Single-spin asymmetry from pomeron-odderon interference

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Work in progress with Paul Hoyer
(University of Helsinki and Nordita)

Outline

- Experimental data of transverse single-spin asymmetry (SSA) in $p^{\uparrow}p \longrightarrow \pi X \longrightarrow$ Motivation for our model
- Perturbative model with soft gluon exchange $\longrightarrow$ dynamics of the process
- Model with Pomeron-odderon interference and results
- Conclusion

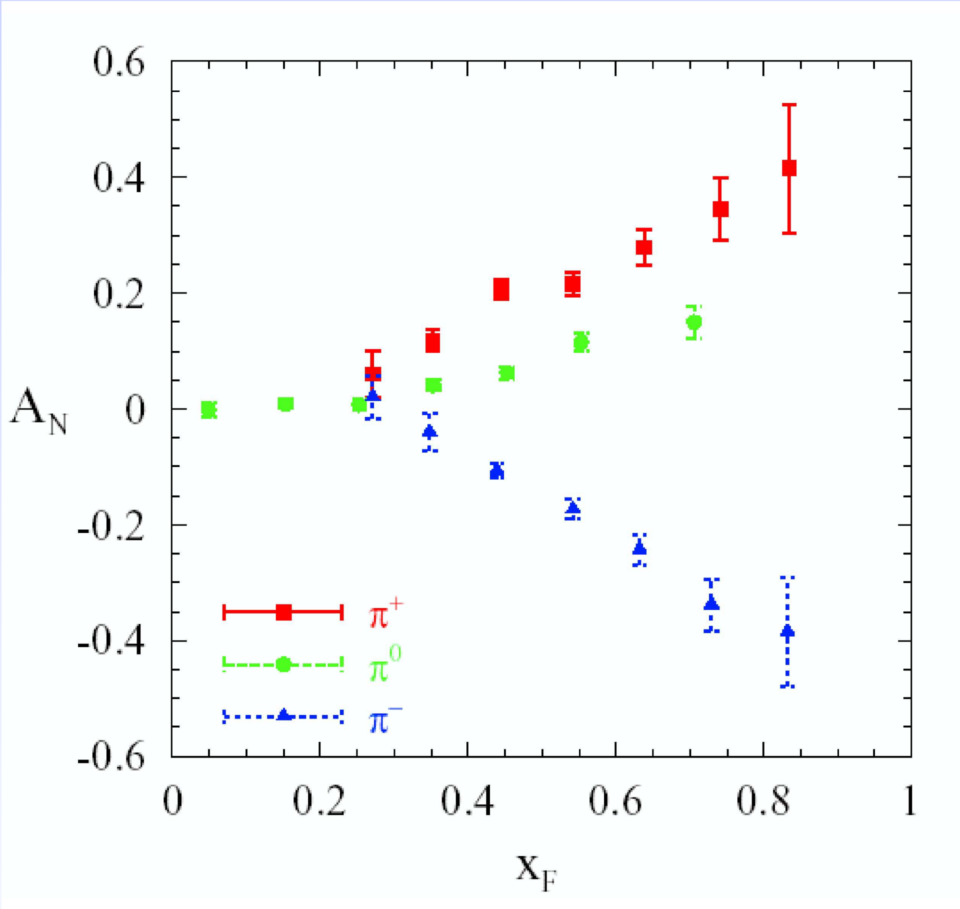
Experimental results for $p^{\uparrow}p \longrightarrow \pi(k_{\perp})X$: E704

FNAL-E704 data ($\sqrt{s} = 20$GeV, $k_{\perp}\sim$1-2GeV):

- Large transverse asymmetries, up to $\sim$40 % for very high $x_F = p_{\pi}/p_{\mathrm{LAB}} \sim 0.85$
- SSA seems to increase with $k_{\perp}$
- π^+ and π^- distributions mirror symmetric

[PLB261(1991)201, PLB264(1991)462]

$$A_N \equiv \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}}$$



Motivation

Experiments $\longrightarrow$ SSA large at very large $x_F \sim 0.8$

- Within factorization the quark that comes from the projectile proton and forms the pion needs to have large $x, z \sim 0.9$

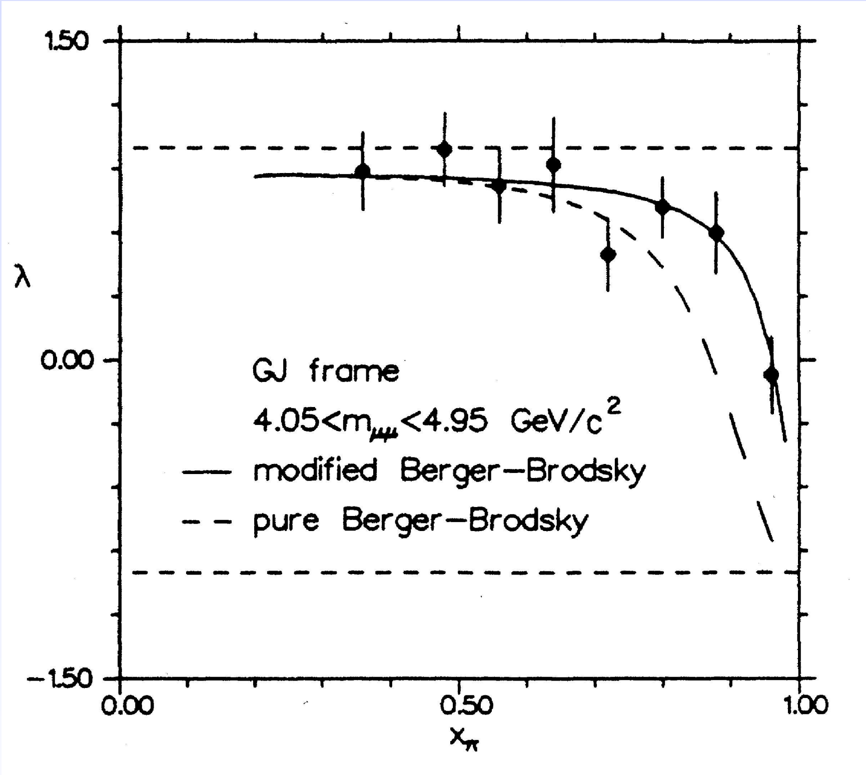
- Physics at large x_F involves the full (multiquark) projectile wave function

- Single quark factorization fails for $k_\perp^2 \to \infty$ with $k_\perp^2(1 - x_F)$ fixed

- Multiquark effects studied and seen previously in (unpolarized) Drell-Yan

[Berger & Brodsky, PRL42(1979)940]

[Conway *et al.*, PRD39(1989)92]



Work (in progress): dynamics of $p^{\uparrow}p \longrightarrow \pi(k_\perp)X$

Dynamical origin of SSA in $p^{\uparrow}p \longrightarrow \pi(k_\perp)X$

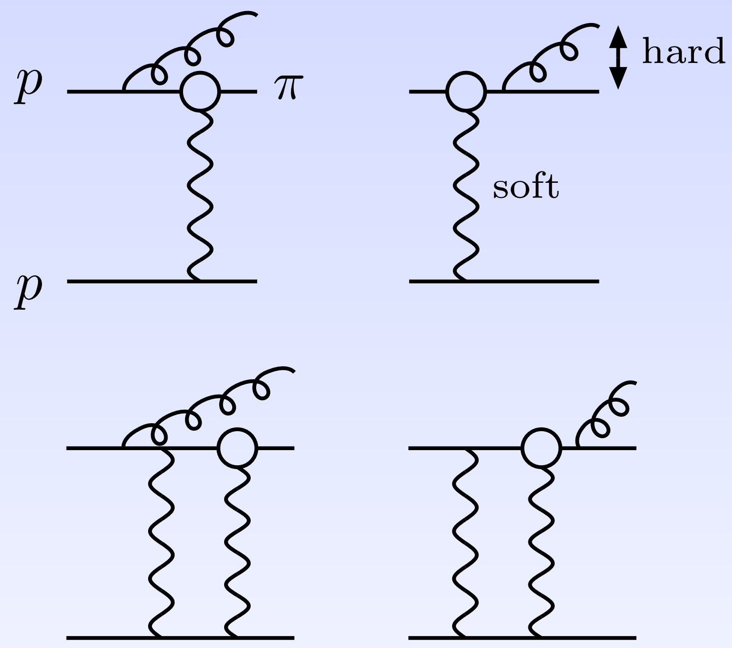
$\longrightarrow$ use a perturbative model

Soft scattering between the target and projectile systems, high $k_\perp$ from gluon emission, $E_{CM} \gg k_\perp > \Lambda_{\mathrm{QCD}}$

$$A_N \sim \sum_{\{\sigma\}} \mathrm{Im}[\mathcal{M}_{+\{\sigma\}}\mathcal{M}^*_{-\{\sigma\}}]$$

$\Rightarrow$ Spin flip and

helicity dependent phase needed



Two gluon exchange $\longleftrightarrow$ Pomeron (imaginary)

One gluon exchange $\longleftrightarrow$ Odderon (real)

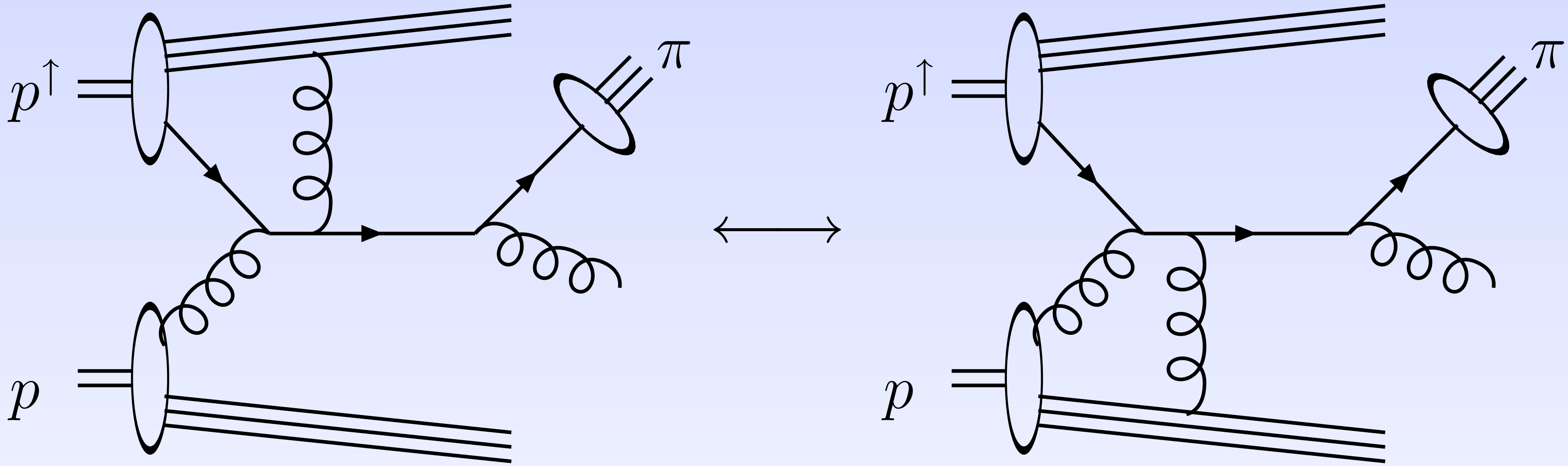
Pauli coupling (the blob) to flip spin

Our dynamics compared to Sivers effect

Different dynamical origin:

Sivers effect: Soft rescattering with the projectile spectators

Our study: Soft rescattering with the (unpolarized) target spectators



$\Rightarrow$ Target dependence?

Our dynamics demands spin flip rescattering. Non flip (Coulomb) rescattering gives a helicity independent phase $\Rightarrow A_N = 0$

Pomeron-odderon interference

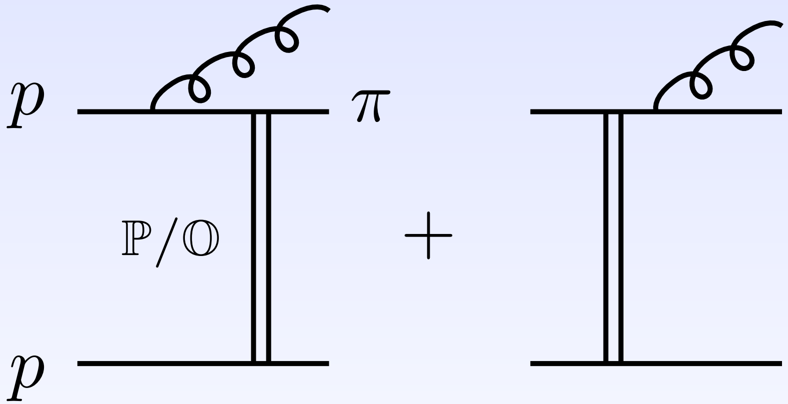
From perturbative model:

- ❑ Spin-flip in soft scattering needed for helicity dependent phase
- ❑ Resolution effect: very soft scattering unable to resolve gluon emission $\rightarrow$ suppression by $p_\perp^{\mathrm{soft}}/k_\perp$ (at fixed x_F)

$\longrightarrow$ Simple model

Regge amplitudes for the pomeron and spin flip odderon exchanges with a 90° phase difference

$$\mathcal{M}^{\mathbb{P}/\mathbb{O}} \sim e^{bt}\left(\frac{s}{s_0}\right)^{\alpha}$$



Gluon emission vertex using perturbation theory

Results

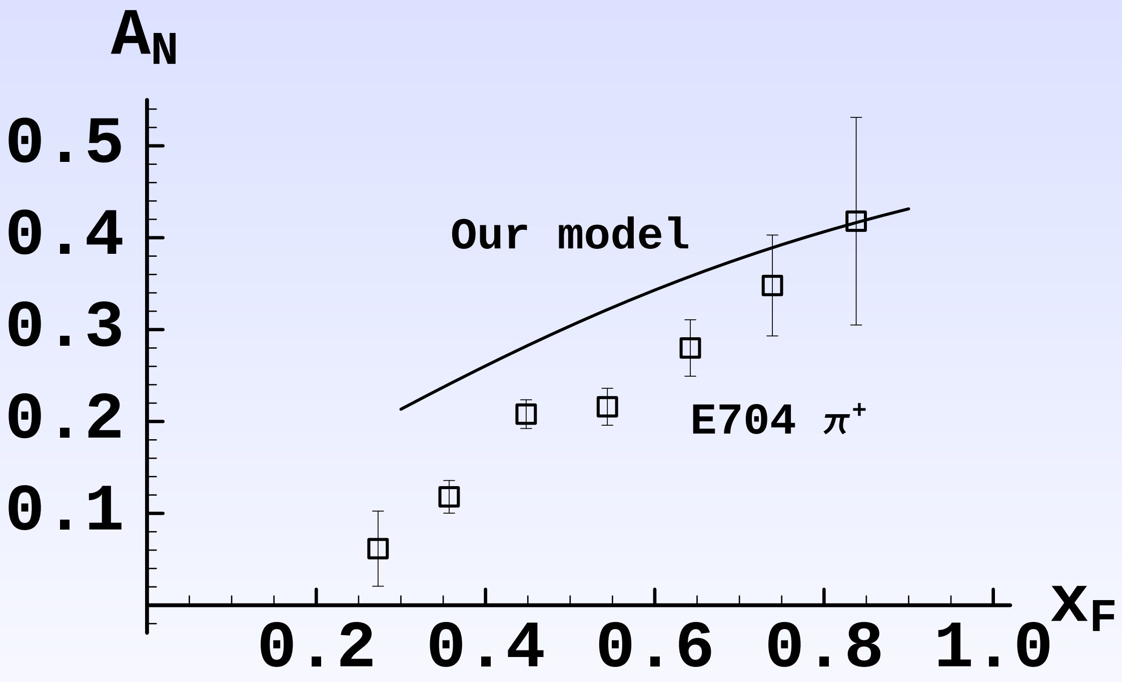
$$A_N \simeq \frac{2(a_0 k_\perp) x_F}{1 + x_F^2}$$

for small ratio of the odderon and pomeron amplitudes $\sim a_0 k_\perp$

(here $a_0 \sim$ strength of the spin-flip coupling)

Comparison to E704 π^+ data with pomeron/odderon exchange only (numerical integration over soft momenta)

Proof of principle that $A_N \neq 0$ is possible



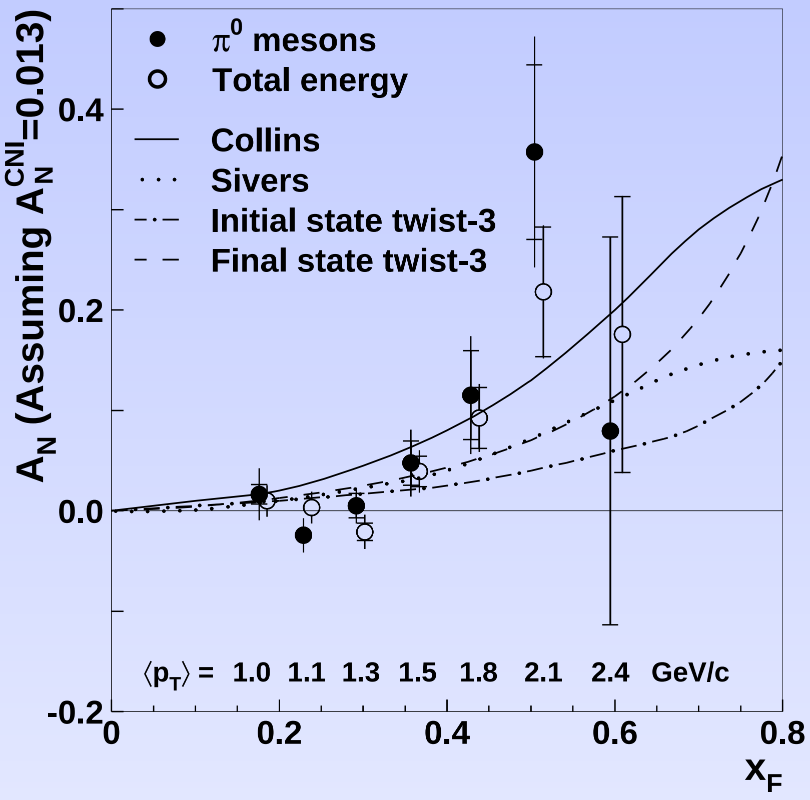
Conclusion

- Multiquark effects arise at $k_\perp^2(1-x_F)$ fixed
- Rescattering from (unpolarized) target spectators can contribute to A_N
- Pomeron-odderon interference can produce a spin-flip and a phase difference, necessary to have $A_N \neq 0$

Experimental results...

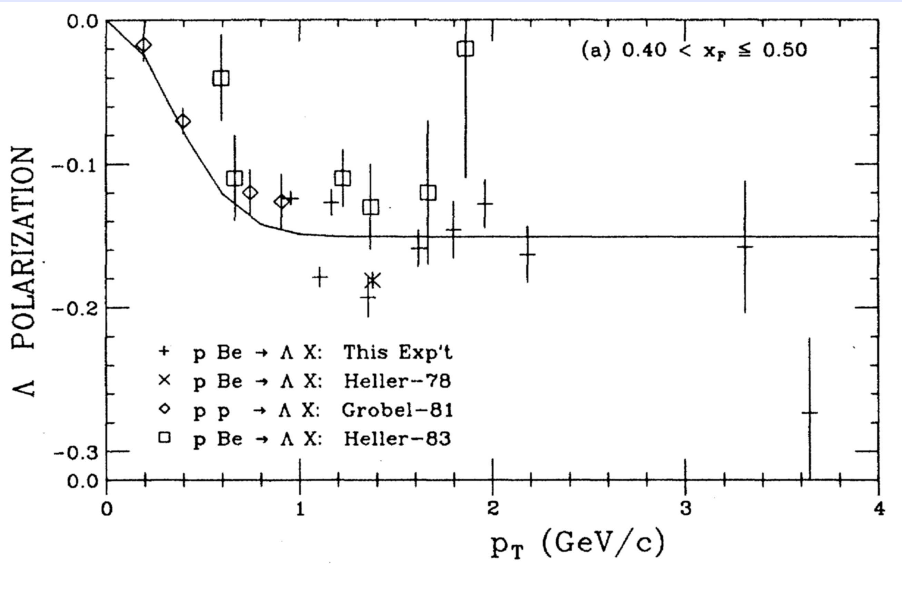
- Recent result from STAR ($\sqrt{s} = 200$ GeV): the asymmetry persists when energy is increased

[PRL92(2004)171801]



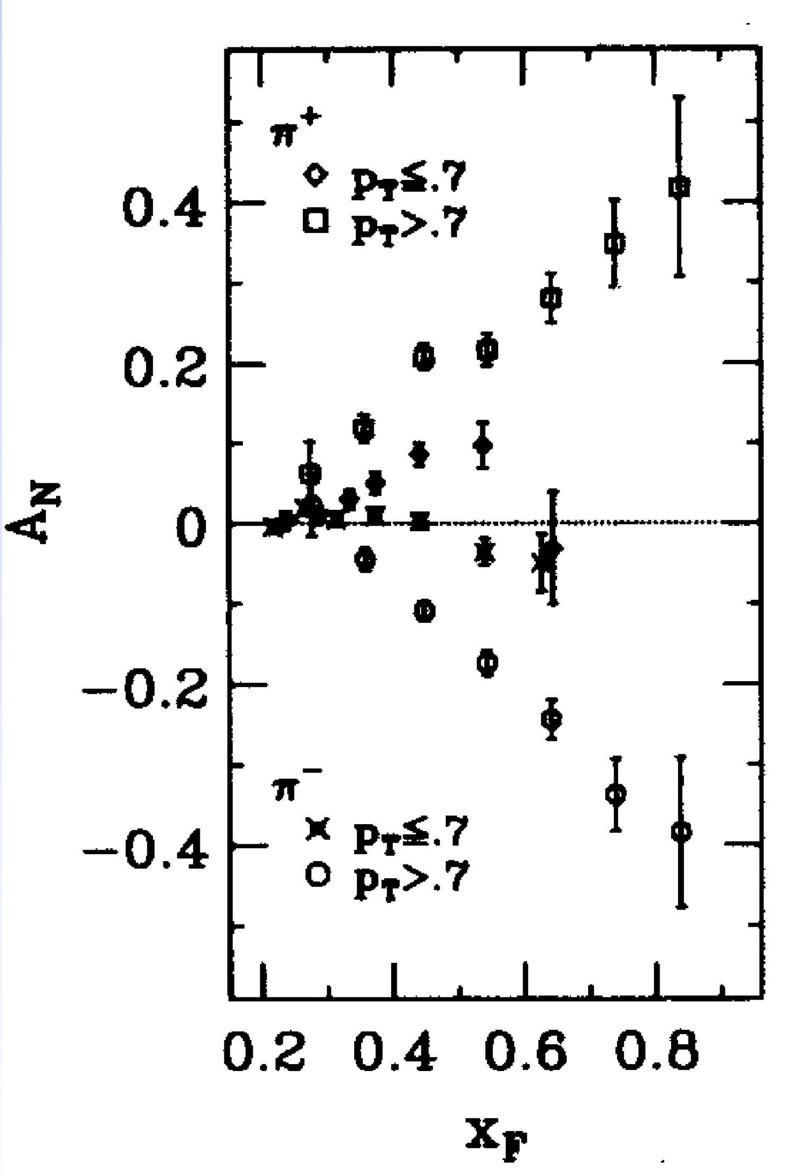
- SSA observed at large $k_\perp$ in $pp \to \Lambda^\uparrow X$ already in the 80's

[Lundberg *et al.*, PRD40(1989)3557]



$k_\perp$ dependence of E704 data

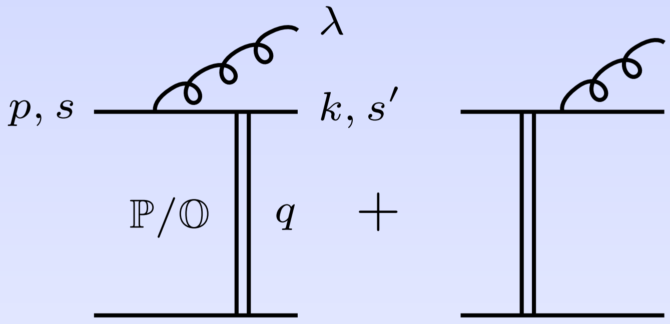
SSA smaller for $k_\perp < 0.7\mathrm{GeV}$ than for $k_\perp > 0.7\mathrm{GeV}$



Details of pomeron-odderon interference

We define, *e.g.*,

$$\mathcal{M}^{\mathbb{P}}_{ss'\lambda} = \bar{u}(p-k,s')[-ie\not{\epsilon}^*_\lambda(k)]u(p,s)\frac{i}{(p-k)^2-m^2}ie^{bt}\left(\frac{x_F s}{s_0}\right)^{\alpha_{\mathbb{P}}} + \bar{u}(p,s')[-ie\not{\epsilon}^*_\lambda(k)]u(p-q,s)\frac{i}{(p-q)^2-m^2}ie^{bt}\left(\frac{s}{s_0}\right)^{\alpha_{\mathbb{P}}}$$



Taking $\alpha_{\mathbb{P}} = 1$ (due to the resolution effect), and $k_\perp \gg q_\perp$

$$\mathcal{M}^{\mathbb{P}}_{++\lambda} \simeq i\lambda x_F^{(1-\lambda)/2} e\sqrt{2x_F}(1-x_F)e^{bt}\frac{s}{s_0}\frac{q_\perp e^{i\phi\lambda}}{k_\perp^2 e^{2i\varphi\lambda}}$$

$$\mathcal{M}^{\mathbb{O}}_{+-\lambda} \simeq -\lambda e a_0\sqrt{\frac{2}{x_F}}q_\perp e^{i\phi}e^{bt}\left(\frac{s}{s_0}\right)^{\alpha_{\mathbb{O}}}\frac{x_F^{(3+\lambda)/2} - x_F^{\alpha_{\mathbb{O}}+(1-\lambda)/2}}{k_\perp e^{i\varphi\lambda}}$$

so that

$$A_N \simeq -\frac{2k_\perp a_0\left(\frac{s}{s_0}\right)^{\alpha_{\mathbb{O}}-1}(1-x_F)(x_F^{\alpha_{\mathbb{O}}}-x_F^2)}{(1-x_F)^2(1+x_F^2)+\left[a_0\left(\frac{s}{s_0}\right)^{\alpha_{\mathbb{O}}-1}\right]^2 k_\perp^2\left[(x_F^{\alpha_{\mathbb{O}}-1}-x_F)^2+(1-x_F^{\alpha_{\mathbb{O}}})^2\right]} \stackrel{(\alpha_{\mathbb{O}}=1)}{=} -\frac{2a_0 k_\perp x_F}{1+x_F^2+2a_0^2k_\perp^2}$$