Flavor tagging of neutral D mesons

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Introduction

Flavor tagging of neutral D mesons is fundamental in CP violation analysis in the charm sector:

$D^{*+} \to D^0 \pi^+$; $D^0 \to K_s \pi^+ \pi^-$

$D^0 \to \pi^+ \pi^-$, $K^+ K^-$

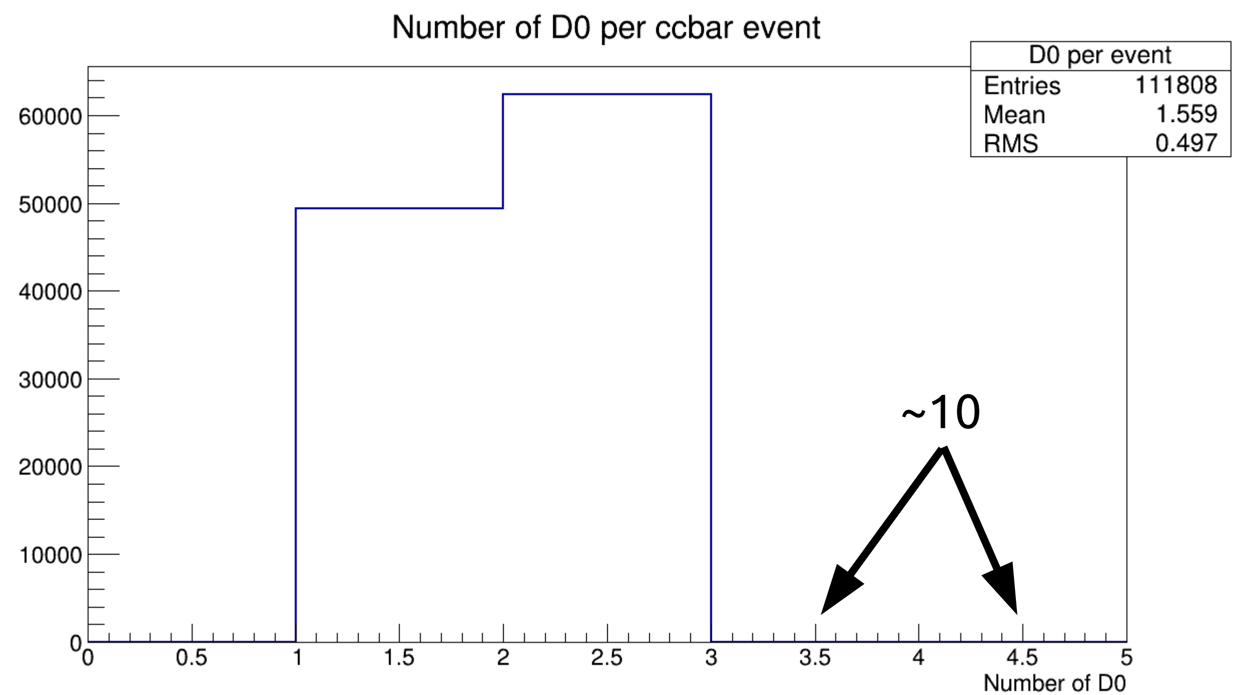
$D^0 \to K \pi$

At present, the standard experimental technique to tag the flavor of D^0 at production is to use this tagging decay:

$D^{*+} \to D^0 \pi^+$

where the charge of (soft) pion determines the flavor of the neutral D.

How many D^0 are produced in a $c\bar{c}$ event?



In 100k $c\bar{c}$ events there are 111808 generated D^0 (at the generator level, no reconstruction).

These events come from the MC production 5.0 ($c\bar{c}$ events without background).

The average number of generated D^0 per event is 1.5.

These D^0 come from:

- 41% directly from virtual photons ($e^+ e^- \rightarrow \gamma^* \rightarrow c\bar{c}$);
- 35% from D^{*0} ($D^{*0} \rightarrow D^0 \pi^0$);
- 24% from D^{*+} ($D^{*+} \rightarrow D^0 \pi^+$) ← at present we use only these for CP violation analysis

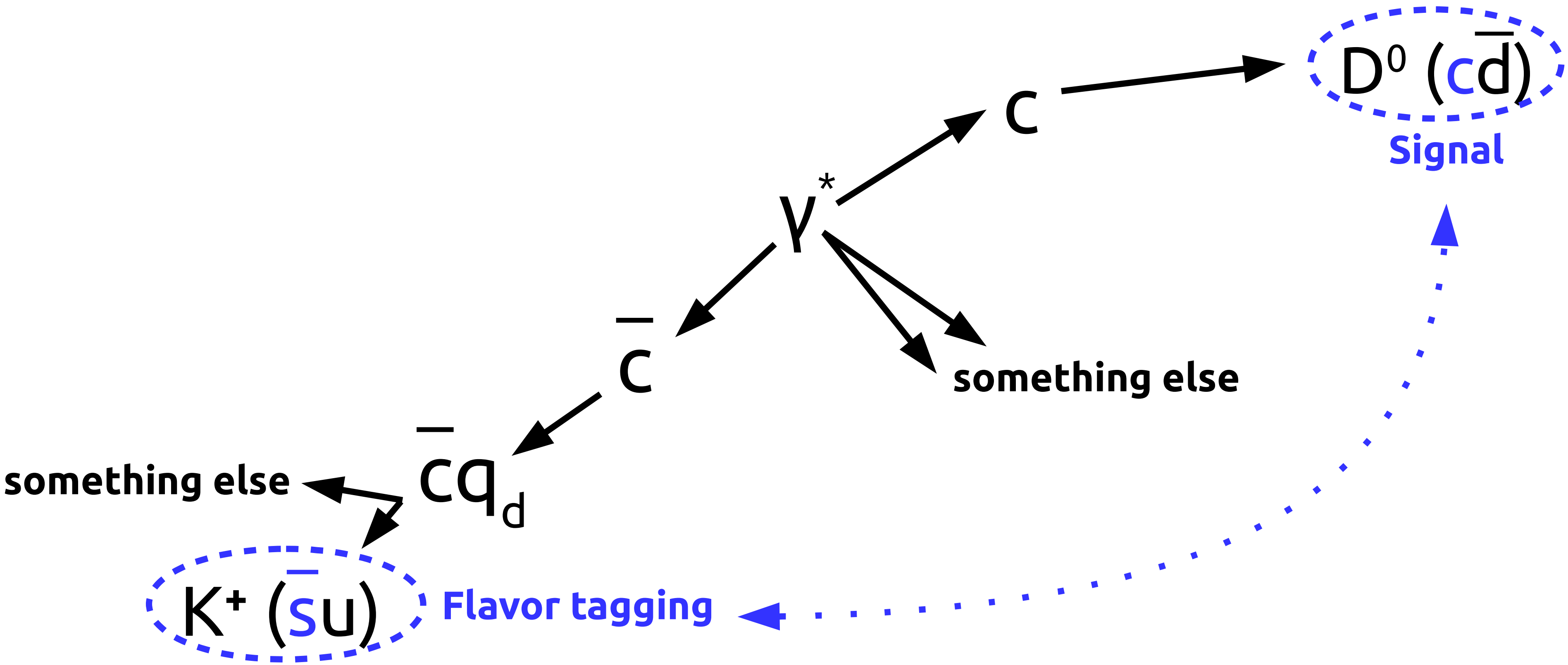
So, now we don't tag ¾ of D^0 produced.

The idea - Principle

The purpose of my work is finding an alternative method to correctly tag the flavor of a D^0, without the (strong) request that it is generated by a D^{*+}:

- increasing the statistics
- providing control samples for other analysis

The idea that I'm investigating is to tag the D^0 flavor looking the rest of the event (= particles not coming from the decay of signal D^0).



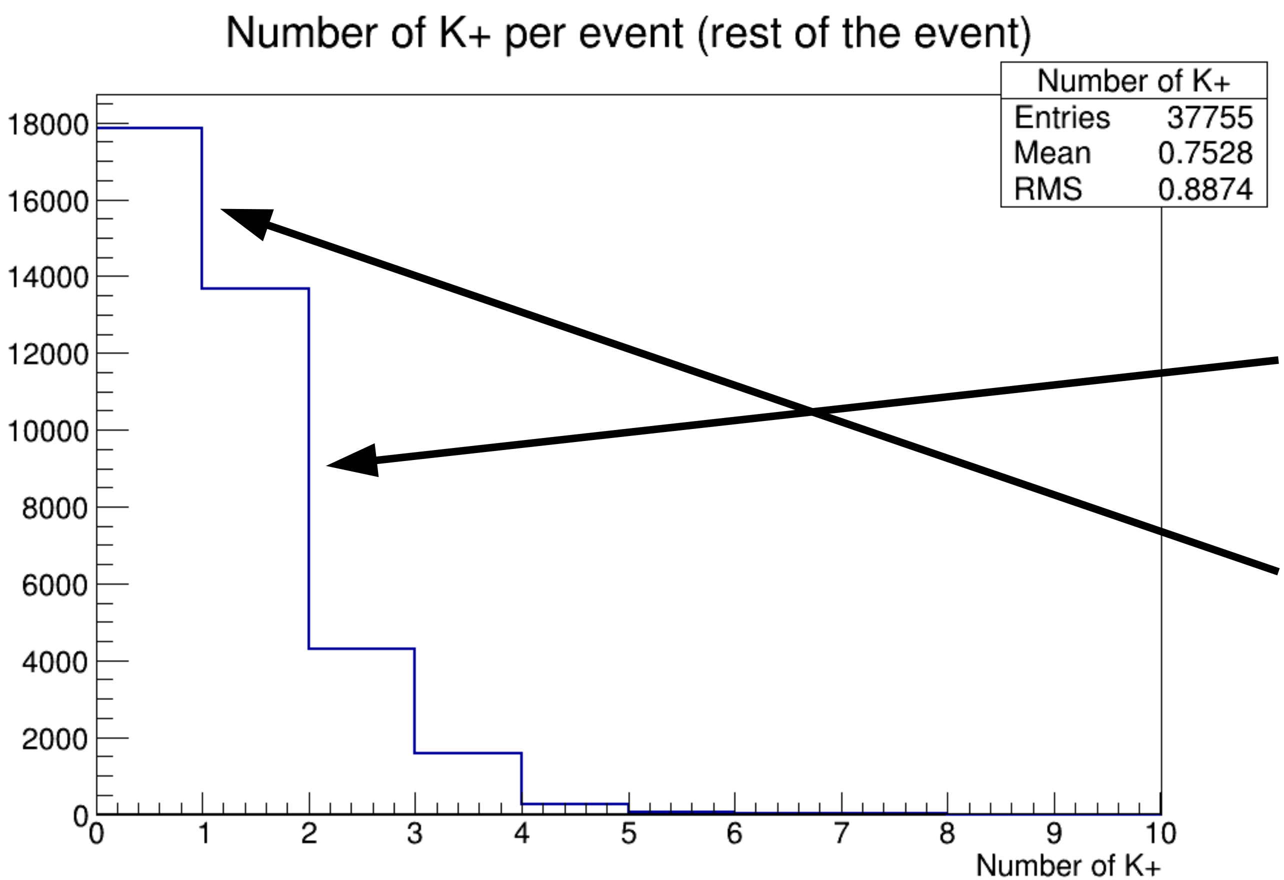
The idea - Minimum criteria

1) a D^0 in the event not coming from a D^{*+};

→ in principle this method can tag also these D^0

2) only one D^0 in the event;

3) only one K^+ candidate in the rest of the event (= ROE).



36% of the events with 1 D^0 have only 1 K^+ in the rest of the event.

50% of the events with 1 D^0 have 0 K^+ in the rest of the event, and are rejected.

Shown events (from MC) with criteria 1 and 2 applied

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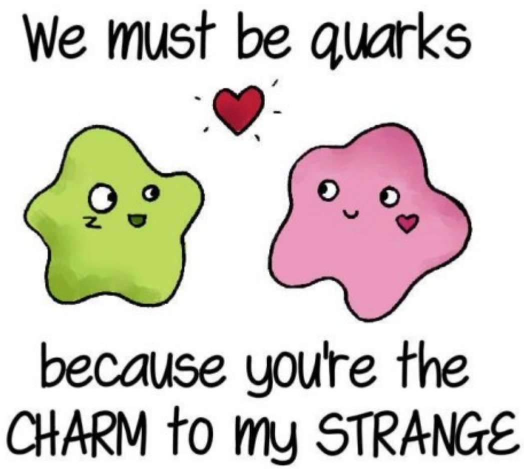

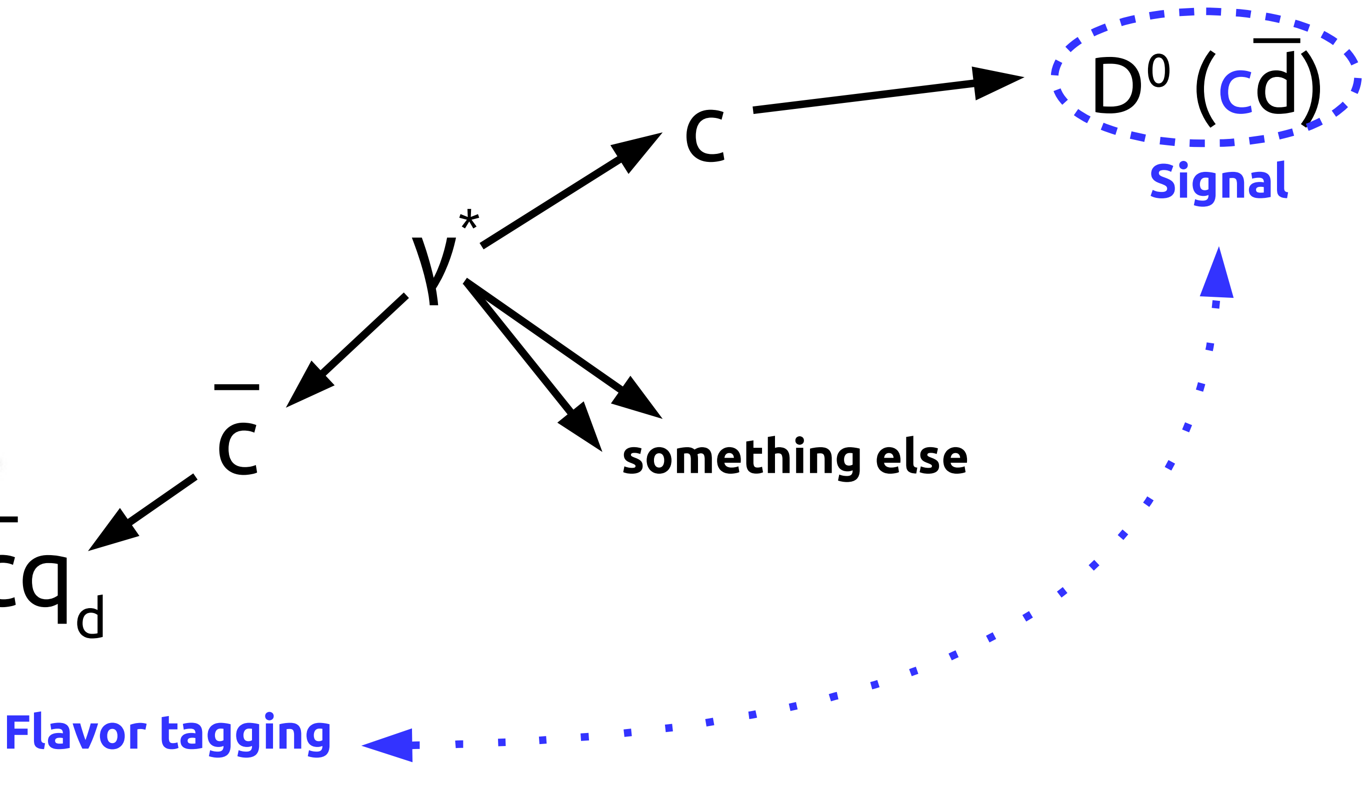

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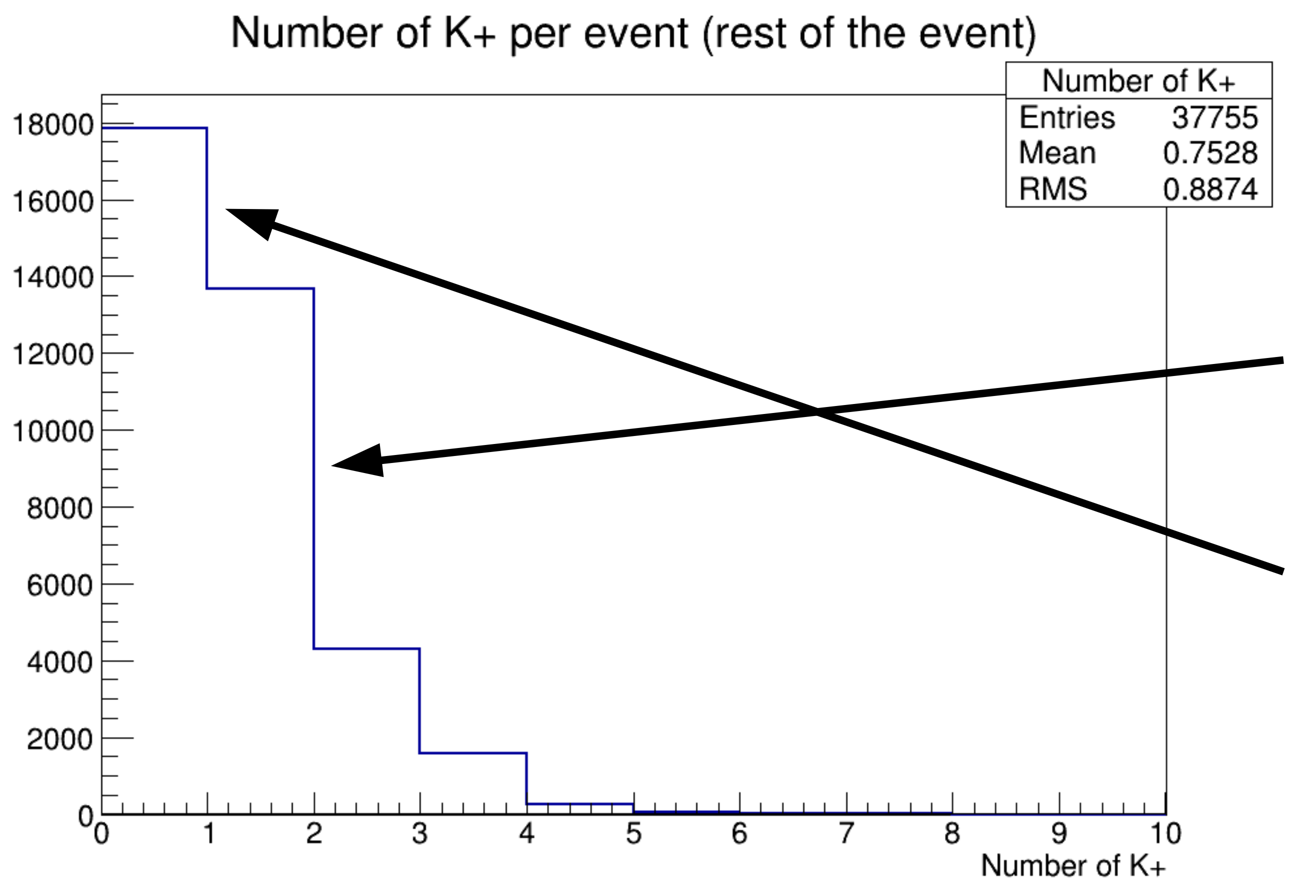

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The analysis process

1) I have generated a sample of 10k ccbar events (using the release 00-05-03 of basf2 software), with detector simulation and reconstruction

   1a) I requested at least 1 D^0 per event

   1b) I "forced" the D^0 to decay in $K^- \pi^+$

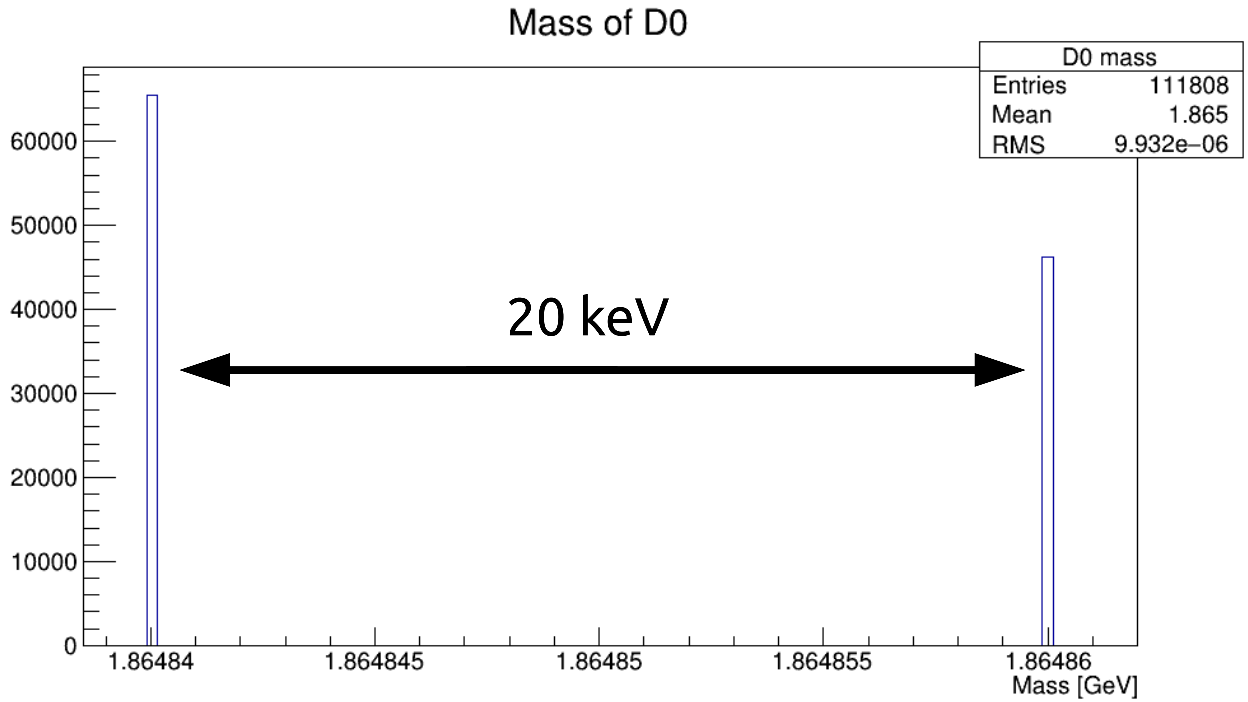
2) From the mDST .root file I reconstructed $D^0 \rightarrow K^- \pi^+$ and K^+, saving the list of candidates in a uDST .root file

3) The data are been analyzed with an analysis module for basf2 that I have written

Analyzing the data event per event with basf2 module instead of using a flat .root file generated using the tools provided by the software I save a lot of time: ~ 15 s vs. ~ 150 s for 10k events.

First look at generated informations

I have found a little* incosistency in the generated MC data: some particles (like D^0) have a different value of generated mass (!!!).



The problem is that some informations used by EvtGen (contained in evt.pdl) are not consistent with the same informations used by PYTHIA (ParticleData.xml).

EvtGen and PYTHIA teams will probably fix this.

*The problem is not critical since the differences between mass values are really small.

Signal events

My signal events must have:
- 1 D^0 correctly reconstructed;
- 1 K^+ correctly reconstructed in the rest of the event (called "tagging K^+"):

A correctly tagging K^+ comes from a D^- or a Λ_c^-.

Examples of signal events are:

$$c\,\bar{c} \rightarrow D^0\, D^-\, X\,;\; D^0 \rightarrow K^-\,\pi^+\,;\; D^- \rightarrow K^+\,\pi^-\,e^-\,\bar{\nu}_e$$

$$D^- \rightarrow K^{*0}\,e^-\,\bar{\nu}_e\,;\; K^{*0} \rightarrow K^+\,\pi^-$$

$$c\,\bar{c} \rightarrow D^0\,\Lambda_c^-\,X\,;\; D^0 \rightarrow K^-\,\pi^+\,;\; \Lambda_c^- \rightarrow \Delta^{--}\,K^{*+}\,;\; K^{*+} \rightarrow K^+\,\pi^0$$

~ 54% of all $c\bar{c}$ events with 1 K^+ in ROE

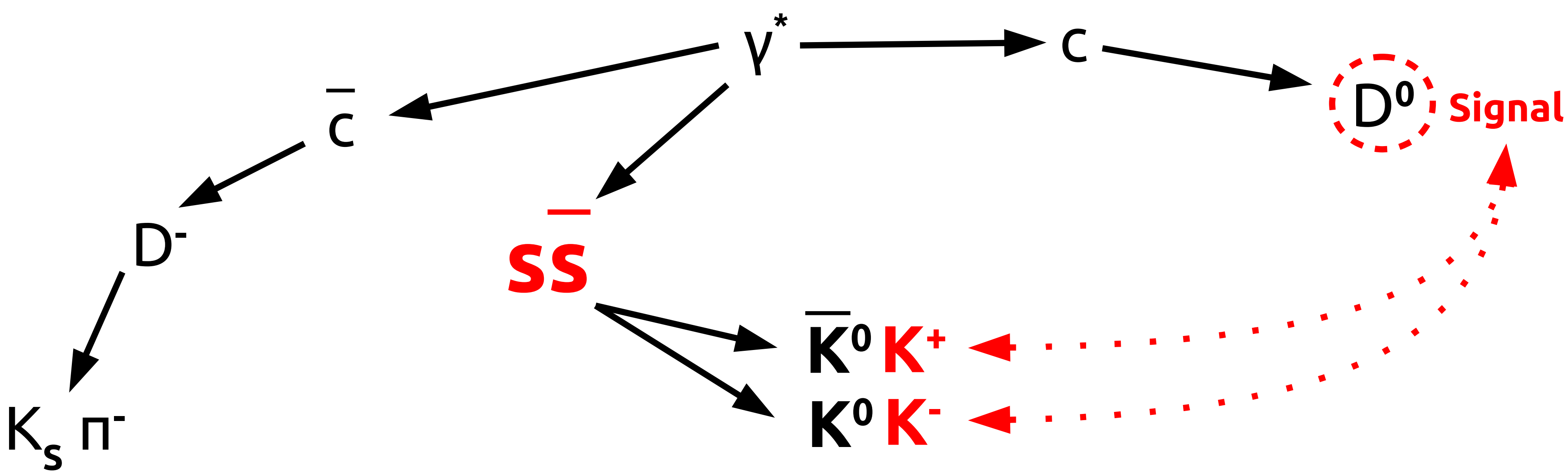
There are two different type of background events: from physics and from reconstruction.

Background events from physics

Background events “from physics” are the following ones:

1) DCS decay of D^- (eg. $D^- \to K^- \pi^0$): ~ 4.4%*
2) “DCS” decay of charmed baryons (eg. $\Lambda_c^- \to \Xi^+ K^- \pi^+$): ~ 2.8%*
3) $c\bar{c}s\bar{s}$ events: ~ 39%*
    3a) K^-/K^- directly from hadronization of s quark: ~ 35%*
    3b) K^-/K^- from the decay of D_s^+/D_s^- : ~ 3.6%*

An example of $c\bar{c}s\bar{s}$ background event:



* Numbers normalized to all $c\bar{c}$ events with 1 D^0 and 1 K^+ in ROE

Background events from reconstruction

Background events "from reconstruction" are the following ones:

1) an event with a "fake" K^+ (a p, π^+, μ^+ or e^+ misedentified)

→ the correlation between the charge of K^+ and flavor of D^0 is lost

2) an event with a not reconstructed K^+

→ this modify the number of K^+ in the rest of event

3) an event with a "tagging" K^+ with the wrong reconstructed charge

→ negligible contribute

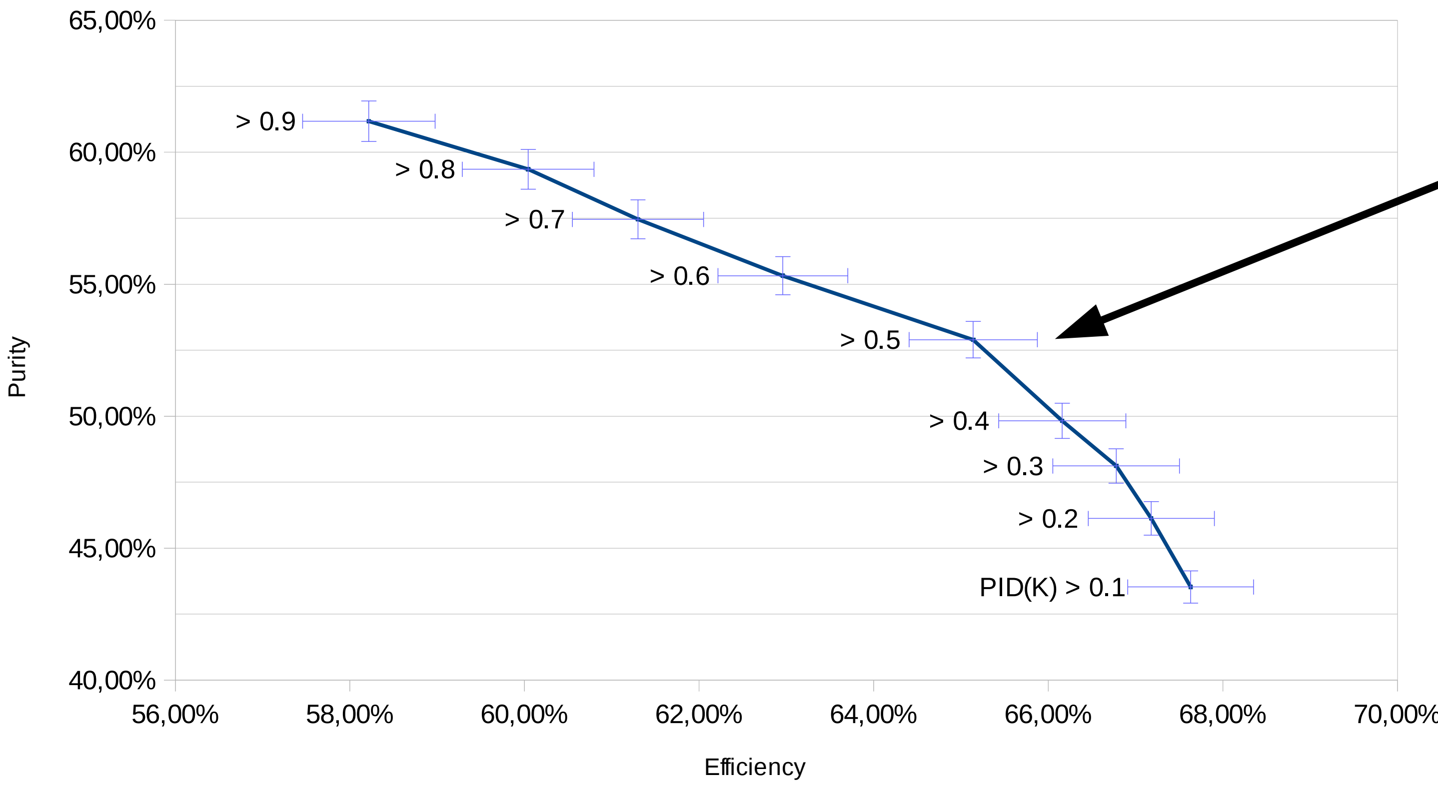
For the first two types of background, is extremely important to tune the parameters for the reconstruction of K^+

Efficiency and purity of reconstructed K^+

The efficiency vs. purity graphs shown is referred to all reconstructed K^+ in rest of event.

→ These numbers are normalized to $c\bar{c}$ events with 1 D^0 correctly reconstructed.

NOTE: no continuum, $b\bar{b}$, τ events included in this study yet.



K^+ with PID(K^+) > 0.5 are considered "standard" inside basf2 software.

There is also a cut on x^2 of fitted track ($x^2 > 10^{-3}$)

Next results are obtained using these cuts.

$$\varepsilon = S / S^v$$

$$p = S / (S+B)$$

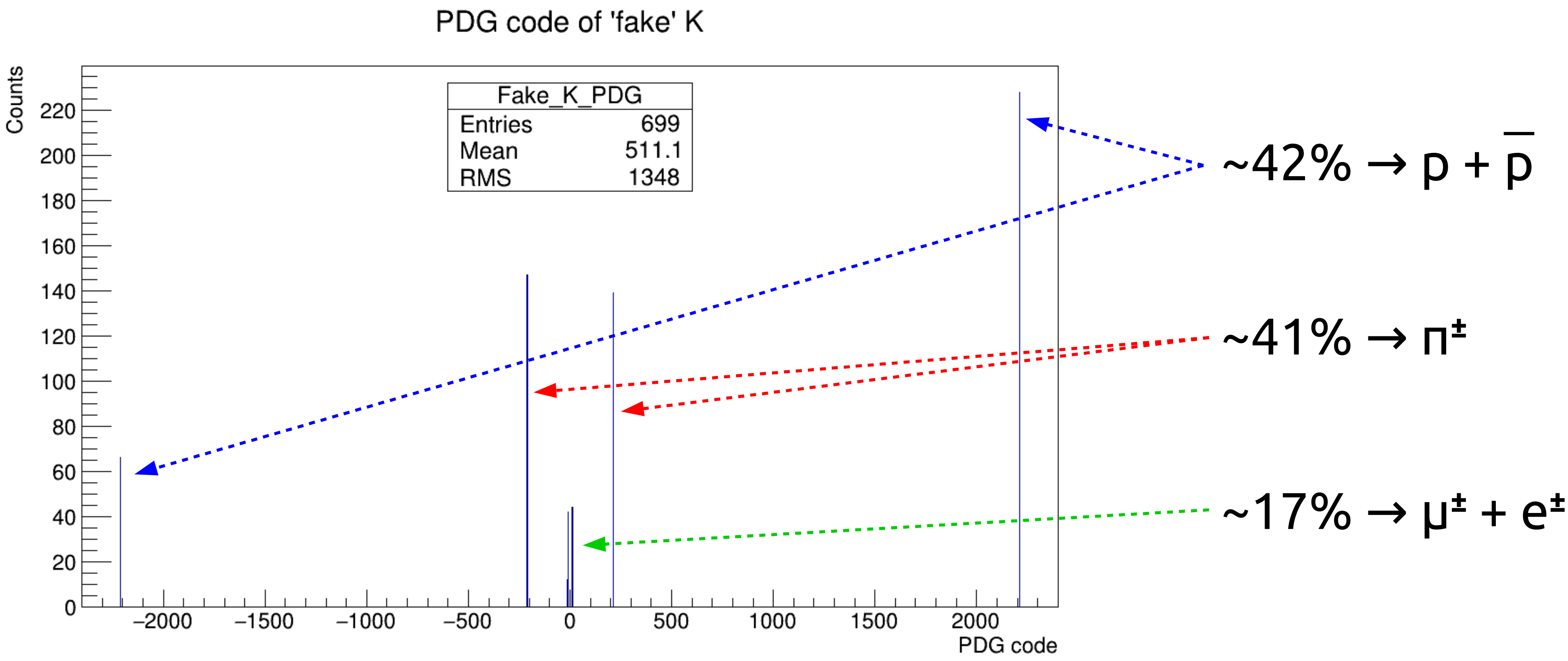
S = number of K correctly reconstructed

S+B = number of K reconstructed

S^v = number of K generated

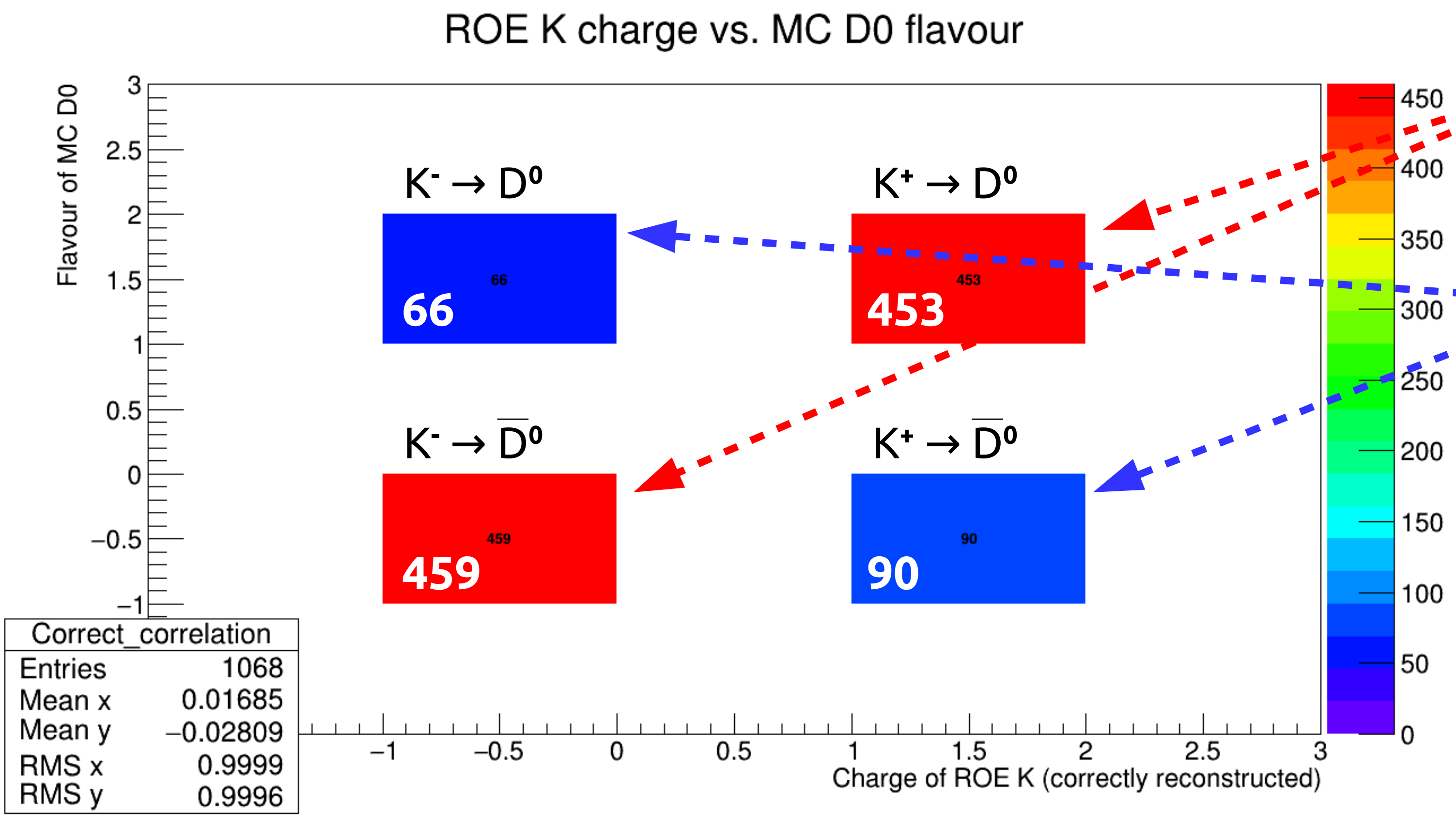
Misidentification of reconstructed K^+

Making the comparison with the generated K^+, we can see that ~40% of reconstructed K^+ are “fake”.



More studies on selection of reconstructed K^+ are necessary in order to reduce the number of misindetifications!

Results with correctly reconstructed K^+



~85% of charged K give us a correct tagging.

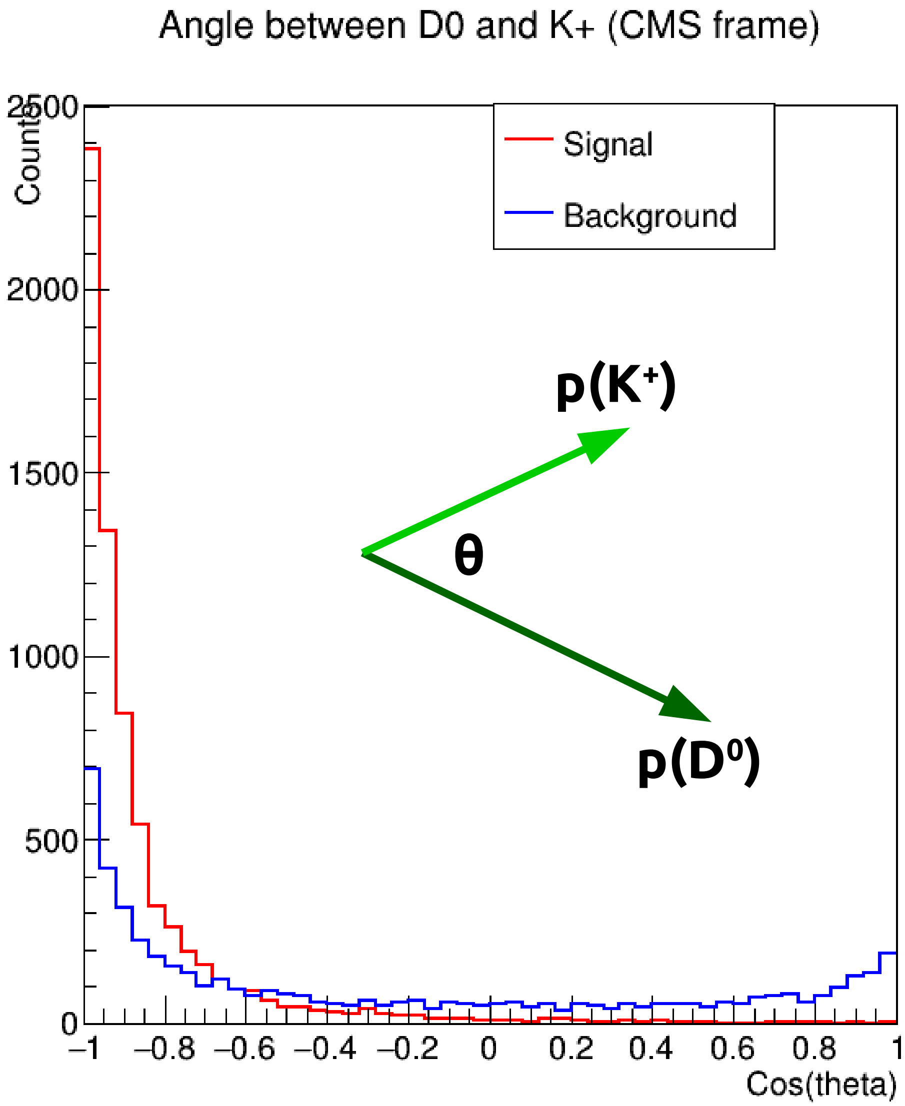
~15% of charged K give us a wrong tagging.

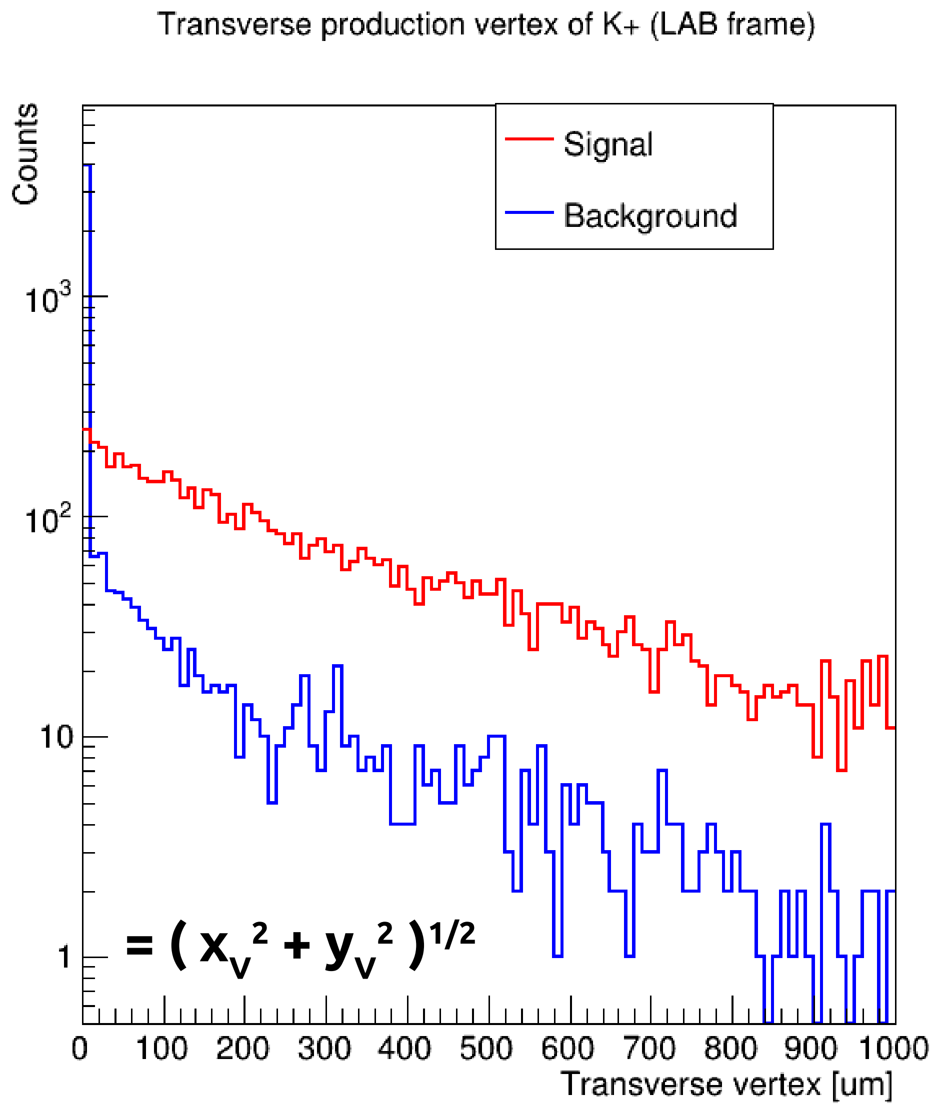
$\varepsilon \approx 22\%$

normalized to events with only 1 D^0 (correctly reconstructed)

Among correct tagging K^+ there are some background events (K^+ coming from virtual photons).
Some kinematics variables are necessary to cut away this "physics" background.

Kinematics of the selected events





Since $c\bar{c}$ are back to back, tagging K^+ tends to go to the opposite direction respect to D^0

Transverse production vertex of K^+ coming from γ^* is within the beam spot (correlated to d_0 of the track)

Data from 100k generated (and not reconstructed) $c\bar{c}$ events!

Conclusions

- Using the better performances of Belle II, it is possible to consider the idea of tagging the D^0 prompt and produced from D^{*0}.

- A deep study to undestand the background (within $c\bar{c}$ events) is going on.

- It's fundamental to fine-tune the selection of reconstructed K^+ to improve the purity of the sample.

- Relative direction between D^0 and K^+ momenta and production vertex of K^+ are some powerful variables to reduce the background. More variables are going to be studied (like the shape of the event).

- $b\bar{b}$, $s\bar{s}$, $d\bar{d}$, $u\bar{u}$ and $c\bar{c}$+bkg events will be analyzed later for a better estimation of the background and mistag levels.

Thank you for the attention!

D, or not D that is the question

Backup slides

Tagging with D^{*+} in BaBar

To estimate the sensitivity achievable at BABAR, as one example of a hadronic decay mode, the (right-sign) decay chain $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+$ ($\mathcal{B} = 3.83\%$) has been investigated using the `BBsim` simulation of the detector response, with the exception that perfect particle identification has been assumed and is discussed below.

D^0 candidates are formed from opposite sign kaons and pions. If the invariant mass is within the accepted window, the D^0 vertex is refitted with the Kalman filter algorithm described in Section 4.5.1. The following selection criteria are applied to D^0 candidates:

- D^0 momentum in the CM frame: $p(D^0)_{CM} > 2.5$ GeV/c and
- D^0 invariant mass: $1.845 < m(D^0) < 1.885$ GeV/c^2.

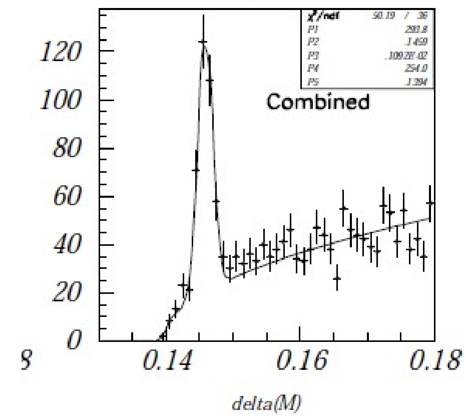
To reconstruct charged D^*s, a D^0 candidate is combined with a charged pion track requiring:

- Slow pion from D^* decay: $p(\pi_s)_{Lab} > 100$ MeV and
- Mass difference Δm: $144.5 < \Delta M < 146.5$ MeV.

The efficiency for these selection criteria is 43%. Figure 12-10 shows the mass difference and D^0 mass distributions. The resolution of the mass difference Δm is $\sigma = 0.41$ MeV. Remaining background in the sample is due to random combinations of pions with a real D^0. Background with a wrong-sign D^* tag could fake a mixing signal. In this sample, the contamination of wrong-sign tags amounts to only 0.15%, considerably less than the background expected from DCS decays.

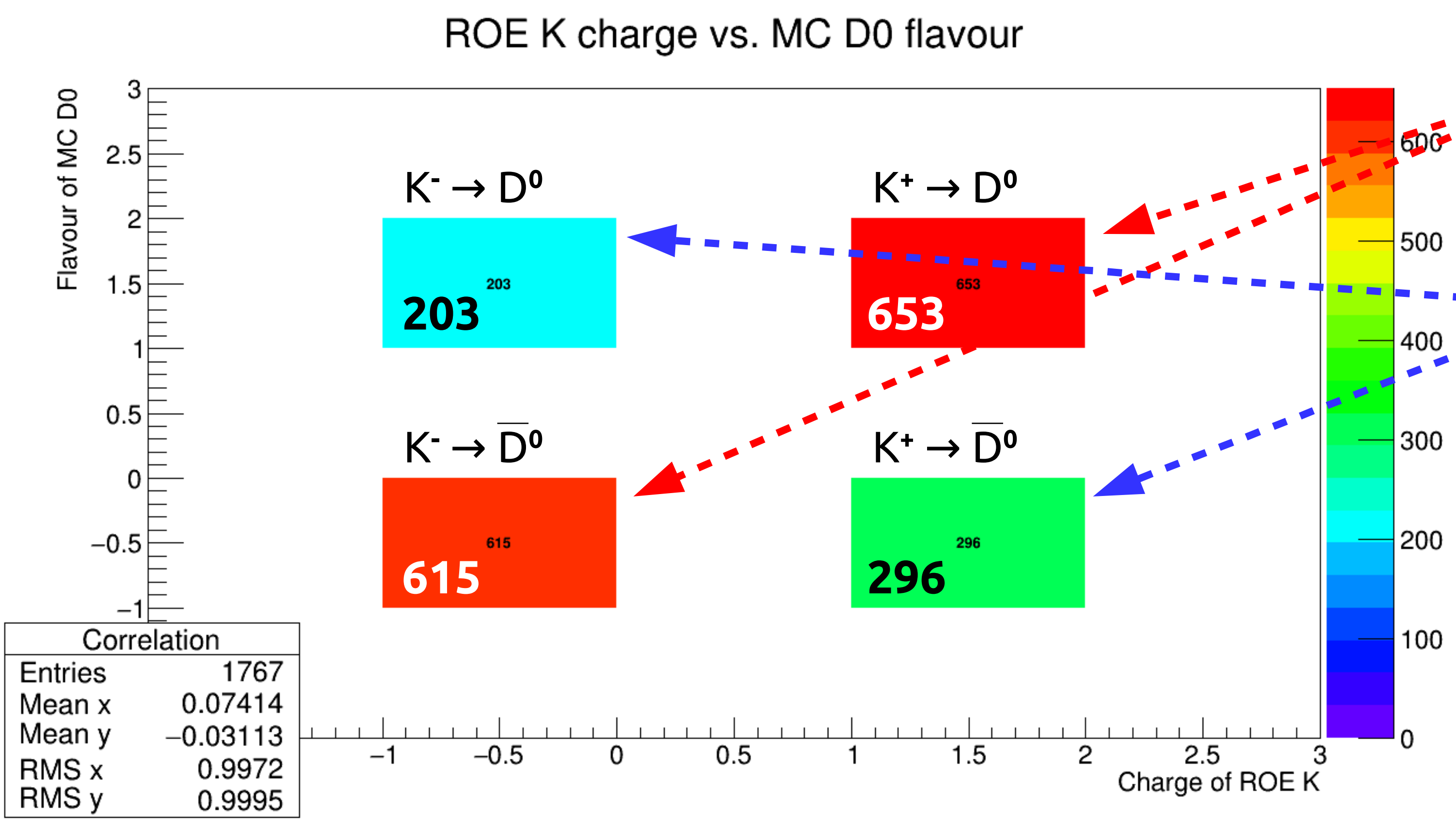
Table 4-6. *D^* reconstruction efficiencies measured using full simulation/reconstruction for the different D^0 decay modes.*

ϵ_{rec}	$D^0 \to K\pi$	$D^0 \to K\pi\pi^0$	$D^0 \to K\pi\pi\pi$
Acceptance (D^0 tracks)	0.85	0.85	0.5
K identification	0.8	0.8	0.8
π identification	0.9	0.9	0.73
π^0 reconstruction	-	0.3	-
vertexing + mass cuts	0.97	0.97	0.95
Acceptance for soft π	0.7	0.7	0.7
Total	0.41	0.12	0.19



Data from "The BaBar Physics Book"

First results



~72% of charged K give us a correct tagging.

~28% of charged K give us a wrong tagging.

$\varepsilon \approx 30\%$
normalized to events with only 1 D^0 (correctly reconstructed)

Among correct tagging K^+ there are background events:
K^+ coming from virtual photons, p and π^+ identified as K^+.
→ the number of "true" tagging K^+ is reduced.