The STAR Spin Research Program at IUCF in FY03

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In parallel with continuing intensive work on the construction, installation and commissioning of the Endcap Electromagnetic Calorimeter (EEMC), the STAR group at IUCF worked extensively during FY03 on a number of physics analysis and planning issues for the STAR spin program. We describe briefly below our recent results and the status of ongoing work on the following issues: (1) measurement of transverse spin analyzing powers and absolute differential cross sections for forward π^0 production in pp collisions at $\sqrt{s}$ = 200 GeV and large Feynman x-values (see also Greg Rakness' report immediately following this one); (2) analysis of measured STAR spin asymmetries for leading charged particle production at mid-rapidity; (3) considerations of jet triggering in STAR and simulation studies of the bias in such triggers and their influence on interpretation of measured jet spin asymmetries; (4) development and comparison of different methods for the absolute energy scale calibration of the EEMC; and (5) work on developing the physics case and detector requirements for proposed future STAR upgrades, with emphasis on an improvement to the forward charged-particle tracking capabilities. All the senior members of the group have been involved in supervising all of this work, but the junior members most responsible for specific analyses are highlighted below.

Greg Rakness was primarily responsible for analysis of STAR data acquired with transversely polarized pp collisions in FY02 (see Fig. 1) and with the 12-tower prototype

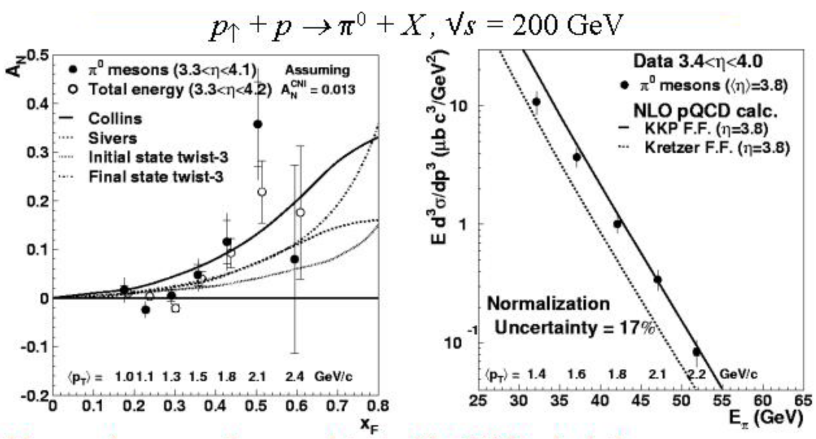

Figure 1. Analyzing power (left) and absolute cross section (right) results for energetic forward π^0 production detected in the prototype EEMC detector at STAR, at moderate p_T (1-2.4 GeV/c) and $x_{Feynman}$ above 0.1. The cross section results are reasonably consistent with pQCD calculations, suggesting a hard-scattering origin of the detected pions, but the analyzing powers show large deviations from zero consistent with observations at much lower energies in fixed-target experiments. The agreement between open and closed symbols for the analyzing power illustrates the insensitivity of the results to details regarding the reconstruction/identification algorithm used for the π^0's.

of the EEMC (including SMD layers) installed in STAR as part of a Forward π^0 Detector (FPD). The results of this analysis have recently been submitted for publication in Physical Review Letters [1].

Jan Balewski has been primarily responsible for the analysis of transverse spin asymmetries for leading charged particles from pp collisions at $\sqrt{s}$ = 200 GeV, reconstructed in the mid-rapidity range ($|\eta| \leq 1.4$) with the STAR TPC. The leading charged particle (LCP) for each event is associated with the reconstructed TPC track of highest transverse momentum transfer p_T. For p_T in excess of 1 GeV/c, it is expected that the LCP arises from jet production, where leading-twist perturbative QCD (pQCD) predicts vanishingly small single-spin effects at mid-rapidity. (Non-vanishing analyzing powers could arise in principle if the pQCD result for hard parton scattering were non-zero, despite the fact that the LCP may arise from either of the two resulting jets at opposite azimuth. For example, quark vs. gluon jet fragmentation differences, or a Sivers effect spin-dependent preference for the direction of *intrinsic* transverse momentum k_T in the incident proton, could lead to a side preference for the LCP.) In combination with the FPD analysis described above, the LCP analysis thus offered STAR the opportunity to demonstrate that it could simultaneously measure, in different kinematic regions, analyzing powers that deviate substantially from zero and that are consistent with zero, as a crosscheck on all the new measurement and analysis procedures put into place for the first polarized proton collider run ever.

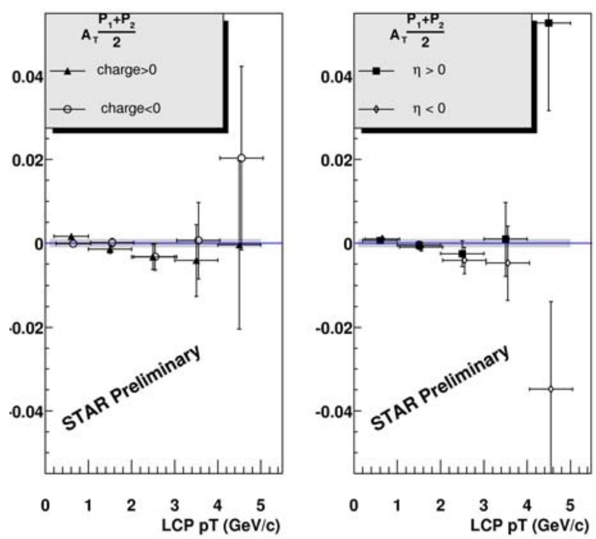

Figure 2. Preliminary results for single-spin transverse asymmetries (product of analyzing power and the average of the two beam polarizations) measured for mid-rapidity leading charged particles with the STAR TPC, plotted as a function of p_T for the choices of opposite charges (left) and opposite pseudo-rapidities (right). A total of 6.1 million events with a minimum of 3 primary tracks, collected with a minimum-bias trigger, were used in the analysis. Spin-dependent luminosity corrections, which can contribute to the extracted asymmetries only at second or higher order, have not been included. The average beam polarization $(P_1+P_2)/2 \approx 0.11$ for the runs included. The estimated systematic uncertainty in the measured asymmetries, of order 0.001, is indicated by the shaded bands.

The LCP analysis furthermore served as a setting for the development of an analysis framework to extract multiple one- and two-spin asymmetries simultaneously from the spin- and azimuthally-dependent yields measured in an azimuthally symmetric detector such as STAR. The measured azimuthal (ϕ) distributions of the yield for each of four beam spin combinations were fitted to a sum of linearly independent terms with no ϕ-dependence, with $\cos(\phi)$ dependence and with $\cos(2\phi)$ dependence, exhausting the physically allowed possibilities for real spin asymmetries. The relative values of the fitting coefficients for different spin combinations permitted extraction of all possible transverse spin asymmetries of physical significance for two transversely polarized spin-1/2 beams, as well as of a number of terms sensitive exclusively to potential instrumental asymmetries. The full set of extracted values were statistically consistent with zero, albeit with relatively large statistical uncertainties for the two-spin asymmetries, since the product of beam polarizations for the FY02 RHIC run was less than 0.03. Figure 2 shows preliminary results for the single-spin transverse analyzing power as a function of LCP p_T for several different subsamples of the full data set. This work has been reported at the SPIN2002 Conference [2] and is presently being prepared for publication.

With the FY03 RHIC polarized proton run, STAR's attention has turned in large part to jet production and longitudinal spin correlations A_{LL}. It is anticipated that the earliest information about the gluon contribution to the proton spin from RHIC collisions will arise from such two-spin longitudinal asymmetries for jet production, because it is an abundant process that can be usefully probed with the limited luminosity available at the current stage of the RHIC spin program. However, in contrast to the (much weaker) direct photon production channel envisioned for the eventual detailed mapping of the gluon helicity preference $\Delta G(x)$, jet production has substantial leading-order contributions from several partonic hard-scattering subprocesses, namely, quark-quark, quark-gluon and gluon-gluon scattering. Interpretation of A_{LL} measurements for inclusive jet or dijet production in terms of $\Delta G(x)$ will thus rely on an accurate understanding of the relative contributions from these different partonic subprocesses. Significant differences between the fragmentation functions for quark vs. gluon jets can lead to substantial sensitivity of these relative contributions to details of the jet triggering and reconstruction algorithms used in the experiment and analysis. In order to assess the interpretation uncertainties arising from such biases, Renee Fatemi has begun a set of detailed simulations of jet production based on the code PYTHIA and STAR detector response. These simulations will eventually be used to study predictions of spin observables as one changes the input fragmentation functions or parton distributions, as well as the jet triggering and reconstruction algorithms. Some initial results from the simulations are shown in Fig. 3.

In addition to the simulations, the IUCF group has contributed strongly to the hardware and software design of potential jet triggers. We have modified the design of firmware built into the front-end electronics for both barrel and endcap EMC's in order to minimize the effect of small correlated noise fluctuations among the many towers summed together in a "jet patch". We have influenced the design of STAR Level 0 trigger software to facilitate triggering on jets whose transverse energy is split among two of the hard-wired jet patches, in order to minimize significant geometry-dependent variations in efficiency and trigger bias. This added flexibility gives us the option of comparing biases for trigger algorithms that go beyond the three simplest possibilities described in the Fig. 3 caption, and eventually of comparing A_{LL} results for different triggering choices, in order to assess the level of trigger bias experimentally. The integrated luminosity available for pp collisions during the FY03 RHIC run was too small to permit measurements of statistical precision that would allow extraction of meaningful constraints on $\Delta G(x)$, but we hope to make far more significant asymmetry measurements for jet production in the FY05 RHIC run.

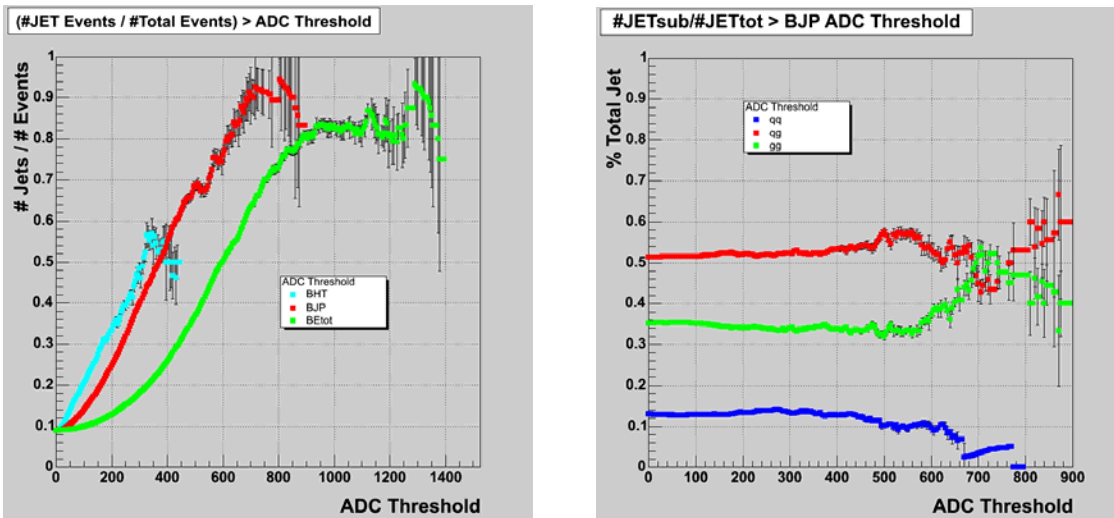

Figure 3. Simulations showing the jet triggering/reconstruction efficiency (left) and subprocess contributions (right) for several different choices of jet trigger types based on the one half of the STAR Barrel EMC (BEMC) that was available during the FY03 run. The simulated sample contains 0.35 million events generated by $2 \rightarrow 2$ parton hard scatterings with a partonic p_T of at least 5 GeV/c. The three types of jet trigger considered are: BHT = trigger requirement that at least one (out of 1200) BEMC tower transverse energy surpass the ADC threshold indicated on the x-axis; BJP = trigger requirement that the BEMC transverse energy summed over at least one of 6 hard-wired jet "patches" exceed the indicated threshold; BEtot = trigger requirement that the transverse energy summed over all BEMC jet patches exceed the indicated threshold. The calibration of the ADC in each case is about 12 MeV/channel (of transverse energy). The simulations are for one particular jet finder based on TPC tracks plus BEMC energy.

A major area of concentration in the analysis work carried out by the IUCF STAR group during FY03 was the cross-comparison of different methods for calibrating the 240 towers of EEMC readout instrumented for the May 2003 pp RHIC run. The high voltage settings for the 240 phototubes were originally set to achieve desired absolute energy calibrations tied to integrated charge measurements made with a 300 μCi ^{60}Co source scanned past the 12 towers in each of a number of 6° azimuthal subsectors of the EEMC. The data obtained in the pp collision run were then used to check the actually achieved energy calibrations in several distinct ways, each of which required development of significant amounts of analysis software: (1) relative gains for towers at the same pseudo-rapidity (η) but different azimuth were determined by comparing the inverse slopes of the spectra acquired for a tower when none of its nearest neighbors fired, under the assumption that the resulting spectra are dominated by minimum-ionizing particles (MIPs) confined within a single tower; (2) absolute gains could be obtained from the location of MIP peaks observed in spectra gated on the requirement of a TPC track projected to enter and exit the same EEMC tower; (3) a second absolute gain determination was made for towers near η=1 by comparing the recorded EEMC shower transverse energy to the TPC track transverse momentum (p_T > 1.5 GeV/c) for charged particles aimed toward a single tower and passing TPC dE/dx cuts emphasizing electrons; and (4) a third absolute gain calibration was deduced from the requirement of reconstructing the correct π^0 invariant mass from closely spaced EEMC tower energy clusters centered in non-adjacent towers. Jan Balewski, Renee Fatemi, Jason Webb and Piotr Zolnierczuk all played central roles in this analysis.

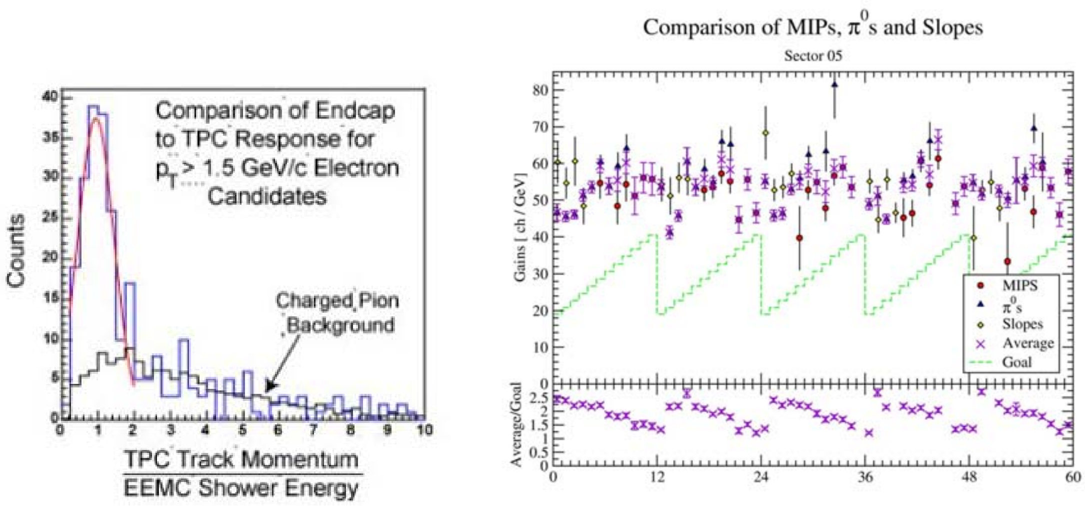

Figure 4. Some results of energy calibration analyses for the instrumented patch of EEMC used in STAR during the May 2003 pp collision run. The left-hand panel shows the p/E spectrum obtained for electron candidates tracked through the TPC to the EEMC, where the EEMC gain calibration has been adjusted to place the electron peak centroid at p/E = 1.0. The right panel compares the absolute gains in ADC channels/GeV of shower energy determined for one representative 30° sector (60 towers) of the EEMC, from several different approaches described in the text, to the (green) line representing the original goals. The slope of the goal gains reflects the desire to match spectra in transverse energy, rather than in full shower energy, to facilitate imposition of E_T thresholds at the hardware trigger level.

The bottom line of the calibration analyses is that all methods relying on collision data are in reasonable agreement with one another, within their respective uncertainties and the uncertainty in calorimeter sampling fraction. However, as can be seen in Fig. 4, the scheme used during the run for adjustment of high voltages did not succeed in achieving the transverse energy matching incorporated in the originally desired gains, but came closer to matching towers in full shower energy, and at a gain considerably higher than desired. We are currently determining the flaws in the 2003 procedures used, so that for subsequent runs we can, as desired, adjust the upper end of the ADC range for all towers to correspond to E_T = 60 GeV, well above the upper end of the energy range of daughter electrons and positrons from W decay. W decay is of great interest to the spin physics program, as it provides a clean way of studying the flavor-dependence of sea antiquark polarizations in a polarized proton.

In studying the sea antiquark polarizations, positrons and electrons from $W^{\pm}$ decay detected in the EEMC are of special interest, because in this region one gets the kinematically cleanest separation of effects from low-x antiquarks vs. higher-x (predominantly valence) quarks. Extraction of the flavor dependence of the antiquark polarization then relies on charge sign discrimination for the W's and their daughters. This becomes problematic part way through the EEMC region with STAR's present tracking capabilities, due to rapid deterioration in the TPC resolution obtainable beyond η=1. This has led us to propose a STAR upgrade to the forward tracking capabilities, which is now accepted as part of the STAR Decadal Plan. The forward tracking upgrade is also being closely integrated with plans to improve the inner tracking detectors, to enhance STAR's resolution of displaced vertices for particles with charmed or bottom quarks and to improve the overall rate capabilities of the detector. The IUCF group is collaborating with STAR groups from MIT, Yale and LBNL to develop the plans for such improved tracking. As part of that effort, we have initiated simulation studies regarding the improvements in charge sign discrimination achievable for W's in the endcap region, e.g., with inner silicon microstrip barrels and Gas Electron Multiplier chambers directly in front of the EEMC. Figure 5 shows some initial, encouraging results of relevant simulations. In addition, Steve Vigdor has been one of the leaders of the development of the entire STAR upgrade plan, and has also been considering the long-term benefits for other aspects of the spin program. For example, the proposed inner microvertex detectors should make it feasible to identify and analyze b-quark jets in studies of the effect of the (explicit chiral symmetry breaking) quark mass terms in the QCD Lagrangian on transverse spin asymmetries in hard scattering.

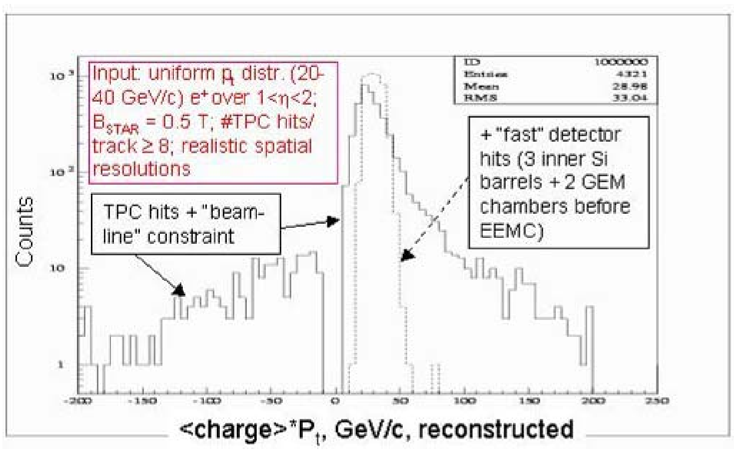

Figure 5. Results of preliminary tracking simulations (from N. Smirnov, Yale University) illustrating the dramatic improvement in resolution and charge sign determination anticipated from proposed upgrades to STAR forward tracking.

1. J. Adams *et al.,* LANL-Cornell preprint hep-ex/0310058.

2. J. Balewski *et al.,* in *SPIN 2002,* eds. Y.I. Makdisi, A.U. Luccio, and W.W. MacKay, AIP Conf. Proc. **675**, 418 (2003).