Understanding Hadronization Timescales Using Jets

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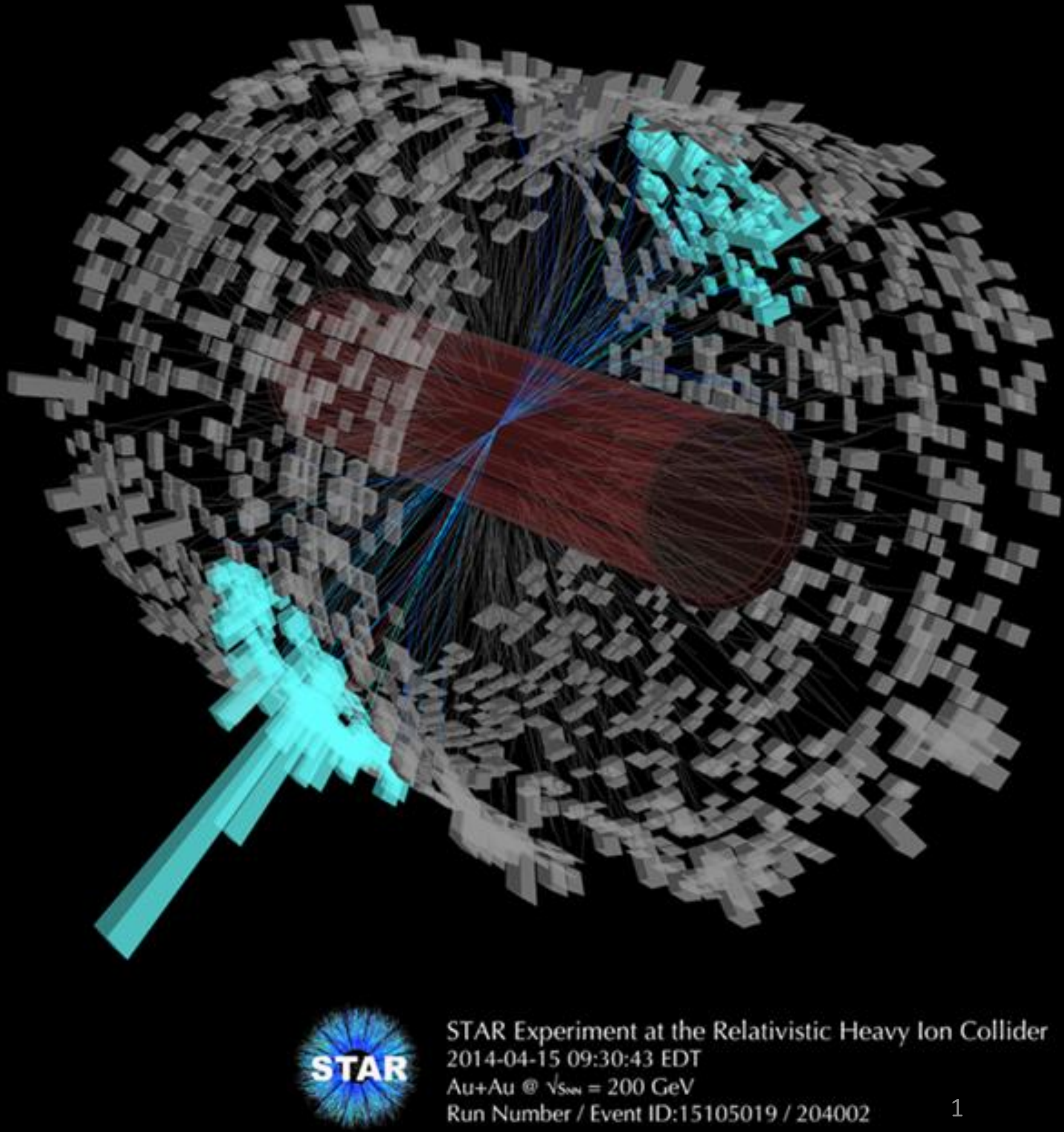
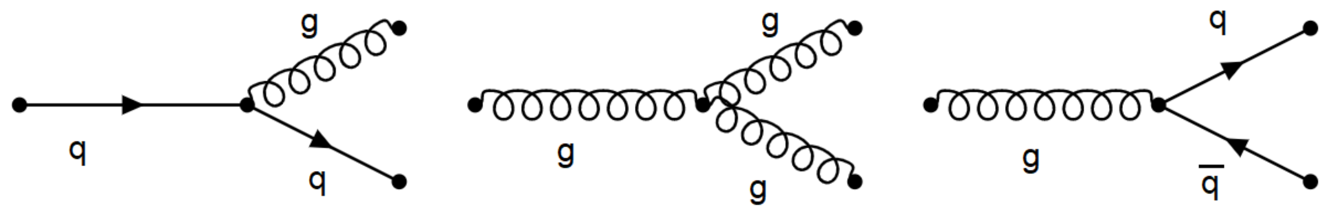
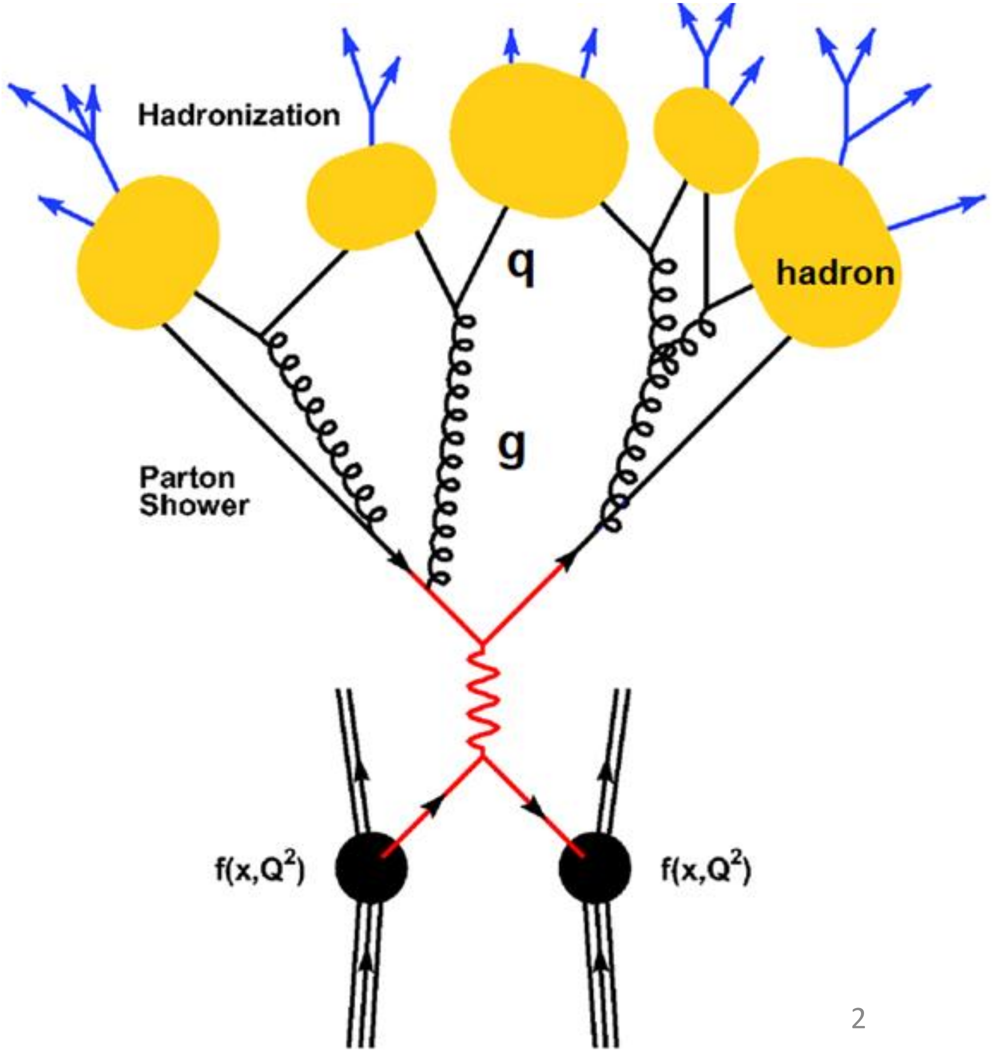


Introduction

- **Partons** are quarks (q) or gluons (g)
- Scattered partons originate **parton showers**
- The possible **splittings** are:



- Parton showers ends with **hadronization**

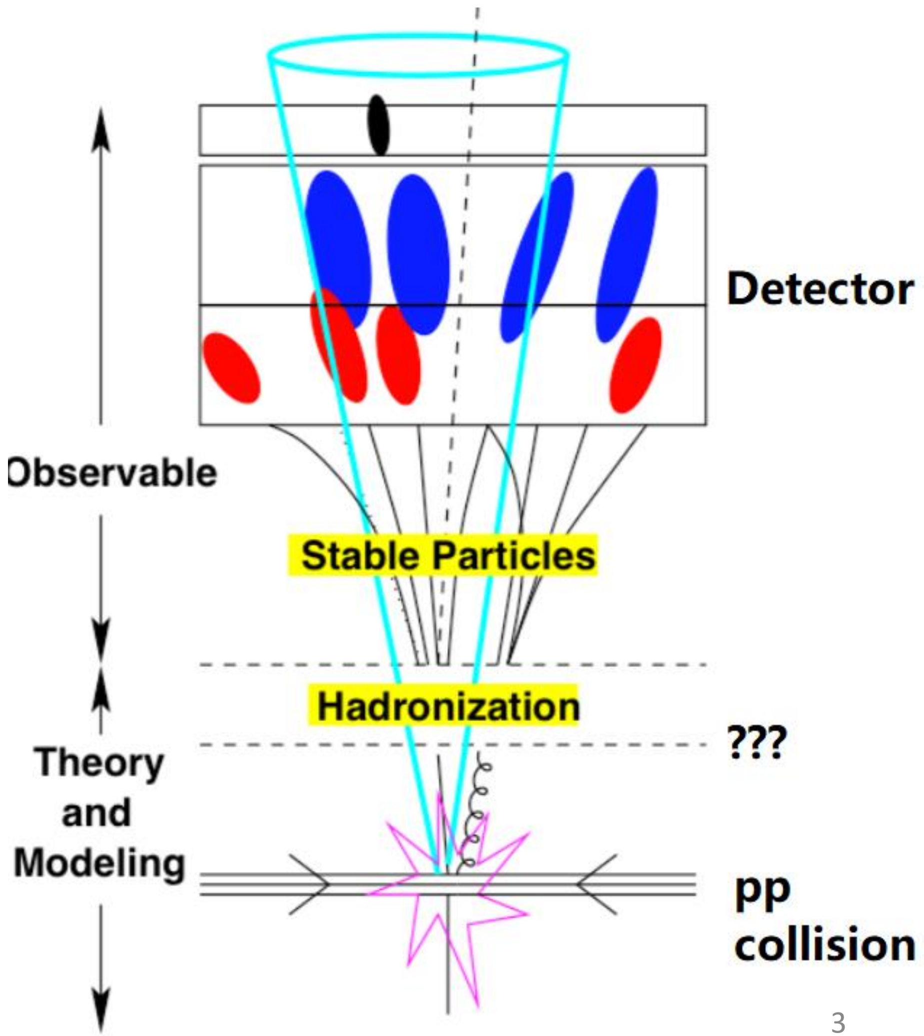


Introduction

- A **jet** is the result of a set of rules for how to group the detected particles together

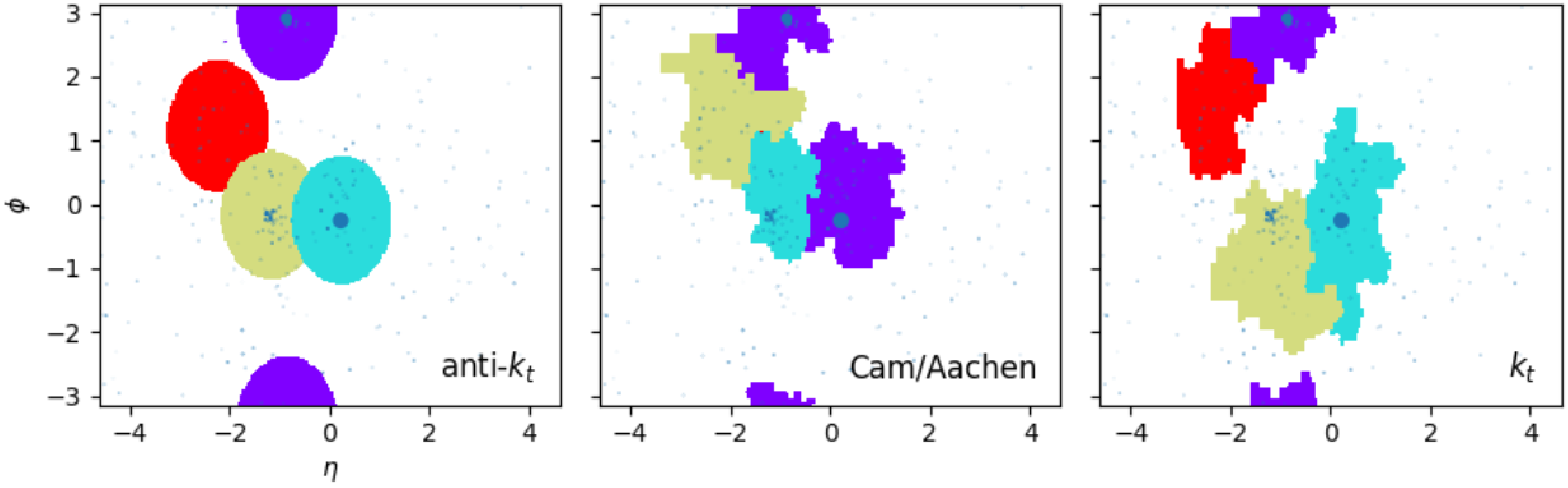
- The grouping of a pair of particles is called a **clustering**

- Clustering is done by computers by using **jet algorithms**



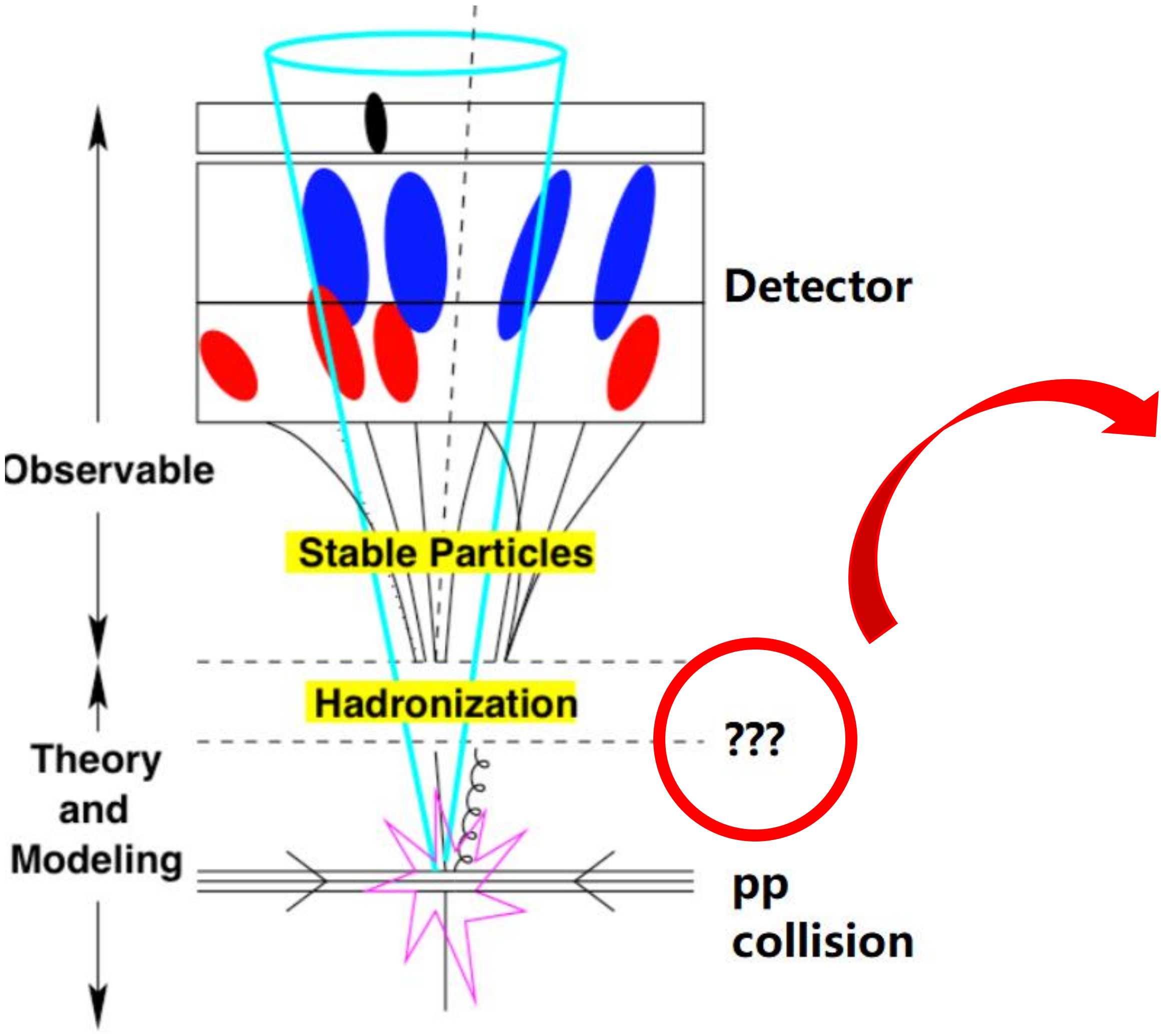
Introduction

favours clusterings of hard particles | clusters independently of energy | favours clusterings of soft particles



Hard particles – particles with high energy
Soft particles – particles with low energy

Motivation



Hadronization marks the transition of Quantum Chromodynamics (**QCD**) from its perturbative regime to its non-perturbative regime

We are interested in understanding if the **jet formation time** can be related to the timescale of the hadronization process

Simulations and Conditions

Center of mass energies

Jet transverse momentum bins

- **PYTHIA 8.2** → generate the events (pp collisions)
- **FastJet** → find the jets produced in each event
- **ROOT** → plot the jet substructure variables

- Initial clustering: **anti-kt algorithm**, R=0.6
- Reclustering: **Cambridge/Aachen (C/A)** algorithm, R=1

$\sqrt{s}$ Energies:

- 200 GeV (typical RHIC)
- 5 TeV (typical LHC)
- 14 TeV (extreme LHC)

p_T Ranges:

- $15 < p_T < 20$ GeV/c
- $200 < p_T < 300$ GeV/c

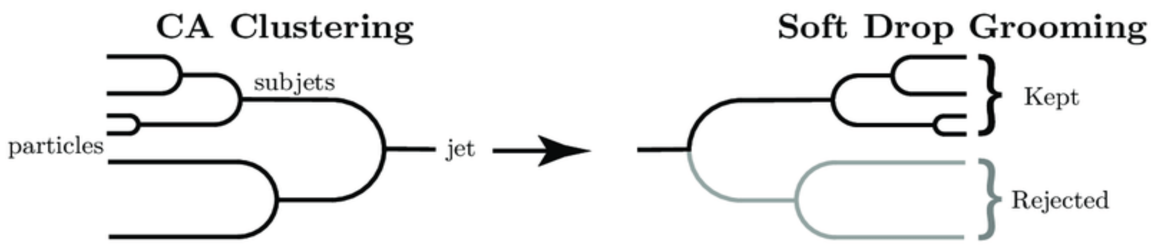
SoftDrop

- We employ the **SoftDrop algorithm** to the jet after being reclustered with the C/A algorithm
- The SoftDrop algorithm **de-clusters** the jet, meaning it splits the jet into two **subjets**
- The subjets are submited to the **SoftDrop criterion**:

$$\frac{\min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} > 0.1$$

$\mathbf{p_{T\,1}}$ → transverse momentum of one subjet
$\mathbf{p_{T\,2}}$ → transverse momentum of the other

- If the subjets don't pass this criterion, the hard subjet is taken as the full jet and the process is repeated until two suitable candidates are found



Formation Time

- The two subjets found using SoftDrop are then used to calculate de **formation time (τ_F)**

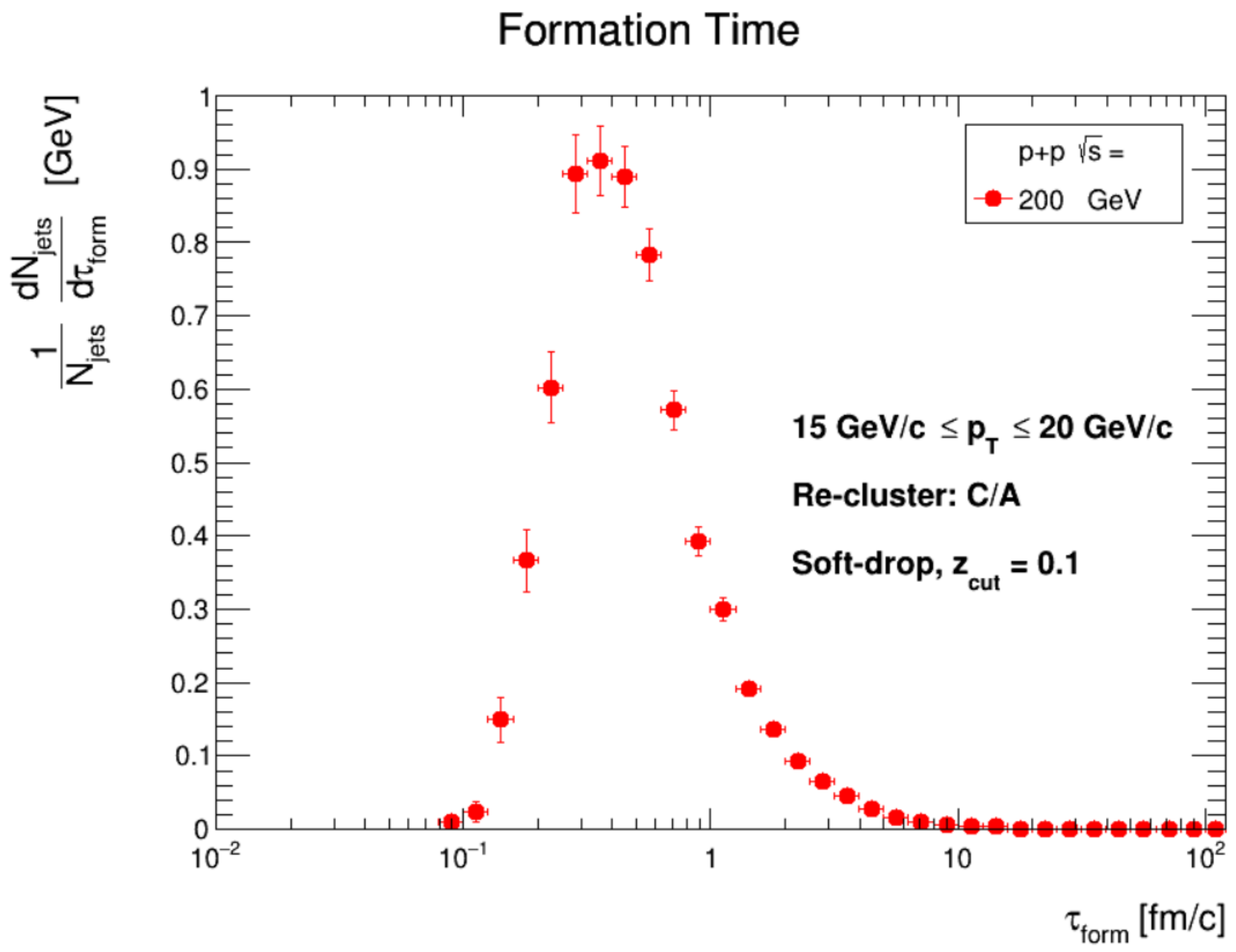
- The **formation time** represents the time a parton takes to split into two, and for these two new particles to behave independently

- It's calculate using the formula:

$$\tau_{form} \approx \frac{1}{2\,E\,z(1-z)(1-\cos\theta_{12})}$$

E → jet energy
z → jet momentum fraction
θ_{12} → angle between sub-jets or jet particles

Results

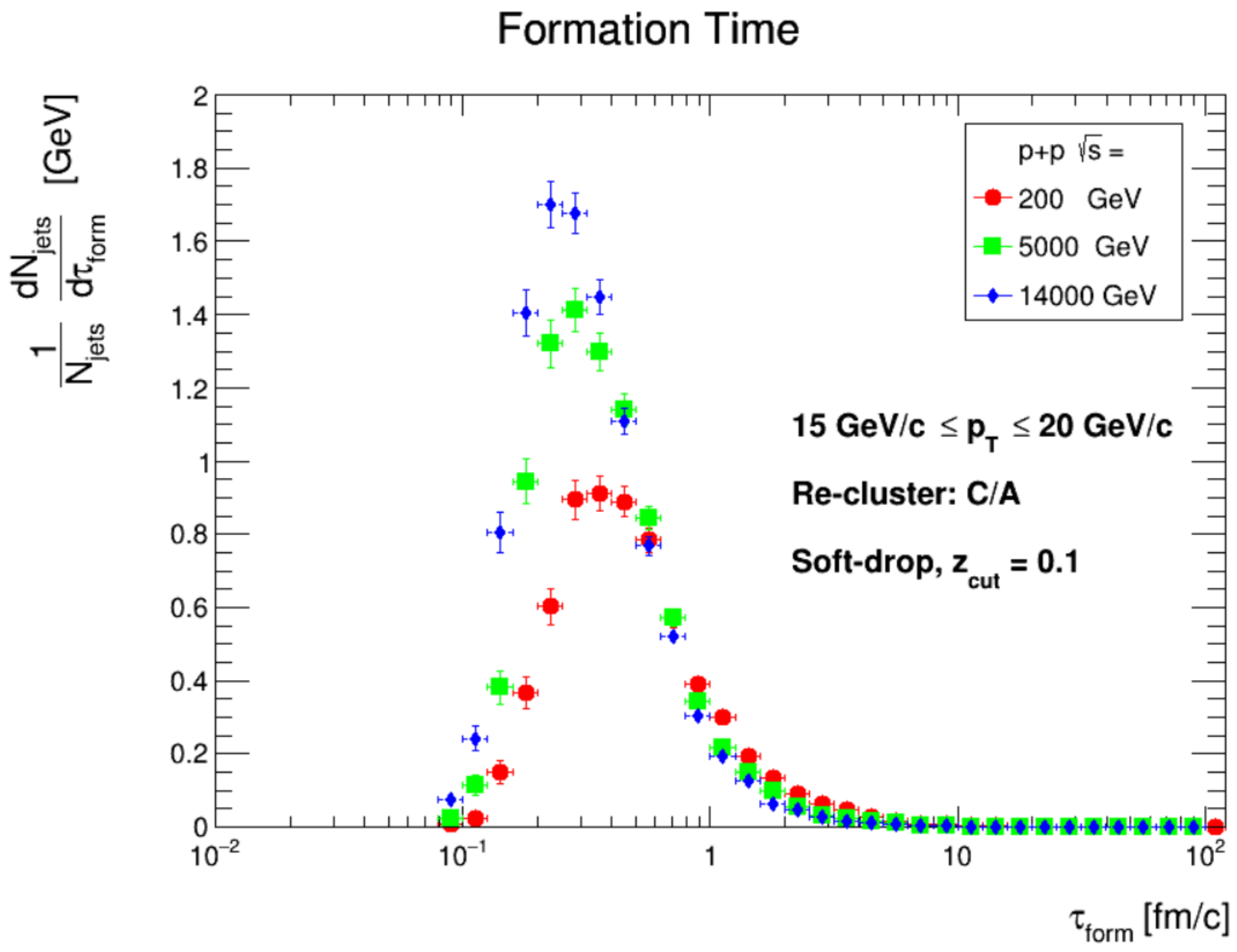


- **Formation time** – calculated using the first pair of subjets that pass the SoftDrop criterion

- This is called the τ_{form} of the **1st SoftDrop emission**

- The simulations were run for 200 GeV pp-collisions and for jets with 15 < p_T < 20 GeV/c

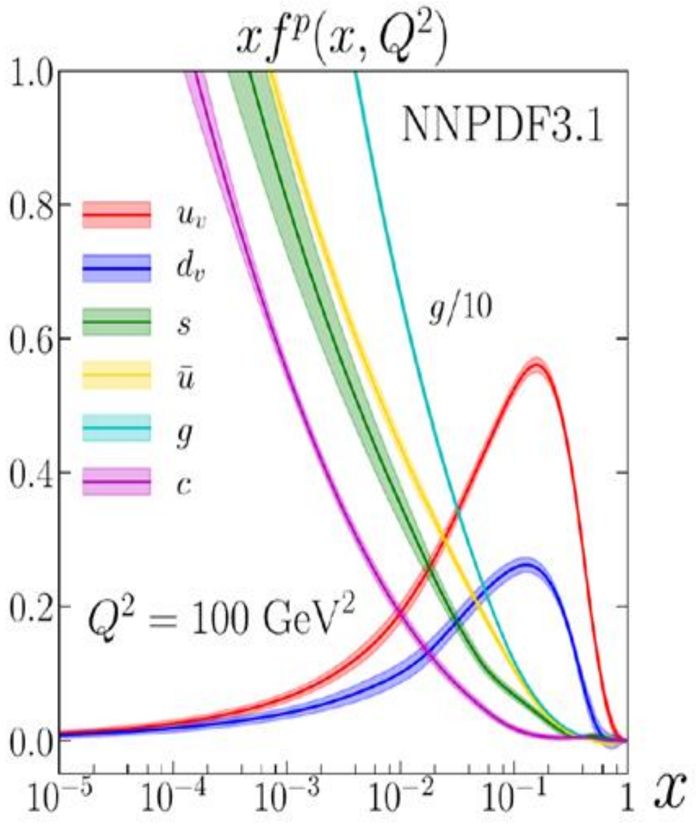
Results



- Same variables being plotted: τ_{form} of the **1st SoftDrop emission**
- Look at **different center of mass energies**
- **Observation**:
  Larger $\sqrt{s}$ $\Rightarrow$ Smaller τ_{form}

Particle Distribution Functions (PDFs)

Proton PDFs



Bjorken x:

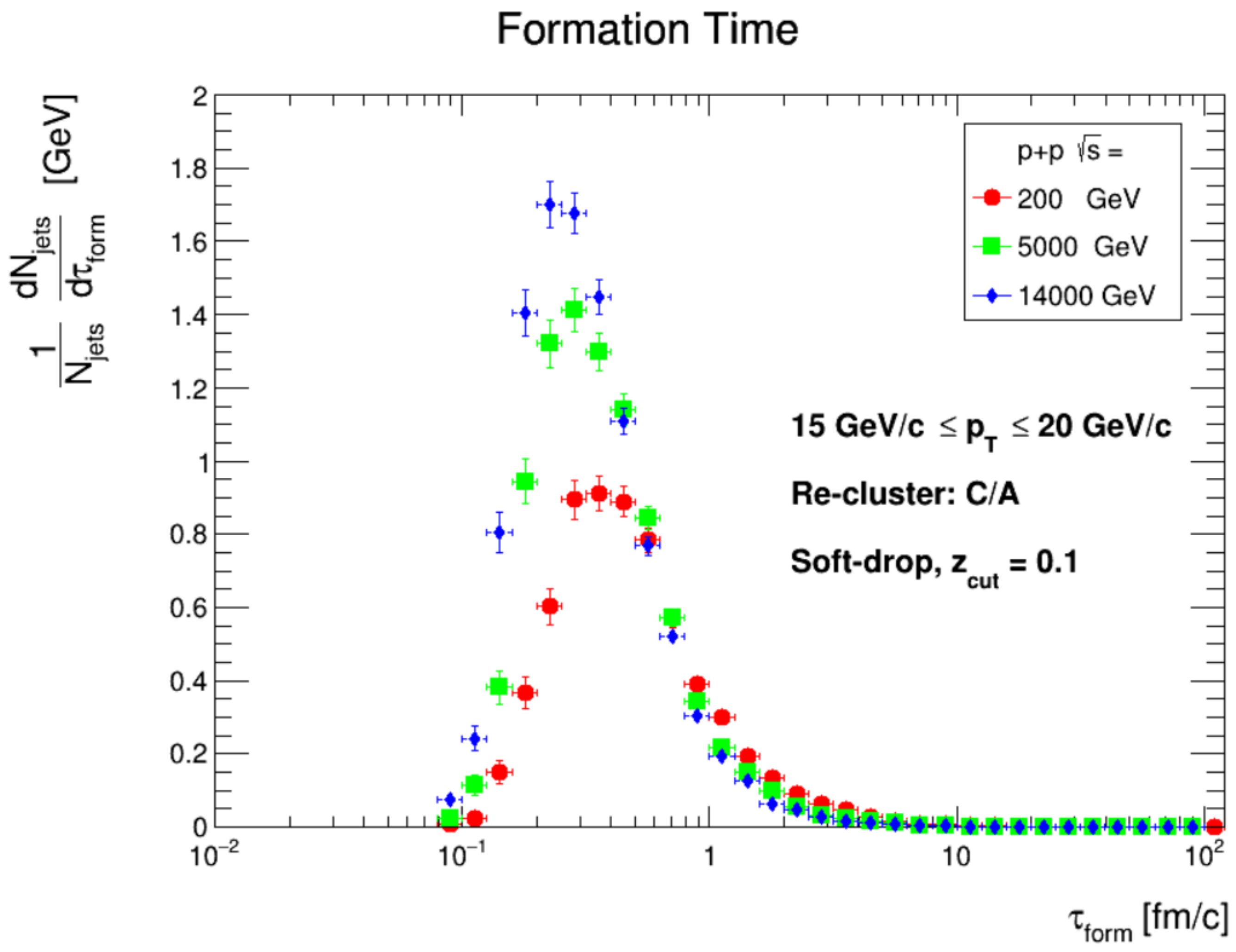
$$x \sim \frac{p_T}{\sqrt{s}/2}$$

p_T → jet transverse momentum
√s → CM collision energy

Fixing the p_T ,

- **Smaller √s ⇒ Larger x ⇒ More quark-initiated jets**
- **Larger √s ⇒ Smaller x ⇒ More gluon-initiated jets**

Results



Conclusion:

Since:

Larger √s ⇒ Smaller τ_{form}

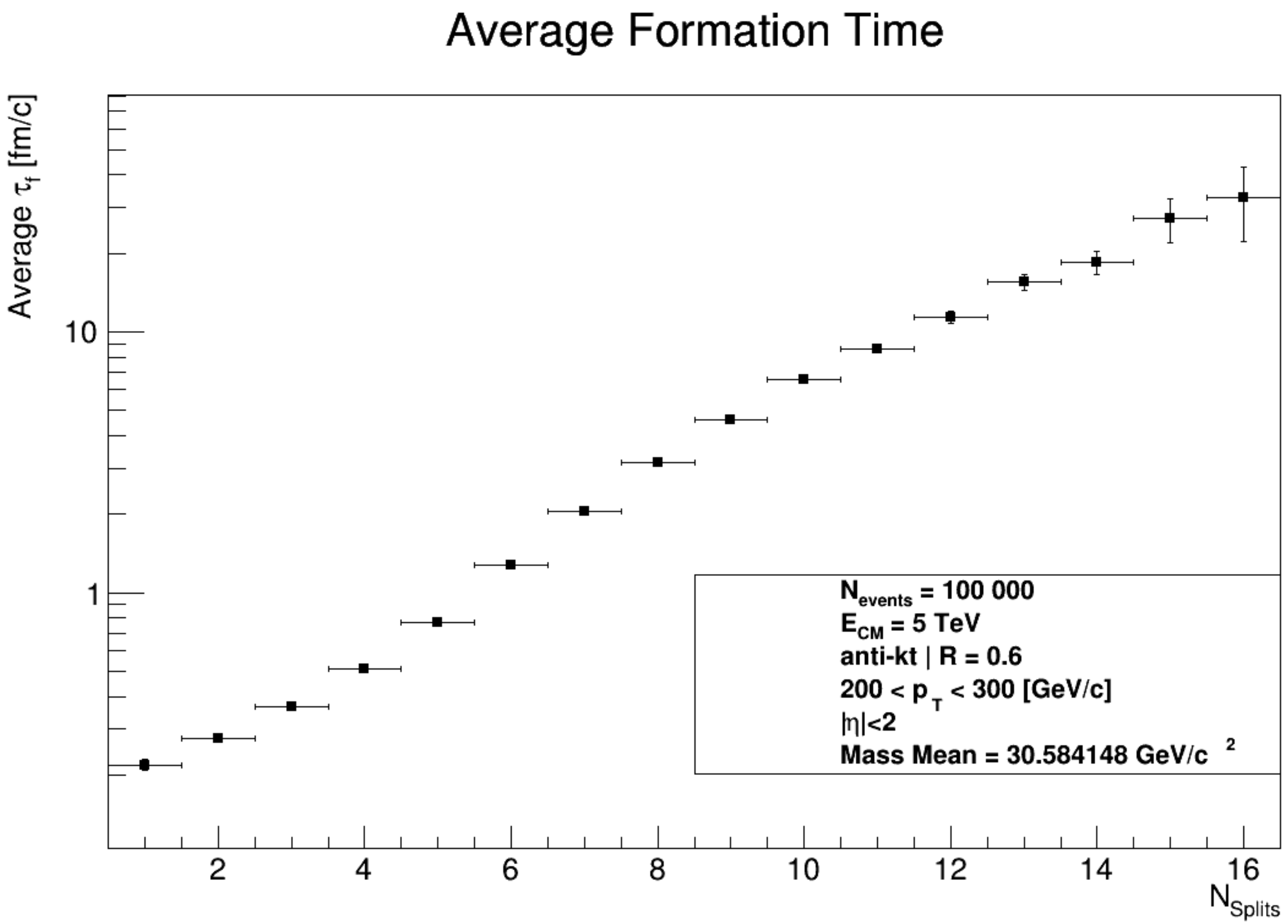
Larger √s ⇒ More gluon-initiated jets

one concludes that

⇒ Gluons likely radiate more

Results

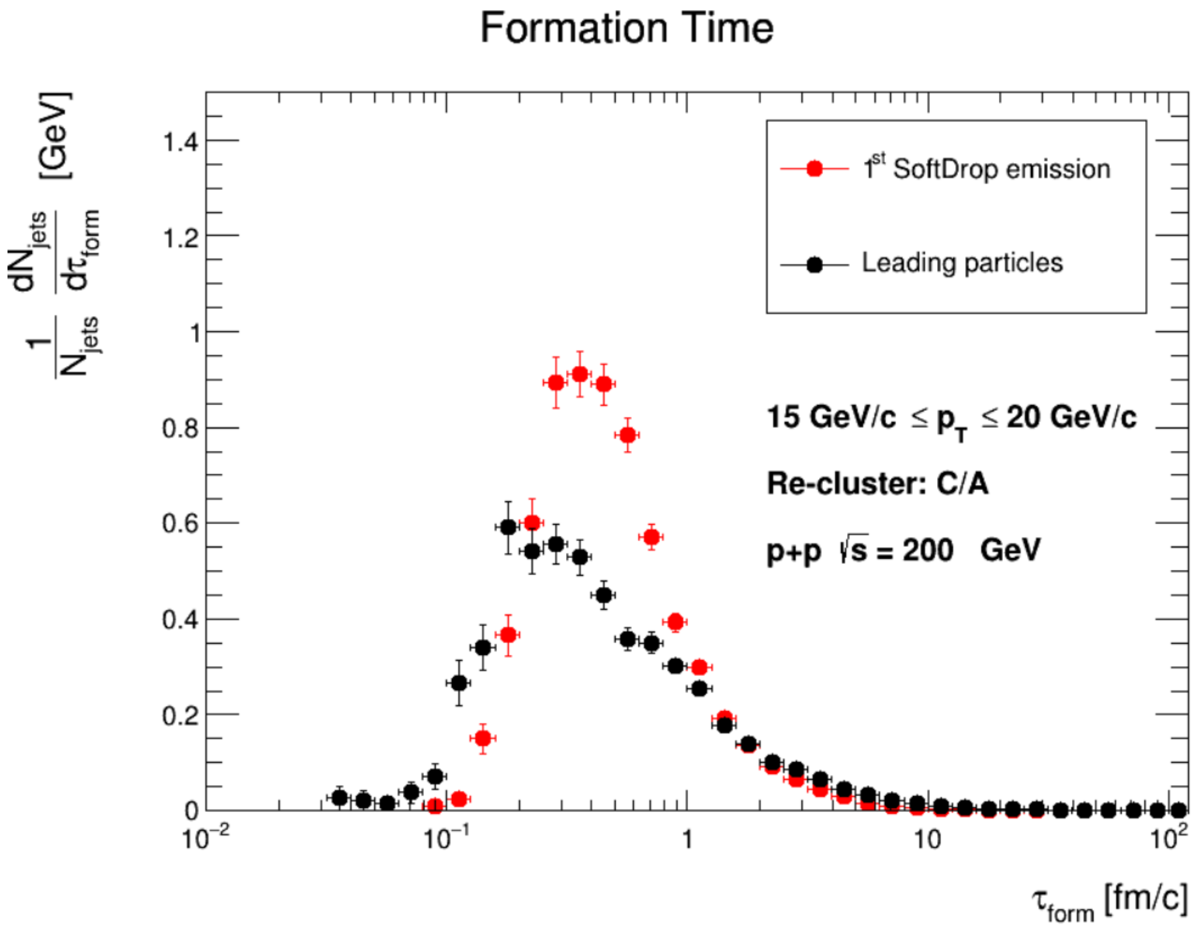
Number of splits

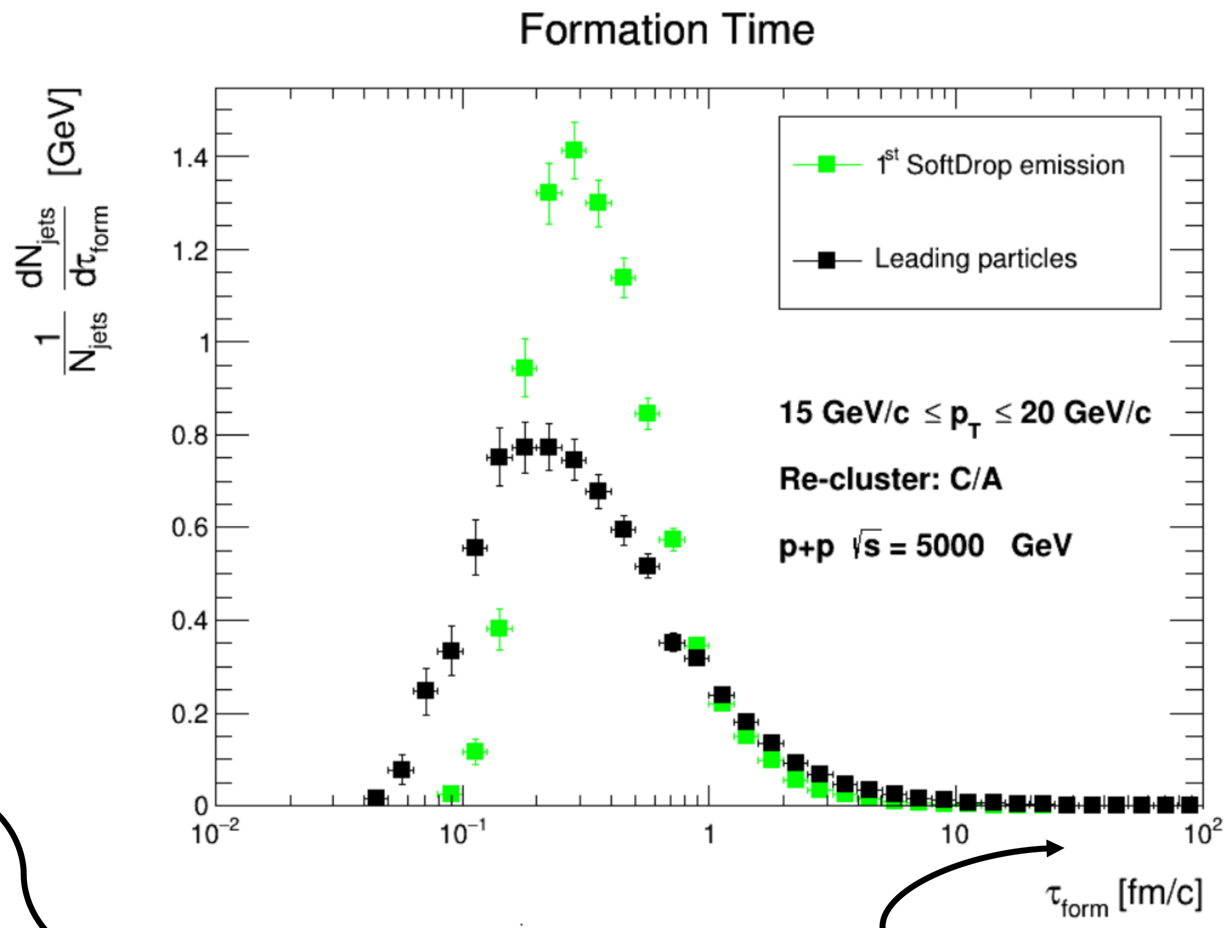


- Looking at just one value of **√s** and one **p_T range**
- We can observe how the **formation time** evolves as we go through the declustering tree
- **Observation:**
  As the number of splits increases, so does the formation time

Results

τ_F using leading charged particles





Both distributions **overlap for large formation times**

Conclusions

Recall: The formation time is an observable that exploits the jet clustering algorithm to study the parton shower along its time axis

- From looking at the τ_{form} for collisions with different √s, we conclude that **gluon splittings occur quicker, on average, than the quark splitting**

- From going along the sequential splits of a parton shower, we conclude that the **average value of the formation time increases along the parton shower**

- From looking at the τform calculated using subjets and calculated using the leading particles, we conclude that **τform can hint at the transition from the perturbative to the non-perturbative QCD**. We'll explore this in future work.

Our thanks to...

Our supervisors:

Dr. Liliana Apolinário
Dr. Raghav Kunnawalkam

We hope you enjoyed it!

Any questions?