Damping and spin-asymmetry of forward neutrons

Boris Kopeliovich

Universidad Técnica Federico Santa María
Valparaiso, Chile

In collaboration with:

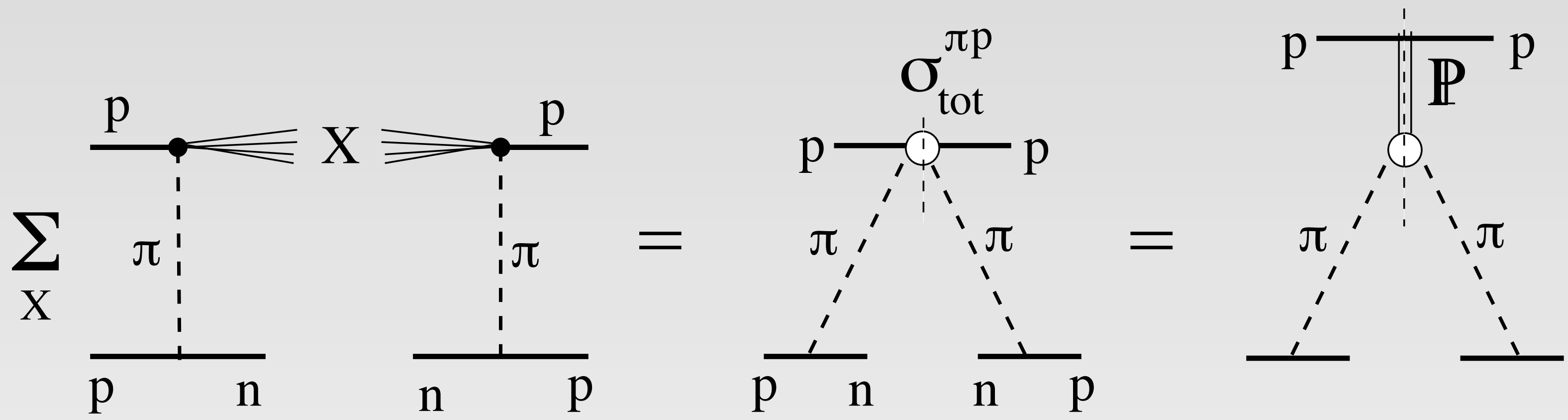
Irina Potashnikova

Ivan Schmidt

Jacques Soffer

Born approximation

Triple-Regge phenomenology



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

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

$$q_L = (1-z)\, m_N\,; \qquad t = -\frac{1}{z}\,(q_L^2 + q_T^2)$$

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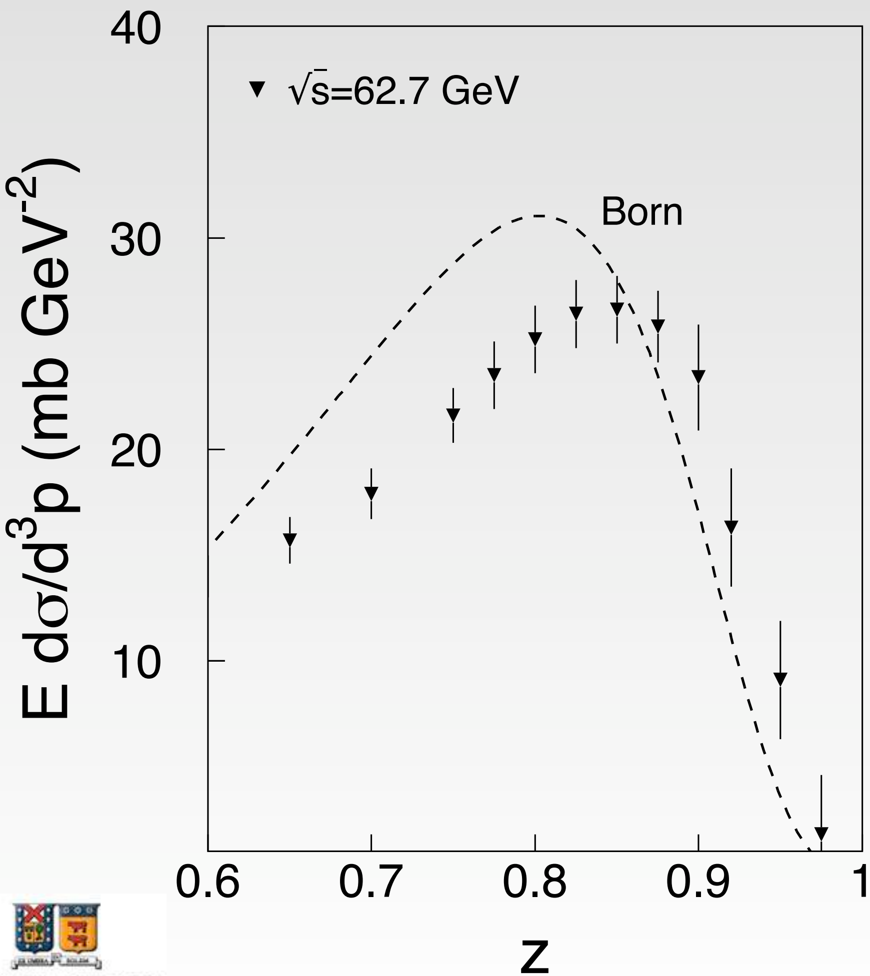
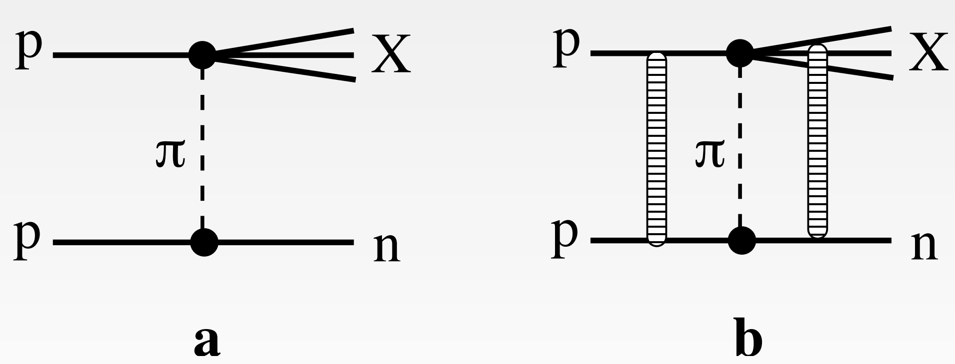
Born approximation

$$z\frac{d\sigma^{B}_{p\to n}}{dz\,dq_T^2} = \frac{g^2_{\pi^+pn}}{(4\pi)^2}\,\frac{|t|\,F^2(t)}{(m_\pi^2 - t)^2}(1-z)^{1-2\alpha_\pi(t)}\sigma^{\pi^+p}_{tot}(M_X^2)$$



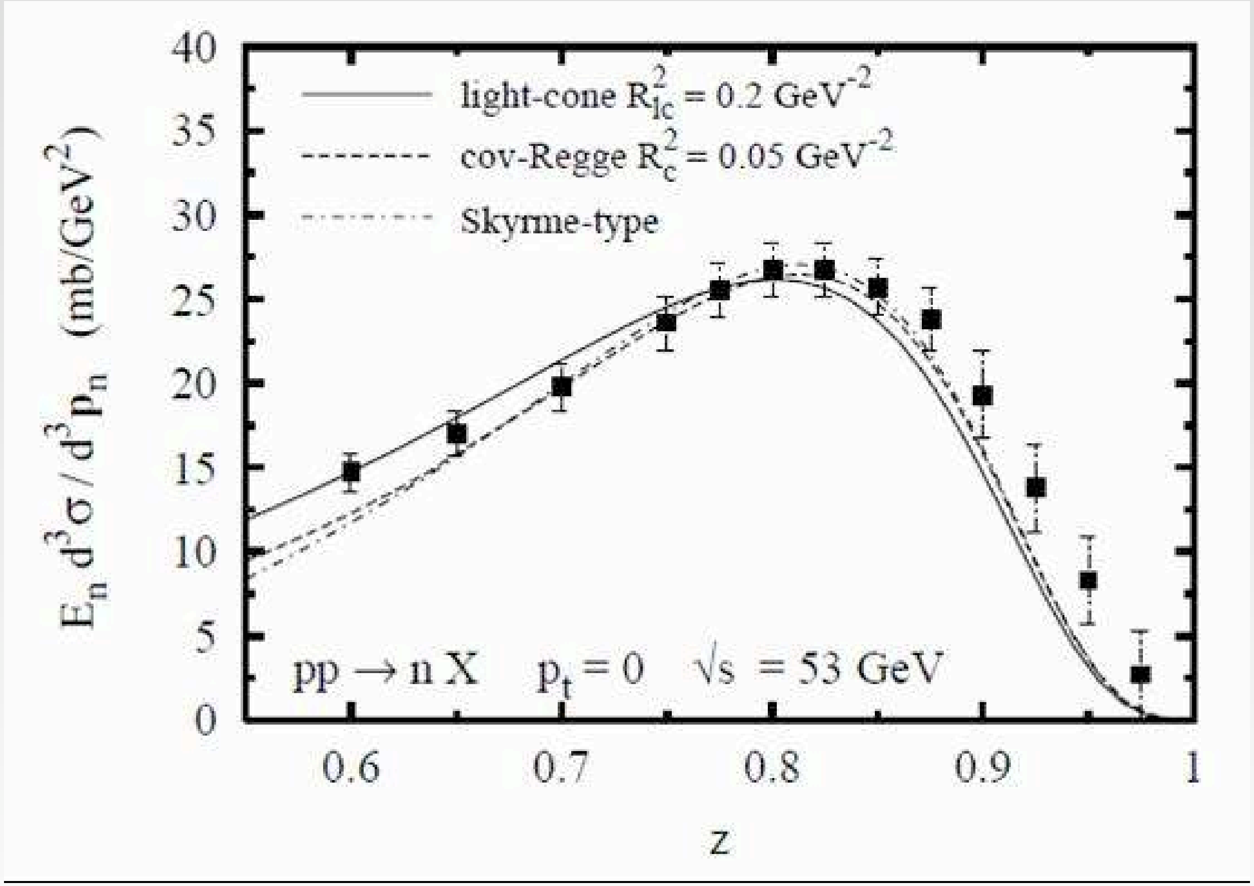
What is missed?

Absorptive corrections

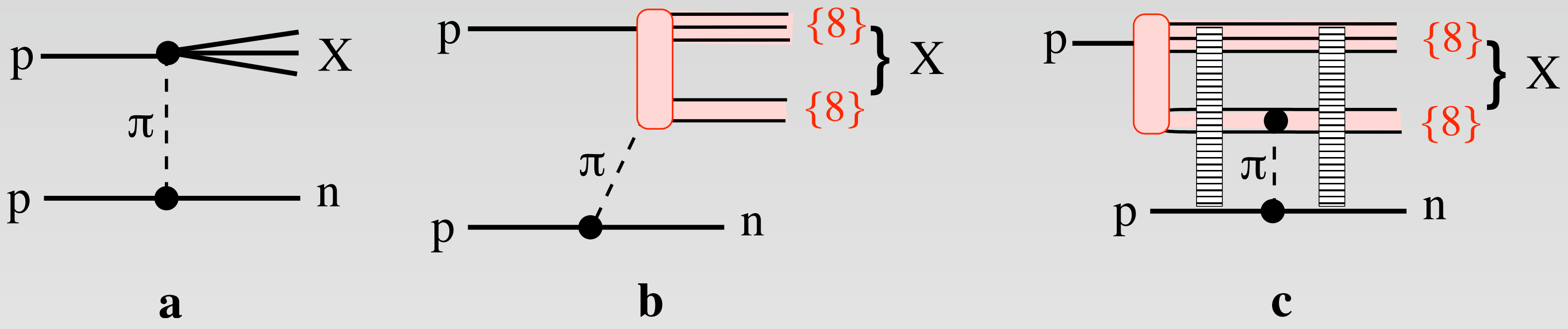


Absorptive corrections: State of Art

U.D. Alesio and H.J. Pirner, Eur.Phys.J. A7(2000)109
N.N. Nikolaev et al. Phys.Rev. D60(1999)014004



Absorptive corrections

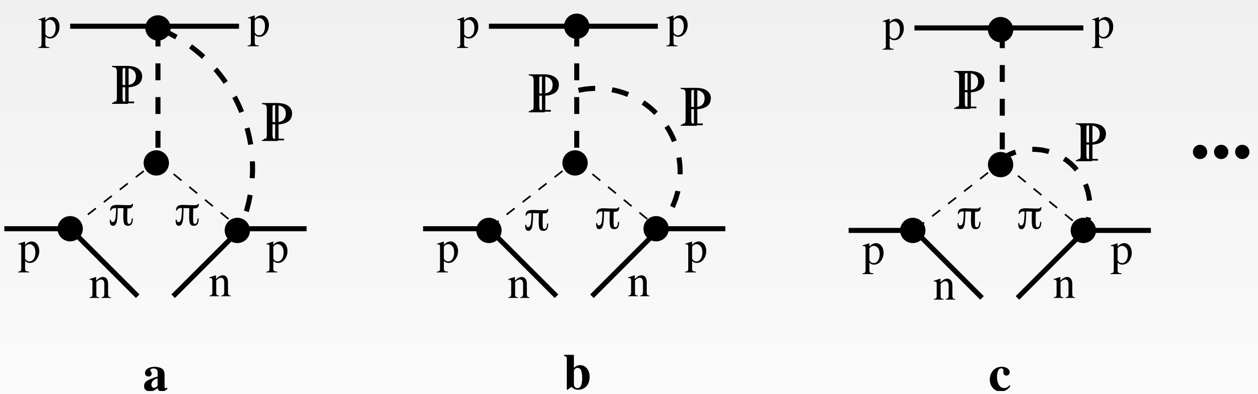


The survival probability amplitude $S(b)$ for a color octet-octet dipole is rather low.

- What has been missed in previous calculations?

Reggeon calculus:

a: was included;
b: was neglected;
c: was overlooked.



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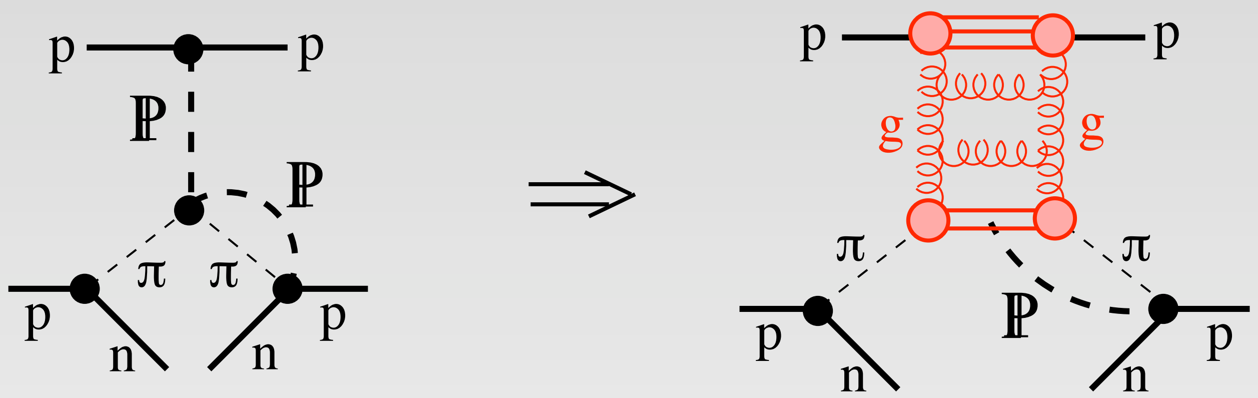
Absorptive corrections

Structure of the missed graph



- Interaction of the target with the proton remnants leads to eikonal-type graphs (a: included);
- Interaction with radiated gluons (Pomeron ladder rungs) results in a small triple-Pomeron coupling (b: neglected);
- Interaction with the pion remnants is as important, as the first contribution (c: should be added).

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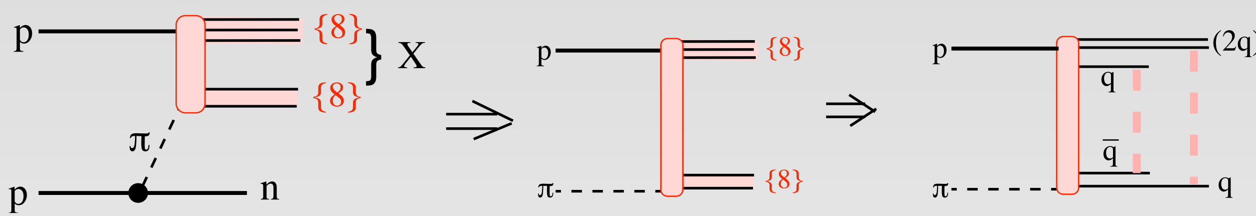
Survival probability amplitude S(b)

- **Dipole representation**

$1/N_c$ expansion:



$$S^{(5q)}(b) = S^{(3q)}(b)\, S^{(q\bar{q})}(b) = \left[1 - \mathrm{Im}\Gamma^{(3q)p}(b)\right] \left[1 - \mathrm{Im}\Gamma^{(\bar{q}q)p}(b)\right]$$

$$\mathrm{Im}\Gamma^{(\bar{3}3)p}(b,z) = \int d^2r\, W_{\bar{3}3}(r, M_X^2) \mathrm{Im} f_{el}^{\bar{3}3}(\vec{b}, \vec{r}, x, \alpha)$$

$$W_{\bar{3}3}(r, M_X^2) = \frac{1}{2\pi\, B_{el}^{\pi p}(M_X^2)} \exp\left[-\frac{r^2}{2B_{el}^{\pi p}(M_X^2)}\right]$$

The partial dipole amplitude $f_{el}^{\bar{3}3}(\vec{b}, \vec{r}, s, \alpha)$ is calculated in the saturated model fitted to photoproduction and DIS data.

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Survival probability amplitude S(b)

$$\mathrm{Im}\mathbf{f}_{\mathbf{el}}^{\bar{\mathbf{q}}\mathbf{q}}(\vec{\mathbf{b}},\vec{\mathbf{r}},\mathbf{x},\alpha) = \frac{\sigma_0}{8\pi B}\left\{\exp\left[-\frac{[\vec{b}+\vec{r}(1-\alpha)]^2}{2B}\right]\right.$$

$$+ \quad \exp\left[-\frac{(\vec{b}-\vec{r}\alpha)^2}{2B}\right] - 2\exp\left[-\frac{r^2}{R_0^2(x)} - \frac{[\vec{b}+(1/2-\alpha)\vec{r}]^2}{2B(s)}\right]\left.\right\}$$

The partial amplitude reproduces the total dipole-proton cross section,

$$2\int d^2b\,\mathrm{Im}f_{el}^{\bar{q}q}(\vec{b},\vec{r},x,\alpha) \equiv \sigma_{\bar{q}q}(r,x) = \sigma_0\left[1-e^{-r^2/R_0^2(x)}\right],$$

and the pion-proton elastic slope,

$$B = B_{el}^{\pi p} - \frac{1}{3}\langle r_{ch}^2\rangle_\pi - \frac{1}{8}R_0^2$$

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Survival probability amplitude S(b)

- **Hadronic representation**

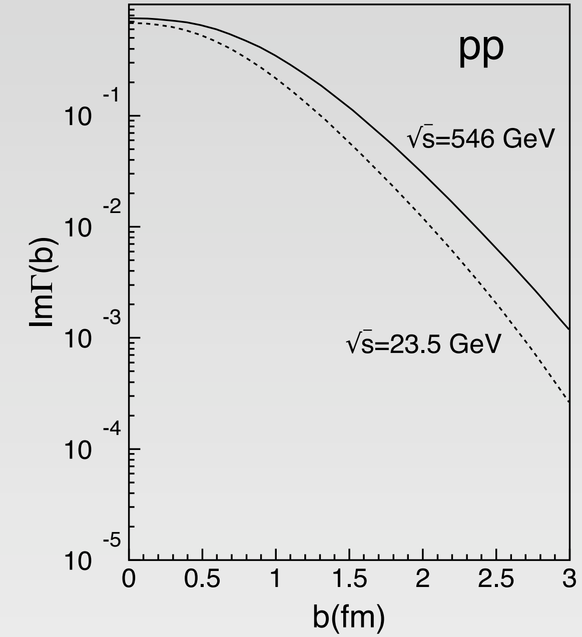
  The 5-quark Fock state can be expanded over the hadronic basis,

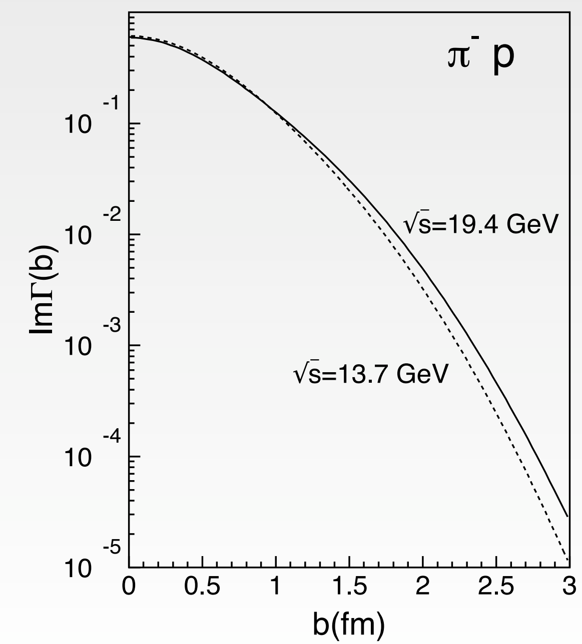
$$|\{3q\}_8\{\bar{q}q\}_8\rangle = d_0|p\rangle + d_1|N\pi\rangle + ...$$

  Assuming that the $|\pi N\rangle$ component dominates,

$$\begin{aligned} S^{(hadr)}(b) &= S^{\pi p}(b)\, S^{pp}(b) \\ &= \left[1 - \mathrm{Im}\Gamma^{pp}(b)\right]\left[1 - \mathrm{Im}\Gamma^{\pi p}(b)\right] \end{aligned}$$

  The partial amplitudes $\mathrm{Im}\Gamma^{hp}(b)$ can be extracted directly from data.





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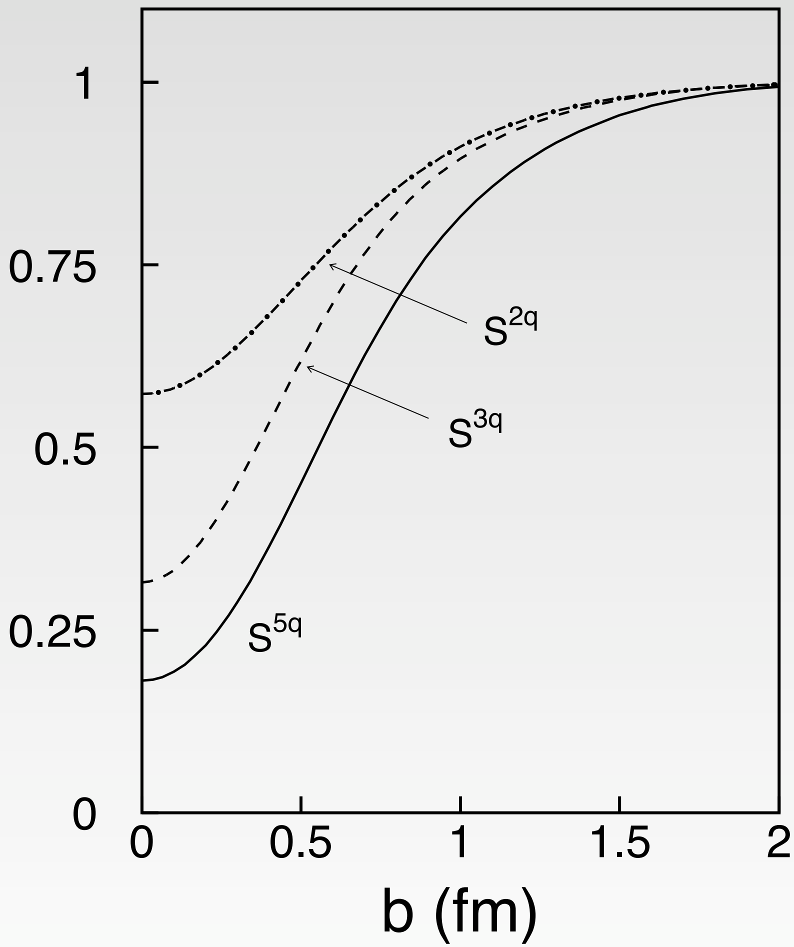
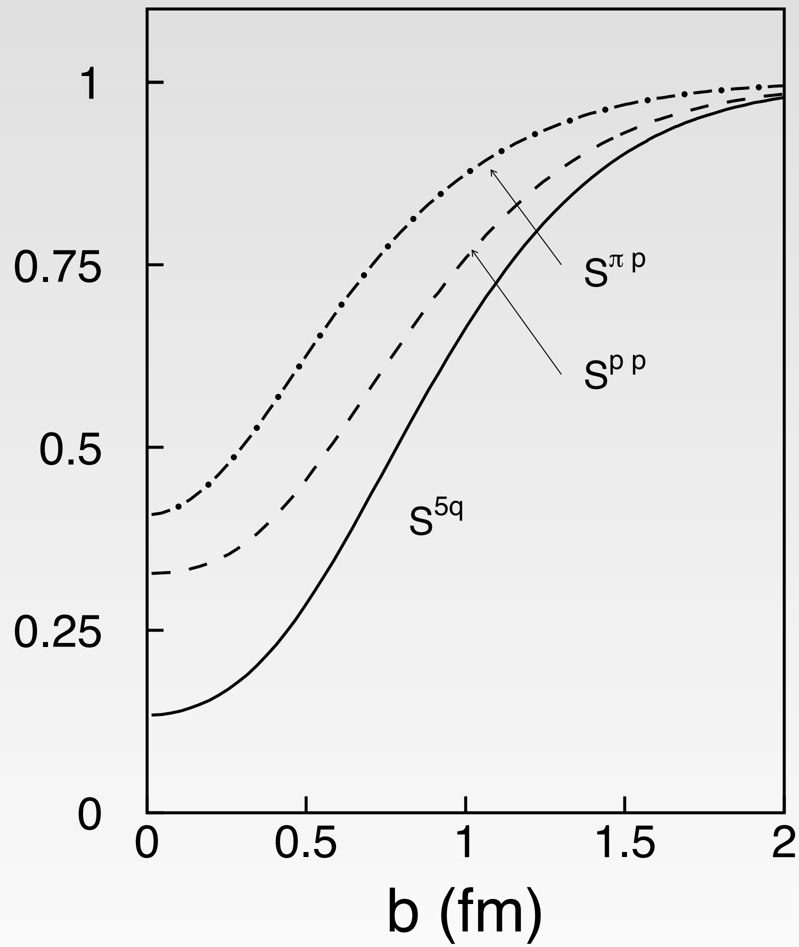
Survival probability amplitude S(b)

Dipole representation



Hadronic representation



Impact parameter representation

Absorption effects factorize in impact parameters

$$f_{p\to n}(\vec{b},z) = \mathbf{S}(\mathbf{b})\times\frac{1}{\sqrt{z}}\,\bar{\xi}_n\left[\sigma_3\,q_L\,\theta_0^B(b,z) - i\,\frac{\vec{\sigma}\cdot\vec{b}}{b}\,\theta_s^B(b,z)\right]\xi_p$$

Born amplitudes:

$$\theta_0^B(b,z) = N(z)\left\{i\,\frac{\pi\alpha'_\pi}{2z\beta^2}\,K_0(b/\beta) + \frac{1}{1-\beta^2\epsilon^2}\,\left[K_0(\epsilon b) - K_0(b/\beta)\right]\right\}\;;$$

$$\theta_s^B(b,z) = \frac{1}{b}N(z)\left\{i\,\frac{\pi\alpha'_\pi}{2z\beta^3}\,K_1(b/\beta) + \frac{1}{1-\beta^2\epsilon^2}\,\left[\epsilon\,K_1(\epsilon b) - \frac{1}{\beta}\,K_1(b/\beta)\right]\right\}$$

$$\begin{aligned}
N(z) &= \frac{1}{2}\,g_{\pi^+pn}\,z(1-z)^{\alpha'_\pi(m_\pi^2+q_L^2/z)}e^{-R_1^2q_L^2/z}A_{\pi p\to X}(M_X^2)\\
\epsilon^2 &= q_L^2 + zm_\pi^2\,,\\
\beta^2 &= \frac{1}{z}\,\left[R_1^2 - \alpha'_\pi\,\ln(1-z)\right]
\end{aligned}$$

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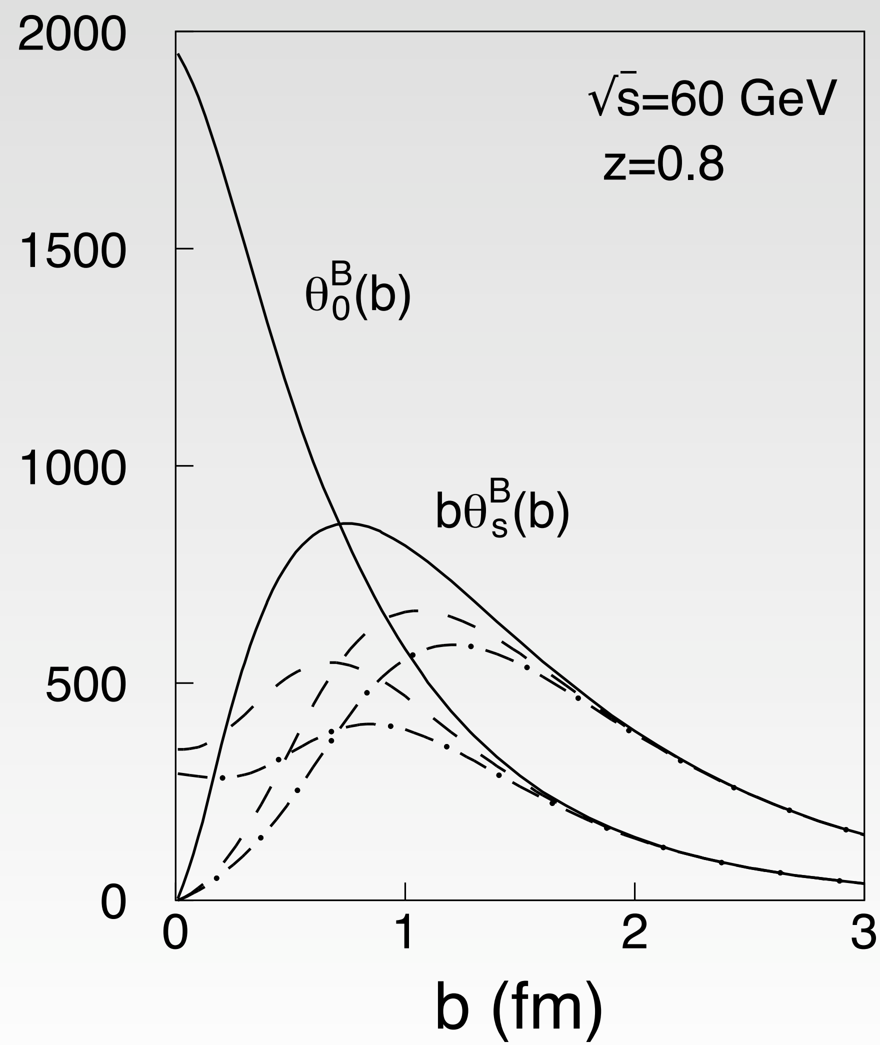
Absorption corrections

Partial spin amplitudes corrected for absorption

Real parts of partial spin amplitudes for neutron production, non-flip, $\theta_0(b, z)$, and spin-flip, $b\theta_s(b, z)$. Solid curves show the result of Born approximation. Dashed and dot-dashed curves include absorptive corrections calculated in the dipole approach ($\times S^{(5q)}(b, z)$) and in hadronic model ($\times S^{(hadr)}(b, z)$), respectively



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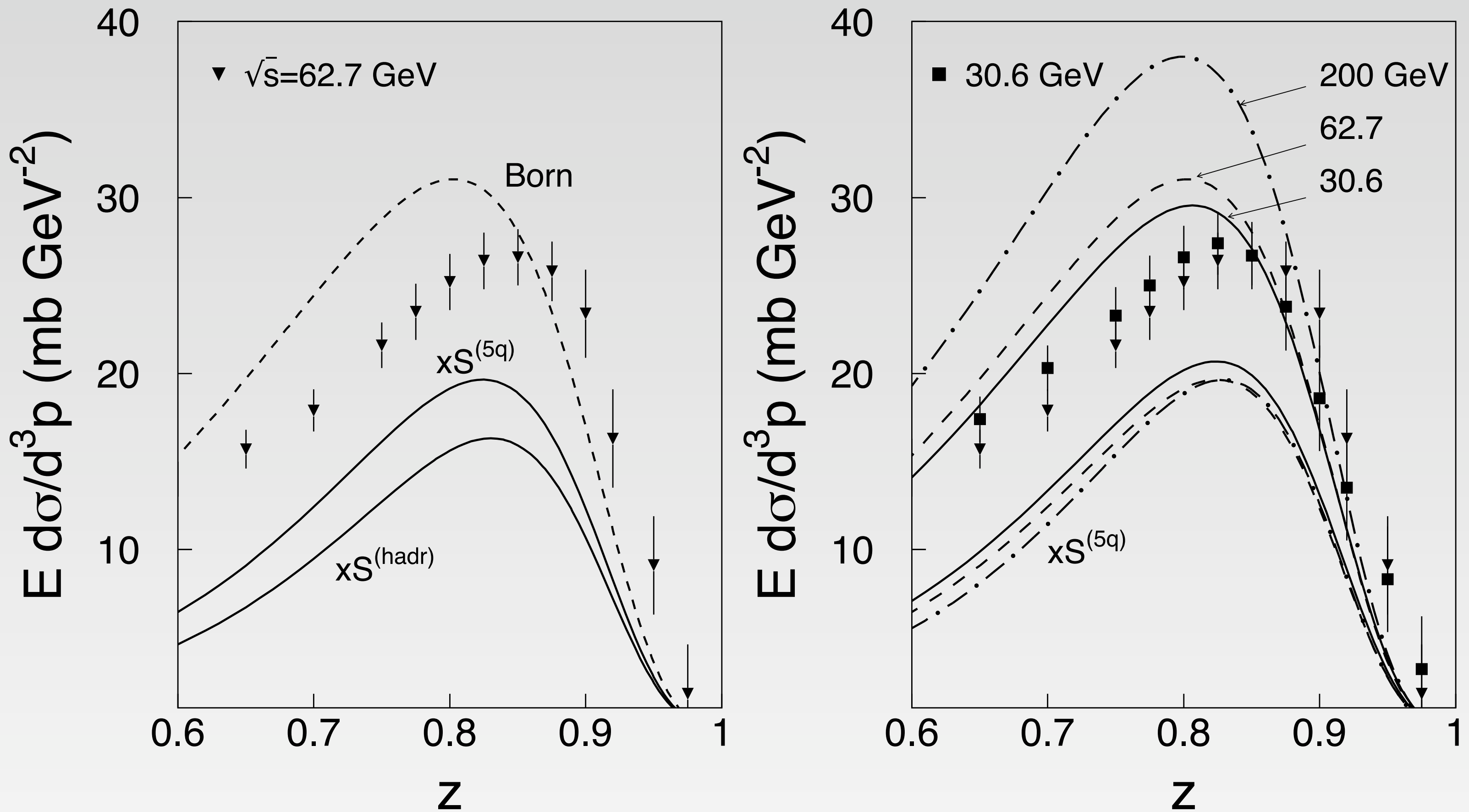
Cross section



- The two models for absorptive corrections lead to similar results.
- The absorption corrected cross section considerably underestimates the ISR data.

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Cross section

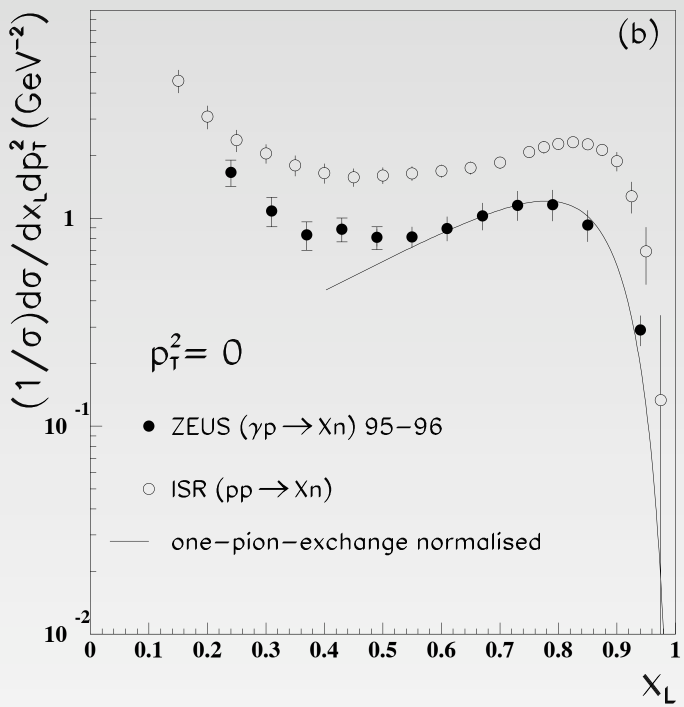
Challenging the ISR data

- The normalization of the data has systematic uncertainty **20%**

- There is a strong evidence from the recent measurements by ZEUS of leading neutron production in DIS that the normalization of the ISR data is **twice** overestimated. According to Regge factorization the ratio

$$\frac{dN}{dz dq_T^2} = \frac{1}{\sigma_{tot}^{hp}} \frac{d\sigma_{hp\to Xn}}{dz dq_T^2},$$

should be universal, i.e. independent of the particle h.



- The ratio of the pion-to-proton structure functions measured at small x by ZEUS is about $1/3$, **twice** as small as was expected.

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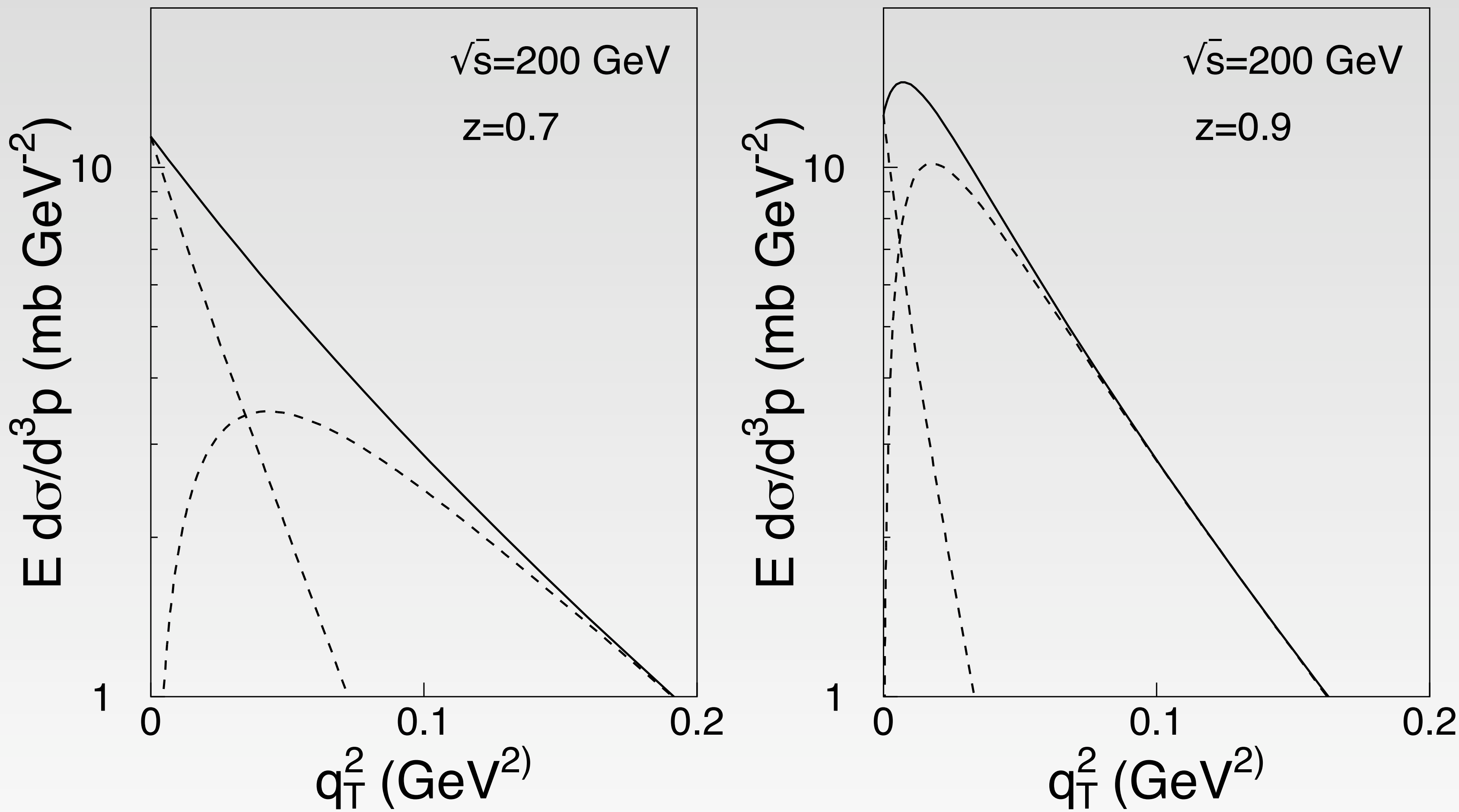
Cross section

q_T-dependence



Spin-flip contribution rises towards $z = 1$

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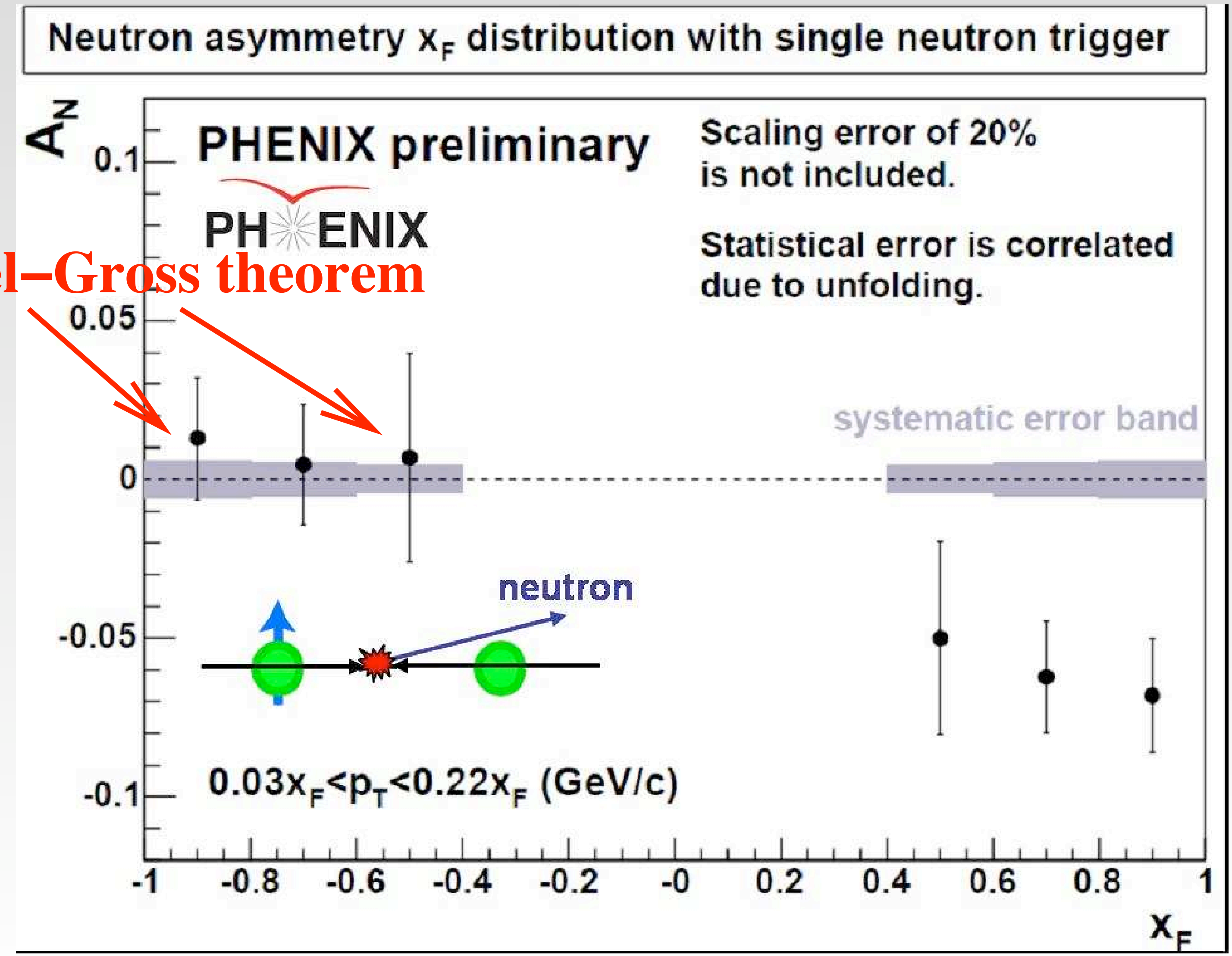
Single-spin asymmetry A_N

PHENIX measurements



Abarbanel–Gross theorem

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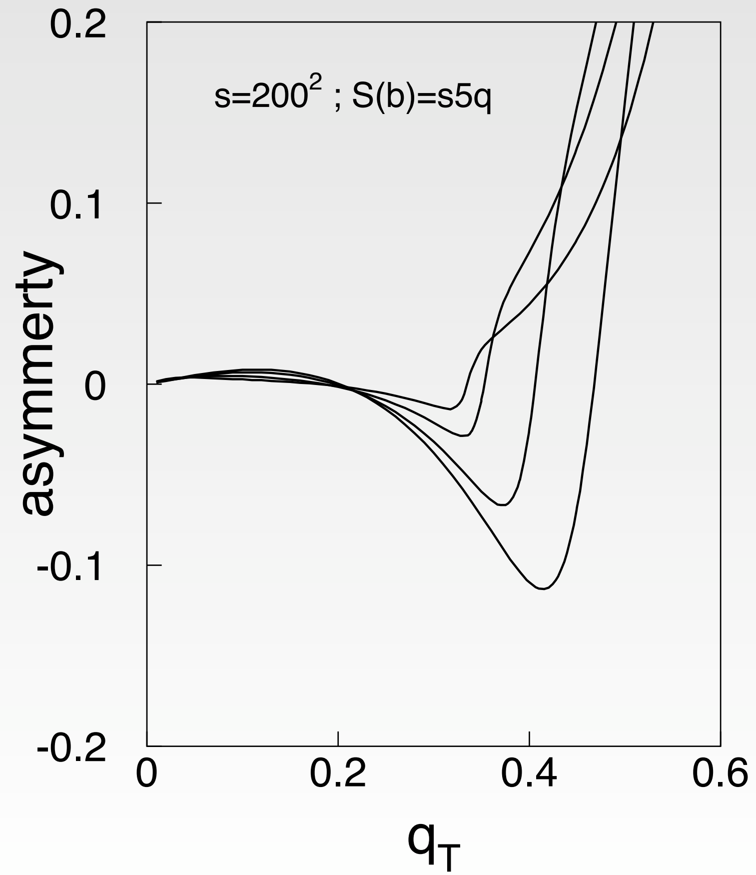
Single-spin asymmetry A_N

$$f_{p\to n}(\vec{q},z) = \frac{1}{\sqrt{z}}\bar{\xi}_n\left[\sigma_3\, q_L\, \phi_0(q_T,z) + \vec{\sigma}\cdot\vec{q}_T\phi_s(q_T,z)\right]\xi_p$$

$$A_N(q_T,z) = \frac{2q_T q_L \phi_0(q_T,z)\phi_s(q_T,z)}{q_L^2\left|\phi_0(q_T,z)\right|^2 + q_T^2\left|\phi_s(q_T,z)\right|^2}\,\sin(\delta_0-\delta_s)\,,$$

The phase shift between spin-flip and non-flip amplitudes emerges due to absorptive corrections, which affect the real and imaginary parts differently.

Fixed $z = 0.6,\ 0.7,\ 0.8,\ 0.9$:



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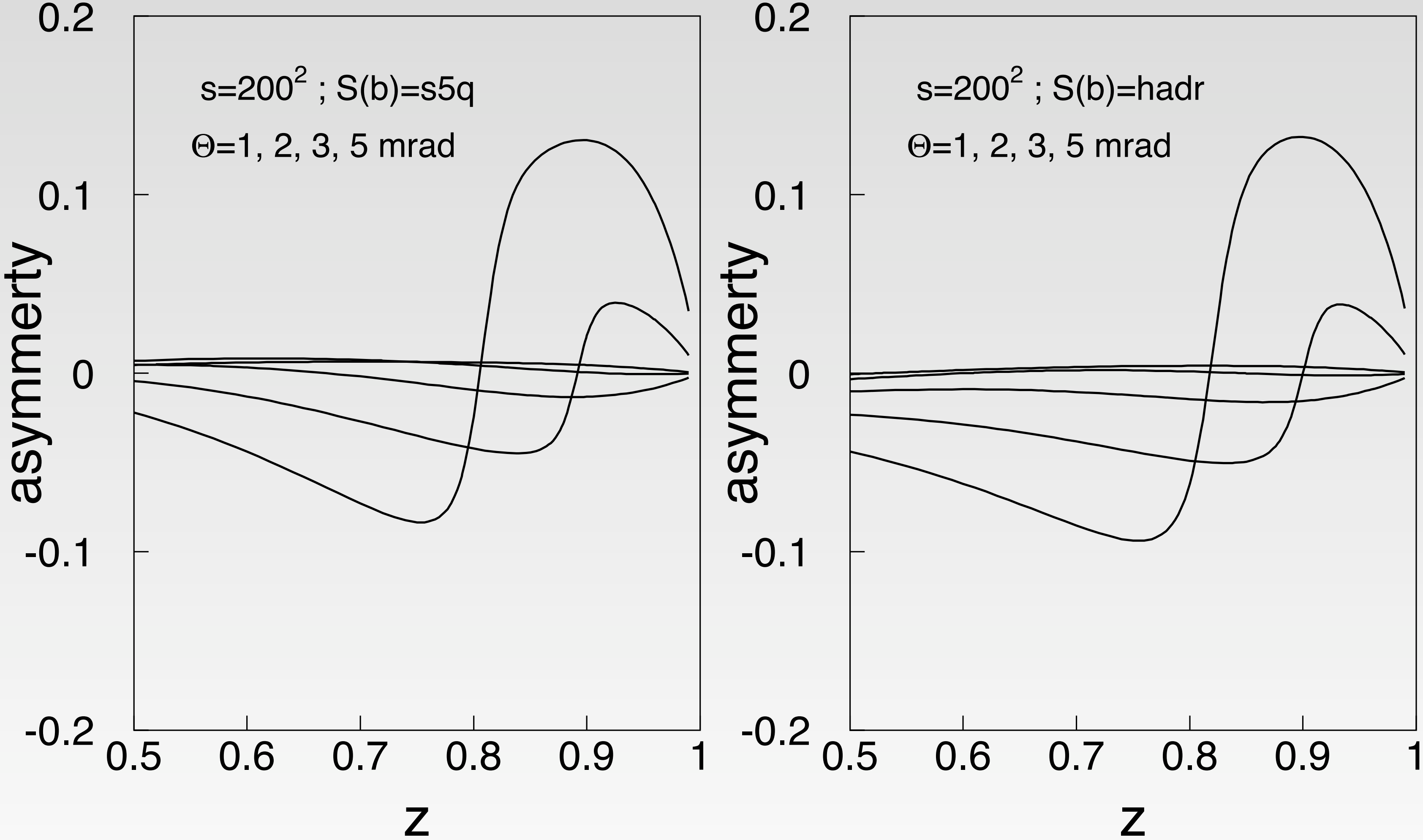
Single-spin asymmetry A_N

Fixed angle $\theta = 1,\ 2,\ 3,\ 4,\ 5$ mrad, $q_T = \theta z \sqrt{s}/2$



Asymmetry at $\theta =$ 1-2 mrad is vanishingly small

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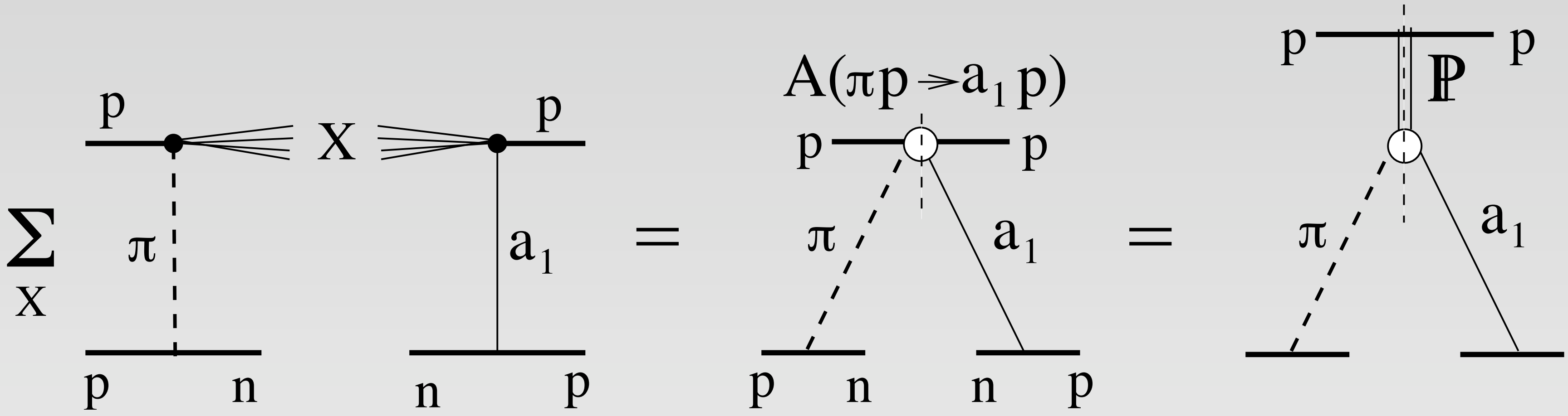
Interference with a_1 meson



Advantages:

- a_1 and pion have similar Regge trajectories, but different signatures, so the amplitudes have the optimal for spin asymmetry phase shift, $\pi/2$;
- The process $\pi p \to a_1 p$ is diffractive, so the $\pi - a_1$ interference does not fall with energy

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Interference with a_1 meson

Problems :

- The cross section of $\pi p \to a_1 p$ is more than order of magnitude suppressed compared to $\pi p \to \pi p$;
- The $a_1 NN$ non-flip coupling is several times smaller than πNN;
- At $z < 0.7$ the spin-flip cross section is order of magnitude less that the non-flip one;
- Additional suppression by an order of magnitude is due to smallness of $q_T \approx 0.1 GeV$.

The asymmetry is measured at such a small $q_T^2 \approx 0.01 GeV^2$, that available mechanisms fail to explain the observed strong effect.

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Summary

- Pion exchange is usually associated with the spin-flip amplitude. However, the amplitude of inclusive process mediated by pion exchange acquires a substantial non-flip part.

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Summary

- Pion exchange is usually associated with the spin-flip amplitude. However, the amplitude of inclusive process mediated by pion exchange acquires a substantial non-flip part.
- One should not convolute the survival **probability** with the **cross section**, but work with the **amplitudes**.
- We identified the projectile system which undergoes initial and final state interactions as a color octet-octet 5-quark state. Absorptive corrections are calculated within two very different models, color-dipole light-cone approach, and in hadronic representation. Nevertheless the results are very similar.

Summary

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- The cross section corrected for absorption is about twice lower than the ISR data. However, comparison with DIS data shows that there is a problem with the normalization of the ISR data.
- Absorption corrections generate a relative phase between the spin-flip and non-flip amplitudes. The resulting asymmetry is rather large, but not at such small transverse momenta, $q_T^2 \sim 0.01\,\mathrm{GeV}^2$.
- These transverse momenta are proper for CNI, while there is no room for Coulomb effects here. No hadronic mechanism has been known so far, which could provide such a large asymmetry at so small q_T. The observed large A_N for neutrons is becoming a **serious challenge** for theory.