Isolated photon transverse single spin asymmetries with sPHENIX

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U.S. DEPARTMENT OF ENERGY | Office of Science

RBRC RIKEN BNL Research Center

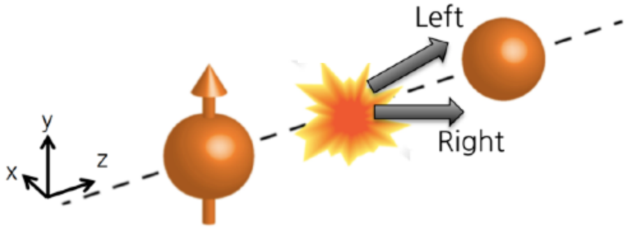
Brookhaven National Laboratory

Transverse Single Spin Asymmetry

Transverse Single Spin Asymmetry $A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$

In the polarized p+p collision, A_N is defined by a left-right cross-section asymmetry

Non-zero TSSA at forward rapidity has been observed in p+p collisions at RHIC.

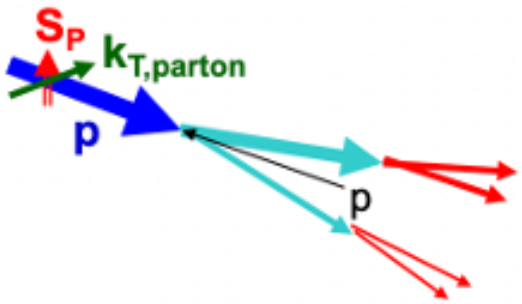


Possible sources of TSSA

Initial state effects:

Correlation between proton spin and Parton k_T

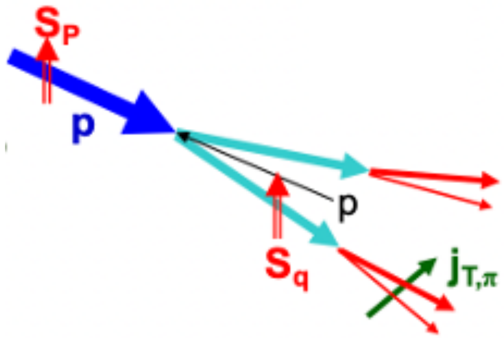
Related to q-g correlation & g-g correlation



Final state effects:

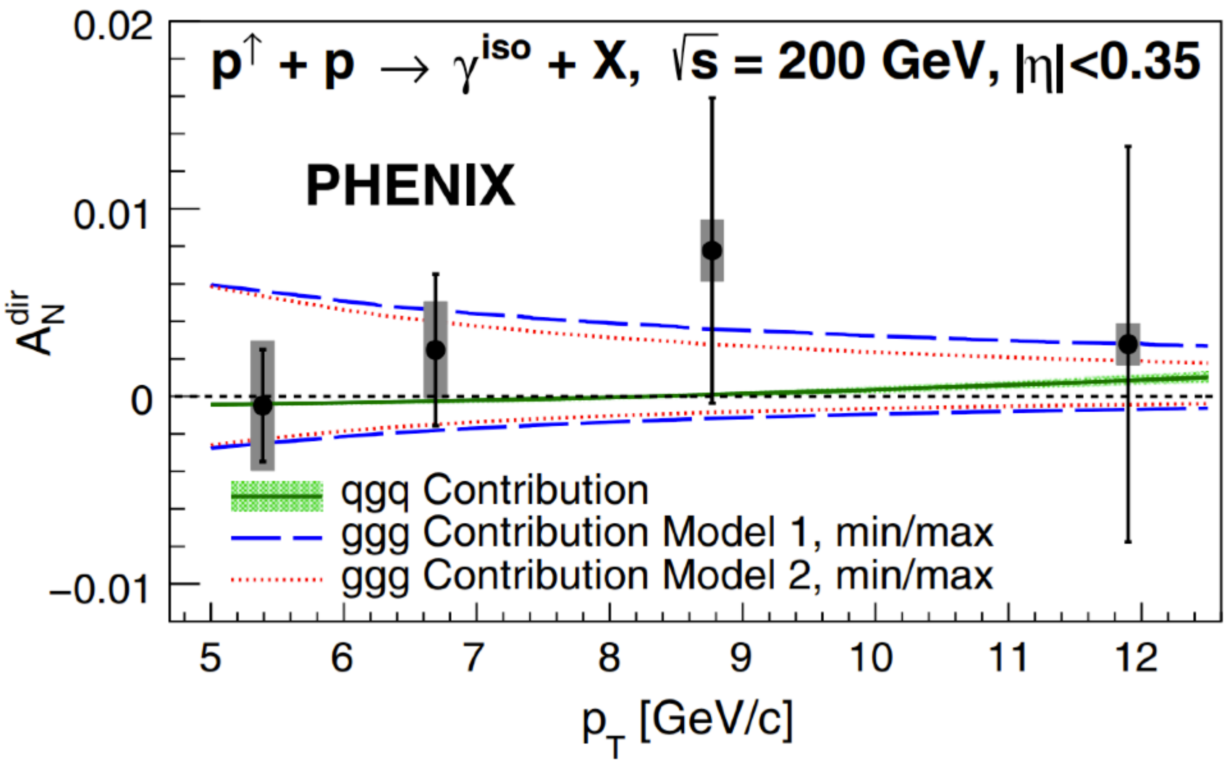
Spin momentum correlation in a Fragmentation Function

Related to q-g FF correlation



Previous Direct photons A_N at midrapidity

PHENIX collaboration, PRL127, 162001 (2021)



- **Quark–gluon Compton scattering** is the dominant source of direct photons at midrapidity
- Photons interact **only electromagnetically**

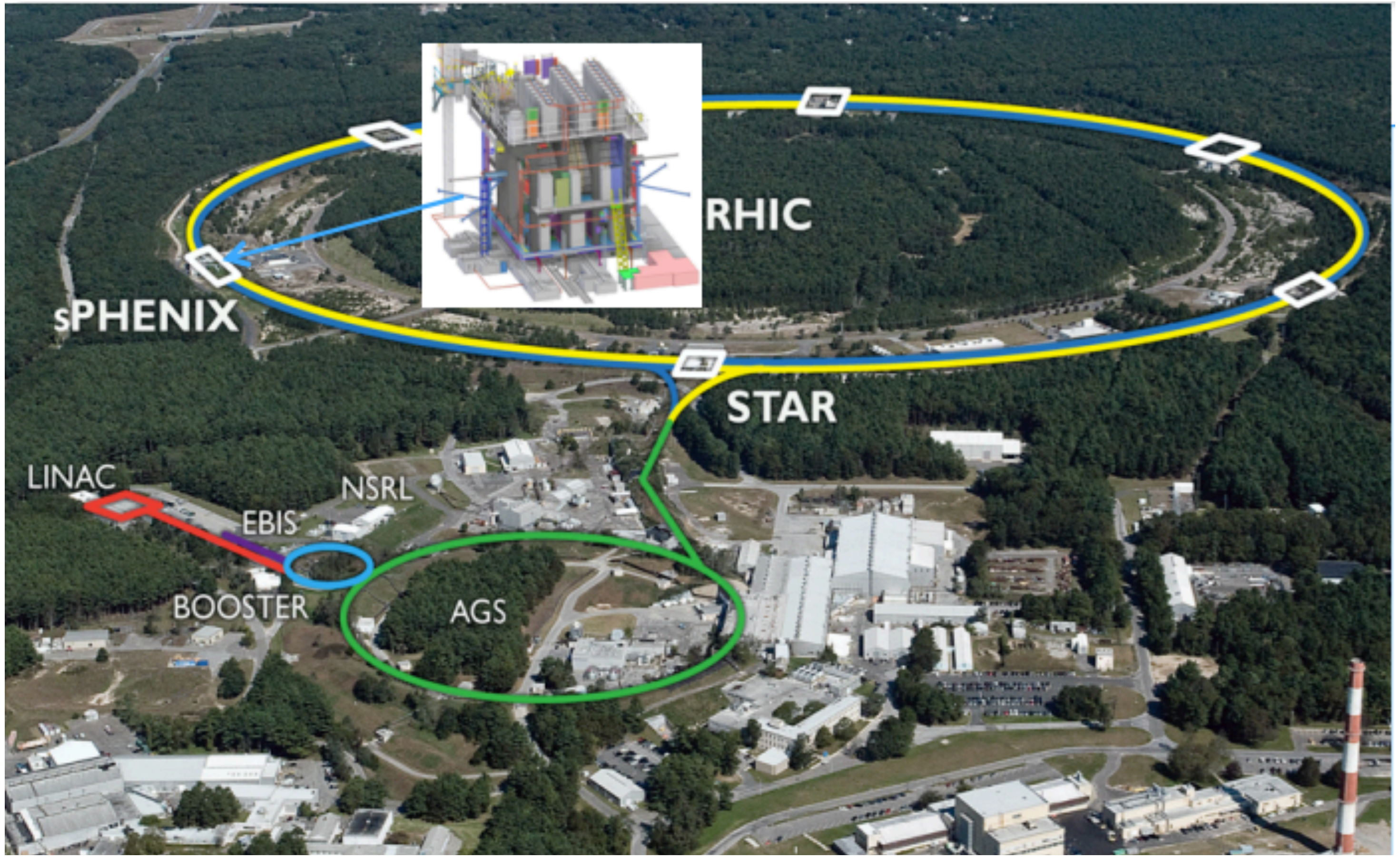
→ **No final-state effect**

- Midrapidity direct photons play as a **golden probe of the initial state effect & gluon-gluon correlation functions**

- But still significant uncertainties remain across all bins

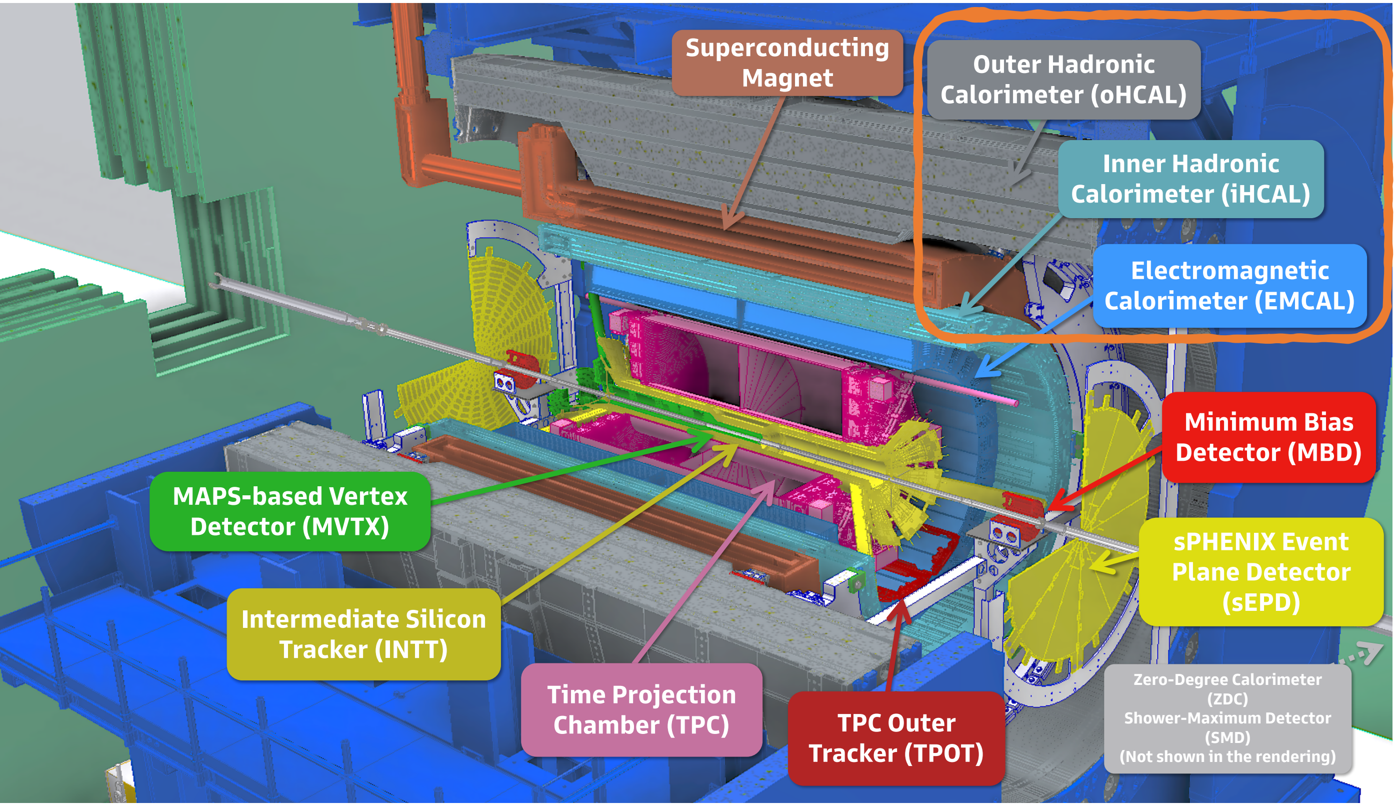
- **The increased statistics in sPHENIX offer the potential for reduced uncertainties**
  → stronger constrains on tri-gluon correlator

sPHENIX experiment



- The only brand new detector at RHIC in nearly 20 years
- Installed in 2023 on the site where PHENIX once stood
- Commissioning began with the Au+Au collisions in Run-2023
- Transversely polarized p+p collisions, additional Au+Au collisions in Run-2024
- Au+Au data taking is ongoing

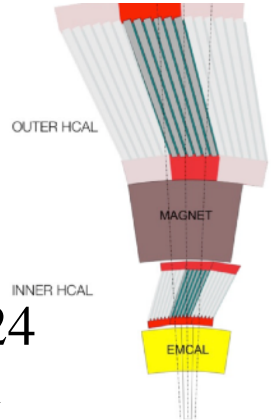
sPHENIX detector



sPHENIX Calorimeter system

- Full azimuthal coverage

- $|\eta| < 1.1$ **in** $|z_{vtx}| < 10$cm



EMCal

Granularity : $\Delta\phi \times \Delta\eta = 0.024 \times 0.024$

EMCal clusters used for photon energy & identification

Inner/Outer HCal

Granularity : $\Delta\phi \times \Delta\eta = 0.1 \times 0.1$

Mainly used for photon isolation

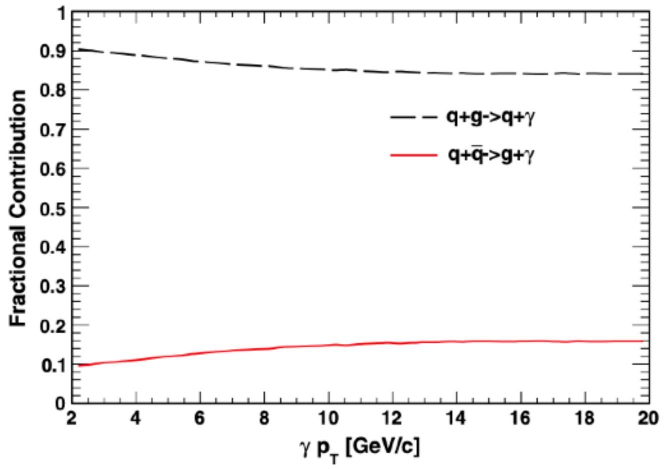
15 kHz high data taking rate!

The larger and more hermetic acceptance of sPHENIX compared to PHENIX will enhance statistics of direct photons for A_N measurements!

Direct photon and background source

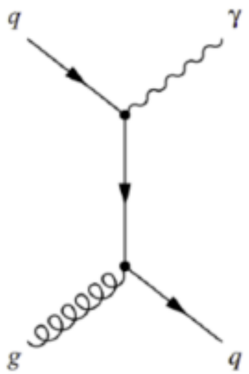
Direct photon

PHENIX collaboration, PRD82, 072001 (2010)

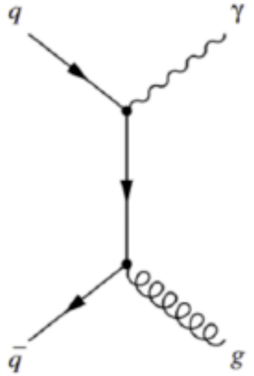


- Produced primarily via hard scattering processes, $qg \rightarrow q\gamma$ is the dominant source (~90%) at midrapidity in p+p collisions $\sqrt{s}$ = 200 GeV
- Background photons from the fragmentation photons and decay photons are not negligible.
- **Isolated photons** provide a cleaner probe of direct photons.
  Isolation requirements suppress contributions from fragmentation and decay photons

Direct photons



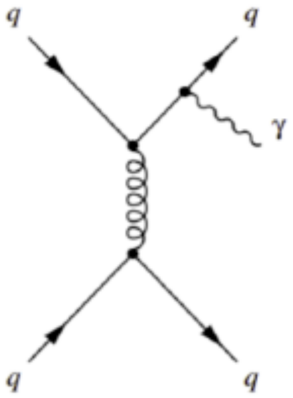
Quark-gluon Compton scattering



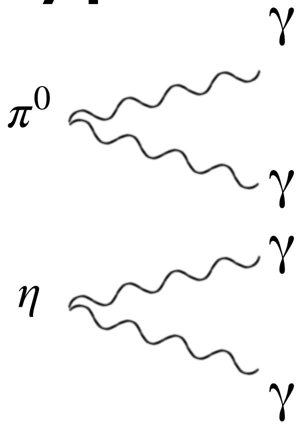
Quark-antiquark annihilation

Background photons

Fragmentation photons

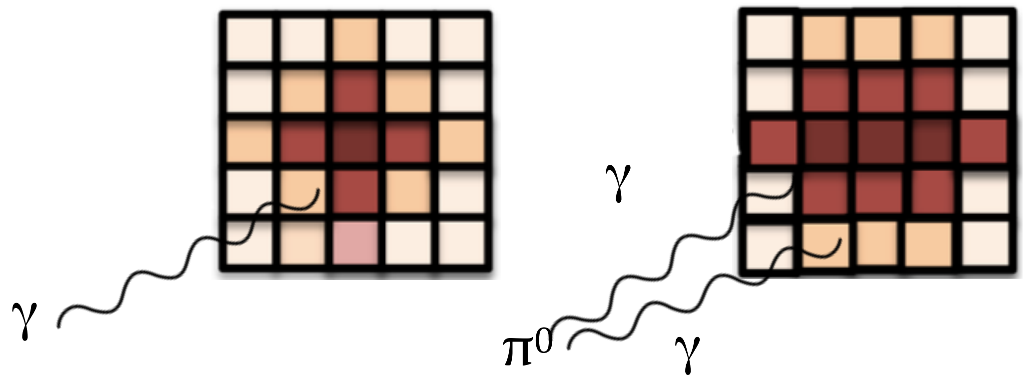


Decay photons



Photon Identification

- Prompt photons (direct + fragmentation photons) are distinguished from background photons (photons decayed from hadrons e.g. π^0, η) using various shower shapes in EMCAL



Broader shower shape in EMCAL

Decay photons tend to have broader distributions in EMCal

One of the strongest shower shape variables

2nd moment of energy weighted EMCal tower distribution in η

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

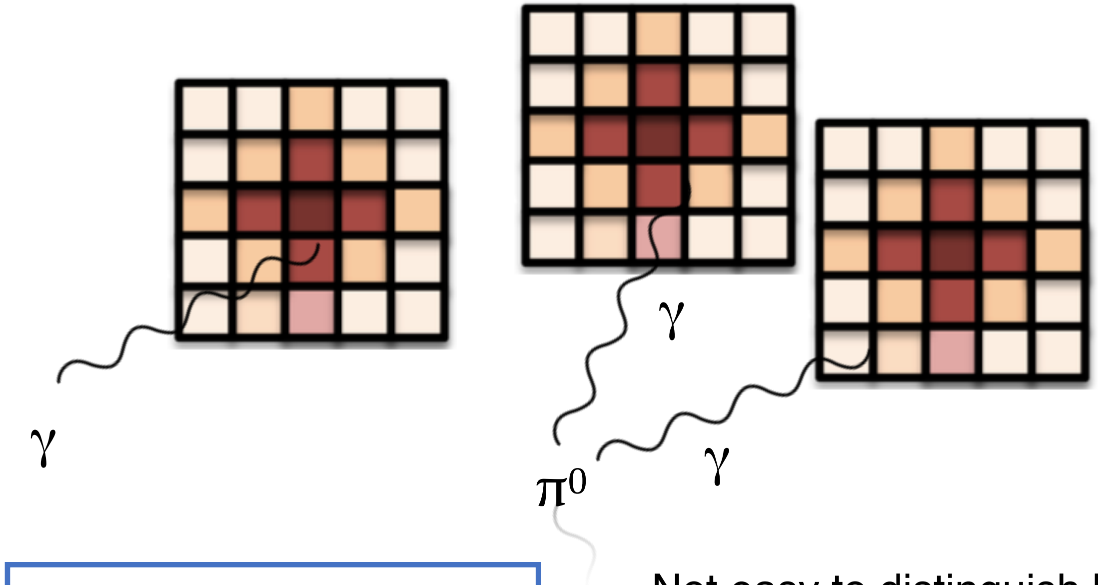
Multi-variable shower shape cuts applied to suppress the background from decay photons

Photon identification : tagging cut

[sPHENIX Performance Results]

Neutral meson Tagging: Photon

- photons decayed from neutral meson, (e.g. π^0, η) with high opening angle
  -> hard to separate them by shower shape analysis
  -> Dominant background source for direct photon at low p_T

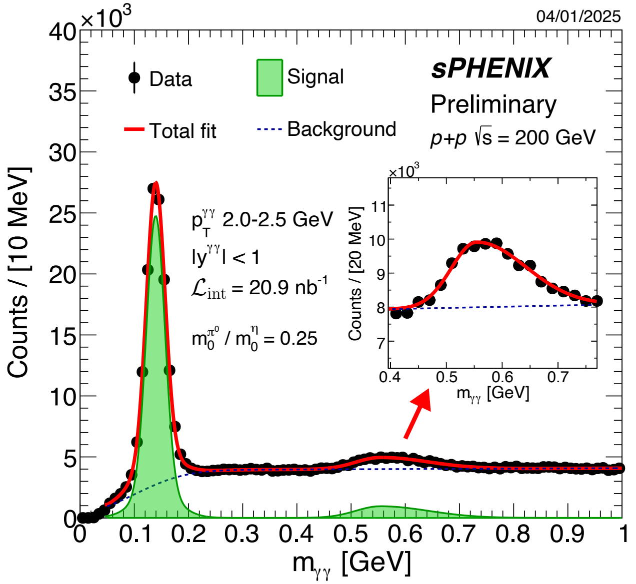


Not easy to distinguish by shower shape only

NOTE: This cut has *not* been applied to the preliminary cross-section results shown in later this talk.

Tagging method

Reject photons that, with any other EM cluster, yield $m_{\gamma\gamma}$ in the π^0/η mass window(s).



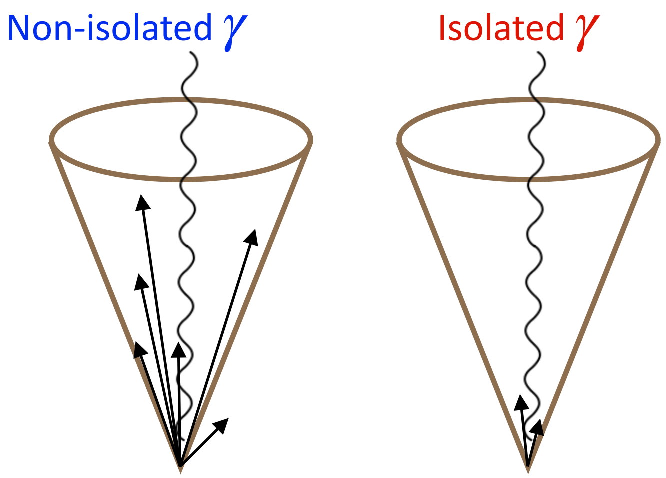
Decay photons with high opening angles can also be distinguished through the tagging method!

Planning to apply this method for exploring the lower p_T region

Photon isolation condition

Photon isolation

- Isolation energy E_T^{iso} : Summing up E_T of all towers within an isolation cone of radius, excluding E_T of the cluster of interest
- π^0/η mesons are typically part of jet $\rightarrow$ with more surrounding energy compared to the direct photon $\rightarrow$ tends to be non-isolated.
- **First isolation with full HCal system at RHIC!**



Isolation energy (cone size R = 0.3)

$$E_T^{iso} = \sum_{dr<R=0.3} E_T^{EMCal+HCal} - E_T^{cluster}$$

$E_T^{cluster}$-dependent isolation cut

$$E_T^{iso} < 1.08\ \text{GeV} + 0.03\ \text{GeV} \times E_T^{cluster}$$

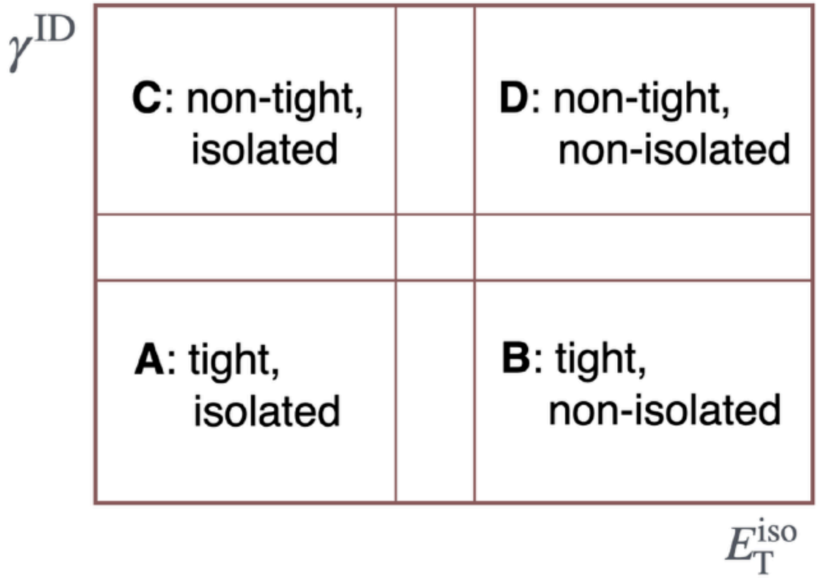
Isolated photon extraction

sPHENIX

- Even after shower shape cuts and isolation cuts, there are remaining background contaminations that are estimated using **a data-driven double sideband method**
- Set the 4 different regions with/without isolation/tight cuts

  Assuming

  → the ratio of background clusters in region C over D should be similar to the ratio of background in region A over B.



The amount of the signal N^{A}_{signal}

$$N^{A}_{\text{signal}} = N^{A}_{\text{raw}} - N^{B}_{\text{raw}} \cdot \frac{N^{C}_{\text{raw}}}{N^{D}_{\text{raw}}}$$

After signal leakage correction with MC :

$$N^{A}_{\text{signal}} = N^{A}_{\text{raw}} - \left[\left(N^{B}_{\text{raw}} - f^{B,\text{MC}} N^{A}_{\text{signal}} \right) \cdot \frac{\left(N^{C}_{\text{raw}} - f^{C,\text{MC}} N^{A}_{\text{signal}} \right)}{\left(N^{D}_{\text{raw}} - f^{D,\text{MC}} N^{A}_{\text{signal}} \right)} \right]$$

$N^{X}_{\text{raw}}, \quad X \in \{A, B, C, D\}$

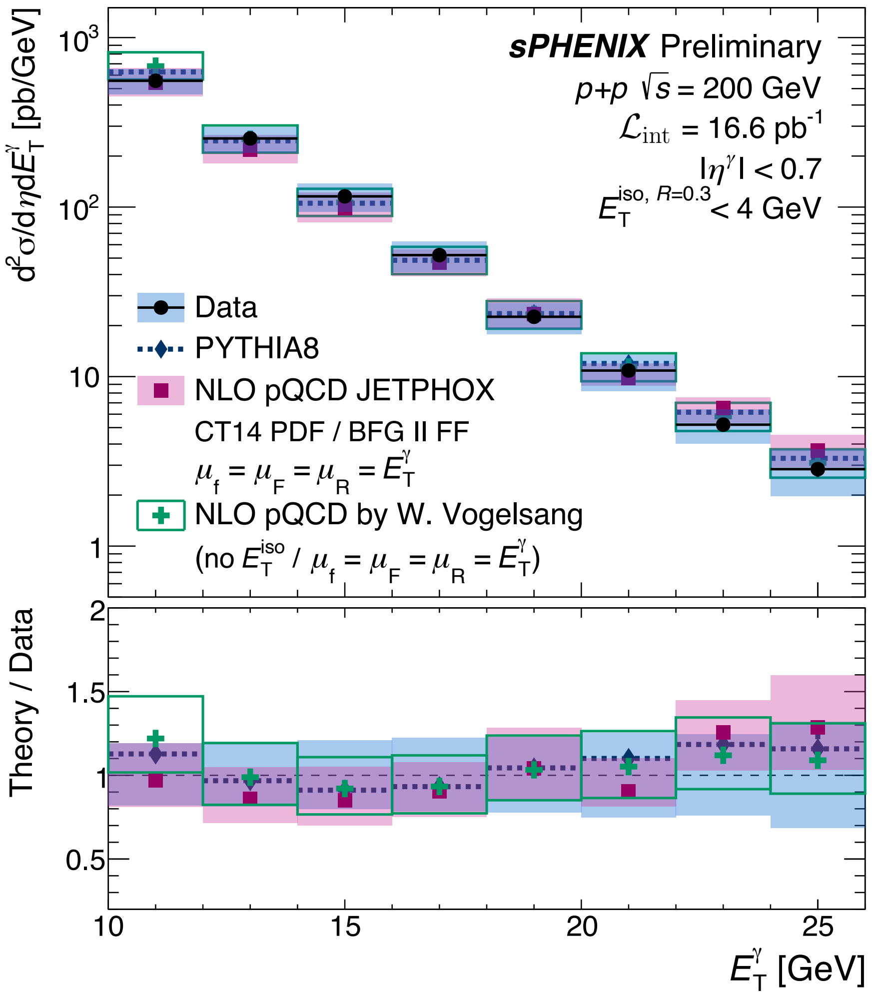
\# of reconstructed clusters in region X

$f^{X,MC}$: Signal leakage fraction driven from MC

N^{A}_{signal} : # of reconstructed signal clusters in region A

sPHENIX isolated photon cross-section

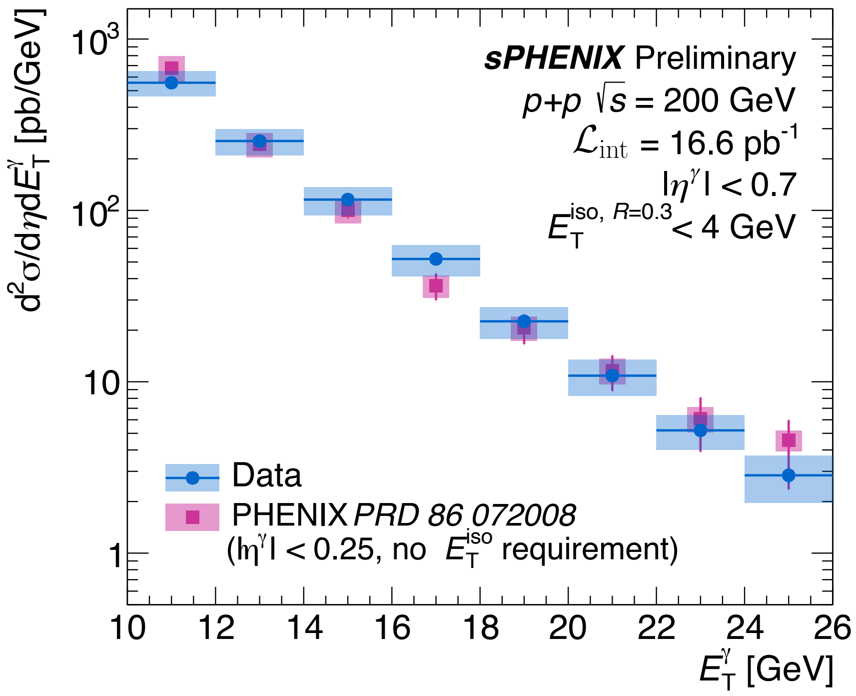
[sPH-CONF-JET-2025-02]



Comparison to theory predictions with several NLO pQCD calculations

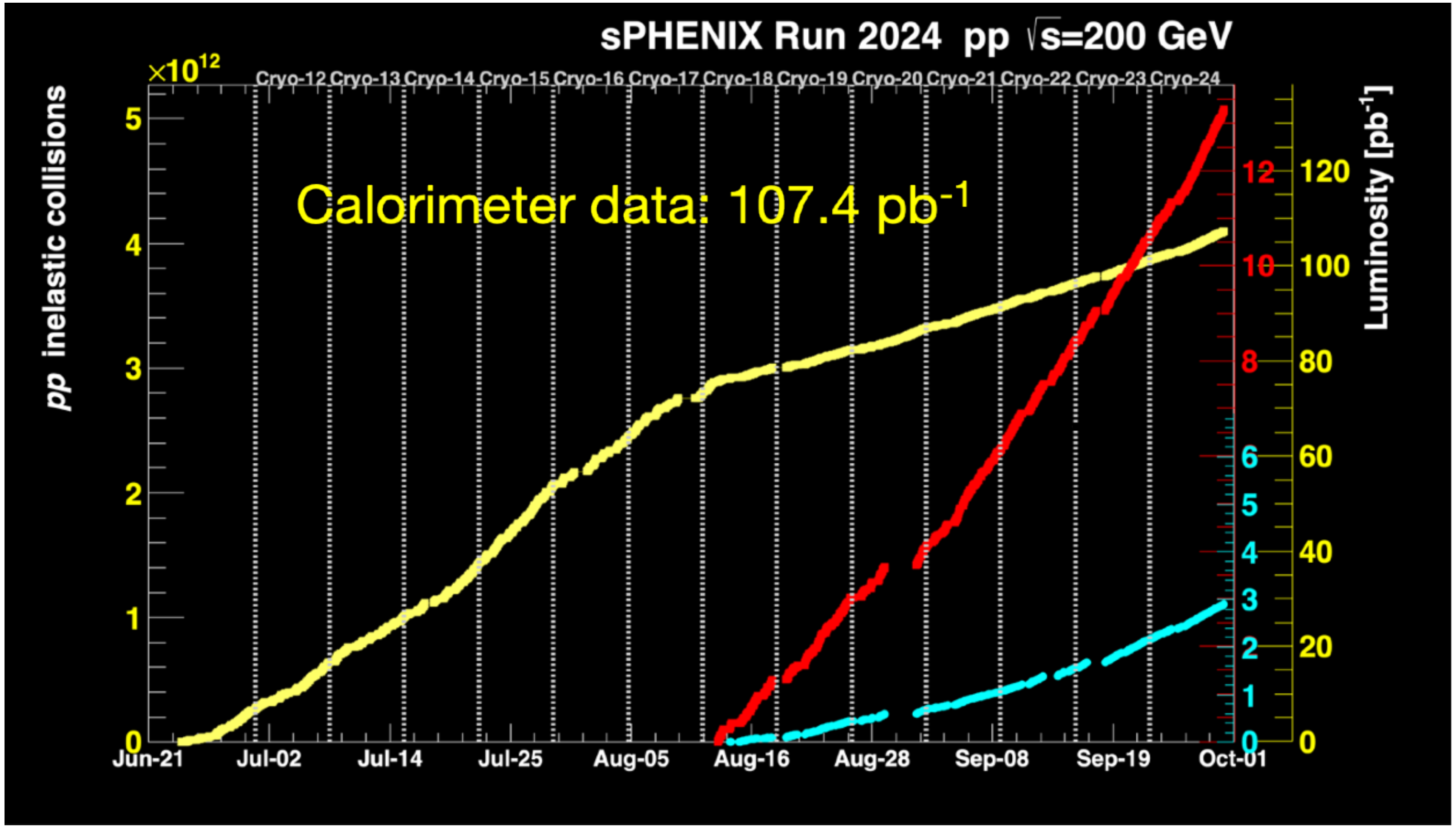
All predictions are consistent with sPHENIX data within uncertainties

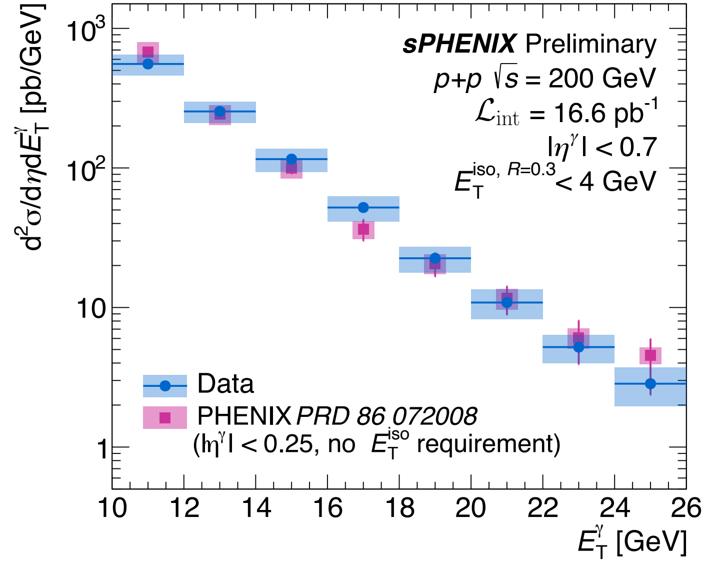
[sPH-CONF-JET-2025-02]



- **sPHENIX data show good agreement with previous PHENIX results!**
- Analysis so far uses **only 15% of the full dataset**
- More **precise** and **higher** p_T results expected with the full dataset

sPHENIX $p^{\uparrow}p$ Run 2024 Summary



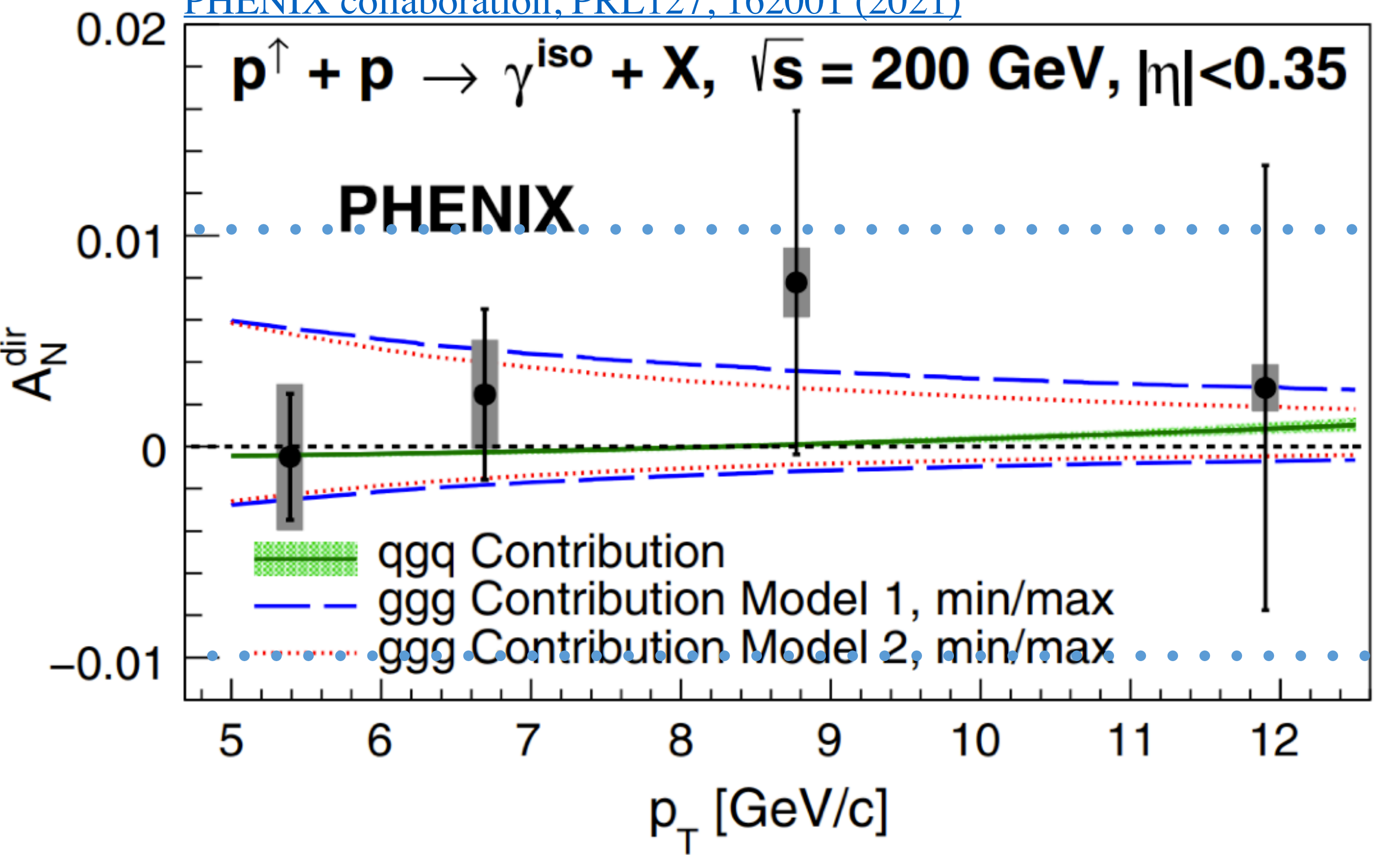


- Analysis so far uses **only 15% of the full dataset**
- More **precise** and **higher** p_T results expected with the full dataset

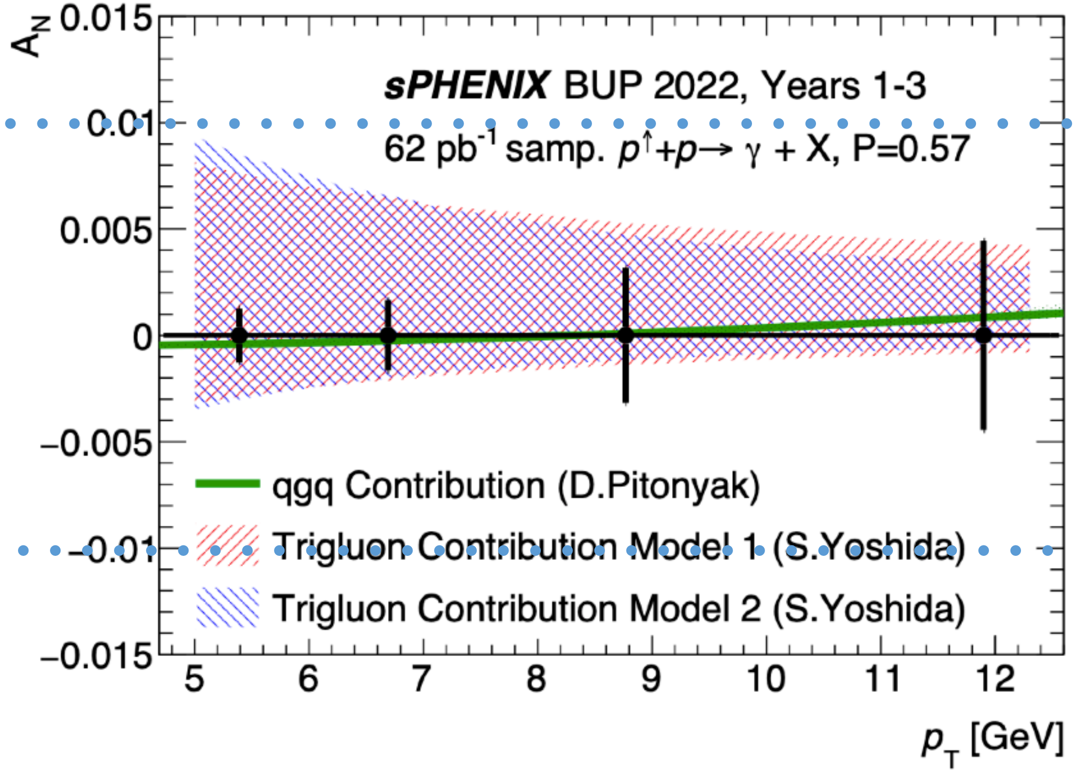
During Run2024, Photon / Jet Trigger 107.4 pb^{-1} recorded : 238.6% the original Run Goal

Statistical Projections of the Isolated Photon A_N

PHENIX collaboration, PRL127, 162001 (2021)



[sPHENIX Beam Use Proposal]

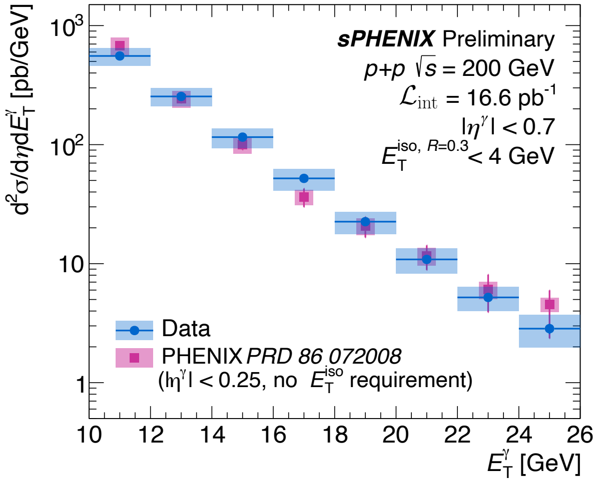


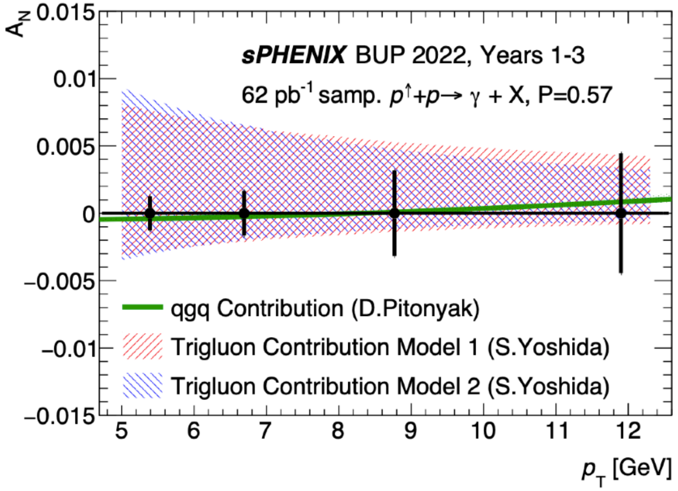
- Thanks to the larger and more hermetic acceptance of sPHENIX, the statistical uncertainties are reduced even with $\mathbf{62\,pb^{-1}}$
- Run-2024 delivered $\mathbf{107.4\,pb^{-1}}$ with the Photon Trigger — **substantial improvement in statistical uncertainties!**

Conclusion

- **Direct photon** A_N provides a clean probe of tri-gluon correlator (no final-state fragmentation).
- **sPHENIX** offers larger and more hermetic acceptance than PHENIX → improved statistics in A_N measurements.
- **Shower-shape and isolation cuts have been optimized for direct photon extraction.**
- Cross-section measurements show **excellent agreement** with theory and PHENIX results.
- A_N extraction is ongoing — **stay tuned!**

Thank you for your attention

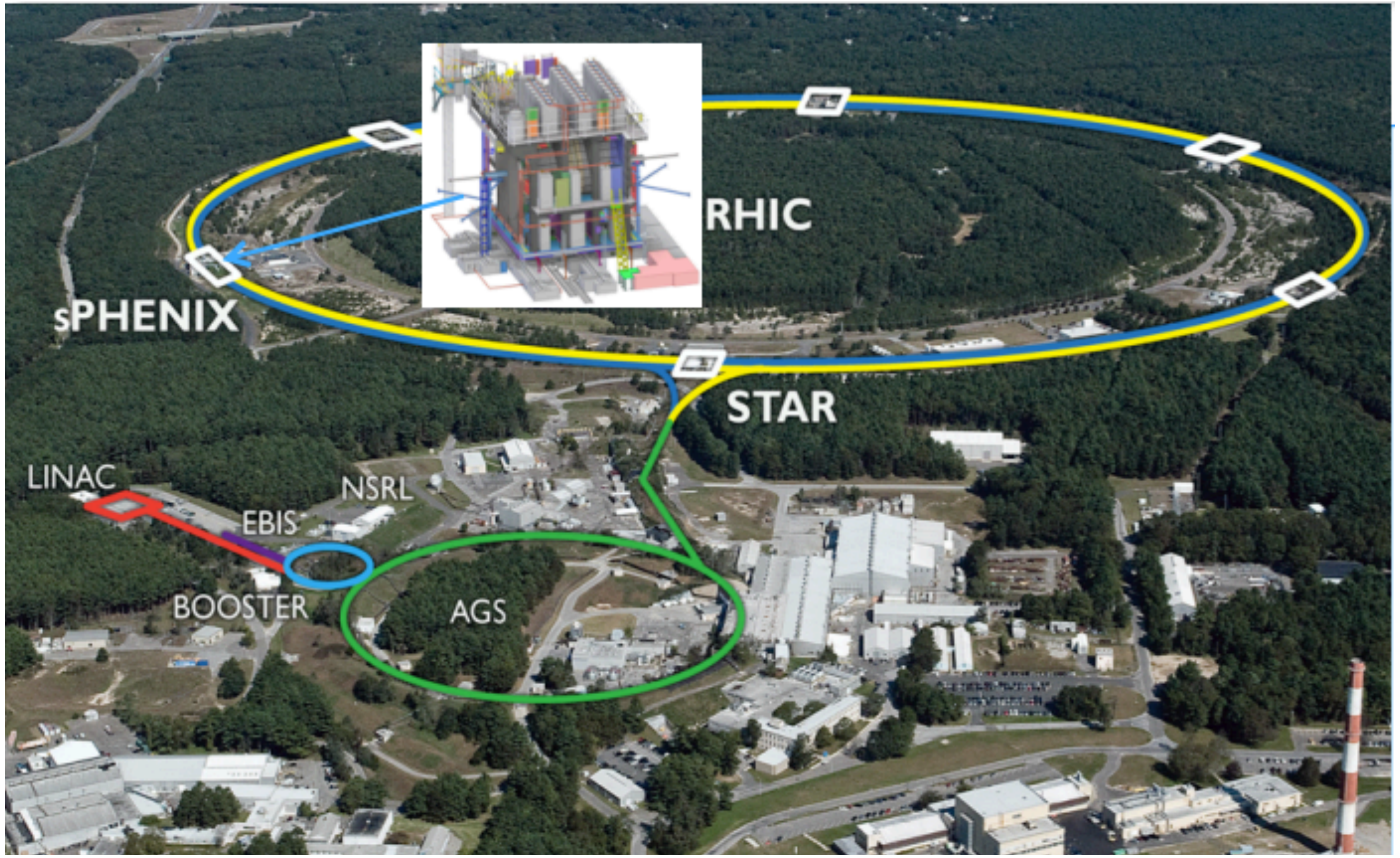




BACKUP

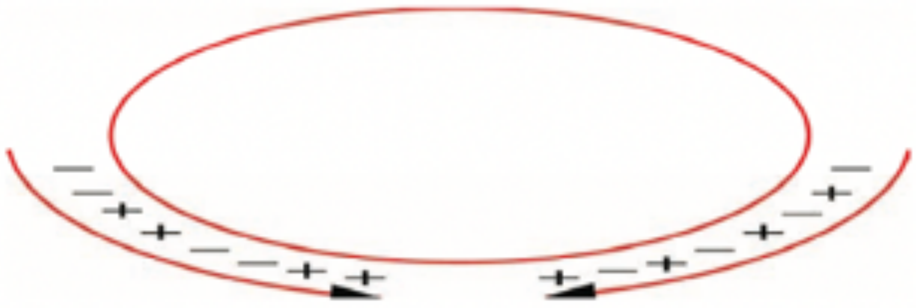
Relativistic Heavy Ion Collider(RHIC)

The world's unique polarized proton collider

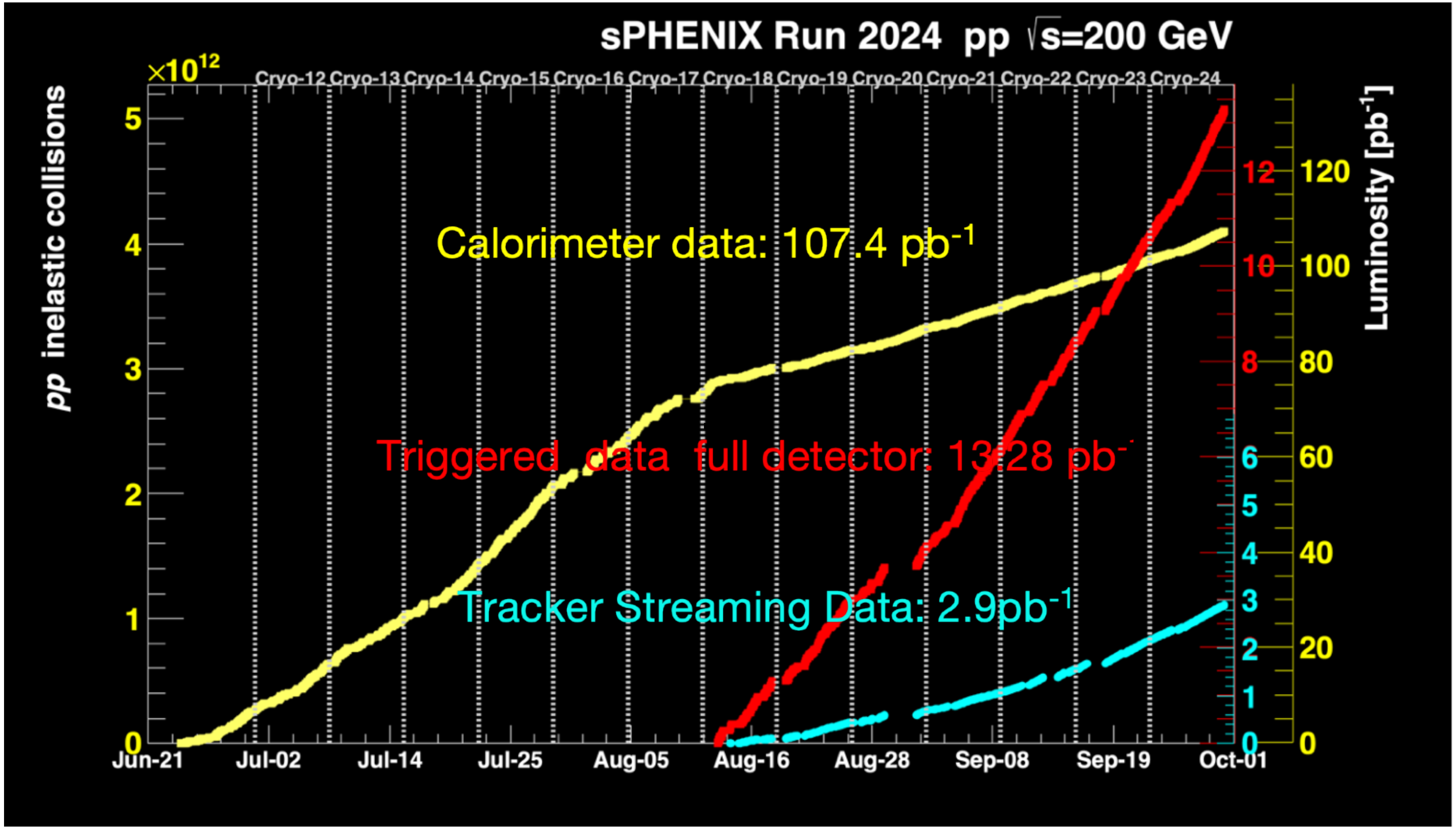


- Polarization: 50 - 60%
- Collision Energy : $\sqrt{s}$ = 62 ~ 510 GeV
- Bunch-by-bunch spin flip

  Each bunch has alternating spin orientation → minimizes detector-related systematics



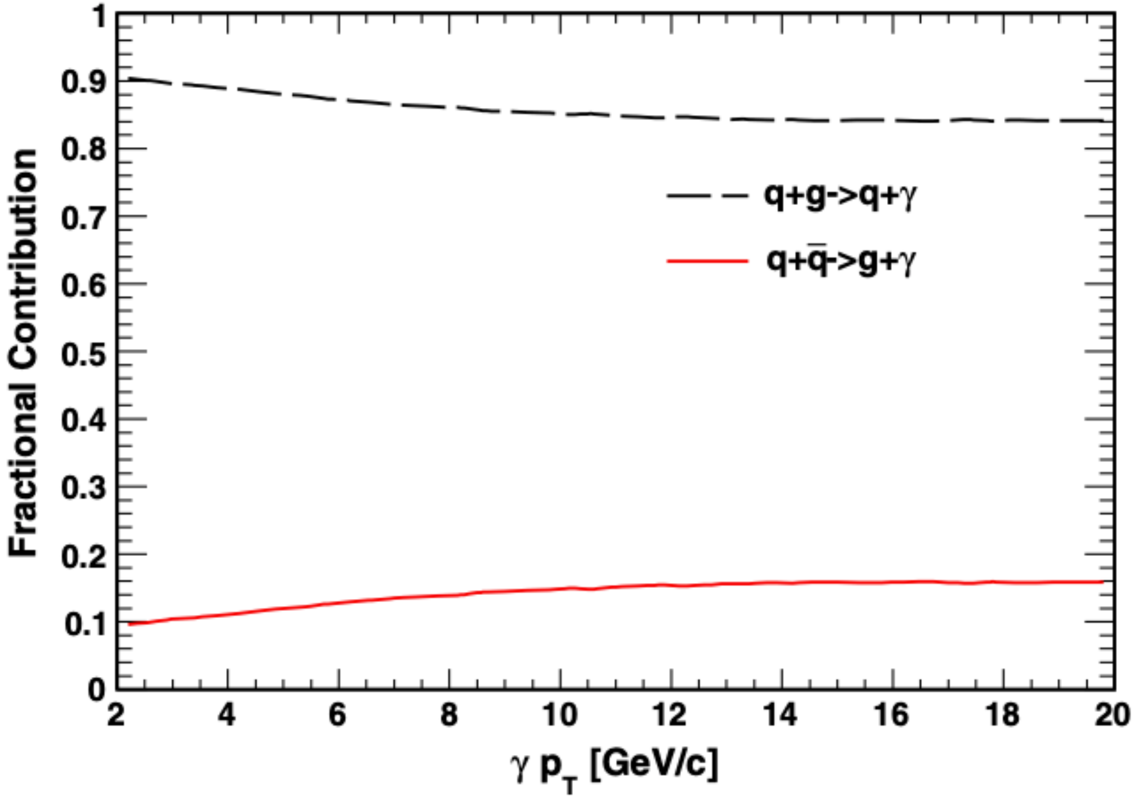
sPHENIX $p^{\uparrow}p$ Run 2024 Summary



During Run2024, Photon / Jet Trigger 107.4 pb-1 recorded : 238.6% the original Run Goal

Direct photons at midrapidity in pp $\sqrt{s}$ = 200 GeV

PHENIX collarboration, PRD82, 072001 (2010)



Fractional contributions of parton scattering processes to inclusive direct photons at midrapidity in pp collisions $\sqrt{s}$ = 200 GeV

- **Quark–gluon Compton scattering** is the dominant source of direct photons
  → Directly related to inital quark & gluon PDF
- Photons interact **only electromagnetically**

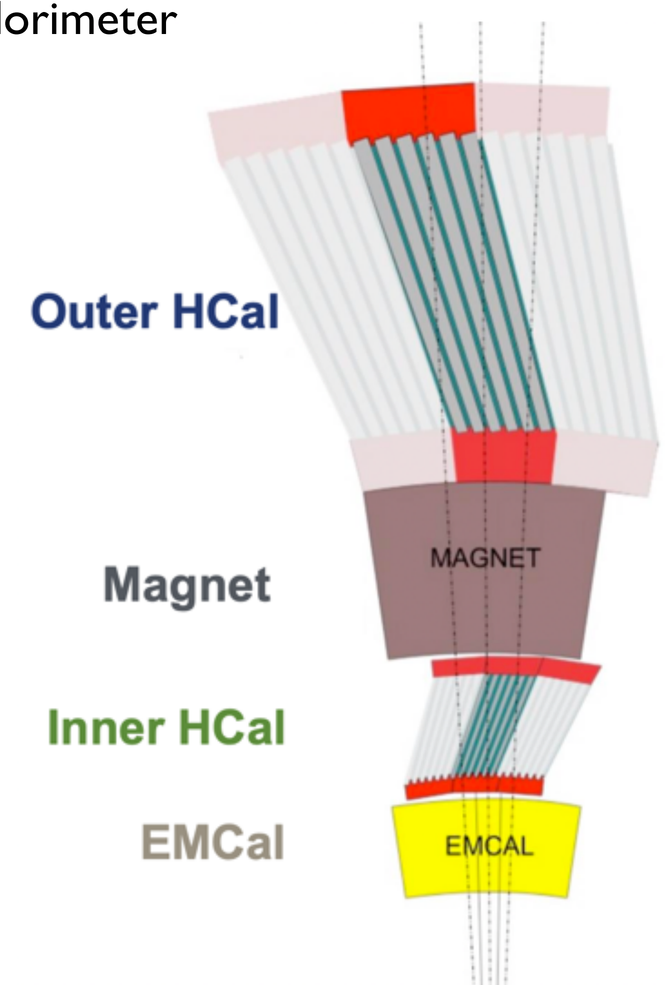
→ **No final-state effect**

- Midrapidity direct photons play as a **golden probe of the initial stage effect & gluon-gluon correlation functions**

sPHENIX Calo system & Tracker systems

sPHENIX Calorimeters

Full Electromagnetic and Hadronic system calorimeter

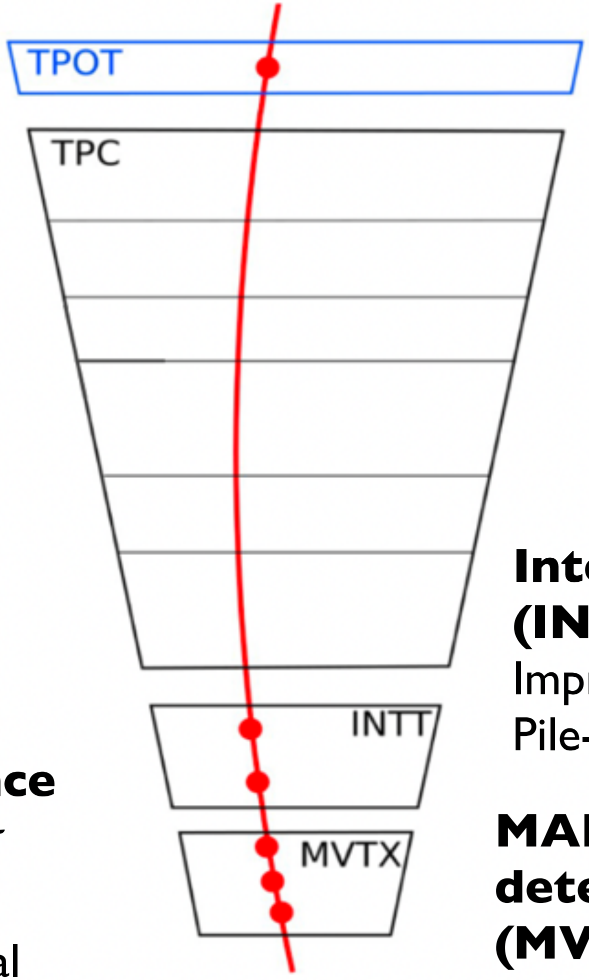


Large Acceptance

$|\eta| < 1.1$ and full 2π azimuthal coverage

Designed to be ideal detector for Jet

sPHENIX Tracking Detectors



TPC Outer Tracker (TPOT)

calibration of space charge distortions

Time Projection Chamber (TPC) (30 < r < 78 cm)

Precise momentum measurement

Intermediate Silicon Tracker (INTT) (7 < r < 12 cm)

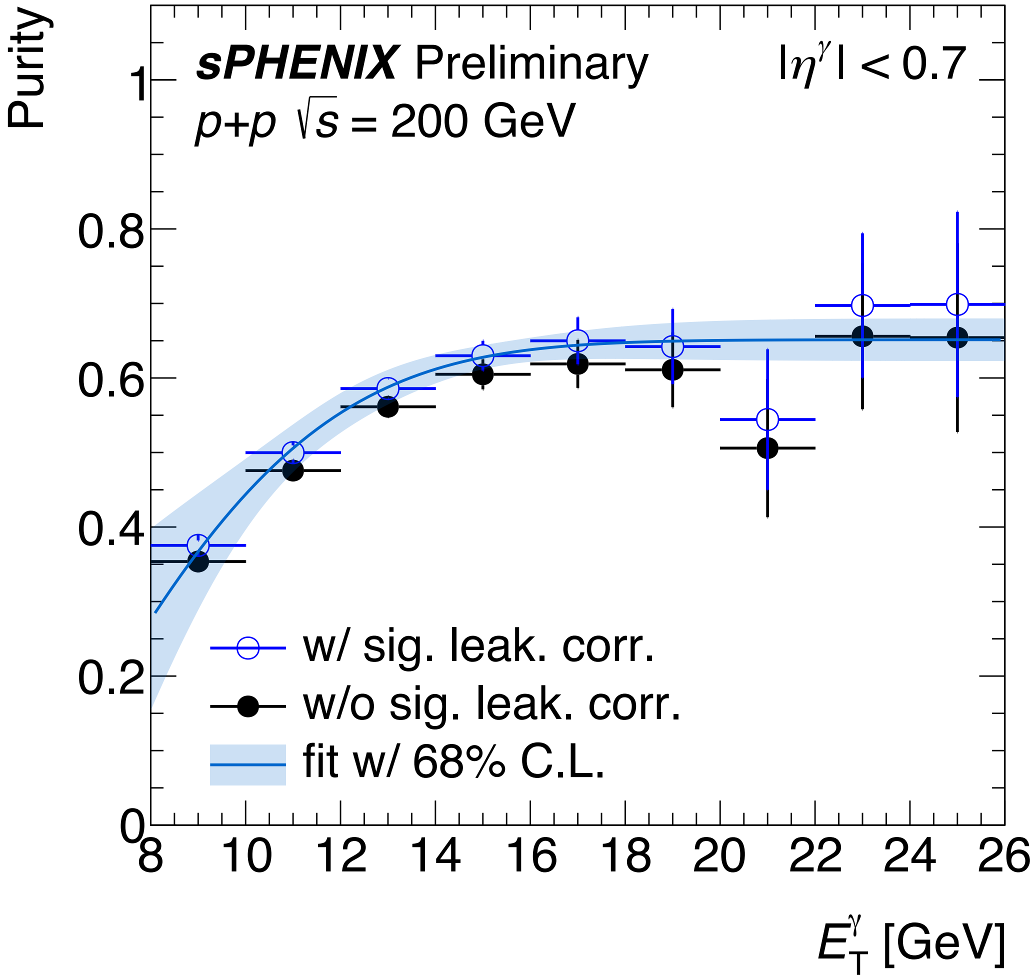
Improving momentum resolution

Pile-up separation

MAPS-based micro-VerTeX detector (MVTX) (2.3 < r < 3.9 cm)

precision vertexing

Purity estimation : double-side band method

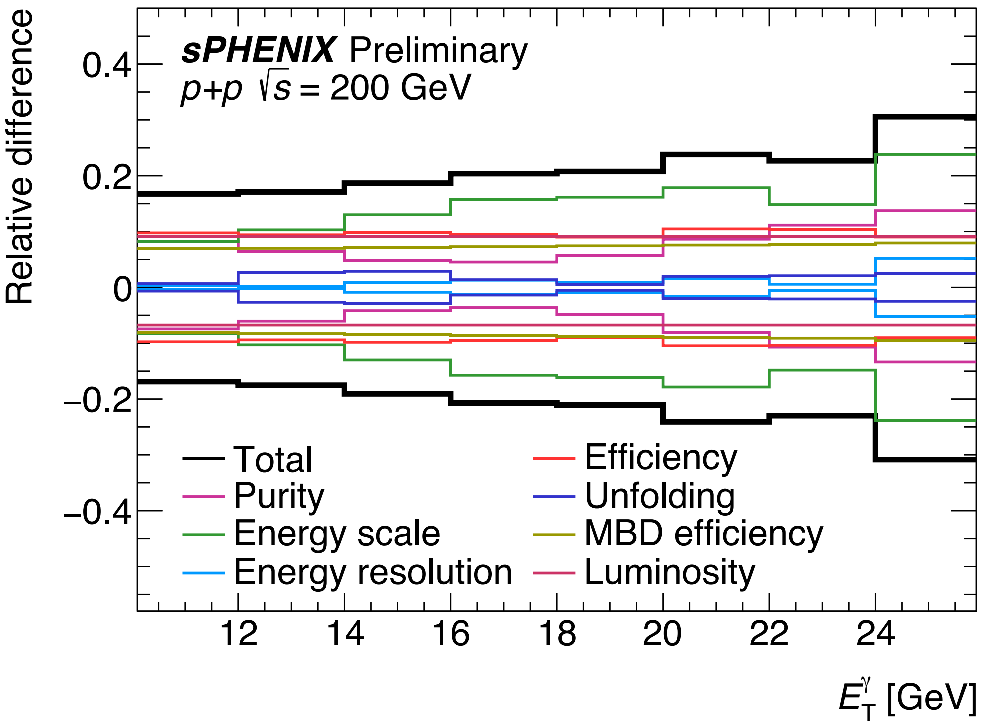


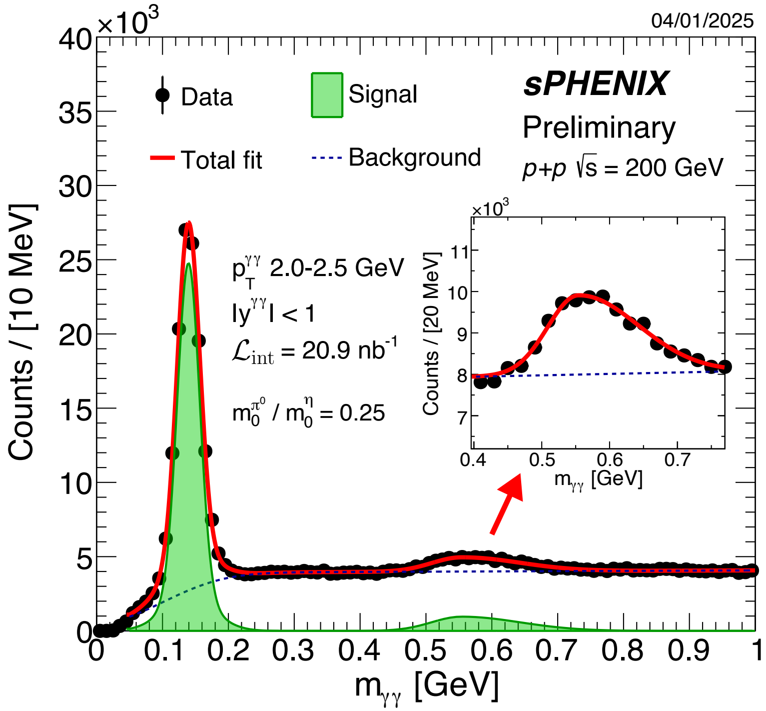
- **Purity estimation from the double-side band method**

-> For low p_T region, significant drop existed

Can be improved by the decay photon tagging method

Systematic uncertainties





- **Energy scale dominates the current systematic uncertainty**
- **Full-data calibration will significantly improve it**