

Cross-sections and SSAs of Identified Forward Hadrons in $p^{\uparrow} + p$ at RHIC

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for  Collaboration
BNL

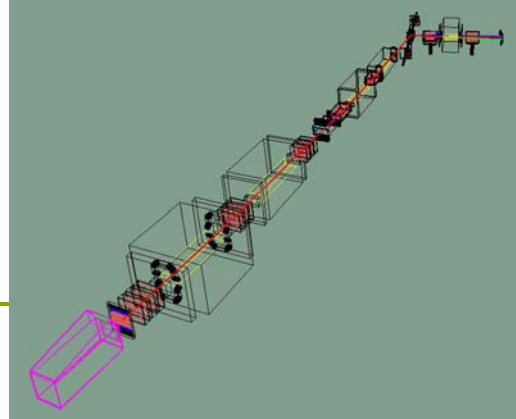
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A Puzzle in “Spin Crisis”

- ❑ Large **S**ingle transverse-**S**pin **A**symmetries (SSAs) observed at forward rapidities (high- x_F) in hadronic reactions in a wide energy range (20-200 GeV): *Where do they come from?*
- ❑ *Can they be described by pQCD? How are they related with the partonic dynamics?*
 - Transverse partonic motion: “Sivers” (in PDF), “Collins” (in FF)
 - Multi-parton correlation: “Twist-3”
- ❑ *Or/and driven by non-pQCD effects?*
- ❑ Coherent description of spin degree of freedom AND spin-averaged cross-section in a consistent theoretical framework required.

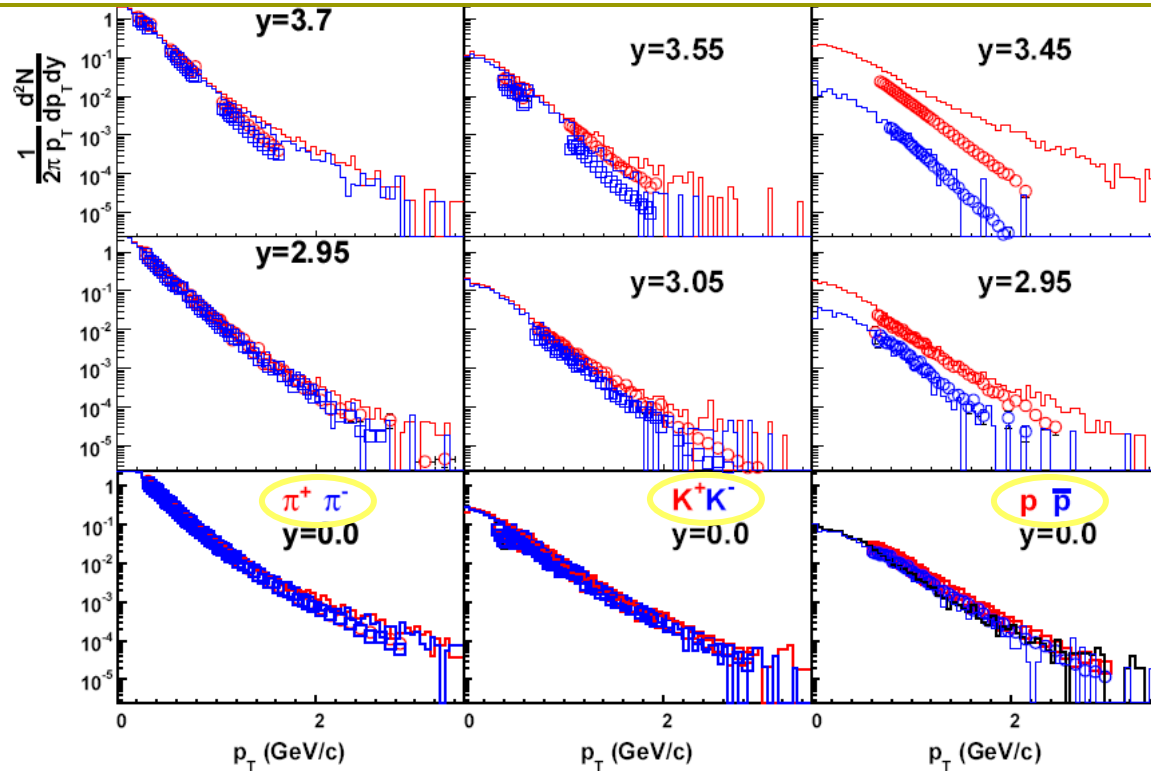
Cross-sections and SSAs



- BRAHMS spin program in $p^\uparrow + p$:
 - RHIC/Run5 (200 GeV), Run6 (62.4 GeV)
 - Measured cross-sections and SSAs of identified charged hadrons utilizing Forward Spectrometer at $2.3^\circ - 6^\circ$
 - SSA Results from 62.4 GeV: PRL 101 042001 (2008)

- This talk: Preliminary results for π^\pm, K^\pm, p from $\sqrt{s} = 200$ GeV
 - Unpolarized cross-sections
 - Single Spin Asymmetries
 - First results on multiplicity-dependence and SSAs for diffractive process
 - x_F, p_T -dependence
 - Energy dependence: comparisons with low-energy data ($\sqrt{s} = 19.4, 62.4$ GeV)

Invariant Yields of π , K , p compared with PYTHIA



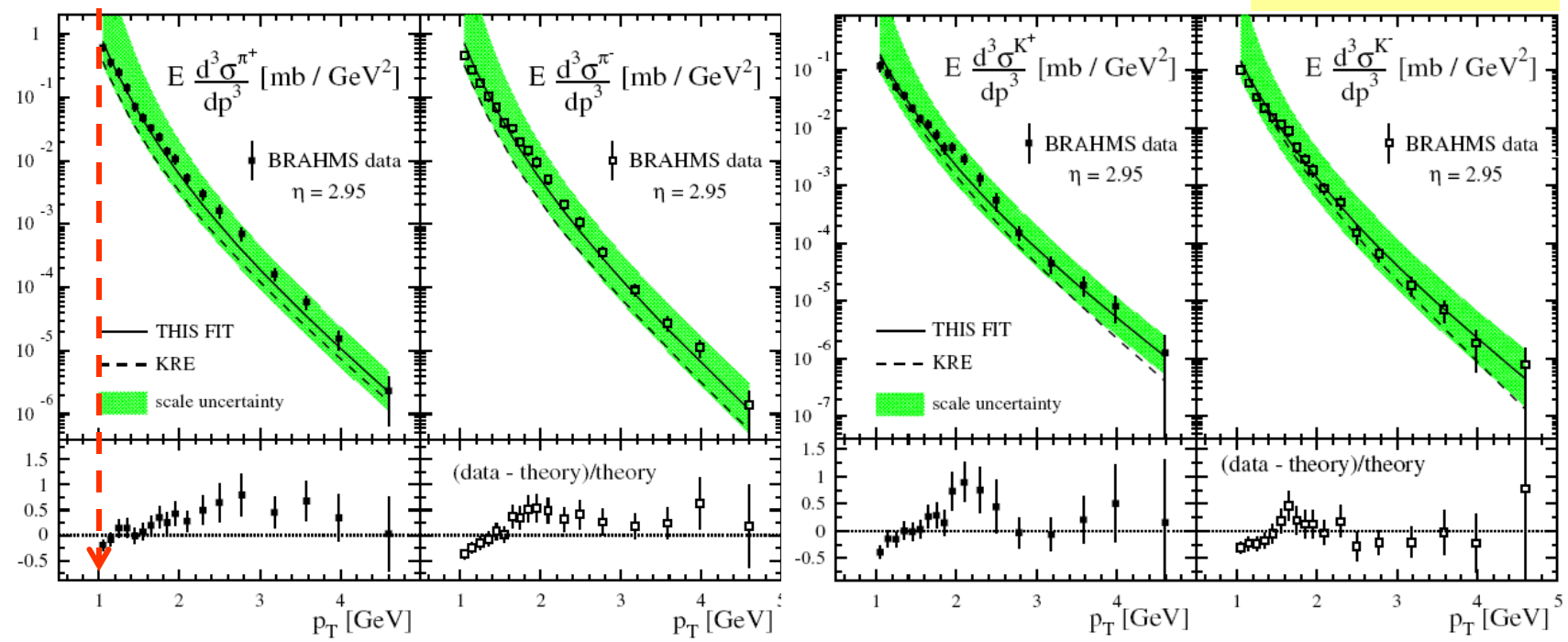
BRAHMS Preliminary

$\sqrt{s}=200$ GeV

- PYTHIA(6.319) in a good agreement at $y=0$ and $y\sim 3$ but:
 - Discrepancies in charge separation for kaons at the most forward rapidities ($y\sim 3.5$)
 - Proton fragmentation/transport in PYTHIA needs to be greatly improved

Cross-sections of π , K compared with the latest NLO pQCD analysis

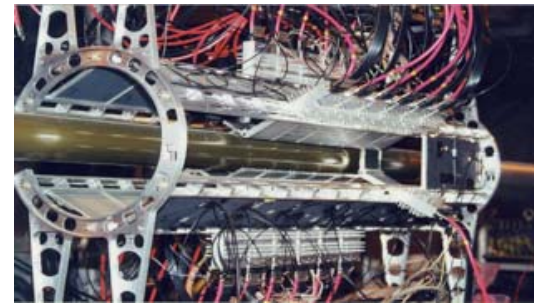
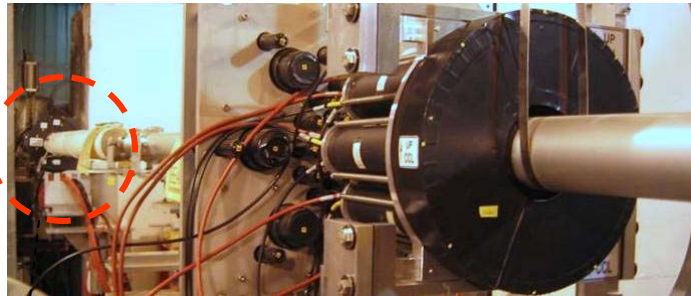
$\sqrt{s} = 200$ GeV



Data: BRAHMS, PRL 98 (2007) NLO: de Florin, Sassot, Stratman, PRD 75, (2007)

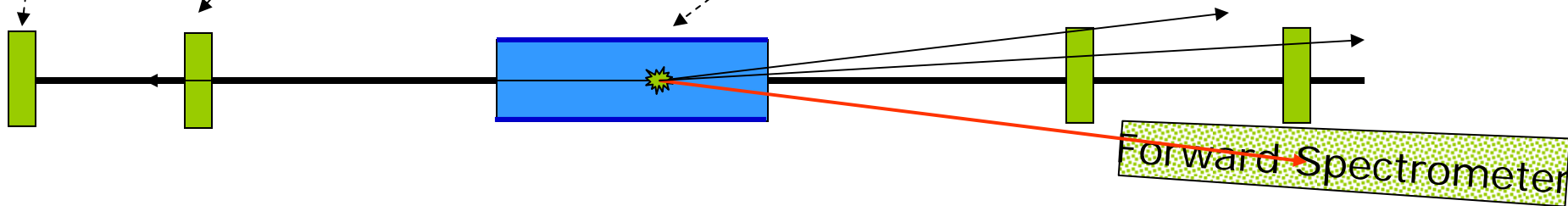
- Fragmentation functions from combined NLO analyses of e^+e^- , pp , SIDIS data.
- Describe BRAHMS 200 GeV π^\pm , K^\pm down to $p_T \sim 1$ GeV/c

Event Characterizations in pp: Inelastic and diffractive events



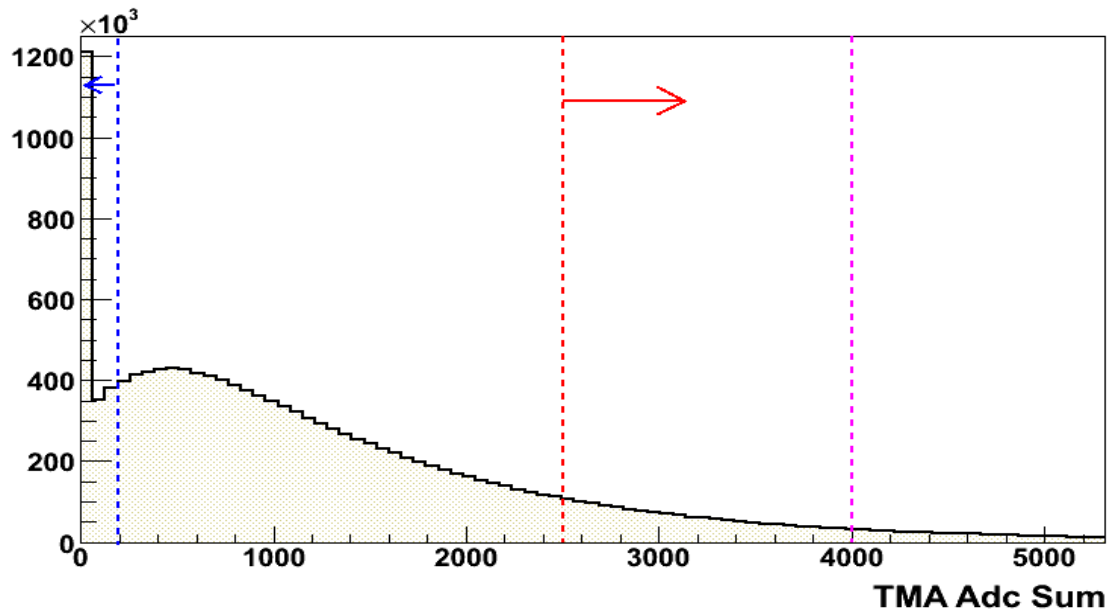
"CC" Counter ($3.25 < |\eta| < 5.25$)

TMA ($-2 < \eta < 2$)



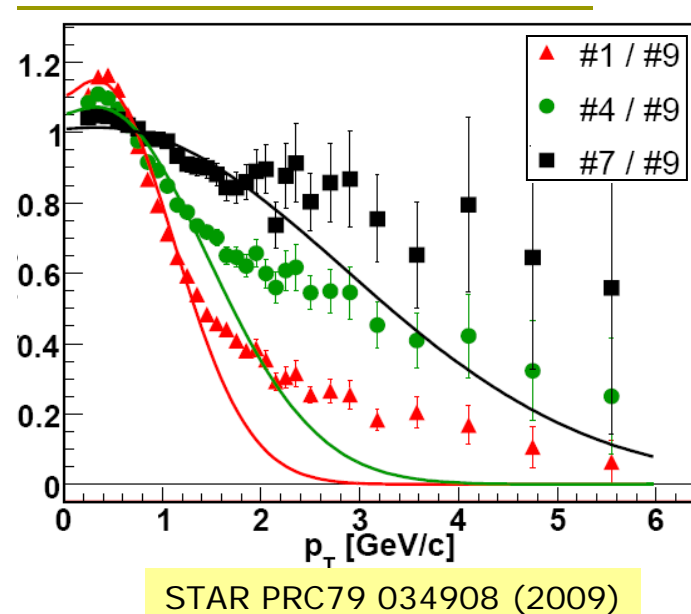
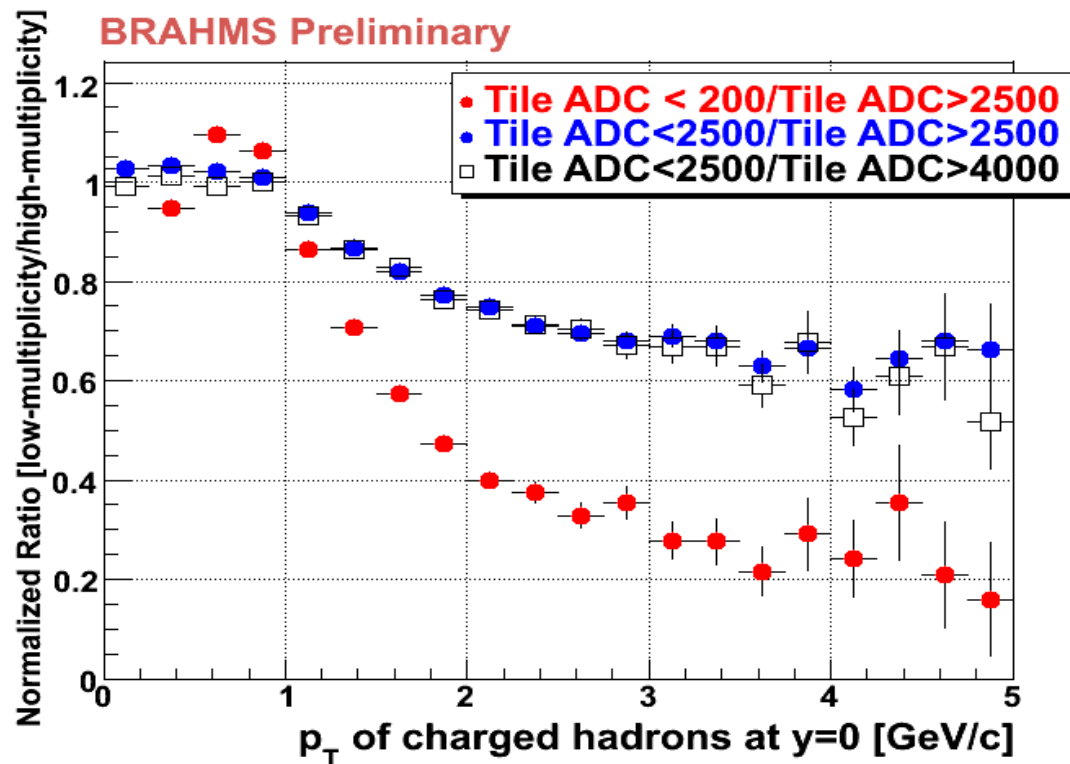
- ❑ Inelastic trigger requires a vertex reconstructed by "CC" counters (Cherenkov radiators)
- ❑ "Single diffractive event" (shown) is characterized as no hit in TMA and CC in backward rapidity.

Multiplicity selection



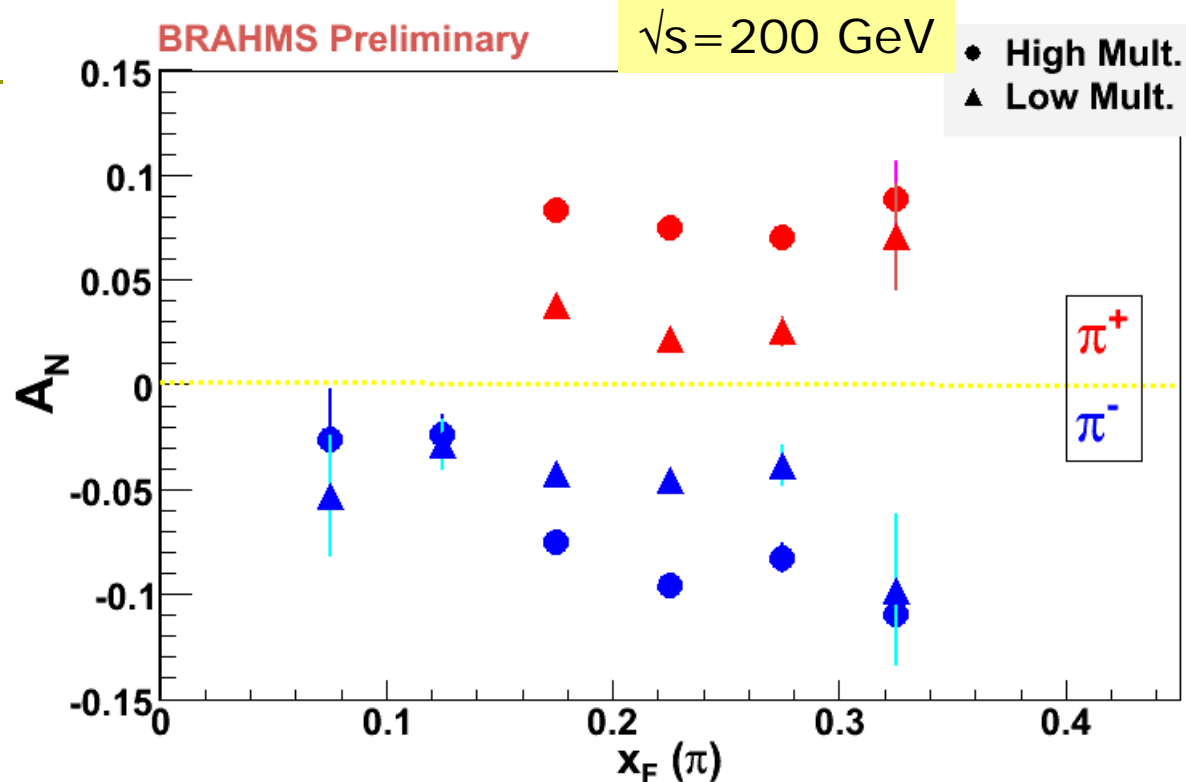
- ❑ “Multiplicity” of the collision is selected using Tile Multiplicity Array (TMA) covering $-2 < \eta < 2$
- ❑ Distribution shows ADC sum of non-diffractive inelastic collisions with 3 multiplicity classes used for the analysis

Multiplicity dependence: Charge hadron production



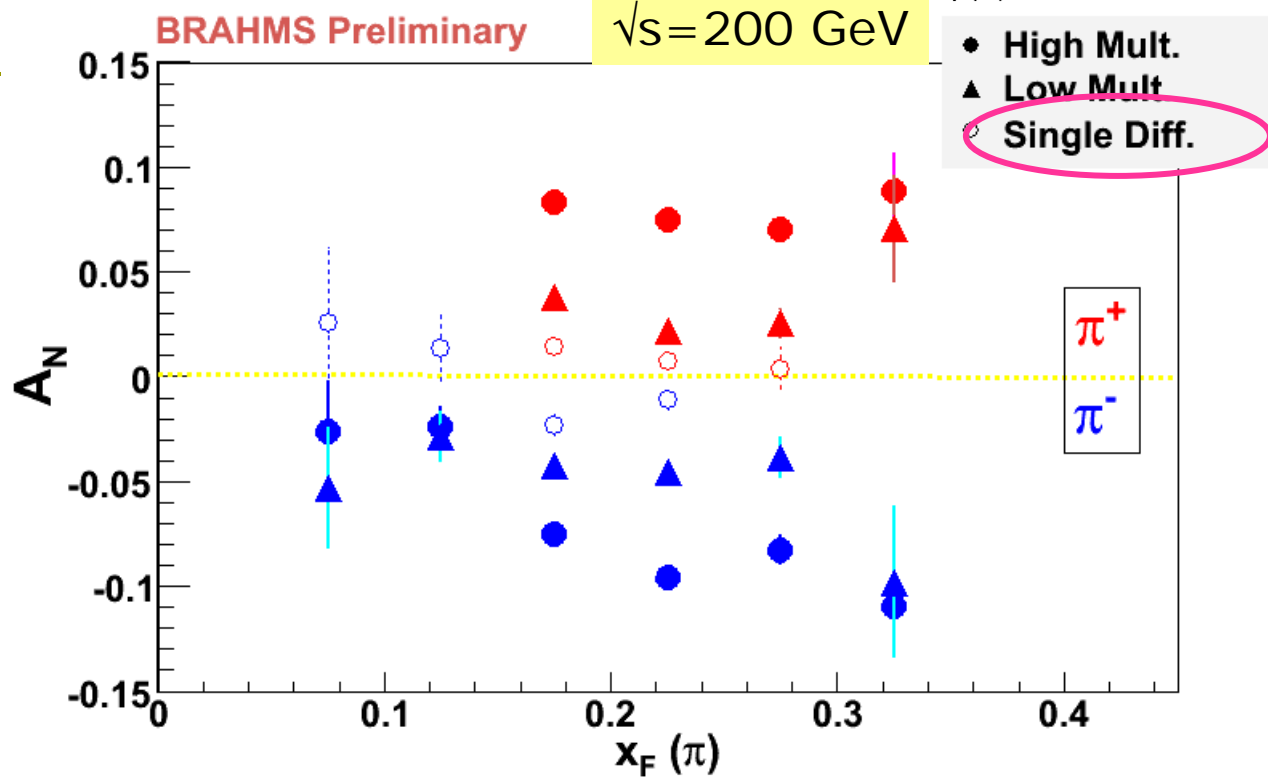
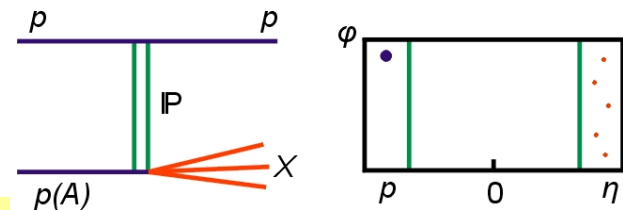
- Multiplicity: sensitive to collision dynamics
 - Impact parameter, hardness of the collision
- Ratio of hadron yields [low-multiplicity/high-multiplicity] decrease with p_T : hardening/enhancement with p_T for high multiplicity events

Multiplicity Dependent SSA (A_N)



- Strong multiplicity dependent SSAs for π^+, π^-
 - Higher-multiplicity events show stronger asymmetries
 - Effect not dominated by p_T -dependence of SSA
- SSA dependence on
 - collision geometry?
 - contribution from hard collisions (Jetty events?)?
 - Energy conservation?

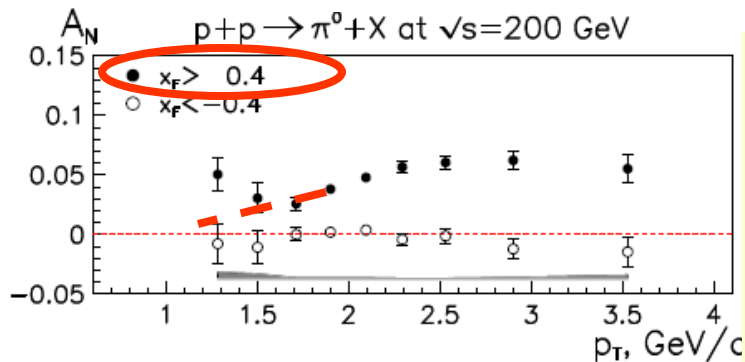
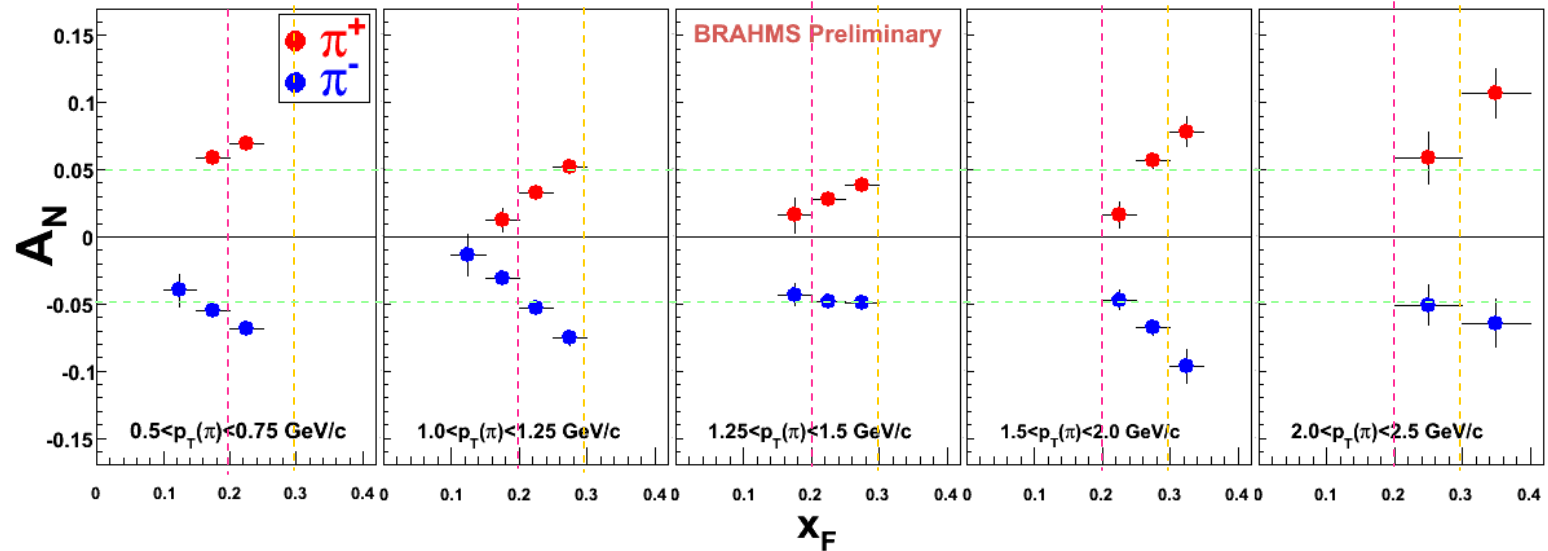
SSA of Diffractive Events



- SSAs in Single diffractive process suppressed compared to low-multiplicity inelastic collisions.

P_T -dependent SSA

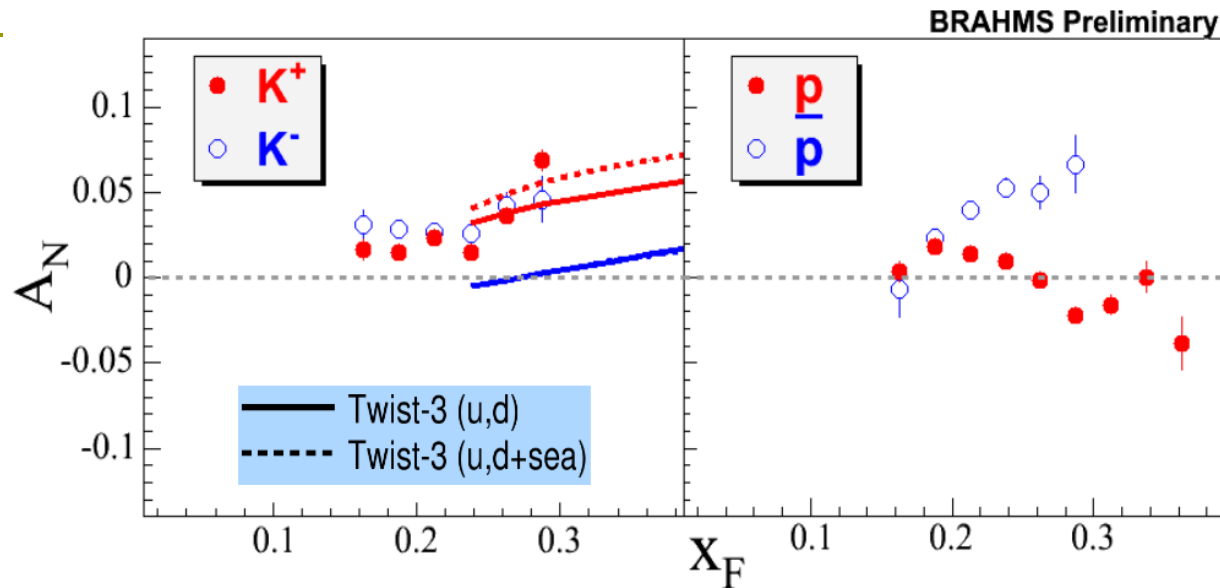
$\sqrt{s}=200$ GeV



STAR PRL 101 222001 (2008)

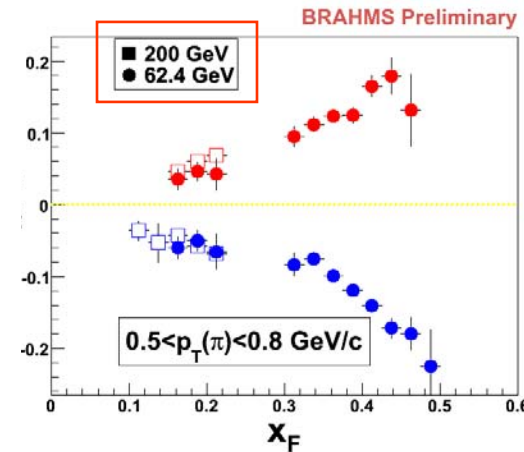
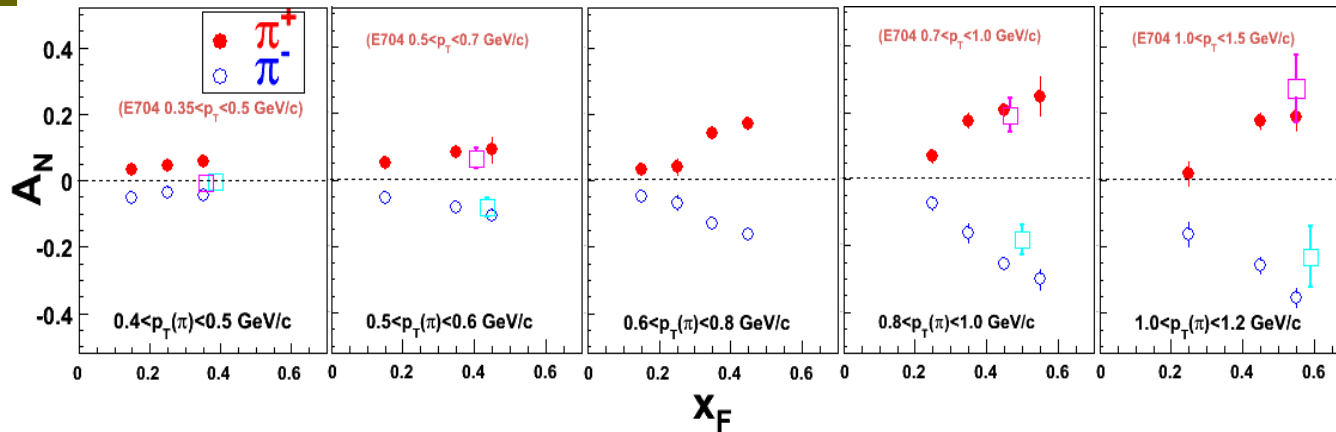
- SSA $A_N(\pi)$: No clear $1/p_T$ -dependence as predicted by pQCD models (as k_T/p_T decrease)
 - Possibly due to non-trivial interplay between soft and hard processes in the kinematic region complicated by limited acceptance
 - More theoretical investigations needed

SSA of kaons and protons



- $A_N(K^+) \sim A_N(K^-)$: positive 2-5% for $0.15 < x_F < 0.3$
- If main contribution to A_N at large x_F is from valence quarks:
 - $A_N(K^+) \sim A_N(\pi^+); A_N(K^-) \sim 0$: disagreement with naïve expectations
- $A_N(\bar{p}) \sim A_N(K^-)$ while $A_N(p) \sim 0$
 - require better understanding of non-leading, sea-quark, gluon FF?

SSA: Energy Dependence



● π^+ ○ π^- : BRAHMS 62.4 GeV PRL 101 042001 (2008)
□ π^+ □ π^- : E704 19.4 GeV PRL 77 2626 (1996)

- SSAs at $\sqrt{s} = 20, 62, 200$ GeV show no significant energy dependence
 - Unlike SIDIS (HERMES/COMPASS)
 - Indication of non-pQCD effect dominance in hadronic collisions at the energy ranges?

Summary

- BRAHMS measurements of cross-sections and SSAs at 200 GeV
- **Cross-sections:**
 - NLO pQCD describe unpolarized cross-section at RHIC in wide kinematic region
 - Understanding on non-valence, non-leading PDF and FF need to be improved
- **SSAs:** Likely driven by interplay between pQCD and significant non-pQCD effects at large- x_F at intermediate/high- p_T ?
 - Energy independence
 - Large SSAs without valence (u,d) quarks (K^- , p_{bar})
 - No clear $1/p_T$ dependence
 - Significant multiplicity dependence
- The energy and flavor dependent cross-sections and asymmetry measurements in a wide kinematic region serve as ingredients for theoretical understanding of rich partonic (and non-partonic) dynamics at RHIC.