CC-MultiPi Selection in FGD1 for 4π acceptance

Neutrino group meeting

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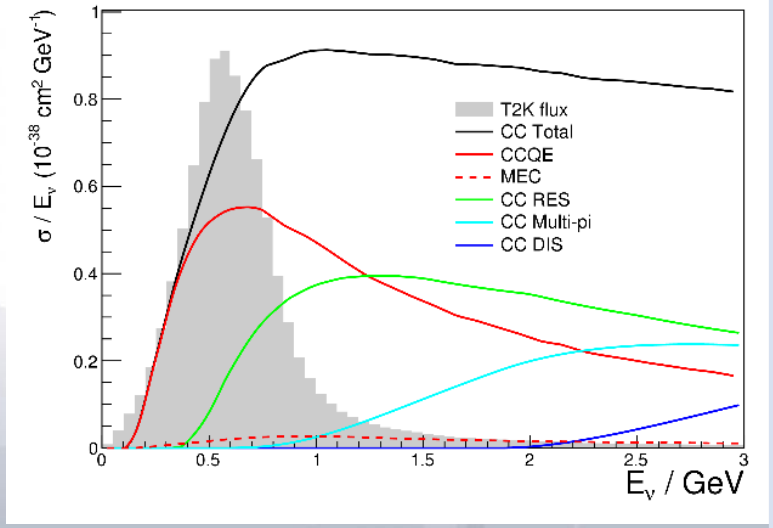
March 14, 2019

Overview

Introduction

Motivation



Why are cross sections important

- To reduce the cross-section uncertainties on the event rate at Super-K.
- To control the bias on the reconstructed energy.

Oscillation analysis requires neutrino energy spectrum, reconstructed using observed lepton kinematics, assuming stationary target

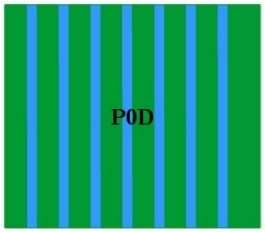
Why CC1π^+ Interactions

We can reduced the bias on the reconstructed lepton kinematics variables, and neutrino flux.

Motivation

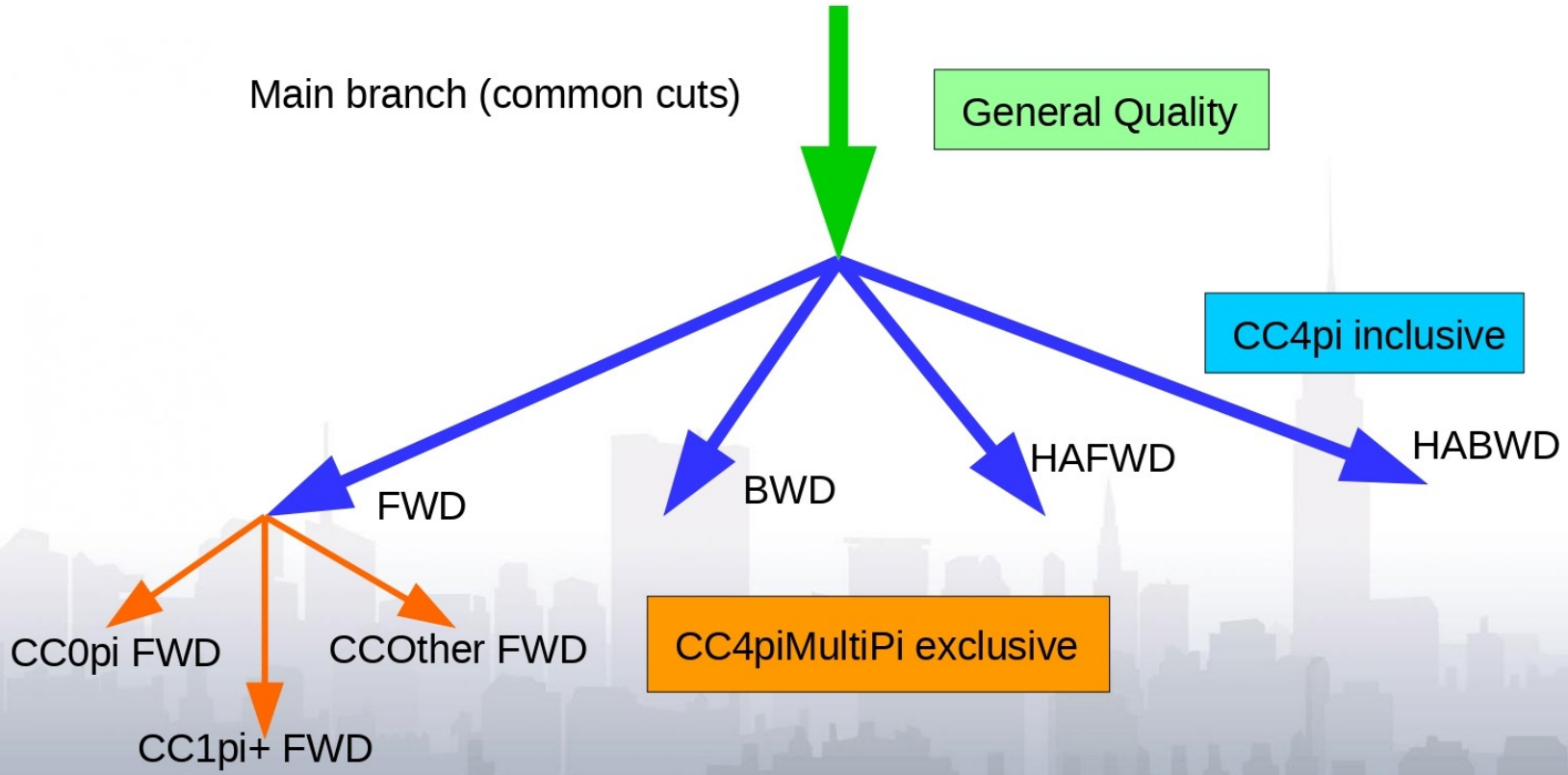
Why CC4piMultiPi Selection

In CC4piMultiPi, the main analysis aims to select μ and π coming out from ν_μ interactions in FGD1 and with segments in TPC2 and TPC1.



NumuCC4piMultiPi selection

NumuCC4piMultiPi selection cuts



0 CC0pi FWD	3 CC0pi BWD	6 CC0pi HAFWD	9 CC0pi HABWD
1 CC1pi+ FWD	4 CC1pi+ BWD	7 CC1pi+ HAFWD	10 CC1pi+ HABWD
2 CCOther FWD	5 CCOther BWD	8 CCOther HAFWD	11 CCOther HABWD

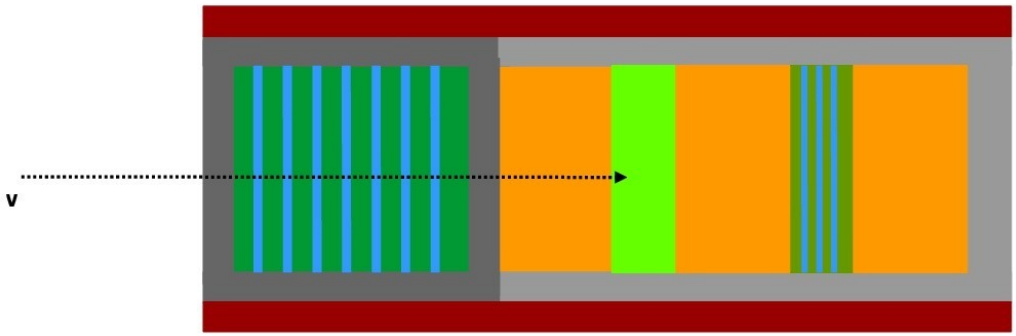
NumuCC4piMultiPi selection cuts

General Quality

1. Event Quality Data,
2. Total Multiplicity,
3. Quality and Fiducial,

CC4pi inclusive
(for FWD, BWD, HAFWD and HABWD)

4. Quality,
5. Veto,
6. PID,
7. 4pi,



CC4piMultiPi exclusive
CC0π (for FWD, BWD, HAFWD and HABWD)

8. CC-0π,
9. ECal π^0 Veto.

CC4piMultiPi exclusive
CC-1π^+ (for FWD, BWD, HAFWD and HABWD)

8. CC-1π^+,
9. ECal π^0 Veto.

CC4piMultiPi exclusive
CC-Other (for FWD, BWD, HAFWD and HABWD)

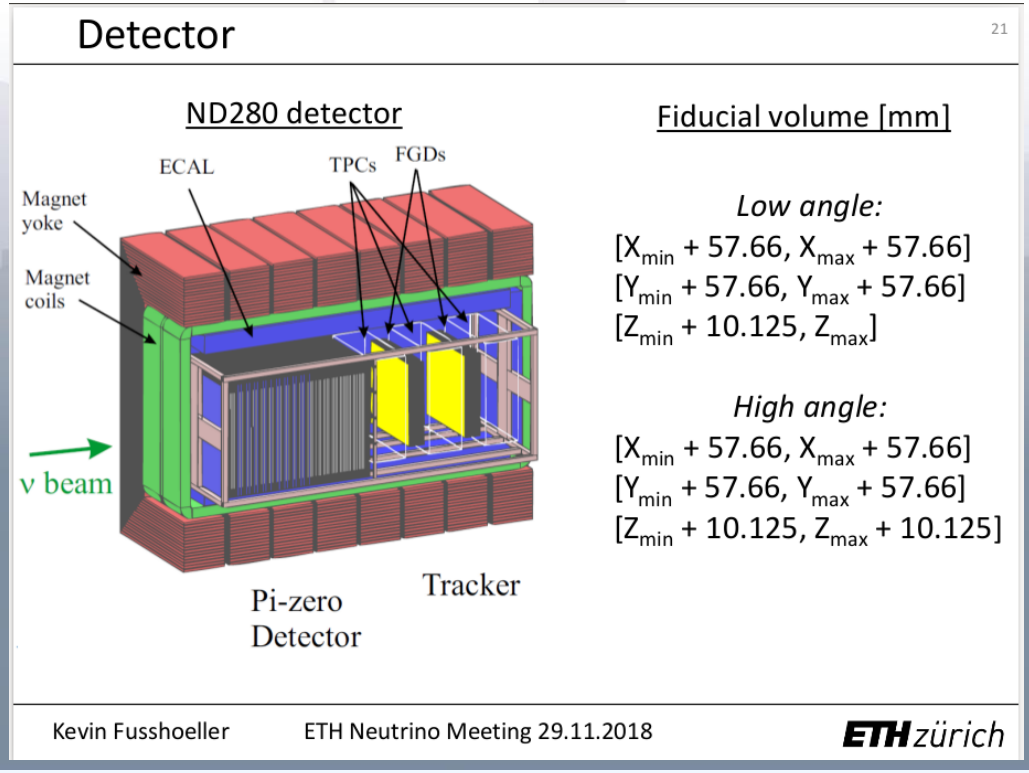
8. CC-Other.

NumuCC4piMultiPi selection cuts: General Quality

1. **Quality cut (Beam and DAQ quality cut):**
   - If Monte Carlo, this cut is ignored,
   - Checks ND280 Good DAQ flag and cuts if negative,
   - Cuts all events which come from a bad spill.

2. **Total multiplicity cut:**
   - Cuts events with strictly less than 1 track.

3. **Track good quality and fiducial volume cut:**
   - Cuts all events which do not have at least one "good quality" track.



NumuCC4piMultiPi selection cuts: General Quality

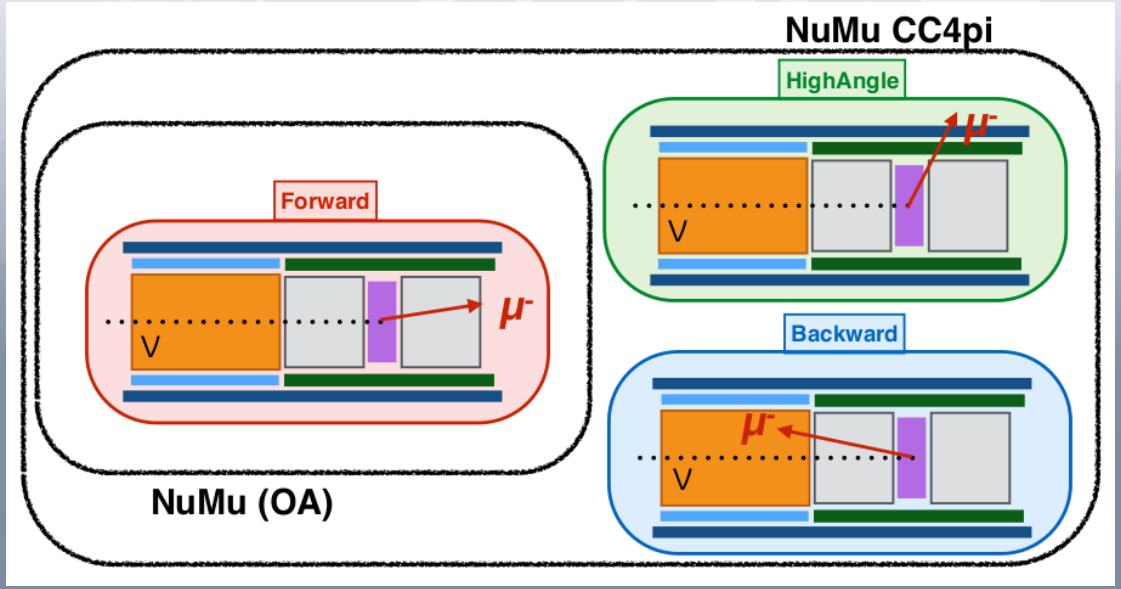
Particle identification

- **Low angle track:**
  - track started in FGD1 fiducial volume (first layer excluded),
  - track with $>$ 18 clusters in the TPC,
  - track with charge $= -1$,
  - sort by momentum (based on curvature).
- **High angle track:**
  - track started in FGD1 fiducial volume (first and last layers excluded),
  - track with < 18 clusters in TPC,
  - Activity in the ECal,
  - track which stops in the Side Muon Range Detector or in the BarrelECal FV (needed to compute the momentum of tracks)
  - Sort by momentum range (based on track length and energy loss within a certain volume)

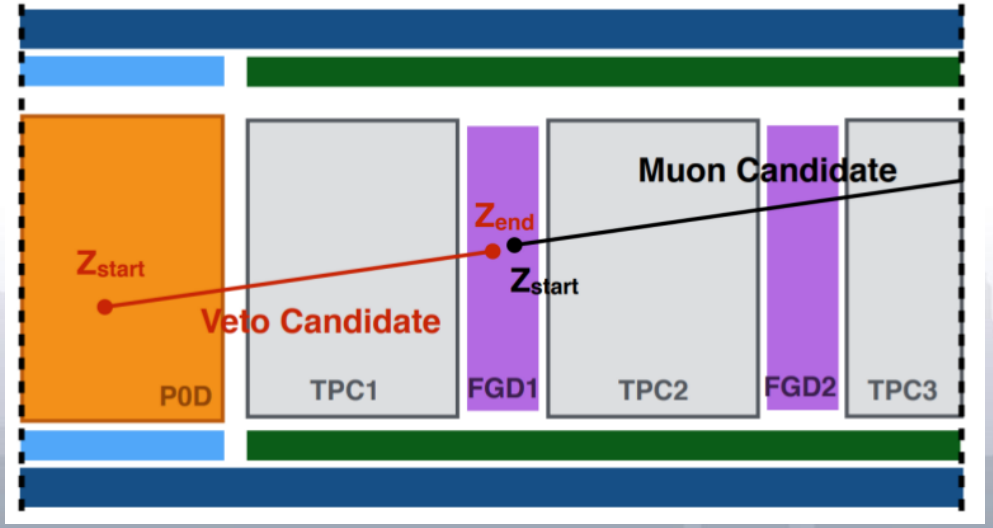
NumuCC4piMultiPi selection cuts: CC4pi inclusive

Comment:

The tracks are tested in order (highest momentum first) until one track passes all cuts. This is to avoid more than one muon candidate.



NumuCC4piMultiPi selection cuts: CC4pi inclusive



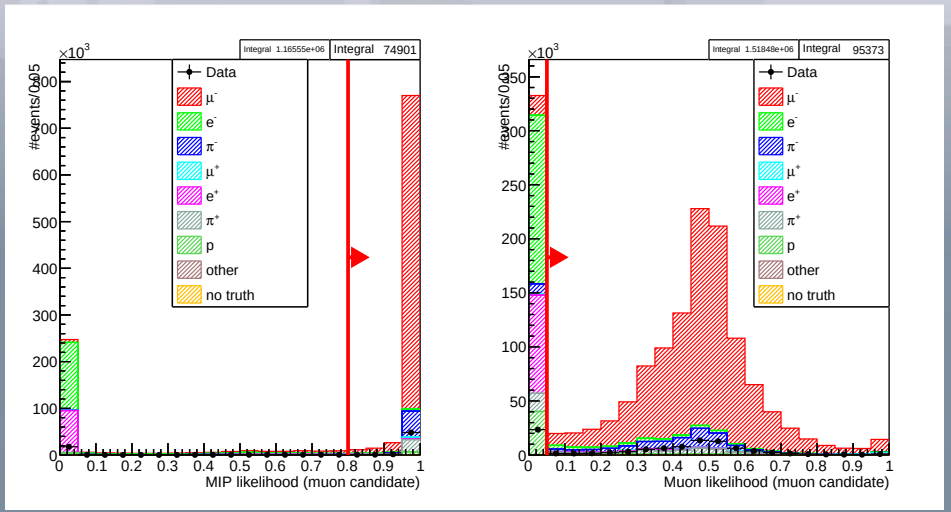
4. **(FWD, BWD and HA) Quality:**
   - $\geq$ 1 forward track,

5. **(FWD, BWD and HA) Veto:**
   - reject events in which the μ^- candidate comes from out FV,
   - reject events in which track is broken in two,

NumuCC4piMultiPi selection cuts: CC4pi inclusive

6. **FWD μ^- PID:**
   - $(L_\mu + L_\pi)/(1 - L_p) > 0.8$ for $P < 500 MeV$,
   - $L_\mu > 0.05$,
   - If $P > 280 MeV$: should not stop in FGD2,
   - If *PIDMipEm* > 15, then the muon candidate should not stop in the barrel ECal and only in certain regions of the Downstream ECal.

6. **BWD μ^- PID:**
   - $L_\mu > 0.05$,



NumuCC4piMultiPi selection cuts: CC4pi inclusive

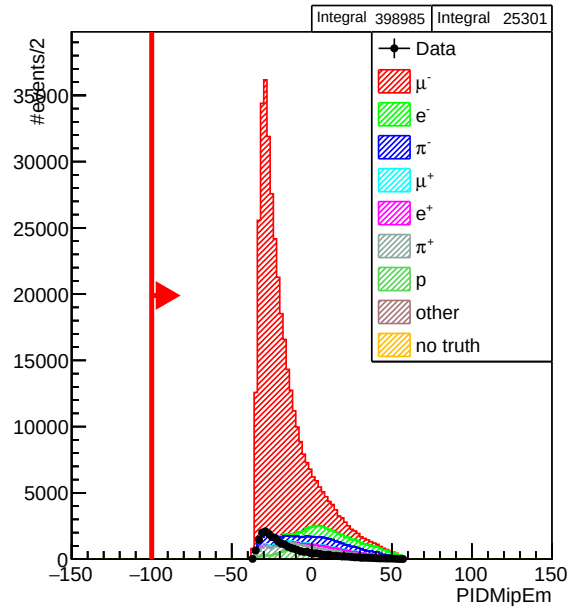
6. **HA μ^- PID:**
   - Enter the SRMD,

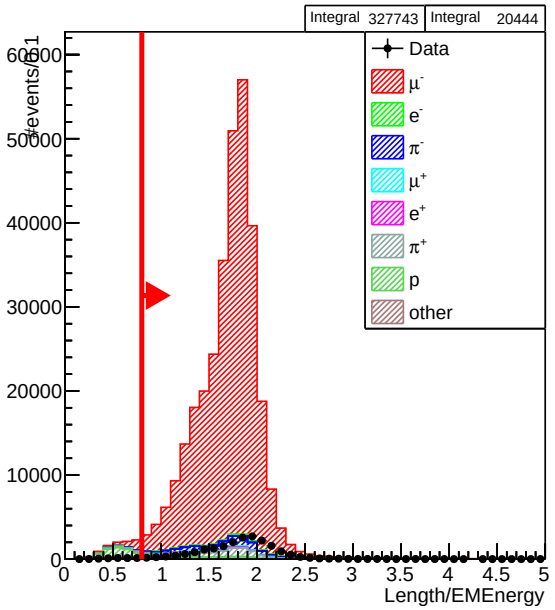
   Or:
   - In ECal: $PIDMipEm > -100$ and $Length > 0$ and $EMEnergy > 0$,
   - In ECal: $PIDMipEm < 0$ and $Length/EMEnergy > 0.8$,
7. **(FWD, BWD and HA) 4pi:**
   - verify that we don't have more than $1\mu^-$ candidate.

Sample/cut	Fwd	Bwd	HAFwd	HABwd
Position	Start in FGD1(2)	Stop in FGD1(2)	Start in FGD1(2) - Stop in ECAL/ SMRD	Stop in FGD1(2) - Start in ECAL/ SMRD
Track Quality	> 18 TPC Hits	> 18 TPC Hits	< 18 TPC Hits	< 18 TPC Hits

Fig from Ciro Riccio's Slides

NumuCC4piMultiPi selection cuts:
CC4pi inclusive

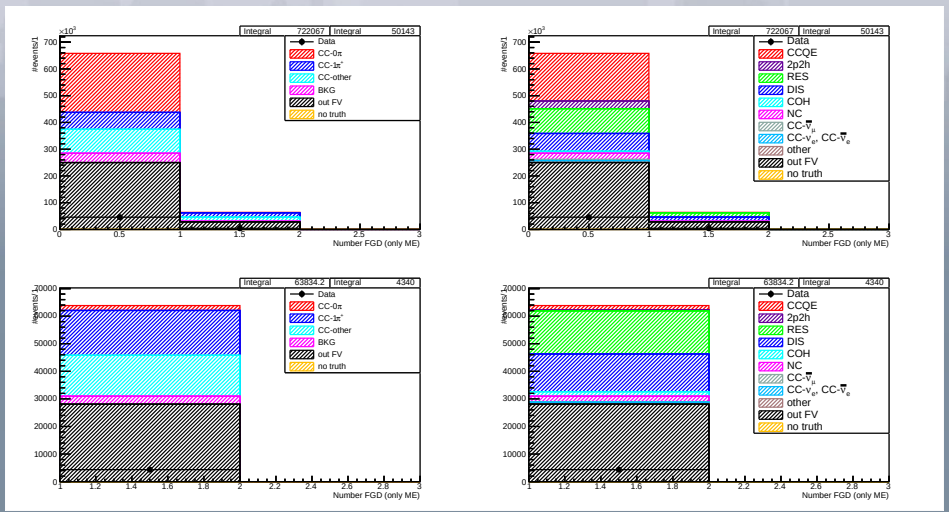




NumuCC4piMultiPi selection cuts: **CC4pi inclusive**

Michel electrons are tagged using the time delay:

- Check that there is a vertex with a delay of at least 100 ns.
- There should be at least be 6 hits in the same time bin as the delayed vertex.
- Number of ME in FGD by topology (left) and reaction (right).



NumuCC4piMultiPi selection cuts: CC4piMultiPi exclusive

CC0π (for FWD, BWD, HAFWD and HABWD):

8. **CC0π:**
   Reject events with:
   - $\pi^{\pm}$ in TPCs,
   - $e^{\pm}$ in TPCs,
   - ME FGD,
   - π FGD,
9. **ECal π^0 Veto.**

CC-1π^+ (for FWD, BWD, HAFWD and HABWD):

8. **CC-1π^+:**
   Reject events with:
   - π^- in TPCs,
   - $e^{\pm}$ in TPCs,

   Select events with either:
   - $(\pi^+ + ME)$ in TPCs $= 1$,
   - ME$= 0$ and $\pi^+(inTPC + inFGD) = 1$,
9. **ECal π^0 Veto.**

CC-Other (for FWD, BWD, HAFWD and HABWD):

8. **CC-Other:**
   Select events with either:
   - $\geq 1e^{\pm}$ in TPCs,
   - $\geq \pi^-$ in TPCs,
   - $> 1(\pi^+ + ME)$ in TPCs.

NumuCC4piMultiPi selection cuts: CC4piMultiPi exclusive

The FGD Pion cut selects pions which are contained in the FGD and thus leave no information in the TPC. The cut is applied after the CC inclusive cuts and is explained in detail in TN152.
Charateristics of the cut:

- Track should be in the same time bunch as the muon.
- Track should have no TPC information.
- Track needs to start and stop in FGD1.
- $-0.3 <$ cosine of track < 0.3
- $-2.0 <$ Pull pion < 2.5

NumuCC4piMultiPi selection cuts: CC4piMultiPi exclusive

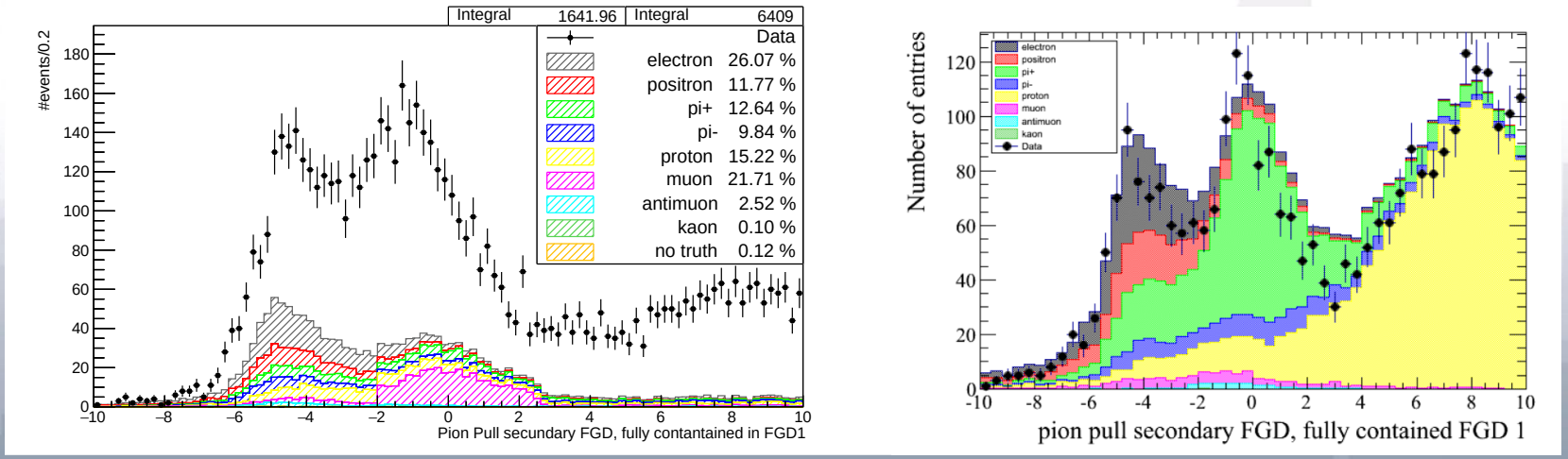
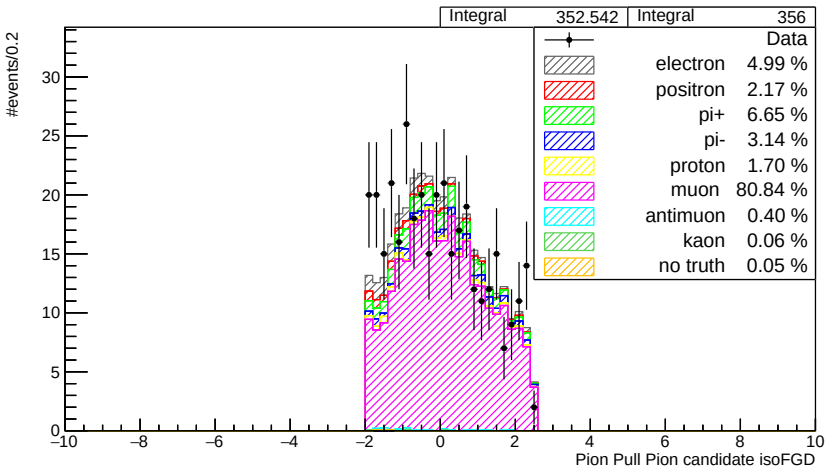


Figure 1: Pion pull for FGD (left) my selection and (right) TN152.

NumuCC4piMultiPi selection cuts: **CC4piMultiPi exclusive**



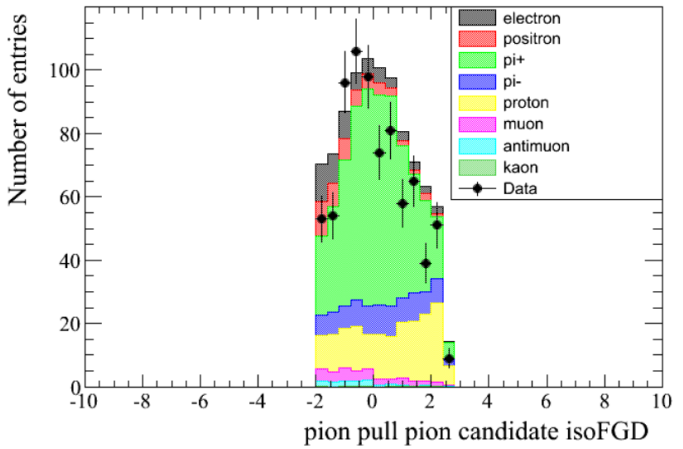


Figure 2: Pion pull for isoFGD pion candidates (left) my selection and (right) TN152.

NumuCC4piMultiPi selection variables

```
//--- info from true vertex
truelepton_PDG,
truelepton_mom,
truelepton_dir,
truelepton_costheta,
truelepton_theta,
truelepton_pos,
truelepton_fgdlayer,
//--- toy variables
NLowAngle,
NHighAngle,
NFwdMuLike,
NBwdMuLike,
NHAFwdMuLike,
NHABwdMuLike,
Toy_CC4pi,
selmu_HMNT,
selmu_mom,
selmu_costheta,
selmu_theta,
selmu_ToF_PoD,
selmu_ToF_ECAL,
selmu_ToF_FGD2,
selmu_likemu,
selmu_likemip,
selmu_end_ecal,
//--- info from true track
selmu_PDG,
selmu_ID,
selmu_truemom,
selmu_truepos,
selmu_trueendpos,
selmu_truedir,
selmu_truefgdlayer,
```

```
selmu_charge,
selmu_dir,
selmu_enddir,
selmu_pos,
selmu_endpos,
selmu_fgdlayer,
selmu_1hit_pos,
selmu_2hit_pos,
selmu_1hit_charge,
selmu_2hit_charge,
selmu_1hit_fitpos,
selmu_2hit_fitpos,
selmu_1hit_deltapos,
selmu_2hit_deltapos,
selmu_1hit_deltapos2,
selmu_2hit_deltapos2,
selmu_pod_nnodes,
//--- info by TPC
selmu_tpc_det,
selmu_tpc_nnodes,
selmu_tpc_charge,
//--- info by FGD
selmu_fgd_det,
selmu_fgd_nnodes,
selmu_fgd_x,
//--- info by ECAL
selmu_ecal_det,
selmu_ecal_nnodes,
selmu_ecal_length,
selmu_ecal_EMenergy,
selmu_ecal_mipem,
```

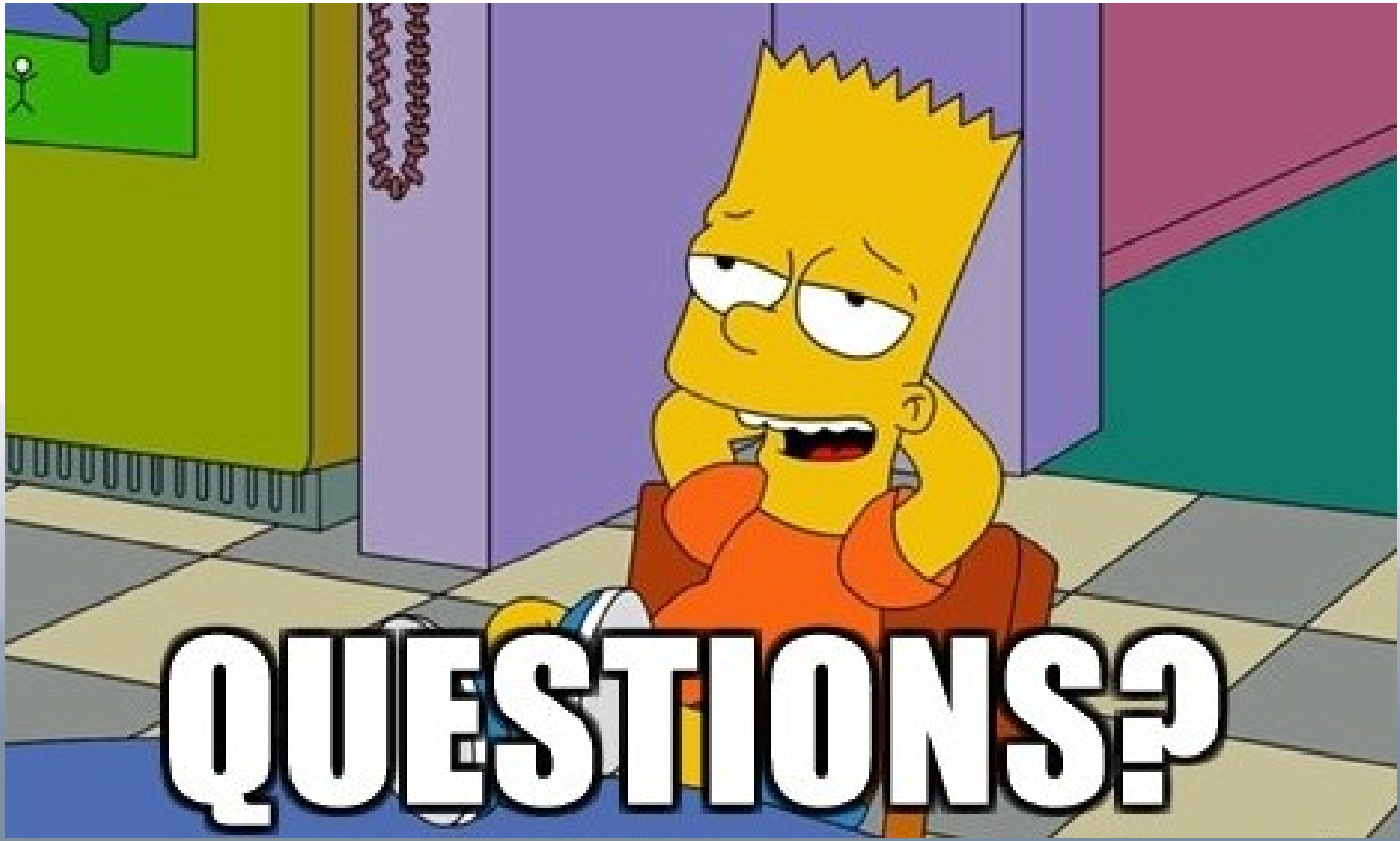
```
PosPionPidLik,
PosPionElPidLik,
PosPionTId,
PosPionIndex,
PosPionParentTId,
PosPionGParentTId,
PosPionTrueMom,
PosPionTrueStartDir,
PosPionVId,
PosPionDir,
PosPionTrueTheta,
PosPionTrueCosTheta,
PosPionPosStart,
PosPionPosEnd,
// --- Pi0 candidates
Pi0ElMom,
Pi0ElPull,
Pi0ElTId,
Pi0ElIndex,
Pi0ElParentTId,
Pi0ElGParentTId,
Pi0ElVId,
Pi0ElDir,
Pi0ElPosStart,
Pi0ElPosEnd,
Pi0PosMom,
Pi0PosPull,
Pi0PosTId,
Pi0PosIndex,
Pi0PosParentTId,
Pi0PosGParentTId,
Pi0PosVId,
Pi0PosDir,
Pi0PosPosStart,
Pi0PosPosEnd,
```

```
// --- ALL TPC sec tracks
TPCSecMom,
TPCSecMuPidLik,
TPCSecPiPidLik,
TPCSecPrPidLik,
TPCSecElPidLik,
TPCSecDetectors,
TPCSecQ,
TPCSecTId,
TPCSecIndex,
TPCSecParentTId,
TPCSecGParentTId,
TPCSecDir,
TPCSecPosStart,
TPCSecPosEnd,
// ---- IsoFGD Pion tracks
FGDPiLength,
FGDPiPiPull,
FGDPiAvgTime,
FGDPiDistance,
FGDPiMuonangle,
FGDPiCosTheta,
FGDPiTId,
FGDPiIndex,
FGDPiParentTId,
FGDPiGParentTId,
FGDPiVId,
FGDPiDir,
FGDPiPosStart,
FGDPiPosEnd,
FGDPiTimeIni,
FGDPiTimeEnd,
FGDPiDeltaTimeIniSelMu,
FGDPiDeltaTimeEndSelMu,
```

```
// ---- Michel Eletrons --
MENHits,
MERawCharge,
MEMinTime,
MEMaxTime,
// ---- TPC1 Tracks ----
TPC1TrackMom,
TPC1TrackCosTheta,
TPC1TrackPhi,
TPC1TrackVId,
TPC1TrackTId,
TPC1TrackParentTId,
TPC1TrackGParentTId,
TPC1TrackPosStart,
TPC1TrackPosEnd,
//---- Add new vareables -
ntruetracks,
ntruefstracks,
ntruechargedpions,
ntrueother,
ntrueotherpdg,

Truepi_mom,
Truepi_costheta,
Truepi_theta,
Truepi_dir,
Truepi_id,
Truepi_pdg,

Truemu_mom,
Truemu_pos,
Truemu_dir,
Truemu_costheta,
Truemu_theta,
Truemu_fgdlayer,
```


QUESTIONS?

NumuCC4piMultiPi selection
first tests

Software and samples

- nd280Highland2 v2r29
- Production 6B for MC
- Production 6M for Data

$$\nu_\mu + p \to \mu^- + \Delta^{++} \to \mu^- + \pi^+ + p,$$
$$\nu_\mu + n \to \mu^- + \Delta^{+} \to \mu^- + \pi^+ + n,$$
$$\searrow \mu^- + \pi^0 + p,$$

	POT (x10^{20}) Data
Run2a	0.35934
Run2w	0.43329
Run3b	0.21728
Run3c	1.36447
Run4a	1.78271
Run4w	1.64277

	POT (x10^{20}) NEUT magnet
Run2a	8.99907
Run2w	12.0341
Run3	30.8013
Run4a	34.9960
Run4w	22.6216

POT = Protons On Target

NumuCC4piMultiPi selection first tests: Events

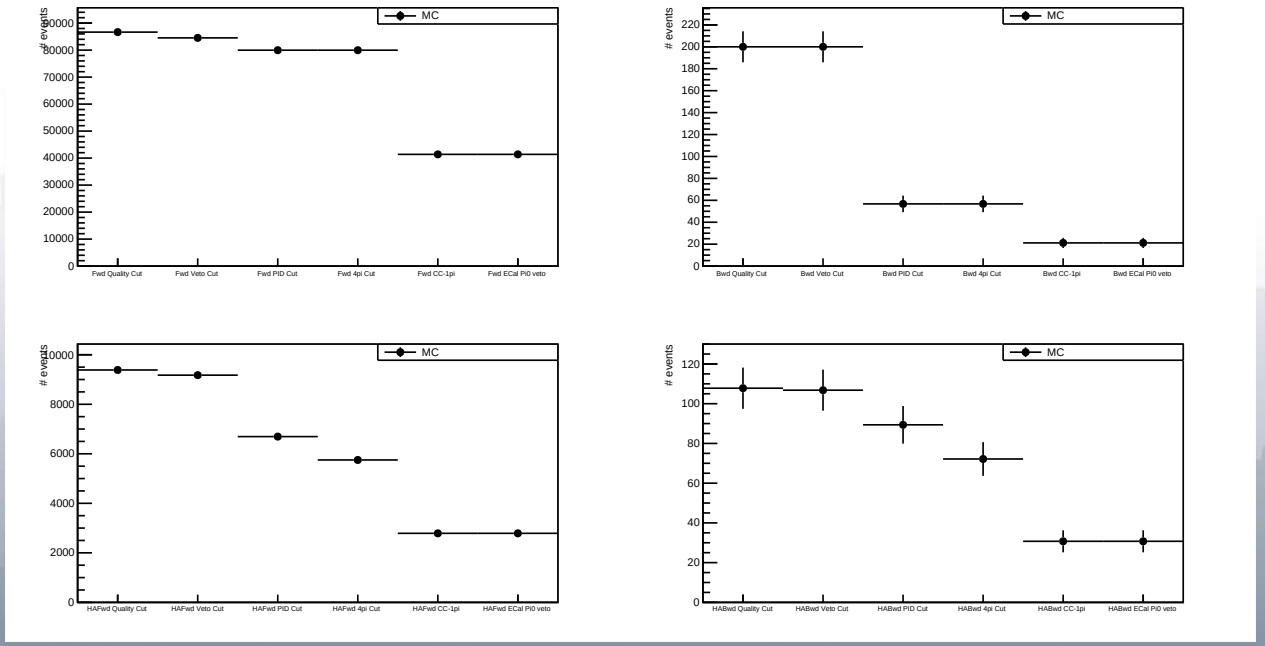


Figure 3: Events of the selection vs cuts (for FWD, BWD, HAFWD and HABWD).

NumuCC4piMultiPi selection first tests: Efficiency and Purity

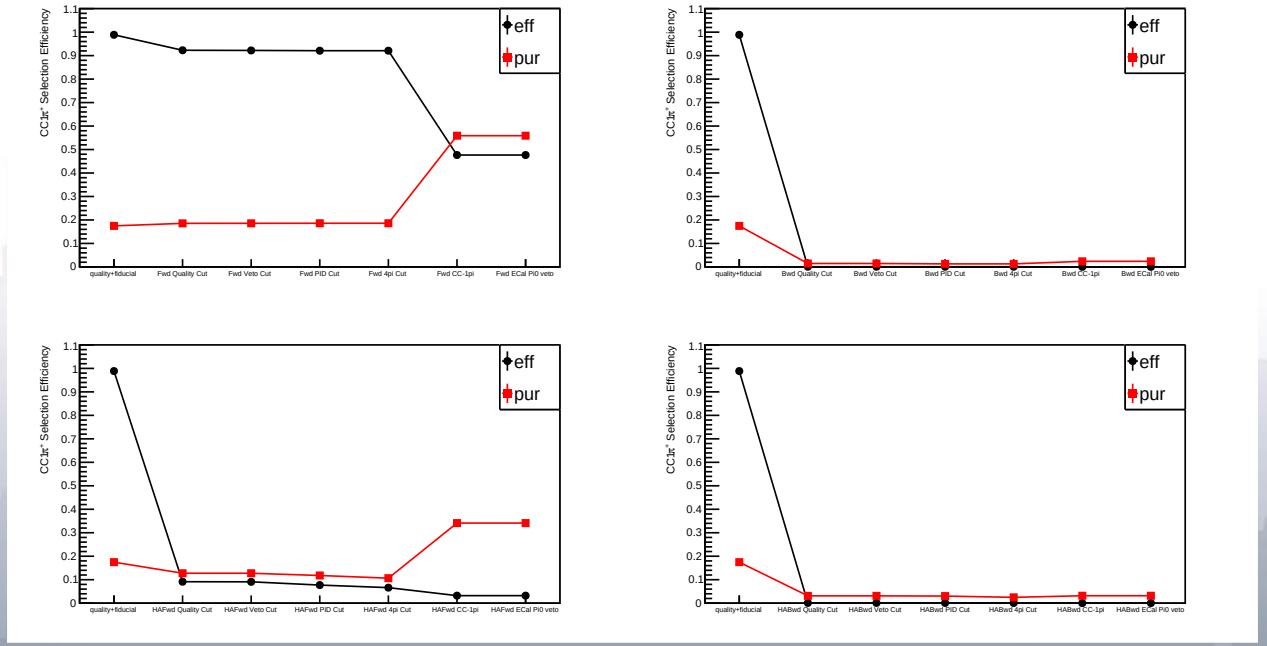


Figure 4: Efficiency and purity of the selection vs cuts (for FWD, BWD, HAFWD and HABWD).

- No difference between Fwd PID cut and Fwd 4PiMultiPi cut because always start looking for fwd muon.
- Ecal Pi0 veto is not activated (Sasha doing tests).

NumuCC4piMultiPi selection first tests: Efficiency and Purity

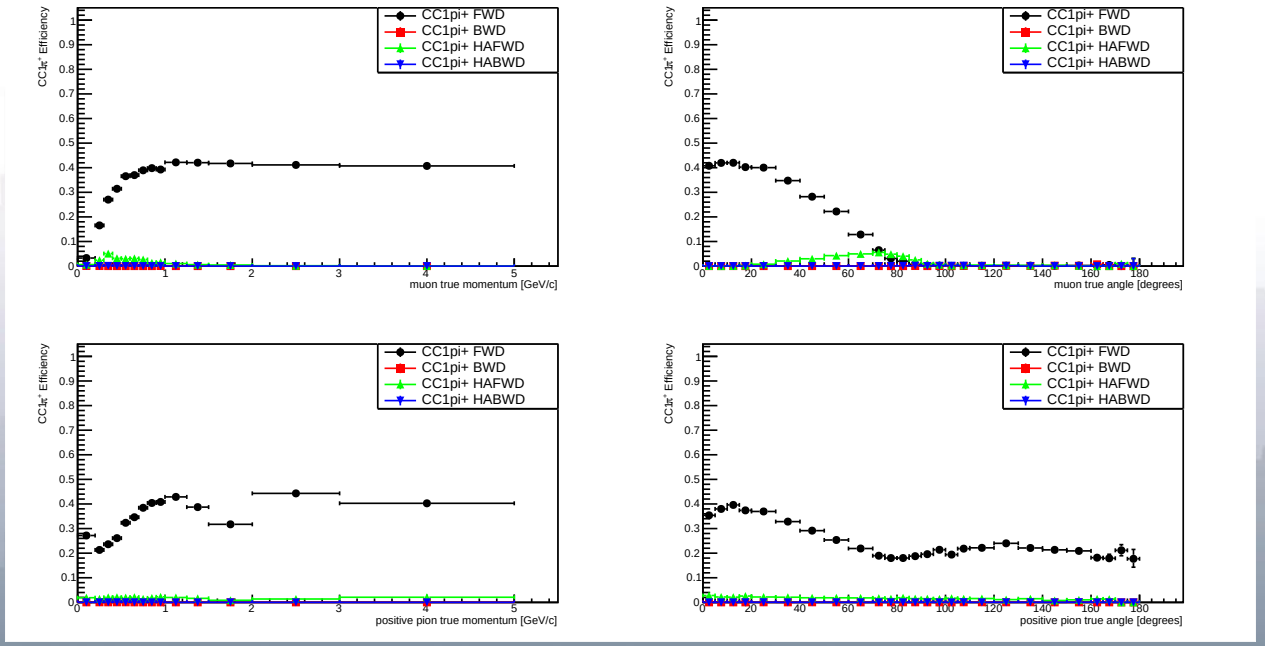


Figure 5: Efficiency of the selection vs cuts (for FWD, BWD, HAFWD and HABWD).

NumuCC4piMultiPi selection first tests: Efficiency and Purity

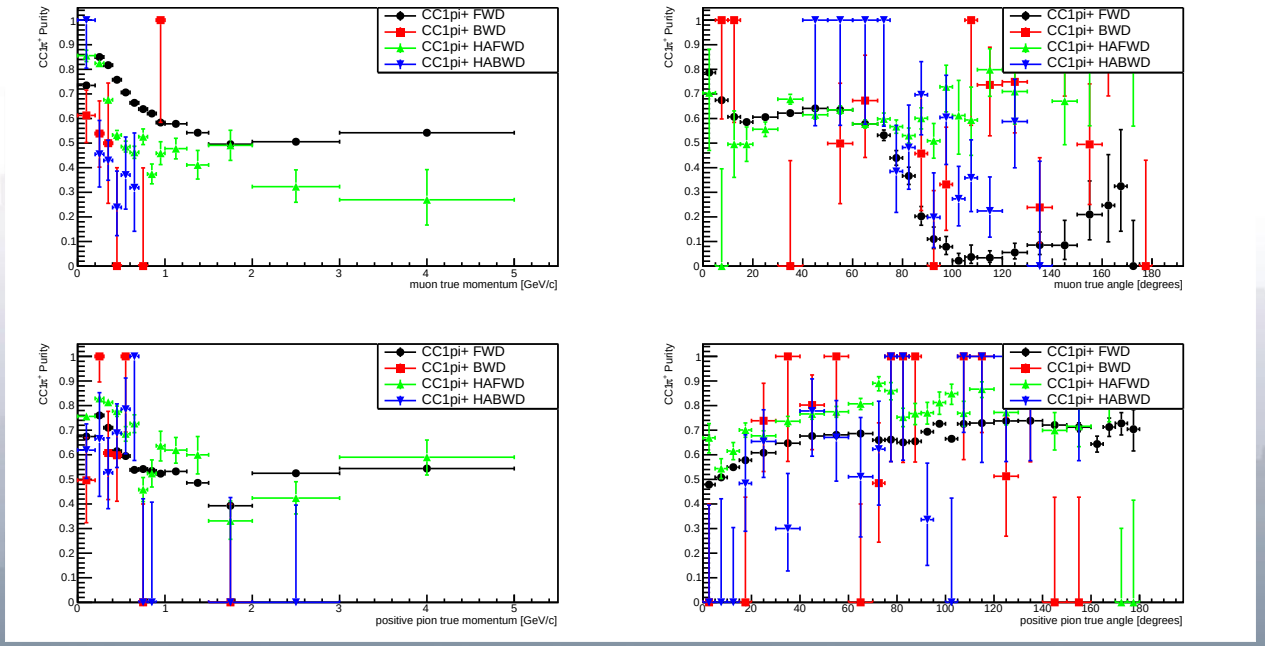


Figure 6: Purity of the selection vs cuts (for FWD, BWD, HAFWD and HABWD).

NumuCC4piMultiPi selection first tests: Kinematics: Muon variables

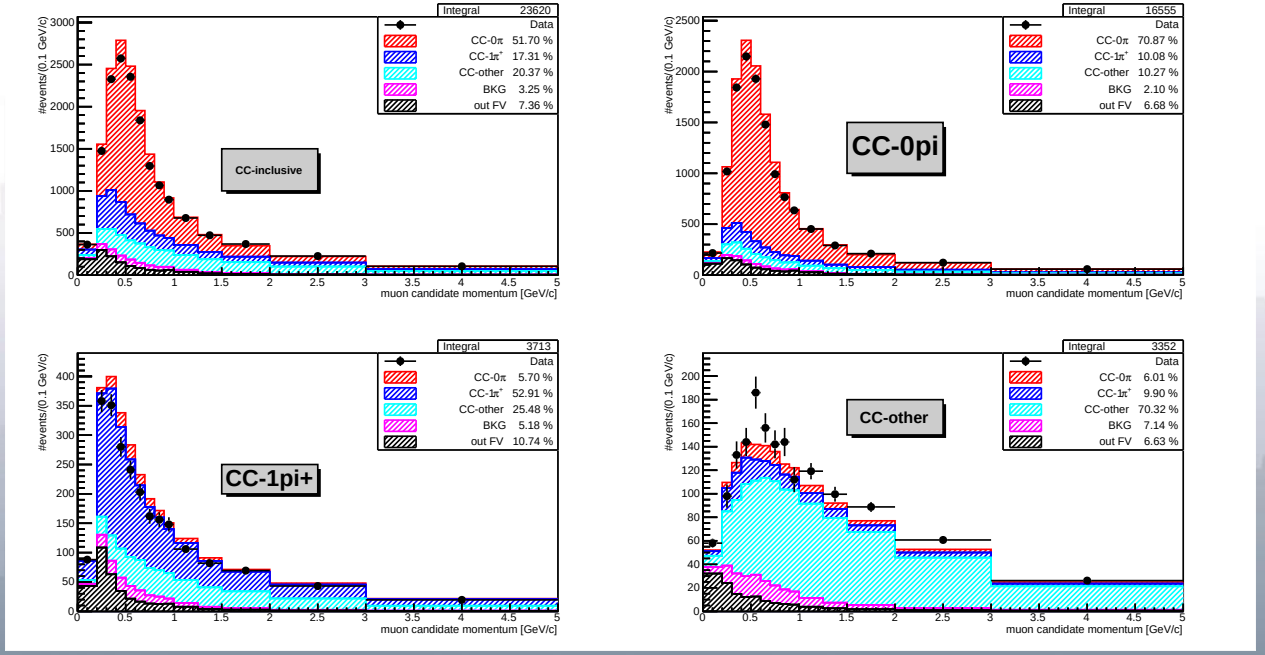


Figure 7: Momentum distribution (for Total, CC0π,CC1$\pi+$ and CCOthers).

NumuCC4piMultiPi selection first tests: Kinematics: Muon variables

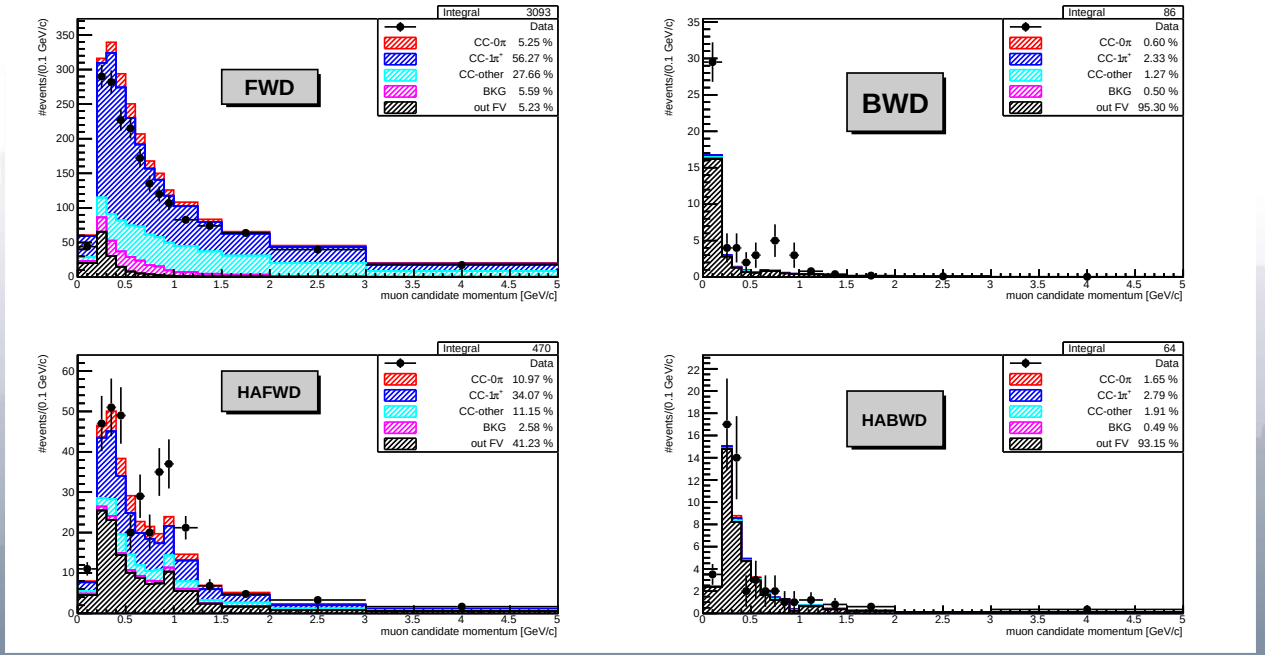


Figure 8: Momentum distribution (for FWD, BWD, HAFWD and HABWD).

NumuCC4piMultiPi selection first tests: Kinematics: Muon variables

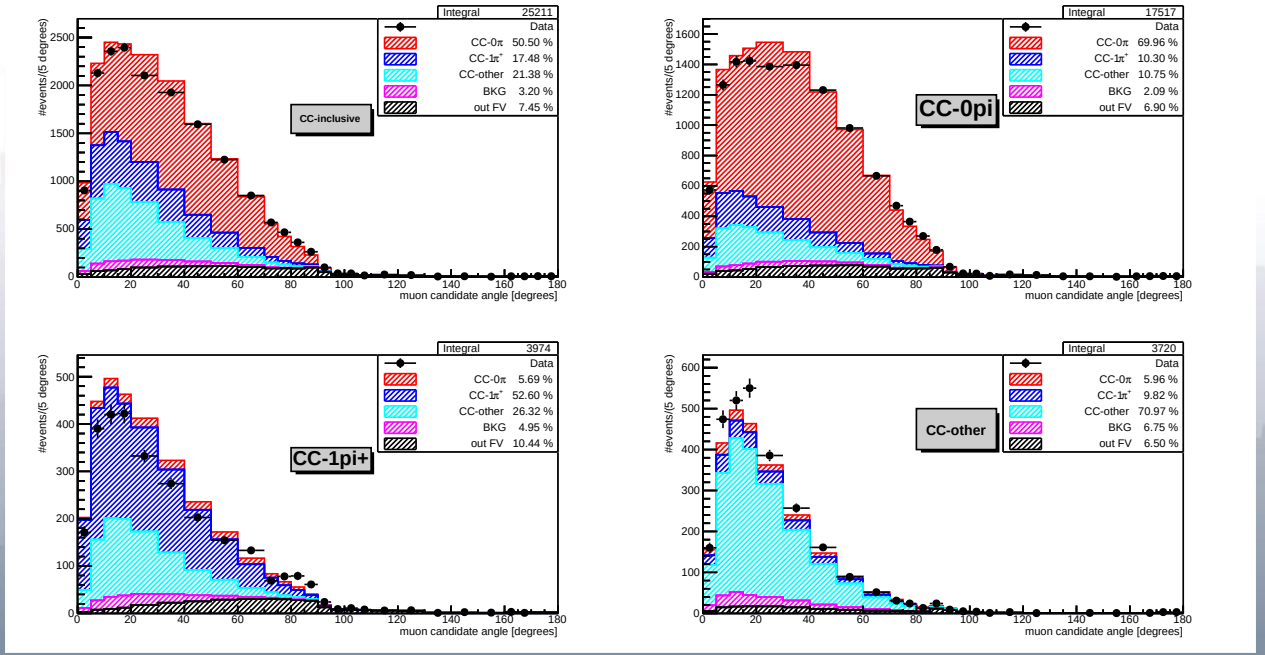


Figure 9: Angular distribution (for Total, CC0π,CC1$\pi+$ and CCOthers).

NumuCC4piMultiPi selection first tests: Kinematics: Muon variables

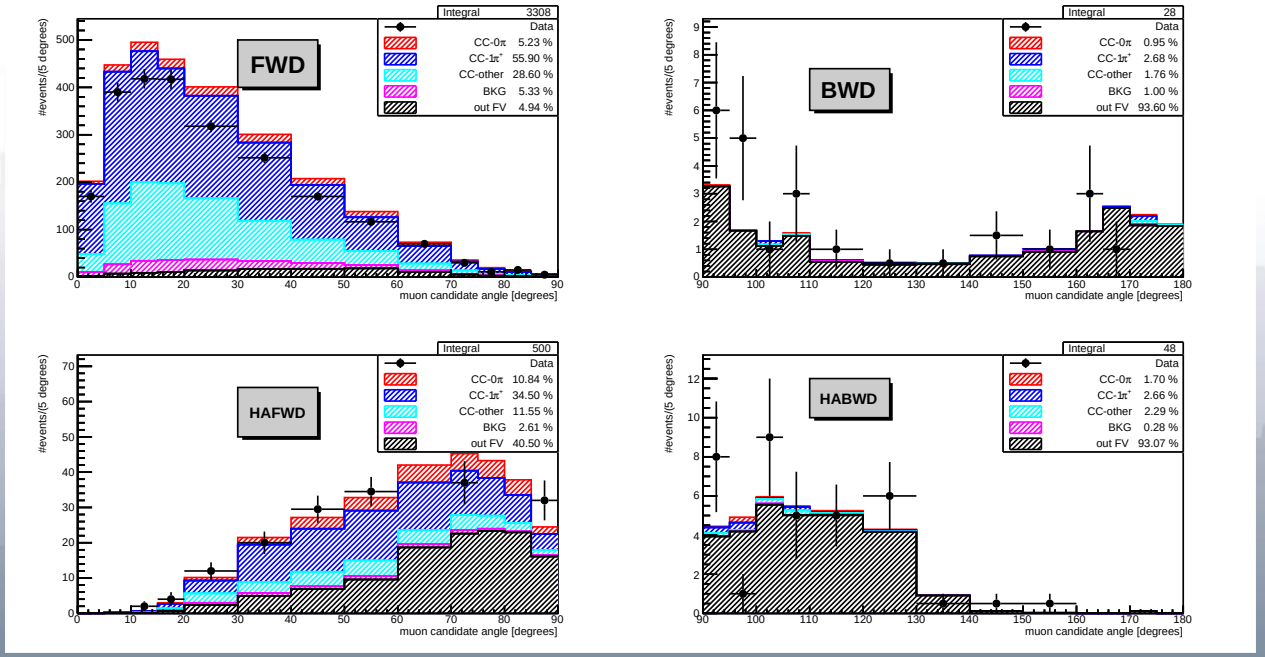


Figure 10: Angular distribution (for FWD, BWD, HAFWD and HABWD).

NumuCC4piMultiPi selection first tests: Kinematics: Muon variables

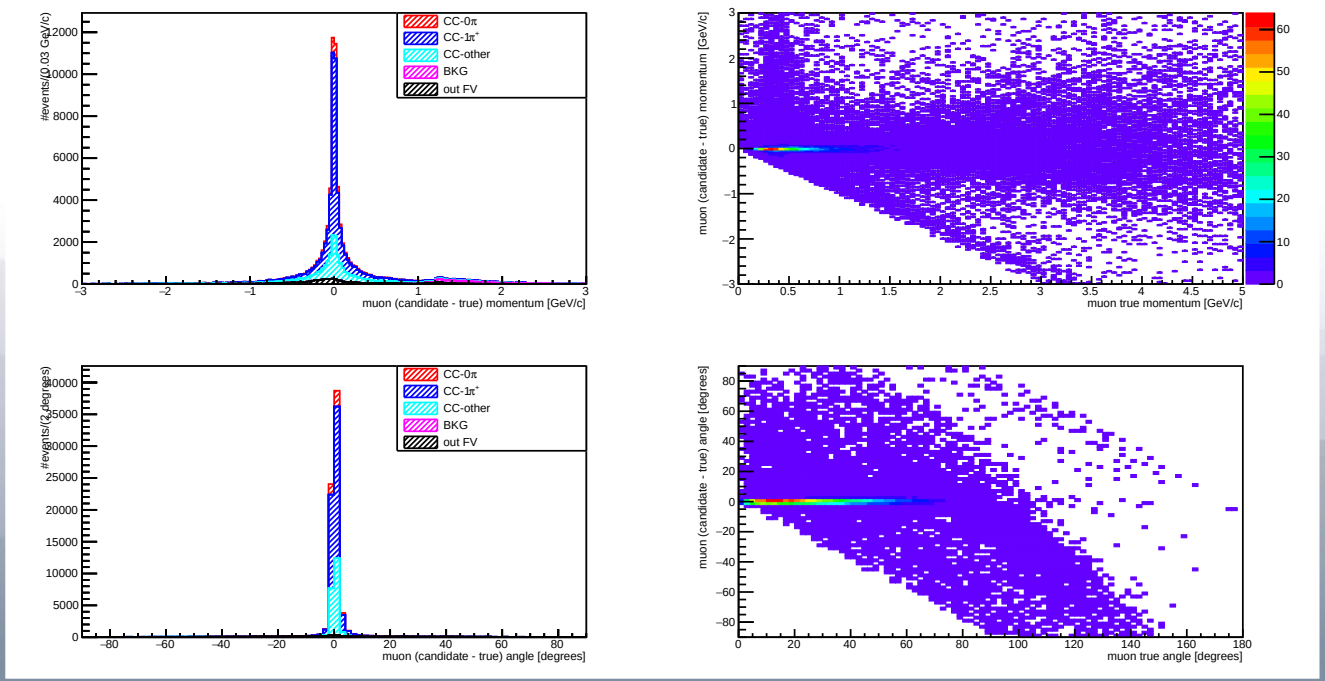


Figure 11: Difference between reconstructed and true muon variables.

NumuCC4piMultiPi selection first tests: Kinematics: Muon variables

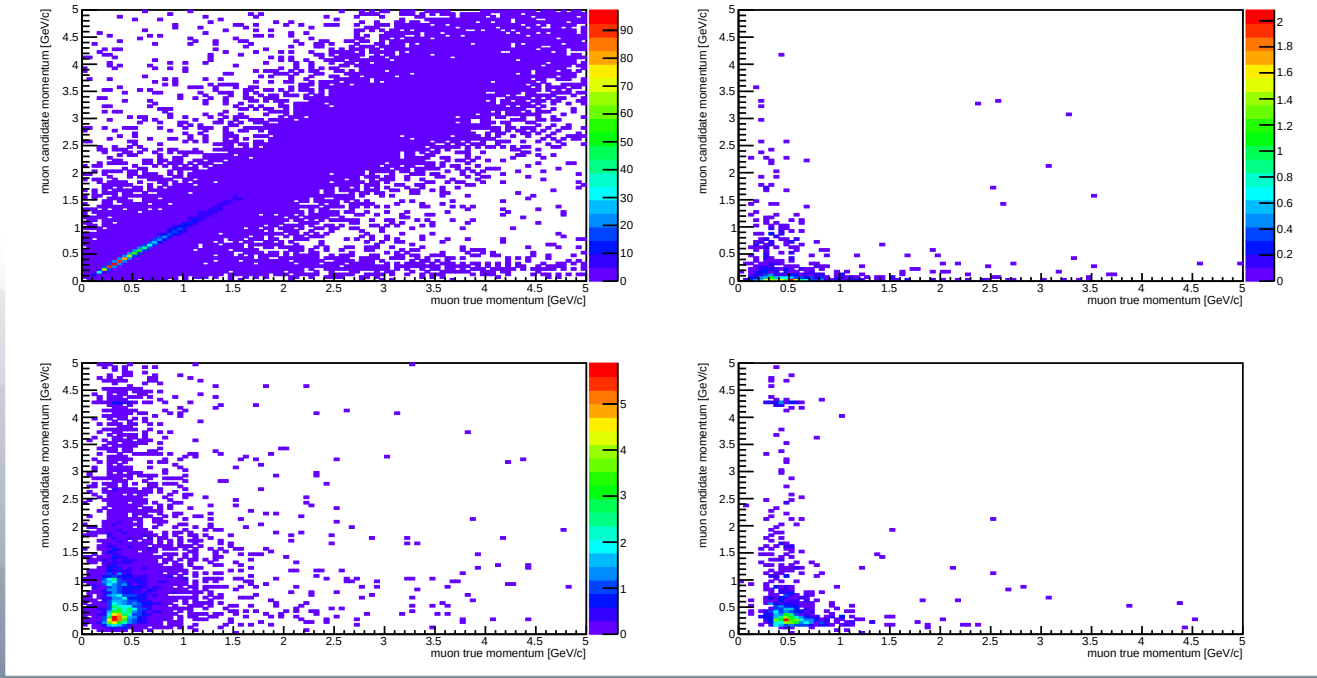


Figure 12: Relationship between reconstructed and true muon momentum (for FWD, BWD, HAFWD and HABWD).

NumuCC4piMultiPi selection first tests: Kinematics: Muon variables

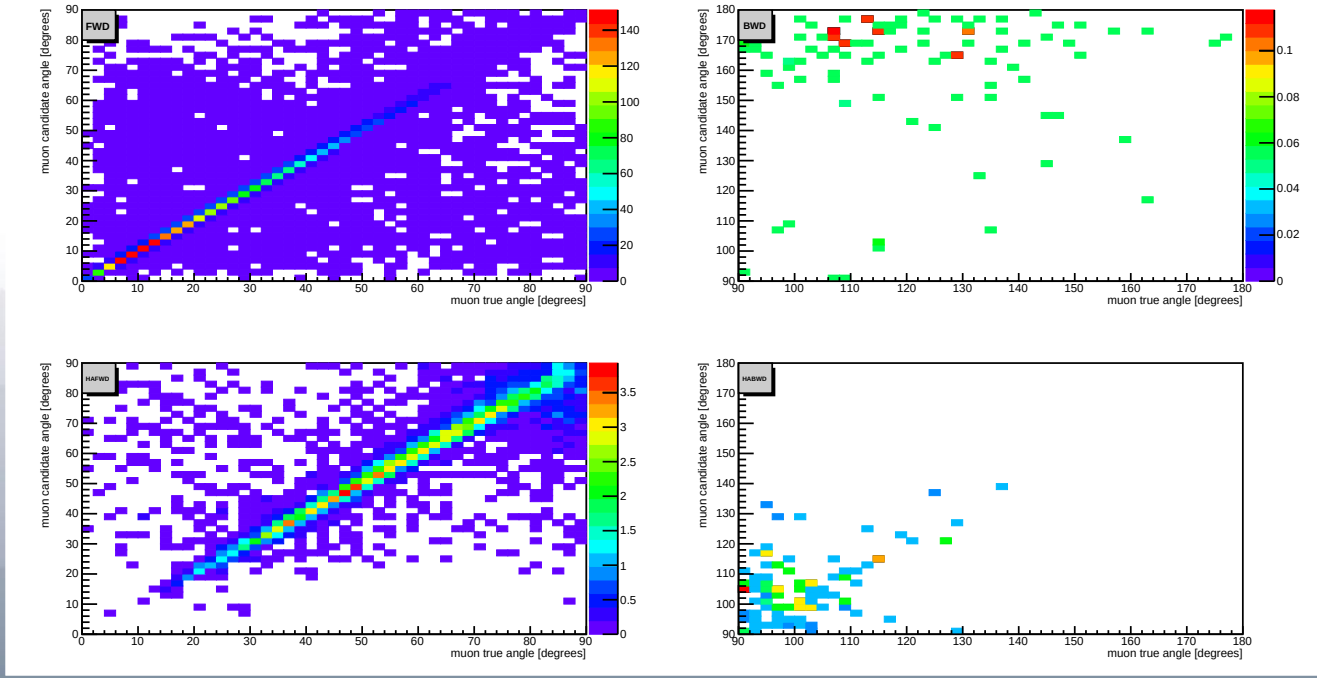


Figure 13: Relationship between reconstructed and true muon angle (for FWD, BWD, HAFWD and HABWD).

NumuCC4piMultiPi selection first tests: Kinematics: Pion variables

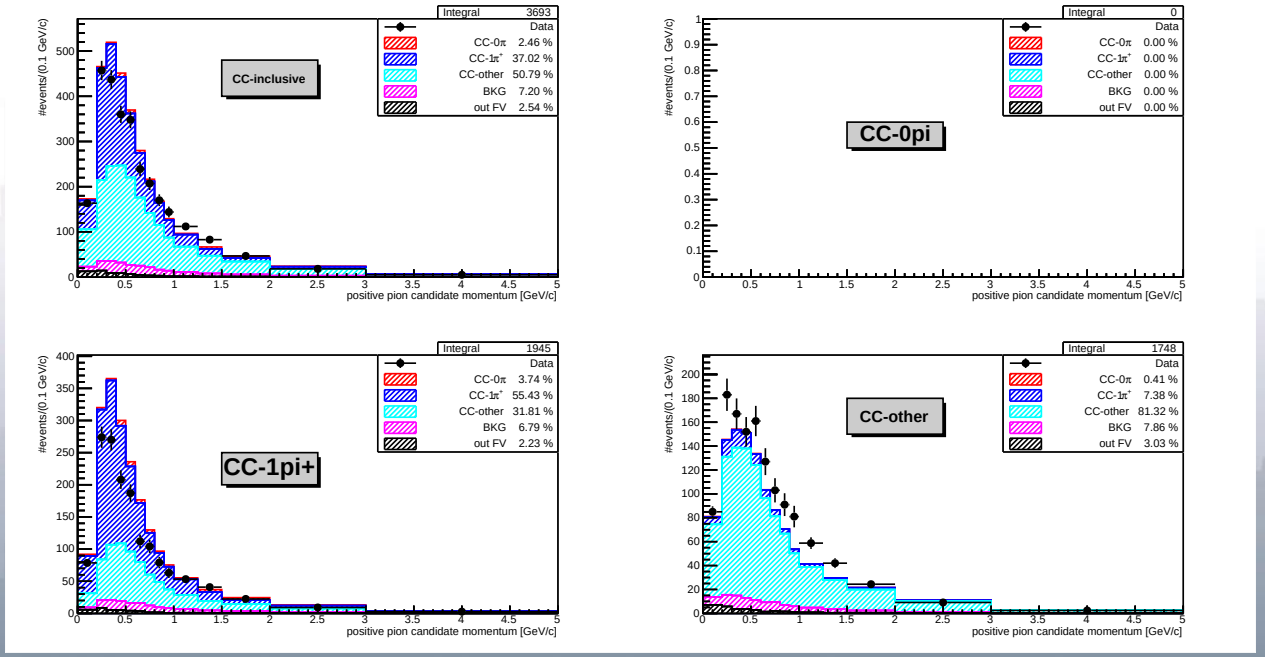


Figure 14: Momentum distribution (for Total, CC0π,CC1$\pi+$ and CCOthers).

NumuCC4piMultiPi selection first tests: Kinematics: Pion variables

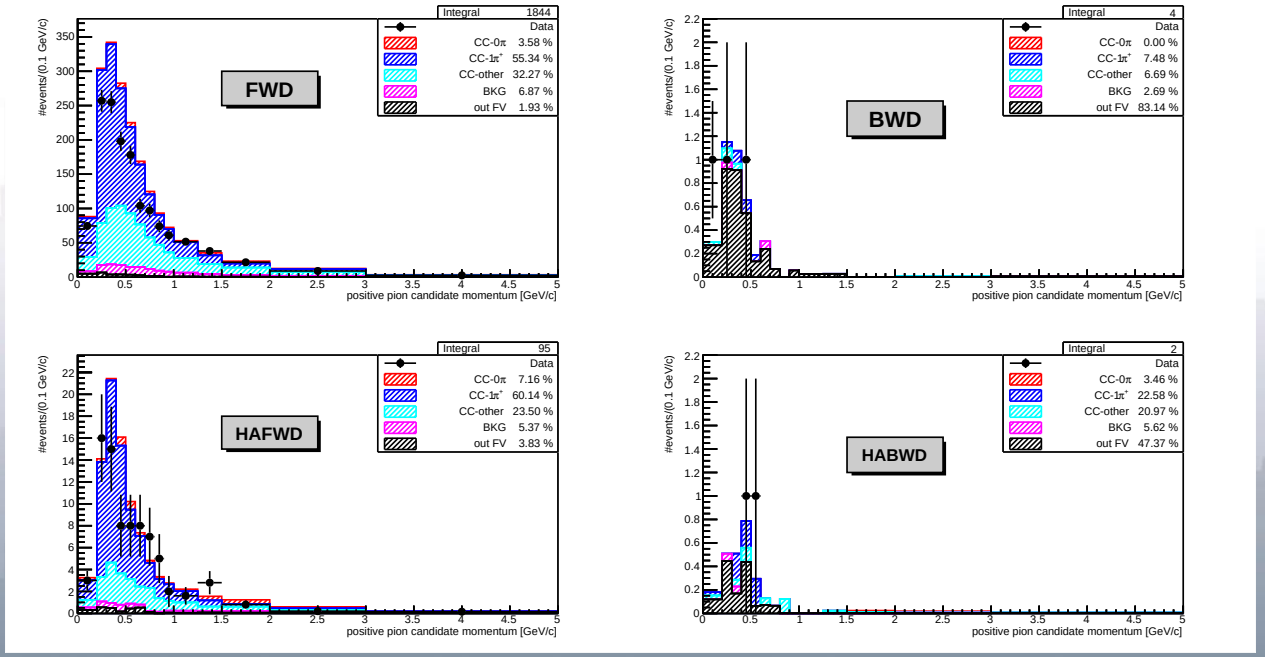


Figure 15: Momentum distribution (for FWD, BWD, HAFWD and HABWD).

NumuCC4piMultiPi selection first tests: Kinematics: Pion variables

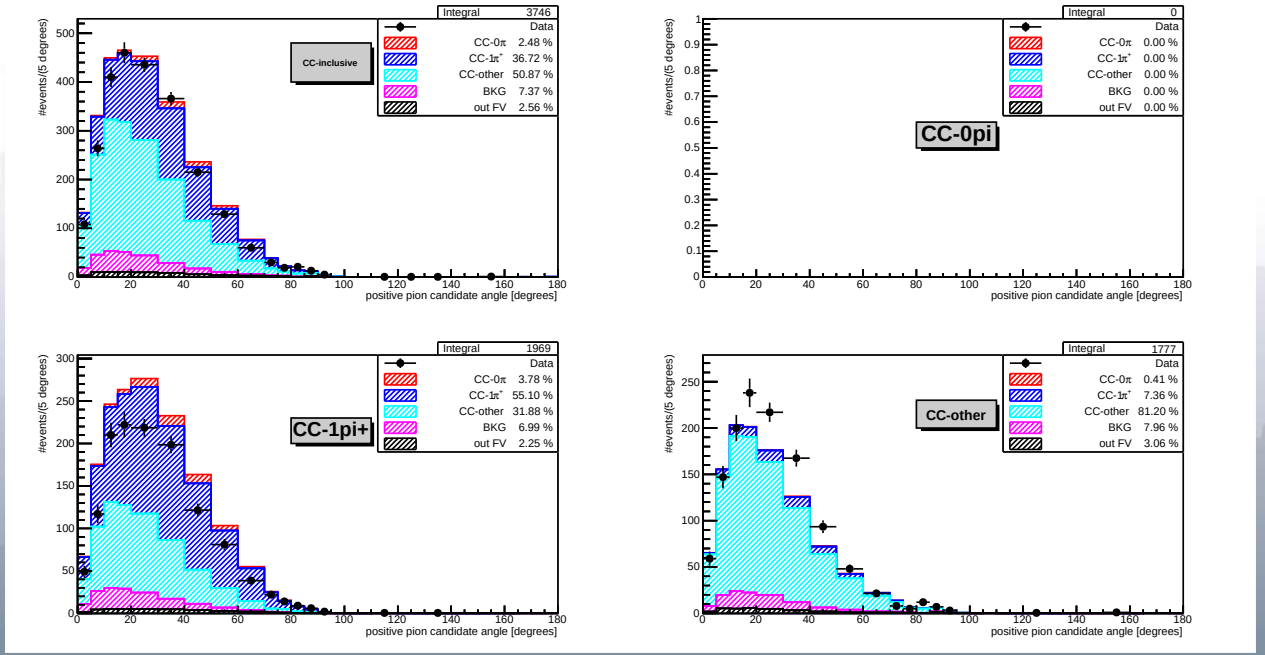


Figure 16: Angular distribution (for Total, CC0π,CC1$\pi+$ and CCOthers).

NumuCC4piMultiPi selection first tests: Kinematics: Pion variables

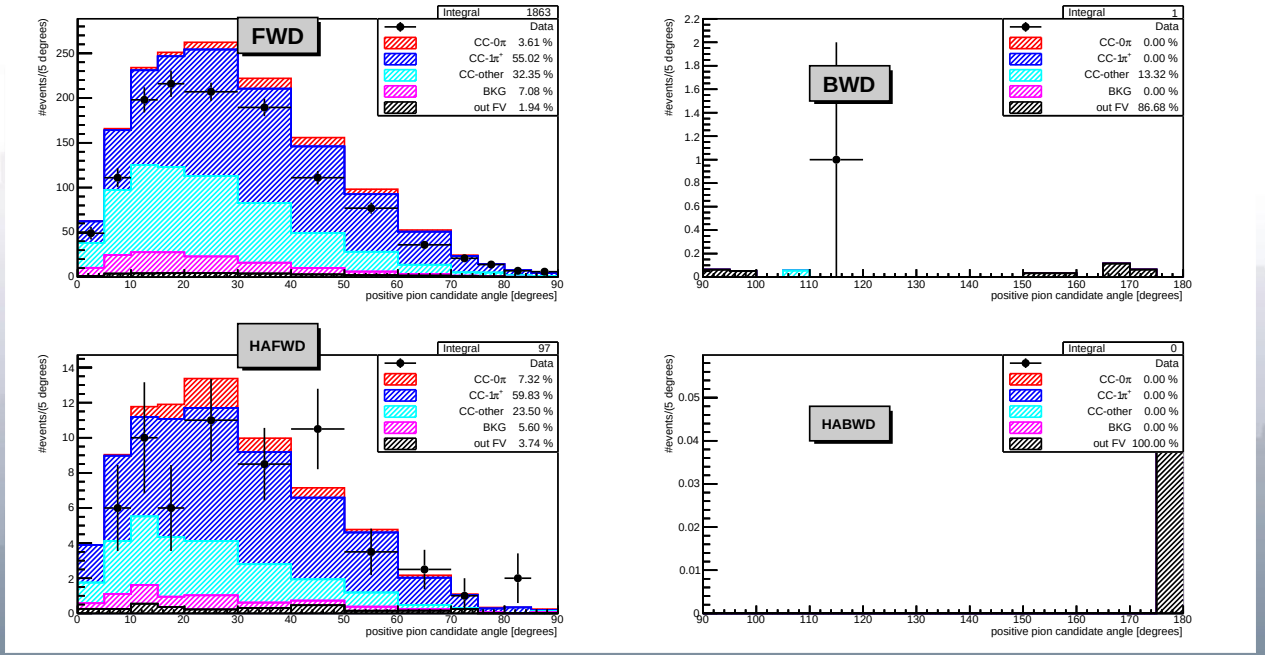


Figure 17: Angular distribution (for FWD, BWD, HAFWD and HABWD).

NumuCC4piMultiPi selection first tests: Kinematics: Pion variables

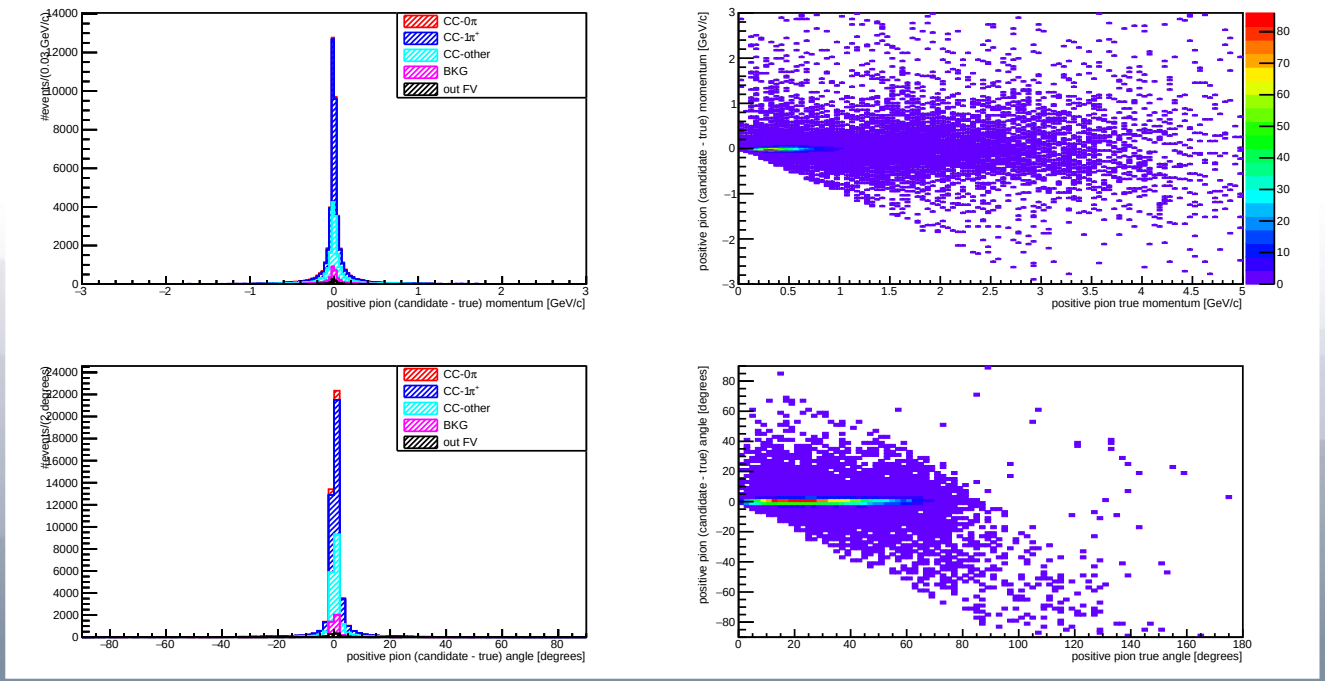


Figure 18: Difference between reconstructed and true pion variables.

NumuCC4piMultiPi selection first tests: Kinematics: Pion variables

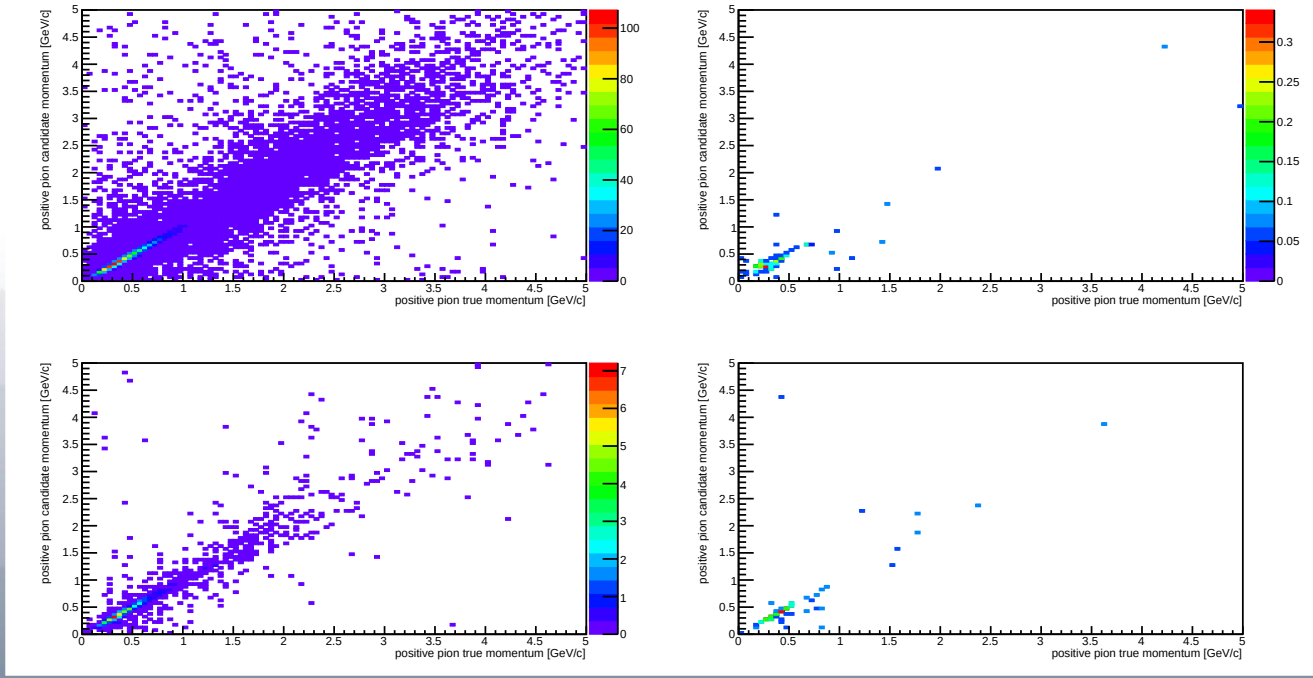


Figure 19: Relationship between reconstructed and true pion momentum (for FWD, BWD, HAFWD and HABWD).

NumuCC4piMultiPi selection first tests: Kinematics: Pion variables

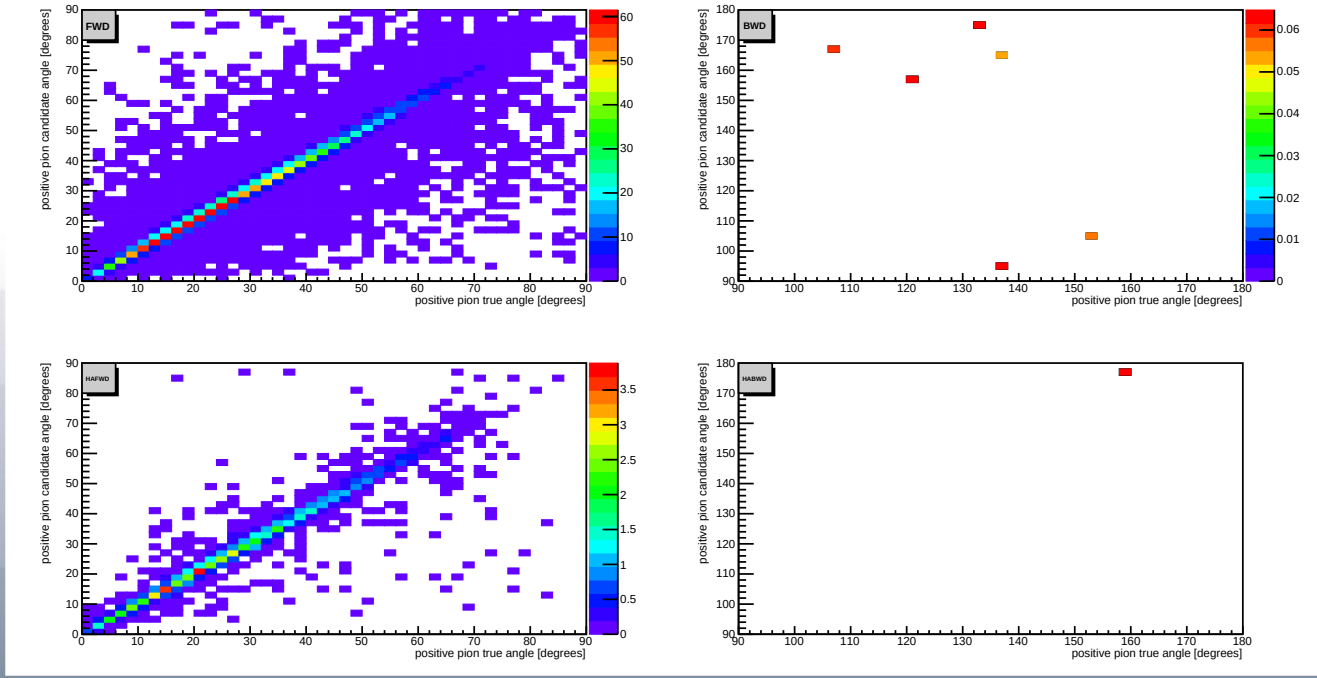


Figure 20: Relationship between reconstructed and true pion angle (for FWD, BWD, HAFWD and HABWD).

NumuCC4piMultiPi selection first tests: Kinematics: Pion and Muon variables

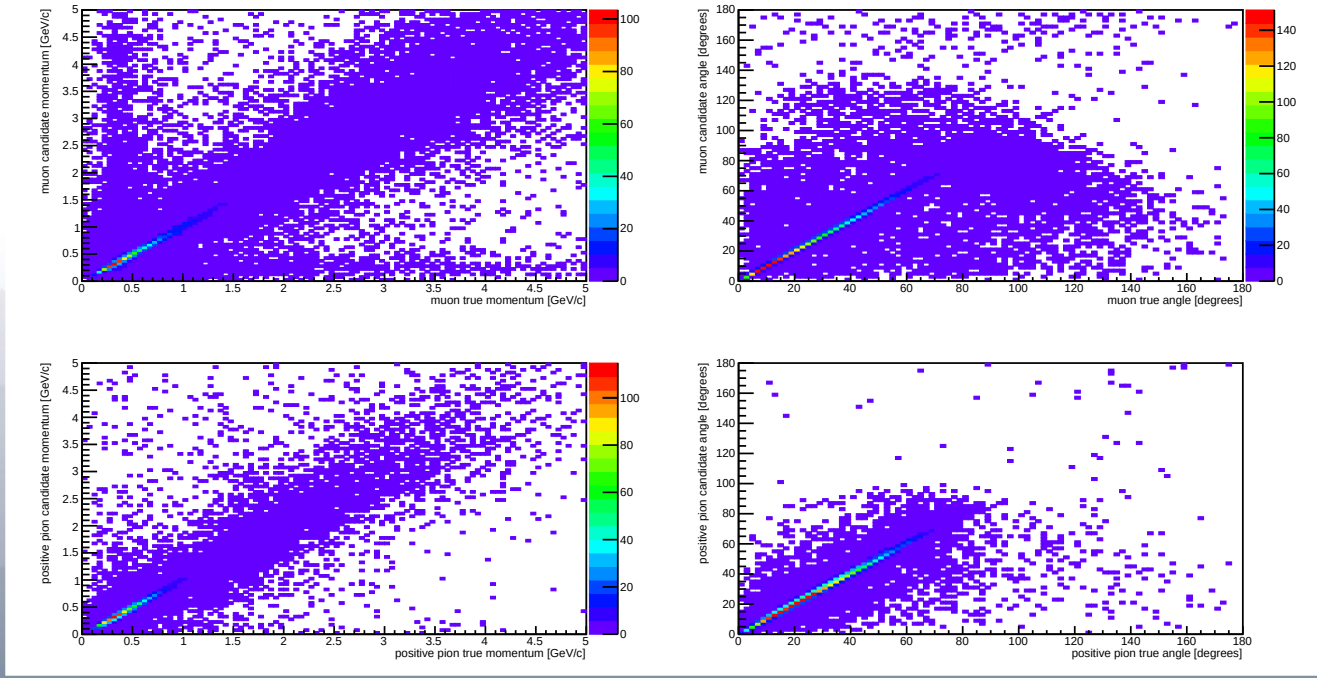


Figure 21: Relationship between reconstructed and true pion and muon variables.

Summary

Until now:

1. The **NumuCC4piMultiPi** selection in FGD1 for 4π acceptance has been implemented and is now working.
2. Created a data base at LXplus.
3. Created a document with all the changes done in Highland2 packages for the NumuCC4pi and NumuCC4piMultiPi selections to work.

Ongoing analyses:

1. Testing the selection.
2. Playing with limits of some cuts to see if I can improve them.

Future work:

1. Improve the π PID (join task with FGD2 and ECal teams).
2. Start working in the systematics.


THANK
YOU
GRACIAS
ARIGATO
SHUKURIA
BOLZÏN
MERCI
BÏYAN
SHUKRIA
DANKSCHEEN
TASHAKKUR ATU
YAQHANYELAY
TINGKI
SUKSAMA
EKHMET
MEHRBANI
GRAZIE
KOMAPSUMNIDA
MAAKE
GOZAIMASHITA
EFCHARISTO
JUSPAXAR
PALDIES
MINMONCHAR
MAKETAU
SIKOMO
EKOJU
HATUR
GUI
UNALCHÉESH
SPASIBO
DENKUUJA
NENACHALHYA
MERSI
YUSPAGARÀTAM
HUI
MAITEKA
WABEEJA
DHANYABAAD
AHHA
ATTO
LAH
SANCO
MERASTAWHY
GAEJTHO
AGUYJE
FAKAAUE
TAVTAPUCH
MEDAWAGSE
BAIKA
SPASSIBO
NUHUN
SNACHALHUYA
CHALTU

Support slides

NumuCC4piMultiPi selection cuts: General Quality