New CVN Variables

Leigh Whitehead and Saul Alonso Monsalve

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Introduction

- Saul has implemented the multi-output version of the CVN
  - Details not give here as he has presented this numberous times
- We have now added a number of new variables to the CAF tree

New Variables

- The complete list of CVN-based variables

```
fTree->Branch("cvnisantineutrino", &fCVNResultIsAntineutrino, "cvnisantineutrino/D");
fTree->Branch("cvnnue",            &fCVNResultNue,            "cvnnue/D");
fTree->Branch("cvnnumu",           &fCVNResultNumu,           "cvnnumu/D");
fTree->Branch("cvnnutau",          &fCVNResultNutau,          "cvnnutau/D");
fTree->Branch("cvnnc",             &fCVNResultNC,             "cvnnc/D");
fTree->Branch("cvn0protons",       &fCVNResult0Protons,       "cvn0protons/D");
fTree->Branch("cvn1protons",       &fCVNResult1Protons,       "cvn1protons/D");
fTree->Branch("cvn2protons",       &fCVNResult2Protons,       "cvn2protons/D");
fTree->Branch("cvnNprotons",       &fCVNResultNProtons,       "cvnNprotons/D");
fTree->Branch("cvn0pions",         &fCVNResult0Pions,         "cvn0pions/D");
fTree->Branch("cvn1pions",         &fCVNResult1Pions,         "cvn1pions/D");
fTree->Branch("cvn2pions",         &fCVNResult2Pions,         "cvn2pions/D");
fTree->Branch("cvnNpions",         &fCVNResultNPions,         "cvnNpions/D");
fTree->Branch("cvn0pizeros",       &fCVNResult0Pizeros,       "cvn0pizeros/D");
fTree->Branch("cvn1pizeros",       &fCVNResult1Pizeros,       "cvn1pizeros/D");
fTree->Branch("cvn2pizeros",       &fCVNResult2Pizeros,       "cvn2pizeros/D");
fTree->Branch("cvnNpizeros",       &fCVNResultNPizeros,       "cvnNpizeros/D");
fTree->Branch("cvn0neutrons",      &fCVNResult0Neutrons,      "cvn0neutrons/D");
fTree->Branch("cvn1neutrons",      &fCVNResult1Neutrons,      "cvn1neutrons/D");
fTree->Branch("cvn2neutrons",      &fCVNResult2Neutrons,      "cvn2neutrons/D");
fTree->Branch("cvnNneutrons",      &fCVNResultNNeutrons,      "cvnNneutrons/D");
```

New Variables

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```
fTree->Branch("cvnisantineutrino", &f                                  isantineutrino/D");
fTree->Branch("cvnnue",            &f                                  nue/D");
fTree->Branch("cvnnumu",           &f                                  numu/D");
fTree->Branch("cvnnutau",          &f                                  nutau/D");
fTree->Branch("cvnnc",             &f                                  nc/D");
fTree->Branch("cvn0protons",       &f                                  0protons/D");
fTree->Branch("cvn1protons",       &fCVNResult1Protons,       "cvn1protons/D");
fTree->Branch("cvn2protons",       &fCVNResult2Protons,       "cvn2protons/D");
fTree->Branch("cvnNprotons",       &fCVNResultNProtons,       "cvnNprotons/D");
fTree->Branch("cvn0pions",         &fCVNResult0Pions,         "cvn0pions/D");
fTree->Branch("cvn1pions",         &fCVNResult1Pions,         "cvn1pions/D");
fTree->Branch("cvn2pions",         &fCVNResult2Pions,         "cvn2pions/D");
fTree->Branch("cvnNpions",         &fCVNResultNPions,         "cvnNpions/D");
fTree->Branch("cvn0pizeros",       &fCVNResult0Pizeros,       "cvn0pizeros/D");
fTree->Branch("cvn1pizeros",       &fCVNResult1Pizeros,       "cvn1pizeros/D");
fTree->Branch("cvn2pizeros",       &fCVNResult2Pizeros,       "cvn2pizeros/D");
fTree->Branch("cvnNpizeros",       &fCVNResultNPizeros,       "cvnNpizeros/D");
fTree->Branch("cvn0neutrons",      &fCVNResult0Neutrons,      "cvn0neutrons/D");
fTree->Branch("cvn1neutrons",      &fCVNResult1Neutrons,      "cvn1neutrons/D");
fTree->Branch("cvn2neutrons",      &fCVNResult2Neutrons,      "cvn2neutrons/D");
fTree->Branch("cvnNneutrons",      &fCVNResultNNeutrons,      "cvnNneutrons/D");
```

Flavour variables:
CC nue, numu, nutau
NC

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```
fTree->Branch("cvnisantineutrino", &fCVNResultIsAntineutrino, "cvnisantineutrino/D");
fTree->Branch("cvnnue",            &fCVNResultNue,            "cvnnue/D");
fTree->Branch("cvnnumu",           &fCVNResultNumu,           "cvnnumu/D");
fTree->Branch("cvnnutau",          &fCVNResultNutau,          "cvnnutau/D");
fTree->Branch("cvnnc",             &f                         nc/D");
fTree->Branch("cvn0protons",       &f                         0protons/D");
fTree->Branch("cvn1protons",       &f                         1protons/D");
fTree->Branch("cvn2protons",       &f                         2protons/D");
fTree->Branch("cvnNprotons",       &f                         Nprotons/D");
fTree->Branch("cvn0pions",         &f                         cvn0pions/D");
fTree->Branch("cvn1pions",         &fCVNResult1Pions,         "cvn1pions/D");
fTree->Branch("cvn2pions",         &fCVNResult2Pions,         "cvn2pions/D");
fTree->Branch("cvnNpions",         &fCVNResultNPions,         "cvnNpions/D");
fTree->Branch("cvn0pizeros",       &fCVNResult0Pizeros,       "cvn0pizeros/D");
fTree->Branch("cvn1pizeros",       &fCVNResult1Pizeros,       "cvn1pizeros/D");
fTree->Branch("cvn2pizeros",       &fCVNResult2Pizeros,       "cvn2pizeros/D");
fTree->Branch("cvnNpizeros",       &fCVNResultNPizeros,       "cvnNpizeros/D");
fTree->Branch("cvn0neutrons",      &fCVNResult0Neutrons,      "cvn0neutrons/D");
fTree->Branch("cvn1neutrons",      &fCVNResult1Neutrons,      "cvn1neutrons/D");
fTree->Branch("cvn2neutrons",      &fCVNResult2Neutrons,      "cvn2neutrons/D");
fTree->Branch("cvnNneutrons",      &fCVNResultNNeutrons,      "cvnNneutrons/D");
```

Proton counting

New Variables

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```
fTree->Branch("cvnisantineutrino", &fCVNResultIsAntineutrino, "cvnisantineutrino/D");
fTree->Branch("cvnnue",            &fCVNResultNue,            "cvnnue/D");
fTree->Branch("cvnnumu",           &fCVNResultNumu,           "cvnnumu/D");
fTree->Branch("cvnnutau",          &fCVNResultNutau,          "cvnnutau/D");
fTree->Branch("cvnnc",             &fCVNResultNC,             "cvnnc/D");
fTree->Branch("cvn0protons",       &fCVNResult0Protons,       "cvn0protons/D");
fTree->Branch("cvn1protons",       &fCVNResult1Protons,       "cvn1protons/D");
fTree->Branch("cvn2protons",       &fCVNResult2Protons,       "cvn2protons/D");
fTree->Branch("cvnNprotons",       &f                         "cvnNprotons/D");
fTree->Branch("cvn0pions",         &f                         "0pions/D");
fTree->Branch("cvn1pions",         &f                         "1pions/D");
fTree->Branch("cvn2pions",         &f                         "2pions/D");
fTree->Branch("cvnNpions",         &f                         "Npions/D");
fTree->Branch("cvn0pizeros",       &f                         "0pizeros/D");
fTree->Branch("cvn1pizeros",       &fCVNResult1Pizeros,       "cvn1pizeros/D");
fTree->Branch("cvn2pizeros",       &fCVNResult2Pizeros,       "cvn2pizeros/D");
fTree->Branch("cvnNpizeros",       &fCVNResultNPizeros,       "cvnNpizeros/D");
fTree->Branch("cvn0neutrons",      &fCVNResult0Neutrons,      "cvn0neutrons/D");
fTree->Branch("cvn1neutrons",      &fCVNResult1Neutrons,      "cvn1neutrons/D");
fTree->Branch("cvn2neutrons",      &fCVNResult2Neutrons,      "cvn2neutrons/D");
fTree->Branch("cvnNneutrons",      &fCVNResultNNeutrons,      "cvnNneutrons/D");
```

Charged pion counting

New Variables

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```
fTree->Branch("cvnisantineutrino", &fCVNResultIsAntineutrino, "cvnisantineutrino/D");
fTree->Branch("cvnnue",            &fCVNResultNue,            "cvnnue/D");
fTree->Branch("cvnnumu",           &fCVNResultNumu,           "cvnnumu/D");
fTree->Branch("cvnnutau",          &fCVNResultNutau,          "cvnnutau/D");
fTree->Branch("cvnnc",             &fCVNResultNC,             "cvnnc/D");
fTree->Branch("cvn0protons",       &fCVNResult0Protons,       "cvn0protons/D");
fTree->Branch("cvn1protons",       &fCVNResult1Protons,       "cvn1protons/D");
fTree->Branch("cvn2protons",       &fCVNResult2Protons,       "cvn2protons/D");
fTree->Branch("cvnNprotons",       &fCVNResultNProtons,       "cvnNprotons/D");
fTree->Branch("cvn0pions",         &fCVNResult0Pions,         "cvn0pions/D");
fTree->Branch("cvn1pions",         &fCVNResult1Pions,         "cvn1pions/D");
fTree->Branch("cvn2pions",         &fCVNResult2Pions,         "cvn2pions/D");
fTree->Branch("cvnNpions",         &f                         "pions/D");
fTree->Branch("cvn0pizeros",       &f                         "pizeros/D");
fTree->Branch("cvn1pizeros",       &f                         "pizeros/D");
fTree->Branch("cvn2pizeros",       &f                         "pizeros/D");
fTree->Branch("cvnNpizeros",       &f                         "pizeros/D");
fTree->Branch("cvn0neutrons",      &f                         "neutrons/D");
fTree->Branch("cvn1neutrons",      &fCVNResult1Neutrons,      "cvn1neutrons/D");
fTree->Branch("cvn2neutrons",      &fCVNResult2Neutrons,      "cvn2neutrons/D");
fTree->Branch("cvnNneutrons",      &fCVNResultNNeutrons,      "cvnNneutrons/D");
```

Pizero counting

New Variables

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```
fTree->Branch("cvnisantineutrino", &fCVNResultIsAntineutrino, "cvnisantineutrino/D");
fTree->Branch("cvnnue",            &fCVNResultNue,            "cvnnue/D");
fTree->Branch("cvnnumu",           &fCVNResultNumu,           "cvnnumu/D");
fTree->Branch("cvnnutau",          &fCVNResultNutau,          "cvnnutau/D");
fTree->Branch("cvnnc",             &fCVNResultNC,             "cvnnc/D");
fTree->Branch("cvn0protons",       &fCVNResult0Protons,       "cvn0protons/D");
fTree->Branch("cvn1protons",       &fCVNResult1Protons,       "cvn1protons/D");
fTree->Branch("cvn2protons",       &fCVNResult2Protons,       "cvn2protons/D");
fTree->Branch("cvnNprotons",       &fCVNResultNProtons,       "cvnNprotons/D");
fTree->Branch("cvn0pions",         &fCVNResult0Pions,         "cvn0pions/D");
fTree->Branch("cvn1pions",         &fCVNResult1Pions,         "cvn1pions/D");
fTree->Branch("cvn2pions",         &fCVNResult2Pions,         "cvn2pions/D");
fTree->Branch("cvnNpions",         &fCVNResultNPions,         "cvnNpions/D");
fTree->Branch("cvn0pizeros",       &fCVNResult0Pizeros,       "cvn0pizeros/D");
fTree->Branch("cvn1pizeros",       &fCVNResult1Pizeros,       "cvn1pizeros/D");
fTree->Branch("cvn2pizeros",       &fCVNResult2Pizeros,       "cvn2pizeros/D");
fTree->Branch("cvnNpizeros",       &fCVNResultNPizeros,       "cvnNpizeros/D");
fTree->Branch("cvn0neutrons",      &f                         "0neutrons/D");
fTree->Branch("cvn1neutrons",      &f                         "1neutrons/D");
fTree->Branch("cvn2neutrons",      &f                         "2neutrons/D");
fTree->Branch("cvnNneutrons",      &f                         "Nneutrons/D");
```

Neutron counting

A few comments

- The main oscillation analysis for the TDR only needs to use two of these variables – the names remain the same as previously
  - Electron neutrino probability: cvnnue
  - Muon neutrino probability: cvnnumu

- All of the other variables are added for future development studies and aren't necessarily "physics ready"
  - This is the first time they are all available in LArSoft for more stringent testing for systematic uncertainties etc
  - Enables exclusive channel studies to begin and investigate any selection biases that could be baked into the CVN outputs
  - For example, the neutron counting doesn't give much information at the moment