Energy resolution studies for cosmic muons

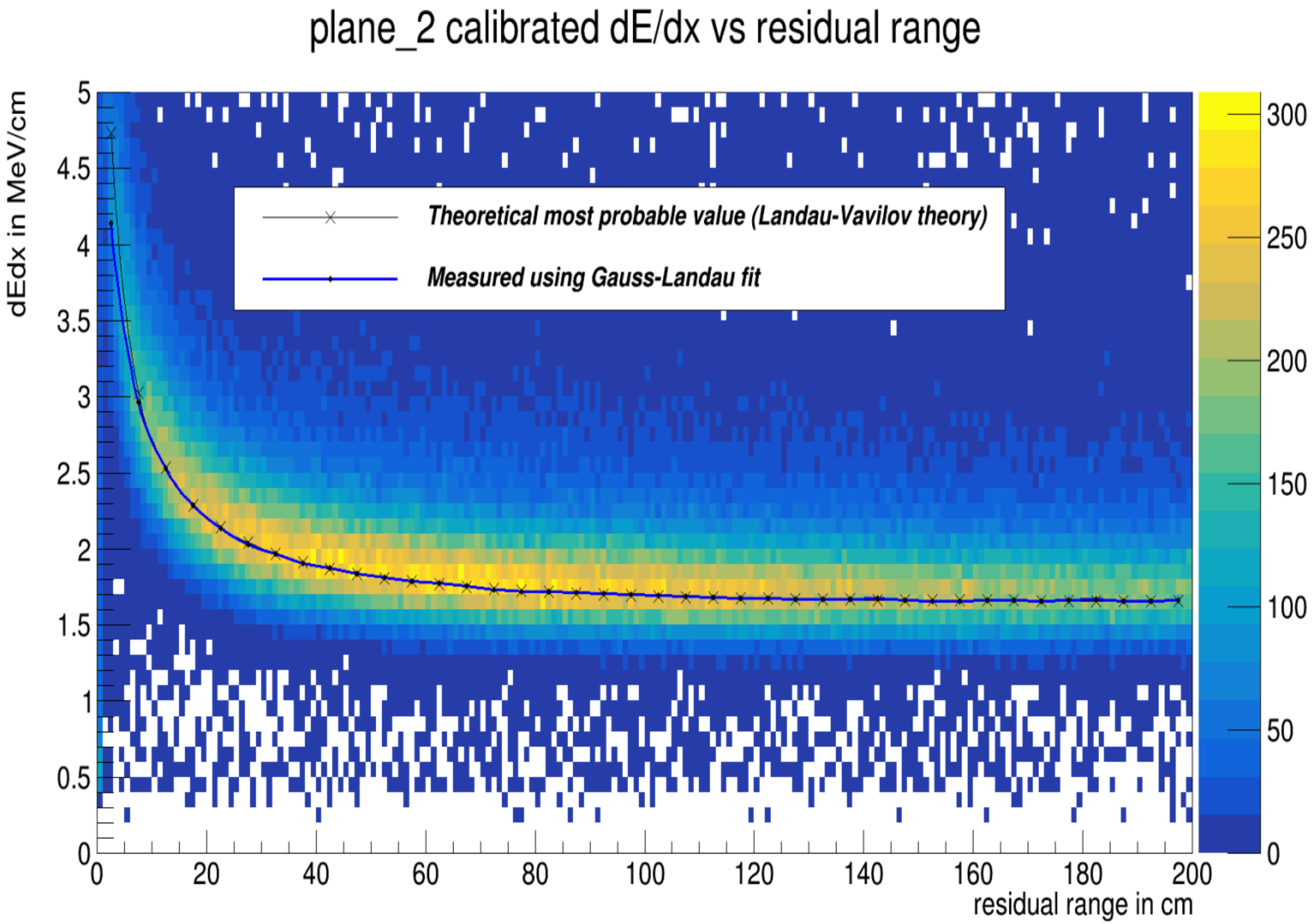
Ajib Paudel

Kansas State University

DRA meeting, Dec 18, 2019

SCE OFF production 2 samples:

- Calibrated dE/dx vs residual range for stopping muons:

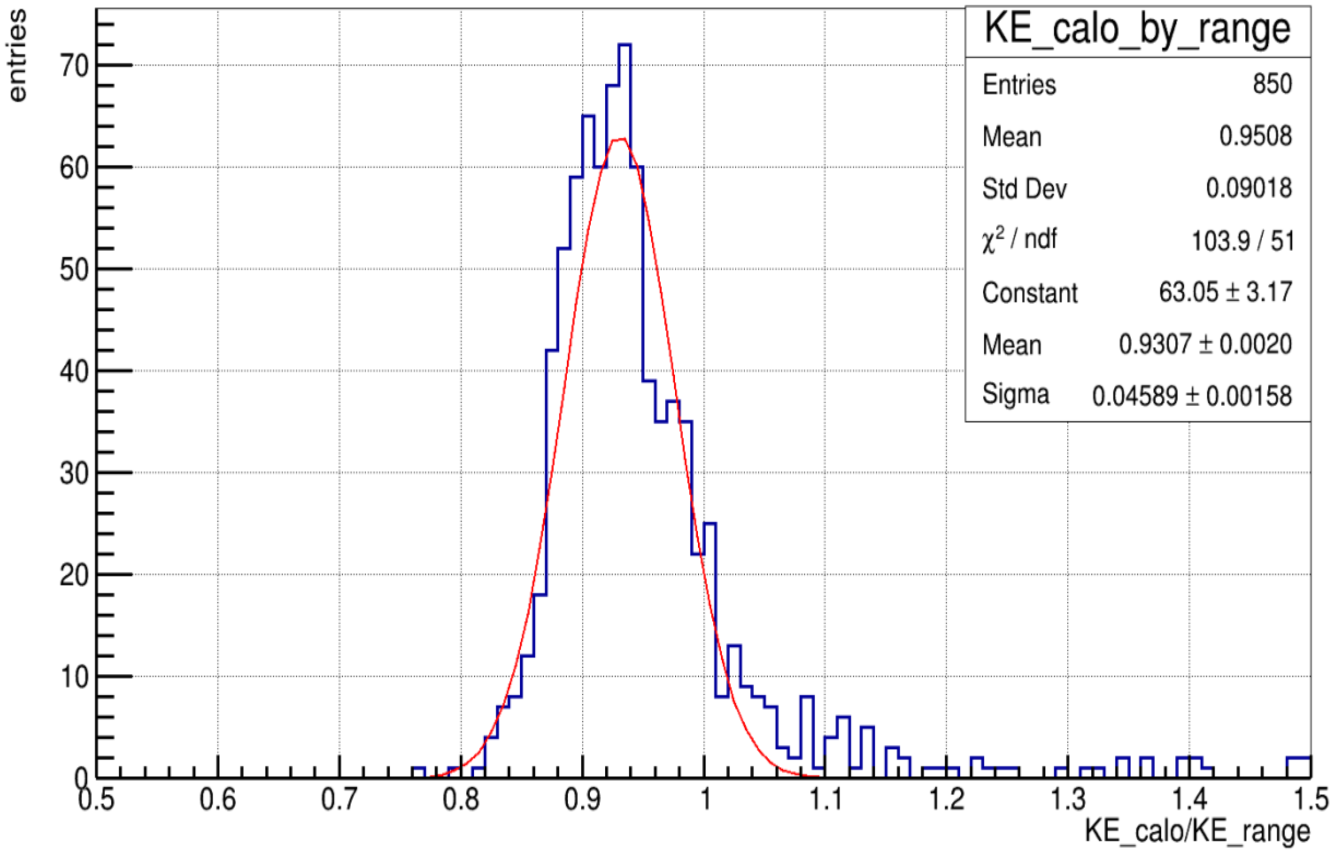


Calibrated dE/dx values in good agreement with theoretical prediction

SCE OFF sample:

KE_calo = Σ (dE/dx)*dx, where dx=trackpitch
KE_range=KE based on the tracklength [range=tracklength=calo->Range()]

KE calo/KE range for stopping muons



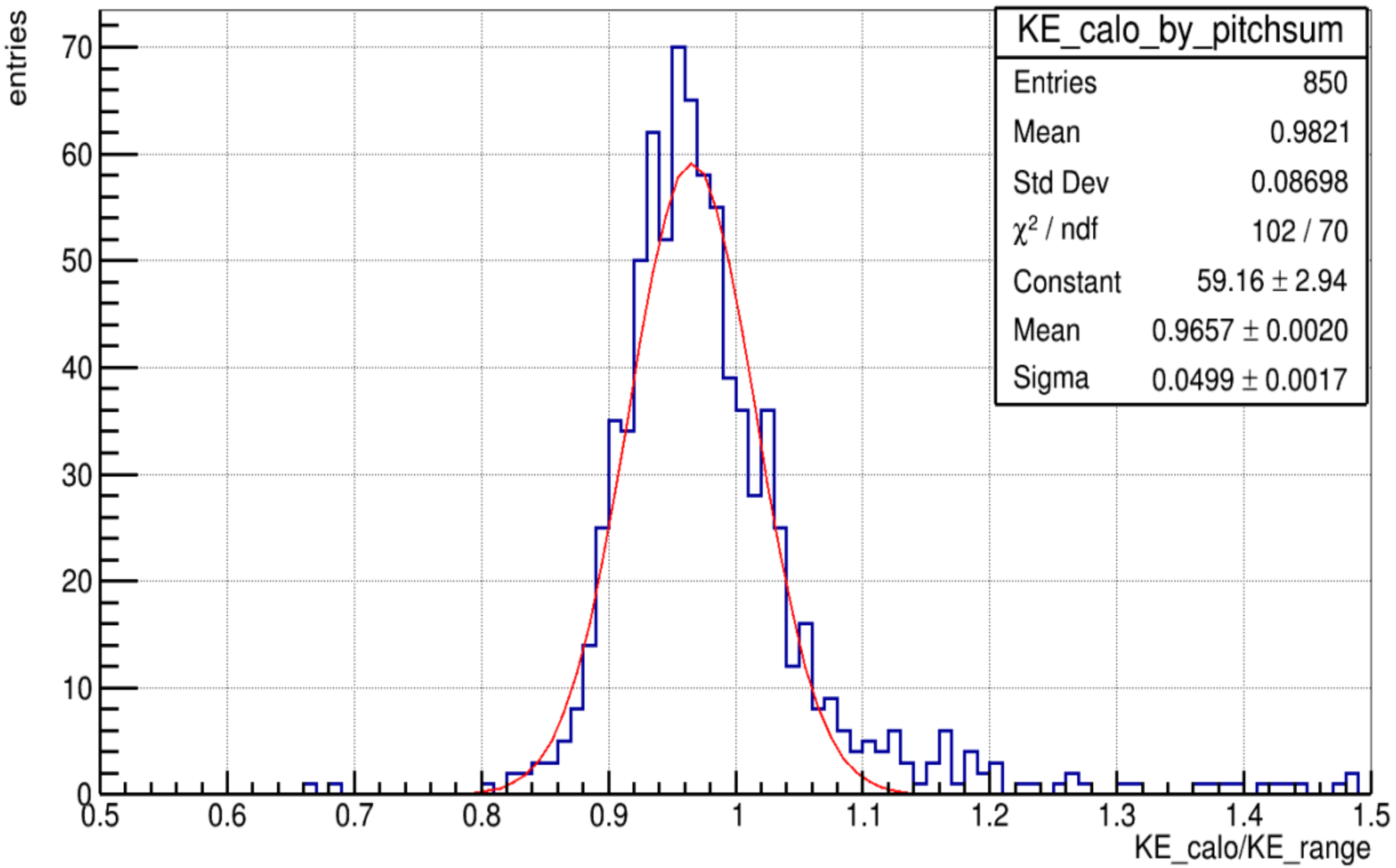
We see, the mean value = 0.9508
Fitted mean =0.9307

We observe KE_calo is around 7% lower than KE_range

SCE OFF sample contd.......

Again we tried to calculate the KE using pitchsum, where pitchsum= Σdx, dx=sum of the trackpitch values

KE_calo/KE_pitchsum



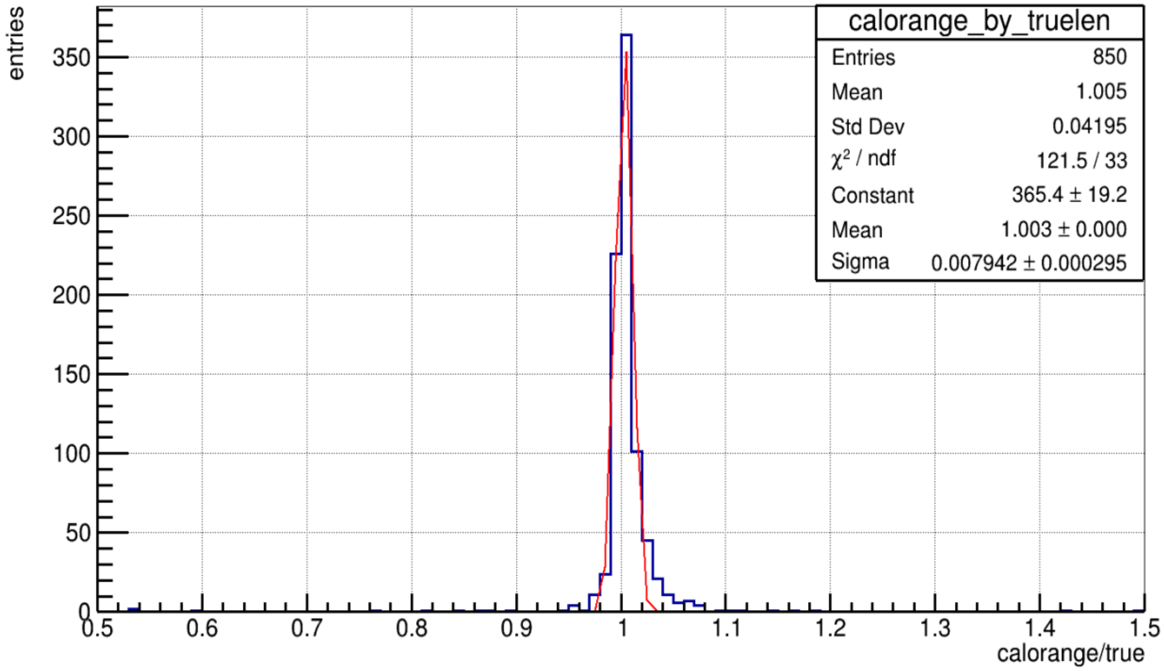
When we use the tracklength as the sum of the pitch values, we get a better agreement between KEcalo and KErange.

In principle, range must be equal to sum of the trackpitch, but as trackpitch is not defined simply as the 3D distance between two hits
Range not always equal to sumpitch.

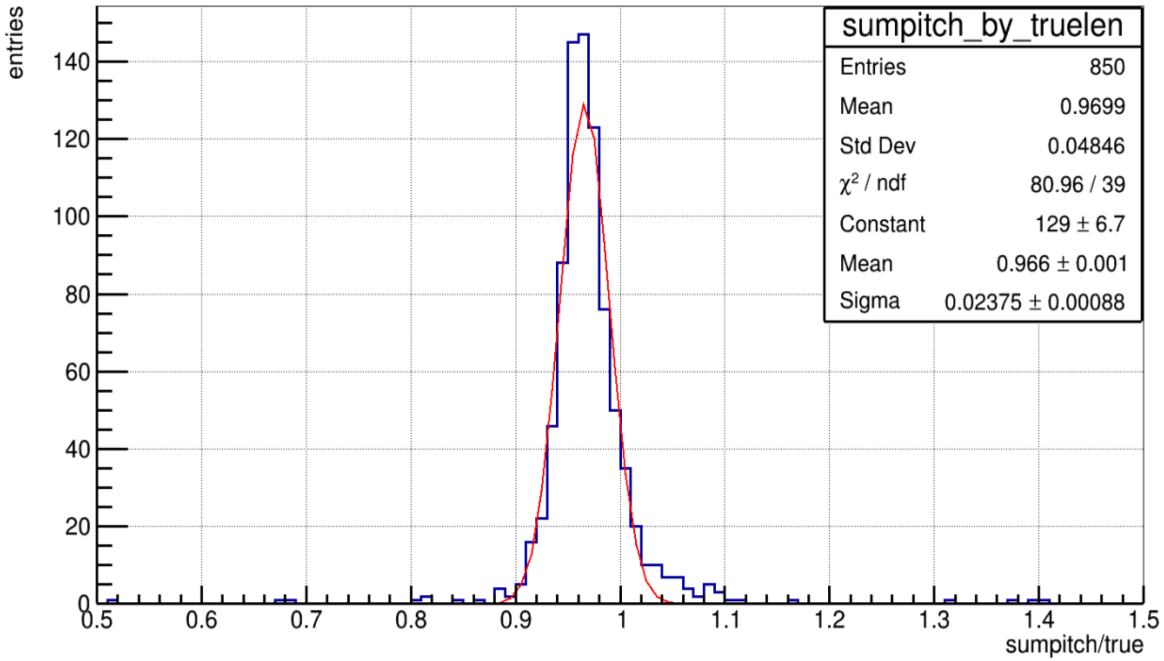
Here the difference is around 3%

SCE OFF contd....

Range/True tracklength



pitchsum/True tracklength



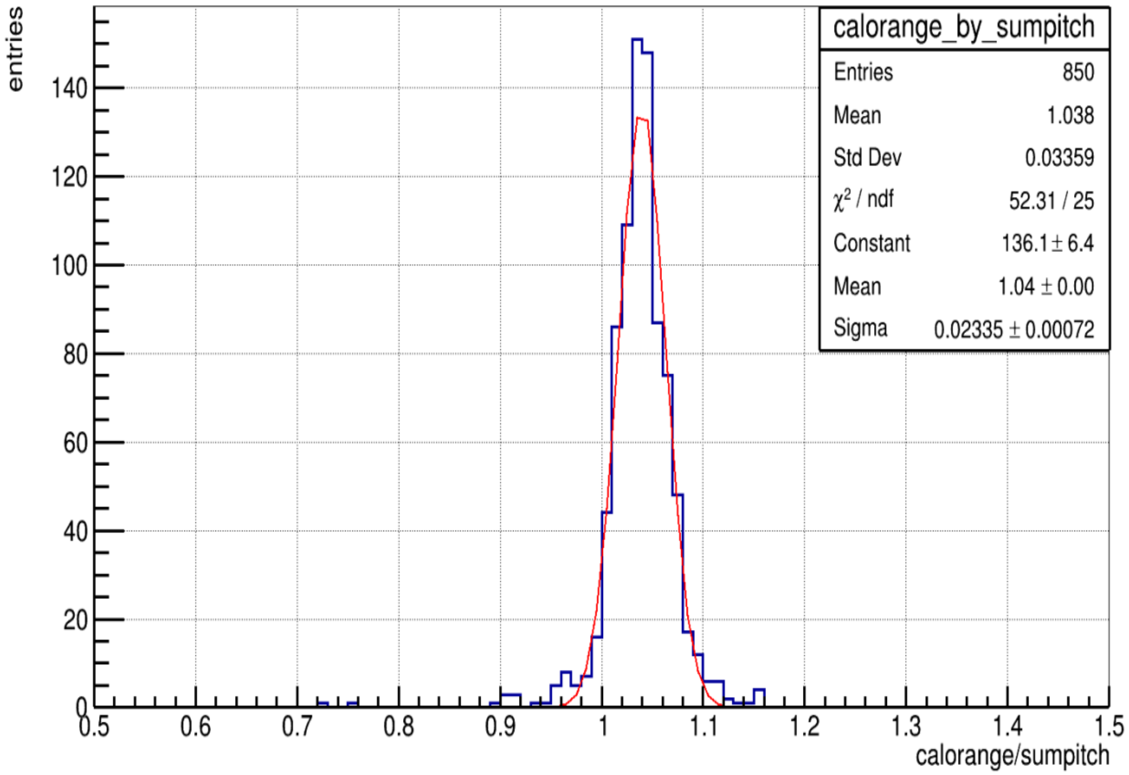
Range/true tracklength = 1.003

Pitchsum/True tracklength = 0.966

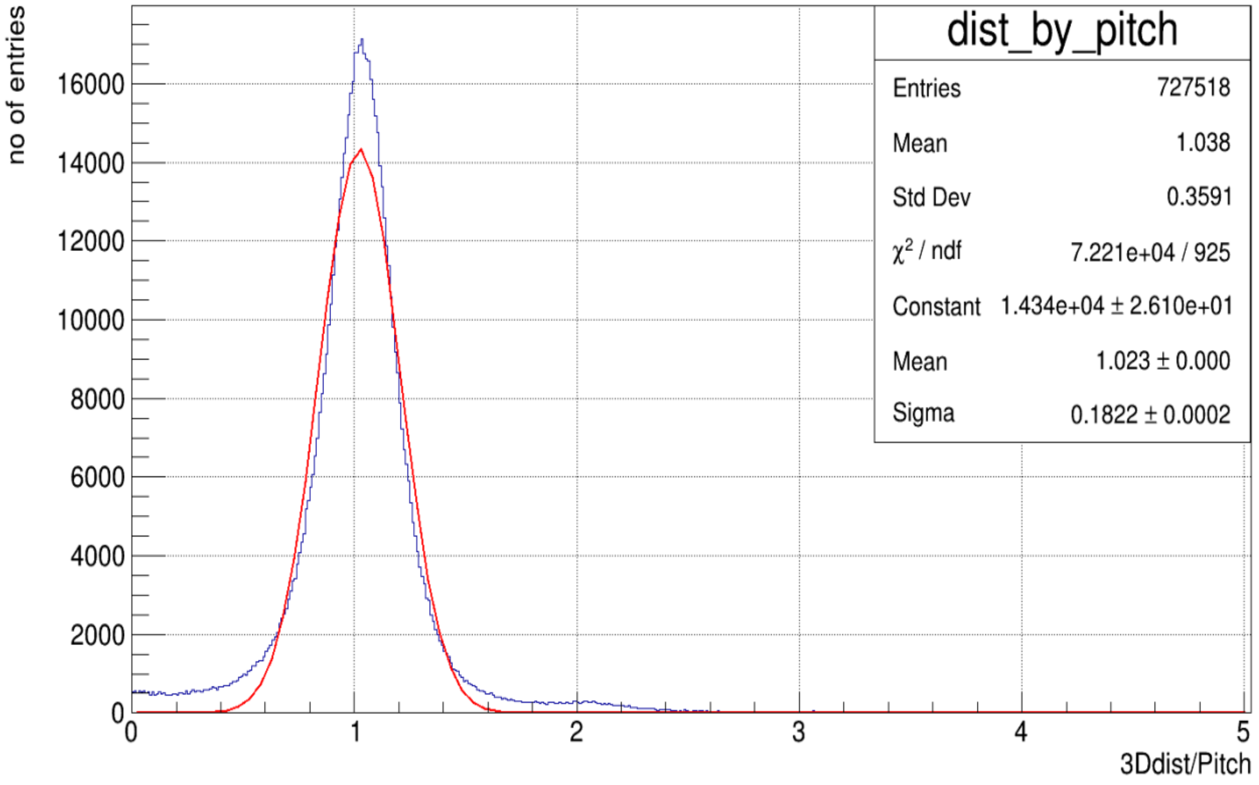
Range shows a better agreement with true tracklength.

SCE OFF contd:

Range/pitchsum



Rato of 3Ddist to pitch



Range/pitchsum = 1.04

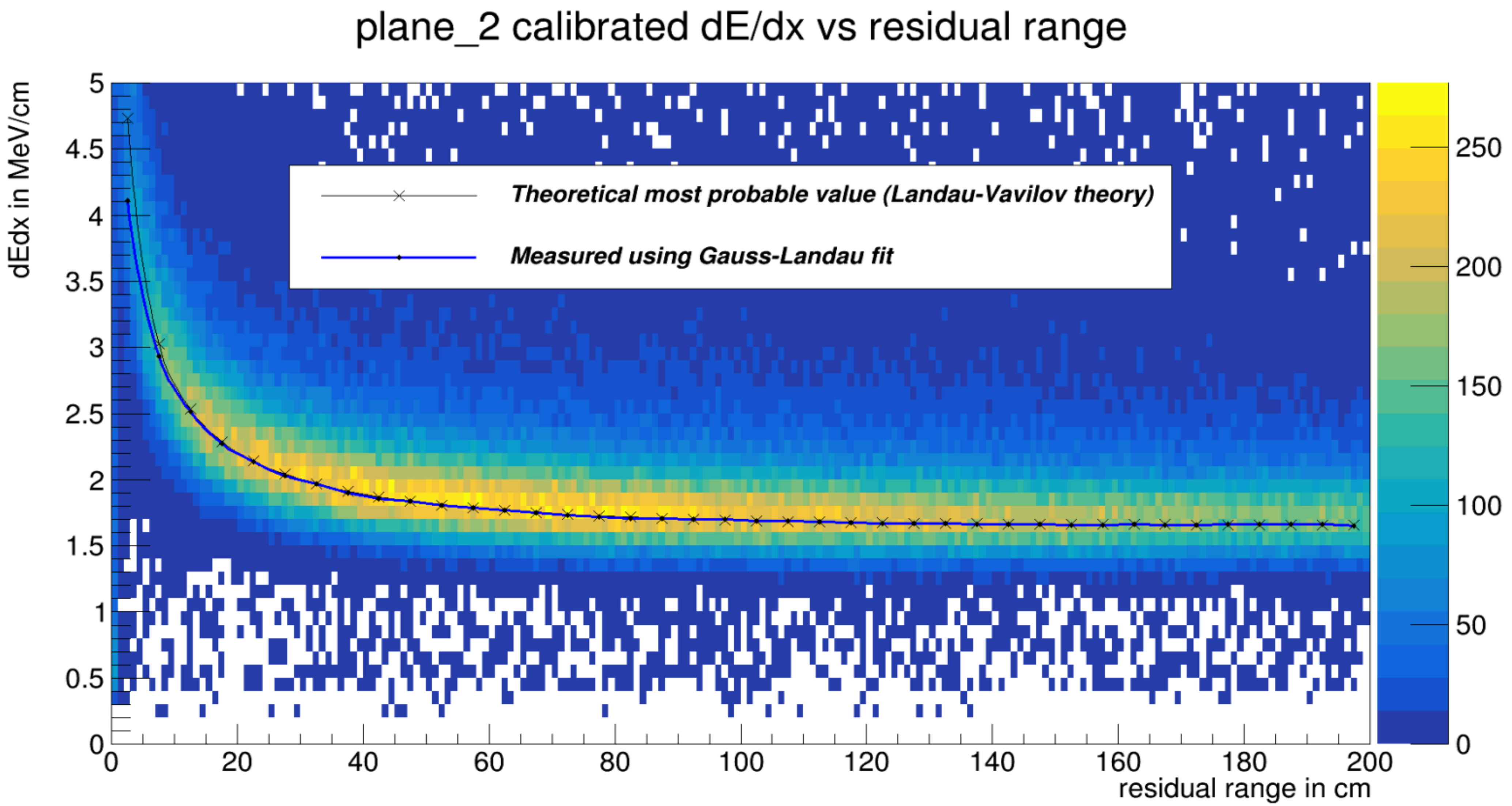
3D dist/pitch = 1.023

3D dist = distance between consecutive hits

These plots shows pitch is underestimated, so when we calculated KEcalo=Σ(dE/dx)*dx , although calibration procedure produces a correct dE/dx at each point but as dx is under-estimated Σ(dE/dx)*dx is lower than it should be.

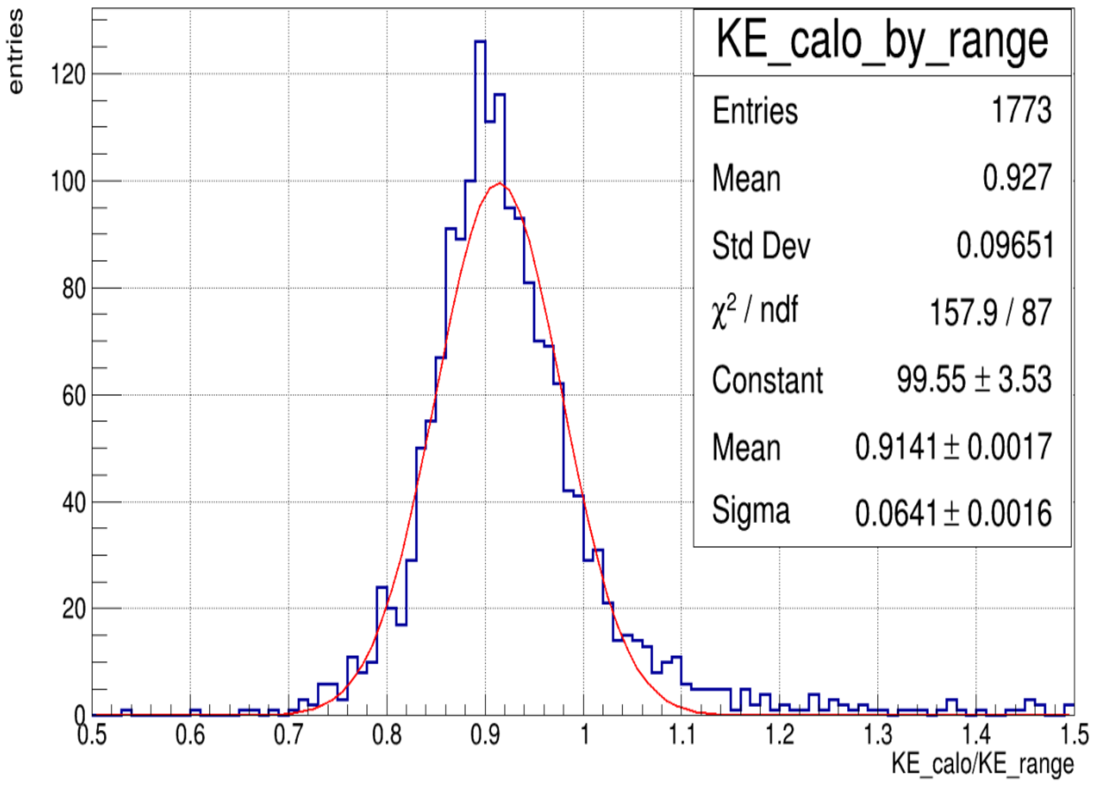
Next few slides shows similar plots for SCE ON sample

SCE ON sample: Calibrated dE/dx vs residual range



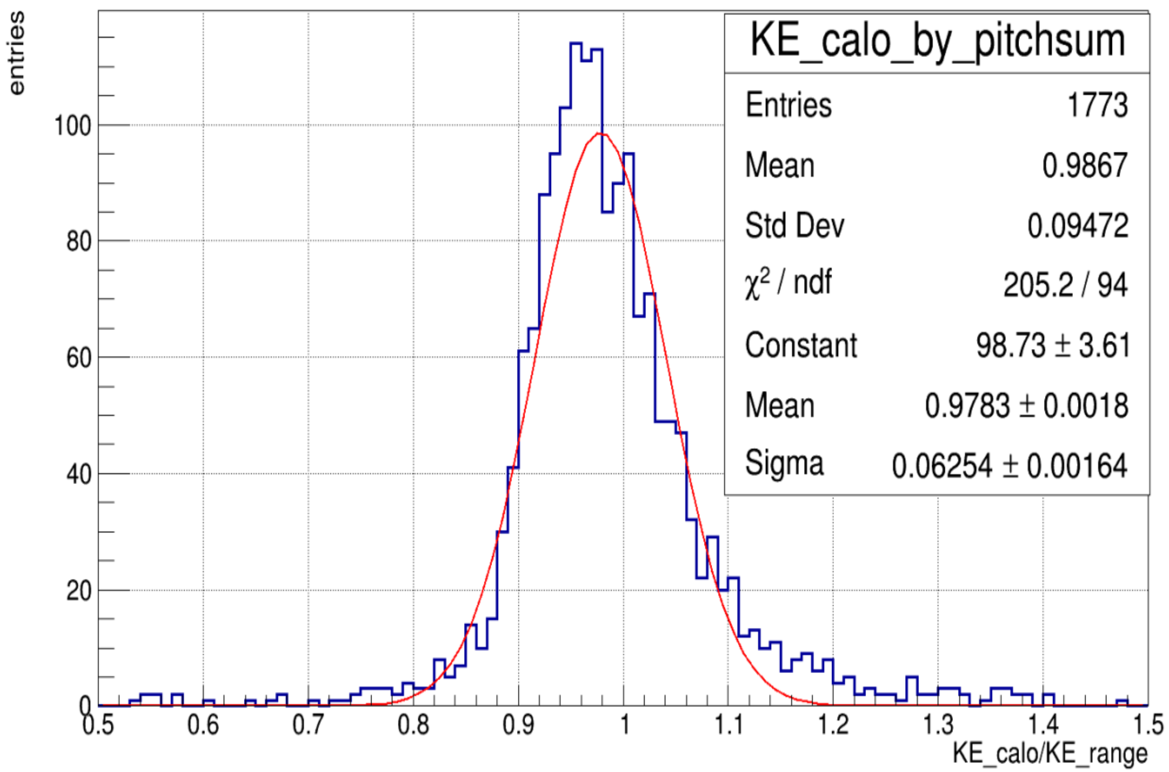
SCE ON sample contd:

KE_calo/KE_range



KE_calo/KE_range = 0.9141

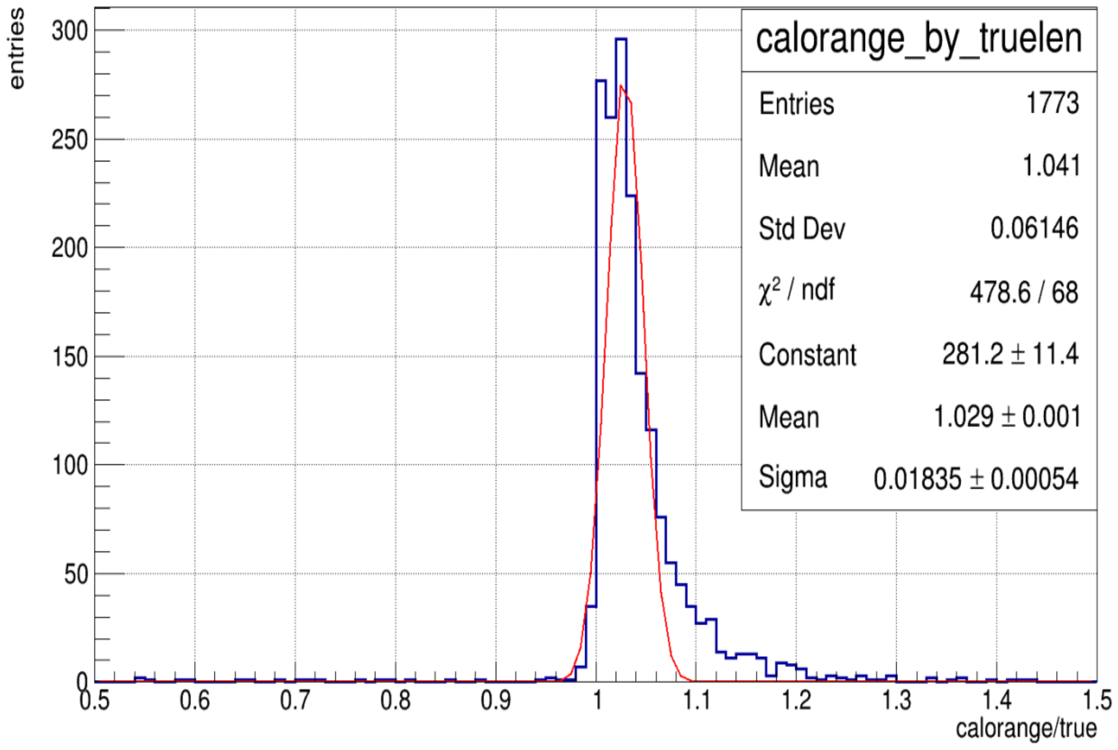
KE_calo/KE_pitchsum



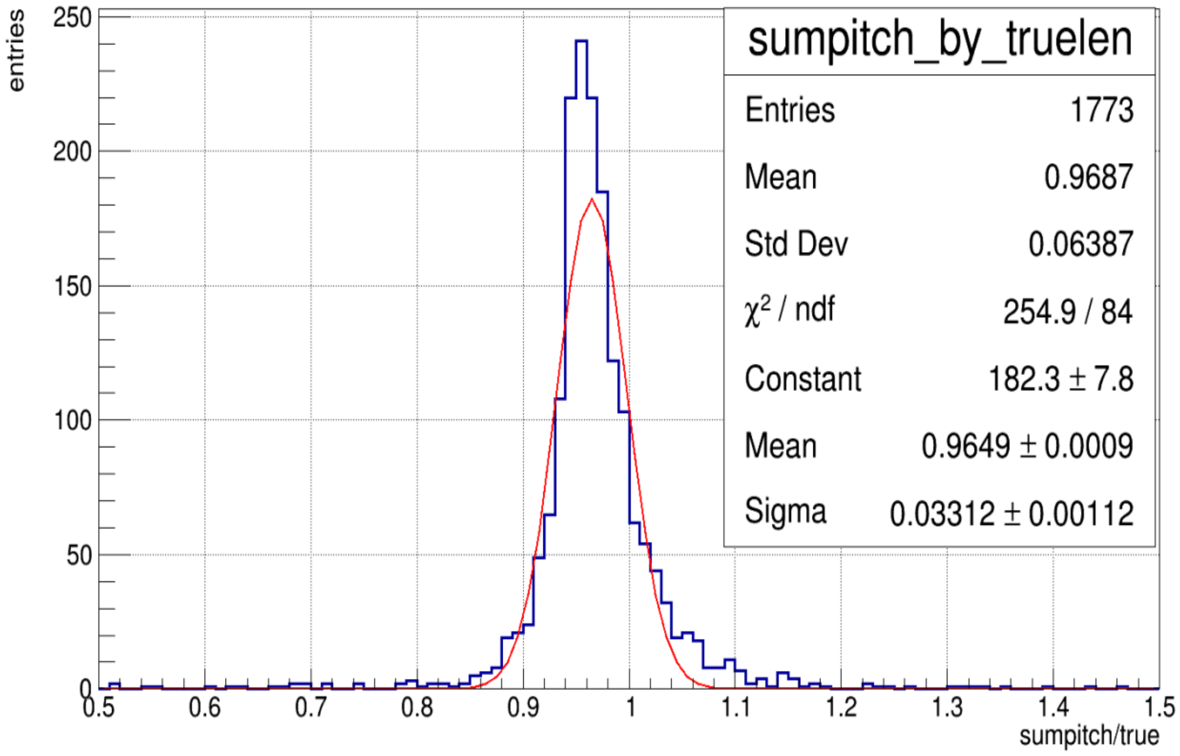
KE_calo/KE_pitchsum = 0.9783

SCE ON sample contd.....

Range/true length



Pitch/true length



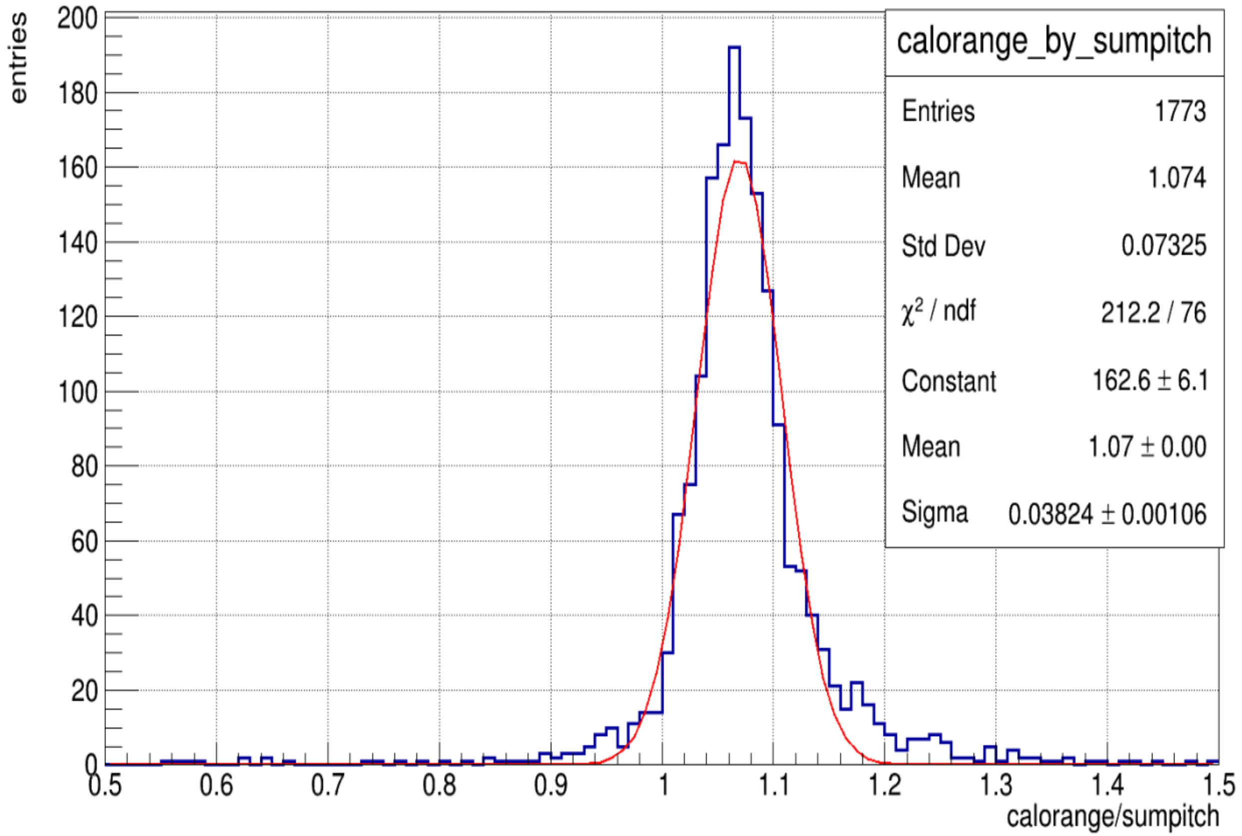
Calorange/true tracklength = 1.029

pitchsum/true tracklength = 0.9649

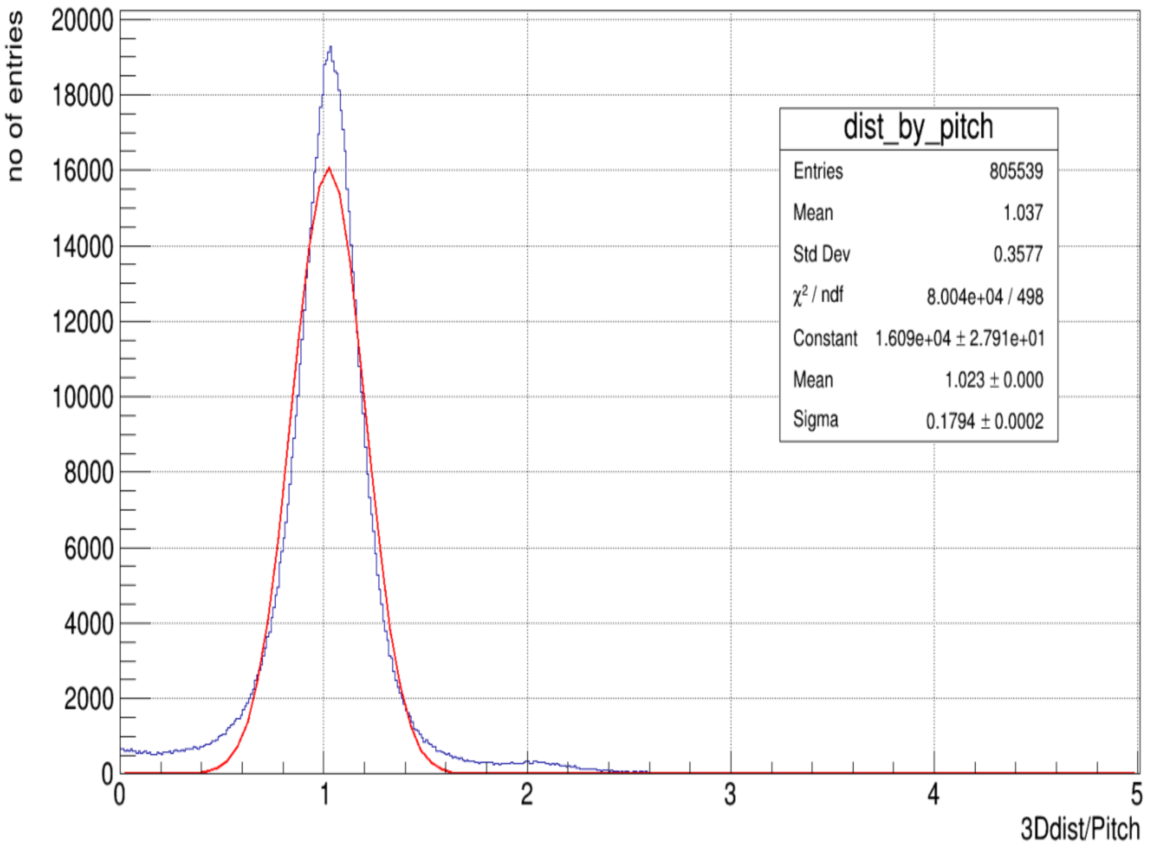
Range appears to be slightly over-estimated and pitchsum appears to be underestimated compared to true tracklength.

SCE ON contd.....

Range/sumpitch



3D dist/pitch

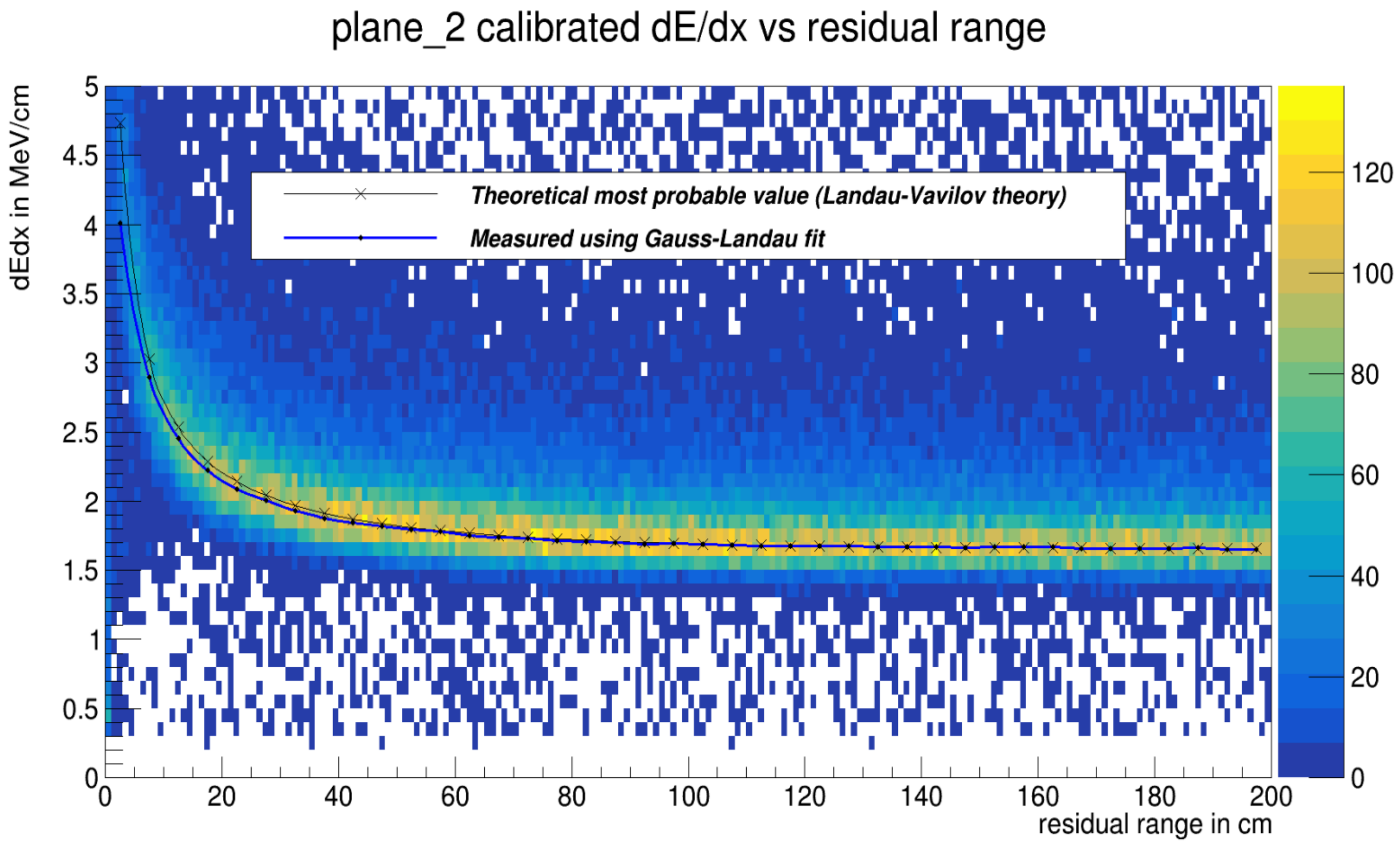


Range/sumpitch = 1.07

3D dist/pitch = 1.023

Pitch is lower than the 3D distance between two hits. Also, as the plot shows ratio only upto 5, so the mean for 3D dist/pitch appears lower.

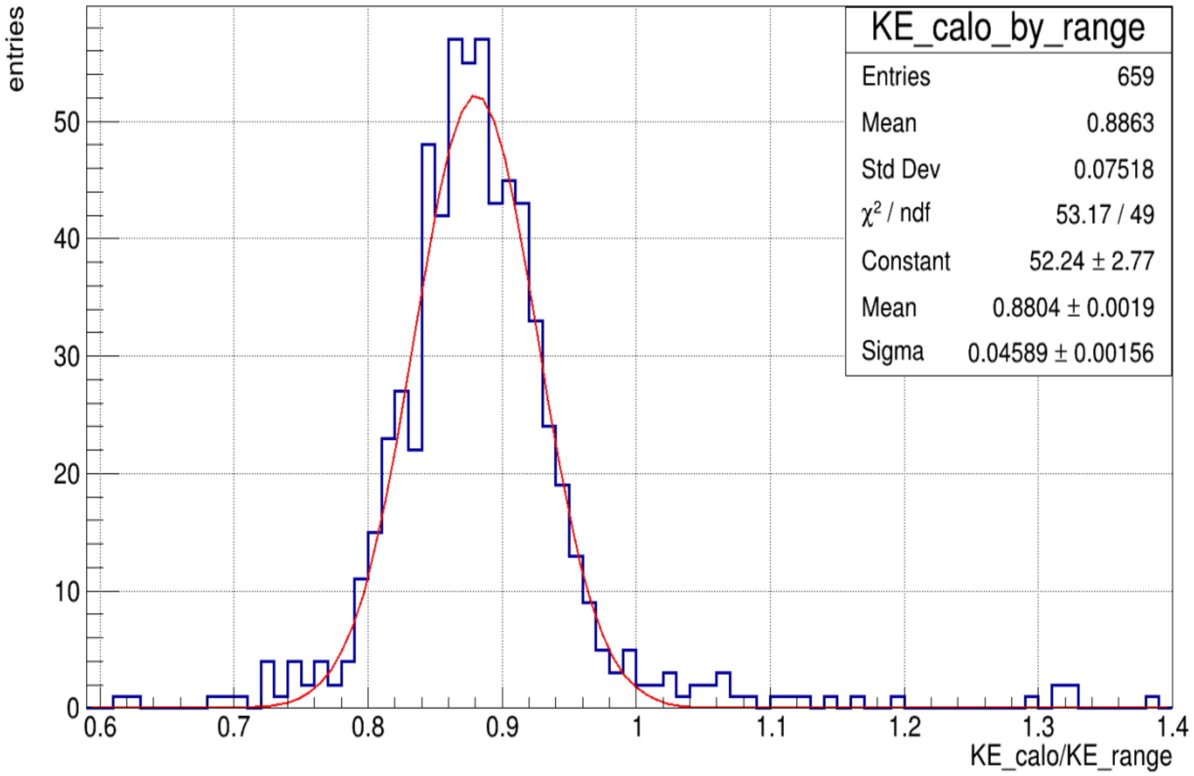
ProtoDUNE-SP data:



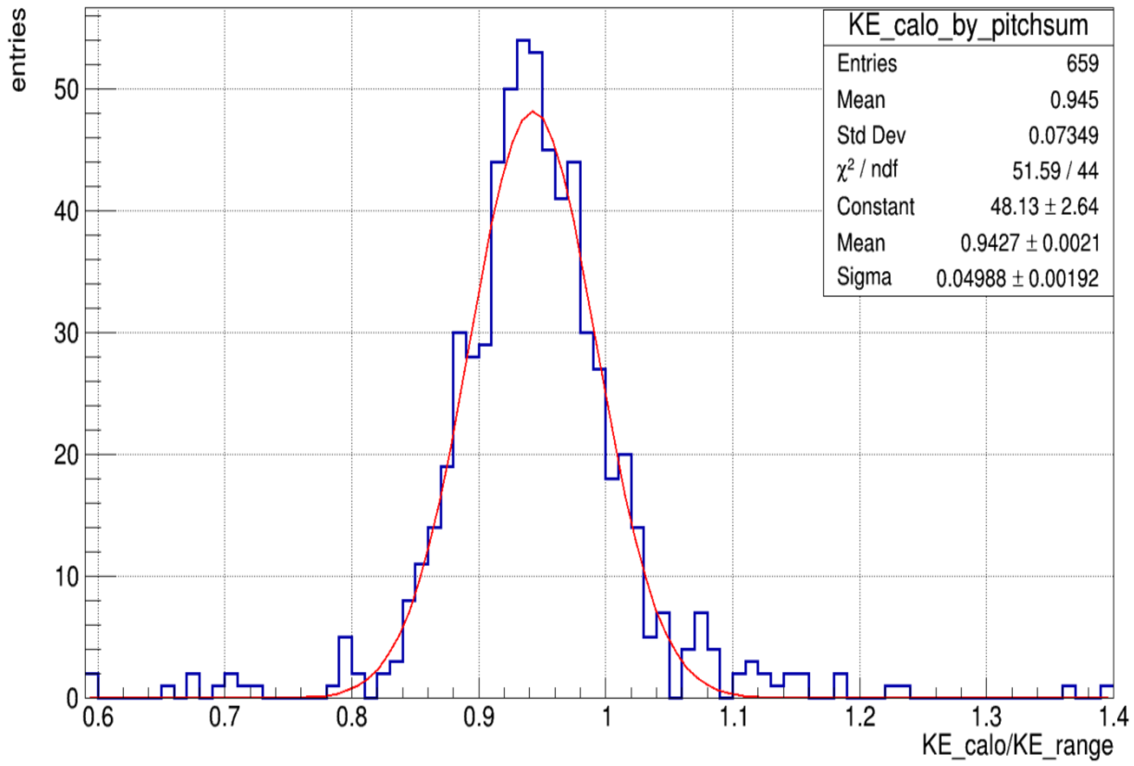
Note: At higher dE/dx there is some disagreement between measured and expected dE/dx

ProtoDUNE-SP data contd....

KE_calo/KE_range



KE_calo/KE_pitchsum

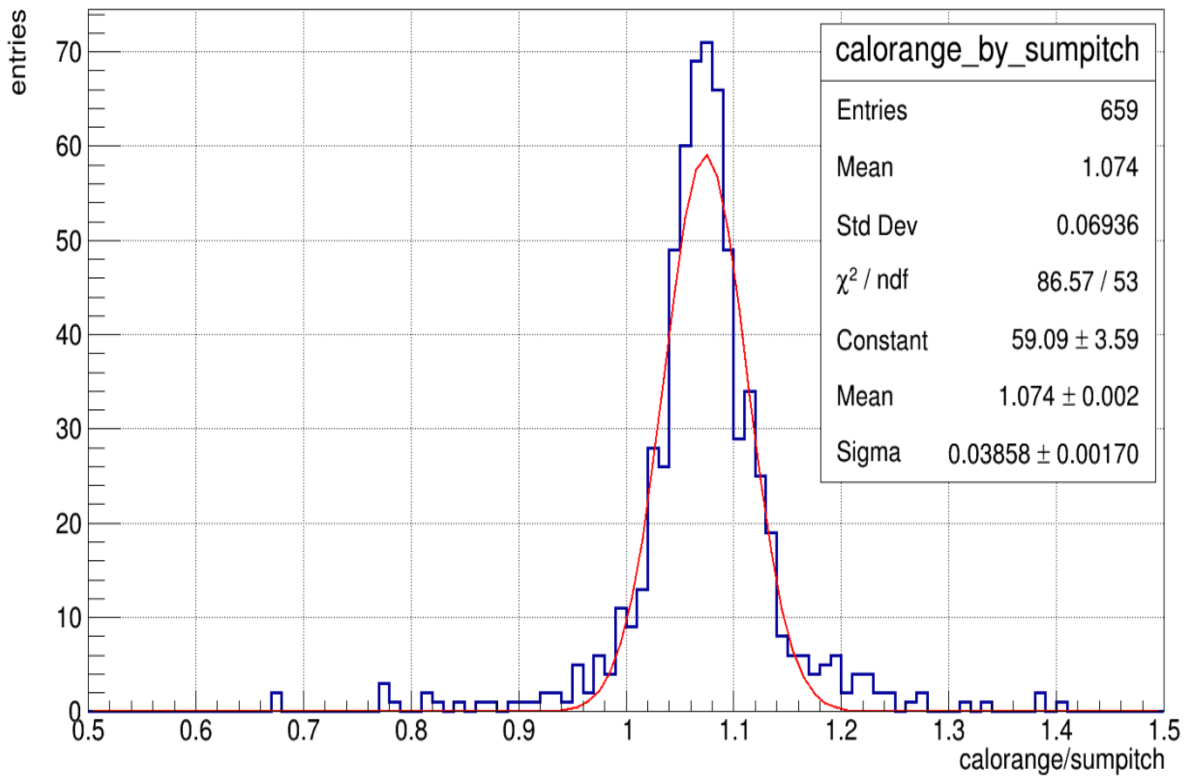


KEcalo/KE_range = 0.8804

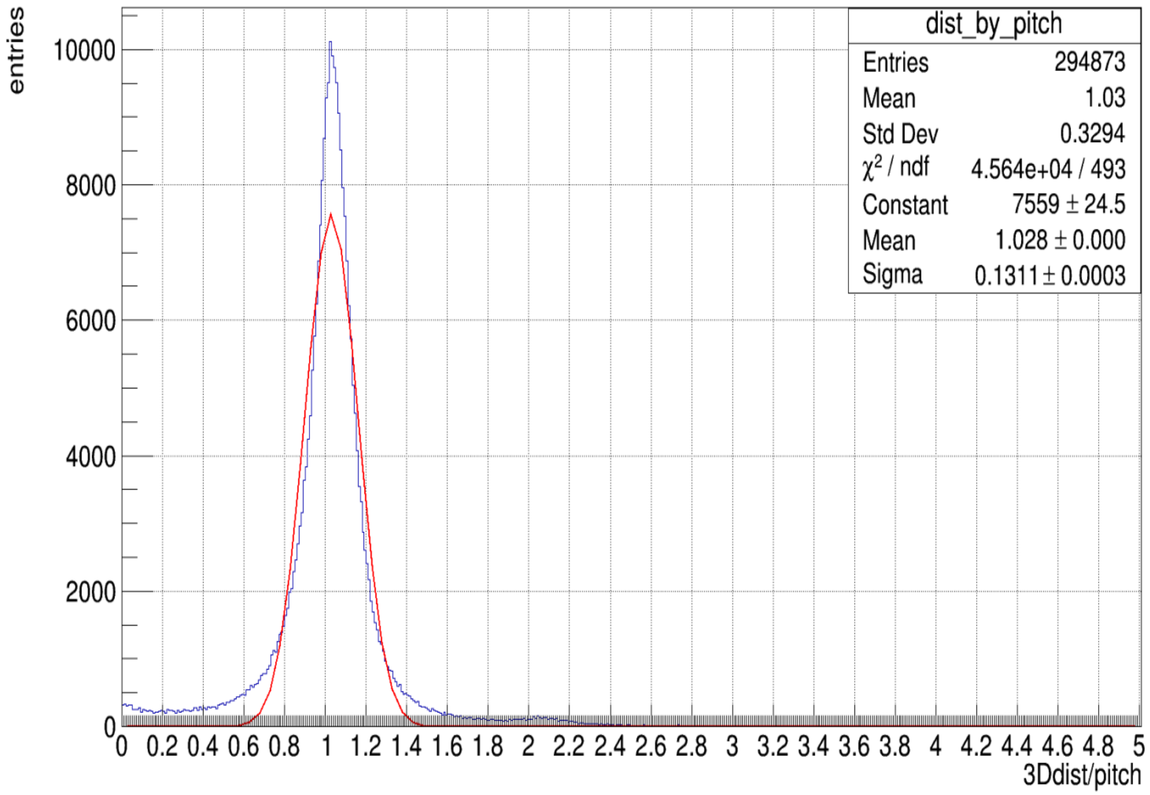
KEcalo/KE_pitchsum = 0.9427

ProtoDUNE-SP data contd....

Range/Pitchsum



3D dist/pitch between hits



Range/Pitchsum=1.074

3D dist/pitch = 1.028

RESULTS and Summary:

Values represent the fitted mean and the error are sigma on mean.

Sample	E_calo/E_range	E_calo/E_pitchsum	range/pitchsum	Range/true tracklength	Pitchsum/true tracklength
MC SCE OFF	0.9307(0.04589)	0.9657(0.0499)	1.04(0.02335)	1.003(0.0079)	0.966(0.0237)
MC SCE ON	0.9141(0.0641)	0.9783(0.06254)	1.07(0.01835)	1.029(0.03312)	0.9649(0.03824)
PROTODUNE-SP DATA	0.8804(0.04589)	0.9427(0.04988)	1.074(0.03858)	Not applicable	Not applicable

- Range is closer to true tracklength compared to pitchsum.
- Pitch values are under-estimated, so when we calculated Ecalo=Σ(dE/dx)*dx , although calibration procedure produces a correct dE/dx at each point but as dx is under-estimated Σ(dE/dx)*dx is lower than it should be.
- We need to find a way to address the issue of range vs sumpitch difference.
- For data there is a larger difference between KEcalo and KErange, this could be because at high dE/dx there is some disagreement between observed values and prediction. At high dE/dx recombination plays a bigger role than in the MIP energy, more precise Efield measurement and accurate recombination model may improve the calorimetric energy resolution. There could be other factors that we need to dig into.

Backups

Definition of TrkPitch in Calorimetry_module.cc

https://nusoft.fnal.gov/larsoft/doxsvn/html/Calorimetry__module_8cc_source.html

```
// find track pitch
double fTrkPitch = 0;
for (size_t itp = 0; itp < tracklist[trkIter]->NumberTrajectoryPoints(); ++itp){

  const auto& pos = tracklist[trkIter]->LocationAtPoint(itp);
  const auto& dir = tracklist[trkIter]->DirectionAtPoint(itp);

  const double Position[3] = { pos.X(), pos.Y(), pos.Z() };
  geo::TPCID tpcid = geom->FindTPCAtPosition ( Position );
  if (tpcid.isValid) {
    try{
      fTrkPitch = lar::util::TrackPitchInView(*tracklist[trkIter], geom->Plane(ipl).View(), itp);

       //Correct for SCE
      geo::Vector_t posOffsets = {0., 0., 0.};
      geo::Vector_t dirOffsets = {0., 0., 0.};
      if(sce->EnableCalSpatialSCE()&&fSCE) posOffsets = sce->GetCalPosOffsets(geo::Point_t(pos),tpcid.TPC);
      if(sce->EnableCalSpatialSCE()&&fSCE) dirOffsets = sce->GetCalPosOffsets(geo::Point_t{pos.X() + fTrkPitch*dir.X(), pos.Y() + fTrkPitch*dir.Y(), pos.Z() + fTrkPitch*dir.Z()},tpcid.TPC);
       TVector3 dir_corr = {fTrkPitch*dir.X() - dirOffsets.X() + posOffsets.X(), fTrkPitch*dir.Y() + dirOffsets.Y() - posOffsets.Y(), fTrkPitch*dir.Z() + dirOffsets.Z() - posOffsets.Z()};

      fTrkPitch = dir_corr.Mag();
    }
    catch( cet::exception &e){
      mf::LogWarning("Calorimetry") << "caught exception "
                                    << e << "\n setting pitch (C) to "
                                    << util::kBogusD;
      fTrkPitch = 0;
    }
    break;
  }
}
```