Transition Form Factors at CLAS and CLAS12

M. Ungaro, M. Taiuti
for the CLAS collaboration

Overview
N* Form Factors are Back in Fashion
Single, Double Meson results
12 GeV Outlook

The discovery of resonances ('50s)

$1750

$200

$0.14

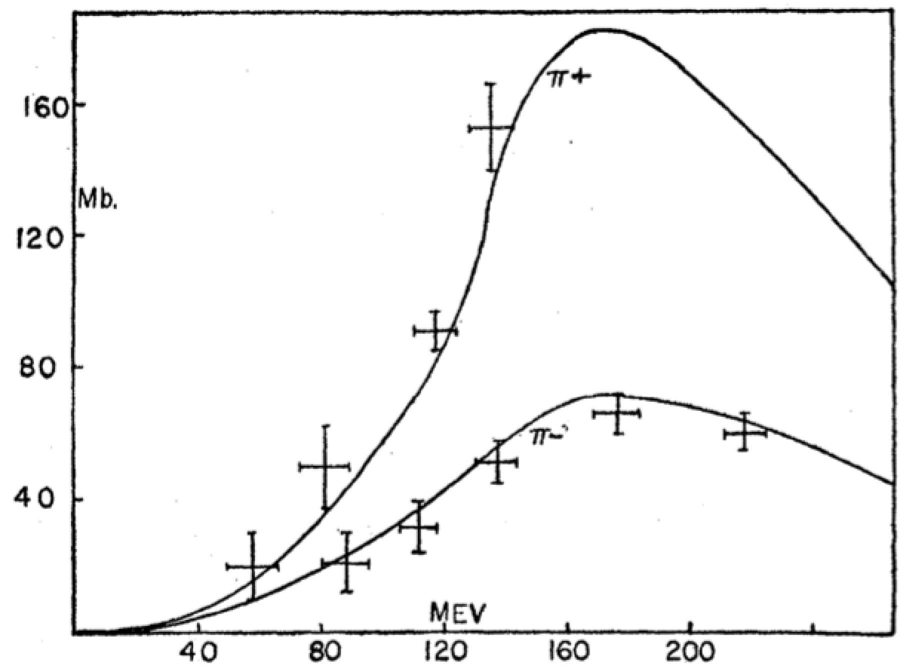


FIG. 3. Total cross sections for scattering of π^+ and π^- mesons in hydrogen (including charge exchange).

Priceless
(at least for scientists)

Why N* ?

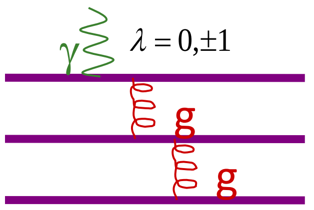
A major goal of hadron physics is to probe the internal structure of the nucleon.

The N spectrum is a direct reflection of the underlying degrees of freedom of the nucleon.*

Electromagnetic transition form factors probe the underlying spatial and spin structure vs distance scale.

Beyond CQM, pQCD

The structure of the nucleon and its excited states is a lot more complex than CQM

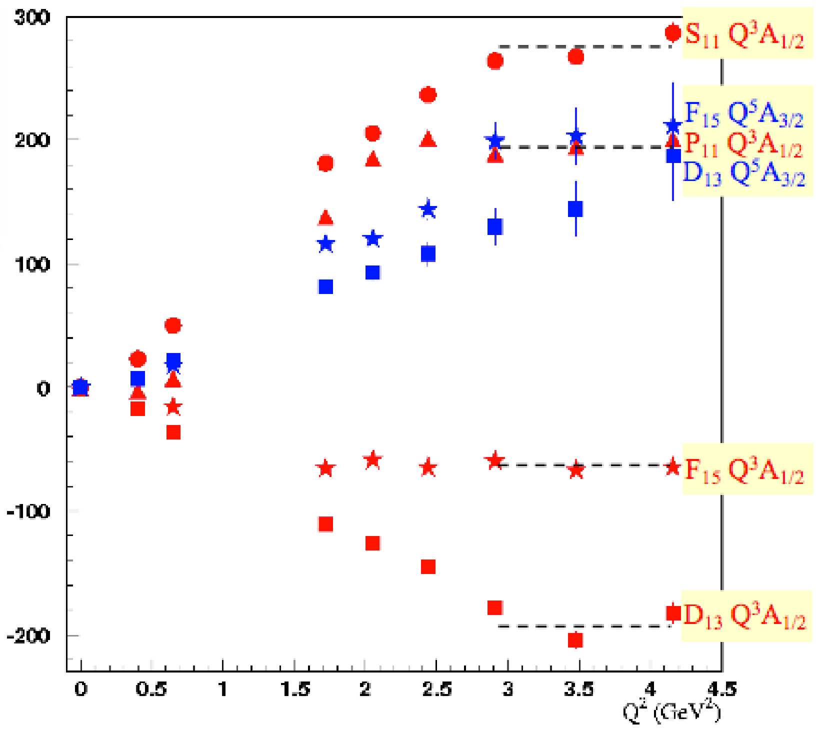


$$A_{1/2} \propto 1/Q^3$$

$$A_{3/2} \propto 1/Q^5$$

$$G_M^* \propto 1/Q^4$$

Constituent Counting Rule tell us what will happen at high Q^2



but pQCD cannot:

- produce mass in the chiral limit
- explain dynamics of quark-gluon interaction at low energy
- explain quark confinement

N* are back in fashion

Even as we speak, we need to fully understand:

- the essential nature of quark confinement.
- the dynamics of quark-gluon interaction at low energy

The role of quarks and gluon in nuclei

Step into the domain of relativistic quantum field theory where the key phenomena can only be understood with non-perturbative methods

Understanding nature using a non-perturbative approach is beginning to become a reality… and measurements of nucleon resonances play a crucial role in all this.

Lattice QCD

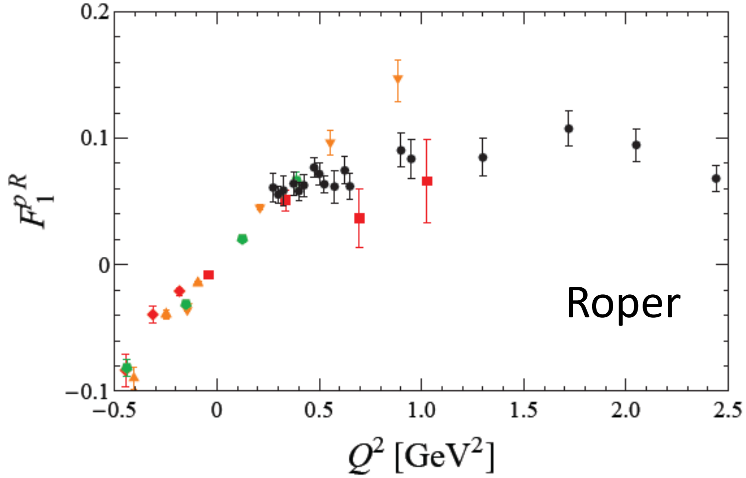
Dynamical Chiral Symmetry Breaking

Light Cone Sum Rule

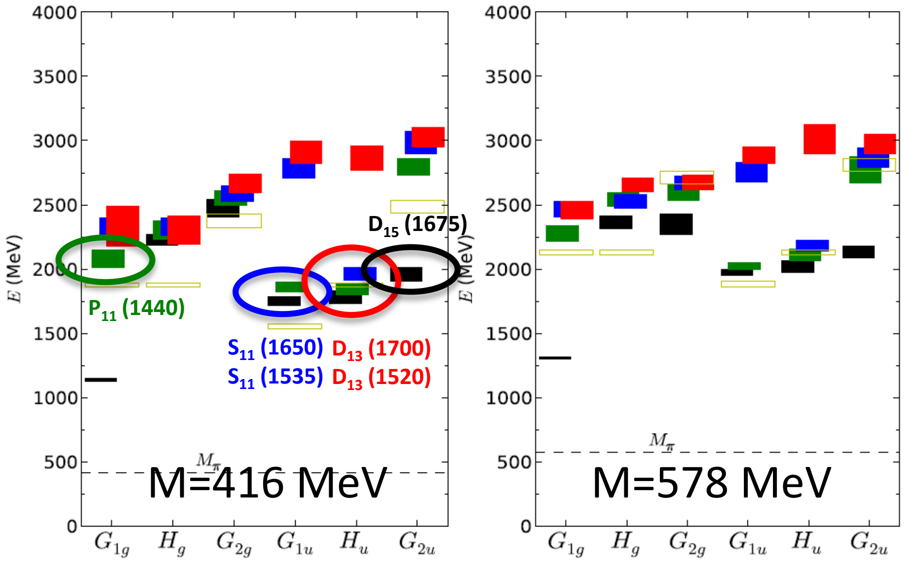
Lattice QCD

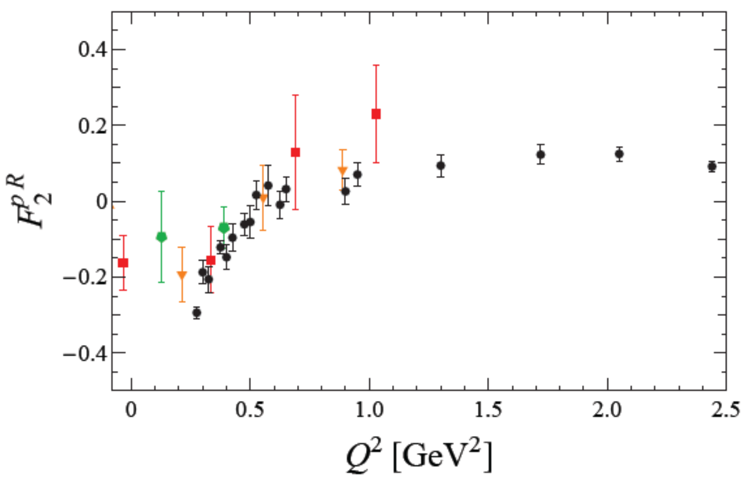
JLAB
Carnegie Mellon
Univ. of Maryland
Trinity College (Dublin)

New Techniques:
Anisotropic Lattices
3 flavors of quarks



First time: baryon spectra for the excited states

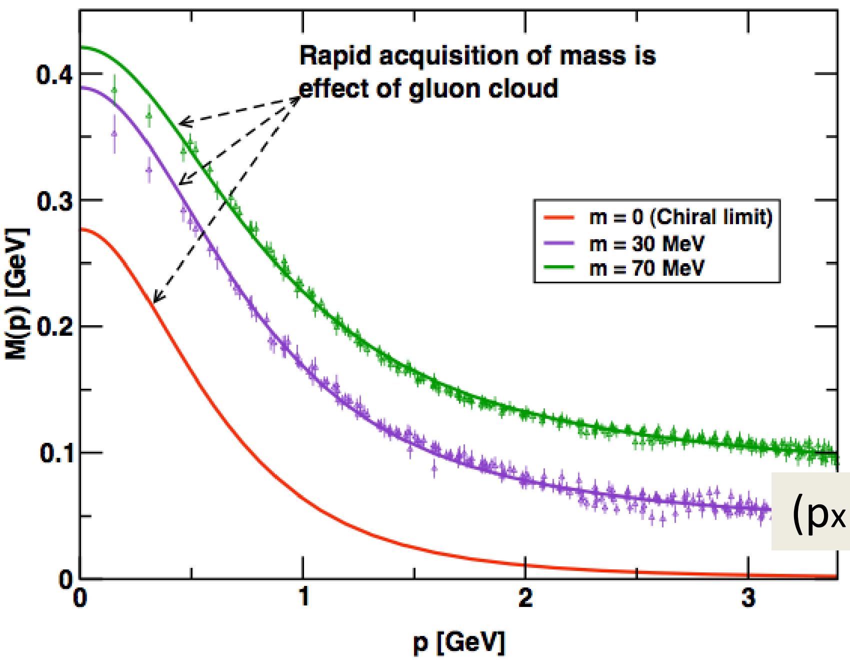




Huey-Wen Lin: radial excitations to calculate form factors

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

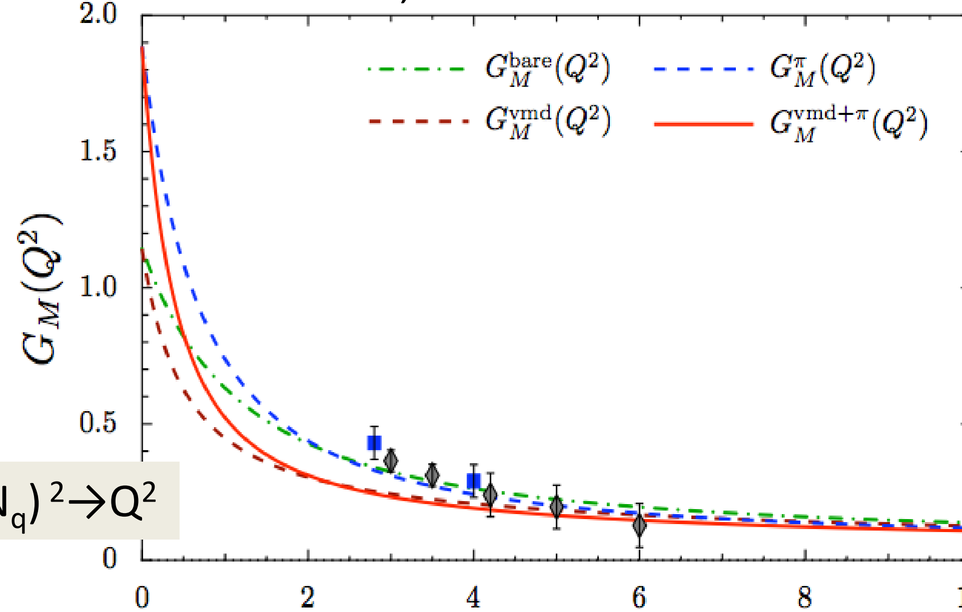
Dynamical Chiral Symmetry Breaking



points: unquenched LQCD
curves: Dyson-Schwinger Equation (DSE) calculation

$(p \times N_q)^2 \rightarrow Q^2$

Cloet, Bentz and Thomas



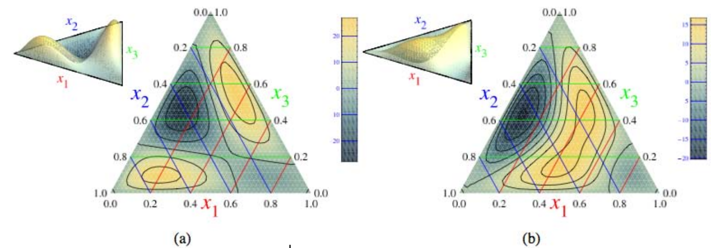
N → Δ transition form factor

We can use high precision measurements of nucleon-resonance transition form factors to chart the momentum evolution of the dressed-quark mass

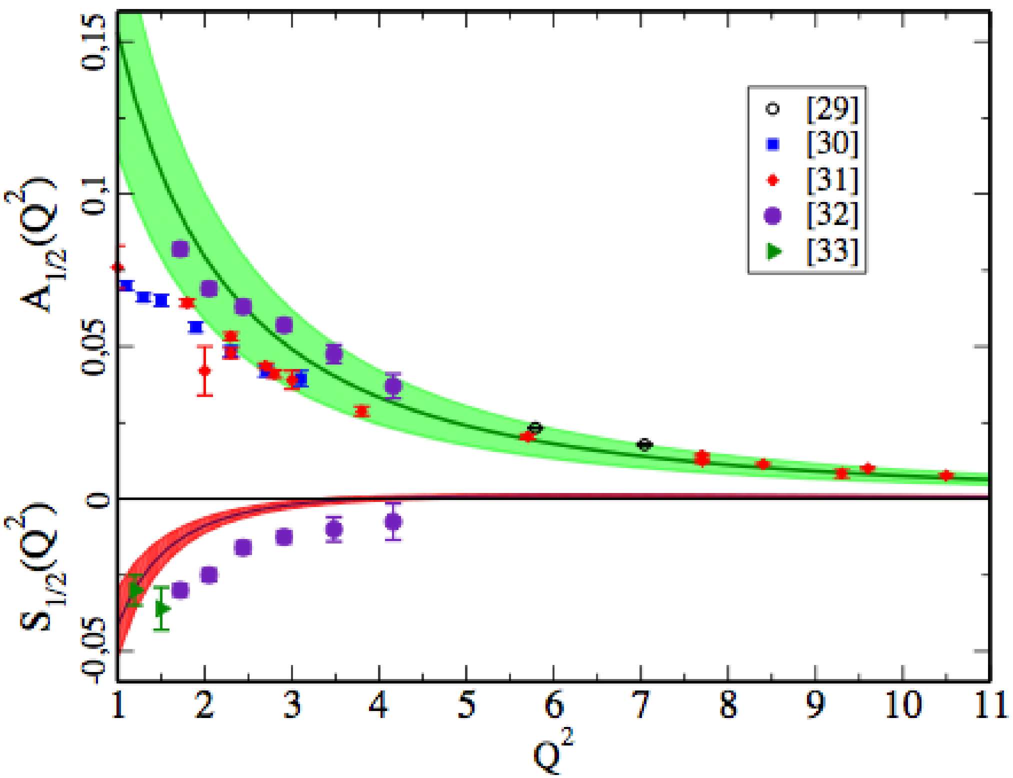
Light Cone Sum Rule

Transition Form Factor ←→ Distribution Amplitudes

DA from Lattice QCD (*Warkentin et al.)* :



Proton $\frac{1}{2}^+$ S_{11} $\frac{1}{2}^-$



29, 30: Dalton and Denizli
31: Brasse parameterization
32: Aznauryan analysys of e1-6 CLAS data

Most of the experimental data presented in the previous slides have been provided by the CLAS Collaboration

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Transition Form Factors of the Nucleon

M.Taiuti

Outline

- Physics motivations
- Status of experiments
- CLAS - a detector for $Q^2 \approx GeV^2/c^2$
- Conclusions

Electromagnetic Interactions with Nucleons and Nuclei

Santorini, Greece, 5-10 October 1999

Nice talk, but you were clutching at straws (ti sei arrampicato sugli specchi)!

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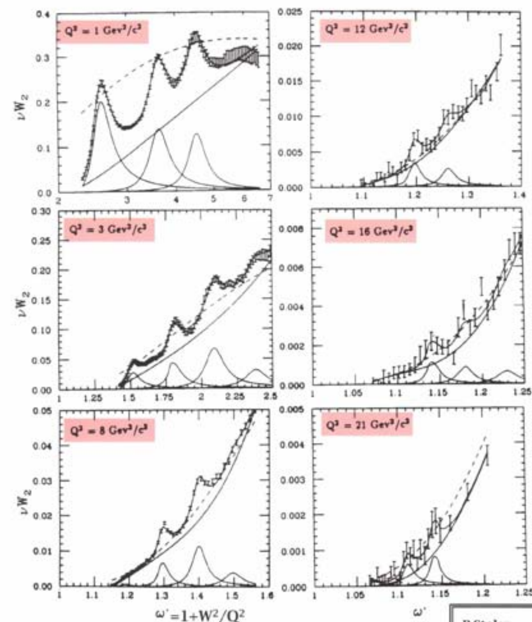


P.Stoler
Phys.Rep. 226(1993)103

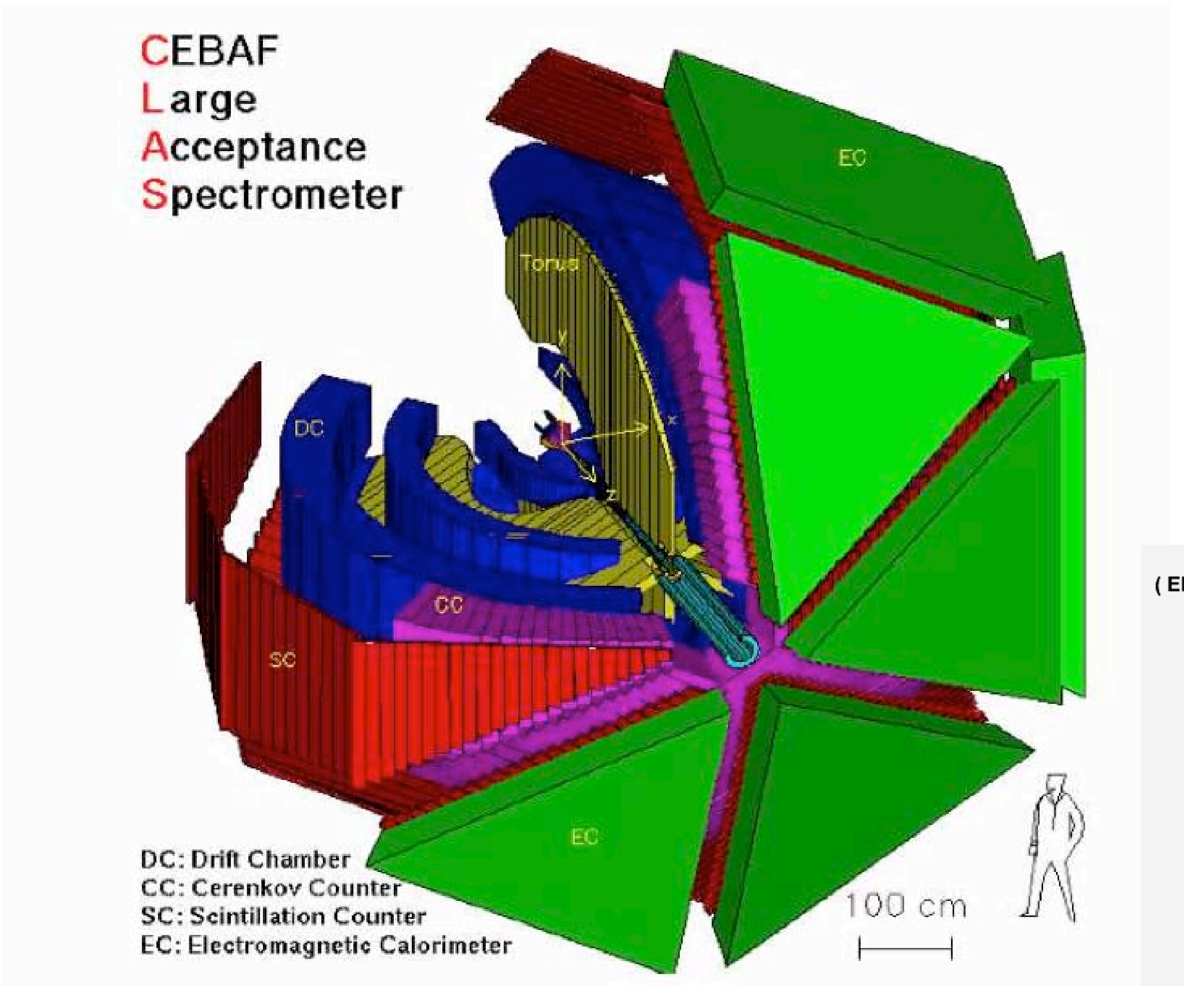
N* Program in CLAS

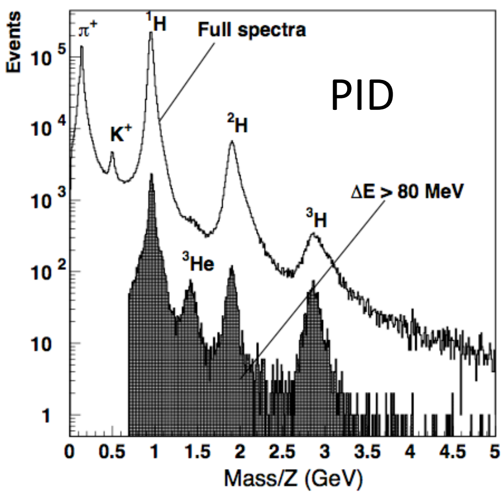
Map the γNN* electrocouplings as a function of photon virtuality with the combined analysis of the major electroproduction channels

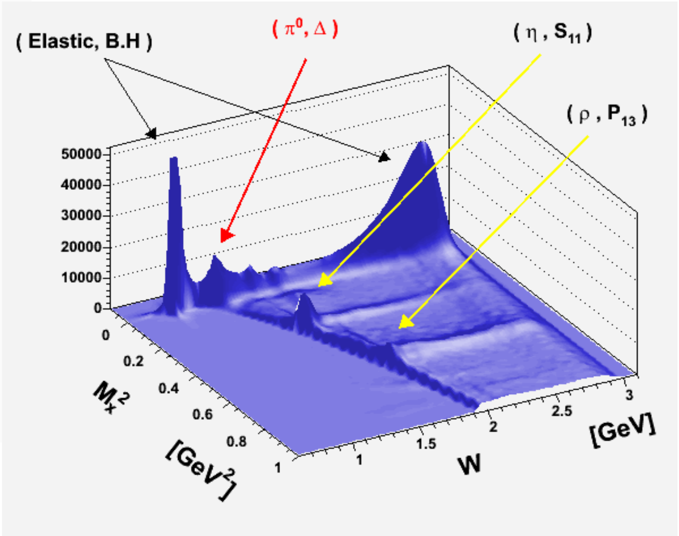
State	$\beta_{N\pi}$	$\beta_{N\eta}$	$\beta_{N\pi\pi}$
$\Delta(1232)P_{33}$	0.995		
$N(1440)P_{11}$	0.55-0.75		0.3-0.4
$N(1520)D_{13}$	0.55-0.65		0.4-0.5
$N(1535)S_{11}$	0.35-0.55	0.45-0.60	<0.1
$N(1620)S_{31}$	0.20-0.30		0.7-0.8
$N(1650)S_{11}$	0.60-0.95	0.03-0.10	0.1-0.2
$N(1685)F_{15}$	0.65-0.70		0.3-0.4
$\Delta(1700)D_{33}$	0.1-0.2		0.8-0.9
$N(1720)P_{13}$	0.1-0.2	0.01-0.15	> 0.7

Several channels with entirely different non-resonant amplitudes allow the reliable determination of electrocouplings

The CLAS Spectrometer







Analysis Tools

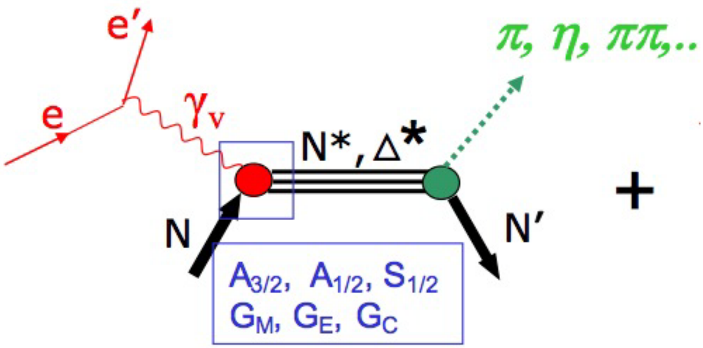
Single pseudoscalar meson production, e.g. Nπ, Nη

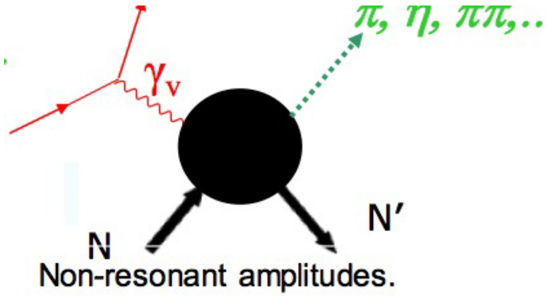
Unitary isobar model (UIM)

- non-resonant amplitudes incorporate nucleon and meson Born terms, vector meson exchanges, Regge terms at high energy
- resonant terms incorporate relativistic Breit-Wigner amplitude with energy-dependent widths
- full amplitude unitarized in K-matrix approximation

Fixed-t dispersion relations (DR)

- resonance amplitudes constructed in same way as in UIM
- non-resonant amplitudes from Born terms and dispersion relation.





Double pion channels, e.g. $p\pi^+\pi^-$

Isobar model (JM)

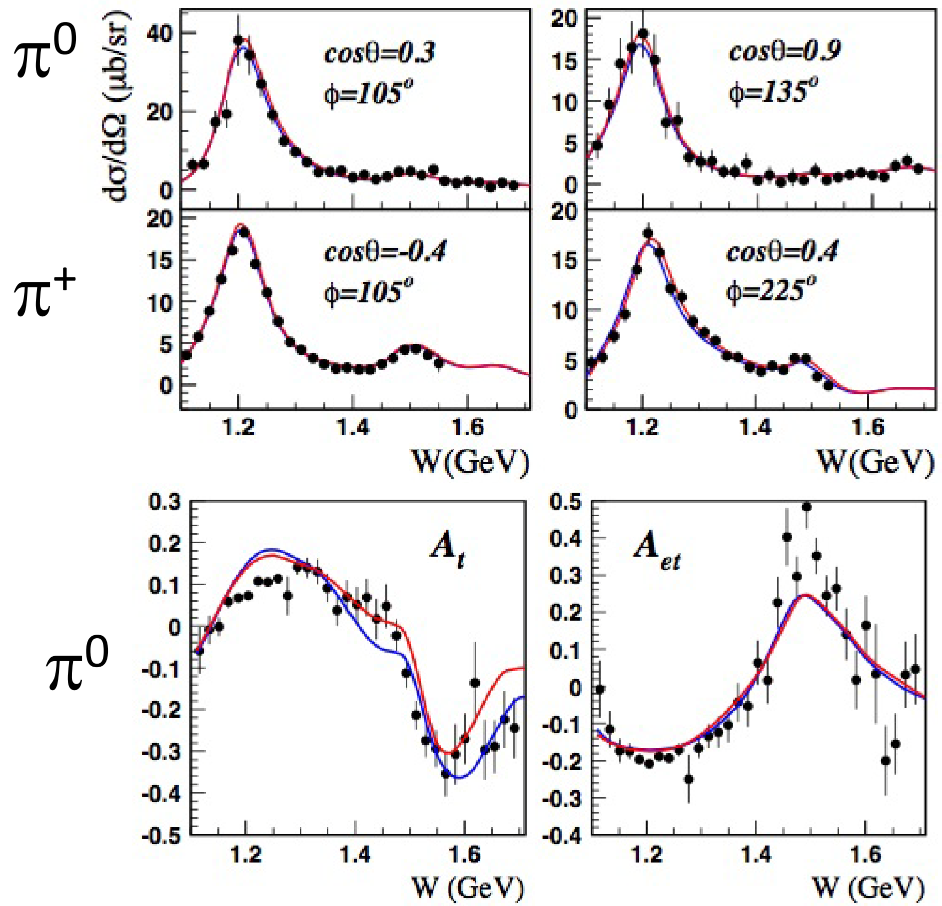
- Includes leading contributions as observed in the data. Fit to 9 single-dimensional projections diff. cross sections.

Selection of CLAS Results

A good summary can be found in
I.G. Aznauryan, V.D. Burkert **arXiv:1109.1720 [hep-ph]**

Single Meson Results

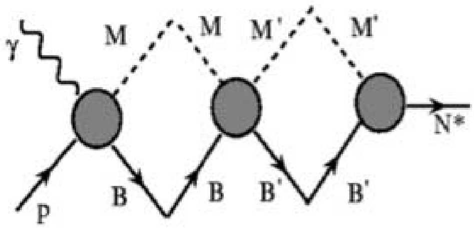
Δ_{33}	$(56, 0^+) \rightarrow (56, 0^+)$
Roper	$(56, 0^+) \rightarrow (56, 0^+)$
$D_{13}(1520)$	$(56, 0^+) \rightarrow (70, 1^-)$

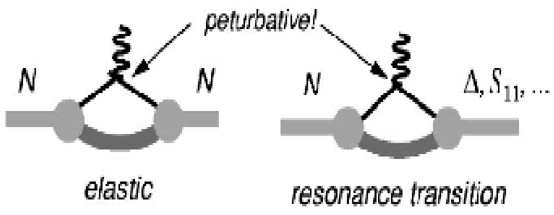


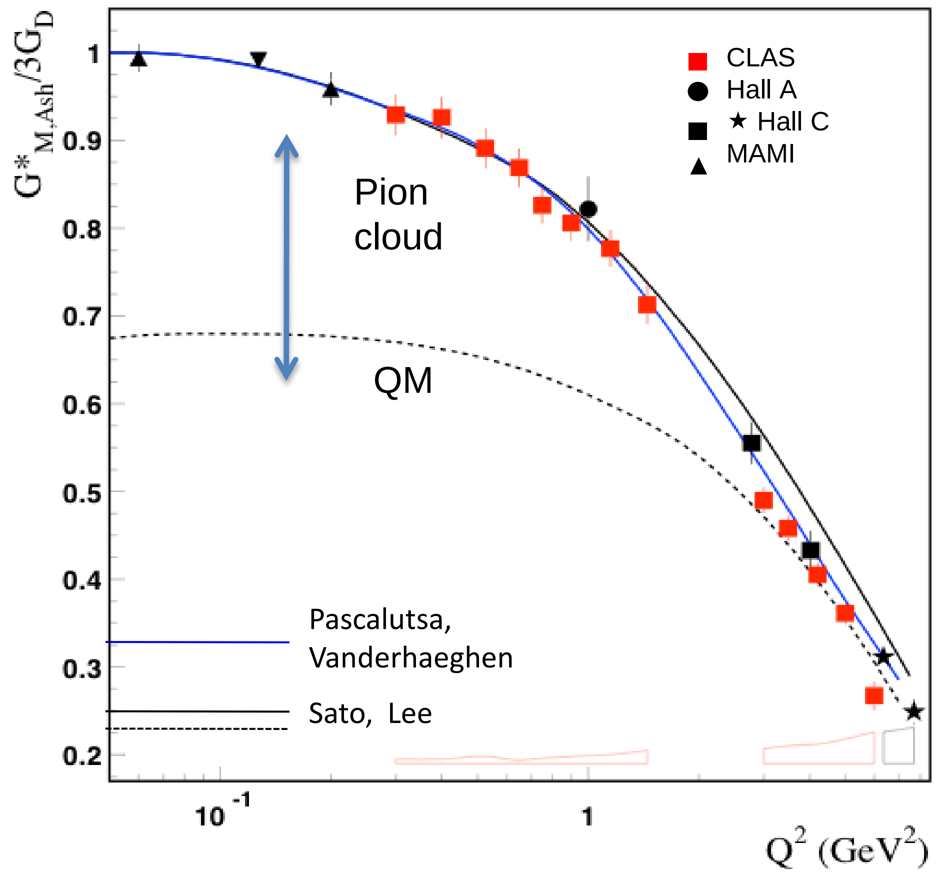
Q^2=0.4 GeV^2/c^2

N → Δ Transition Form Factor

Meson-Baryon Dressing:
Dynamical Reaction Models show huge contribution of pion cloud to Magnetic Form Factor



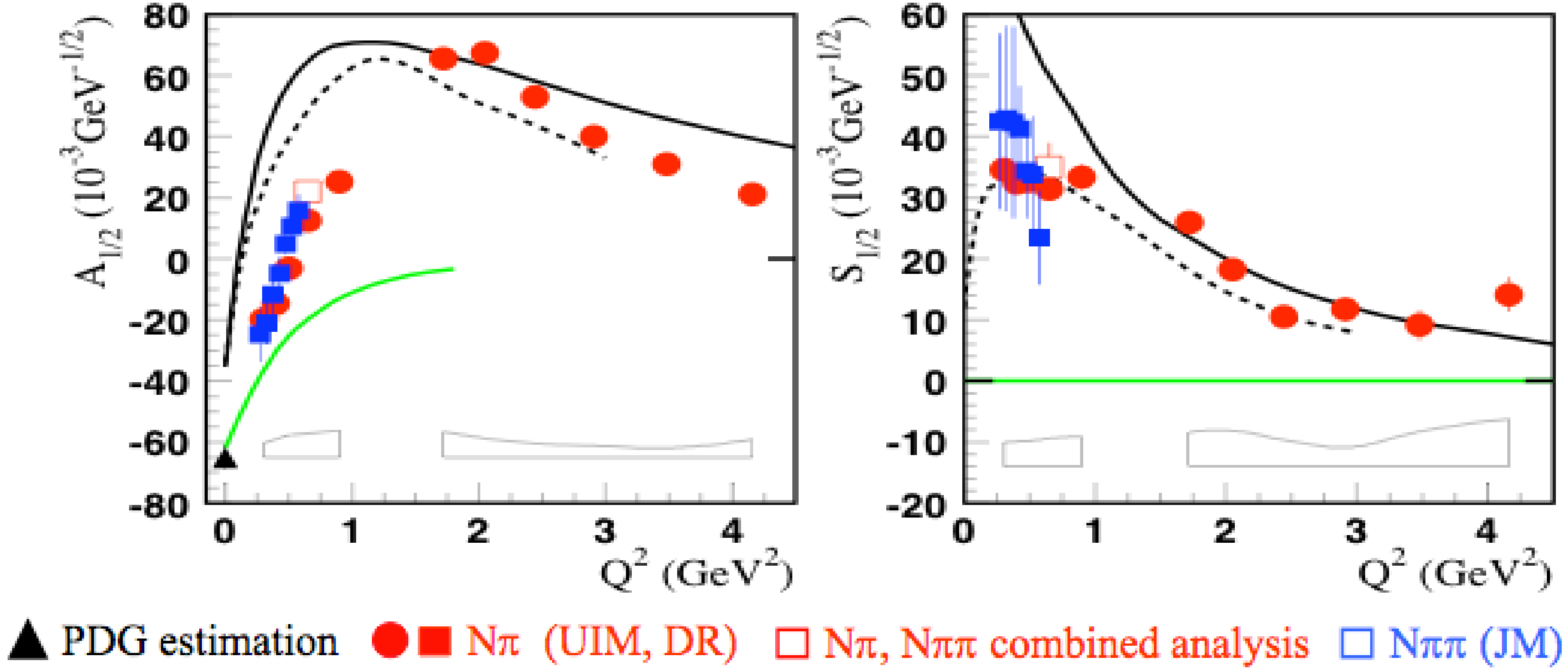




Pascalutsa: Large N_C links N → Δ Transition Form Factor to the e.m. properties of the nucleon!
N → Δ GPD H_M is related to isovector elastic GPD E(x,ξ, t)

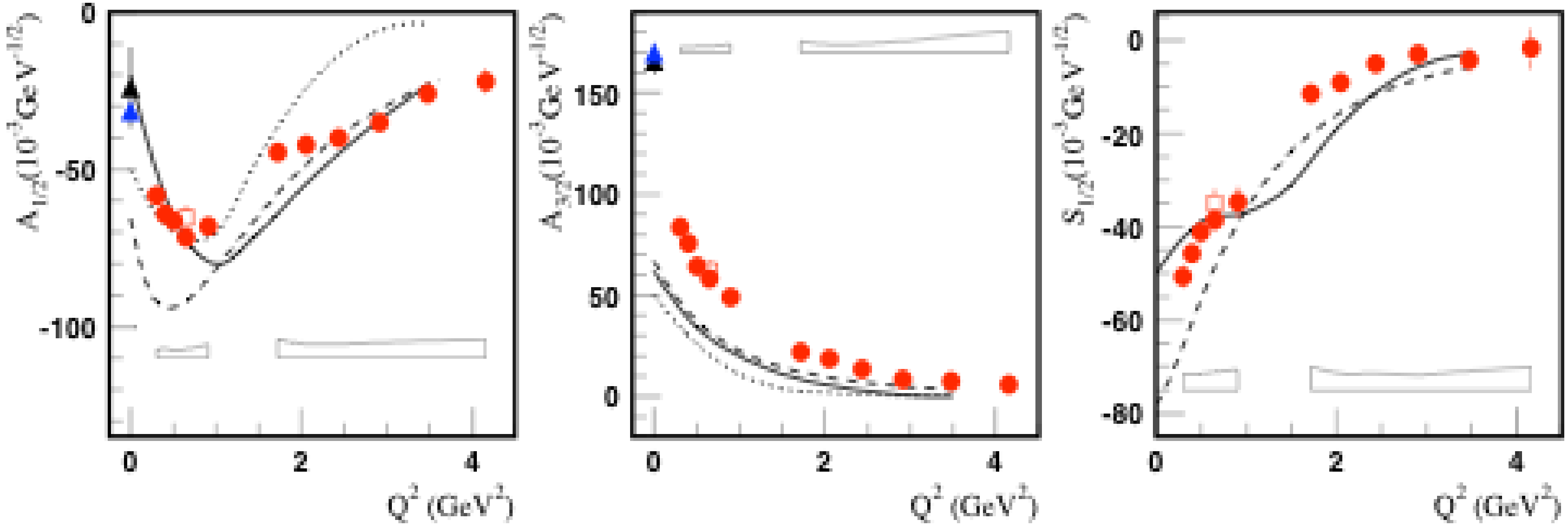
The Roper Resonance

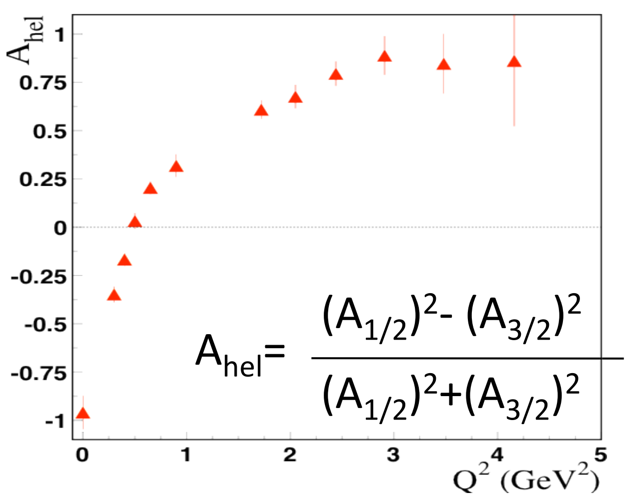
I. Aznauryan et al., Phys.Rev.C78:045209,2008



- 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 radial excitation of nucleon ( )
- Rules out the Roper as a gluonic excitation ( )
- Meson, non resonant contributions necessary at low Q^2?

$D_{13}(1520)$ Transition Amplitudes





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

- First data set that allows determination of $S_{1/2}(Q^2)$
- Very Accurate result for the Transverse Amplitudes
- Clear evidence of helicity switch from helicity=3/2 dominance at Q^2=0 to helicity=1/2 dominance at high Q^2

Double Meson Production

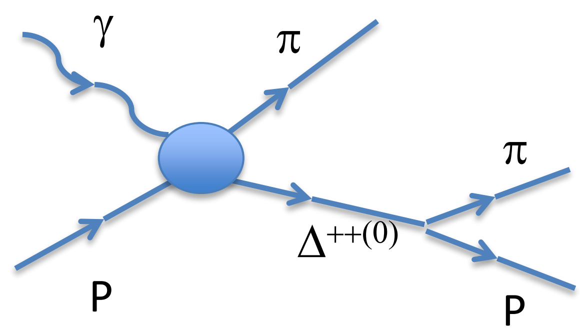
Single, double meson channels are the main players in the resonance region: sensitive to almost all excited proton states

The combined analysis of Nπ, N$\pi\pi$ data is key in the entire N* program: allow us to determine with high precision both the resonant and non-resonant amplitudes

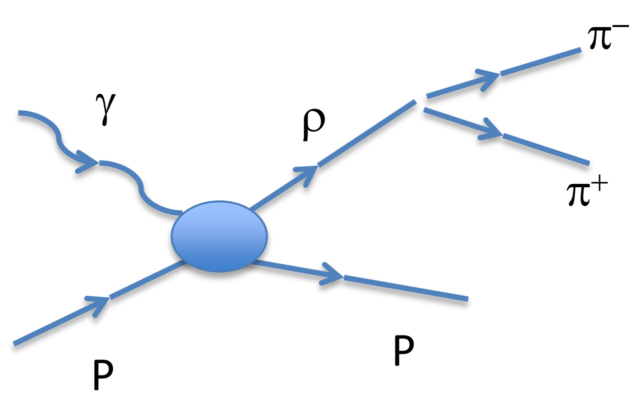
JLAB-MSU meson baryon model for $N\pi\pi$ electroproduction

Channels included:

all N*s with $\pi\Delta$ decays
Reggeized Born Terms
additional $\pi\Delta$ Contact Term



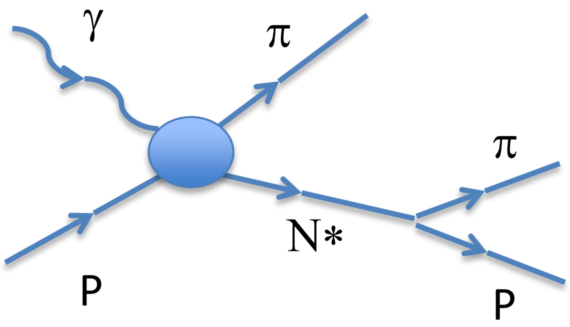
all N*s with ρP decays and 3/2+(1720) candidate
Diffractive Ansatz for non-resonant part
ρ line shrinkage in N* region



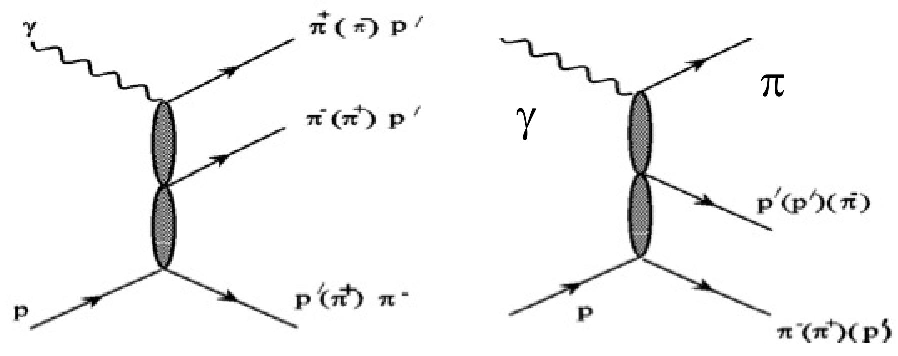
JLAB-MSU meson baryon model for Nππ electroproduction

Channels included:

D_{13}, F_{15}, $P_{33}(1640)$

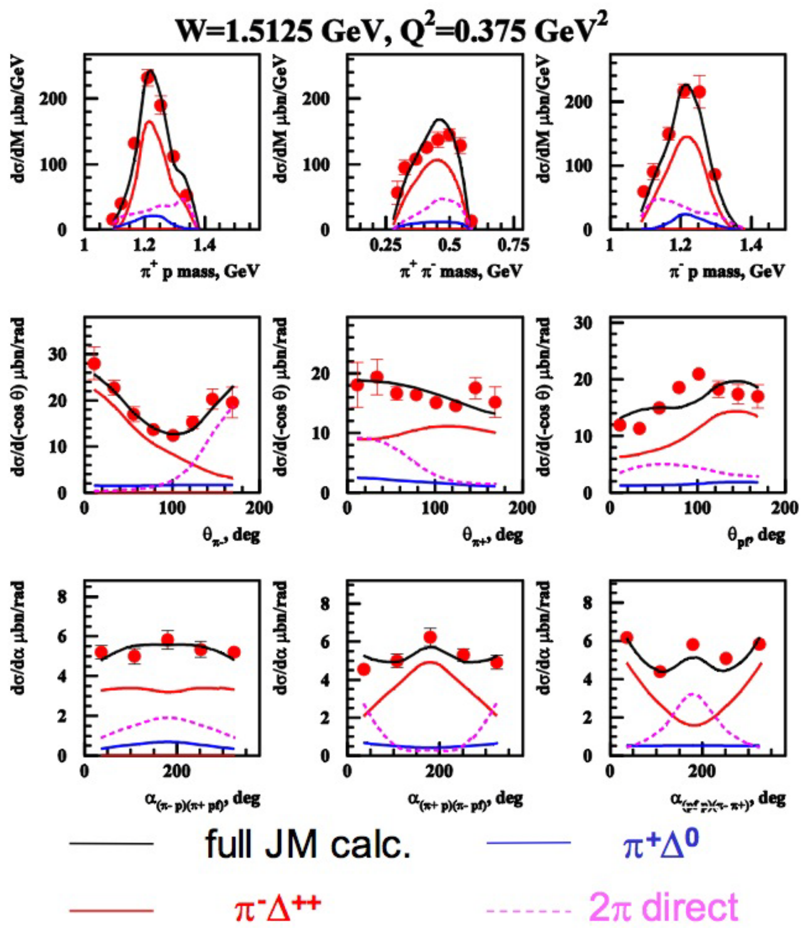


Direct 2 pion production
(required by Unitarity and confirmed by CLAS Pππ data)

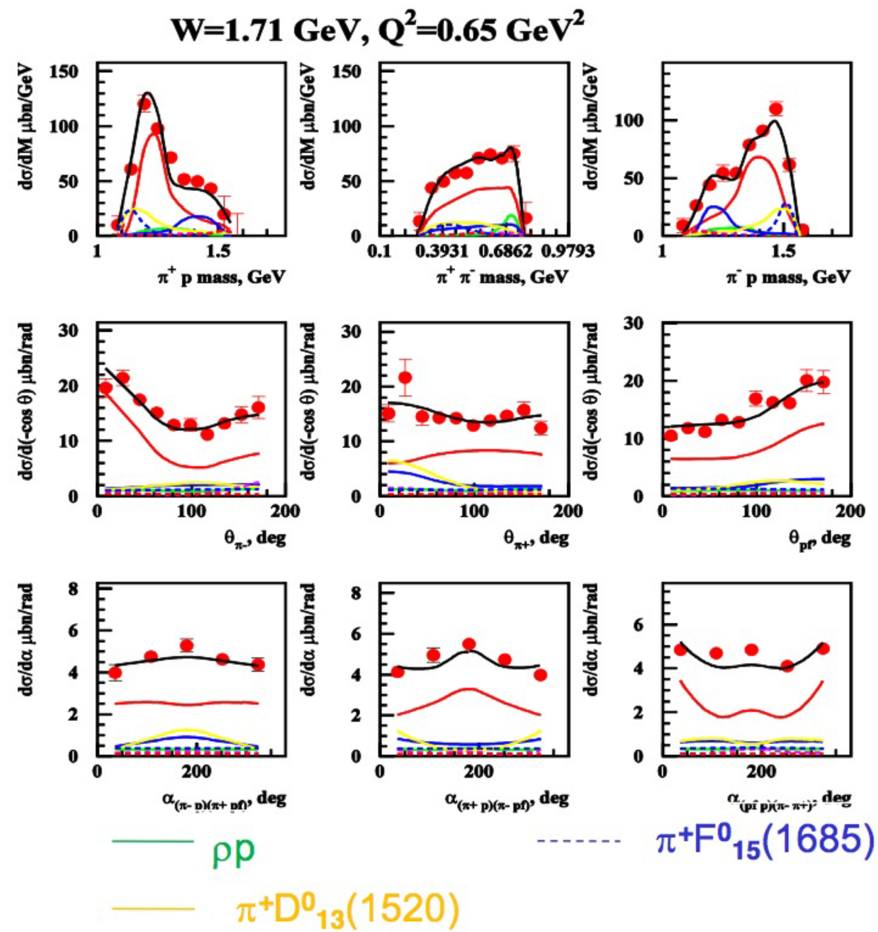


$P\pi^+\pi^-$ Production

Fedotov, PRC 79 (2009)

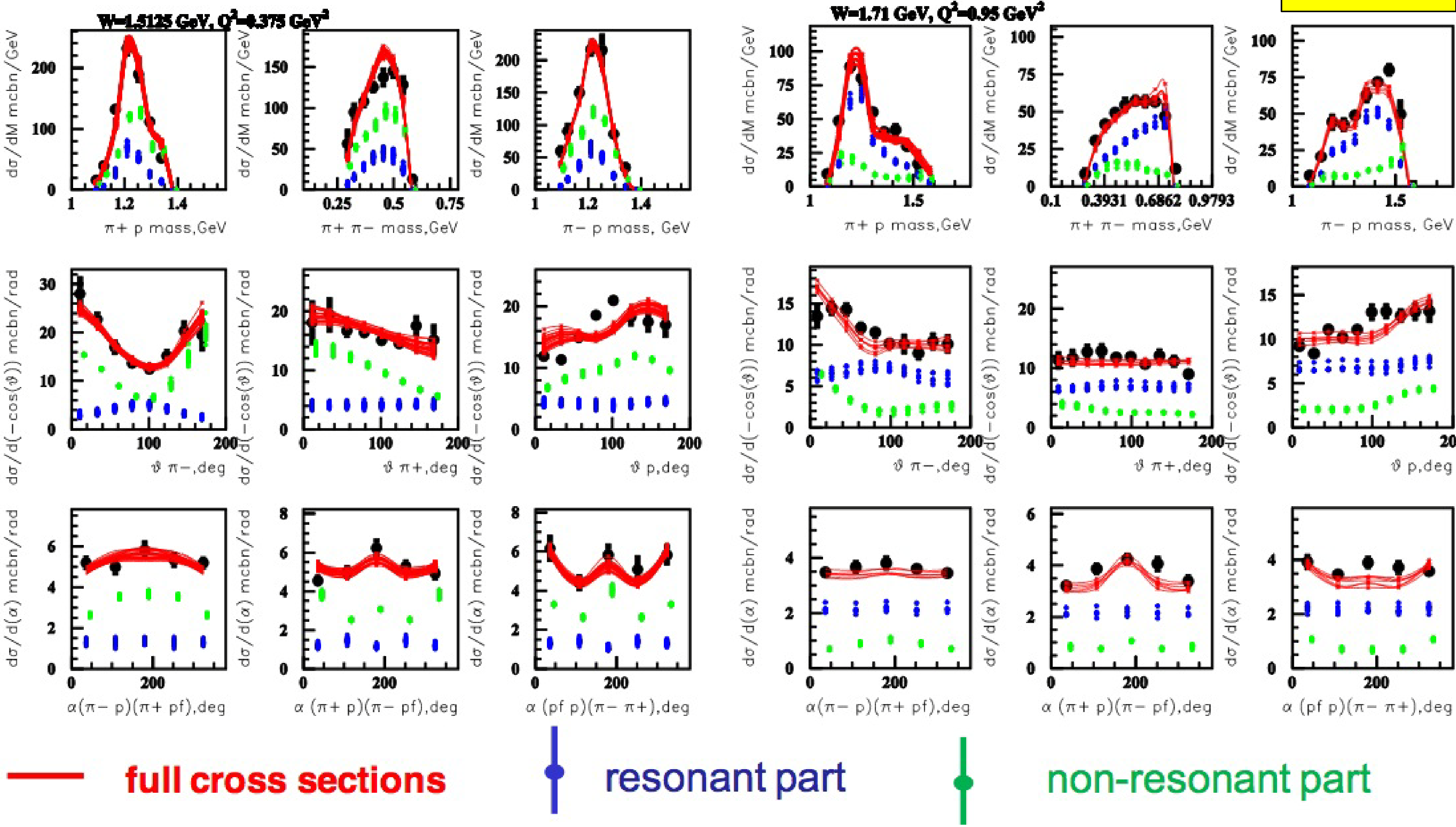


Ripani, PRL 91 (2003)



Resonant, non-resonant parts of Nππ

V. Mokeev



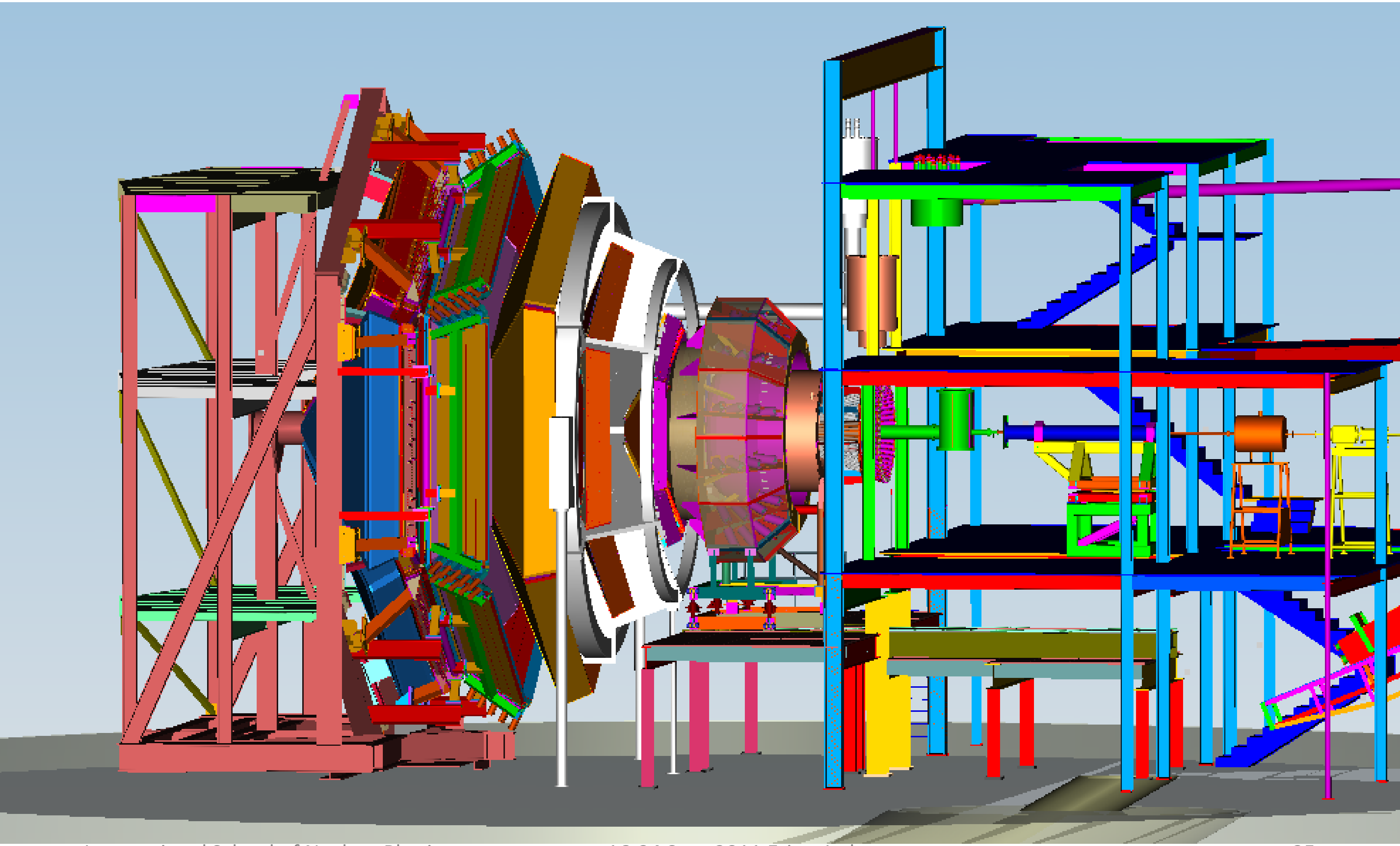
Hall B

Towards 12 GeV

In just 14 months from today

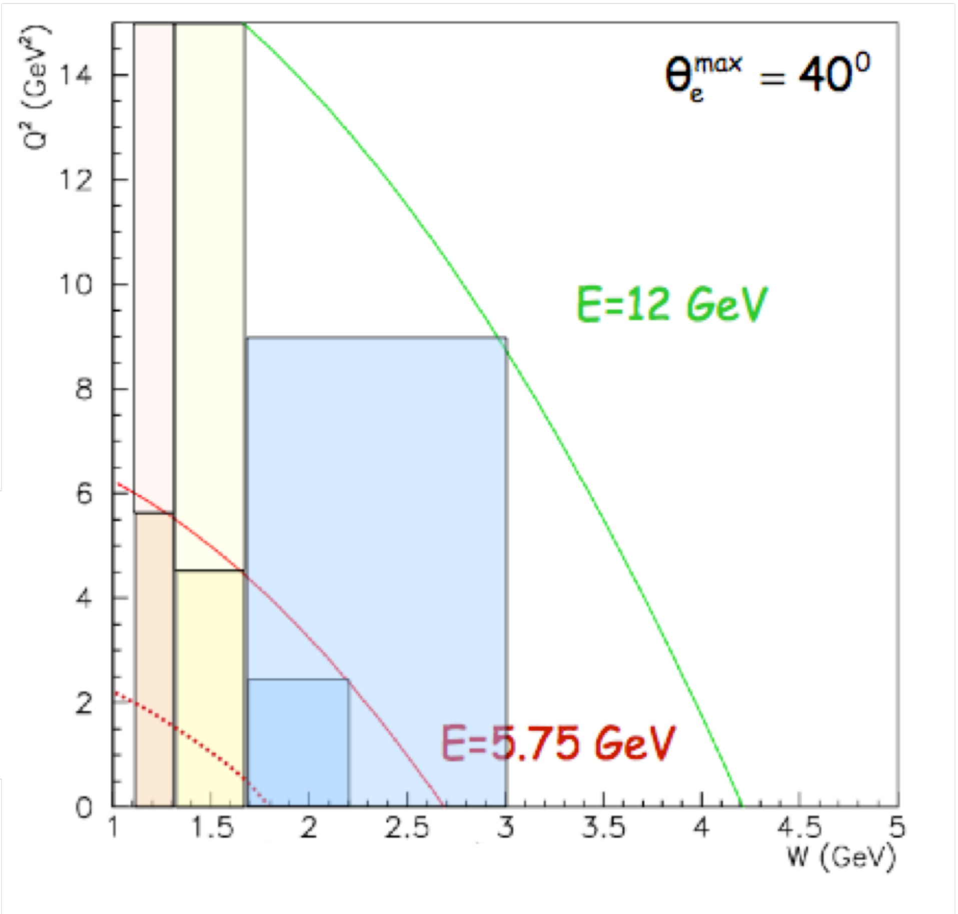
- ✧ Remove much of CLAS May 14, 2012 (est. 5 ½ months)
- ✧ Begin ***CLAS12*** installation Nov 1, 2012
- ✧ Complete ***CLAS12*** installation 4th QT 2014

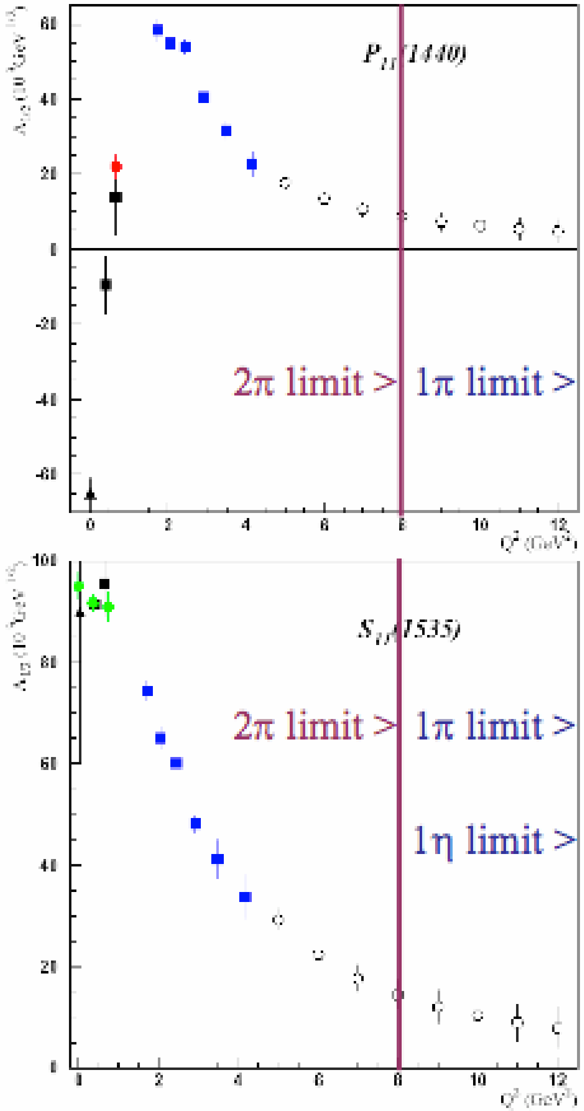
Full *CLAS12* Assembly in Hall B



not so distant future…

60 Days at 10^{35} cm^{-2}s^{-1}



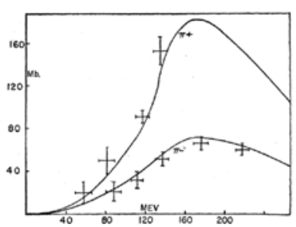


CLAS12 - Experiments & Run Groups

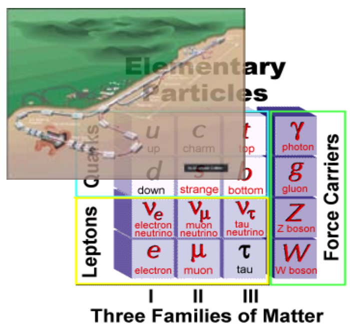
Proposal	Contact Person	Physics	Energy (GeV)	Days requested	PAC days	SR	Parallel Running	Run group days	Comment
E12-09-103	Gothe	N* at high Q^2	11	60	**40**	**B+**			
E12-06-119(a)	Sabatie	DVCS pol. beam	11	80					
PR-11-005	Battaglieri	Meson Spectroscopy	11	80+39	**119**	**A-**			
E12-06-112	Avakian	$ep \rightarrow e\pi^{+/-/0} X$	11	60			119		
E12-06-108	Stoler	DVMP in π^0,η prod L/T separation	11 8.8 6.6	80 20 20			20 20	159	
E12-06-119(b)	Sabatie	DVCS pol. target	11	120			120		Assume polarized experiments run 50% of time w/ reversed field
E12-06- 109	Kuhn	Long. Spin Str.	11	80	**80**	**A**	50	175	
E12-07-107	Avakian	TMD SSA	11	103			5		
E12-09-007(b)	Hafidi	Partonic SIDIS	11	103					
E12-09-009	Avakian	Spin-Orbit Corr.	11	103					
E12-06-106	Hafidi	Color Trans. ρ^0	11	60	**60**	**B+**	60	60	
PR-11-005	Niccolai	DVCS on neutrons	11	90			90	90	
PR-11-006	Jaros	Heavy Photon Search	2.2, 6.6	Test run	**14**		14	14	C2 , Non-CLAS12
E12-06-117	Brooks	Quark Hadronization	11	60	**60**	**A-**	60	60	
E12-06-113	Bültman	Neutron Str. Fn.	11	40	**40**	**A**	40	40	
E12-07-104	Gilfoyle	Neutron mag. FF	11	56	**30**	**A-**	56		007/008 need 26d reversed field
E12-09-007(a)	Hafidi	Partonic SIDIS	11	56				82	
E12-09-008	Contalbrigo	Boer-Mulders/Kaons	11	56			26		
Total				**1366**	**443**			**660**	

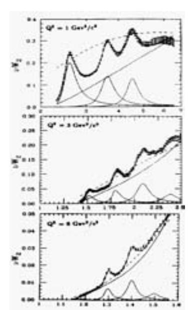
Outlook

50s



60-70s





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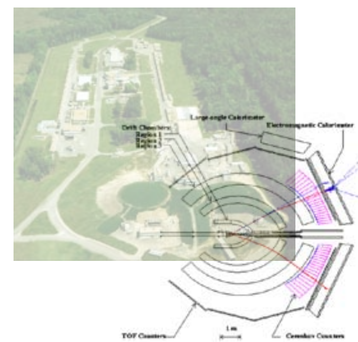

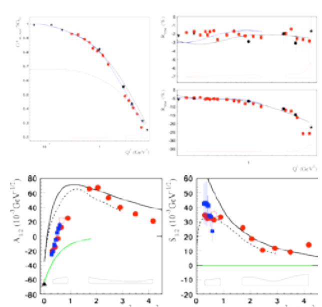

2014-