Measurement of non-prompt D-meson production in pp collisions at $\sqrt{s} = 13$ TeV using Machine Learning (ML) techniques with ALICE

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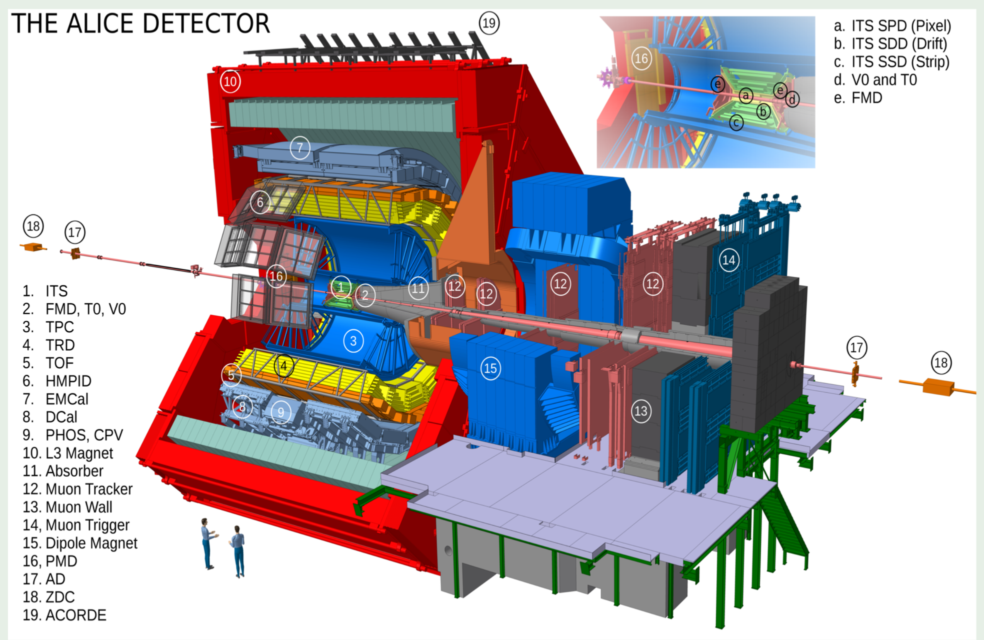
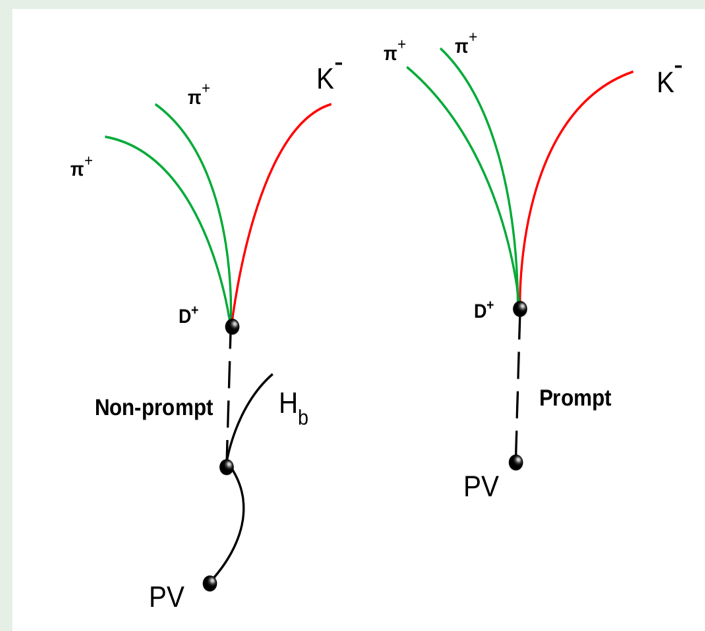
Physics Motivation

- Measurements of the production of hadrons containing charm or beauty quarks in proton–proton (pp) collisions provide an important test of perturbative quantum chromodynamics (pQCD) calculations [1].
- Decay vertices of non-prompt D mesons, originating from beauty-hadron decays, are on average more displaced from the interaction vertex due to the larger mean proper decay lengths of beauty hadrons ($c\tau \approx 500\mu\mathrm{m}$) compared to that of charm hadrons.
- Therefore, exploiting the differently displaced decay-vertex topologies, it is possible not only to separate D mesons from the combinatorial background, but also non-prompt from prompt D mesons.
- From the measurement of non-prompt D-meson yield ratios, it is possible to access the fragmentation fractions of beauty quarks into hadrons and prove and test the assumption of their universality across different collision systems.

Experimental set up and data sample

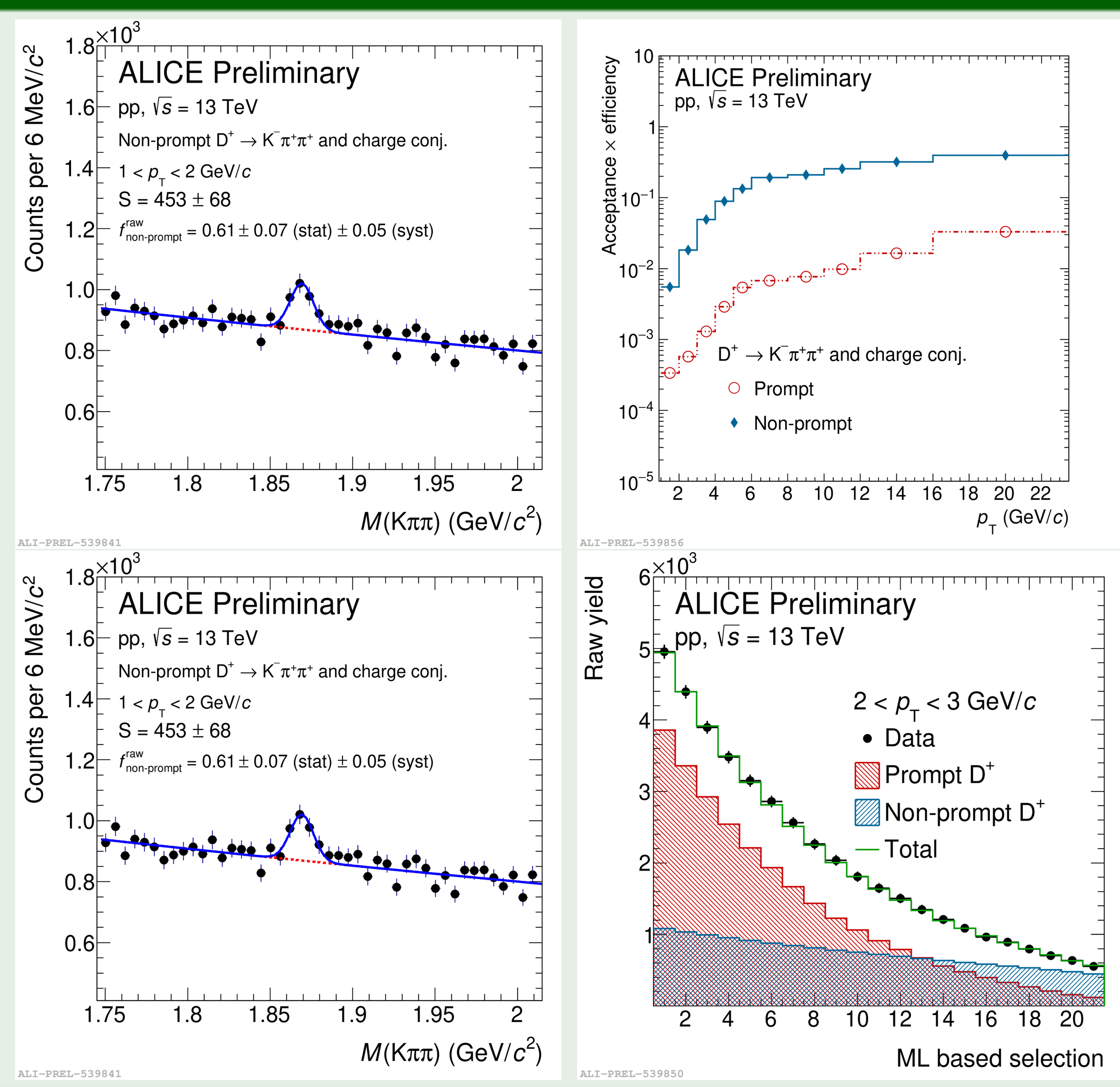
- The main detectors of ALICE (A Large Ion Collider Experiment) used for D-meson reconstruction are:
  1. Inner Tracking System (ITS)
  2. Time Projection Chamber (TPC)
  3. Time-of-Flight(TOF) detector
- Track reconstruction in $|\eta| < 0.8$ with ITS and TPC.
- Particle identification (PID) exploiting particle specific energy loss dE/dx (with TPC) and time-of-flight (with TOF).
- **Data sample used:** pp collisions at $\sqrt{s} = 13$ TeV collected for the period 2016, 2017 and 2018 with integrated luminosity $\mathcal{L}_{\mathrm{int}} = 31.9 \pm 0.5\mathrm{nb}^{-1}$.





D-meson reconstruction

- D mesons and their anti-particles are reconstructed at midrapidity by exploiting their hadronic decay channels $\mathrm{D}^{+} \to \mathrm{K}^{-}\pi^{+}\pi^{+}$ (with B.R. $= (9.38 \pm 0.16)\%$), $\mathrm{D}^{0} \to \mathrm{K}^{-}\pi^{+}$ (with B.R. $= (3.950 \pm 0.031)\%$) and $\mathrm{D}_{s}^{+} \to \phi\pi^{+} \to \mathrm{K}^{+}\mathrm{K}^{-}\pi^{+}$ (with B.R. $= (2.24 \pm 0.08\%)$).
- To reduce the large combinatorial background and to separate the contribution of prompt and non-prompt D mesons, a machine-learning approach based on Boosted Decision Tree (BDT) implemented via XGBoost [2] was adopted. The variables exploited are related to the D meson displaced vertex topology and PID information of the D-meson daughter tracks.
- Fit to the invariant-mass distribution is used to extract the raw yields, where the fit functions are composed of a Gaussian for signal and an exponential for background.
- The raw yield is corrected by the $c_{\Delta y}(\mathrm{Acc} \times \varepsilon)_{\mathrm{non-prompt}}$ term, the detector acceptance, and the reconstruction and selection efficiency of the non-prompt D-meson signal.
- The fraction $f_{\mathrm{non-prompt}}$ of non-prompt D mesons in the extracted raw yield is estimated with a data-driven procedure.

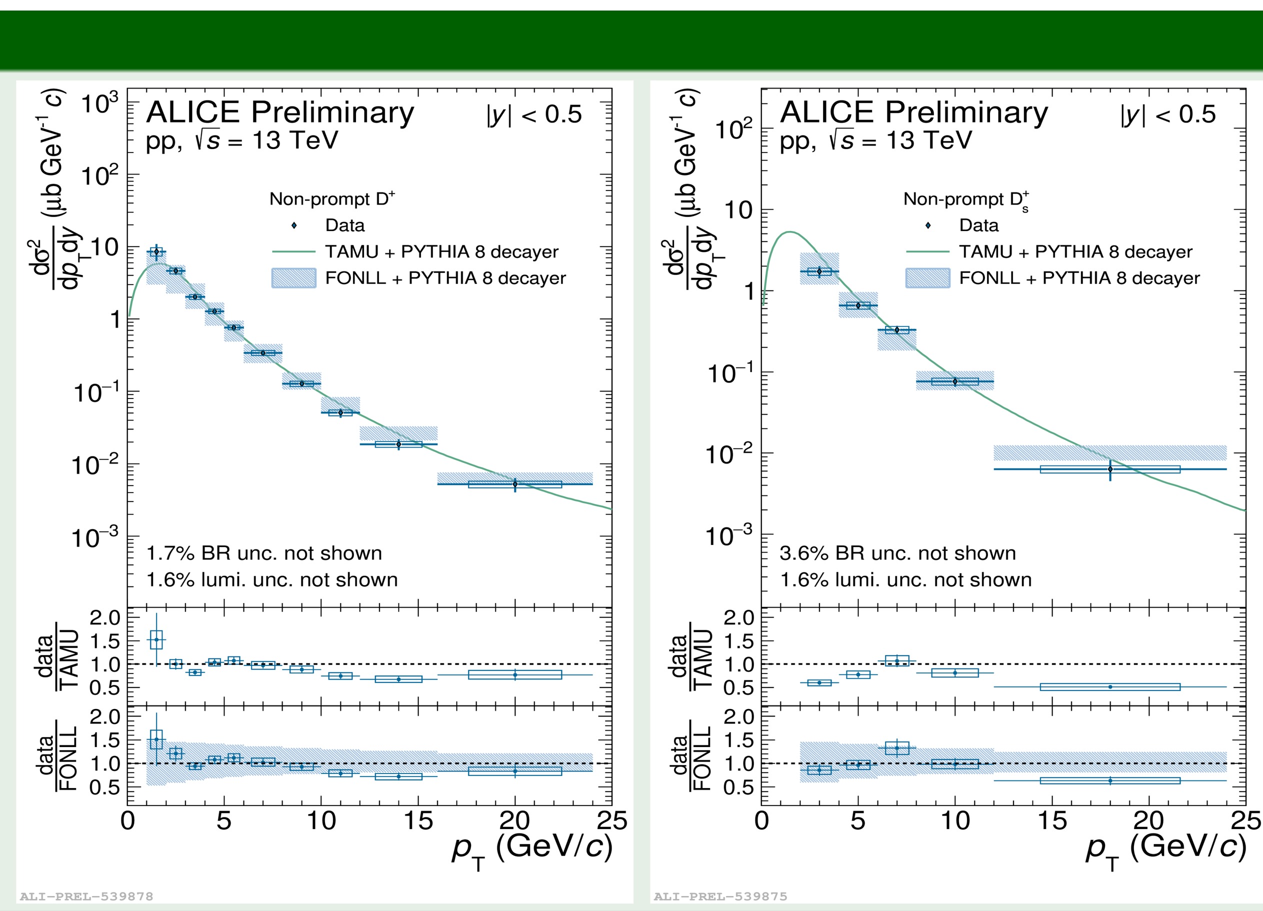


Results

- The p_{T}-differential production yield of non-prompt D mesons is computed as

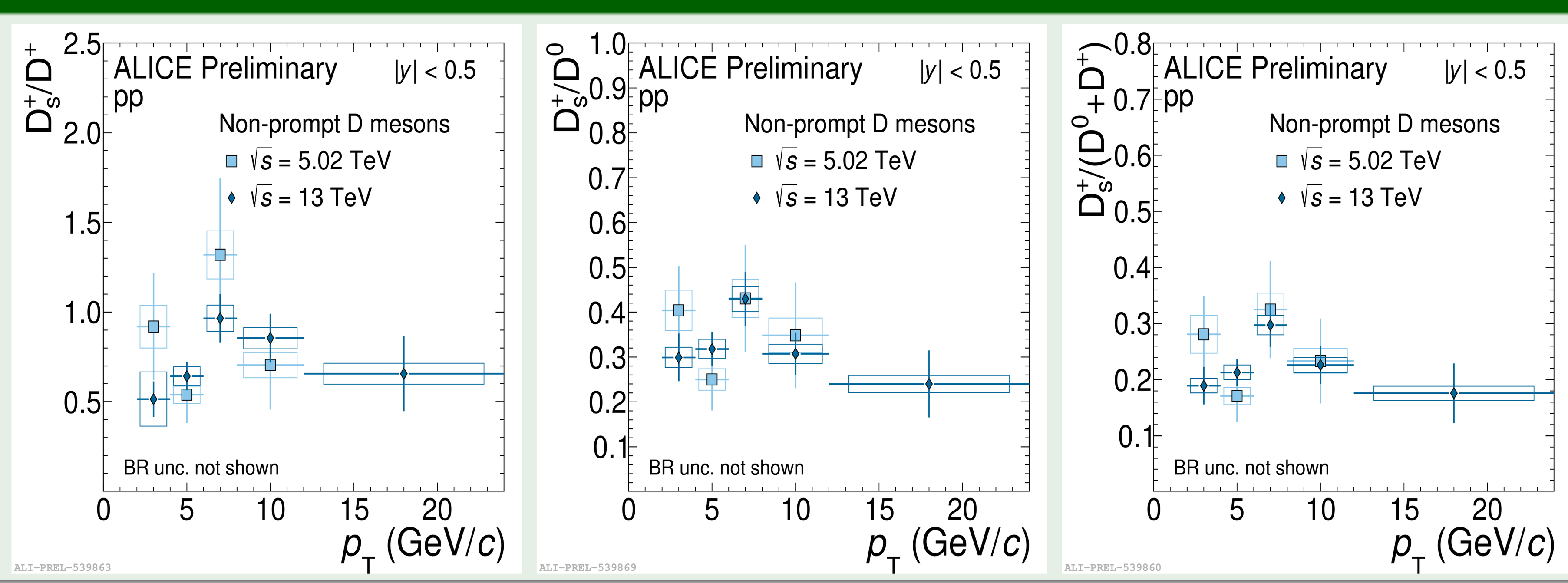
$$\frac{\mathrm{d}N(\mathrm{D}_{\text{non-prompt}})}{\mathrm{d}p_{\mathrm{T}}} = \frac{f_{\text{non-prompt}}(p_{\mathrm{T}}) \cdot N^{\mathrm{D}}_{\mathrm{raw}}(p_{\mathrm{T}})}{2 \cdot \Delta p_{\mathrm{T}} \cdot c_{\Delta y}(p_{\mathrm{T}}) \cdot (\mathrm{Acc} \times \epsilon)_{\text{non-prompt}}(p_{\mathrm{T}}) \cdot \mathrm{BR} \cdot \mathcal{L}_{int}},$$

- The p_{T}-differential cross sections of non-prompt D mesons were measured at midrapidity ($|y| < 0.5$) in pp collisions at $\sqrt{s} = 13$ TeV and compared to predictions based on FONLL calculations [3] as well as to predictions from the TAMU model [4]. A good agreement was found considering the current experimental uncertainties.



D-meson ratios

- The ratios among the p_{T}-differential production cross sections of non-prompt D mesons and the ratios between $\mathrm{D}_{s}^{+}/\mathrm{D}^{+}$, $\mathrm{D}_{s}^{+}/\mathrm{D}^{0}$ and between D_{s}^{+} mesons and the sum of the D^{+} and D^{0} mesons are shown.
- The measured ratios are independent of the collision energy and of the D-meson p_{T} within the current experimental precision [5].



References

[1] ALICE Collaboration: arXiv:2308.04877 [hep-ex].
[2] `https://github.com/hipe4ml/hipe4ml`.
[3] arXiv:hep-ph/9803400.
[4] Phys. Rev. Lett. 131 (Jul, 2023) 012301.
[5] ALICE Collaboration: arXiv:2102.13601v2 [nucl-ex].