Charm hadronization through jets in pp collisions with ALICE

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IX Reunião Geral
Projeto Especial FAPESP "Física e Instrumentação de Altas Energias com o LHC-CERN"
26th March, 2026

Physics motivation

Is hadronization universal for charm particles?

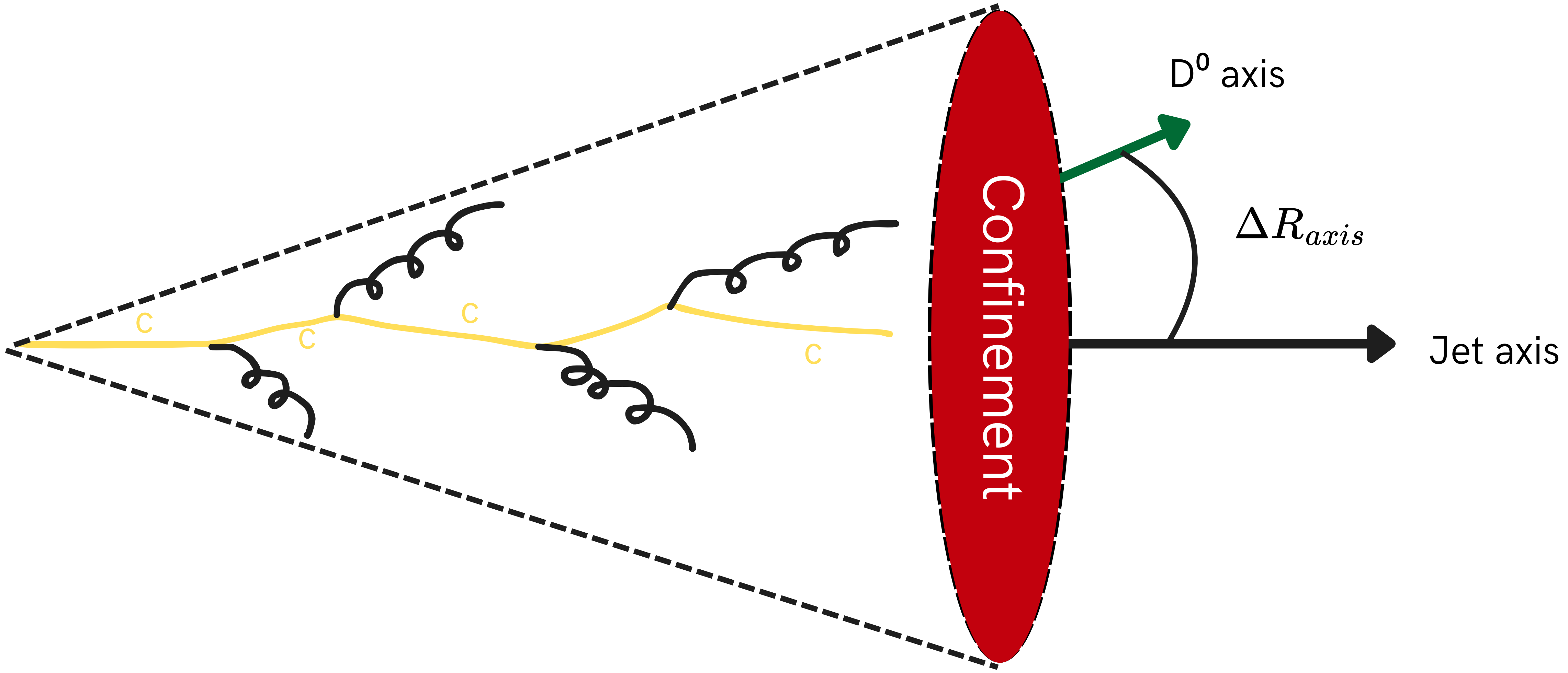
Need to rely on models.

Hadronization is a non-perturbative process.

But is it universal for charm particles?

How far away did the charm quark hadronized with respect to the initiating direction?

$$\Delta R_{axis} = \sqrt{(\Delta\eta)^2 + (\Delta\varphi)^2}$$



arXiv:2301.13798v2: "Measurement of the fraction of jet longitudinal momentum carried by Λ_c^+ baryons in pp collisions"

Decay Topology

Exclusive channel

Reconstruction of D^0

$D^0 \rightarrow K^- + \pi^+$, $B.R. = (3.947 \pm 0.030)\%$

$|y_{D^0}| < 0.8$

$1 < p_{T,D^0} < 36$ GeV/c

P(background) < optimal value (BDT score)

Jet reconstruction

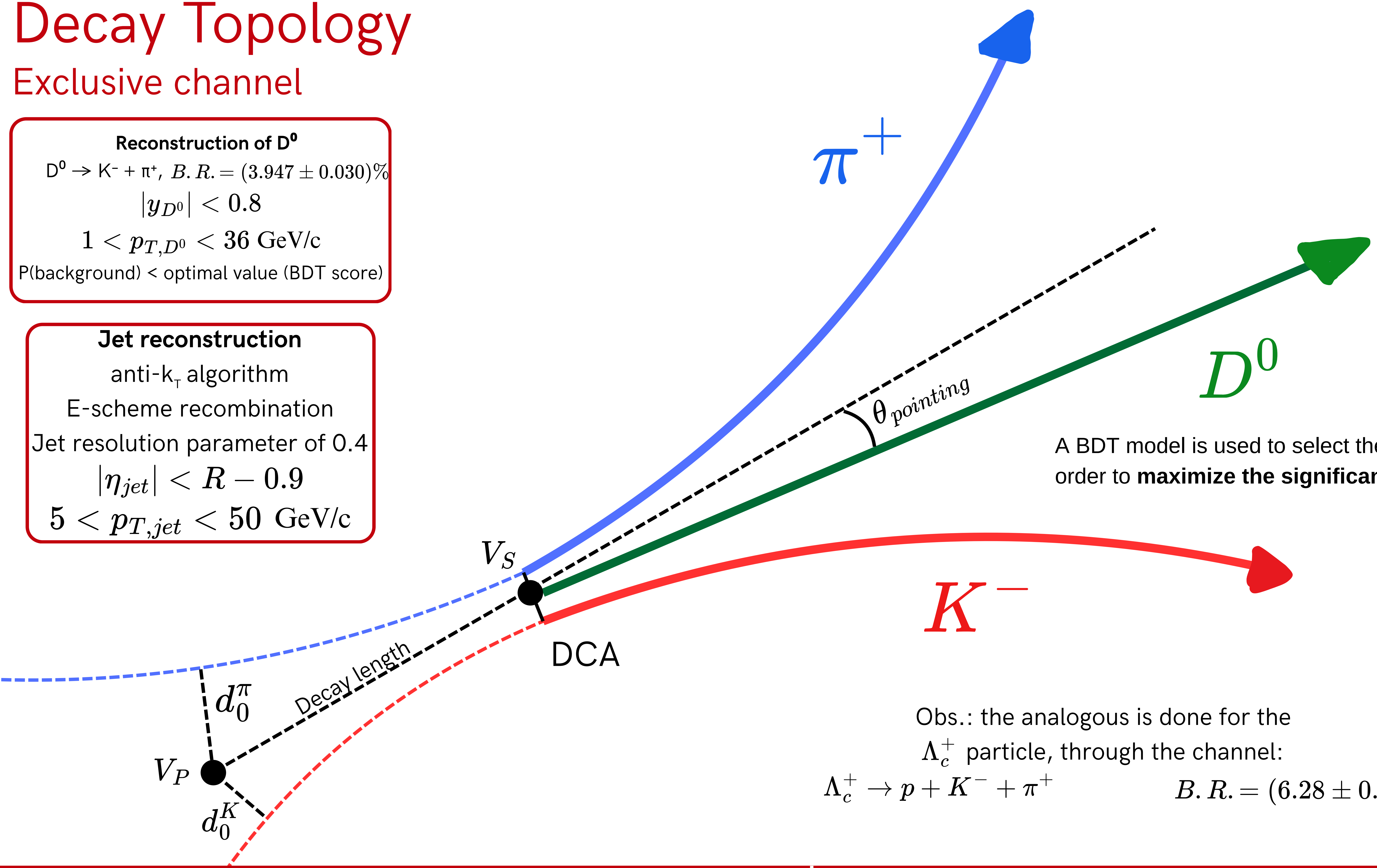
anti-k_T algorithm

E-scheme recombination

Jet resolution parameter of 0.4

$|\eta_{jet}| < R - 0.9$

$5 < p_{T,jet} < 50$ GeV/c



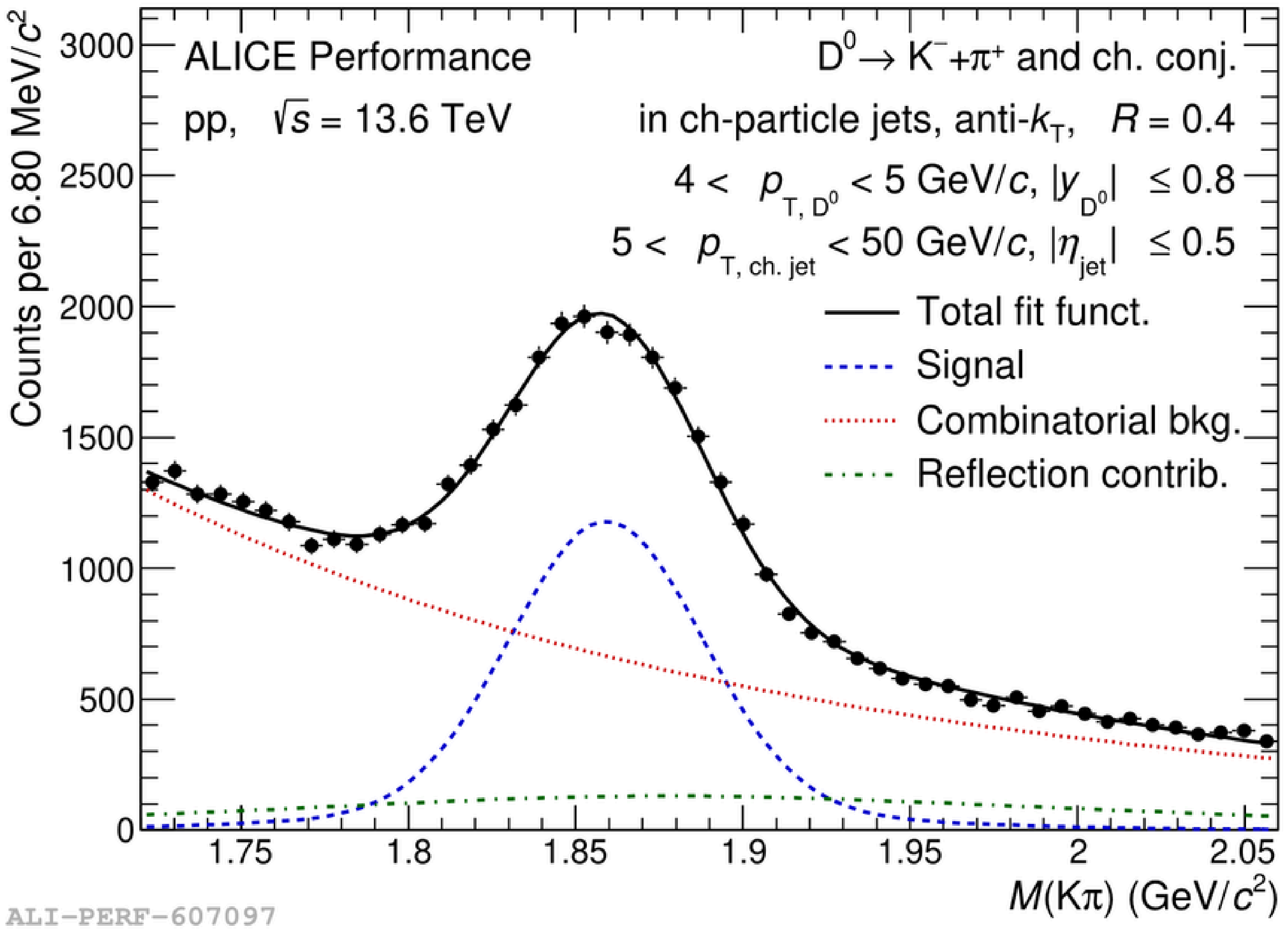
A BDT model is used to select the D^0 candidates in order to **maximize the significance**.

Obs.: the analogous is done for the Λ_c^+ particle, through the channel:

$\Lambda_c^+ \rightarrow p + K^- + \pi^+$ $B.R. = (6.28 \pm 0.32)\%$

Background subtraction

Side-bands method



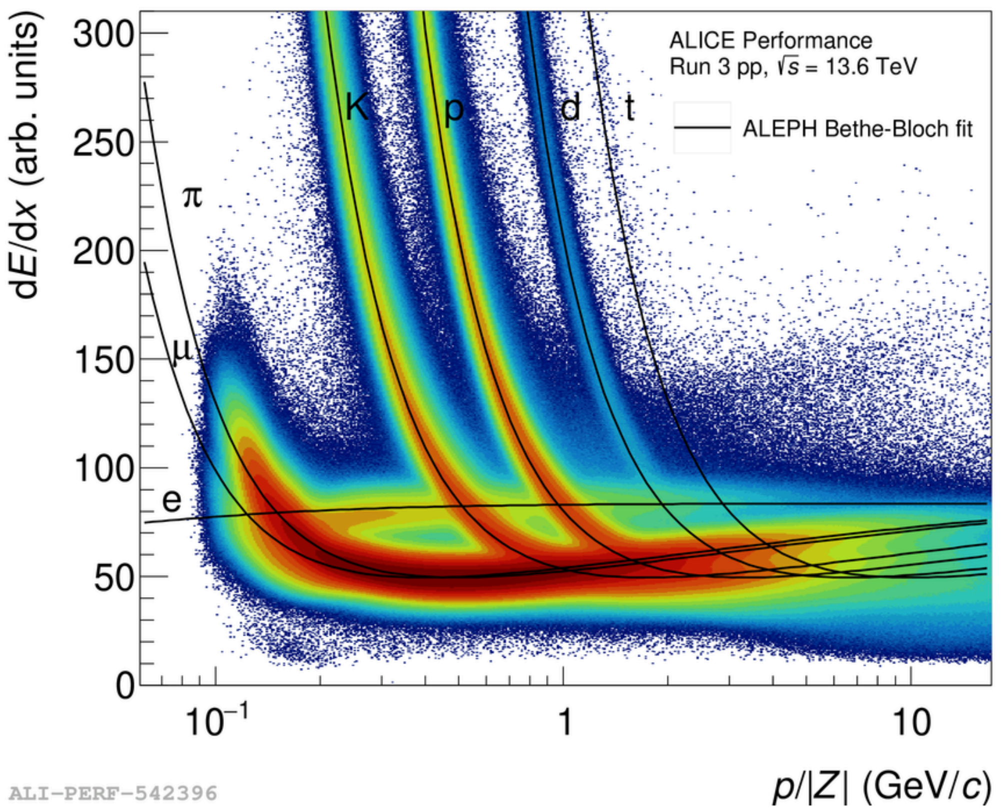
Side-band subtraction method

$$J_S = \beta\left(Y_S - \frac{B_S}{B} Y_{SB}\right)$$

Account for reflections contribution

$$\beta = \frac{S}{S + R_S - \frac{B_S}{B} R}$$

What are reflections?
Inconclusive ID between a kaon or pion



Obs.: reflections contribution is not present in Λ_c^+ distribution.

Both hypothesis are computed and stored as different candidates.

Background estimation:
shape → side-bands
fraction → fit areas

Reflections estimation:
shape → MC fit
fraction → data fit

Efficiencies

Selection efficiency

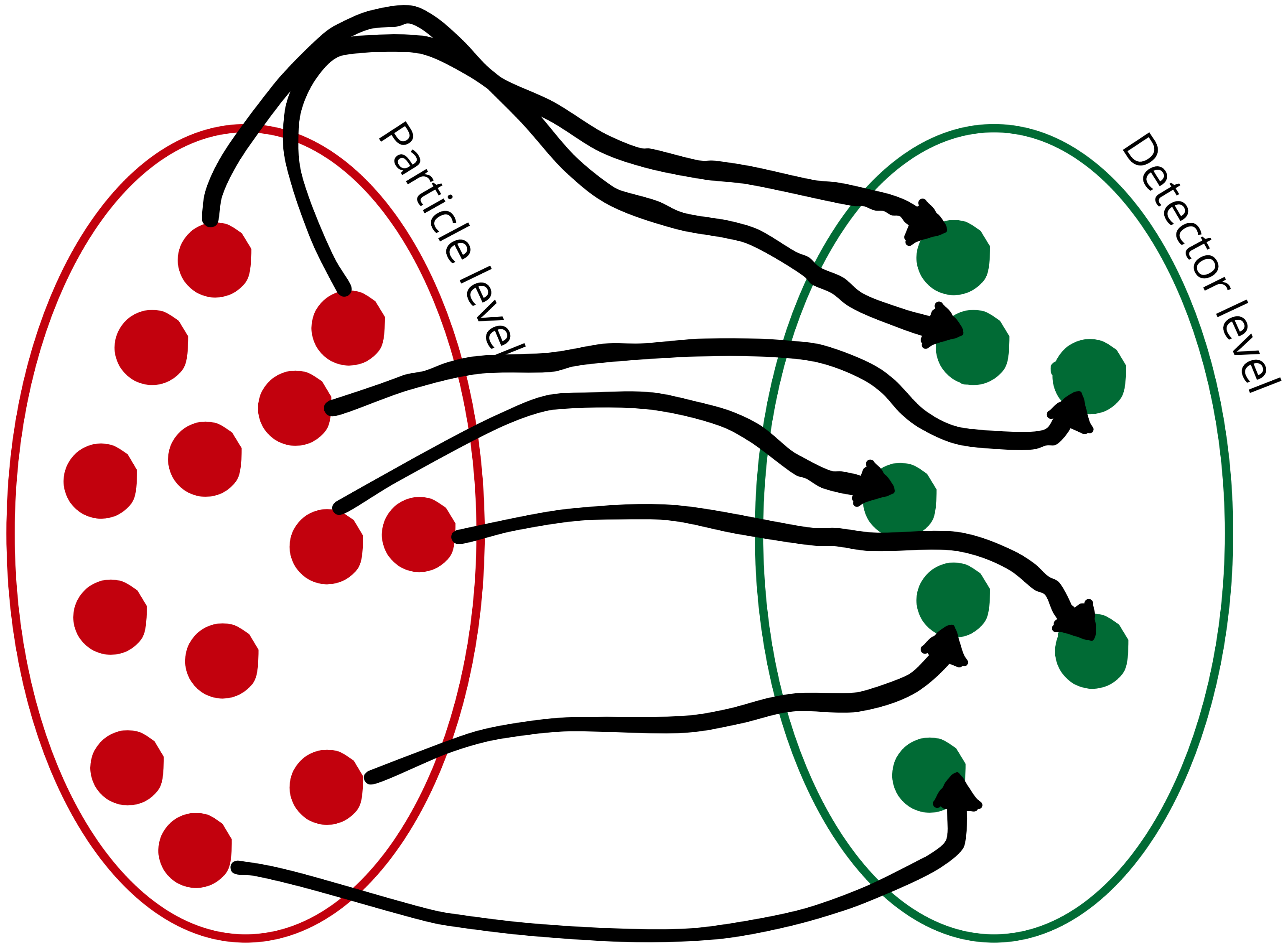
How to estimate the true number of D^0 jets?

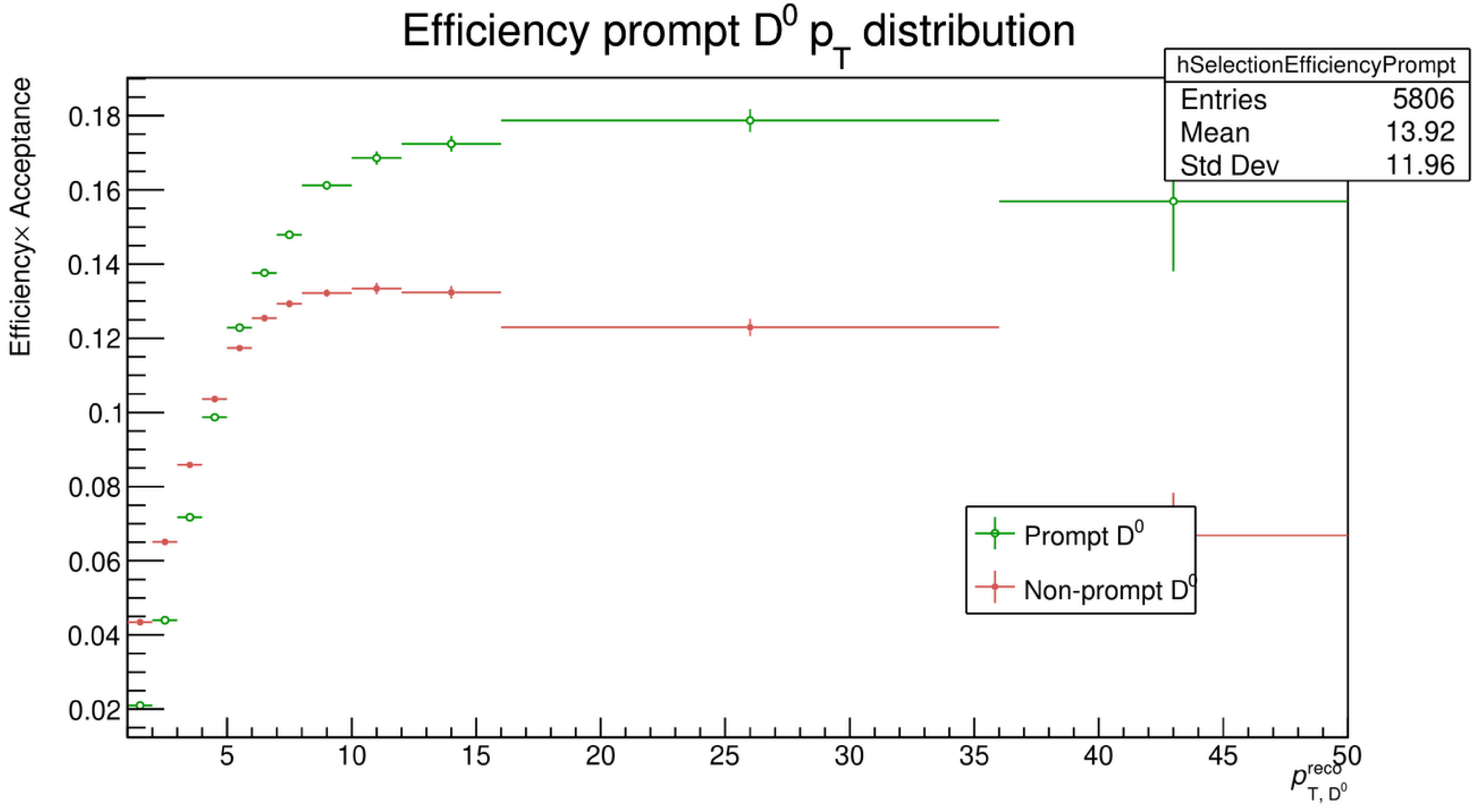
Not all of the D^0 are actually measured, due to limit detector resolution and the **selection cuts** applied to the data

$$\varepsilon(p_{T,D^0}) = \frac{N_{reco}(p_{T,D^0})}{N_{gen}(p_{T,D^0})}$$

Needs to be folded to include detector smearing effects

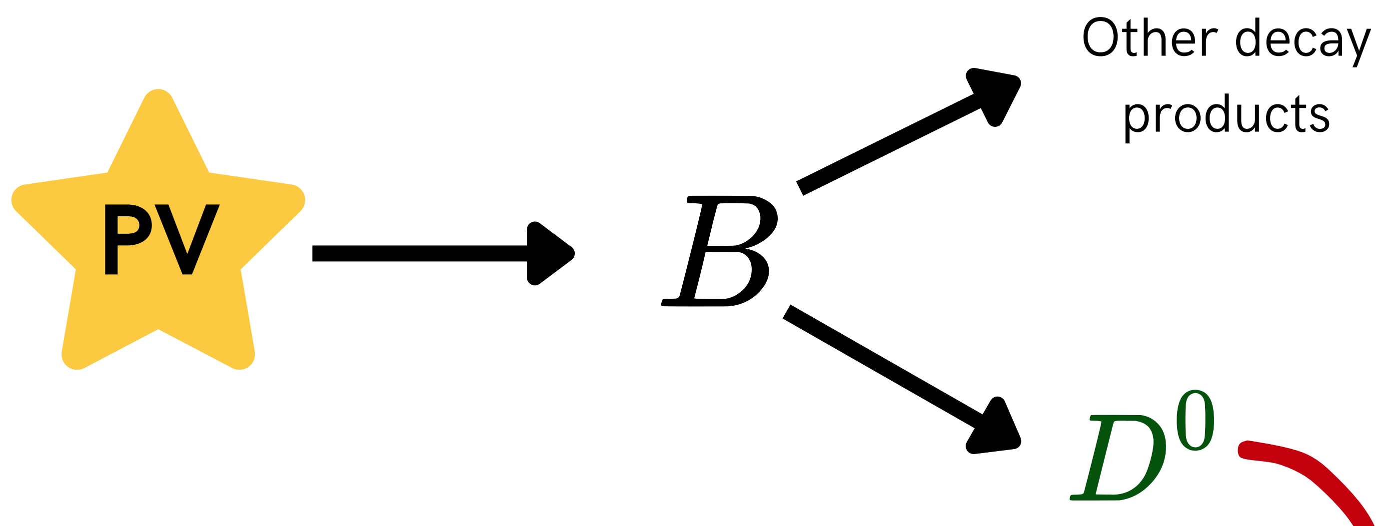
Dependent on the D^0 transverse momentum due to larger displaced vertex for more boosted cases.





Reconstruction steps

Feed-down subtraction



Not all of the measured D^0s were originated from a charm quark parton shower.
These fraction of non-prompt D^0s contaminate the sample and thus needs to be estimated and removed.

This charmed particle came from a beauty parton shower!

5-project on $p_{T,jet} \times \Delta R$

3-apply detector smearing effects

1-pure non-prompt D^0 fs particle sample

$$N^{c\to HF} = N^{b,c\to HF} - \frac{\mathscr{L}_{\text{measured}}}{\mathscr{L}_{\text{POWHEG}}} \times BR\% \times \sum_{p_{\text{T,HF}}} \frac{1}{\varepsilon^{\text{reco}}_{c\to HF}(p_{\text{T,HF}})} R^{b\to HF} \otimes \left[\varepsilon^{\text{particle}}_{b\to HF}(p_{\text{T,HF}}) \times N^{b\to HF}_{\text{POWHEG}}\right]$$

6-scaling by luminosities and BR of D^0 decay channel

4-as applied to background subtracted efficiency corrected distribution

2-only non-prompt selected D^0s should contribute

Shape estimated with truth level PYTHIA+POWHEG simulation of non-prompt D^0's

Reconstruction steps

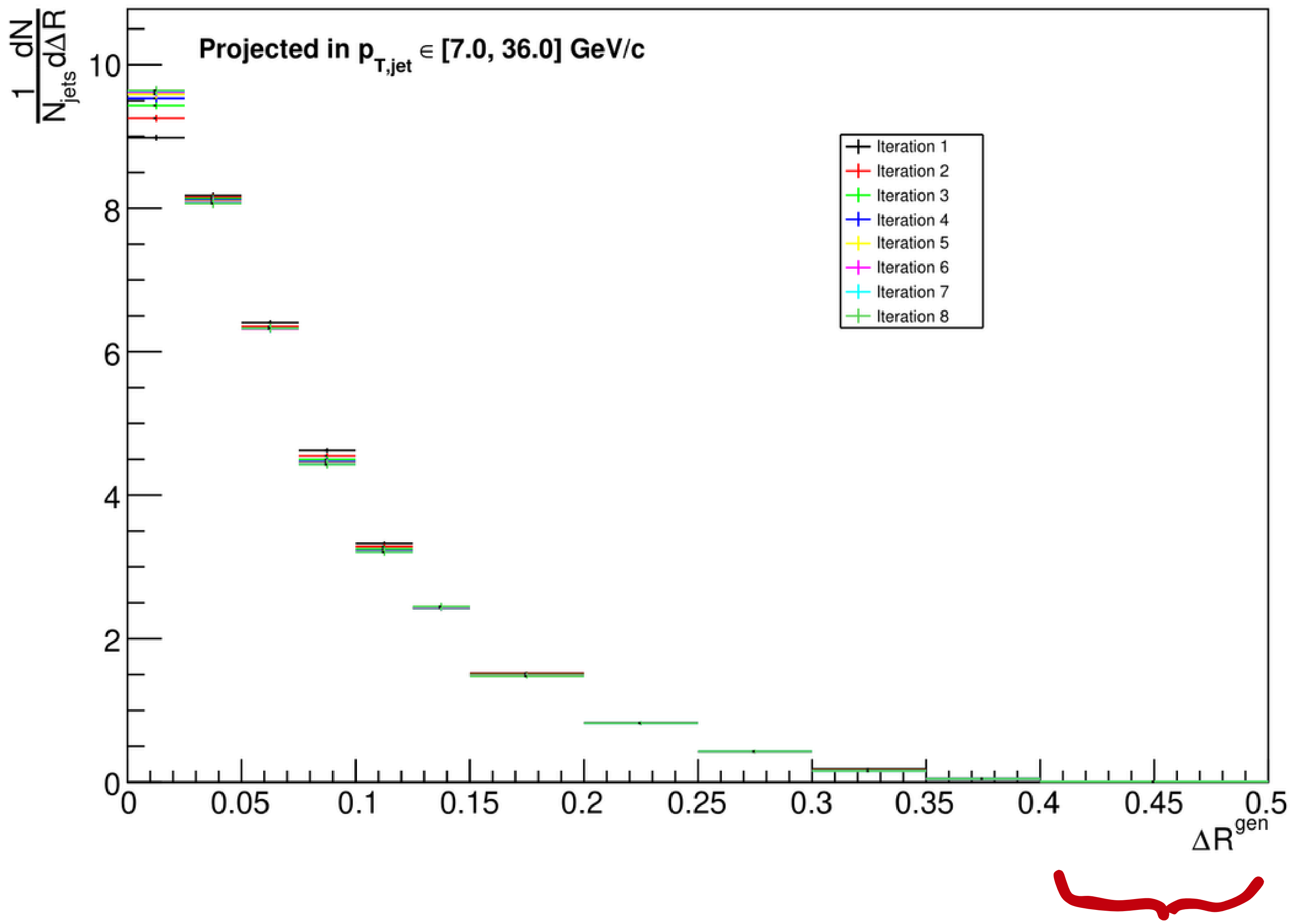
Unfolding

Obs.: Kinematic efficiency correction applied before and after the **unfolding procedure**

Response matrix → transition probability between bins of kinematic variables

$$M = R \times T$$

Unfolded with $\epsilon_{kin}^{particle}$ correction, self-normalized



Obs.: 0.4-0.5 bin was used for padding during the unfolding procedure and will not be included in the reported final result.

Bayesian unfolding

$$p(T/M) = \frac{p(M/T)p(T)}{p(M)}$$

Use a model of the measurement P(M|T) and thus obtain the true T given the measured M distributions

Iterations number

- if it is too high, the bigger the propagated error bars
- if it is too low, can't be sure if the result converges

Closure tests

One method to validate the methodology is through closure tests.

Particle level simulation data

ALICE reconstruction machinery

Corresponding detector level simulation data

Statistical methodology

MC data sample randomly split in 2

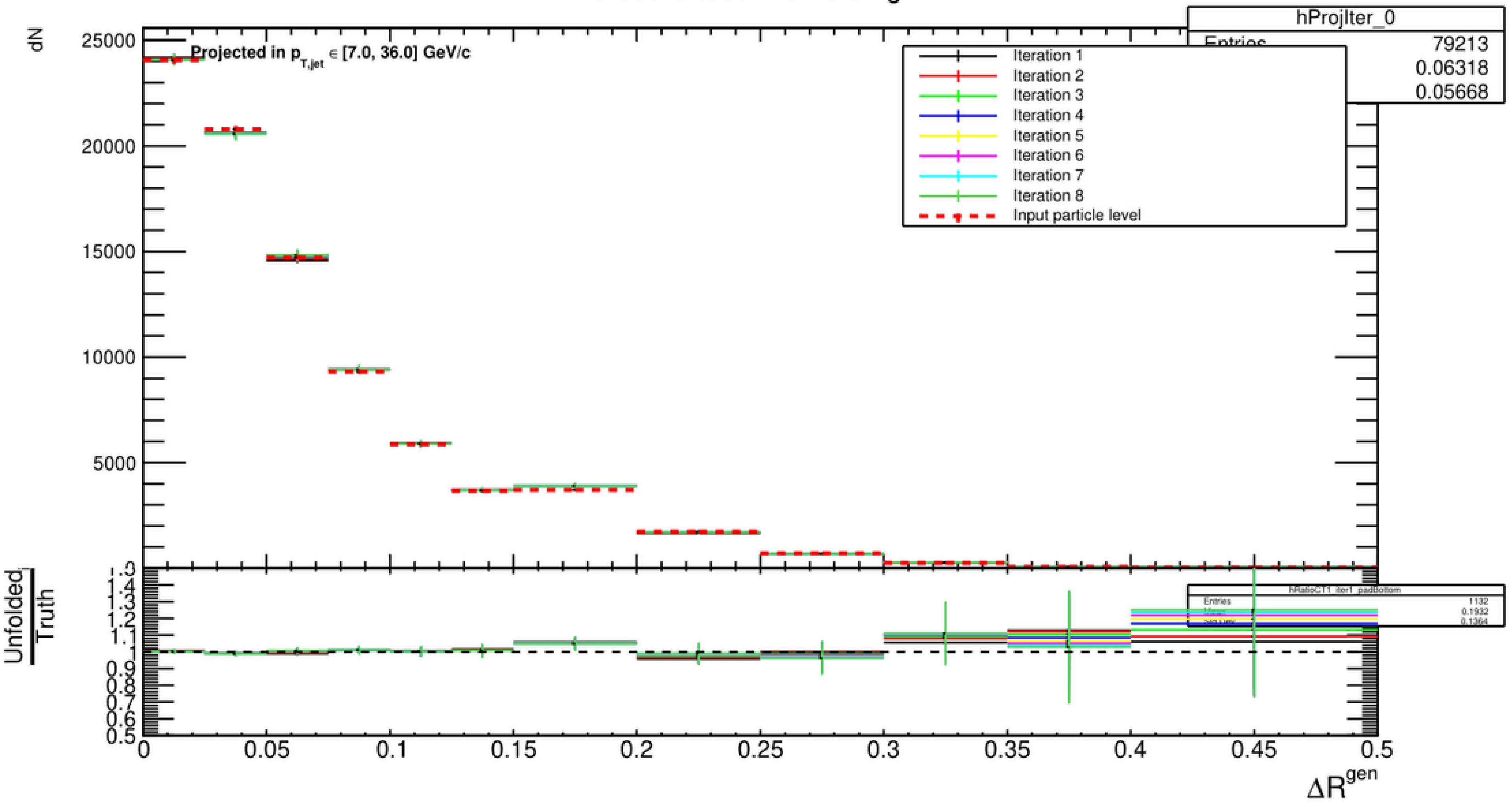
20% - input sample

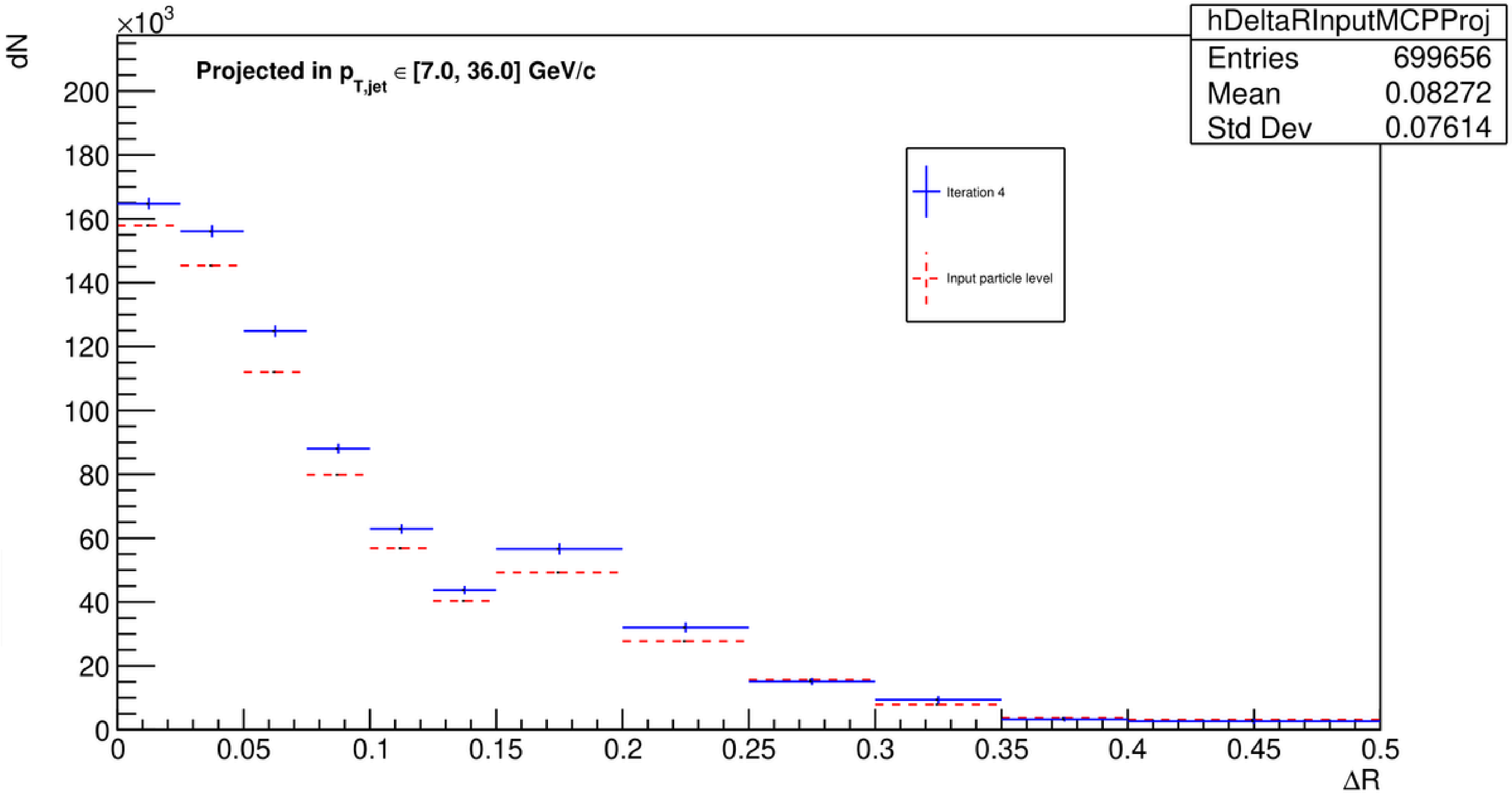
80% - correction sample
efficiencies and response matrices

Closure tests

First: unfolding

Closure test 1: unfolding





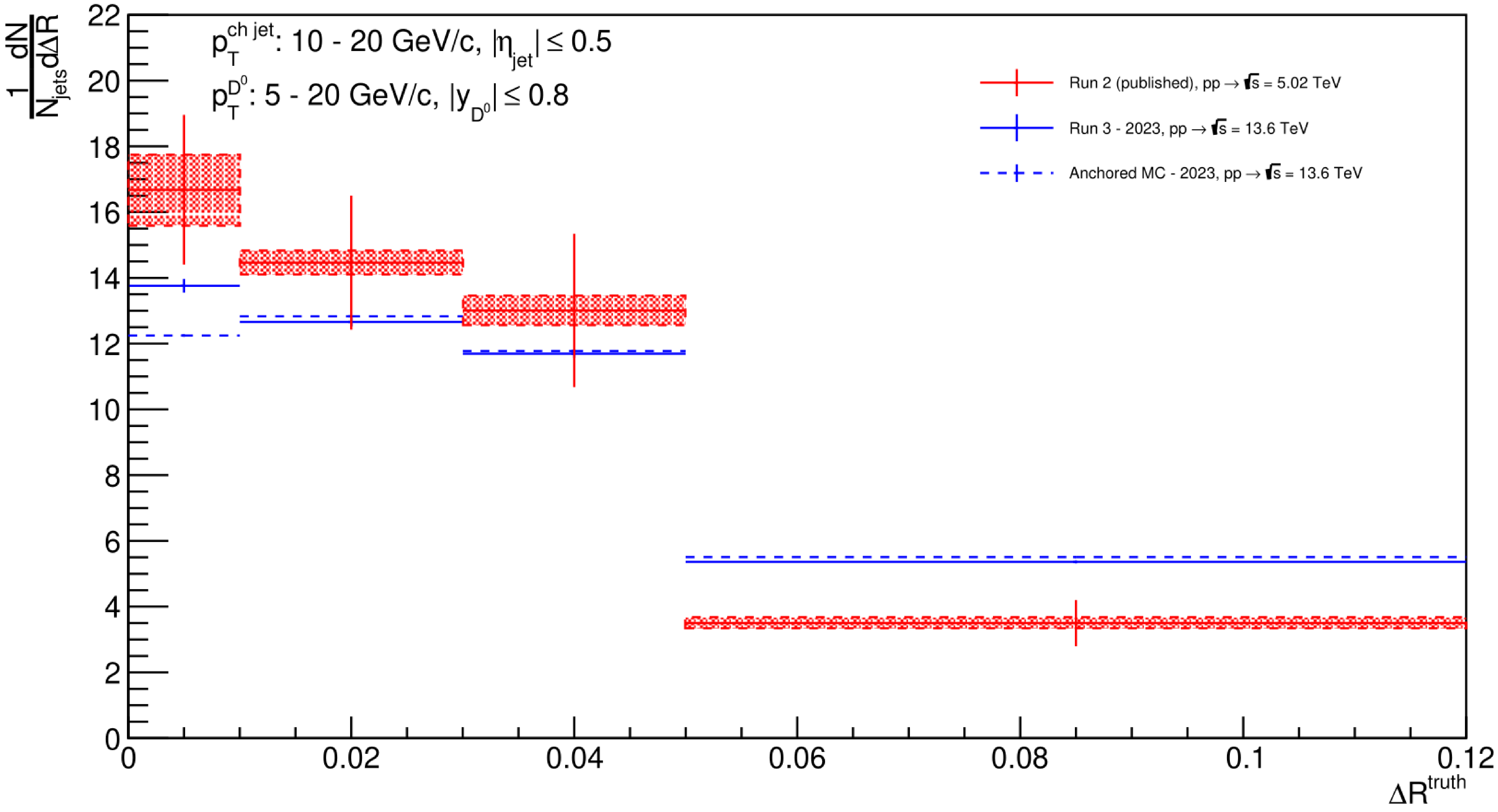
Second:

- background subtraction
- + efficiency correction
- + unfolding

Run 2 measurement

Comparison

Although disagreement is observed with previous result, several points remain opened for this analysis and needs to be investigated and corrected.



Run 2 paper: arXiv:2504.02571v1

Conclusion

The universality of charm quarks hadronization can be explored throughout different heavy-flavor jets.

As the mechanism that describes the parton shower evolution is stochastic, the radial profile observable could be used in other to notice difference in just hadronization for different baryons.

The radial profile measurement is close to its end for the D^0 meson but still has much of the path to be traversed for the baryon. If there is enough time, the Λ_c^+ measurement will also be performed allowing for a more robust comparison result.

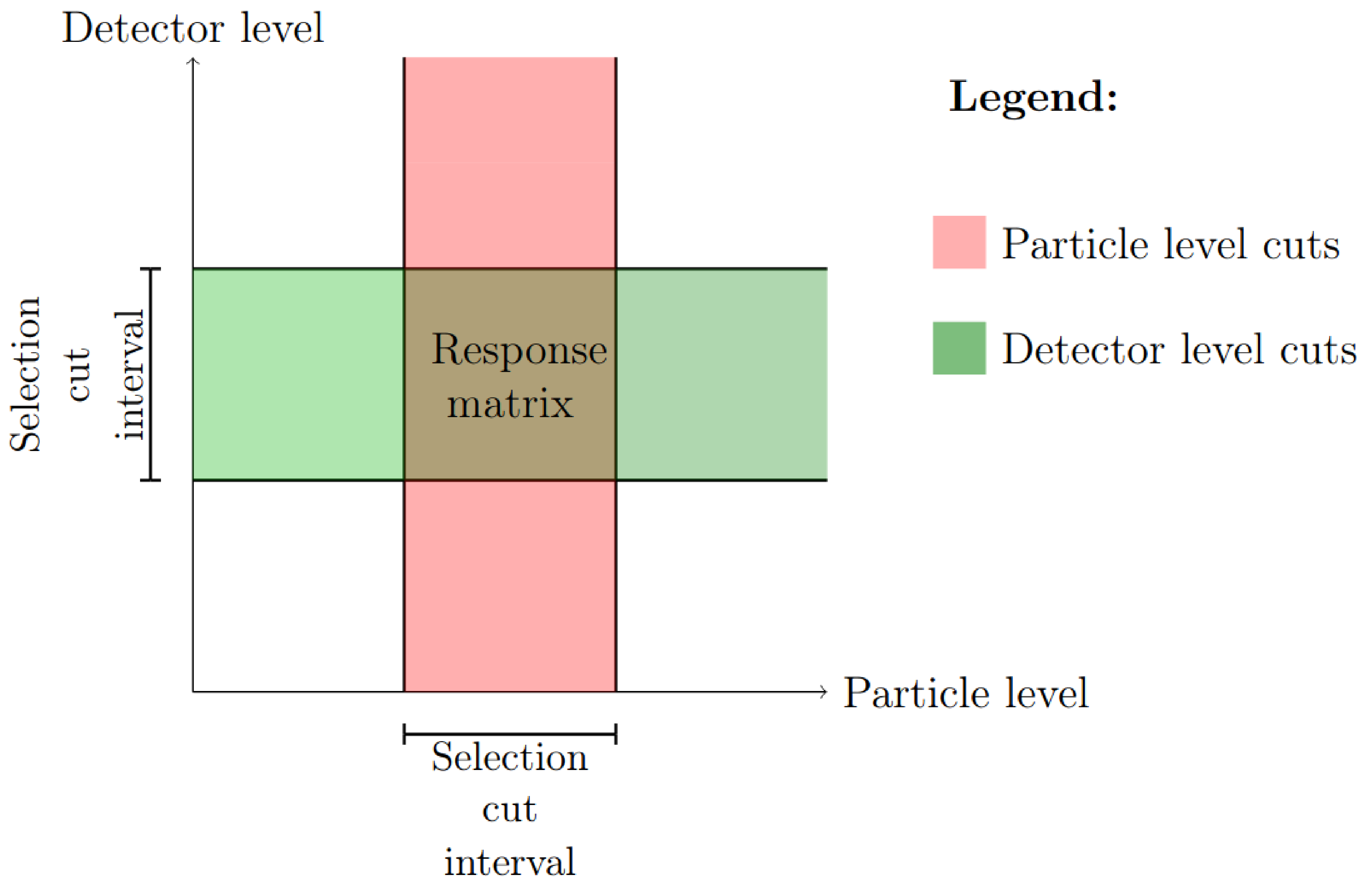
Thank you!

Backup

Efficiencies

Kinematic efficiency

The response matrix can only describe entries within the chosen kinematic range in its definition. This requires correction to data for appropriate usage of the response matrix:



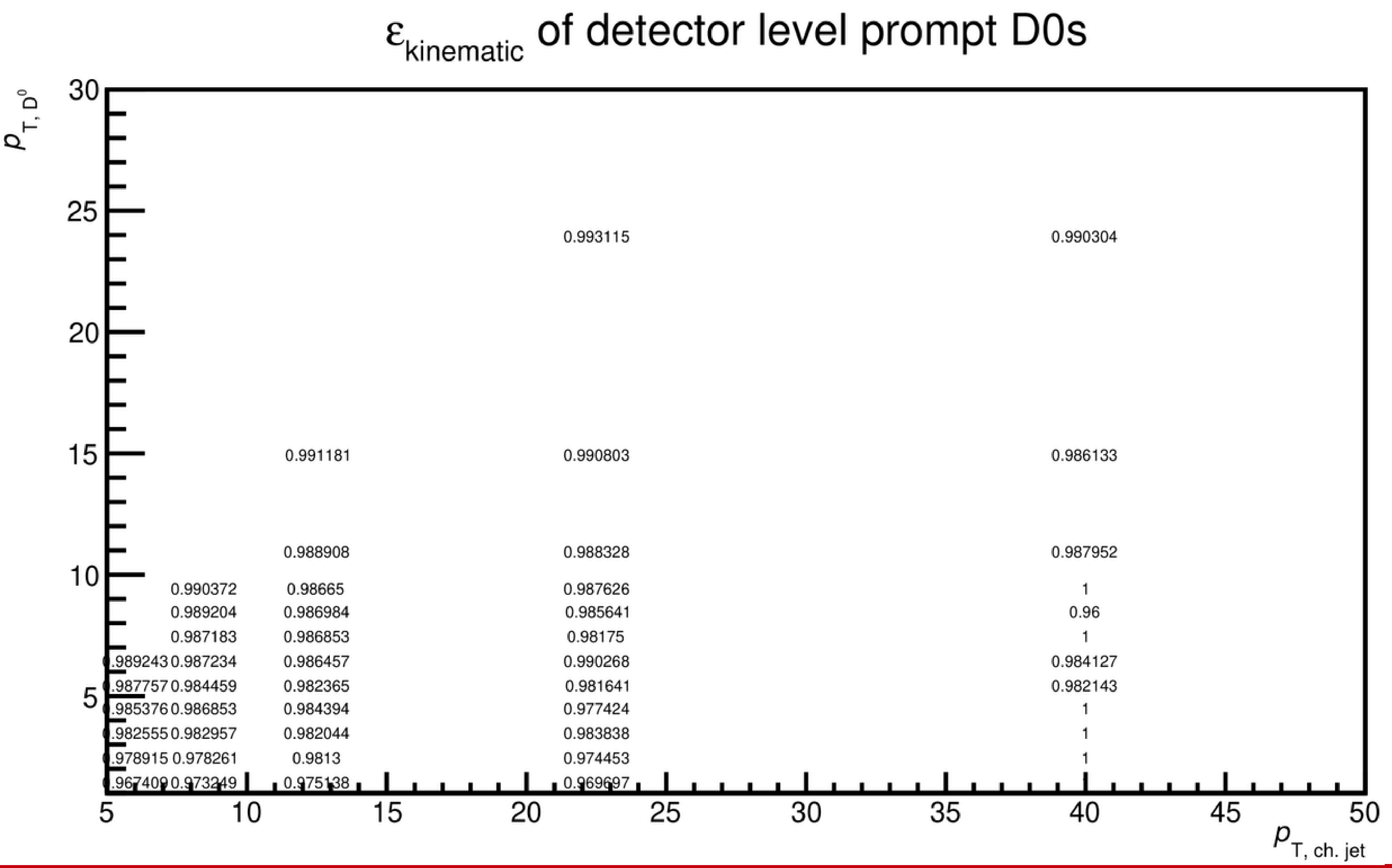
1. removal of not described entries $\times \left(\varepsilon^{particle}_{kinematic}\right)$
2. conversion of the data level to "detector"
3. addition of not described entries $\times \left(\varepsilon^{detector}_{kinematic}\right)^{-1}$

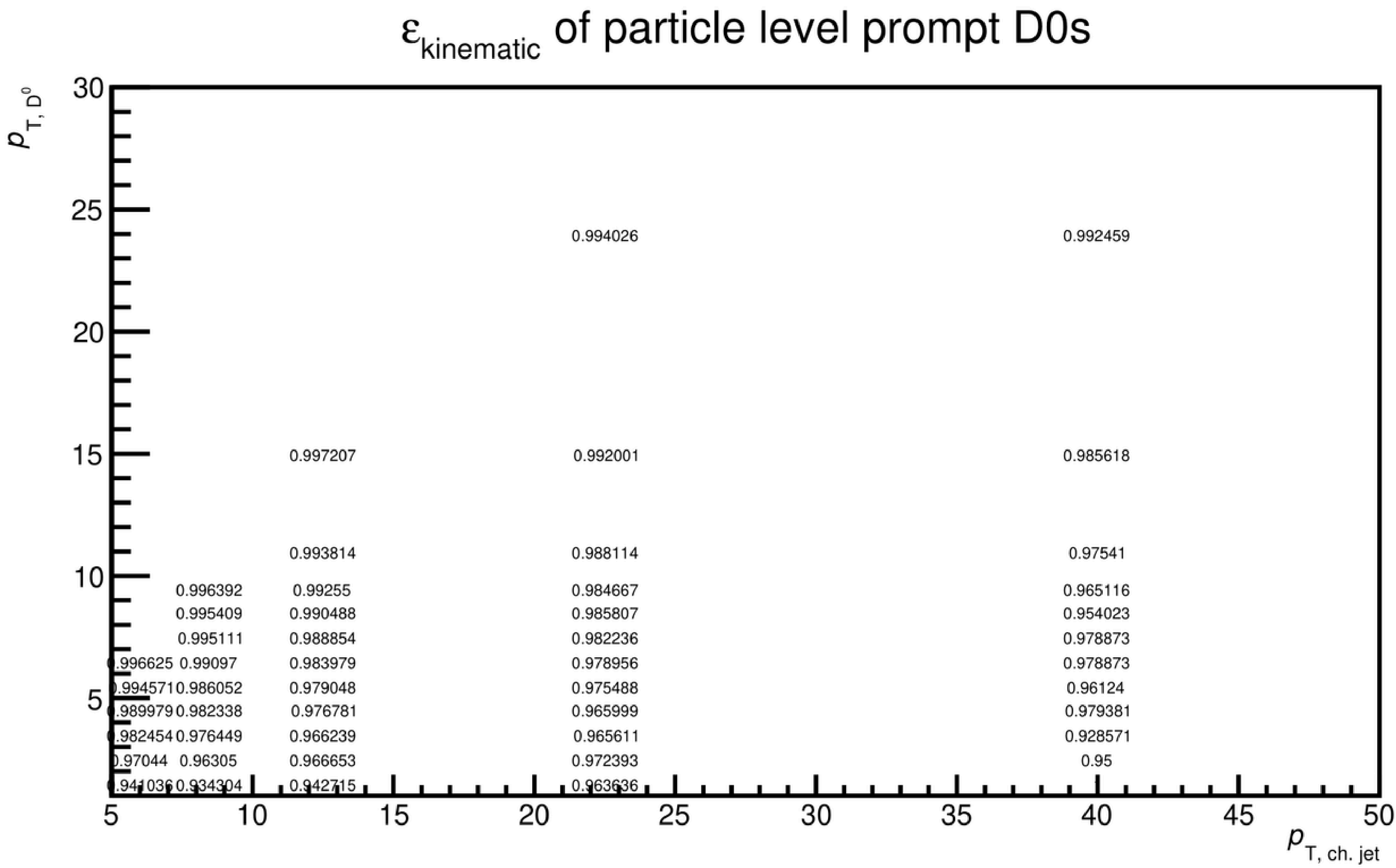
$$\varepsilon^{particle}_{kinematic} = \frac{\text{particle level cuts} \cap \text{detector level cuts}}{\text{particle level cuts}}$$

Efficiencies

Kinematic efficiency

The analogous distributions are also obtained for non-prompt D^0 jets.





Reconstruction

Observable extraction method

Jet reconstruction

anti-k_T algorithm

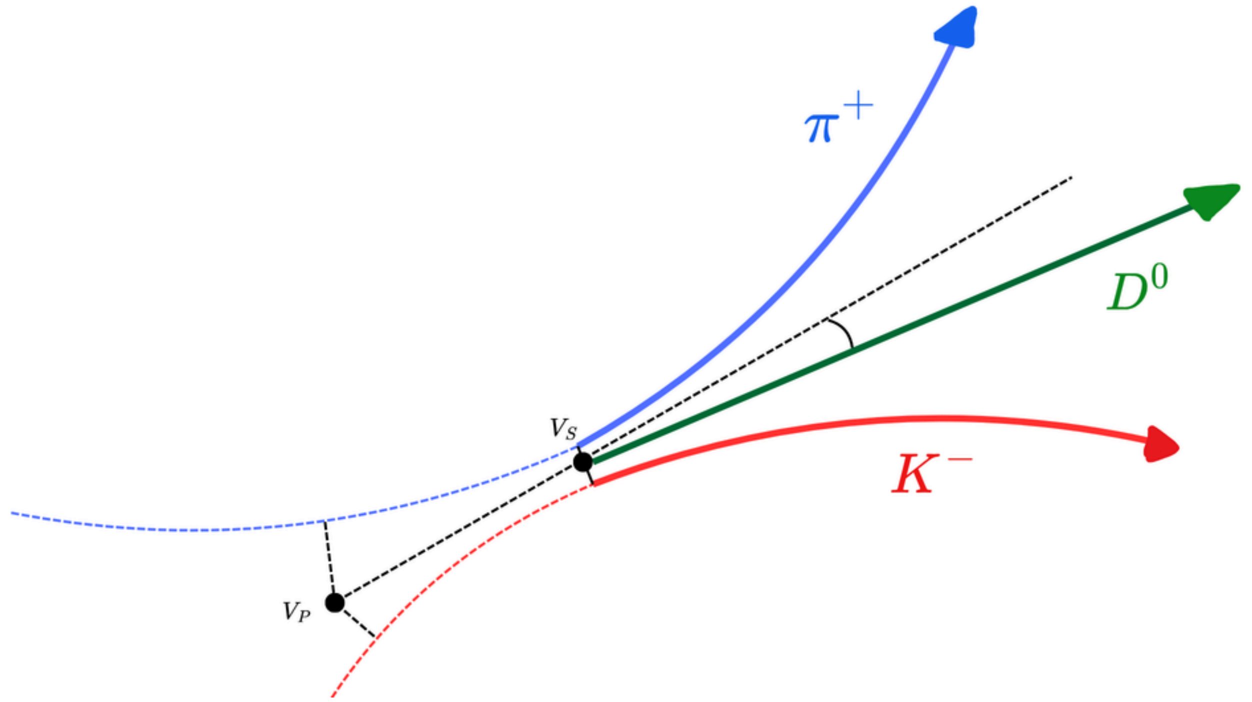
E-scheme recombination

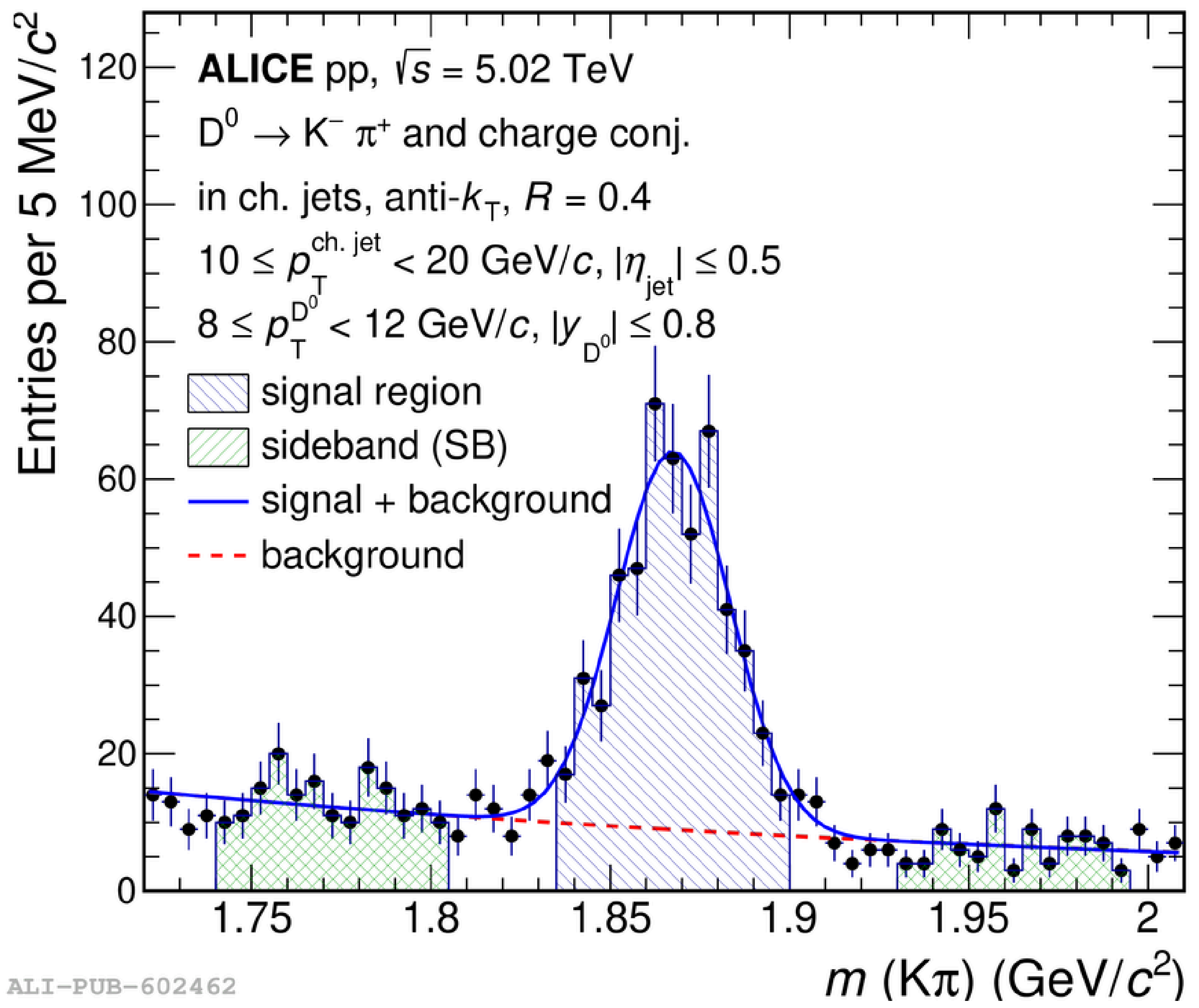
Jet resolution parameter of 0.4

Reconstruction of D^0

$D^0 \rightarrow K^- + \pi^+$ $\quad B.R. = (3.947 \pm 0.030)\%$

Displaced vertex topology cuts





Real D^0 extraction

removal of combinatorial background → side-band method

removal of wrong mass hypothesis D^0 (reflections) → MC-simulation templates

Reconstruction

Observable extraction method

$$\varepsilon(p_{T,D^0}) = \frac{N_{reco}(p_{T,D^0})}{N_{gen}(p_{T,D^0})}$$

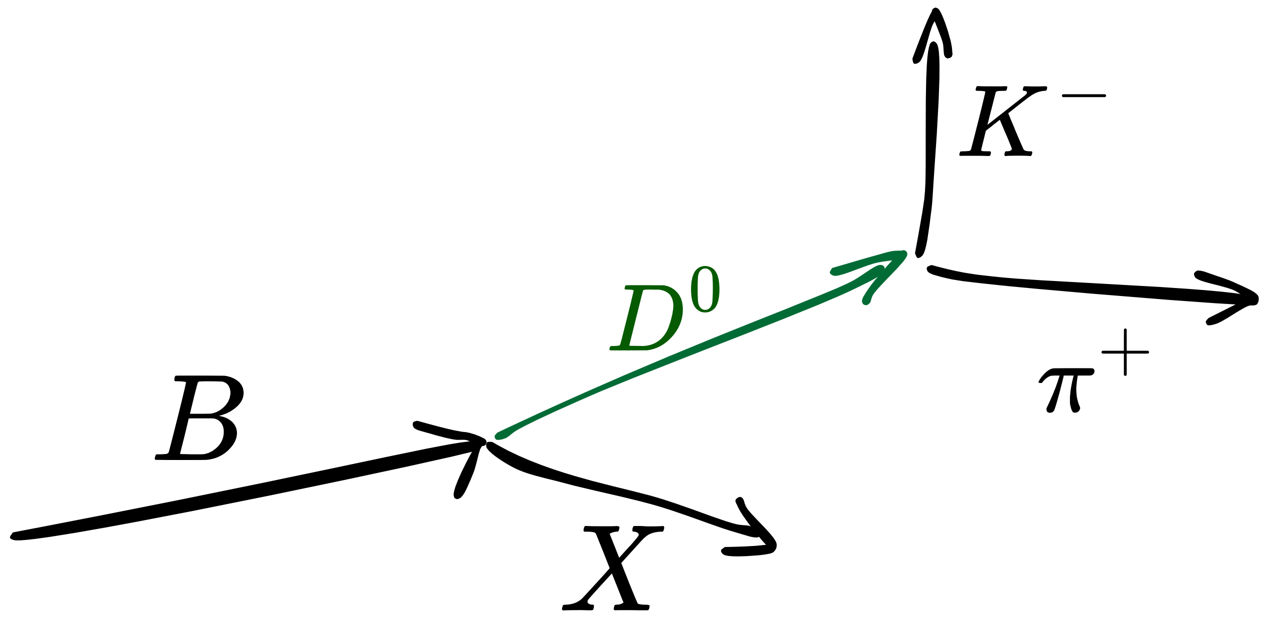
Efficiency correction

estimate the true number of D^0 jets → dependent on the D^0 transverse momentum

B feed-down subtraction

removal of non-prompt D^0's → MC template

$$B \rightarrow D^0 + X$$



Detector effects

smearing due to limited tracking efficiency and p_T resolution → unfolding/bin-by-bin

track merging correction

Financial support

FAPESP

I would like to thank for the financial support given
by the São Paulo Research Foundation FAPESP.
(Grant 2021/06976-6)