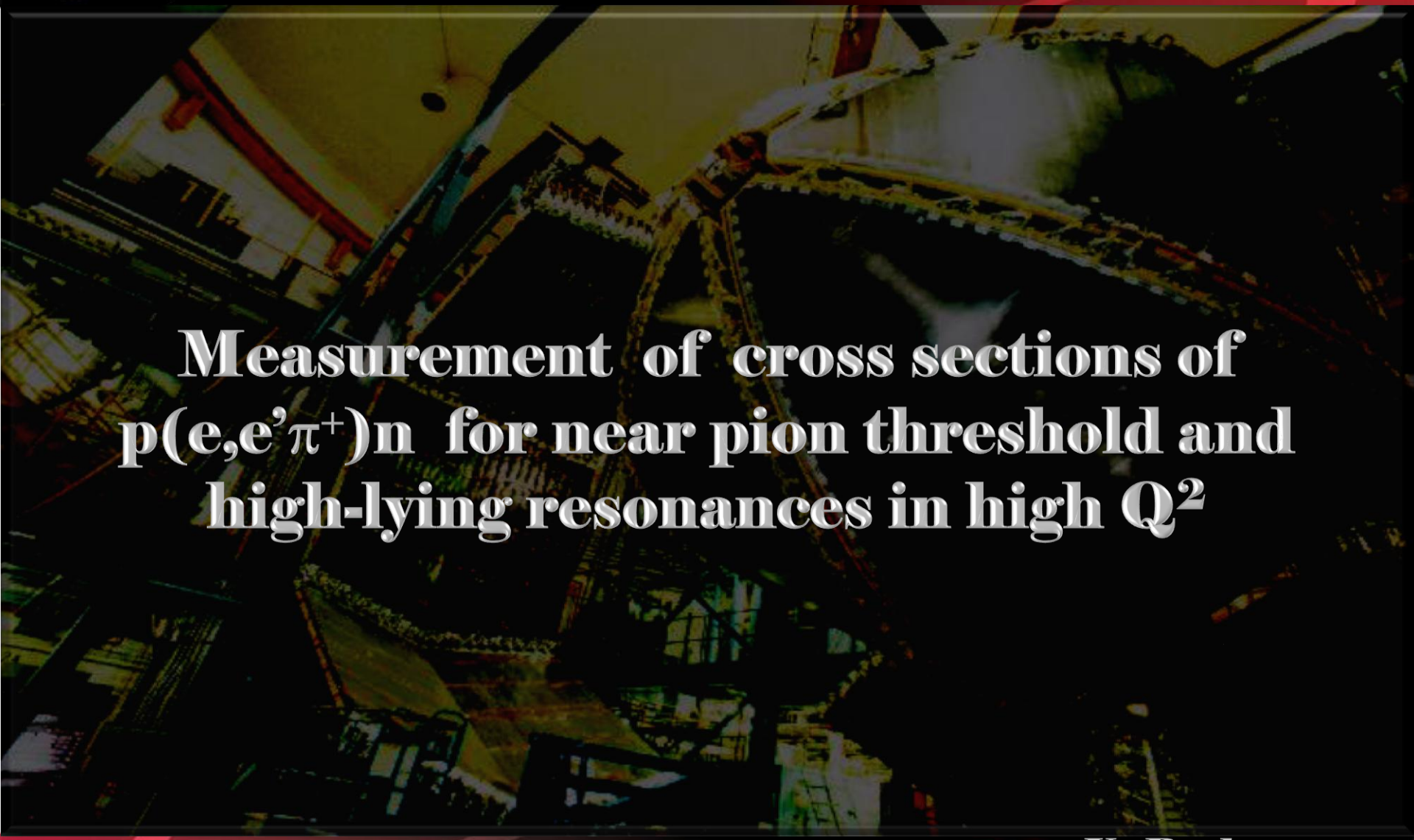
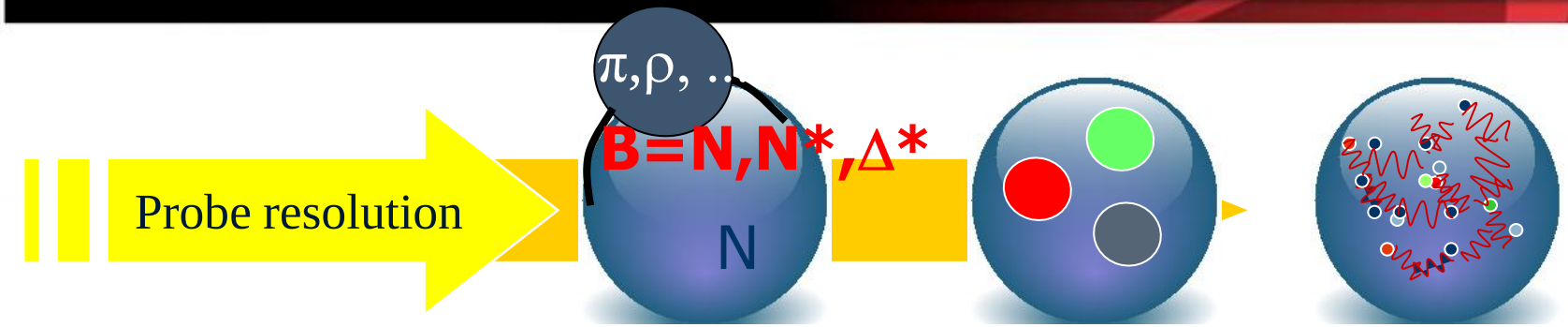


Measurement of cross sections of $p(e,e'\pi^+)n$ for near pion threshold and high-lying resonances in high Q^2

K. Park

Jefferson Lab
Thomas Jefferson National Accelerator Facility

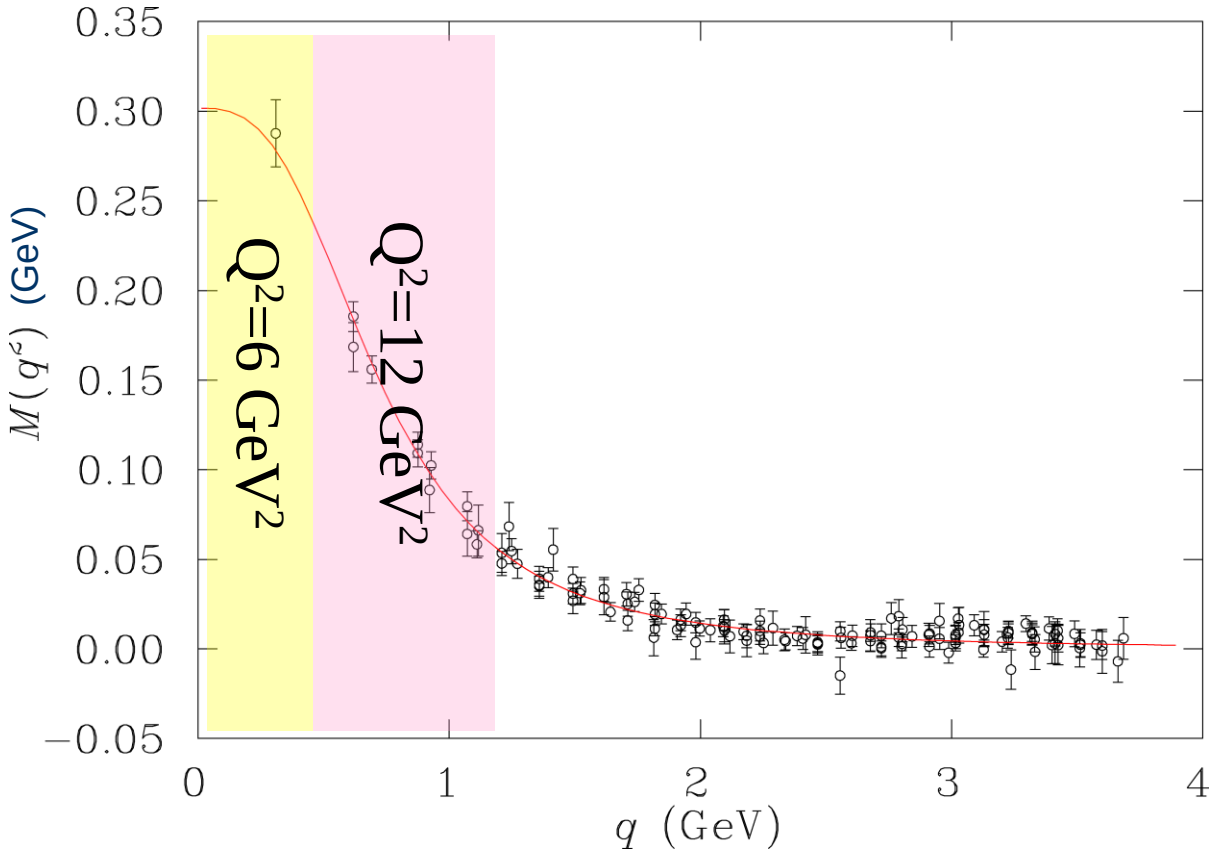
What is the relevant d.o.f in varying distance scale ?



The study of nucleon resonance transitions provides a testing ground for our understanding of these effective D.o.F

Access to the essence of non-perturbative strong interactions

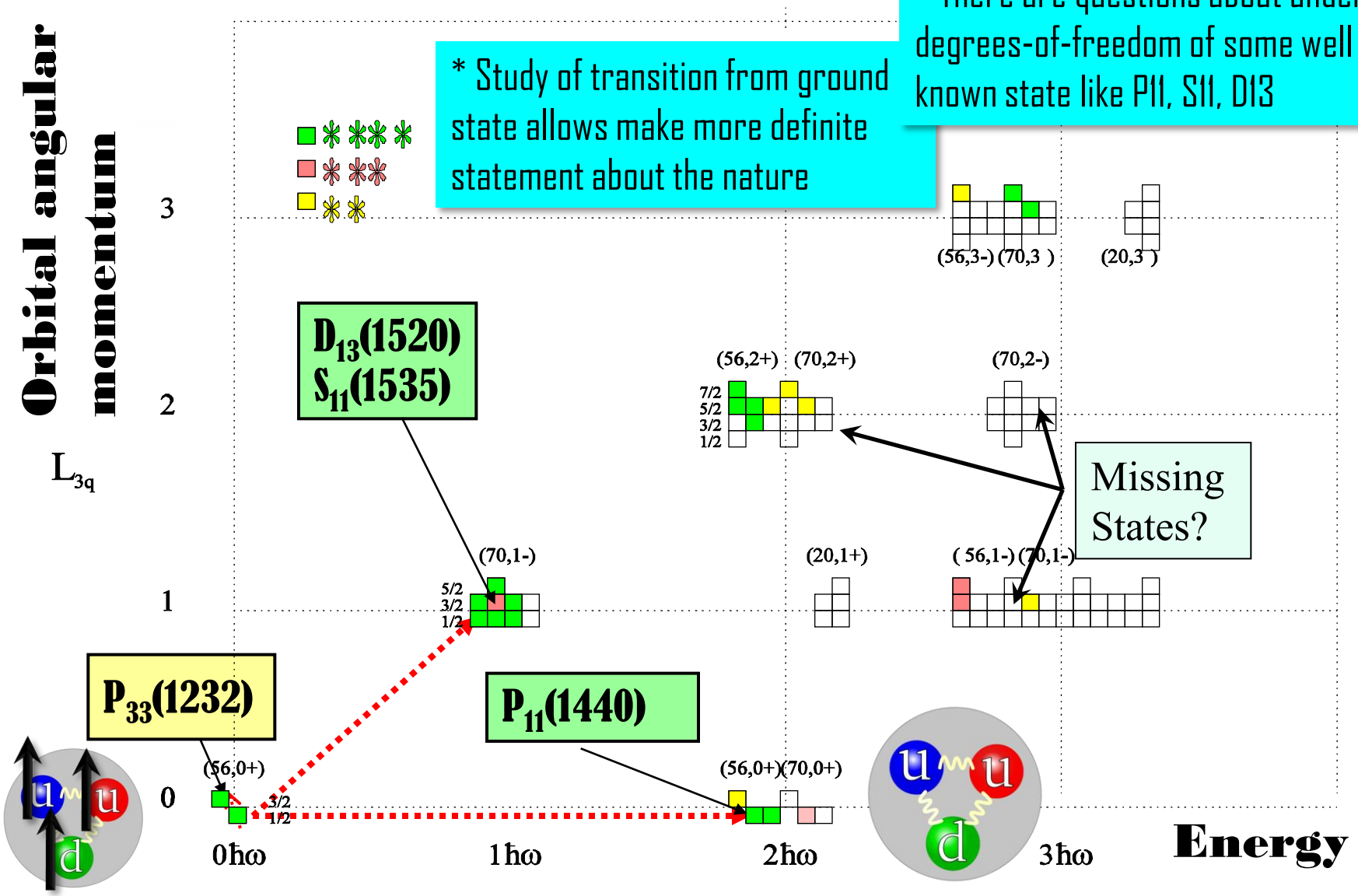
- generation of > 97% of nucleon mass
- enhance capability to map out QCD β function in constituent regime



SU(6)xO(3) Classification of Baryons

* There are questions about underlying degrees-of-freedom of some well known state like P11, S11, D13

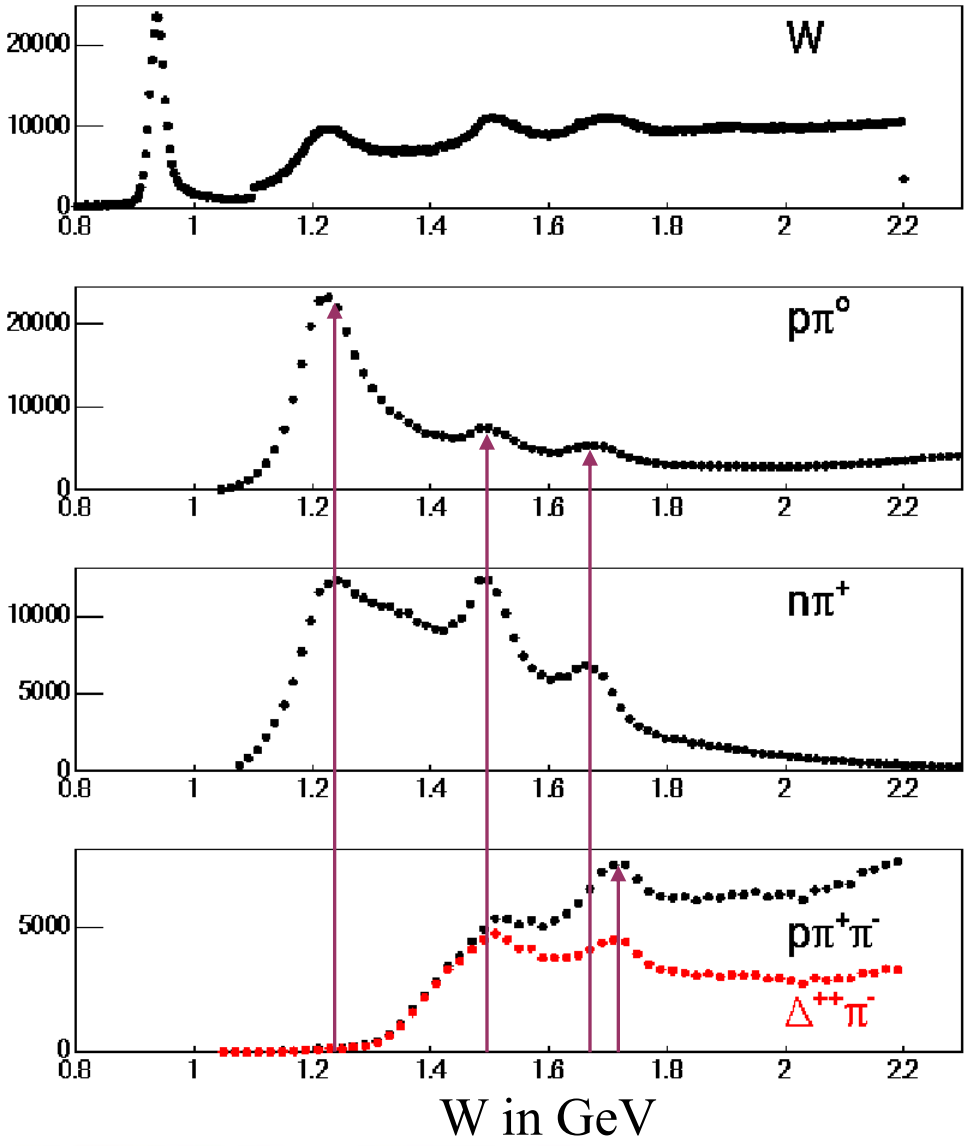
* Study of transition from ground state allows make more definite statement about the nature



Powerful channels
Single and double pion electro-productions

$Q^2 < 4.0\,GeV^2$

- $N\pi\pi$ channel is sensitive to N*s heavier than 1.4 GeV
- Provides information that is complementary to the $N\pi$ channel
- Many higher-lying N*s decay preferentially into $N\pi\pi$ final states



p(e,e')X

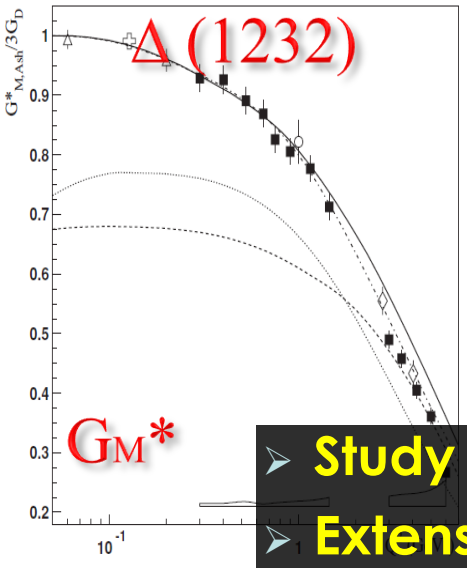
$p(e,e'p)\pi^0$

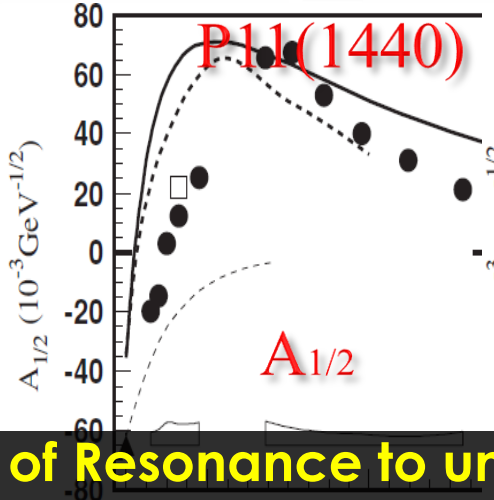
$p(e,e'\pi^+)n$

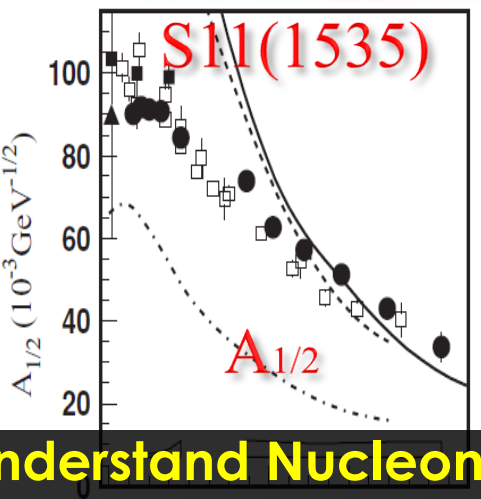
$p(e,e'p\pi^+)\pi^-$

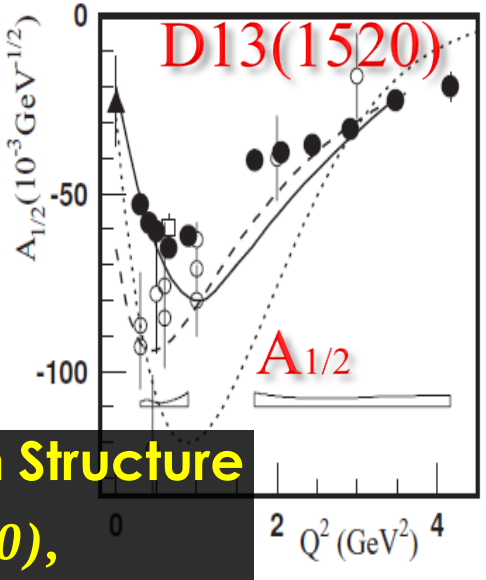
Previously…

PRC 77, 015208 (2008) PRL 97, 112003 (2006)
PRC 78, 045204 (2008) PRC 73, 025204 (2006)
PRC 78, 045209 (2008) PRC 80, 055203 (2009)

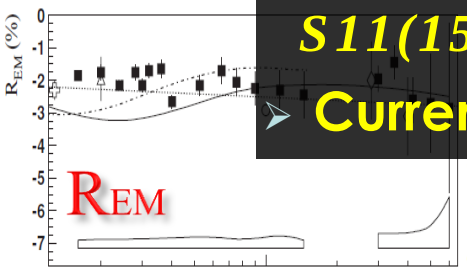


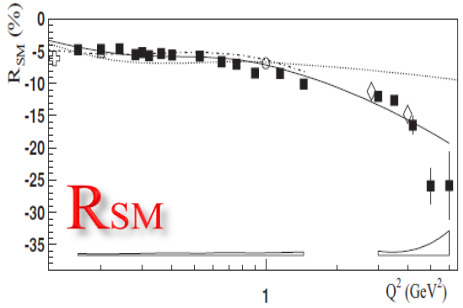


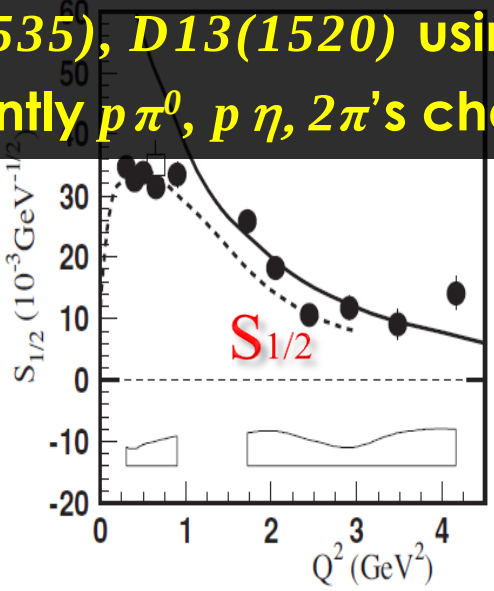


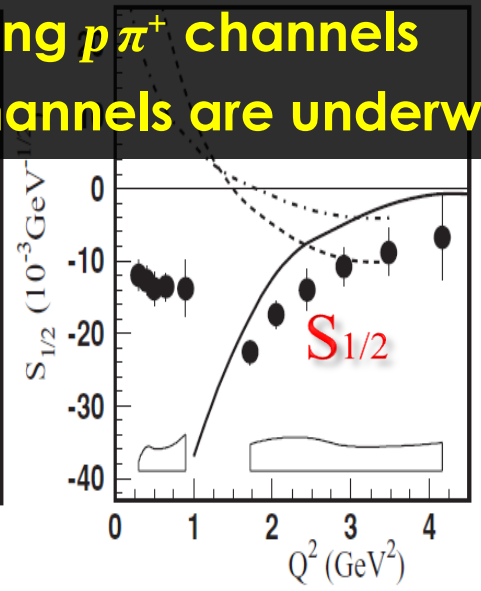


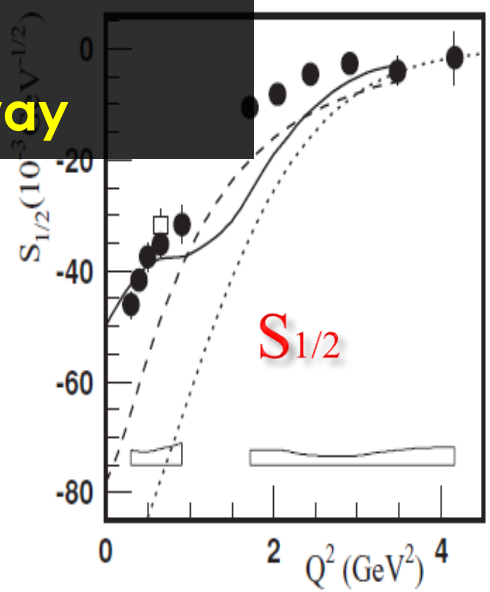
- Study of Resonance to understand Nucleon Structure
- Extensive studies beyond $\Delta(1232)$, $P11(1440)$, $S11(1535)$, $D13(1520)$ using $p\pi^+$ channels
- Currently $p\pi^0$, $p\eta$, 2π's channels are underway







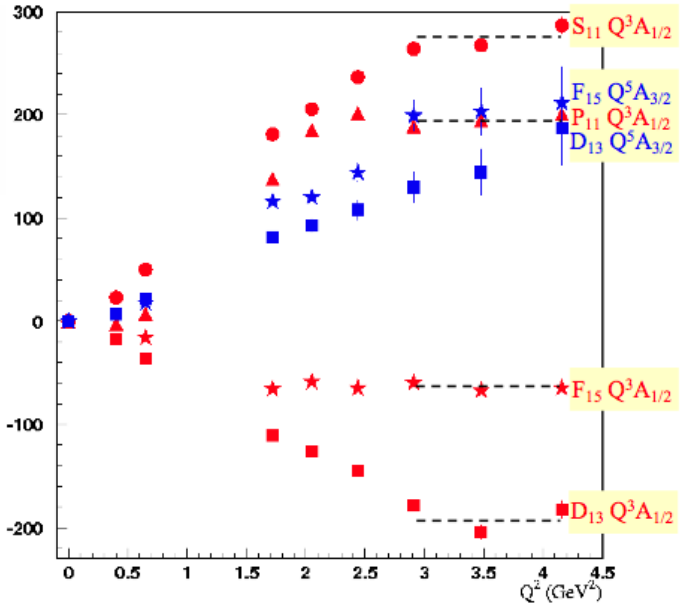




CQM, pQCD and beyond

The structure of the nucleon and its excited states are much more complex than CQM

Constituent Counting Rule at high Q^2



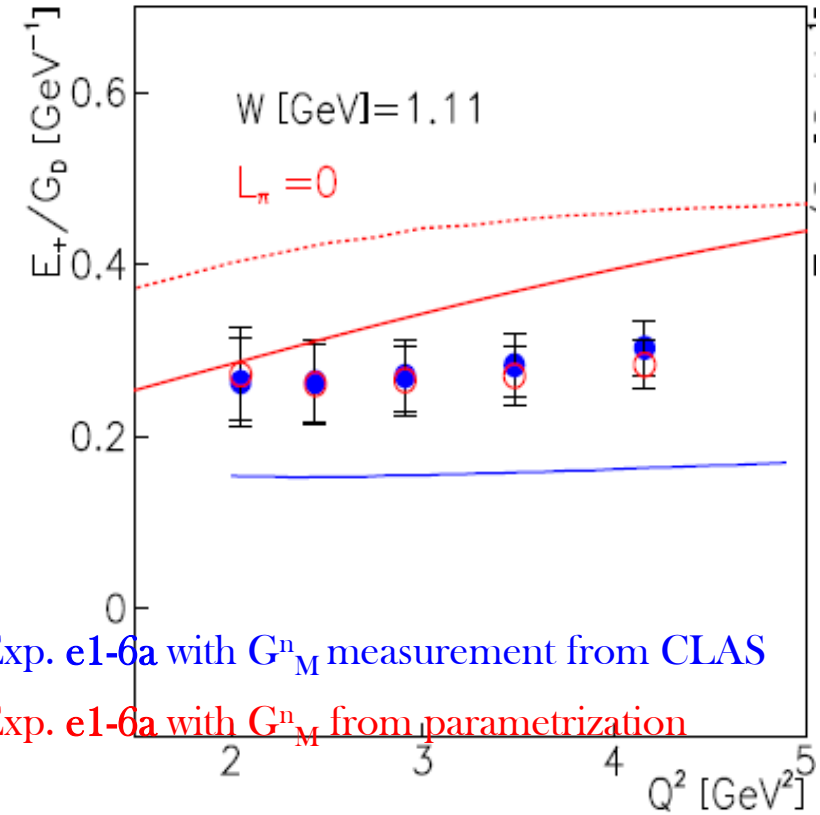
pQCD has some limits

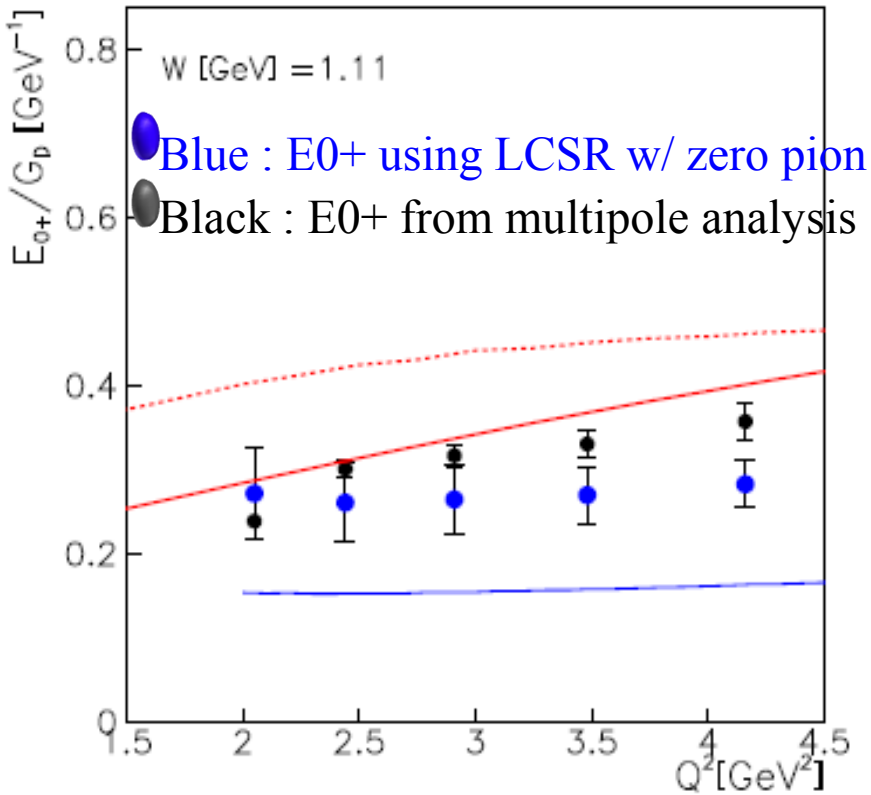
No produce mass in the Chiral limit
No explanation quark-gluon dynamics at low energy
No description of quark confinement

Lattice QCD (LQCD)
Dynamical Chiral Symmetry Breaking (CSB)
Light Cone Sum Rule (LCSR)

LCSR vs. preliminary CLAS data near pion threshold

$$\frac{Q^2}{m_N^2}G_1^{\pi^+ n} = \frac{g_A}{\sqrt{2}}\frac{Q^2}{Q^2+2m_N^2}G_M^n + \frac{1}{\sqrt{2}}G_A, \qquad G_2^{\pi^+ n} = \frac{2\sqrt{2}g_A m_N^2}{Q^2+2m_N^2}G_E^n \ .$$





Blue : E0+ using LCSR w/ zero pion mass

Black : E0+ from multipole analysis

Exp. e1-6a with G^n_M measurement from CLAS

Exp. e1-6a with G^n_M from parametrization

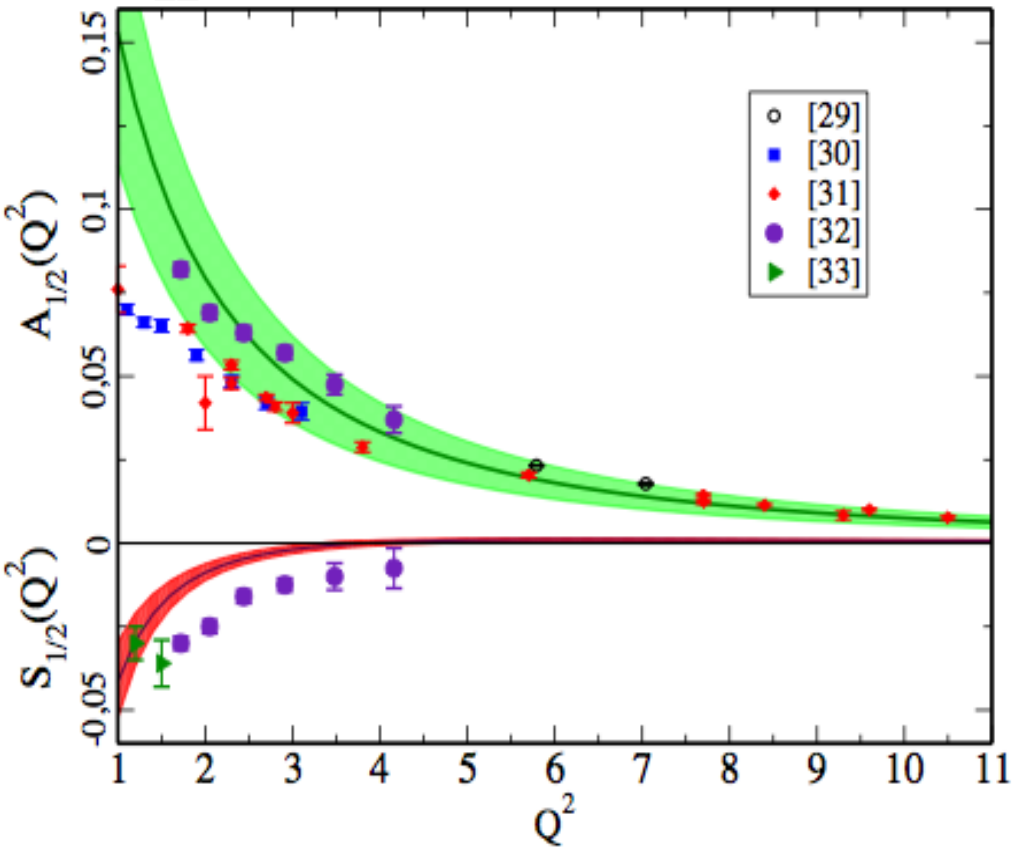
E_{0+}/G_D : LCSR (experimental electromagnetic form factors as input)

E_{0+}/G_D : pure LCSR calculation

E_{0+}/G_D : MAID2007

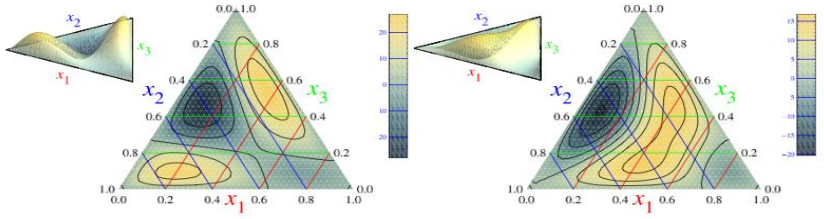
Transition Form Factor ←→ Distribution Amplitudes

$S_{11}(1535)$



Braun et al. Phys.Rev.Lett.103:072001,2009

DA from Lattice QCD (Warkentin, Braun)



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

29, 30: Dalton and Denizli
31: compilation by Stoler
32: Aznauryan analysys of e1-6 CLAS data
33: Old data by Tiator

Experimental data /kinematic bin (e1-f)

- Apr. 04 ~ Jul. 26, 2006
- E0 =5.499GeV (pol. e), LH2 target
- target position = 25cm upstream
- Length = 5cm, Φ= 6mm
- I_B = 2250A
- Trigger = ECin x ECtot x CC
- Total number of runs = 608 (576 Golden runs)

Kinematic binning		
W	1.6 ~2.0 GeV	5(40MeV) , 3(60MeV)
Q^2	1.7 ~4.5 GeV^2	5 (vary)
$\cos\theta_\pi^*$	-1.0 ~ 1.0	10 (0.2)
ϕ_π^*	0° ~ 360°	24 (15°)

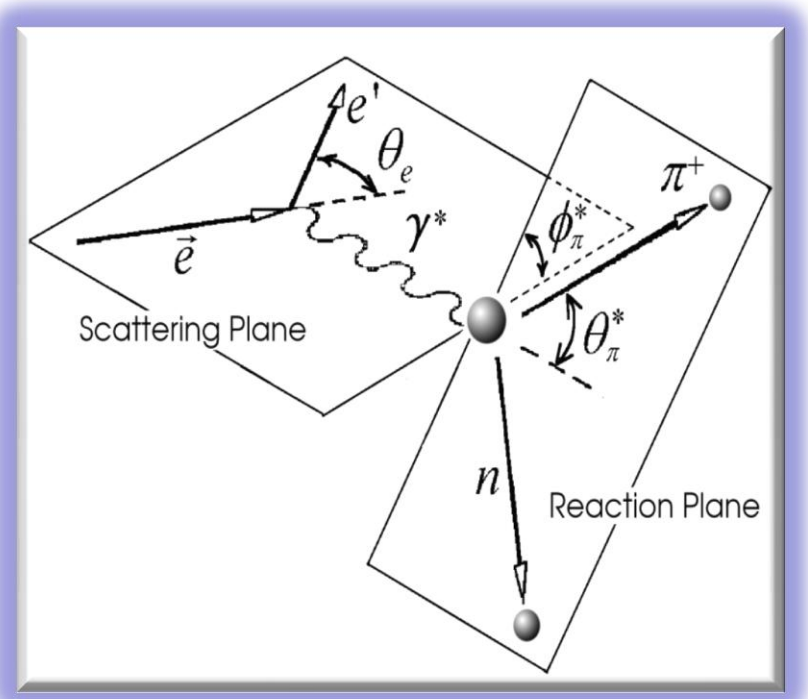
Differential cross sections

- ***Single pion electroproduction***

  Unpol. Xsection w/ one-photon exchange approx.

$$\frac{d^2\sigma^2}{d\Omega_\pi^*} = \frac{p_\pi^*}{k_\gamma^*}\left[\sigma_0 + h\sqrt{2\varepsilon_L(1-\varepsilon)}\sigma_{LT'}\sin\theta_\pi^*\sin\phi_\pi^*\right]$$

$$\sigma_0 = \sigma_T + \varepsilon_L\sigma_L + \varepsilon\sigma_{TT}\sin^2\theta_\pi^*\cos 2\phi_\pi^* + \sqrt{2\varepsilon_L(1+\varepsilon)}\sigma_{LT}\sin\theta_\pi^*\cos\phi_\pi^*$$



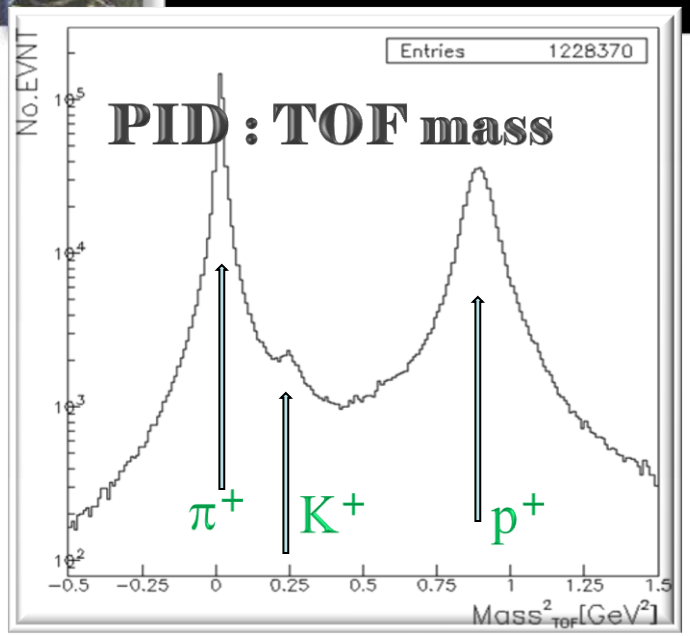
Incident electron energy		
Scattered electron energy		
Electron energy loss	=	$e - e'$
Invariant momentum transfer	=	$2ee'(1-\cos\theta_e)$
Invariant mass of final state	=	$-Q^2 + m_p^2 + 2m_p\nu$
Virtual photon 3-momentum	=	$(Q^2+\nu^2)^{1/2}$

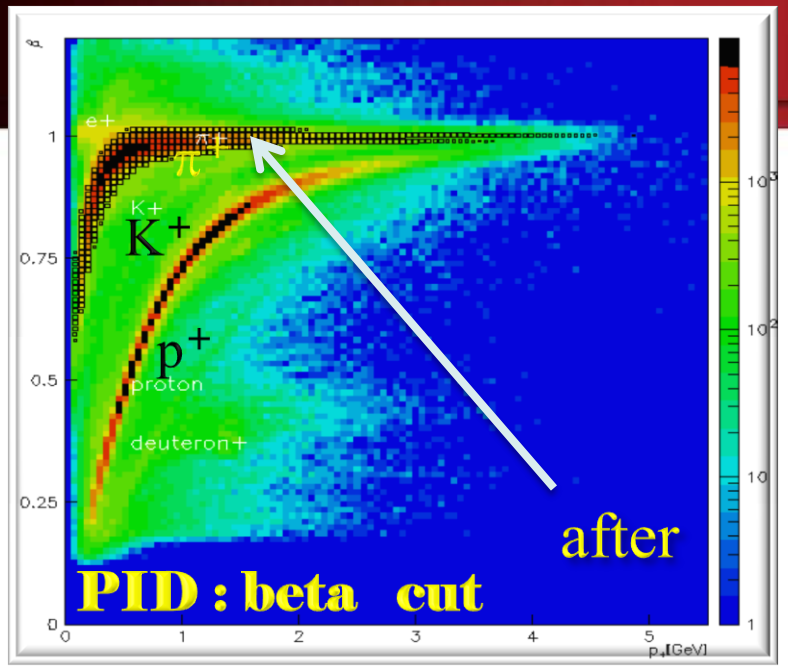
Analysis details

Summary cuts and correction in this analysis

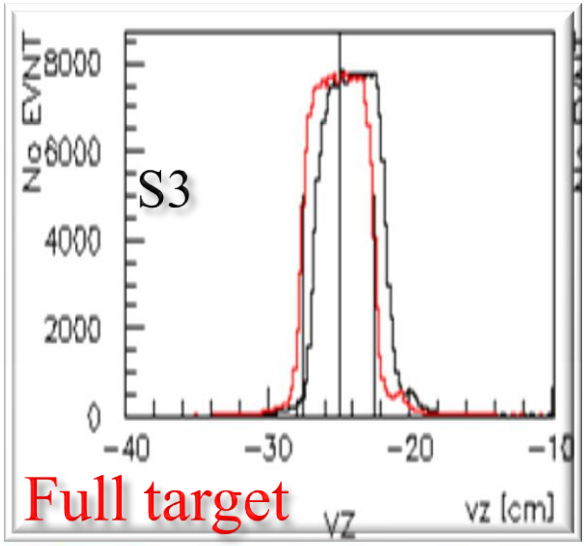
- beam centering and vertex correction
- electron and pion fiducial volume cuts
- electron , pion momentum correction
- CC efficiencies were taken into account after Nphe cut
  200x200 matrix lookup table in terms of CC geom.
- Knock out DC inefficient regions and bad TOF counters
- TOF particle detection efficiencies using $p\pi^+\pi^-$
  lookup table in terms of our final kinematic bins.
- acceptance and radiative corrections

Analysis details

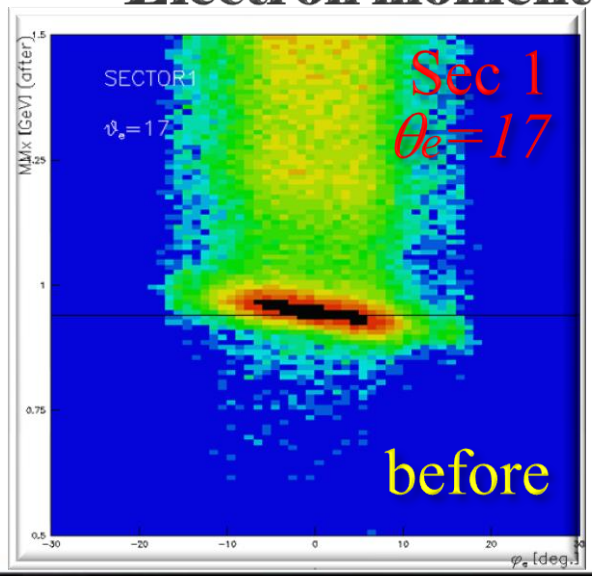


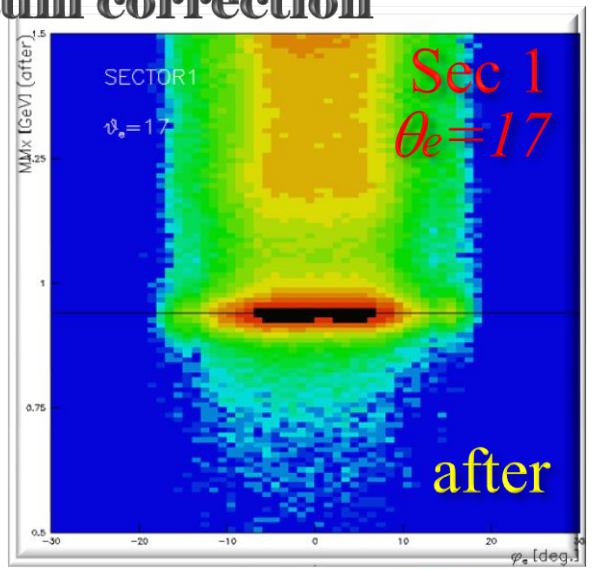


Vertex correction



Electron momentum correction





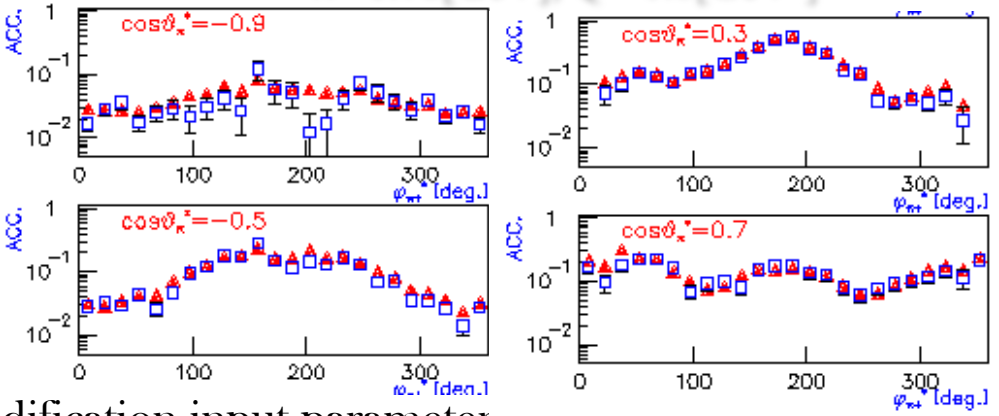
MC simulation

20M basis

634M basis

Kinematic settings	
E_0	5.499 GeV.
W	1.4-2.0GeV
Q^2	1.5-5.0GeV^2
Target position	-27.5, -22.5, 0.2

W=1.78[GeV], Q^2=1.8[GeV^2]



Samples

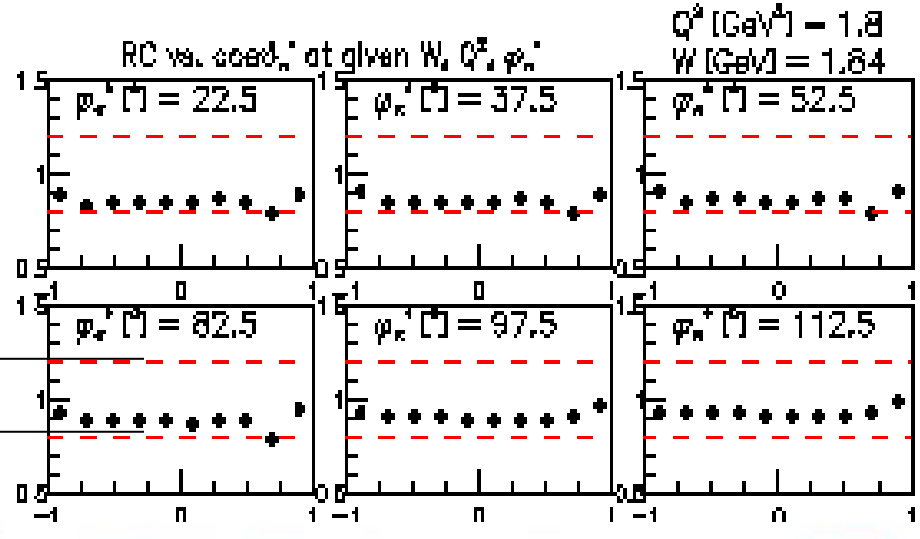
* AAO_RAD for electro-production : modification input parameters. .

Radiative correction

W=1.84[GeV], Q^2=1.80[GeV^2]

- ExcluRad basis exact calculation
- Limited W<2.0GeV, Q2<5.0GeV2
- two MAID (03/07) version tested
- 2 or 3times iteration
- Using final kinematic binning

±20%



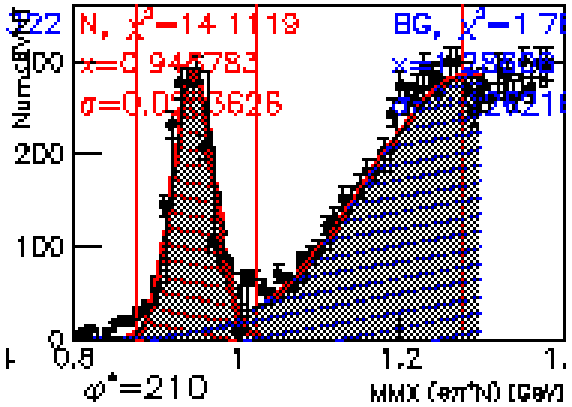
Samples

Background subtraction

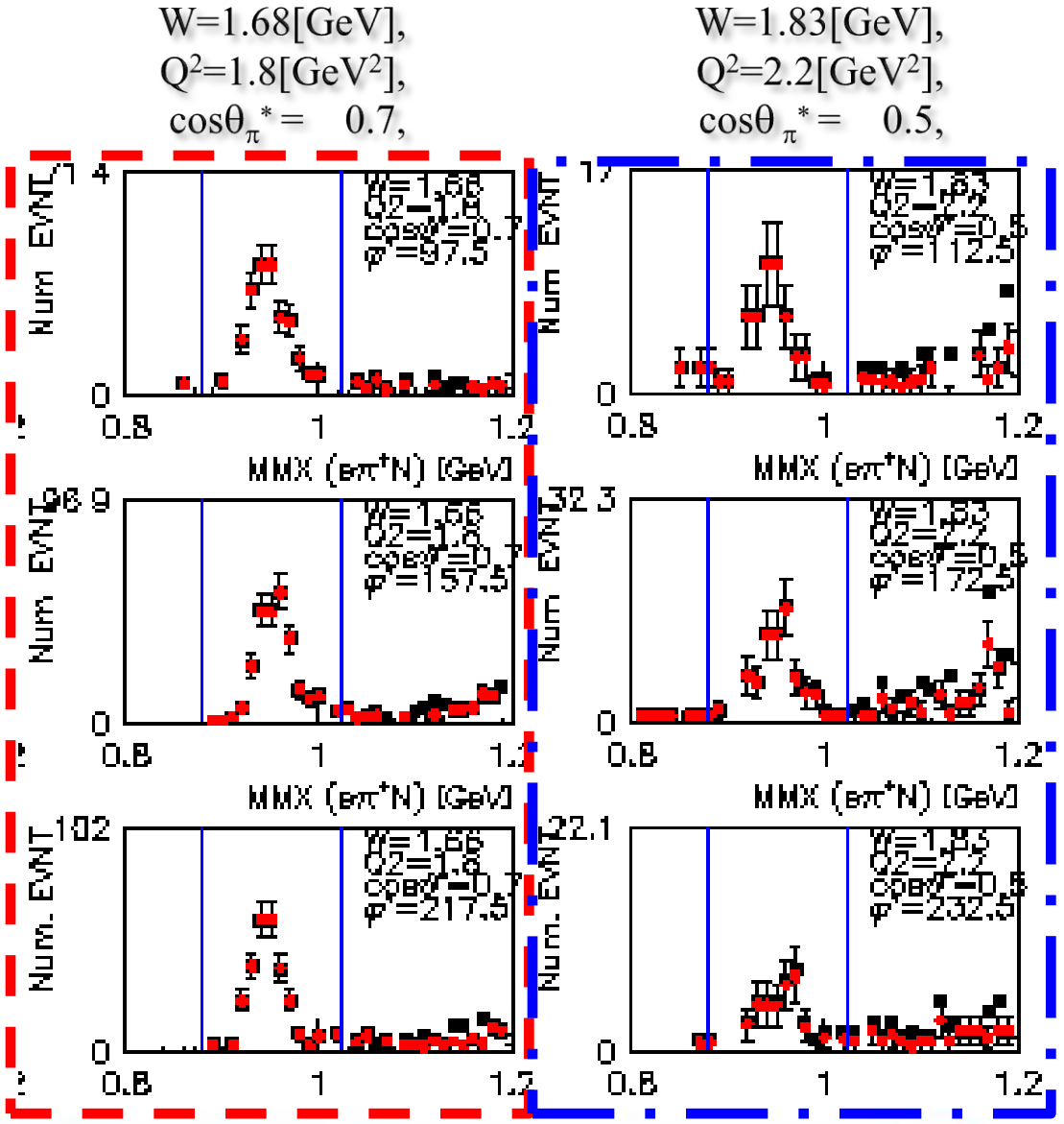
- Fit the background using exp + polynomial function for high mass region
- extrapolate under neutron missing mass region
- BG study using the final binning

BEFORE BG subtraction

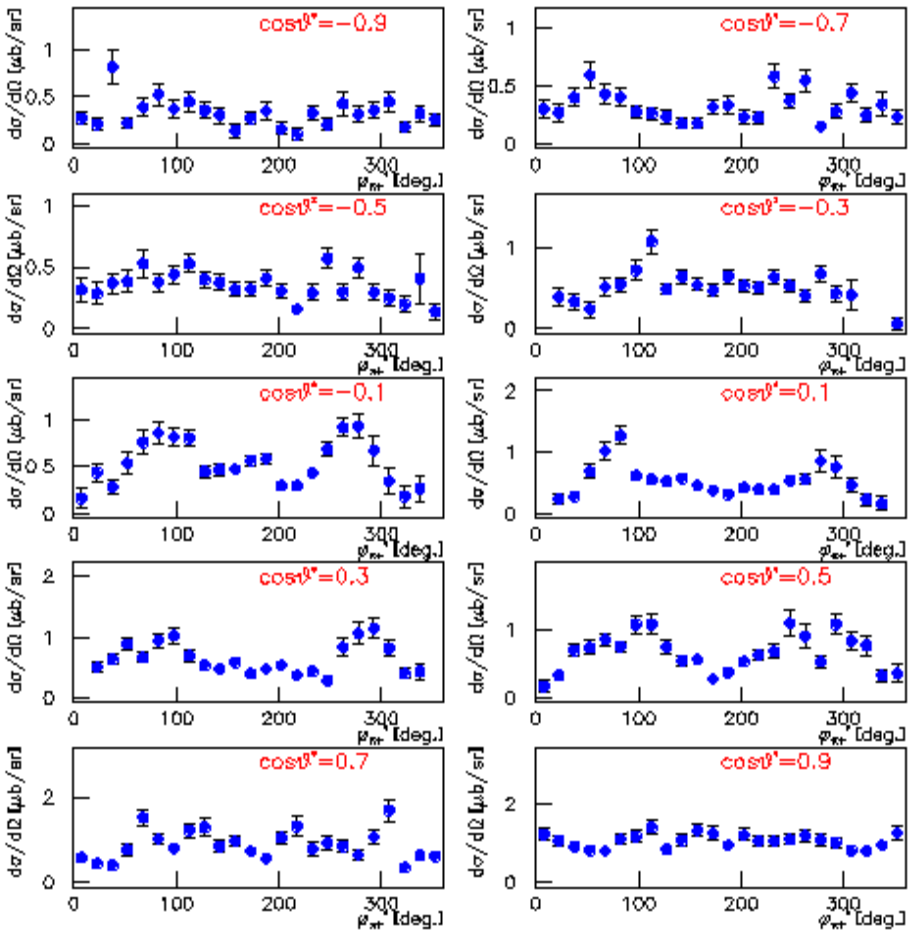
AFTER BG subtraction

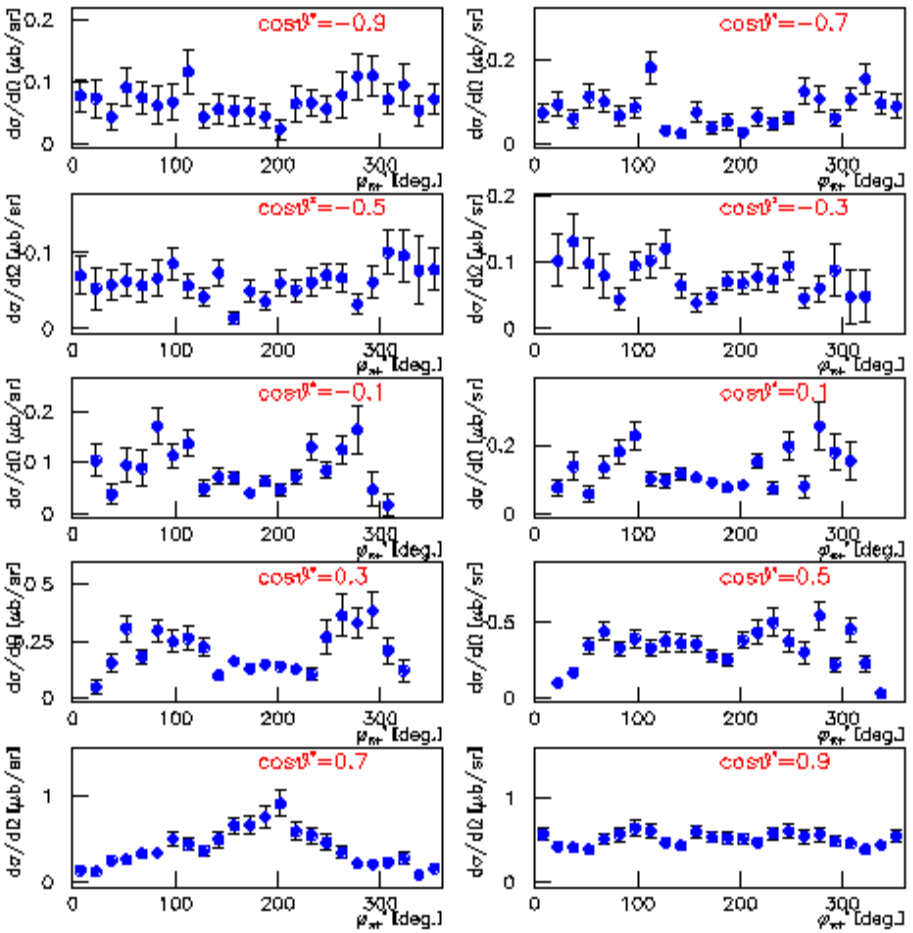


Example



Preliminary differential cross sections

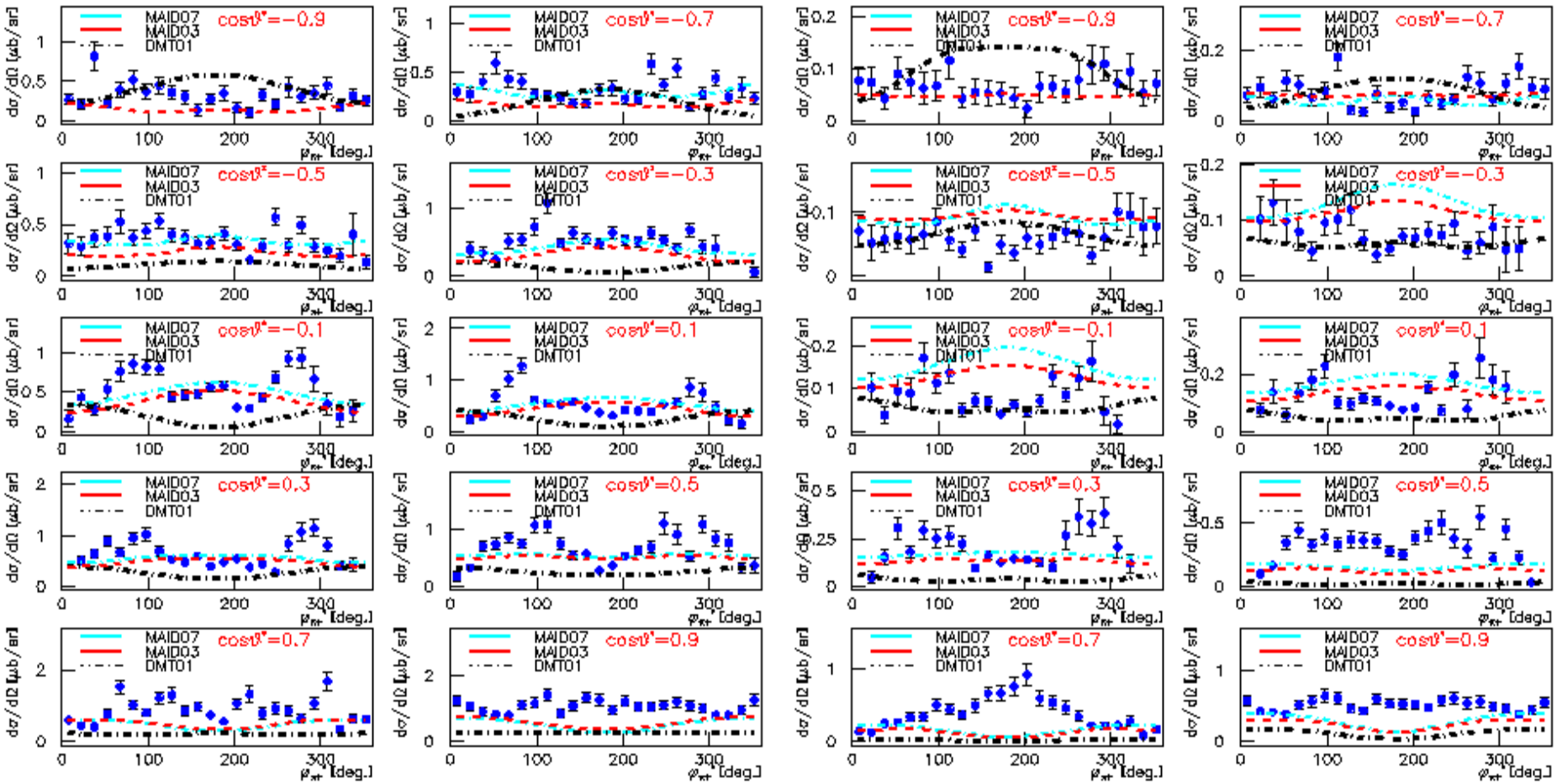




- Exp. e1-f

- Luminosity & virtual photon flux were taken in account

Preliminary differential cross sections



Exp. e1-f

MAID 2003 (Isobar model)

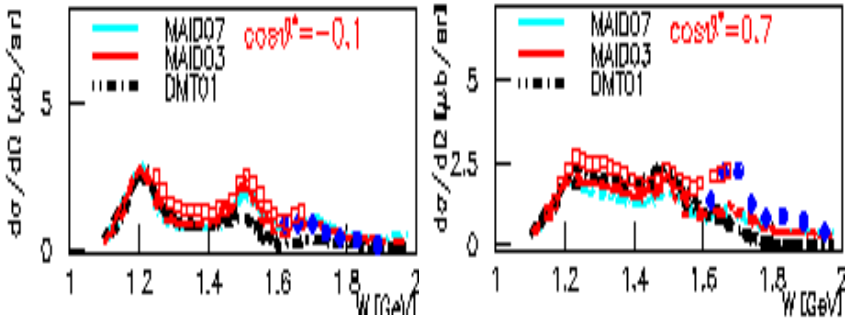
MAID 2007 (Isobar model)

DMT2001 (Dynamic model)

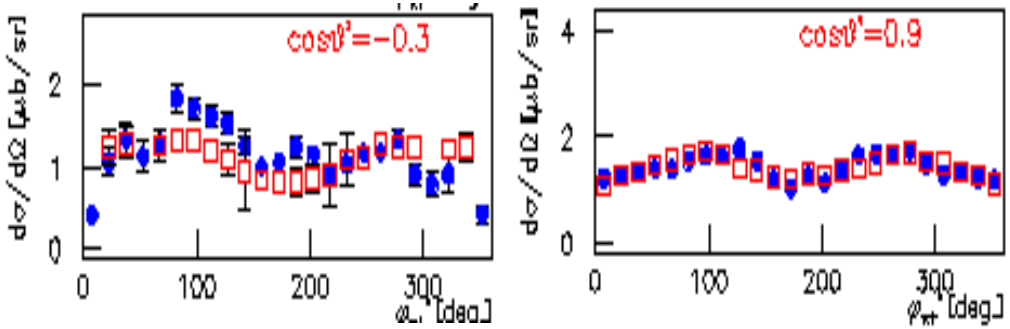
Preliminary cross sections vs. previous data

Overall systematic error in the analysis of " e1f " data is approximately ~10 -20%

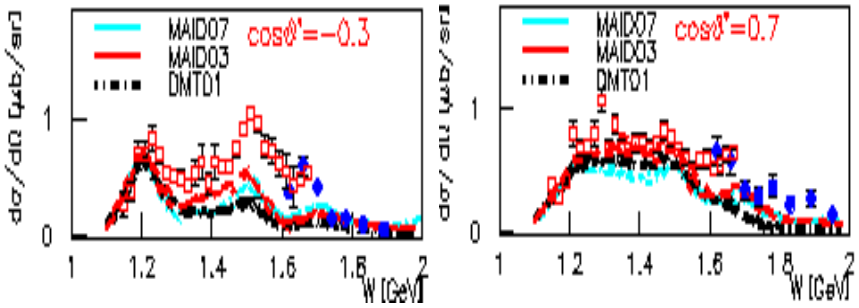
Q^2=1.72[GeV^2], Q^2=1.8[GeV^2], ϕ_π^* = 247.5deg.



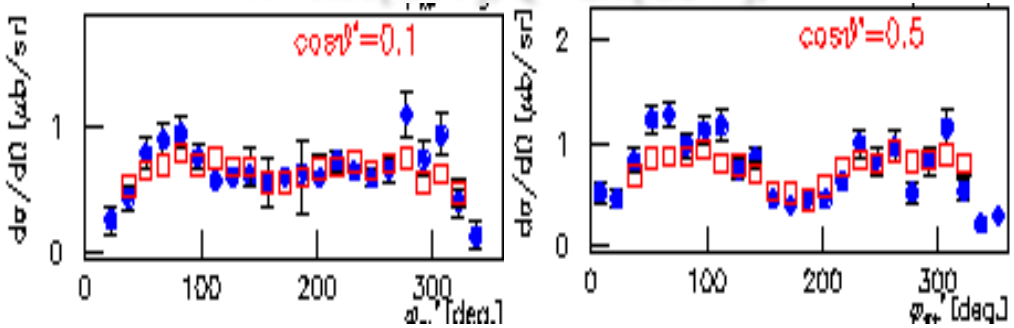
W=1.61[GeV], Q^2=1.72[GeV^2],
W=1.62[GeV], Q^2=1.8[GeV^2],



Q^2=2.91[GeV^2], Q^2=3.15[GeV^2], ϕ_π^* = 262.5deg.



W=1.65[GeV], Q^2=2.44[GeV^2],
W=1.66[GeV], Q^2=2.6[GeV^2],



Exp. e1-f

Exp. e1-6a

MAID 2003 (Isobar model)

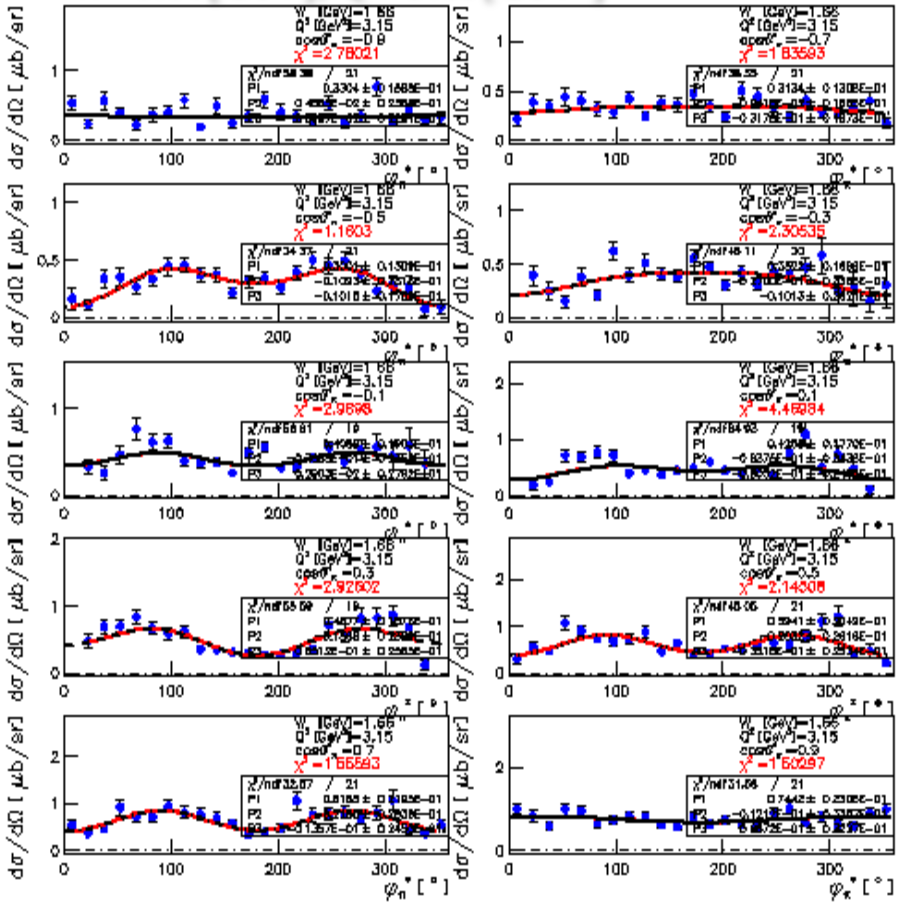
MAID 2007 (Isobar model)

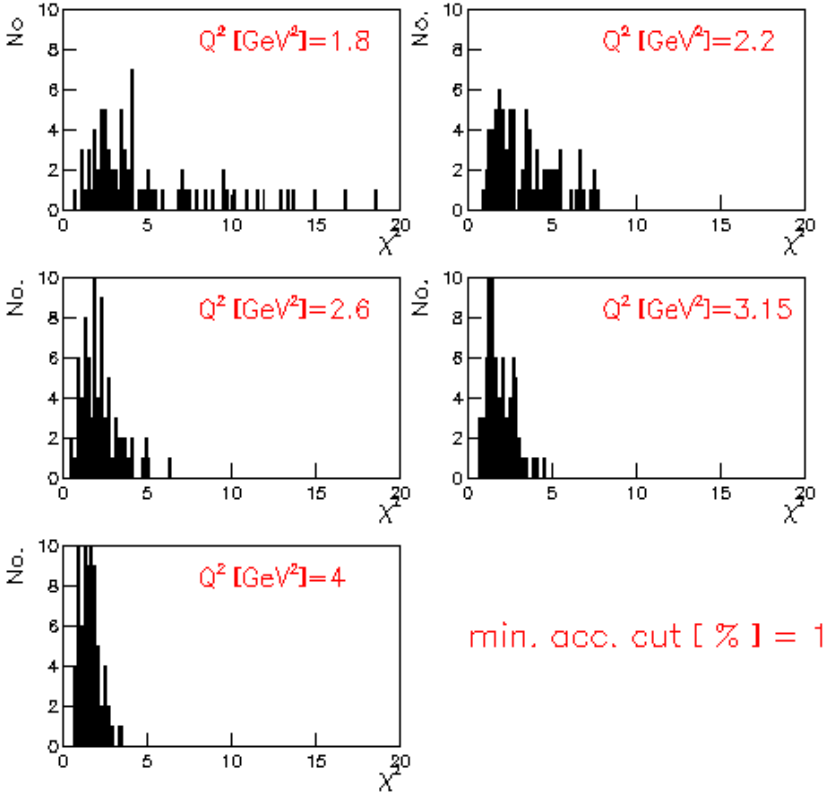
DMT2001 (Dynamic model)

Fitting with A + Bcos ϕ + C cos 2ϕ

1%

W=1.66[GeV], Q^2=3.15[GeV^2]



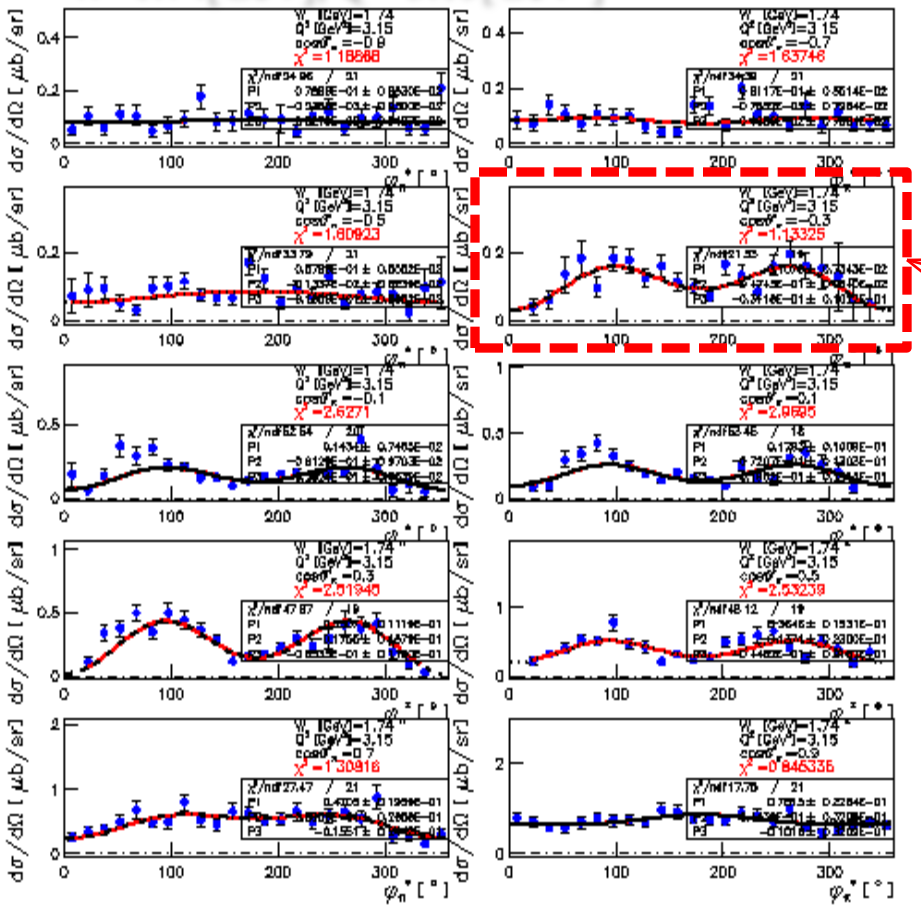


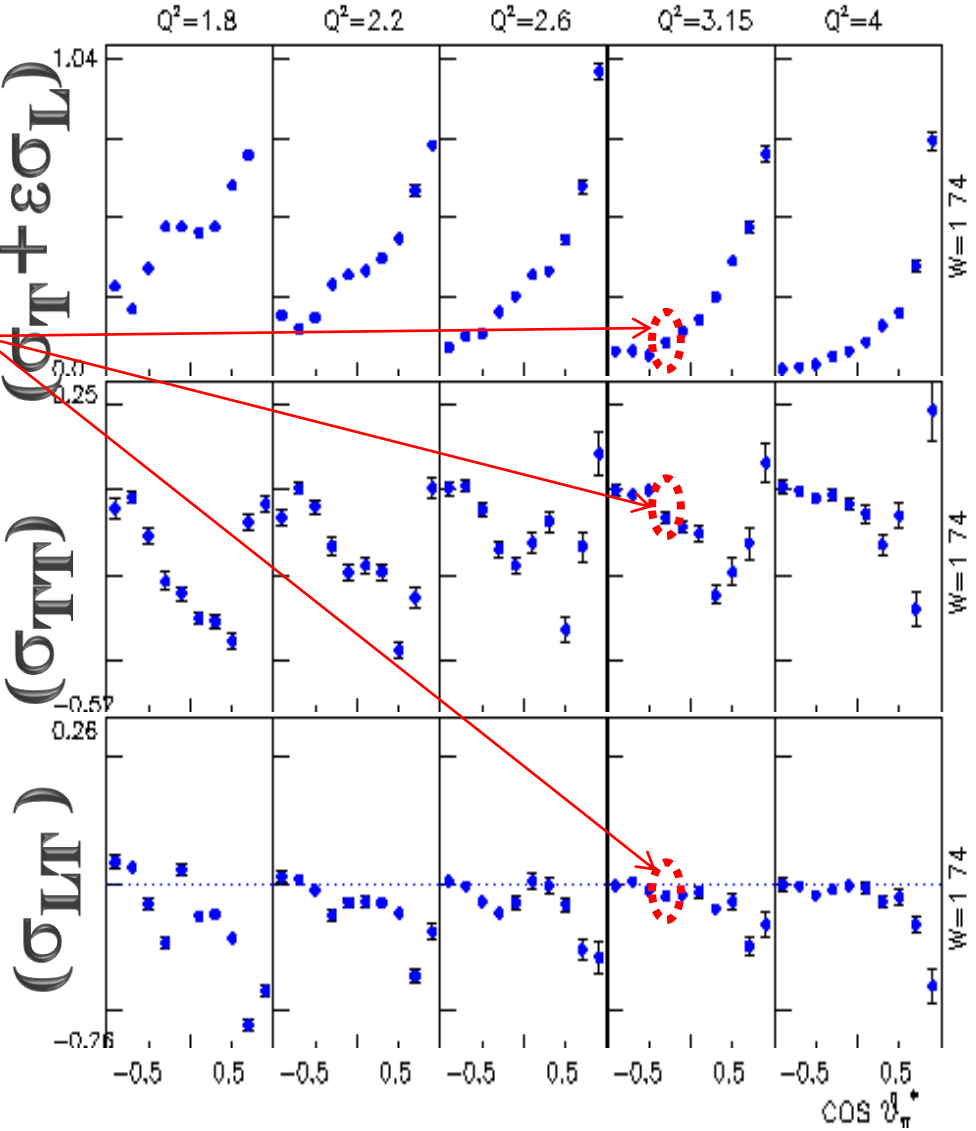
min. acc. cut [%] = 1

Exp. e1-f

Structure functions

W=1.74[GeV], Q^2=3.15[GeV^2]





Exp. e1-f

Summary and Plans

- Single charged pion differential cross sections have been extracted in high lying resonance region (1.6<W<2.0GeV) using CLAS e1-f data set.
- Preliminary results showed consistent with e1-6 data at 1.60GeV<W<1.69GeV.
- These single pion and upcoming double-pion data allow us to study extensively for high-lying resonances.
- Stay tune to finalize data and look forward to extract helicity amplitudes for high resonances.