Spin Asymmetry at Large x_F and $\boldsymbol{k}_\perp$

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[Paul Hoyer and MJ, hep-ph/0611293]

Outline

- Single spin asymmetry in $p^\uparrow p \to \pi X$
  - Definitions
  - Experimental data
- Large x_F coherence effects
- $p^\uparrow p \to \pi X$ at large x_F: sample calculation

Single spin asymmetry (SSA)

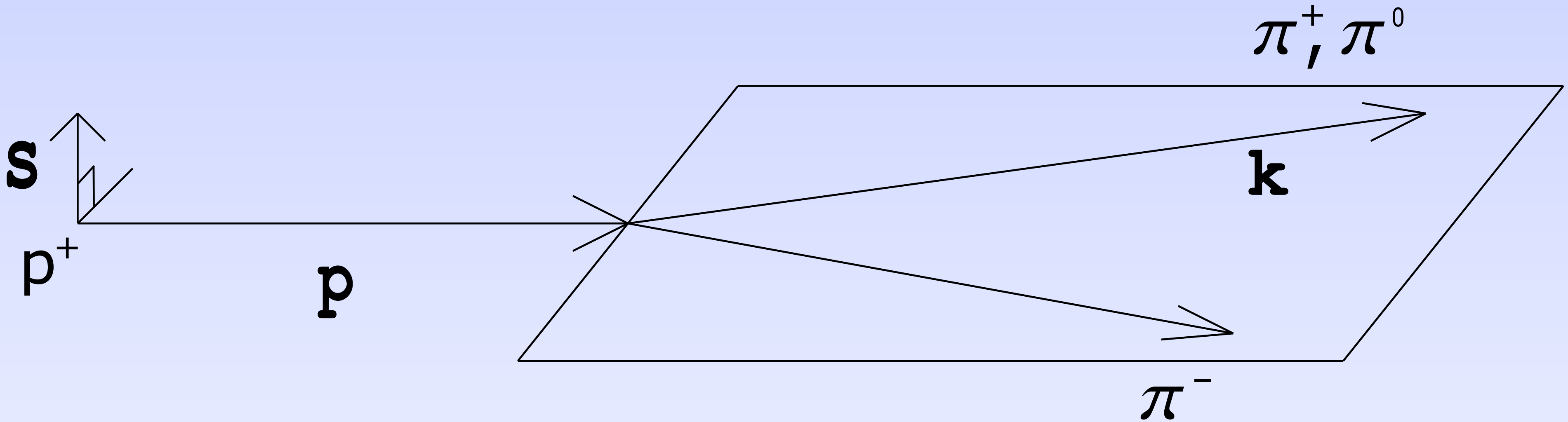
- Single spin asymmetry = dependence of a cross section on a single measured spin
- Parity $\Rightarrow$ transverse spin for $a+b\longrightarrow c+d$ or $a+b\longrightarrow c+X$

Size of the SSA: the analyzing power $\left(|A_N|\leq 1\right)$

$$A_N=\frac{d\sigma^{\uparrow}-d\sigma^{\downarrow}}{d\sigma^{\uparrow}+d\sigma^{\downarrow}}\propto \mathrm{Im}[\mathcal{M}_{\rightarrow}\mathcal{M}^{*}_{\leftarrow}]$$

Helicity flip and a dynamical phase required

Transverse SSA in $p^{\uparrow}p \rightarrow \pi(x_F, k_\perp) + X$



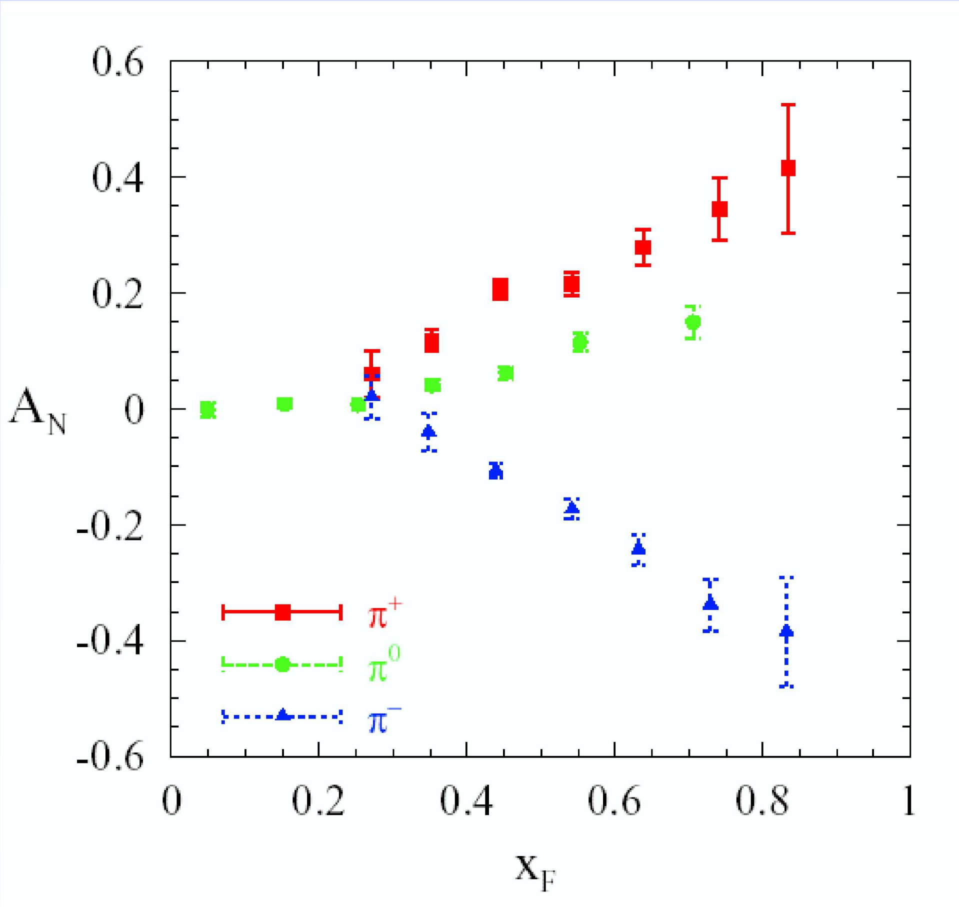
$$\boldsymbol{k} = (x_F\, p_{\text{lab}}, \boldsymbol{k}_\perp)$$

$$A_N(x_F, k_\perp) \cos\phi \equiv \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}}$$

Data for $p^{\uparrow}p \longrightarrow \pi(x_F, \boldsymbol{k}_{\perp}) + X$

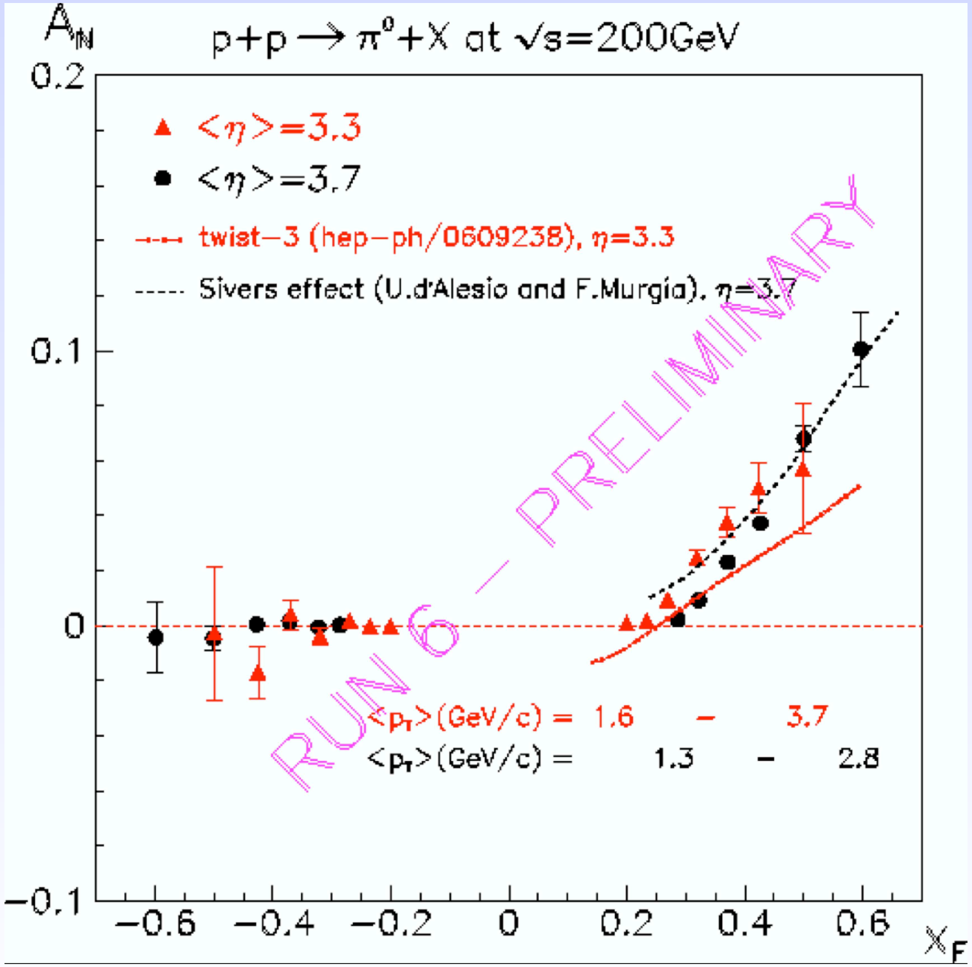
FNAL-E704 data ($\sqrt{s} = 20$GeV, $k_{\perp}$ ~1-2GeV):

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



STAR data: A_N for π^0 production at $\sqrt{s} = 200\mathrm{GeV}$

[arXiv:0705.3483]

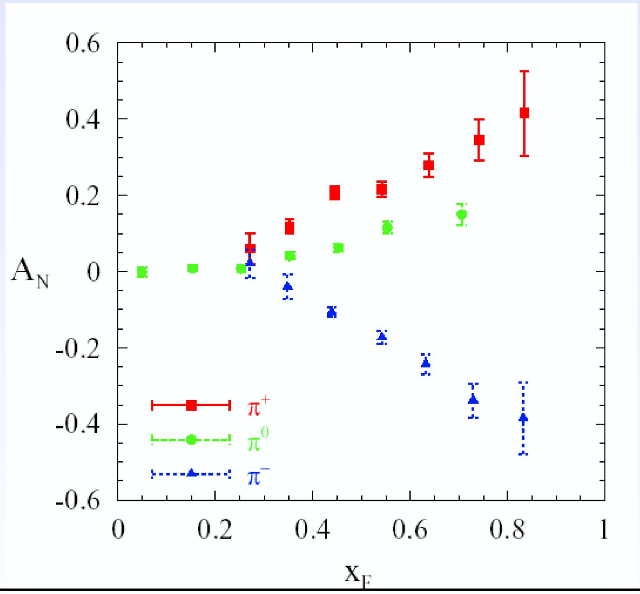


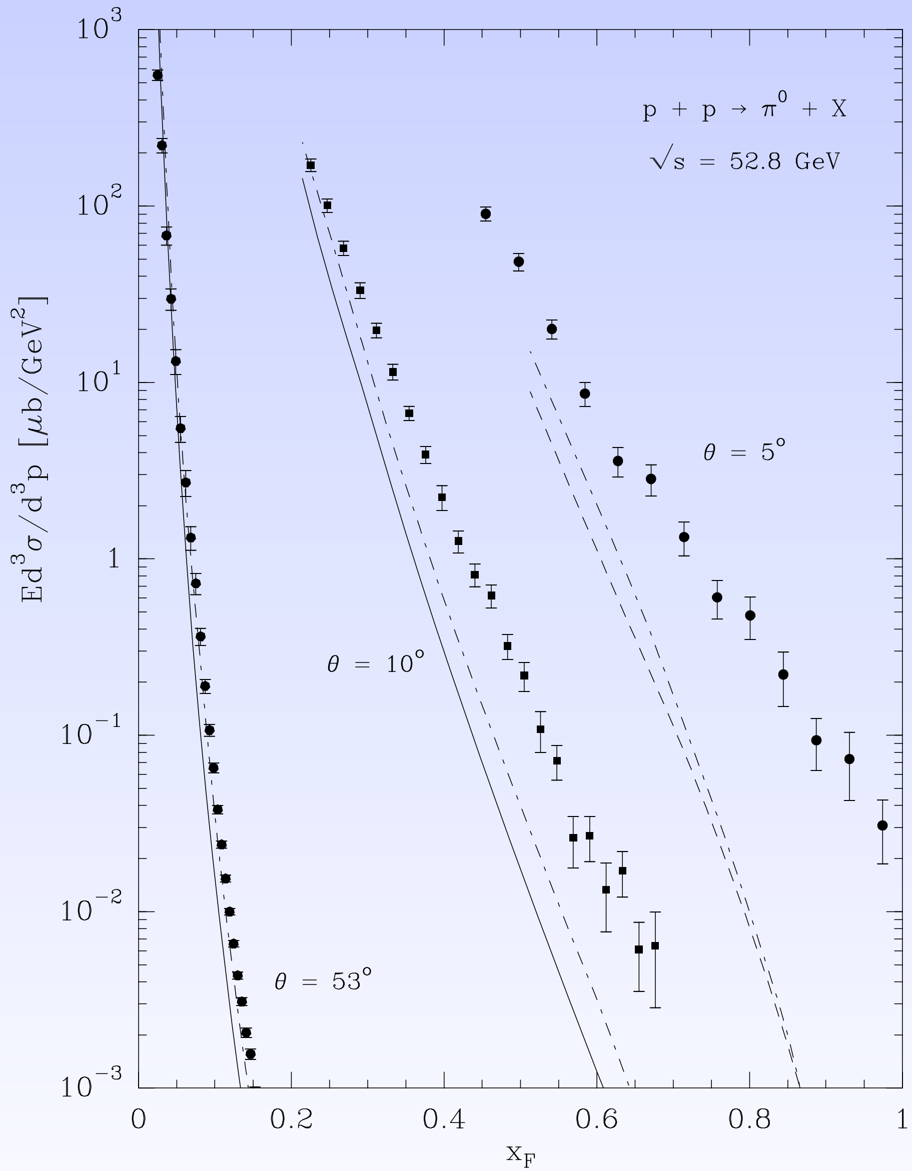
Failure of PQCD for forward π^0

$x_F \simeq 0.8 \Rightarrow$ Distribution and fragmentation functions with $x, z \sim 0.9$

NLO PQCD fails to produce the total cross-section for forward $pp \to \pi^0 X$ for $\sqrt{s} = 52.8$ GeV

[Bourrely, Soffer EPJC36(2004)371]

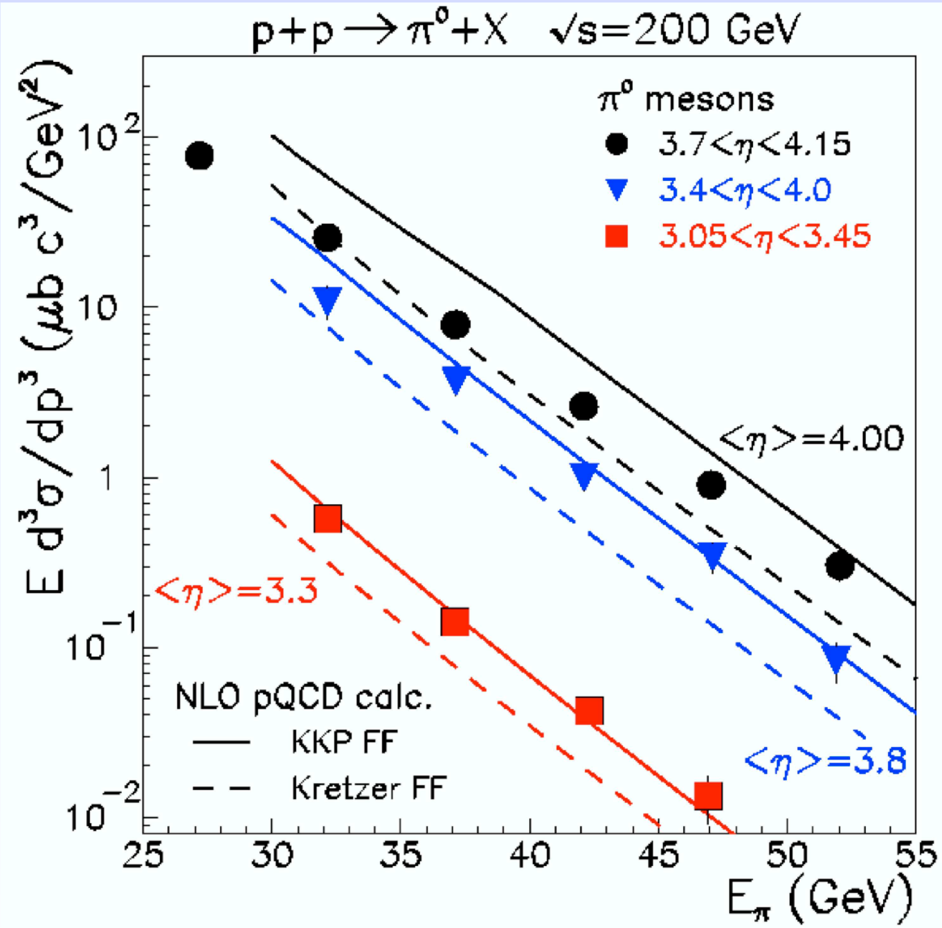


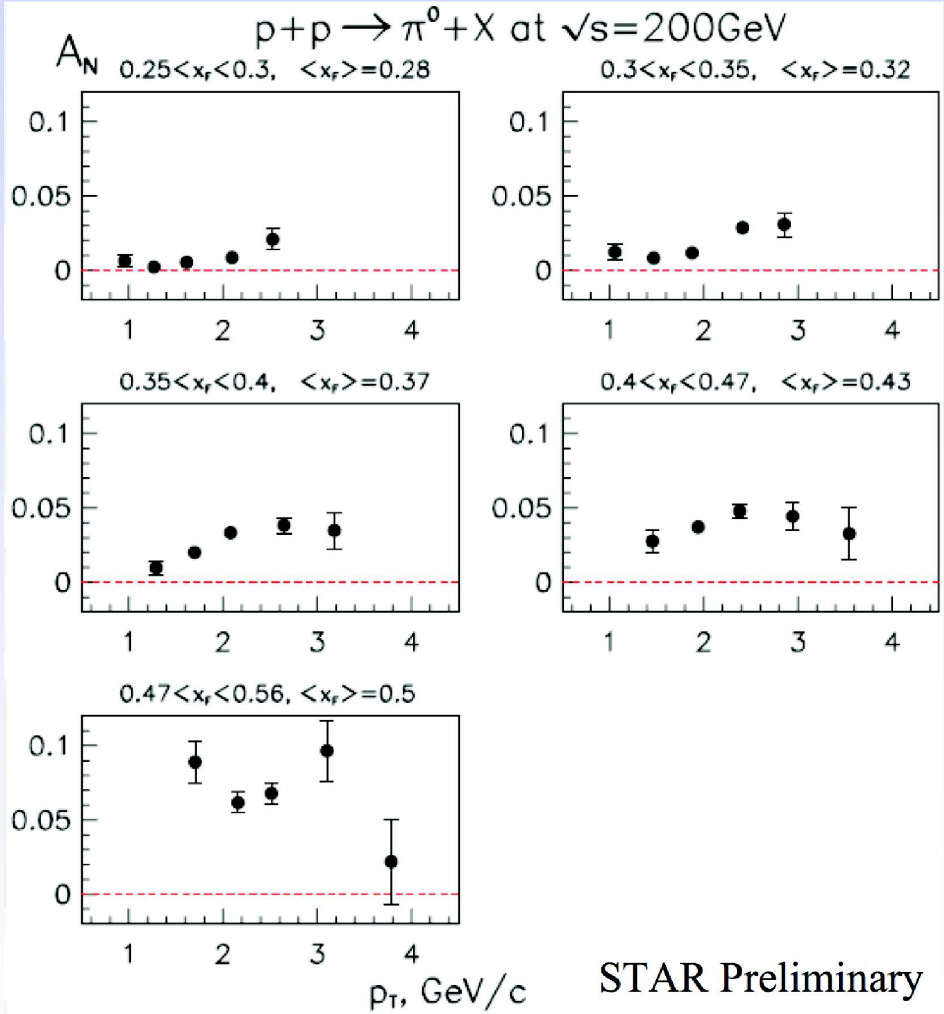


PQCD predictions and STAR results

STAR total cross section is consistent with PQCD

However, the predicted behavior $A_N \propto \Lambda_{QCD}/k_\perp$ is not seen



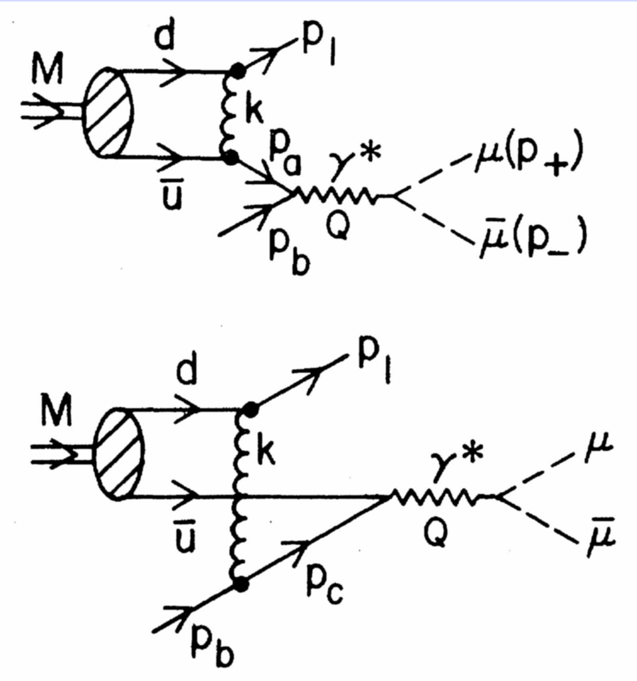


Coherence effects at large x_F

- Large x_F coherence effects studied in (unpolarized) Drell-Yan $\pi p \longrightarrow \mu^+\mu^- X$
- Physics at large x_F involves the full (multiquark) projectile wave function: Single quark factorization fails

  [Berger & Brodsky, PRL42(1979)940]
- Expected longitudinal polarization of the γ^* at large x_F later seen in experiments

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



Large x_F dynamics

The lifetime $\tau = 1/\Delta E$ of a Fock state is determined by the ΔE *wrt.* the proton

$$P^+ \Delta E = m_p^2 - \sum_i \frac{k_{i\perp}^2 + m_i^2}{x_i} \quad \text{with} \quad \sum_i x_i = 1$$

if one of the constituents carries a large momentum fraction $x \sim x_F \to 1$ then other $x_j \sim (1 - x_F) \to 0$

$$\Rightarrow P^+ \Delta E \sim \frac{\Lambda_{QCD}^2}{1 - x_F}$$

A hard quark $(x \text{ fixed}, \; k_\perp \text{ large})$ contributes $P^+ \Delta E \sim k_\perp^2$

$\Rightarrow$ Factorization requires $\Lambda_{QCD}^2/(1 - x_F) \ll k_\perp^2$

Large x_F dynamics

We study $p^{\uparrow}p \to \pi(x_F, \boldsymbol{k}_\perp) + X$ for $k_\perp \to \infty$ with $k_\perp^2(1 - x_F)$ fixed, $\quad k_\perp^2(1 - x_F) \sim \Lambda_{QCD}^2$

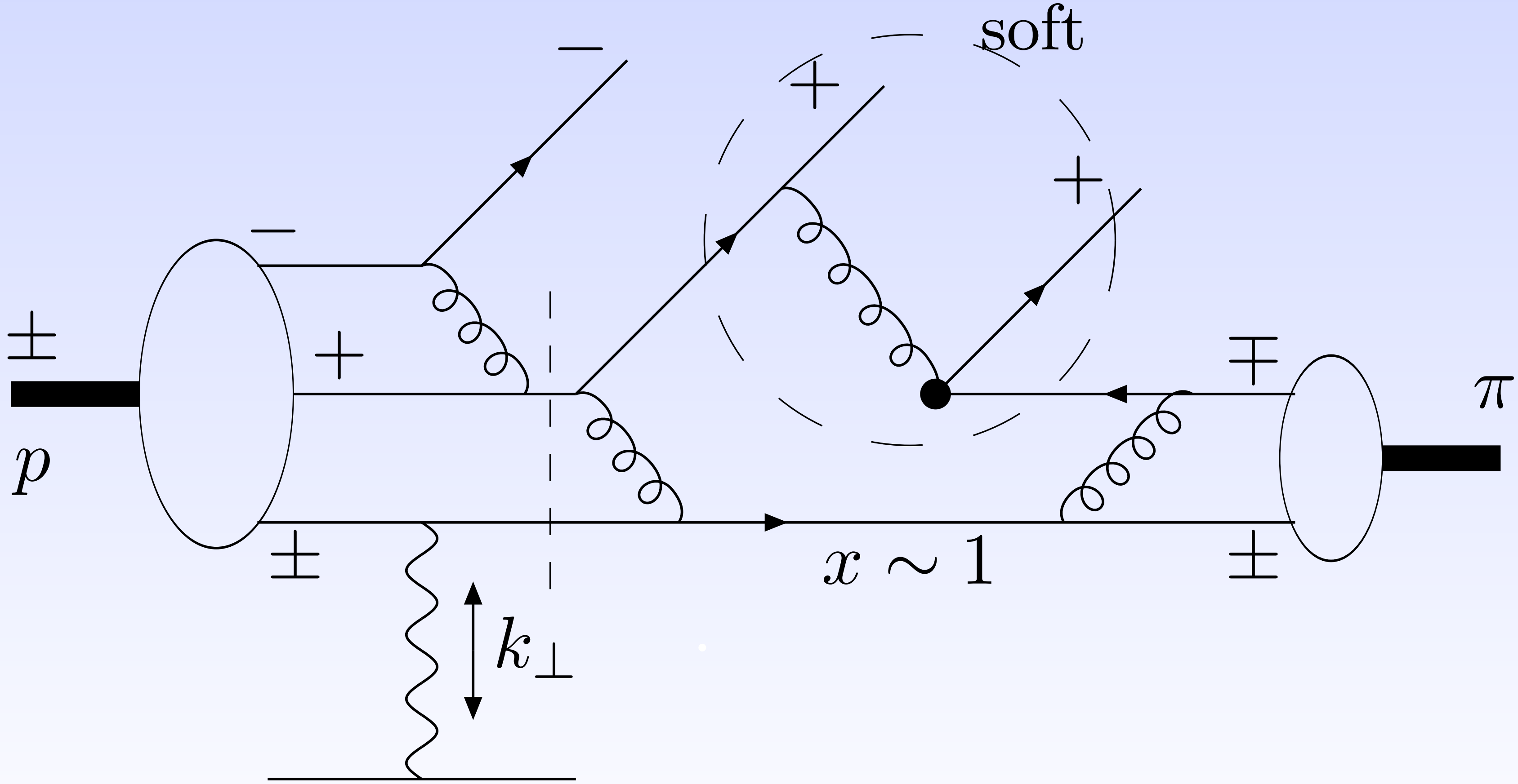
$\Rightarrow$ No single quark factorization

Soft part of the amplitude $\left(\text{scale } \Lambda_{QCD}^2/(1 - x_F)\right)$ becomes coherent with the hard interactions $\left(\text{scale } k_\perp^2\right)$

$\Rightarrow$ naturally large A_N ?

A mechanism for a sizeable A_N in $p^{\uparrow}p \to \pi X$

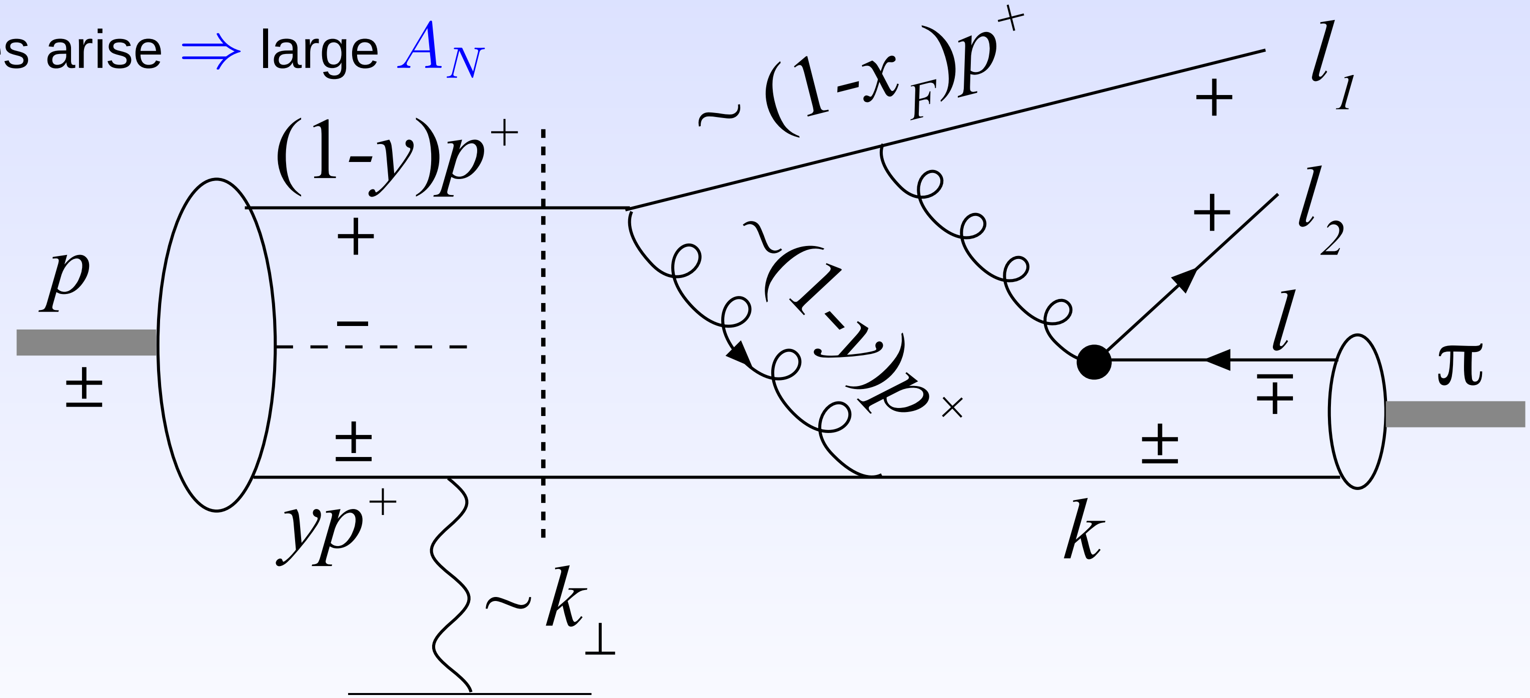
- Overall coherence at fixed $k_\perp^2(1-x_F)$



A sample calculation

- We drop one quark from the proton and the gluon exchange inside the pion
- Only a single diagram, Abelian gluons and $s \to \infty$
- The soft quark-antiquark pair has a (constituent) mass $M \sim \Lambda_{QCD}$ to allow the spin flip, otherwise massless quarks

$\Rightarrow$ large phases arise $\Rightarrow$ large A_N



Conclusion

- Multiquark effects arise at $k_\perp^2(1-x_F)$ fixed
- If soft and hard parts of the amplitudes are coherent large asymmetries may arise naturally
- Our mechanism for A_N supported by the observed $k_\perp$ dependence?