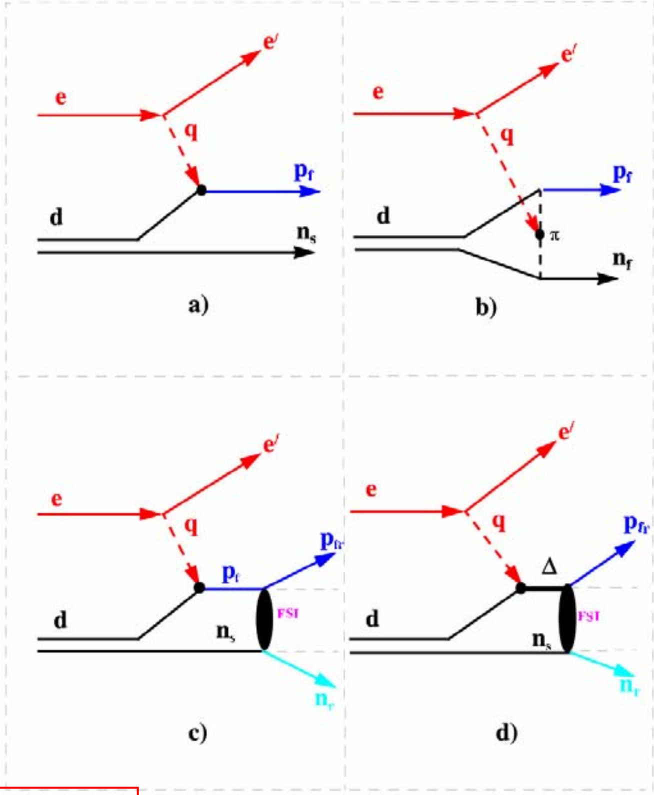
Rescattering in Few Body Systems:
Correlations? A tool

- S-matrix singularities: on-shell matrix elements
  - Low momentum components in the w.f.
  - FSI's dominate even at large Q^2
- Correlations in (e,e'p) channels?
- Tool: CT, YN scattering, Pentaquarks, Exotics
  - $^2H(\gamma,p\pi^-)p$, $^2H(\gamma,KY)N$, ….
- Exploit 6 GeV data sets (g10, eg3 runs,…)
- Dedicated experiments? 12 GeV

Low energies: Phys. Rep. 69 (1981)1
High energies: Phys. Lett. B609 (2005) 49 & Phys. Rev. C73 (2006) 044003
nucl-th/0603009

The physical picture

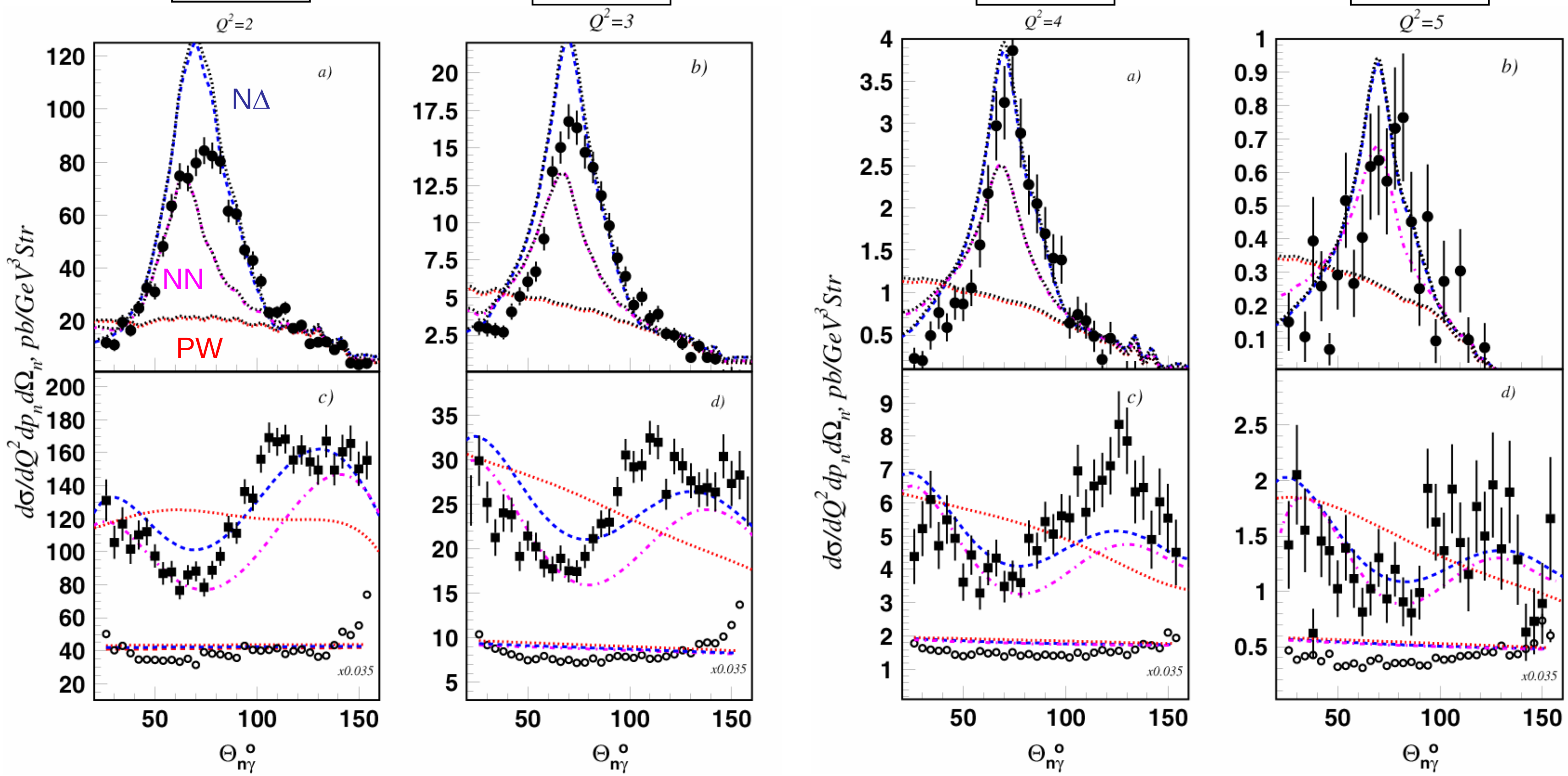
- The photon interacts with a nucleon at rest
- The fast nucleon scatters with the second nucleon, also at rest
- It recoils at 90° off the fast nucleon
  - About 70° off the photon direction
- This happens in the quasi-free kinematics
  - NN: $X_N=1$
  - ΔN: $X_\Delta=1/(1+(m_\Delta^2-m^2)/Q^2)$
- On-shell elementary matrix elements
  - Unitarity!!
- Low momentum of the deuteron w.f.
  - Even though large recoil momentum



Well under control ⇒ A TOOL

D(e,e'p)n CLAS kinematics

Q^2=2 Q^2=3 Q^2=4 Q^2=5

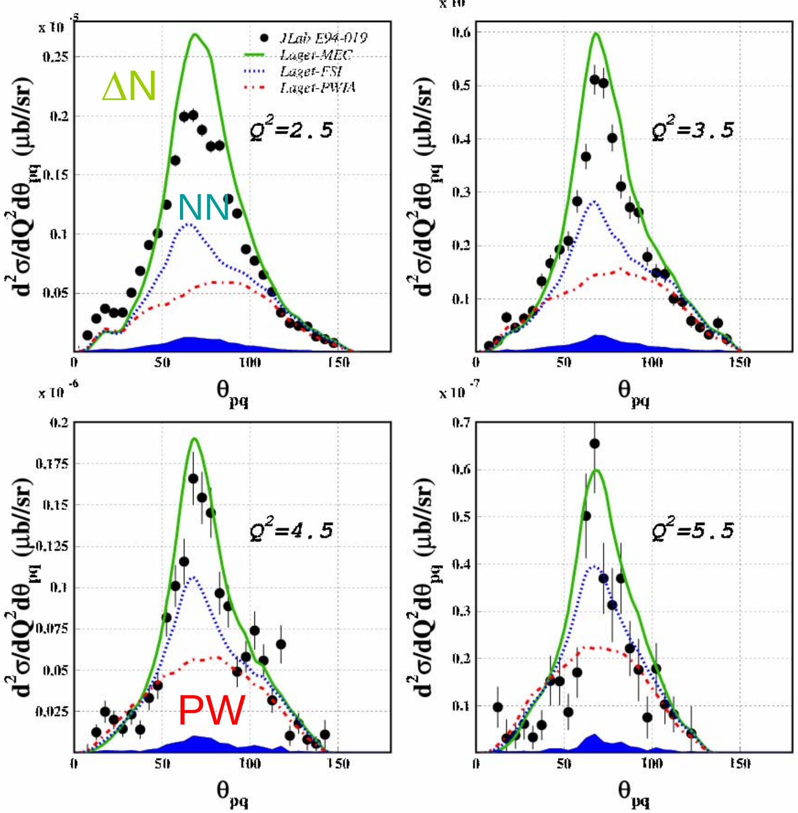


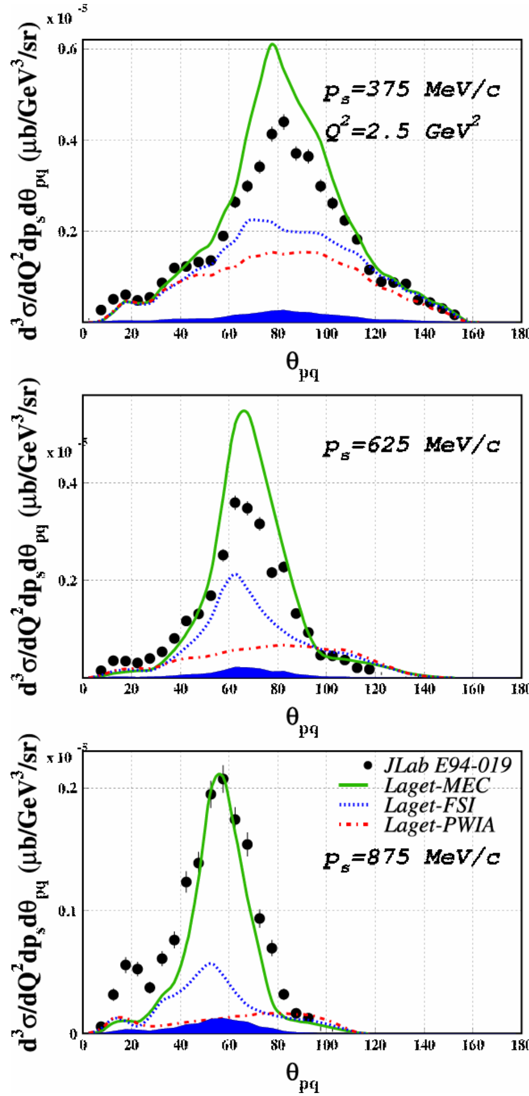
500

P_n = 250

K. Egiyan

D(e,e'n)p CLAS kinematics

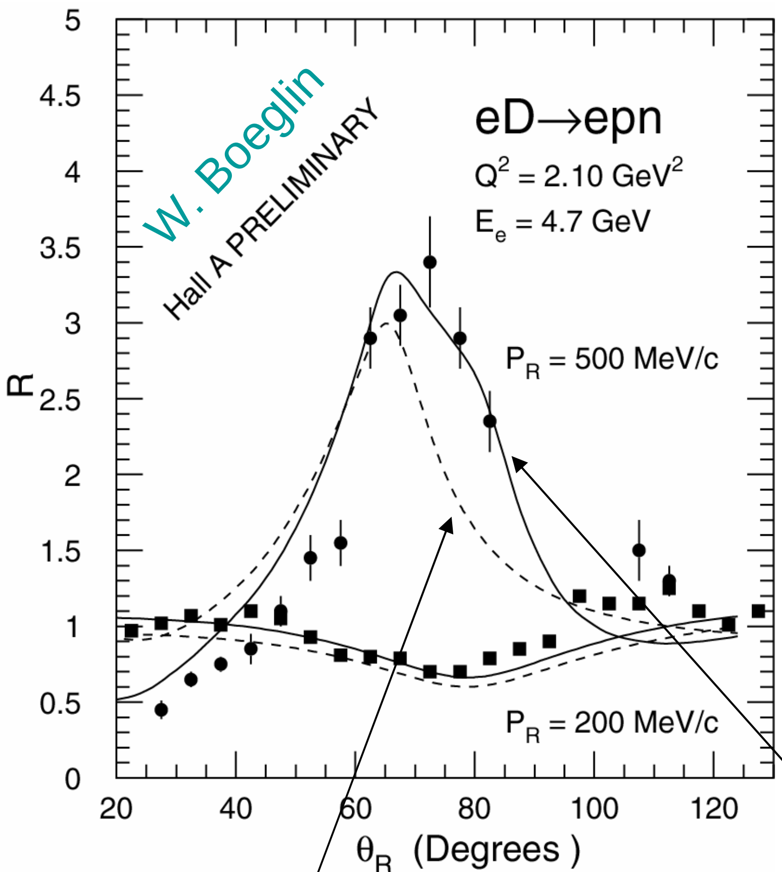


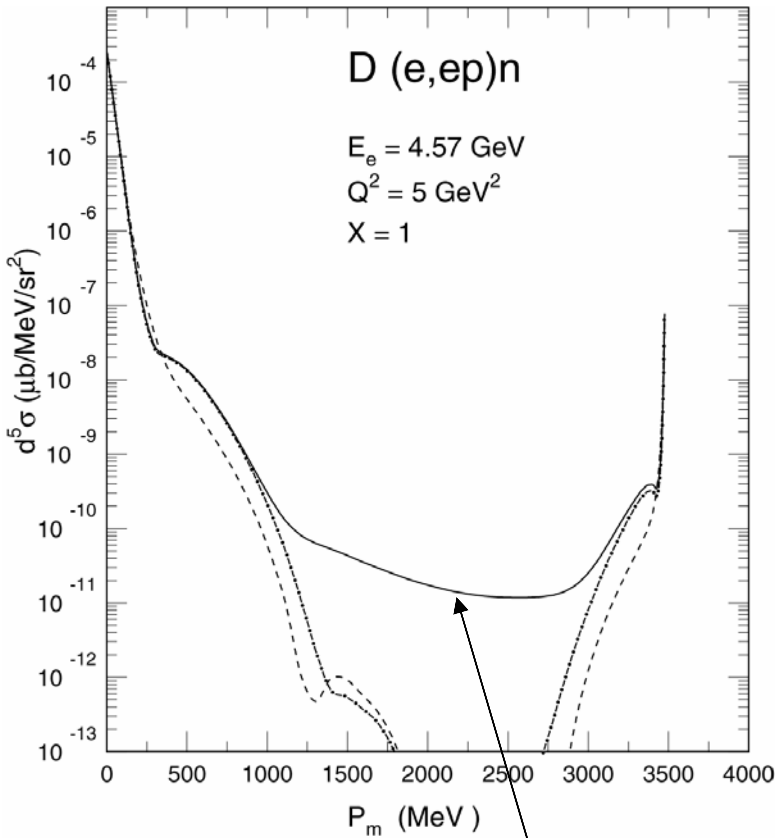


- $X_N=1$
- $X_\Delta=1/(1+(m_\Delta^2-m^2)/Q^2)$ ~0.85

C. Butuceanu thesis

D(e,e'p)n coplanar kinematics



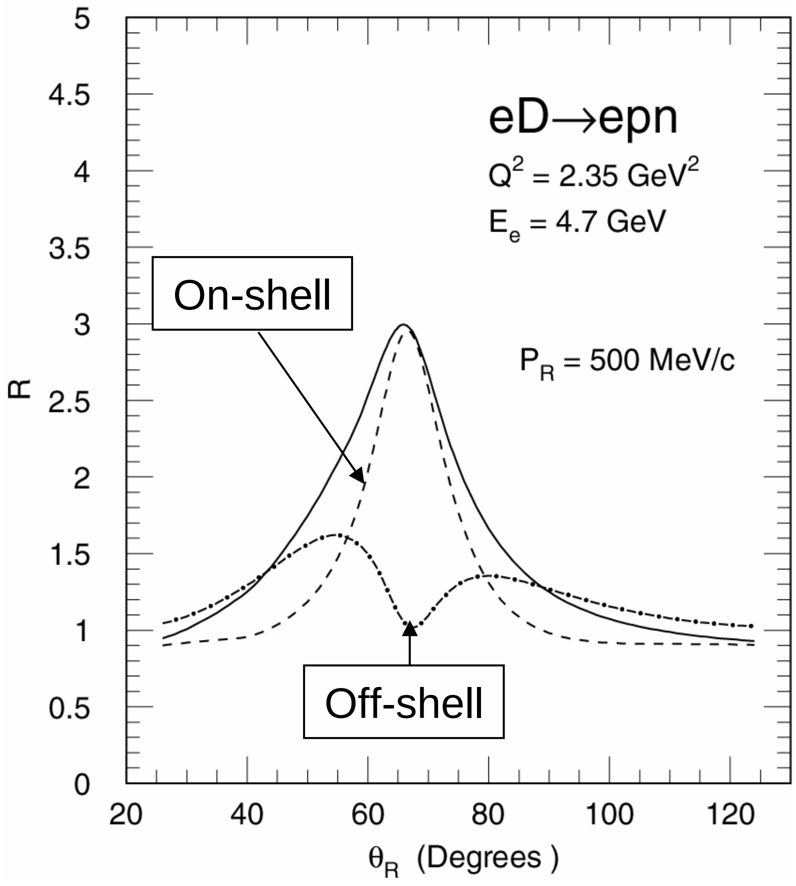


On-shell NP scattering

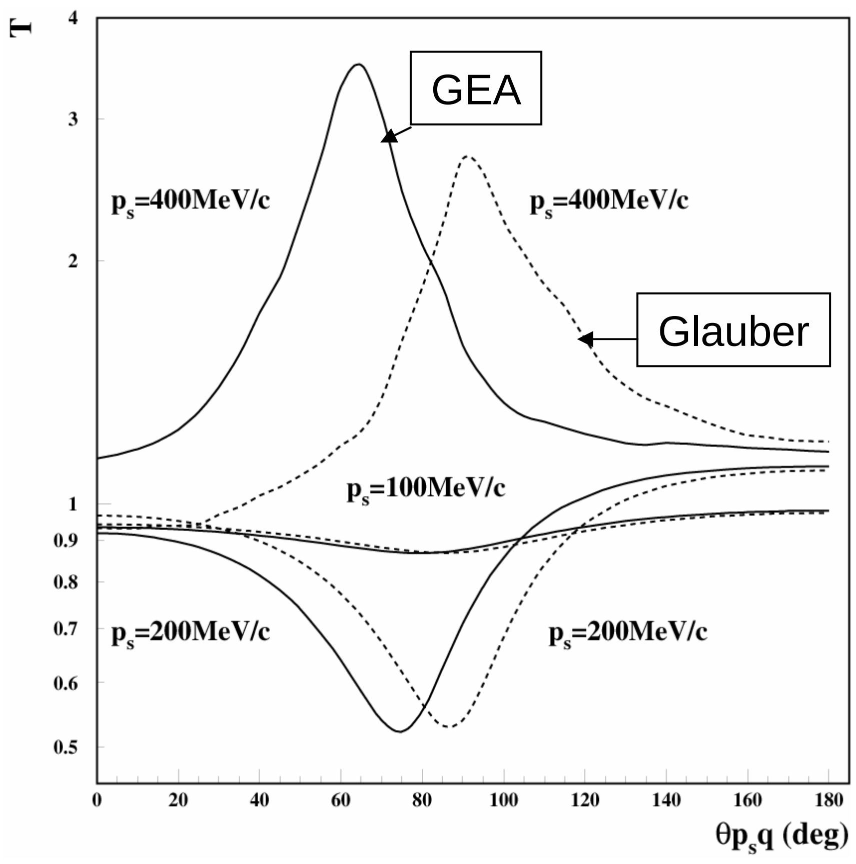
Full Relativistic EM current

- On-shell $\Delta N \rightarrow NP$ scattering
- Spectator nucleon at rest

D(e,e'p)n: Diagrams vs Glauber



Principal (off-shell) part vanishes at X=1



Frankfurt, Sargsian, Strikman, PRC56 (1996) 1124

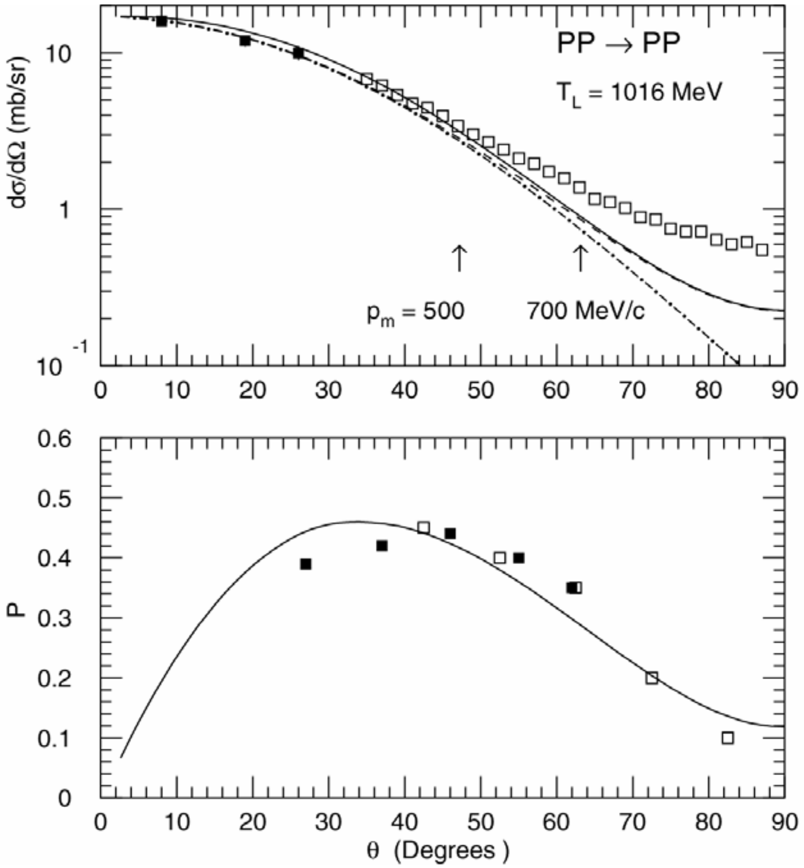
Full angular dependency inside the integral mandatory!!

NN scattering

$$T_{pp} = (m_2 m_1 | \alpha + i\gamma(\vec{\sigma_1} + \vec{\sigma_2}) \cdot \vec{k}_\perp$$
$$+ \text{spin} - \text{spin terms} \, | m'_p m_p)$$

$$\alpha = -\frac{W p_{cm}}{2m^2} (\epsilon + i) \, \sigma_{NN} \, \exp[\frac{\beta_N}{2} t_r]$$

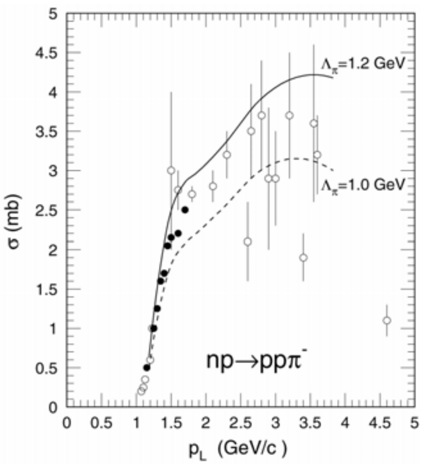
- Small spin-orbit contribution to unpolarized cross section
- Fine up to p_m~600 MeV/c
- Next step: use numerical amplitudes from SAID:
  - On-shell: technical issue only
  - Off-shell: extrapolation??

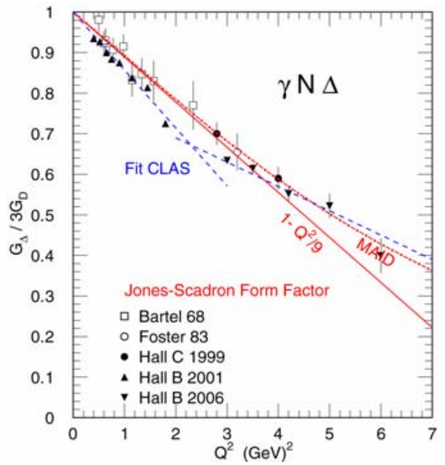


Data: COSY

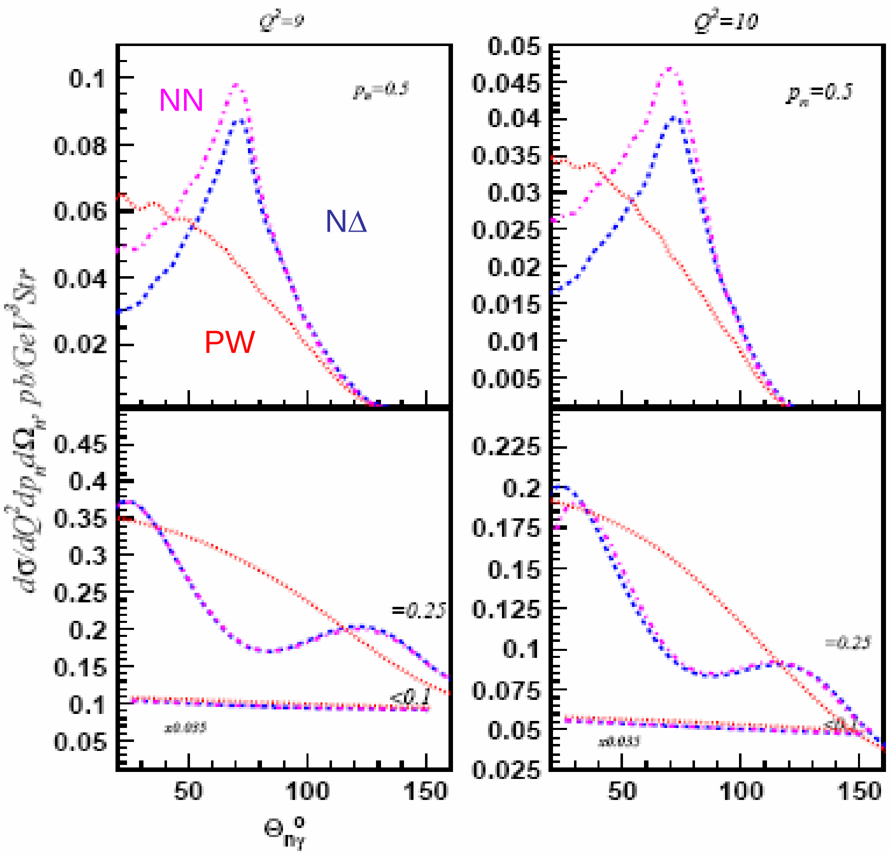
ΔN transition amplitude

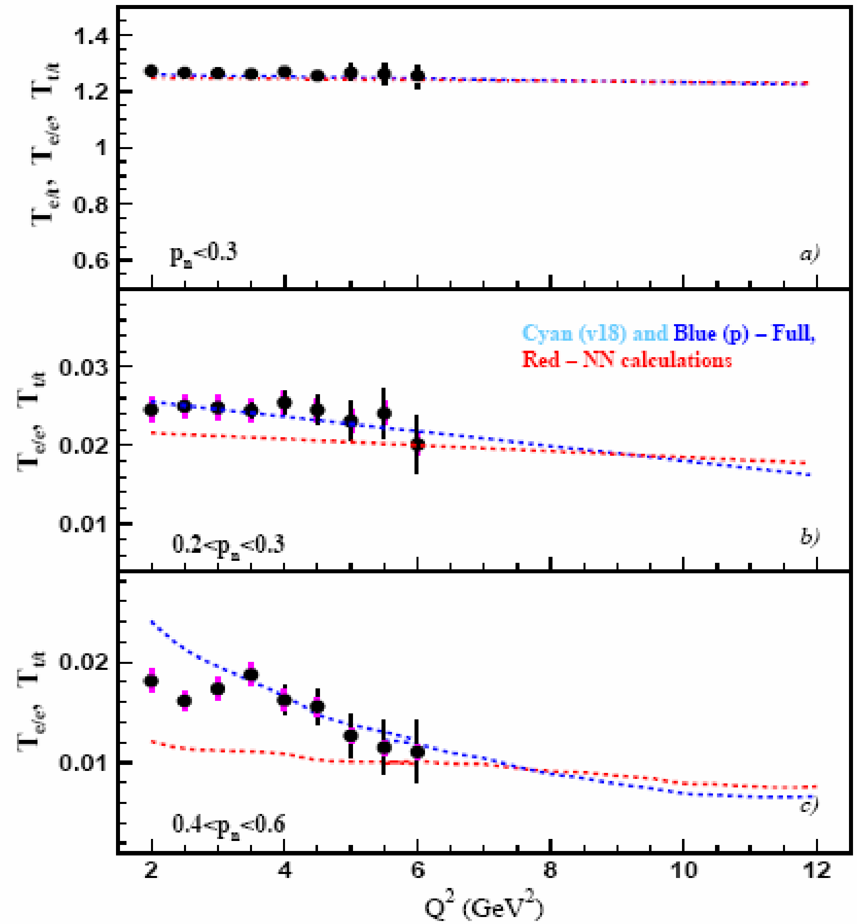
- $\pi + \rho$ exchange
  - Λ_π =1.1 GeV
- Calibrated against $\gamma D \rightarrow pn$ channel
- Relativistic $\gamma N \rightarrow N\pi$ amplitude
- Latest $\gamma N\Delta$ EM Form Factor
- Room for fine tuning
  - ~15%





$^2H(e,e'p)n$ at 12 GeV

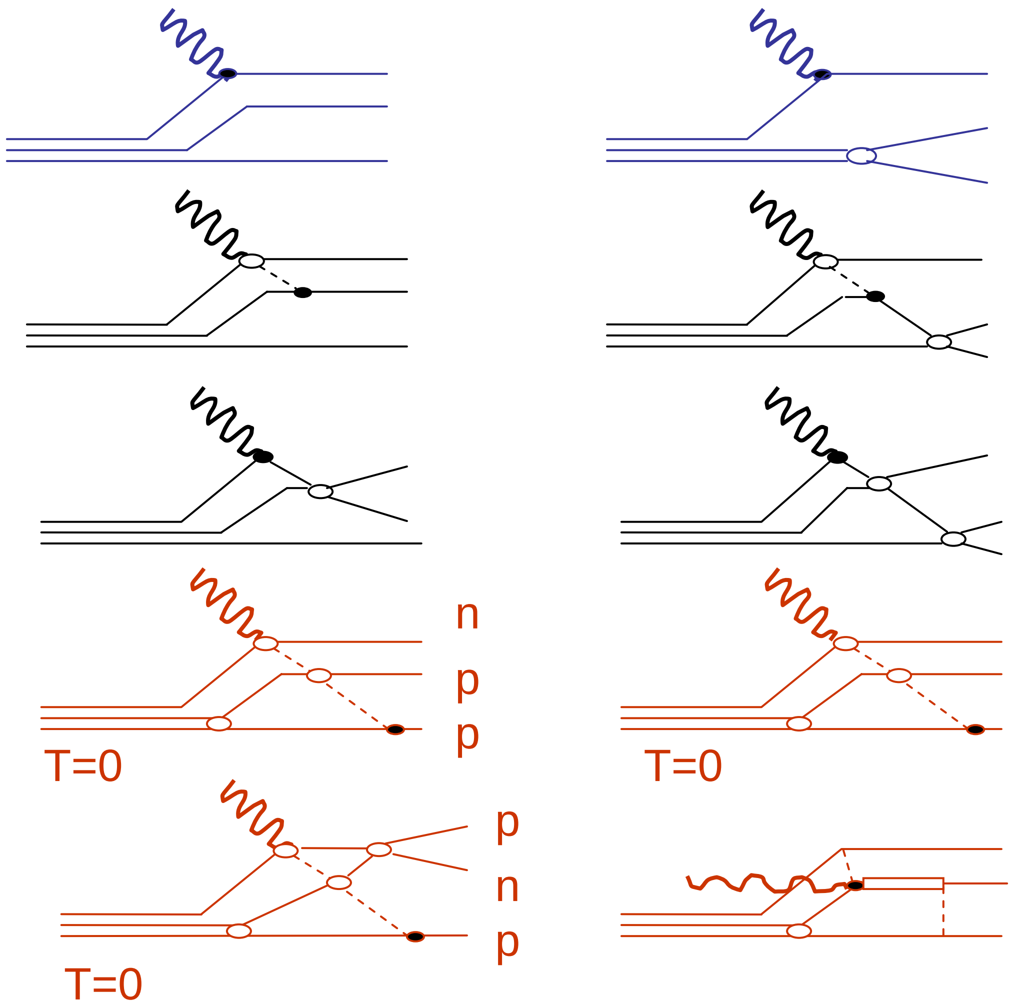




12 GeV Proposal by Kim!

^{3}He 3 Body Disintegration

Ground State Faddeev WF (Paris potential)



1Body

2 Body

3 Body

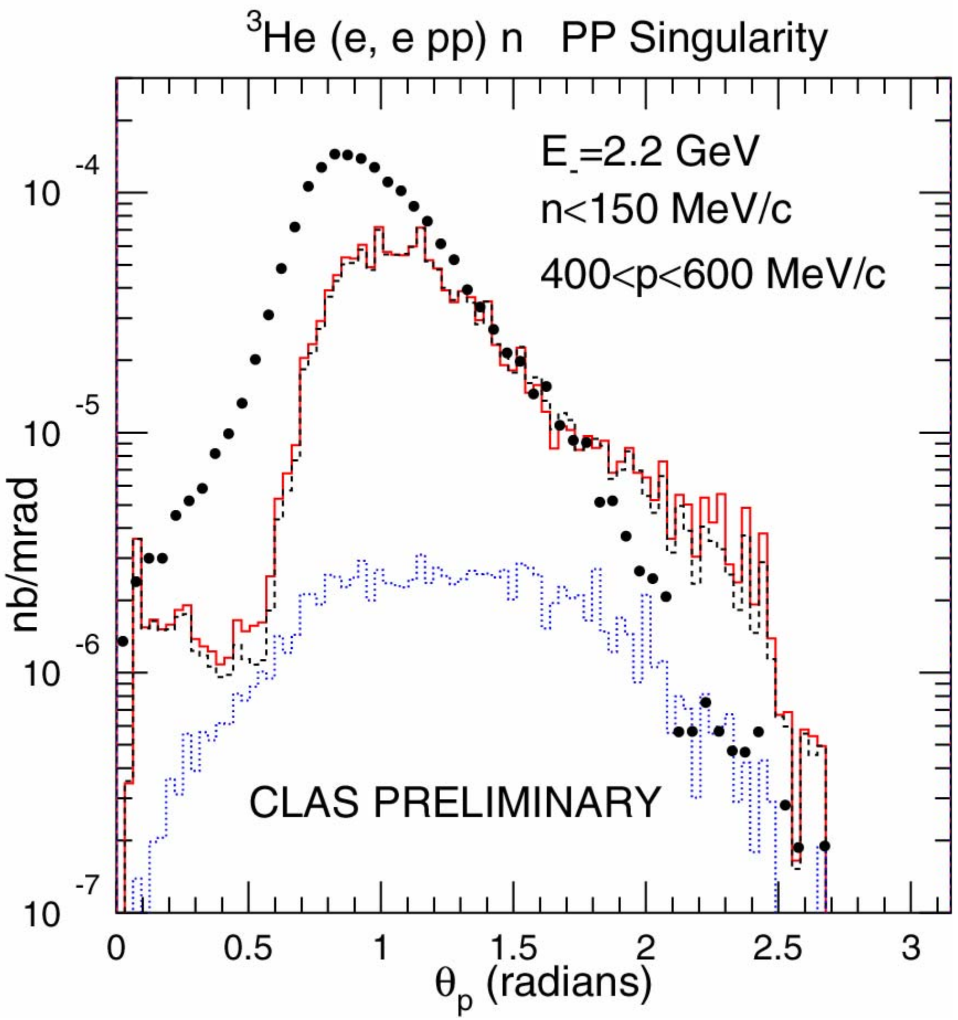
+FSI

Antisymmetry: all ppn permutations

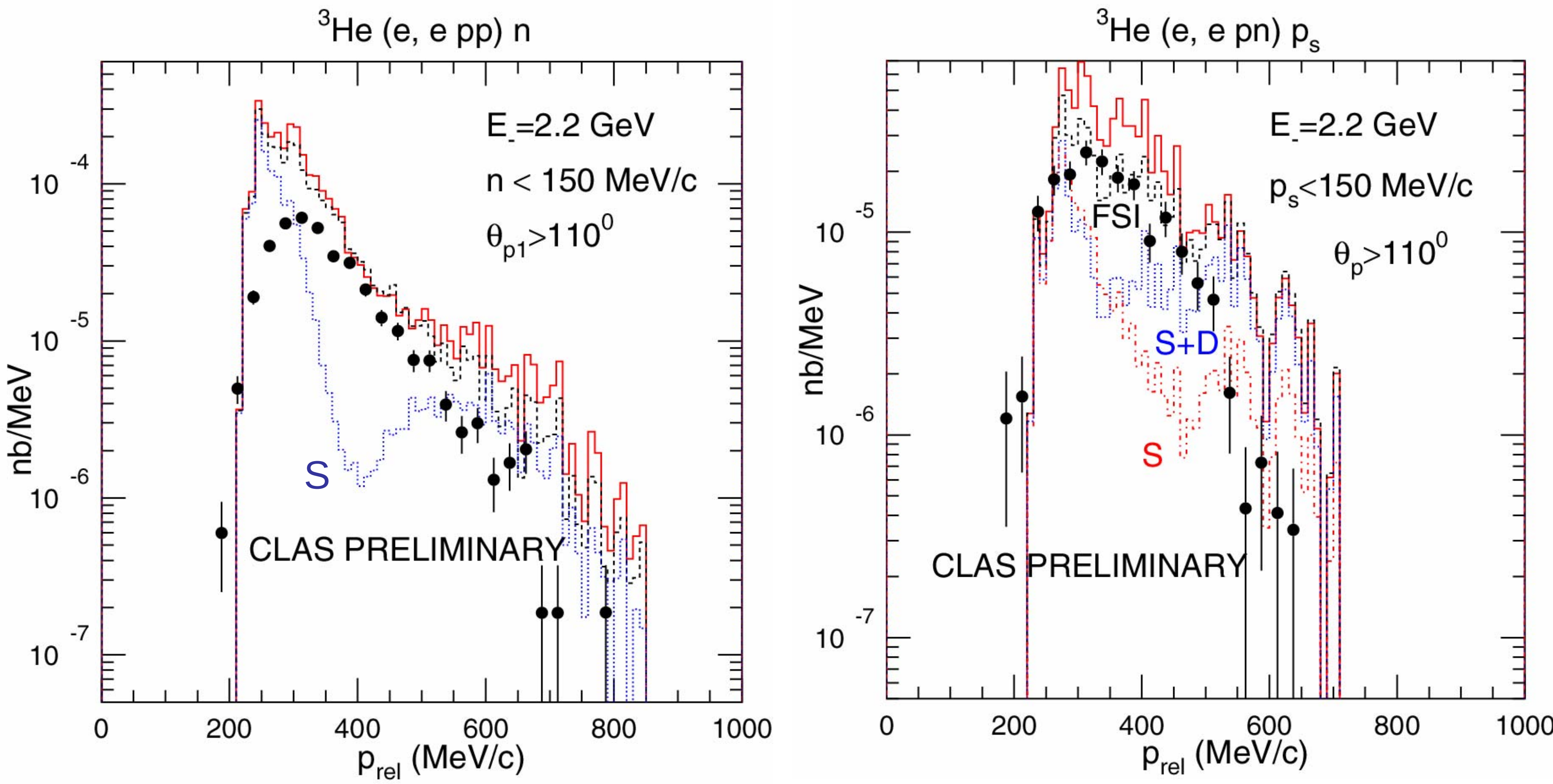
$^3He(e,e'pp)n_s$

- PP pair at rest (n_s~0)
- Strong on-shell FSI (x30!)
- Weak Δ contribution
- Data and model integrated over CLAS geometry with the same cuts
- Correlations?!

B. Zhang thesis



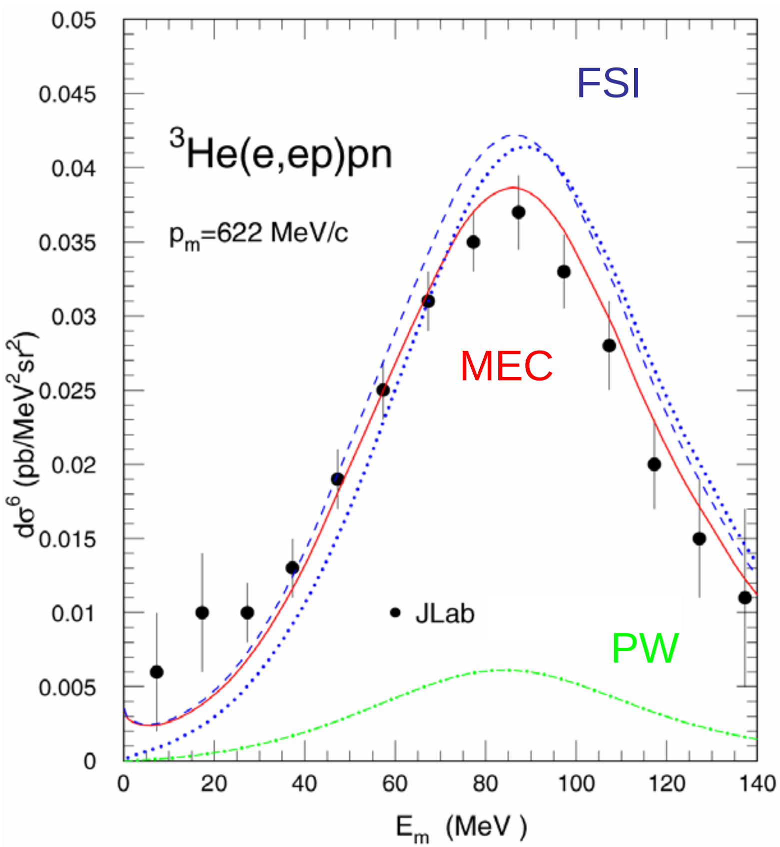
$^3He(e,e'pp)n_s$ /(e,e'pn)p_s

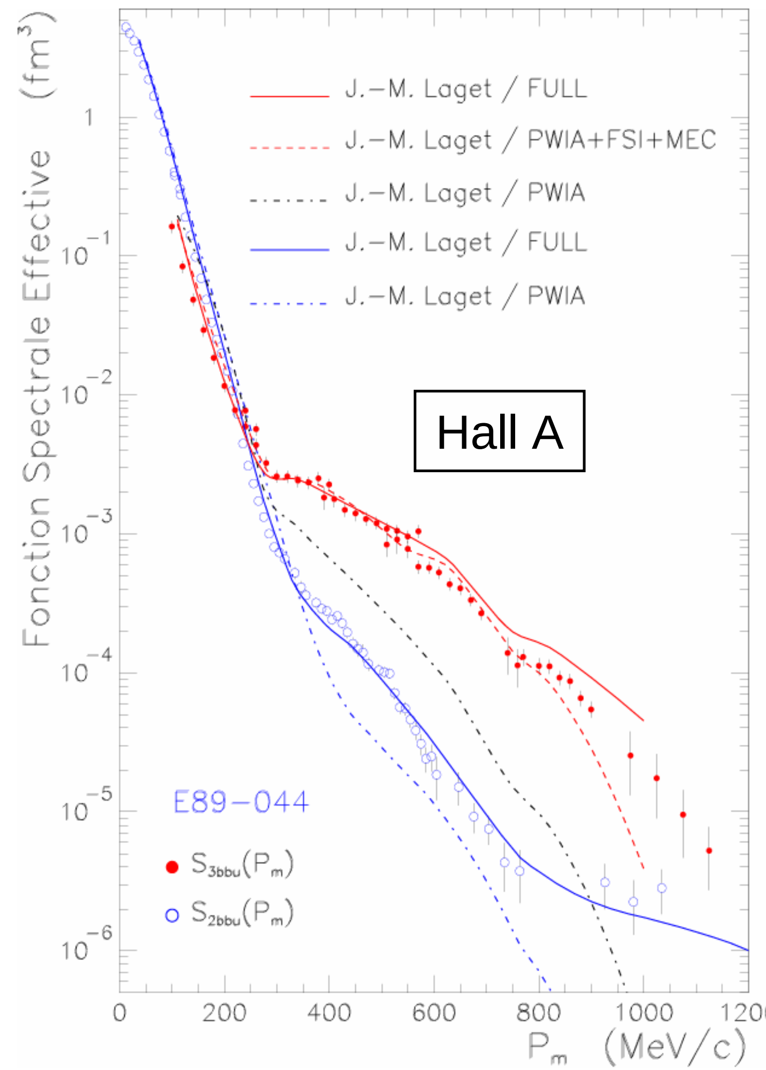


p_{rel}: relative momentum in the pair which absorbs the photon (PW)

B. Zhang thesis

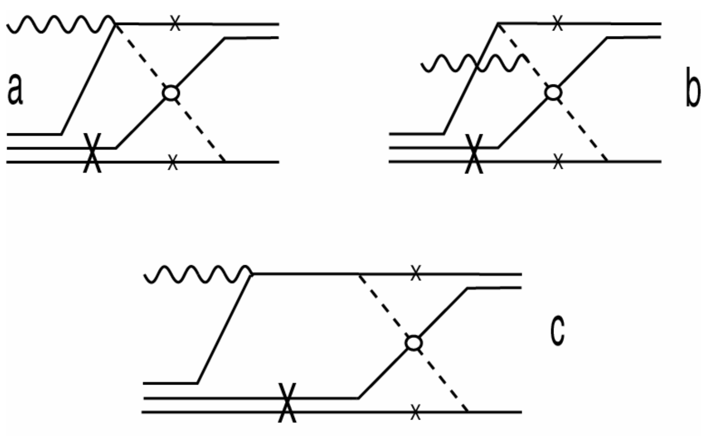
$^3He(e,e'p)np/^2H$

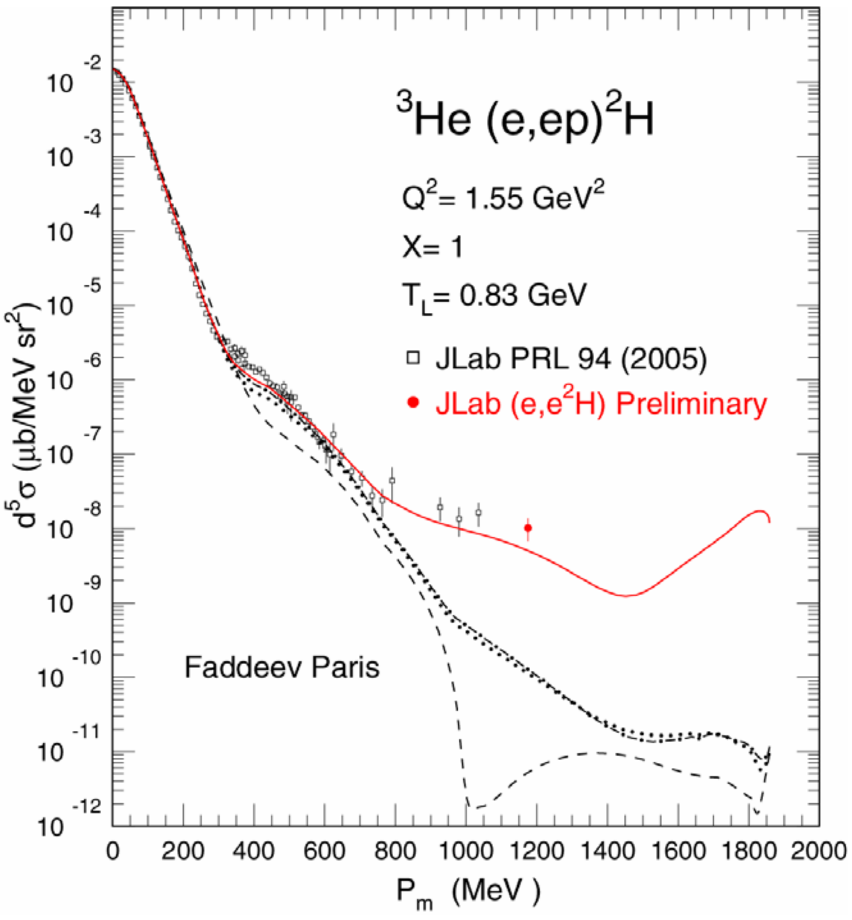




- Disintegration of a pair at rest: correlations
- FSI dominate: X=1
- Spectral functions up to 1 GeV/c !!!
- Data: PRL 94 (2005) 082305

$^3He(e,e'p)^2H$





- X=1: On-shell nucleon propagation
- 2body mechanisms dominate up to 600 MeV/c
- Above 3body mechanisms take over
- Data: PRL94(2005) 192302
- Theory: PRC72 (2005) 024001

- Glauber double scattering?

Prospects: Correlations?

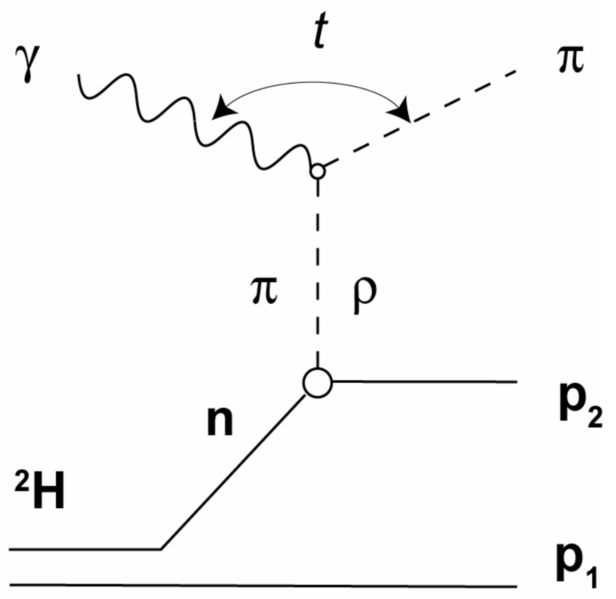
- FSI's dominate almost all the phase space
  - Unitarity!
- Much smaller for backward slower nucleon
  - $\Rightarrow$ Colinear kinematics ?
- Correlations:
  - Direct determination: hopeless
  - However, realistic w. f., that contain correlation, are needed to reproduce the data
- Rescattering: A Tool!

$\gamma^2H \rightarrow pp\pi^-$

$$\frac{d\sigma}{d\vec{p_1}[d\Omega_\pi]_{cm2}} = \frac{1}{(2\pi)^5}\frac{|\vec{\mu}_{c.m.}|m^2}{24|\vec{k}|E_1 Q_f}\sum_{\epsilon,M,m_1,m_2}\left|\sum_{i=I}^{III}\mathcal{M}_i(\vec{k},\epsilon,M,\vec{p_\pi},\vec{p_1},m_1,\vec{p_2},m_2) - \mathcal{M}_i(\vec{k},\epsilon,M,\vec{p_\pi},\vec{p_2},m_2,\vec{p_1},m_1)\right|^2$$

Quasi-free

$$\mathcal{M}_I(\vec{k},\epsilon,M,\vec{p_\pi},\vec{p_1},m_1,\vec{p_2},m_2) = i\sum_{m_n m_l m_s}\sum_{ls}(lm_l sm_s|1M)(\frac{1}{2}m_n\frac{1}{2}m_1|sm_s) u_l(|\vec{p_1}|)Y_l^{m_l}(\vec{p_1})T_{\gamma n}(\vec{p_2},m_2,-\vec{p_1},m_n)$$



If p1<<p2

$$\frac{d\sigma}{d\vec{p_1}d\Omega_\pi} = (1+\beta_1\cos\theta_1)\rho(|\vec{p_1}|)\frac{d\sigma}{d\Omega_\pi}(\gamma n \rightarrow \pi^- p)$$

Momentum distribution: Paris

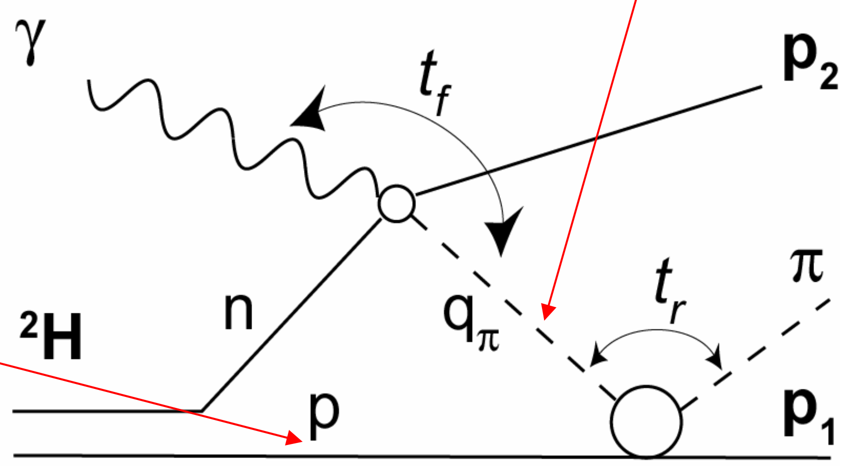
Regge (√s>2 GeV)

$\gamma^2H \rightarrow pp\pi^-$: πp rescattering

$$\mathcal{M}_{II}(\vec{k},\epsilon,M,\vec{p_\pi},\vec{p_1},m_1,\vec{p_2},m_2) = i\sum_{m_n m_p}(\frac{1}{2}m_n\frac{1}{2}m_p|1M)\int\frac{d^3\vec{p}}{(2\pi)^3}\frac{u_0(p)}{\sqrt{4\pi}}\frac{1}{q_\pi^2-m_\pi^2+i\epsilon}$$
$$\frac{m}{E_p}T_{\gamma n}(\vec{p_2},m_2,-\vec{p},m_n)T_{\pi N}(\vec{p_1},m_1,\vec{p},m_p) + D \text{ wave part}$$

$$\mathcal{M}_{II} = \mathcal{M}_{II}^{on} + \mathcal{M}_{II}^{off}$$

$$\mathcal{M}_{II}^{on} = \frac{\pi}{(2\pi)^3\sqrt{\pi}}\sum_{m_n m_p}\frac{1}{2P}(\frac{1}{2}m_n\frac{1}{2}m_p|1M)$$
$$\int_0^{2\pi}d\phi\int_{|p_{min}(p\pi)|}^{p_{max}(p\pi)}pu_0(p)dp\frac{m}{E_p}\left[T_{\gamma n}T_{\pi N}\right]_{q_\pi^2=m_\pi^2}$$
$$+D \text{ wave part}$$



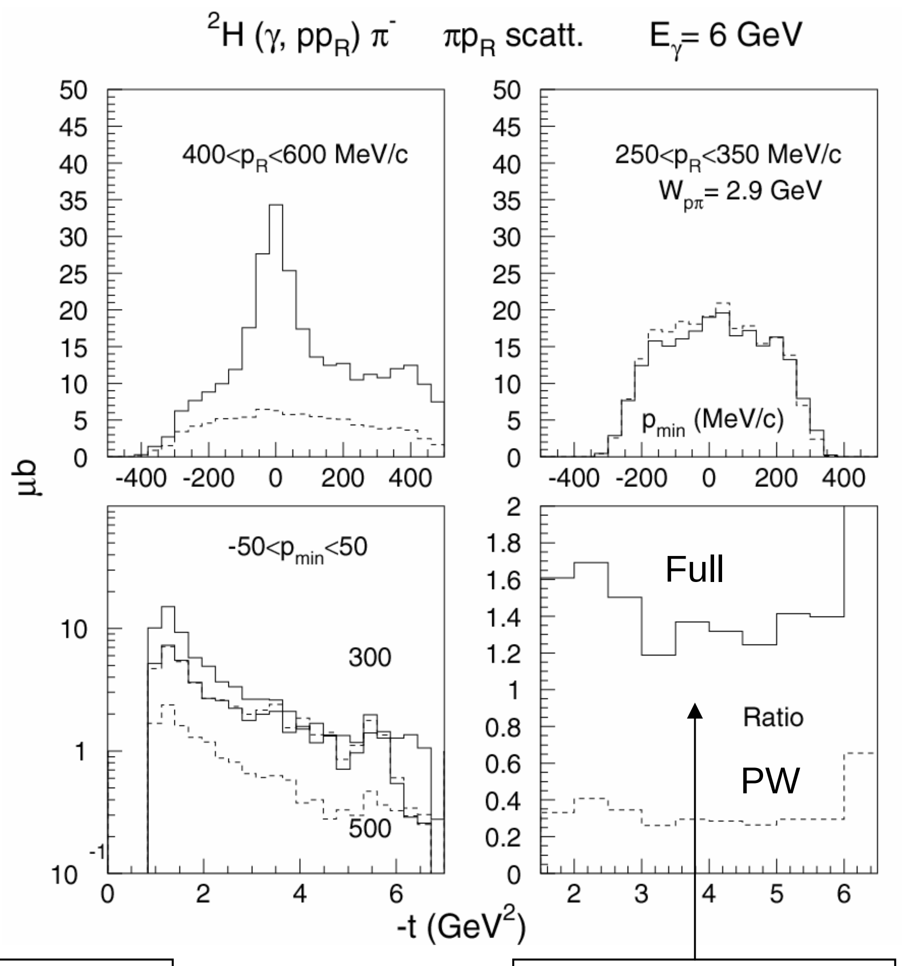
Maximum when p_{min}=0
p_{min}: minimal value of the spectator proton momentum for which π is on-shell

$$T_{\pi N} = (m_1|f(Q_s,t_r) + g(Q_s,t_r)\vec{\sigma}\cdot\vec{k}_\perp|m_p)$$

$$f(Q_s,t_r) = -\frac{Q_s p_{c.m.}}{m}(\epsilon+i)\sigma_{\pi^- p}\exp[\frac{\beta_\pi}{2}t_r]$$

$\gamma^2H \rightarrow pp\pi^-$: CLAS kinematics

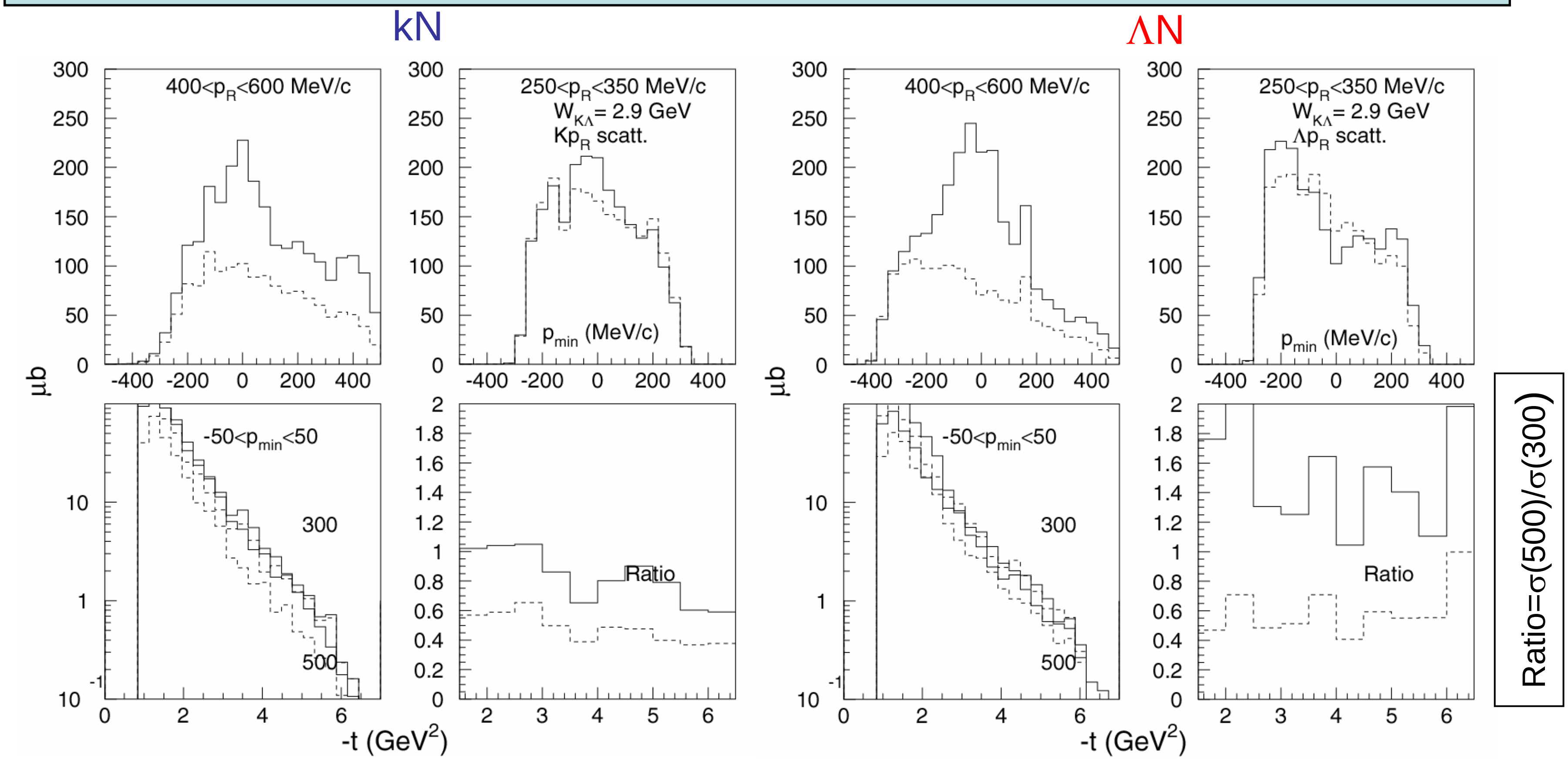
- ~2π spectrometer
- 6 sectors: $11<\theta<140^0$
- 6 blind regions (in ϕ)
- Monte Carlo
- Same (soft and hard) cuts as in experiment
- P_{min}~0
- Evolution of the peak with *t* (hard scale)
- CT?



6 to 12 GeV

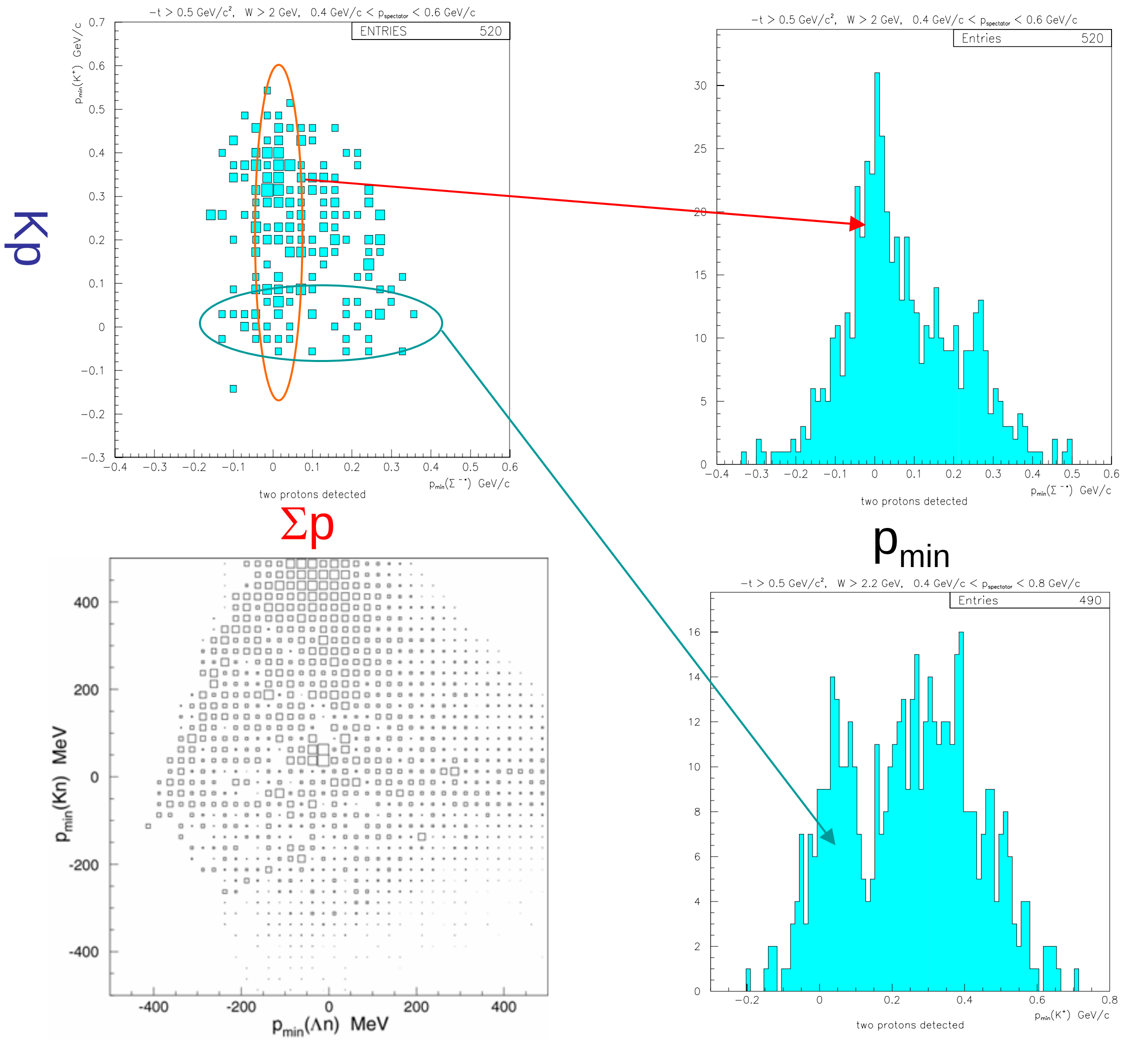
Ratio=σ(500)/σ(300)

Strange sector



- Last chance to see CT
- Determine K^+N cross section (pentaquarks?)
- Determine YN cross section

Strange sector: CLAS



P. Nadel-Turonski
R. Davis
(APS Poster)

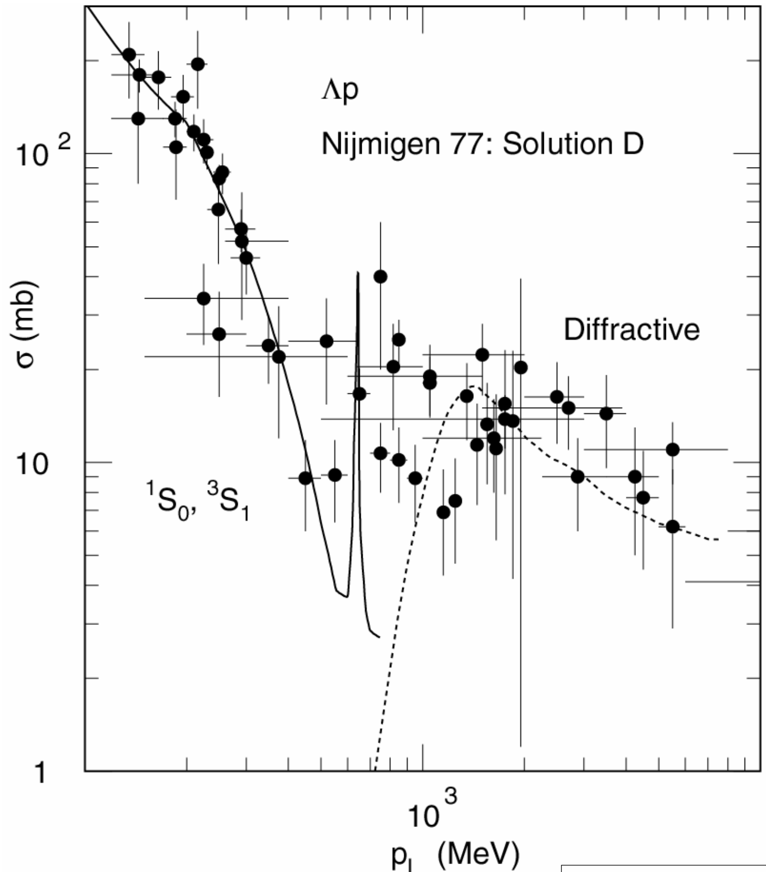
$\gamma^2H \rightarrow K^+ p \Sigma^-(1385)$

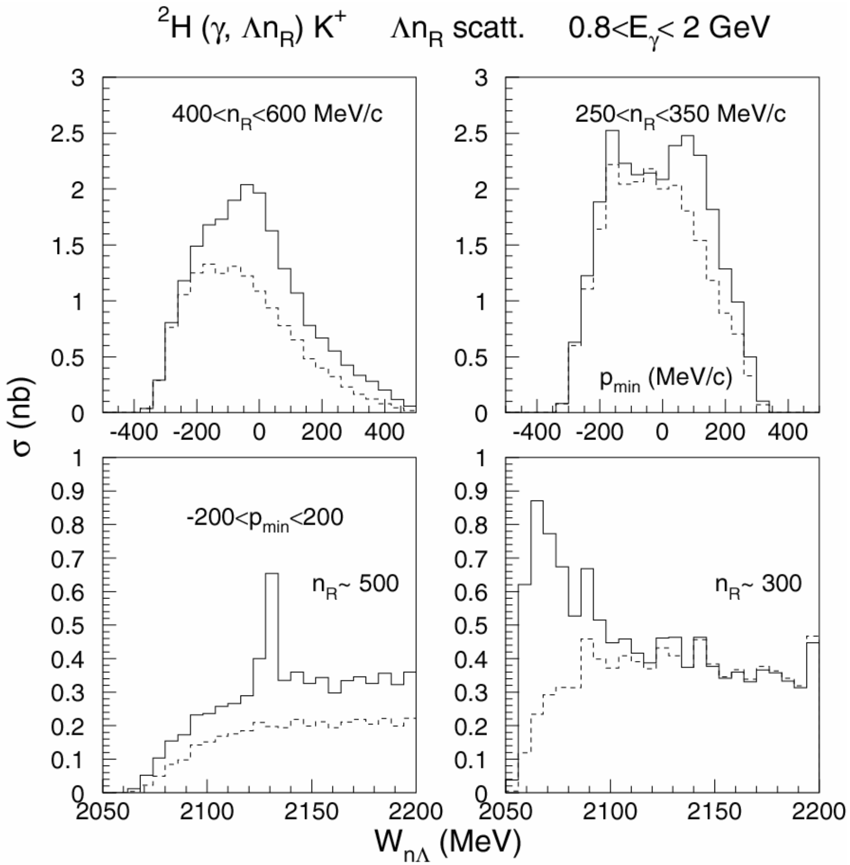
g10
W(KΣ)>2 GeV

Statistics!
Acceptance?
Cuts?

→ 6 – 12 GeV

Strange sector: ΛN Interaction



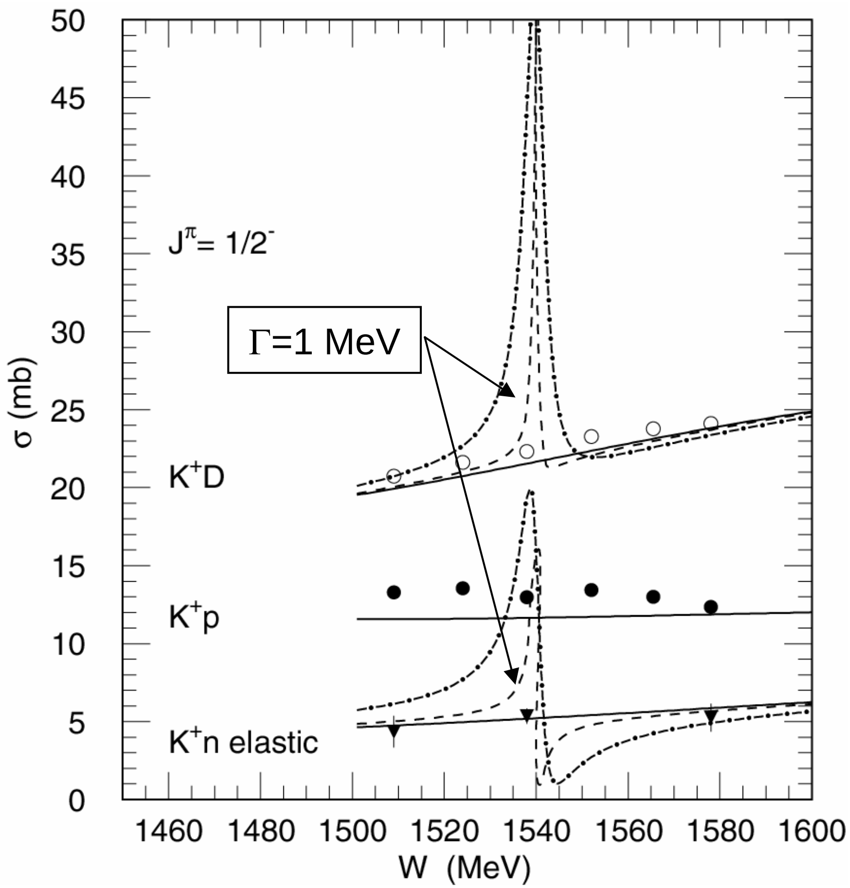


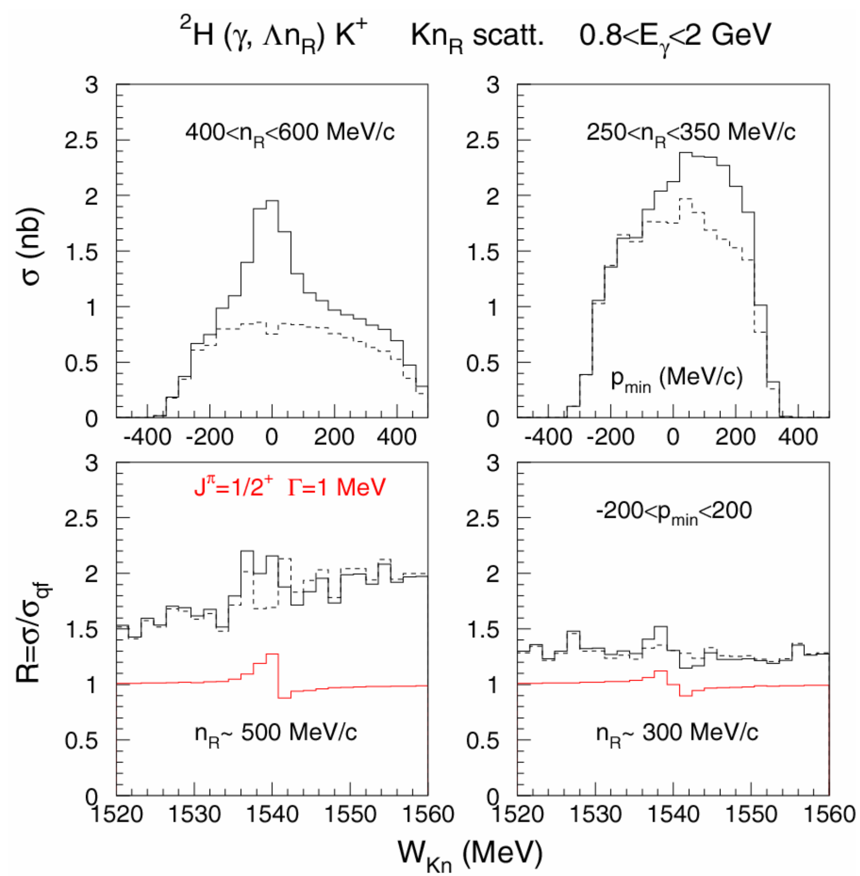
Cusp at the Σ threshold?
High Energy Diffractive Scattering

Prospects: Mesons

- $^2H(\gamma,p\pi^-)p$:
  - Low *t*: test case ($\sigma[\pi p]$ and $\sigma[pp]$ well known)
  - High *t*: CT?
- Strange sector:
  - CT (Strange quark, $\sigma[KN]$ well known)
  - YN interaction
- Vector mesons: ρN, φN scattering
- Cascade?
- Look for signals in the data base (g10, eg3,…)
- Monte Carlo the theory in the actual CLAS acceptance
- 12 GeV

Strange sector: Pentaquark





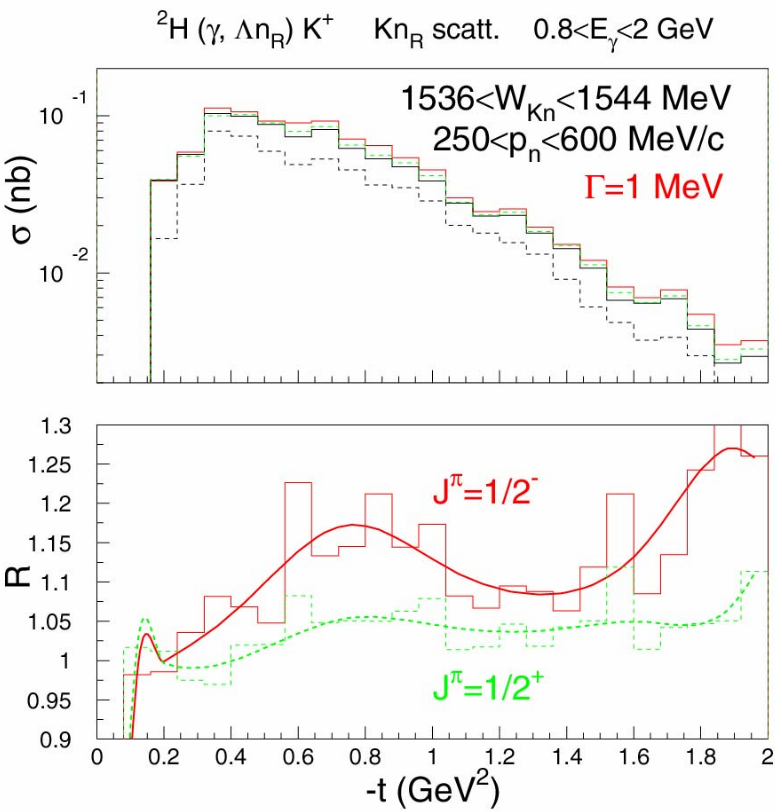
Unlikely to see a narrow state in KN scattering sector

Strange sector: Pentaquark

- Stringent upper limit on the width
- Actual CLAS acceptance
- Free parameters: Mass and Width only

$$f^0 = -\frac{2M_R g_R^2}{Q_s^2 - M_R^2 + iM_R\Gamma}\frac{E_n + m}{2m} - \frac{4\pi Q_s}{m}\frac{e^{i\delta}\cos\delta}{p_k}$$

$$\frac{g_R^2}{4\pi} = \frac{M_R\Gamma}{[p_k(E_n + m)]_{c.m.}}$$



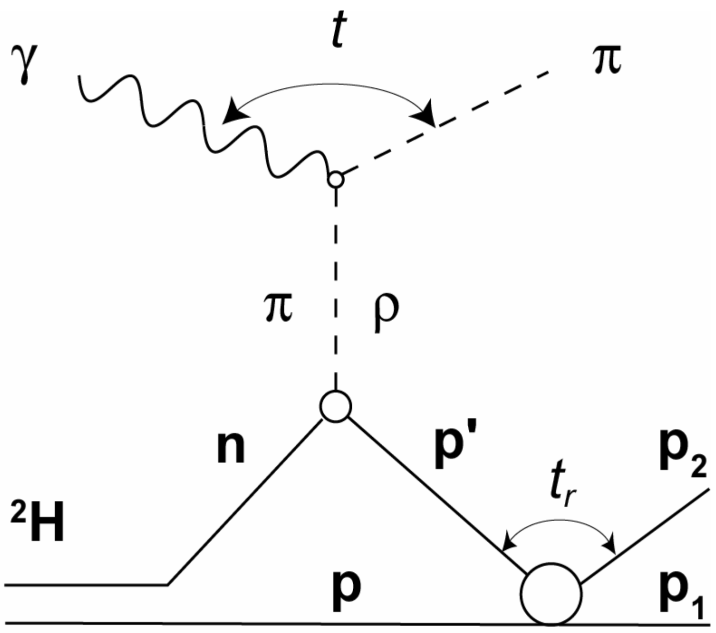
$\gamma^2H \rightarrow pp\pi^-$: pp rescattering

$$\mathcal{M}_{III}(\vec{k},\epsilon,M,\vec{p_\pi},\vec{p_1},m_1,\vec{p_2},m_2) = i \sum_{m_n m_p m'_p} (\frac{1}{2}m_n\frac{1}{2}m_p|1M) \int \frac{d^3\vec{p}}{(2\pi)^3} \frac{u_0(p)}{\sqrt{4\pi}} \frac{1}{p^{o\prime} - E'_p + i\epsilon}$$
$$\frac{m}{E_p} T_{\gamma n}(\vec{p'}, m'_p, -\vec{p}, m_n) T_{pp}(\vec{p_2}, m_2, \vec{p_1}, m_1, \vec{p'}, m'_p, \vec{p}, m_p) + D \text{ wave part}$$

$$\mathcal{M}_{III} = \mathcal{M}^{on}_{III} + \mathcal{M}^{off}_{III}$$

$$T_{pp} = (m_2 m_1|\alpha + i\gamma(\vec{\sigma_1} + \vec{\sigma_2}) \cdot \vec{k}_\perp + \text{spin} - \text{spin terms}\, |m'_p m_p)$$

$$\alpha = -\frac{W p_{cm}}{2m^2}(\epsilon + i)\, \sigma_{NN}\, \exp[\frac{\beta_N}{2} t_r]$$



σ_{NN} : experimental total cross section

β_N : fit forward angular distribution

Maximum when $p_{min}=0 \Rightarrow$ spectator nucleon at rest