Title

Shyam Bhuller

University of Bristol

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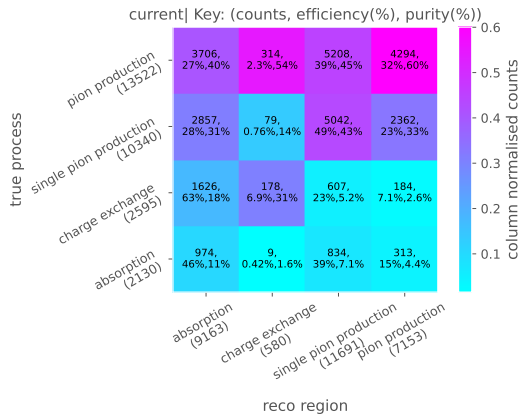
- Current selection is not great.
- Assess each region, understand the particle content of each process
- start with absorption region.



cex events in abs region

- generated tables which tells us the particle content using backtracked truth information
- tables show the number of γ and $\pi^{\pm}$ from the beam interaction
- In absorption region cex events:
  1. 219 have no γ
  2. 384 have 2 γ, 859 have 1 γ
  3. 164 have > 2 γ
- identify the γ that was missed $\rightarrow$ high efficiency γ selection

$\pi^{\pm}$	γ	counts	fractions
0	1	859	0.53
0	2	384	0.24
0	0	219	0.13
0	3	117	0.07
0	4	33	0.02
0	5	12	0.01
0	6	2	0.00

pip and spip events in abs region

- pip events in abs region:
  1. 1328 have no γ
  2. 2411 have no $\pi^{\pm}$
  3. 1317 have > 1 γ, 1061 have 1 γ
  4. 1295 have > 0 $\pi^{\pm}$
- identify the $\pi^{\pm}$ and γ that was missed $\rightarrow$ high efficiency $\pi^{\pm}$ and γ selection
- spip events in abs region:
  1. 2175 have no pions, 651 have 1 $\pi^{\pm}$, 31 have 2 $\pi^{\pm}$
  2. 2212 have at least 1 PFO not originating from the beam interaction
- the events with 2 backtracked $\pi^{\pm}$ is likely due to broken tracks

pip

$\pi^{\pm}$	γ	counts	fractions
0	1	741	0.20
0	0	620	0.17
0	2	520	0.14
1	0	497	0.13
0	3	305	0.08
1	1	282	0.08
2	0	180	0.05
1	2	156	0.04
0	4	152	0.04
1	3	51	0.01

spip

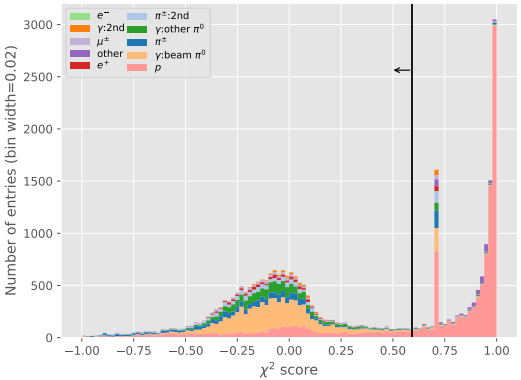
$\pi^{\pm}$	γ	counts	fractions
0	0	2175	0.76
1	0	651	0.23
2	0	31	0.01

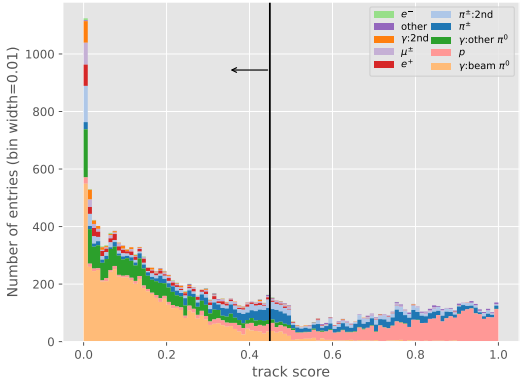
How to select misidentified events

- processes in the absorption region have many pip and cex events with γ which we can try to select.
- try to distinguish selected pip events and cex events using a pion selection.
- to identify as many PFOs as possible, use a higher efficiency selection than currently used.

Photon selection

- Plots show all PFOs for **events in the absorption region**



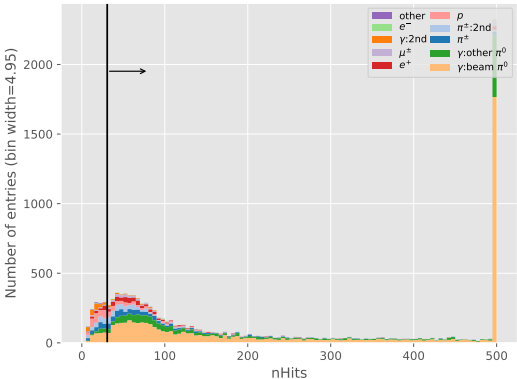


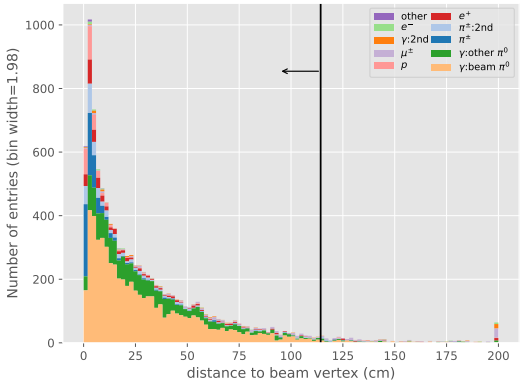
- χ^2 score is a combination of the proton χ^2 fit and pion χ^2 fit

$$\frac{(\chi^2/ndf)_p - (\chi^2/ndf)_\pi}{(\chi^2/ndf)_p + (\chi^2/ndf)_\pi}$$

Photon selection

- Plots show all PFOs for **events in the absorption region**

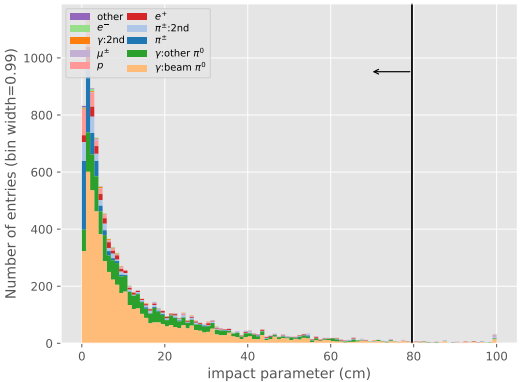


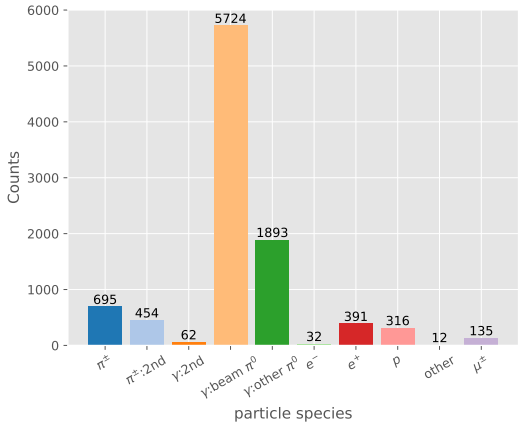


- nHits cut to remove tracks
- distance to beam vertex excludes muons and γ from other π^0s

Photon selection

- Plots show all PFOs for **events in the absorption region**





- large number of photons selected which did not originate from a beam π^0

Photon selection performance tables

for particle type p;

$$\text{Relative efficiency} = \frac{N(p)_{selected}}{N(p)_{abs}} \quad (1)$$

$$\text{purity} = \frac{N(p)_{selected}}{N_{selected}} \quad (2)$$

Counts

	$\pi^{\pm}$	$\pi^{\pm}$:2nd	γ:2nd	γ:beam π^0	γ:other π^0	e^-	e^+	p	other	$\mu^{\pm}$
chi2 score	2317	1428	352	6899	2309	57	639	12566	582	532
track score	2031	1253	286	6515	2180	56	563	3577	166	481
nHits	866	667	254	6160	2056	49	515	580	37	307
beam dist	704	500	96	5872	1963	44	430	323	12	271
beam ip	697	465	66	5782	1911	32	400	317	12	165

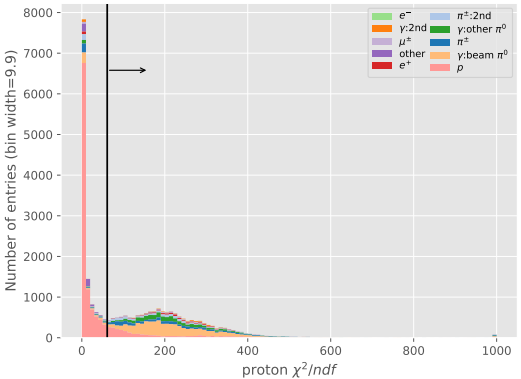
Purity

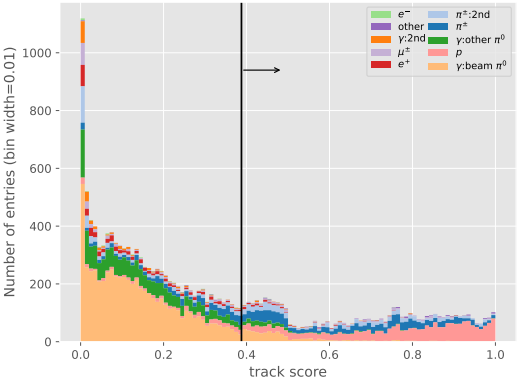
	$\pi^{\pm}$	$\pi^{\pm}$:2nd	γ:2nd	γ:beam π^0	γ:other π^0	e^-	e^+	p	other	$\mu^{\pm}$
chi2 score	8.37	5.16	1.27	24.92	8.34	0.21	2.31	45.40	2.10	1.92
track score	11.87	7.32	1.67	38.08	12.74	0.33	3.29	20.91	0.97	2.81
nHits	7.54	5.80	2.21	53.61	17.89	0.43	4.48	5.05	0.32	2.67
beam dist	6.89	4.89	0.94	57.48	19.22	0.43	4.21	3.16	0.12	2.65
beam ip	7.08	4.72	0.67	58.72	19.41	0.32	4.06	3.22	0.12	1.68

Relative efficiencies

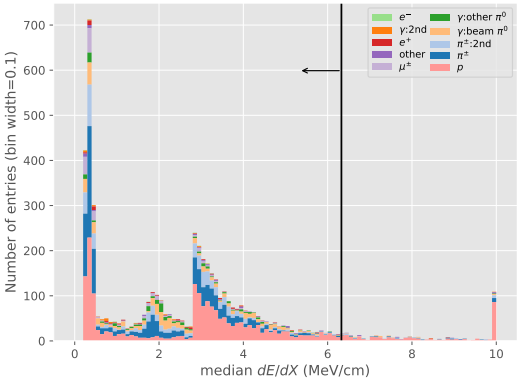
	$\pi^{\pm}$	$\pi^{\pm}$:2nd	γ:2nd	γ:beam π^0	γ:other π^0	e^-	e^+	p	other	$\mu^{\pm}$
chi2 score	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
track score	87.66	87.75	81.25	94.43	94.41	98.25	88.11	28.47	28.52	90.41
nHits	37.38	46.71	72.16	89.29	89.04	85.96	80.59	4.62	6.36	57.71
beam dist	30.38	35.01	27.27	85.11	85.02	77.19	67.29	2.57	2.06	50.94
beam ip	30.08	32.56	18.75	83.81	82.76	56.14	62.60	2.52	2.06	31.02

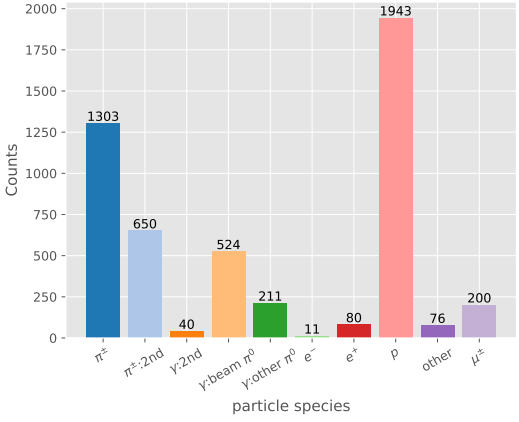
Pion selection





Pion selection





- high efficiency pion selection is difficult in the absorption region due to the large number of protons in these events.

Pion selection tables

Counts

	$\pi^{\pm}$	$\pi^{\pm}$:2nd	γ:2nd	γ:beam π^0	γ:other π^0	e^-	e^+	p	other	$\mu^{\pm}$
chi2 proton	2317	1428	352	6899	2309	57	639	12566	582	532
track score	1980	1212	284	6447	2154	56	557	2597	113	476
median dEdX	1336	674	42	542	213	11	82	2204	88	202

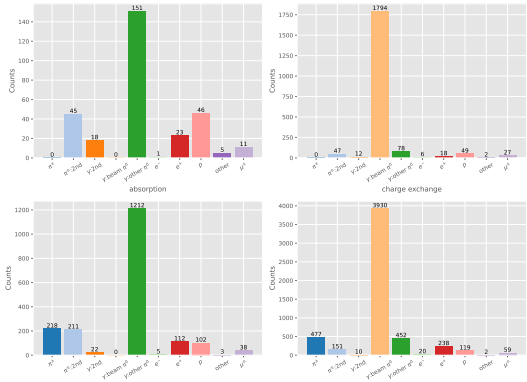
Purity

	$\pi^{\pm}$	$\pi^{\pm}$:2nd	γ:2nd	γ:beam π^0	γ:other π^0	e^-	e^+	p	other	$\mu^{\pm}$
chi2 proton	8.37	5.16	1.27	24.92	8.34	0.21	2.31	45.40	2.10	1.92
track score	12.47	7.63	1.79	40.61	13.57	0.35	3.51	16.36	0.71	3.00
median dEdX	24.77	12.50	0.78	10.05	3.95	0.20	1.52	40.86	1.63	3.74

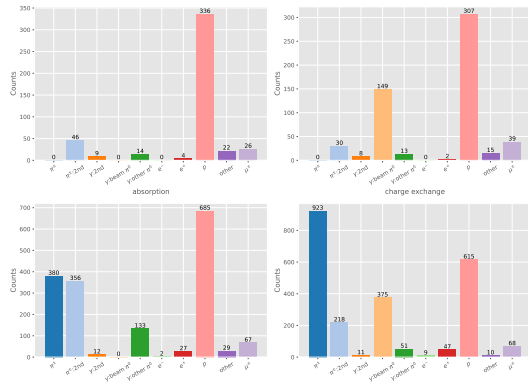
Relative efficiencies

	$\pi^{\pm}$	$\pi^{\pm}$:2nd	γ:2nd	γ:beam π^0	γ:other π^0	e^-	e^+	p	other	$\mu^{\pm}$
chi2 proton	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
track score	85.46	84.87	80.68	93.45	93.29	98.25	87.17	20.67	19.42	89.47
median dEdX	57.66	47.20	11.93	7.86	9.22	19.30	12.83	17.54	15.12	37.97

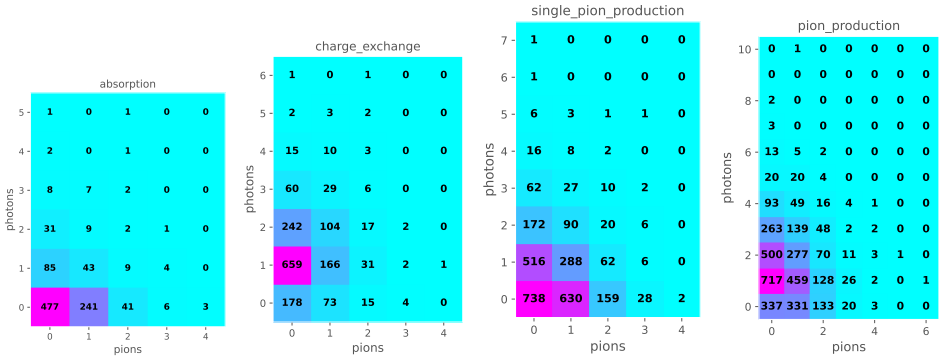
- in general, loose photon selection is good, a large number of photons from non beam π^0s are being selected in the single pion production region



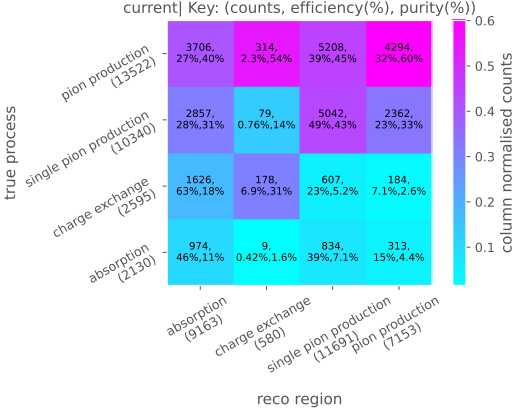
- loose pion selection is not great, protons are misidentified for each process
- for cex and pip processes, photons can be misidentified as pions

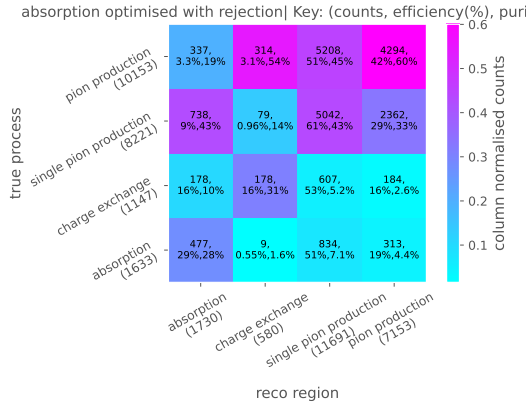


- matrices show the number of events and the number of selected pions and photons in the absorption region



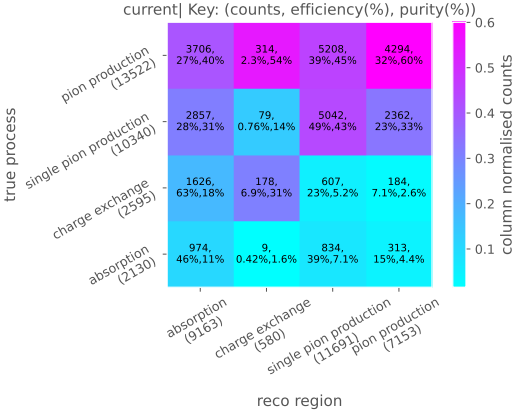
- abs events can be selected by requiring 0γ and $0\pi^{\pm} \rightarrow$ spip will be the dominant background
- all other events can be excluded from the selection, or we can migrate some events to other regions
- $1\gamma + 0\pi^{\pm}$ can be moved to cex
- $> 1\gamma + > 0\pi^{\pm}$ can be moved to pip

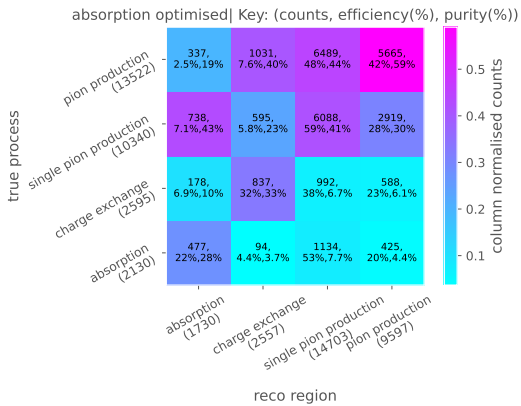




- left is current confusion matrix, right includes optimisation made to absorption region:

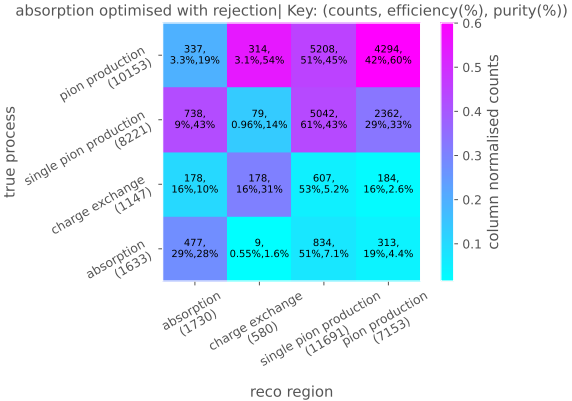
high efficiency γ	high efficiency $\pi^{\pm}$	action
0	0	keep in abs
$\neq 0$	$\neq 0$	remove

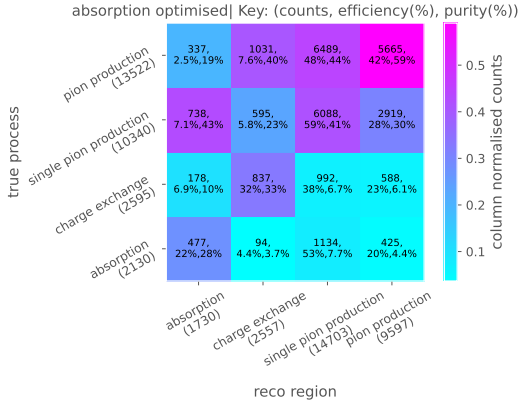




- left is current confusion matrix, right includes optimisation made to absorption region:

high efficiency γ	high efficiency $\pi^{\pm}$	action
0	0	keep in abs
1	0	move to cex
>1	>0	move to pip





- absorption region improves, single pion production is a dominant background
- events can be migrated to the charge exchange region, without reducing the purity

- tables show the event compositions in abs region after the optimisation
- tables count the number of backtracked beam photons and pions
- most events have no photons or charged pions we can select
- might be able to improve abs region if we can optimise other regions and migrate potential abs candidates.
- better proton ID would reduce misidentified abs events as pip or spip.

spip

$\pi^{\pm}$	γ	counts	fractions
0	0	658	0.89
1	0	78	0.11
2	0	2	0.00

cex

$\pi^{\pm}$	γ	counts	fractions
0	0	133	0.75
0	1	35	0.20
0	2	7	0.04
0	3	2	0.01
0	5	1	0.01

pip

$\pi^{\pm}$	γ	counts	fractions
0	0	224	0.66
0	1	48	0.14
1	0	48	0.14
0	2	5	0.01
1	1	4	0.01
2	0	4	0.01
0	3	3	0.01
1	2	1	0.00

Next step

- Assess other regions, repeat same procedure to see what can be done to clean the regions
- run fit for Data and MC for the different region identifications

Backup

efficiency

	$\pi^{\pm}$	$\pi^{\pm}$:2nd	γ:2nd	γ:beam π^0	γ:other π^0	e^-	e^+	p	other	$\mu^{\pm}$
chi2 score	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
track score	93.65	93.03	79.79	94.85	95.32	94.53	91.55	36.65	39.24	96.08
nHits	11.48	23.01	71.54	86.68	86.06	87.06	80.00	3.60	5.09	24.74
beam dist	8.75	15.69	31.69	82.27	82.41	73.13	65.31	1.89	1.79	18.45
beam ip	8.52	14.40	19.26	80.36	73.42	43.78	51.35	1.83	1.72	9.40

purity

	$\pi^{\pm}$	$\pi^{\pm}$:2nd	γ:2nd	γ:beam π^0	γ:other π^0	e^-	e^+	p	other	$\mu^{\pm}$
chi2 score	18.40	9.70	1.04	15.97	7.27	0.20	2.41	35.78	1.43	7.80
track score	23.70	12.41	1.14	20.83	9.52	0.26	3.04	18.03	0.77	10.31
nHits	6.91	7.30	2.43	45.27	20.45	0.56	6.31	4.21	0.24	6.32
beam dist	6.09	5.76	1.24	49.67	22.64	0.55	5.96	2.56	0.10	5.44
beam ip	6.52	5.80	0.83	53.31	22.16	0.36	5.15	2.72	0.10	3.05

efficiency

	$\pi^{\pm}$	$\pi^{\pm}$:2nd	γ:2nd	γ:beam π^0	γ:other π^0	e^-	e^+	p	other	$\mu^{\pm}$
chi2 proton	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
track score	92.60	91.65	78.94	93.93	94.63	94.53	90.78	29.42	31.13	95.75
median dEdX	83.81	71.54	10.53	11.14	12.68	11.44	15.35	26.89	27.84	72.68

purity

	$\pi^{\pm}$	$\pi^{\pm}$:2nd	γ:2nd	γ:beam π^0	γ:other π^0	e^-	e^+	p	other	$\mu^{\pm}$
chi2 proton	18.40	9.70	1.04	15.97	7.27	0.20	2.41	35.78	1.43	7.80
track score	24.54	12.80	1.18	21.60	9.90	0.27	3.15	15.16	0.64	10.76
median dEdX	37.38	16.82	0.26	4.31	2.23	0.05	0.90	23.32	0.97	13.75

backtrack particle counts

pion_production

$\pi^{\pm}$	γ	counts	fractions
0	1	741	0.20
0	0	620	0.17
0	2	520	0.14
1	0	497	0.13
0	3	305	0.08
1	1	282	0.08
2	0	180	0.05
1	2	156	0.04
0	4	152	0.04
1	3	51	0.01

γ	counts	fractions
0	1328	0.36
1	1061	0.29
2	695	0.19
3	359	0.10
4	174	0.05
5	58	0.02
6	21	0.01
7	6	0.00
8	3	0.00
11	1	0.00

$\pi^{\pm}$	counts	fractions

single_pion_production

$\pi^{\pm}$	γ	counts	fractions
0	0	2175	0.76
1	0	651	0.23
2	0	31	0.01

γ	counts	fractions
0	2857	1.00

$\pi^{\pm}$	counts	fractions
0	2175	0.76
1	651	0.23
2	31	0.01

non-beam	counts	fractions
1	787	0.28
0	645	0.23
2	606	0.21

- In absorption region pip events:
  1. 1328 have no γ
  2. 2411 have no $\pi^{\pm}$
  3. 1317 have > 1 γ, 1061 have 1 γ
  4. 1295 have > 0 $\pi^{\pm}$
- identify the $\pi^{\pm}$ and γ that was missed $\rightarrow$ high efficiency $\pi^{\pm}$ and γ selection

- In absorption region cex events:
  1. 219 have no γ
  2. 384 have 2 γ, 859 have 1 γ
  3. 164 have > 2 γ
- identify the γ that was missed $\rightarrow$ high efficiency γ selection

- In absorption region spip events:
  1. 2175 have no pions, 651 have 1 $\pi^{\pm}$, 31 have 2 $\pi^{\pm}$
  2. 2212 have at least 1 PFO not originating from the beam interaction
- the events with 2 backtracked $\pi^{\pm}$ is likely due to broken tracks