Deuteron breakup at high Q^2 and higher missing masses

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Contents

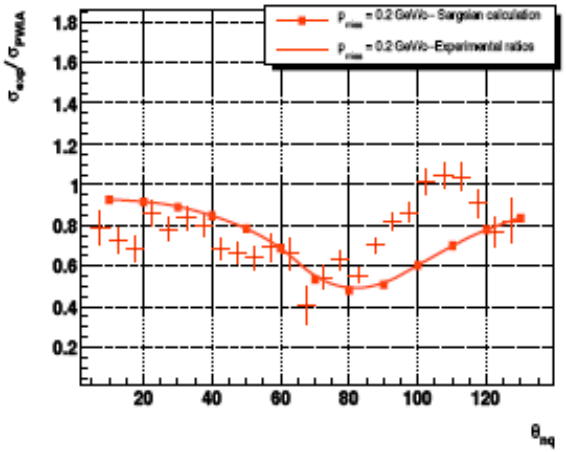
- Towards really high p_m: A proposal for 6 GeV
- A 12 GeV example
- Higher missing masses : Resonance Re-Scattering

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

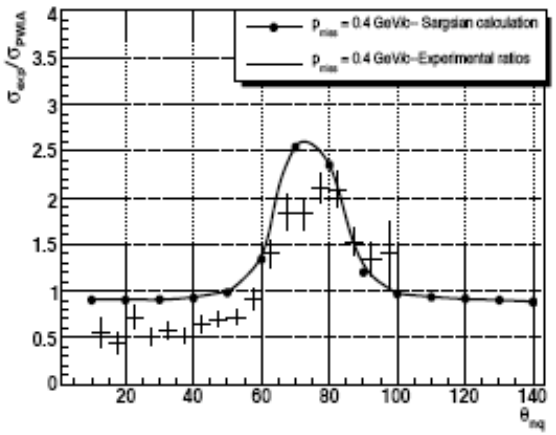
- experiments in Hall A and Hall B (CLAS)
- test generalized eikonal approximation (Glauber based)
- next: short distance structure of the deuteron
- study nucleon resonance (future)

Calculations

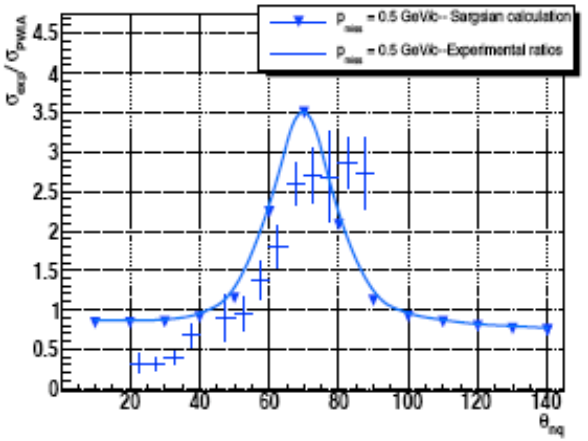
p_m=0.2 GeV/c



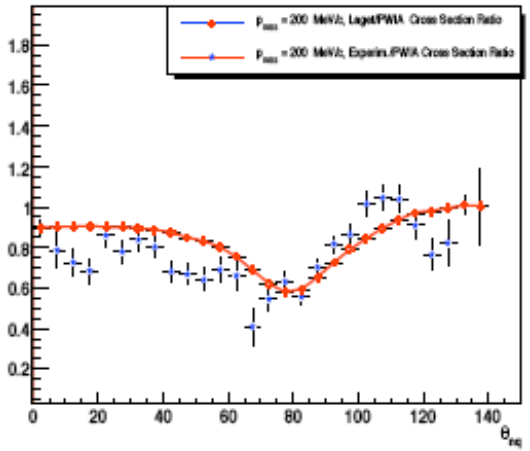
p_m=0.4 GeV/c

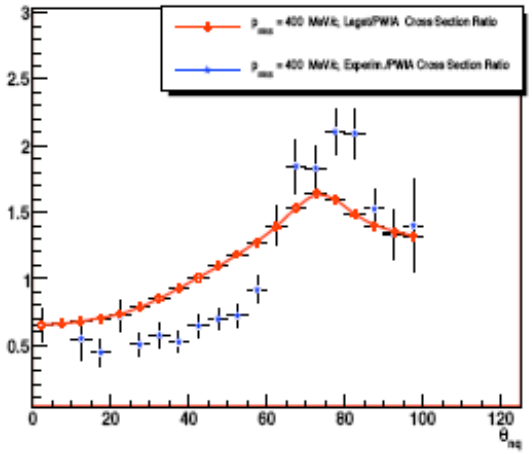


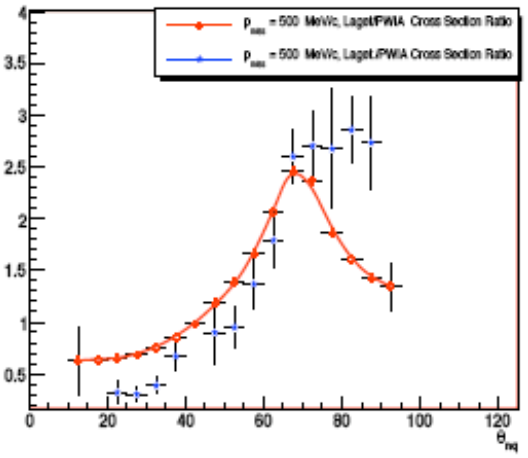
p_m=0.5 GeV/c



M.Sargsian

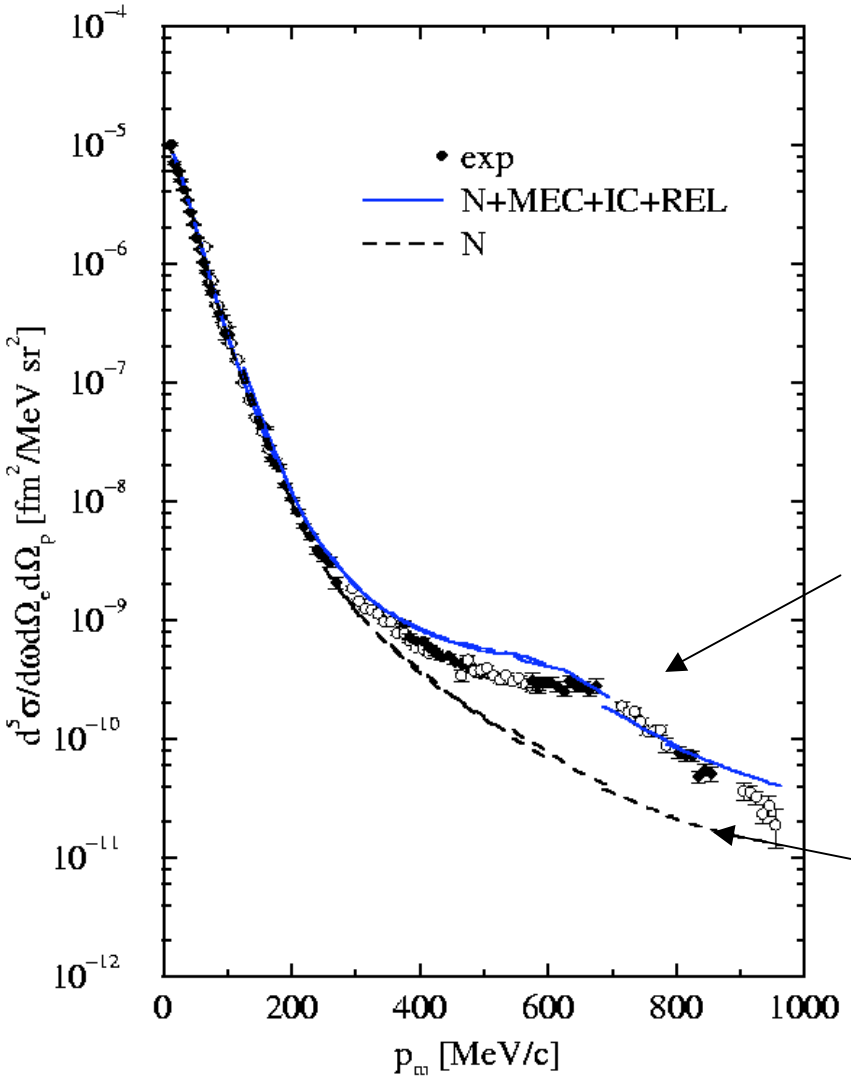






J.M. Laget

Experiments at low(er) Q^2



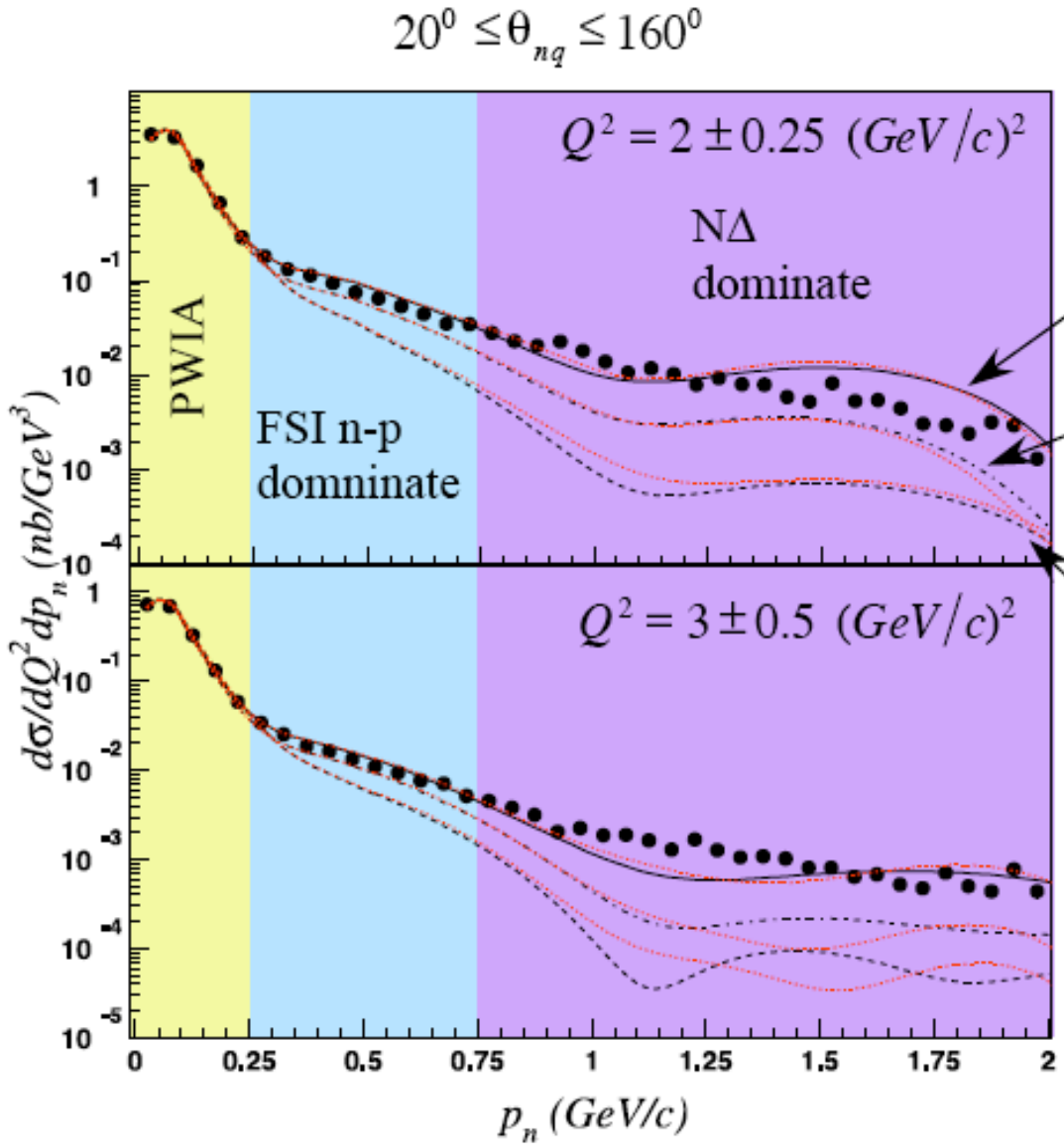
IC+MEC

dominated by Δ excitation

FSI included

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

Momentum Dependence from CLAS



PWIA+FSI+NΔ

PWIA+FSI

PWIA

black: Paris potential

red: V18 potential

Problems

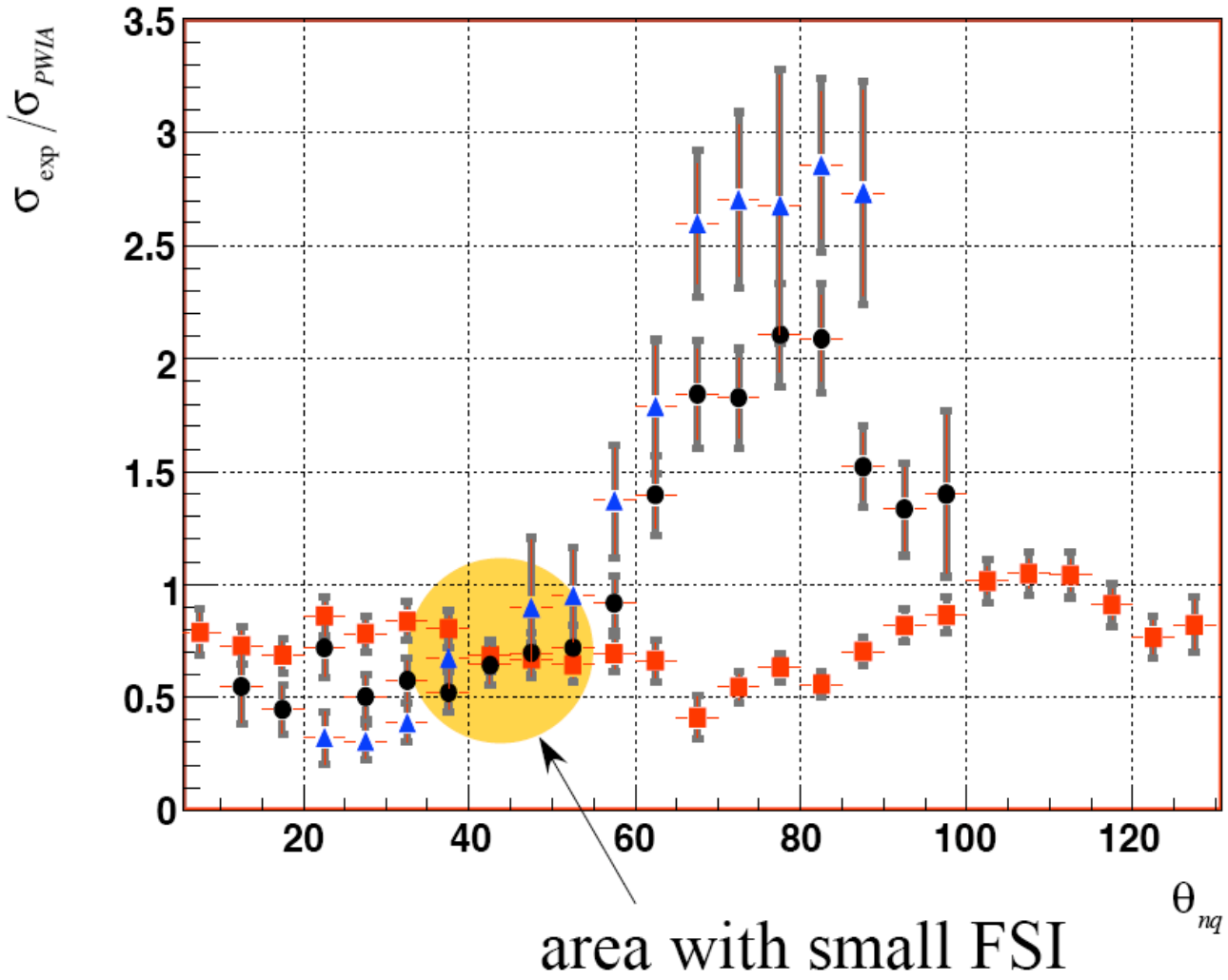
Low Q^2 :
- FSI
- NΔ and other resonance contributions

High Q^2: CLAS :
- not well defined kinematics
- integrated over very large kinematical range
- many different reaction mechanism contribute

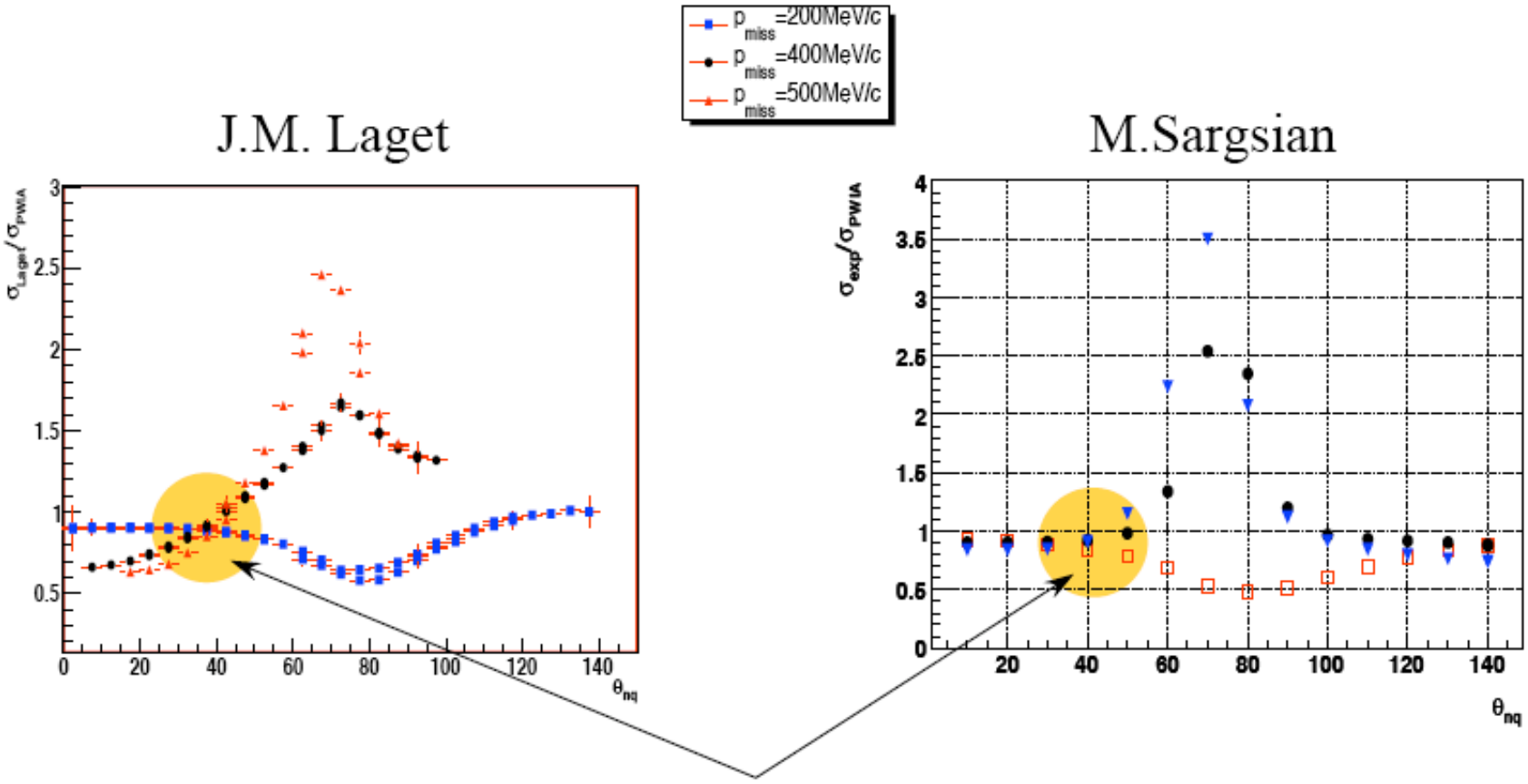
optimize kinematics to:

- maximize cross section
- minimize competing reaction mechanisms
- $p_f \approx 1.5 \cdot p_m$

Experimental Guidance



Theoretical Guidance

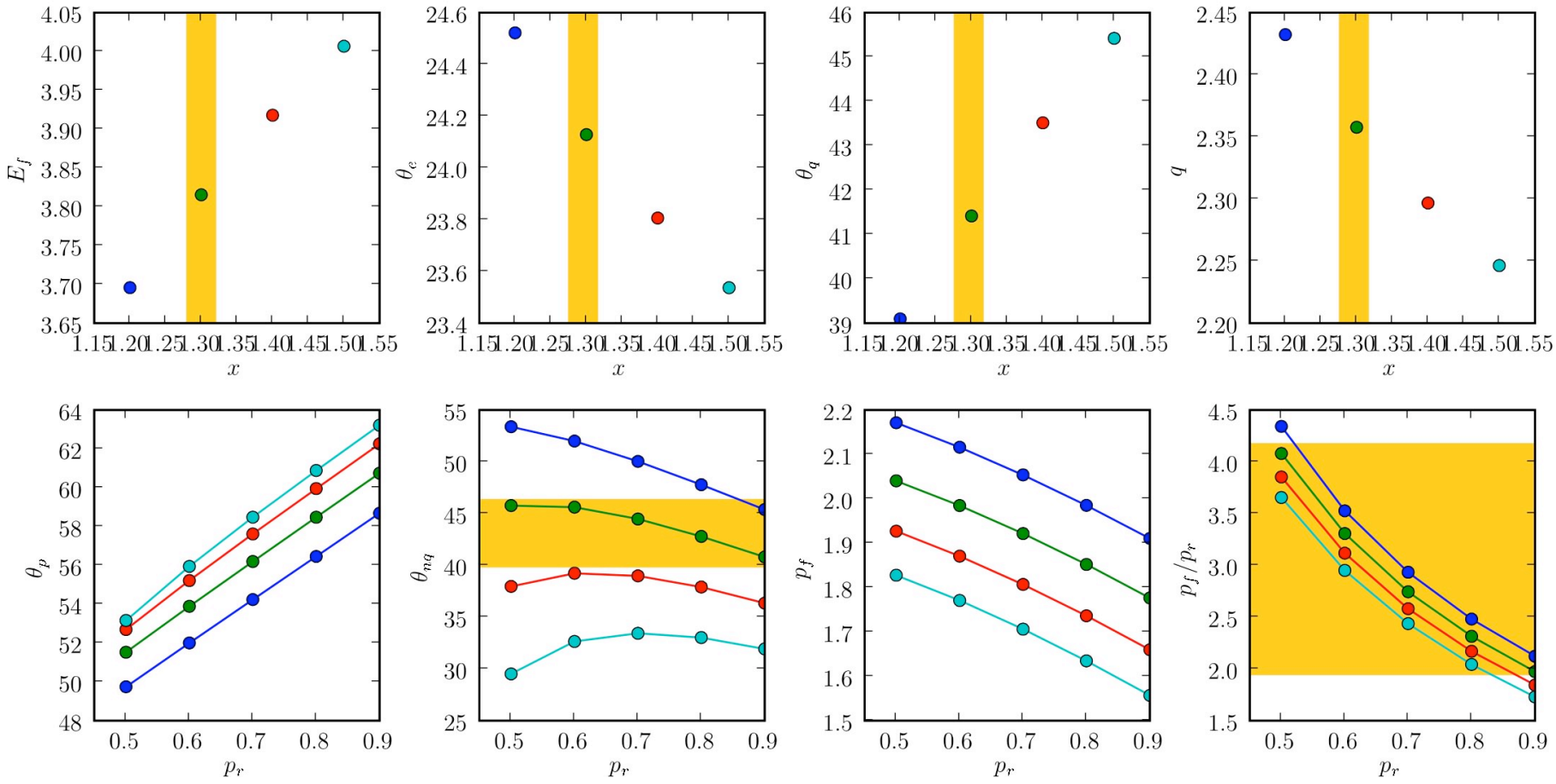


area with small FSI

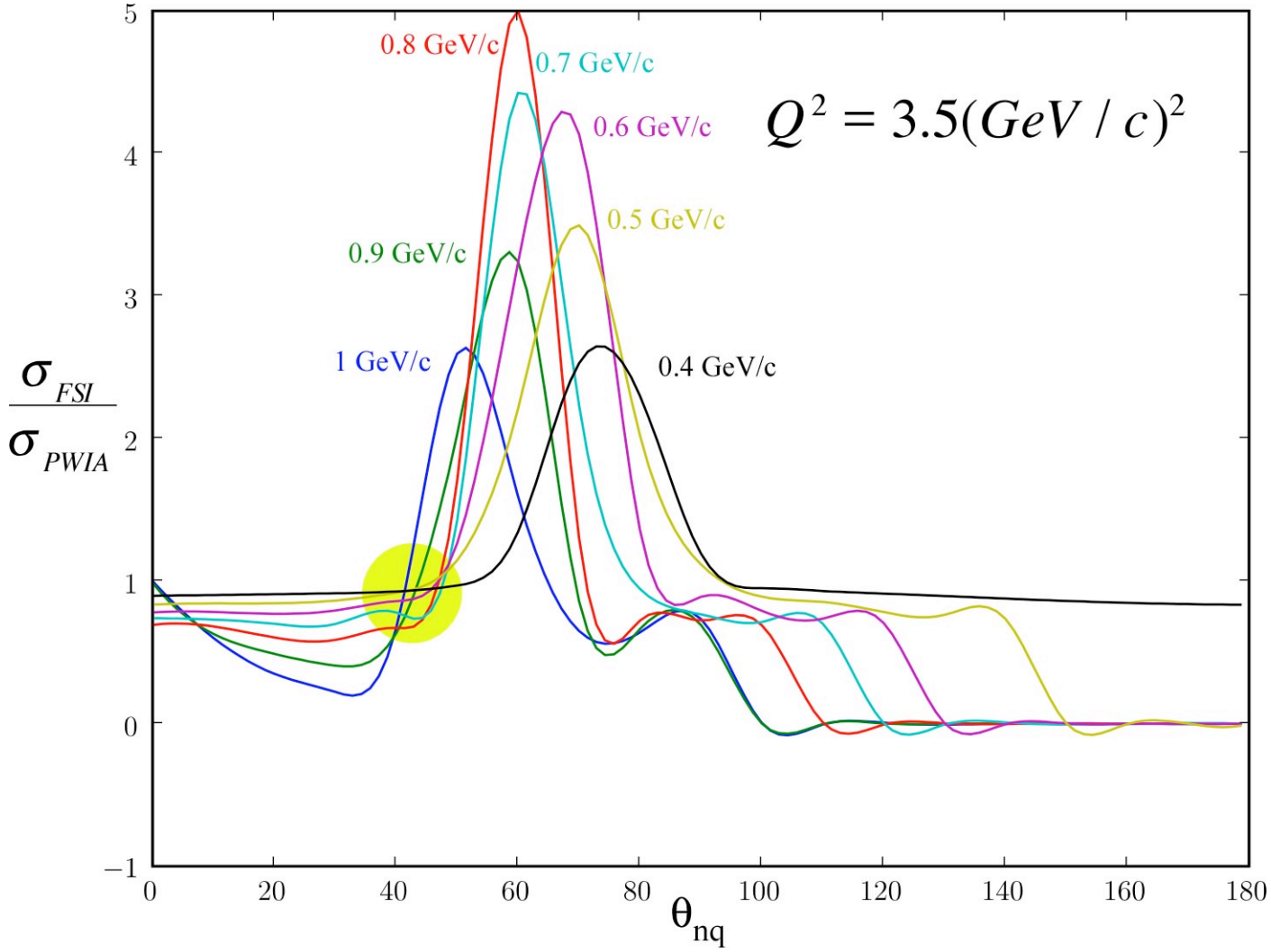
needs to be checked with additional calculations

Kinematics Overview

$Q^2 = 3.5\ (GeV/c)^2 \quad E_{inc} = 5.25\ (GeV/c)$



Angular Distribution up to p_m = 1GeV/c



Calculation: M.Sargsian

Feasibility Studies using Standard Spectrometers in Hall A

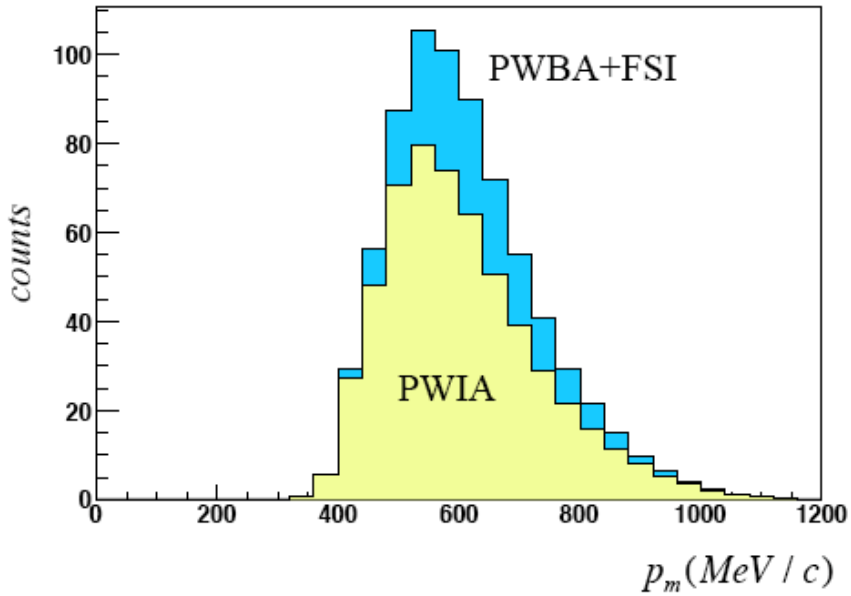
Proposal for the next PAC (the last for 6 GeV)

Beam energy 5.25 GeV
Spectrometer p_{max} = 4 GeV/c
Electron arm fixed at:
Q^2 = 3.5 $(GeV/c)^2$
x = 1.30

Vary proton arm to measure :
p_m = 0.5, 0.6, 0.7, 0.8, 0.9, 1.0 GeV/c

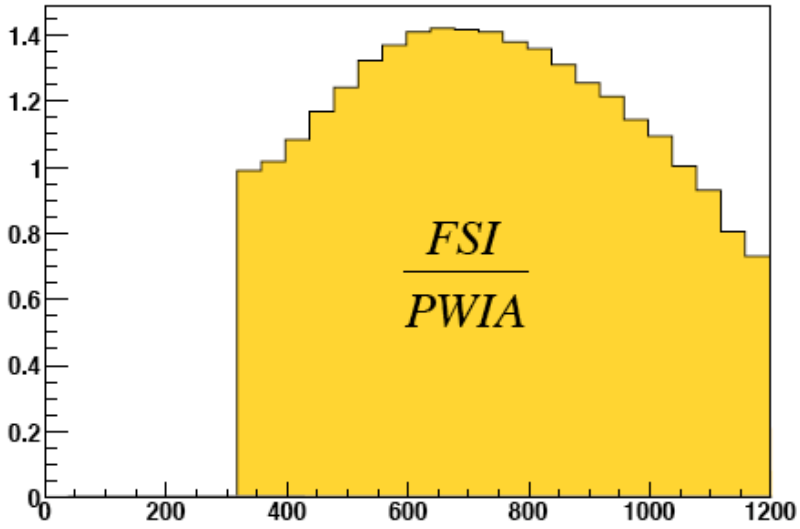
Count Rates (MCEEP estimate)

no cuts
beam current 100μA
target: 15cm liquid deuterium
integration time: 1 h

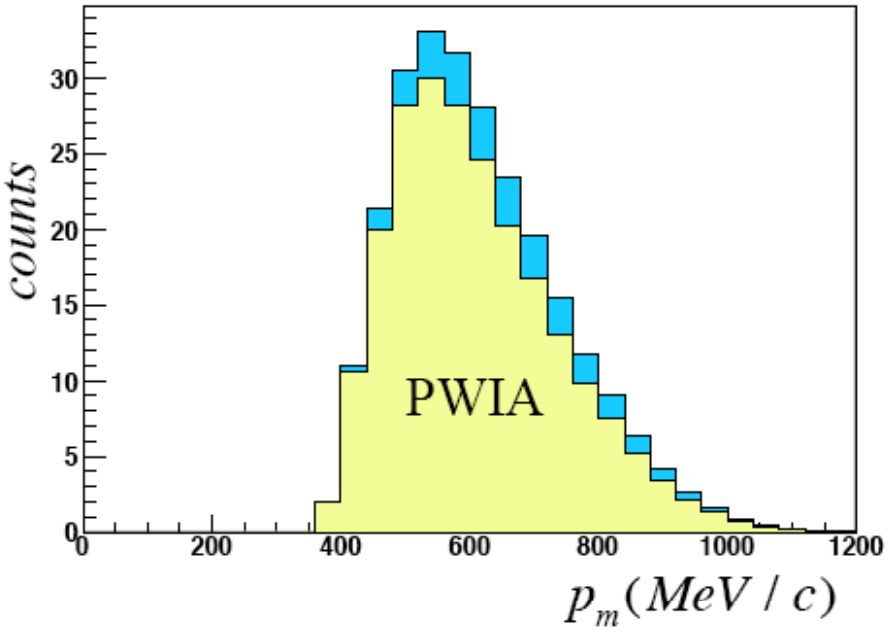


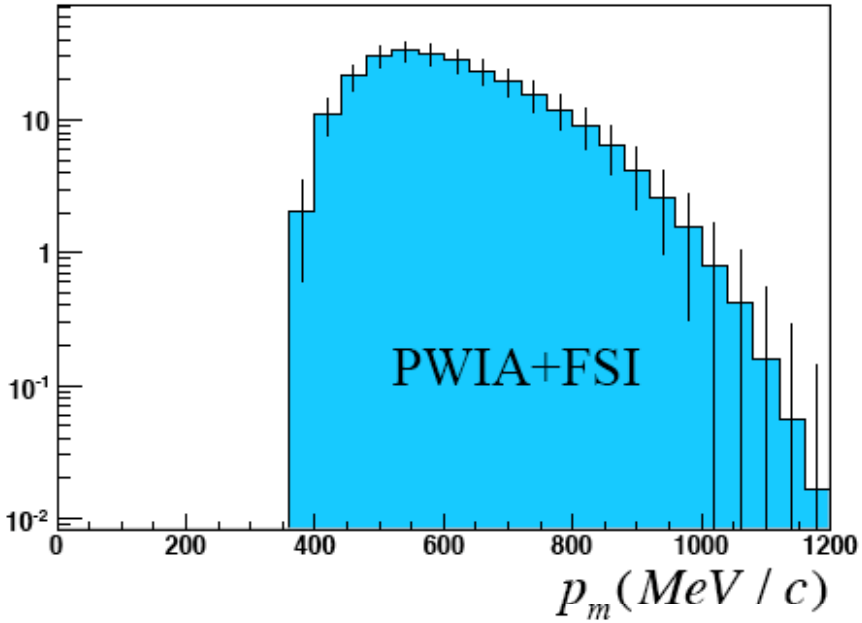
estimated FSI effects: 30-40%

FSI: J.M.Laget (interpolated)

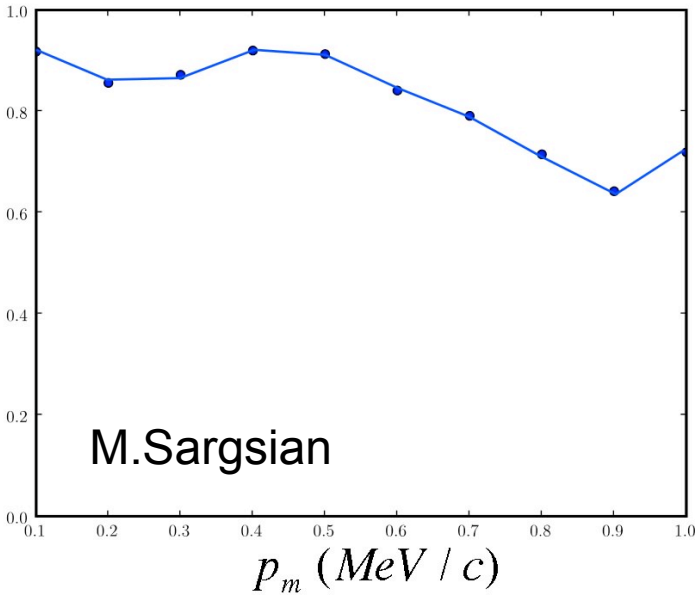


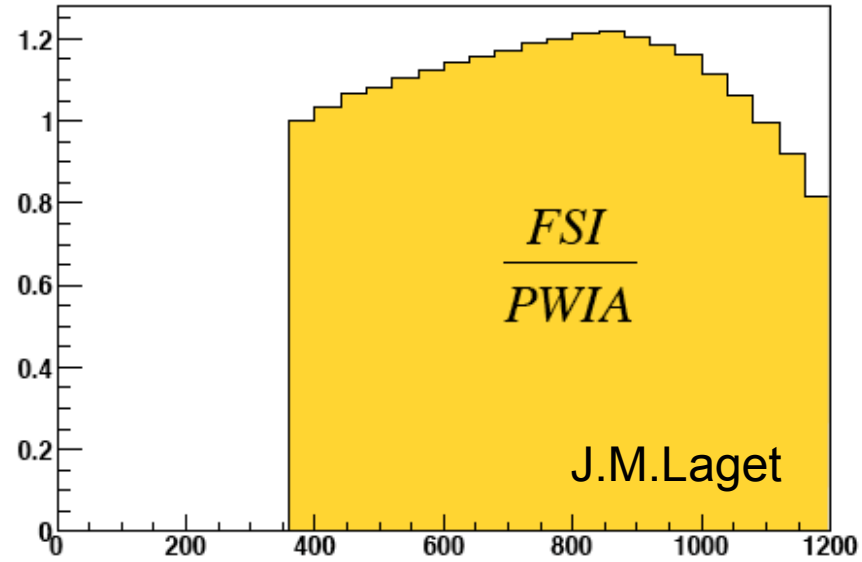
Counts/Hr and 100μA 15 cm LD with Cuts



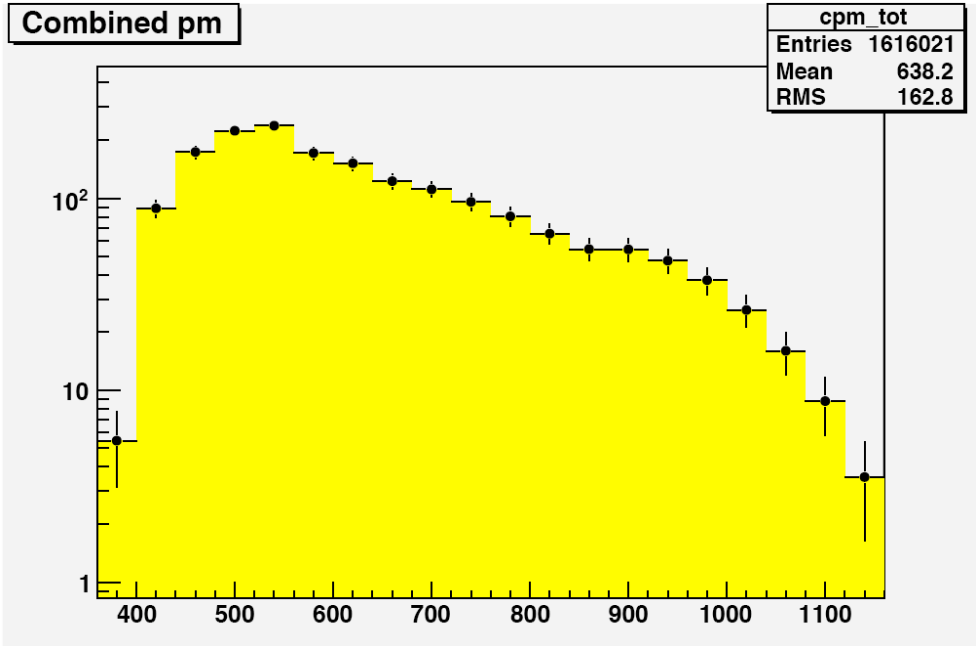


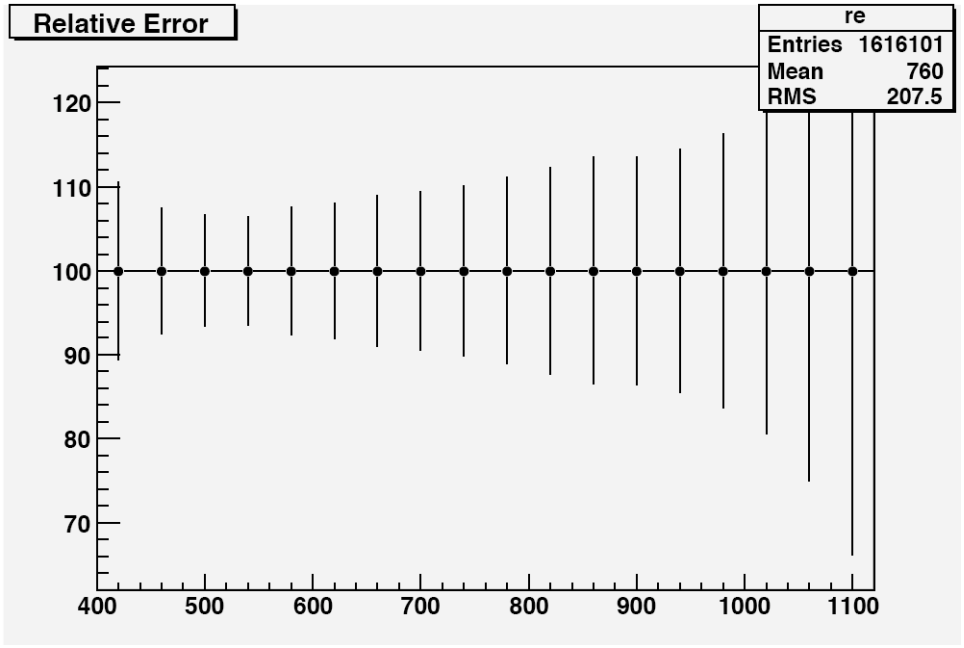
$\frac{\sigma_{FSI}}{\sigma_{PWIA}}$





after about 250 Hr beam time :





Applied Cuts:

$$Q^2 = 3.5 \pm 0.25 \ \ (GeV/c)^2$$

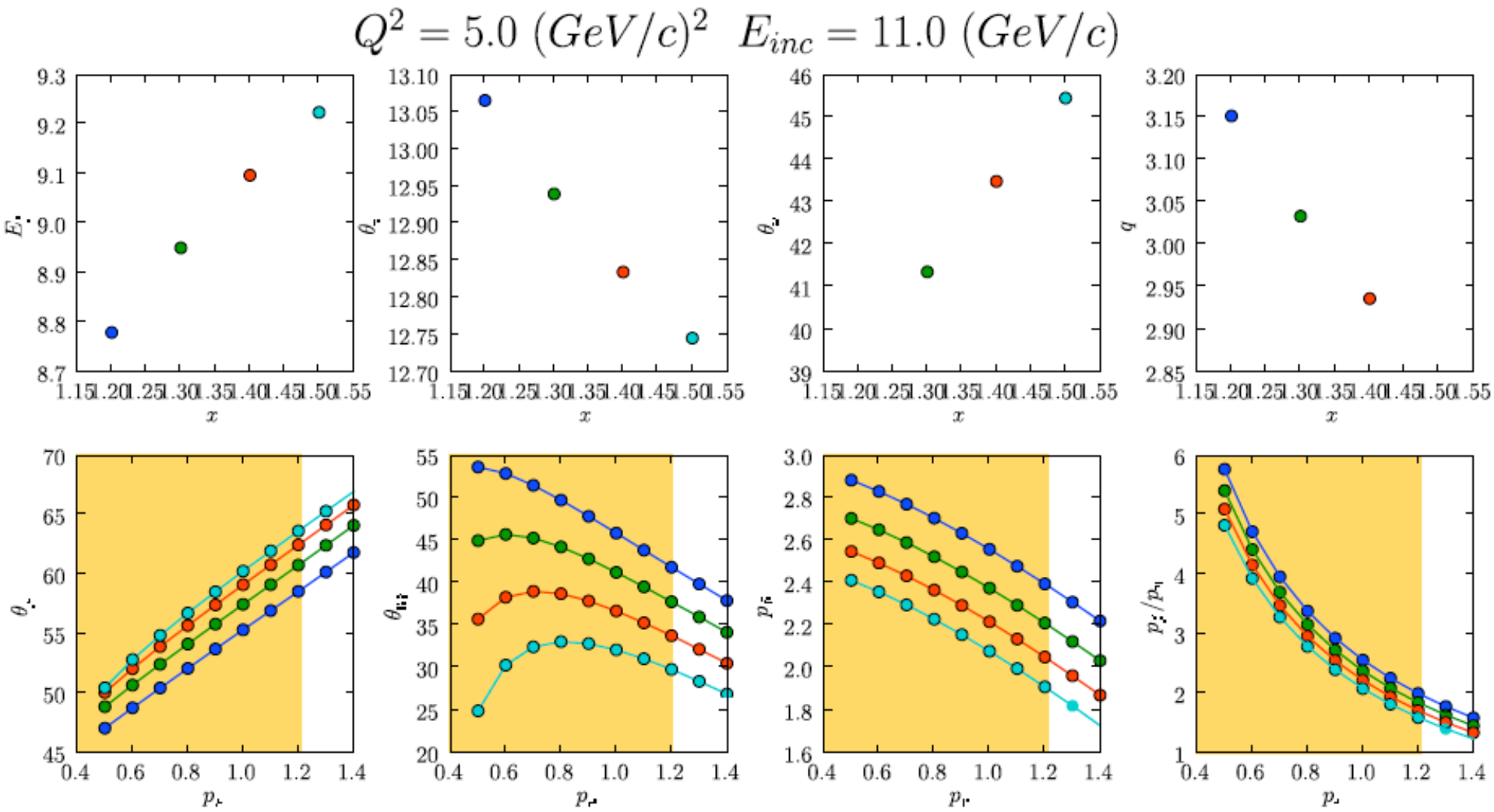
$$\theta_{nq} = 40^0 \pm 5^0$$

$$\Delta p_m = \pm 20\, MeV/c$$

$$R_{e,p} > 0.01$$

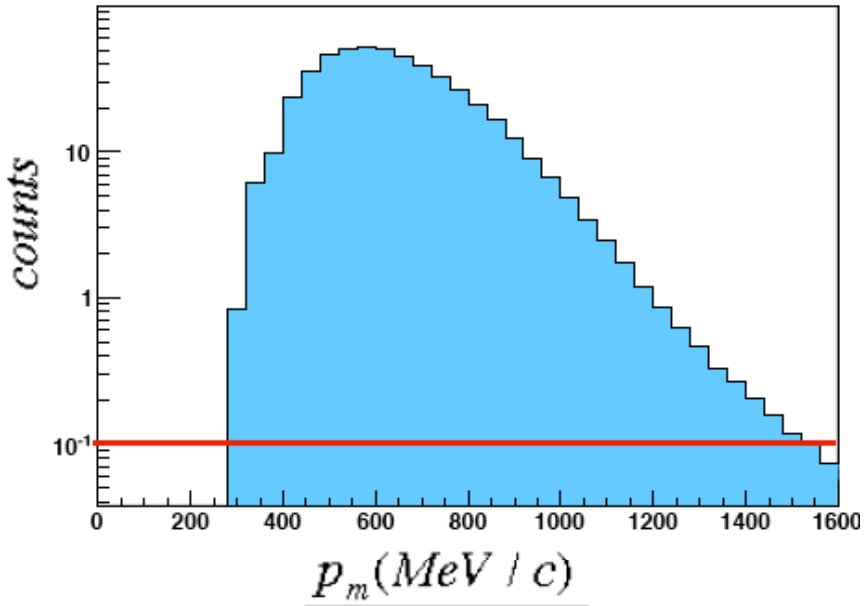
$$-2 \le E_m \le 15\, MeV$$

12 GeV Example I



Count Rates

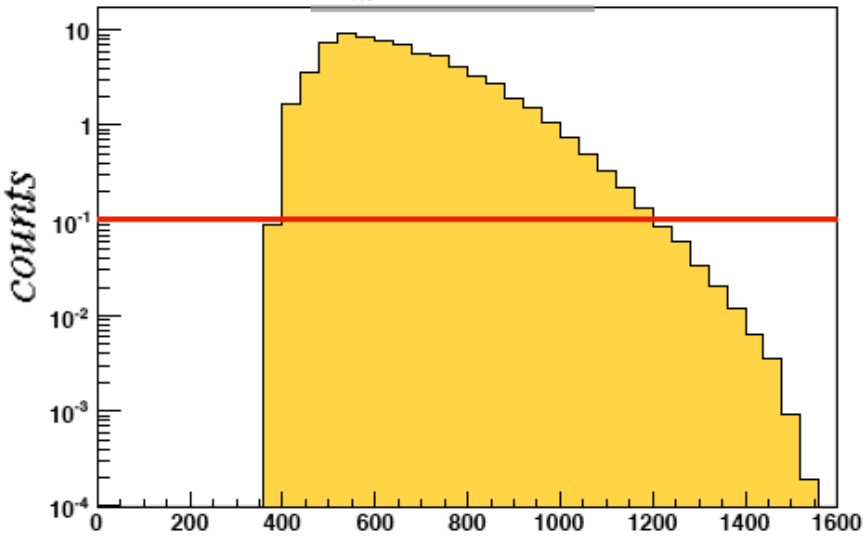
No cuts:



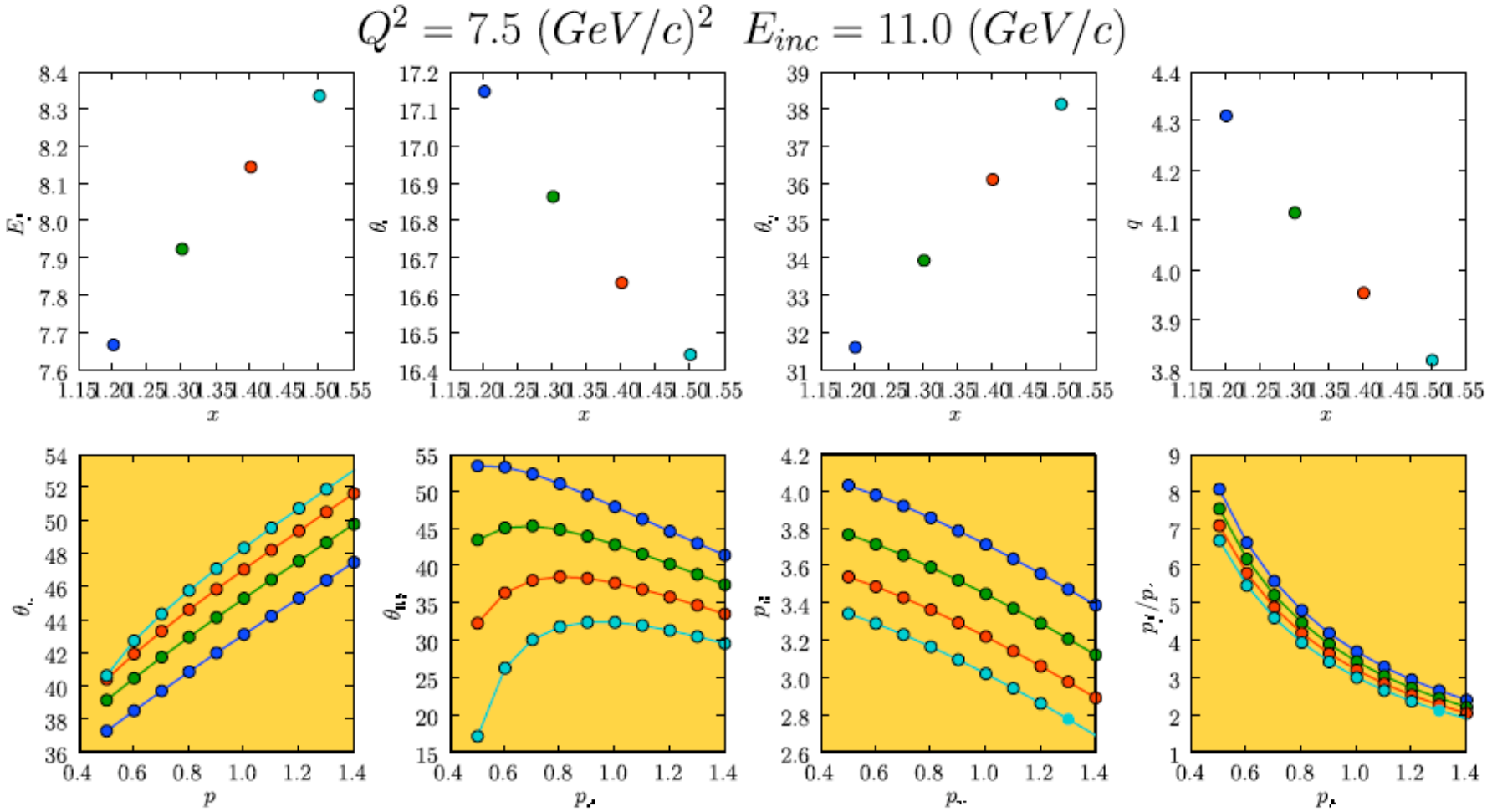
Cuts:

$Q^2 = 5.0 \pm 0.25 \ \ (GeV/c)^2$

$\theta_{nq} = 45^0 \pm 5^0$

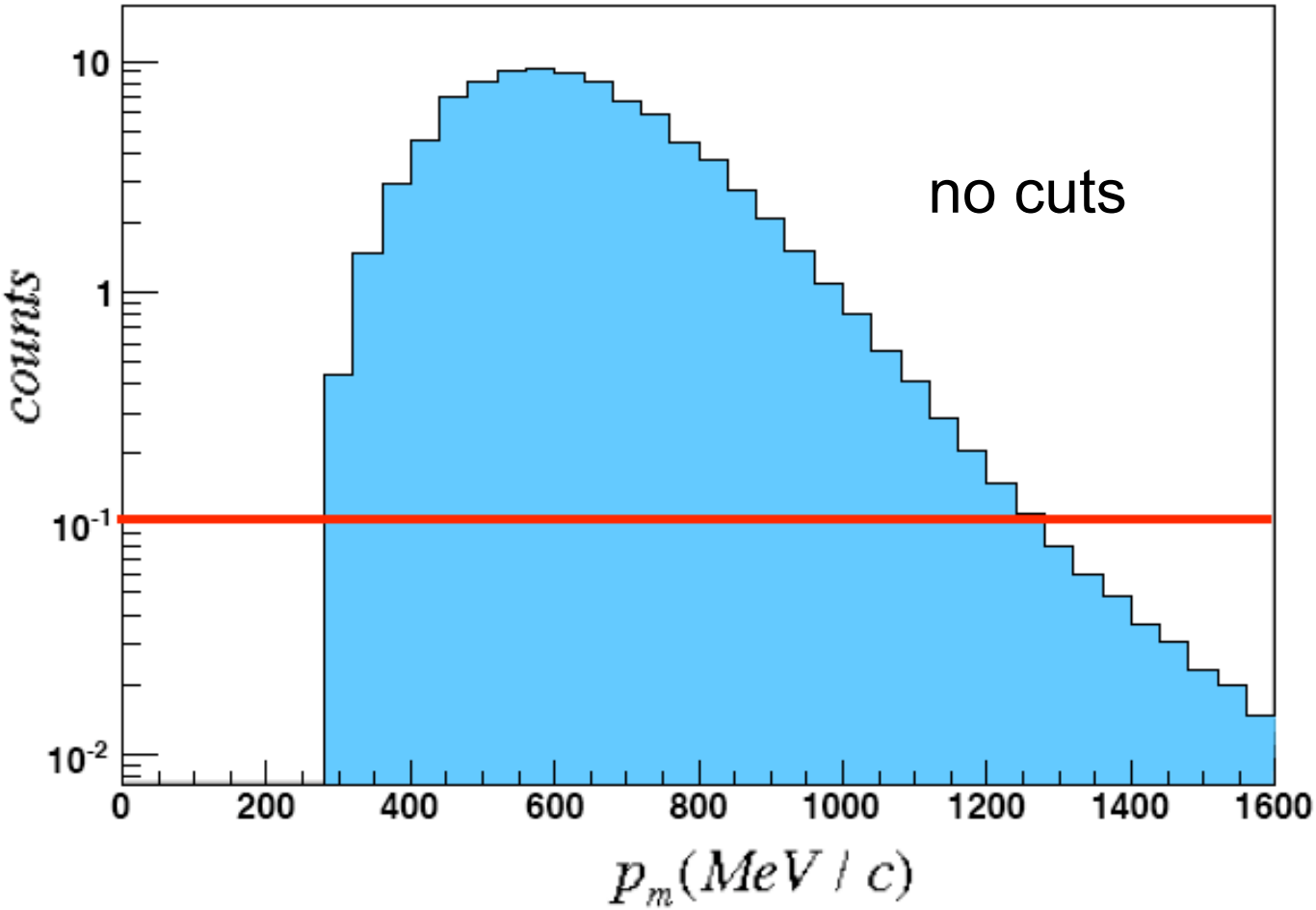


11 GeV Example II



missing momenta up to 1.4-1.5 GeV/c

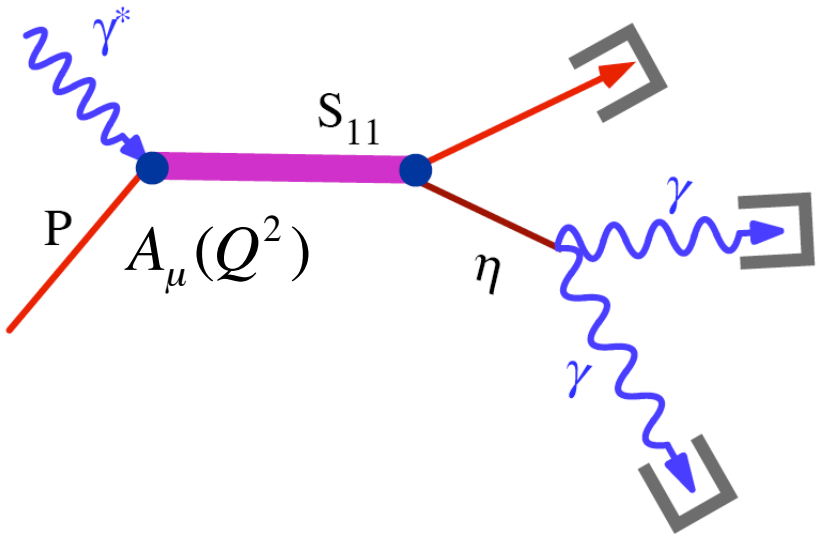
Count Rates


no cuts
counts
10
1
10^{-1}
10^{-2}
0
200
400
600
800
1000
1200
1400
1600
$p_m(MeV/c)$

High M_{miss} Example: Re-scattering of Nucleon Resonances: S_{11}

Reaction Mechanisms

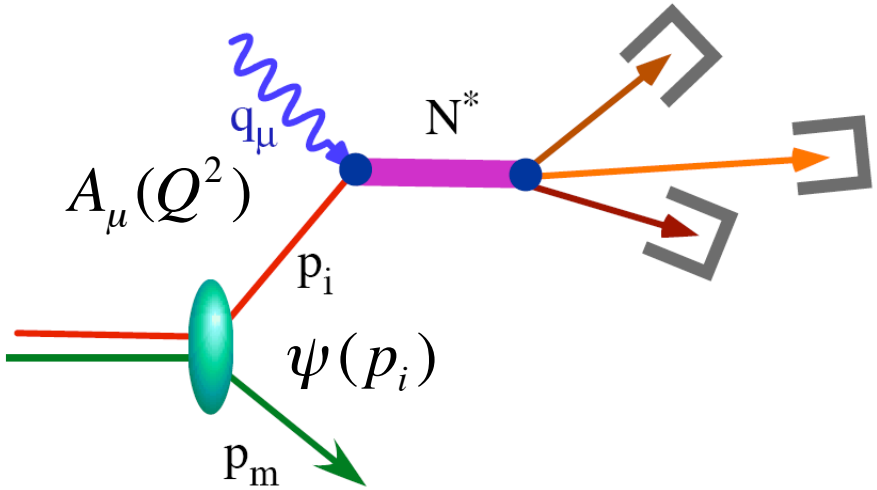
PWIA: no rescattering



free nucleon :

total amplitude:

$A_\mu(Q^2)$

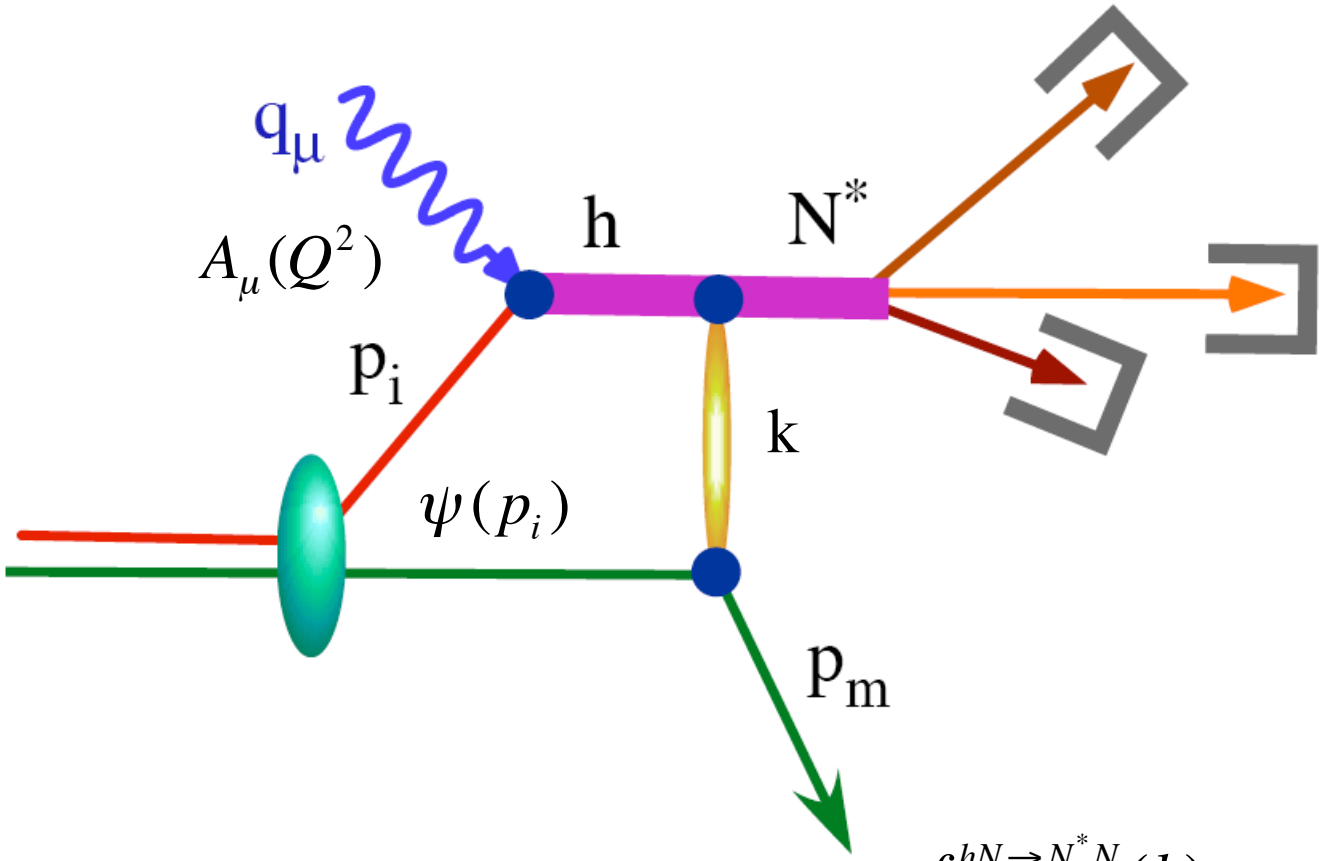


PWIA : no rescattering

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
provided necessary data.

Model Calculations

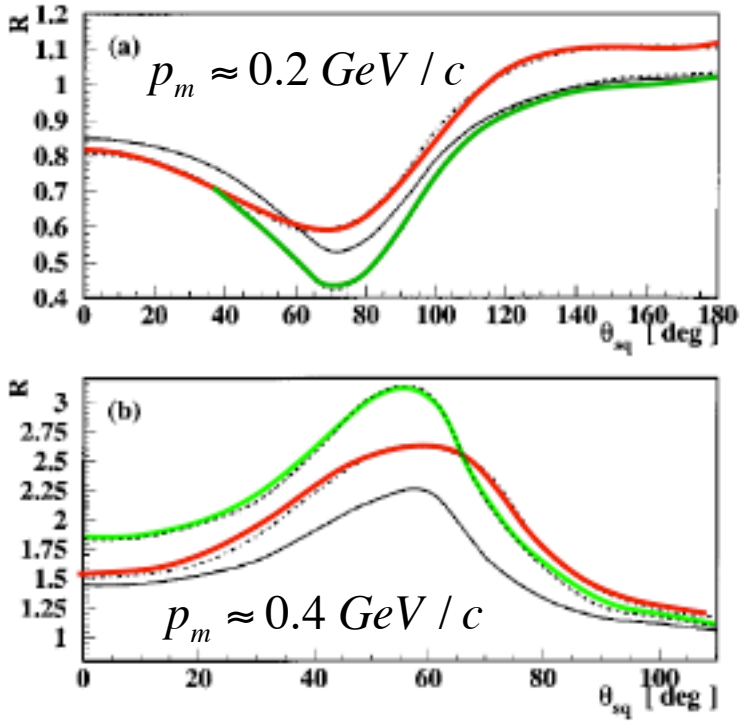
L.Frankfurt et al.

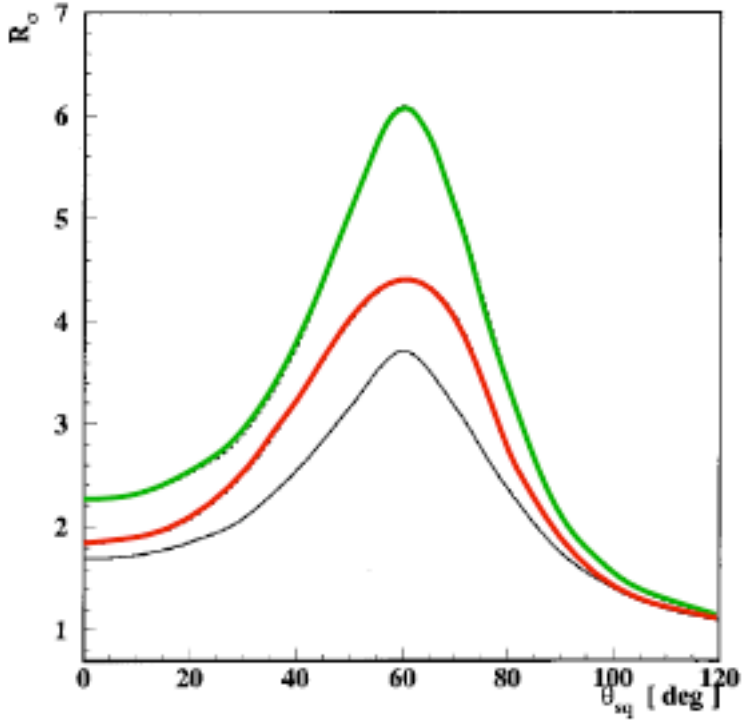
PRC, C60 (1999) 055202

- 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

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

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





S_{11} as NN amplitude

S_{11}N amplitude within CQM

ηN final state within ECL

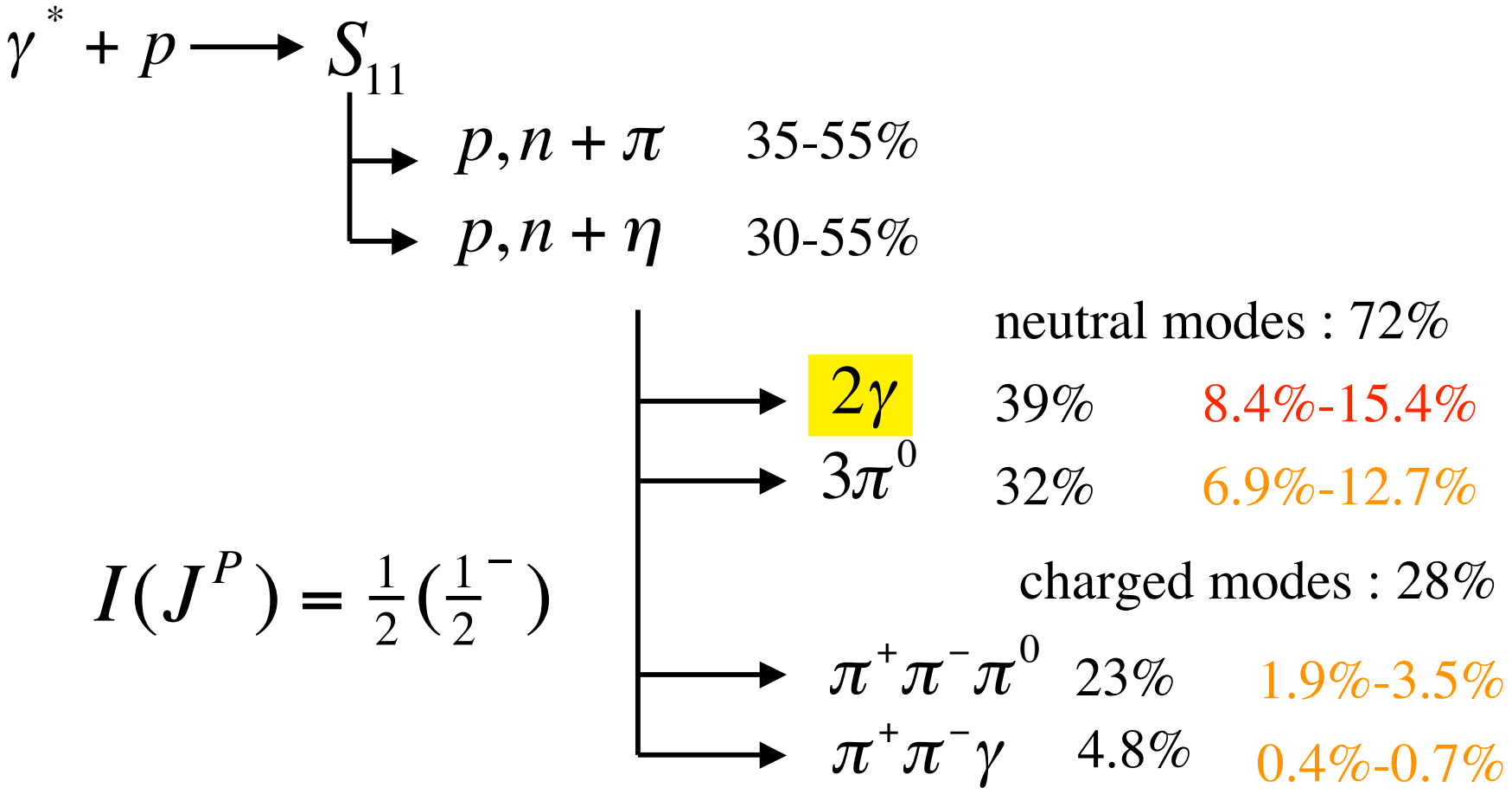
Example of information obtainable from rescattering :

- within CQM : spatial parameters
- fit amplitude to data

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

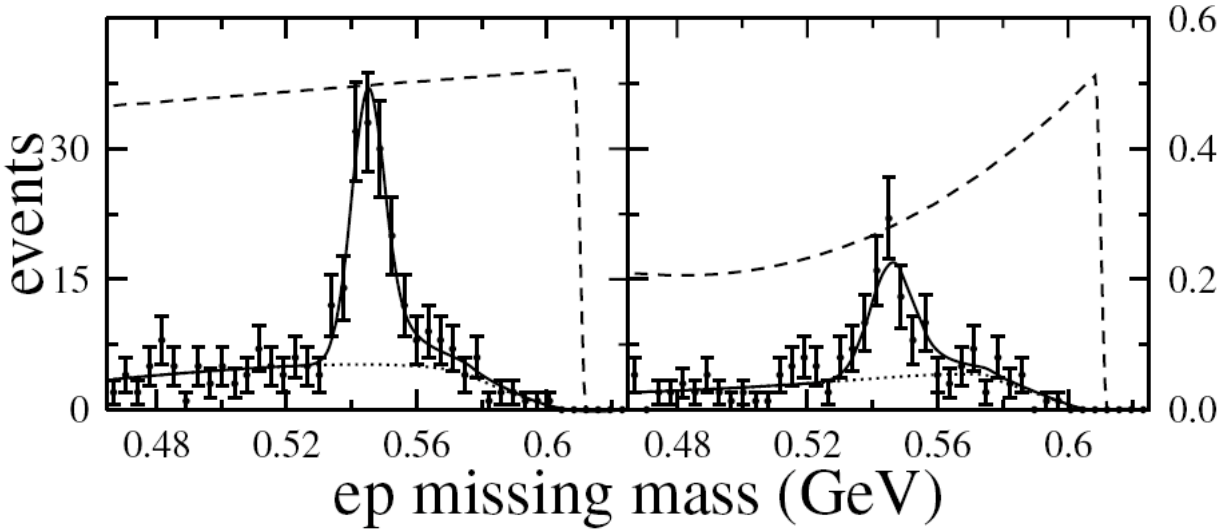
$$\sigma^{tot}_{hN} = \sigma^{tot}_{NN}\frac{\langle r_h^2\rangle}{\langle r_N^2\rangle} \qquad b \approx \frac{1}{3}\left(\langle r_h^2\rangle + \langle r_N^2\rangle\right)$$

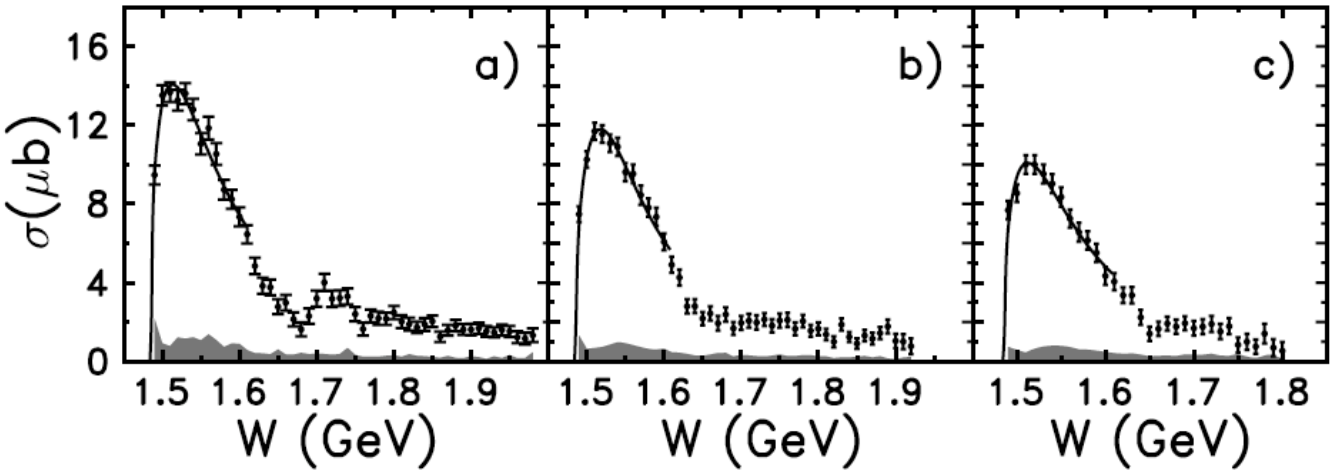
S_{11} Properties



η electro-production CLAS results

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

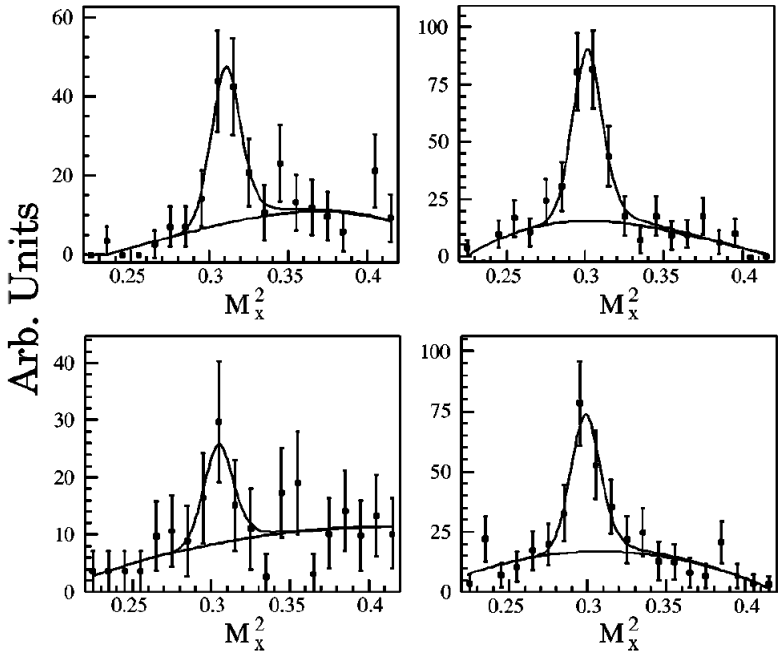


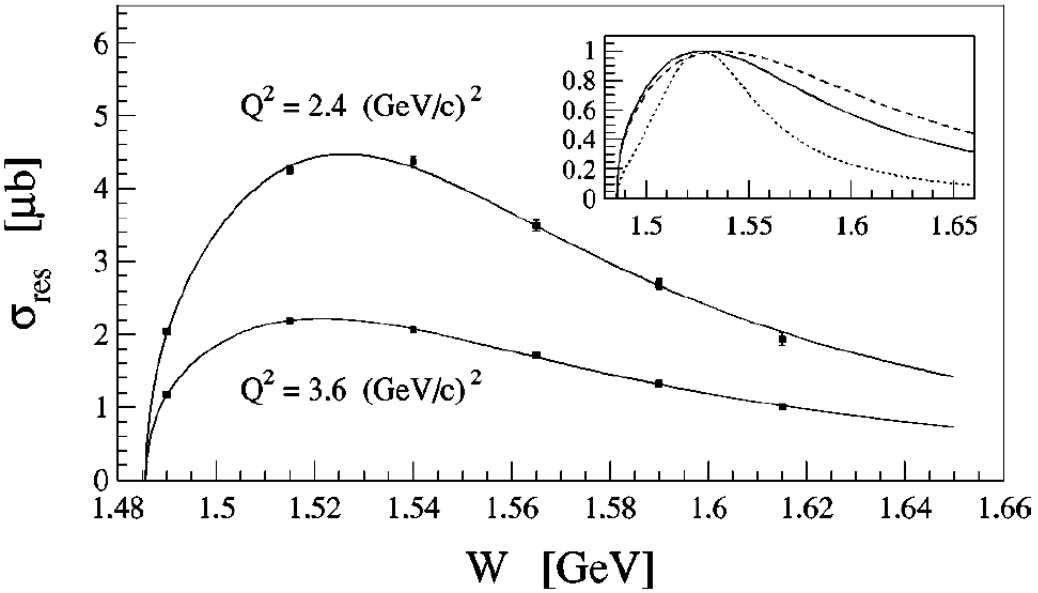


Q^2=0.625 Q^2=0.875 Q^2=1.125

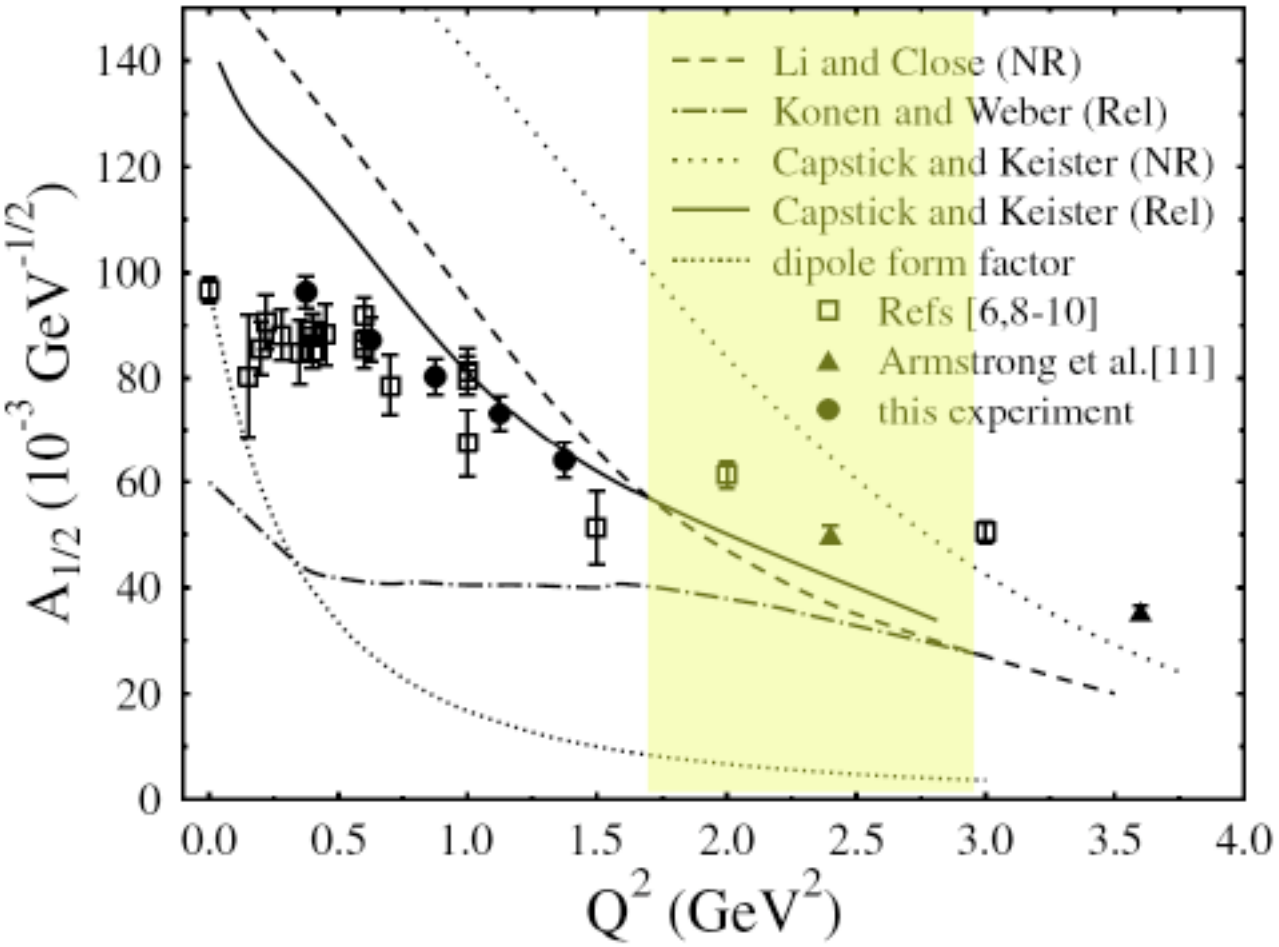
Hall C results

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





Summary of electro-production results

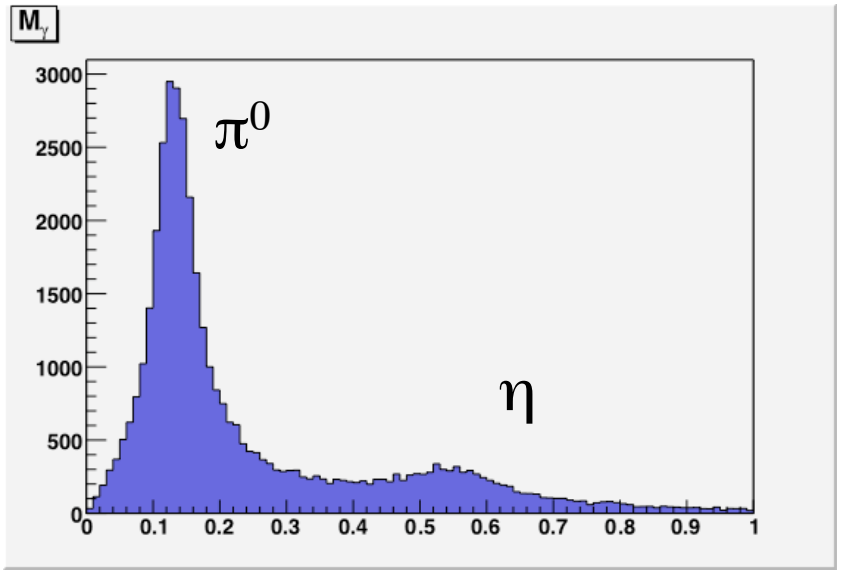


R.Thompson et.al. PRL 86 (2001) 1702

η production off the proton

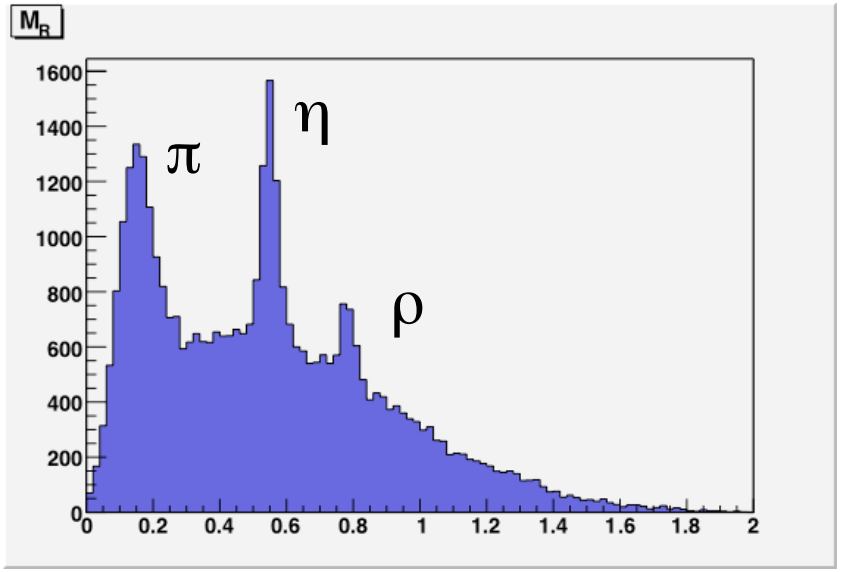
small sample of e6 CLAS data

p(e,e'pγγ)X



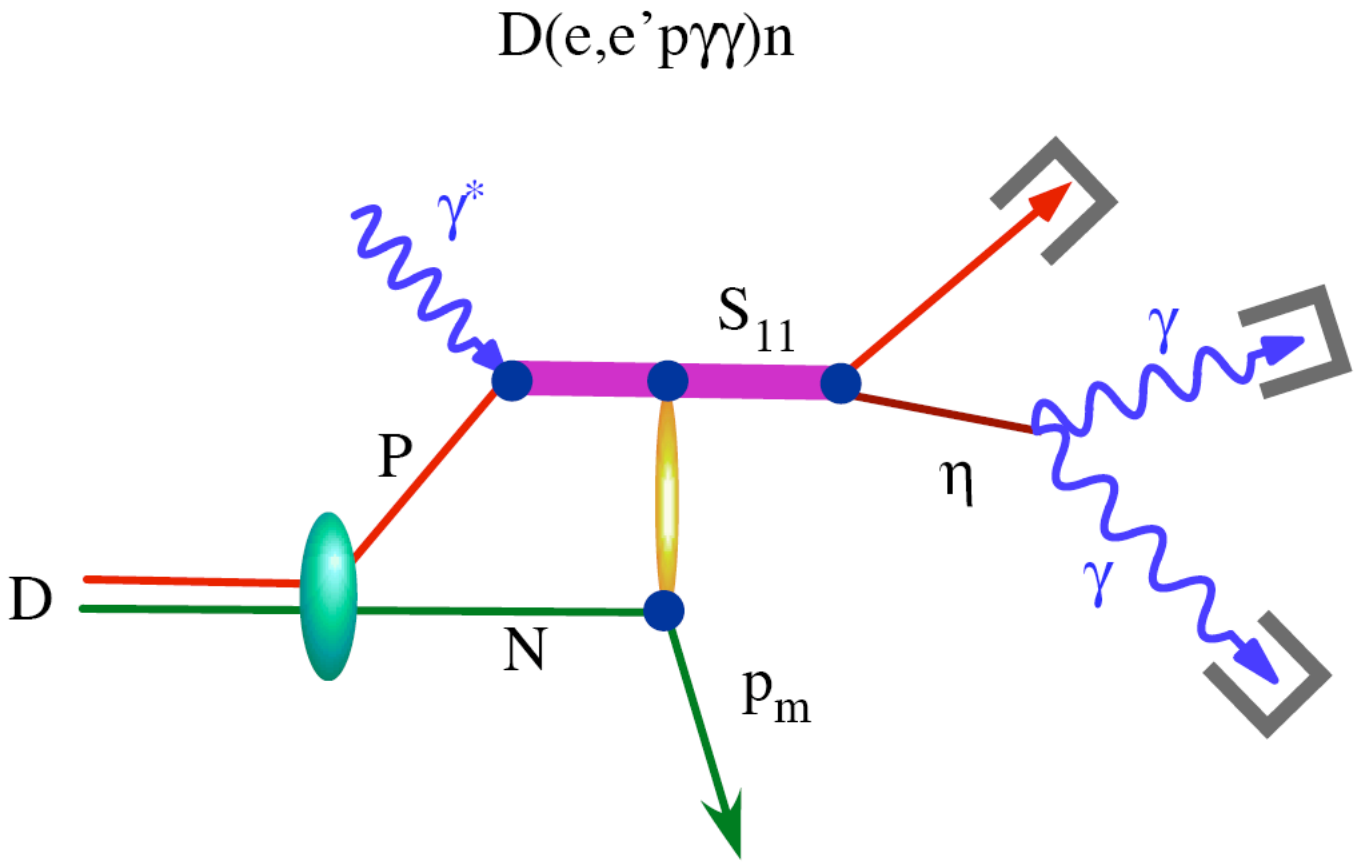
2γ invariant mass

p(e,e'p)X

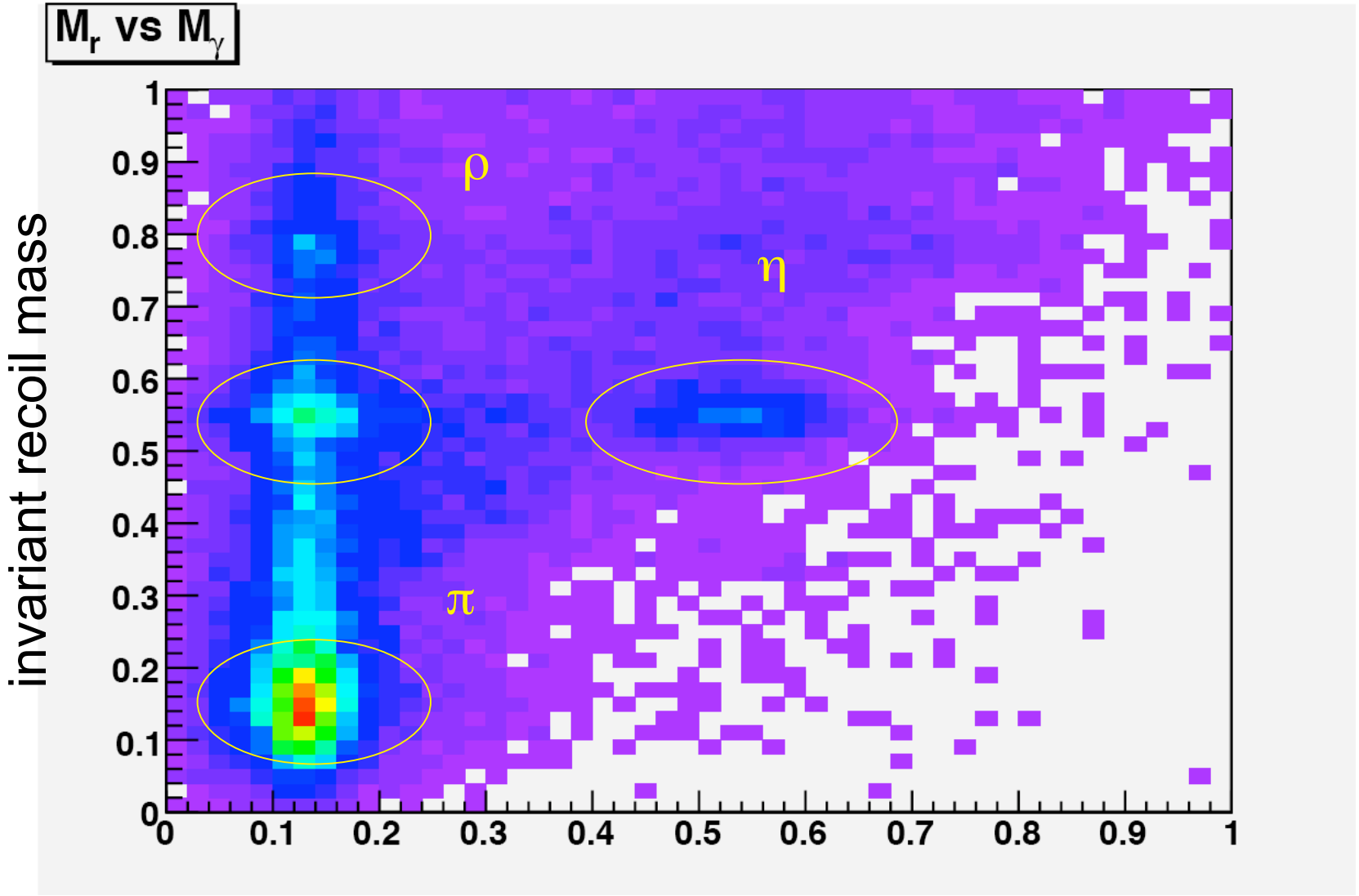


M_{inv} of recoiling system

η electro-production off the deuteron



- small sample of e6 CLAS data (about 1.7%)


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

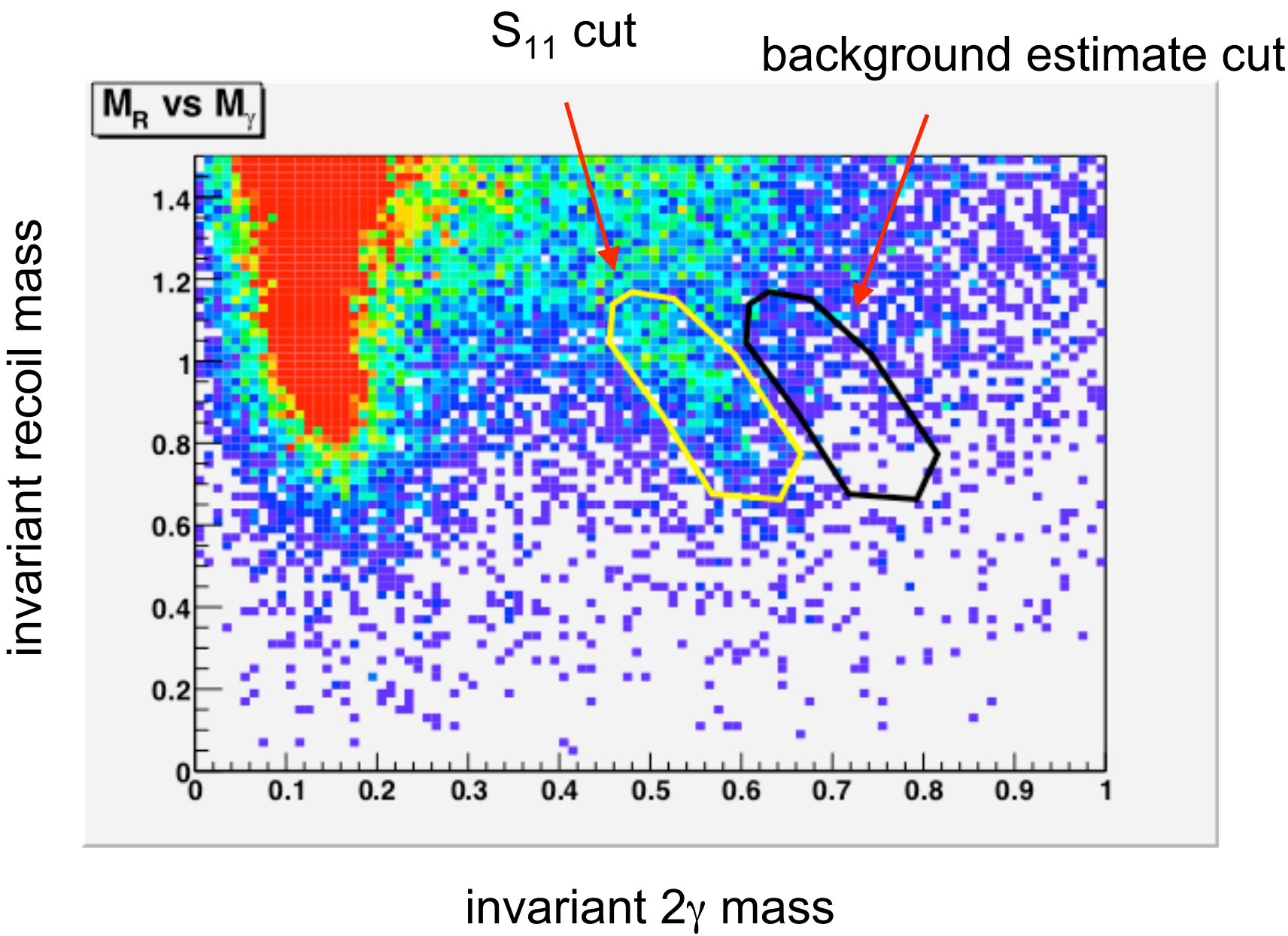
Analysis :

Event selection criteria

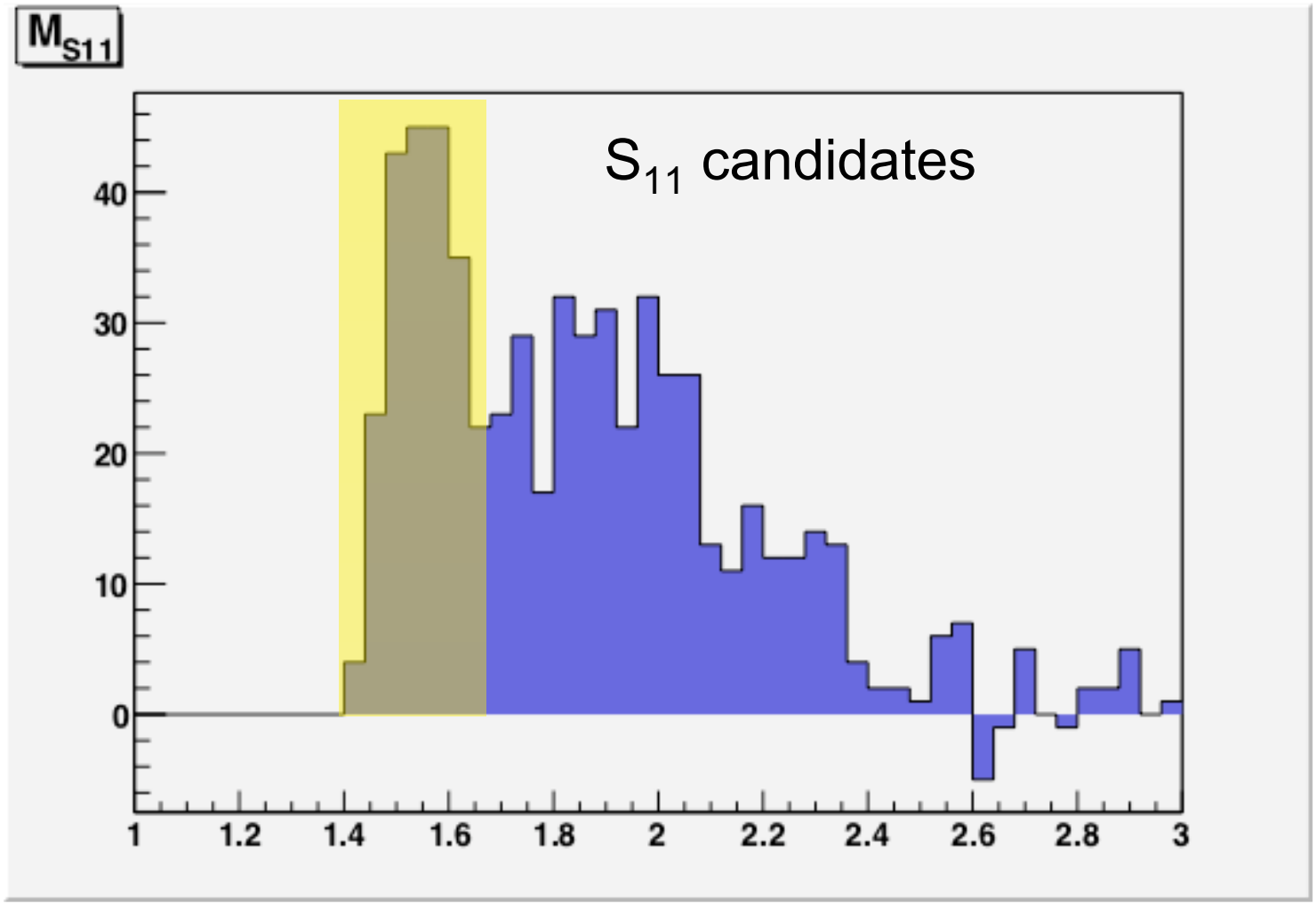
- scattered electron $\rightarrow q^{\mu}$
- proton $\rightarrow p_p^{\mu}$
- 2 photons $\rightarrow k_1^{\mu}, k_2^{\mu}$

$$p_{\eta}^{\mu} = k_1^{\mu} + k_2^{\mu}$$
$$p_{S_{11}}^{\mu} = p_{\eta}^{\mu} + p_p^{\mu}$$
$$p_m^{\mu} = q^{\mu} + p_D^{\mu} - p_{S_{11}}^{\mu}$$

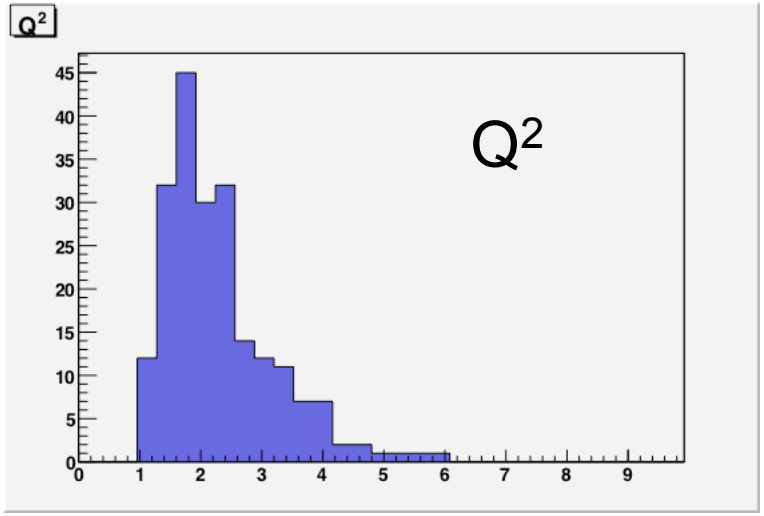
} Apply cuts to invarant masses

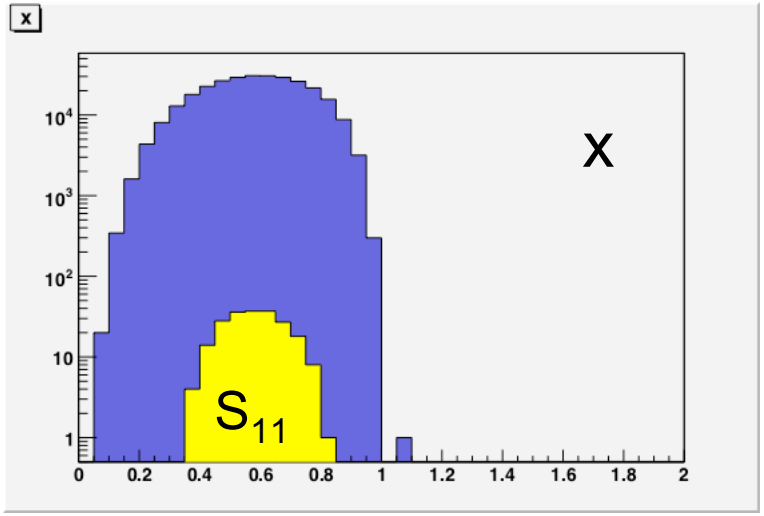

S_{11} cut
background estimate cut
M_R vs M_γ
invariant recoil mass
invariant 2γ mass
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0.1
0.3
0.5
0.7
0.9

cut on invariant resonance mass

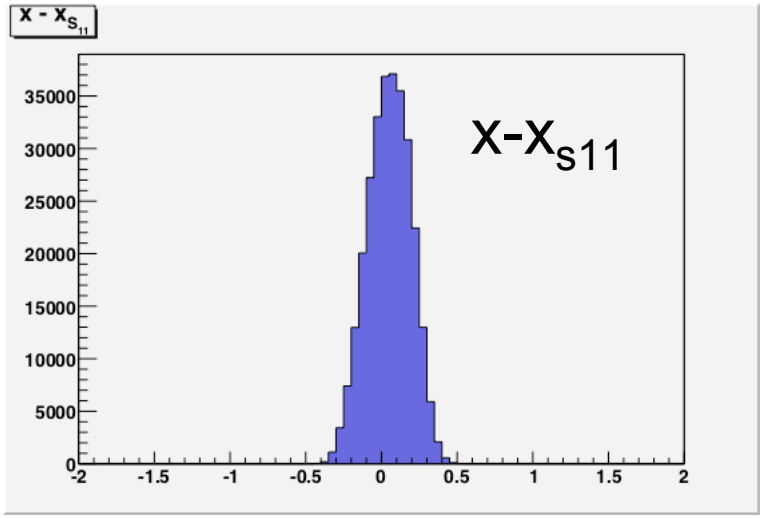


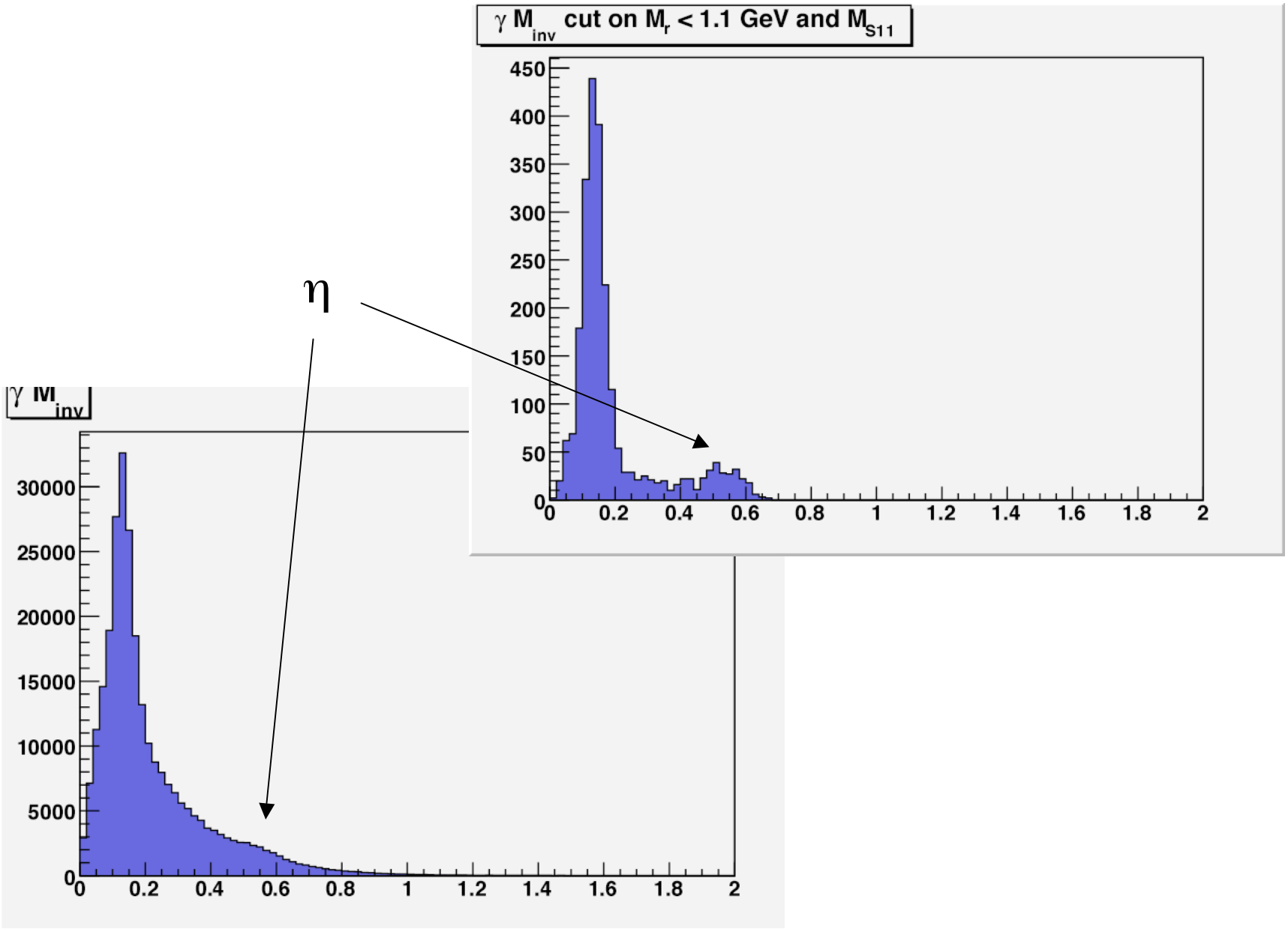
Kinematical Variables





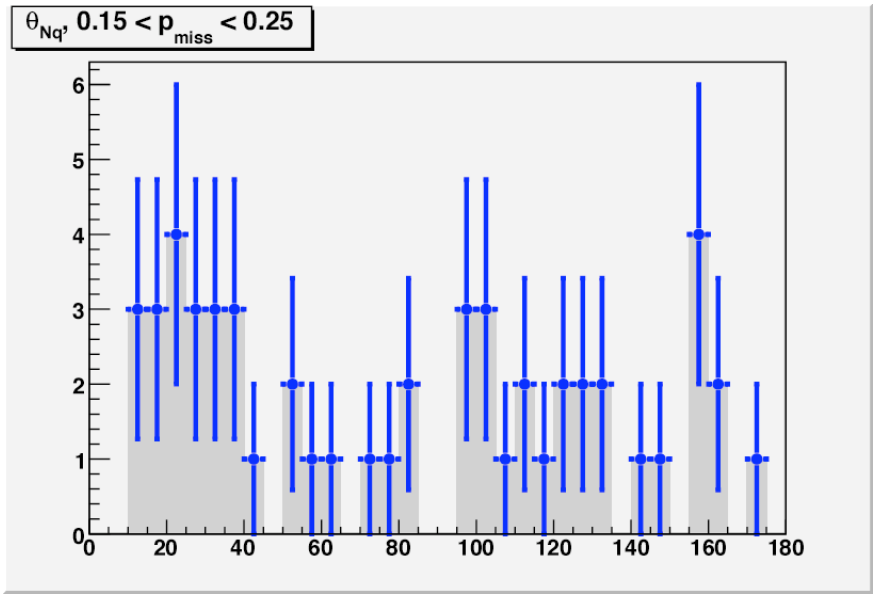
$$x = 1 - \frac{M_R^2 - M^2}{Q^2 + M_R^2 - M^2}$$




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

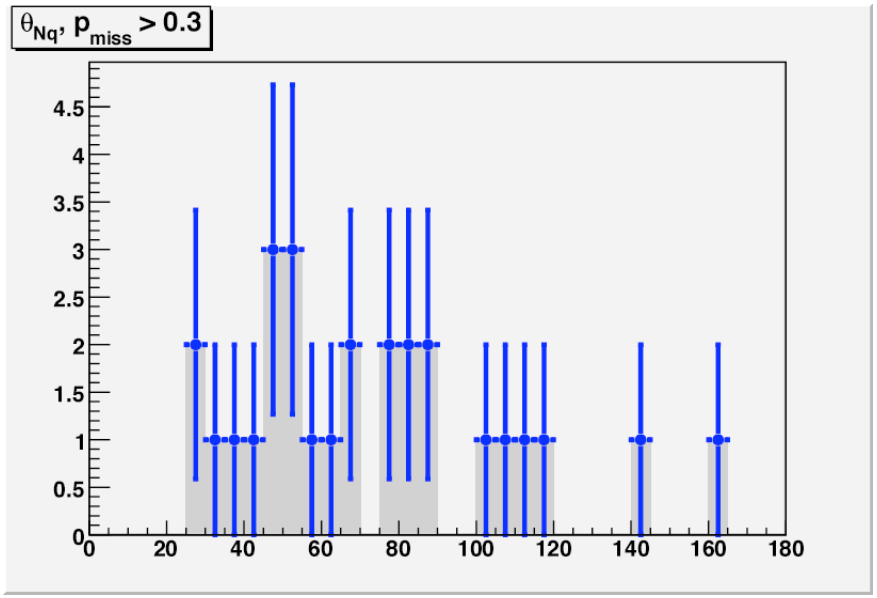
no phase space correction

small p_m
53 events



remember:
1.7 % of all data !

large p_m
27 events



Summary

- ✓ New results confirm general GEA description with room for improvements
- ✓ JLAB uniquely suited for high p_m study: high p_m in the Deuteron should be measured as soon as possible provides guidance for 12 GeV program
- ✓ Start using Deuteron as femto-technology lab: resonance re-scattering
- ✓ real photon can also be used: new detector systems: GlueX/Hall D will be available for other physics