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Colloquia: Transversity 2011

Transverse-spin physics at RHIC/PHENIX

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Summary. — The PHENIX experiment at the Relativistic Heavy Ion Collider (RHIC) probes the proton's transverse-spin structure by measuring asymmetries in transversely polarized proton+proton collisions. The large single-transverse-spin asymmetries observed at high-x_F arise from either the Sivers effect, the Collins effect or higher-twist effects. PHENIX aims to disentangle these effects with complementary measurements which provide sensitivity to each effect. This talk summarizes PHENIX's current measurements and a planned upgrade to the experiment to better measure each effect.

PACS 13.85.Ni – Inclusive production with identified hadrons.
PACS 13.88.+e – Polarization in interactions and scattering.
PACS 14.20.Dh – Protons and neutrons.
PACS 25.40.Ep – Inelastic proton scattering.

1. – Introduction

Currently, three proposed effects aim to explain the forward single spin asymmetries of hadrons: a proton spin-quark transverse-momentum correlation function (Sivers) [1], a non-zero quark transversity distribution coupled with a spin-dependent fragmentation function (Collins) [2] and higher-twist effects [3, 4]. The solution to the origin of these asymmetries and the larger issue of the transverse-spin structure of the proton are top priorities of the PHENIX collaboration. PHENIX contributes to this exciting area of physics by continuing the measurement of forward single spin asymmetries, and also pursues other measurements which are sensitive to either the Sivers or Collins effects separately. The unique capabilities of the PHENIX detector enable it to perform these measurements, and it is pursuing an aggressive upgrade program to make decisive new measurements in the long term.

The structure of the following proceedings is split up as follows: sect. **2** describes the PHENIX detector; sect. **3** describes the inclusive A_N measurements; sect. **4** describes the transversity measurements; and sect. **5** describes an upgraded PHENIX detector which

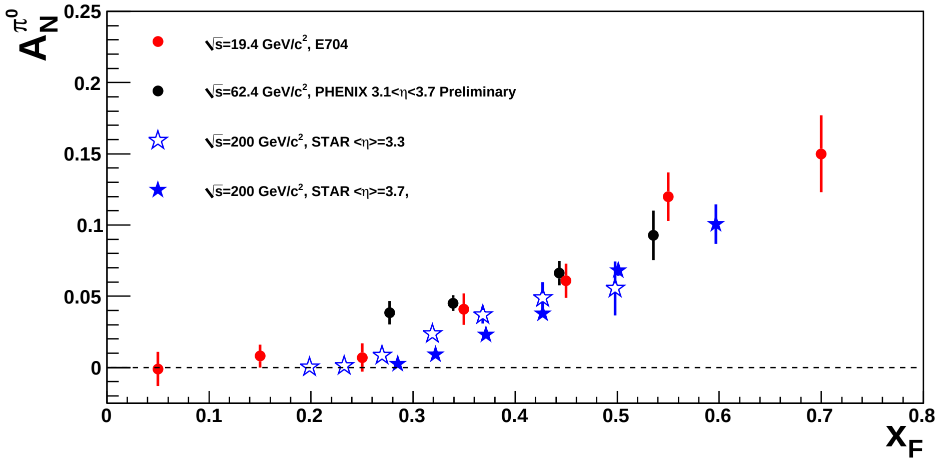

Fig. 1. – Data from the E704 [5], PHENIX and STAR [6] experiments on the forward single-spin asymmetries of neutral pions.

is currently being proposed and will greatly extend the capabilities of the experiment. PHENIX also pursues dedicated Sivers measurements, but these are omitted from the talk and these proceedings due to time and space constraints. The next few RHIC runs are expected to include significant running periods of transverse $p + p$ collisions. Currently, PHENIX has acquired a dataset of $8\,\mathrm{pb}^{-1}$ but over the next two years we expect to accumulate $33\,\mathrm{pb}^{-1}$. Therefore, projected error bars for near-term future measurements are included where relevant.

2. – Experimental setup

This section briefly reviews the important instrumentation for the transverse-spin measurements done at the PHENIX detector at RHIC. Two back-to-back spectrometer arms each covering roughly $\pi/2$ in the azimuthal angle cover the pseudorapidity region $|\eta| < 0.35$. These arms include charged tracking, particle identification and a fine-grained electromagnetic calorimeter. Measurements with charged particles and neutral mesons are shown in these proceedings. Measurements at forward rapidity are done with a pair of electromagnetic calorimeters covering the full azimuthal angle range and pseudorapidity of roughly $3.1 < |\eta| < 3.8$. These calorimeters are used to measure the asymmetries of neutral pions and eta mesons.

3. – Inclusive A_N measurements

Inclusive A_N measurements are presented in two rapidity regions: at forward rapidities ($3.1 < \eta < 3.8$) where the asymmetries are non-zero and at mid-rapidity ($|\eta| < 0.35$) where the asymmetries are consistent with zero.

3˙1. *Forward rapidity measurements.* – Three inclusive A_N measurements at forward rapidity are presented from the PHENIX collaboration. The first two are sensitive to $A_N^{\pi^0}$ but are done at different center of mass energies ($\sqrt{s}$), 62 and 200 GeV. The third measurement is for eta mesons at $\sqrt{s} = 200\,\mathrm{GeV}$. The $\sqrt{s} = 62\,\mathrm{GeV}$ result for neutral pions

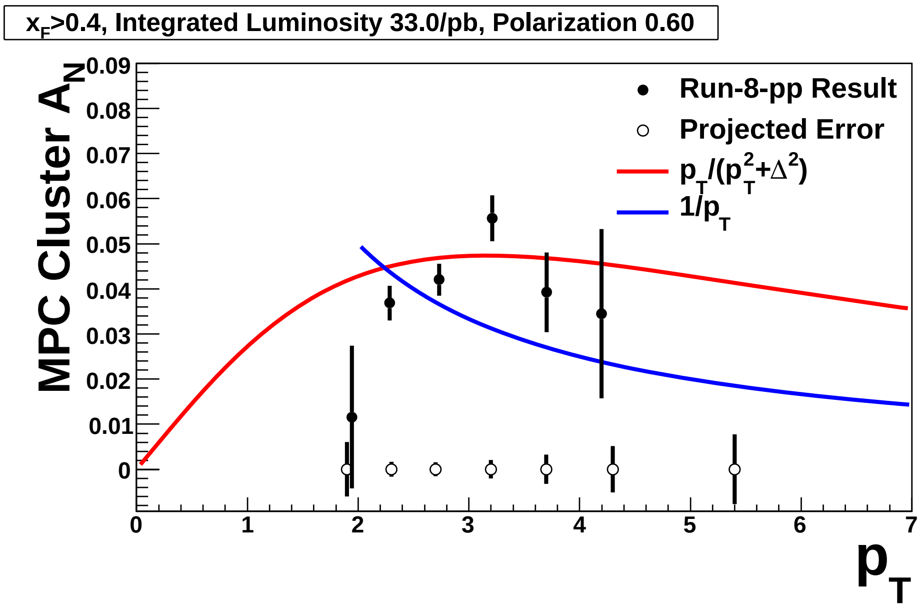

Fig. 2. – Transverse-single-spin asymmetries of inclusive electromagnetic clusters in the forward rapidity. Data points are shown in filled circles; projected error bars for near-term RHIC running are shown in open circles. The parametrizations for the asymmetries are described in the text.

is shown in fig. 1 along with results performed by the E704 and STAR collaborations at $\sqrt{s} = 19.4$ and $200\,\text{GeV}/c^2$, respectively. While each experiment's acceptance differs, the plot shows that the asymmetries are roughly the same over an order of magnitude in $\sqrt{s}$.

The next inclusive A_N measurement is not a direct measurement of $A_N^{\pi^0}$. Detector effects prevent the measurement of a two-photon π^0 which is the traditional method. Instead, a single merged cluster is used as a proxy for the two-photon method. This allows the measurement to explore the most interesting high-x_F and high-p_T region where higher-twist effects are expected to dominate, but it also introduces backgrounds. The dominant sources of background are from eta mesons and direct photons. The inclusive cluster A_N is shown in fig. 2. The plot includes the measured asymmetries, projected error bars for the next two RHIC runs, and, for comparison, two parametrizations for the expected asymmetry's shape. The first parametrization is a simple p_T^{-1} shape which includes the expected falloff at high p_T but also the drawback that $A_N(p_T = 0)$ diverges. The other parametrization includes the falloff at high p_T while ensuring that the asymmetry is zero at p_T of zero.

The last forward inclusive A_N measurement is for eta mesons. Figure 3 shows the results plotted *versus* p_T. The asymmetries are the same sign and magnitude as the neutral pion asymmetries but with large statistical errors. This result contradicts the preliminary results released by the STAR collaboration. The tension between the datasets may be resolved by recent theoretical work using twist-3 functions which predicts the eta meson to have asymmetries larger than the π^0 [7]. When both experiments publish their data, it will be interesting to investigate the statistical significance of the tension in the data.

3˙2. *Mid-rapidity measurements.* – The A_N measurement at mid-rapidity has been updated since our earlier publication [8] on the same topic. The previous publication was

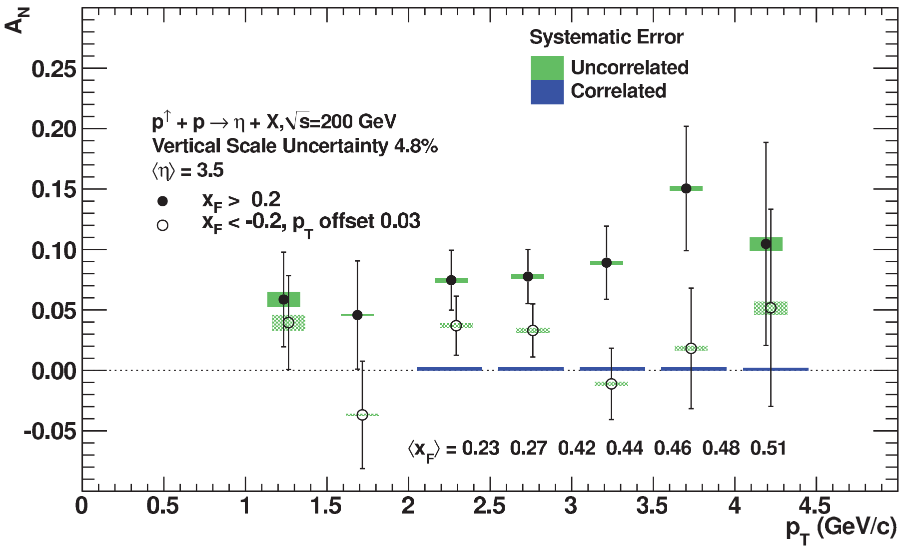

Fig. 3. – Transverse-single-spin asymmetries for eta mesons in the forward and backward regions.

used to constrain the gluon Sivers function and it is expected that the updated dataset may contribute as well. The analysis has been expanded to include both neutral pions and eta mesons, and with modest pseudorapidity cuts. All asymmetries are statistically consistent with zero but with a precision more than twenty times that of the previous publication. The neutral pion results are shown in fig. 4 with a comparison to the previous results.

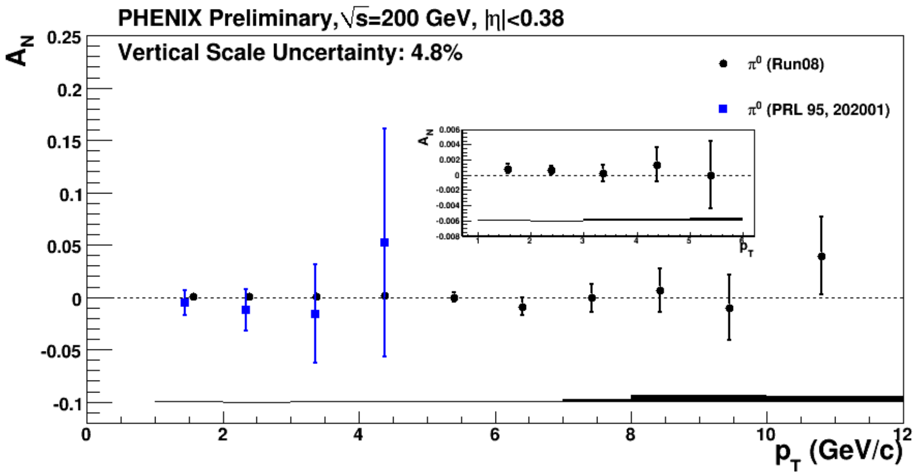

Fig. 4. – Mid-rapidity single-transverse-spin asymmetries for neutral pions. Black circles are the new preliminary data; blue squares are the previous publication [8]. The error bars have improved by a factor of twenty since the earlier publication.

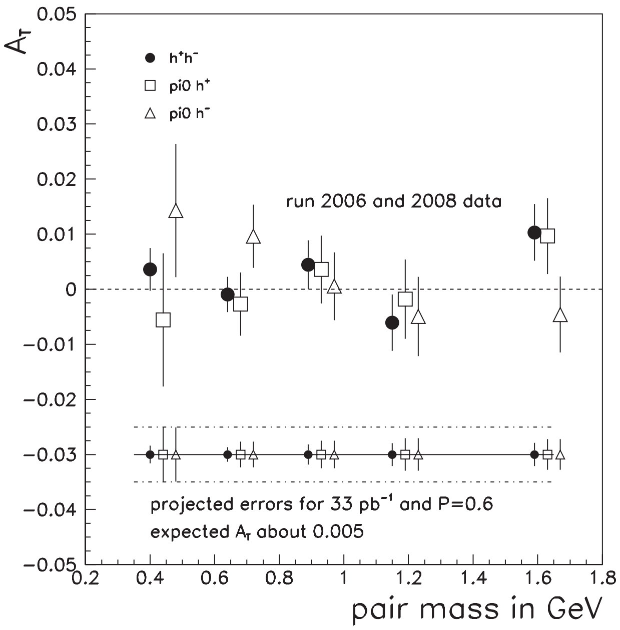

Fig. 5. – IFF asymmetries for different combinations of positively and negatively charged hadrons, and neutral pions plotted against the pair mass. Shown at the bottom are projected error bars for near-term RHIC running.

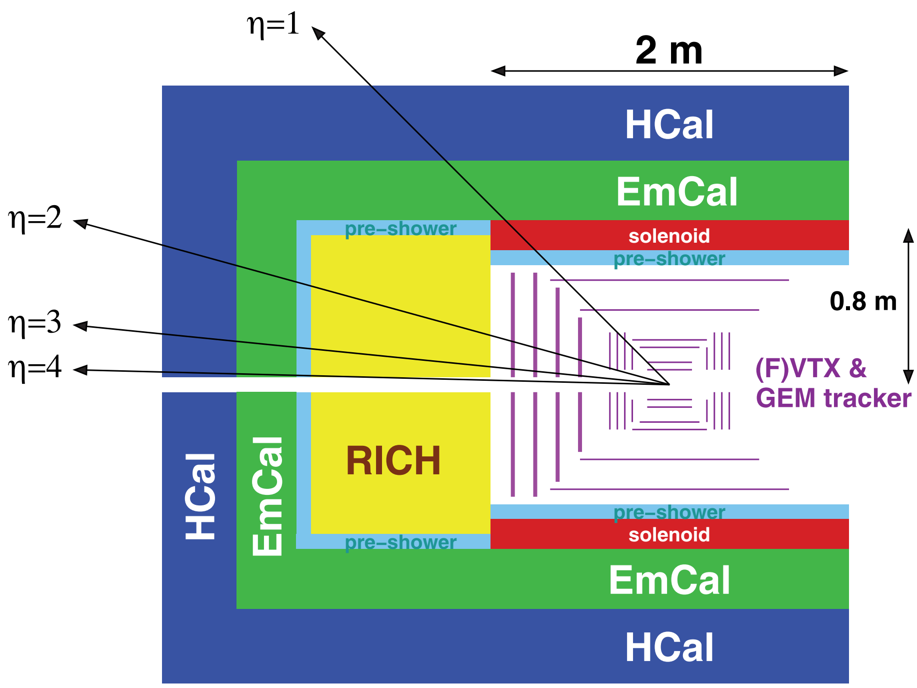

Fig. 6. – The planned upgrade to PHENIX now in the design stage.

4. – Transversity measurements

In addition to the inclusive A_N measurements, PHENIX also pursues dedicated channels for the measurement of the transversity distributions. The channel discussed here utilizes a di-hadron fragmentation function called the interference fragmentation function (IFF) to access the transversity distribution. The necessary analyzing fragmentation function has been measured by the BELLE collaboration [9]. The IFF exhibits a hadron pair mass dependence, and therefore the PHENIX asymmetries are extracted in pair mass bins with a minimum p_T cut. Results from a measurement done at mid-rapidity are shown in fig. 5. The asymmetries are consistent with zero for all combinations of positively charged hadrons, negatively charged hadrons and neutral pions. The same figure also shows the projected error bars for our near term running.

5. – Future PHENIX upgrade

In the long term PHENIX plans a major upgrade of its experimental capabilities. The planned upgrade is shown in fig. 6. The instrumentation in the forward region is the most significant for spin physics. The forward region is the area in which large transverse-spin effects have been observed before, and also the region where effects from the valence region are easiest to observe. In the forward region the planned detectors are: a hadronic calorimeter for jet reconstruction, identified charged particle tracking, and an electromagnetic calorimeter. Together these systems will allow new measurements of transversity through the IFF and Collins channels. Dedicated Sivers measurements will be possible by measuring A_N for inclusive jets and direct photons. In addition, the role of higher-twist distribution functions can be careful mapped by studying the p_T dependence. Lastly, the upgraded detector will be used for Drell-Yan measurements in the electron/positron decay channel. By studying different angular correlations measurements of both the Sivers and Transversity distributions will be possible.

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