Can one study N*N scattering inside the deuteron ?

Werner Boeglin
Florida International University
Miami

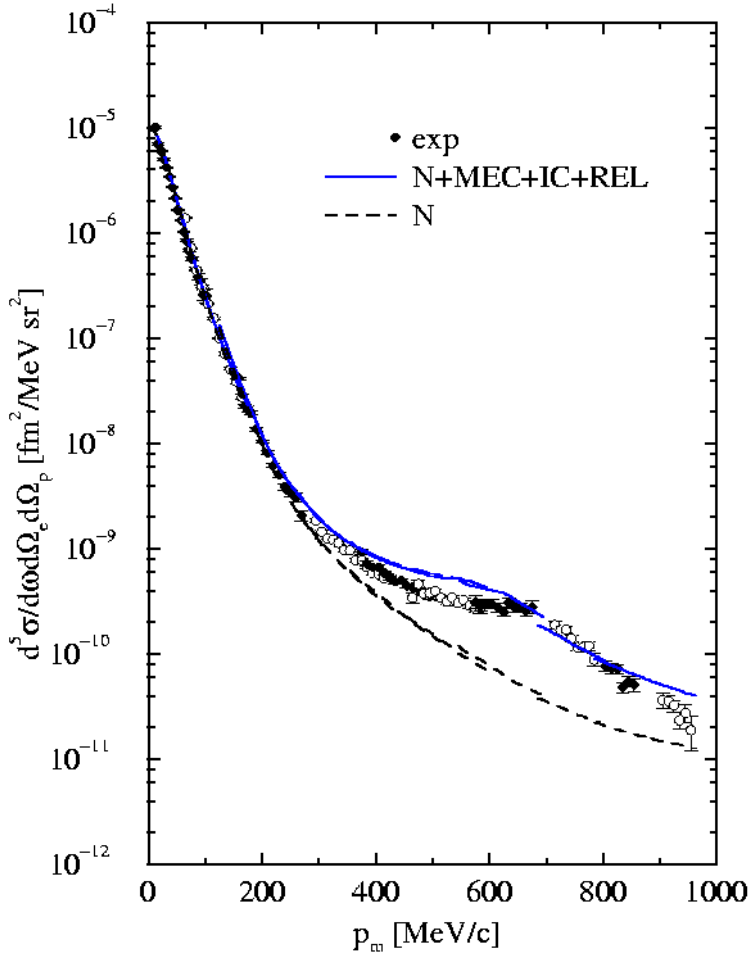
dedicated to Kim Egiyan

Introduction

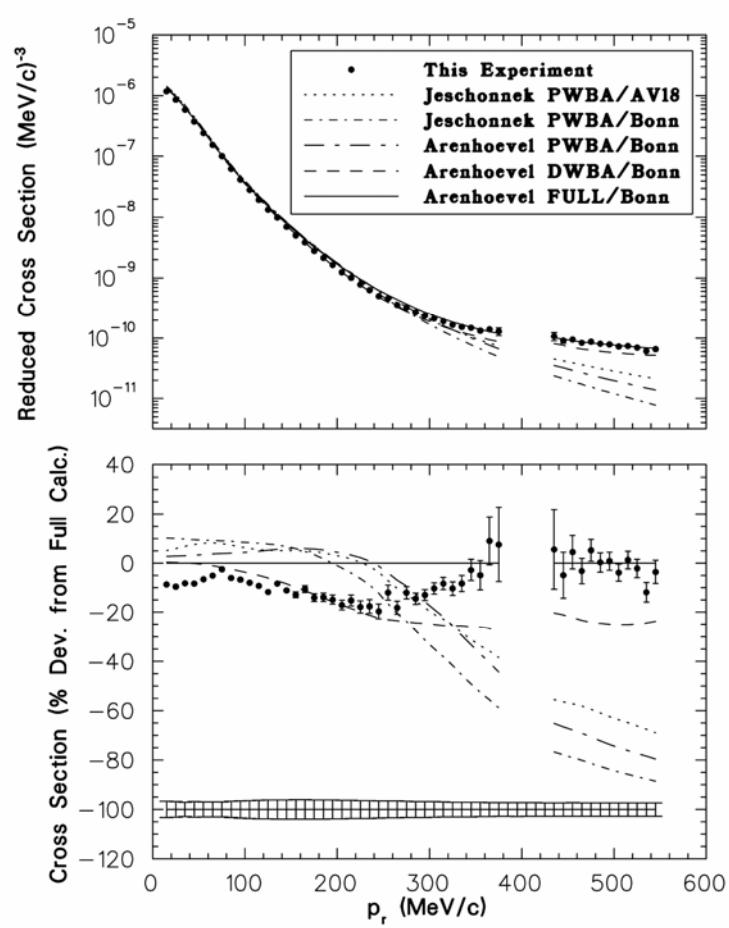
- D(e,e'p)n : FSI dominant at many kinematical settings
- problematic to study SRC
- Idea: study new physics via FSI
- create 'beam' of N* resonances in the deuteron

Example : S_{11} (1535) electro- and (possibly) photo-production off the deuteron at large Q^2

Experiments at low(er) Q^2



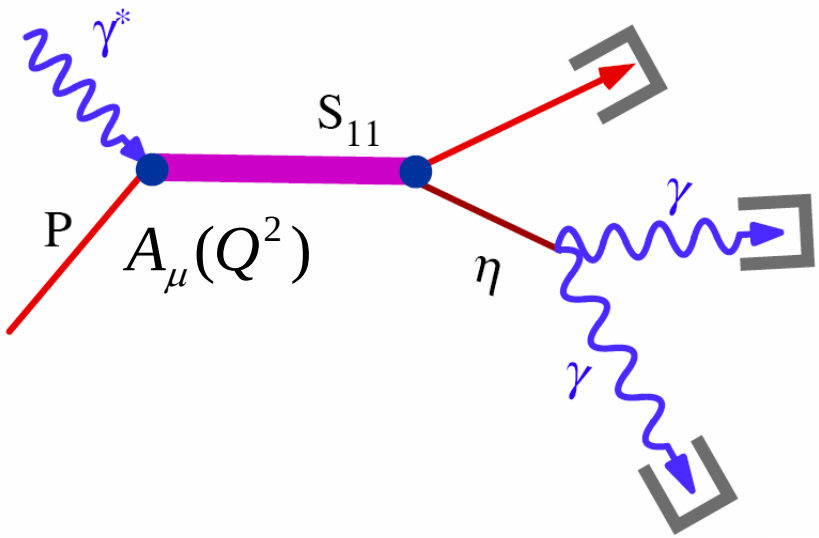
MAMI $Q^2 = 0.33$ (GeV/c)^2
Blomqvist et al.



JLAB $Q^2 = 0.67$ (GeV/c)^2
Ulmer et al.

Reaction Mechanisms

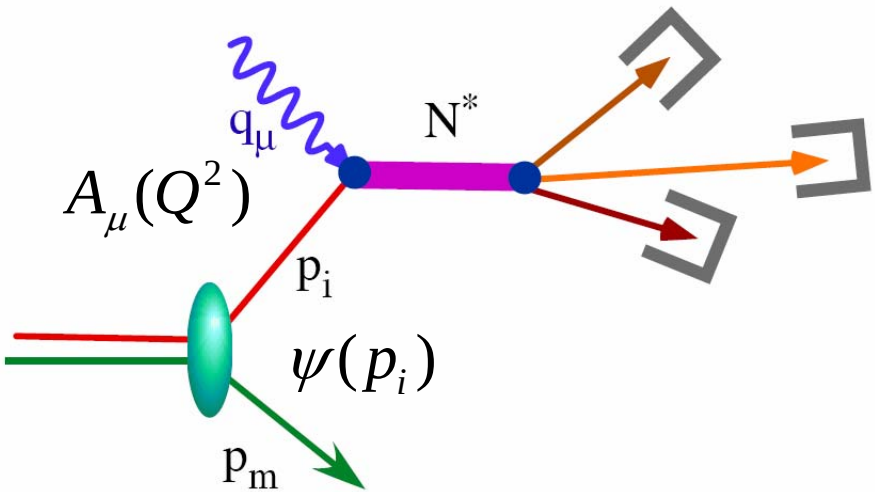
PWIA: no rescattering



free nucleon :

total amplitude:

$A_\mu(Q^2)$

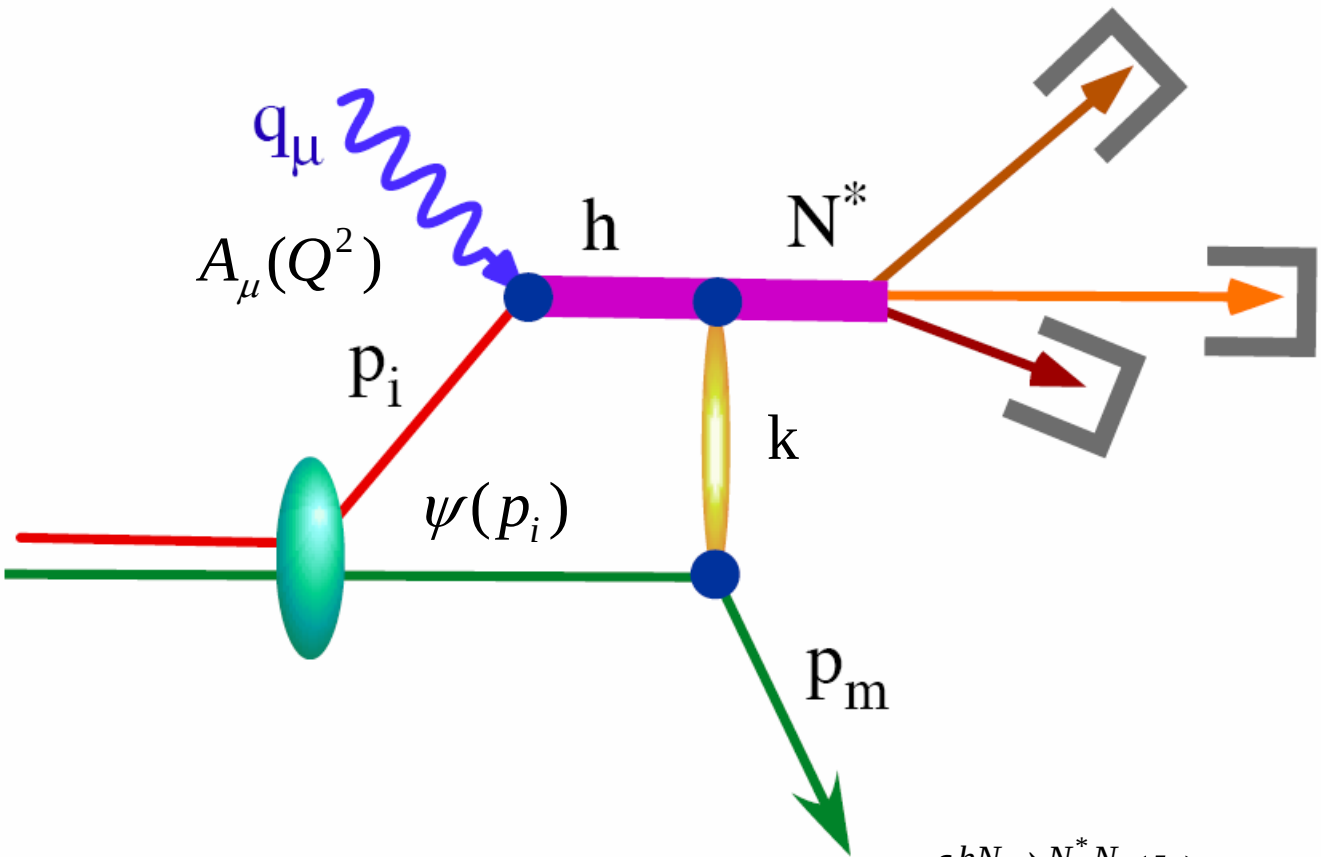


PWIA : no rescattering

total amplitude:

$F_a^\mu \propto \psi(p_i) A_\mu(Q^2)$

Rescattering



$$F_b^\mu \propto \sum_h \int \psi(p_m - k) A_h^\mu(Q^2) \frac{f^{hN \to N^* N}(k)}{[-k_z + \Delta + i\varepsilon]} d^3k$$

Necessary conditions to extract resonance information :

- D(e,e'p)n needs to be understood
- resonance production mechanism needs to be under control
- large Q^2 : Eikonal approximation is valid

recent JLAB experiments have and will provide necessary data

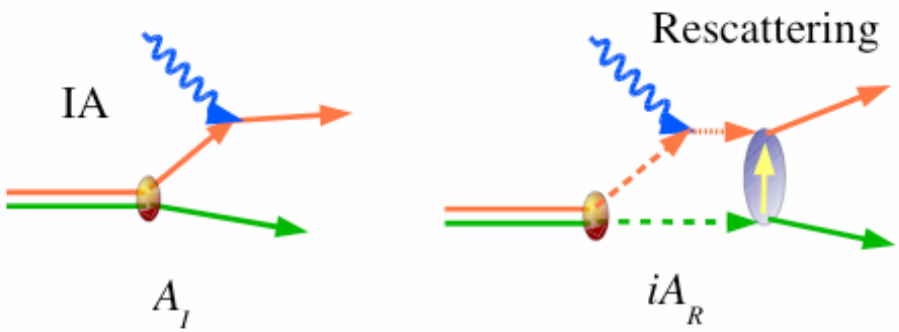
D(e,e'p)n at JLAB at high Q^2

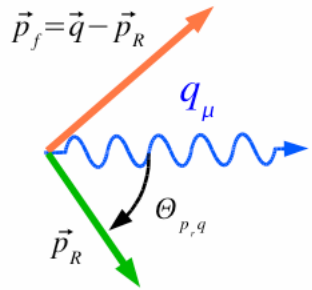
- experiments in Hall A and Hall B (CLAS)
- test generalized eikonal approximation (Glauber based)
- short distance structure of the deuteron
- relativistic effects: current operator and deuteron structure
- Q^2 dependence of MEC and IC
- search for Color Transparency

Eikonal Approximation

- FSI described as sequential (soft) scatterings
- successfully used in hadron scattering
- for nucleons at rest $\Rightarrow$ Glauber approximation
- for moving nucleons $\Rightarrow$ Generalized Eikonal Approximation

FSI as Re-Scattering





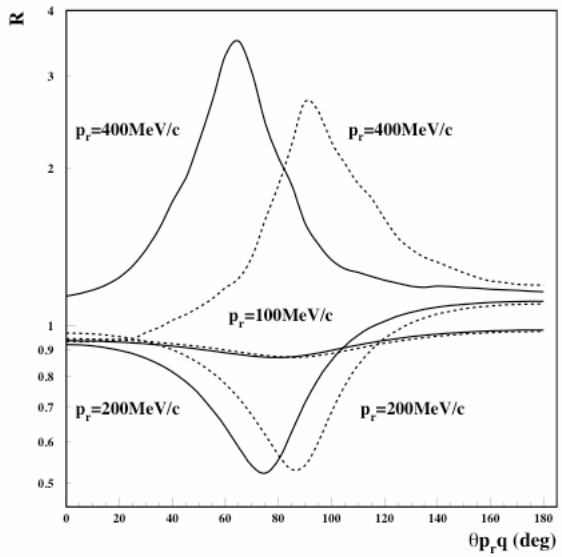
total scattering amplitude: $A = A_I + iA_R$

cross section: $\sigma \sim |A|^2 = |A_I + iA_R|^2$

$$\sigma \sim |A_I|^2 - 2|A_I||A_R| + |A_R|^2$$

at high energies iA_R is mainly imaginary

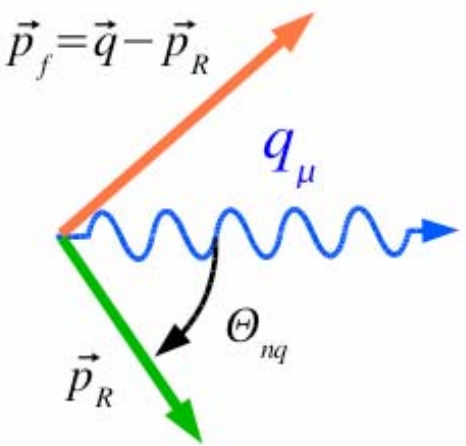
$$R = \frac{\sigma}{\sigma_I} = 1 - 2\frac{|A_I||A_R|}{|A_I|^2} + \frac{|A_R|^2}{|A_I|^2}$$



Hall A Experiment

(final analysis of Q^2 = 3.5 $(GeV/c)^2$ in progress)

- Q^2 = 0.8, 2.1 and 3.5 $(GeV/c)^2$: constant for each set
- p_{miss} = 0.2, 0.4 and 0.5 GeV/c : angular distribution
- $20^o \le \theta_{pq} \le 140^o$



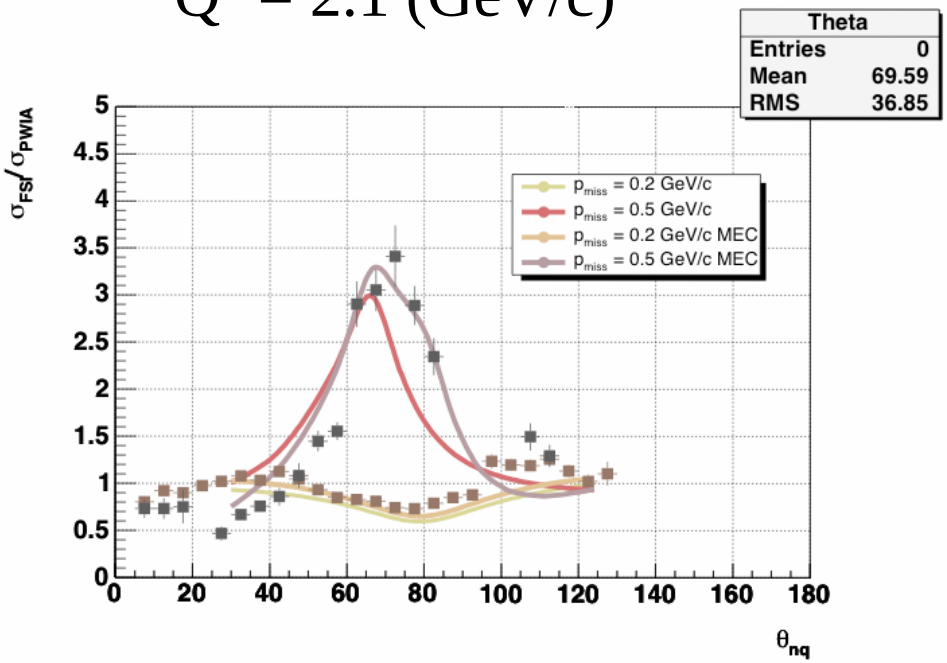
Goals:

- angular distributions
- R_{LT} as a function of Q^2 and p_{miss}

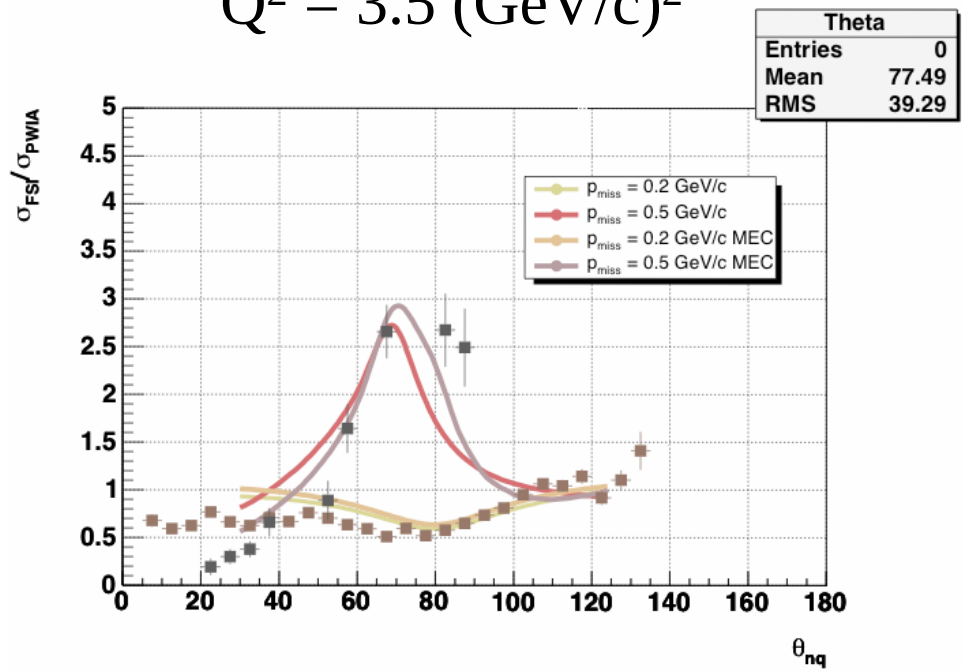
Comparison to Calculations

PRELIMINARY

$Q^2 = 2.1$ (GeV/c)^2



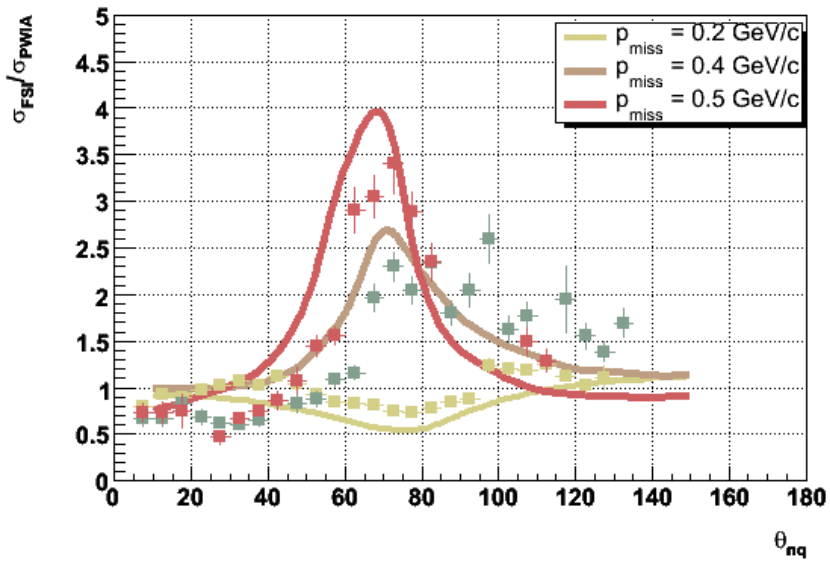
$Q^2 = 3.5$ (GeV/c)^2

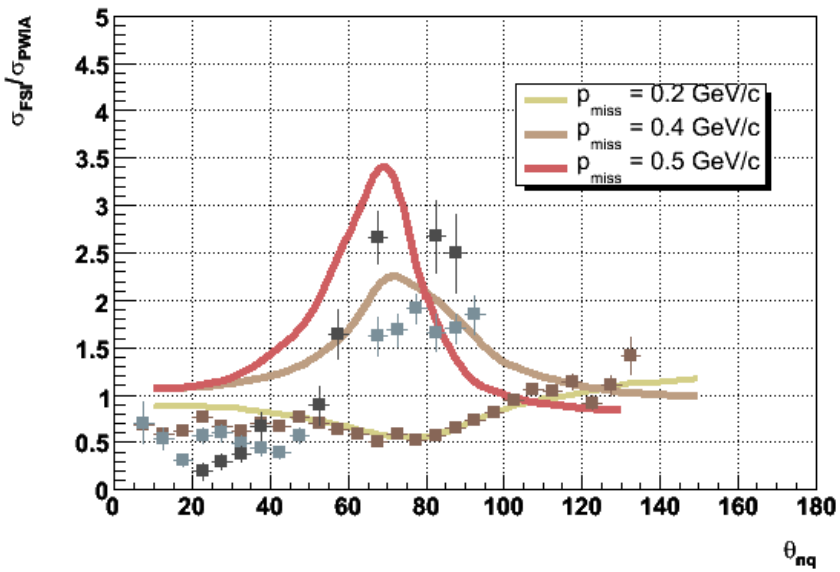


Calculation J.M. Laget

$Q^2 = 2.1$ (GeV/c)^2 $Q^2 = 3.5$ (GeV/c)^2

PRELIMINARY





Calculation: M. Sargsian

D(e,e'p)n with CLAS

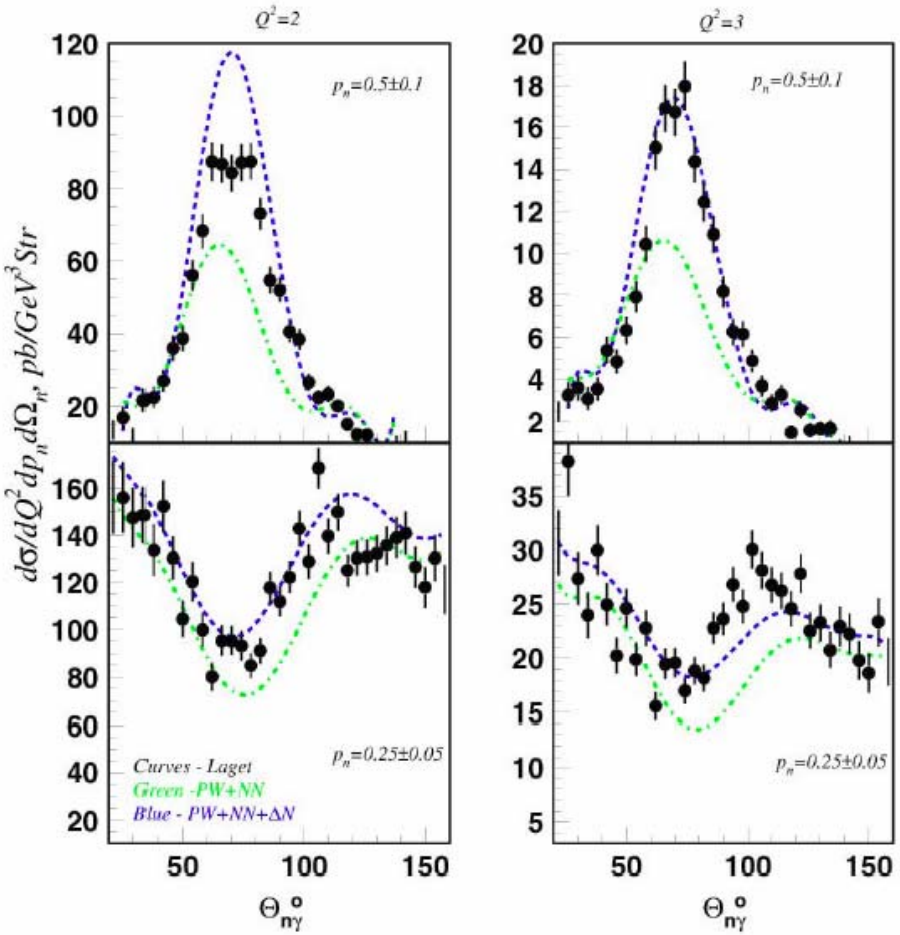
Kim Egiyan et.al.

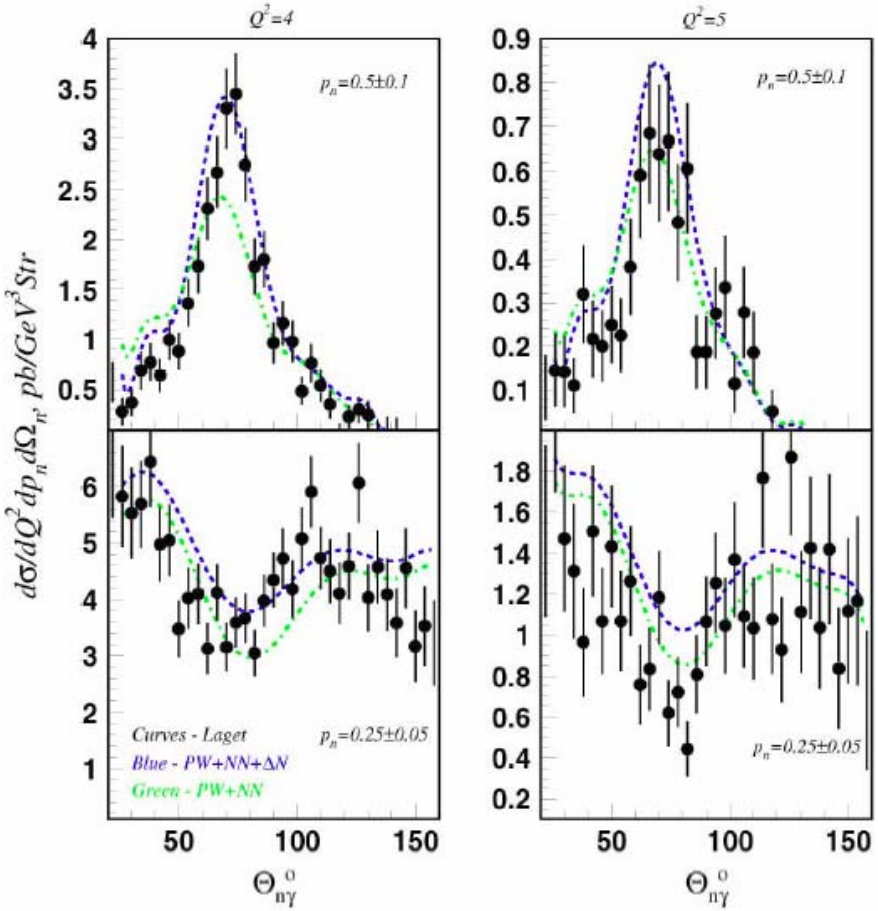
- CEBAF Large Acceptance Spectrometer
- Simultaneous measurement of kinematics
- focus on Q^2 dependence
- ultimate goal: search for Color Transparency effects
- e6 running period

E_{inc} = 5.76 GeV
Q^2 = 2, 3, 4, 5 $(GeV/c)^2$

PRELIMINARY

PRELIMINARY





^{3}He 2-body break-up at JLAB

Hall A Experiment E89-044

Kinematics:

$Q^2 = 1.55$ (GeV/c)^2, kept constant
q = 1.502 GeV/c, w = 0.840 GeV, $x_b = 0.98$

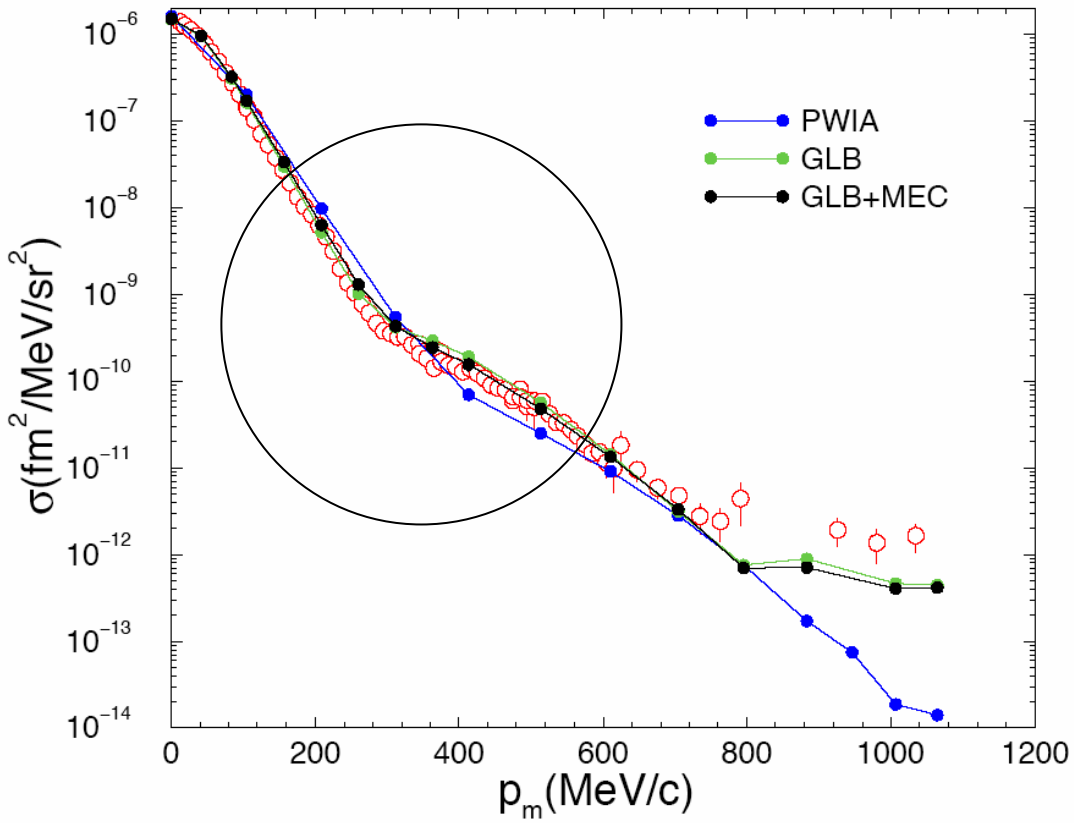
cross sections for $0 \leq p_m \leq 1$ GeV/c
R_{LT} for $p_m \leq 0.66$ GeV/c

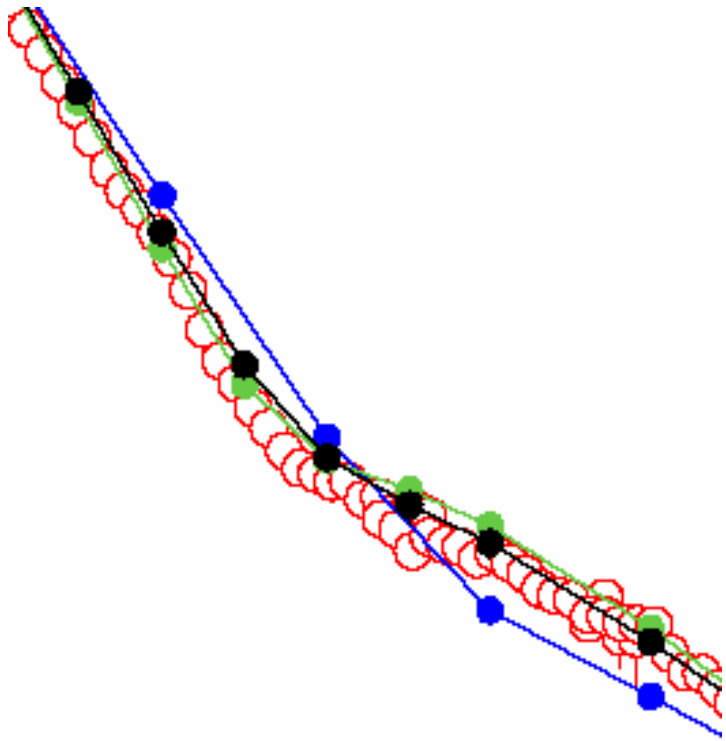
M.Rvachev PRL94(2005)192302

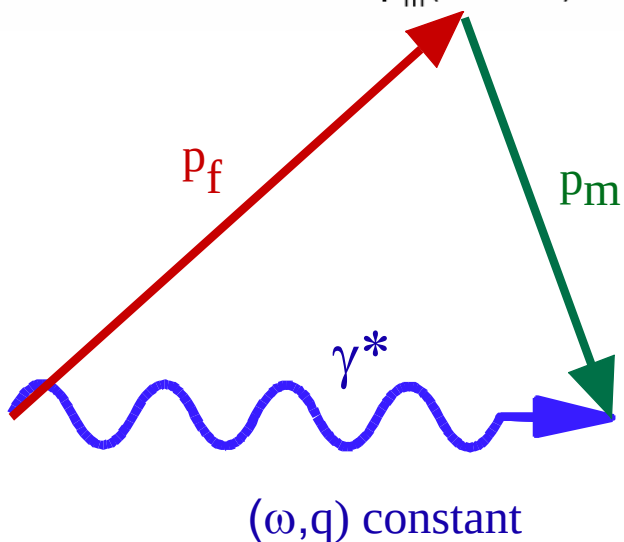
R.Schiavilla et al. nucl-th0508048

Argonne V18+U|X

Glauber + MEC







S_{11} Properties

$$\gamma^* + p \longrightarrow S_{11}$$

- $p, n + \pi$ 35-55%
- $p, n + \eta$ 30-55%

$$I(J^P) = \tfrac{1}{2}(\tfrac{1}{2}^-)$$

neutral modes : 72%

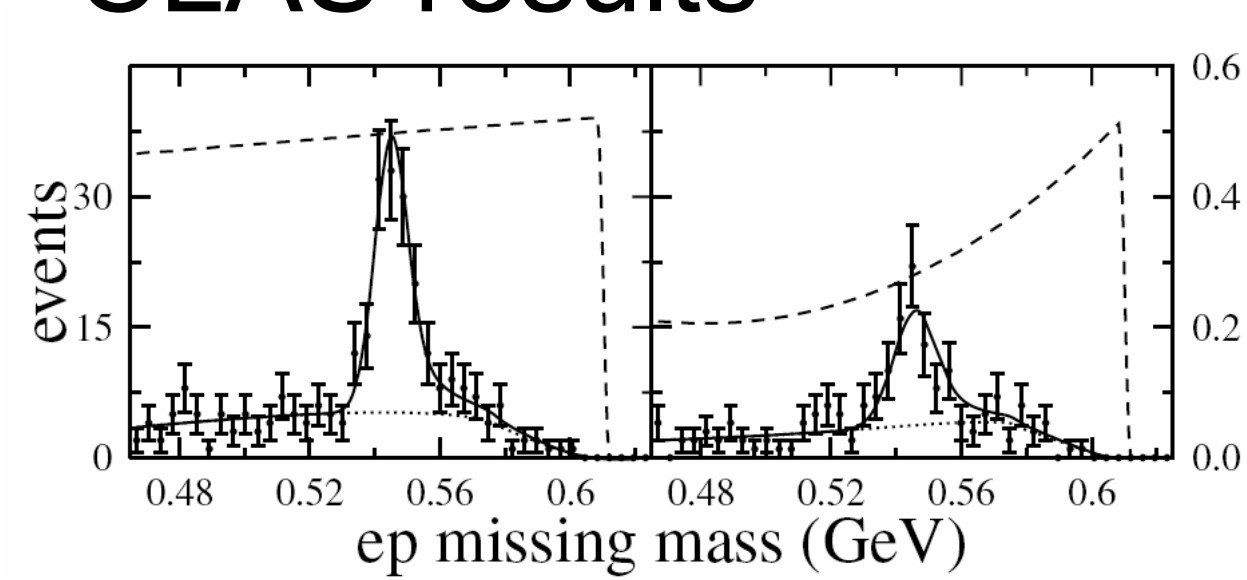
- 2γ 39% 8.4%-15.4%
- $3\pi^0$ 32% 6.9%-12.7%

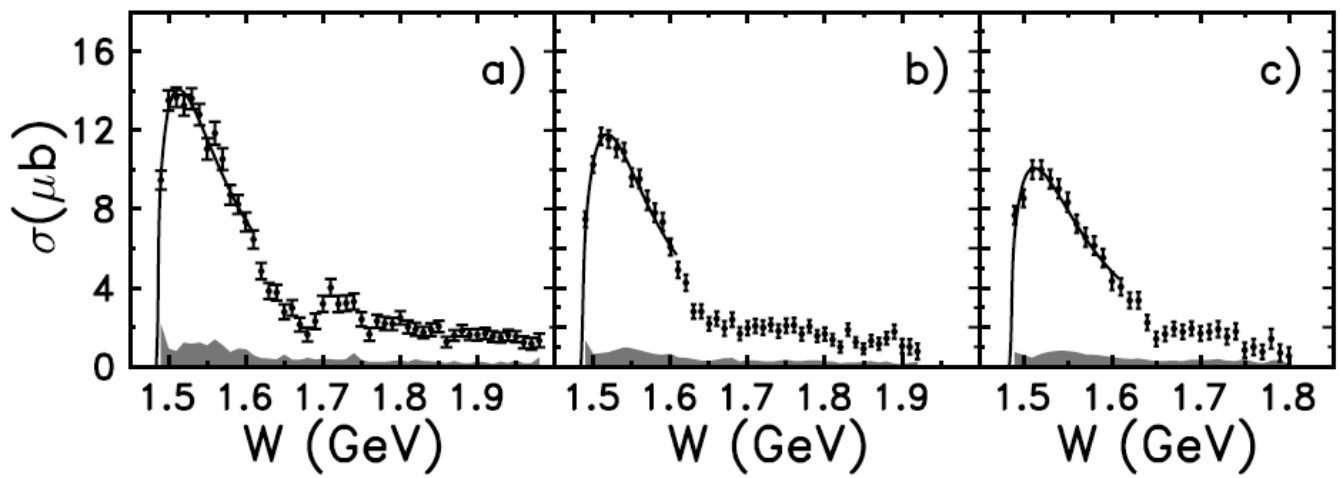
charged modes : 28%

- $\pi^+\pi^-\pi^0$ 23% 1.9%-3.5%
- $\pi^+\pi^-\gamma$ 4.8% 0.4%-0.7%

η electro-production CLAS results

R.Thompson et.al.
PRL 86 (2001) 1702

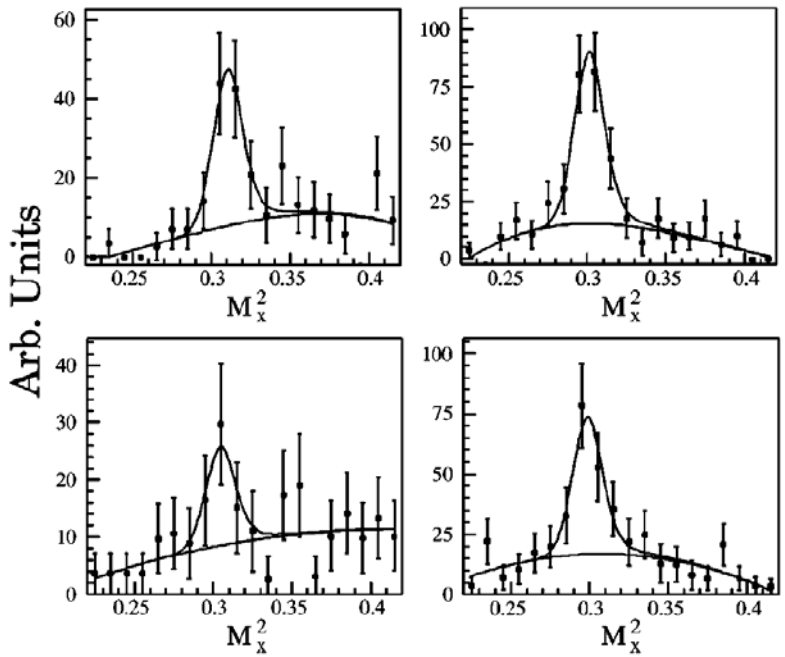


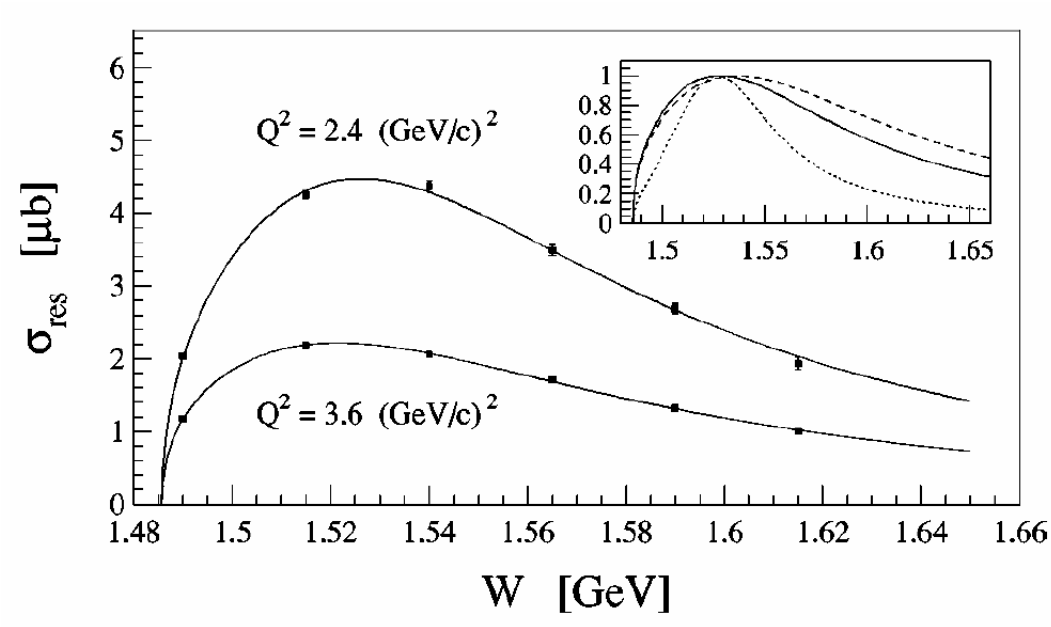


Q^2=0.625 Q^2=0.875 Q^2=1.125

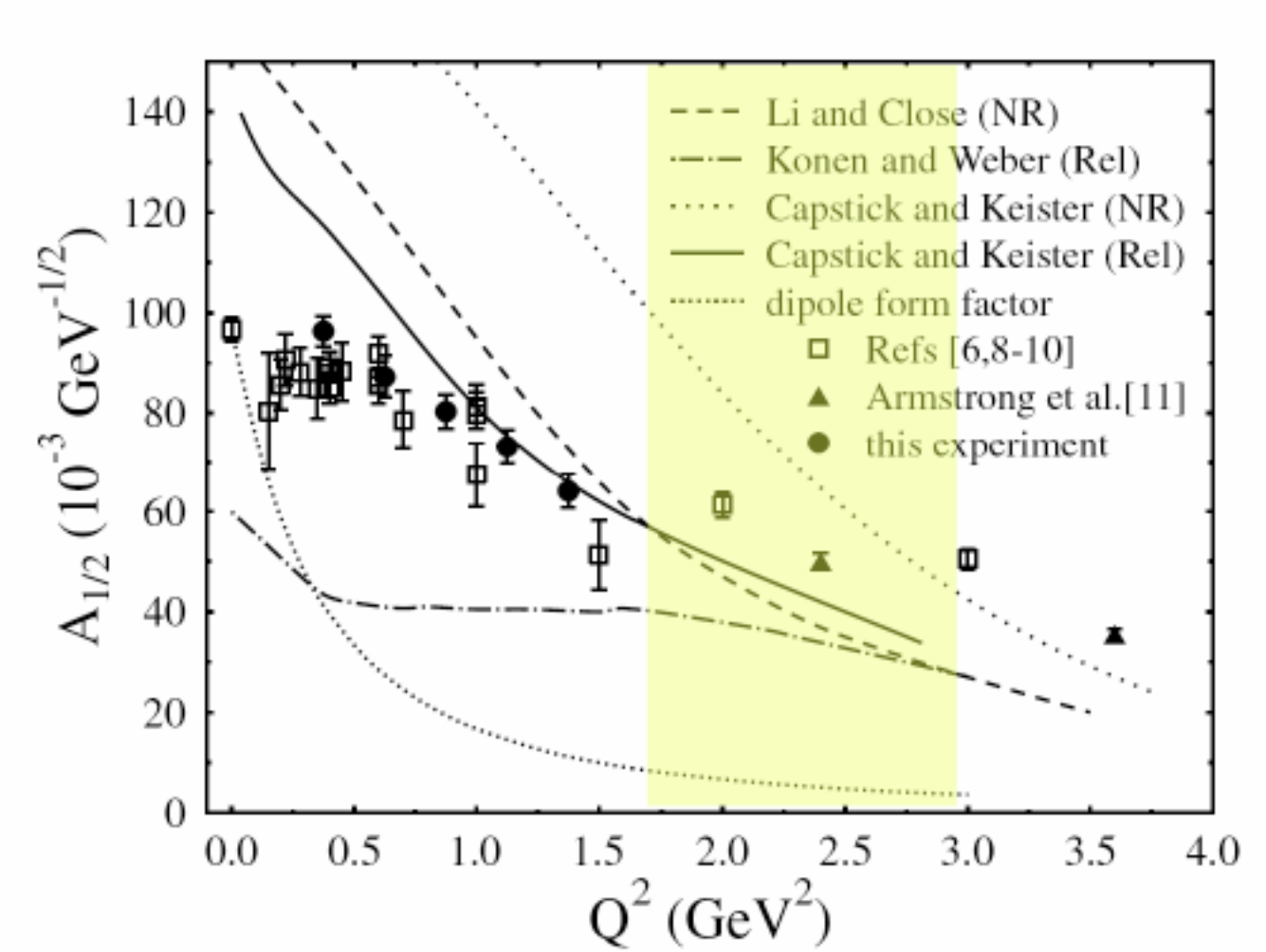
Hall C results

C.S.Armstrong et al. PRD 60 (1999) 052004





Summary of electro-production results

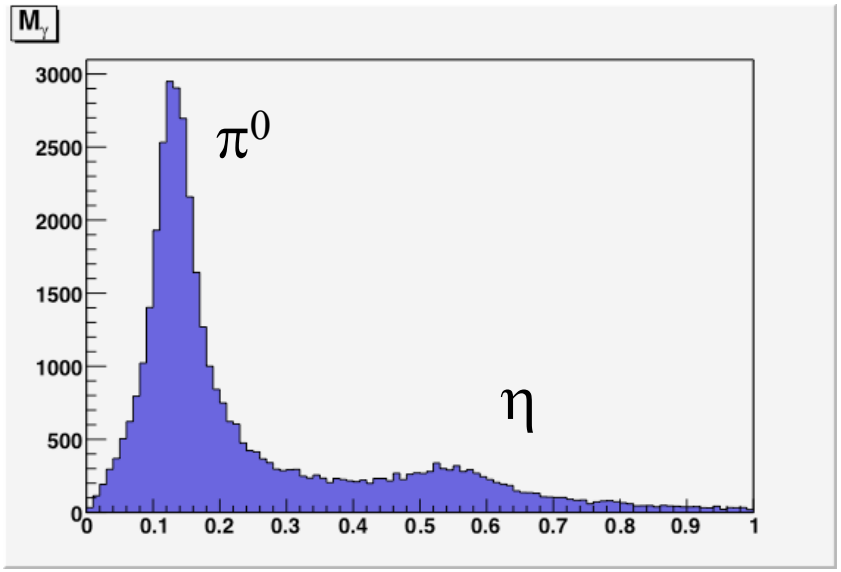


R.Thompson et.al. PRL 86 (2001) 1702

η production off the proton

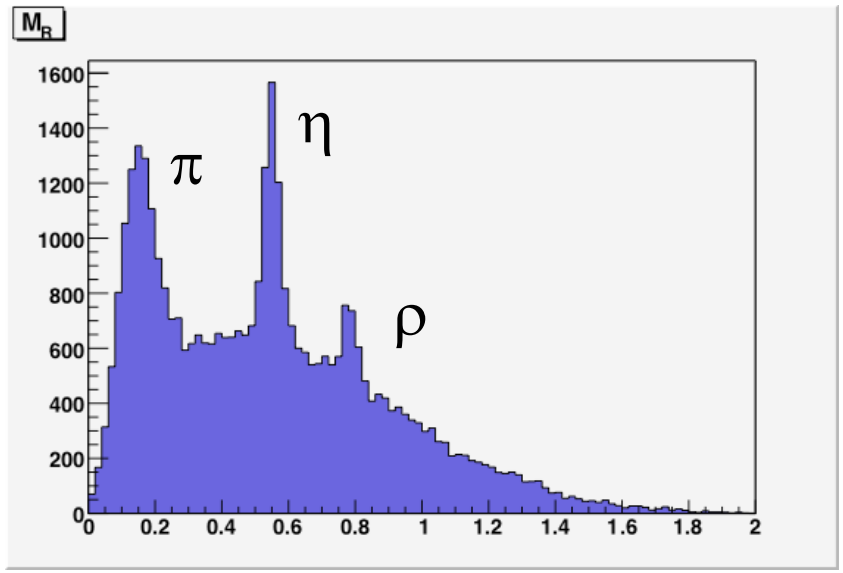
small sample of e6 CLAS data

p(e,e'pγγ)X

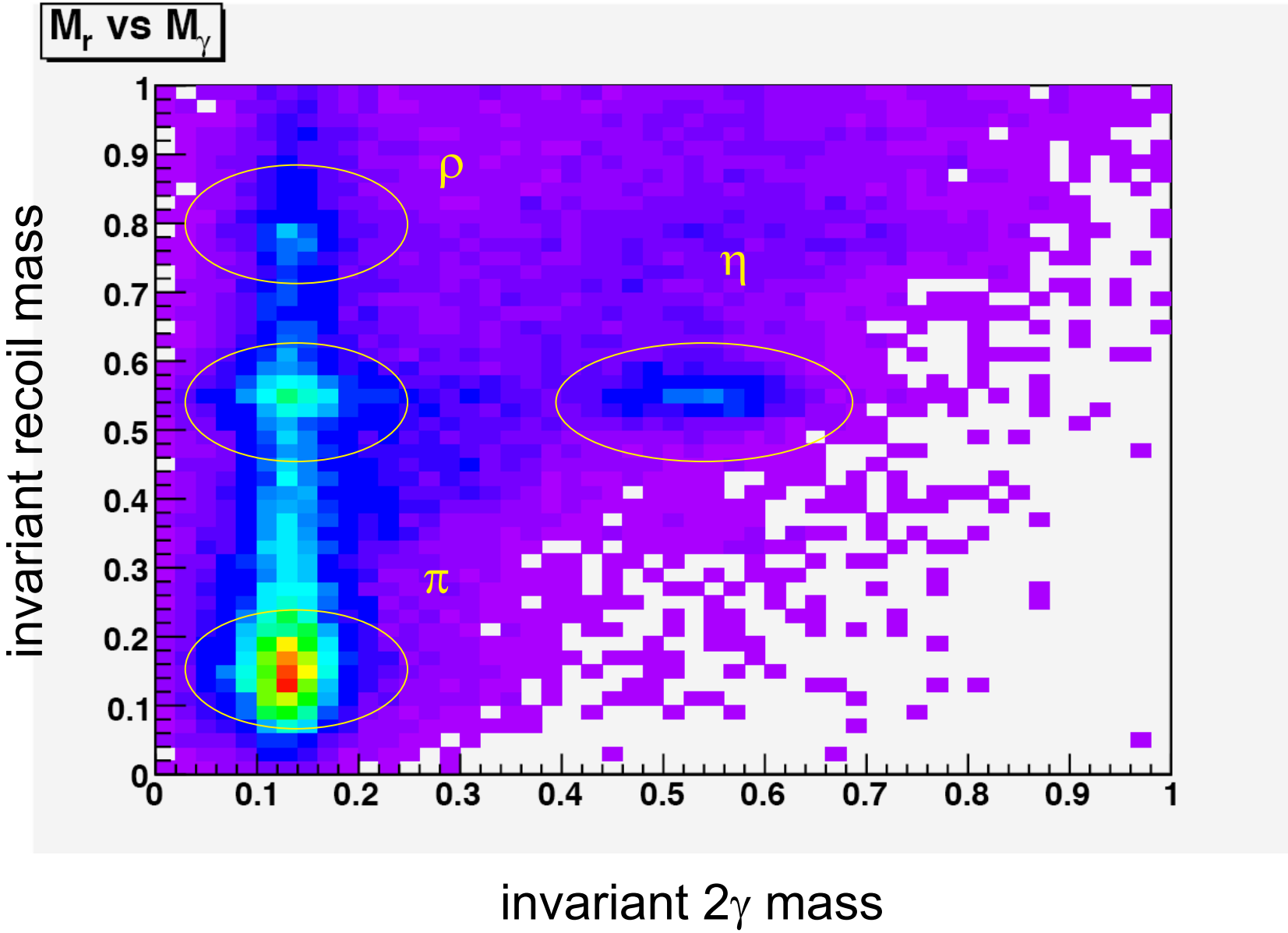


2γ invariant mass

p(e,e'p)X



M_{inv} of recoiling system


M_r vs M_γ
invariant recoil mass
invariant 2γ mass
ρ
η
π
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

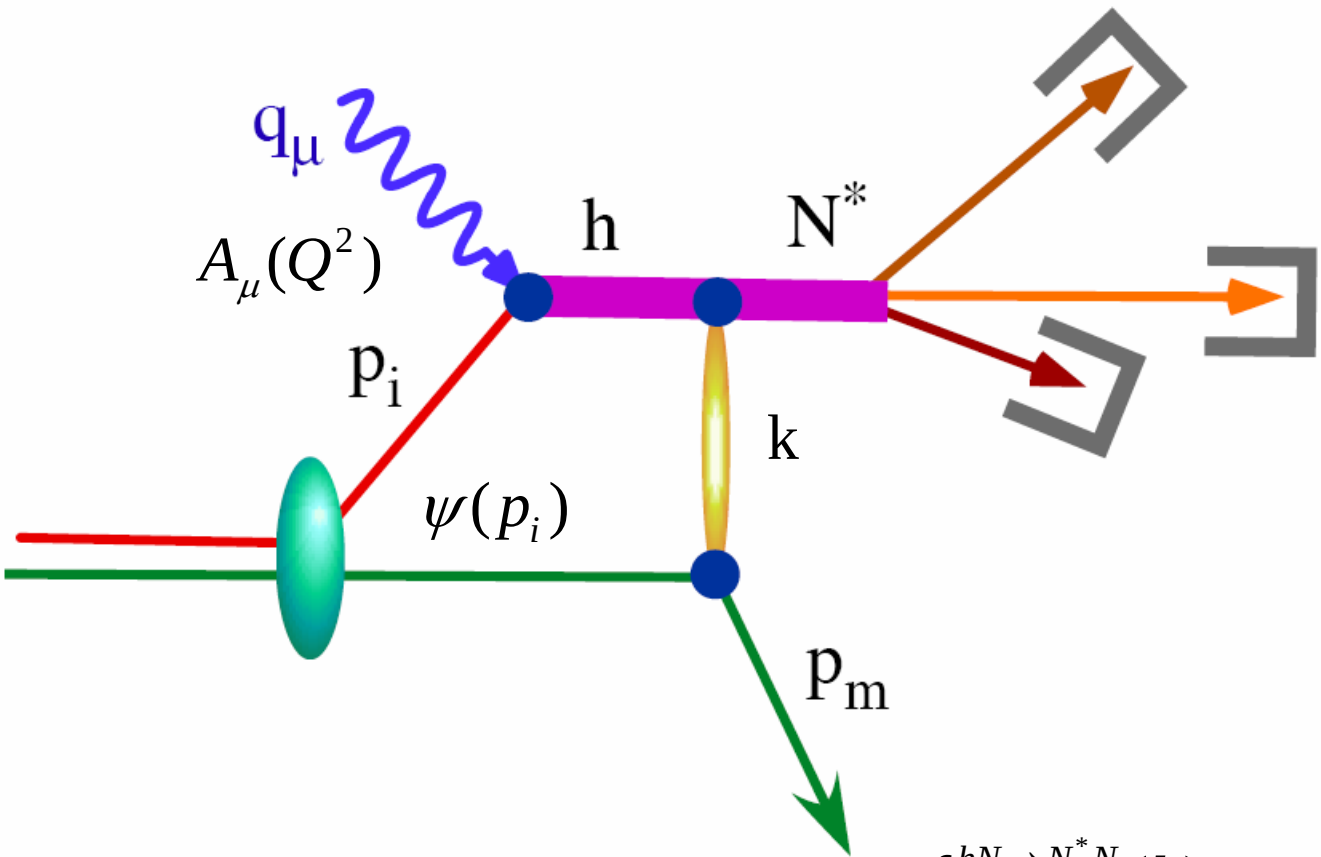
Model Calculations

L.Frankfurt et al.

PRC, C60 (1999) 055202

- general eikonal approximation for rescattering
- 2 models for S_{11}
- constituent quark model (CQM)
- effective chiral lagrangian (ECL) based:
  S_{11} as a superposition of $N\pi$, $N\eta$,ΛK and
  ΣK states

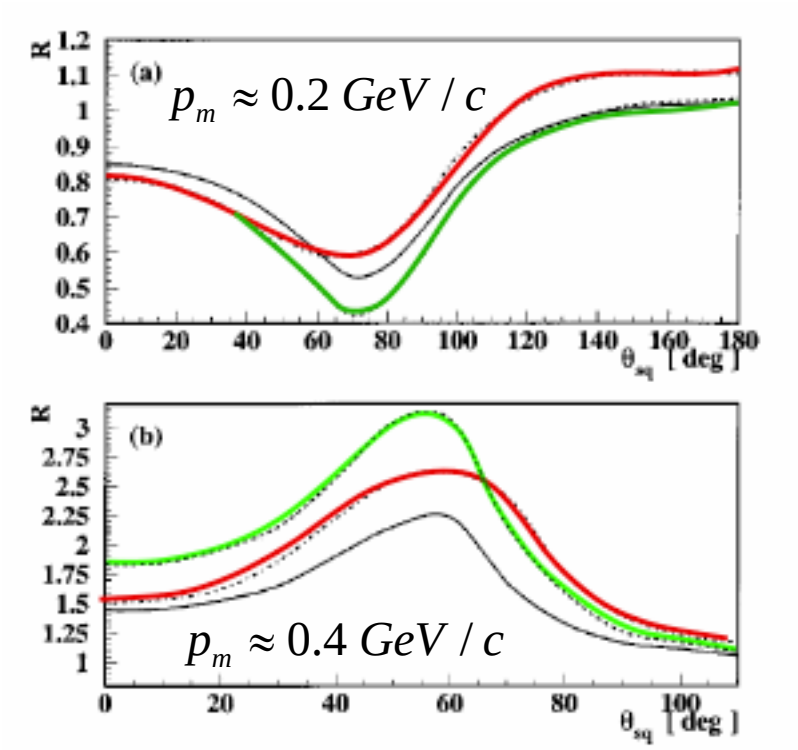
Rescattering

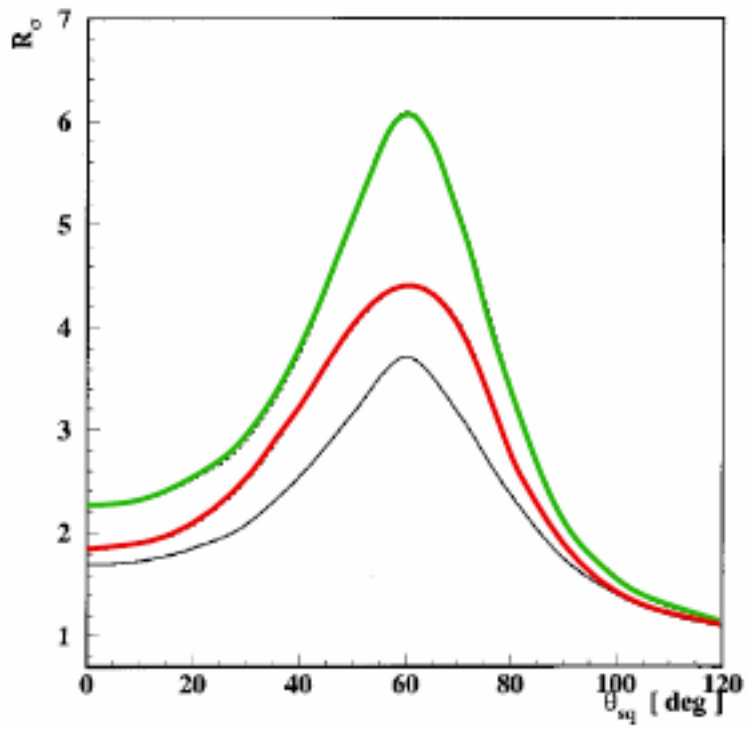


$$F_b^\mu \propto \sum_h \int \psi(p_m - k) A_h^\mu(Q^2) \frac{f^{hN \to N^* N}(k)}{[-k_z + \Delta + i\varepsilon]} d^3k$$

$$R = \frac{\sigma(Q^2, W, \vec{p}_m)}{\sigma^{PWIA}(Q^2, W, \vec{p}_m)}$$

$$R_\sigma = \frac{\sigma(p_m \approx 0.4\ GeV/c)}{\sigma(p_m \approx 0.2\ GeV/c)}$$





S_{11} as NN amplitude

S_{11}N amplitude within CQM

ηN final state within ECL

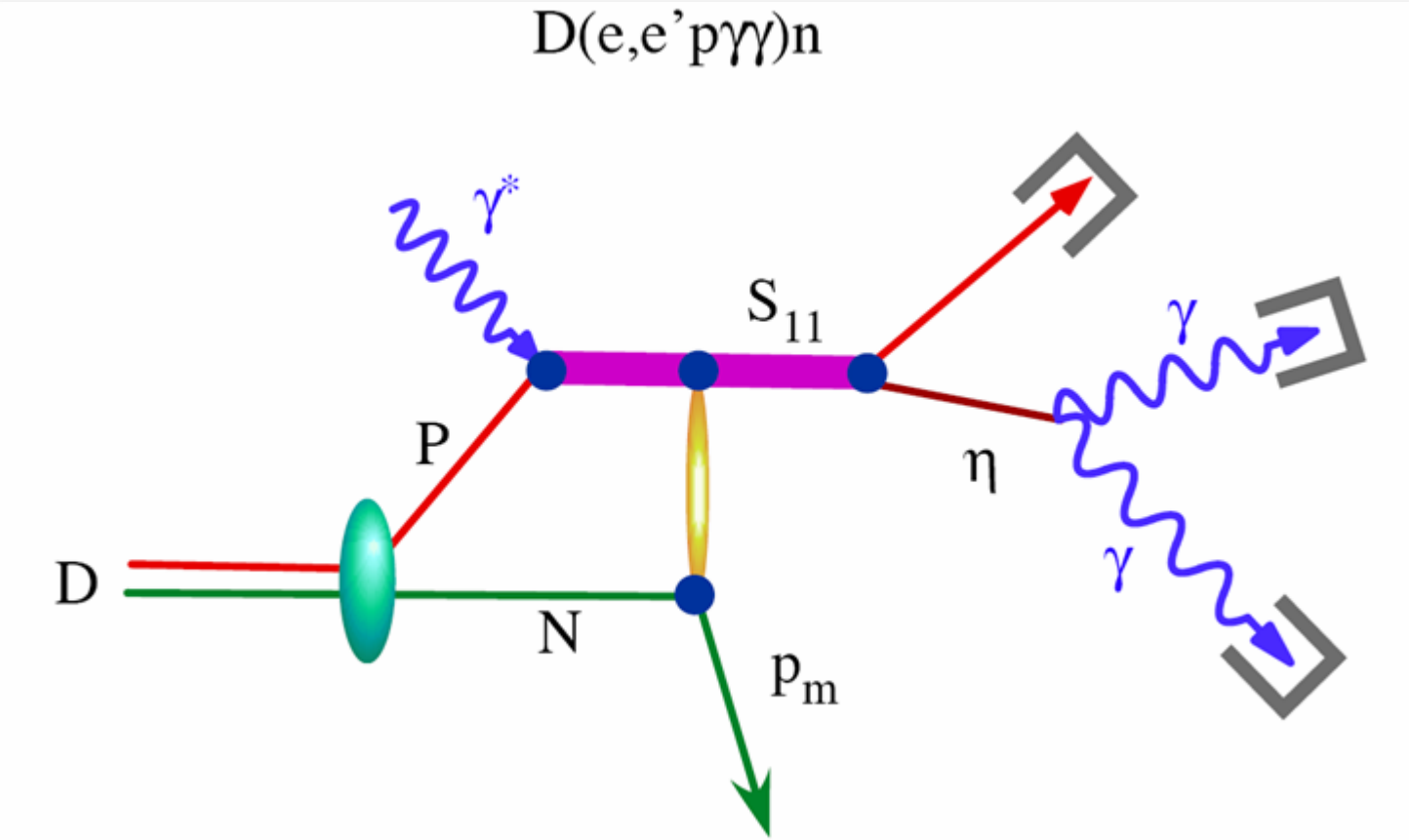
Example of information obtainable from rescattering :

- within CQM : spatial parameters
- fit amplitude to data

$$f^{hN\to N^*N}(t) = \sigma^{tot}_{N^*N}(i+\alpha)e^{(b/2)t}$$

$$\sigma^{tot}_{hN} = \sigma^{tot}_{NN}\frac{\left\langle r_h^2\right\rangle}{\left\langle r_N^2\right\rangle} \qquad b \approx \frac{1}{3}\left(\left\langle r_h^2\right\rangle + \left\langle r_N^2\right\rangle\right)$$

η electro-production off the deuteron



- small sample of e6 CLAS data (about 1.7%)
- thanks to S. Stepanyan

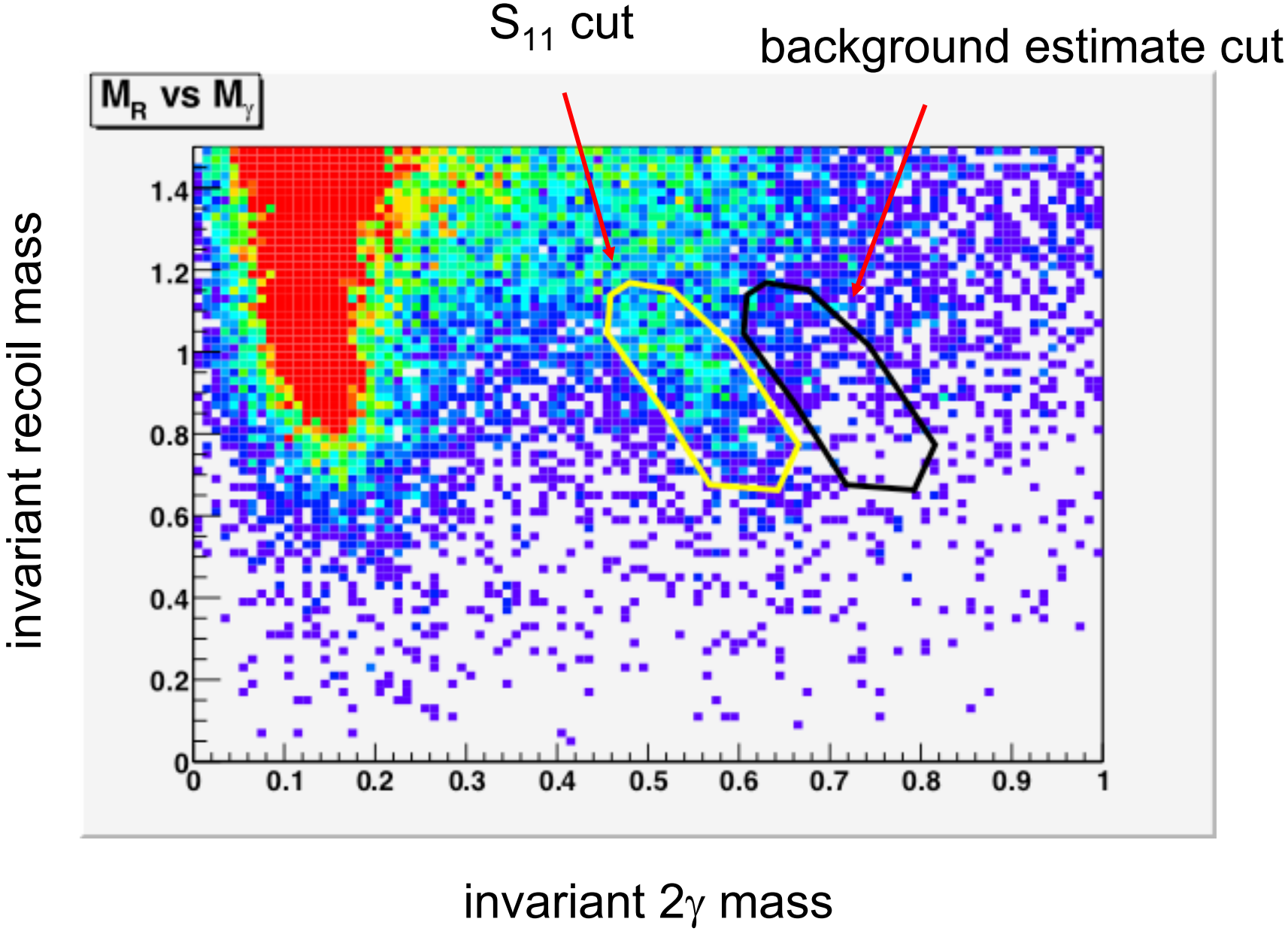
Analysis :

Event selection criteria

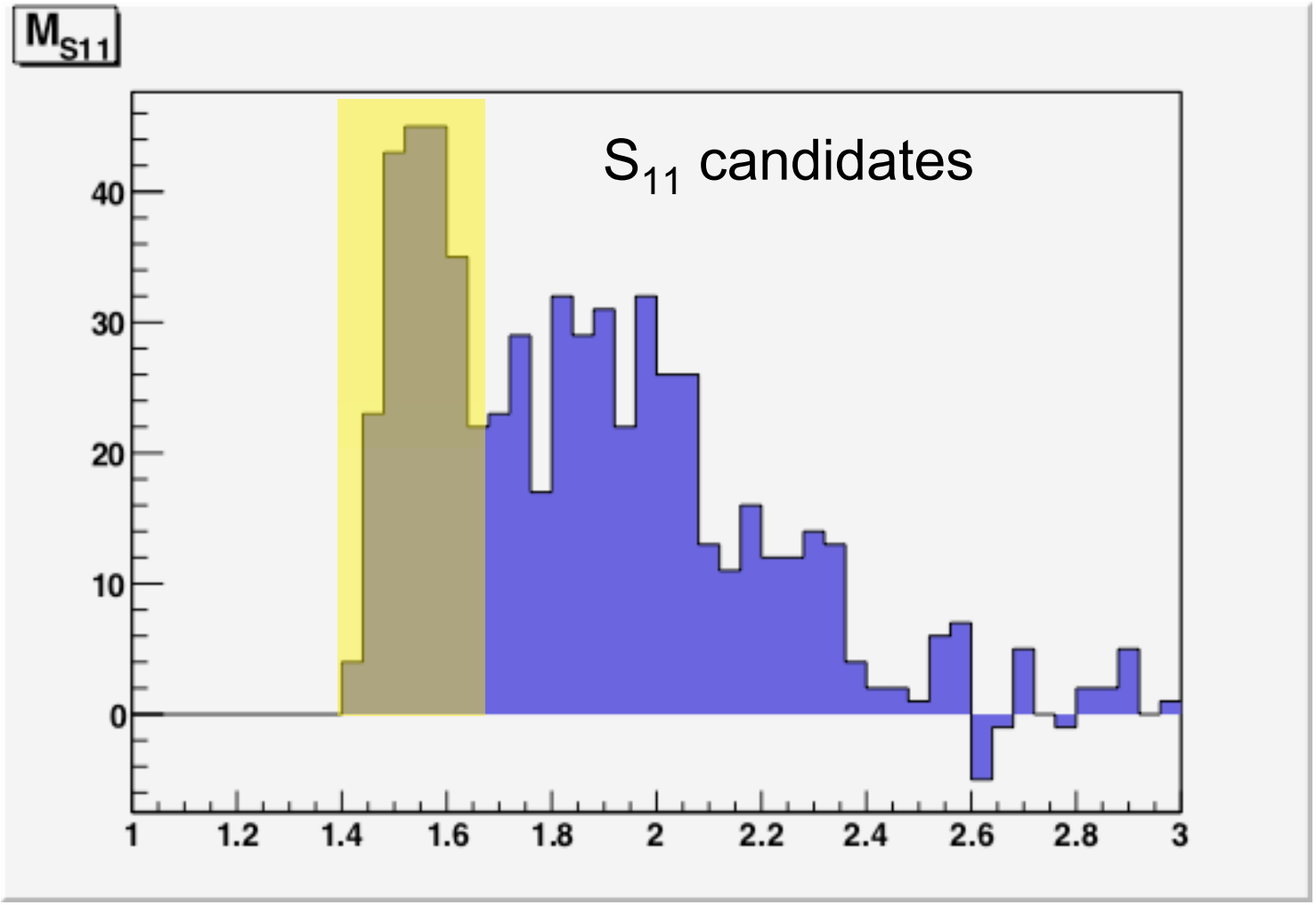
- scattered electron $\rightarrow q^{\mu}$
- proton $\rightarrow p_{p}^{\mu}$
- 2 photons $\rightarrow k_{1}^{\mu}, k_{2}^{\mu}$

$$p_{\eta}^{\mu} = k_{1}^{\mu} + k_{2}^{\mu}$$
$$p_{S_{11}}^{\mu} = p_{\eta}^{\mu} + p_{p}^{\mu}$$
$$p_{m}^{\mu} = q^{\mu} + p_{D}^{\mu} - p_{S_{11}}^{\mu}$$

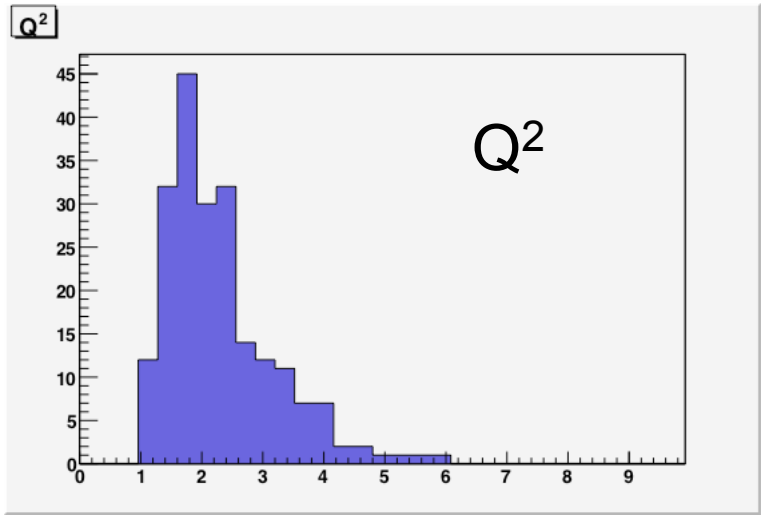
} Apply cuts to invarant masses

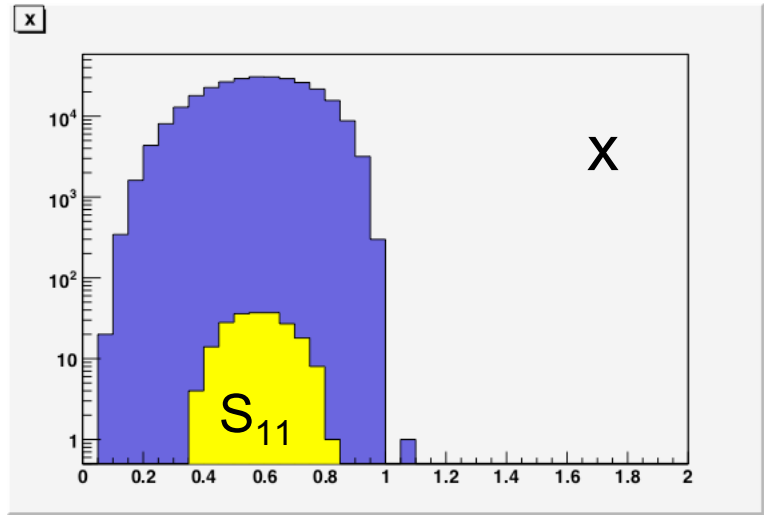

S_{11} cut
background estimate cut
M_R vs M_γ
invariant recoil mass
invariant 2γ mass
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0.1
0.3
0.5
0.7
0.9

cut on invariant resonance mass

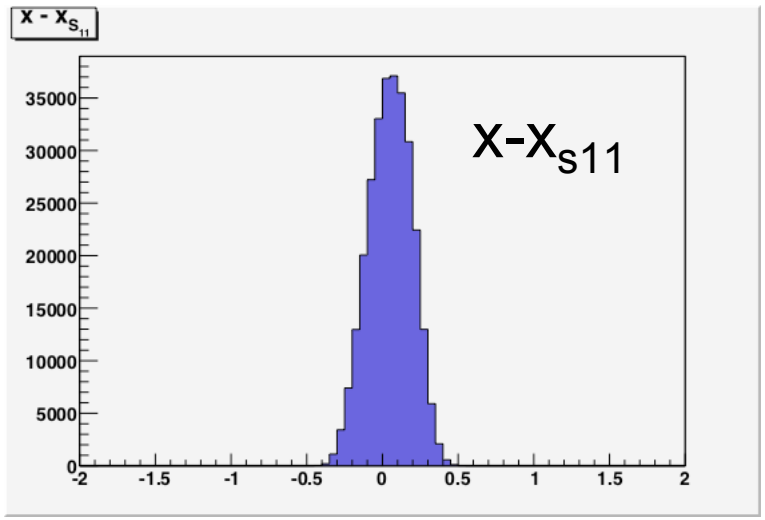


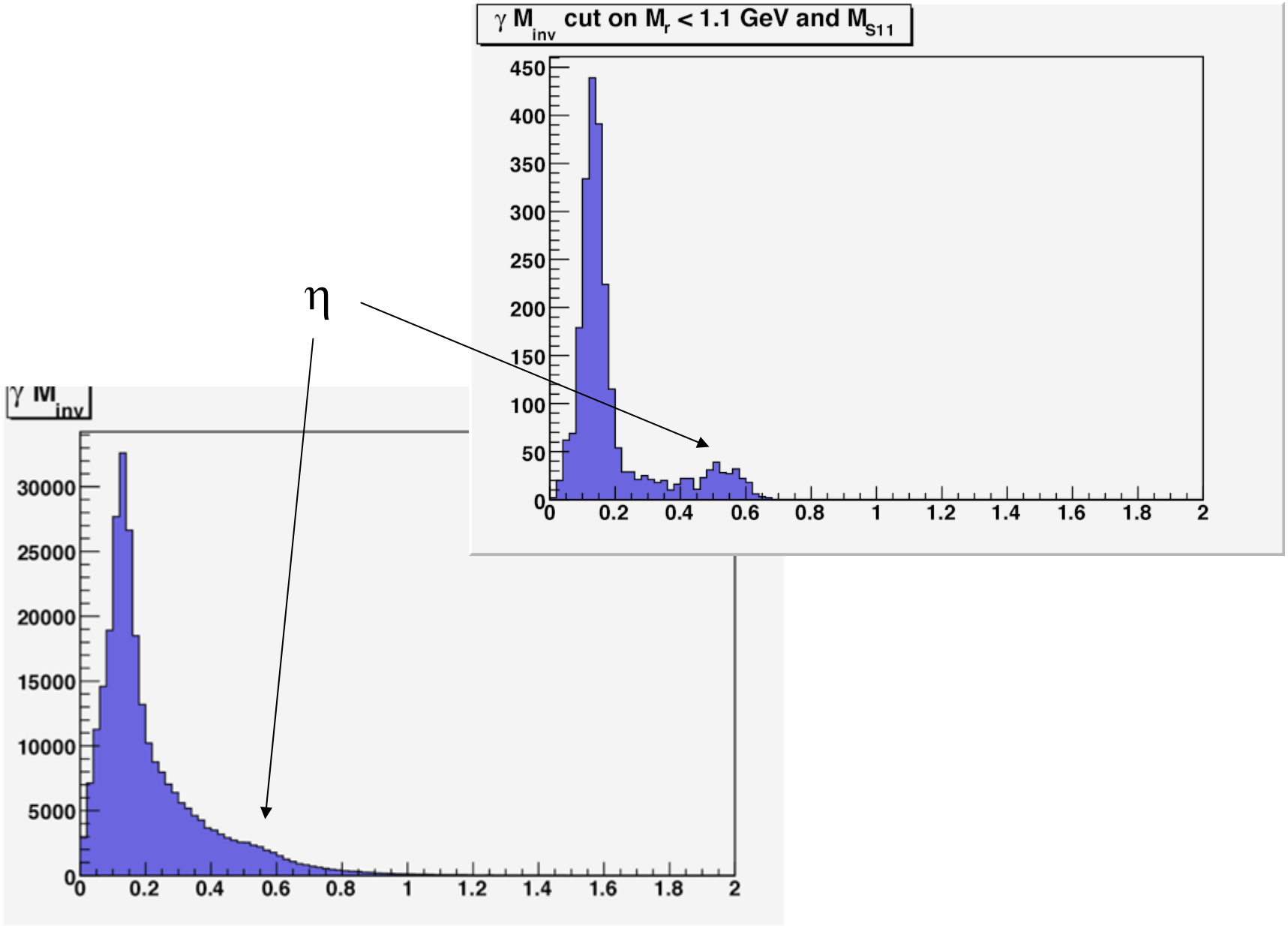
Kinematical Variables





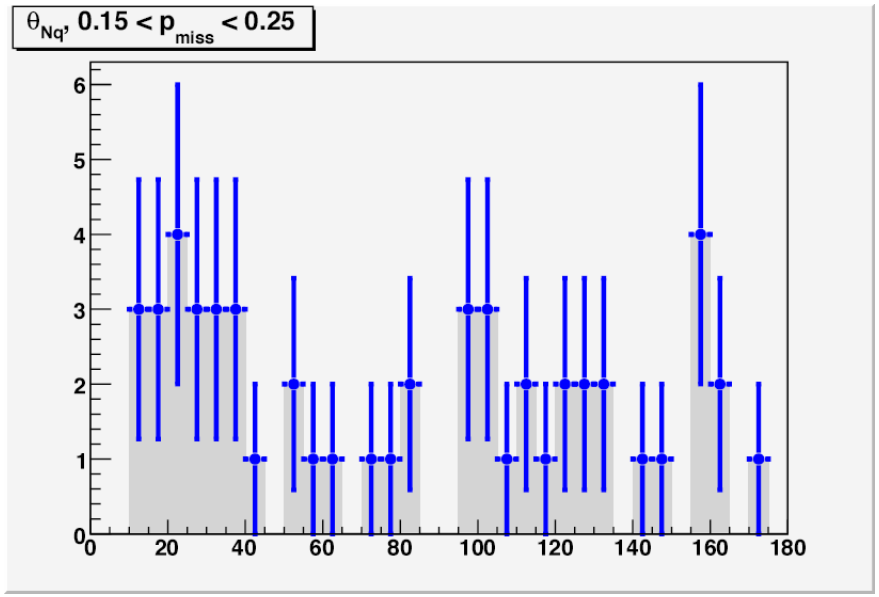
$$x = 1 - \frac{M_R^2 - M^2}{Q^2 + M_R^2 - M^2}$$




γ M_inv cut on M_r < 1.1 GeV and M_S11
450
400
350
300
250
200
150
100
50
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
η
γ M_inv
30000
25000
20000
15000
10000
5000
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

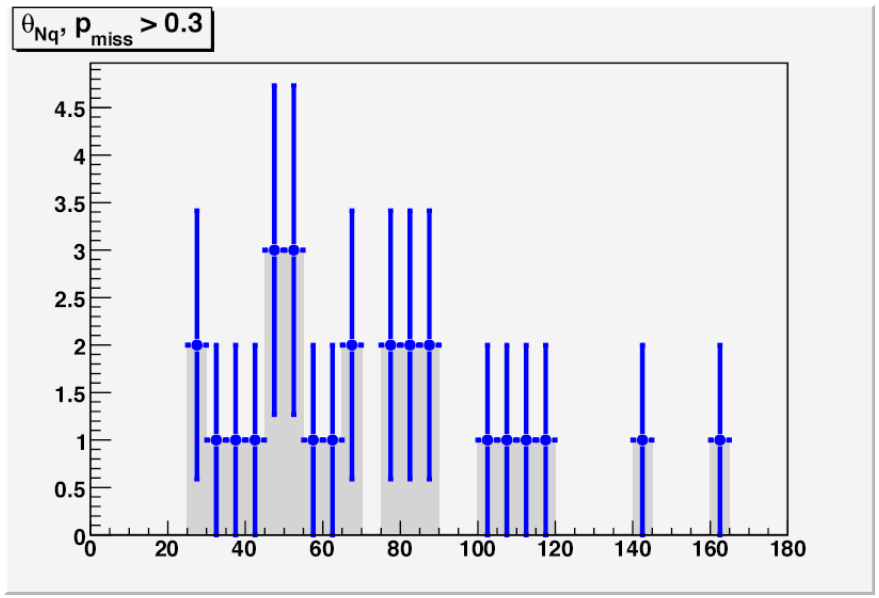
no phase space correction

small p_m
53 events



remember:
1.7 % of all data !

large p_m
27 events

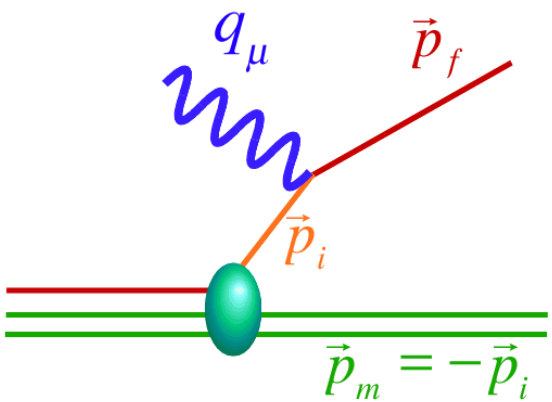


Summary

- ✓ N^* electro-production off the deuteron : access to new information on excited nucleons
- ✓ JLAB uniquely suited for this study
- ✓ previous experiments provide foundation for a clear interpretation of new results
- ✓ re-scattering in photo production under investigation

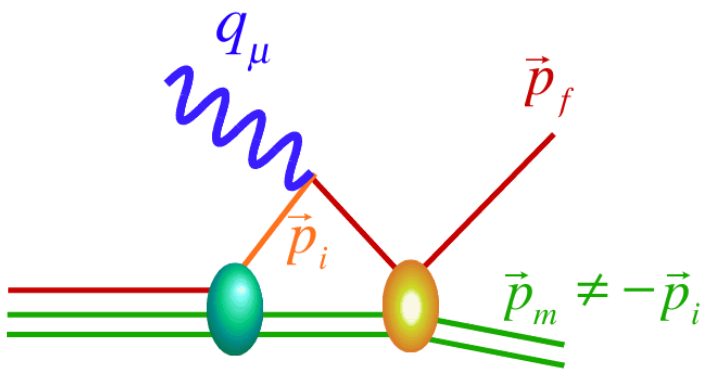
D(e,e'p) Reaction Mechanisms

PWIA



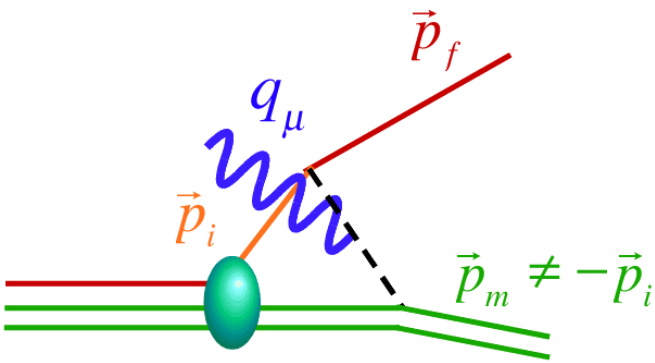
$$\frac{d\sigma}{d\omega d\Omega_e d\Omega_N} = k\sigma_{eN} S(E_m, p_m)$$

FSI



$$\frac{d\sigma}{d\omega d\Omega_e d\Omega_N} = k\sigma_{eN} D(E_m, p_f, p_m)$$

MEC



IC