HF-jets in Heavy-ion Collisions at the LHC

R. Guernane (LPSC Grenoble CNRS/IN2P3–UGA)
on behalf of the **[ALICE-HF]** Project

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Daejeon, Korea

QCD shower flavour dependence

- **Color factors** reflect basic properties of QCD
  - Different emission properties due to the different amounts of colour charge carried by **quarks** and **gluons**

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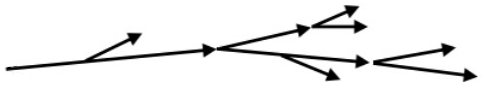
Narrower shower profile

Fewer emissions in the shower



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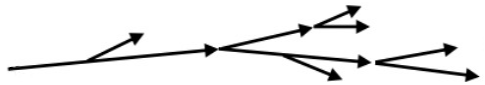
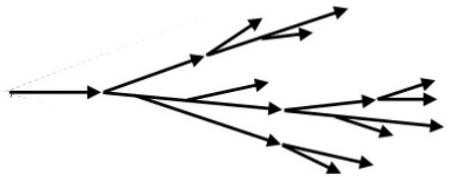


Gluon-initiated shower
Broader shower profile
Higher number of emissions



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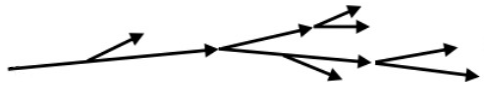

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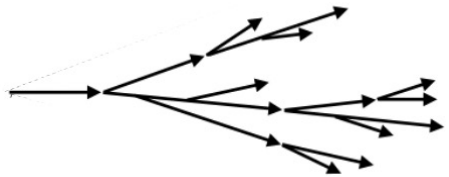

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  - So-called **“dead-cone” effect** is a fundamental feature of all gauge field theories
  - Sizeable implications for **charm** and **beauty** quarks

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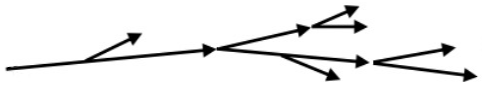

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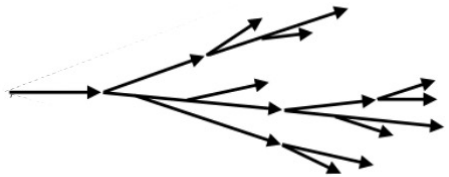

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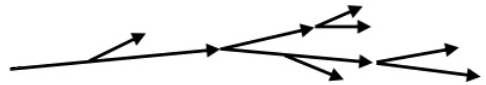

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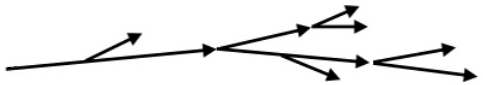

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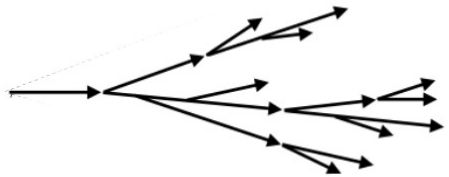

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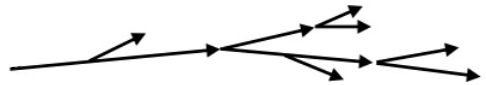
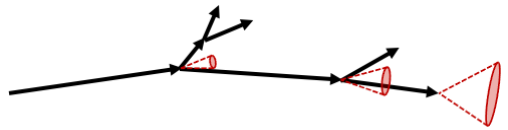
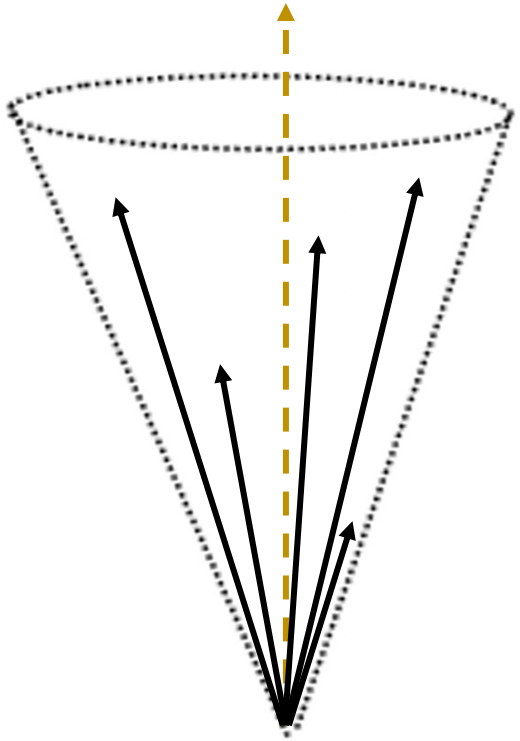


Heavy-quark-initiated shower
Suppression of small angle emissions
Harder fragmentation



Heavy-flavour jets

Well controlled probe
Heavy-flavour jet production is perturbatively calculable down to low p_T



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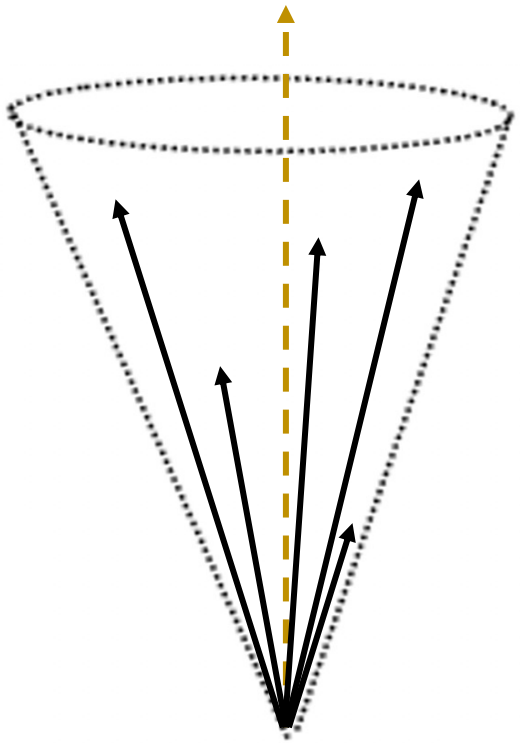
The large mass of the heavy-quark suppresses thermal production and production during the process of hadronisation



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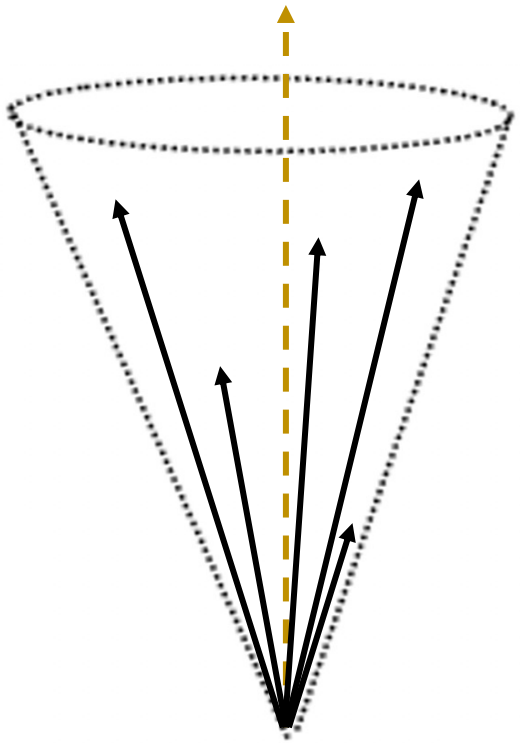

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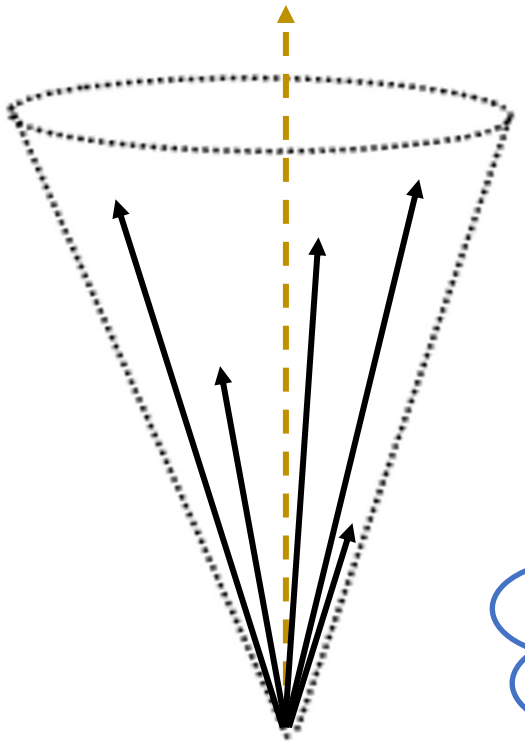

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At low energies heavy-quarks provide unique access to mass effects in the shower

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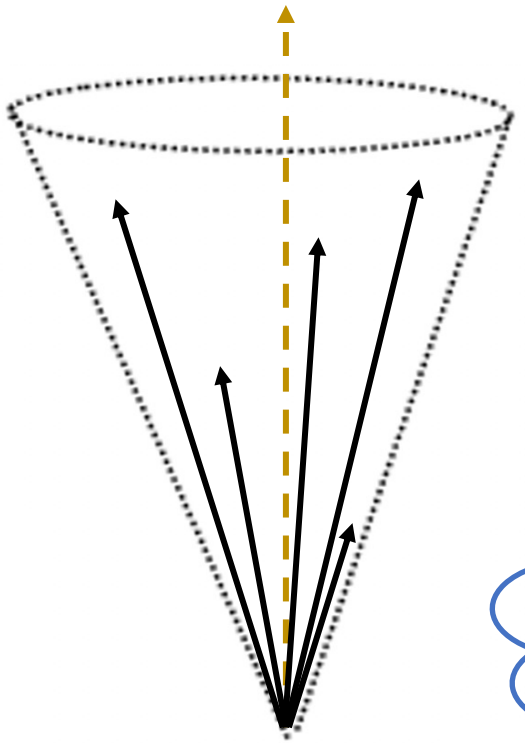

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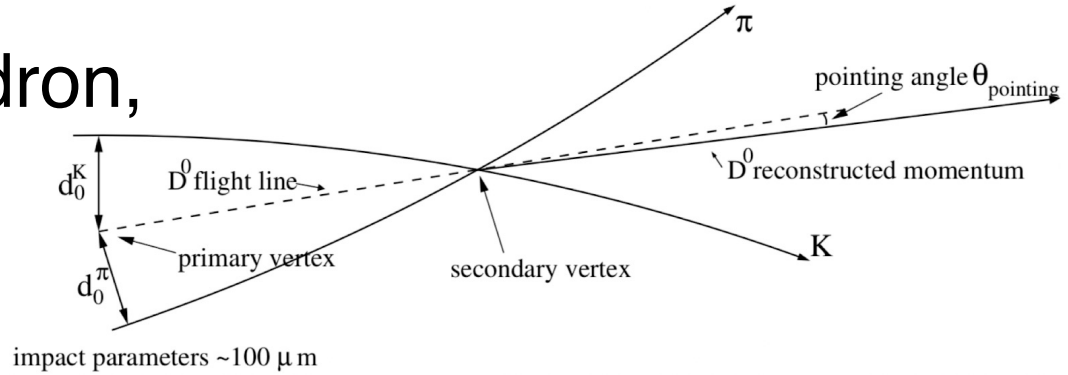
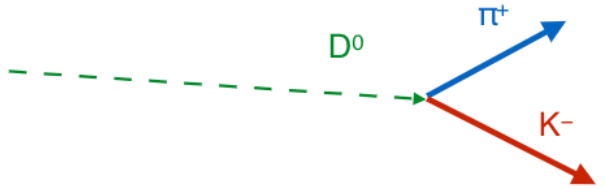
Hadronisation mechanisms
Baryons vs mesons
Fragmentation in QGP

HF-jet tagging at ALICE

- Tagged by fully reconstructing the HF hadron, **Vit Kučera, Inha University**
  - Reconstruction in ALICE possible via **hadronic decays**
    - Identify decay products with ALICE' **PID** capabilities
    - Exploit **topological** constraints (displaced production vertex)
    - Select **candidates** and extract **signal** via **invariant mass fit**
    - The HF hadron is our best proxy for the final kinematics of the heavy-quark in the shower





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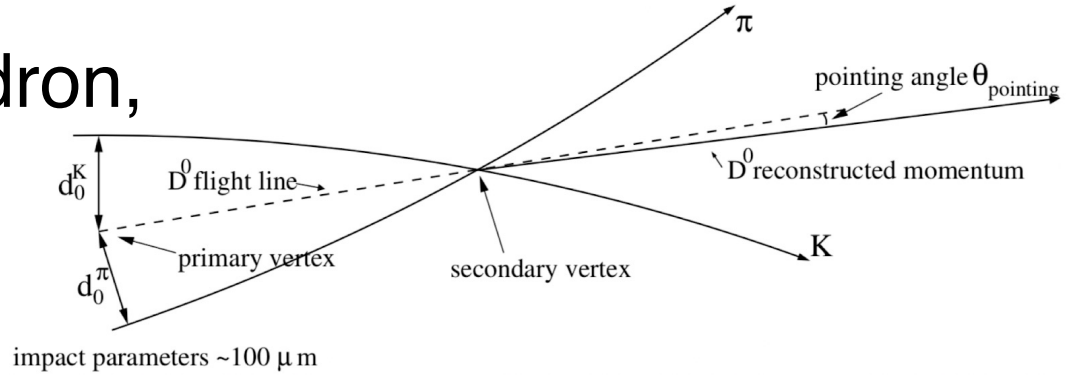

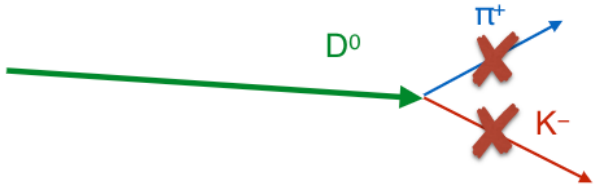

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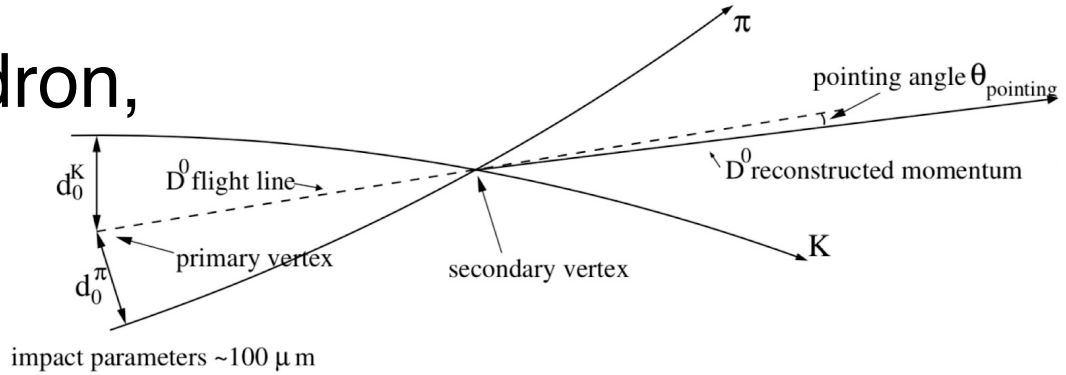

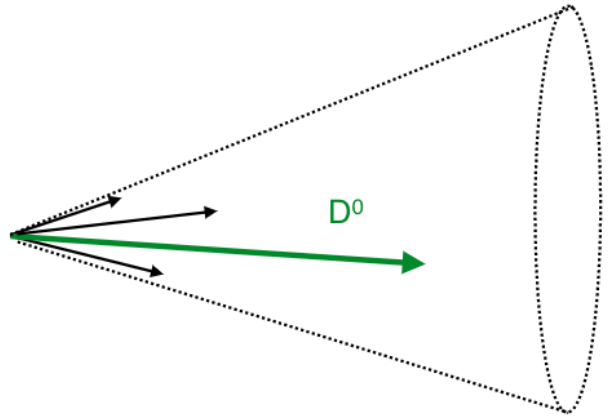

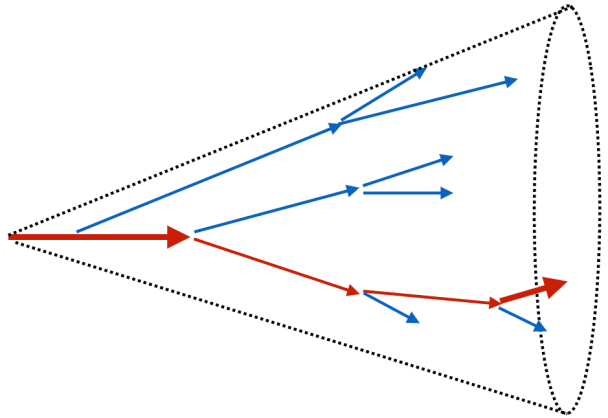

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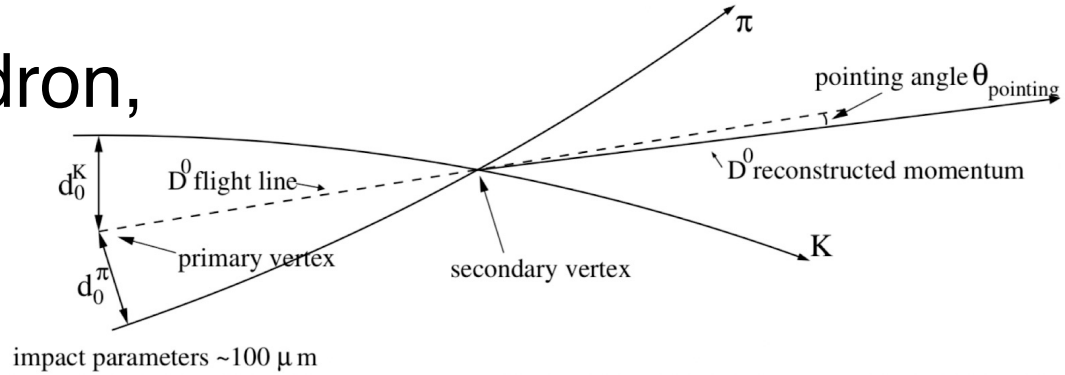
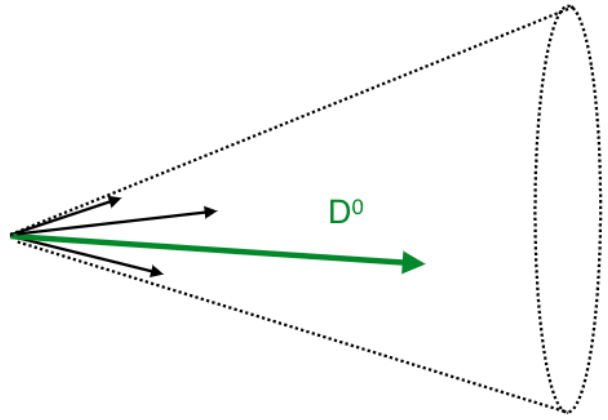
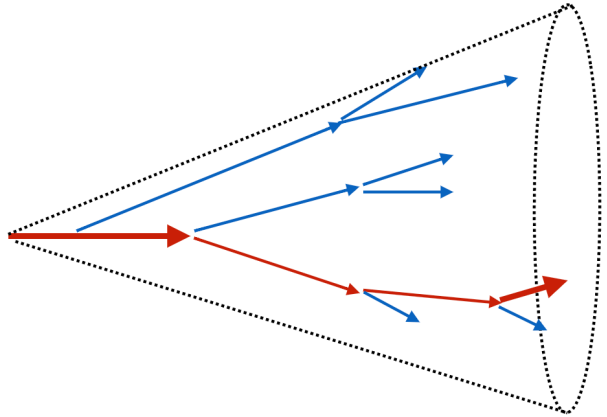
- Jet–D^0 correlations with ML, **IPHC Strasbourg**







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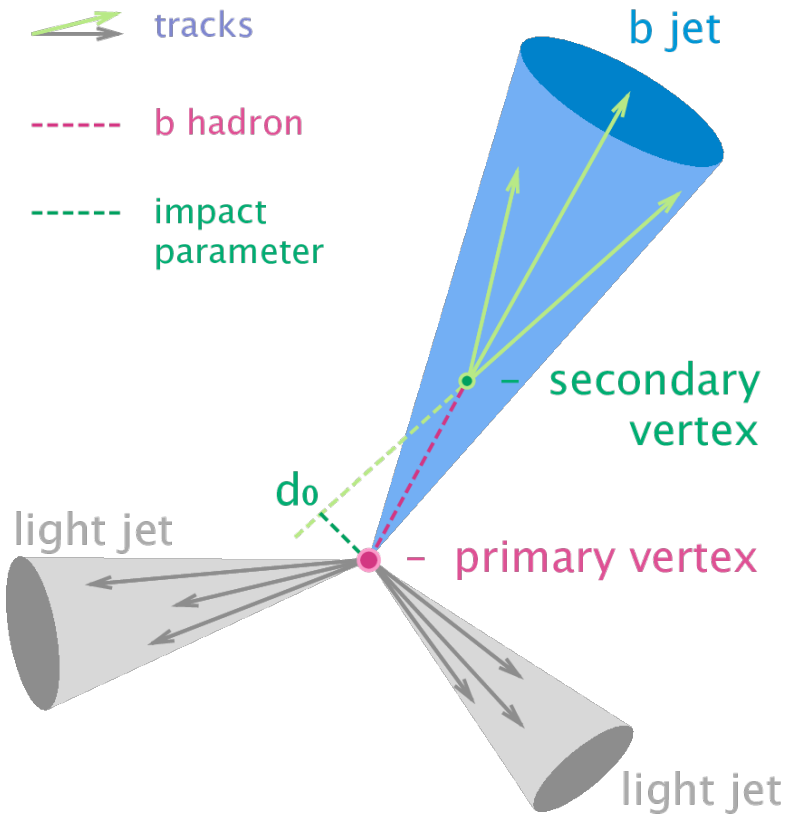
- *b*-jets are tagged using algorithms that exploits the **long life time of the *b* hadrons** (no beauty hadron reconstruction)
  - Low level taggers
    - Impact parameter and secondary vertex based, JHEP 01 (2022) 178, LPSC Grenoble, Hyungjun Lee, SKKU for LHC Run 3



http://bartosik.pp.ua/hep_sketches/btagging

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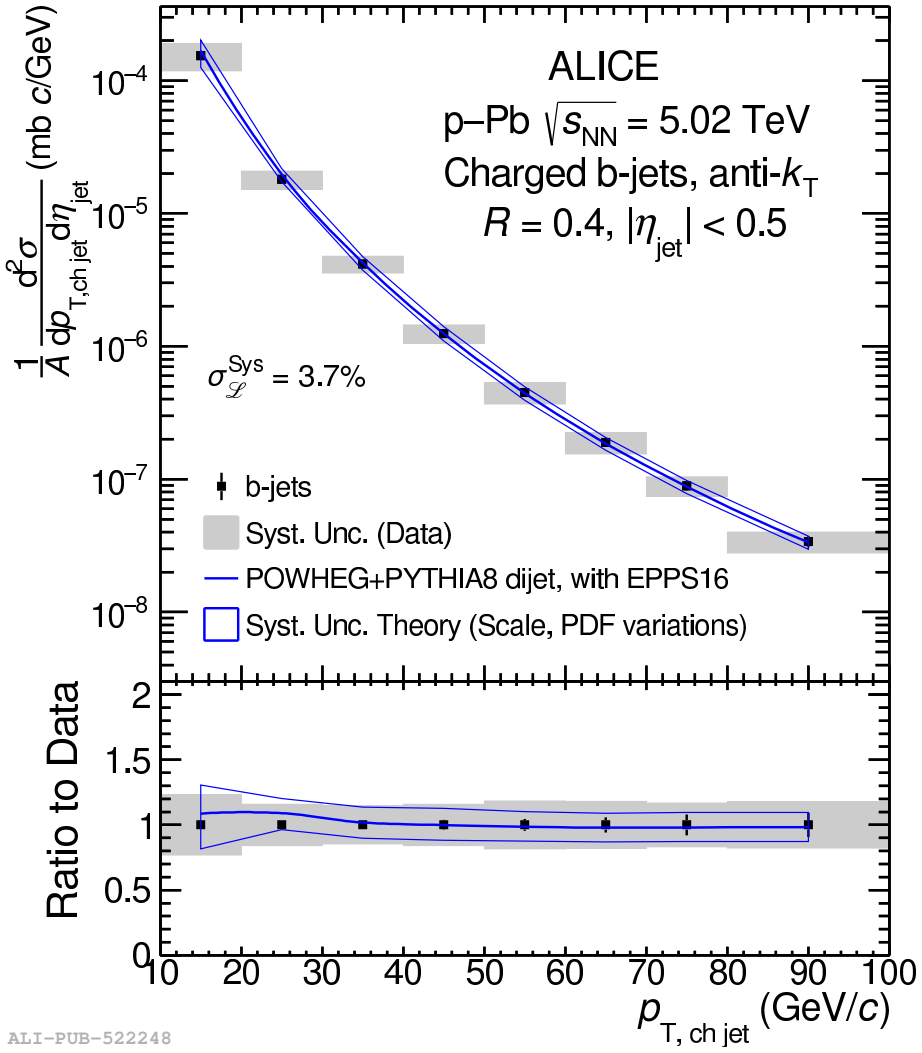

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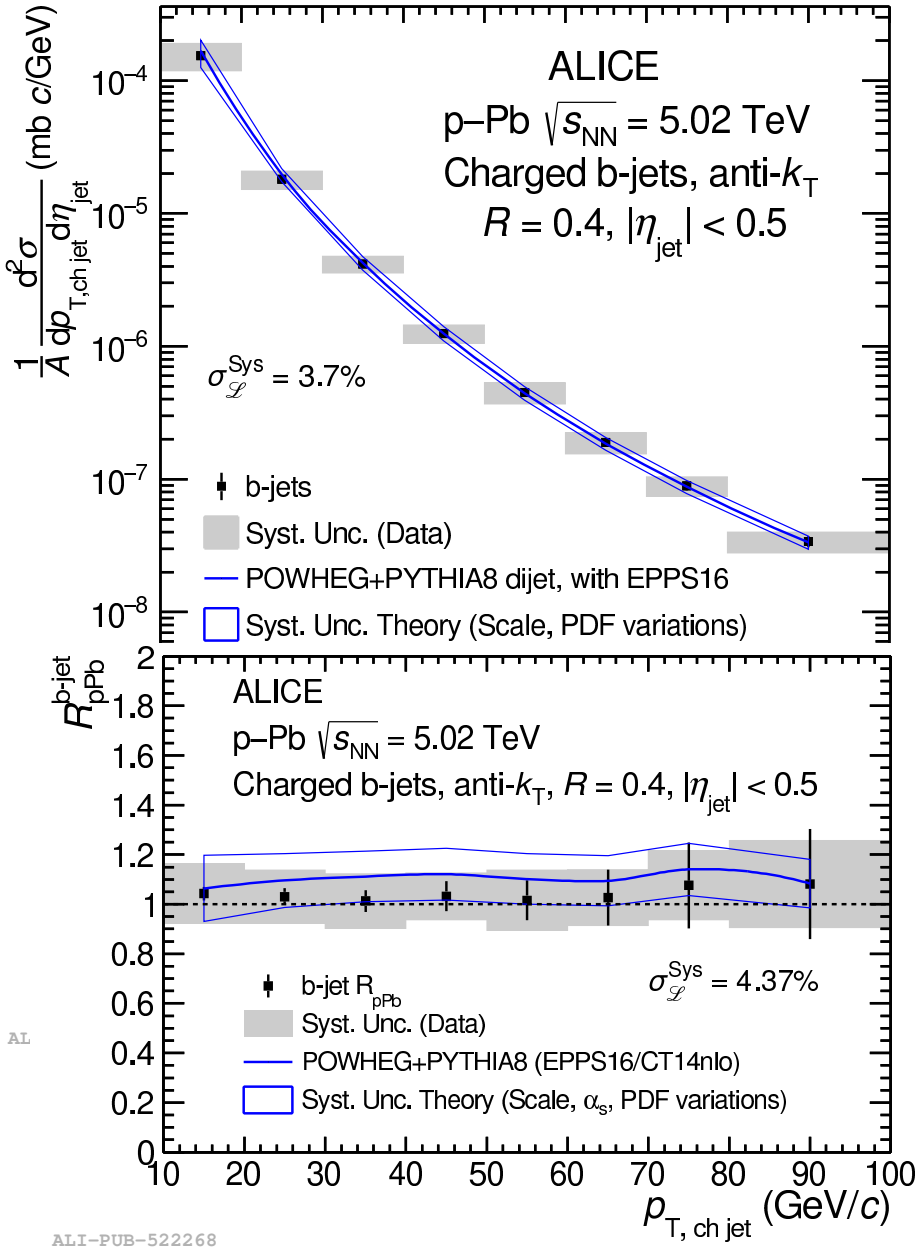

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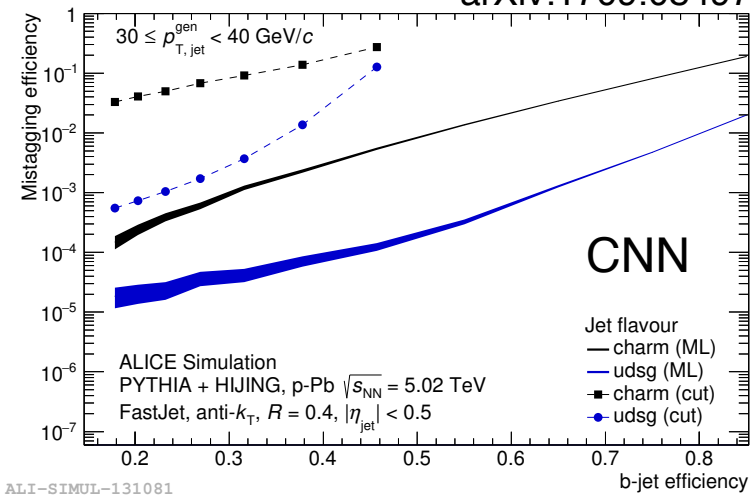
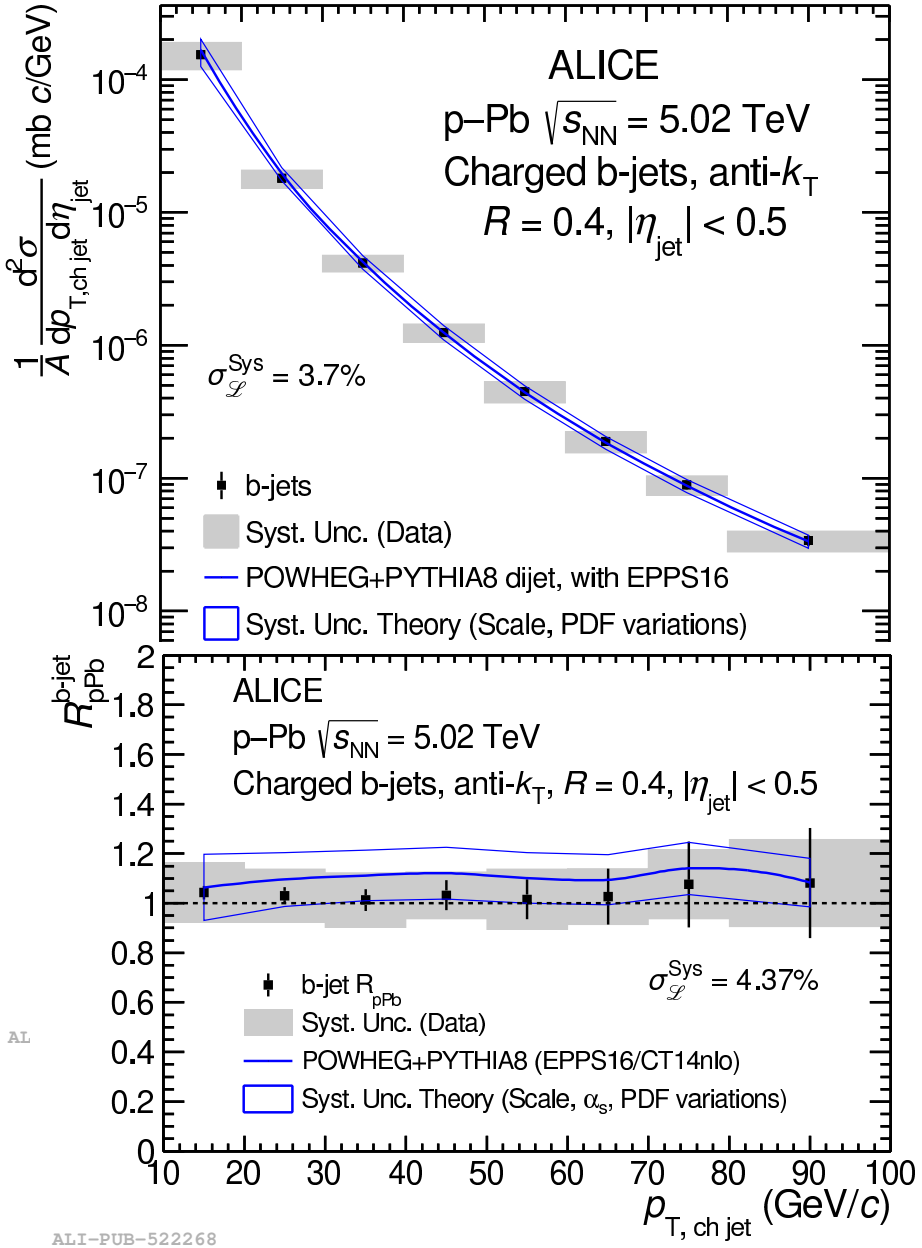
  - High level taggers
    - Applied deep-learning techniques to several low-level parameters

arXiv:1709.08497

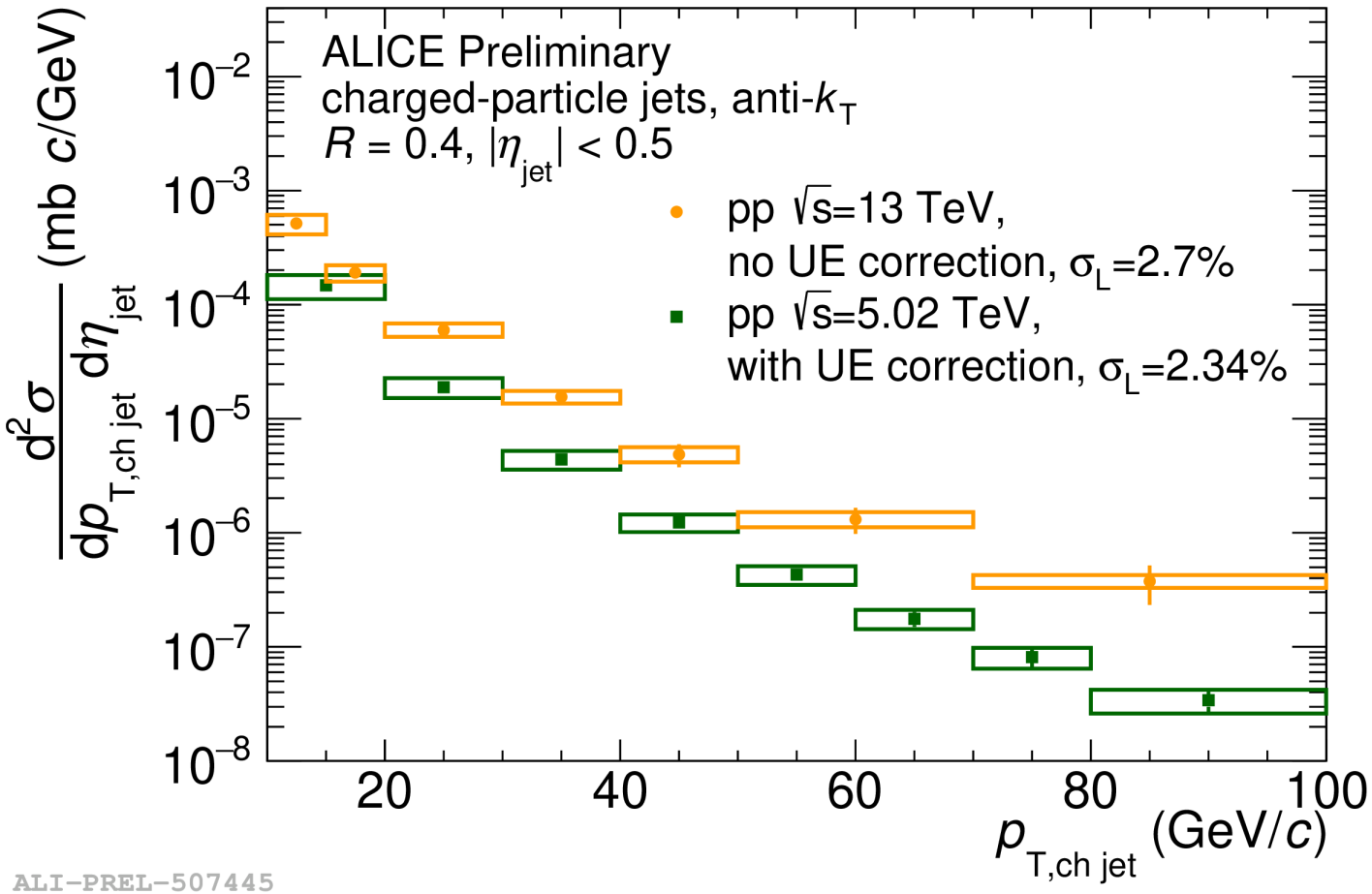


- Flavour tagging with **graph neural networks** in pp collisions at ALICE for LHC Run 3, **Changhwan Choi, Sanghoon Lim, Pusan National University**



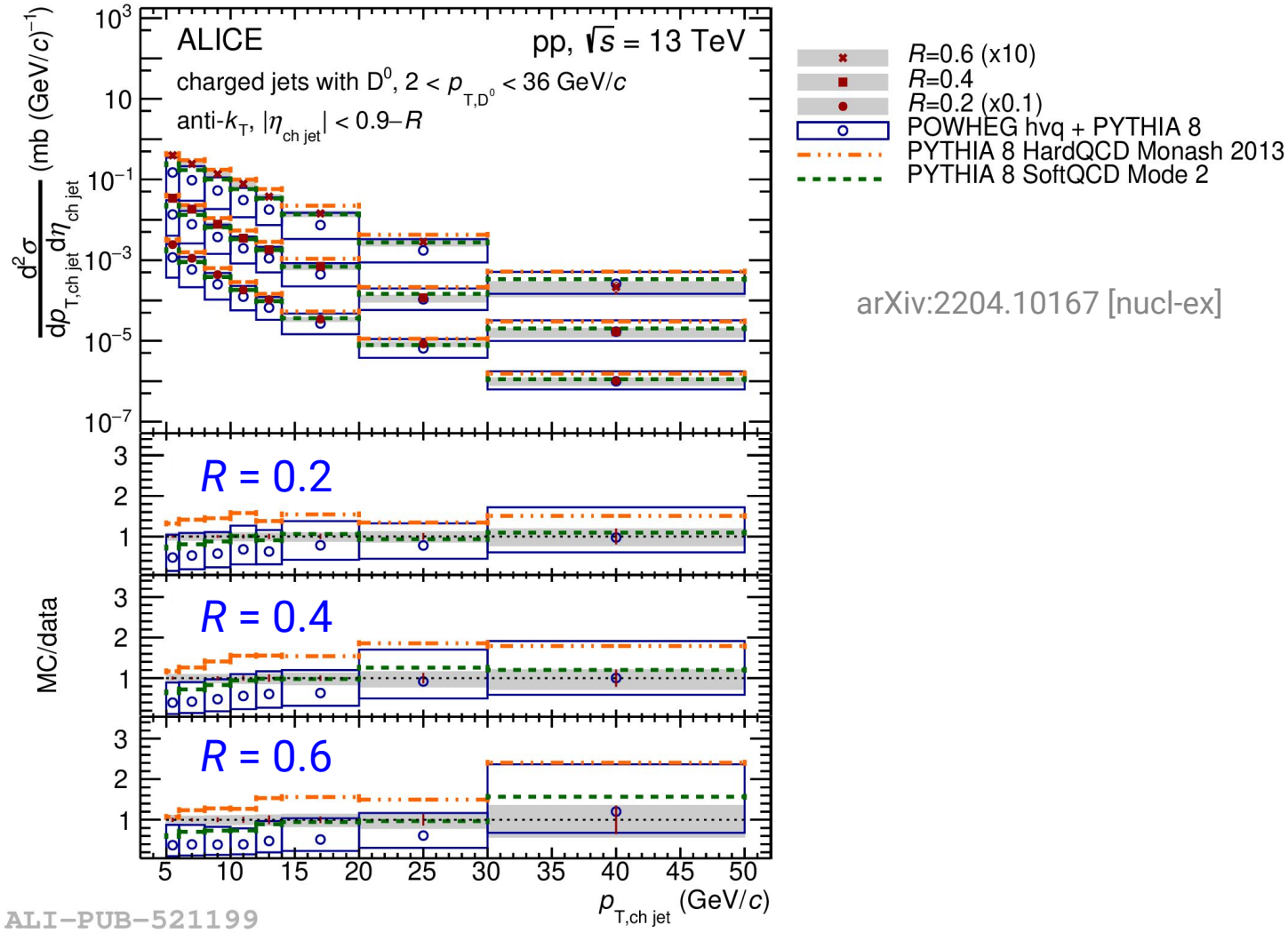
Beauty-jet production in pp collisions

- Identification of *b*-jets using impact-parameter distributions
- A **hardening of the p_T spectrum** can be observed at higher collision energies



Charm-jet production in pp collisions

- Jet resolution parameter dependence
  - Probes the **angular profile** of the parton shower
- Agreement with pQCD calculations in pp collisions
  - Calibrated baseline for Pb–Pb collisions



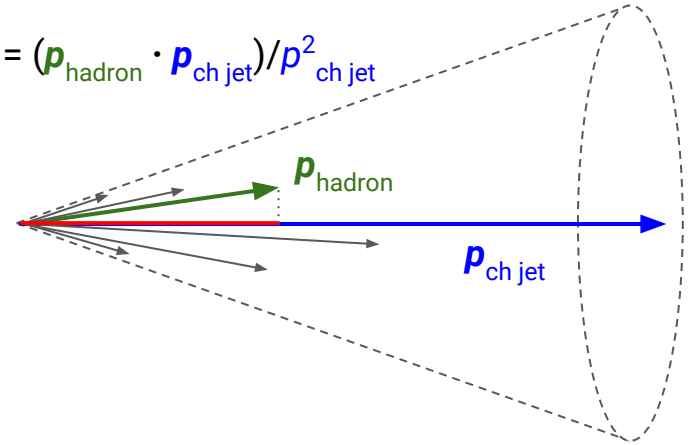
ALI-PUB-521199

arXiv:2204.10167 [nucl-ex]

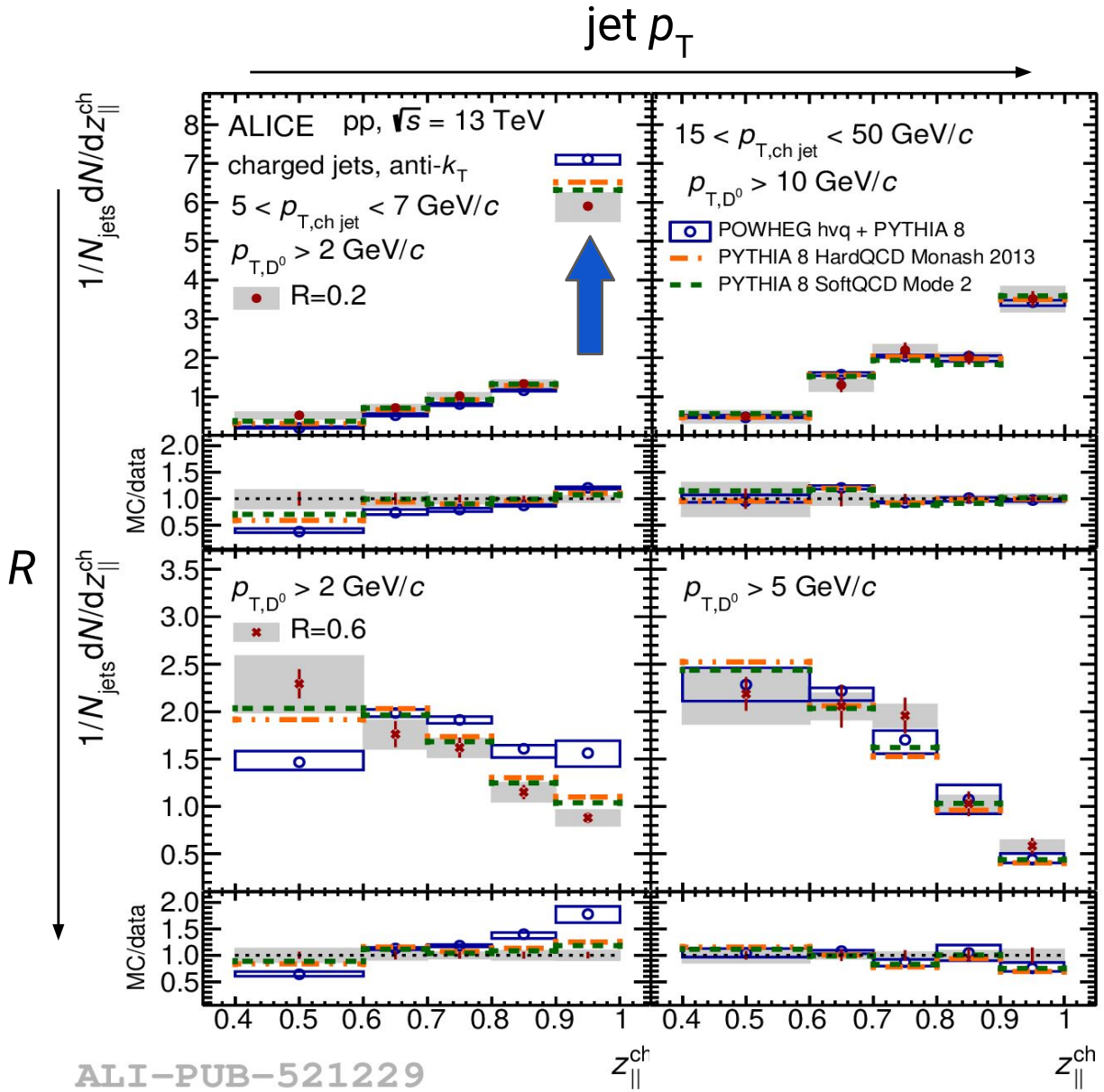
D^0 fragmentation function

- HF-tagged jets provide a handle on the **evolution of quarks to hadrons**

$$z^{ch}_{||} = (\boldsymbol{p}_{hadron} \cdot \boldsymbol{p}_{ch\ jet})/p^2_{ch\ jet}$$



- Measured in a wide phase-space region:
  - $\sqrt{s}$ = 5.02 TeV, 13 TeV
  - Jet $p_T \in$ [5, 50] GeV/c
  - D^0 $p_T \in$ [2, 36] GeV/c
  - R = 0.2, 0.4, 0.6



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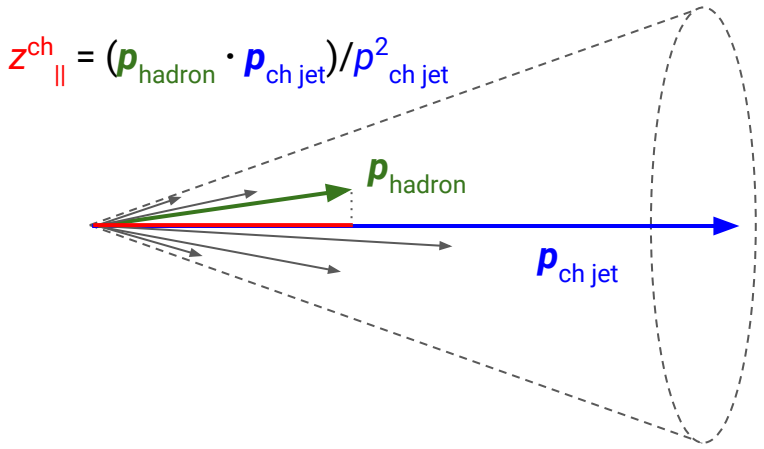
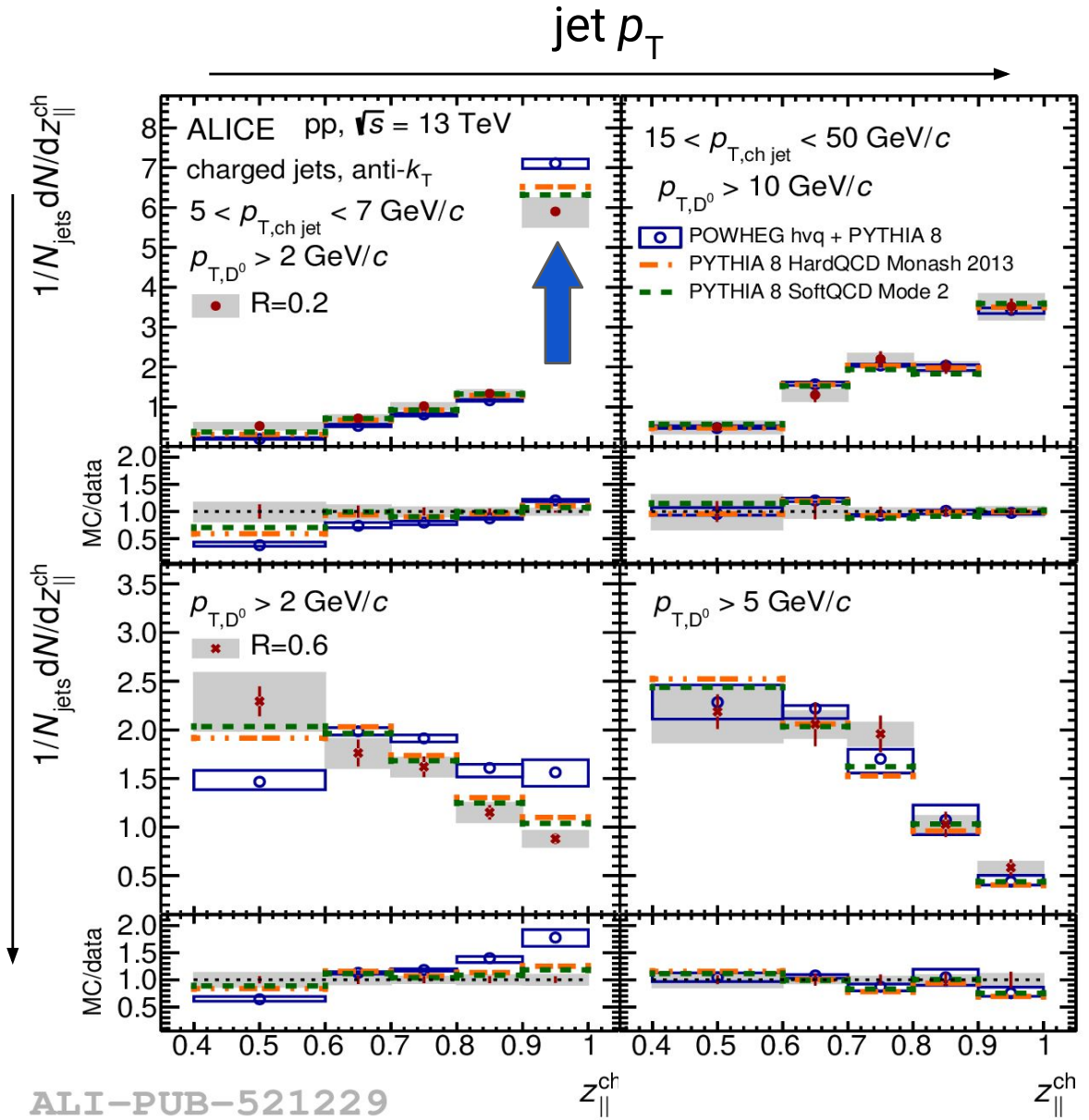
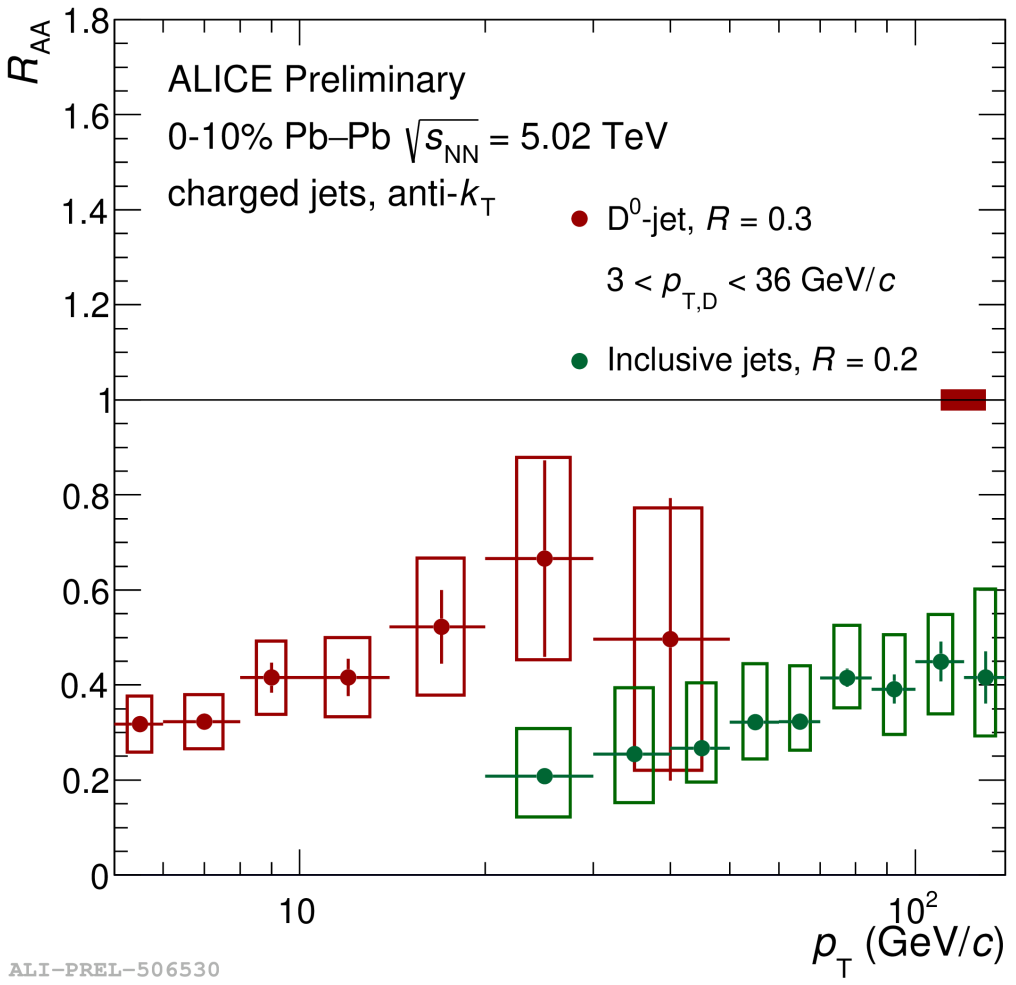


- Good description by models at **high jet p_T** and **small R**
- Hint of a **softer fragmentation** in data w.r.t. model predictions (especially NLO) for **low p_T** jet and **larger R**
- The **core** of the jet ($R = 0.2$) is dominated by the HF hadron, as expected from the **suppression of small angle emissions**
- At **large angles** ($R > 0.2$) the charm quark **emissions are recovered**



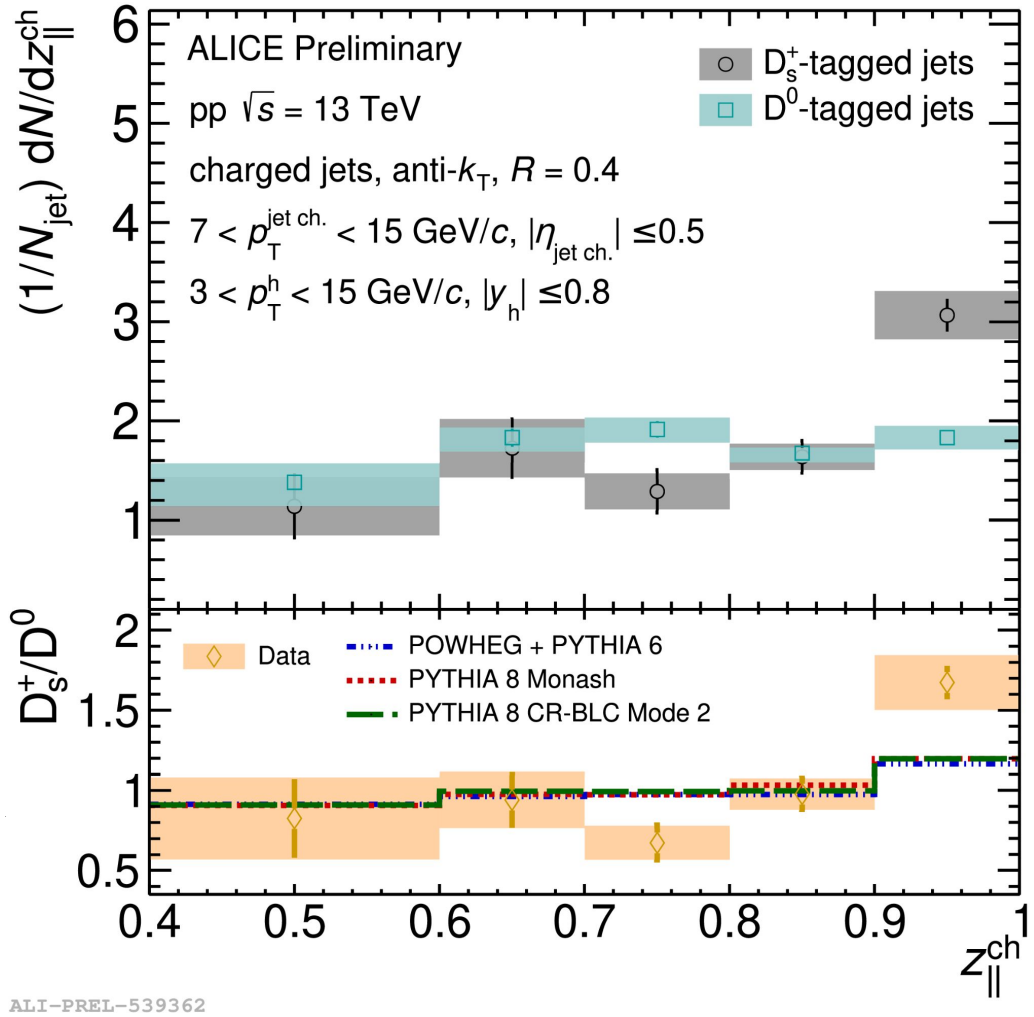
Modification of charm jets in Pb–Pb

- Ratio of normalised differential yields of D^0-tagged jets in **central Pb–Pb** and **pp collisions**
- Hint of **higher R_{AA} of charm jets compare to inclusive jets**
  - Mass dependence of parton energy loss
    - Casimir color factors
    - Dead-cone effect



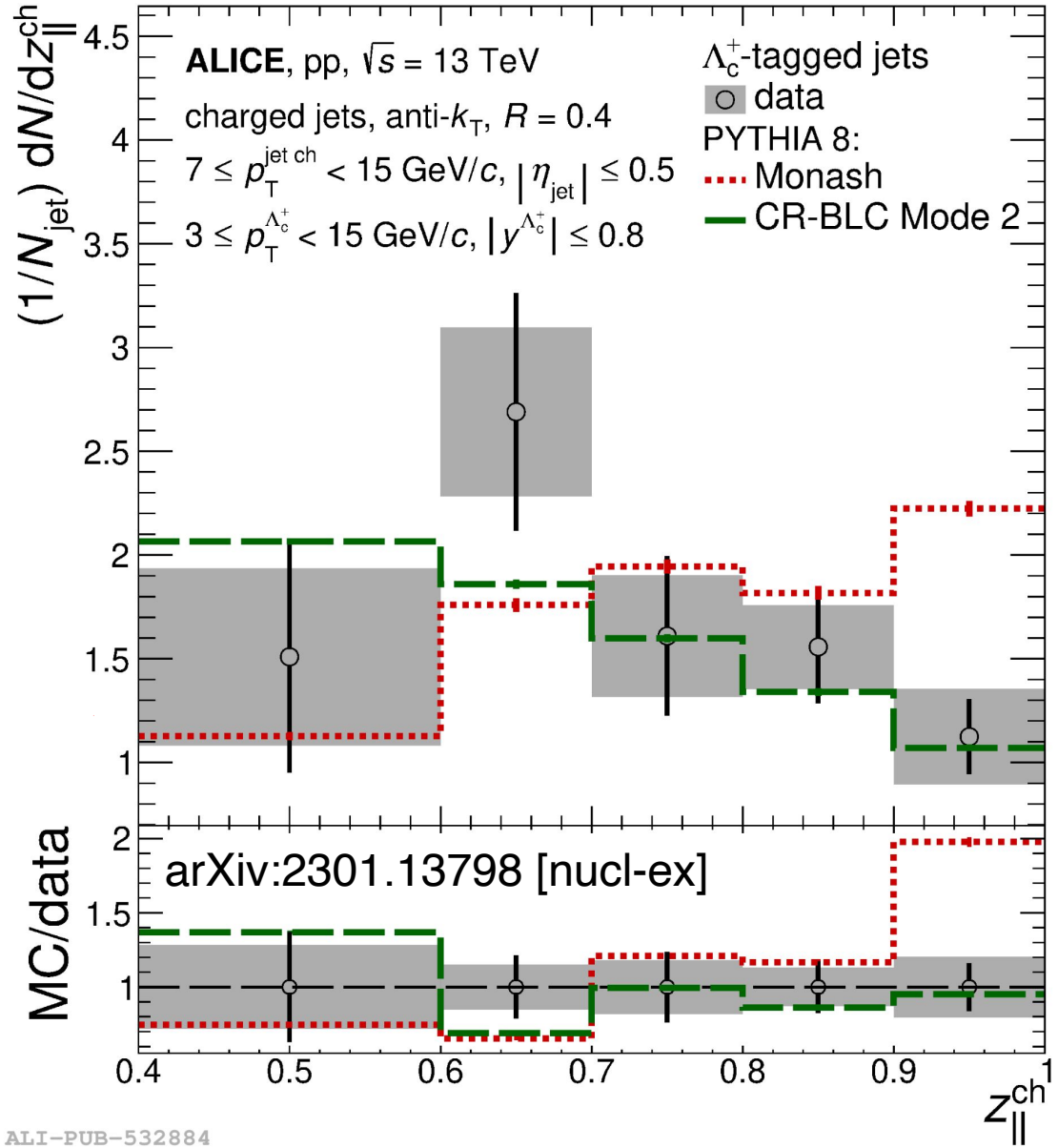
D_s fragmentation function

- First $z^{ch}_{\parallel}$ measurement for D_s
  - Exploring the effect of **strangeness** in the production of strange charm hadrons
- Hint of **harder fragmentation** into D_s than into D^0



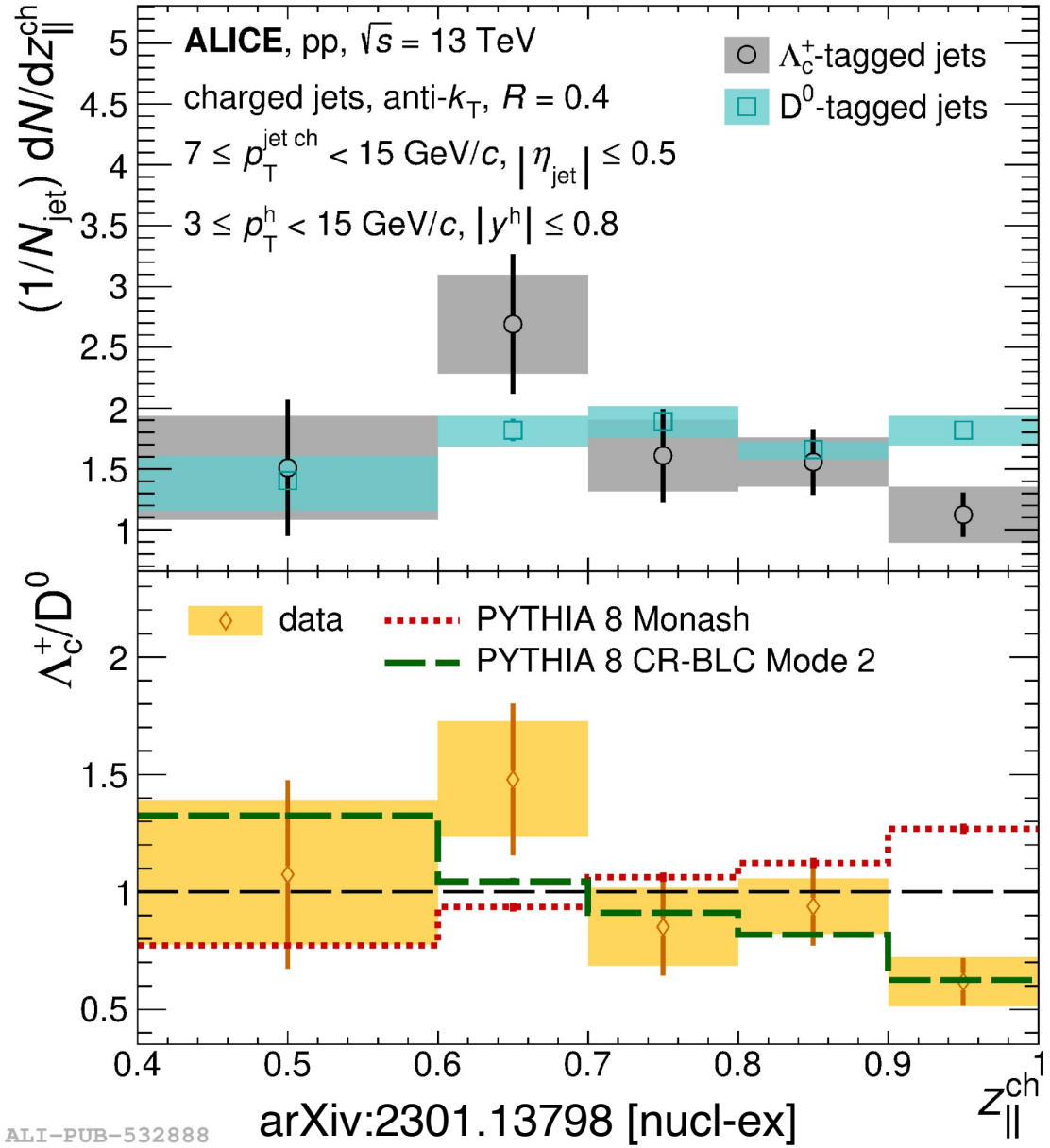
Λ_c fragmentation function

- The study of charm-baryon production in jets can provide insights into **hadronization mechanisms in pp collisions**
  - A more differential look at the **baryon-to-meson ratio enhancement** in pp w.r.t. ee/ep collisions
    - First $z^{ch}_{\parallel}$ measurement for **Λ_c in hadronic collisions**
    - Proof of **feasibility** of heavy-flavour baryon fragmentation measurements down to low p_T
    - Strong **discrimination power for hadronisation models**



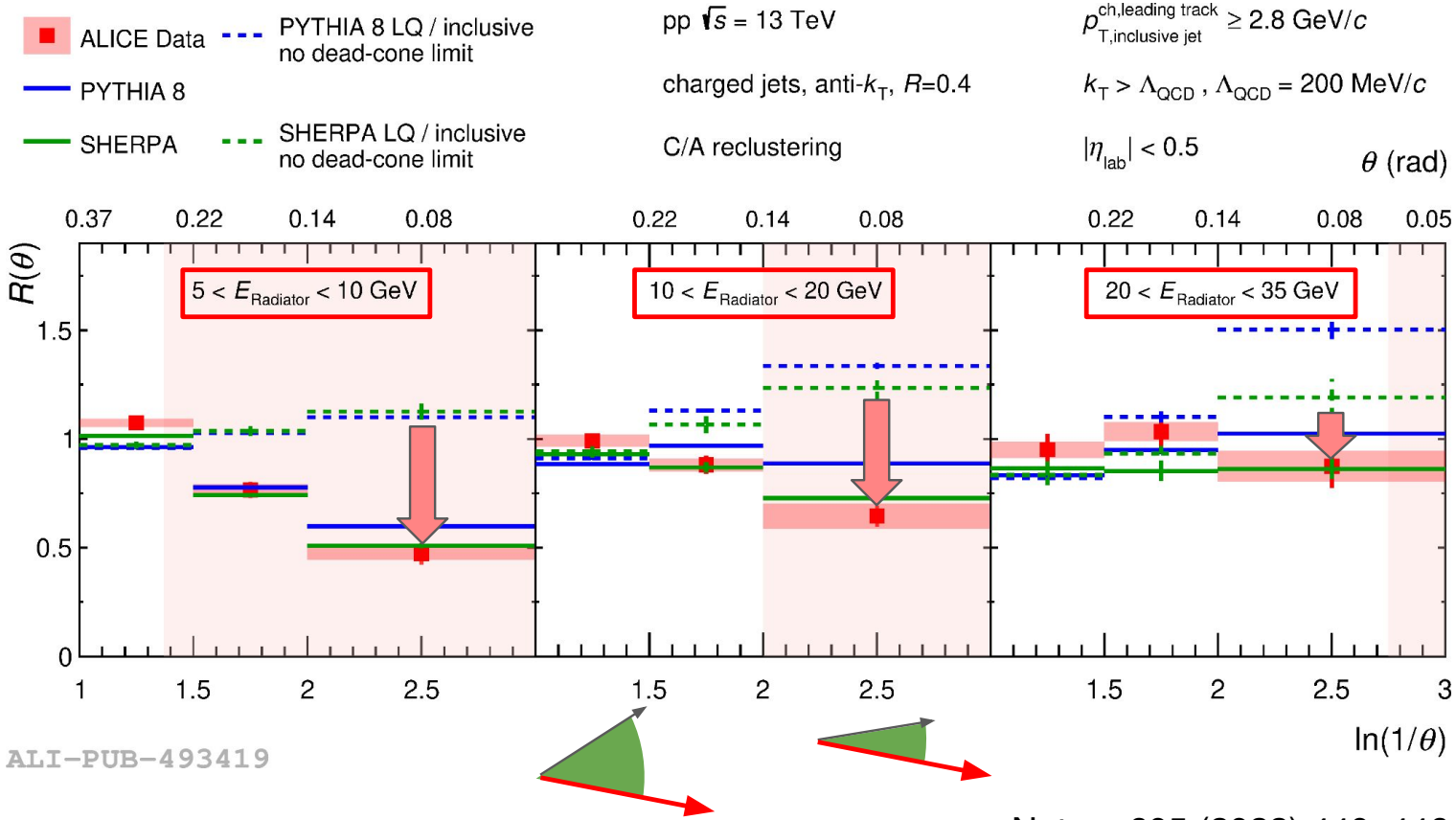
Λ_c fragmentation function

- The study of charm-baryon production in jets can provide insights into **hadronization mechanisms in pp collisions**
  - A more differential look at the **baryon-to-meson ratio enhancement** in pp w.r.t. ee/ep collisions
    - First $z^{ch}_{\parallel}$ measurement for **Λ_c in hadronic collisions**
    - Proof of **feasibility** of heavy-flavour baryon fragmentation measurements down to low p_T
    - Strong **discrimination power for hadronisation models**
  - Hint of **softer fragmentation** into Λ_c than into D^0
    - New way of constraining hadronisation mechanisms (e.g. local parton density dependence of fragmentation)



Dead-cone effect

- Ratio of **emission angle** distributions for **charm quarks** and **inclusive partons** reveals the dead-cone effect
  - First **direct observation** in QCD
- Significant suppression of small-θ emissions at low energy
- Dead cone narrows with increasing E_{Radiator}



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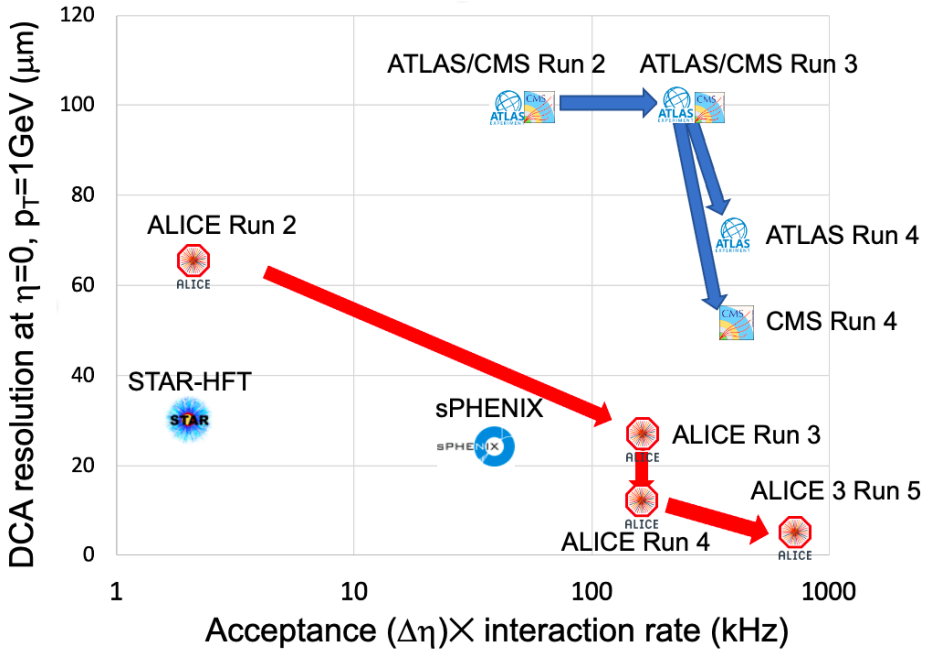
Summary

- Heavy-flavour jets are excellent probes for **perturbative and non-perturbative QCD processes**
  - More data and better tracking resolution in **Run 3** → better accuracy
  - Address the **beauty sector** (fully reconstructed *b*-hadrons in jets)
- Better characterisation of hadronisation mechanisms from **fragmentation functions of Λ_c and D^0, Ξ_c under study at Inha Univ.**
  - Local parton multiplicity effects
- **Substructure** of charm and beauty jets
  - Low p_T: dead-cone effect for charm vs beauty
  - High p_T: Casimir colour factors for quarks vs gluons
- Pb–Pb collisions: **probe to study QGP**
  - Modification of heavy-quark fragmentation
  - Mass dependence of parton energy loss
- ALICE' **upgrade program beyond LHC Run 3,** Inha Univ., PNU, SKKU, IPHC, LPSC, IP2I
  - **LS3 (2026–2028):** new upgrades for LHC Run 4
    - ITS3: truly cylindrical silicon layers made of ultra-thin wafer-size MAPS
      - Improve heavy flavour particle performance
  - **Beyond Run 4:** continue the heavy-ion programme during the HL-LHC era
    - Proposal of a new experiment ALICE 3 with "nearly-massless" tracker installed during LS4
      - **Multi-charm** and **beauty** particles



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