Probing jet substructure with 2-point & projected 3-point energy correlators in pp collisions at 13 TeV with ALICE

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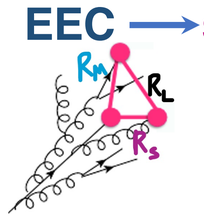
Motivation

Jet substructure ⟶ radiation history of initiating parton ⟶ probe QCD at different energy scales.

The N-point Energy Correlator (ENC) encodes the evolution of jets from partonic to hadronic regimes in its slopes.

EEC ⟶ scale dependence of energy flow ⟶ slopes of the curve distinguish hadronic and partonic regimes.



EEEC ⟶ shape dependence of energy flow (3-pronged structure) + $1 \rightarrow 3$ splittings.

E3C = EEEC projected along R_L ⟶ slope in the partonic regime is the same as EEEC.

E3C/EEC ratios probe perturbative physics by eliminating detector & hadronization effects.

Scaling dimensions of operators & ENC

QFT operators have a scaling/mass dimension $\Delta_{\mathbb{O}}$. For e.g., in 3+1D, scalar field $[\phi] = 1$, fermion field $[\psi] = 3/2$.

Quantum mechanical effects ⟶ $\Delta_{\mathbb{O}}$ gets shifted by "anomalous dimensions", $\gamma_{\mathbb{O}}$: $\Delta_{\mathbb{O}} = \Delta_{\mathbb{O},\,classical} + \gamma_{\mathbb{O}}$

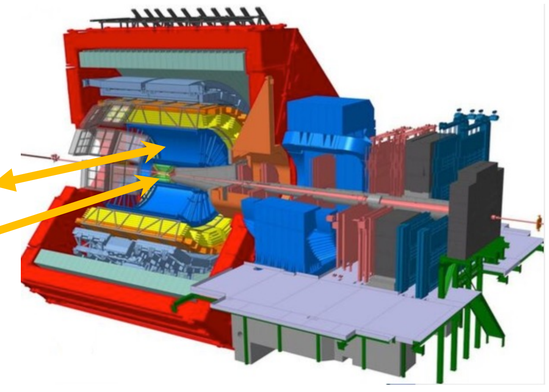
At leading log approximation [1] :

$$ENC(R_L) = \frac{-d}{dR_L}\left[(1,1)\exp\left(\frac{-\gamma^{(0)}(N+1)}{\beta_0}\ln\frac{\alpha_S(R_L\mu)}{\alpha_S(\mu)}\right)(x_q,x_g)\right]H_J(\mu)$$

ALICE detector

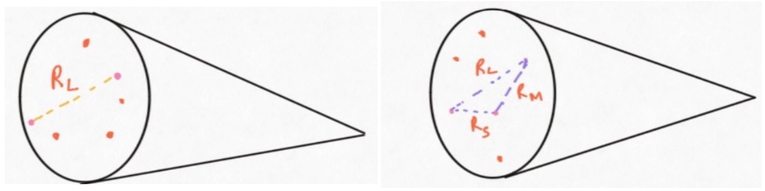
Charged anti-k_T jets, R = 0.4

Time Projection Chamber (TPC) & Inner Tracking System (ITS): good angular & p_T resolution



The EEC & E3C

Keep only the largest side, R_L, for the E3C.



Analysis method

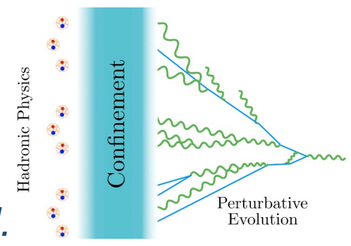
Constructing the ENC: Weighted histogram as a function of R_L (largest distance between N particles). For N point correlator, the weight is: $p_T^i\, p_T^j\, p_T^k \ldots p_T^N/(p_{T,\mathrm{jet}})^N$

Correction method: low R_L migration ⟶ bin-by-bin correction

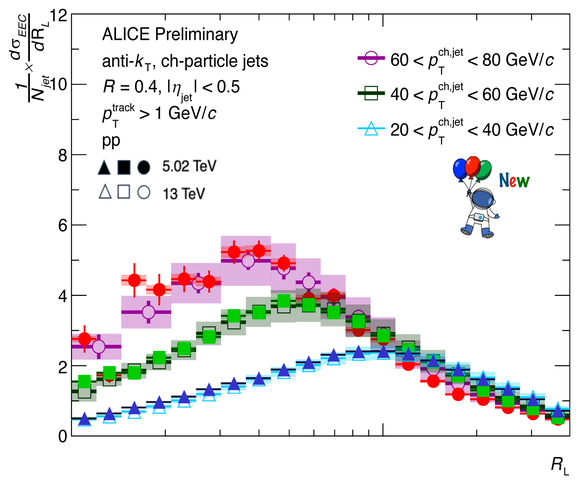
$$f_{corr}\left(R_L^{\mathrm{det}}, p_{T,\mathrm{jet}}^{\mathrm{det}}\right) = ENC_{\mathrm{det}}/ENC_{\mathrm{true}}$$
$$ENC_{\mathrm{true}}\left(p_{T,\mathrm{jet}}^{\mathrm{true}}\right) = (1/f_{corr})ENC_{\mathrm{det}}(p_{T,\mathrm{jet}}^{\mathrm{det}})$$

Probing jet evolution with EEC & E3C

Higher p_T jets are more perturbative ⟶ curves shift to the left ⟶ elongating the partonic region ⟶ ***angular ordering*** *of QCD.*



EEC is $\sqrt{s}$ independent! [2].



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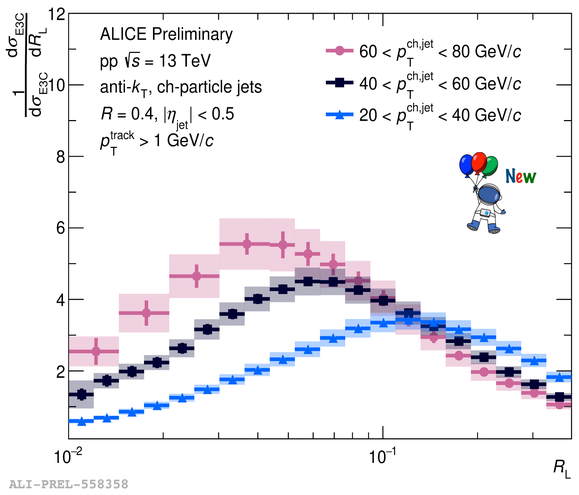

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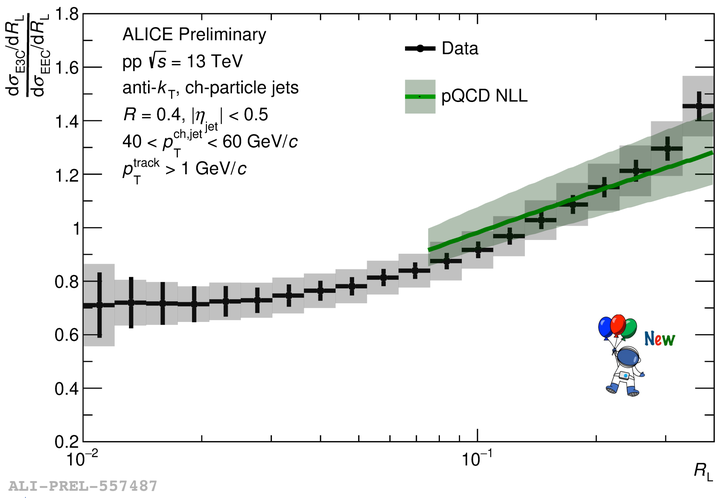
pQCD Comparison: E3C/EEC



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Shape comparison of the theory vs data ⟶ Good agreement within uncertainty bands! [4]

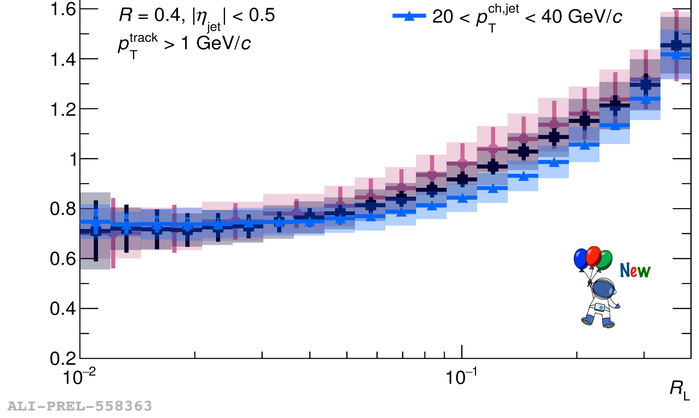
E3C/EEC : γ, running α_S, perturbative physics

$$\frac{E3C}{EEC} \approx \frac{\gamma^{(0)}(4)}{\gamma^{(0)}(3)}\exp\left(\frac{\gamma^{(0)}(3)-\gamma^{(0)}(4)}{\beta_0}\ln\frac{\alpha_S(R_L\mu)}{\alpha_S(\mu)}\right)$$

$\gamma_{N+1} > \gamma_N$ (theory) reproduced in data (slope > 1).

Lowest p_T bin ⟶ different slope ⟶ consistent w/ expectation of ***running of α_S!****

* *The slopes here roughly agree with [3]*



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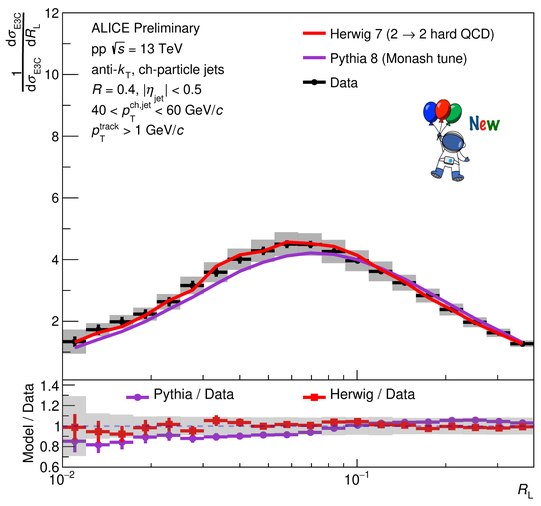
Model Comparison: E3C & E3C/EEC



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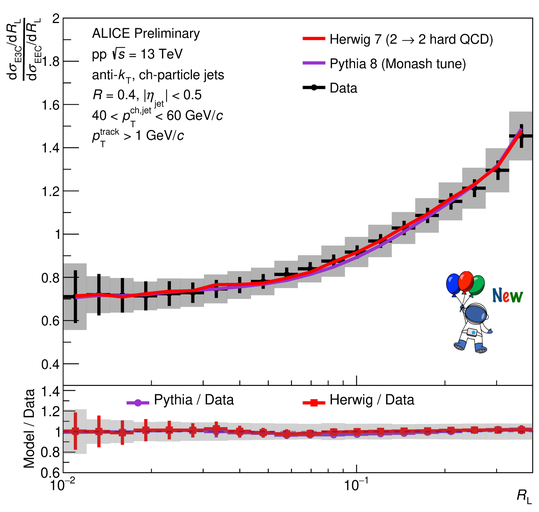

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Summary:

- ***Slopes of the ENC allow clear separation of physics at different scales ⟶ difficult in substructure measurements.***
- ***E3C/EEC ratios access pQCD ⟶ reduce detector and non-perturbative (hadronization) effects!***
- ***Collision energy independence of EEC confirmed in data!***

[1] PhysRevLett.130.051901
[2] See talk by Wenqing Fan (https://indi.to/wxQJT)
[3] Measurement of energy correlators in jets & α_S extraction at CMS - BOOST 2023.
[4] arXiv:2205.03414

See posters by:
Anjali Nambrath, Beatrice Liang (ALICE)
Andrew Tamis (STAR)

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