10/05/23

Secondary Kaon Analysis
General update

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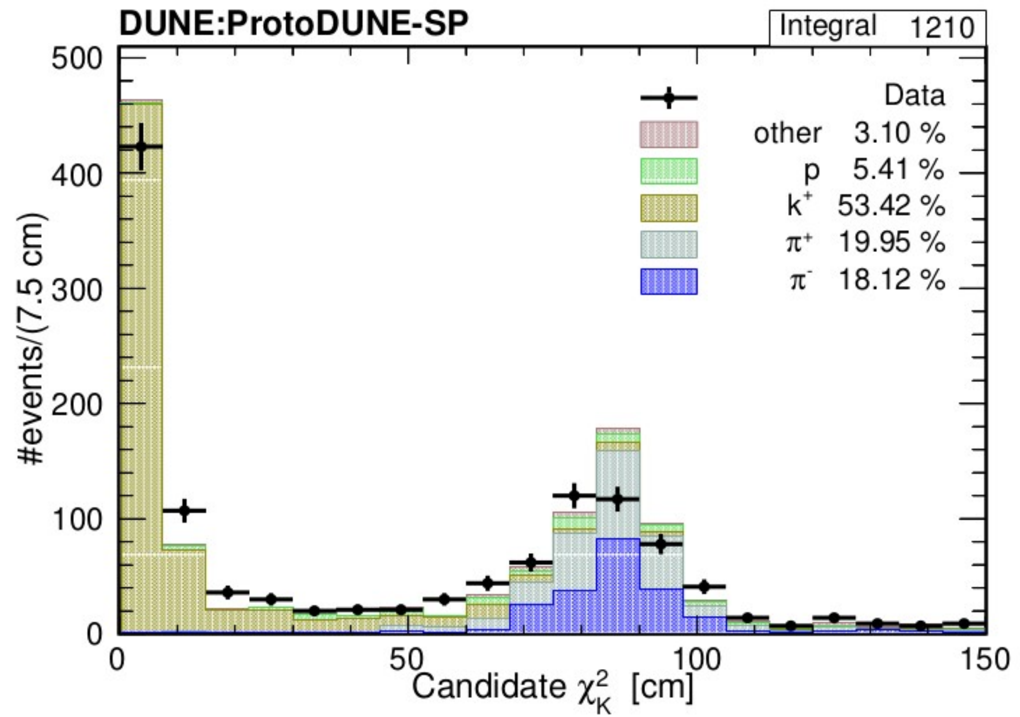
Update

- PhD dissertation ready → it will be deposited next Monday (finally!!).
- Evaluation of systematic uncertainties ‘finished’.
- Selection and dEdx final plots ready.

General recap

- The main objective of this analysis is to provide a direct characterization of low energy kaons in LAr → important for proton decay searches at DUNE FD.
- Since no low energy kaons were produced in the beam, we look for secondary kaons.
- The selection is based in the main decay channel of the kaon ($\mu^+\nu_\mu$) (see this and this).
- A sample of around 500 kaons is obtained from 6 and 7 GeV runs with ~50% purity.



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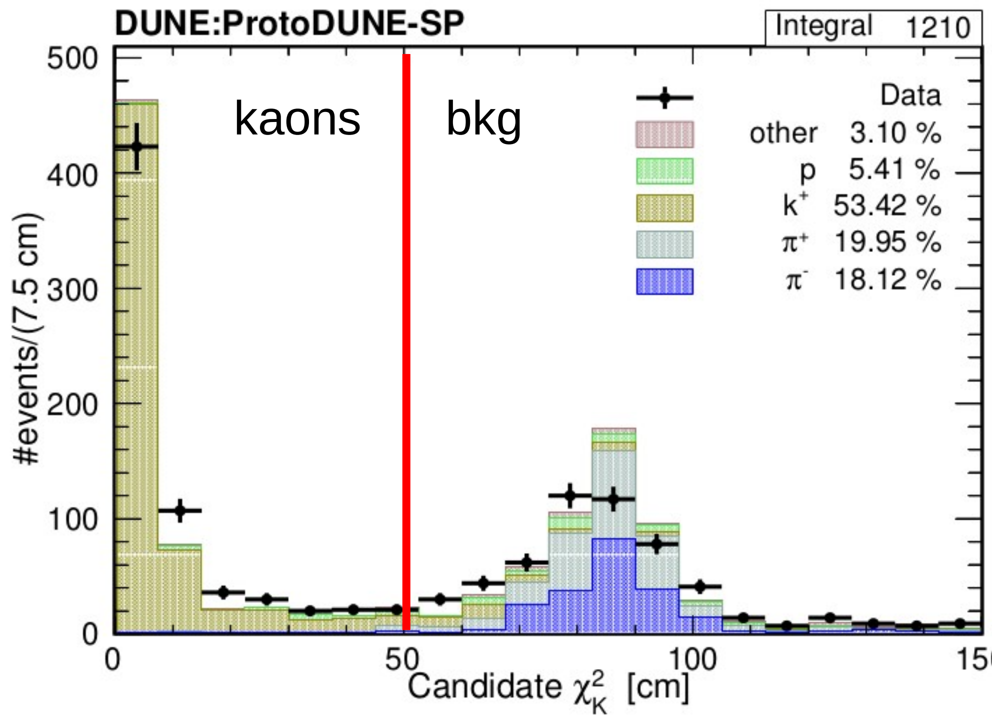
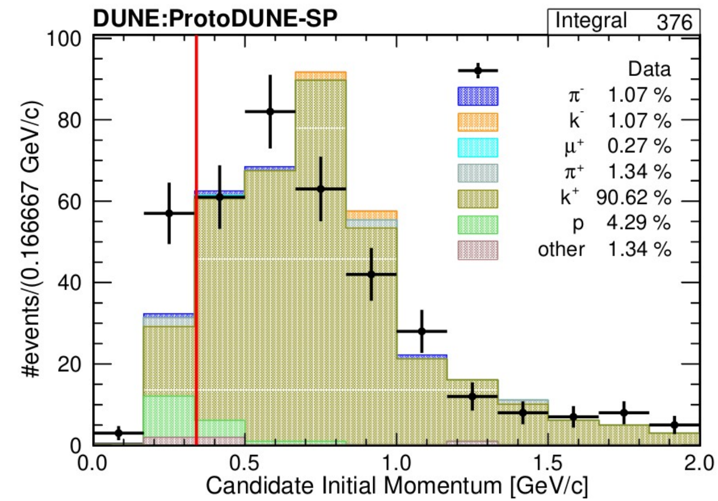
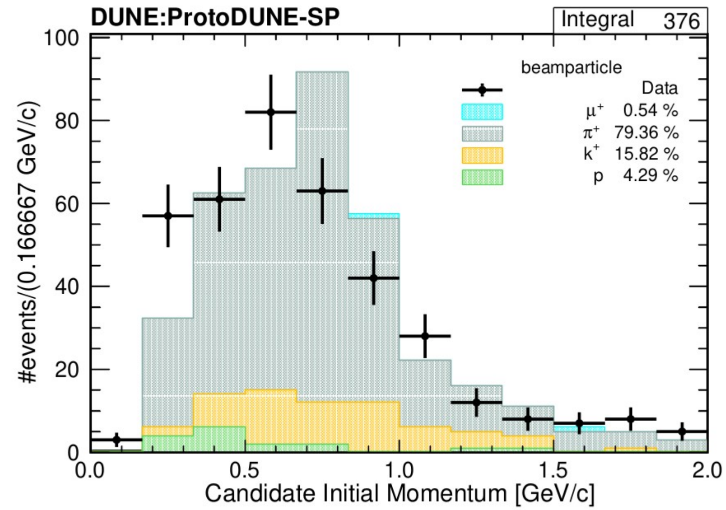


K⁺ initial momentum

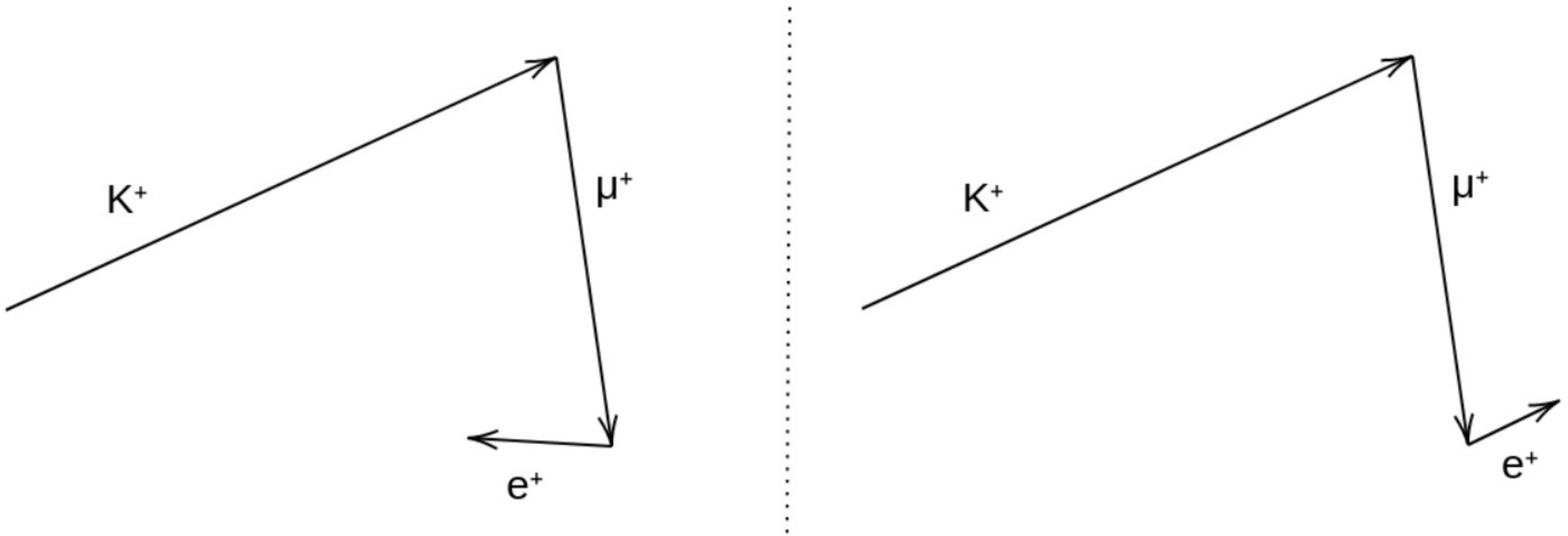
- The initial momentum of the kaon can be computed from the calorimetric information (they are stopping).
- In general they are below 1 GeV. Approximately 100 < 0.5 GeV. Expected momentum from proton decay is 0.34 GeV (red line). We can reconstruct low energy K^+.
- The proportion of beam triggers is 85% pions, 10% protons, 5% kaons. Beam kaons are the most efficient producing secondary kaons (because of strangeness conservation).



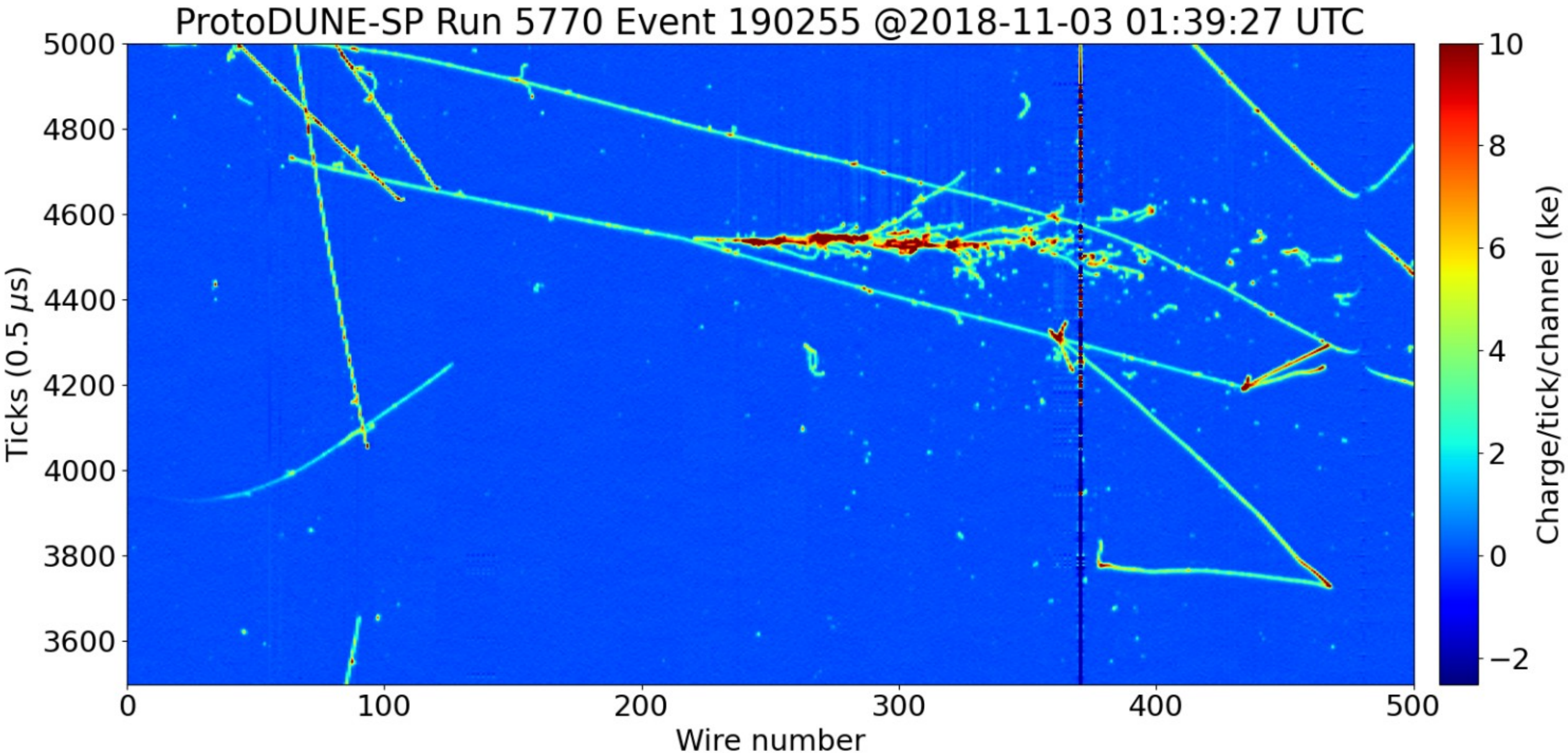


Event Displays

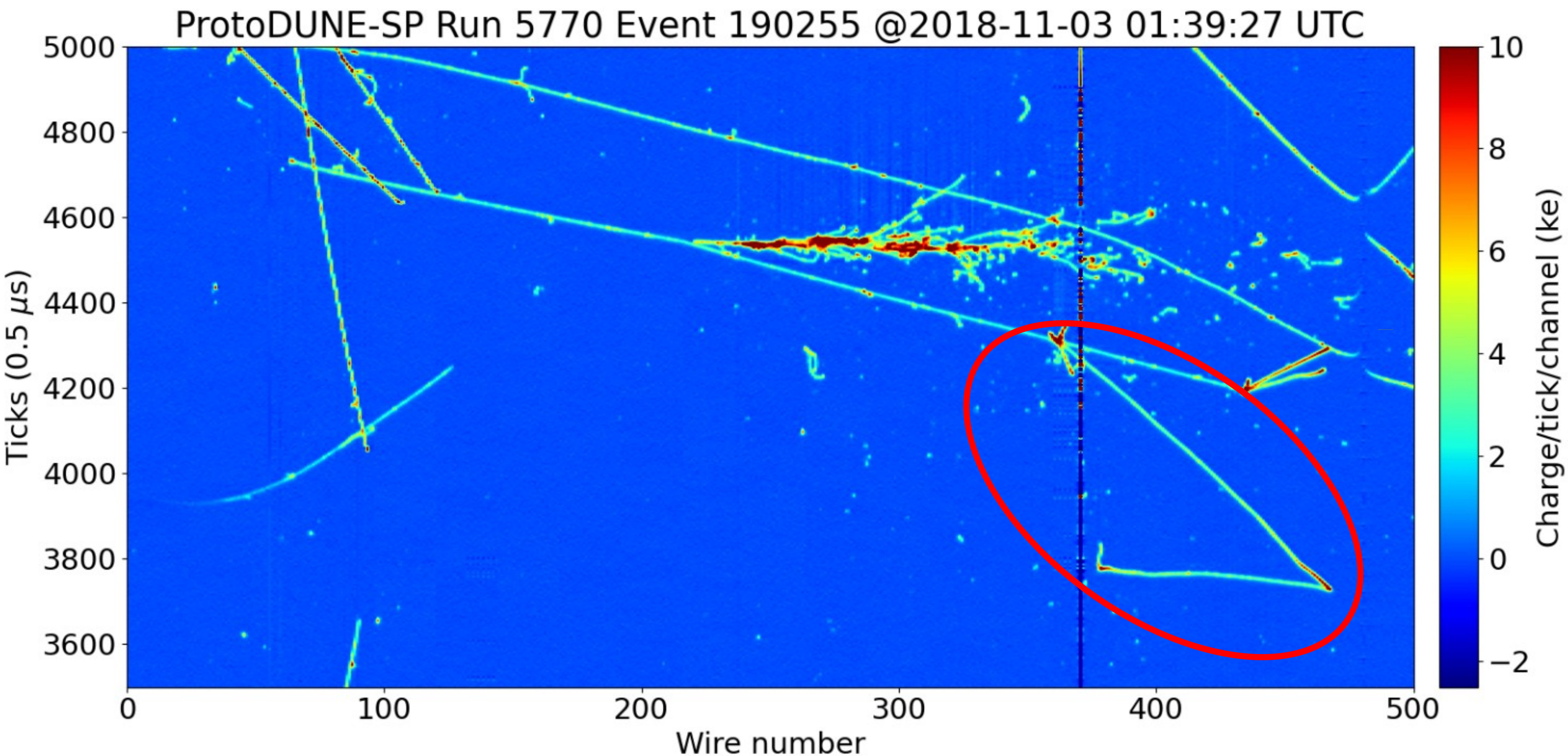
- Stopping K^+ can be identified by the 'hook' topology, $K^+ \rightarrow \mu^+ \rightarrow e^+$



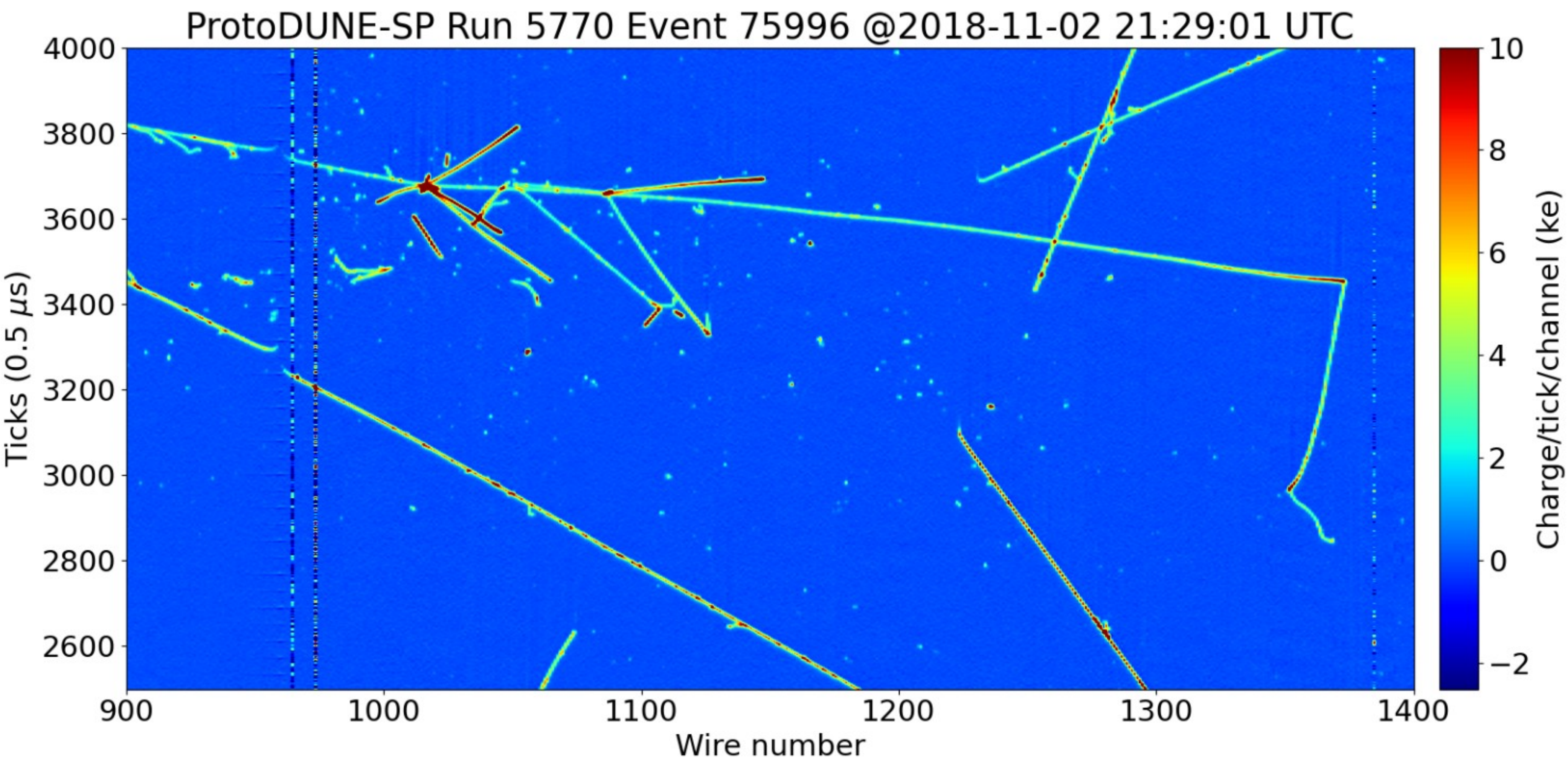
Event Displays



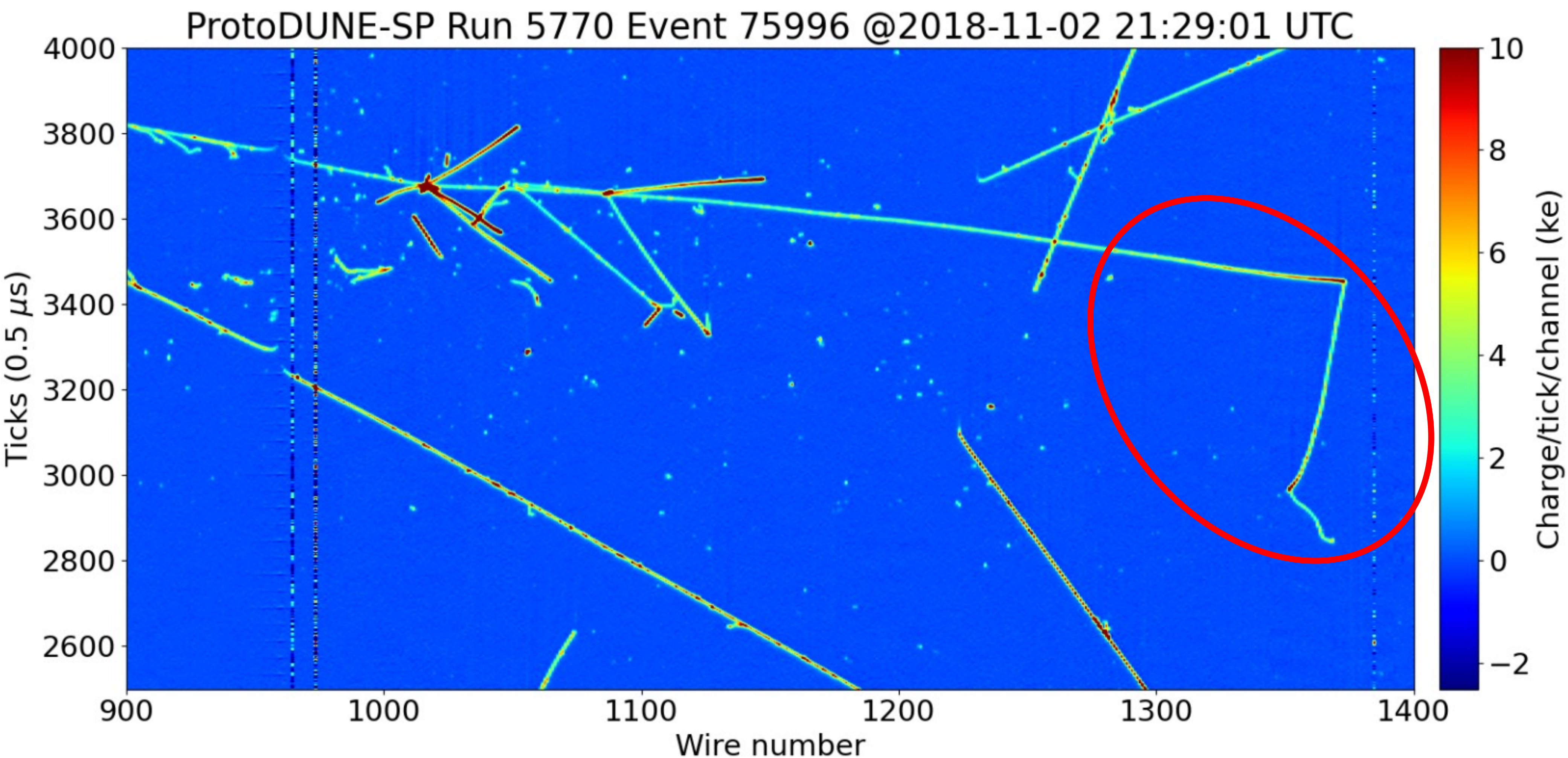
Event Displays



Event Displays

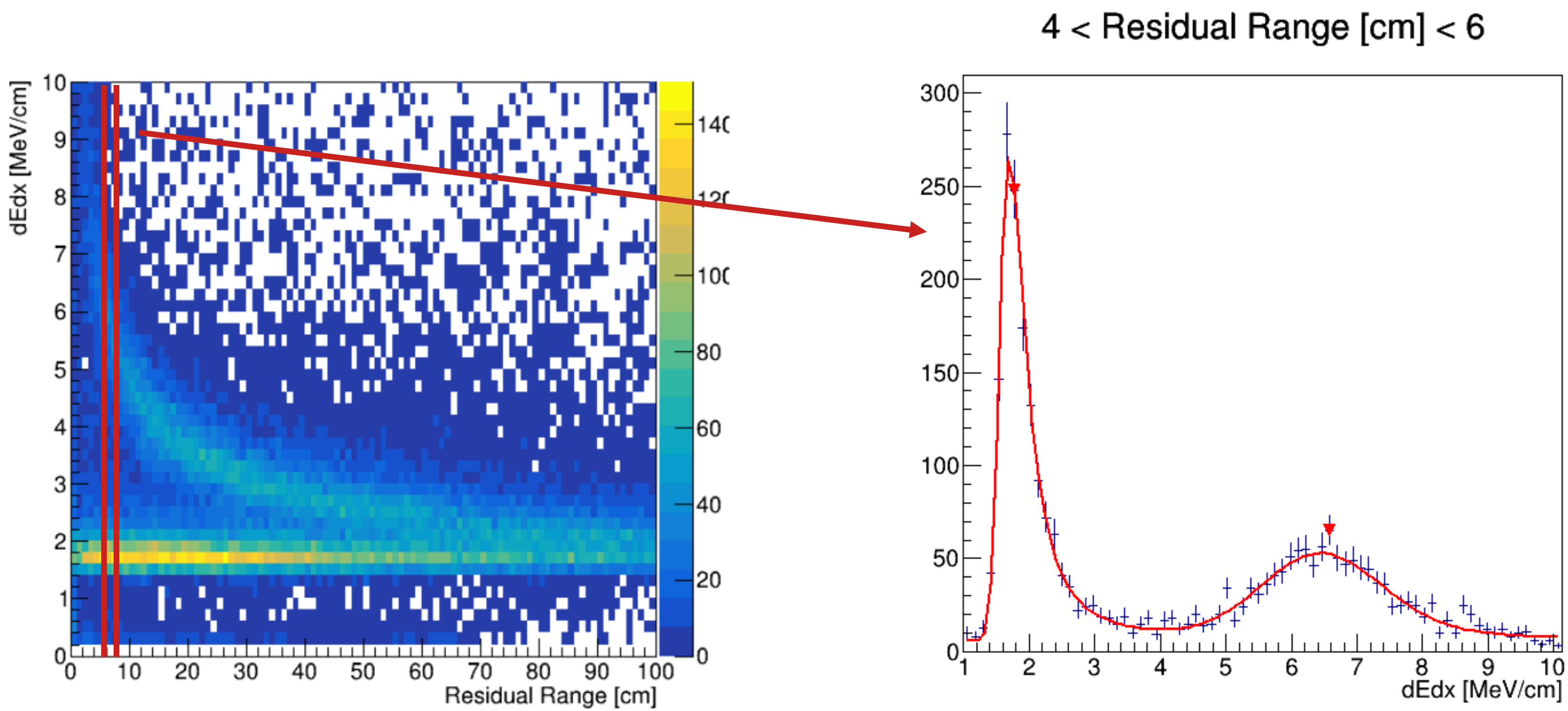


Event Displays



dE/dx extraction

- Both distributions can be seen in the 2D plot dEdx vs RR.
- They can be fitted separately by slicing in the 2D plot in RR slices.

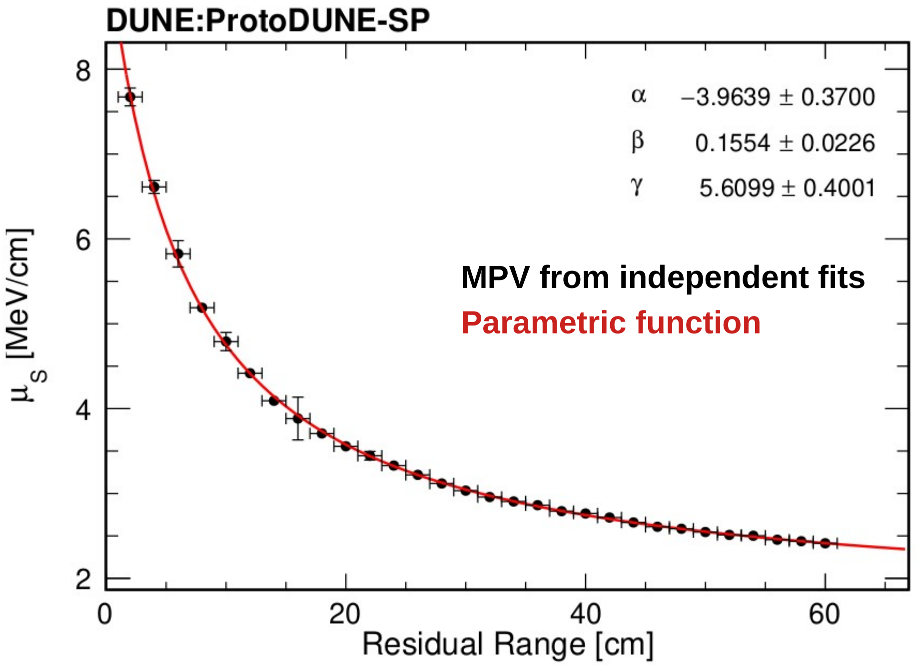


Fitting

- We divide the 2D histogram (dEdx vs RR) in RR slices so signal and background can be fitted.
- The coherent fit approach is used (see this) to consider correlation between bins.
- Particularly, the function used to describe the signal MPV is:

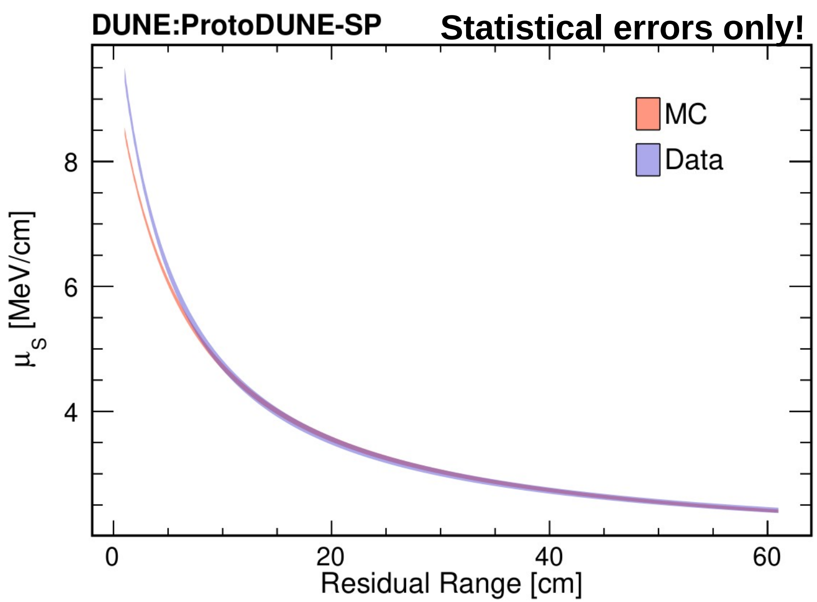
$$\mu_S(x) = \alpha \left[\frac{\beta x - 1}{\beta x + 1} + \gamma \right]$$

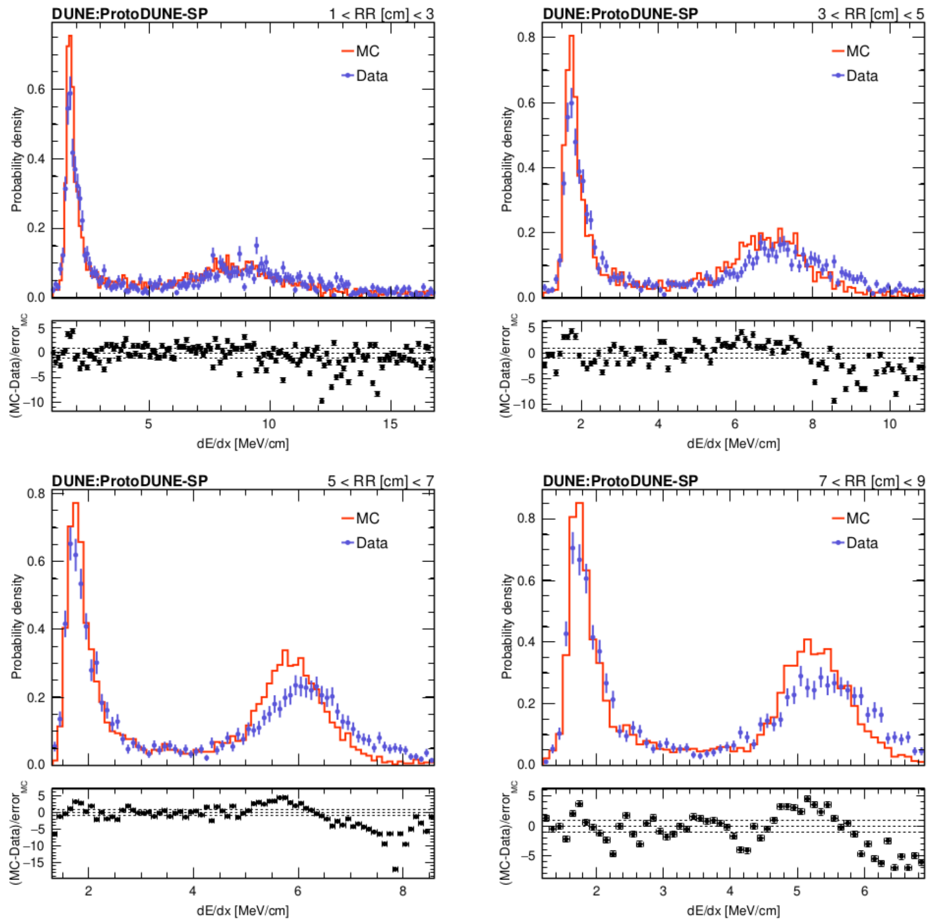
- The fit converges well in MC and data, and provides a good estimation of the errors (MINOS). Details in previous talk.



Fitting result

- Apparent discrepancy (before systematic error evaluation) between data and MC for low residual range (low momentum).
- This can be observed in the 1D histograms, is not effect of the fitting procedure.





Systematic uncertainties

- Systematic uncertainties affect our result in different ways:
  - During the selection, some events may or may not pass the event selection depending on the uncertainty propagation (thus, not entering the histograms that have to be fitted).
  - If the systematic uncertainty affects dEdx or RR, the histograms to be fitted are modified.
  - If the systematic uncertainty varies the weight of the events, they will contribute differently to the histograms.
- In other words, the systematic propagation will modify the histograms to be fitted and the final result. The procedure is repeated over several toy experiments, and the systematic error is computed for the parameters of the fit as the variation over toys.

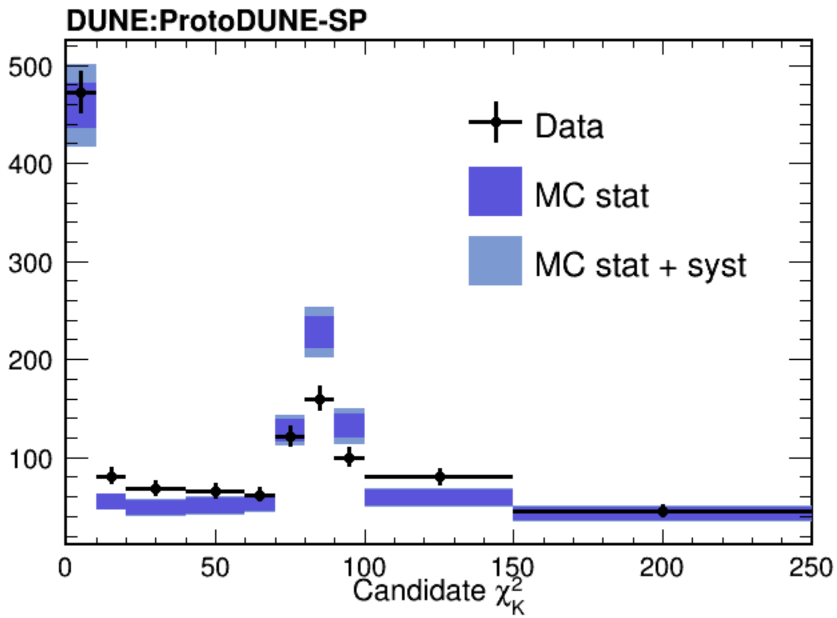
Systematic Uncertainties

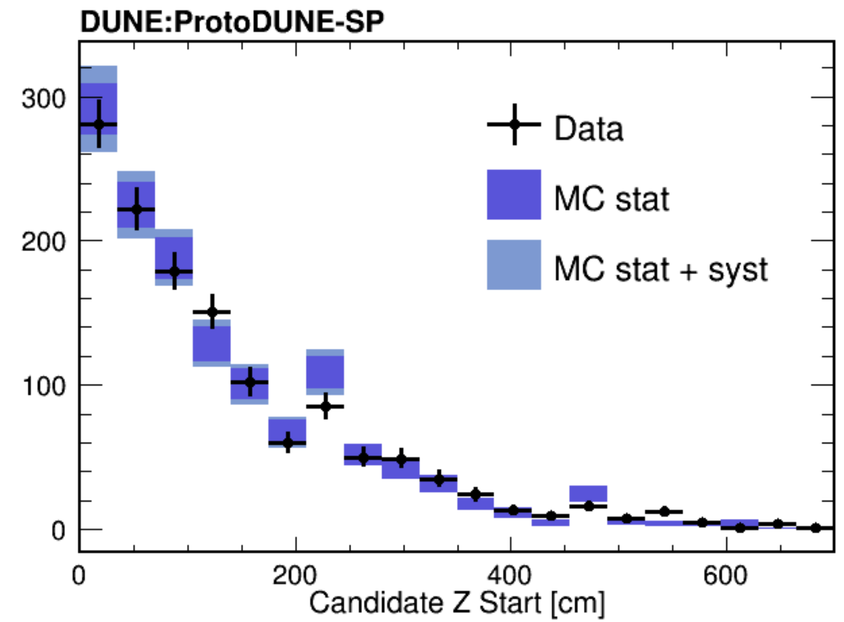
Table 7.1: Summary of systematic uncertainties considered.

Systematic error source	Propagation model	Correction
Calorimetry Calibration	Variation	No
SCE (geometric level)	Variation	No
Recombination	Variation	Yes
Broken tracks in APAs borders	Efficiency-like	Yes
Beam PID Efficiency	Efficiency-like	Yes
Beam species composition	Normalisation	Yes
Beam momenta composition	Normalisation	Yes

Systematic uncertainty: selection result

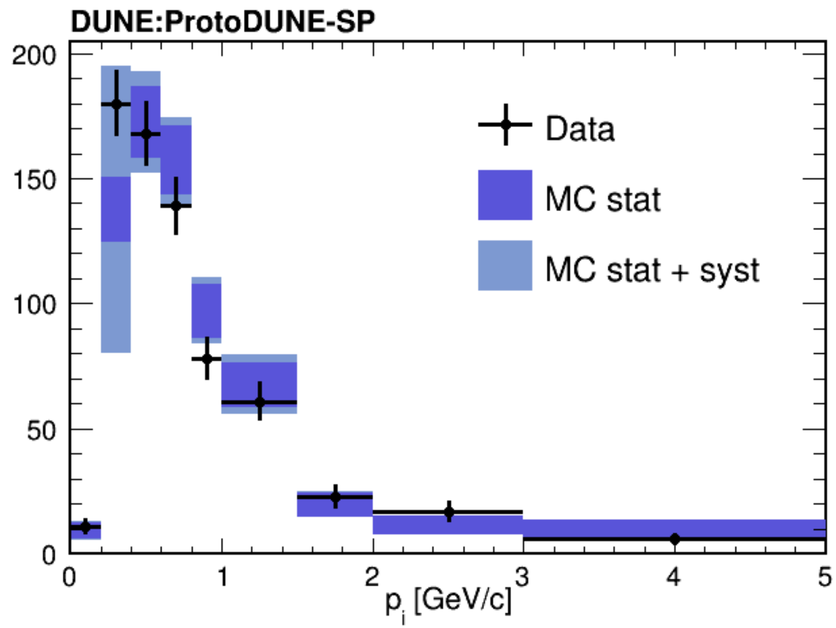
- In general, after the error propagation, data and MC show good agreement.
- The differences in chi² distributions are due to the worst energy resolution in data.
- In the Z starting position the correction of the broken tracks can be observed.

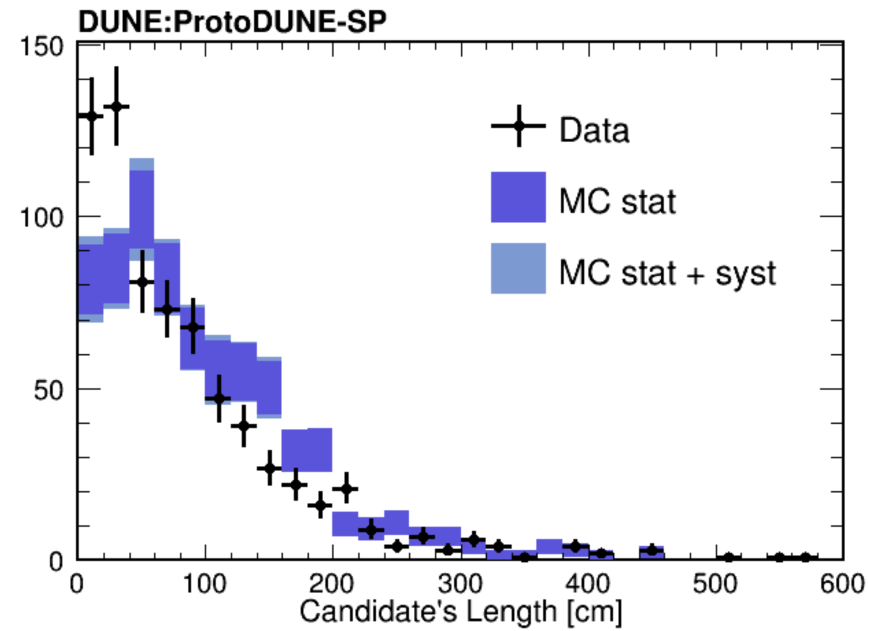




Systematic uncertainty: K^+ kinematics

- Kaons are slightly less energetic and shorter in data than in MC.
- The bin with a large error on the momentum distribution is due to the broken tracks systematic.



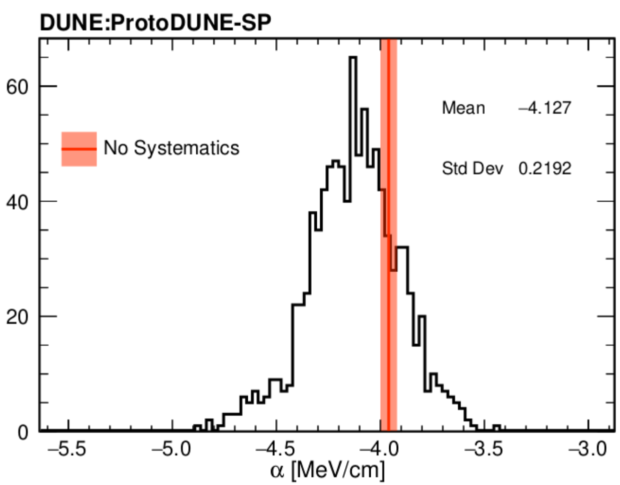


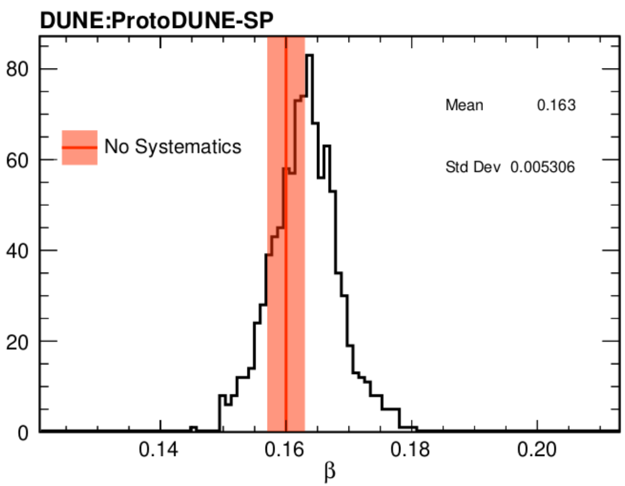
Systematic uncertainty: K^+ dEdx

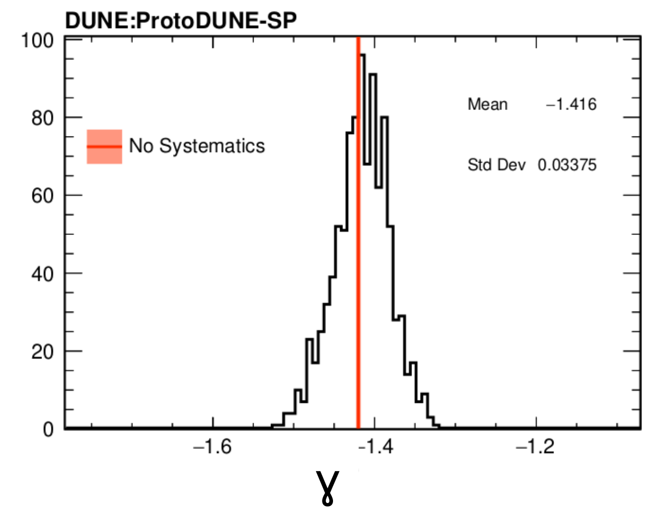
Systematic	σ_{rel} (%)		
	α	β	γ
Calorimetry Calibration	1.1	0.7	0.2
Recombination	4.9	3.1	2.2
Space Charge Geometric Effect	0.4	0.7	0.1
Broken Tracks on APAs	0.1	0.1	0.1
Beam PID Efficiency	0.2	0.3	0.1
Beam Specie normalisation	0.1	0.2	0.1
Beam Momentum normalisation	0.0	0.0	0.0
Quadratic Sum	5.0	3.3	2.2
Total Correlated	5.2	3.2	2.4

Systematic uncertainty: K^+ dEdx

- The propagation to the dEdx measurement is done by repeating the fit procedure in multiple toy experiments.
- 1000 toys used.
- Apart from the spread (error) obtained, it is worth noticing than the parameters prefer different values after the error propagation.

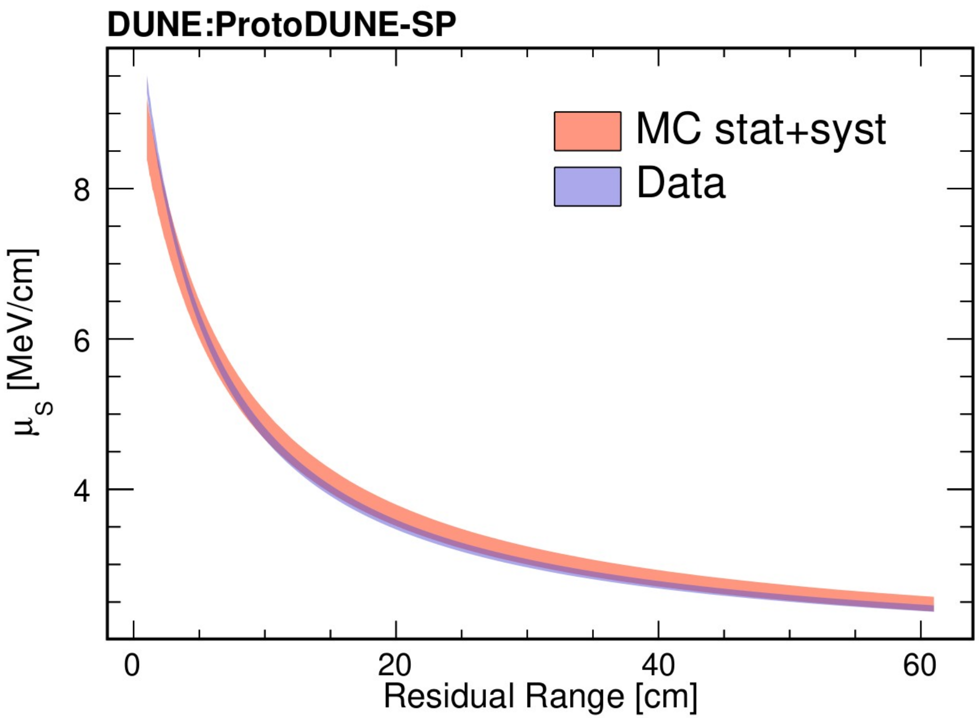


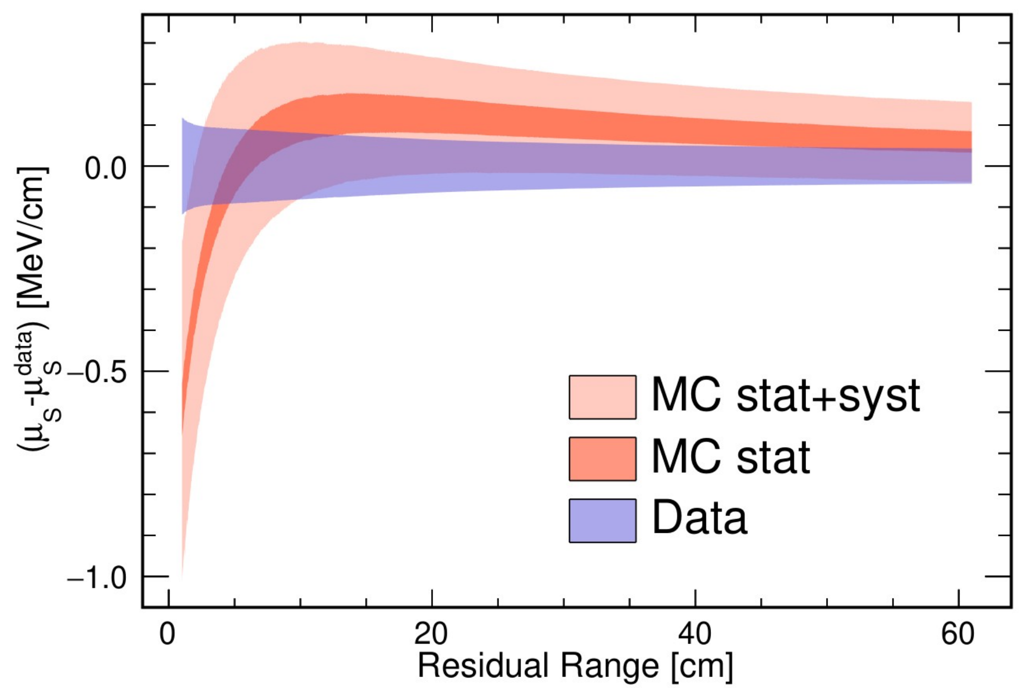




Systematic uncertainty: K^+ dEdx

- The error propagation has decreased the difference between data and MC for low residual range, but it is till present and it is significant.

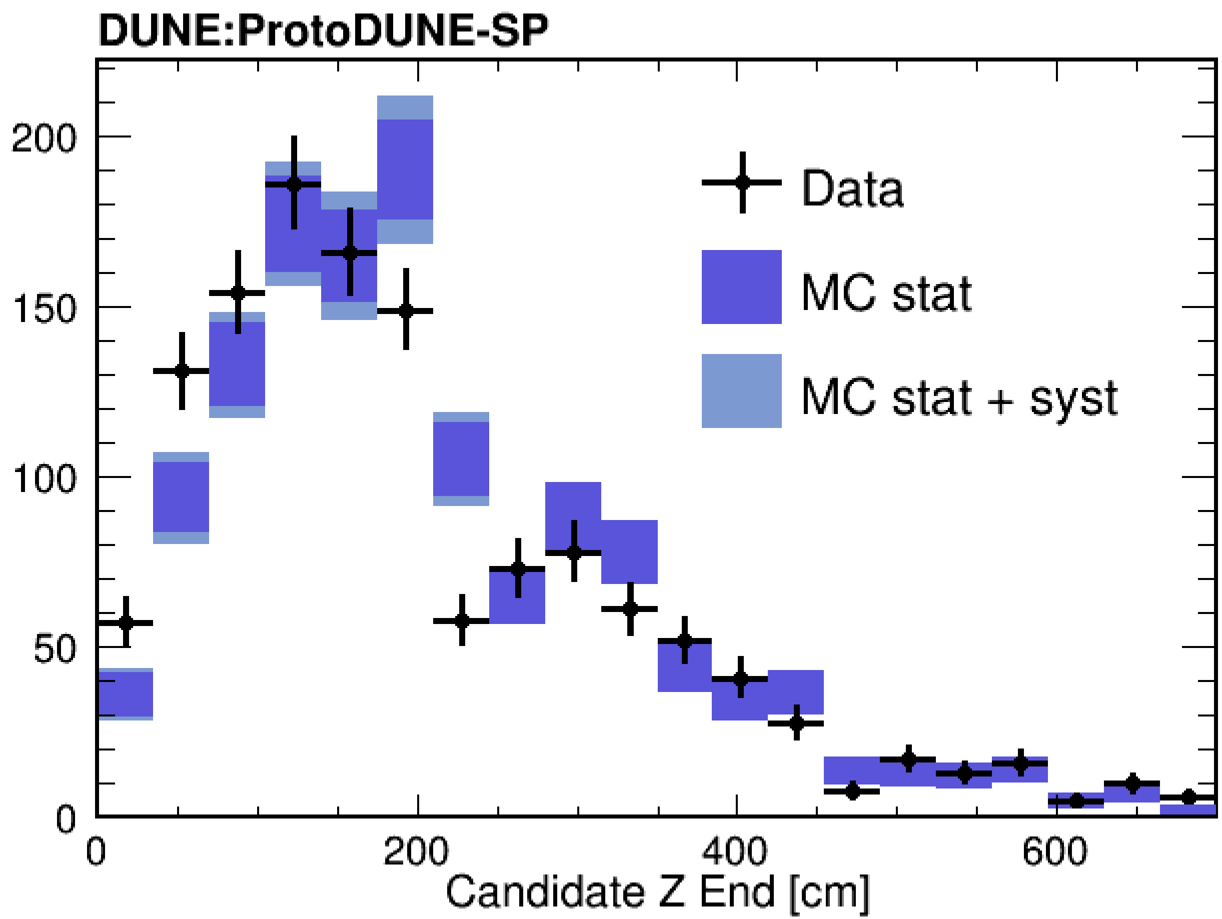




Conclusions

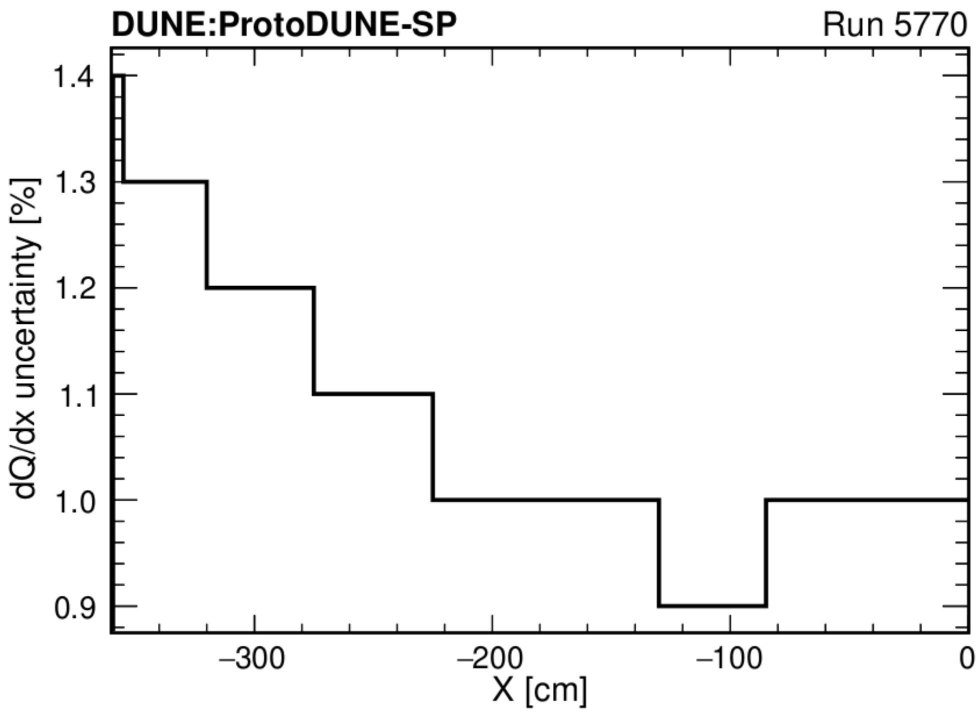
- PhD dissertation about to be deposited.
- The secondary kaon selection allows us to check the capabilities of ProtoDUNE-SP to reconstruct/identify low energy kaons.
- The dE/dx study shows a discrepancy between data and MC, even after the systematic evaluation → needs to be understood.
- Final results will vary slightly since I'm running again with small modifications.
- Next steps:
  - Start working in the technical note.
  - Study in depth the dEdx discrepancy.
  - Study the feasibility of a XS measurement (some work already ongoing).

Backup


DUNE:ProtoDUNE-SP
Data
MC stat
MC stat + syst
0
50
100
150
200
0
200
400
600
Candidate Z End [cm]

Calorimetric calibration uncertainty

- The calorimetric calibration has an associated uncertainty. It affects the dQ/dx and hence
  - The selection result,
  - The fitting procedure.
- I studied the effect of the electron lifetime and SCE correction. Uncertainty map obtained as function of X.



Recombination uncertainty

	Data	MC	Ratio
α	0.905 ± 0.015	0.920 ± 0.015	0.98 ± 0.02
β	0.220 ± 0.007	0.212 ± 0.005	1.04 ± 0.04

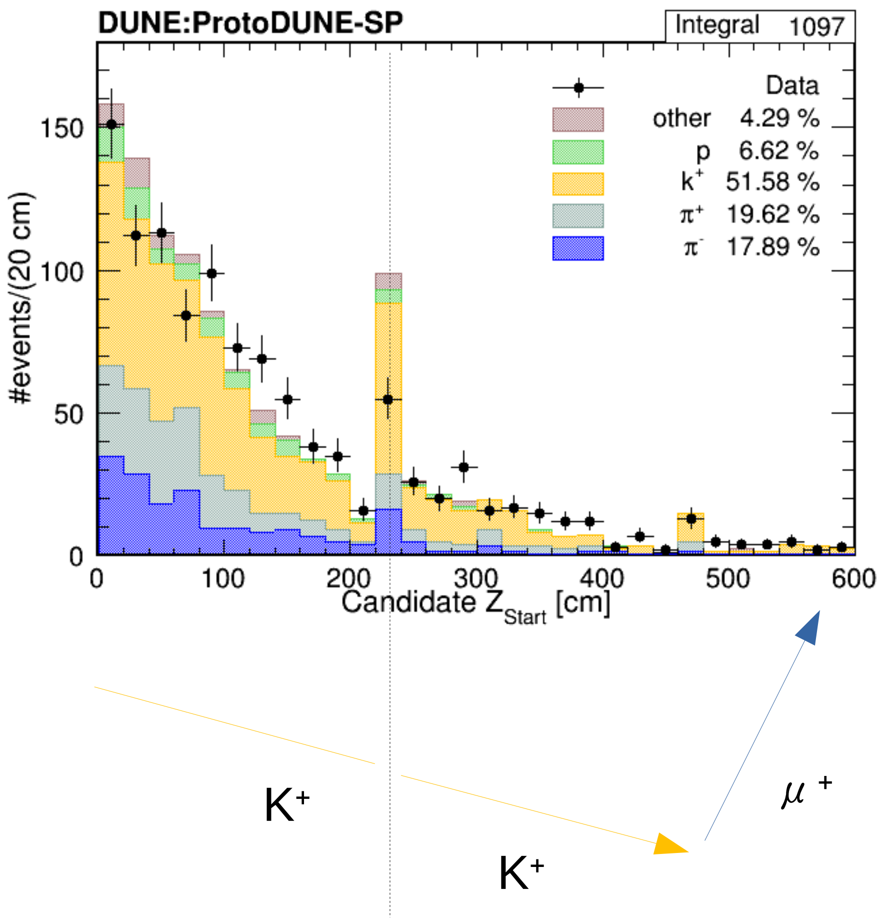
- Recombination parameters measured different in data and MC.
- Uncertainty propagated by varying the MC parameters to match the ones of data using correlated throws.
- It is the systematic affecting the most the selection AND the dE/dx measurement.

SCE (geometric)

- SCE affects geometric properties (length, position, direction, residual range) of tracks, thus the selection result and the fitting algorithm.
- SCE varied in multiple toy experiments a 5%.
- The variation has been applied globally (equal to all voxels) and locally (different in each voxel). The local variation generates a slightly larger effect, but not significant.

Broken tracks

- The amount of broken tracks between APAs is larger in MC than in data.
- This generates more shorter kaon tracks in MC than in data: different contributions to different RR bins.
- This effect can be propagated as an (efficiency) weight.
- Weight value is known (~0.5). Small analysis done (control sample) to evaluate the uncertainty in the weight: 0.50 +- 0.06.



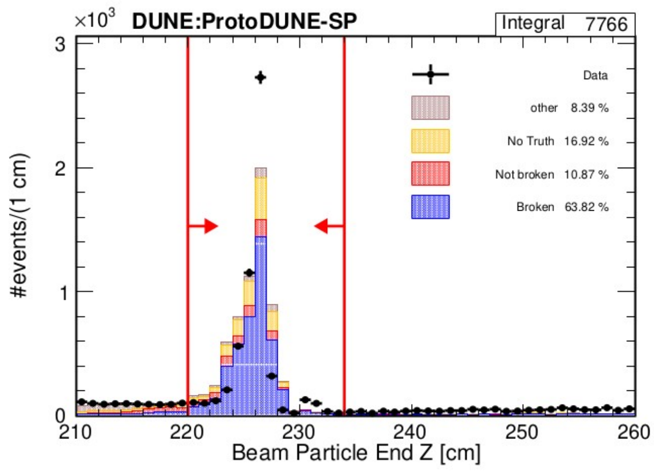
Broken tracks: control sample

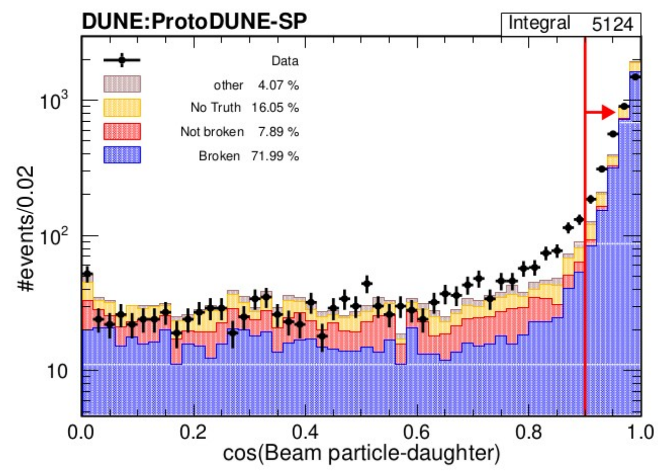
- 1 GeV/c pions and muons sample used to measure the effect.
- The breaking efficiency is defined as

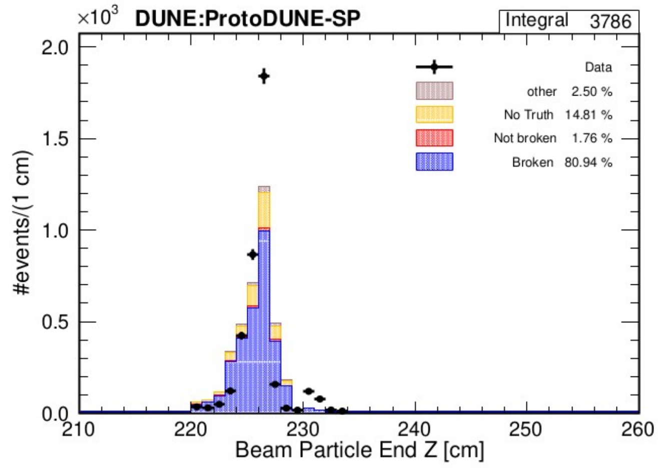
$$\epsilon = \frac{N_{Broken}}{N_{Z>220}}, \tag{7.15}$$

where $N_{Z>220}$ represents the number of tracks reaching, at least, the electron diverters region, and N_{Broken} represents the number of broken tracks. Naturally, not all of the tracks ending in the region between APAs are necessarily broken, so a small selection can be done to maximize the amount of selected broken tracks. From the MC information it is easy to determine which tracks are truly broken: one can simply look at the true Z end position of the track, and check if the track truly stops near the APA region (meaning that it is not broken) or it stops further away from it (meaning that it is broken). Broken tracks are the ones that:

Broken tracks: control sample

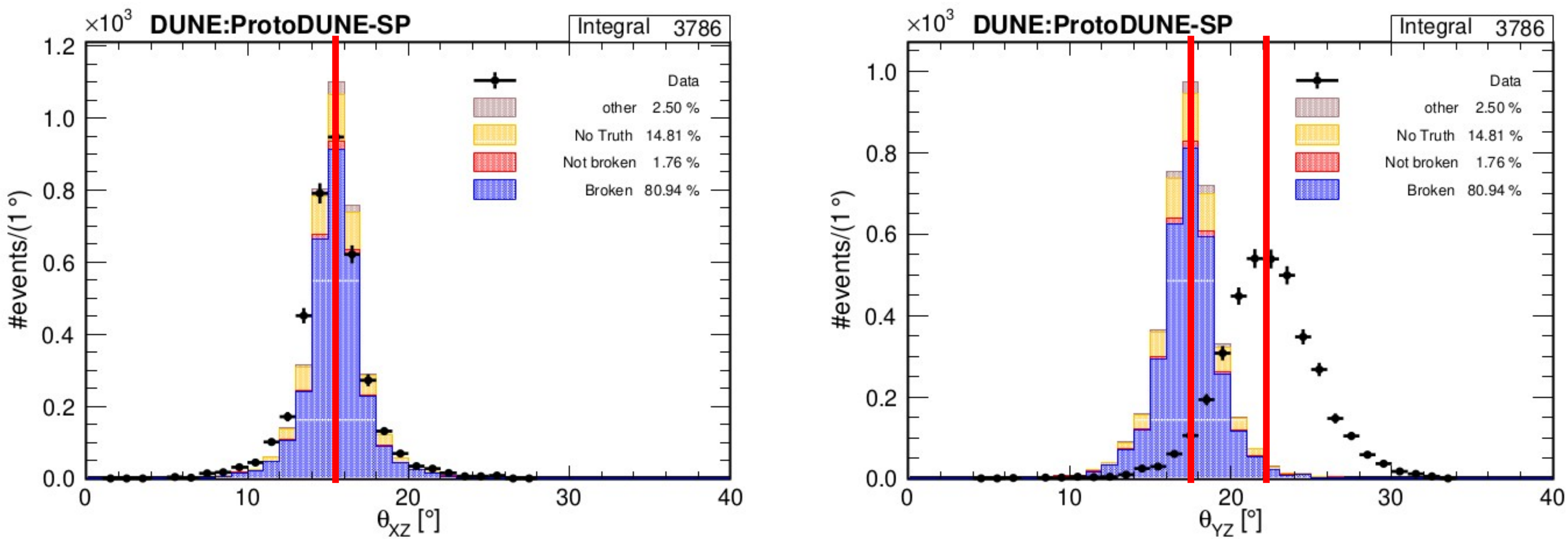






Broken tracks: control sample

- Error estimated by subsampling different angles and measuring the maximum deviation with respect the whole sample value



Broken tracks: control sample

- Error estimated by subsampling different angles and measuring the maximum deviation with respect the whole sample value.
- This was repeated for larger momentum and a small dependence was found. Not considered here.

Table 7.8: Broken track efficiency measured for different subsamples of the control sample. Errors shown are statistical.

	ϵ_{data}^{CS}	ϵ_{MC}^{CS}	r_{CS}
$\theta_{XZ}^{low}, \theta_{YZ}^{low}$	0.222 ± 0.006	0.465 ± 0.008	0.477 ± 0.016
$\theta_{XZ}^{low}, \theta_{YZ}^{high}$	0.213 ± 0.007	0.475 ± 0.008	0.449 ± 0.018
$\theta_{XZ}^{high}, \theta_{YZ}^{low}$	0.243 ± 0.006	0.472 ± 0.007	0.516 ± 0.015
$\theta_{XZ}^{high}, \theta_{YZ}^{high}$	0.272 ± 0.008	0.492 ± 0.006	0.553 ± 0.017

Broken tracks: weight assignment

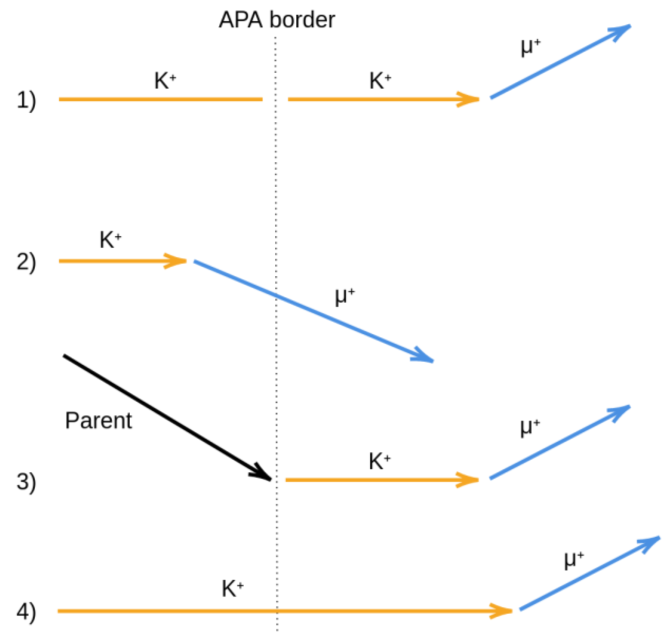
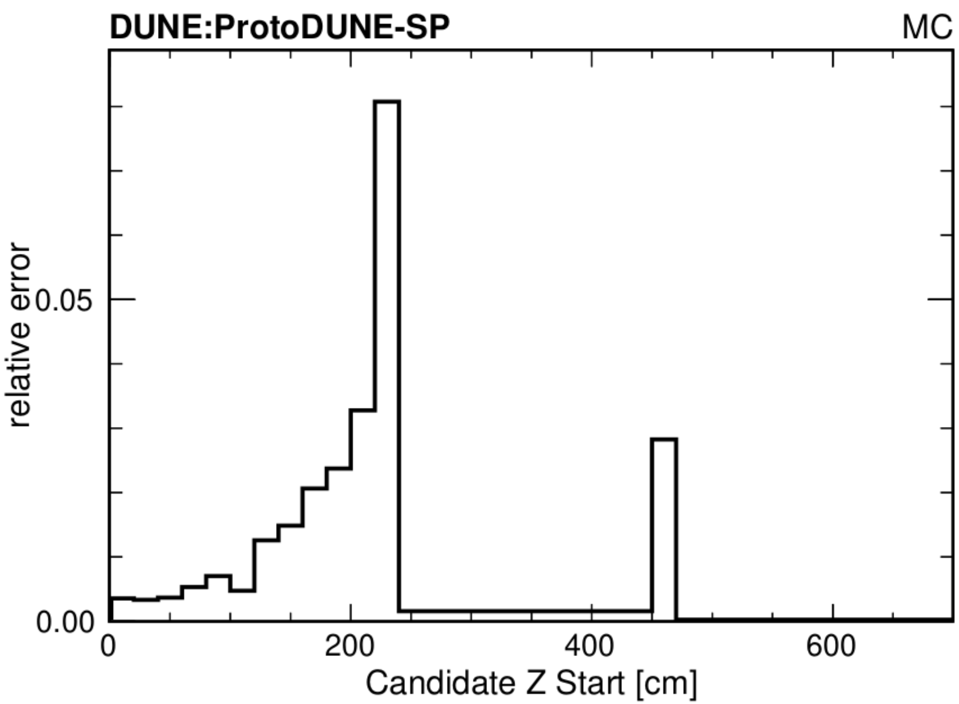
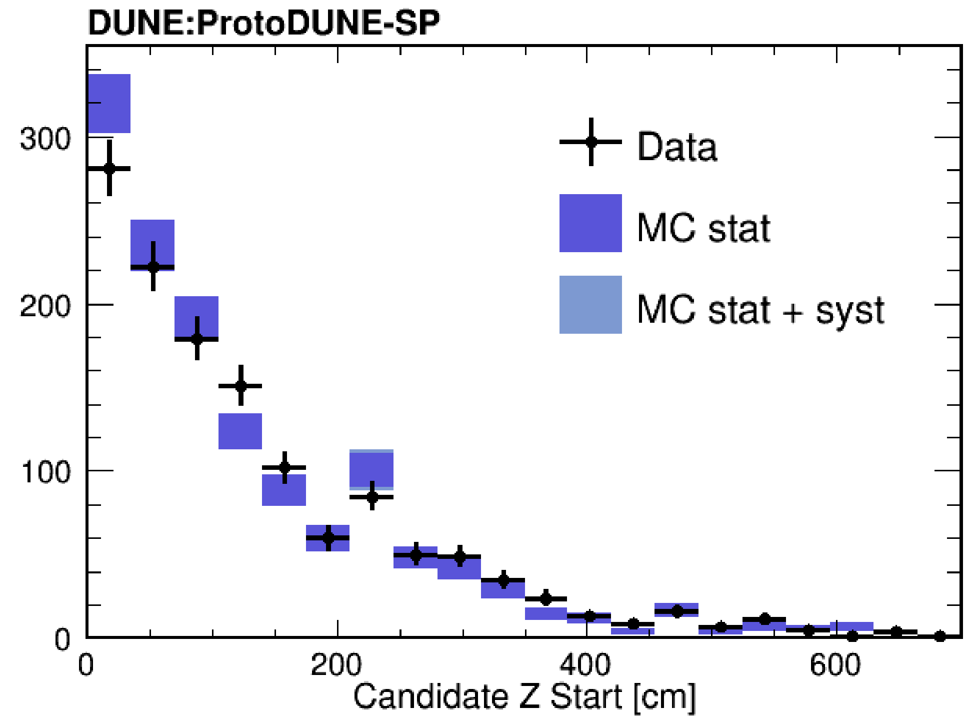


Figure 7.17: Topologies to be considered when assigning efficiency and inefficiency weights in the broken tracks systematic. From top to bottom: broken track that has to be weighted by the efficiency ratio; non broken track that starts naturally in the electron diverters regions and does not have to be weighted; non broken tracks that does not have to be weighted; and non broken track that has to be weighted by the inefficiency ratio.

Broken tracks: effect

- This systematic generates a migration of tracks starting in the diverters regions towards more upstream locations by the assignment of weights.





Other systematics

- Pandora beam PID efficiency, beam momentum normalization and particle specie normalization are propagated to consider secondary effects. They only modify the proportion of beam pion/proton/kaon events at 6 and 7 GeV, and the kaons' dE/dx should be independent of the particle that generated the kaon. However, it can affect secondarily to the effects previously commented. They are propagated as weights.