# Charged hadron multiplicities inside of jet:
## Accessing Hadron Entropy?

**C-J. Naïm** and **Z. Tu**

*Center for Frontiers in Nuclear Science*

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Stony Brook University

# Entropy and Continuum Distribution

**Neumann entropy**:

$$S = -\sum_{i=1}^{N} (p_i \log p_i) \underset{N\to\infty}{\sim} \log N \underset{N\to\infty}{\longrightarrow} \infty$$

**Generalisation to a continuum distribution**:

$$S[F] := -\int F(x) \ln F(x) \mathrm{d}x$$

with $F(x)$ can be $xf(x)$ (PDF) or $zD(z)$ (FF).

**Barone, Drago and Ma relation** PhysRevC.62.062201:

$$D(z) \simeq zf\left(2 - \frac{1}{z}\right) \simeq zf(z)$$

when $z \to 1$ ($z = \frac{1}{1-(1-1/z)} \simeq 2 - \frac{1}{z}$).

# Entropy and Quantum Entanglement

Based on PhysRevD.95.114008:

- **Von Neumann Entropy in DIS:** Interpreted as the entropy of entanglement between the spatial region probed by Deep Inelastic Scattering and the rest of the proton.
- **Entanglement Entropy and Parton Multiplicity:** Assuming the hadron multiplicity is proportional to the multiplicity of color-singlet dipoles: relation between the parton structure function and the entropy of produced hadrons.

$$S_{\text{partons}} = \ln\left(xg\left(x, Q^2\right)\right) \equiv S_{\text{hadrons}}$$

**Can we apply the same idea with the FF?**

$$S_{\text{hadrons}} \overset{?}{\equiv} \ln\left(zD\left(z, \mu^2\right)\right)$$

# PYTHIA information

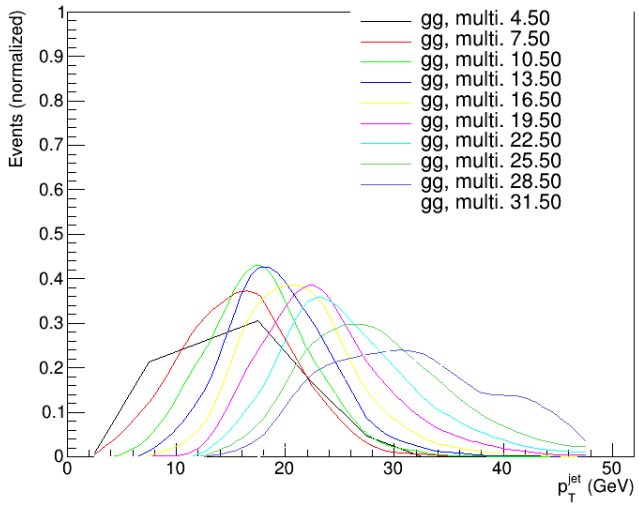
- pp collisions
- Hard QCD processes:
  1. gg to gg;
  2. gg to $q\bar{q}$.
- Anti-$k_\perp$ algorithm;
- Jet information:
  1. $R^{\text{Jets}} = 0.4$;
  2. $p_\perp^{\text{Jet}}$: not cut
- Initial-State Radiation (ISR): on/off
- Final-State Radiation (FSR): on/off

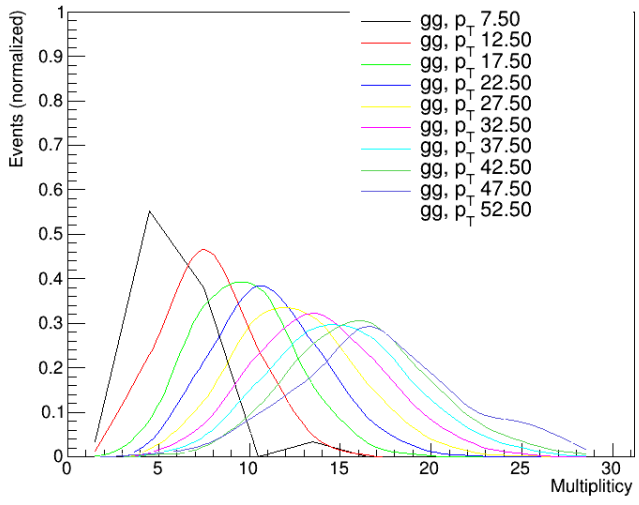
**Observable:**

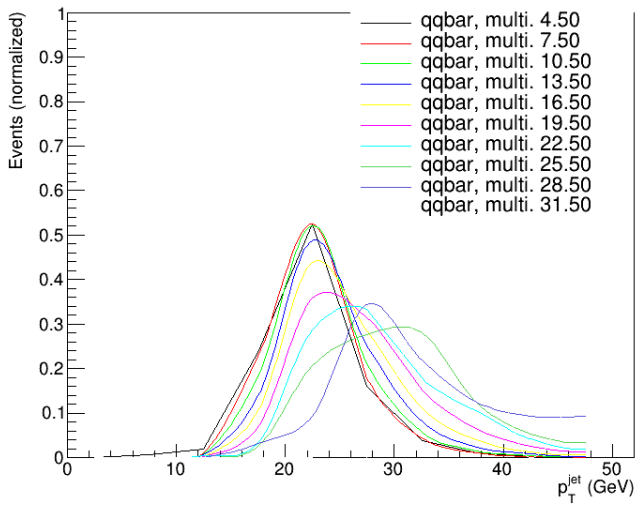
**Multiplicity:** Charged-hadron number inside of jet, N.

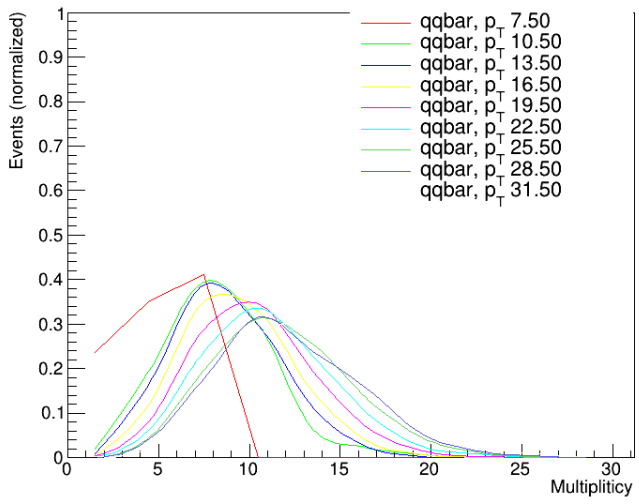
# Multiplicity in jet - pp collisions at $\sqrt{s} = 500$ GeV

## ISR and FSR activated



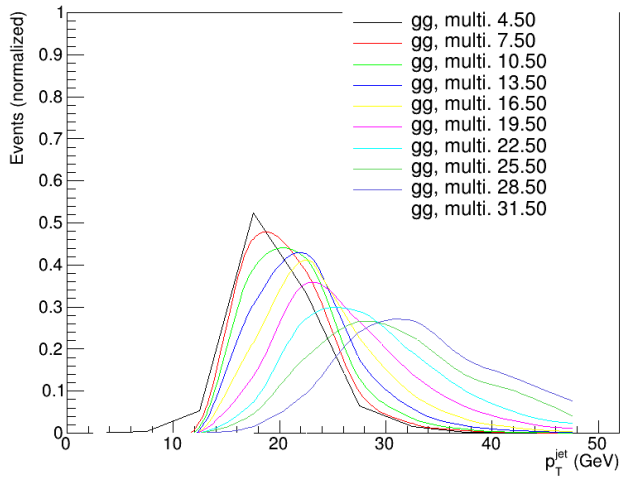



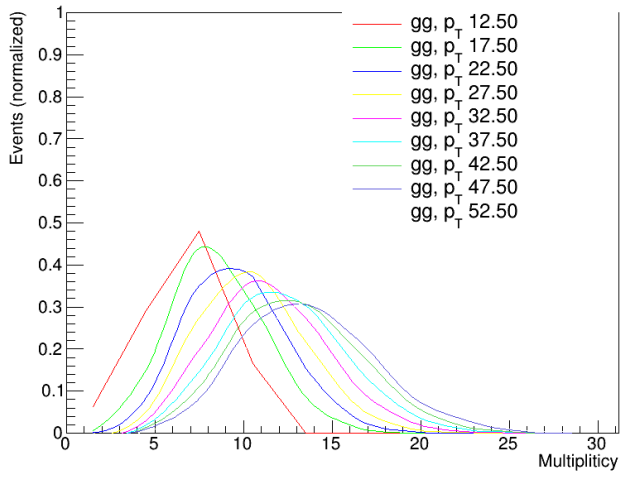



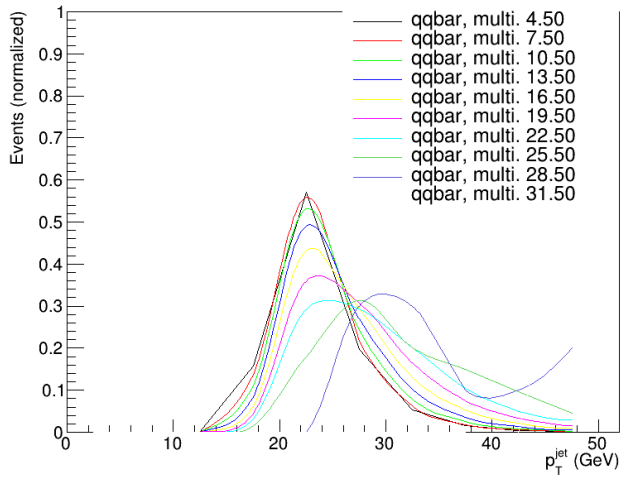

- $p_T^{\text{jets}}$ and multiplicity: large $p_T^{\text{jets}}$ dependence.

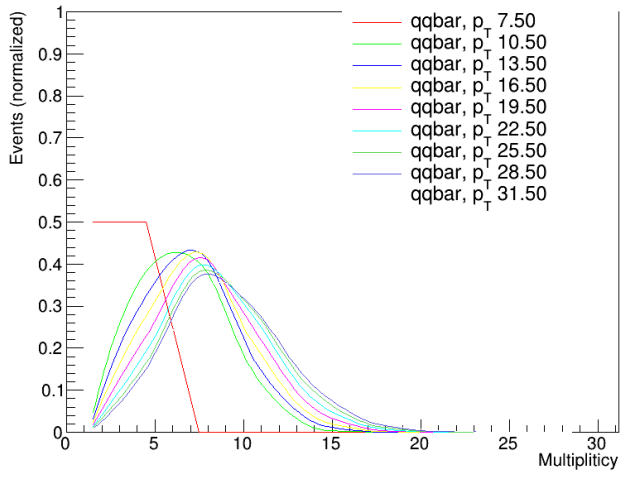
# Multiplicity in jet - pp collisions at $\sqrt{s} = 500$ GeV

## ISR and FSR not activated



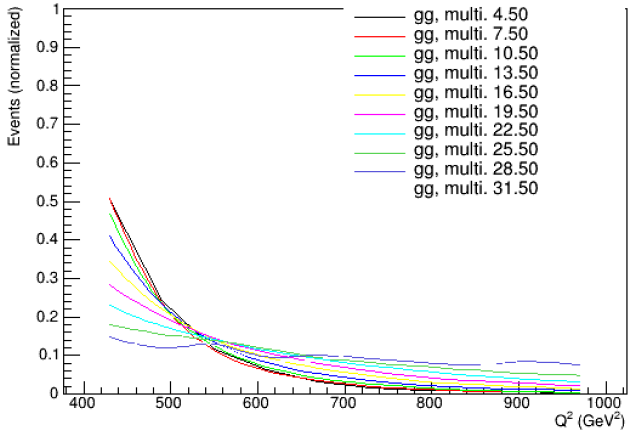



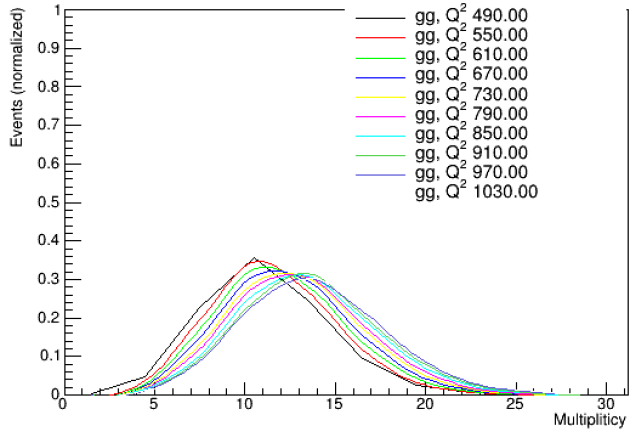



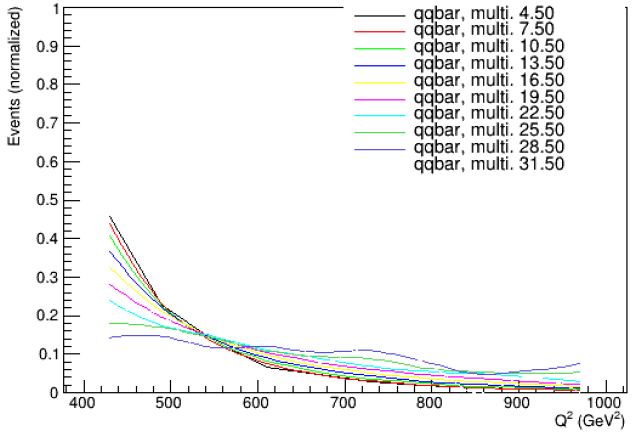

- $p_T^{\text{jets}}$ and multiplicity: less multiplicity compare to gg channel.

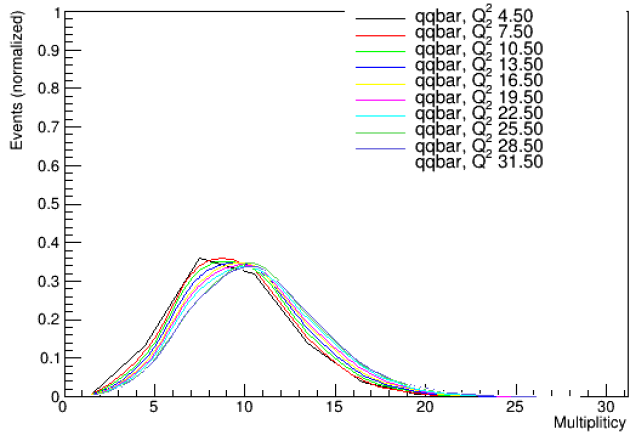
# Multiplicity in jet - pp collisions at $\sqrt{s} = 500$ GeV

## ISR and FSR not activated



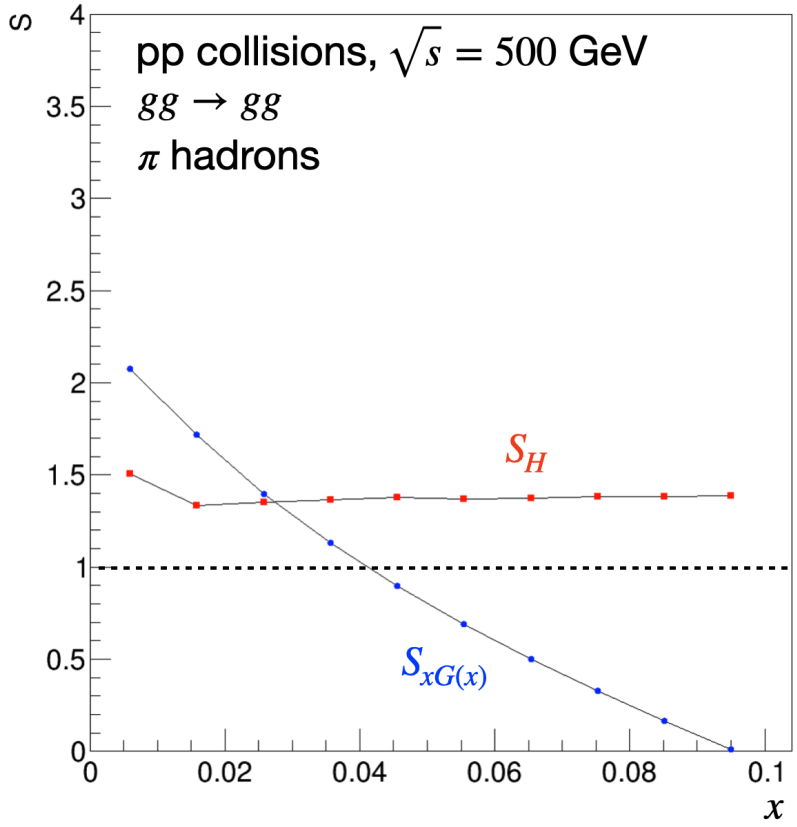



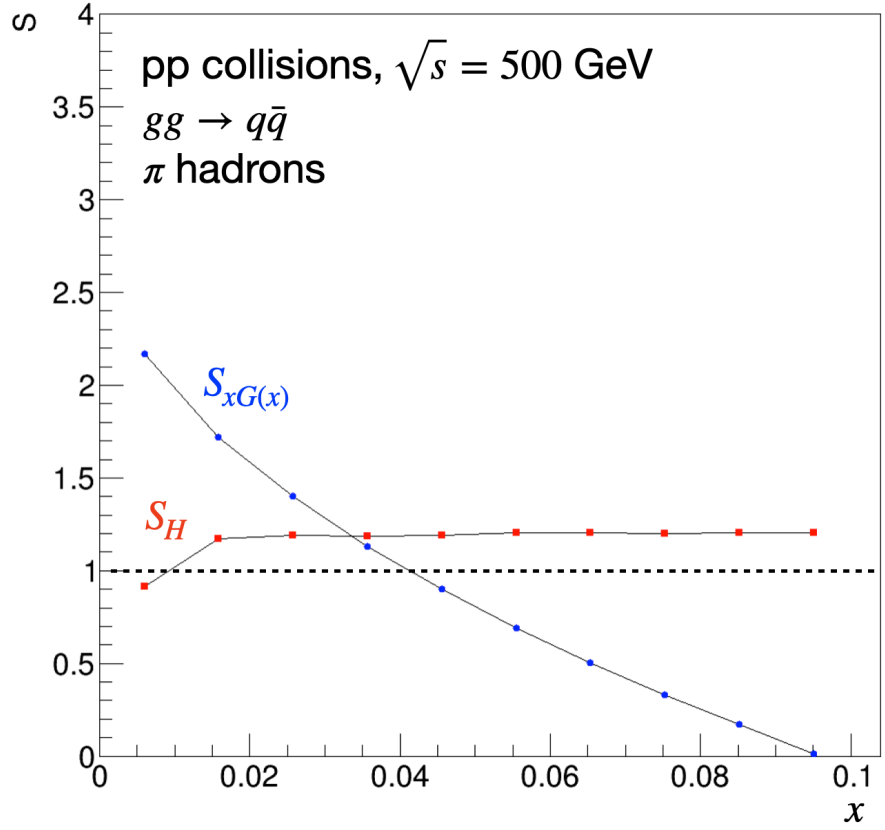




- $Q^2$ and multiplicity: not a large dependence.

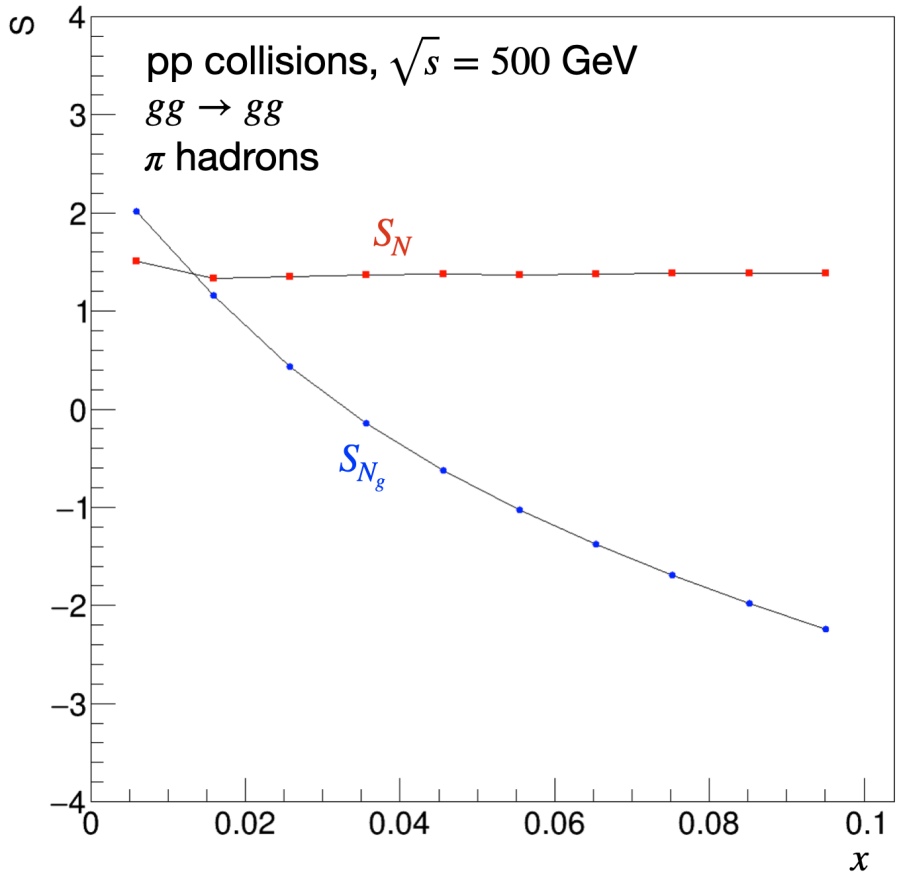
# xG(x), Multiplitiy, and Entropy

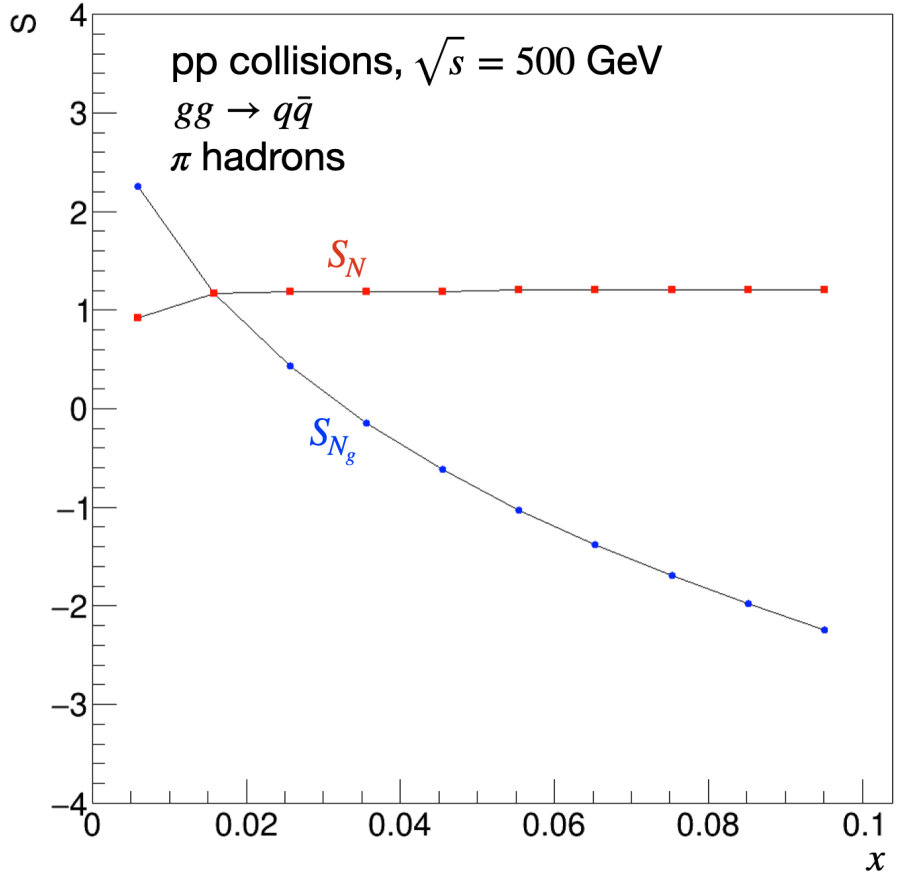



- **Left**: $gg \to gg$ and **Right**: $gg \to q\bar{q}$.

# $N_g$, Multiplicity, and Entropy



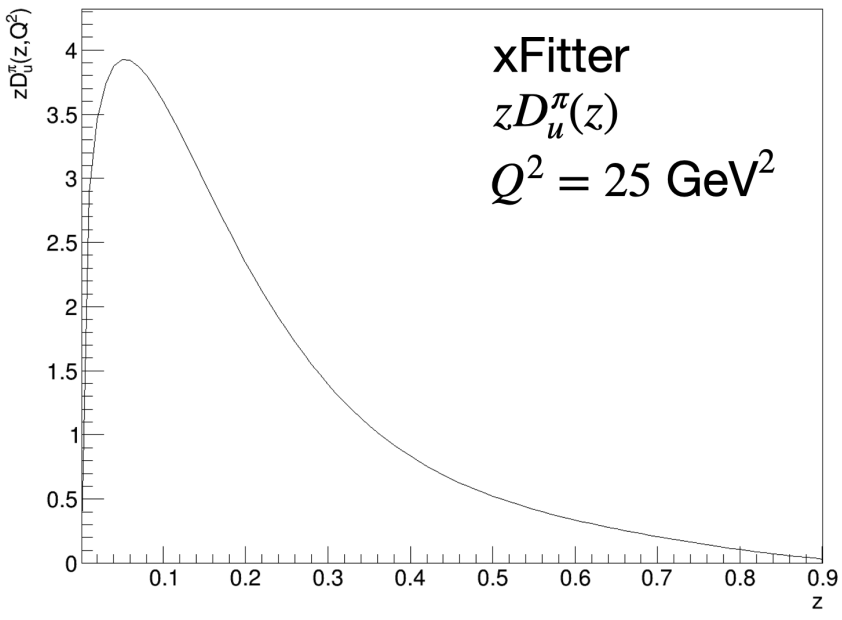



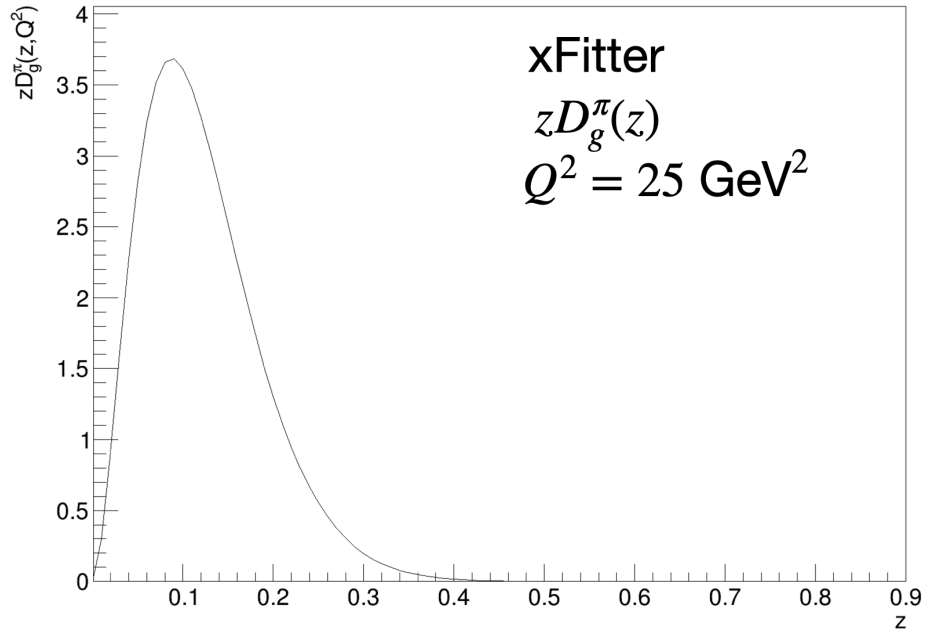

- **Left**: $gg \to gg$ and **Right**: $gg \to q\bar{q}$.

# Fragmentation Function

## xFitter framework

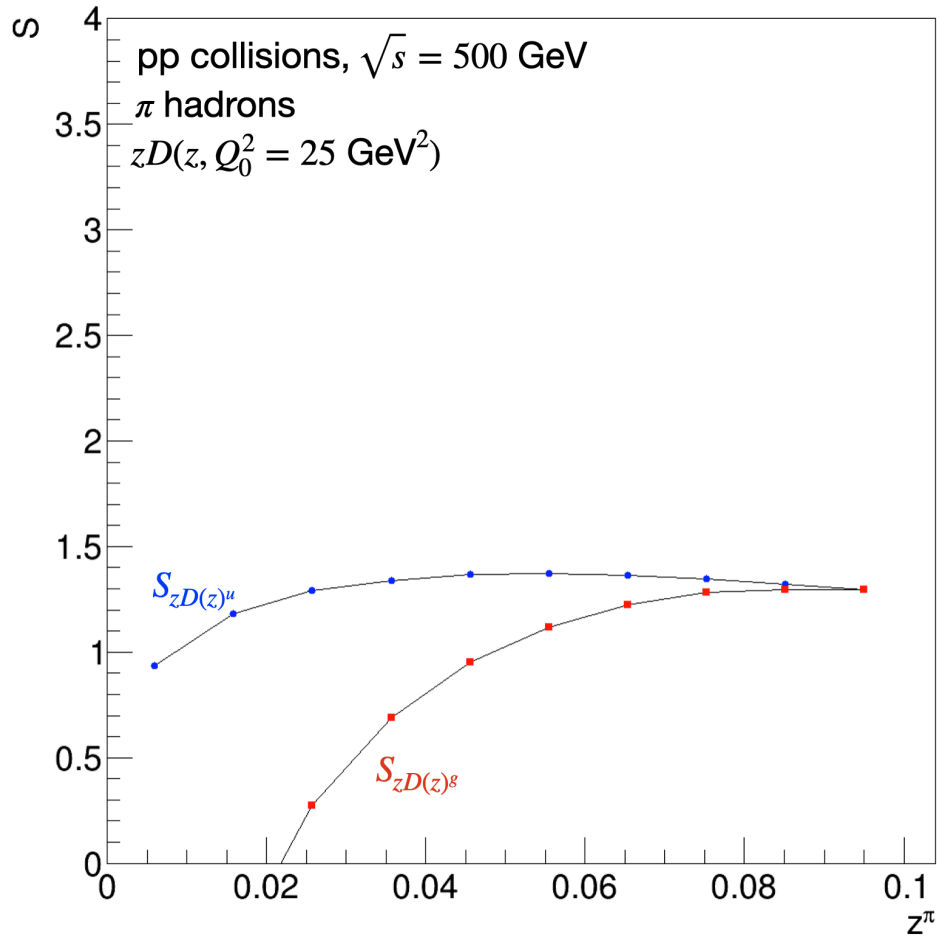
$$D_i^{\pi^\pm}(z, Q_0) = \frac{\mathcal{N}_i z^{\alpha_i}(1-z)^{\beta_i}[1+\gamma_i(1-z)^{\delta_i}]}{B[2+\alpha_i, \beta_i+1]+\gamma_i B[2+\alpha_i, \beta_i+\delta_i+1]}$$




- **Left**: $zD_z^u(z)$ and **Right**: $zD_z^g(z)$ at NLO and $Q^2 = 20$ GeV$^2$

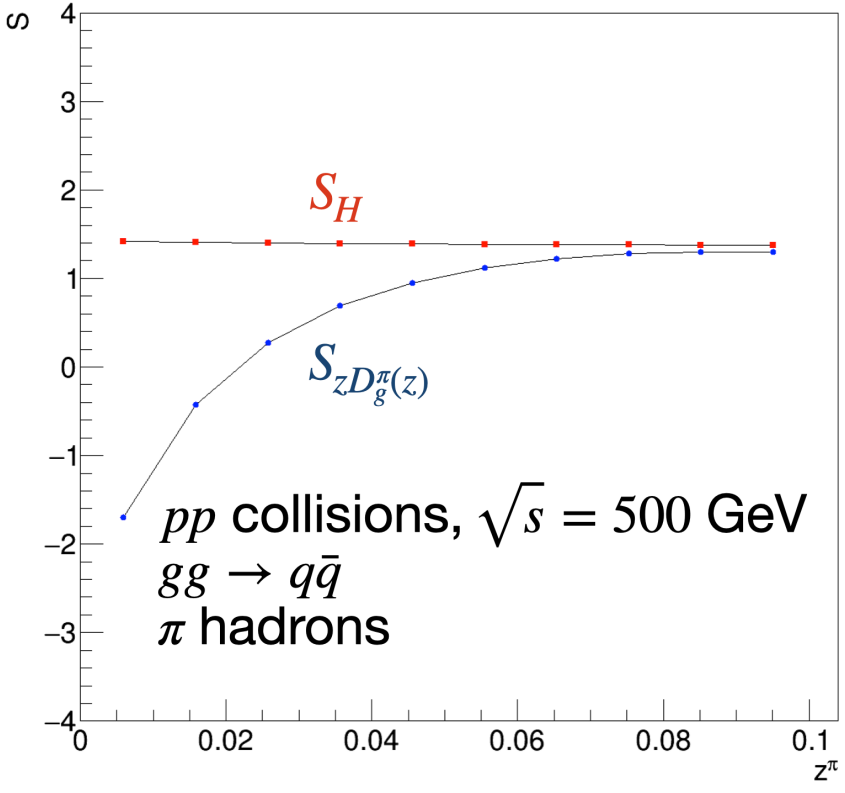
# Fragmentation Function, multiplitiicy and Entropy I

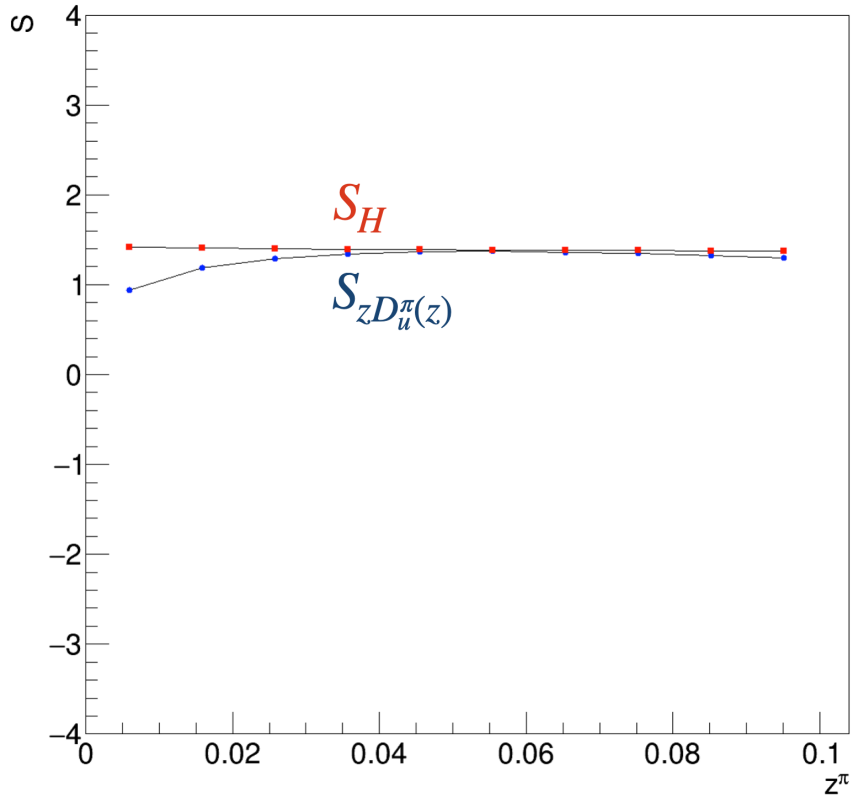



- $D_z^g(z)$ vs $D_z^u(z)$: less gluon at small $z$.

# Fragmentation Function, multiplitiy and Entropy II

**Comparison between $S_{zD(z)}$ and the multiplicity ($q\bar{q}$)**

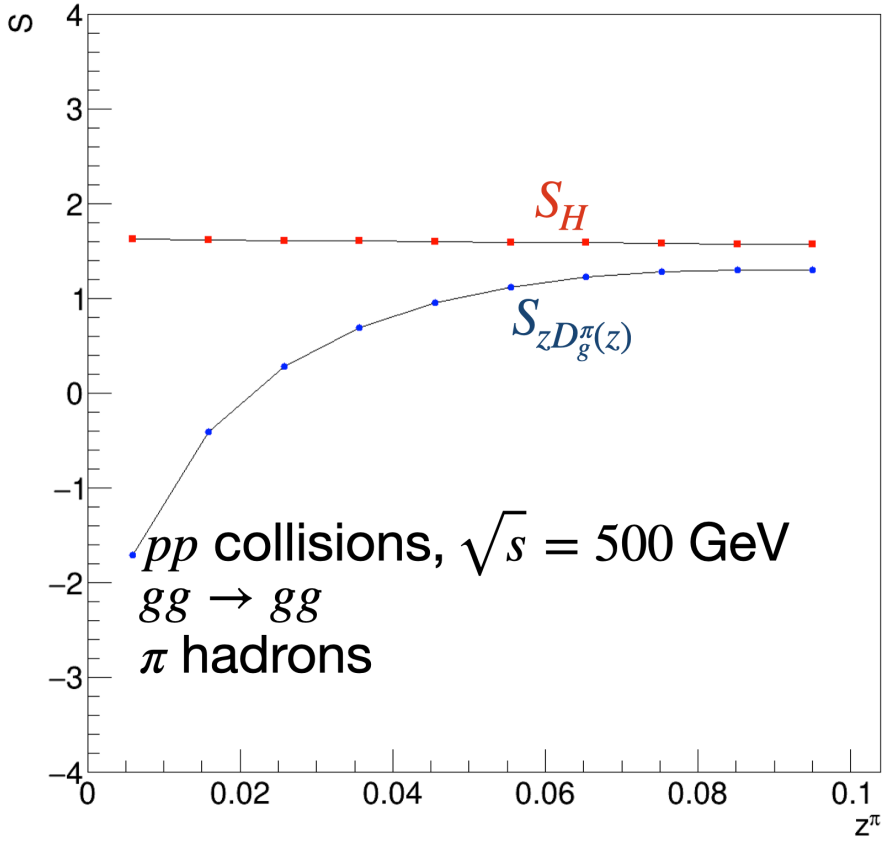


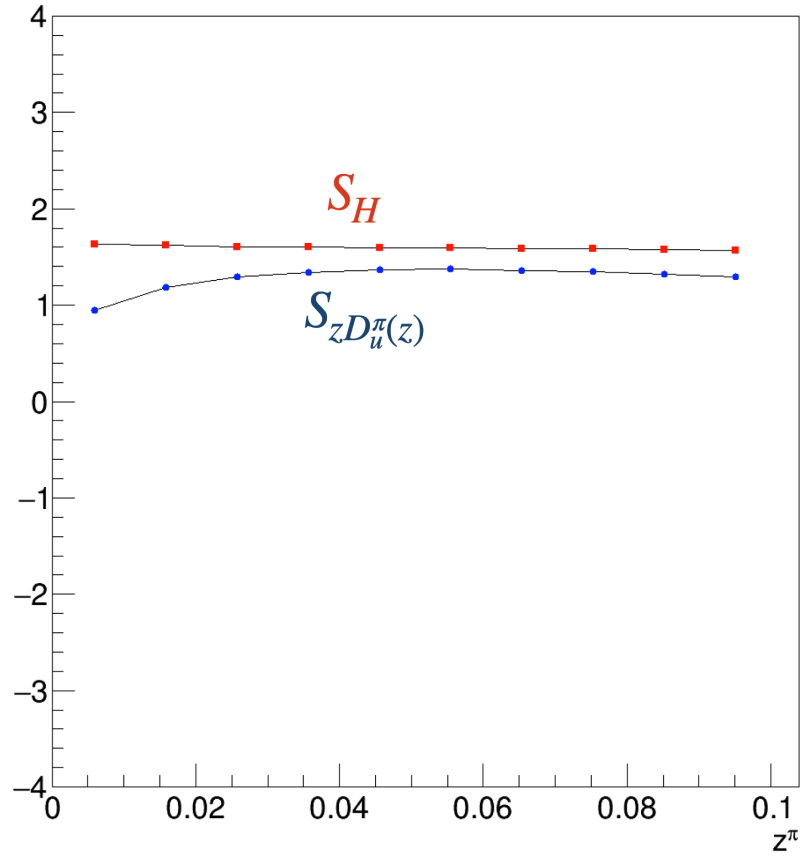




- **Left**: $D_z^g(z)$ and **Right**: $D_z^u(z)$.

# Fragmentation Function, multiplitiicy and Entropy III

**Comparison between $S_{zD(z)}$ and the multiplicity (gg)**




- **Left**: $D_z^g(z)$ and **Right**: $D_z^u(z)$.

# Conclusion

- We observe a higher hadron multiplicity in $gg \to gg$ compared to $gg \to q\bar{q}$.
- The maximum entropy is reached more quickly in $gg \to q\bar{q}$.
- Small dependence of multiplicity on $Q^2$.
- Disagreement between $S_{xGx}$ and $S_H$.
- $S_{zDz}$, work in progress.