Meson production and baryon resonances with CLAS

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Jefferson Lab

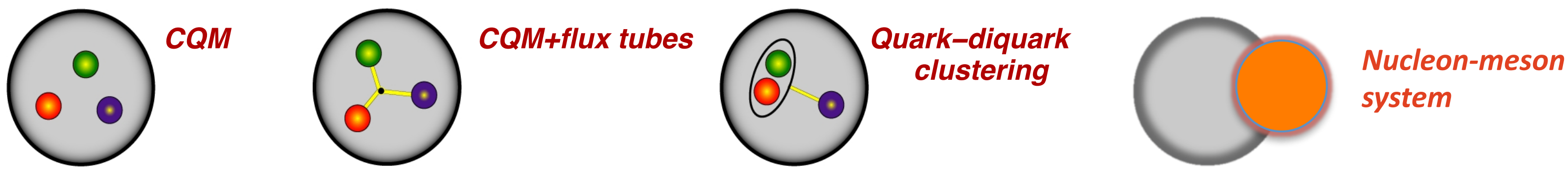
MESON 2010, June 14, 2010, Kracow

Outline

- Why study baryon excitations?
- How do we search for new states?
- Meson photo-production data
- Pion electroproduction and N* transitions
- The future at 12 GeV

Why do we study excited baryons?

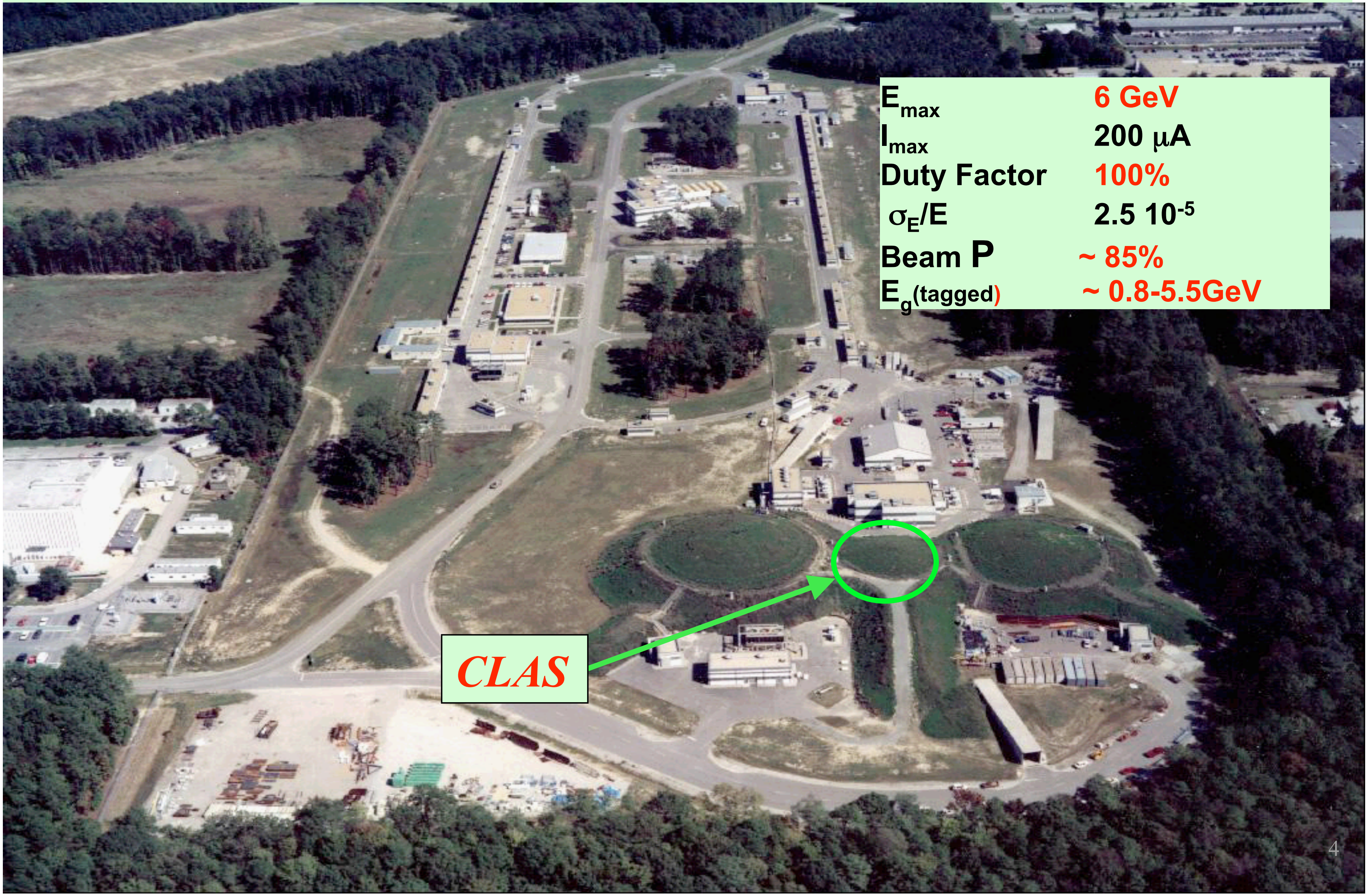
- The N* spectrum reflects the underlying degrees of freedom of the nucleon.



  - *Many states predicted in symmetric quark models have not been observed in elastic πN scattering*
  - *Electromagnetic probe and other decay channels may be sensitive to undiscovered states*

- Two main components of the experimental N* program with CLAS
  - *The search for new states in an unbiased way*
  - *Study of transition form factors of prominent resonances to reveal their structure at different distance scales*

The CEBAF cw electron accelerator



The CLAS Collaboration

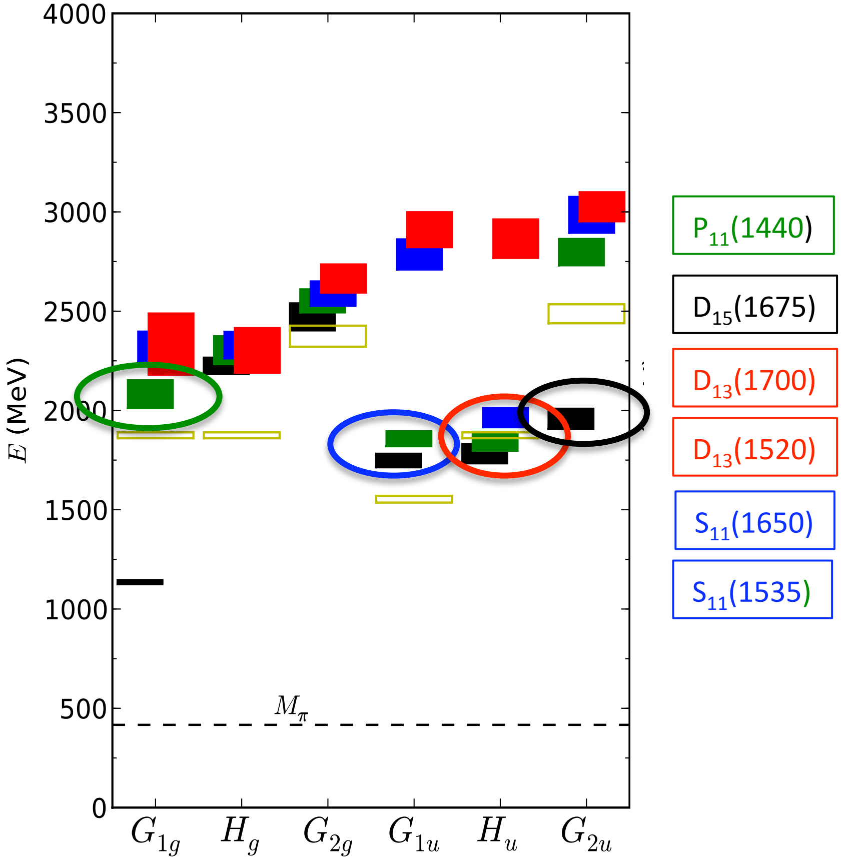
Arizona State University, Tempe, AZ
University Bari, Bari, Italy
University of California, Los Angeles, CA
California State University, Dominguez Hills, CA
Carnegie Mellon University, Pittsburgh, PA
Catholic University of America
CEA-Saclay, Gif-sur-Yvette, France
Christopher Newport University, Newport News, VA
University of Connecticut, Storrs, CT
Edinburgh University, Edinburgh, UK
University Ferrara, Ferrara, Italy
Florida International University, Miami, FL
Florida State University, Tallahassee, FL
George Washington University, Washington, DC
University of Glasgow, Glasgow, UK

University of Grenoble, Grenoble, France
Idaho State University, Pocatello, Idaho
INFN, Laboratori Nazionali di Frascati, Frascati, Italy
INFN, Sezione di Genova, Genova, Italy
Institut de Physique Nucléaire, Orsay, France
ITEP, Moscow, Russia
James Madison University, Harrisonburg, VA
Kyungpook University, Daegu, South Korea
University of Massachusetts, Amherst, MA
Moscow State University, Moscow, Russia
University of New Hampshire, Durham, NH
Norfolk State University, Norfolk, VA
Ohio University, Athens, OH

Old Dominion University, Norfolk, VA
Rensselaer Polytechnic Institute, Troy, NY
Rice University, Houston, TX
University of Richmond, Richmond, VA
University of Rome Tor Vergata, Italy
University of South Carolina, Columbia, SC
Thomas Jefferson National Accelerator Facility, Newport News, VA
Union College, Schenectady, NY
Virginia Polytechnic Institute, Blacksburg, VA
University of Virginia, Charlottesville, VA
College of William and Mary, Williamsburg, VA
Yerevan Institute of Physics, Yerevan, Armenia
Brazil, Germany, Morocco and Ukraine,
, have individuals or groups involved with CLAS,
but with no formal collaboration at this stage.

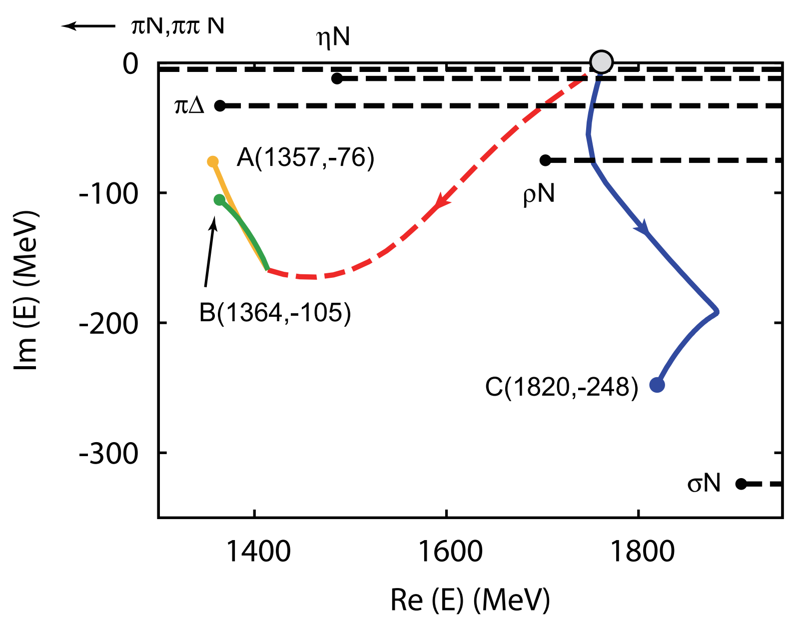
Baryon spectrum in LQCD and dynamical coupling

LQCD – Nucleon spectrum with dynamical quarks



J.M. Bulava, et al. , Phys.Rev.D79:034505,2009.

Dynamics of P_{11}-states: The bare quark model state at ~1740 MeV through coupling to inelastic channels generates a pole near 1820 MeV and 2 poles near 1360 MeV. The latter may be identified with the "Roper" resonance.



N. Suzuki et al. (EBAC), Phys.Rev.Lett.104:042302,2010

Search for undiscovered states.

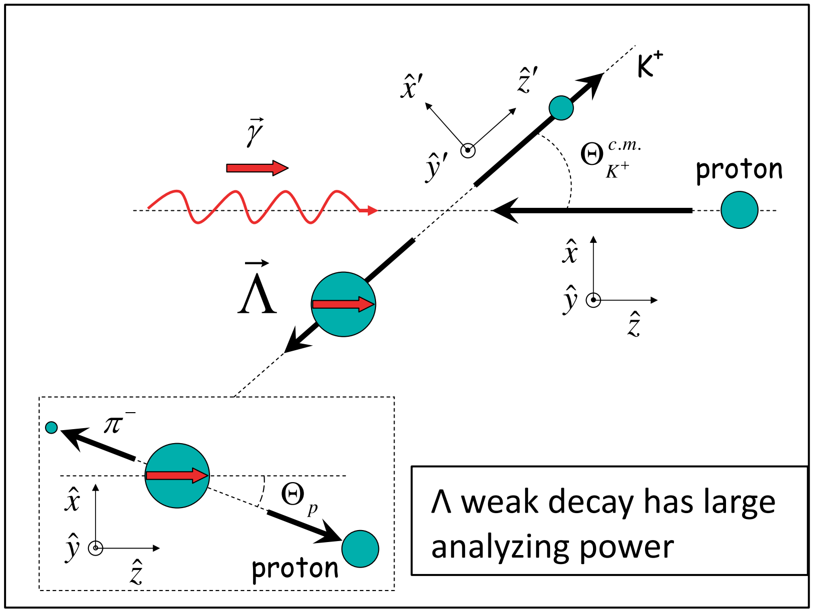
- Aim for very precise and “complete” or nearly complete measurements in $\gamma p \to \pi N$, ηN, KY, and $\gamma n \to \pi N$, $K^0 Y$.

- Other reactions, e.g. $\gamma p \to \omega p$, $\pi^+\pi^- p$, K^*Y, $\gamma n \to \pi^+\pi^- n$, are measured simultaneously, but will not be “complete”.

- All channels are measured in same setup simultaneously, eliminates many systematic uncertainties.

- Theory support from the JLab Excited Baryon Analysis Center (EBAC), and groups around the world.

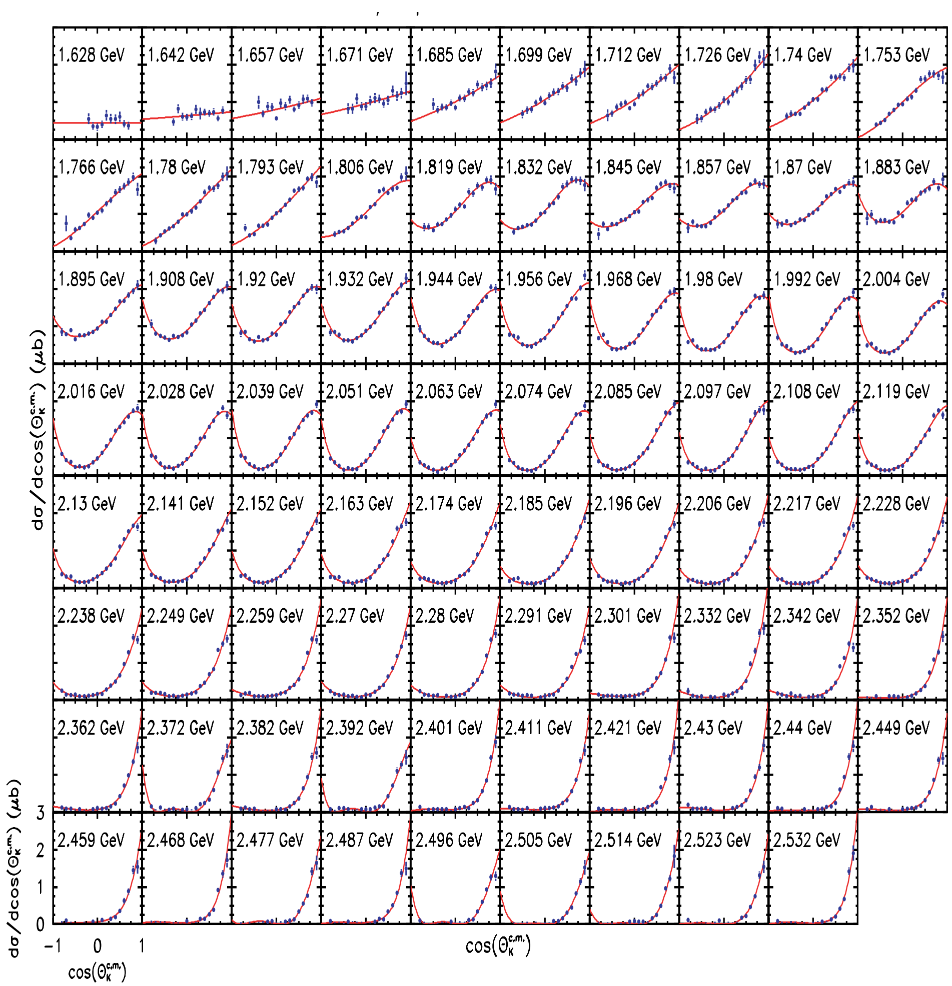
Complete experiments in KΛ production

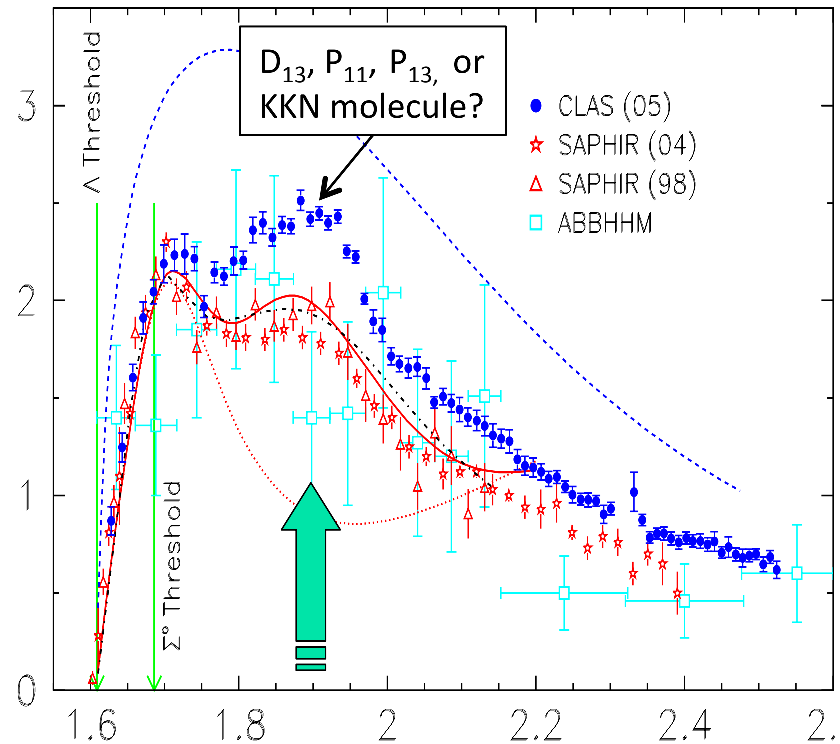


- Process described by 4 complex, parity conserving amplitudes
- 8 well-chosen measurements are needed to determine amplitude.
- 16 observables will be measured in CLAS ➠ allows many cross checks.
- 8 observables measured in reactions without recoil polarization.

Photon beam		***Target***			***Recoil***			***Target - Recoil***								
					x'	*y'*	*z'*	*x'*	*x'*	*x'*	*y'*	*y'*	*y'*	*z'*	*z'*	*z'*
		x	*y*	*z*				*x*	*y*	*z*	*x*	*y*	*z*	*x*	*y*	*z*
unpolarized	σ_0		***T***			***P***		$T_{x'}$		$L_{x'}$		**Σ**		$T_{z'}$		$L_{z'}$
linearly P_γ	**Σ**	***H***	***P***	***G***	$O_{x'}$	***T***	$O_{z'}$	$L_{z'}$	$C_{z'}$	$T_{z'}$	***E***		***F***	$L_{x'}$	$C_{x'}$	$T_{x'}$
circular P_γ		***F***		***E***	$C_{x'}$		$C_{z'}$		$O_{z'}$		***G***		***H***		$O_{x'}$	

Differential & total cross section of $\gamma p \rightarrow K^{+}\Lambda$



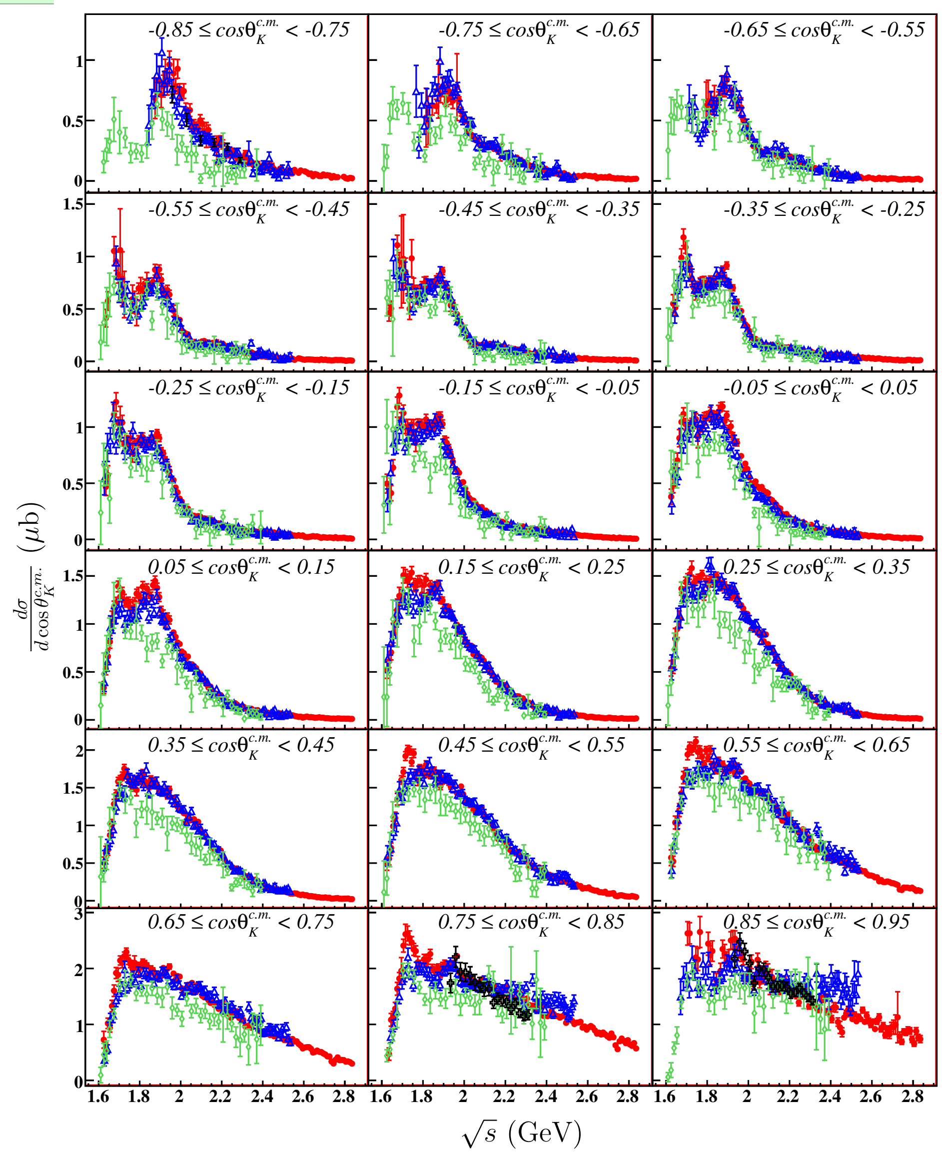


- Different interpretations of the structure near 1.9GeV cannot be resolved with crs data alone.

Compare CLAS’09, CLAS’05, SAPHIR

$\gamma p \longrightarrow K^+\Lambda$

New, more precise data with larger kinematic coverage and analyzed in different topologies, confirm CLAS’05 results.

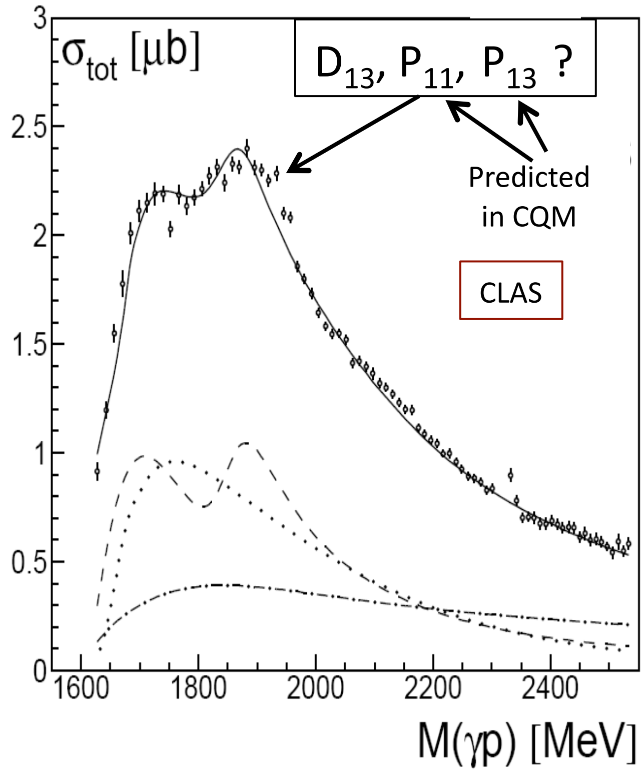


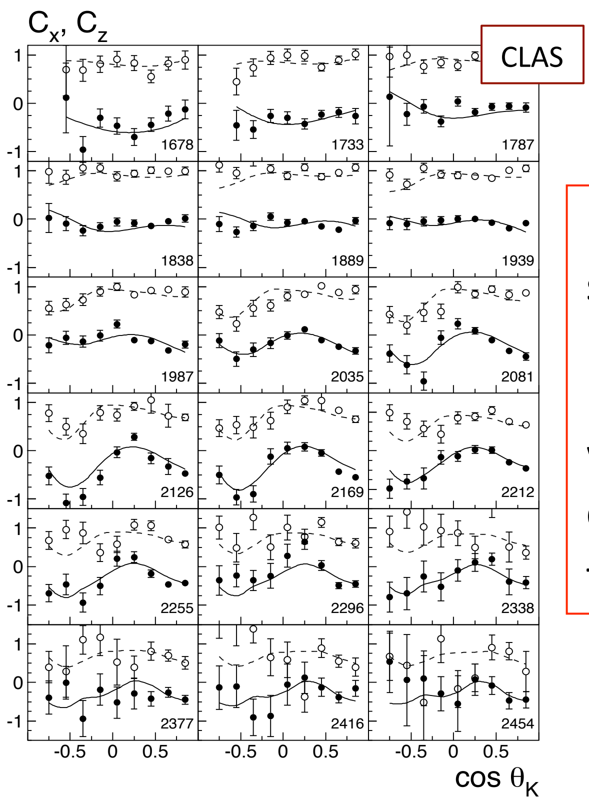
- CLAS’09
- CLAS’05
- SAPHIR’04

Polarization transfer $\vec{\gamma} p \rightarrow K^+ \vec{\Lambda}$

R. Bradford et al., Phys.Rev.C75:035205,2007
R. Bradford et al., Phys.Rev.C73:035202,2006

Fit: BG Model - A.K. Nikonov et al., Phys.Lett.B662:245-251, 2008.

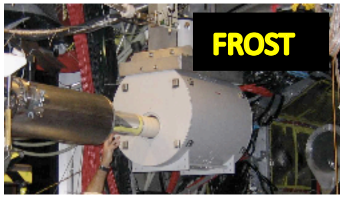




- BG analysis requires P_{13} state to fit the data.
- Existence of $N(1900)P_{13}$ would be evidence against q(qq) di-quark model with tightly bound di-quark.

Double spin asymmetry E with FROST

CLAS

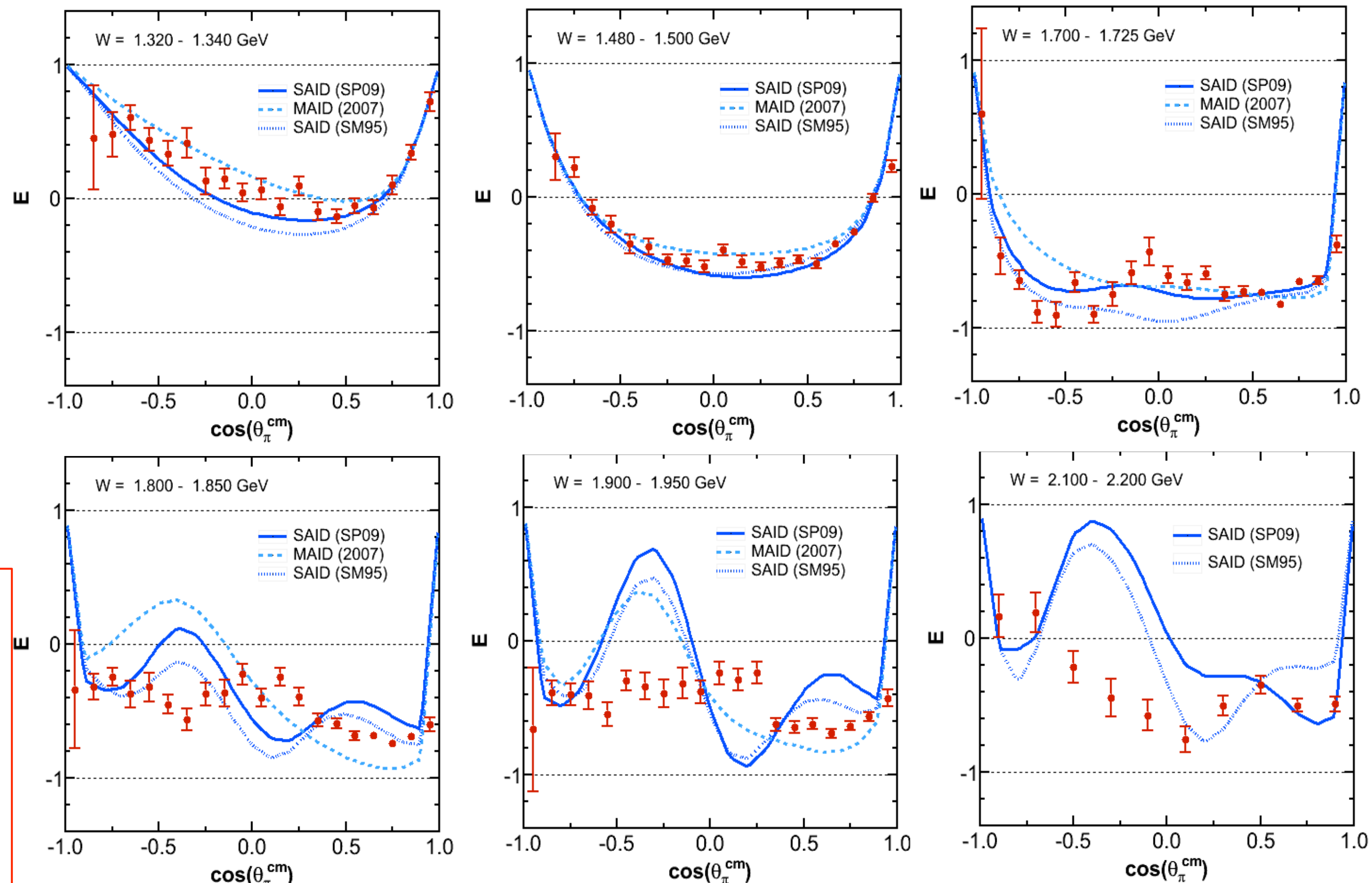


FROST run I with longitudinal target polarization completed in 2008.

- At W> 1.8 GeV, much strength is missing in SAID & MAID, leaving ample room for new excited states.

FROST run II with transverse proton polarization is underway, and on track for completion by July 22. This completes the data taking for the CLAS resonance search program on proton targets.

$\vec{\gamma}\vec{p} \rightarrow n\pi^+$ 6 of 30 energy bins (preliminary)



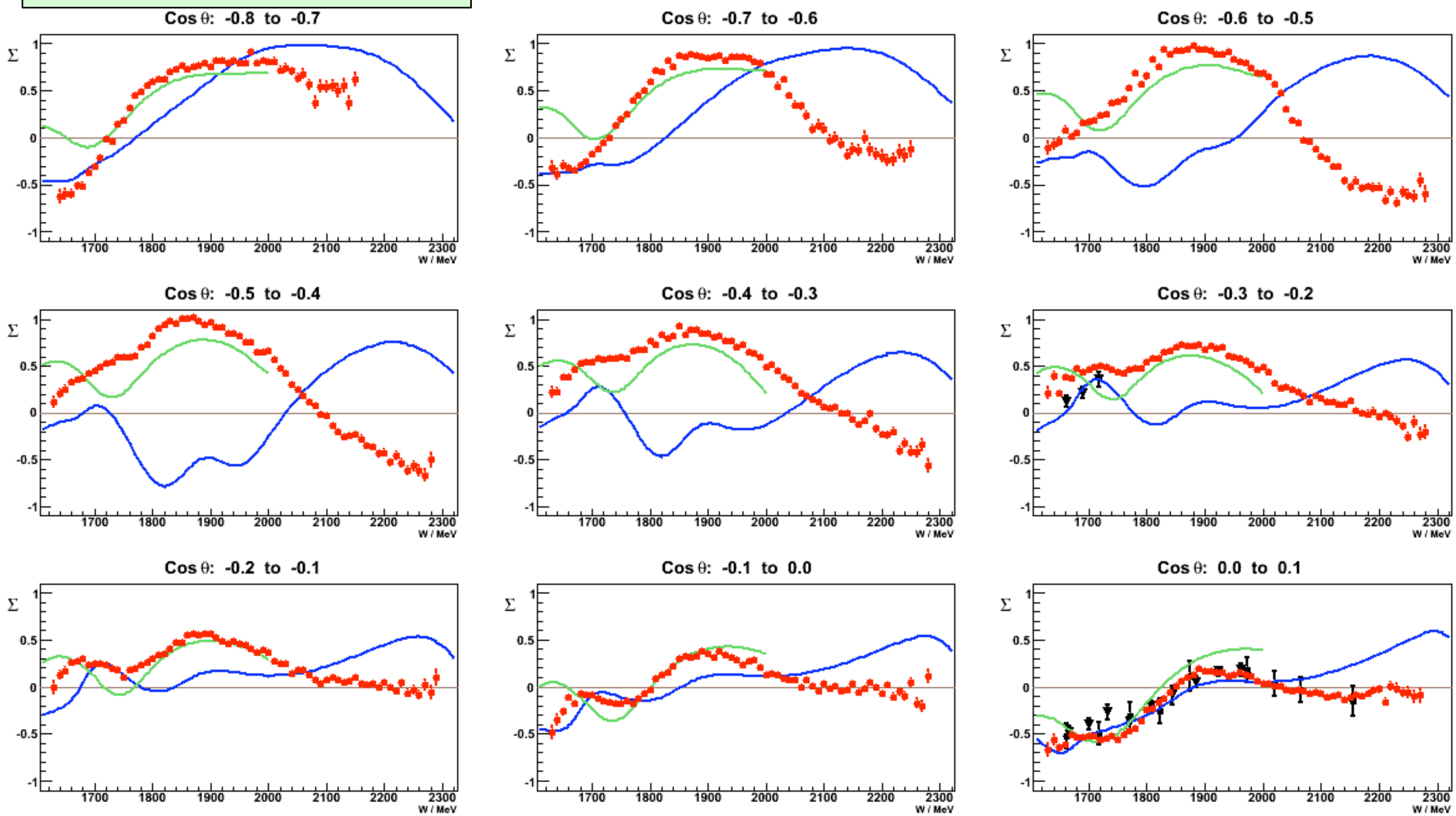
➪ Analysis of the asymmetry E for the $K^+\Lambda$ final state will discriminate P_{13}/D_{13} from the P_{11} assignment of the structure at 1930 MeV in the total cross section.

Beam asymmetry Σ for $\tilde{\gamma} n \rightarrow p\pi^-$

CLAS

Electromagnetic interaction not iso-spin conserving => need equivalent measurements on neutrons.

Samples of beam asymmetry



➪ Results will put strong constraints on resonance analysis

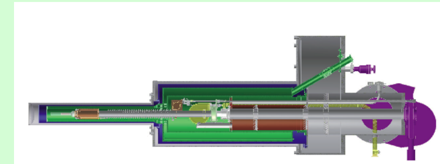
Search for S=0 states in single meson production on protons & neutrons

✔ (red) - published, ✔ (black) - acquired, ✔ (blue) - in progress, ✔ (green) - planned

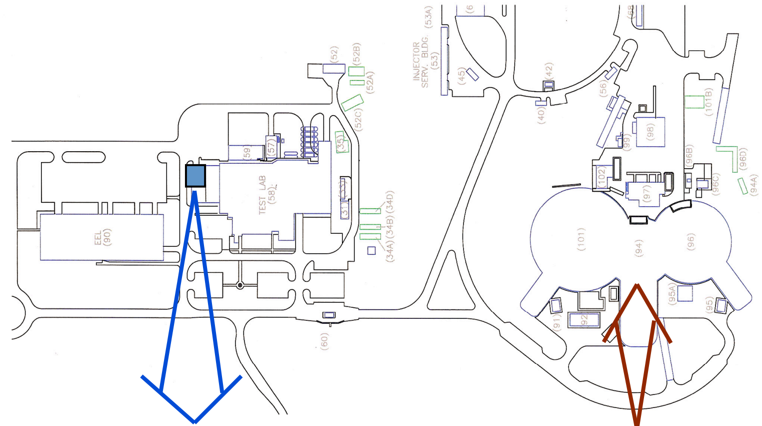
	σ	Σ	T	P	E	F	G	H	T_x	T_z	L_x	L_z	O_x	O_z	C_x	C_z
Proton targets																
$p\pi^0$	✔ (red)	✔ (black)	✔ (blue)		✔ (black)	✔ (blue)	✔ (black)	✔ (blue)								
$n\pi^+$	✔ (red)	✔ (black)	✔ (blue)		✔ (black)	✔ (blue)	✔ (black)	✔ (blue)								
$p\eta$	✔ (red)	✔ (black)	✔ (blue)		✔ (black)	✔ (blue)	✔ (black)	✔ (blue)								
$p\eta'$	✔ (red)	✔ (black)	✔ (blue)		✔ (black)	✔ (blue)	✔ (black)	✔ (blue)								
$p\omega$	✔ (red)	✔ (black)	✔ (blue)		✔ (black)	✔ (blue)	✔ (black)	✔ (blue)								
$K^+\Lambda$	✔ (red)	✔ (black)	✔ (blue)	✔ (red)	✔ (black)	✔ (blue)	✔ (black)	✔ (blue)	✔ (blue)	✔ (blue)	✔ (black)	✔ (black)	✔ (black)	✔ (black)	✔ (red)	✔ (red)
$K^+\Sigma^0$	✔ (red)	✔ (black)	✔ (blue)	✔ (red)	✔ (black)	✔ (blue)	✔ (black)	✔ (blue)	✔ (blue)	✔ (blue)	✔ (black)	✔ (black)	✔ (black)	✔ (black)	✔ (red)	✔ (red)
$K^{0*}\Sigma^+$	✔ (red)	✔ (black)									✔ (black)	✔ (black)				
Neutron targets																
$p\pi^-$	✔ (red)	✔ (black)	✔ (green)		✔ (green)	✔ (green)	✔ (green)	✔ (green)								
$p\rho^-$	✔ (black)	✔ (black)	✔ (green)		✔ (green)	✔ (green)	✔ (green)	✔ (green)								
$K^-\Sigma^+$	✔ (black)	✔ (black)	✔ (green)		✔ (green)	✔ (green)	✔ (green)	✔ (green)								
$K^0\Lambda$	✔ (black)	✔ (black)	✔ (green)	✔ (black)	✔ (green)	✔ (green)	✔ (green)	✔ (green)	✔ (green)	✔ (green)	✔ (green)	✔ (green)	✔ (black)	✔ (black)	✔ (black)	✔ (black)
$K^0\Sigma^0$	✔ (black)	✔ (black)	✔ (green)	✔ (black)	✔ (green)	✔ (green)	✔ (green)	✔ (green)	✔ (green)	✔ (green)	✔ (green)	✔ (green)	✔ (black)	✔ (black)	✔ (black)	✔ (black)
$K^{0*}\Sigma^0$	✔ (black)	✔ (black)														

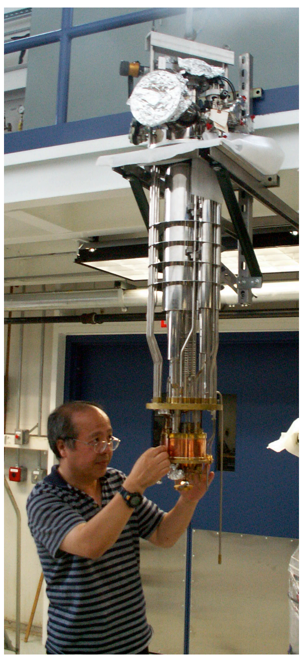
The combination of measurements on proton and neutron targets provides an unprecedented set of data in the search for new baryon states.

HDIce - Polarizing Laboratory



Production run expected to begin early 2011 with longitudinal polarization.

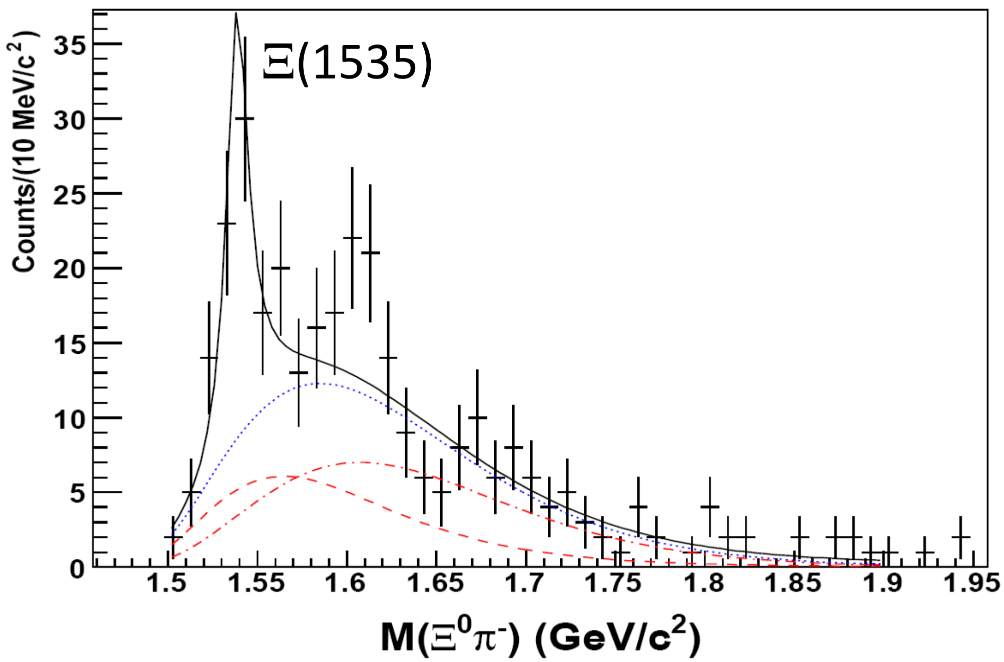




Search in $\gamma p \rightarrow \pi^- K^+ K^+ \Xi^0$

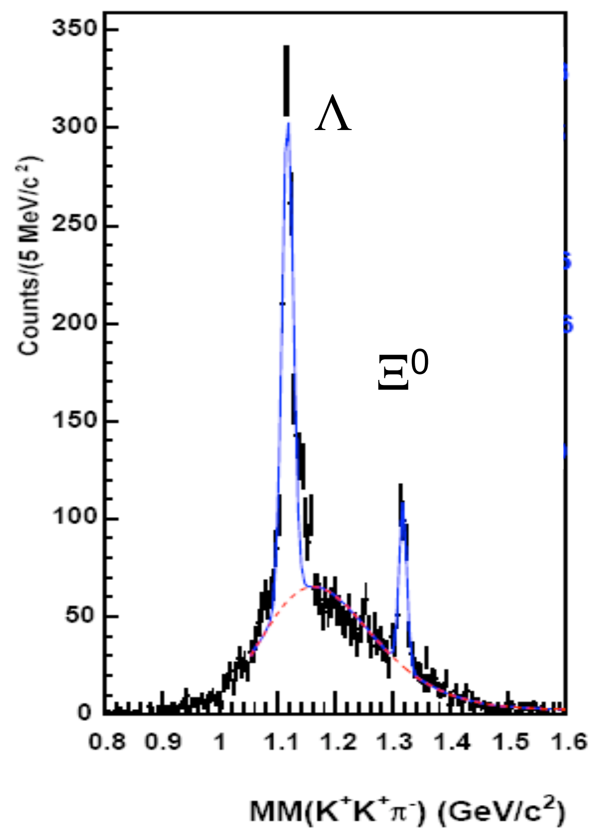
CLAS

- Only 6 states known, several w/o spin/parity
- Advantage is narrow widths of Ξ baryons
- Low rate



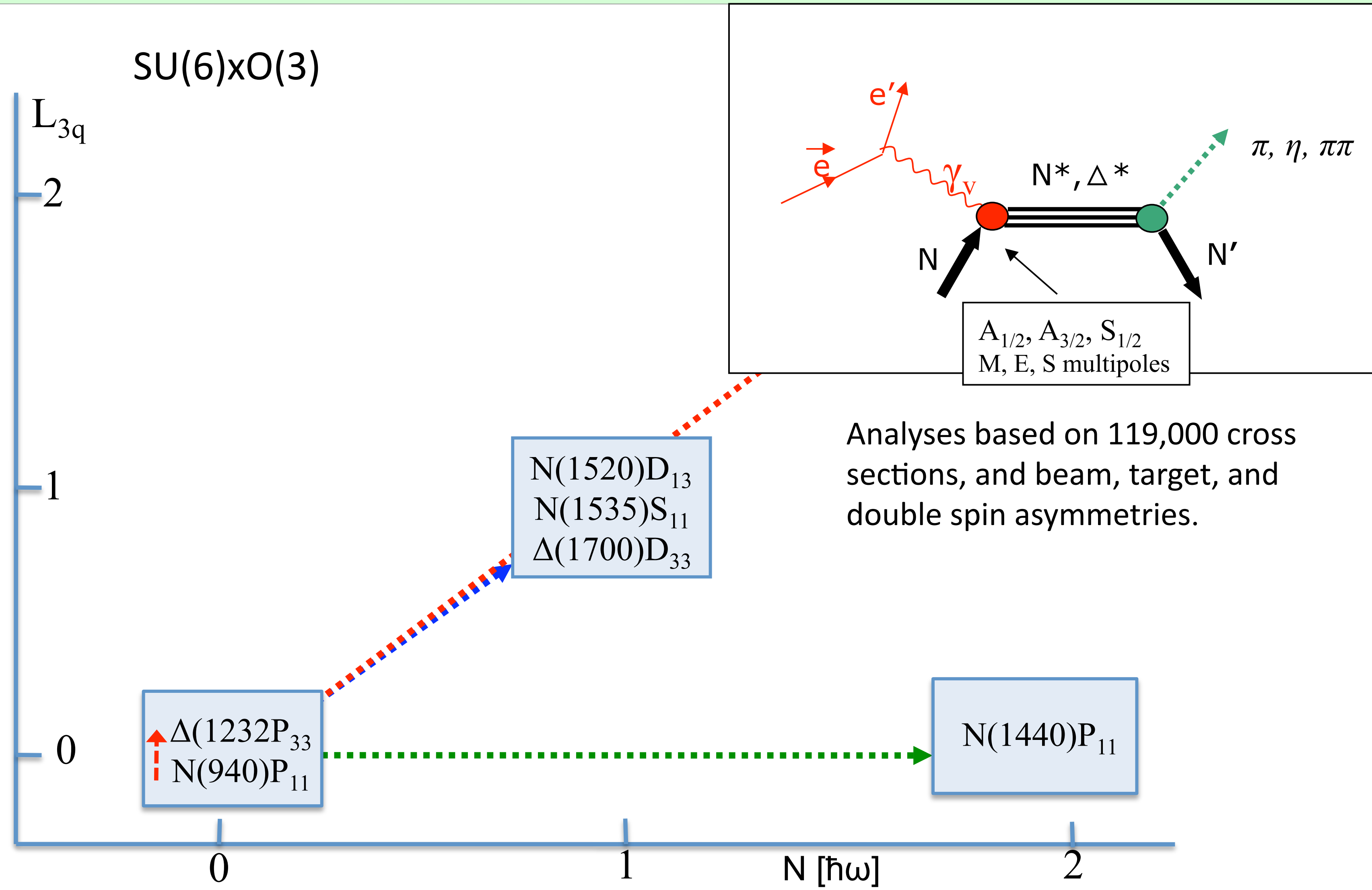
A Ξ* state at 1.620 GeV and 50 MeV width could be the 1* candidate in PDG. Such a state would be consistent with a dynamically generated Ξπ state (E. Oset et al.). Structure not significant.

L. Guo et al., Phys.Rev.C76:025208,2007.



- Data taken with higher statistics at higher energy in 2008 in analysis.

Electroexcitation of S=0 baryon states



Analyses based on 119,000 cross sections, and beam, target, and double spin asymmetries.

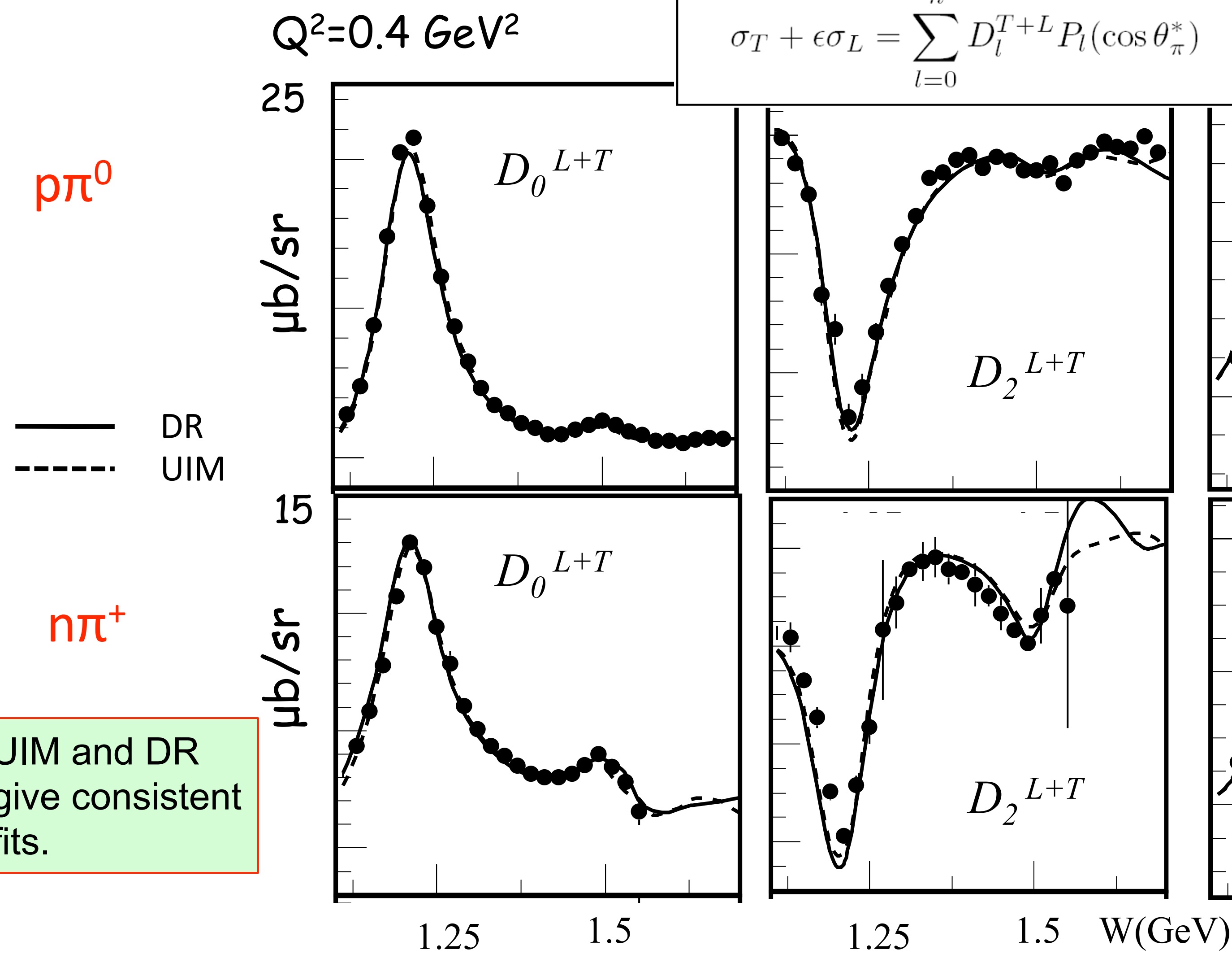
1^{st} through 3^{rd} nucleon resonance regions

State	$\beta_{N\pi}$	$\beta_{N\eta}$	$\beta_{N\pi\pi}$
$\Delta(1232)P_{33}$	0.995		
$N(1440)P_{11}$	0.55-0.75		0.3-0.4
$N(1520)D_{13}$	0.55-0.65		0.4-0.5
$N(1535)S_{11}$	0.35-0.55	0.45-0.60	
$\Delta(1700)D_{33}$	0.1-0.2		0.8-0.9
$N(1720)P_{13}$	0.1-0.2		> 0.7

- $N\pi$ and $N\pi\pi$ for $P_{11}(1440)$
- $N\pi$ and $N\eta$ for $S_{11}(1535)$
- $N\pi\pi$ for $D_{33}(1700)$ and $P_{13}(1720$

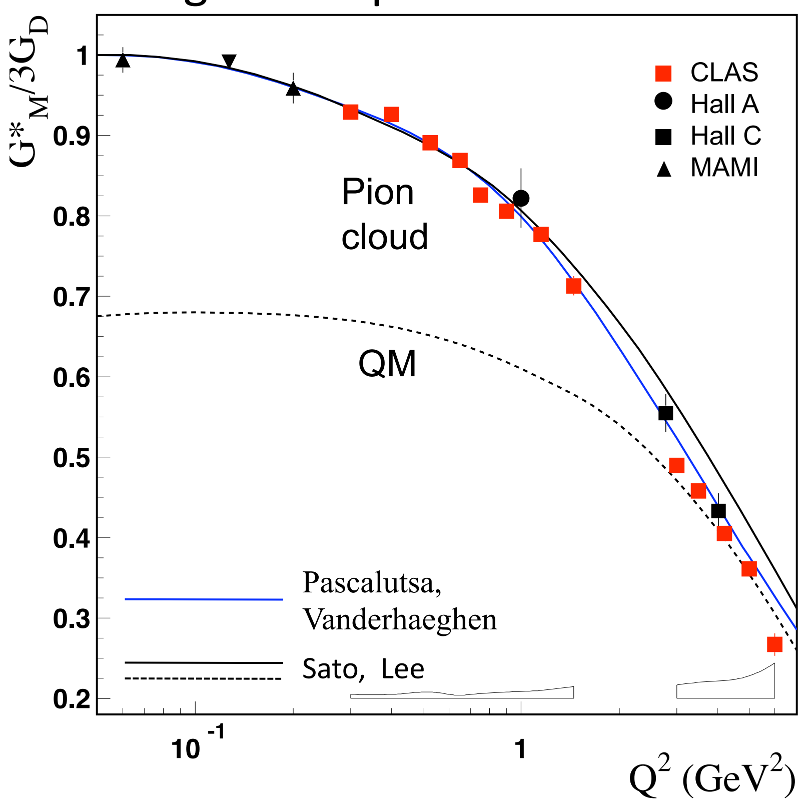
Legendre Moments for ep→eNπ at low Q^2 *CLAS*

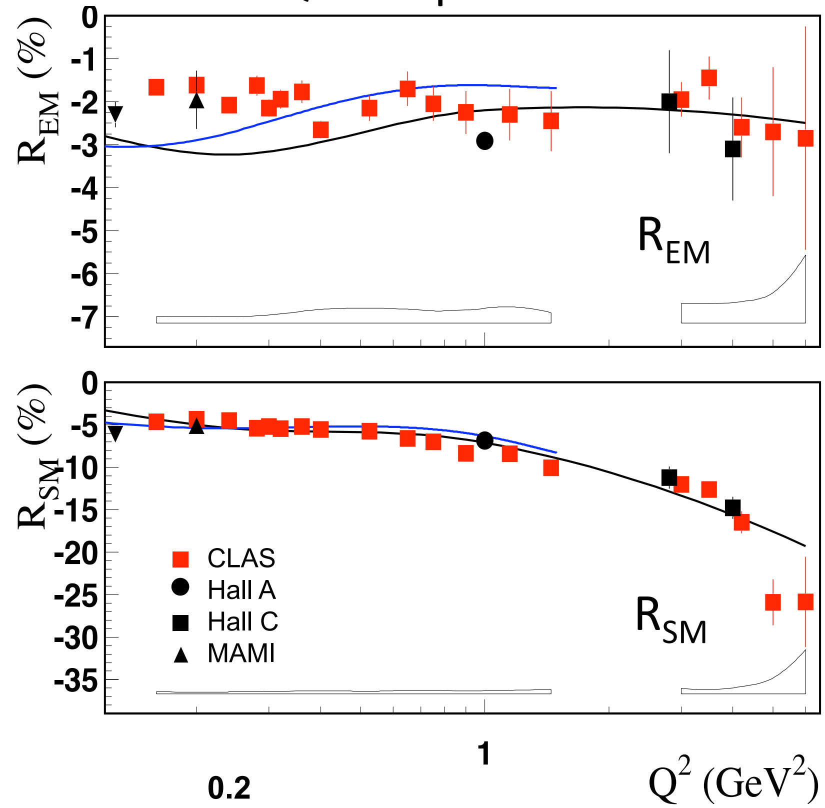
$$\sigma_T + \epsilon\sigma_L = \sum_{l=0}^{n} D_l^{T+L} P_l(\cos\theta_\pi^*)$$



UIM and DR give consistent fits.

NΔ Transition form factors



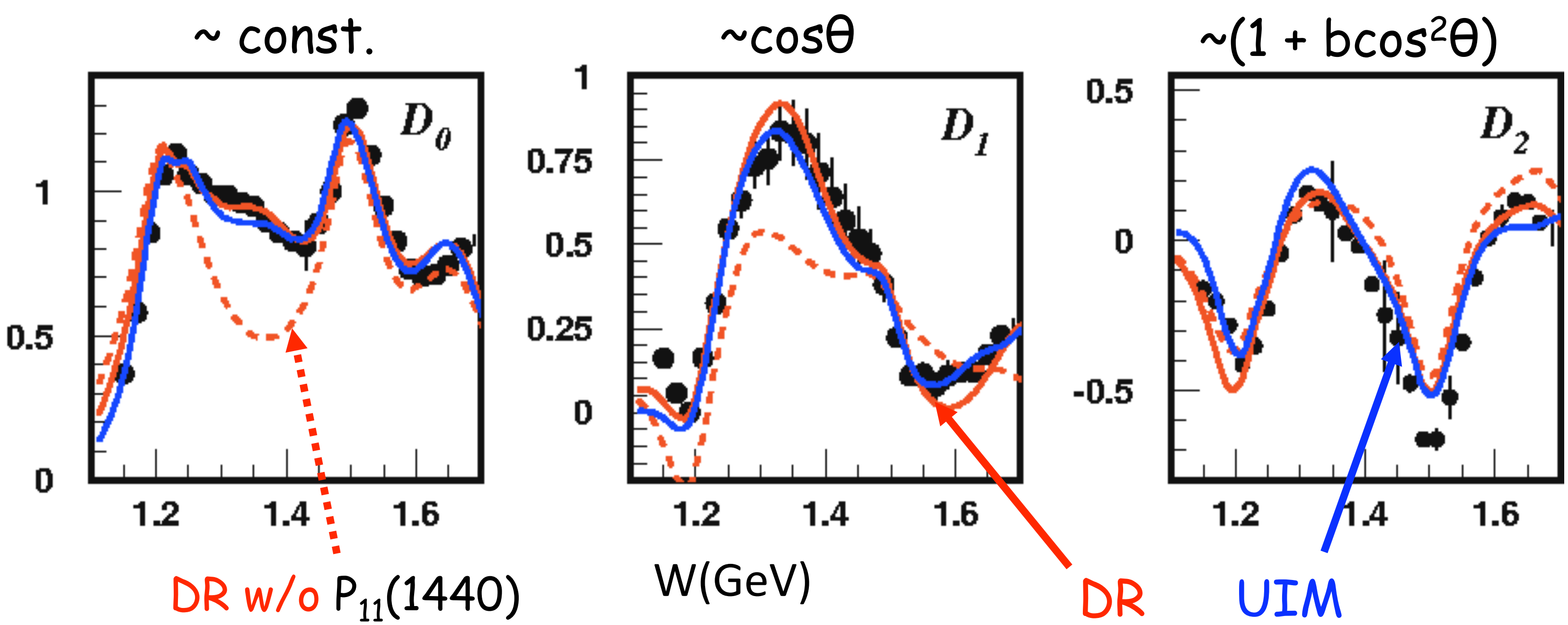


- No sign for onset of asymptotic behavior, $R_{EM} \rightarrow +100\%$, $R_{SM} \rightarrow$ const.
- R_{EM} remains negative and small, R_{SM} increases in magnitude with Q^2.
- Large meson-baryon contributions needed to describe multipole amplitudes

Influence of the "Roper" N(1440)P_{11} *CLAS*

$n\pi^+$

$Q^2 = 2.05\ GeV^2$



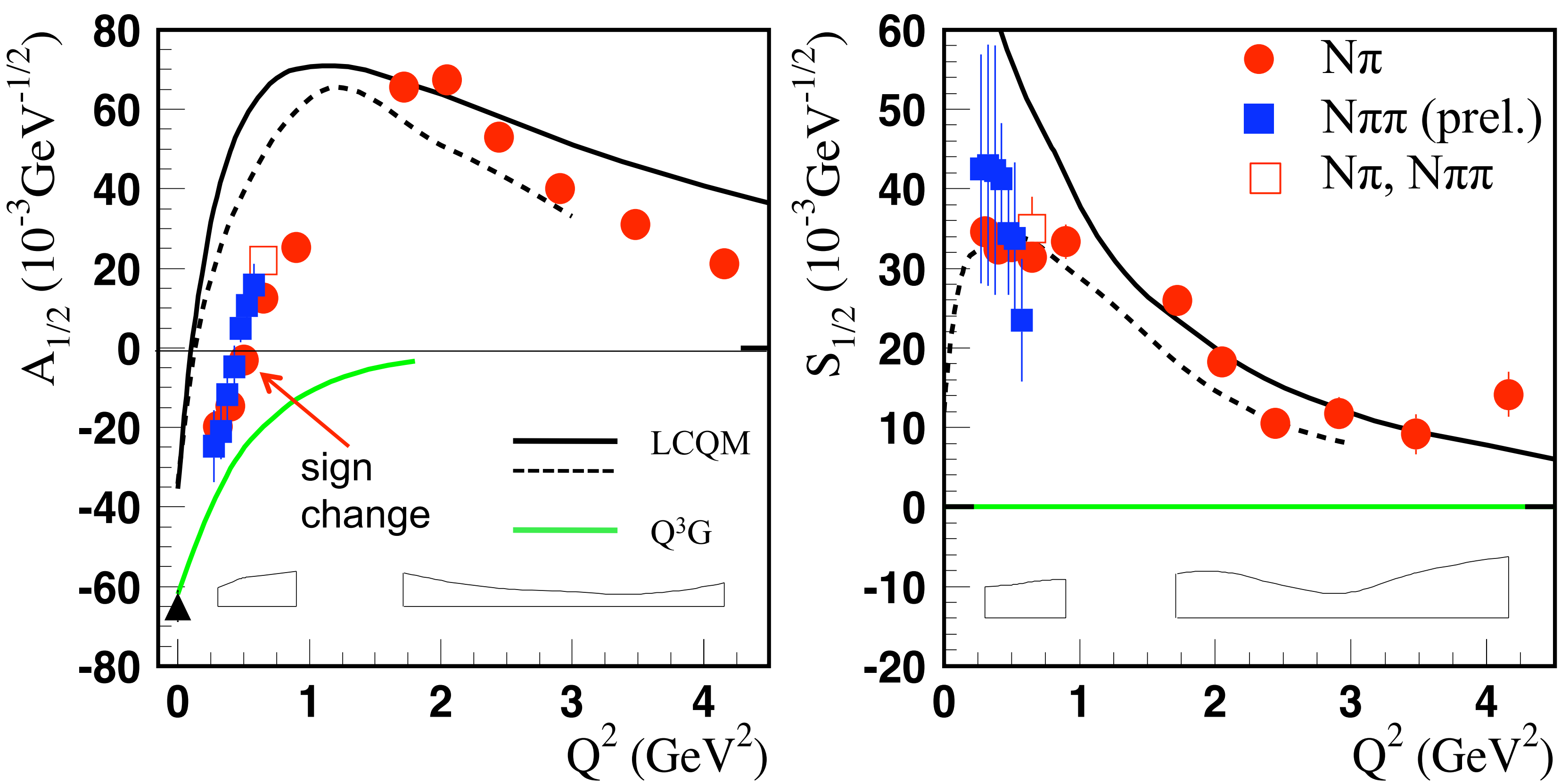
total cross section shows strong signal from Roper

sensitive to Roper resonance in s-p interference

little sensitivity to Roper resonance

Helicity amplitudes for the "Roper"

CLAS



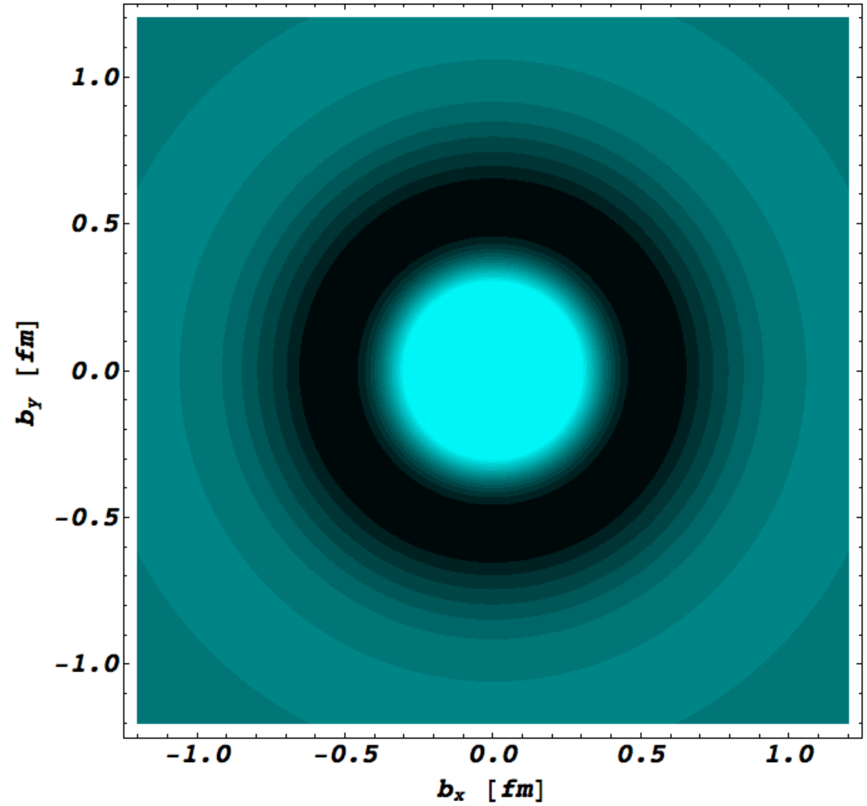
- Sign change of $A_{1/2}$ observed in both channels at same Q^2
- Magnitudes of $A_{1/2}$ and $S_{1/2}$ consistent in the two channels.
- High Q^2 behavior consistent with dominant radial excitation of nucleon.
- Rules out the "Roper" as a gluonic excitation

Transition charge density of the "Roper"

Tiator, Vanderhaeghen, 2008

$$F_1 = \sqrt{\frac{M^* M_N \kappa}{\pi \alpha Q_-^2} \frac{\tau}{1+\tau}} \left(A_{1/2} + \frac{\sqrt{2}(M^* + M_N)}{k} S_{1/2} \right)$$

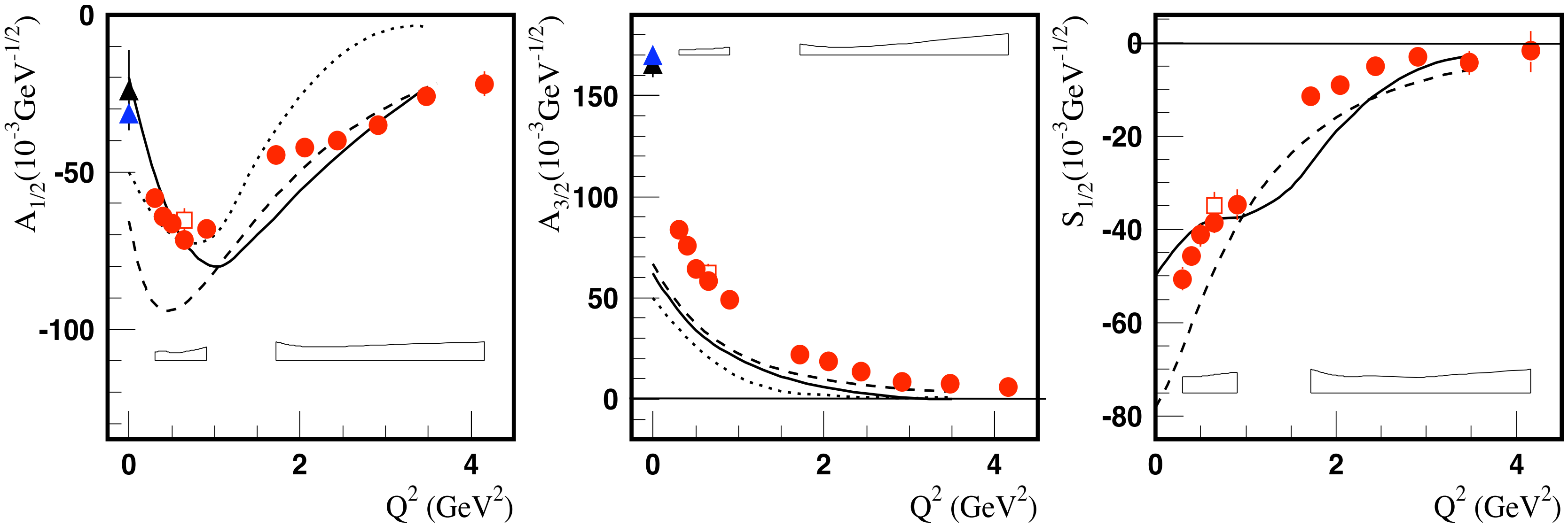
$$\rho_0^{NN^*}(\vec{b}) = \int_0^\infty \frac{dQ}{2\pi} Q\, J_0(b\,Q) F_1^{NN^*}(Q^2),$$

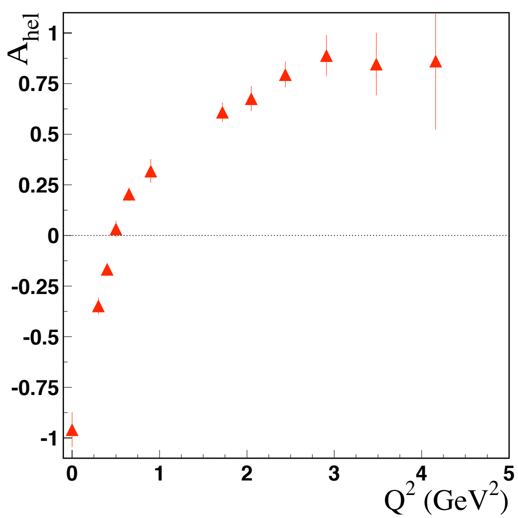


The transition of p→$N^+(1440)P_{11}$ in LF helicity +1/2 → +1/2 is dominated by ***up*** quarks in a central region of radius ~0.4 fm, and by ***down*** quarks in an outer band up to ~0.8 fm.

Light (**dark**) regions: **positive** (**negative**) charge densities

Helicity amplitudes for $\gamma pN(1520)D_{13}$ *CLAS*



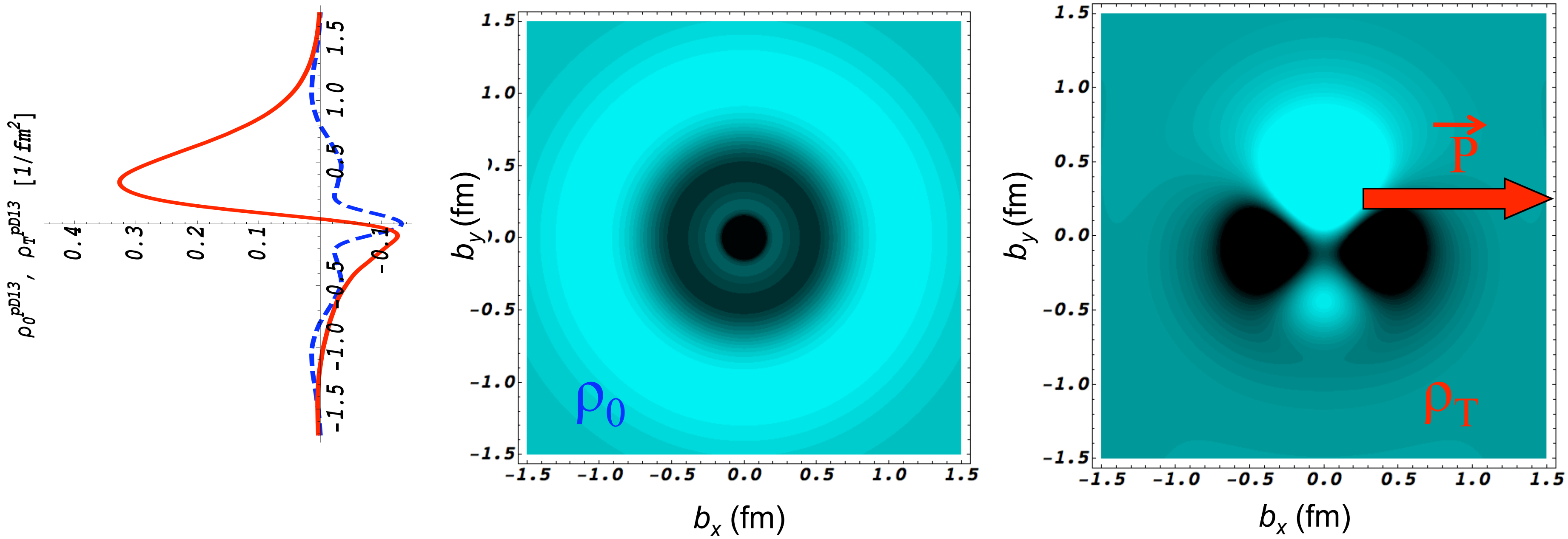


- First data set that allows determination of $S_{1/2}(Q^2)$
- Clear evidence of helicity switch from λ=3/2 dominance at Q^2=0 to λ=1/2 dominance at high Q^2

  => This is a stringent prediction of the CQM.

$$A_{hel} = \frac{(A_{1/2})^2 - (A_{3/2})^2}{(A_{1/2})^2 + (A_{3/2})^2}$$

Transition charge density of $\gamma pN(1520)D_{13}$

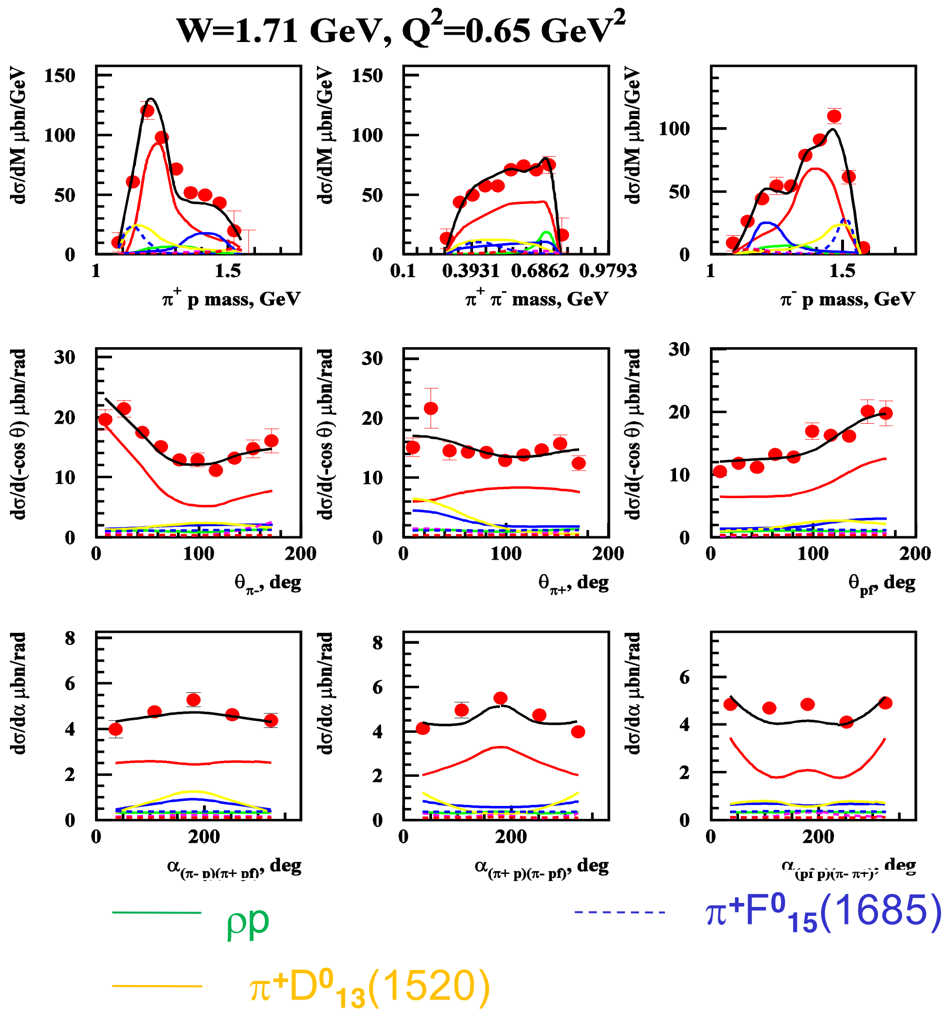


- Proton and $N(1520)D_{13}$ are in LF helicity +½ state, transition is dominated by d-quarks in radius ~0.4 fm in center, and by u-quarks in a region up to 1.3 fm.
- Very strong quadrupole pattern extending to large radius.
- Proton and $N(1520)D_{13}$ polarized along x-axis with opposite spin projections
- Nearly full flavor separation perpendicular to polarization vector in transverse space.

N* resonance studies in ep → ep$\pi^+\pi^-$ *CLAS*

M.Ripani et al, PRL 91 (2003), 022002

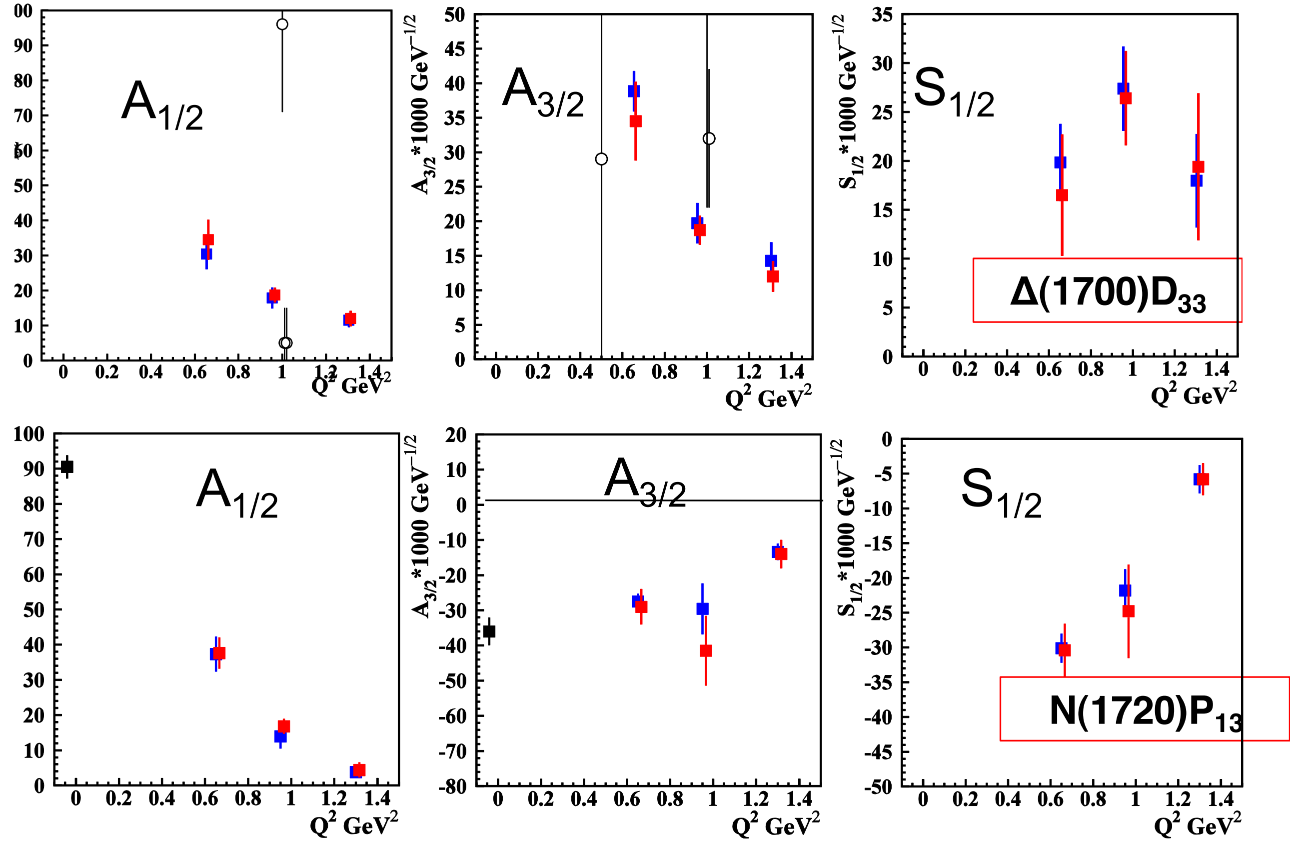
Developed model JM09 to analyze sets of nine independent, 1-dim. cross sections at fixed Q^2 and W.



Helicity amplitudes for high mass states

CLAS

- Regular Breit-Wigner amplitude
- Unitarized Breit-Wigner amplitude



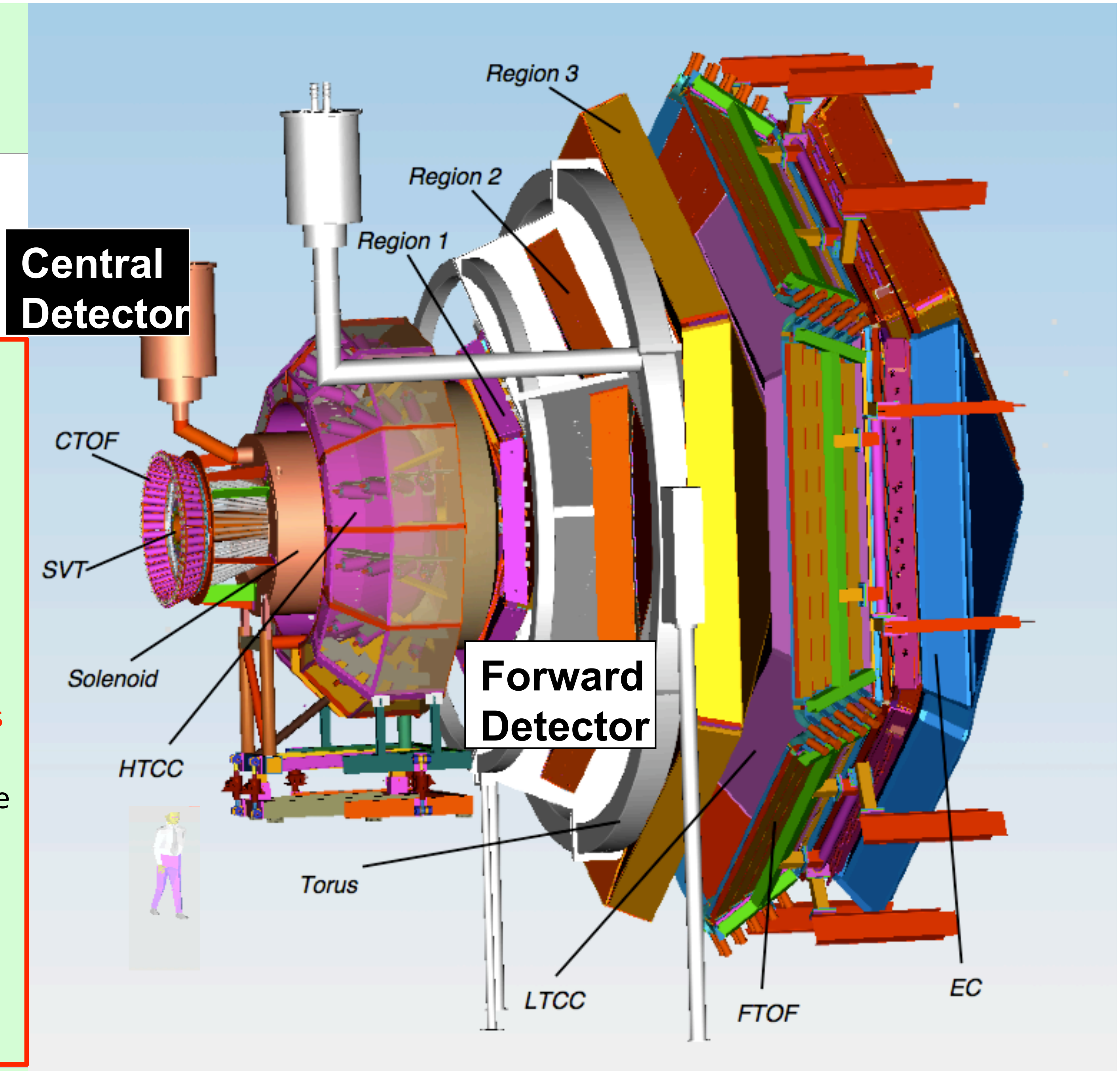
=> First consistent extraction of transition form factors for these states

CLAS12

CLAS12 supports a broad program in hadronic physics.

Plans to study excited baryons and mesons:

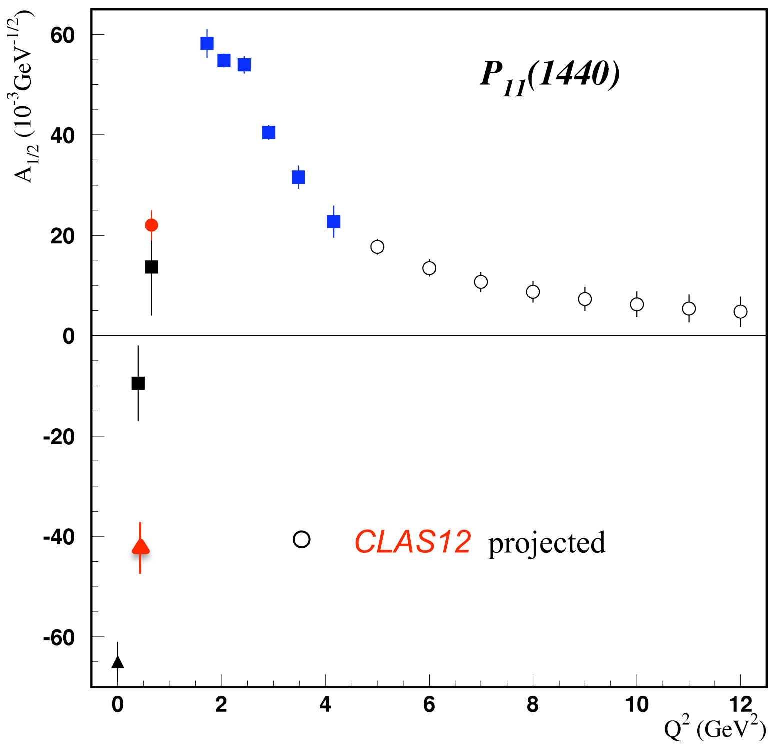
- Search for excited Ξ* , Ω^-
- Search for hybrid mesons
- Forward tagger to replace current tagging system.
- Transition form factors at high Q^2



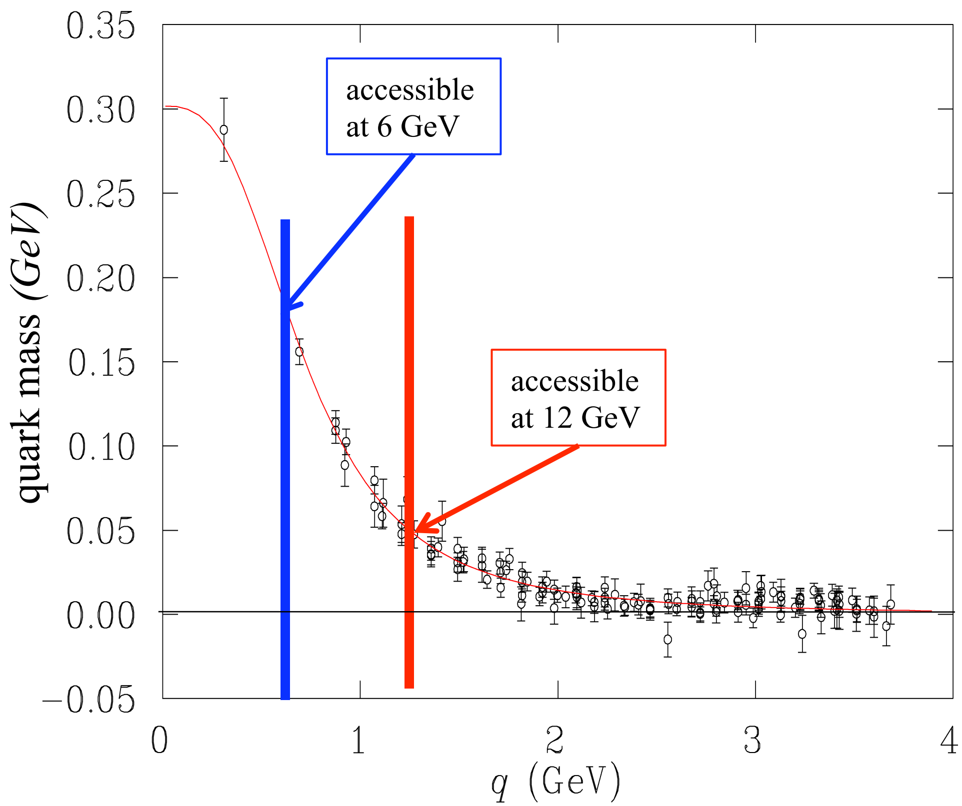
Resonance Transitions at12 GeV

CLAS12

Approved experiment E12-09-003 will extend access to transition ff for many prominent states in the range to Q^2=12GeV^2.



Electromagnetic form factors are sensitive to the effective quark mass.



At 12 GeV we probe much of the transition from effective d.o.f., i.e. constituent quarks, to elementary quarks.

Conclusions

- The N* program on proton targets is close to achieving the goal of "complete" measurements for $K^+\Lambda$ ($K^+\Sigma^0$) channels on proton target and nearly complete measurements on several other channels.
- Plan to complete the program on neutrons in 2011 with polarized HD target.
- Transition amplitudes for lower mass states reveal information about the transverse charge and current distribution for these transitions. These will be extended to higher Q^2 with CLAS12.
- A program is being developed to search for doubly-strange baryons (cascades) after the 12 GeV upgrade.