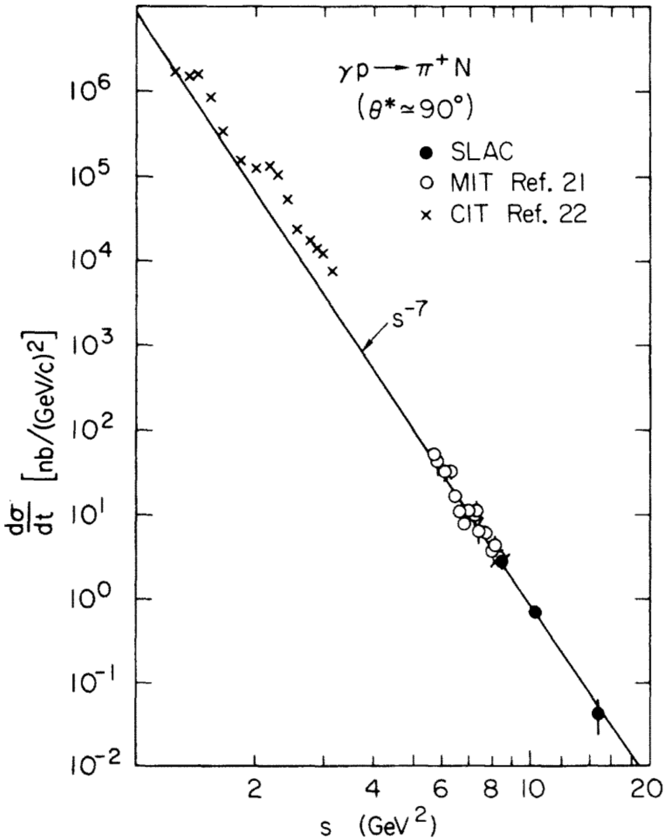
Channel coupling in exclusive reactions at high energies and high momentum transfers

- Mostly high energy ($\sqrt{s}$): above ρ threshold
- Issues: degrees of freedom?
- Toward JLab12
- Lessons for lower $\sqrt{s}$

Scaling

Large *t* and *u* (≈ *s*)

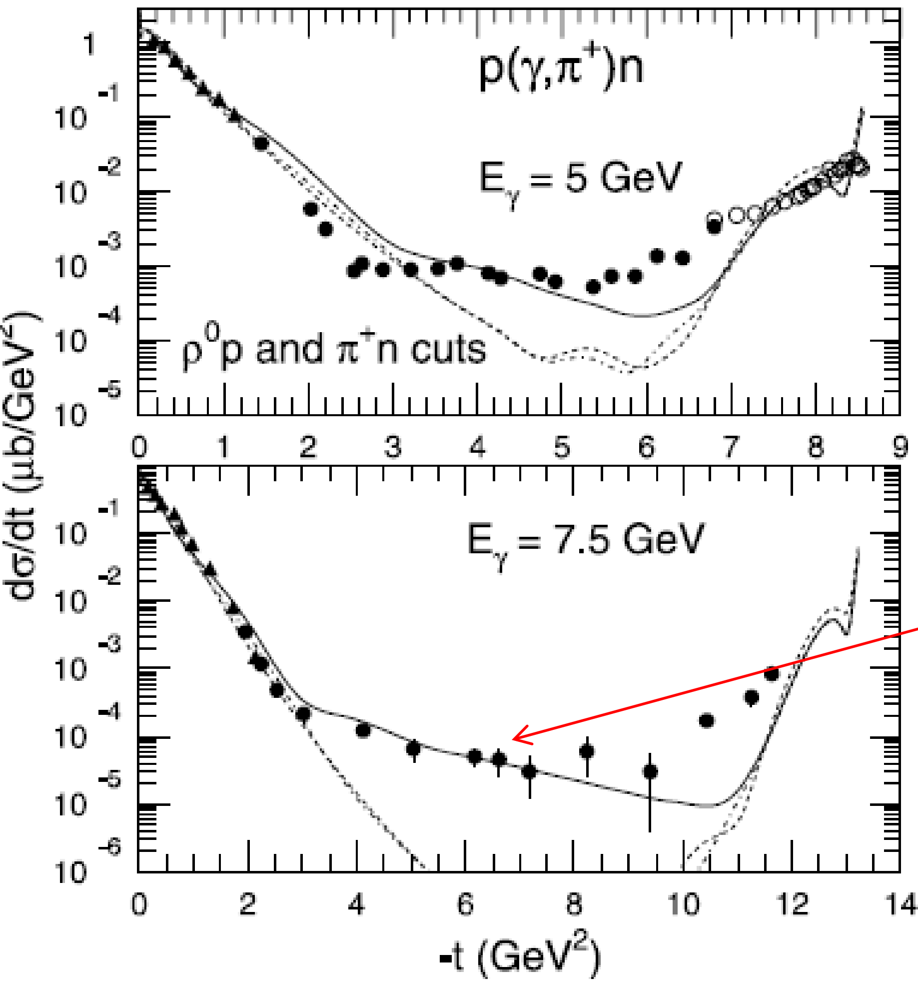


- Dimensional Scaling: dσ≈ s^{-N}
- Advocate pQCD
- But strong channel coupling mimics scaling

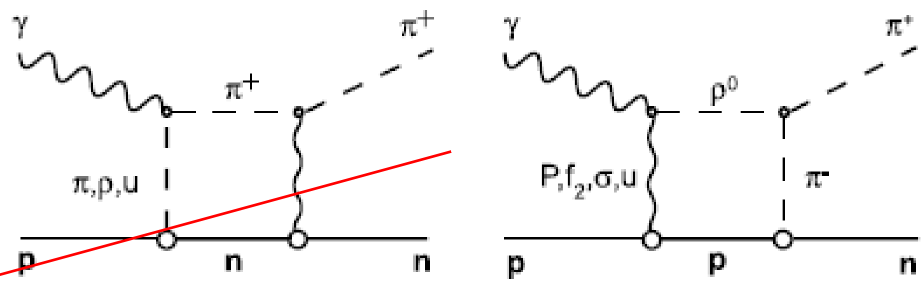
Available energies too low

Windows and opportunities at 12+ GeV?

p(γ,π⁺)n: cuts

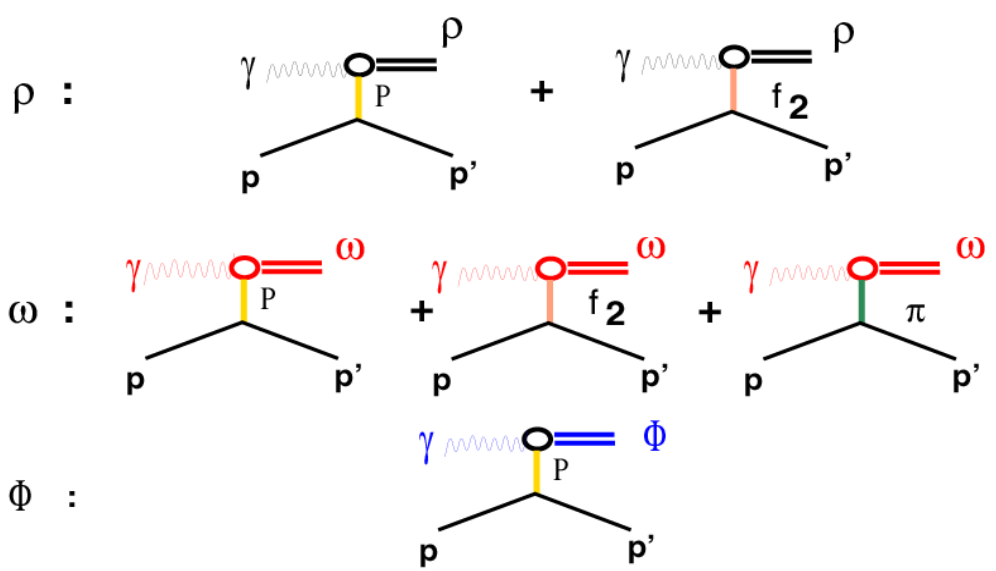


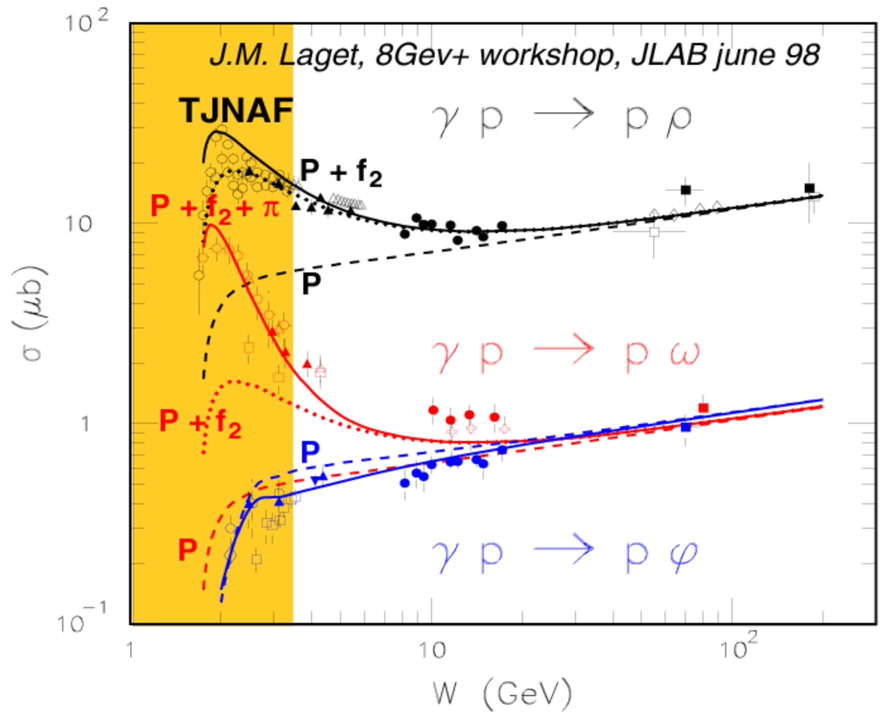
- Low t: π and ρ Regge
- Low u : N and Δ Regge
- Large u/t : channel coupling



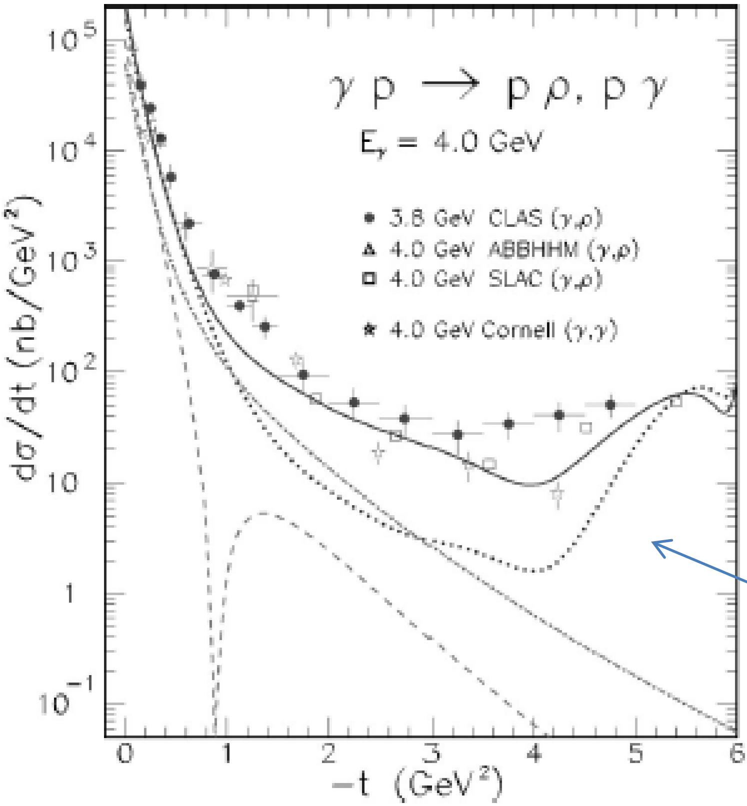
- Intermediate energies:
  - -one channel dominates: ρ
  - -Forward peaked cross section
- High energies?

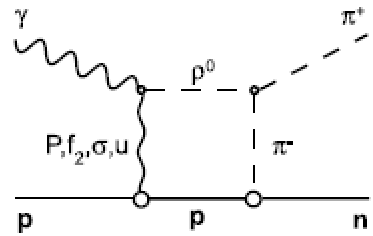
γ p $\to$ p V: dominant processes

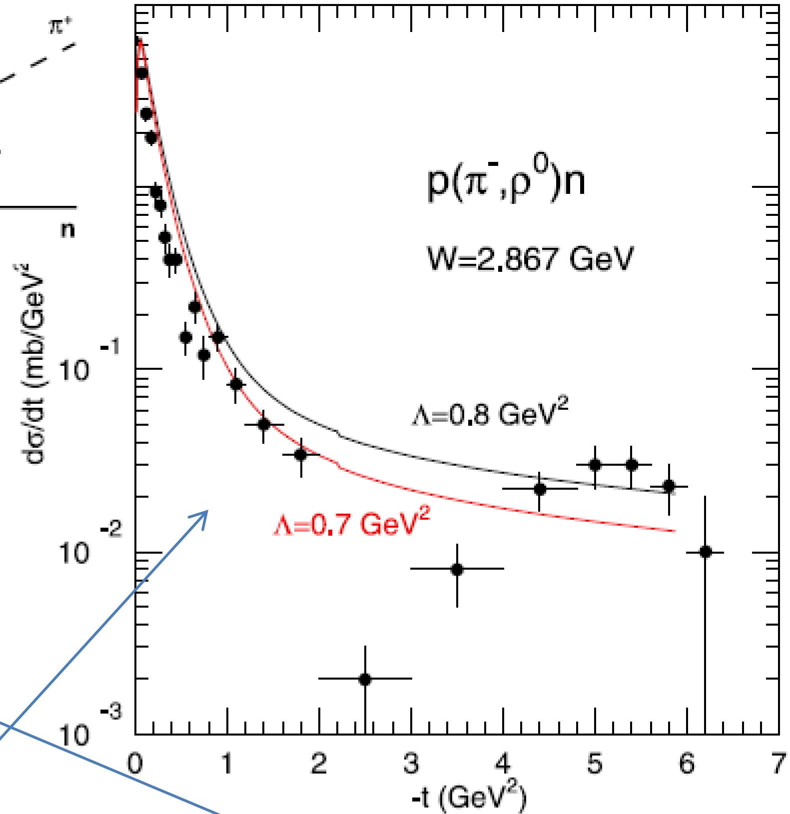




$p(\gamma,\pi^+)n$: $\rho^0 p$ cut





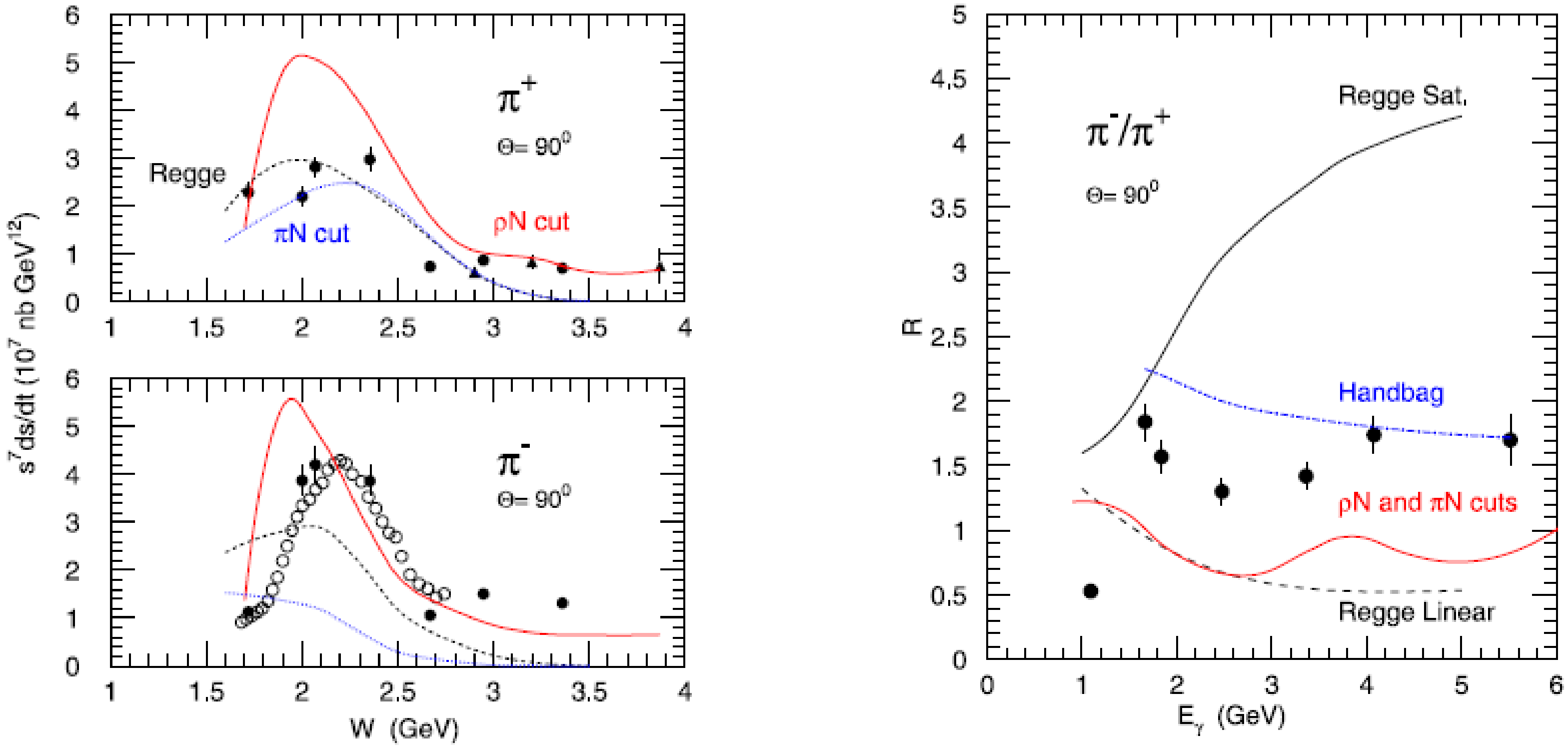


Regge

$$T_{loop} = -i\frac{mp_{c.m.}}{16\pi^2\sqrt{s}}\int d\Omega_p \sum_{m_p,m_\rho} (m_f|T_{\rho\pi}(t_\pi)|m_p,m_\rho)(m_p,m_\rho|T_{\gamma\rho}(t_\gamma)|m_i)$$

Parameter free!

p(γ,π⁺)n: scaling

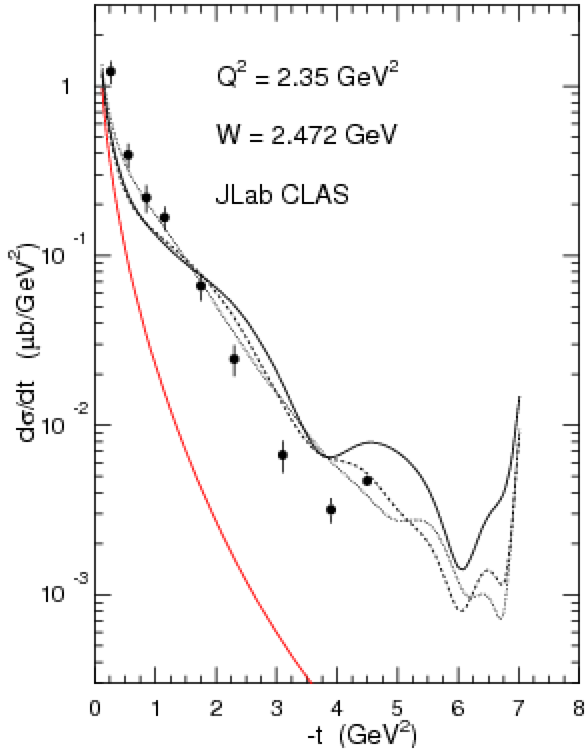


- No quarks explicitly needed!
- Natural explanation of scaling and deviations at low energies

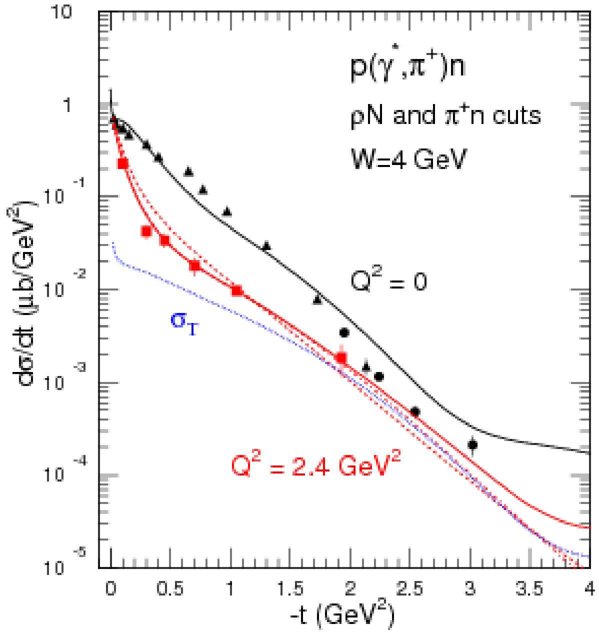
Threshold for ρ production

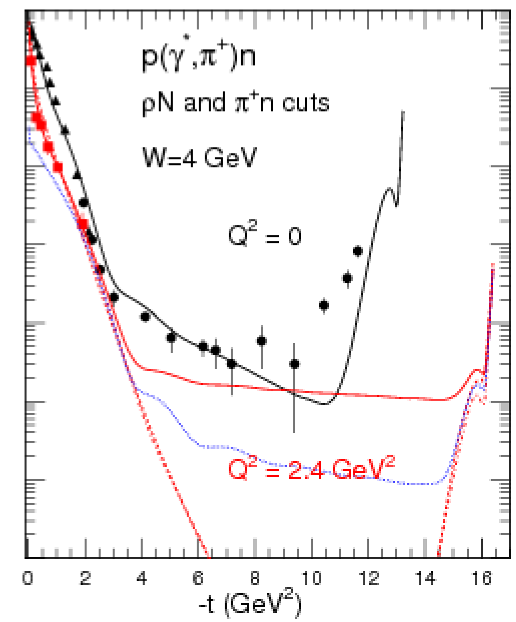
Virtual photons: p(e,e'π+)n

See K.Park talk



HERMES

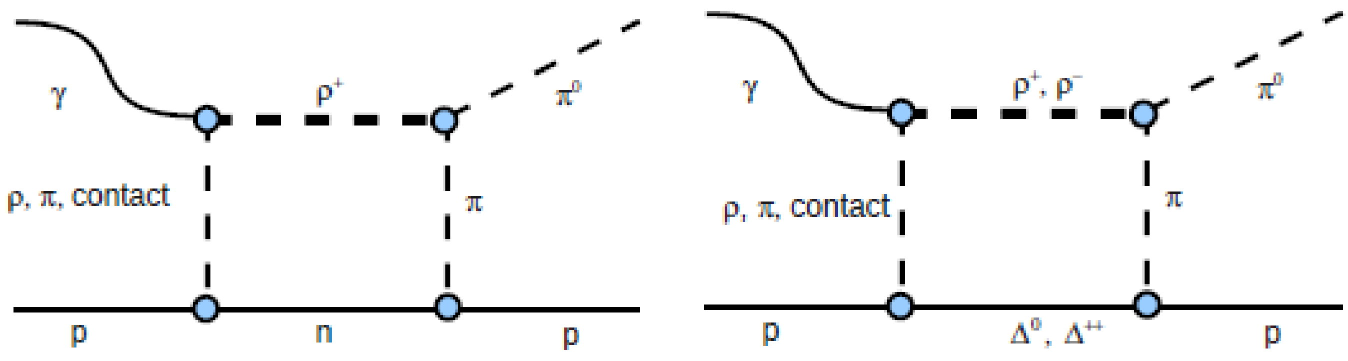




- *t* dependent EM form factors
- To date: *t* not large enough
- →JLAB12

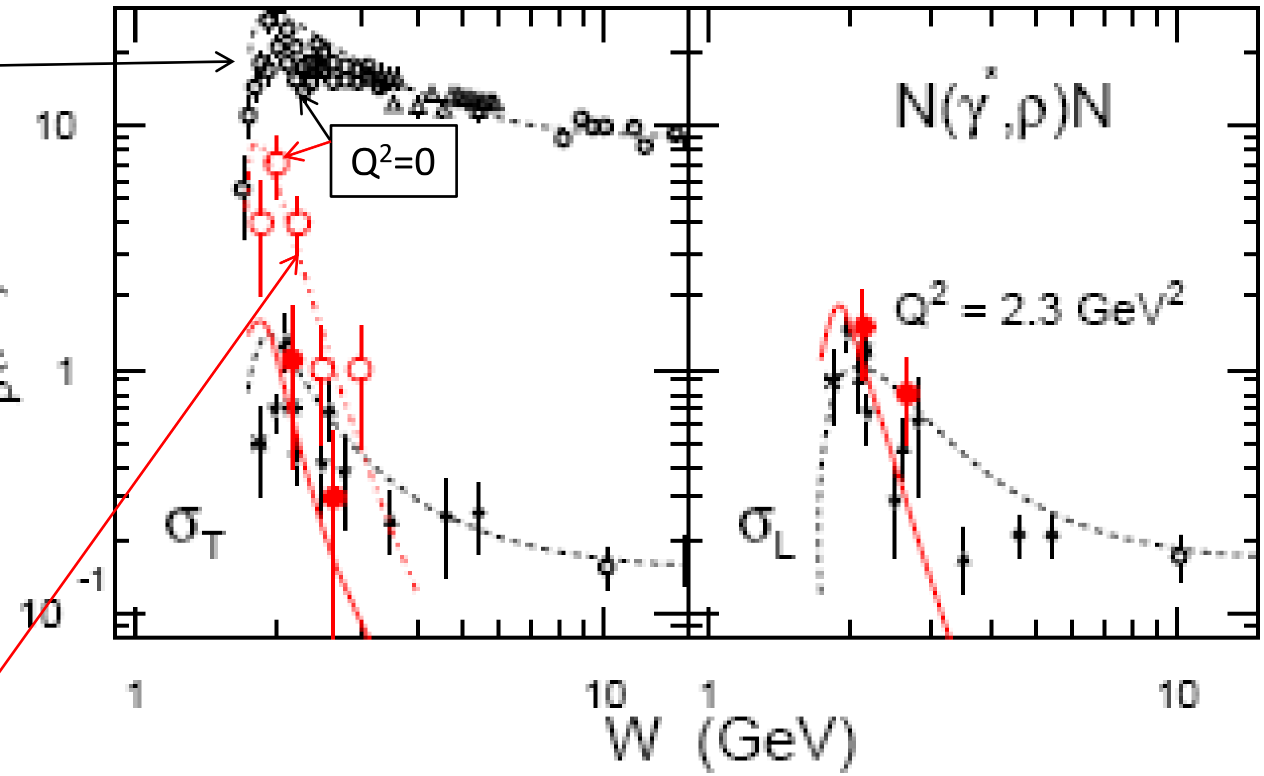
Other approaches:
- Kroll: Tranversity
- Mosel: s-channel

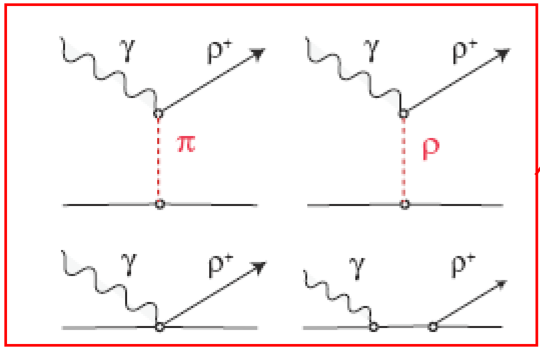
$p(e,e'\pi^0)p$: $\rho^+ n$ and $\rho^{+-}\Delta$ cuts



- ρ^+ cross section: large at $Q^2 \approx 3$ GeV^2 (CLAS)
  small at Q^2=0
- $\rho \rightarrow \pi$ cross section larger than $\omega \rightarrow \pi$ cross section
- Δ intermediate states as important as neutron one

P(e,e'ρ⁺)N





Gauge invariant

CLAS data at Q^2=2.3

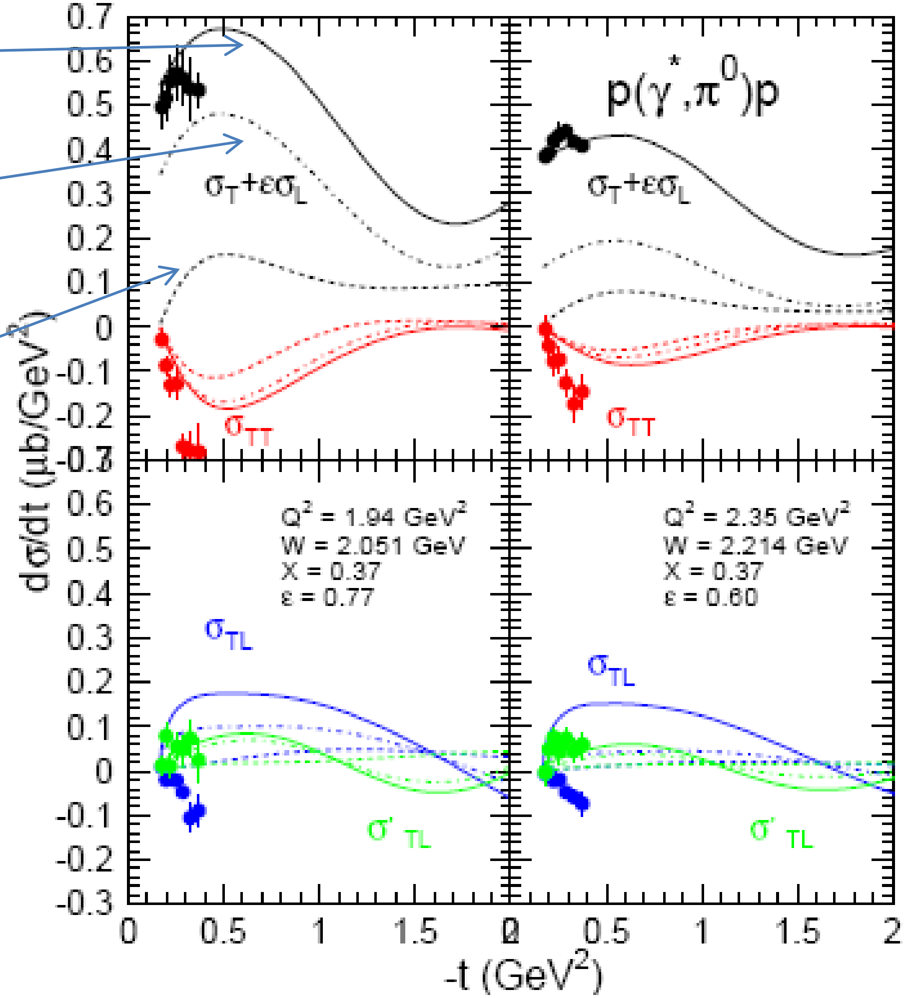
JLab HallA kinematics

ρn and ΔN cuts

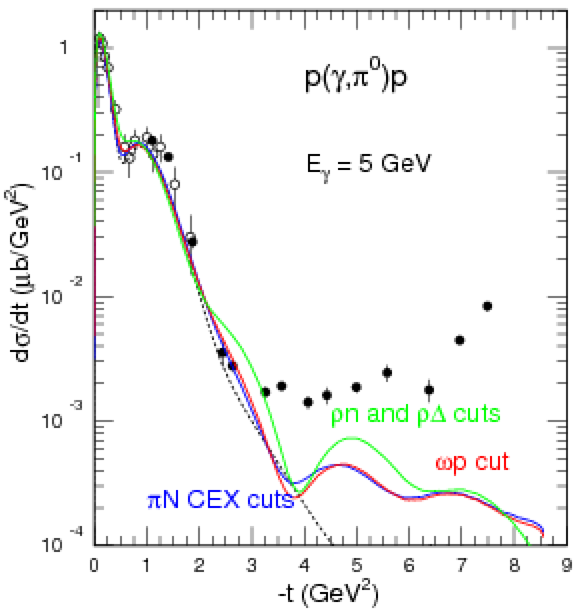
ρ+n cut

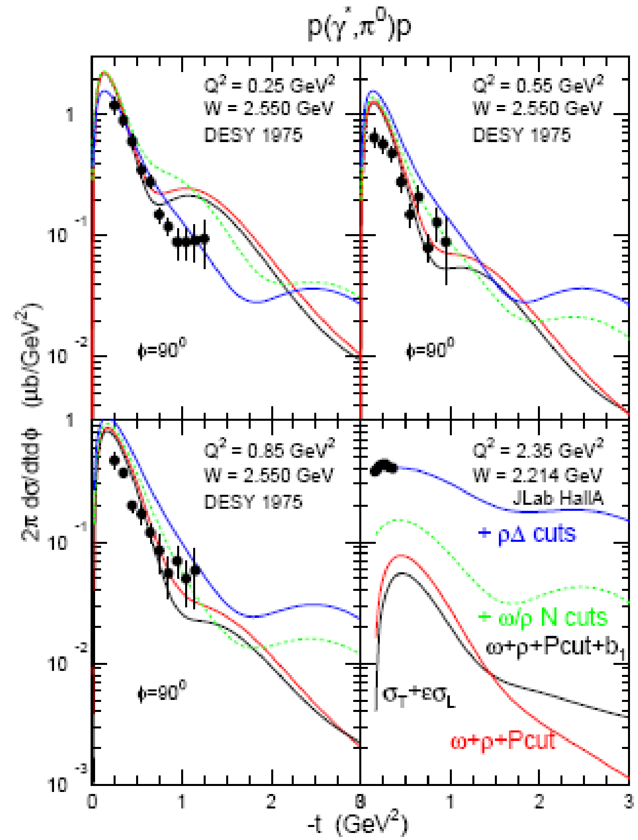
Regge poles

Wider kinematics in CLAS



p(e,e’π^0)p: low Q^2





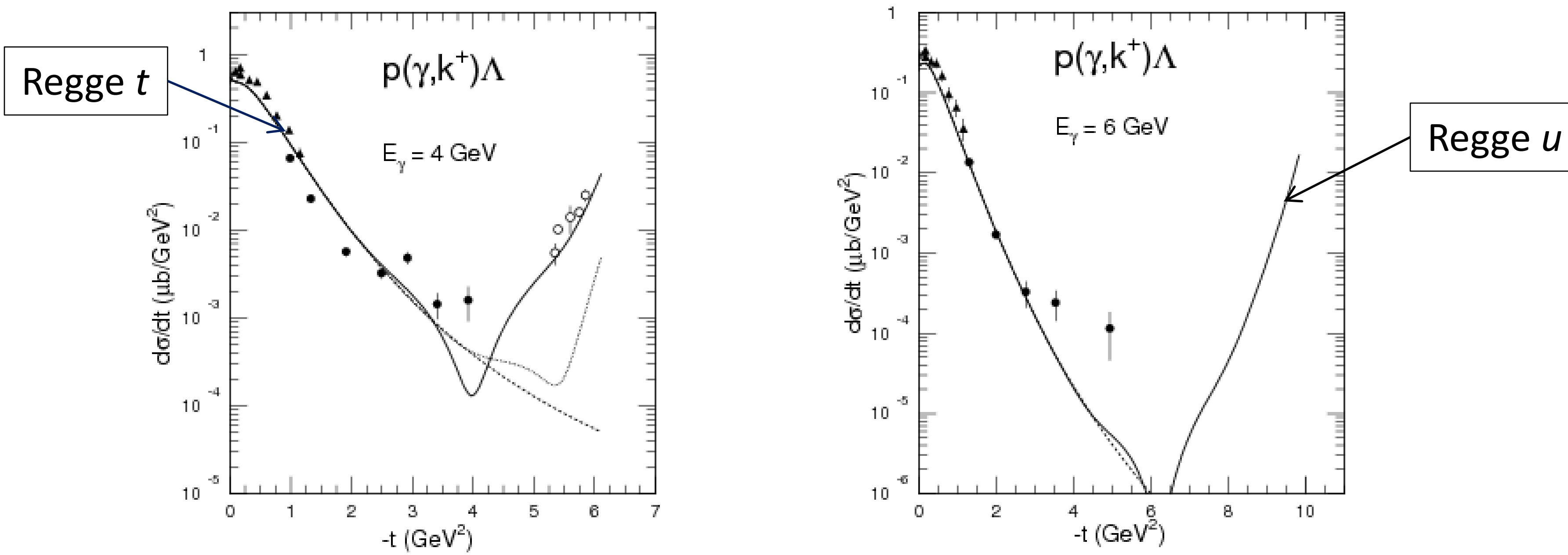
- Does not compromise the good agreement at Q2=0
- Helps to get rid of the node, for Q2<1 GeV^2
- A fine tuning of the EM form factors may improve the picture

Other approaches: Kroll, Golstein & al. (tranversity)
(Strictly valid at high Q2, low t)

Light to heavy quark sector

- Hadronic picture of the light quark sector:
  - large t (scaling)
  - large Q^2 (DVCS, π^0,…)
  - No quark explicitly needed
- Consistent links between various channels
- Comes from the large production and absorption cross sections of the ρ
- Coupling to the ρ^0 survives at high energy (π^+, Compton,…)
- Coupling to the ω and $\rho^\pm$ suppressed at high energy (π^0,…)
- → Strange quark sector
- → Heavy quark sector at JLab12 (ϕ, J/ψ,….)
  - Weak channel coupling ?
  - Quark/gluon picture makes more sense ?

Strange Quark sector



1. Large *t* and *u*: data not conclusive
2. Channel coupling: less important?
3. Coupling to the ρ: under study
4. Toward JLab12

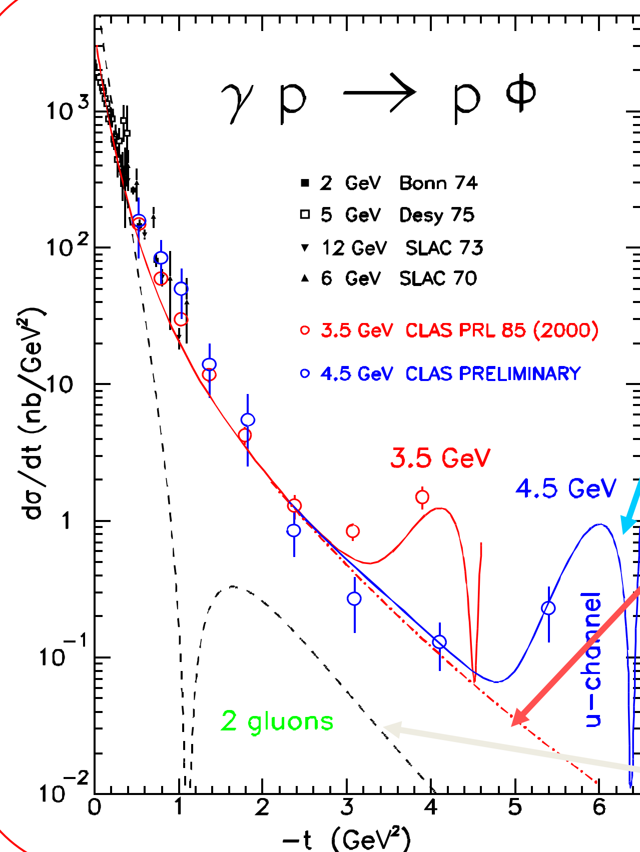
φ Meson Photoproduction at High Transfer *t*
JLab Exp. 93-031 (CLAS)

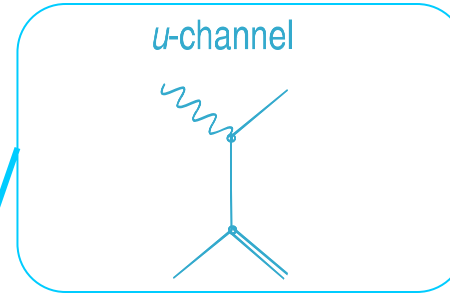
Strange Quarks
Gluon Exchange

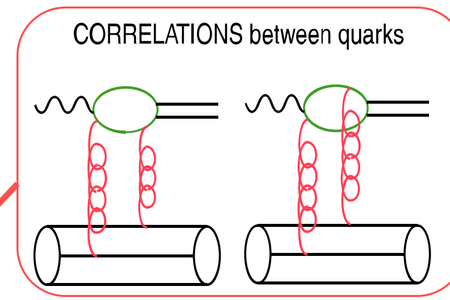
High t
Small Impact *b*

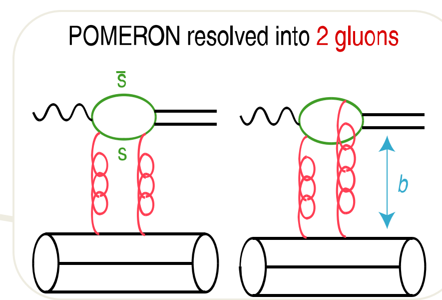
Quark Correlations

Gluon Propagator
From Lattice



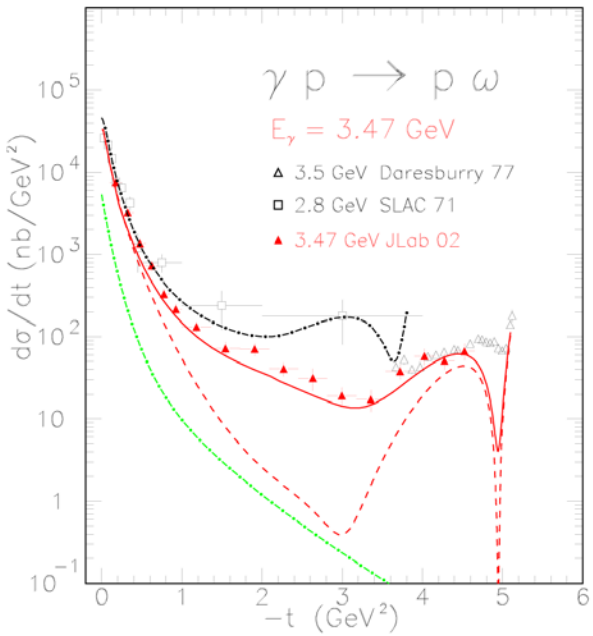


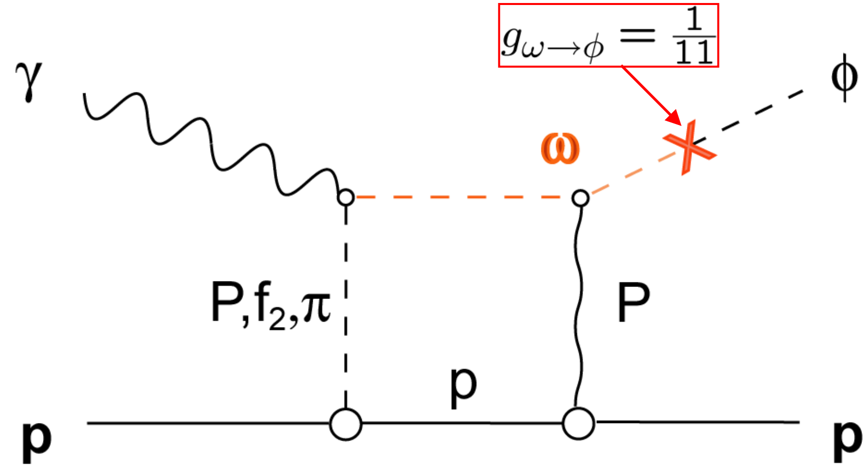




To be extended up to E_{γ} =11 GeV

ωφ mixing: nucleon target





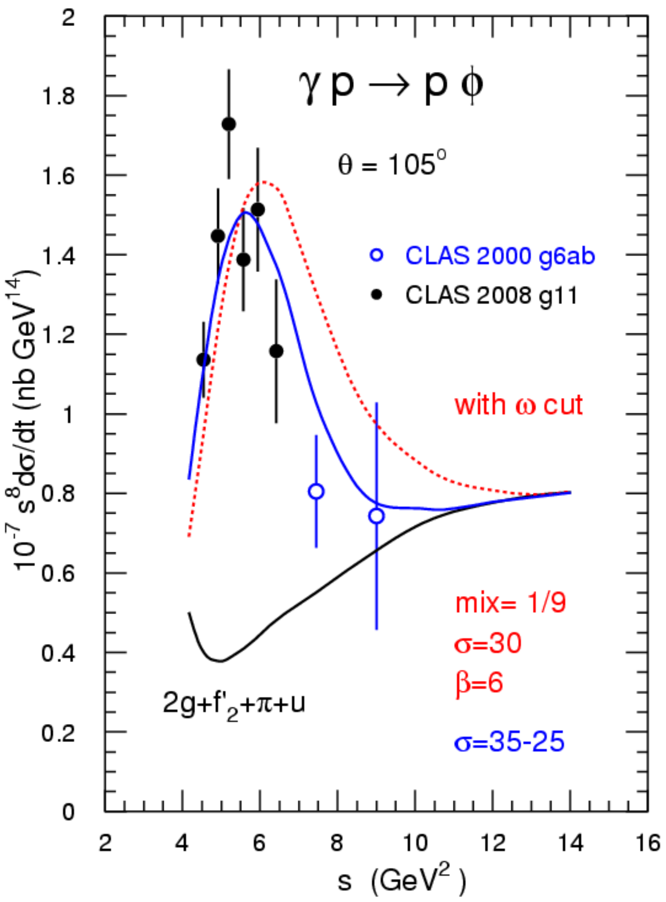
$$T_{\omega p} = -i\frac{p_{c.m.}\sqrt{s}}{m}\sigma_\omega e^{0.5\beta_\omega t_{\omega\phi}}$$

$\sigma_\omega \sim 25$ mb

$$T_{loop} = -i\frac{m p_{c.m.}}{16\pi^2\sqrt{s}}\int d\Omega_p \sum_{m_p}(m_f|T_{\omega p}(t_{\omega\phi})|m_p)(m_p|T_{\gamma\omega}(t_{\gamma\omega})|m_i)$$

No free parameters!

Approach to scaling



- 2 gluon exchange scales for s> 12 GeV^2
- The oscillation around scaling comes from coupling to the ω channel
- No data above Eγ= 4.5 GeV
- **Coupled channel effects suppressed at high energies**
- → 12 GeV+ ?
- → p(e,e'ϕ)p

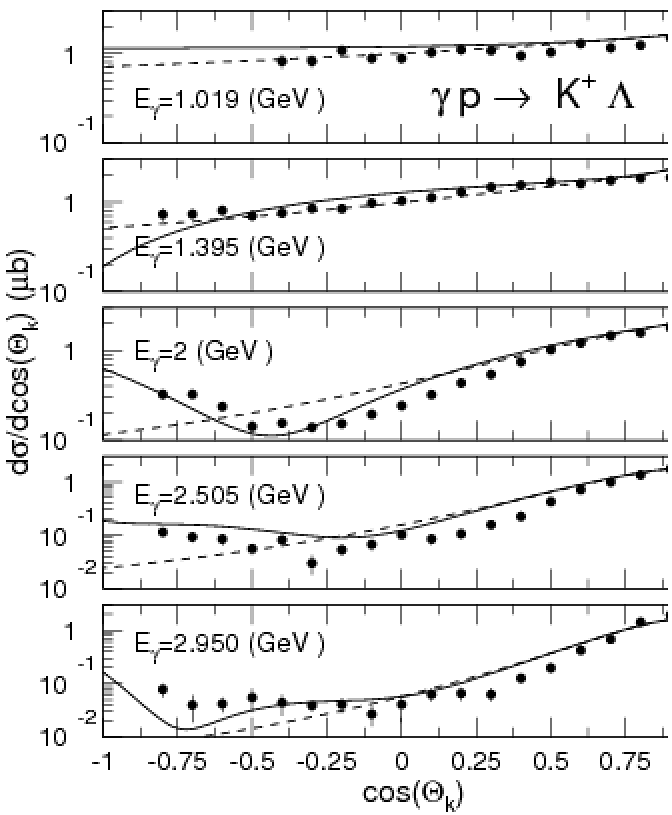
Conclusion (large $\sqrt{s}$)

- Light quark sector:
  - Large unitarity corrections
  - Hadronic picture still successful
  - Issue: equivalence between hadronic and quark descriptions?
- Strange quark sector:
  - Smaller unitarity corrections
  - Large enough cross sections
  - Quarks and partons are expected to make more sense
- Charmed quark sector
  - Small cross sections
  - At stake: gluonic structure of the nucleon

Back to lower √s

- √s decreases → narrower range in t
- Hadronic picture makes more sense than quark one
- Many coupled channels
- Select the prominent resonances and determine their transition form factors at the highest Q^2
  - Physical Background?
- Regge poles average through the resonances
  - Be carefull not to add resonances and Regge amplitudes!

$K^+\Lambda$ at low energies



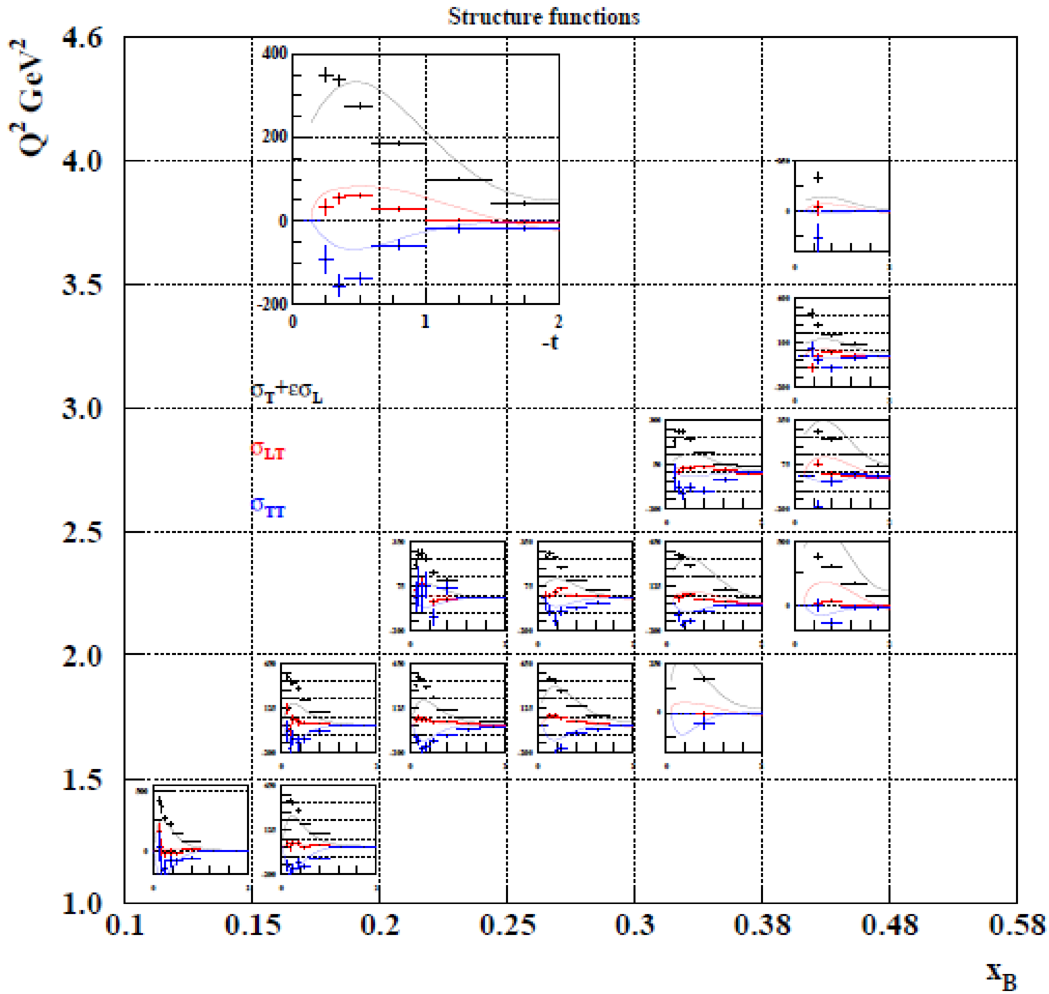
- Forward: K and K* Regge
- Backward: Λ and Σ* Regge

- Many overlaping resonances
- Regge averages over resonances

- Coupling with the π channels
- Under study

Back-up slides

JLab HallB kinematics

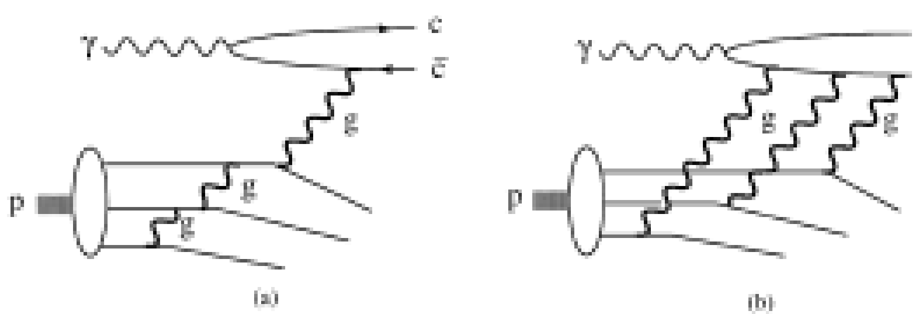


Charm in Nuclei at Threshold

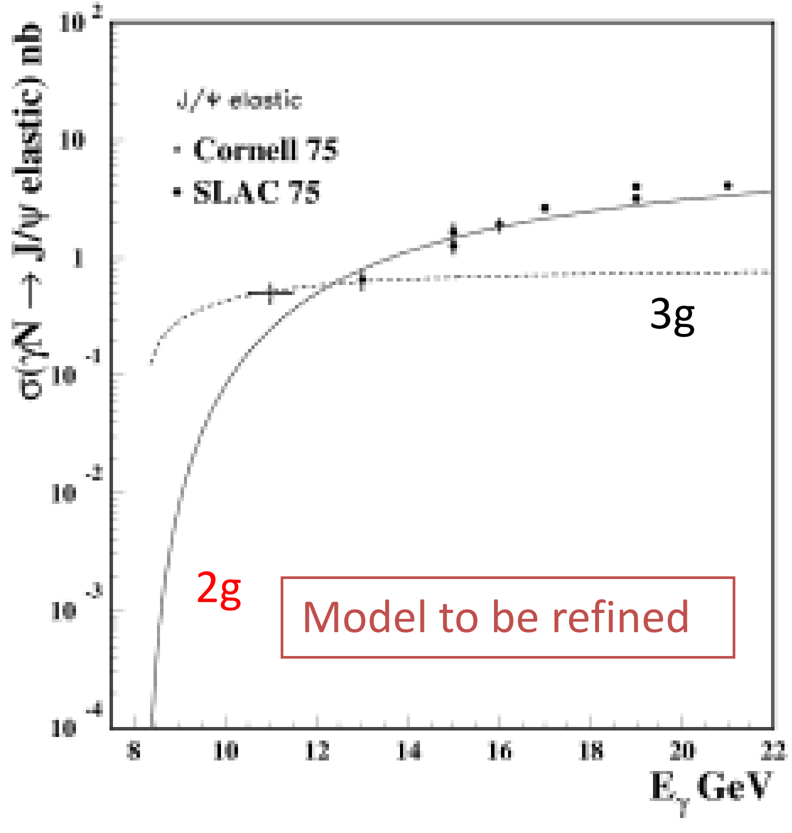
- Large t_{min}, large m_c: *Partons makes more sense*
- $l_F \leq 1$ fm: Access to $\sigma_{J/\Psi N}$
  - *Scattering of a full fledge charmonium (NO CT)*
- Search for Charmonium bound states
  - *Attractive Van der Waals forces?*
- Gluonic structure of the nucleon
- Virgin field!!

$\color{red}{2}$ vs 3 gluon exchange

(Brodsky et al., PLB498 (2001) 23)



$x \to 1 \quad xg(x) \approx (1-x)^{ns}$

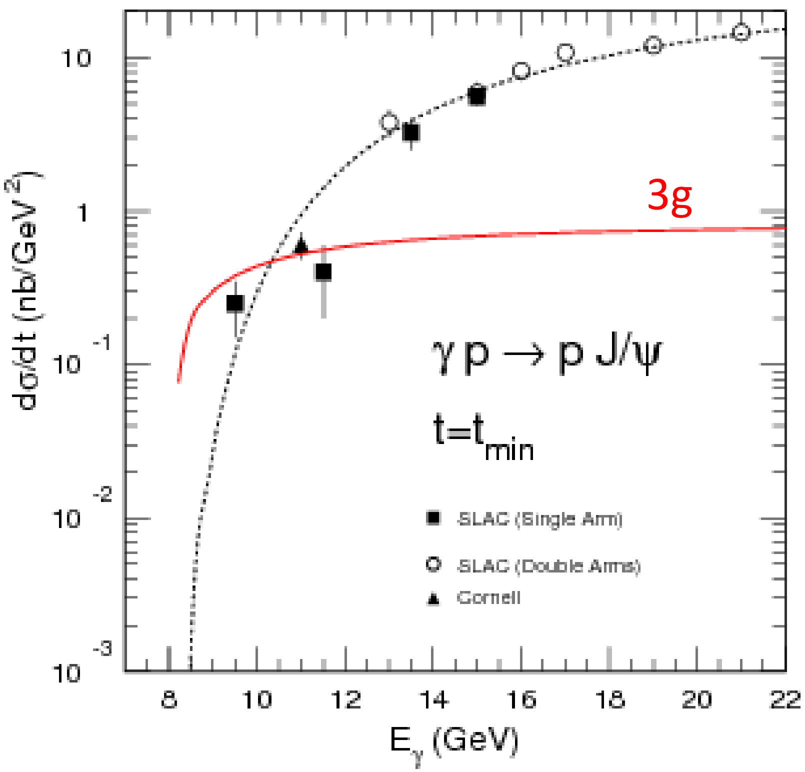


- $d\sigma/dt = N\,(1-x)^2\,F^2_{2g}(t)$ 2 gluons
- $d\sigma/dt = N\,(1-x)^0\,F^2_{3g}(t)$ 3 gluons

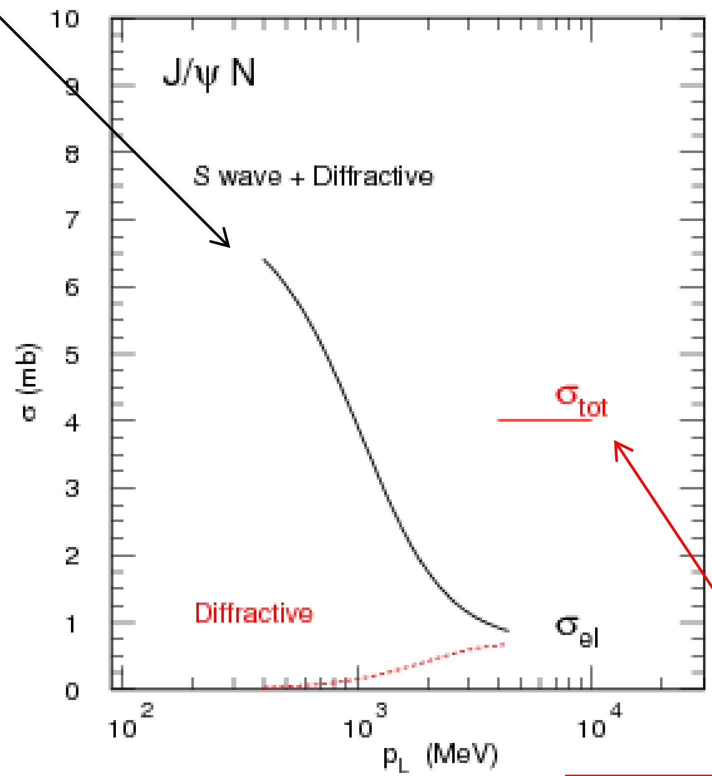
$x \approx (E_{th} / E)_\gamma = (s_{th}-m^2)/(s-m^2)$

Experiment badly needed near threshold

J/ψ Cross sections

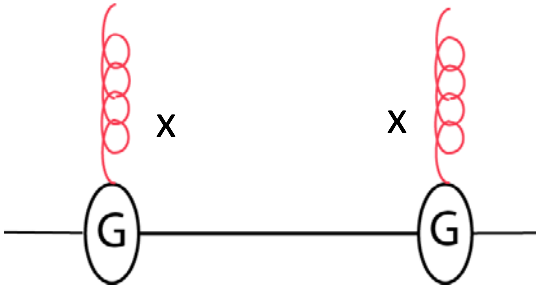


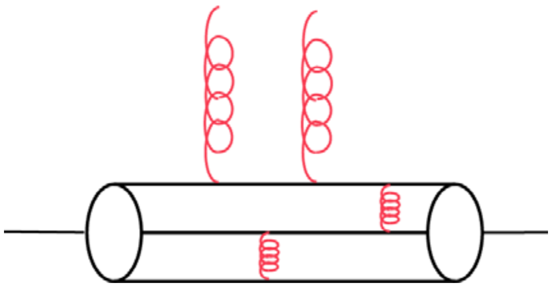
a=0.24 fm (Brodsky, Miller)

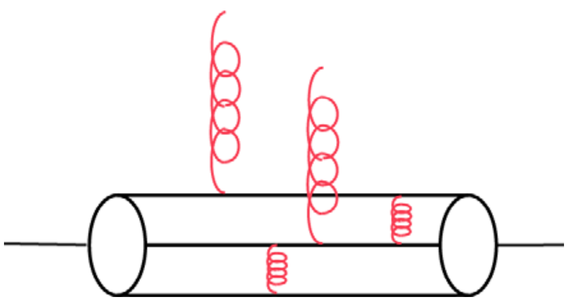


Nuclei (SLAC)

Models of the nucleon







Pertubative gluon propagator
Link with gluon density xg(x)
Energy dependency
But t=0
[Ryskin et al., Brodsky et al.]

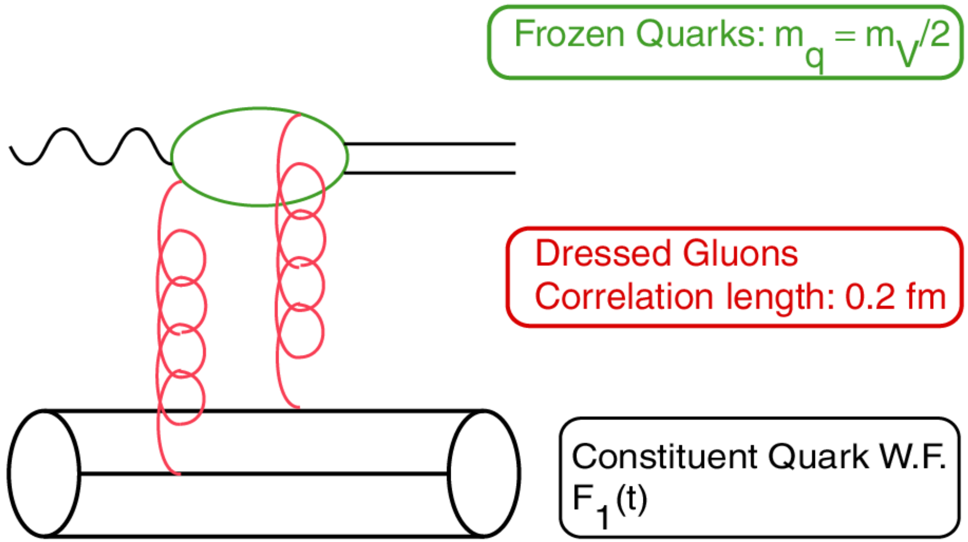
Coupling to the same quark
$t \neq 0 \Rightarrow F1(t)$
But energy independent
[Donnachie-Landshoff]

Non perturbative gluon prop.

Coupling to different quarks
Large t
Quark correlations
[Cano-Laget]

$\Leftrightarrow$ Gluon GPD ?

Non Perturbative Partonic Regime



Frozen $\alpha_s = 0.23$

Constituents of: - Exchanged Quanta

- Hadrons

Constants Fixed from Other Channels:

- Lattice calc.: gluon dressed propagator
- $F_1(t)$: proton correlated w.f.
- ϕ radiative decay: ϕ w.f.

Issues

- Light quark sector:
  - Channel coupling mimics scaling
- Strange and charmed quark sectors:
  - Partons make more sense
- JLab12 and higher?
- Few nucleon targets: Color Tansparency?

VCS and DVCS*: Phys. Rev. C76, 052201(R) 2007*

Charged pion*: Phys. Lett. B685, 146 (2010)*

Neutral pion*: Phys. Lett. B895,199 (2011)*

ϕ ***meson****: Phys. Lett. B680, 417 (2009)*

J/ψ meson*: Phys. Lett. B498, 23 (2001)*

Deuterium: Phys. Rev. C73, 044003 (2006); C75,014002 (2007)