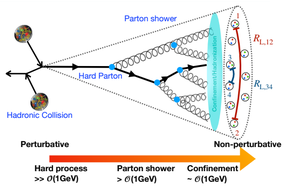
Probing the shower properties of charm quarks using energy-energy correlators with ALICE

Probing the shower properties of charm quarks using energy-energy correlators with ALICE

Preeti Dhankher (UC Berkeley and LBNL) on behalf of the ALICE Collaboration

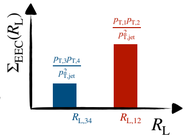
I. Unravel different QCD scales with jet substructure

- Jets probe a wide range of interaction Q^2
- QCD emissions in parton showers are angular ordered. The early splittings (perturbative) are wider ($R_{L,12}$) and the late splittings (non-perturbative) are narrower ($R_{L,34}$)



II. What are the energy-energy correlators (EECs)?

- EEC jet substructure observable: how is energy distributed within a jet?
- Derived from quantum field theory, & IRC-safe observable → precise theoretical calculations



Calculating the Σ_{EEC} observable

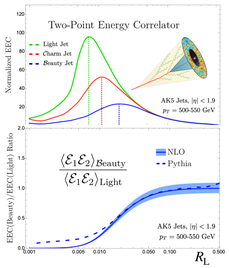
1. Construct anti-k_T jets
2. Calculate the energy weight ($p_{T,i}p_{T,j}/p_{T,jet}$) for each pair (i,j) of tracks inside the jet.
3. Count the number of weighted track pairs as a function of R_L

$$\Sigma_{EEC}(R_L) = \frac{1}{N_{jet}} \sum_{N} \int \sum_{i,j} dR'_L \frac{p_{T,i}p_{T,j}}{p_{T,jet}^2} \delta(R'_L - R_{L,ij}) \quad \text{where } R_{L,ij} = \sqrt{\Delta\phi_{ij}^2 + \Delta\eta_{ij}^2}$$

III. Why are we interested in EECs?

- $\Sigma_{EEC}(R_L)$ probes jet dynamics from perturbative (large R_L) to non-perturbative scales (small R_L).
- Mass effects due to the dead-cone imprinted on angular scale (R_L) and amplitude
- Ratio of heavy to light flavor jet EECs shows large suppression at smaller angles → due to the dead-cone effect

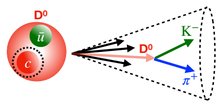
EECs probe detailed structure of QCD radiation from heavy quarks: a precision test of mass-dependent effects in parton showers and hadronization



arXiv:2210.09311

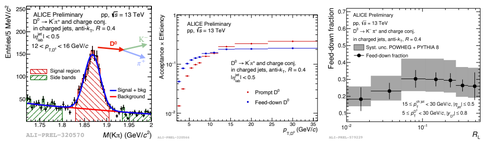
IV. How to measure charm-tagged jet EECs?

1. Reconstruct D^0-meson candidates from decay daughter tracks using topological and particle identification selections

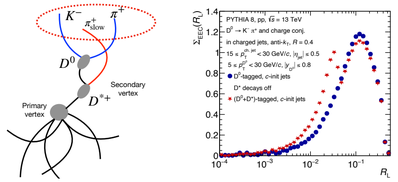


$D^0 \to K^- + \pi^+$ and charge conjugate

2. D^0-tagged charged jets: anti-k_T jet algorithm (R = 0.4) for each D^0 candidate → calculate $\Sigma_{EEC}(R_L)$
3. Remove background D^0 candidates using side-band subtraction

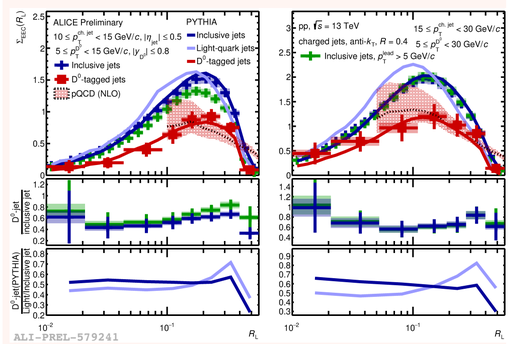


4. Correct for D^0-tagged jet reconstruction efficiency
5. **Feed-down correction:** beauty feed-down ($B \to D^0$) estimation using POWHEG + PYTHIA 8. Corrected for non-prompt D^0 reconstruction efficiency.
6. **Detector effects:** Correct $\Sigma_{EEC}(R_L)$ for track momentum resolution, angular resolution, and both single-track and pair inefficiencies
7. **Removed $D^{*\pm}$ contribution** using the ratio $\frac{D^{*\pm} \text{ decay turned Off}}{D^{*\pm} \text{ decay turned On}}$ calculated from PYTHIA 8 simulations



Many thanks to Kyle Lee and collaborators for providing the pQCD calculations.

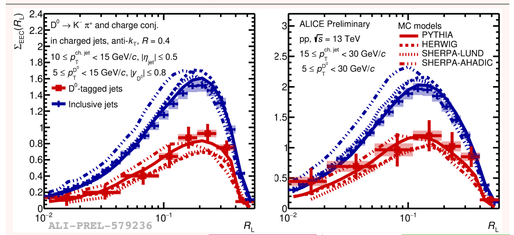
V. Charm-tagged jet EECs



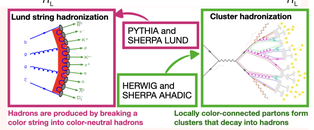
- Charm-tagged jet EECs have a lower amplitude than inclusive jet EECs → expected from the "dead-cone effect"
- Striking peak similarity of charm-tagged and inclusive jet (gluon dominated) → complex interplay: flavor effects in the shower vs. non-perturbative hadronization effects
- Leading particle p_T cut in inclusive jet at low $p_{T,jet}$: bias towards quark-initiated jets → hints at a shift towards light quark-initiated jet MC!
- pQCD calculations reproduce general shape, with some tension near peak → reflects limitations in the treatment of hadronization
- Ratio of charm-tagged to light-quark jets, both quark-initiated, shows significantly more suppression at small angles

Outlook: adding beauty-tagged jets and extending to higher $p_{T,jet}$ with Run 3 data will allow a more systematic study of mass effects in parton shower and hadronization

VI. Probing charm hadronization



- Lund string-based models provides the best description of both EECs?
- HERWIG: overpredicts inclusive jets and underpredicts charm-tagged jets



- SHERPA AHADIC predicts a peak at lower R_L for both EECs → suggests later hadronization compared to other models.

VII. Summary and outlook

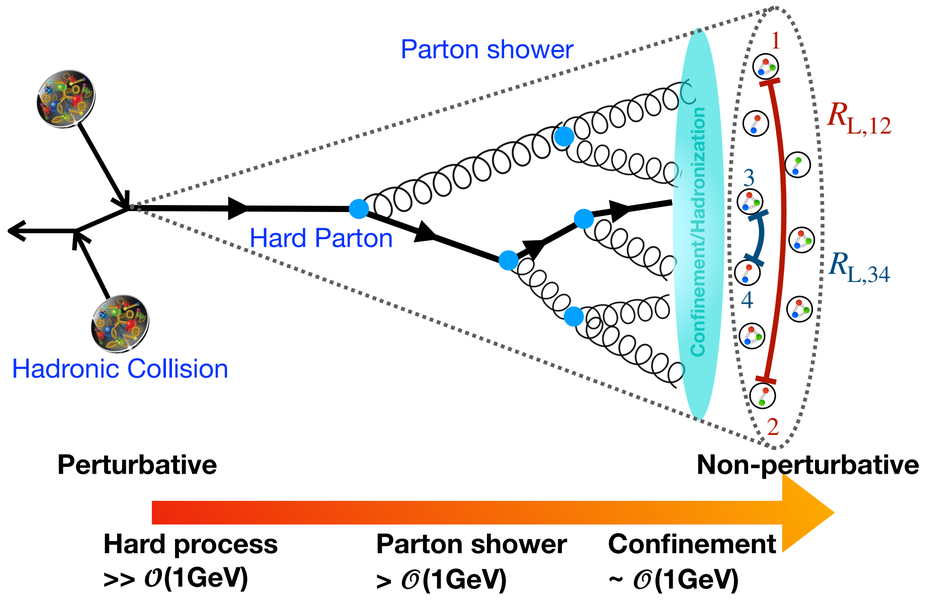
1. Charm-tagged vs. inclusive jet EECs:
   - Difference in amplitude → expected from the "dead cone effect"
   - Striking similarity in peak positions → complex interplay: flavor effects in the shower vs. non-perturbative hadronization effects
2. pQCD calculation comparison to charm-tagged jets → needs improved theoretical modeling of heavy quark jets, particularly in the transition region
3. MC model comparisons show sensitivity to different hadronization mechanisms

Preeti Dhankher
UCB/LBNL

27 Sept. 2024

Hard Probes
Nagasaki, Japan

EECs: how is energy distributed within a jet?



QCD emissions in parton showers are angular ordered.

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Energy weight

Soft contribution (MPI, UE) power suppressed by energy weight

$$\Delta R_{L,ij} = \sqrt{\Delta\phi_{ij}^2 + \Delta\eta_{ij}^2}$$

1. Energy weighted two particle correlation inside jet
2. Derived from QFT & IRC safe observable→ precise theoretical calculations
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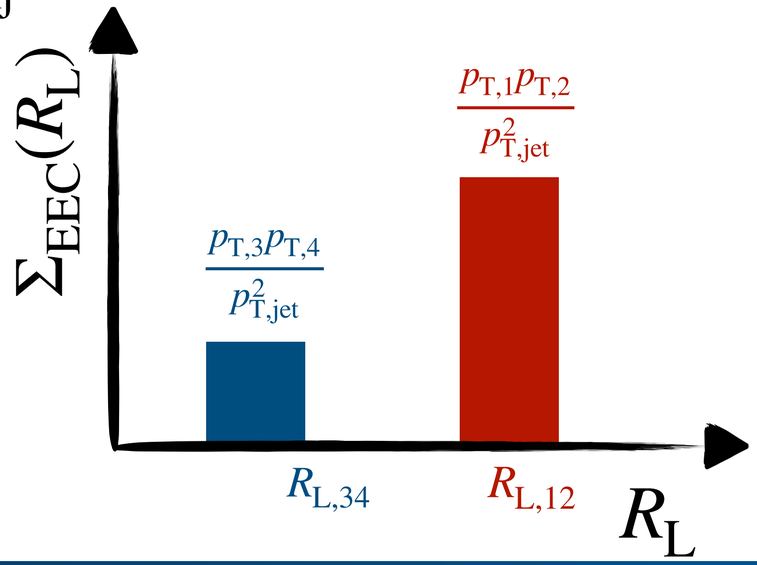
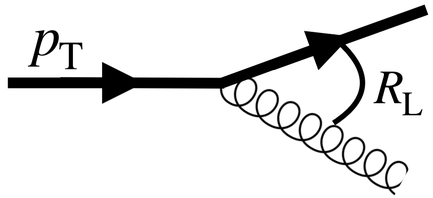


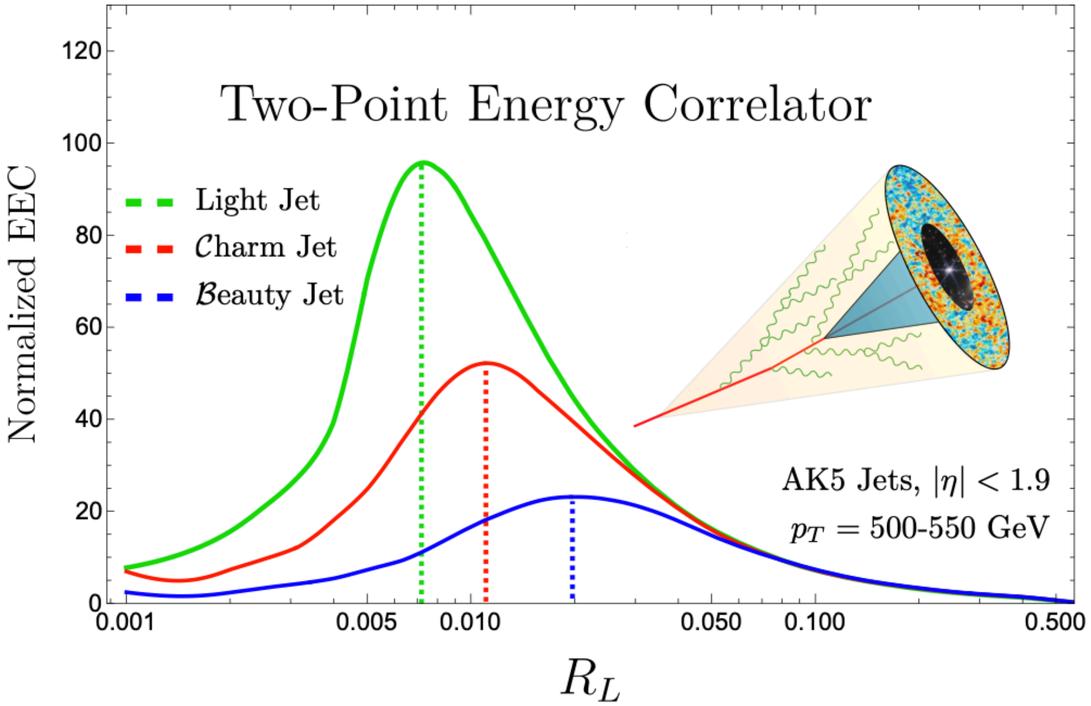
arXiv:2210.09311

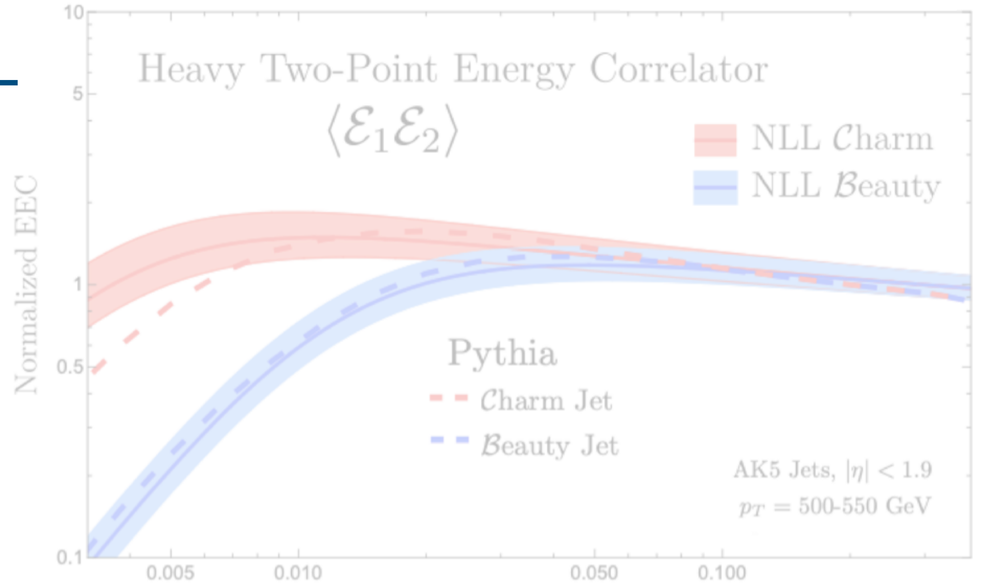
HF energy-energy correlators

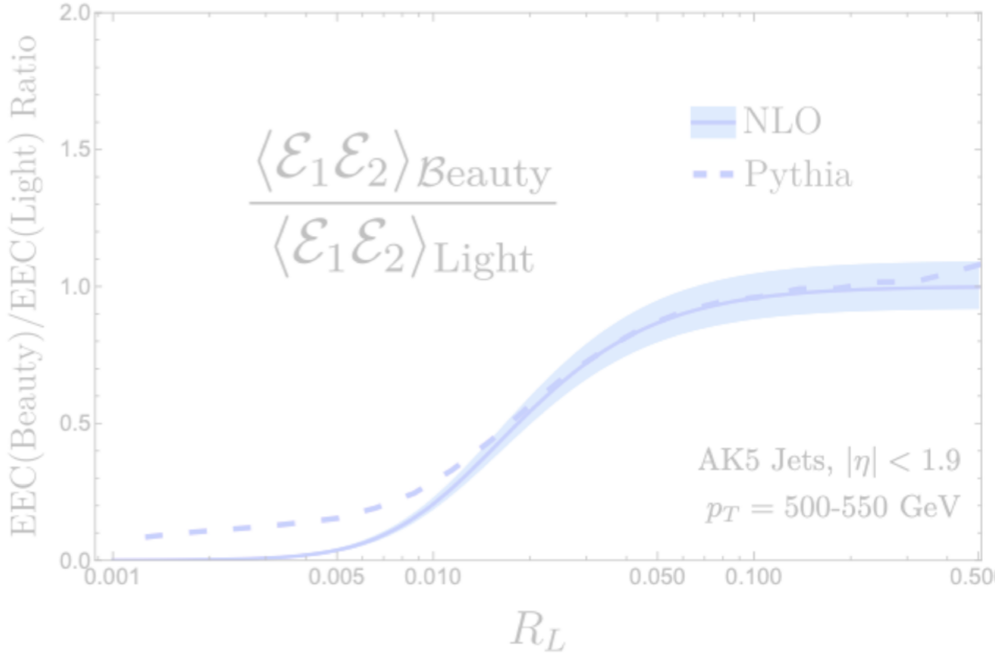
- Scaling behavior identical to massless case for larger R_L.

$$\text{virtuality} \sim p_T R_L + m$$









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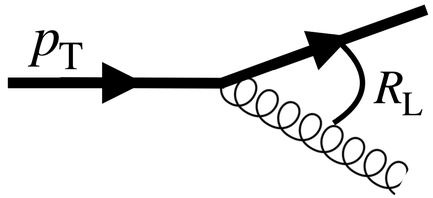
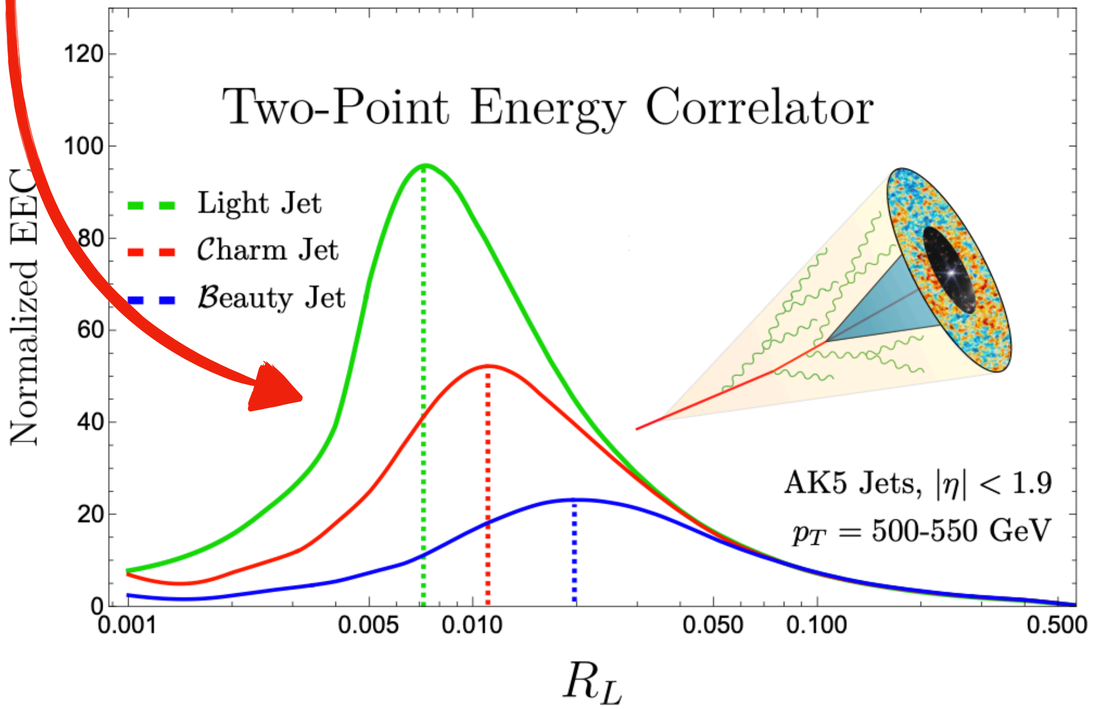
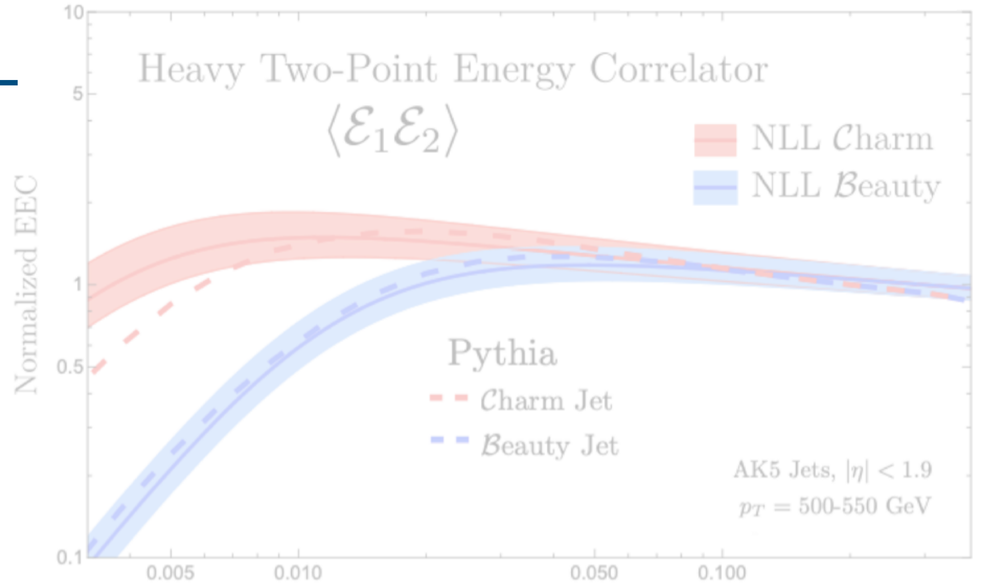
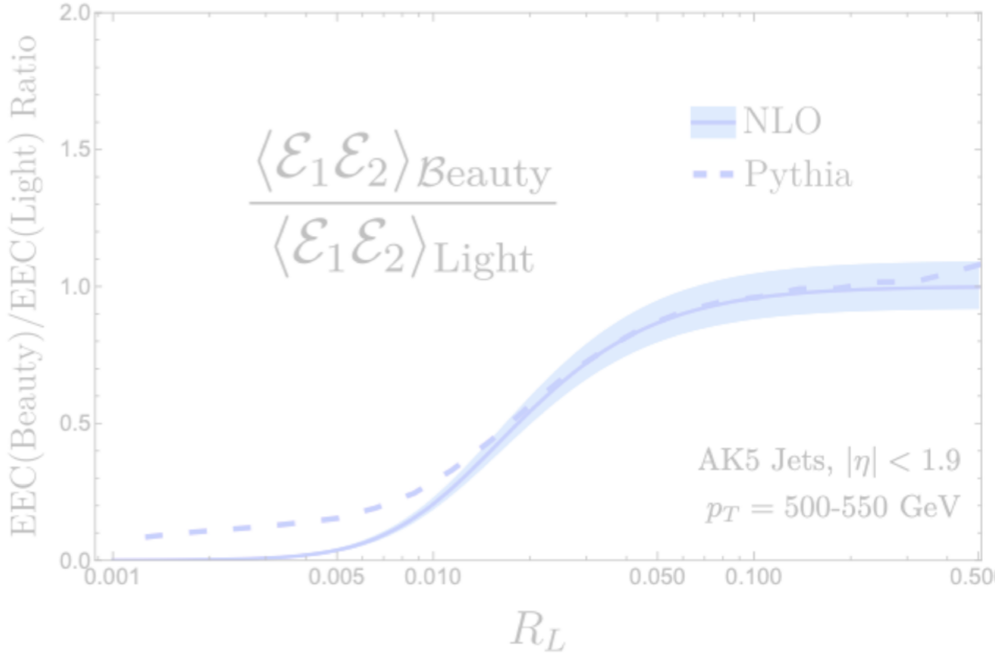


- A turn-over for $R_{\mathrm{L}} \to m_{\mathrm{Q}}/p_{\mathrm{T}}$







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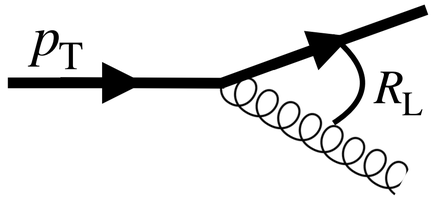
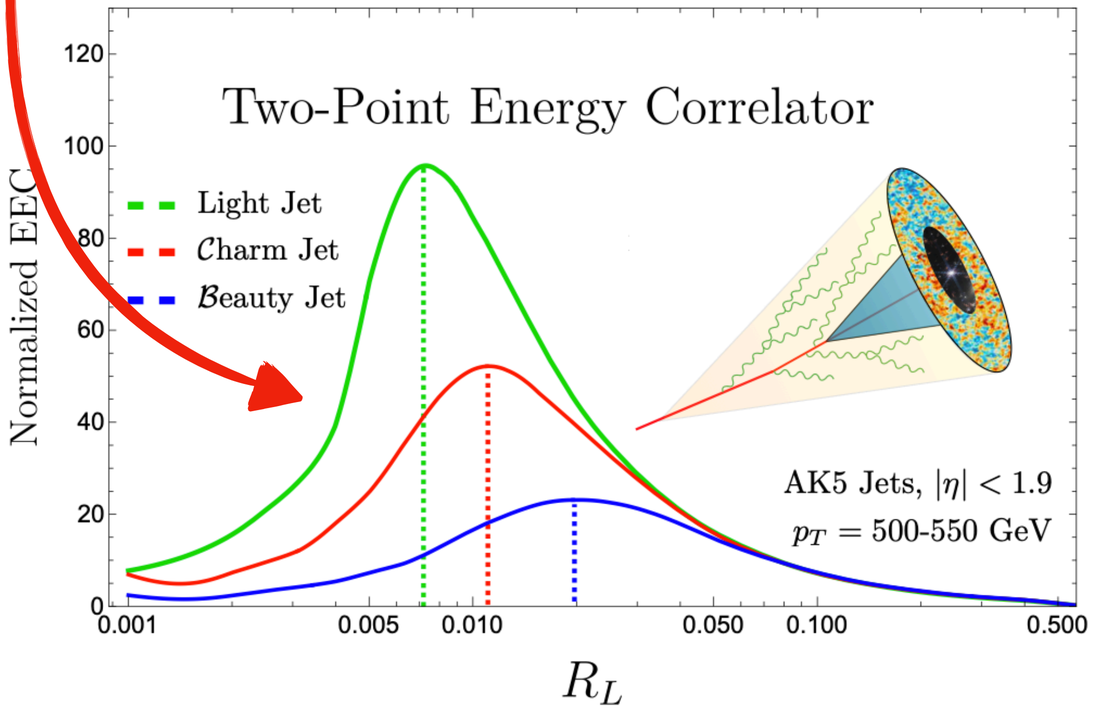
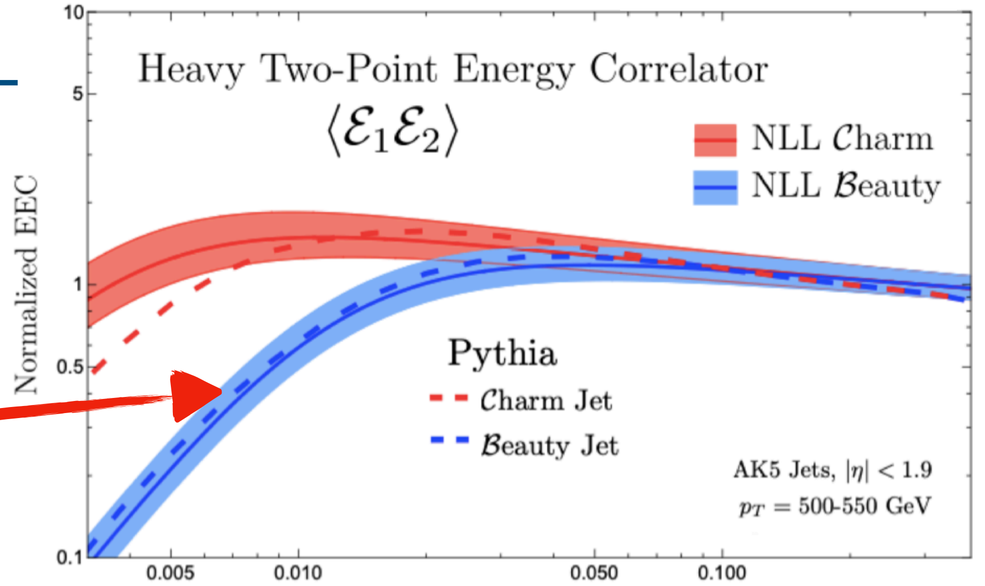
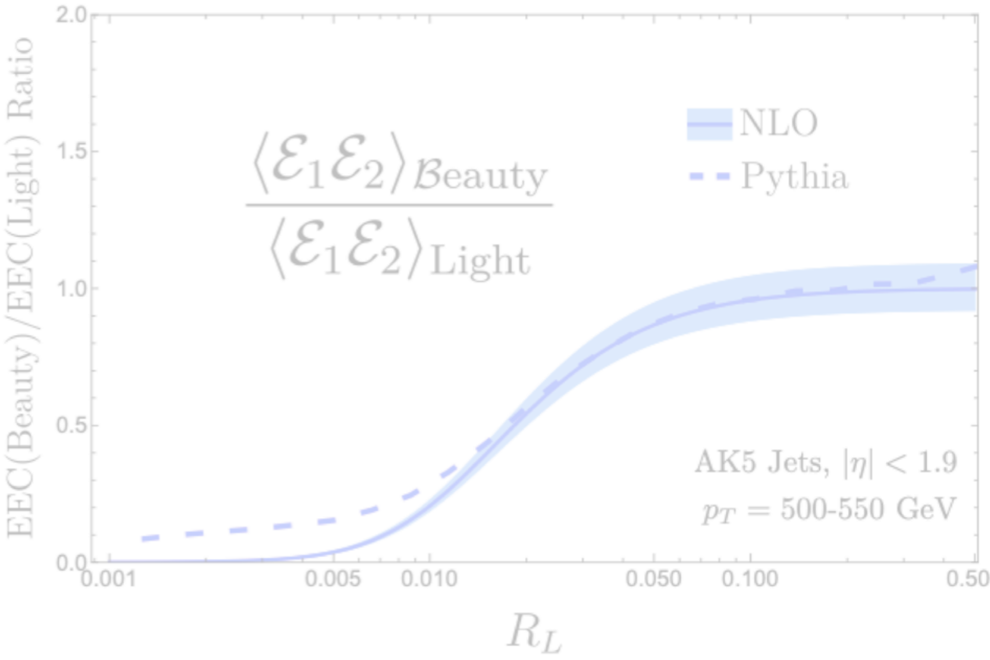


- A turn-over for $R_{\mathrm{L}} \to m_{\mathrm{Q}}/p_{\mathrm{T}}$
- The change in the slope is perturbative effect contrary to massless jets: $R_{\mathrm{L}} \to \Lambda_{\mathrm{QCD}}/p_{\mathrm{T}}$







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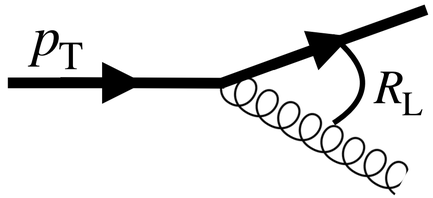

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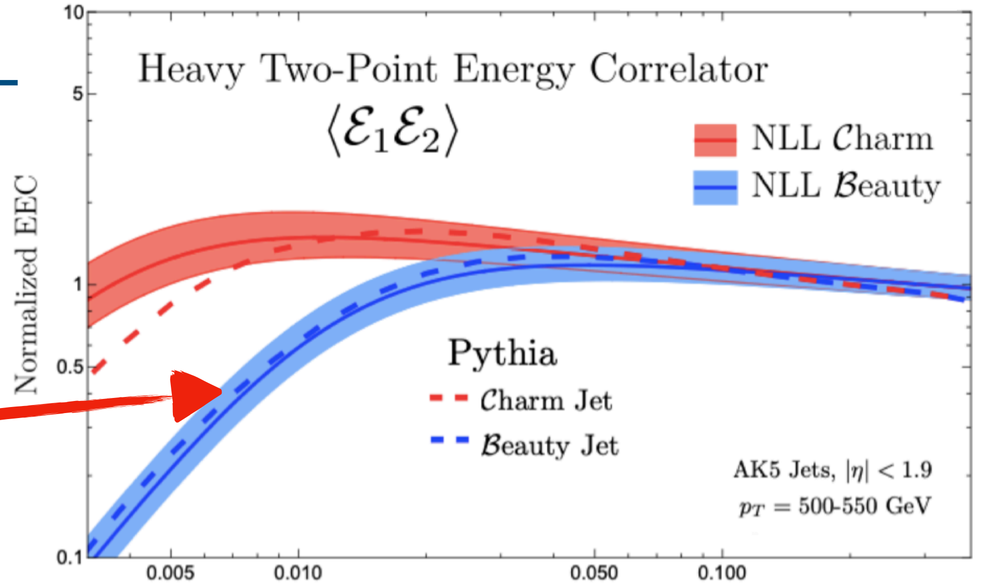
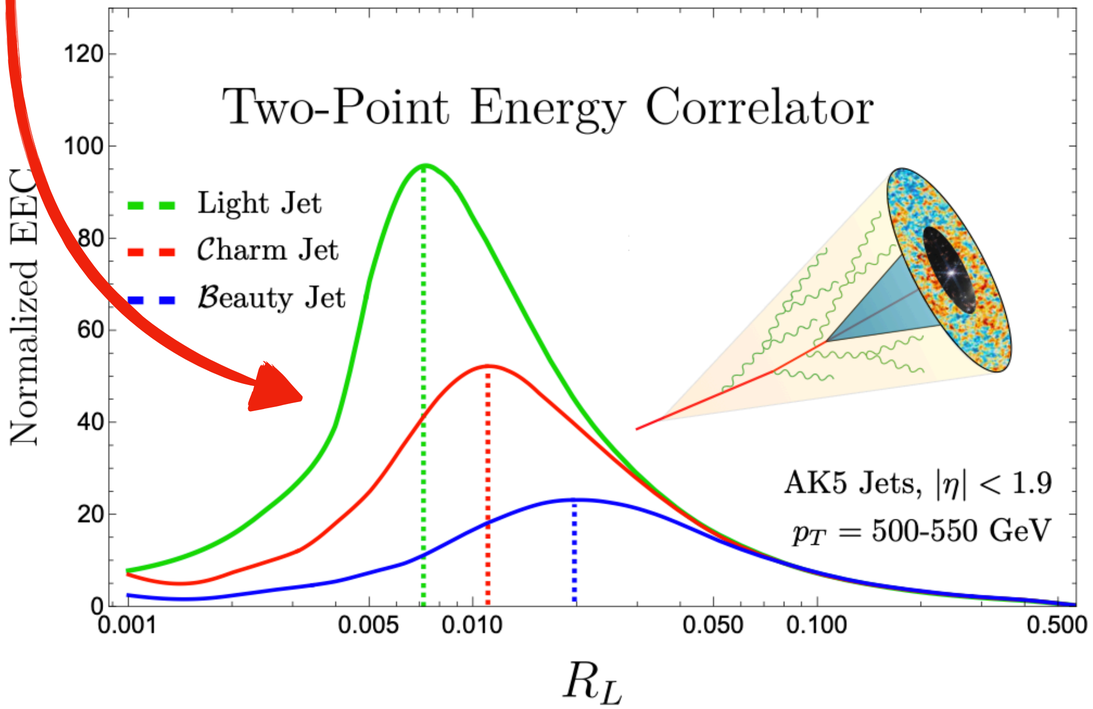
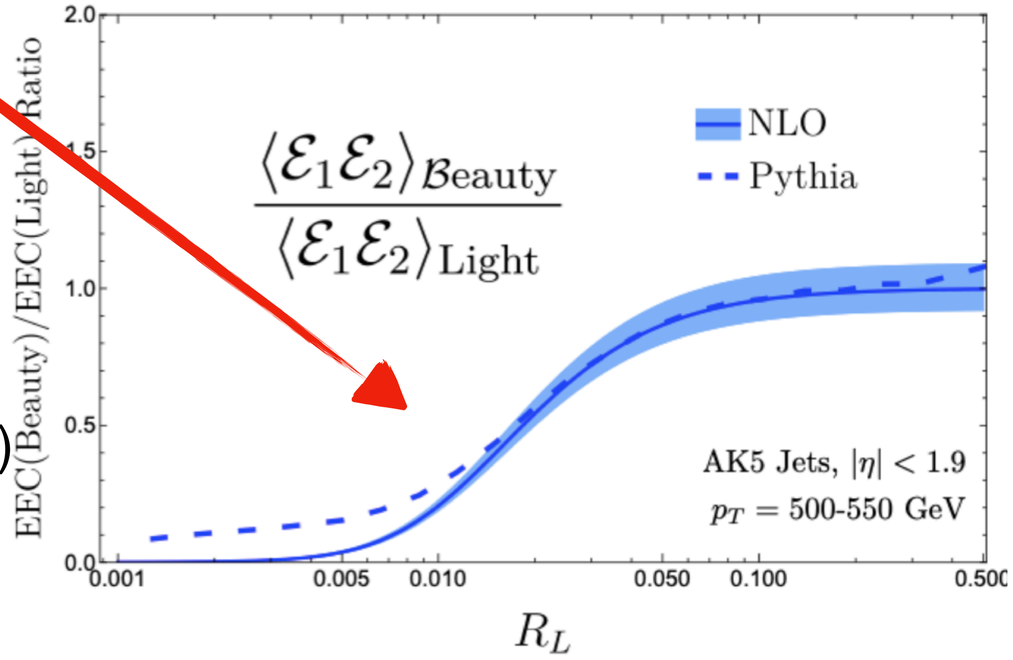


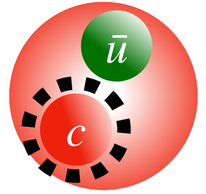


Ratios of the massive to light EECs isolate mass effects.

Small angle suppression (<*m*/*E*) →**"dead-cone" effect**



Charming energy-energy correlators



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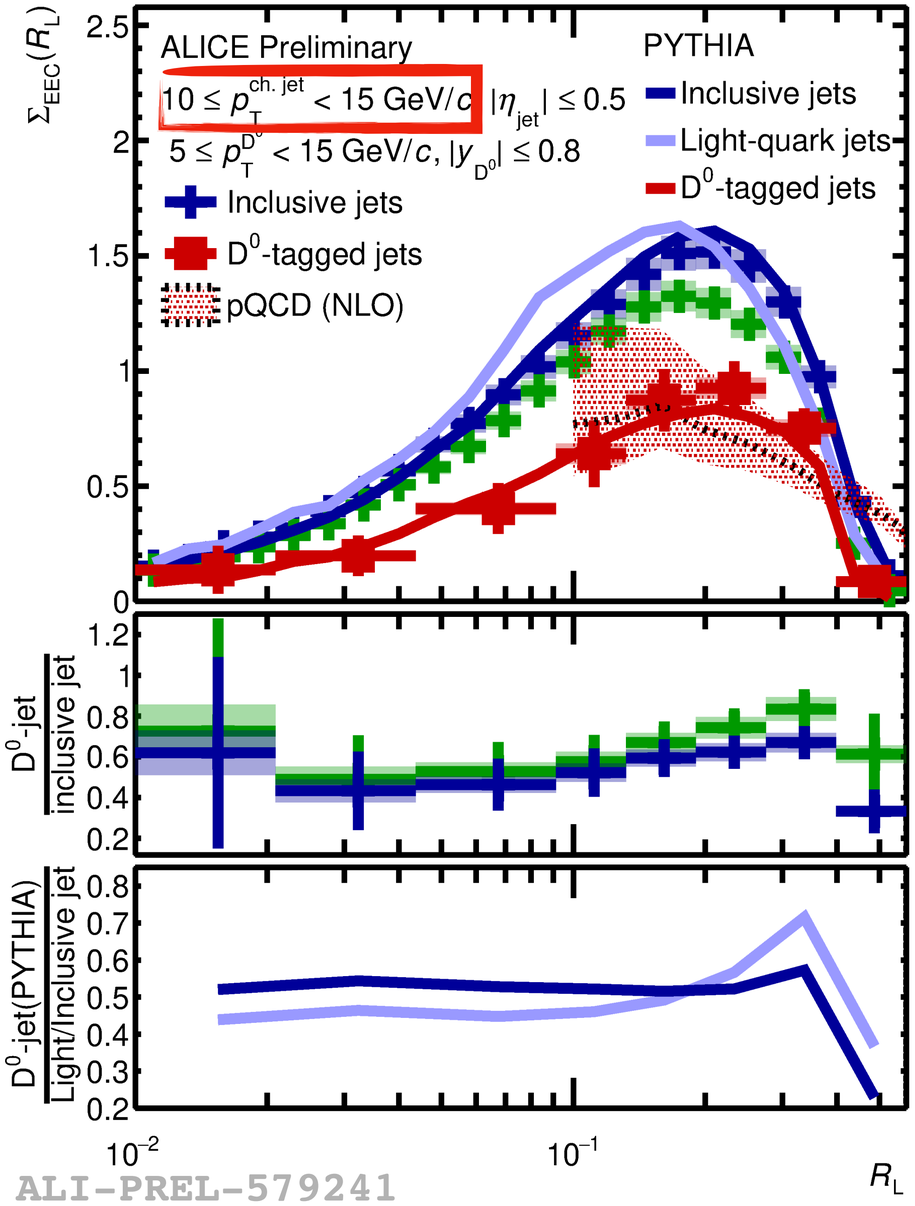

ALI-PREL-579241

*pQCD calculation by Kyle Lee and collaborators

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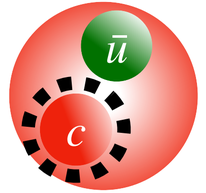

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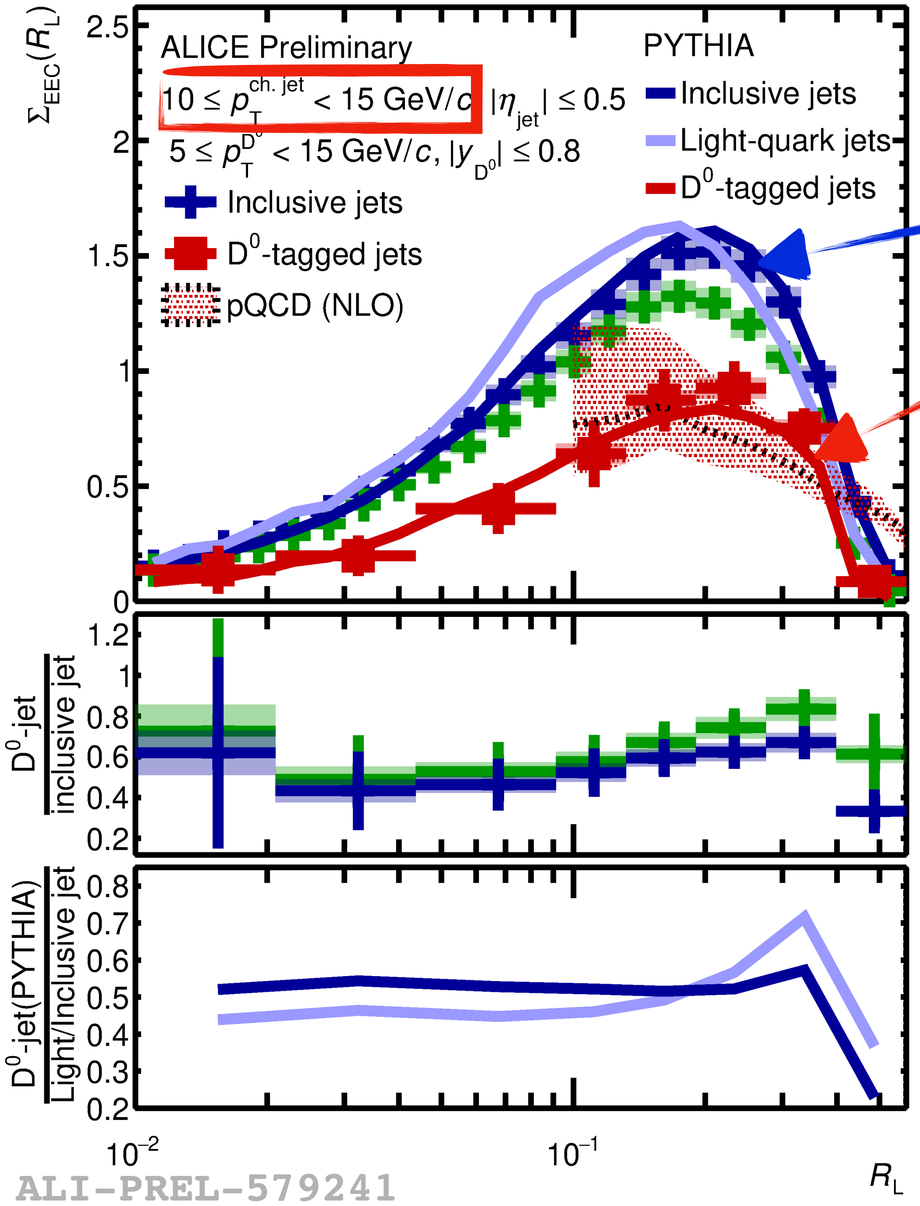

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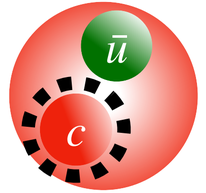

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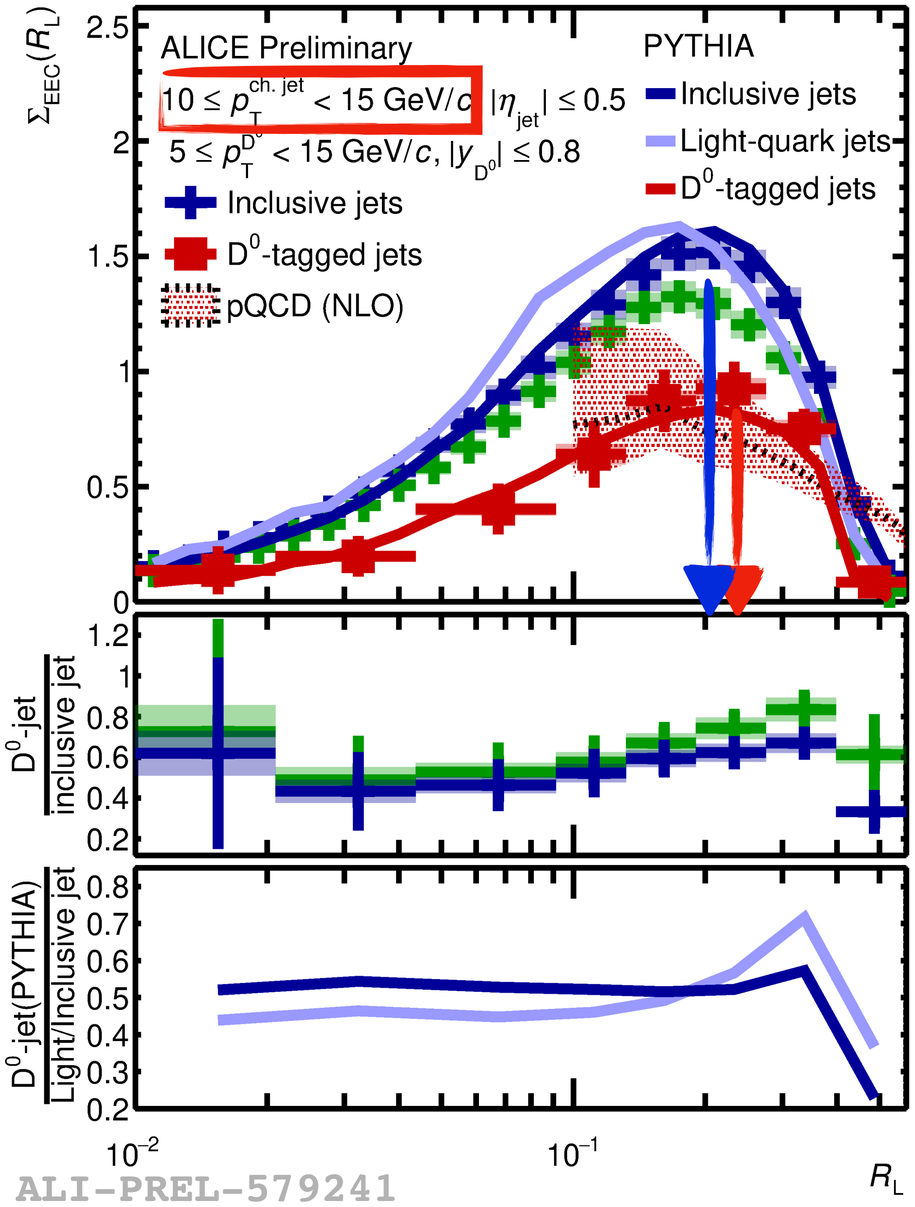

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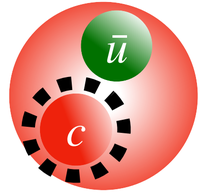

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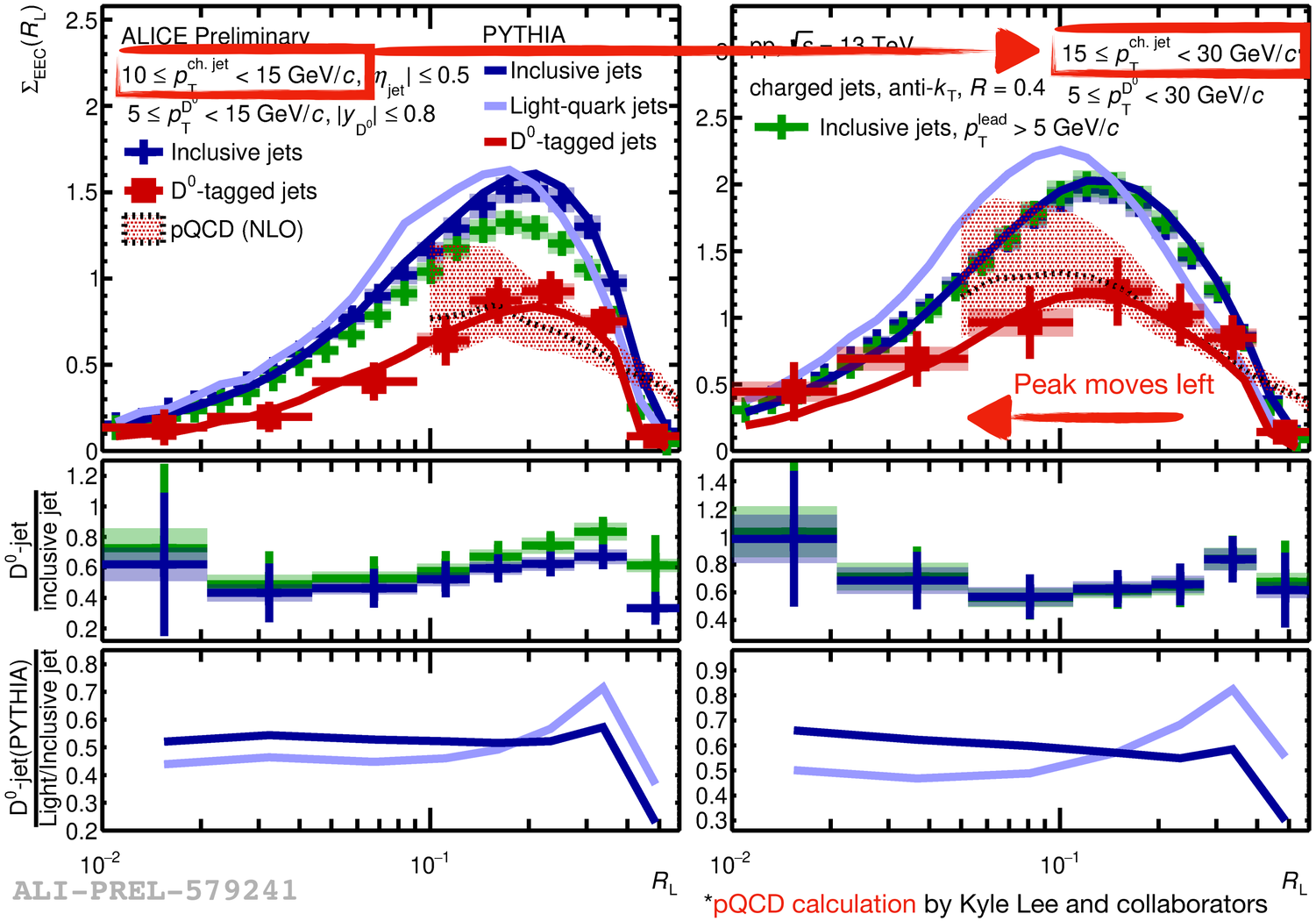

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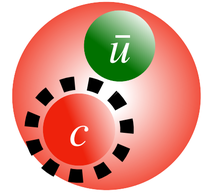

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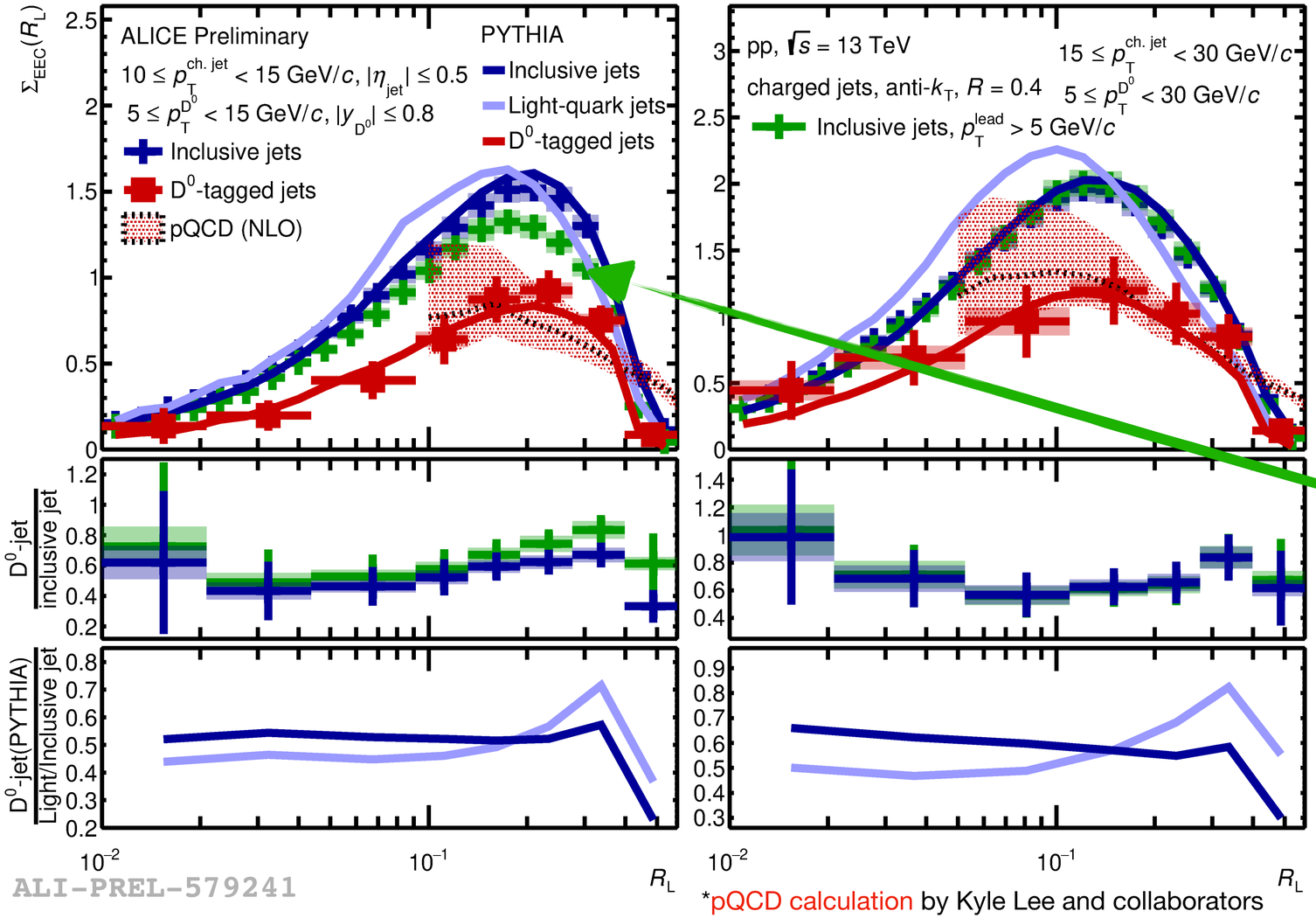

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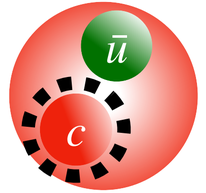

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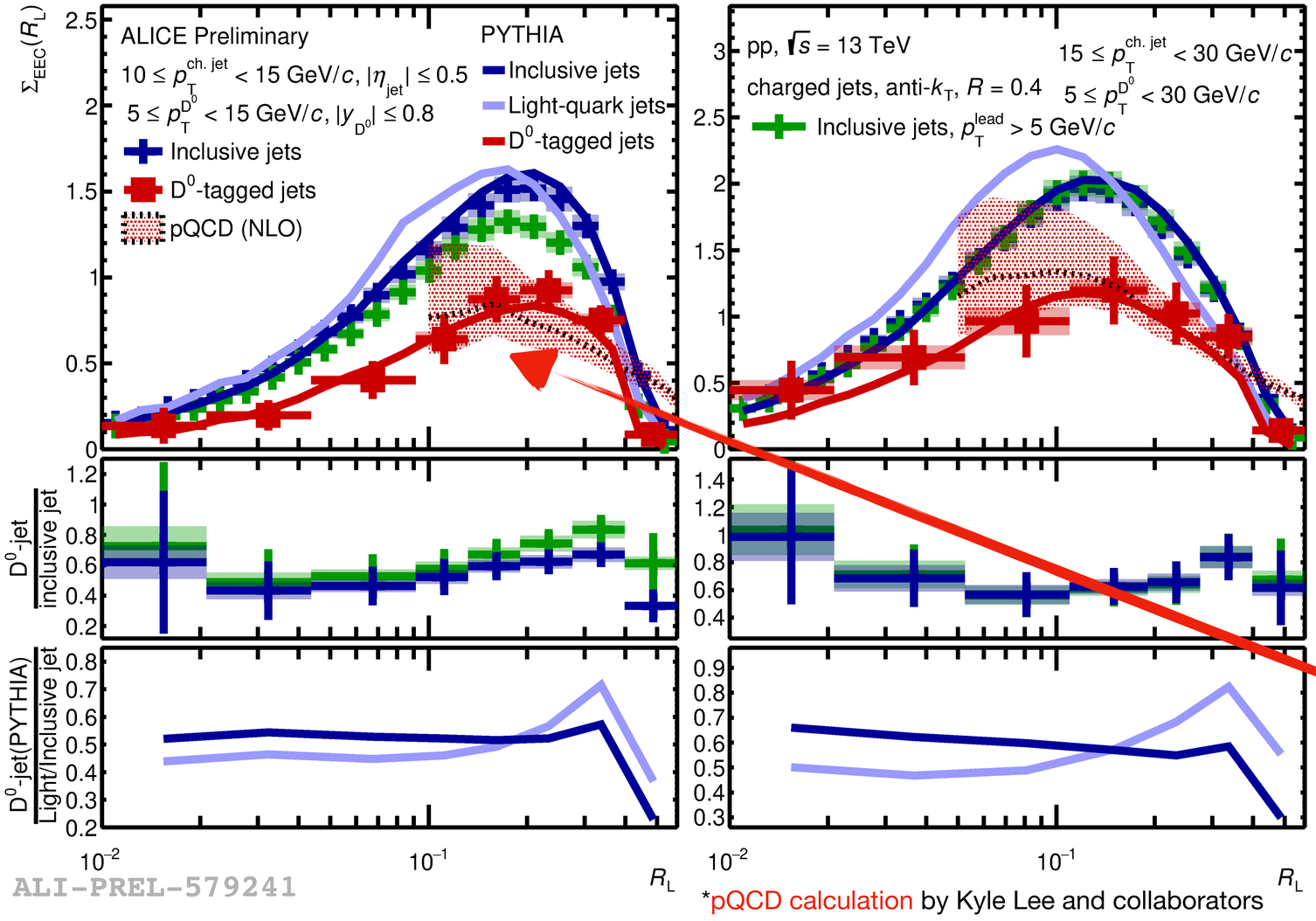

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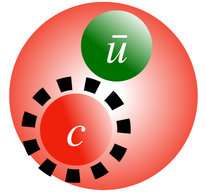

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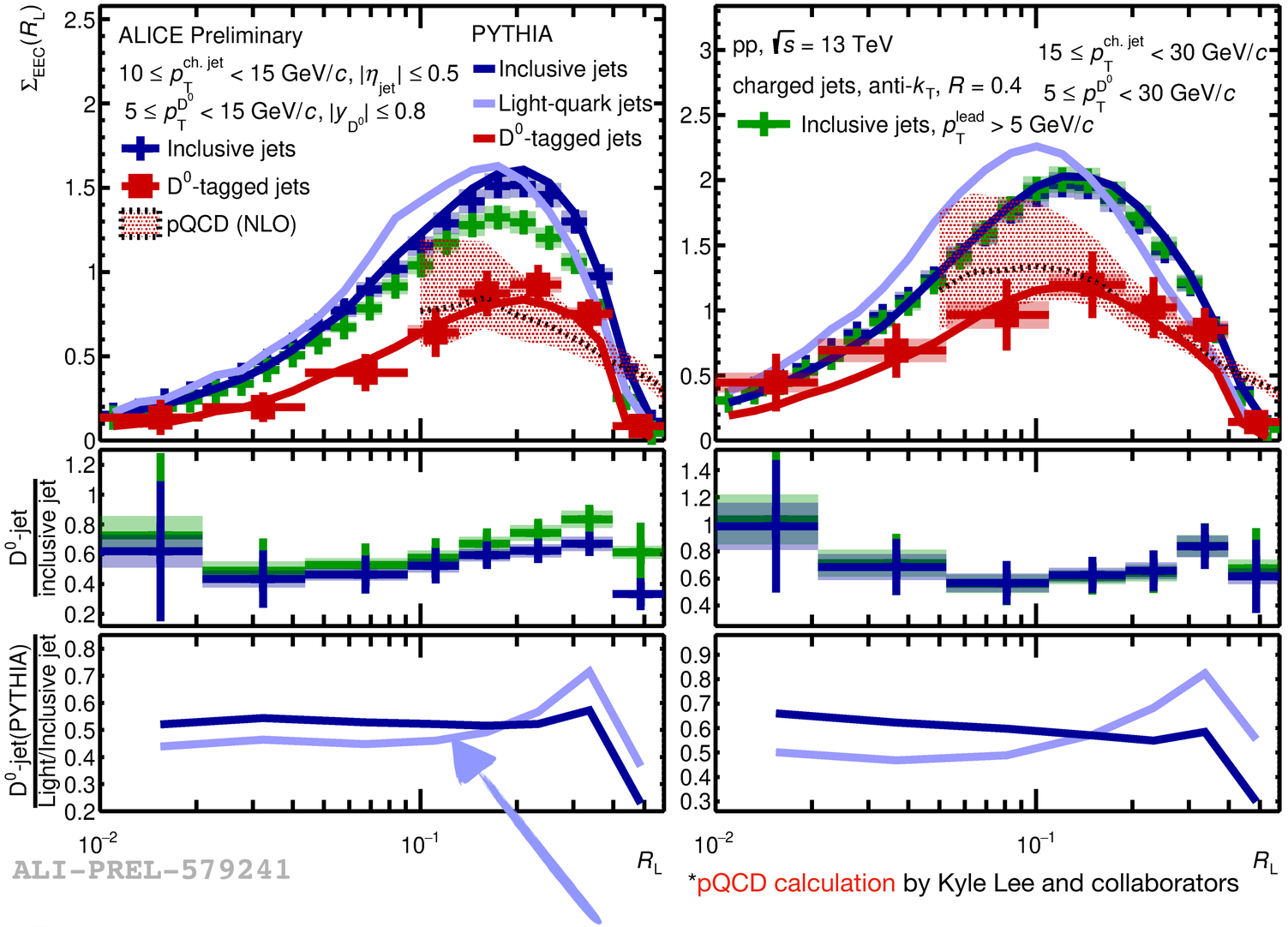

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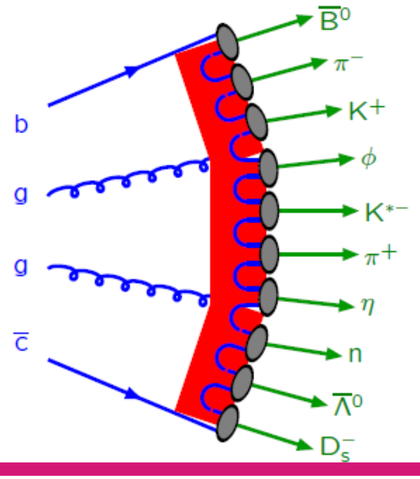
Sensitivity to hadronization vs. parton shower

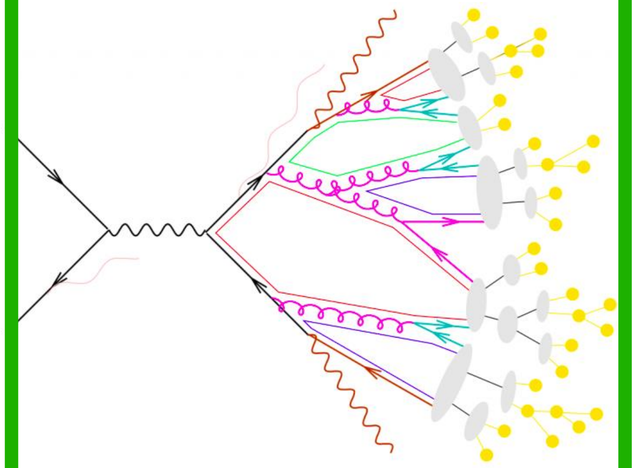
Lund string hadronization



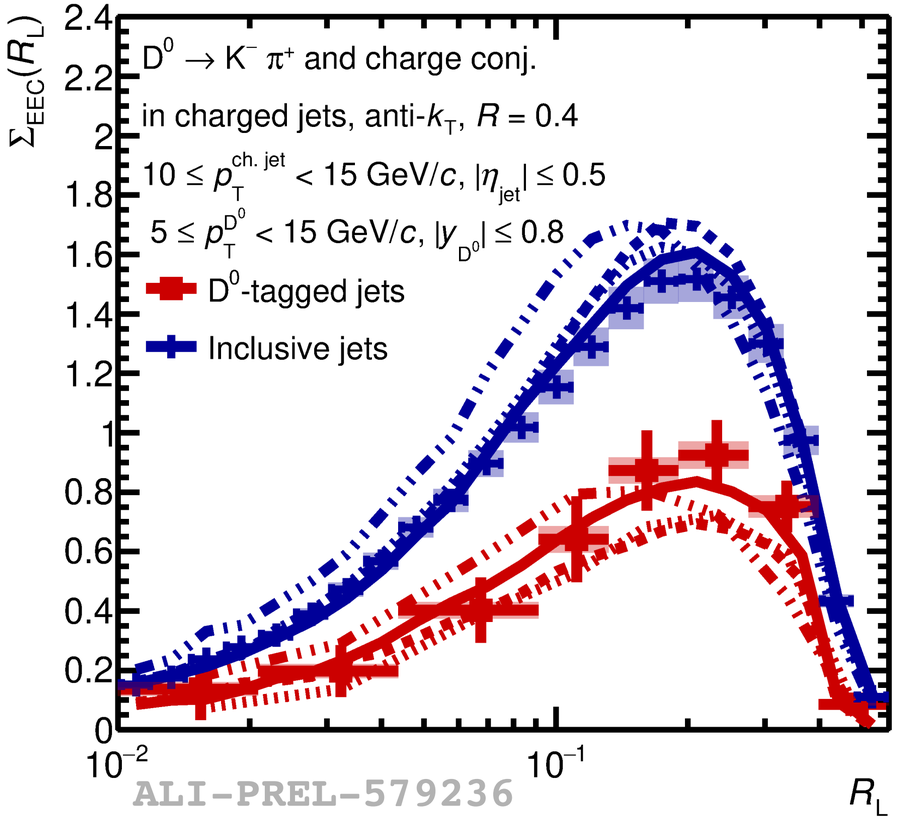
PYTHIA and
SHERPA LUND

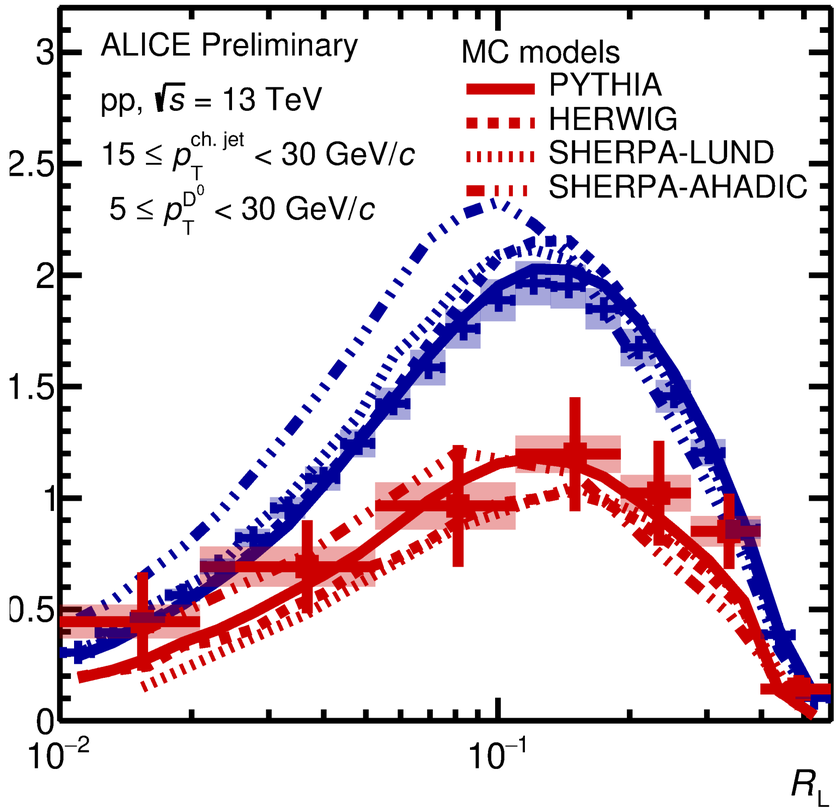
HERWIG
and
SHERPA AHADIC

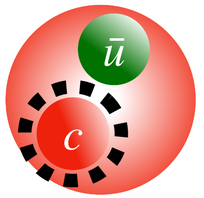
Cluster hadronization



Sensitivity to hadronization vs. parton shower







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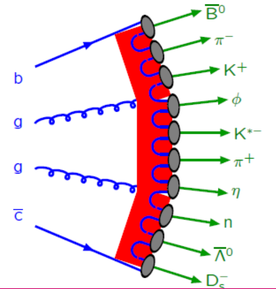
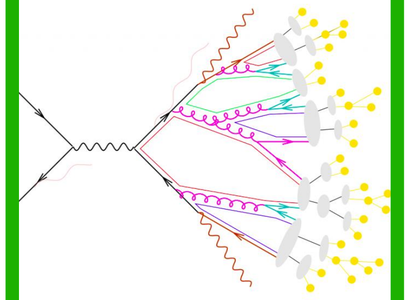
Lund string hadronization



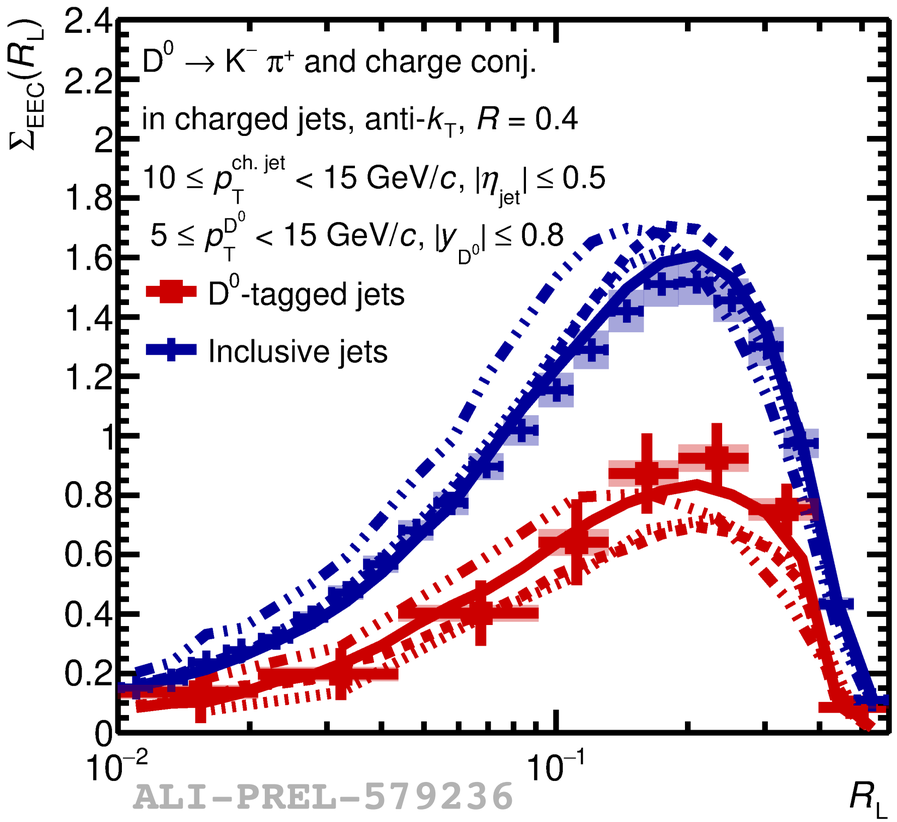
PYTHIA and SHERPA LUND

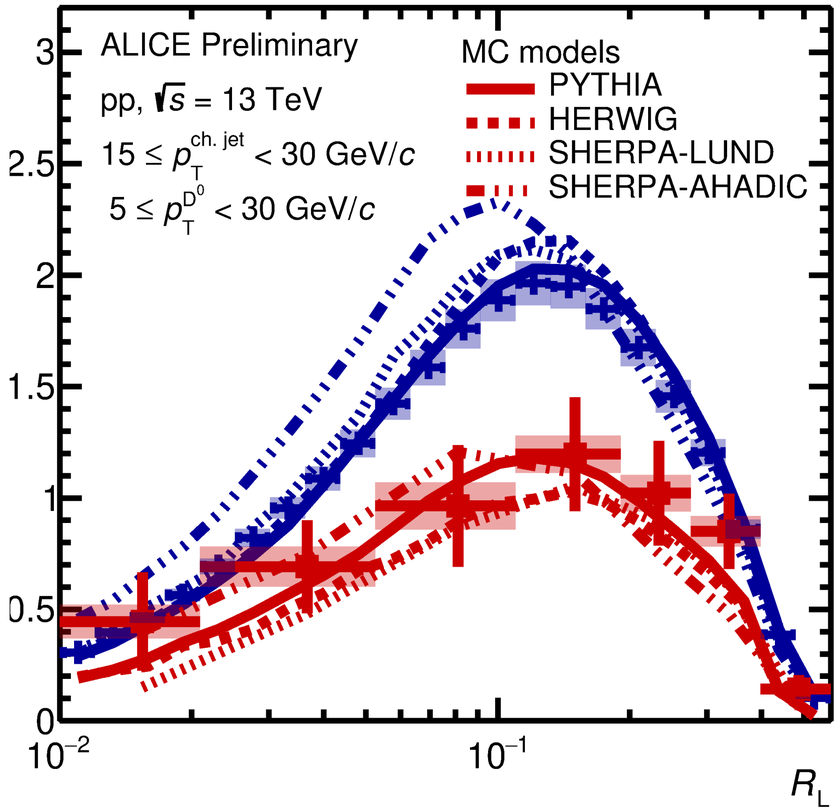
HERWIG and SHERPA AHADIC

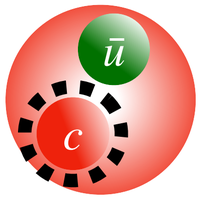
Cluster hadronization



Sensitivity to hadronization vs. parton shower







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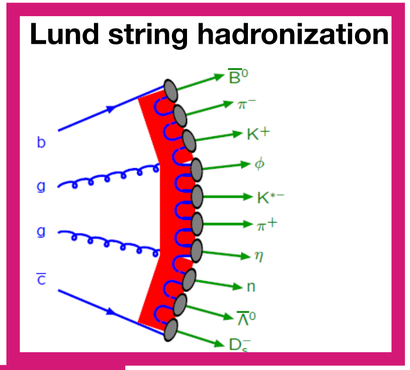
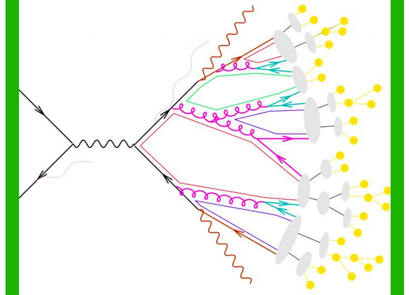


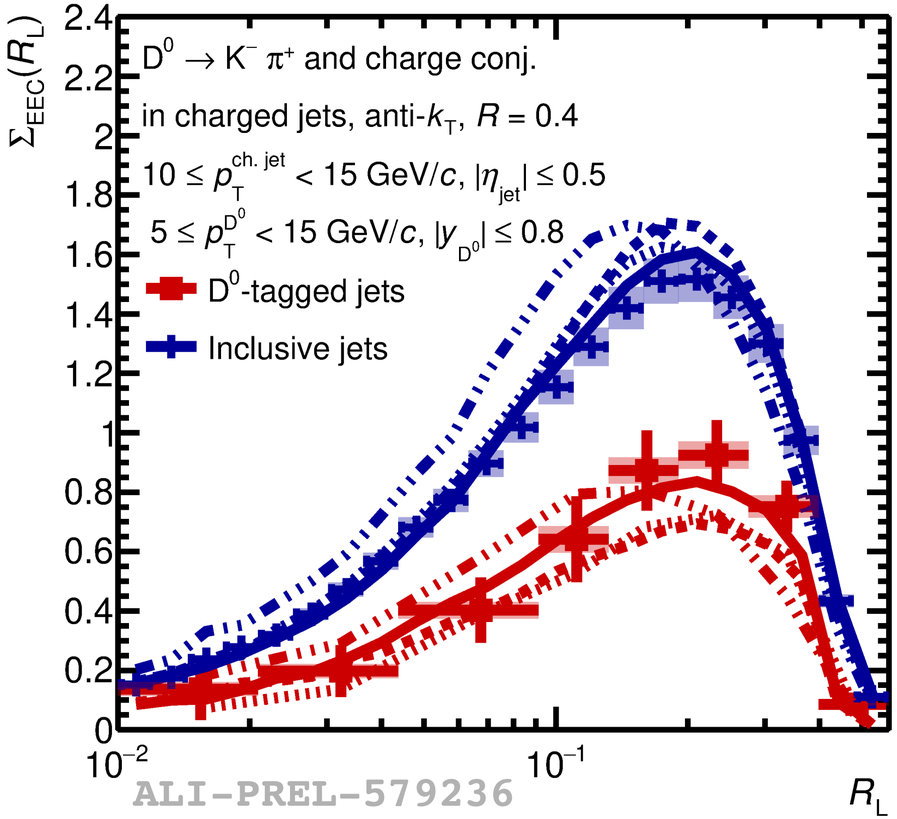
PYTHIA and SHERPA LUND

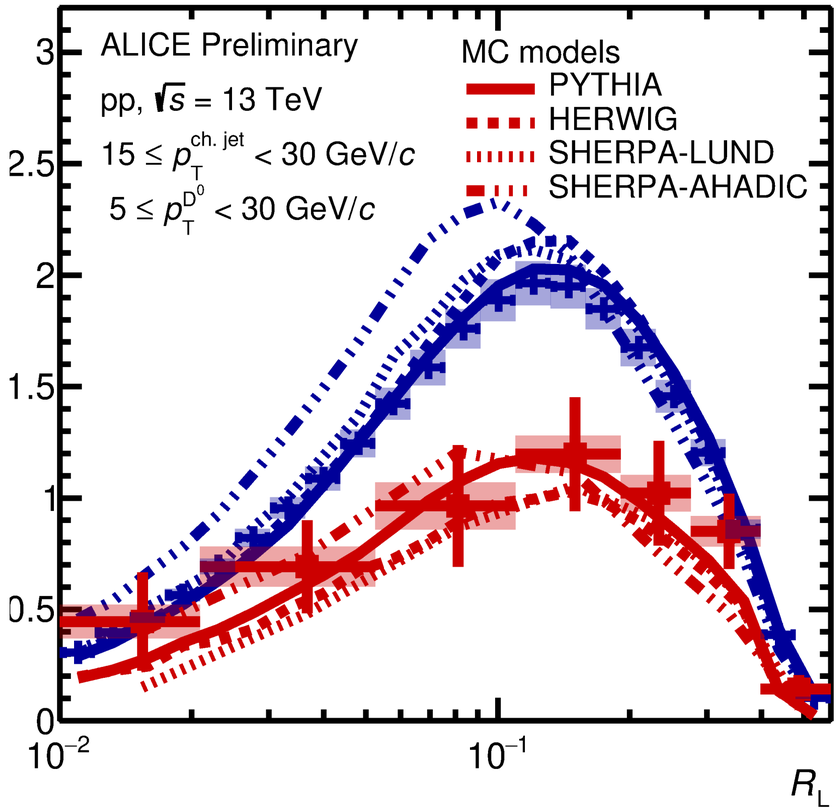
HERWIG and SHERPA AHADIC

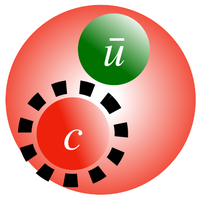


- **Lund-string** based model provides the **best description** of both EECs?

Sensitivity to hadronization vs. parton shower







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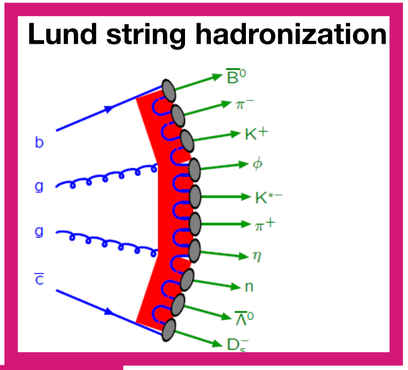
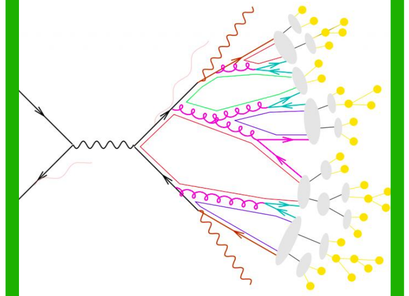


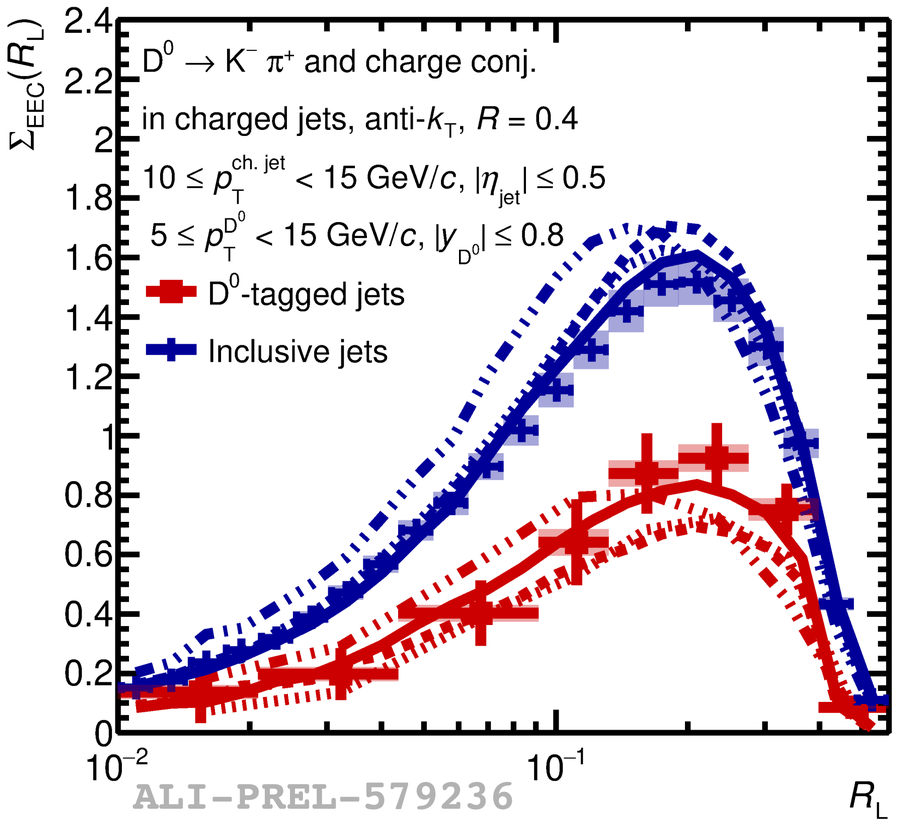
PYTHIA and SHERPA LUND

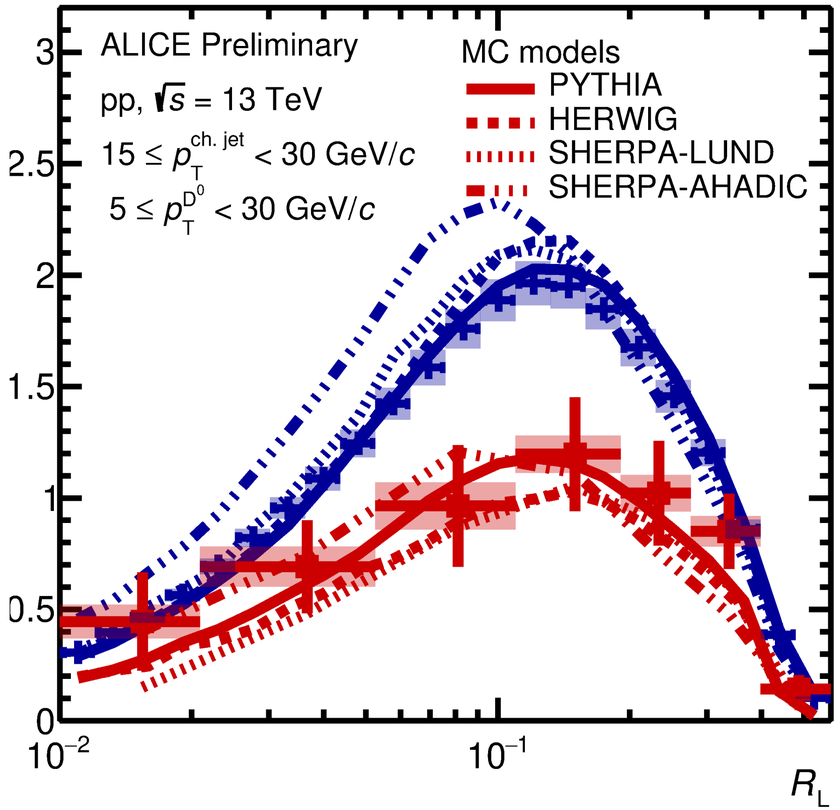
HERWIG and SHERPA AHADIC

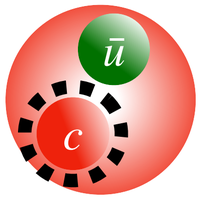


- **Lund-string** based model provides the **best description** of both EECs?
- **HERWIG:** overpredicts inclusive jets and underpredicts charm-tagged jets → Sensitivity to hadronization vs. parton shower implementations.

Sensitivity to hadronization vs. parton shower







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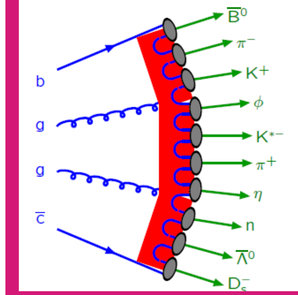
Lund string hadronization



PYTHIA and
SHERPA
LUND

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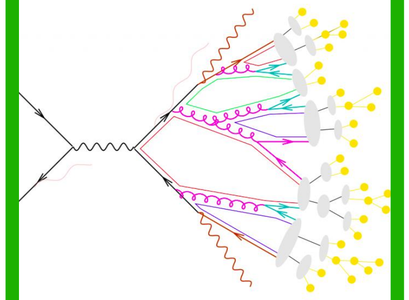
Cluster hadronization



- **Lund-string** based model provides the **best description** of both EECs?
- **HERWIG:** overpredicts inclusive jets and underpredicts charm-tagged jets → Sensitivity to hadronization vs. parton shower implementations.
- **SHERPA AHADIC**: predicts peak at lower R_L for both EECs →suggests later hadronization compared to other models.

Thank you

ありがとうございます