Transverse Single-Spin Asymmetries at RHIC

Virgile Mahaut - CEA - Université Paris-Saclay

April 14, 2026

Outline

Transverse Single Spin Asymmetries

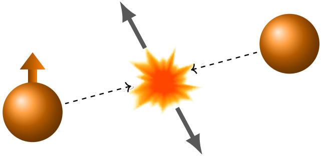
What spin-dependence in the $p^\uparrow p \to hX$ cross section?
(or any other product, photon, jet, onium ...)

Transverse Single Spin Asymmetries

What spin-dependence in the $p^{\uparrow}p \to hX$ cross section?
(or any other product, photon, jet, onium ...)
➜ **Azimuthal modulation** in inclusive hadron production: $d\sigma_h = d\sigma_0(1 - PA_N \sin\phi)$

Transverse Single Spin Asymmetries

What spin-dependence in the $p^{\uparrow}p \to hX$ cross section?
(or any other product, photon, jet, onium ...)
➜ **Azimuthal modulation** in inclusive hadron production: $d\sigma_h = d\sigma_0(1 - PA_N \sin\phi)$
➜ or equivalently **Left-Right asymmetry**: $\epsilon(\phi) = PA_N \sin\phi$



Standard

$$\epsilon(\phi) = \frac{N_L - N_R}{N_L + N_R}$$

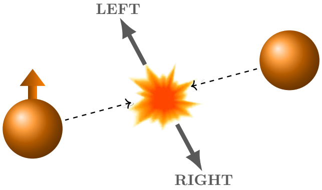
$$N_L, N_R = N(\phi), N(\phi + \pi)$$

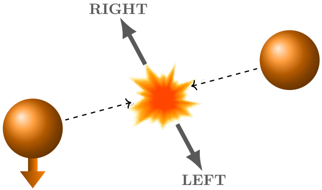
Transverse Single Spin Asymmetries

What spin-dependence in the $p^{\uparrow}p \to hX$ cross section?
(or any other product, photon, jet, onium ...)

➜ **Azimuthal modulation** in inclusive hadron production: $d\sigma_h = d\sigma_0(1 - PA_N \sin\phi)$

➜ or equivalently **Left-Right asymmetry**: $\epsilon(\phi) = PA_N \sin\phi$





Standard

$$\epsilon(\phi) = \frac{N_L - N_R}{N_L + N_R}$$

Relative Luminosity

$$\epsilon(\phi) = \frac{N_L^{\uparrow}/\mathcal{L}^{\uparrow} - N_L^{\downarrow}/\mathcal{L}^{\downarrow}}{N_L^{\uparrow}/\mathcal{L}^{\uparrow} + N_L^{\downarrow}/\mathcal{L}^{\downarrow}}$$

Geometric formula

$$\epsilon(\phi) = \frac{\sqrt{N_L^{\uparrow}N_R^{\downarrow}} - \sqrt{N_L^{\downarrow}N_R^{\uparrow}}}{\sqrt{N_L^{\uparrow}N_R^{\downarrow}} + \sqrt{N_L^{\downarrow}N_R^{\uparrow}}}$$

$N_L, N_R = N(\phi), N(\phi + \pi)$

pre-RHIC puzzle

➜ In collinear leading-twist framework, A_N heavily suppressed:

- $A_N \propto \alpha_S \frac{m_q}{E_{\mathrm{CM}}} \to 0$ (chirality conservation)

Kane, Pumplin, Repko, PRL 41 (1978), 1689

pre-RHIC puzzle

➜ In collinear leading-twist framework, A_N heavily suppressed:

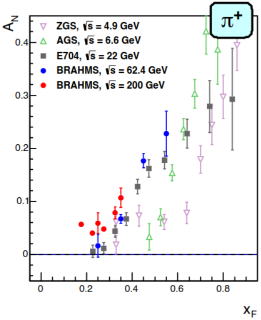
- $A_N \propto \alpha_S \frac{m_q}{E_{\rm CM}} \to 0$ (chirality conservation)

Kane, Pumplin, Repko, PRL 41 (1978), 1689

➜ In sharp contrast,
large experimental asymmetries are measured

- **Mid-1970s:** Large pion A_N (ZGS 76)
- **1980s-2000s:** Large A_N at higher energies (FNAL, AGS)
- **2000s-:** A_N at collider energies 50-500 GeV (RHIC)

$x_F = 2p_L/\sqrt{s}$



EPJA 52:156 (Aschenauer, D'Alesio, Murgia)
PRL 36 (1976) 929 (ZGS)
PLB 264 (1991) 462 (E704)
PLB 459 (1999) 412 (AGS)

pre-RHIC puzzle

➜ In collinear leading-twist framework, A_N heavily suppressed:

- $A_N \propto \alpha_S \frac{m_q}{E_{\mathrm{CM}}} \to 0$ (chirality conservation)

Kane, Pumplin, Repko, PRL 41 (1978), 1689

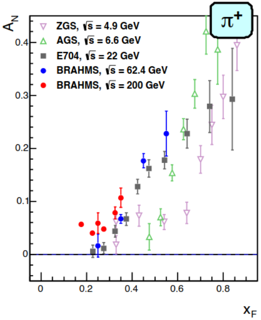
➜ In sharp contrast,
large experimental asymmetries are measured

- **Mid-1970s:** Large pion A_N (ZGS 76)
- **1980s-2000s:** Large A_N at higher energies (FNAL, AGS)
- **2000s-:** A_N at collider energies 50-500 GeV (RHIC)

➜ Beyond the collinear leading-twist picture

- Higher-Twist multi-parton correlations (Collinear Twist-3)
- Intrinsic parton's k_{T} (Transverse Momentum Dependent)

$x_F = 2p_L/\sqrt{s}$



EPJA 52:156 (Aschenauer, D'Alesio, Murgia)
PRL 36 (1976) 929 (ZGS)
PLB 264 (1991) 462 (E704)
PLB 459 (1999) 412 (AGS)

Collinear-Twist 3 (CT3) correlations

Multi-parton correlations in Collinear Twist-3 factorization

Qiu, Sterman PRD 59.014004 (1998)

Initial-/Final-state collinear correlators: A, B, C

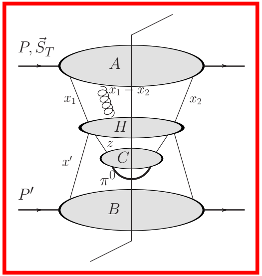
H: Hard perturbative part

$$d\sigma(\vec{S}_T) \propto \underbrace{\sum_{a,b,c} \phi^{(3)}_{a/A}(x_1, x_2, \vec{s}_T) \otimes \phi_{b/B}(x') \otimes \hat{\sigma} \otimes D_{c\to\pi}(z)}_{\text{"Sivers-like"}}$$

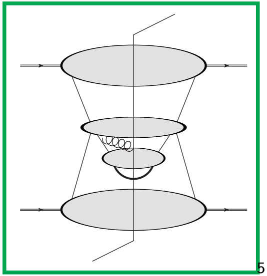
$$+ \underbrace{\sum_{a,b,c} h_{a/A}(x, \vec{s}_T) \otimes \phi^{(3)}_{b/B}(x'_1, x'_2) \otimes \hat{\sigma}'' \otimes D_{c\to\pi}(z)}_{\text{"Boer-Mulders"-like (small)}}$$

$$+ \underbrace{\sum_{a,b,c} h_{a/A}(x, \vec{s}_T) \otimes \phi_{b/B}(x') \otimes \hat{\sigma}' \otimes D^{(3)}_{c\to\pi}(z_1, z_2)}_{\text{"Collins"-like}}$$

Twist-3 correlator in polarized p



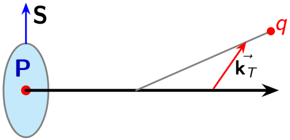
Twist-3 correlator in final state



Transverse-Momentum-Dependent (TMD) Factorization

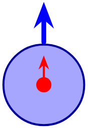
➜At least two mechanisms involved

➜**Sivers Mechanism** (Initial State)

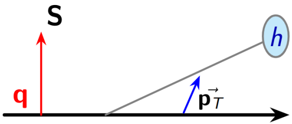


Proton spin and quark $\vec{k}_{\mathrm{T}}$ correlation

➜**Collins Mechanism** with transversity (Final State)



$\otimes$



Proton spin and quark spin correlation

Hadron $\vec{p}_{\mathrm{T}}$ and quark spin correlation

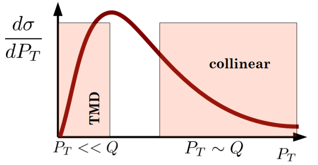
TMD $\Longleftrightarrow$ CT3 framework

- Non-perturbative effects involved:
  - Interference with CT3 correlators (qgq,ggg)
    $P_{\mathrm{T}} \sim Q > \Lambda_{\mathrm{QCD}}$
  - TMD effects (Sivers and Collins)
    $Q \gg P_{\mathrm{T}} > \Lambda_{\mathrm{QCD}}$

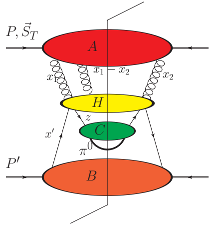
- Intermediate p_{T}: frameworks overlap
  e.g Quark Sivers TMD & twist-3 ETQS function

$$-\int d^2\boldsymbol{k}_\perp \frac{\boldsymbol{k}_\perp{}^2}{M} \underbrace{f_{1T}^{\perp,q}(x,\boldsymbol{k}_\perp{}^2)|_{\mathrm{SIDIS}}}_{\text{Sivers TMD PDF}} = \underbrace{T_{q,F}(x,x)}_{\text{twist-3 ETQS function}}$$

- Higher energy at RHIC:
  - Expand (x_F, p_T) reach (and overlap region)
  - Primary probe of gluon mechanisms

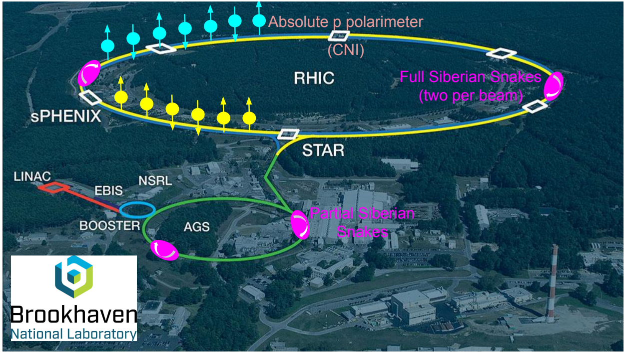


Ji, Qiu, Vogelsang, Yuan
PRL 97, 082002 (2006)



Twist-3 ggg correlator
$\leftrightarrow$ gluon Sivers TMD
C-odd/C-even
less known
more details (R. Boussarie)

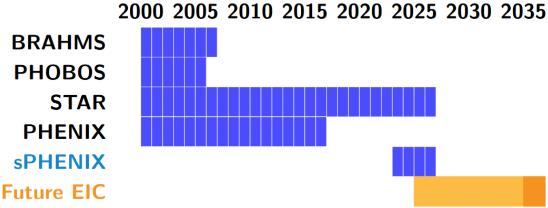
Relativistic Heavy Ion Collider



RHIC (First collisions in 2000)

- First and only polarized proton collider
- Example for physics $p^{\uparrow}p^{\uparrow}$ run 2024:
  - $E_{\mathrm{CM}} = 200\,\mathrm{GeV}$
  - $2.1 \cdot 10^{11} p/\mathrm{bunch}$ (2×111)
  - Average Polarization 55%/58%

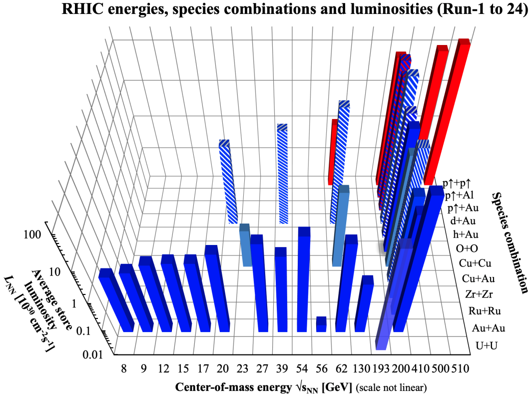
- RHIC
  (June 12, 2000 → February 6, 2026)
- Conversion to EIC

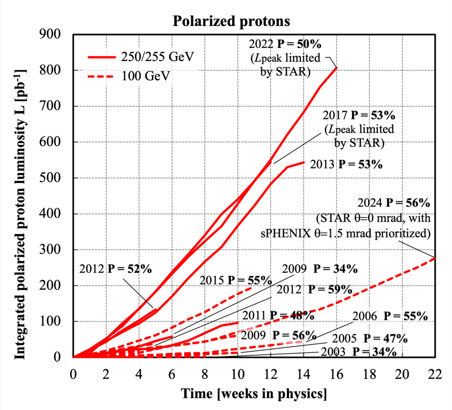


$p^{\uparrow}p^{\uparrow}$ collisions at RHIC

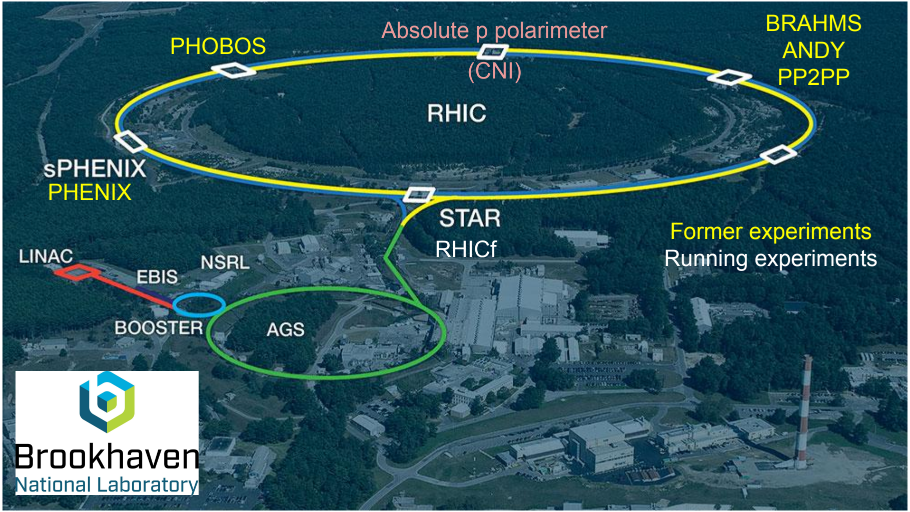
➜Large versatility:

- 10 types of accelerated nuclei
- $p^{\uparrow}p^{\uparrow}$ collisions at 62, 200, 500 and 510 GeV



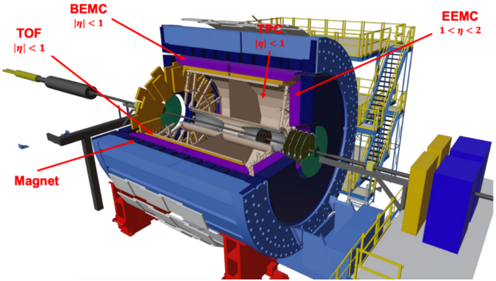


Experiments at RHIC

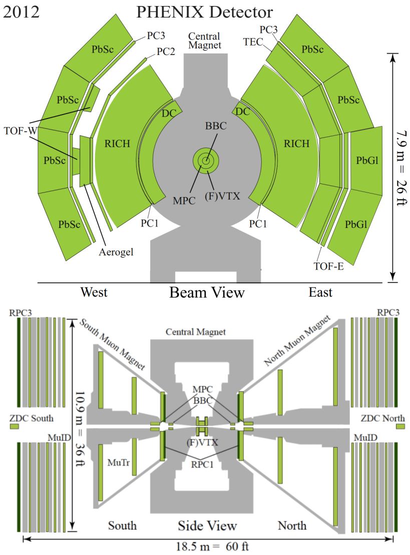


STAR

- ElectroMagnetic Calorimeter (EMCal) (full ϕ)
    - Central BEMC: $|\boldsymbol{\eta}| < \mathbf{1}$
    - Forward EEMC: $\mathbf{1.08} < \boldsymbol{\eta} < \mathbf{2.0}$
    - Angular Resolution $\sim 50 \times 50\,\mathrm{mrad}$
- TimeOf Flight (TOF) (**full** $\boldsymbol{\phi}$, $|\boldsymbol{\eta}| < \mathbf{1}$)
    - Improves track Particle Identification (PID)
- TimeProjectionChamber (TPC) (**full** $\boldsymbol{\phi}$, $|\boldsymbol{\eta}| < \mathbf{1}$)
    - Main detector for tracking and PID



- High precision studies of photons/leptons
- Central arms ($|\eta| < \mathbf{0.35}$, **Half-azimuth**)
- Fine-granularity EMCal
  - Radius of 5m
  - Half azimuthal coverage ($\pi/2$ on each side)
  - Spatial resolution $11 \times 11\,(8 \times 8)\,\mathrm{mrad}$ PbSc (PbGl)
- Dedicated muon arms (**full** ϕ, $\mathbf{1.4} < |\eta| < \mathbf{2.4}$)
  - Charged track momentum, muon identification
  - Clean separation: J/Ψ from Ψ', $\Upsilon(1S)$ from $\Upsilon(2S, 3S)$



sPHENIX experiment

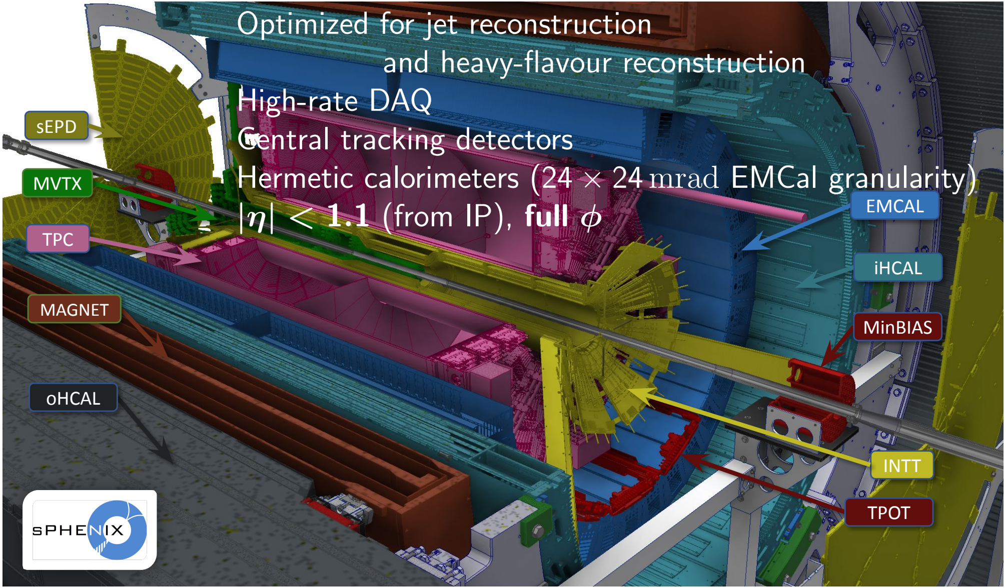
Optimized for jet reconstruction
and heavy-flavour reconstruction

High-rate DAQ

Central tracking detectors

Hermetic calorimeters ($24 \times 24\,\mathrm{mrad}$ EMCal granularity)

$|\eta| < \mathbf{1.1}$ (from IP), **full** $\boldsymbol{\phi}$



Single Spin Asymmetries

1. → Neutral Meson A_N

2. → Direct Photon A_N

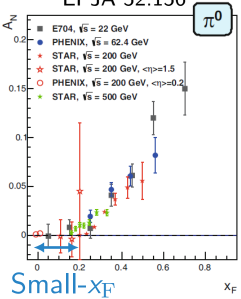
3. → Quarkonia A_N

4. → Hadron-in-jet A_N

5. → Di-hadron A_N

Neutral Meson A_N: $p^{\uparrow}p \rightarrow \pi^0 X$ (My Thesis)

EPJA 52:156



➜Early-measured asymmetries at large x_F.
Small x_F less explored (gluon-dominated)

➜RHIC with PHENIX, STAR shows A_N mostly independent of energy

➜Complex phenomenological description:

- Quark- and Gluon- initiated subprocesses
- Initial-State Effects (Sivers TMD PDF, CT3)
- Final-State Effects (Collins TMD function, CT3)

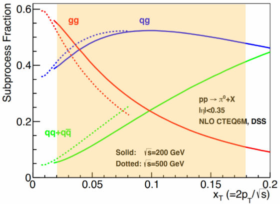
arXiv 1501.01220

Aschenauer et al

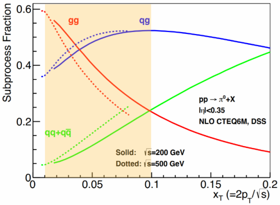
$\pi^0 \rightarrow$ mix of partonic processes

- Low p_{T} : $qg \approx gg > qq$
- Mid-p_{T}: $qg > gg \approx qq$

PHENIX $\neq$ sPHENIX
Upper p_T limit from cluster merging
$(\theta_{\gamma\gamma,\min} = 2m_\pi/E_\pi)$



PHENIX range ($|\eta| < 0.35$)
Run $p^{\uparrow}p$ 2015 (200 GeV)



sPHENIX range ($|\eta| < 1.5$)
Run $p^{\uparrow}p$ 2024 (200 GeV)

Neutral Meson A_N: $p^{\uparrow}p \to \pi^0 X$ (My Thesis)

➜First small-x_F $p^{\uparrow}p \to \pi^0 X$ asymmetry A_N at sPHENIX

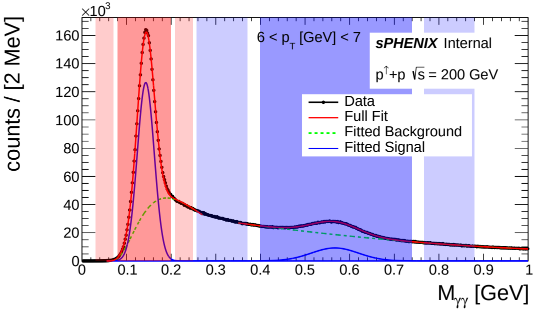
- Minimum Bias Detector (collisions)
- EMCal: $\Delta E/E = 3.5\% \oplus 13.3\%/\sqrt{E}$

$$A_N(\phi) = \frac{1}{P}\frac{N^{\uparrow}(\phi)/\mathcal{L}^{\uparrow} - N^{\downarrow}(\phi)/\mathcal{L}^{\downarrow}}{N^{\uparrow}(\phi)/\mathcal{L}^{\uparrow} + N^{\downarrow}(\phi)/\mathcal{L}^{\downarrow}} \text{ (Rel. Lumi)}$$

(Geometric)

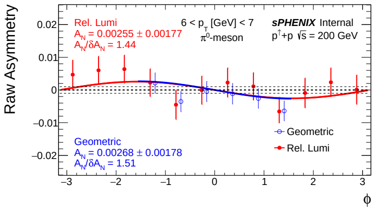
$$A_N(\phi) = \frac{1}{P}\frac{\sqrt{N^{\uparrow}(\phi)N^{\downarrow}(\phi+\pi)} - \sqrt{N^{\downarrow}(\phi)N^{\uparrow}(\phi+\pi)}}{\sqrt{N^{\uparrow}(\phi)N^{\downarrow}(\phi+\pi)} + \sqrt{N^{\downarrow}(\phi)N^{\uparrow}(\phi+\pi)}}$$

$\phi \in [-\pi/2, \pi/2]$ (**full azimuth**)



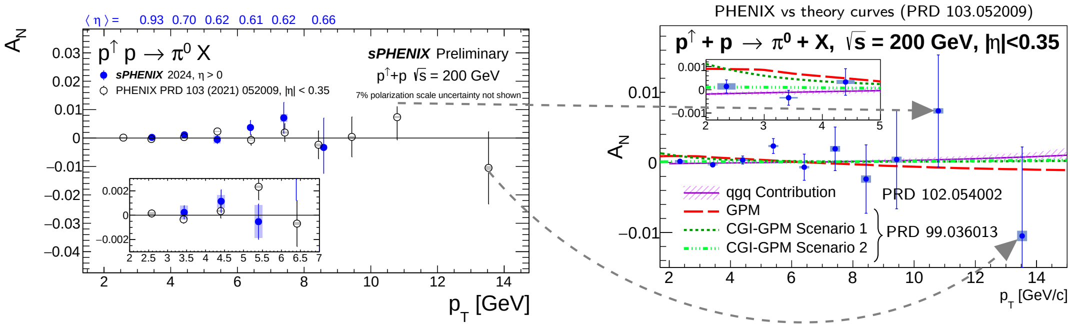
$$A_N^{\mathrm{total}} = (1-r)\ A_N + r\ A_N^{\mathrm{bk}}$$

Fit performed for bins in p_T, η and x_F



Neutral Meson A_N: $p^{\uparrow}p \rightarrow \pi^0 X$ (My Thesis)

Preliminary results on π^0 A_N (sPHENIX March 2025) alongside PHENIX results 2021



- ≠ acceptance: $|\eta| < 0.35, \phi \in [0, \pi]$ (PHENIX), $0 < \eta < 1.5, \phi \in [0, 2\pi]$ (sPHENIX)
- Compared with theory predictions:
  Color-Gauge Invariant Generalized Parton Model (PRD 99 (2019) 036013 U. D'Alesio et al)
  twist-3 *qgq* correlator (PRD 102 (2020) 054002 JAM, J. Cammarota et al.)

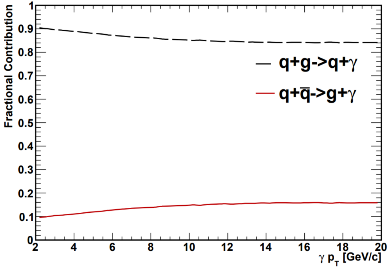
Direct Photon A_N: $p^{\uparrow}p \rightarrow \gamma X$

➜Direct Photon Production:

- Compton scattering: $d\hat{\sigma}$: $qg \rightarrow q\gamma$ (90% at mid-η)
- Annihilation: $d\hat{\sigma}$: $q\bar{q} \rightarrow g\gamma$ (10% at mid-η)

➜Cleaner probe:

- Mostly sensitive to initial-state effects (no fragmentation)
- Good power to constrain gluon-gluon correlations



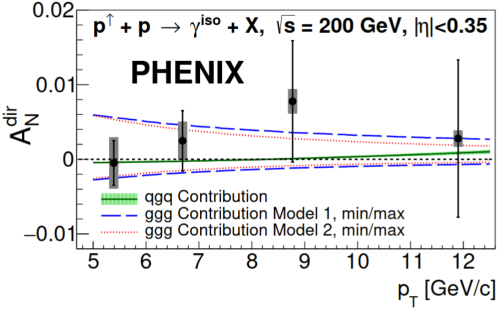
PHENIX, PRD 82 (2010) 072001

Suppression of non-prompt photons (fragmentation, decay) through isolation cuts and shape variables
$\rightarrow$ experimentally challenging

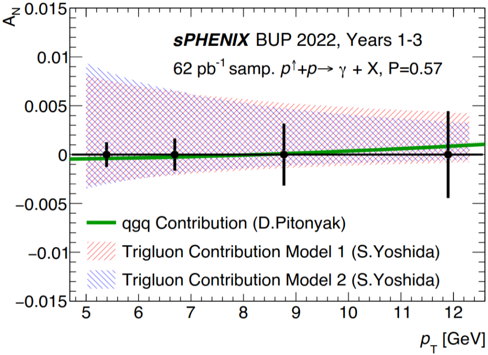
Direct Photon A_N: $p^\uparrow p \to \gamma X$

First Direct Photon A_N extracted at RHIC by the PHENIX Collaboration

PHENIX, PRL 127 (2021) 162001



sPHENIX BUP (Simulations)



➜Ongoing work from sPHENIX towards Direct-γ A_N with more statistics
Already results for the prompt-γ cross section (J. Hwang, Spin 2025)

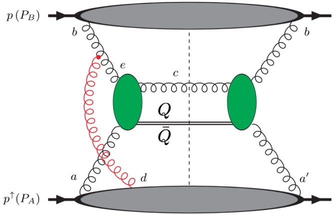
Quarkonia A_N, J/Ψ: $p^{\uparrow}p \to J/\Psi X$

➜ J/Ψ **production** (only quarkonia A_N measured at RHIC)

- Dominated by gluon fusion: $g + g \to \mathcal{Q}\bar{\mathcal{Q}}[^3S_1^{(1)}] + g \qquad \mathcal{Q} = c, b$
- Almost no quark-initiated process
- Cleaner probe to C-even gluon Sivers TMD (and ggg correlator)
- Almost no Collins effect. Described in the framework of the Color Singlet Model (CSM)

➜ Challenges specific to the J/Ψ

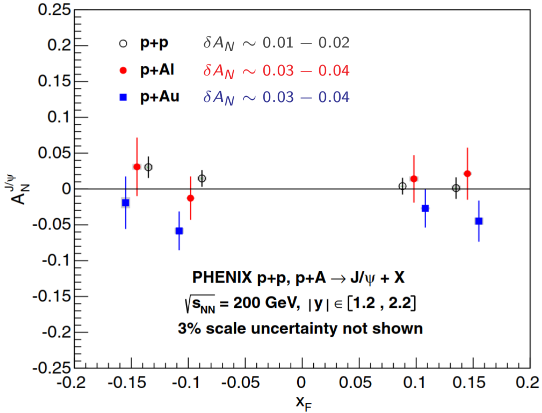
- Contributions from the color octet channel don't yield A_N
- Feed-down from $\chi_c, \Psi', B \sim 40\%$ (PHENIX, PRD 85 (2012) 092004)
  (All strong decays included in Distribution/Fragmentation Functions)



(PRD 96 (2017) 036011)
U. D'Alesio, F. Murgia, C. Pisano, P. Taels

Quarkonia A_N, J/Ψ: $p^\uparrow p \to J/\Psi X$

PHENIX PRD 98 (2018) 012006



➜**2015** $p^\uparrow + p$, $p^\uparrow + \mathrm{Al}$, $p^\uparrow + \mathrm{Au}$: $p^\uparrow + \mathrm{Al}$ **consistent with zero slight negative** $p^\uparrow + \mathrm{Au}$ A_N**, positive backward** $p^\uparrow + p$ **(2σ)**

Quarkonia A_N, J/Ψ: $p^{\uparrow}p \to J/\Psi X$

J/ψ transverse single spin asymmetries A_N (PHENIX)

- Measured with **large yields** in $p^{\uparrow}$+p and $p^{\uparrow}$+A at $\sqrt{s_{NN}} = 200$ GeV.
- Forward / backward rapidity ($1.2 < |y| < 2.2$), $A_N(x_F, p_T)$:
  - $p^{\uparrow}$+Al: A_N consistent with 0
  - $p^{\uparrow}$+p: hint of small positive A_N (2σ)
  - $p^{\uparrow}$+Au: hint of small negative A_N (2σ)
- Sensitive to C-even gluon Sivers function / tri-gluon correlators

Other quarkonia: Cleaner, color-singlet dominated, isolated gluon-spin effects

- χ_c, η_c: C-even quarkonia
  (Reduced usable yields, separation $\chi_{c,1}/\chi_{c,2} \to 45$ MeV difference)
- Υ: Smaller color octet contribution
  (PRL 112 (2014) 212001 W.J. den Dunnen, J.-P. Lansberg, C. Pisano, M. Schlegel)

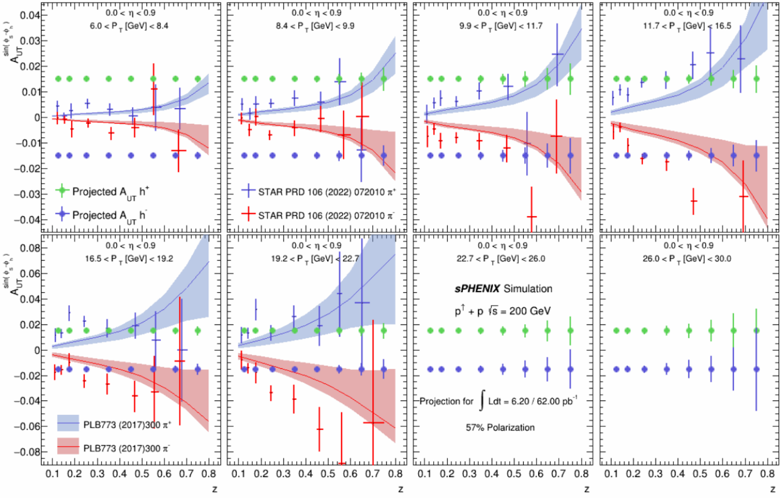
Hadron in jets

$p^{\uparrow}p \to (\text{jet h})\ X$

Access to Collins Fragmentation Function and **transversity PDF**

Ongoing analysis (preliminary)

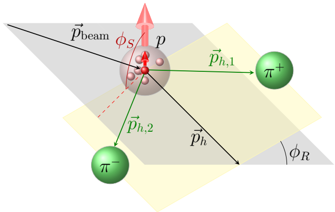
Statistical projection for sPHENIX



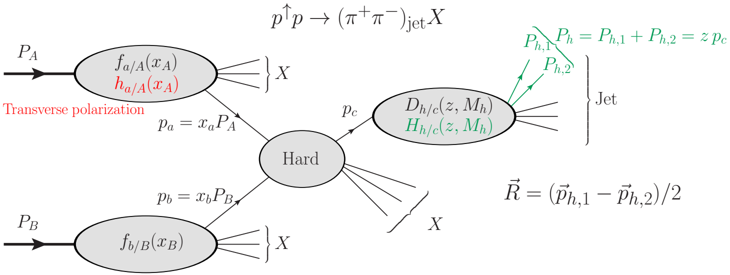
RHIC Cold QCD Plan 2024-2028

Di-hadron TSSA $p^{\uparrow}p \to (\pi^+\pi^-)_{\rm jet}X$

➜Access to chiral-odd **transversity PDF** h and chiral-odd Interference Fragmentation Function (IFF) $H_q^{\sphericalangle}$ in **leading-twist collinear factorization** (PRD 70 (2004) 094032, A. Bacchetta, M. Radici)

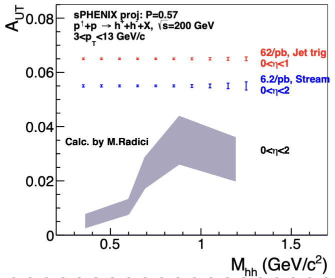


$$\frac{d\sigma_{UT}^{\sin(\phi_R-\phi_S)}}{d\sigma_{UU}} \sim \sum_{a,b,c}\int \frac{dx_a dx_b}{16\pi z}\, h_{a/A}(x_a)\, f_{b/B}(x_b)\, \frac{d\Delta\hat{\sigma}_{a^\uparrow b\to c^\uparrow}}{d\hat{t}}\, \frac{|\boldsymbol{R}|}{M_h}\, H^{\sphericalangle}_{h/c}(z, M_h)$$



$$\vec{R} = (\vec{p}_{h,1} - \vec{p}_{h,2})/2$$

Statistical projection for sPHENIX



RHIC Cold QCD Plan 2024-2028

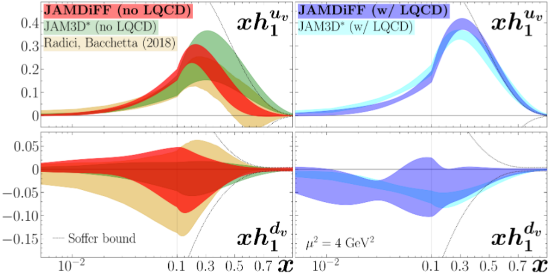
TSSA and transversity PDF and Di-hadron FF (DiFF)

➜Transversity extracted using both:

- single-hadron observables (TMD & twist-3)
- di-hadron observables

➜Some recent examples of DiFF fits

- PRL 120 (2018) 192001
  (global fit $p^{\uparrow}p$, SIDIS)
  M. Radici, A. Bacchetta
- JAM: PRD 109 (2024) 3, 034024
  (global fit $p^{\uparrow}p$, $e^{+}e^{-}$, SIDIS)
  C. Cocuzza, A. Metz, D. Pitonyak, A. Prokudin, N. Sato, R. Seidl
- MAP: JHEP 02 (2026) 051
  (Unpolarized DiFFs at NNLO with and without NN, $e^{+}e^{-}$ data)
  V.M., L. Polano, A. Bacchetta, V. Bertone, M. Cerutti, M. Radici, L. Rossi



arXiv 2306.12998 (JAM) 2024
JAM3D: TMD and collinear twist-3
JAMDiFF, R. B. (2018): DiFF framework

Main ideas

➔ Large Transverse Single Spin Asymmetries A_N at large x_F:
Strong NP effects beyond collinear leading-twist and pQCD

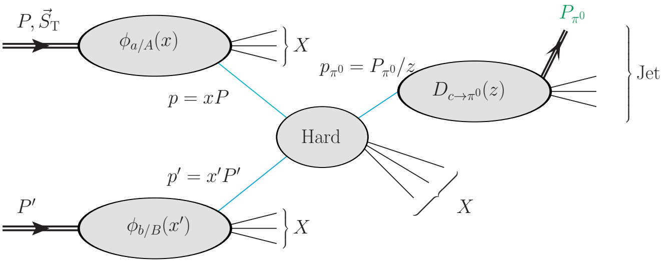
➔ **RHIC:** First opportunity to measure A_N at collider energies (50 - 500 GeV)

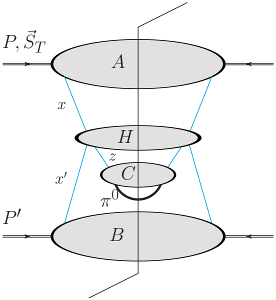
- Neutral Meson A_N: Historic probe for large A_N
  - Currently new statistics in underexplored kinematic domain (mid-y, low x_F, high E)
  - Progress in the phenomenological expression
- Direct-γ A_N:
  - Most recent, isolation/ shower-shape cuts make it challenging
  - Clean probe to initial-state Sivers Gluon TMD/Twist-3
- Quarkonia A_N
  - J/Ψ results: gg fusion dominated but CO contamination and χ_c feed-down
  - Possibly more statistics and resolution on J/Ψ, Υ with sPHENIX
- Other channels: open charm D^0, hadron-in-jet, di-hadrons

Backup

Factorization beyond leading twist

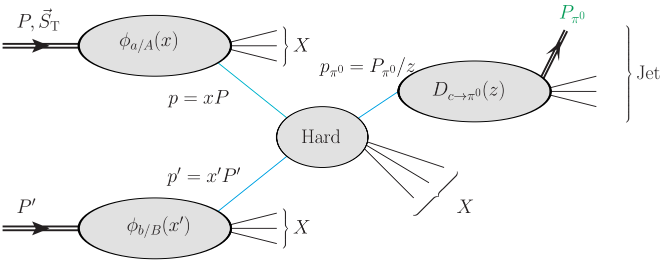
➜At leading-twist: $d\sigma = \sum_{a,b,c} \phi_{a/A}(x) \otimes \phi_{b/B}(x') \otimes d\hat{\sigma}_{ab\to c} \otimes D_{c\to\pi^0}(z)$

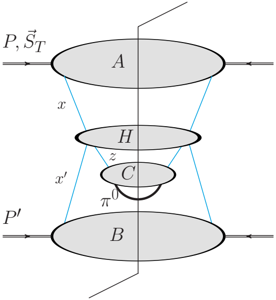




Factorization beyond leading twist

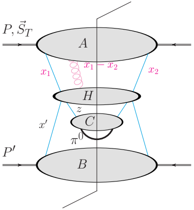
➜At leading-twist: $d\sigma = \sum_{a,b,c} \phi_{a/A}(x) \otimes \phi_{b/B}(x') \otimes d\hat{\sigma}_{ab\to c} \otimes D_{c\to\pi^0}(z)$

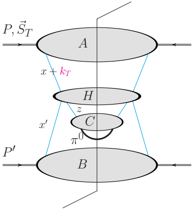




➜Beyond leading-twist:

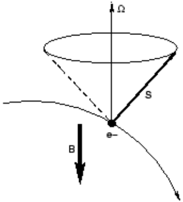
$$d\sigma = \sum_{a,b,c} \phi^{(3)}_{a/A}(x_1, x_2) \otimes \phi_{b/B}(x') \otimes d\hat{\sigma}_{ab\to c} \otimes D_{c\to\pi^0}(z) + \cdots$$
$$d\sigma = \sum_{a,b,c} \phi_{a/A}(x, k_T) \otimes \phi_{b/B}(x') \otimes d\hat{\sigma}_{ab\to c} \otimes D_{c\to\pi^0}(z) + \cdots$$



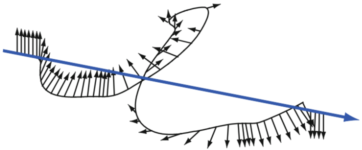


Polarized protons at RHIC

1. **Polarization at the source (OPPIS)**
    - Pass unpolarized proton through polarized Rb vapor
    - Electron polarization transferred to the proton
    - Eventual proton polarization at the exit of OPPIS $\sim$ 80-85%



2. **Depolarization in synchrotrons and Siberian snakes**
    - Spin precesses $\approx$ 200 times ($G\gamma = 1.79x107$ at 100 GeV) about vertical guide field B_y in one turn
    - Spin precesses about horizontal fields (e.g focusing magnets)
    - Resonance between precessions $\rightarrow$ strong depolarization
    - Solution: Partial (AGS) and **full siberian snakes** (RHIC)
    - Vertical spin is unchanged, horizontal spin components flip sign each turn $\rightarrow$ horizontal kicks cancel



Siberian snake (spin flip)
Derbenev et al, Part. Accel., 8, 115 (1978)

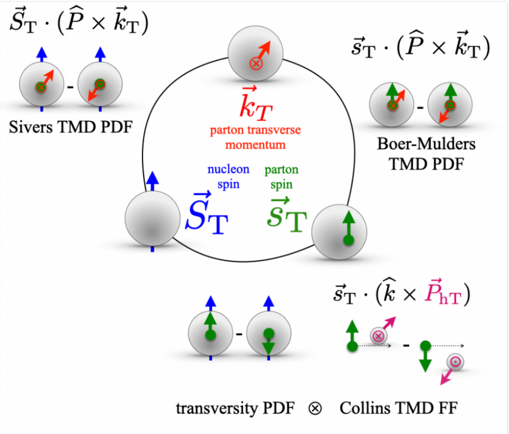
Backup - Transverse-Momentum Dependent (TMD) framework

TMD factorization

Sivers effect: Parton Distribution Functions (PDF) correlating the ingoing proton transverse spin and the parton transverse momentum (initial-state effect)

Collins effect: Chiral-odd Fragmentation Functions (FF) correlating the transverse spin of fragmenting parton and the outgoing hadrons' transverse momentum (final-state effect)

Boer-Mulders effect: Chiral-odd Parton Distribution Functions (PDF) correlating the parton's transverse momentum and the parton transverse polarization $\vec{s}_T$ (initial-state effect)



Quarkonia, χ_c

➜**PHENIX $\chi_c \to J/\psi\,\gamma$ measurement (p+p, 200 GeV)** (PRD 85 (2012) 092004)

- Reconstruct $\chi_c \to J/\psi\,\gamma \to e^+e^-\,\gamma$ in the central arms.
- Measured feed-down fraction: $F^{\chi_c}_{J/\psi} = 32 \pm 9\%$
- Implies (no detector effects): $\sigma_{\chi_c \to J/\psi\,\gamma} \approx F^{\chi_c}_{J/\psi}\,\sigma_{J/\psi} \sim 1.2\ \mu$b.

➜$\chi_{c1,2}$ at PHENIX in practice:

- Conditional acceptance and efficiency of the $\chi_{c1,2}$ decay:

$$\frac{N_{\chi_c}}{N_{J/\psi}} = F^{\chi_c}_{J/\psi}\,\underbrace{\frac{\mathrm{Acc.}\epsilon(\chi_c \to J/\psi\gamma \to \ell\ell\gamma)}{\mathrm{Acc.}\epsilon(J/\psi \to \ell\ell)}}_{\text{conditional acc.} \times \text{eff.}}$$

- PHENIX: conditional acc. $\times$ eff. ~ 0.1 at low p_{T} and 0.3 at high p_{T}
  low $E_\gamma \sim$ EMCal sensitivity, small S/N, strong cuts (isolation, identification)
- $N_{\chi_c}/N_{J/\psi} \approx \mathcal{O}(3-10\%)$

Quarkonia A_N: Prospects at sPHENIX

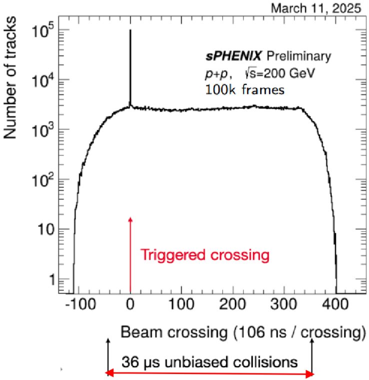
sPHENIX provides:

- Much larger midrapidity coverage:

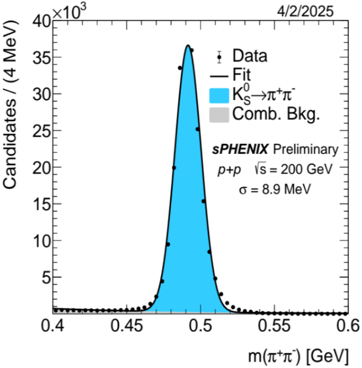
$$\text{PHENIX: } |\eta| < 0.35,\ \Delta\phi \simeq \pi \quad \Rightarrow \quad \text{sPHENIX: } |\eta| < 1.1,\ \Delta\phi = 2\pi$$

  $\Rightarrow$ More J/ψ and Υ.
- Modern tracking + EMCal + HCal: precise dilepton mass resolution and better control of non-prompt / background contributions.
- Good Υ mass resolution: clean separation of $\Upsilon(1S)$, $(2S)$, $(3S)$ even in high-multiplicity environments.

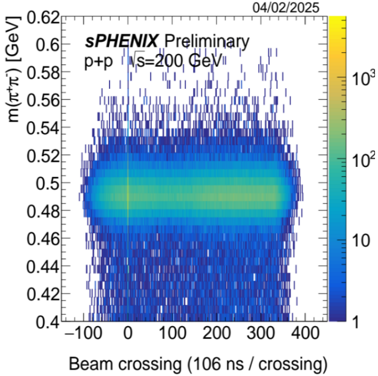
Backup - Open Heavy Flavour Measurements at sPHENIX



Track bunch crossing for K_s^0



K_s^0 reconstruction (all crossings)



π^+/π^- invariant mass vs crossing

Uniform detection of K_s^0 peak at all beam crossings: streaming works!

At 1 MHz collision rate, we increased the 15 kHz minimum-bias trigger to more than 200 kHz recorded "unbiased *pp* collisions"