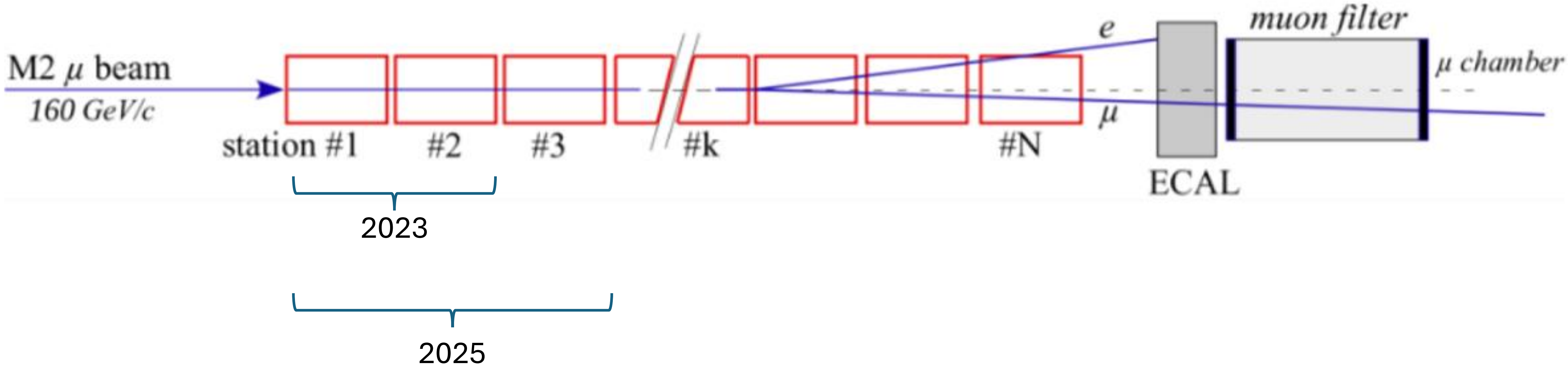
Background study using MESMER generator

Katie Ferraby

03/11/25

MUonE experiment



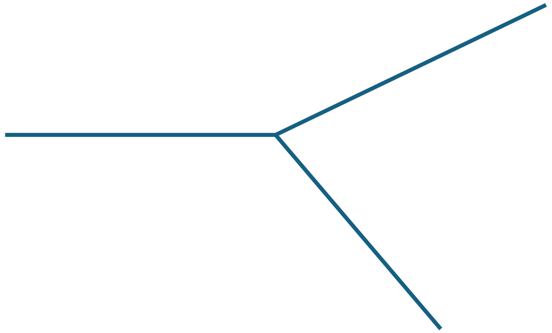
The analysis problem

Looking at 2023 set-up simulations

General cuts:

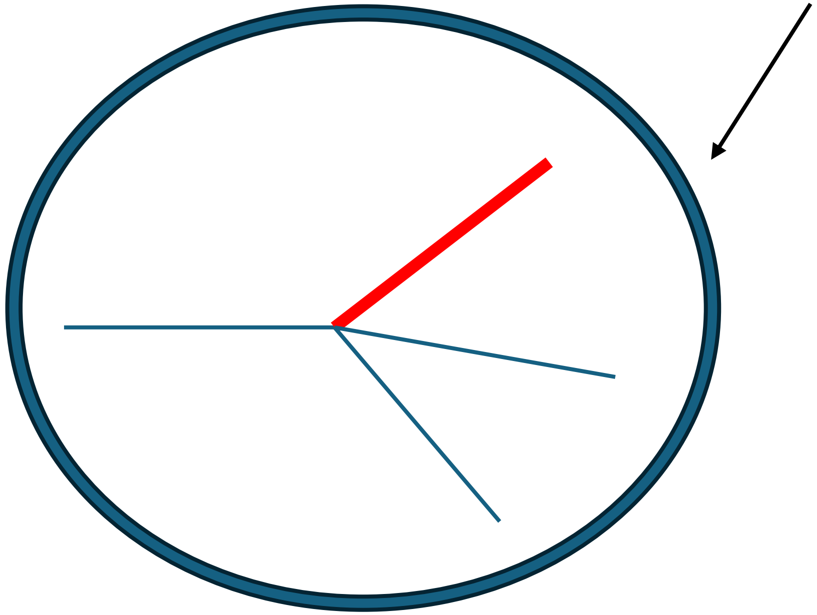
- Cut if not reconstructed
- Cut if total number of tracks is >4

Background events look like signal events if any of the outgoing tracks are not detected or not reconstructed.

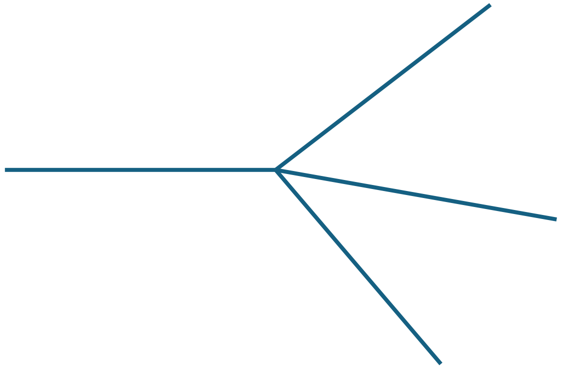


2 outgoing tracks
(Signal)

Looking at these events



2 outgoing tracks
(Background events that look like signal events)



3 outgoing tracks
(Background)

More problems

In the original analysis of the background events, the physics results made no sense, and our conclusion was that noise was overwhelming in the analysis.

We checked how many equivalent events we were using for the analysis, and it was much too low for a meaningful study of physics variables.

$$\text{Equivalent number of events} = \frac{\left(\sum \omega_i\right)^2}{\sum \omega_i^2}$$

Equivalent events

1502 files of 100e3 events / 3000 = 150,200,000 / 3000 = **~50,000 equivalent events for bkg**
15 files of 10e3 / 3 = 150,000 / 3 = **~50,000 equivalent events for signal**

- Equivalent number of events for bkg and signal – 50,000 events
- After events with less than 1e-3 weight were cut, each 100e3 background simulation file was reduced to ~40e3 events.

- Even though events have been cut, the number of equivalent events remain the same because the events that were removed had such small weights to be negligible to the weight calculation/equivalent event calculation.

Normalisation

*Z_carbon = 6
*Wnorm = 1340 for signal
*Wnorm = 14.92 for bkg

```
slurm-3560000.out: N weights = 9942 , Wnorm = 1340
slurm-3559975.out: N weights = 9958 , Wnorm = 1340
slurm-3559977.out: N weights = 9954 , Wnorm = 1340
```

Pull N_weights and Wnorm from the log files of the generation and reconstruction job

Rescale the background histogram to the signal histogram for meaningful comparison:

$$\text{luminosity}_{\text{signal}} = \frac{N_{\text{weight, signal}}}{w_{\text{norm, signal}} * z_{\text{carbon}}}$$

$$\text{luminosity}_{\text{background}} = \frac{N_{\text{weight, background}}}{w_{\text{norm, background}}}$$

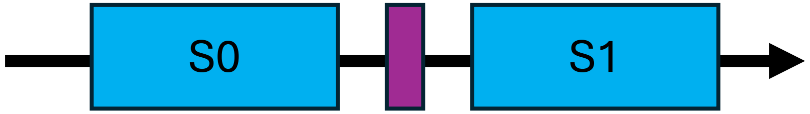
histogram_background->Scale($\frac{\text{luminosity}_{\text{signal}}}{\text{luminosity}_{\text{background}}}$)

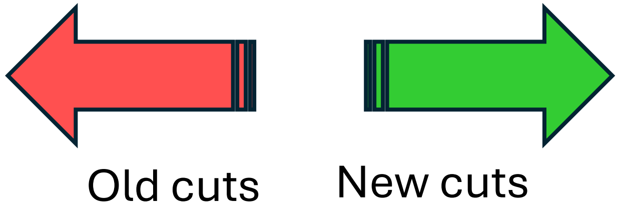
Signal: N_weights_signal / w_norm_signal = 111.39 => Signal luminosity: 1.899
Bkg: N_weights_bkg / w_norm_bkg = 9.48e7 => Background luminosity: 8.48e7

Normalisation factor = 111.394 / (9.47785e7 * 6) = 1.96e-7

Normalisation factor: 1.96e-7

Elastic cuts:





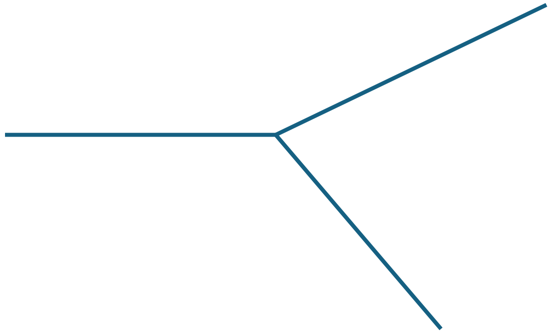
Cut 0: no cuts

Cut 1: theta_max < 32 mrad && theta_min >=0.2 mrad

Cut 2: cut #1 + N stubs on S1 <=14

Cut 3: cut #2 + |modified_Acoplanarity| < 0.4

Cut 4: cut #3 + |z_vertex - z_target| <= 3 cm (target thickness)



Best vertex

Cut 5: cut #4 + chi2_vertex (KF) <= 20

Cut 6: Fiducial region

- single-muon in the first station within a fiducial region |X,Y|<1.5cm

Cut 7: Elasticity cut

- Elasticity cut as $|\theta_\mu^{rec} - \theta_\mu^{exp}(\theta_e^{rec})| < 0.2$ mrad

$$\text{Ratio} = \frac{\text{background integral}}{\text{signal integral}}$$

$$\text{Fractional error on ratio: } \sqrt{\left(\frac{err_1}{v_1}\right)^2 + \left(\frac{err_2}{v_2}\right)^2}$$

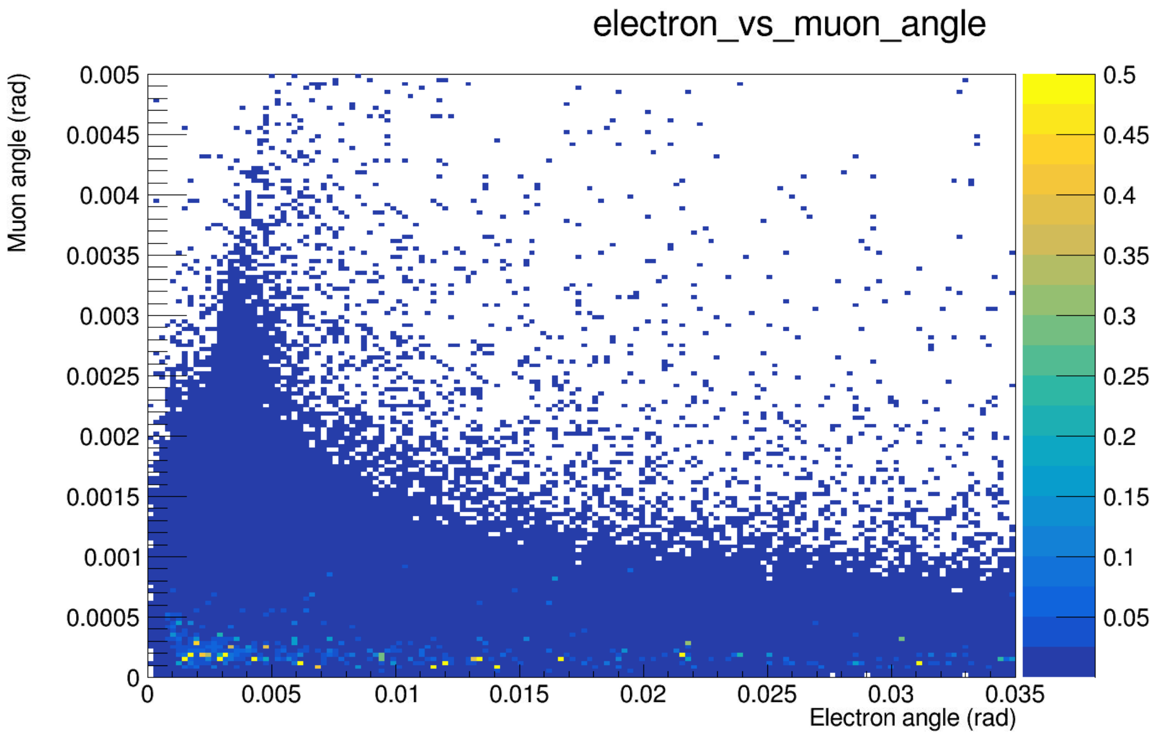
The number of effective entries is defined as : (Sum of weights)^2 / (Sum of weight^2)
where the sum is considered on all histogram bins.

In case of an unweighted histogram this number is then equivalent to the number of entries of the histogram.
For a weighted histogram, this number corresponds to the hypotetical number of unweighted entries
a histogram would need to have the same statistical power.

Err = $\sqrt{N}$
V = N
N = effective entries

Old cuts, cut 0

Cut 0: no cuts

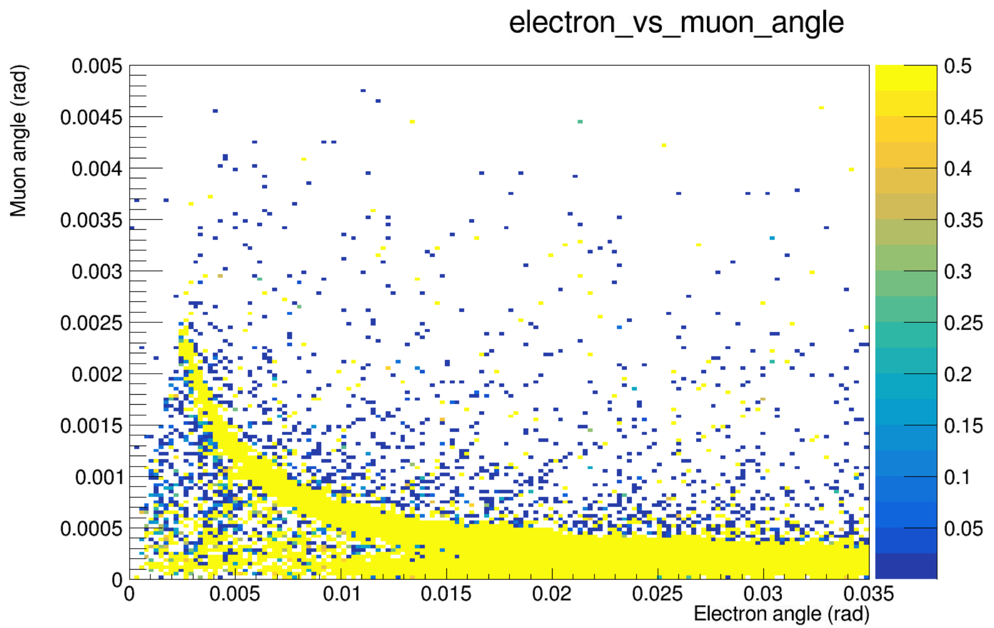


electron_vs_muon_angle	
Effective entries	93.767
Integral	45.714
Mean	0.011
Std Dev	0.009

BKG

Ratio = 45.714 / 37593.275 = 0.00122

Fractional error: 0.1033



electron_vs_muon_angle	
Effective entries	7402.131
Integral	37593.275
Mean	0.022
Std Dev	0.008

SIGNAL

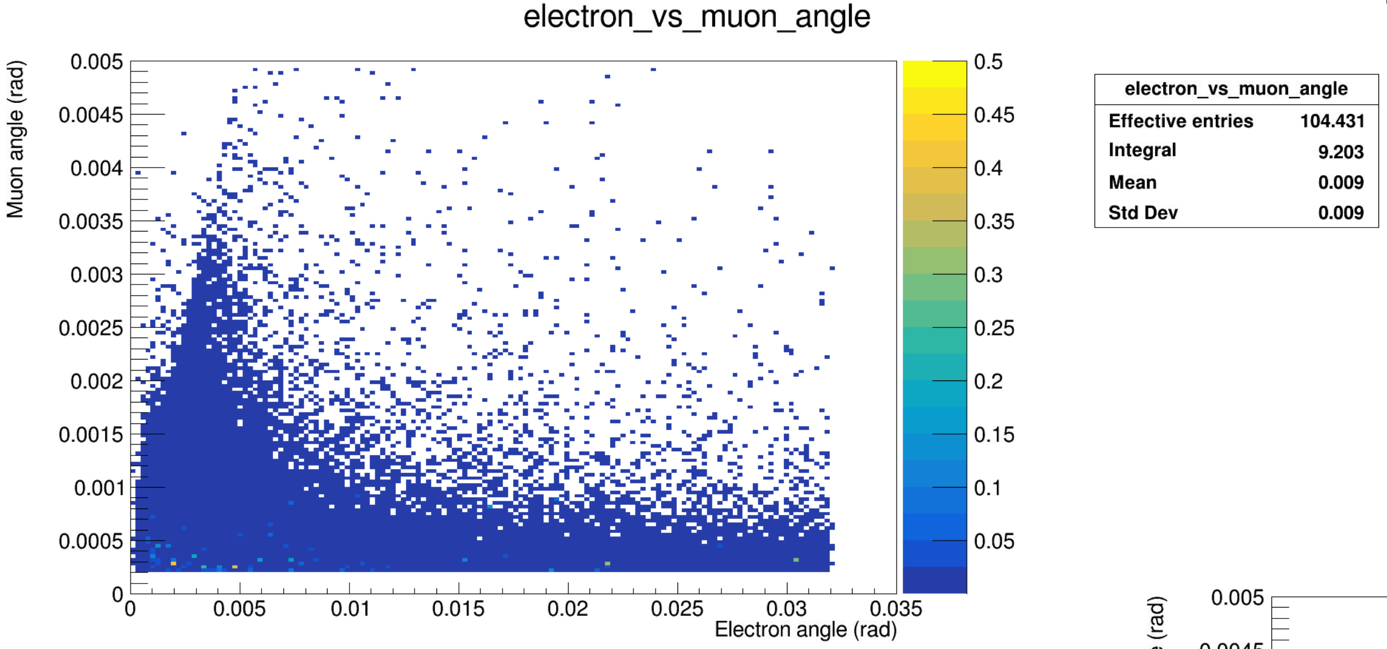
Cut 3

<u>Old cuts, cut 3:</u>

Cut 1: theta_max < 32 mrad && theta_min >=0.2 mrad

Cut 2: cut #1 + N stubs on S1 <=14

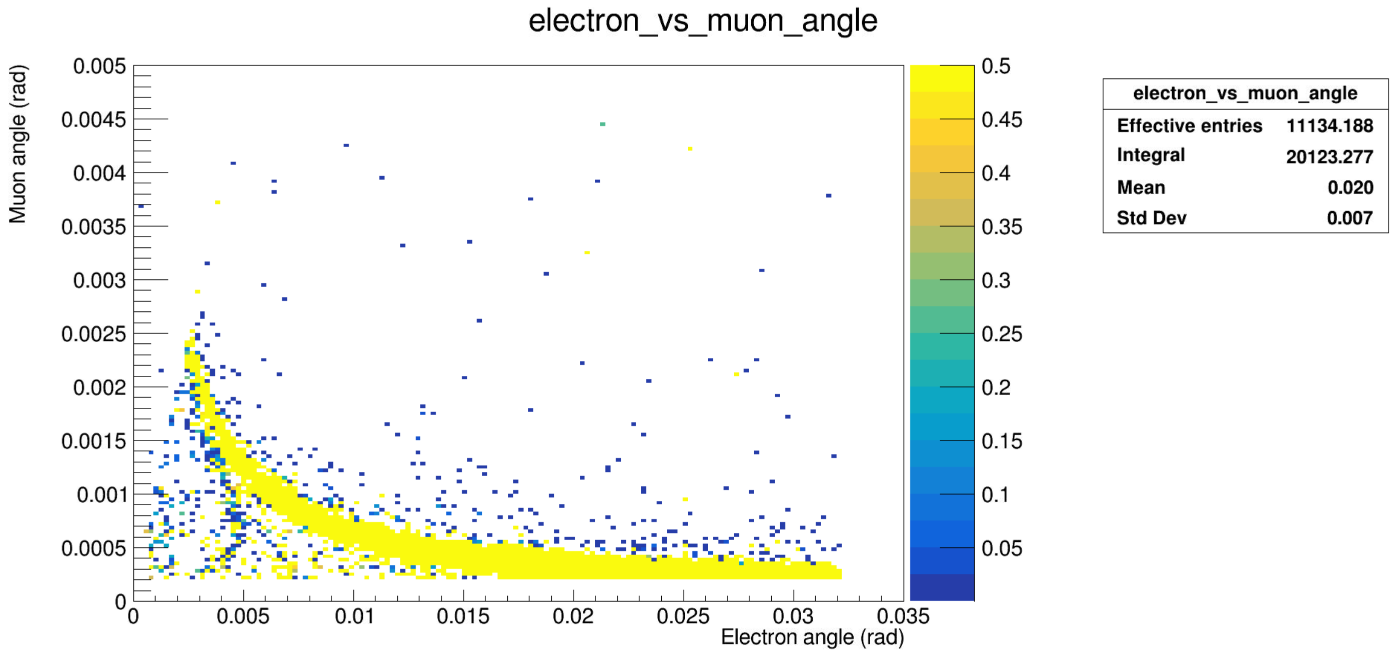
Cut 3: cut #2 + |modified_Acoplanarity| < 0.4



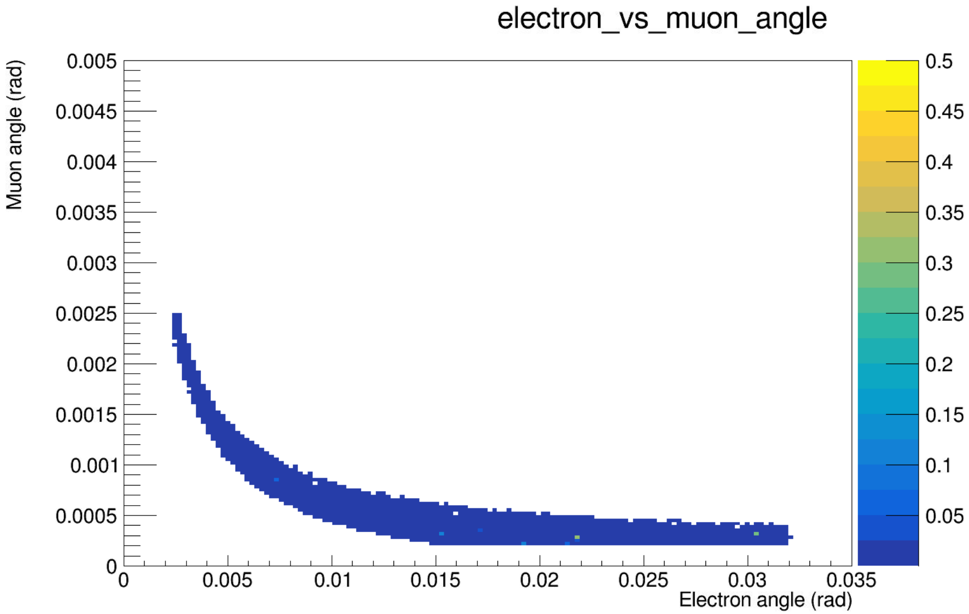
BKG

Ratio: 9.203 / 20123.277 = 0.000457

Fractional error: 0.0979



SIGNAL



electron_vs_muon_angle	
Effective entries	17.257
Integral	1.983
Mean	0.021
Std Dev	0.007

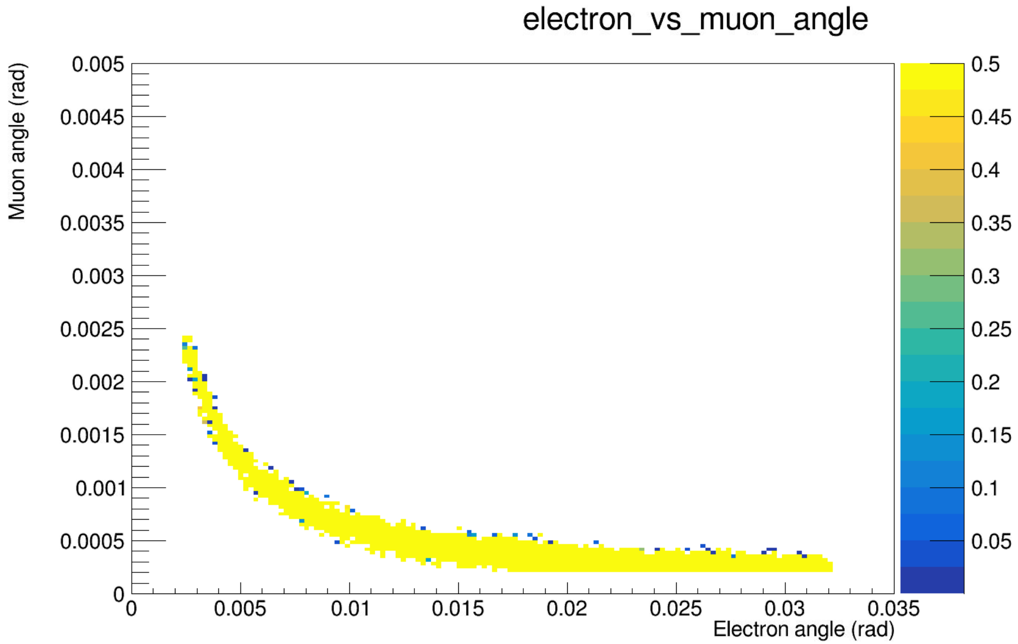
Old cuts, cut 7:

Cut 1: theta_max < 32 mrad && theta_min >=0.2 mrad
Cut 2: cut #1 + N stubs on S1 <=14
Cut 3: cut #2 + |modified_Acoplanarity| < 0.4
Cut 4: cut #4 + |z_vertex - z_target| <= 3 cm (target thickness)
Cut 5: cut #3 + chi2_vertex (KF) <= 20
Cut 6: Fiducial region
Cut 7: Elasticity cut

BKG

Ratio = 1.983 / 18513.749 = 0.00011
Fractional error: 0.2407
Result: (0.011 +/ 0.0026) %

We need to achieve a better rejection or know the background error 10 times more precisely to control the contamination

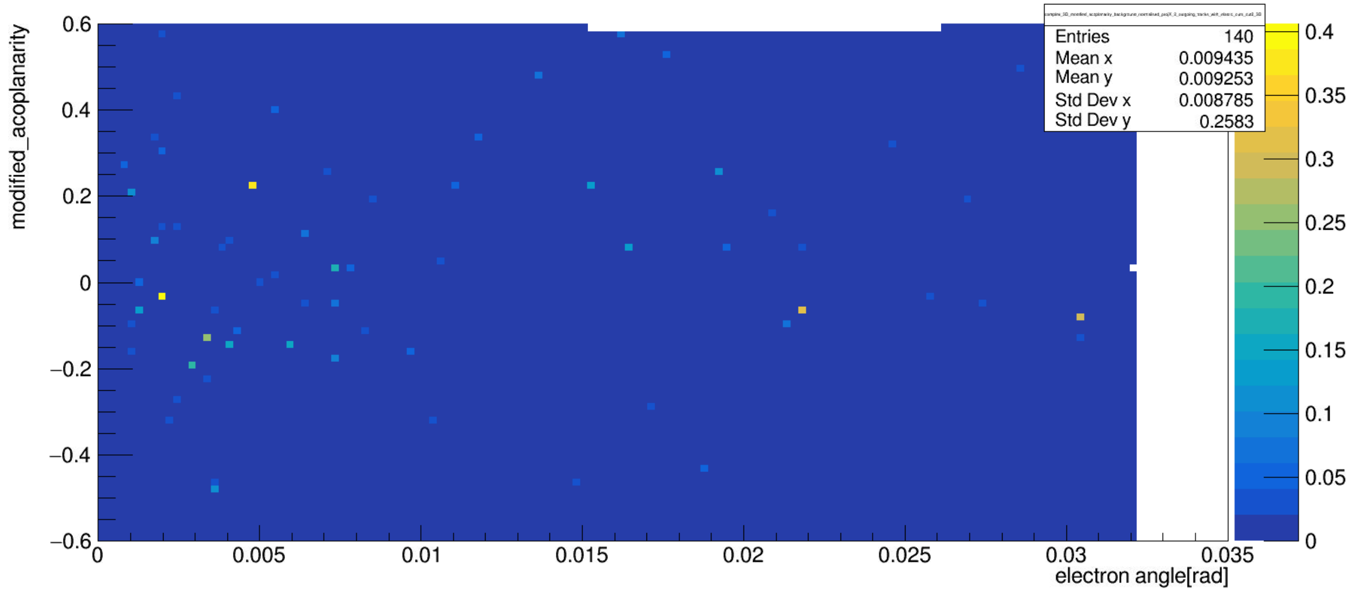


electron_vs_muon_angle	
Effective entries	10295.695
Integral	18513.749
Mean	0.020
Std Dev	0.007

SIGNAL

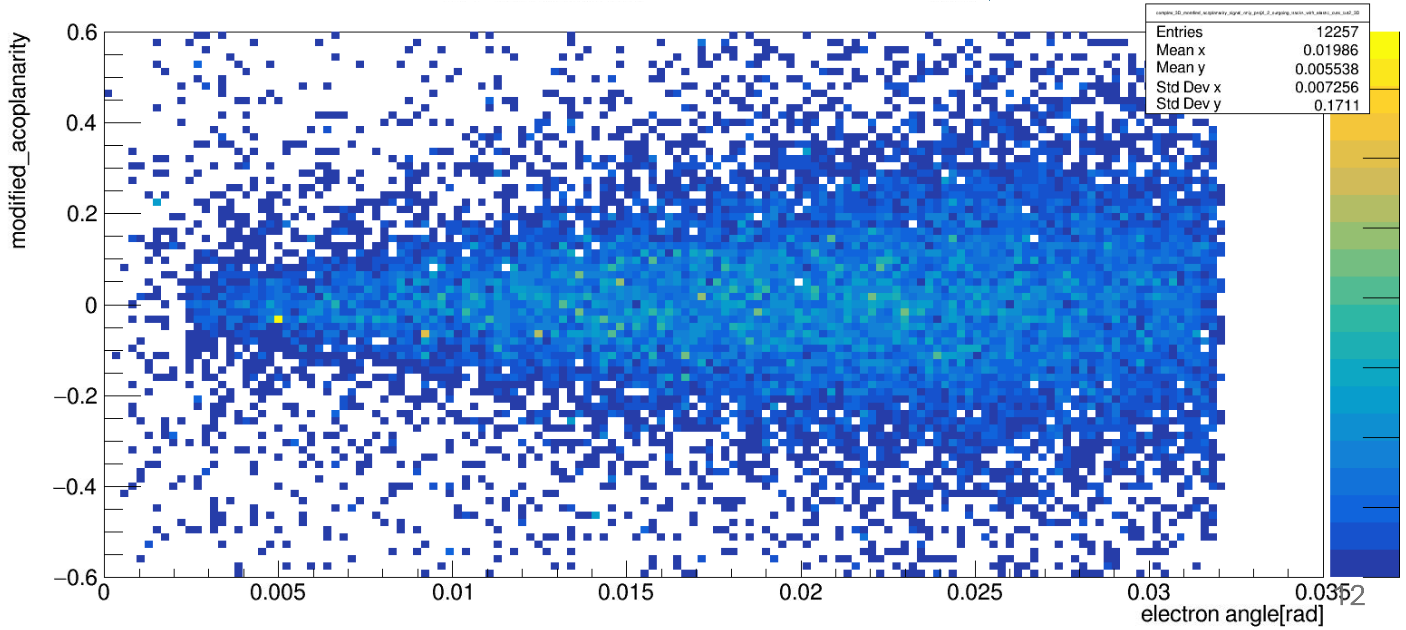
Modified acoplanarity cut analysis

OLD CUTS, cut 2 (before the modified acoplanarity cut)



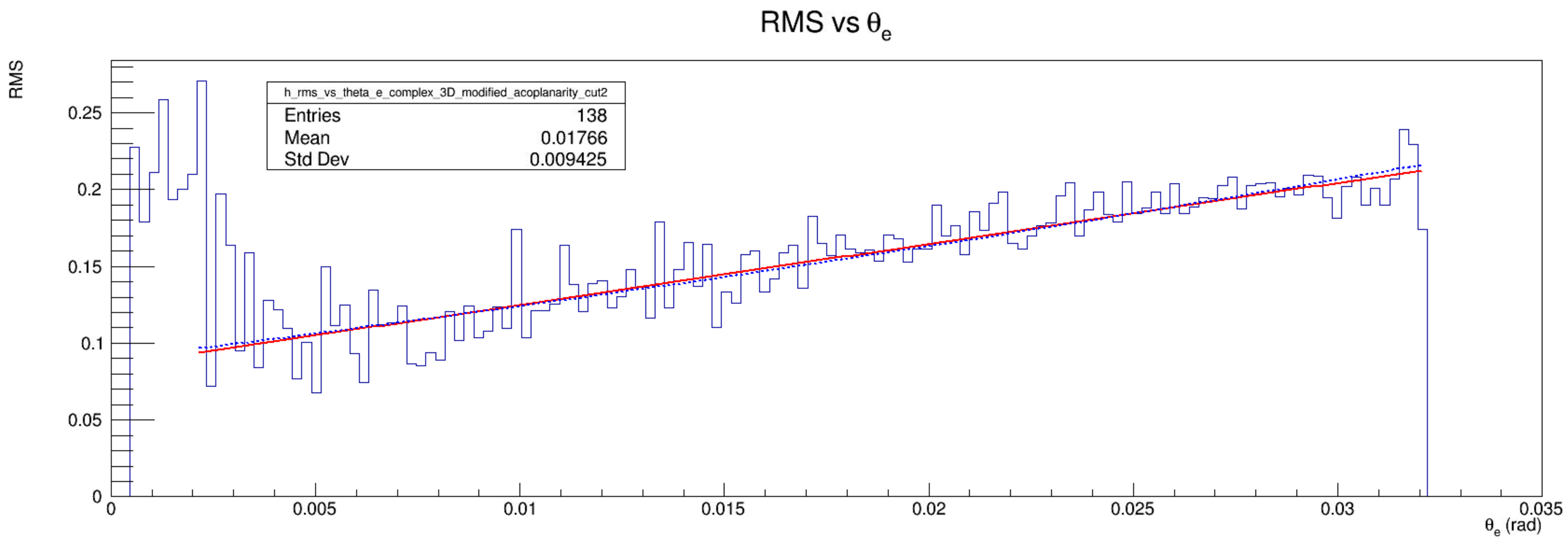
Background is ~flat

Signal is a ~cone



Modified acoplanarity cut analysis

Modified acoplanarity vs electron angle plot => Make RMS vs electron angle plot => Find the best fit of the RMS plot



Linear fit
Quadratic fit

Cut 2 on signal plot

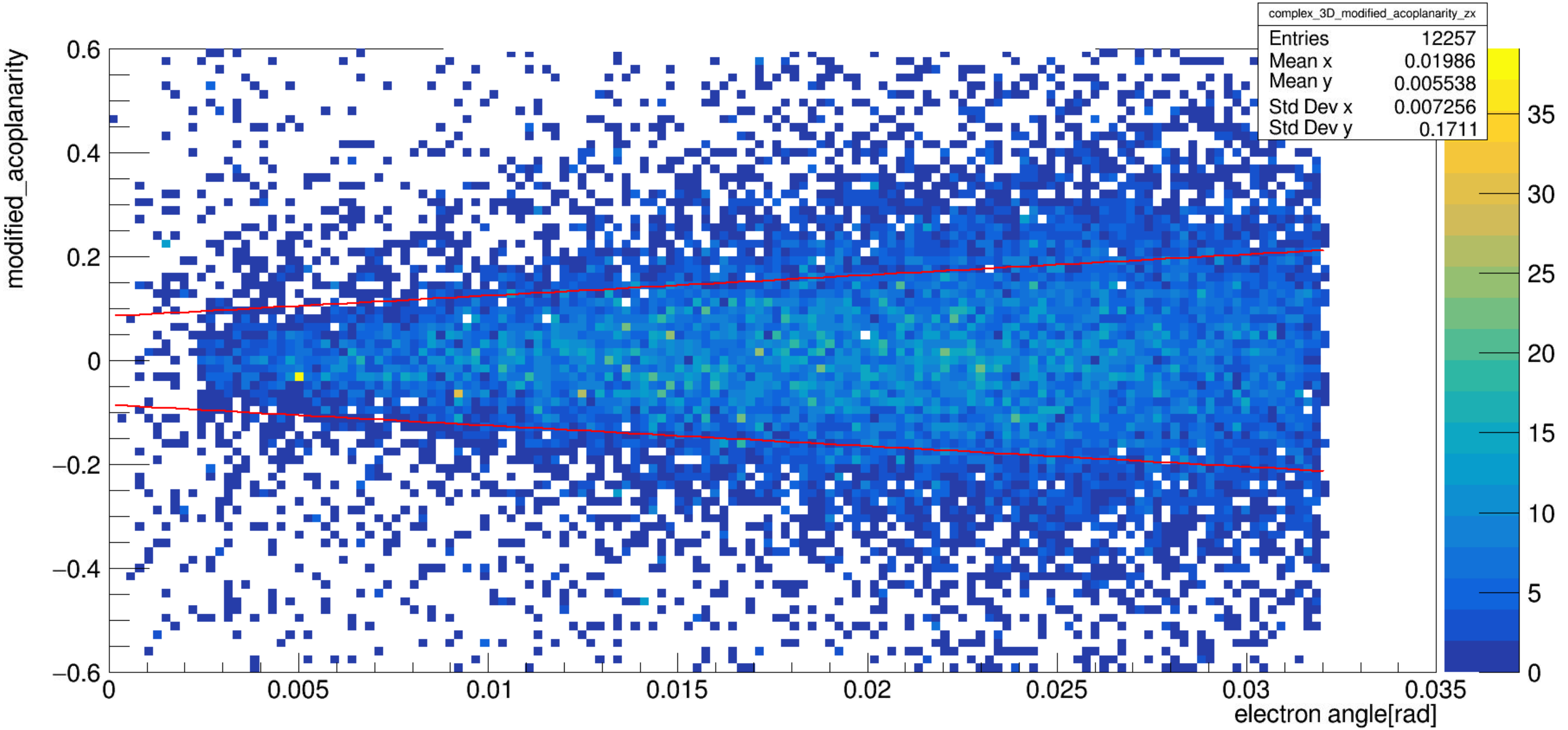
Cut 3: cut #2 + |modified_Acoplanarity| < **0.4**

Cut 3: cut #2 + |modified_Acoplanarity| < **RMS fit**

The linear fit is a better fit

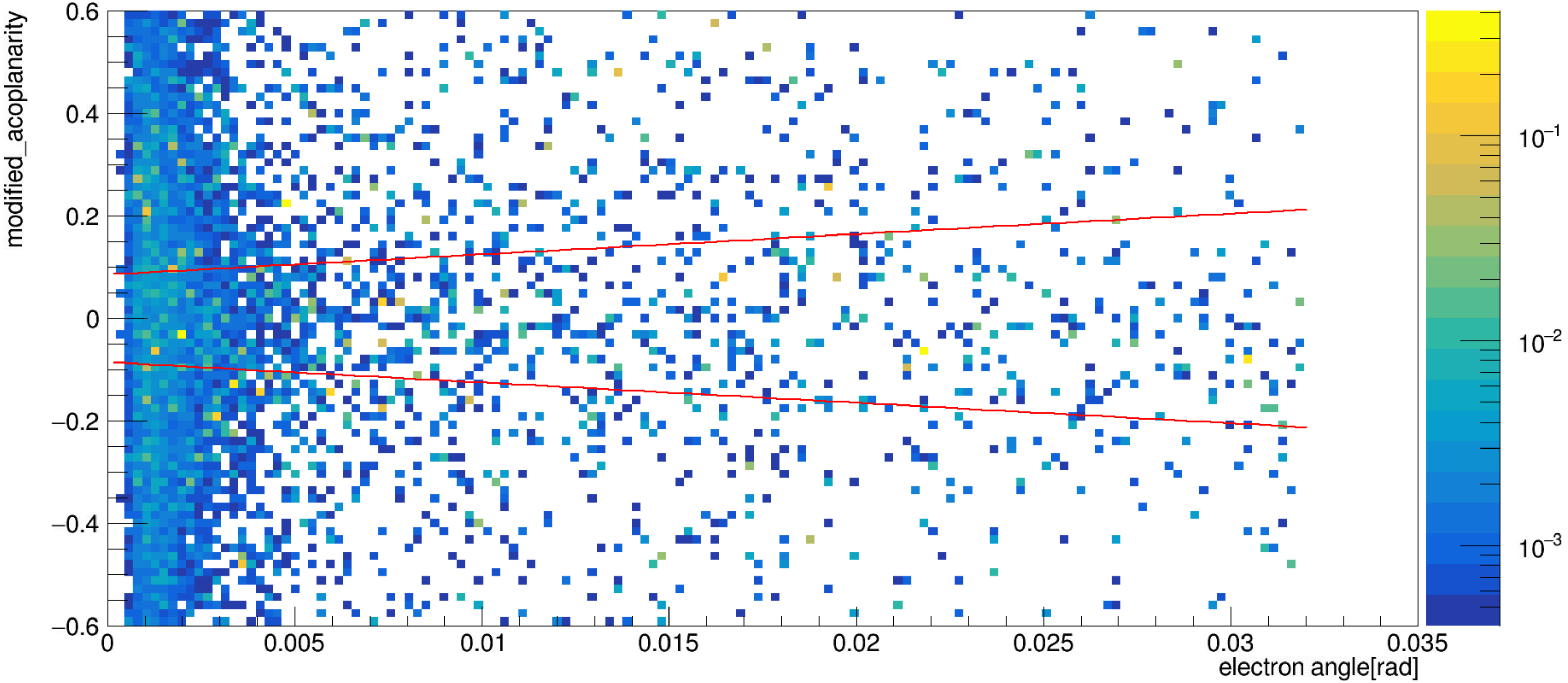
Modified acoplanarity cut analysis

Use the best fit from RMS plot (for signal file, cut 2) to fit modified acoplanarity vs electron angle



Cut 2, signal file

Modified acoplanarity cut analysis



Cut 2, background file

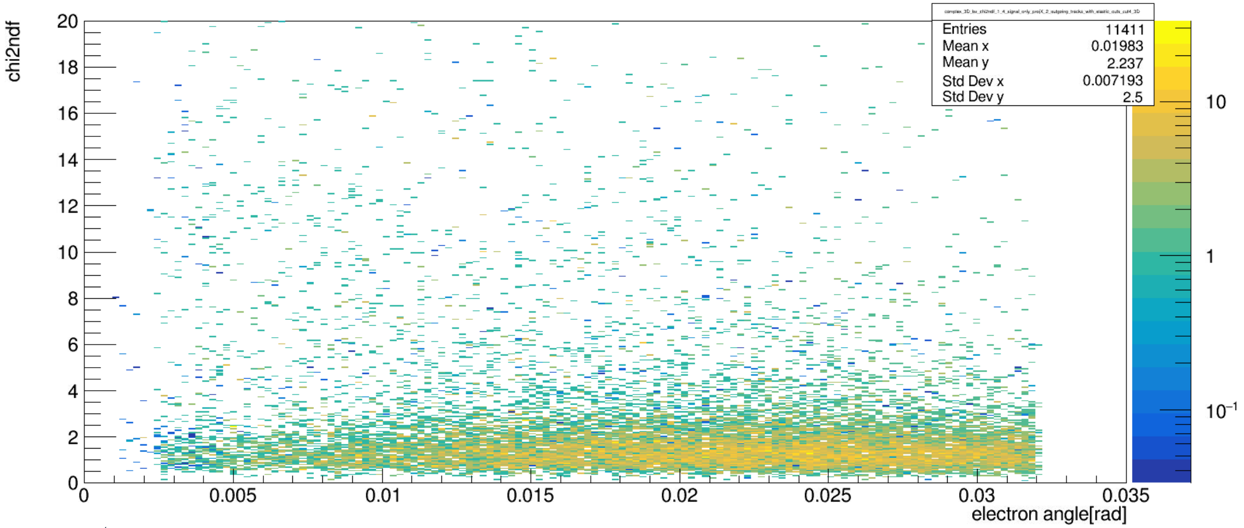
Chi2ndf cut analysis

OLD CUTS, cut 4 (before chi2ndf cut)

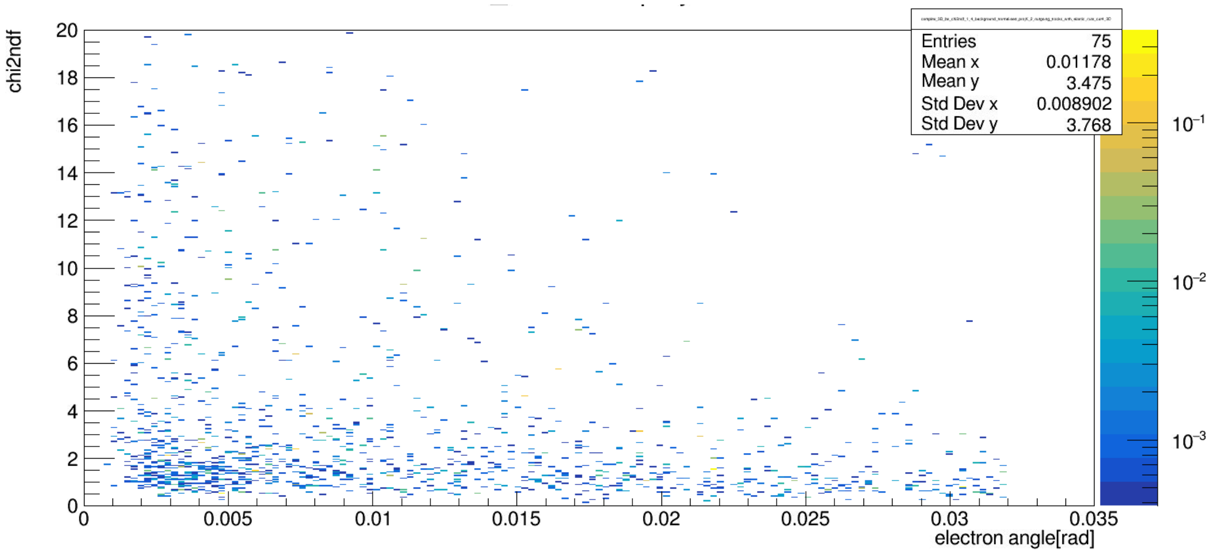
Cut 5: cut #3 + chi2_vertex (KF) <= 20 **(ORIGINAL)**

Cut 5: cut #3 + chi2_vertex (KF) <= 5 **(NEW)** → Based on the majority of events having chi2ndf <= 5

Signal file



Background file



<u>**Cut 7**</u>

New elastic cut analysis

Cut 1: theta_max < 32 mrad && theta_min >=0.2 mrad

Cut 2: cut #1 + N stubs on S1 <=14

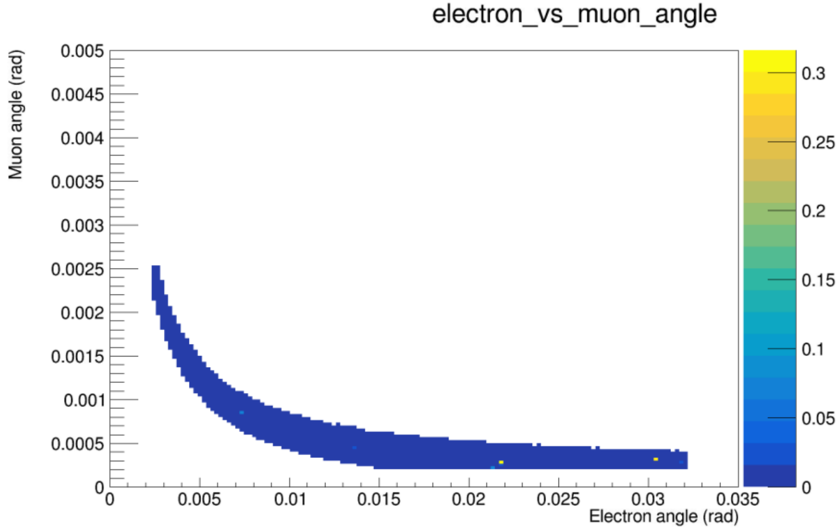
Cut 3: cut #2 + |modified_Acoplanarity| < fit on signal file's cut 2 RMS plot

Cut 4: cut #4 + |z_vertex - z_target| <= 3 cm (target thickness)

Cut 5: cut #3 + chi2_vertex (KF) <= 5

Cut 6: Fiducial region

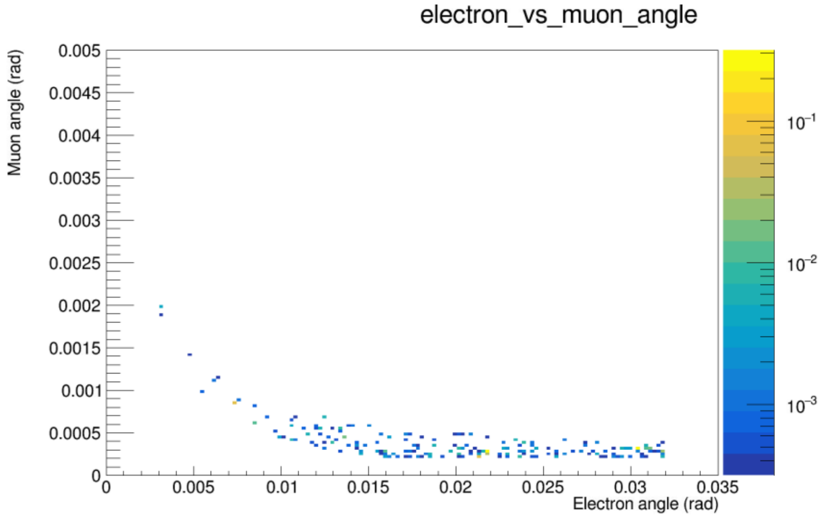
Cut 7: Elasticity cut



electron_vs_muon_angle	
Effective entries	7.271
Integral	1.189
Mean	0.023
Std Dev	0.007

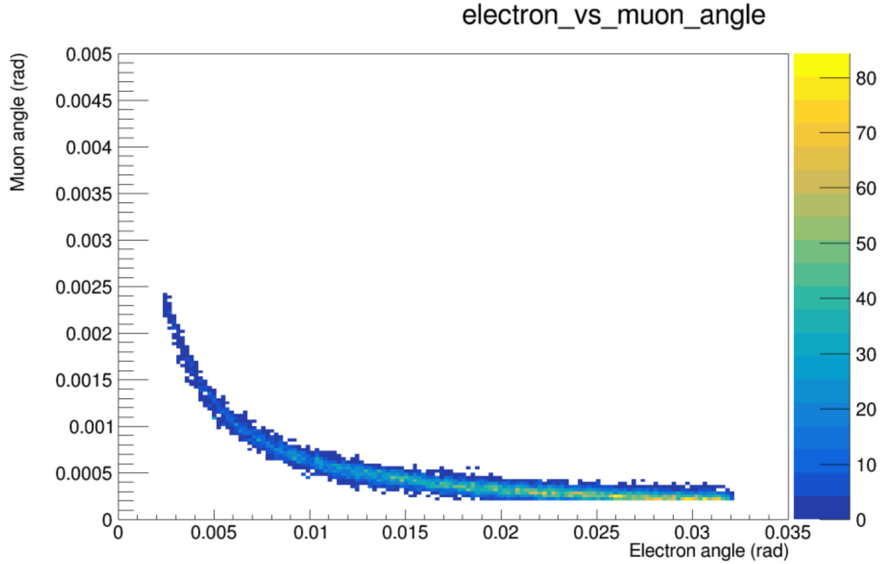
BKG

Log z



electron_vs_muon_angle	
Effective entries	7.271
Integral	1.189
Mean	0.023
Std Dev	0.007

BKG



electron_vs_muon_angle	
Effective entries	7831.066
Integral	14162.708
Mean	0.020
Std Dev	0.007

SIGNAL

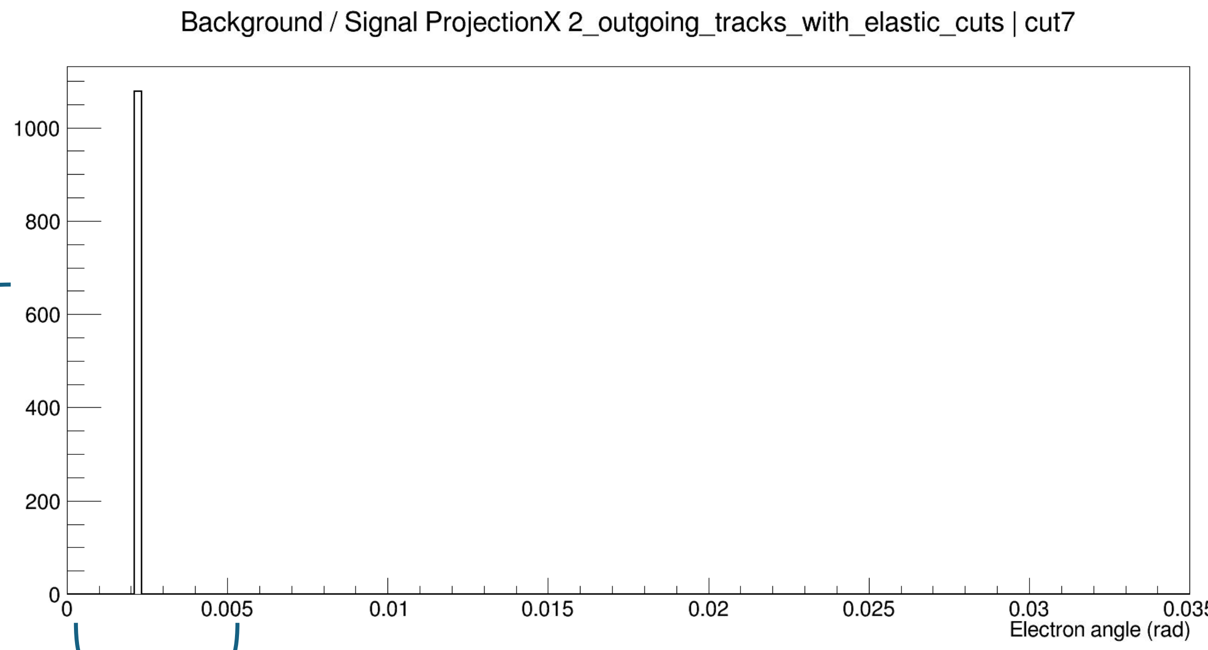
Ratio: 1.189 / 14162.708 = 0.000084

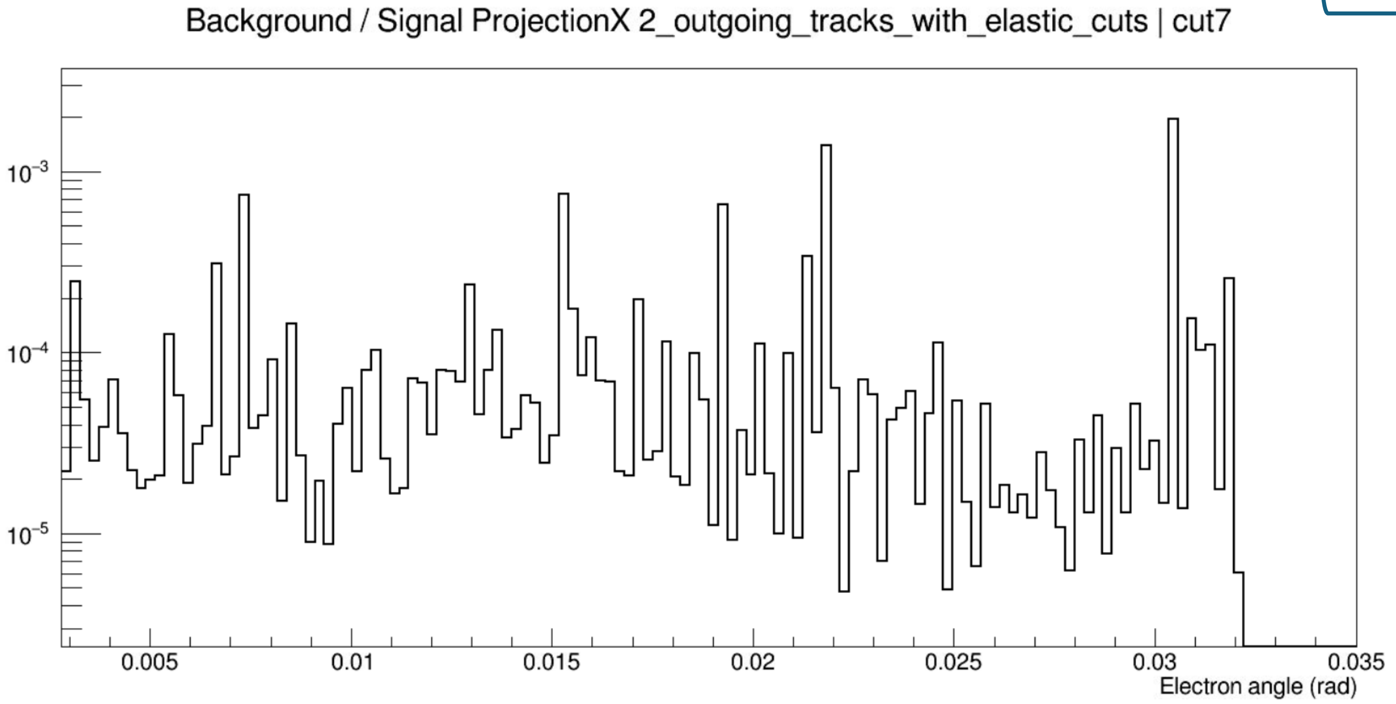
Fractional error: 0.37 → This result is better than the previous result with the old cuts

Where is the contamination located?

$$\text{Ratio} = \frac{h_{background} \rightarrow \text{ProjectionX()}}{h_{signal} \rightarrow \text{ProjectionX()}}$$

Ignoring this peak, the ratio is flat. No area is more contaminated than another area.





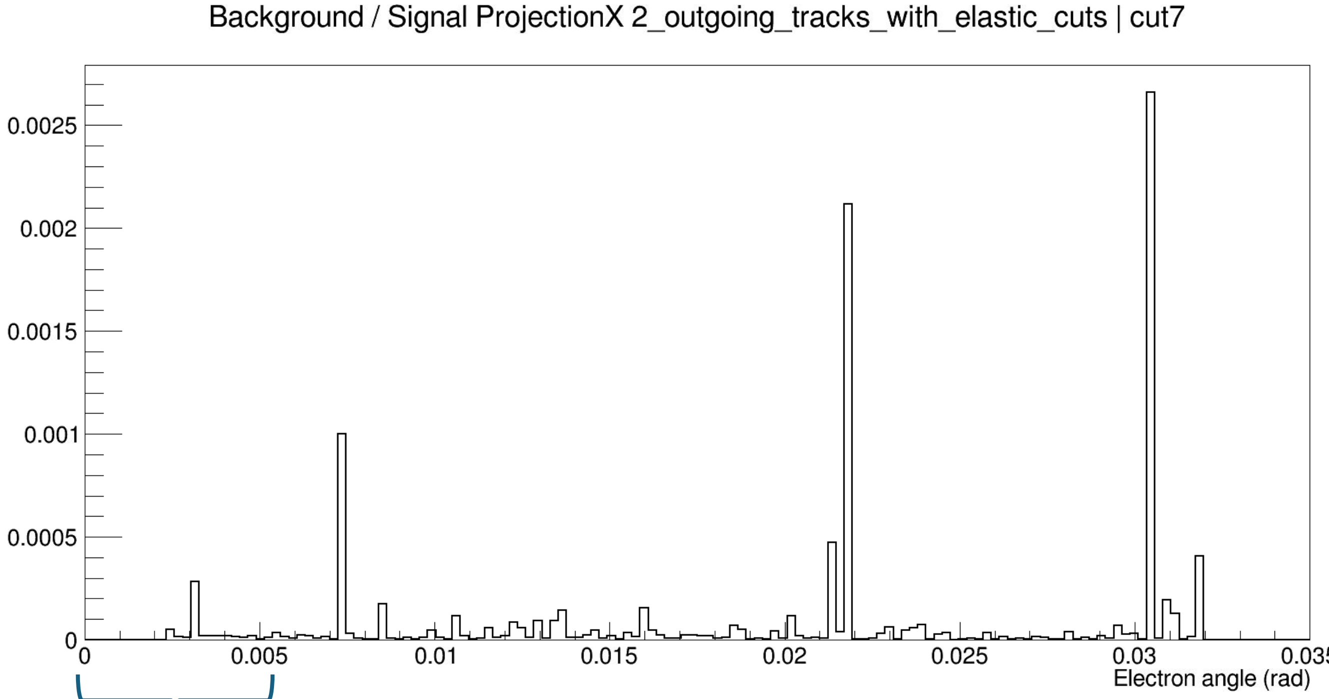
This is the region where we aren't sure if the particles are muons and electrons.

The peak is due to low statistics in this region (dividing by a small number = blown up peak)

Ratio for new cuts

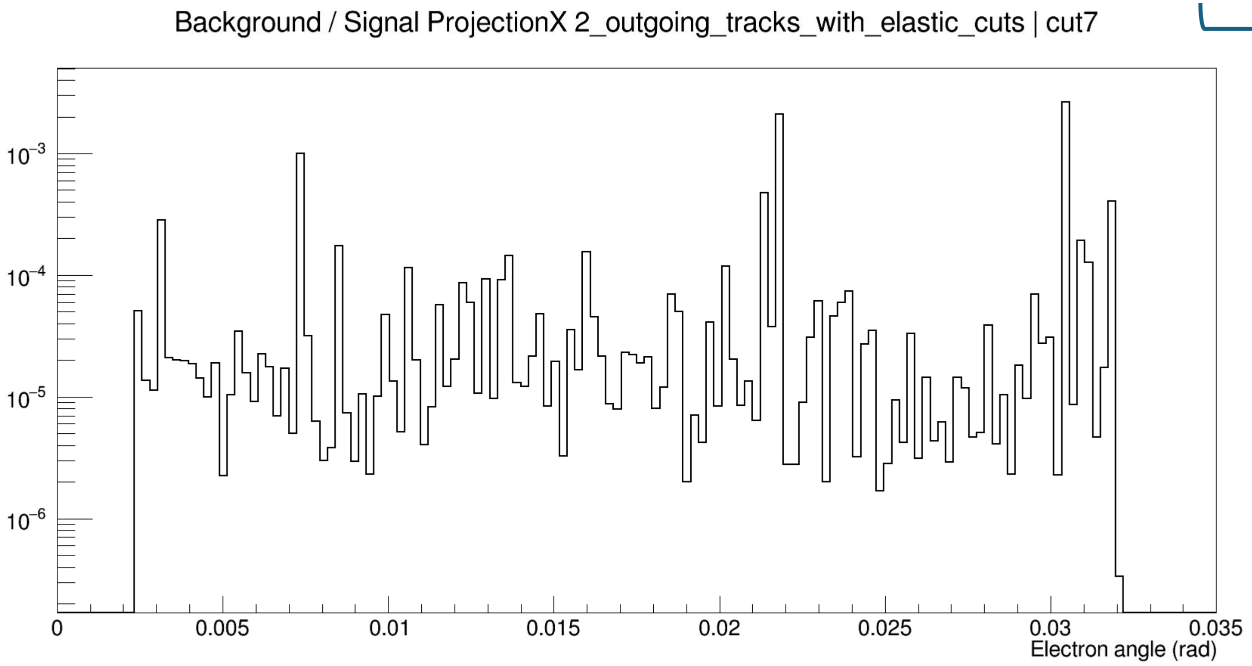
Contamination can likely be resolved with the muon filter in the 2025 test beam and simulations.

The normalisation region is used only for systems as barely affected by the running of alpha.



"Unknown PID" region

Normalisation region



The main problematic peak is at 0.0075 radians (under investigation).

Conclusion

- I’m using:
  - ~50,000 equivalent events – background events
  - ~50,000 equivalent events – signal events
  - Normalisation factor: 1.95884791e-7

- We can change the modified acoplanarity and chi2ndf cuts to improve the elastic event selection

- New cut 3: |modified_Acoplanarity| < RMS fit (under testing)
- New cut 5: chi2_vertex (KF) <= 5 (under testing)

- Ratio (**old cuts**): Result: (0.011 +/ 0.0026) %
  - We need to achieve a better rejection or know the background error 10 times more precisely to control the contamination

- Ratio (**new cuts**): Result: (0.0084 +/ 0.0031) %
  - The result is better than the previous result => still room for improvement

- I’m still currently investigating how many signal events are lost with each cut to ensure that we aren’t suppressing too much signal whilst trying to suppress the background