6 GeV Beam Kaon Inelastic Cross Section Measurement Update

Richie Diurba (Minn.) and Jake Calcutt (MSU)

diurb001@umn.edu

Outline

1. Continued discussion on MPV vs. mean on energy loss measurement.
2. Discussion of systematic uncertainties adapted from current PDSPThinSliceFit.
3. Cross section plots of all three beam particle species.

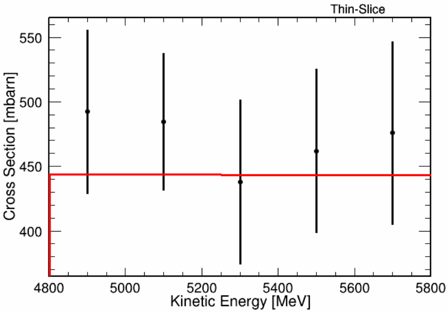
Previous presentation, which outlines the selection cuts and the high approx. 90% purity, is in the back-up slides.

All of plots use the PDSPThinSliceFitter package in protoduneana. It uses a template fit with Baker-Cousins multinomial statistics.

Recap of Last "Official" Update

Uses the LAriat thin-slice measurement (Will use true traj. on Prod4a).

- $\sigma(\mathrm{KE}) = \frac{\mathrm{M_{atomic}}}{\mathrm{N_{avo.} r_{pitch} \rho_{Ar}}} \ln[\frac{\mathrm{N_{inc.}(KE)}}{\mathrm{N_{inc.}(KE) - N_{int.}(KE)}}]$

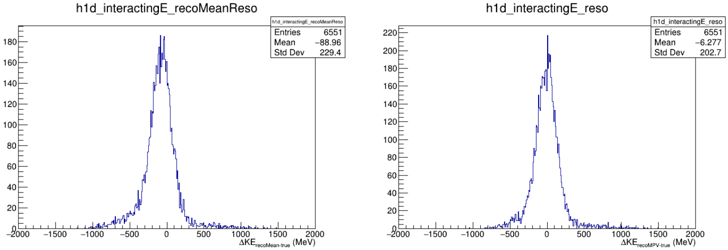


Preliminary fit with only statistical errors shown at WIN2021.

Focus now on implementing systematics and finishing the MC-to-MC fit.

Return to the Energy Loss Debate (Mean vs. MPV)

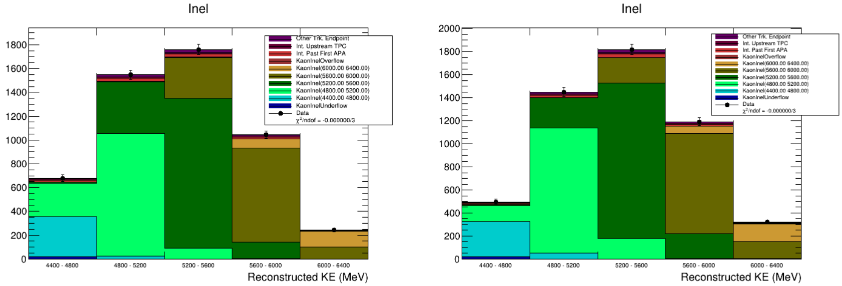
- Use Francesca's method which fits the MPV on each wire in the first APA and the mean of the track pitch to calculate the energy loss.
  - Francesca et al. suggest then scaling the dE/dx from the MPV to the mean for the calculation.
  - I have been using only the fitted MPV. I am currently searching for the obscure DZero webpage that warned against the above.
- There appears to be an issue though because the former is correct and the latter does not work for many slices of Landau fits, which would converge to a mean.



Resolution using the upscaled mean (left) and the fitted MPV (right).

Interaction Histograms for Mean and MPV

Bins are expanded from 200 Mev to 400 MeV. This change will be explained in the next section.



Interaction point histogram for mean (left) and MPV (right)

I believe that the MPV calculation is more reasonable given these plots at the moment. This is not defensible and more investigations need to be made on why this is observed.

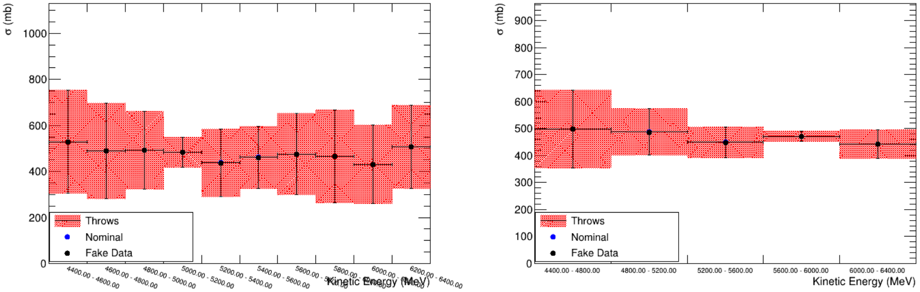
Systematics Discussion

Jake has a fabulous set of systematics added to PDSPThinSliceFitter that can be adapted for any analysis.

- Calorimetry: 2% uncertainty on gain constant. Current dQ/dx calibration uncertainty is approx. 1.7%.
  - Regenerate histograms with new gain values to evaluate impact.
- Beam resolution: Identical to steps outlined by Jake but for 6 GeV.
- Efficiency of beam cut: Reweight around MC CV rate of this selection cut occurring. See Jake's slides for how this would work or AbsCexDriver.cxx.
- Impact of the electron diverter effect: Same as above but for the track length in z cut. Systematic is useless until Prod 4a is available, which simulates the diverters.

All work above originates from Jake's original systematics.
(Here is a link to Jake's slides)

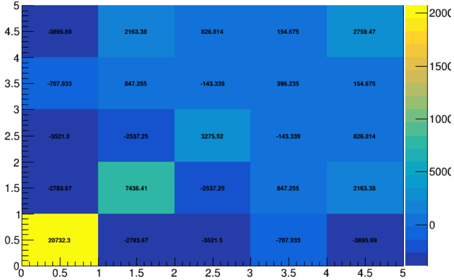
Plot of MC-to-MC Fitted Cross Section with Systematics of 200 MeV Bins and 400 MeV Bins



Fitted cross section with 200 Mev and 400 MeV sized bins.

200 MeV-sized bins are too small, especially to cover calorimetric uncertainties, decided to now use 400 MeV bins.

Covariance Matrix of Cross Section

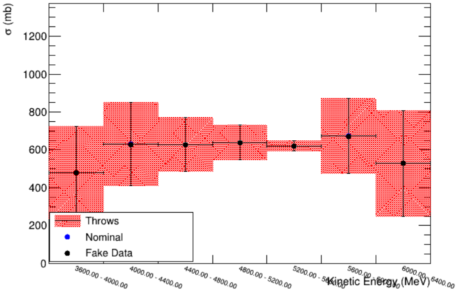


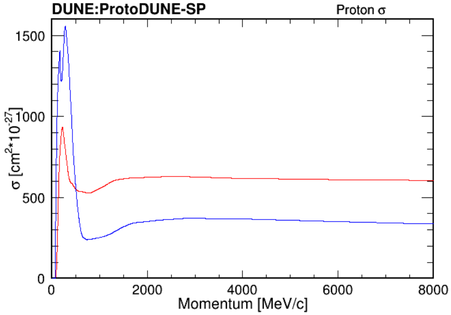
Post fit covariance matrix (left) and the resulting cross section covariance matrix (right) from correlated throws of the fit covariance matrix.

Square root of the diagonal of the cross section covariance matrix, right, serves as the systematics of the cross section plot.

Plot of Proton MC-to-MC Fitted Cross Section

Same parameters and selection as the kaon cross section.

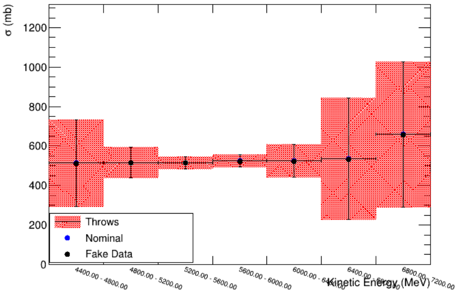


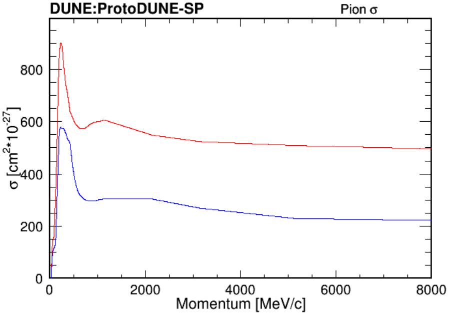


Fitted MC proton cross section (left) and the Geant4 input cross section (right, red).

Plot of Pion MC-to-MC Fitted Cross Section

One added parameter necessary for the pion fit which includes the muon content from the beam. PDSPThinSliceFitter then fits two fluxes, one for pions and one for muons, that get fed into the overall result.





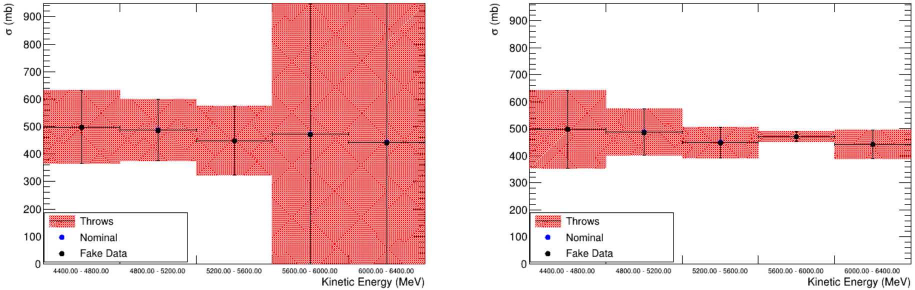
Fitted MC pion cross section (left) and the Geant4 input cross section (right, red).

Conclusion

- Systematics have been added to the current fitter at 6 GeV.
- MC-to-MC fits show good agreement with Geant4 for all three particles.
- To Do:
  - Add Geant4 systematic and process Prod4a data.
  - Confirm calorimetry calibration systematic (Update to be given this Tuesday).
- Plan to finish thesis and move to technical note, will discuss with Tingjun et al. on what the next four months look like for the 6 GeV studies.

Backup Slides

Cross Section for Mean and MPV



Cross Section for mean (left) and MPV (right)

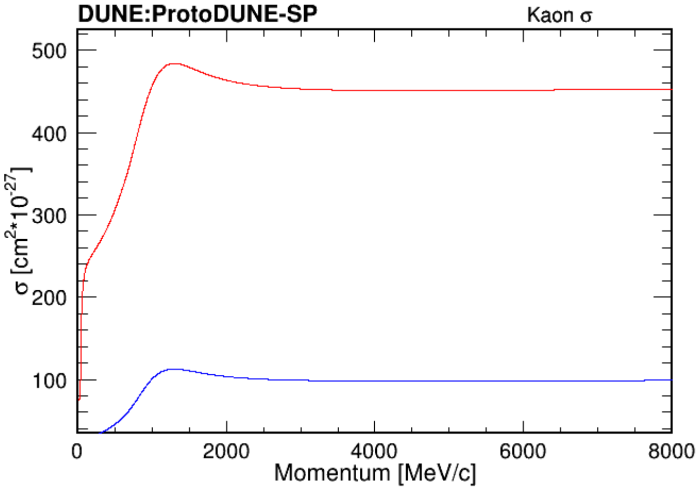
Introduction to High Momentum Test Samples

Total number of cumulative triggers for specific beam momentum settings as a function of candidate particle trigger.

Momentum (GeV/c)	Pion-like (k)	Proton-like (k)	Electron-like (k)	Kaon-like (k)
0.3	0	0	242.5	0
0.5	1.5	1.5	296.3	0
1	381.8	420.8	262.7	0
2	333.0	128.1	173.5	5.4
3	284.1	107.5	113.2	15.6
6	394.5	70.1	197.0	27.9
7	343.7	58.4	112.9	28.2

Kaon Cross Section in G4

Measuring inelastic cross section most feasible.



Kaon cross section from GEANT 4 with inelastic (red) and elastic (blue)

Beamline Monitoring Particle Tagging

Beamline monitor candidate beam particle selection.

Candidates	High Pressure Cherenkov	Low Pressure Cherenkov
$\pi+/\mu$	1	1
p+	0	0
K+	1	0

General Beamline Tracking Cuts:

- $|x_{beamline} - x_{TPC} + 2.5| < 0.5$
- $|y_{beamline} - y_{TPC}| < 1$
- $|z_{beamline} - z_{TPC+29}| < 4$
- Track must exist with a length.

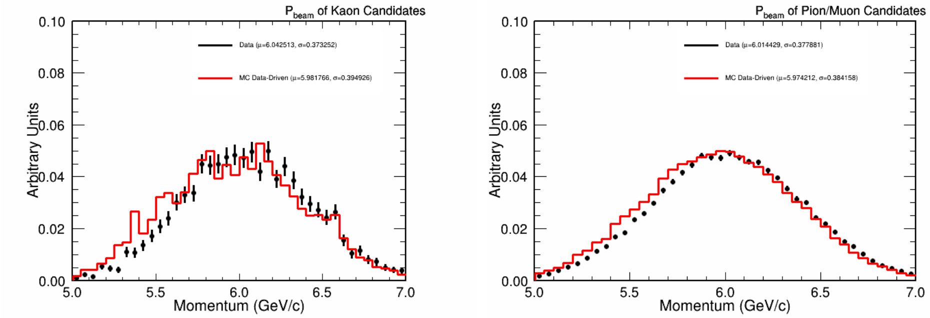
6 GeV Beam Sample with Beamline Cuts

The overall effect of these cuts is a high purity sample amongst all hadrons in the beam. This includes separating pions from muons.

Particle	Total MC Events	True Inel.	Wrong Particle Bkg.	Other Endpoint
Kaon	6706	6011 (89.6%)	636	59
Pion	88724	86314 (94.2%)	5068	42
Proton	15396	14752 (95.8%)	644	0

Beam sample distribution for particles stopping in APA3 selected by beam reco in Production 4. Sample is of approximately 40k events, around a third of the MC.

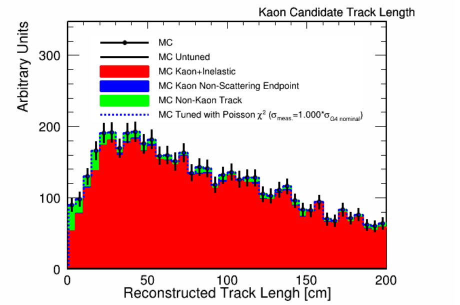
Beam Momentum Distribution

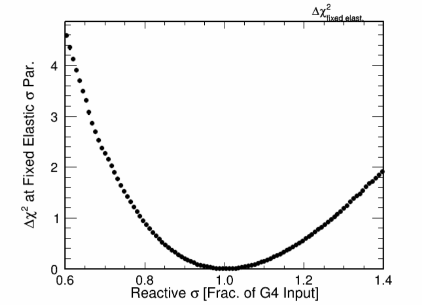


Distribution of beam momentum for kaon candidates (left) and pion/muon candidates (right)

Reweighting the Track Length Distribution

- Tests were done initially to see how well Geant4Reweight can measure the cross section using track distributions.





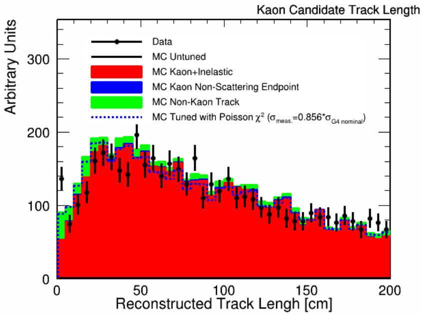
Space charge effect corrected reconstructed track length plot with MC-to-MC fitted cross section (left) and the sensitivity of the fit (right).

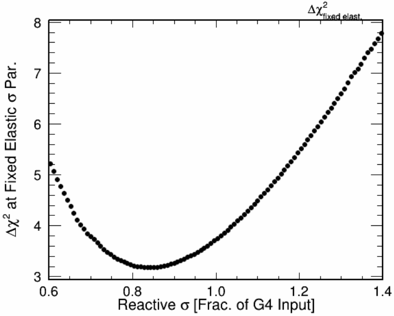
More studies planned on other track length metrics and selection cut impact.
Method pioneered by Ajib Paudel and Heng-Ye Liao.

Track Length Method Fit to a Small Data Sample

On a sample of data, this method hints at a lower cross section.

Total MC Events	Kaon Inel.	Non-Kaon	Kaon Non-Inel.
6706	6011 (89.6%)	636	59





Reconstructed track length plot with fitted cross section (left) and the sensitivity of the cross section (right). Approximately 3.5k kaons in data with both datasets normalized. Data contains approximately half of all 6 GeV data events.

Thin-Slice Method Cross Section Extraction

Thanks to Francesca, Tingjun, Jake, and Libo for their help in understanding thin-slice techniques.

- Bin the interaction point in kinetic energy.
- Either fit using templates or unfold the true and reco interacting kinetic energy.
- Scale the interacting histogram based on the true incident histogram to measure the cross section.

Two formulas will be used:

- E-slice method:
  $\sigma(\mathrm{KE}) = \frac{\mathrm{M_{atomic}}}{\mathrm{N_{avo.}} \Delta \mathrm{E_{bin\,size}} \rho_{\mathrm{Ar}}} < \mathrm{dE/dx_{Bethe-Bloch}} > \ln[\frac{\mathrm{N_{inc.}(KE_{bin})}}{\mathrm{N_{inc.}(KE_{bin})} - \mathrm{N_{int.}(KE_{bin})}}]$
  - Every bin receives only one entry with this method.
- Generic thin-slice method: $\sigma(\mathrm{KE}) = \frac{\mathrm{M_{atomic}}}{\mathrm{N_{avo.}} \mathrm{r_{pitch}} \rho_{\mathrm{Ar}}} \ln[\frac{\mathrm{N_{inc.}(KE)}}{\mathrm{N_{inc.}(KE)} - \mathrm{N_{int.}(KE)}}]$

Pre-Fit Test Event Selection Cuts

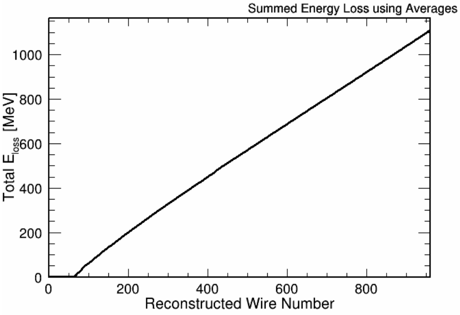
1. Event must be a good trigger with desired particle ID.
2. Must pass beamline monitoring spatial cuts.
3. Calorimetric reco products exist for the track.
4. Interacting point must be within APA3 ($z < 226\,cm$).
    - Incident hits in APA3 still considered even if particle stops at $z > 226\,cm$.

All error bars will be statistics only unless specified.

Interaction Point Kinetic Energy Calculation

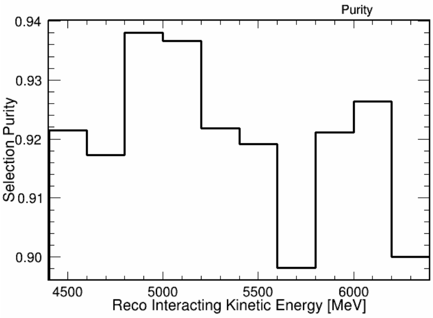
1. Fit a Landau of the dE/dx and find the mean track pitch per collection wire. Scale the MPV to the average dE/dx using Bethe-Bloch.
2. E_{loss} is a running sum of the average dE/dx*pitch for each wire.

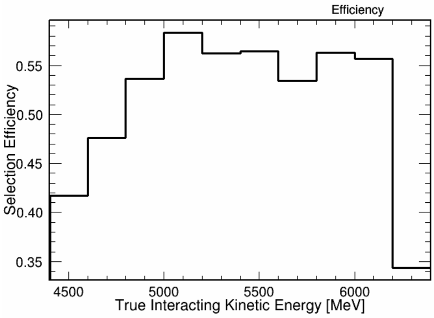
Investigations ongoing to understand performance of this method.



Thanks to Francesca for developing this method.

Binned Purity and Efficiency





Measured efficiency and purity of the kinetic energy at the interaction point for 200 MeV bins.

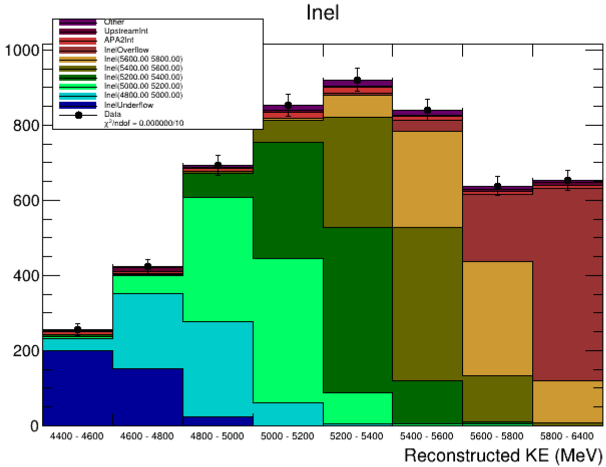
Efficiency dips at low true kinetic energy and high kinetic energy are due to interacting points past APA3 and failing beam cuts, respectively.

Fitting using PDSPThinSliceFitter

Developed by Jake Calcutt and available in protoduneana.

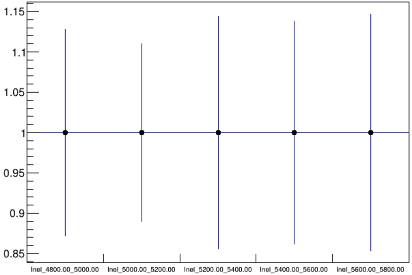
- See Jake's previous *talk* in the session for a description of the template fitting.

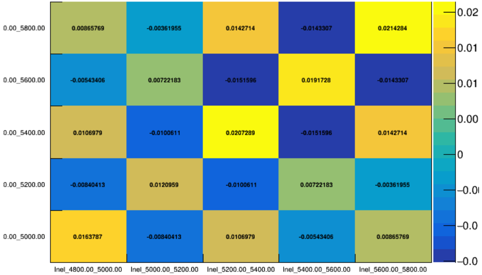
Will show fit of MC to itself.



PDSP Thin-Slice MC-to-MC Fit

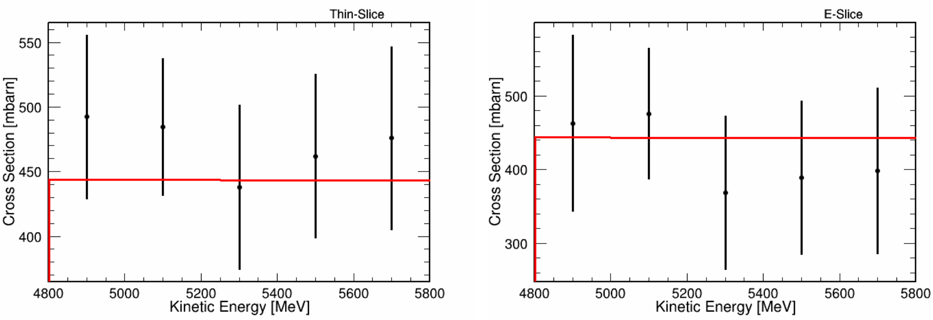
Consider only 4.8-5.8 GeV for the measurement and statistical errors only.





Parameters measured fitting MC to itself (left) and its covariance matrix (right).

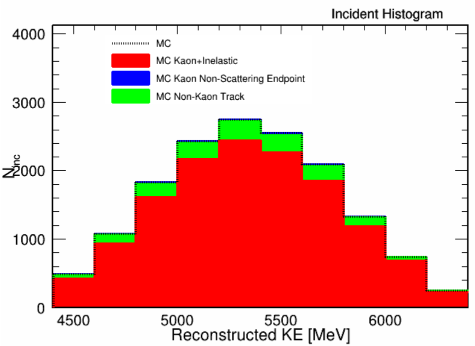
MC-to-MC Cross Section Extraction

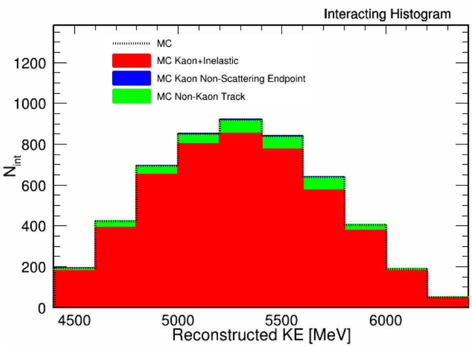


Cross section extracted from fit (black) compared to GEANT4 (red) for the “default” thin-slice method (left) and the e-slice method (right). Uncertainties come from decomposing the covariance matrix and taking the square root of the diagonal from throwing Gaussian vector elements at the decomposed matrix.

Overbinned Incident and Interacting Histograms in MC

Histogram	Total Entries	Kaon Inel.	Non-Kaon	Kaon Non-Inel.
Incident	15,527	13,783 (88.8%)	1,595	149
Interacting	5,206	4,803 (92.3%)	362	41





Kaon incident and interacting histogram as a thin-slice from energy bin-to-energy bin. Each bin entry is one occurrence of a particle entering that bin for tracks ending at APA3.