U.S. DEPARTMENT OF ENERGY
Office of Science

JETSCAPE

NSF

Interplay of prompt and non-prompt photons in photon-triggered jet observables

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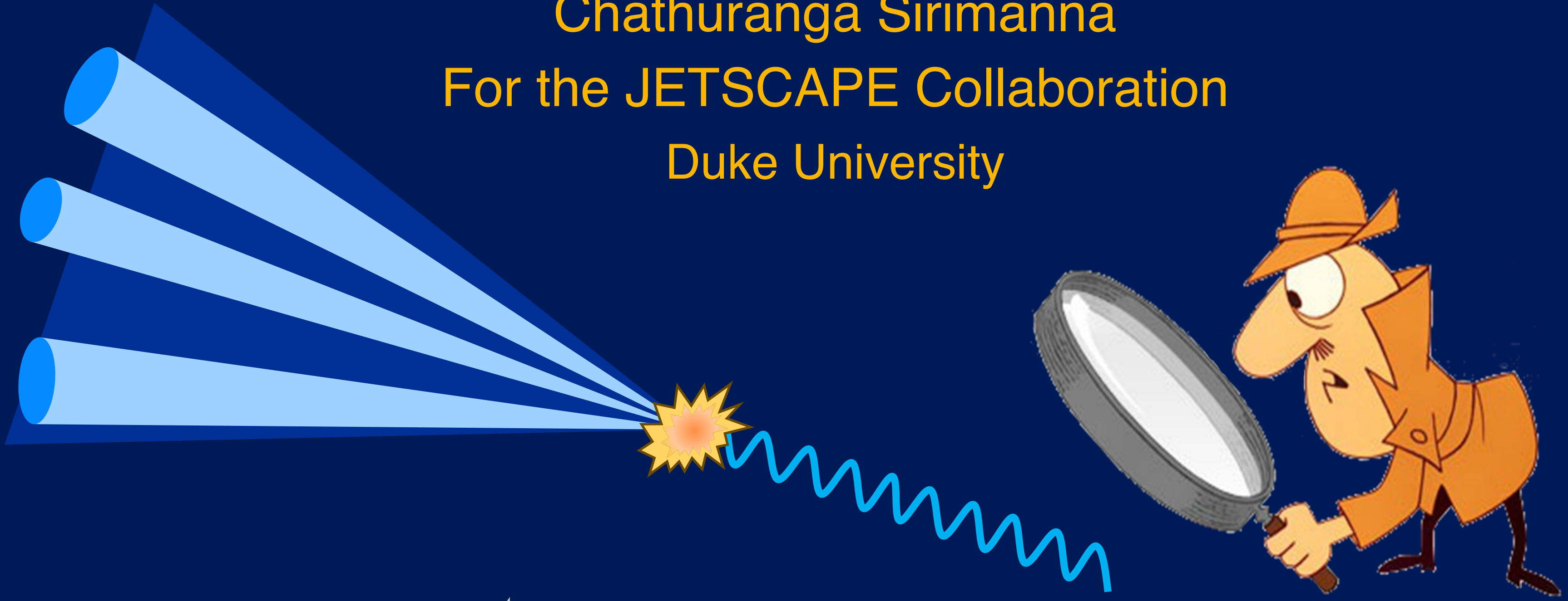

HP2024
NAGASAKI

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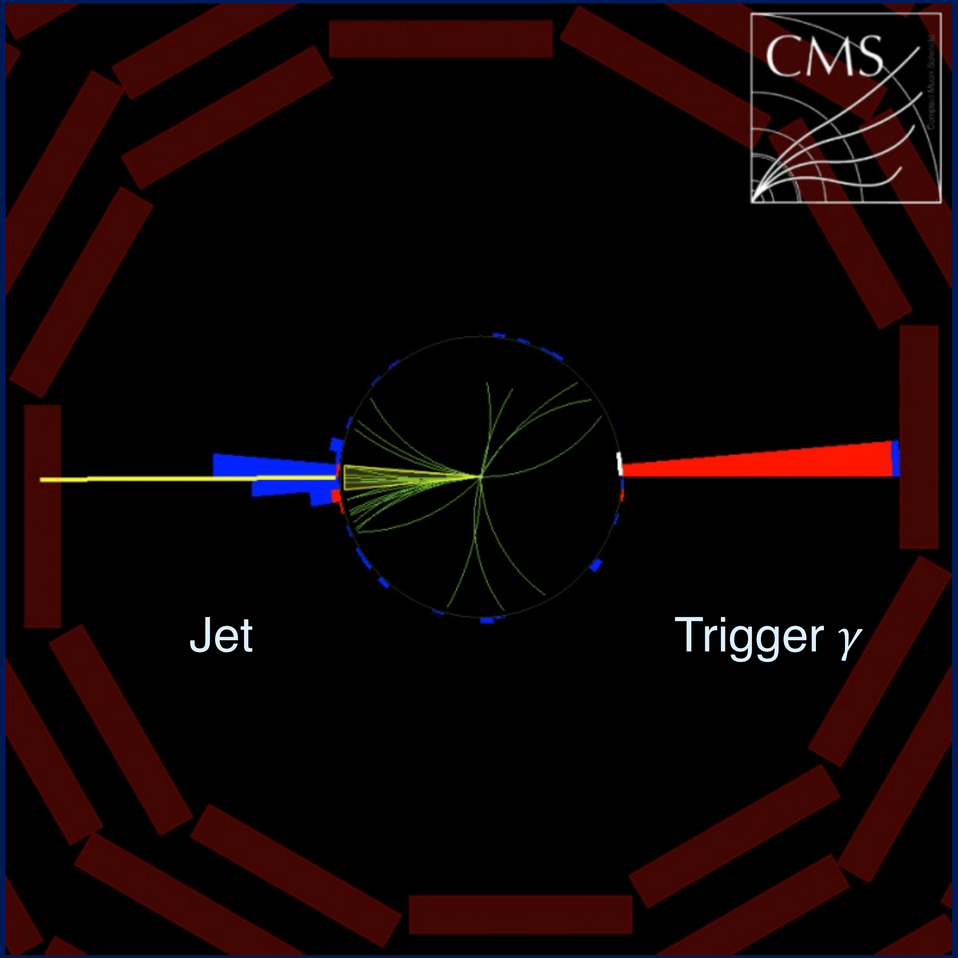
Outline

- Introduction: JETSCAPE framework and multistage evolution
- Photon triggered jets
- Simulating jet evolution with JETSCAPE framework
- Simultaneous description of leading hadron and jet spectrum
- This study: 5.02 TeV
  - γ-jet: asymmetry, correlation, and R_{AA}
  - Groomed jets substructure using photon triggered jets
- Summary



https://github.com/JETSCAPE/JETSCAPE GitHub

Manual (arXiv:1903.07706), JETSCAPE PP19 tune (arXiv:1910.05481), JETSCAPE AA23 tune (arXiv:2204.01163)

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Introduction

- JETSCAPE: General, modular and extensive framework
- No single model can describe all stages of jet evolution
- Multi-stage jet evolution
  - Different stages depending on the virtuality, Q and Energy, E of the partons
- One can customize the framework by using their own modules
- ASCII, Gzip, and HepMC output formats

Initial State
- Trento (2+1D, 3+1D)
- External Reader

Hard Collision
- Pythia Gun
- PGun

Soft Medium
- Music (2+1D, 3+1D)
- External Reader
- Brick
- Gubser

Energy loss
- MATTER
- LBT
- MARTINI
- AdS/CFT

Hadronization
- Lund String
  - Colorless
  - Colored
- Hybrid

Pre-generated Trento Initial

Pre generated 2+1D VISHNU Hydro profiles

Pythia Hard Scattering

MATTER – Medium modified DGLAP evolution in High Virtuality

LBT – Linearized Boltzmann Transport model with HT gluon emission

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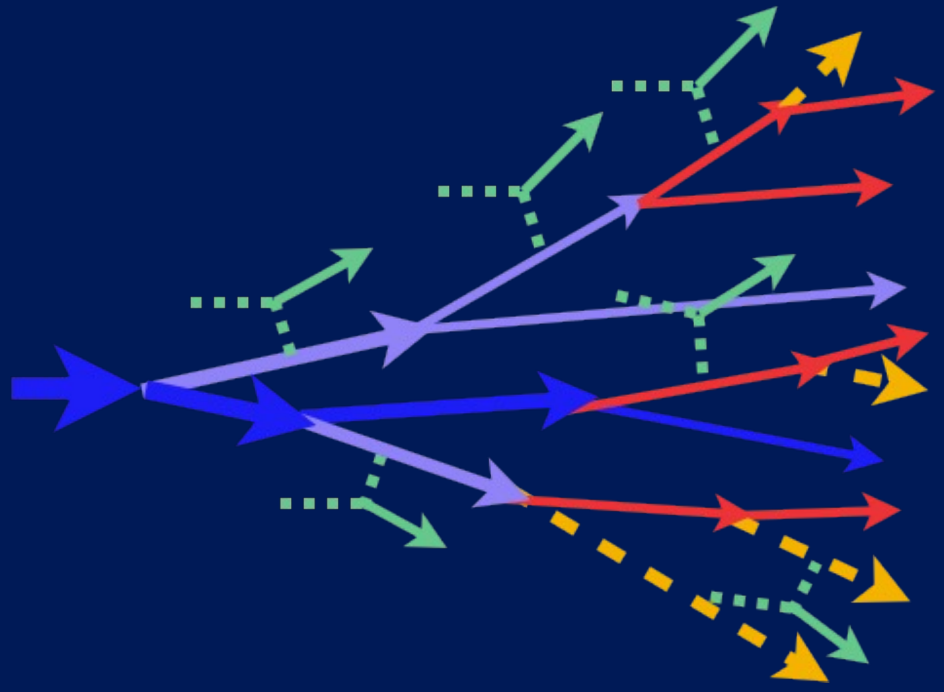
JETSCAPE framework: Multistage Evolution

- Large Q, Large E: Dominated by radiation with few scatterings (DGLAP, HT)
  - MATTER *(Majumder(13), Kordell, Majumder(17), Cao, Majumder(17))*
- Small Q, Large E: Scattering driven emission, mostly by medium effects (Transport, AMY, HT)
  - LBT *(Wang, Zhu(13), Luo, et al.(15,18),Cao, et al.(16,17), He, et al.(18))*
  - MARTINI *(Schenke, Gale, Jeon(09), Park, Jeon, Gale(17, 18))*
- Small Q & E: Nearly thermal, strongly coupled (AdS/CFT)
  - AdS/CFT *(Chesler, Rajagopal(14, 15), Pablos, et al.(15, 16, 17), and others)*



Virtuality Separation Scale: Q_0

Switching between modules parton by parton depending on the virtuality and energy

Large Q: $Q > Q_0$
Small Q: $Q < Q_0$

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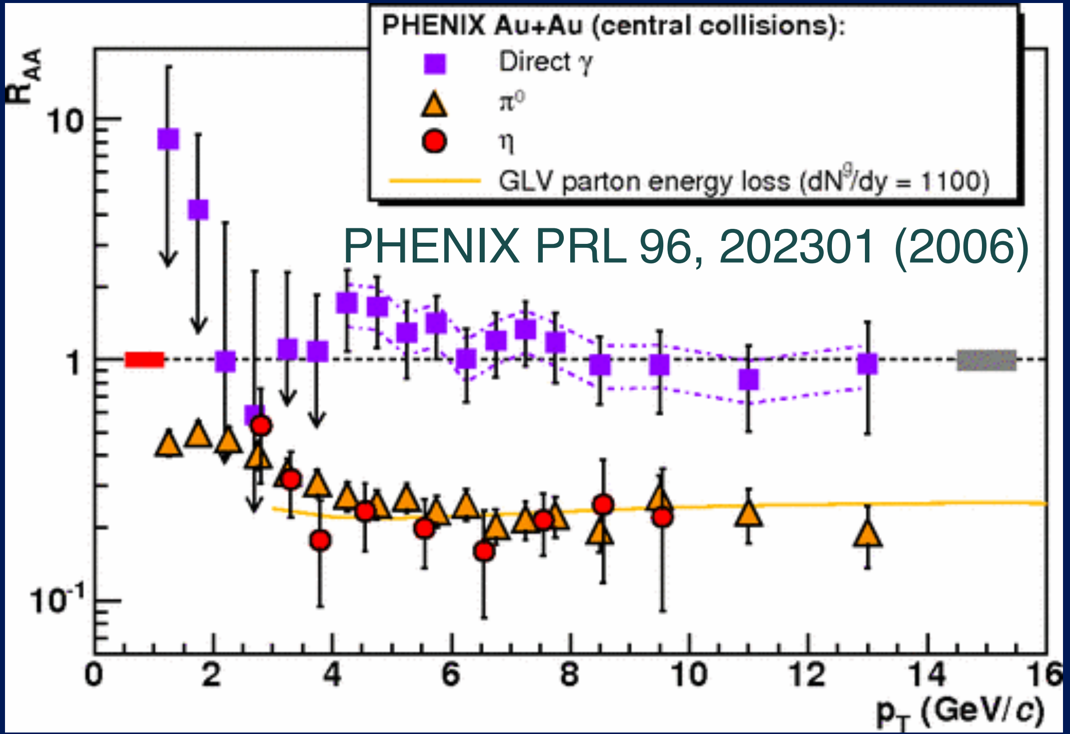
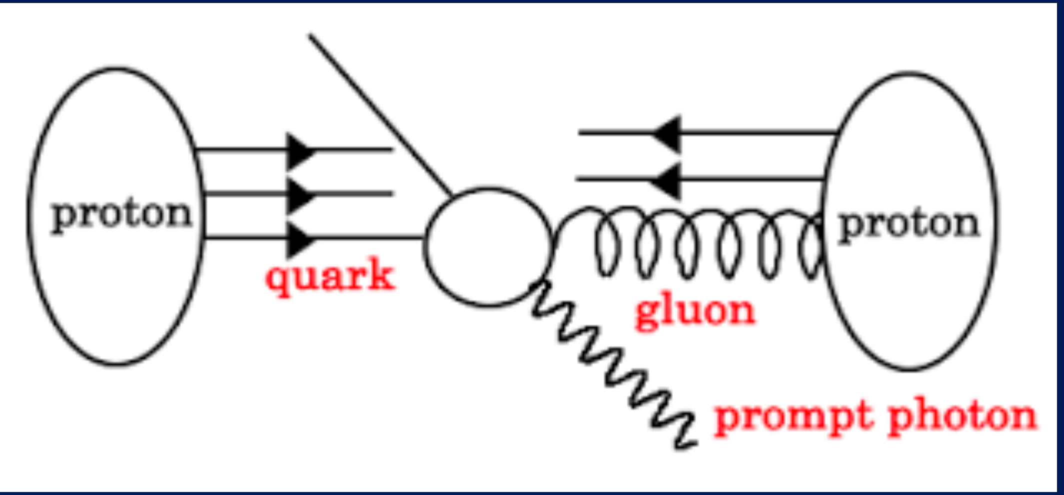
Prompt photons as Probes of QGP

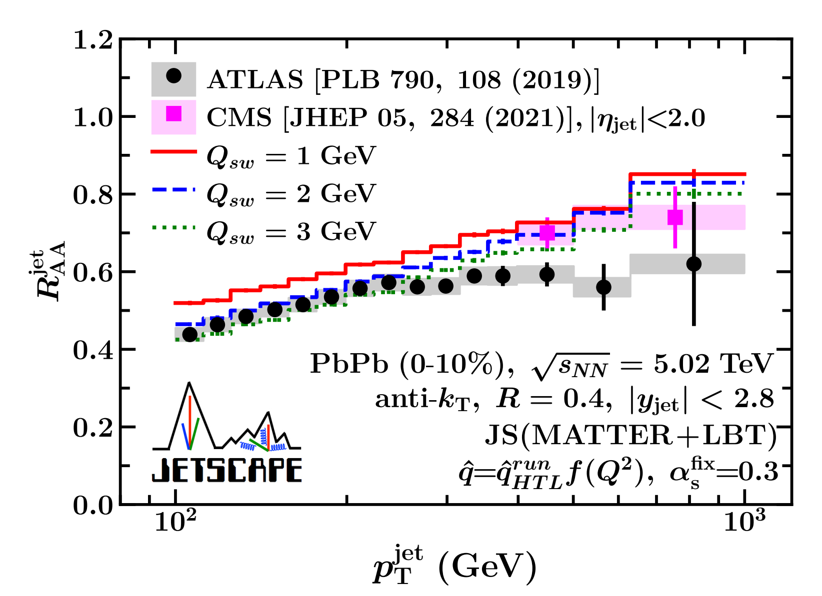
- Prompt photons - produced directly in the hard sub-processes
- Photons – doesn't interact with medium
- Can be used to estimate the energy and the direction of jet initiating parton (before the energy loss) – Calibrated probe of the QGP
  - Limited Statistics: Challenging to measure experimentally
- Important probe to study jet energy loss (Wang, Huang, and Sarcevic, PRL 77 (1996) 231-234)
- Isolation criteria is necessary to identify the prompt photons
  - Same isolation criteria used in experimental analysis (CMS-HIN-13-006, CMS-HIN-16-002, PLB 789 (2019) 167)
- Isolated photons mainly consist of prompt photons
  - Isolated Non-prompt photons make considerable contribution

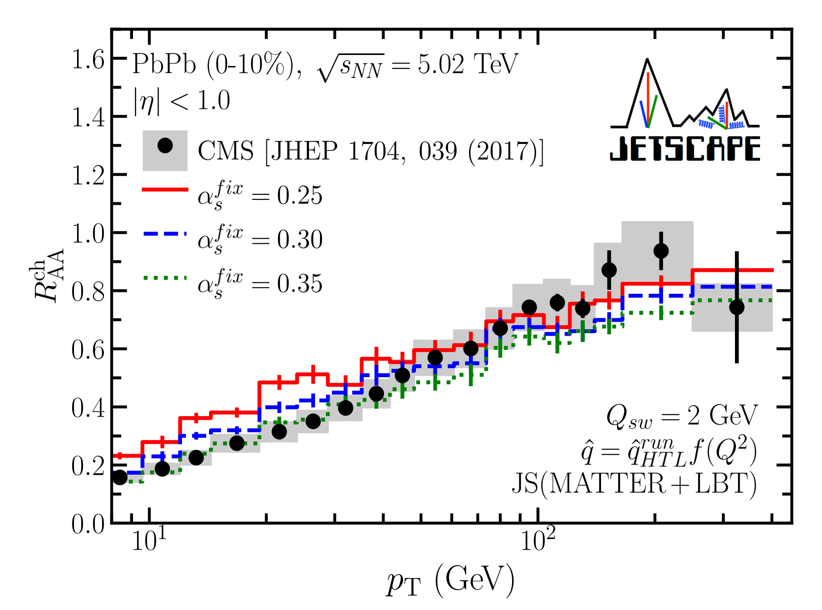




Simultaneous Description of Leading Hadrons and Jets

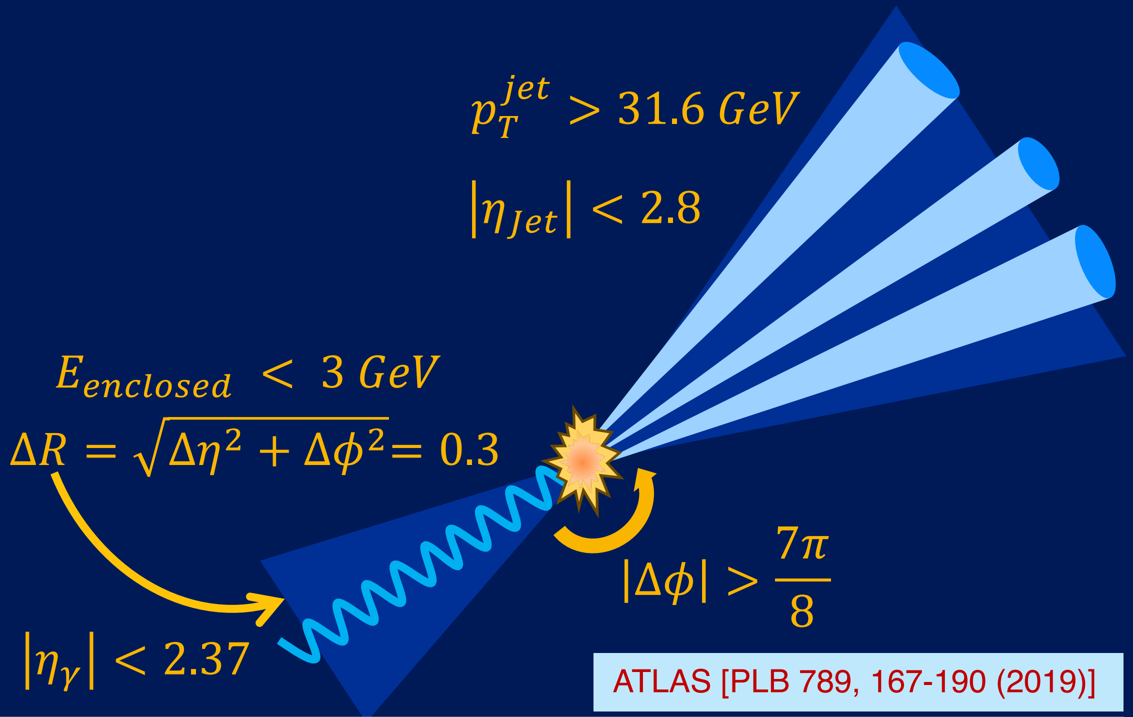
- Parameters tuned for simultaneously describe leading hadron and jet spectra
  - Blue line of each plot: $Q_{sw} = Q_0 = 2\ GeV, \alpha_s^{fix} = 0.3, \tau_0 = 0.6\ fm/c$, and $T_c = 160\ MeV$
  - AA23 tune
- Not tuned using Bayesian calibration
  - See Peter Jacobs's talk on Monday, 3.40 pm for more details on Bayesian calibration
- Same tune can be used to accurately describe number of different observables (Different E_{CM}, centrality, etc.)
- JETSCAPE AA paper: Phys.Rev.C 107 (2023) 3, 034911, arXiv: 2204.01163
  - Further information on parameter tuning



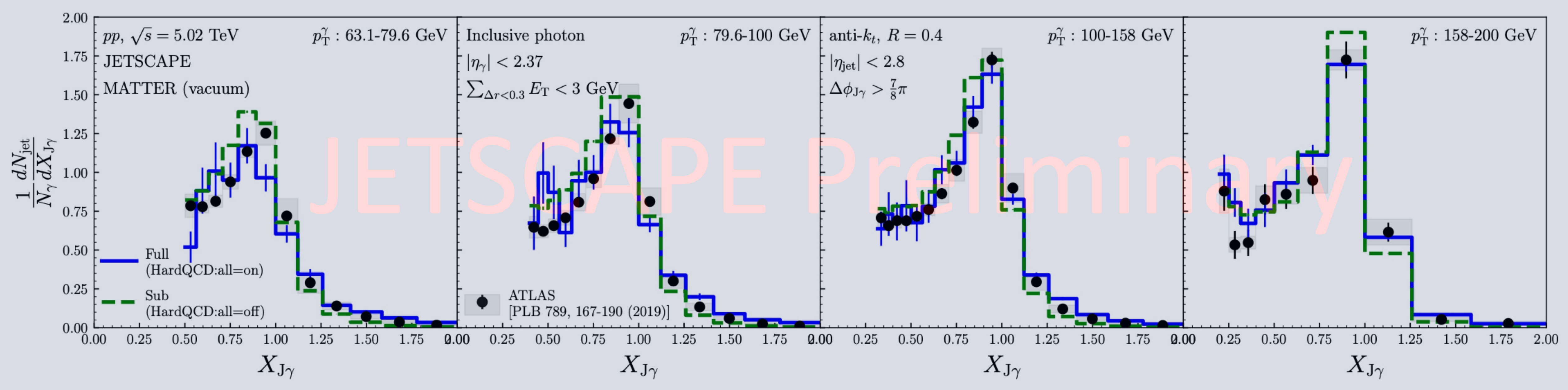


γ-jet Asymmetry – p-p

- γ-jet Asymmetry: $X_{J\gamma} = \frac{p_T^{jet}}{p_T^{\gamma}}$
- 5.02 TeV p-p: Full Events and Prompt Photon Events
  - $p_T^{jet} > 31.6\ GeV$; $|\eta_\gamma| < 2.37$; R = 0.4, $|\eta_{Jet}| < 2.8$, $|\Delta\phi| > \frac{7\pi}{8}$
  - Isolation cut (E < 3 GeV) $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.3$
- p-p simulation using JETSCAPE PP19 tune
- Full events: Have better description with relatively large error bars

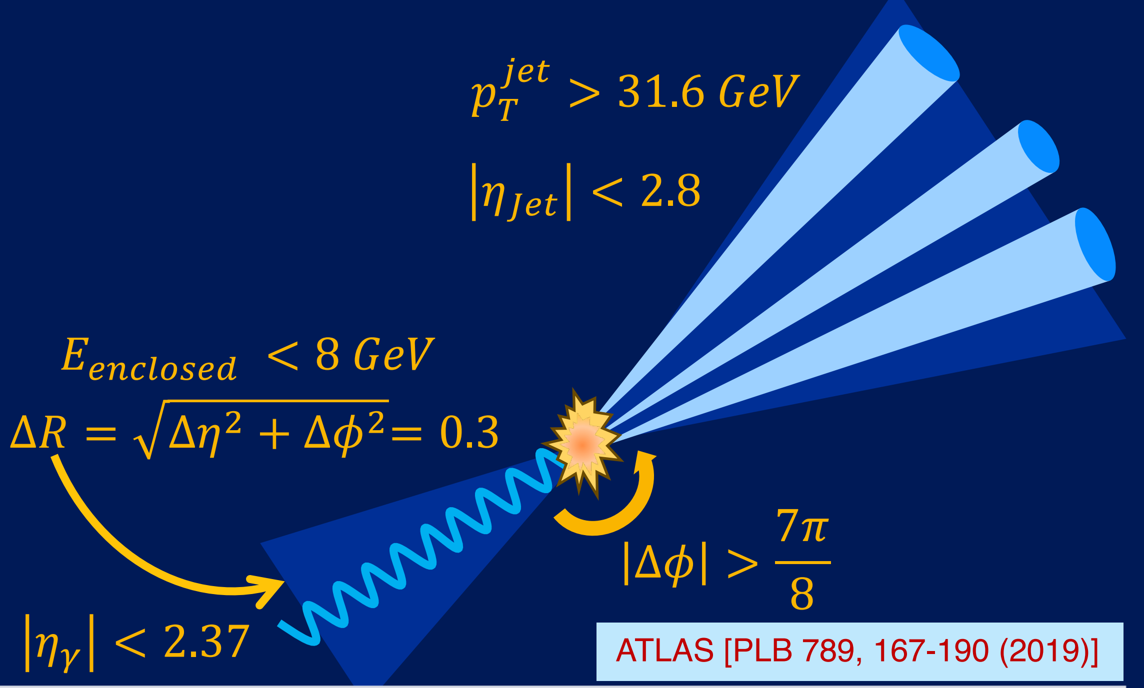


ATLAS [PLB 789, 167-190 (2019)]

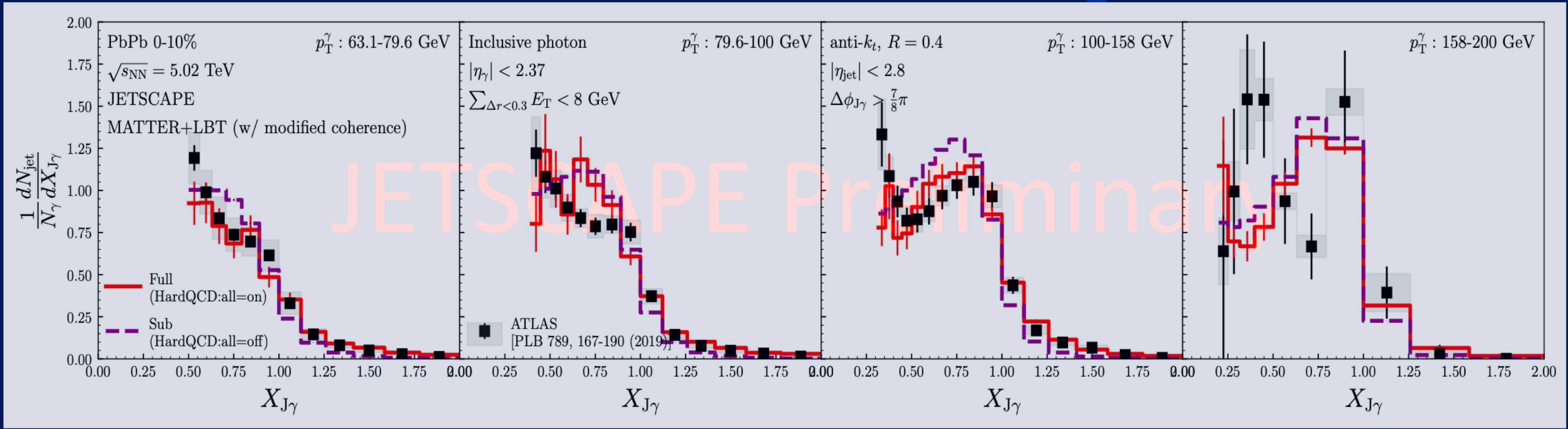


γ-jet Asymmetry – Central PbPb

- 5.02 TeV PbPb: Full Events and Prompt Photon Events
  - $p_T^{jet} > 31.6\ GeV$; $|\eta_\gamma| < 2.37$; $R = 0.4, |\eta_{Jet}| < 2.8, |\Delta\phi| > \frac{7\pi}{8}$
  - Isolation cut (E < 8 GeV) $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.3$
- Unfolded experimental results
- Full events: Have better description with relatively large error bars



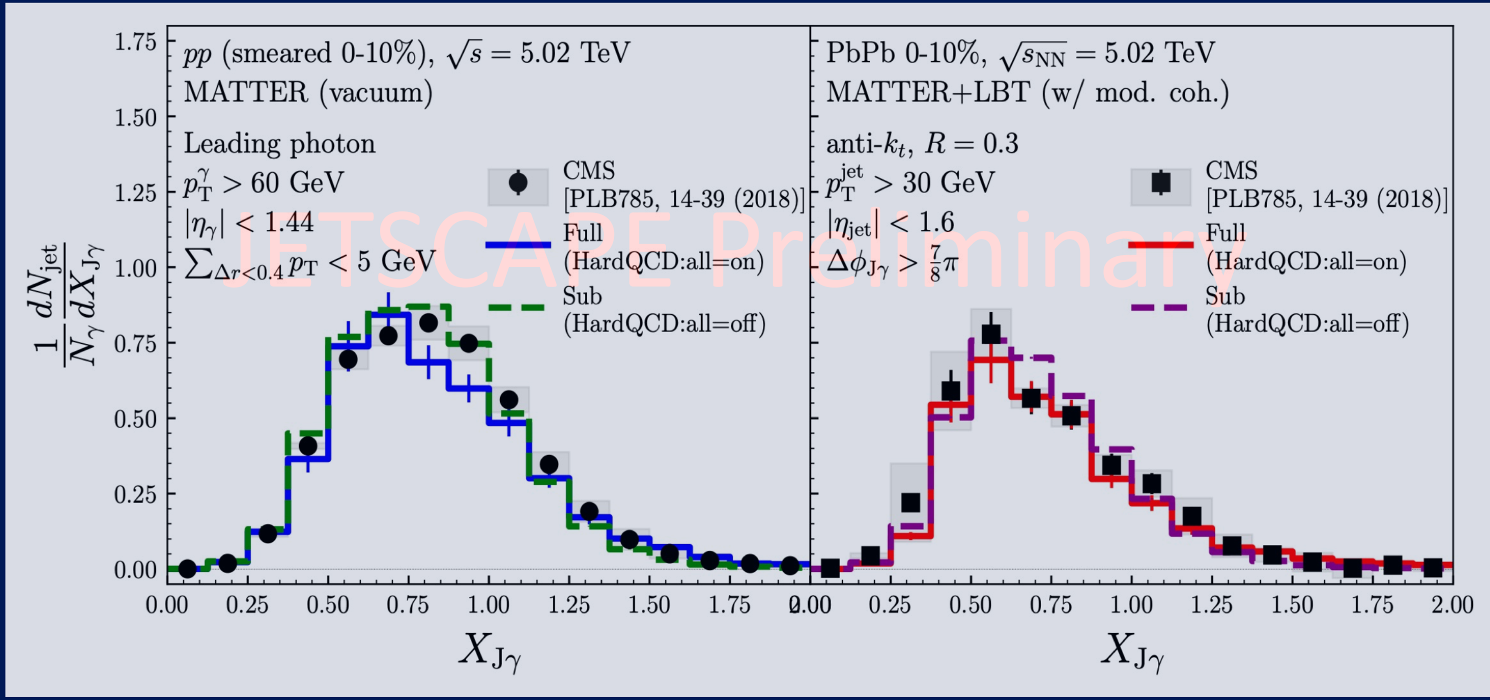
ATLAS [PLB 789, 167-190 (2019)]

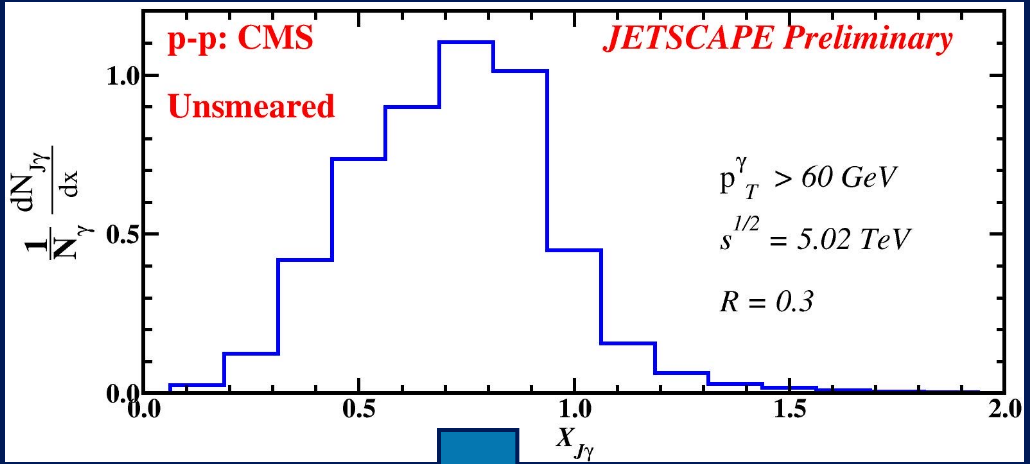


γ-jet Asymmetry – p-p and Central PbPb

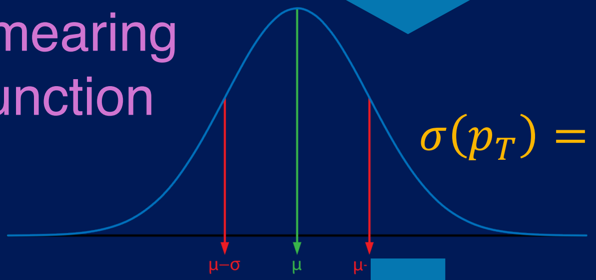
- 5.02 TeV: Full Events and Prompt Photon Events
  - $p_T^{jet} > 30\ GeV$, $|\eta_\gamma| < 1.44$, R = 0.3, $|\eta_{jet}| < 1.6$, $|\Delta\phi| > \frac{7\pi}{8}$
  - Isolation cut (E < 5 GeV) $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.4$
- Full events: Have better description with large error bars
- Same JETSCAPE Events
- Smeared jet p_T (p-p and PbPb)

CMS [PLB 785, 14-39 (2018)]

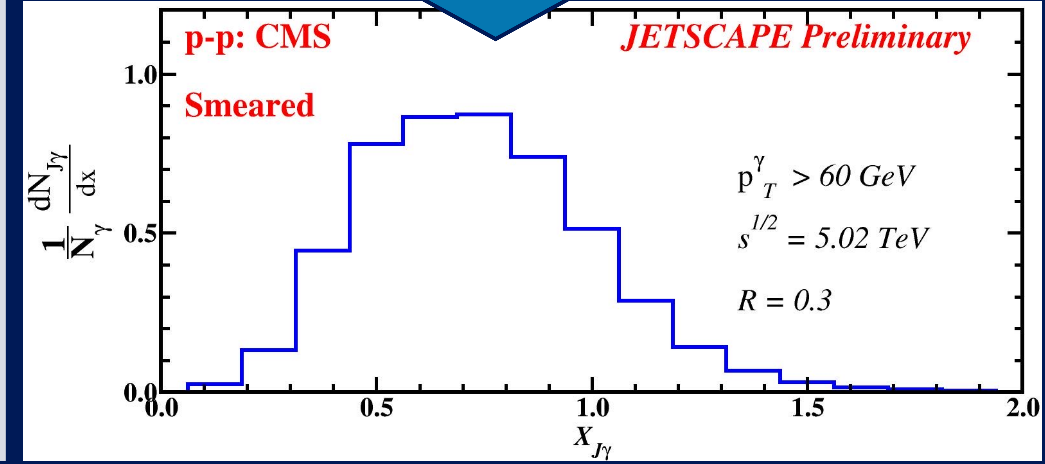




Smearing Function



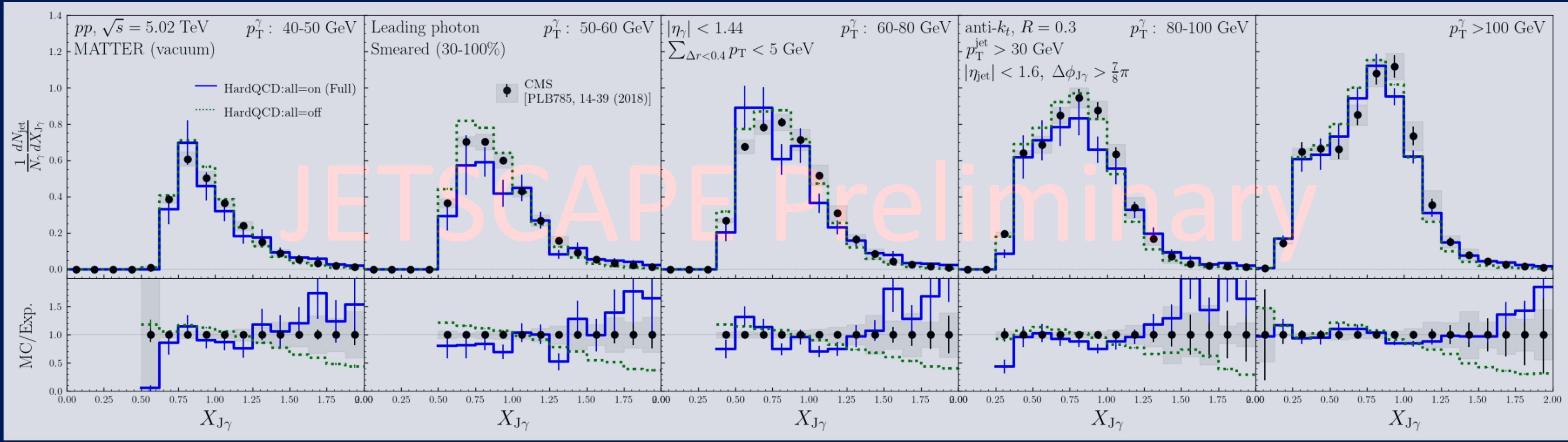
$$\sigma(p_T) = \sqrt{C^2 + \frac{S^2}{p_T} + \frac{N^2}{p_T^2}}$$



γ-jet Asymmetry – Smeared p-p

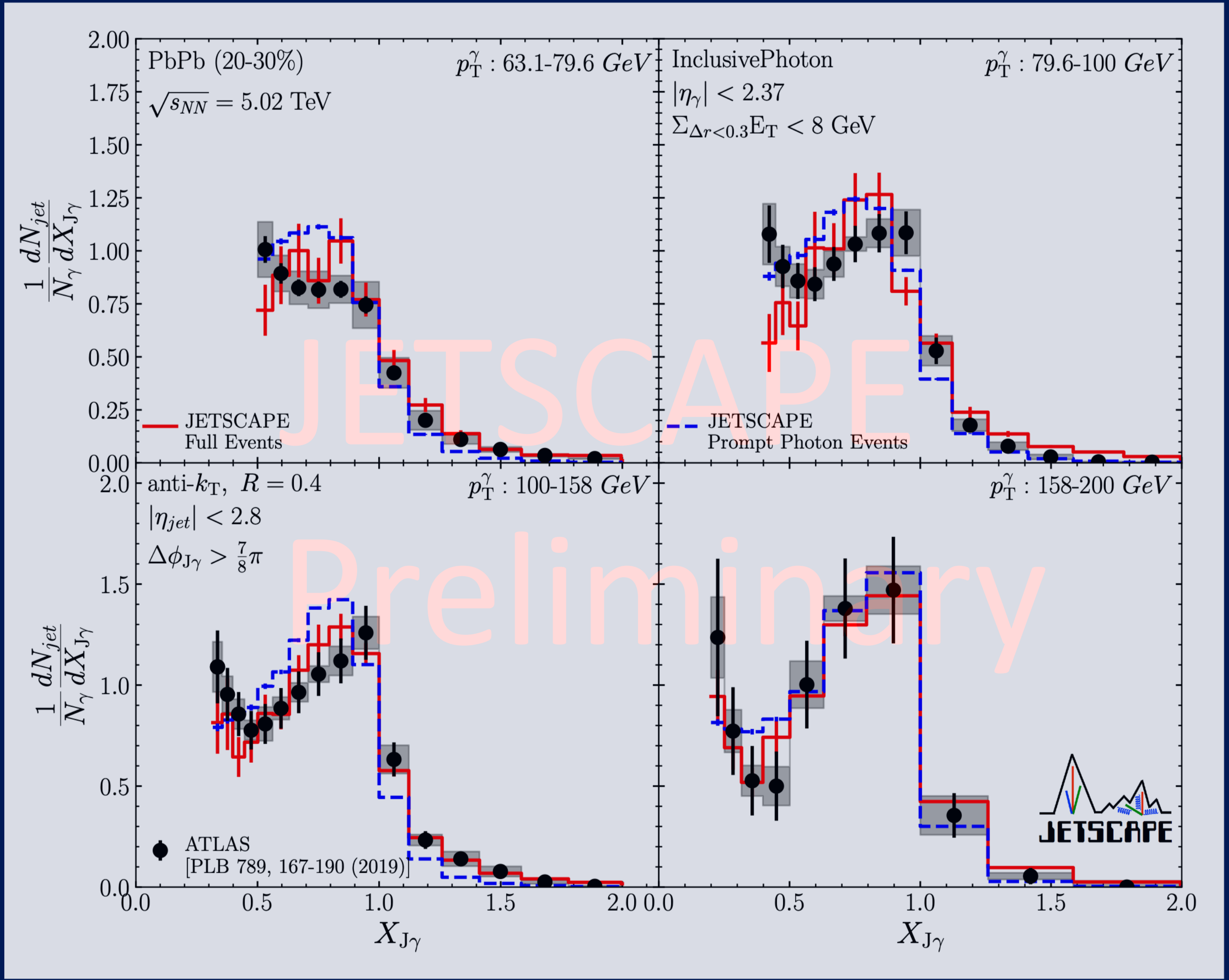
- 5.02 TeV p-p: Full Events and Prompt Photon Events
  - $p_T^{jet} > 30\ GeV,\ |\eta_\gamma| < 1.44,\ \mathrm{R} = 0.3, |\eta_{jet}| < 1.6,\ |\Delta\phi| > \frac{7\pi}{8}$
  - Isolation cut (E < 5 GeV) $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.4$
- Full events: Have better description with large error bars
- Ratio plots: Shows large deviation at large $X_{J\gamma}$
  - Wide angle photon radiation after initial hard scattering

CMS [PLB 785, 14-39 (2018)]



γ-jet Asymmetry – Peripheral PbPb

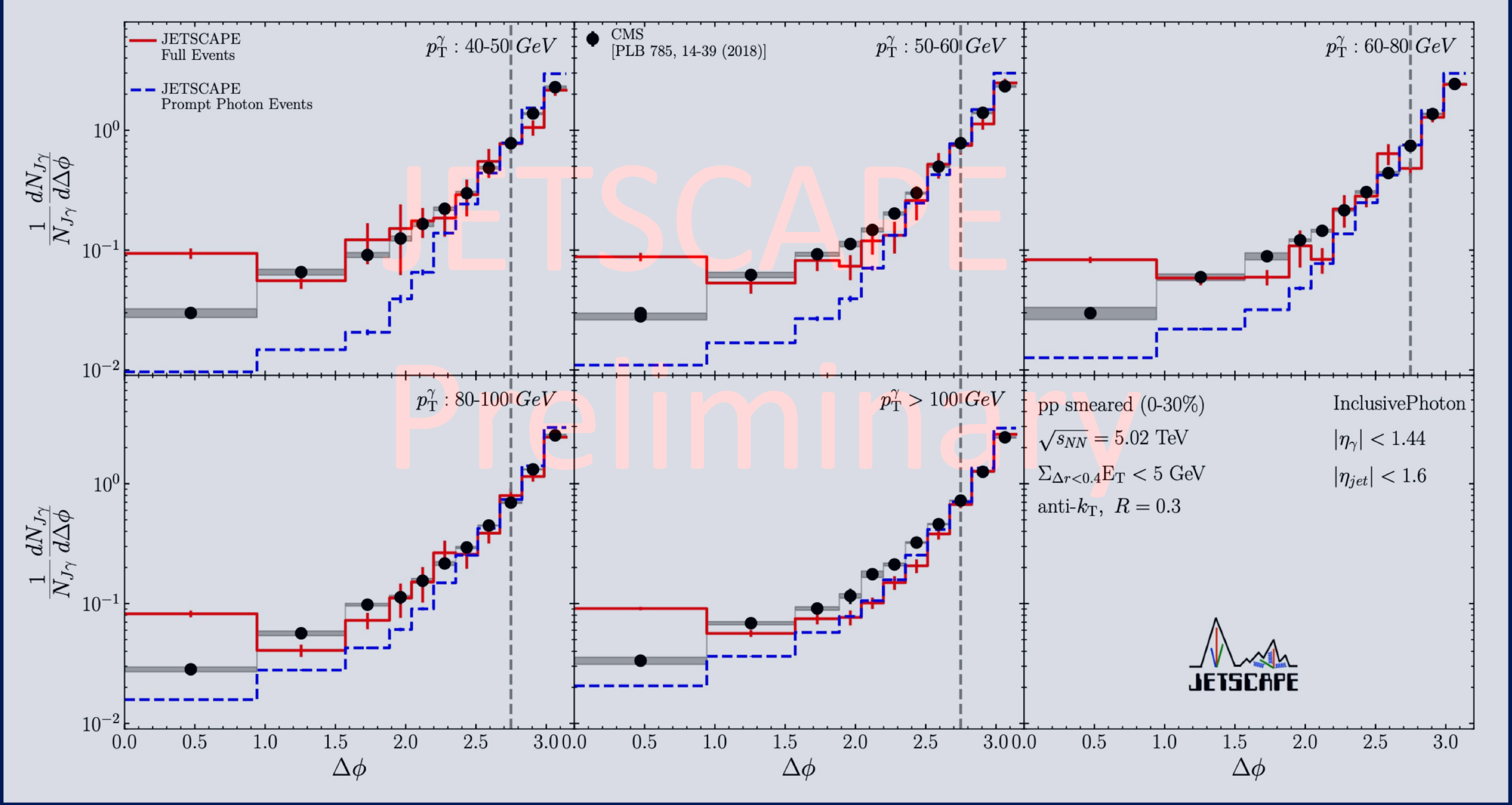
- 5.02 TeV PbPb: Full Events and Prompt Photon Events
- Deviated from experimental results
  - Similar behavior can be seen in the central events
- Full Events: Significantly better agreement
  - Larger Statistical Errors
  - Need larger number of events: More computer power
- Non-prompt photons: Important for direct photon observables



ATLAS [PLB 789, 167-190 (2019)]

γ-jet Correlation - pp

- 5.02 TeV pp: Full Events and Prompt Photon Events
- Prompt Photon Events: Deviated from experimental results
- Full Events: Significantly better agreement
  - Larger Statistical Errors
  - Overestimate the smallest bin
- $\Delta\phi > \frac{7\pi}{8}$: Similar in large p_T^γ



CMS [PLB 785, 14-39 (2018)]

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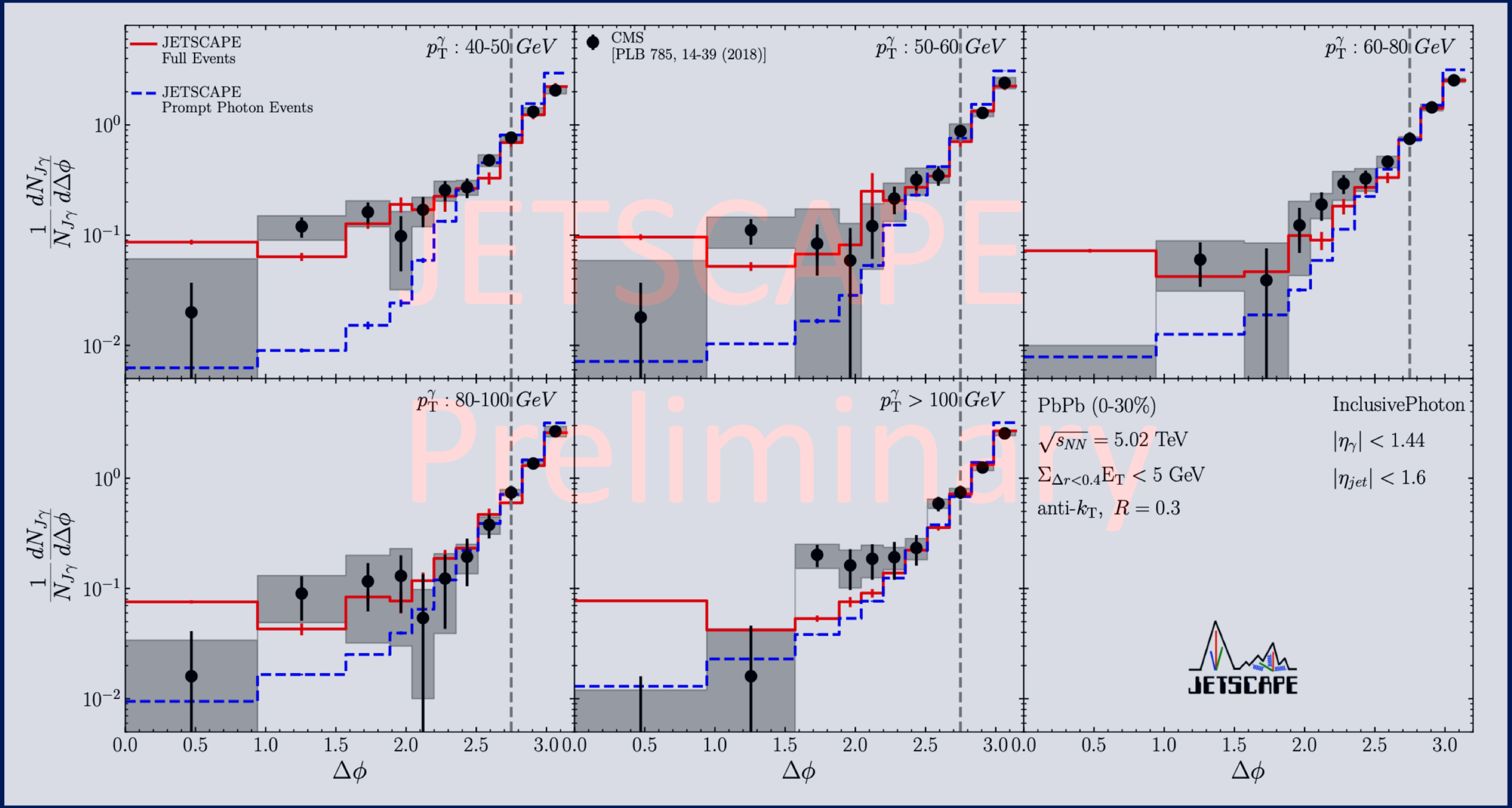
γ-jet Correlation - PbPb

- 5.02 TeV PbPb: Full Events and Prompt Photon Events
- Same Behavior as pp
- Prompt Photon Events: Deviated from experimental results
- Full Events: Significantly better agreement
  - Larger Statistical Errors
  - Overestimate the smallest bin
- $\Delta\phi > \frac{7\pi}{8}$: Similar in large p_T^γ



CMS [PLB 785, 14-39 (2018)]

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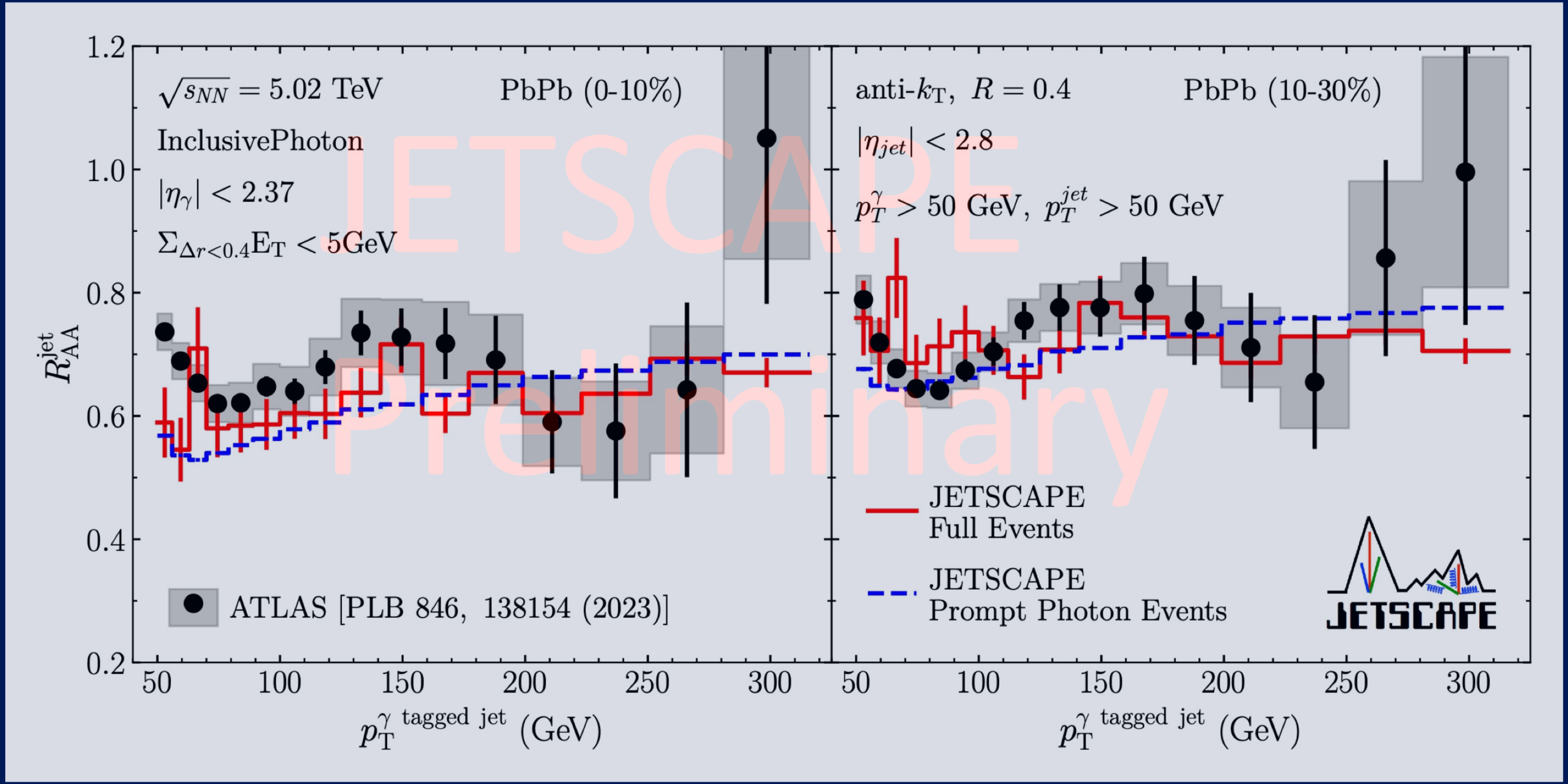
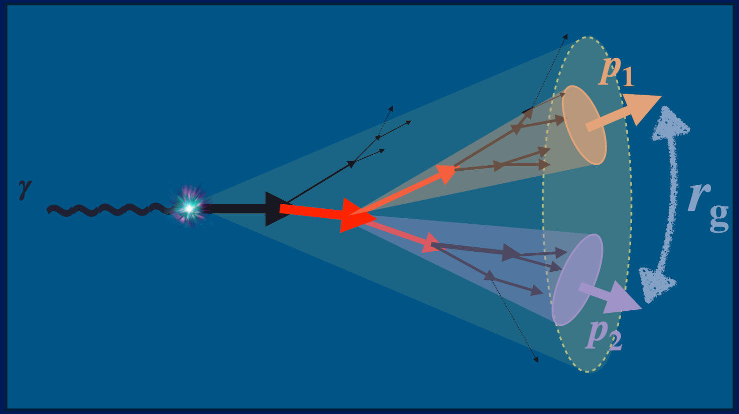
γ-jet– R_{AA}

- 5.02 TeV: Full Events and Prompt Photon Events
- Two centralities
- Full events captures most of the features
- Statistical Errors are significant
- More statistics or Different approach?
- Full Events: Significantly better agreement
  - Larger Statistical Errors
  - Need larger number of events: More computer power
- Non-prompt photons: Important for direct photon observables



ATLAS [PLB 846, 138154 (2023)]

Groomed Jet Substructure with γ-triggered jets

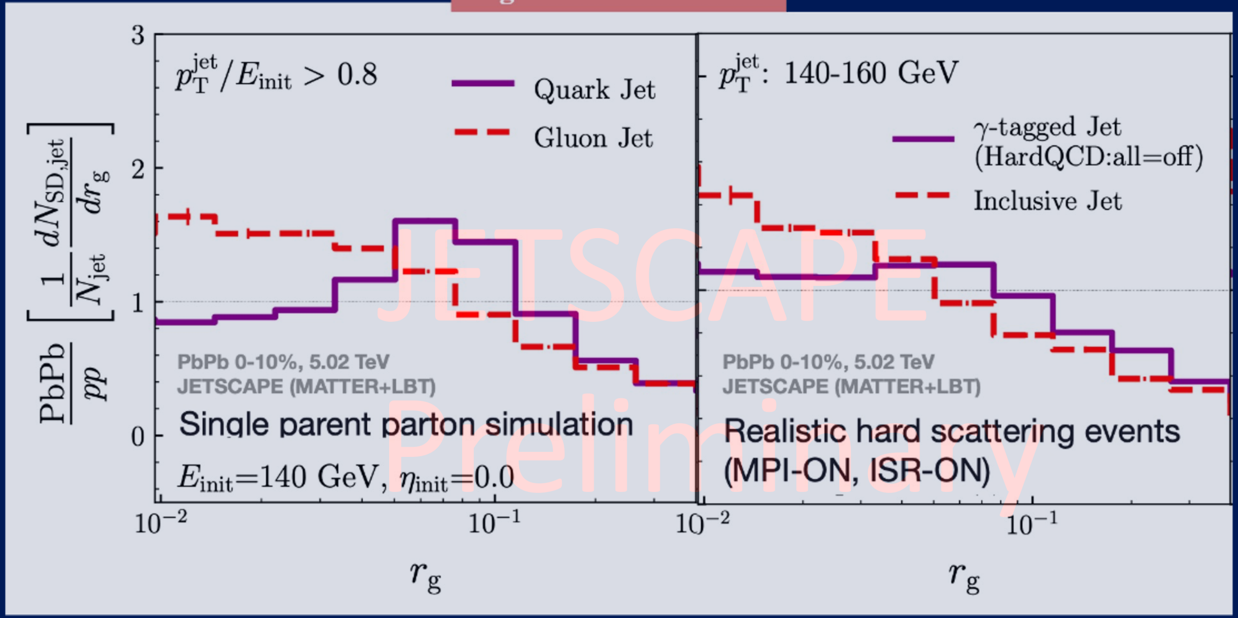


- Prompt Photon Events Only
- Soft Drop grooming $(z_{cut} = 0.2, \beta = 0)$
- Prominent modification of quark jets
- Manifestation of quark jet characteristics in γ -tagged jets

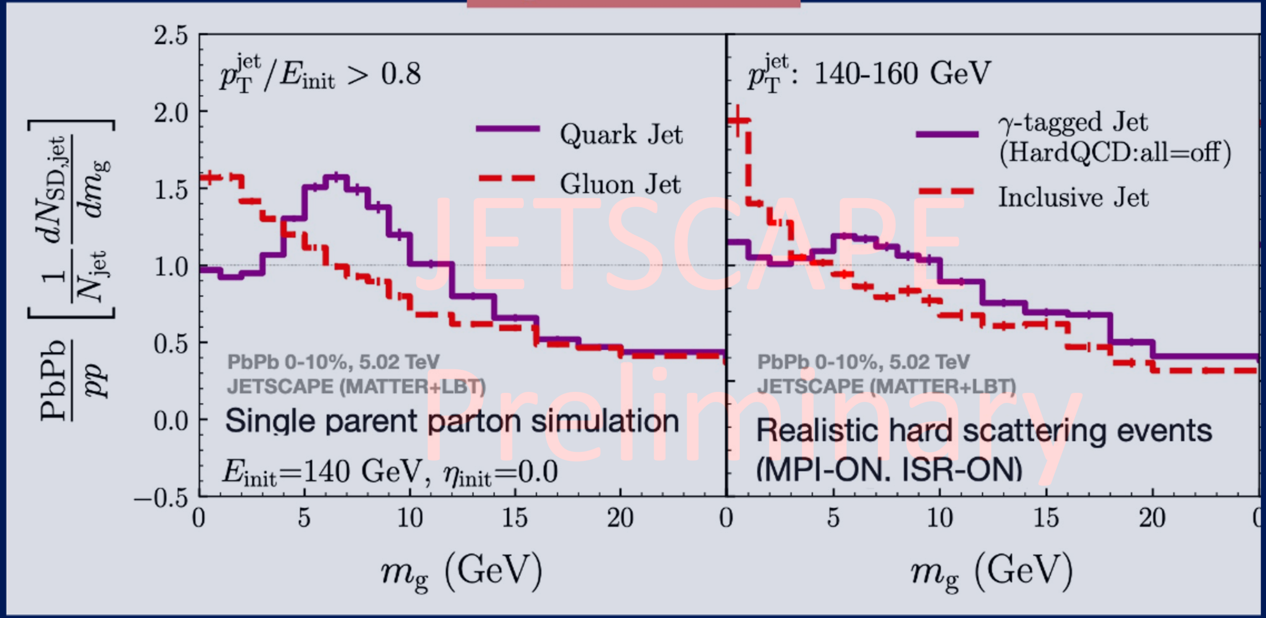
Yasuki Tachibana's talk
Monday, 5.50 pm

$$m_g = \sqrt{(p_1 + p_2)_\mu (p_1 + p_2)^\mu}$$

r_g-distribution



m_g-distribution



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Summary and Future Directions

- Photon observables - an independent, parameter free verification of the multistage evolution

- Using the prompt photon events from hard scattering might not be sufficient
  - Prompt photon events are rare: Computer intensive simulation
  - Full events shows a better description of all results with relatively large error bars
  - Isolated Non-prompt photons make considerable contribution

- Groomed Jet substructure with photon-tagged jets: Increasing interest from the community

- Full event analysis with reduced statistical uncertainty for both central and peripheral PbPb events
  - More statistics or Different approach?
- Include more physics in our simulations

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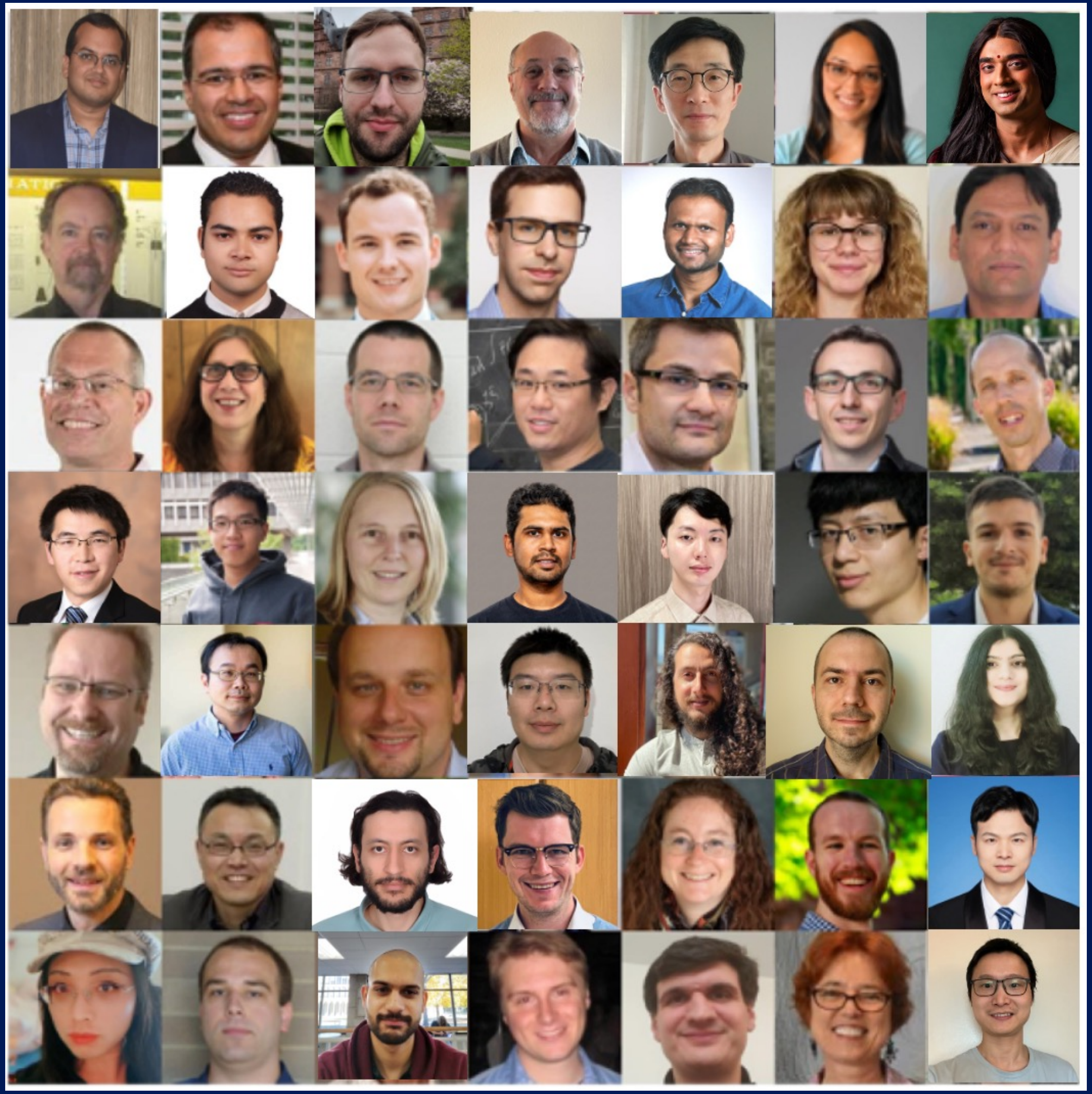
The JETSCAPE Collaboration



➢ JETSCAPE at HP2024

- Peter Jacobs: Multi-Observable Analysis of Jet Quenching Using Bayesian Inference (Parallel 4: high pt in small systems, Monday 3.40 pm)
- Yasuki Tachibana: Extraction of jet-medium interaction details through jet substructure for inclusive and gamma-tagged jets (Parallel 5: jet substructure, Monday 5.50 pm)
- Hendrik Roch: Effects of hadronic reinteraction on jet fragmentation from small to large systems (Parallel 5: jet substructure, Monday 6.10 pm)
- Yayun He: Energy-energy correlators of inclusive jets in heavy-ion collisions (Parallel 9: jet EEC, Tuesday 9.20 am)
- Sangyong Jeon: Correlations between hard probes and bulk dynamics in small systems (Parallel 21: jets in small systems, Tuesday 4.15 pm)
- Rainer Fries: X-SCAPE as a universal Event Generator for e+p, e+e- and pp collisions (Poster)

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