Photon-jet correlations in p-p and A-A collisions

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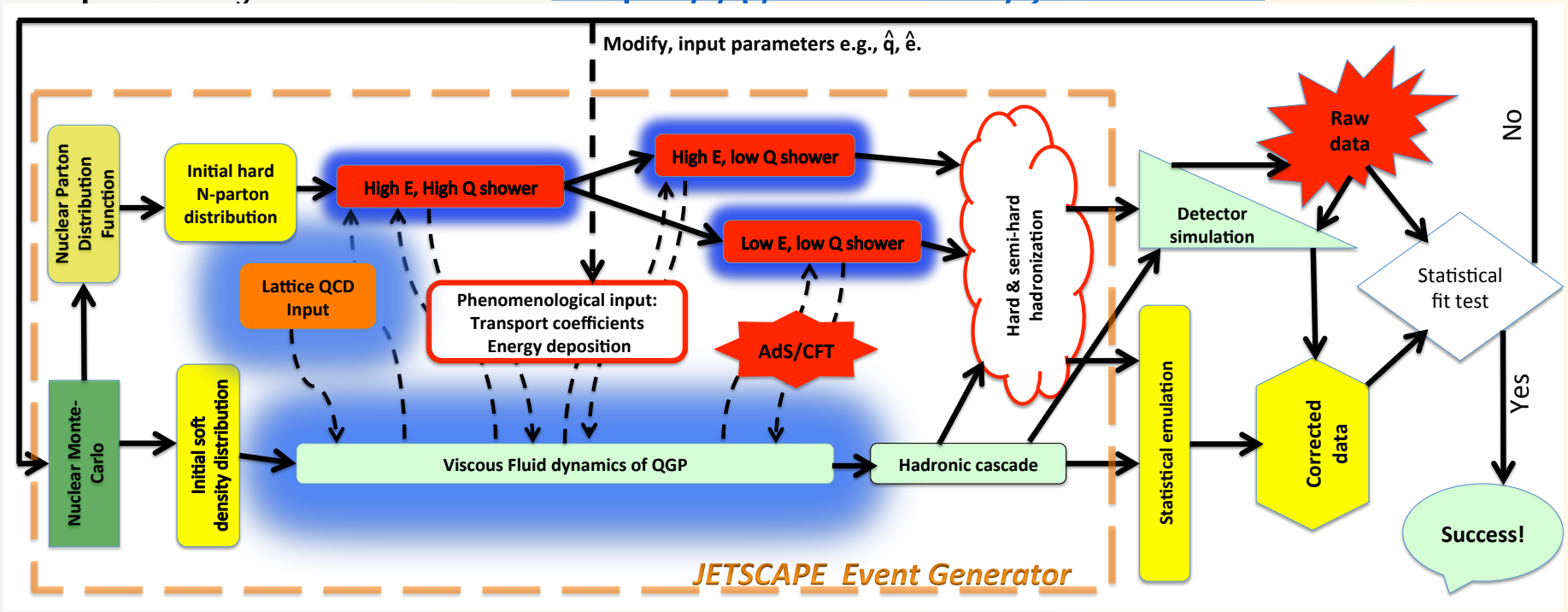
Outline

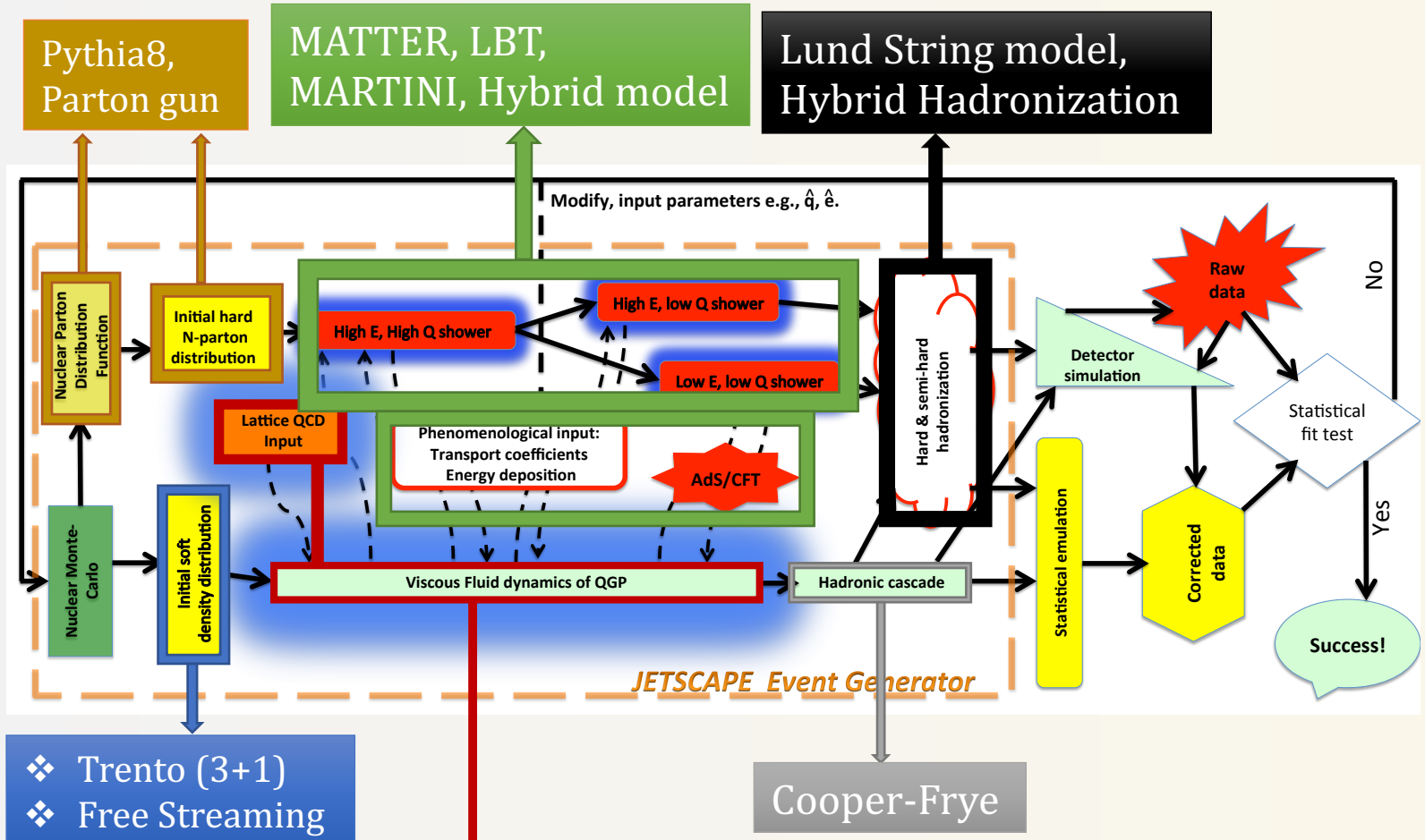
- JETSCAPE framework
- Simulating jet evolution with JETSCAPE framework
- Leading hadron and jet
- Photons
- Summary

JETSCAPE framework

- Jet Energy loss Tomography with a Statistically and Computationally Advanced Program Envelope
- General, modular and extensive framework
- JETSCAPE is public for almost 3 years
- JETSCAPE 3.0 publicly available at https://github.com/JETSCAPE

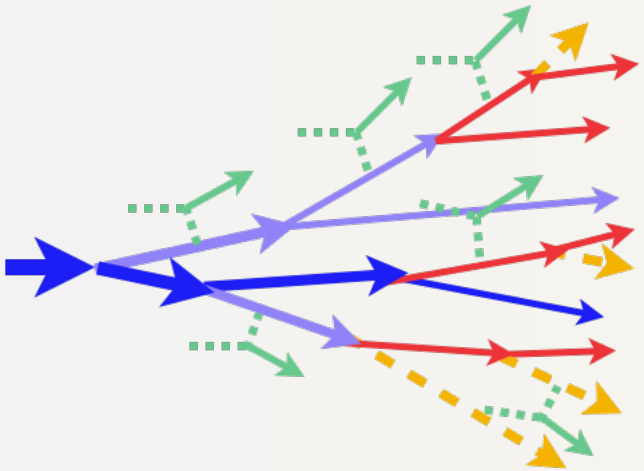


JETSCAPE framework



- ASCII, Gzip, and HepMC output formats
- Multi-stage jet evolution
- Different stages depending on the virtuality, Q and energy, E of the partons
- No single model can describe all stages of jet evolution

JETSCAPE framework: Multi-stage evolution



Virtuality Separation Scale: Q_0

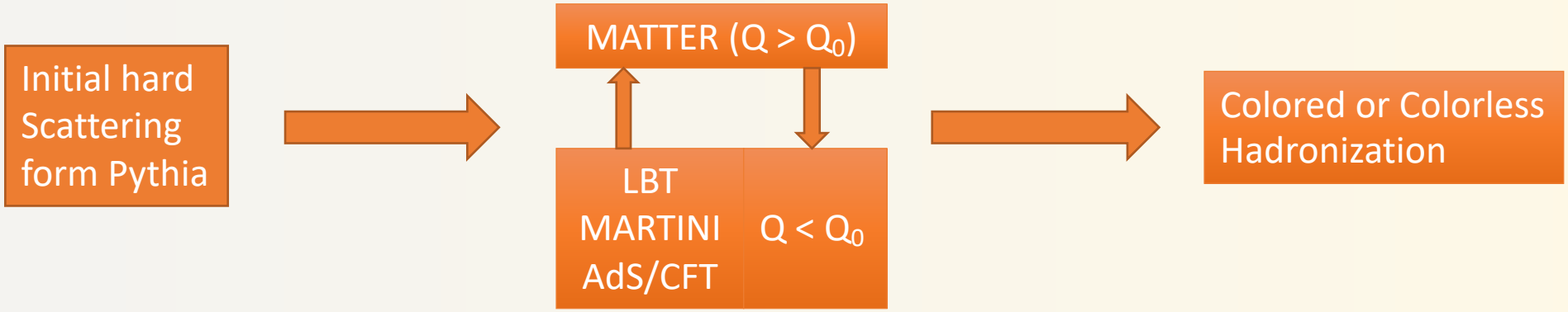
Switching between modules parton by parton depending on the virtuality and energy

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

- 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 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, Small E: Nearly thermal, strongly coupled approach (AdS/CFT)
  - AdS/CFT *(Chesler, Rajagopal(14, 15), Pablos, et al.(15, 16, 17), and others)*

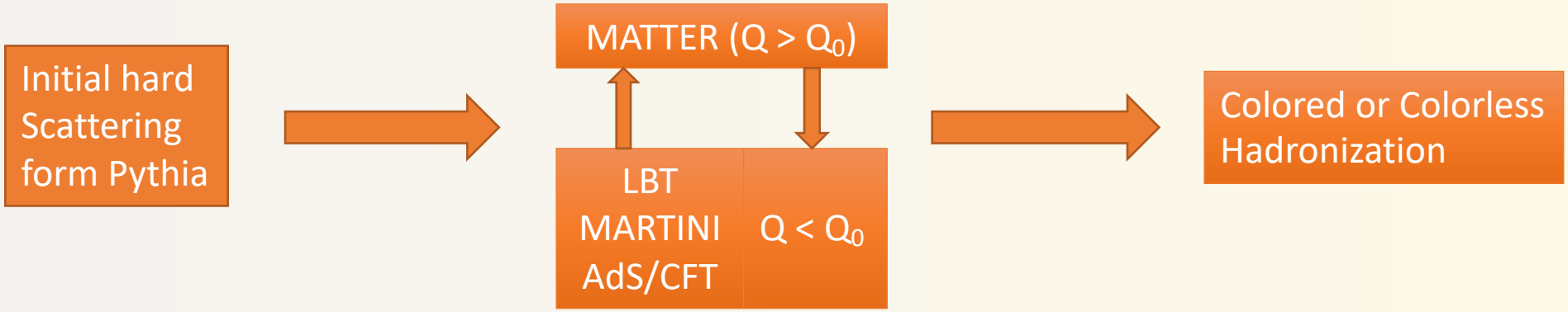
Simulating jet evolution with JETSCAPE framework

- Settings used in our simulations
  - PP baseline: MATTER vacuum shower
  - Common settings for PbPb 2.76 TeV and 5.02 TeV
    - Virtuality separation scale, Q_0 = 2 GeV
    - Recoil ON in MATTER and LBT
    - Recoil OFF in MARTINI and AdS/CFT
    - Hadronization: Colored and Color randomized (Colorless) hadronization using Lund string model (Pythia8)
  - Event averaged hydro is used for 2.76 TeV
  - Event by event hydro profiles with reuse hydro is used for 5.02 TeV



Simulating jet evolution with JETSCAPE framework

- Initial hard scattering from Pythia with initial state radiation
- Trento (2+1) initial conditions
- MATTER, LBT and MARTINI (only for leading hadron and jet analysis) energy loss modules
- Event averaged hydro (2.76 TeV) and event by event hydro (5.02 TeV)
- Hadronization
  - Colored – keep track of the color of partons throughout the shower
  - Color randomized – No color information required, and randomly assign color at the time of hadronization



Leading hadron: 2.76 TeV

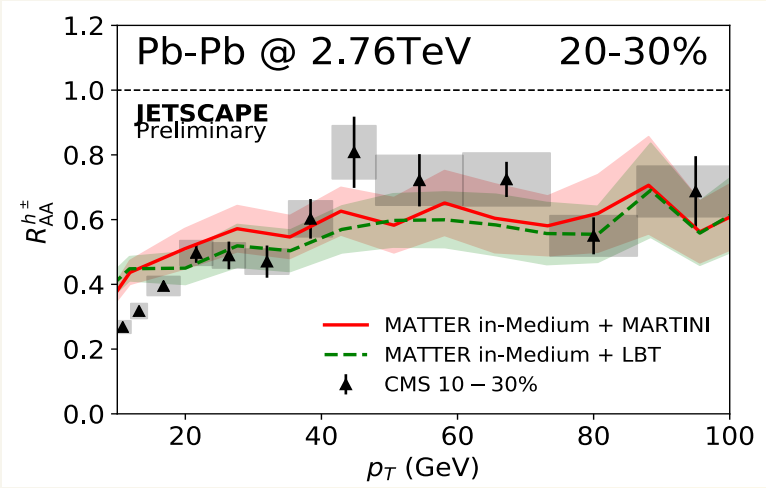
- JETSCAPE 1.0 – 2.76 TeV

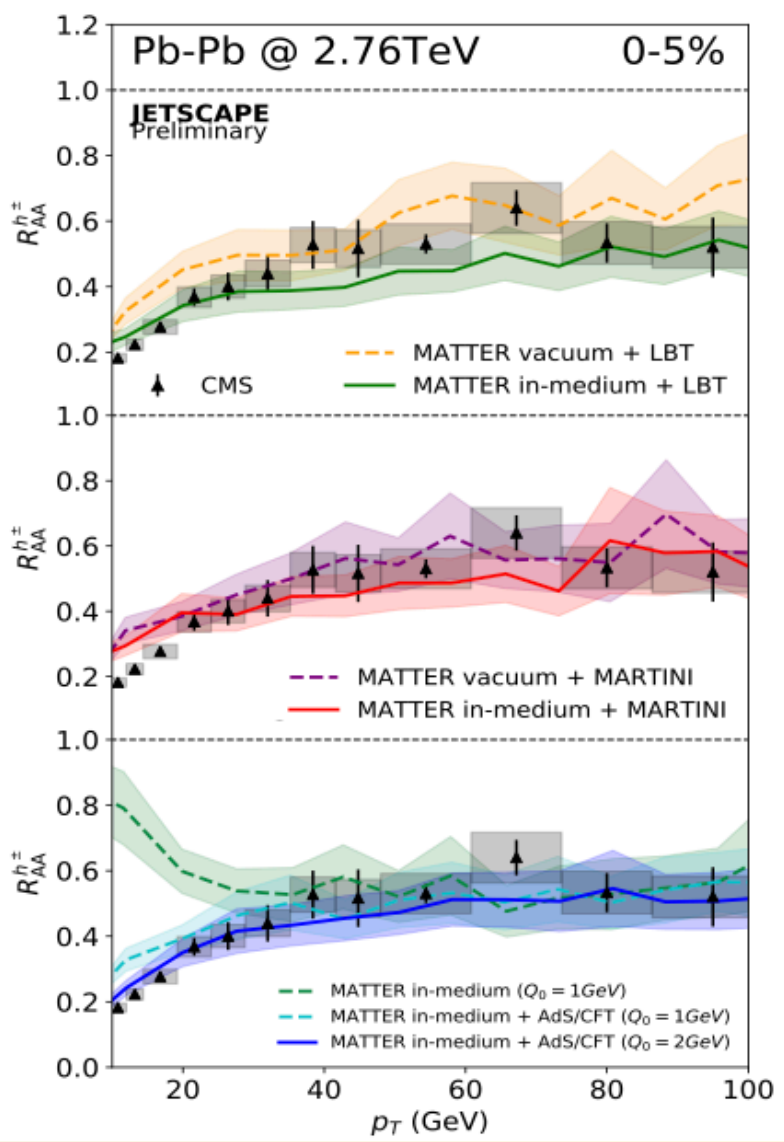
- MATTER – high virtuality partons
- LBT, MARTINI, AdS/CFT – low virtuality partons

- Q_0 can be used to finetune the low p_T region

All module combinations can explain the data reasonably well compared to a given single module

*CMS from Eur.Phys.J. **C72** (2012)*

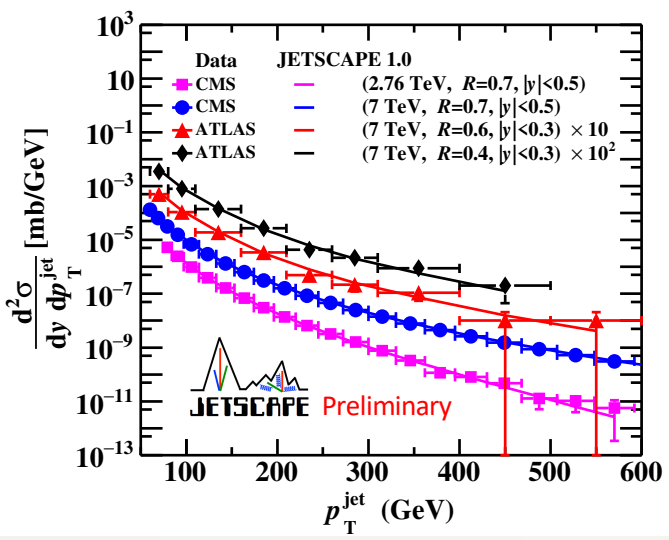


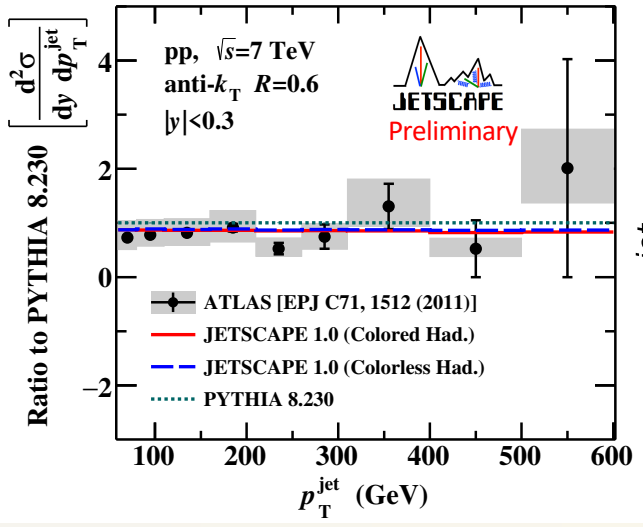


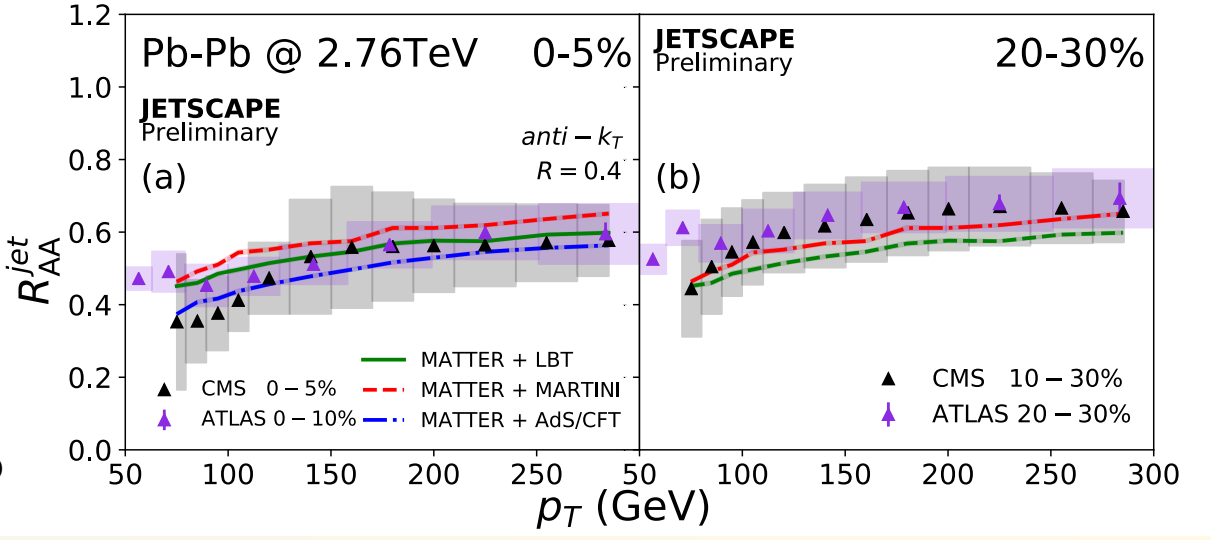
Jet: 2.76 TeV and 7 TeV p-p

- JETSCAPE 1.0
- 2.76 TeV PbPb- used the same tune used for hadron spectrum
- MATTER + LBT – Recoil on
- Reasonable description with data

CMS for 2.76 TeV from PRC 96, 015202 (2017)
CMS for 7 TeV from PRD 87, 112002 (2013)
ATLAS from EPJ C71, 1512 (2011)

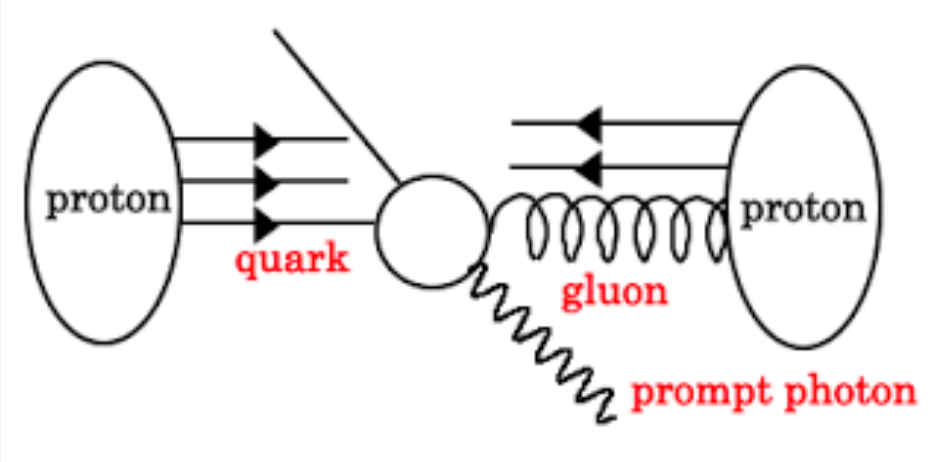






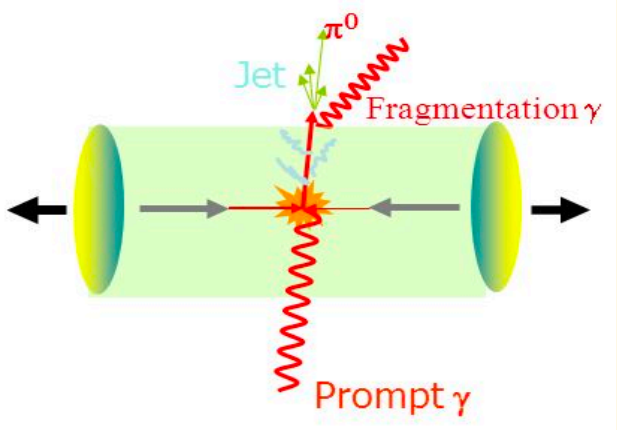
Photons

- Prompt photons - are produced directly in the hard sub-processes
- These prompt photons can be used to estimate the energy and the direction of jet initiating parton (before the energy loss) – Calibrated probe of the QGP
- Isolation criteria is necessary to identify the prompt photons
- Isolated photons mainly consist of prompt photons

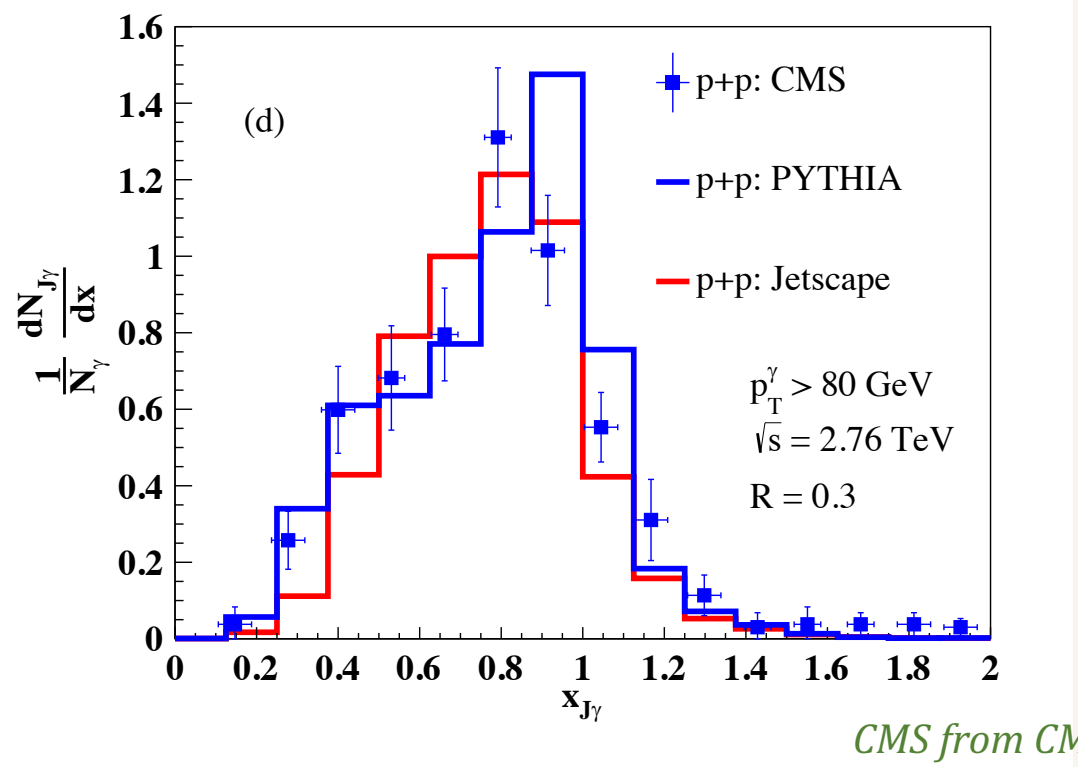


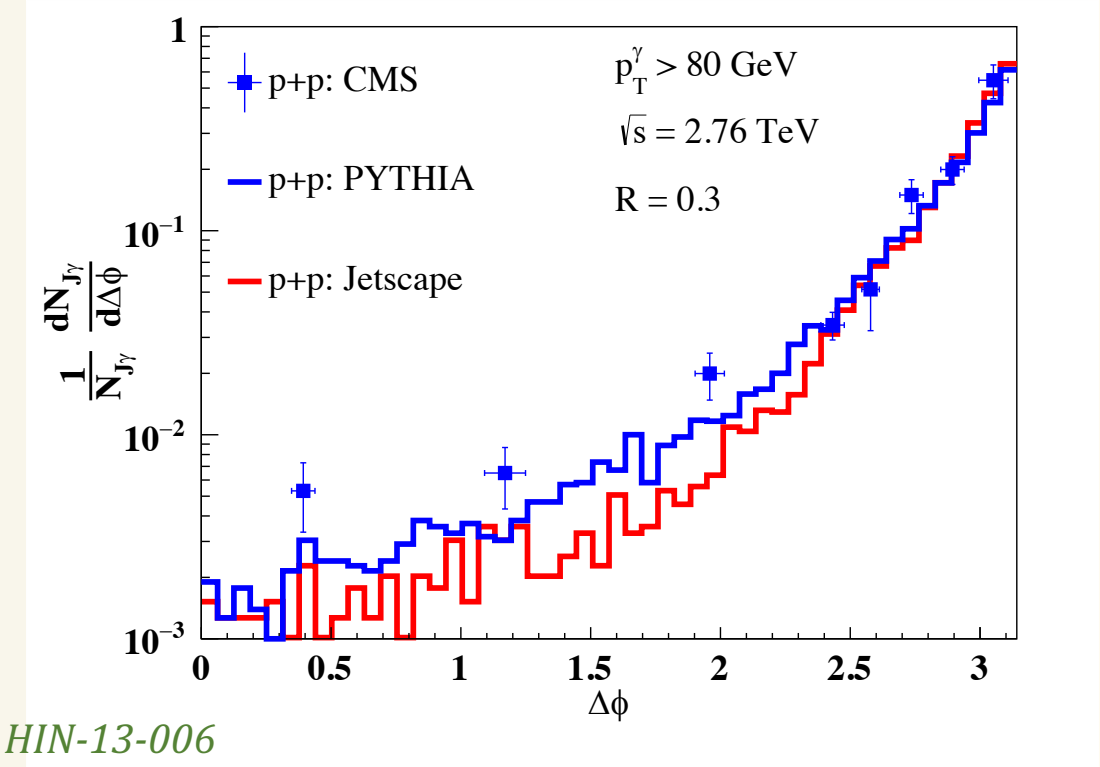
Photon Simulation

- Same set of parameters tuned for leading hadron and jet analysis were used
- an independent, parameter free verification of the multistage evolution
- Even though medium induced terms for energy loss is included in the framework, medium induced photon emission terms are not included in the Sudakov
- Photons included in the analysis
  - Photons from initial hard scattering (prompt photons)
  - Photons radiated from intermediate shower
  - Photons radiated by hadrons in the process of hadronization and final state hadronic radiation are included



Photon Results





CMS from CMS PAS HIN-13-006

JETSCAPE 1.0
Framework was not supported for photon propagation

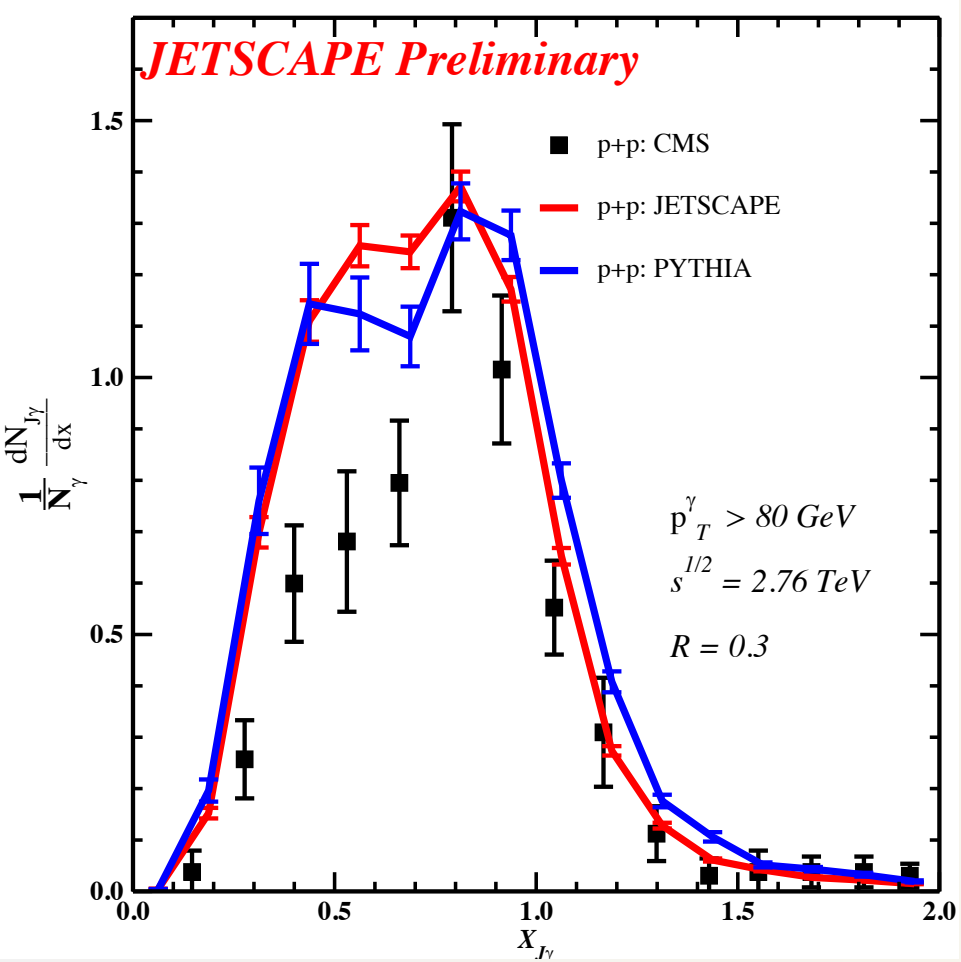
Used hard photons directly from Pythia gun
Low Statistics

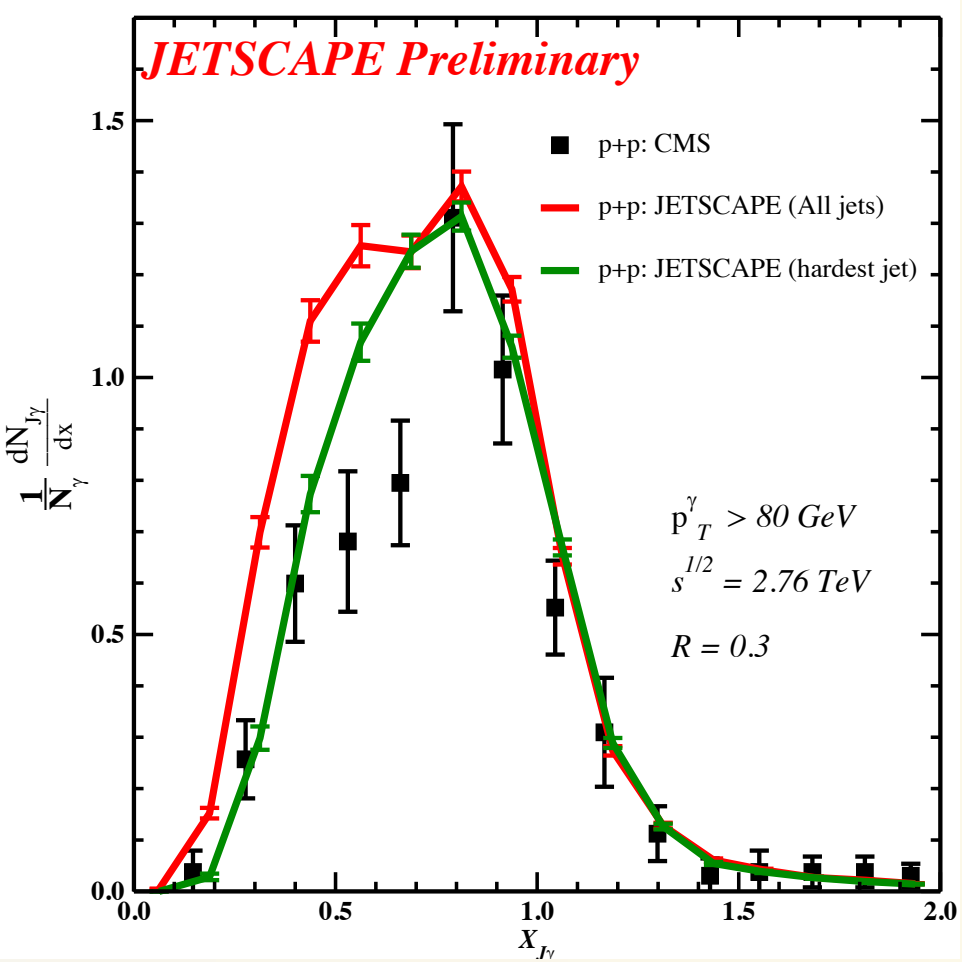
Photon Results

- JETSCAPE 2.0 – 2.76 TeV and 5.02 TeV
- 2.76 TeV pp results only. Ongoing analysis for PbPb
  - Both photon-jet p_T imbalance and azimuthal correlation
- 5.02 TeV PbPb results with low statistics. Ongoing analysis with more statistics
  - photon-jet p_T imbalance
- Further examination with more statistics required

Photons: P-P 2.76 TeV

Gamma-Jet transverse momentum imbalance (Gamma-Jet Asymmetry)





JETSCAPE 2.0

$$X_{J\gamma} = \frac{p_T^{jet}}{p_T^{\gamma}}$$

$$p_T^{jet} > 30\ GeV$$

$$|\eta_{\gamma}| < 1.44$$

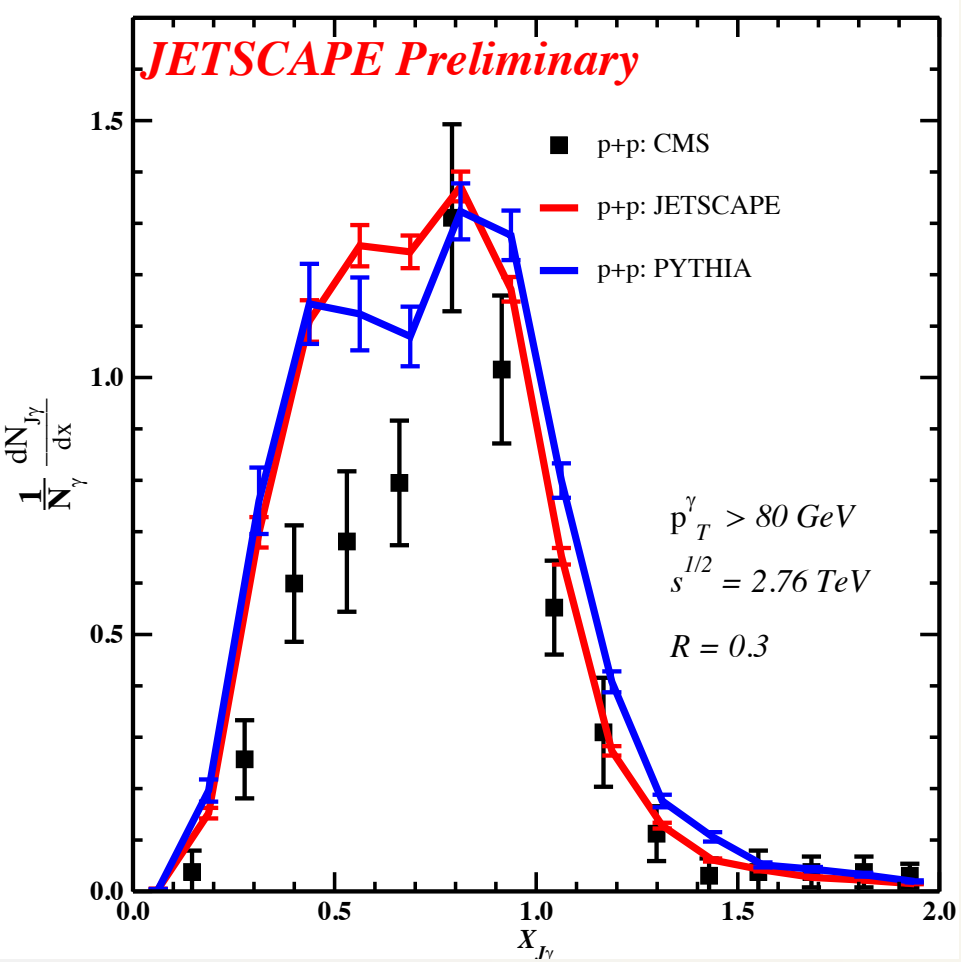
$$|\eta_{jet}| < 1.6$$

Isolation cut (E < 5GeV)

$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.4$

CMS from CMS PAS HIN-13-006

Photons: P-P 2.76 TeV

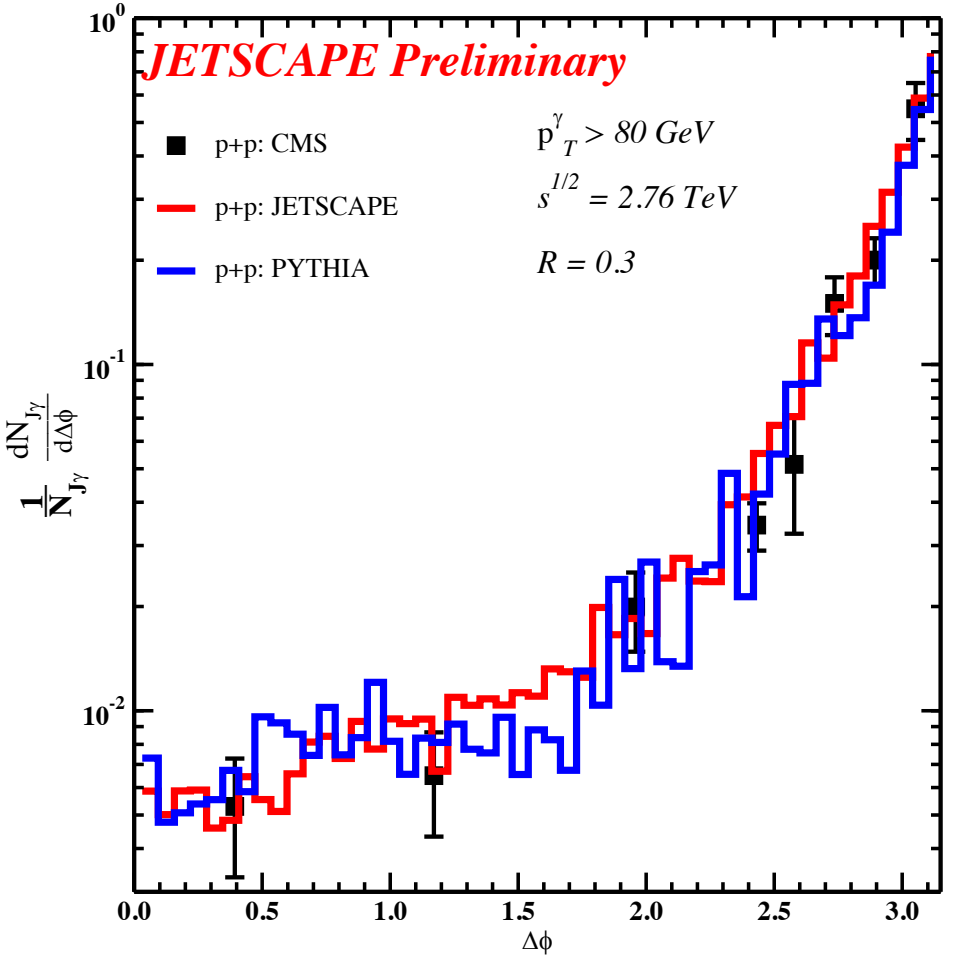


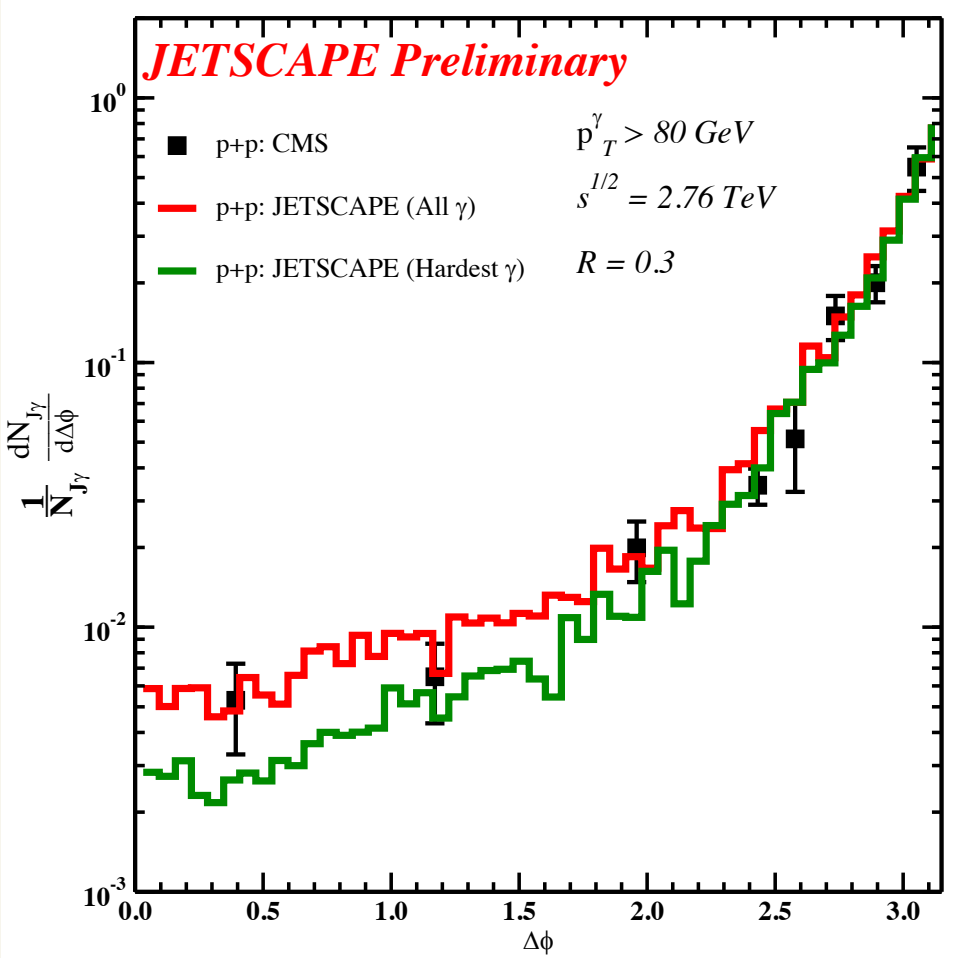
- Mismatch with experimental data (0.25 to 0.8) – may be due to NLO effects
- Look into different p_T^{γ} regions to understand the behavior
- Study other photon observables

CMS from CMS PAS HIN-13-006

Photons: P-P 2.76 TeV

Gamma-Jet Azimuthal correlation





JETSCAPE 2.0

$$\Delta\phi = |\phi^{jet} - \phi^{\gamma}|$$

$$p_T^{jet} > 30\ GeV$$

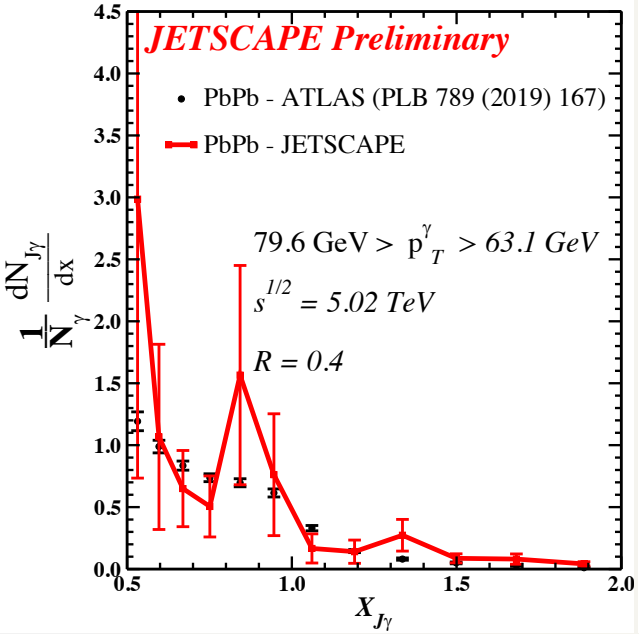
$$|\eta_{\gamma}| < 1.44$$

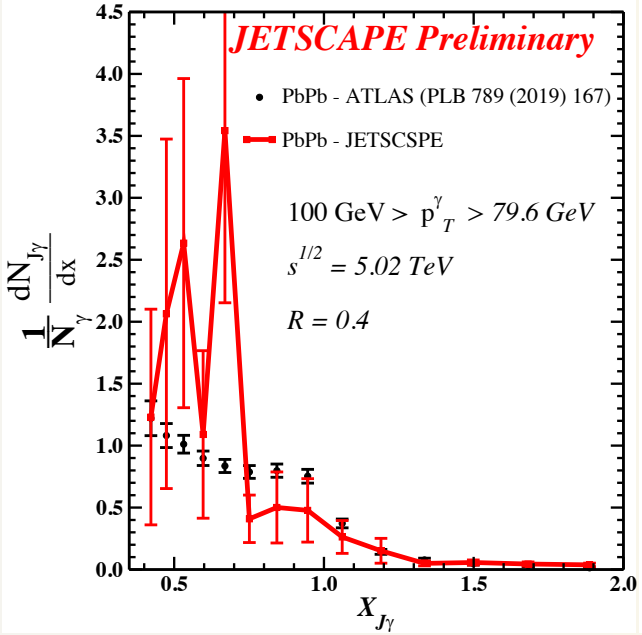
$$|\eta_{jet}| < 1.6$$

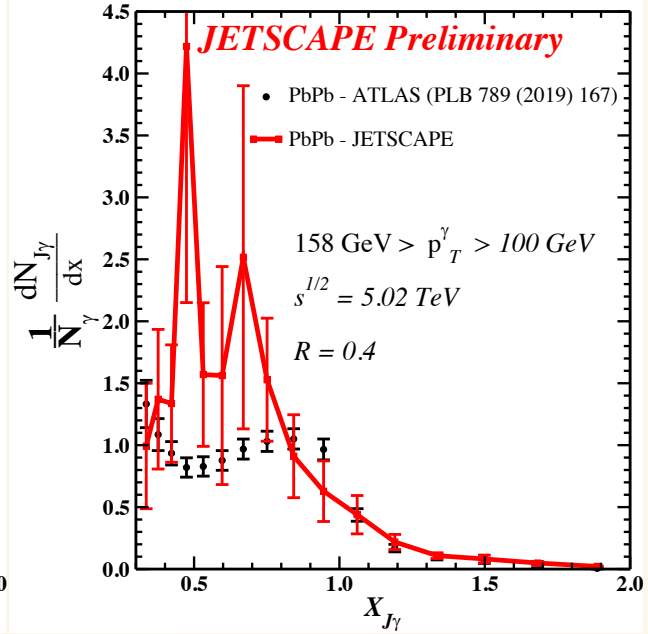
Isolation cut (E < 5GeV)
$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.4$

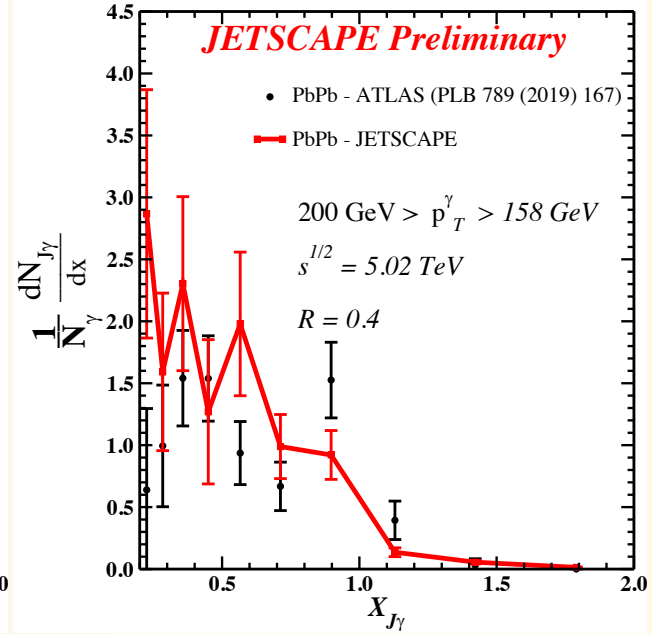
CMS from CMS PAS HIN-13-006

Photons: A-A 5.02 TeV









Gamma-Jet transverse momentum imbalance (Gamma-Jet Asymmetry)

$p_T^{jet} > 31.6\ GeV$; $|\eta_\gamma| < 2.37$ (excluding the region $1.37 < |\eta_\gamma| < 1.52$); $|\eta_{Jet}| < 2.8$

Isolation cut (E < 8GeV) $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.4$

Summary

- JETSCAPE is a general, modular and extensive framework that can be used to simulate heavy ion collisions
- Multi-stage evolution can describe all the stages of jet evolution significantly better than single module evolution
- JETSCAPE can describe most of the observables by using the same set of parameters for different center of mass energy
- Photon observables - an independent, parameter free verification of the multistage evolution

Future directions

- Pb-Pb analysis with higher statistics (5.02 TeV and 2.76 TeV) using JETSCAPE 3.0
- P-P analysis at 5.02 TeV with higher statistics using JETSCAPE 3.0
- More module combinations (MATTER+MARTINI, MATTER+AdS/CFT)
- More photon observables to better understand the limits of these module combinations