

Measurement of the Isolated Photon Transverse Single Spin Asymmetry with the sPHENIX Detector

Rowan Kelleher (Univ. of Michigan) on behalf of the sPHENIX Collaboration

The 17th International Conference on Meson-Nucleon Physics and the
Structure of the Nucleon, Stony Brook University, Oct 19-23, 2026

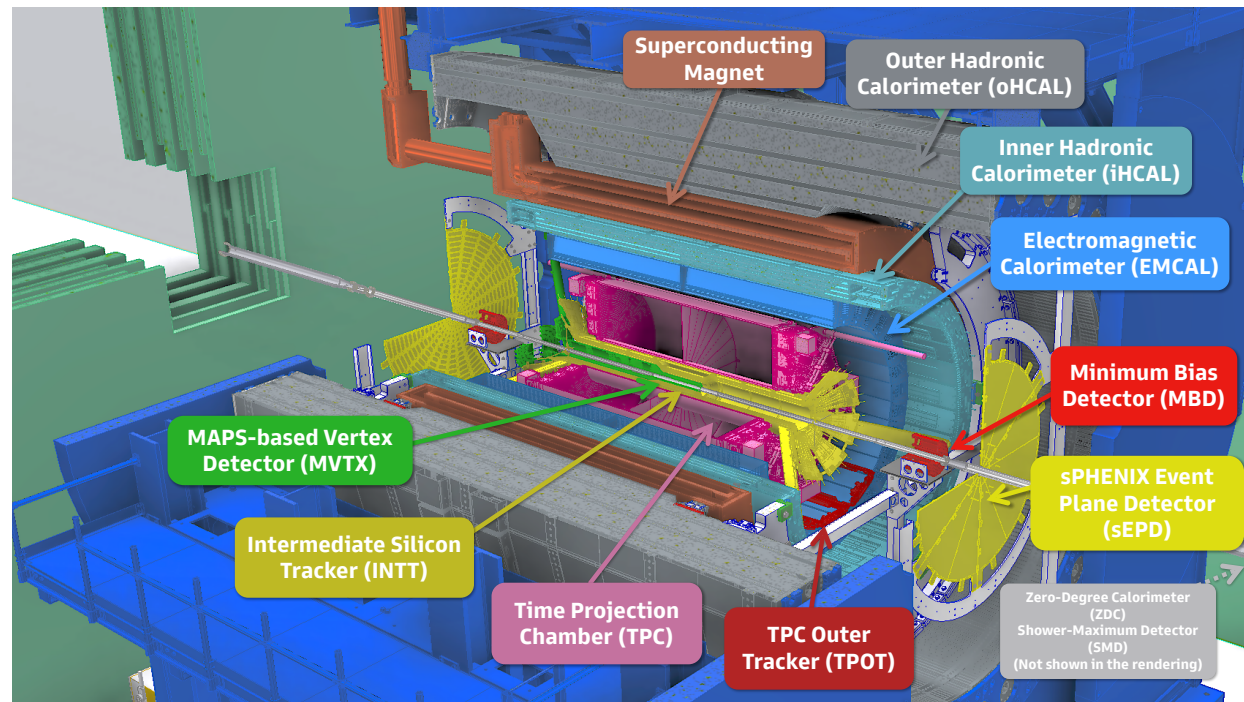


U.S. DEPARTMENT
of **ENERGY**

Office of
Science

Latest detector at RHIC

- Large acceptance
 - Full azimuth acceptance
 - $|\eta| < 1.1$
- High precision tracking
- Hadronic + electromagnetic calorimetry at mid-rapidity



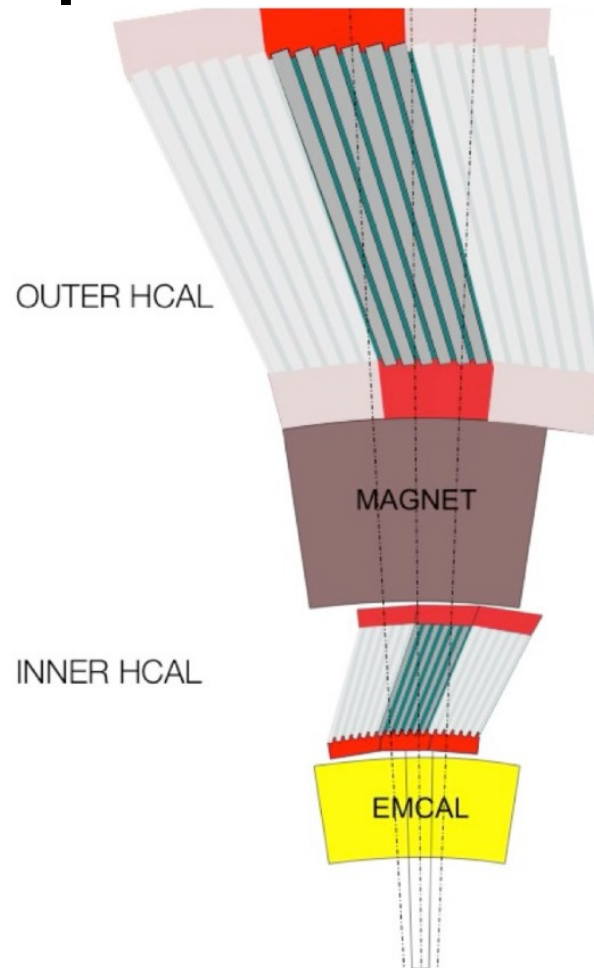
sPHENIX Experiment

SPHENIX Calorimeters

- EMCAL tower size:
 - $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$
- iHCAL & oHCAL tower size:
 - $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$

This analysis:

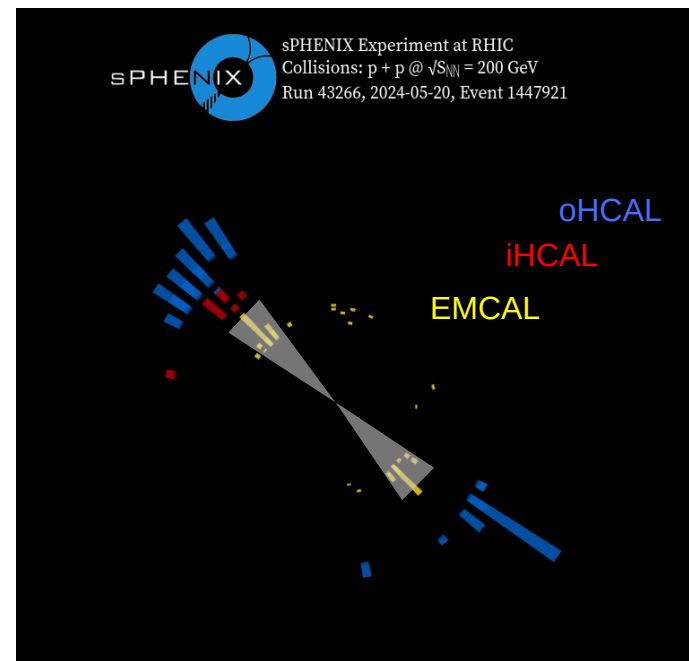
- Reconstruct photons in EMCAL
- Measure surrounding energy in EMCAL, iHCAL, oHCAL
 - Require small surrounding energy for isolated photons
- Mid-rapidity measurement



Dataset used in this analysis:

- Transversely polarized proton-proton collisions recorded in 2024 at $\sqrt{s} = 200$ GeV
- Average polarization: 52%
- Integrated luminosity: 58 pb^{-1} (this analysis)
- Reconstructed primary vertex along beam direction: $|z_{\text{vtx}}| < 60 \text{ cm}$
- Pseudo-rapidity fiducial cut: $|\eta| < 0.7$
 - Isolation cone has radius $R = 0.4$

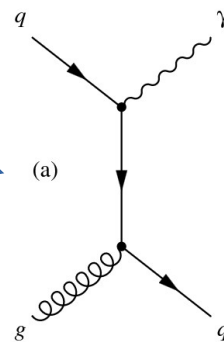
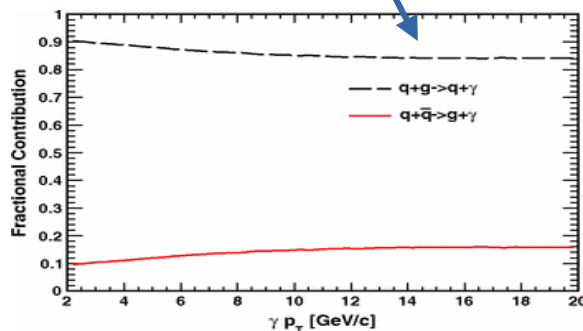
*Example p+p collision at sPHENIX
(calorimeter response in x-y plane)*



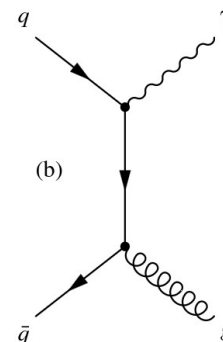
Prompt photons

- Prompt photons = direct photons + fragmentation photons
- **Direct photons:** produced in the hard scattering
 - Provide access to initial state gluons
 - No final state hadronic effects, **clean probe** of initial state correlations

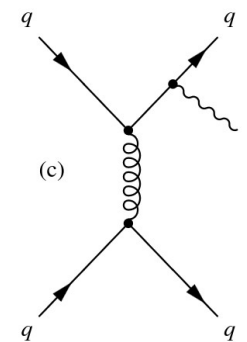
At RHIC, direct photons are primarily produced in Compton scattering



Compton scattering



Annihilation



Fragmentation

Direct photons

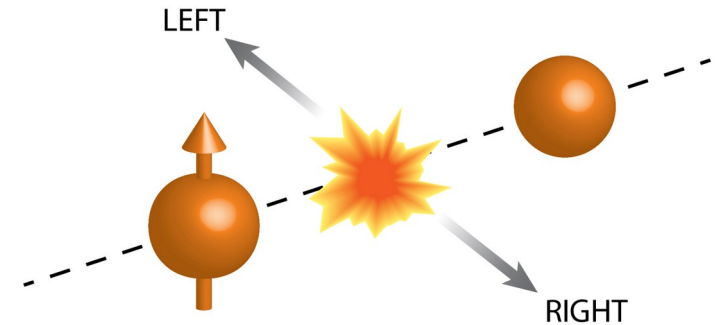
PHENIX collaboration,
PRD82, 072001 (2010)

Isolated Photon TSSA

Transverse single spin asymmetry (A_N)

- Left-right asymmetry of photon production in polarized proton collisions
 - Positive $A_N \rightarrow$ **more photons** are produced to the **left** than to the **right**, relative to the spin direction

$$A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$



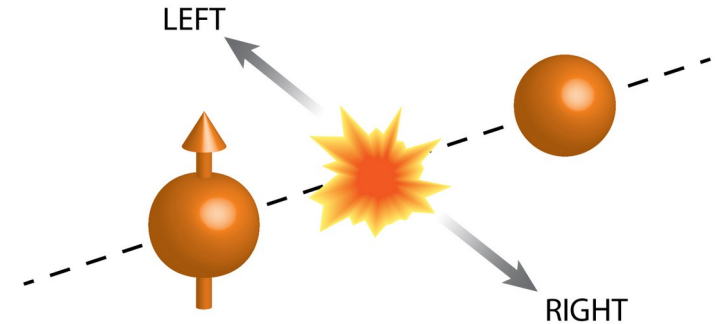
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Twist-3 correlators

- Quark-**gluon** Compton scattering:
 - Access to initial state gluons in polarized proton
 - Sensitive to quark-gluon-quark and **tri-gluon correlations**
- Isolated photon TSSA provides opportunity to **improve constraints** on correlations
 - Important for improving our understanding of spin-momentum correlations in the polarized proton



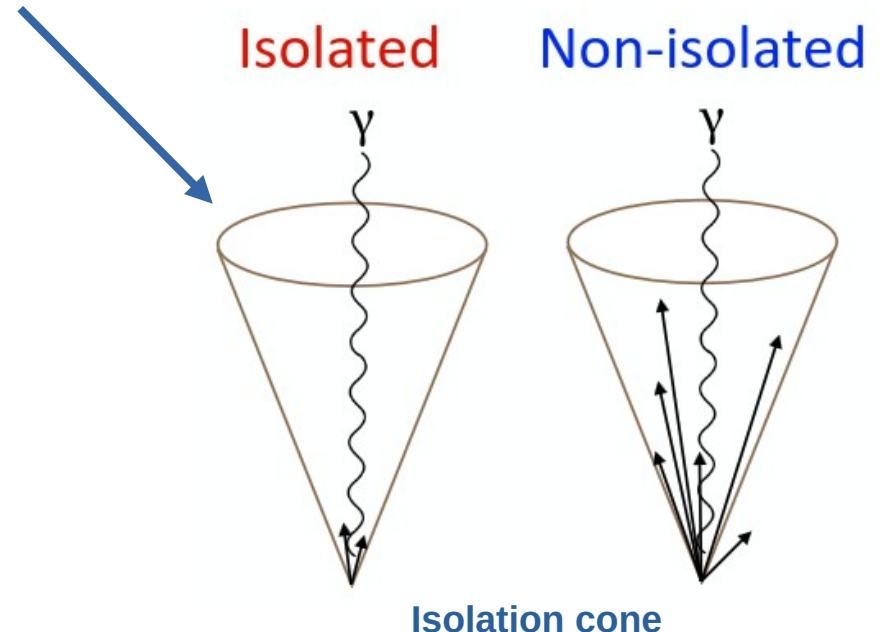
Photon Identification

Photon reconstruction

- EMCAL towers are clustered together to form photon candidates

Isolation requirement

- Require surrounding energy deposit in *all calorimeters* to be small
 - Sum up energy in EMCAL/iHCAL/oHCAL
 - Isolation cone radius: $R = 0.4$
 - Subtract energy of candidate cluster



Photon reconstruction

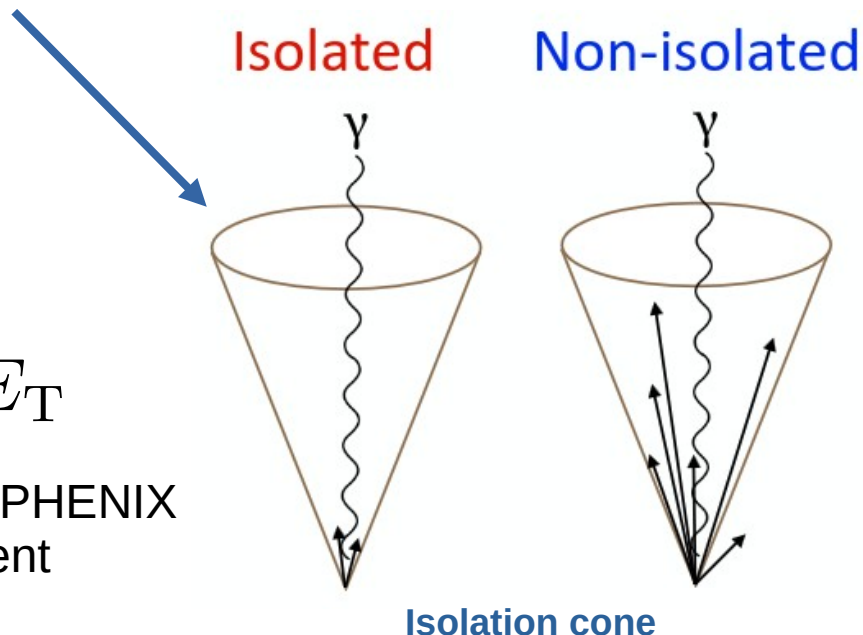
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- Require surrounding energy deposit in *all calorimeters* to be small
 - Sum up energy in EMCAL/iHCAL/oHCAL
 - Isolation cone radius: $R = 0.4$
 - Subtract energy of candidate cluster
- **Suppresses background contributions:**
 - Mostly neutral mesons, often produced in jets
 - Reduces fragmentation photon contribution

$$E_T^{\text{iso}} < 0.490 \text{ GeV} + 0.037 \cdot E_T$$

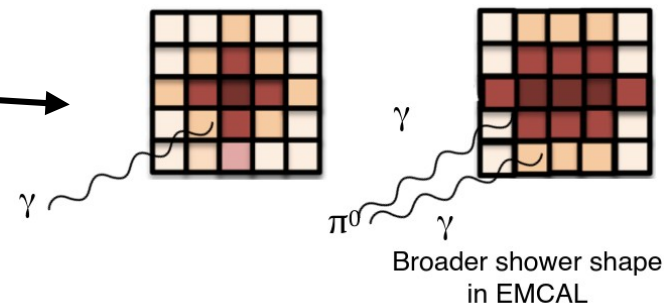
- Isolation + photon ID method inherited from the sPHENIX isolated prompt photon cross-section measurement
 - *Preprint available on arxiv: [2607.03892](https://arxiv.org/abs/2607.03892)*



Photon Identification

Photon ID

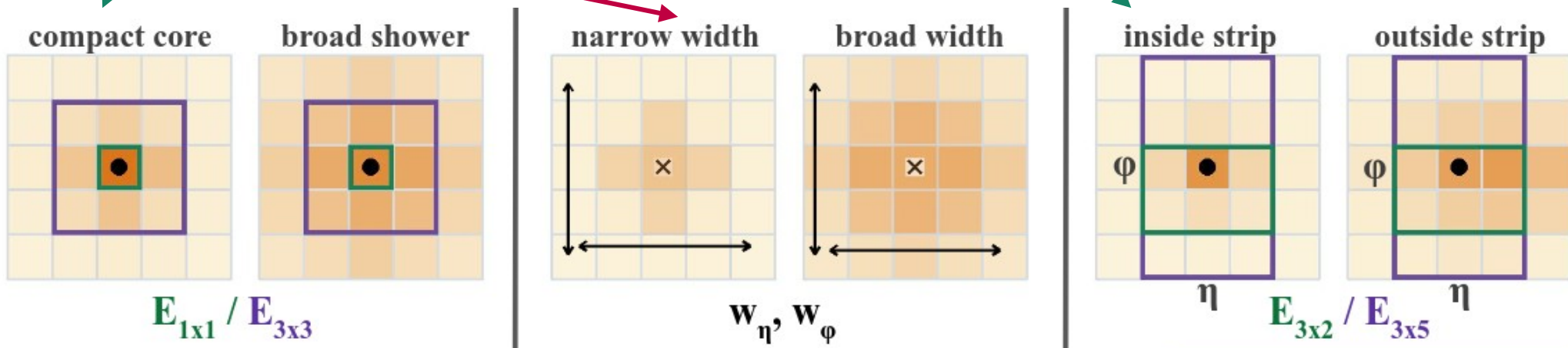
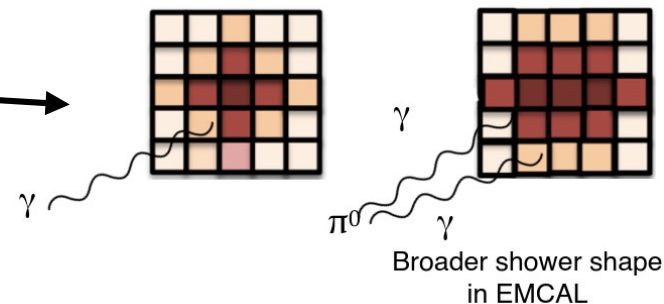
- Photons produce narrow clusters in EMCAL
- Neutral hadrons leave signature in shower shape
- Boosted Decision Tree (BDT) optimized for photon ID



Photon Identification

Photon ID

- Photons produce narrow clusters in EMCAL
- Neutral hadrons leave signature in shower shape
 - Boosted Decision Tree (BDT) optimized for photon ID
- BDT inputs:
 - Primary vertex position
 - Cluster η and E_T
 - Energy ratios
 - Energy weighted **second moment of EMCAL** towers in η and ϕ



Neutral meson veto

- Largest background: **neutral meson decay photons passing ID and isolation cuts**
- Mass veto:
 - Pair each photon candidate with other clusters in event
 - If the pair makes an invariant mass inside π^0 or η meson mass window, reject from sample

Isolated photon sample

- Signal is defined as **tight + isolated** clusters that **pass the meson veto**
 - Signal yield: N^A
- Define three **background regions**:
 - Background yields: N^B , N^C , and N^D

γ^{ID} (BDT response)	A: tight, isolated	B: tight, non-isolated
	C: non-tight, isolated	D: non-tight, non-isolated
	$E_{\text{T}}^{\text{iso, reco}}$	

Data-driven purity estimation

- The source of the primary background depends on the energy range
- Estimate background contribution to region A (signal) → estimate purity

$$N_A^{\text{sig}} = N^A - N_A^{\text{bg}}$$

Background-corrected
signal yield

Signal yield:
tight + isolated
+ tagging veto

Estimated background yield
(see next two slides)

$$P = \frac{N_A^{\text{sig}}}{N^A}$$

Estimate purity

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Estimate purity

Low energy ($E_T < 8$ GeV)

- Primary background: separated **neutral meson decay photons missed in tagging veto**

High energy ($E_T \geq 8$ GeV)

- Primary background: **neutral mesons** where decay photons **merge into single** cluster

Purity Estimation

Missing ratio method ($E_T < 8 \text{ GeV}$)

- Primary background: separated **neutral meson decay photons missed in tagging veto**

Steps:

Purity Estimation

Missing ratio method ($E_T < 8$ GeV)

- Primary background: separated **neutral meson decay photons missed in tagging veto**

Steps:

1. Estimate ratio of missed to tagged neutral mesons with Monte Carlo


$$R_h = \frac{N_{\text{miss}}^h}{N_{\text{tag}}^h}$$

Purity Estimation

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2. Estimate residual background from missing ratio

I. Number of missed meson decay photons in region A $\longrightarrow N_{h,\text{miss}}^{\text{data}} \approx R_h N_{h,\text{tag}}^{\text{data}}$

Missing ratio method ($E_T < 8$ GeV)

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3. Compute background fraction:

4. Compute purity:

$$r_h = \frac{N_{h,\text{miss}}^{\text{data}}}{N_A} \approx \frac{R_h N_{h,\text{tag}}^{\text{data}}}{N_A}$$

$$P = 1 - \frac{R_{\pi^0} N_{\pi^0,\text{tag}}^{\text{data}}}{N_A} - \frac{R_{\eta} N_{\eta,\text{tag}}^{\text{data}}}{N_A}$$

Purity Estimation

Double sideband method ($E_T \geq 8$ GeV)

- Primary background: **neutral mesons** where decay photons **merge into single** cluster
- At larger E_T , isolation energy and shower shapes are *uncorrelated*

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$$\frac{N_A^{\text{bg}}}{N_B} = \frac{N_C}{N_D}$$

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- Estimate background using N^B , N^C , and N^D :

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- Estimate background using N^B , N^C , and N^D :
- Compute signal yield:

$$\frac{N_A^{\text{bg}}}{N_B} = \frac{N_C}{N_D}$$

$$N_A^{\text{bg}} = \frac{N_B N_C}{N_D}$$

$$N_{\text{sig}}^A = N_A - \frac{N_B N_C}{N_D}$$

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Purity Estimation

Double sideband method ($E_T \geq 8$ GeV)

$$N_{\text{sig}}^A = N_A - \frac{N_B N_C}{N_D}$$

- Some signal photons leak into background (regions B, C, and D)
 - Correct for signal leakage:

$$f_X = \frac{N_{X,\text{sig}}}{N_{A,\text{sig}}}$$

Leakage fraction
estimated in MC

$$N_X^{bg} = N_X - f_X N_A^{sig}$$

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$E_T^{\text{iso, reco}}$

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$$P = \frac{N_{\text{sig}}^A}{N_A}$$

Purity

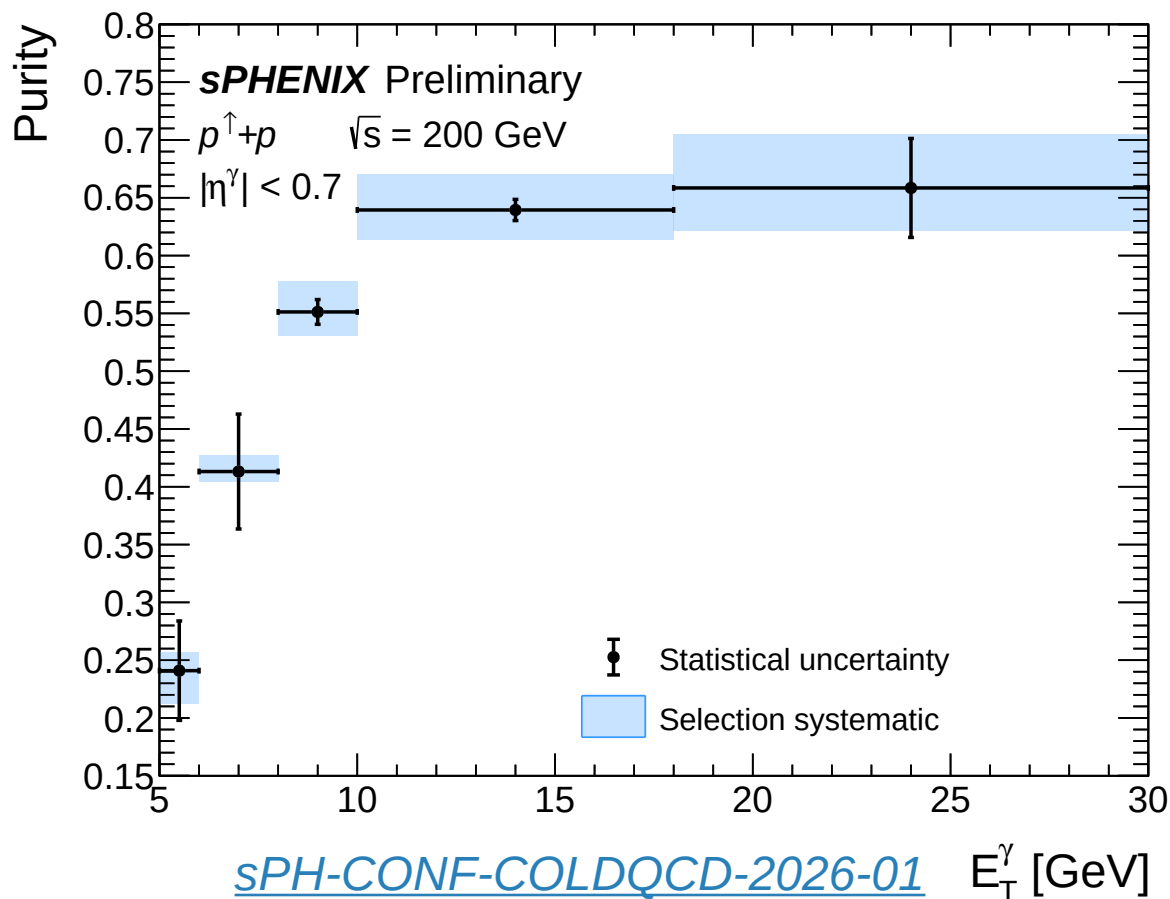
Purity Result

Isolated photon purity

- **Asymmetric decays** with one high energy and one low energy photon are **missed by tagging**

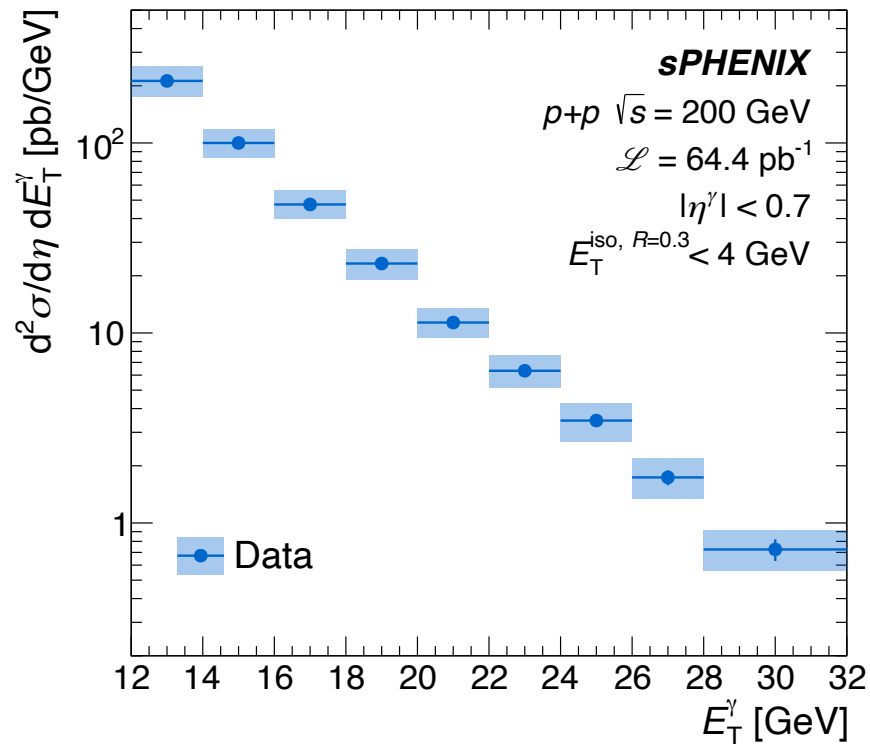
Purity estimation method:

- $E_T < 8$ GeV
 - Missing-ratio method
- $E_T \geq 8$ GeV
 - ABCD Method



Isolated photon cross section

- Preprint available on arxiv: [2607.03892](https://arxiv.org/abs/2607.03892)
- TSSA applies additional spin QA





Isolated Photon TSSA



Transverse single spin asymmetry (A_N)

- Left-right asymmetry of photon production in polarized proton collisions

Extraction steps:

Isolated Photon TSSA

Transverse single spin asymmetry (A_N)

- Left-right asymmetry of photon production in polarized proton collisions

Extraction steps:

1. Measure the raw asymmetry with spin-dependent ϕ distributions

$$A(\phi) = \frac{N^\uparrow(\phi) - R N^\downarrow(\phi)}{N^\uparrow(\phi) + R N^\downarrow(\phi)}, \quad R = \frac{L^\uparrow}{L^\downarrow} \quad \leftarrow \text{Relative luminosity}$$

Isolated Photon TSSA

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3. Correct for polarization and purity

$$A_{N,\text{raw}} = \frac{\epsilon_N}{\mathcal{P}_{\text{beam}}} \longrightarrow A_N^{\gamma,\text{iso}} = \frac{A_{N,\text{raw}}^A - A_{N,\text{raw}}^{\text{bg}}}{P}$$

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← **Relative luminosity**

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Observed small neutral meson A_N
[SPH-CONF-COLDQCD-2025-01](#)

3. Correct for polarization and purity

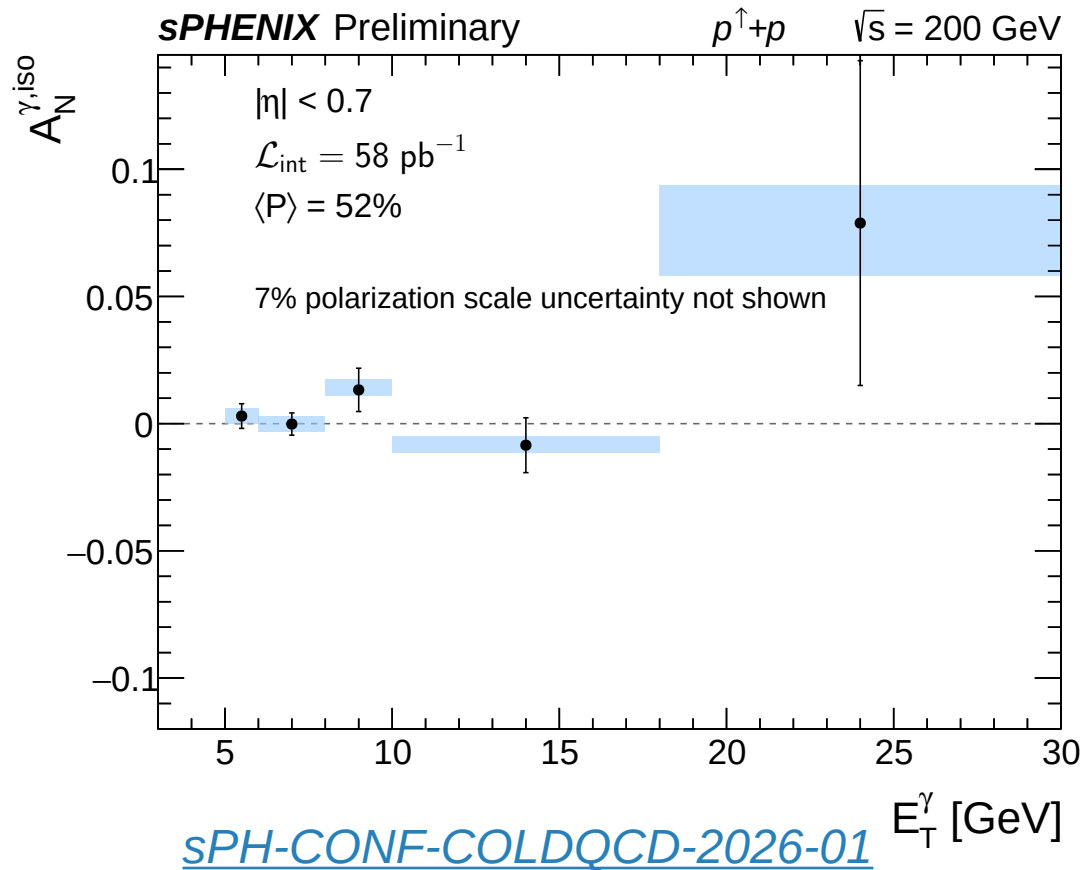
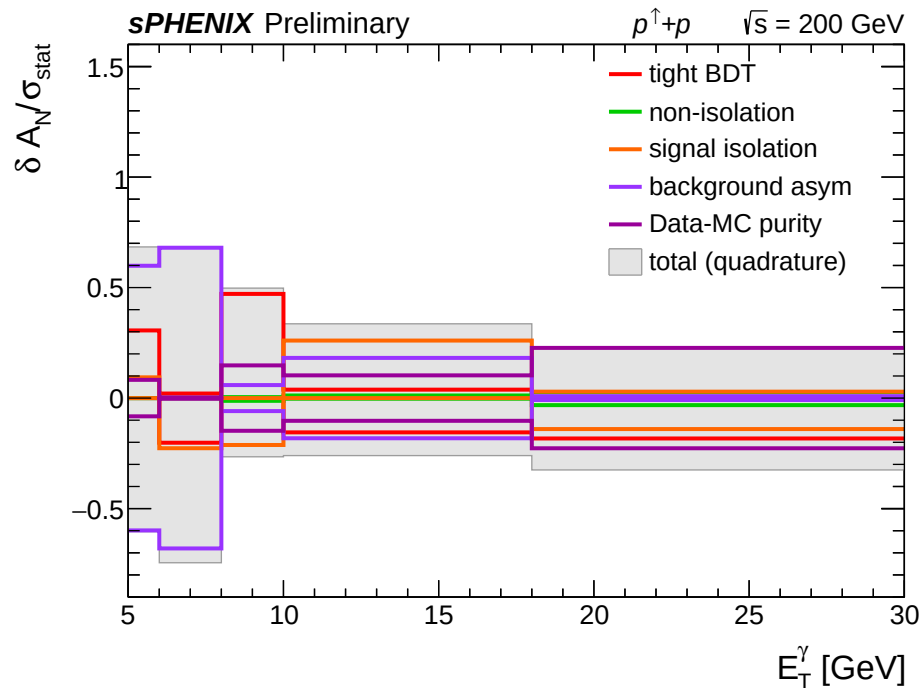
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Fully corrected result

Preliminary Result

Preliminary isolated photon TSSA

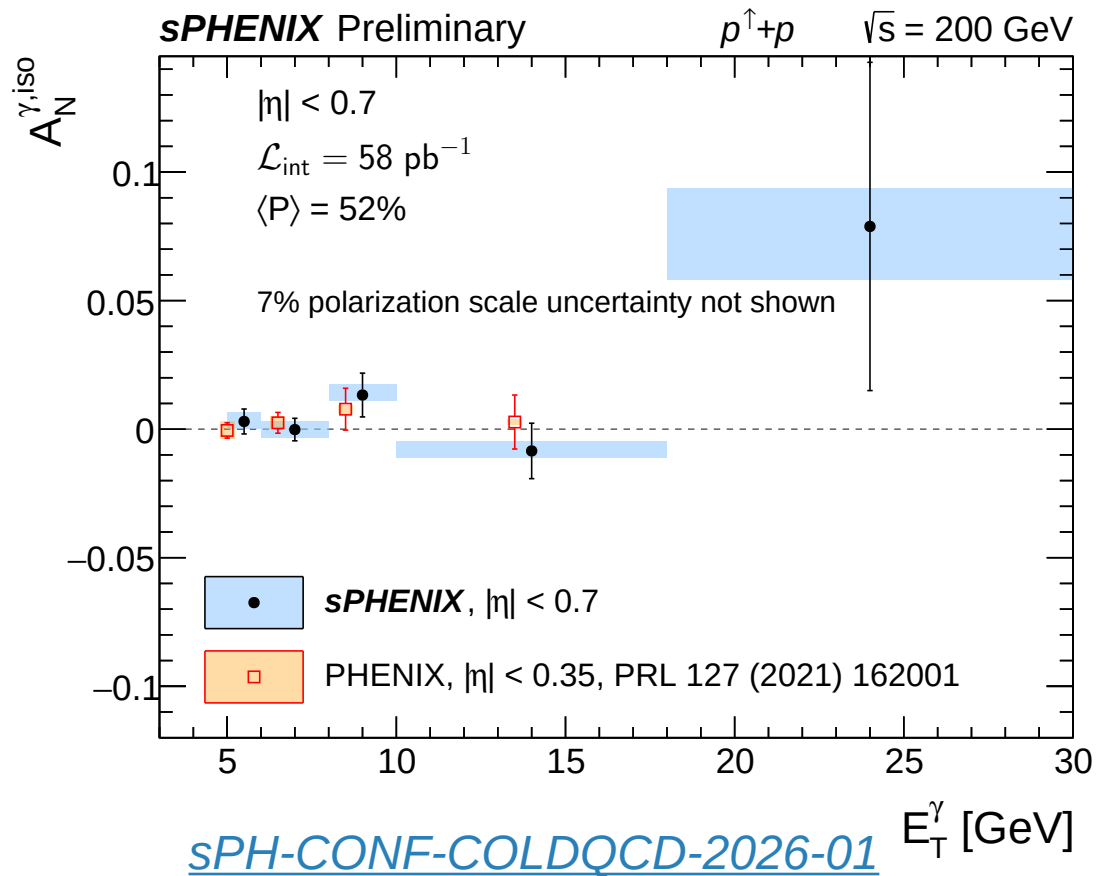
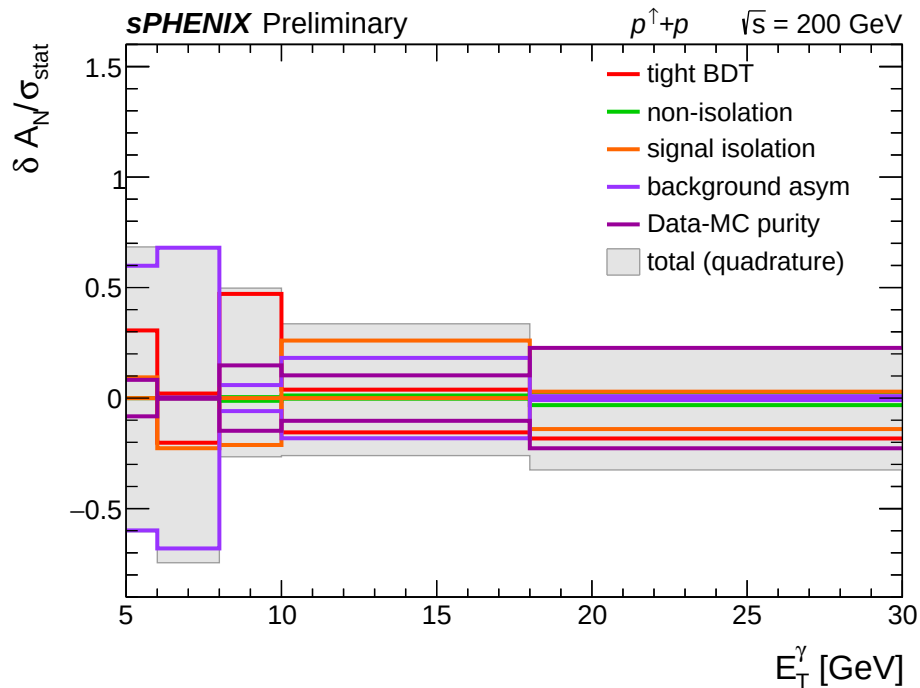
- Consistent with PHENIX's result



Preliminary Result

Preliminary isolated photon TSSA

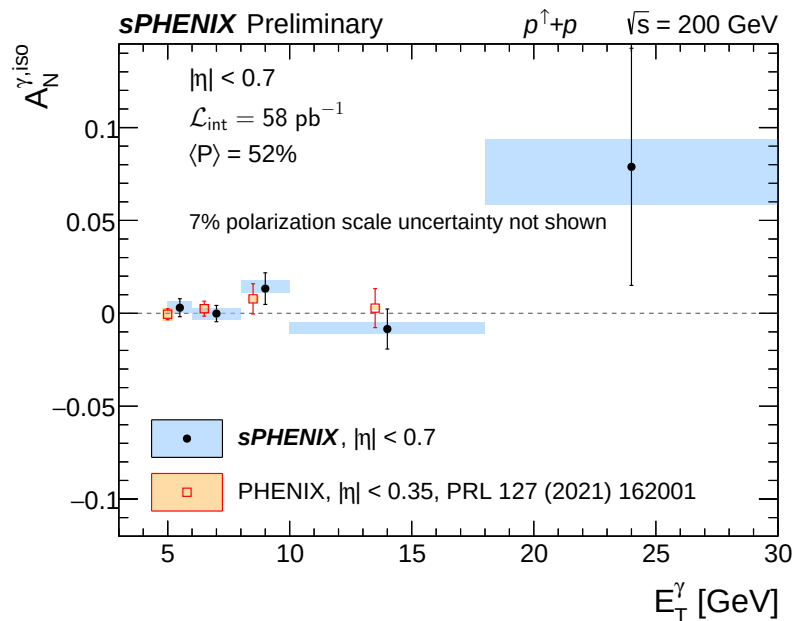
- Consistent with PHENIX's result



Isolated photon TSSA with sPHENIX

- ▶ New preliminary sPHENIX result
- ▶ Isolated photons → clean EM probe
- ▶ Sensitive to initial state gluons in the polarized proton
 - ▶ Provides constraints on quark and gluon correlations in the polarized proton
- ▶ [sPH-CONF-COLDQCD-2026-01](#)

Thank you for your attention!





Backup



Transverse Single Spin Asymmetry (TSSA)

- Non-zero forward rapidity asymmetry observed at RHIC

Sources of TSSA

- Initial state
 - Correlations between proton spin and parton momentum
- Final state
 - Spin-momentum correlation in fragmentation

Isolated Photons

- Produced primarily in quark gluon Compton scattering
 - Sensitive to initial state quark-gluon-quark and trigluon correlations
- No fragmentation $\rightarrow$ no final state effects
 - Clean probe of initial state correlations

Shower Shapes

Shower shape variables used for BDT input

- E_T - Reconstructed cluster transverse energy
- $E_{1 \times 1} / E_{3 \times 3}$ - Ratio of the energy in the central tower to the sum of the towers in a 3x3 grid
- $w_\eta(w_\phi)$ - Energy weighted second moment of $\eta(\phi)$ in the cluster center-of-gravity frame

$$w_\eta = \frac{\sum_i E_i (\eta_i - \bar{\eta})^2}{\sum_i E_i}$$

- Z_{vtx} - reconstructed collision vertex position along the beam axis
- η - Reconstructed cluster pseudorapidity
- $E_{t1} = (E_1 + E_2 + E_3 + E_4) / E_{\text{tot}}$ - fraction of cluster energy in the 2x2 block around the center of gravity
- $E_{t2} = (E_1 + E_2 - E_3 - E_4) / E_{\text{tot}}$ - η weighted energy asymmetry observable
- $E_{t3} = (E_1 - E_2 - E_3 + E_4) / E_{\text{tot}}$ - ϕ weighted energy asymmetry observable
- $E_{t4} = E_3 / E_{\text{tot}}$ the diagonal-corner tower fraction
- $E_{3 \times 2} \times E_{3 \times 5}$ Ratio of energies in 3 x 2 and 3 x 5 ($\eta \times \phi$) tower regions selected around cluster center of gravity

