Изучение нуклонных резонансов на детекторе CLAS

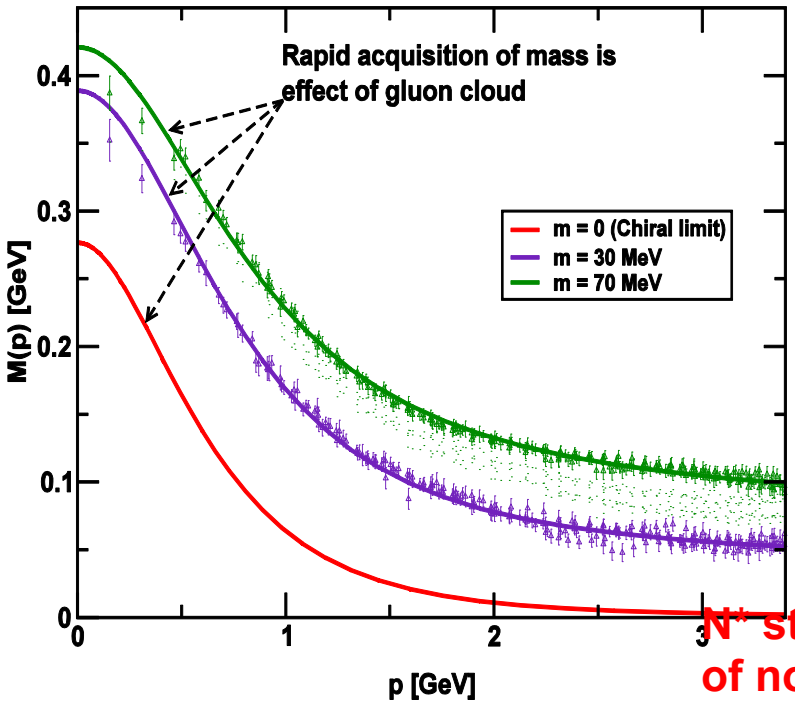
Е.Исупов 13.09.2011

The studies of N* electrocouplings: motivation & objectives

Our experimental program seeks to determine

g_VNN* transition helicity amplitudes (electrocouplings) at photon virtualities $0.2 < Q^2 < 5.0$ GeV^2 for most of the excited proton states analyzing major meson electroproduction channels combined.

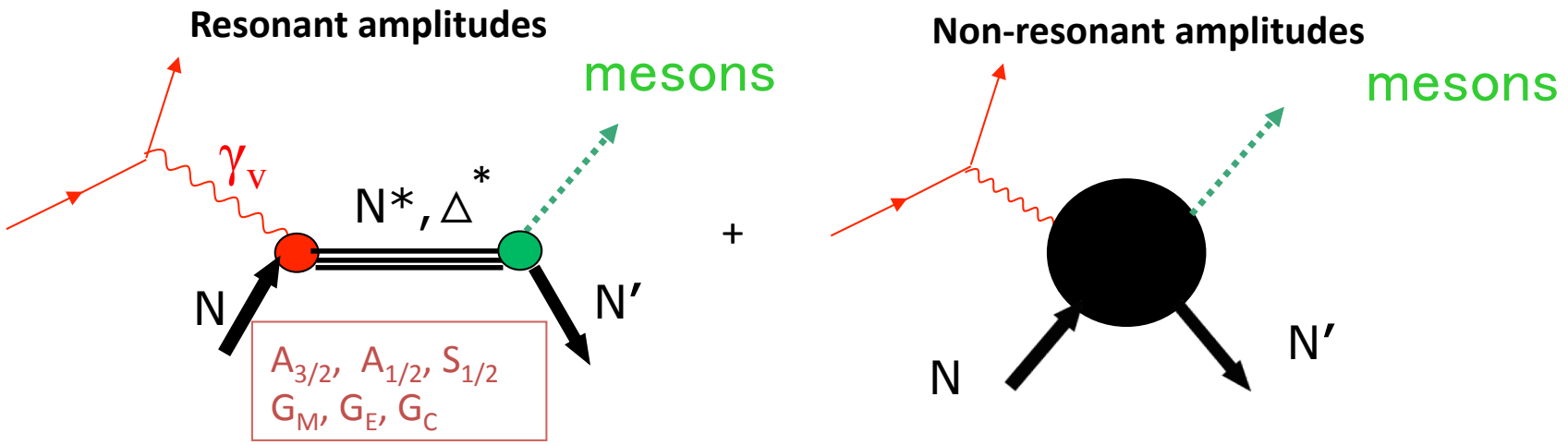
This comprehensive information allows us to:



- **pin-down active degrees of freedom in N* structure at various distances;**
- **study the non-perturbative strong interactions which are responsible for N* formation and their emergence from QCD;**
- **uniquely access the origin of more than 97% of dressed quark masses, their chromo- and electro- anomalous magnetic moments generated through dynamical chiral symmetry breaking, and explore the origin of confinement .**

N* studies are key to the exploration of non-perturbative strong interactions and confinement.

N* parameters from analyses of exclusive electroproduction channels

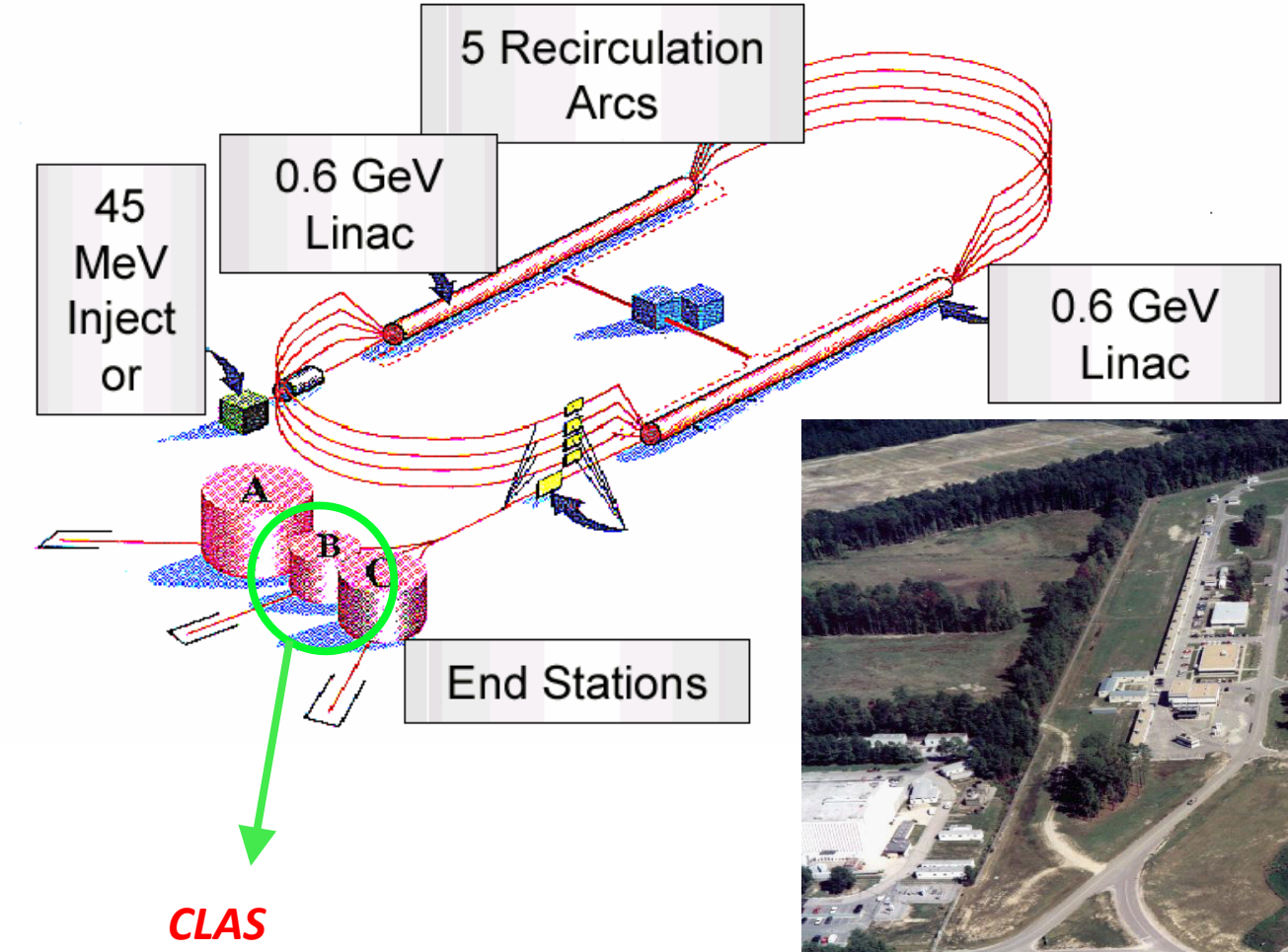


- **Separation of resonant and non-resonant contributions represents most challenging part, and can be achieved within the framework of reaction models.**

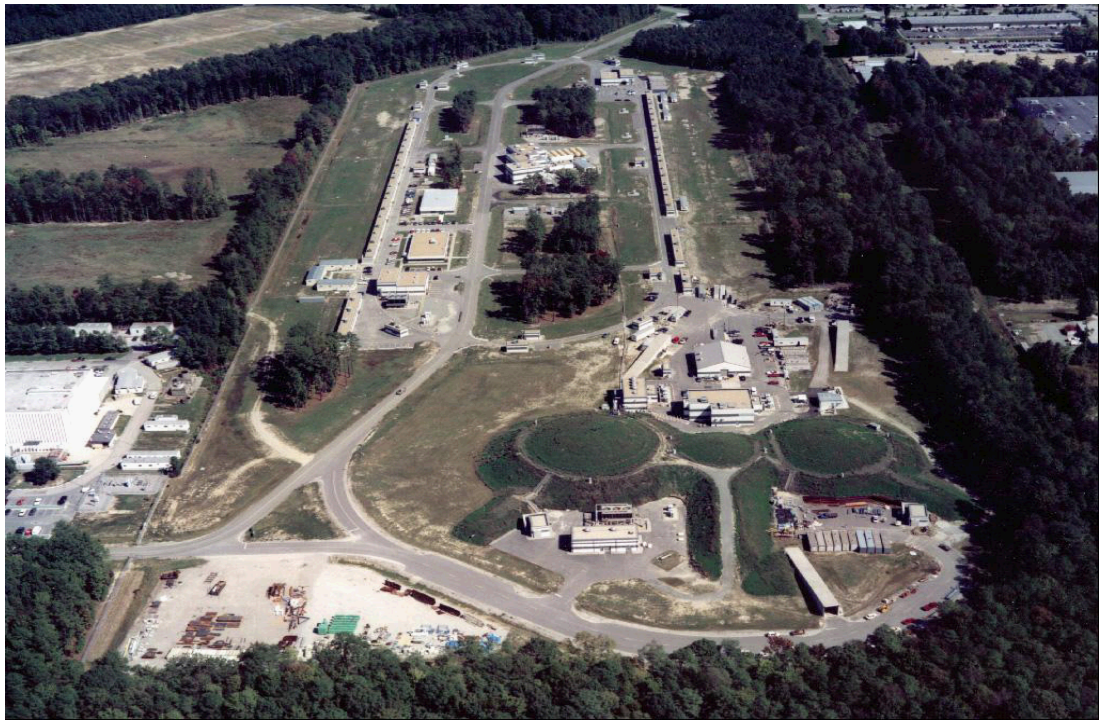
- **N* ‘s can couple to various exclusive channels with entirely different non-resonant amplitudes, while their electrocouplings should remain the same.**

- **Consistent results from the analyses of major meson electroproduction channels Npi and pi^+pi^-p show that model uncertainties in extracted N* electrocouplings are under control.**

Ускоритель электронов непрерывного действия в Jefferson Lab – CEBAF



E_{max}	~ 6 GeV
I_{max}	~ 200 mA
Duty Factor	~ 100%
s_E/E	~ $2.5\ 10^{-5}$
Beam P	~ 80%
$E_{g(tagged)}$ GeV	~ 0.8- 5.5



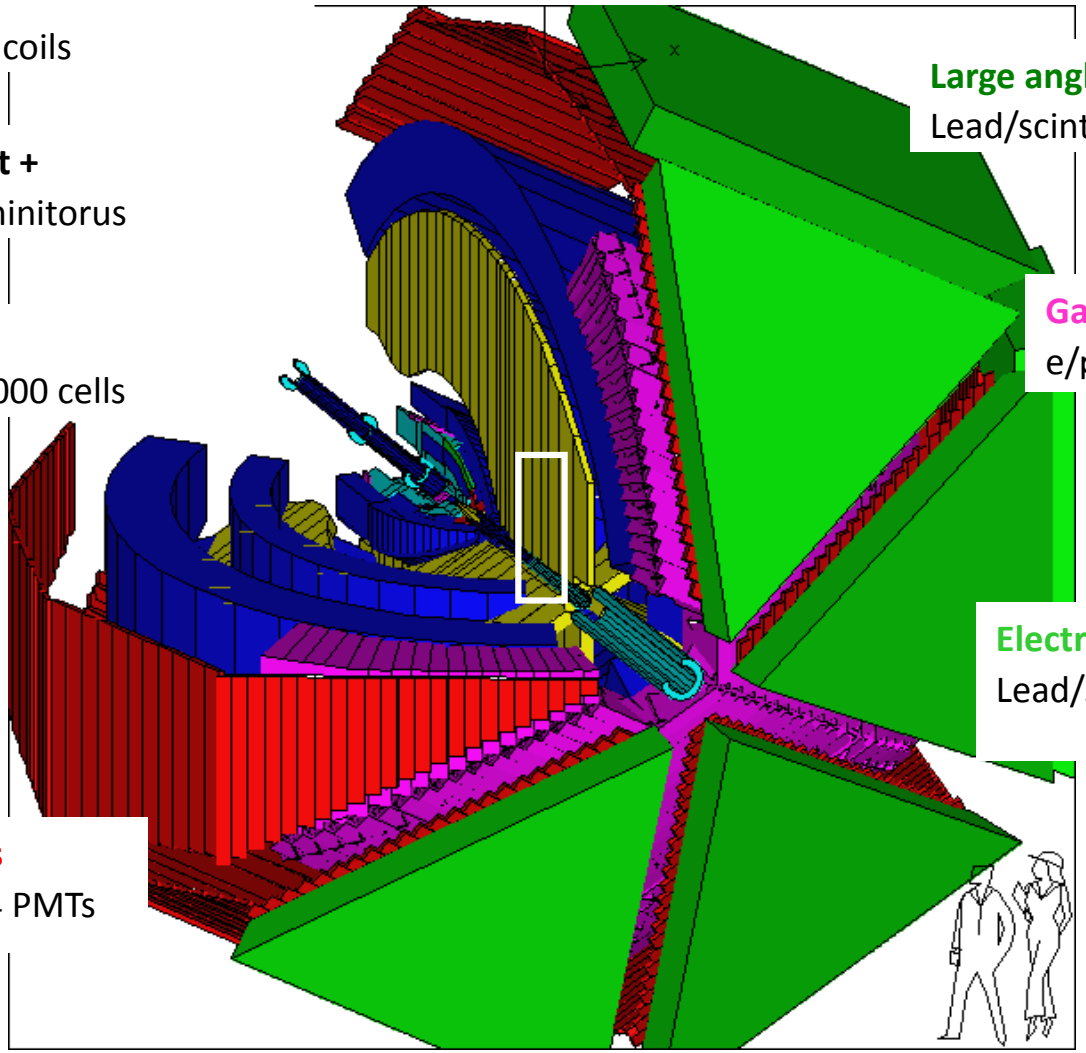
CEBAF Large Acceptance Spectrometer

Torus magnet
6 superconducting coils

Liquid D_2 (H_2)target +
g start counter; e minitorus

Drift chambers
argon/CO_2 gas, 35,000 cells

Time-of-flight counters
plastic scintillators, 684 PMTs



Large angle calorimeters
Lead/scintillator, 512 PMTs

Gas Cherenkov counters
e/pi separation, 216 PMTs

Electromagnetic calorimeters
Lead/scintillator, 1296 PMTs

Опубликованные данные по рождению двух пионов, полученные в коллаборации CLAS/SINP

1.31 < W < 1.56 ГэВ
$0.2 < Q^2 < 0.6$ ГэВ^2 $\Delta Q^2=0.05$ ГэВ^2 **G.V.Fedotov-** G. Fedotov *et al.*, PRC
120000 отобранных событий 79,015204 (2009)

1.41 < W < 2.10 ГэВ
$0.5 < Q^2 < 1.5$ ГэВ^2 $\Delta Q^2=0.3$ ГэВ^2 **E.N.Golovach -**M. Ripani *et al.*,
150000 отобранных событий PRL 91,022002 (2003)

$\Delta W=25$ MeV
$\Delta W/W<2\%$

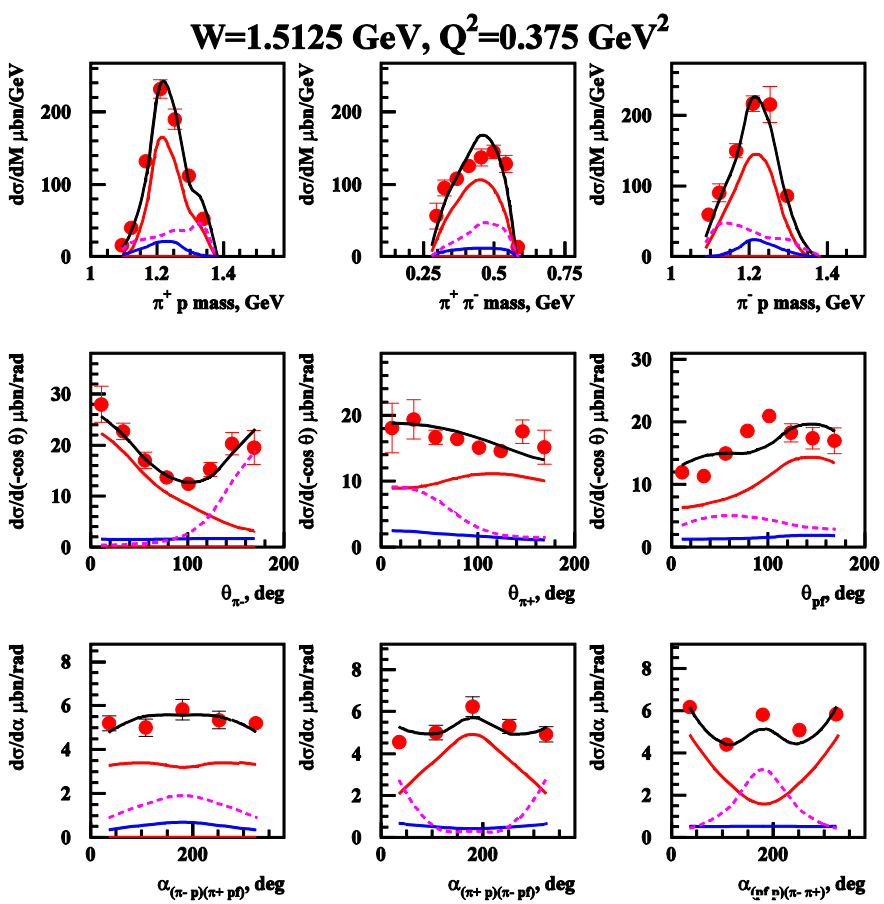
> 10000 точек измеренных сечений реакции $ep \rightarrow e'p\,\pi^+\pi^-$

Текущий статус анализа данных

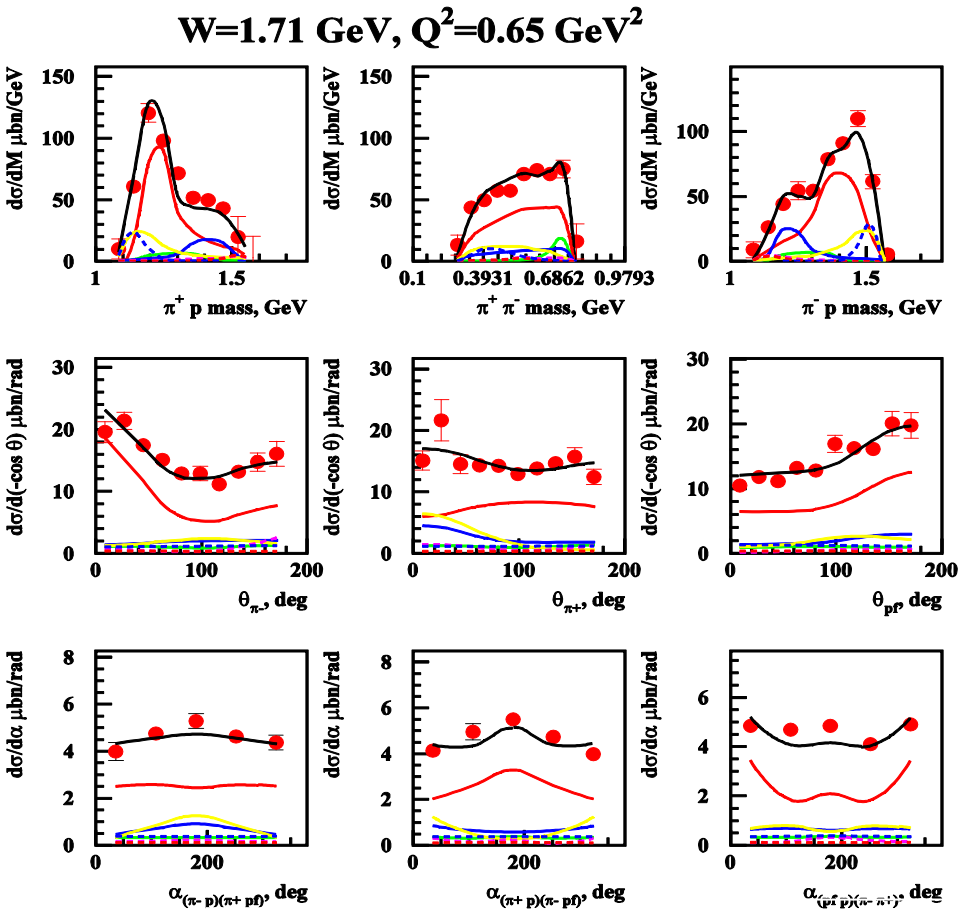
- Е. Исупов – Двухпионный анализ при высоких переданных импульсах виртуального фотона.
- Е. Головач – Фоторождение двух пионов
- Н. Шведунов – Электорождение положительного пиона на протоне внутри дейтрона.

The CLAS data on pi^+pi^-p differential cross sections and description within the JM model

G.V.Fedotov et al, PRC 79 (2009), 015204



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



full JM calc.

$pi^+\Delta$

rho p

$pi^+F^0_{15}(1685)$

$pi\Delta^{++}$

2p direct

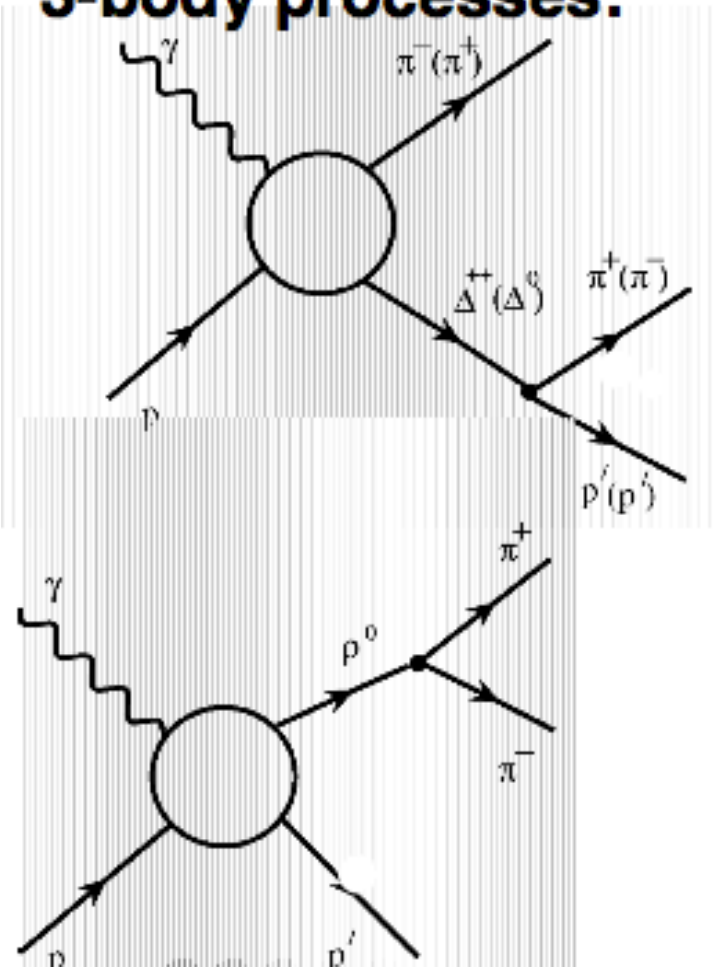
$pi^+D^0_{13}(1520)$

JLAB-MSU meson-baryon model (JM) for $\pi^+\pi^-$p electroproduction

V.I. Mokeev , V.D. Burkert, T.-S.H. Lee *et al.*, Phys. Rev. C80, 045212 (2009)

Isobar channels included:

3-body processes:



$\pi^-\Delta^{++}$

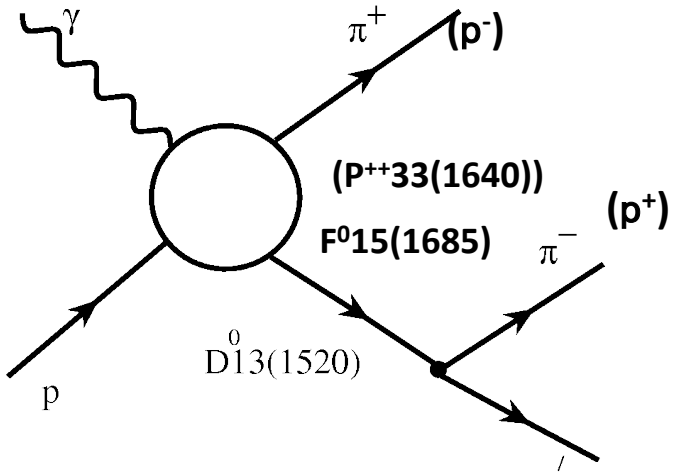
- All well established N*s with $\pi\Delta$ decays and $3/2^+(1720)$ candidate.
- Reggeized Born terms with effective FSI and ISI treatment (absorptive approximation).
- Extra $\pi\Delta$ contact term.

ρ^0p

- All well established N*s with ρp decays and $3/2^+(1720)$ candidate.
- Diffractive ansatz for non-resonant part and ρ-line shrinkage in N* region.

JLAB-MSU meson-baryon model (JM) for pi^+pi^-p electroproduction

3-body processes:

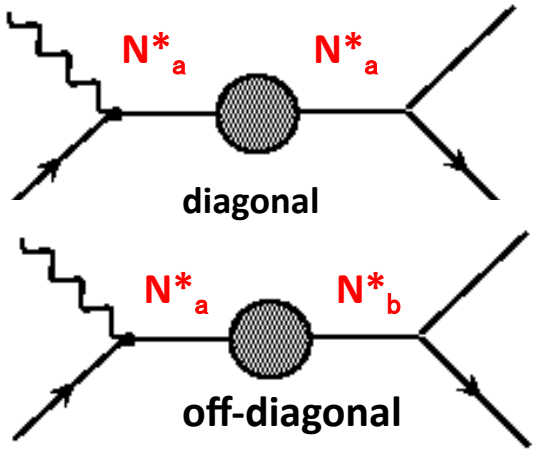


Isobar channels included:

- $p^+D^0_{13}(1520)$, $p^+F^0_{15}(1685)$, $p^-P^{++}_{33}(1640)$ isobar channels observed for the first time in the CLAS data at W > 1.5 GeV.

Unitarized Breit-Wigner Anstaz for resonant amplitudes

I.J.R.Aitchison, Nuclear Physics , A189 (1972), 417



Inverse of JM unitarized N* propagator:

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

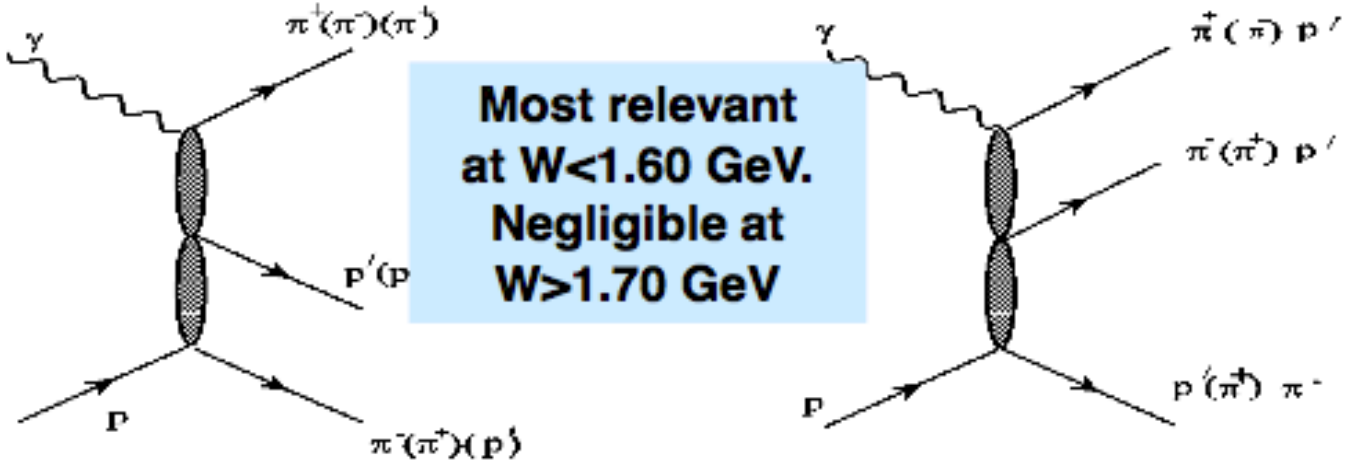
Off-diagonal transitions incorporated into JM:

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

Jefferson Lab

JLAB-MSU meson-baryon model (JM) for $\pi^+\pi^-$p electroproduction

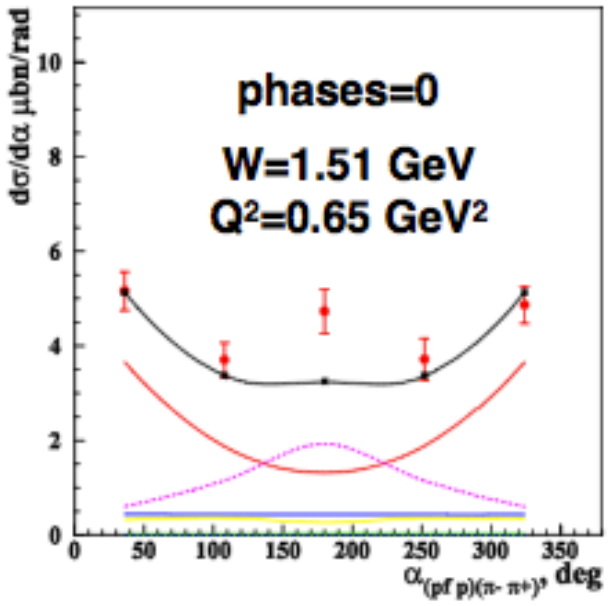
Direct 2π production required by unitarity:

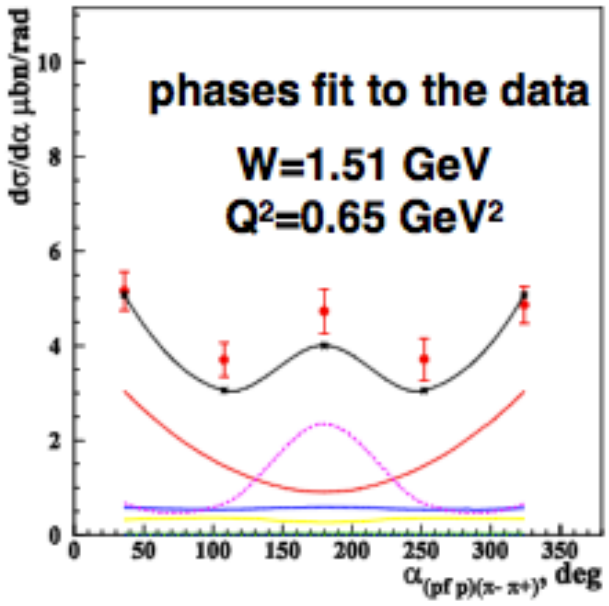


Most relevant at W<1.60 GeV. Negligible at W>1.70 GeV

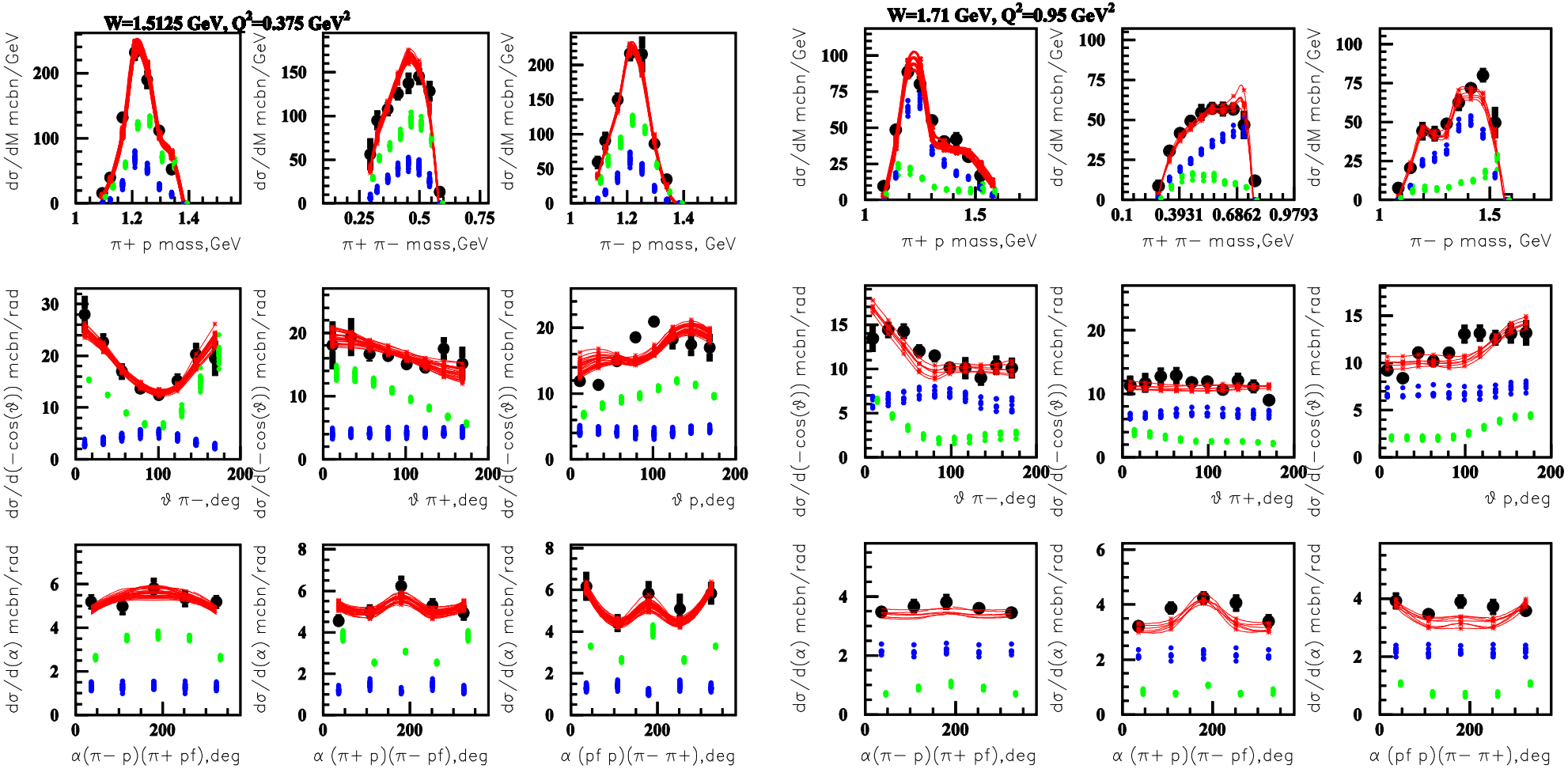
- Lorentz invariant contraction of the initial and the final particle spin-tensors
- exponential propagators for two unspecified exchanges

Magnitudes and relative phases fit to the data





Resonant & non-resonant parts of Npipi cross sections as determined from the CLAS data fit within the framework of JM model



full cross sections resonant part non-resonant part

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γ_vNN* electrocouplings from the CLAS data on Nπ/Nππ electroproduction

Nππ CLAS preliminary.

Nπ CLAS

I. Aznauryan, V. Burkert, et al., PRC 80,055203 (2009).

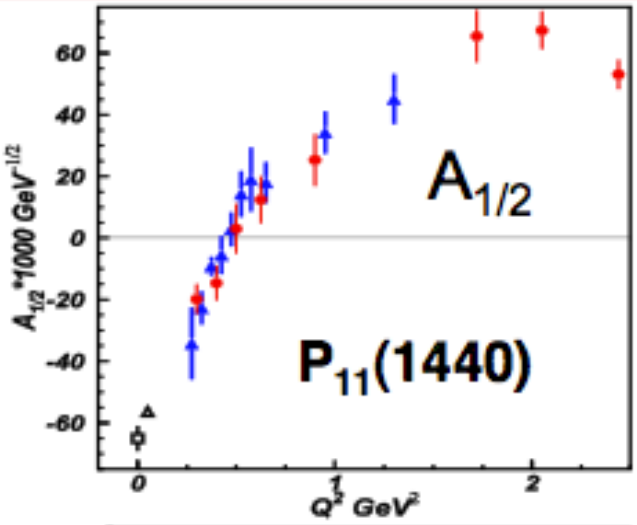
Nπ world

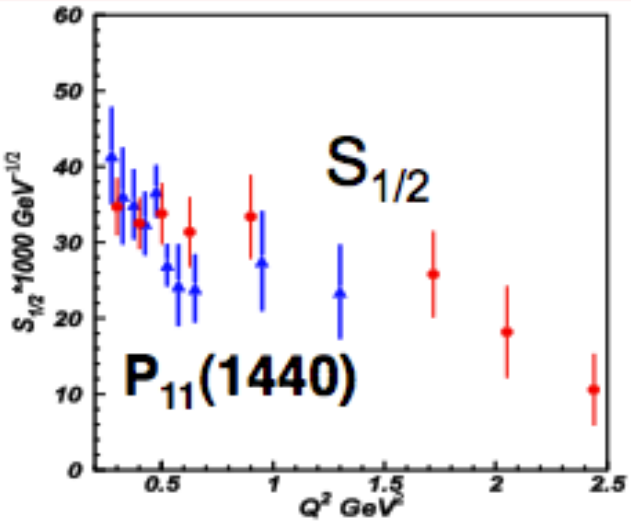
V. Burkert, et al., PRC 67,035204 (2003).

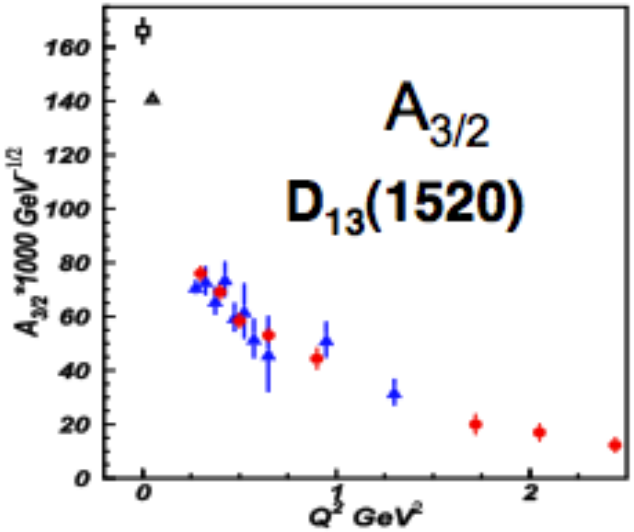
Nπ Q^2=0, PDG.

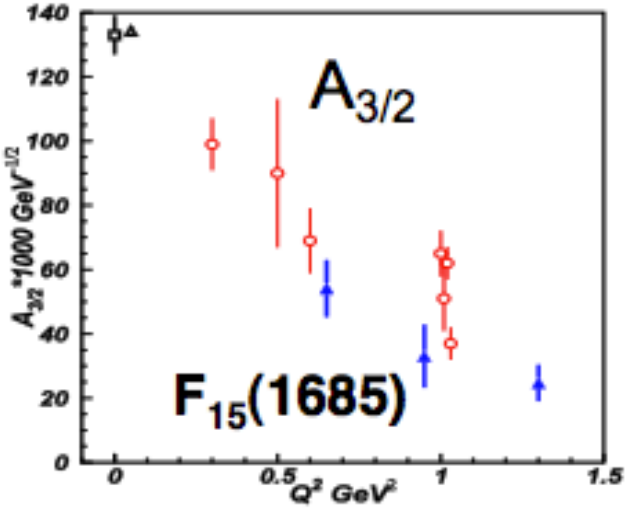
Nπ Q^2=0, CLAS

M. Dugger, et al., PRC 79,065206 (2009).









Good *agreement* between the electrocouplings obtained from the *Nπ and Nππ channels.* *N* electrocouplings are measurable and model independent quantities.*

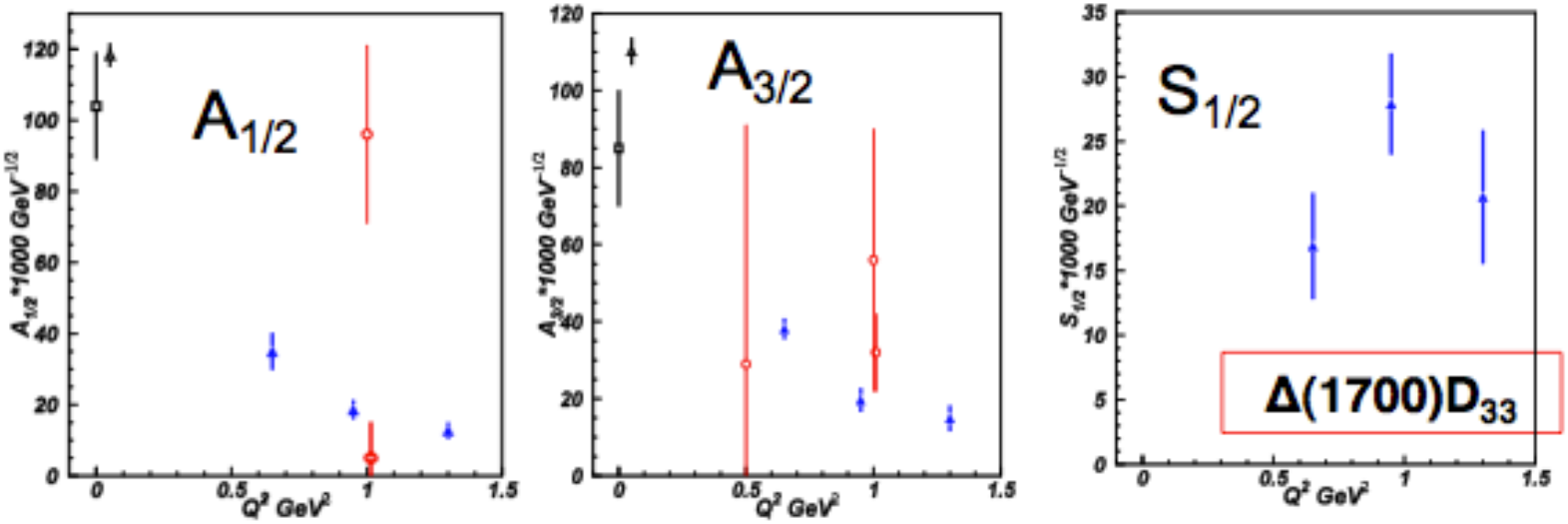
High lying resonance electrocouplings from $\gamma p \rightarrow \pi^+\pi^- p$

Nππ CLAS preliminary.

Nπ world
V.D.Burkert, et al., PRC 67, 035204 (2003).

Nπ Q^2=0, PDG.

Nπ Q^2=0, CLAS
M.Dugger, et al., PRC 79,065206 (2009).



Studies of $\pi^+\pi^-p$ electroproduction offer best opportunity for extraction of electrocouplings for N* states with masses above 1.6 GeV. Most of them decay preferably to Nππ final states.

Electrocouplings of $S_{31}(1620)$, $S_{11}(1650)$, $F_{35}(1685)$, $D_{33}(1700)$, and $P_{13}(1720)$ states were obtained for the first time from the $\pi^+\pi^-p$ electroproduction data.

All CLAS results on N* electrocouplings can be found in:
www.jlab.org/~mokeev/resonance_electrocouplings/

Mystery of $P_{11}(1440)$ structure is solved

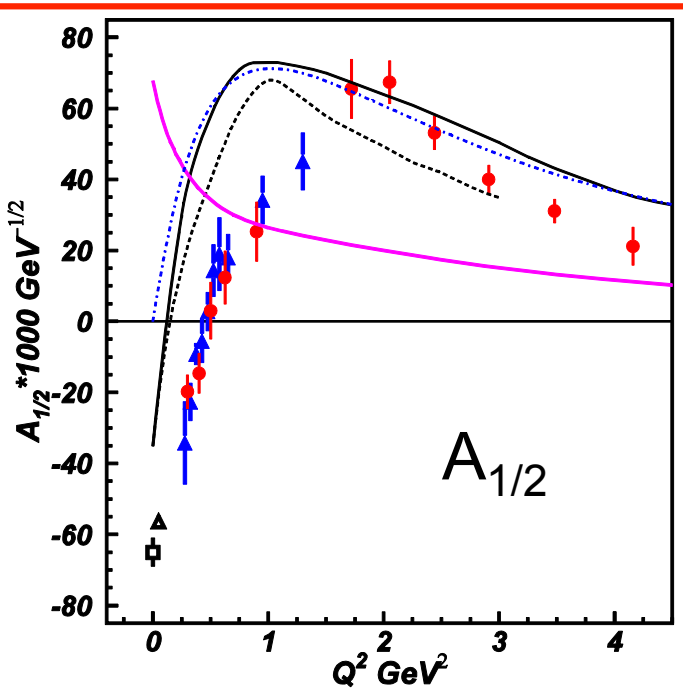
Quark models:

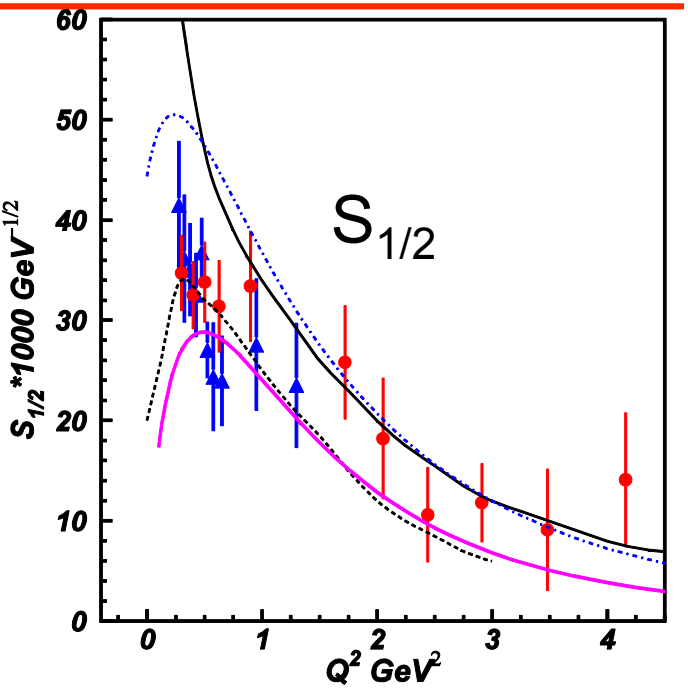
—— I. Aznauryan LC

------ S. Capstick LC

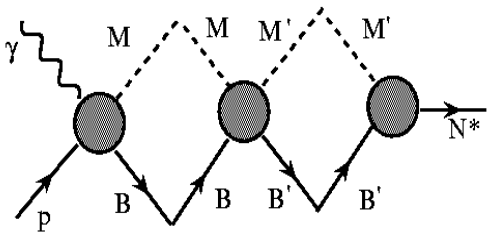
Relativistic covariant approach by G.Ramalho /F.Gross .

EBAC-DCC MB dressing (absolute values).





Meson-baryon dressing amplitudes:



The electrocouplings are consistent with *$P_{11}(1440)$* structure as a combined contribution of: a) internal quark core as a first *radial excitation of three dressed quarks in the ground proton state, and b) external meson-baryon dressing*.

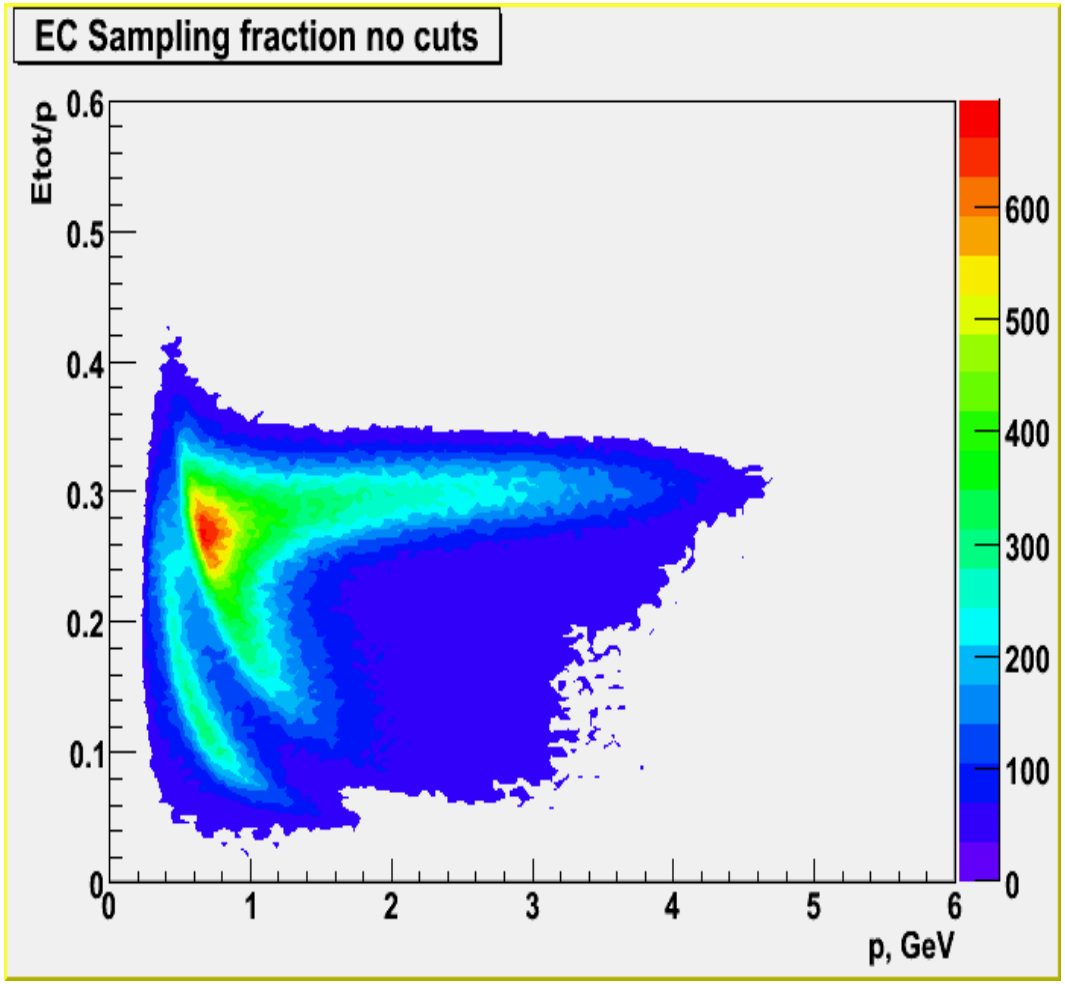
See work Phys Rev D84(2011) 014004 by I.T. Obukhovsky, A. Faessler….

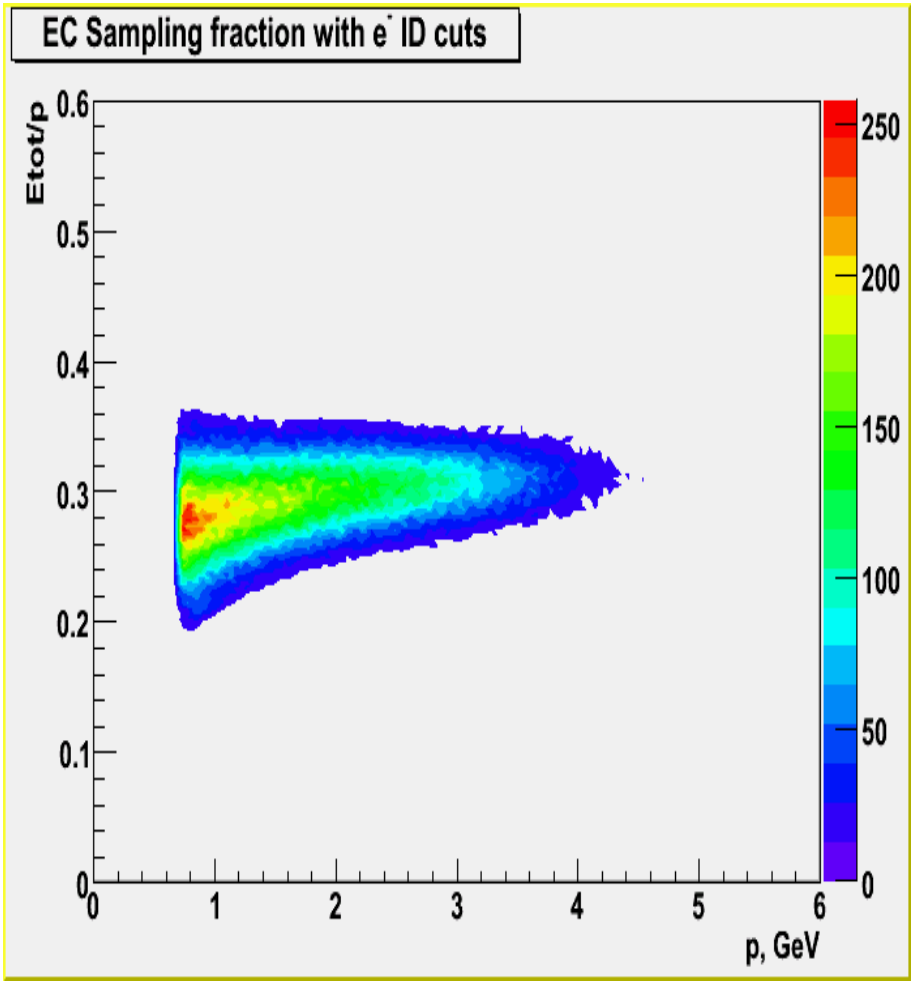
Analysis of e1-6 data, E=5.7 GeV

Event Selection

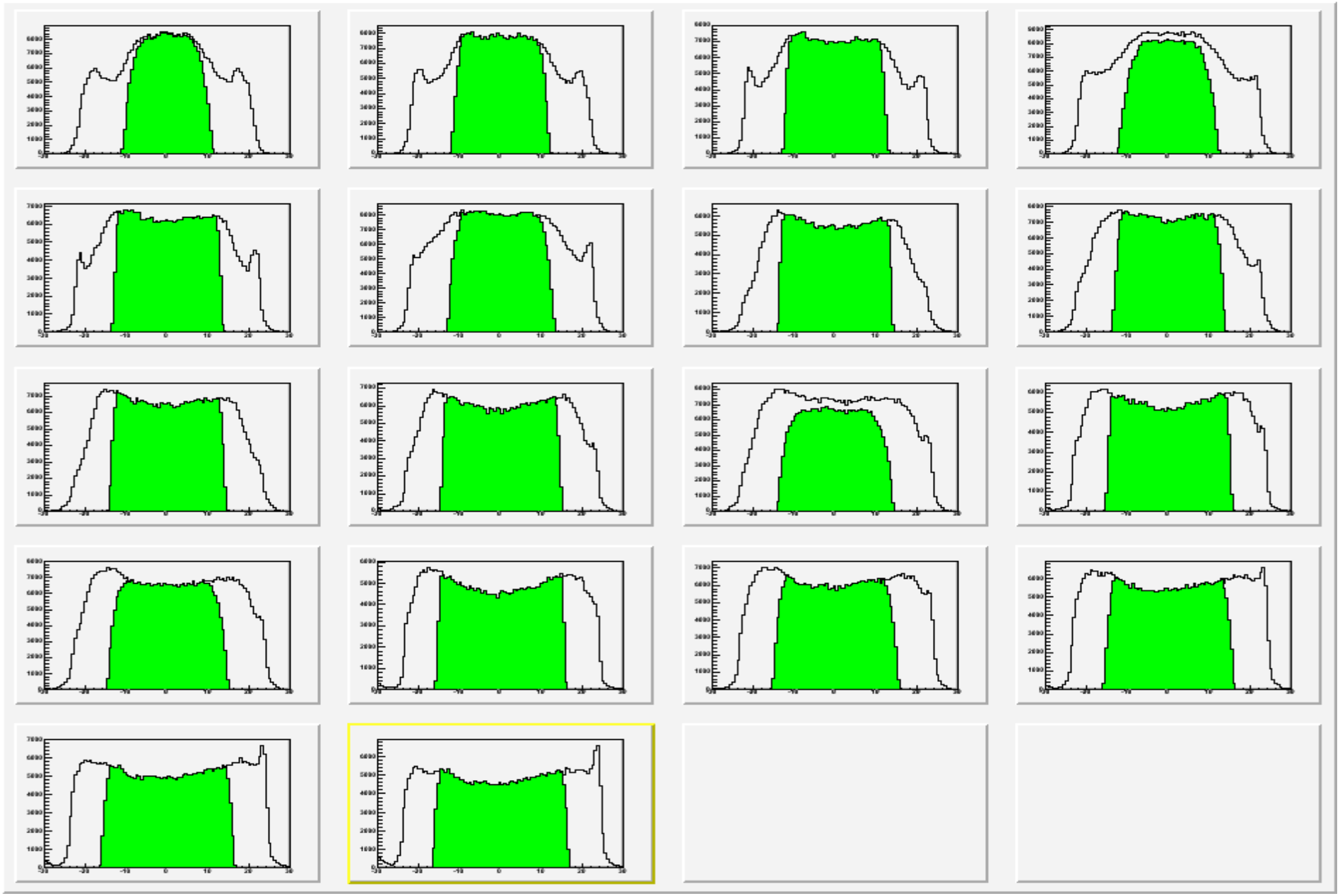
- Electron ID
  - Calorimeter cuts
  - Cherenkov cut
  - Fiducial cuts
  - Zvertex cut
  - Momentum corrections
  - Zvertex corrections

EC sampling fraction before and after electron ID cuts





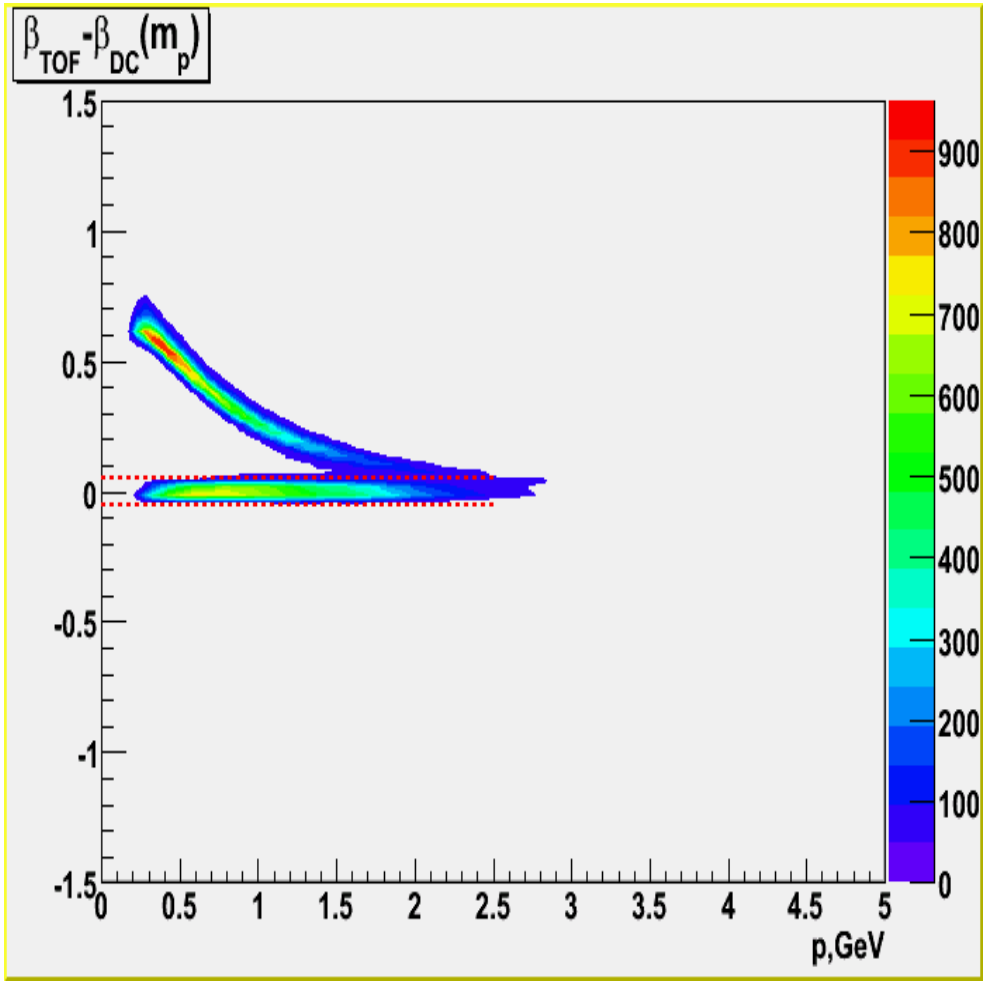
Example of electron fiducial cut

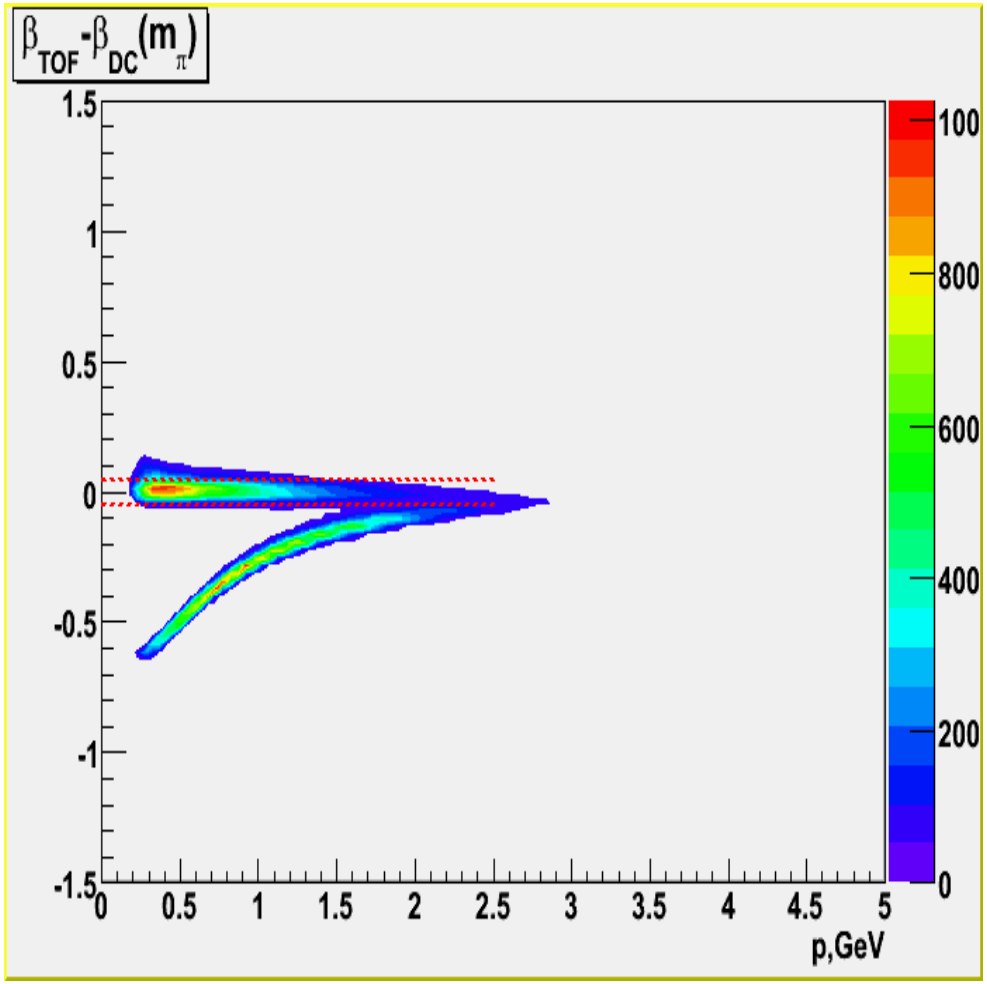


Charged hadrons ID

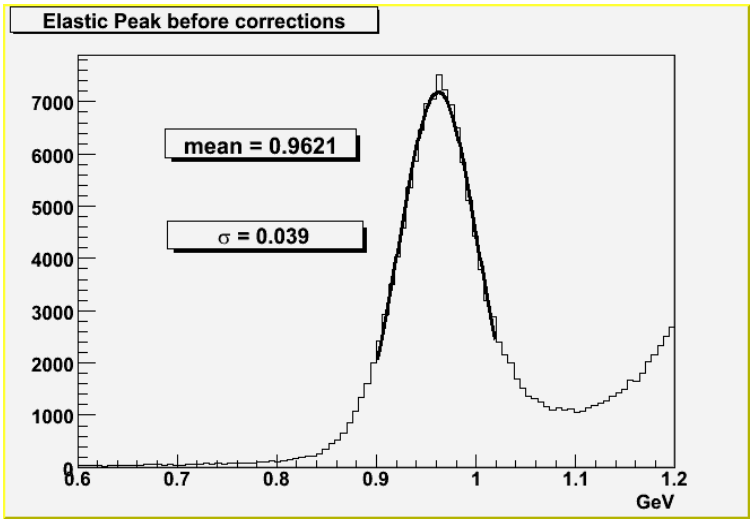
- Beta vs Momentum cuts
- Fiducial cuts
- Momentum corrections for positive pion
- Energy loss corrections for proton

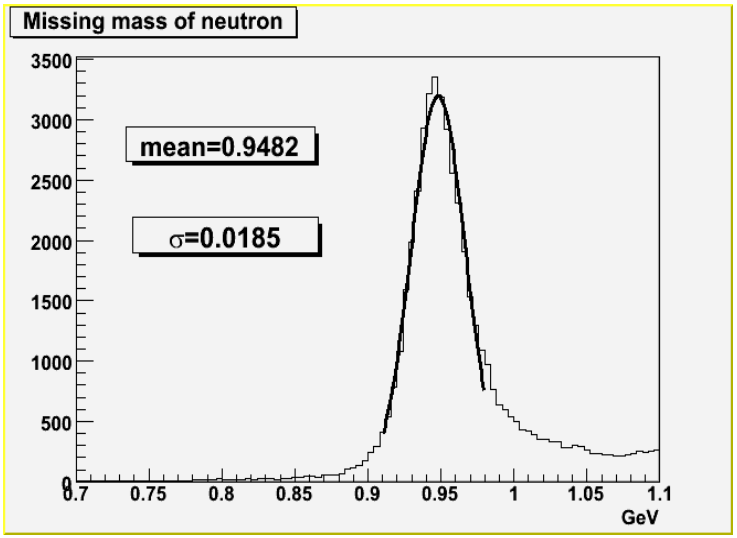
Delta beta vs Momentum for charged hadrons

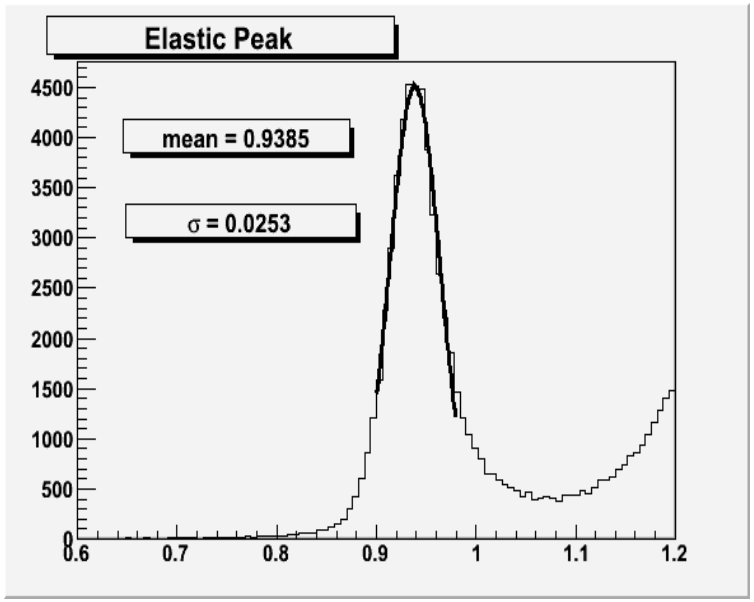


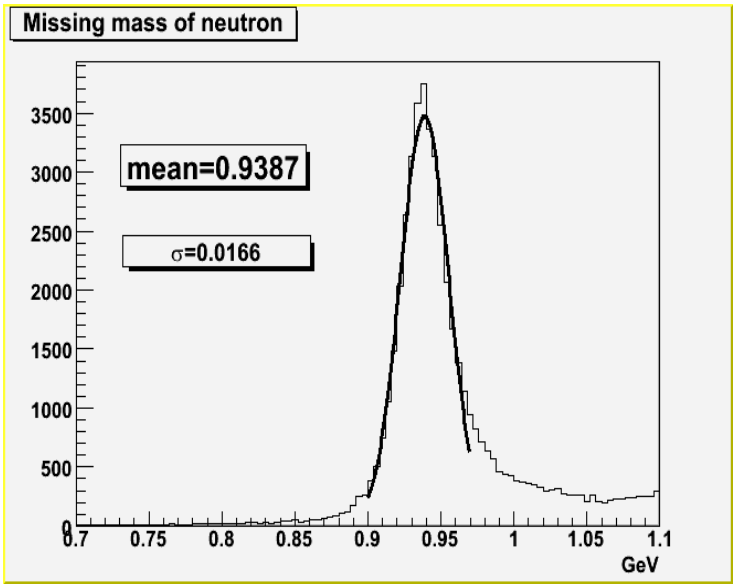


Elastic and missing mass of neutron peaks

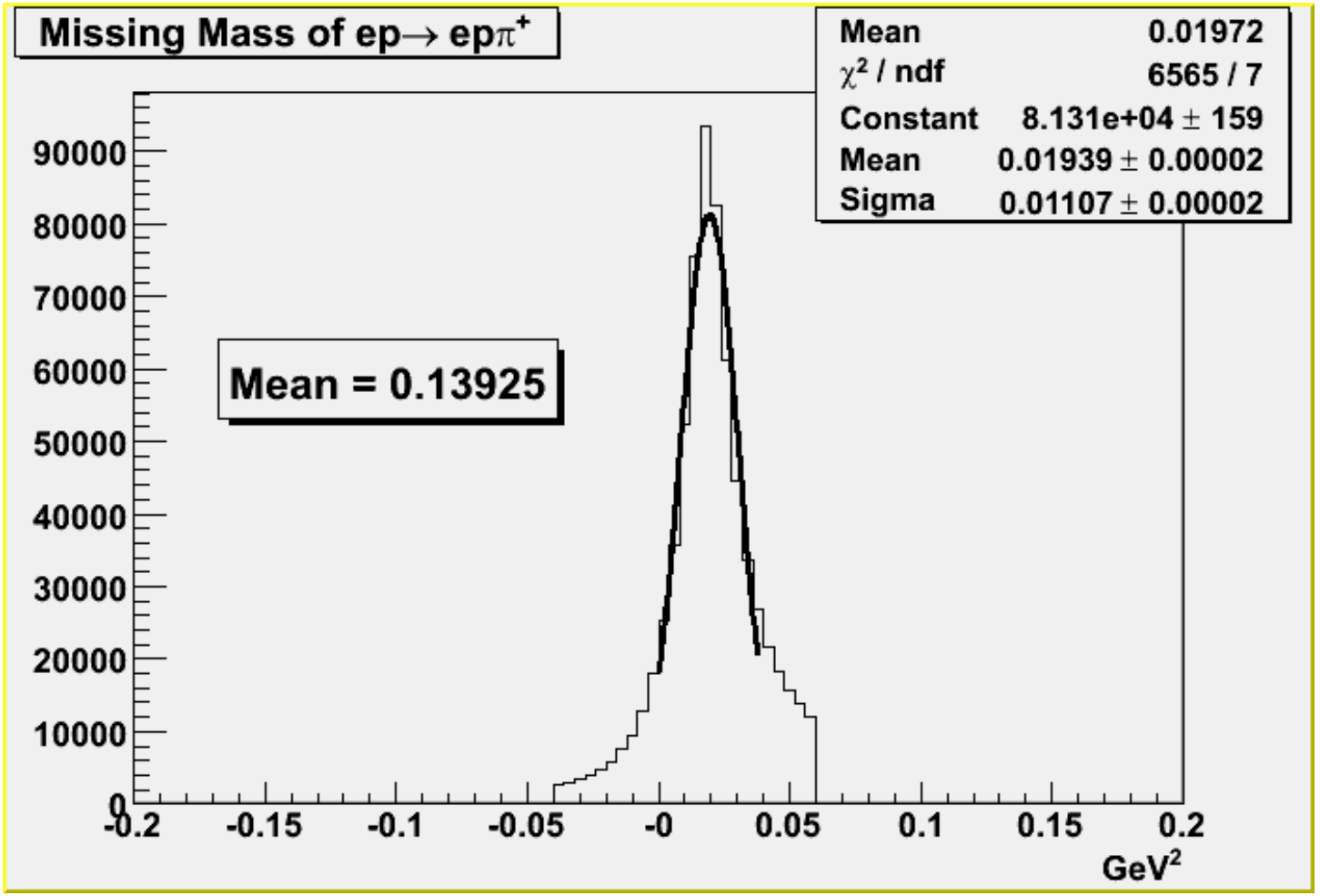








Missing Mass of negative pion



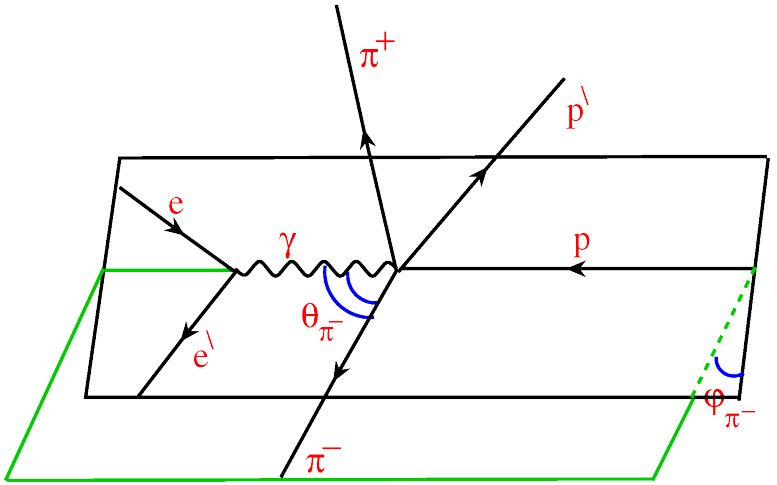
3-body final state kinematics variables

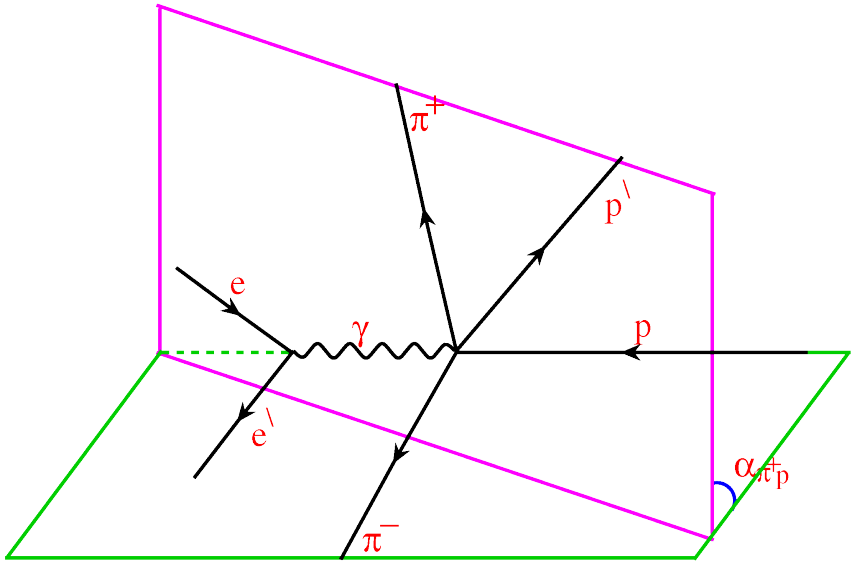
3-body final state kinematics variables:

$M_{\pi\pi}$, $M_{p\pi}$ are invariant masses of the $\pi^+\pi^-$ and $p\pi^+$ systems respectively;

$d\Omega = d(\cos\theta)d\varphi$ is solid angle for emitted π^-;

$\alpha_{p\pi^+}$ is the angle between two planes on the plot.





Cross-section extraction

$$\frac{d^7\sigma}{dWdQ^2d\tau} = \frac{1}{L}\cdot\frac{\Delta N}{eff\cdot\Delta W\Delta Q^2\Delta\tau}$$

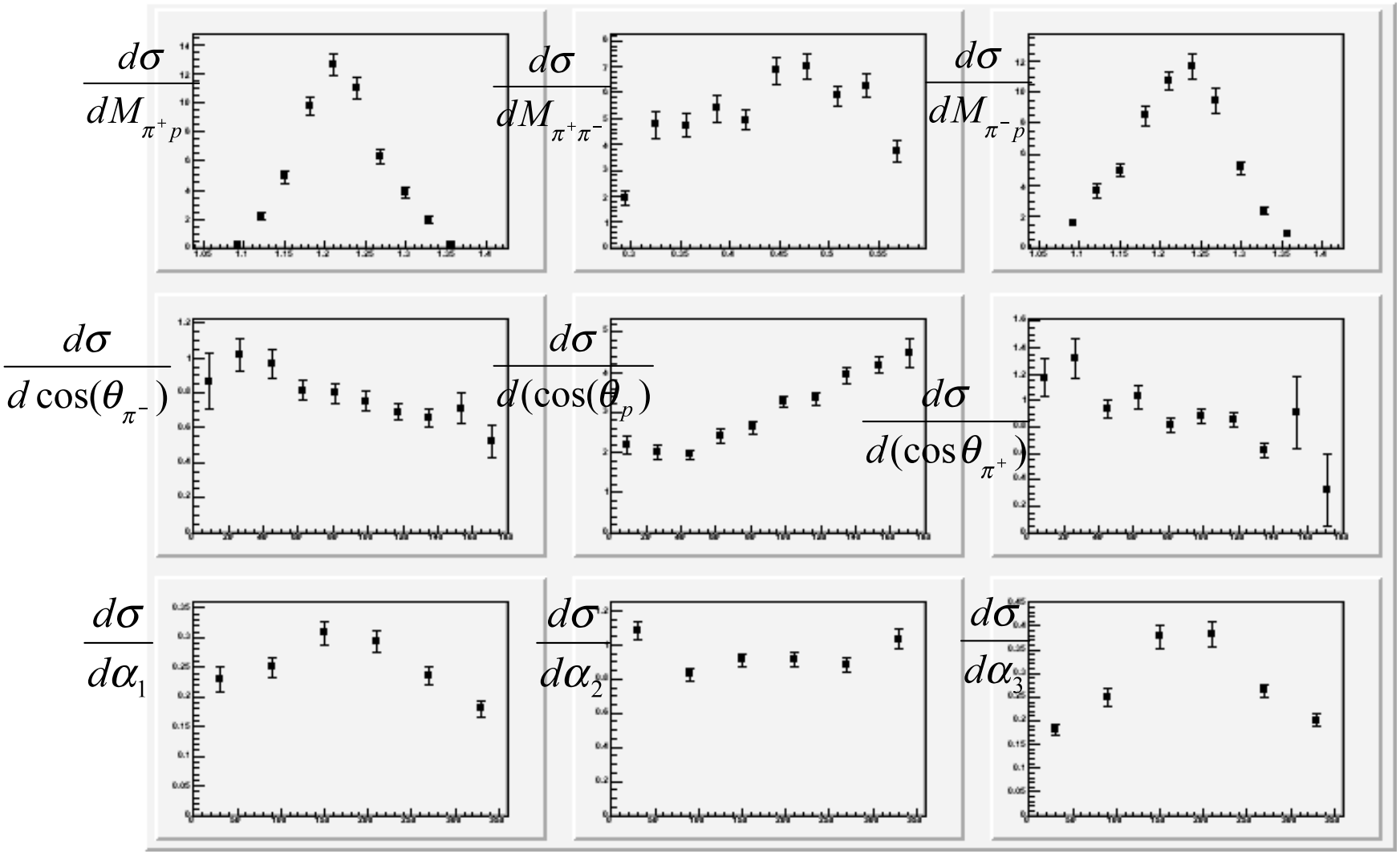
7-dim differential cross-section

$$d\tau = dM_{\pi^+\pi^-}\, dM_{\pi^+ p}\, d\cos(\theta_{\pi^-})\, d\varphi_{\pi^-}\, d\alpha_{\pi^+ p}$$

L – luminosity, ΔN – number of events inside multidimensional cell, eff-efficiency determined from monte-carlo simulation. Then we obtain virtual photon cross-section

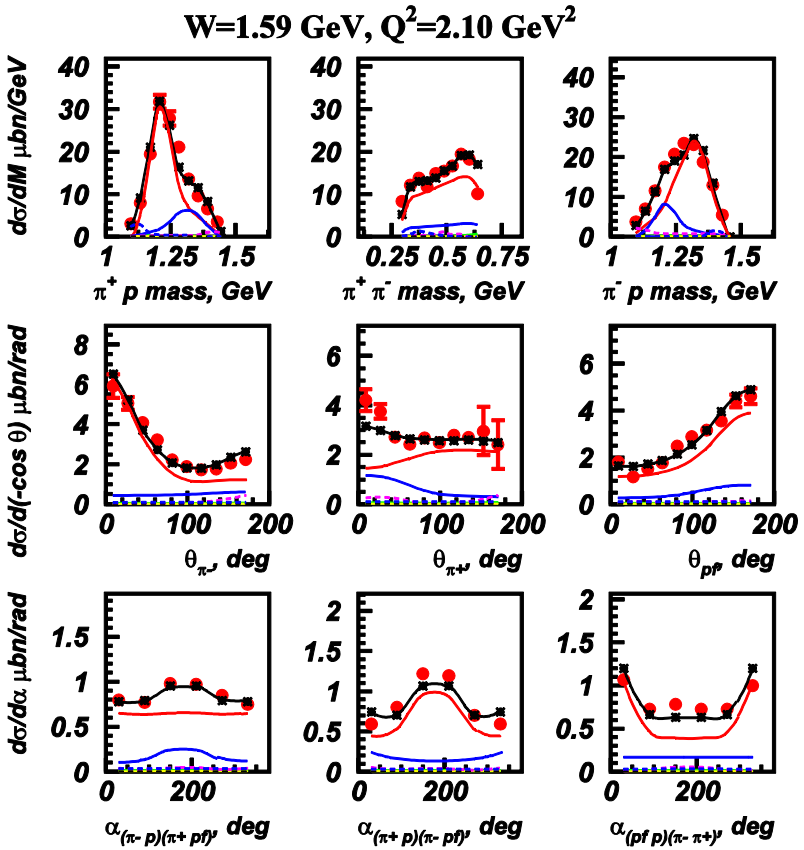
$$\frac{d^5\sigma}{d\tau} = \frac{1}{\Gamma_v}\frac{d^7\sigma}{dWdQ^2d\tau}$$

$3.5<Q^2<4.2$ GeV^2 $1.5<W<1.525$ GeV

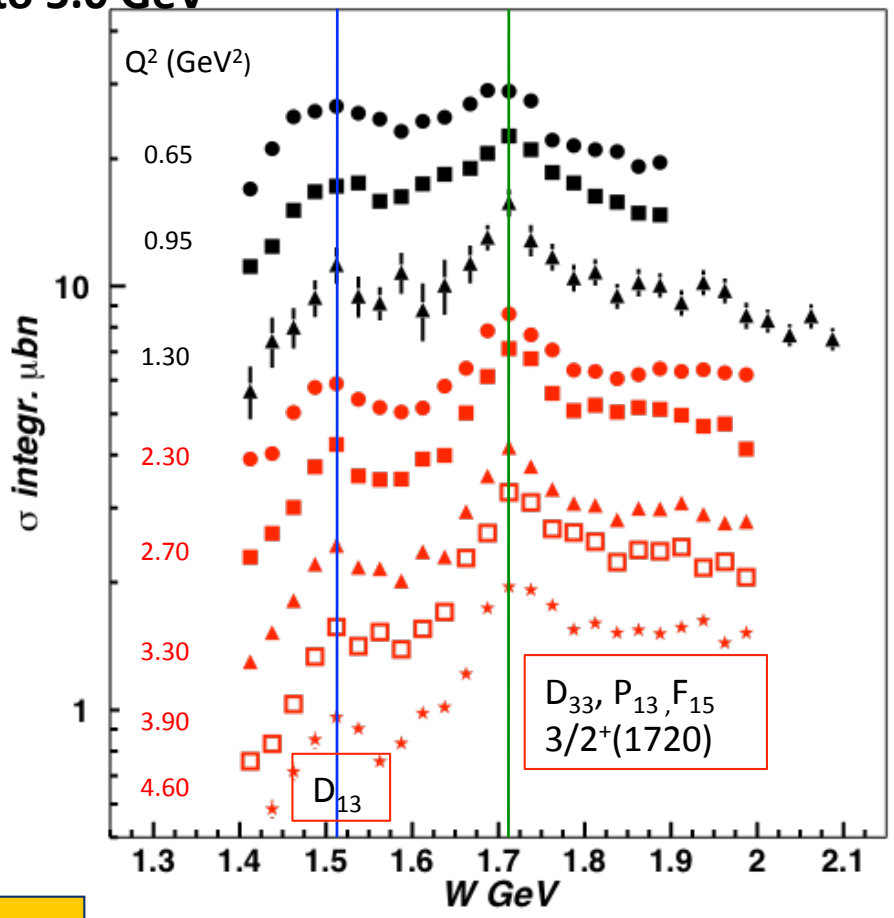


N* studies in $\pi^+\pi^-$p electroproduction with CLAS at high photon virtualities

g_vNN*electrocouplings will become available for most excited proton states with masses less then 2.0 GeV and at photon virtualities up to 5.0 GeV^2

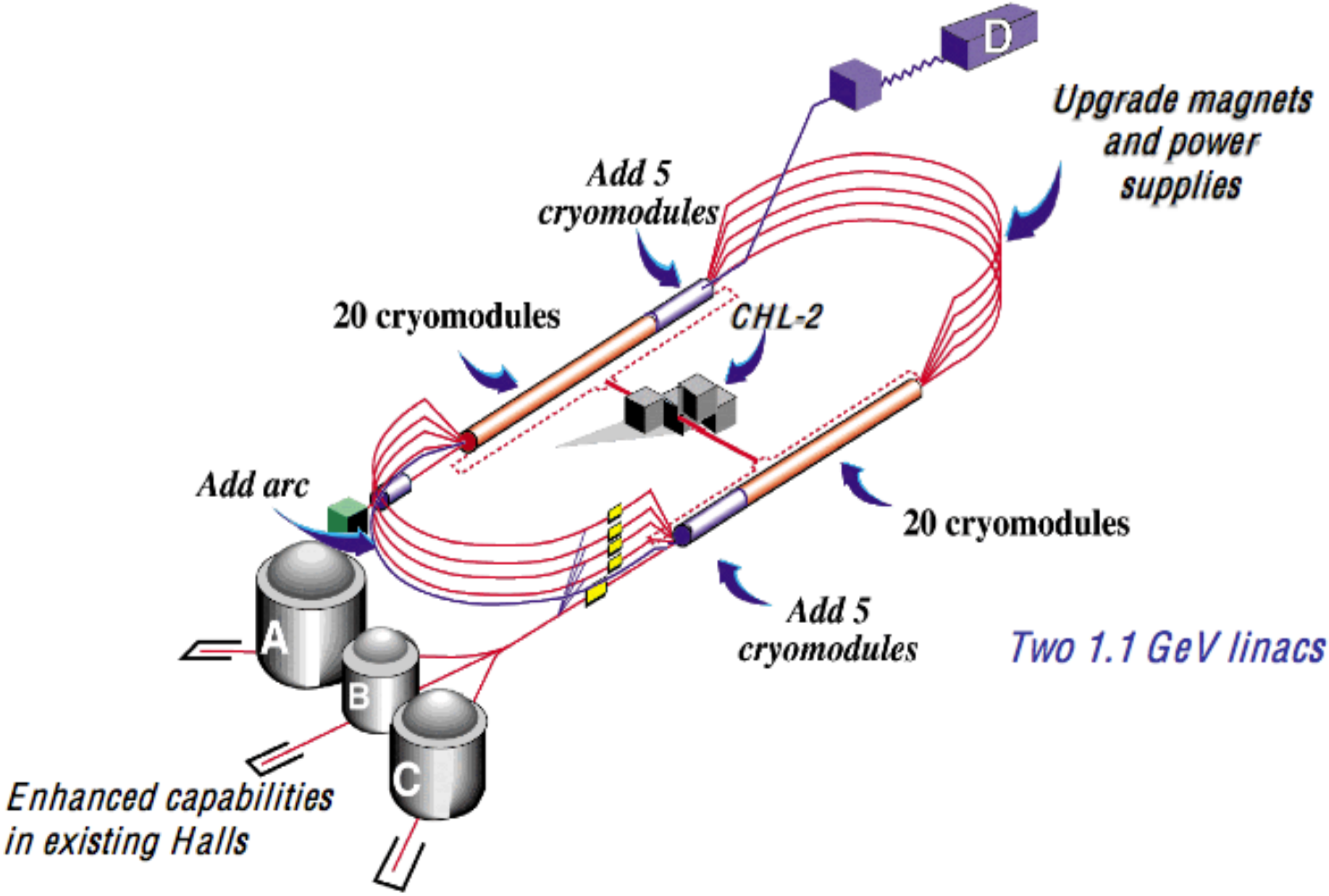


Extension of JM model toward high Q^2



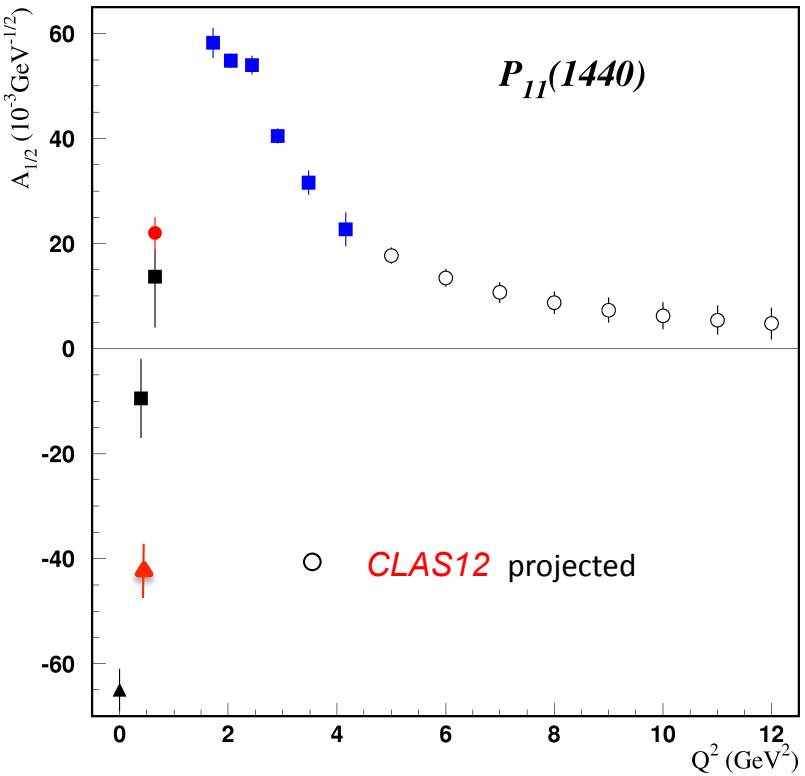
Resonance structures become more prominent with increasing Q^2.

12 GeV CEBAF

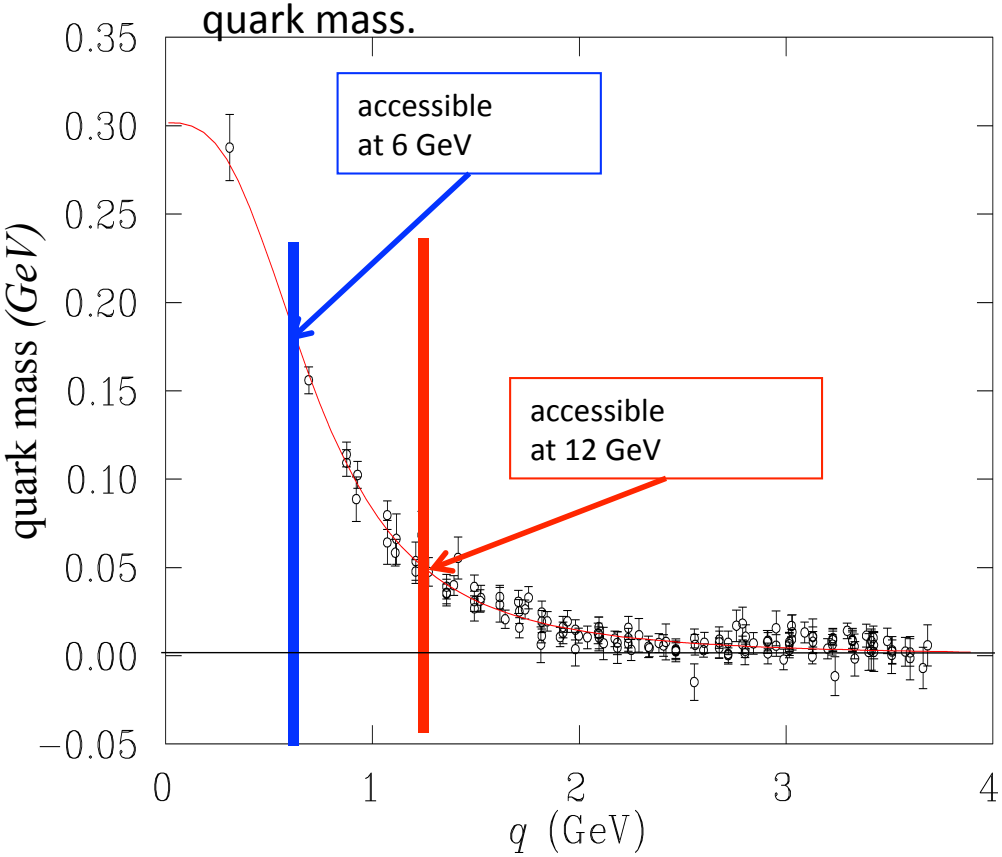

D
Upgrade magnets and power supplies
Add 5 cryomodules
20 cryomodules
CHL-2
Add arc
20 cryomodules
Add 5 cryomodules
Two 1.1 GeV linacs
A
B
C
Enhanced capabilities in existing Halls

Resonance Transitions at 12 GeV

Experiment E12-09-003 will extend access to transition FF for many prominent states in the range up to Q^2=12GeV^2.



Electromagnetic form factors are sensitive to the dynamical dressed quark mass.



In this experiment we will probe the transition from “dressed quarks” to current pQCD quarks for the first time.

Nucleon Resonance Studies with CLAS12

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http://www.physics.sc.edu/~gothe/research/pub/nstar12-12-08.pdf.

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Основные выводы

- На детекторе CLAS впервые получены детальные данные по дифференциальным и интегральным сечениям реакции ππ-рождения в области энергий возбуждения N* и при виртуальностях фотонов $0.2<Q^2<5.0$ ГэВ^2.
- Из анализа данных при $0.2<Q^2<1.5$ ГэВ^2 установлены все основные механизмы электророждения ππ-пар в резонансной области. Развита мезон-барионная модель JM, хорошо воспроизводящая все имеющиеся данные по ππ электророждению. Впервые установлены: прямое 2π электророждение, изобарные каналы D13(1520), F15(1685), P33(1640). Достигнуто надежное разделение резонансных/ нерезонансных частей сечений
- Впервые из данных по сечениям электророждения ππ-пар на протонах определены электромагнитные формфакторы большинства резонансов с массами менее 1.8 ГэВ в области $0.2<Q^2<1.5$ ГэВ^2.
- Анализ данных позволил устнановить активные степени свободы в структуре N*. Показано что структура низколежащих N* (M<1.6 ГэВ) формируется от внешнего мезон-барионного облака и кора 3 конституентных кварков
- Изучение двухпионного канала является эффективным способом определения электромагнитных формфакторов высоколежащих N* (M>1.6 ГэВ) большинство из которых распадается с эмиссией пар заряженных пионов
- PAC 44 одобрил эксперимент по исследованию структуры N* при больших Q^2 . Впервые будет получена информация по электромагнитным формфакторам N* при $5<Q^2<12$ГэВ^2 обеспечивающая доступ к структуре одетых кварков и позволяющая изучать конфайнмент в барионном секторе на основе КХД.

Спасибо за внимание!