Measuring the Photon-Jet Momentum Balance with the sPHENIX Detector at 200 GeV

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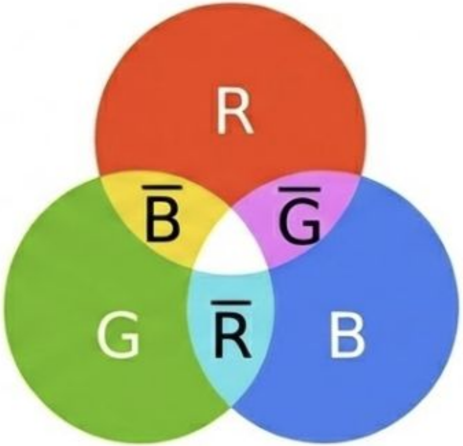
01/06/2026

Quantum Chromodynamics (QCD)

QCD = quantum field theory of the strong interaction



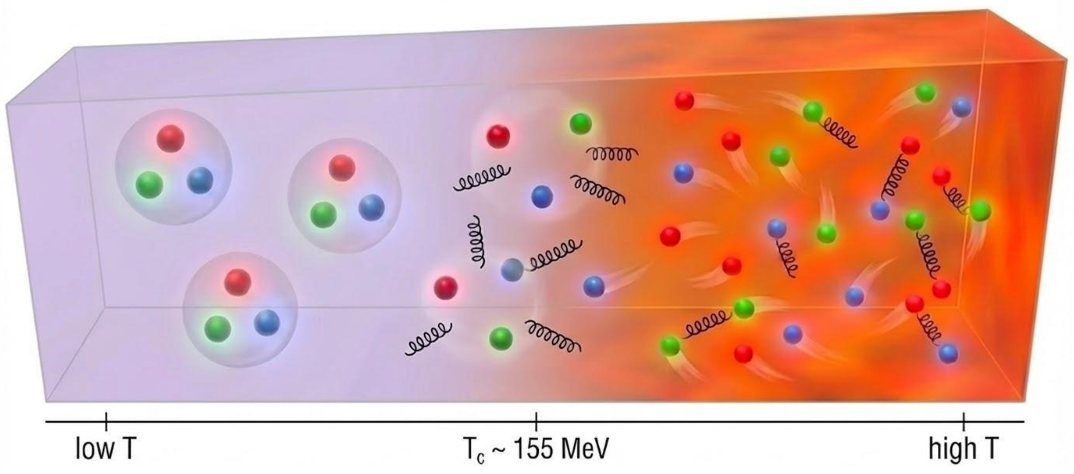
Image

- Quarks and gluons carry *color charge*
- QCD changes with scale
  - Confinement at large distance/low T
  - Weak coupling at short distance (high Q^2) – pQCD/jets

Quark Gluon Plasma (QGP)

QGP = high-temperature deconfined phase of QCD

- **Deconfined** → quarks and gluons move freely through a common medium
- **Medium behaves** like a strongly interacting *liquid*
- **Cooling** through the crossover $T_c \approx 155$ MeV → hadronization (p, n, mesons)

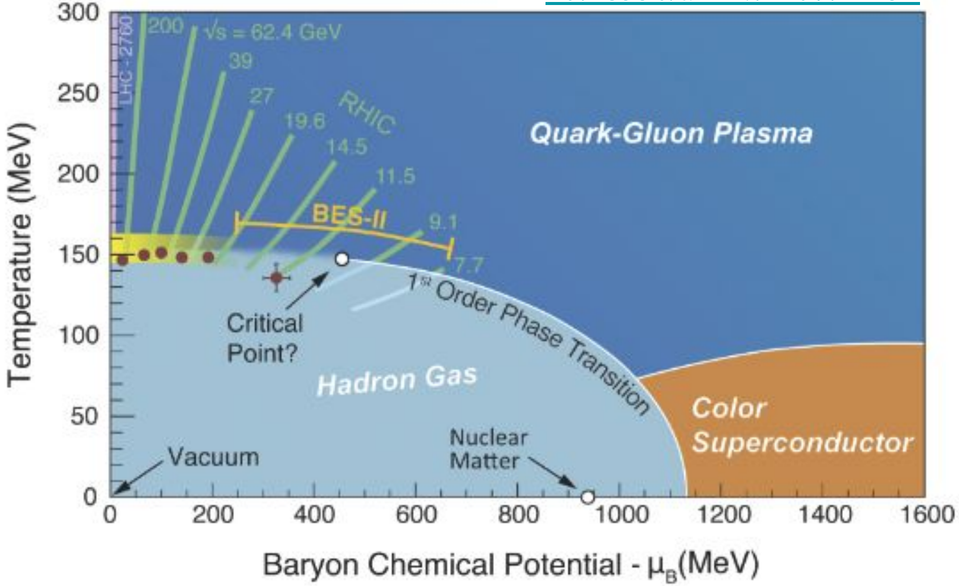


Quark Gluon Plasma (QGP) – QCD Phase Diagram

QGP = high-temperature deconfined phase of QCD

- **QCD phase diagram** – temperature vs baryon density
  - **High T** → QGP
  - **Low T** → hadronic matter
- **LHC & RHIC** create QGP in *complementary regimes*
  - **LHC** → hottest QGP
  - **RHIC** → cooler, quark-rich QGP

10.48550/arXiv.2207.12452



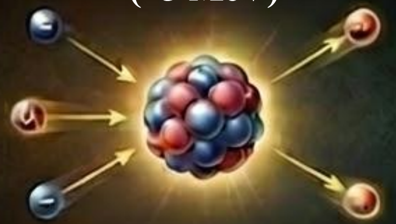
Why use Particle Colliders?

To resolve structure → probe wavelength must be ≤ object size ($\lambda \sim h/p$)

19th Century Physics (~eV)

Great for atoms & molecules
Blind to nuclei & quarks

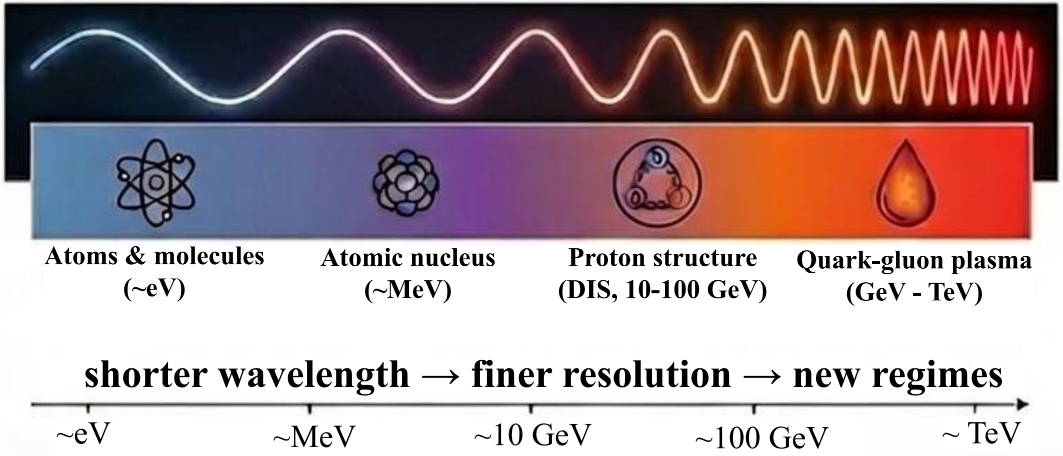
Rutherford's 1911 Experiment (~5 MeV)



Used α-particles to see inside atoms – discovered the nucleus

Today's Colliders (GeV-TeV)

Resolve partons in protons, create fm-scale QGP droplets

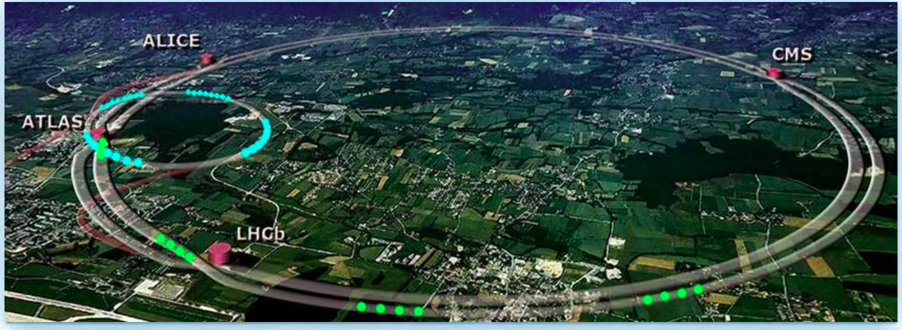


LHC and RHIC: Complementary Colliders

Historically → high energy colliders served *two primary missions*:

- **Energy frontier** → discover fundamental constituents & test the Standard Model
- **QCD-matter frontier** → create & study new phases of strongly interacting matter (QGP)

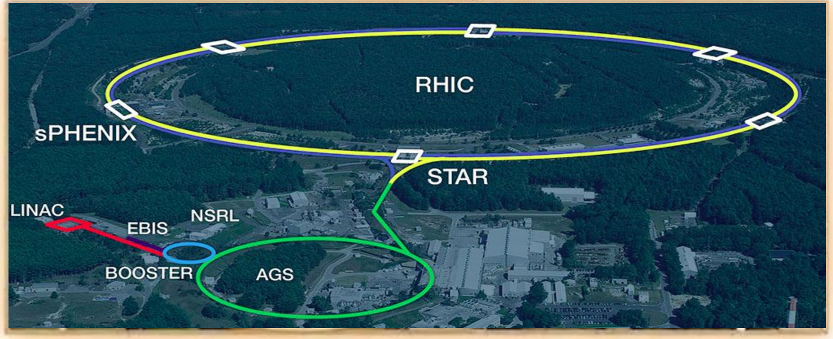
Large Hadron Collider



- **27 km collider at CERN** (Geneva, Switzerland)
- **Built as energy frontier collider →** electroweak symmetry breaking, Higgs, BSM
- **Later** incorporated heavy-ion program (ALICE, ATLAS HI, CMS HI)

Image

Relativistic Heavy Ion Collider

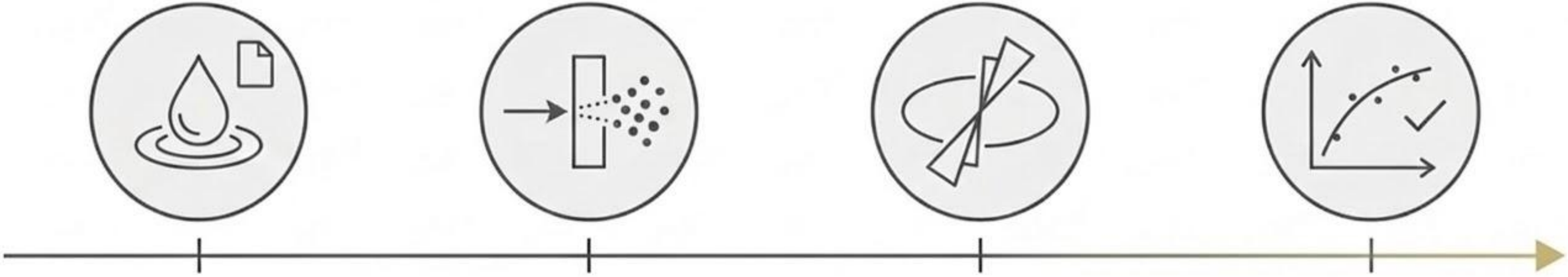


- **3.8 km collider at Brookhaven National Lab** (Long Island, NY)
- **QCD-matter focused** → create and study QGP, map the QCD phase diagram, & provide complementary regime to the LHC

Image

QGP Program Shift: Discovery → Precision

From discovery to quantitative, calibrated characterization



2005 (RHIC)
RHIC White Papers: sQGP near-perfect liquid

mid–2000s (RHIC)
Hard-probe suppression: high-p_T suppression

2010–2011 (LHC)
First LHC Pb–Pb run dijet imbalance observed

2014–Now
Global analyses infer transport coefficients

Discovery focus — Quantify QGP properties with calibrated probes — **Precision focus**

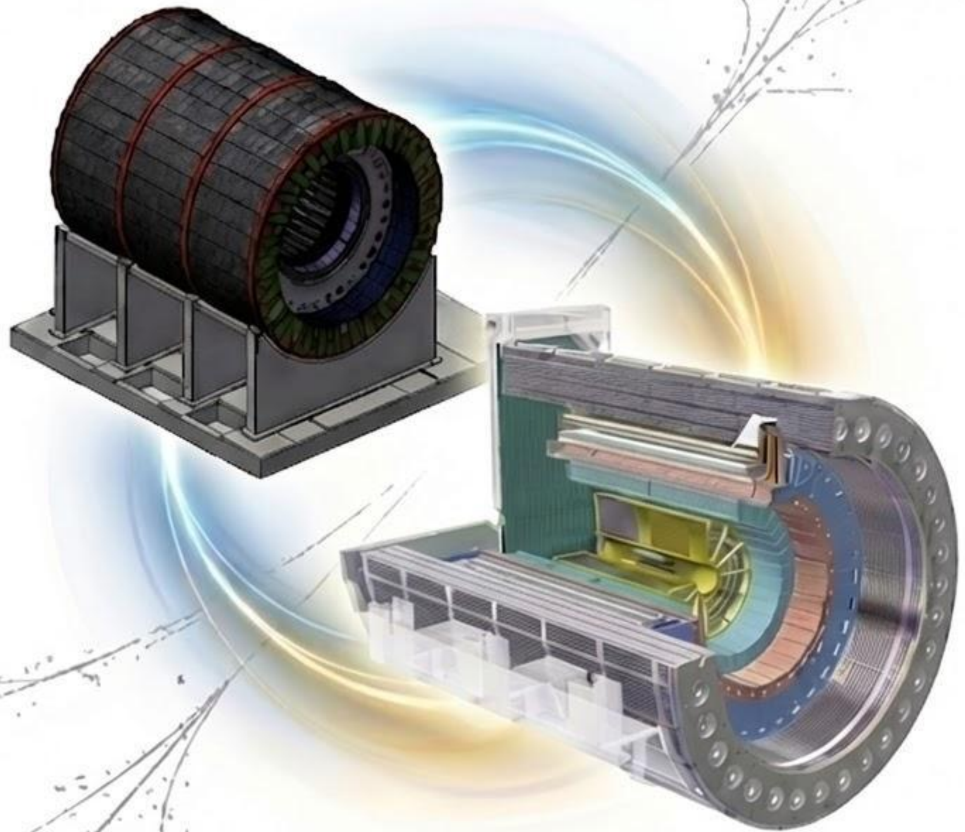
Why RHIC matters now

Complementary $\sqrt{s_{NN}} = 200$ GeV regime; Beam Energy Scan; sPHENIX: precision jets and photon-tagged probes.

sPHENIX Experiment at RHIC

Large acceptance midrapidity detector at $\sqrt{s_{NN}} = 200$ GeV

- Full azimuth and $|\eta| \lesssim 1.1$
- Purpose-built for precision jets, isolated photons, and heavy flavor
- Final phase of the RHIC science mission



Images: top, bottom

sPHENIX Subsystems

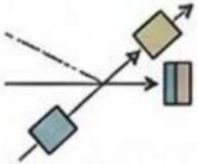
Reference

Tracking system (MVTX, INTT, TPC, TPOT)

Silicon vertex detectors & time-projection chamber inside a 1.4 T solenoid

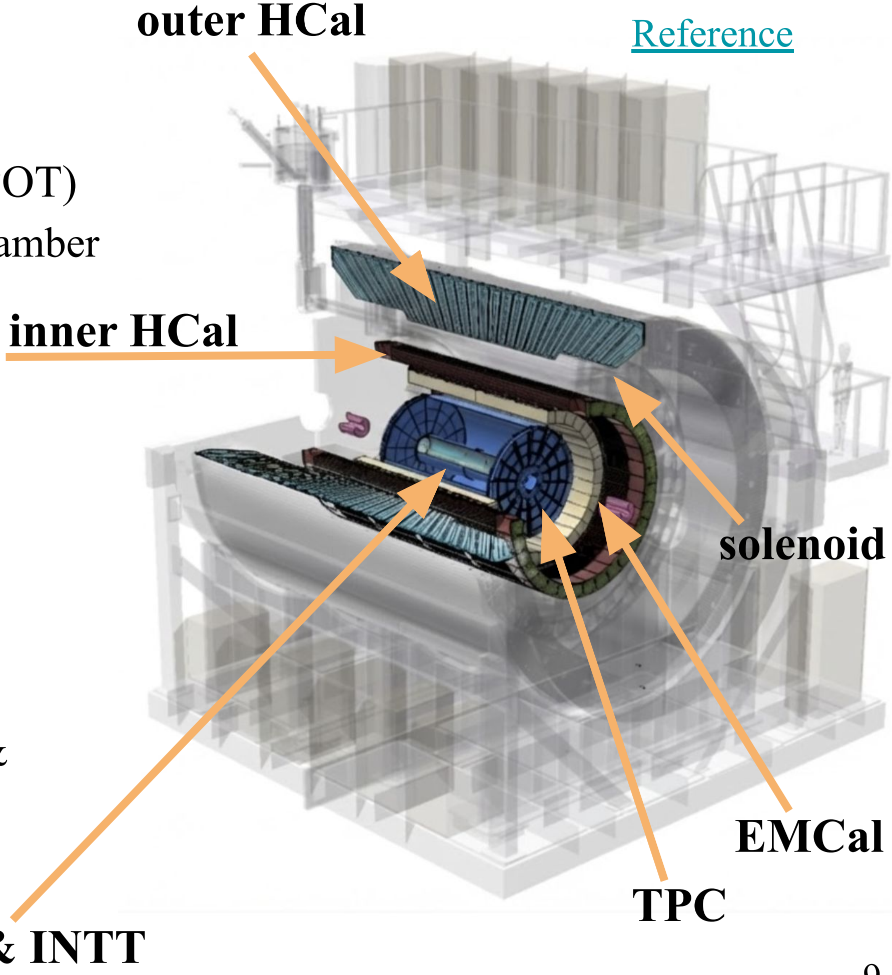
Calorimetry (EMCal, HCal)

Electromagnetic & hadronic calorimeters (inner/outer HCal)



Forward detectors (MBD, sEPD, ZDC)

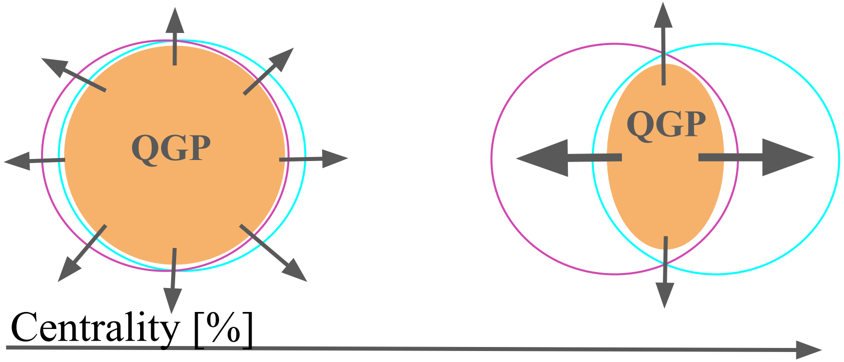
Provide minimum-bias triggers, centrality, & event-plane information

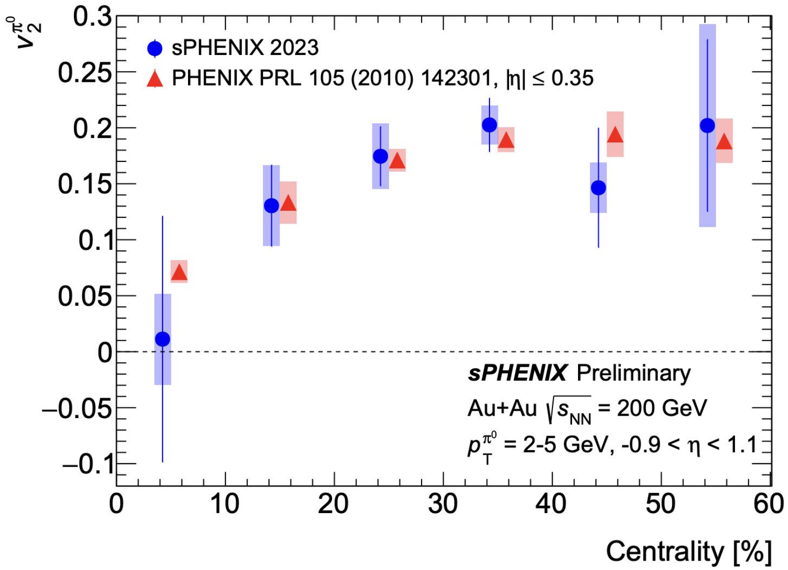


First Public sPHENIX Result: Elliptic Flow (v_2)

Second order Fourier coefficient of the azimuthal particle distribution: $v_2 = \langle \cos[2(\phi - \Psi_2)] \rangle$

- **Large v_2** → strong collective response of the medium
- **Low viscosity system –** initial spatial anisotropy is efficiently converted into final-state momentum anisotropy
- **sPHENIX observes non-zero v_2** in line with previous PHENIX results

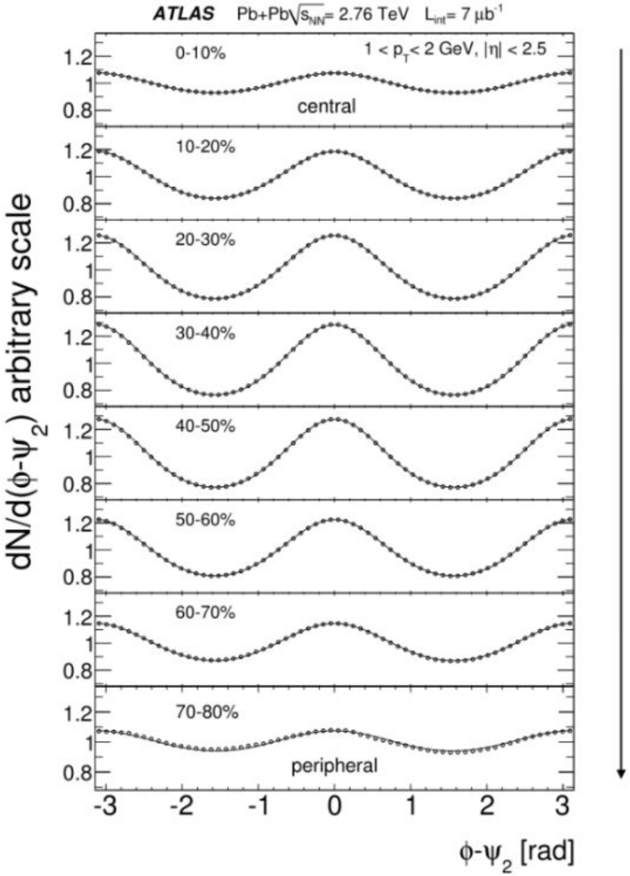


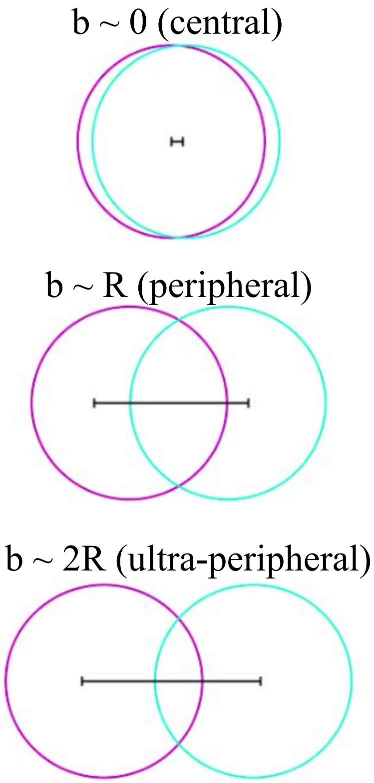


Public result I generated – first sPHENIX [conference note]

Geometry Drives v_2

- **Centrality ↔ impact parameter *b*** determines the initial collision geometry
- **Non-central collisions** produce eccentric overlap region in transverse plane
- **Spatial eccentricity** creates anisotropic pressure gradients
- **Stronger expansion** along *short* axis generates elliptic flow ($v_2 > 0$)





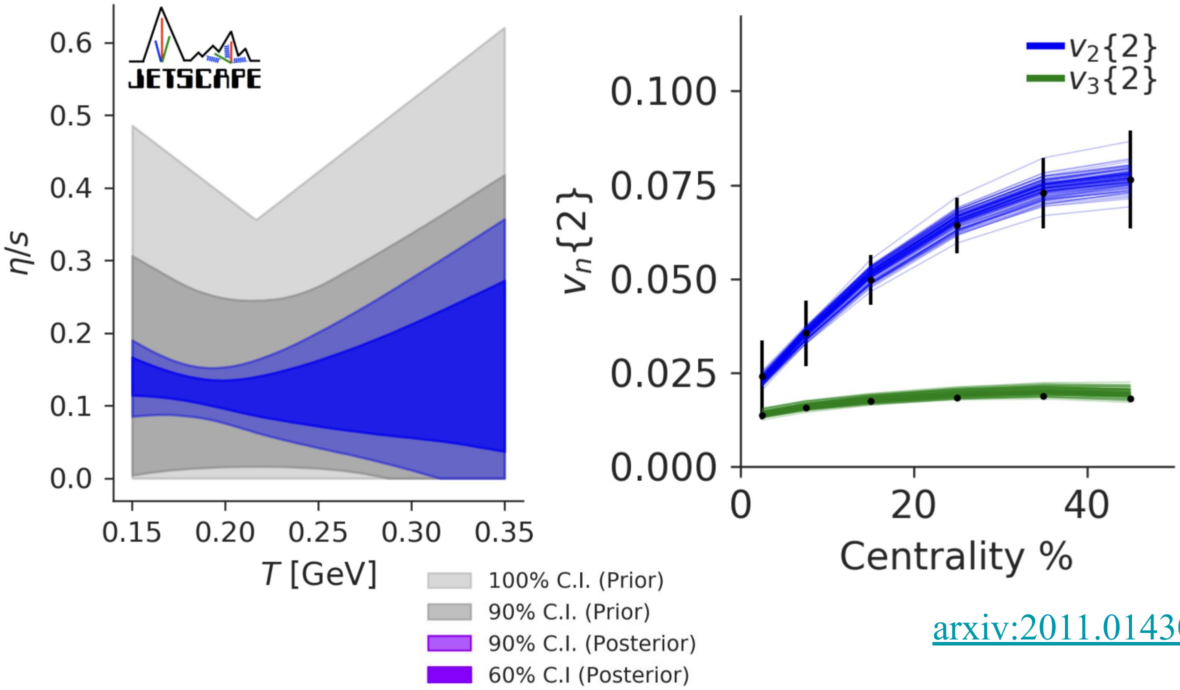
ATLAS source

Constraints on η/s

Viscosity damps anisotropy: larger η/s washes out v_2 (more momentum diffusion)

RHIC v_2 is matched by small η/s ~ O(0.1) i.e. the medium responds efficiently to the initial geometry

- strong coupling/short mean free path → *almost perfect fluid*

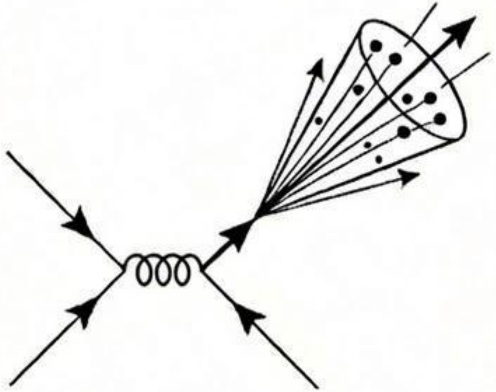


arxiv:2011.01430

Flow constrains bulk transport → hard probes test color interactions and energy loss

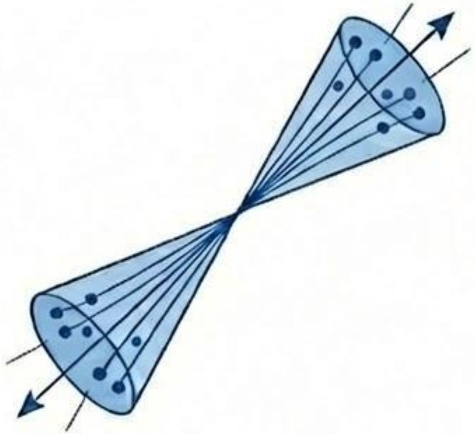
Jets: high-p_T probes of QCD and the QGP

What are jets?



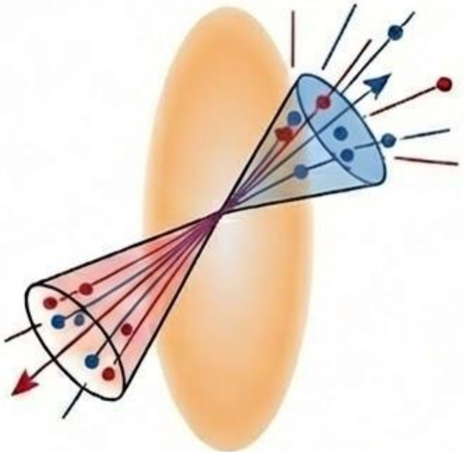
- **Collimated spray of hadrons** from hard-scattered quark or gluon
- **First observed in e^+e^- collisions** as the experimental manifestation of quarks & gluons

Jets in vacuum (pp)



- **High-energy pp** → back to back jets ~follow pQCD expectations
- **Since 1970s** → jet measurements central to confirming gluons and testing asymptotic freedom in the quark-parton picture

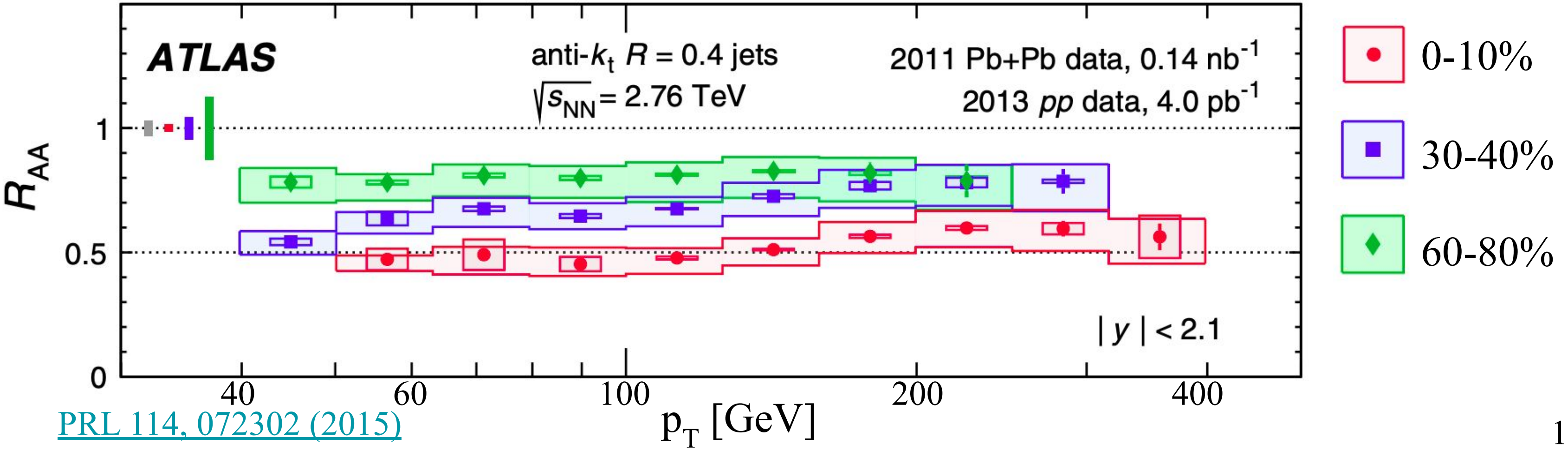
Jets in QGP (AA)



- **Heavy-ion collisions** → jets traverse the QGP & lose energy
- **Changes in jet yields** or internal structure vs vacuum baseline reflect response of the QGP

Jet Quenching: Colored Probes Are Strongly Suppressed

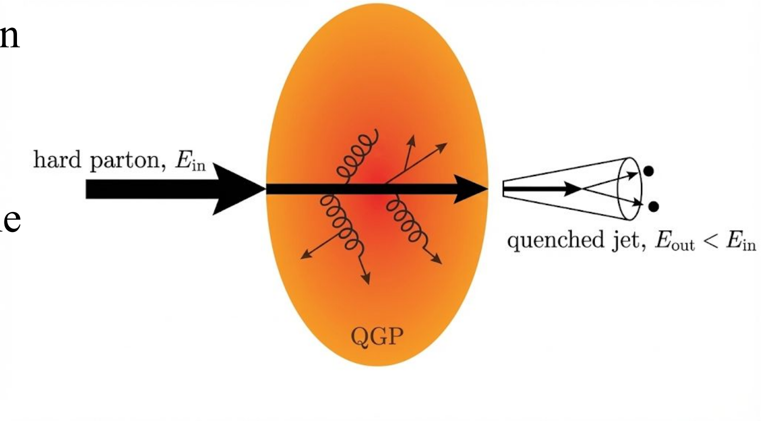
- **Nuclear Modification Factor:** $R_{AA}(p_T) = \dfrac{(1/N^{AA}_{\text{evt}})\, \mathrm{d}^2 N_{AA}/\mathrm{d}p_T \mathrm{d}y}{\langle T_{AA}\rangle\, \mathrm{d}^2\sigma_{pp}/\mathrm{d}p_T \mathrm{d}y}$
  - $\mathbf{R_{AA} = 1}$ → no nuclear modification
  - $\mathbf{R_{AA} < 1}$ → suppression
  - $\mathbf{R_{AA} > 1}$ → enhancement
- **Hard-process yields in A+A** should scale with the number of binary NN collisions ~ $\langle T_{AA} \rangle$

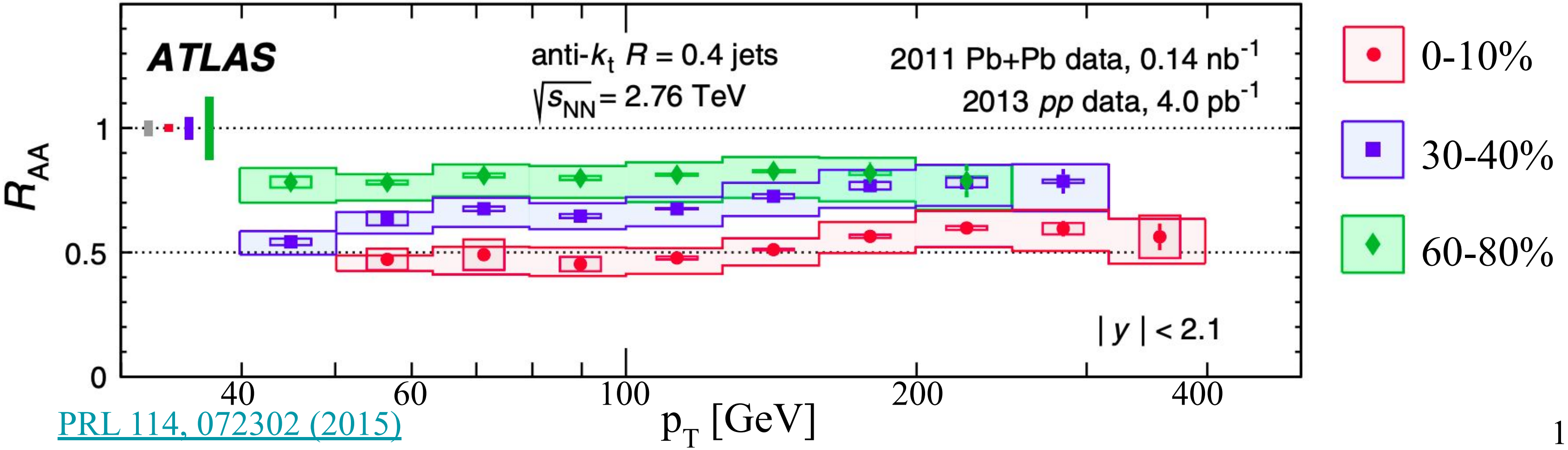


PRL 114, 072302 (2015)

Jet Quenching: Colored Probes Are Strongly Suppressed

- **Inclusive jet suppression in Pb+Pb**: $R_{AA} < 1$ – strongest in 0-10% central collisions, closer to unity in peripheral
- **Jet Quenching**: energetic colored partons lose energy in the QGP (medium-induced radiation + scattering) → reduced reconstructed jet yield at fixed p_T





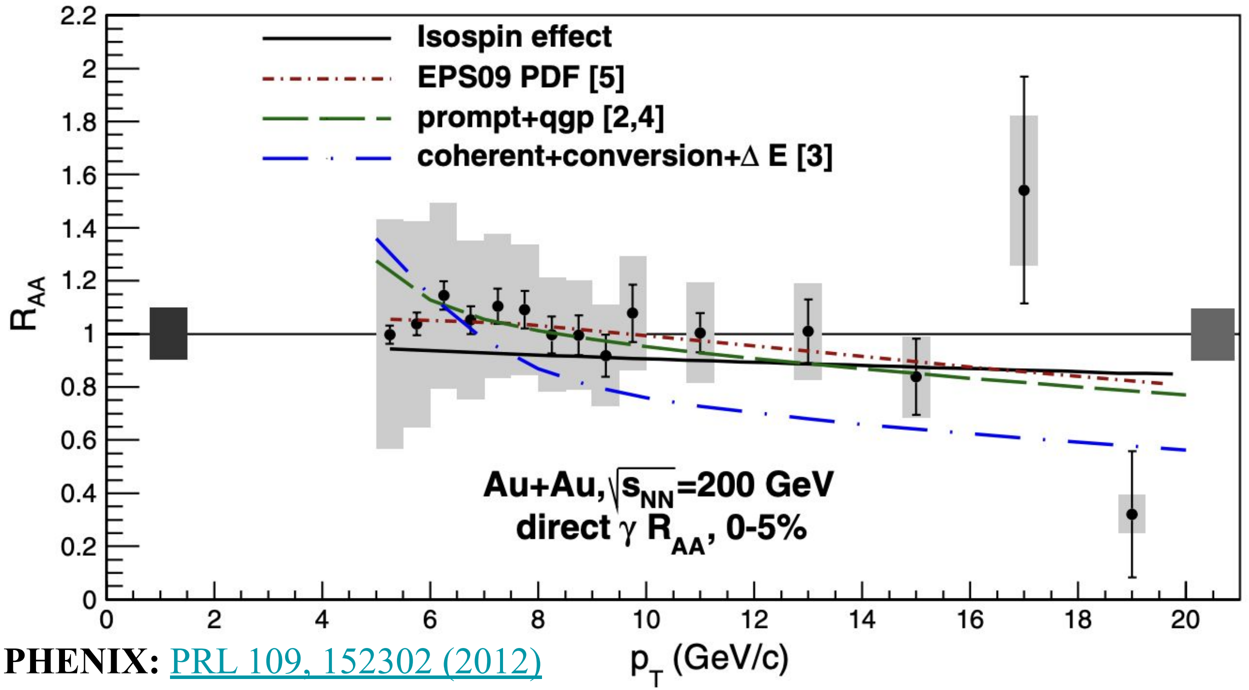
PRL 114, 072302 (2015)

Prompt Photons – Color Neutral Tages

- **Direct photons** → photons *not* from hadron decays ($\neq \pi^0 \rightarrow \gamma\gamma$, $\eta \rightarrow \gamma\gamma$)

- **At high p_T** → spectrum dominated by *prompt photons* from hard parton scatterings, calculable in pQCD

- **Photons are *color neutral*** → do not suffer final-state strong interactions at RHIC and the LHC



PHENIX: PRL 109, 152302 (2012)

Prompt Photons – Color Neutral Tages

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- **At high p_T** → spectrum dominated by *prompt photons* from hard parton scatterings, calculable in pQCD

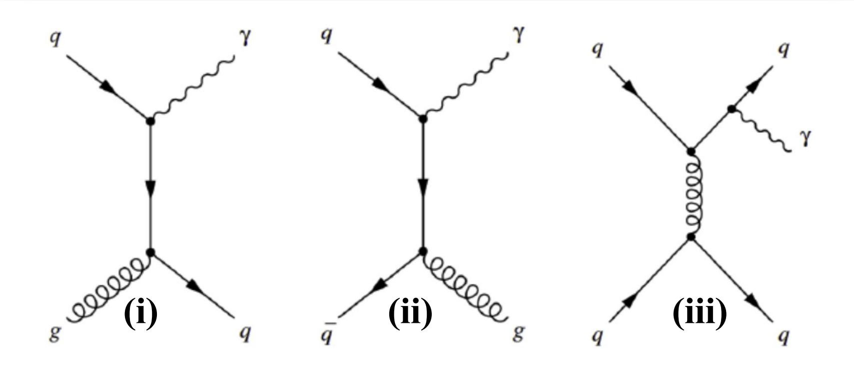
- **Photons are *color neutral*** → do not suffer final-state strong interactions at RHIC and the LHC

- **Prompt photons** → subset of direct photons (produced immediately in the hard scattering of partons)

  (i) Quark gluon compton scattering: $g + q \rightarrow \gamma + q$

  (ii) Quark antiquark annihilation: $q + \text{qbar} \rightarrow \gamma + g$

  (iii) Fragmentation: parton (q or g) → γ + (jet of hadrons)



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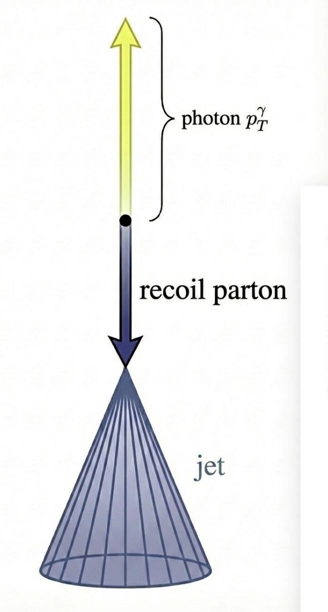
Photon-Jet Momentum Balance at the LHC

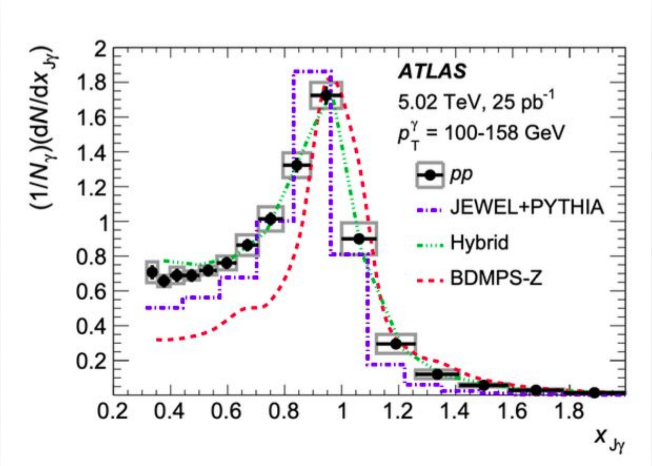
Phys. Lett. B 789 (2019) 167

Observable: $x_{J\gamma} = p_T^{\text{jet}} / p_T^{\gamma}$ (per-photon jet yield $\mathbf{(1/N_\gamma)dN/dx_{J\gamma}}$ for isolated γ+jet pairs)

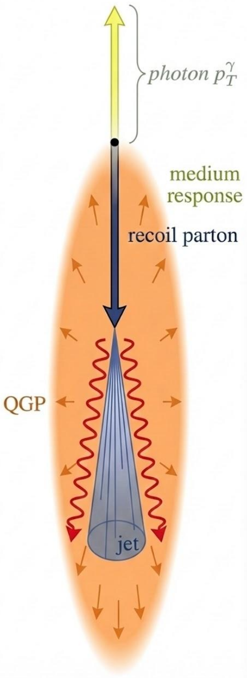
p+p baseline: Jets in *vacuum*



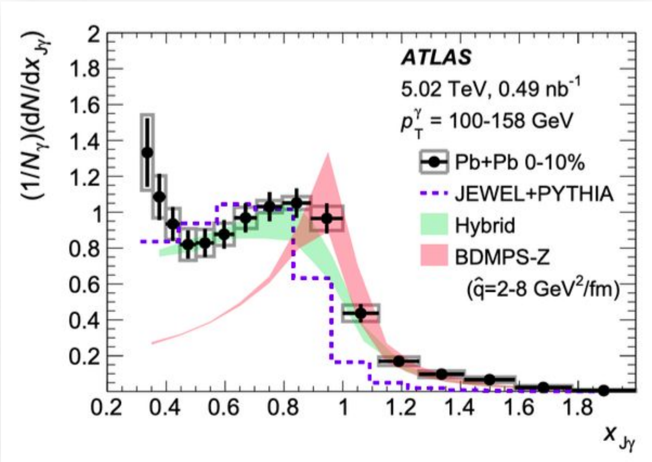
Narrow peak near $\mathbf{x_{J\gamma} \sim 0.9}$ i.e. jets in vacuum almost balance the photon



Central Pb+Pb: Jets in QGP



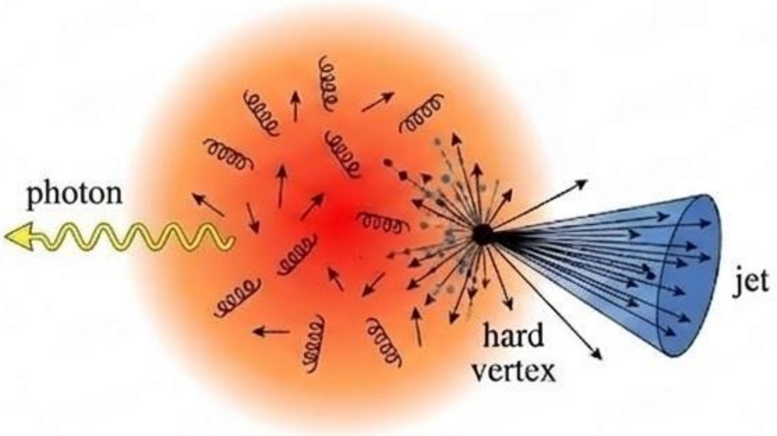
Peak *suppressed* & shifted to lower $x_{J\gamma}$ i.e. recoil jet loses energy to the QGP



Photon-Jet Momentum Balance at RHIC

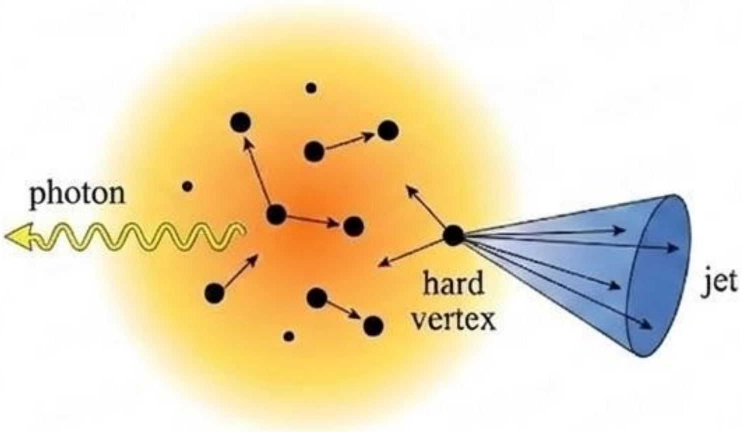
Question: What *new information* can a RHIC $x_{J\gamma}$ measurement add beyond the LHC result?

LHC Regime



- Very hot, high density, small-x QGP
- Initial state gluon/sea dominated ($x \sim 10^{-2}$)
- Busy underlying event w/ high multiplicity

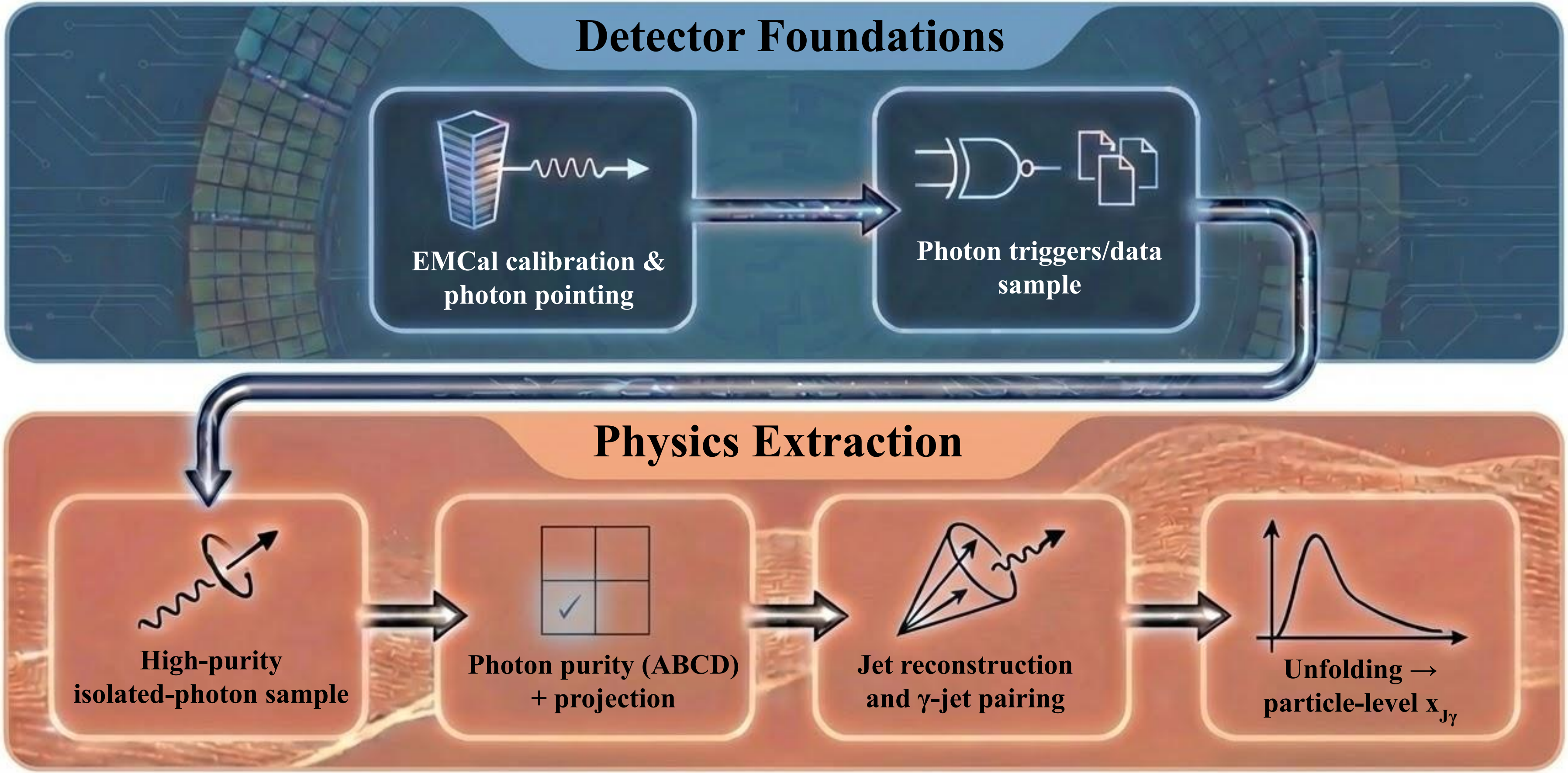
RHIC Regime



- Cooler QGP in different kinematic regime
- Initial state valence-quark dominated ($x \sim 10^{-1}$)
- Cleaner environment with lower multiplicity

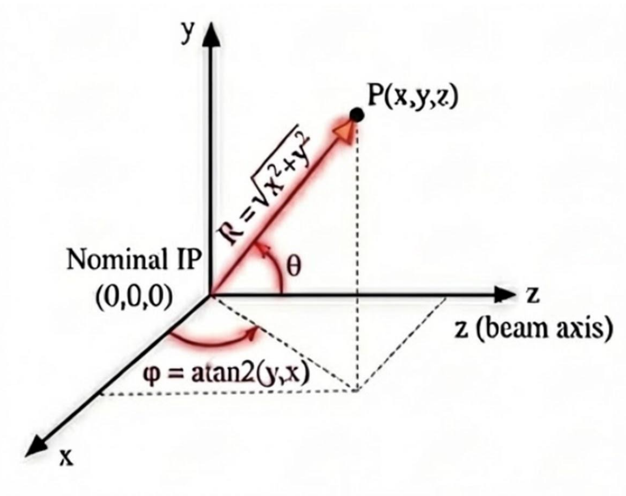
Goal: Perform the first fully unfolded, per-photon $x_{J\gamma}$ measurement at RHIC and compare to ATLAS result to test how jet quenching depends on flavor, scale, and medium conditions

Roadmap to a Photon-Jet $x_{J\gamma}$



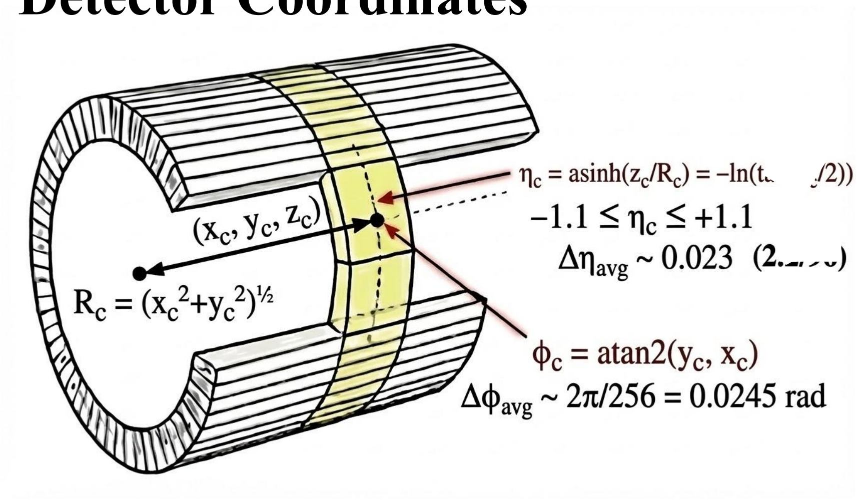
sPHENIX Coordinate System

Global Coordinates



- **Continuous:** (x, y, z) ⇒ (φ, η) abt beam axis
- **Origin** at nominal IP = (0, 0, 0), z along beam
- **φ** = atan2(y, x), **θ** from +z
- **Pseudorapidity:** η = -lntan(θ/2)

Detector Coordinates

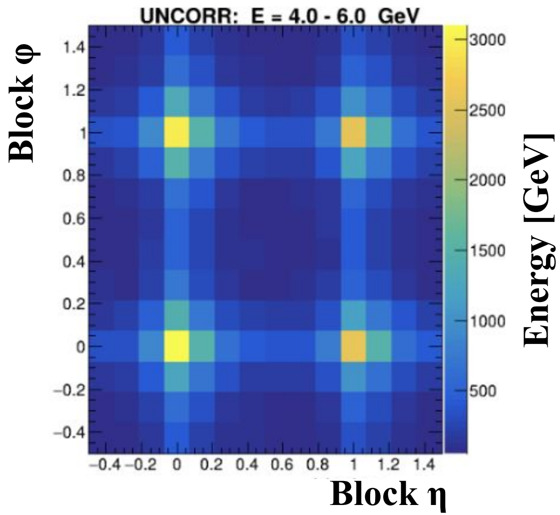


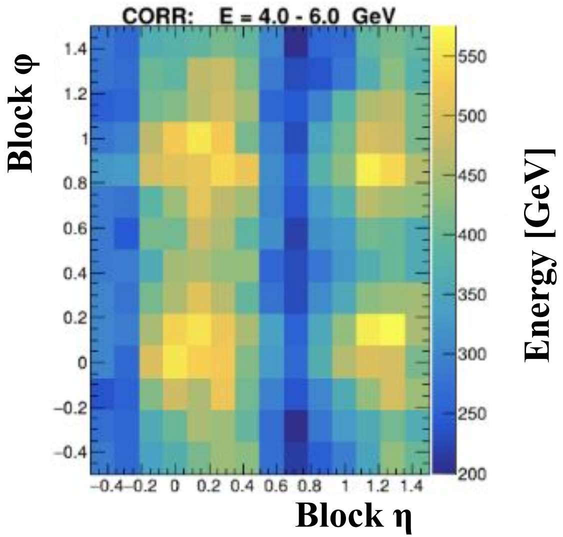
- **Tower center:** (x_c, y_c, z_c) in the global frame
- $\mathbf{R_c}$ → distance from the beam line
- **Indices:** (i_η, i_φ) are integer tower labels
- **Granularity:** (i_η, i_φ) corresponds to finite Δη x Δφ patch

EMCal Cluster Position Correction

Photons set the kinematics→ uniform pointing and isolation across the EMCal are essential

- **EMCal showers spread laterally** → *but* each tower integrates what is produced inside its own boundaries
- **Energy-weighted barycenter** — $x_{\mathrm{CG}} = \frac{\sum_i x_i E_i}{\sum_i E_i}$ — exhibits *geometric bias*
    - *Finite segmentation* pulls estimate toward the *center of the hit cell*
- **Position dependent correction** → deliver unbiased impact points across cell

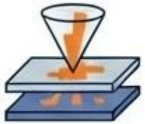




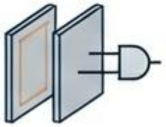
sPHENIX Triggering System

sPHENIX optimized for high-rate jet and photon measurements – employs trigger system to select rare high-p_T processes

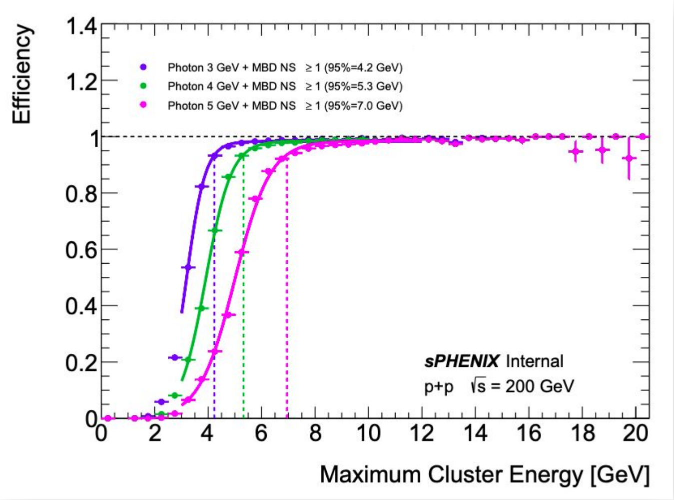
Photon trigger → EMCal towers clustered into non-overlapping regions – any region exceeding preset threshold is *flagged by the trigger*

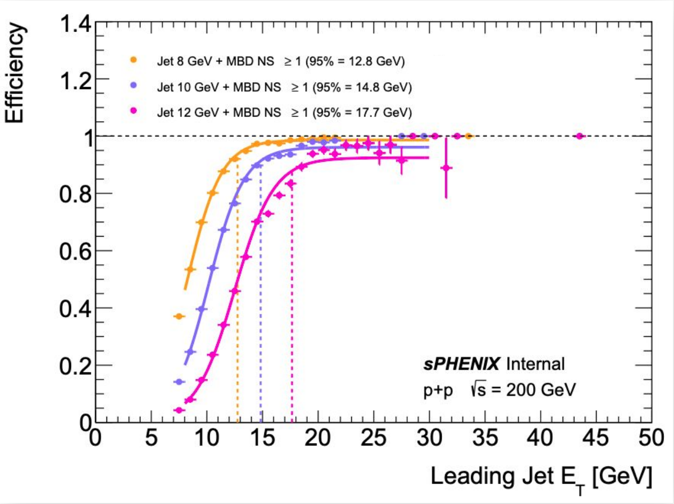


Jet Trigger → identify high-energy deposits in both EMCal and HCal



Combined with a minimum-bias trigger requiring *at least one* PMT in N&S MBD to fire in coincidence





Isolated Photon Sample

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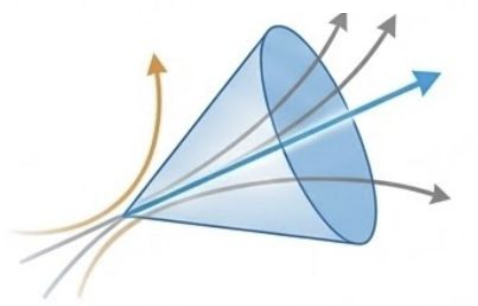
Two ingredients of isolated photon selection:

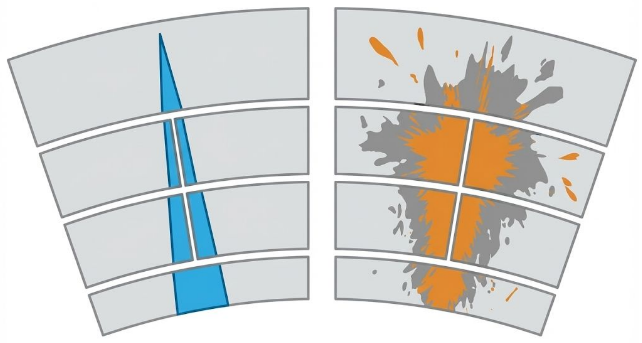
i) Cluster Isolation

$$\Sigma E_T^{\Delta R<0.3} = \sum_{i \in \mathrm{EMCal} \cup \mathrm{HCal}} E_{T,i}$$



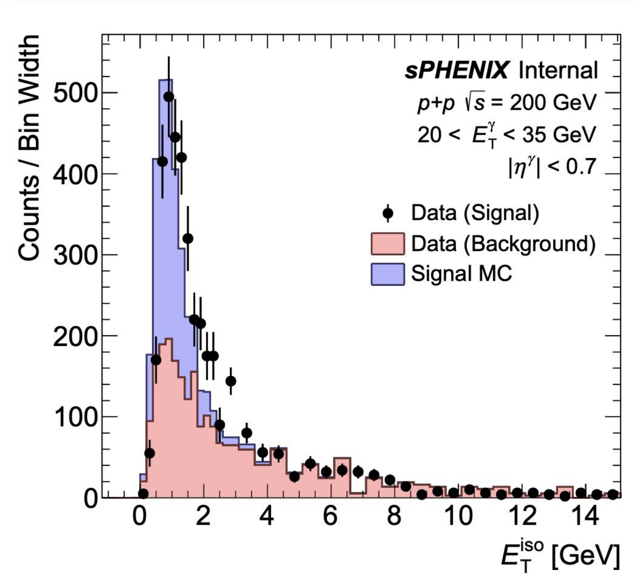
- **Sliding E_T^{iso} cut**
  tune in signal MC for ~flat prompt-γ efficiency vs E_T^{γ}
- **Non-isolated sideband**
  background control region

ii) Shower-Shape (SS) ID



- **SS cuts** → compact EM γ vs broad hadronic/merged π^0
- **Loose** quality *preselection* → **tight** γ-ID working point

Validation



Isolation E_T^{iso}: tight vs non-tight γ-ID (compared to signal MC)

Photon Purity and Yield Projection

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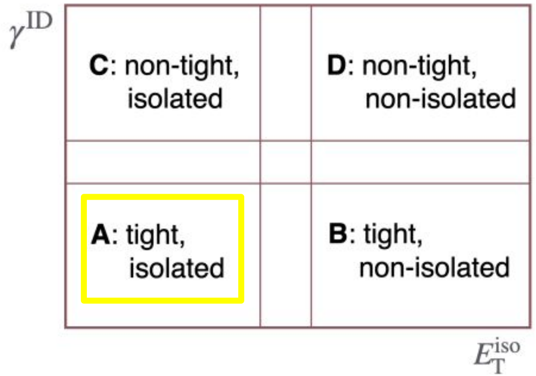
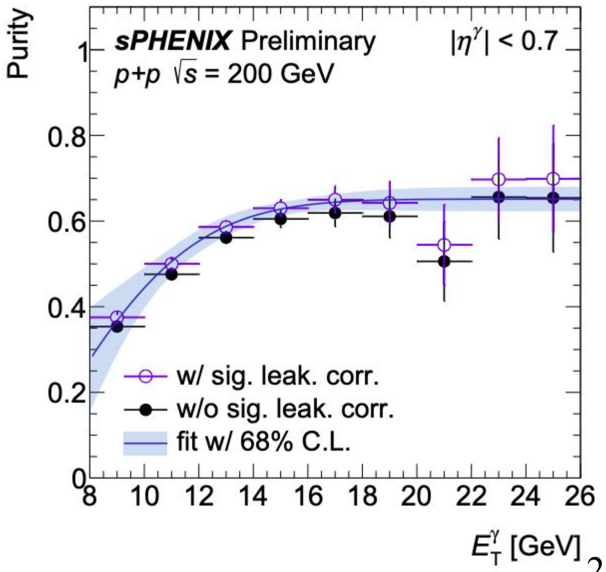
Purity – define 4 regions

A: tight & isolated (signal region)	**B:** tight & non-isolated
C: non-tight & isolated	**D:** non-tight & non-isolated

- **Sideband regions** *B, C, D* model the background in *A*
- **Purity rises** from ~40% at E_T^γ ~10 GeV to ≳ 60% above ~15 GeV





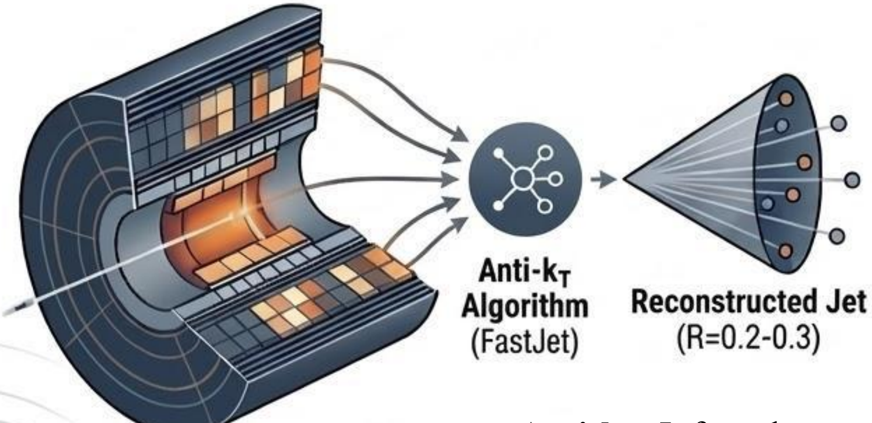
Estimated sample (0-10% AuAu)

- **Yields:** Scale 2022 BUP isolated-γ rates to ~7nb^{-1}
- **Corrections:** apply isolation efficiency (random-cone UE) + post-selection purity
- **Result**: ~1.5e4 (20-30 GeV) and ~8e2 (>30 GeV) selected photons

Jet Reconstruction & γ–Jet Pairing

Jet Reconstruction

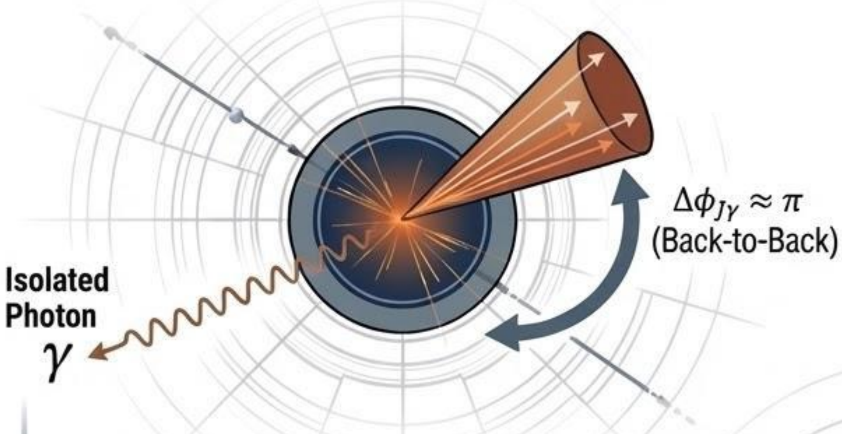
- Jets built from EMCal + HCal towers via anti-k_T algorithm with a small radius R = 0.2-0.3 within central $|\eta| \lesssim 1.1$ acceptance



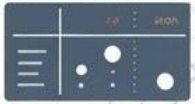
Anti-k_T: Infrared- and collinear-safe clustering algorithm forming ~conical jets

γ–Jet Pairing

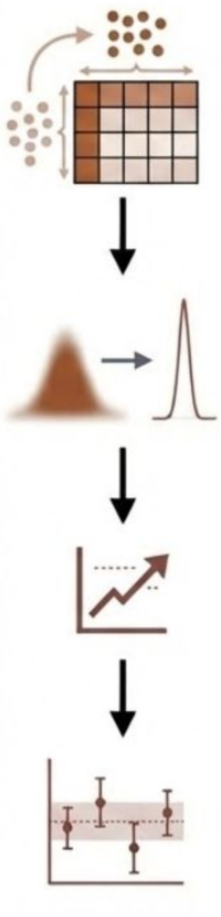
- For each *tight, isolated* photon, associate all jets that pass a p_T^{jet} threshold & satisfy a back-to-back topology



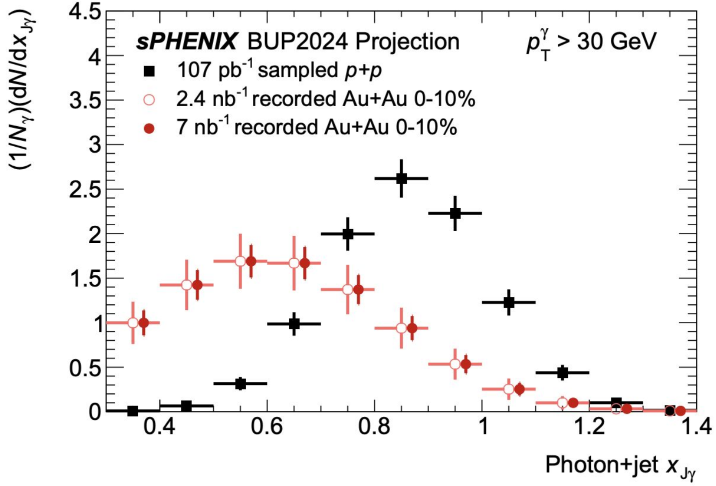
Result: Detector-level $(E_T^{\gamma}, p_T^{jet})$ distribution



Final Unfolding and Measurement



1. **Build 2D response matrix** from MC γ+jet events (matching data pipeline)
2. **Perform iterative Bayesian unfolding** to obtain particle-level γ+jet yields for pp and each AuAu centrality
3. **Convert to the per-photon momentum-balance:** $\left(\frac{1}{N_\gamma}\right)\frac{dN}{dx_{J\gamma}}$
4. **Evaluate systematic uncertainties**



sPHENIX BUP 2022 projection for $x_{J\gamma}$ in *pp* and 0-10% AuAu

Summary & Timeline

sPHENIX Run Timeline

Run 2024 p+p

collected ~13 pb^{-1}
all subsystem triggered data

Run 2025 Au+Au

collected 6.6 nb^{-1} of all subsystem triggered data (switched back to pp on 12/8/25)

Run 2025 pp (ongoing)

PAC "must-do" target of 13 pb^{-1}
additional all-subsystem triggered data

Analysis Steps

A) Foundations
M0-M2, Jan-Feb 2026

B) Embedding & isolation tuning
M2–M4, Mar–Apr 2026

C) Background control & detector-level spectra
M4–M6, May–Jun 2026

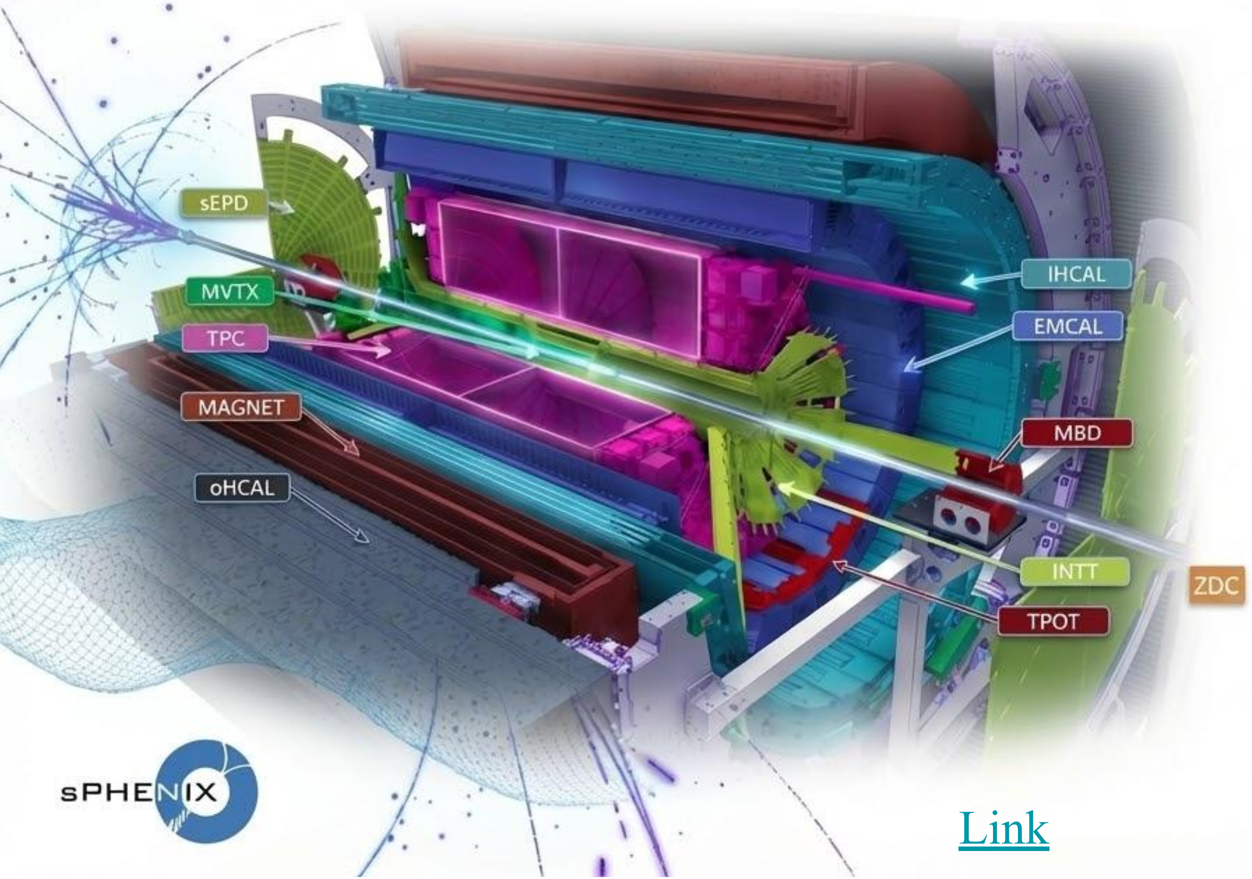
D) Response & first unfolded results
M6–M9, Jul–Sep 2026

E) Full AuAu & systematics
M9–M12, Oct–Dec 2026

F) Thesis Integration
M12–M16, Jan–Apr 2027

BACKUP

sPHENIX Breakdown



TRACKING

- **MVTX** (Monolithic Vertex Detector)
- **INTT** (Intermediate Tracker)
- **TPC** (Time Projection Chamber)
- **TPOT** (Time Projection Chamber Outer Tracker)

CALORIMETRY

- **EMCal** (Electromagnetic Calorimeter)
- **IHCal** (Inner Hadronic Calorimeter)
- **OHCal** (Outer Hadronic Calorimeter)
- **ZDC** (Zero Degree Calorimeter)

EVENT CHARACTERIZATION

- **sEPD** (Event Plane Detector)
- **MBD** (Minimum Bias Detector)

Link

TRIGGER DETAILS

RAW

Increment every event, regardless of state of DAQ

LIVE

Update only when **busy** signal is **inactive**, i.e. count triggers when system is ready to accept new data.

SCALED

Increment based on scaledown factor (nEvents you skip) for a particular trigger.

Why does this make sense?

Scaledown factor → how many live triggered events you skip. Scaledown of 0 means record data for every event that particular trigger fires, a scaledown of 1 is every other event, and so on.
Scaledown factor = 0 → skip 0 events that the live trigger fires – i.e. live/scaled counts = 1.

- Scaledown factors are **runwise** – apply to run-by-run distributions before combining list of run numbers.

Addition Info ATLAS xJ Results

3 Slides:

1) Breakdown theory overlays slide 18

Theory Overlay Details

Strategy used by ATLAS (and transferable to sPHENIX)

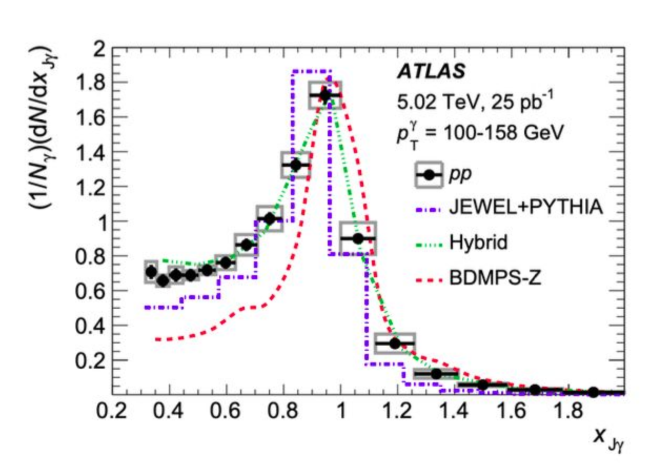
- First validate vacuum baseline in pp so you don't confuse bad baseline with medium physics
- Compare AA to multiple, qualitatively different energy loss models including event generators & analytic formulaisms

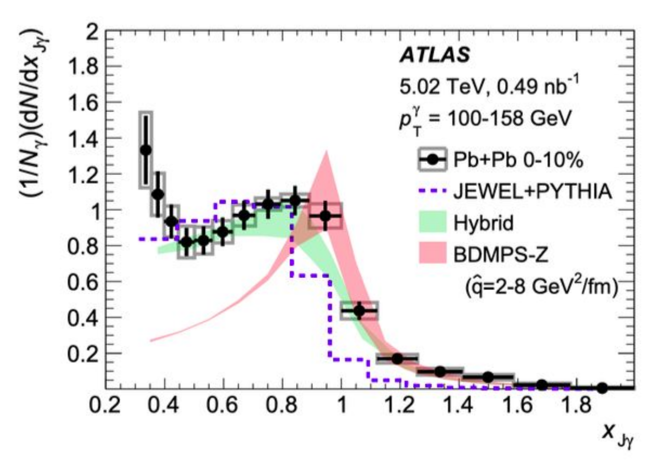
JEWEL & Hybrid ask → "If I simulate the full event and modify the shower in medium, do I reproduce the distribution?"

- JEWEL → microscopic scatterings → more event by event fluctuations and stronger angle broadening
- Hybrid → continuous energy drain → smoother path length dependent shift of entire distribution

BDMPS-Z asks → "can canonical pQCD radiative energy loss mechanism + a single strength what explain observed suppression?"

- Isolated medium induced radiation as mechanisms tested





Why does $x_{J\gamma}$ hit Maxima around 0.9 and not 1 in those Plots?

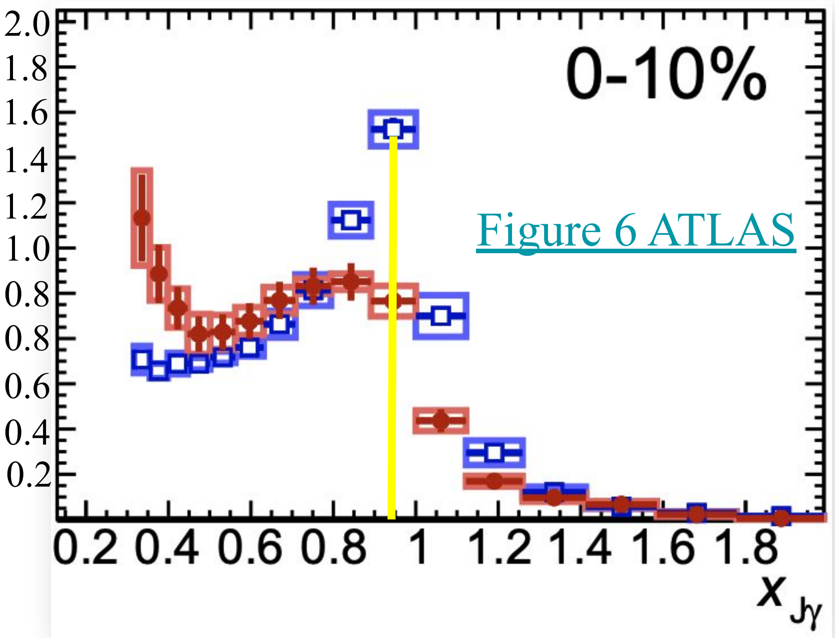
pp peak at ~ 0.9 → $x_{J\gamma} = 1$ true in ideal LO 2 → 2 picture where photon and the (single) recoil parton are back to back with equal p_T

- At NLO its often 2 → 3 (or more) where photon recoils against a *system of partons* (quark + an extra radiated gluon)
  - No single jet has to carry full recoil
- Even if recoil mostly one quark – radiates gluons at a range of angles → with finite cone some of that radiation lies outside jet

PbPb peak similar but left shifted (within mid x_J range)

- Tight, isolated photons engineered to be dominated by prompt Compton/annihilation photons – main shift dominated by recoil jet losing energy out of reconstructed jet cone

100-158 GeV (same as slide 18)



What Contributes to *RHS* of Peak in *pp* vs PbPb

$x_{J\gamma} > 1 \rightarrow$ *measured* jet p_T > *measured* photon p_T in that event/bin

pp contributions

- **Not pure LO 2→2 topology:** higher order QCD (2→3, parton shower) means photon recoils against a multi-parton/multi-jet system, so leading recoil jet can exceed p_T^{γ}
- **Pairing/selection criteria:** analysis pairs each γ w/ highest-p_T jet passing Δφ + threshold cuts – preferentially selecting jets slightly harder than photon when multiple recoil jets
- **Detector resolution/bin migration:** finite jet p_T resolution produces upward tail in measured p_T^{jet} relative to photon
- **Fragmentation leakage:** a high-z fragmentation photon from leg of a hard initial dijet event passes isolation and paired with away-side jet from dijet – should be small contribution

100-158 GeV (same as slide 18)

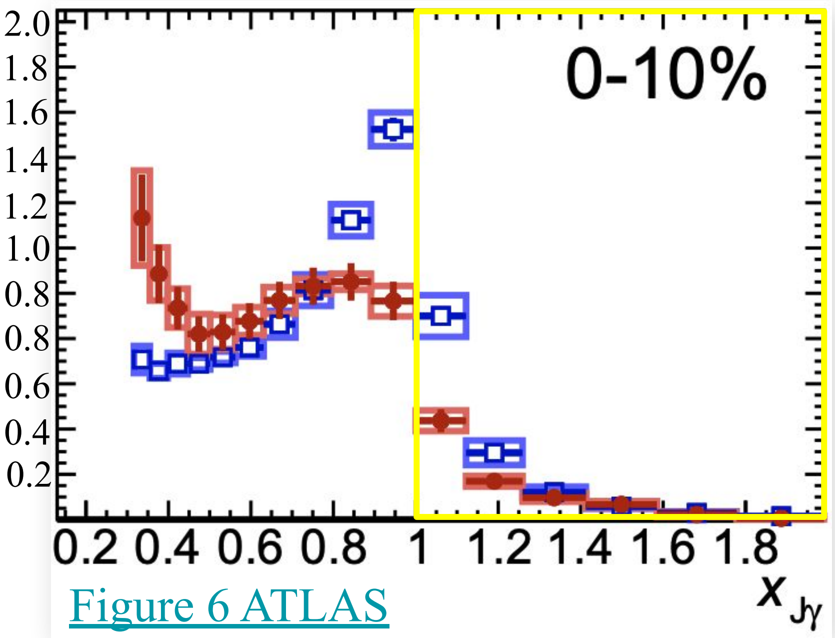


Figure 6 ATLAS

What Contributes to *RHS* of Peak in *pp* vs PbPb

$x_{J\gamma} > 1 \rightarrow$ *measured* jet p_T > *measured* photon p_T in that event/bin

AA additional contributions (still vacuum contributors)

- **Quenching suppresses RHS overall:** medium-induced radiation + out-of-cone transport lowers p_T^{jet} at fixed p_T^{γ}
- **Selection bias from jet p_T:** from quenching – many recoil jets shift to lower p_T & fixed jet p_T cut preferentially keeps event where the recoil jet lost little in-cone energy – remaining RHS dominated by "survivors" of cut not full recoil ensemble
- **UE fluctuations + subtraction smear jet p_T:** residual background fluctuations broaden reco jet p_T distribution
- **Isolation/purity differences:** AA environment changes iso efficiency and purity – residual fragmentation leakage or fake-photon contamination can distort tails

100-158 GeV (same as slide 18)

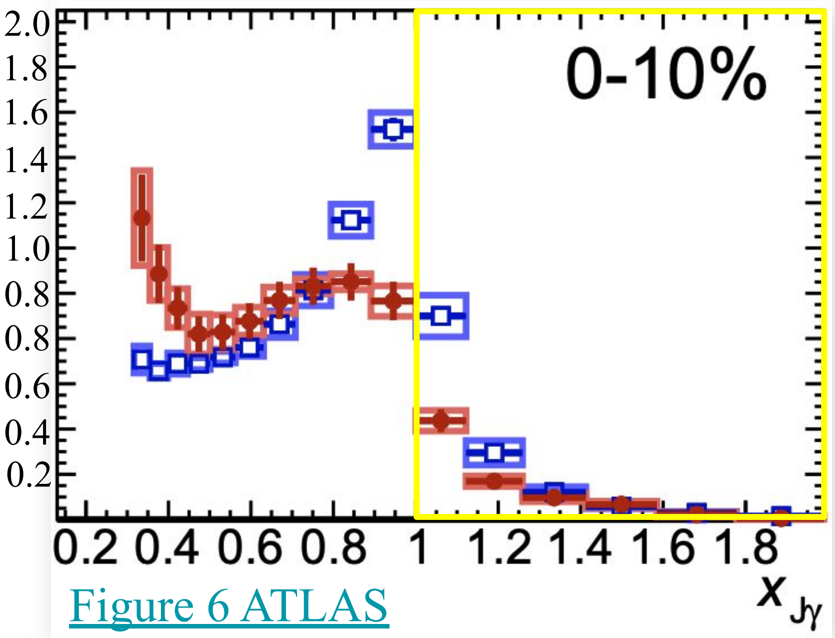


Figure 6 ATLAS

Additional info on SS Cut Definitions

3 Slides:

1) Shower-Shape (SS) Criteria – Window Sums

2) Shower-Shape (SS) Criteria – et1 and 2nd Moments

3) Tight γ Selection

Shower-Shape (SS) Criteria – Window Sums

A) Window sums: let E_{ij} → energy in tower index (i, j) with ($i \in [0,95]$ in η, $j \in [0,255]$ in φ)

- **Choose a center (i_0, j_0)** (usually the cluster seed or CoG) – for **odd** *m, n* define half-sizes: $h_\eta = \frac{m-1}{2}, \quad h_\phi = \frac{n-1}{2}$
  - **Then the window sum** (symmetric patch) is: $\boxed{E_{m\times n}(i_0, j_0) = \sum_{i=i_0-h_\eta}^{i_0+h_\eta} \sum_{j=j_0-h_\phi}^{j_0+h_\phi} E_{ij}}$
    - **h_η = (m−1)/2** → how many tower steps you extend up and down in η from the center index i_0
    - **h_ϕ = (n-1)/2** → how many steps you extend left and right in ϕ from the center index j_0
  - **ϕ-wrapping:** if *j* steps outside [0, 255], wrap modulo 256 so sums cross the 0/2π boundary cleanly
- **EGS → 1x1:** $h_\eta = h_\phi = 0$ → just the center tower, $E_{11} = E_{i0,\, j0}$, **3x3:** $h_\eta = h_\phi = 1$ → indices $[i_0 - 1, i_0 + 1] \times [j_0 - 1, j_0 + 1]$

Strip windows (when not odd): variables that *probe elo* $E_{32} = \sum_{|i|\le 1} \sum_{j\in\{0,s\}} E_{ij}$, $E_{35} = \sum_{|i|\le 1,\, |j|\le 2} E_{ij}$, $\frac{E_{32}}{E_{35}} = \frac{\sum_{|i|\le 1} \sum_{j\in\{0,s\}} E_{ij}}{\sum_{|i|\le 1,\, |j|\le 2} E_{ij}}$

- **Rectangular strips** instead of odd x odd squares:
  - where s = ±1 picks the CoG side in ϕ

Shower-Shape (SS) Criteria – et1 and 2nd Moments

B) 2x2 core energy fraction (et1) – let a clusters *total* energy be $\mathbf{E_{tot}} = \sum_{\mathbf{i \in cluster}} \mathbf{E_i}$

- **Find the 4 EMCal towers** whose centers are *closest* to the cluster CoG – these **form a 2x2 core with energies $\mathbf{E_{1\to4}}$**
  - **et1** → fraction of the cluster's E_{total} carried by the four towers immediately surrounding the cluster CoG
  - $\boxed{\mathrm{et1} = \dfrac{E_1 + E_2 + E_3 + E_4}{E_{\mathrm{tot}}}}$ → tight photons are expected to be compact, so et1 **should be ~1 for signal**

C) Seed-excluded, energy-weighted second moments (cluster "widths") – let each EMCal tower in a cluster have coordinates (η_i, ϕ_i) and energy E_i

- **Let (η_{COG}, ϕ_{COG})** be a cluster center-of-gravity used by the photon ID
- **For either axis a ∈ {η, ϕ}**, define the seed-excluded second moment →

$$w_a^{\mathrm{cogX}} \equiv \frac{\sum_{i \neq \mathrm{CoG}} E_i \left(a_i - a_{\mathrm{COG}}\right)^2}{\sum_{i \neq \mathrm{CoG}} E_i}$$

- **Measures energy-weighted spread** of the cluster around the CoG
  - *Narrow*, EM-like clusters give small $w_{\eta,\phi}$, *broader*, multi-tower (hadronic/merged π^0) clusters push them up
- **Seed tower dominates the energy sum** → removing it makes width sensitive to the shape of the surrounding shower

Tight γ Selection

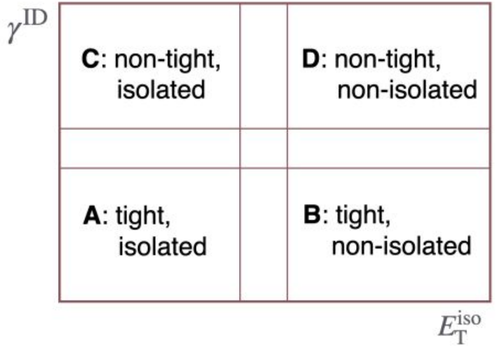
Pre-selection (loose γ-ID quality-gate): $\frac{E_{11}}{E_{33}} < 0.98\,, \quad 0.6 < \mathrm{et1} < 1.0\,, \quad 0.8 < \frac{E_{32}}{E_{35}} < 1.0\,, \quad w_{\eta}^{\mathrm{cogX}} < 0.6$

Tight γ-ID (**five** SS variables; compact, EM-like showers)

- **(1 & 2) Seed-excluded widths** (around CoG, exclude the seed tower) → $0 < w_a^{\mathrm{cogX}} < 0.15 + 0.006\,E_T^{\gamma} \quad \text{for } a \in \{\eta,\ \phi\}$
- **(3) Core-to-cluster compactness** (odd×odd window sums) → $0.4 < \frac{E_{11}}{E_{33}} < 0.98$
- **(4) 2×2 core energy fraction (et1)** → $0.9 < \mathrm{et1} < 1.0$, $\mathrm{et1} = \frac{E_1 + E_2 + E_3 + E_4}{E_{\mathrm{tot}}}$
- **(5) Elongation veto (strip ratio)** → $0.92 < \frac{E_{32}}{E_{35}} < 1.0$

ABCD regions (for purity & sidebands)

- **Purpose:** estimate the signal purity of your tight & isolated photon sample
- **Axes** → γ-ID (tight vs non-tight, w/ 5 SS variables), and isolated vs non-isolated
  - **Non-tight** → fails any two of five tight SS requirements
  - **Non-isolated** → $E_T^{\mathrm{iso}} > 1 + 1.08128 + 0.0299107 * E_T^{\mathrm{reco}}$



Isolated Photon Projection

- N^{sel}_{γ} → number of selected photon candidates after baseline ID/iso working point and luminosity scaling
- p_{UE} → UE-only isolation false-fail probability from the random cone-study using PPG04 results
    - i.e. the chance that UE fluctuations alone push the cone energy above the isolation ut
- ε_{iso} → isolation efficiency i.e. $\boldsymbol{\varepsilon_{iso} = 1 - p_{UE}}$
- P_{pp} → **purity** for pp found by PPG12 & P_{AA} → **post-isolation** purity in AuAu
- $(S/B)_{\gamma} = P_{AA}/(1- P_{AA})$

Cent	E_T^{γ}	N_{γ}^{sel}	p_{UE}	ε_{iso}	P_{pp}	P_{AA}	$N_{\gamma}^{true} = P_{AA}N^{sel}$	$(S/B)_{\gamma}$
0–10%	20–30 GeV	14867	0.2071	0.7929	0.70	0.650	9664	1.86
0–10%	>30 GeV	800	0.2071	0.7929	0.70	0.650	520	1.86

N_{sel}^{γ} → Number of Selected Candidate Estimate

- **2022 Beam Use Proposal Estimates in table** 4.1 give

  N_{γ} (p_T > 20 GeV) = 47k and 2.4k at luminosity of $21 nb^{-1}$

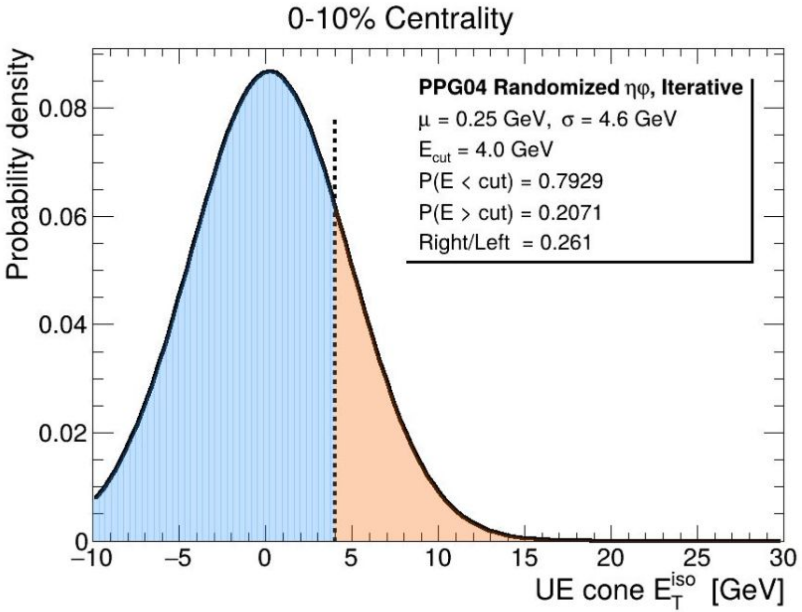
- With current run projection of $7 nb^{-1}$ set a scale factor:
  - $s_L = 7/21 = 0.3333$
- $\mathbf{N_{\gamma}^{sel}(>20)} = 47k*s_L = 15667$
- $\mathbf{N_{\gamma}^{sel}(>30)} = 2.4k*s_L = 800$
- **20-30 GeV bin** → 15667-800=1**4867**

Signal	Au+Au 0–10% Counts	$p+p$ Counts
Jets $p_T > 20$ GeV	22 000 000	11 000 000
Jets $p_T > 40$ GeV	65 000	31 000
Direct Photons $p_T > 20$ GeV	47 000	5 800
Direct Photons $p_T > 30$ GeV	2 400	290
Charged Hadrons $p_T > 25$ GeV	4 300	4 100

Table 4.1: Projected counts for jet, direct photon, and charged hadron events above the indicated threshold p_T from the sPHENIX proposed 2023–2025 data taking. These estimates correspond to the 28 cryo-week scenarios.

Random-Cone Study, False-Fail Rate for Isolated Photons

- **PPG04 quantities** UE fluctuations using randomized towers after iterative pedestal subtraction
  - Results **correspond to R = 0.4**
- **Set a fixed isolation threshold at E_{cut} = 4 GeV** – and take the UE-only **failure probability** in centrality slice *c* with Gaussian parameters (μ_c, σ_c) as:
  - $p_{\mathrm{UE}}(c) = \frac{1}{2}\,\mathrm{erfc}\!\left(\frac{E_{\mathrm{cut}} - \mu_c}{\sqrt{2}\,\sigma_c}\right)$
- **From table 4** in appendix of PPG04 IAN can use two bins:
  - ($\mu_{0\text{-}5\%}$, $\sigma_{0\text{-}5\%}$) = (0.31, 4.80) GeV and
  - ($\mu_{5\text{-}10\%}$, $\sigma_{5\text{-}10\%}$) = (0.19, 4.40) GeV
- p_{UE}(0-5%) = 0.221, p_{UE}(5-10%) = 0.193
  - Because these are both equal centrality widths (5%), take the 0-10% value as arithmetic mean of the two:



$$p_{\mathrm{UE}}(0\text{–}10) = \frac{p_{\mathrm{UE}}(0\text{–}5) + p_{\mathrm{UE}}(5\text{–}10)}{2} = 0.2071, \qquad \boxed{\varepsilon_{\mathrm{iso}}(0\text{–}10) = 1 - p_{\mathrm{UE}}(0\text{–}10) = 0.7929}.$$

Calculation Specifics - P_{AA} Estimate

- **Start** with the pp sample at the same working point – given purity from PPG12 P_{pp}
  - Then for some sample size N: $S_{pp} = P_{pp} N$ (true photons), while $B_{pp} = (1 - P_{pp})\,N$ (background)
- **Random-cone study** measured signal isolation efficiency ε_{iso} (the fraction of true photons that pass the isolation cut in AuAu)
- **For first order mapping** – assume isolation mainly affects signal acceptance without changing background odds
  - Scale the signal and leave background as it was – i.e. $S_{AA} = \varepsilon_{iso} S_{pp}$, $B_{AA} = B_{pp}$
- **Now recompute AuAu purity** from the definition P = S/(S + B)

$$\boxed{P_{AA} = \frac{S_{AA}}{S_{AA} + B_{AA}} = \frac{\varepsilon_{\text{iso}}\, P_{pp}}{1 - P_{pp} + \varepsilon_{\text{iso}}\, P_{pp}}}$$

- **If fold in background change in AuAu** → can use data-driven number measured from ID sideband
- Formula: $P_{AA} = \dfrac{\varepsilon_{\text{iso}}\, P_{pp}}{\kappa_B\,(1 - P_{pp}) + \varepsilon_{\text{iso}}\, P_{pp}}$ → κ_B the background isolation survival in AuAu relative to the pre-isolated sideband

$$\kappa_B \approx \frac{\text{NonTight that **pass iso** in Au+Au}}{\text{All **NonTight** in Au+Au}} = \frac{N_{\text{idSB, pass}}}{N_{\text{idSB, total}}}$$

Advantages for this Measurement at RHIC (vs ATLAS PbPb)

R	Window size
0.2	3×4
0.3	5×5
0.4	7×7
0.5	9×9
0.6	11×11

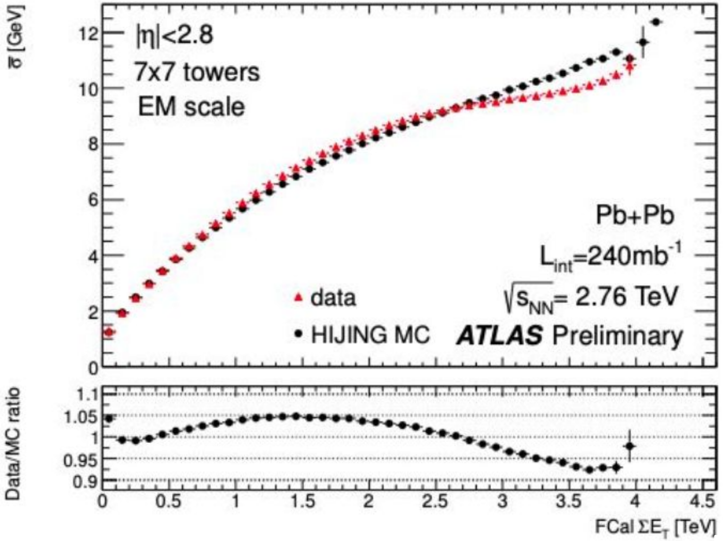
- **ATLAS measures** the per-event width σ in fixed calorimeter windows
  - **7x7 window** → R~0.4 (Table 1 in ATLAS note here)
- **In figure 9 of note** – the *right-most* (most central) points (FCal ΣE_T~3.4-3.5 TeV) give **σ ~ 13-14 GeV**
  - **RHIC RC** with R = 0.4 gives **σ=4.6 GeV**
- $\sigma_{LHC}/\sigma_{rhic}$ **~ 14/4.6 ~ 3.0** → LHC UE fluctuations are **~3x larger for same area**

Hardness-to-noise Check (x_T/σ) – $x_T = 2p_T^{hard}/\mathrm{sqrt}\{s_{NN}\}$

- **ATLAS (5.02 TeV)** – take a representative p_T^{hard} ~ 45 GeV
  - B/w $p_T^{\gamma} \geq 63.1$ and $p_T^{jet} > 31.6$ GeV (from ATLAS $x_{J\gamma}$ paper)
  - x_T **~ 0.018**, with σ ~ 14 GeV, x_T/σ **~ 1.3e-3**
- **RHIC (200 GeV) – p_T^{hard} ~ 20 GeV** (for 20-30 GeV bin) → x_T **= 0.20**
  - With σ = 4.6 GeV, x_T/σ **~ 4.3e-2**

RHIC x_T/σ is ~30x larger

- At **fixed E_T^{iso} isolation should be cleaner** with higher purity
  - Fewer true photons get rejected out by noise
  - Fewer fakes from random soft activity than at LHC



Bjorken-x Regimes at RHIC vs the LHC

- **From calculations on previous slide**
  - Take RHIC at RHS red line $x \sim 10^{-1}$
  - LHC take at $x \sim 10^{-2}$
- **RHIC** sits in the **valence-quark dominated regime**
- **LHC** sits in **gluon/sea dominated regime**
- **RHIC has abundant hard quarks** to scatter on moderate-x gluons
  - $qg \rightarrow \gamma q$ (Compton) is a clean leading contribution
- **More valence quarks** → more clean compton scattering topologies → easier isolation at RHIC