Pion structure function at small x

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Cyprus, June 27, 2012

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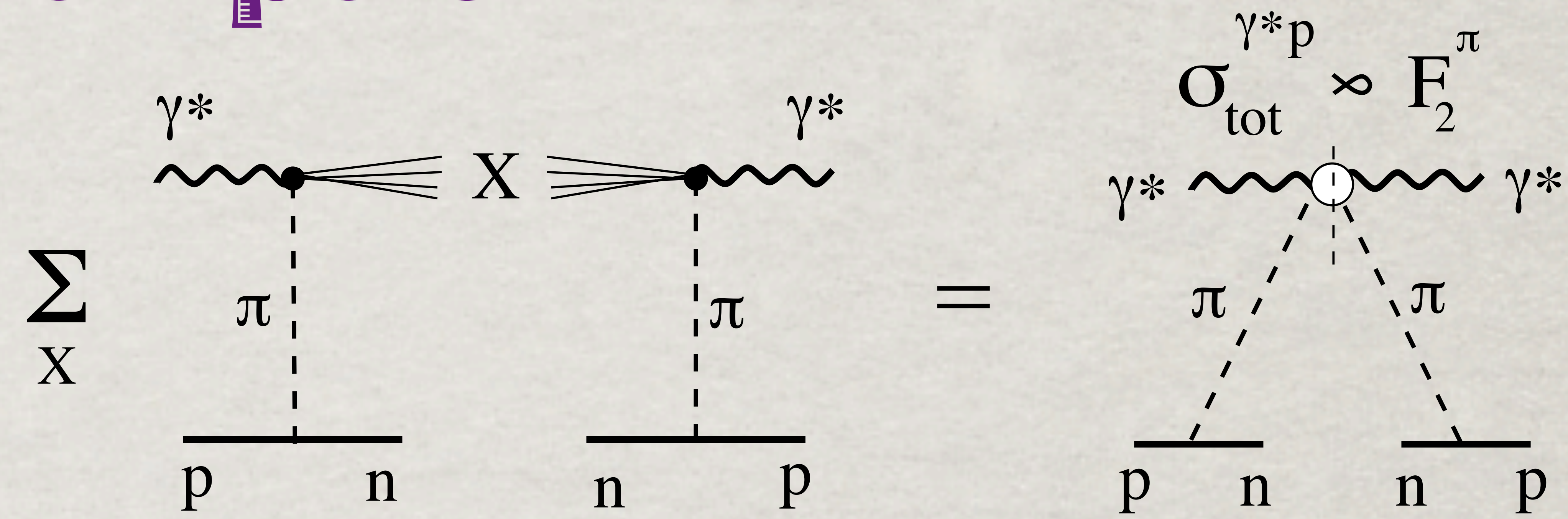
Phys.Rev. D85 (2012) 114025
Phys.Rev. D84 (2011) 114012
Phys.Rev. D78 (2008) 014031
Z.Phys. C73 (1996) 125

Píon pole

$$\gamma^* + p \to X + n$$

$$z = \frac{p_n^+}{p_p^+} \to 1 \qquad M_X^2 = (1-z)s$$



The source of information about $F_2^\pi(x_\pi, Q^2)$ at small $x_\pi = \dfrac{x}{1-z}$

The amplitude includes both non-flip and spin-flip terms

$$A^B_{p\to n}(\tilde{q}, z) = \bar{\xi}_n \left[\sigma_3\, q_L + \frac{1}{\sqrt{z}}\,\tilde{\sigma}\cdot\tilde{q}_T\right] \xi_p\, \phi^B(q_T, z) \qquad q_L = \frac{1-z}{\sqrt{z}}\, m_N$$

$$\phi^B(q_T, z) = \frac{\alpha'_\pi}{8}\, G_{\pi^+ pn}(t)\, \eta_\pi(t)\, (1-z)^{-\alpha_\pi(t)} A_{\gamma^*\pi\to X}(M_X^2)$$

$$\sum_X |A_{\gamma^*\pi^+\to X}(M_X^2)|^2 = \frac{4\pi^2\alpha_{em}}{x_\pi}\, F_2^\pi(x_\pi, Q^2)$$

Educated guess

$$R_{\pi/p}(x,Q^2) = F_2^{\pi}(x,Q^2)/F_2^{p}(x,Q^2) = ?$$

The small q-qbar dipole, $\gamma^* \to \bar{q}q$, is a good counter of valence quarks, so one could (naively) expect $R_{\pi/p}(x,Q^2) = 2/3$

However, the proton has a considerable pion component: $p \to N\pi$

It can be evaluated relying on the observed deviation from the Gottfried sum rule:

$$R_{\pi/p} = \frac{2}{3 + 2\langle n_\pi \rangle}$$

DY E866: $\langle n_\pi \rangle = 0.36$

NMC: $\langle n_\pi \rangle = 0.44$

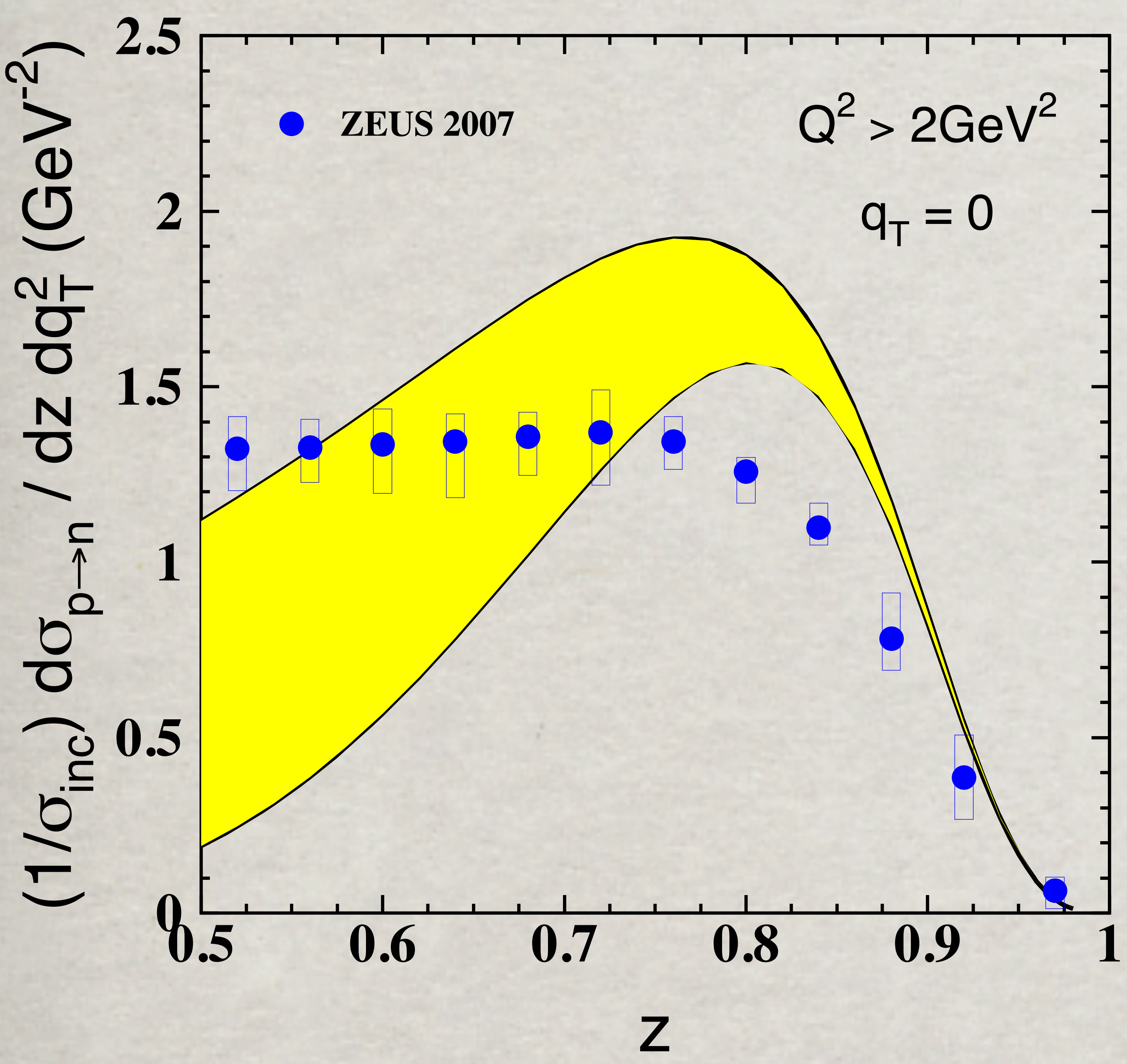
HERMES $\langle n_\pi \rangle = 0.48$

Adding the poorly known contribution of the iso-scalar mesons, our guess is

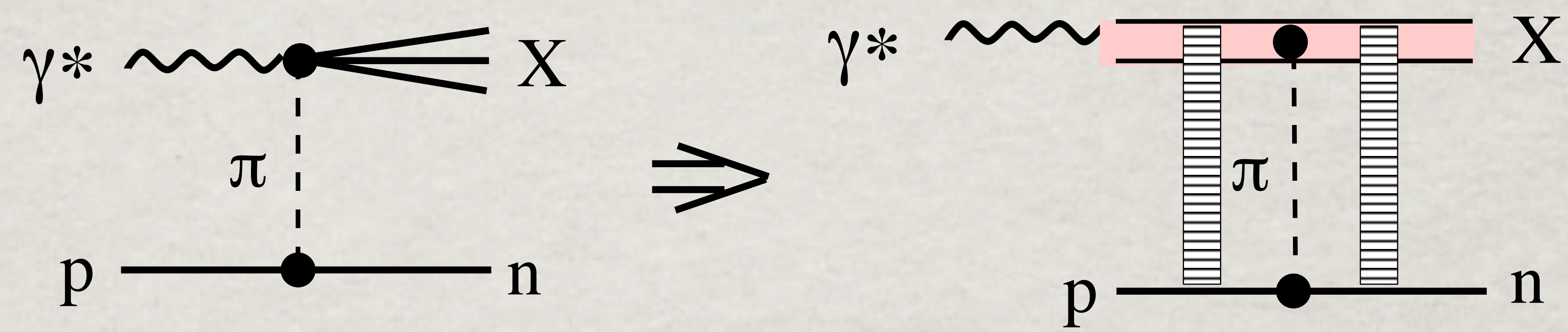
$$R_{\pi/p} = \frac{1}{2}$$

This is our trial value for further calculations

Absorptive corrections



Born approximation



Initial/final state interactions

The Born amplitude in impact parameters:

$$\mathbf{f^B_{p\to n}(\tilde b, z) = \bar\xi_n \left[\sigma_3\, q_L\, \theta^B_0(b,z) - i\, \frac{\tilde\sigma\cdot\tilde b}{b\sqrt{z}}\, \theta^B_s(b,z)\right] \xi_p}$$

$$\mathbf{\theta^B_0(b,z) = \int d^2q_T\, e^{i\tilde b \tilde q_T}\, \phi^B(q_T,z)}$$

$$\mathbf{\theta^B_s(b,z) = \frac{1}{b}\int d^2q_T\, e^{i\tilde b \tilde q_T}\, (\tilde b\cdot\tilde q)\, \phi^B(q_T,z)}$$

$$\mathbf{\theta^B_{0,s}(b,z) \Rightarrow \theta^B_{0,s}(b,z)\, S_{abs}(b,z)} \longrightarrow \mathbf{S_{abs}(b) = 1 - \mathrm{Im}\, f_{el}(b)}$$

And back to momentum representation

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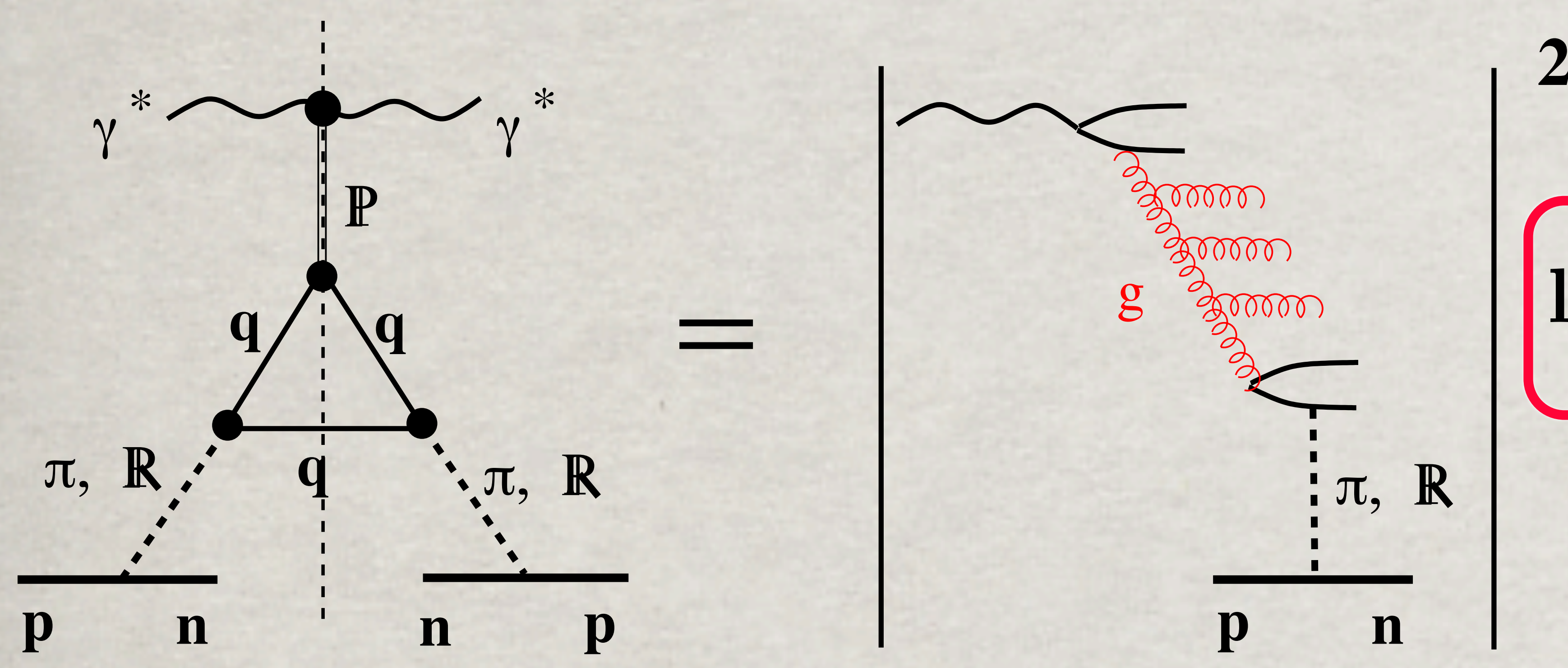
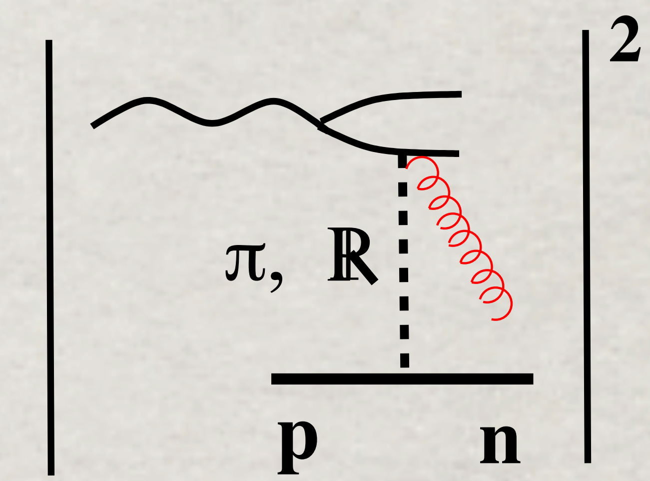
Absorptive corrections



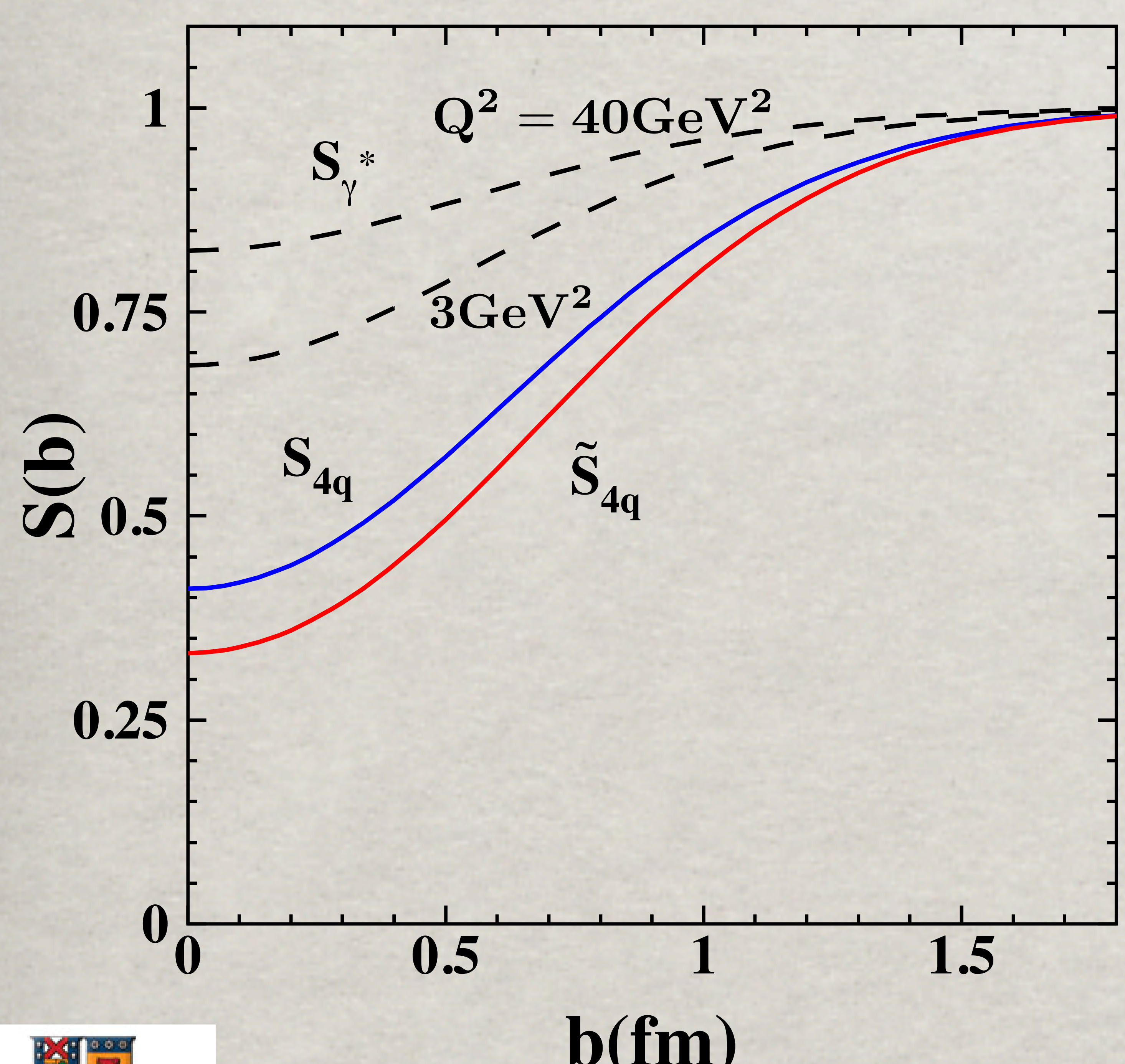
$$l_c^{4q} = \frac{1}{q_L} = \frac{\sqrt{z}}{(1-z)m_N}$$

Dominates at large z



$$l_c^{\bar{q}q} = \frac{1}{2xm_N}$$

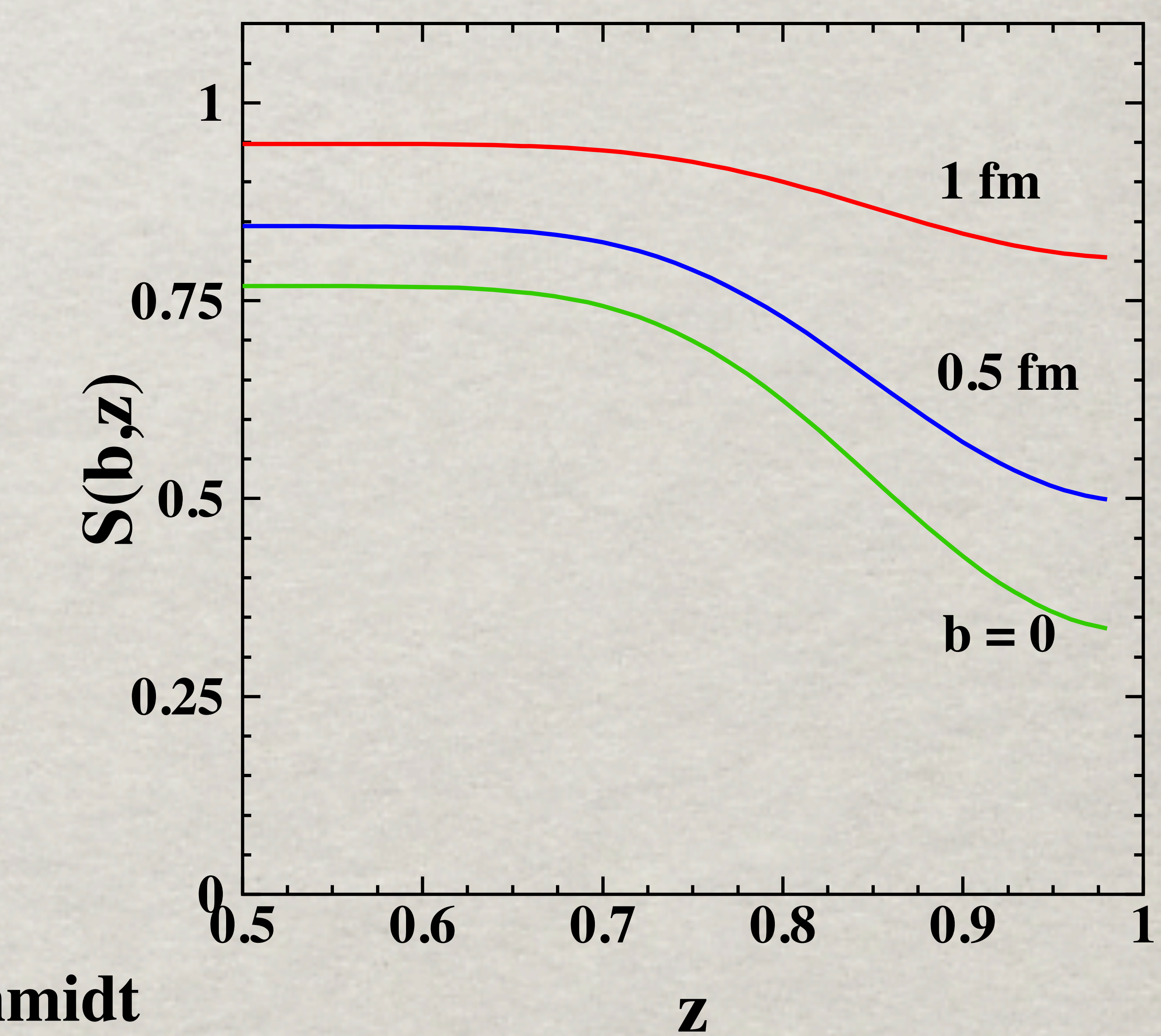
Dominates at small z



$$S(b) = S_{4q}(b)\, F_N(q_L) + S_{\gamma^*}(b)\left[1 - F_N(q_L)\right]$$

$$F_N(q_L) = \left(1 + q_L^2 L^2\right)^{-1}$$

$$L = 1\,\text{fm}$$



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Phys.Rev. D85 (2012) 114025

Other Reggeons

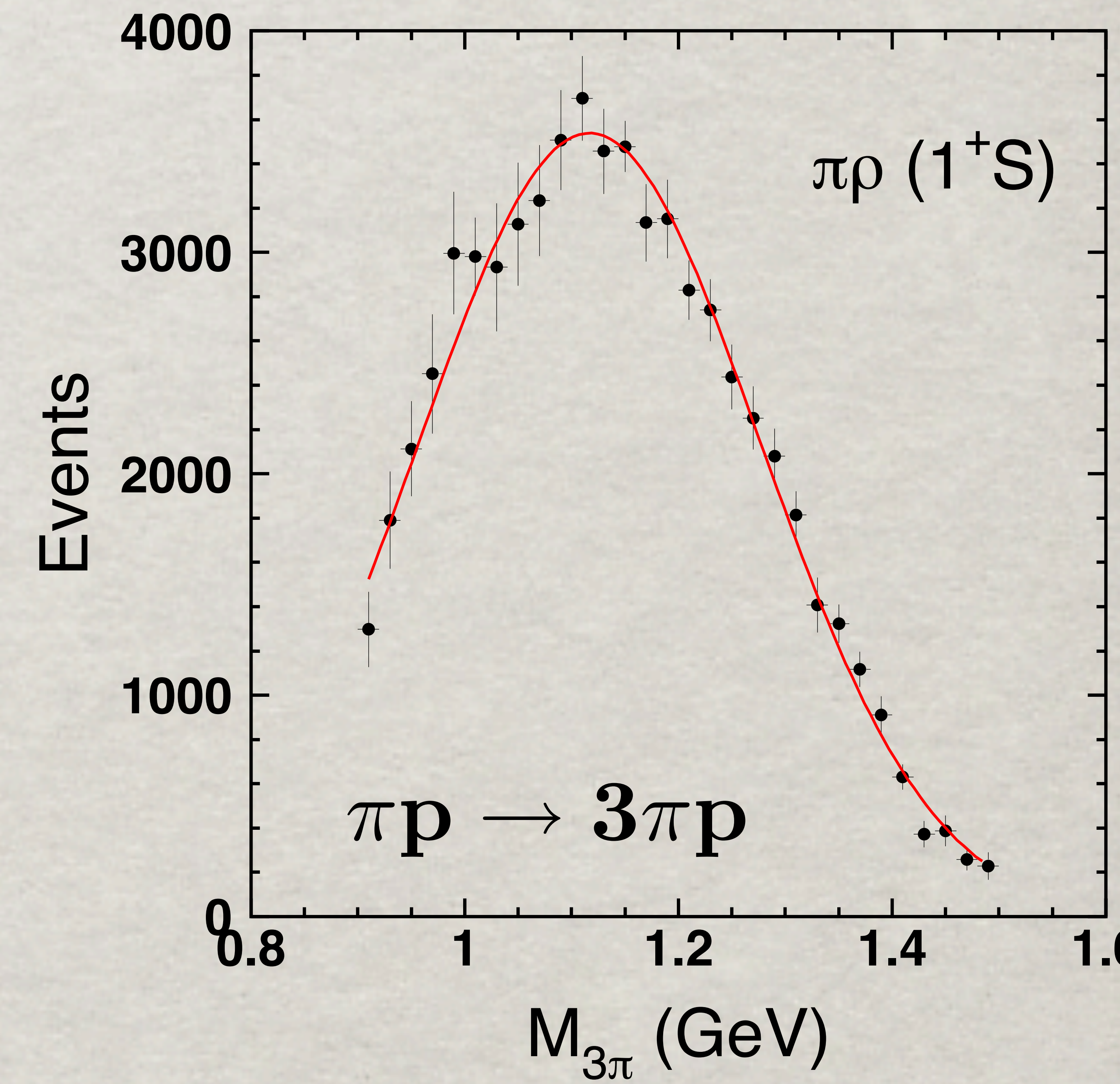
The natural parity Reggeons ρ and $\mathbf{a_2}$ are well fixed by the Regge phenomenology. They are spin-flip and important for neutron production at z->1, because have higher intercepts.

$\mathbf{a_1}$ is a very weak pole in the dispersion relation, no $\mathbf{a_1}$-dominance in the axial current. The $\pi\rho$ cut can be treated as an effective $\tilde{\mathbf{a}}_1$-pole.

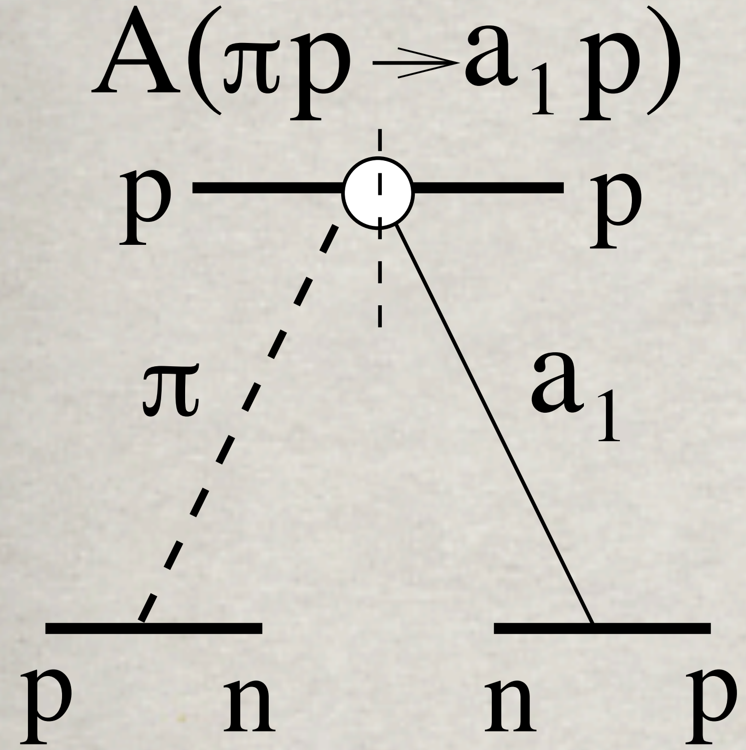
PCAC and the 2d Weinberg sum rule lead to

$$\frac{\mathbf{g_{aNN}}}{\mathbf{g_{\pi NN}}} = \frac{\mathbf{m_a^2\, f_\pi}}{\mathbf{2m_N\, f_\rho}} \approx \mathbf{0.5}$$

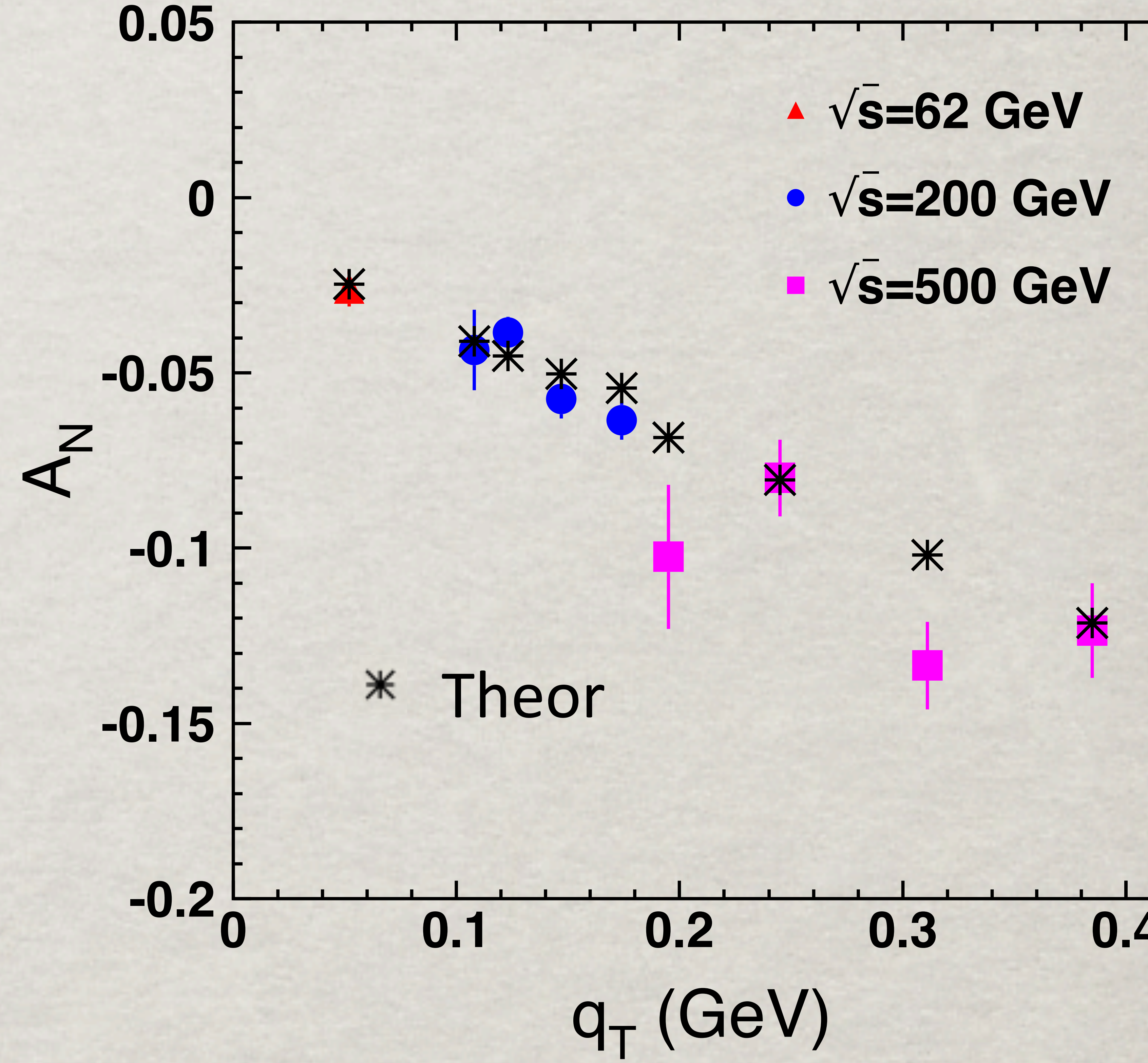
$$\mathbf{f_a} = \mathbf{f_\rho} = \frac{\sqrt{2}\mathbf{m_\rho^2}}{\gamma_\rho}$$



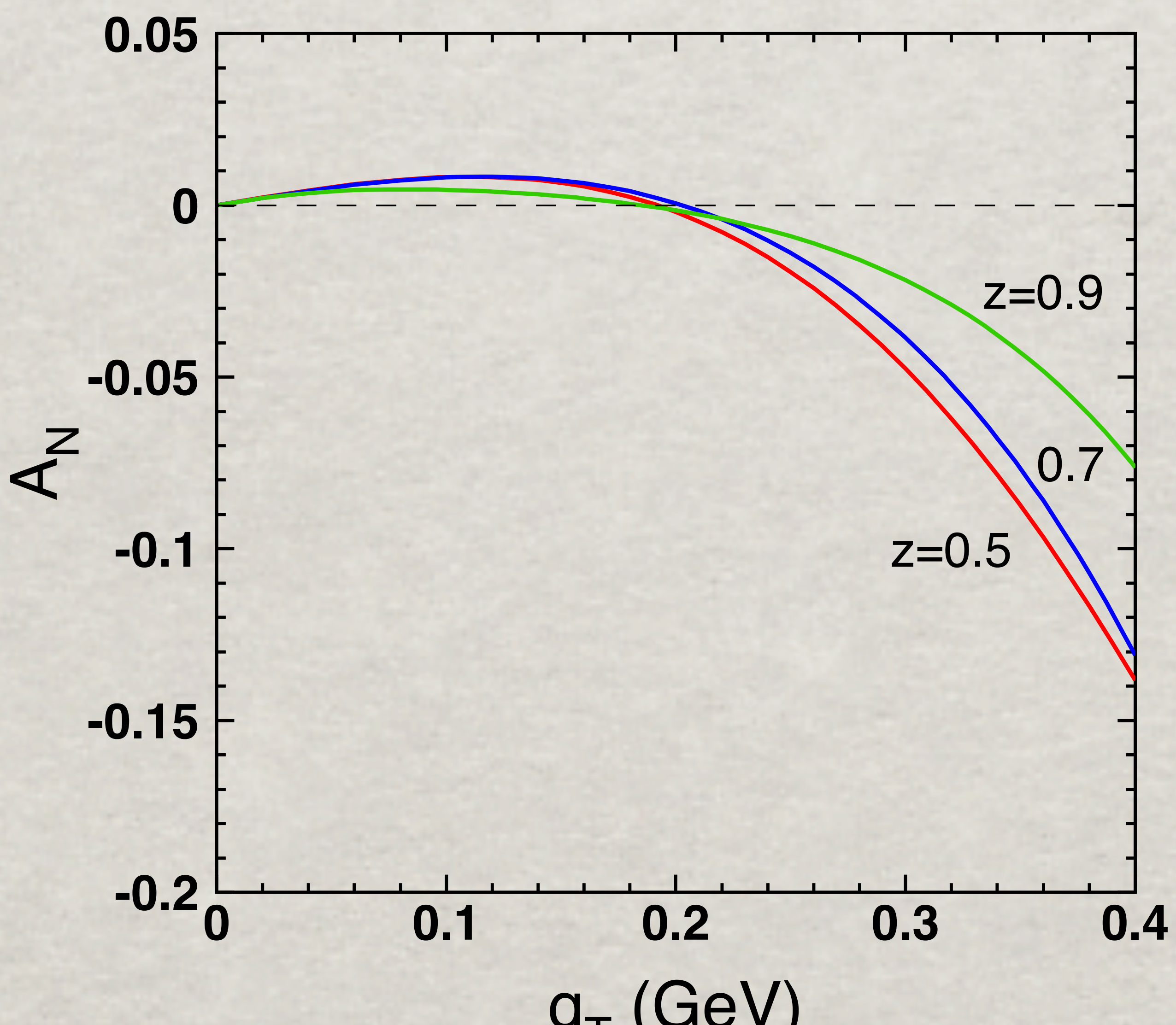
Other Reggeons



With such a coupling $\pi - \tilde{\mathbf{a}}_1$ interference well explains PHENIX data on azimuthal asymmetry of neutrons.

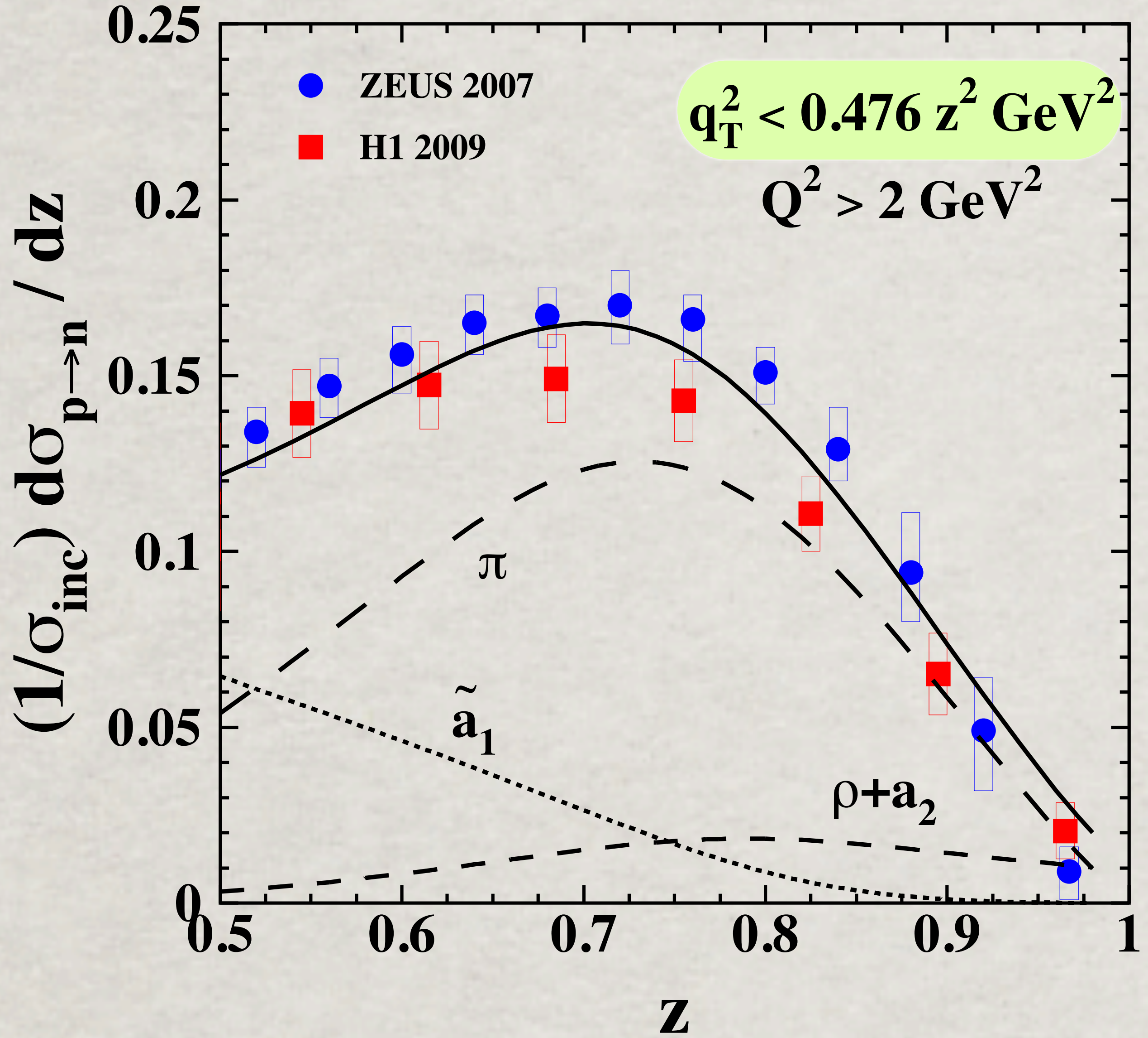


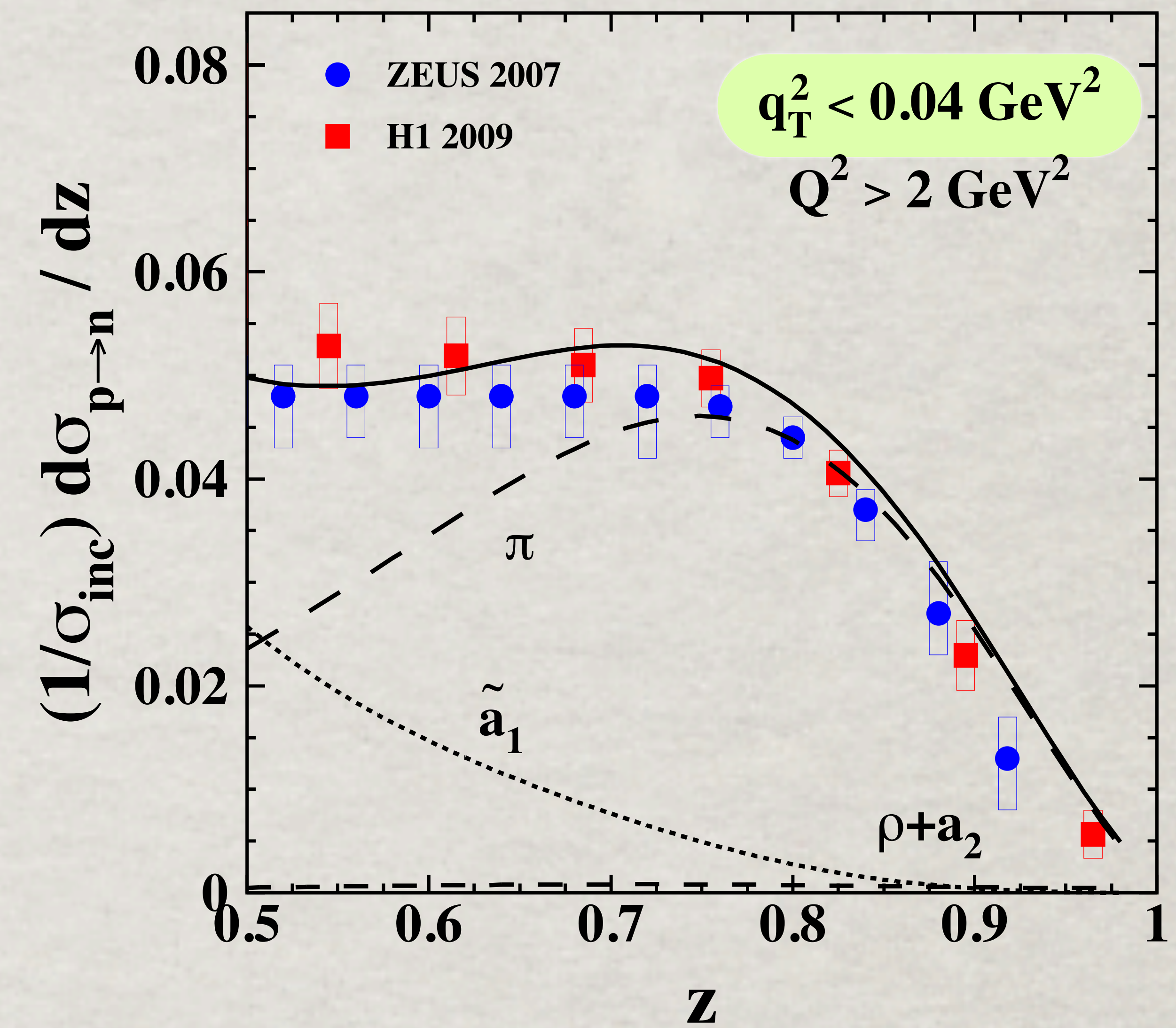
Neither the pion pole, nor adding the absorptive corrections can explain the observed asymmetry.



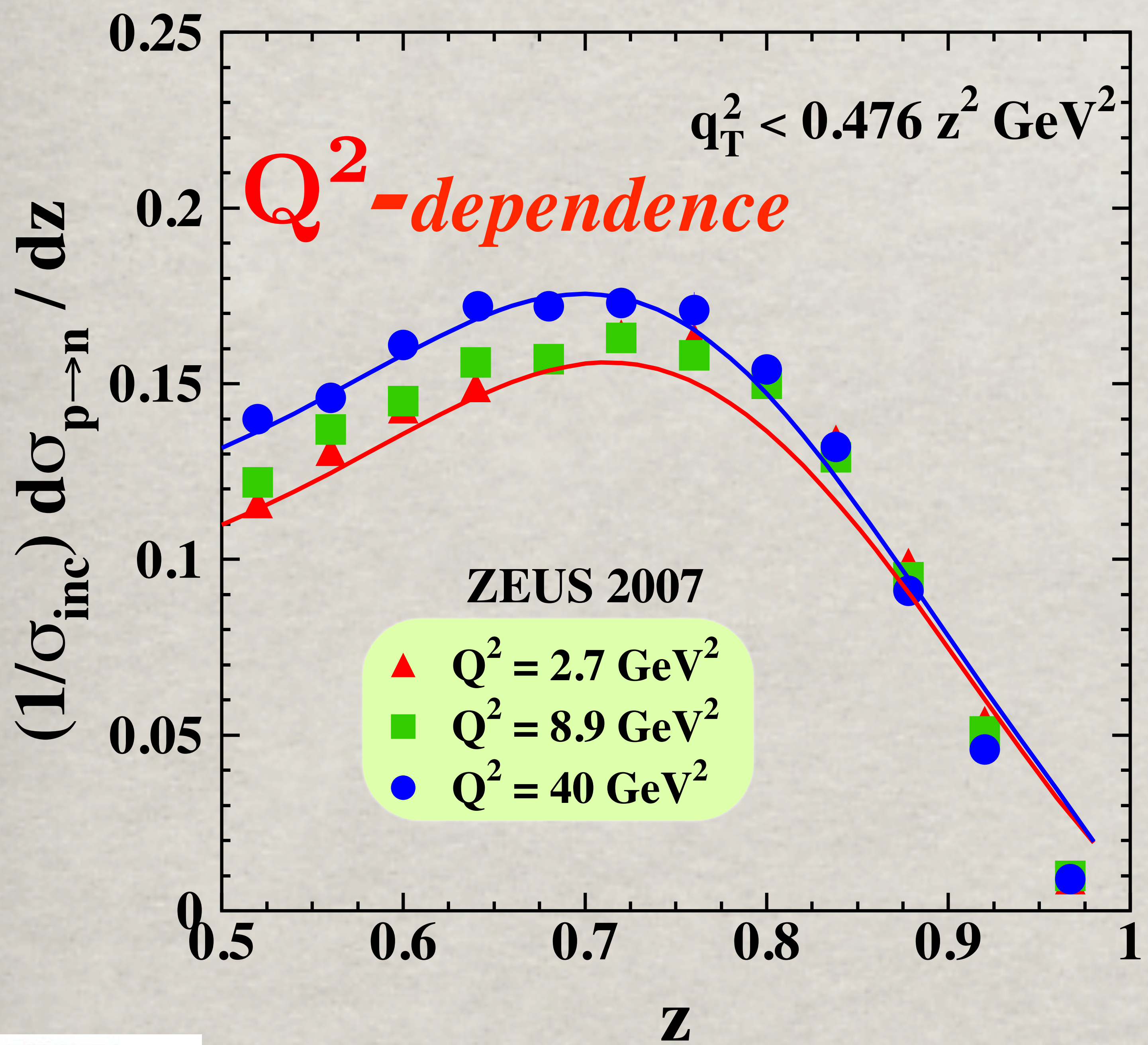
Results

z-dependence

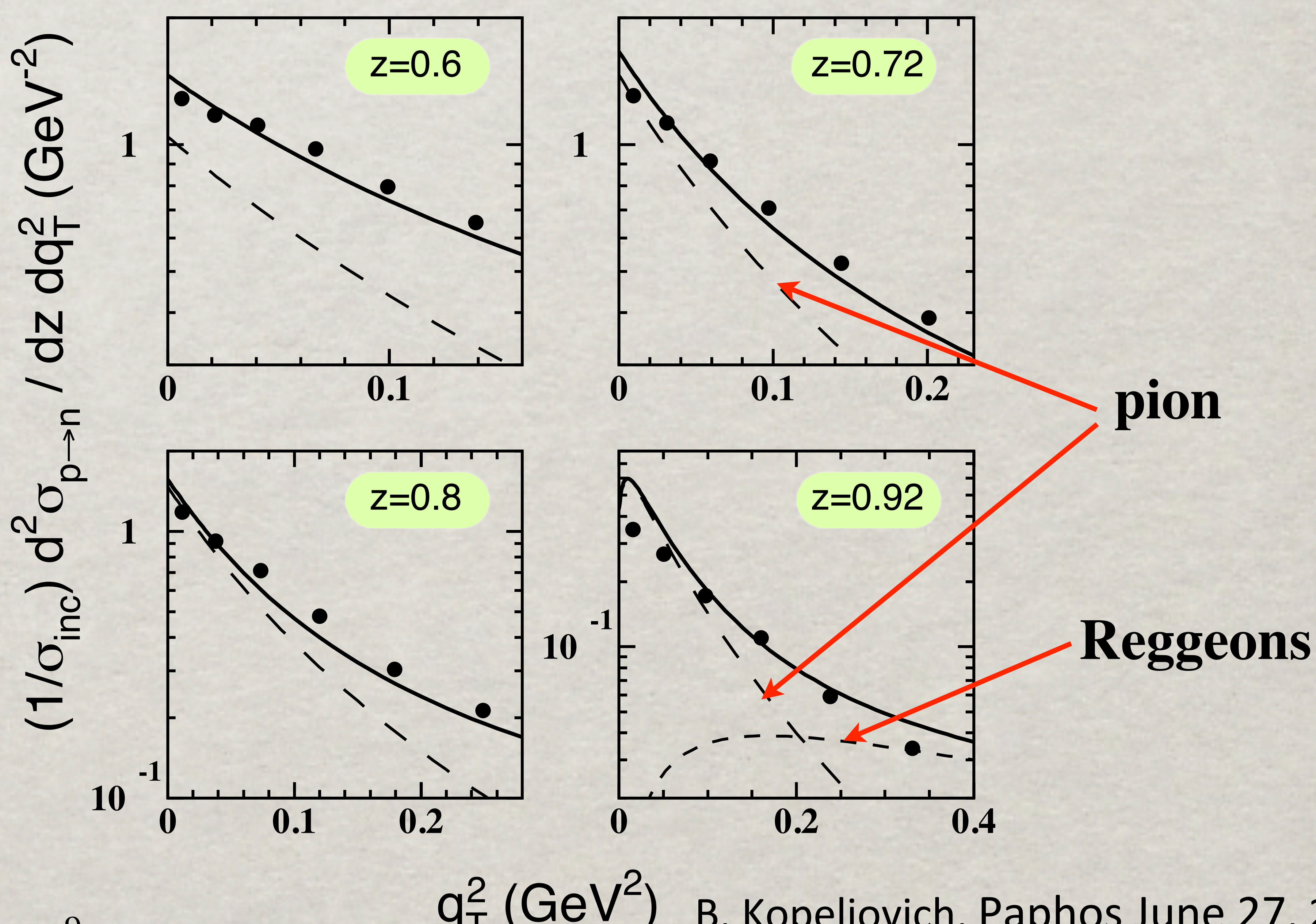




Q^2-*dependence*



q_T-dependence

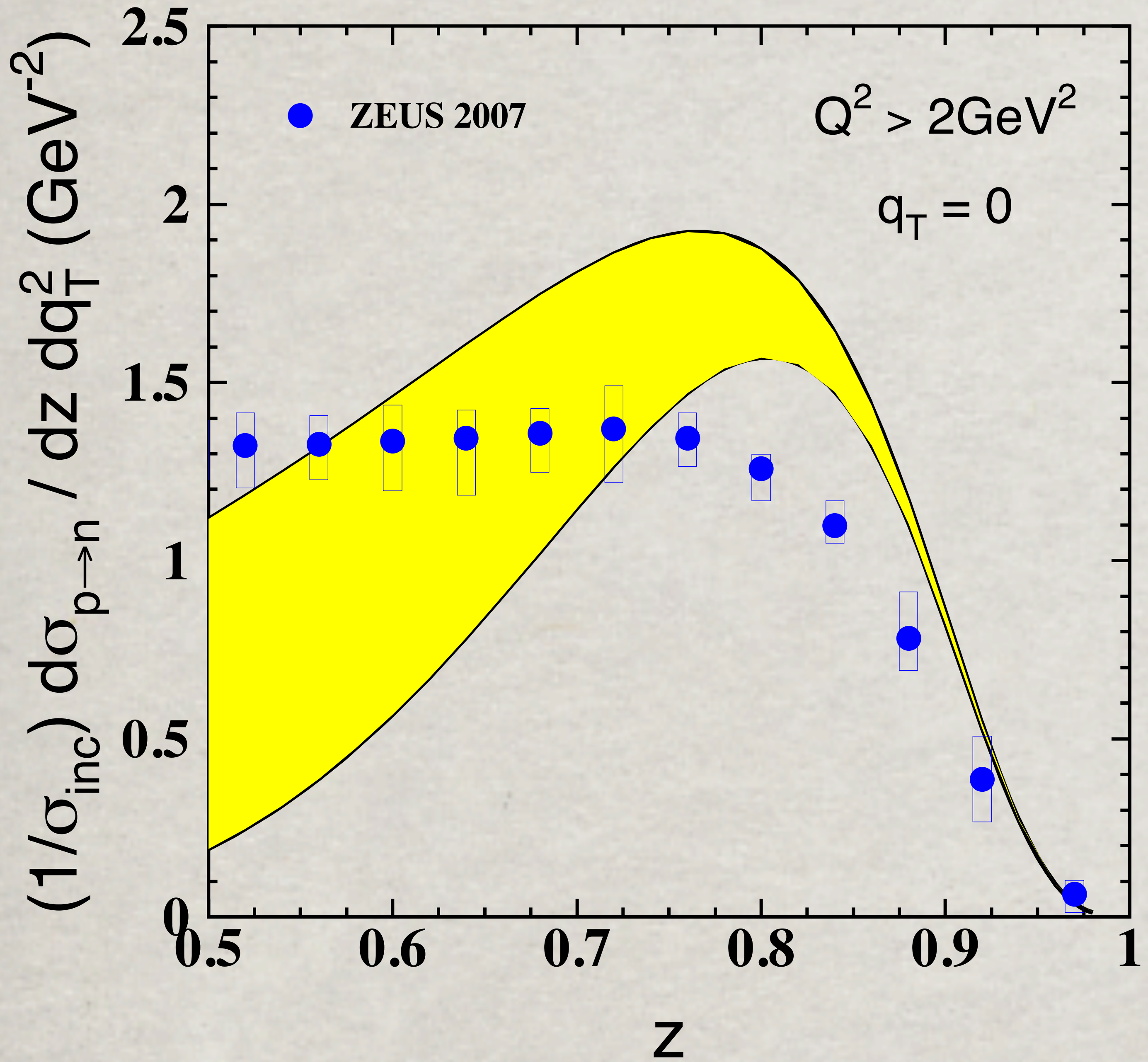


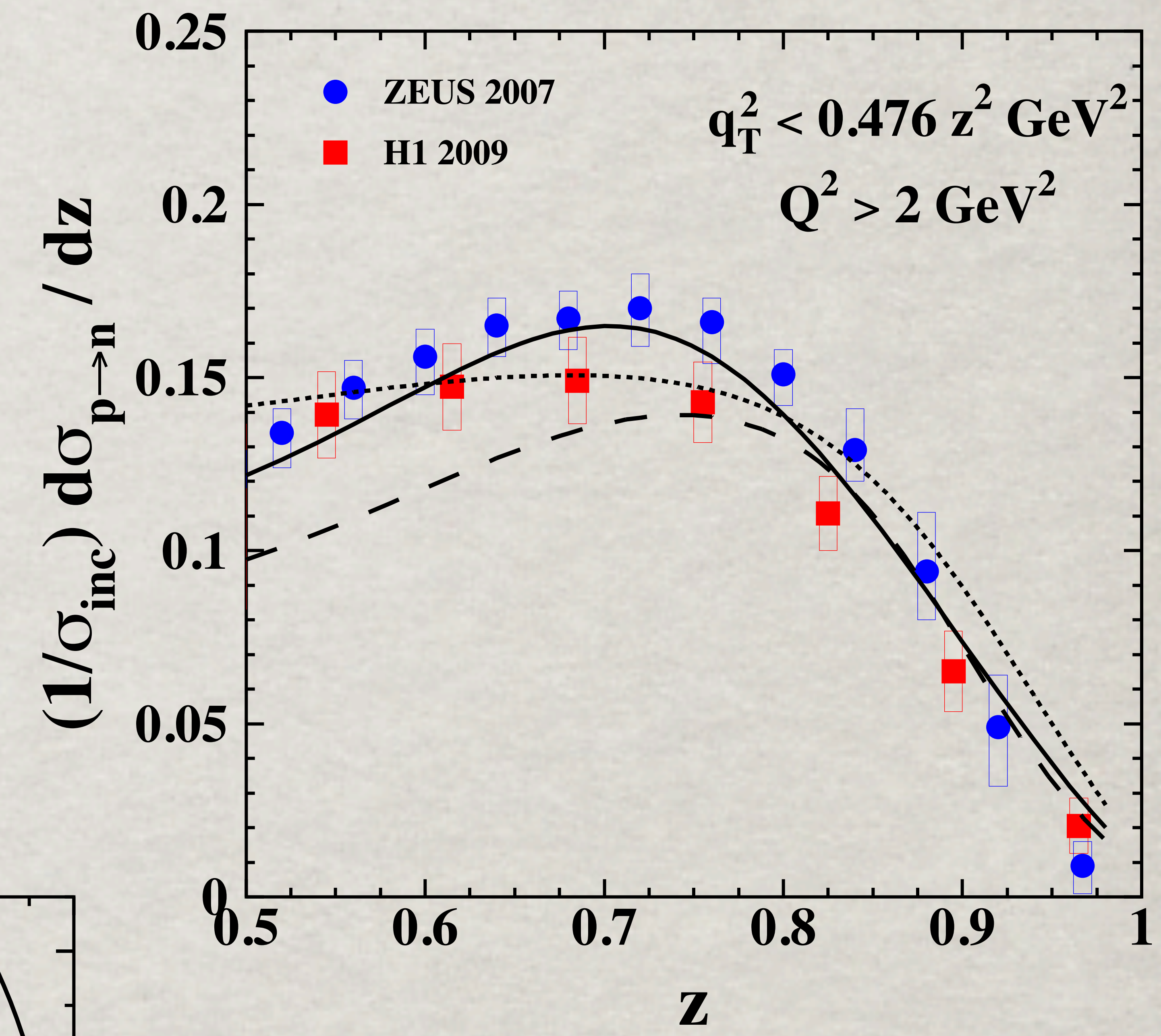
Summary

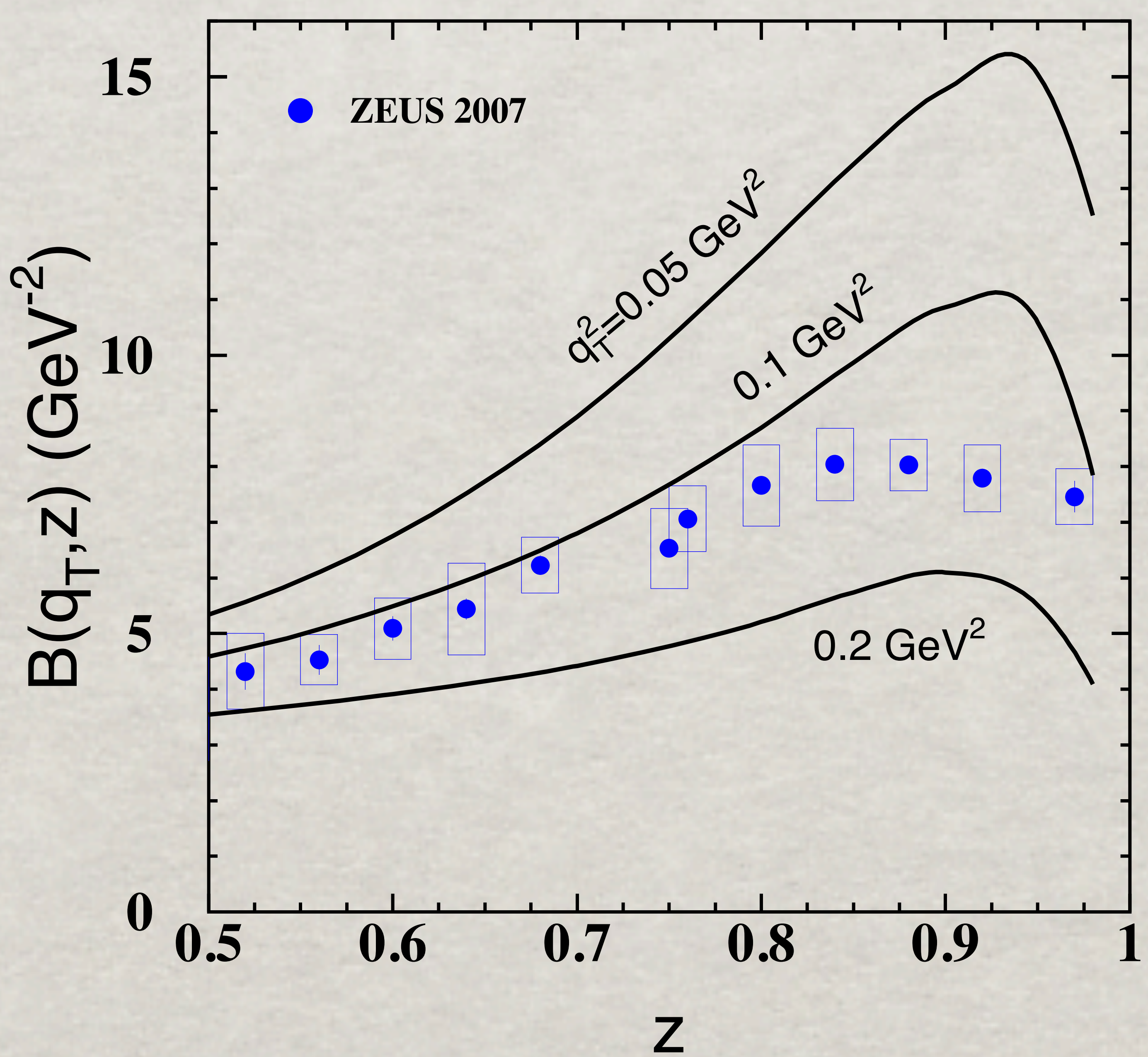
- Starting the bottom-up description with a plausible assumption $R_{\pi/p} = F_2^{\pi}(x, Q^2)/F_2^{p}(x, Q^2) = 1/2$ we reached a good agreement with DIS data, basing on model dependent calculations of the absorptive corrections and iso-vector Reggeons.

- The top-down strategy, determination of the pion structure function starting from DIS data on leading neutron production, is supposed to be least model dependent. However, the necessity of correcting for absorption brings a considerable theoretical uncertainty. Even with a plausible assumption that $F_2^{\pi}(x, Q^2) \propto F_2^{p}(x, Q^2)$ the coefficient $R_{\pi/p}$ can be extracted from data with a theoretican uncertainty of 20-30%.

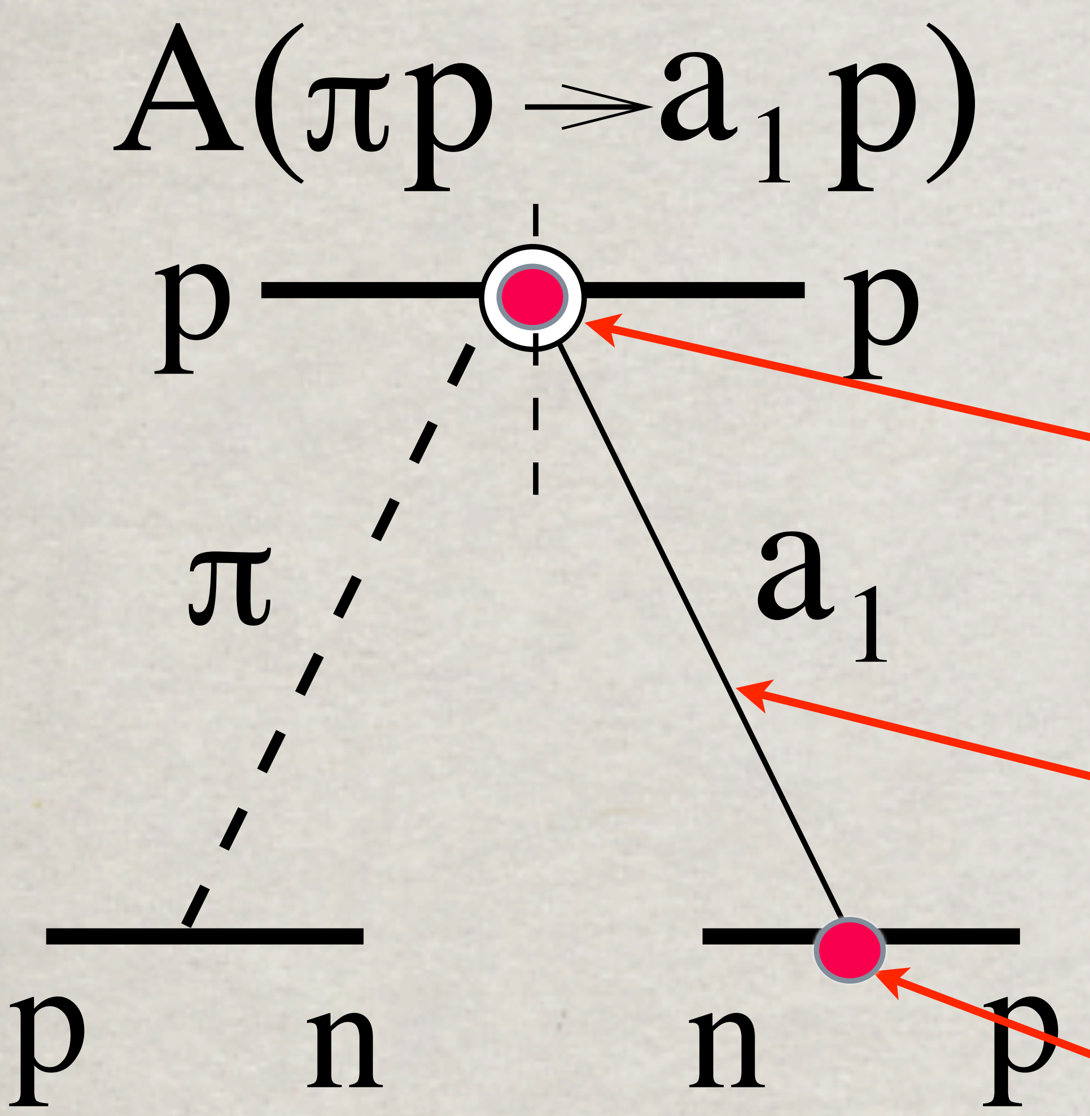
Backups


ZEUS 2007
Q² > 2GeV²
q_T = 0
(1/σ_inc) dσ_p→n / dz dq²_T (GeV⁻²)
z


ZEUS 2007
H1 2009
q²_T < 0.476 z² GeV²
Q² > 2 GeV²
(1/σ_inc) dσ_p→n / dz
z


ZEUS 2007
q²_T=0.05 GeV²
0.1 GeV²
0.2 GeV²
B(q_T,z) (GeV⁻²)
z

Backups



Three unknowns:

$$\mathbf{A(\pi p \to a_1 p) = \sqrt{d\sigma(\pi p \to a_1 p)/dq_T^2|_{q_T=0}}}$$

Regge trajectory $\alpha_{\mathbf{a_1}}(\mathbf{t})$

$\mathbf{a_1}$ -nucleon coupling $\mathbf{g_{a_1 np}}$

$$\mathbf{A_N^{(\pi-a_1)}(q_T, z) = q_T \frac{4m_N\, q_L}{|t|^{3/2}} (1-z)^{\alpha_\pi(t)-\alpha_{a_1}(t)} \frac{\mathrm{Im}\, \eta_\pi^*(t)\, \eta_{a_1}(t)}{|\eta_\pi(t)|^2}}$$

$$\times \left(\frac{\mathbf{d\sigma_{\pi p\to a_1 p}(M_X^2)/dt|_{t=0}}}{\mathbf{d\sigma_{\pi p\to \pi p}(M_X^2)/dt|_{t=0}}}\right)^{1/2} \frac{\mathbf{g_{a_1^+ pn}}}{\mathbf{g_{\pi^+ pn}}}$$

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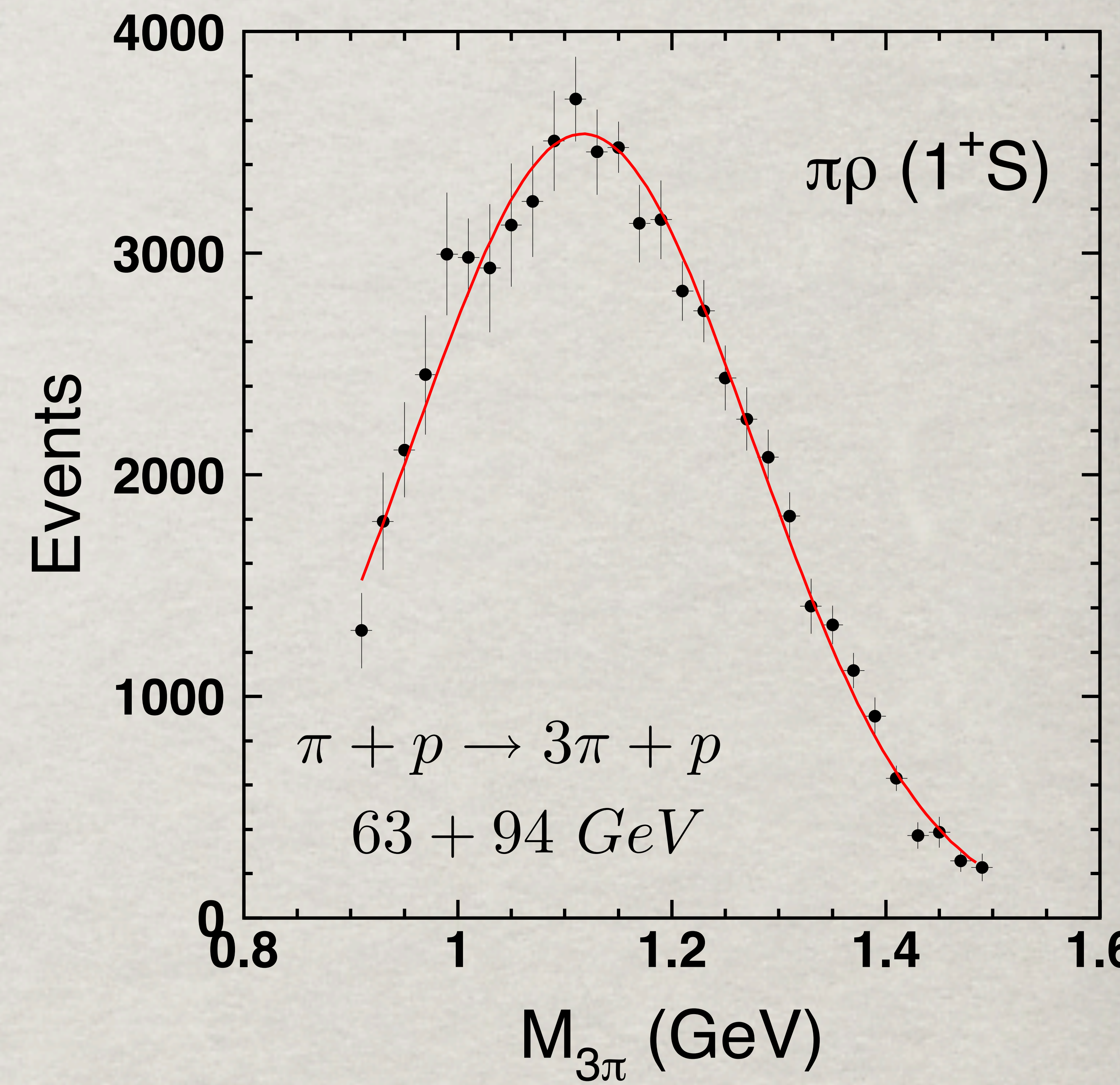
Backups

The $\mathbf{a_1}$ is a very weak pole: no axial-vector dominance for the axial current.

Nevertheless, the invariant mass distribution of diffractively produced $\pi\!-\!\rho$ in $\mathbf{1^+S}$ state forms a peak, dominated by the Deck mechanism, with a similar position and width as $\mathbf{a_1}$. This singularity in the dispersion relation can be treated as an effective pole "a" with mass $\mathbf{m_a = 1.1\,GeV}$.



The cross section of $\pi + \mathbf{p} \to (\pi\rho)_{\mathbf{1^+S}} + \mathbf{p}$ was measured up to 94 GeV.

$$\left.\frac{\mathbf{d}\sigma_{\pi\mathbf{p}\to\mathbf{ap}}(\mathbf{E_{lab}} = \mathbf{94}\,\mathrm{GeV})}{\mathbf{dq_T^2}}\right|_{\mathbf{q_T=0}} = \mathbf{0.8 \pm 0.08}\,\frac{\mathrm{mb}}{\mathrm{GeV}^{\mathbf{2}}}$$

Extrapolated to the RHIC energy range correcting for absorption.

Backups

PCAC miraculously relates the pion-nucleon coupling with the axial constant

$$g_{\pi NN} = \frac{\sqrt{2} m_N \, G_A}{f_\pi}$$

Goldberger-Treiman relation

G_A represents the contribution to the dispersion relation of all axial-vector states heavier than pion. Assuming dominance of the 1^+S a-peak, we get

$$G_A = \frac{\sqrt{2} f_a \, g_{aNN}}{m_a^2}$$

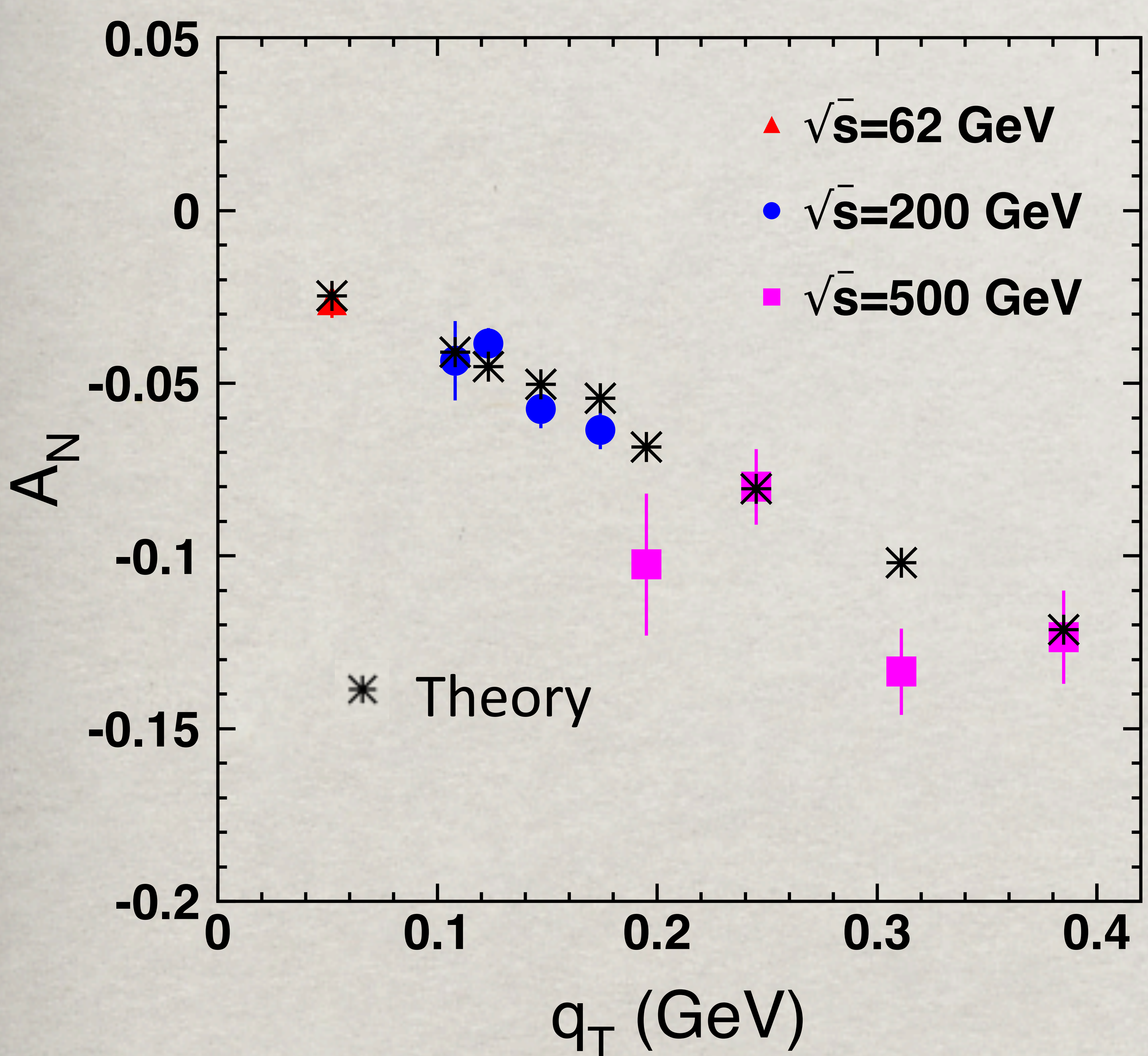
The dispersion integrals for vector and axial currents are related by the 2d Weinberg sum rule

$$f_a = f_\rho = \frac{\sqrt{2} m_\rho^2}{\gamma_\rho}$$

Thus,

$$\frac{g_{aNN}}{g_{\pi NN}} = \frac{m_a^2 \, f_\pi}{2 m_N \, f_\rho} \approx 0.5$$

Backups



The data agree well with independence of energy

$$A_N^{(\pi-a)}(q_T,z) = q_T\,\frac{4m_N\,q_L}{|t|^{3/2}}\,(1-z)^{\alpha_\pi(t)-\alpha_a(t)}$$

$$\times\,\frac{\mathrm{Im}\,\eta_\pi^*(t)\,\eta_a(t)}{|\eta_\pi(t)|^2}\left(\frac{d\sigma_{\pi p\to ap}(M_X^2)/dt|_{t=0}}{d\sigma_{\pi p\to\pi p}(M_X^2)/dt|_{t=0}}\right)^{1/2}\frac{g_{apn}}{g_{\pi pn}}$$

Theoretical uncertainty is not large, about 30%