Measurements of single and double D^0 meson production in pp collisions at $\sqrt{s}$ = 13.6 TeV with ALICE

ICHEP 2024, Prague, Czech Republic

Andrea Tavira García, on behalf of the ALICE collaboration

1. Introduction

We measured the D^0 non-prompt fraction in pp collisions using Run 3 data from ALICE. This measurement can be used to **test pQCD** calculations in the beauty sector.
It was already performed in Run 2 [1], but in Run 3 we can:

- **Improve the precision** with respect to Run 2, thanks to much larger data samples.
- Get **more granular results**, even down to $p_T = 0$.
- Provide tighter constraints for **distinguishing different hadronisation implementations in models** (EPOS [2], PYTHIA [3] with different tunes).

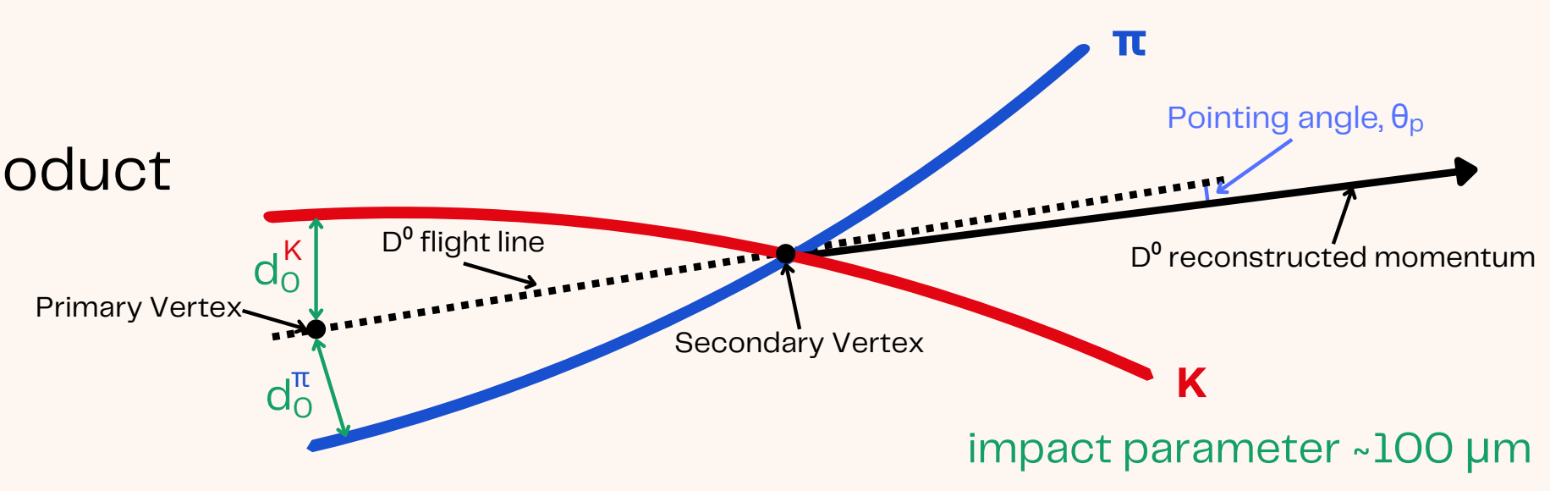
We can also measure double D^0 production in Run 3 to investigate and **distinguish single and double parton scattering** better.

3. Methodology

To select D^0 mesons, we trained a set of Boosted Decision Trees (BDTs) using candidates with $0 < p_T < 24$ GeV/c with **three different classes**: prompt D^0, non-prompt D^0 and combinatorial background.

To perform the model training, we used **variables that exploit the differences in the topology and the particle identification (PID)** between our classes, in particular:

- Daughter impact parameter product
- Cosine of pointing angle
- Decay length
- TPC + TOF PID information



The distributions of the variables for prompt and non-prompt D^0 mesons were taken from an ideal MC, and those for the background were obtained from sidebands of the data invariant-mass distribution. To separate between prompt and non-prompt candidates accepted by the model, we used a data-driven approach called **cut-variation:**

1. Define a **set of cuts on the non-prompt BDT score** to get different prompt and non-prompt D^0 contributions. For each cut, we can define an equation of the type:

$$(\mathrm{Acc} \times \epsilon)_i^{\mathrm{prompt}} \cdot N_{\mathrm{prompt}} + (\mathrm{Acc} \times \epsilon)_i^{\mathrm{non\text{-}prompt}} \cdot N_{\mathrm{non\text{-}prompt}} = Y_i$$

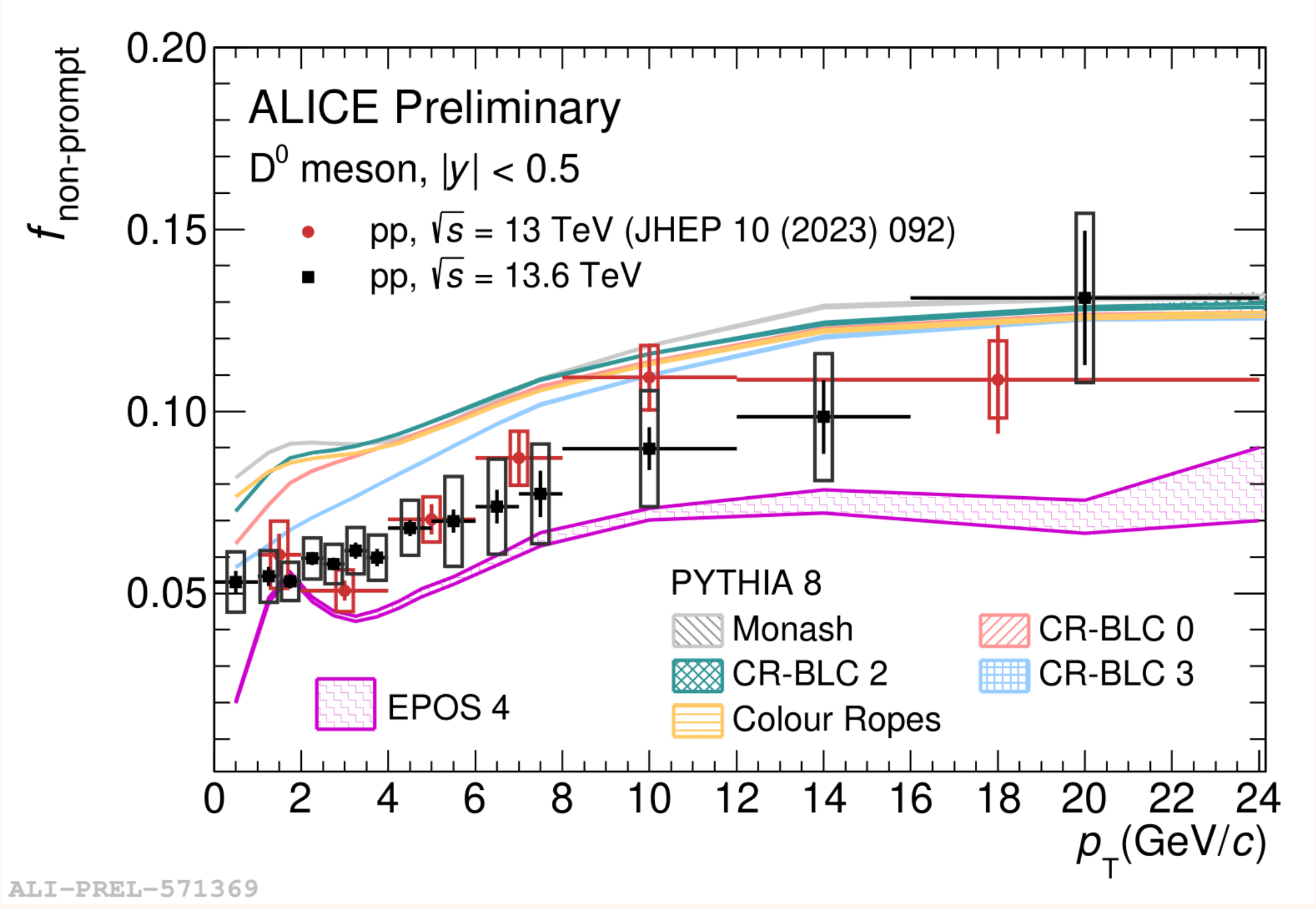
where Y is the raw-yield, and (Acc x ε) is the acceptance multiplied by the efficiency.

2. From the full set of cuts, we obtain a system of equations that can be solved iteratively by **minimising the χ^2.**

3. Once we have the number of prompt (N_p) and non-prompt (N_{np}) candidates, **extract the fraction** per cut as

$$f_{\mathrm{non\text{-}prompt}} = \frac{(\mathrm{Acc} \times \epsilon)^{\mathrm{non\text{-}prompt}} \cdot N_{\mathrm{non\text{-}prompt}}}{(\mathrm{Acc} \times \epsilon)^{\mathrm{non\text{-}prompt}} \cdot N_{\mathrm{non\text{-}prompt}} + (\mathrm{Acc} \times \epsilon)^{\mathrm{prompt}} \cdot N_{\mathrm{prompt}}}$$

5. Results and outlook

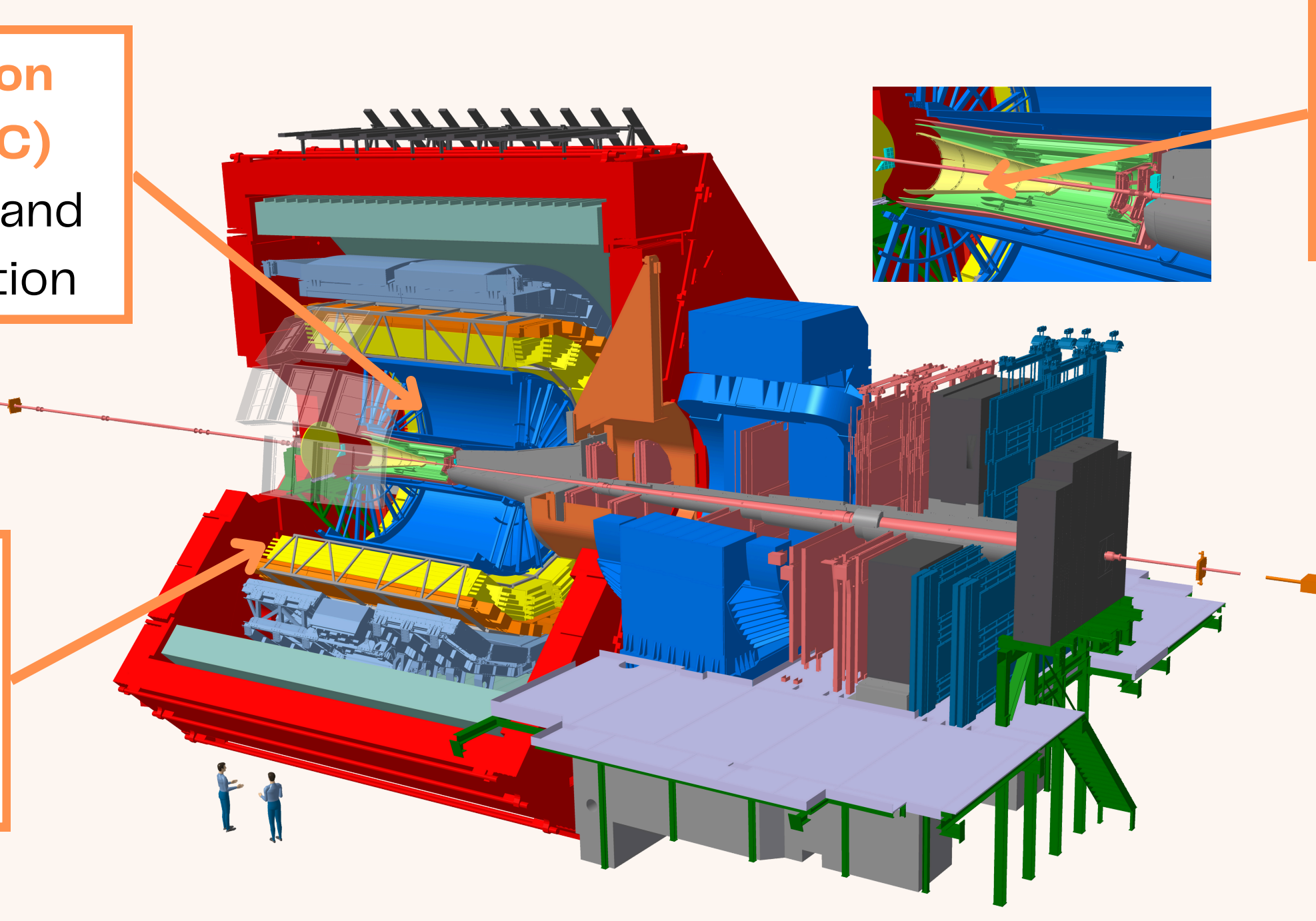


ALI-PREL-571369

- The D^0 non-prompt fraction obtained with Run 3 data (in **black**), taken at $\sqrt{s}$ = 13.6 TeV, is compared with the results from Run 2 (in **red**), taken at $\sqrt{s}$ = 13 TeV, and several theoretical models:
  - **Run 2 and Run 3** results are **compatible** with each other.
  - **PYTHIA**-based models tend to slightly overestimate the data, independently of the tune employed.
  - **EPOS 4** tends to underestimate the data.

- In Run 3, we are **dominated by systematic uncertainties**, which are being reduced in view of the results publication.
- A **higher granularity**, especially at low p_T, is achieved thanks to access to higher statistics.
- The non-prompt fraction at **$0 < p_T < 1$ GeV/c** is successfully measured.

2. Experimental apparatus: ALICE in Run 3



Time Projection Chamber (TPC)
Used for tracking and particle identification

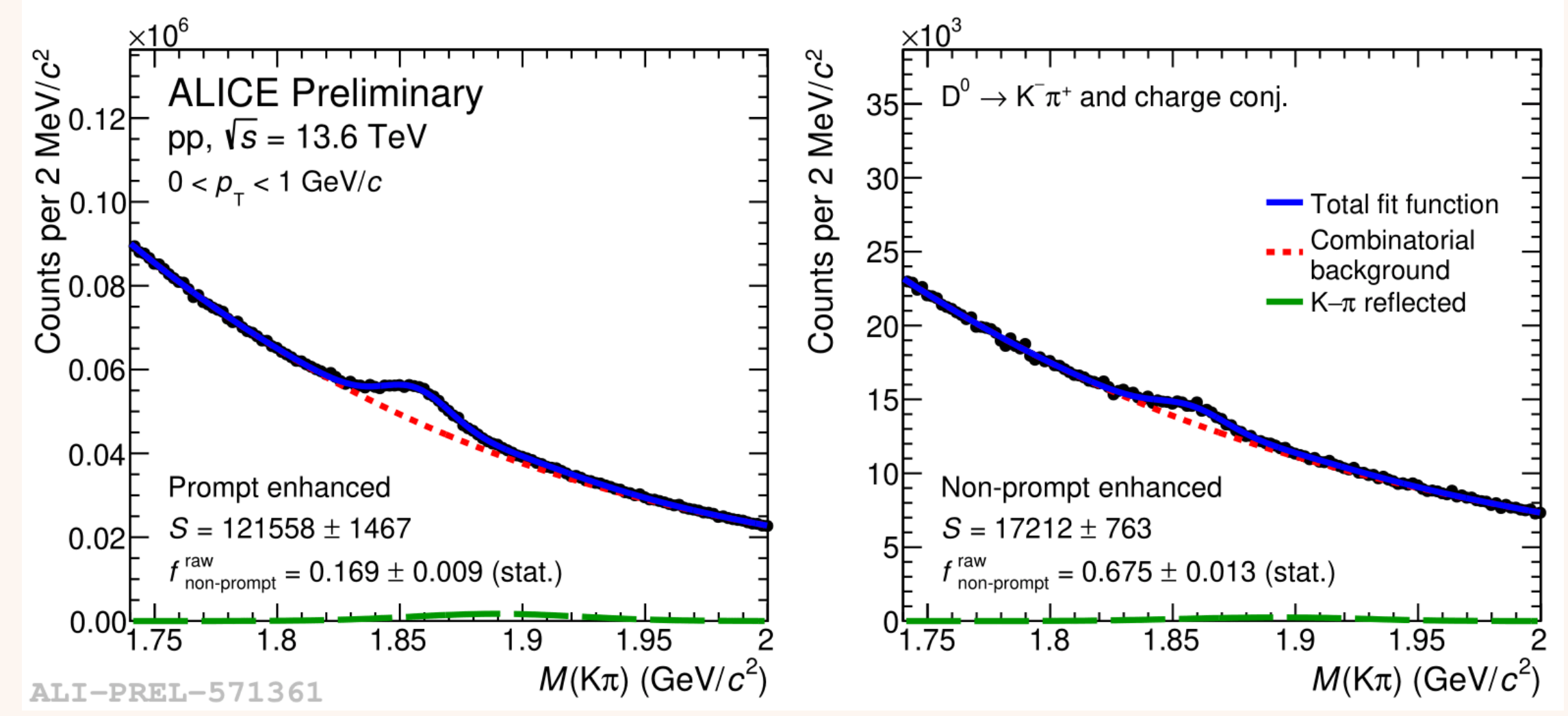
Inner Tracking System (ITS)
Used for tracking and vertexing

Time-of-Flight detector (TOF)
Used for particle identification

D mesons are reconstructed from hadronic decay channels using the **Central Barrel**, mainly ITS, TPC and TOF. The barrel covers the pseudorapidity region $|\eta| < 0.9$.

4. Analysis

We started by selecting a working point that maximised the significance of the signal by applying some cuts to the background BDT score. Then, we defined a set of cuts on the non-prompt BDT score, and we **extracted the raw yields and the efficiencies** for each cut:



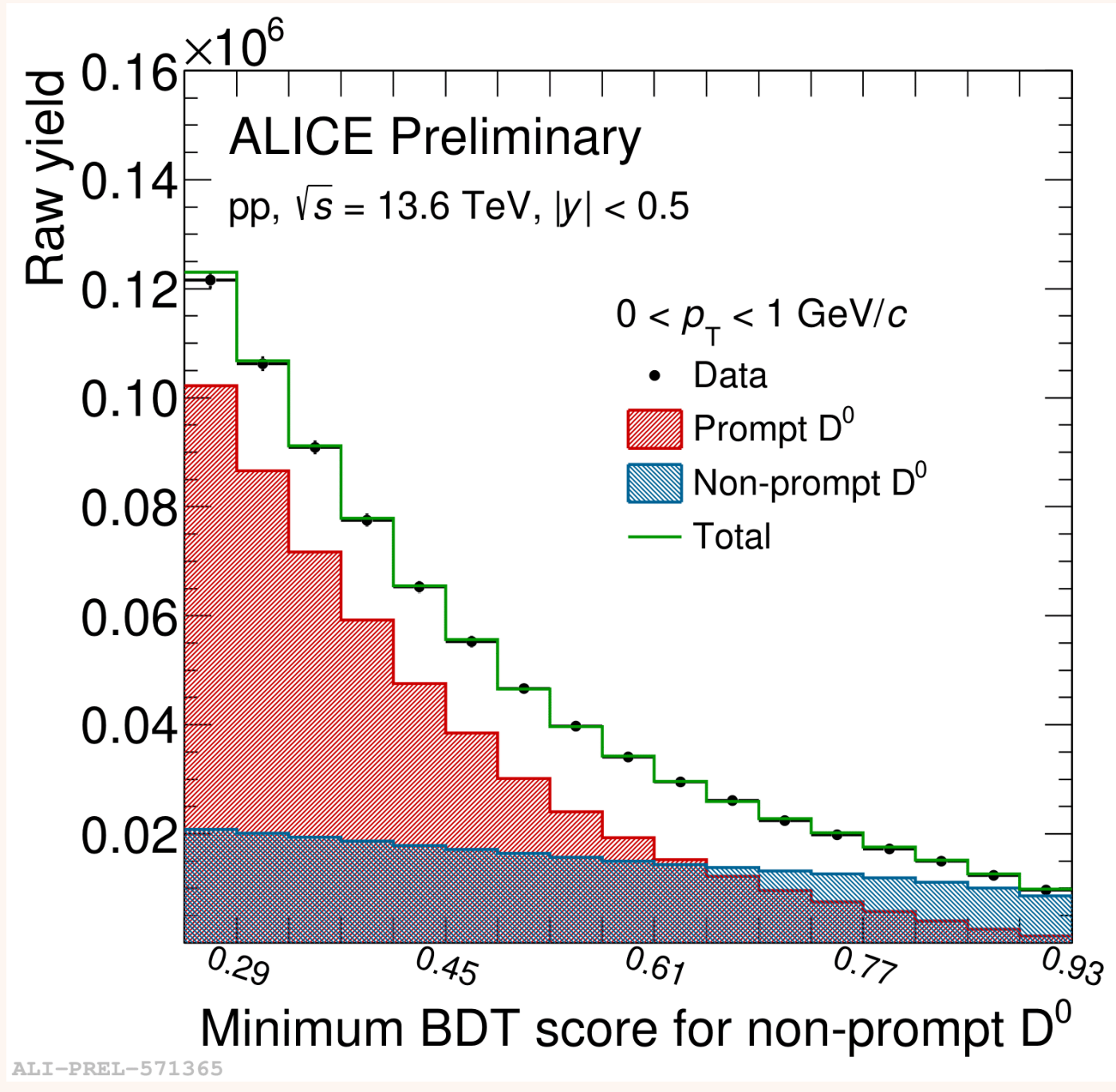
Invariant-mass fit:

- **Signal function:** single Gaussian
- **Background function:** third-degree polynomial
- **Reflection function:** double Gaussian

Efficiency extraction:

- Calculated using a MC anchored to our data sample

Solving the system of equations, we get:

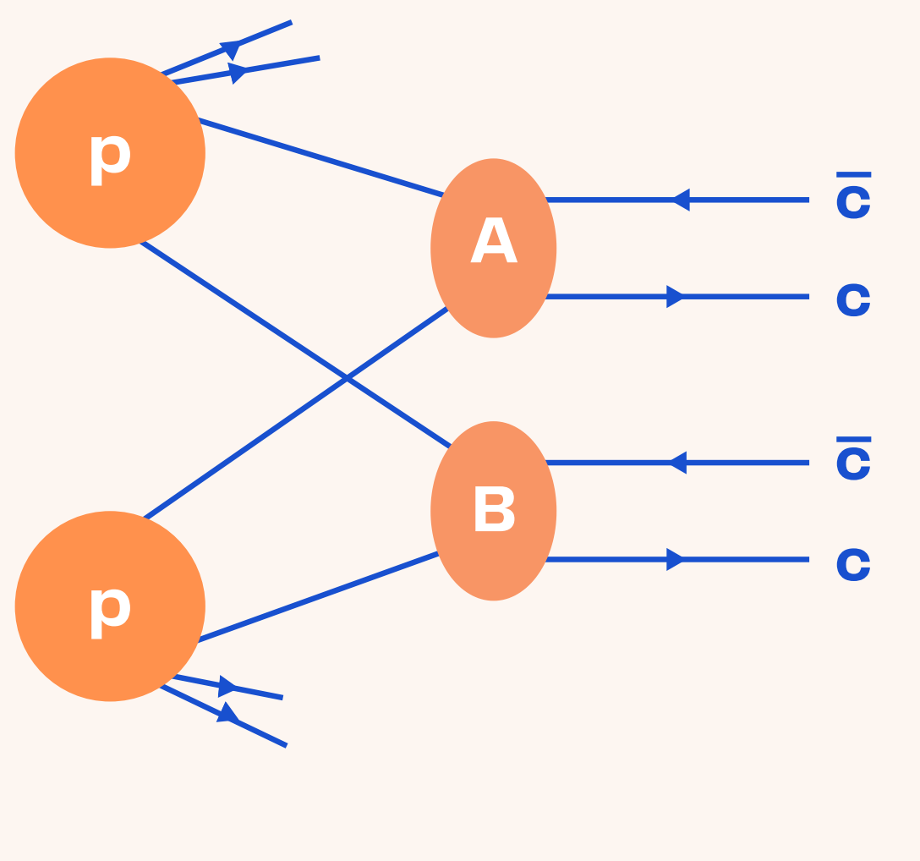


- The **red** and **blue** templates contain the corrected prompt and non-prompt yields, respectively.
- The **green line** represents the result of fitting the sum of the two corrected yields to the data.
- The **black points** represent the measured raw yields.

Systematic uncertainties considered

- **Raw-yield extraction:** between 4% and 7%.
- **Data vs MC discrepancies for topological distributions:** around 7% in all p_T ranges.
- **ML selections:** largest uncertainty at high p_T, up to 15%. At low p_T, its values are around 5%.
- **p_T weighting:** around 2% in all ranges.

6. Perspectives: study of double D^0 production



We can study the double production of D^0 mesons to investigate **double parton scattering (DPS)** [4]. In general, we measure the DPS cross section for the production of particles A and B as:

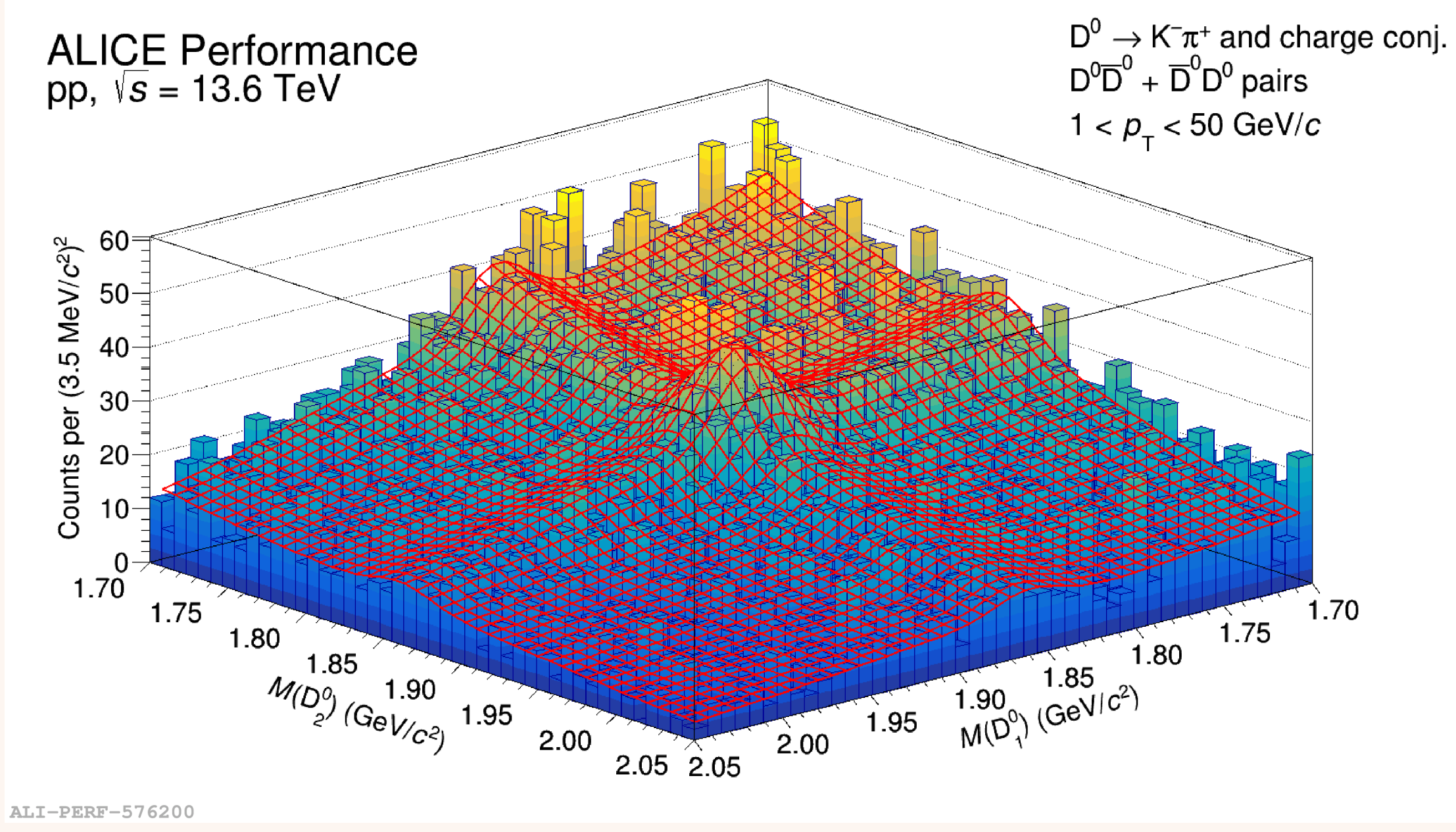
$$\sigma_{\mathrm{DPS}}^{AB} = \frac{N}{\mathcal{L} \times (\mathrm{Acc} \times \epsilon) \times BR_{\mathrm{A}} \times BR_{\mathrm{B}}},$$

where N is the raw yield, which can be obtained via a 2D invariant mass fit; $\mathcal{L}$ is the integrated luminosity; (Acc x ε) is the acceptance multiplied by the efficiency, calculated using MC simulations; and $BR_{A,B}$ is the branching ratio of the decays from which particles A and B are reconstructed, respectively.

For the double D^0 production case, to distinguish DPS from single parton scattering (SPS), we can look at different types of D^0 meson pairs:

- **Opposite-sign pairs**, like $\overline{D}^0 D^0$, will be primarily produced by SPS.
- **Like-sign pairs**, such as $D^0 D^0$, will mostly come from DPS.

The image shows the 2D invariant-mass fit of opposite-sign pairs ($D^0\overline{D}^0$ + $D^0\overline{D}^0$), which will be used to extract the SPS raw yield and will be compared with the DPS one.



Related literature

[1] **ALICE** Collaboration, *J. High Energ. Phys. 2023, 92 (2023)*.
[2] T. Sjöstrand *et al.*, *Comput. Phys. Commun.* 191 (2015) 159–177.
[3] K. Werner, *Phys.Rev.C 108 (2023) 6, 064903*.
[4] **LHCb** Collaboration, *J. High Energ. Phys. 2012, 141 (2012)*.