Energy correlators for massive parton fragmentation

Advancing the Understanding of Non-Perturbative QCD Using Energy Flow

CFNS workshop

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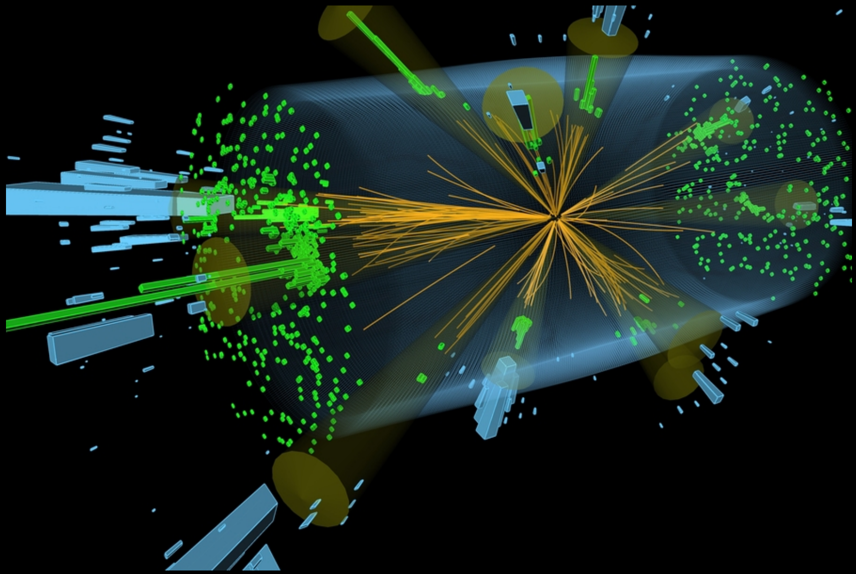
Based on work with Ian Moult, Kyle Lee and Evan Craft
(to appear soon)

QCD at Colliders

Almost every particle collider event contains jets

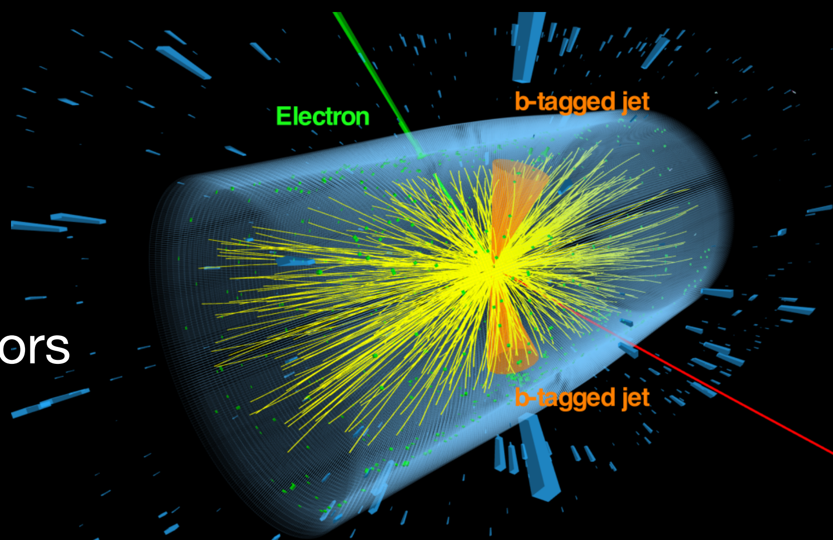


A very powerful method to study jets is studying their kinematic properties (jet substructure).

Presence of mass increases the complexity of computations; introduces an extra scale.

Study of heavy quarks at colliders

- Heavy flavor fragmentation
- Tuning of MC generators

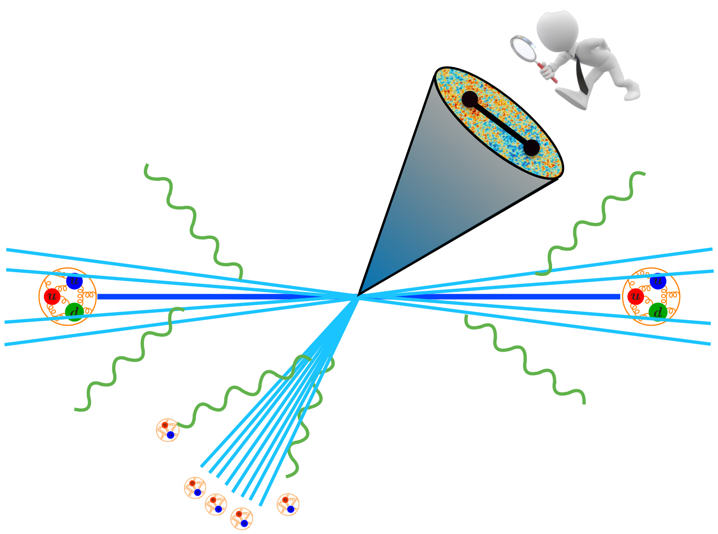


- QGP interactions
- Dead-cone effect

A full understanding of QCD requires understanding and incorporating such mass effects!

Jet substructure

Study the internal structure of a jet



Any physics dynamics will be imprinted in the energy distributions inside the jet.

Well-defined in QFT!

- Distribution of energy inside the jet is described by correlation functions of the energy flow operators ⇒energy correlators.

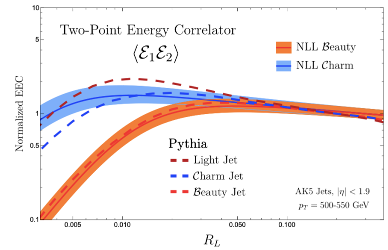
$$\langle \Psi \mid \varepsilon(\vec{n}_1)\varepsilon(\vec{n}_2)\ldots\varepsilon(\vec{n}_n) \mid \Psi \rangle$$

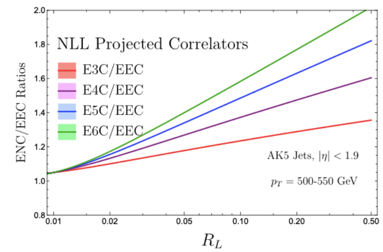
[Basham, Brown, Ellis, Love]

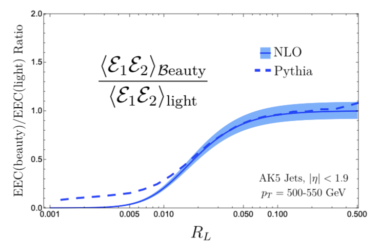
$$\mathcal{E}(\vec{n}) = \lim_{r\to\infty} \int_0^\infty dt\; r^2 n^i T_{0i}(t, r\vec{n})$$

Energy correlators for massive partons

- **Scaling behavior**
- **Jet spectrum**
- **Dead-cone effect**







Energy correlators for massive parton fragmentation

Factorization formula

- A general formula for colliders
- Can calculate any higher point correlator for massive partons

$$\Sigma\left(z, p_T^2, M_Q, \mu\right) = \int_0^1 dx x^N \vec{J}^{[N]}\left(R_L, x, M_Q, \mu\right) \cdot \vec{H}\left(x, p_T^2, \mu\right)$$

[Craft, Lee, Mecaj, Moult]

Energy correlator jet function

Hard function: includes pdfs and jet algorithm effects

Two-point energy correlator

The simplest jet substructure observable

Theory prediction: $\langle \Psi \mid \varepsilon(\vec{n}_1)\varepsilon(\vec{n}_2) \mid \Psi \rangle \sim \sum \theta^{\gamma_i} \mathcal{O}_i(\vec{n}_1)$

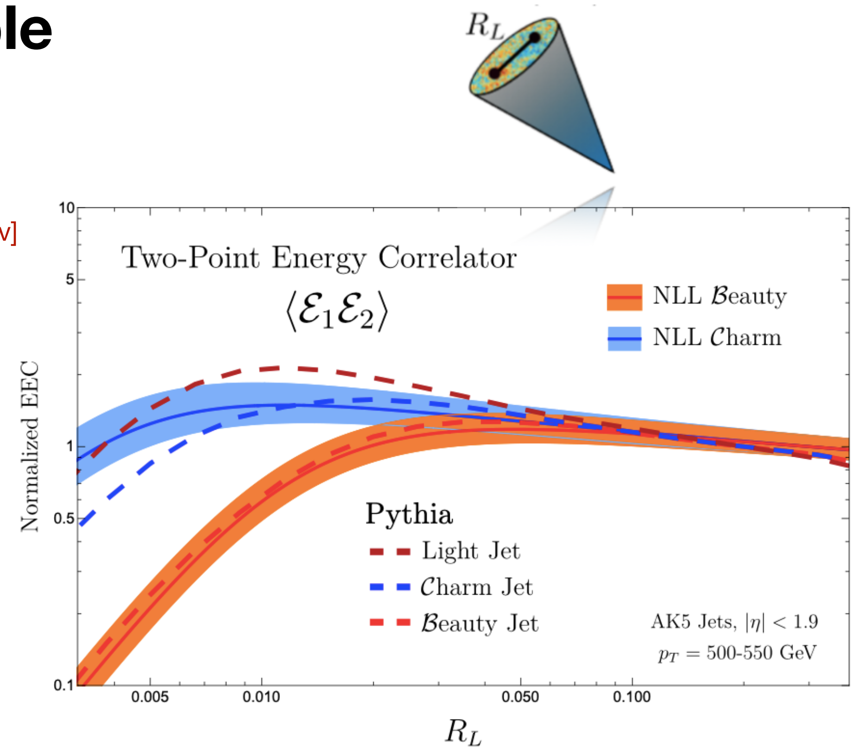
[Hofman, Maldacena]
[Chang, Kologlu, Kravchuk, Simmons Duffin, Zhiboedov]

- A simple and clean observable to probe intrinsic scale effects.

Massive partons: turn over around $R_L \sim M_Q/p_T$

momentum exchange $\sim p_T R_L + M_Q$

- For large angular distance same as massless behaviour



[Craft, Lee, Mecaj, Moult]

Higher point correlators

Jet spectrum

- Can be observed at the high energies at high precision

- Ratio of the higher-point correlators with the two-point isolates anomalous scaling!

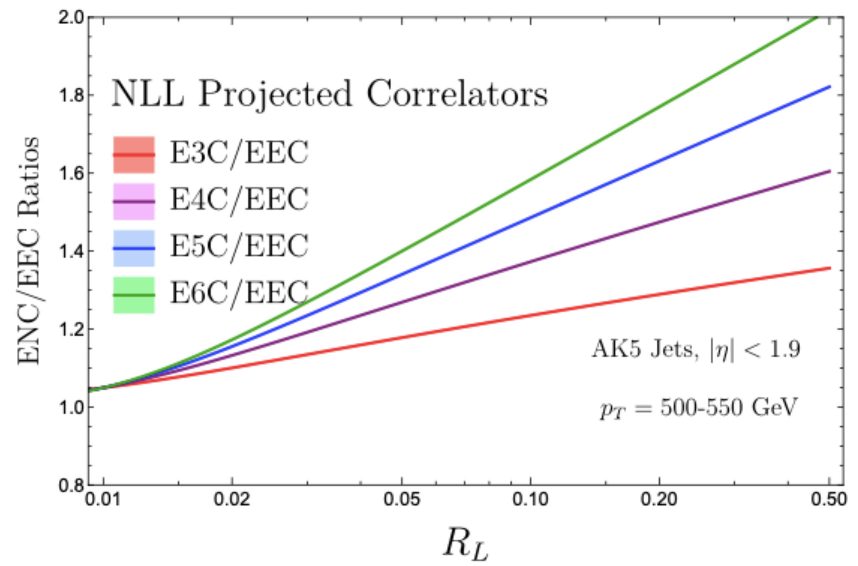
- The anomalous scaling behavior depends on N (slope increases with N)

  $\Downarrow$

- First hand probe of the anomalous dimensions of QCD operators.

- Mass effects cancel in the ratio.

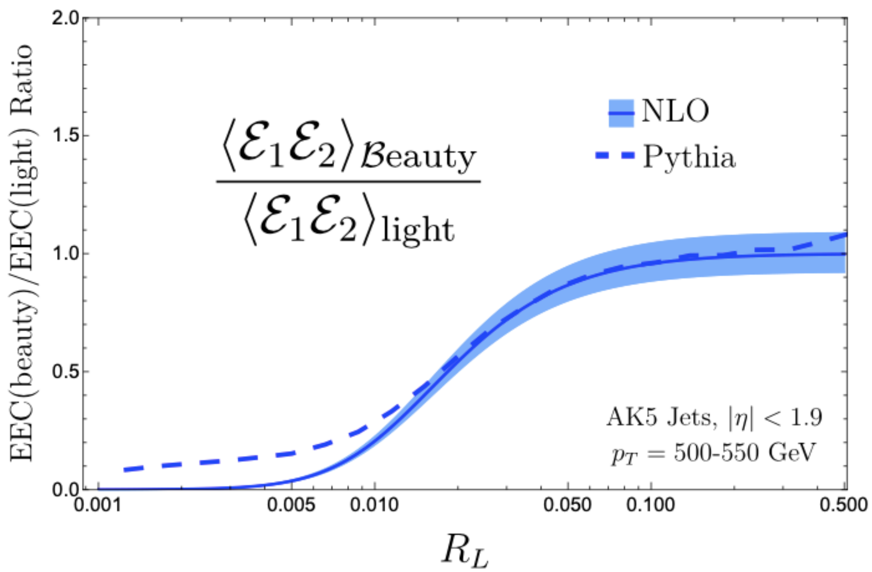
- The same scaling behavior as in massless limit; UV poles are independent of the IR Physics.



[Craft, Lee, Mecaj, Moult]

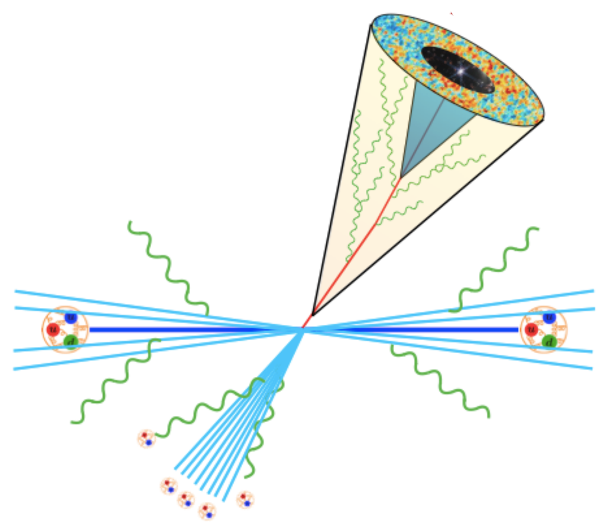
The dead-cone effect

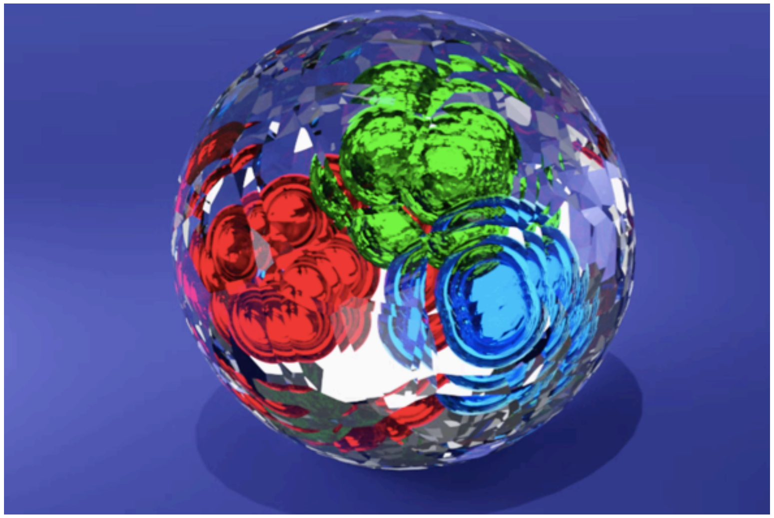
Intrinsic mass effects



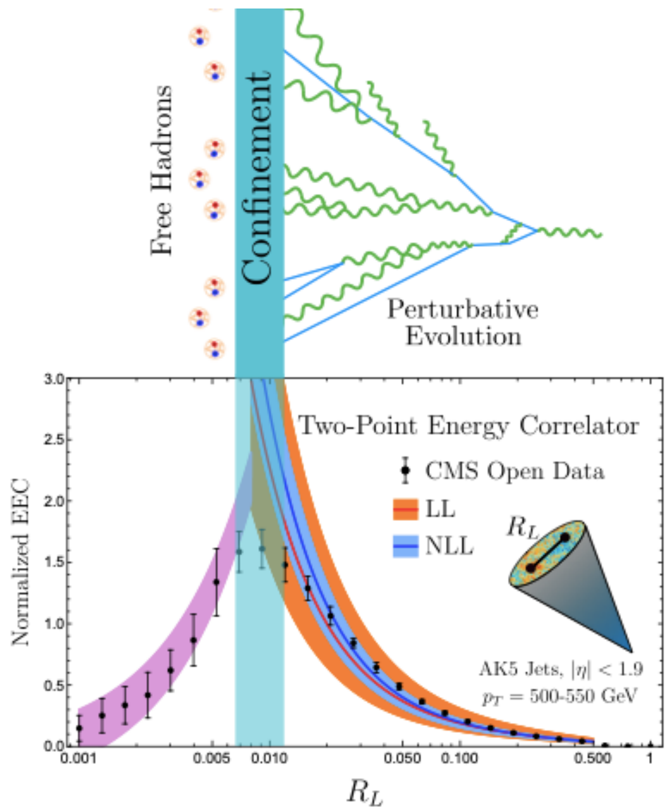
[Craft, Lee, Mecaj, Moult]

- **Suppression of gluon emission at smaller angular scale**
- **Scale related to the mass of the heavy quark**





Confinement transition in jet substructure?



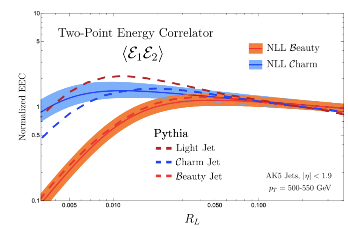
Any underlying dynamics will be imprinted in the energy correlators, including hadronization transition.

Conclusions

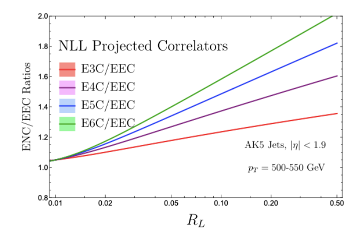
- Factorization formula for calculating energy correlators for massive parton fragmentation at colliders.

$$\Sigma\left(z, p_T^2, M_Q, \mu\right) = \int_0^1 dx x^N \vec{J}^{[N]}\left(R_L, x, M_Q, \mu\right) \cdot \vec{H}\left(x, p_T^2, \mu\right)$$

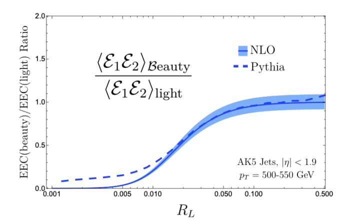
- Can probe scaling behavior from mass effects in a clean way



- Probe anomalous dimensions with higher point correlators



- Probe theoretical fundamental effects: dead-cone



Thank you!