

# Master-2 internship: Analysis of data from the Time Projection Chambers of the T2K Near Detector

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# Selection Criteria

- TCut c1 = "NTracks>0";
- TCut c2 = "trTpcdEdxMeas>0";
- string select; TCut c3; TCut c4;
- TCut c5 = "trTpcMomentum>=300";
- TCut c6 = "trTpcMomentum<=2000";
- TCut c7 = "**trTrueTrackID==sTrueTrackID**";

The seventh cut is to match the reconstructed tracks to their corresponding true tracks.

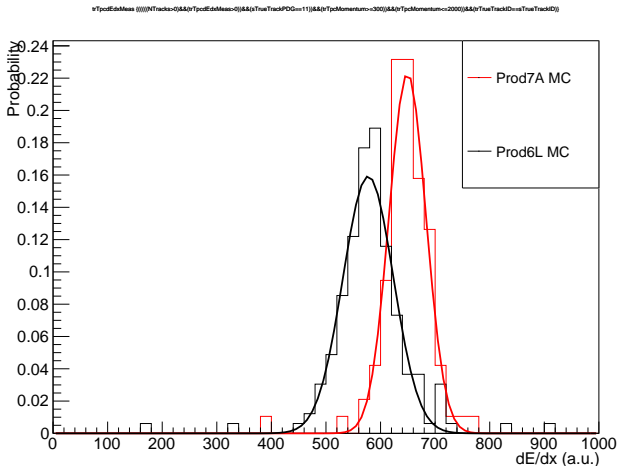
# Selection Criteria

```
switch (particle_index)
{
case 0:select="_negative_charge";c3="trTpcCharge==-1";c4="";break;
case 1:select="_negative_muons";c3="";c4="sTrueTrackPDG==13";break;
case 2:select="_negative_electrons";c3="";c4="sTrueTrackPDG==11";break;
case 3:select="_negative_pions"; c3="";c4="sTrueTrackPDG==-211";break;

case 4:select="_positive_charge";c3="trTpcCharge==1";c4="";break;
case 5:select="_positive_antimuons";c3="";c4="sTrueTrackPDG==-13";break;
case 6:select="_positive_positrons";c3="";c4="sTrueTrackPDG==-11";break;
case 7:select="_positive_pions";c3="";c4="sTrueTrackPDG==211";break;
case 8:select="_positive_protons";c3="";c4="sTrueTrackPDG==2212";break;

case 9:select="_pgun_muons";c3="";c4="sTrueTrackPDG==13";break;
}
```

# Results for negatively charged electrons



**Figure:** Distribution of the energy loss for negatively charged electrons with momenta between 300 and 2000 MeV/c.

# Results for negatively charged electrons

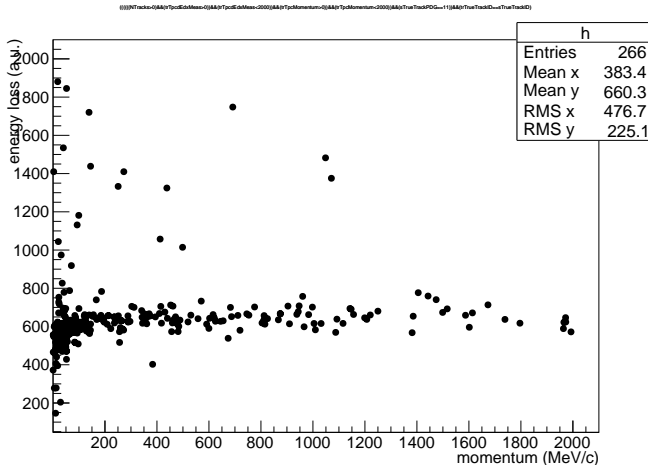
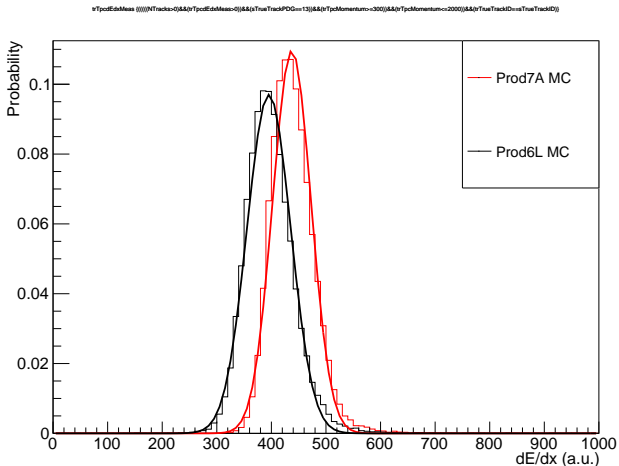


Figure: Energy loss distribution of negatively charged electrons as a function of momentum in Prod7A.

# Results for negatively charged muons



**Figure:** Distribution of the energy loss for negatively charged muons with momenta between 300 and 2000 MeV/c.

# Results for negatively charged muons

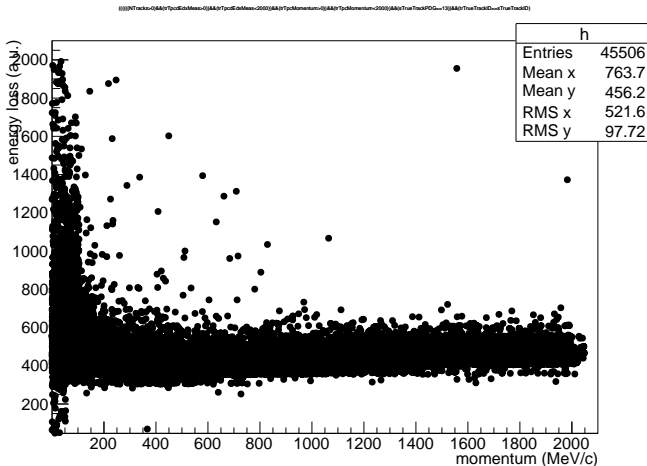


Figure: Energy loss distribution of negatively charged muons as a function of momentum in Prod7A.





# Results for negatively charged pions

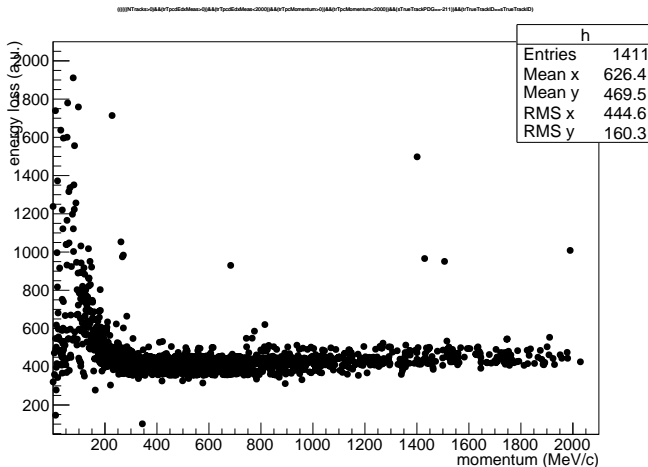
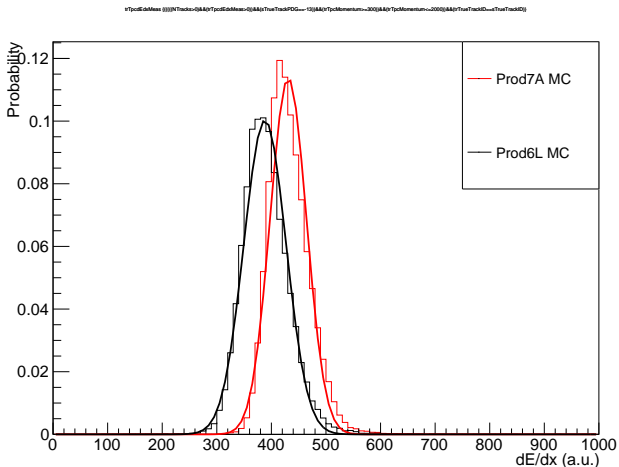


Figure: Energy loss distribution of negatively charged pions as a function of momentum in Prod7A.

# Results for positively charged antimuons



**Figure:** Distribution of the energy loss for positively charged antimuons with momenta between 300 and 2000 MeV/c.

# Results for positively charged antimuons

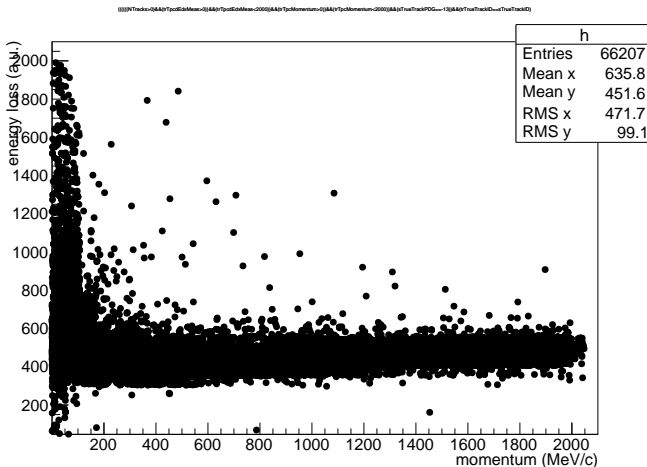
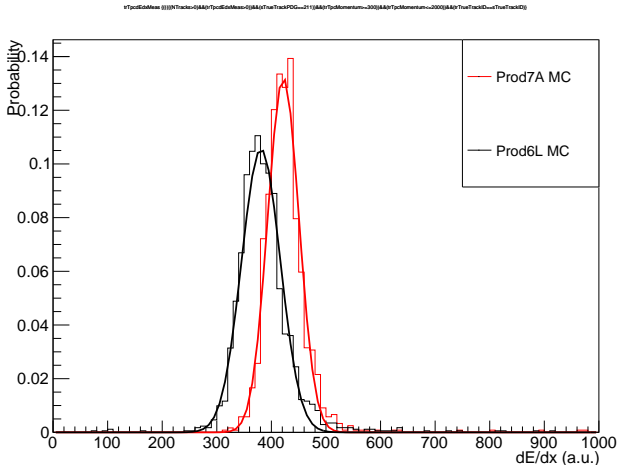


Figure: Energy loss distribution of positively charged antimuons as a function of momentum in Prod7A.

# Results for positively charged pions



**Figure:** Distribution of the energy loss for positively charged pions with momenta between 300 and 2000 MeV/c.

# Results for positively charged pions

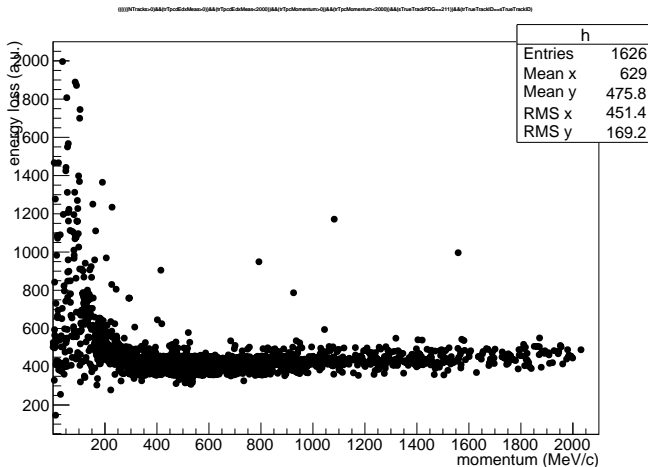
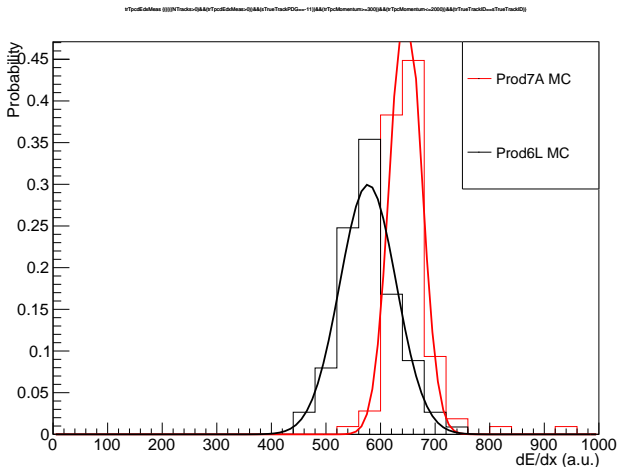


Figure: Energy loss distribution of positively charged pions as a function of momentum in Prod7A.

# Results for positively charged positrons



**Figure:** Distribution of the energy loss for positively charged positrons with momenta between 300 and 2000 MeV/c.

# Results for positively charged positrons

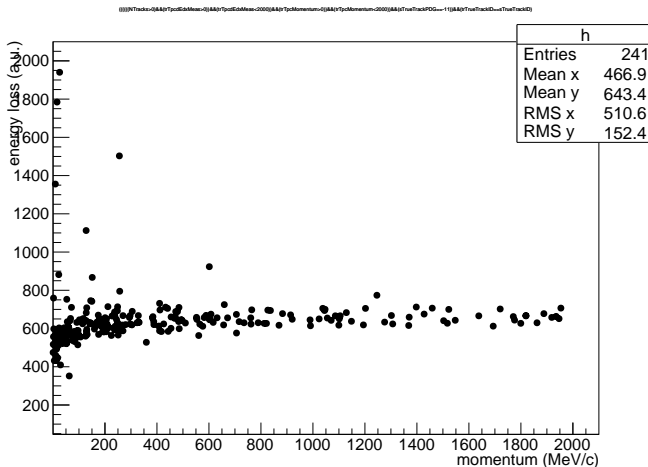
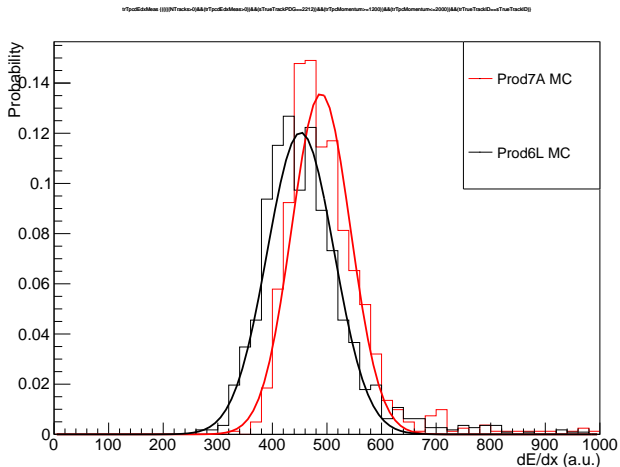


Figure: Energy loss distribution of positively charged positrons as a function of momentum in Prod7A.

# Results for positively charged protons



**Figure:** Distribution of the energy loss for positively charged protons with momenta between 1200 and 2000 MeV/c.



# Results for positively charged protons

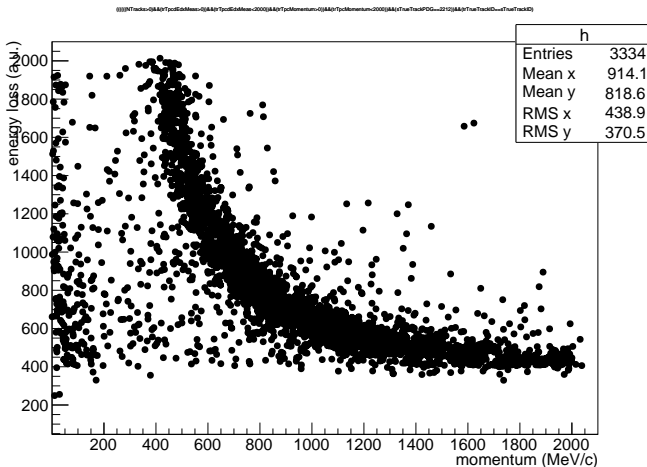
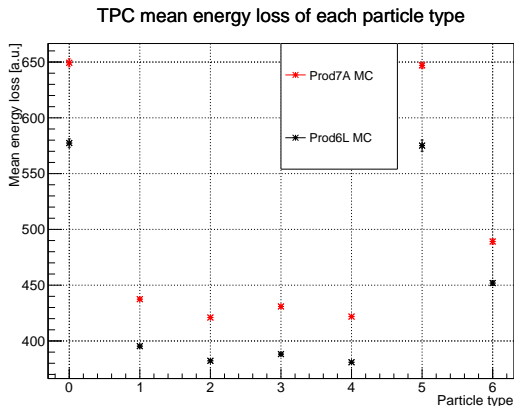
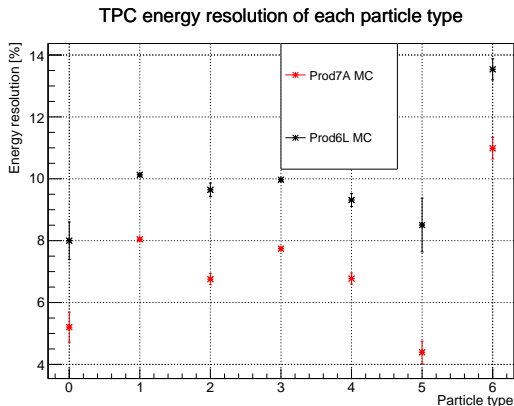


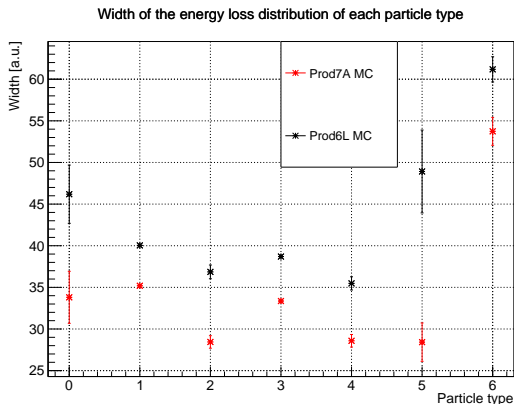
Figure: Energy loss distribution of positively charged protons as a function of momentum in Prod7A.



**Figure:** TPC mean energy loss of different true particle types whose momenta are between 300 and 2000 MeV/c (between 1200 and 2000 MeV/c for protons) in Prod7A MC and Prod6L MC (red and black). On the "particle type" axis, 0, 1, 2, 3, 4, 5, 6 stands for "electrons", "muons", "negative pions", "antimuons", "positive pions", "positrons", and "protons".



**Figure:** TPC energy resolution for different true particle types whose momenta are between 300 and 2000 MeV/c (between 1200 and 2000 MeV/c for protons) in Prod7A MC and Prod6L MC (red and black). On the "particle type" axis, 0, 1, 2, 3, 4, 5, 6 stands for "electrons", "muons", "negative pions", "antimuons", "positive pions", "positrons", and "protons".



**Figure:** Width of the energy loss distribution of different true particle types whose momenta are between 300 and 2000 MeV/c (between 1200 and 2000 MeV/c for protons) in Prod7A MC and Prod6L MC (red and black). On the "particle type" axis, 0, 1, 2, 3, 4, 5, 6 stands for "electrons", "muons", "negative pions", "antimuons", "positive pions", "positrons", and "protons".

# Summary

The TPC mean energy loss [a.u.] of different true particle types

Productions: 7A.MC 6L.MC

Momentum range [ 300, 2000 ] ([ 1200, 2000 ] for protons) [MeV/c]

Electrons 649.337 +/- 3.62249 577.405 +/- 3.79156

Muons 437.48 +/- 0.210827 395.37 +/- 0.190233

Negative Pions 421.026 +/- 0.983625 382.213 +/- 1.09381

Antimuons 430.927 +/- 0.187374 388.227 +/- 0.161752

Positive Pions 421.861 +/- 0.898014 380.918 +/- 0.94621

Positrons 647.034 +/- 2.94094 575.094 +/- 5.03098

Protons 489.151 +/- 2.30336 451.903 +/- 2.09408

# Summary

The TPCs' energy resolution [%] of different true particle types

Productions: 7A.MC 6L.MC

Momentum range [ 300, 2000 ] ([ 1200, 2000 ] for protons) [MeV/c]

Electrons 5.20571 +/- 0.482148 7.9992 +/- 0.608059

Muons 8.04409 +/- 0.032148 10.1273 +/- 0.036204

Negative Pions 6.75589 +/- 0.179177 9.64365 +/- 0.217536

Antimuons 7.74121 +/- 0.0284759 9.96833 +/- 0.0309361

Positive Pions 6.7756 +/- 0.179328 9.31398 +/- 0.209202

Positrons 4.39287 +/- 0.356648 8.50617 +/- 0.868403

Protons 10.9863 +/- 0.346469 13.539 +/- 0.341049

# Summary

Width [a.u.] of energy loss distribution of different true particle types

Productions: 7A.MC 6L.MC

Momentum range [ 300, 2000 ] ([ 1200, 2000 ] for protons) [MeV/c]

Electrons 33.8026 +/- 3.12508 46.1878 +/- 3.49784

Muons 35.1913 +/- 0.139615 40.0403 +/- 0.141838

Negative Pions 28.444 +/- 0.751448 36.8593 +/- 0.824734

Antimuons 33.359 +/- 0.12185 38.6997 +/- 0.119015

Positive Pions 28.5836 +/- 0.754065 35.4786 +/- 0.791999

Positrons 28.4234 +/- 2.30402 48.9185 +/- 4.97576

Protons 53.7397 +/- 1.67576 61.183 +/- 1.51491

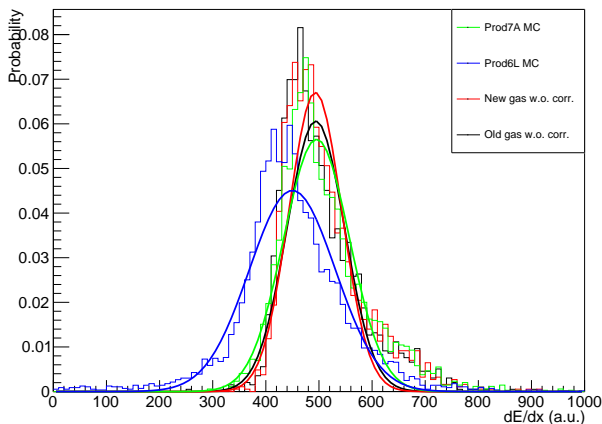
# Conclusion on the results for different true particle types

- There are differences in energy resolution between Prod7A MC and Prod6L MC for all types of true particles.



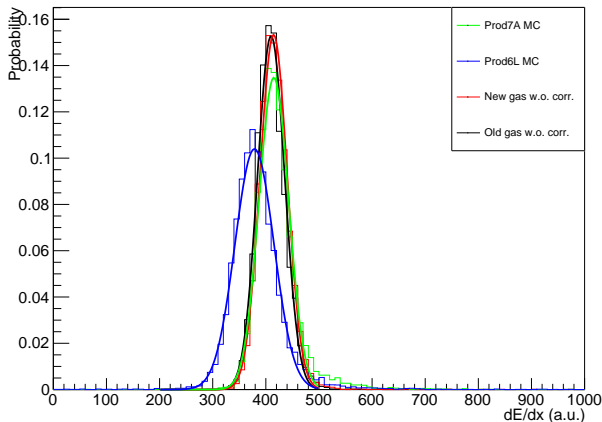
- Last time, I presented that the TPCs' energy resolutions for particle-gun muons in the old and new gas mixtures are different from that of muons in Prod6L MC.
- This time, I will show you that the difference in energy resolution is still present even when the TPC-related corrections were turned off.

## Energy loss distribution in the TPCs



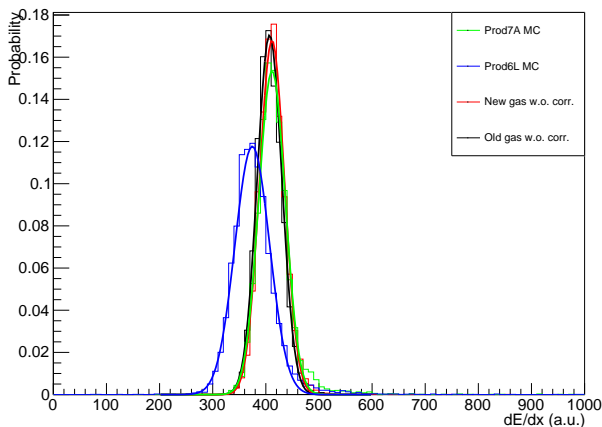
**Figure:** Energy loss distribution of particle gun muons in the new and old gas mixtures (red and black), and of muons in Prod7A MC and Prod6L MC (green and blue) with momenta between 100 and 200 MeV/c.

## Energy loss distribution in the TPCs



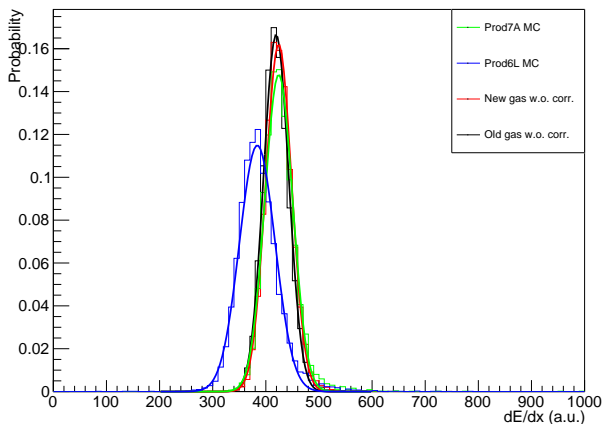
**Figure:** Energy loss distribution of particle gun muons in the new and old gas mixtures (red and black), and of muons in Prod7A MC and Prod6L MC (green and blue) with momenta between 200 and 400 MeV/c.

## Energy loss distribution in the TPCs



**Figure:** Energy loss distribution of particle gun muons in the new and old gas mixtures (red and black), and of muons in Prod7A MC and Prod6L MC (green and blue) with momenta between 400 and 600 MeV/c.

## Energy loss distribution in the TPCs



**Figure:** Energy loss distribution of particle gun muons in the new and old gas mixtures (red and black), and of muons in Prod7A MC and Prod6L MC (green and blue) with momenta between 600 and 800 MeV/c.

## Energy loss distribution in the TPCs

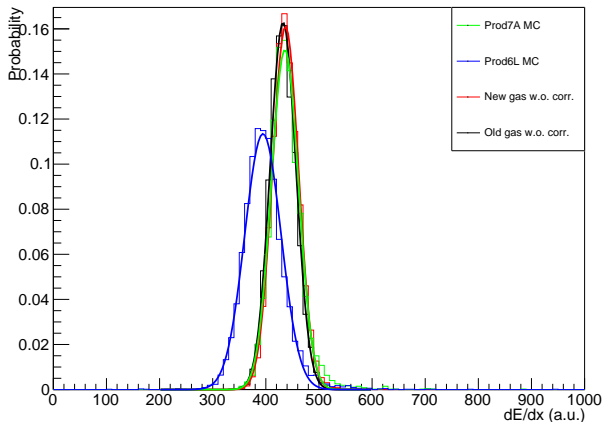
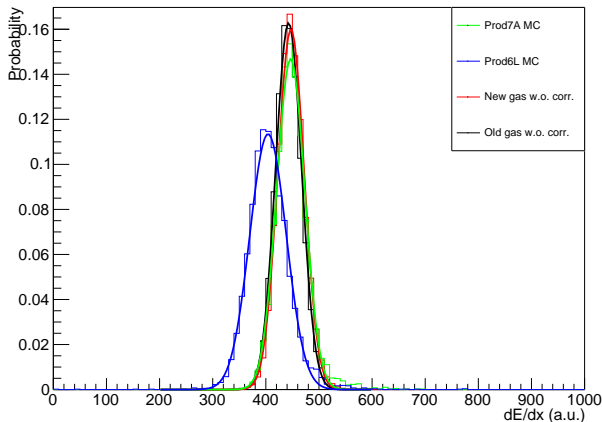


Figure: Energy loss distribution of particle gun muons in the new and old gas mixtures (red and black), and of muons in Prod7A MC and Prod6L MC (green and blue) with momenta between 800 and 1000 MeV/c.

## Energy loss distribution in the TPCs



**Figure:** Energy loss distribution of particle gun muons in the new and old gas mixtures (red and black), and of muons in Prod7A MC and Prod6L MC (green and blue) with momenta between 1000 and 1200 MeV/c.

# MC Prod7 Muon Gun for Old and New Gas Mixtures

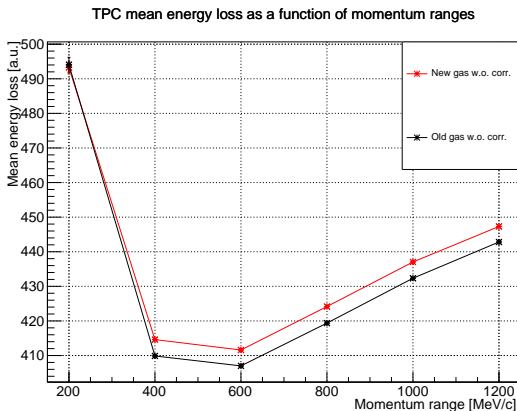


Figure: Mean energy loss of the particle gun muons in the new and old TPCs' gas mixtures (red and black) as a function of the momentum ranges.



# MC Prod7 Muon Gun for Old and New Gas Mixtures

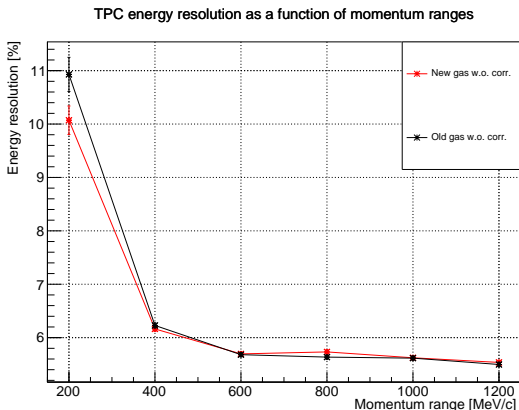


Figure: Energy resolution of the particle gun muons in the new and old TPCs' gas mixtures (red and black) as a function of the momentum ranges.

# MC Prod7 Muon Gun for Old and New Gas Mixtures

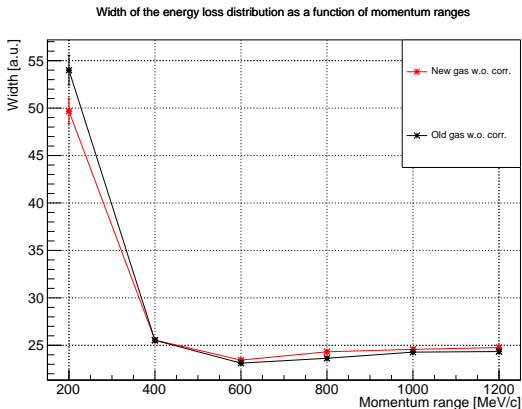


Figure: Width of the particle gun muons in the new and old TPCs' gas mixtures (red and black) as a function of the momentum ranges.

# MC Prod7 Muon Gun for Old and New Gas Mixtures

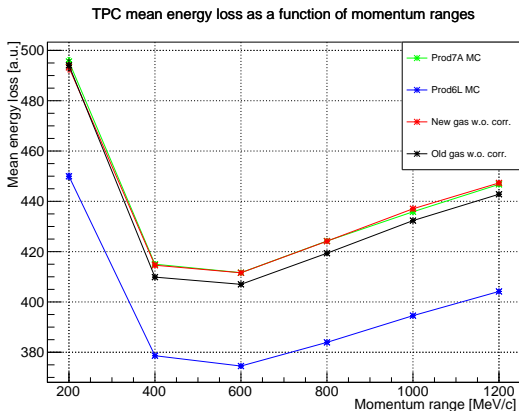


Figure: Mean energy loss of the particle gun muons in the new and old TPCs' gas mixtures (red and black) and of muons in Prod7A MC and Prod6L MC (green and blue) as a function of the momentum ranges.

# MC Prod7 Muon Gun for Old and New Gas Mixtures

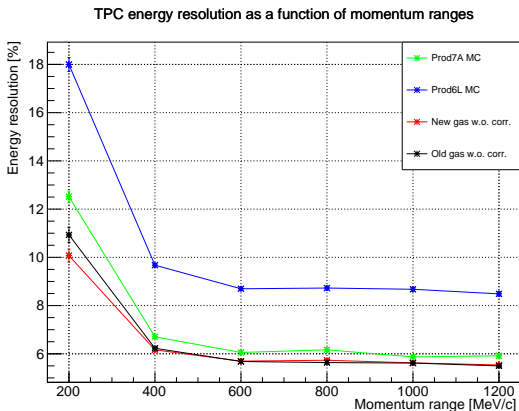
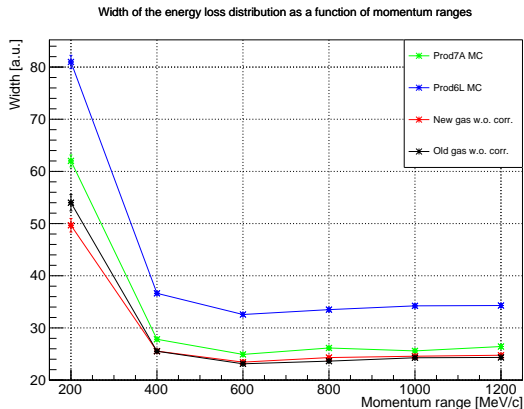


Figure: Energy resolution of the particle gun muons in the new and old TPCs' gas mixtures (red and black) and of muons in Prod7A MC and Prod6L MC (green and blue) as a function of the momentum ranges.

# MC Prod7 Muon Gun for Old and New Gas Mixtures



**Figure:** Width of the particle gun muons in the new and old TPCs' gas mixtures (red and black) and of muons in Prod7A MC and Prod6L MC (green and blue) as a function of the momentum ranges.

# MC Prod7 Muon Gun for Old and New Gas Mixtures

The TPCs' mean energy loss [a.u.] for the momentum ranges [MeV/c]

Productions: 7AMC 6LMC NewGas7.wo.corr. OldGas7.wo.corr.

[100, 200] 495.568 +/- 1.57603 449.969 +/- 1.19793 493.259 +/-  
1.83923 494.059 +/- 2.13898

[ 200, 400 ] 415.006 +/- 0.345813 378.63 +/- 0.347026 414.602 +/-  
0.260002 409.872 +/- 0.263187

[ 400, 600 ] 411.625 +/- 0.309795 374.519 +/- 0.338978 411.596  
+/- 0.227067 407.006 +/- 0.224924

[ 600, 800 ] 424.222 +/- 0.36778 383.934 +/- 0.393894 424.163 +/-  
0.235989 419.374 +/- 0.23399

[ 800, 1000 ] 435.845 +/- 0.390602 394.548 +/- 0.434749 437.039  
+/- 0.240301 432.34 +/- 0.237271

[ 1000, 1200 ] 446.745 +/- 0.438964 404.177 +/- 0.487608 447.31  
+/- 0.244542 442.819 +/- 0.241024

# MC Prod7 Muon Gun for Old and New Gas Mixtures

The TPCs' energy resolution [%] as a function of momentum ranges [MeV/c]

Productions: 7AMC 6LMC NewGas7.wo.corr. OldGas7.wo.corr.

[ 100, 200 ] 12.5133 +/- 0.235587 17.9961 +/- 0.28737 10.0716 +/- 0.266482 10.9298 +/- 0.319224

[ 200, 400 ] 6.70482 +/- 0.0636185 9.67533 +/- 0.076895 6.16316 +/- 0.0451134 6.22849 +/- 0.0480619

[ 400, 600 ] 6.05462 +/- 0.0617412 8.69672 +/- 0.0693205 5.69571 +/- 0.042549 5.681 +/- 0.0396791

[ 600, 800 ] 6.16467 +/- 0.0676429 8.72675 +/- 0.0831054 5.73268 +/- 0.0413498 5.63555 +/- 0.0392261

[ 800, 1000 ] 5.87232 +/- 0.0736326 8.676 +/- 0.0887577 5.62281 +/- 0.0406472 5.61613 +/- 0.0391255

[ 1000, 1200 ] 5.91662 +/- 0.0790914 8.48454 +/- 0.0940184 5.53596 +/- 0.0417537 5.49734 +/- 0.0407289

# MC Prod7 Muon Gun for Old and New Gas Mixtures

Width [a.u.] of energy loss distribution as a function of momentum ranges  
[MeV/c]

Productions: 7AMC 6LMC NewGas7.wo.corr. OldGas7.wo.corr.

[ 100, 200 ] 62.012 +/- 1.15072 80.9768 +/- 1.27498 49.6789 +/-  
1.30133 53.9998 +/- 1.55973

[ 200, 400 ] 27.8254 +/- 0.263 36.6337 +/- 0.289205 25.5526 +/-  
0.186353 25.5288 +/- 0.196309

[ 400, 600 ] 24.9223 +/- 0.253449 32.5709 +/- 0.25794 23.4433 +/-  
0.174652 23.122 +/- 0.16099

[ 600, 800 ] 26.1519 +/- 0.286059 33.505 +/- 0.317213 24.3159 +/-  
0.174868 23.6341 +/- 0.163975

[ 800, 1000 ] 25.5942 +/- 0.320103 34.231 +/- 0.348155 24.5739  
+/- 0.17713 24.2807 +/- 0.168629

[ 1000, 1200 ] 26.4322 +/- 0.352381 34.2926 +/- 0.377742 24.7629  
+/- 0.186277 24.3433 +/- 0.179868

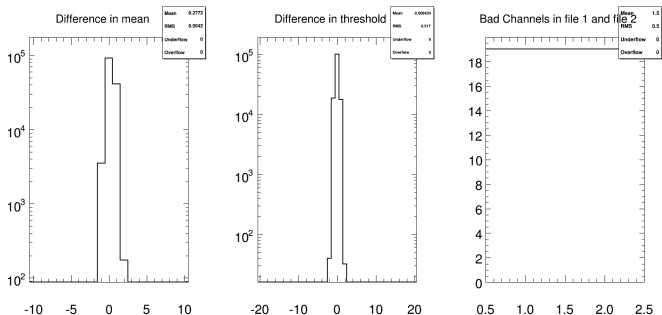


## Conclusion on the result for the old and new gas mixtures

- Even after turning off the TPC-related corrections, using the old gas mixture for Prod7A MC still results in the difference in energy resolution compared to Prod6L MC. This concludes that the change in gas mixture is not the reason for the difference.
- Combining this with the fact that the difference is present in all types of particles, one can suspect that the problem lies in the new GEANT4 version used in Prod7A MC.
- To confirm this suspicion, I will run the muon gun in Argon using two different GEANT4 versions, v4.9.4.p04 and v4.10.1, then look for the difference in energy loss distribution.

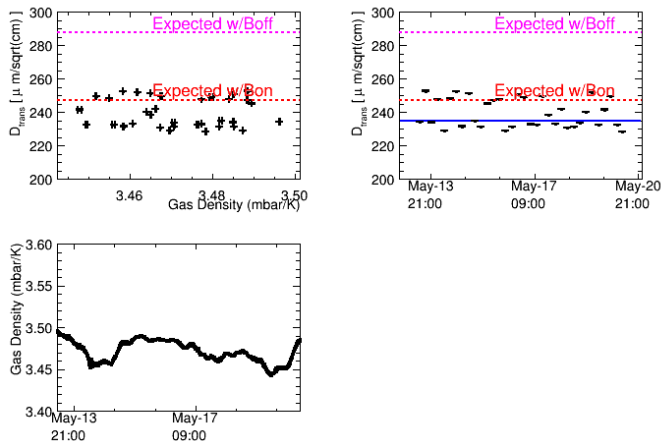
- During the last week, I also learned how to check the quality of the TPCs' data taken from 12 May to 19 May.
- Figures 46, 47, 48, 51, 43, 45, and 44 was sent to me by an on-site TPC expert shifter.
- Figures 49, 50, and 51 was generated using the following ND280 software's commands:
  - ◇ `toolTPCStatus.exe -s 2018 05 12 18 00 00 -e 2018 05 19 18 00 00 -i 86400 -p`
  - ◇ `toolSparkCounter.exe -s 2018 05 12 18 00 00 -e 2018 05 19 18 00 00 -i 86400 -p`

# TPC Data Quality Check: 12 May 2018 - 19 May 2018



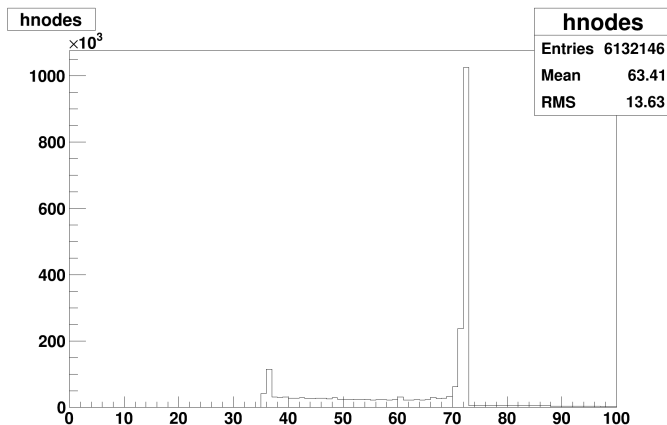
**Figure:** Response of each electronic channel when there is no signal, want the difference in the mean and threshold between two consecutive weeks to be very peaked at zero and the number of bad channels (with much larger RMS) to be constant, and if not, update the list of bad channels.

# TPC Data Quality Check: 12 May 2018 - 19 May 2018



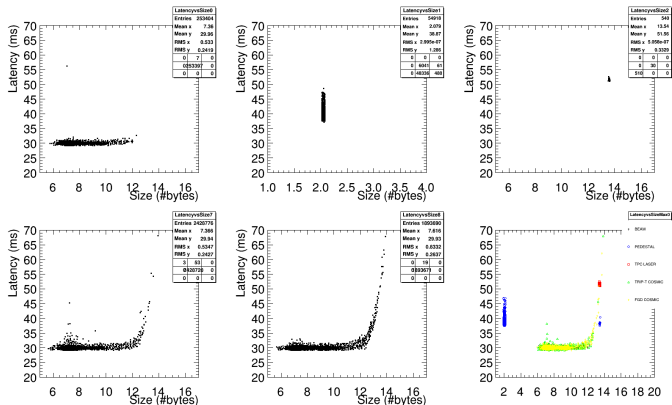
**Figure:** Transverse diffusion of the drifting electrons. Want it to be fairly constant. The "expected without B field" line is known to be overestimated.

# TPC Data Quality Check: 12 May 2018 - 19 May 2018



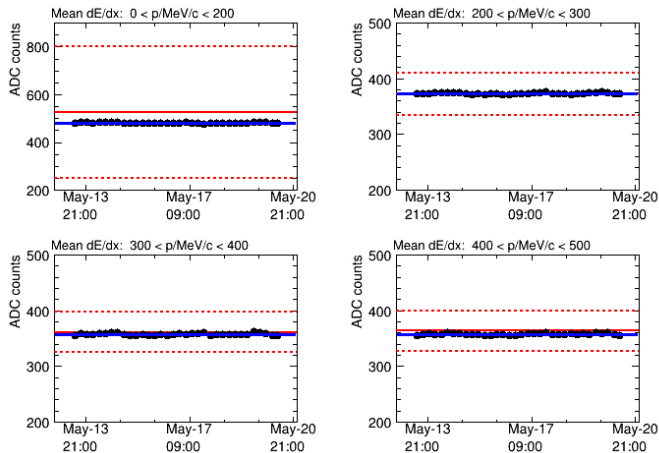
**Figure:** Number of nodes for the reconstructed tracks. The plot should have a smaller peak at 36 nodes for tracks crossing one MicroMegas module and a bigger peak at 72 nodes for tracks crossing two MicroMegas modules.

# TPC Data Quality Check: 12 May 2018 - 19 May 2018



**Figure:** Time taken by the TPCs to read out an event. We don't want it to be too long, so that the next event can be read. Should always have the same kind of shape, and with the laser on. There are various triggers: beam in black, pedestal in blue, laser in red, cosmics triggered in Trip-T detectors in green, and cosmics triggered with the FGD in yellow.

# TPC Data Quality Check: 12 May 2018 - 19 May 2018



**Figure:** Mean of the  $dE/dx$  for 12 bins in momentum. The blue line is the mean of the last week. The red solid and dotted lines are respectively the mean and RMS of the week before. Should be fairly constant from one week to the other.

# TPC Data Quality Check: 12 May 2018 - 19 May 2018

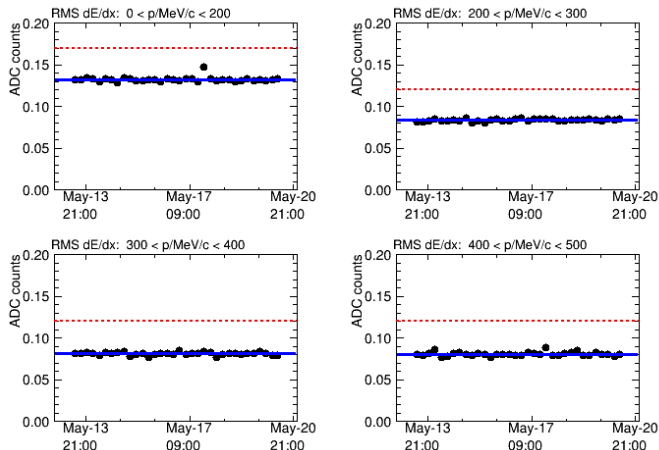
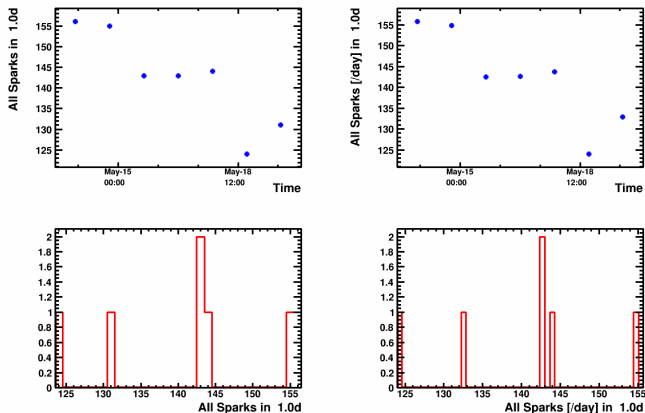


Figure: Same plots but with the RMS of the  $dE/dx$ . Should be below the red dotted line for all the 12 momentum bins.

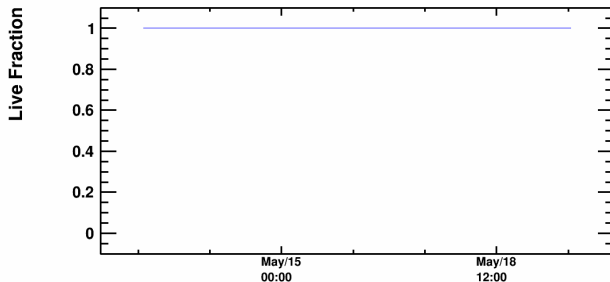


# TPC Data Quality Check: 12 May 2018 - 19 May 2018



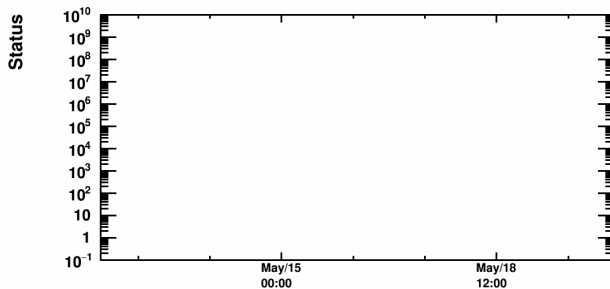
**Figure:** The MicroMegas modules occasionally sparks. The rate should not be too high or too low, but be around 160 sparks per day in the whole three TPCs, which corresponds to around 2.2 per module.

# TPC Data Quality Check: 12 May 2018 - 19 May 2018



**Figure:** Evolution of the TPC livetime over one week. TPC live fraction is defined as the fraction of time of a day during which the TPC takes data in nominal conditions.

# TPC Data Quality Check: 12 May 2018 - 19 May 2018



**Figure:** Evolution of the flag giving the TPC data quality status over one week. A value of zero is given if the data quality is good. A bad status (non zero value) is given when the detector is not in normal conditions.

# The End