

Title

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Introduction

- ▶ from this talk, Richie and Jake recommended all analysers to adjust the beam particle selection
- ▶ proposal was to adjust fiducial cut from $z < 220$ cm to $30 < z < 220$ cm
- ▶ also change fiducial volume in **truth** to $30 < z < 220$
- ▶ both observed an improvement in beam selection purity \times efficiency
- ▶ fiducial volume only applies to the beam particles (final state PFOs outside fiducial volume still considered)
- ▶ assess for 2GeV beam pion selection

Current Selection vs New Selection

Description	Criteria
Beam trigger preselection	pion/muon like beam trigger (has calorimetry, has PFOs, track pandora tag)
z fiducial cut	$z_{end} < 220 \text{ cm}$
x,y beam quality	$\delta_{xy} < 3$
z beam quality	$3 < \delta_z < 3$
beam direction quality	$\cos(\theta) > 0.95$
muon veto	michel score < 0.55
proton veto	median $dE/dX < 2.4$
beam scraper veto	$r_{inst} < 1.5$

Description	Criteria
z fiducial cut (reco + true)	$30 < z_{end} < 220 \text{ cm}$
Beam trigger preselection	pion/muon like beam trigger (has calorimetry, has PFOs, track pandora tag)
x,y beam quality	$\delta_{xy} < 3$
beam direction quality	$\cos(\theta) > 0.95$
muon veto	michel score < 0.55
proton veto	median $dE/dX < 2.4$
beam scraper veto	$r_{inst} < 1.5$

$$\delta_{xy} = \sqrt{\left(\frac{x - \mu_x}{\sigma_x}\right)^2 + \left(\frac{y - \mu_y}{\sigma_y}\right)^2}, \delta_z = \frac{z - \mu_z}{\sigma_z}, \cos(\theta) = \hat{n}_x \mu_{\hat{n}_x} + \hat{n}_y \mu_{\hat{n}_y} + \hat{n}_z \mu_{\hat{n}_z}$$

$$r_{inst} = \sqrt{n_x^2 + n_y^2}; n_x = \frac{X_{inst}^{reco} - \mu_{X_{inst}}}{\sigma_{X_{inst}}}; n_y = \frac{Y_{inst}^{reco} - \mu_{Y_{inst}}}{\sigma_{Y_{inst}}},$$

- ▶ New selection updates z fiducial cut and removes z quality cut
- ▶ z quality cut removed since beam z start position is outside fiducial volume
- ▶ xy quality and direction quality cuts use truncated start positions (i.e. position when beam is 30cm into the TPC)

Beam particle selection efficiency

- ▶ purity:

$$p = \frac{\text{number of events } i \text{ selected}}{\text{total number of events selected}} \quad (1)$$

- ▶ for old selection:

$$e = \frac{\text{number of events } i \text{ selected}}{\text{total number of events } i} \quad (2)$$

- ▶ for new selection:

$$e_f = \frac{\text{number of events } i \text{ selected}}{\text{total number of events } i \text{ in fiducial region}} \quad (3)$$

Current Selection performance

	total counts	π^+ :inel counts	π^+ :inel e	π^+ :inel p
noselection	141548	57803	1	0.408
PiBeamSelection	102443	57034	0.987	0.557
PandoraTagCut	89274	56446	0.977	0.632
CaloSizeCut	87403	55699	0.964	0.637
HasFinalStatePFOsCut	84822	54551	0.944	0.643
APA3Cut	68290	49437	0.855	0.724
DxyCut	54513	47307	0.818	0.868
DzCut	49667	44395	0.768	0.894
CosThetaCut	47580	43392	0.751	0.912
MichelScoreCut	47372	43229	0.748	0.913
MedianDEdXCut	45716	42376	0.733	0.927
BeamScrapperCut	29247	27629	0.478	0.945

► See other sections for plots

New Selection performance

	total counts	π^+ :inel counts	π^+ :inel e	π^+ :inel p
noselection	141548	57803	1	0.408
APA3Cut	74313	40073	0.693	0.539
TrueFiducialCut	56621	35177	0.609	0.621

	total counts	π^+ :inel counts	π^+ :inel e_f	π^+ :inel p
fiducial cuts	56621	35177	1	0.621
PiBeamSelection	38931	35020	0.996	0.900
PandoraTagCut	38931	35020	0.996	0.900
CaloSizeCut	38931	35020	0.996	0.900
HasFinalStatePFOsCut	38112	34342	0.976	0.901
DxyCut	34378	33464	0.951	0.973
CosThetaCut	33071	32492	0.924	0.982
MichelScoreCut	32946	32376	0.920	0.983
MedianDEdXCut	32489	32116	0.913	0.989
BeamScrapperCut	20617	20388	0.580	0.989

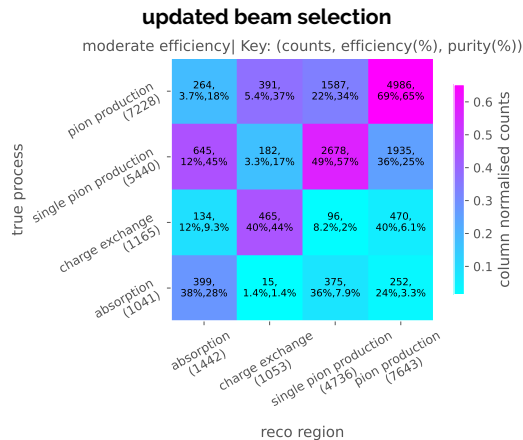
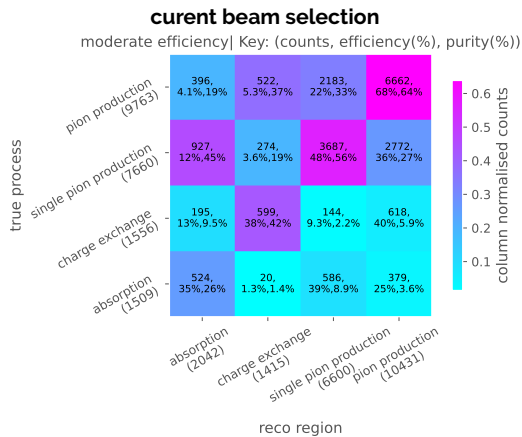
► See other sections for plots

comparing selection performance

selection	counts	p	e	e_f
current	27629	0.945	0.478	-
new	20388	0.989	0.353	0.580

- ▶ new selection has better purity
- ▶ e decreases by 12.5%, but e_f looks reasonable.
- ▶ further reduction in the number of events will increase MC stat error, and favour higher efficiency region identification

Comparing region identification



- ▶ moderate efficiency selection performs similarly for both selections

Region fit performance

current beam selection

	μ_{abs}	μ_{cex}	μ_{spip}	μ_{pip}
fit value	0.8	1.0	0.52	1.11
uncertainty	0.2	0.1	0.07	0.05

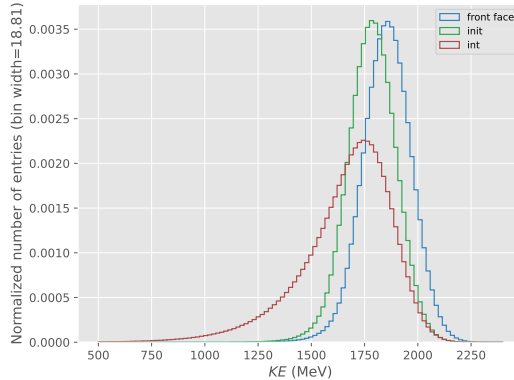
updated beam selection

	μ_{abs}	μ_{cex}	μ_{spip}	μ_{pip}
fit value	0.9	1.1	0.67	1.16
uncertainty	0.3	0.2	0.09	0.06

- ▶ μ_{spip} for updated selection is larger
- ▶ other fit values are relatively similarly
- ▶ region fit cross checks TBD

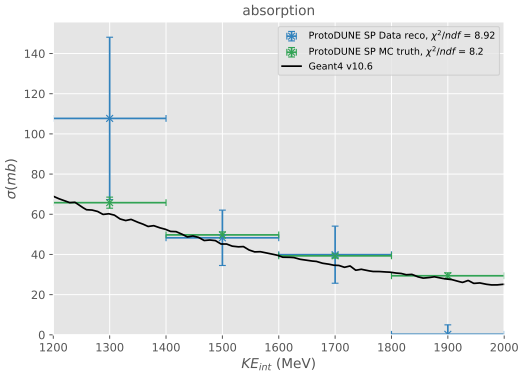
Modified KE_{init}

- ▶ fiducial volume is not at the start of the TPC, therefore, KE measured at front face is not KE_{init}
- ▶ KE_{init} is the Kinetic energy the beam particle has at $z = 30$ cm
- ▶ example of KE at front face, init and int using toy MC.

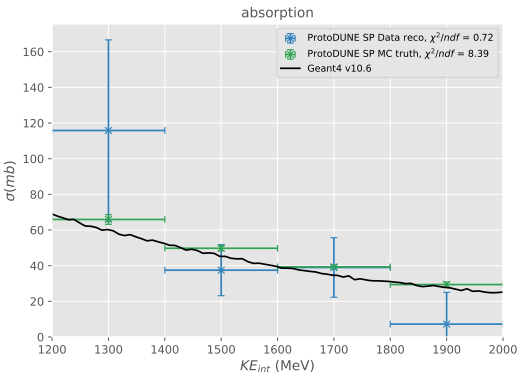


Comparing measured cross sections for different selections

curent beam selection



updated beam selection

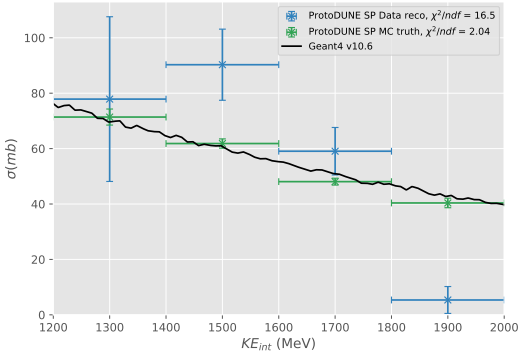


► errors are Data stat + MC stat

Comparing measured cross sections for different selections

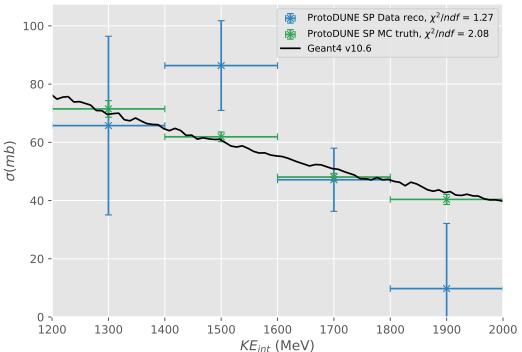
curent beam selection

charge exchange



updated beam selection

charge exchange

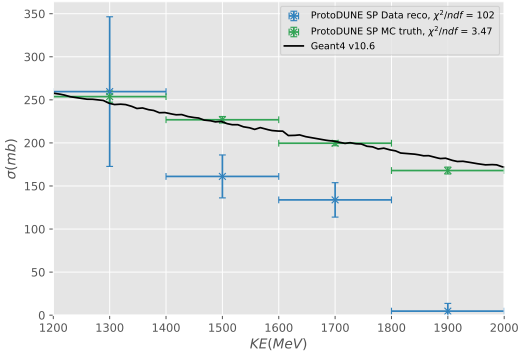


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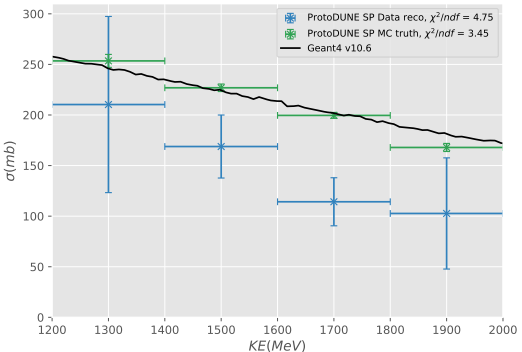
curent beam selection

single pion production



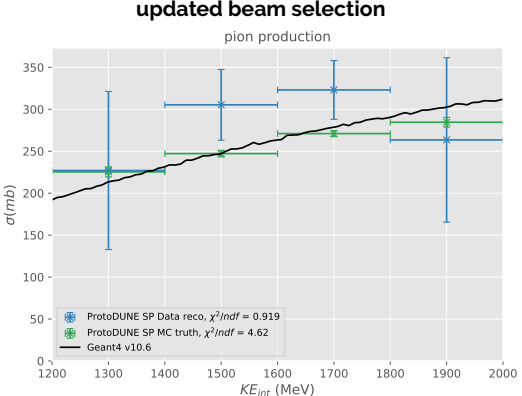
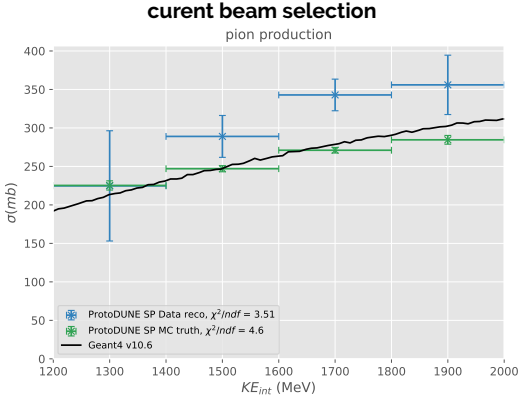
updated beam selection

single pion production



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Comparing measured cross sections for different selections

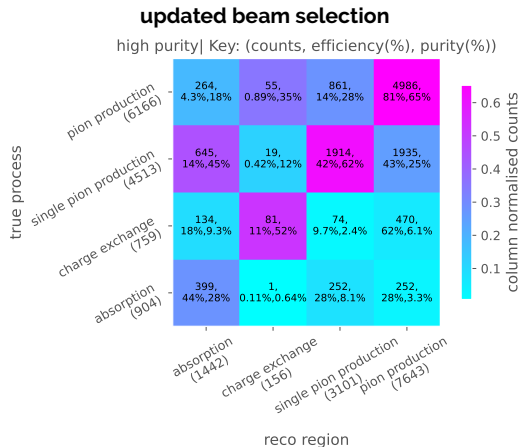
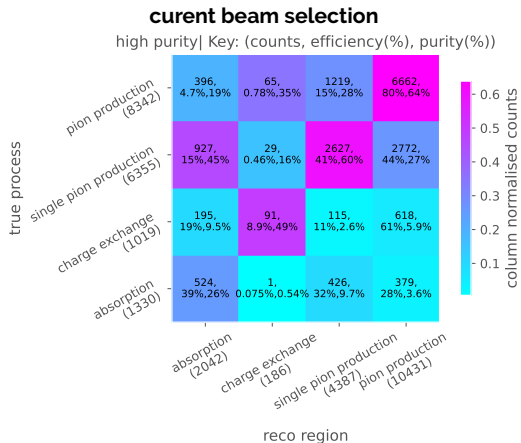


► errors are Data stat + MC stat

Summary

- ▶ New selection from hadron analysis group implemented in code
- ▶ total selection efficiency drops, but purity and selection efficiency in fiducial region is better
- ▶ whole analysis runs, some changes in the kinetic energy calculation were required.

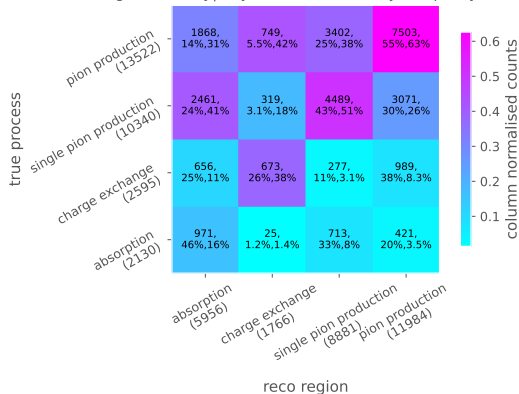
region identification comparison



region identification comparison

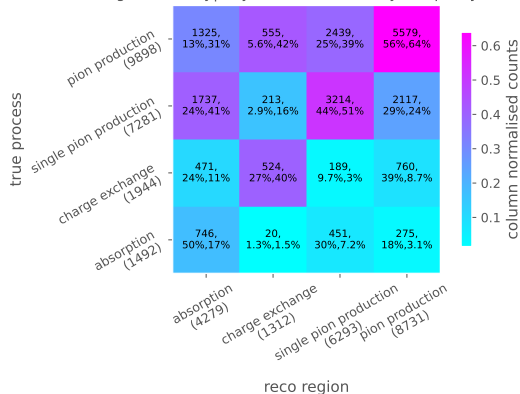
current beam selection

high efficiency | Key: (counts, efficiency(%), purity(%))



updated beam selection

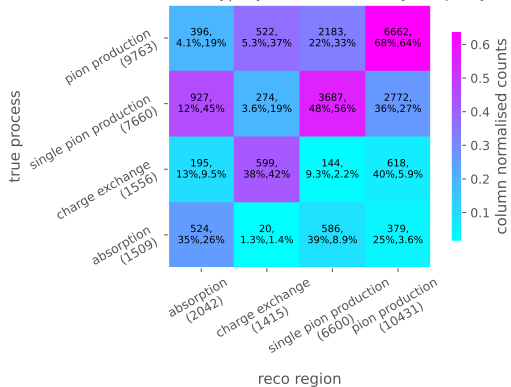
high efficiency | Key: (counts, efficiency(%), purity(%))



region identification comparison

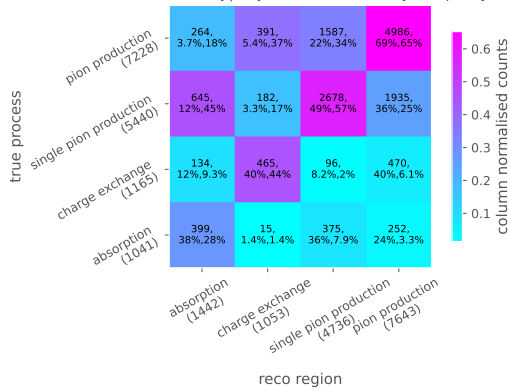
current beam selection

moderate efficiency | Key: (counts, efficiency(%), purity(%))

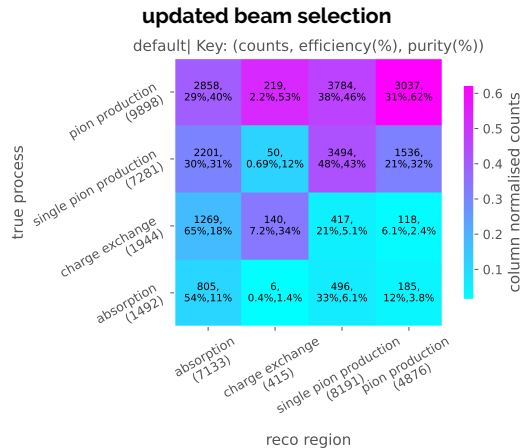
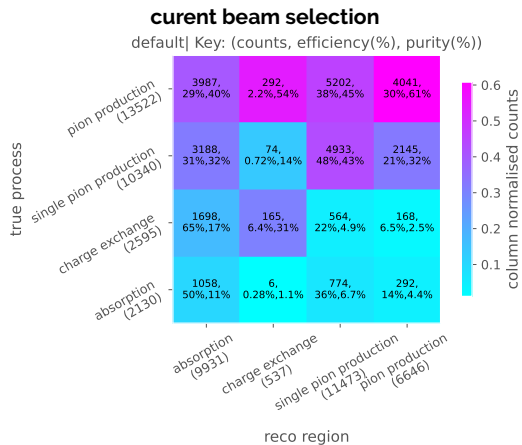


updated beam selection

moderate efficiency | Key: (counts, efficiency(%), purity(%))



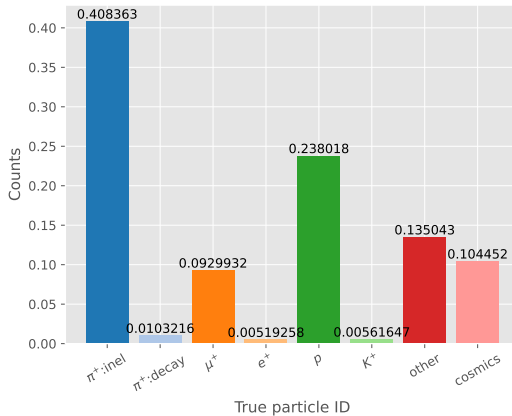
region identification comparison



Current Selection

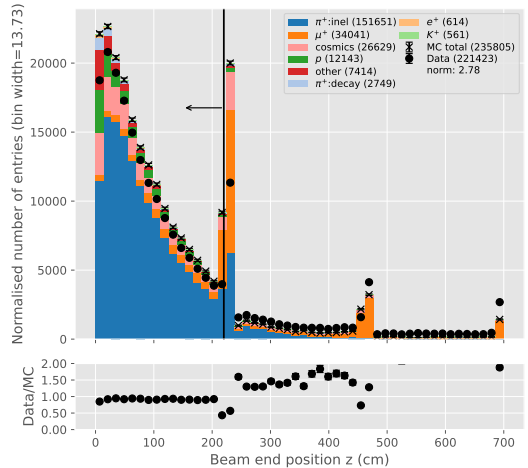
Beam trigger and preselection

- ▶ bar chart shows initial beam composition in MC
- ▶ Beam trigger selection only selects beam particles identified by beam PID as pion/muon
- ▶ preselection removes events where:
 - ▶ beam particle has no reconstructed calorimetry
 - ▶ beam particle has no final state PFOs (can't do region identification)
 - ▶ beam particle pandora tag is track



End z position cut

- ▶ exclude beam interactions past 220 cm
- ▶ vetos on muons, avoid regions where the electron diverter effect causes some tracks to end prematurely

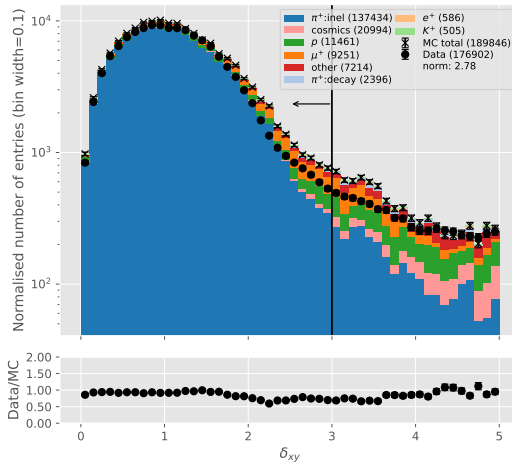


Beam quality δ_{xy}

▶ δ_{xy} :

$$\delta_{xy} = \sqrt{\left(\frac{x - \mu_x}{\sigma_x}\right)^2 + \left(\frac{y - \mu_y}{\sigma_y}\right)^2}$$

▶ μ 's and σ 's obtained by fitting gaussians to the beam particle start positions



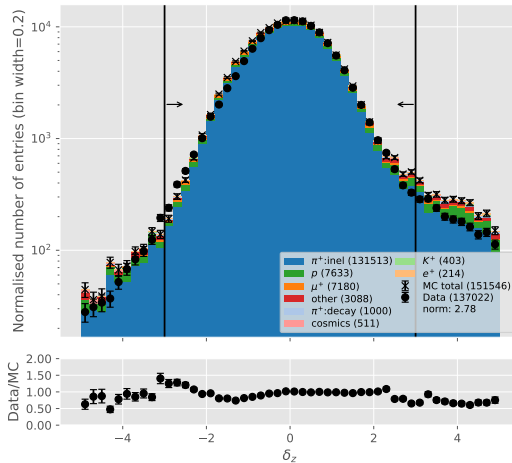
	μ_x	σ_x	μ_y	σ_y
Data	-27.75 ± 0.02	4.20 ± 0.01	424.69 ± 0.01	4.53 ± 0.01
MC	-30.65 ± 0.02	4.07 ± 0.02	422.29 ± 0.02	3.66 ± 0.02

Beam quality δ_z

▶ δ_z :

$$\delta_z = \frac{Z - \mu_z}{\sigma_z}$$

▶ μ 's and σ 's obtained by fitting gaussians to the beam particle start positions



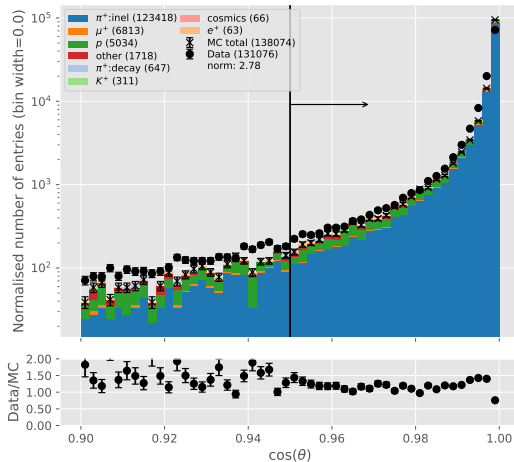
	μ_x	σ_x
Data	4.018 ± 0.004	1.141 ± 0.003
MC	0.109 ± 0.001	0.2017 ± 0.0008

Beam quality $\cos(\theta)$

- ▶ $\cos(\theta)$:

$$\cos(\theta) = \hat{n}_x \mu_{\hat{n}_x} + \hat{n}_y \mu_{\hat{n}_y} + \hat{n}_z \mu_{\hat{n}_z}$$

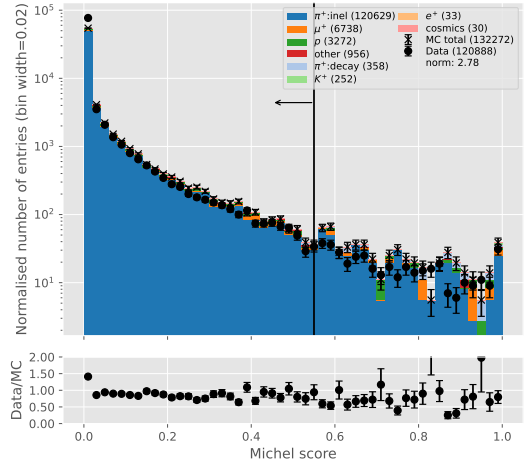
- ▶ μ 's obtained by fitting computing numeric average of \hat{n} .



	$\mu_{\hat{n}_x}$	$\mu_{\hat{n}_y}$	$\mu_{\hat{n}_z}$
Data	-0.1410 ± 0.0005	-0.1941 ± 0.0009	0.8413 ± 0.0005
MC	-0.1605 ± 0.0008	-0.159 ± 0.001	0.8629 ± 0.0008

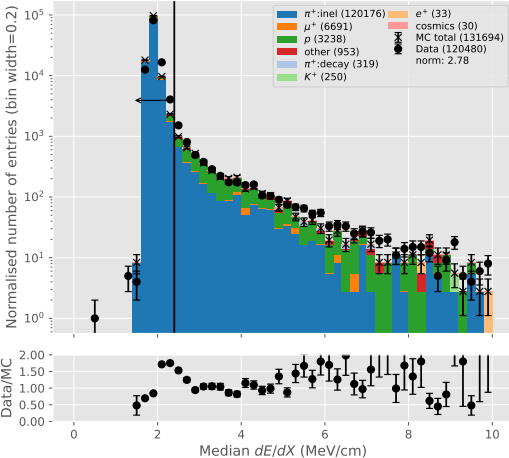
Michel score

- ▶ Michel score used to veto on muons in 1GeV pion analysis, but muons at 2GeV travel further into the TPC → end z becomes an effective muon veto



Median dE/dX

- ▶ veto protons from sample
- ▶ **TODO** adjust plot range

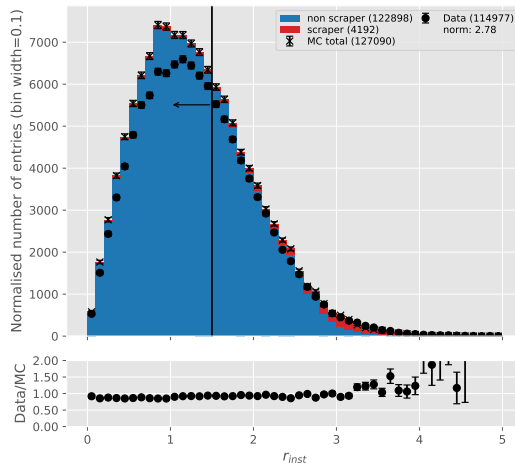


Beam scraper

- ▶ remove events where P_{inst} not accurate
- ▶ this occurs when beam particles travel through some material prior to being measured at the beam spectrometer
- ▶ cut on radial distance r_{inst} to exclude particles which enter the TPC off-axis

$$r_{inst} = \sqrt{n_X^2 + n_Y^2};$$

$$n_X = \frac{X_{inst}^{reco} - \mu_{X_{inst}}}{\sigma_{X_{inst}}}; \quad n_Y = \frac{Y_{inst}^{reco} - \mu_{Y_{inst}}}{\sigma_{Y_{inst}}}$$



selection tables and performance: counts

	Remaining events	π^+ :inel	π^+ :decay	μ^+	e^+	p	K^+	other	cosmics
noselection	141548	57803	1461	13163	735	33691	795	19115	14785
PiBeamSelection	102443	57034	1196	12932	540	5403	224	14164	10950
PandoraTagCut	89274	56446	1087	12856	281	5182	213	3181	10028
CaloSizeCut	87403	55699	1035	12772	232	4907	210	2837	9711
HasFinalStatePFOsCut	84822	54551	989	12245	221	4368	202	2667	9579
APA3Cut	68290	49437	862	3328	211	4123	182	2595	7552
DxyCut	54513	47307	360	2583	77	2746	145	1111	184
DzCut	49667	44395	233	2451	23	1811	112	618	24
CosThetaCut	47580	43392	129	2424	12	1177	91	344	11
MichelScoreCut	47372	43229	115	2407	12	1165	90	343	11
MedianDEdXCut	45716	42376	94	2373	4	519	74	267	9
BeamScrapperCut	29247	27629	66	1017	4	320	47	158	6

selection tables and performance: efficiency

	Remaining events	π^+ :inel	π^+ :decay	μ^+	e^+	p	K^+	other	cosmics
noselection	1	1	1	1	1	1	1	1	1
PiBeamSelection	0.724	0.987	0.819	0.982	0.735	0.160	0.282	0.741	0.741
PandoraTagCut	0.631	0.977	0.744	0.977	0.382	0.154	0.268	0.166	0.678
CaloSizeCut	0.617	0.964	0.708	0.970	0.316	0.146	0.264	0.148	0.657
HasFinalStatePFOsCut	0.599	0.944	0.677	0.930	0.301	0.130	0.254	0.140	0.648
APA3Cut	0.482	0.855	0.590	0.253	0.287	0.122	0.229	0.136	0.511
DxyCut	0.385	0.818	0.246	0.196	0.105	0.082	0.182	0.058	0.012
DzCut	0.351	0.768	0.159	0.186	0.031	0.054	0.141	0.032	0.002
CosThetaCut	0.336	0.751	0.088	0.184	0.016	0.035	0.114	0.018	0.001
MichelScoreCut	0.335	0.748	0.079	0.183	0.016	0.035	0.113	0.018	0.001
MedianDEdXCut	0.323	0.733	0.064	0.180	0.005	0.015	0.093	0.014	0.001
BeamScrapperCut	0.207	0.478	0.045	0.077	0.005	0.009	0.059	0.008	0.000

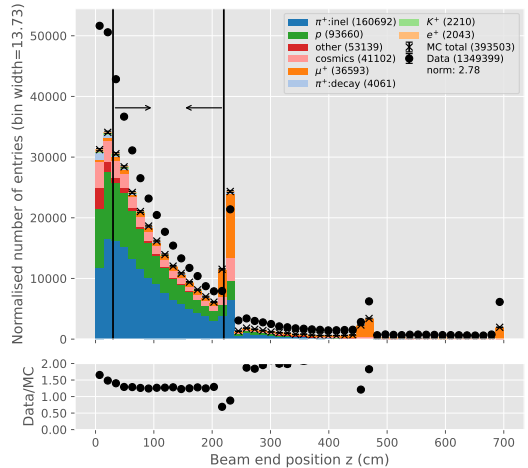
selection tables and performance: purity

	Remaining events	π^+ :inel	π^+ :decay	μ^+	e^+	p	K^+	other	cosmics
noselection	1	0.408	0.010	0.093	0.005	0.238	0.006	0.135	0.104
PiBeamSelection	1	0.557	0.012	0.126	0.005	0.053	0.002	0.138	0.107
PandoraTagCut	1	0.632	0.012	0.144	0.003	0.058	0.002	0.036	0.112
CaloSizeCut	1	0.637	0.012	0.146	0.003	0.056	0.002	0.032	0.111
HasFinalStatePFOsCut	1	0.643	0.012	0.144	0.003	0.051	0.002	0.031	0.113
APA3Cut	1	0.724	0.013	0.049	0.003	0.060	0.003	0.038	0.111
DxyCut	1	0.868	0.007	0.047	0.001	0.050	0.003	0.020	0.003
DzCut	1	0.894	0.005	0.049	0.000	0.036	0.002	0.012	0.000
CosThetaCut	1	0.912	0.003	0.051	0.000	0.025	0.002	0.007	0.000
MichelScoreCut	1	0.913	0.002	0.051	0.000	0.025	0.002	0.007	0.000
MedianDEdXCut	1	0.927	0.002	0.052	0.000	0.011	0.002	0.006	0.000
BeamScraperCut	1	0.945	0.002	0.035	0.000	0.011	0.002	0.005	0.000

New Selection

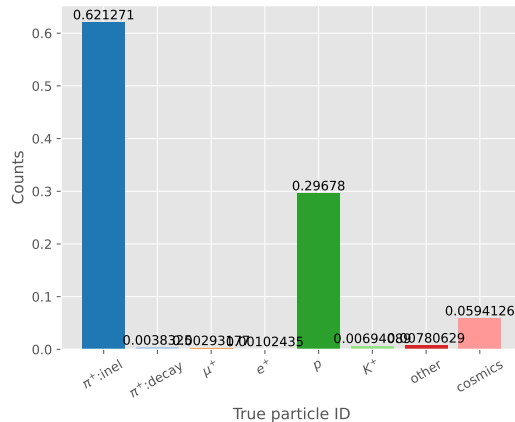
Fiducial cuts

- ▶ only analyse beam interactions which occur within $30 < z < 220$ cm in reco and truth



Beam trigger and preselection

- ▶ after fiducial cuts, only significant backgrounds are protons and cosmics
- ▶ Beam trigger selection only selects beam particles identified by beam PID as pion/muon
- ▶ preselection removes events where:
 - ▶ beam particle has no reconstructed calorimetry
 - ▶ beam particle has no final state PFOs (can't do region identification)
 - ▶ beam particle pandora tag is track

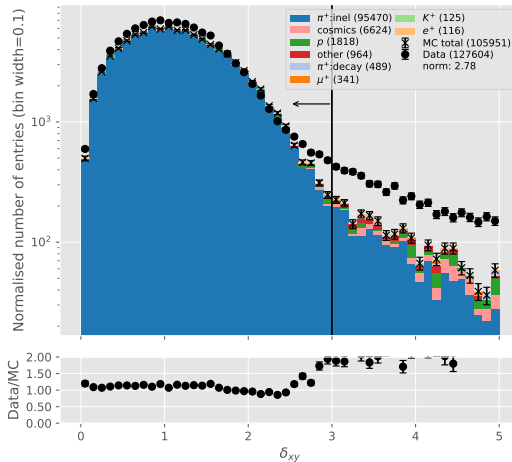


Beam quality δ_{xy}

▶ δ_{xy} :

$$\delta_{xy} = \sqrt{\left(\frac{x - \mu_x}{\sigma_x}\right)^2 + \left(\frac{y - \mu_y}{\sigma_y}\right)^2}$$

- ▶ for this selection x and y are truncated start positions
- ▶ μ 's and σ 's obtained by fitting gaussians to the beam particle truncated start positions
- ▶ plot normalisation should be recalculated



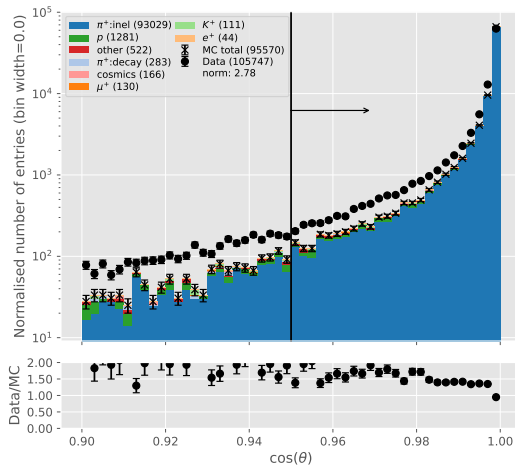
	μ_x	σ_x	μ_y	σ_y
Data	-33.01 ± 0.02	4.13 ± 0.02	417.59 ± 0.01	3.83 ± 0.02
MC	-36.91 ± 0.03	3.89 ± 0.04	416.25 ± 0.03	3.64 ± 0.04

Beam quality $\cos(\theta)$

► $\cos(\theta)$:

$$\cos(\theta) = \hat{n}_x \mu_{\hat{n}_x} + \hat{n}_y \mu_{\hat{n}_y} + \hat{n}_z \mu_{\hat{n}_z}$$

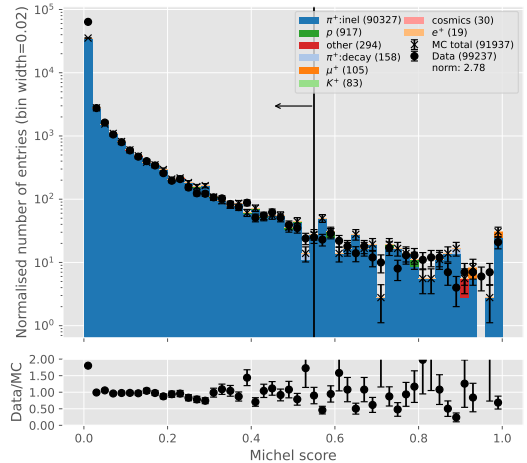
- μ 's obtained by fitting computing numeric average of \hat{n} .
- directions calculated using truncated start positions and end positions



	$\mu_{\hat{n}_x}$	$\mu_{\hat{n}_y}$	$\mu_{\hat{n}_z}$
Data	-0.1531 ± 0.0005	-0.2036 ± 0.0008	0.8912 ± 0.0005
MC	-0.1828 ± 0.0007	-0.183 ± 0.001	0.9150 ± 0.0008

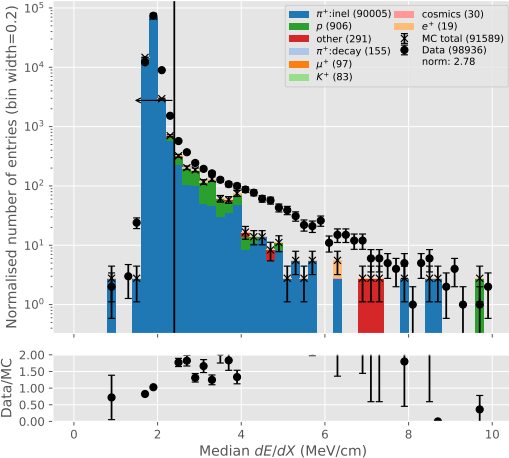
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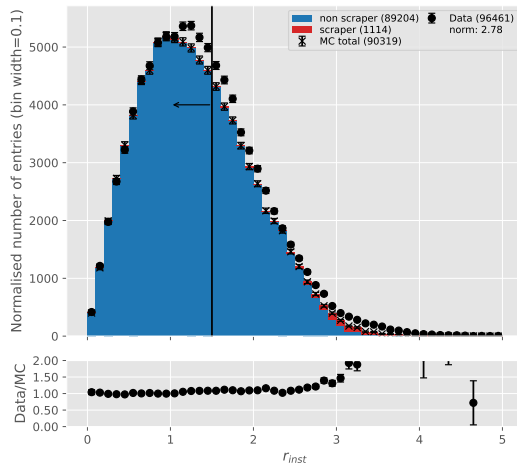


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APA3Cut	74313	40073	515	3109	99	22265	532	1334	6386
TrueFiducialCut	56621	35177	217	166	58	16804	393	442	3364
	Remaining events	π^+ :inel	π^+ :decay	μ^+	e^+	p	K^+	other	cosmics
fiducial	56621	35177	217	166	58	16804	393	442	3364
PiBeamSelection	38931	35020	182	137	43	706	47	375	2421
PandoraTagCut	38931	35020	182	137	43	706	47	375	2421
CaloSizeCut	38931	35020	182	137	43	706	47	375	2421
HasFinalStatePFOsCut	38112	34342	176	123	42	654	45	347	2383
DxyCut	34378	33464	102	47	16	461	40	188	60
CosThetaCut	33071	32492	57	38	7	330	30	106	11
MichelScoreCut	32946	32376	56	35	7	326	30	105	11
MedianDEdXCut	32489	32116	54	34	3	164	25	84	9
BeamScraperCut	20617	20388	41	24	3	99	12	45	5

selection tables and performance: efficiency

	Remaining events	π^+ :inel	π^+ :decay	μ^+	e^+	p	K^+	other	cosmics
noselection	1	1	1	1	1	1	1	1	1
APA3Cut	0.525	0.693	0.352	0.236	0.135	0.661	0.669	0.070	0.432
TrueFiducialCut	0.400	0.609	0.149	0.013	0.079	0.499	0.494	0.023	0.228

	Remaining events	π^+ :inel	π^+ :decay	μ^+	e^+	p	K^+	other	cosmics
fiducial	1	1	1	1	1	1	1	1	1
PiBeamSelection	0.688	0.996	0.839	0.825	0.741	0.042	0.120	0.848	0.720
PandoraTagCut	0.688	0.996	0.839	0.825	0.741	0.042	0.120	0.848	0.720
CaloSizeCut	0.688	0.996	0.839	0.825	0.741	0.042	0.120	0.848	0.720
HasFinalStatePFOsCut	0.673	0.976	0.811	0.741	0.724	0.039	0.115	0.785	0.708
DxyCut	0.607	0.951	0.470	0.283	0.276	0.027	0.102	0.425	0.018
CosThetaCut	0.584	0.924	0.263	0.229	0.121	0.020	0.076	0.240	0.003
MichelScoreCut	0.582	0.920	0.258	0.211	0.121	0.019	0.076	0.238	0.003
MedianDEdXCut	0.574	0.913	0.249	0.205	0.052	0.010	0.064	0.190	0.003
BeamScrapperCut	0.364	0.580	0.189	0.145	0.052	0.006	0.031	0.102	0.001

selection tables and performance: purity

	Remaining events	π^+ :inel	π^+ :decay	μ^+	e^+	p	K^+	other	cosmics
noselection	1	0.408	0.010	0.093	0.005	0.238	0.006	0.135	0.104
APA3Cut	1	0.539	0.007	0.042	0.001	0.300	0.007	0.018	0.086
TrueFiducialCut	1	0.621	0.004	0.003	0.001	0.297	0.007	0.008	0.059

	Remaining events	π^+ :inel	π^+ :decay	μ^+	e^+	p	K^+	other	cosmics
fiducial	1	0.621	0.004	0.003	0.001	0.297	0.007	0.008	0.059
PiBeamSelection	1	0.900	0.005	0.004	0.001	0.018	0.001	0.010	0.062
PandoraTagCut	1	0.900	0.005	0.004	0.001	0.018	0.001	0.010	0.062
CaloSizeCut	1	0.900	0.005	0.004	0.001	0.018	0.001	0.010	0.062
HasFinalStatePFOsCut	1	0.901	0.005	0.003	0.001	0.017	0.001	0.009	0.063
DxyCut	1	0.973	0.003	0.001	0.000	0.013	0.001	0.005	0.002
CosThetaCut	1	0.982	0.002	0.001	0.000	0.010	0.001	0.003	0.000
MichelScoreCut	1	0.983	0.002	0.001	0.000	0.010	0.001	0.003	0.000
MedianDEdXCut	1	0.989	0.002	0.001	0.000	0.005	0.001	0.003	0.000
BeamScraperCut	1	0.989	0.002	0.001	0.000	0.005	0.001	0.002	0.000