Diffractive electroproduction of vector mesons

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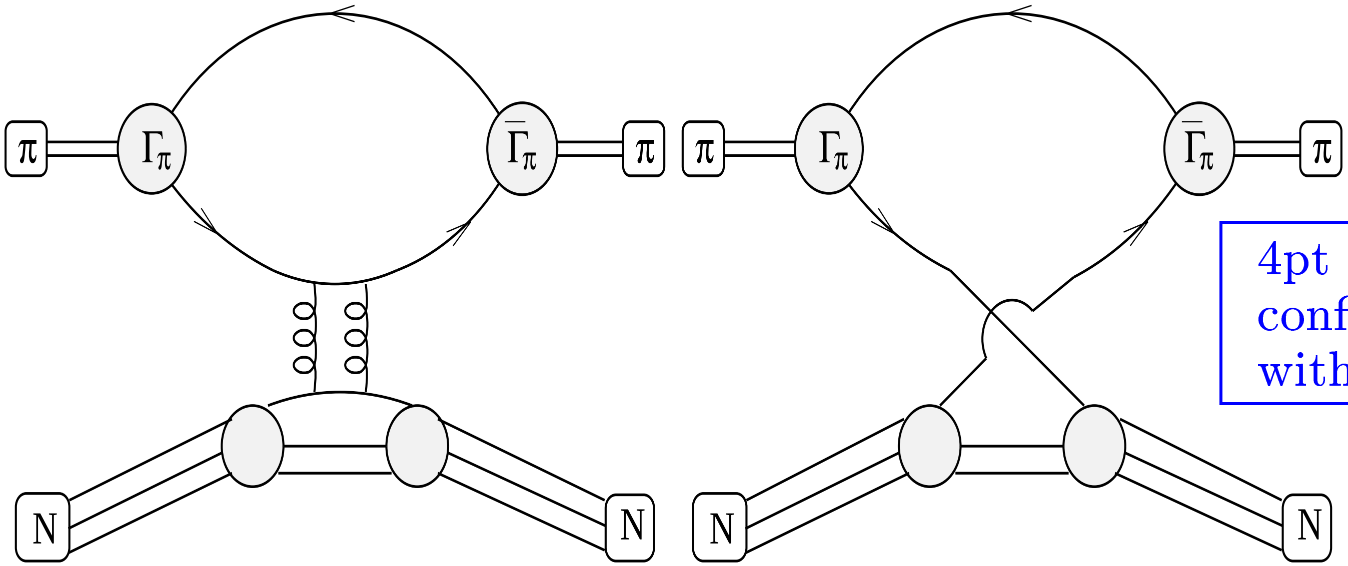
- Quark-nucleon Pomeron-exchange interaction
- Parameter fit to πN and KN elastic scattering
- Predictions of vector meson electroproduction
- Effects of hadron structure on diffraction

For diffractive process $\pi^+ N \to \pi^+ N$ consider two mechanisms:

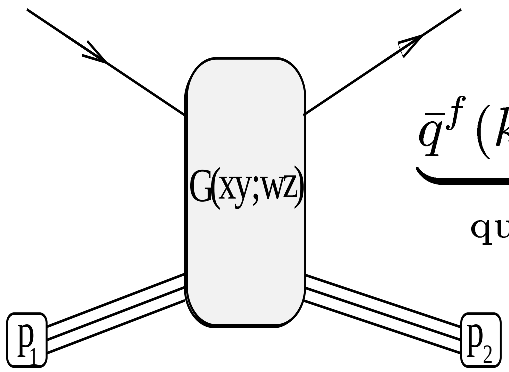


4pt funct. describes how confined quark interacts with on-shell nucleon

By focussing on diffractive processes, this 4pt funct. takes simple form ... called "Pomeron exchange."

- no flavor exchanged
- forward peaked (diffractive)
- before/after spins unchanged
- nearly universal s dependence: $\sigma_{\rm el} \propto s^{2\alpha_0}$, $\alpha_0 > 0$
- s-channel helicity conservation

In this approach, “Pomeron exchange” is high-energy interaction between confined quark and on-shell nucleon.



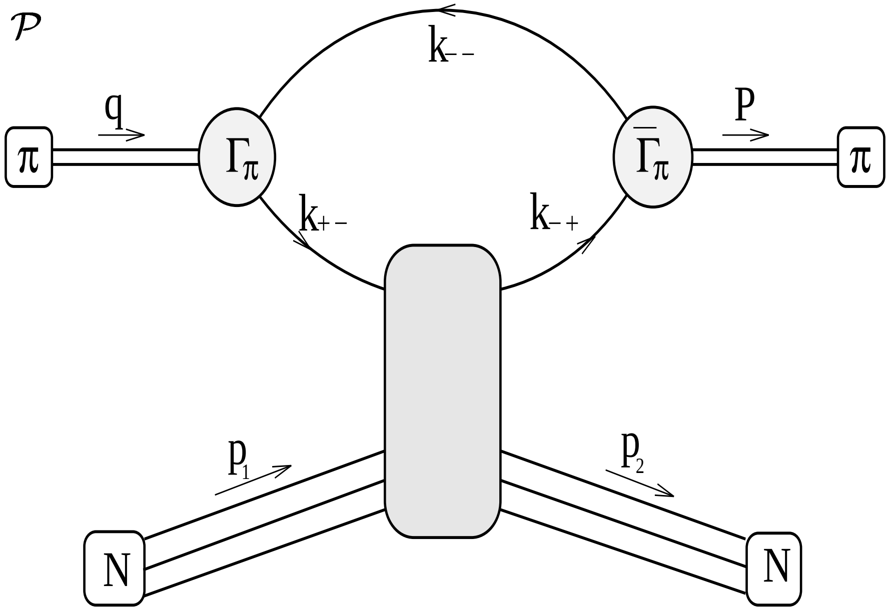
$$\underbrace{\bar{q}^f(k')\beta_f\gamma_\mu q^f(k)}_{\text{quark coupling}} \quad \underbrace{\bar{u}_N(p_2)3\beta_u\gamma_\mu u_N(p_1)F_1(t)G(s,t)}_{\mathrm{N}+\mathcal{P}}$$

Model assumptions:

1. near flavor independence — $\beta_f,\ f = u, d, ...$
2. quark coupling $\propto \gamma_\mu$ — wrong C-parity
3. $G(s,t) = (\alpha_1\ s)^{\alpha_0+\alpha_1 t}$ — like a Regge trajectory

$G(s,t)$ describes exchange mechanism and nucleon structure.

$$T_{\pi N\to\pi N} = i\Lambda_\mu(q,P)\ \underbrace{\bar{u}_N(p_2)3\beta_u\gamma_\mu u_N(p_1)\ F_1(t)G(s,t)}_{\mathrm{N}+\mathcal{P}}$$



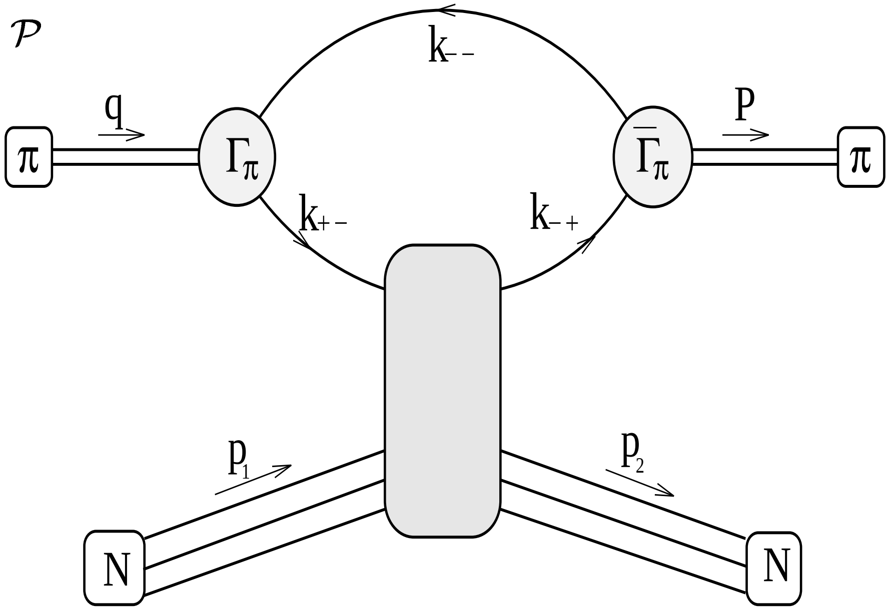
$$\Lambda_\mu(q,P) = \Lambda_\mu^u(q,P) + \Lambda_\mu^{\bar{d}}(q,P),$$

$$\Lambda_\mu^u(q,P) = 2N_c\,\mathrm{tr}\int \tilde{\mathrm{d}}k\ \Gamma_\pi S_d(k_{--})\bar{\Gamma}_\pi S_u(k_{-+})\beta_u\gamma_\mu S_u(k_{+-})$$
$$\Lambda_\mu^{\bar{d}}(q,P) = 2N_c\,\mathrm{tr}\int \tilde{\mathrm{d}}k\ \bar{\Gamma}_\pi S_u(k_{--})\Gamma_\pi S_d(k_{-+})\beta_d\gamma_\mu S_d(k_{+-})$$

- $S_u(k)$, Γ_π : Burden, Roberts and Thompson, PLB 371 (1996) 163.
- $\alpha_0 \Leftarrow s$ dependence; $\alpha_1 \Leftarrow t$-slope of $\sigma_{\pi N}$.
- $\beta_u = \beta_d \Leftarrow$ magnitude of $\sigma_{\pi N}$.

KN scattering requires inclusion of s quark propagator and K BS amplitude. Everything else is same.

$$T_{KN\to KN} = i\Lambda_\mu(q,P)\ \underbrace{\bar{u}_N(p_2)3\beta_u\gamma_\mu u_N(p_1)\ F_1(t)G(s,t)}_{\mathrm{N}+\mathcal{P}}$$



$$\Lambda_\mu(q,P) = \Lambda_\mu^u(q,P) + \Lambda_\mu^{\bar{s}}(q,P),$$

$$\Lambda_\mu^u(q,P) = 2N_c\,\mathrm{tr}\int \tilde{\mathrm{d}}k\ \Gamma_K S_s\,(k_{--})\bar{\Gamma}_K S_u(k_{-+})\beta_u\gamma_\mu S_u(k_{+-})$$

$$\Lambda_\mu^{\bar{s}}(q,P) = 2N_c\,\mathrm{tr}\int \tilde{\mathrm{d}}k\ \bar{\Gamma}_K S_u(k_{--})\Gamma_K S_s\,(k_{-+})\beta_s\,\gamma_\mu S_s\,(k_{+-})$$

- $S_s(k)$, Γ_K : Burden, Roberts and Thompson, PLB 371 (1996) 163.
- $\beta_s \Leftarrow$ magnitude of σ_{KN}.
- slope of σ_{KN} is a prediction.

Confined-quark propagator: $S_f(p) = -i\gamma\cdot p\; \sigma_V^f(p^2) + \sigma_S^f(p^2)$

$$\bar\sigma_S^f(x) = \frac{1-e^{-b_1^f x}}{b_1^f x}\,\frac{1-e^{-b_3^f x}}{b_3^f x}\left(b_0^f + b_2^f\,\frac{1-e^{-\Lambda x}}{\Lambda x}\right) + \bar m_f\,\frac{1-e^{-2(x+\bar m_f^2)}}{x+\bar m_f^2} + C_{m_f}^f\, e^{-2x}$$

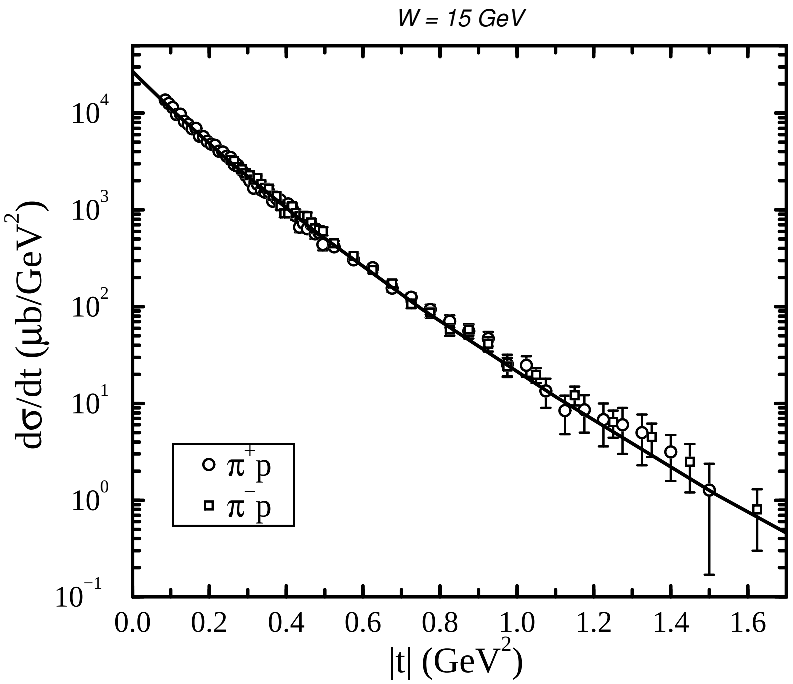
$$\bar\sigma_V^f(x) = \frac{2(x+\bar m_f^2)-1+e^{-2(x+\bar m_f^2)}}{2(x+\bar m_f^2)^2}$$

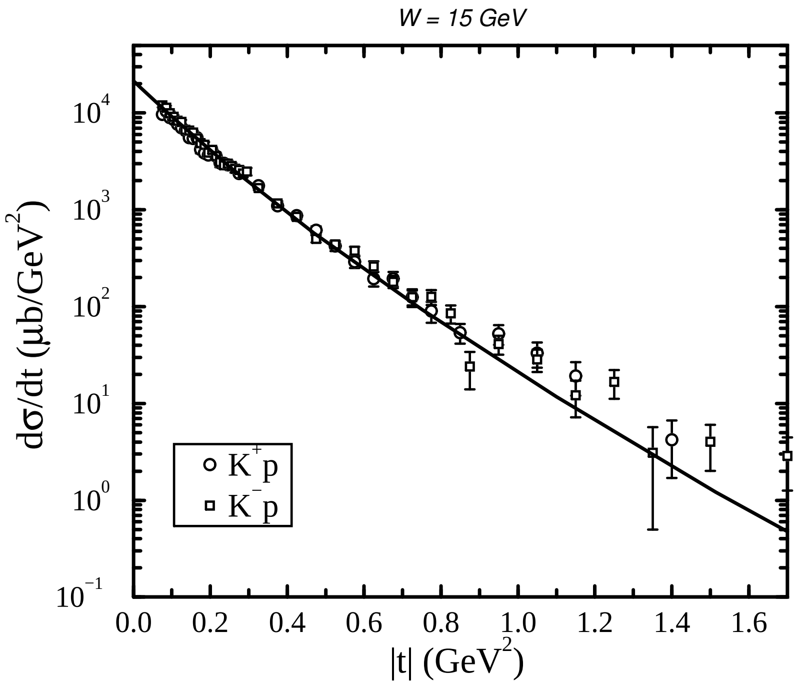
$x = k^2/\lambda^2$, $\bar\sigma_S^f = \lambda\sigma_S^f$, $\bar\sigma_V^f = \lambda^2\sigma_V^f$, $m_f = \lambda\bar m_f$, $\Lambda = 10^{-4}$, $\lambda = 0.566$ GeV.

f	b_0^f	b_1^f	b_2^f	b_3^f	$C_{m_f=0}^f$	$C_{m_f\neq 0}^f$	m_f
u, d	0.131	2.90	0.603	0.185	0.121	0.00	5.1 MeV
s	0.105	same	0.740	same	1.69	same	127.5 MeV

- Confinement: $\sigma_V(p^2)$ and $\sigma_S(p^2)$ are *entire*.
- Has correct pQCD limit and exhibits dχsb.

Burden, Roberts and Thompson, PLB 371 (1996) 163.



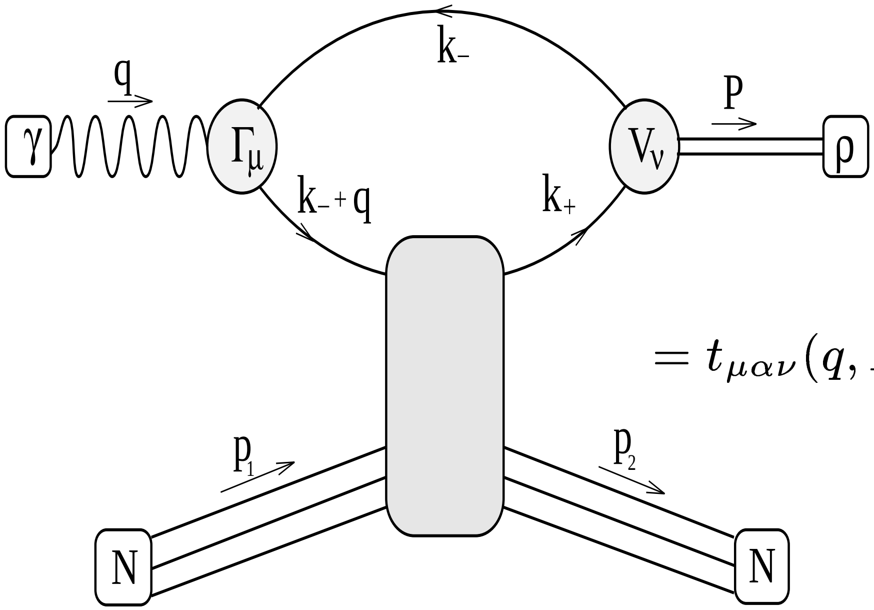


$\frac{d\sigma}{dt} \approx A\, e^{-bt}$

$$b_{\pi N} = 8.7 \text{ GeV}^{-2}$$
$$b_{KN} = 8.3 \text{ GeV}^{-2}$$

- $b_{\pi N} \neq b_{KN}$ $\Rightarrow$ different quark substructure, $r_K < r_\pi$.
- s- and t-dep of Pomeron is flavor *independent*.
- Quark-nucleon Pomeron exchange parameters are determined.

All 4 parameters fixed. Now consider vector meson electroproduction:



$$= t_{\mu\alpha\nu}(q,P)\,\varepsilon_\nu^{\lambda_\rho}\;\underbrace{\bar{u}(p_2)3\beta_u\gamma_\alpha u(p_1)\;G(W^2,t)F_1(t)}_{\mathrm{N}\,+\,\mathcal{P}}$$

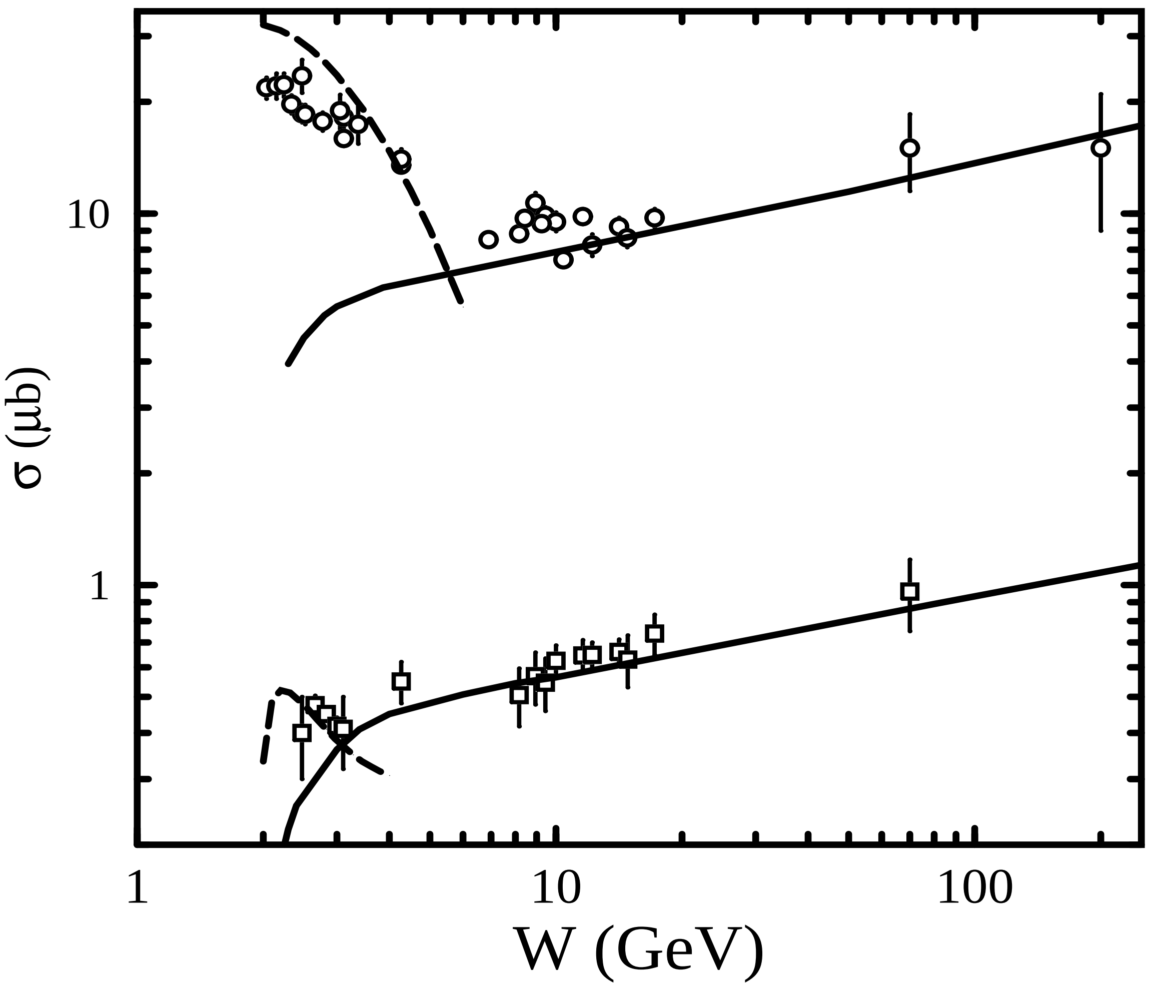
$$t_{\mu\alpha\nu} = 2N_c e_0\;\mathrm{tr}\!\int\!\tilde{\mathrm{d}}k S_u(k_-)\Gamma_\mu S_u(k_-+q)\beta_u\gamma_\alpha S_u(k_+)V_\nu$$

New Elements :

1. Dressed quark-photon vertex: $\Gamma_\mu(k,k)$
   - Must satisfy WTI: $(p_\mu - p'_\mu)i\Gamma_\mu(p,p') = S^{-1}(p) - S^{-1}(p')$.
   - BC vertex $\Rightarrow$ WTI, pQCD limit, determined from $S(p)$.
2. ρ-meson BS amplitude: $V_\nu(k;P) = n_\rho\left(e^{-k^2/a^2} + \frac{c}{1+k^2/b^2}\right)(\gamma_\nu + P_\nu\;\gamma\cdot P/m_\rho^2)$
   - Parameters determined from decays: $\rho \to e^+e^-$, $\rho \to \pi^+\pi^-$.

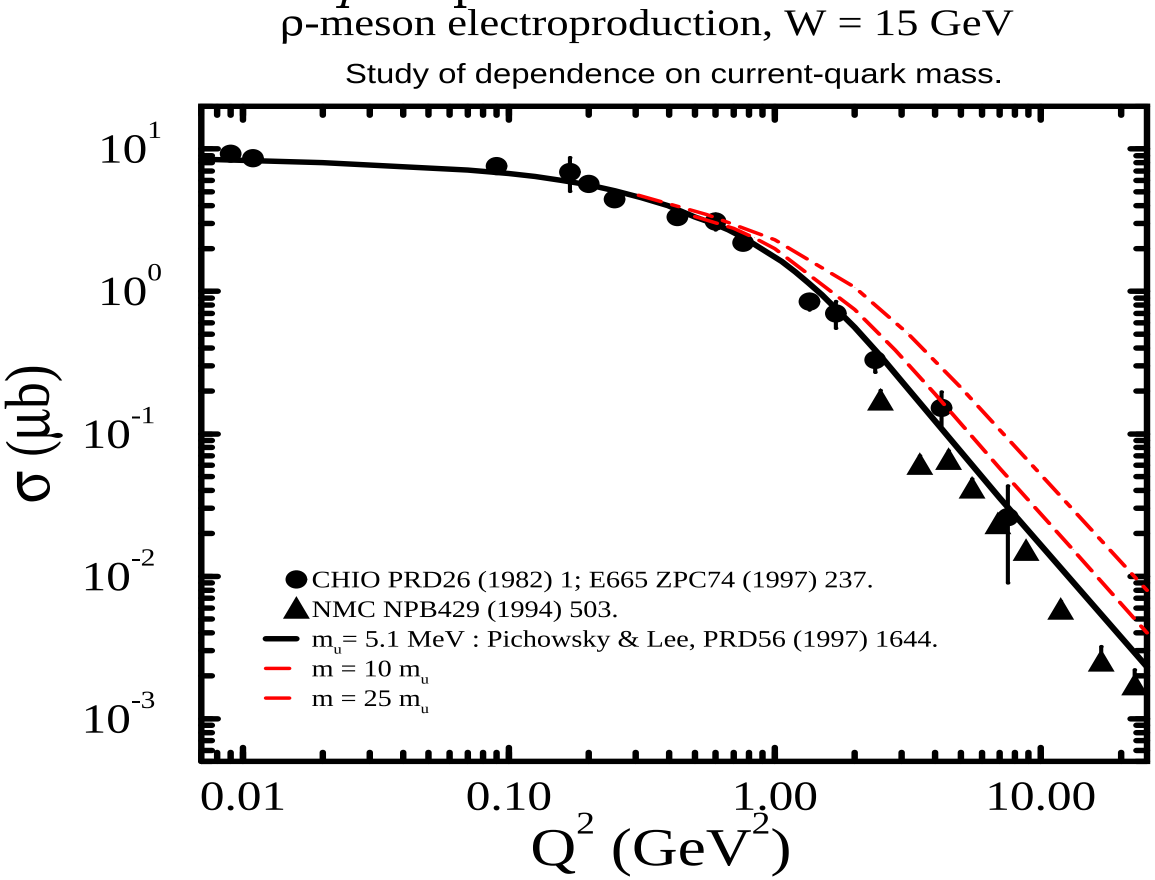
All q^2 dependence from quark loop.

W dependence of ρ and ϕ photoproduction ($q^2 = 0$) :



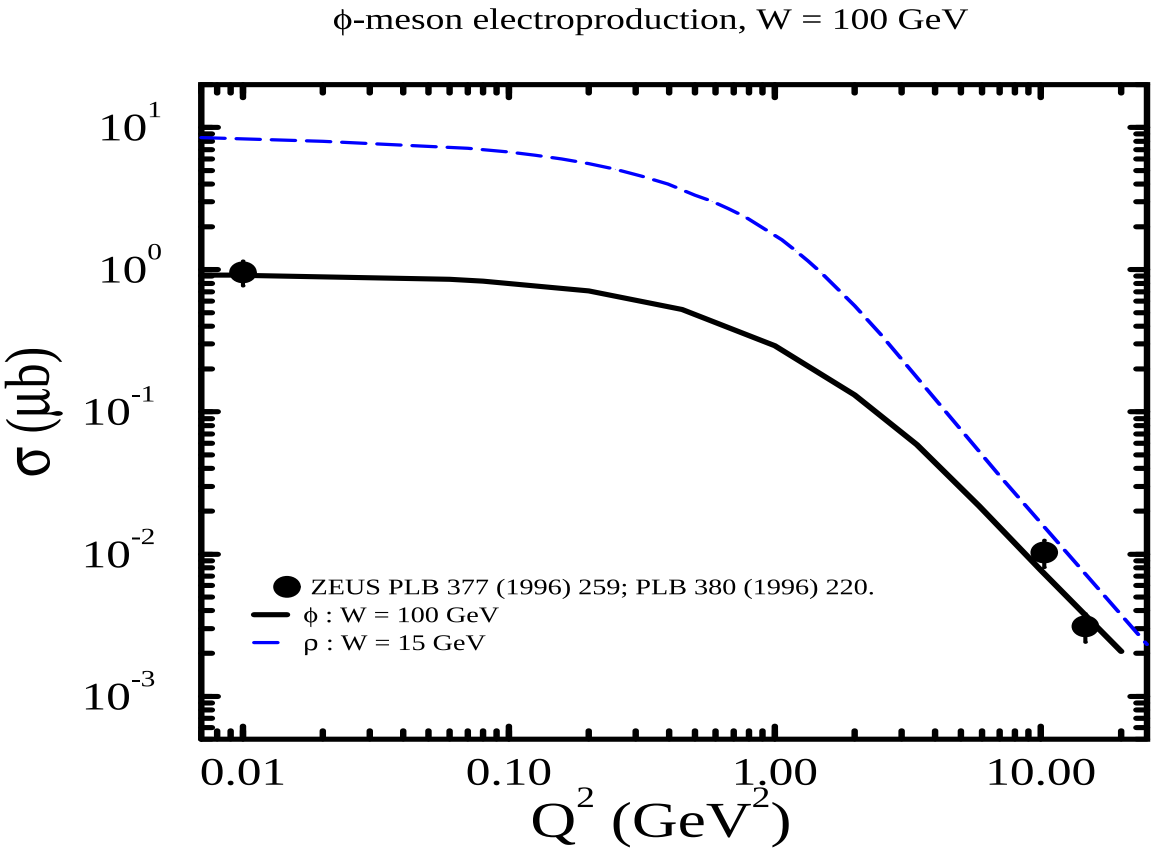
- slow rise with W due to $\alpha_0 = 0.08$.
- Pomeron dominates $\gamma N \to \phi N$ at 3 GeV.

Prediction of q^2 dependence is:



Current-quark mass in quark propagator $S_f(k)$

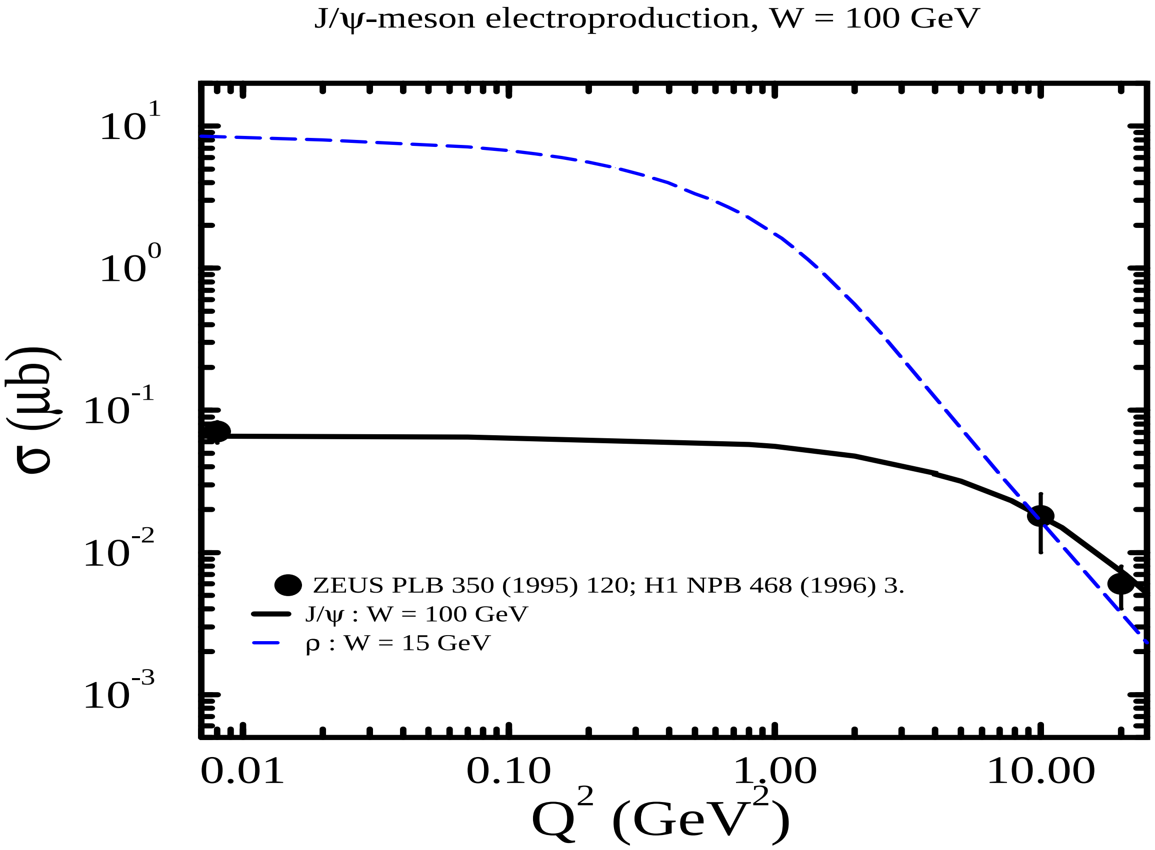
determines onset of asymptotic-q^2 behavior.



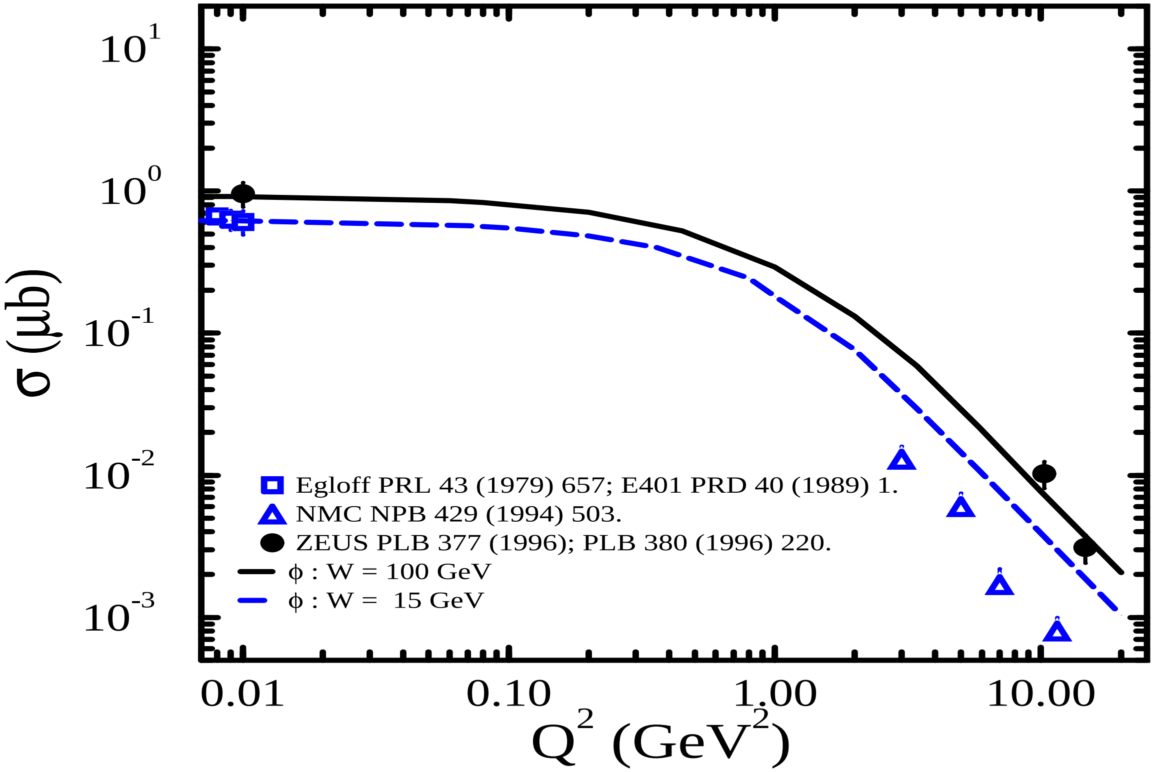
Since $m_s \gg m_u$, σ_ϕ reaches asymp later than σ_ρ.

Good agreement with recent data from HERA.

Finally, prediction of J/ψ electroproduction is:



J/ψ reaches asymptotic behavior at very large q^2!



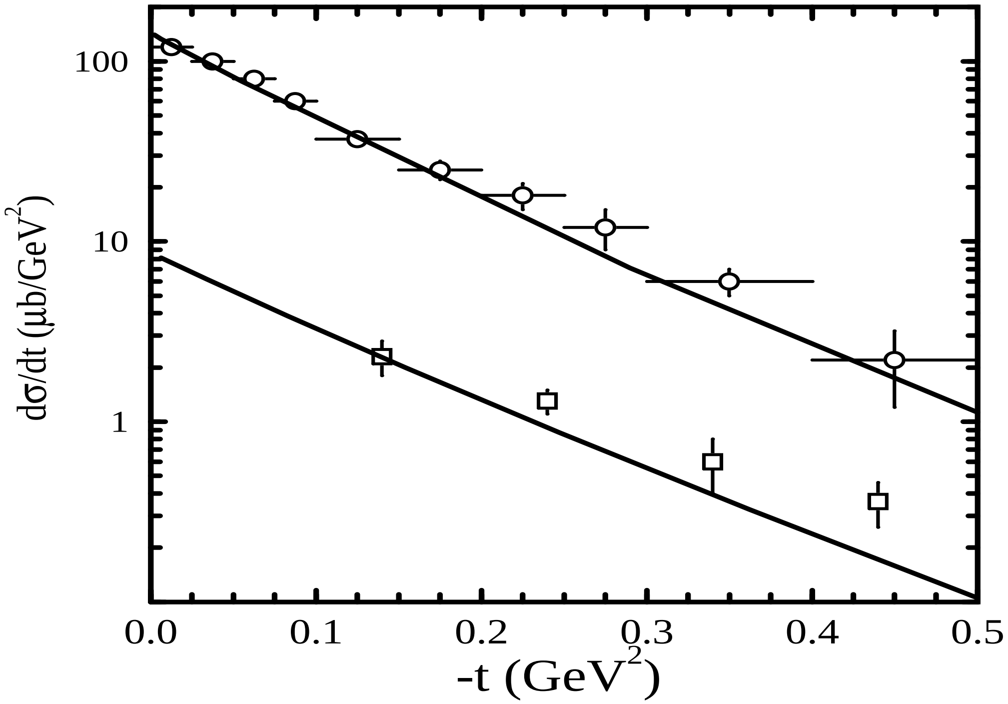
• Model successfully describes *all* data for ϕ electroproduction on *nucleon*.

• NMC data is ϕ electroprod on Carbon, Calcium and Deuterium. Seems to be incompatible with this model.

$\star$ If NMC$_\phi$ *is* representative of ϕ production on nucleon, then at large-q^2 Pomeron energy dependence changes?!?

Need more data here.

t dependence of ρ and ϕ photoproduction ($q^2 = 0$) at $W = 80$ GeV :



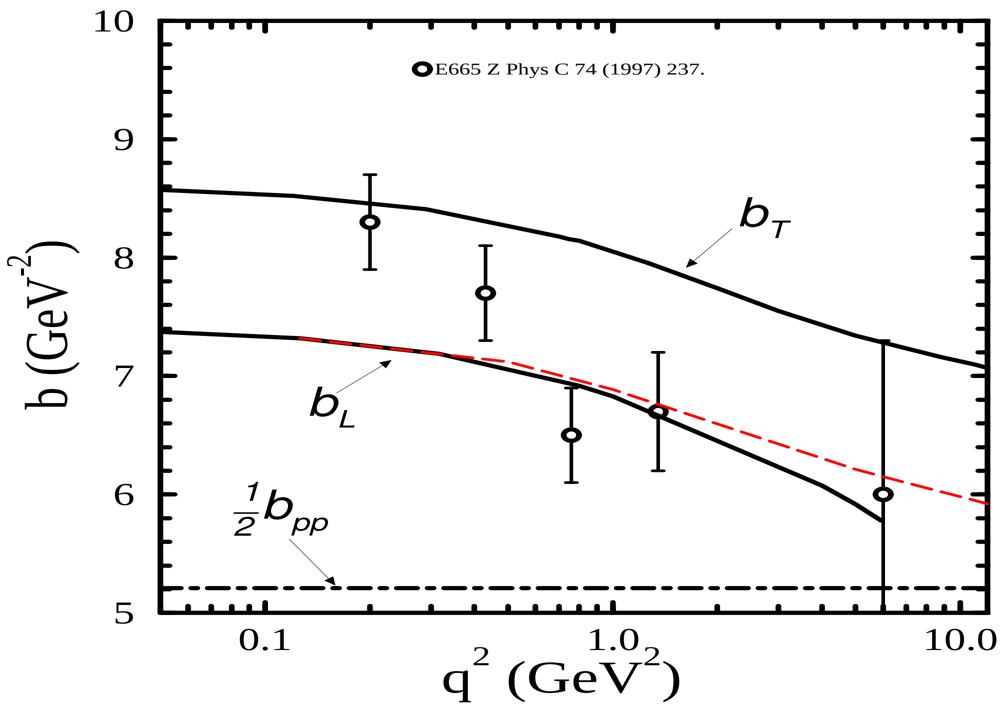
$$\frac{d\sigma}{dt} = A \;\; e^{bt}$$

$$b(W, q^2) = 4.68 \;\; \mathrm{GeV}^{-2} + b_{\mathrm{loop}}(q^2) + 2\alpha_1 \ln(\alpha_1 W^2)$$

- All W dependence comes from Pomeron exchange.
- All q^2 dependence comes from quark loop.

Examine q^2 dependence on b...

$b(q^2)$ for longitudinal (L) and transverse (T) photons in ρ production at $W = 15$ GeV:



- Effective γ–ρ size decreases with q^2.
- Size is smaller for longitudinal photons.
- If we destroy short-distance correlations in ρ meson by "turning off" tail of BS amplitude: b_T unaffected while b_L gets bigger (dashed curve).
  $\Rightarrow b_L$ gets contributions from pQCD, b_T doesn't.

Concluding remarks:

- Dyson-Schwinger framework describes exclusive processes at all energies.

  Single framework for low- and high-energy phenomena.

  e.g., form factors and diffraction.

  Predicts low- and high-q^2 electroproduction cross section.

- q^2 dependence of electroproduction depends on m_f in $S(k)$.

  Explains why σ_ϕ/σ_ρ and $\sigma_{J\psi}/\sigma_\rho$ increase with q^2.

  Raises questions about normalization of NMC$_\phi$ data.

  $\Rightarrow$ Little evidence for strong W dependence at large q^2.

  Need additional ϕ data at $W = 15$ GeV for large q^2... E665?

- Some obs. sensitive to large-k^2 BS amplitude at large q^2.

  e.g., b_L gets small, b_T stays big.

  Interplay of perturbative and non-perturbative QCD is not trivial.