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ALICE measurements sensitive to the underlying event and hadronization

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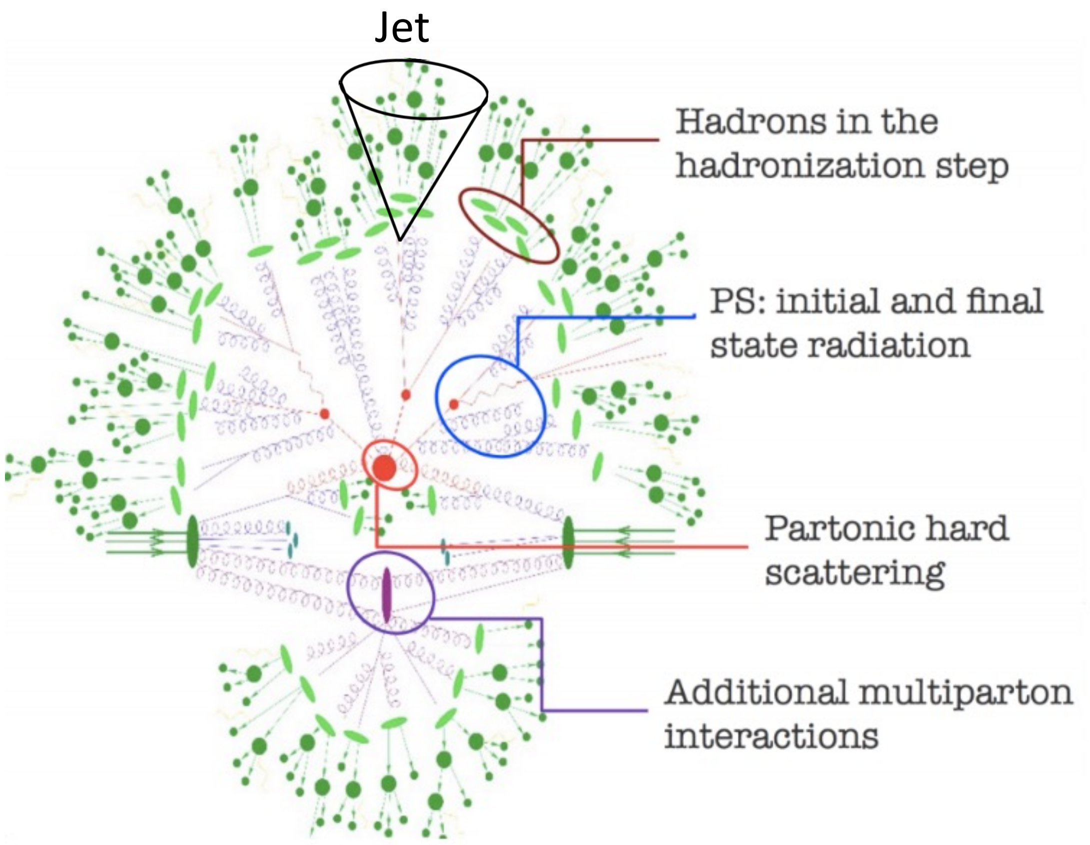
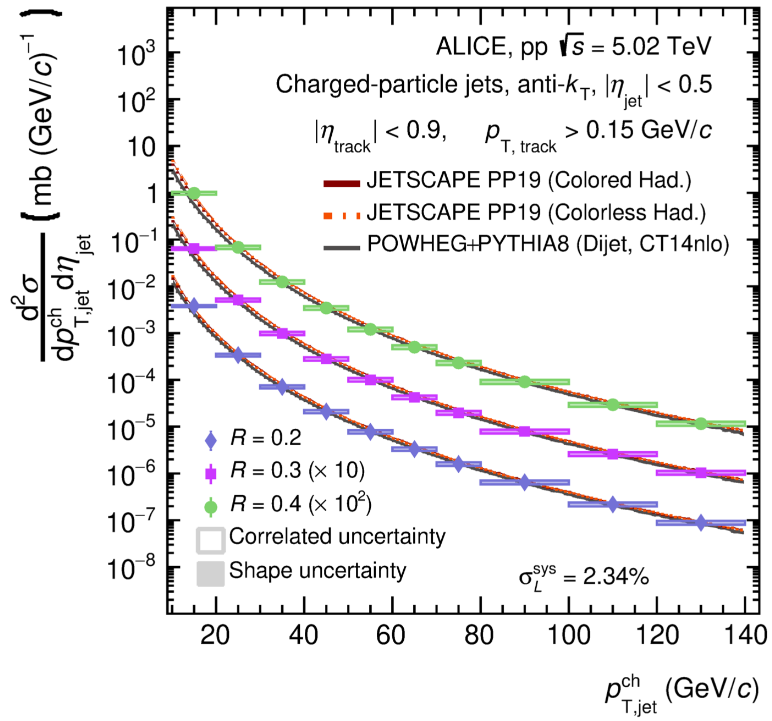
Introduction

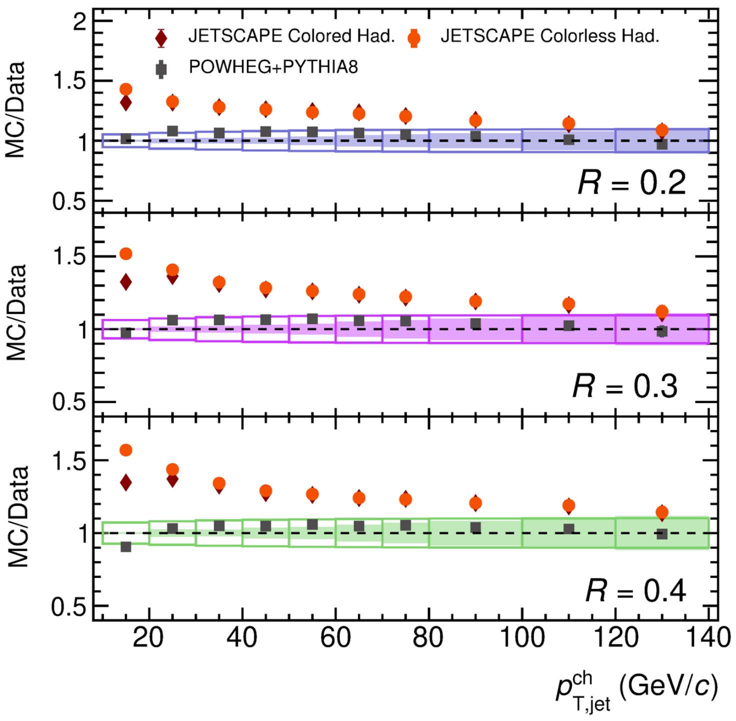
- High energy collisions involve several processes: hard process, parton shower, confinement, and hadronization
- Collimated spray of hadrons produced from the fragmentation and hadronization is called a jet
- Jets are well-calibrated probe – described by the pQCD calculations
- Jets can be affected by NP effects: hadronization, underlying event, and MPIs
- This talk: jet observables sensitive to UE and hadronization



Inclusive charged-particle jet production in pp collisions

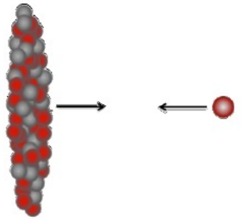
arXiv:2307.10860





- Important test for pQCD calculations
- Baseline for heavy-ion studies
- JETSCAPE overestimates data at low pT
  - The presence of NP effects: such as ISR, soft particle production, and MPIs
- NLO prediction with POWHEG+PYTHIA8 agree with data within uncertainties
- NLO term is important for jet production

Inclusive charged-particle jet production in p-Pb collisions



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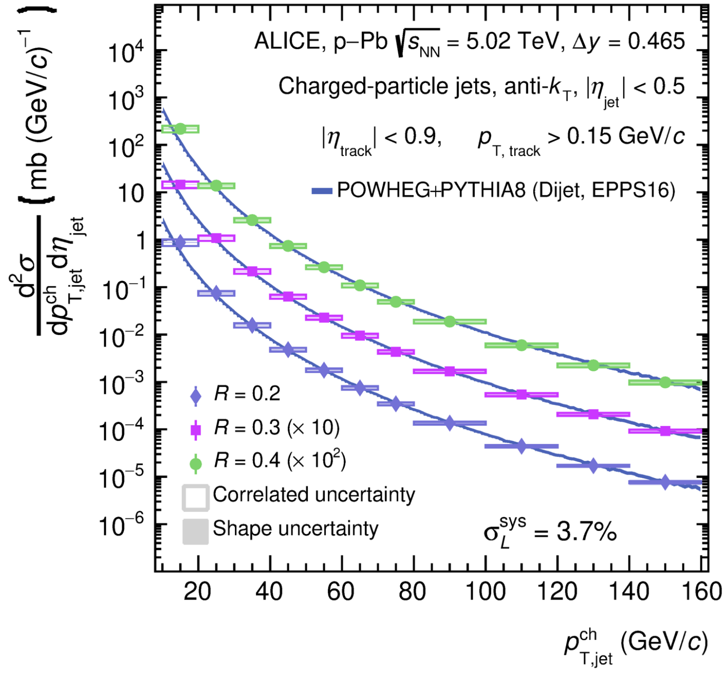
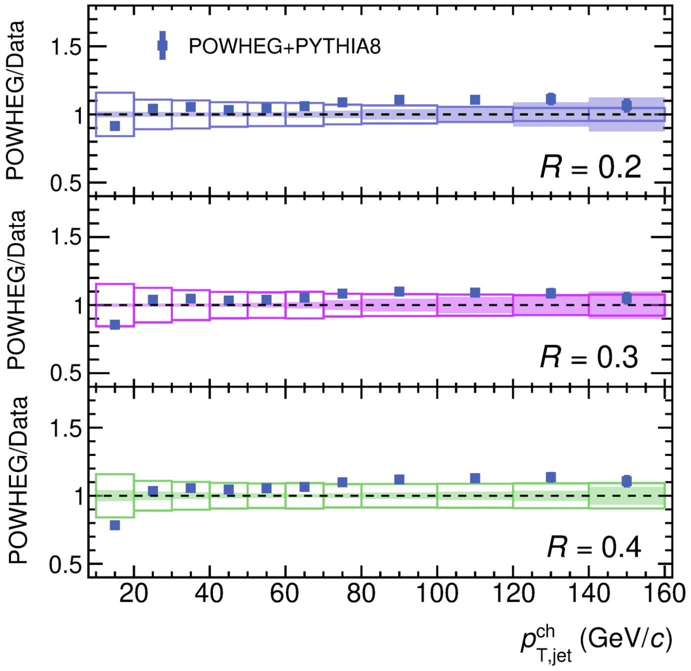
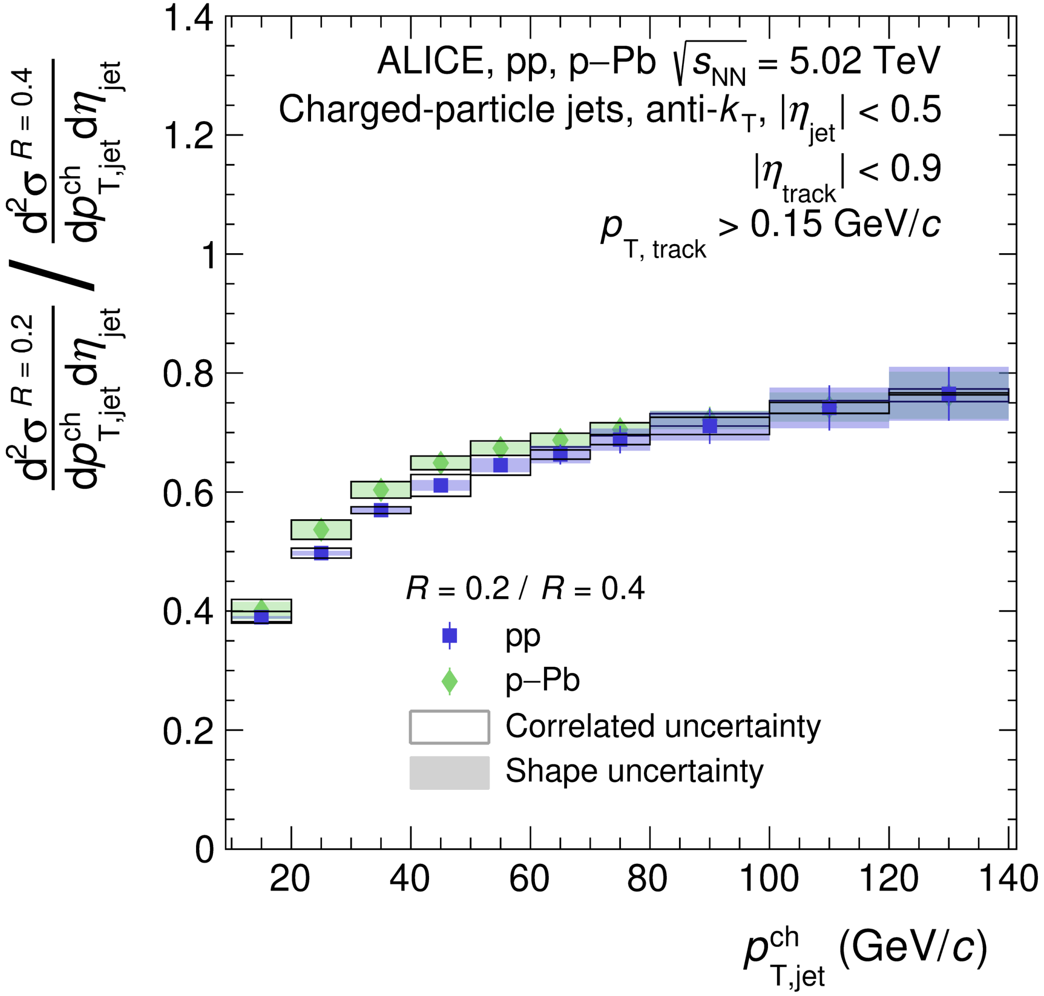


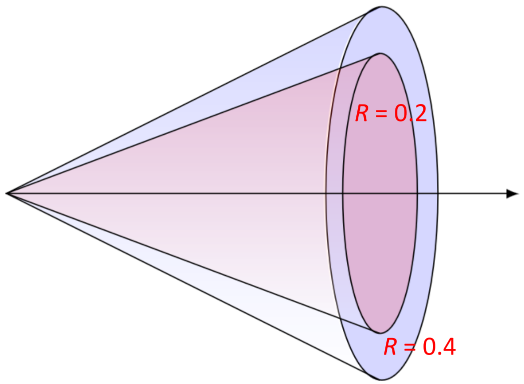


- Study of cold nuclear matter effects
- Shed light on collectivity-like effects
- Potential constrain of nPDF
- Reference for Pb–Pb collision
- NLO prediction with POWHEG+PYTHIA8 agree with data within uncertainties

Inclusive charged-particle jet cross section ratio

arXiv:2307.10860



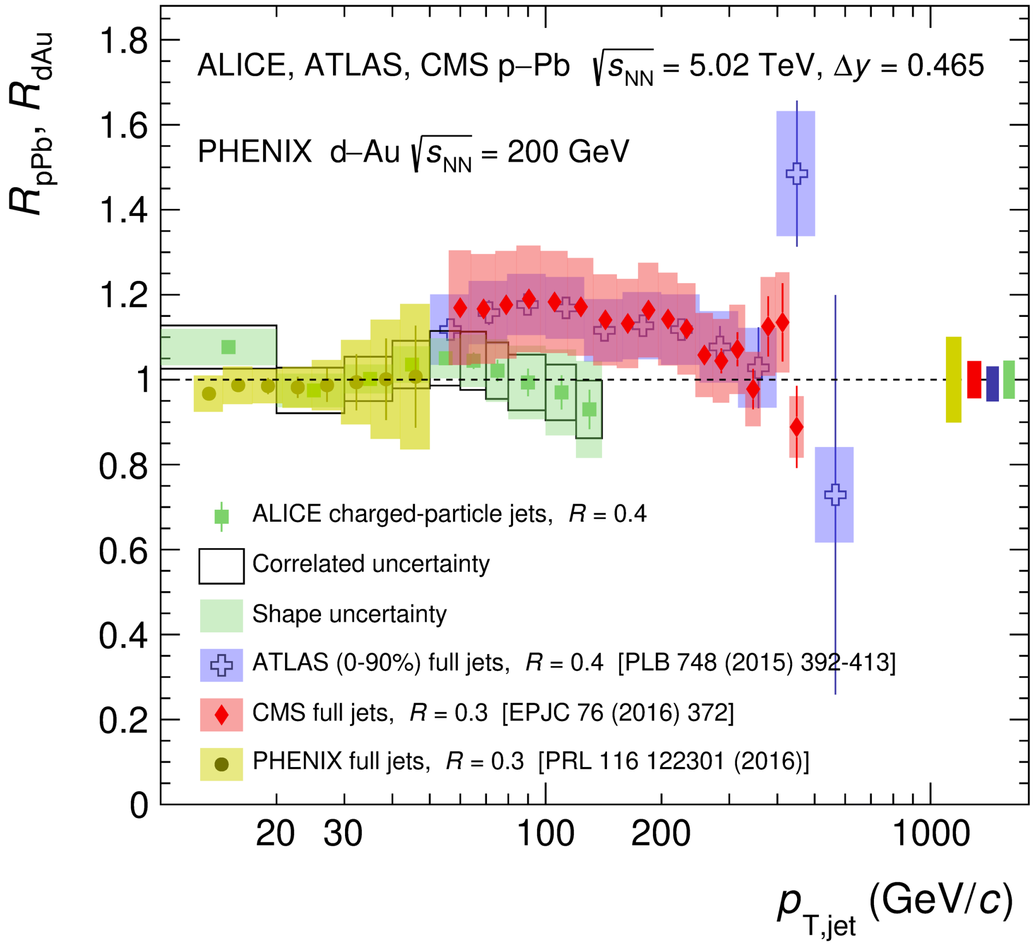


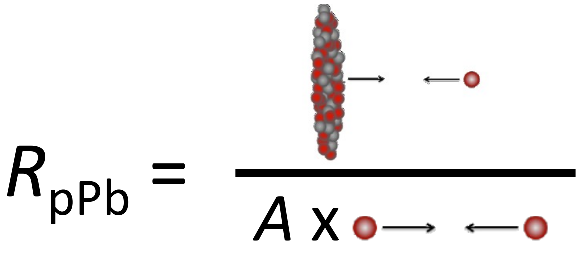
$\sigma_{R=0.2}/\sigma_{R=0.4}$

- Probe the internal structure of jet
- Ratios allow for uncertainties cancellation
- Sensitive to fragmentation and Hadronization
- p–Pb consistent with pp within uncertainties
- Fragmentation patterns constant across collision systems
- Jets become more collimated at high p_T

Inclusive charged-particle nuclear modifaction factor

arXiv:2307.10860





- Can we separate cold nuclear matter effects from those of a strongly interacting medium?
- Jet R_{pPb} is consistent with unity; no significant nuclear matter effects on jet production
- Jet quenching, if present, is below the sensitivity of the current measurement
- Consistent with measurements from ATLAS, CMS, and PHENIX with different acceptance and/or collisions energies

Energy-energy correlators

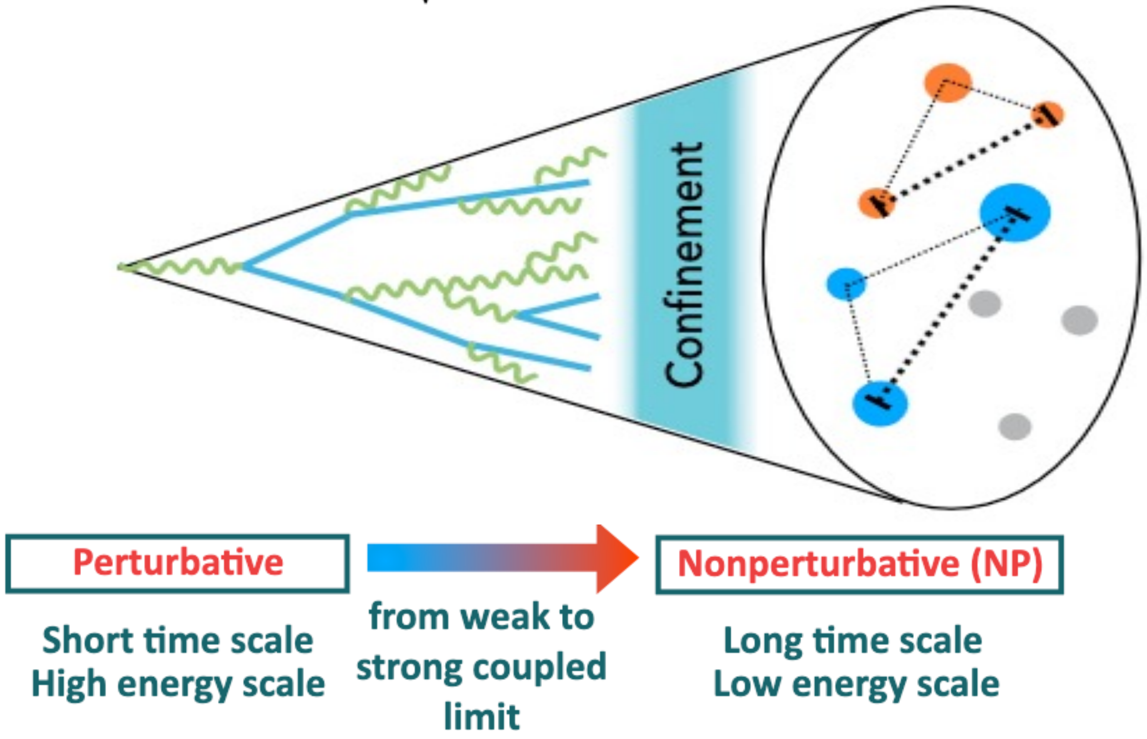
$$\frac{d\sigma_{\mathrm{EEC}}}{dR_{\mathrm{L}}} = \sum_{i,j} \int d\sigma(R'_{\mathrm{L}}) \frac{p_{\mathrm{T},i}\, p_{\mathrm{T},j}}{p_{\mathrm{T,jet}}^2} \delta(R'_{\mathrm{L}} - R_{\mathrm{L},ij})$$

Energy weight

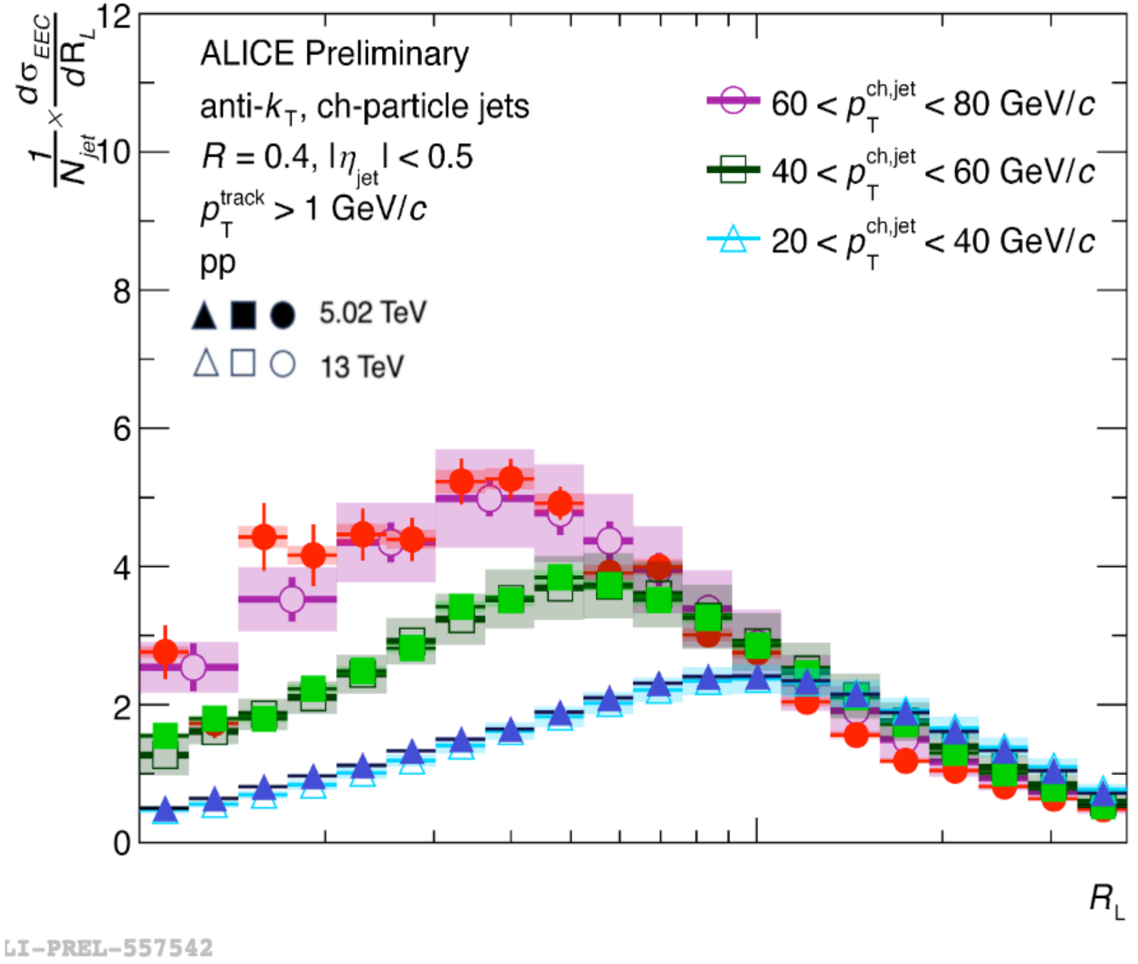
$$R_{\mathrm{L}} = \sqrt{\Delta\varphi_{ij}^2 + \Delta\eta_{ij}^2}$$

W. Fan QM23

- Probe hadronization scale
- MPI and UE suppressed by the energy weight
- Can be compared to pQCD calculation
- EEC (R_{L}) corresponds to
  - at small R_{L}: free hadrons
  - at large R_{L} : perturbative quark and gluon interactions
  - At mid R_{L} : $R_{\mathrm{L}} \propto \frac{\Lambda_{\mathrm{QCD}}}{p_{\mathrm{T}}^{\mathrm{jet}}}$



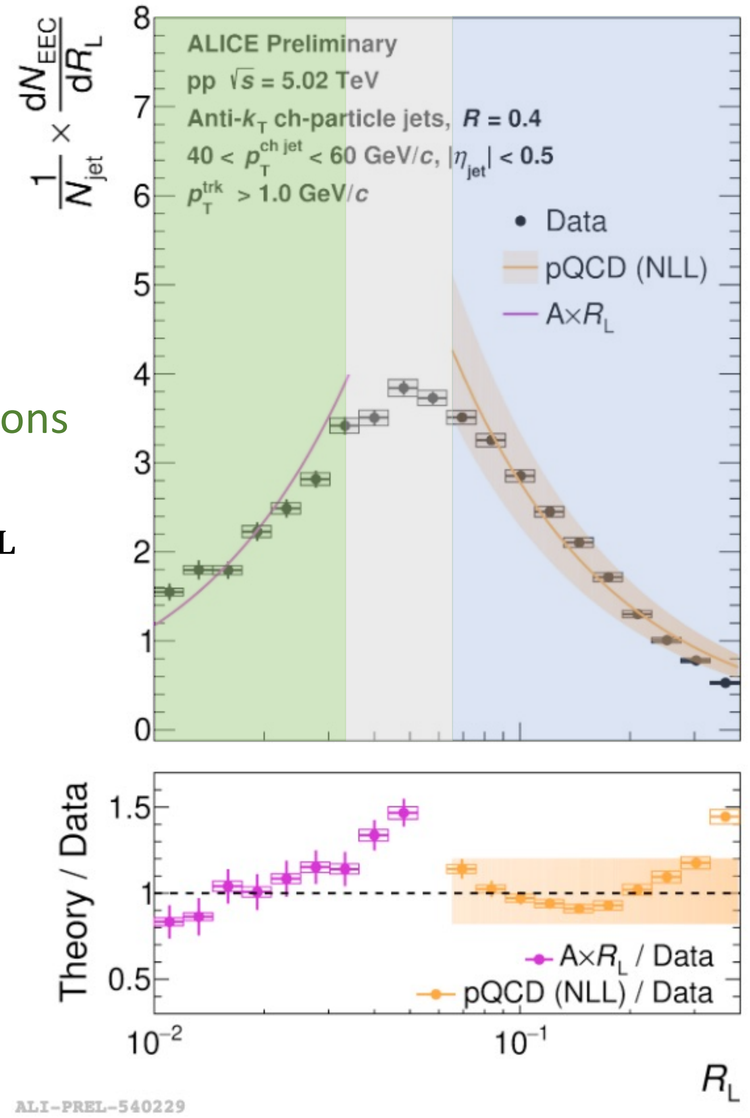
Energy-energy correlators



- EEC measured in pp collisions at $\sqrt{s} = 5.02$ and 13 TeV
- No significant collision energy dependence observed
- Different scaling behavior observed in the perturbative (large R_L) and NP region (small R_L)
- Transition position shifts to lower R_L for higher jet p_T range

Measure QCD hadronization scale

Transition



Free hadrons

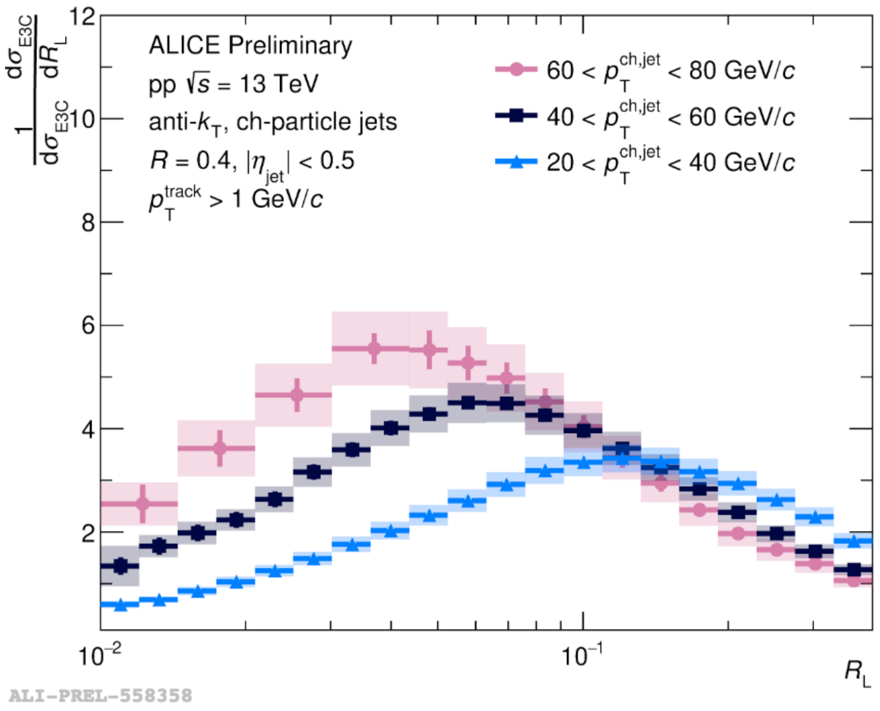
$$\frac{d\sigma}{dR_L} \propto R_L$$

Quarks/gluons

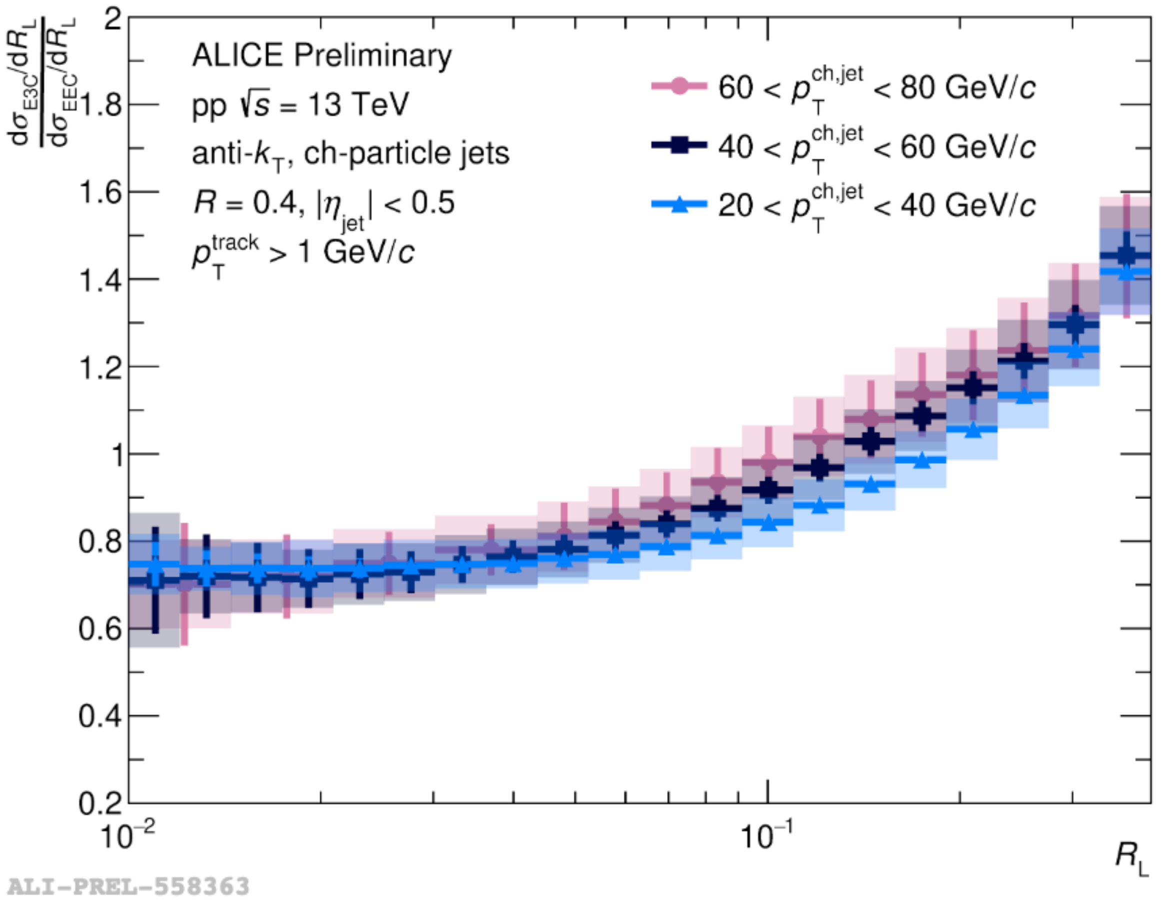
pQCD scaling deviates near transition region – increasing NP effects

Three-point energy correlator

- E3C measured in pp collisions at $\sqrt{s} = 13$ TeV
- Probe higher order QCD dynamics: $1 \rightarrow 3$
- Separation of NP and perturbative scaling behavior also observed in E3C



E3C/EEC ratio

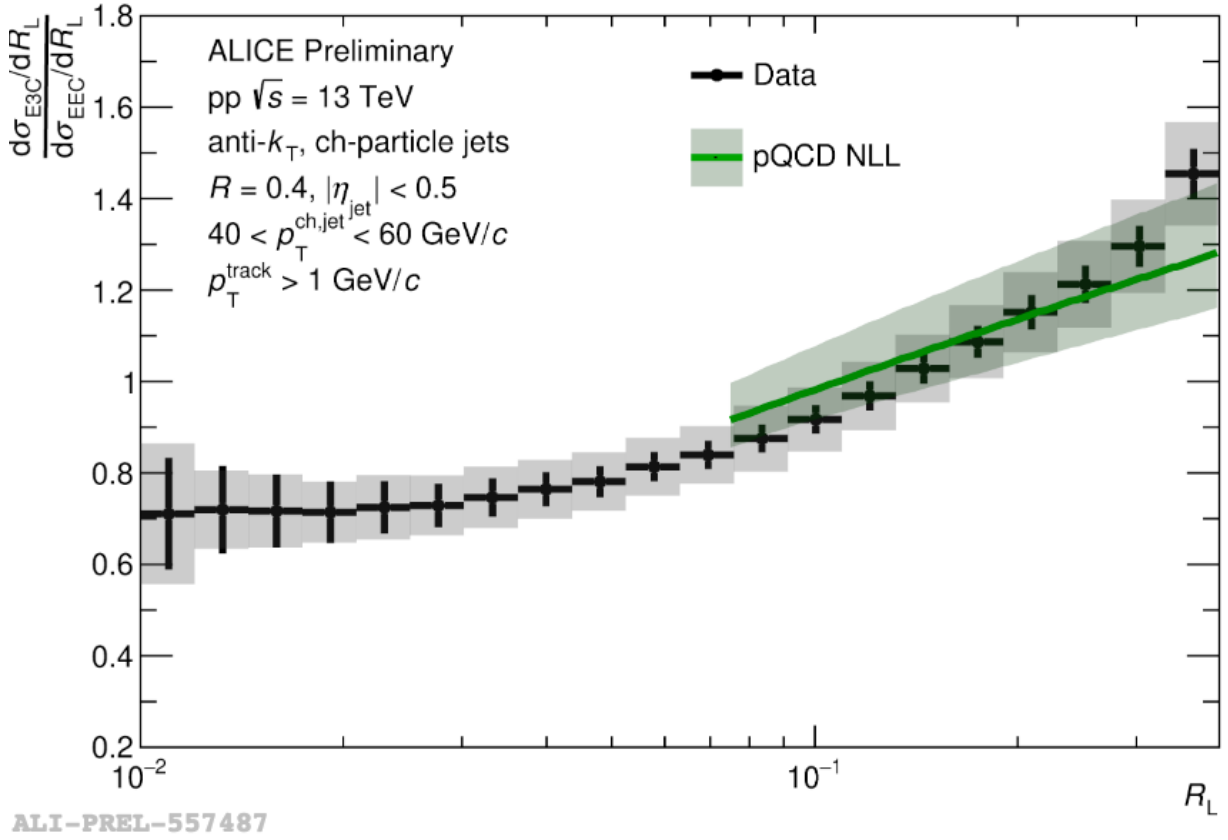


Small R_L : free hadrons

Large R_L: sensitive to α_s

- Isolate perturbative scaling behavior
- Extraction of α_s from jet substructure
- E3C/EEC $\propto \alpha_s(Q)\ln R_L + \mathcal{O}(\alpha_s^2)$
- High precision calculation: most uncertainties cancel out

E3C/EEC ratio

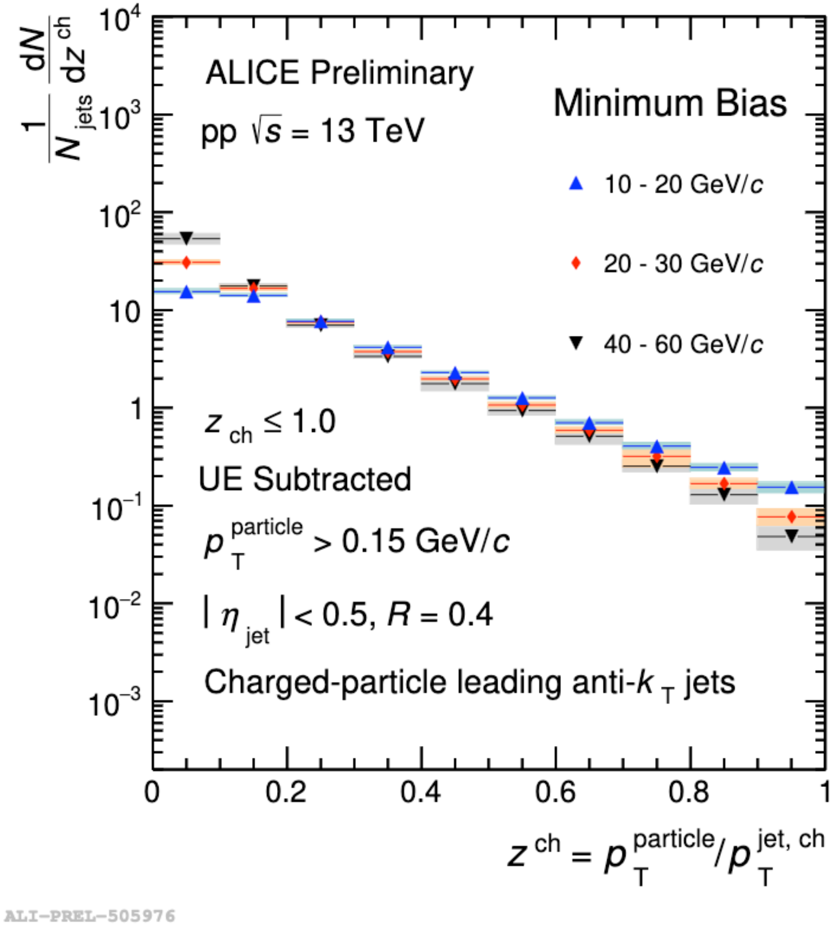


- Isolate perturbative scaling behavior
- Extraction of α_s from jet substructure
- E3C/EEC $\propto \alpha_s(Q)\ln R_\mathrm{L} + \mathcal{O}(\alpha_s^2)$
- High precision calculation: most uncertainties cancel out
- Good agreement with pQCD calculations

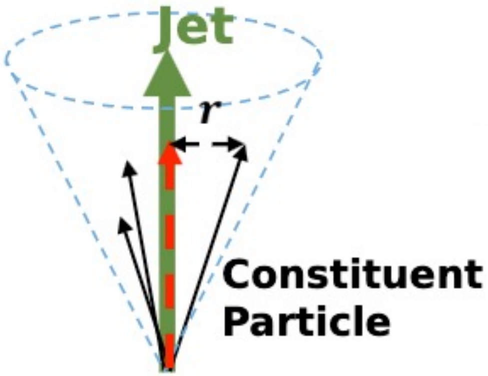
Small R_L : free hadrons

Large R_L: sensitive to α_s

Fragmentation function in MB and HM

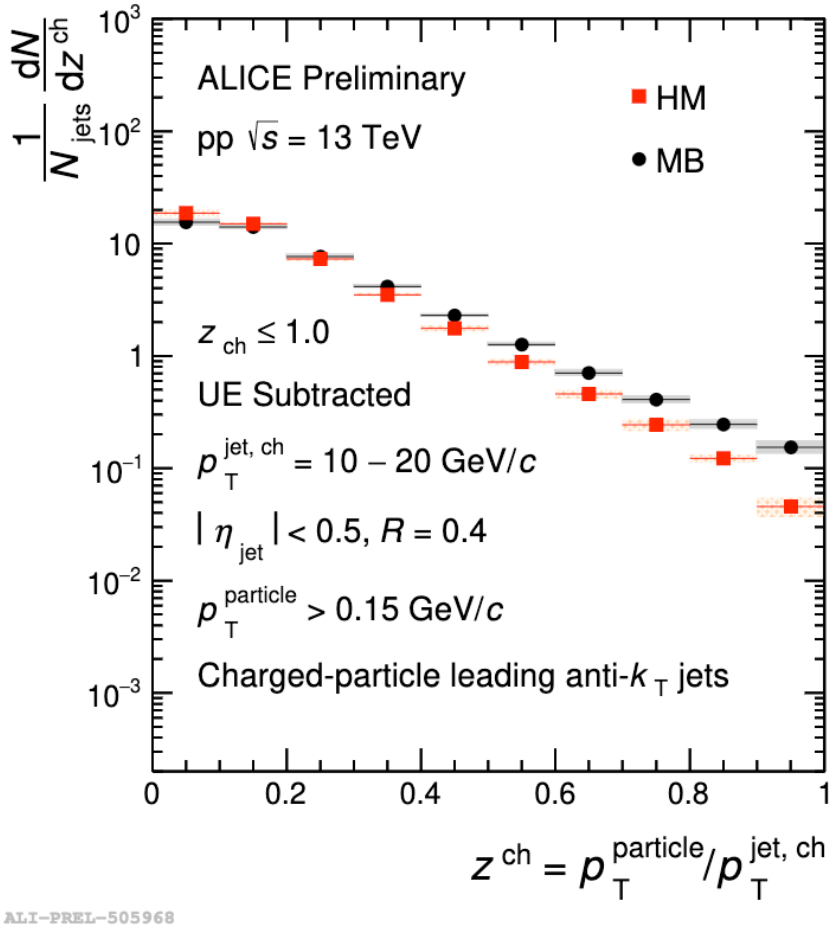


$$z^{\mathrm{ch}} = \frac{p_{\mathrm{T}}^{\mathrm{track}}}{p_{\mathrm{T}}^{\mathrm{ch\,jet}}}$$

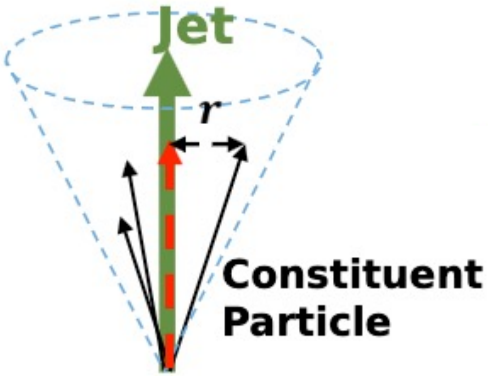


- Scaling of z^{ch} with the leading charged-particle jet p_{T}
- Consistent in different p_{T} intervals
  - Probability of jet constituents having a given fraction of jet p_{T} is independent of total jet p_{T} in this kinematic range

Fragmentation function in MB and HM



$$z^{ch} = \frac{p_T^{track}}{p_T^{ch\,jet}}$$

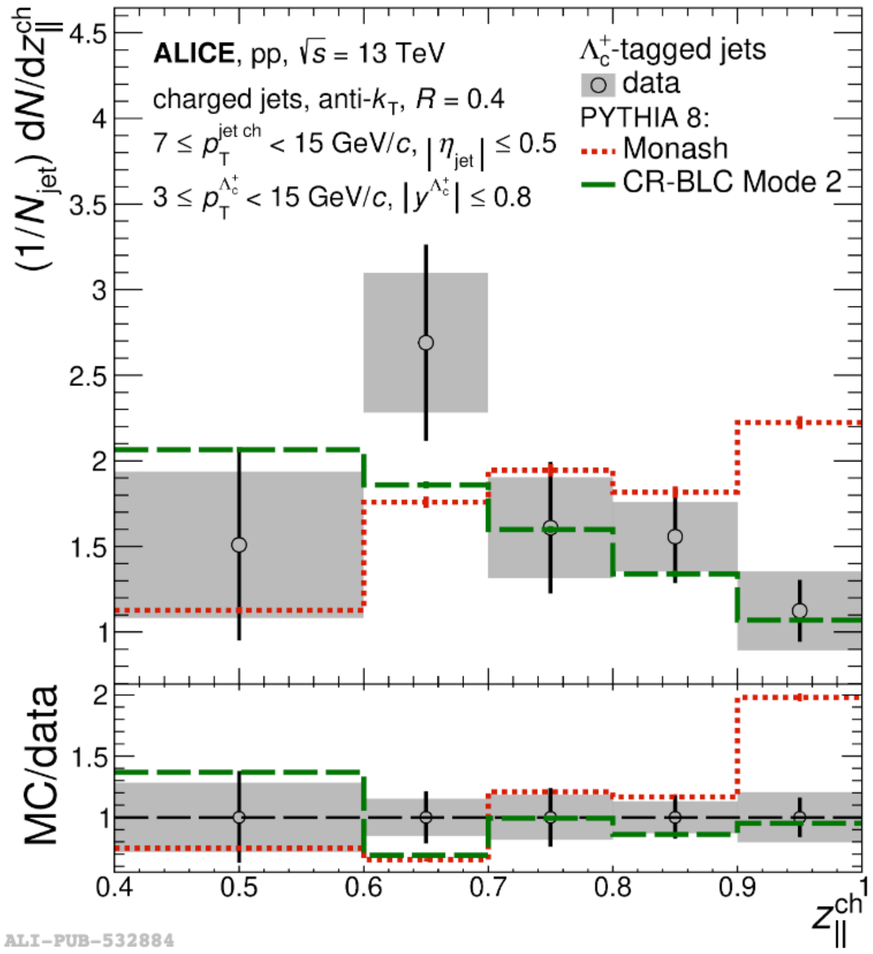


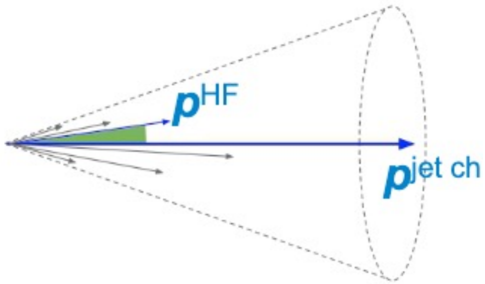
- z^{ch} distributions show softening of jets in HM
- More interactions between the jet and partons

Λ_c-baryon and D^0-meson fragmentation

Λ_c in jet

arXiv:2301.13798



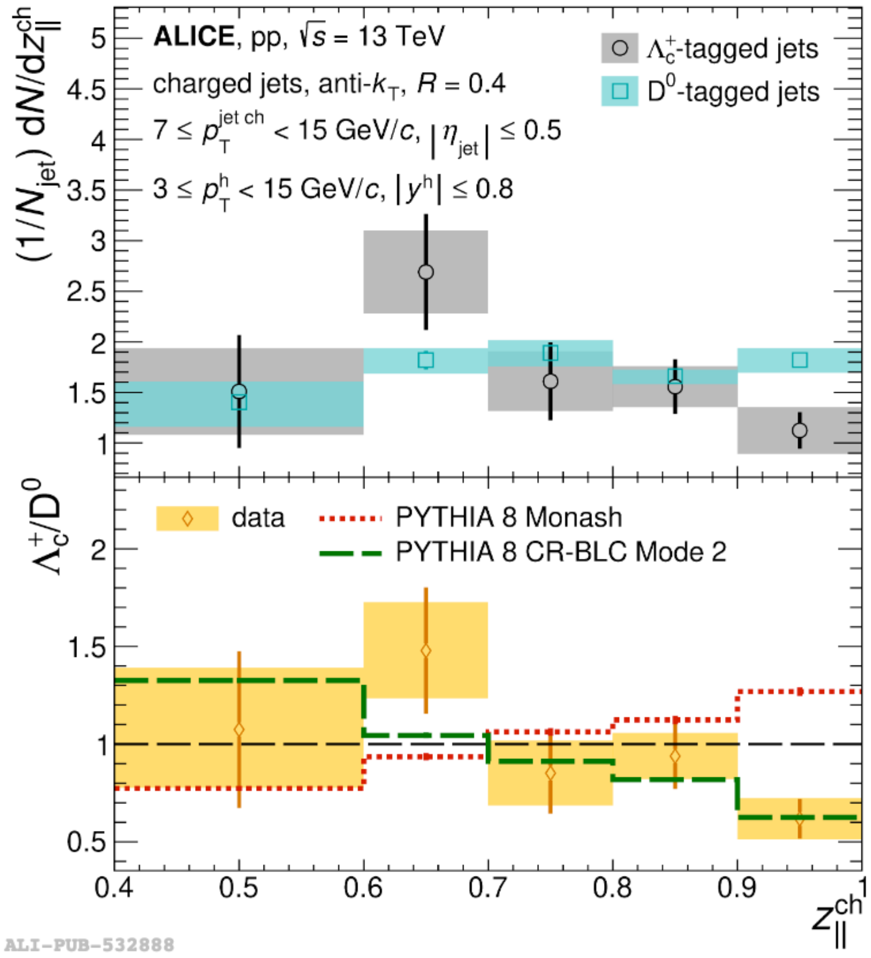


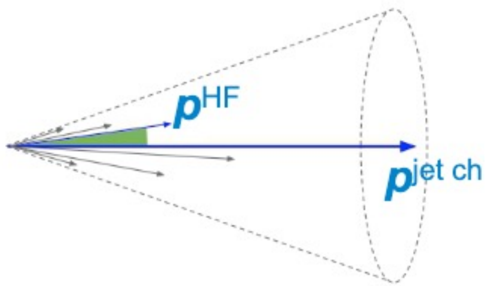
$$z_{\parallel}^{\mathrm{ch}} = \frac{\boldsymbol{p}^{\text{jet ch}} \cdot \boldsymbol{p}^{\text{HF}}}{\boldsymbol{p}^{\text{jet ch}} \cdot \boldsymbol{p}^{\text{jet ch}}}$$

- Heavy quarks are formed in initial hard scatterings
- Measurement in jets can provide more differential insights into hadronization mechanisms
- Different hadron species - images of the quark composition
- Parallel momentum fraction
- Flavor-dependent production and fragmentation
- Test of fragmentation models: mesons vs. baryons
- Best agreement with data: Pythia 8 SoftQCD with enhanced color reconnection.

Λ_c-baryon and D^0-meson fragmentation

Λ_c vs. D^0 in jet   arXiv:2301.13798





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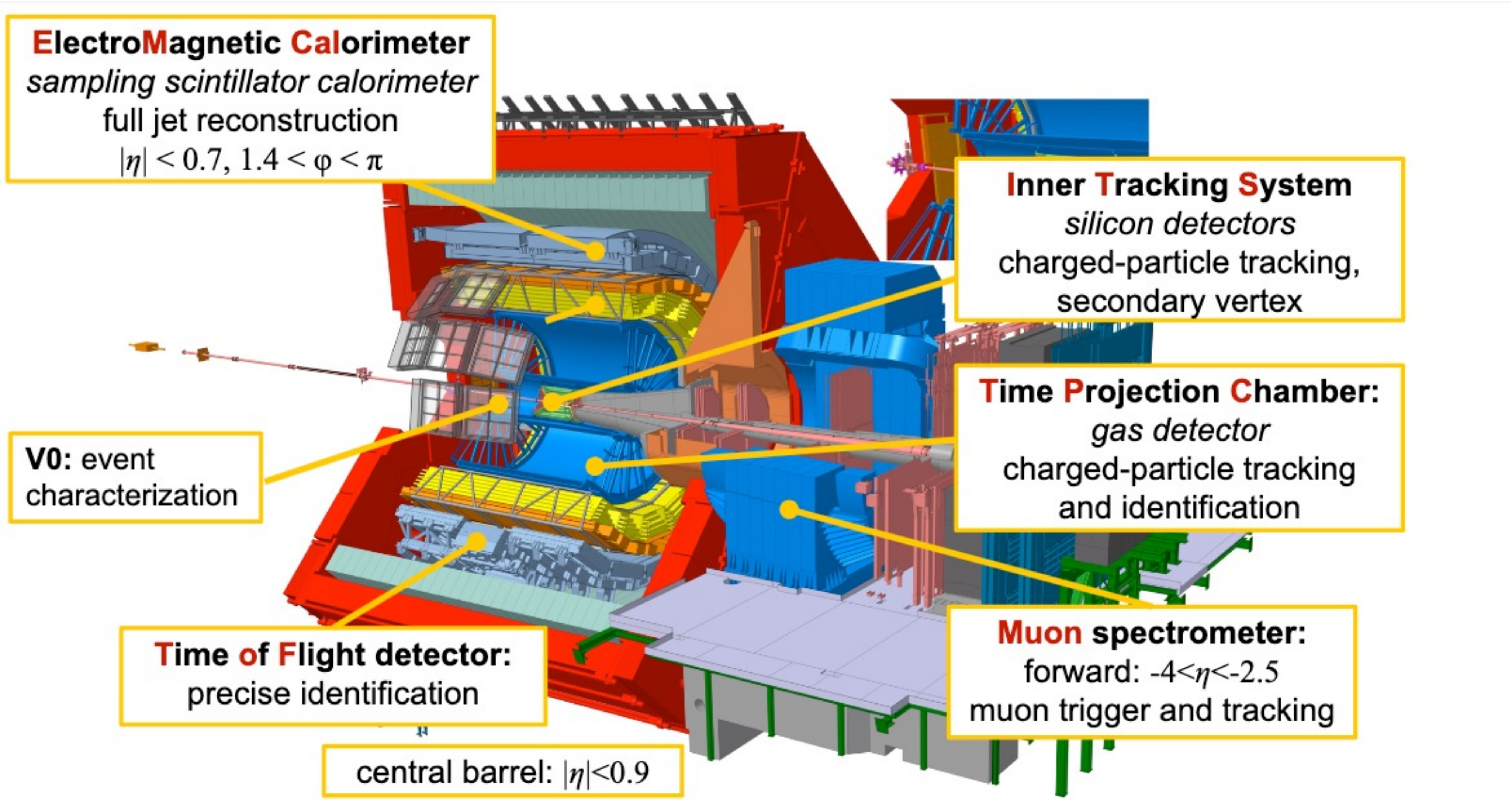
- Heavy quarks are formed in initial hard scatterings
- Measurement in jets can provide more differential insights into hadronization mechanisms
- Different hadron species - images of the quark composition
- Parallel momentum fraction
- Flavor-dependent production and fragmentation
- Test of fragmentation models: mesons vs. baryons
- Best agreement with data: Pythia 8 SoftQCD with enhanced color reconnection.
- Indication of softer fragmentation of $c \rightarrow \Lambda_c$ than $c \rightarrow D^0$

Summary

- ALICE Collaboration has measured several jet observables sensitive to the UE and hadronization
  - ✓Inclusive jet production in small systems
  - ✓Energy-energy correlators
  - ✓Jet fragmentation function
- Jet is an indispensable tool
  - ✓ Stay tune for more exciting results from the Run 3 data!

Extra slides

ALICE detector



Determination of EA in ALICE

Online data triggers based on V0 detectors:

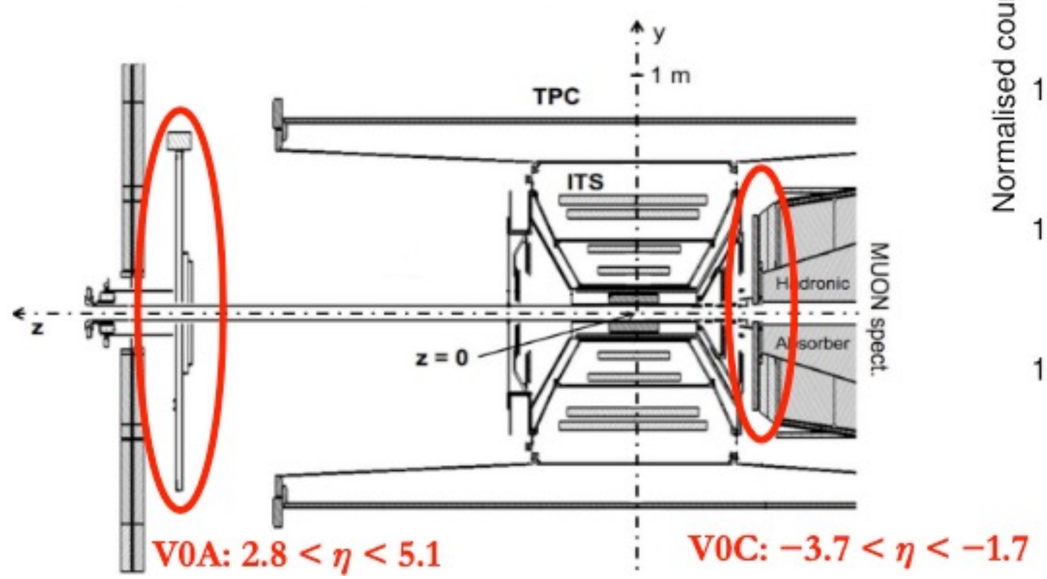
- Minimum-bias (MB) trigger $\rightarrow L_{Int} \approx 32\ nb^{-1}$
- High-multiplicity (HM) trigger $\rightarrow L_{Int} \approx 10^4\ nb^{-1}$

Offline event activity (EA) selection:

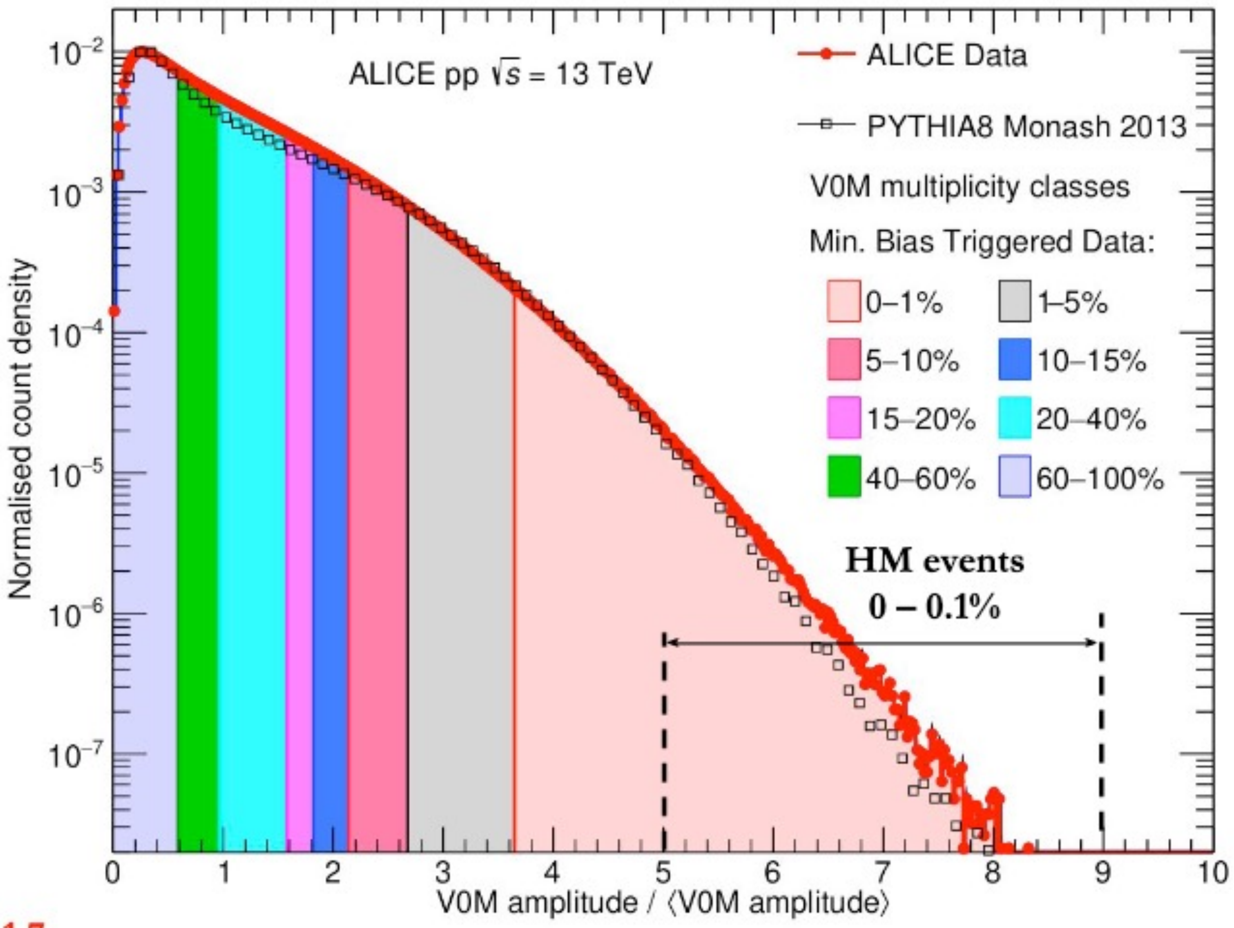
V0M = V0A + V0C → sum of signals

Characterization of EA in terms of V0M/⟨V0M⟩

⟨V0M⟩ - mean of MB distribution



ALICE, Eur.Phys.J.C 82 (2022) 6, 514

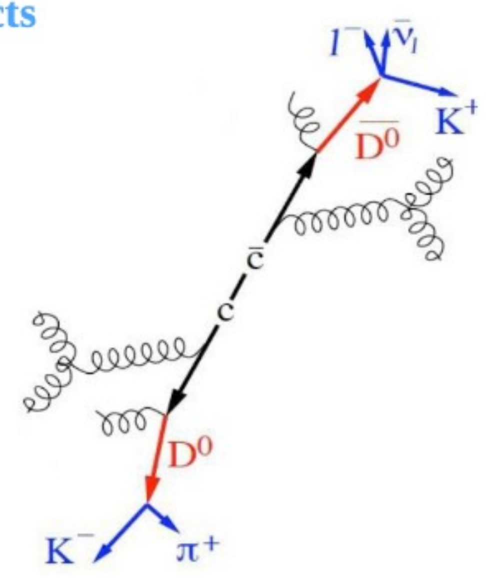


Heavy-flavor reconstruction

Identification of decay products

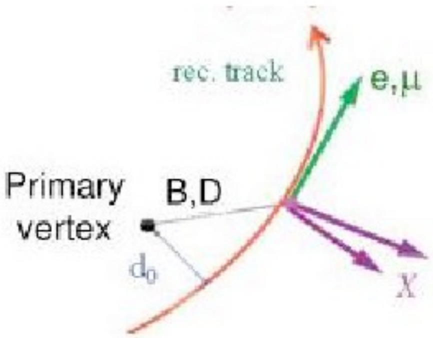
hadronic decay channel:

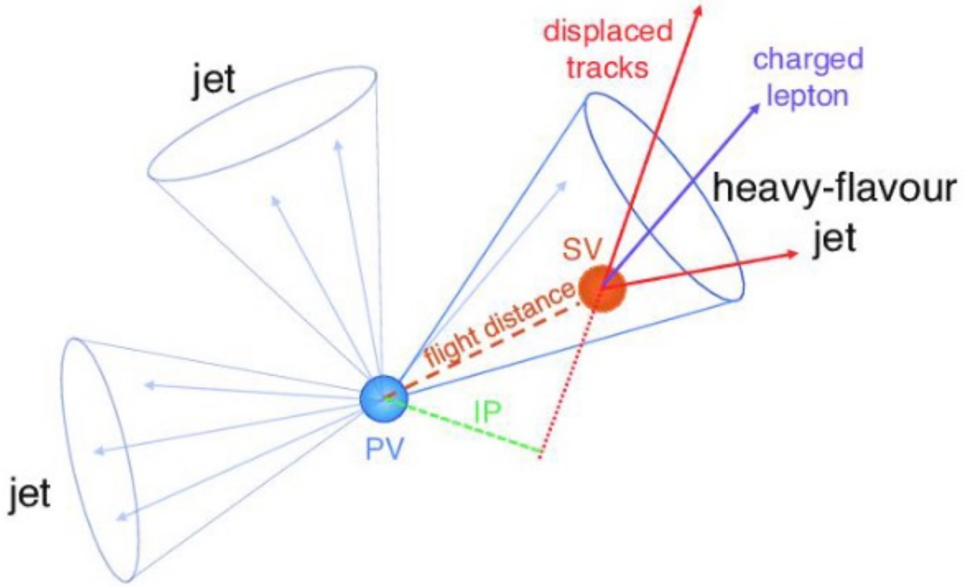
$D^0 \rightarrow K^- \pi^+$
$D^{*+} \rightarrow D^0 (\rightarrow K^- \pi^+)\pi^+$
$D^+ \rightarrow K^- \pi^+ \pi^+$
$D_S^+ \rightarrow \Phi(\rightarrow K^+ K^-)\pi^+$
$\Lambda_c^+ \rightarrow p K^- \pi^+$
$\Xi_c^0 \rightarrow \Xi^- \pi^+$
$\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+$
$\Sigma_c \rightarrow \Lambda^+_c \pi$
$\Omega_c \rightarrow \Omega^- \pi^+$



semi-leptonic decay channel:

c,b $\rightarrow \mu$
c,b $\rightarrow$ e





Finding the location of the decay (secondary vertex)