Single spin asymmetry of leading neutrons

Boris Kopeliovich
Valparaiso, Chile

Veli Lošinj
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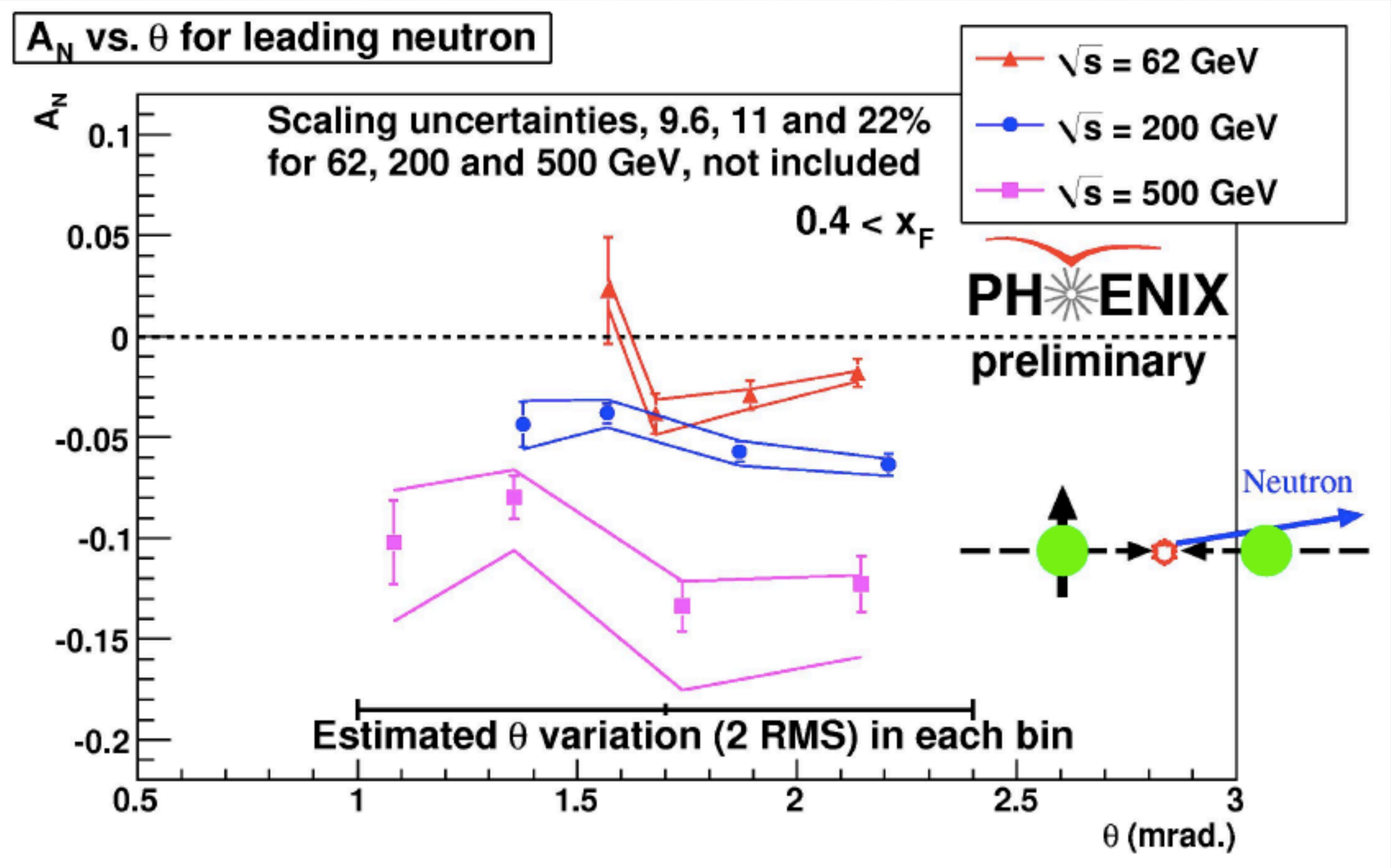
In collaboration with:

Irina Potashnikova
Ivan Schmidt
Jacques Soffer

Single-spin asymmetry of leading neutrons

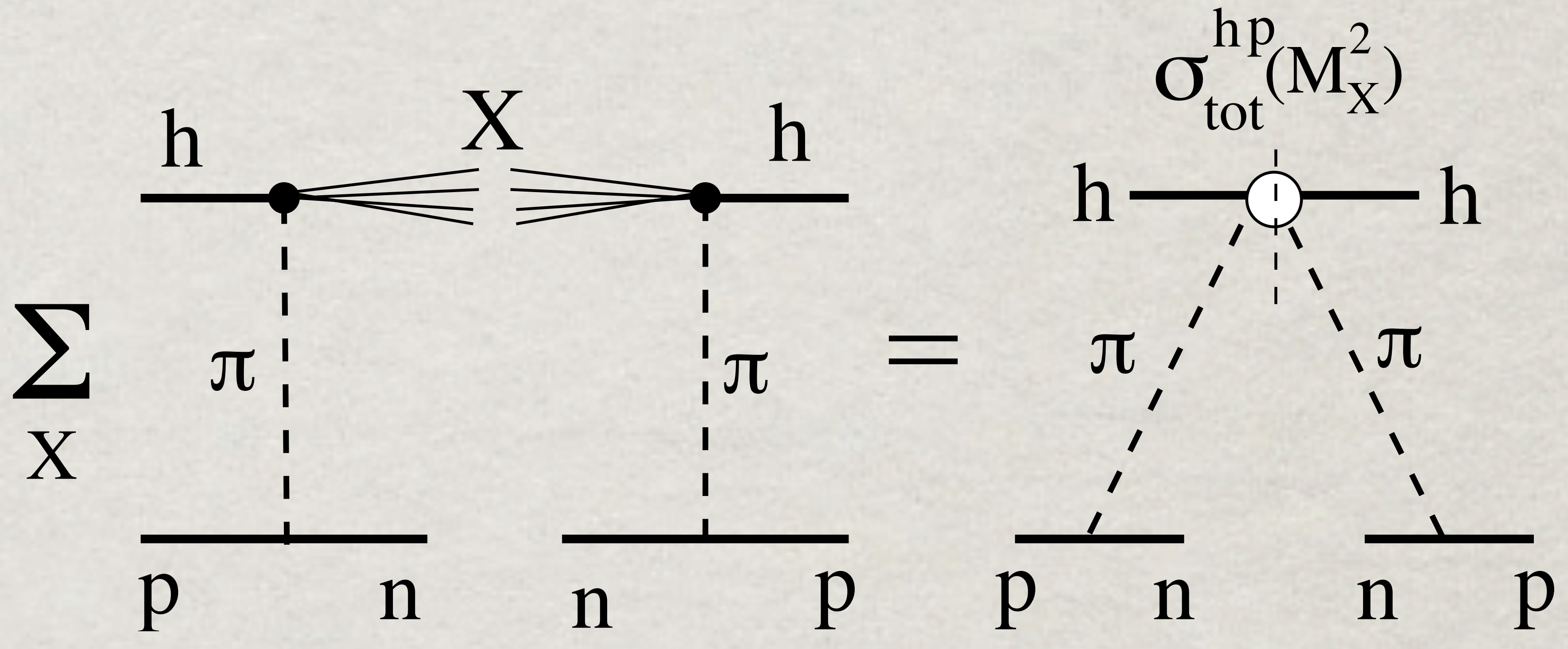
$$\mathbf{p + p \rightarrow n + X}$$



Pion pole

$$\mathbf{p + p \to n + X}$$

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



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

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

BK, I.Potashnikova, I.Schmidt, J.Soffer
Phys. Rev. D78, 014031, 2008

$$\mathbf{q_L = \frac{1 - z}{\sqrt{z}}\, m_N}$$

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

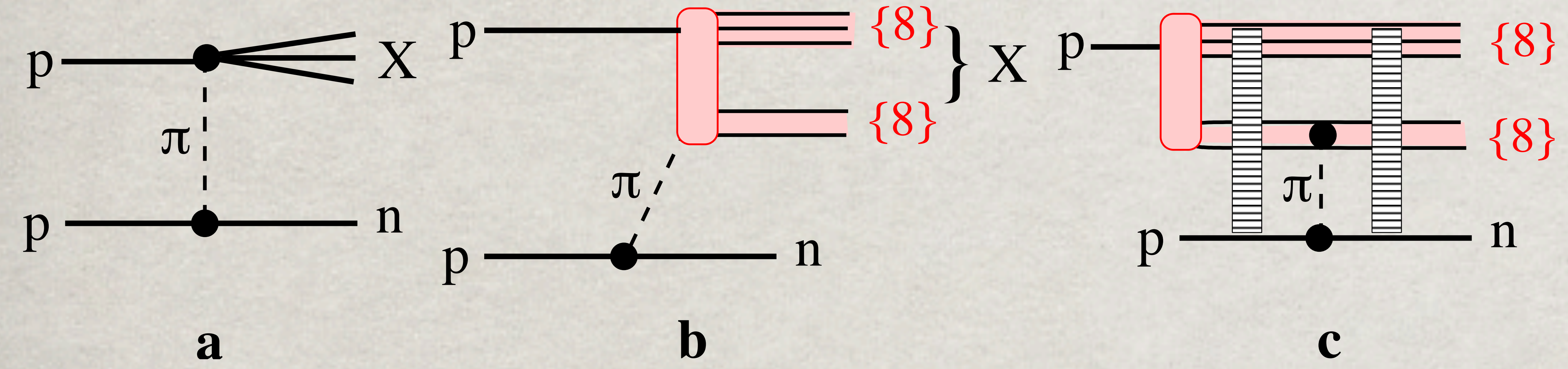
Both amplitudes have the same phase

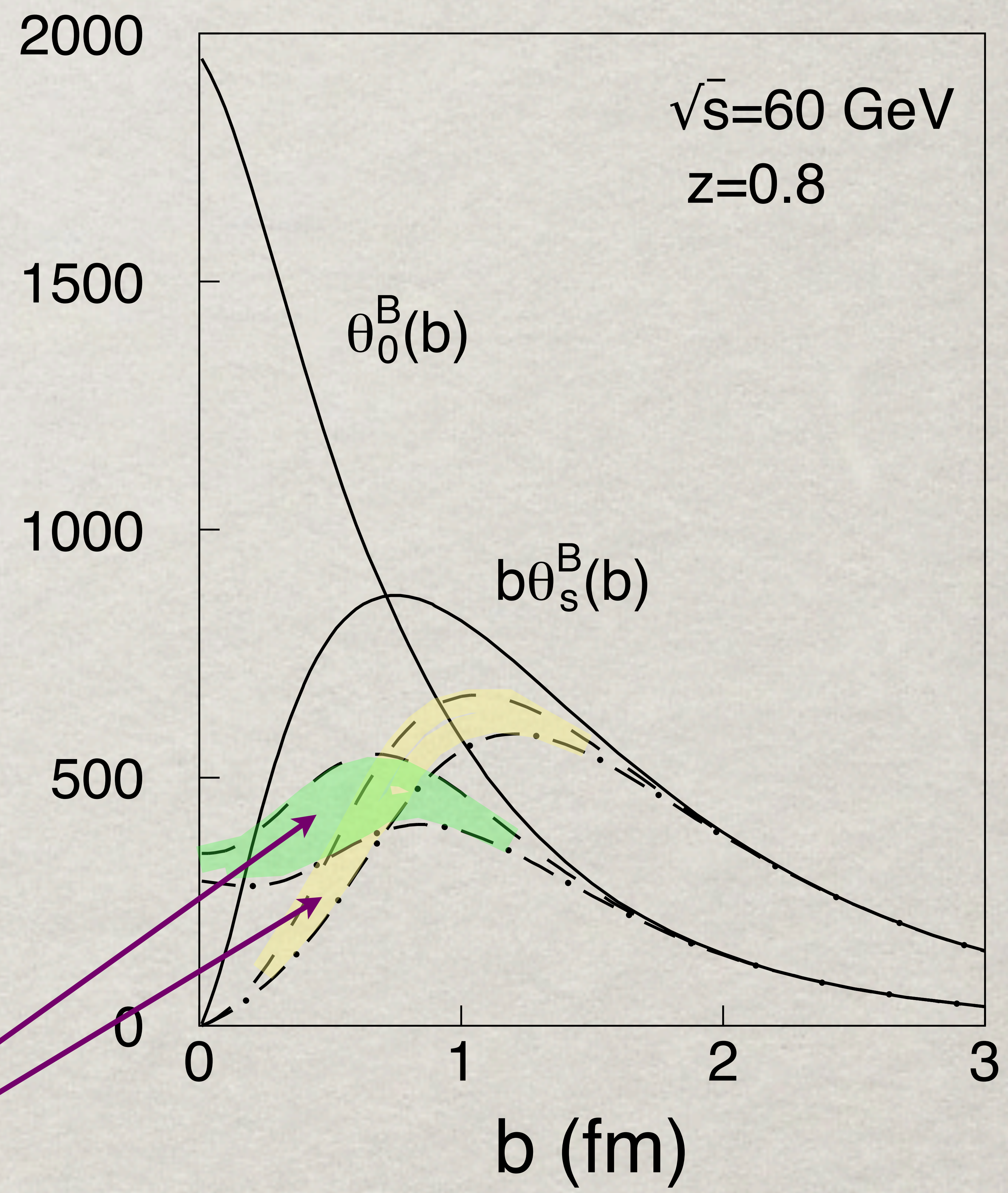
$$\mathbf{\eta_\pi(t) = i - ctg\left[\frac{\pi\alpha_\pi(t)}{2}\right]}$$

No single-spin asymmetry can appear

Absorptive corrections

Initial/final state interactions

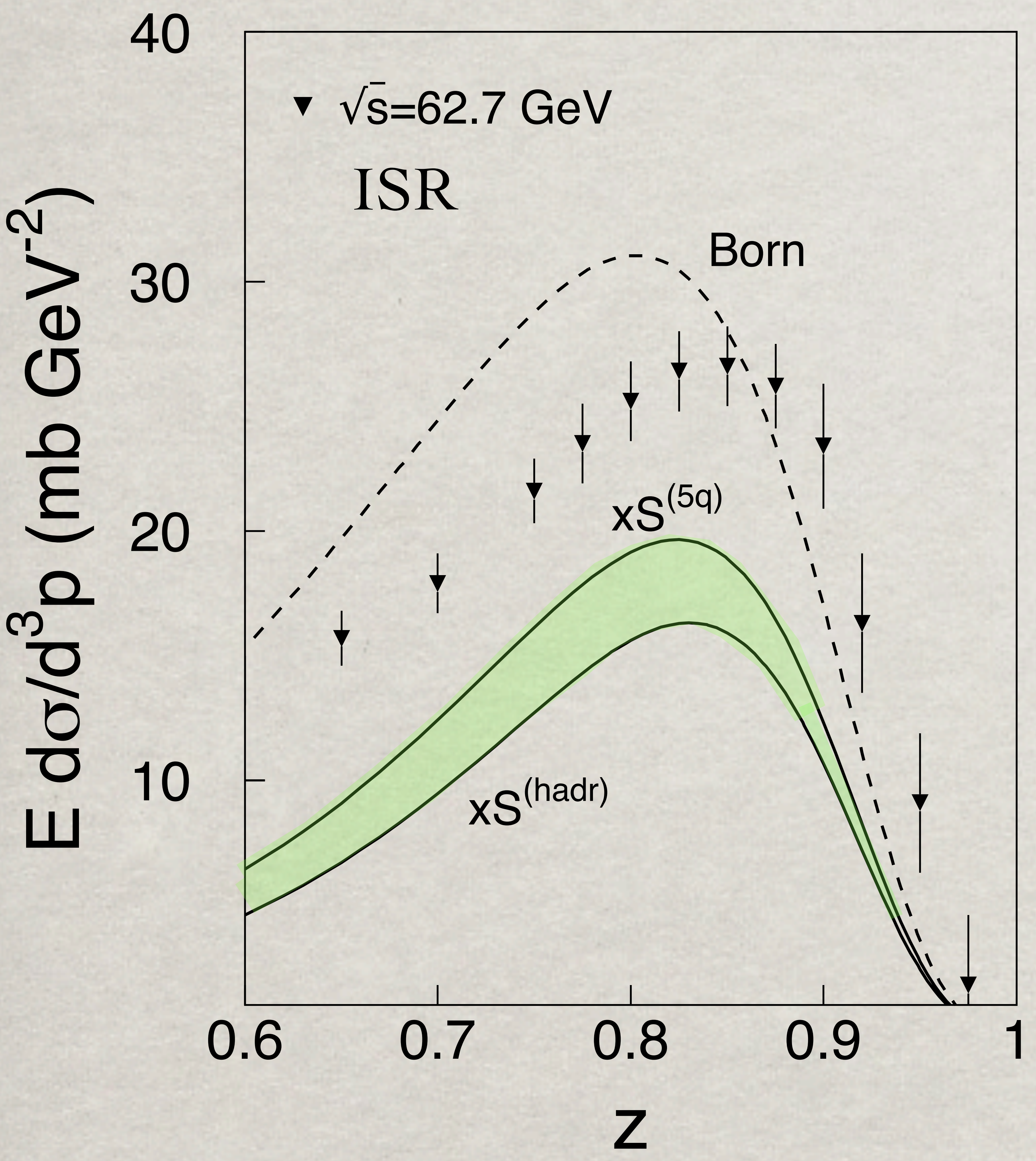


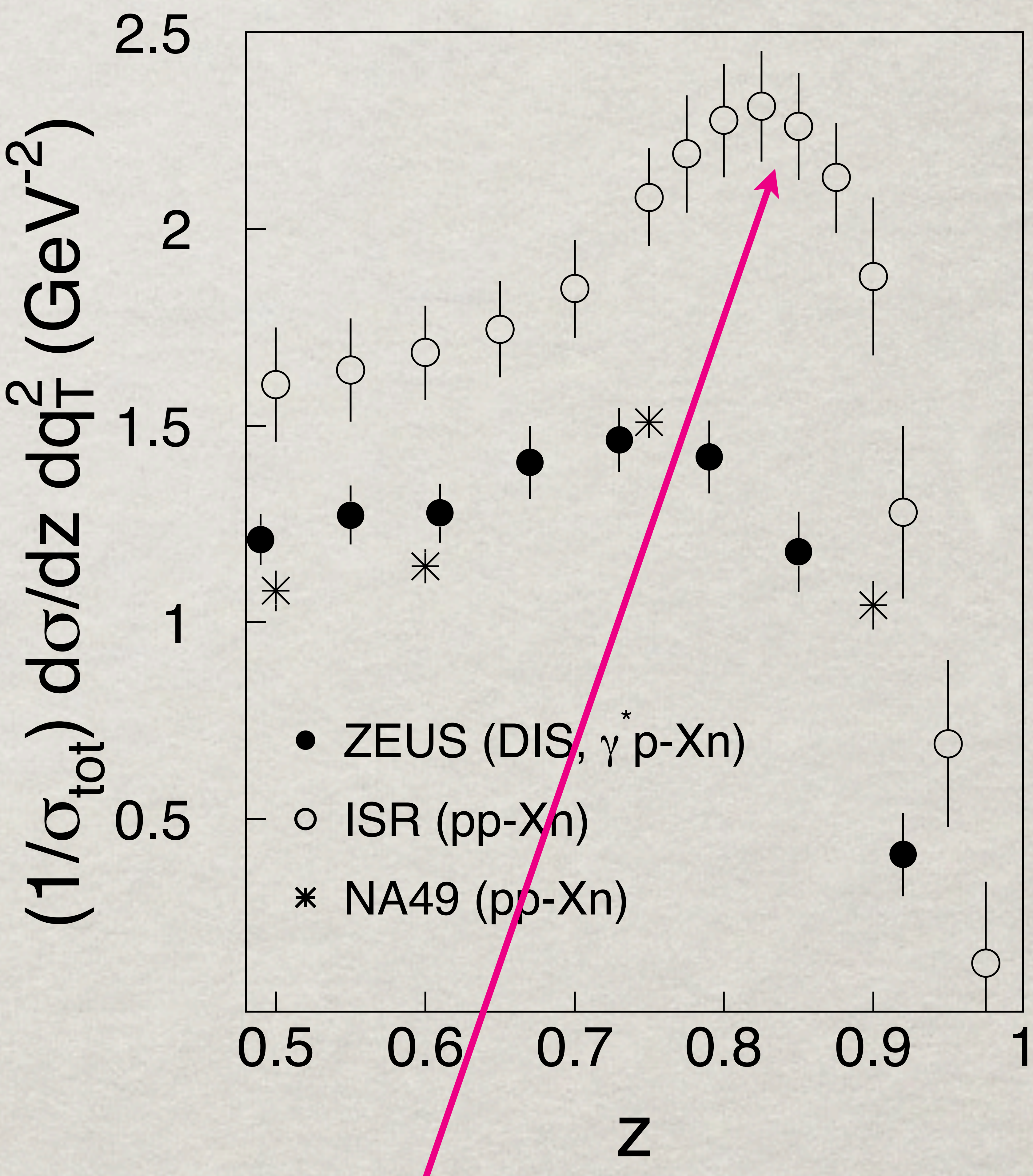


$$\mathbf{f^B_{p\to n}(\tilde b, z) = \bar\xi_n \left[\sigma_3\, q_L\, \theta^B_0(b,z) - i\,\frac{\tilde\sigma\cdot\tilde b}{b\sqrt{z}}\,\theta^B_s(b,z)\right]\xi_p}$$

$$\boxed{\mathbf{\theta_{0,s}(b,z) = \theta^B_{0,s}(b,z)\, S_{abs}(b,z)}}$$

Cross section: theory vs data



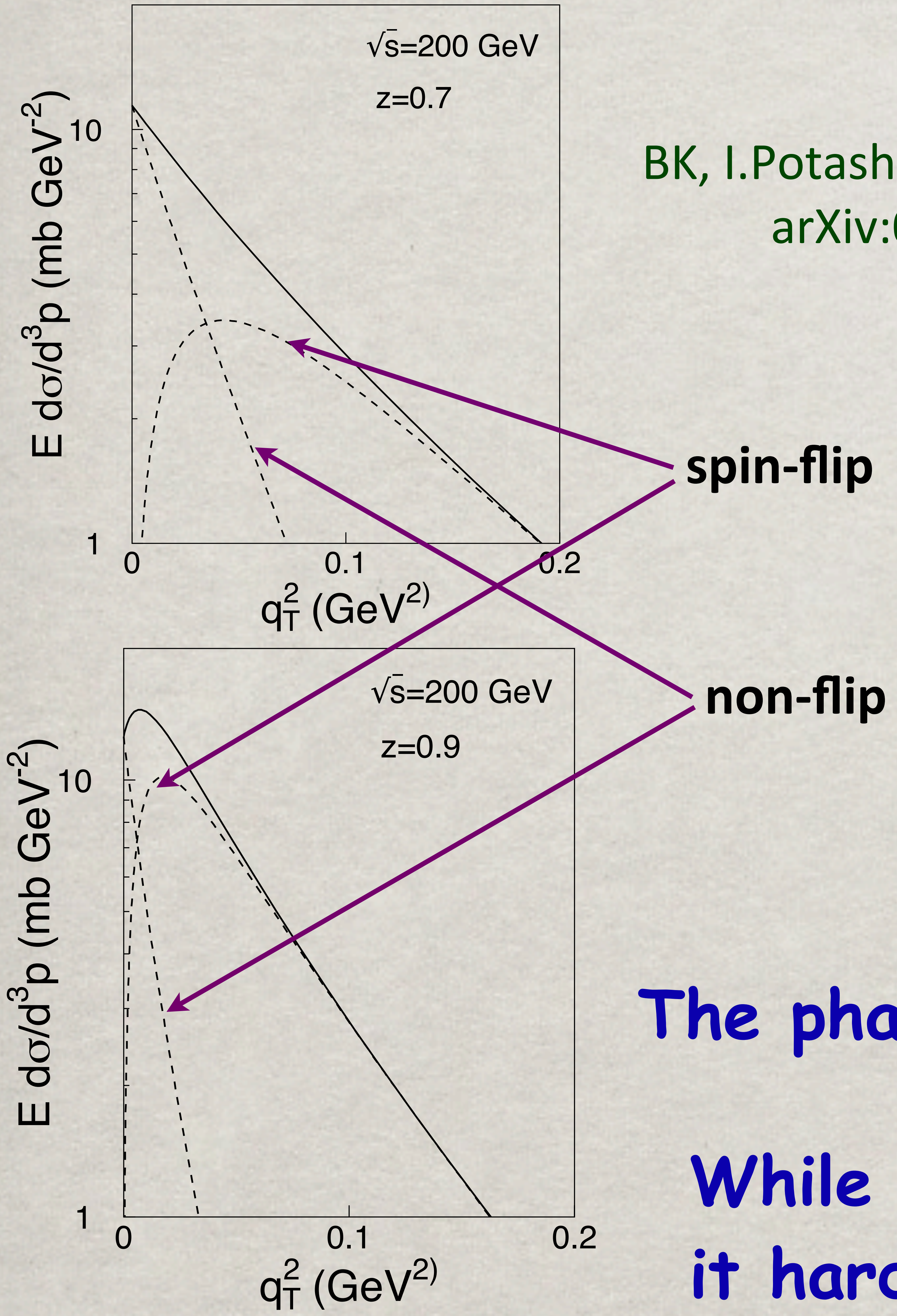


**Underestimated theory,
or overestimated data?**

**The main suspect is the
normalization of the ISR data.**

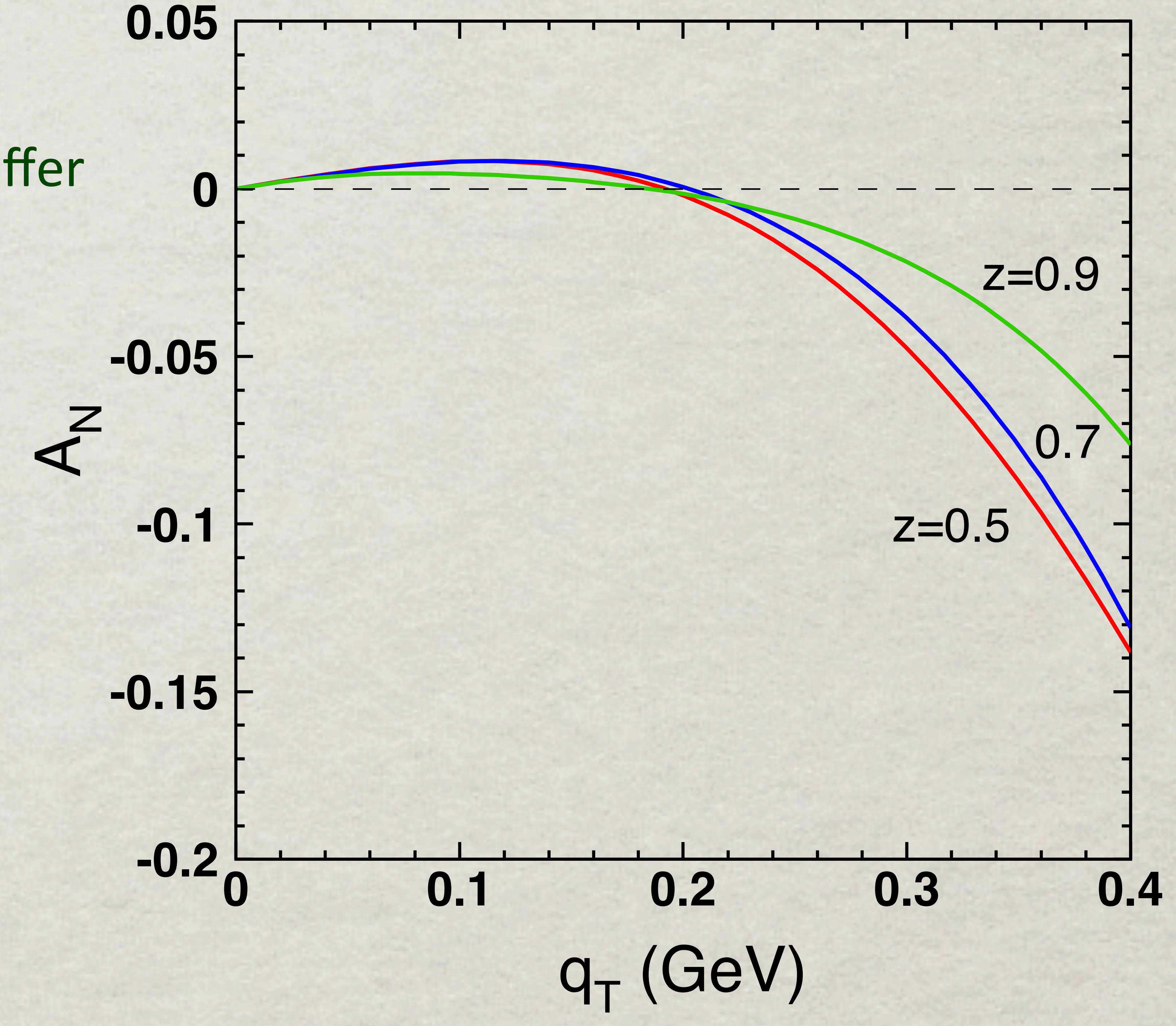
Single-spin asymmetry from absorption

BK, I.Potashnikova, I.Schmidt, J.Soffer
arXiv:0807.1449 [hep-ph]



spin-flip

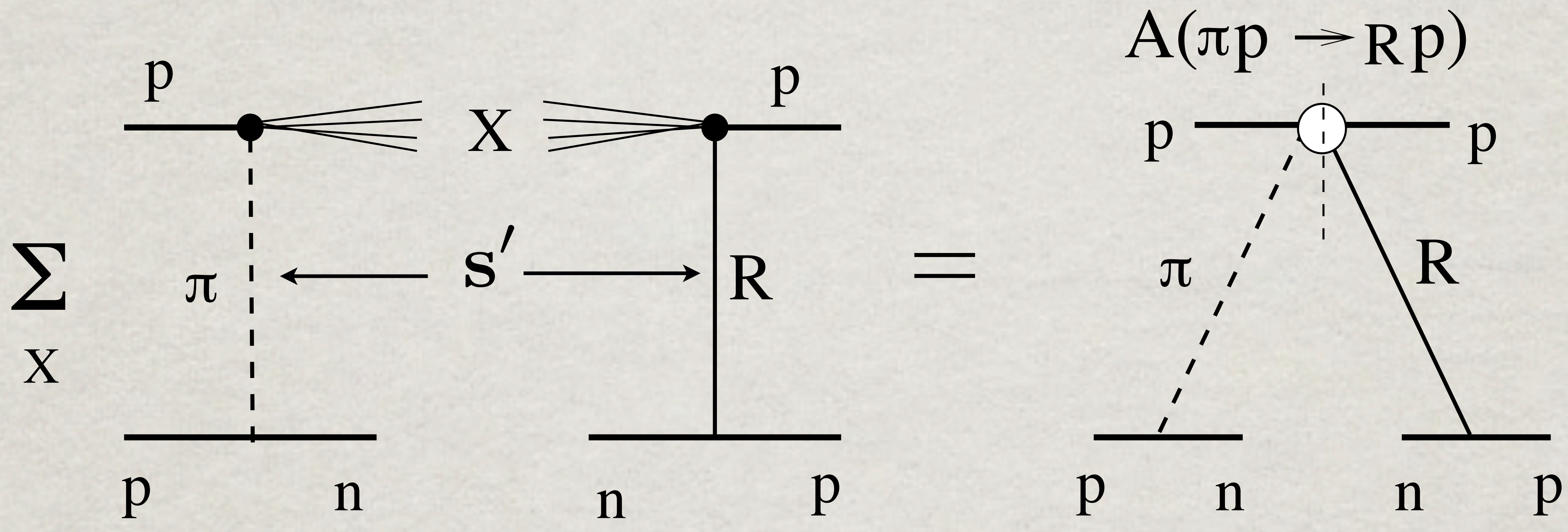
non-flip



The phase shift is too small to explain the PHENIX data

While absorption strongly reduces the cross section, it hardly affects the spin asymmetry

Interference with other Reggeons



The c.m. collision energy squared in $\pi \mathbf{p} \to \mathbf{R}\mathbf{p}$ is very high,

$$\mathbf{M}_{\mathbf{X}}^{\mathbf{2}} = (\mathbf{1} - \mathbf{z})\mathbf{s} \quad \Longleftrightarrow \quad \mathbf{s}' = \mathbf{s}_{\mathbf{0}}/(\mathbf{1} - \mathbf{z})$$

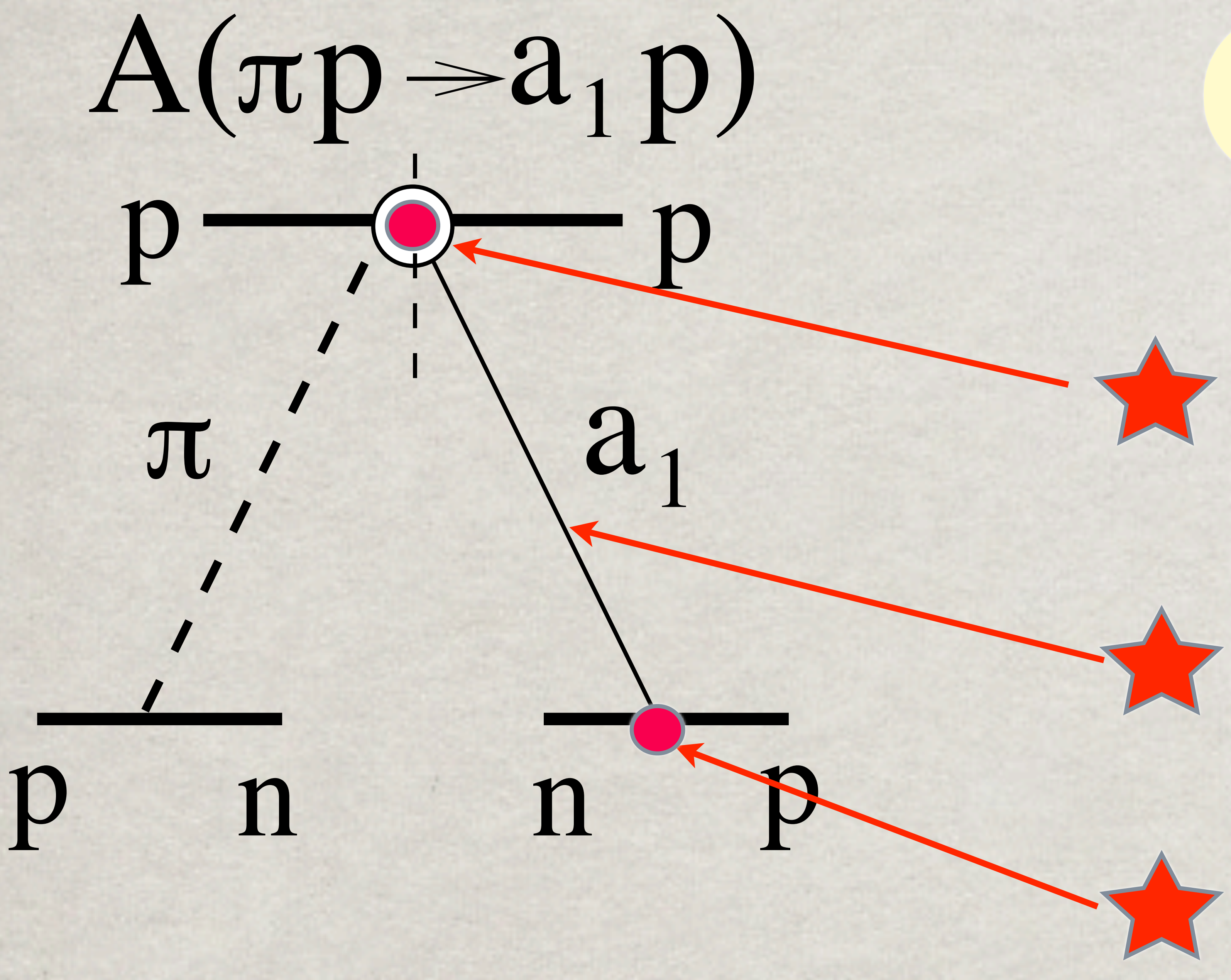
The forward production amplitude
for natural parity hadrons (Reggeons)
is vanishingly small

$$\mathbf{A}(\pi \mathbf{p} \to \mathbf{R}\mathbf{p})_{\mathbf{R}=\rho,\mathbf{a_2},\omega\dots} \propto \mathbf{1}/\mathbf{M}_{\mathbf{X}}$$

Only unnatural parity states can be
produced diffractively

$$\mathbf{A}(\pi \mathbf{p} \to \mathbf{a_1}\mathbf{p}) \approx \mathbf{const}$$

Pion - a_1 interference



Three unknowns:

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

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

a_1 -nucleon coupling $g_{a_1 np}$

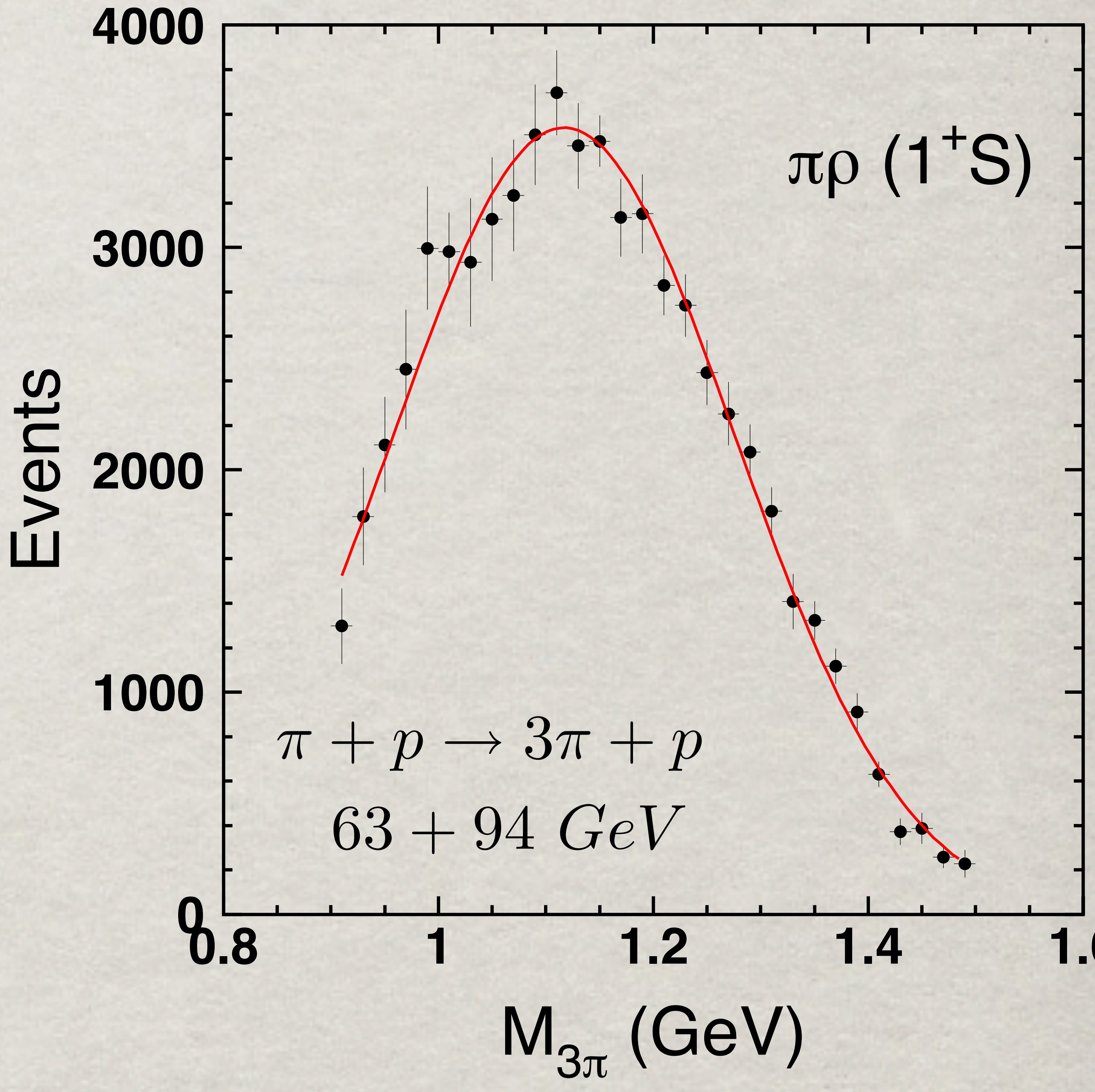
$$A_N^{(\pi-a_1)}(q_T,z) = q_T \frac{4m_N\, q_L}{|t|^{3/2}} (1-z)^{\alpha_\pi(t)-\alpha_{a_1}(t)} \frac{\mathrm{Im}\,\eta^*_\pi(t)\,\eta_{a_1}(t)}{|\eta_\pi(t)|^2}$$

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

a_1 production cross section

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.

aNN coupling

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,

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

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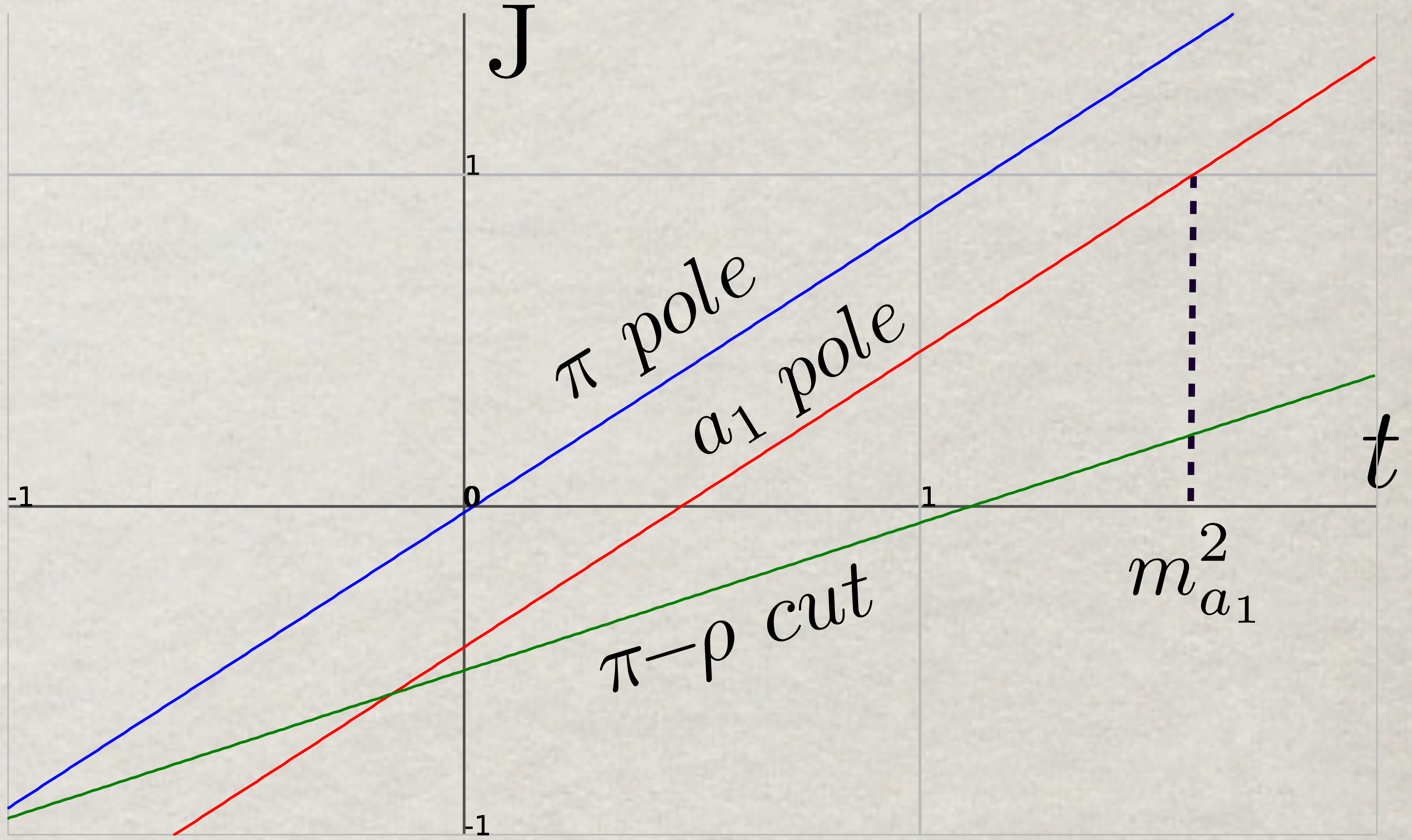
Regge trajectories

Assuming the universal slope of Regge trajectories $\alpha'_{\mathbf{a_1}} = \mathbf{0.9\,GeV^{-2}}$

$$\alpha_{\mathbf{a_1}}(\mathbf{t}) = -\mathbf{0.43} + \mathbf{0.9\,t}$$



The π–ρ cut state is more important, it has trajectory

$$\alpha_{\pi-\rho}(\mathbf{t}) = \alpha_\pi(\mathbf{0}) + \alpha_\rho(\mathbf{0}) - \mathbf{1} + \alpha'_{\mathbf{R}}\,\mathbf{t}/\mathbf{2}$$

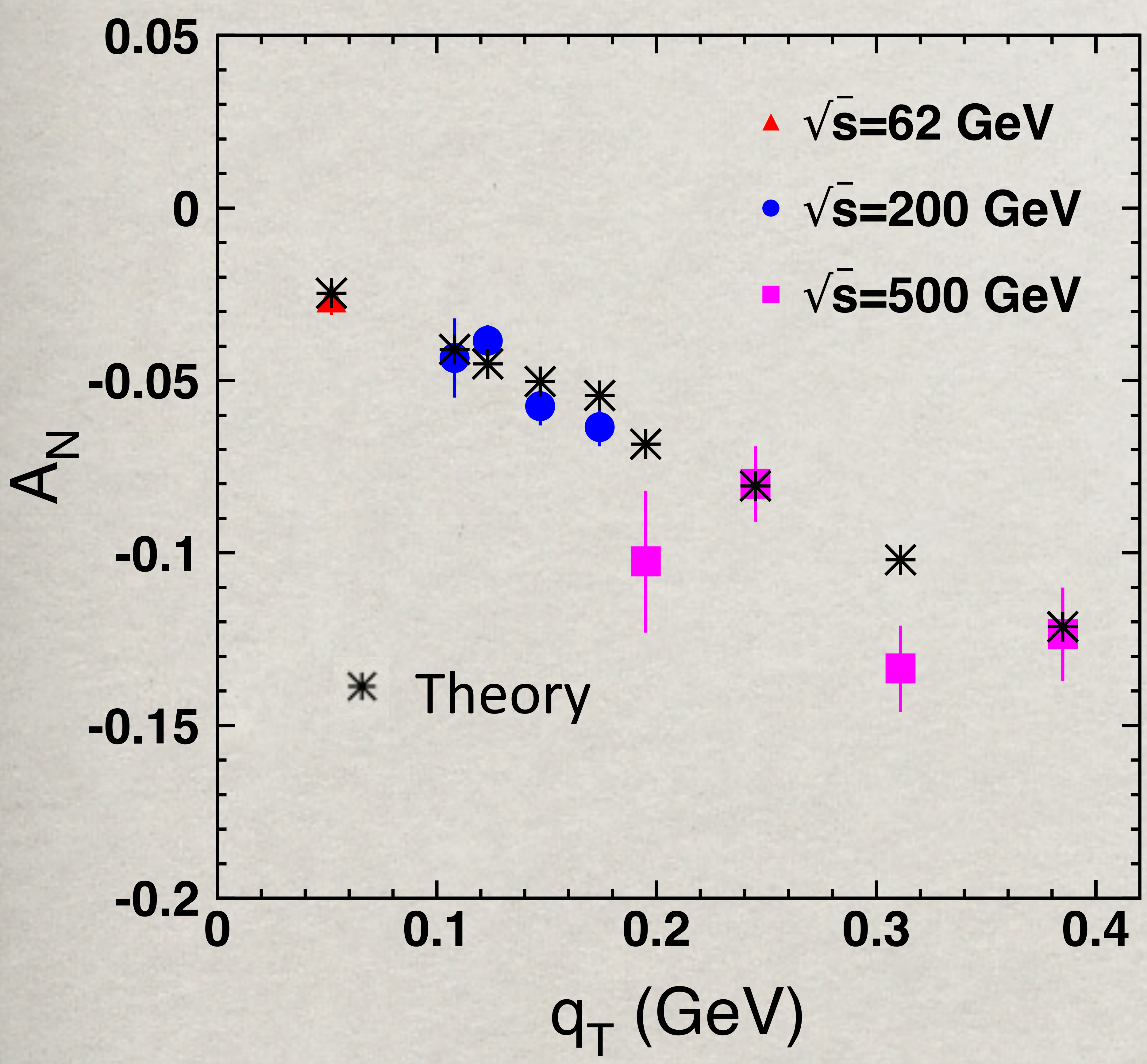
The signature factor of the effective $\mathbf{1^+S}$ state

$$\eta_{\mathbf{a}}(\mathbf{t}) = -\mathbf{i} - \mathbf{tg}\left[\pi\alpha_{\mathbf{a}}(\mathbf{t})/\mathbf{2}\right]$$

The phase shift relative the pion pole is large

$$\phi_{\mathbf{a}}(\mathbf{t}) - \phi_\pi(\mathbf{t}) \approx \frac{\pi}{\mathbf{2}}\left[\mathbf{1.5} + \mathbf{0.45\,t}\right]$$

Results



The data agree well with independence of energy

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

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

Theoretical uncertainty is not large, about 30%

Summary

- **While the cross section of leading neutron production agree well with a single pion model, $\Omega\Omega$ the spin effect are more sensitive to presence of different mechanisms.**

- **In spite of the strong absorption corrections, the gained phase shift between spin-flip and non-flip amplitudes is far too small to explain PHENIX data on single spin asymmetry.**

- **In addition to pion, other hadronic states may be important, provided that their quantum numbers allow diffractive production, $\pi + \mathbf{p} \to \mathbf{a} + \mathbf{p}$. This process is dominated by $\mathbf{a_1}$ meson and $\pi{-}\rho$ in $\mathbf{1^+S}$ state. We modeled them by an affective pole, whose parameters were found employing PCAC and current algebra sum rules. The model provides an excellent parameter-free description of data on single-spin asymmetry.**