Progress on anti-Helium analysis with NAIA

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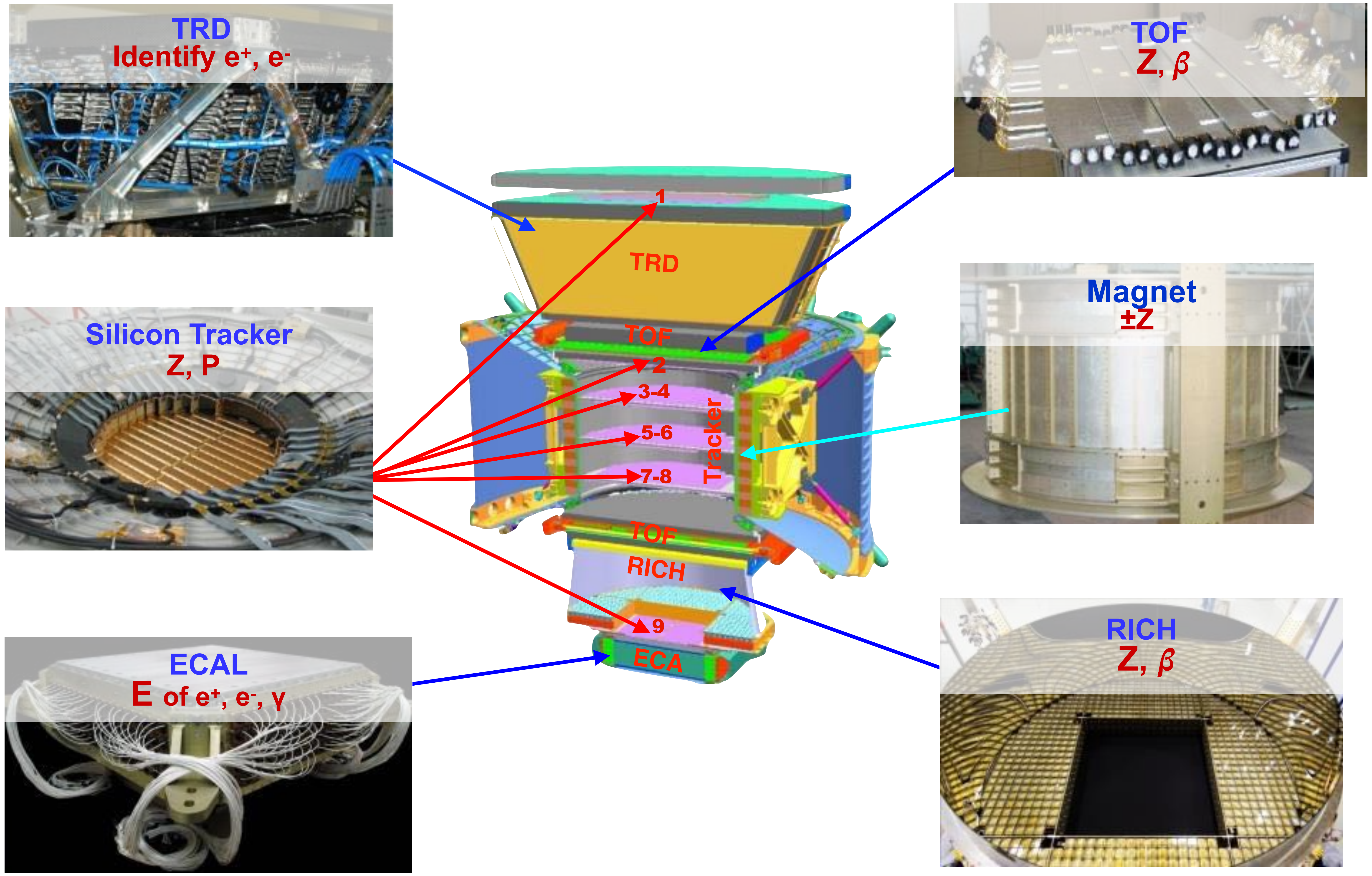
21/Apr/2023

AMS SUBDETECTORS

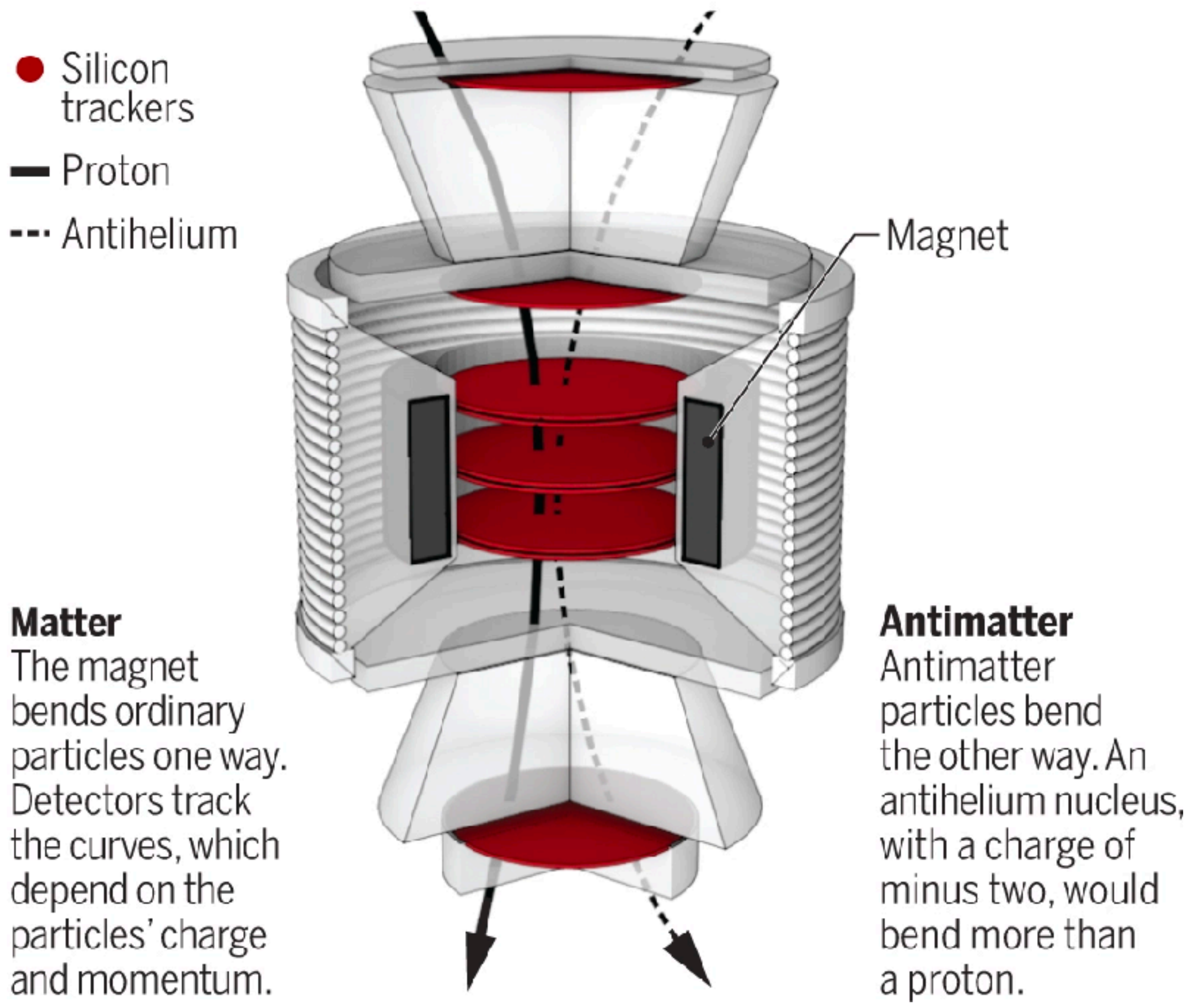
Particles and nuclei are defined by their charge (**Z**) and energy (**E ~ P**) or rigidity **R=P/Z**

Both quantities are measured redundantly and independently by AMS sub-detectors: Tracker, TOF, TRD, ECAL, RICH



Antimatter particles in cosmic rays are unique messengers for the search of dark matter annihilation signals in the Galaxy or the presents of large domains of antimatter in the universe.

AMS collaboration has publish the results of the positrons, anti-Protons. Now we need to search for heavier antimatters in the cosmic rays with AMS. Antihelium is a very interesting topic since till now we have no clear evidence that we have antihelium in cosmic rays.



This analysis

- Step1: Selection of events with charge compatible to helium/anti-helium in good quality. From the propagation theory of the cosmic ray, anti-helium is unlikely to be produced in the cosmic rays, that means, even there are some, should be very small amount. That make the most of the events with negative charge are backgrounds. Anti-helium should share the similar distribution behaviour of most variables with helium, that make the signals.

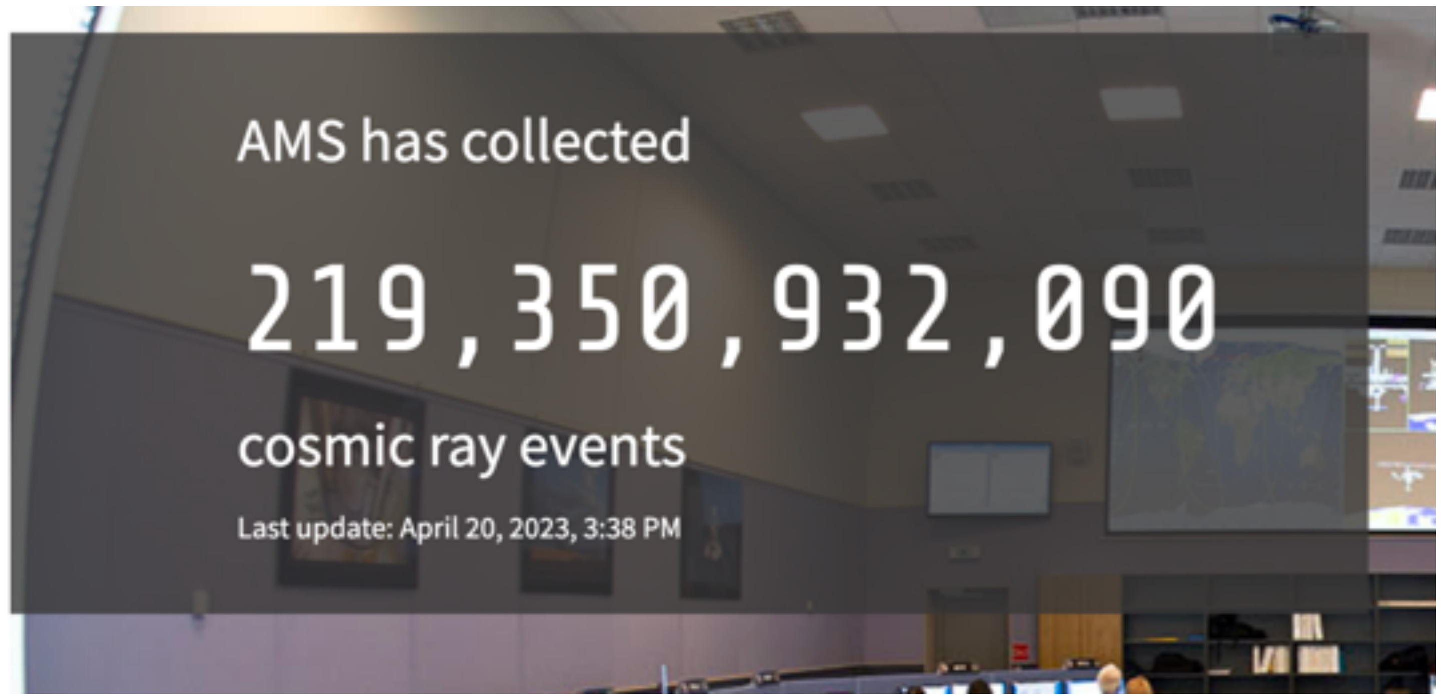
- Step2: Study each variables possibly can be used to discriminate signals from backgrounds, both in Monte Carlo (MC) and the flight data. Select variables which have a large difference behaviour in signals and backgrounds.

- Step3: Employ the variables found in the second step, and perform machine learning with TMVA integrated in ROOT. Train the MC data to get the classifier, apply to the flight data, find the most efficient cut, and get the final result of the anti-helium events, and also significance of the analysis.

Step 1

- Selection of events with charge compatible to helium/anti-helium in good quality.

Data used for the analysis



- Ntuple:
  /storage/gpfs_ams/ams/groups/AMS-Italy/ntuples/v1.0.0/ISS.B1236/pass8

  from 1305853512.root to 1635855691.root

  20 May 2011 —> 2 Nov 2021

  Extend to 1668126894
  11 November 2022

- Rigidity: GBL

Selections:

Trigger:

HasPhysicsTrigger;

RTI Selections;

TOF:

Beta>0.3;

Good hits on Upper TOF: GoodPathlength(0b0011);

Charge in TOF (charge - 0.75f, Max);

Charge in Upper TOF (charge - 0.5f, charge + 1.0f);

Charge in Lower TOF (charge - 0.5f, charge + 1.0f);

TofPlus.Chi2Coo < 10.0f

TofPlus.Chi2Time < 10.0f

Inner Tracker:

fabs(R)>GeoCutoff;

fabs(R)>2.5;

Fiducial volume in inner tracker;

Hits on Y side = 7;

Hits ChiSquare < 10;

Hits ChiSquare_X < 10;

Hits ChiSquare_Y < 10;

Charge on each layer (charge - 0.4f, charge + 0.6f);

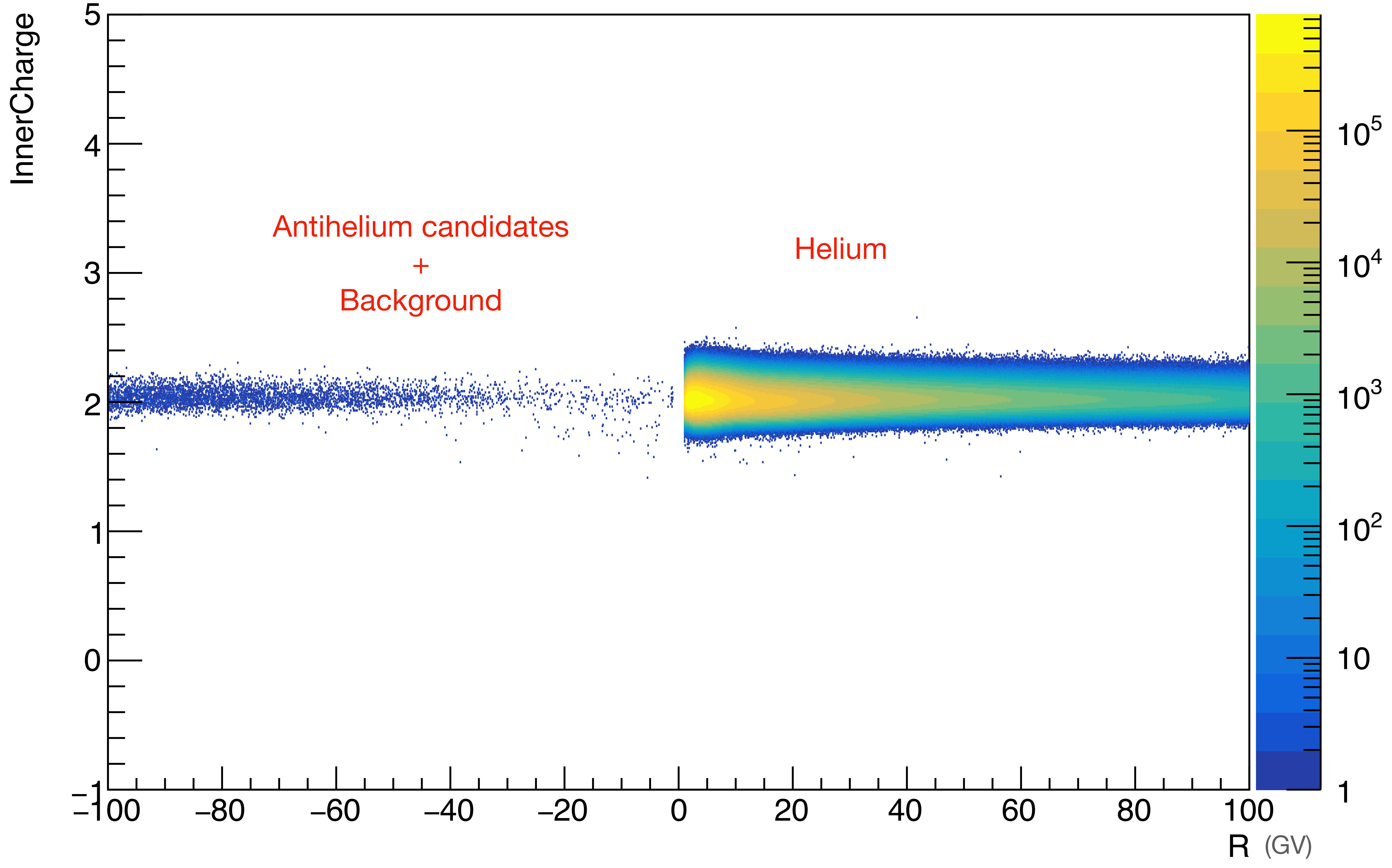
ChargeRMS<0.55;

ChargeRMS/InnerCharge < 0.3;

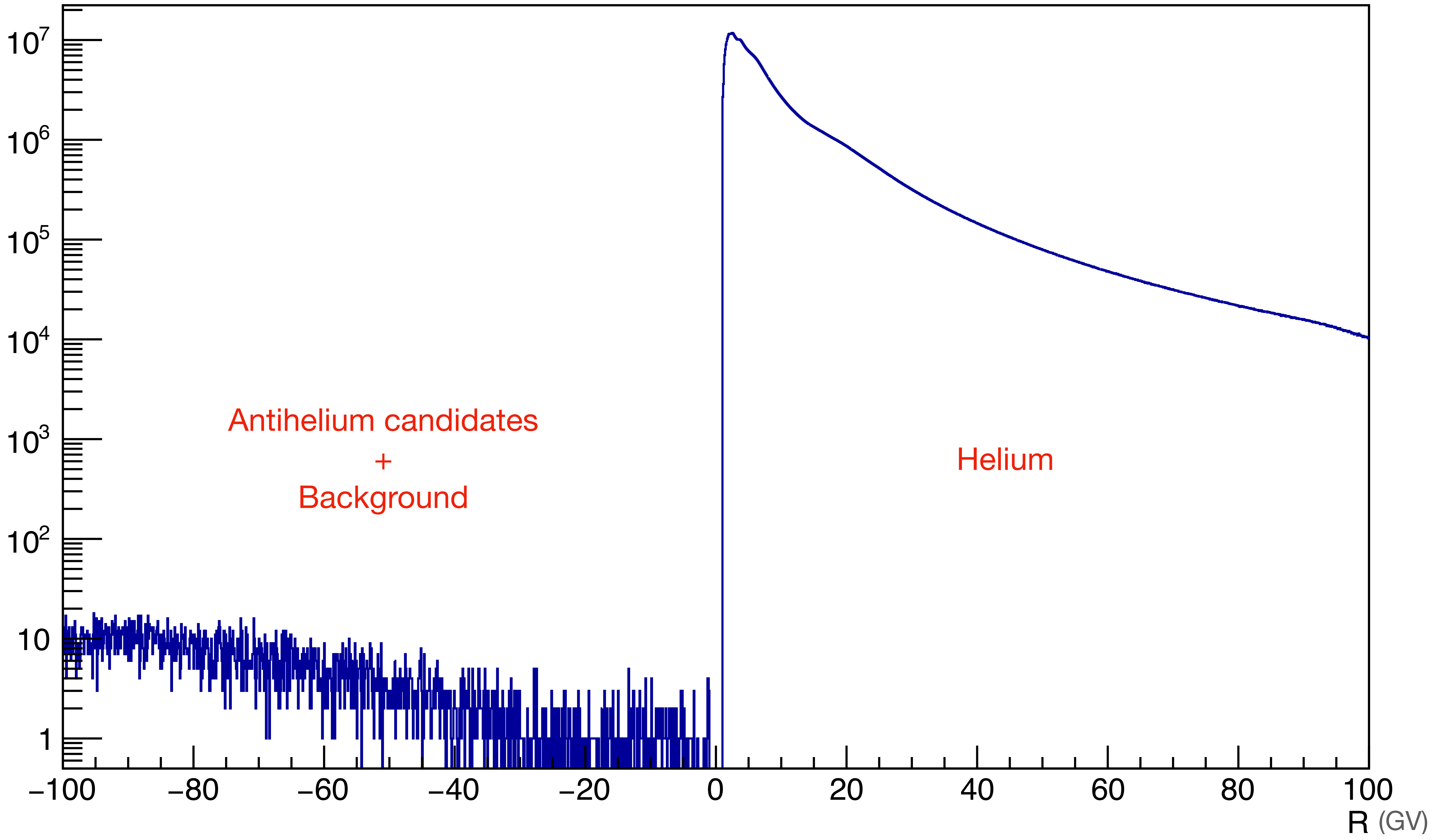
f_InvRigErrR<=10;

fGet_PartialRigidity_SameSignNum>=3;

fGet_PartialRigidity_Rigidity_MaxDiffInvR<=20;



From the propagation theory of the cosmic ray, antihelium is unlikely to be produced in the cosmic rays, that means, even there are some, should be very small amount. That makes the search for antihelium much more difficult.

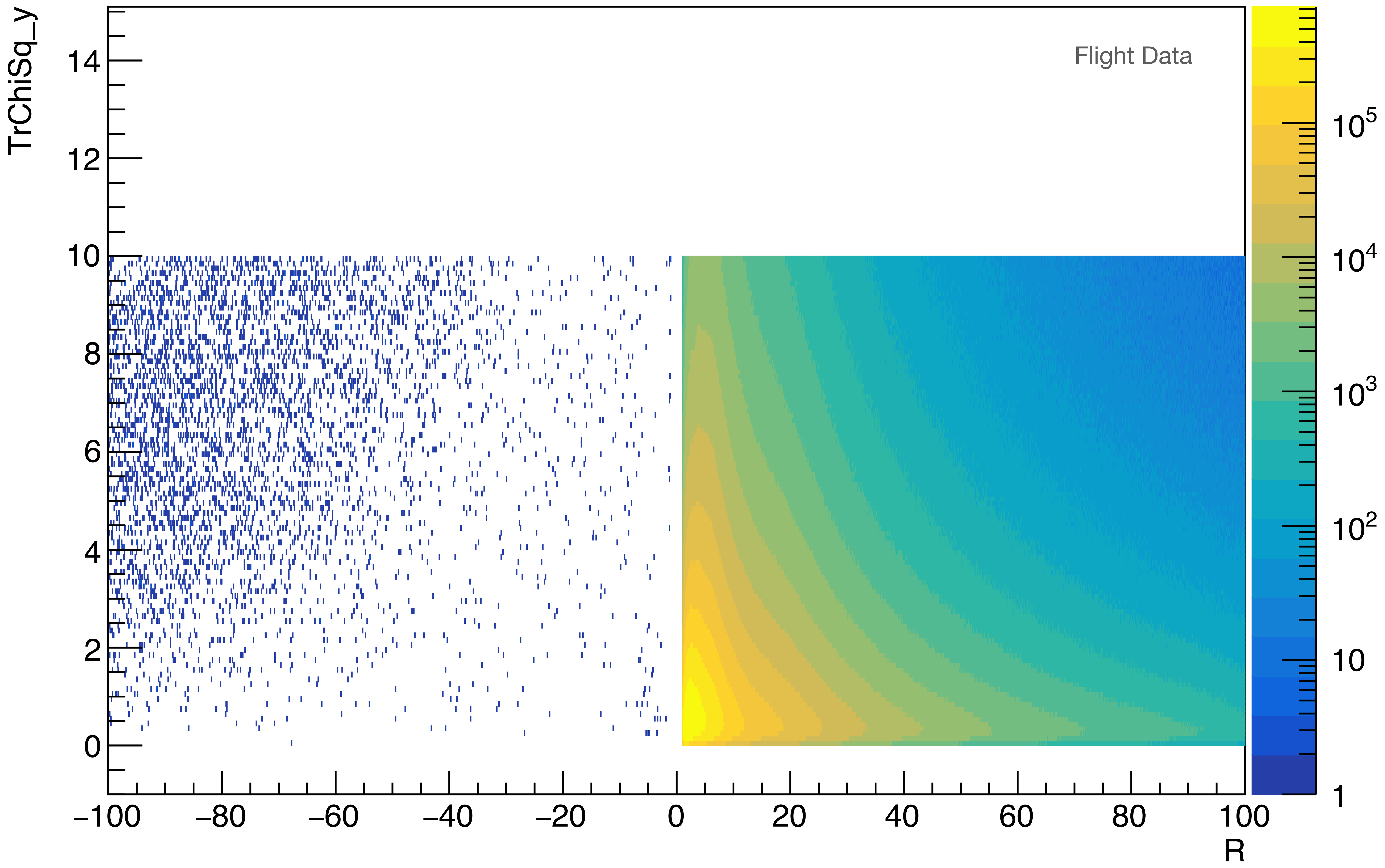


The background is mostly from the particle scattering in the detecter. Due to the scattering, some of the helium events are reconstructed with negative charge.
In this analysis, the most challenge job is to characterise the background and find discriminating variables.

Step 2

- Study each variables possibly can be used to discriminate signals from backgrounds, both in Monte Carlo (MC) and the flight data. Select variables which have a large difference behaviour in signals and backgrounds.

For example, we are examining several variables that are closely related to the equality and properties of the trajectory reconstructed in the inner tracker of the AMS.
These variables are defined from the very beginning to be as sensitive as possible to particle scattering and resolution effects in the inner tracker.



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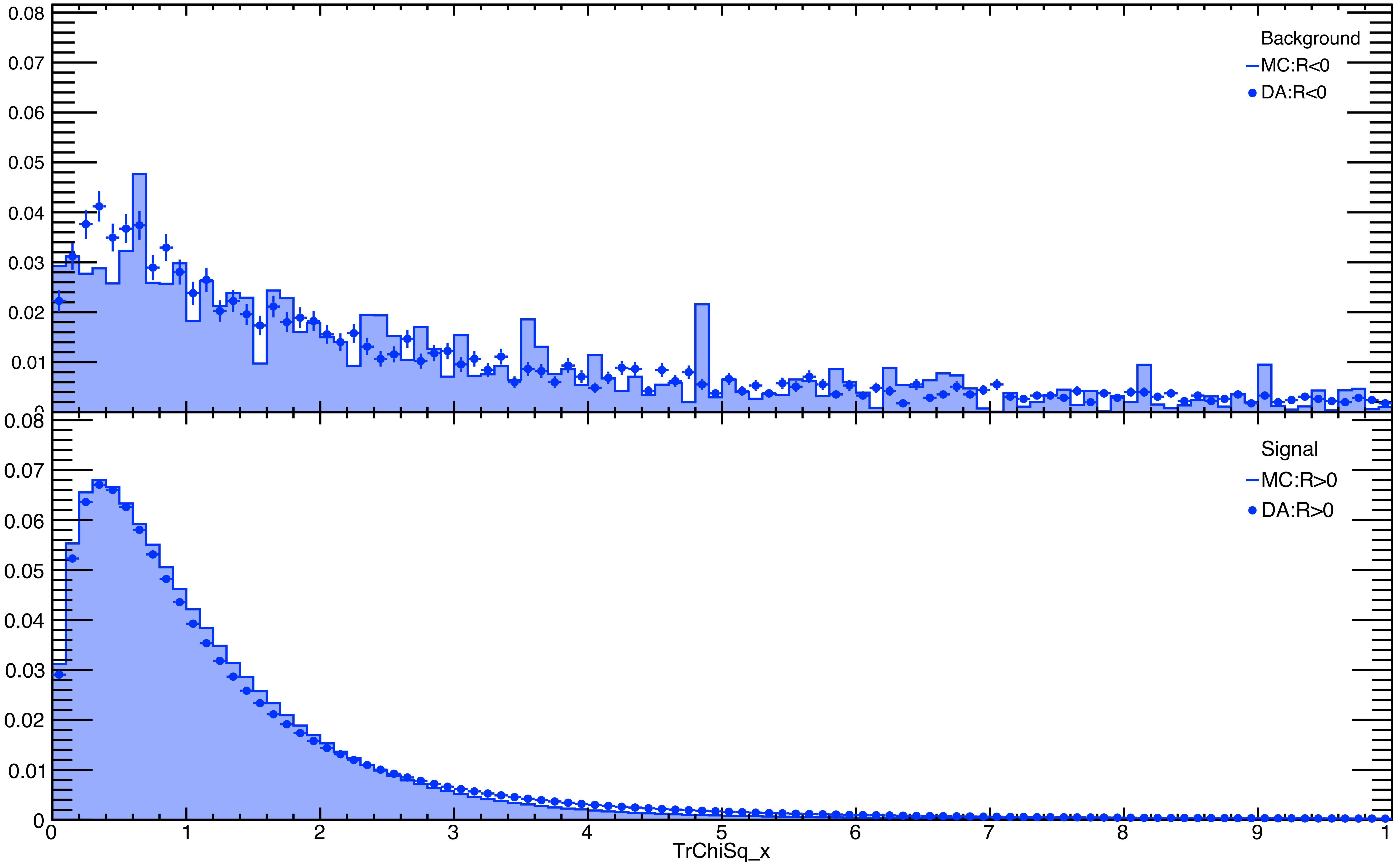

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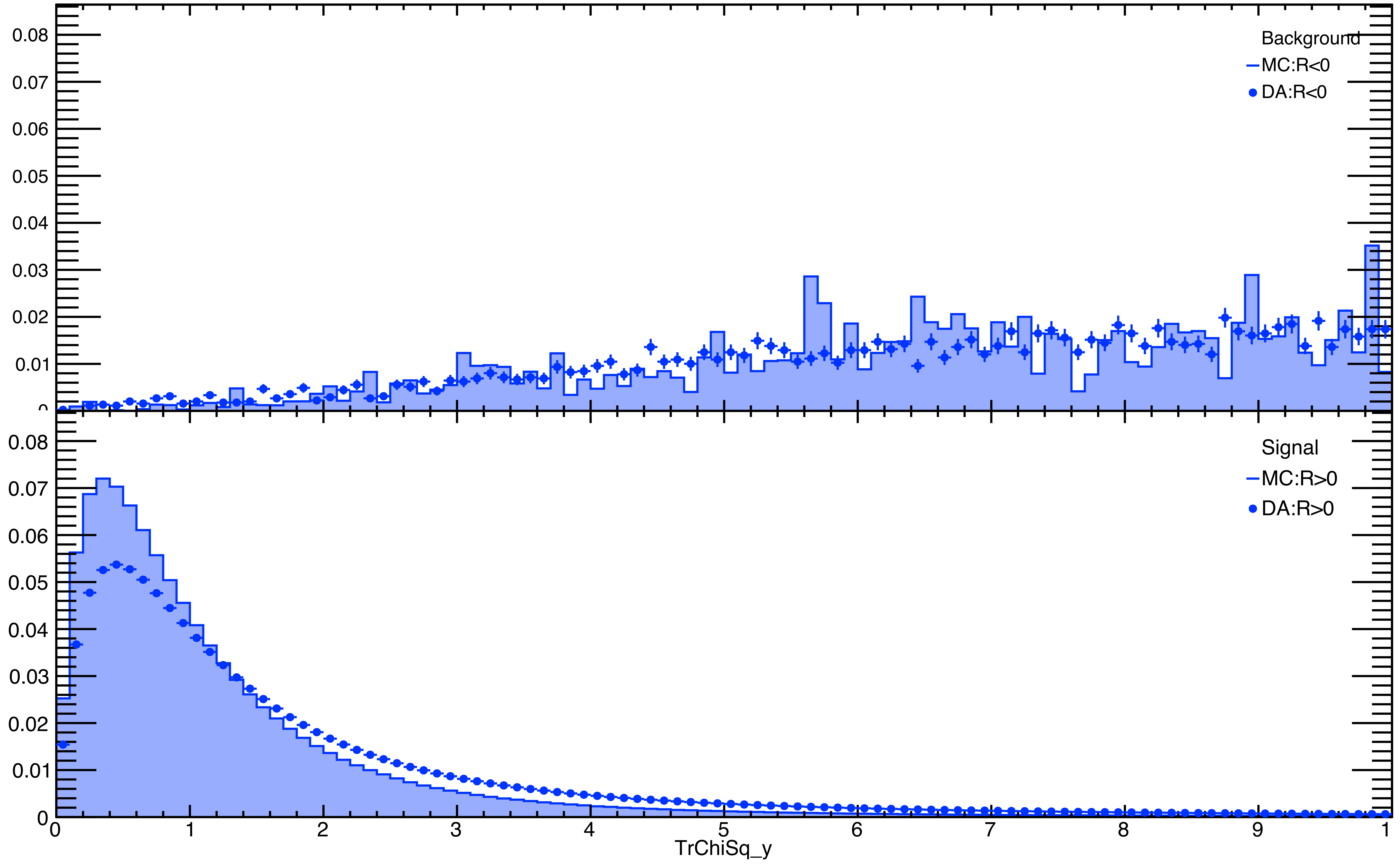

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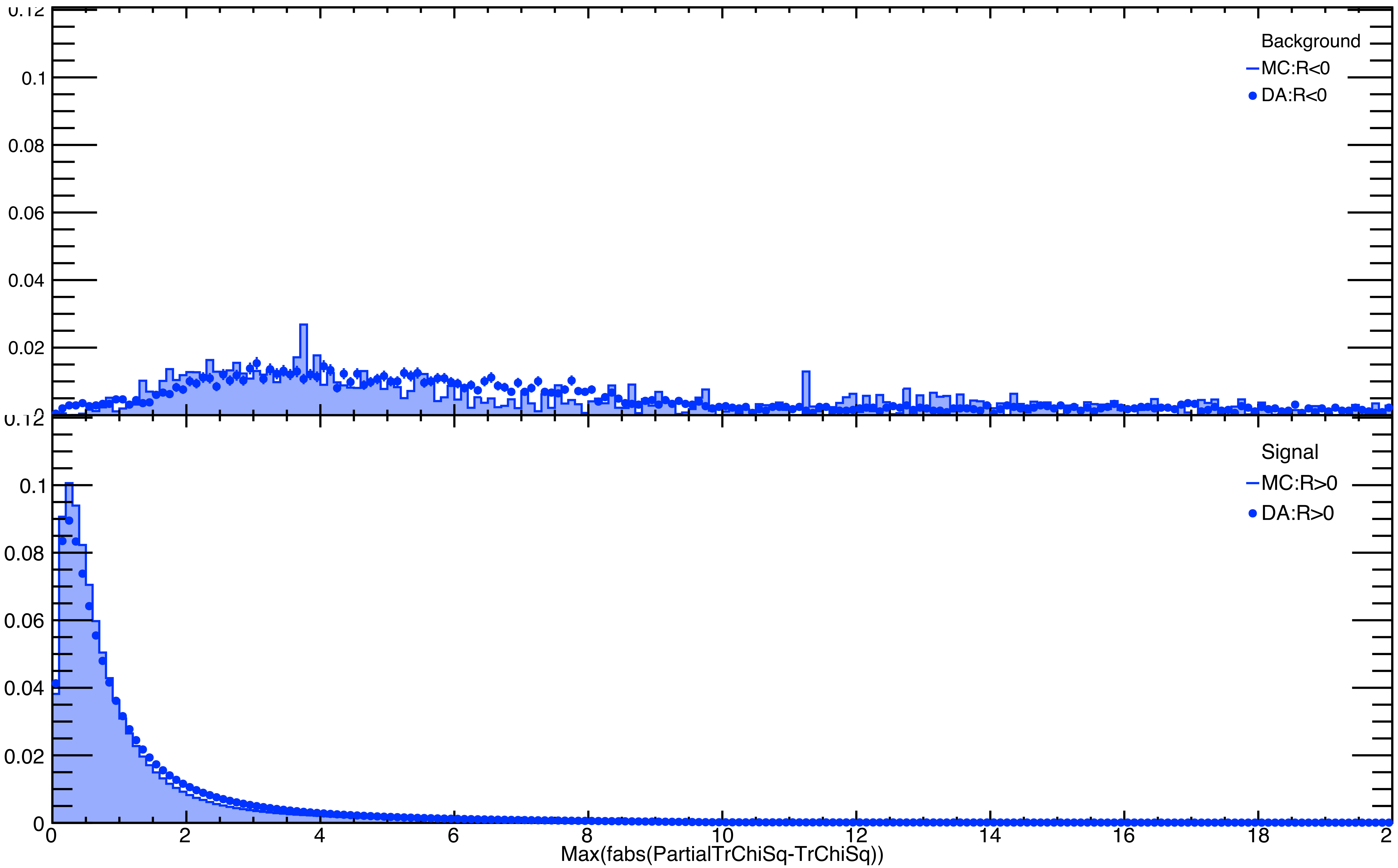

PartialTrChiSq: Normalized chi-square obtained from a fit where a given layer 'i' was excluded.

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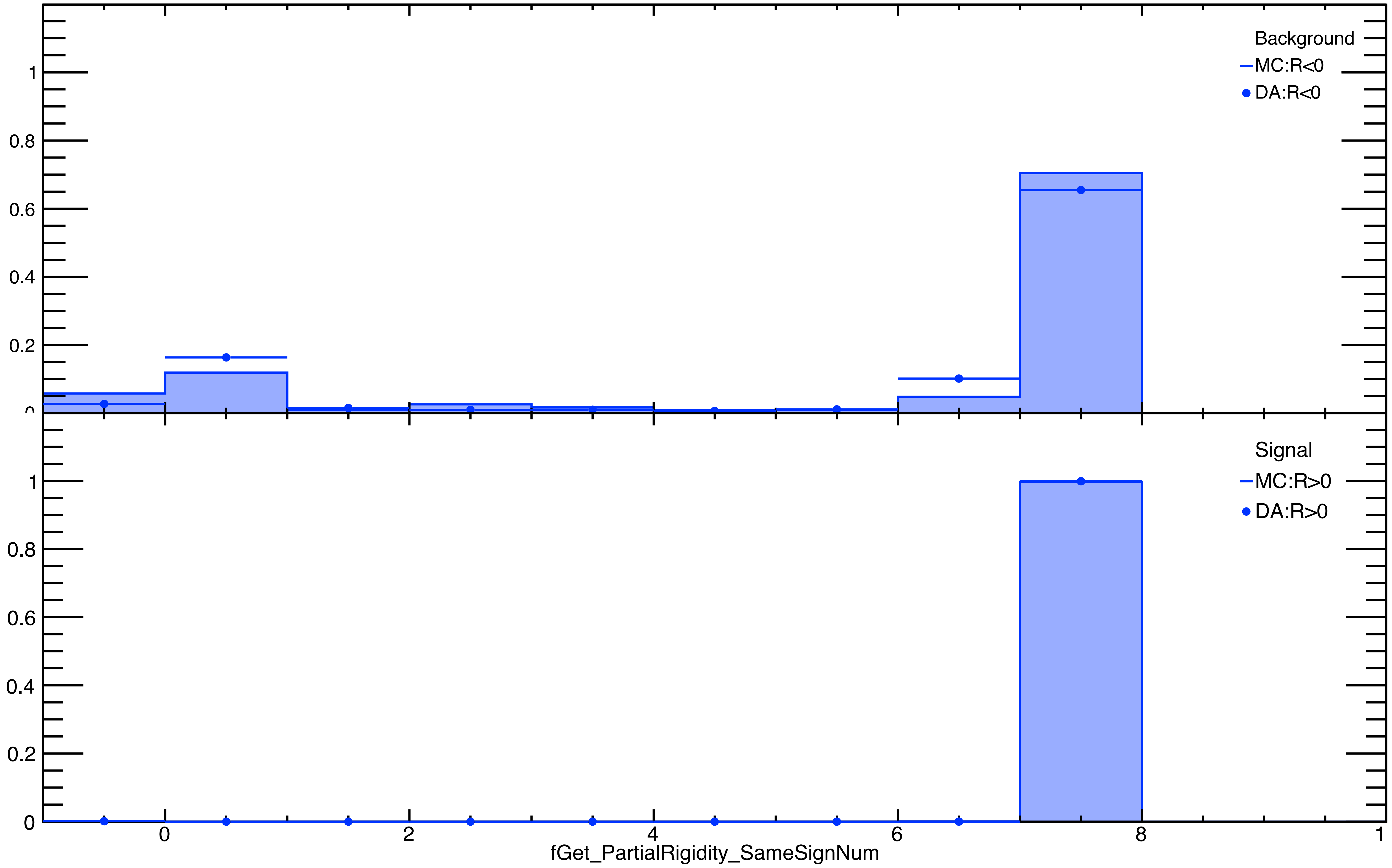
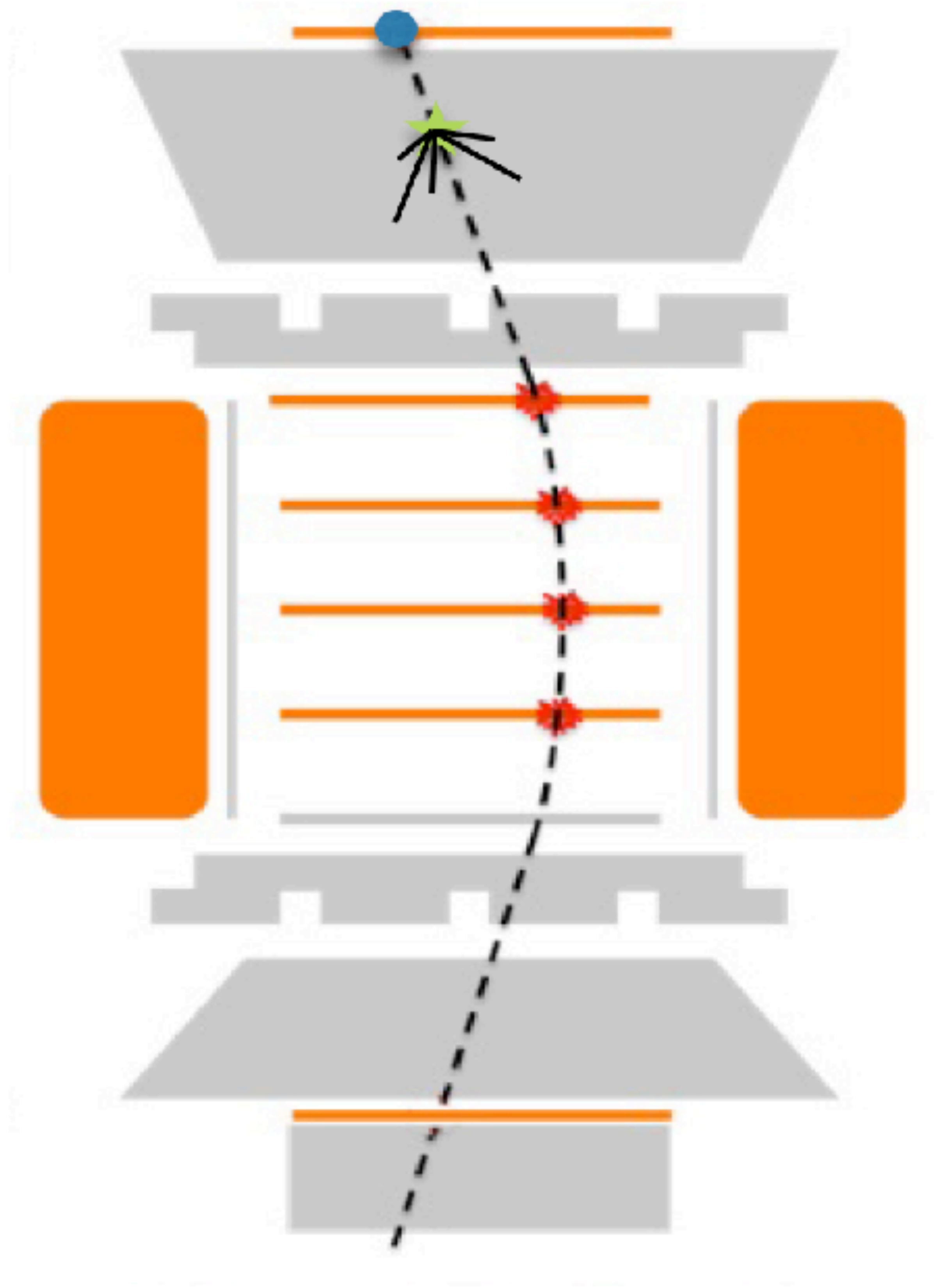


PartialRigidity: Rigidity obtained from a fit where the hit on an a given layer 'i' is not considered.

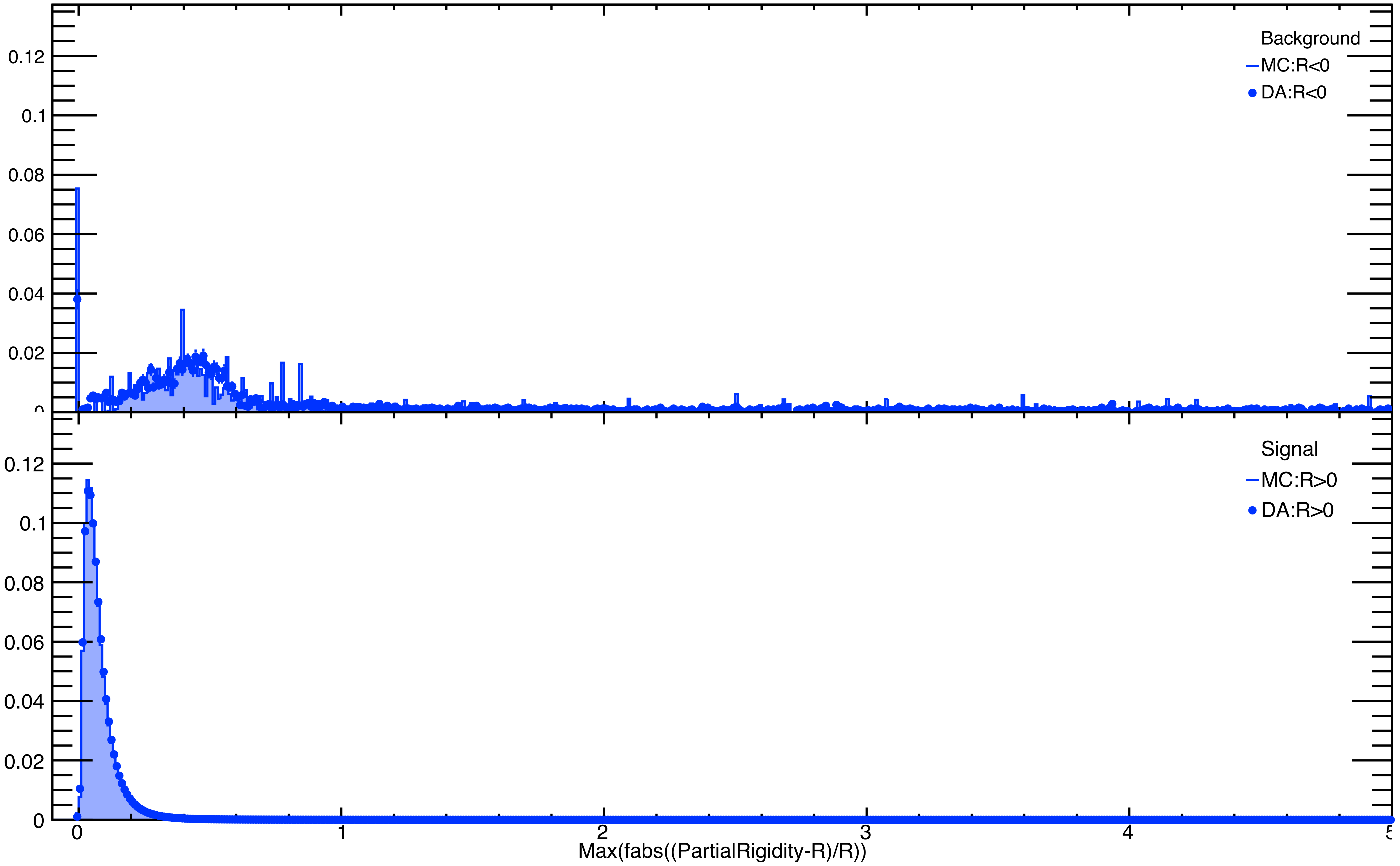
SameSignPatialRNum

PartialRigidity: Rigidity obtained from a fit where the hit on a given layer 'i' is not considered. We have 7 PartialRigidity in total, considering 7 layers of the inner tracker.

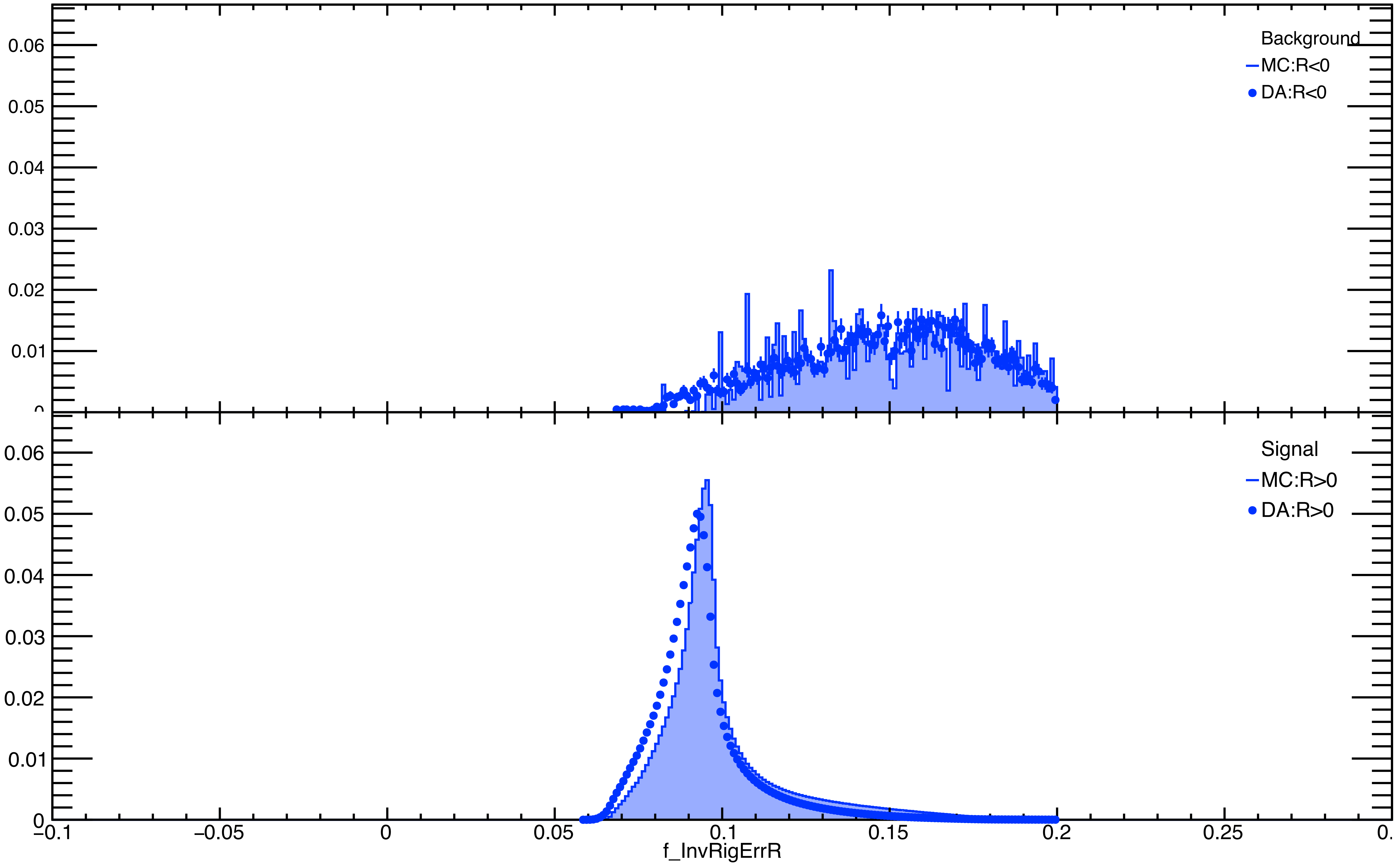
SameSignPatialRNum: the total count of the case that PartialRigidity have the same sign as the general reconstructed rigidity.



For example, we are examining several variables that are closely related to the equality and properties of the trajectory reconstructed in the inner tracker of the AMS. These variables are defined from the very beginning to be as sensitive as possible to particle scattering and resolution effects in the inner tracker.



For example, we are examining several variables that are closely related to the equality and properties of the trajectory reconstructed in the inner tracker of the AMS. These variables are defined from the very beginning to be as sensitive as possible to particle scattering and resolution effects in the inner tracker.

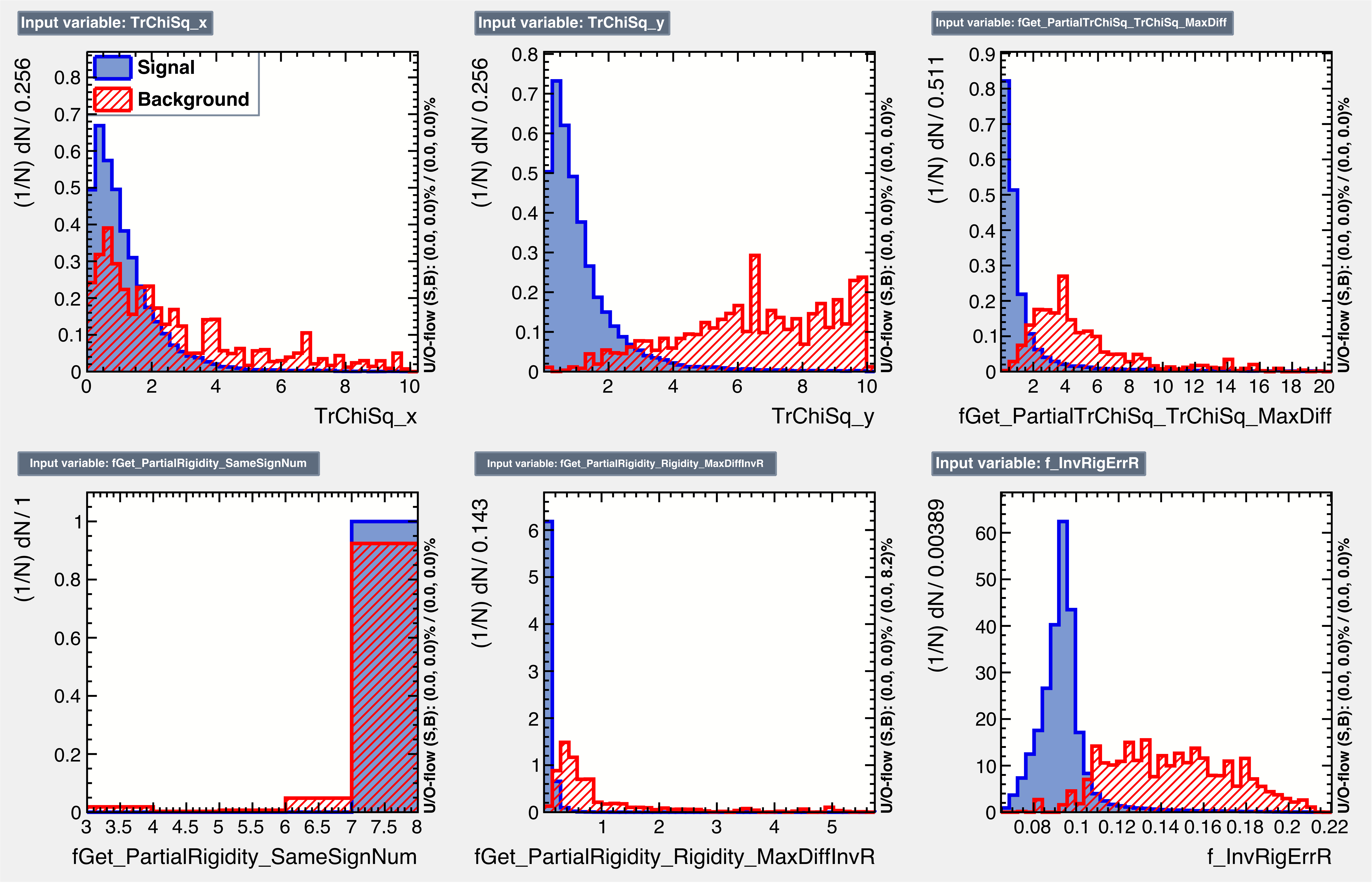


InvRigErr: Error on the deflection (= 1 / rigidity) estimation, for each available fit and span.

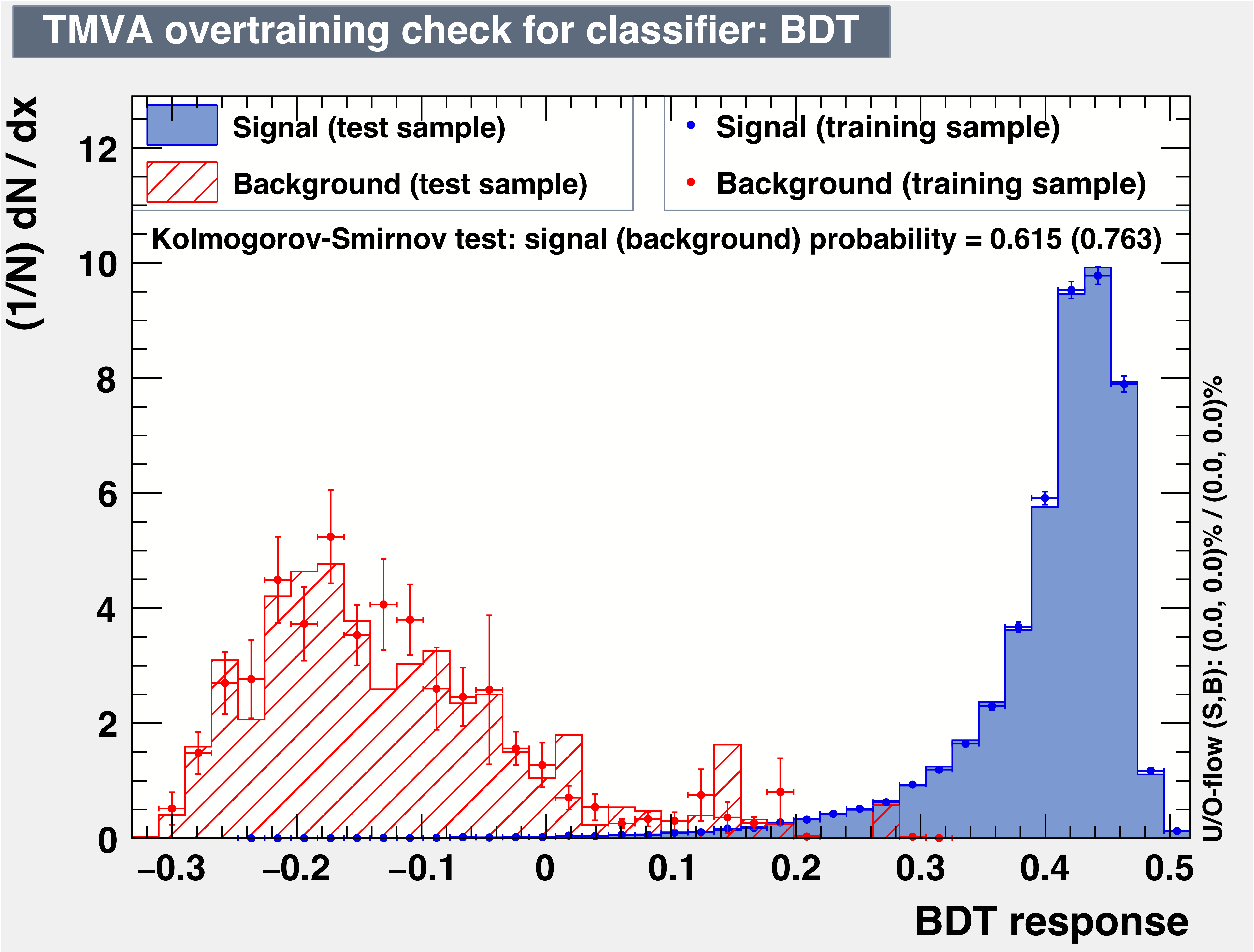
Step 3

- Employ the variables found in the second step, and perform machine learning with TMVA integrated in ROOT. Train the MC data to get the classifier, apply to the flight data, find the most efficient cut, and get the final result of the anti-helium events, and also significance of the analysis.

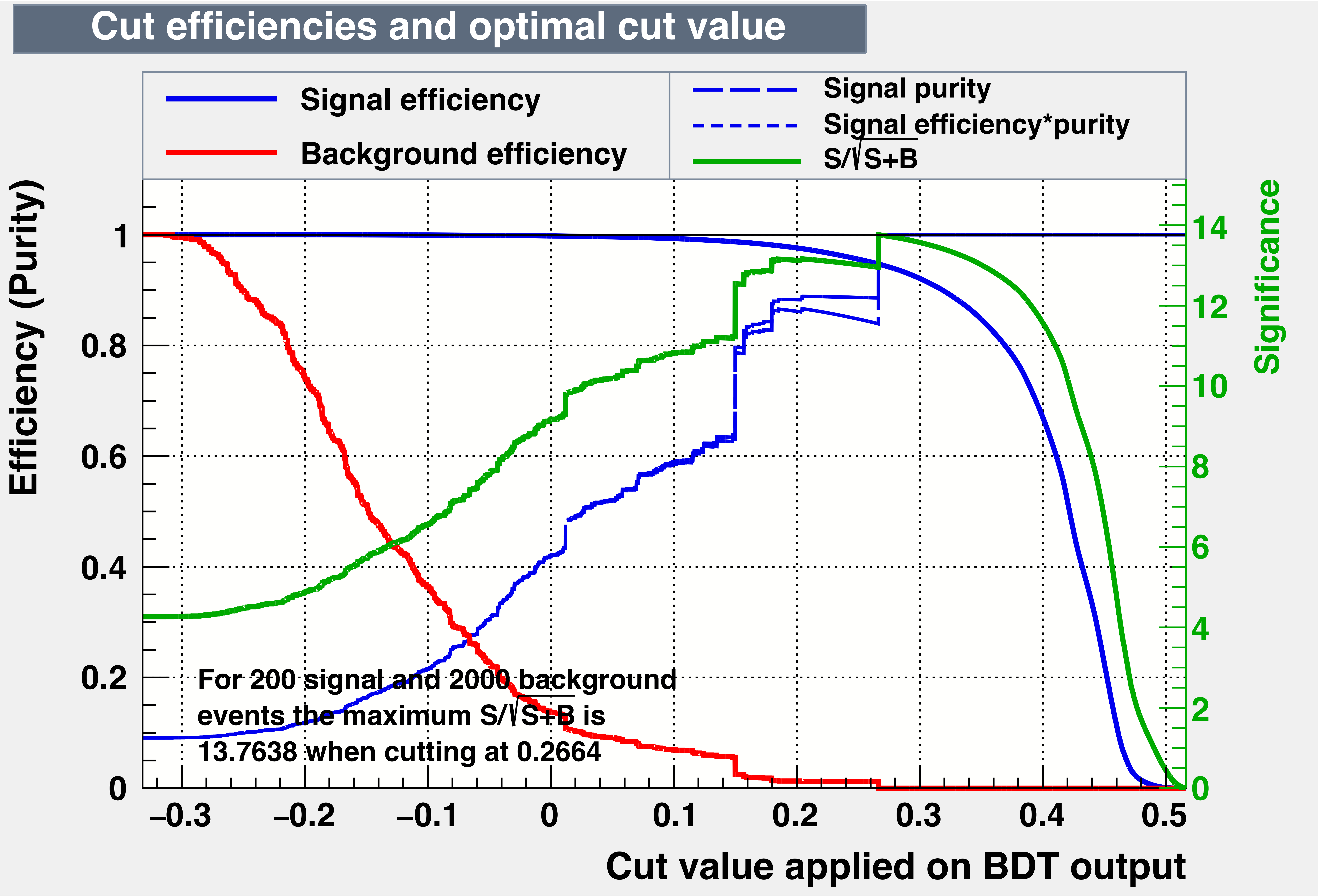
- Machine learning with TMVA



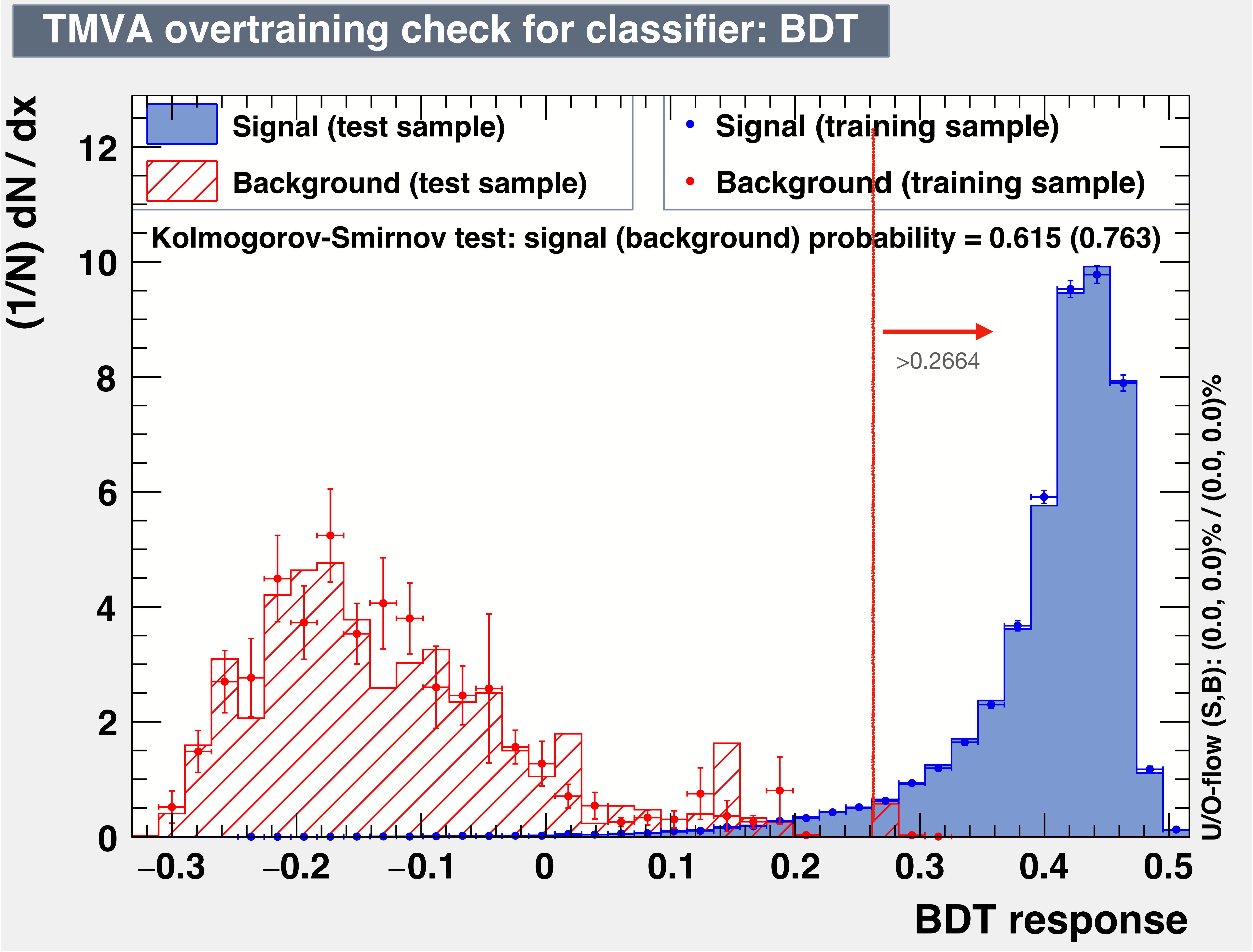
- Machine learning with TMVA



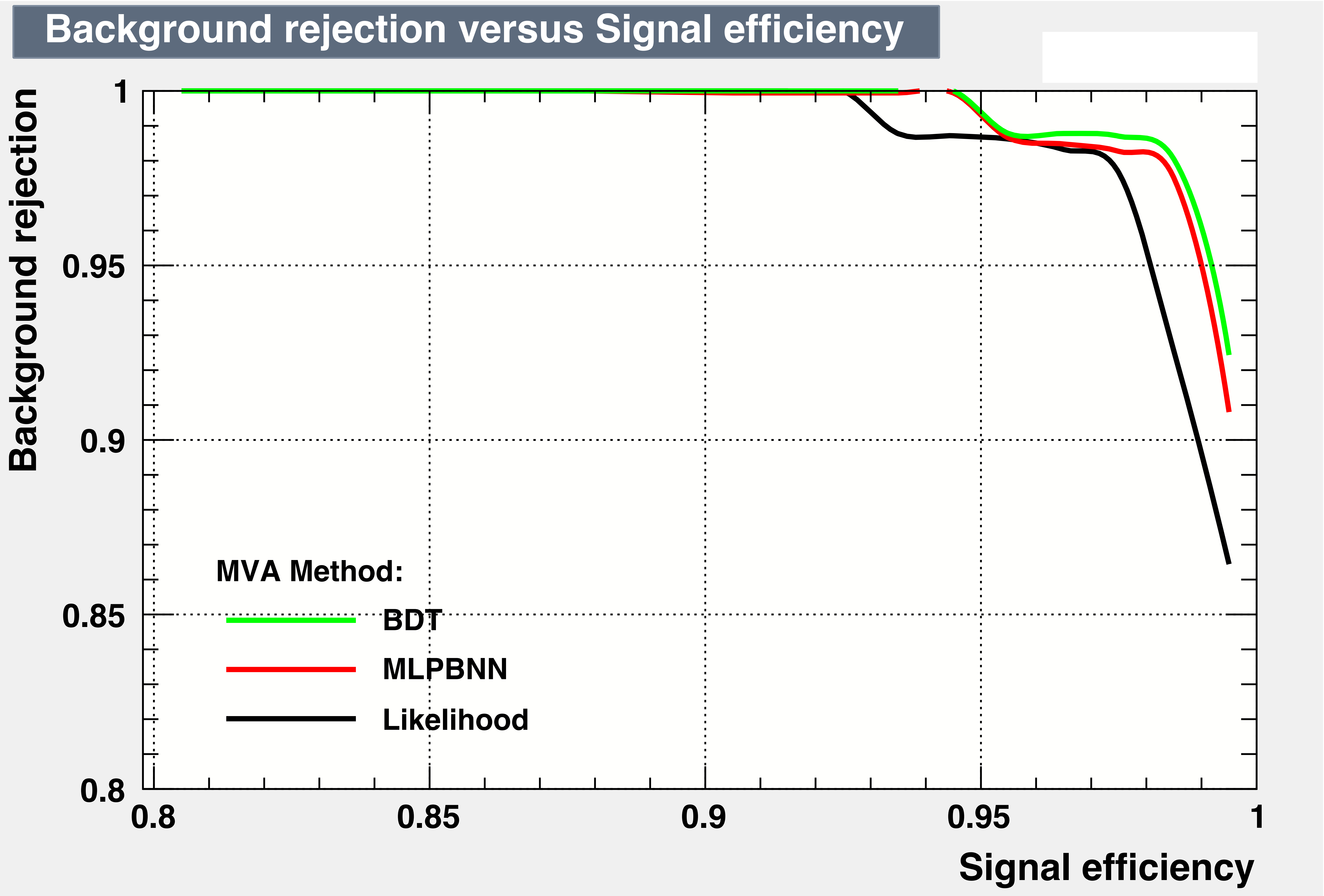
- Machine learning with TMVA



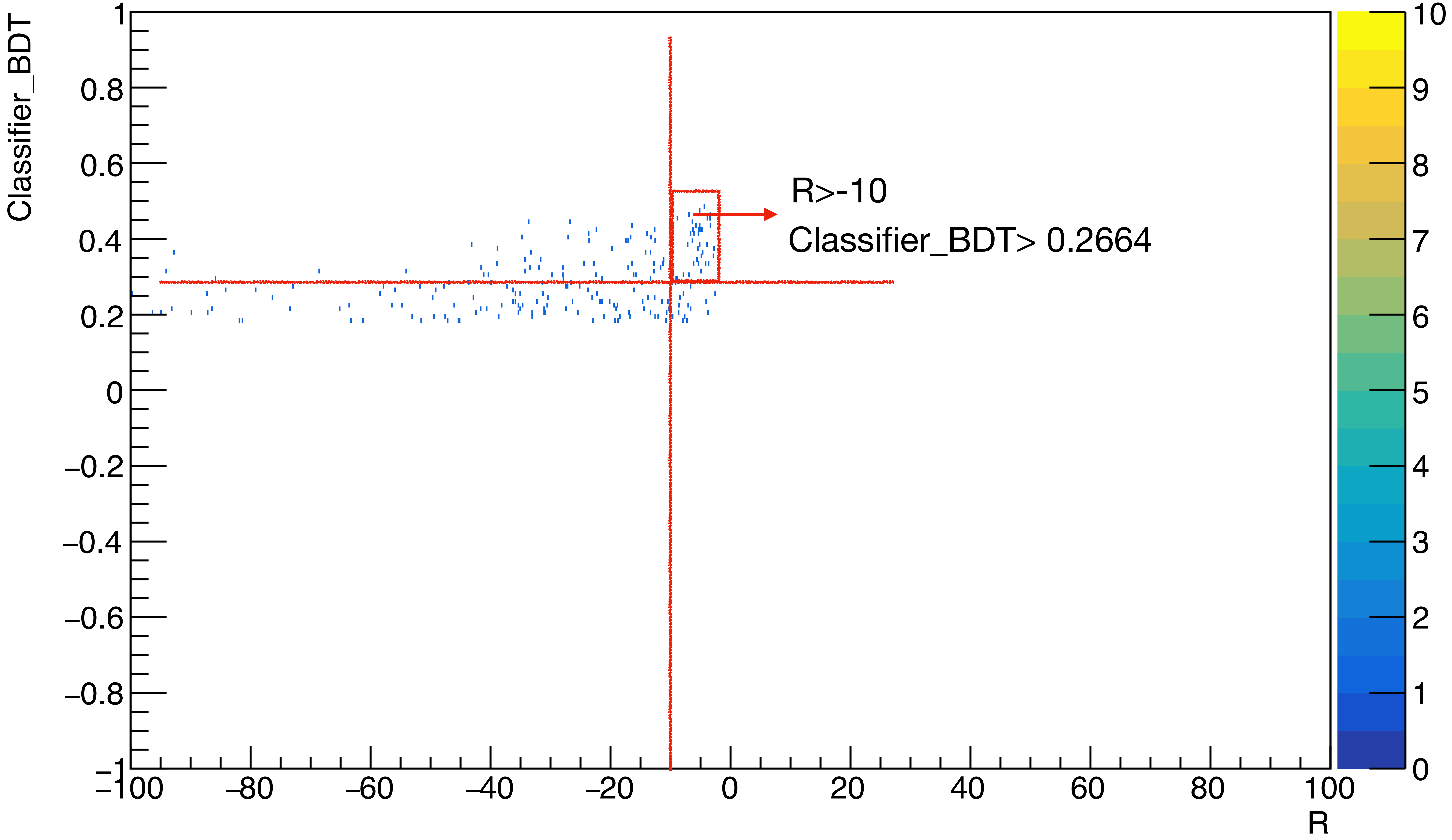
- Machine learning with TMVA



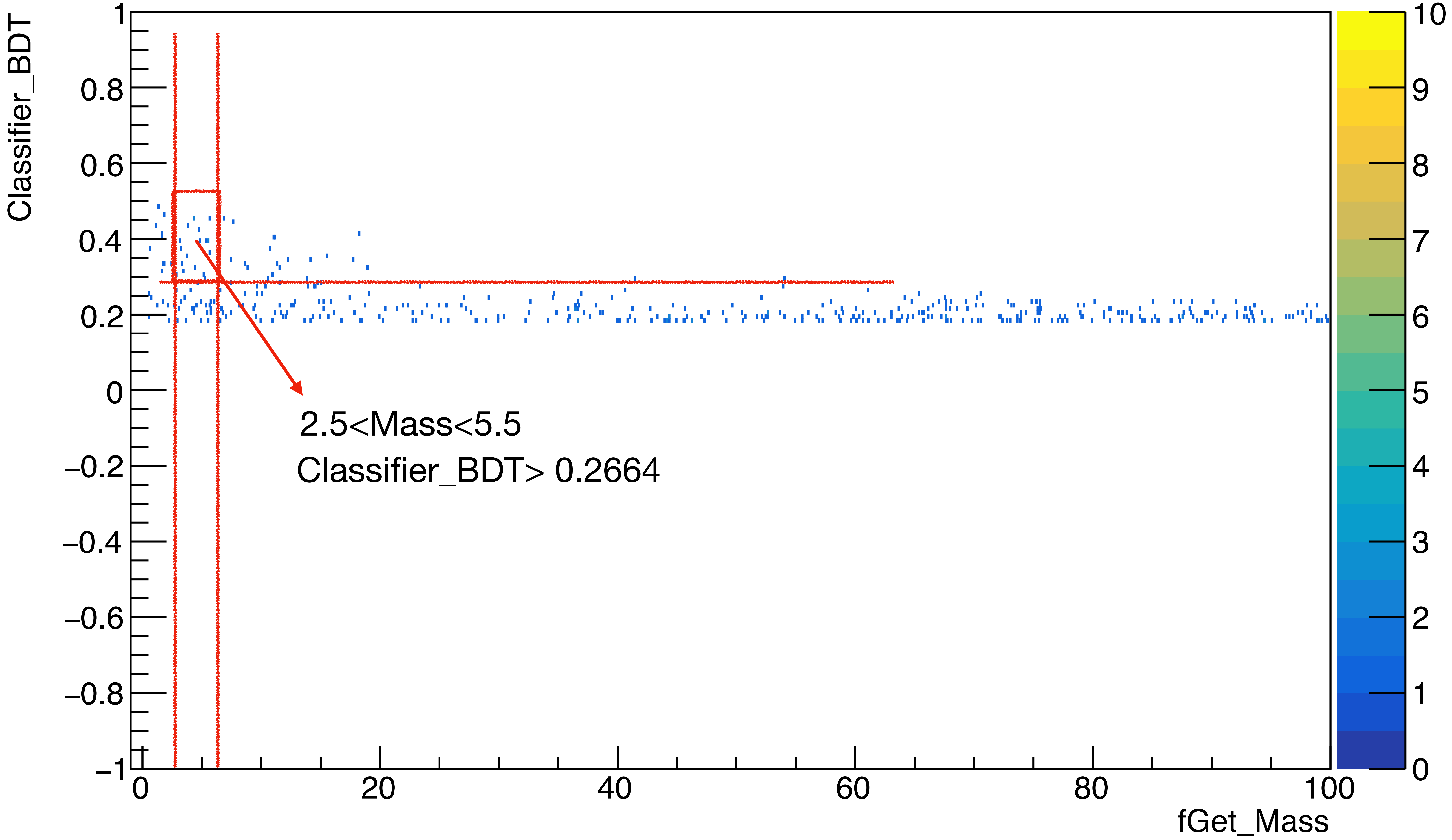
- Machine learning with TMVA



- Machine learning with TMVA

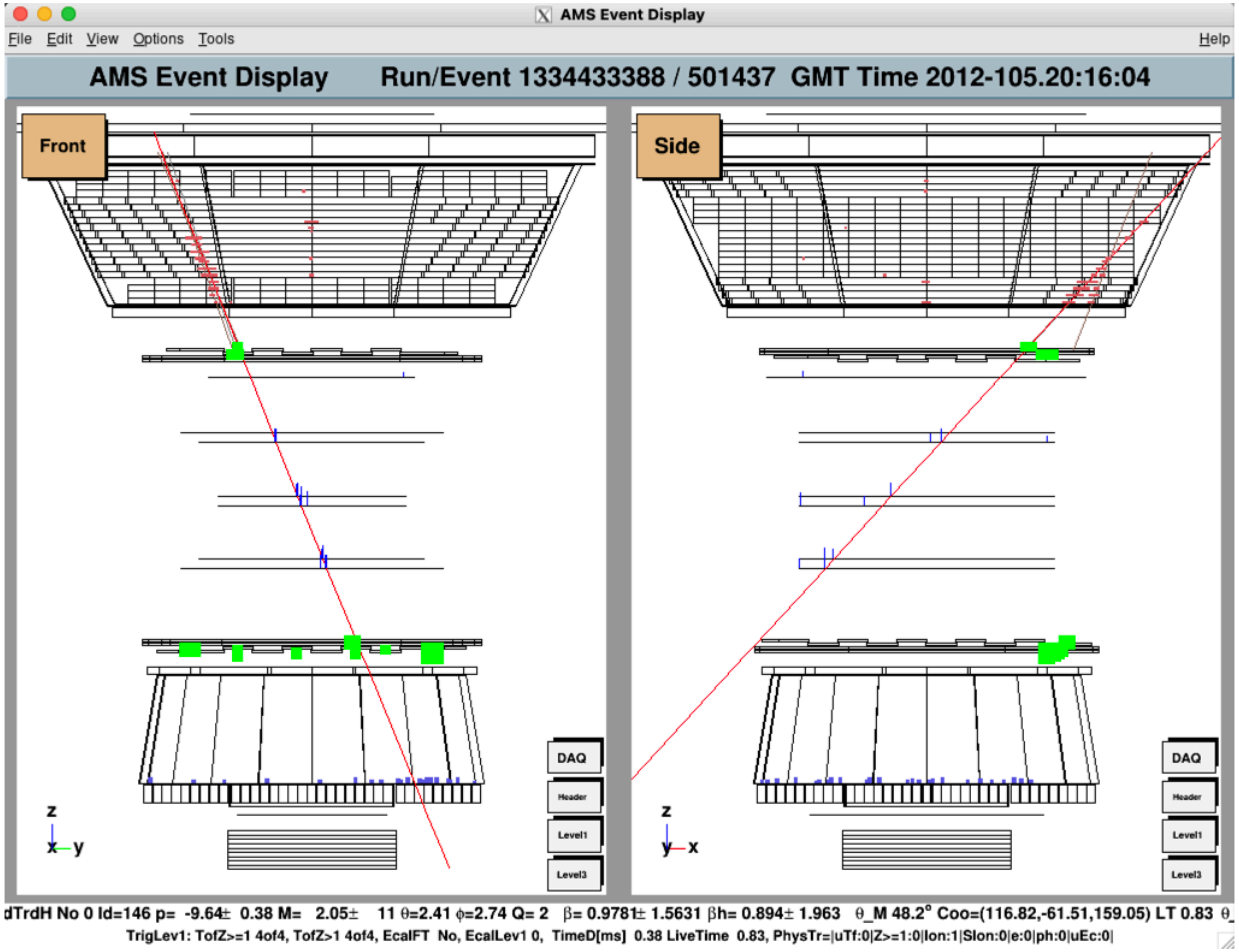


- Machine learning with TMVA

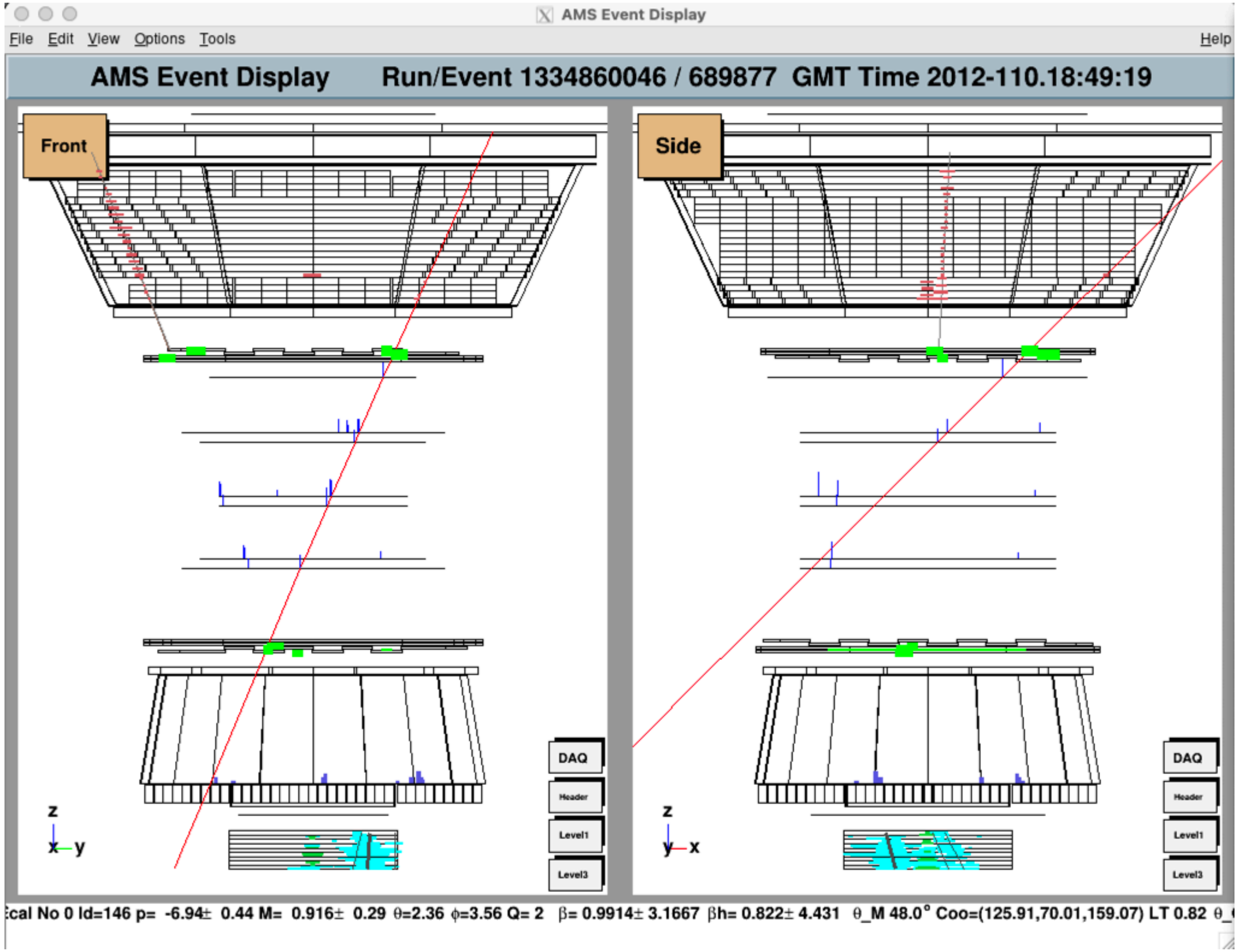


16 events are selected

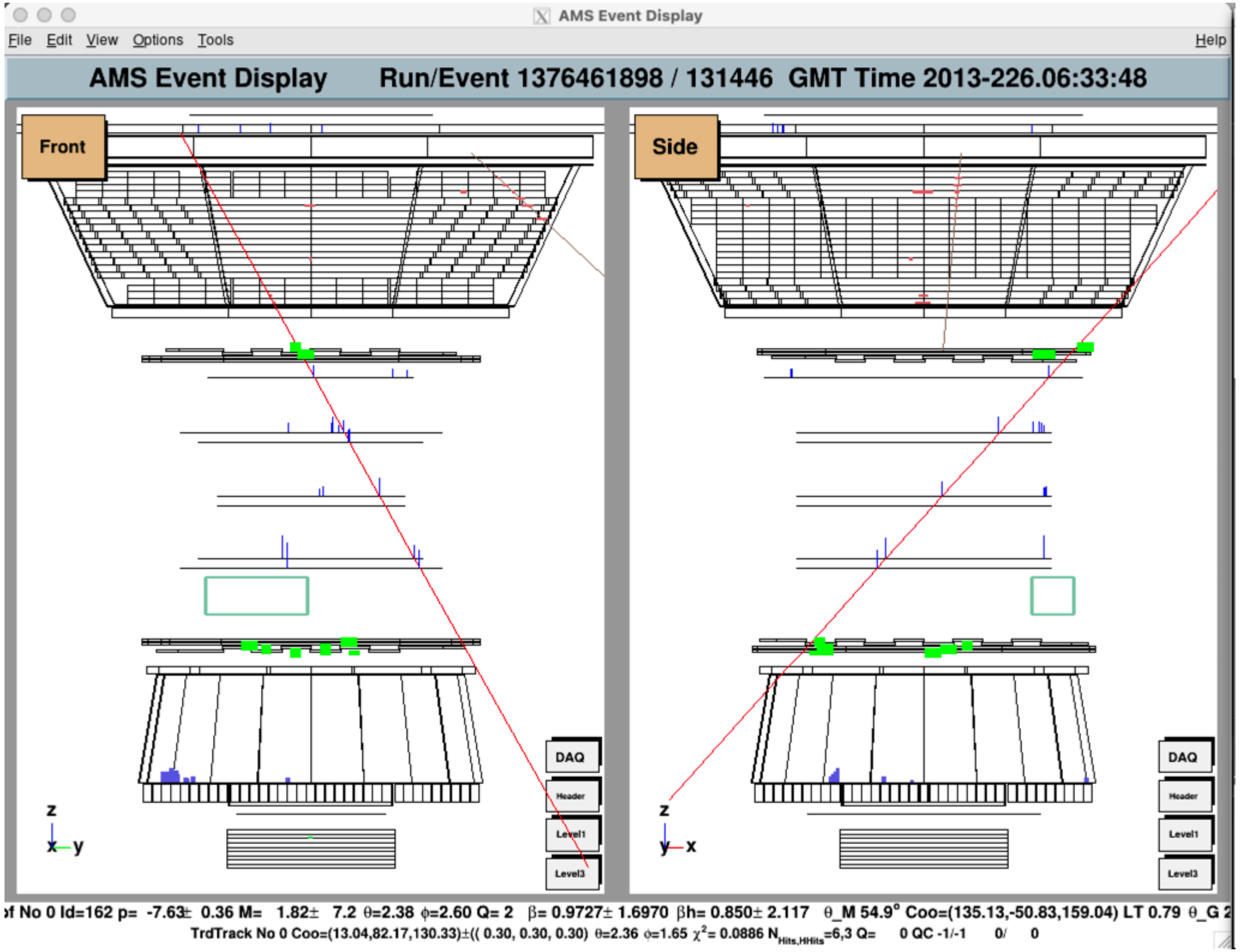
Rigidity	fGet_Mass	Classifie
-4.155466	3.3172924	0.3391640
-5.014126	4.7047009	0.4291344
-3.463379	4.3850002	0.4505071
-13.37936	5.2818250	0.2979018
-3.300295	3.8681356	0.4371778
-4.886028	3.4584949	0.3173286
-23.51782	4.8802719	0.3900631
-26.56441	4.6708421	0.2809770
-7.851791	2.5491530	0.3037104
-16.11696	2.8199522	0.3077684
-11.61245	4.4773721	0.3269315
-17.49713	3.1556532	0.3964821
-4.825552	3.7487182	0.3576721
-3.384918	4.3955674	0.4585976
-2.755248	3.2264525	0.3757808
-12.52079	5.3917627	0.3904516



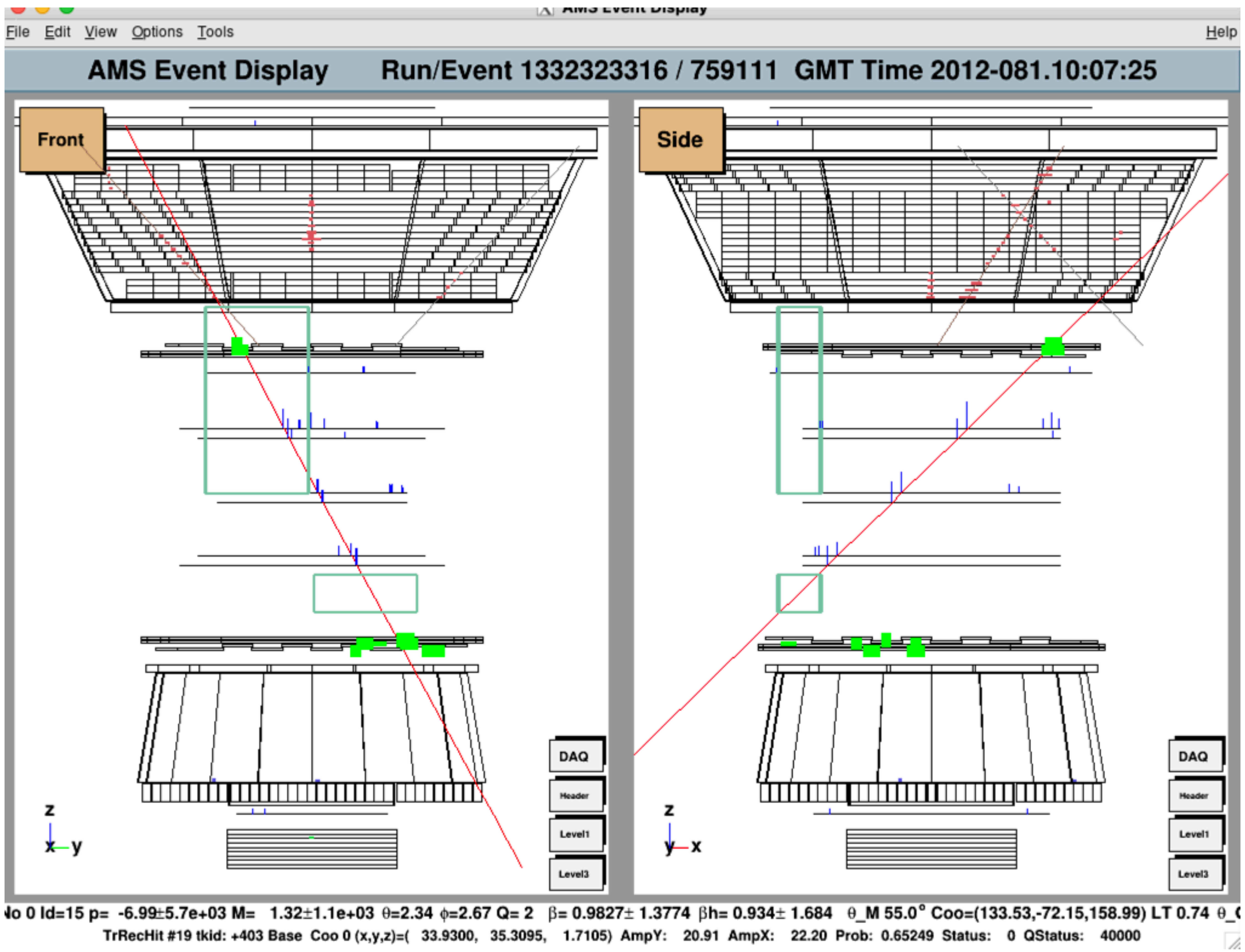

```
Run            = 1334433388
EventNo        = 501437
NAntiCluster   = 0
NTrTrack       = 1
NParticle      = 1
NAcc           = 0
Chi2Coo        = 0.307314
Chi2Time       = 0
fGet_NHitsOnInnerTrackerLayers = 7
fGet_NHitsSecondTrack = 0
InnerCharge      = 1.87051
f_InnerChargeRMS_InvZ = 0.0405794
Rigidity         = -5.01413
fGet_Mass        = 4.7047
TrChiSq_x        = 0.106252
TrChiSq_y        = 1.47036
fGet_PartialTrChiSq_TrChiSq_MaxDiff = 1.00508
fGet_PartialRigidity_SameSignNum = 7
fGet_PartialRigidity_Rigidity_MaxDiffInvR = 0.068851
f_InvRigErrR     = 0.0892833
Classifier_MLPBNN = 0.999993
Classifier_BDT   = 0.429134
```



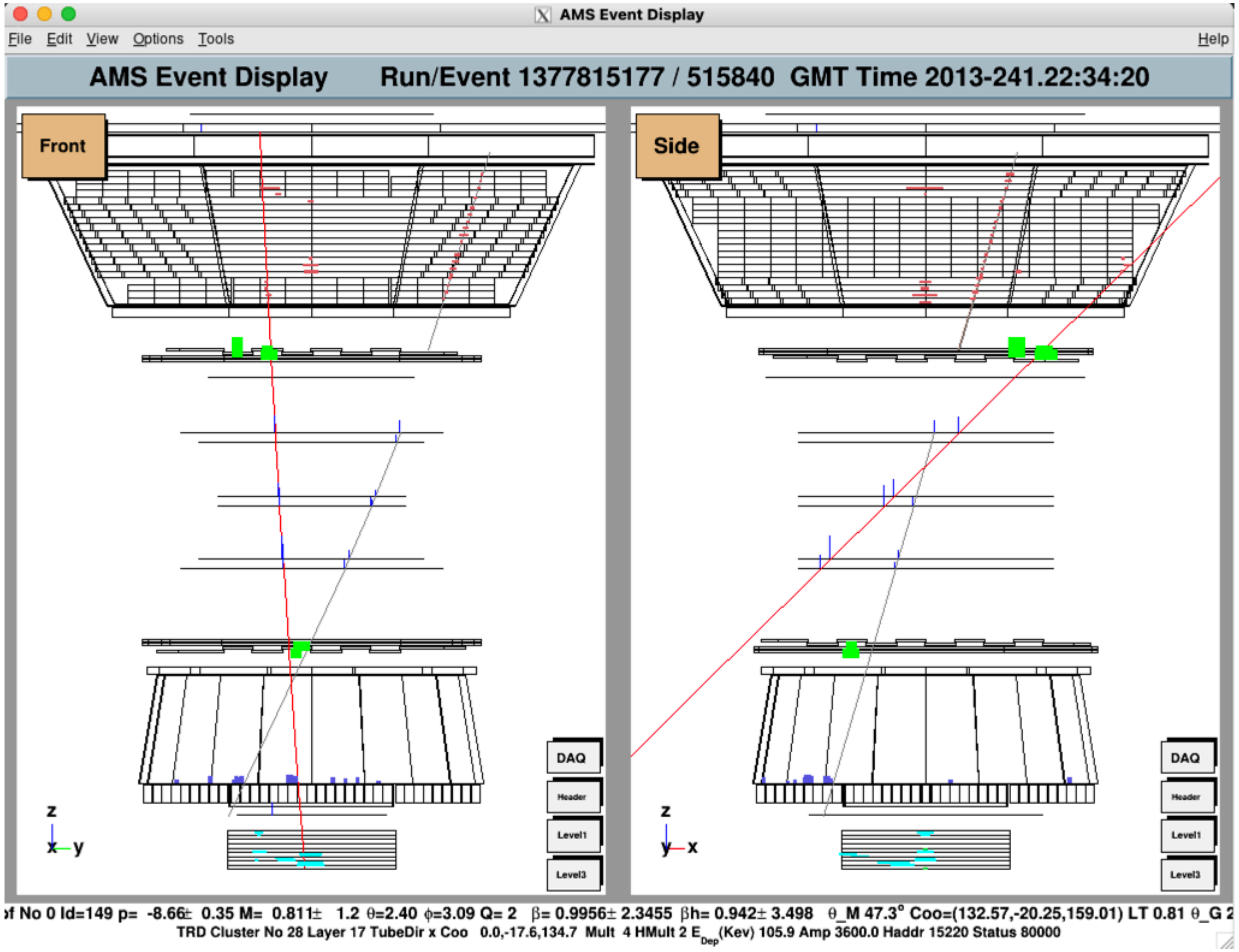

```
Run                = 1334860046
EventNo            = 689877
NAntiCluster       = 3
NTrTrack           = 1
NParticle          = 1
NAcc               = 2
Chi2Coo            = 0.246051
Chi2Time           = 0
fGet_NHitsOnInnerTrackerLayers = 7
fGet_NHitsSecondTrack = 0
InnerCharge        = 1.82917
f_InnerChargeRMS_InvZ = 0.0364261
Rigidity           = -3.46338
fGet_Mass          = 4.385
TrChiSq_x          = 0.149578
TrChiSq_y          = 0.258094
fGet_PartialTrChiSq_TrChiSq_MaxDiff = 0.174338
fGet_PartialRigidity_SameSignNum = 7
fGet_PartialRigidity_Rigidity_MaxDiffInvR = 0.0108208
f_InvRigErrR       = 0.0885172
Classifier_MLPBNN  = 0.999993
Classifier_BDT     = 0.450507
```



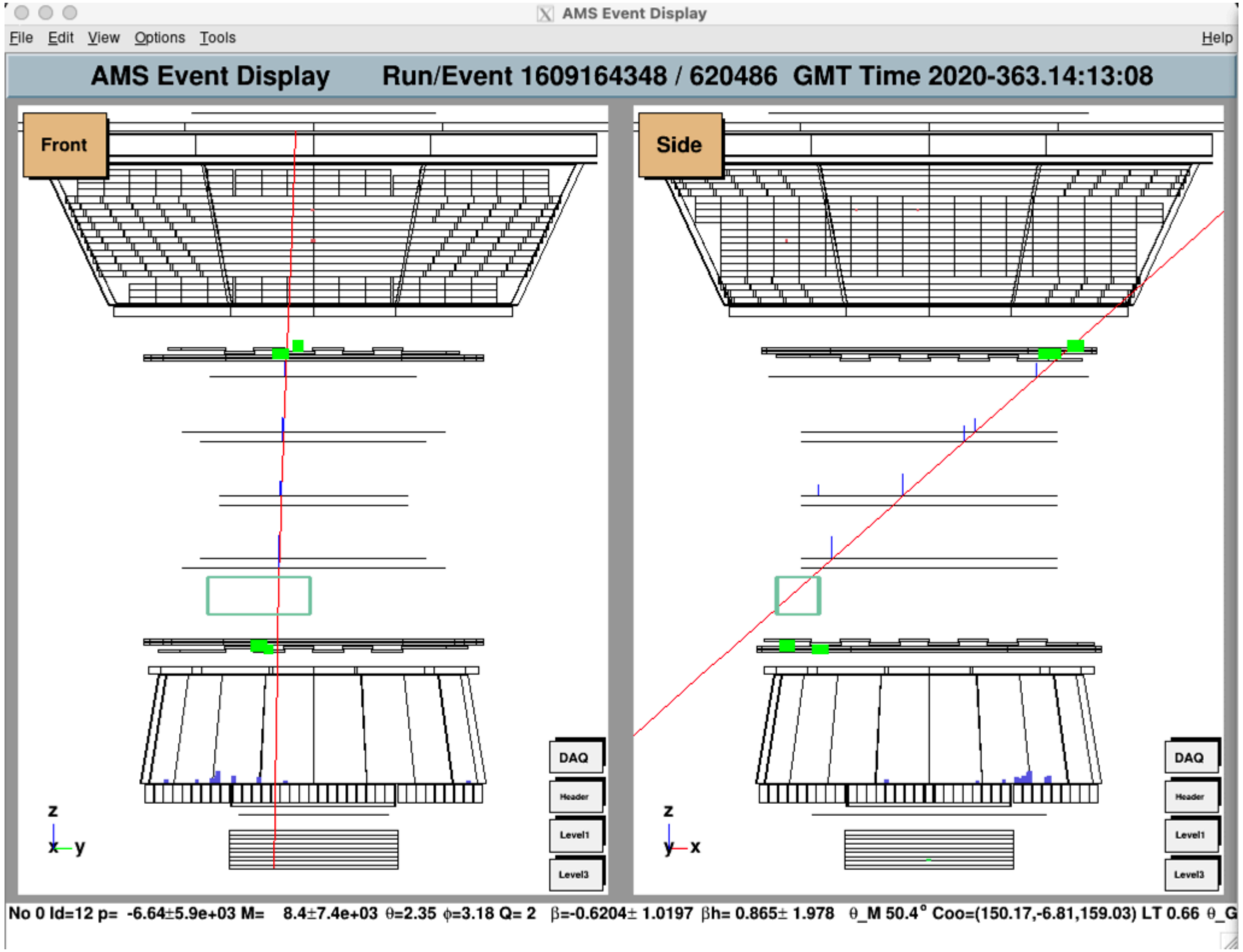

```
Run              = 1376461898
EventNo          = 131446
NAntiCluster     = 1
NTrTrack         = 1
NParticle        = 1
NAcc             = 2
Chi2Coo          = 1.15787
Chi2Time         = 0
fGet_NHitsOnInnerTrackerLayers = 7
fGet_NHitsSecondTrack = 0
InnerCharge      = 1.89491
f_InnerChargeRMS_InvZ = 0.0695198
Rigidity         = -3.3003
fGet_Mass        = 3.86814
TrChiSq_x        = 0.518366
TrChiSq_y        = 2.24132
fGet_PartialTrChiSq_TrChiSq_MaxDiff = 1.25023
fGet_PartialRigidity_SameSignNum = 7
fGet_PartialRigidity_Rigidity_MaxDiffInvR = 0.0352063
f_InvRigErrR     = 0.0855699
Classifier_MLPBNN = 0.999992
Classifier_BDT   = 0.437178
```



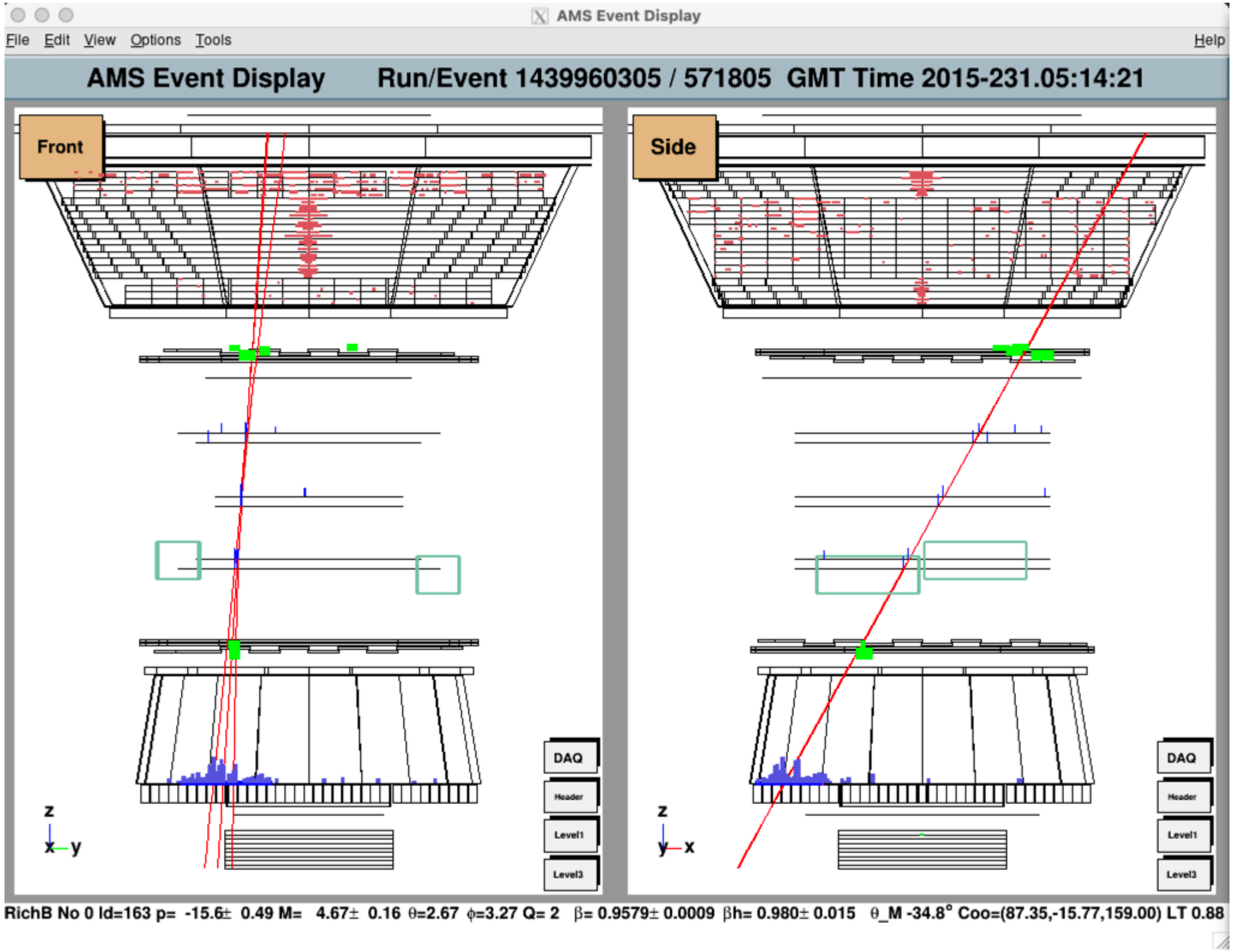

```
Run                = 1332323316
EventNo            = 759111
NAntiCluster       = 3
NTrTrack           = 1
NParticle          = 1
NAcc               = 2
Chi2Coo            = 0.0191071
Chi2Time           = 0
fGet_NHitsOnInnerTrackerLayers = 7
fGet_NHitsSecondTrack = 0
InnerCharge        = 2.08079
f_InnerChargeRMS_InvZ = 0.0924954
Rigidity           = -4.15547
fGet_Mass          = 3.31729
TrChiSq_x          = 4.59196
TrChiSq_y          = 1.57525
fGet_PartialTrChiSq_TrChiSq_MaxDiff = 0.406596
fGet_PartialRigidity_SameSignNum = 7
fGet_PartialRigidity_Rigidity_MaxDiffInvR = 0.0684011
f_InvRigErrR       = 0.0869998
Classifier_MLPBNN  = 0.999808
Classifier_BDT     = 0.339164
```




```
Run              = 1377815177
EventNo          = 515840
NAntiCluster     = 0
NTrTrack         = 2
NParticle        = 1
NAcc             = 0
Chi2Coo          = 0.175049
Chi2Time         = 0
fGet_NHitsOnInnerTrackerLayers = 7
fGet_NHitsSecondTrack = 6
InnerCharge      = 1.99409
f_InnerChargeRMS_InvZ = 0.0714793
Rigidity         = -4.88603
fGet_Mass        = 3.45849
TrChiSq_x        = 5.4213
TrChiSq_y        = 2.45188
fGet_PartialTrChiSq_TrChiSq_MaxDiff = 1.10161
fGet_PartialRigidity_SameSignNum = 7
fGet_PartialRigidity_Rigidity_MaxDiffInvR = 0.0960503
f_InvRigErrR     = 0.0910096
Classifier_MLPBNN = 0.996822
Classifier_BDT   = 0.317329
```




```
Run            = 1609164348
EventNo        = 620486
NAntiCluster   = 1
NTrTrack       = 1
NParticle      = 1
NAcc           = 1
Chi2Coo        = 0.549233
Chi2Time       = 0
fGet_NHitsOnInnerTrackerLayers = 7
fGet_NHitsSecondTrack = 0
InnerCharge    = 2.01776
f_InnerChargeRMS_InvZ = 0.0518979
Rigidity       = -2.75525
fGet_Mass      = 3.22645
TrChiSq_x      = 1.18188
TrChiSq_y      = 2.04888
fGet_PartialTrChiSq_TrChiSq_MaxDiff = 1.16847
fGet_PartialRigidity_SameSignNum = 7
fGet_PartialRigidity_Rigidity_MaxDiffInvR = 0.175722
f_InvRigErrR   = 0.0975805
Classifier_MLPBNN = 0.999976
Classifier_BDT  = 0.375781
```




```
Run             = 1439960305
EventNo         = 571805
NAntiCluster    = 2
NTrTrack        = 3
NParticle       = 3
NAcc            = 2
Chi2Coo         = 1.3671
Chi2Time        = 0.00765185
fGet_NHitsOnInnerTrackerLayers = 7
fGet_NHitsSecondTrack = 7
InnerCharge     = 1.58676
f_InnerChargeRMS_InvZ = 0.1291
Rigidity        = -7.85179
fGet_Mass       = 2.54915
TrChiSq_x       = 6.57171
TrChiSq_y       = 3.5158
fGet_PartialTrChiSq_TrChiSq_MaxDiff = 2.4638
fGet_PartialRigidity_SameSignNum = 7
fGet_PartialRigidity_Rigidity_MaxDiffInvR = 0.116095
f_InvRigErrR    = 0.0880656
Classifier_MLPBNN = 0.972937
Classifier_BDT  = 0.30371
```

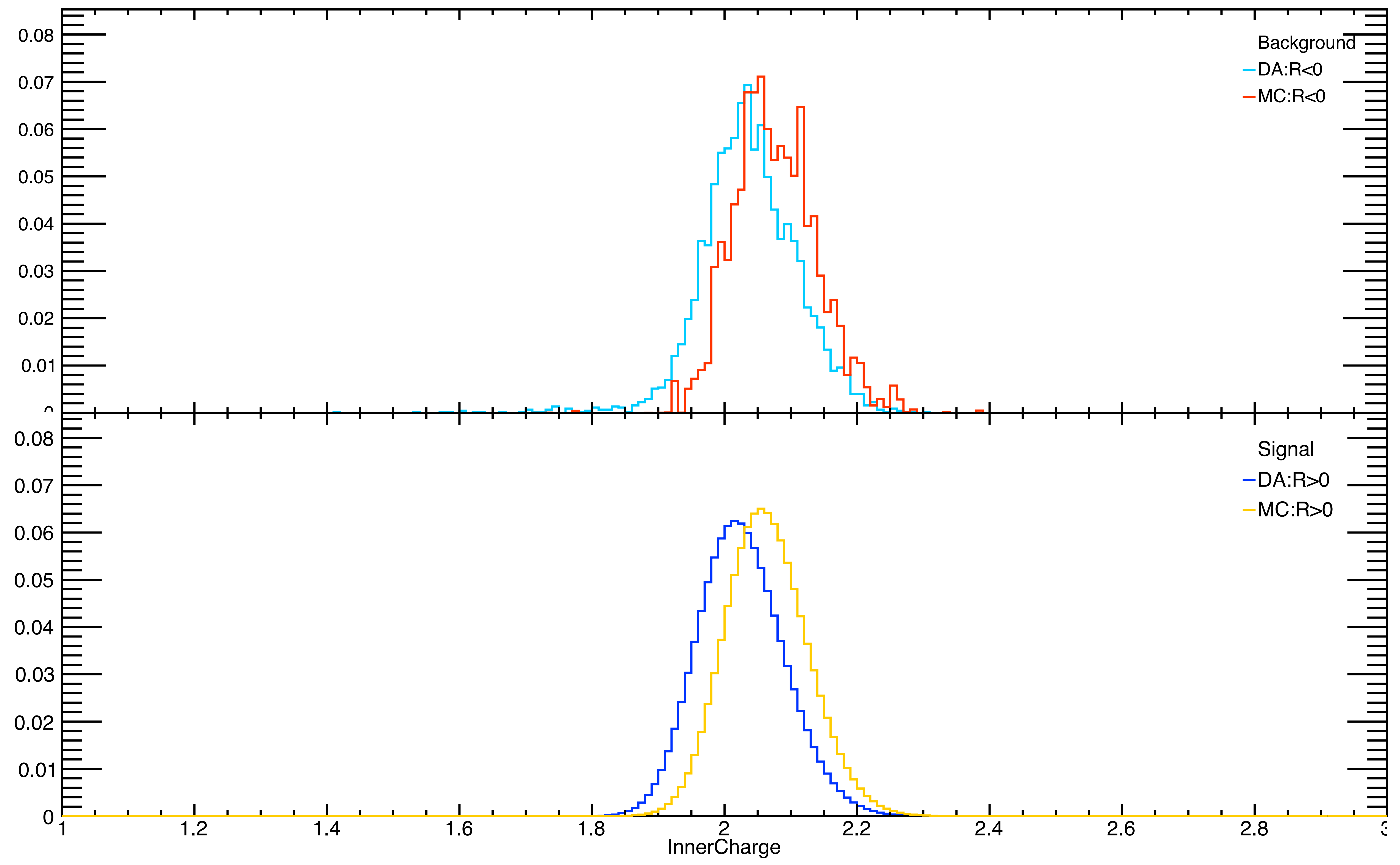
Conclusion:

1: No candidates of antihelium from 2.5 GV to 5 GV is selected.

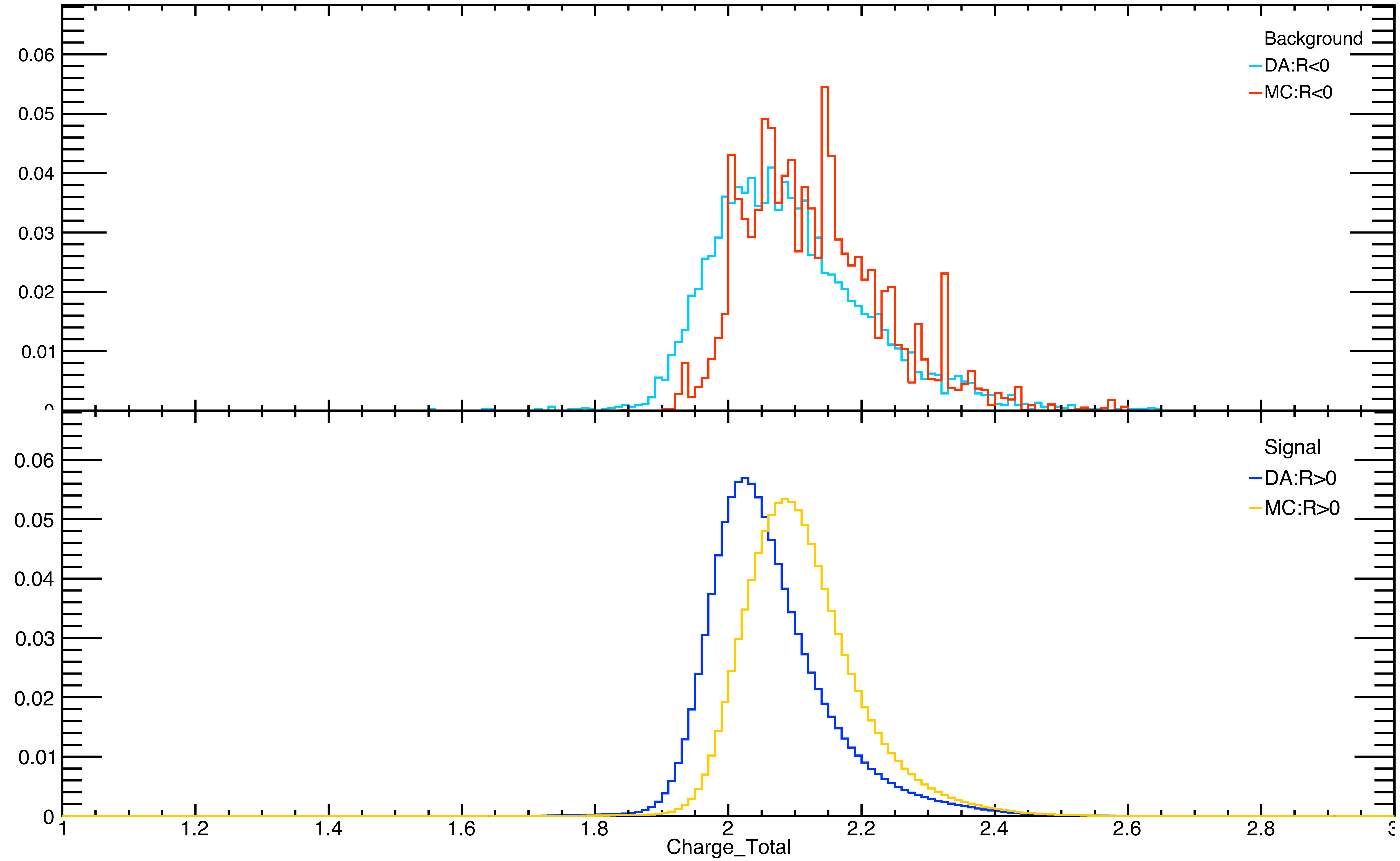
2: Rich can provide more precise Beta measurement in rigidity range 5 GV to 30 GV. Searching antihelium candidates in this range is on going.

Besides the data analysis, I was also working on the data taking operation of AMS, with regularly taking the “TEE” shifts, which monitor the detector performances and health status at the AMS POCC (payload operation control center) 24 hours a day and 7 days a week.

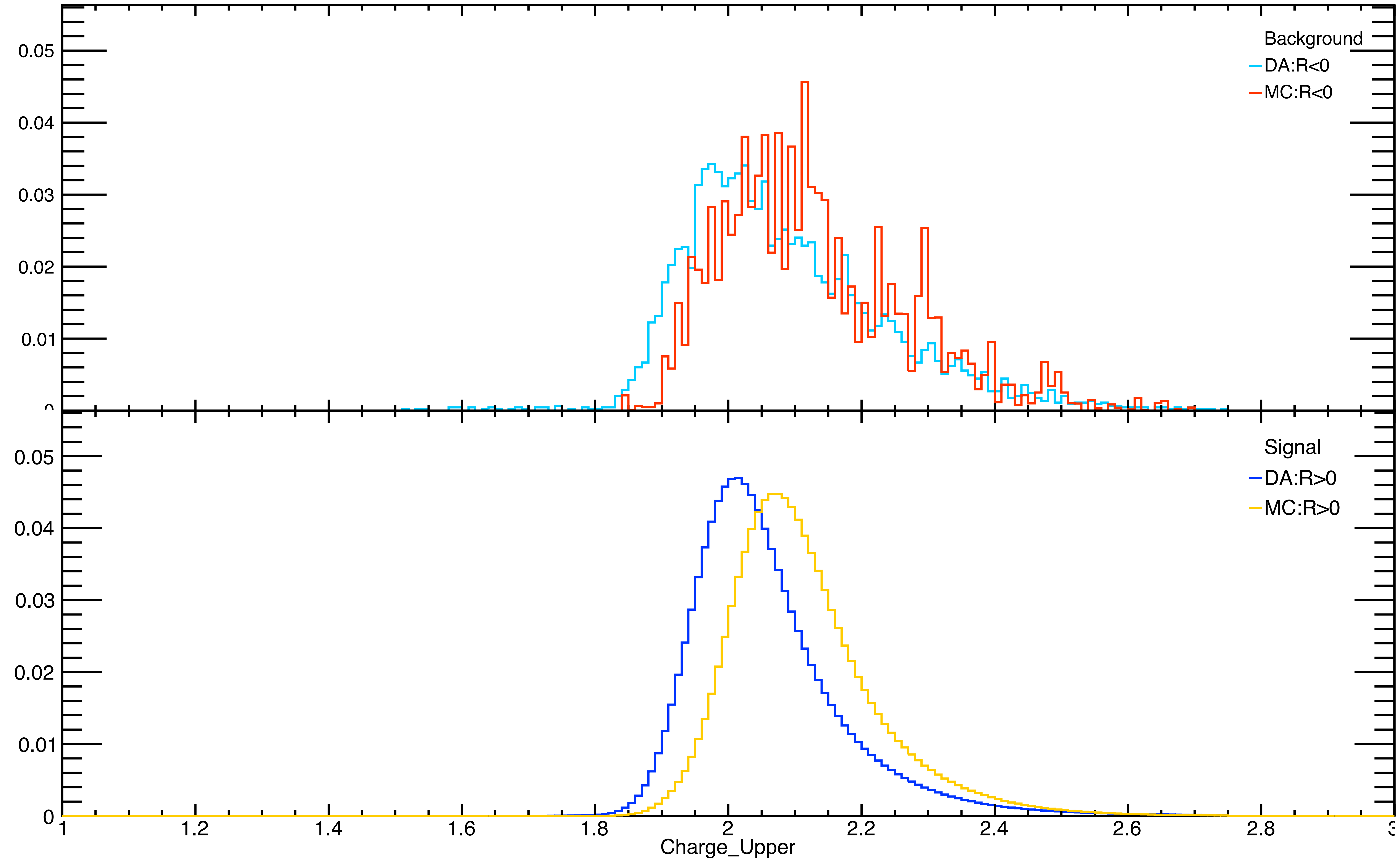
NAIA Control Plots

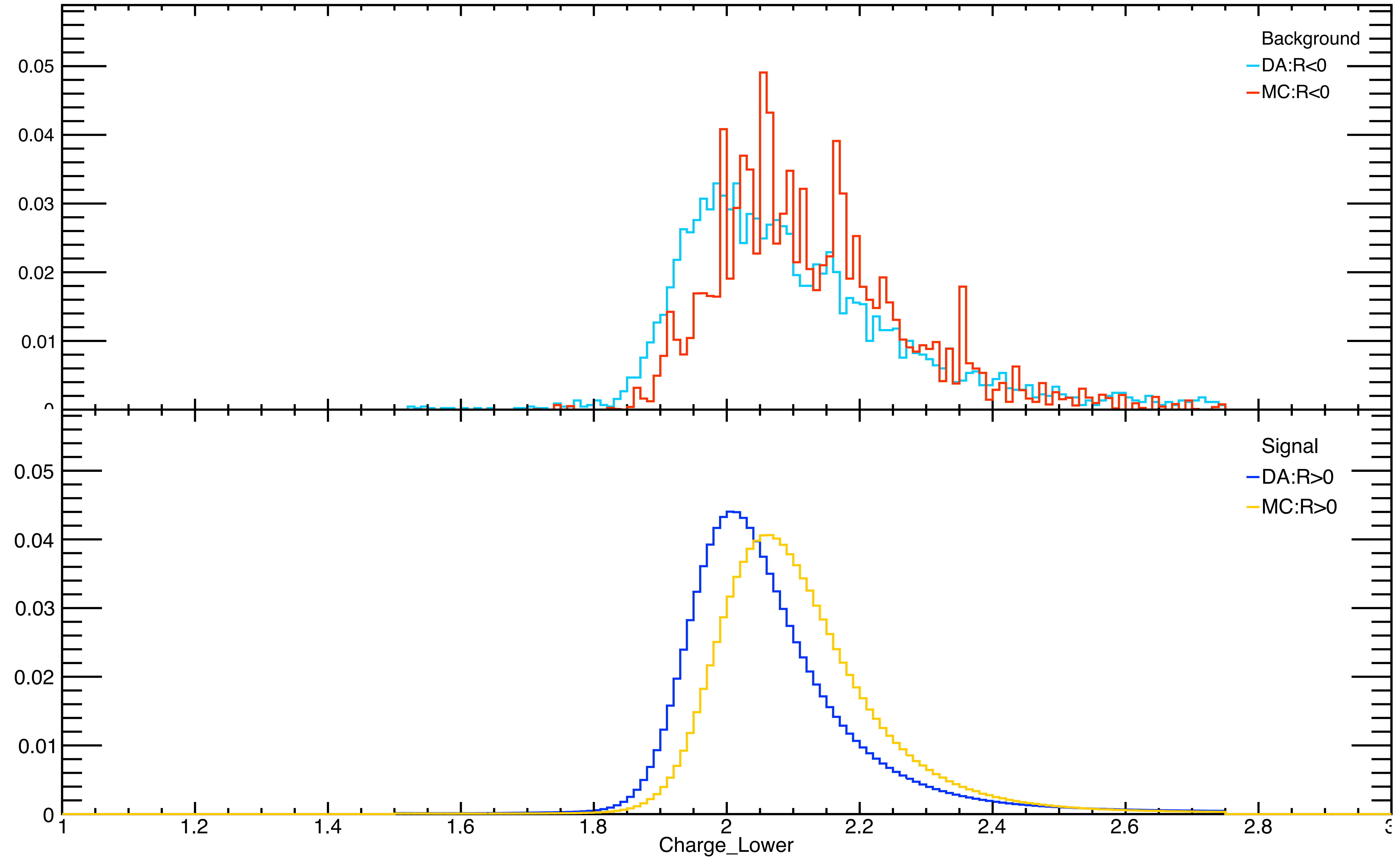


Background
DA:R<0
MC:R<0
Signal
DA:R>0
MC:R>0
InnerCharge

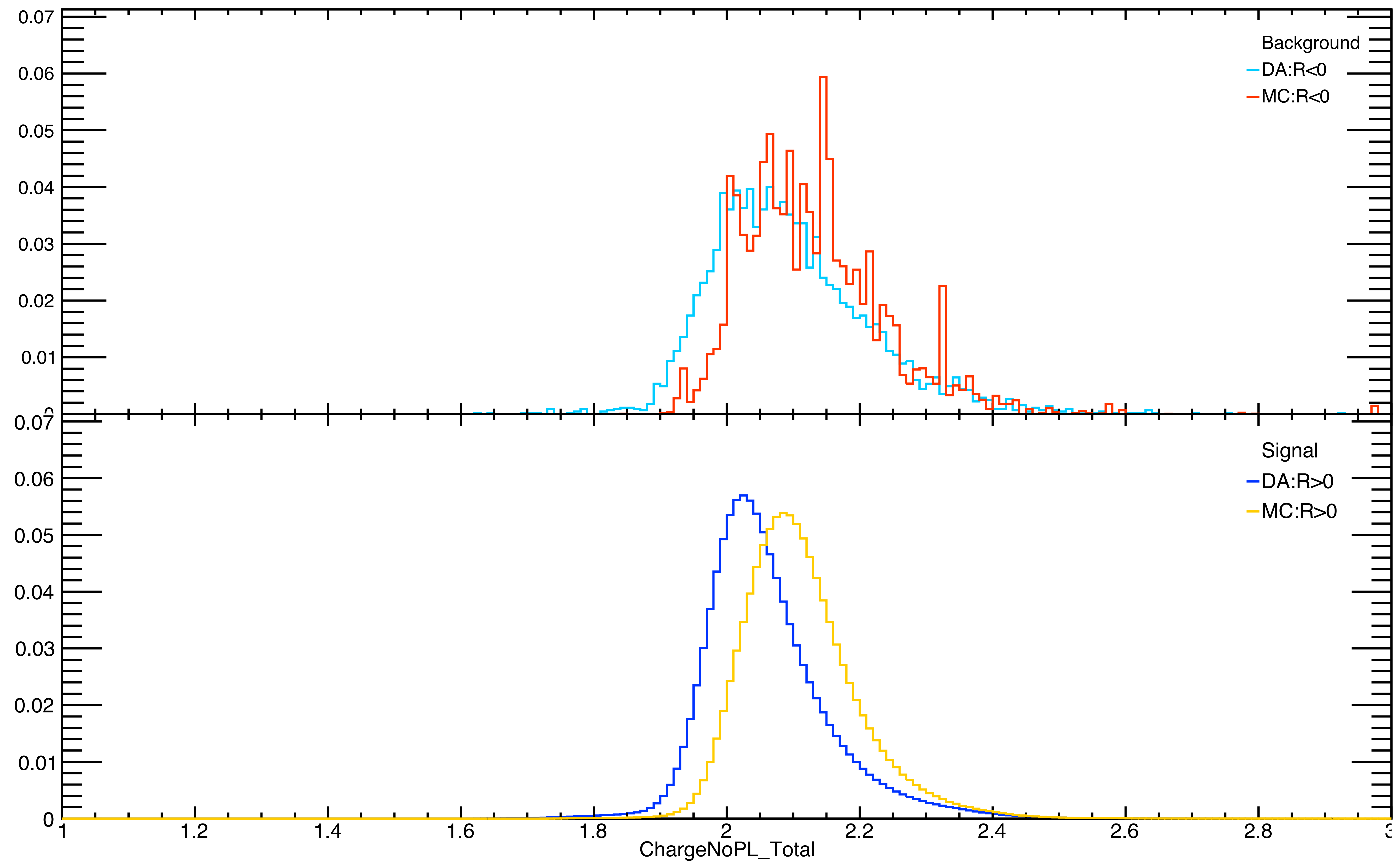


Background
DA:R<0
MC:R<0
Signal
DA:R>0
MC:R>0
0.06
0.05
0.04
0.03
0.02
0.01
0
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
Charge_Total

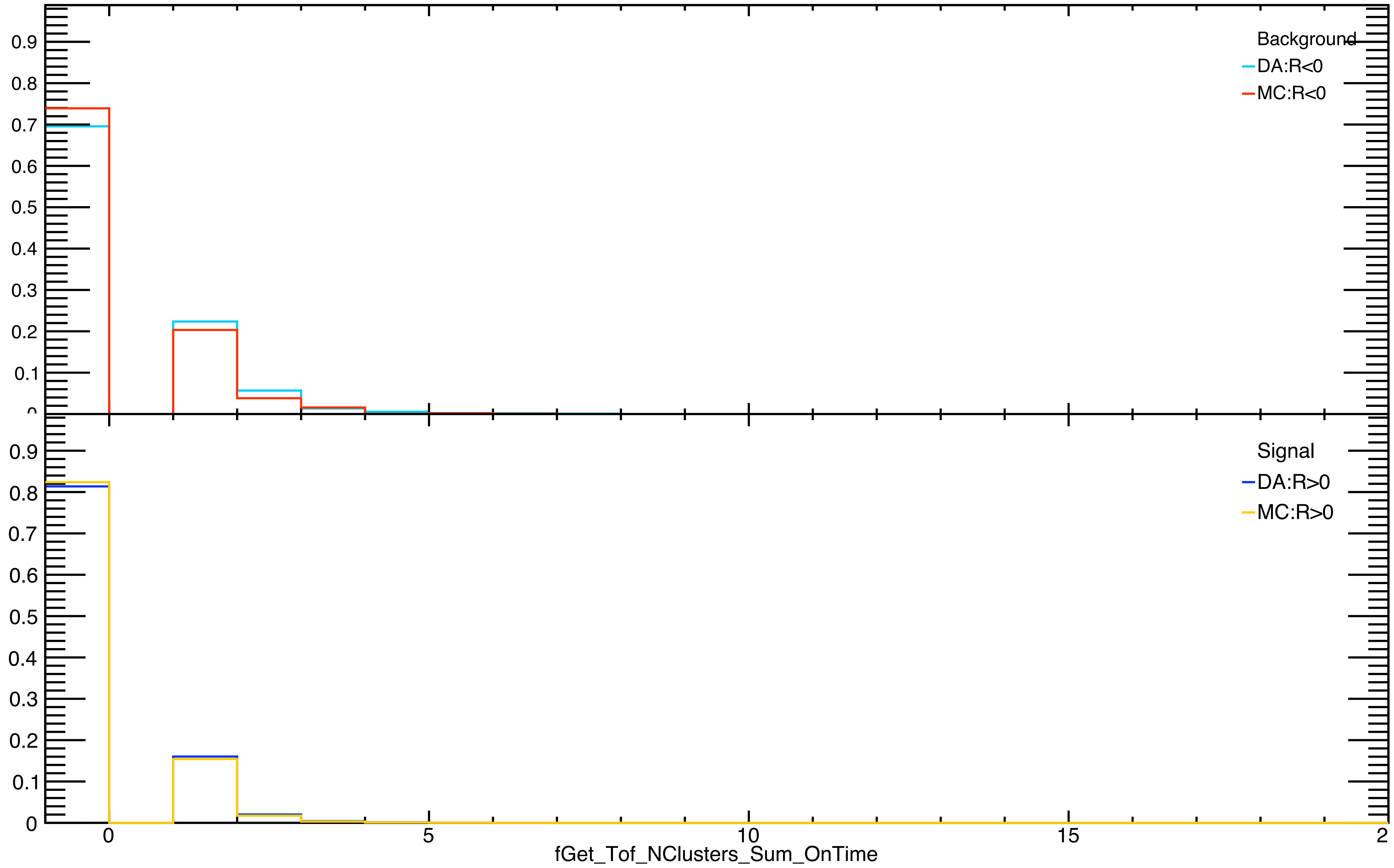

Background
DA:R<0
MC:R<0
Signal
DA:R>0
MC:R>0
Charge_Upper



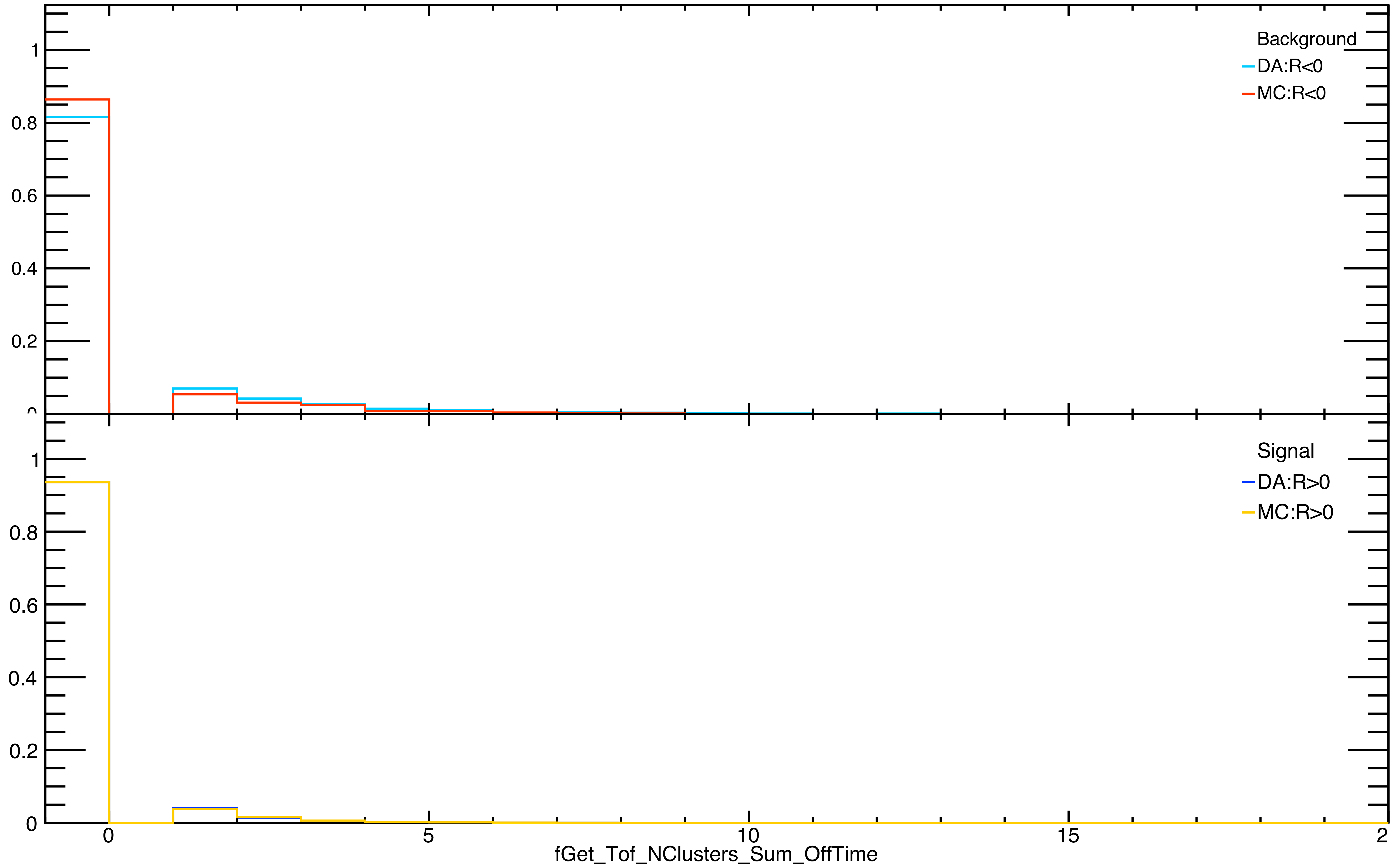
Background
DA:R<0
MC:R<0
Signal
DA:R>0
MC:R>0
0.05
0.04
0.03
0.02
0.01
0
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
Charge_Lower



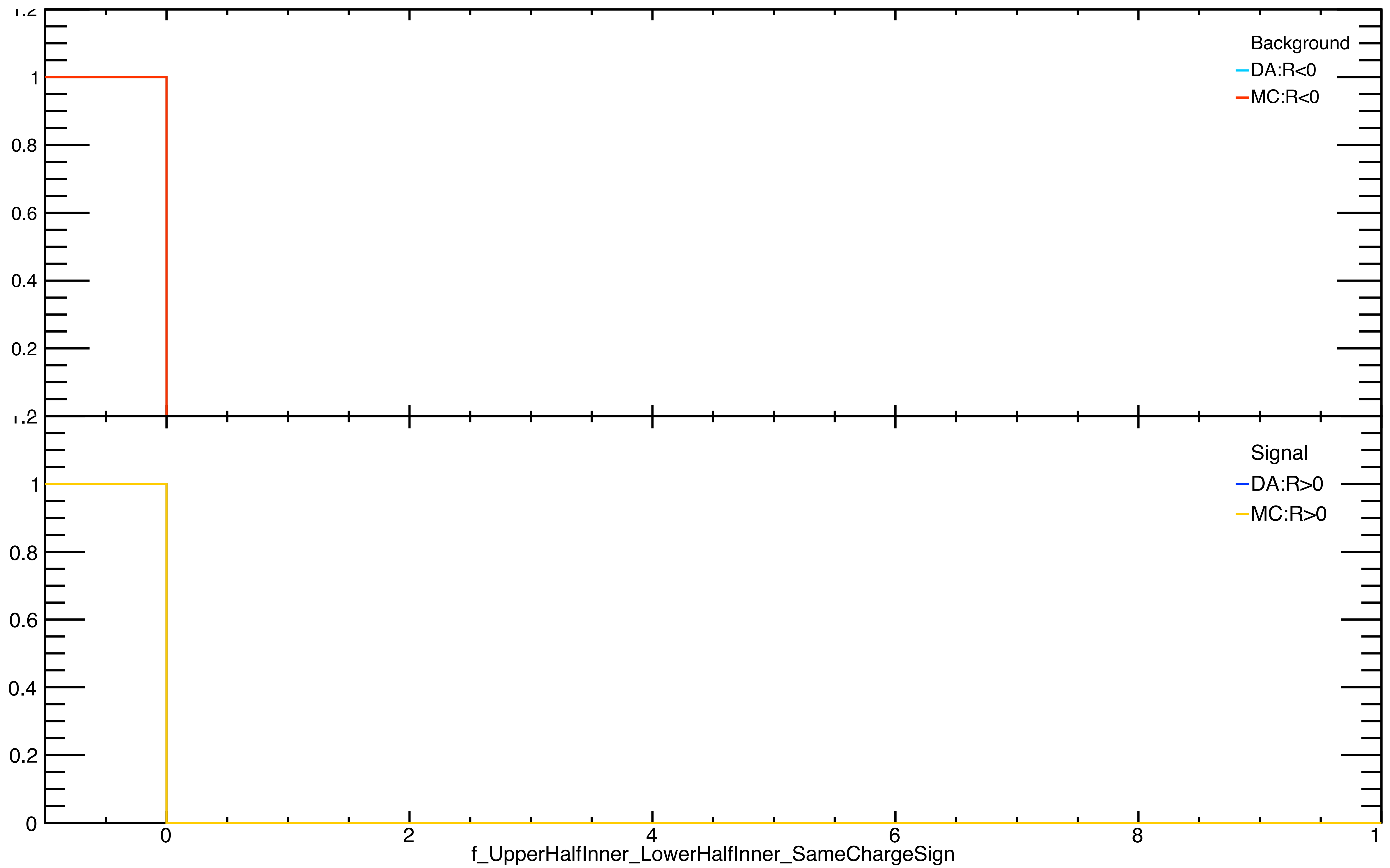
Background
DA:R<0
MC:R<0
Signal
DA:R>0
MC:R>0
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
ChargeNoPL_Total



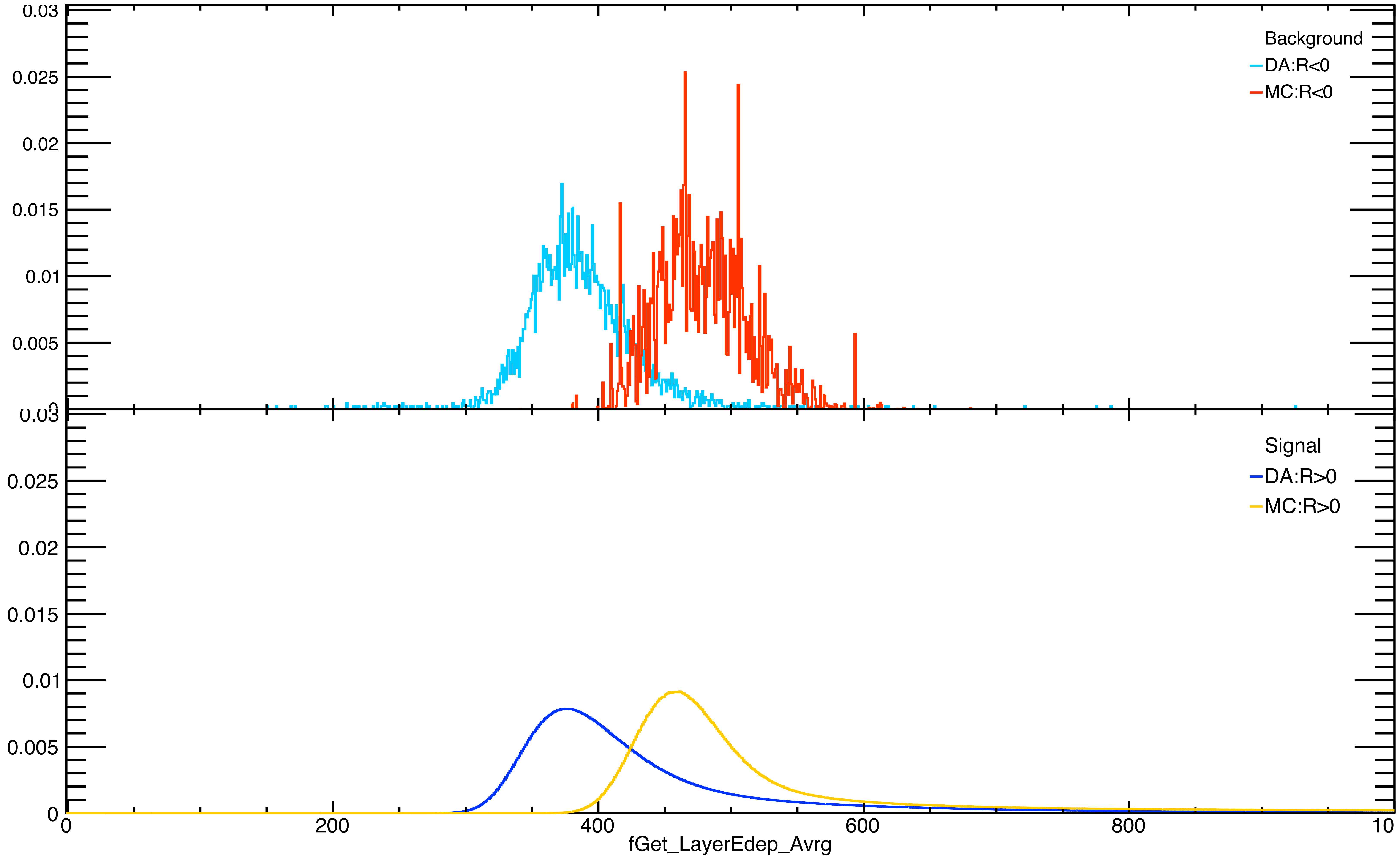
Background
DA:R<0
MC:R<0
Signal
DA:R>0
MC:R>0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
2
fGet_Tof_NClusters_Sum_OnTime

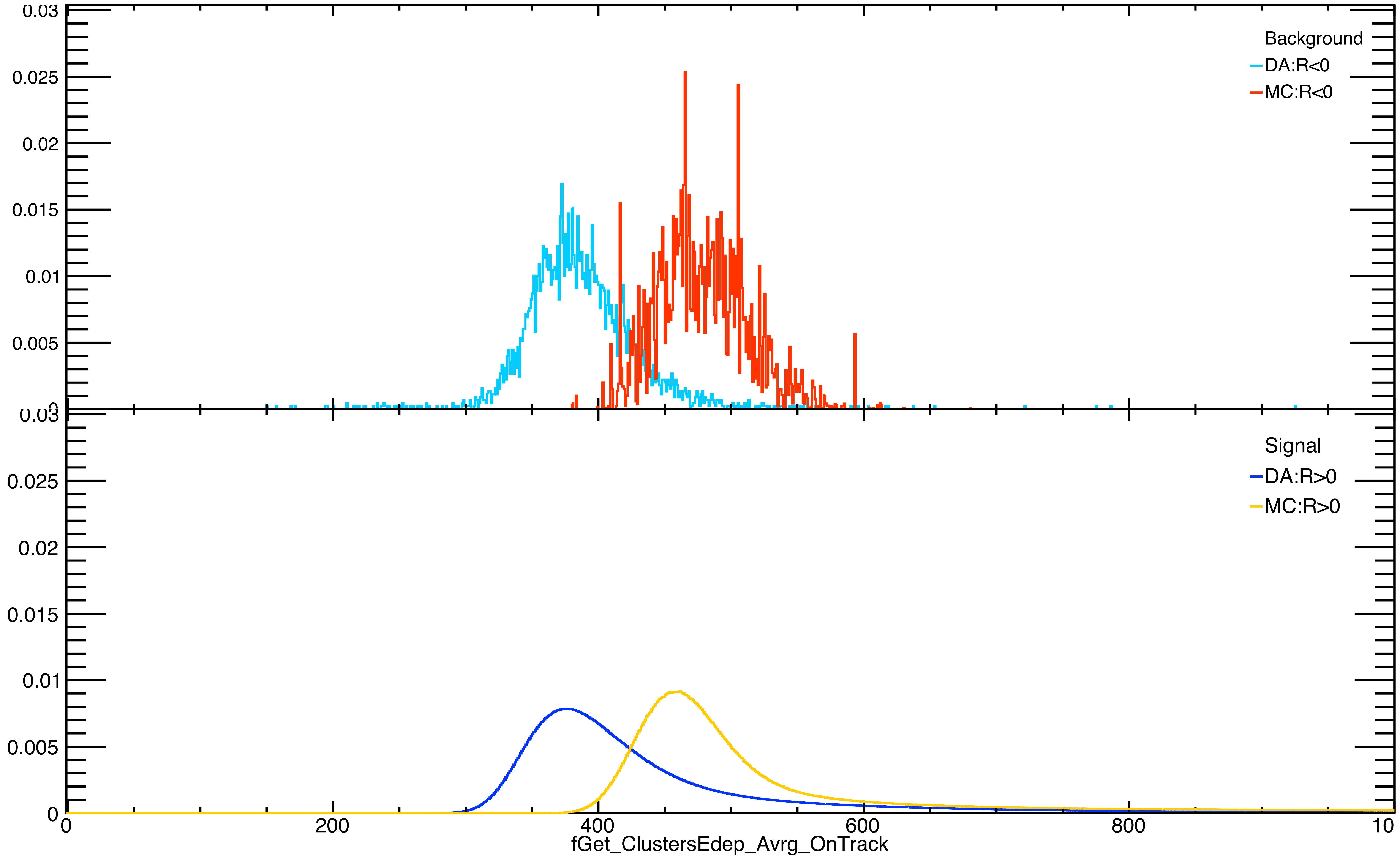


Background
DA:R<0
MC:R<0
Signal
DA:R>0
MC:R>0
fGet_Tof_NClusters_Sum_OffTime

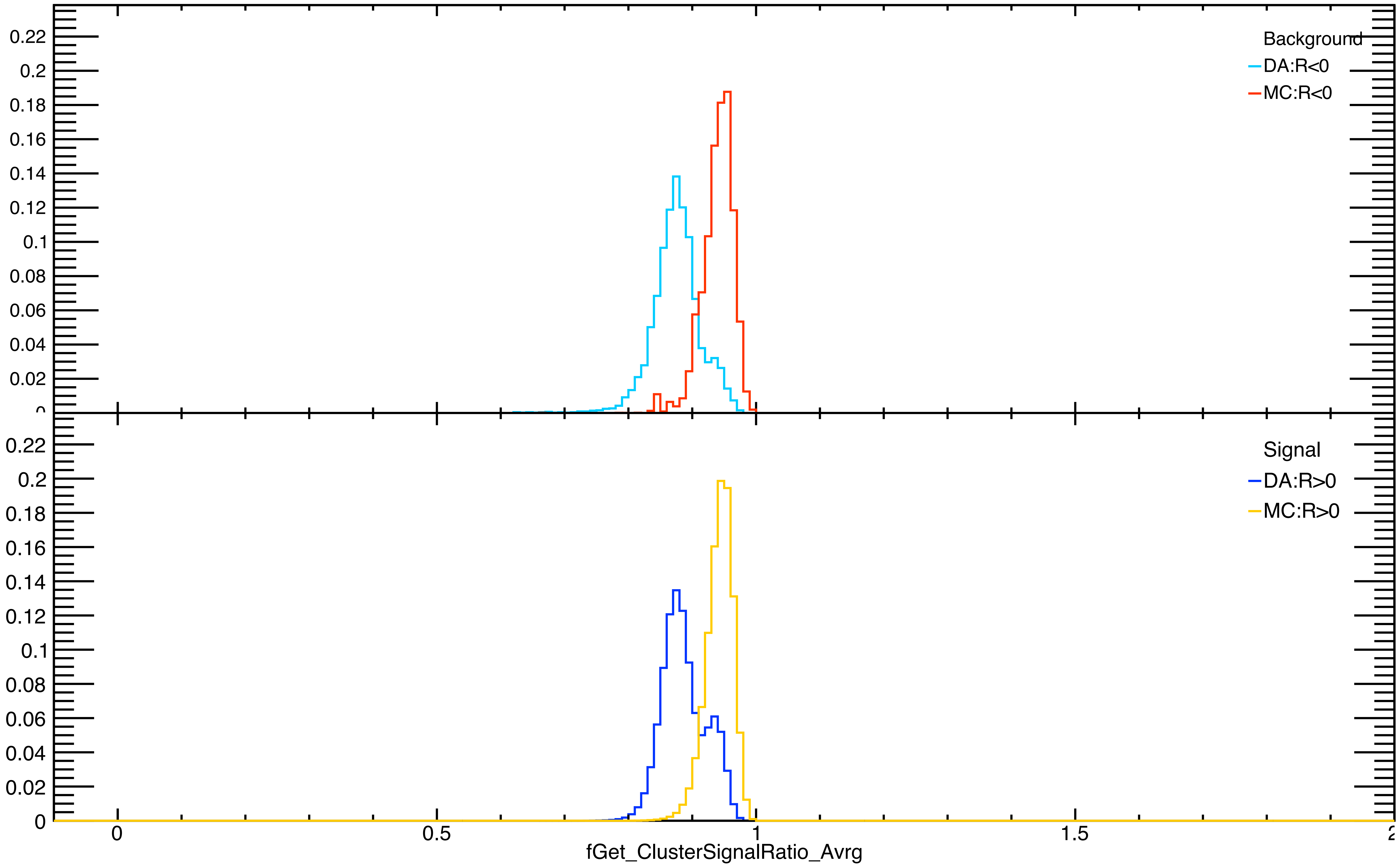


Background
DA:R<0
MC:R<0
Signal
DA:R>0
MC:R>0
f_UpperHalfInner_LowerHalfInner_SameChargeSign


Background
DA:R<0
MC:R<0
Signal
DA:R>0
MC:R>0
fGet_LayerEdep_Avrg
0
200
400
600
800
10
0.03
0.025
0.02
0.015
0.01
0.005
0



Background
DA:R<0
MC:R<0
Signal
DA:R>0
MC:R>0
0.03
0.025
0.02
0.015
0.01
0.005
0
0
200
400
600
800
10
fGet_ClustersEdep_Avrg_OnTrack


Background
DA:R<0
MC:R<0
Signal
DA:R>0
MC:R>0
fGet_ClusterSignalRatio_Avrg
0
0.5
1
1.5
2
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0

End