The Diagrammatic Method

Well suited near S-matrix singularities

Momentum space calculations

Meson photo-production sectors

^{2}H Electro-disintegration

^{3}He Electro-disintegration channels

Low energies: Phys. Rep. 69 (1981)1

High energies: Phys. Lett. B609 (2005) 49 & nucl-th/0507035

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

$$\frac{d\sigma}{d\vec{p_1}[d\Omega_\pi]_{cm2}} = \frac{1}{(2\pi)^5}\frac{|\vec{\mu}_{c.m.}|m^2}{24|\vec{k}|E_1Q_f}\sum_{\epsilon,M,m_1,m_2}\left|\sum_{i=I}^{III}\mathcal{M}_i(\vec{k},\epsilon,M,\vec{p_\pi},\vec{p_1},m_1,\vec{p_2},m_2)\right.$$
$$\left. -\mathcal{M}_i(\vec{k},\epsilon,M,\vec{p_\pi},\vec{p_2},m_2,\vec{p_1},m_1)\right|^2$$

Quasi-free

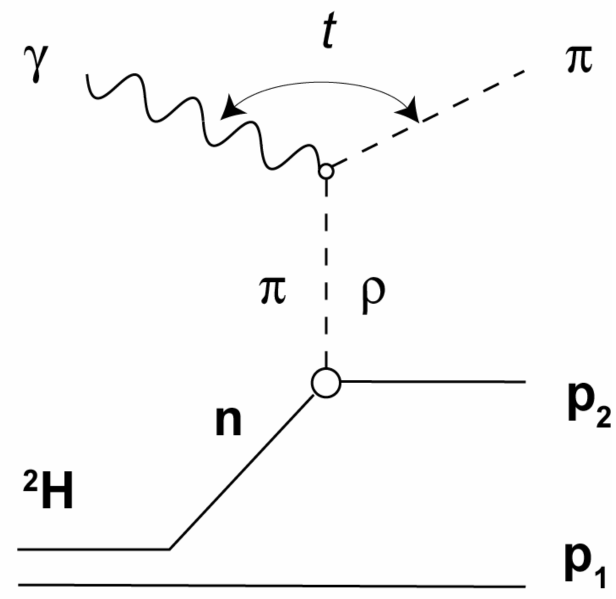
$$\mathcal{M}_I(\vec{k},\epsilon,M,\vec{p_\pi},\vec{p_1},m_1,\vec{p_2},m_2) =$$
$$i\sum_{m_n m_l m_s}\sum_{ls}(lm_l sm_s|1M)(\frac{1}{2}m_n\frac{1}{2}m_1|sm_s)$$
$$u_l(|\vec{p_1}|)Y_l^{m_l}(\vec{p_1})T_{\gamma n}(\vec{p_2},m_2,-\vec{p_1},m_n)$$

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)

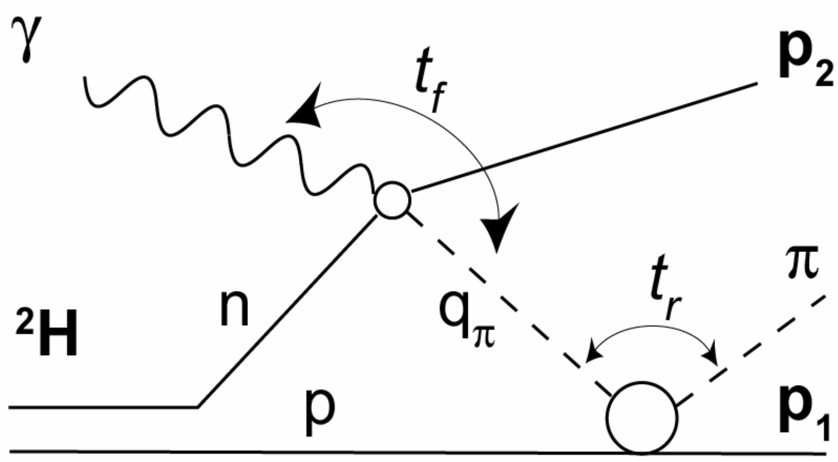


$\gamma^2H \rightarrow pp\pi^-$: πp rescattering

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

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

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



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

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

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

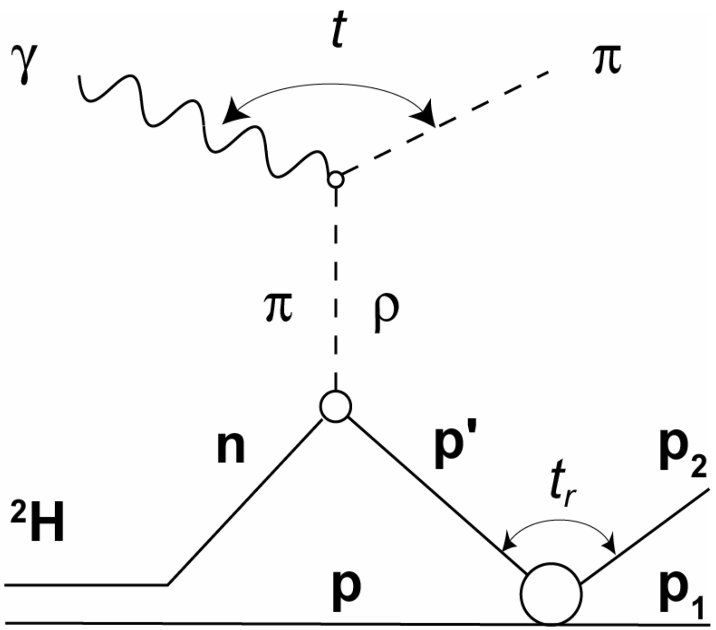
$\gamma^2H \to pp\pi^-$: pp rescattering

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

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

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

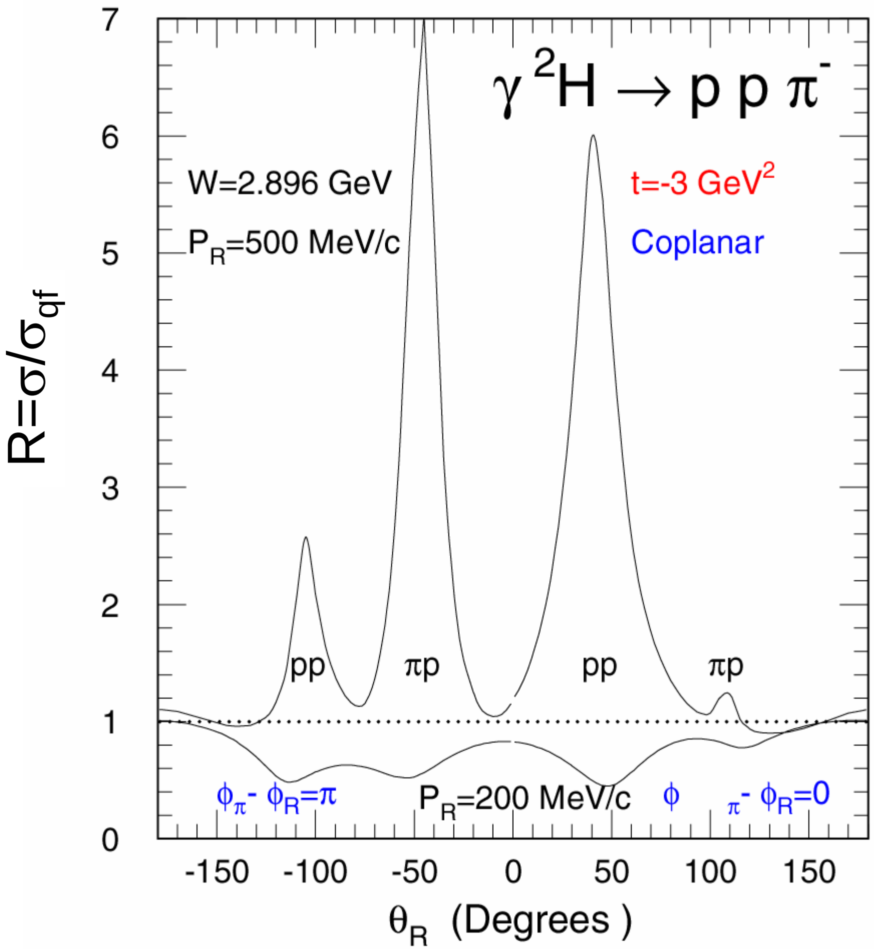
$$\alpha = -\frac{W p_{cm}}{2m^2}(\epsilon + i)\,\sigma_{NN}\,\exp[\frac{\beta_N}{2}t_r]$$

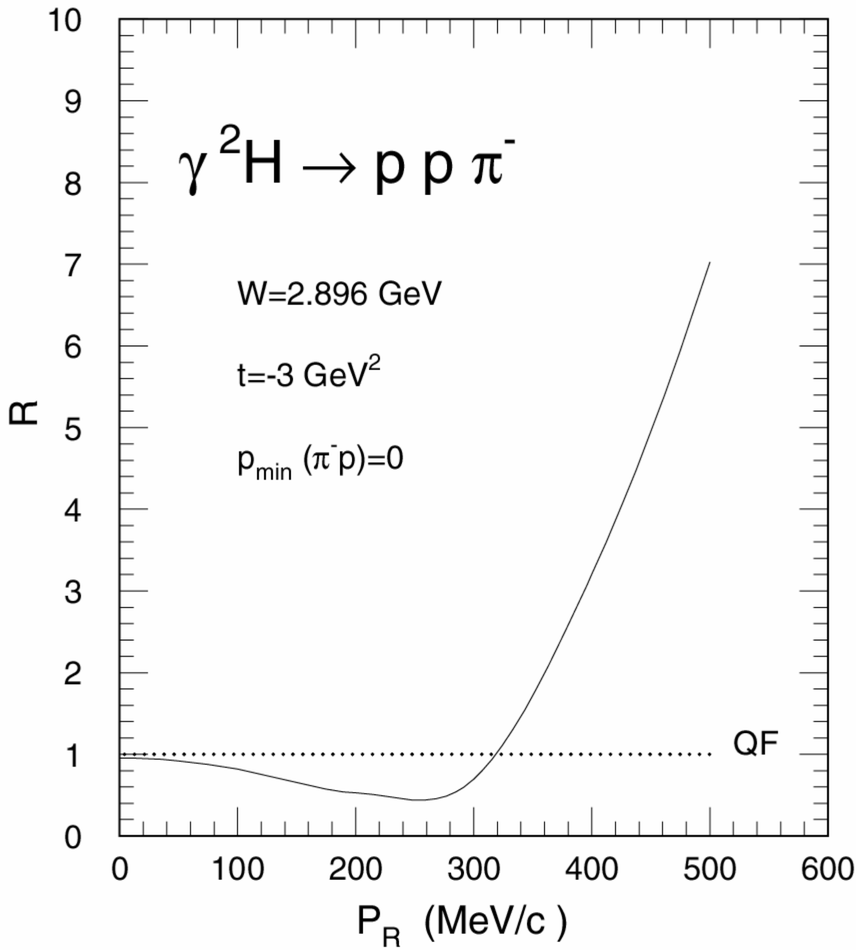


σ_{NN} : experimental total cross section
β_N : fit forward angular distribution

Maximum when p_{min}=0 ⇒ spectator nucleon at rest

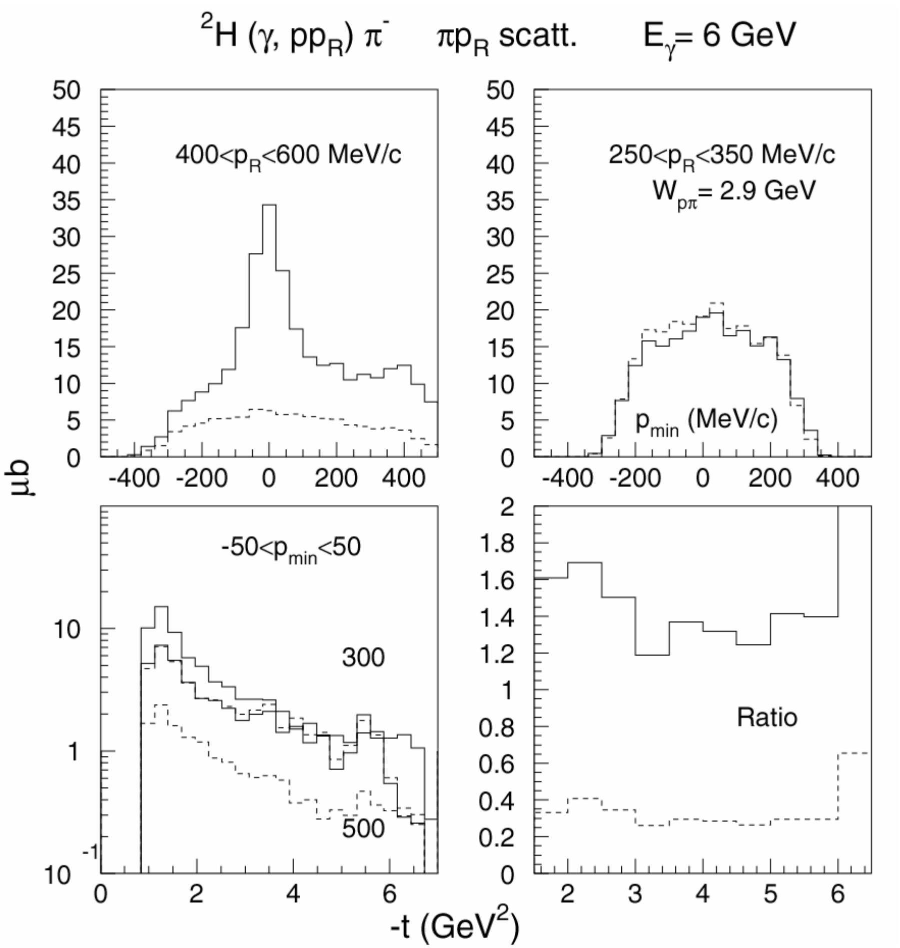
$\gamma^2H \rightarrow pp\pi^-$: coplanar kinematics





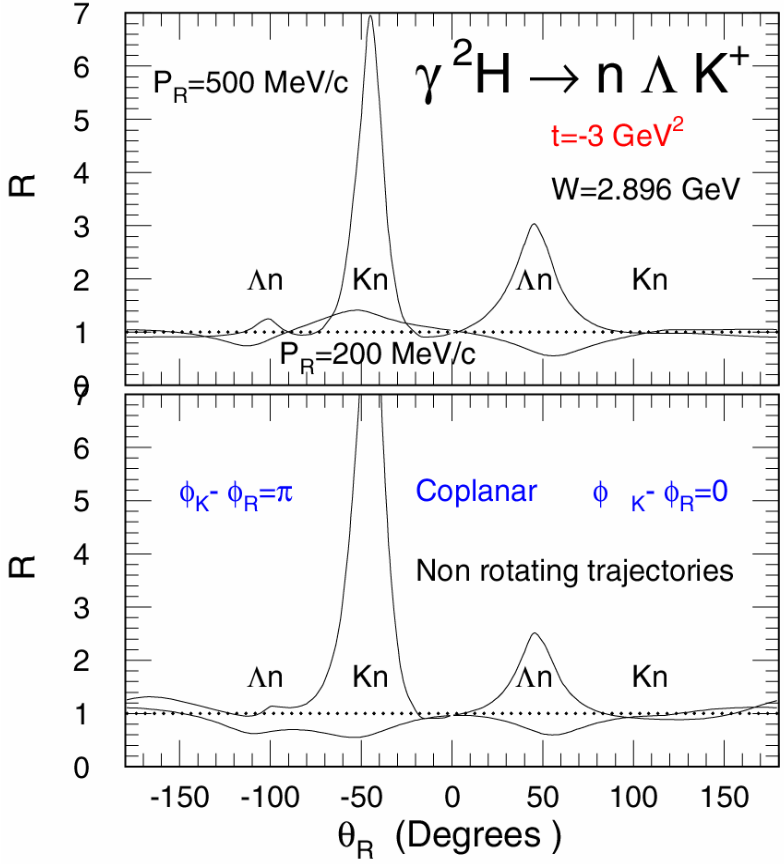
$\gamma^2H \rightarrow pp\pi^-$: CLAS kinematics

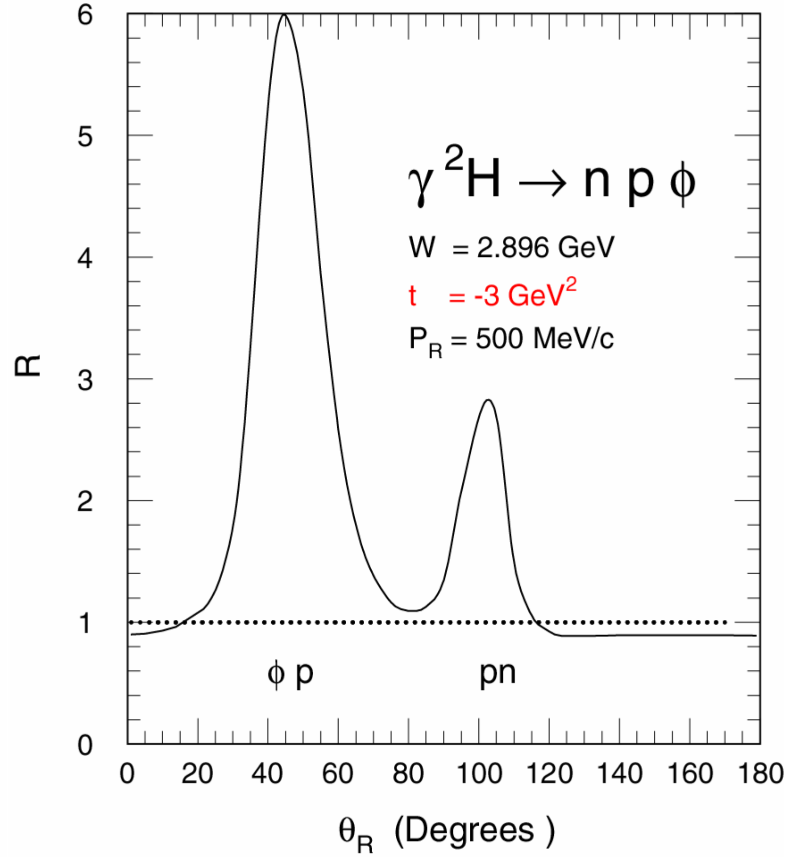
- $\sim 2\pi$ spectrometer
- 6 sectors: $11 < \theta < 140^0$
- 6 blind regions (in ϕ)
- Monte Carlo
- Same (soft and hard) cuts as in experiment
- $P_{min} \sim 0$
- Evolution of the peak with t (hard scale)
- CT?



6 to 12 GeV

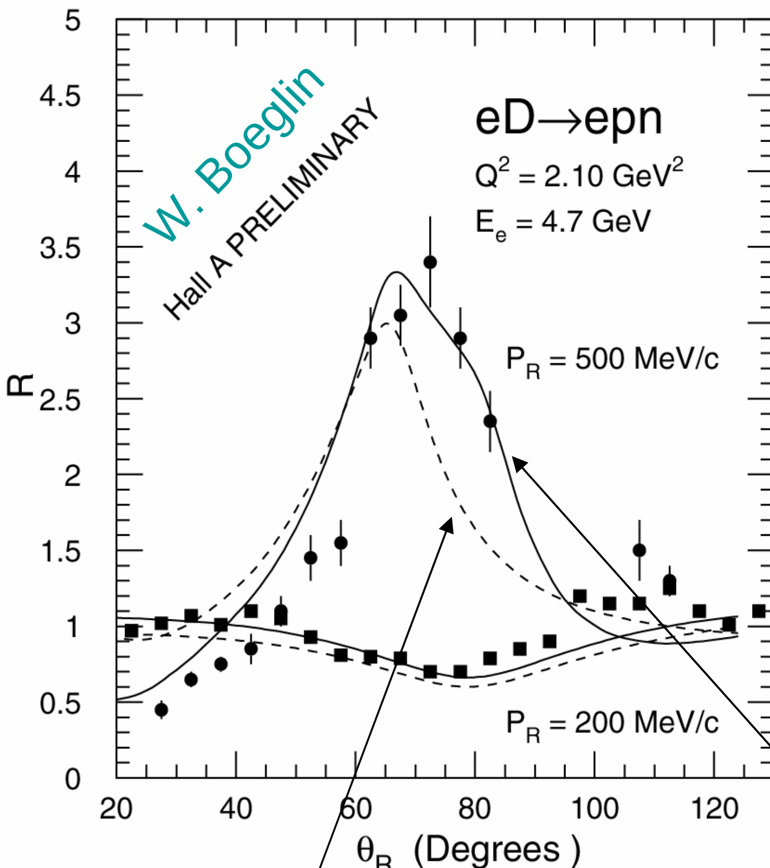
Strange sector

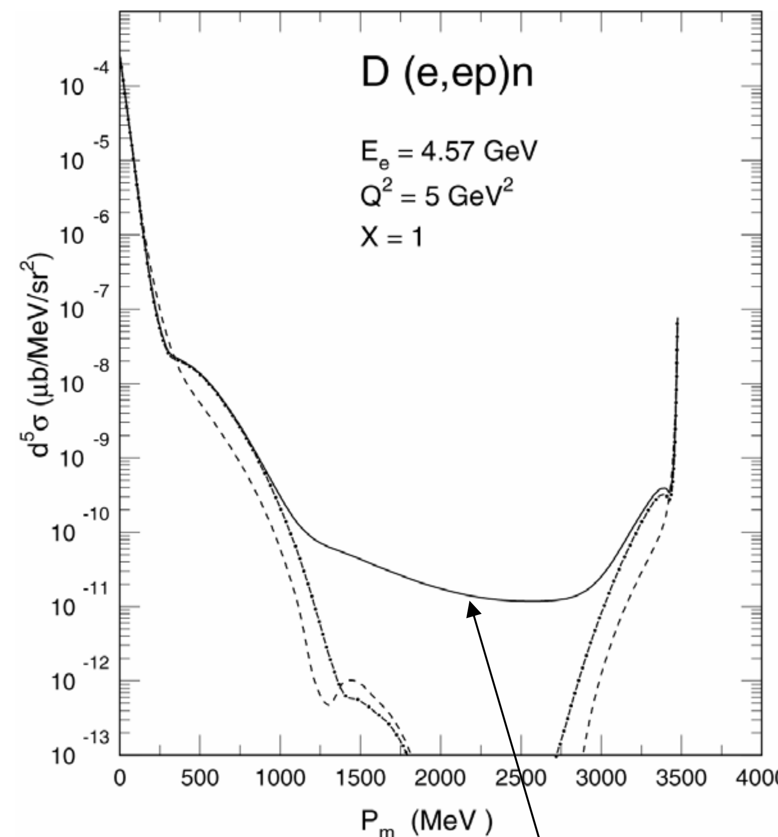




- Last chance to see CT
- Determine K^+N cross section (pentaquarks?)
- Determine ϕ,J/ψN cross sections (QGP)

D(e,e'p)n coplanar kinematics



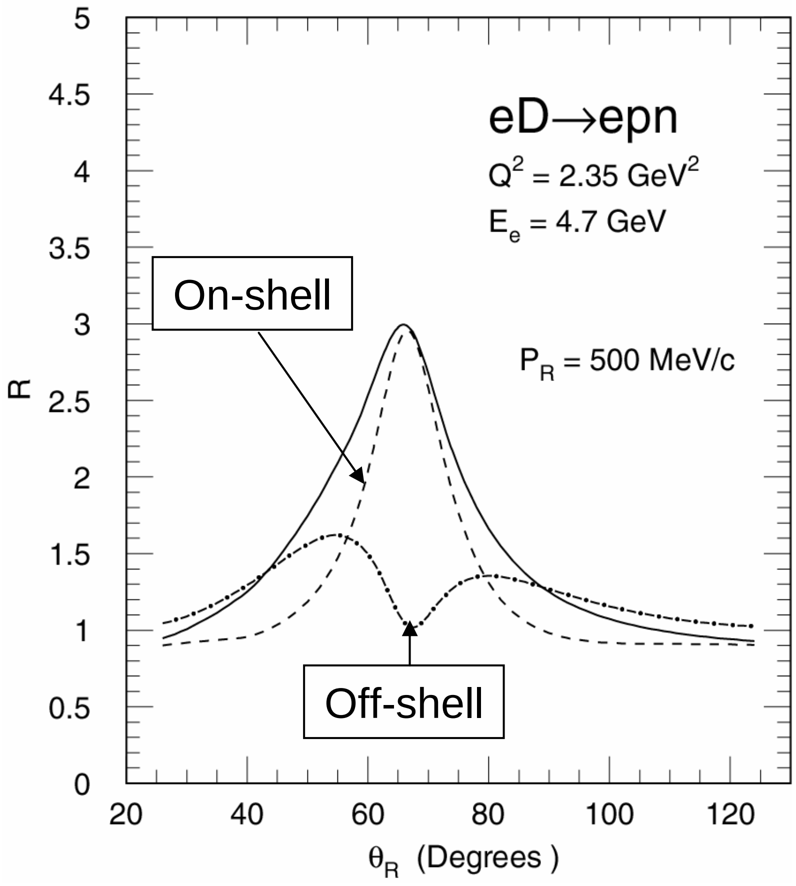


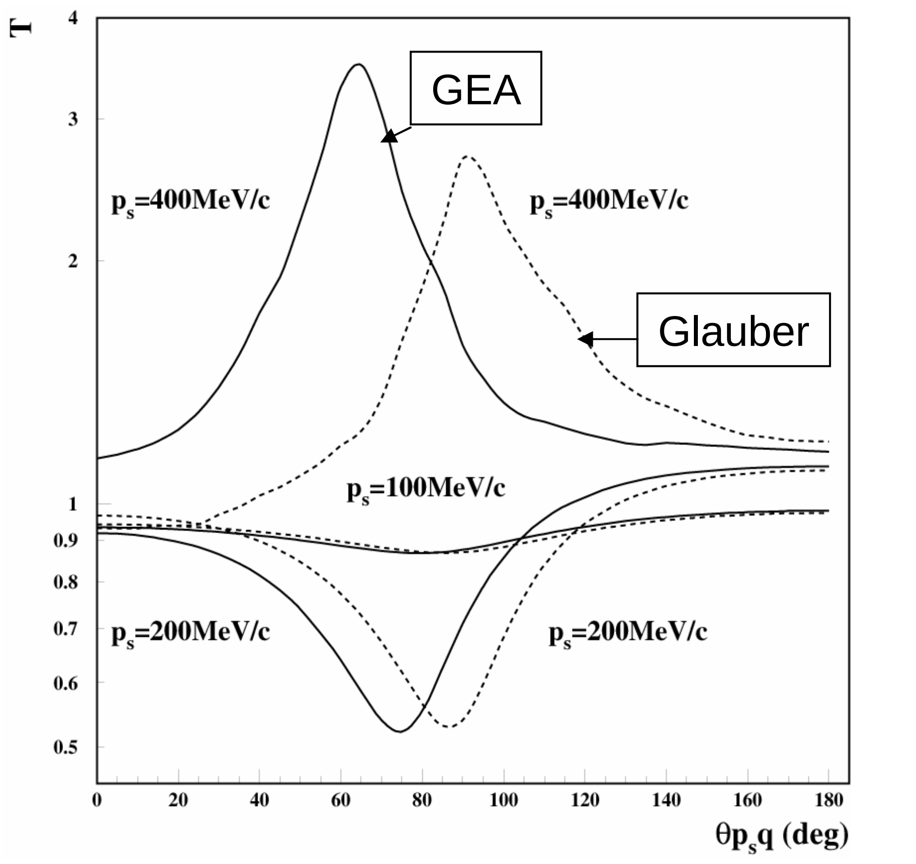
NP scattering

Full Relativistic EM current

- On-shell ΔN→NP scattering
- Spectator nucleon at rest

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



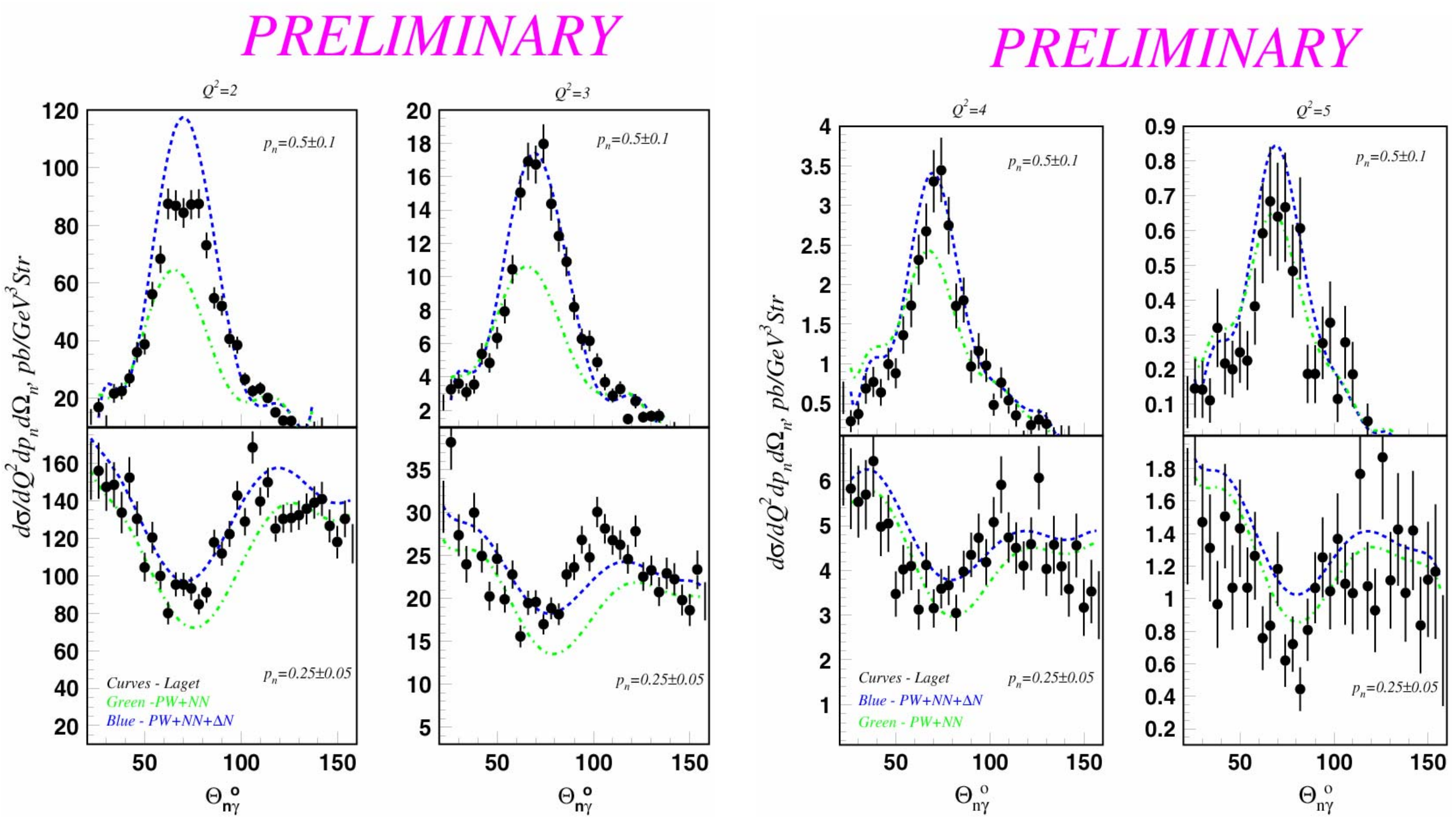


Principal (off-shell) part vanishes at X=1

Frankfurt, Sargsian, Strikman, PRC56 (1996) 1124

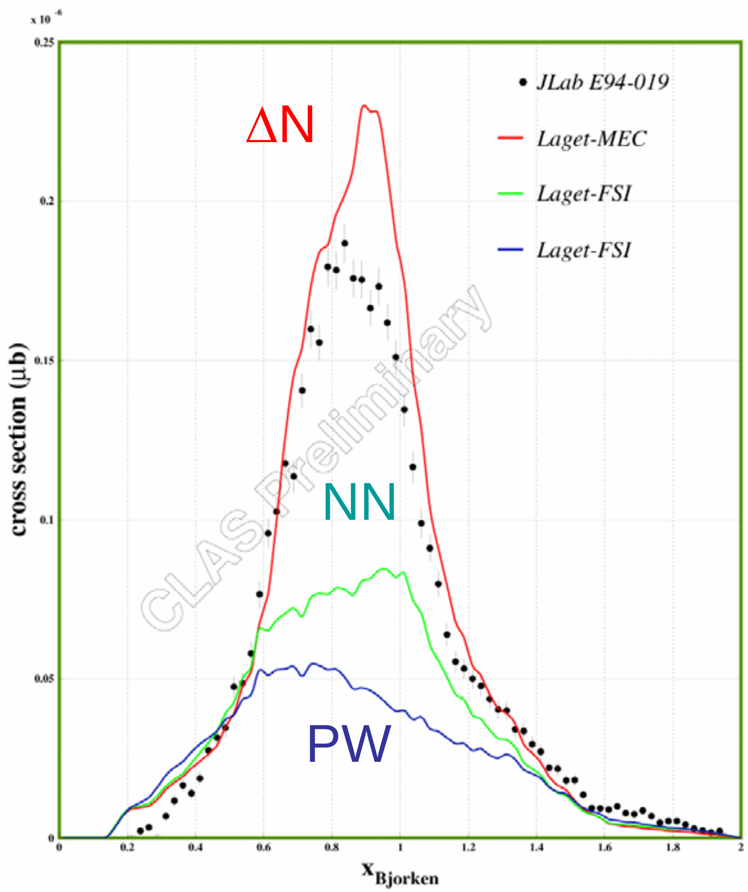
Full angular dependency inside the integral mandatory!!

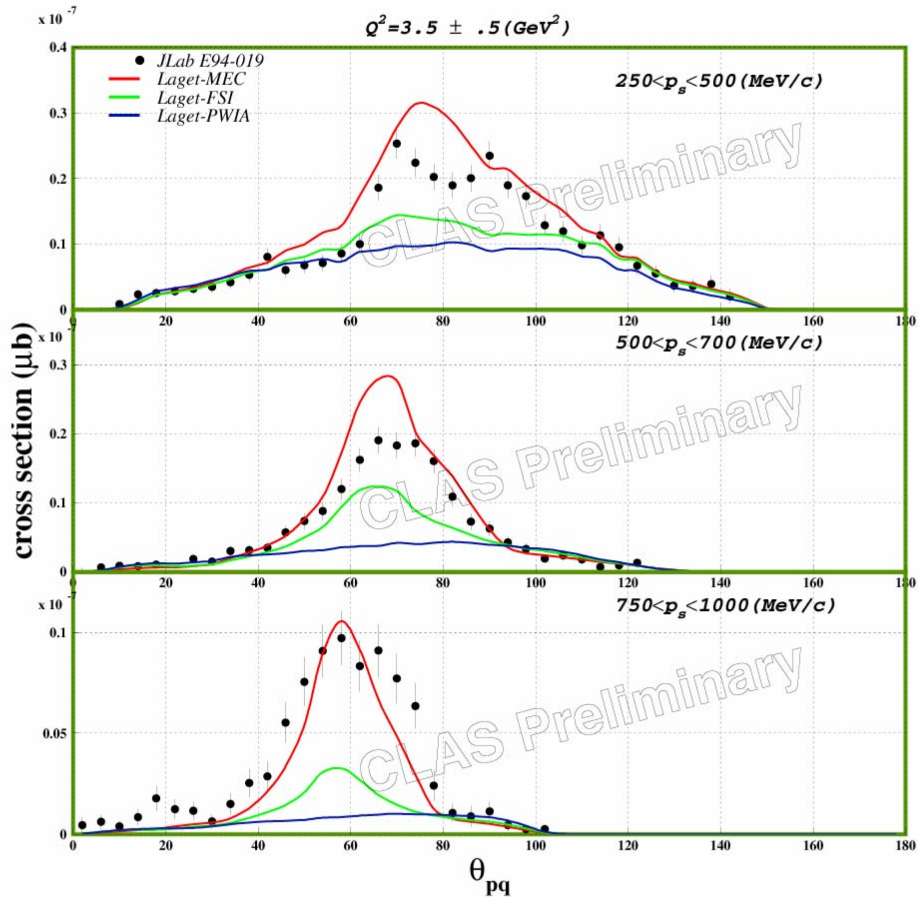
D(e,e'p)n CLAS kinematics



K. Egiyan

D(e,e'n)p CLAS kinematics



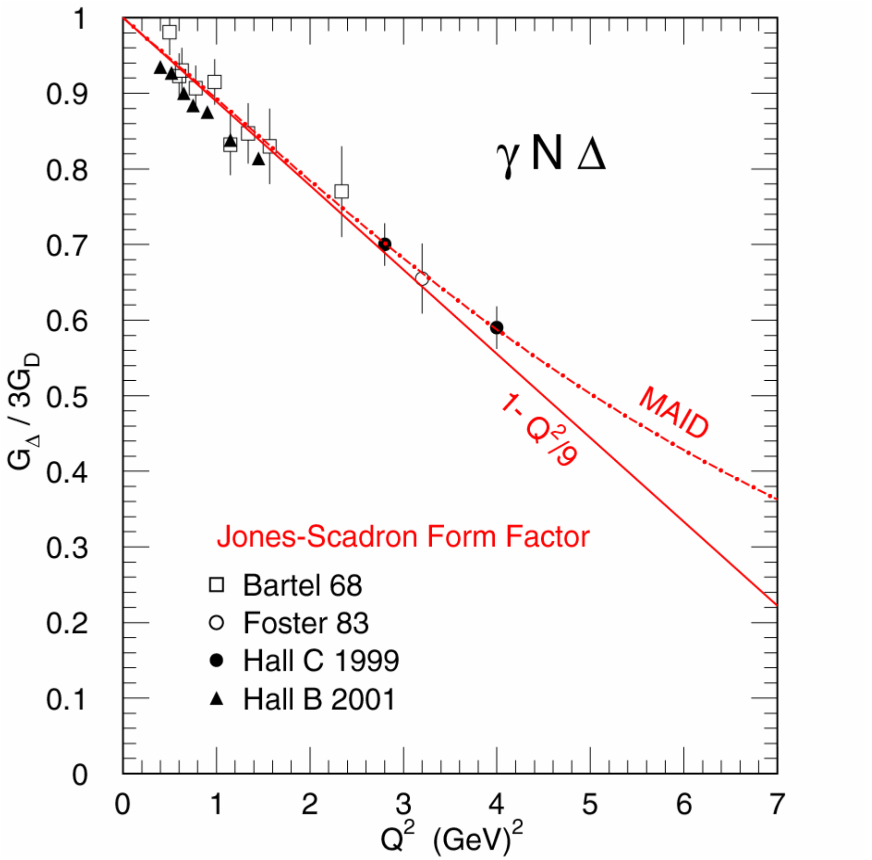


- $X_N=1$
- $X_\Delta=1/(1+(m_\Delta^2-m^2)/Q^2) \sim 0.85$

C. Butuceanu thesis

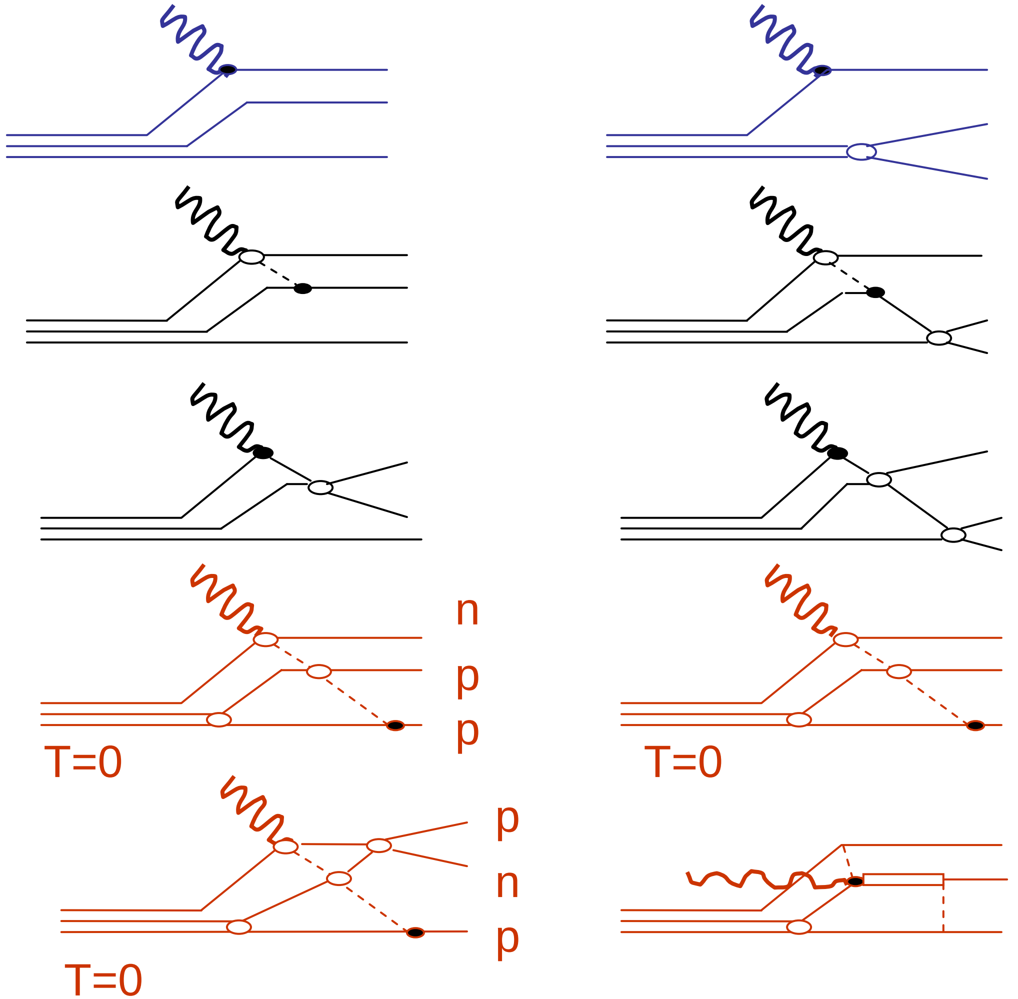
ΔN transition amplitude

- π + ρ exchange
- Calibrated against γD→pn channel
- Relativistic γN→Nπ amplitude
- Latest γNΔ EM Form Factor
- Room for fine tuning



^{3}He 3 Body Disintegration

Ground State Faddeev WF (Paris potential)



1Body

2 Body

3 Body

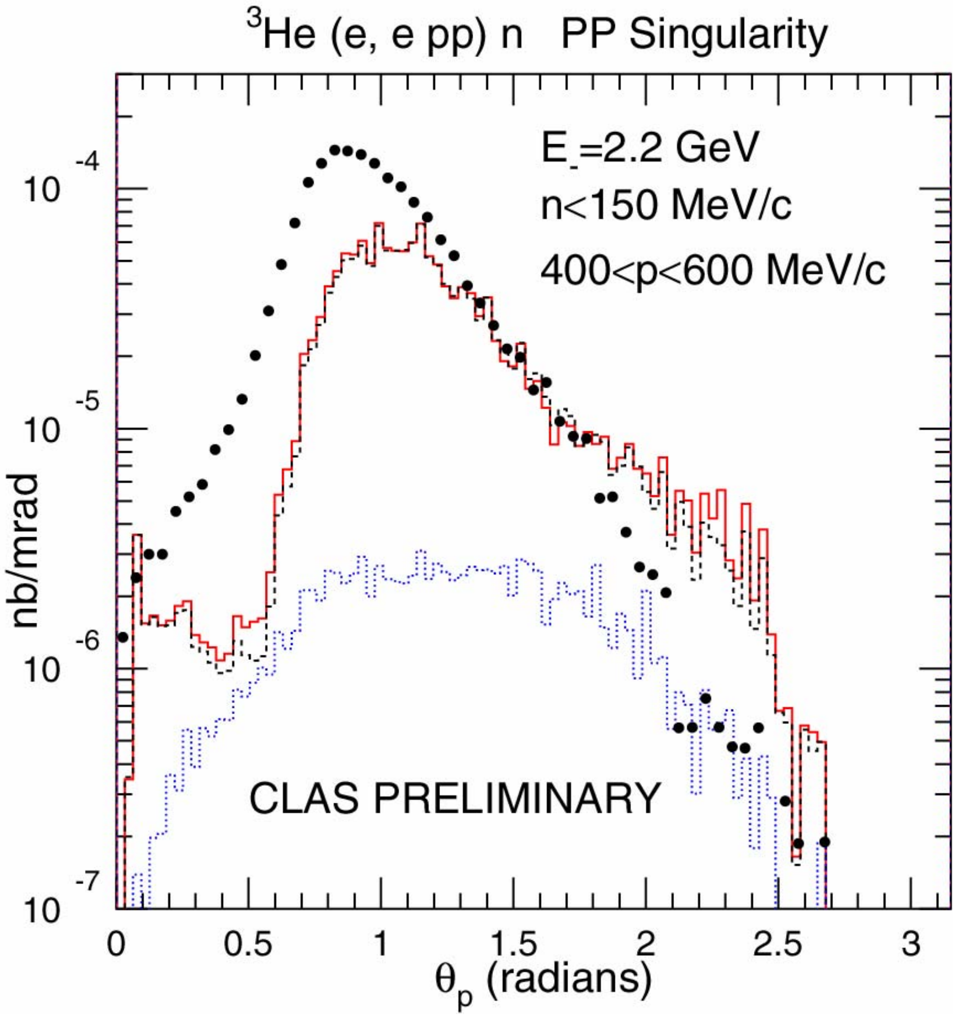
+FSI

Antisymmetry: all ppn permutations

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

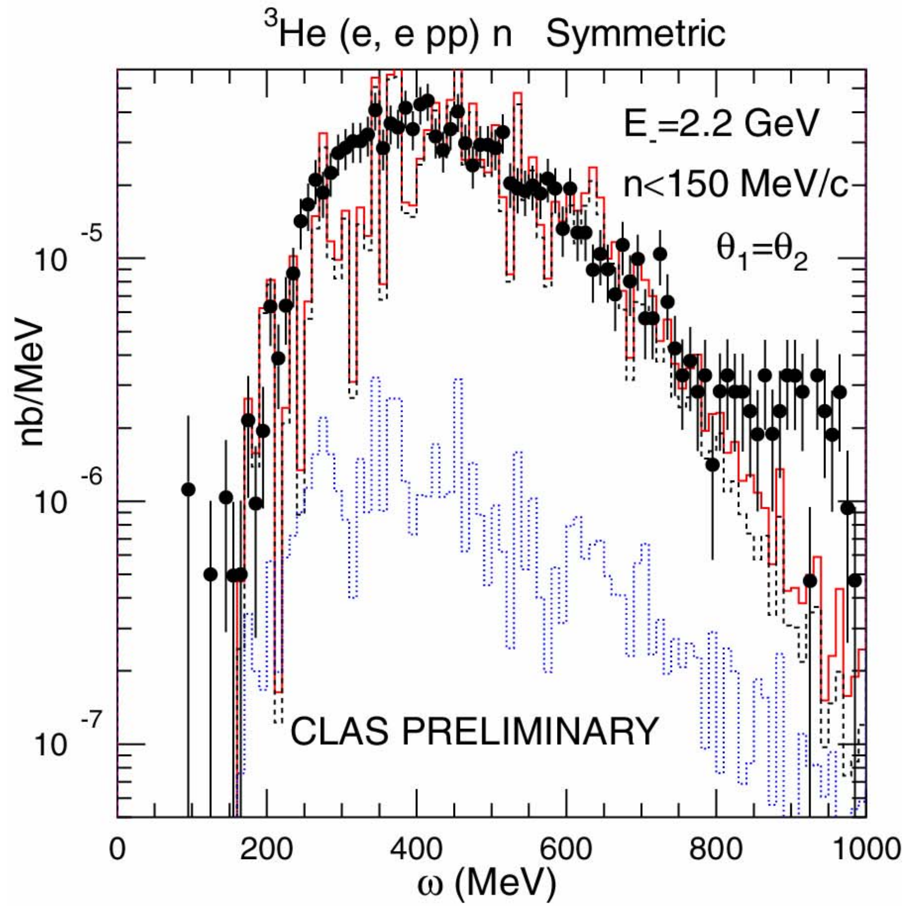
- PP pair at rest (n_s~0)
- Strong on-shell FSI (x30!)
- Weak Δ contribution
- Data and model integrated over CLAS geometry with the same cuts
- Data to be corrected for detection efficiency

B. Zhang thesis



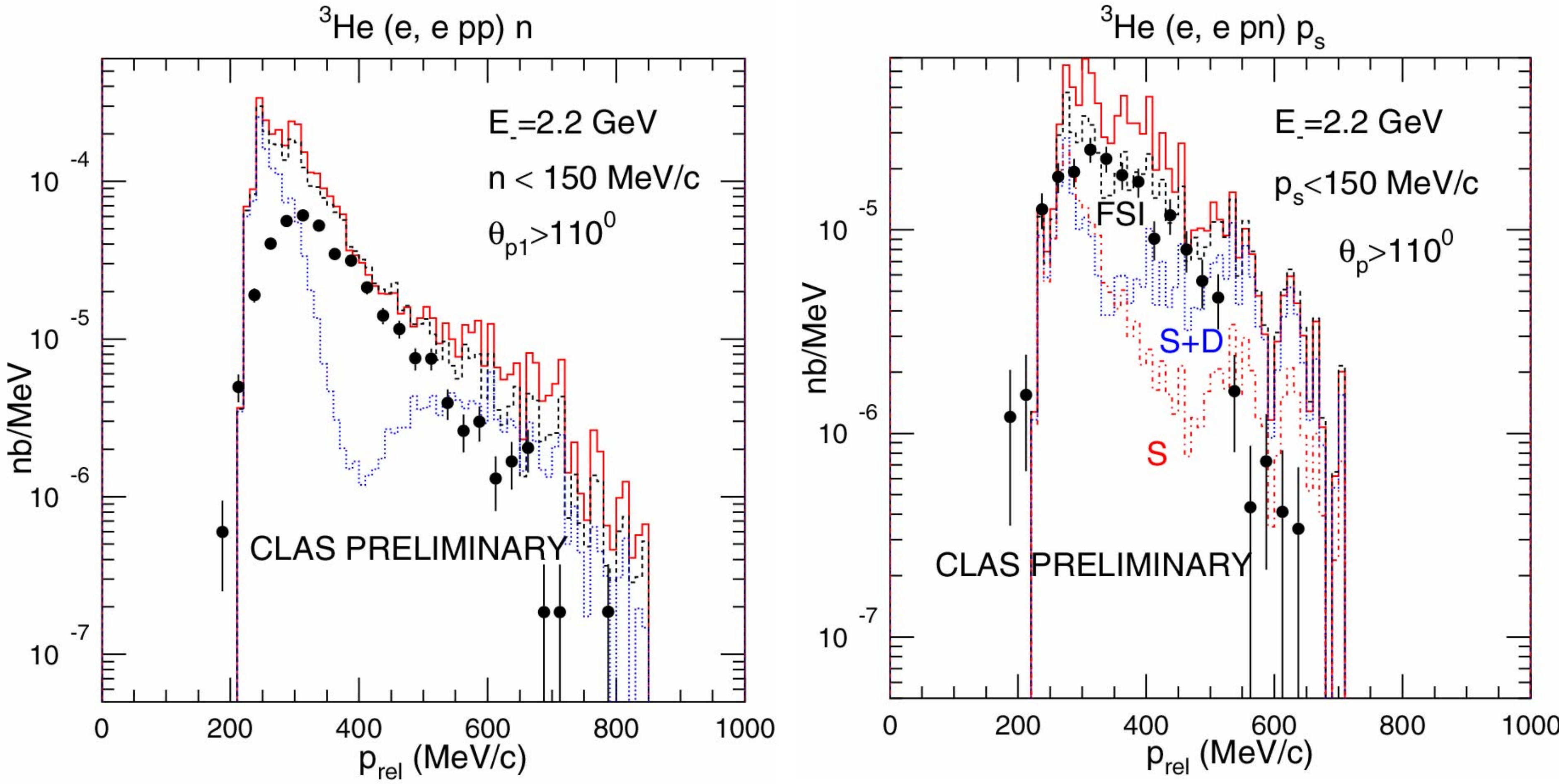
$^{3}He(e,e'pp)n_s$

- 2body FSI dominate by about a factor 40
- Good account of the energy variation



B. Zhang thesis

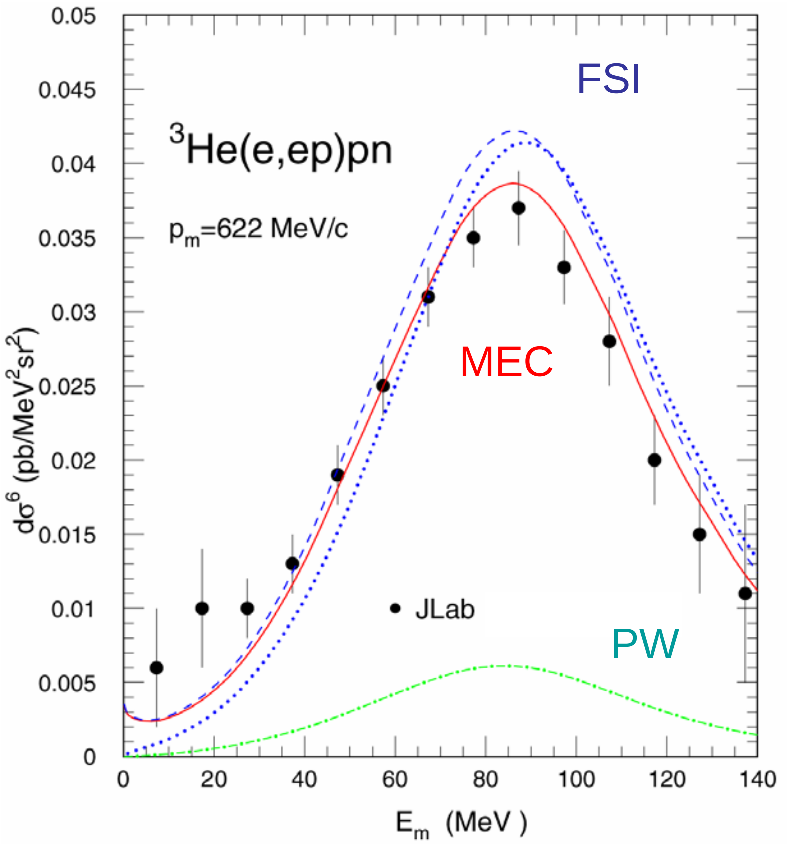
$^3He(e,e'pp)n_s/(e,e'pn)p_s$



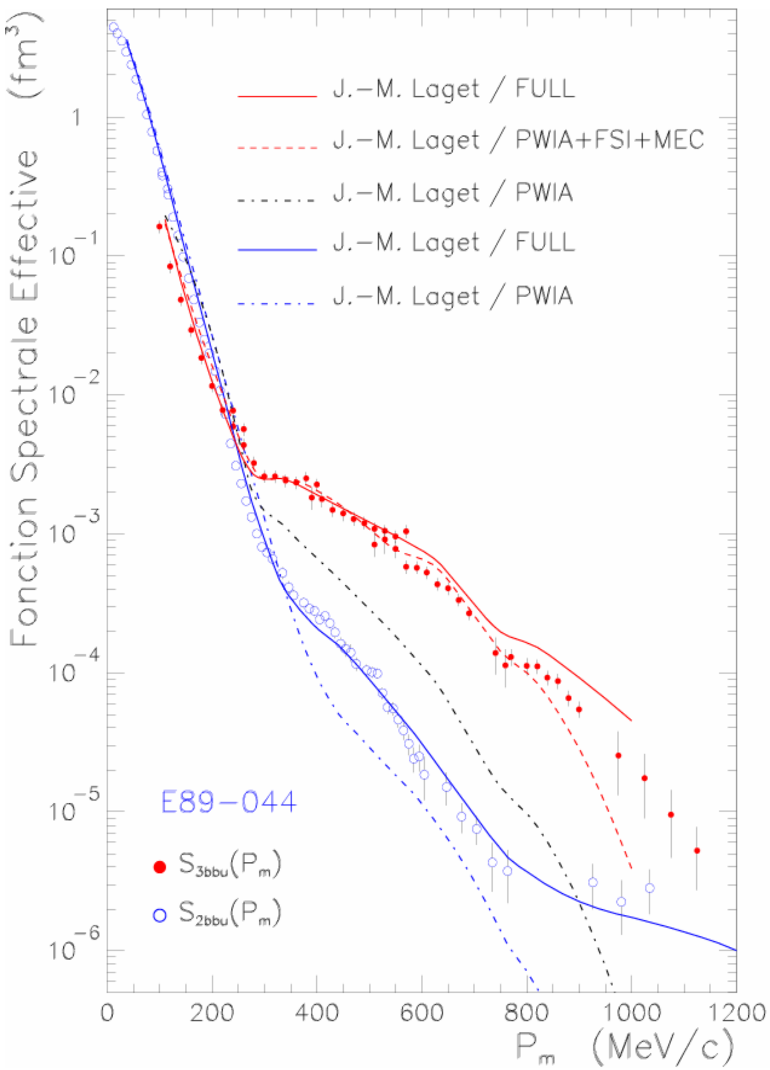
p_{rel}: relative momentum in the pair which absorbs the photon (PW)

B. Zhang thesis

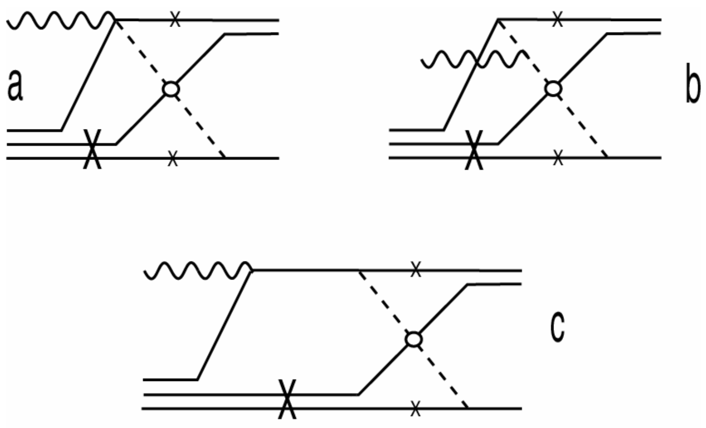
$^3He(e,e'p)np/^2H$

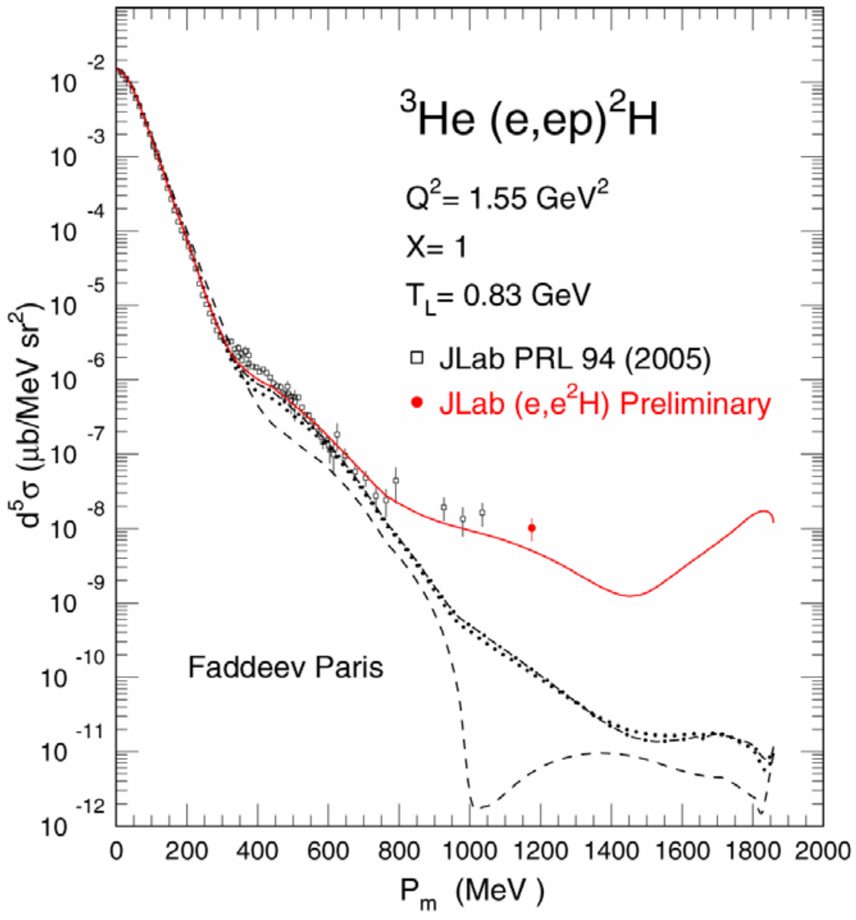


- Disintegration of a pair at rest: correlations
- FSI dominate: X=1
- Spectral functions up to 1 GeV/c !!!
- Data: PRL 94 (2005) 082305



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





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

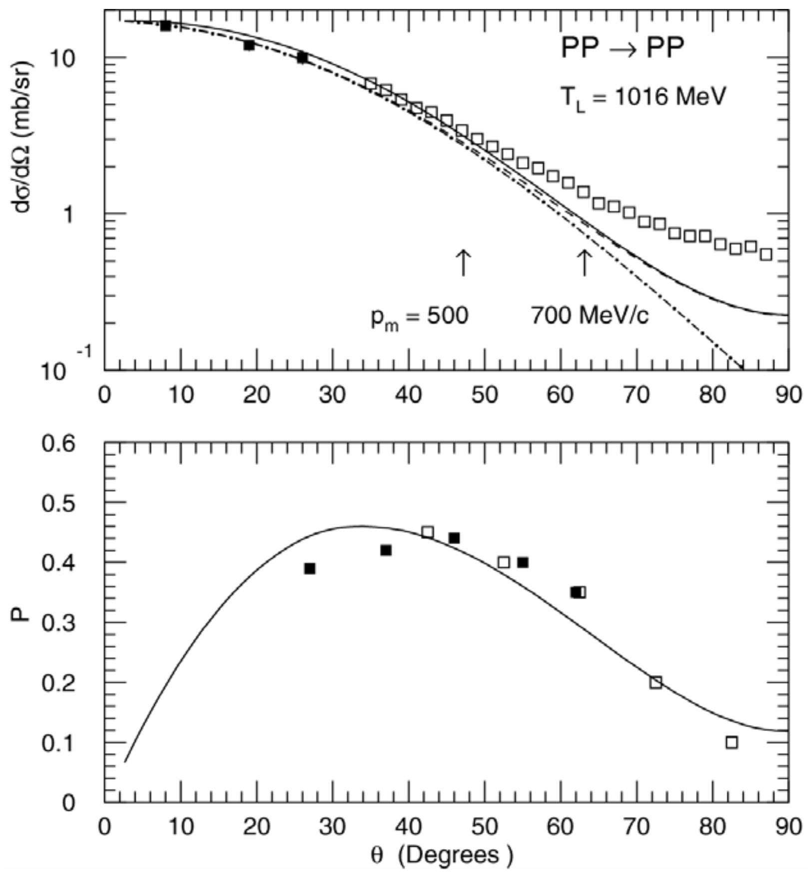
- Glauber double scattering?

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
- Above, many body interaction dominate
- Next step: use numerical amplitudes from SAID:
  - On-shell: technical issue only
  - Off-shell: extrapolation??



Data: COSY

Conclusion

- Diagrammatic method is on solid ground near singularities (X=1, …):
  - Low momentum components of the nuclear wave function
  - On-shell elementatry matrix elements
  - At high energy: simple description (Regge, diffraction,…)
- Powerfull tool
  - Color transparency (strange sector)
  - Scattering cross-section of instable hadrons (Λ,ϕ,J/ψ,…)
  - Exotics (pentaquark in KN sector,..) ?
- 6 to 12 GeV
- High momentum components of the nuclear wave function: hopeless?