The sPHENIX Spin-Dependent Cold QCD Program

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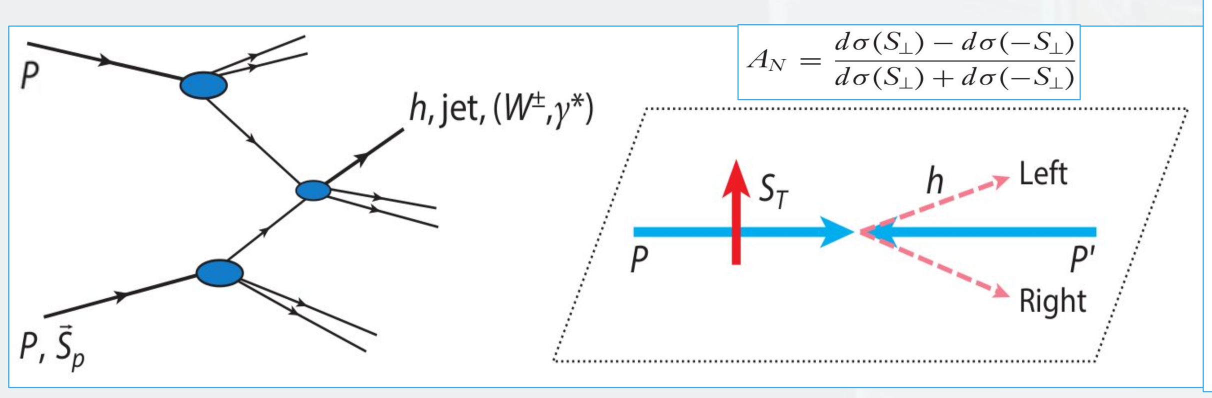
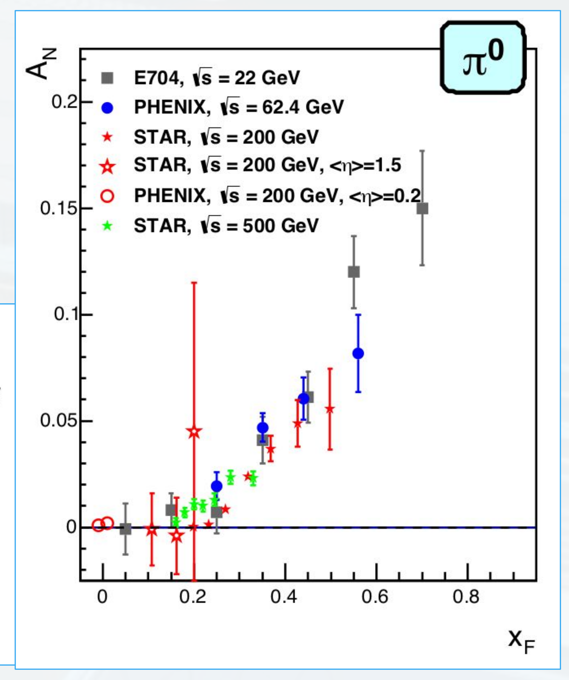
Overview

- sPHENIX is a new detector at BNL's Relativistic Heavy Ion Collider (RHIC).
- **sPHENIX will enable an array of cold QCD measurements in *p+p* collisions**, in addition to studies of the quark-gluon plasma in Au+Au collisions.
- The measurement of **transverse-spin-dependent asymmetries** in the production of photons, mesons, and jets will contribute to our understanding of the partonic and spin structure of the nucleon.
- Measuring these asymmetries particularly relies on the **sPHENIX calorimeter system**, designed for high-resolution measurements of photons, electrons, hadrons, and jets.
- This poster comments on the cold QCD opportunities at sPHENIX, and presents the status of commissioning the electromagnetic calorimeter after the first Au+Au beams have collided in sPHENIX.

Transverse-spin-dependent Asymmetries in Polarized *pp* Collisions

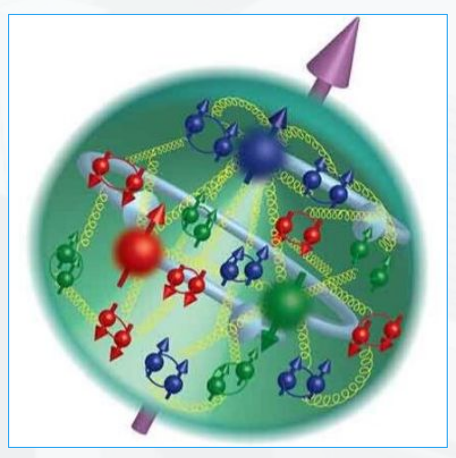
- Sizeable transverse-spin-dependent asymmetries (TSAs) observed in azimuthal distribution of final-state hadrons, jets and photons produced in transversely polarized $p^{\uparrow}p$ collisions
- Origin of TSAs still not well-understood
- Measuring left-right asymmetry A_N can shed light on partonic and spin structure of the nucleon





(Left, center) Definition of A_N in $p^{\uparrow}p \rightarrow h\,X$. (Right) A_N in π^0 production measured by several experiments at various center-of-mass energies.

TSAs as Probes of Nucleon Structure



TSAs can be interpreted in the framework of *QCD factorization*, in which cross-sections are decomposed into a hard scattering term and a non-perturbative portion.

The latter encodes nucleon structure and the hadronization process in terms of *parton distribution functions* (PDFs) and *fragmentation functions* (FFs), respectively.

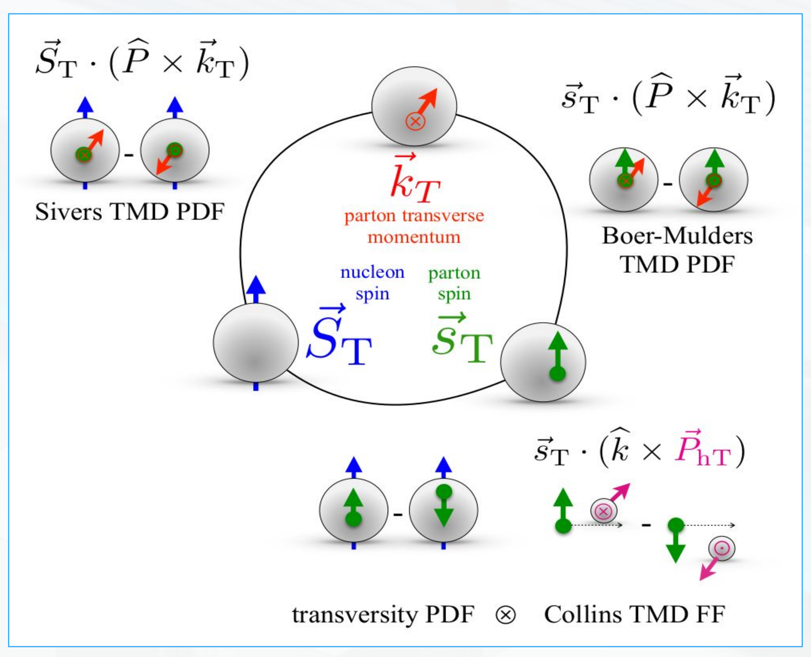
Two schemes exist for explaining the observed azimuthal asymmetries:

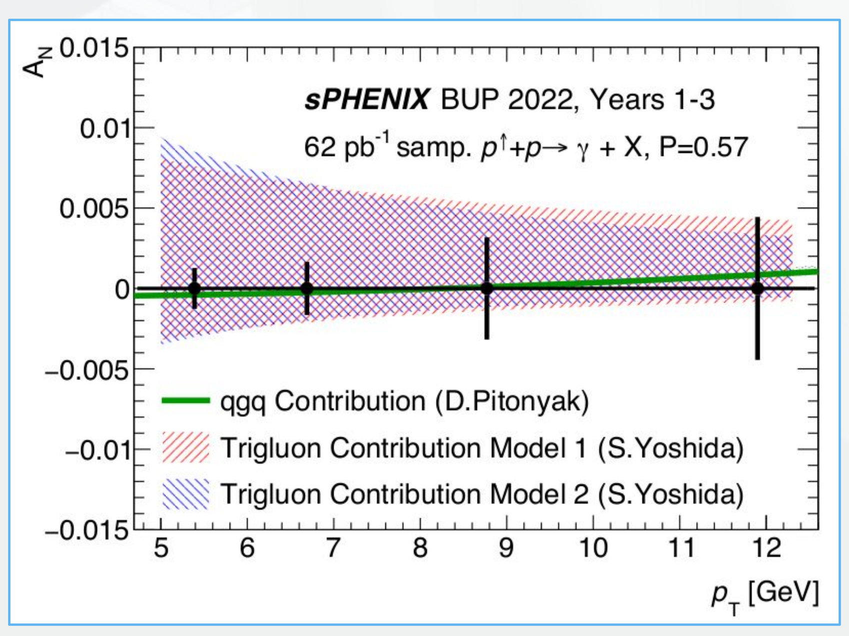
Transverse-momentum-dependent (TMD) Scheme

The collinear leading-twist model is extended to incorporate parton transverse momentum. Azimuthal modulations are generated by nonzero correlations between nucleon spin, parton spin and parton transverse momentum (right). This scheme requires two scales $Q_1 \ll Q_2$.

Example channels in $p^{\uparrow}p$ collisions:

- A_N in Drell-Yan process and angular correlations in back-to-back dijet production (Sivers TMD PDF)
- Azimuthal distribution of hadrons within a jet (transversity PDF x Collins TMD FF)





Projection plot for statistical uncertainties in A_N for direct photon production at sPHENIX.

Collinear Twist-3 Scheme

Azimuthal modulations are generated by quantum mechanical interference of multi-parton states, in particular nonzero quark-gluon-quark and tri-gluon correlations. Only one scale is observed in this scheme.

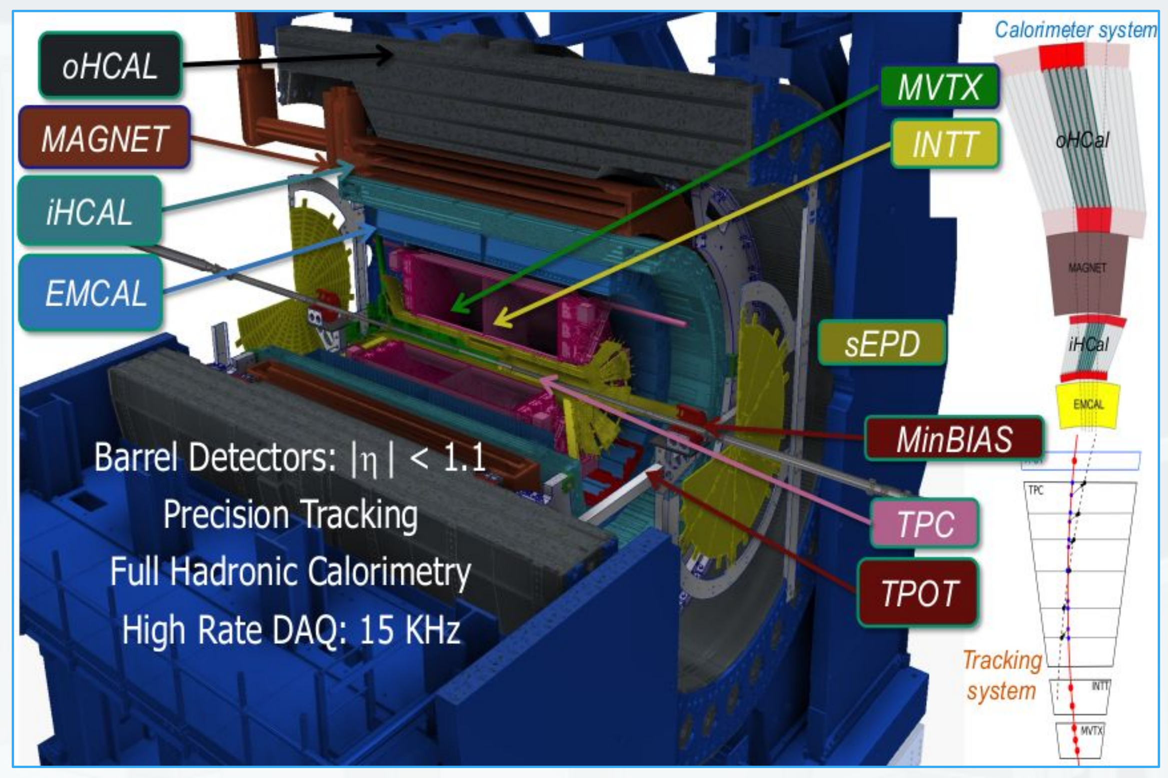
Example channels in $p^{\uparrow}p$ collisions:

- A_N in inclusive jet, direct photon (left), π^0, η, J/ψ, Υ and heavy-flavor meson production (Efremov-Teryaev-Qiu-Sterman [ETQS] function)
- Angular correlations of dihadrons (leading-twist interference fragmentation functions)

These two schemes are not unrelated. For example, at leading order the twist-3 ETQS function $F_{FT}(x,x)$ can be related to the TMD Sivers function $f_{1T}^{\perp}(x,k_T^2)$ by the integral relation

$$\pi F_{FT}(x,x) = \int d^2\vec{k}_T\, \frac{k_T^2}{2M^2} f_{1T}^{\perp}(x,k_T^2)$$

The sPHENIX Detector



The sPHENIX detector at RHIC comprises:

- Precision tracking detectors
  - MAPS-based vertex detector (MVTX)
  - Intermediate silicon strip tracker (INTT)
  - Time-projection chamber (TPC)
- Hadronic and electromagnetic calorimeters
- A 1.5T superconducting solenoid magnet

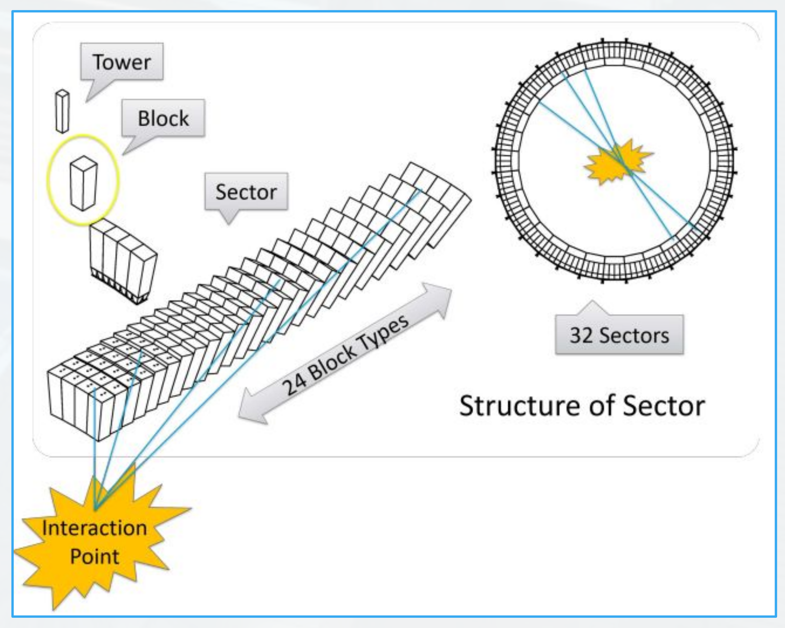
with all detectors covering pseudorapidity $|\eta| < 1.1$ and full azimuthal acceptance.

sPHENIX is scheduled to run 2023-2025, with transversely polarized *pp* collisions in 2024.

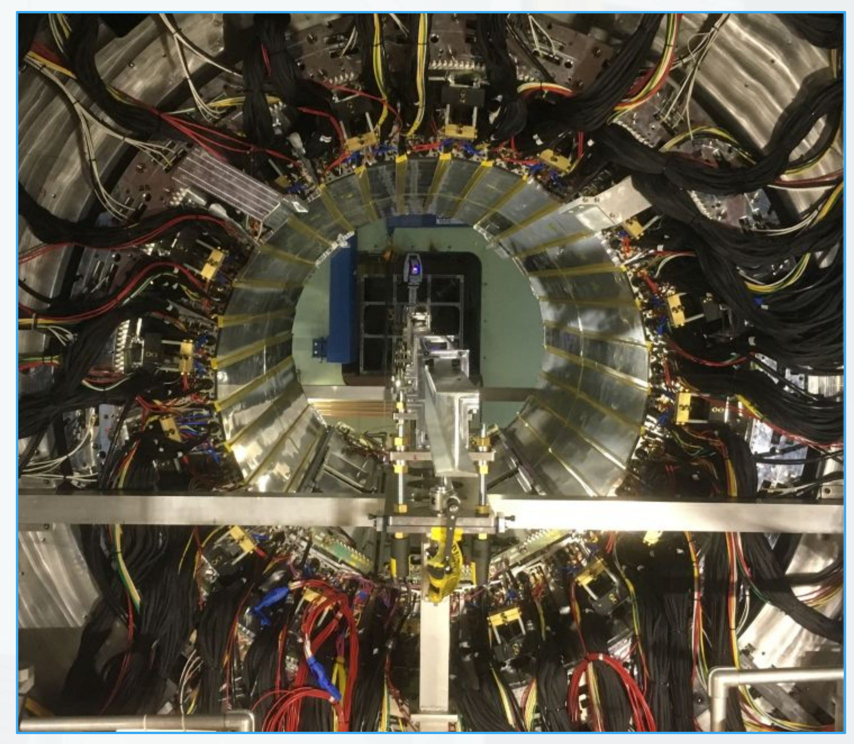
The sPHENIX Electromagnetic Calorimeter

The sPHENIX electromagnetic calorimeter (EMCal) is **designed to measure the energy of electrons, positrons and photons**. It is composed of 6,144 blocks of tungsten and scintillating fiber, arranged into a 2D-projective geometry (below, left). The energy resolution was measured as $\sigma(E)/\langle E\rangle = 3.5(0.1) \oplus 13.3(0.2)/E$ percent in a test beam campaign at Fermilab.

Incoming electrons or photons produce an electromagnetic shower of secondary photons and e^+e^- pairs. The light deposited in the scintillating fibers is read out by silicon photomultipliers (SiPMs), the signal from which is passed through analog-to-digital converters (ADCs) to obtain a measure of the energy contained in the shower.



Arrangement of blocks into sectors, with each block pointed toward the interaction point.

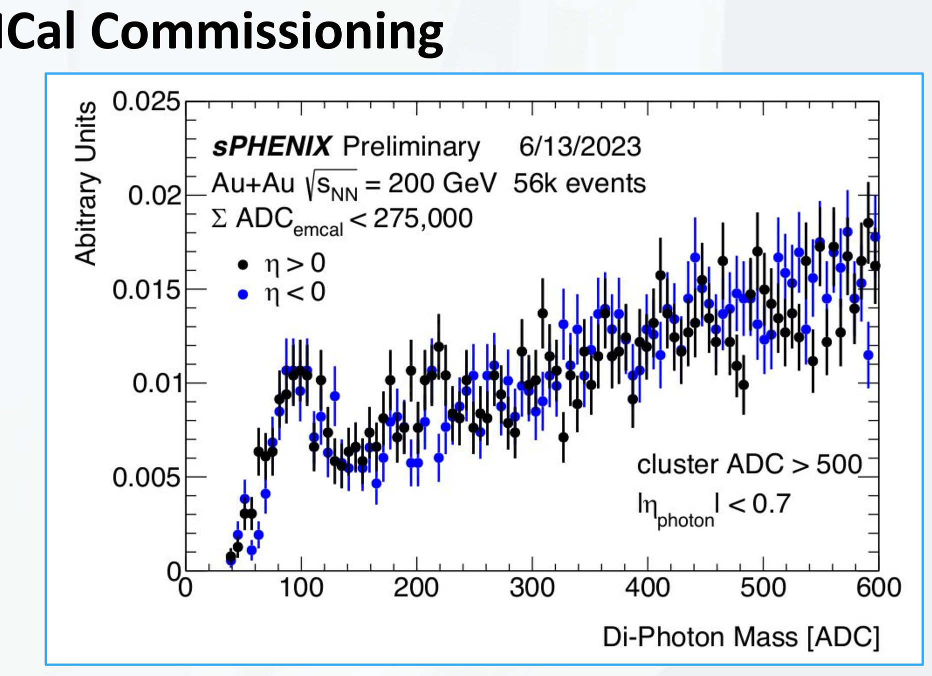


The EMCal exposed during construction of sPHENIX. Here readout and high-voltage cables are visible.

sPHENIX EMCal Commissioning

The 2023 RHIC run (April-August) served as the commissioning period for sPHENIX. Ongoing efforts to understand and calibrate the EMCal data include:

- Identifying and masking "hot" towers
- Identifying the π^0 and η resonances in the di-photon mass distribution (right)
- Determining the EMCal energy scale, i.e. the conversion factor from ADC value to units of energy
- Deriving a position-dependent correction factor to account for non-uniformity at block and sector boundaries



Diphoton mass distribution from 2023 AuAu collision data, in units of ADC value. The peak near 100 corresponds to the π^0.

Summary and Outlook

- The newly constructed sPHENIX experiment at RHIC **took first data in April 2023** and will run until 2025.
- sPHENIX will enable a range of **new and improved Cold QCD measurements** during the 2024 polarized *pp* RHIC run:
  - Transverse-momentum-dependent effects can be probed via the distribution of hadrons within a jet.
  - Related higher-twist collinear effects can be probed via A_N in inclusive jet, direct photon, and meson production.
- Such measurements will help further illuminate the spin structure of the nucleon.

References and Acknowledgements

1. E. Aschenauer et al. "The RHIC Cold QCD Plan for 2017 to 2023: A Portal to the EIC" 2016
2. J. Cammarota et al. "Origin of single transverse-spin asymmetries in high-energy collisions" 2020
3. M. Perdekamp, F. Yuan "Transverse Spin Structure of the Nucleon" 2015

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