Transverse Single Spin Asymmetries for identified charged hadrons in pp collisions at 200 GeV and 62 GeV

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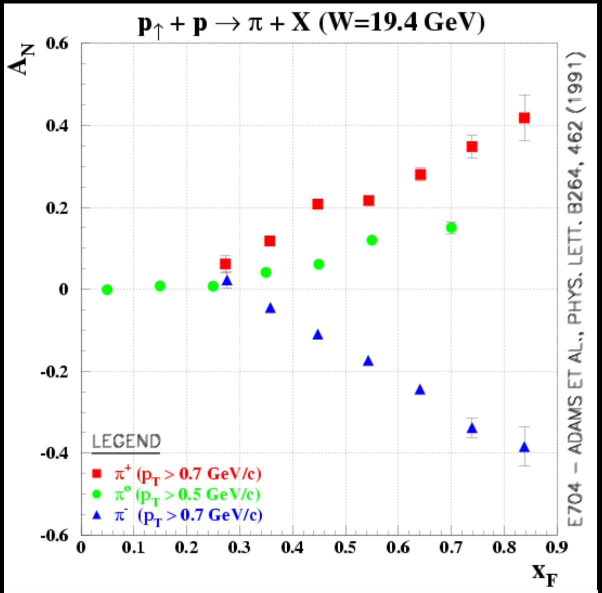
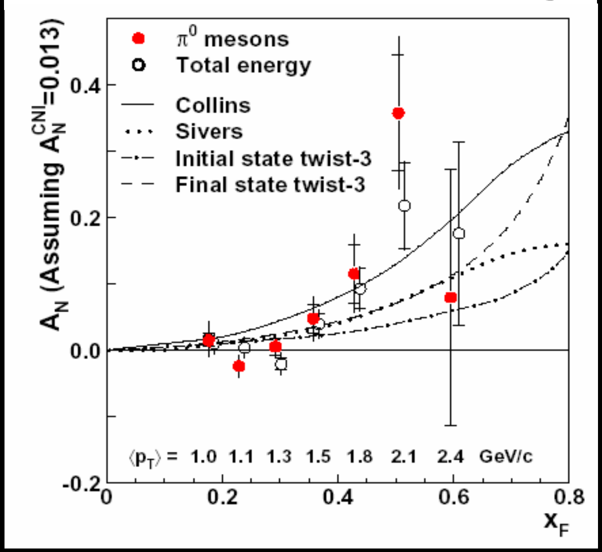
Single transverse Spin Asymmetry (SSA): Introduction

- Large SSAs have been observed at forward rapidities in hadronic reactions: E704/FNAL & @AGS. and STAR/RHIC
- SSA is suppressed in naïve parton models ($\sim\alpha_s m_q/Q$)
- Non-zero SSA at partonic level requires
  - Spin Flip Amplitude, anda relative phase
- SSA: Unravelling the spin-orbital motion of partons?





Beyond Naïve Parton Models to accommodate large SSA

- Spin and Transverse-Momentum-Dependent parton distributions
  - -"Final state" in Fragmentation (Collins effect),
  - -"Initial state" in PDF (Sivers effect)
- Twist-3 effects
  - -Hadron spin-flip through gluons
    - -Efremov, Teryaev (final state)
    - -Qiu, Sterman (initial state)
- Or combination of above
  - -Ji, Qiu, Vogelsang, Yuan…

Challenge to have a consistent partonic description with data from 19, 200 and now 62 GeV:

-Energy dependent SSA vs x_F, p_T,

-Flavor dependent SSA

-Cross-section

BRAHMS SSA measurements in $p^{\uparrow}+p \rightarrow \pi/K/p + X$ at 200/62 GeV

- Spin Asymmetries are defined as

$$A_N = (\sigma^+ - \sigma^-)/(\sigma^+ + \sigma^-) = \varepsilon / \mathcal{P}$$

For non-uniform bunch intensities

$$e = (N+/L+ - N-/L-) / (N+/L+ + N-/L-)$$
$$= (N+ - L^*N-) / (N+ + L^*N-)$$

where L = relative luminosity = L+ / L-

and the yield of in a given kinematic bin with the beam spin direction is N+ (up) and N- (down).

- Most of the systematic error in N^+/N^- cancel out
- Uncertainties on relative luminosity $\mathcal{L}$ estimated to be < 0.3%

BRAHMS measures identified hadrons (π,K,p,pbar)

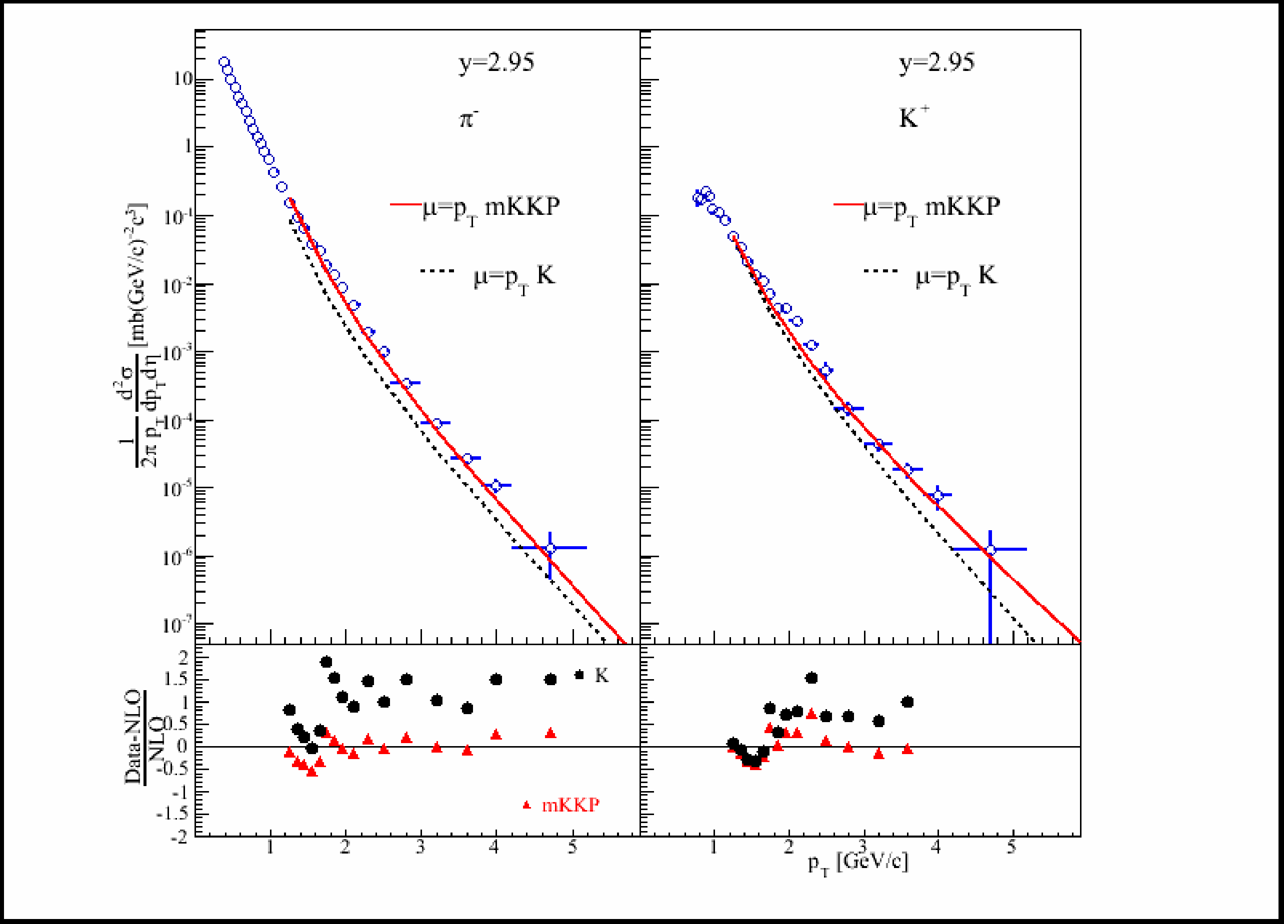
in the kinematic ranges of

- $0 < x_F < 0.35$ and $0.2 < p_T < 3.5$ GeV/c at $\sqrt{s}$=200 GeV
- $0 < x_F < 0.6$ and $0.2 < p_T < 1.5$ GeV/c at $\sqrt{s}$=62 GeV for

- x_F, p_T, flavor, $\sqrt{s}$ dependent SSA
- cross-section of un-polarized hadron production

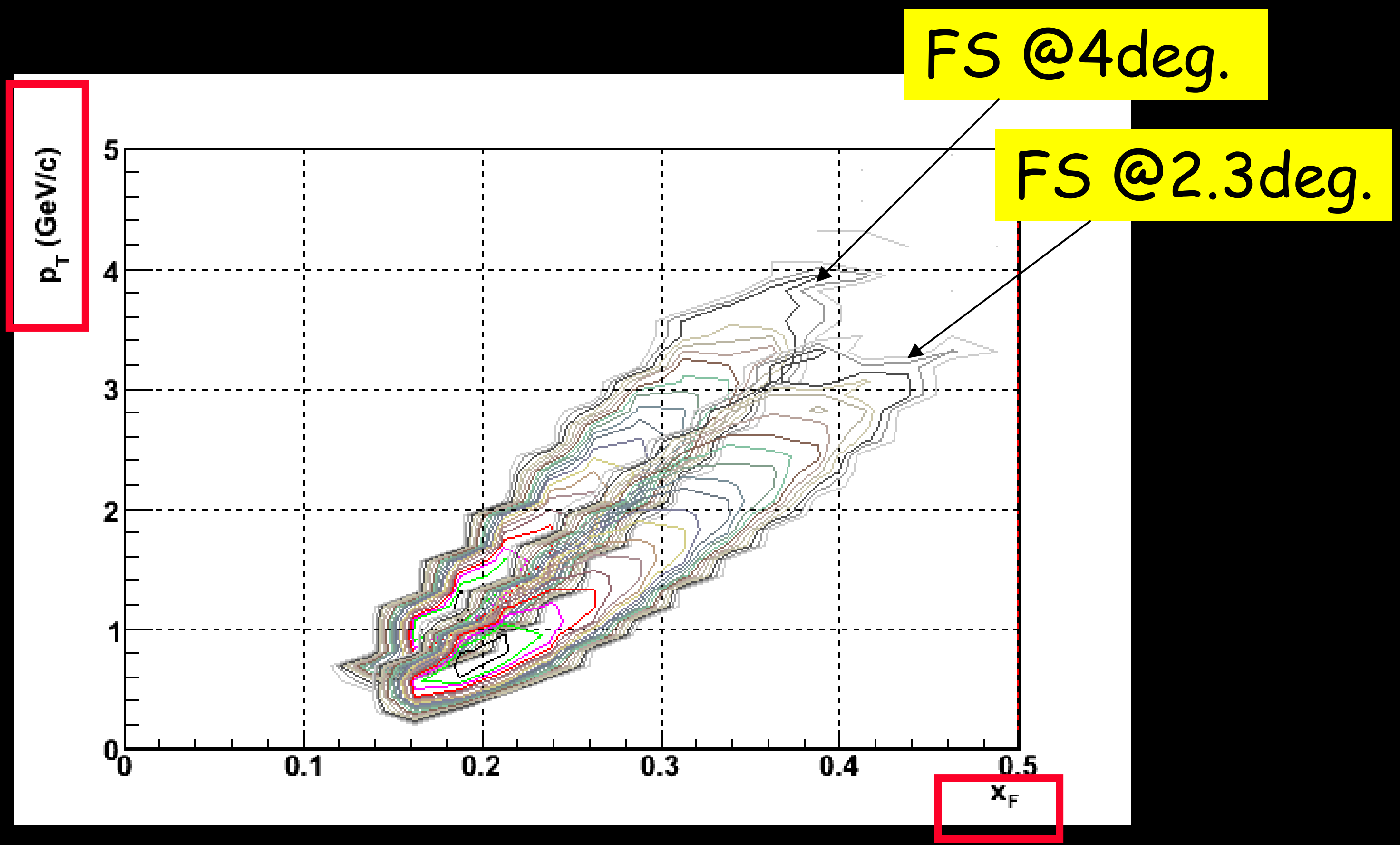
  (constraint for theoretically consistent description)

Does pQCD explain inclusive spectra at 200 GeV at large rapidities?



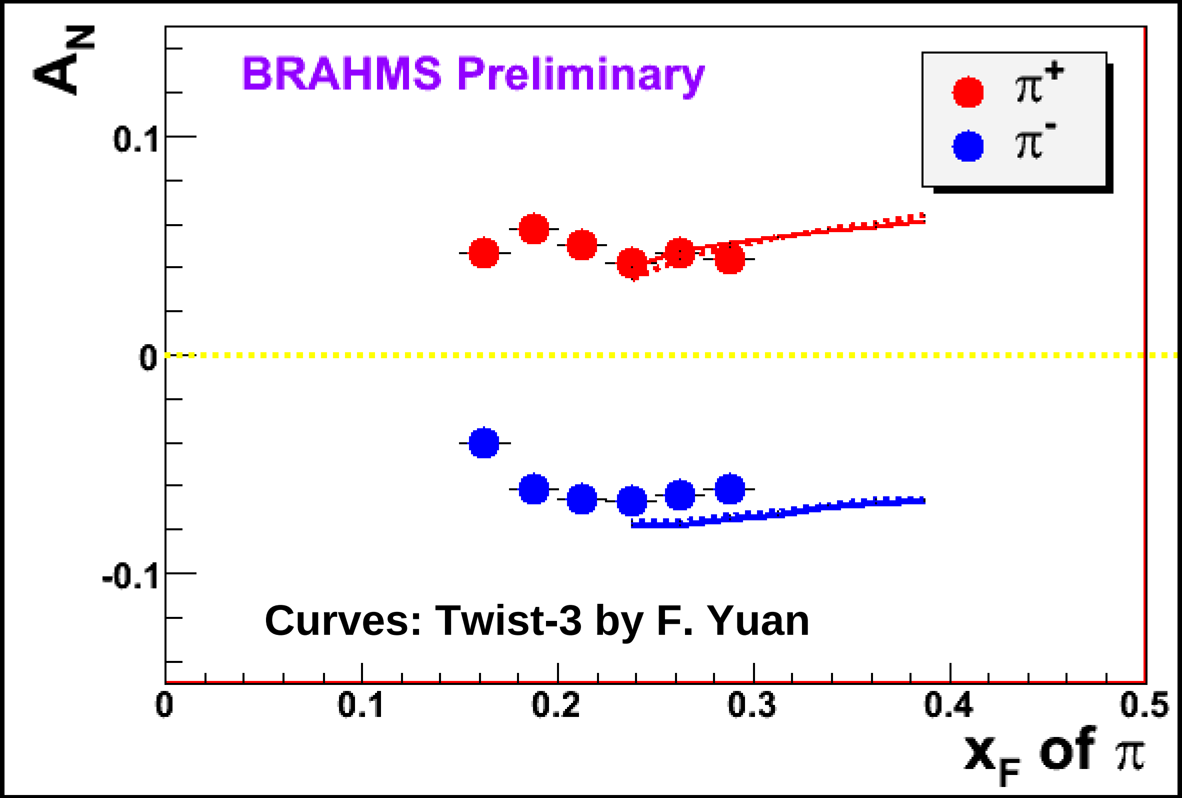
Yes, for pT > 1.5 GeV/c; NLO pQCD by Vogelsang.

BRAHMS FS Acceptance at 2.3 deg. and 4 deg. /Full Field (7.2 Tm) at $\sqrt{s}$ = 200 GeV



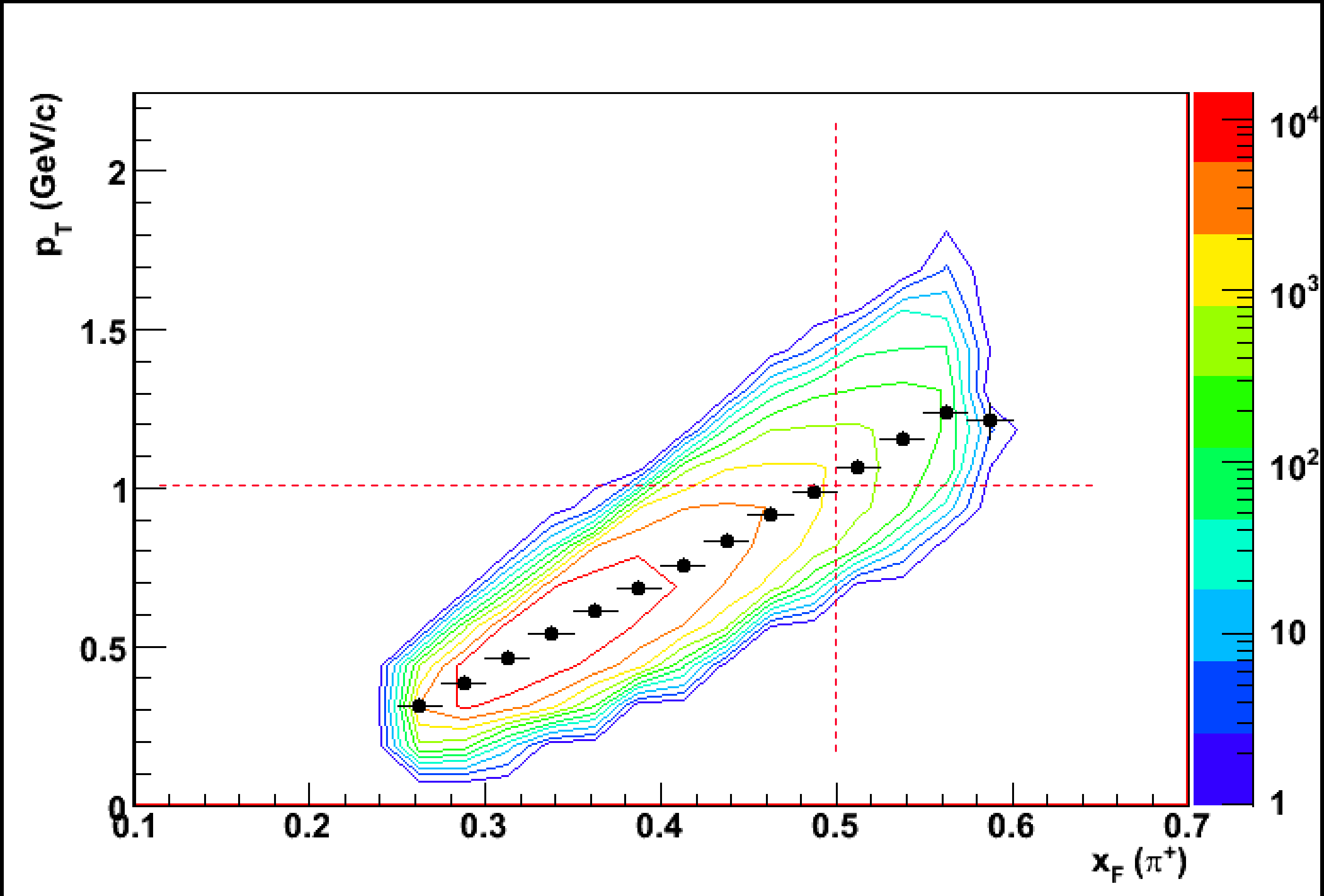
- Strong x_F-p_T correlation due to limited spectrometer solid angle acceptance

$A_N(\pi)$ at 2.3 deg. at $\sqrt{s}$ = 200 GeV compared with Twist-3

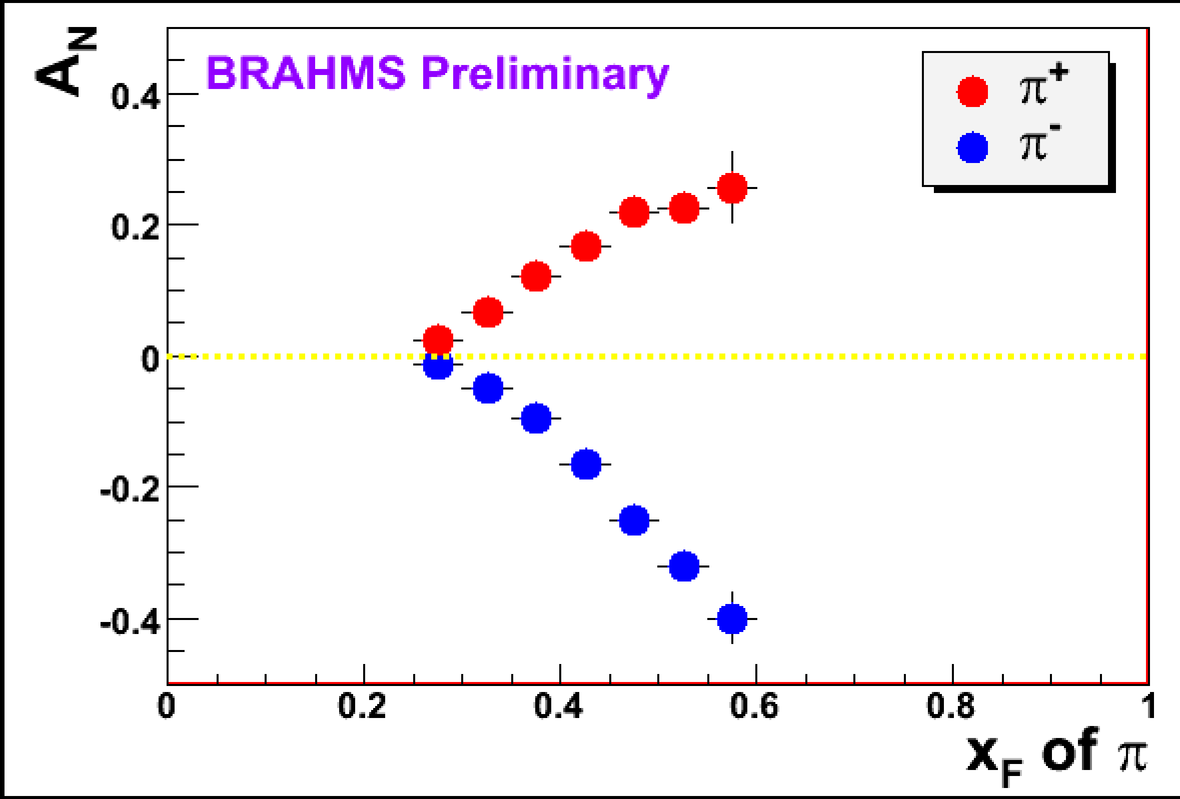


- **Twist-3 parton correlation** calculation provide by F. Yuan
- - Kouvarius, Qiu, Vogelsang, Yuan
- Solid lines: two-flavor (*u*, *d*) fit
- Dashed lines: valence + sea, anti-quark
- Calculations done (valid) only for $\langle p_T(\pi) \rangle$ > 1 GeV/c

Kinematic coverage at $\sqrt{s}$ = 62.4 GeV (FS at 2.3 and 3 deg)

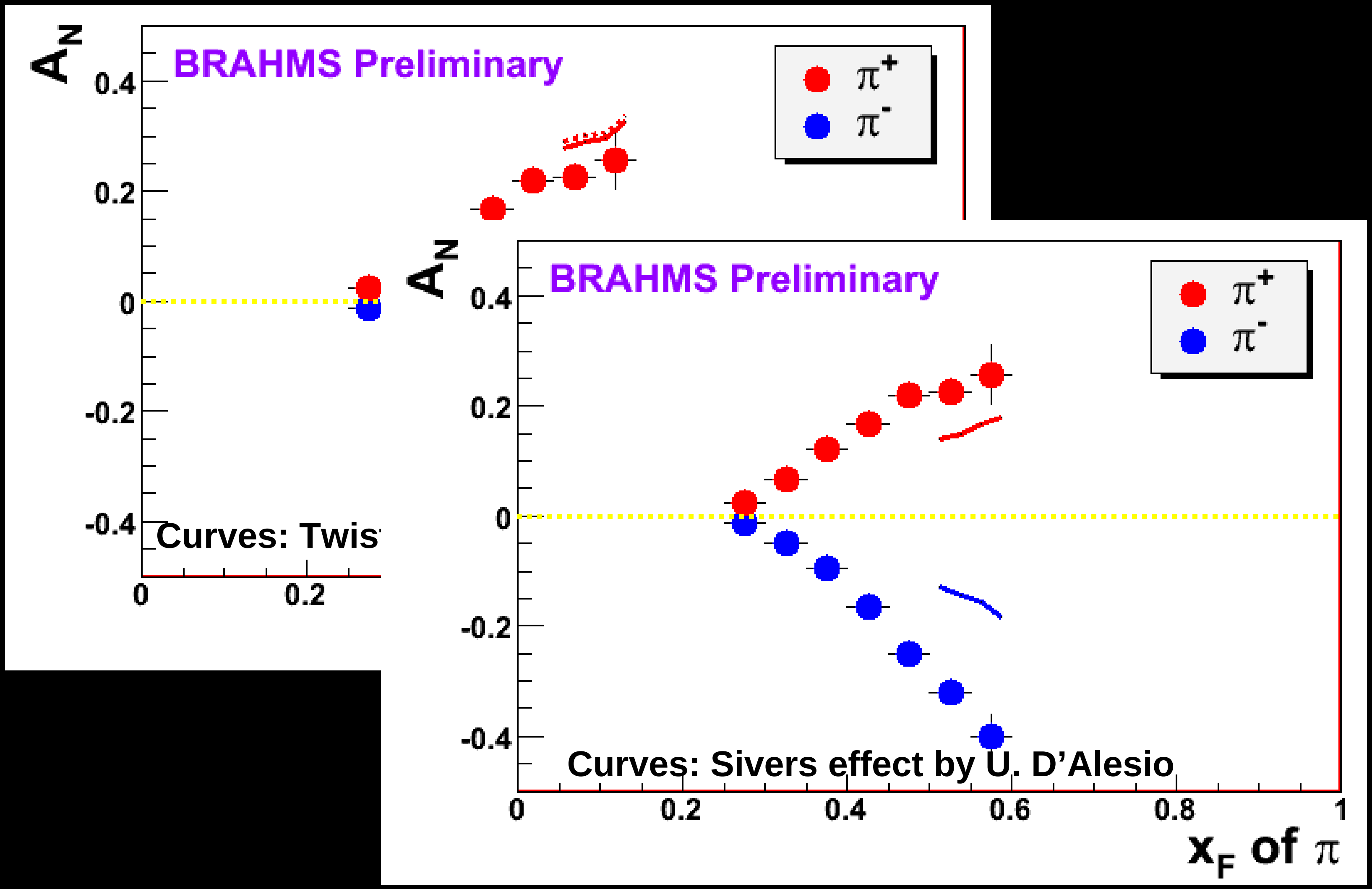


$A_N(\pi)$ at $\sqrt{s}$ = 62 GeV

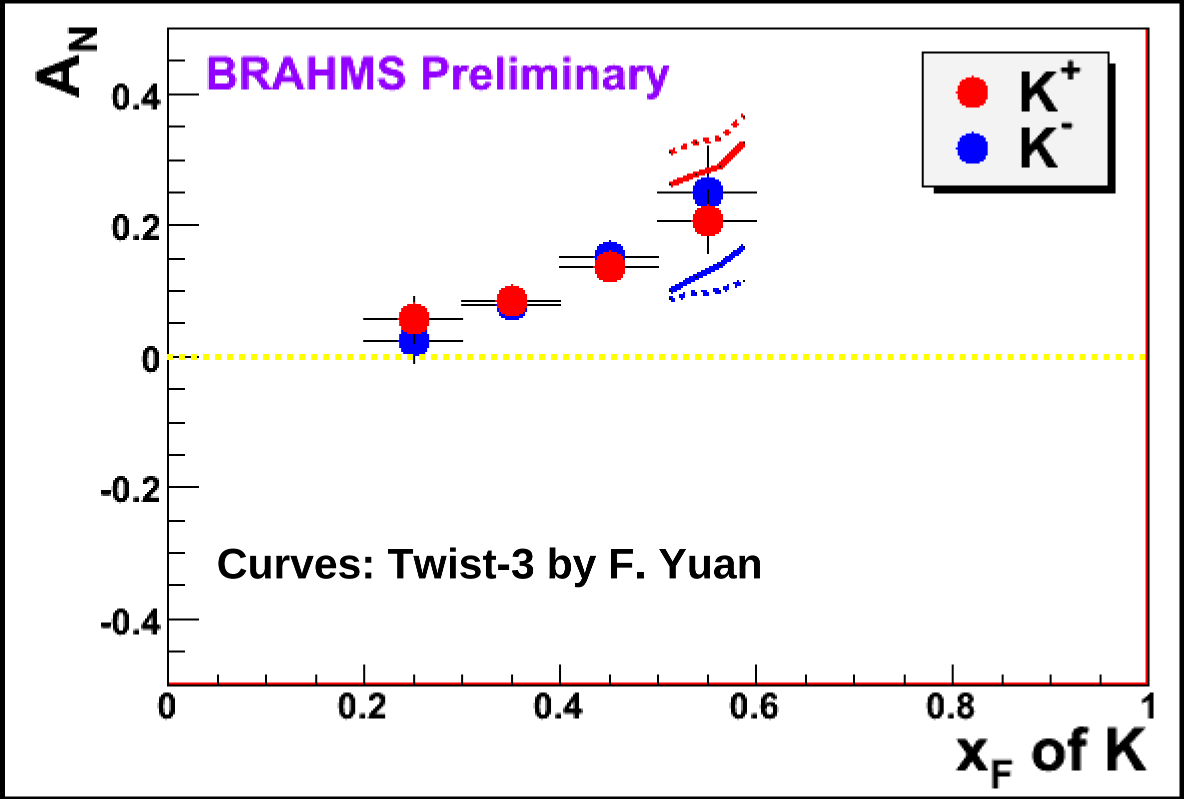


- Large $A_N(\pi)$: 40% at x_F~0.6 p_T~1.3 GeV
- Strong x_F -p_T dependence
- $|A_N(\pi^+)/A_N(\pi^-)|$ decreases with x_F-p_T

$A_N(\pi)$ at $\sqrt{s}$ = 62 GeV compared with Twist-3 and Sivers



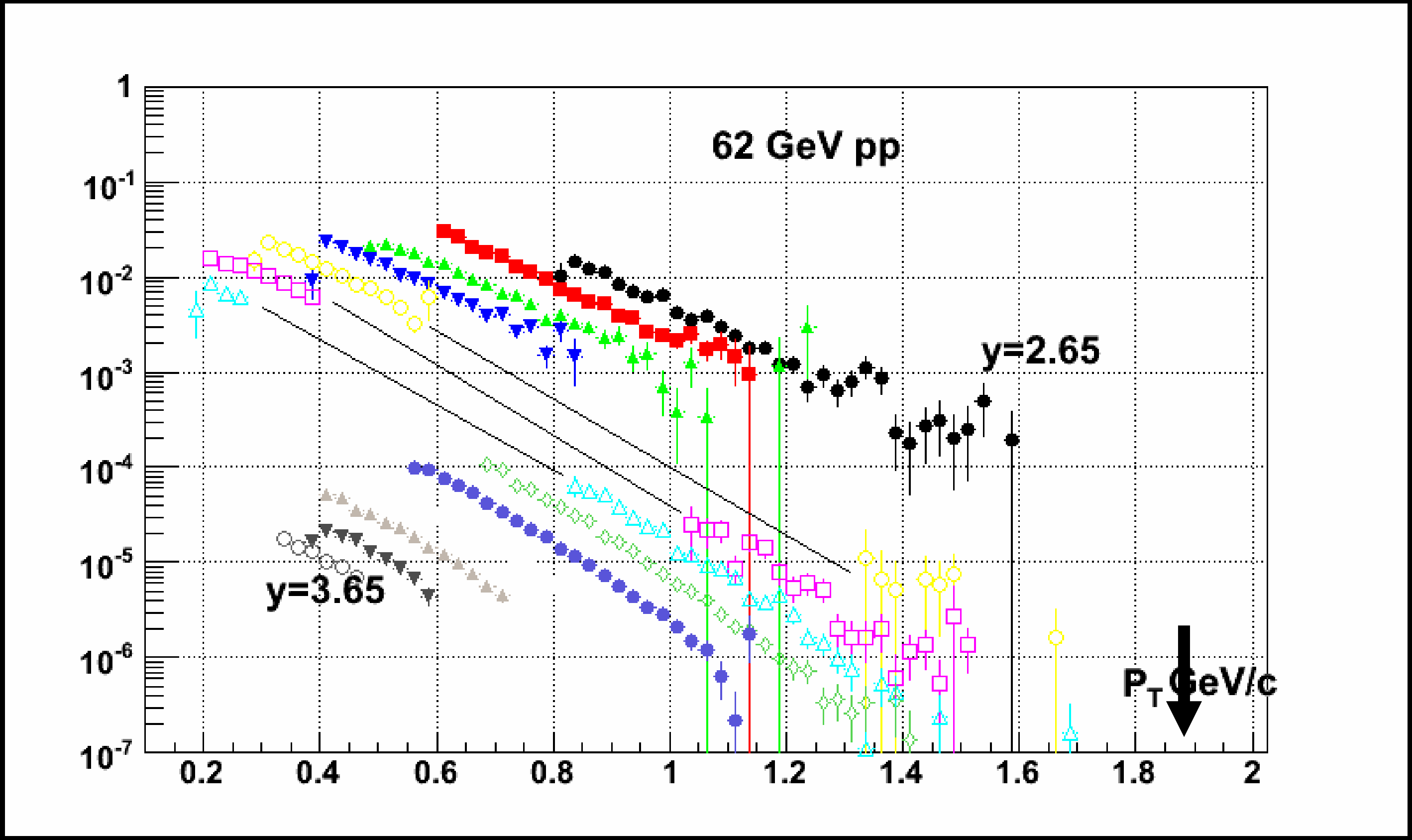
$A_N(K)$ at $\sqrt{s}$ = 62 GeV compared with Twist-3



Experiments shows that An is the same for K+ and K-
Calculations have clear difference between K+ and K-

Spectra of pi- at 62 GeV

Is it reasonable to expect pQCD to work at 62 GeV?
Earlier work by Soffer et al. NO
BRAHMS have preliminary spectra for pi- at forward rapidity that can be compared to NLO pQCD.



Summary

- BRAHMS measures A_N of identified hadrons at 62 GeV and 200 GeV
- P, K cross-section at 200 GeV described by NLO pQCD
- **Large SSAs seen for pions and kaons**

  Suggesting:

  - Sivers mechanism plays an important role.
  - described (qualitatively) by Twist-3
  - main contributions are from leading (favored) quarks

  Open Questions:

  - where the large positive $A_N(K^-)$ come from then?
  - Sea quark contributions not well understood: A_N(K-) and A_N(pbar)
  - how well is pQCD applicable at 62 GeV
- - what can (not) be learned from A_N at $p_T < 1$ GeV/c
  - $A_N(-x_F) \sim 0$ set limits on Sivers-gluon contribution?
  - can A_N (p, pbar) be described in the consistent framework?
  - What are the theoretical uncertainties, pT ~ 1 GeV valid for QCD description? In particular for 62 GeV.