Jet-medium photons as a probe of early time dynamics and parton energy loss mechanisms

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Introduction

- Jet energy loss in QGP medium
  - well-established signal of QGP existence
  - can study the properties of QGP medium
- Several approaches to jet-quenching reproducing data across many systems
- Photons: complementary probes with λ_{mfp} larger than the medium size
- In this talk
  1. First dynamical calculation of jet-medium photons, compared with data
  2. Photons as potential probes of jet-energy loss
- Specific models to consider
  1. MARTINI (Schenke et al. Phys. Rev. C 80 (2009))
  2. CUJET (Xu et al. JHEP 08 (2014) 063)

MARTINI and CUJET

MARTINI:

- Solves rate equation

$$\frac{\mathrm{d}P(p)}{\mathrm{d}t} = \int_k \left(P(p+k)\frac{\mathrm{d}\Gamma_{\mathrm{AMY}}(p+k,k)}{\mathrm{d}k} - P(p)\frac{\mathrm{d}\Gamma_{\mathrm{AMY}}(p,k)}{\mathrm{d}k} \right) \tag{1}$$

- Radiative energy loss: all orders in opacity expansion

CUJET:

$$\frac{\mathrm{d}P(p)}{\mathrm{d}t} = \int_{k>0} P(p)\frac{\mathrm{d}\Gamma_{\mathrm{DGLV}}(p,k)}{\mathrm{d}k} \tag{2}$$

- Leading order in opacity expansion, explicit formation time dependence

Both:

- Collisional energy loss on the same footing as radiation
- LPM effect addressed in both

Event Generation

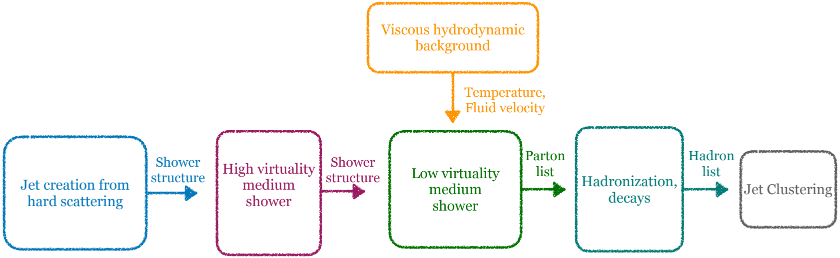


Figure 1: Flow of Physical information

Event Generation: A Modular Adventure

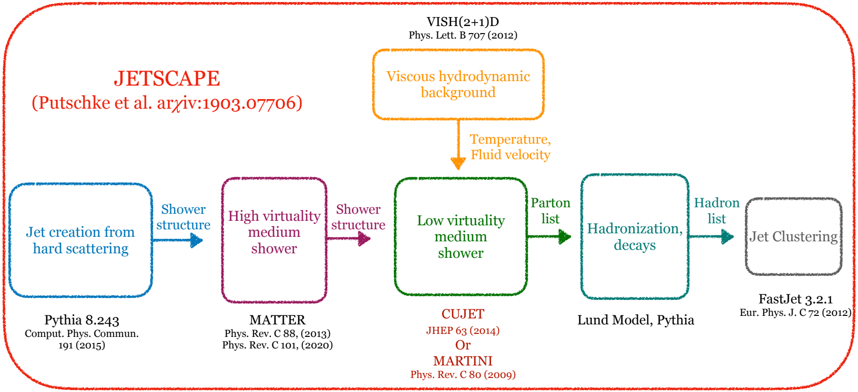


Figure 2: Workflow for event generation

Charged Hadron R_{AA}

- $\eta/s = 0.08$
- MC-Glauber initial condition

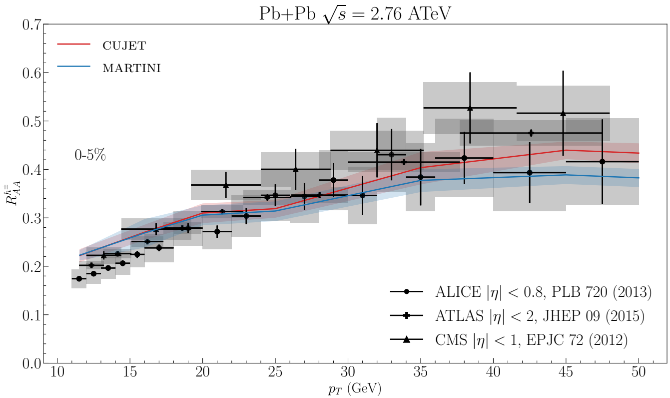


Figure 3: Charged Hadron R_{AA}, central

Charged Hadron R_{AA}

Good agreement for semi-central events

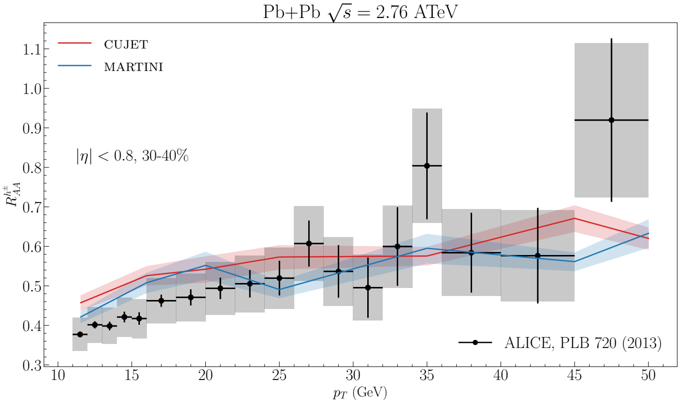


Figure 4: Charged Hadron R_{AA}, semi-central

Jet R_{AA}

Similarly for jets, good agreement at very central...

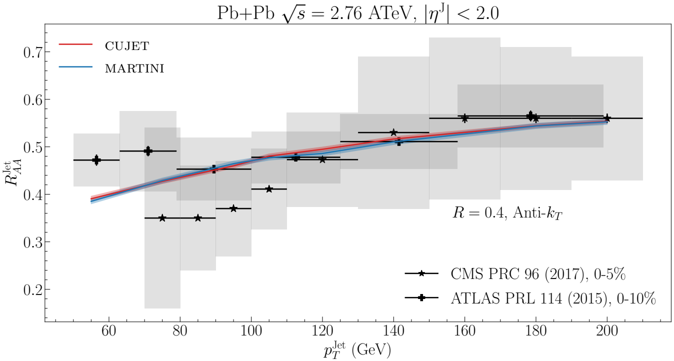


Figure 5: Jet R_{AA}, central

Jet R_{AA}

... and semi-central events

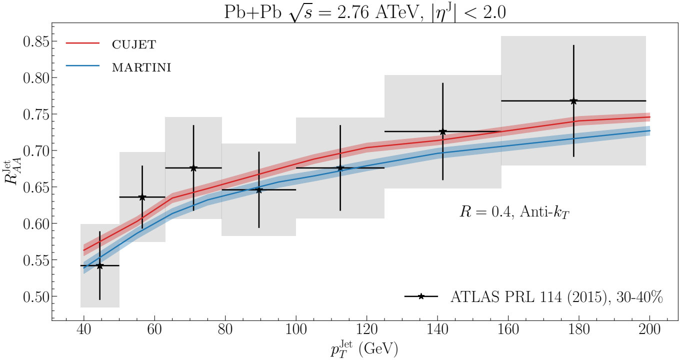
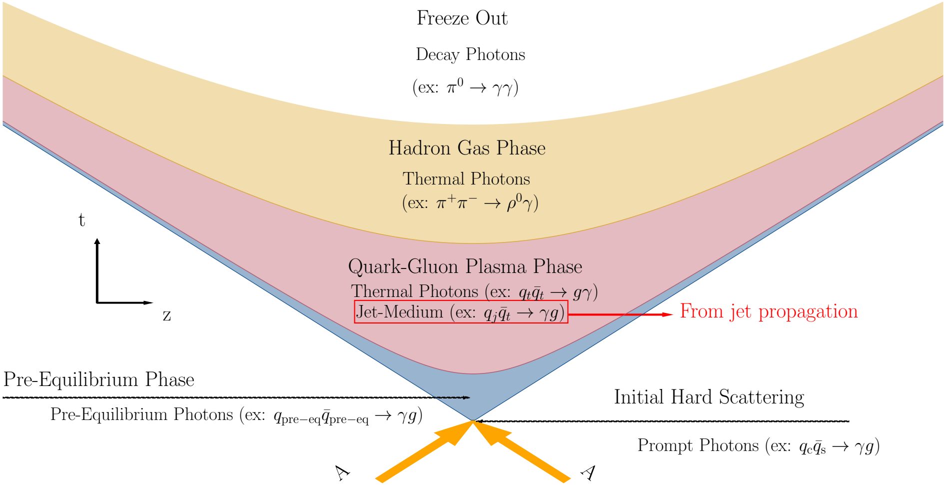


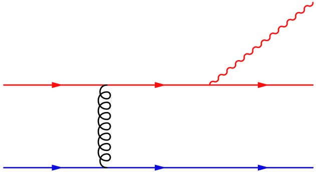
Figure 6: Jet R_{AA}, semi-central

Photons in HIC

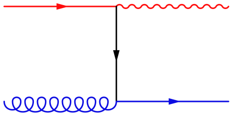


Photons from Jet-Medium Interactions

- Two main photon production channels available to a jet in QGP
  1. Jet-Bremsstrahlung: kicks from the medium impart virtuality which is radiated as a photon
  2. Jet-Conversion: very soft exchanges with the medium "convert" a fermion jet to a photon which inherits its energy and momentum



(a) Sample Bremsstrahlung Diagram



(b) Sample Conversion Diagram

Jet-Medium Photons

- Similar to other radiative/collisional energy loss channels, jet medium photons are computed by

$$f_\gamma(k) = \int \mathrm{d}^4x \; \mathrm{d}^3p \; P_{\mathrm{j}}(\mathbf{p}, \mathbf{x}, t) \frac{\mathrm{d}\Gamma(\mathbf{p}, \mathbf{k})}{\mathrm{d}^3p \; \mathrm{d}^3k} \tag{3}$$

- MARTINI: Bremsstrahlung rates have been computed within AMY-McGill and tabulated (Schenke et al. Phys. Rev. C 80 (2009))
- CUJET: No bremsstrahlung photons (work in progress)

Conversion Photons

- Can convert to photons via (at LO in α_s)
  1. QCD Compton Scattering
  2. $q\bar{q}$ Annihilation
- Both have a t-channel, dominated by small momentum transfers
- Conversion: assume all the contribution comes from that region of phase-space
- In that limit:

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}^3p\ \mathrm{d}^3k}(\mathbf{p},\mathbf{k}) = e_f^2 \frac{2\pi\alpha\alpha_\mathrm{s}}{3}\ \frac{T}{p}\left[\frac{1}{2}\ln\frac{2pT}{m_q^2} - 0.36149\right]\delta^{(3)}(\mathbf{p}-\mathbf{k}) \tag{4}$$

- Conversion photon spectrum: directly proportional to parton spectrum!

Photon Yield: MARTINI

- Prompts: dominant as p_T increases
- Medium sources lose significance beyond $p_T \approx 5$ GeV
- 12% (Conv.) + 18%(Brem.) = 30% of total yield for $p_T \in [5, 10]$ GeV
- (Prompt,Pre-Eq,Thermal) from C. Gale et al. (Phys.Rev.C 105 (2022) 1, 014909)

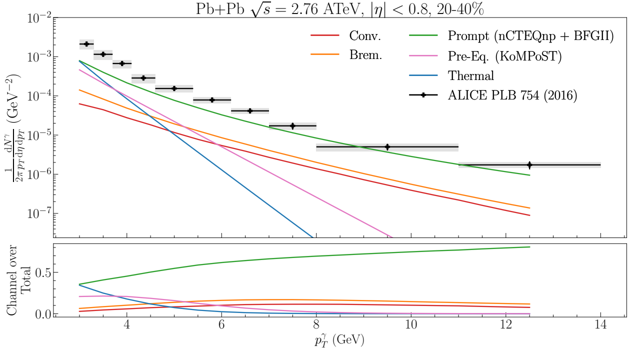


Figure 8: Photon yield, separated by channel

Jet-Medium Photons: MARTINI

- Compare total photon spectrum with & without jet-medium contribution
- Pre-Eq. Photons of dashed line from J. Churchill et al. (Phys.Rev.C 103 (2021) 2, 024904)
- Jet-Medium: nearly 30% of photon yield at intermediate p_T

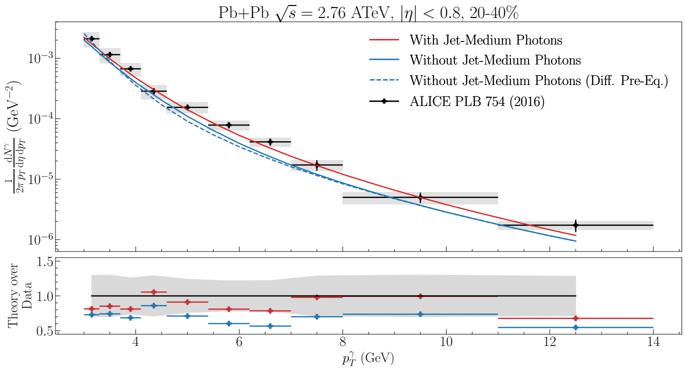


Figure 9: Photon yield with and without jet-medium photons

Conversion Photons: Comparison

- Spectra:
  (Pre-Eq + Thermal + Prompt + (conv. or conv.) + ~~Brem~~)
- ≈ 5% difference at most central collision: entirely due to jet-conv.

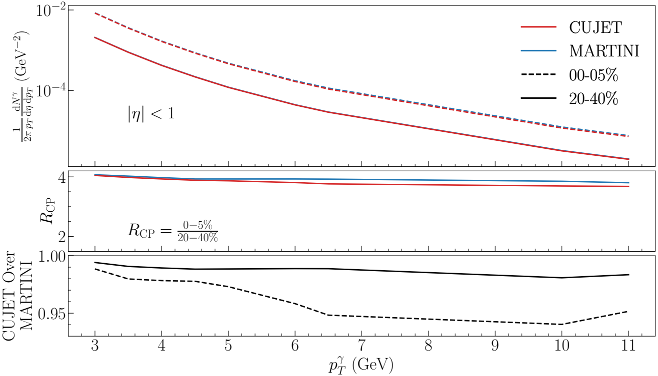


Figure 10: Semi-total photon spectra

Conclusion & Outlook

- Presented the first dynamical calculation of jet-medium photons with realistic jet distribution, realistic hydro background
- Jet-medium γ contribute significantly: $\sim 30\%$ of total yield for intermediate p_T
- Jet-Conversion Photons: directly proportional to underlying jet distribution, dependent on jet-energy loss mechanisms.
- Added CUJET into JETSCAPE: allowing for fair comparison between CUJET and MARTINI
- Setting the stage for a multi-messenger comparison of (any) energy loss mechanisms
  - Introduce bremsstrahlung photons to CUJET
  - Extend the work to $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, RHIC Energies
  - More observables (ex: Jet-Medium photon v_2)