Basics tests on energy reconstruction: CRP gaps and hits reconstruction

A.Meregaglia (LP2I Bordeaux)

Work done in collaboration with A.Tonazzo (APC Paris), D.Autiero (IP2I Lyon) and E.Pennacchio (IP2I Lyon)

Simu/Reco meeting - 11th March 2024

Introduction

- To study the neutrino reconstructed energy we started from basic information i.e. MC trutho info, G4 energy deposits and Hit energy.
- We want to validate and understand each step and we focus on the easiest part which is the **muon energy reconstruction**.
- We used official MC files of neutrino interactions and specific simulated files with only muons obtained with the same fcl configuration file as neutrino MC.

General info

Official Nu MC files

- Input files (https://wiki.dunescience.org/wiki/Production) copied at Lyon (small stat for now)
    - prodgenie_nu_dunevd10kt_1x8x6_3view_30deg.fcl (non-oscillated neutrinos)
- DUNE version v9_81_00d01
- Custom made analyzer to extract infos from branches:
    - simb::MCTruths_generator_GenieGen
    - simb::MCParticle_largeant_G4
    - sim::SimEnergyDeposits_largeant_LArG4DetectorServicevolTPCActive_G4
    - recob::Hits_gaushit_Reco1

Custom muon files

- Muons of 1.5 GeV momentum were generated using the same detector configuration as for official MC production.
- Electrons of 1.5 GeV were also produced.
- The same analyzer was used on the output file.

Selections

Official Nu MC files

- Only CCQE events were selected at generator level (interaction type 1001).
- NuMu CC QE = 13.28% of the events (667 out of 5000 events).
- Ask for muon contained = 1.6% (80 out of 5000 events).

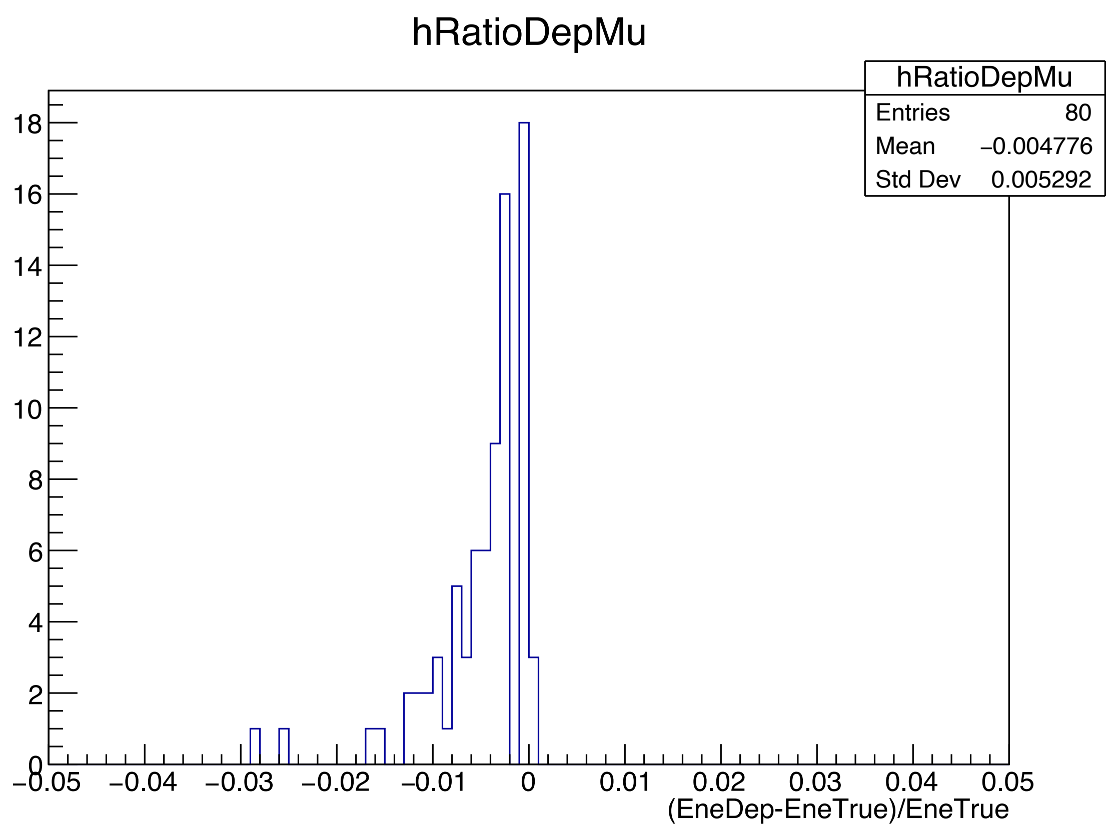
Custom muon files

- Ask for muon contained (avoid gap at Y=0 between CRP) = 91% (91 out of 100 events).

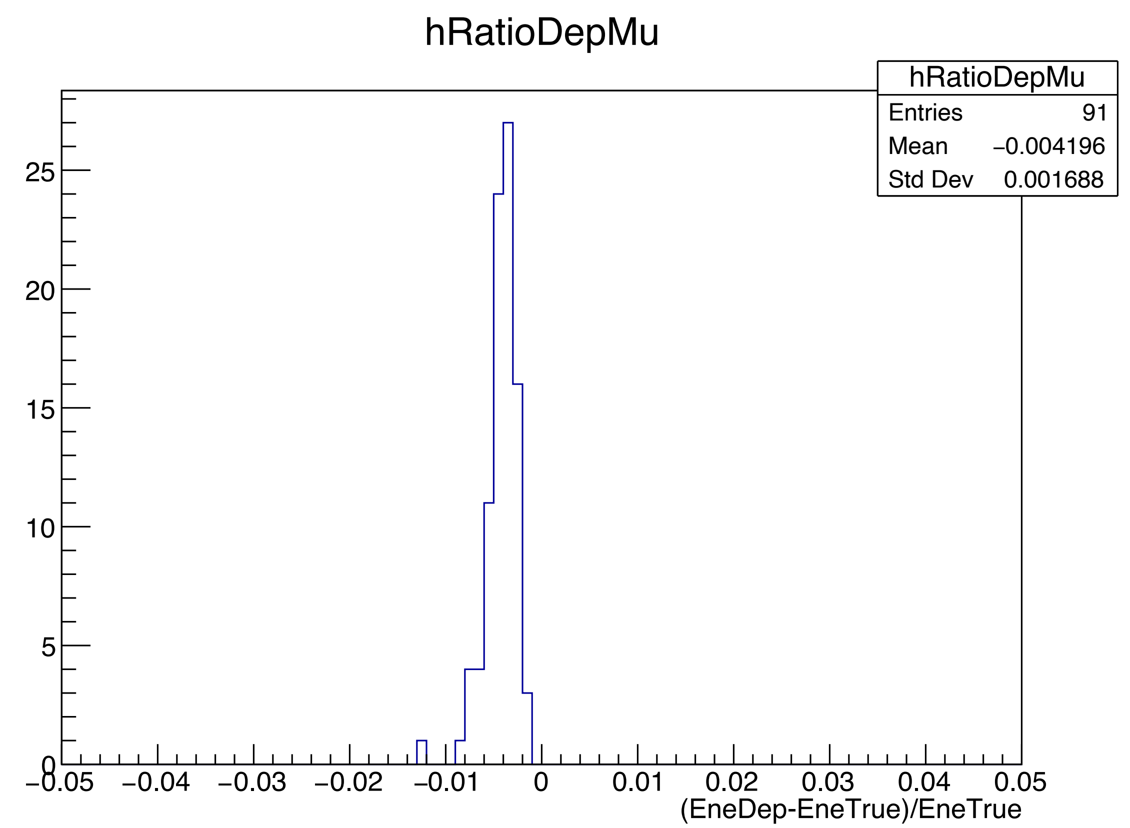
Check on energy deposits

- We compared the sum of the deposited energy with the true kinetic energy.
- For the NuQE events we included deposits with the correct PDG of the particle and depostis from electrons issued by the particle under study.

NuQEMC



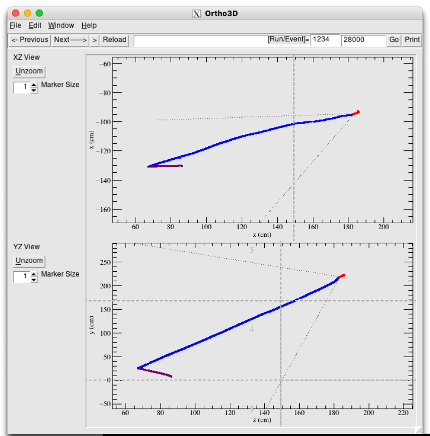
Custom muon files



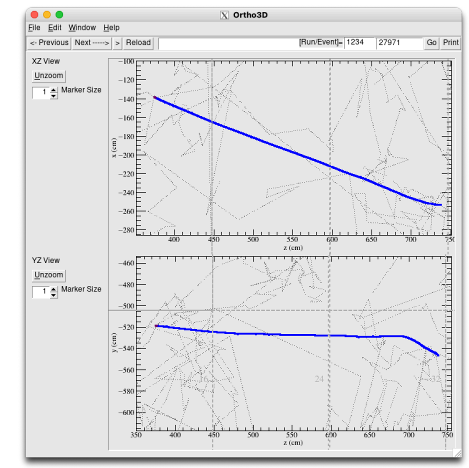
Small shift and tail probably due to the CRP gaps in Z.

Energy deposits Vs muon energy

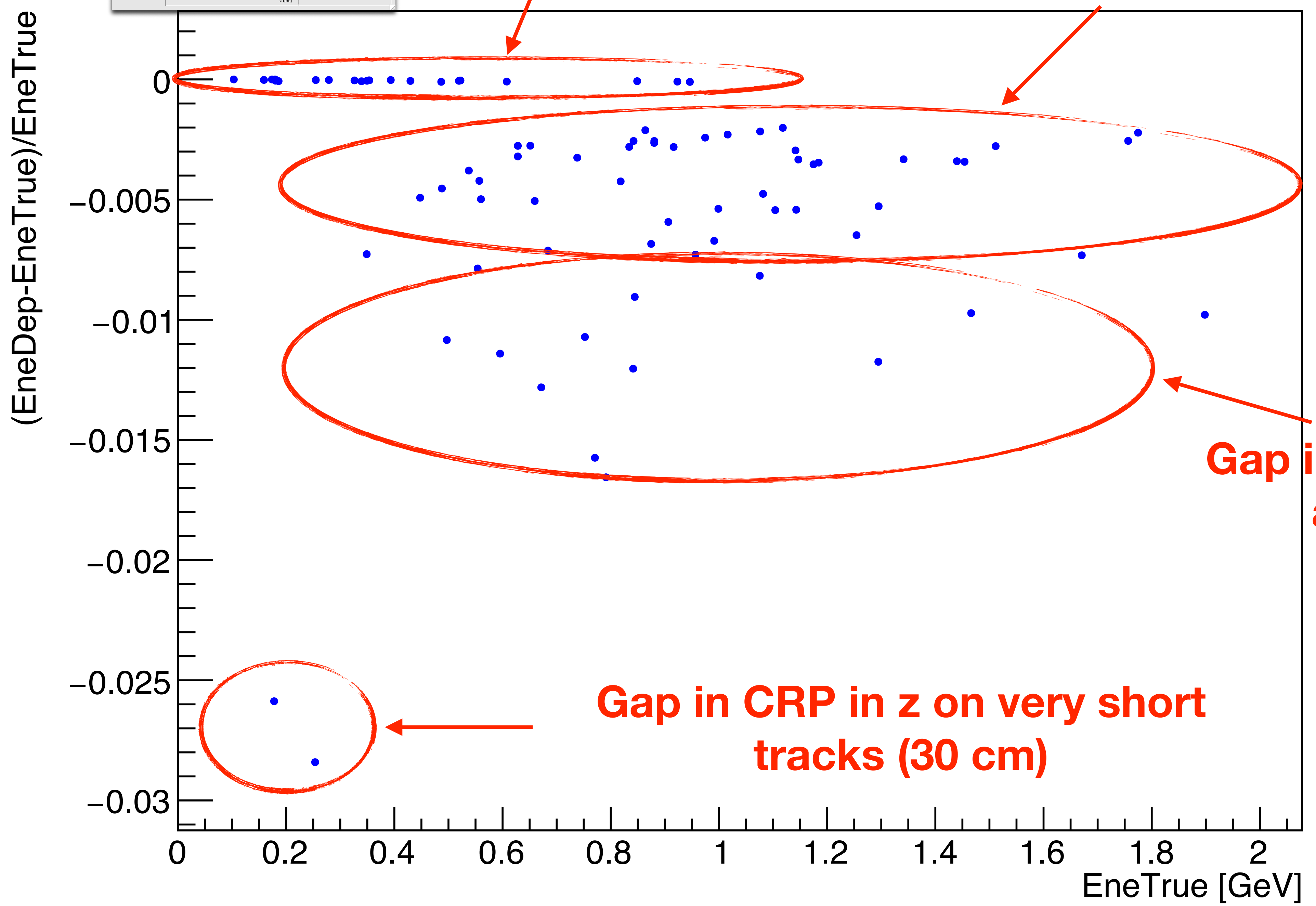
NuQEMC

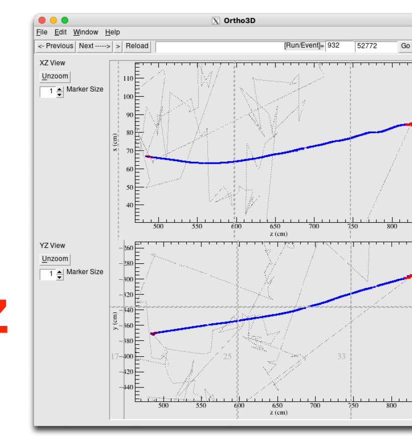


Gap in CRP in z which becomes more important at low energy and high angle (loss of 1 cm minimum to be compared to track length)



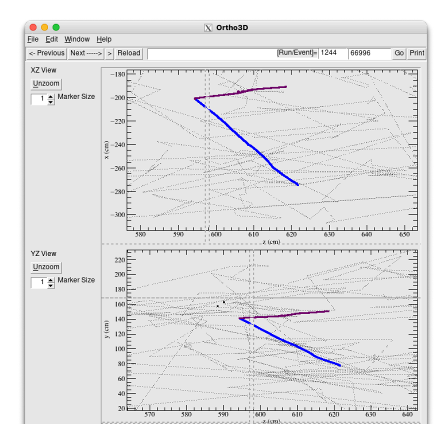
No CRP gap





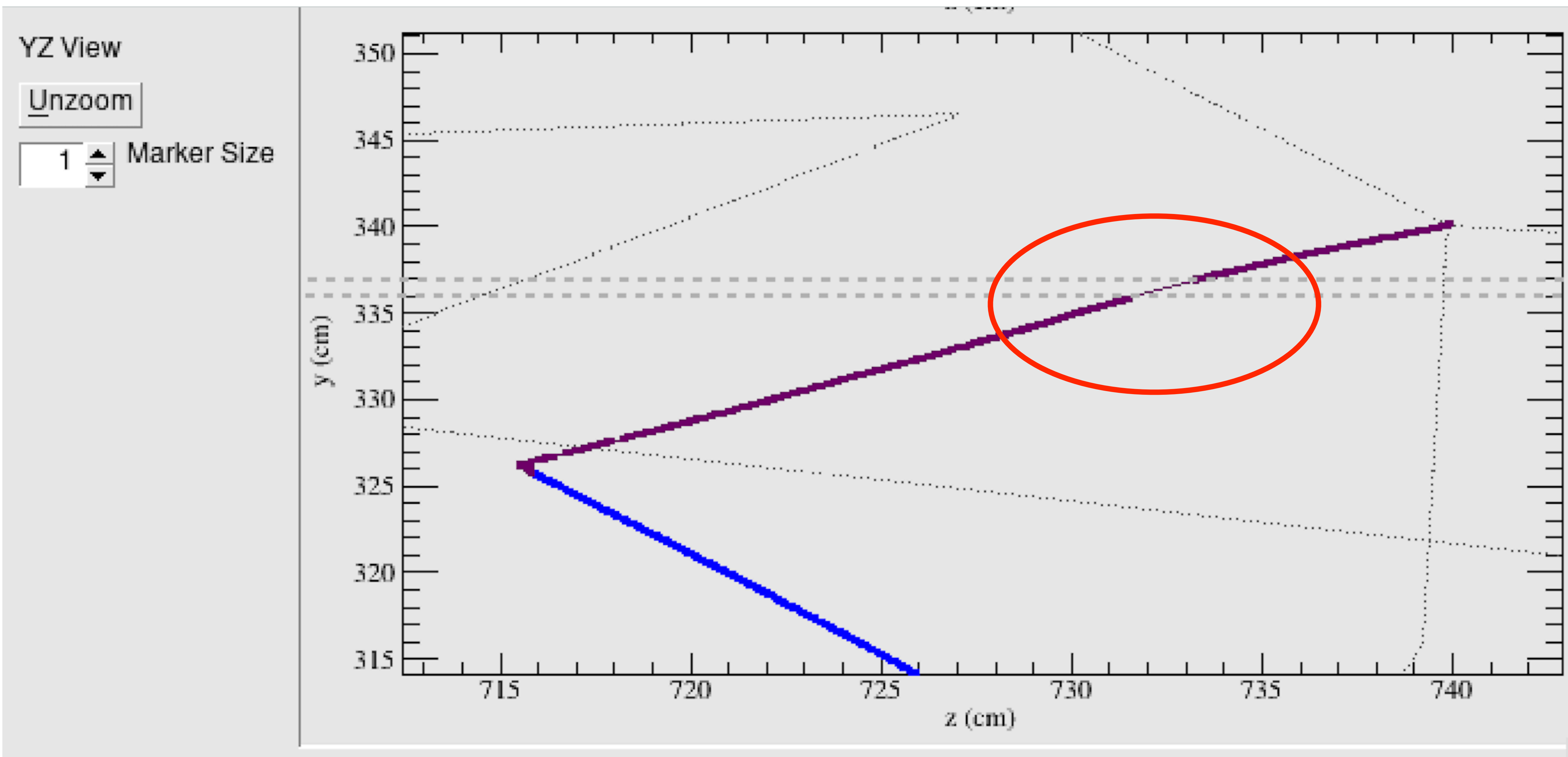
Gap in CRP in z and y

Gap in CRP in z on very short tracks (30 cm)



CRP gap

- It is clear that gaps in the CRP represent a loss of deposited energy with respect to true one.
- Is that accounted correctly?

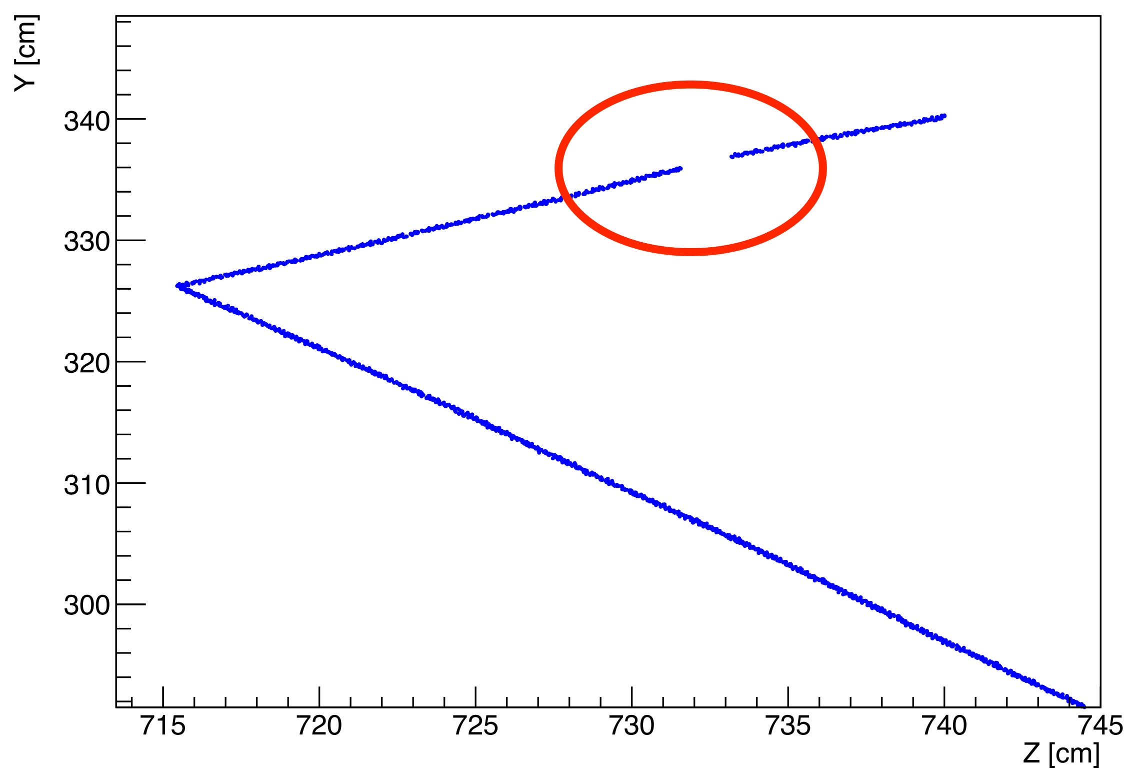


CRP gap

- An additional check was carried out since Dom suggested it could be a display issuse (although we see a tail in the deposited energy distribution with respect to true one).
- From the file we use:

```
art::Ptr<sim::SimEnergyDeposit> SimEnergyDeposit(SimEnergyDepositVector.at(kk));
    fEDep.push_back(SimEnergyDeposit->Energy());
    fEDepStartX.push_back((SimEnergyDeposit->Start()).X());
    fEDepStartY.push_back((SimEnergyDeposit->Start()).Y());
    fEDepStartZ.push_back((SimEnergyDeposit->Start()).Z());
```

- We directly plot those variables confirming that the energy deposits are already lost at the level of SimEnergyDeposit.



CRP gap: status and work to be done

- The actual gap in the MC simulation is 5 mm.
- Real life is different and from discussions with D.Autiero, V.Galymov and D.Duchesneau we have:
  - **gap between 2 CRP** = 6mm (dead edge of each CRP) x 2 + 4mm (gap between CRPs) = **16mm**
  - **gap between super structures**= 2 x 6mm (dead edge of each CRP) + 20mm (gap between CRPs) = **32mm**
- To do:
  - The real gap is much larger and it should be correctly included in the MC for next MC production (mid 2024?)
  - The charge deposited in the gap is not totally lost. Probably edge channels will recover part of it. A detailed COMSOL simulation is needed (work ongoing by Y.Kermaidic).
  - Once the two previous points are assessed a proper evaluation of the gap impact in particular for EM showers is needed.

Hit reconstruction

- A second step of our work is the comparison of the deposited energy with the one reconstructed summing up the Hits.
- We use the **Utility** function by D.Brailsford to know which G4 particle contributed to the hit.
- We select the hit of the muon and look at the energy in the collection plane.
- When testing Edep Vs hit energy we applied the electron lifetime correction using the X position of the energy deposit. The used velocity is 1.60563 mm/µs and the electron lifetime 10.4 ms. The readout is assumed at 3200 mm (but this is just an overall scale factor).
- Recombination correction on EDep is also applied: $$\mathcal{R}_{reco} = \frac{A}{1 + \frac{k}{\mathcal{E}\rho}\frac{E^{corr}_{reco}}{d}}$$

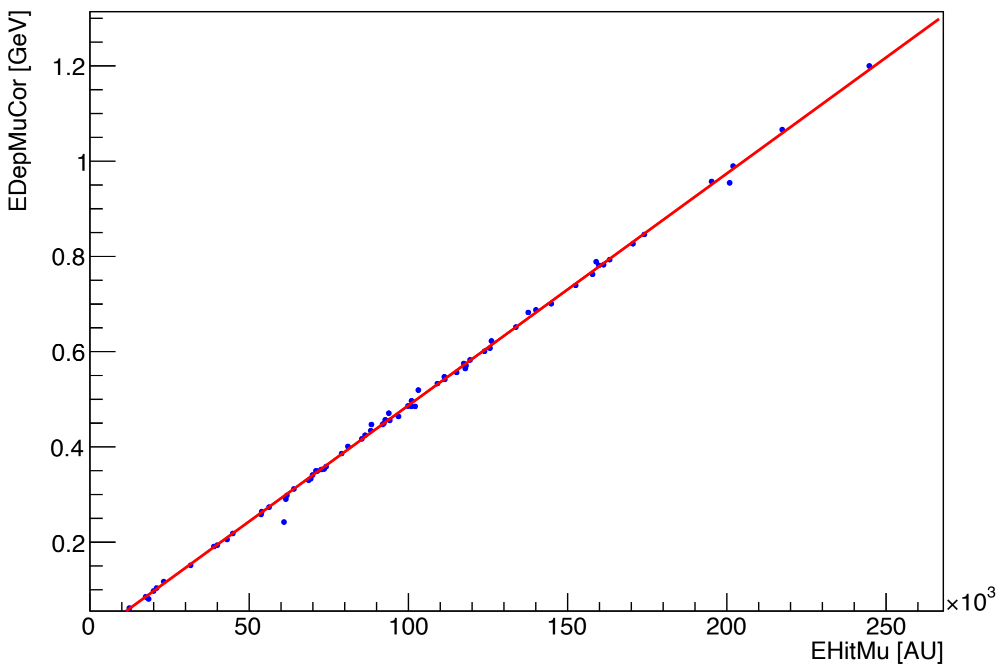
with $A = 0.800 \pm 0.003$ and $k = 0.0486 \pm 0.0006$ $(\mathrm{kV/cm})(\mathrm{g/cm^2})/\mathrm{MeV}$, as measured by the ICARUS collaboration [49]. This parametrization is valid in the range $0.1 < \mathcal{E} < 1.0\,\mathrm{kV/cm}$ and $1.5 < \mathrm{d}E/\mathrm{d}x < 30\ \mathrm{MeV/(g/cm^2)}$ and it will be used for all the calculations performed in this thesis work. Figure 2.4 shows the inverse of the recombination factor as a function

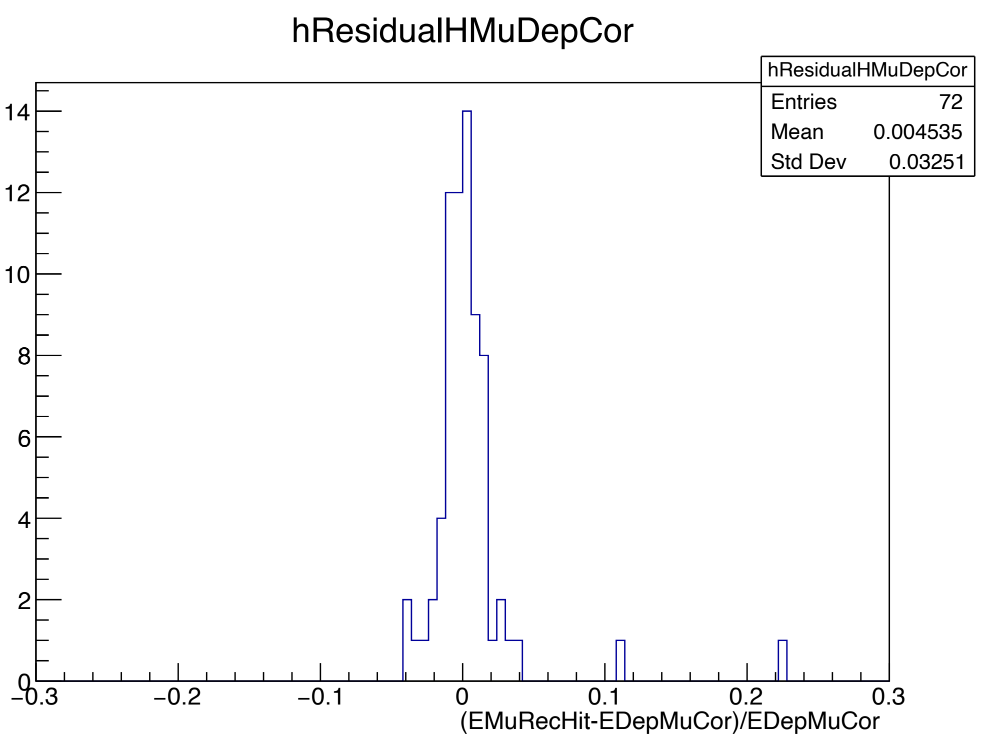
From Davide Caiulo’s thesis (under D.Autiero’s supervision)

- We use the data itself to calibrate and obtain a conversion between hit integral and energy deposited. Note that in the linear fit we impose the line to go through (0,0).

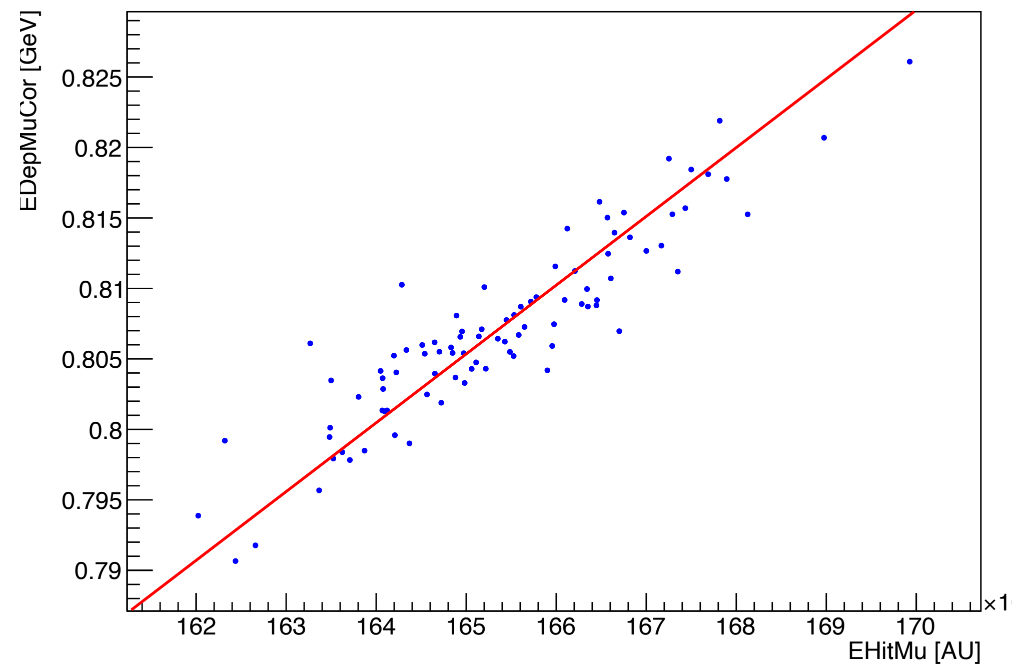
Hit energy reconstruction

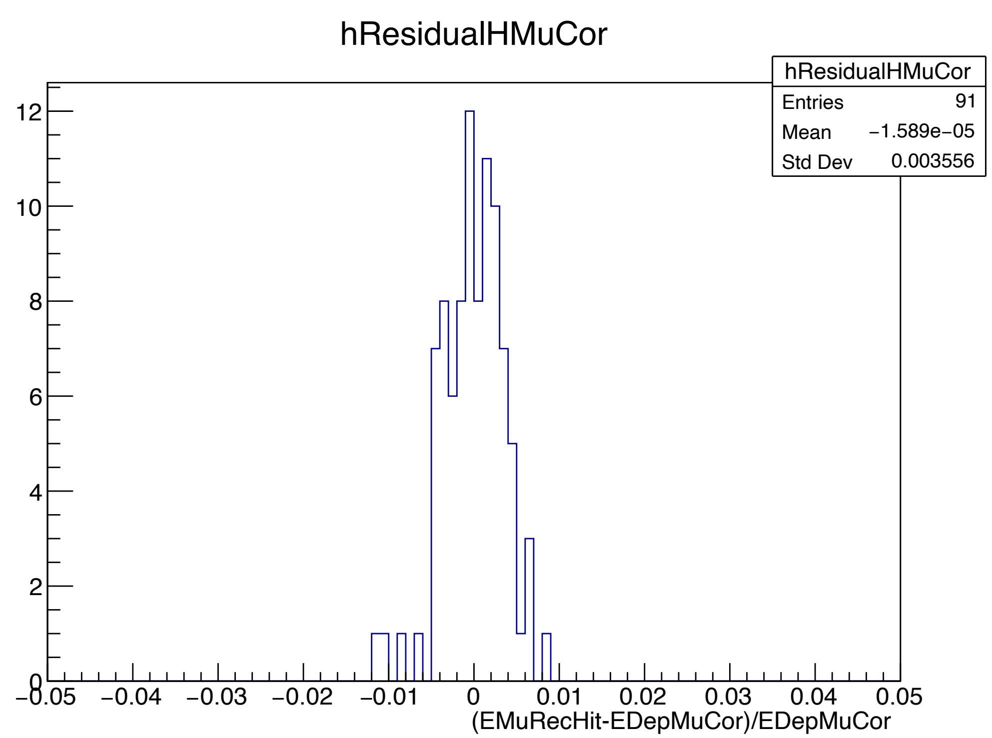
NuQEMC





Custom muon files

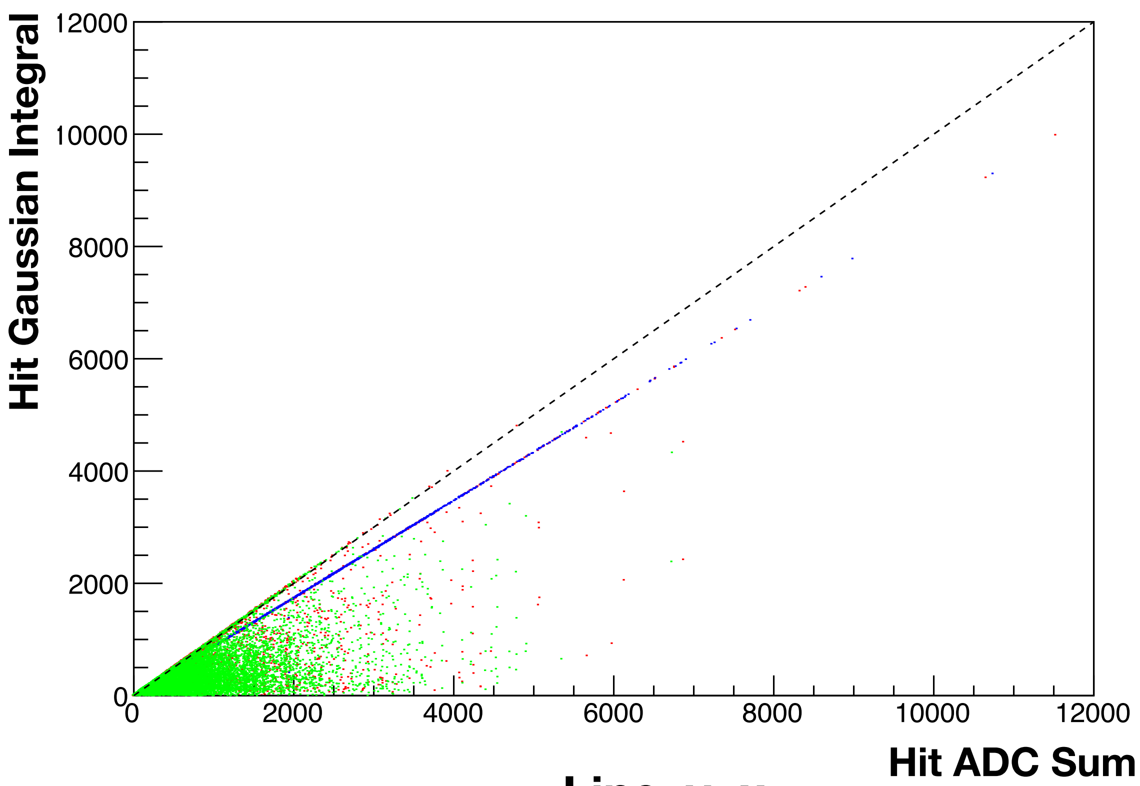




Events with only good hits
(10% of events with hits badly fitted with chi2=-1)

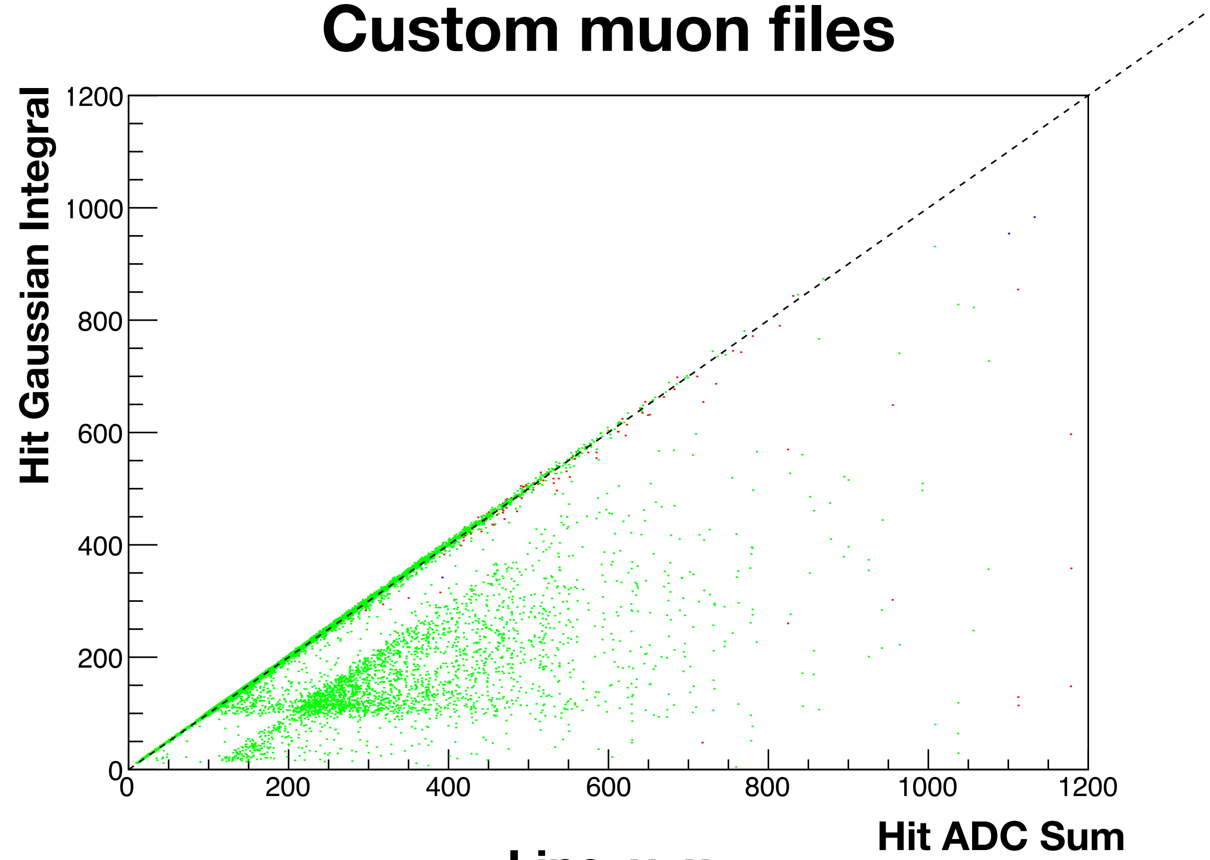
Hits study

NuQEMC



Line: y=x
Blue: chi2=-1 (0.2%)
Red: chi2>10 (0.5%)
Green: 0<chi2<10 (99.3%)

Custom muon files



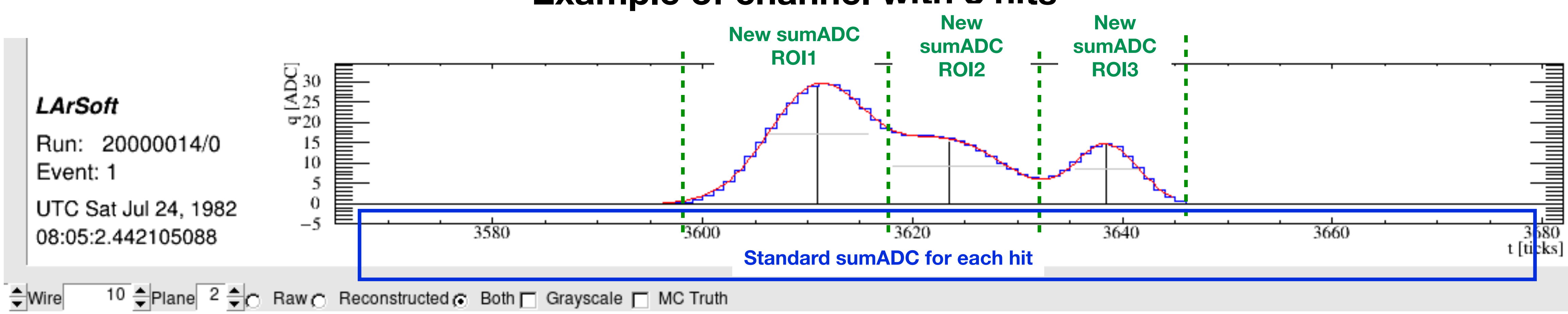
Line: y=x
Blue: chi2=-1 (0.004%)
Red: chi2>10 (0.1%)
Green: 0<chi2<10 (99.9%)

- We compared the ADCsum of the hits with their Gaussian integral and several points have to be understood:
  - Why the integral of the gaussian fit is always smaller than the ADC sum?
  - Why for badly reconstructed hits the integral is a constant fraction of sumADC and not sumADC itself?
  - In the following reconstruction step for the particle energy reconstruction the Gaussian integral is normally used: why?

Hit reconstruction

- After further checks we understood that for channels with only one hit the Gaussian integral and the ADC sum are almost equivalent.
- However, for channels with more than one hit, SumADC function integrates the whole ROI therefore several hits on the same channel have differen integral but the same SumADC.
- A quick fix was applied in a custom version of larreco and tested on the same events.
- The sumADC integrates ADC in a range of ± 2 σ around the Gaussian mean.
- In case the integration ranges of two hits overlap a correction is applied in order to avoid ADC double counting, using the rms of the two Gaussians as weights to split the common interval.

Example of channel with 3 hits

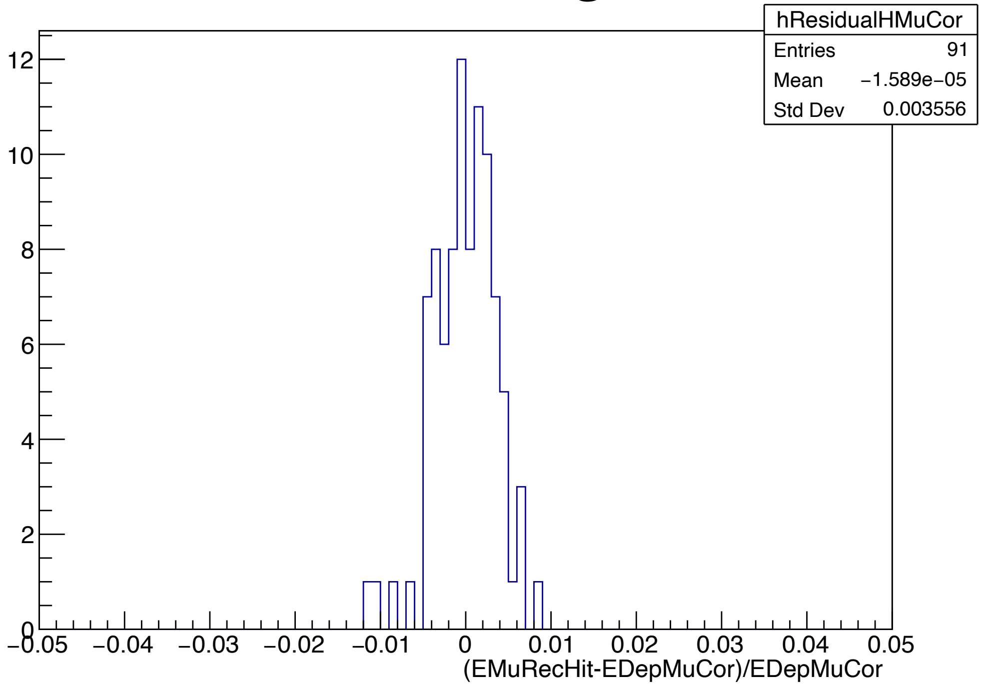


The 3 hits are correctly fitted with different Gaussian integrals, but each one has the same ADC sum of the whole ROI. In the modified version each one has a different sumADC

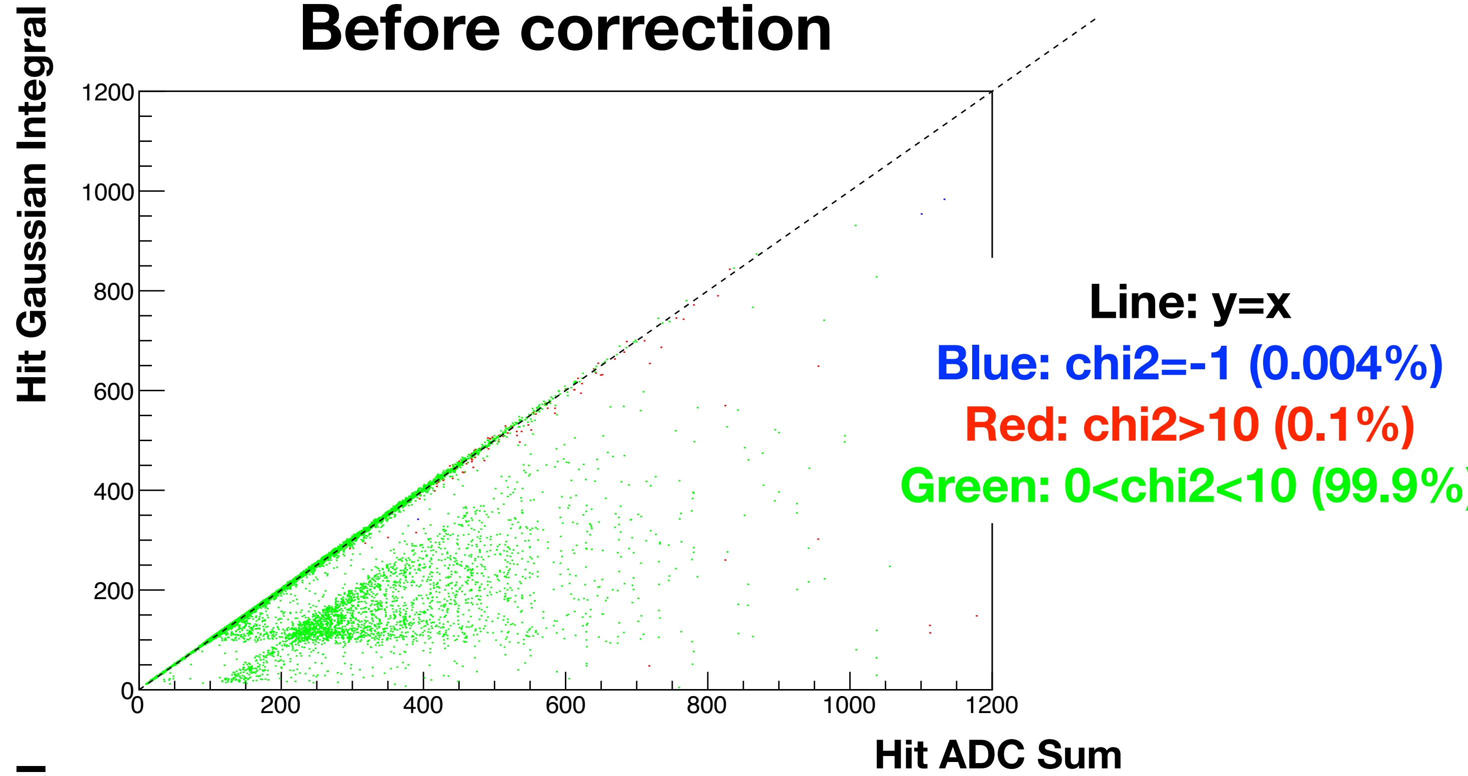
Hits study

Custom muon files

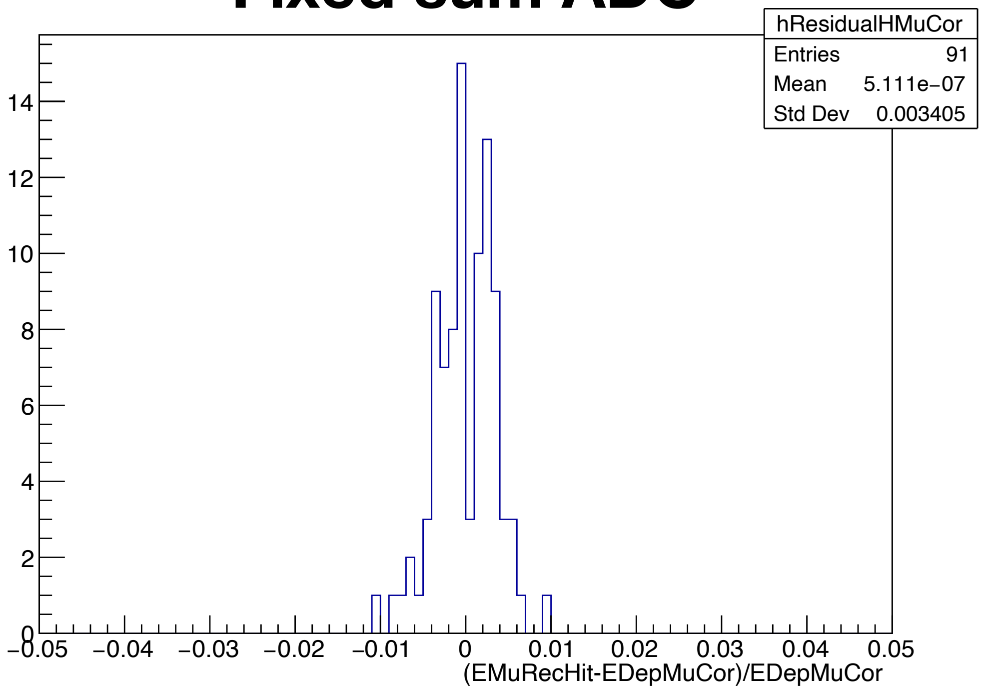
Gauss integral



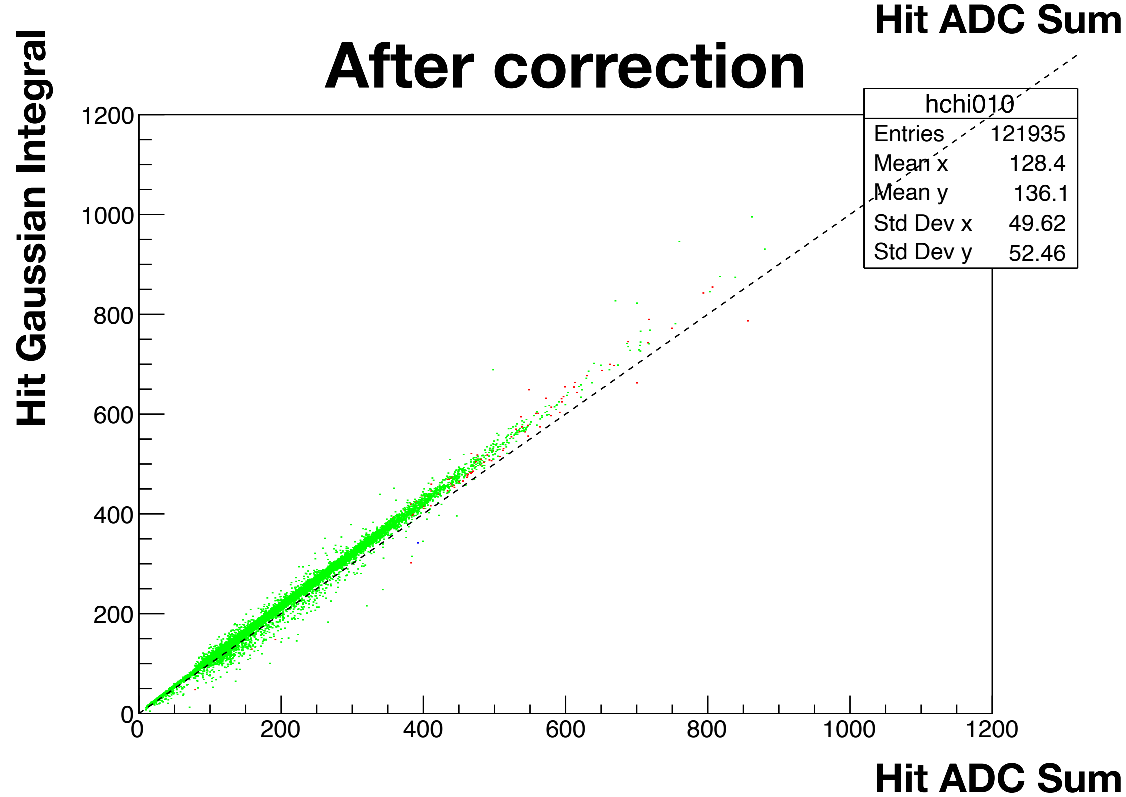
Before correction



Fixed sum ADC



After correction

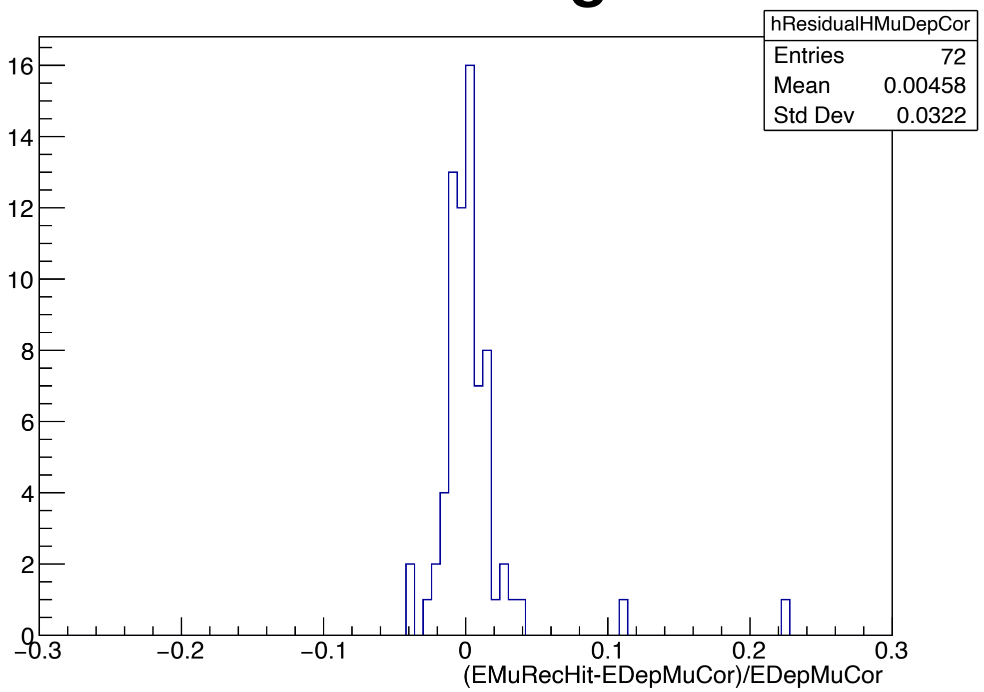


No resolution improvement (0.3%) but correct agreement between integral and sumADC

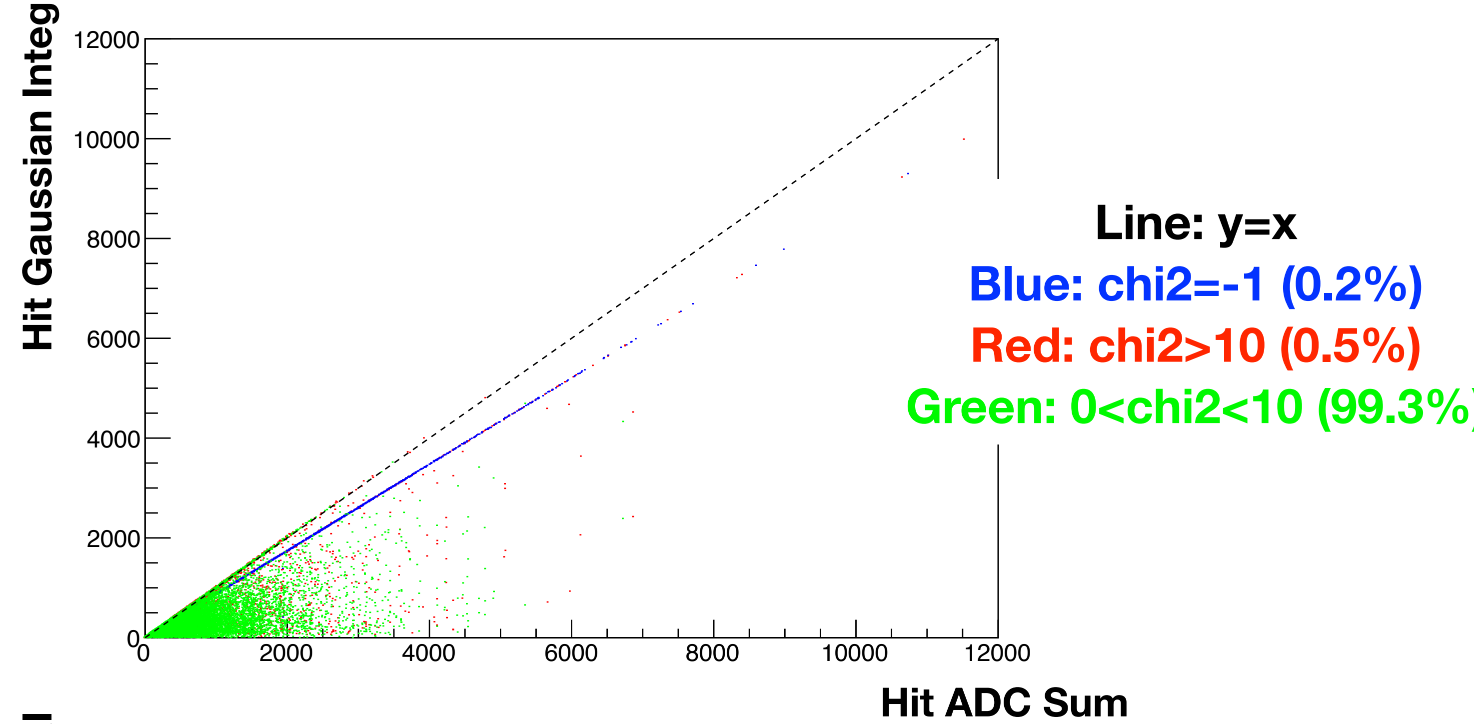
Hits study

NuQEMC (Events with only good hits)

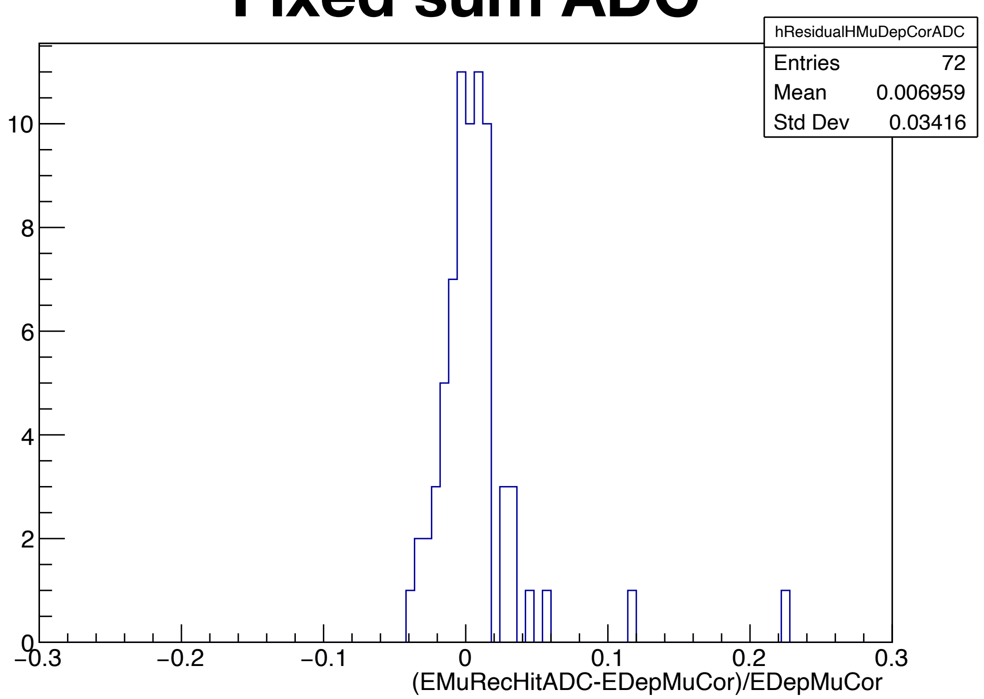
Gauss integral



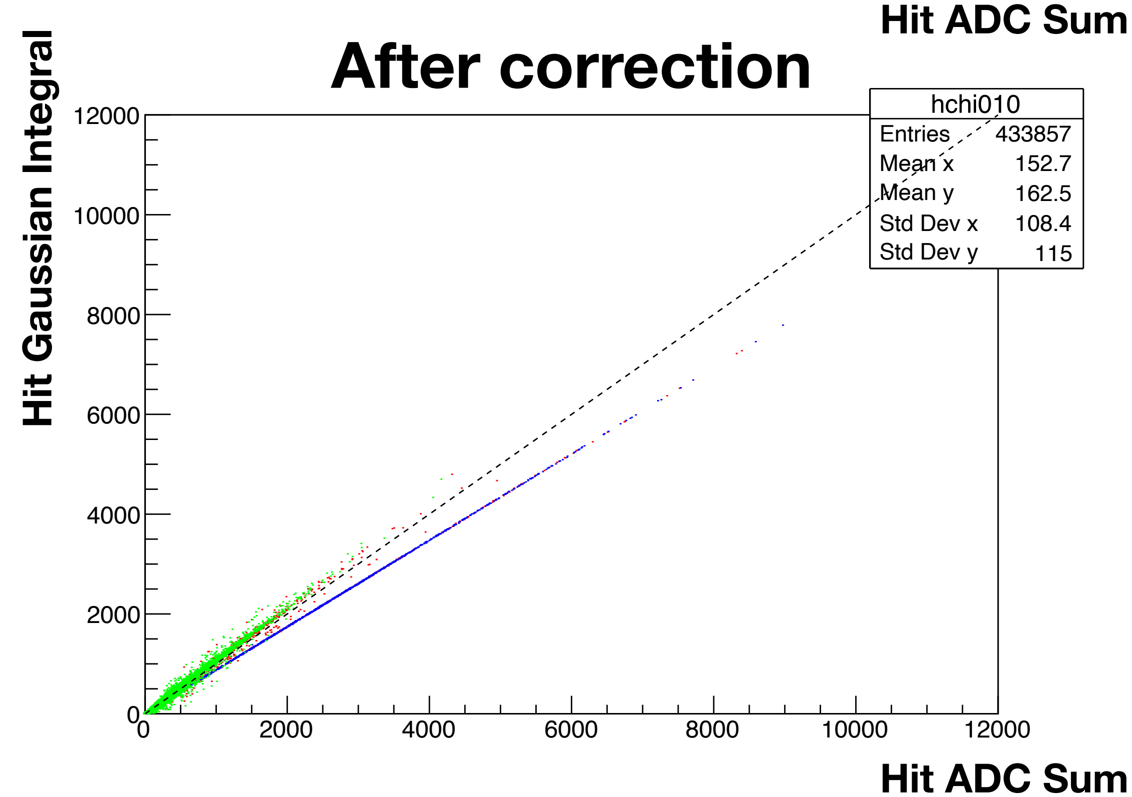
Before correction



Fixed sum ADC



After correction



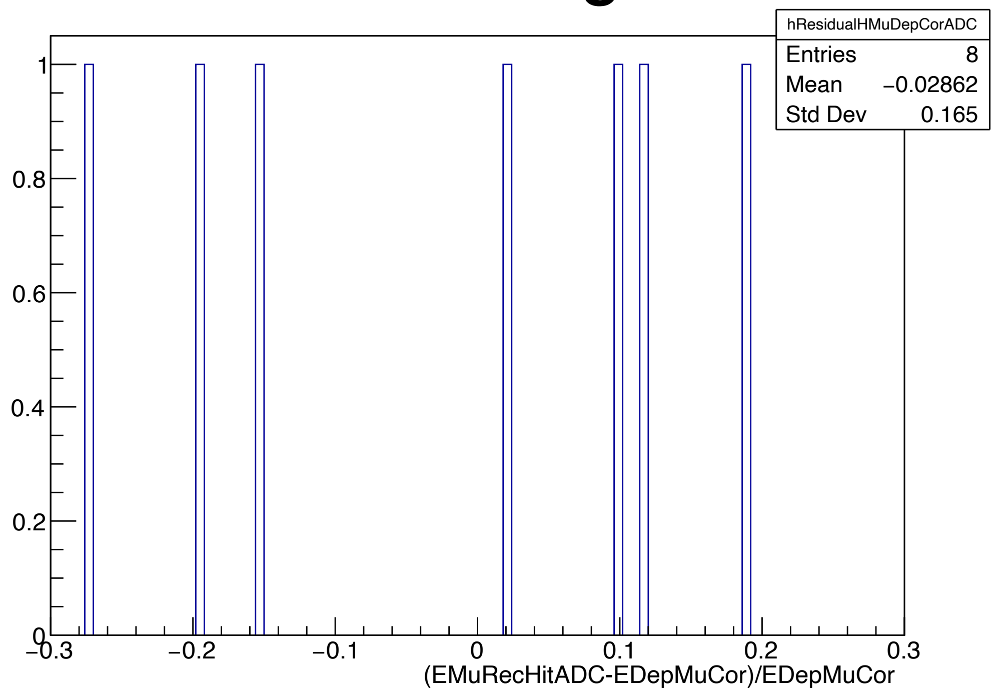
No resolution improvement (3%) but correct agreement between integral and sumADC

Hits study

NuQEMC

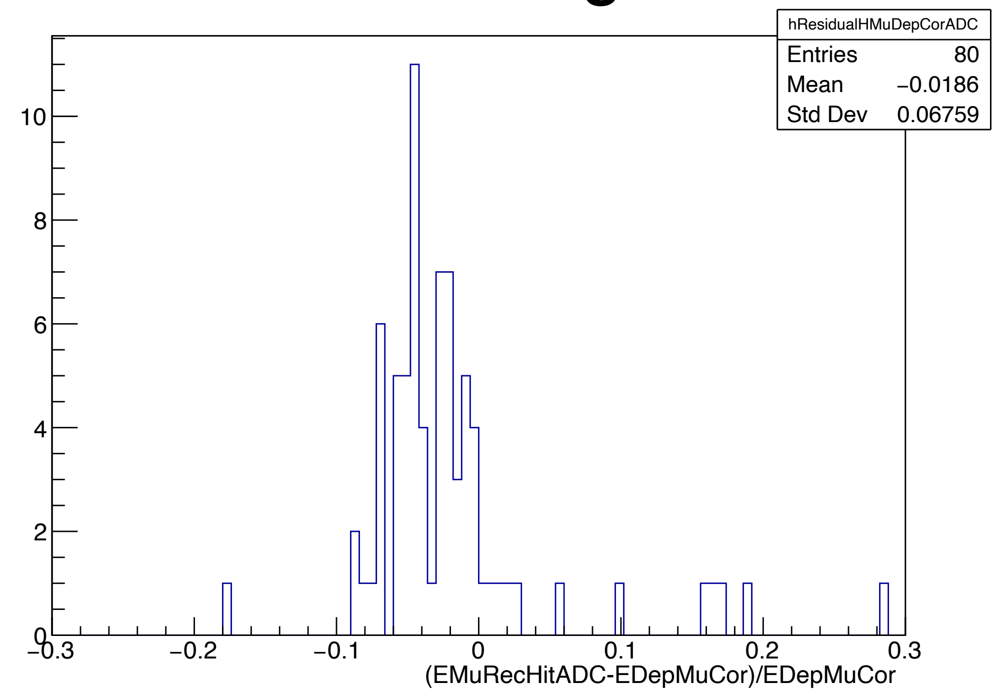
Events with bad hits

Gauss integral

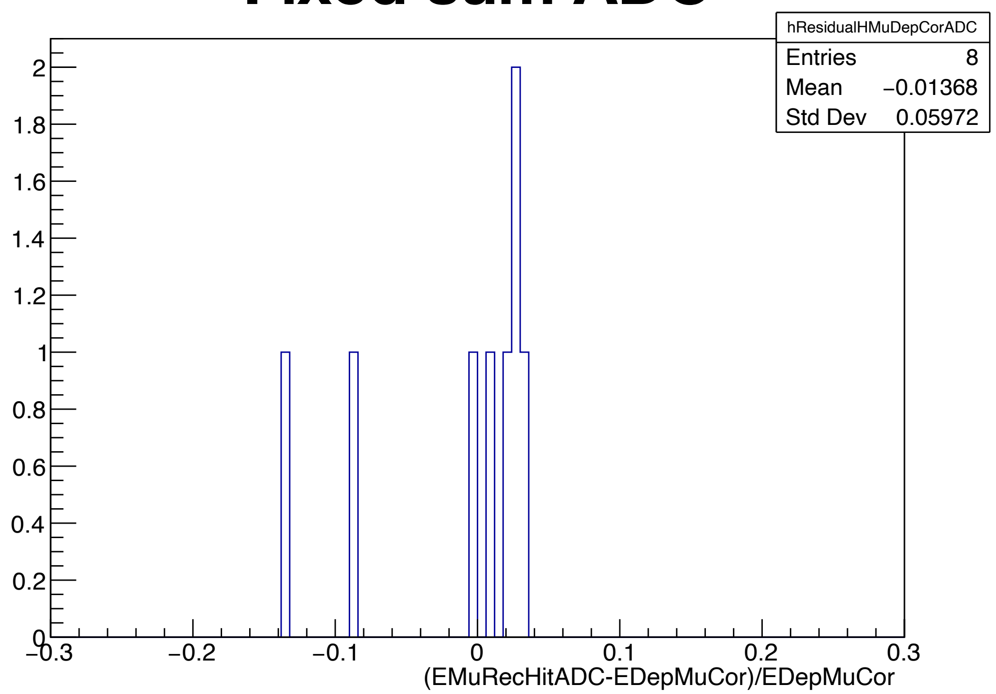


All events

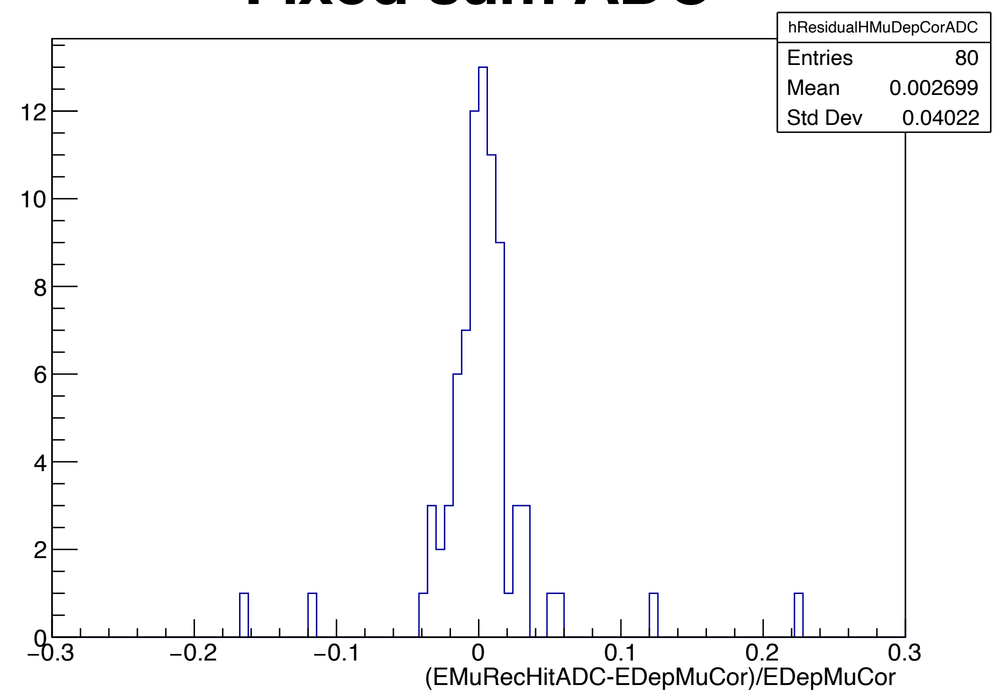
Gauss integral



Fixed sum ADC



Fixed sum ADC



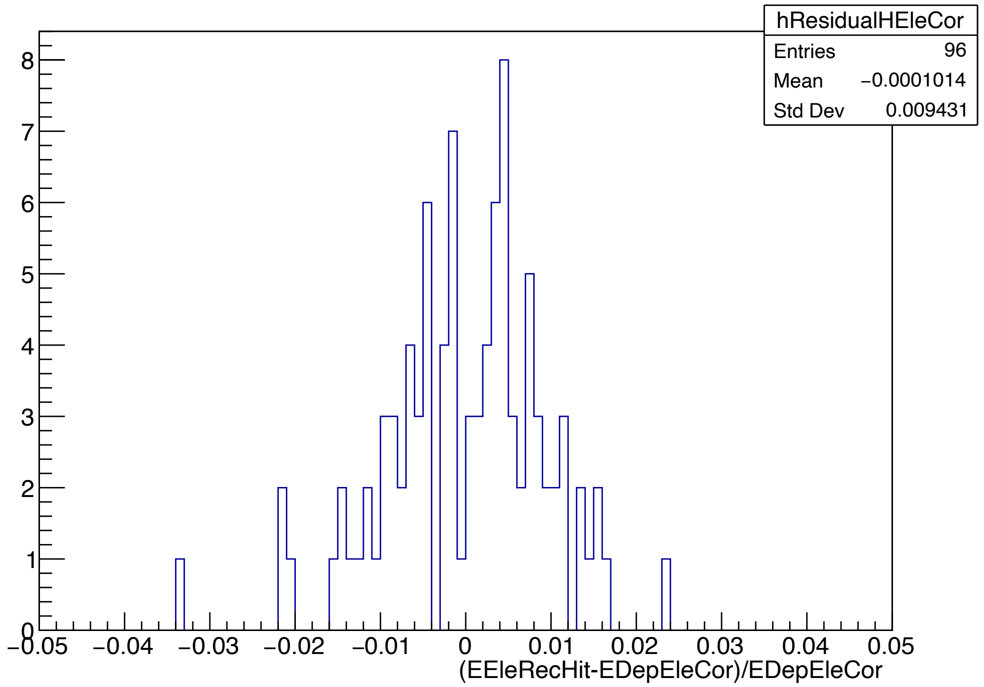
Resolution improvement from 16% to 6%

Resolution improvement from 6.8% to 4%

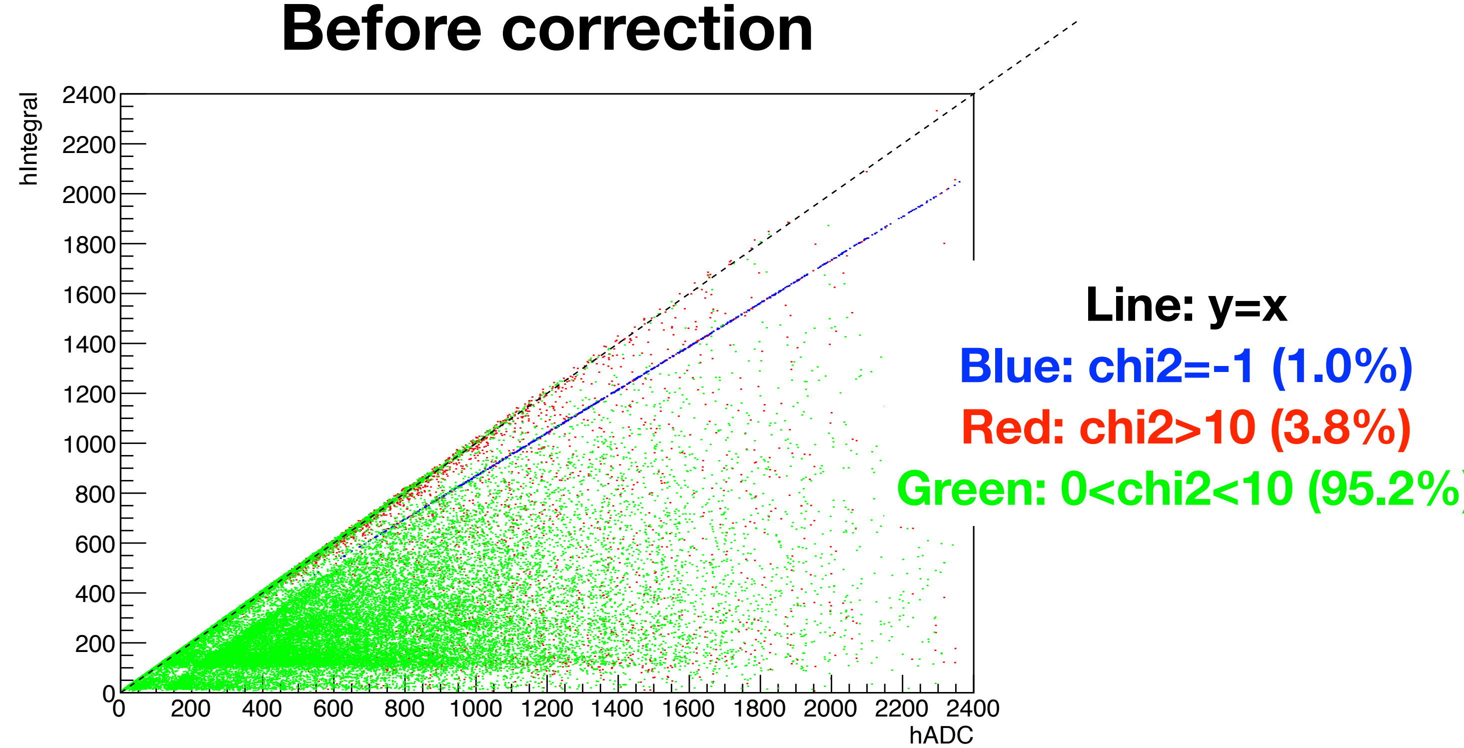
Hits study

Custom electron files (All events : each event has 1-2% of badly fitted hits)

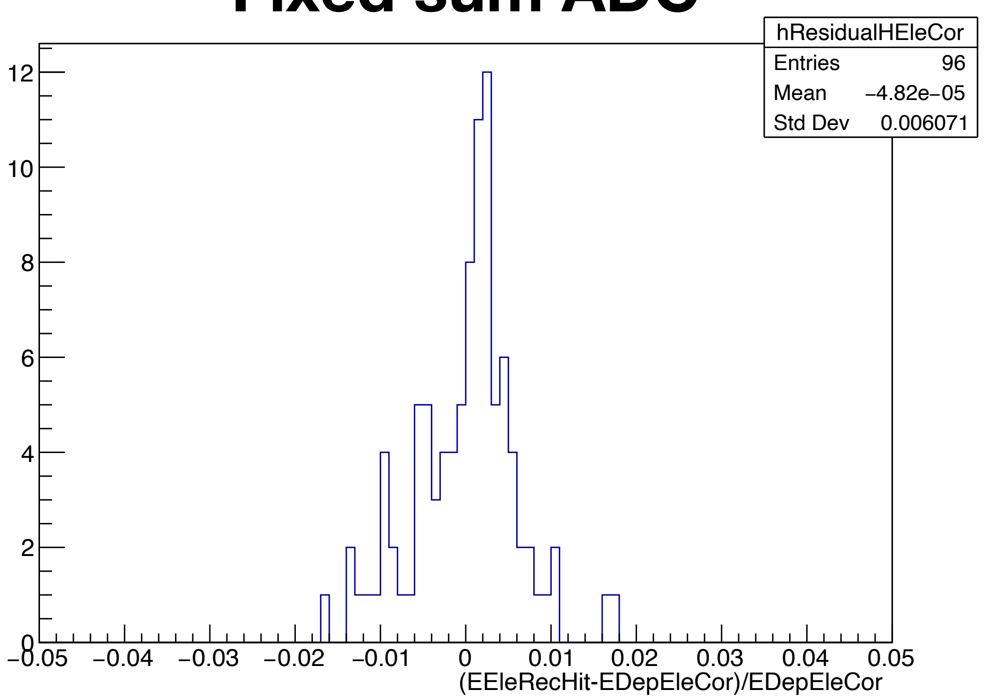
Gauss integral



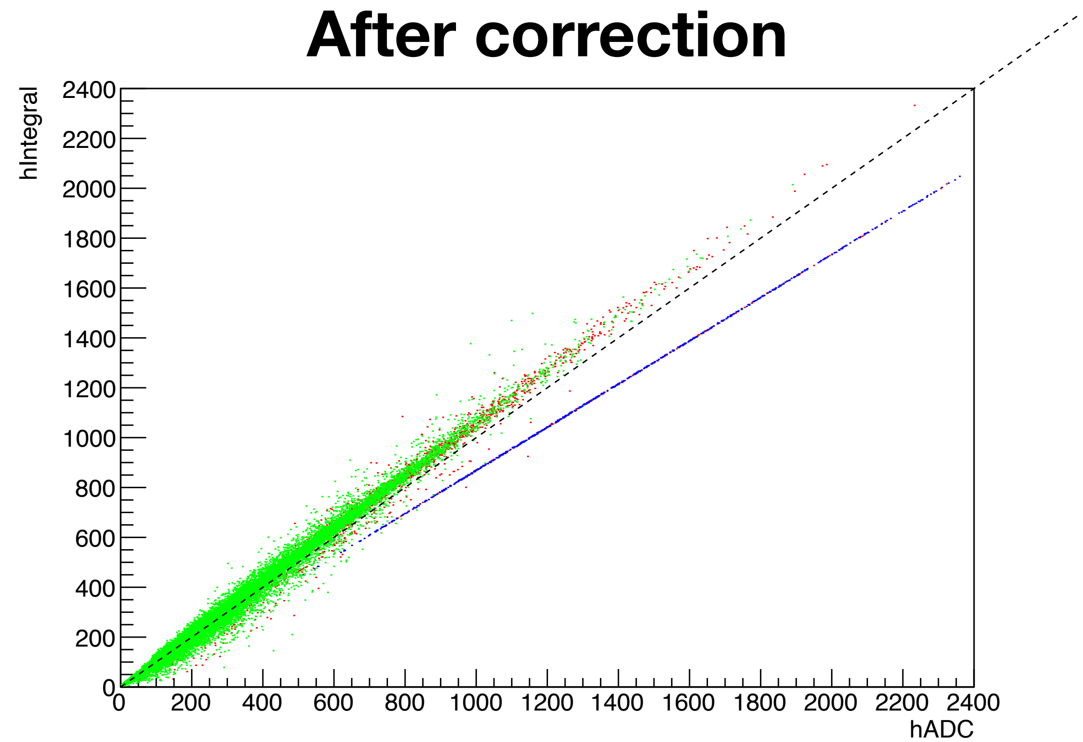
Before correction



Fixed sum ADC



After correction



Resolution improvement (from 0.9% to 0.6%) and correct agreement between integral and sumADC

Hit reconstruction summary

- SumADC was modified for tests in the private code version. **A fix in the official code is desirable**.
- The **integral-SumADC linearity is restored**.
- The use of SumADC to estimate the energy yields almost **identical results** to the use of hits integral on the muon file and on the neutrino QE events **with only good hits**.
- The use of SumADC **on badly reconstructed hits** (chi2=-1) shows an **important improvement in the energy determination both for muons and electrons**.

Is there a valid reason to use Gaussian integrals instead of sum ADC to estimate the deposited energy?

Conclusions

- This work is a first step in our study for neutrino energy reconstruction.
- Two points that needs specific attention in the future are:
    - ➡ The correct treatment of gaps in CRPs.
    - ➡ The hit energy reconstruction.
- Some possible improvements have been tested and suggested.
- An open question is: is there a valid reason to use Gaussian integrals instead of sum ADC as default way to estimate the deposited energy?