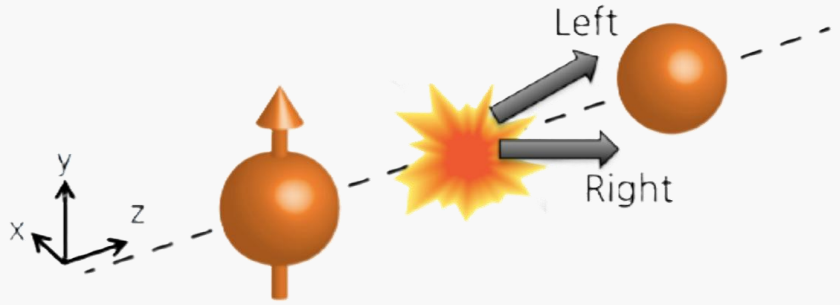
The 13th Circum-Pan-Pacific Symposium on High Energy Spin Physics (PacificSPIN)
2026/10/27-30
Institute of Physics, Academia Sinica



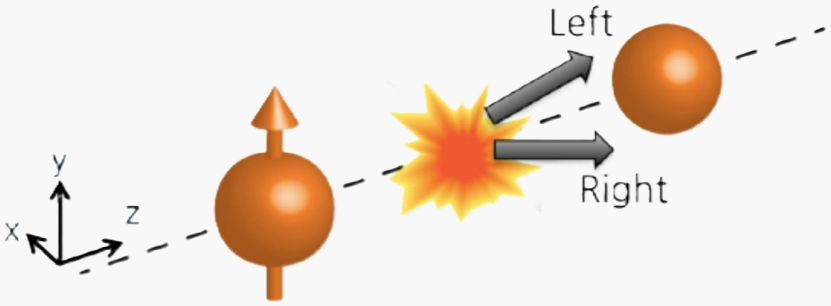
sPHENIX measurement of isolated-γ transverse single-spin asymmetry

Ryotaro Koike on behalf of the sPHENIX collaboration
Kyoto University / RIKEN

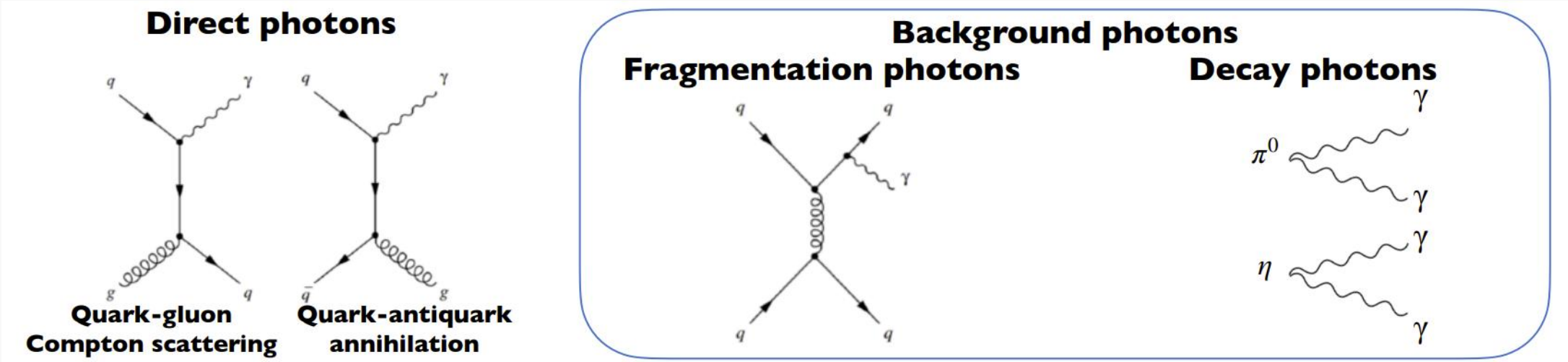
Introduction

- **Transverse Single Spin Asymmetry (TSSA) A_N**
  - An observable in $p^{\uparrow} + p$
  - Left/Right asymmetry of a specific produced particle with respect to the beam-proton's spin orientation

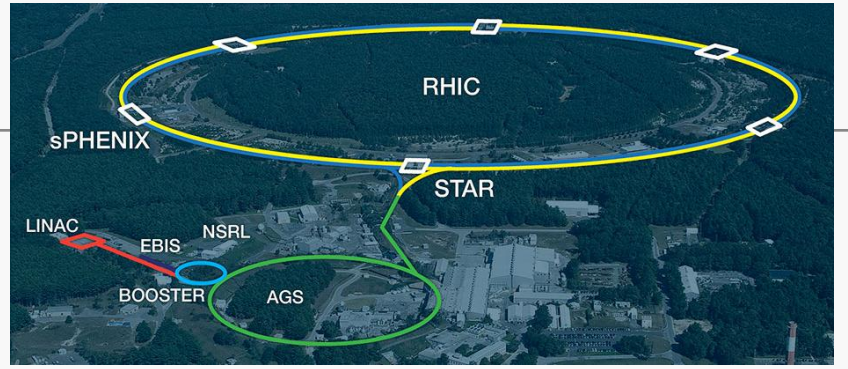
$$A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$



- **Advantages of isolated-γ TSSA**
  - Isolated-γ: experimental method to measure direct-γ
  - Insensitive to final state interaction
  - Sensitive to initial state, providing constraints on quark-gluon-quark and **tri-gluon** correlations (collinear twist-3 correlations) inside polarized proton



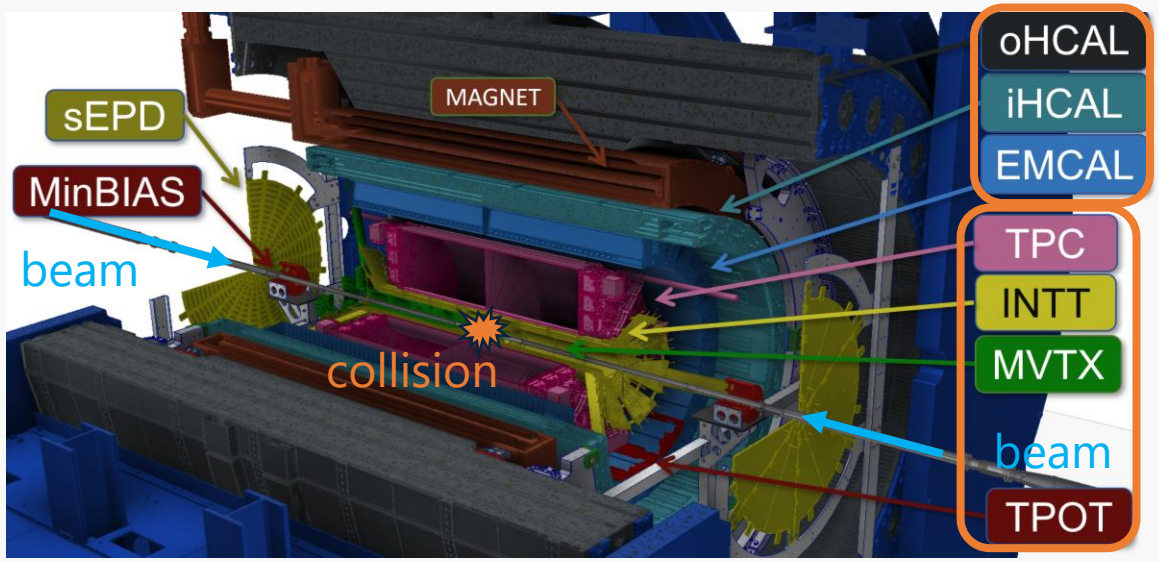
sPHENIX experiment



- **Overview**
  - Conducted at Relativistic Heavy Ion Collider (RHIC)
    - The only accelerator that provides $p^{\uparrow} + p$ collisions
  - sPHENIX collected $p^{\uparrow} + p, \mathrm{Au} + \mathrm{Au}, \mathrm{O} + \mathrm{O}$ data at $\sqrt{s_{NN}} = 200$ GeV during 2024~2026

Species	Detectors required for analysis	Available $\mathcal{L}_{\mathrm{int}}$ (2024)	Available $\mathcal{L}_{\mathrm{int}}$ (2026)
$p^{\uparrow} + p$	Calorimeters	$90\ \mathrm{pb}^{-1}$	$25\ \mathrm{pb}^{-1}$
	All detectors (trackers in trigger mode)	$13\ \mathrm{pb}^{-1}$	$12\ \mathrm{pb}^{-1}$
	Trackers in streaming mode	$2.9 + 9.7\ \mathrm{pb}^{-1}$	$9.7\ \mathrm{pb}^{-1}$

- **sPHENIX detectors**
  - Standard modern detector configuration
  - Full azimuth coverage
  - Large pseudo-rapidity acceptance: $|\eta| < 1.1$
  - First mid-rapidity hadronic calorimeter at RHIC



Isolated-γ measurement in sPHENIX

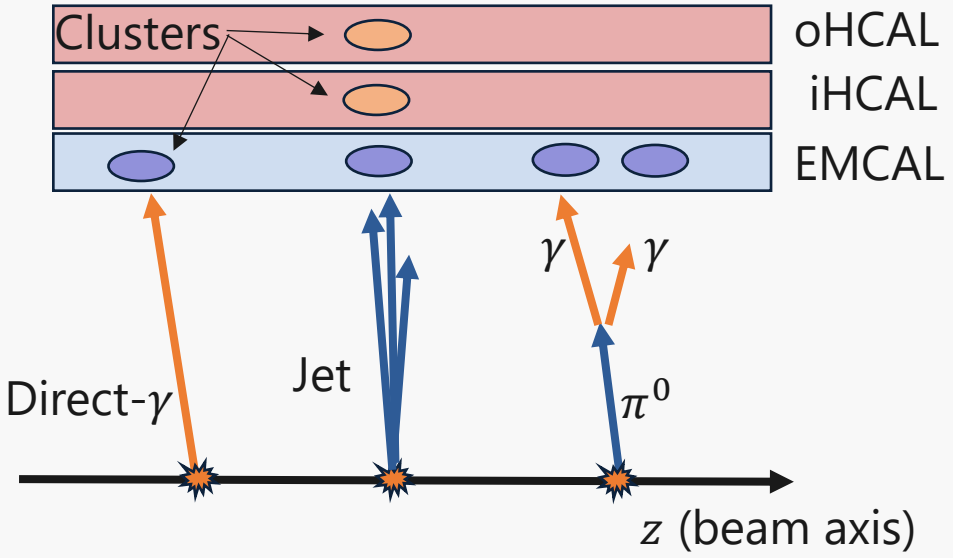
- **Calorimeter-based measurement**
  - EMCAL for photon detection
    - An EMCAL tower covers $\Delta\phi\times\Delta\eta = 0.025\times0.025$
  - Energy deposits in adjacent towers are bundled together to form a cluster
  - iHCAL and oHCAL are used for isolation
    - $\Delta\phi\times\Delta\eta = 0.1\times0.1$

EMCAL block = 2x2 towers



- **Data set**
  - Run 2024 data set of $\sim 58\ \mathrm{pb}^{-1}$ (after QA for runs and beam polarizations)
  - Average polarization of $\sim 52\%$ for both beams

  - Vertex cut: $|z_{\mathrm{vtx}}| < 60\ \mathrm{cm}$
  - Fiducial cut: $|\eta| < 0.7$



Photon cluster selection

- **Backgrounds**
  - Main component: decay photons from neutral mesons ($\pi^0 \to 2\gamma$ and $\eta \to 2\gamma$)
  - High-p_{T} meson produces a merged cluster
    - Merged π^0-clusters appears from ~5 GeV and dominates above ~10 GeV

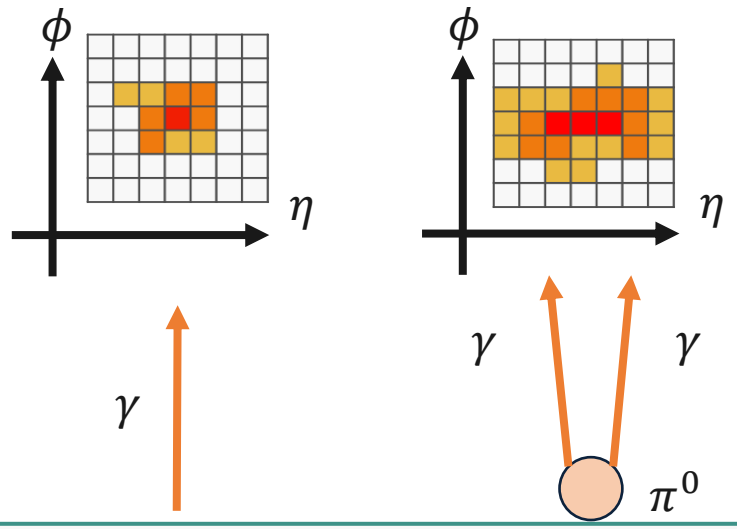
- **3 cuts for photon selection**

① and ② are inherited from sPHENIX isolated prompt photon cross-section measurement [arxiv: 2607.03892]

① Shower shape cut

for photon identification

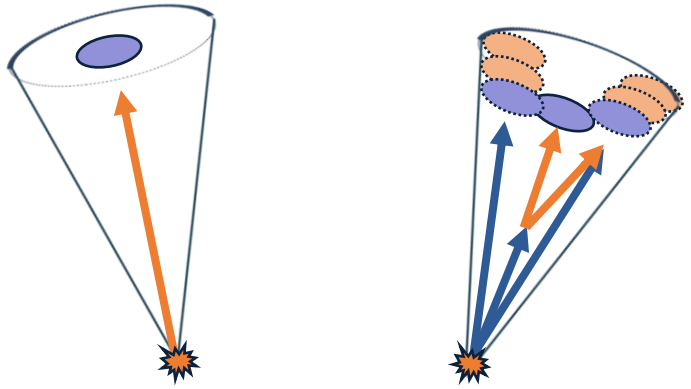
Single γ | Merged π^0



② Isolation cut

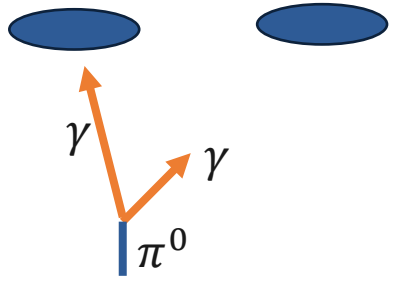
for background suppression

Direct-γ likely to be isolated | Neutral meson in jet



③ Meson tag veto

for a decay photon rejection

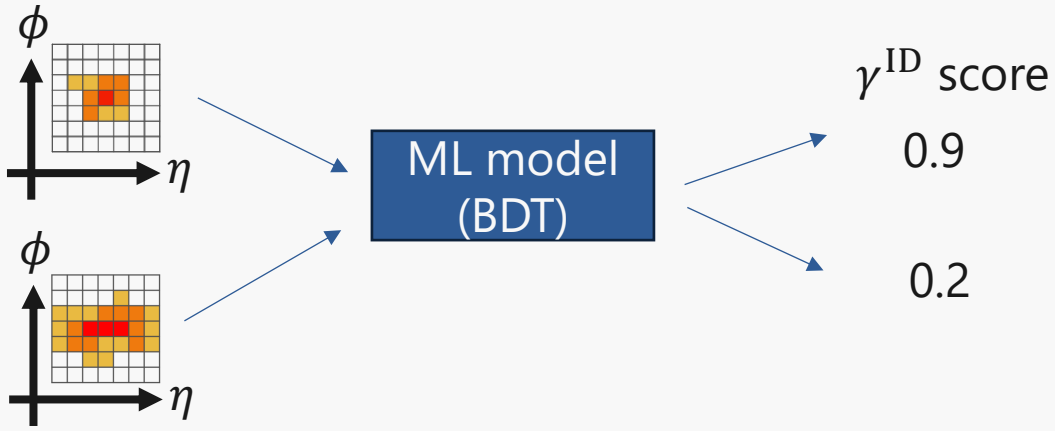


Photon cluster selection

① Shower shape cut

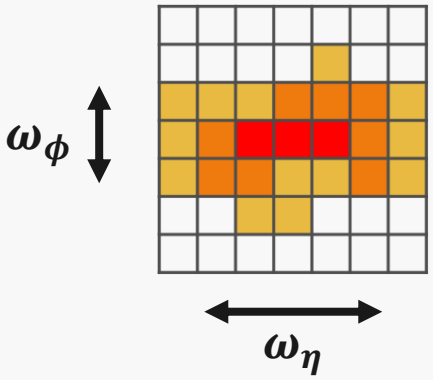
- Distinguish single-γ clusters based on cluster shapes
- Machine learning model (Boosted Decision Tree; BDT) optimized for photon identification

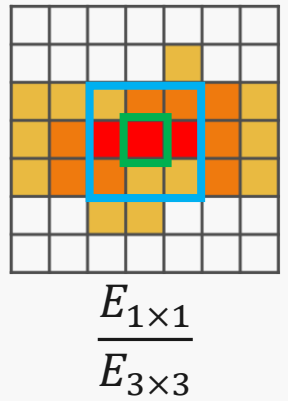
- Inputs to BDT
  - Primary vertex position along the beam axis: z_{vtx}
  - Cluster η and E_{T}
  - Energy weighted second moment of η and ϕ: ω_η, ω_ϕ
  - Energy ratios: $\frac{E_{1\times1}}{E_{3\times3}}, E_{t1}, E_{t2}, E_{t3}, E_{t4}, \frac{E_{3\times2}}{E_{3\times5}}$



- The candidate cluster is *tight* (γ like) if

$$\gamma^{\mathrm{ID}} > 0.8156 - 0.00156[\mathrm{GeV}^{-1}] \cdot E_{\mathrm{T}}$$





Photon cluster selection

② Isolation cut

- Suppress background contributions from
  - Neutral mesons, often produced in jets
  - Fragmentation photons
- Isolation energy is defined as

$$E_{\mathrm{T}}^{\mathrm{iso}} := \Sigma_{\text{isolation cone}} E_{\mathrm{T}} - E_{\mathrm{T}}$$

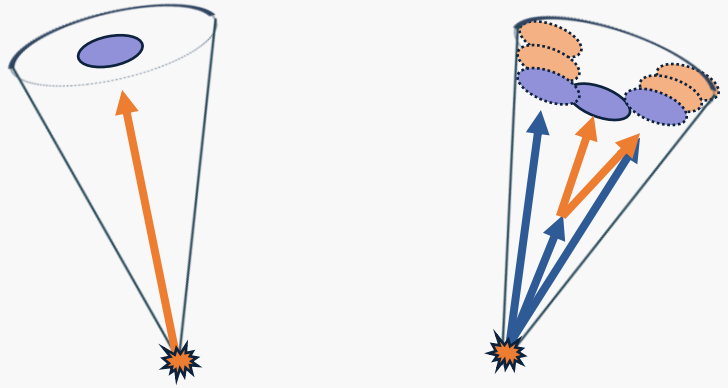
Integrate over clusters within the isolation cone, except for the EMCAL cluster of interest

- The candidate cluster is *isolated* if

$$E_{\mathrm{T}}^{\mathrm{iso}} < 0.490\ [\mathrm{GeV}] + 0.037 \cdot E_{\mathrm{T}}$$

Surrounding energy to be less than a few % of the energy of candidate cluster

Isolation cone:
$\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.4$



Direct-γ likely to be isolated

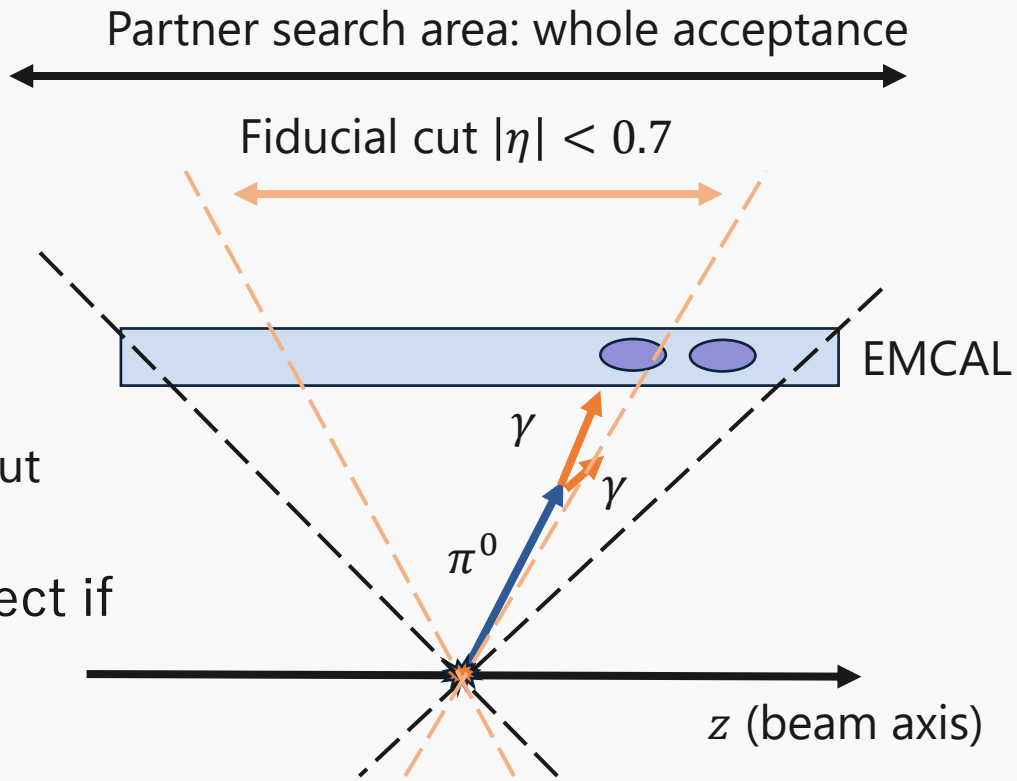
Non-isolated example

Candidate EMCAL cluster
Other EMCAL cluster
Other HCAL cluster

Photon cluster selection

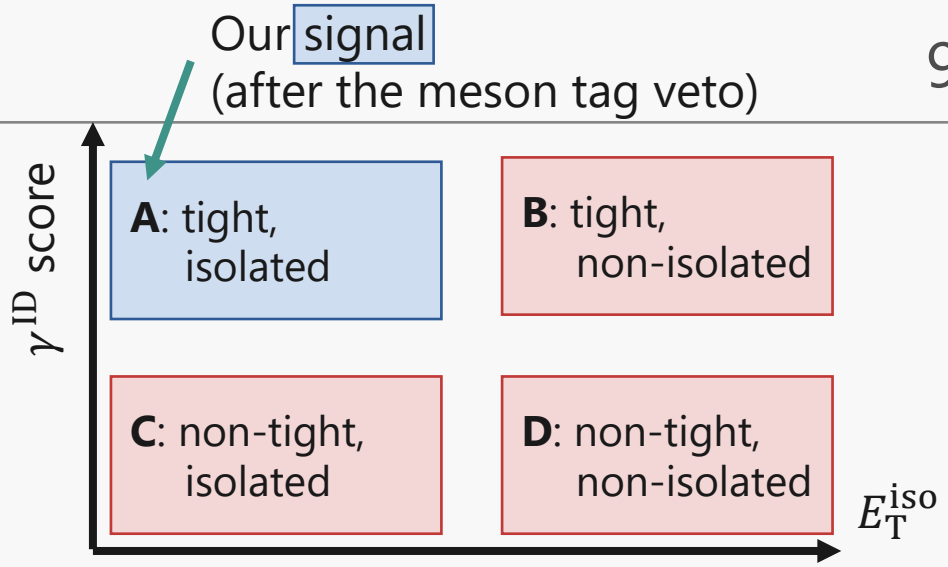
③ Meson tag veto

- Signal candidate:
  - within the fiducial cut
  - pass the shower shape cut
  - pass the isolation cut
- Partner cluster: scan all clusters above threshold
  - No requirement for shower shapes, isolation, or fiducial cut
  - Current threshold: 0.5 GeV
- Calculate the invariant mass of the pair, $M_{\gamma\gamma}$, and reject if
  - $M_{\gamma\gamma} \in [0.10, 0.20]$ GeV (π^0)
  - $M_{\gamma\gamma} \in [0.45, 0.65]$ GeV (η)



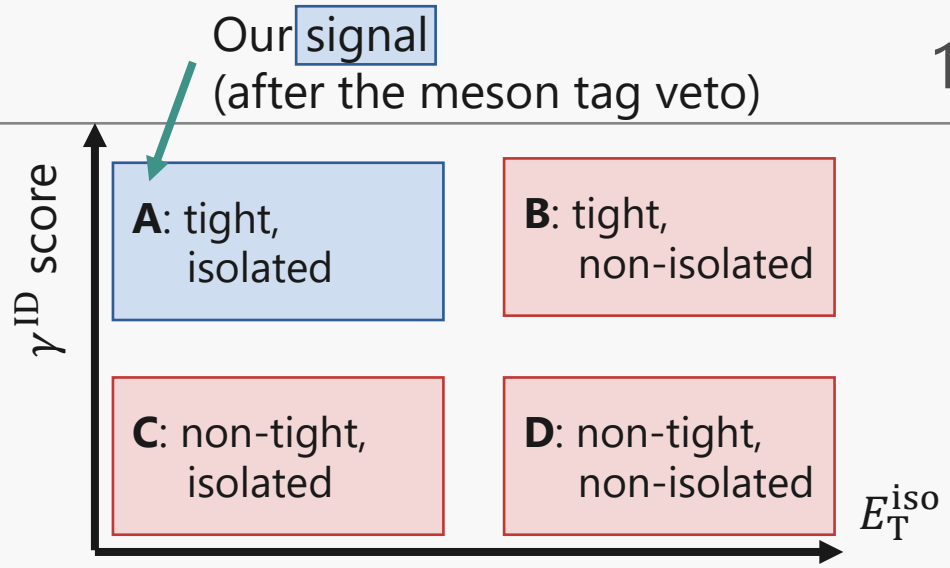
Purity estimation

- Signals obtained applying all the cuts.
- Non-negligible backgrounds still reside in our signal samples.



Purity estimation

- Signals obtained applying all the cuts.
- Non-negligible backgrounds still reside in our signal samples.



We employed a hybrid method for purity estimation, reflecting a fact that background components have different characteristics depending on the E_{T}

Low E_{T} region

Primary background:
- separated decay photons

→ Missing ratio method
(same as PHENIX)

High E_{T} region

Primary background:
- merged clusters from π^0/η

→ ABCD method
(same as sPHENIX cross section)

Purity estimation

- **Missing ratio method**
  - for low E_{T} region $(5 < E_{\mathrm{T}} < 8\ \mathrm{GeV})$
  - Steps:
    1. Estimate ratio of missed to tagged neutral mesons with Monte Carlo $R_h = \frac{N_{h,\,\mathrm{miss}}}{N_{h,\mathrm{tag}}}$
    2. Estimate residual background from the missing ratio
    $$N_{h,\mathrm{miss}}^{\mathrm{data}} \sim R_h N_{h,\mathrm{tag}}^{\mathrm{data}}$$
    3. Compute background fraction
    4. Compute purity

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

  - Limitations:
    There need to be exist separated π^0 with a decent percentage.
    → not applicable above 10 GeV

Purity estimation

Background regions were utilized for the estimation

ABCD method

- for high E_{T} region $(E_{\mathrm{T}} \geq 8\ \mathrm{GeV})$
- Steps:
  1. (Assuming the γ^{ID} and $E_{\mathrm{T}}^{\mathrm{iso}}$ are uncorrelated,)
     Ratio of background yields in **C to D** is the same as **A to B**
  2. Estimate N_A^{bg} from N_B, N_C, N_D

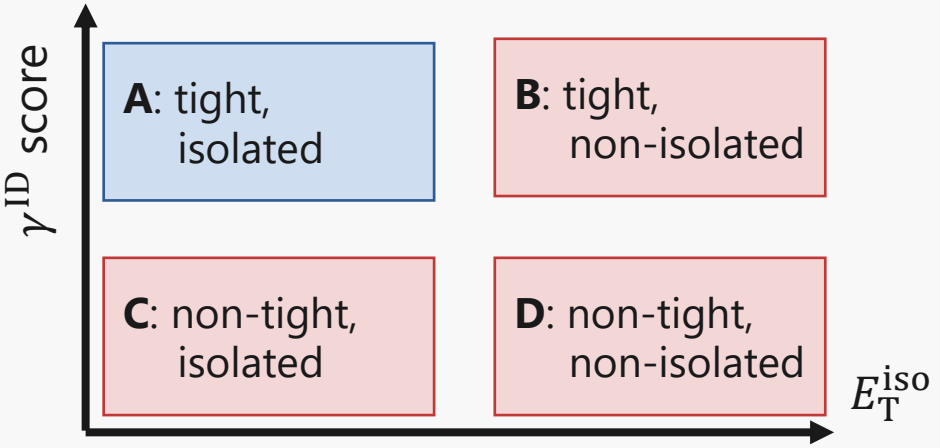
$$N_A^{\mathrm{bg}} = \frac{N_B N_C}{N_D}$$

  3. Compute signal yield

$$N_A^{\mathrm{sig}} = N_A - N_A^{\mathrm{bg}}$$

  4. Compute purity

$$P = \frac{N_A^{\mathrm{sig}}}{N_A}$$



- Limitations:
  Not applicable for low E_{T} as separated π^0 introduces correlation between γ^{ID} and $E_{\mathrm{T}}^{\mathrm{iso}}$

Purity estimation

Background regions were utilized for the estimation

- **ABCD method**
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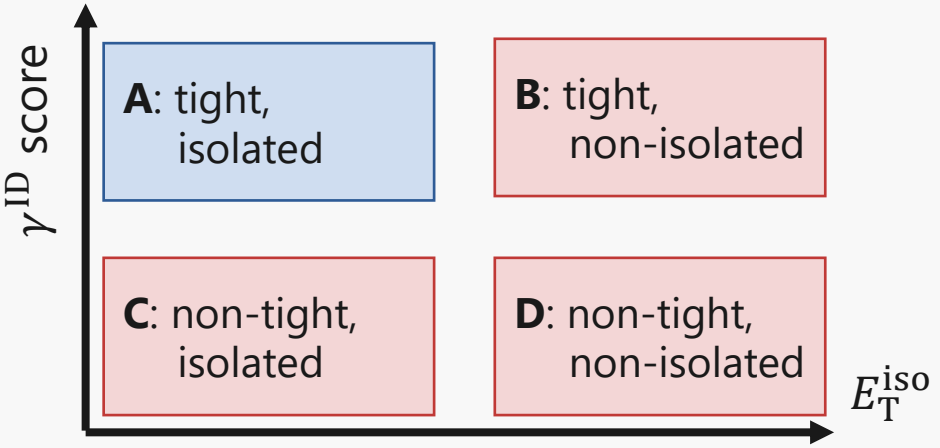
$$N_A^{\mathrm{bg}} = \frac{N_B N_C}{N_D}$$

    3. Compute signal yield

$$N_A^{\mathrm{sig}} = N_A - N_A^{\mathrm{bg}}$$

    4. Compute purity

$$P = \frac{N_A^{\mathrm{sig}}}{N_A}$$



In the analysis, signal leakage (from A to B,C,D) is corrected for by following steps:

3.1. Evaluate leakage fractions in MC: $f_X \coloneqq N_{X,\mathrm{sig}}/N_{A,\mathrm{sig}}$

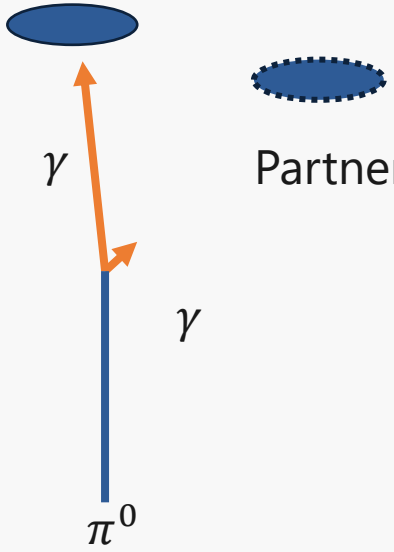
3.2. Get signal yield by solving leakage corrected equation

$$N_A^{\mathrm{sig}} = N_A - \frac{(N_B - f_B N_A^{\mathrm{sig}})(N_C - f_C N_A^{\mathrm{sig}})}{N_D - f_D N_A^{\mathrm{sig}}}$$

- Limitations:
  Not applicable for low E_{T} as separated π^0 introduces correlation between γ^{ID} and $E_{\mathrm{T}}^{\mathrm{iso}}$

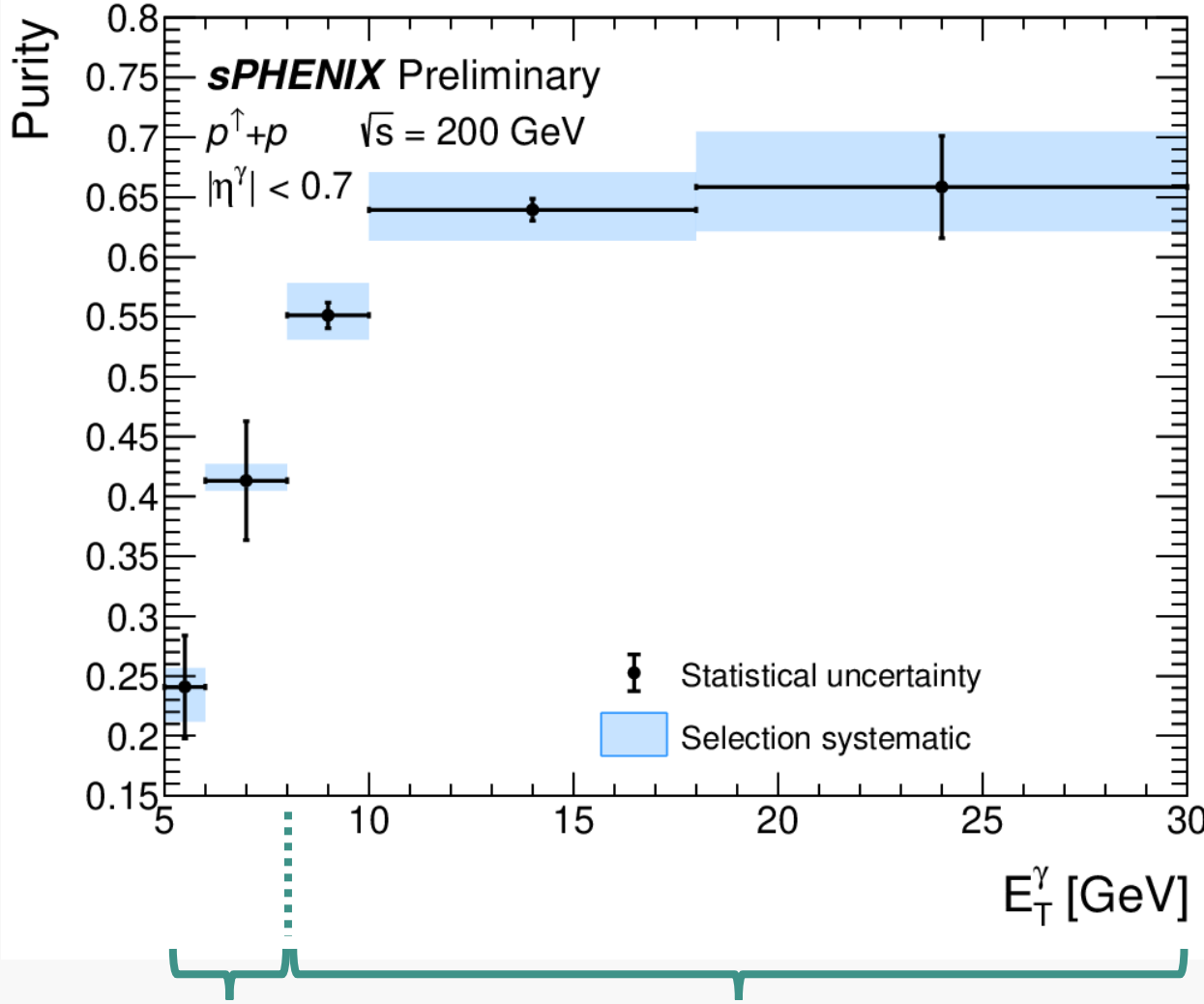
Purity result

- **Low purity at low E_T comes from**
  - Large production cross section of π^0 relative to prompt-γ
  - Large background of neutral mesons that survived the meson tag veto.



Partner cluster energy too low

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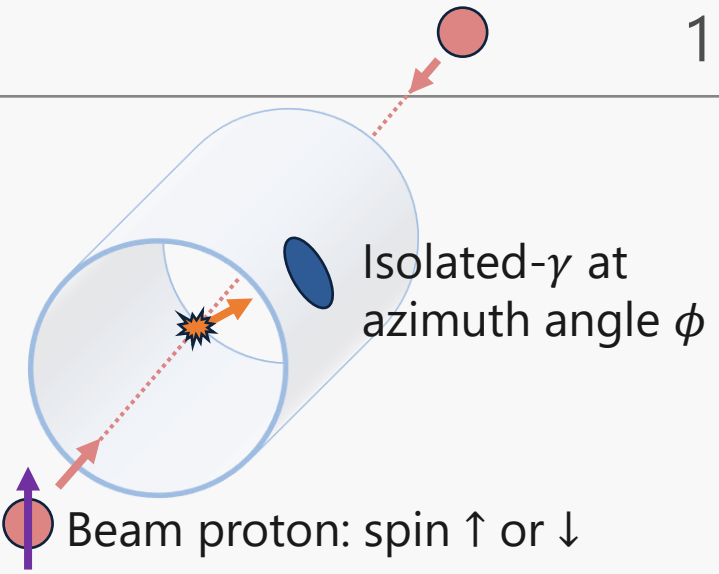
missing ratio method

ABCD method

TSSA extraction

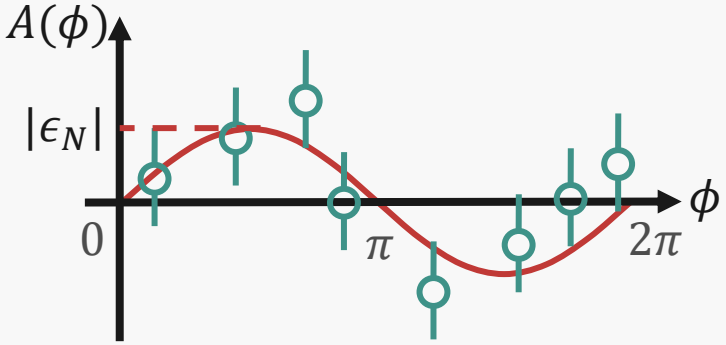
Isolated-γ TSSA is extracted from the signal samples

$$A(\phi) = \frac{N^{\uparrow}(\phi) - R \cdot N^{\downarrow}(\phi)}{N^{\uparrow}(\phi) + R \cdot N^{\downarrow}(\phi)}, \qquad R = \frac{\mathcal{L}^{\uparrow}}{\mathcal{L}^{\downarrow}} : \text{Relative luminosity}$$



⇩ Extract amplitude by sine curve fitting

$$A(\phi) = -\epsilon_N \cdot \sin(\phi)$$



⇩ Correct for polarization and purity

$$A_{N,\mathrm{raw}} = \frac{\epsilon_N}{\mathcal{P}_{\mathrm{beam}}}$$

$$A_N^{\gamma,\mathrm{iso}} = \frac{A_{N,\mathrm{raw}} - A_{N,\mathrm{raw}}^{\mathrm{bg}}}{P}$$

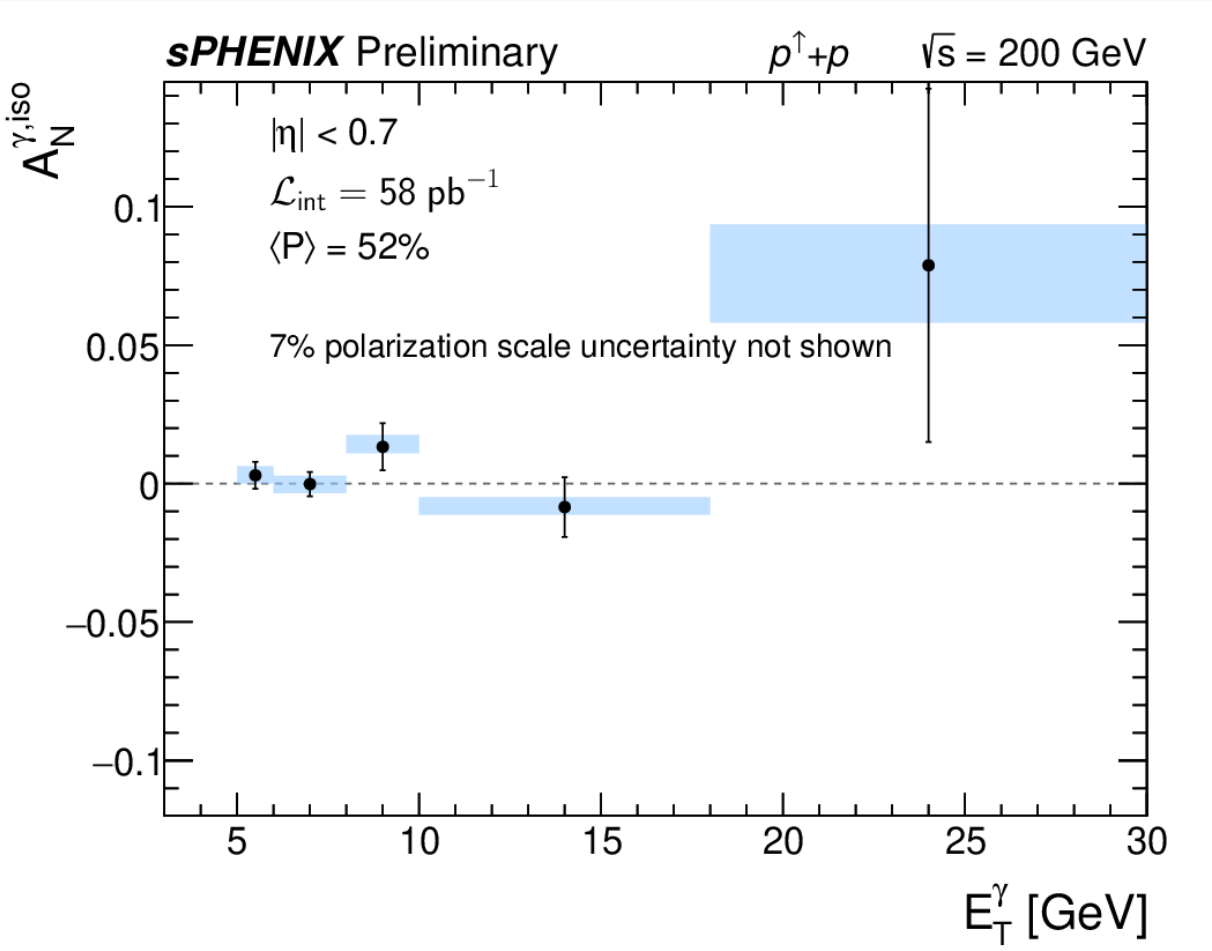
Fully corrected result

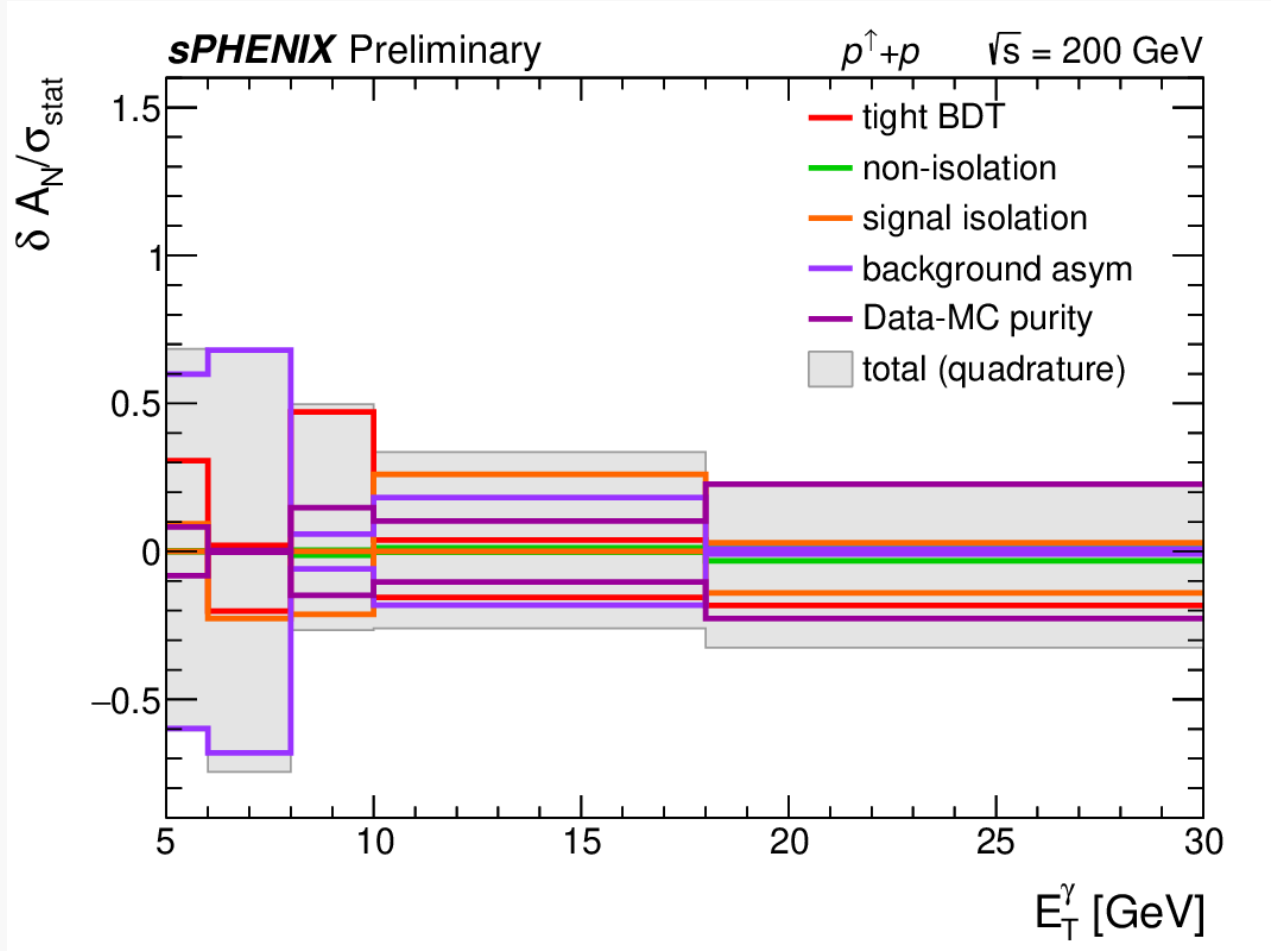
* Background $A_N^{\pi^0}$ is measured to be small in sPHENIX.
  sPH-CONF-COLDQCD-2025-01
  We set A_N^{bg} as 0 and included the residual effect as systematic uncertainty.
* TSSA is evaluated for each beam and then combined.

Preliminary result

- Asymmetry consistent with 0

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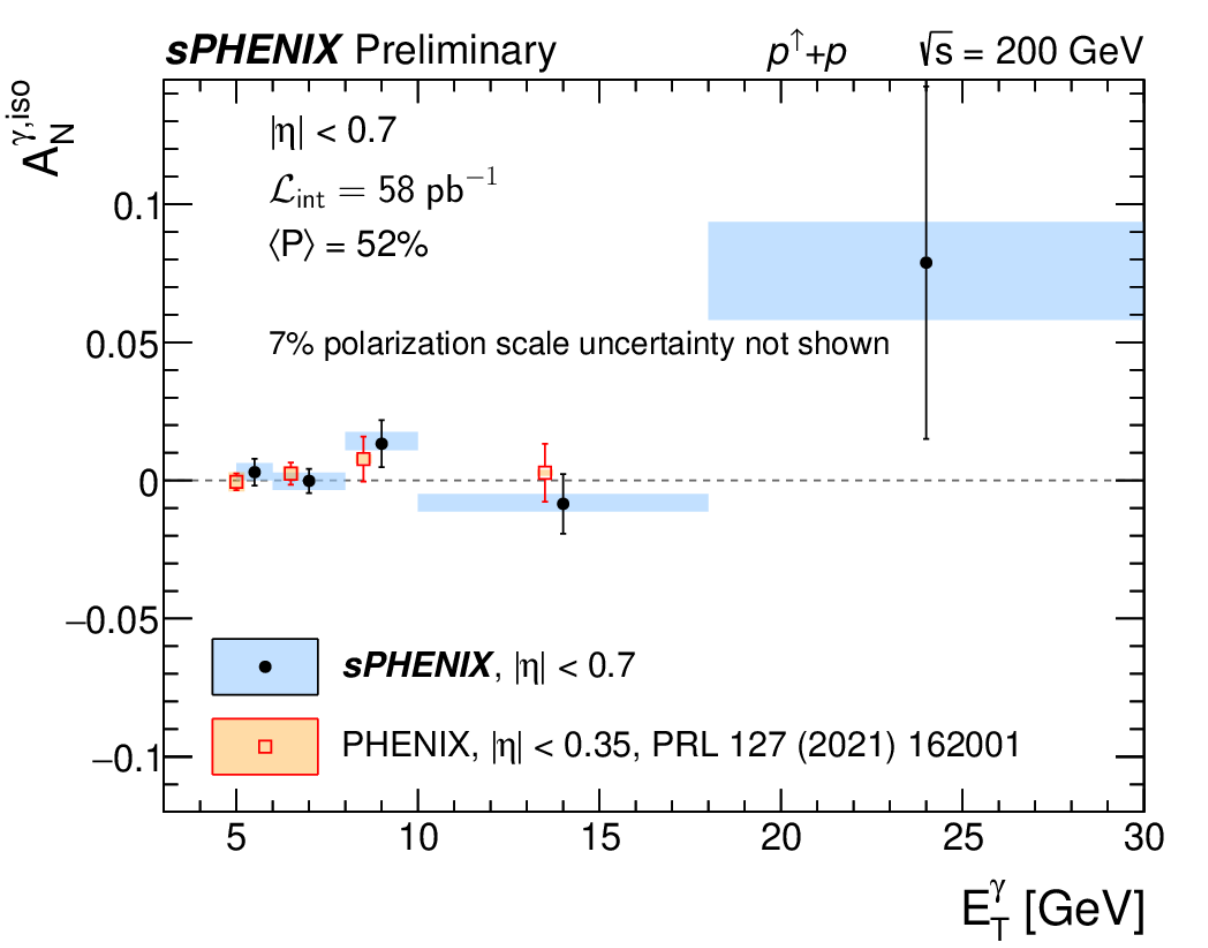


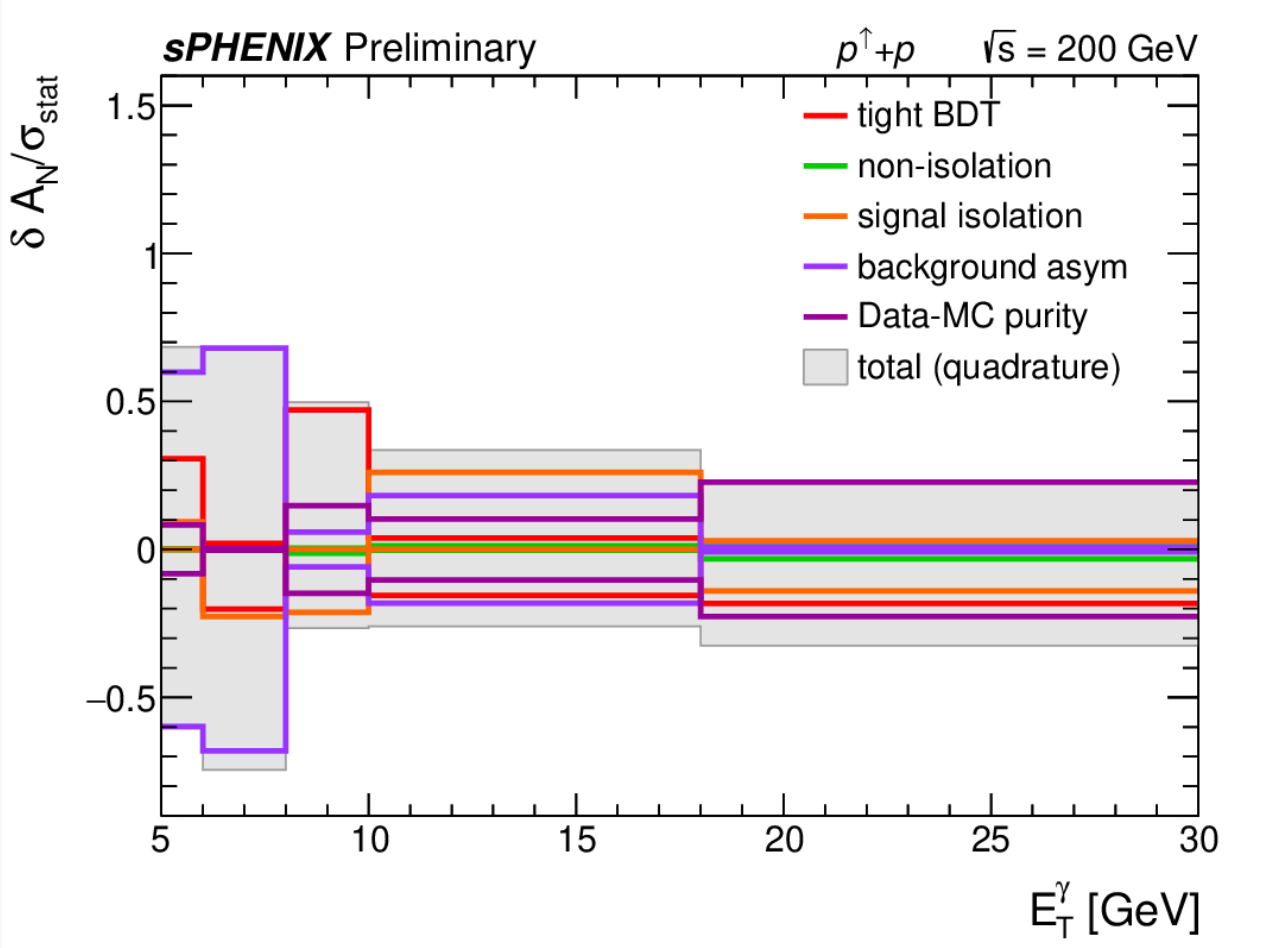


Preliminary result

- **Asymmetry consistent with 0**
  - also consistent with PHENIX's result

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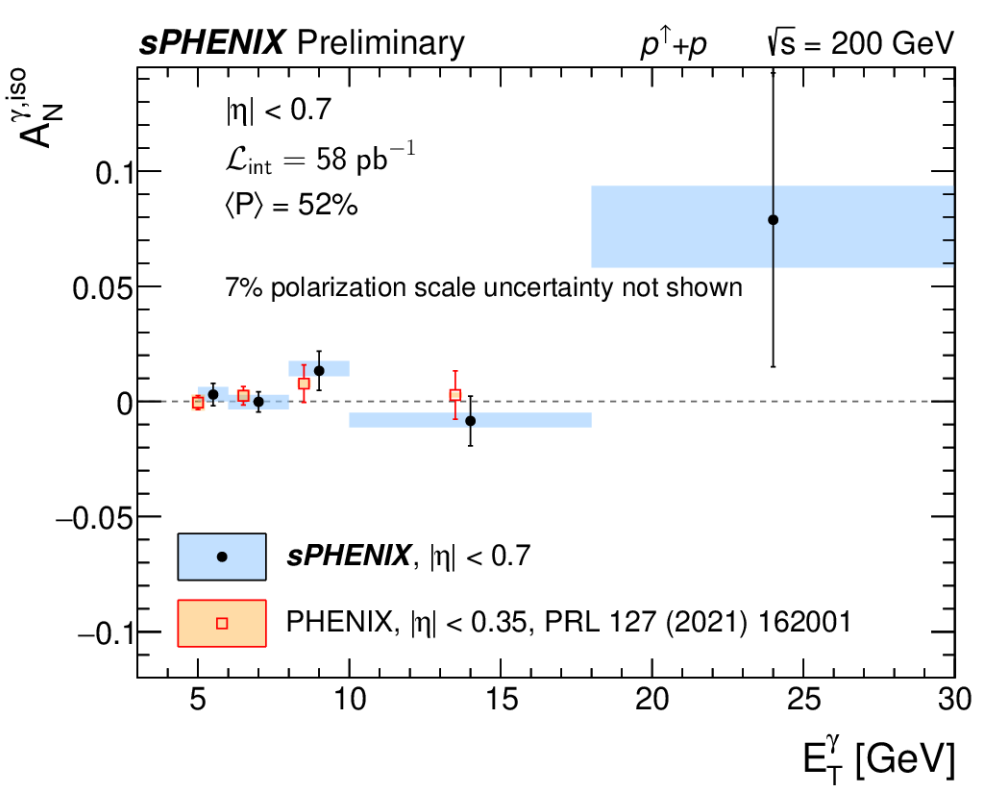




Summary and outlook

- **Isolated-γ TSSA**
  - Sensitive to internal structure of polarized proton, especially to a quark-gluon-quark correlation or tri-gluon correlation
- **Preliminary result from sPHENIX is reported**
  - Run 2024 data
  - Consistent with 0
  - Consistent with PHENIX's result
- **Ongoing works to improve the precision**

sPH-CONF-COLDQCD-2026-01



Stay tuned!

sPHENIX public results will be updated on
https://www.sphenix.bnl.gov/PublicResults

Backup

Statistical uncertainty comparison with PHENIX

- Scale > 1: worse than PHENIX
- Scale < 1: better than PHENIX

E_T-independent scale factors between sPHENIX and PHENIX statistical uncertainty on A_N

	Efficiency ($\sqrt{\text{Eff.}}$)	η coverage ($\sqrt{\Delta\eta}$)	ϕ coverage	Pol. ($1/P$)	Lumi. ($\sqrt{L}$)	Total
sPHENIX	50%	1.4	2π	51.5%	57.59 pb^{-1}	-
PHENIX	60%	0.7	π	59%	60 pb^{-1}	-
scale	1.1	0.71	0.90	1.15	1.02	0.825

$\sin(\phi)$ effect

A_N statistical uncertainty for sPHENIX result scaled to PHENIX condition compared with PHENIX result

E_T (GeV)	P_{sPHENIX}	P_{PHENIX}	$\text{scale}_{\text{total}}$	$\sigma_{\text{stat}}^{\text{sPHENIX}}$	$\sigma_{\text{stat}}^{\text{PHENIX}}$	$\sigma_{\text{stat}}^{\text{sPHENIX*}}$
5-6	0.24	0.48	1.16	0.0048	0.0030	0.0041
6-8	0.41	0.60	1.00	0.0044	0.0040	0.0044
8-10	0.55	0.70	0.93	0.0085	0.0081	0.0091
10-18	0.64	0.83	0.93	0.0108	0.0105	0.0116

sPHENIX true stat. error

If the conditions listed here (Eff., η coverage, ϕ coverage…) are the same, sPHENIX should get this σ_{stat}.

Remaining difference may be explained by uncertainty in energy scale, efficiency, and purity