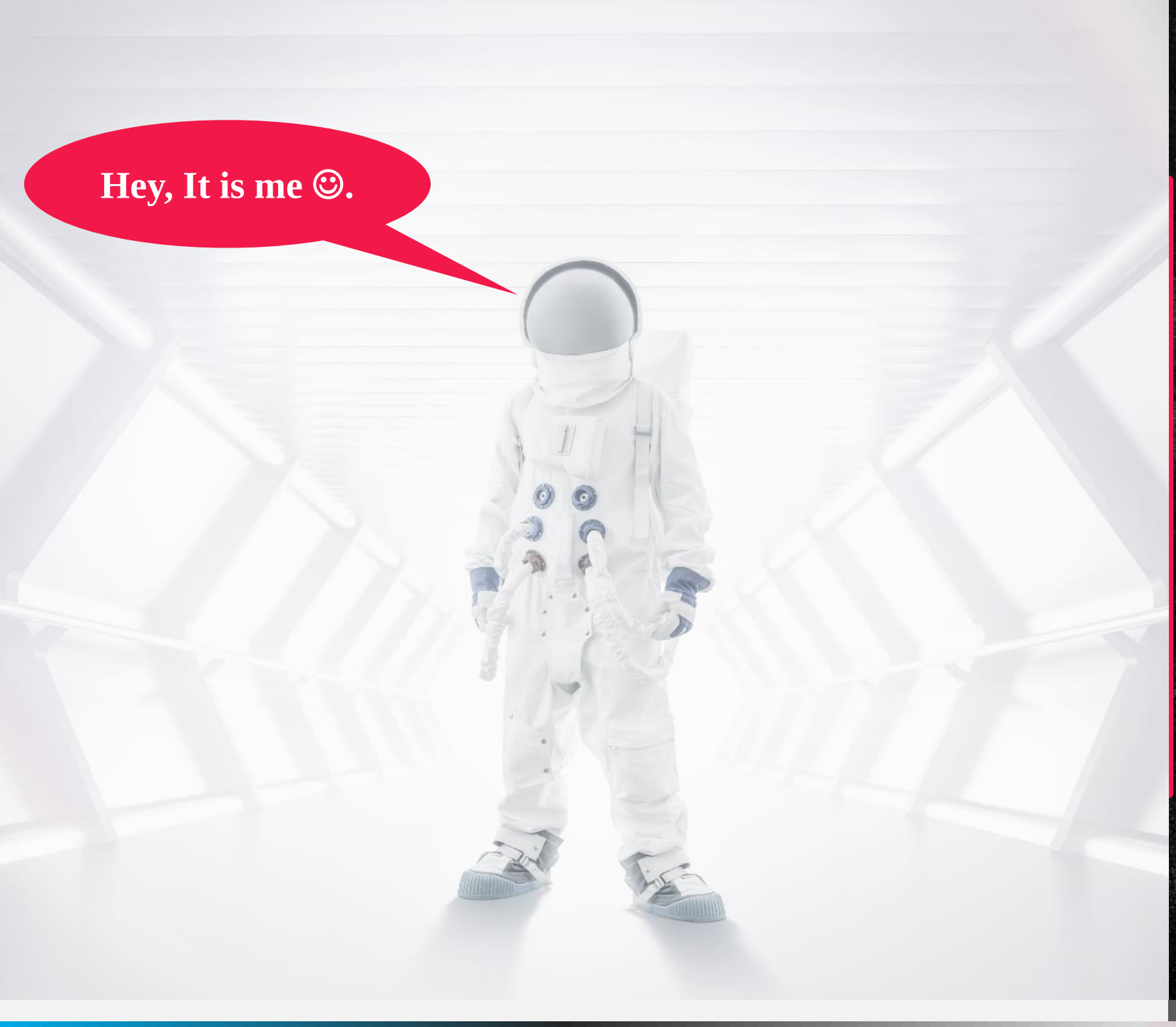
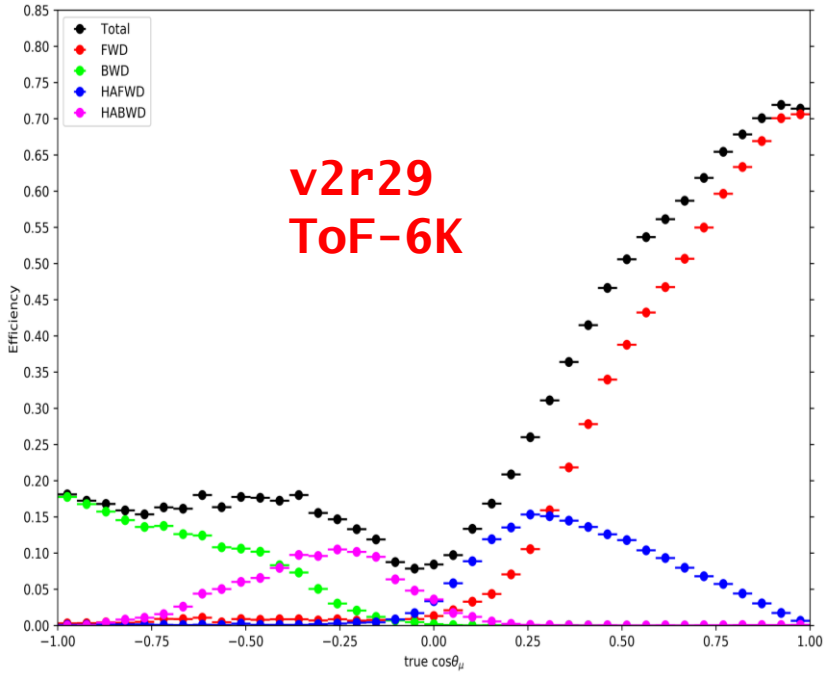


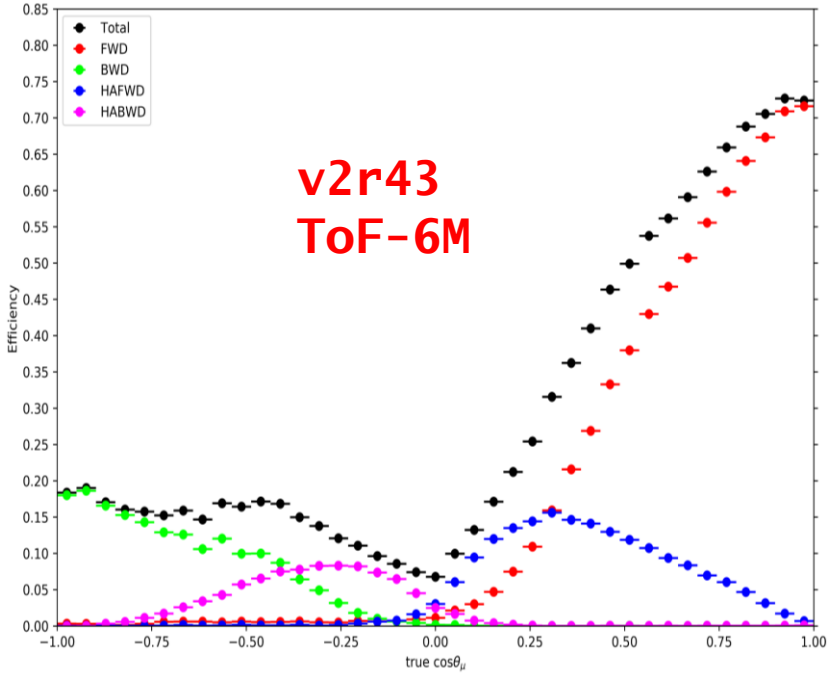
$\nu_\mu CC1\pi^+$ interactions on Carbon (FGD1) with 4π acceptance

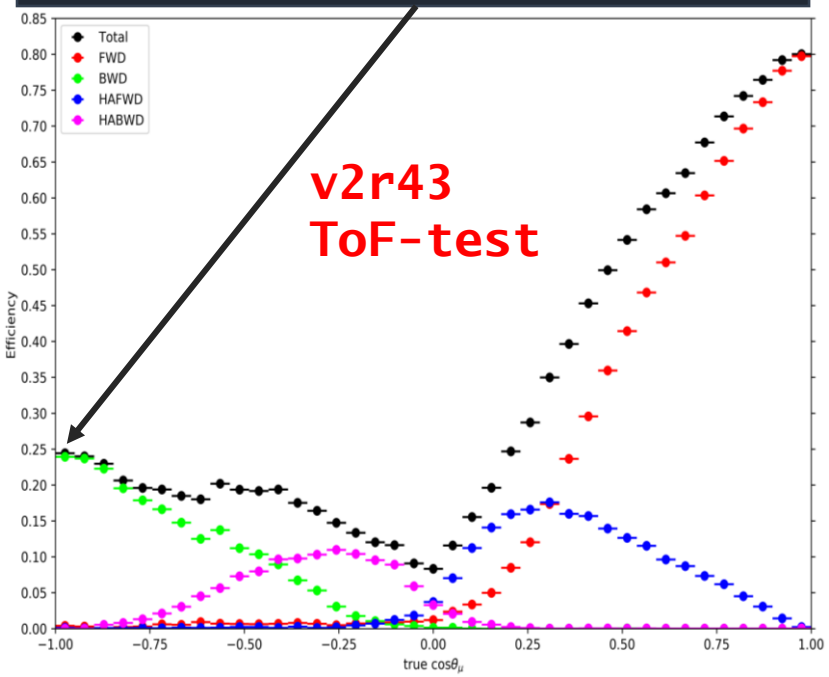
NEUTRINO GROUP MEETING

CC inclusive Efficiency

Increase of 5% in the BWD efficiency with respect to the one reporter in TN-245





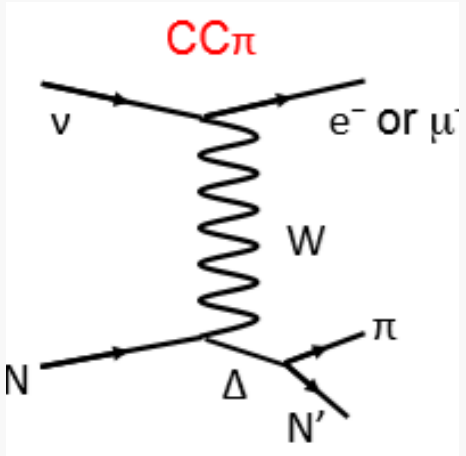


	Old (6K)		New (6M)		test	
	$\Delta\mu$	$\Delta\sigma$	$\Delta\mu$	$\Delta\sigma$	$\Delta\mu$	$\Delta\sigma$
kP0D_FGD1_ToF_MC_TrueFwd_Track	-1.099	0.220	-1.100	0.436	-1.100	0.220
kP0D_FGD1_ToF_MC_TrueBwd_Track	-1.000	2.160	-2.480	10.400	-1.000	2.160
kP0D_FGD1_ToF_Sand_Track	-0.128	1.768	-0.145	1.940	-0.145	1.940
kP0D_FGD1_ToF_MC_TrueFwd_Shower			-1.190	4.420	-1.190	4.420
kP0D_FGD1_ToF_MC_TrueBwd_Shower			-0.730	0.417	-0.730	0.417
kP0D_FGD1_ToF_Sand_Shower			0.012	0.330	0.012	0.330

Muon cosine of theta efficiency for **CC inclusive**. Using highland2 **v2r29** with **ToF-6K** (left), **v2r41** with **ToF-6M** (center) and **v2r43** with **ToF-test**. Selection **NumuCC4piMultiPi v0r0**

Signal and Efficiency

$$\nu_\mu + p \rightarrow \mu^- + \pi^+ + p$$
$$\nu_\mu + n \rightarrow \mu^- + \pi^+ + n$$

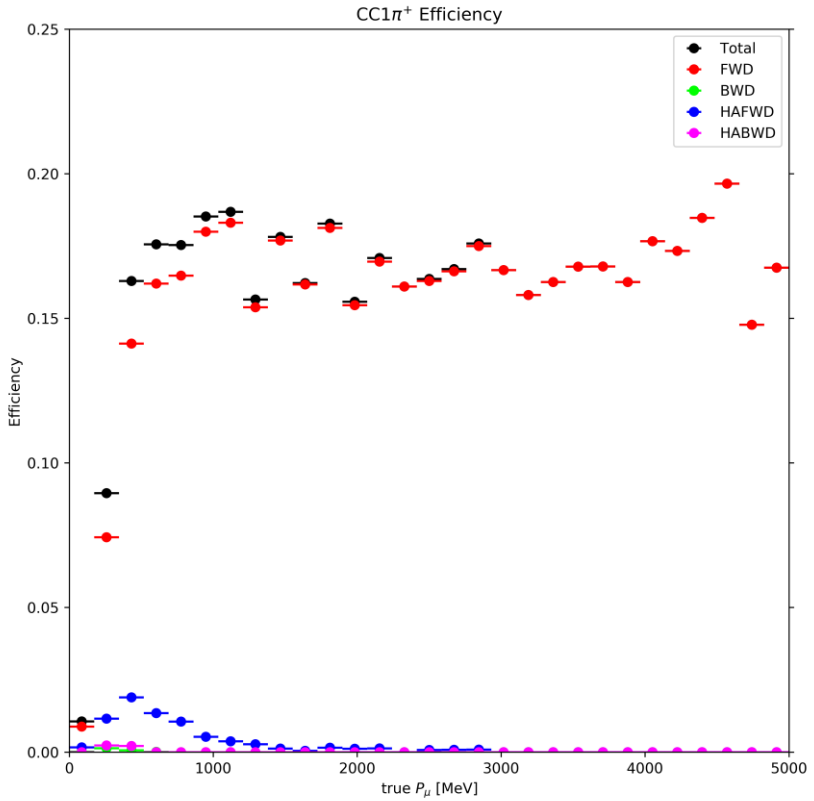


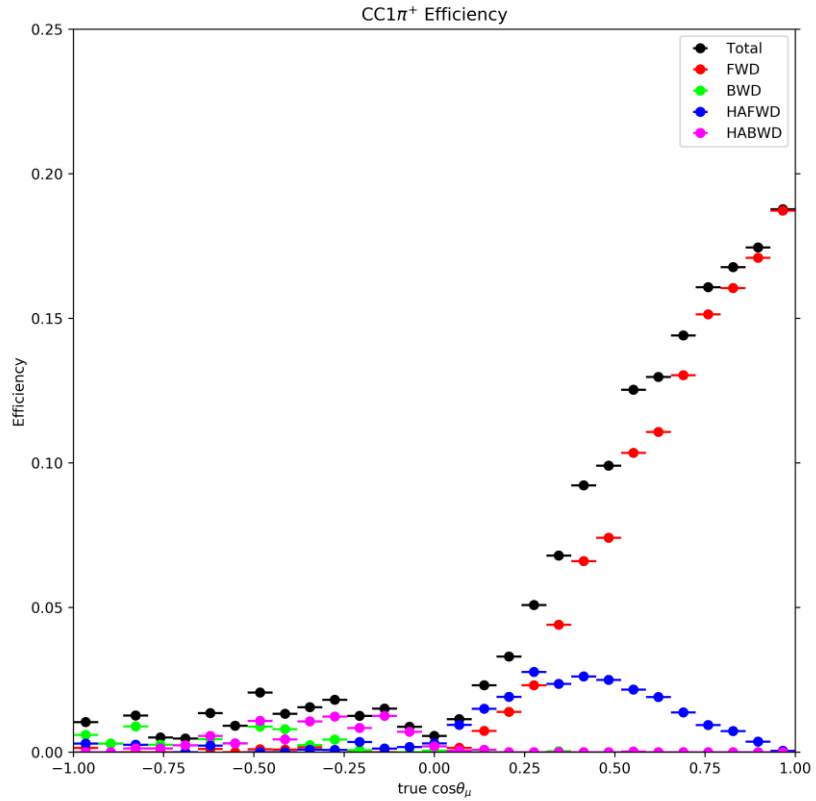
Software:

- ✓ nd280Highland v2r43
- ✓ ToF Correction
  - ✓ Test correction: mix between 6M and 6K
- ✓ Prod6T for NEUT MC (Flattrees)
  - ✓ 2air, 2water, 3air, 4air, 4water, 8air and 8water

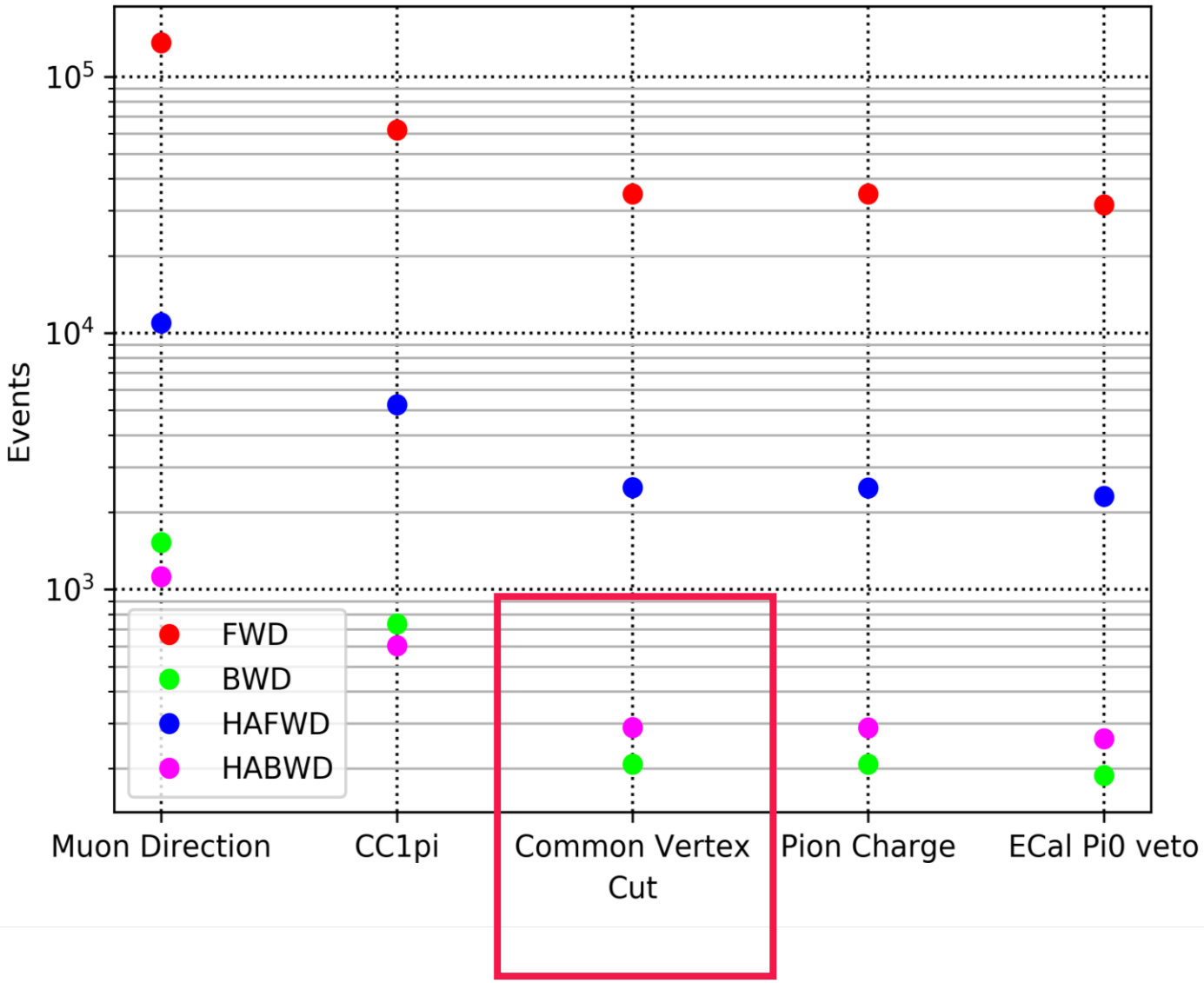
Signal:

- ✓ 1 muon (in 4π acceptance)
- ✓ 1 π^+ (FGD , TPC and ECal)
- ✓ ME tagging
- ✓ π^0 ECal veto
- ✓ Contamination of my CC1π^+ sample: CCother and CC0π.
- ✓ Contamination of protons in the pion sample for FGD and ECal.





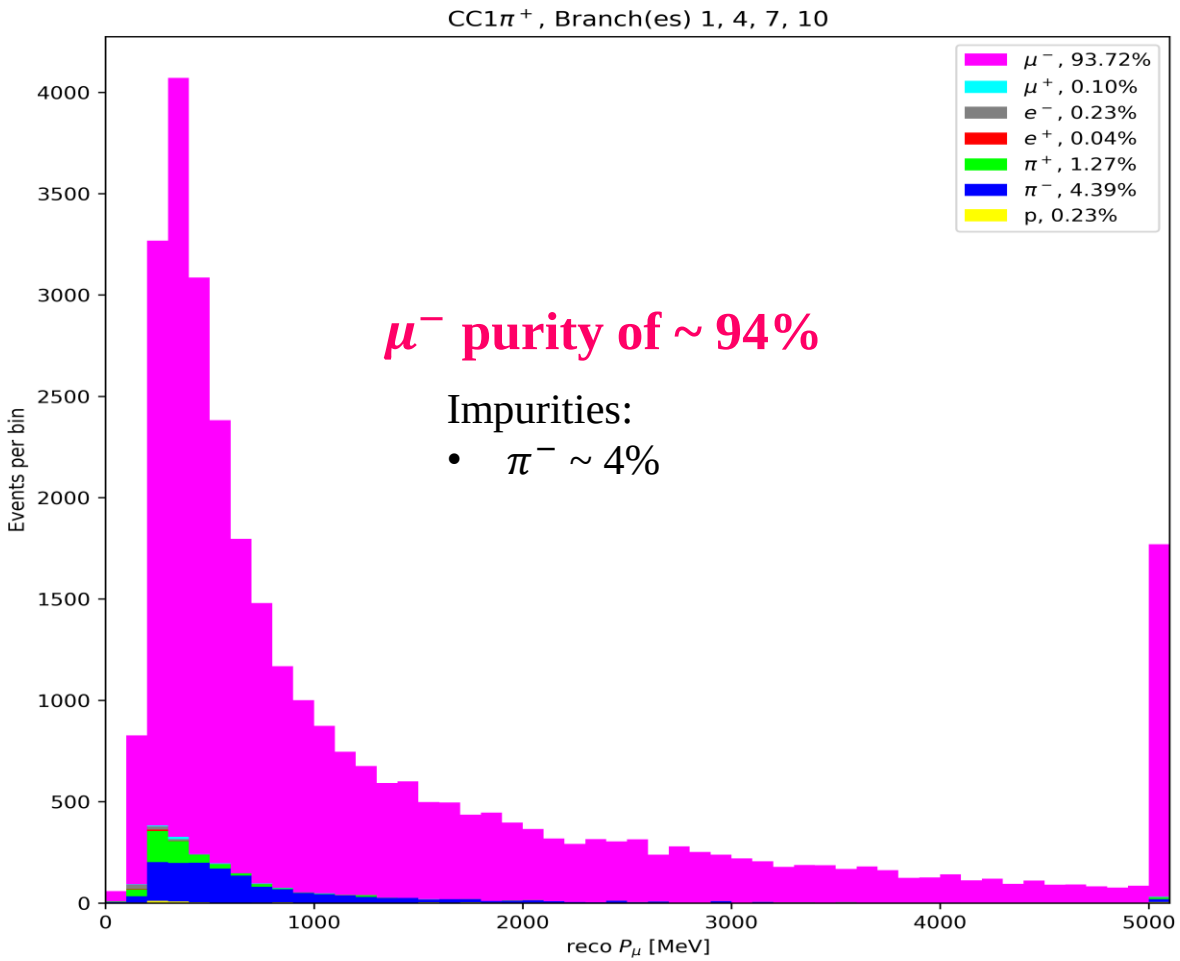
Number of True Event vs. Cut

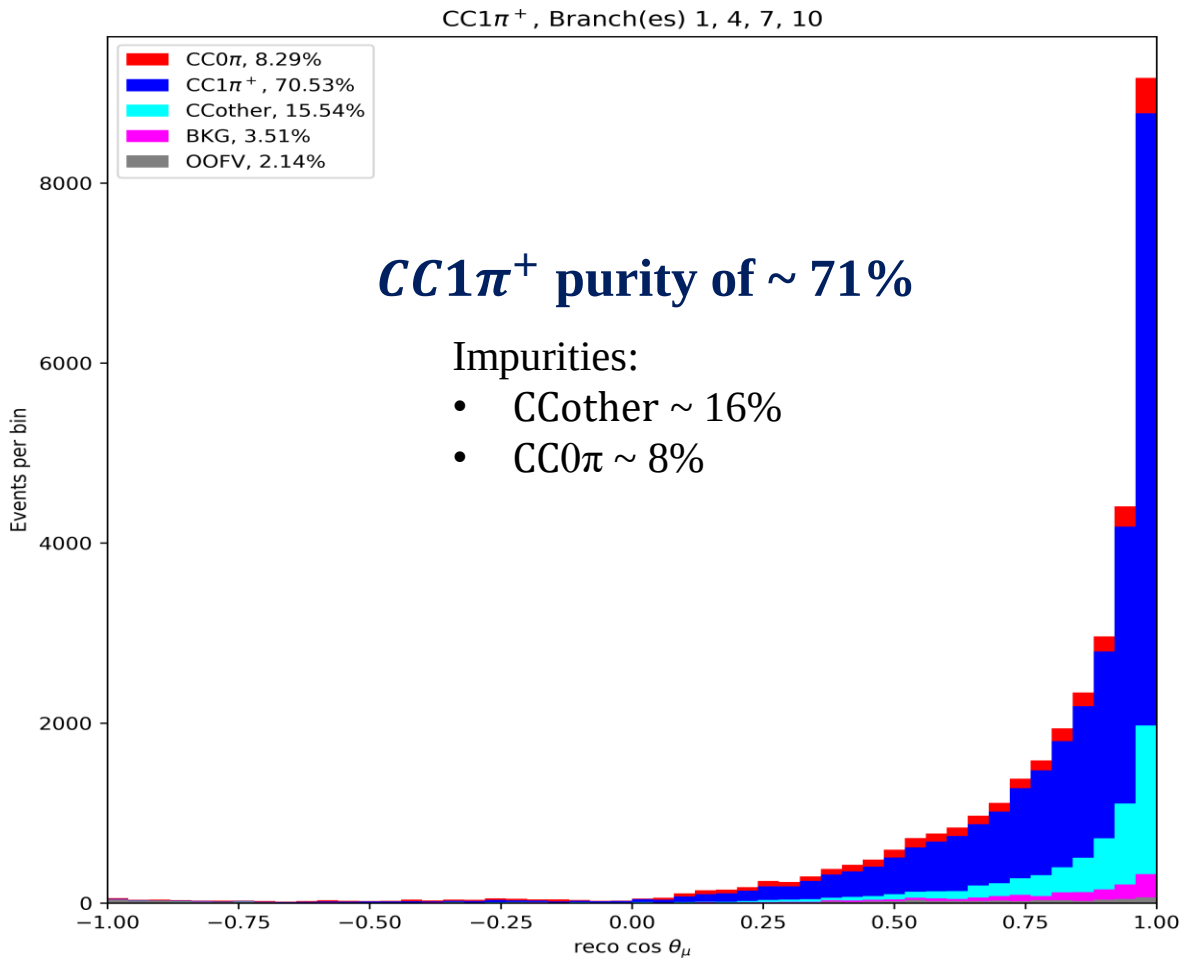


Number of true CC1π^+ events in the reco CC1π^+ alone and in the reco CCinclusive (CC1π^++ CCother + CC0π)

	CC1π^+	CC1π^+ + CCother + CC0π
FWD	31683	111313
BWD	188	1057
HAFWD	2307	8378
HABWD	262	835

Muon Kinematics

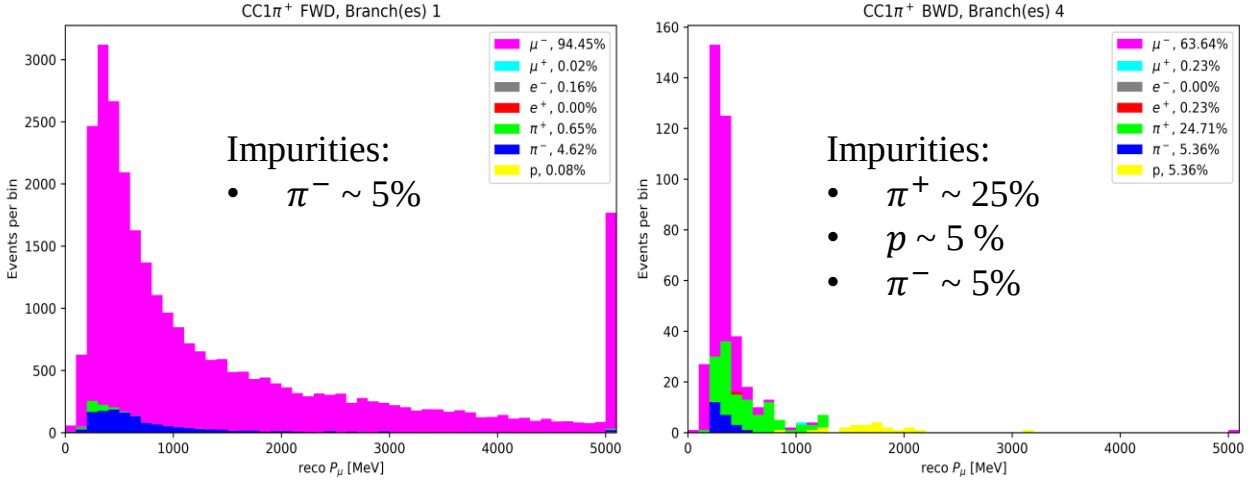


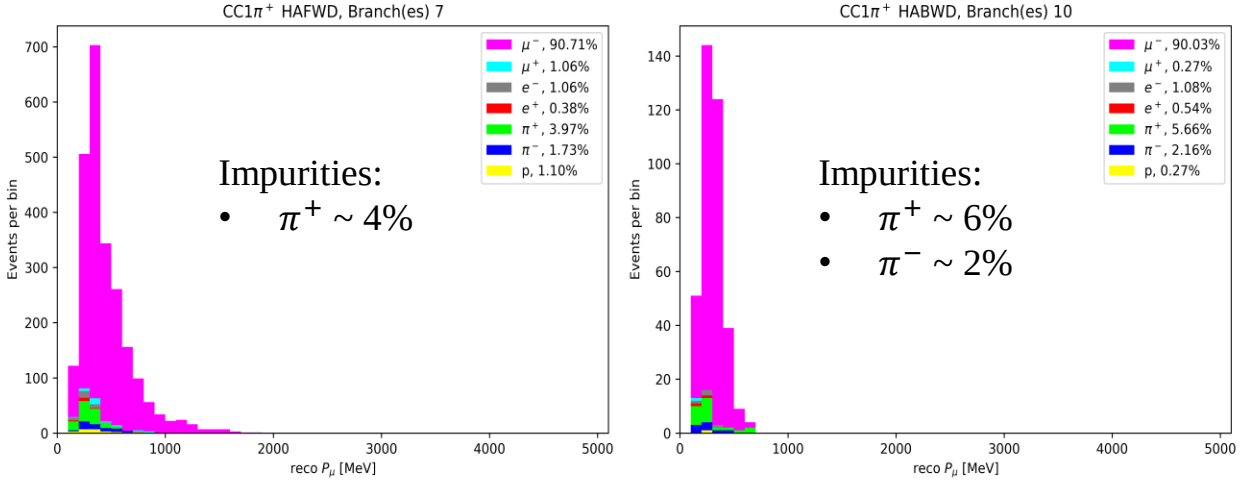


Muon momentum distribution for CC1π^+ (4π acceptance) using true particle ID

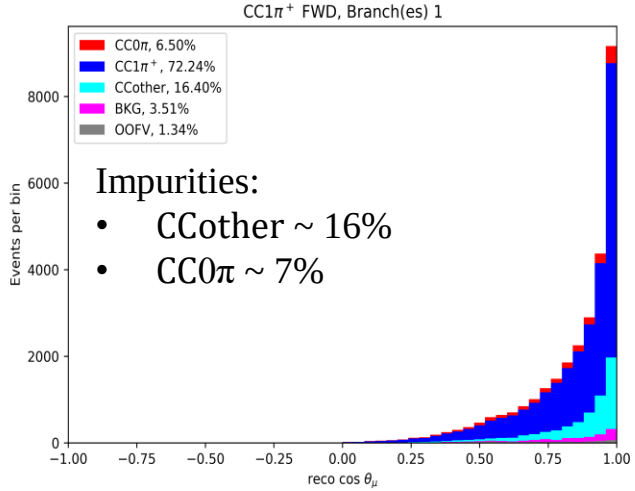
Muon cosine of theta distribution for CC1π^+ (4π acceptance) using true topology

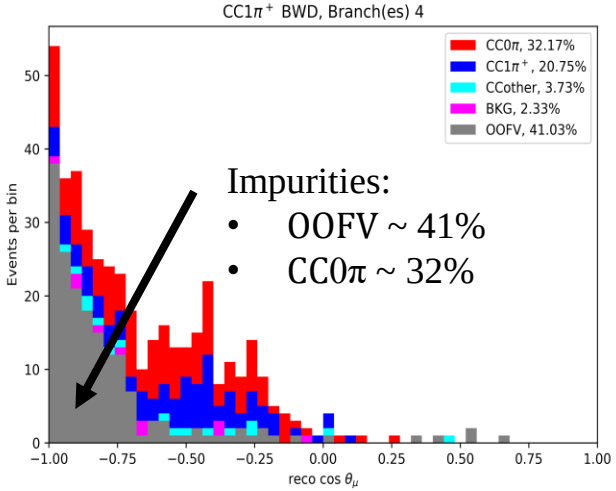
Muon Kinematics

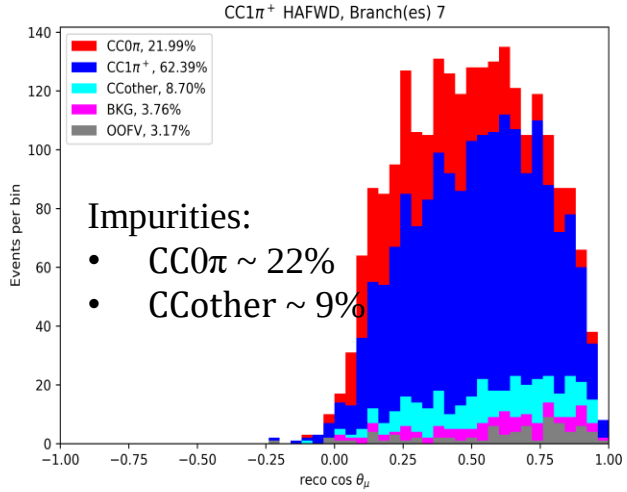


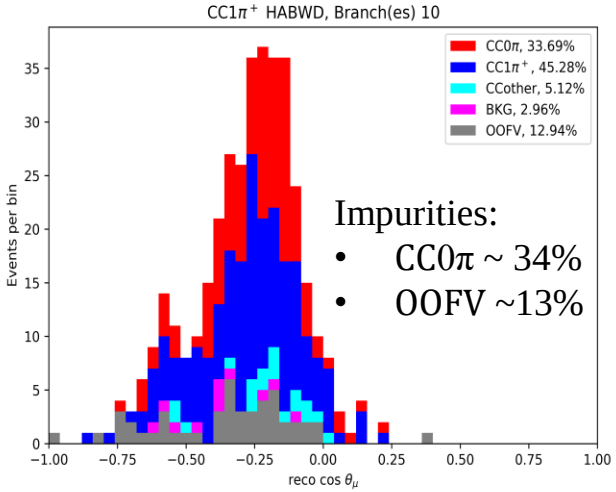


Muon momentum distribution for CC1π^+ using true particle ID



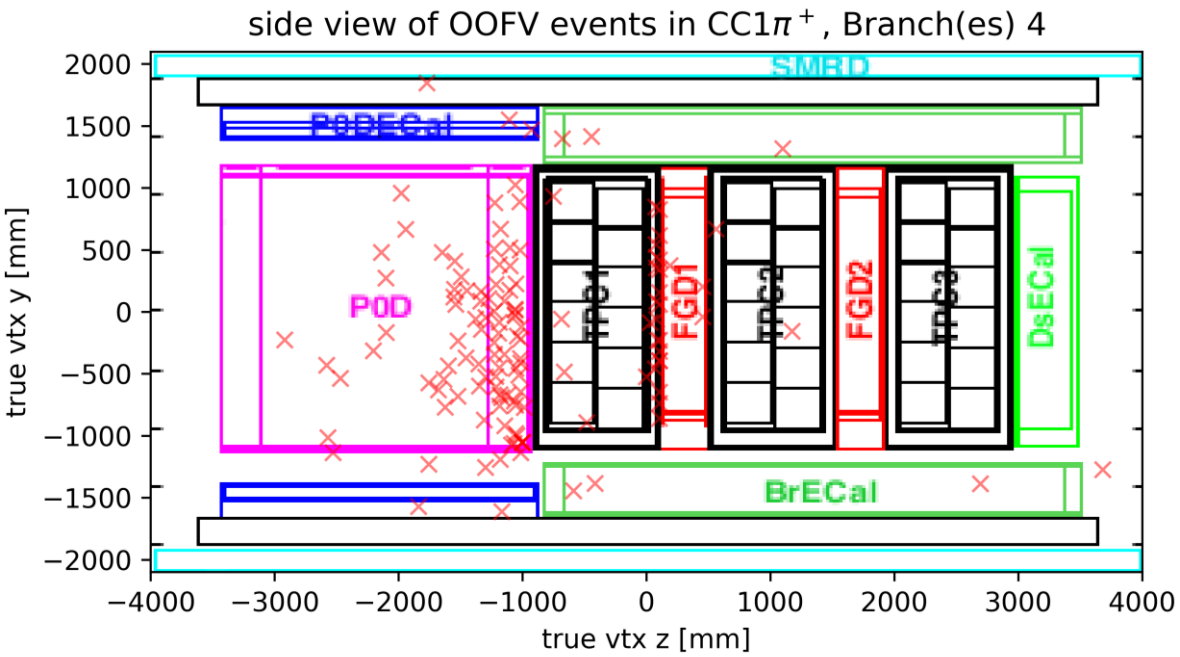




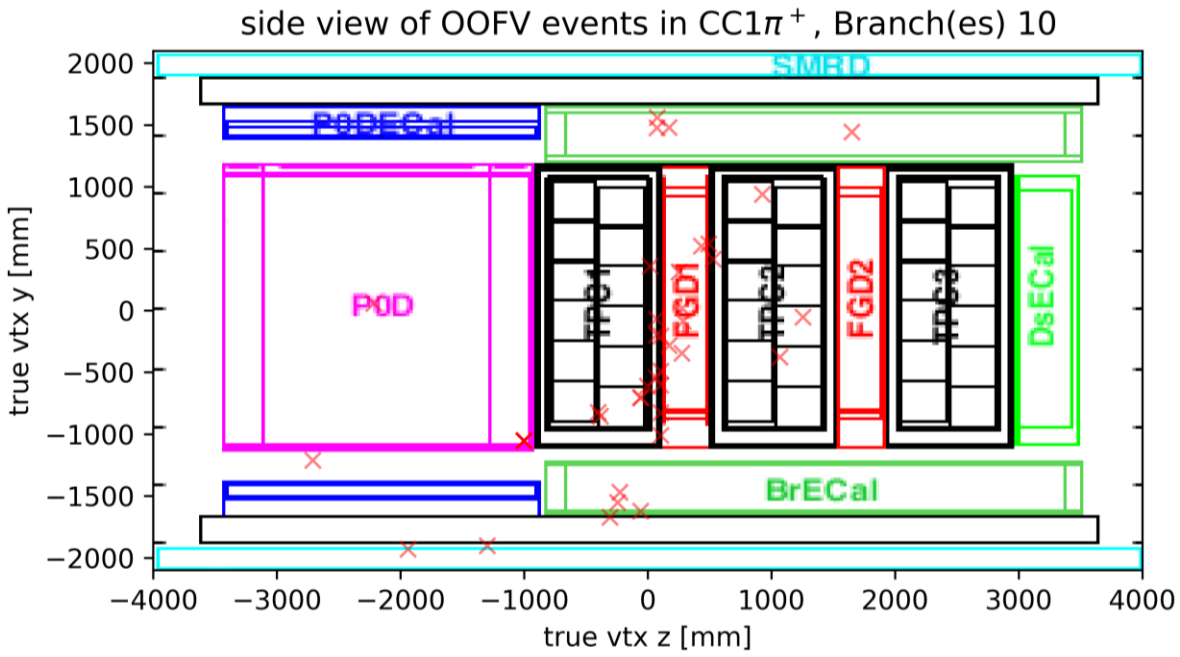


Muon cosine of theta distribution for CC1π^+ using true topology

Event Migration: OOFV



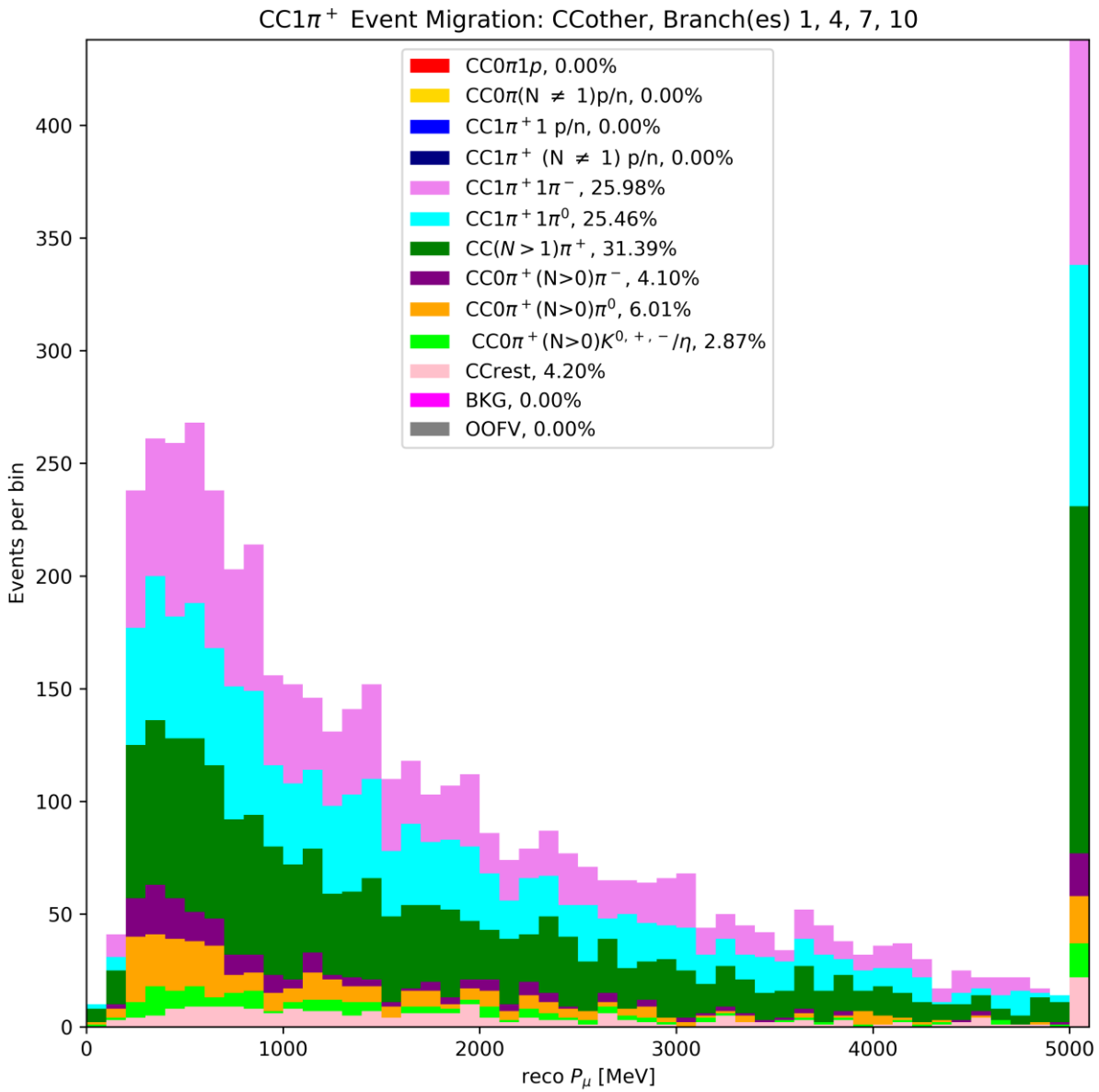
BWD



HABWD

- ✓ In the BWD region, the OOFV is a huge problem because it represents ~ 41%.
- ✓ In the HABWD region the OOFV represents ~13%.

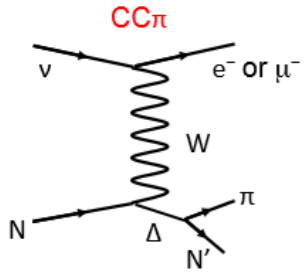
Event Migration: CCother



Muon momentum distribution for CC1π^+ (4π acceptance) that are true CCother events based on true composition. This represents ~ 16%.

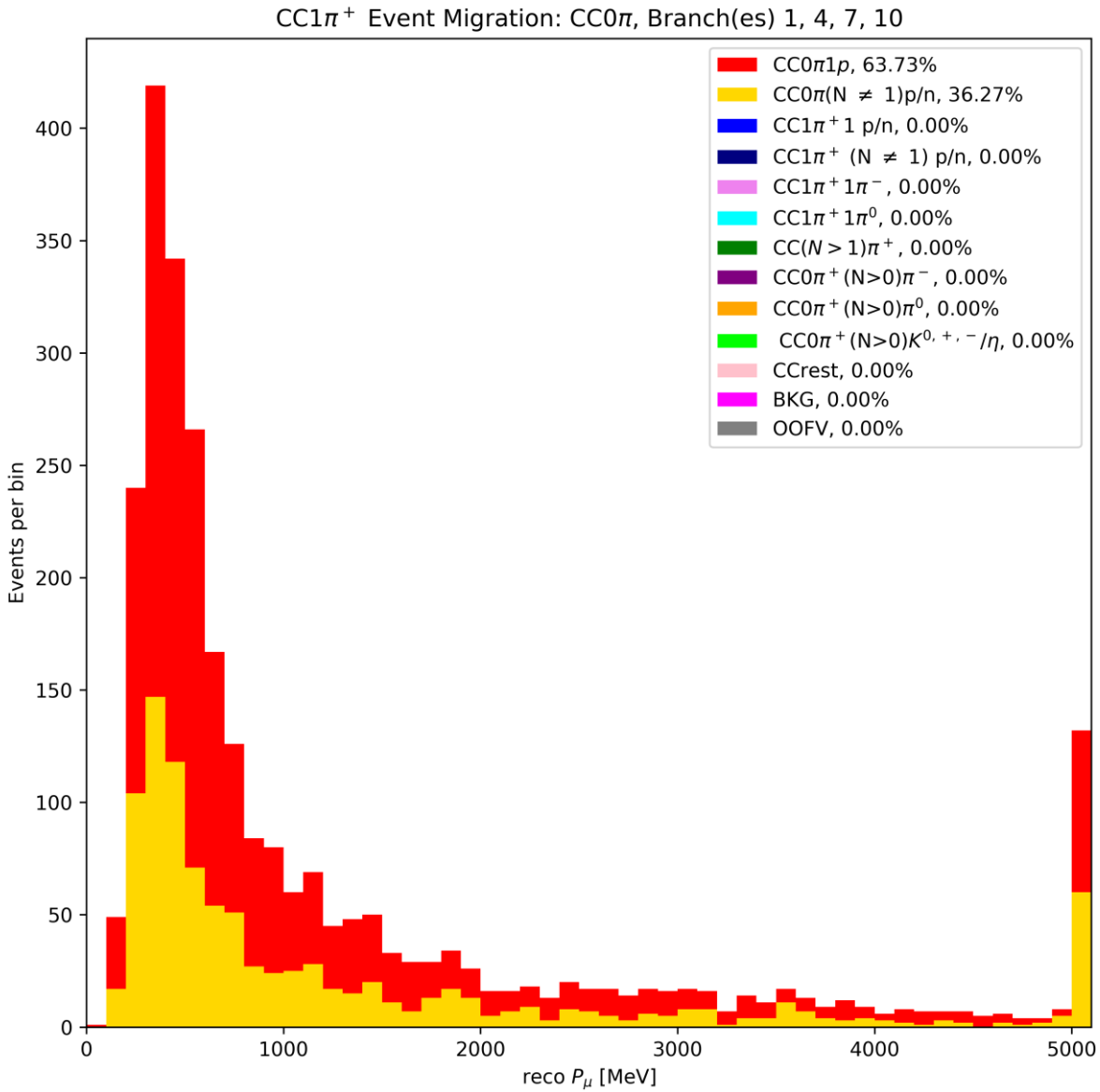
- ~ 31% are CC$(N > 1)\pi^+$
- ~ 26% are CC $1\pi^+ 1\pi^-$
- ~ 25% are CC $1\pi^+ 1\pi^0$

The ECal π^0 veto already reduced the CCother event migration from ~30% to ~16% but we can see that a large contribution came from π^0.



$$\nu_\mu + n \rightarrow \mu^- + \pi^0 + p$$

Event Migration: CCother



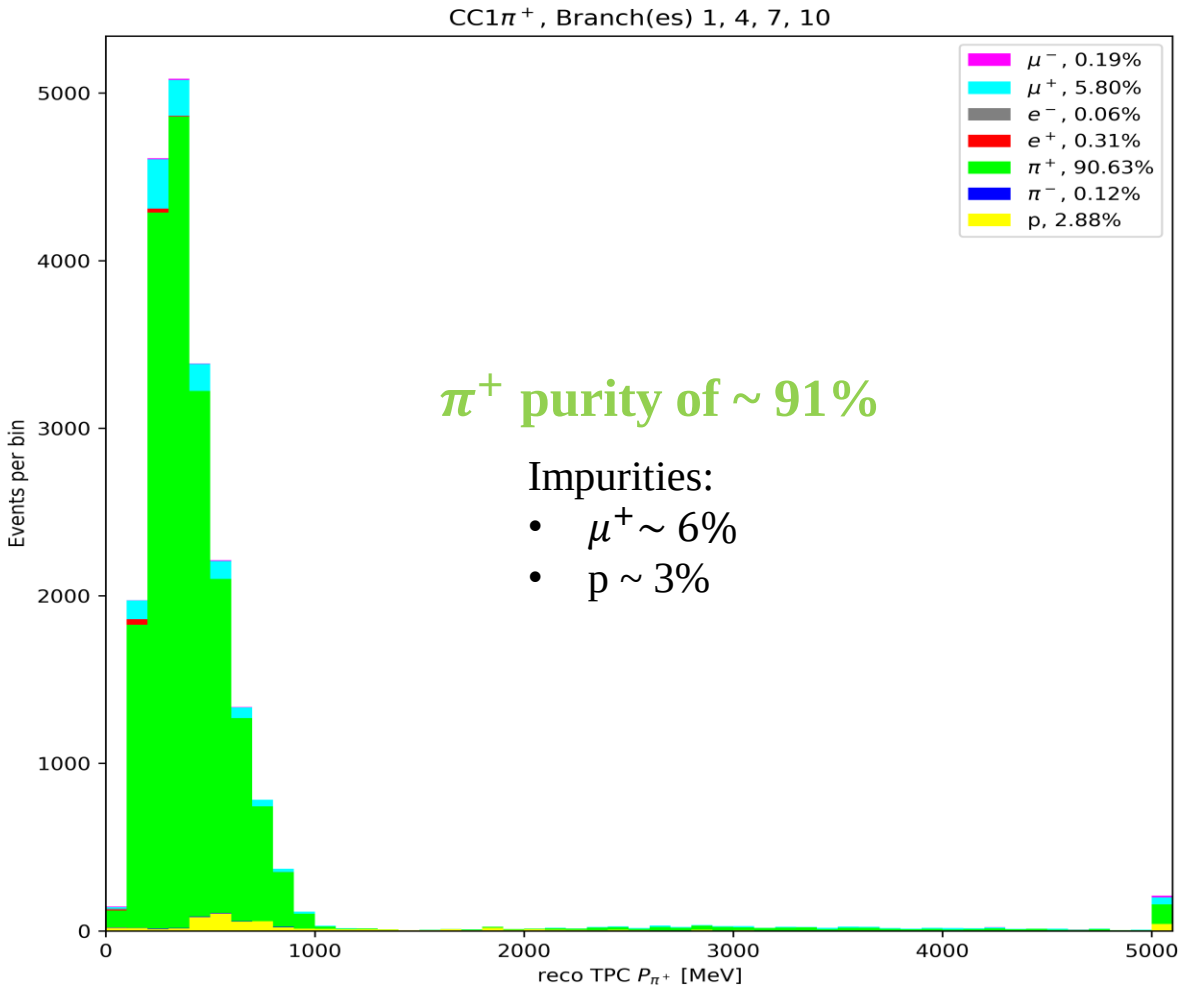
Muon momentum distribution for CC1π^+ (4π acceptance) that are true CC0π events based on true composition. This represents ~ 8%.

~ 64% are CC0π1p (CC1π^+)

~ 36% are CC0π(N≠1)p (CC1$\pi^+1p \rightarrow$ CC1π^+)

Because of true protons that are identified as positive pions (mainly in FGD and ECal).

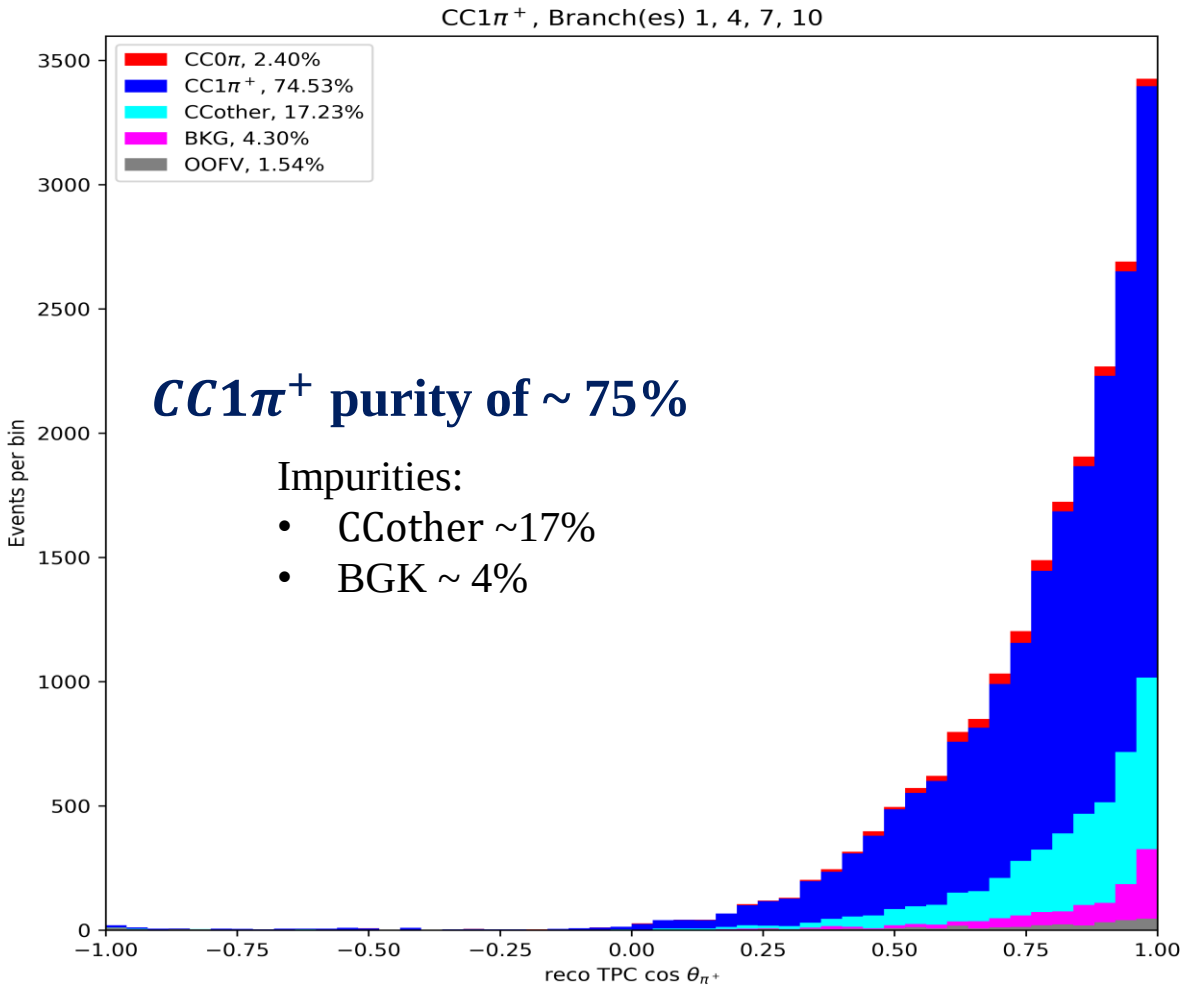
Positive Pion Kinematics



π^+ purity of ~ 91%

Impurities:
- μ^+ ~ 6%
- p ~ 3%

TPC positive pion momentum distribution for CC1π^+ (4π acceptance) using true particle ID

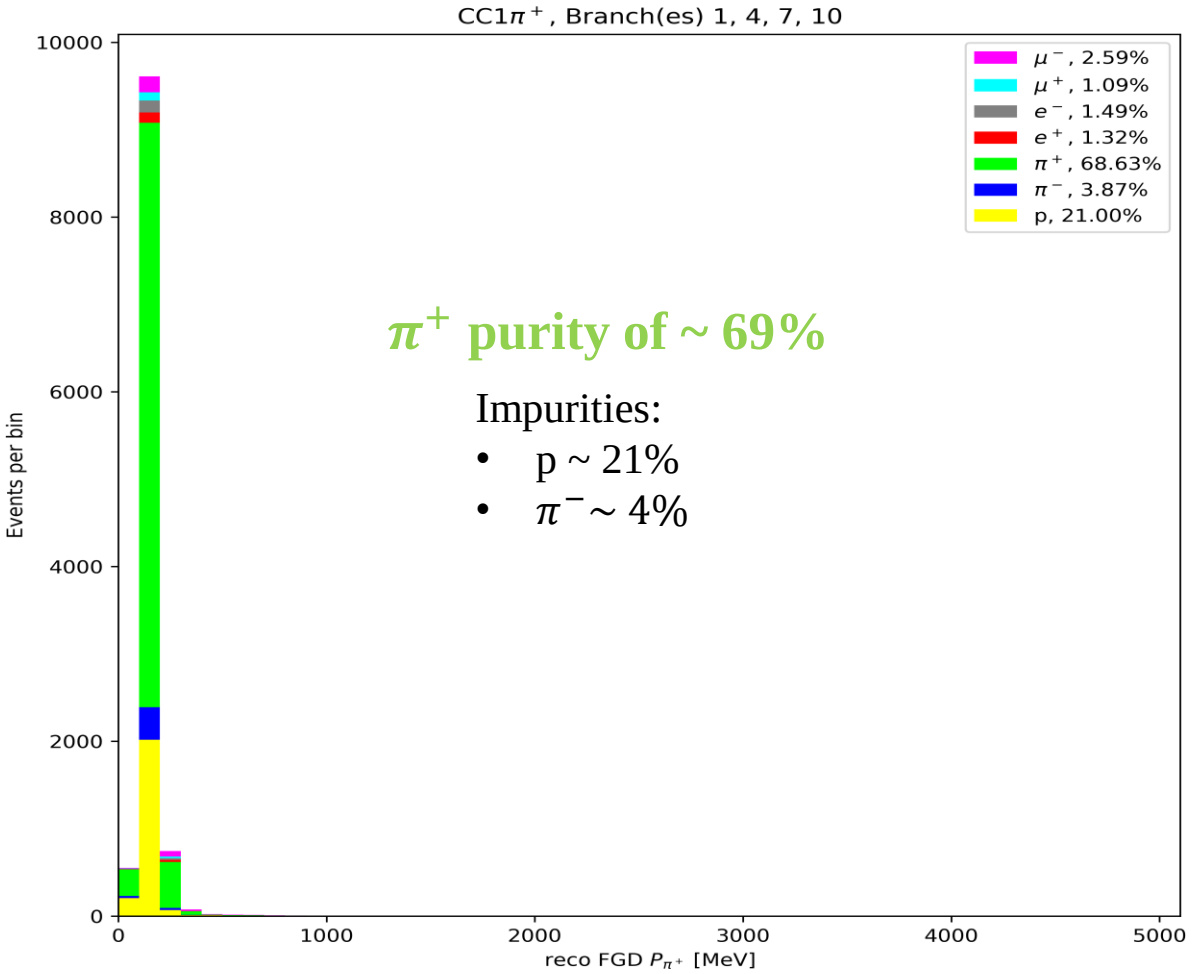


$CC1\pi^+$ purity of ~ 75%

Impurities:
- CCother ~17%
- BGK ~ 4%

TPC positive pion cosine of theta distribution for CC1π^+ (4π acceptance) using true topology

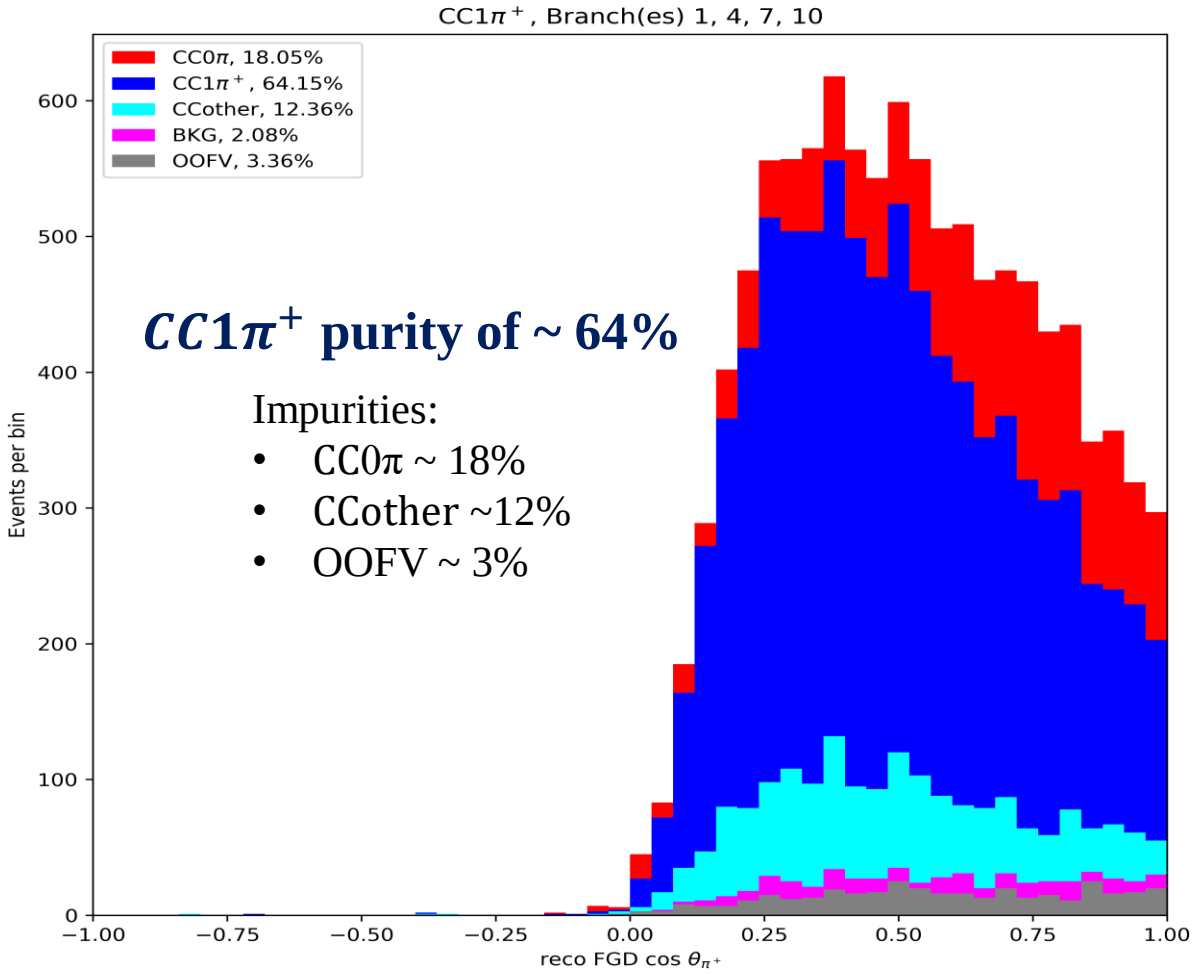
Positive Pion Kinematics



π^+ purity of ~ 69%

Impurities:
- p ~ 21%
- π^- ~ 4%

FGD positive pion momentum distribution for CC1π^+ (4π acceptance) using true particle ID

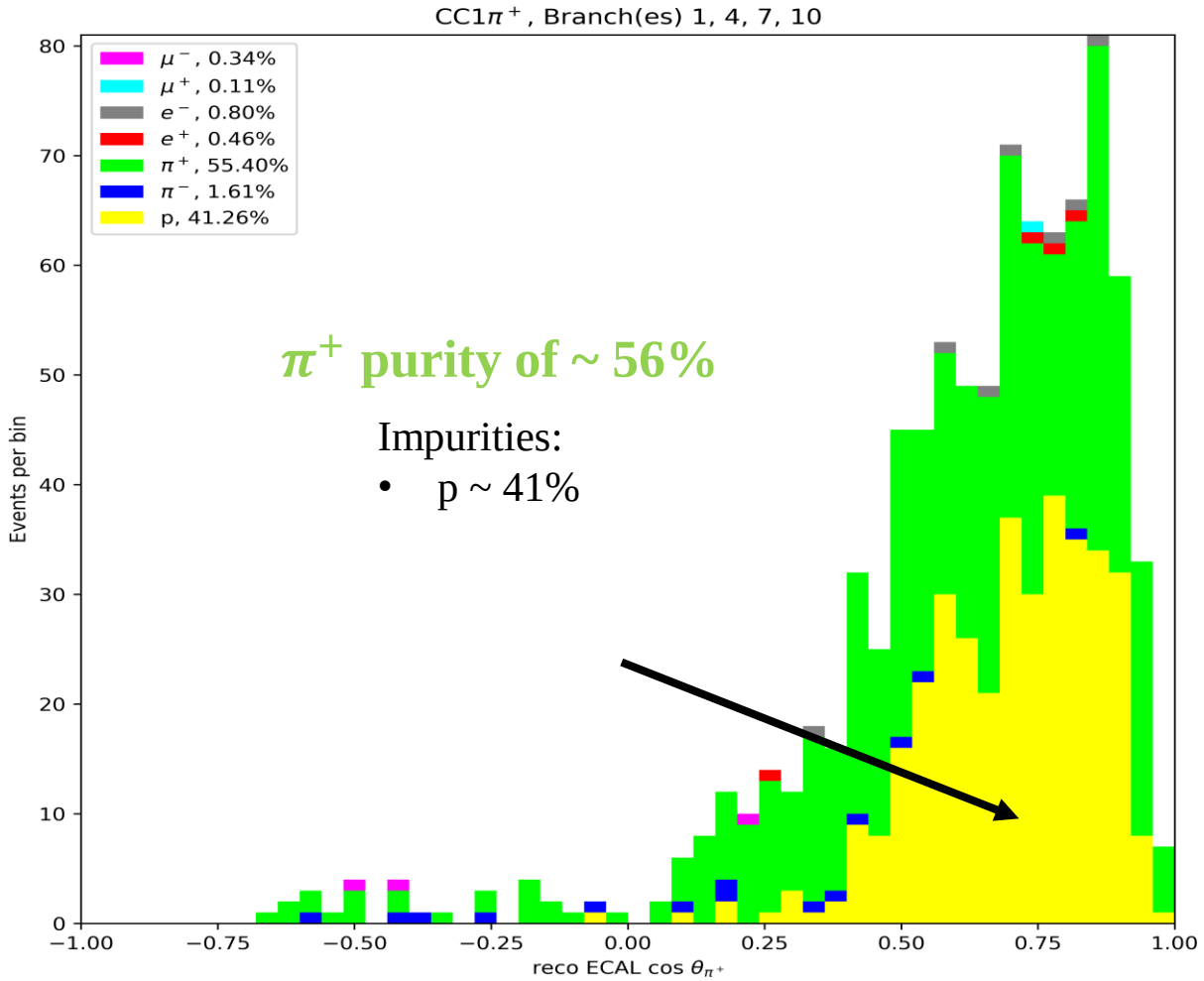


$CC1\pi^+$ purity of ~ 64%

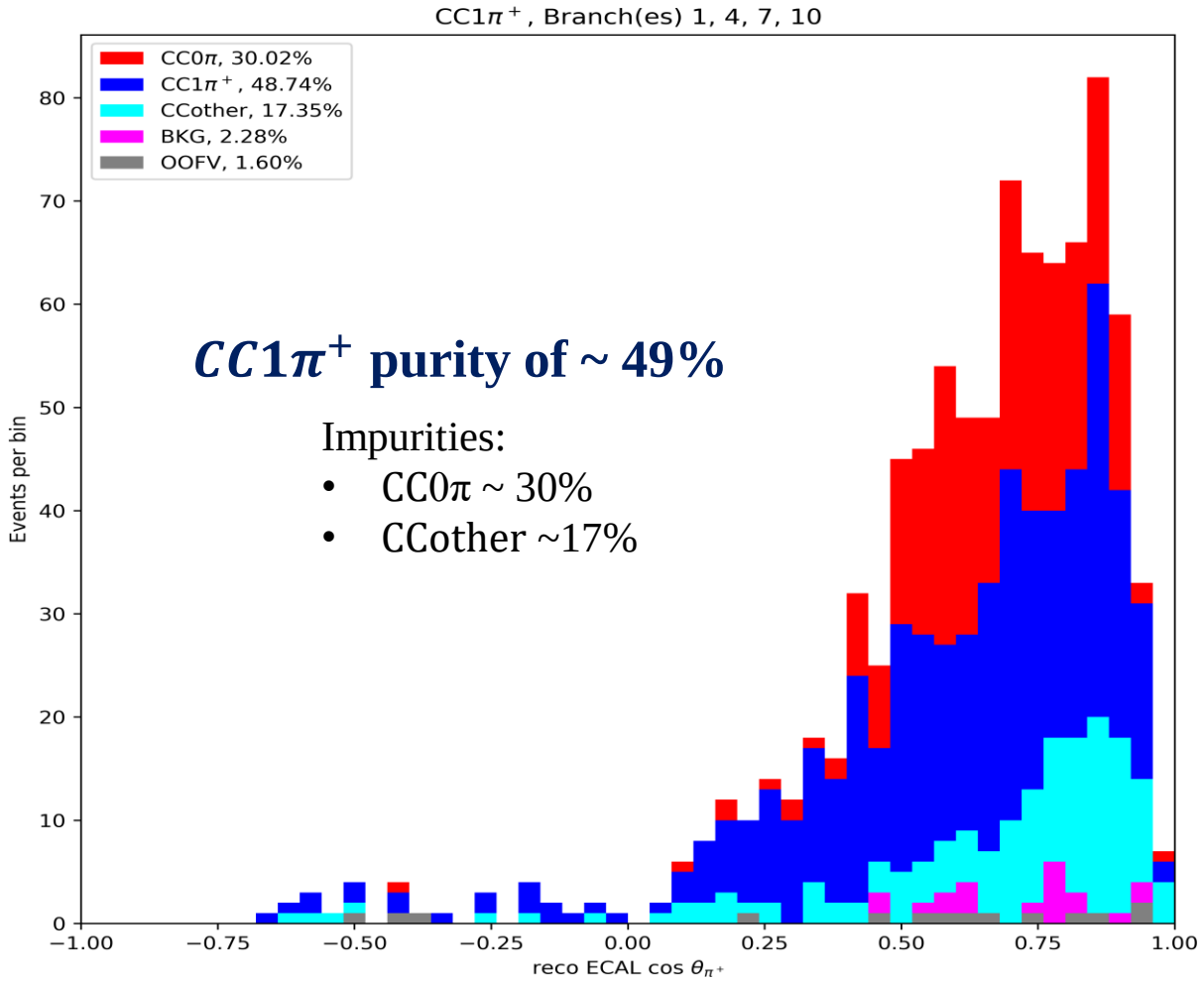
Impurities:
- CC0π ~ 18%
- CCother ~12%
- OOFV ~ 3%

FGD positive pion cosine of theta distribution for CC1π^+ (4π acceptance) using true topology

Positive Pion Kinematics



ECal positive pion cosine of theta distribution for CC1π^+ (4π acceptance) using true particle ID



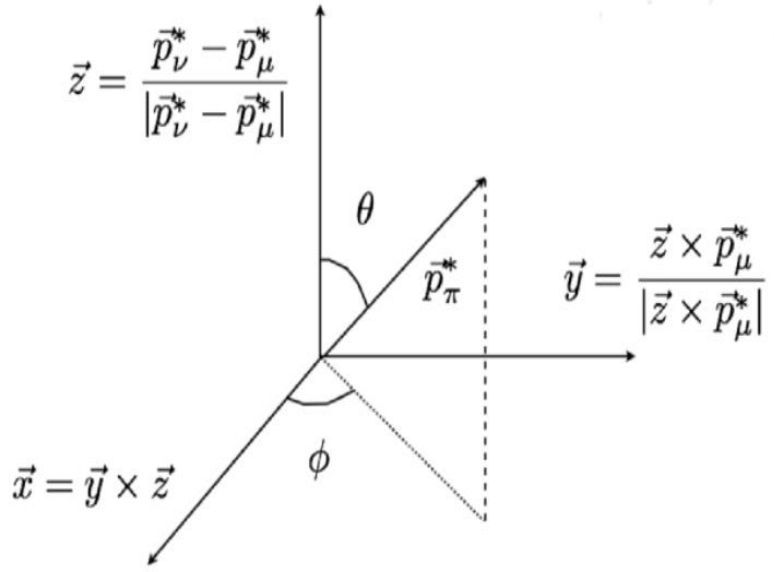
ECal positive pion cosine of theta distribution for CC1π^+ (4π acceptance) using true topology

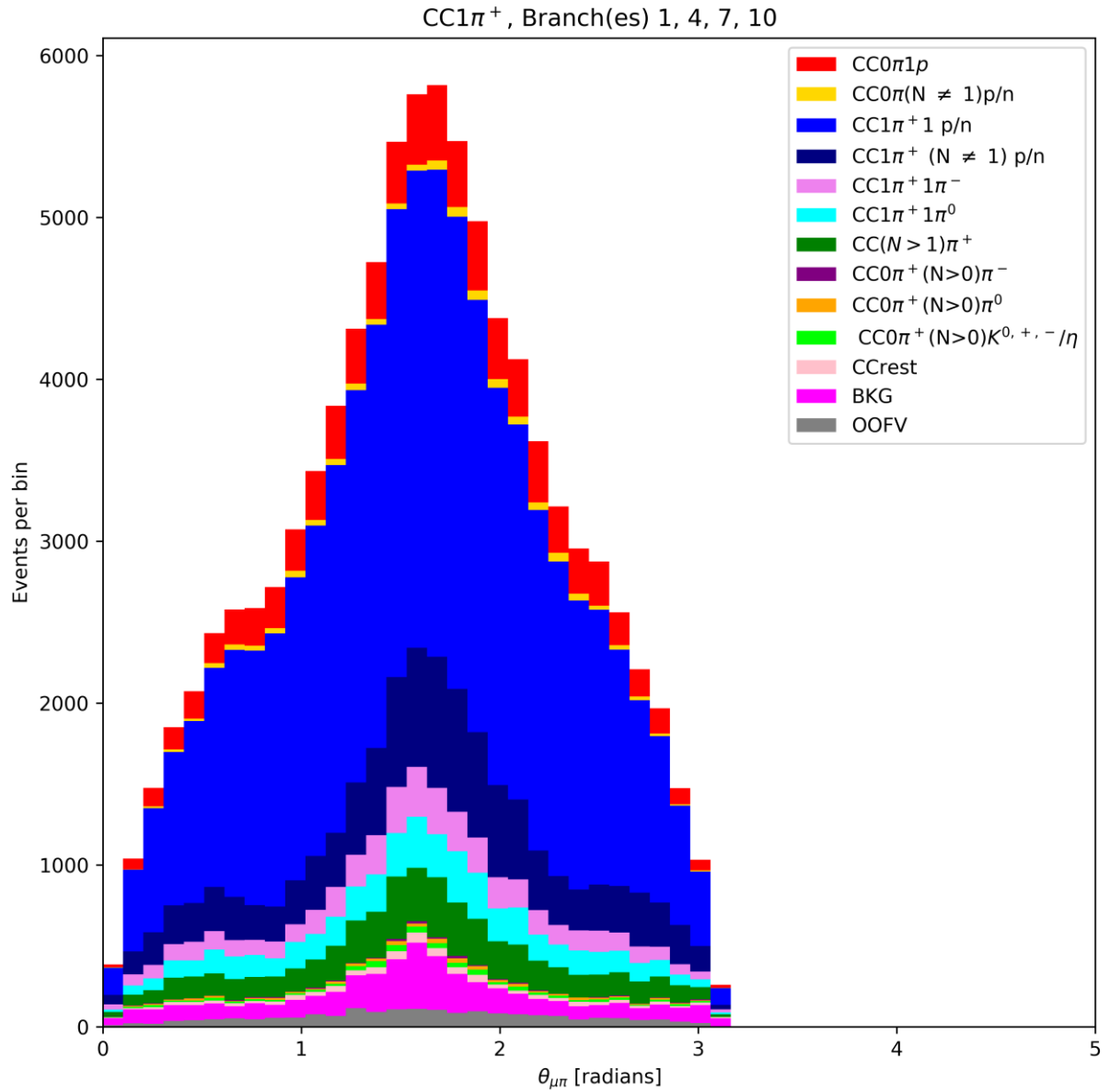
Special Angular Variables

The angle between the muon and the pion will be:

$$\cos\theta_{\mu\pi} = \frac{\vec{k}_\mu * \vec{k}_\pi}{|\vec{k}_\mu| * |\vec{k}_\pi|}$$

Definition of the Adler's Angles at the nuclear level is illustrated in the figure below. The momenta of the particles are defined in the $\vec{q} = \vec{p}_\nu - \vec{p}_\mu$ rest frame.





Special Angular Variables

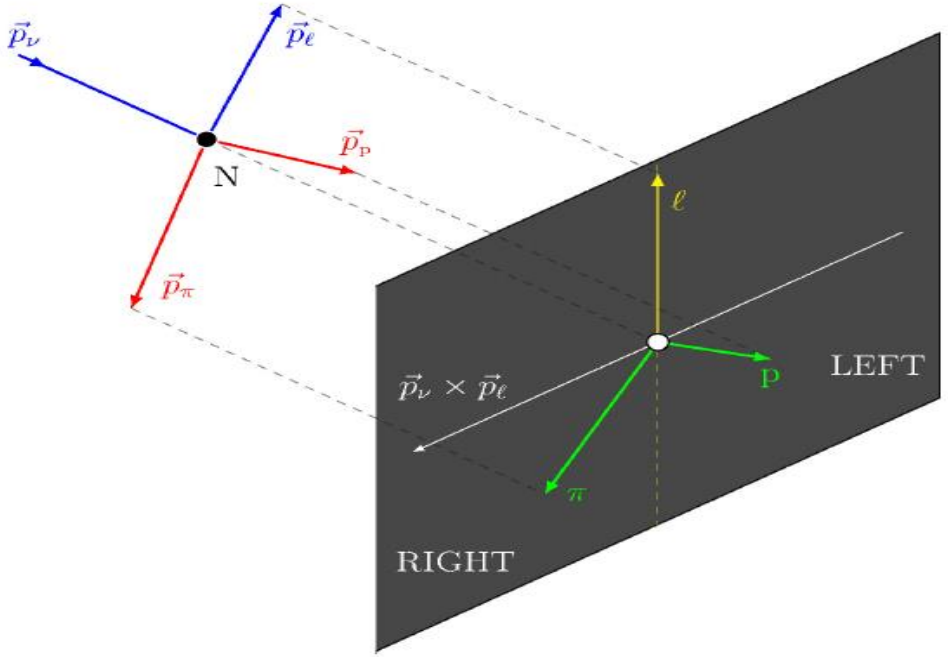
The asymmetry between BWD and FWD muon and pion production with respect to the direction of the incident ν_μ:

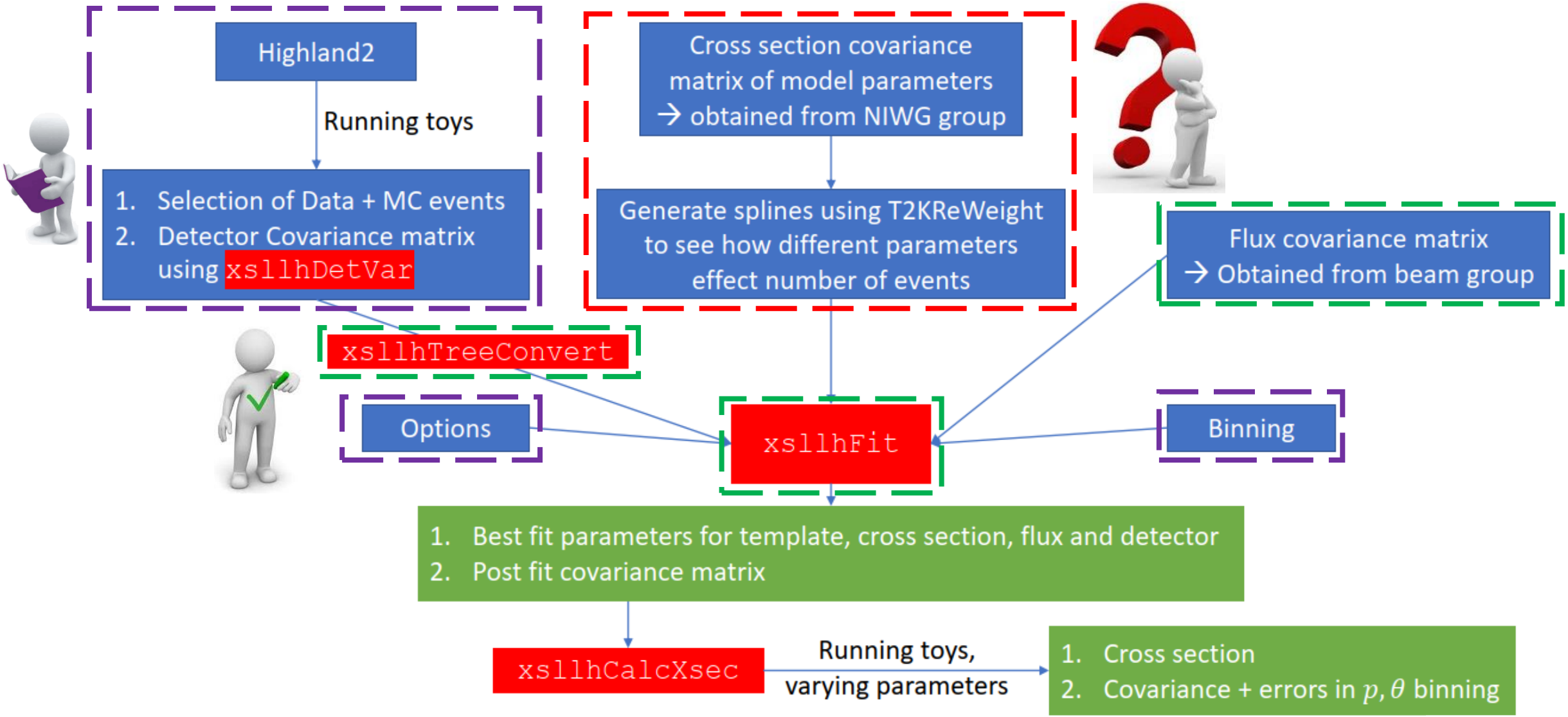
$$A_{FB} = \frac{N_{\cos\theta>0} - N_{\cos\theta<0}}{N_{\cos\theta>0} + N_{\cos\theta<0}}$$

The asymmetry between left and right pion production with respect to the direction of the incident ν_μ:

$$A_{LR} = \frac{N_L - N_R}{N_L + N_R}$$

Preliminary	A_{FB}	A_{LR}
Muon (CC inclusive)	0.879	
Muon (CC1π^+)	0.973	
Pion (CC1π^+)	0.979	0.024

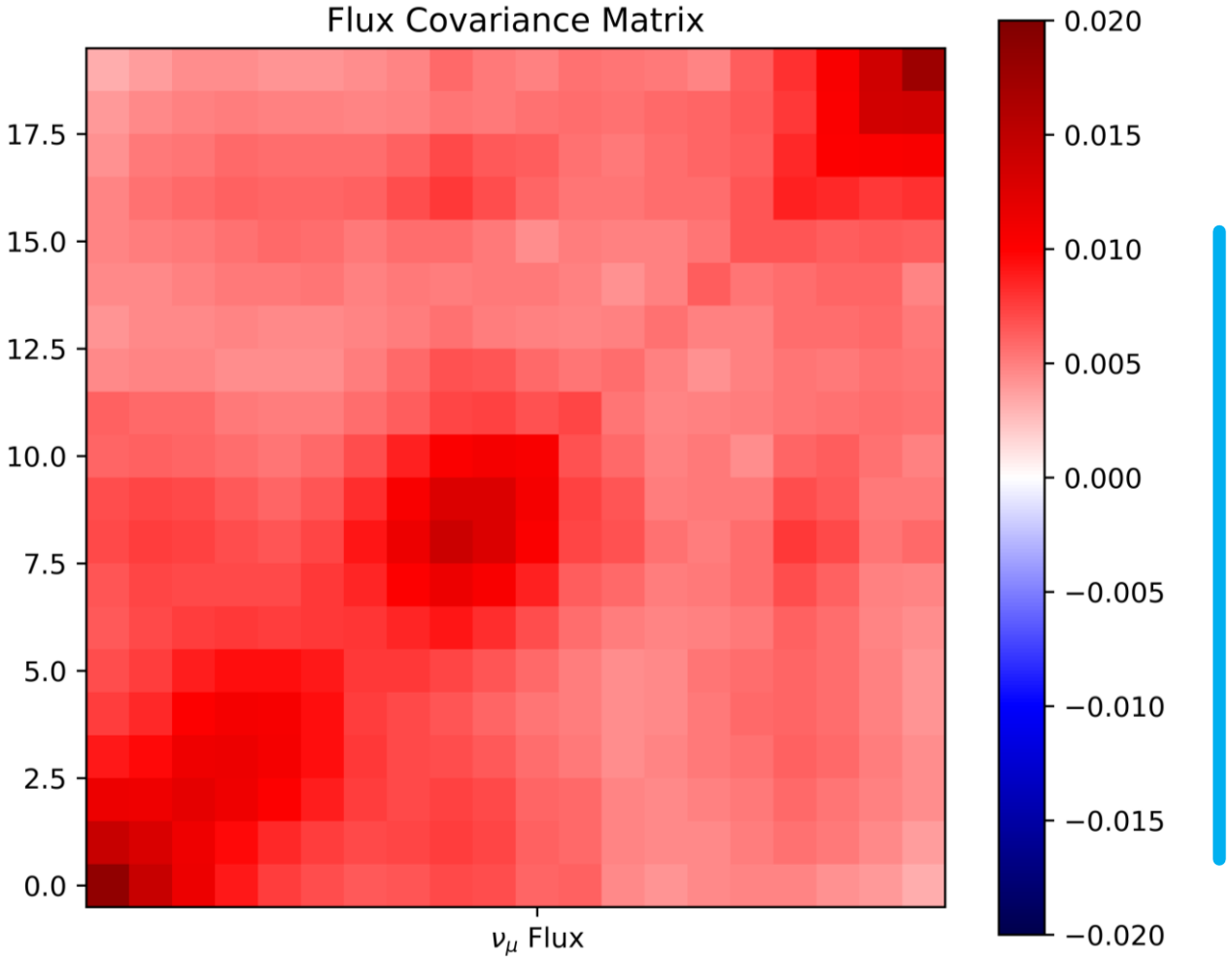




ETH zürich

Caspar Schloesser

Flux Covariance Matrix



Flux covariance matrix for muon neutrinos!!!

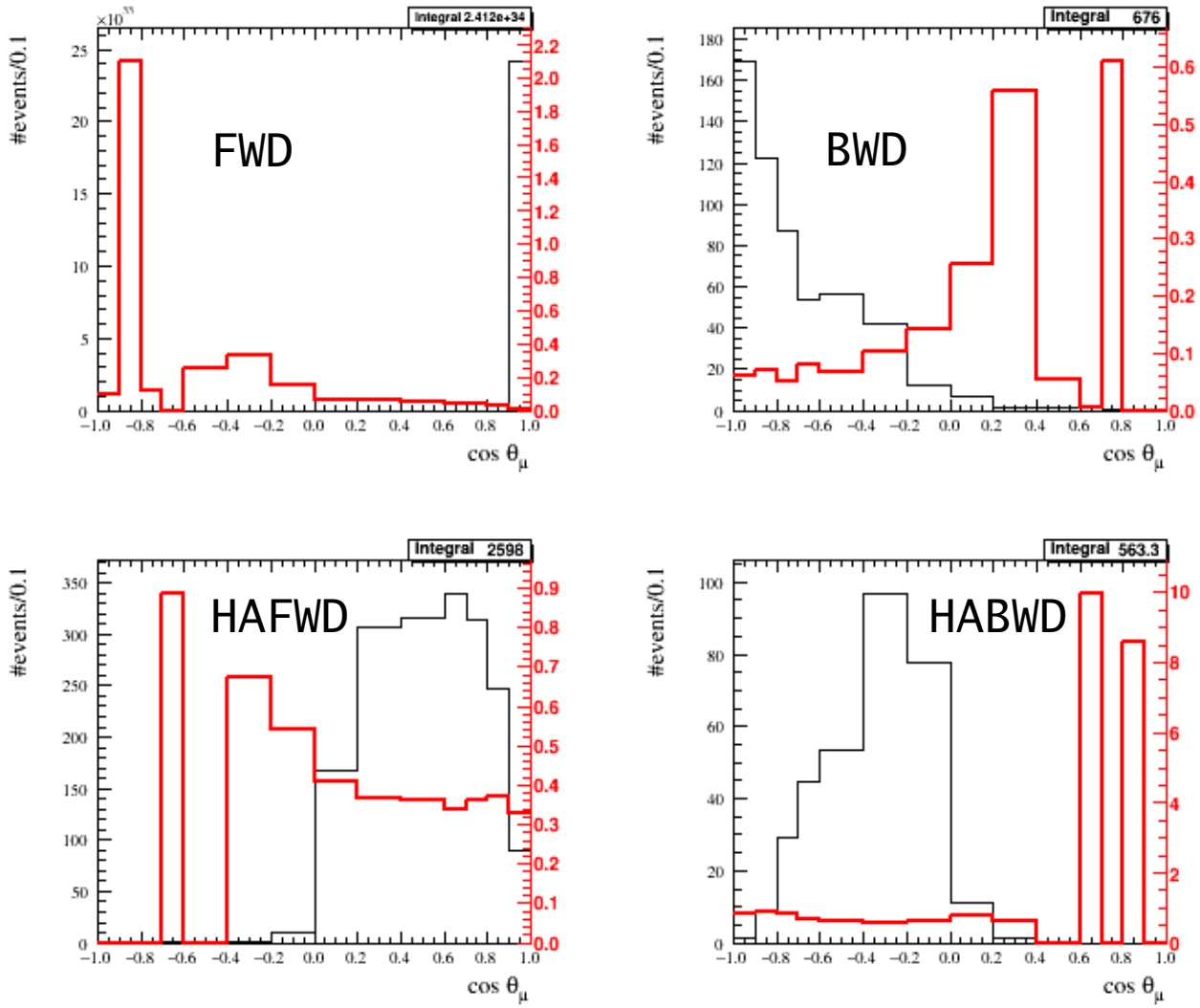
```
1
 0000  0100 14 1
 0100  0200 14 1
 0200  0300 14 1
 0300  0400 14 1
 0400  0500 14 1
 0500  0600 14 1
 0600  0700 14 1
 0700  0800 14 1
 0800  1000 14 1
 1000  1200 14 1
 1200  1500 14 1
 1500  2000 14 1
 2000  2500 14 1
 2500  3000 14 1
 3000  3500 14 1
 3500  4000 14 1
 4000  5000 14 1
 5000  7000 14 1
 7000 10000 14 1
10000 30000 14 1
```

Binning (20 bins) used for the flux

Detector: Systematics

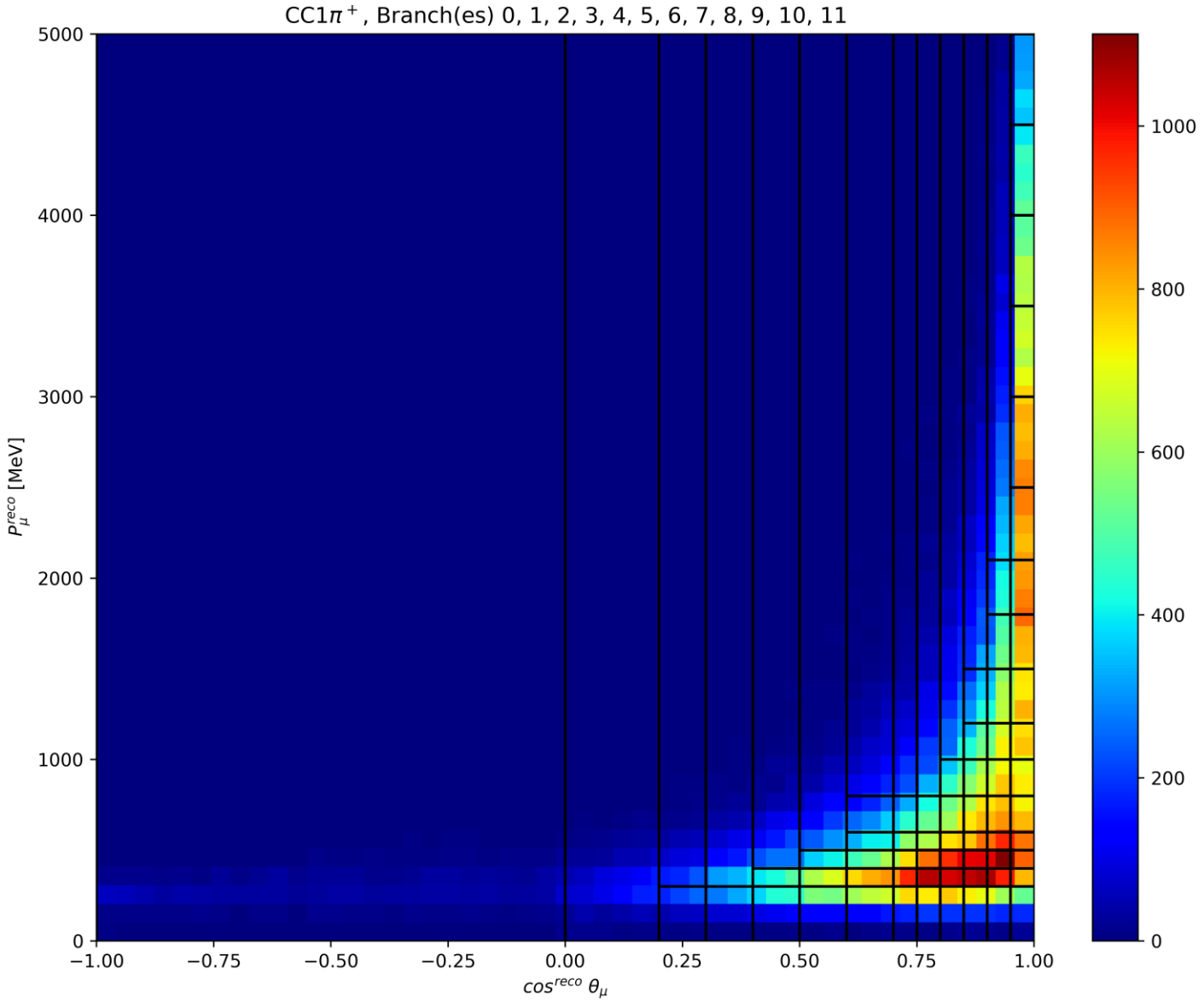
Weights	Weights	Variations
ChargeIDEff	TpcP0dMatchEff	BFieldDist
TpcClusterEff	FgdECalMatchEff	MomScale
TpcTrackEff	FgdECalSMRDMatchEff	MomResol
TpcFgdMatchEff	ECalTrackEff	MomRangeResol
FgdTrackEff	ECalPID	TpcPid
MichelEleEff	ECalPiZeroVetoPileUp	FgdPid
PileUp	P0DVeto	ECalEMResol
FgdMass	SIPion	ECalEMScale
OOFV	SIProton	ToFResol
SandMu	FluxWeight	
TpcECalMatchEff		

- ✓ 30 systematics
- ✓ 300 toys
- ✓ Memory problem when running systematics study:
  - all_syst configuration with more than 300 toys,
  - single systematics configuration with more than 10 toys.



Muon cosine of theta distribution for CC1π^+ (black line) and the relative error in % (red line)

Detector: Signal, Sample and Binning

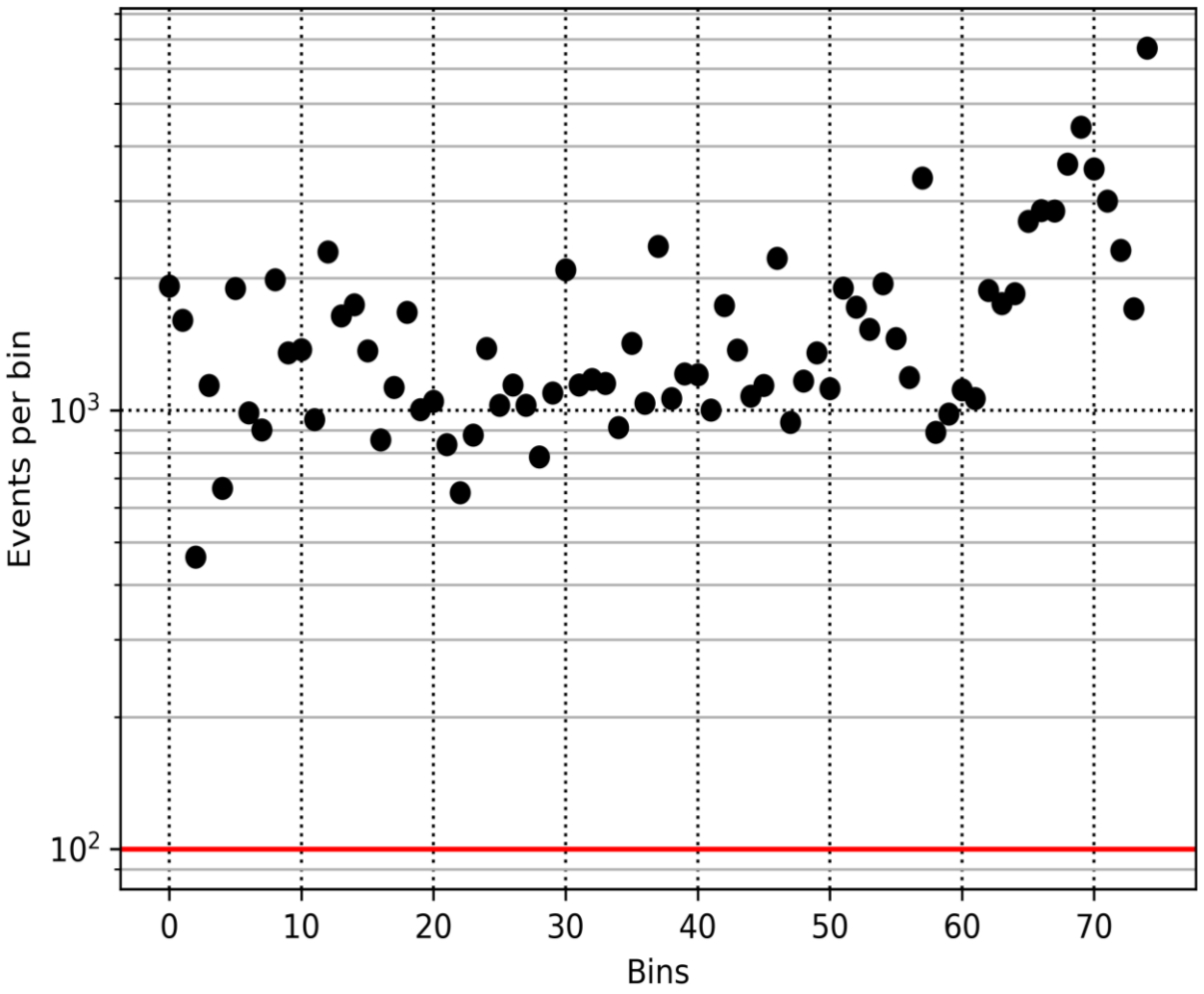


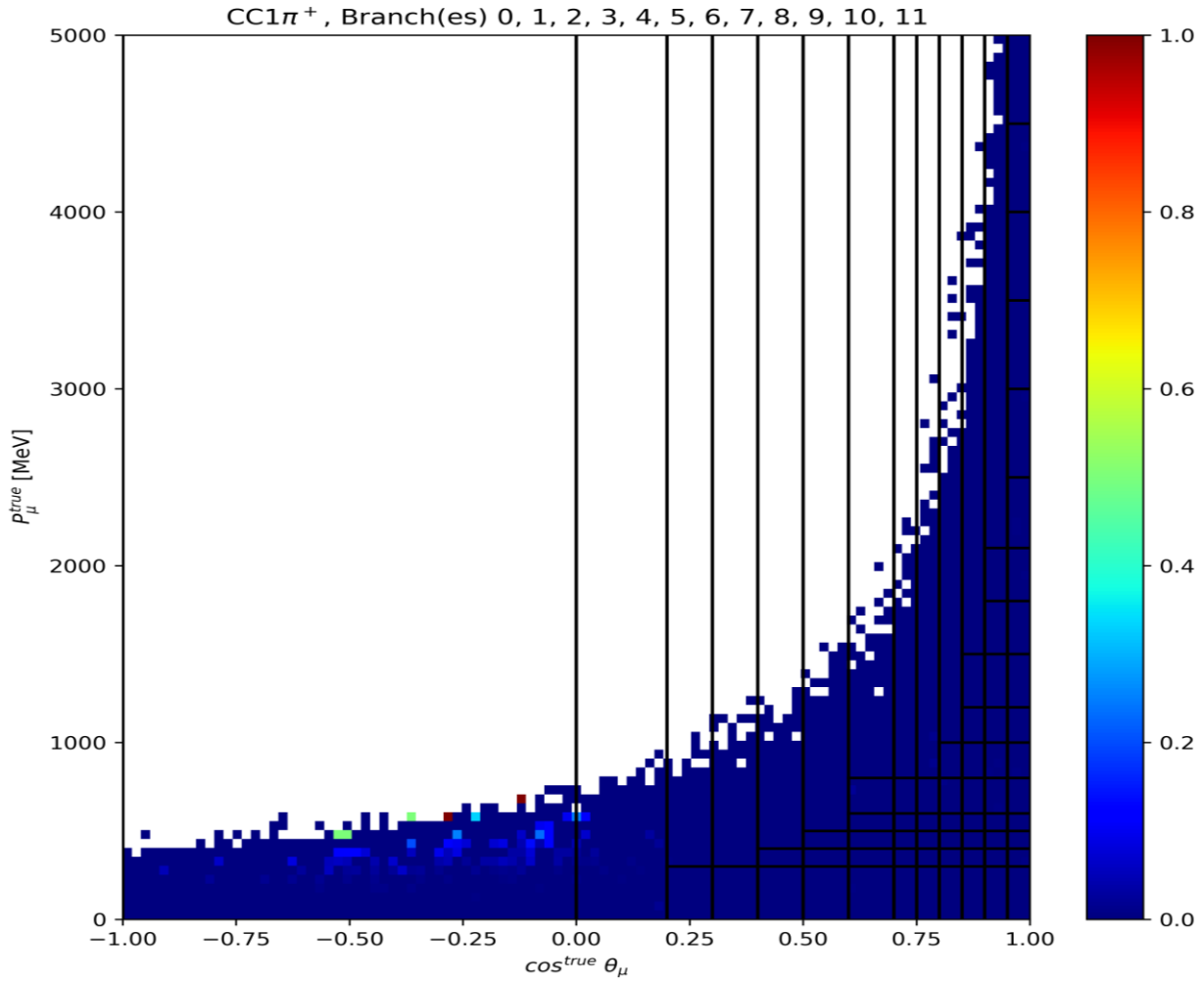
- ✓ **Signal: CC1π^+**
- ✓ 3 Samples: CC1π^+ (4π), CCother (4π) and CC0π (4π)

Binning (75 bins) to be used for the 4π samples.

- ✓ Number of events per bin around 100 or higher,
- ✓ No bins without signal events,
- ✓ The bin width must be greater than the resolution,
- ✓ The efficiency should be flat within the bin

Detector: Signal, Sample and Binning

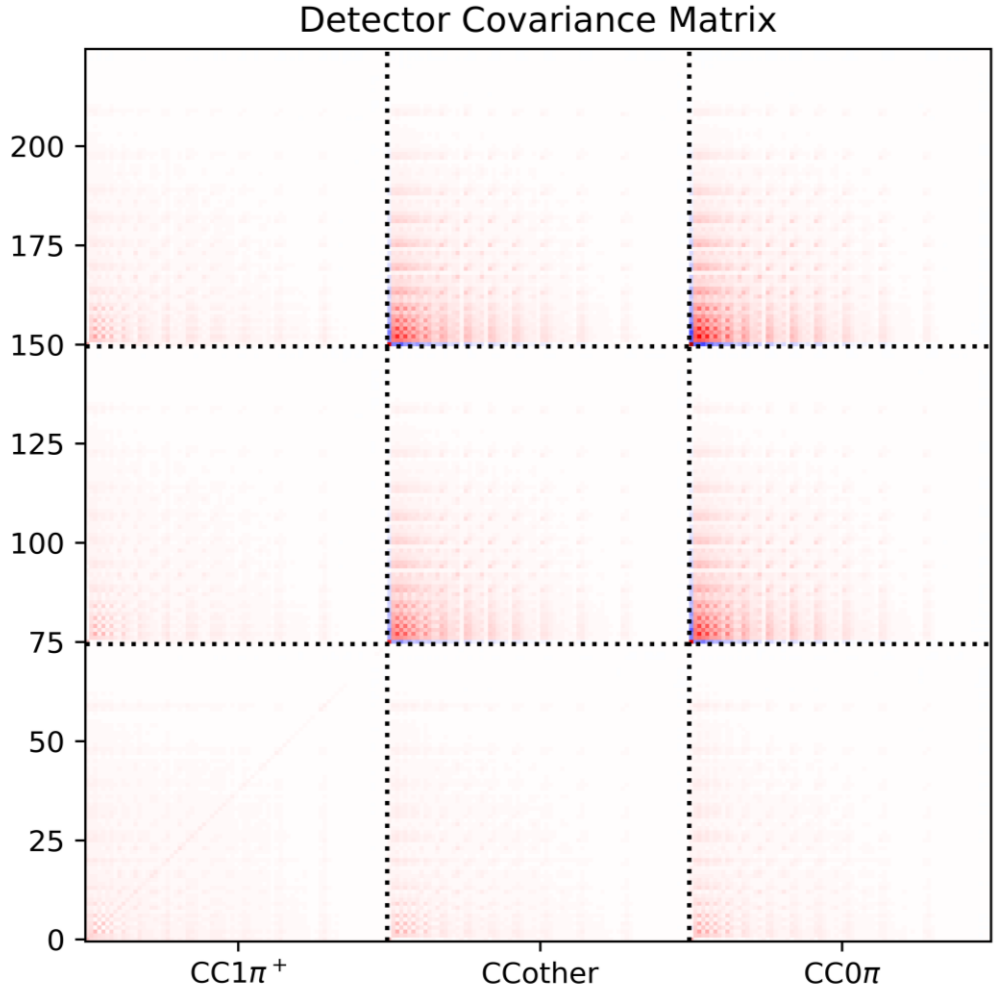


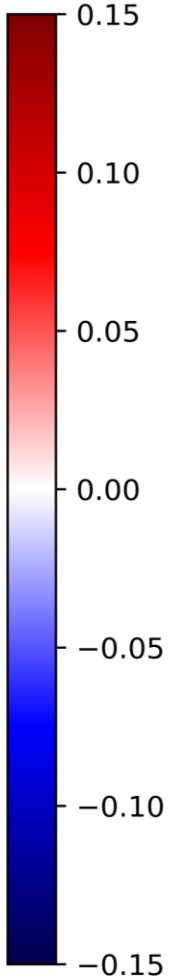


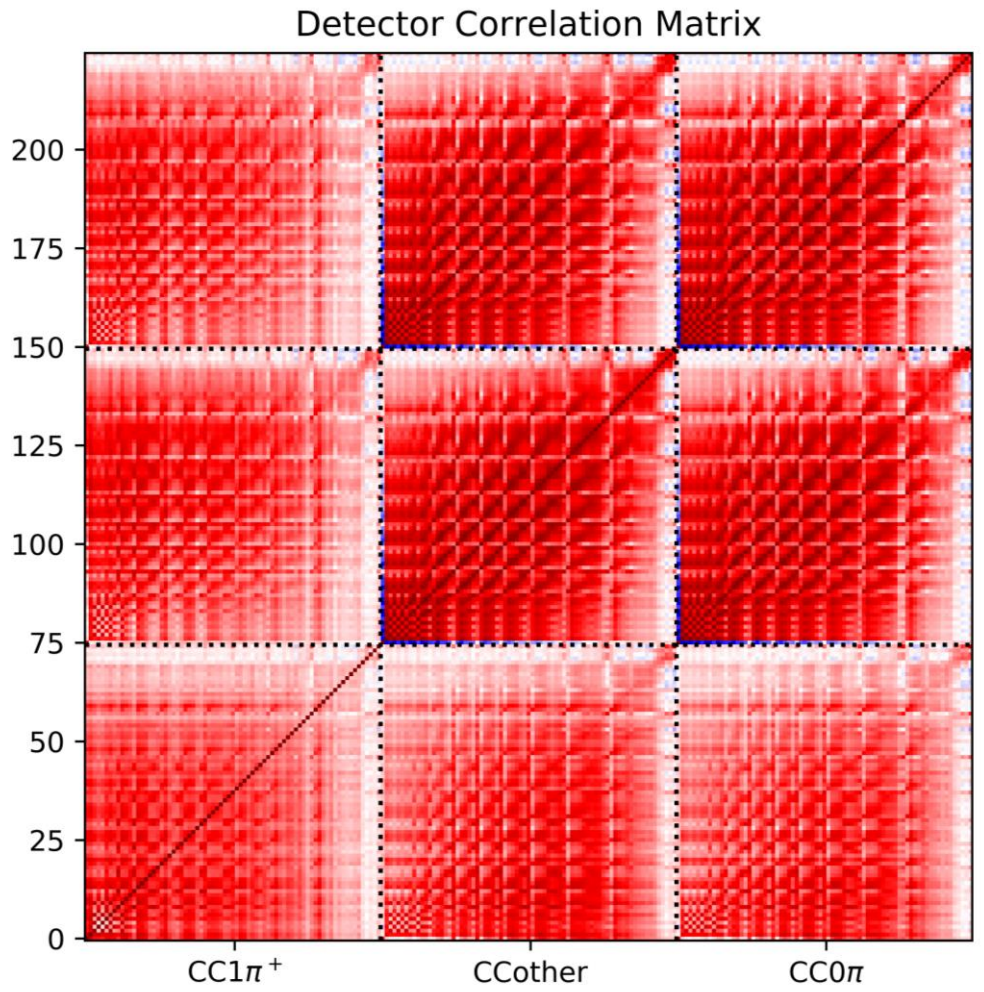
✓ Number of signal events per bin.

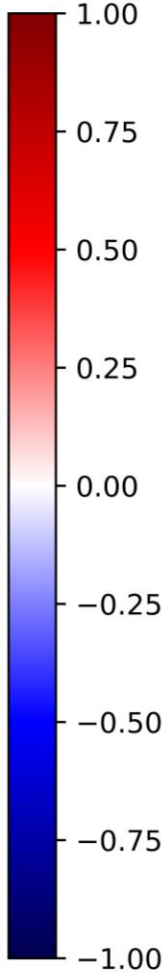
✓ 2D efficiency for signal events within the 3 samples

Detector Covariance and Correlation Matrix

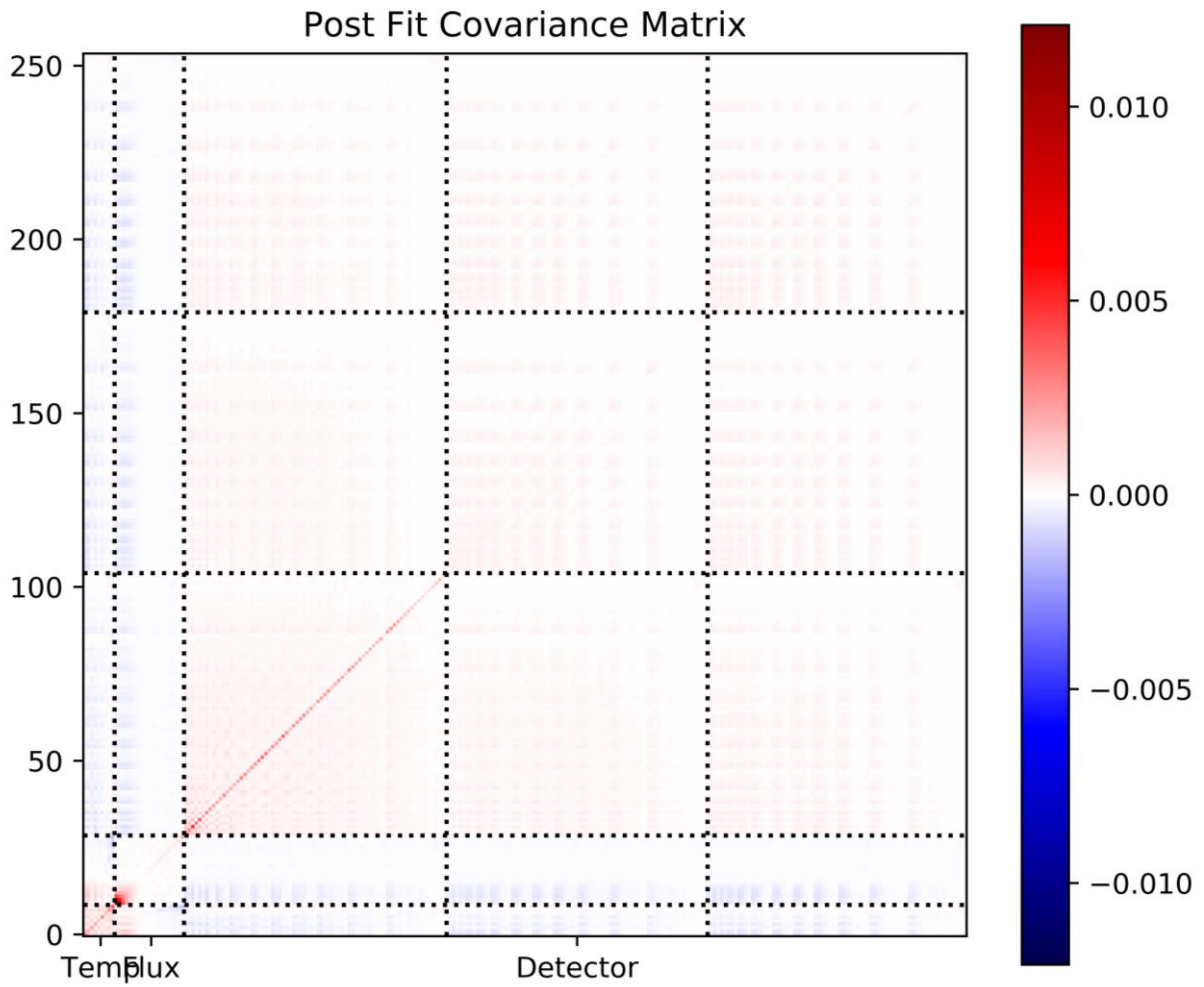


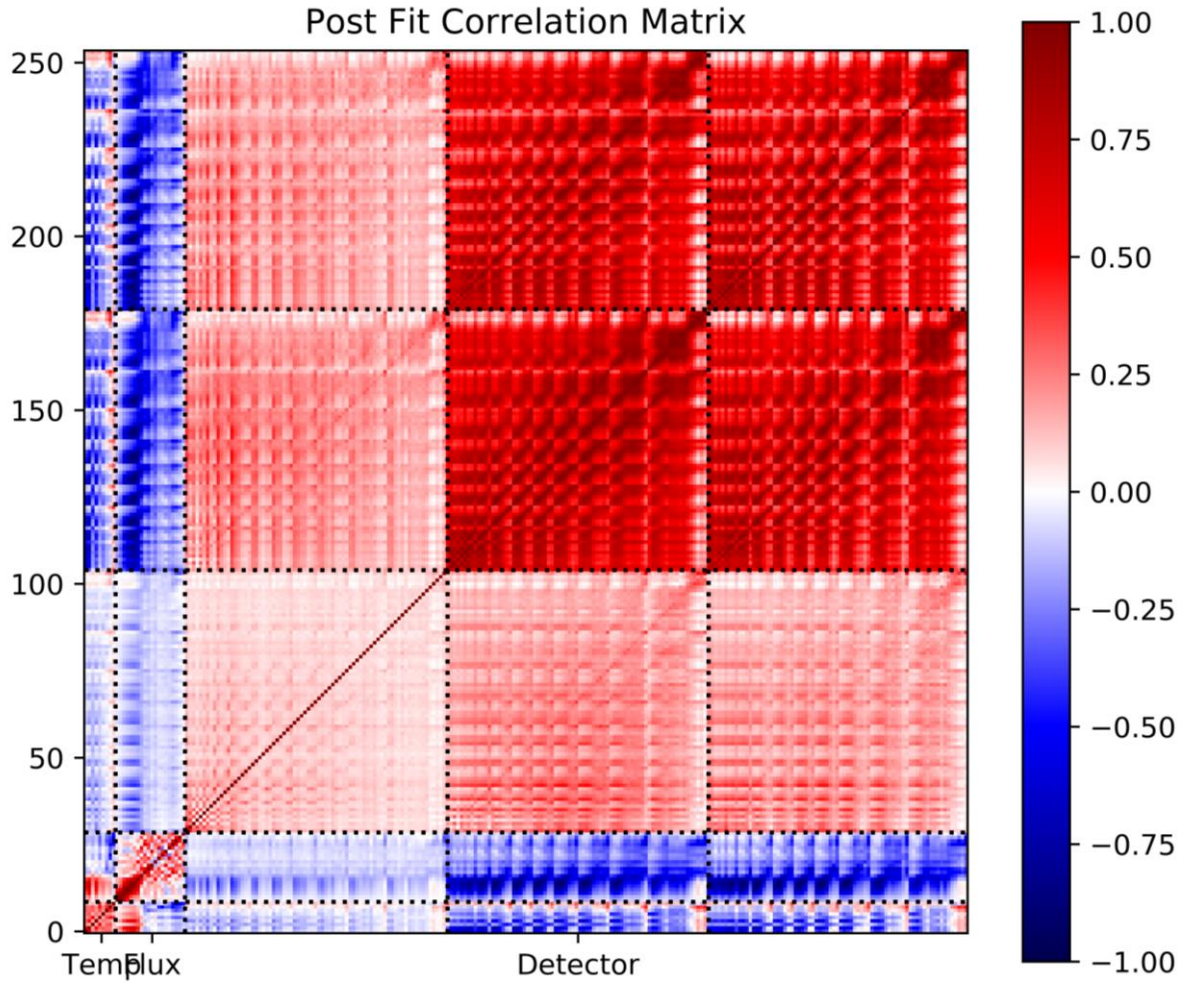






Post Fit Covariance and Correlation Matrix





Summary

- ✓ The values of the ToF correction that we apply have a great impact on the efficiency of the selection.
- ✓ Huge contribution (~41%) of OOFV events in the BWD direction coming from P0D ECal.
- ✓ Common vertex cut removes a lot of OOFV. Can this cut be improved for the BWD direction?
- ✓ The contamination in the CC1π^+ sample comes from CCother and CC0π.

The CCother events are composed of CC($N > 1$)π^+, CC $1\pi^+$ $1\pi^-$ and CC $1\pi^+$ $1\pi^0$

The CC0π events are composed of CC0π1p and CC0π(N≠1)p

- ✓ The main impurity in the pion sample comes from protons and is mostly in FGD and ECal.
- ✓ Adler's angles and the asymmetry studies.
- ✓ Optimizing the binning for the samples.
- ✓ T2KReWeight.
- ✓ Memory problem when running systematics study:
  - all_syst configuration with more than 300 toys,
  - single systematics configuration with more than 10 toys.

Thank You

Danaisis Vargas Oliva

dvargas@ifae.es