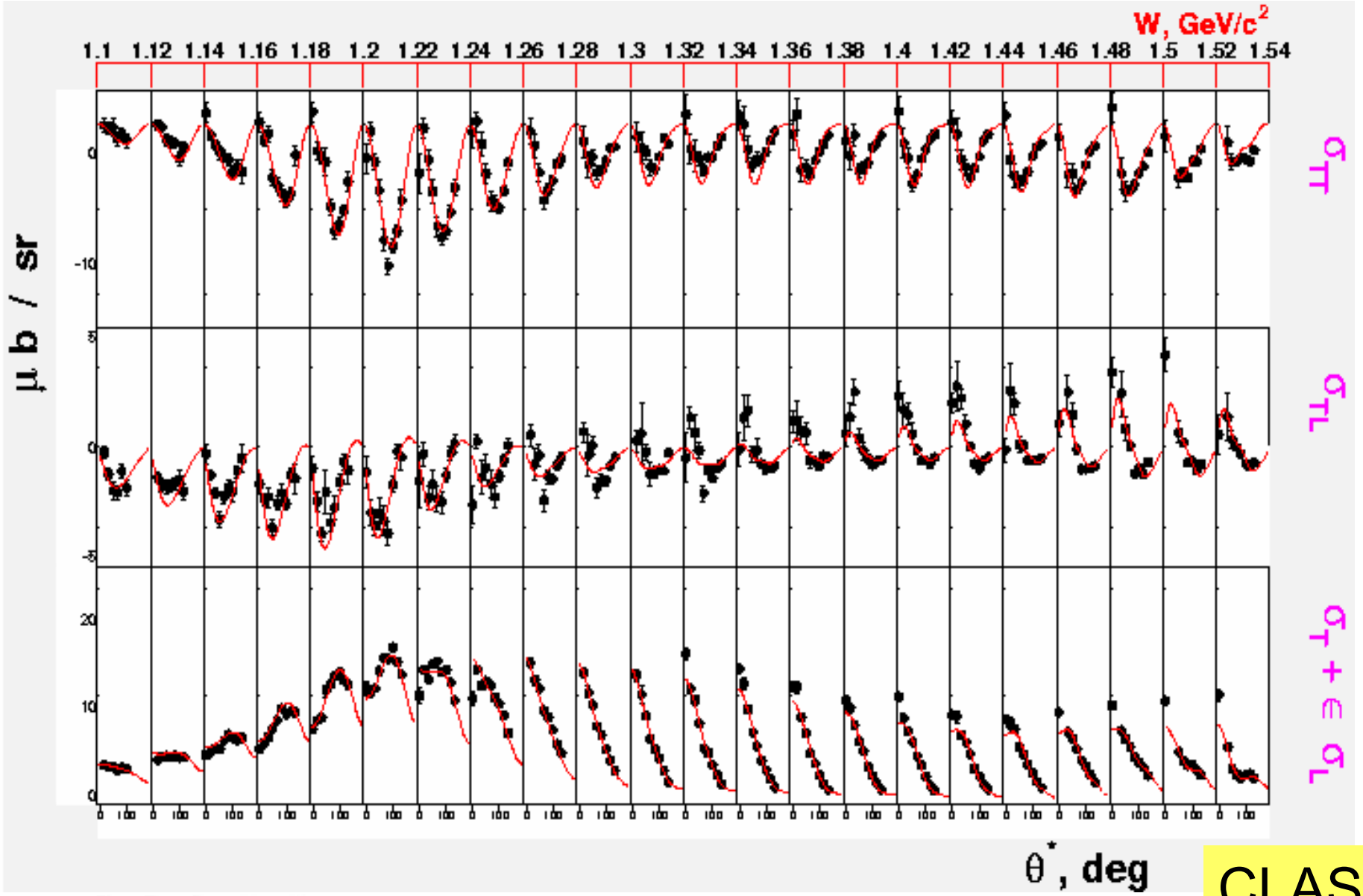
$W = 1.232\ GeV$

Results sensitive to non-resonant contributions



Parametrisations of available data

π^+ Electroproduction



CLAS

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- helicity amplitudes are sensitive to the difference in wave functions of N and N*
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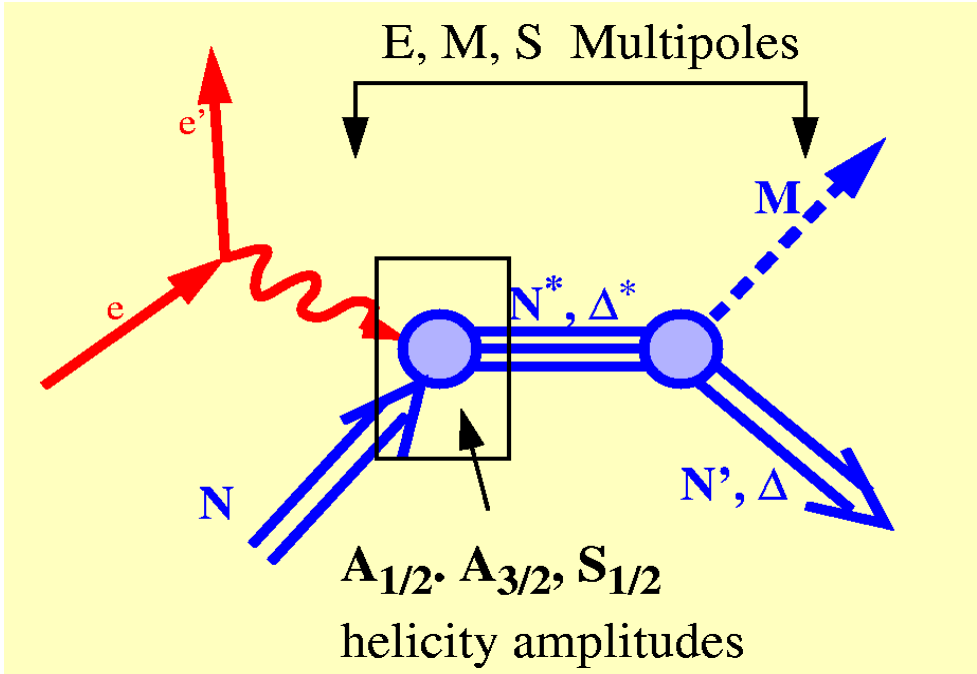
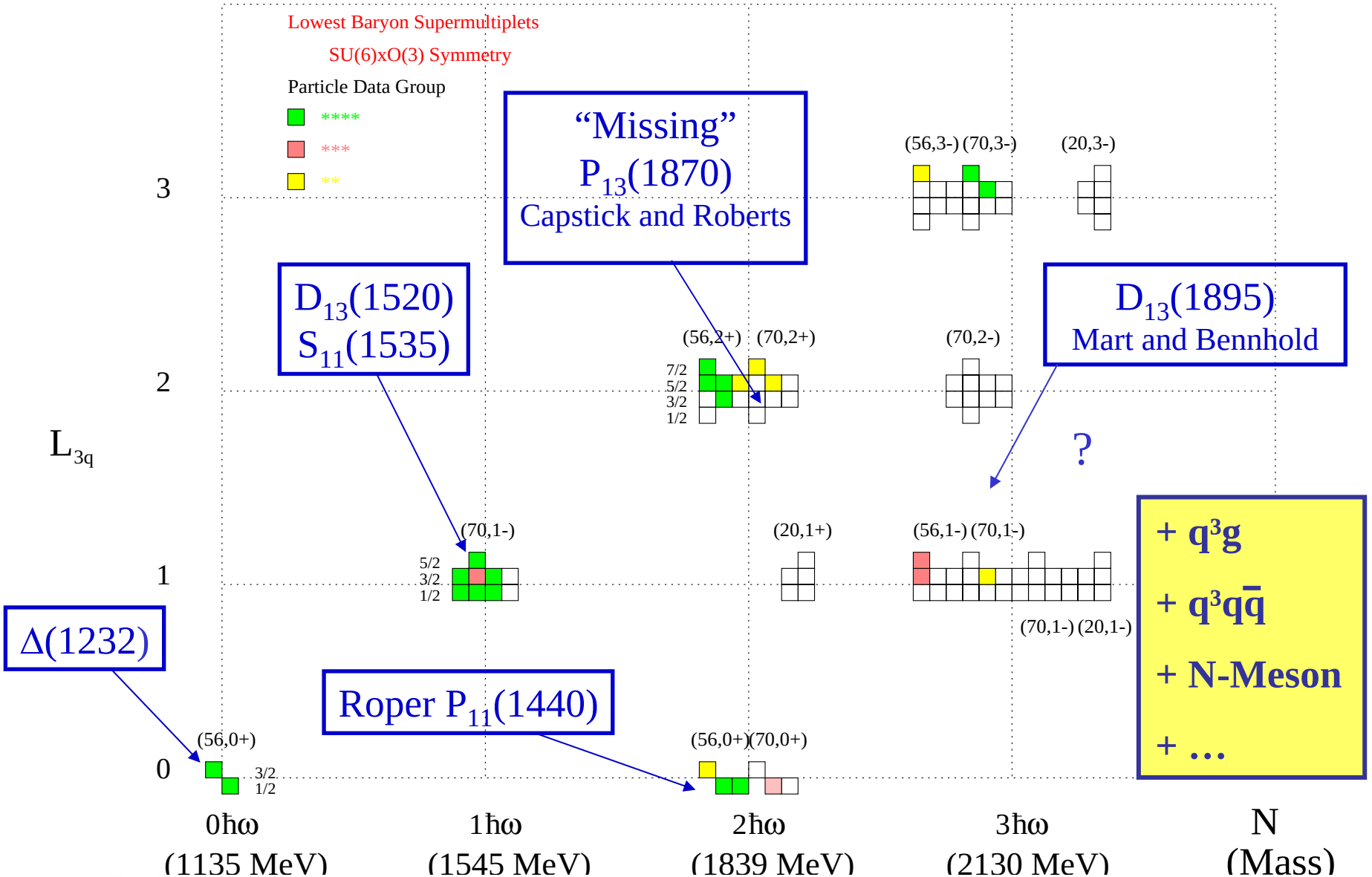
- varying Q^2 allows to change the spatial resolution and enhances different multipoles
- sensitive to missing resonance states



Quark Model Classification of N*



"Missing" Resonances?

Problem: symmetric CQM predicts many more states than observed (in πN scattering)

Possible solutions:

1. di-quark model — old but always young

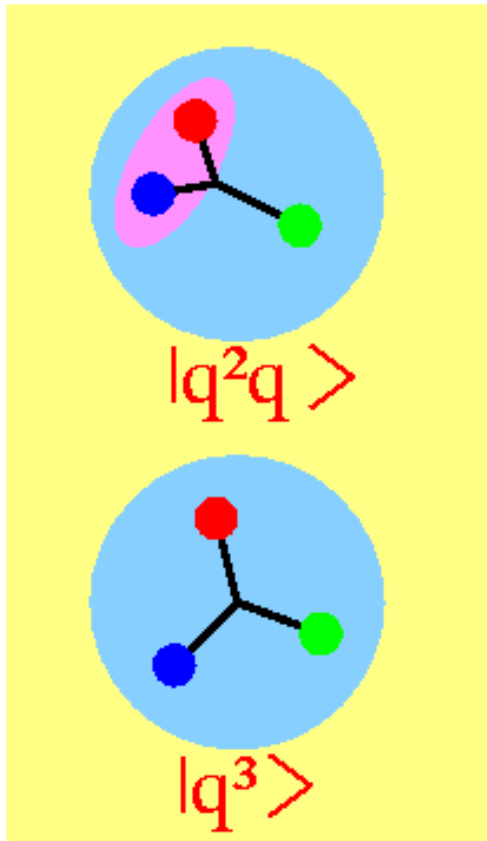
   fewer degrees-of-freedom
   open question: mechanism for q^2 formation?

2. not all states have been found

   possible reason: decouple from πN-channel
   model calculations: missing states couple to
   Nππ (Δπ, Nρ), Nω, KY

3. chiral symmetry approach — new

   all baryonic and mesonic excitations beyond the groundstate octets and decuplet are generated by coupled channel dynamics (not only Λ(1405), Λ(1520), $S_{11}(1535)$ or $f_0(980)$)



γ coupling not suppressed → electromagnetic excitation is ideal

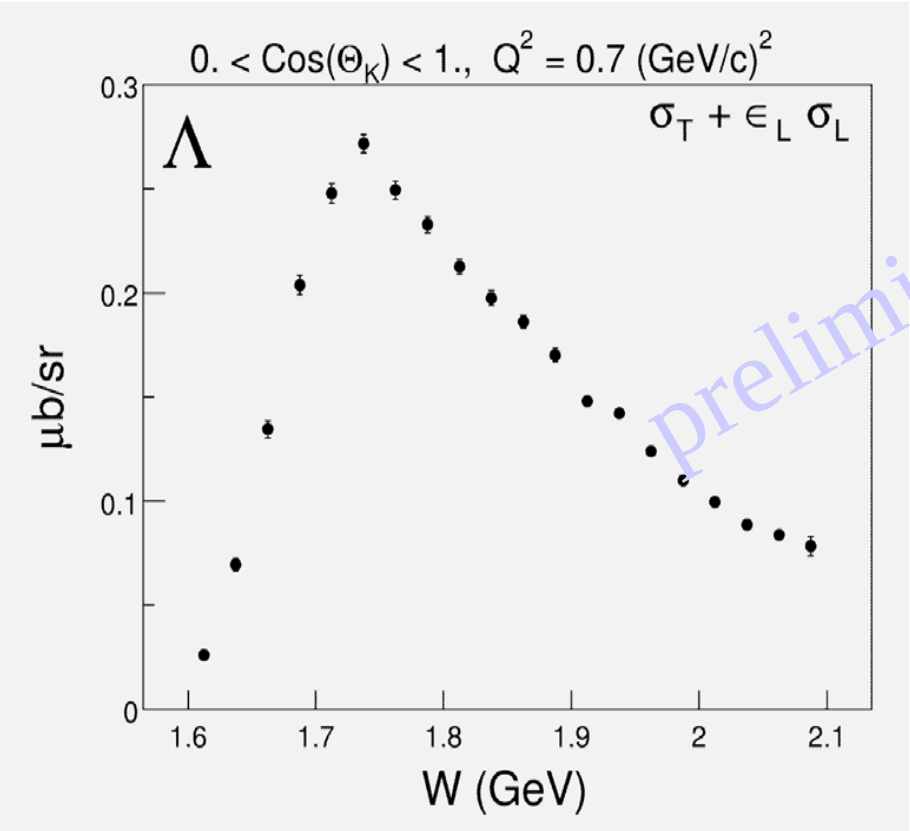
Resonances in Hyperon Production?

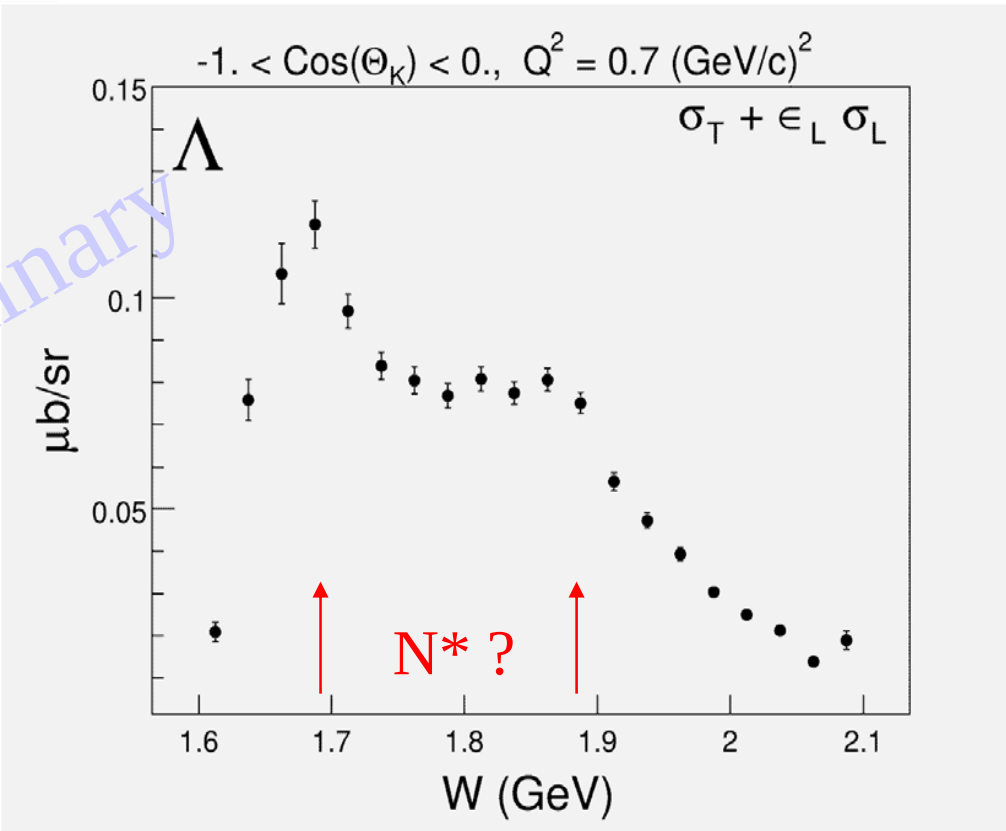
CLAS

$\gamma^* p \longrightarrow K^+ Y$

forward hemisphere

backward hemisphere





Λ Photoproduction off the Proton

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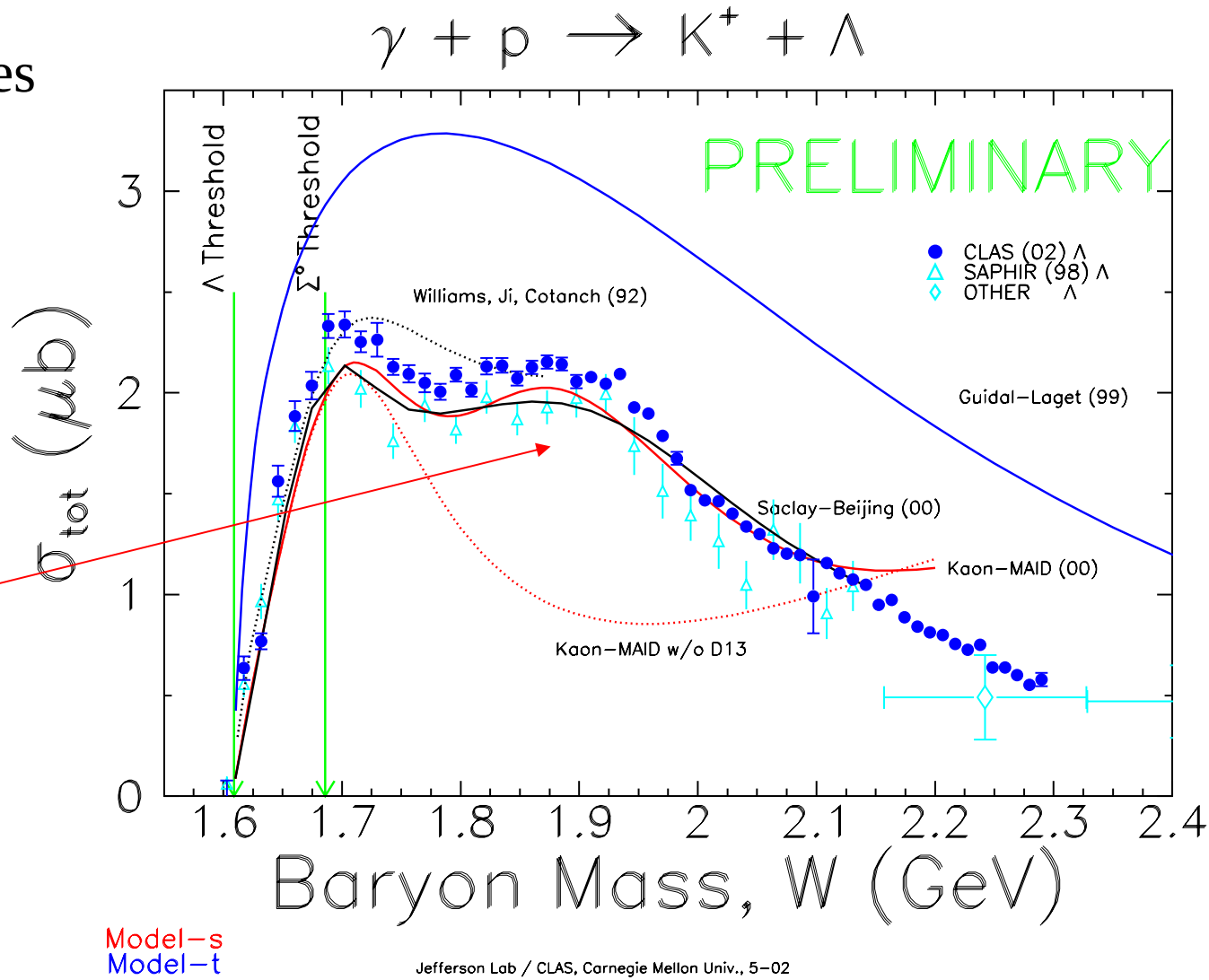
Dominant resonances

$S_{11}(1650)$
$P_{11}(1710)$
$P_{13}(1720)$

Bump at 1.9 GeV
$D_{13}(1895)$?



Carnegie Mellon

Resonances in $\gamma^* p \longrightarrow p\pi^+\pi^-$

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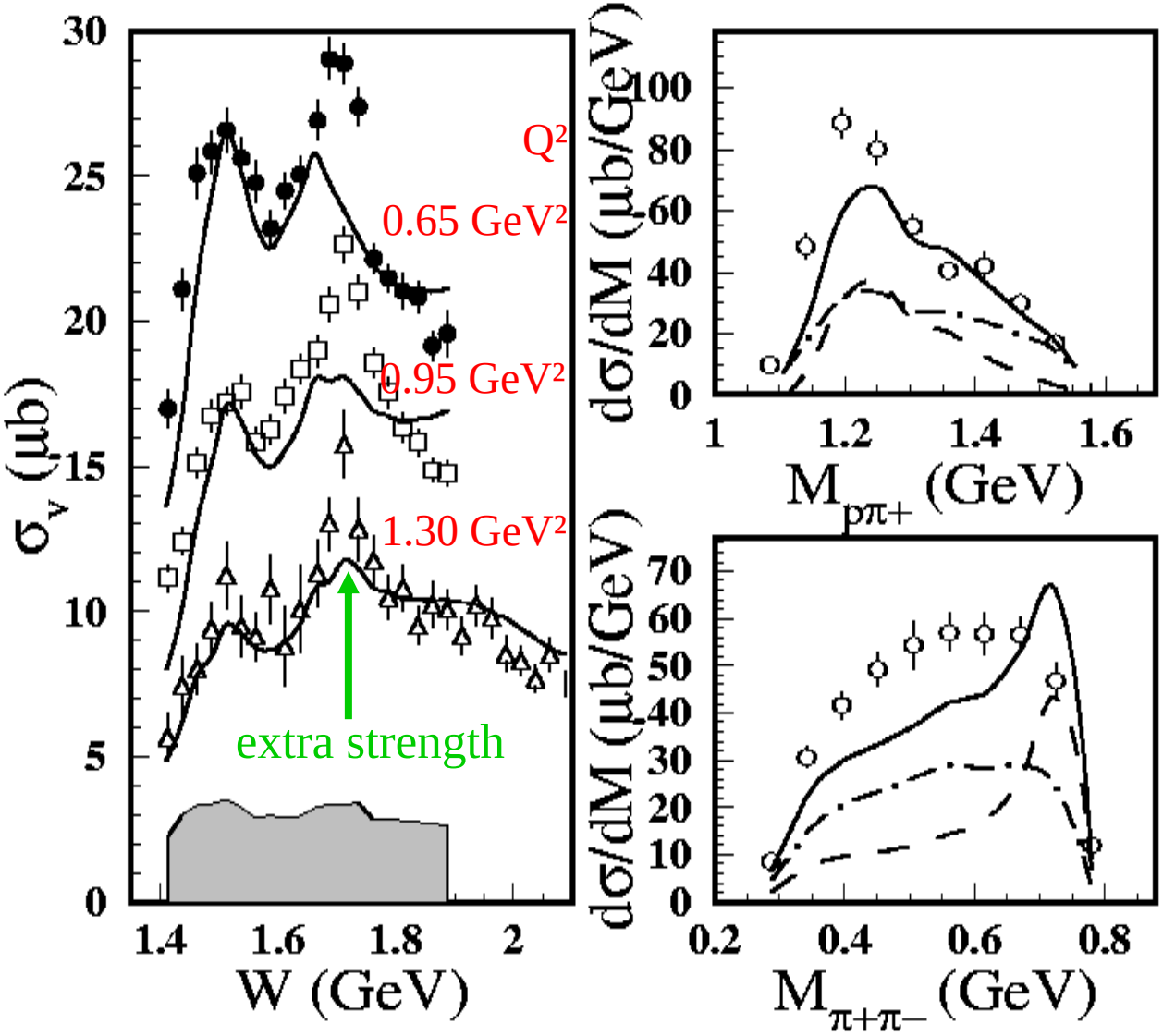
Analysis performed by Genova-Moscow collaboration

Step #1:

use the best information presently available

$\Gamma_{N\pi\pi}$: PDG

$\Gamma_{N\gamma}$: expt. Data or SQTM



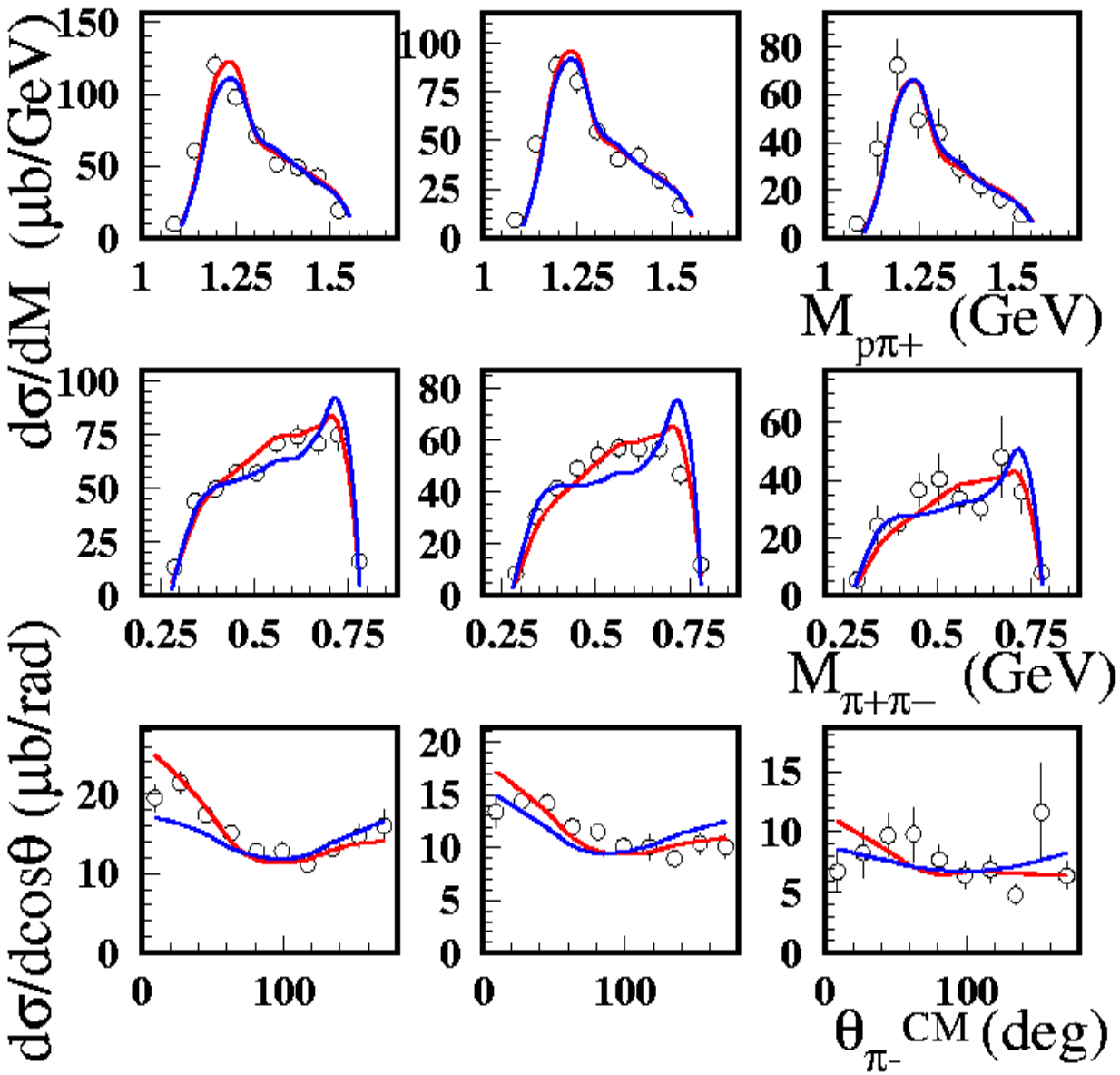
Attempts to fit observed extra strength

CLAS

Step #2:

- vary parameters of the photocouplings
- vary parameters of known P_{13}, P_{11}, D_{13}
- introduce new P_{13}

New $P_{13}(1720)$ consistent with predictied missing P_{13}, but at lower mass.



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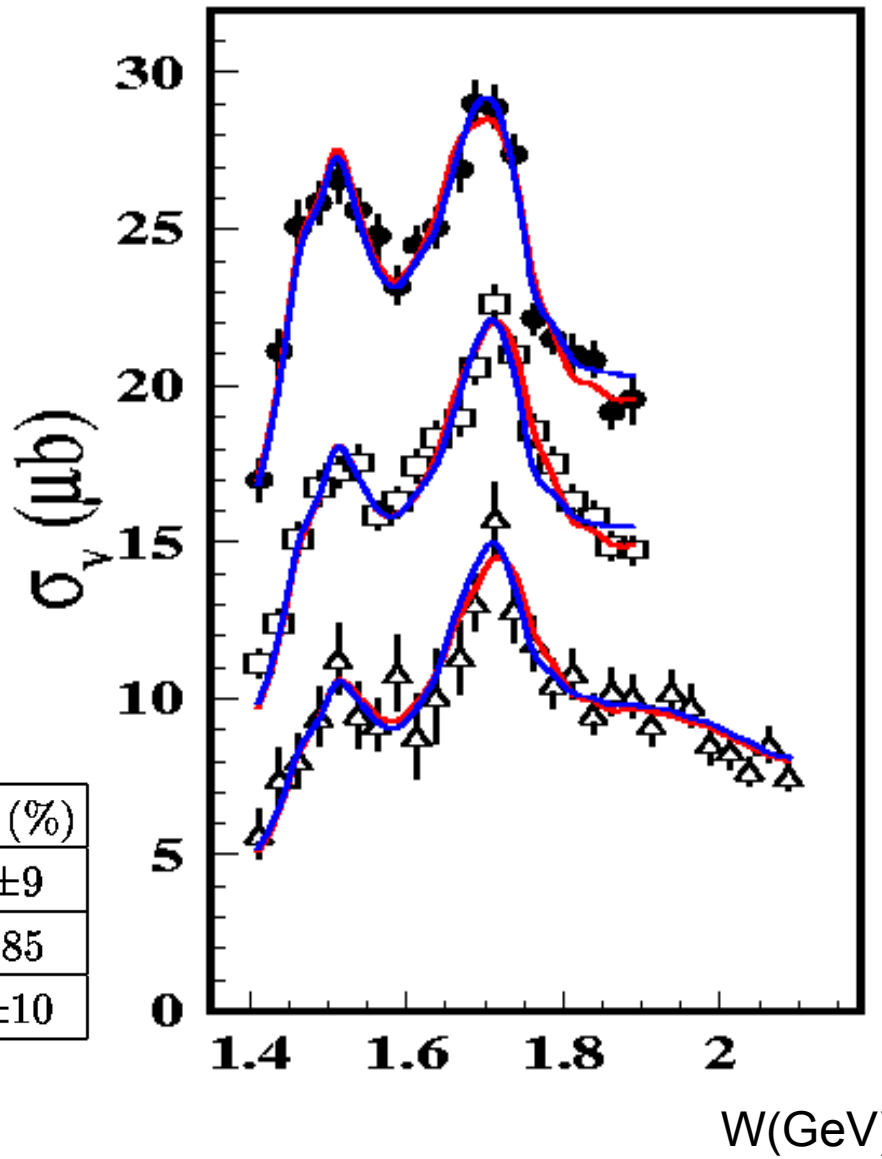
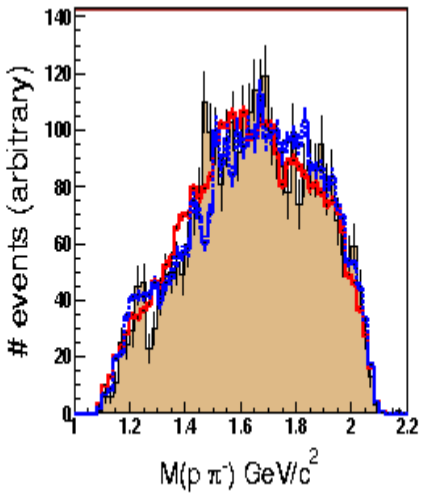


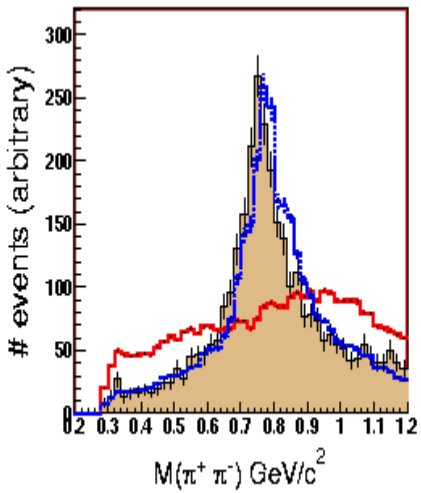
	M (MeV)	Γ (MeV)	$\frac{\Gamma_{\pi\Delta}}{\Gamma}$ (%)	$\frac{\Gamma_{\rho N}}{\Gamma}$ (%)
PDG P_{13} (B)	1725±20	114±19	63±12	19±9
PDG [1]	1650-1750	100-200	N/A	70-85
new P_{13} (C)	1720±20	88±17	41±13	17±10

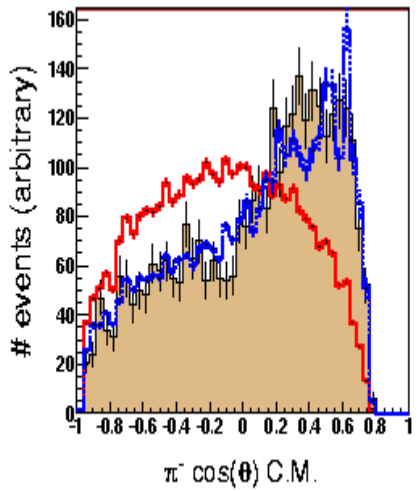
PWA in $\gamma p \longrightarrow p\pi^+\pi^-$

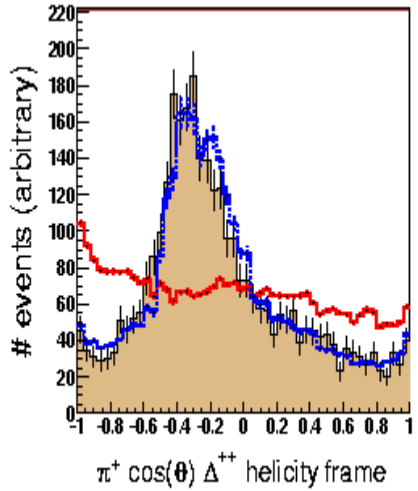
CLAS

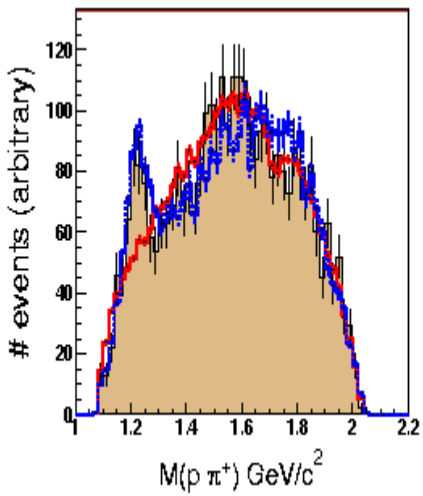
W=2240 MeV

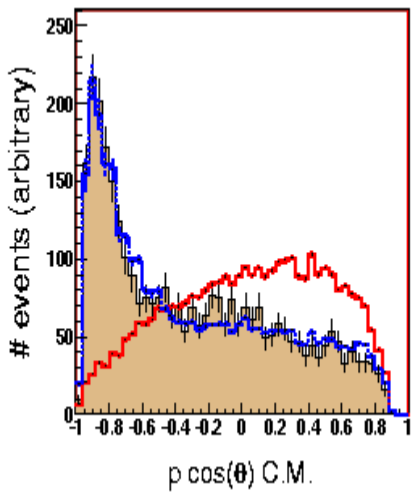


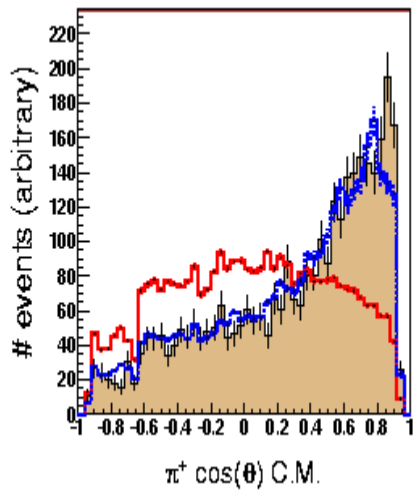


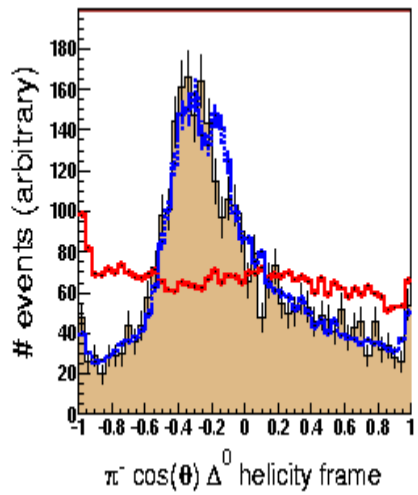






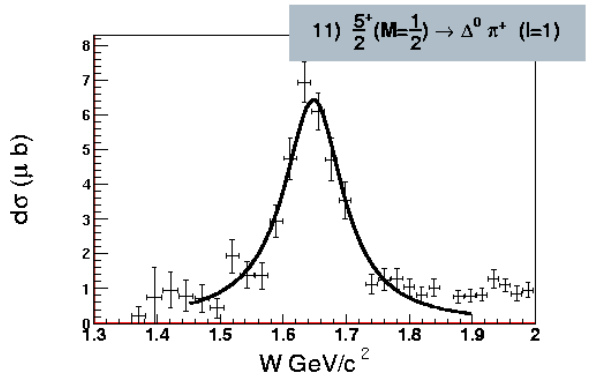


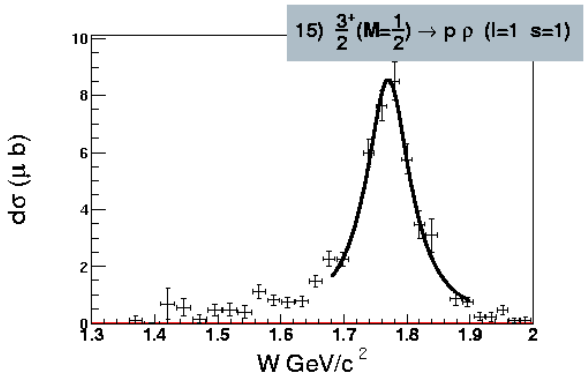


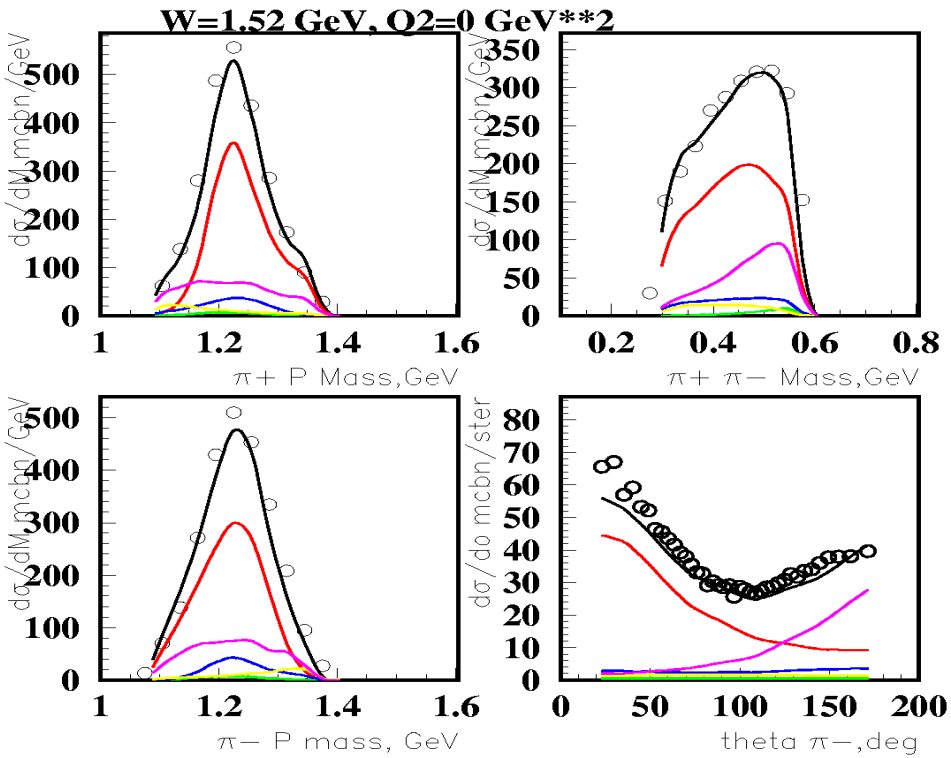


Resonances in $\gamma p \longrightarrow p\pi^+\pi^-$

CLAS





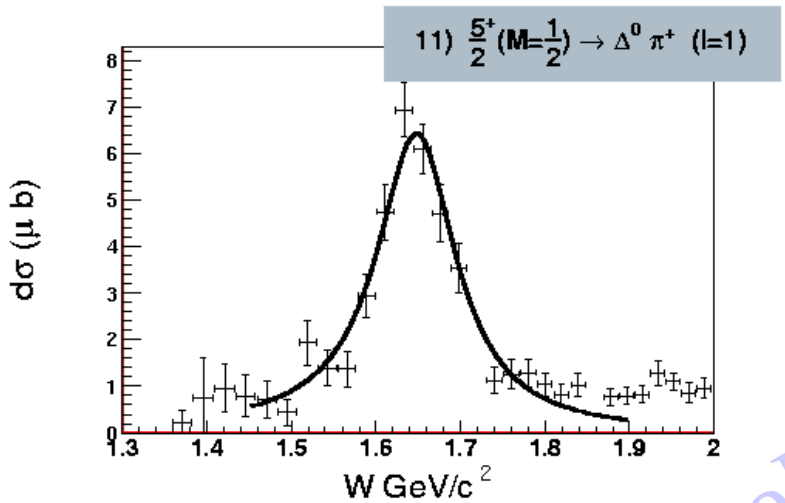


J^P	M	Isobars	# of waves
$\frac{1}{2}^+$	$\frac{1}{2}$	$\Delta\pi$	2
$\frac{1}{2}^-$	$\frac{1}{2}$	$\Delta\pi$	2
	$\frac{1}{2}$	$(p\rho)_{(s=1/2;\ell=0)}$	1
$\frac{3}{2}^+$	$\frac{1}{2}, \frac{3}{2}$	$(\Delta\pi)_{(\ell=1)}$	4
	$\frac{1}{2}, \frac{3}{2}$	$(p\rho)_{(s=1/2;\ell=1)}$	2
$\frac{3}{2}^-$	$\frac{1}{2}, \frac{3}{2}$	$(\Delta\pi)_{(\ell=0,2)}$	8
	$\frac{1}{2}, \frac{3}{2}$	$(p\rho)_{(s=3/2;\ell=0,2)}$	4
$\frac{5}{2}^+$	$\frac{1}{2}, \frac{3}{2}$	$(\Delta\pi)_{(\ell=1)}$	4
	$\frac{1}{2}, \frac{3}{2}$	$p\sigma$	2
$\frac{5}{2}^-$	$\frac{1}{2}, \frac{3}{2}$	$(\Delta\pi)_{(\ell=2)}$	4
t-channel ρ	$\frac{1}{2}, \frac{3}{2}$	$\lambda_\rho = \frac{1}{2}, \frac{1}{2}$	4
Total # of waves			**37**

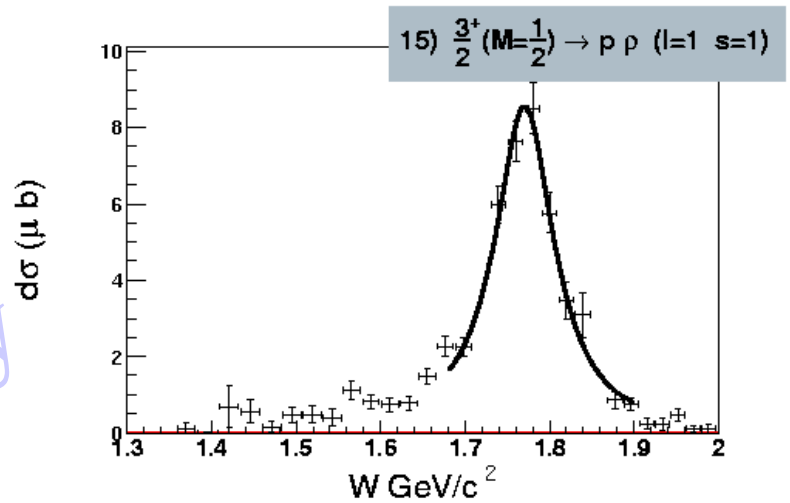
Resonances in $\gamma p \longrightarrow p\pi^+\pi^-$

CLAS

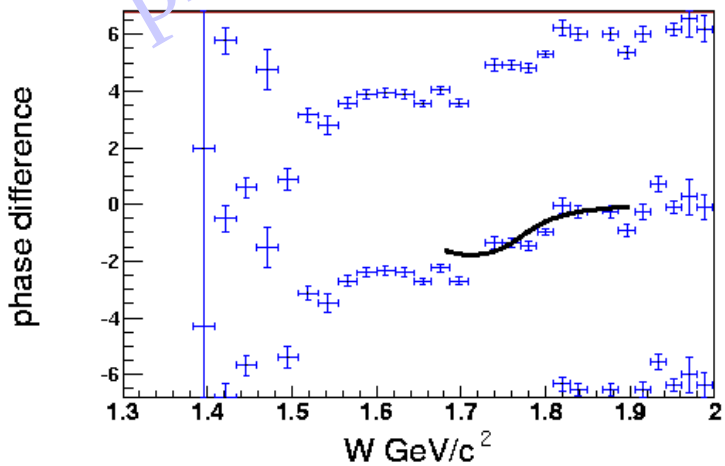
$F_{15}(1680)$



$P_{13}(1720)$

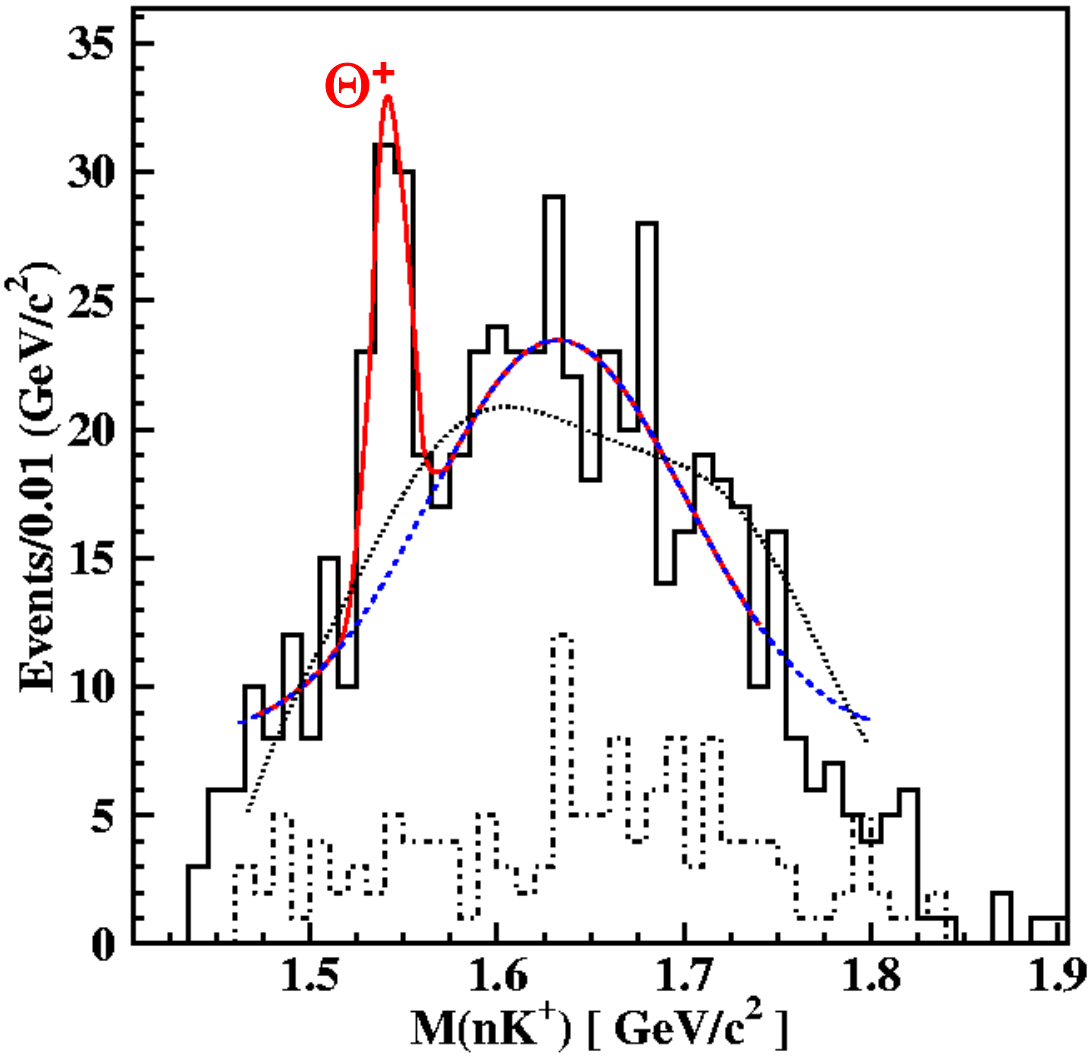


preliminary

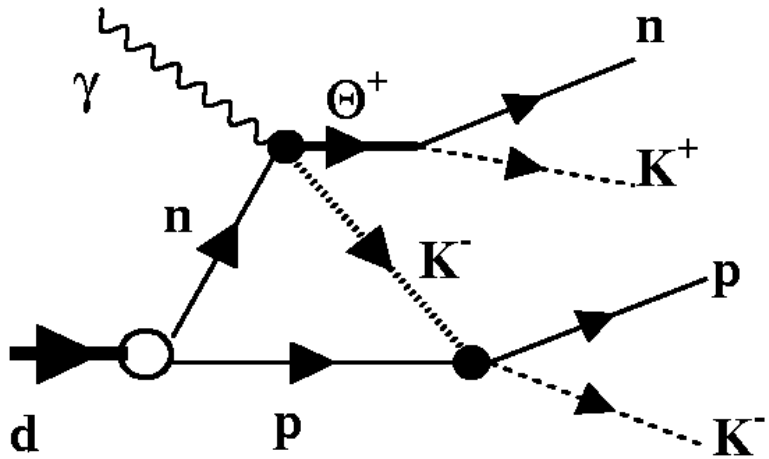


JLab: Θ⁺ – Exclusive Process I

CLAS



$\gamma d \rightarrow K^- K^+ p(n)$

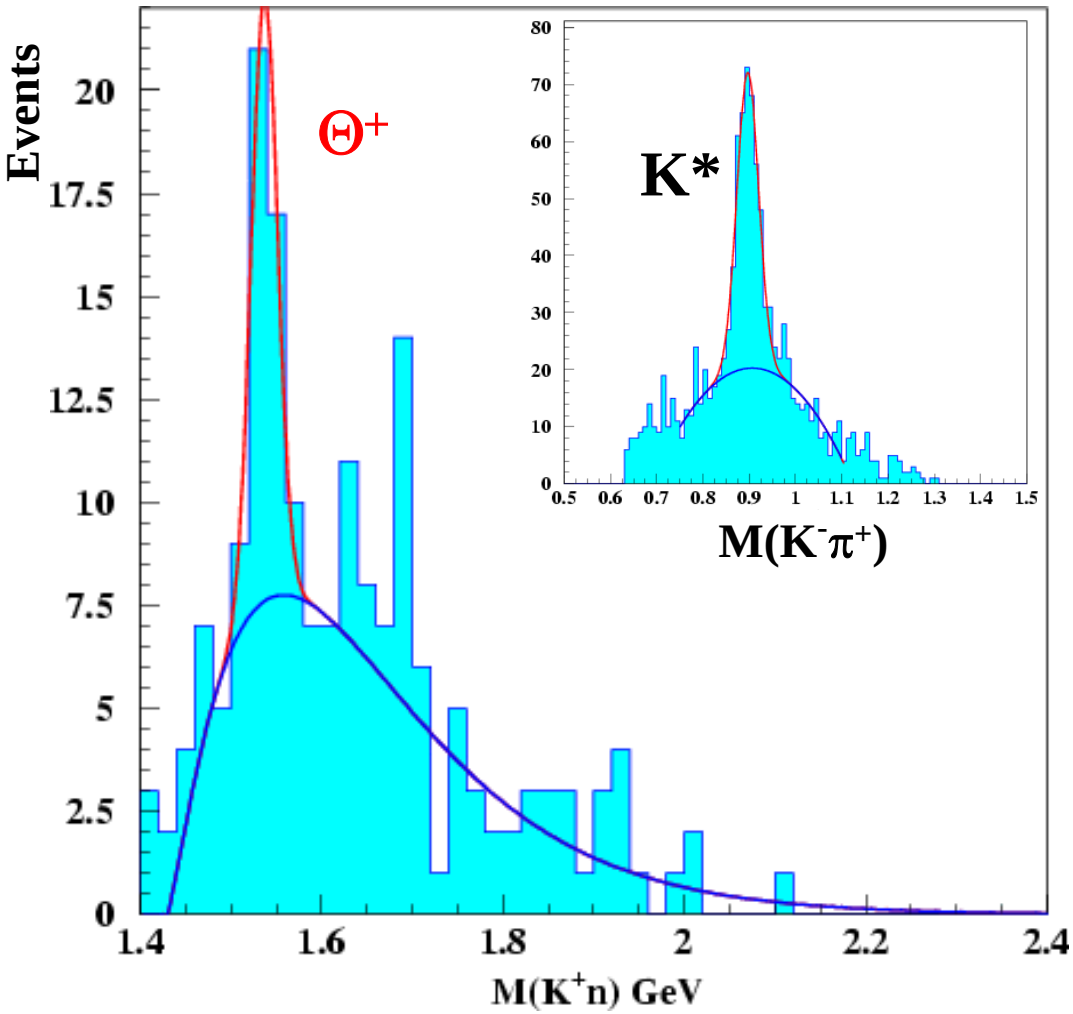


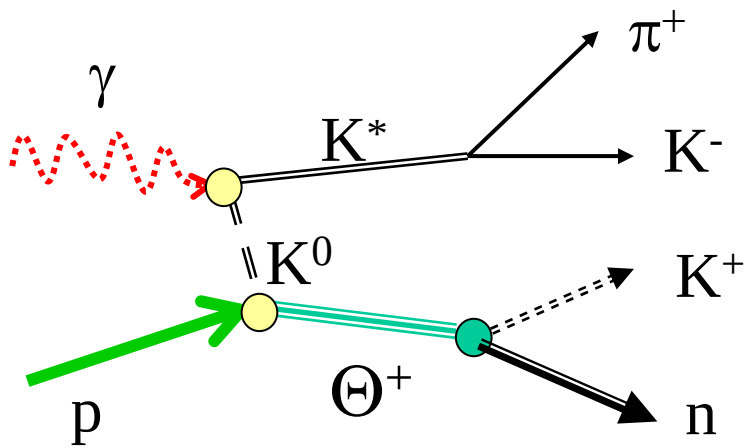
Mass 1.542±0.005 GeV/c²
Γ< 21 MeV/c²
Significance 5.2±0.6 σ

JLab: Θ⁺ – Exclusive Process II

CLAS

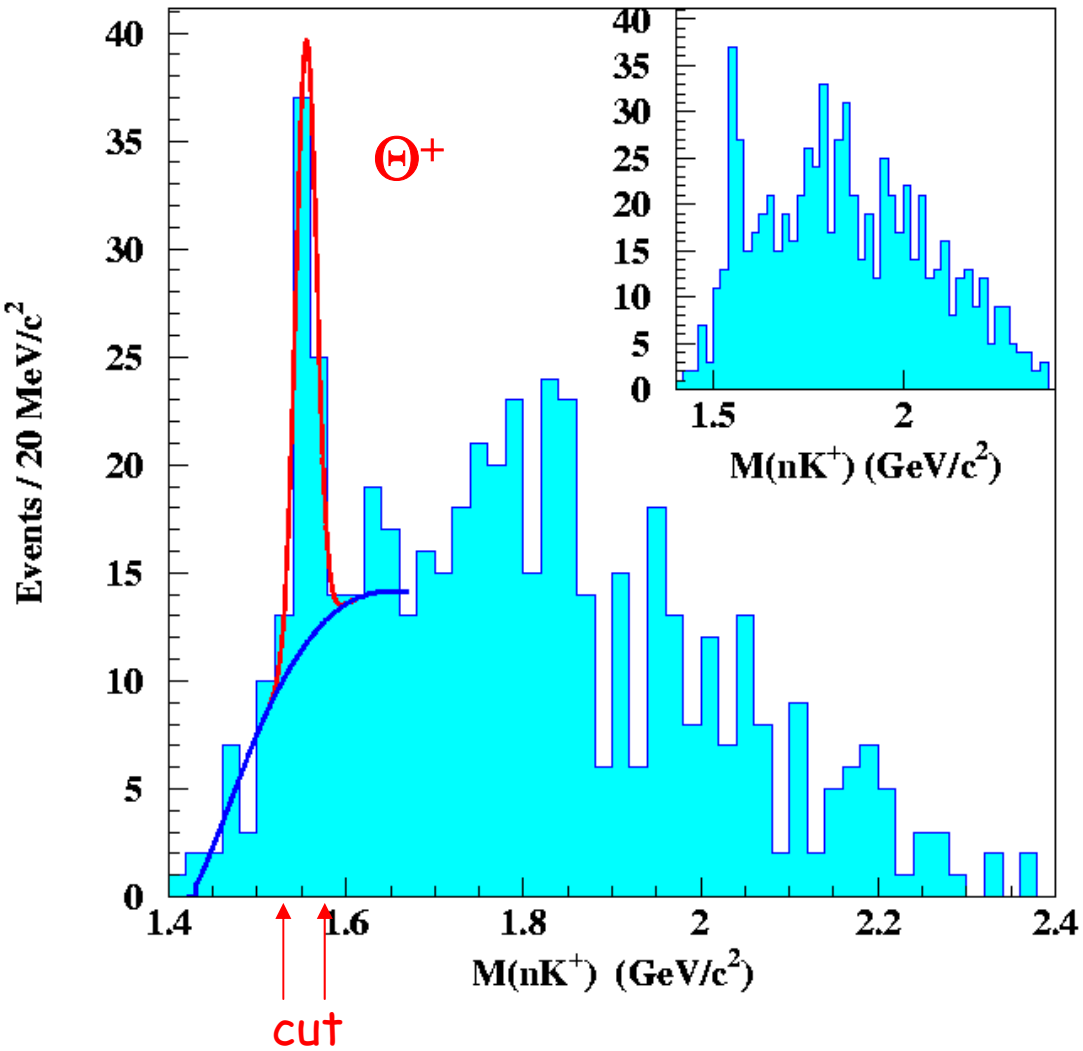
$\gamma p \rightarrow \pi^+ K^- K^+ (n)$



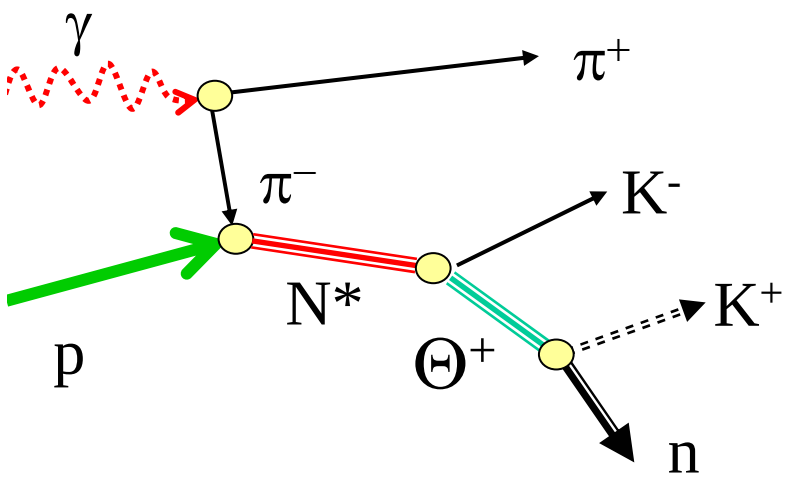


JLab: Θ⁺ – Exclusive Process III

CLAS



$\gamma p \rightarrow \pi^+ K^- K^+ (n)$



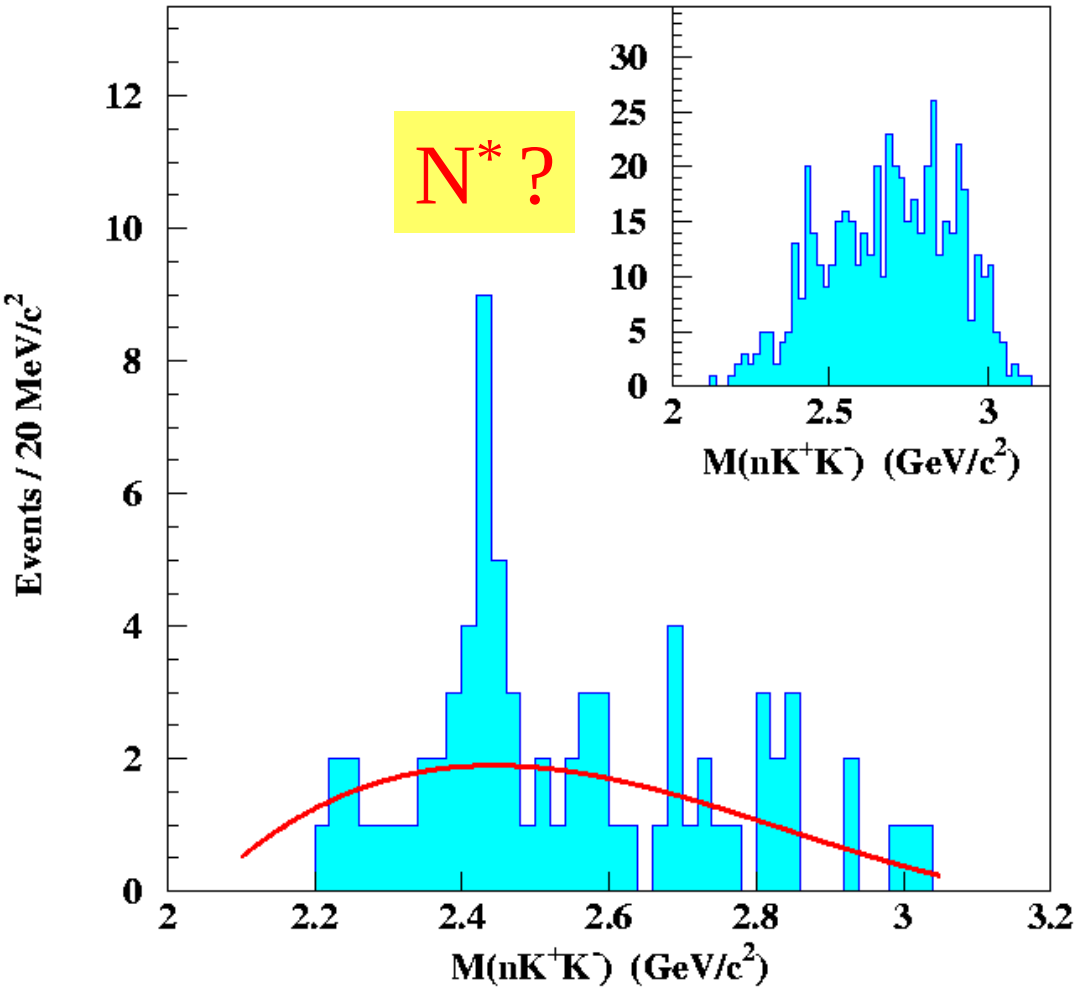
combined analysis II & III

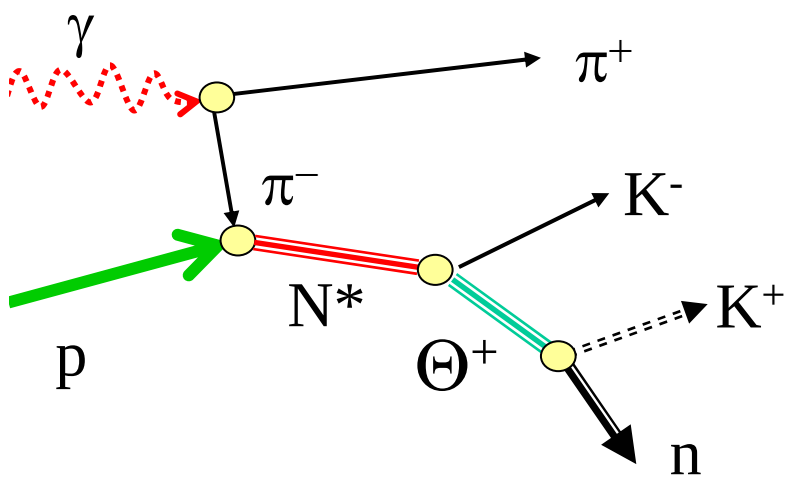
Mass 1.555±0.010 GeV/c²
Γ< 26 MeV/c²
Significance 7.8±1.0 σ

JLab: Θ⁺ – Exclusive Process III

CLAS

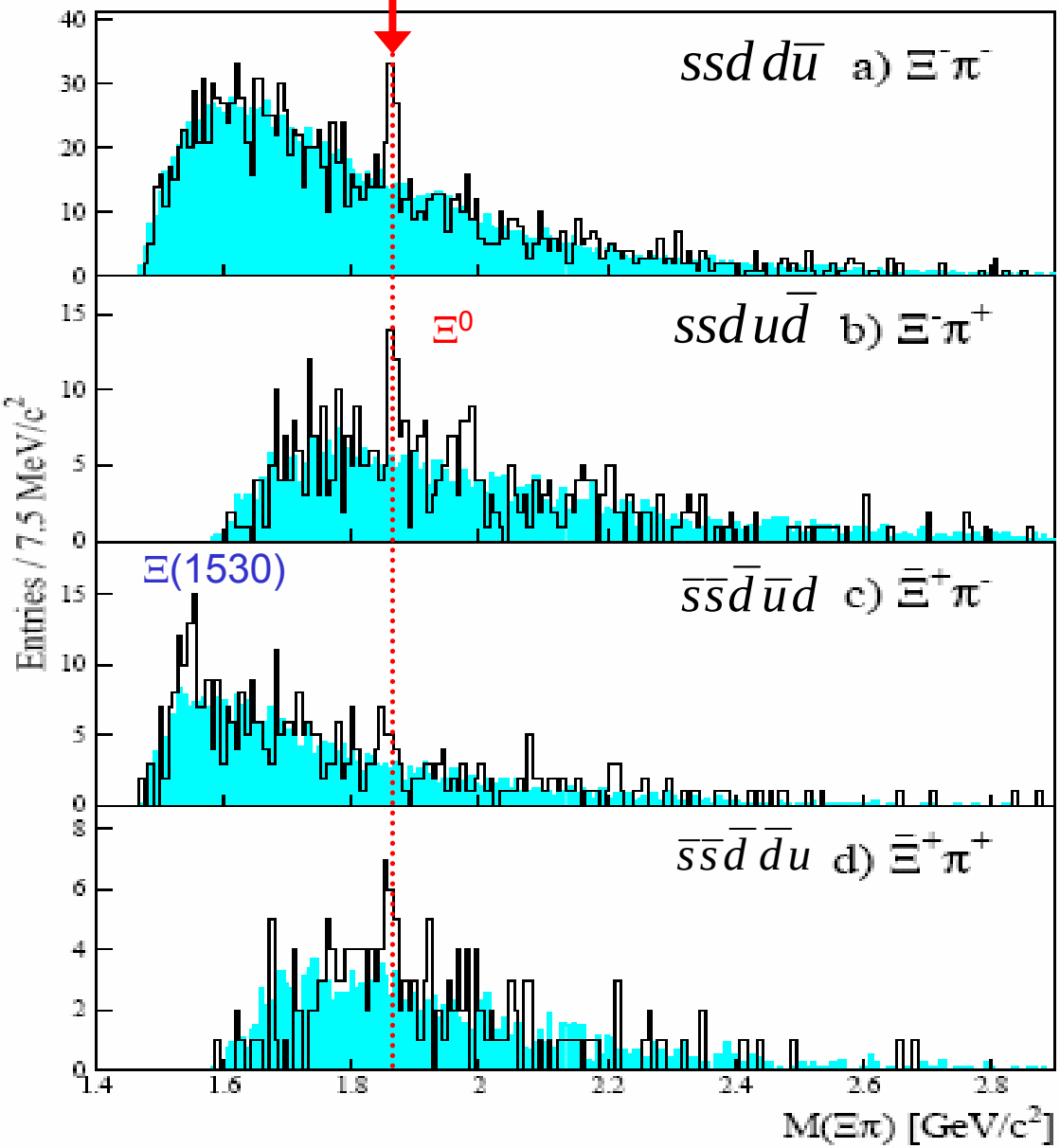
$\gamma p \rightarrow \pi^+ K^- K^+ (n)$



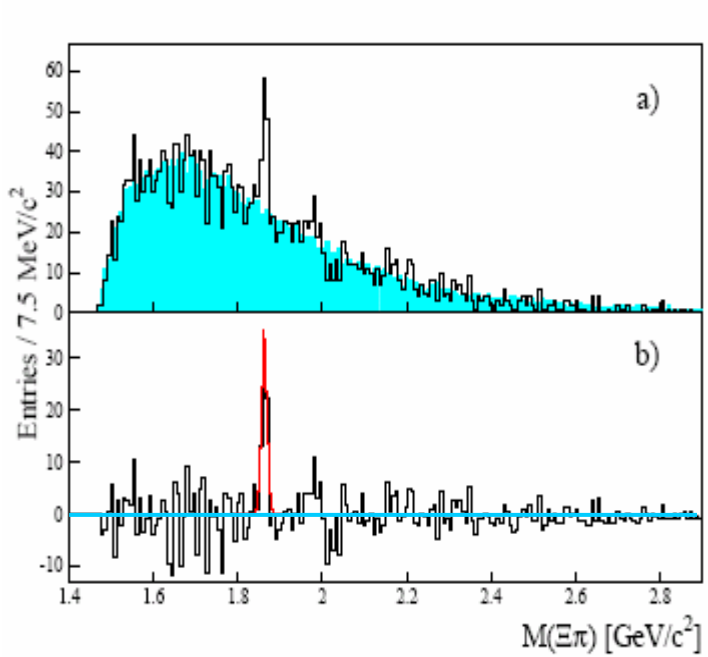


Mass ~ 2.440 GeV/c²

Outlook: Observation of Exotic Ξ^{--}



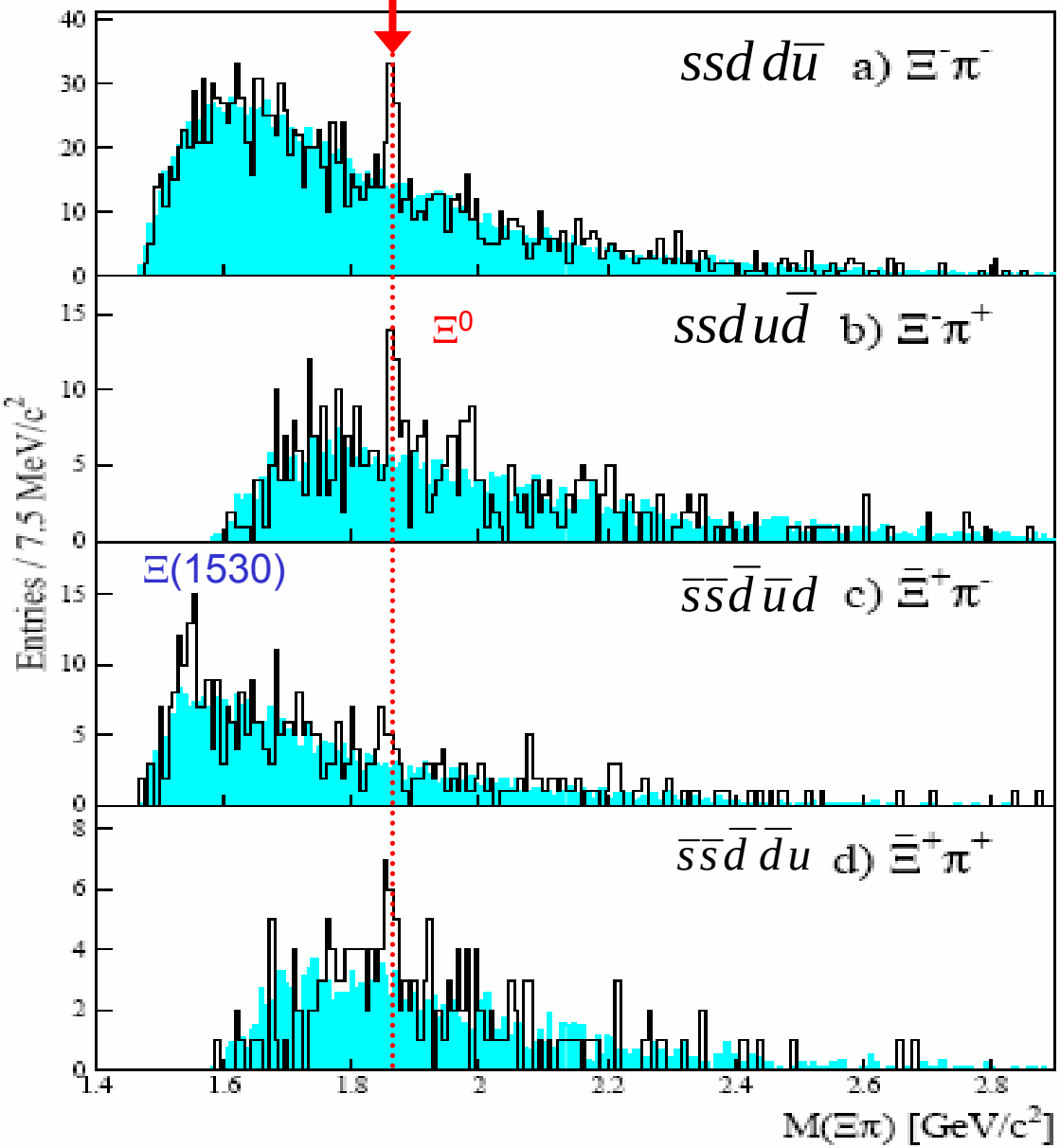
combined analyis NA49



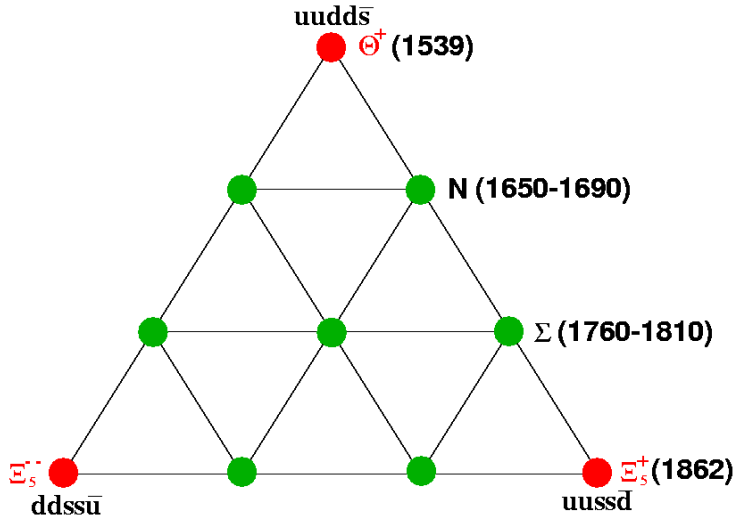
M=1.862± 0.002 GeV/c²
Γ< 18 MeV/c²

CERN SPS hep-ex/0310014

Outlook: Observation of Exotic Ξ^{--}



Diakonov et al. **Hep-ph/9703373**
Diakonov, Petrov **hep-ph/0310212**
Jaffee, Wilczek **hep-ph/0307341**
Jaffee, Wilczek **hep-ph/0312369**
R.A. Arndt et al. **nucl-th/0312126**



PAC 25 at JLab

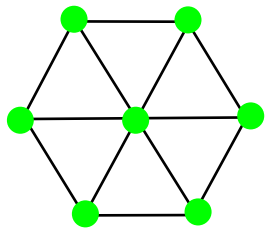
M=1.862± 0.002 GeV/c²

CERN SPS hep-ex/0310014

Hadron multiplets

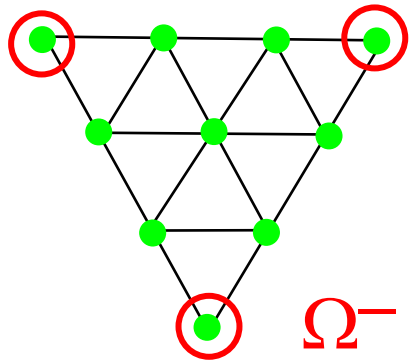
Mesons $q\bar{q}$

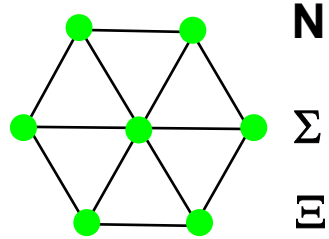
$$3 \otimes \bar{3} = 8 \oplus 1$$



Baryons qqq

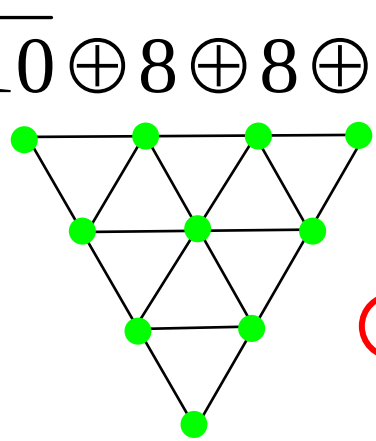
$$3 \otimes 3 \otimes 3 = 10 \oplus 8 \oplus 8 \oplus 1$$

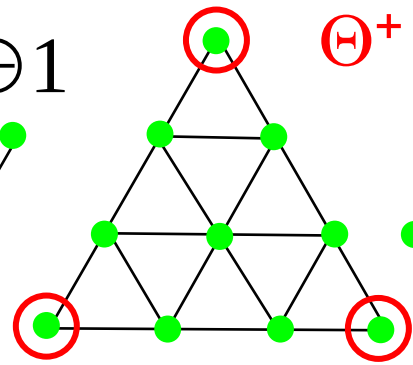


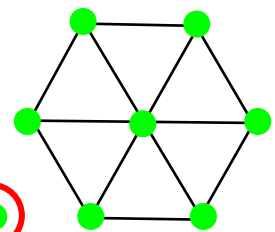


Baryons built from meson-baryon, or $qqqq\bar{q}$

$$8 \otimes 8 = 27 \oplus 10 \oplus \overline{10} \oplus 8 \oplus 8 \oplus 1$$

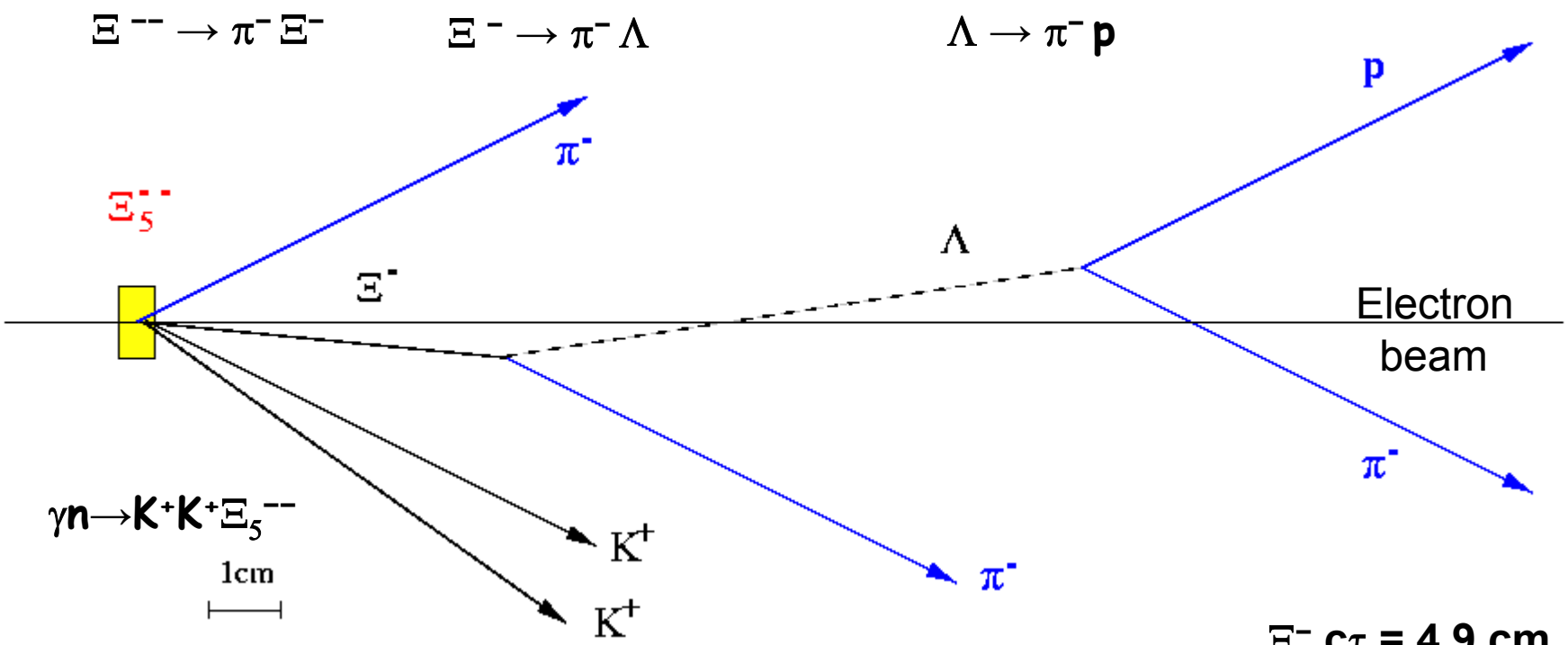






. . .

New Tools: Exploit Weak Decays in Direct Reconstruction



Ξ^- $c\tau$ = 4.9 cm

Λ $c\tau$ = 7.9 cm

Negatives bend outwards

$\langle\gamma\beta\rangle$ ~ 1.5

New Tools: Frozen Spin Target for CLAS

Technical problem:

build polarized target for tagged photon beam

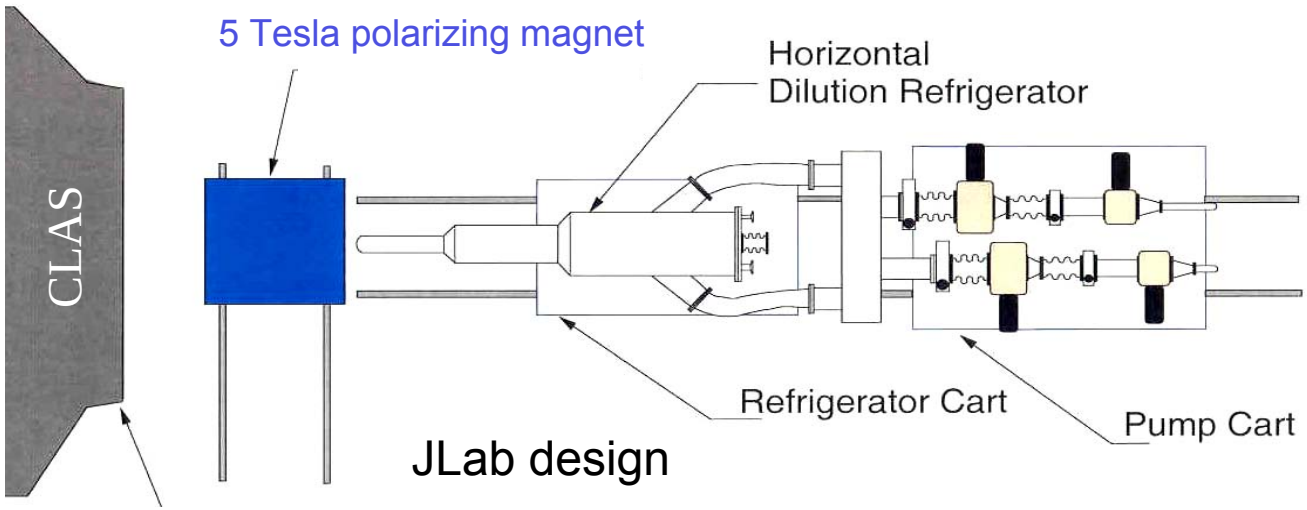
- minimum obstruction of CLAS solid angle
- low distortion of particle trajectories in magnetic field

Solution:

- frozen spin target
- temperature 50mK
- magnetic field 5kG

Status:

- design in progress at JLab
- procurement started for polarizing magnet

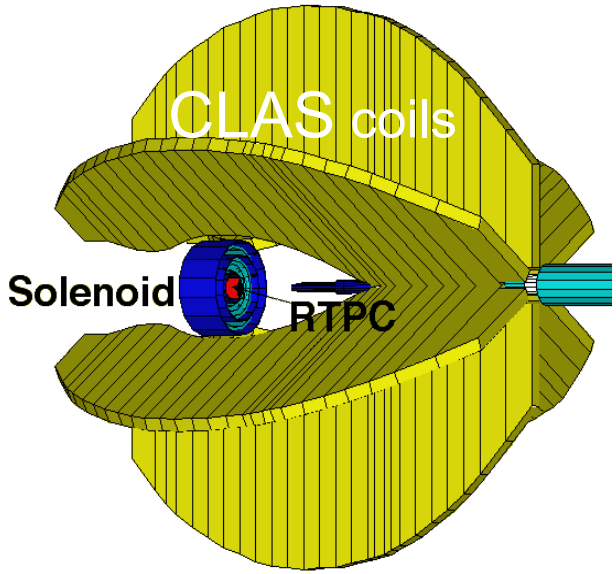


JLab design

New Tools: Bound Nucleon Structure (BoNuS)

Physics issue:

tag process off a neutron bound in deuterium by detecting the spectator proton in coincidence with the scattered e'



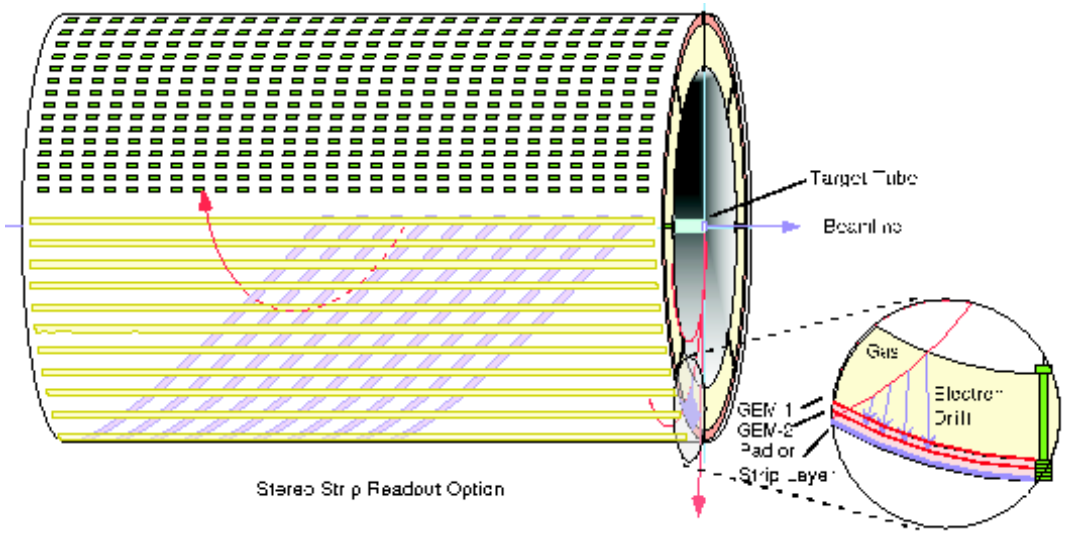
Technical problem:

spectator protons have

- - low momentum and low range
- - isotropic angular distribution (no correlation)
- - high rate

Solution:

- - high pressure gas target
- - surrounded by radial drift chamber
- - GasElectronMultiplier gap

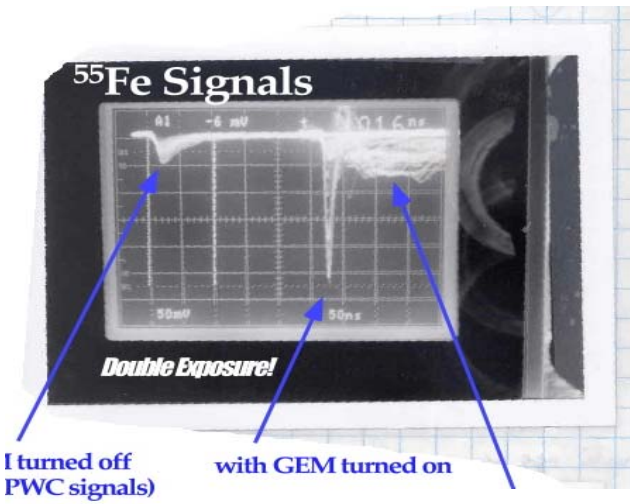


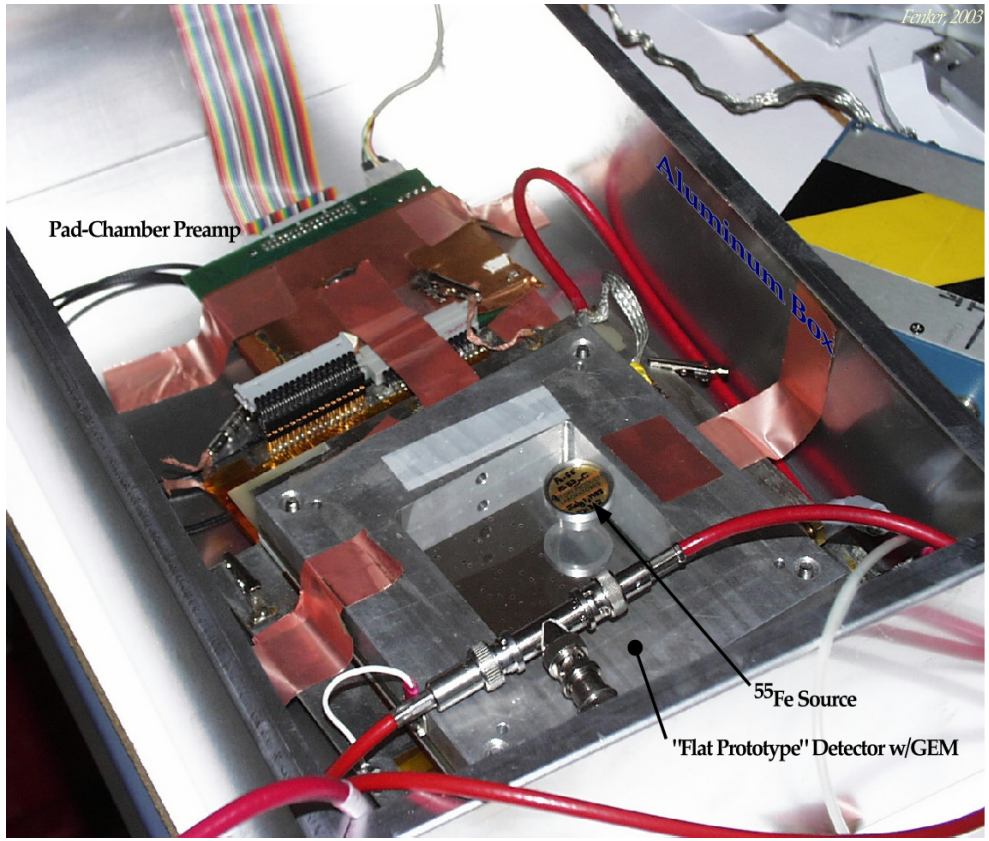
New Tools: BoNuS Detector

- Radial Time Projection Chamber (RTPC)

  Goal: detect spectator protons with momenta as low as 70 MeV/c

- Cylindrical prototype with GEM readout being developed by Howard Fenker
- Flat GEM prototype has been built and is being tested





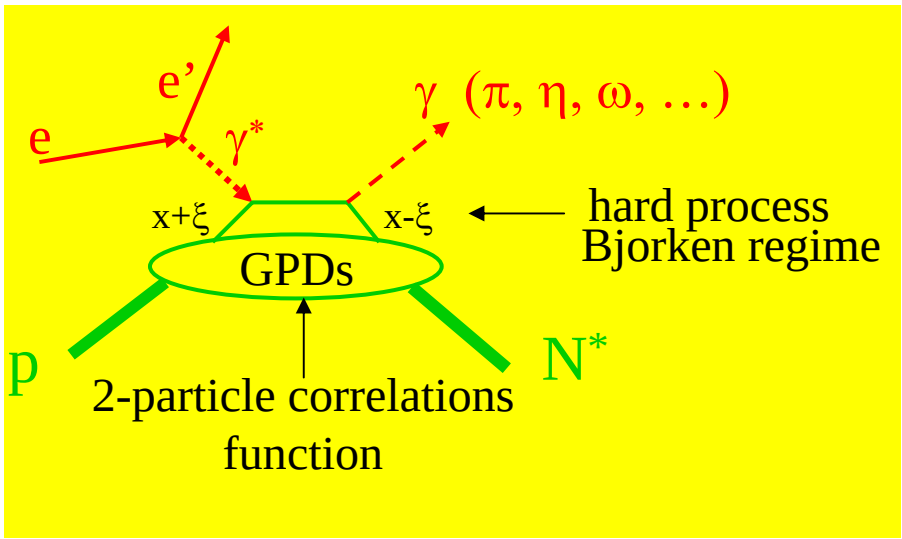
New Tools: Gas Cherenkov Counter

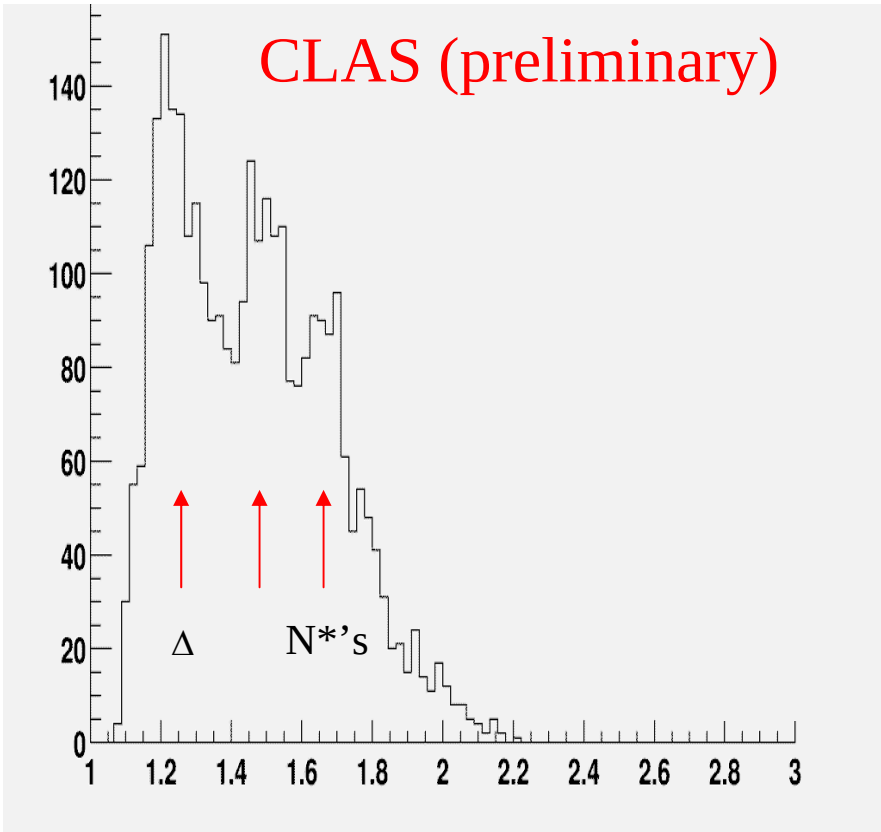
- Needed for E-03-106 (GDH Integral at very low Q^2), M. Ripani, et al.

multilayer μ-metal + iron shield

New Tools: DVCS in N* Physics

$ep \rightarrow e'\gamma N^*$



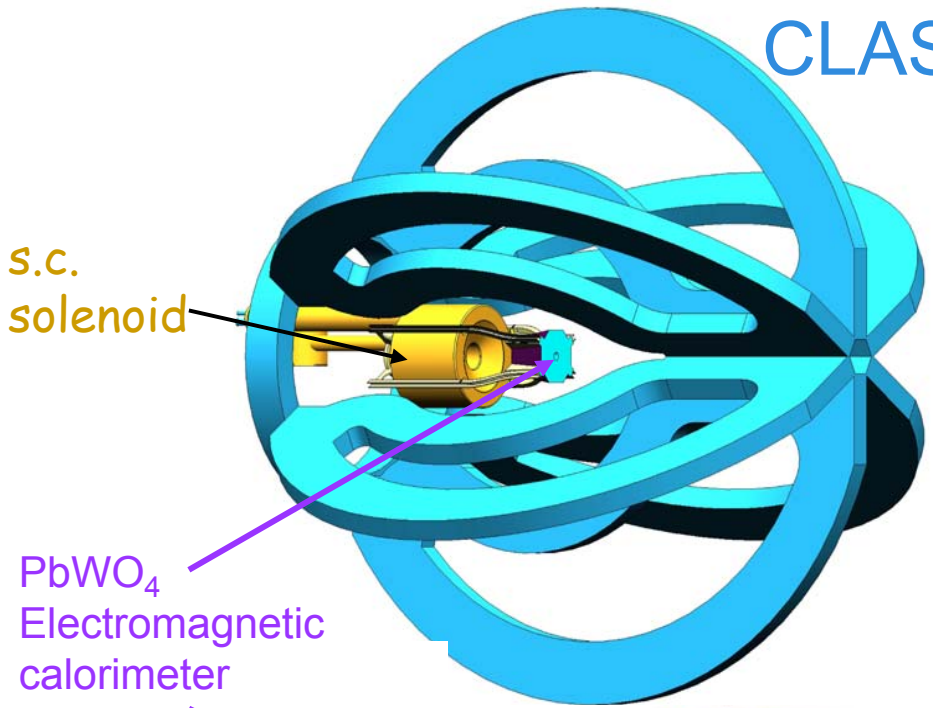


- t, ξ dependence of N* transition
- map out transition-GPDs
- decouple γ virtuality from momentum transfer to the nucleon
- study nucleon dynamics at the parton level

New Tools: Setup for DVCS

Physics Goal

measure ξ, t, Q^2 - dependence of $ep \rightarrow e'p\gamma$ in a wide kinematics range to constrain GPD models.

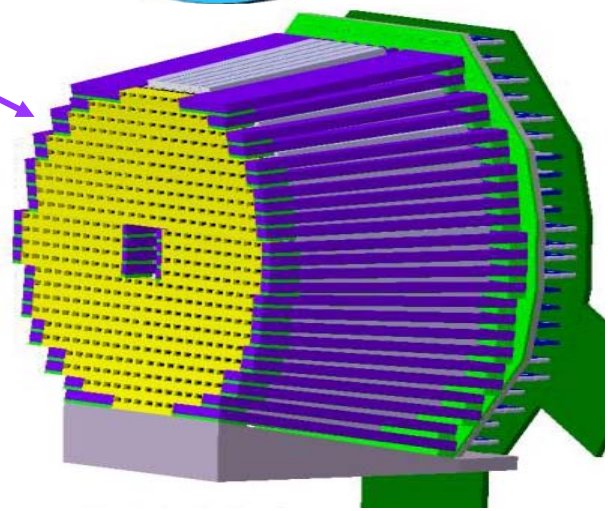


Technical Problem

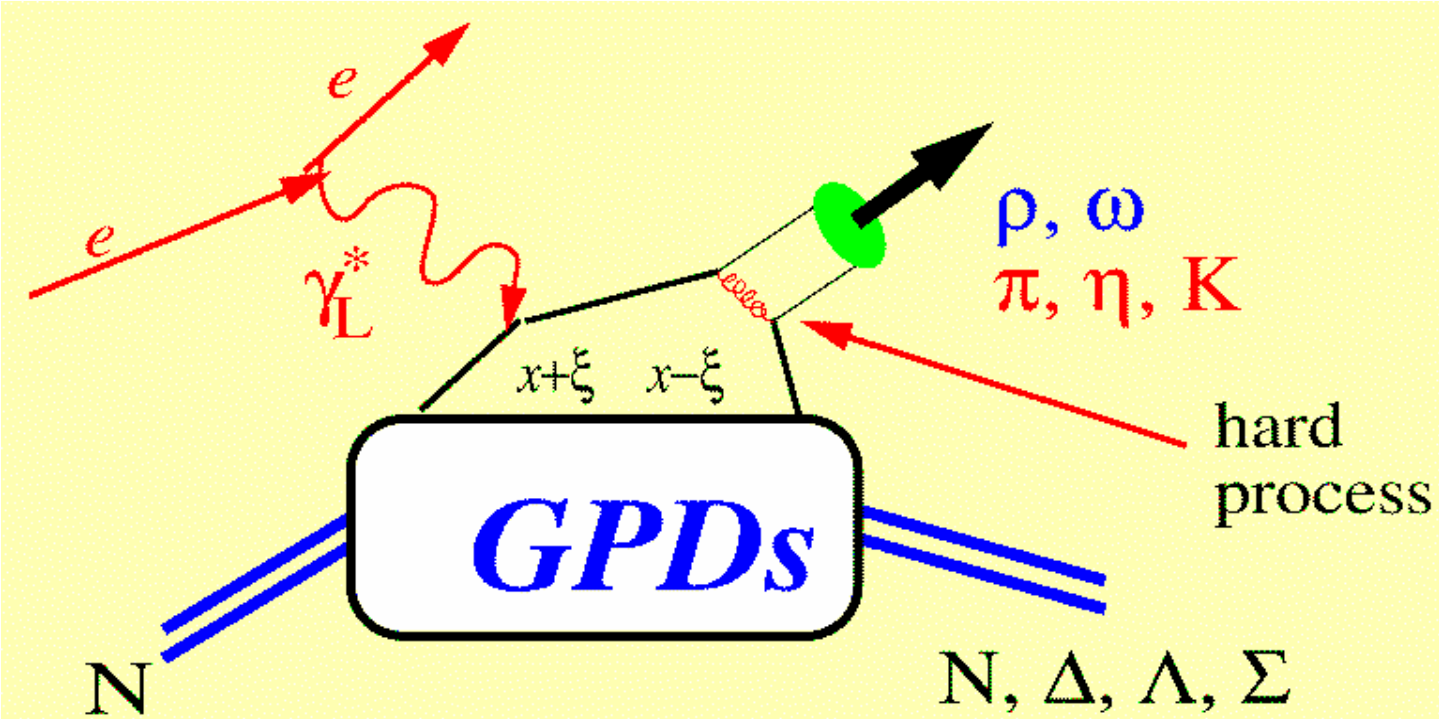
- need to detect all final state particles to identify process
- double luminosity to 2×10^{34} cm^{-2} s^{-1}

Technical solution

- add forward calorimeter (436 lead $PbWO_4$ crystals)
- readout via avalanche photodiodes (APD)
- super conducting 5 Tesla solenoid Møller shield



Deeply Virtual Meson Production

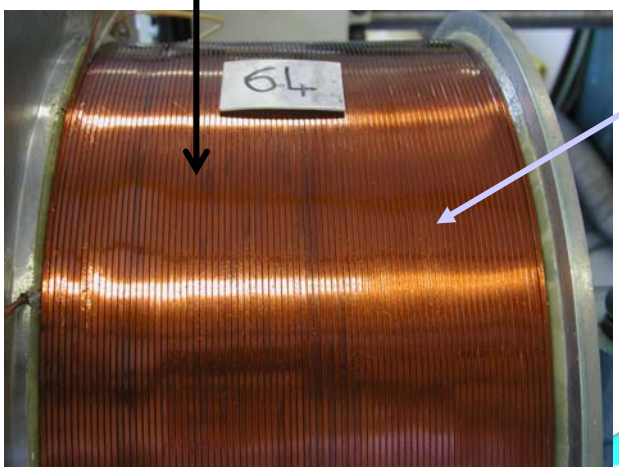


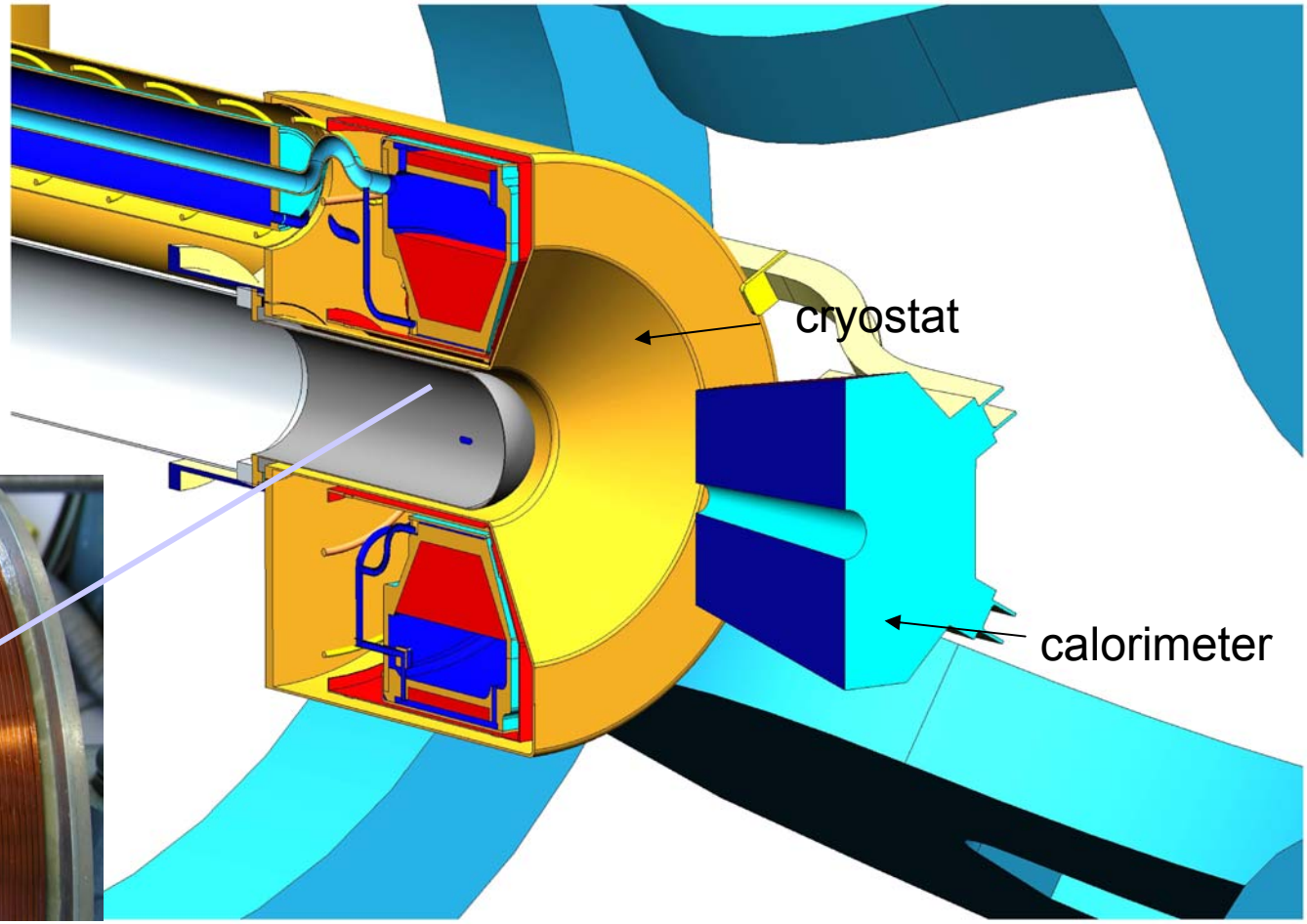
- Final state selects the quark flavors u, d, s
  => probes the GPD structure complementary to DVCS
- Filter for spin-(in)dependent GPDs

DVCS Experiment

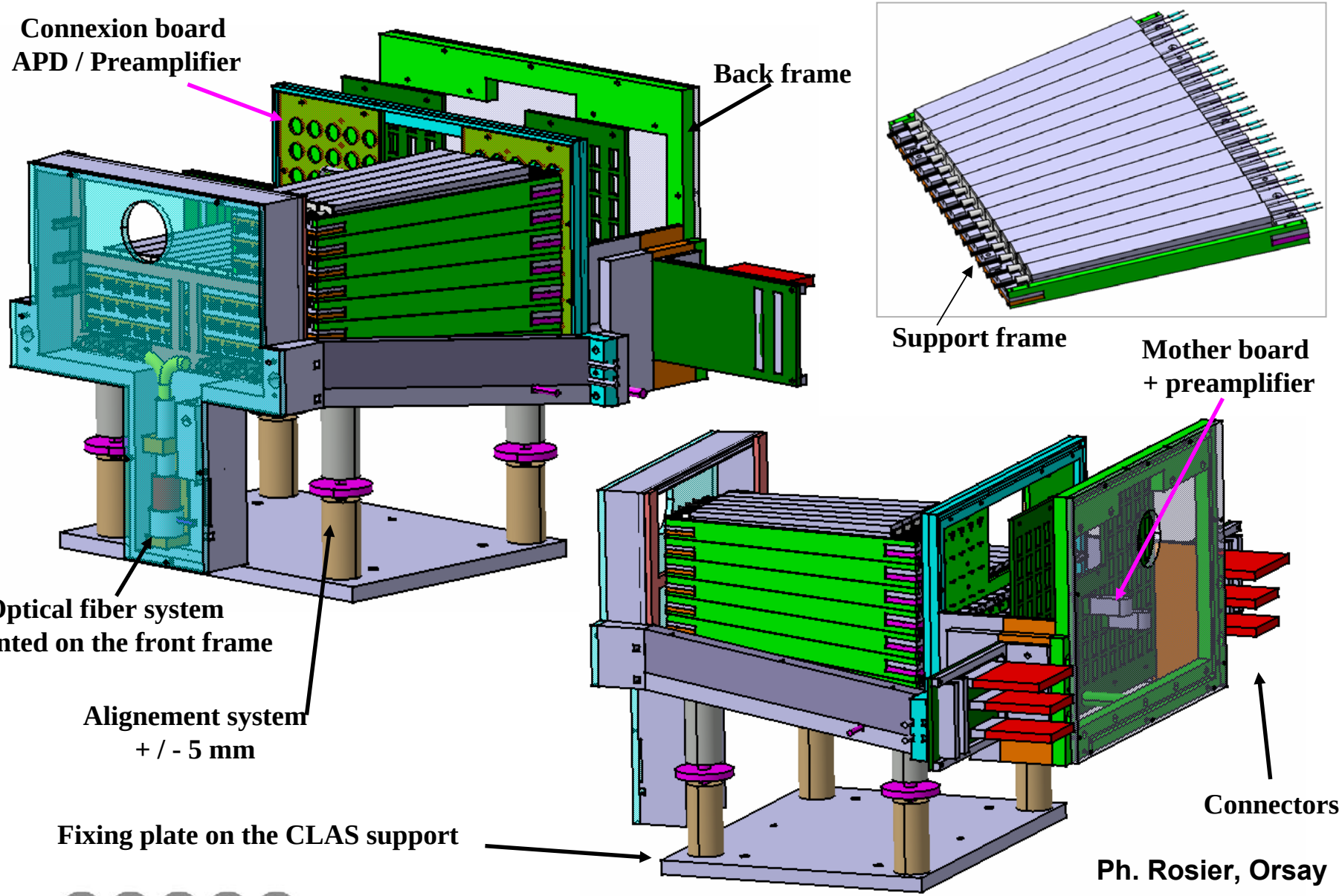
Superconducting solenoid: needed for shielding Møller electrons
$PbWO_4$ e.m. calorimeter needed for photon detection

Solenoid under construction at SACLAY



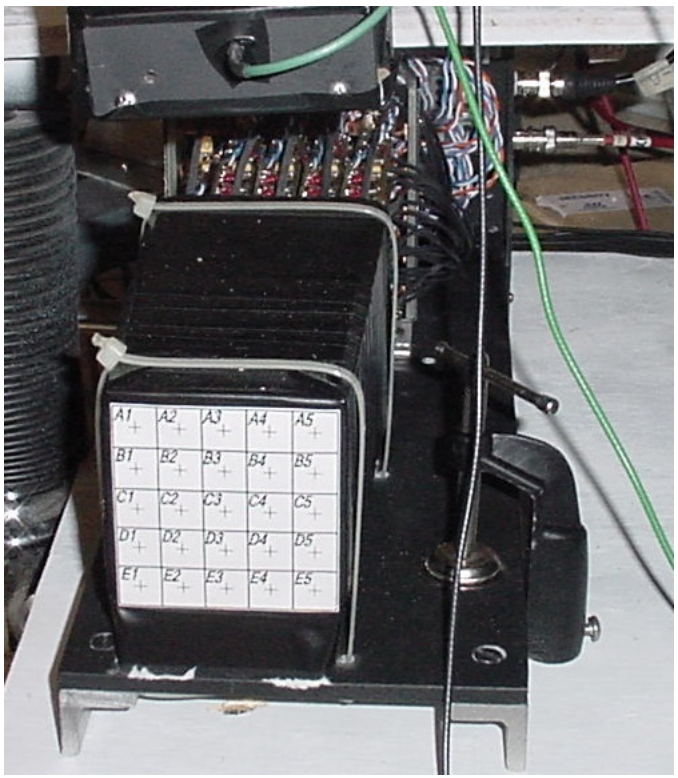


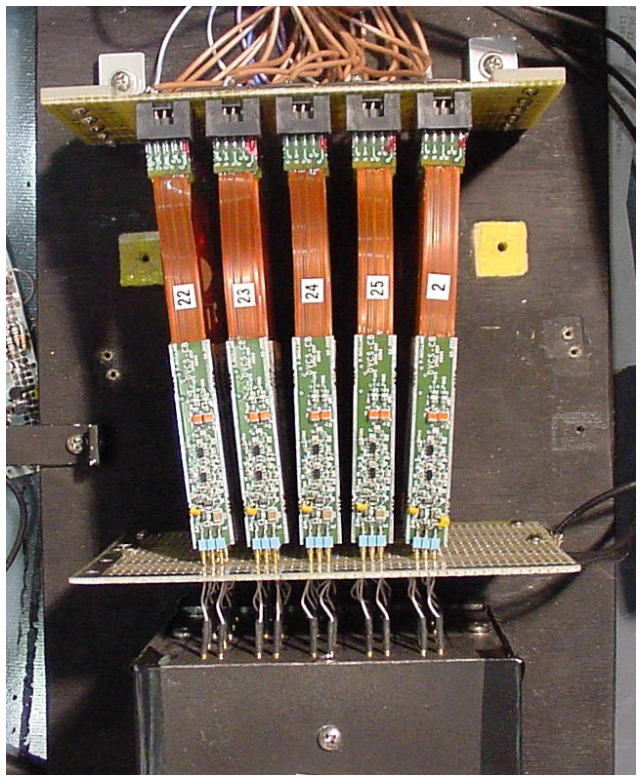
DVCS - 100 Crystal Prototype for Test Run

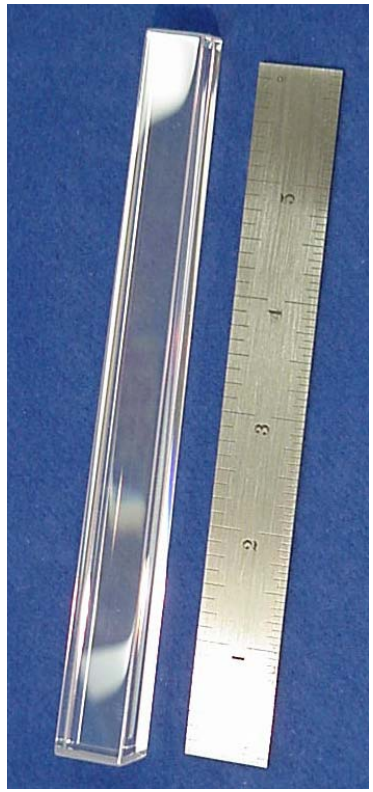


DVCS Experiment

- $PbWO_4$ crystal calorimeter
  - 440 tapered crystals, APDs, on site (ITEP, JLab)
  - Mechanical structure in final design stage (Orsay)
  - Preamps - designs being evaluated (ITEP, Orsay)
  - 5 x 5 crystal prototype built and being tested

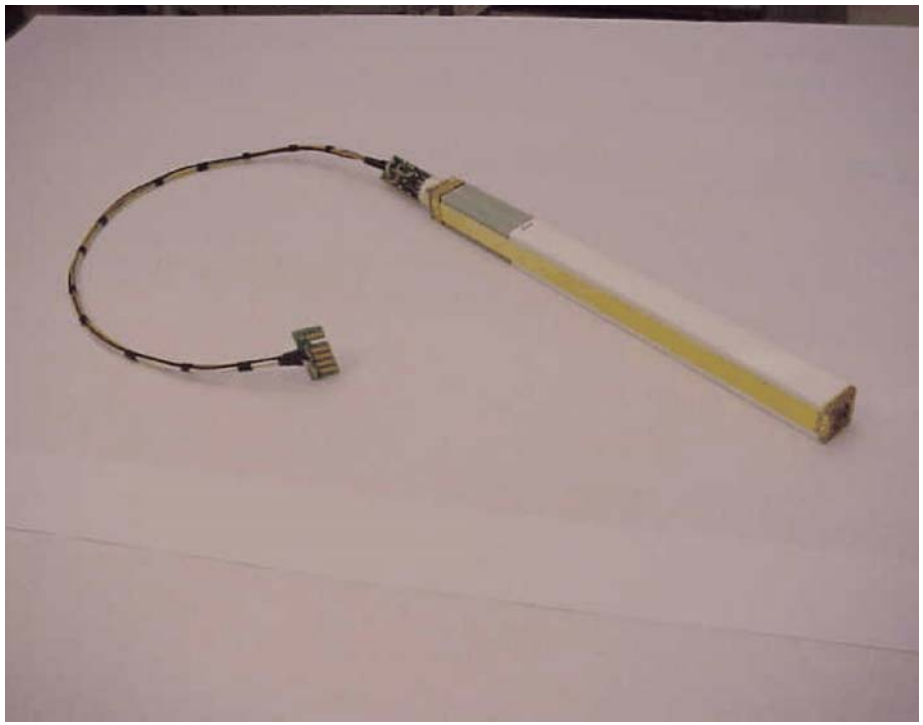




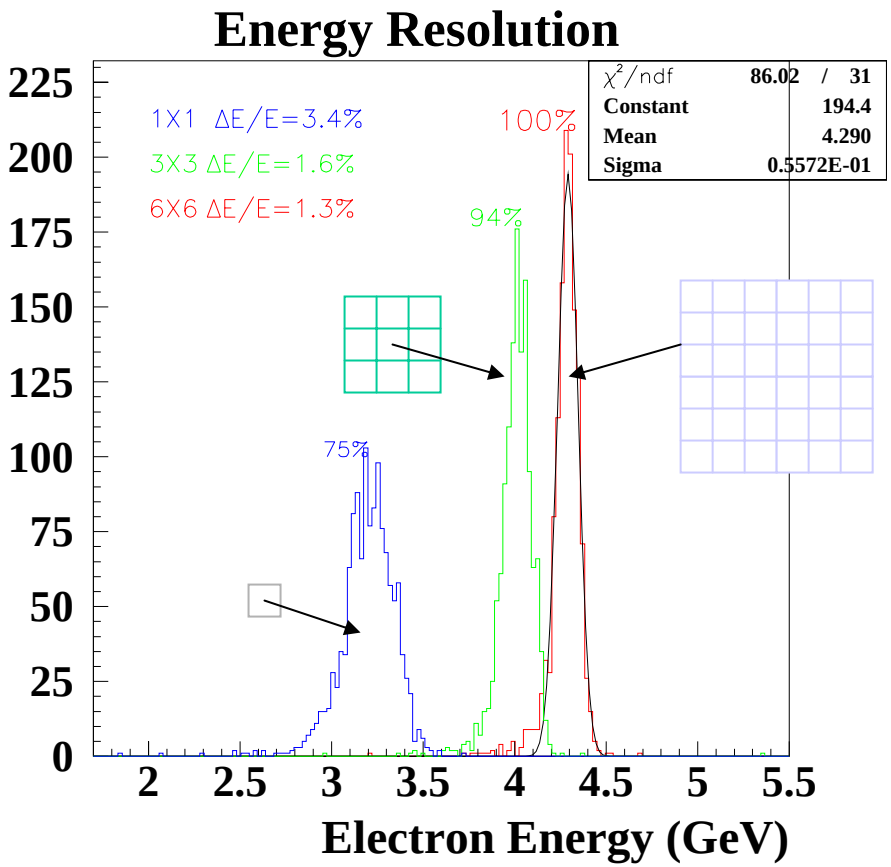


PrimEx Experiment

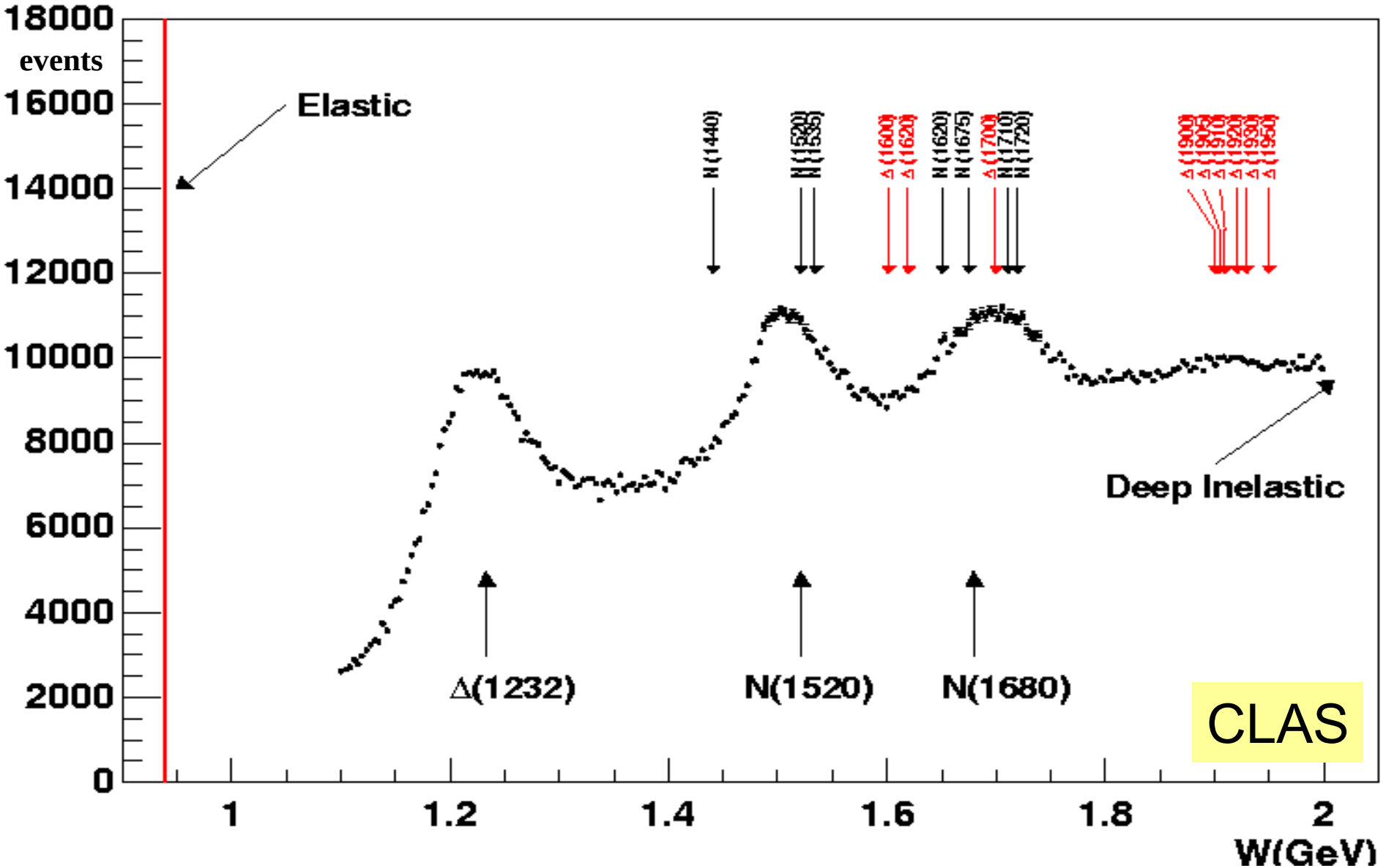
$PbWO_4$ crystal channel



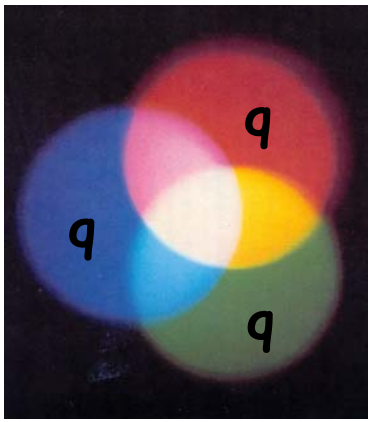
Electron beam test results

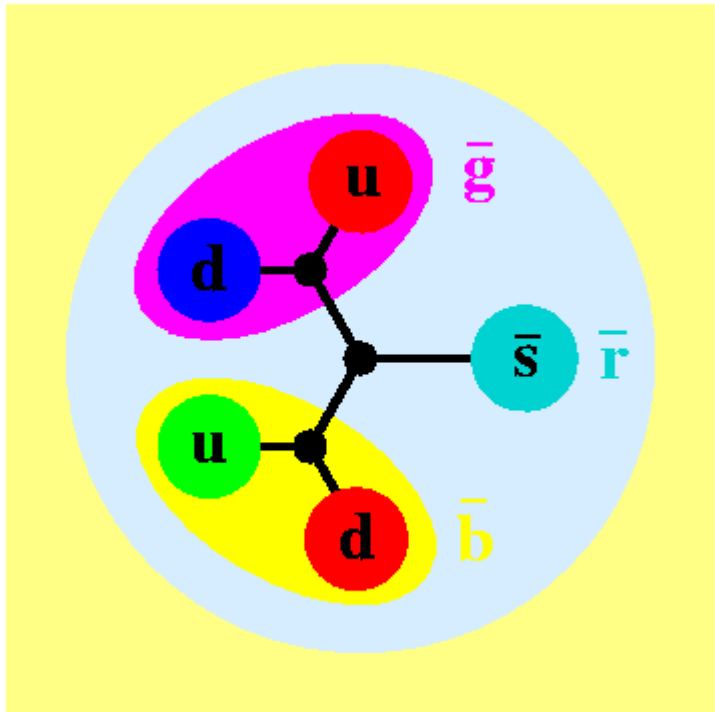


ep → e'X at 4 GeV


18000
events
16000
14000
12000
10000
8000
6000
4000
2000
0
Elastic
N(1440)
N(1520)
N(1535)
Δ(1600)
Δ(1620)
N(1620)
N(1675)
Δ(1700)
N(1710)
N(1720)
Deep Inelastic
Δ(1232)
N(1520)
N(1680)
CLAS
1
1.2
1.4
1.6
1.8
2
W(GeV)

A di-quark model for pentaquarks





JW hep-ph/0307341

JM hep-ph/0308286

SZ hep-ph/0310270

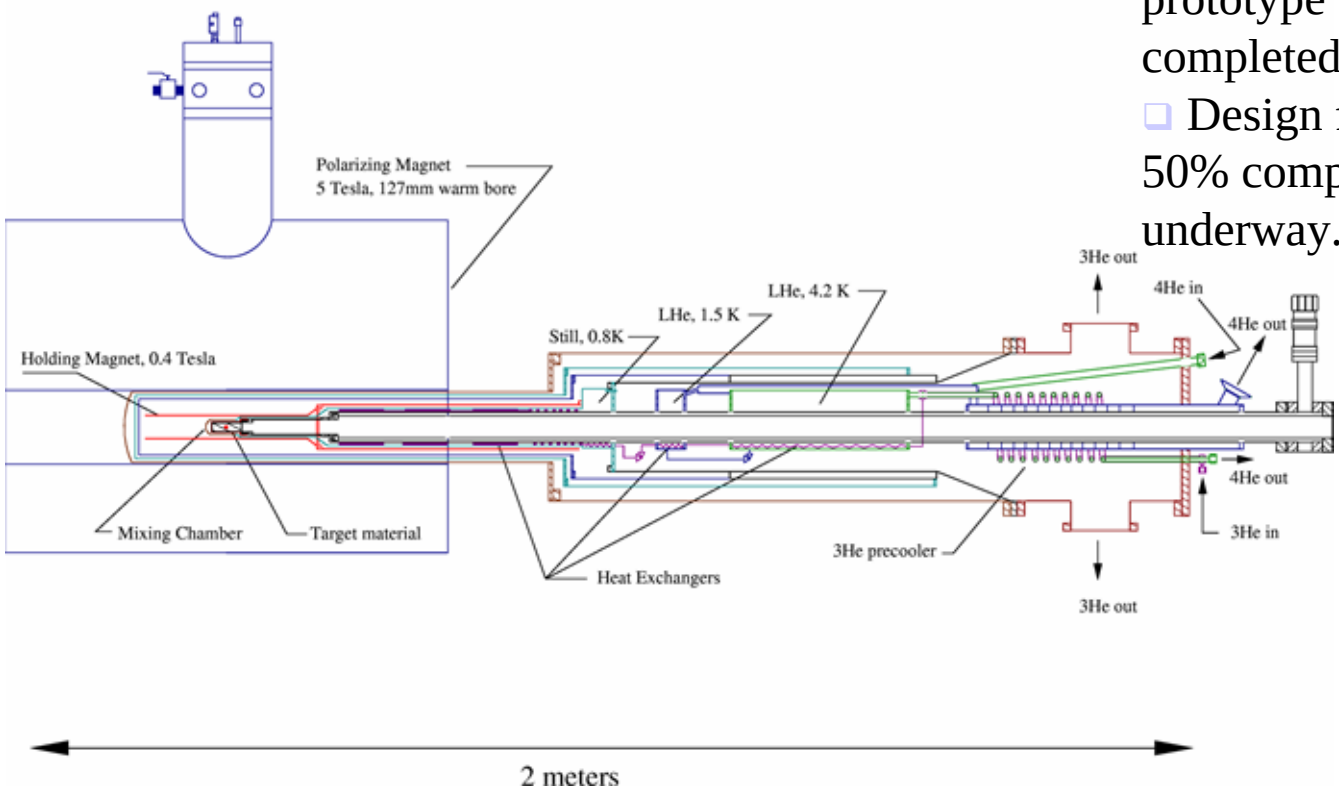
Decay Width: $\left\langle [ud][ud]\bar{s} \mid [uud][u\bar{s}] \right\rangle = \frac{1}{2\sqrt{6}}\Gamma \approx \frac{200\,MeV}{\left(2\sqrt{6}\right)^2} \approx 8\,MeV$

Mass Prediction for Ξ^{--} is 1.75 instead of 2.07 GeV

Frozen Spin Target

- Needed for Search for missing N* in pion and kaon photoproduction, Experiment E-02-112, F. Klein et al., E-03-105, S. Strauch et al.

Work by Target group (Chris Keith, et al.)



- Polarizing magnet ordered, estimated delivery: Feb. 2004
- Longitudinal holding magnet; prototype constructed – being tested
- Transverse holding magnet: prototype for “racetrack” design completed
- Design for dilution refrigerator 50% completed, construction underway.