

Stopping kaon analysis

Feasibility study

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Previous work

Anselmo Cervera studied the feasibility of analysing stopping kaons from the beam,

https://indico.fnal.gov/event/13110/contributions/17509/attachments/11655/14865/stoppingKaon_131016.pdf

Alexander Izmaylov studied the feasibility of analysing secondary stopping kaons,

https://indico.fnal.gov/event/10641/contributions/4416/attachments/3108/3716/Kaon_24_01_2017.pdf

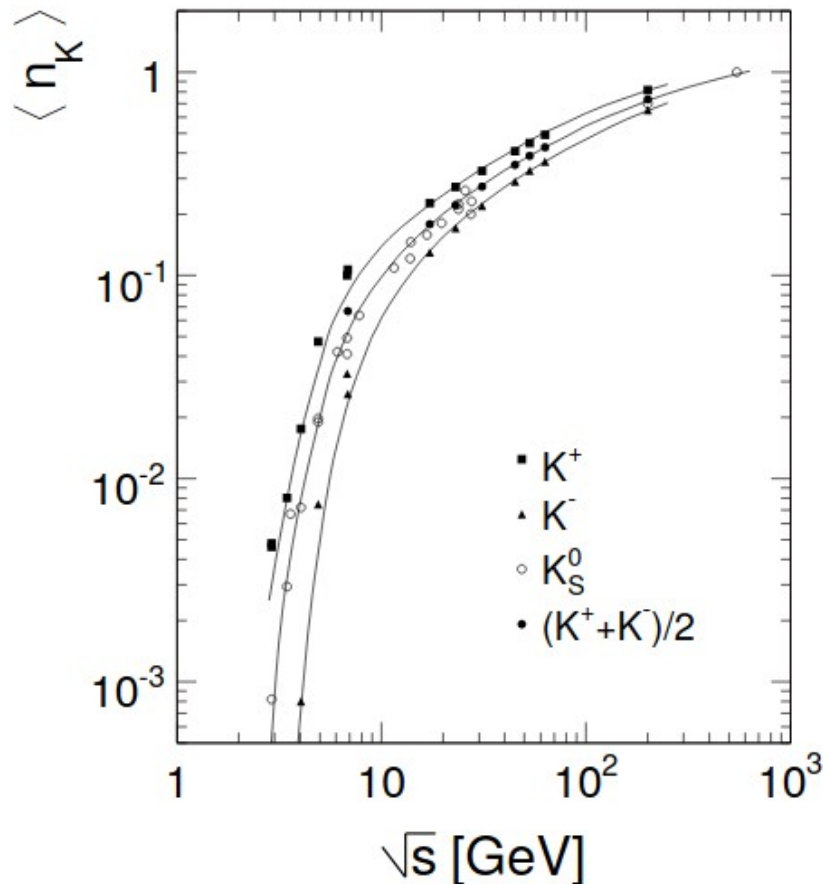
Motivation

- Understanding energy loss of low momentum K in liquid argon. This could be use afterwards for a XS measurement
- Relevant for proton decay searches in DUNE FD. $P \sim 340 \text{ MeV}$

$$p \rightarrow K^+ \nu$$

- Develop a kaon PID in protoDUNE-SP.
- Beam runs have provided few (none) low energy kaons, so **secondary kaons are studied instead.**
- This analysis has been done with the 17k files of PDSPProd4_MC_6GeV_reco1_sce_datadriven_v1_00.

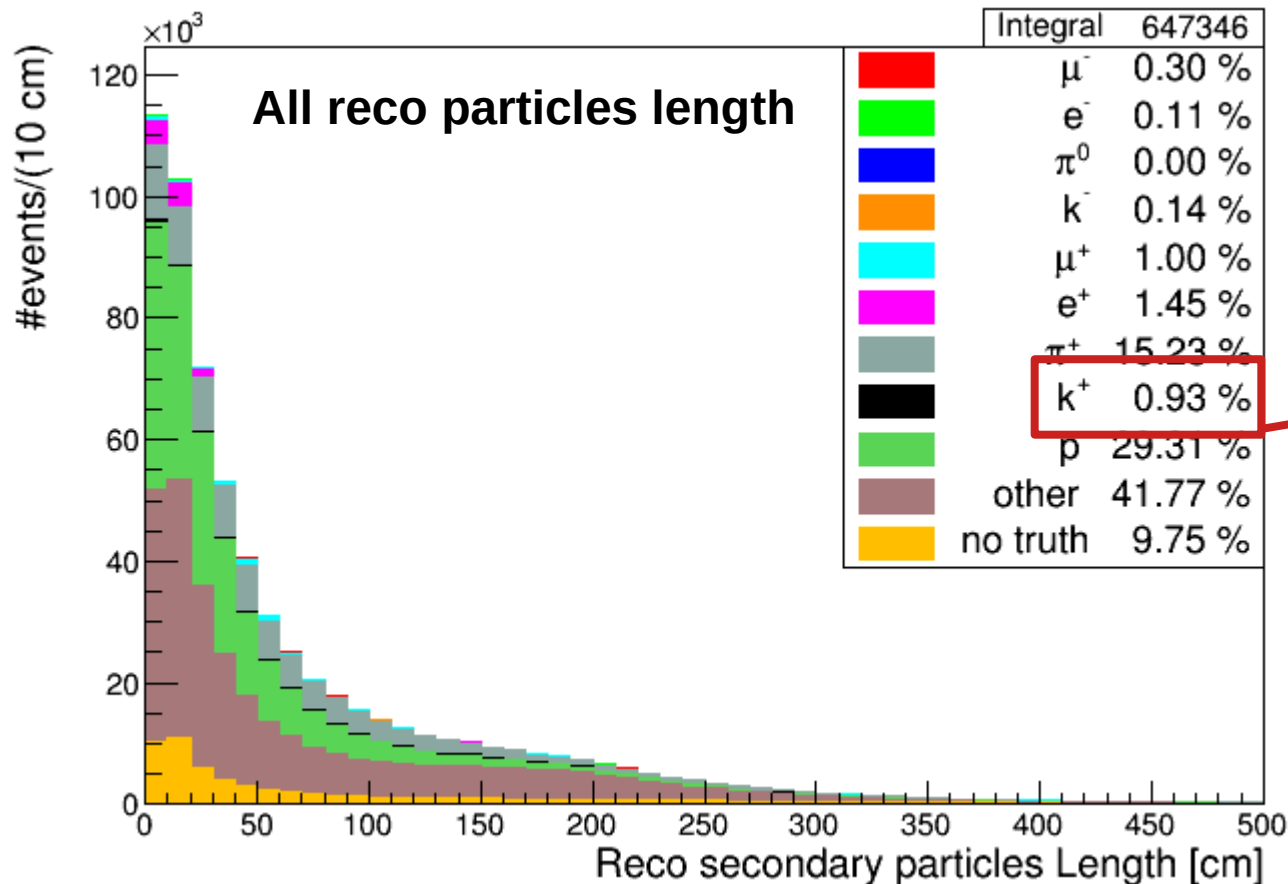
Secondary kaons



Summary from arXiv:1004.1889
p-p collisions
For 7 GeV expect ~1%
(e.g. Nucl. Phys. B123 (1977)
361)

- Produced in hadron interactions (generated by protons, pions and kaons from the beam)
- Lower momentum
- Larger multiplicity for nucleus
- Strangeness conservation $\rightarrow$ produced with Λ and Σ
- Since our scope for the moment is studying dEdx, higher order kaons (tertiary, etc) can also be considered, so from now **secondary $\equiv$ non-primary**

Secondary Kaons: abundance



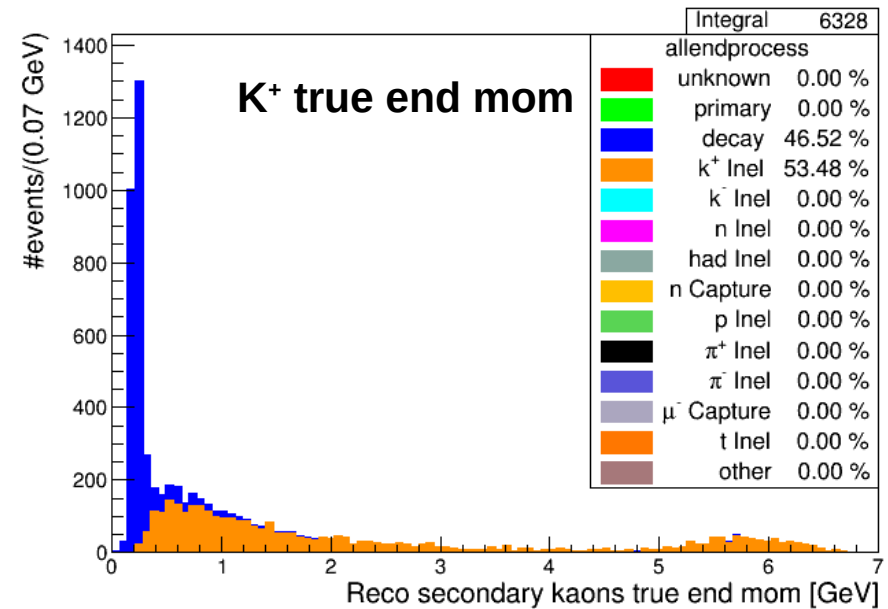
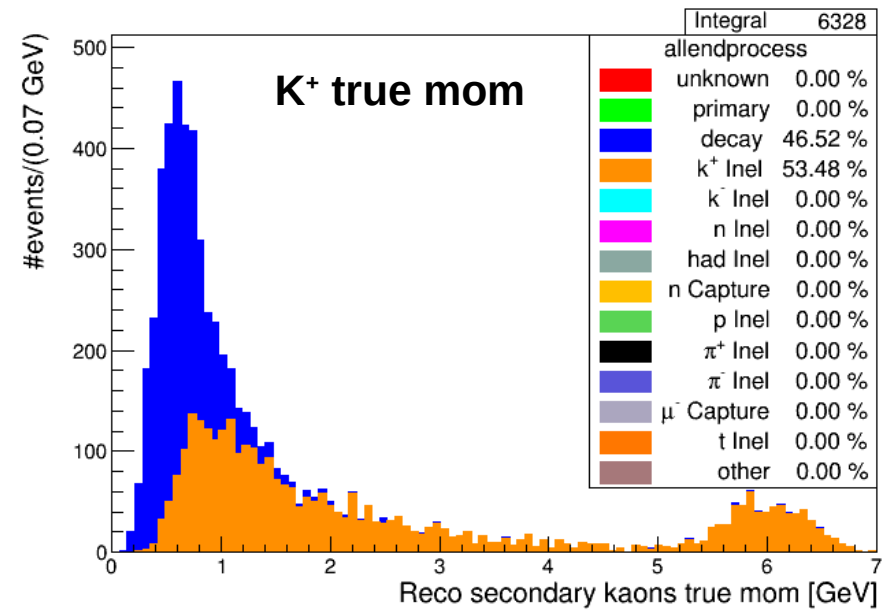
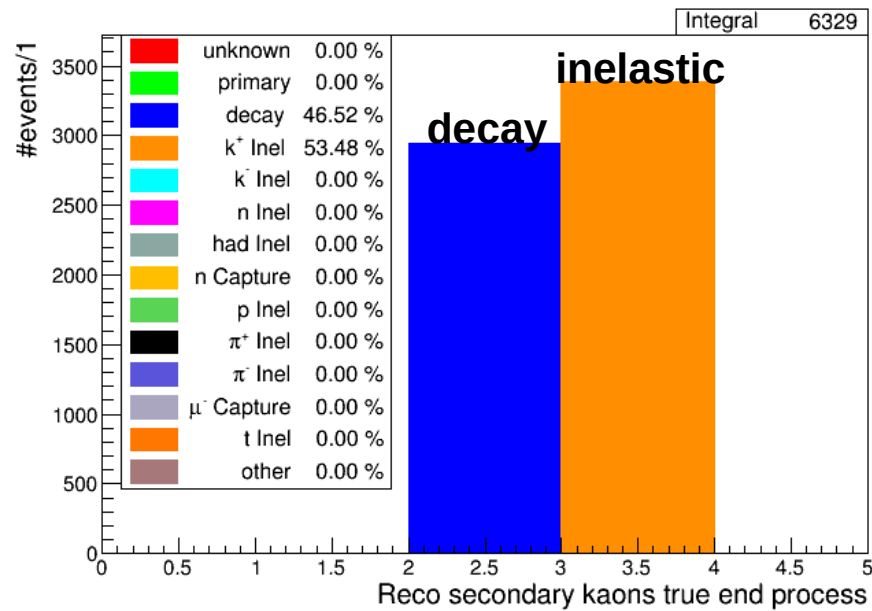
Only 5% of the beam events generate secondary kaons.

Less than 1% of the reconstructed non primary particles are kaons

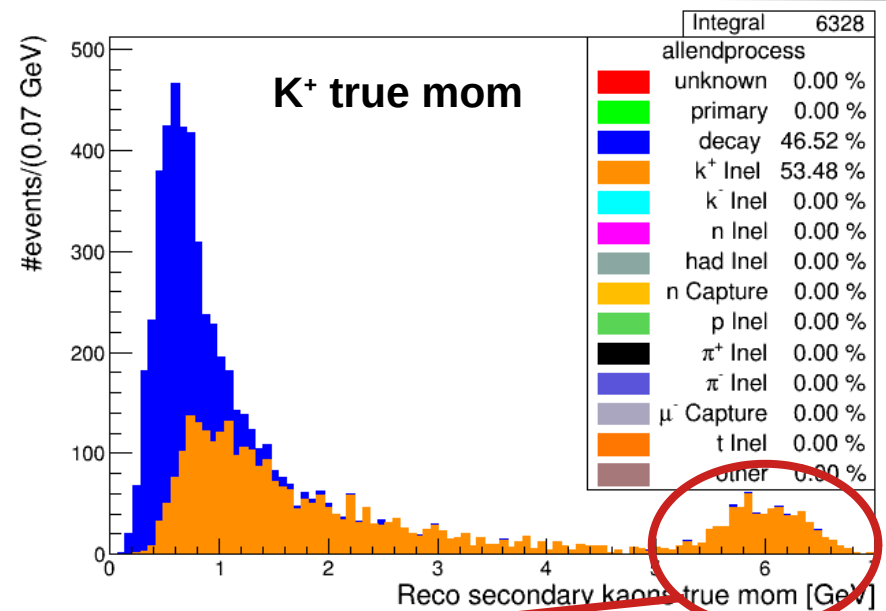
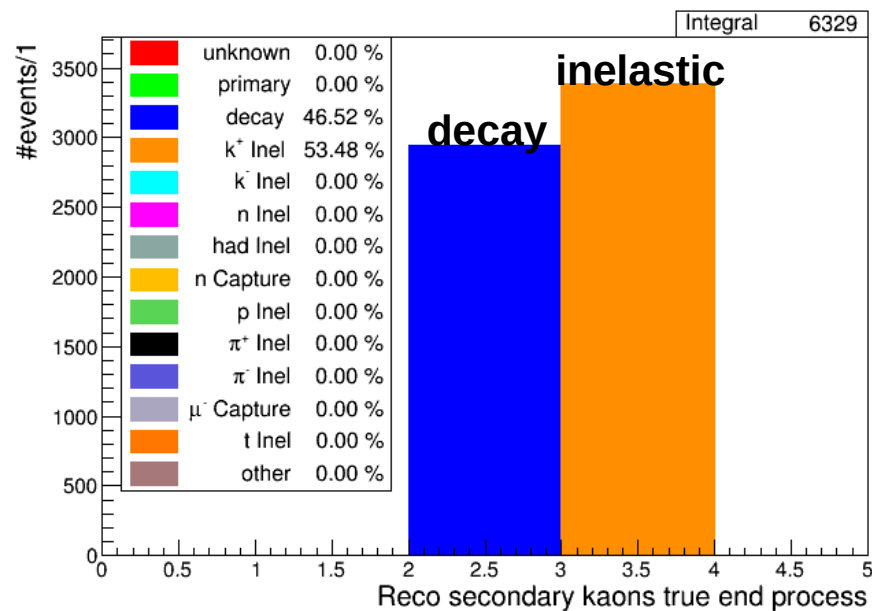
Complicated selection!

The reconstruction efficiency of secondary kaons is 35%

Secondary Kaons: kinematics

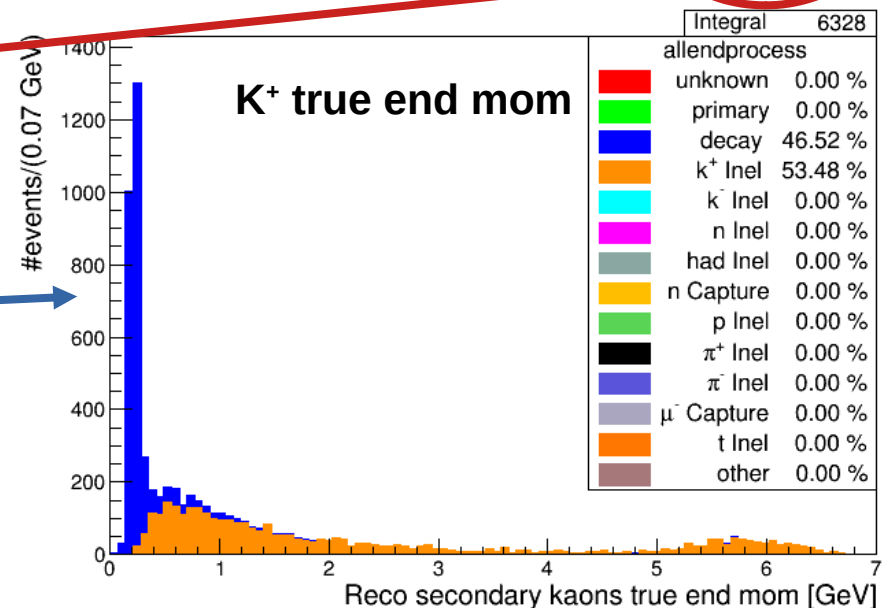


Secondary Kaons: kinematics



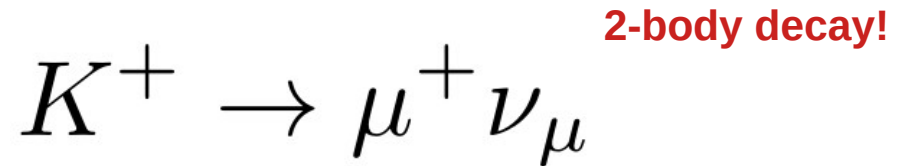
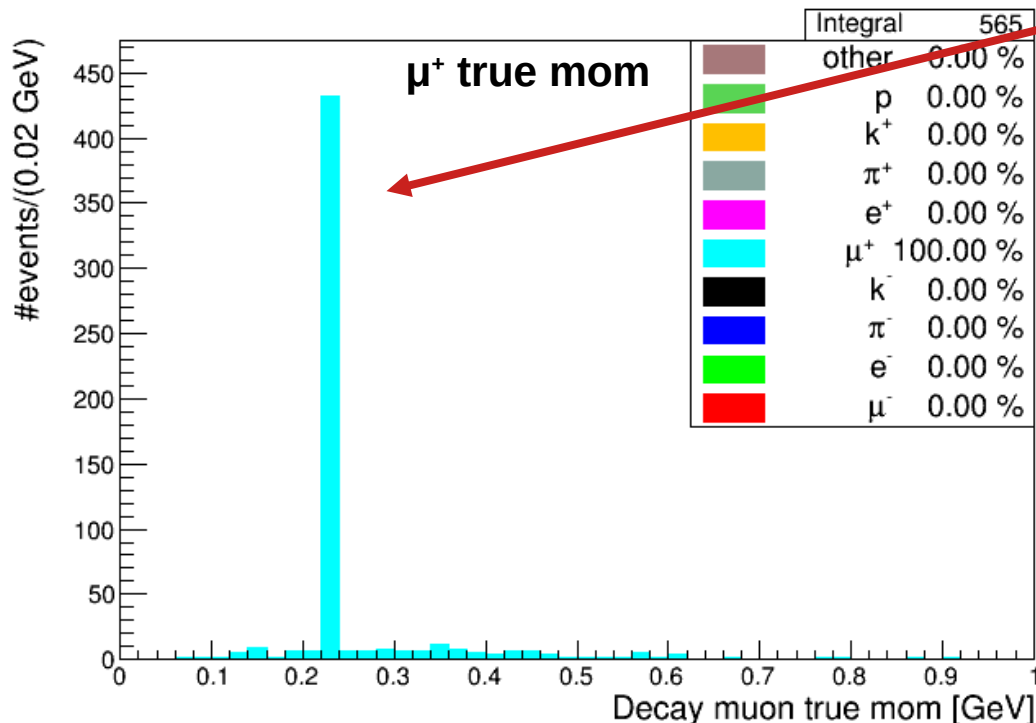
Reconstruction problem? Beam particle broken. See backup.

Decaying kaons apparently decay at rest (the end mom is non zero because it has been evaluated in the penultimate point of the trajectory).



Stopping kaons: identification strategy

Identify K^+ by its decay products (63% BR)
+ additional cuts in the kaon
candidates biasing as less as
possible in dEdx measurement.



The muon momentum should be centred in ~ 235 MeV (K^+ decay at rest in many occasions).

This makes the reconstruction chain even more complicated: at least three tracks (the primary, the stopping kaon, and the final muon) have to be properly reconstructed and related.

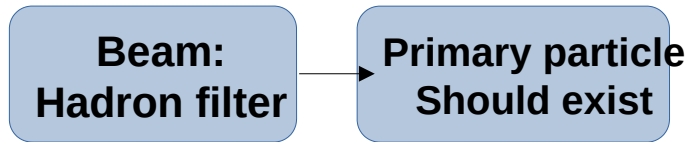
Muons from a kaon decay have a 53% reco efficiency (which does not mean a correct matching with the kaon).

Stopping kaons selection

**Beam:
Hadron filter**

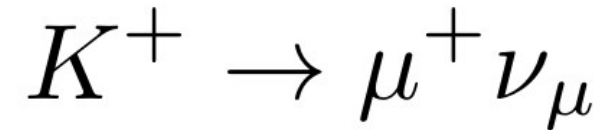
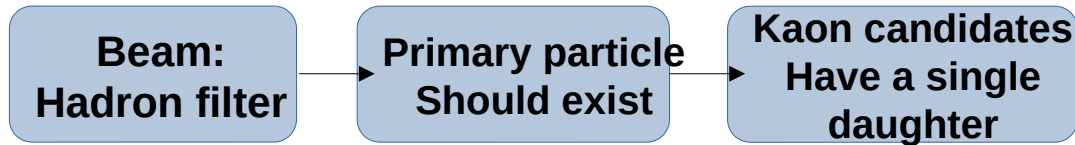
Only consider events generated by hadrons, PDG = 211, 321, 2212

Stopping kaons selection



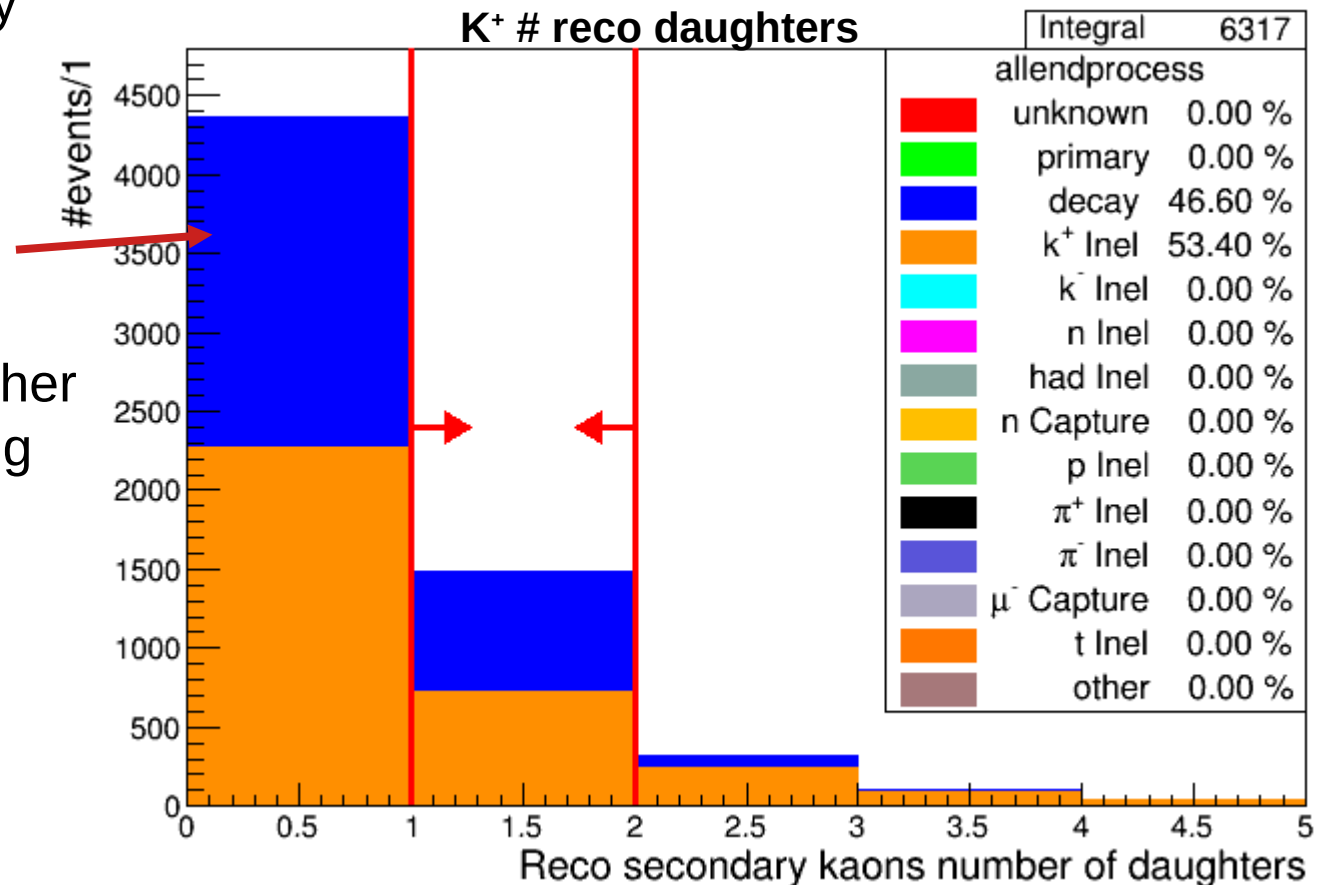
Only look for kaons generated by the beam particle.

Stopping kaons selection

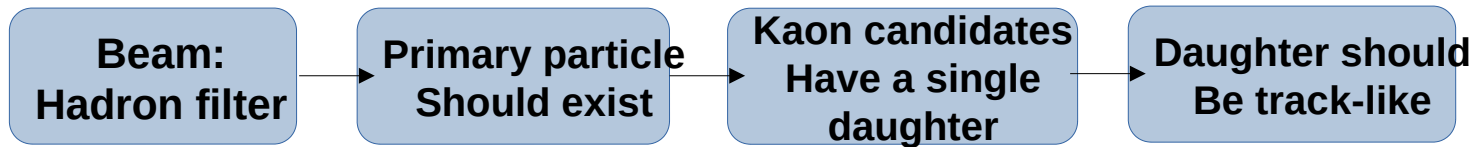


Candidates should have only one daughter

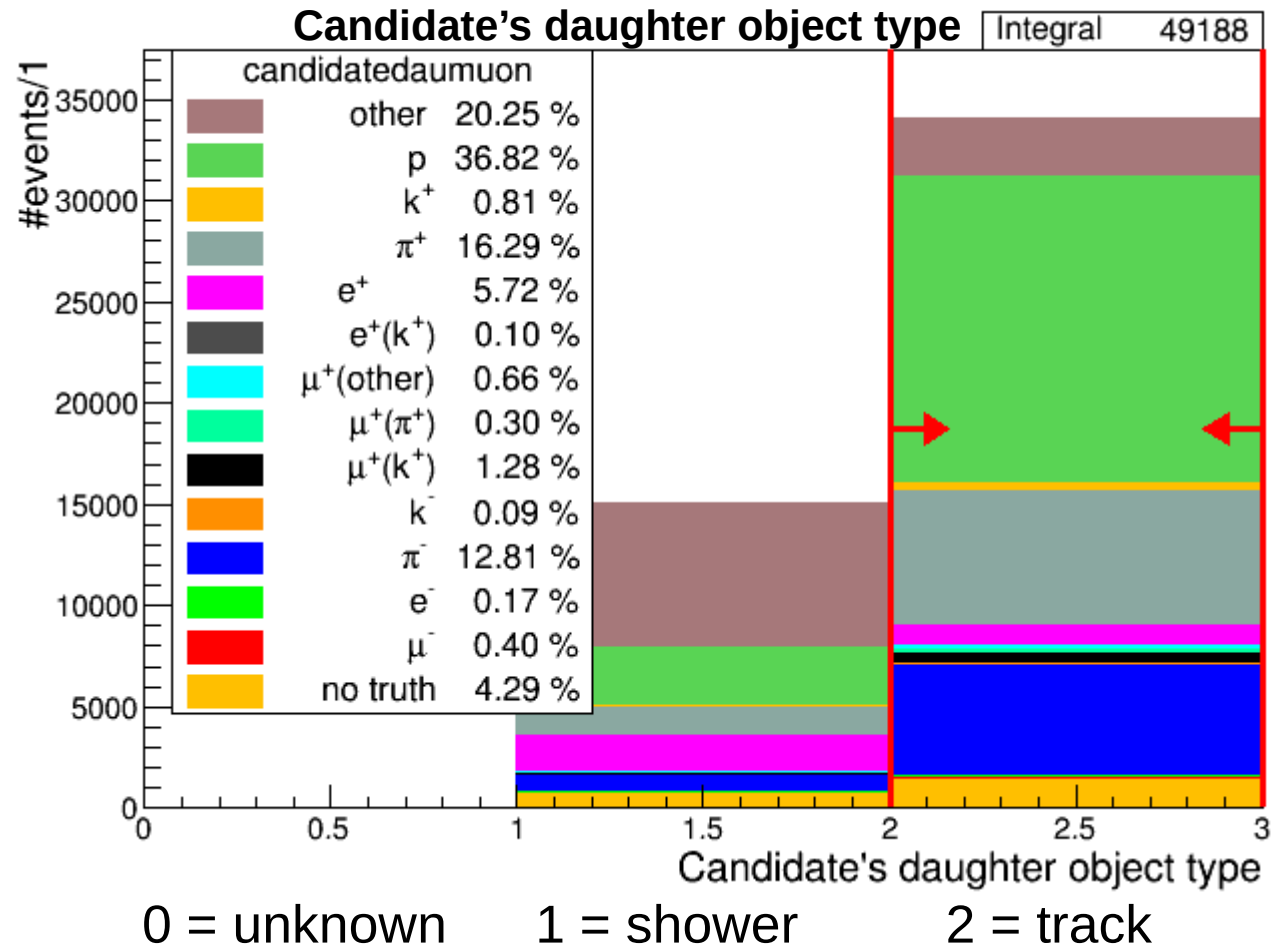
Problem: several decaying kaons (~2/3) have no reconstructed daughters! Either the parent-daughter matching fails or both tracks are reconstructed as one (see backup). We are trying to recover some of them.



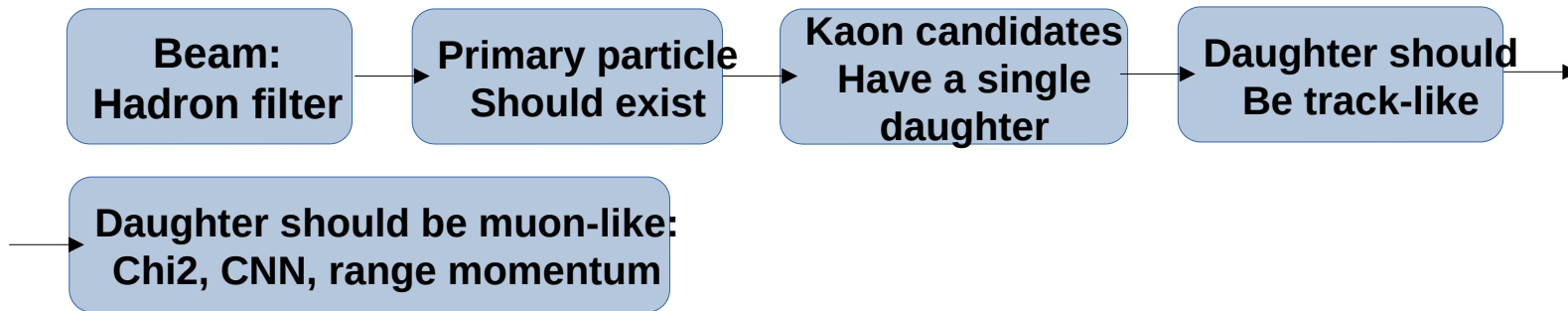
Stopping kaons selection



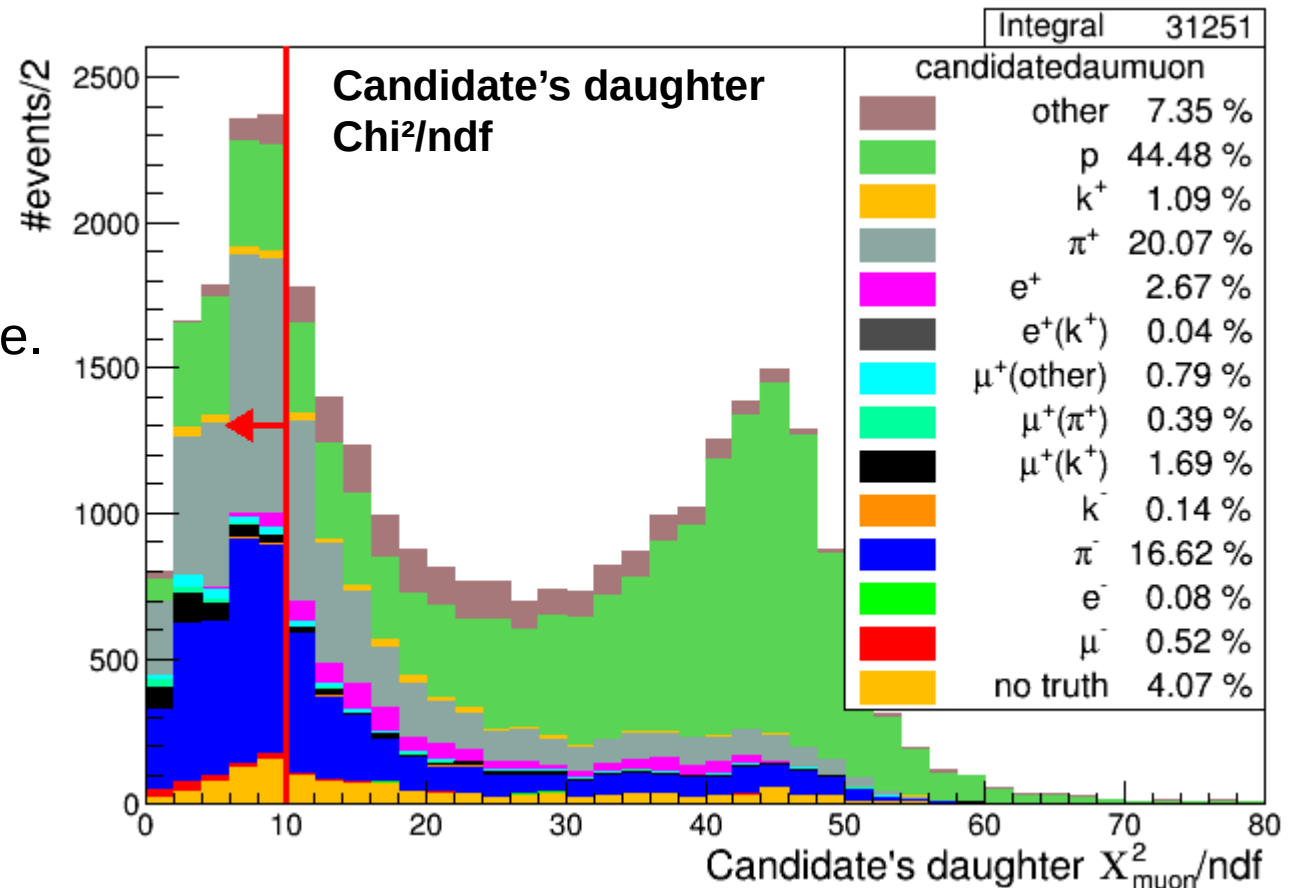
Muons are usually track-like objects



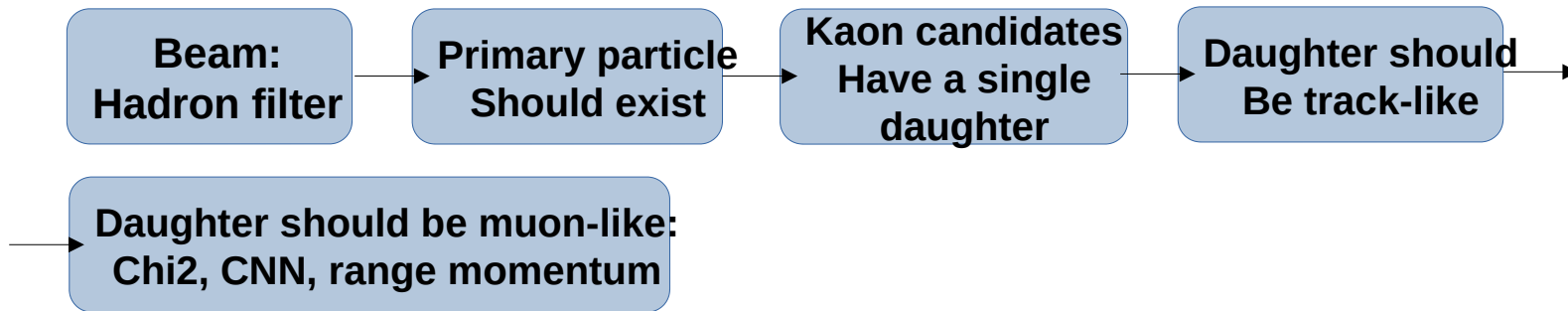
Stopping kaons selection



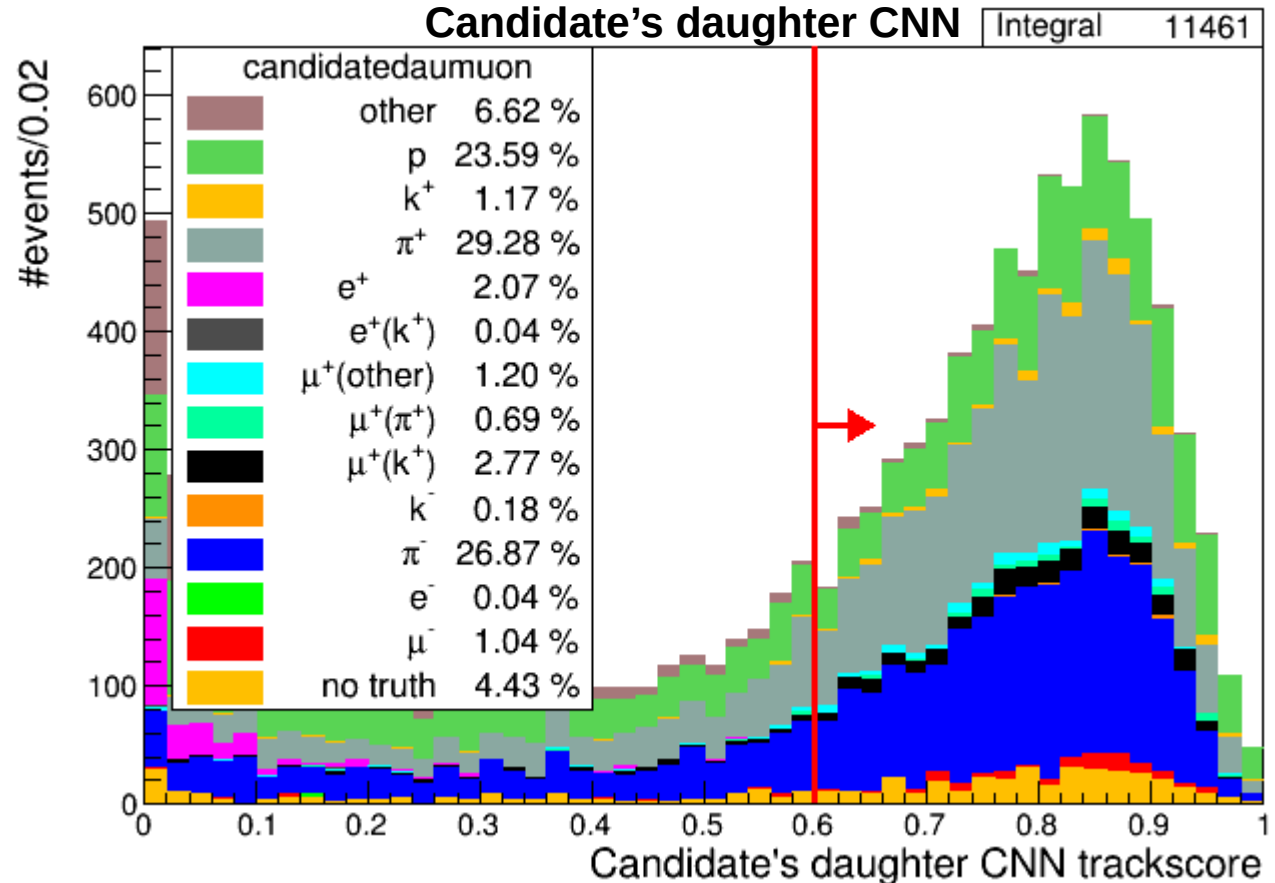
Cut on candidate's daughter χ^2/ndf to clean up the sample. This removes part of the protons but not the pions



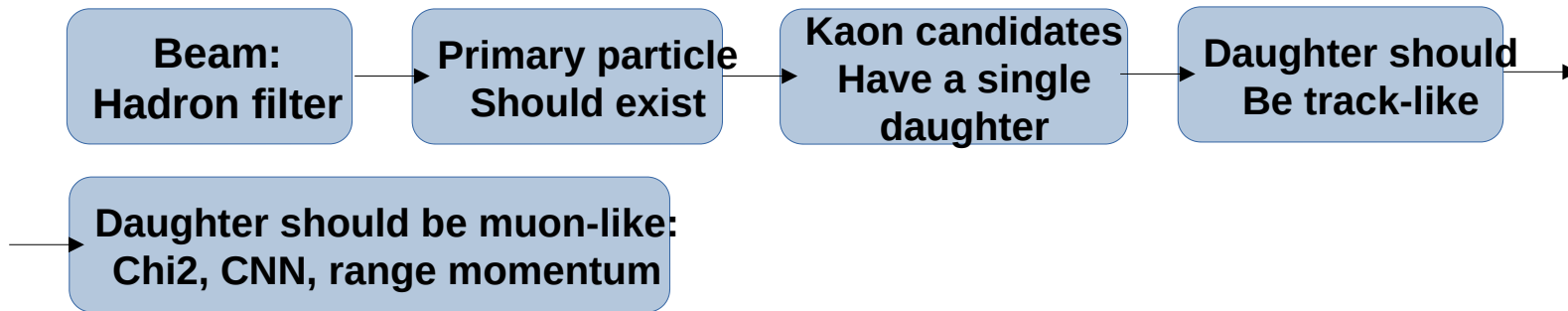
Stopping kaons selection



Cut on candidate's daughter
CNN trackscore

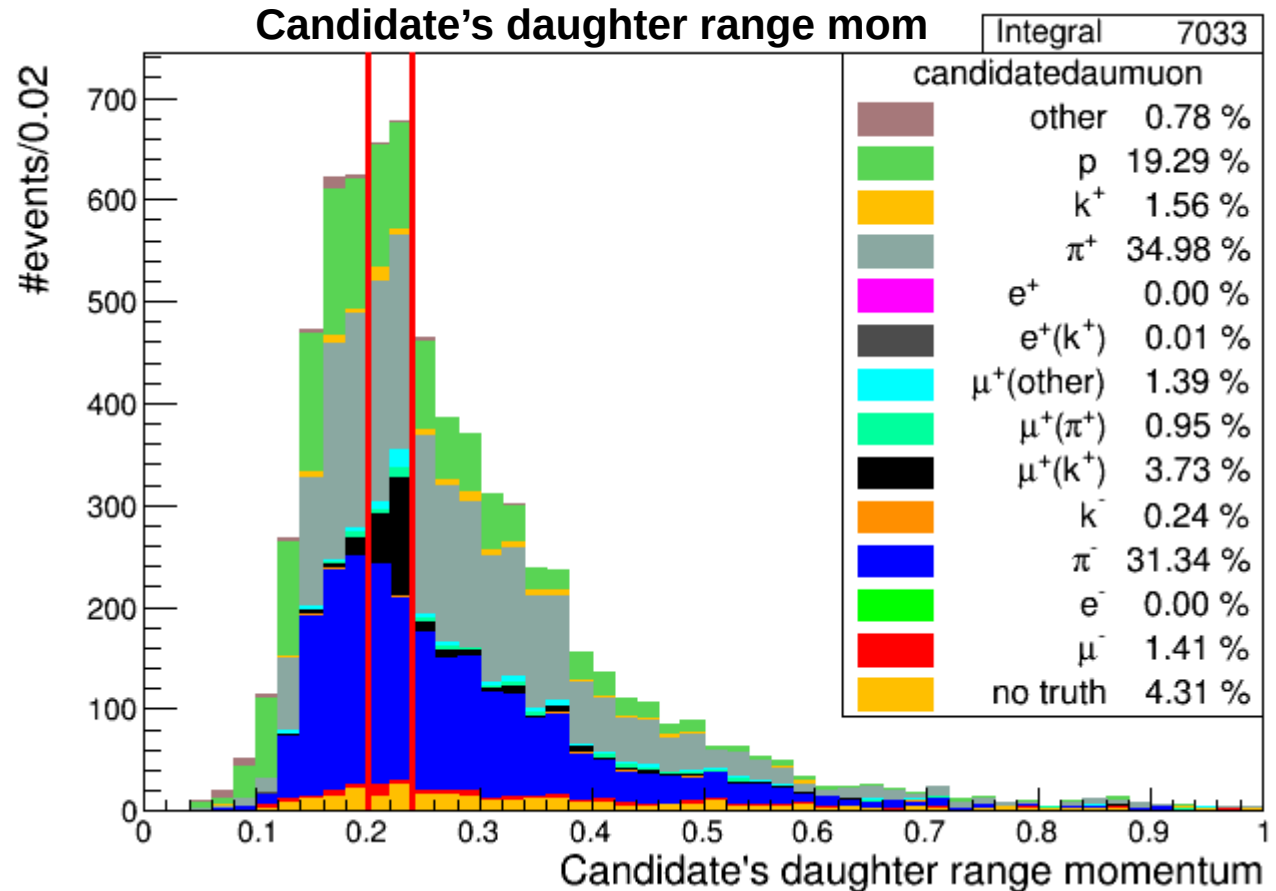


Stopping kaons selection

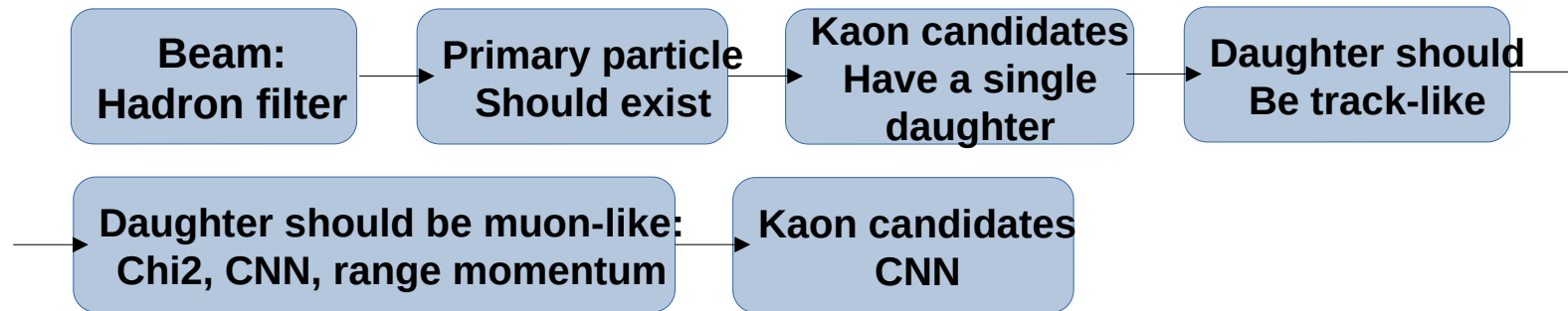


Cut on candidate's daughter range momentum to select particles with momentum compatible with ~ 235 MeVs.

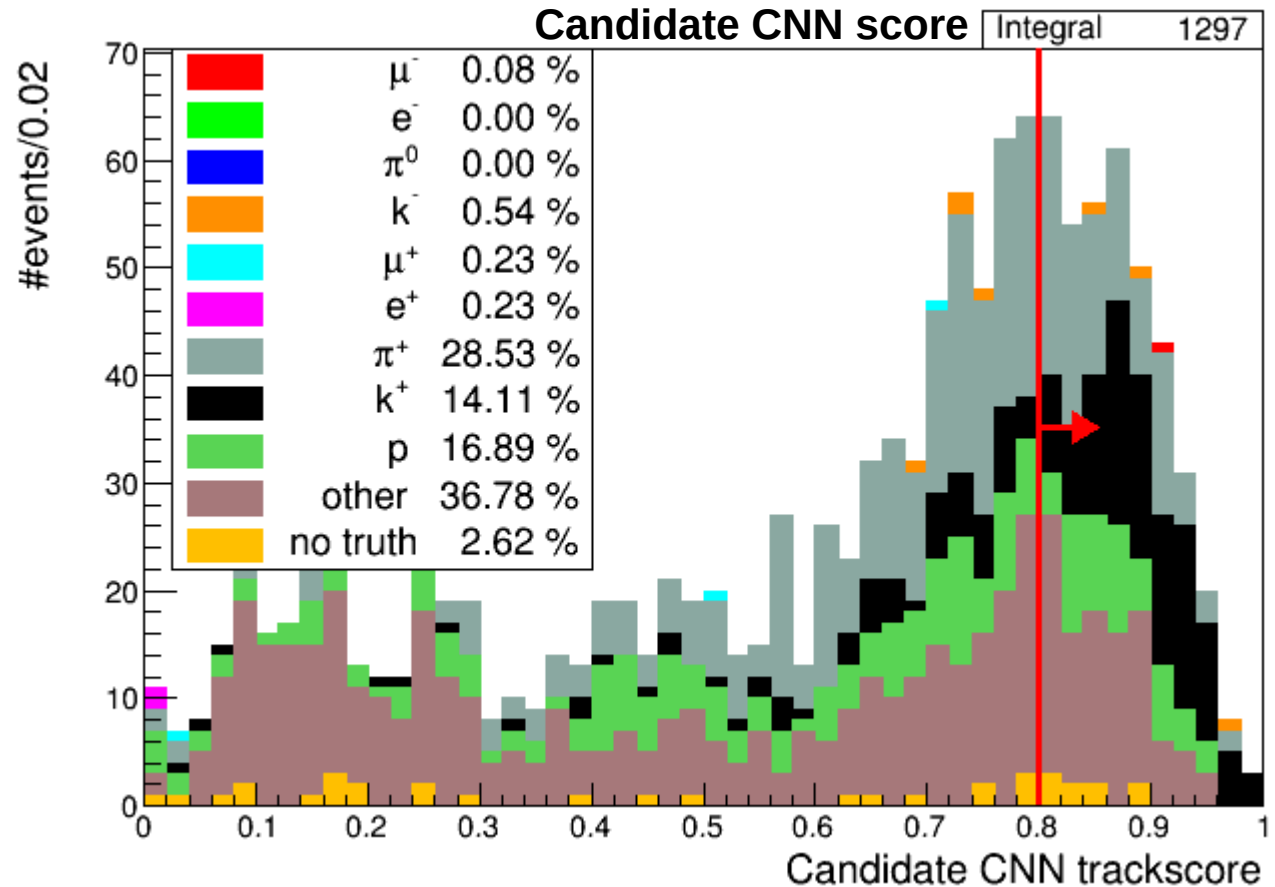
These three variables (chi2, CNN, range momentum) are probably correlated. However, more statistics are needed to perform 2D cuts.



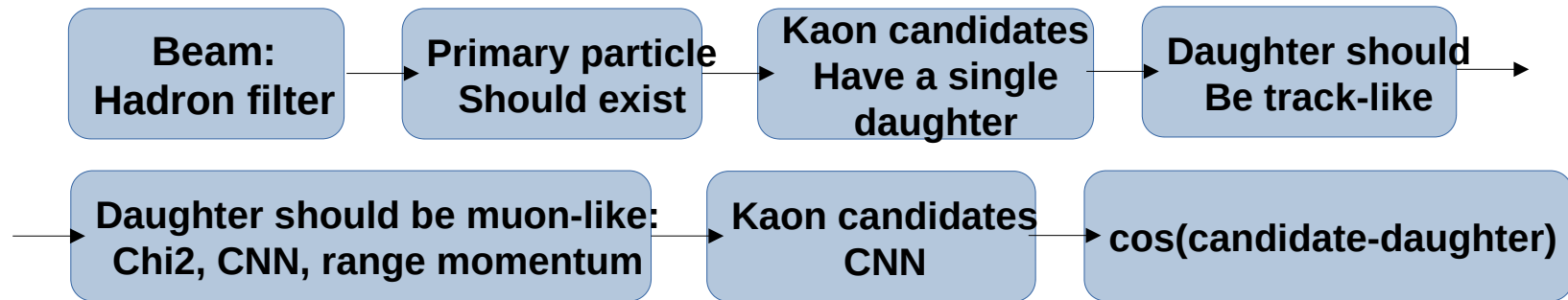
Stopping kaons selection



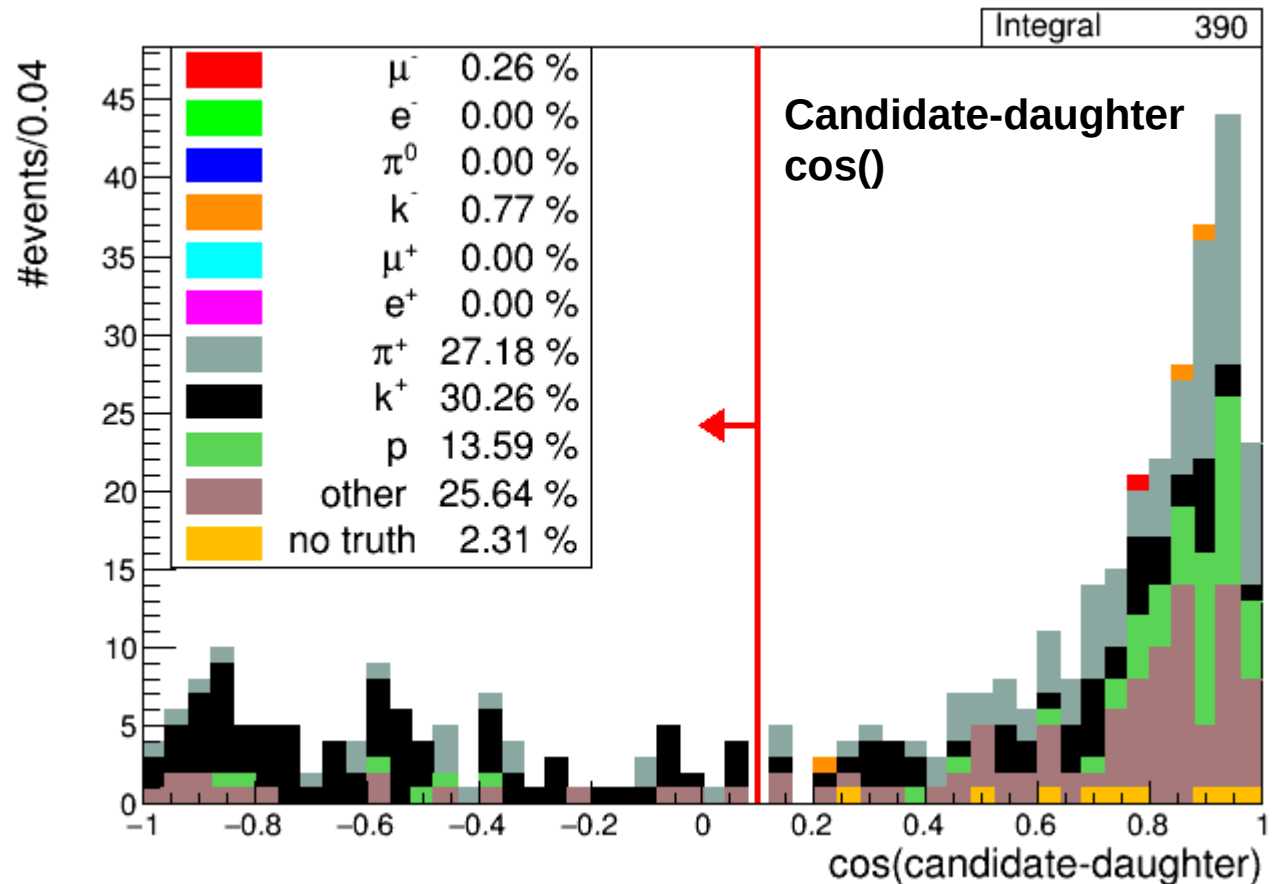
After cutting in the daughter, come back to the candidate to keep cleaning up the sample. Try to bias as less as possible. Does CNN use 'energy' information? If so, how much would it be biasing the final measurement?



Stopping kaons selection



As the kaon is decaying at rest the distribution of the cosine should be isotropic

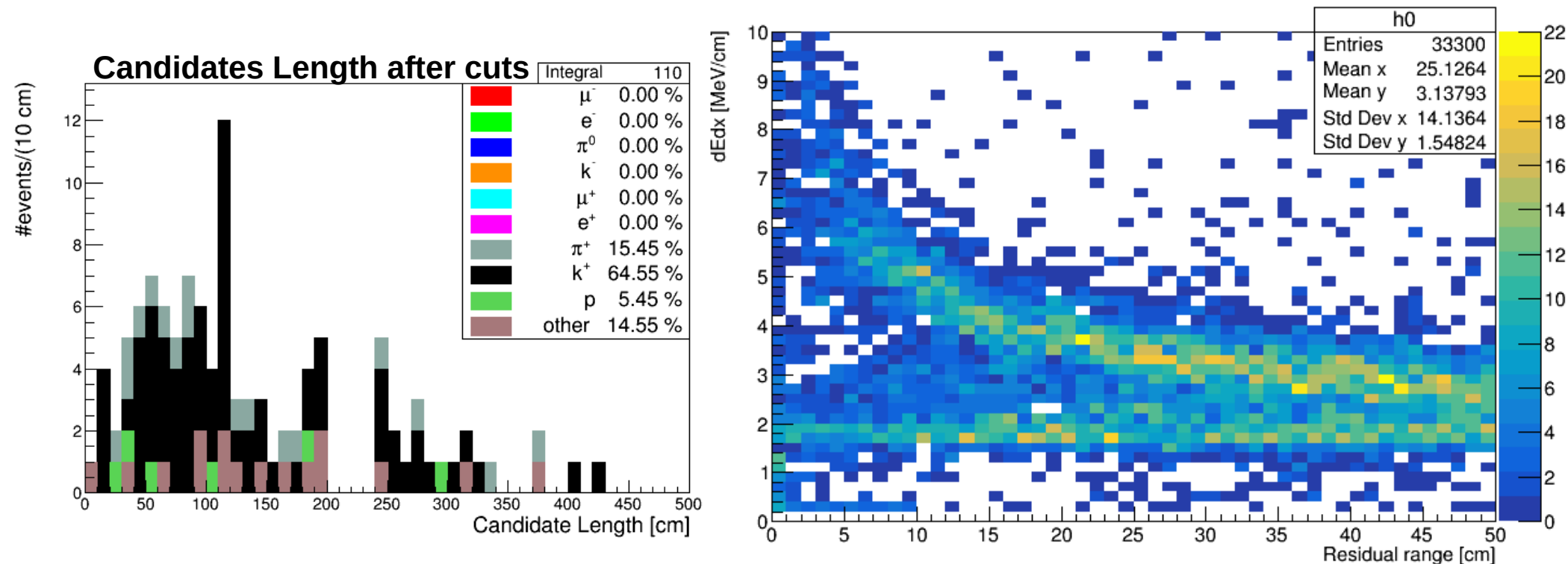


Stopping kaons selection

After all the cuts, we have a final population of 71 kaons with a purity of 65%.

The main source of contamination are π^+ and π^- (15% and 15% respectively) and protons (5%).

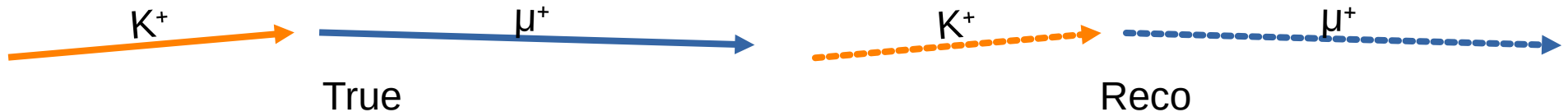
In the dEdx vs Residual range plot we can clearly appreciate the kaon signal and the pion contamination.



Stopping kaons selection: efficiency

Two kind of true candidates are considered for the efficiency computation:

1. True kaons that decay into a muon

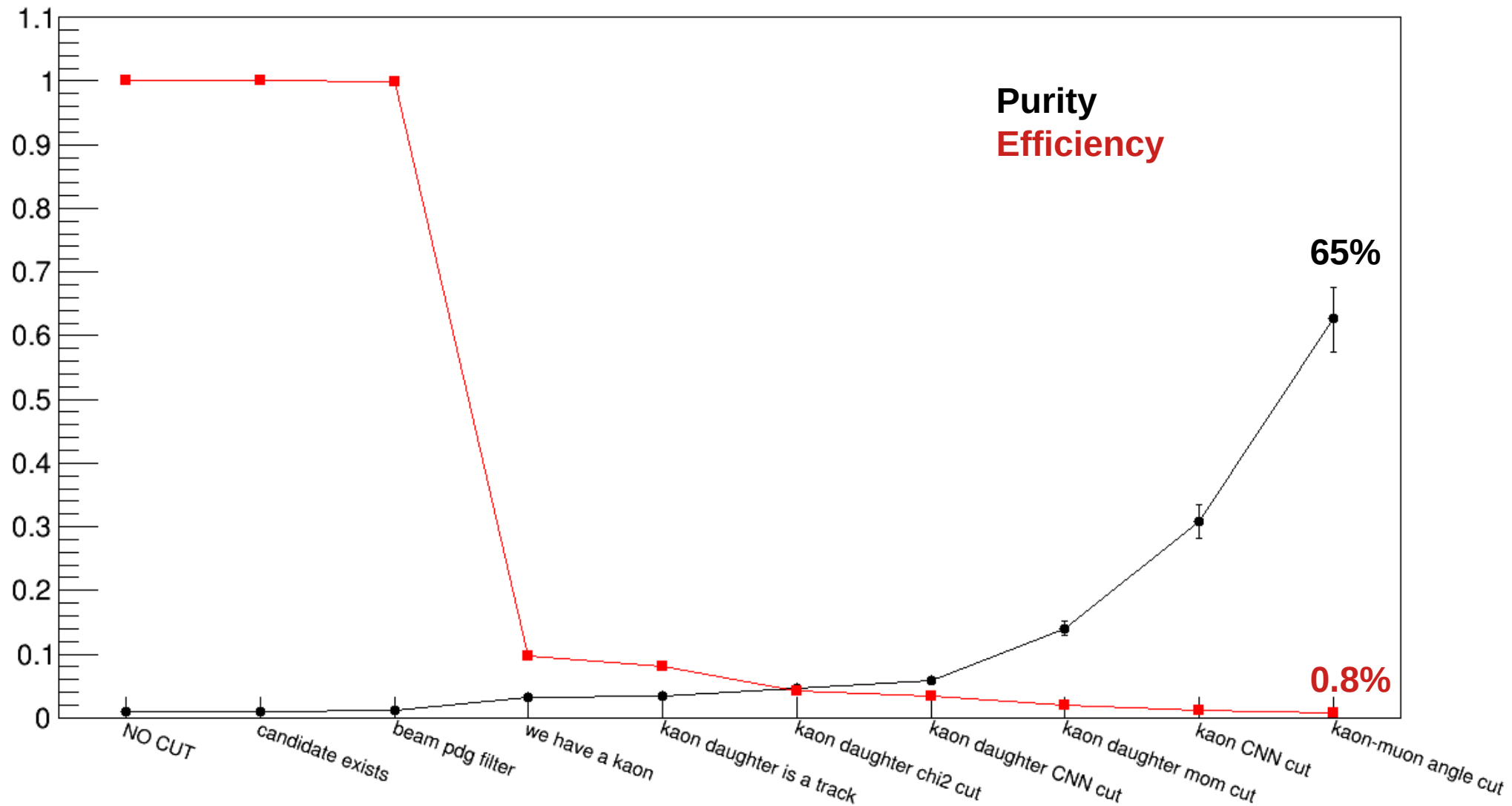


2. Chain of true kaons decaying into a muon



This is generating an underestimation of the efficiency for chains, because the definition is not unique. This is being studied for having more realistic values of the efficiency.

Stopping kaons selection: efficiency



Stopping kaons selection: feasibility

The MC used has 73000 primary pions, 12000 primary protons and 4000 primary kaons. So the selection efficiencies respect to the number of trigger events are, respectively, 0.08%, 0.02% and 0.3%.

Considering all the good runs at 6 GeV, 415 kaons are expected.

Considering all the good runs **without comments** at 6 GeV, 210 kaons are expected.

Considering all the good runs at 7 GeV and assuming same efficiency than at 6 GeV, 360 extra kaons are expected.

The stopping kaons analysis is difficult but not impossible.

There are also several expected improvements:

- The shown selection has not yet been optimized. PD information could be used?
- Larger statistics will allow to exploit correlations between variables, so cuts will be more efficient.
- Secondary kaon multiplicity is expected to increase with energy, so at 7 GeV runs the available number of kaons should be larger.
- Probably some of the kaons without daughters could be recover.

Next steps

P (GeV)	Data π Triggers	MC π events	Needed
6	210k	73k	(5-10)x210k
7	344k	5k	(5-10)x344k

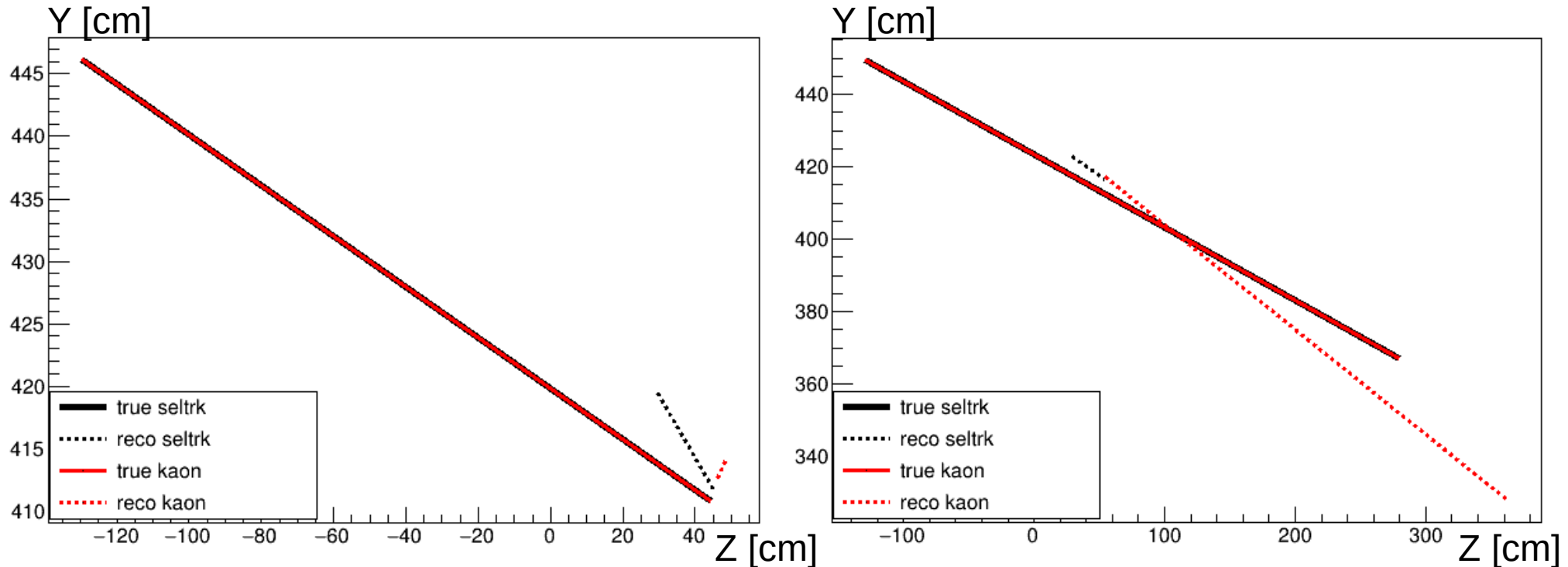
More MC statistics are needed to improve the selection. A good start point would be having the same MC as available data.

It would be good to repeat the analysis at 7 GeV since the multiplicity of kaons is expected to be larger and there is more data. Unfortunately, the available MC is low at that energy (<2k files from production 2).

Start looking at data to see the effects of the reconstruction (broken tracks between APAs, etc.).

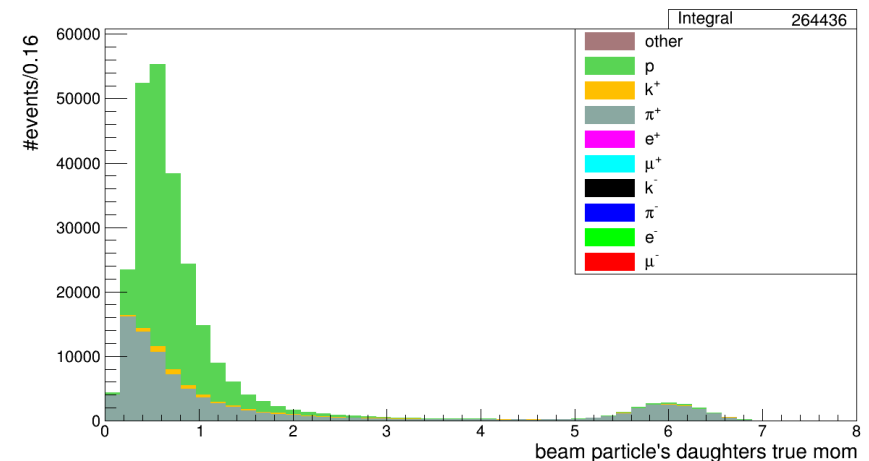
Backup

Beam particles reconstructed as daughters



The primary particle that creates the event is associated to two different tracks.

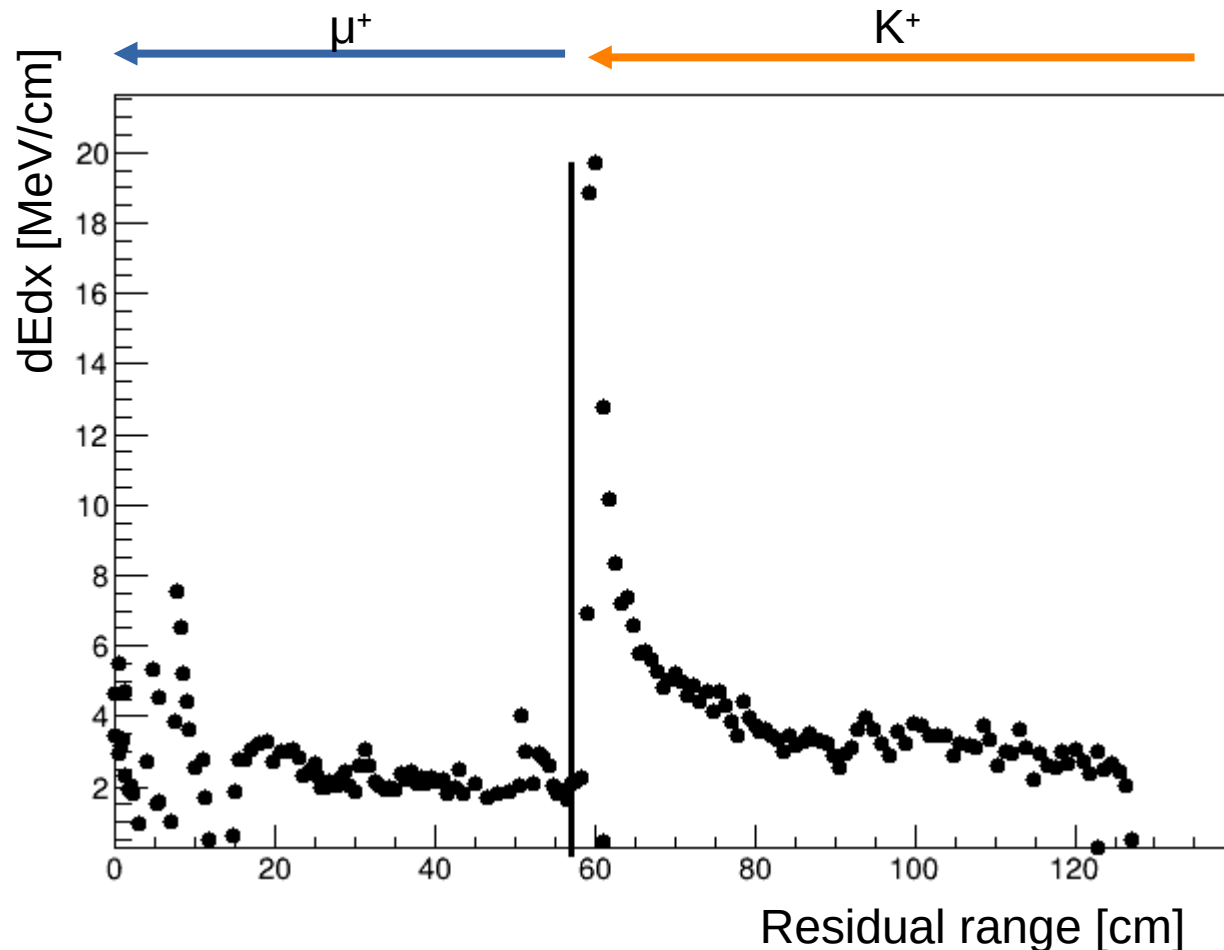
This happens not only with primary kaons but also with pions and protons.



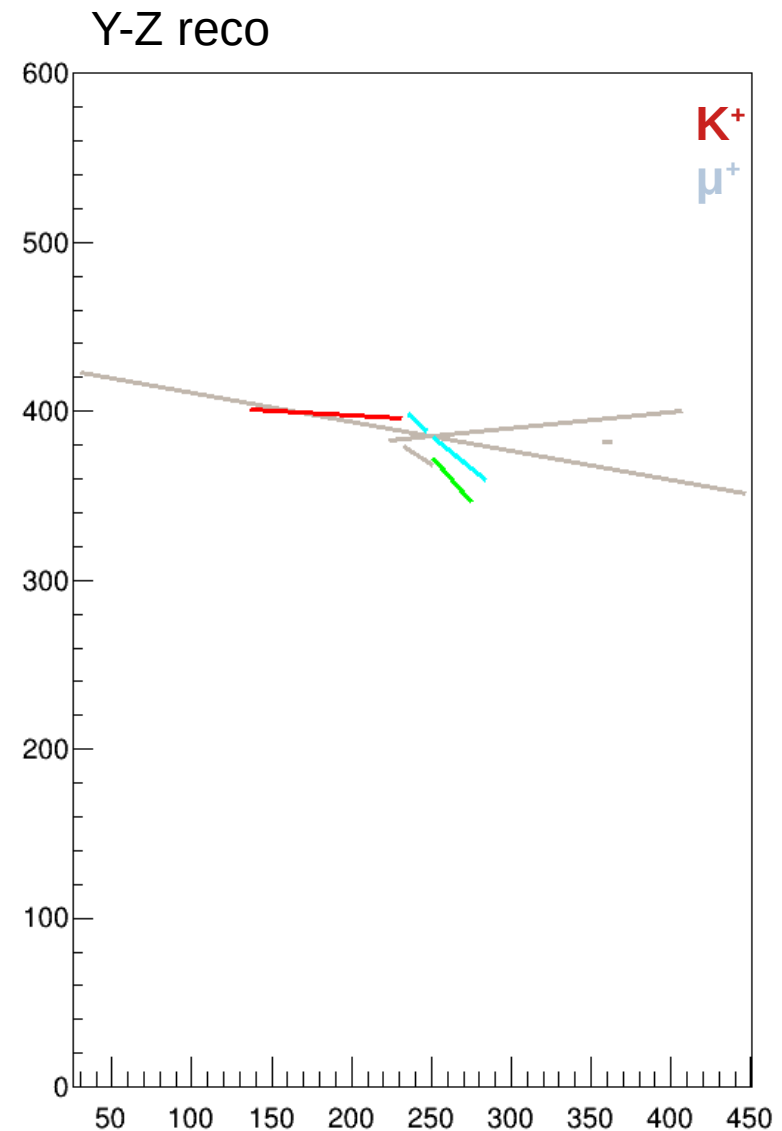
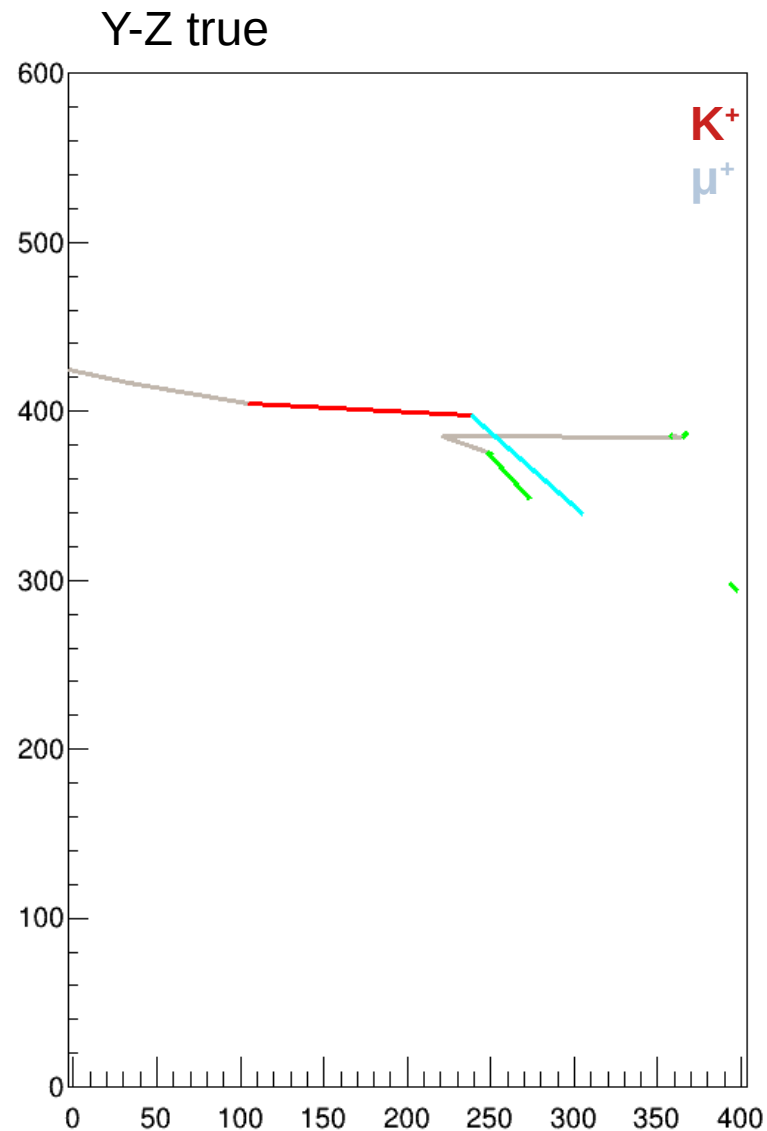
Kaon and muon reconstructed together

This can be clearly seen on the dEdx vs ResRange plot.

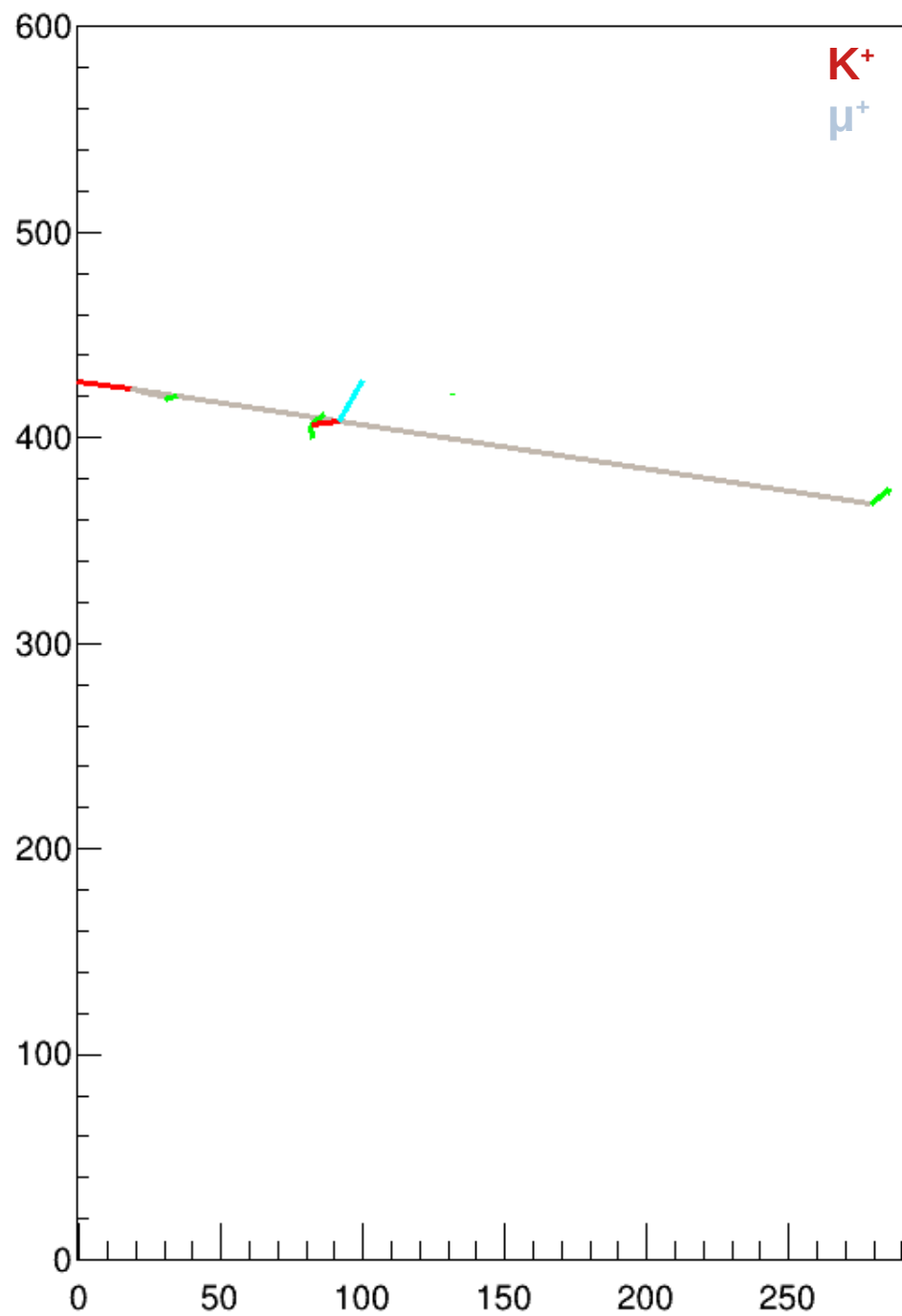
Could it be possible to separate these events? I hand scanned 100 of them and only 5% looked clearly separable, and that would mean 100 additional candidates.



Kaon and muon not matching



Y-Z true



Y-Z reco

