# Measurement of Energy Correlators Inside Jets


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On behalf of CMS Collaboration

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### 1. Multipoint Energy Correlators

- Multipoint energy correlators describe the internal correlations between particles within a jet.
- It allows perturbative calculations at high orders - valuable inputs for testing fundamental theories of QCD.
- The two multipoint energy correlators we have measured are -

$$E2C = \frac{d\sigma^{[2]}}{dx_L} = \sum_{i,j}^{n} \int d\sigma \frac{E_i E_j}{E^2} \delta(x_L - \Delta R_{i,j}), \quad (1)$$

$$E3C = \frac{d\sigma^{[3]}}{dx_L} = \sum_{i,j,k}^{n} \int d\sigma \frac{E_i E_j E_k}{E^3} \delta(x_L - max(\Delta R_{i,j}, \Delta R_{i,k}, \Delta R_{j,k})) \quad (2)$$

- Describes mapping of various stages that partons undergo in jet formation.

### 2. Data Samples Used

- 2016 data collected by the CMS experiment at $\sqrt{s} = 13$ TeV
- Four different Monte-Carlo models used -
  - PYTHIA8.240
  - HERWIG7.1.4
  - MG5_aMC@NLO + PYTHIA8.240
  - MG5_aMC@NLO + HERWIG7.1.4

### 3. Event Selection Criteria

- Events are required to pass the Single-jet HLT with jet $p_T > 60$ GeV
- Selection -
  - Events are required to originate from the Primary Vertex
  - Jets must have - $p_T > 30$ GeV , $|\eta| < 2.1$ & $n_{jets} \geq 2$
  - Back-to-back jets with $|\Delta\phi| > 2$

### 4. Analysis Strategy

- 8 $p_T$ intervals considered within - 97 GeV $< p_T <$ 1784 GeV - To test energy dependence
- All neutral & charged particles with $p_T > 1$ GeV considered.
- RoofUnfold package has been used to unfold the data.
- 3D unfolding used. Three dimensiosns are - particle pair's (triplet's) $x_L$ , energy weight, and the $p_T$ of the jet.
- Systematic Uncertainties - Largest uncertainty (2–10% ) arises from the alternative modeling, depending on $x_L$ and $p_T$ region

### 5. Measurement of E2C & E3C

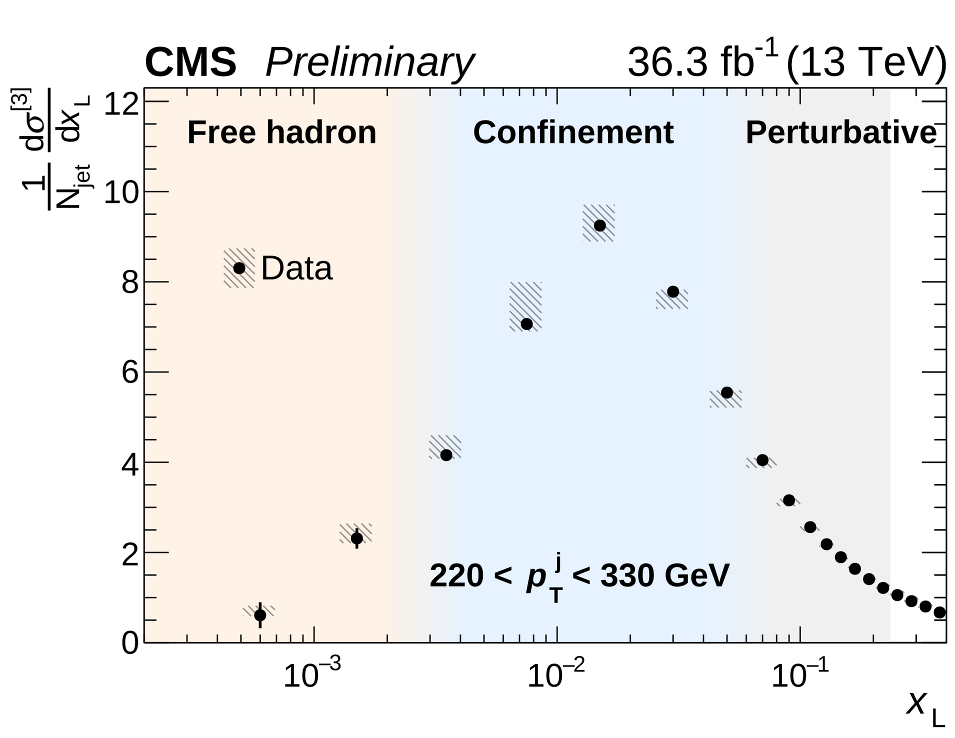


**Figure 1:** *Unfolded data distribution of E3C using jets in the $p_T$ range between 220 and 330 GeV*

- The distribution shows 3 distinct regions -
  - Quantum interactions of quarks and gluons at the largest $x_L$
  - Sharp transition where quarks and gluons are confined
  - Noninteracting hadrons at smallest $x_L$.
- Unfolded data distributions compared to multiple MC predictions shows approxiately 5-10 % difference.
- Difference is larger in the nonperturbative(NP) region.

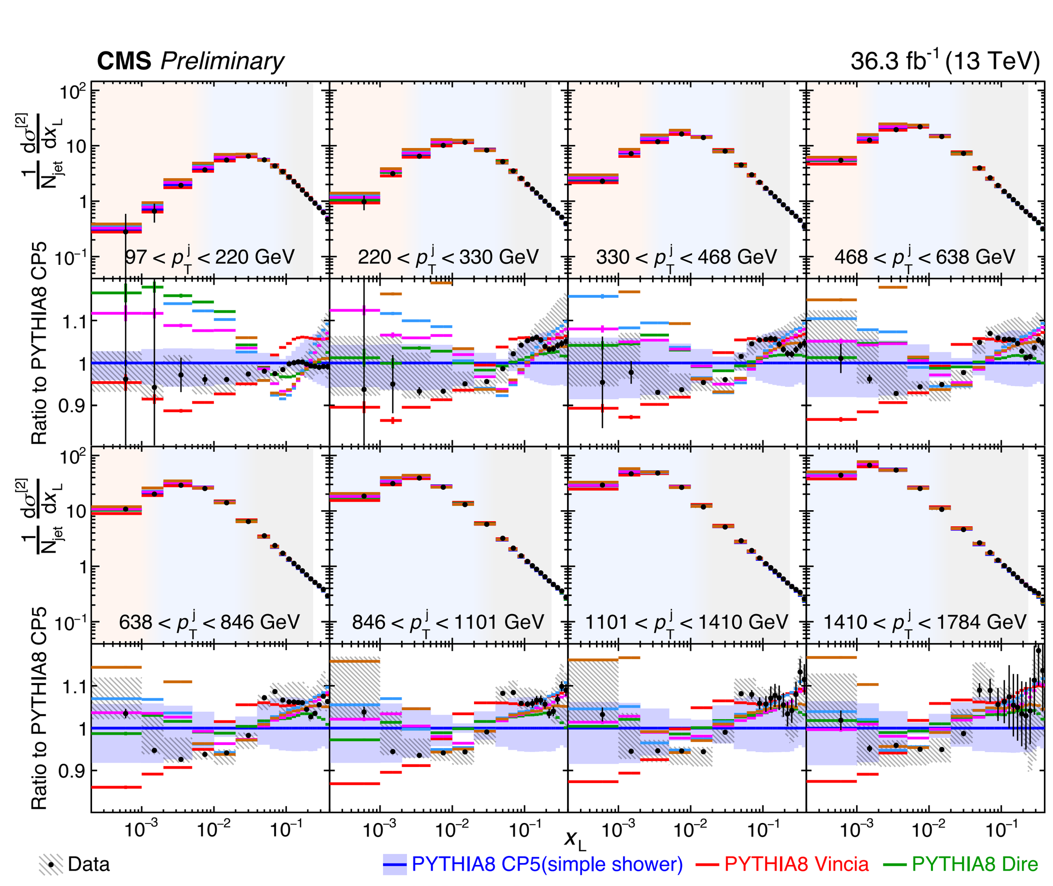


**Figure 2:** *Unfolded E2C distributions in data compared with MC predictions*

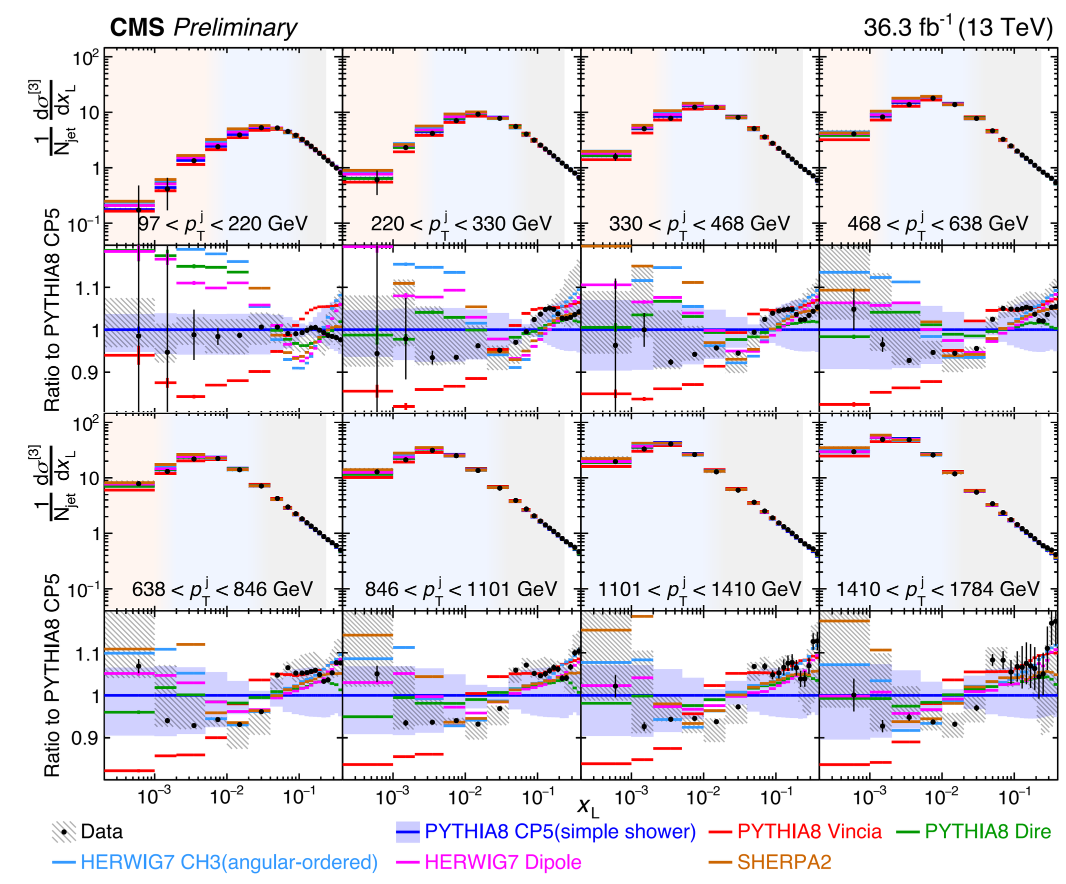


**Figure 3:** *Unfolded E3C distributions in data compared with MC predictions*

### 6. Extraction of $\alpha_s$ & Asymptotic Freedom

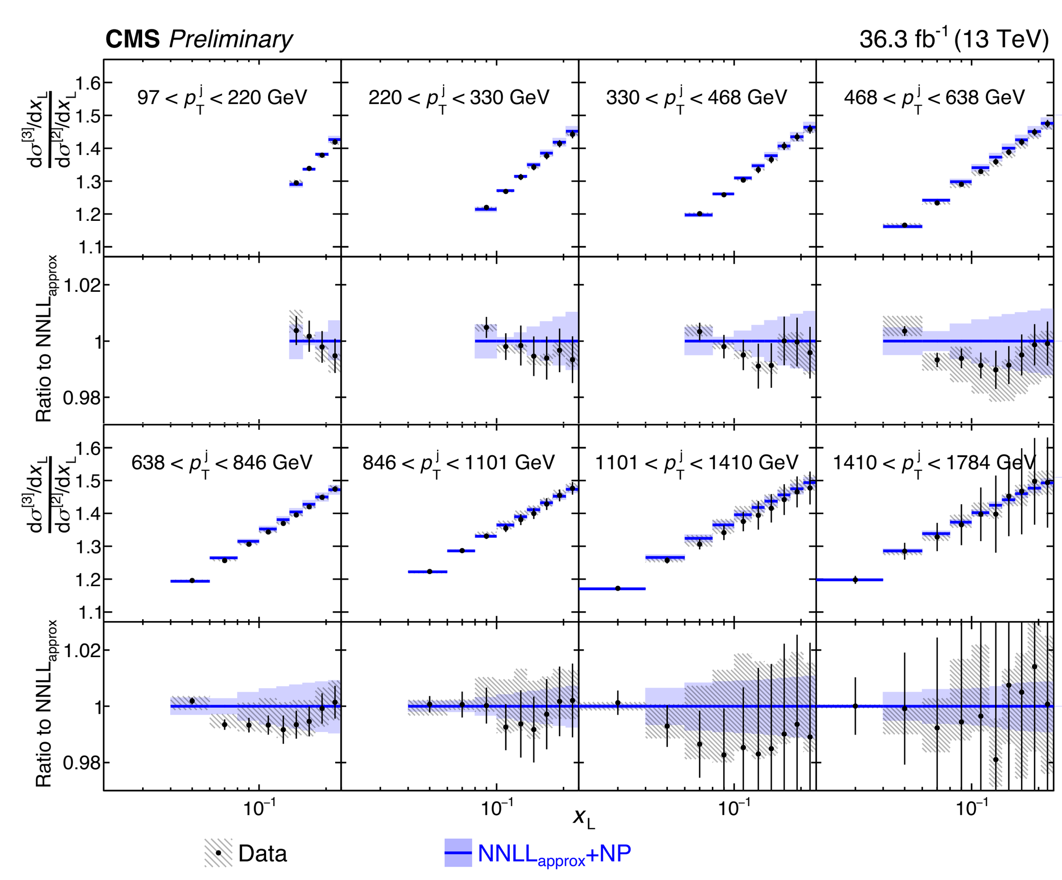


**Figure 4:** *Unfolded E3C/E2C distributions in data, compared to theoretical predictions in the perturbative region*

- Ratio of E3C/E2C used to extract the $\alpha_s$ value.
- Ratio reduces the systematic uncertainty - hard scattering and NP uncertainties cancels out.
- The slopes in the ratio distributions decrease with the jet $p_T$ - $\alpha_s$ gets smaller at higher energy scales
- The measured $\alpha_s$ value is - $0.1229^{+0.0014}_{-0.0012}(stat)^{+0.0030}_{-0.0033}(theo.)^{+0.0023}_{-0.0036}(exp.)$

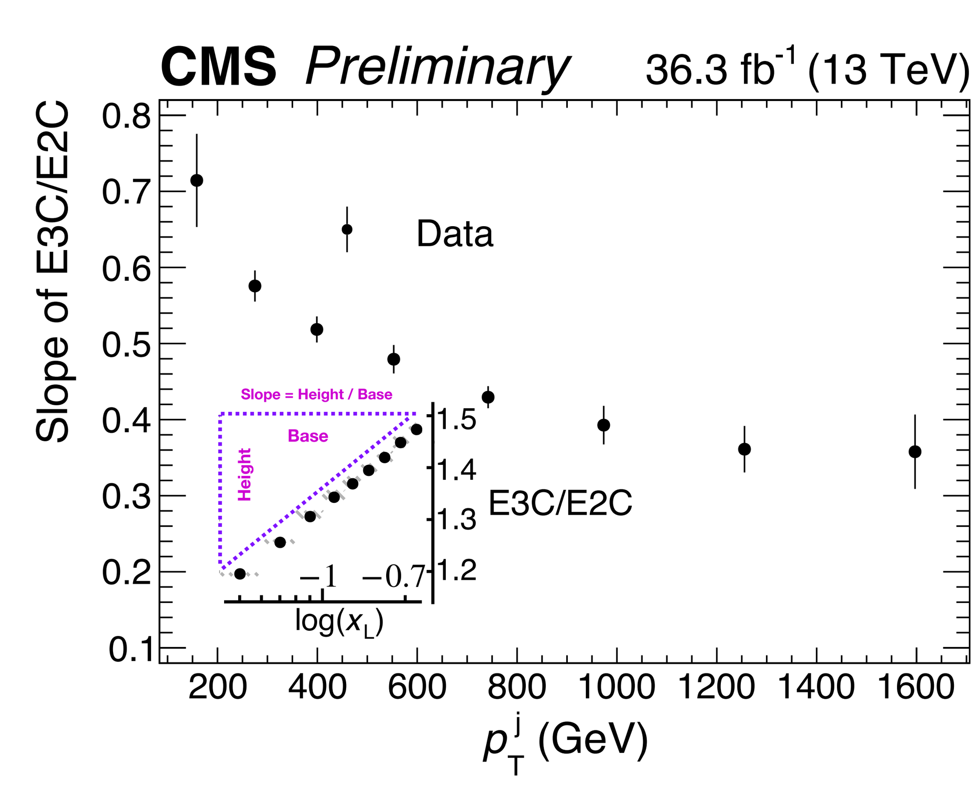


**Figure 5:** *Fitted slopes of E3C/E2C data distributions as function of jet $p_T$*

### 7. Conclusions & Discussions

- The measurement of the two-point and three-point energy correlators is presented in this work.
- Provide approaches to understand the time scale of hadron formation.
- The $\alpha_s(m_z)$ value extracted from the ratio of E3C/E2C is $0.1229^{+0.0040}_{-0.0050}$ - most precise determination of $\alpha_s$ using jet substructure techniques to date.

### 8. Acknowledgements


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### References


[1] **CMS PAS:** Measurement of energy correlators inside jets and determination of the strong coupling constant