Single Spin Asymmetries at RHIC

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pp spin analysis
Overview

- Introduction
- Kinematic variables
- RHIC and transverse Spin.
- PHENIX results
- STAR results
- Spin in BRAHMS
  - methods
  - Preliminary Physics results
  - Prospects for future measurements

Single Transverse Spin Asymmetry

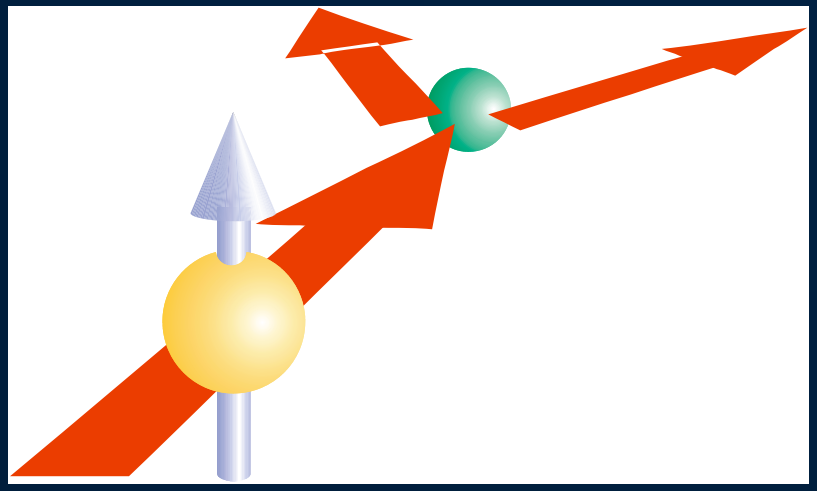
$A_n = (\sigma^+ - \sigma^-) / (\sigma^+ + \sigma^-)$

Where the spin cross section is determined with the spin direction defined by $k_b \times k_{pi}$

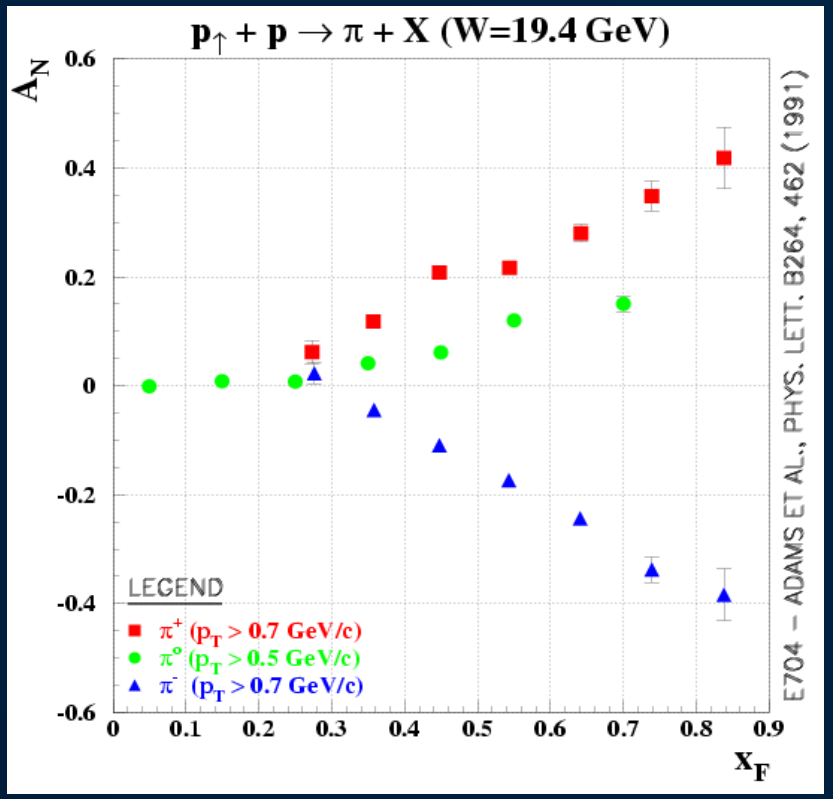
- Simple (naïve) QCD predicted early these to be small.
- Non-zero Single Transverse Spin Asymmetry (SSA/ A_n) requires
  - Spin Flip Amplitude
  - Phase difference
- The study of these may help uncover transverse quark structure of the nucleon.

Transverse Single-Spin Asymmetries

Left Right



Low energy data (FNAL E704) show clear differences between π^{+-} and π^0.



Single Transverse Spin Asymmetries

- The non-zero values have been explained in terms of several models as
  - Transversity x Spin-dependent fragmentation function in the outgoing (Collins effect)
  - Intrinsic-k_T imbalance in the initial nucleon (Sivers effect)
  - Higher-twist effects
  - Or combination of above
- Other channels were measured in E704 results

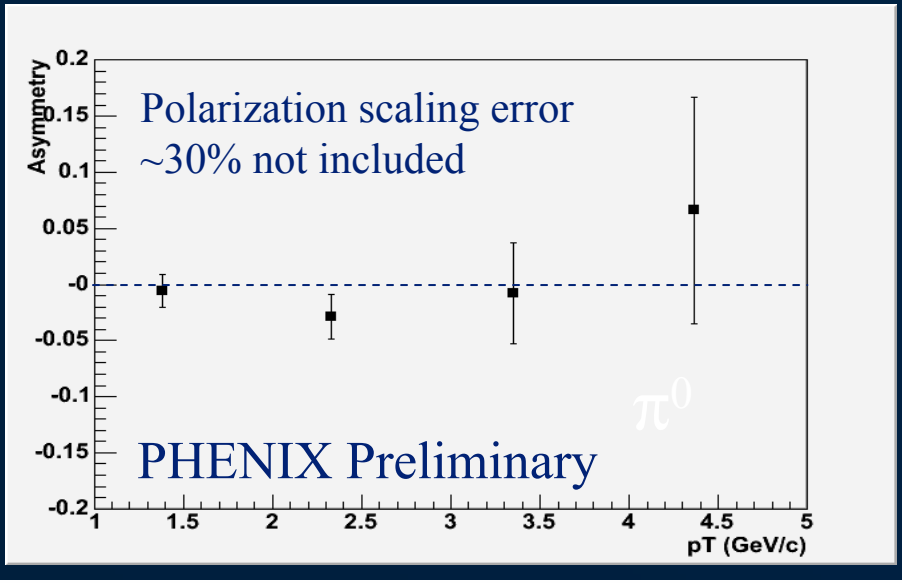
$$A_N(\bar{p}\uparrow p \to \pi X)$$
$$A_N(p\uparrow p \to \Lambda X)$$
$$D_{NN}(p\uparrow p \to \Lambda X)$$

RHIC experiments

- PHENIX and STAR has an extensive SPIN program, primarily focused on measurement with longitudinal polarization to address fundamental questions about the spin structure of the nucleon e.g. as ΔG the spin content due to gluon.
- STAR has a dedicated program for transverse spin measurements at large x_F, while PHENIX have investigated mid-rapidity a bit.
- BRAHMS has developed a program to measure transverse single spin asymmetries at intermediate x_F

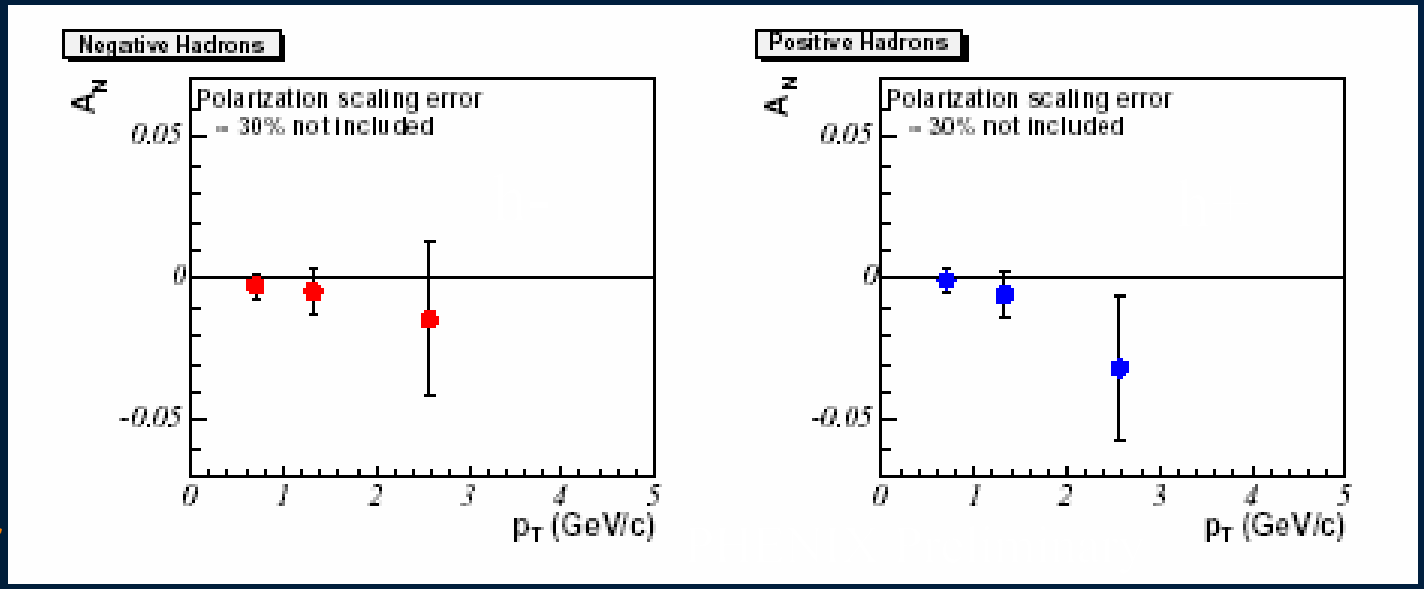
PHENIX Results: Central Rapidity

Neutral pions



A_N for both charged hadrons and neutral pions consistent with zero.

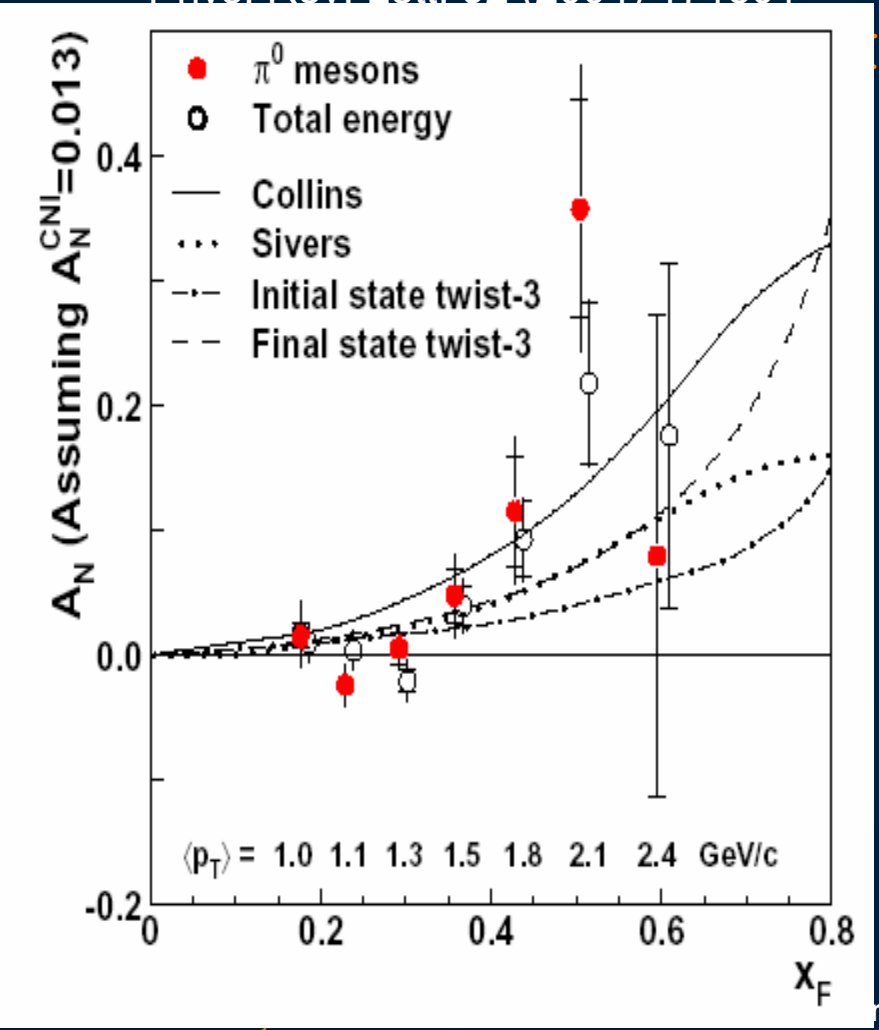
Charged hadrons



Large Analyzing Powers at RHIC

First measurement of A_N for forward π^0 production at $\sqrt{s}$=200GeV
From Run-2 data where the Polarization was rather small ~ 25%.

STAR collaboration, hep-ex/0310058;
Phys. Rev. Lett. **92** (2004) 171801



Similar to **FNAL E704** result at $\sqrt{s}$ = 20 GeV

in agreement with several models including different dynamics:

- Sivers: spin and $k_\perp$ correlation in initial state (related to orbital angular momentum?)
- Collins: Transversity distribution function & spin-dependent fragmentation function

  → suppressed? (hep-ph/0408356)
- Qiu and Sterman (initial-state) / Koike (final-state) twist-3 pQCD calculations

Questions Raised by STAR

- p_T dependence?
- $x_F<0$?
- A_N with mid-rapidity correlation?
- Spin dependence in jet?
- Heavy flavors??

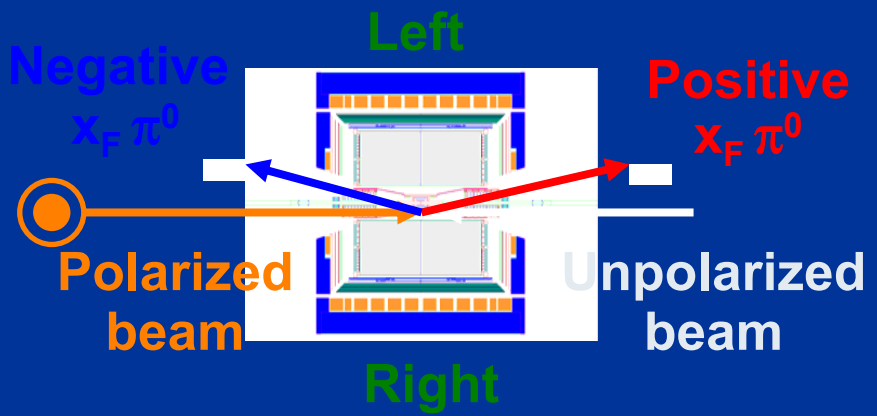
RHIC Run3 data analysis for FPD

RHIC-Run3 (2003 May)

Polarization ~ 30%

0.5/pb with transverse pol. in 2 weeks

(0.4/pb with longitudinal pol. In 2 weeks)



positive A_N = more π^0 going
left to polarized beam

Polarization is measured by RHIC pC CNI polarimeter

FPD East North & South

"Cross ratio" method

$$A = \frac{1}{P}\left(\frac{\sqrt{N_L^{\uparrow} \cdot N_R^{\downarrow}} - \sqrt{N_R^{\uparrow} \cdot N_L^{\downarrow}}}{\sqrt{N_L^{\uparrow} \cdot N_R^{\downarrow}} + \sqrt{N_R^{\uparrow} \cdot N_L^{\downarrow}}}\right)$$

FPD West South

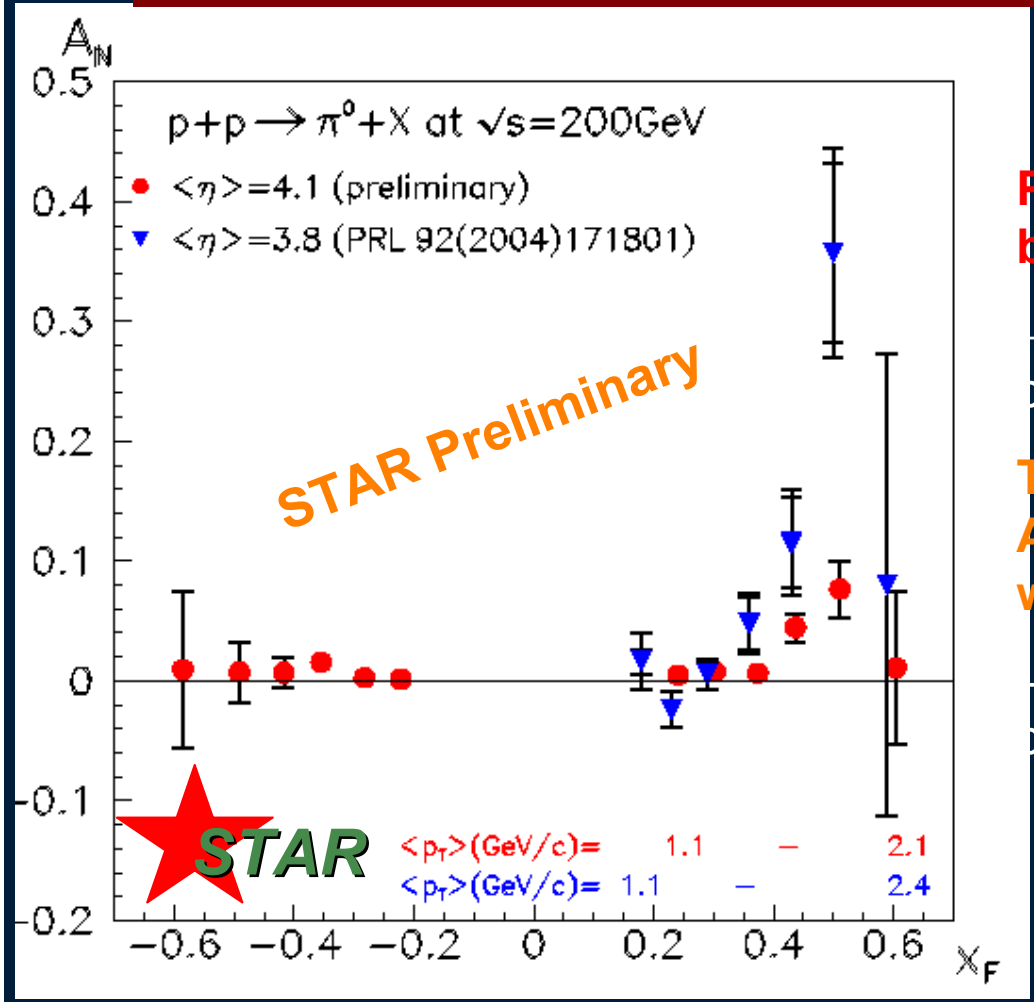
Single arm measurement

$$A = \frac{1}{P}\left(\frac{N^{\uparrow} - RN^{\downarrow}}{N^{\uparrow} + RN^{\downarrow}}\right) \qquad R = \frac{L^{\uparrow}}{L^{\downarrow}}$$

Relative luminosity R is measured by BBC

2 measurements are consistent → averaged

Measurement of A_N for forward π^0 production at $\sqrt{s}$=200GeV



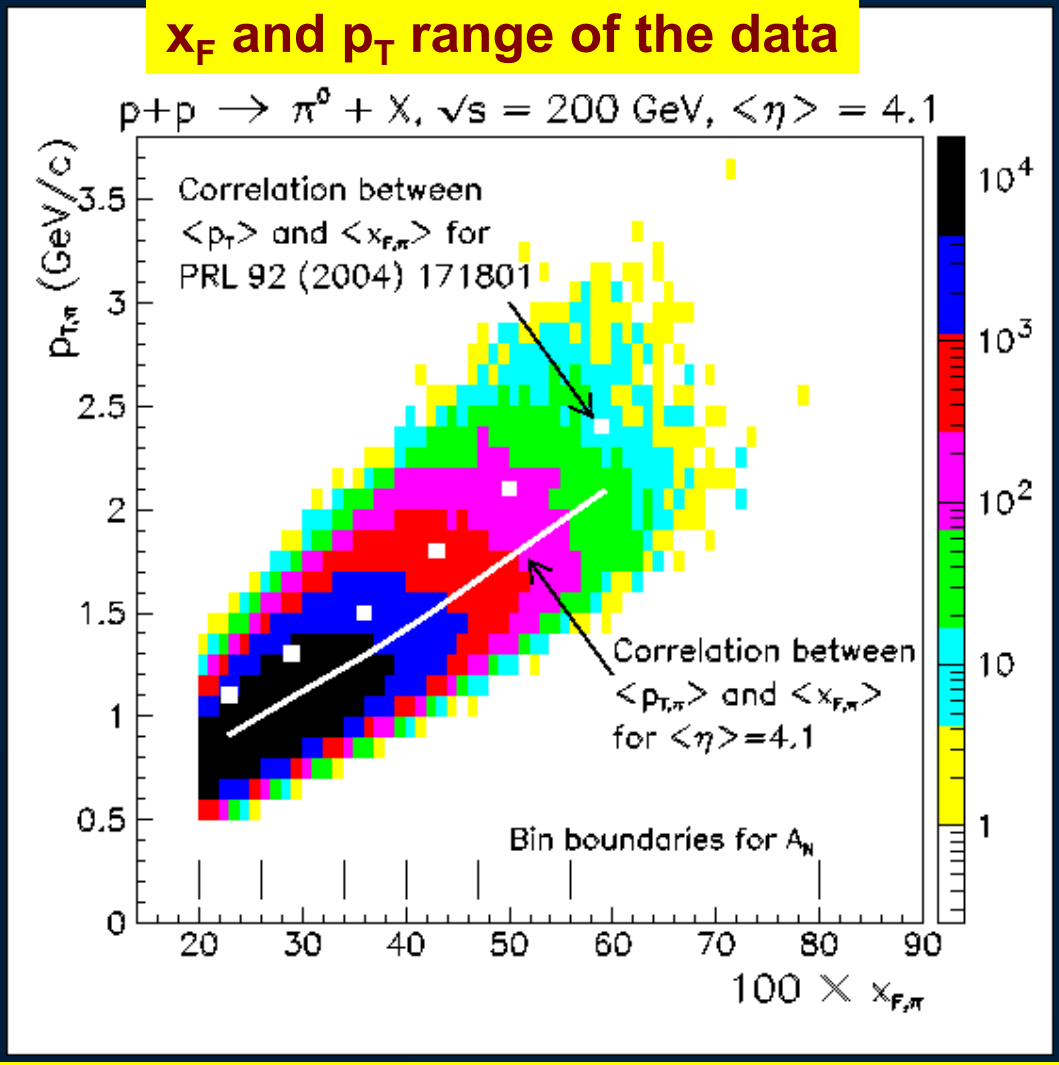
Positive A_N at large positive x_F has been confirmed

→ Larger significance to be non-zero & positive than published data

The first measurement of negative x_F A_N has been done, and is consistent with zero

→ Sensitive to twist-3 gluon-gluon correlation

x_F and p_T range of the data



Mapping of A_N in x_F and p_T plane has begun !

The unique feature of BRAMS is the large rapidity coverage.

What does the measurement consist of

- $A_n = (\sigma^+ - \sigma^-) / (\sigma^+ + \sigma^-)$

  Where the spin cross section is determined with the spin direction defined by $k_b \times k_{pi}$

  The k are the momenta of the beam and detected particle respectively. In the BRAHMS FS thus the spin direction point down.

  Experimentally this is determined from

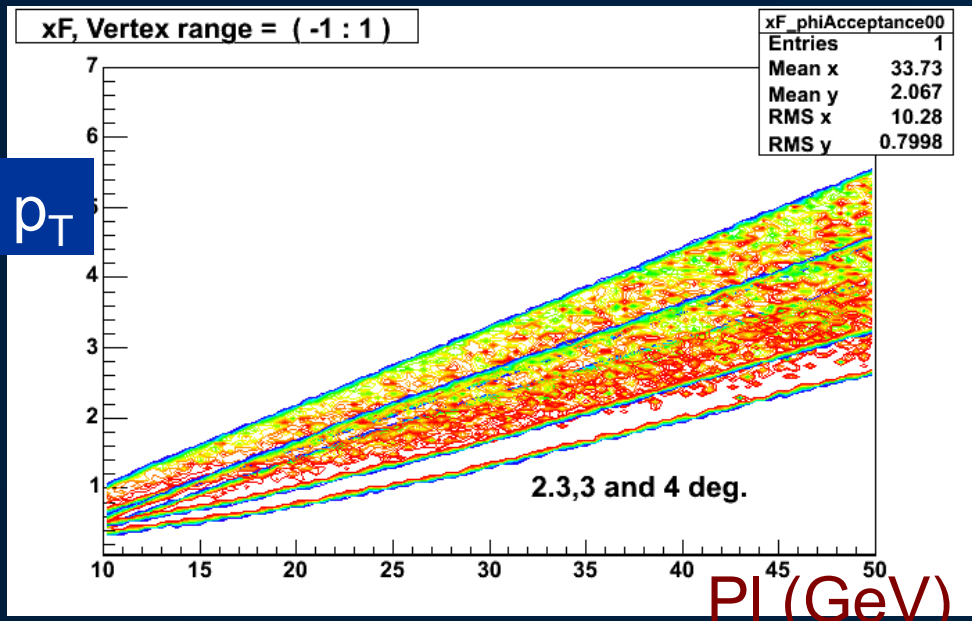
  $A_n = 1/P\ \varepsilon$

  With $\varepsilon = (N^+ - N^-) / (N^+ + N^-)$ where the is the yield of pion in a given kinematic bin with the beam spin direction (up). The normal RHIC definition of + thus is down just to confuse you.

Variables

- The kinematic variables of interest are Feynman x (x_F) and p_T.
- The BRAHMS acceptance in these variables are

Nominal coverage for 2.3, 3 and 4 deg in x_F-p_T space. Thus is in range of 1-3 GeV/c.
The <pt> value at .25 is ~ 1.6 slightly larger than for STAR π^0



Measuring raw asymmetries.

$\varepsilon = (N^+ - N^-) / (N^+ + N^-)$ equation assumed that each bunch has same luminosity.
This needs need not be the case and the generalized equation is
$= (N^+ / L^+ - N^- / L^-) / (N^+ / L^+ + N^- / L^-)$
$= (N^+ - L*N^-) / (N^+ + L*N^-)$ where $L = L^+ / L^-$

The Polarisation pattern is +-+-+-… for the Blue beam
And ++--++--++--++--… for the Yellow beam (away from spectrometer).

For all the data runs used in the last ~4 days of the RHIC run the polarization is ~45%. There are some issue with the measurements of Blue polarization using the CNI.

RHIC in RUN-4

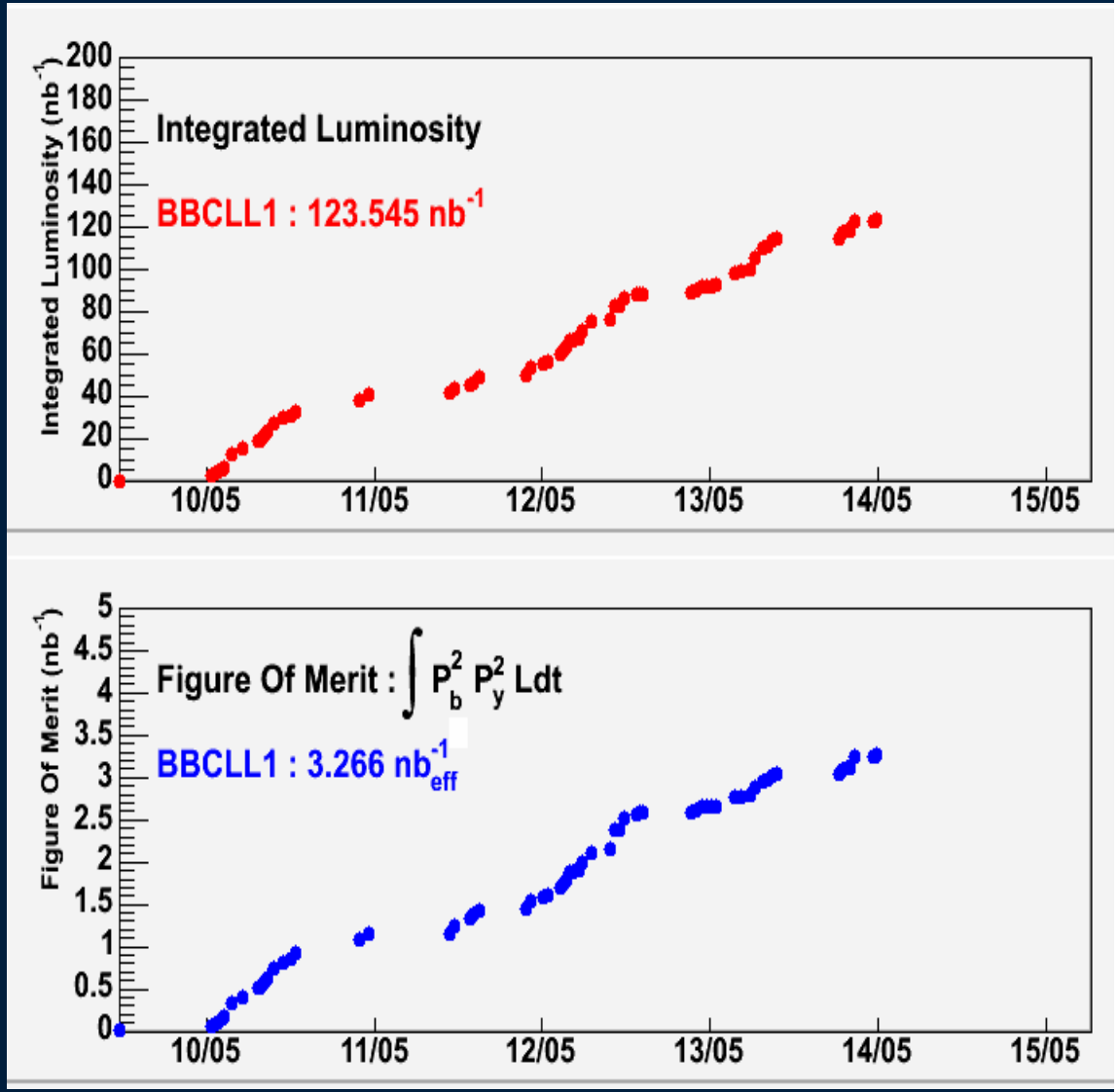
The Run was machine development though a 4 day physics runs took place.

$30nb^{-1}$/day

P_B~40%

(AGS) 50%

Performance plot as reported by Phenix

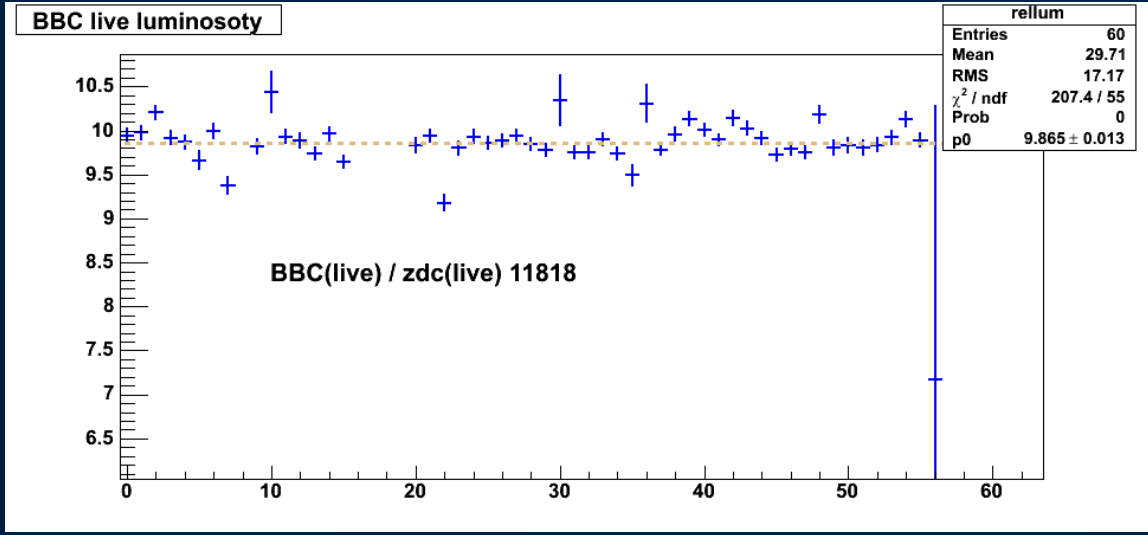


Luminosity vs Bunch

Luminosties for + and – are deduced from the live rates of several set of measures

- BB coincidencs
- ZDC coincidences
- INL coinc
- Misc singles

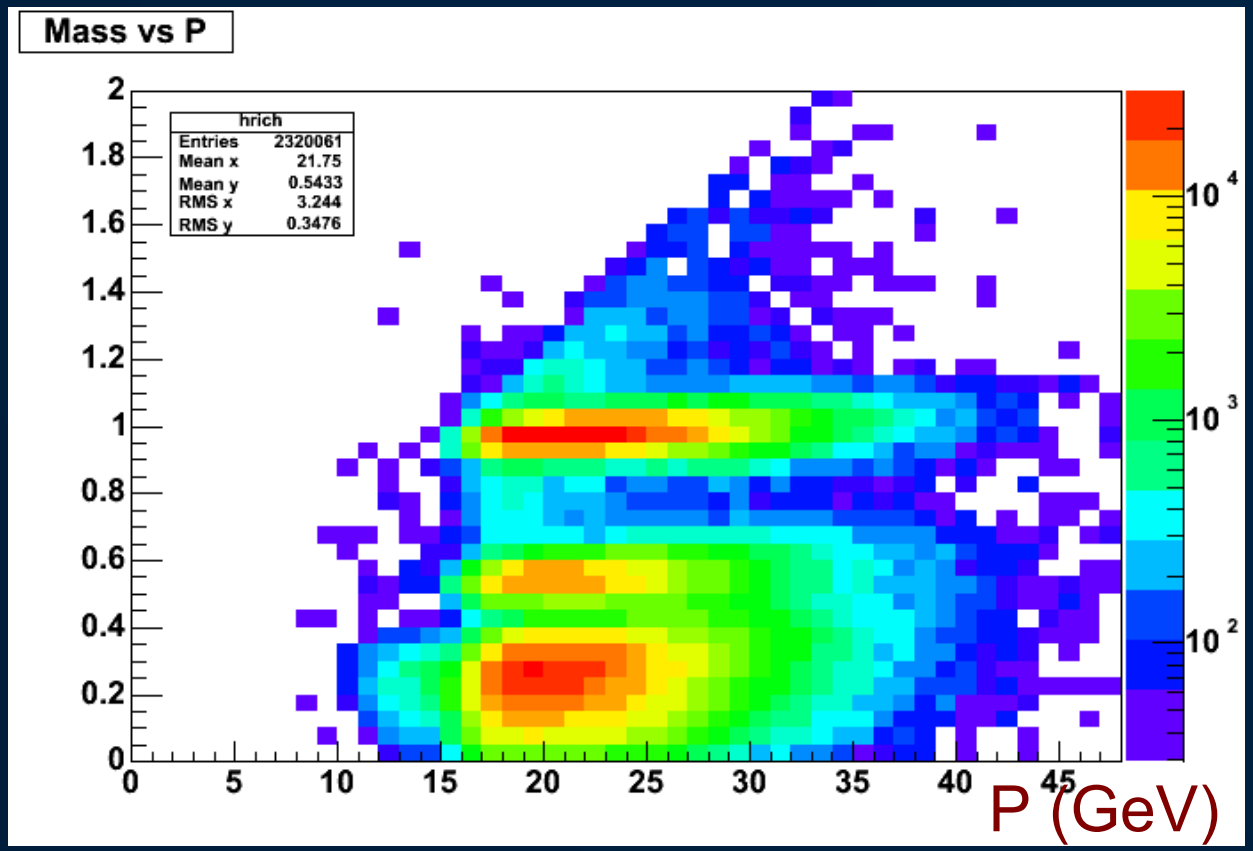
All these found to be within a range of .5-.8%.



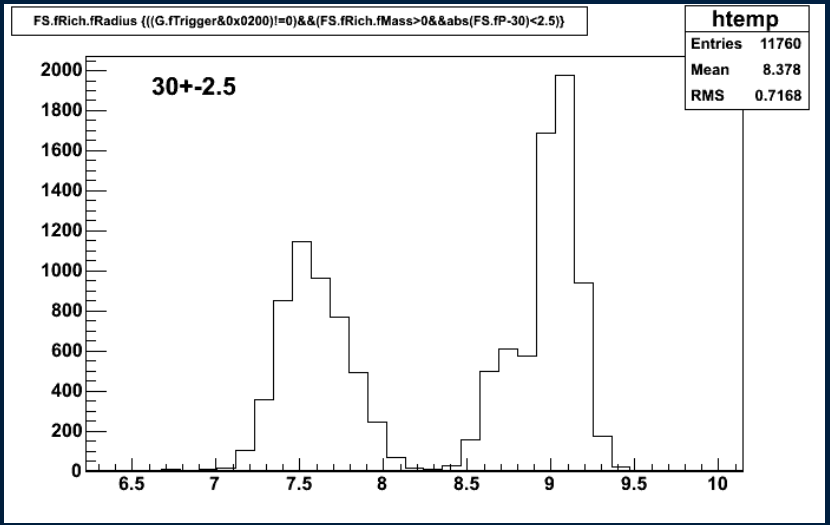
Track Selection Criteria

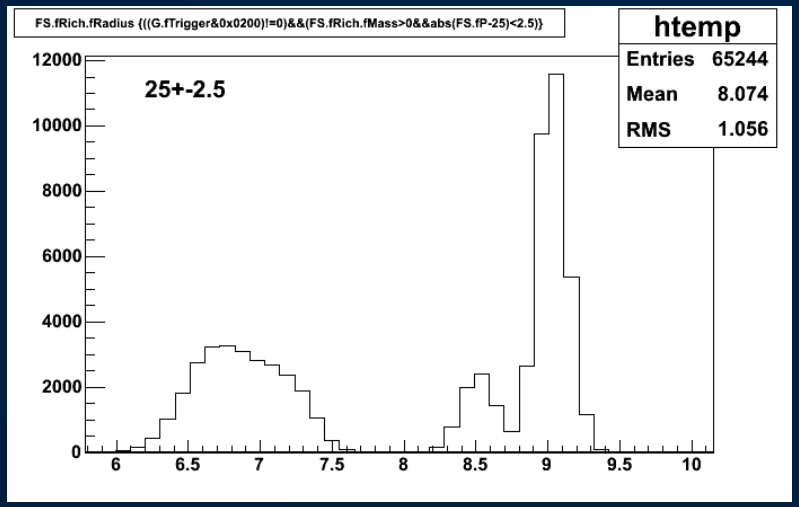
- Spectrometer Triggers
- Momentum from FS track
- Tracks being clean through spectrometer.
- -30< InelVertex <30 cm
- Good Bunches Only (selected per store)
- 0< Mass < .400 (or .350)

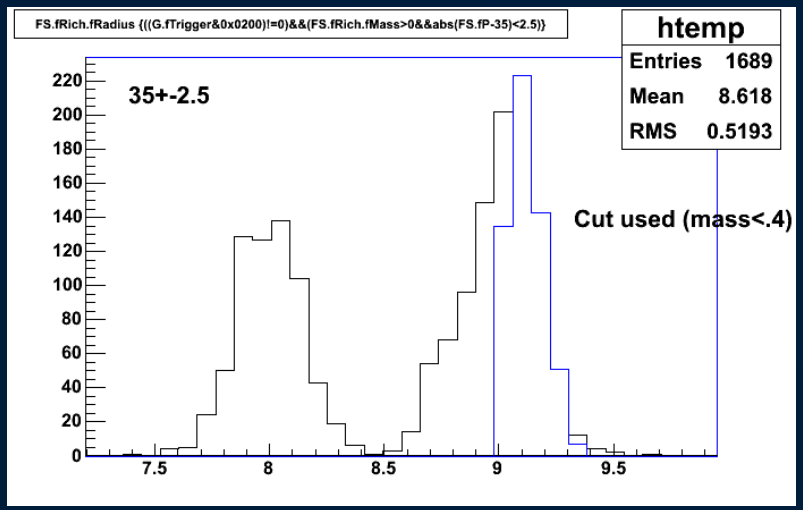
PID using RICH



Individual bins for PID



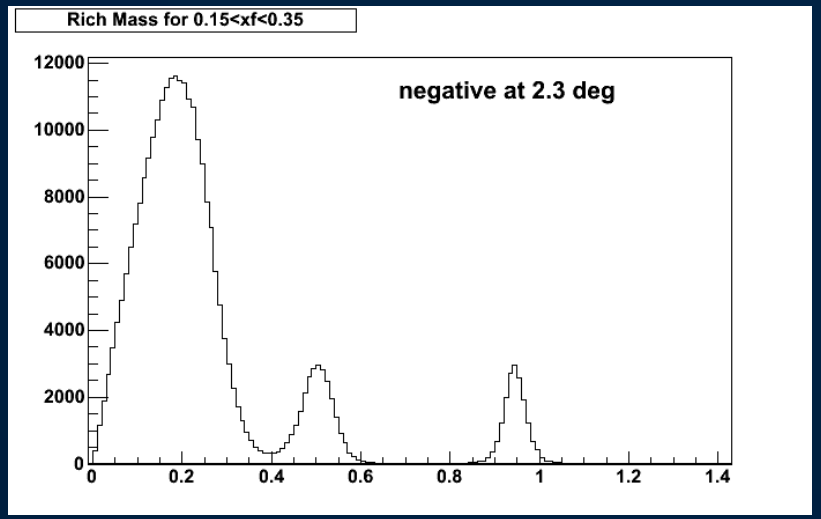


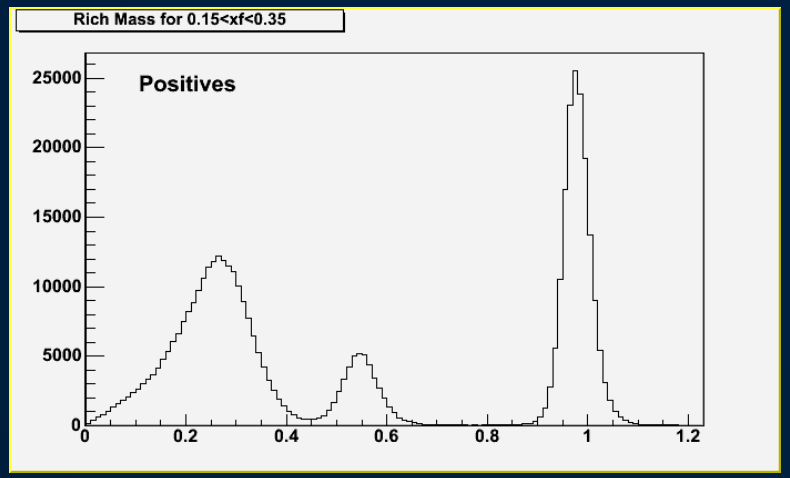


Yields that can be used for analysis

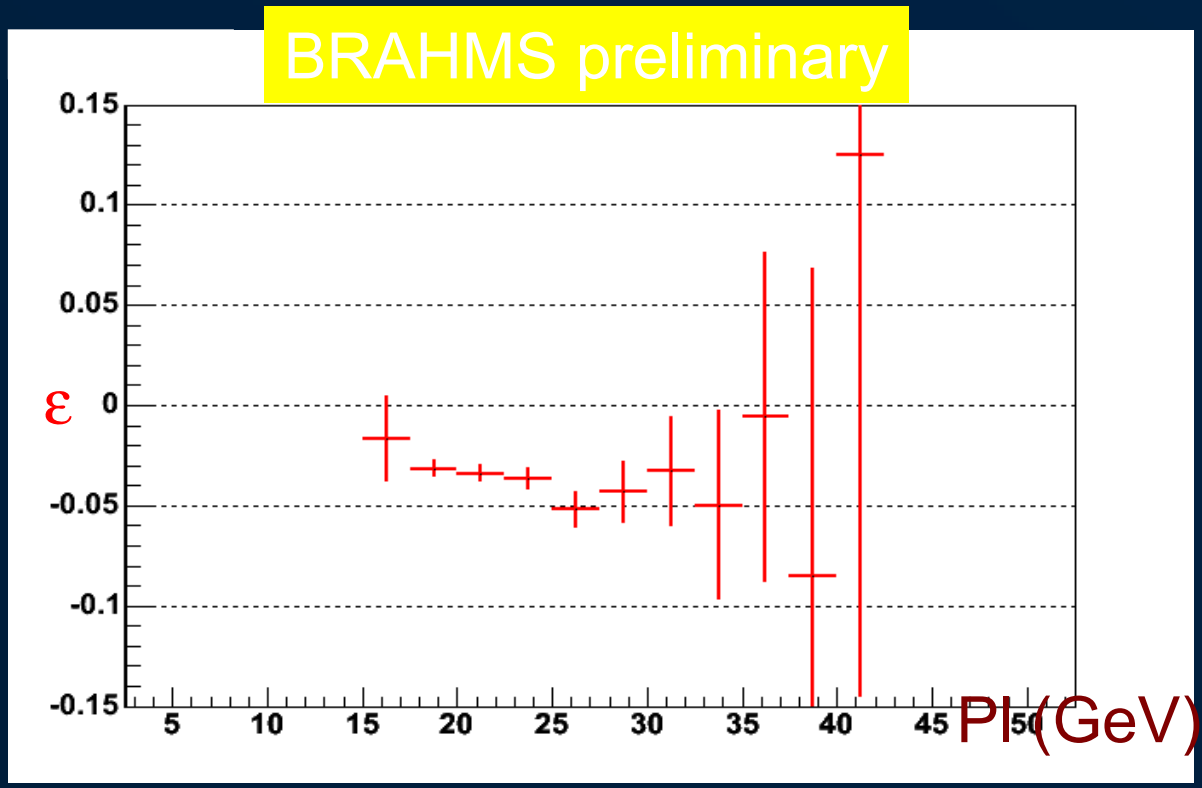
	positive	negative
pion	219K	216K
kaon	46K	26K
proton	165K	17K

Integrated yields of π, K and proton in x_F range 0.15-0.35



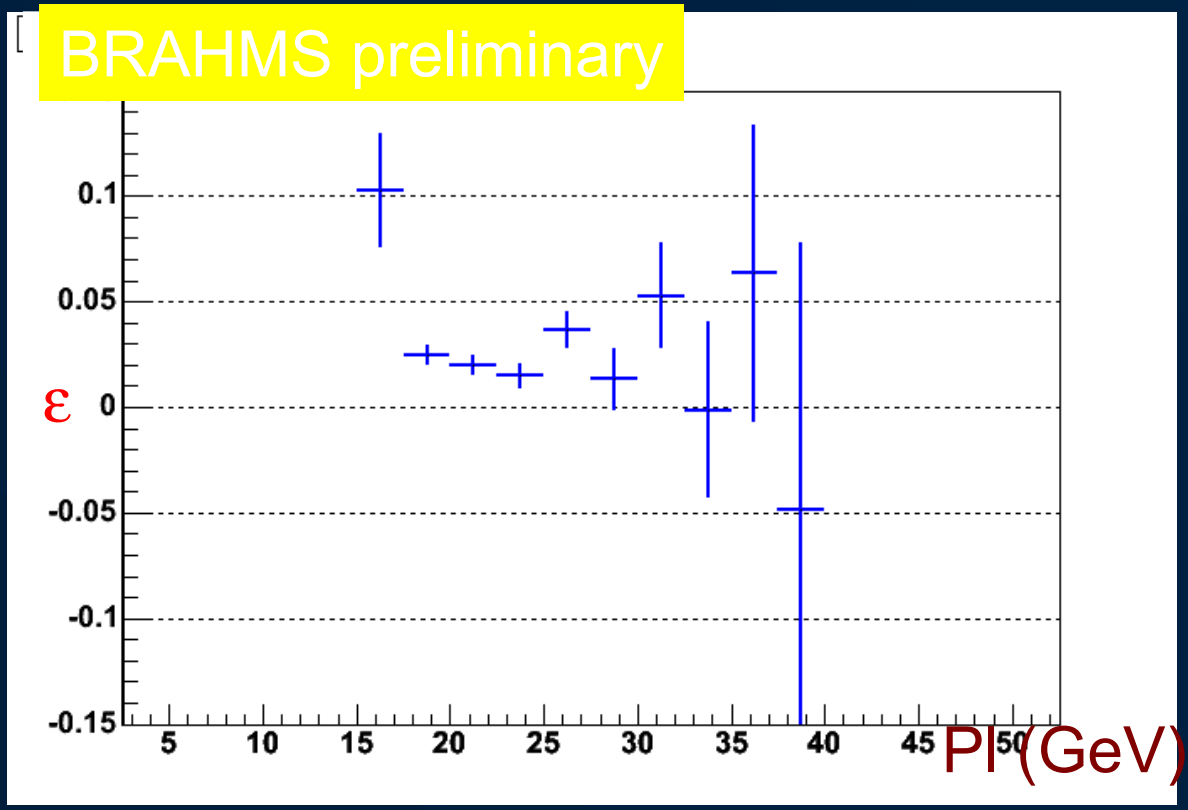


π^- ε vs. x_F * 100



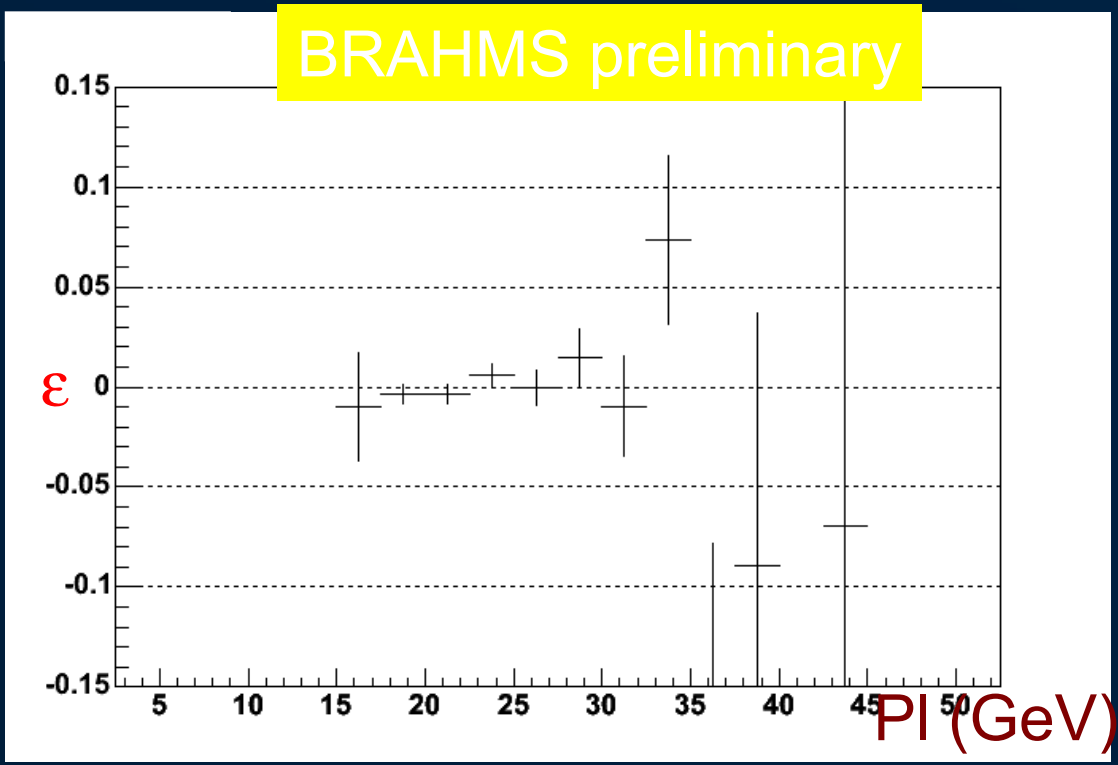
$\langle\varepsilon\rangle \sim -0.035 \Rightarrow A_N = -0.08 \pm 0.005 \pm [0.015]$ in $0.17 < x_F < 0.32$

$\pi+$ ε vs. x_F * 100

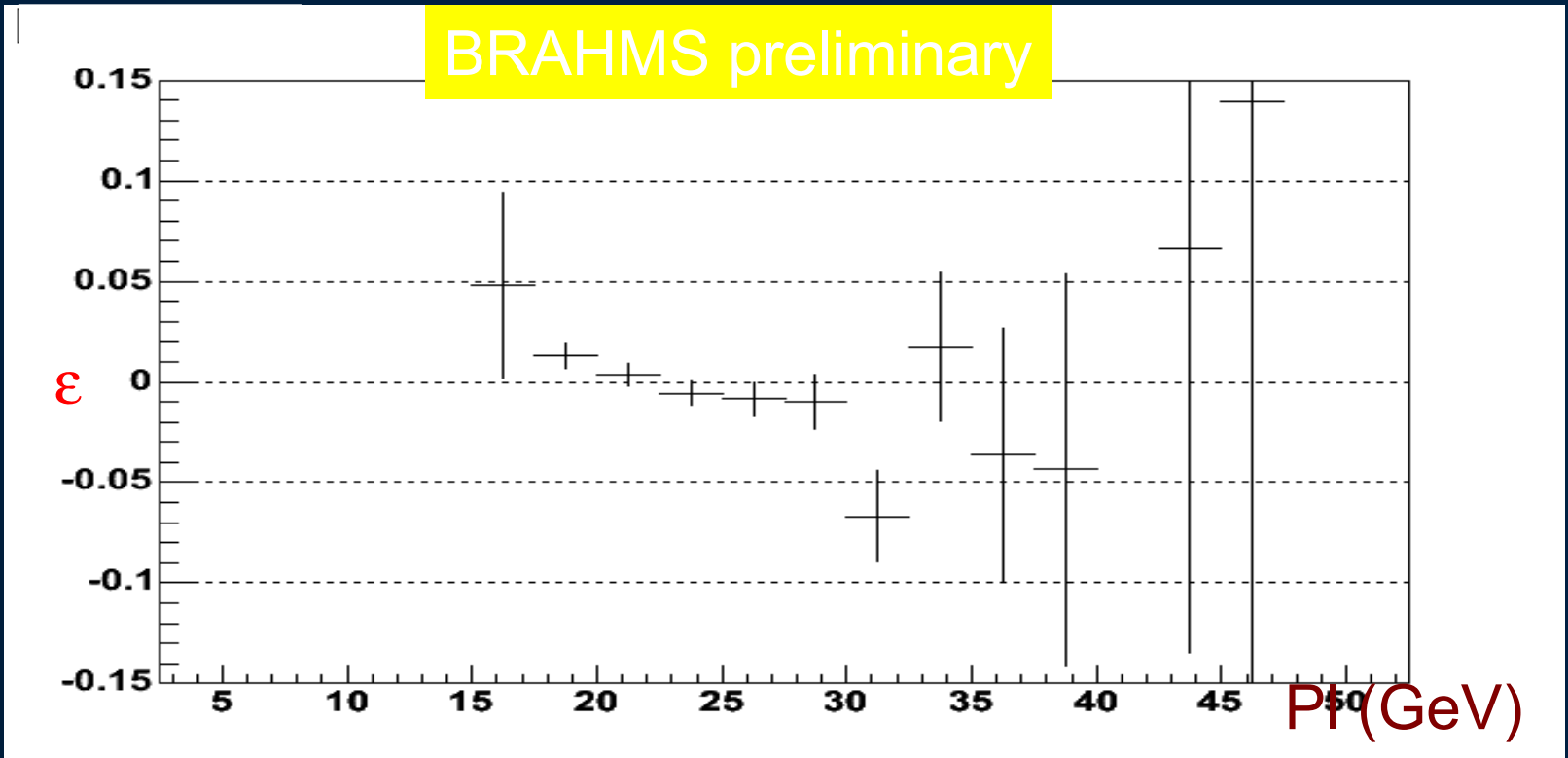


$\langle\varepsilon\rangle \sim +0.02 \Rightarrow A_N = +0.05 \pm 0.01 \pm [0.015]$ in $0.17 < x_F < 0.32$

π^+ with yellow Pol.



This corresponds to negative x_F, and is consistent with 0.



The proton An is consistent with 0. Analyzing power

Conclusions

- BRAHMS has obtained the first preliminary result for single spin asymmetries for p+ and p- in 200 GeV pp collisions at RHIC in the x_F range of 0.17 to 0.32.
- The value for π+ and π- are significantly different from each other and the π- < 0 at ~ 3 sigma level and π+ >0 at ~ 1 sigma level
- The negative x_F for pions are consistent with 0 (as also found by STAR)
- The protons is found to have An ~0.
- The upcoming run-5 should enable BRAHMS to extend the measurements to xF ~ 0.45 and to get some information on p_t-dependence at xF~0.25

Thanks for your attention