Resonance/Parton Duality in Electroproduction of Pions

Murat Kaskulov, Ulrich Mosel

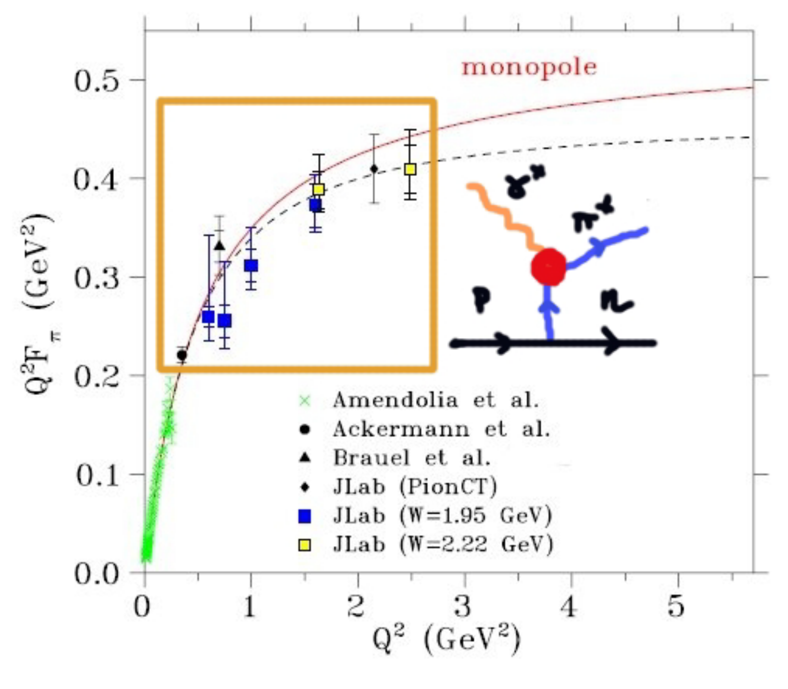
Institut für Theoretische Physik

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Pion e.m. Formfactor

- Pion e.m. FF at larger Q^2 mainly from JLAB, extracted from model for long. X-section

$$\sigma_L \propto \left[\frac{F_\pi(Q^2)}{t - m_\pi^2 + i0^+} \right]^2$$

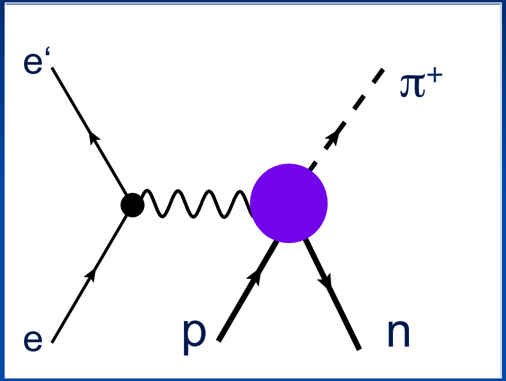


VGL model:

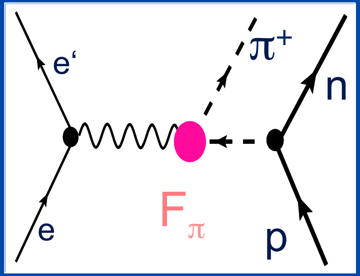
t-channel exchange + Born-graph

and $F_p = F_\pi$

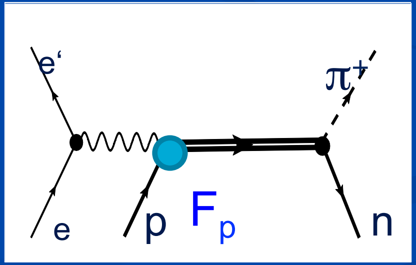
Electro-Pionproduction



=



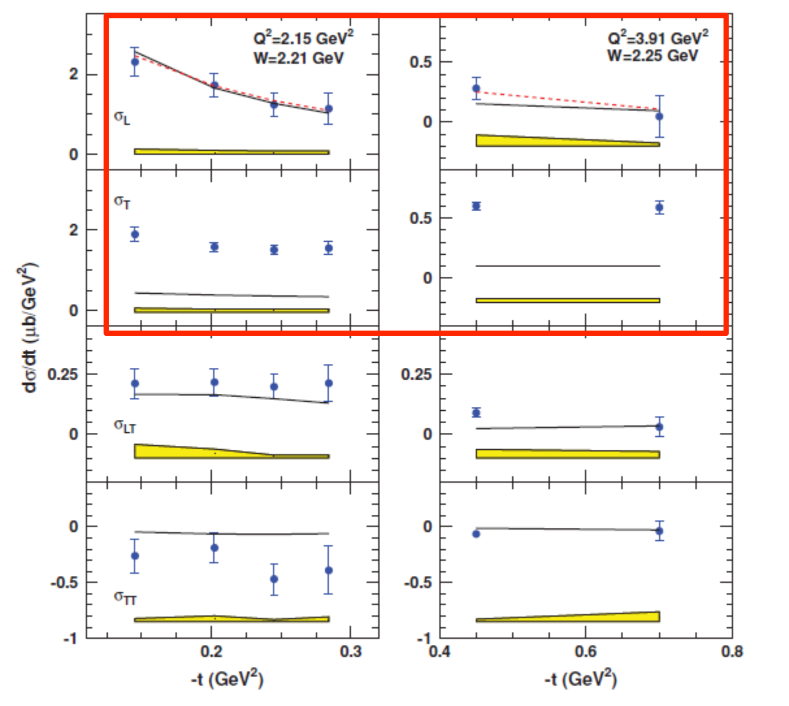
+



*L*ong and *T*ransv Pion Production

- VGL model
  very good for *L*
  dramatically bad for *T*

Nagging thought: can F_π be reliably extracted from a model that fails for *T*?



Data from π-CT Exp. at JLAB,
T. Horn et al., PR C78, 058201 (2008)

General Motivation

- Extraction of pion formfactor relies on model for pion-electroproduction: how good is it?
- QCD (handbag) predicts: $\sigma_L/\sigma_T \propto Q^2$ but σ_T is large, and grows, in JLAB, HERMES data
- Where does pQCD start to work: at JLAB@6 or JLAB@12 or ...?
- Description in terms of partons (GPDs) or hadrons?

Extended VGL Model

- Current for π^+ production

$$-iJ_s^\mu(\gamma^* p \to \pi^+ n) = \sqrt{2} g_{\pi NN} \bar{u}_{s'}(p')\gamma_5 \left[\mathcal{F}_{\gamma\pi\pi}(Q^2,t)\frac{(k+k')^\mu}{t-m_\pi^2+i0^+} + \mathcal{F}_s(Q^2,s,t)\frac{(p+q)_\sigma \gamma^\sigma \gamma^\mu + M_p\gamma^\mu}{s-M_p^2+i0^+} + [\mathcal{F}_{\gamma\pi\pi}(Q^2,t) - \mathcal{F}_s(Q^2,s,t)]\frac{(k-k')^\mu}{Q^2} \right] u_s(p),$$

Reggeize pion propagator

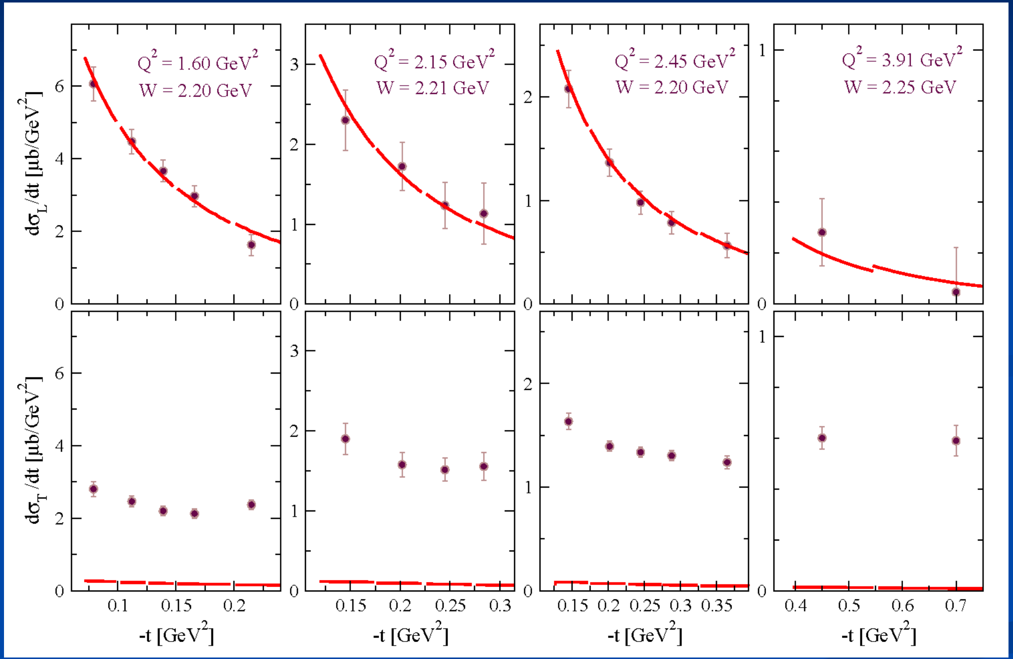
$$\mathcal{D}(t) = \frac{1}{t-m_\pi^2+i0^+} \Longrightarrow \mathcal{R}[\alpha_\pi(t)] = \left[\frac{1+e^{-i\pi\alpha_\pi(t)}}{2}\right](-\alpha'_\pi)\Gamma[-\alpha_\pi(t)]e^{\alpha_\pi(t)\ln(\alpha'_\pi s)},$$

Different e.m. formfactors for π and p, still gauge invariant (Gross-Riska)

Will this cure T problem??

Extended VGL Model

- Extended VGL model very good for *L*
- **still dramatically bad for *T***



L

T

Data: Jlab, Horn et al.

Electro-Pionproduction Facts

Observe

1. $$\sigma_{\mathrm{T}}(e,e'\pi)(Q^2) \sim \sigma_{\mathrm{DIS}}(Q^2)$$ Bebek et al, 1978

2. $$\sigma_L/\sigma_T \to 0 \quad \text{for} \quad Q^2 \to \infty$$ for DIS

Transverse strength by DIS

- Take excl. limit of DIS:

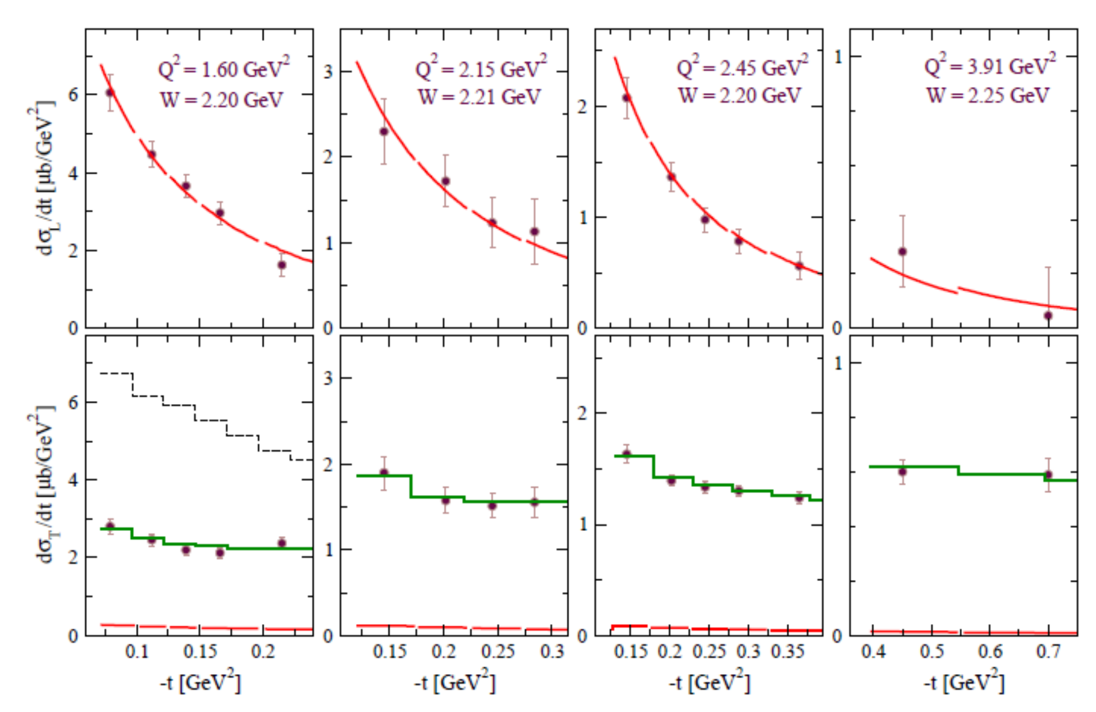
$$p(e,e'\pi^+)X \rightarrow p(e,e'\pi^+)n \quad \text{for} \quad z \rightarrow 1$$

and add excl. DIS cross section:

$$\sigma = \sigma(t-\text{channel} + \text{Born}) + \sigma(\text{DIS})$$

‚exclusive' DIS describes *T*

- Use PYTHIA to calculate DIS
- Excellent Description of *L*, determined by *t*-channel + Born (red)
- Excellent description of *T*, determined by DIS (green)



Institut für Theoretische Physik
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

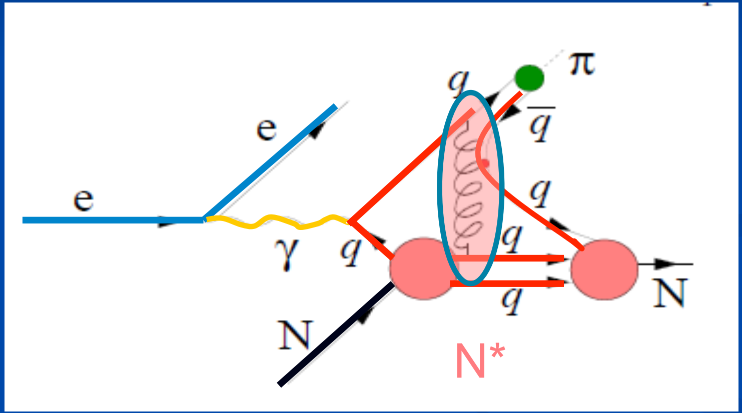
Improvement: Amplitudes

- Model works very well, but cannot give mixed *LT* X-sections
- String breaking gives only X-sections, not amplitudes

Partons in Electro-Pionproduction

- Use PYTHIA to calculate excl. DIS

- Stringbreak → DIS



- DIS = N* (W > 2 GeV, resonances overlap)

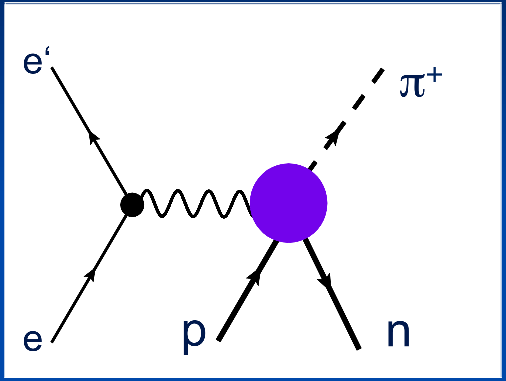
Improvement: amplitudes

- Exps. (JLAB, HERMES) cover W ~ 2 – 4 GeV, region of overlapping nucleon resonances all with pion decay channels

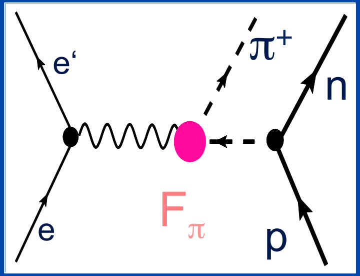
- Add sum over (many) N*s to Born-term

- Use duality to connect N* properties with partons

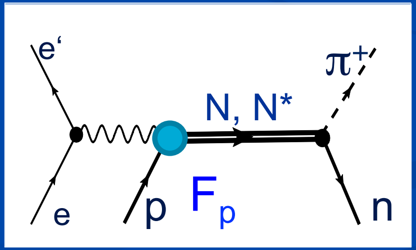
Electro-Pionproduction



=



+ $\sum_{N^*}$



N* contribution to π⁺ production

- Current for π^+ production

$$-iJ_s^\mu(\gamma^* p \to \pi^+ n)$$
$$= \sqrt{2} g_{\pi NN} \bar{u}_{s'}(p')\gamma_5 \Big[\mathcal{F}_{\gamma\pi\pi}(Q^2,t)\frac{(k+k')^\mu}{t-m_\pi^2+i0+}$$
$$+\mathcal{F}_s(Q^2,s,t)\frac{(p+q)_\sigma \gamma^\sigma \gamma^\mu + M_p \gamma^\mu}{s-M_p^2+i0+}$$
$$+[\mathcal{F}_{\gamma\pi\pi}(Q^2,t)-\mathcal{F}_s(Q^2,s,t)]\frac{(k-k')^\mu}{Q^2}\Big] u_s(p),$$

- Replace

$$\frac{F_s(Q^2,M_p)}{s-M_p^2+i0+} \to \sum_i r(M_i)c(M_i)\frac{F(Q^2,M_i^2)}{s-M_i^2+i0+},$$

and

$$\sum_i \to \int_{M_p^2}^\infty dM_i^2 \rho(M_i^2).$$

e.m. Coupling strong

Density of N* resonances

Institut für Theoretische Physik
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

N*-parton connection

- Local Bloom-Gilman duality:

$$F_2^p(x_B, Q^2) = \sum_i (M_i^2 - M_p^2 + Q^2) W(Q^2, M_i) \delta(s - M_i^2),$$

with $$W(Q^2, M_i) = r^2(M_i)[F(Q^2, M_i)]^2, \quad F(0, M_i) = 1.$$

- Integrate over M_i

$$F_2^p(x_B, Q^2) = (s - M_p^2 + Q^2) r^2(s) [F(Q^2, s)]^2 \rho(s).$$

Density of resonances

Relation between structure function F_2 and formfactor F

N*-parton connection

Duality

$$F_2^p(\omega') \propto (\omega' - 1)^3,$$

$$\omega' = 1 + W^2/Q^2$$

$$F(Q^2, M_i^2) = \left(\frac{1}{1 + \xi \frac{Q^2}{M_i^2}}\right)^2,$$

$$(\omega' - 1)^3 \propto Q^2 \frac{(\omega' - 1)^4}{\xi^4} r^2(s)\rho(s).$$

$$r^2(s)\rho(s) \propto \frac{1}{Q^2(\omega' - 1)} = \frac{1}{s}.$$

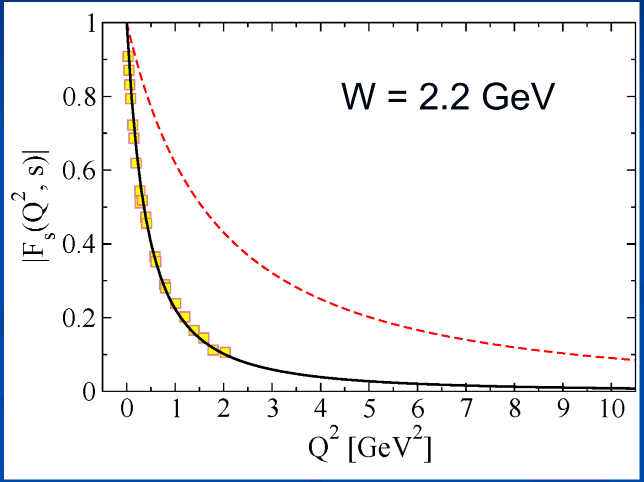
e.m. coupling *r(s)* decreases with *s*

-> *Integral over all resonances converges*

N* contribution to π^+ production

- ‚effective Born-Term FF'

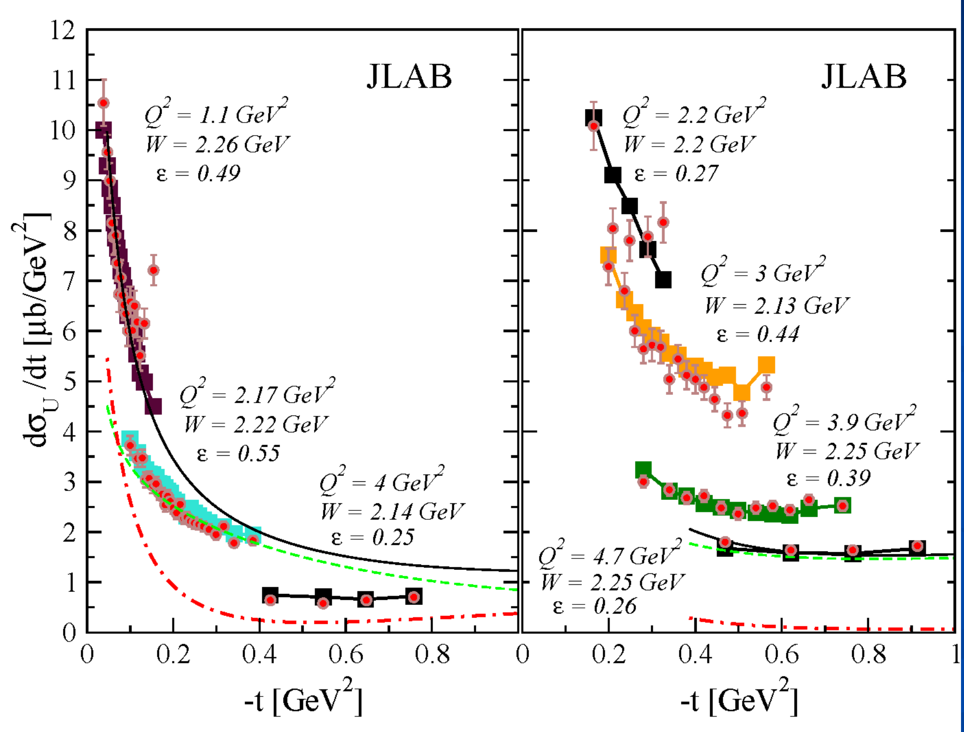
$$F_s(Q^2, s) = \frac{\int_{M_p^2}^{\infty} ds_i \frac{s_i^{-\beta}}{s - s_i + i0^+} \left(\frac{1}{1 + \xi \frac{Q^2}{s_i}} \right)^2}{\int_{M_p^2}^{\infty} ds_i \frac{s_i^{-\beta}}{s - s_i + i0^+}},$$



harder for higher resonances:
consequence of BG duality

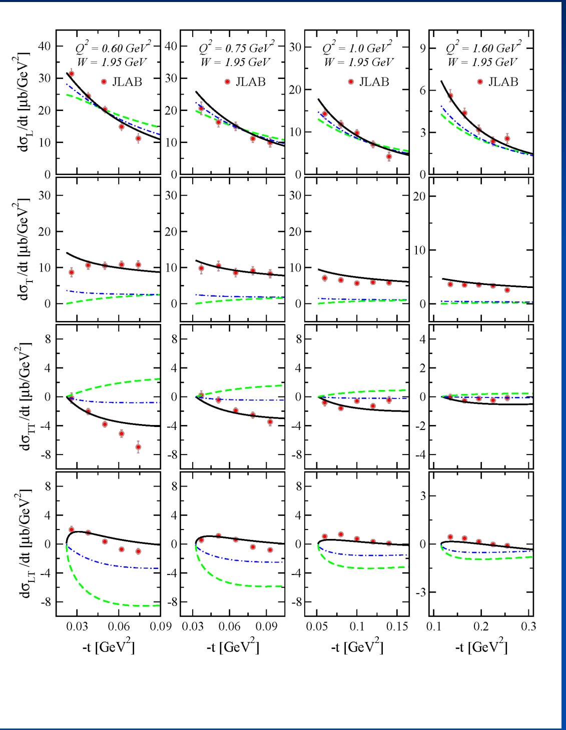
Dashed: model
Solid: free proton

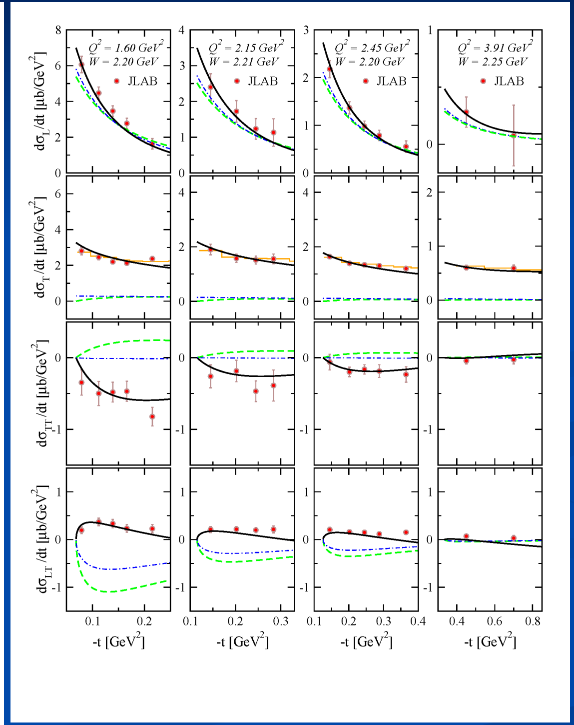
Q^2-, ε-dependence



N* contribution to π^+ production

Perfect agreement over wide range of Q^2





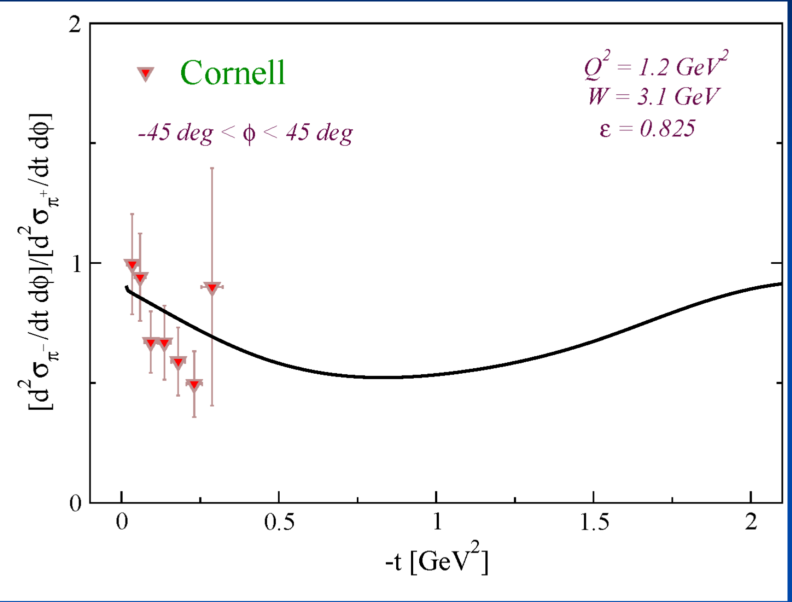
Data from F-π2, π-CT expts.

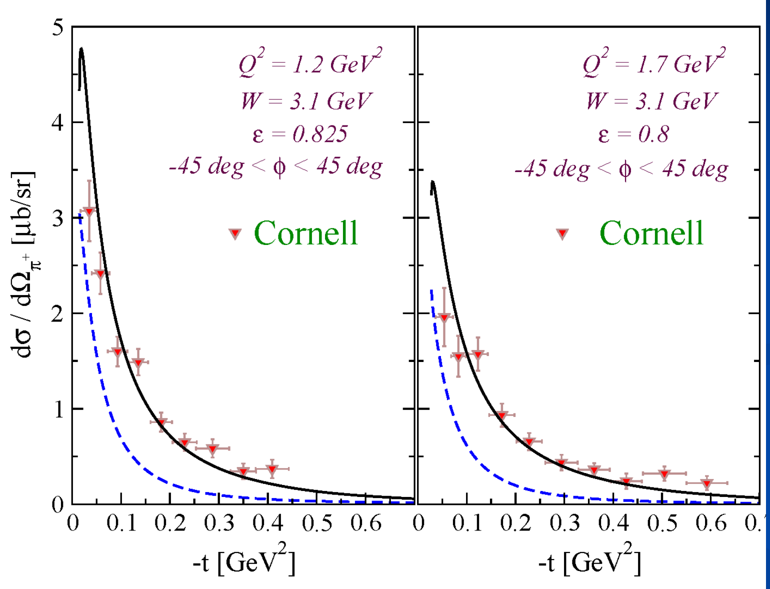
Green: *t*-channel

dashed: *t* + Born

solid: *t* + Born + res

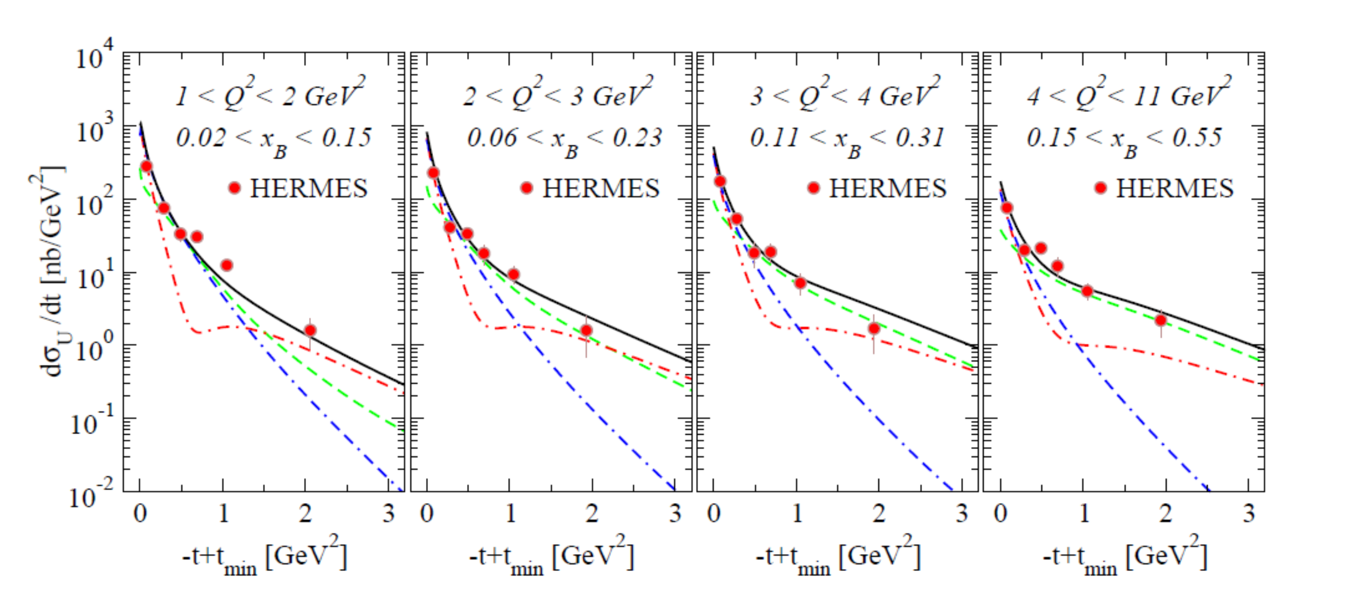
Benchmark for JLAB@12





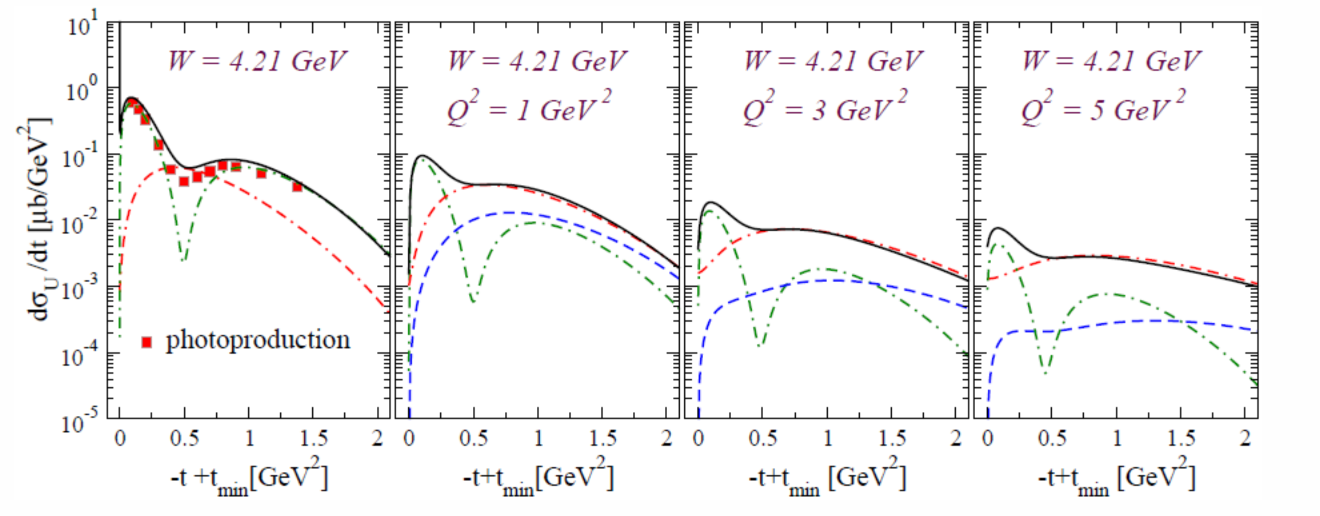
W ~ 3 GeV

π^+ production at HERMES



Red: resonance, Green: L, blue: t-channel

π_0 photo- + electroproduction



Data: HERMES

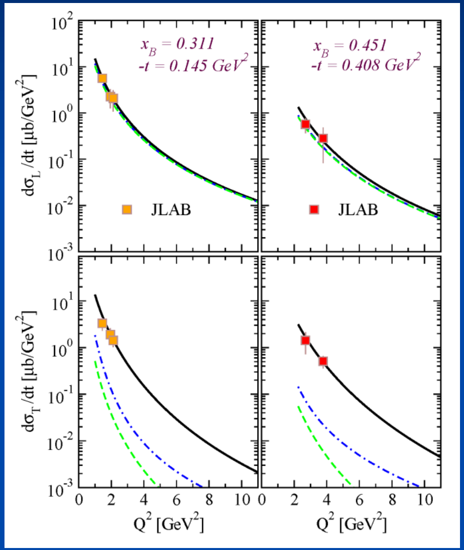
dash-dash-dotted: resonance, dash-dotted: *t*-channel, dashed: *L*-contrib

M. Kaskulov, arXiv:1105.1993 [nucl-th]

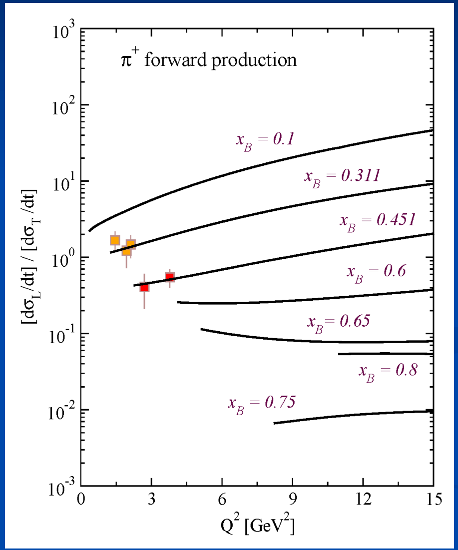
Q^2 scaling of *L* and *T*

L

T



L/T



Hard scattering Prediction:

$\sigma_L/\sigma_T \sim Q^2$

T very different from hard scattering prediction (Horn et al)

Res/parton model predicts increase with Q^2 only for small *x*

Summary

- Any good reaction model of pion production has to describe both *T* and *L* components
- Transverse strength from resonance contributions
- Cornell, DESY and JLAB data are all described, with same model, same parameters
- Transverse pion production does not follow QCD scaling law at JLAB@5 and JLAB@12
- QCD scaling for *L/T* holds only for small $x < 0.5$

References

- Neutral pion electroproduction in p(e,e′π0)p above s√>2 GeV
  Murat M. Kaskulov. May 2011. 12 pp. e-Print: arXiv:1105.1993 [nucl-th]
- Exclusive pion electroproduction off nucleons and nuclei.
  Murat M. Kaskulov, Ulrich Mosel (Giessen U.). Mar 2011. 15 pp. NAPP 2010, e-Print: arXiv:1103.1602 [nucl-th]
- Beam spin asymmetry in deeply virtual π production.
  Murat M. Kaskulov, Ulrich Mosel. Jan 2011. 5 pp. SPIN 2010, e-Print: arXiv:1101.6042 [hep-ph]
- Deep exclusive charged π electroproduction above the resonance region.
  Murat M. Kaskulov, Ulrich Mosel (Giessen U.). Jan 2010. 29 pp. Phys.Rev. C81 (2010) 045202
  e-Print: arXiv:1001.1952 [hep-ph]
- Deep exclusive electroproduction of pi+ from data measured with the HERMES detector at DESY.
  Murat M. Kaskulov, Ulrich Mosel (Giessen U.). Apr 2009. 10 pp., Phys.Rev. C80 (2009) 028202
  e-Print: arXiv:0904.4442 [hep-ph]
- Deeply inelastic pions in the exclusive reaction p(e, e' pi+)n above the resonance region.
  Murat M. Kaskulov, Kai Gallmeister, Ulrich Mosel (Giessen U.). Apr 2008. 4 pp.
  Phys.Rev. D78 (2008) 114022, e-Print: arXiv:0804.1834 [hep-ph]