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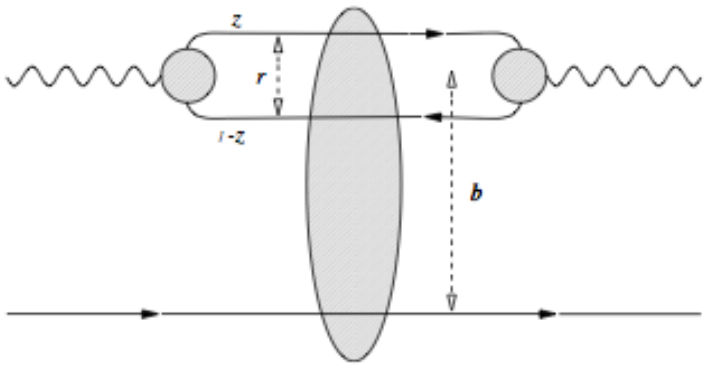
Diffractive meson production at HERA with AdS/QCD holographic wavefunctions

Ruben Sandapen

DIS 2013, Marseille

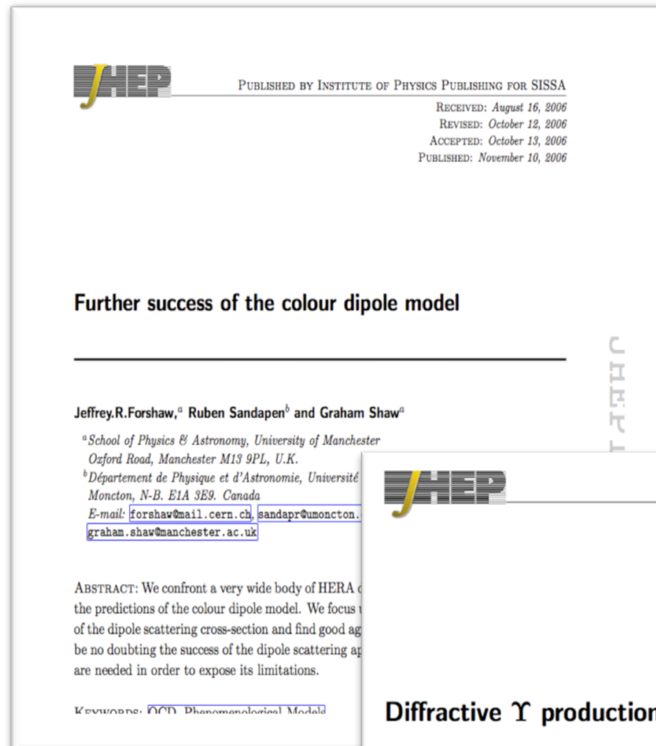
Diffractive scattering in the color dipole model



$$\Im m\, A^{\lambda} = \int \Psi^{\gamma,\lambda}_{h,\bar{h}}(r,z)\,\sigma(r,W)\,\Psi^{\rho,\lambda}_{h,\bar{h}}(r,z)$$

- The universal dipole cross-section is well constrained by the very precise DIS F_2 HERA data. Also used to make predictions for the LHC

- We use here a Color-Glass-Condensate dipole model by G. Soyez (2007). Other (forward) dipole models that fit the F_2 data give similar results


JHEP
Published by Institute of Physics Publishing for SISSA
Received: August 16, 2006
Revised: October 12, 2006
Accepted: October 13, 2006
Published: November 10, 2006

Further success of the colour dipole model

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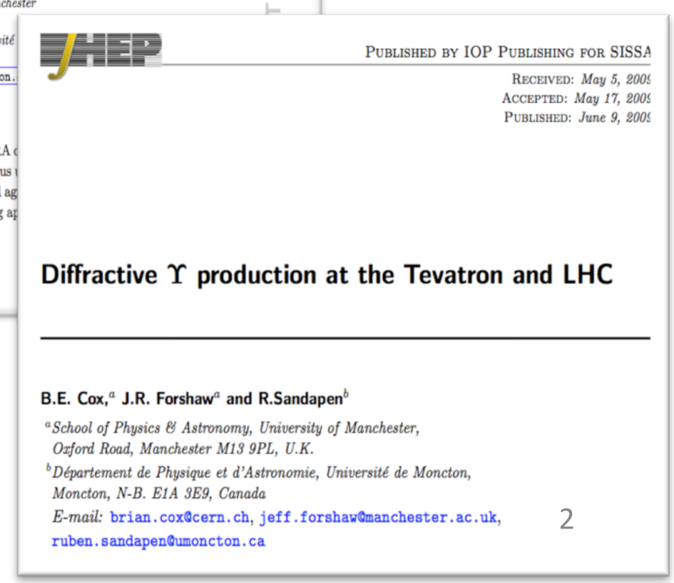
Abstract: We confront a very wide body of HERA
the predictions of the colour dipole model. We focus
of the dipole scattering cross-section and find good ag
be no doubting the success of the dipole scattering ap
are needed in order to expose its limitations.


JHEP
Published by IOP Publishing for SISSA
Received: May 5, 200
Accepted: May 17, 200
Published: June 9, 200

Diffractive Υ production at the Tevatron and LHC

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- ✓ F_2^c
- ✓ DVCS
- ✓ F_2D^3
- ✓ J/Ψ

Light-front wavefunctions

- J. R. Forshaw, RS & G. Shaw PRD (2004) D69 094013
- J. Nemchik et al. Z.Phys. C75 (1997) 71.

Spinor wavefunction x Scalar wavefunction

$$\Psi^{\rho\{\lambda\}}_{h,\bar{h}}(\mathbf{k},z) \propto S^{\rho,\lambda}_{h,\bar{h}}(\mathbf{k},z) \times \phi(\mathbf{k},z)$$

$$S^{\rho,\lambda}_{h,\bar{h}}(\mathbf{k},z) = \frac{\bar{u}_h(\mathbf{k})}{\sqrt{z}}\gamma^{\mu} \cdot e^{\lambda}_{\mu} \frac{v_{\bar{h}}(-\mathbf{k})}{\sqrt{1-z}}$$

Scalar part is not computable from first principles in QCD (confinement)

Earlier: Boost a non-relativistic Schroedinger wavefunction (Boosted Gaussian)

$$\phi_{LC}\left(\frac{k^2+m_f^2}{4z(1-z)}-m_f^2\right) \leftrightarrow \phi_{CM}(\vec{L})$$

Now: Use AdS/QCD light-front wavefunction

Light-Front Schroedinger Equation (LFSE) and wavefunctions

Brodsky & de Teramond (PRL, 2009)

In light-front QCD, the meson wavefunction has a factorized form

$$\phi(\zeta, z, \varphi) = \frac{\Phi(\zeta)}{\sqrt{2\pi\zeta}} f(z) e^{iL\varphi}$$

Massless quarks

$$\zeta = \sqrt{z(1-z)}r \qquad z = \frac{k^+}{P^+}$$

where

$$\left(-\frac{d^2}{d\zeta^2} - \frac{1-4L^2}{4\zeta^2} + U(\zeta)\right)\Phi(\zeta) = M^2\Phi(\zeta)$$

Holographic LFSE

S. Brodsky & G. de Teramond (PRL, 2009)

$$\left(-\frac{d^2}{d\zeta^2}-\frac{1-4L^2}{4\zeta^2}+U(\zeta)\right)\Phi(\zeta)=M^2\Phi(\zeta)$$

- If

$$U(\zeta)=0$$

$$\zeta \leftrightarrow z_5$$

$$(m_5 R)^2 \leftrightarrow L^2-(J-2)^2$$

Massless quarks

then LFSE in 4D maps onto EOM of strings propagating freely in 5D AdS

- Breaking the conformal symmetry in AdS yields the interacting potential in 4D

$$U(z_5)=\frac{1}{2}\varphi''(z_5)+\frac{1}{4}\varphi'(z_5)^2+\frac{2J-3}{2z_5}\varphi'(z_5)$$

Quadratic dilaton profile

Phenomenological & theoretical arguments constrain the dilation profile to be quadratic

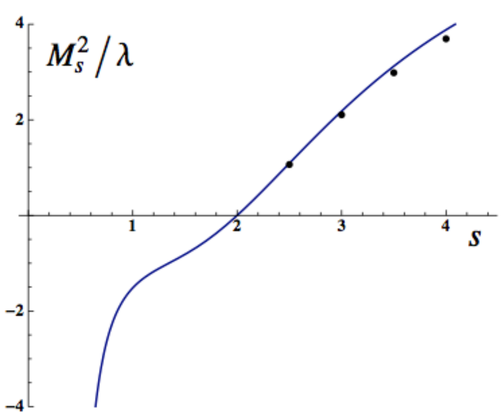
S. Brodsky, G. de Teramond & H. G. Dosch (2013) **arXiv:1302.5399**

$$\varphi \propto z_5^p$$

$$\Longrightarrow p = 2$$

$$\varphi = \kappa^4 z_5^2$$

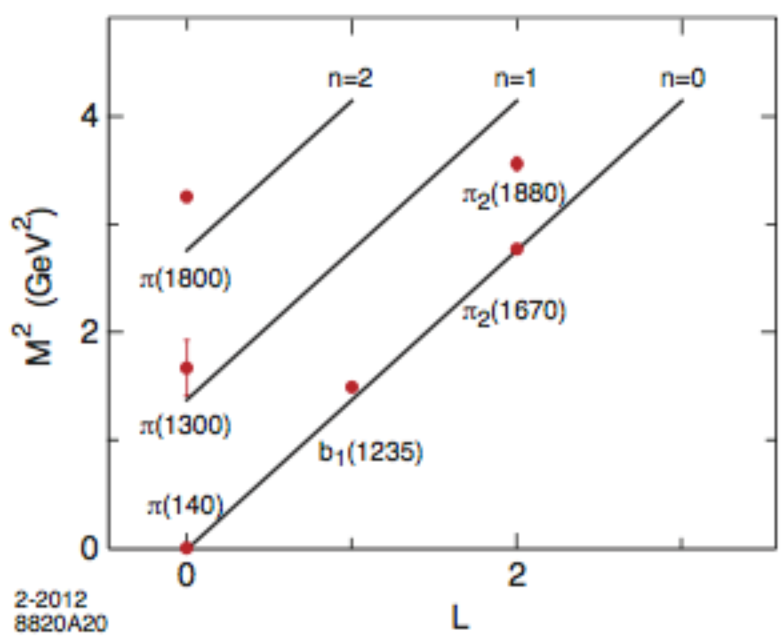
- Massless pion in the chiral limit
- Linear Regge trajectories
- Conformal symmetry in 1D

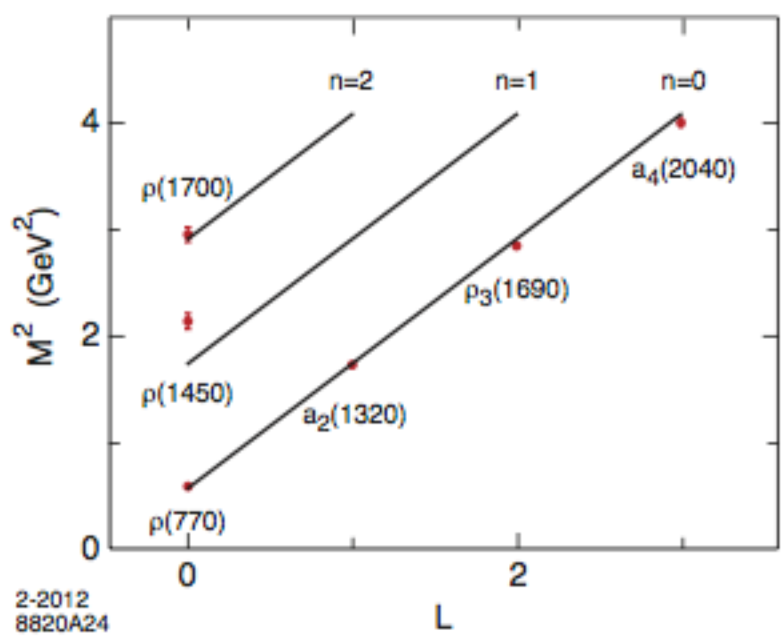


$$U(\zeta) = \kappa^4 z_5^2 + 2\kappa^2 (J-1)$$

Eigenvalues of the holographic LFSE

$$M_{nL,S}^2 = 4\kappa^2\left(n + L + \frac{S}{2}\right)$$





- Massless pion
- ρ meson family : κ=0.54 GeV

Figure from Stan Brodsky

Solving the holographic LFSE for the ρ

$$\rho : S = 1, n = 0, L = 0$$

$$M_\rho^2 = 2\kappa^2$$

$$\phi(z,\zeta) \propto f(z)\exp\left(-\frac{\kappa^2\zeta^2}{2}\right)$$

Compare Polchinski-Strassler expression in AdS to Drell-Yan-West expression in LFQCD for charged pion EM form factor

$$f(z) = \sqrt{z(1-z)}$$

Massive quarks

The Fourier conjugate to ζ squared is the invariant mass squared of the quark-antiquark pair

$$\zeta^2 \sim M^2_{q\bar{q}}$$

$$M^2_{q\bar{q}} = \frac{k^2}{z(1-z)} \rightarrow \frac{k^2 + m_f^2}{z(1-z)}$$

$$\phi_{1S}(z,\zeta) \propto \sqrt{z(1-z)}\exp\left(-\frac{\kappa^2\zeta^2}{2}\right)\exp\left(-\frac{m_f^2}{2\kappa^2 z(1-z)}\right)$$

Prescription by Brodsky & de Teramond to account for massive quarks

AdS/QCD versus Boosted Gaussian (BG) wavefunction

A parameterization which accommodates both AdS/QCD and BG

$$\phi_{1S}(z,\zeta) \propto [z(1-z)]^{\beta} \exp\left(-\frac{\kappa^2\zeta^2}{2}\right)\exp\left(-\frac{m_f^2}{2\kappa^2 z(1-z)}\right)$$

Boosting in 4D | NR SE with harmonic oscillator potential → (Solve & Boost) → BG wavefunction

Duality 4D/5D | Holographic LFSE with quadratic dilaton → (Solve) → AdS/QCD wavefunction

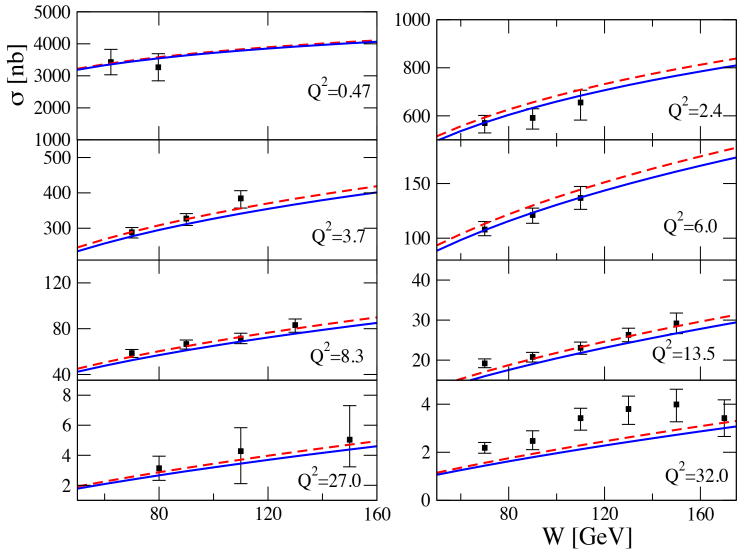
Boost invariant

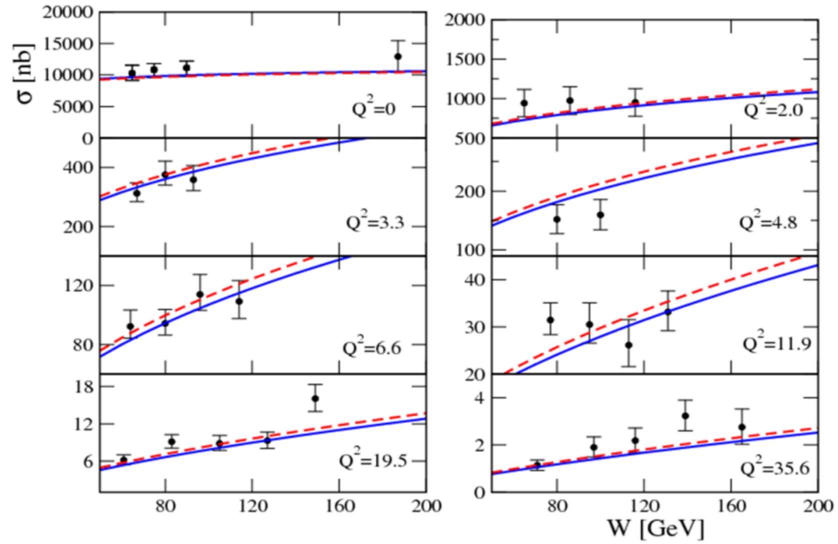
BG: κ is a free parameter to be fixed by decay width datum and $\beta=1$.

AdS/QCD: κ is fixed by the ρ mass and $\beta=0.5$. We have a prediction for decay width.

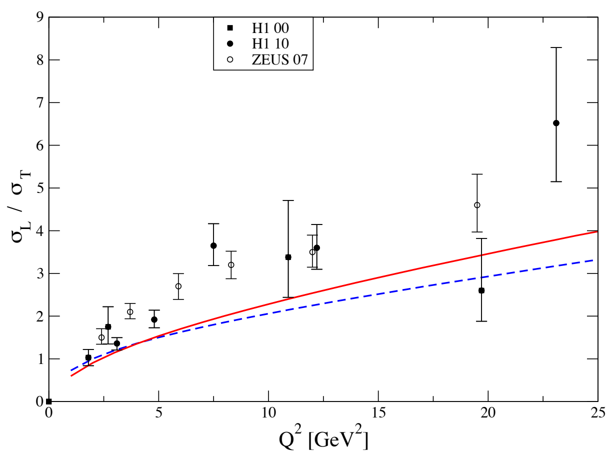
Data prefer AdS/QCD wavefunction

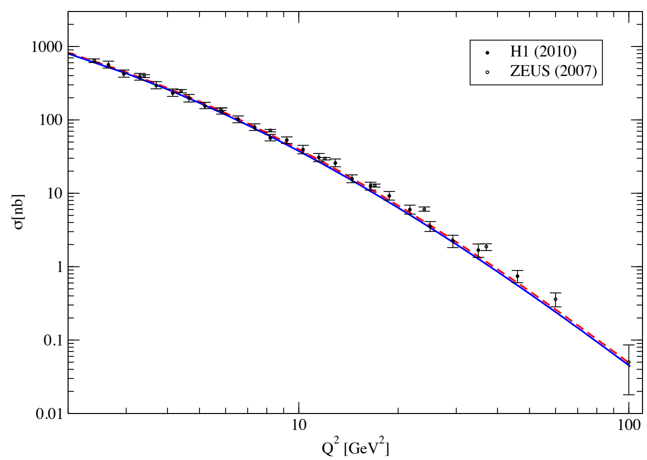
J. R. Forshaw & R. Sandapen (PRL, 2012)





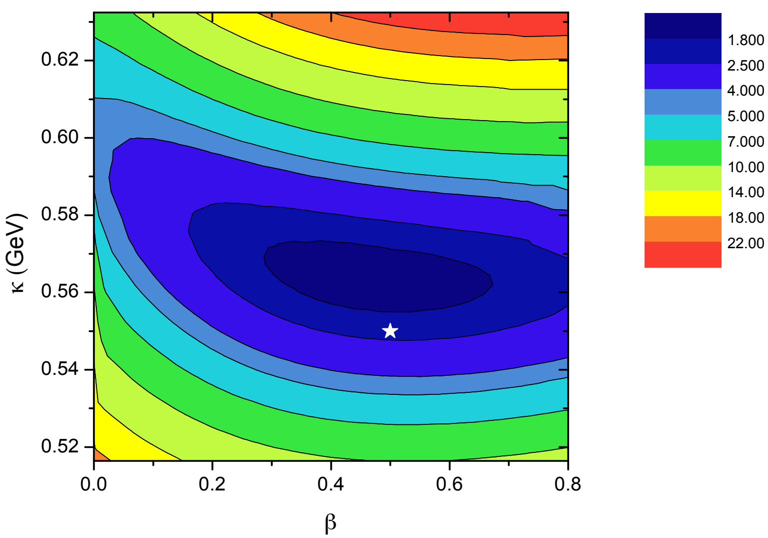
Blue: AdS/QCD
Red: Fit





χ^2 contour plot

$$\phi_{1S}(z,\zeta) \propto [z(1-z)]^{\beta} \exp\left(-\frac{\kappa^2\zeta^2}{2}\right)\exp\left(-\frac{m_f^2}{2\kappa^2 z(1-z)}\right)$$



JRF & RS, PRL (2012)

- White star is the AdS/QCD prediction
- BG prediction lies on far right

Prediction for the electronic decay width

JRF & RS (PRL, 2012)

$$f_\rho = \left(\frac{3\Gamma_{e^+e^-} M_\rho}{4\pi\alpha_{em}^2} \right)^{1/2}$$

$$f_\rho = \frac{1}{2} \left(\frac{N_c}{\pi} \right)^{1/2} \int_0^1 dz \left(1 + \frac{m_f^2 - \nabla^2}{M_\rho^2 z(1-z)} \right) \phi_L(z, \zeta = 0)$$

AdS/QCD $\Gamma_{e^+e^-} = 6.66\ KeV$

Experiment $\Gamma_{e^+e^-} = 7.04 \pm 0.06\ KeV$

Distribution Amplitudes for the ρ meson

JRF & RS (PRL, 2012)

- Moment of twist-2 DA of the longitudinally polarized ρ

$$\varphi(z,\mu) = \left(\frac{N_c}{\pi}\right)^{1/2} \frac{1}{2f_\rho} \int db\mu J_1(\mu r)\left(1 + \frac{m_f^2 - \nabla^2}{M_\rho^2 z(1-z)}\right)\phi(z,\zeta)$$

$$\int_0^1 dz(2z-1)^2\varphi(z,\mu)$$

  - AdS/QCD: 0.228, μ~1 GeV
  - Sum Rules: 0.24 +/- 0.02 , μ=2 GeV
  - Lattice: 0.24 +/- 0.04 at μ=2 GeV

- Can extend to twist-2 and twist-3 DAs of the transversely polarized ρ

Useful to compute power corrections in radiative B decay to the ρ: see talk by RS in WG2

Eur. Phys. J. C (2012) 72:1869
DOI 10.1140/epjc/s10052-012-1869-5

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

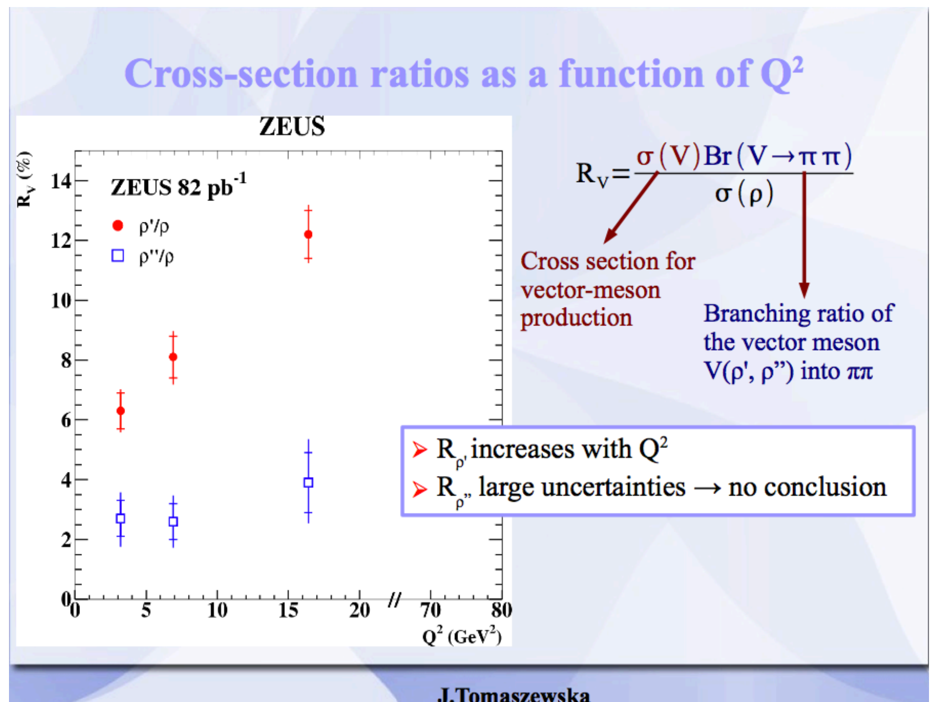
Exclusive electroproduction of two pions at HERA

The ZEUS Collaboration

- By measuring the spectra of two-pion electroproduction, ZEUS extracted the cross-section ratios:

$$R_{\rho'(\rho'')} \equiv \frac{\sigma(\gamma^* p \to \rho'(\rho'')p) \times BR(\rho'(\rho'') \to \pi^+\pi^-)}{\sigma(\gamma^* p \to \rho p)}$$

- The BR of ρ' and ρ" to pions are not well measured.



Branching ratios and mixing

- Branching ratios from an analysis by Donnachie & Mirzaie

A. Donnachie and H. Mirzaie, *Evidence for two ρ′ (1600) resonances*, *Z.Phys.* **C33** (1987) 407.

$$B_{\rho' \to \pi^+\pi^-} = 0.0593 \pm 0.0126 \qquad B_{\rho'' \to \pi^+\pi^-} = 0.0787 \pm 0.0445 \ .$$

- Mixing angle as a free parameter

$$|\rho\rangle = |1S\rangle \ ,$$

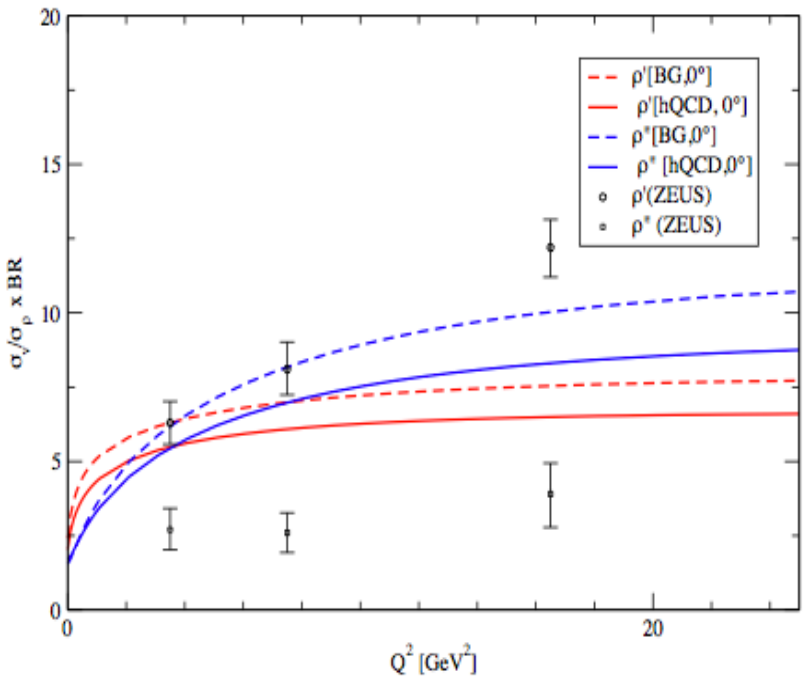
$$|\rho'\rangle = -\cos\theta|2S\rangle + \sin\theta|3S\rangle \ ,$$

$$|\rho''\rangle = \sin\theta|2S\rangle + \cos\theta|3S\rangle$$

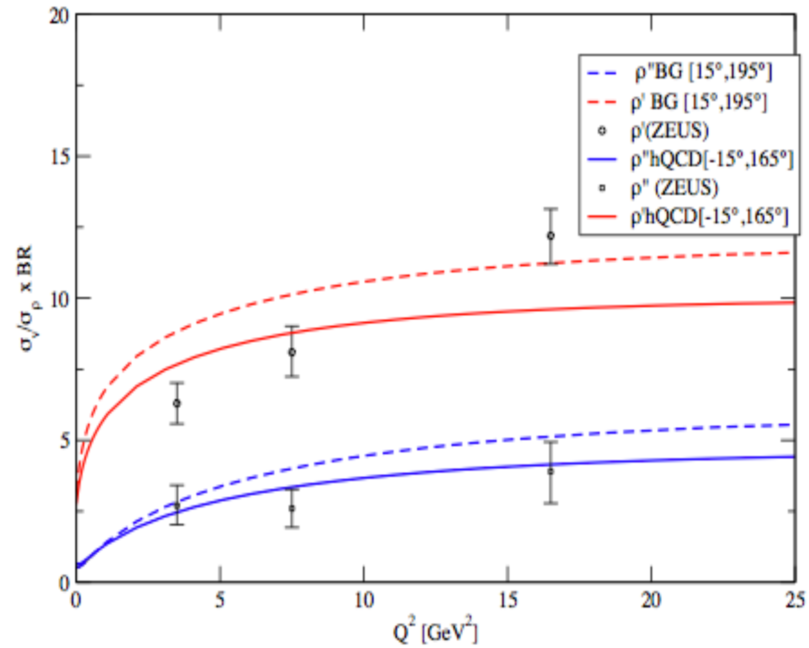
Predictions for ratios of cross-sections

Prelim.

No mixing



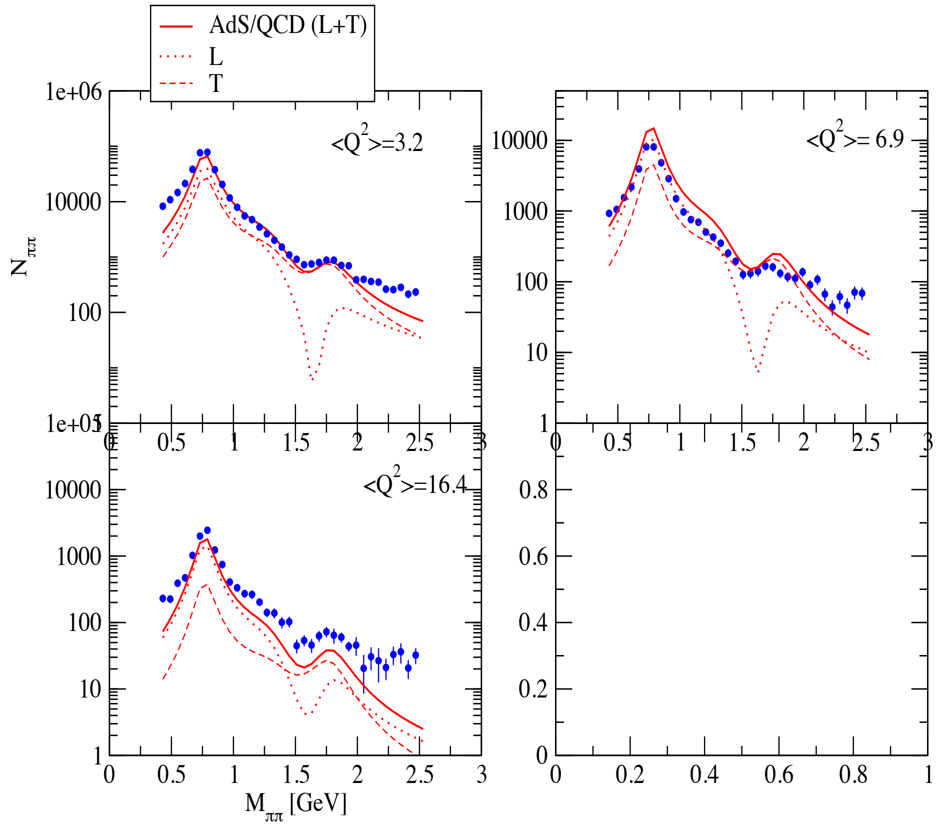
With mixing



- Reasonable description of the available data with a mixing angle of $\theta = 15$ deg.
- But can also fix $\theta=0$ deg. and then adjust BR to fit data.

The two-pion spectra

Prelim.



- Data from ZEUS Collaboration (2012)
- AdS/QCD predictions : dotted (L), dashed (T), solid (L+T)
- Predictions sensitive to the Breit-Wigner distributions but not to wavefunction (AdS/QCD or BG)
- Need to predict over a wider Q^2 range

$$\frac{\mathrm{d}\sigma^L}{\mathrm{d}M^2_{\pi\pi}} = \frac{1}{16\pi}\int \mathrm{d}t|\mathcal{A}^L(s,t;M^2_{\pi\pi})|^2$$

$$BW_V(M^2_{\pi\pi}) = \frac{M_V^2}{M_V^2 - M^2_{\pi\pi} - iM_V\Gamma_V(M^2_{\pi\pi})}$$

$$\mathcal{A}^L(s,t,Q^2;M^2_{\pi\pi}) = \sum_V \sqrt{BR_V} \times \mathcal{A}^L_V(s,t,Q^2) \times BW_V(M^2_{\pi\pi})$$

Conclusions & Outlook

- AdS/QCD wavefunction preferred to BG wavefunction by HERA data on diffractive ρ production

- Data may allow for quantum mechanical mixing between radial excitations of the ρ

- Work is in progress for the two-pion mass spectra

Acknowledgements

- Financial support from University of Moncton & Mount Allison University
- Useful discussions with Stan Brodsky & Guy de Teramond