VALIDATION OF
Π^{0}/η veto

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MOTIVATION

- In $B \to X\gamma$ decay, having a prompt photon (hard photon) candidate in the final state.
- Asymmetric decays of $\pi^0 \to \gamma\gamma$ and $\eta \to \gamma\gamma$ are dominant backgrounds to these radiative meson decays.
- We use a BDT Classifier that helps to differentiate the γ coming from the π^0 and η.
- To estimate data/MC of the efficiency of π^0/η veto, $B^- \to D^0\pi^-$ will be used.
- Where the primary π^- will be treated as the primary photon. This will provide a highly clean comparison of the efficiency of π^0 veto between data and MC.
- We will evaluate the systematic uncertainty due to the data/MC difference of the π^0 probability.
- We have Generic MC for 200 fb^{-1} MC15ri_b BGx1 on release-06-00-07 of the BASF2 framework.

π^0/η VETO

- π^0/η veto, the tool would provide a probability that a given hard photon (γ_{hard}) decayed from π^0or η using a multi-variate analysis (MVA) technique.
- The hard photon is typically a photon decayed from B meson directly and thus expected to have a large energy.
- The hard photon candidate is paired with soft photon (γ_{soft}) candidates in the event (ROE), and then calculate the π^0-like orη-like probabilities are based on the variables sensitive to discriminate signals from backgrounds.
- There are two types of variables, one is for soft photon (γ_{soft}) candidates to select real photon in the hadronic events, the other is for the pair to select $\pi^0$and η.

SOFT PHOTON SELECTIONS BEFORE MVA

Following are the types of selections we have used-

- **Loose- Selection Cut**
- **Standard- Selection Cut, Standard Energy Cut and Standard Timing Cut**
- **Tight - Selection Cut, Tight Energy Cut and Tight Timing Cut**
- **Cluster - Selection Cut, Standard Energy Cut, Standard Timing Cut and NHits cut**
- **Both- Selection Cut, Tight Energy Cut, Tight Timing Cut and NHits cut**

Refer-The latest belle II note is written by Yuma-san et. al.
https://docs.belle2.org/record/2238/files/BELLE2-NOTE-PH-2021-013.pdf

VARIABLES FOR SOFT PHOTON CANDIDATES

First, to suppress the soft photon candidates, following selections cuts are applied before MVA.

- **Selection Cut-** abs(gamma_hard_MotherPDG1)==511 && abs(gamma_hard_mcPDG)==22

We are working only Loose selection mode so we are taking only **Selection Cut**

- **Energy Cut-**

	π^0 candidate	η candidate
forward endcap (clusterReg==1)	$E > 0.025(0.03)$ GeV	$E > 0.035(0.06)$ GeV
barrel (clusterReg==2)	$E > 0.02(0.03)$ GeV	$E > 0.03(0.06)$ GeV
backward endcap (clusterReg==3)	$E > 0.02(0.04)$ GeV	$E > 0.03(0.06)$ GeV

- **Timing cut-**
  - Standard timing selection: abs(clusterTiming) < 200 ns
  - Tight timing selection: abs(clusterTiming) < 200 && abs(clusterTiming/clusterErrorTiming)<2.0

- **NHits Cut-** "gamma_soft_clusterNHits>=2 "

VARIABLES FOR THE PAIR OF HARD AND SOFT PHOTON

1. pi0CosHel
2. InvM
3. gamma_soft_E
4. gamma_soft_minC2TDist
5. gamma_soft_ZernikeMVA
6. gamma_soft_clusterTheta
7. gamma_soft_clusterNHits
8. gamma_soft_clusterSecondMoment

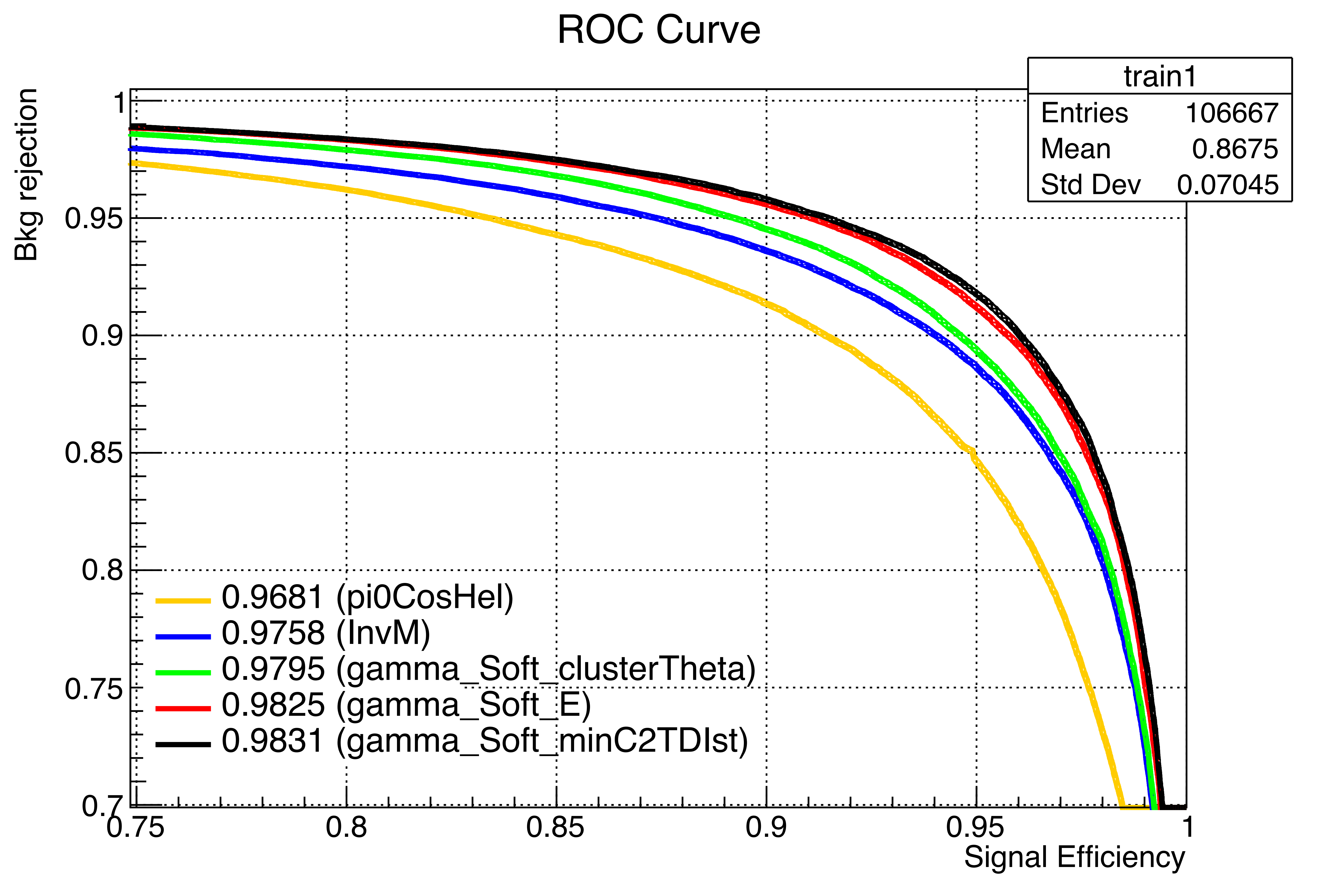
Decreasing order in variable importance

To see distribution of each variable check "Backup" slides

ROC FOR DIFFERENT VARIABLES

AUC Score	Train	Test
pi0CosHel	0.9681	0.9680
InvM	0.9758	0.9753
gamma_soft_E	0.9795	0.9789
gamma_soft_minC2TDist	0.9825	0.9820
gamma_soft_ZernikeMVA	0.9831	0.9825
gamma_soft_clusterTheta	0.9835	0.9834
gamma_soft_clusterNHits	0.9835	0.9835
gamma_soft_clusterSecondMoment	0.9835	0.9835

Table for Train Test AUC Score for different variable



Train ROC curve for different variables(adding them up top to bottom)

CONTROL DECAY CHANNEL

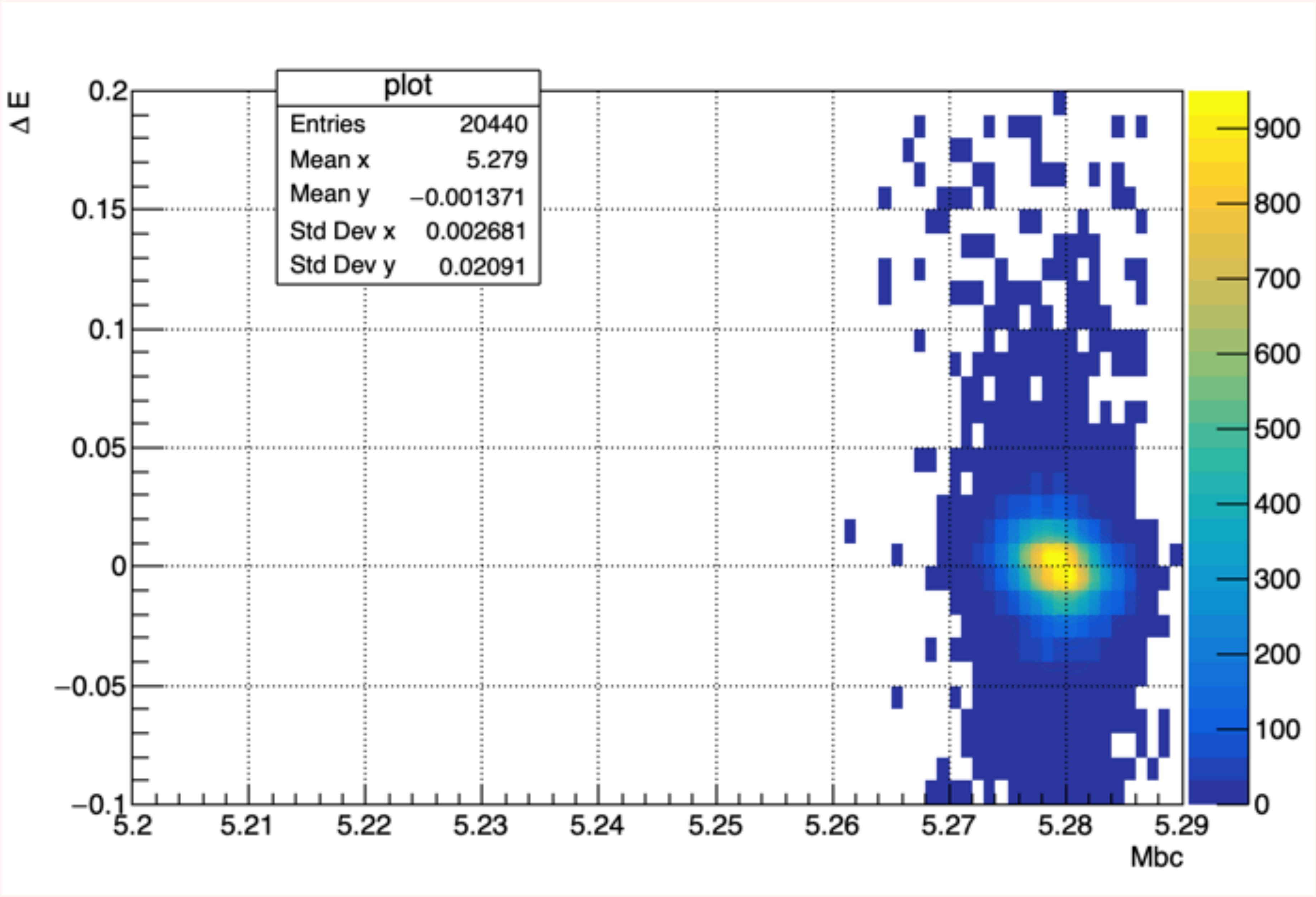
- **The decay channel of interest :** $B^- \rightarrow D^0[K^-\pi^+]\pi^-$
- **Fast negative charged pion(π^-) will be used as a proxy for (π^0/η) veto as it mimics the hard photon candidates. Theoretically, the veto should select all the fast pion candidates. We have used this (π^0/η) veto on our reco script on fast (π^-) candidates.**
- **We have run on Generic MC for 200 fb^{-1} MC15ri_b BGx1 on "light-2203-Zeus" of the BASF2 framework.**

Refer-The latest belle II note is written by Watanuki et all;
BELLE2-NOTE-TE-2021-025 DRAFT Version 1.0

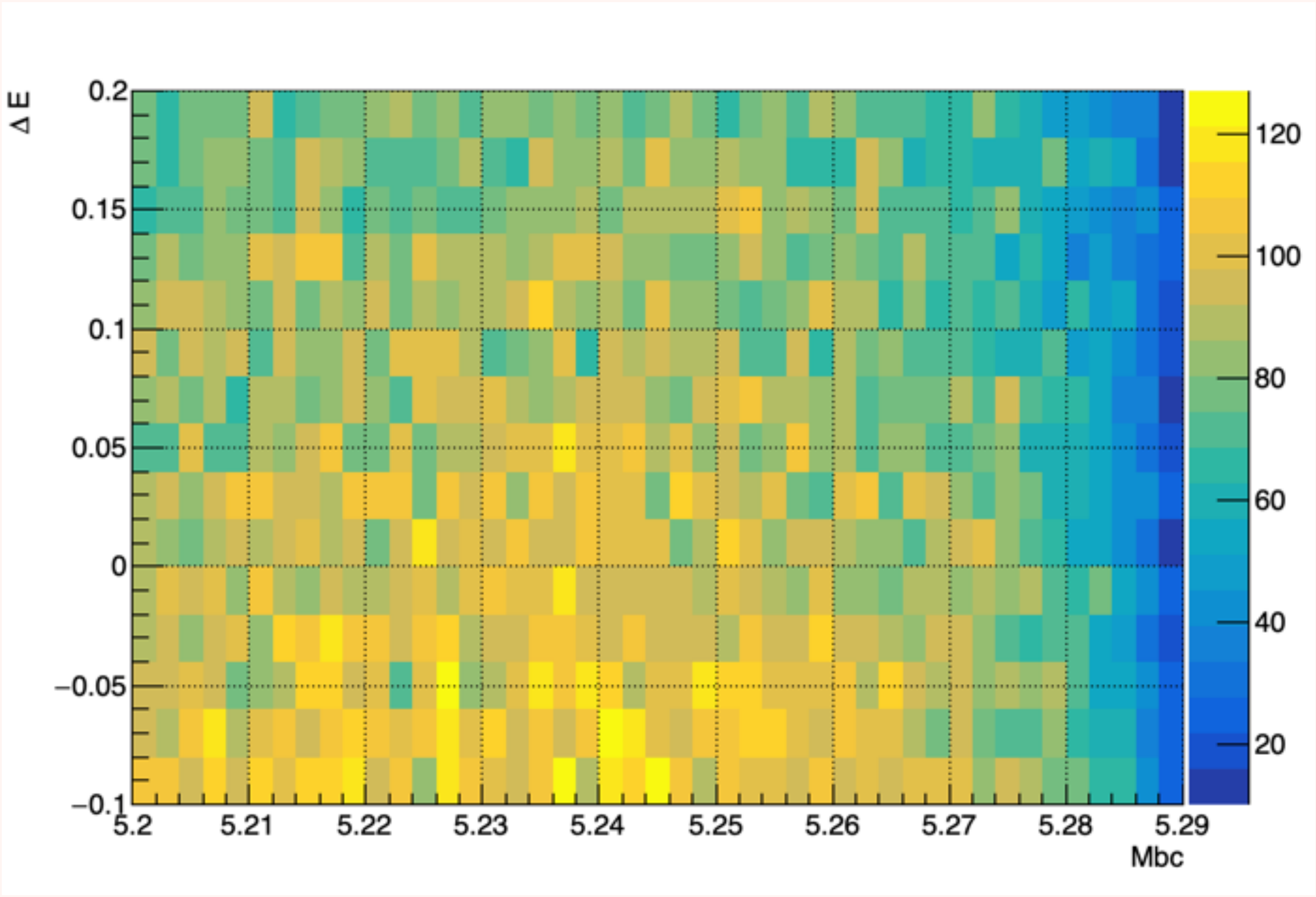
CUTS IN THE RECONSTRUCTION SCRIPT

- **Good Track Cut - “abs(dz) < 2.0 cm and abs(dr) < 0.5 cm”**
- D^0 **mass cut - “ 1.6 < M < 2.2” (GeV/c^2)**
- B^- **Mbc mass cut - “5.2 < Mbc <5.3” (GeV/c^2)**
- ΔE **cut - “-0.1 < deltaE < 0.2” (GeV)**
- **Kaon and pion BinaryPiD cut - “PIDPairProbabilityExpert(211,321,ALL) > 0.1”**

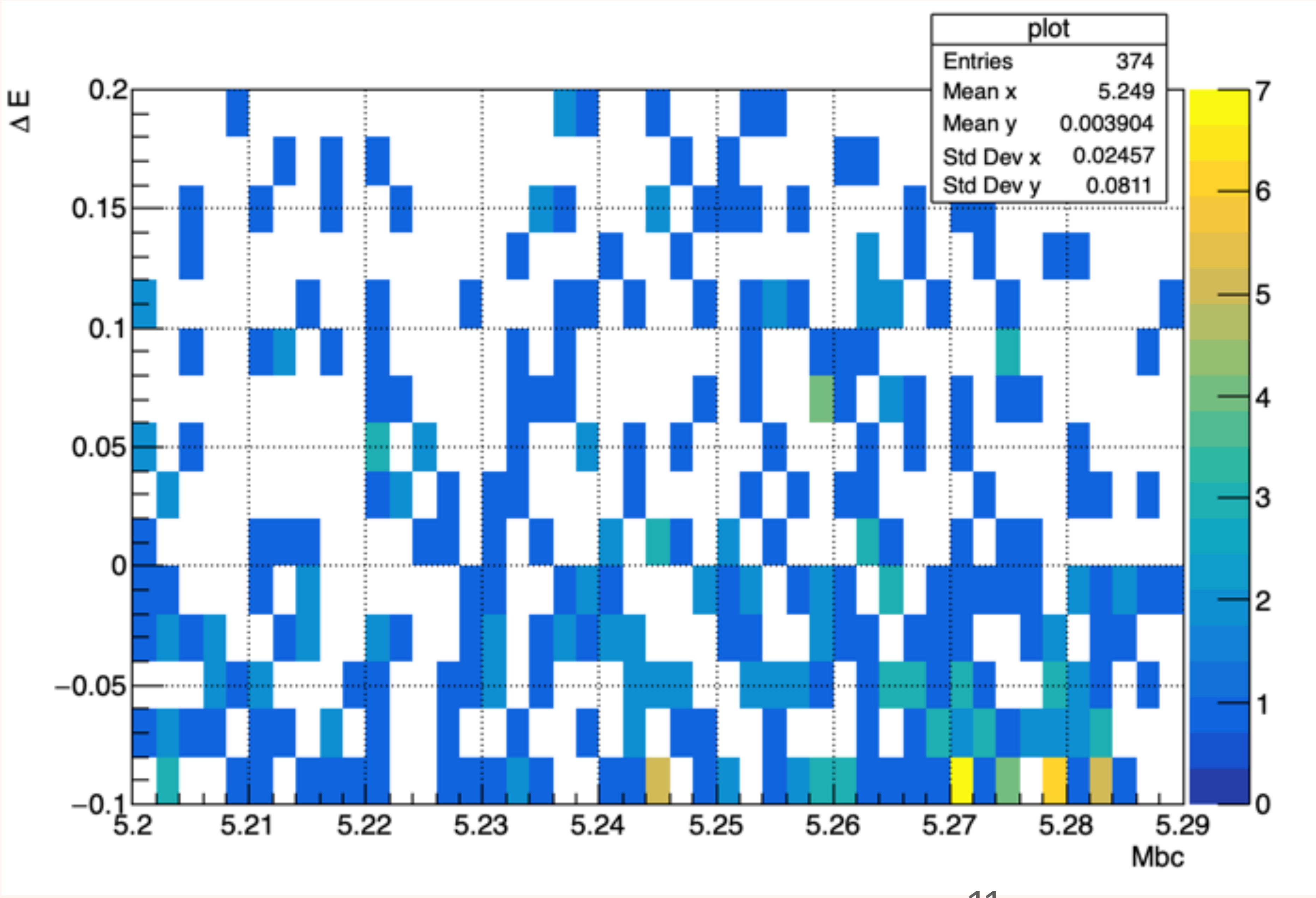
2D SCATTER PLOT BETWEEN M_{bc} AND ΔE



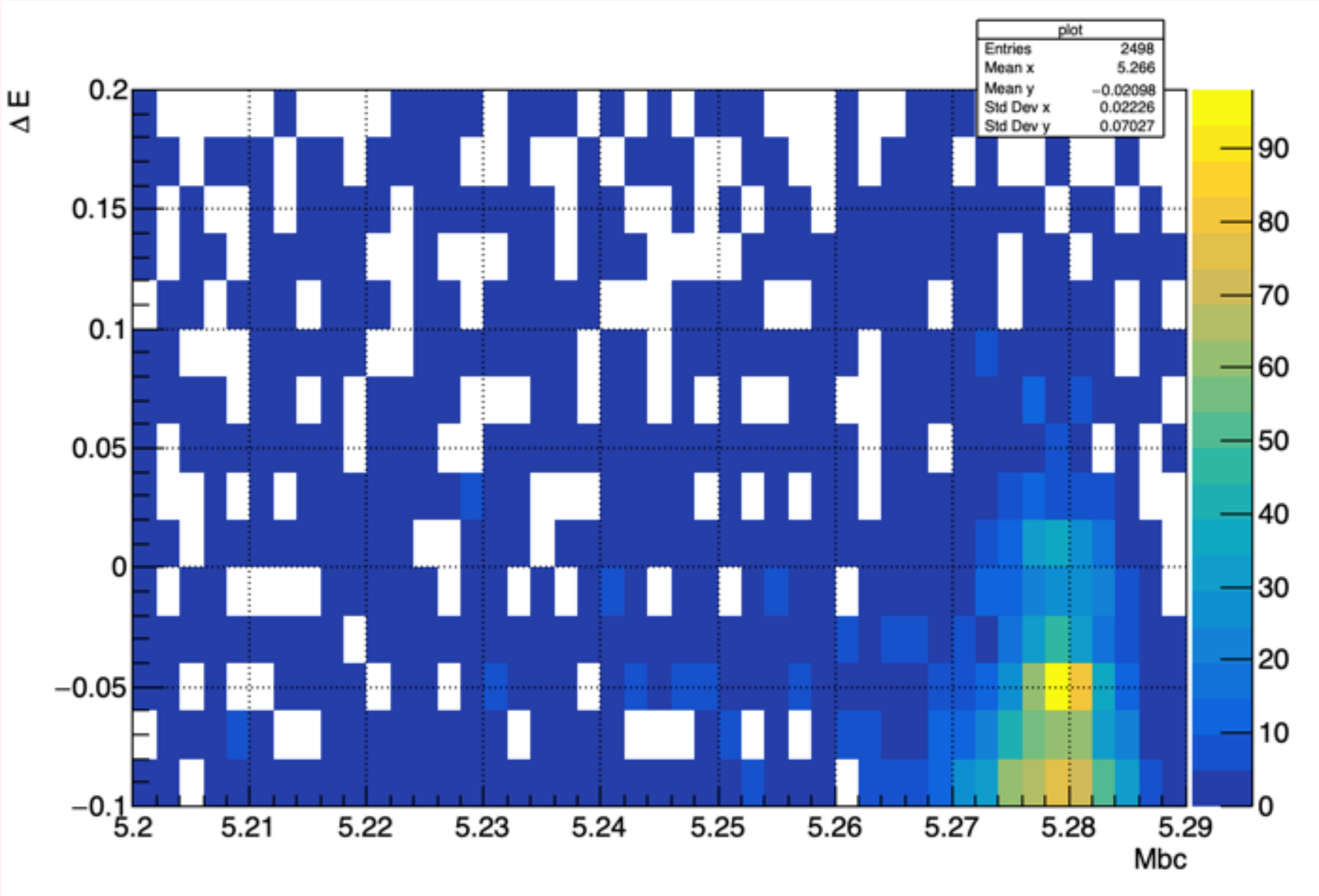
Signal; 2d scatter plot (colz)



Qqbar; 2d scatter plot (colz)



Mixed; 2d scatter plot (colz)



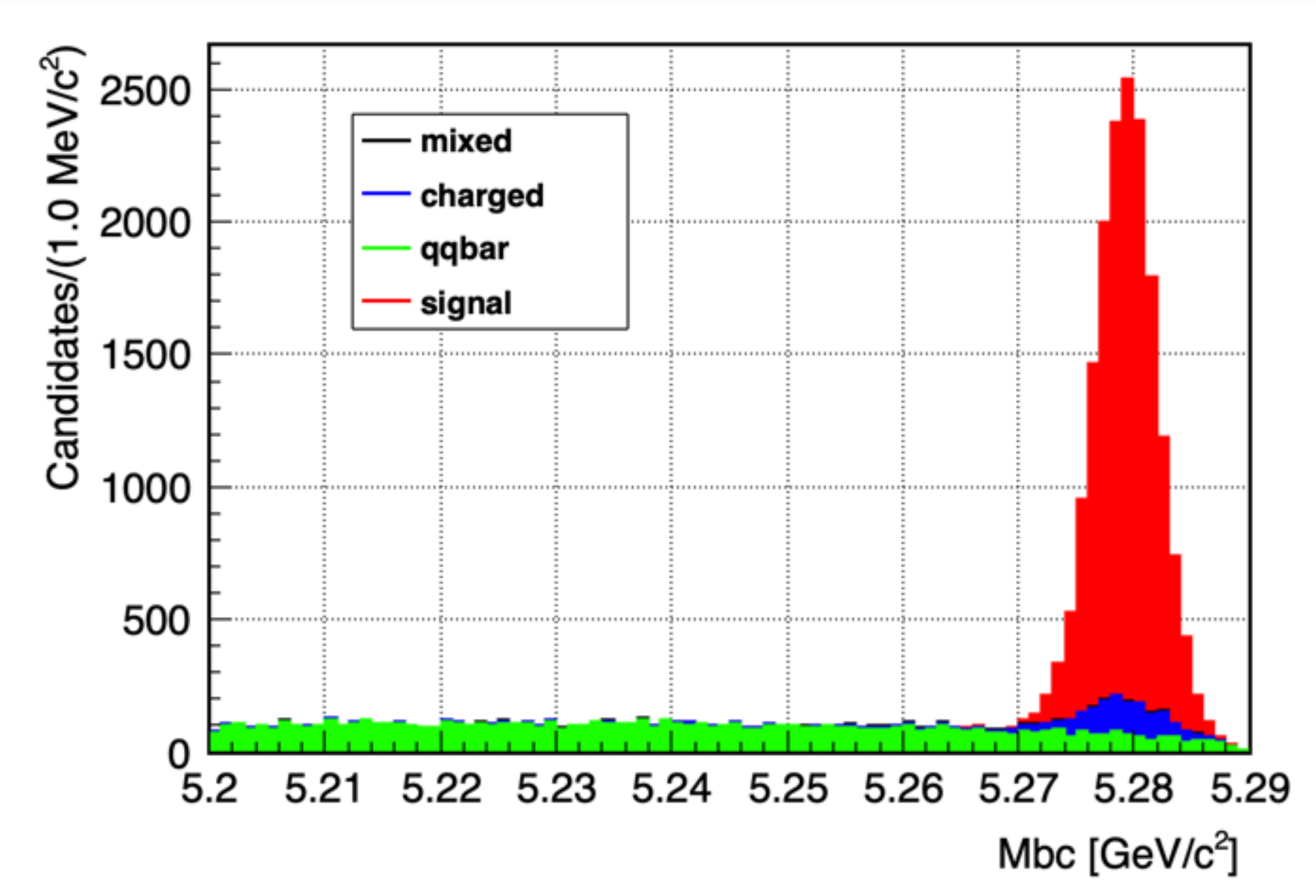
Charged; 2d scatter plot (colz)

- Signal represents the correctly reconstructed $B^- \rightarrow D^0[K^-\pi^+]\pi^-$ channel (isSignal==1)
- Background shows all other misreconstructed events except the above B- channel (isSignal!=1)

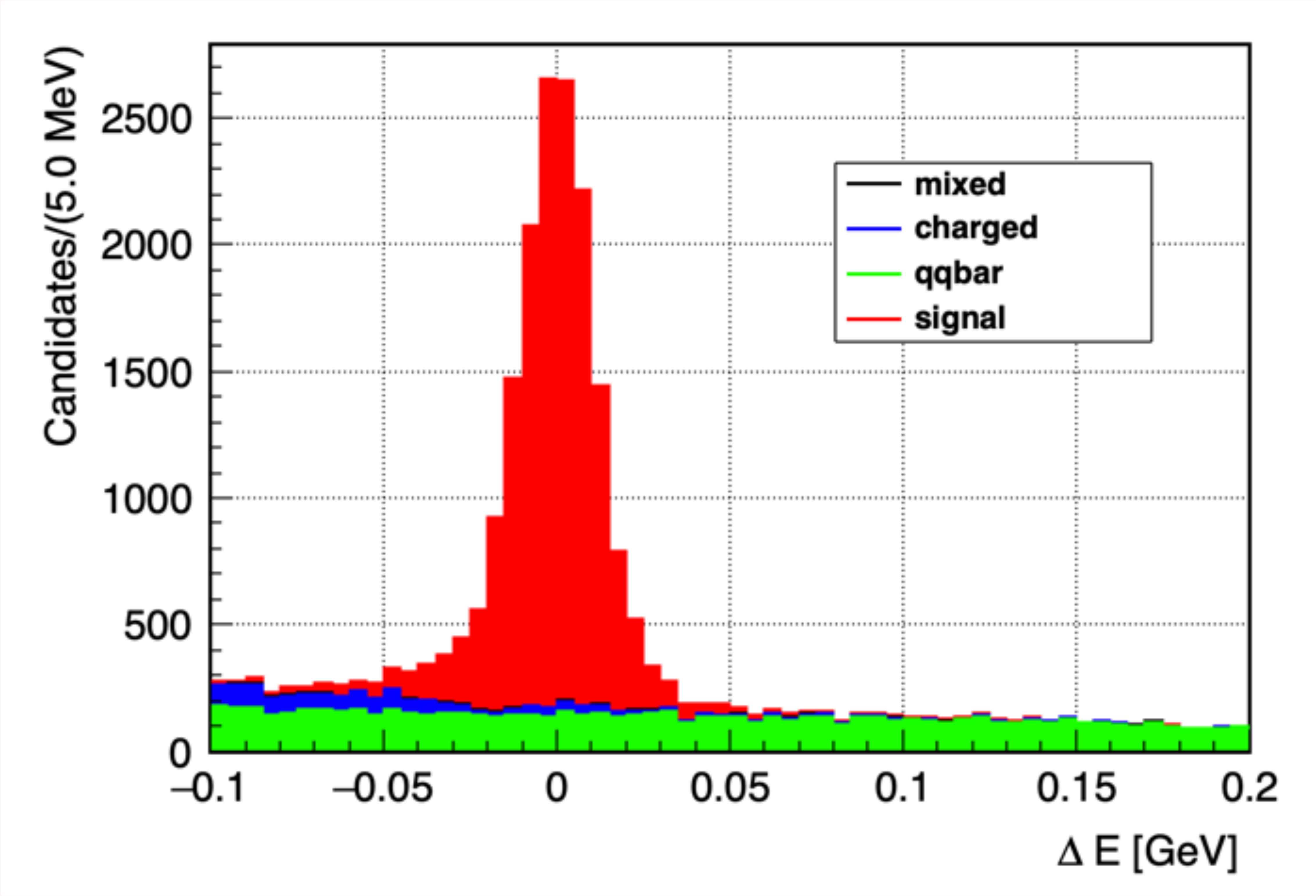
FROM THE PLOTS-

- **We could see a concentrated Signal at 5.28 GeV/c^2 (M_bc X-axis) and at 0 GeV (ΔE Y-axis) and its range varies at [5.27 - 5.29] GeV/c^2**
- **From the qqbar 2D Scatter plot, we could see a uniform background or confirm background throughout.**
- **From the Charged 2D Scatter plot, we could see a peaking Background at 5.28 GeV/c^2 (M_bc X-axis) and in the Negative Range of the Y-axis.**
- **From the Mixed 2D Scatter plot, we could see a sub-Dominant (less prominent) Background throughout.**

M_{bc} AND ΔE PLOT



M_{bc} plot for B- decay channel after all cuts

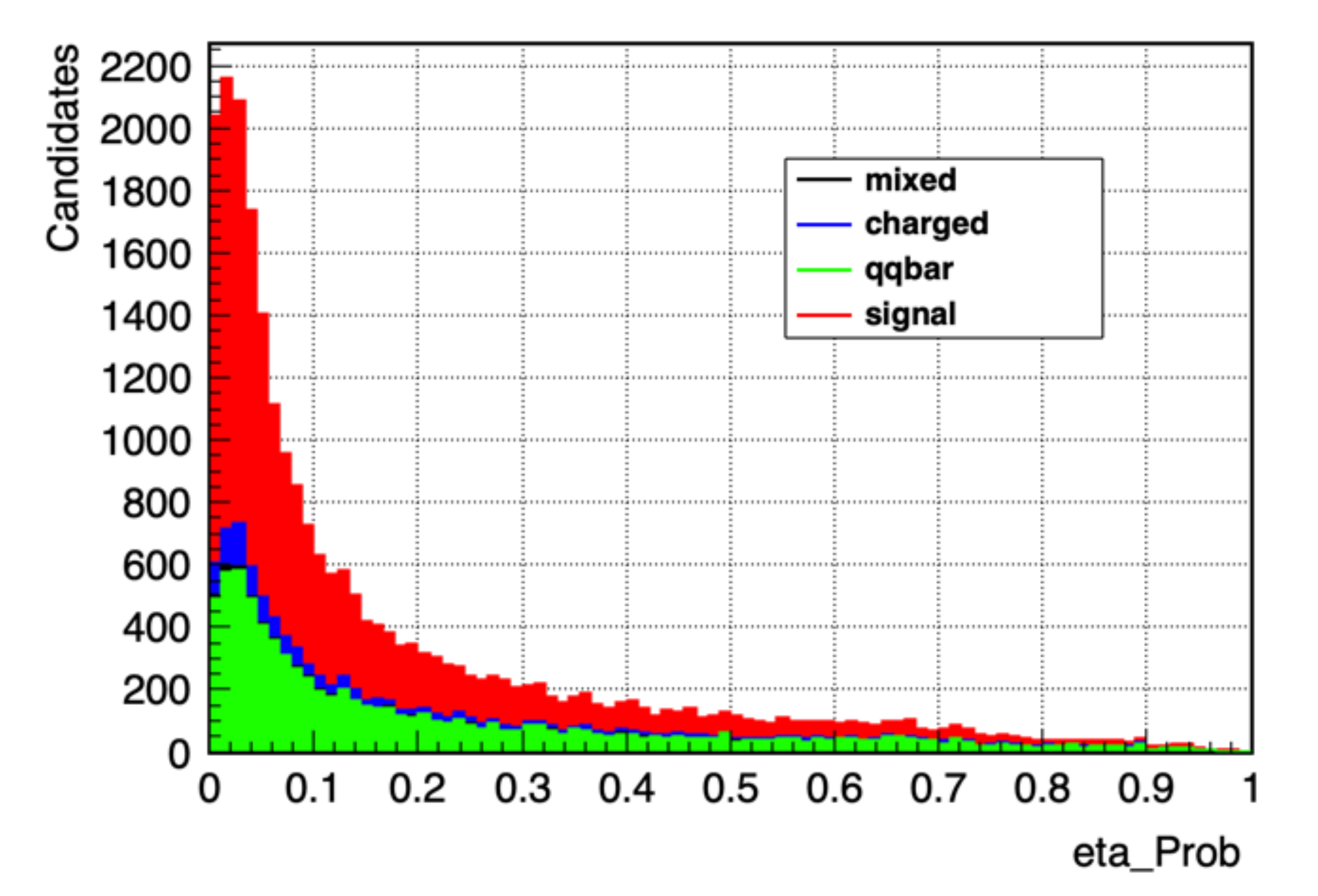


ΔE plot fro B– decay channel after all cuts

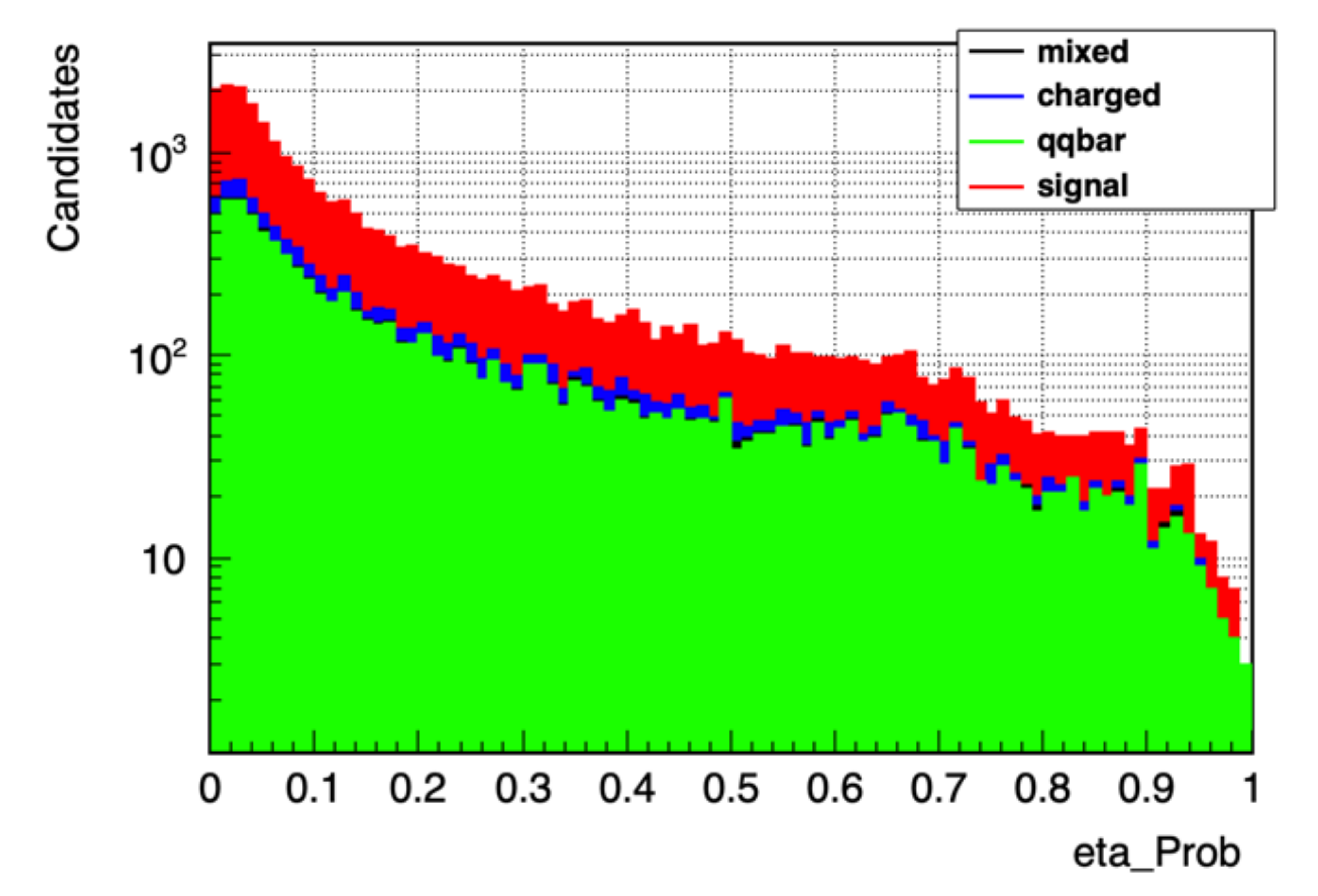
Cuts Used-
D0_Km_binaryPID_211_321<0.6
D0_pip_binaryPID_211_321>0.6
R2<0.3 and chiProb>0.001

- **Signal represents the correctly reconstructed $B^- \to D^0[K^-\pi^+]\pi^-$ channel (isSignal==1)**
- **Background shows all other misreconstructed events except the above B- channel (isSignal!=1)**

η PROBABILITY PLOT

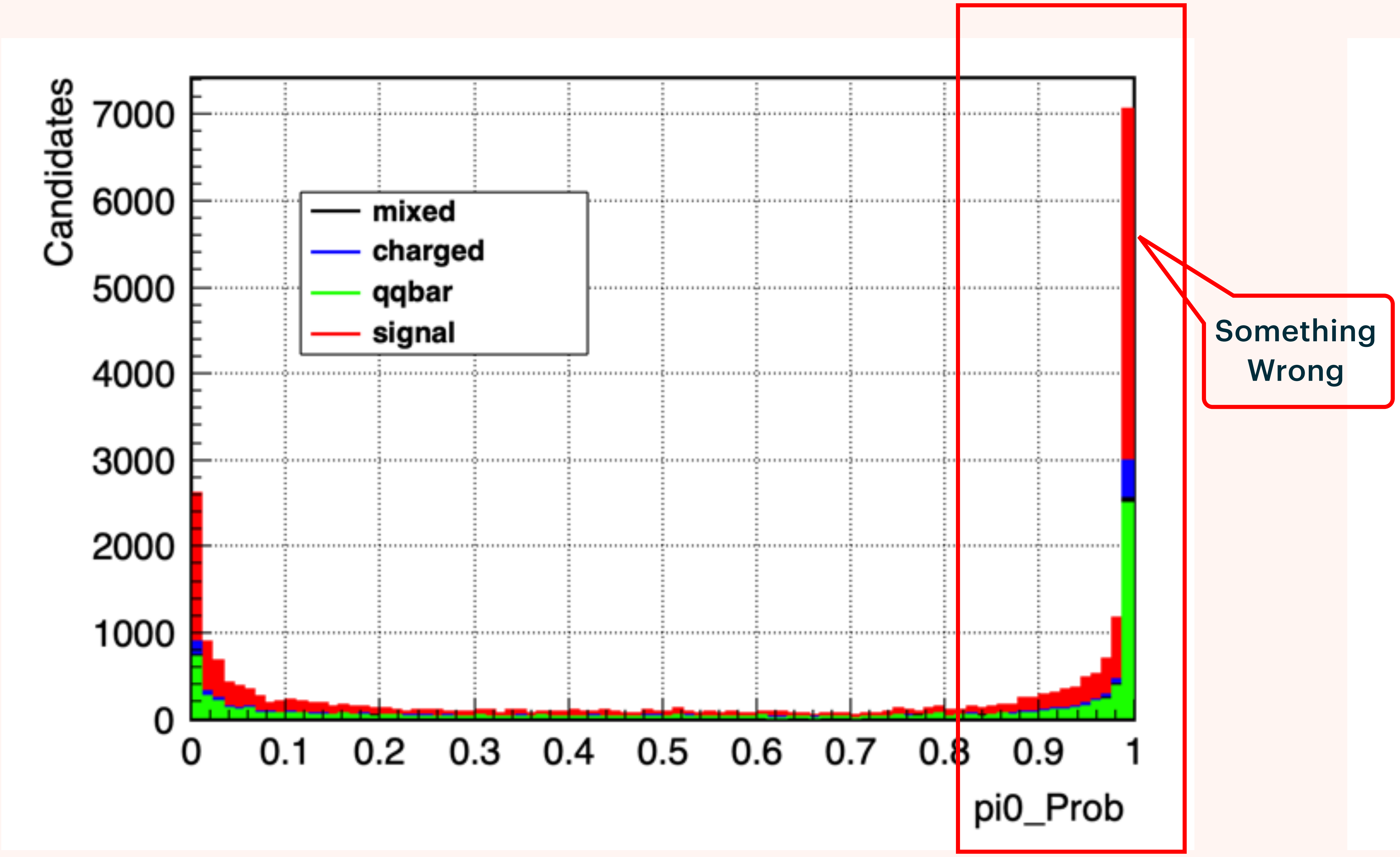


η probability plot after all cuts

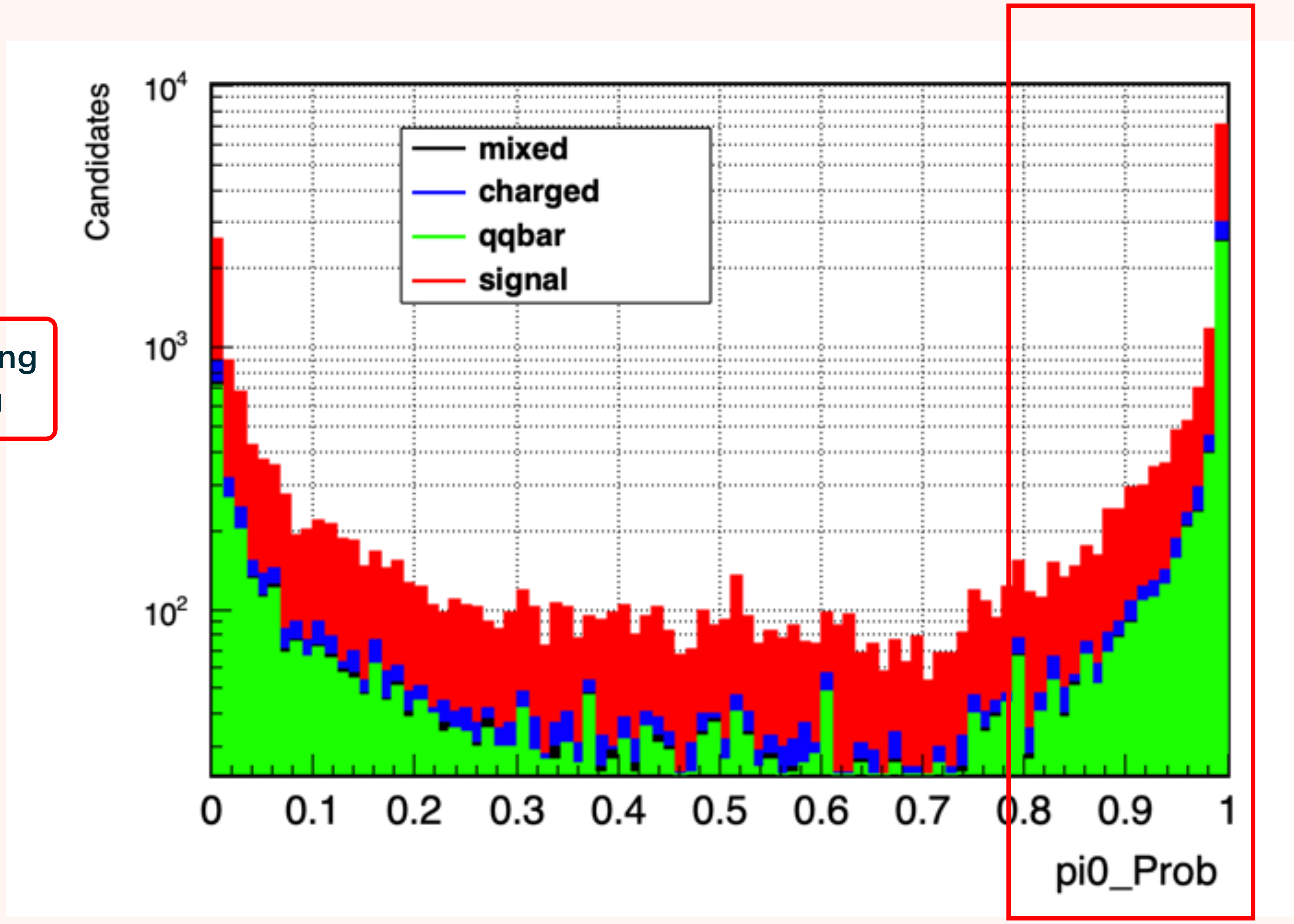


η probability plot in log scale after all cuts

π^0 PROBABILITY PLOT



π^0 probability plot after all cuts



π^0 probability plot in log scale after all cuts

- In Ideal case Scenario Sig π^0 prob should not peak at 1
- We used the existing Veto

SOLVING THE PROBLEM BY-MASS HYPOTHESIS

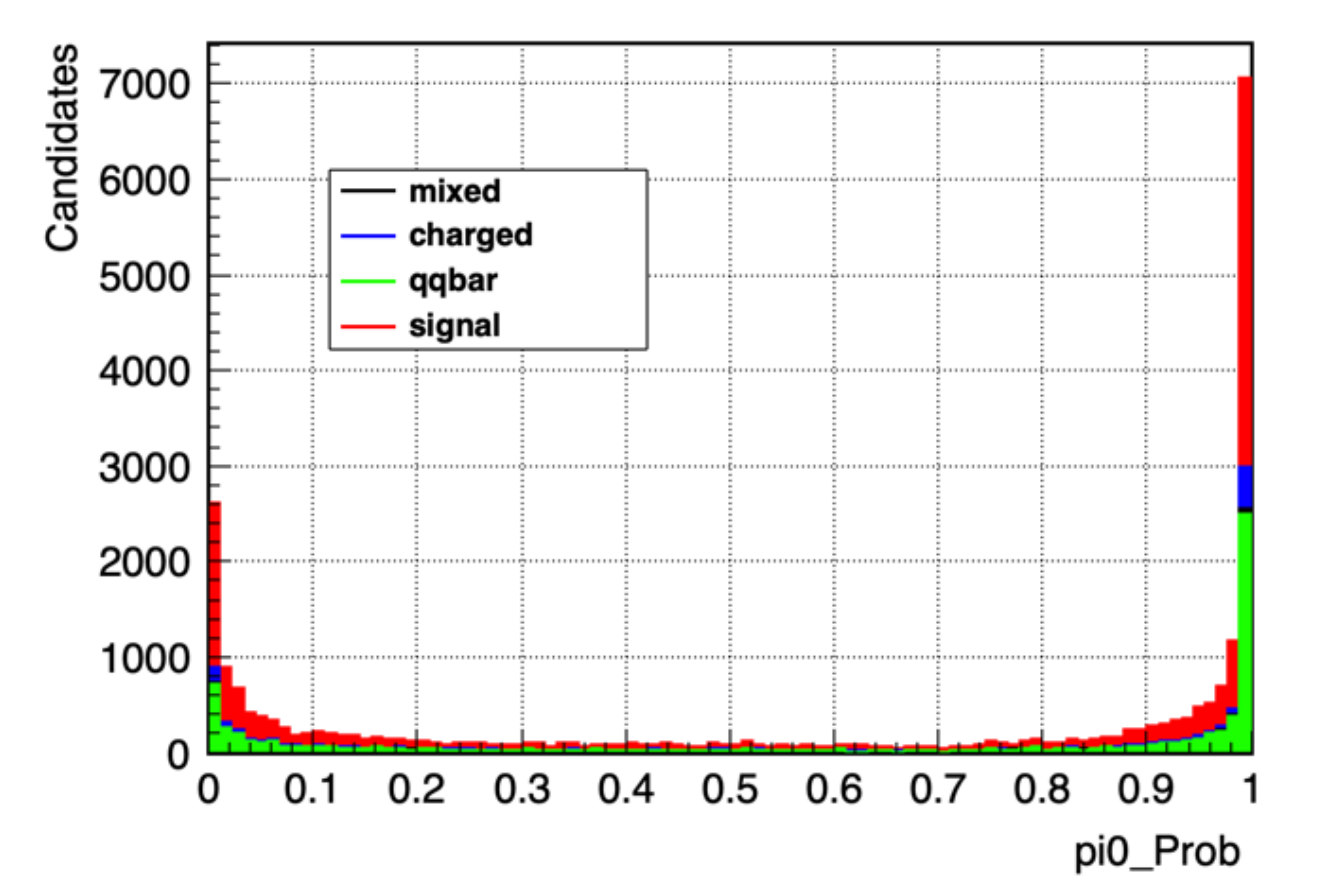
- **Pion mass hypothesis** $B^- \to D^0[K^-\pi^+]\pi^-$
- **Electron mass hypothesis (very close to "photon mass hypothesis" using super-relativistic theory E≈p as $\frac{m^2}{p} << 1$ for electron)**

$$B^- \to D^0[K^-\pi^+]e^-$$

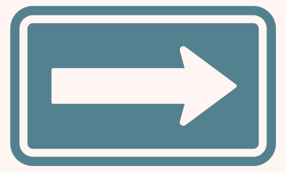
- **So we used 3 basic channel decays to find out the problem, investigating each training variable**

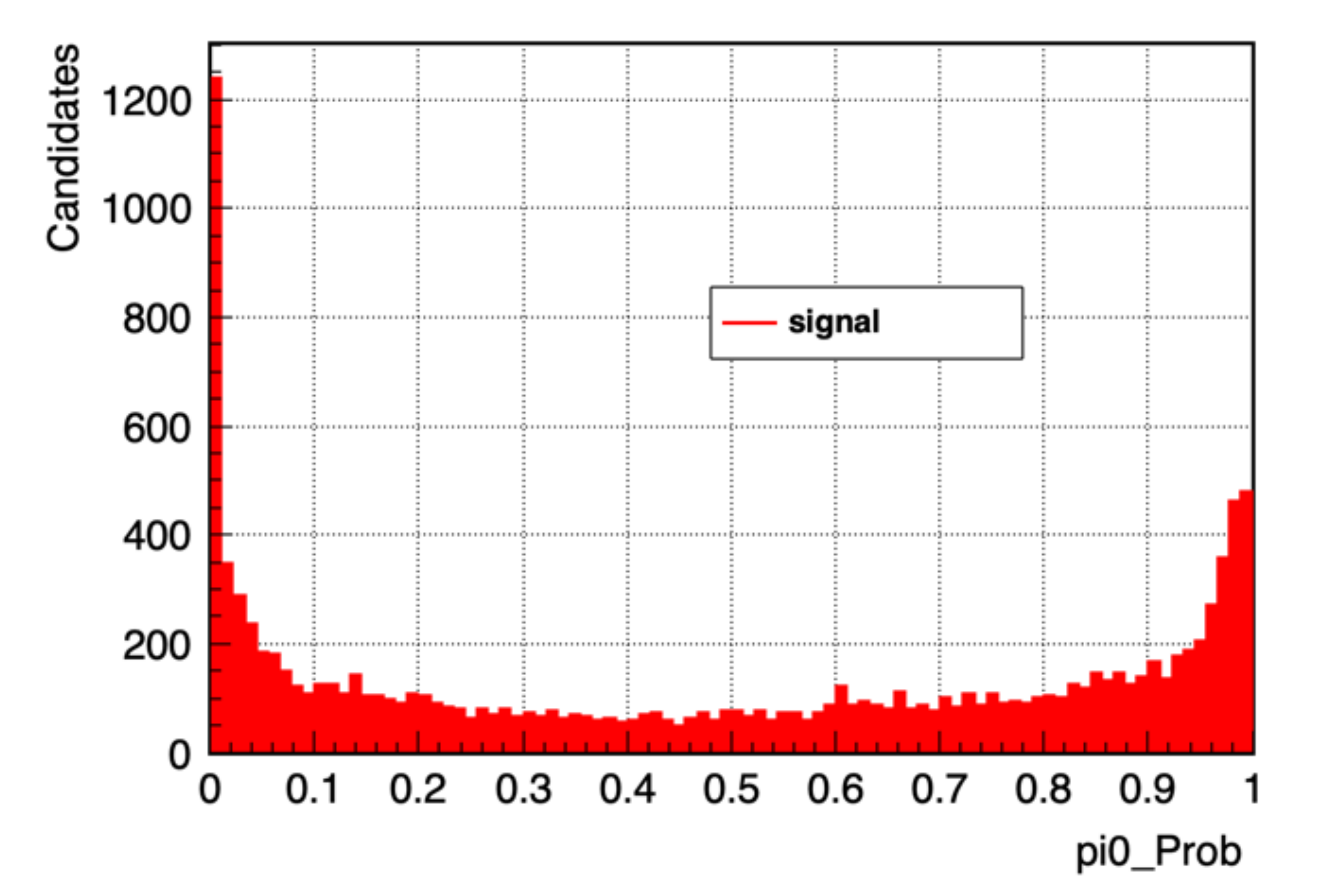
$\pi^0 \to \gamma\gamma$ $\pi^0 \to \pi^+\gamma$ $\pi^0 \to e^-\gamma$ -allowChargeViolation=True

π^0 PROBABILITY PLOT COMPARISON



π^0 probability plot for pion mass hypothesis





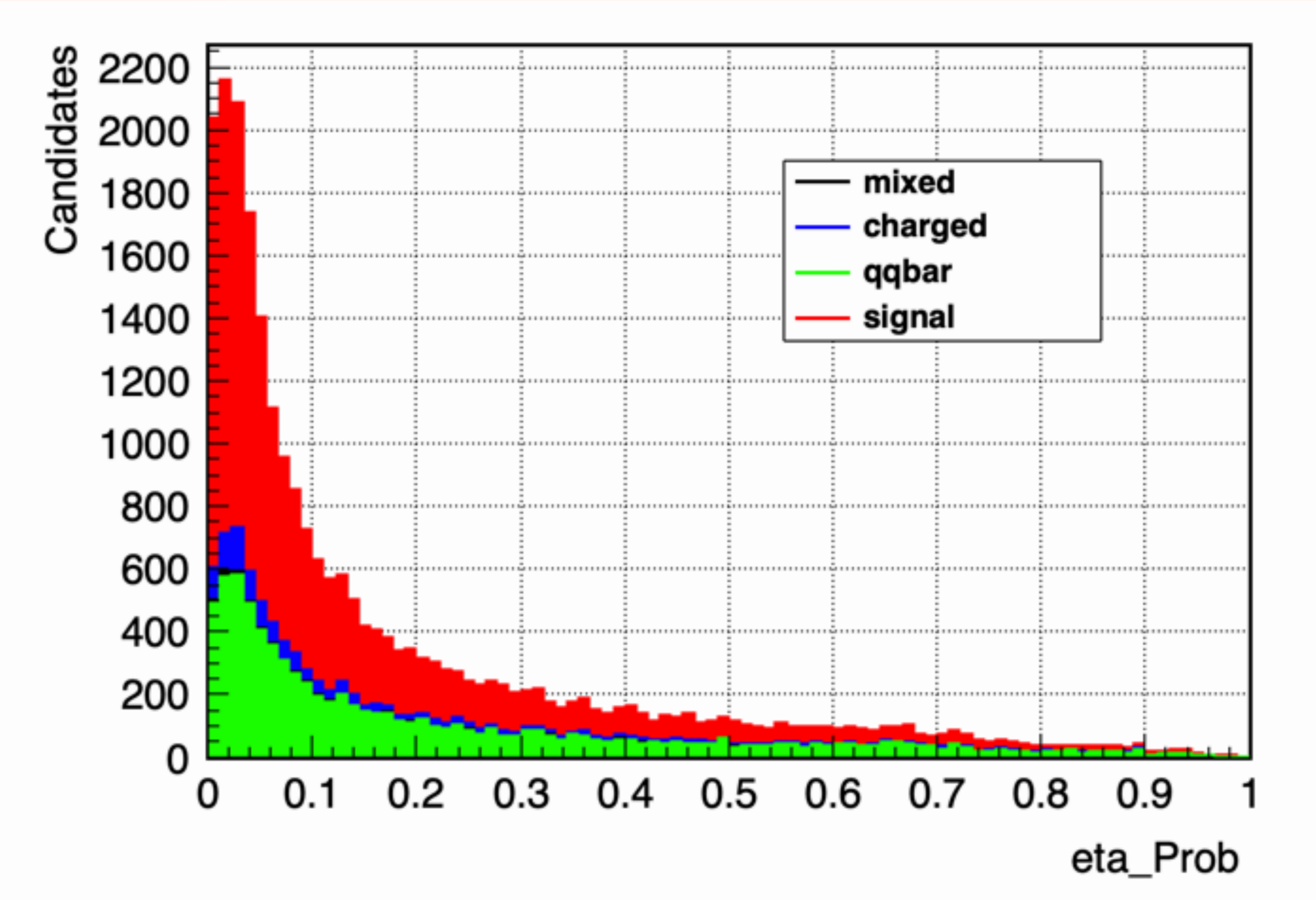
π^0 probability plot for B- decay channel for electron mass hypothesis

Signal represents the correctly reconstructed $B^- \rightarrow D^0[K^-\pi^+]\pi^-$channel (isSignal==1)

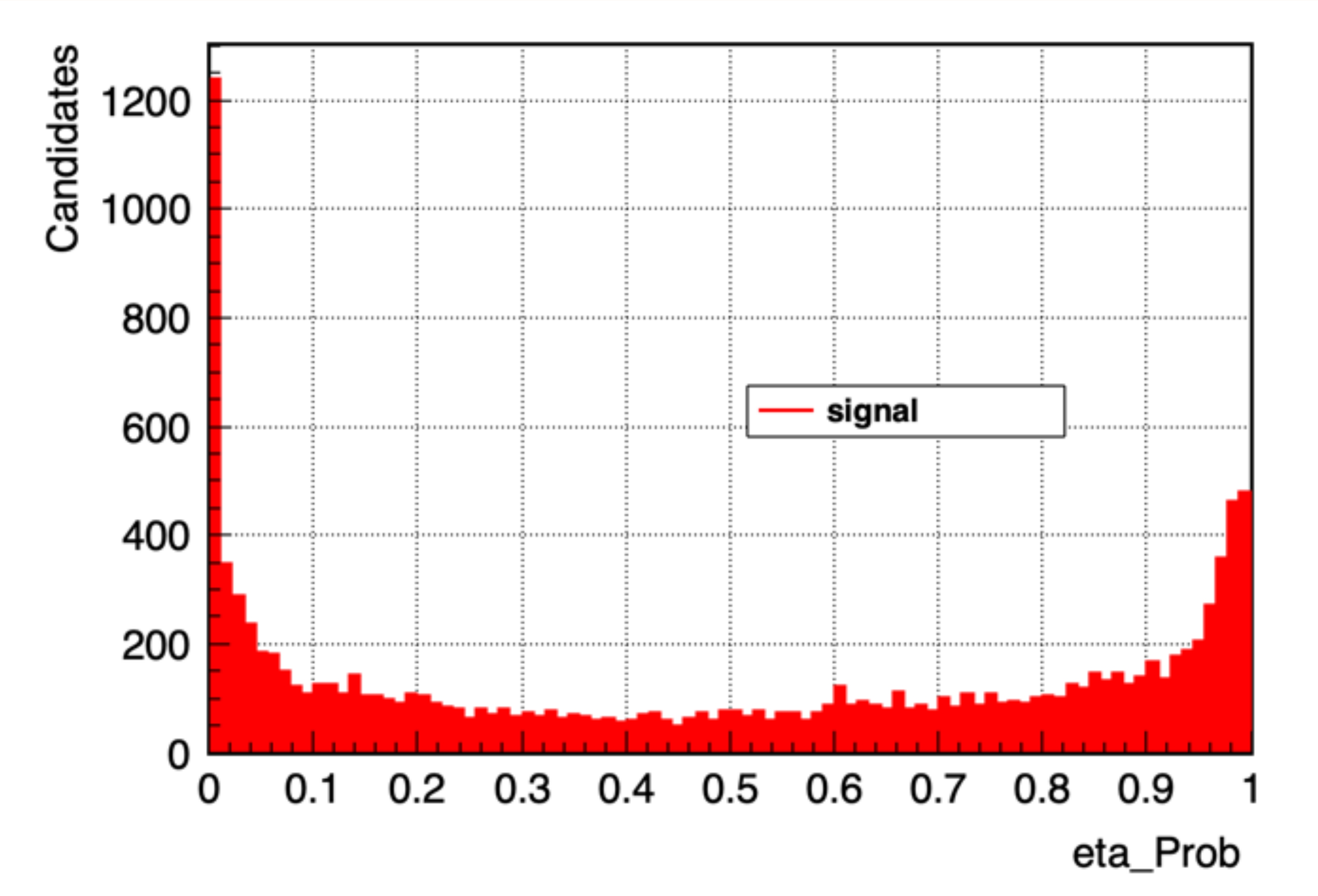
Signal represents the correctly reconstructed $B^- \rightarrow D^0[K^-\pi^+]e^-$channel

η PROBABILITY PLOT COMPARISON

$B^- \to D^0[K^-\pi^+]\pi^-$

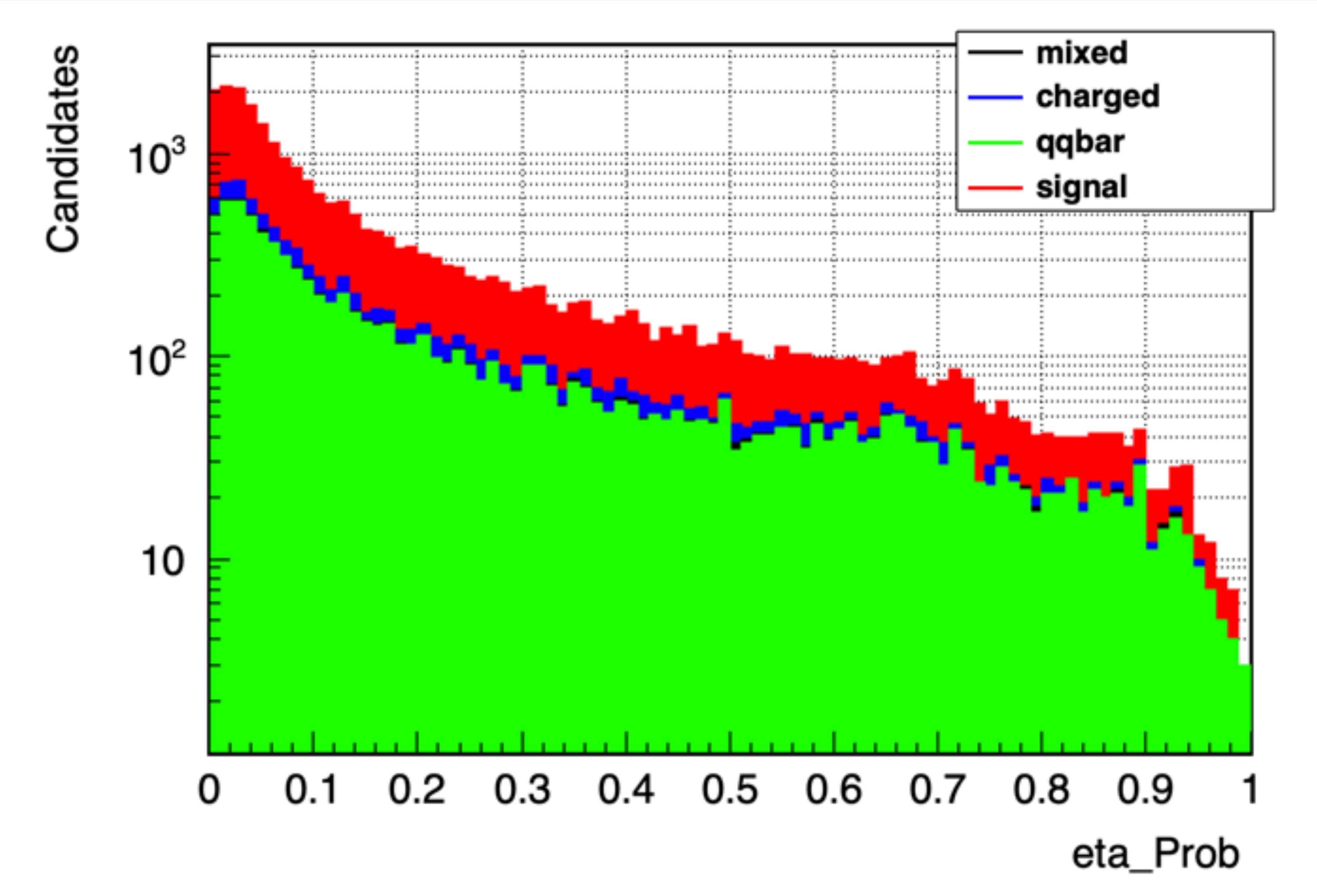


η probability plot for pion mass hypothesis

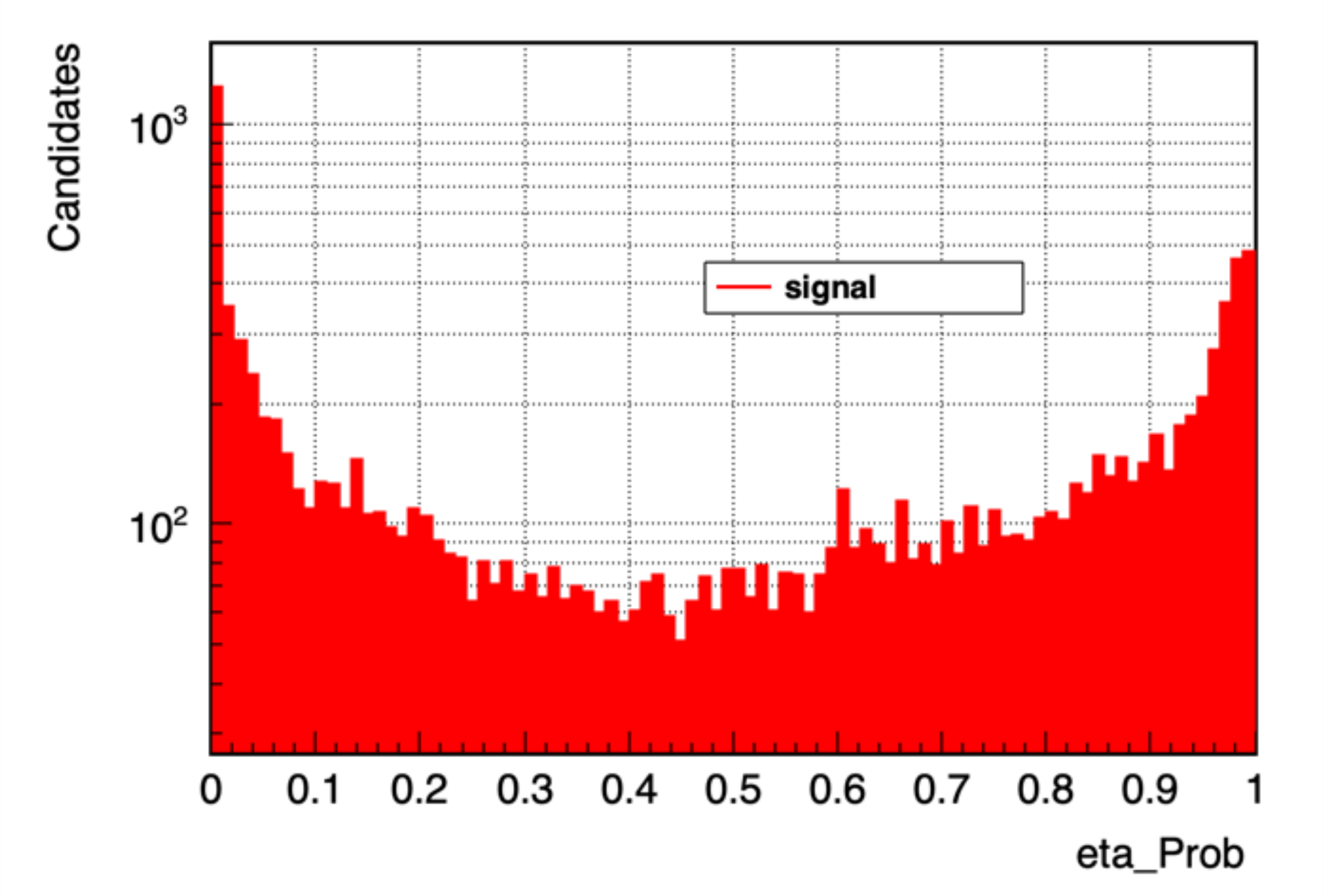


η probability plot in log scale for electron mass hypothesis

$B^- \to D^0[K^-\pi^+]e^-$



η probability plot in log scale for pion mass hypothesis

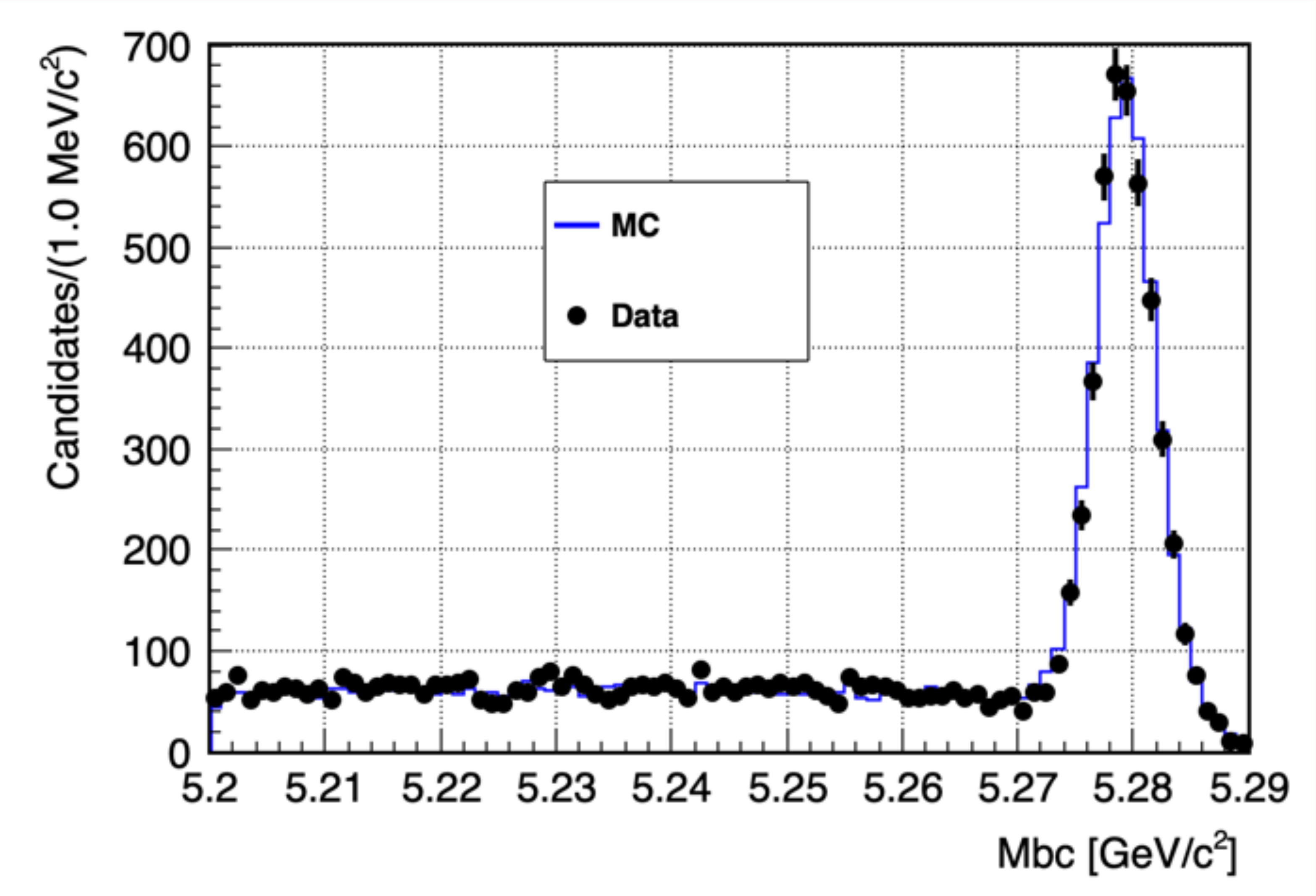


η probability plot in log scale for electron mass hypothesis

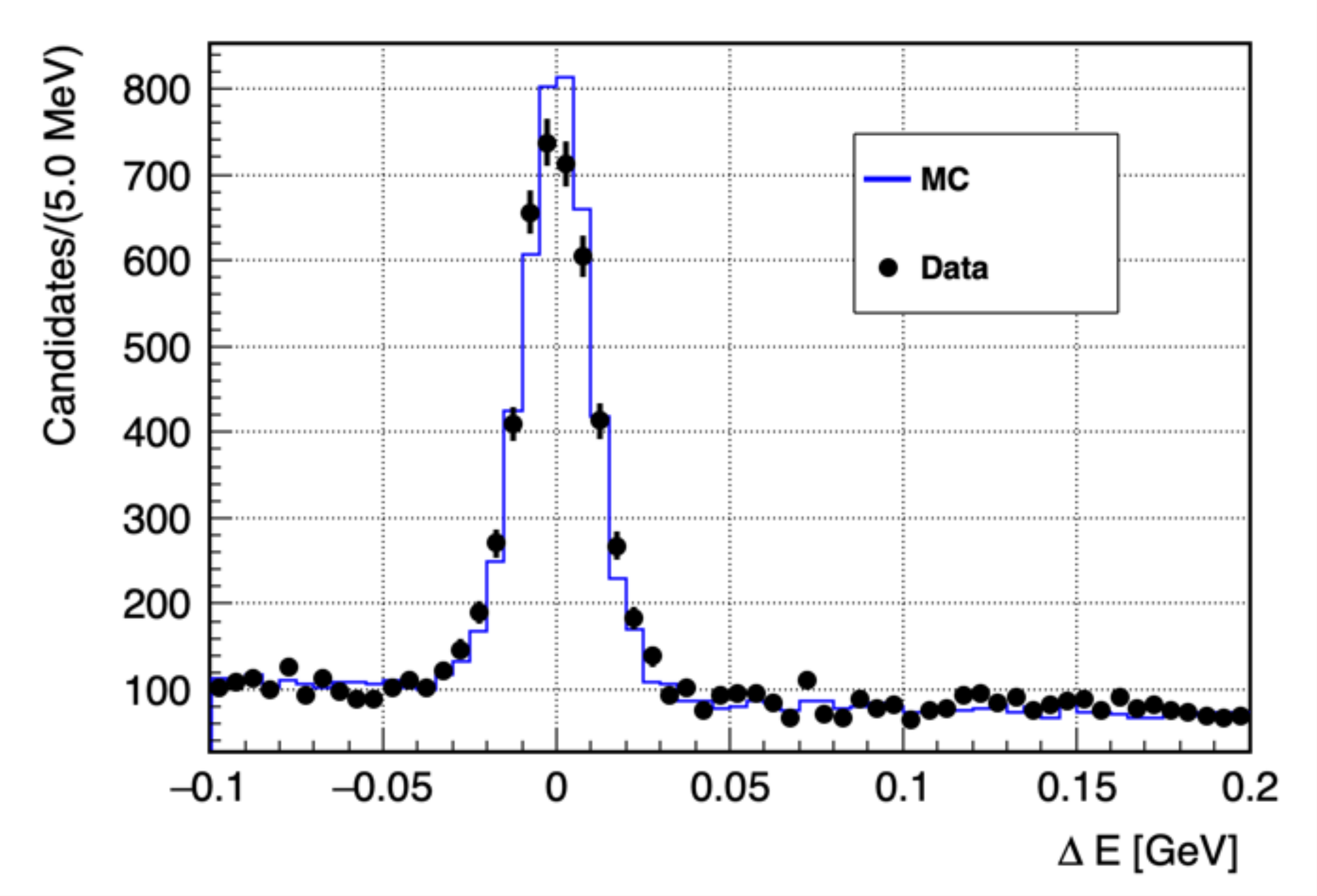
CASE : 1
FOR PION MASS HYPOTHESIS

RESOLVING η PROBABILITY

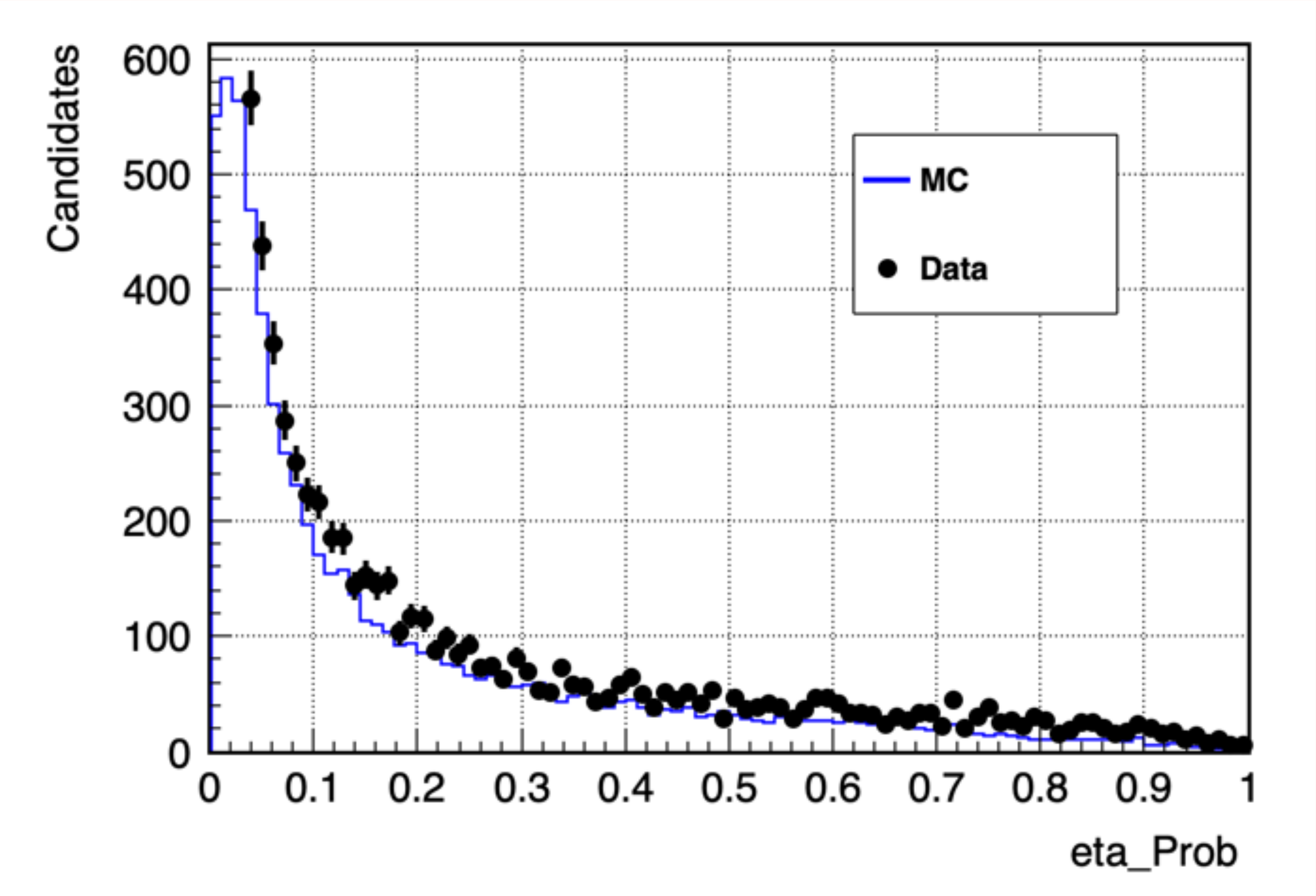
DATA-MC AGREEMENT



Data-MC M_{bc} plot of B– decay channel for η



Data-MC ΔE plot for B- decay channel fro η



Data-MC agreement of η Prob plot

- **Comparison of several variables between Chunk2 Proc13 dataset and MC15ri_a for $B^- \to D^0\pi^-$ channel.**
- **One can see non-negligible discrepancy between data and MC in $B^- \to D^0\pi^-$ channel.**

BLUE indicates the MC events

Black indicates the data with error bars.

All the MC and the Data points in the plot are scaled.

FITTING

New fit model for $B^- \to D^0\pi^-$ modes

Component	Shape ΔE	Shape M_{bc}	Parameters	Yield
Continuum	Exponential	ARGUS	Floated	Floated
$B\overline{B}$	CB	CB	Fixed	Fixed
$B^- \to D^0\pi^-$	Cruijff	Gaussian	Floated	Floated

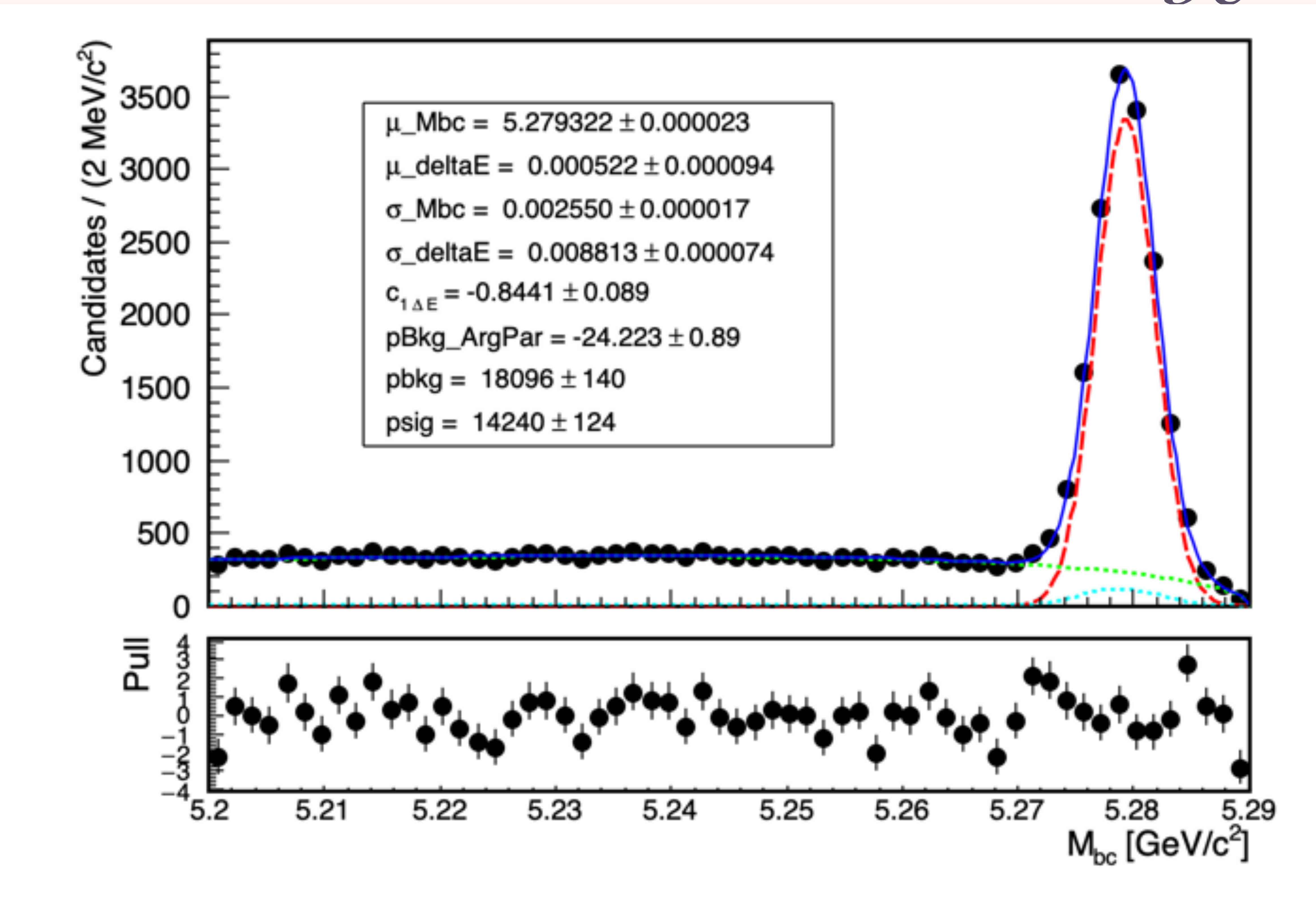
$B\bar{B}$ Background yield- 863 Signal yield- 13718 Percentage - 6.03%

$B\bar{B}$ combinatorial background can have a peaking component in signal region (M_{bc} > 5.28(GeV/c^2)). Thus combinatorial background distribution is modeled by Crystal Ball (CB) and kept fixing with the fitting results of MC.

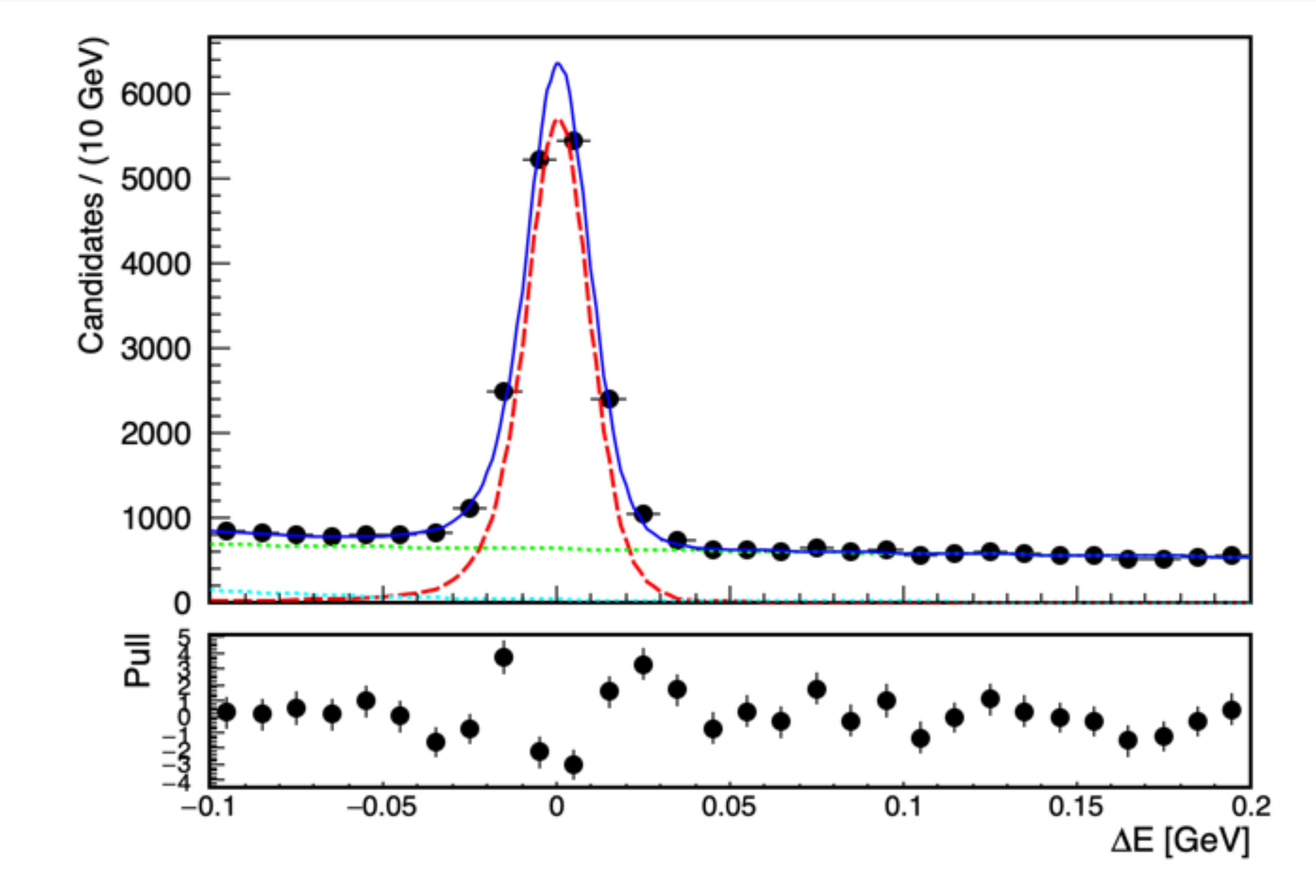
CUTS USED

- Kaon and pion BinaryPiD cut - “ D0_Km_binaryPID_211_321 < 0.6 && D0_pip_binaryPID_211_321 > 0.6 && piF_binaryPID_211_321 > 0.6 ”
- nCDCHits Cut - “ piF_nCDCHits>20 && D0_Km_nCDCHits >20 && D0_pip_nCDCHits >20 ”
- chiProb cut - “ chiProb > 0.001 ”
- D0 mass cut - “1.855 < D0M < 1.875”

2D-MC-$M_{bc}\Delta E$ FIT FOR ETA



2D MC- M_{bc} Fit



2D-MC-ΔE Fit

M_{bc}- Single Gaussian

ΔE - Cruijff

- ✳Signal Yield (Fit) = 14305 ± 124
- ✳ Signal Yield (TM) = 14240

$<< 1\sigma$

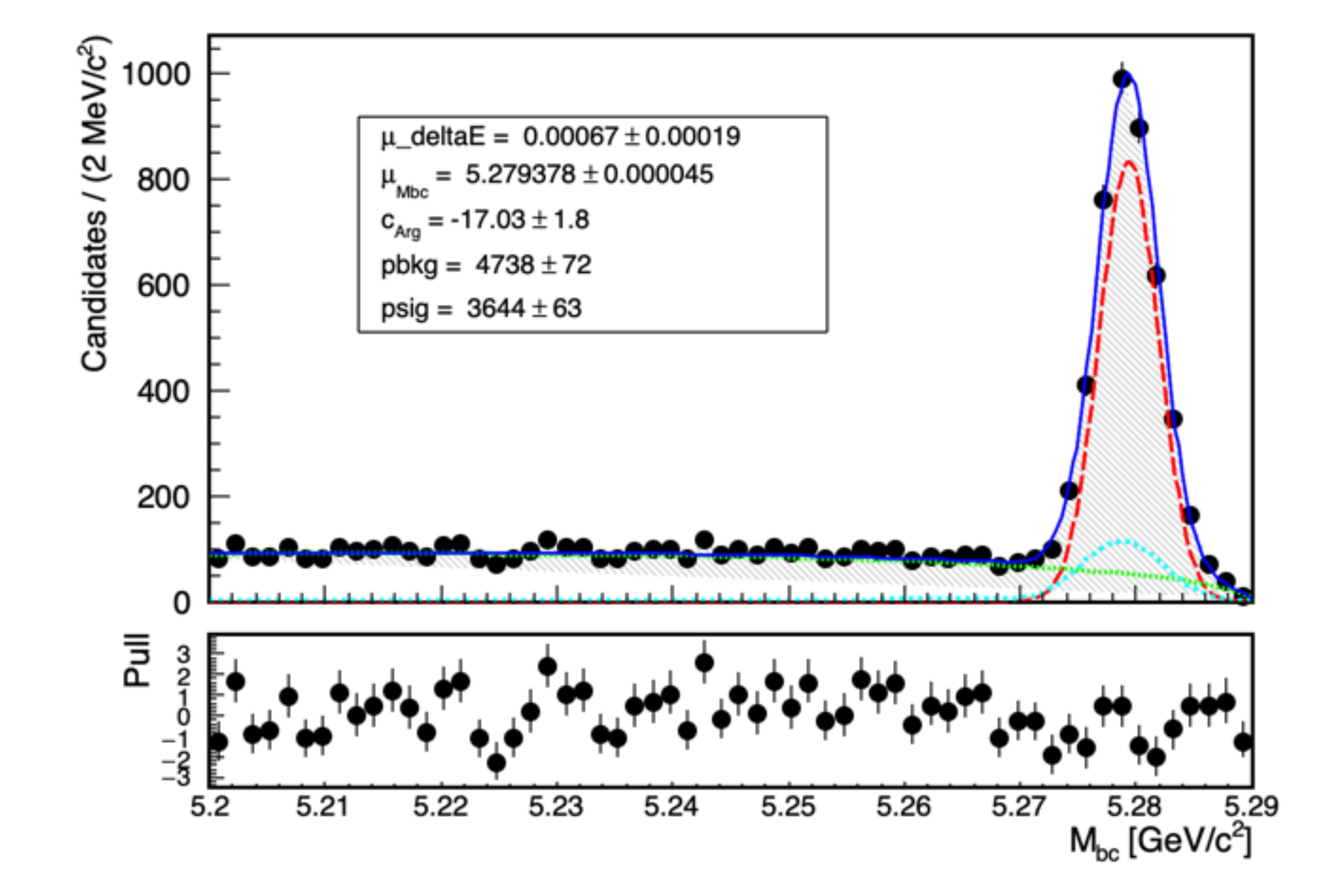
- ✳Background Yield (Fit) - 18096 ± 140
- ✳Background Yield (TM)- 18066
- ✳ Background Yield (charged)- 863

$<< 1\sigma$

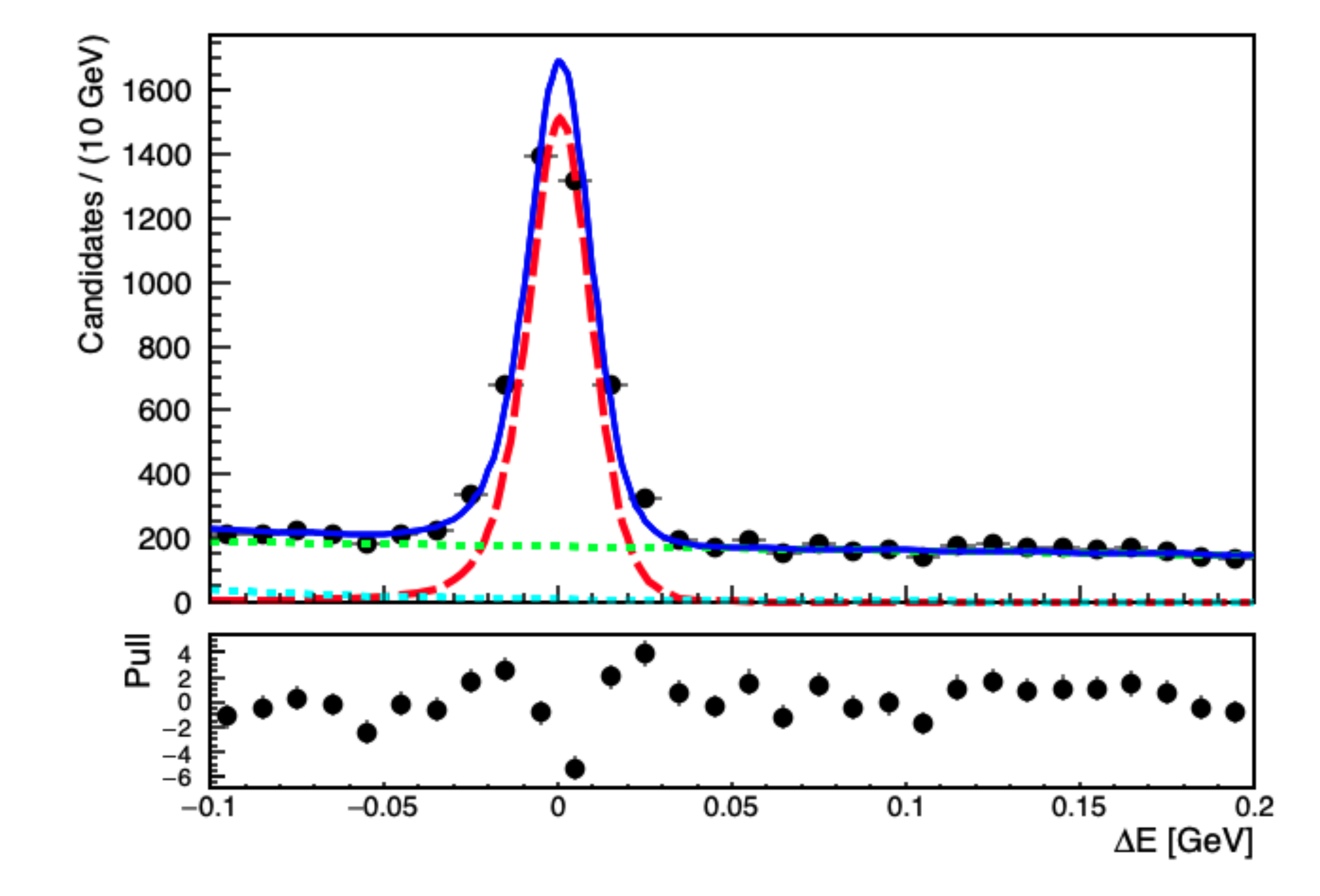
Green - Background
Red- signal
Cyan - $B\bar{B}$ (charged + mixed)
Blue- Both

To see 1D $M_{bc}\Delta E$ MC - Data check "Backup" slides

DATA 2D-$M_{bc}\Delta E$ FIT



2D M_{bc} Fit



New 2D ΔE Fit

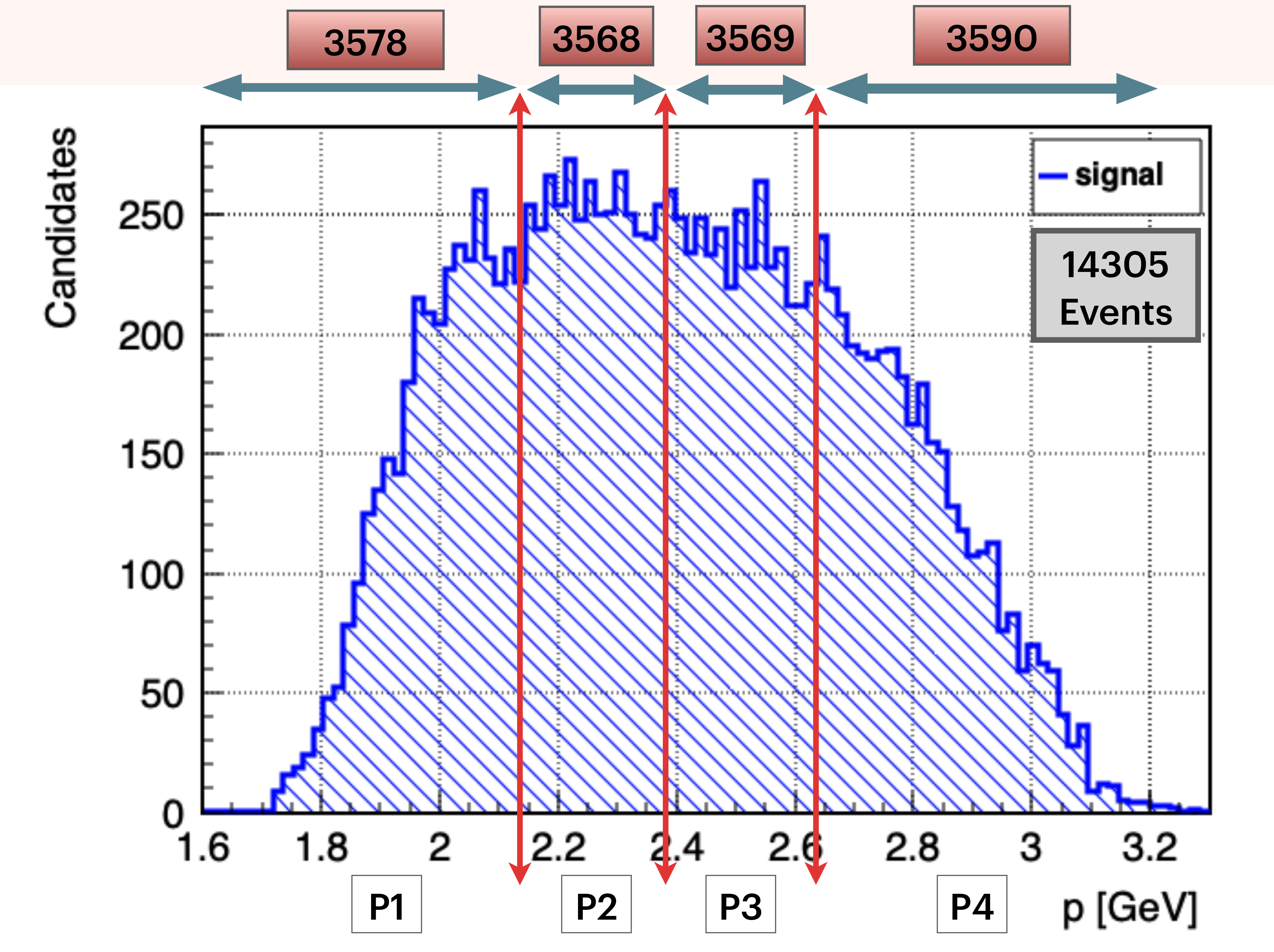
Green - Background
Red- signal
Cyan - $B\bar{B}$ (charged + mixed)
Blue- Both

To see 2D $B\bar{B}$ background fit check “Backup” slides

SYSTEMATICS FOR PION MASS HYPOTHESIS

Mode	ϵ_{Data}	ϵ_{MC}	$R_{Data/MC}$
$B^- \to D^0[K^-\pi^+]\pi^-$	0.9606 ± 0.0031	0.9596 ± 0.0017	1.0010 ± 0.0036

$$\epsilon_{Data} = \frac{Fit^{Data}_{etaProb<0.8}}{Fit^{Data}_{etaProb>0.8} + Fit^{Data}_{etaProb<0.8}} \qquad \epsilon_{MC} = \frac{Fit^{MC}_{etaProb<0.8}}{Fit^{MC}_{etaProb>0.8} + Fit^{MC}_{etaProb<0.8}}$$



Momentum(piF_p) Binning distribution

MOMENTUM BINNING

- Divided the momentum into 4 bins - p1,p2,p3,p4
  - 1.6 < p < 2.142 indicates p1 consists of 3578 signal events
  - 2.142 < p < 2.381 indicates p2 consists of 3568 signal events
  - 2.381 < p < 2.638 indicates p3 consists of 3569 signal events
  - 2.638 < p < 3.3 indicates p3 consists of 3590 signal events

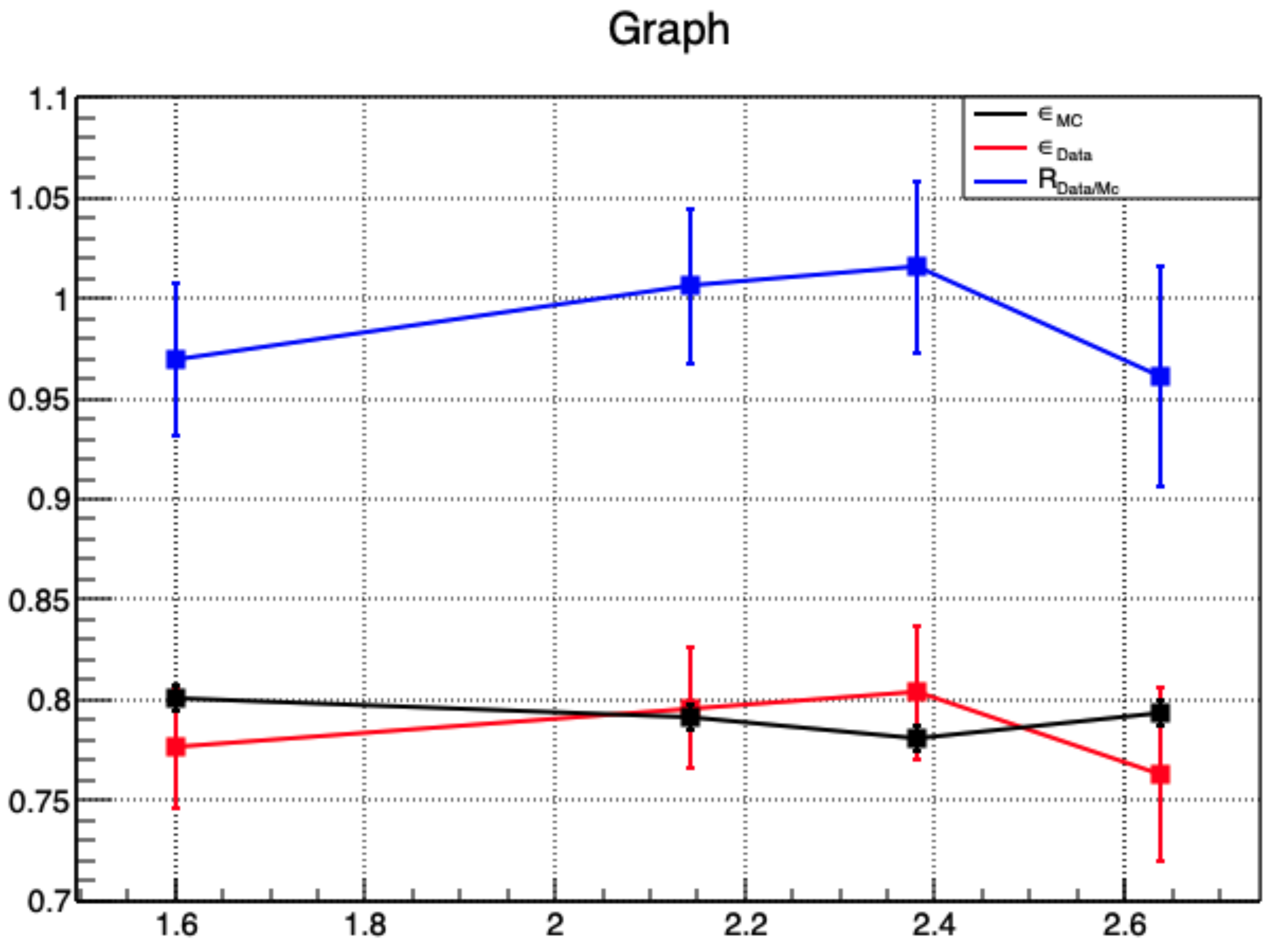
MOMENTUM BINNING SYSTEMATICS

piF_p bin distribution

	ϵ_{MC}	ϵ_{DATA}	$R_{Data/MC}$
P_1 (1.6 < p < 2.142)	0.8010 ± 0.0063	0.7765 ± 0.0301	0.9694 ± 0.0383
P_2 (2.142) < p < 2.381))	0.7917 ± 0.0063	0.7963 ± 0.0295	1.0058 ± 0.0381
P_3 (2.381 < p < 2.638)	0.7813 ± 0.0064	0.8041 ± 0.0332	1.0156 ± 0.0427
P_4 (2.638 < p < 3.3)	0.7941 ± 0.0063	0.7633 ± 0.0431	0.9612 ± 0.0548

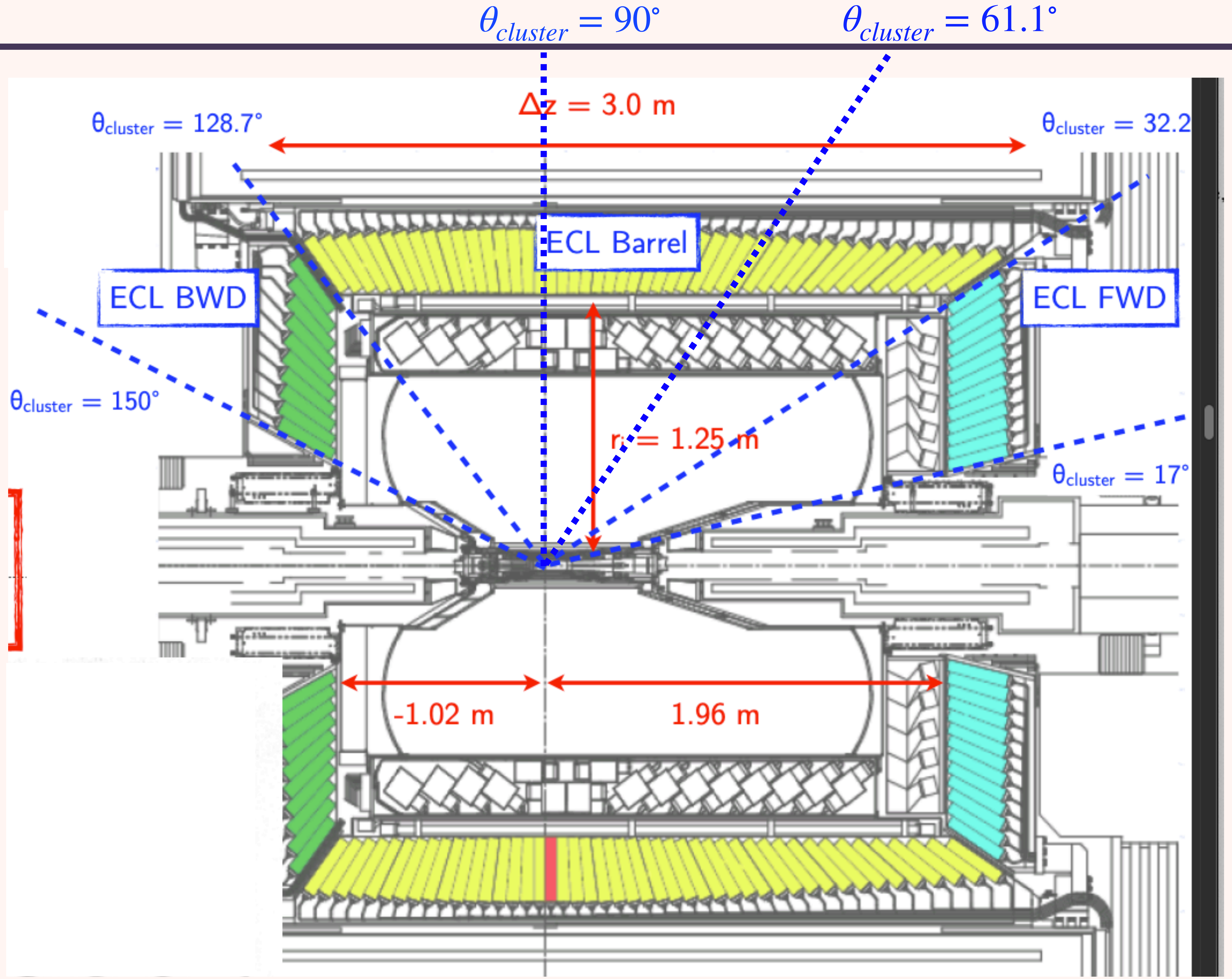
$$\epsilon_{Data} = \frac{Fit^{Data}_{etaProb<0.8}}{Fit^{Data}_{etaProb>0.8} + Fit^{Data}_{etaProb<0.8}}$$

$$\epsilon_{MC} = \frac{Fit^{MC}_{etaProb<0.8}}{Fit^{MC}_{etaProb>0.8} + Fit^{MC}_{etaProb<0.8}}$$

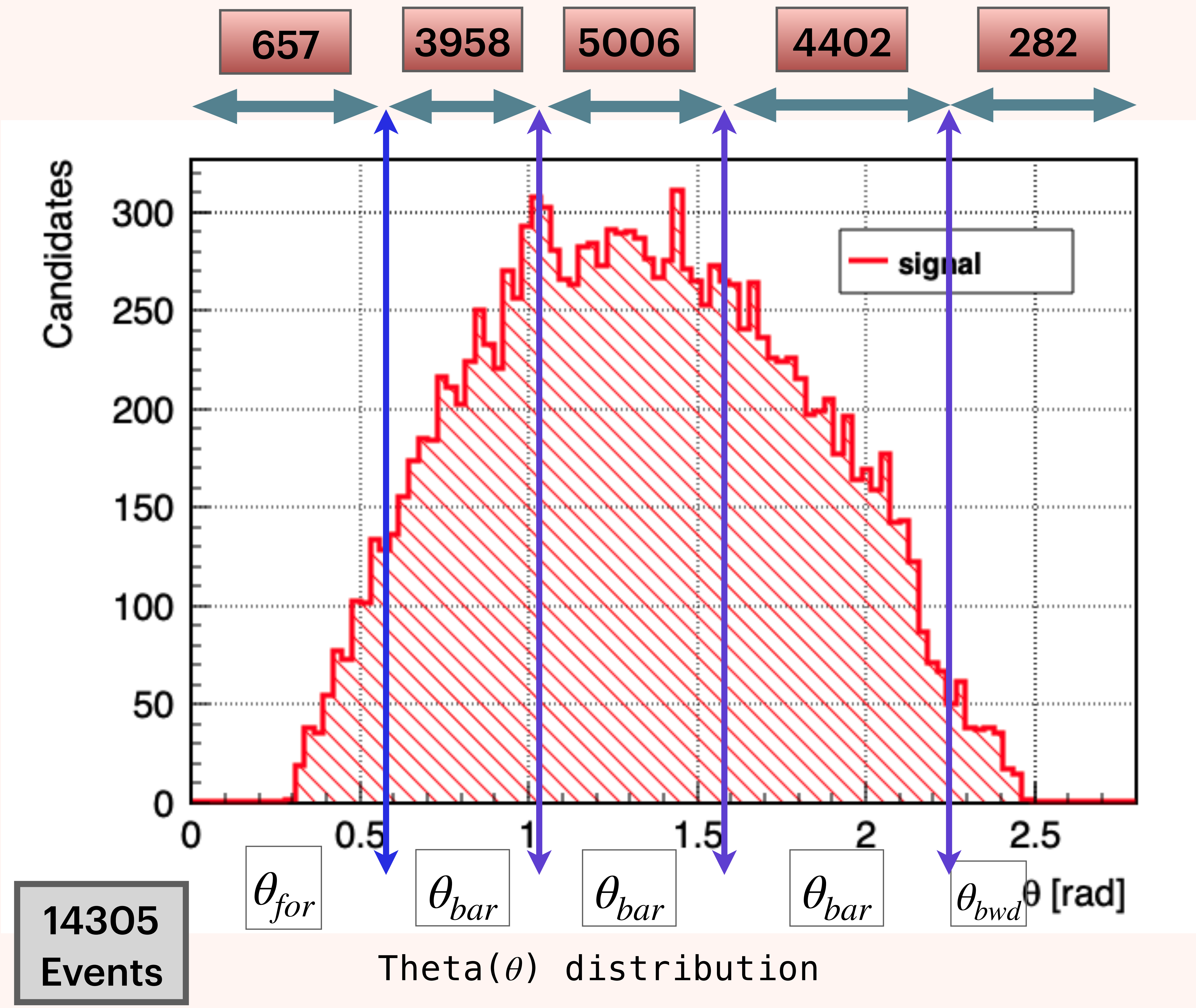


Systematics distribution for the Momentum (piF_p) Binning

THETA BINNING



Ref-https://indico.belle2.org/event/1307/sessions/378/attachments/3070/5670/mmilesi_ECLPid_B2SKW_2020.pdf



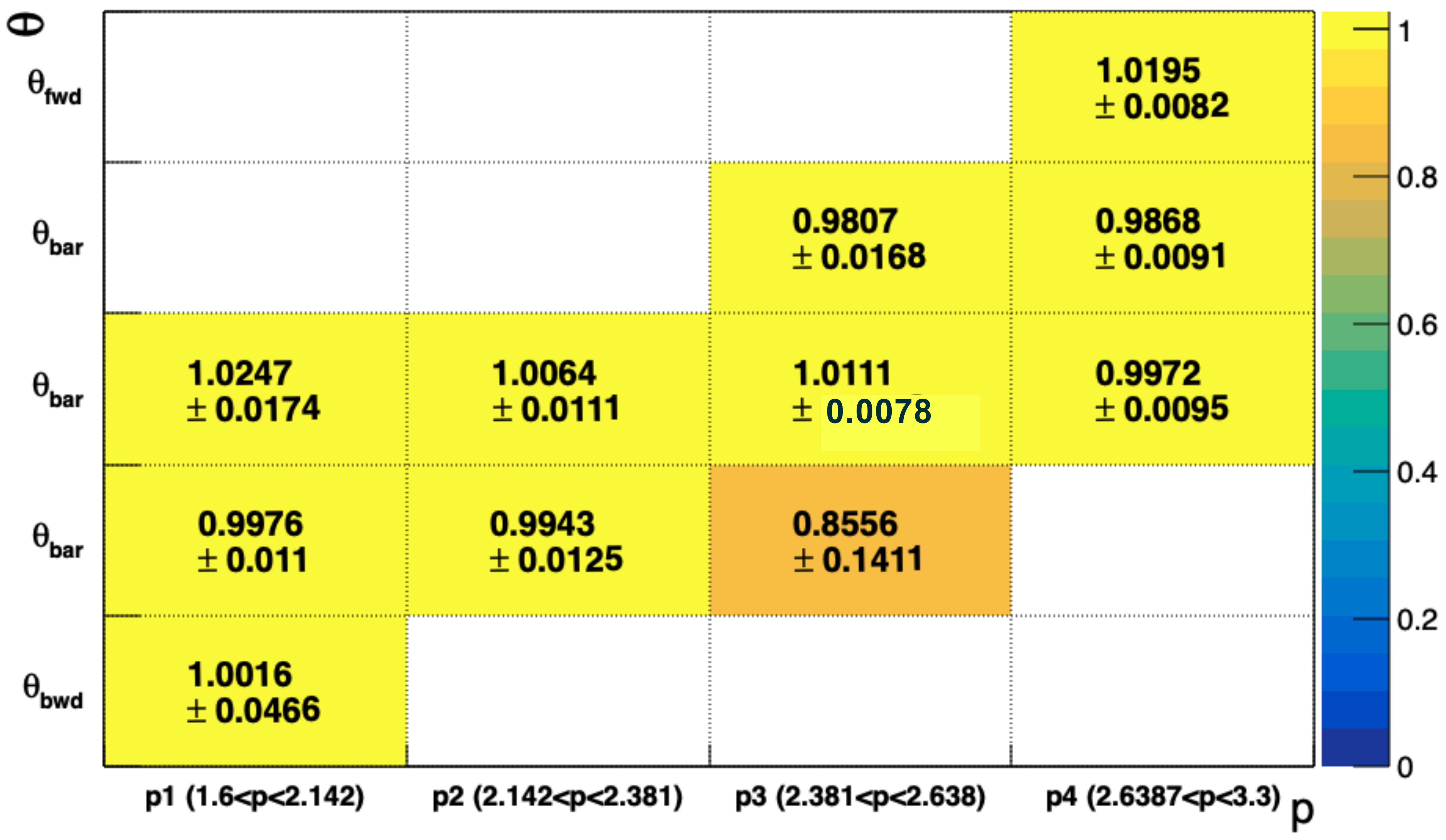
THETA BINNING

- **Divided the Theta into 5 parts -**
  - θ_{for} **- Forward endcap region** $17^\circ < \theta_{for} < 32.2^\circ$ **or** $0.297 < \theta_{for} < 0.562$ **(rad)**
  - θ_{bar} **- Barrel region** $32.2^\circ < \theta_{bar} < 61.1^\circ$ **or** $0.562 < \theta_{bar} < 1.0664$ **(rad)**
  - θ_{bar} **- Barrel region** $61.1^\circ < \theta_{bar} < 90^\circ$ **or** $1.0064 < \theta_{bar} < 1.571$ **(rad)**
  - θ_{bar} **- Barrel region** $90^\circ < \theta_{bar} < 128.7^\circ$ **or** $1.571 < \theta_{bar} < 2.246$ **(rad)**
  - θ_{bwd} **- Backward endcap region** $128.7^\circ < \theta_{bwd} < 150^\circ$ **or** $2.246 < \theta_{bwd} < 2.618$ **(rad)**

MOMENTUM THETA BINNING SYSTEMATICS

	P_1 (1.6 < p < 2.142)	P_2 (2.142) < p < 2.381))	P_3 (2.381 < p < 2.638)	P_4 (2.638 < p < 3.3)
Theta1 (fwd)				1.0195 ± 0.0082
Theta2 (bar)			0.9807 ± 0.0168	0.9868 ± 0.0091
Theta2 (bar)	1.0247 ± 0.0174	1.0064 ± 0.0111	1.011 ± 0.0078	0.9972 ± 0.0095
Theta 4 (bar)	0.9976 ± 0.011	0.9943 ± 0.0125	0.8556 ± 0.1411	
Theta 5 (bwd)	1.0016 ± 0.0466			

$R_{Data/Mc}$ Tabular Distribution



$R_{Data/Mc}$ colz 2D Distribution

To see ϵ_{Mc} and ϵ_{Data} statistics and colz plot check “Backup” slides

ACKNOWLEDGEMENT

Dr. Gagan B. Mohanty- TIFR, Mumbai

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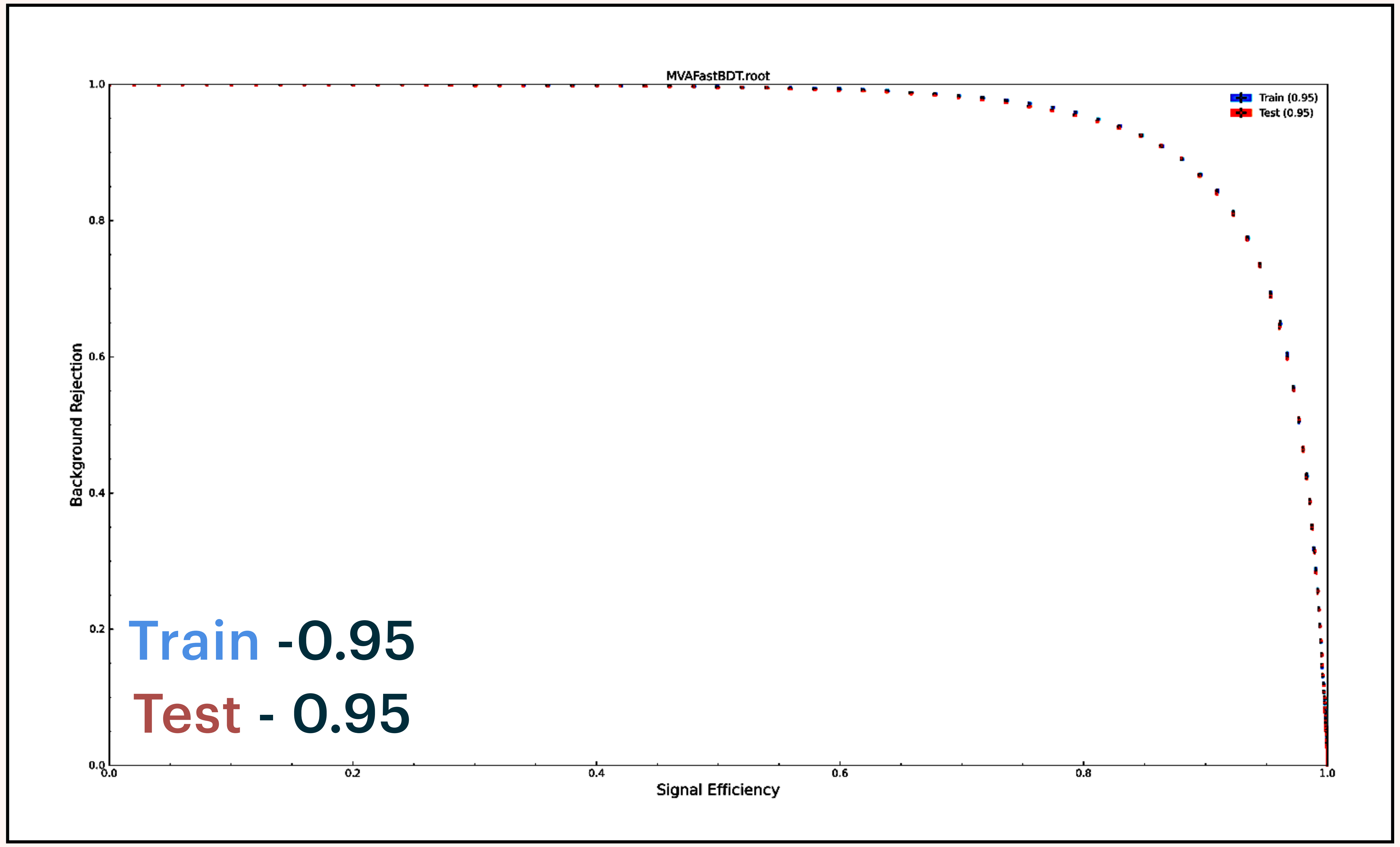
Dr. Md Nasim - IISER Berhampur

Dr. Sandeep Chatterjee - IISER Berhampur

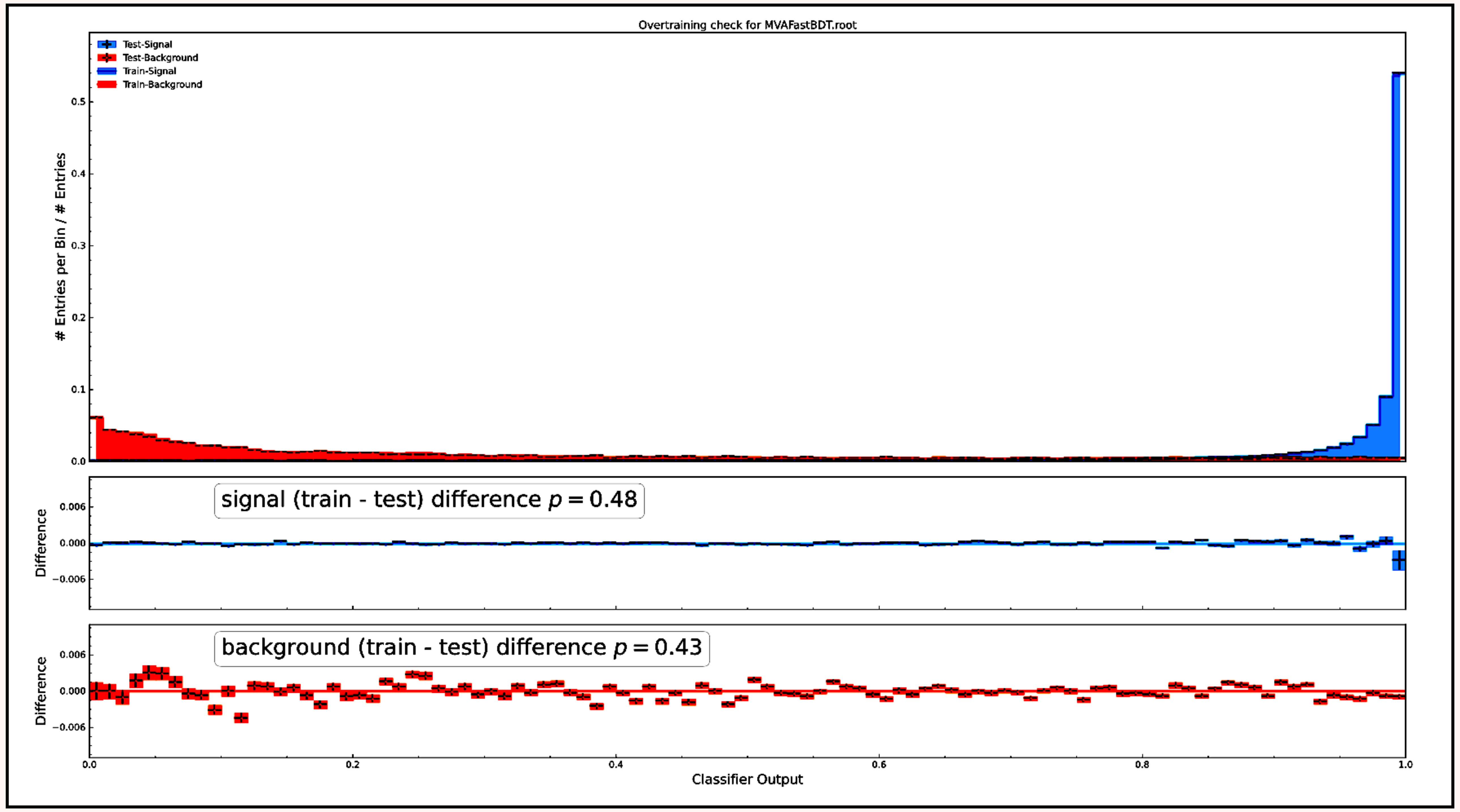
THANK YOU.

BACK UP SLIDES

ROC CURVE AND KS PLOT FOR LOOSE CUT



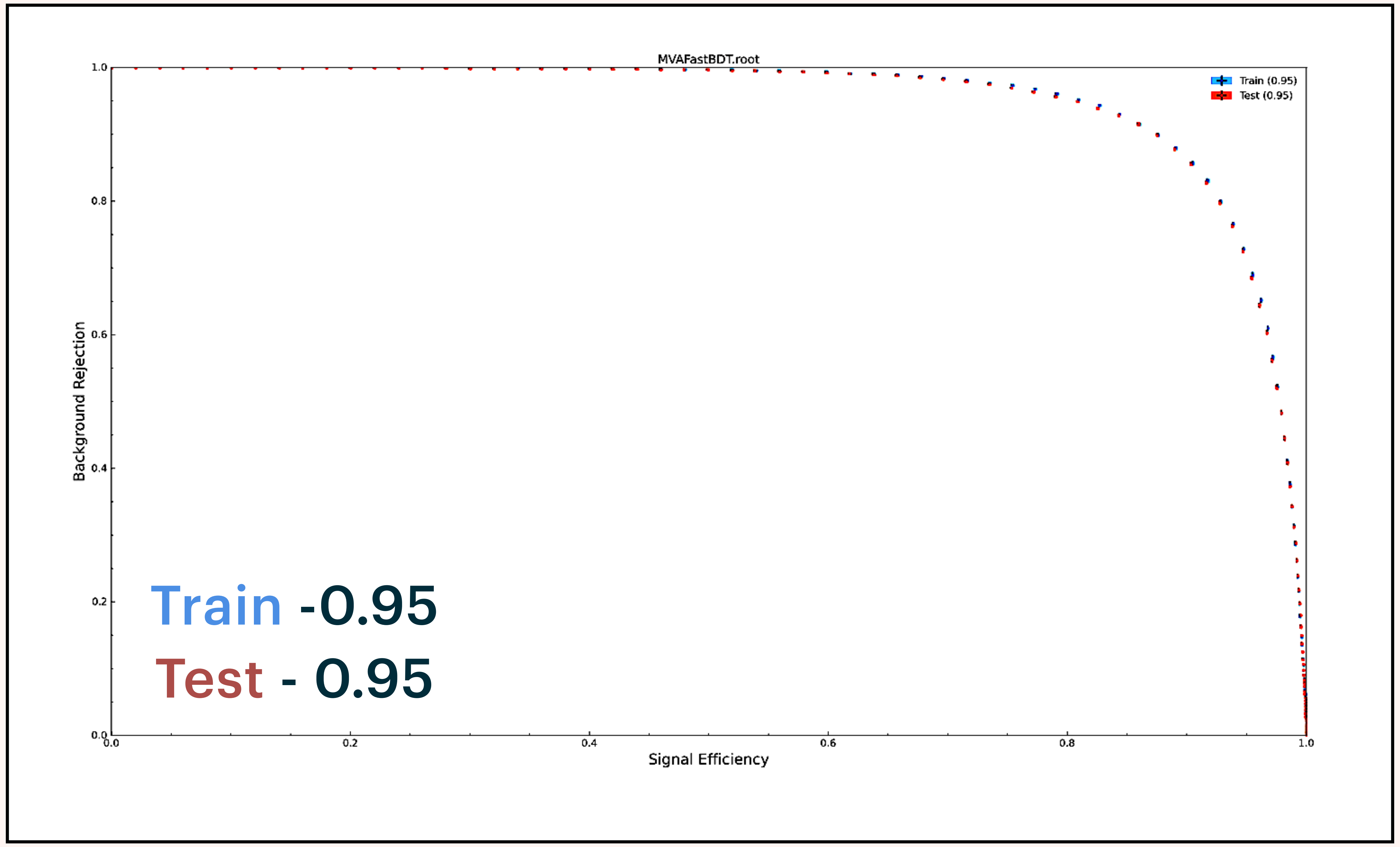
ROC plot of pi0 for Loose Cut



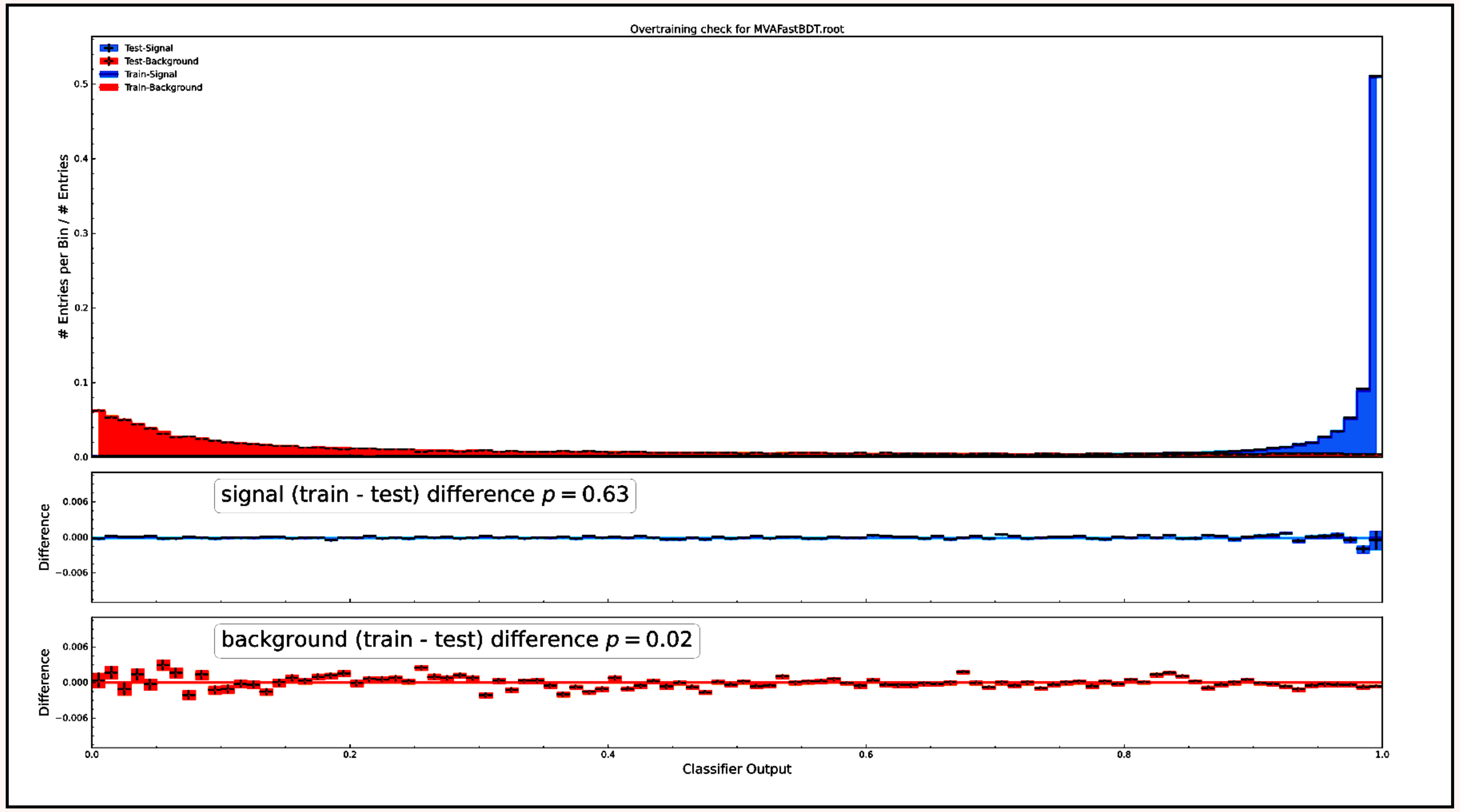
Ks probability plot of pi0 for Loose Cut

*KS test probability greater than 0.05 for signal and background. • We conclude that the MVA is not overtrained.

ROC CURVE AND KS PLOT FOR STANDARD CUT

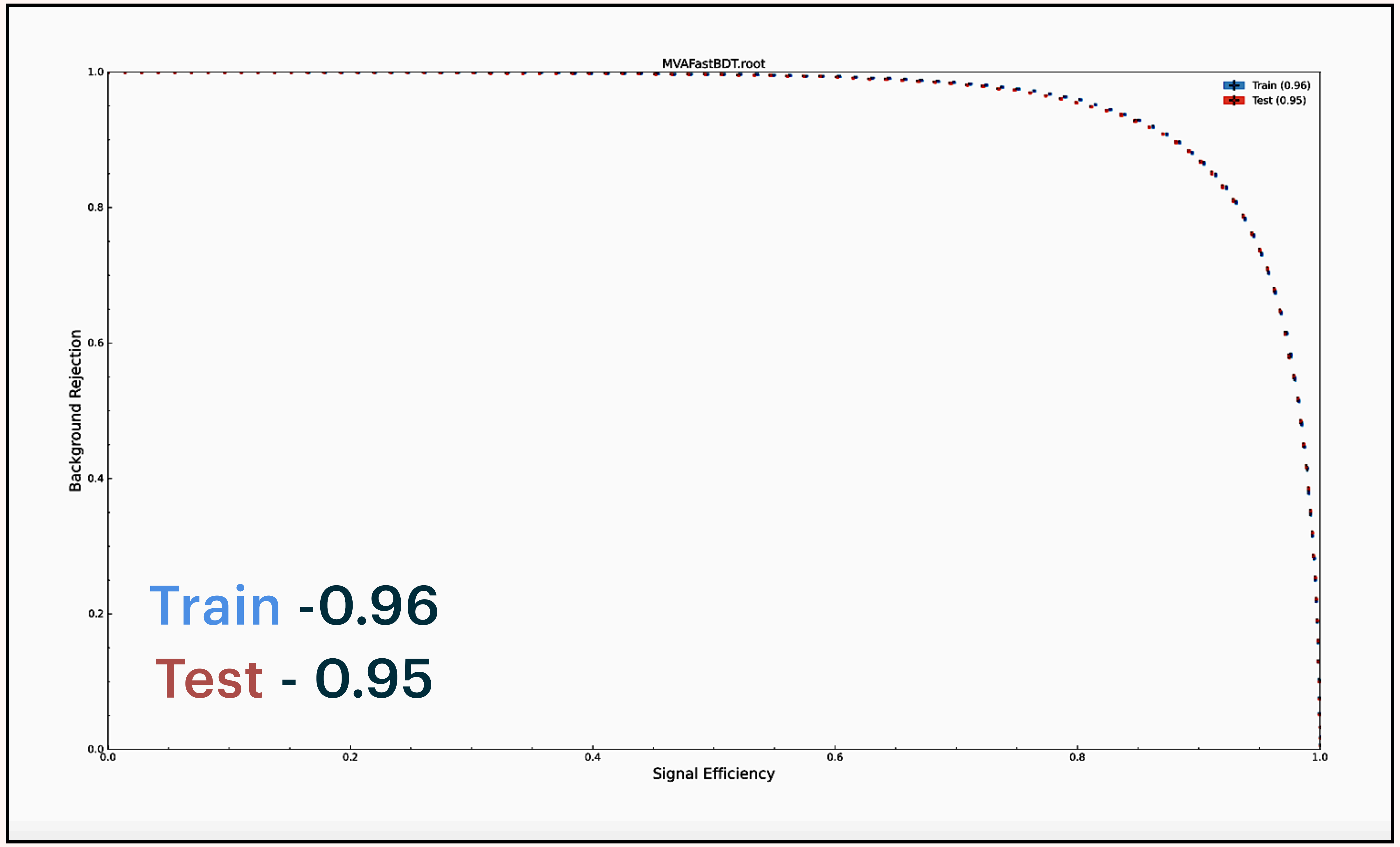


ROC plot of pi0 for Standard Cut

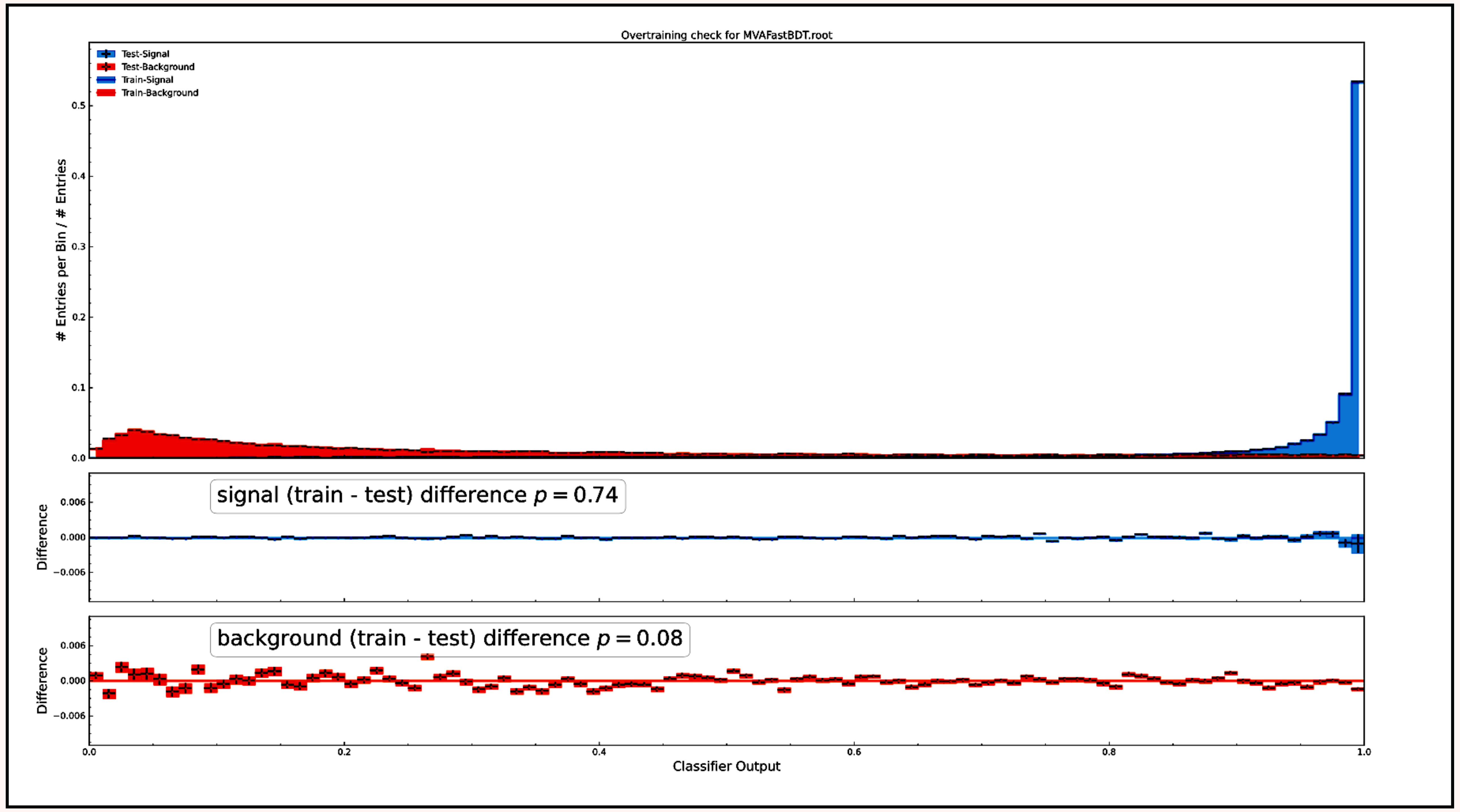


Ks probability plot of pi0 for Standard Cut

ROC CURVE AND KS PLOT FOR TIGHT CUT

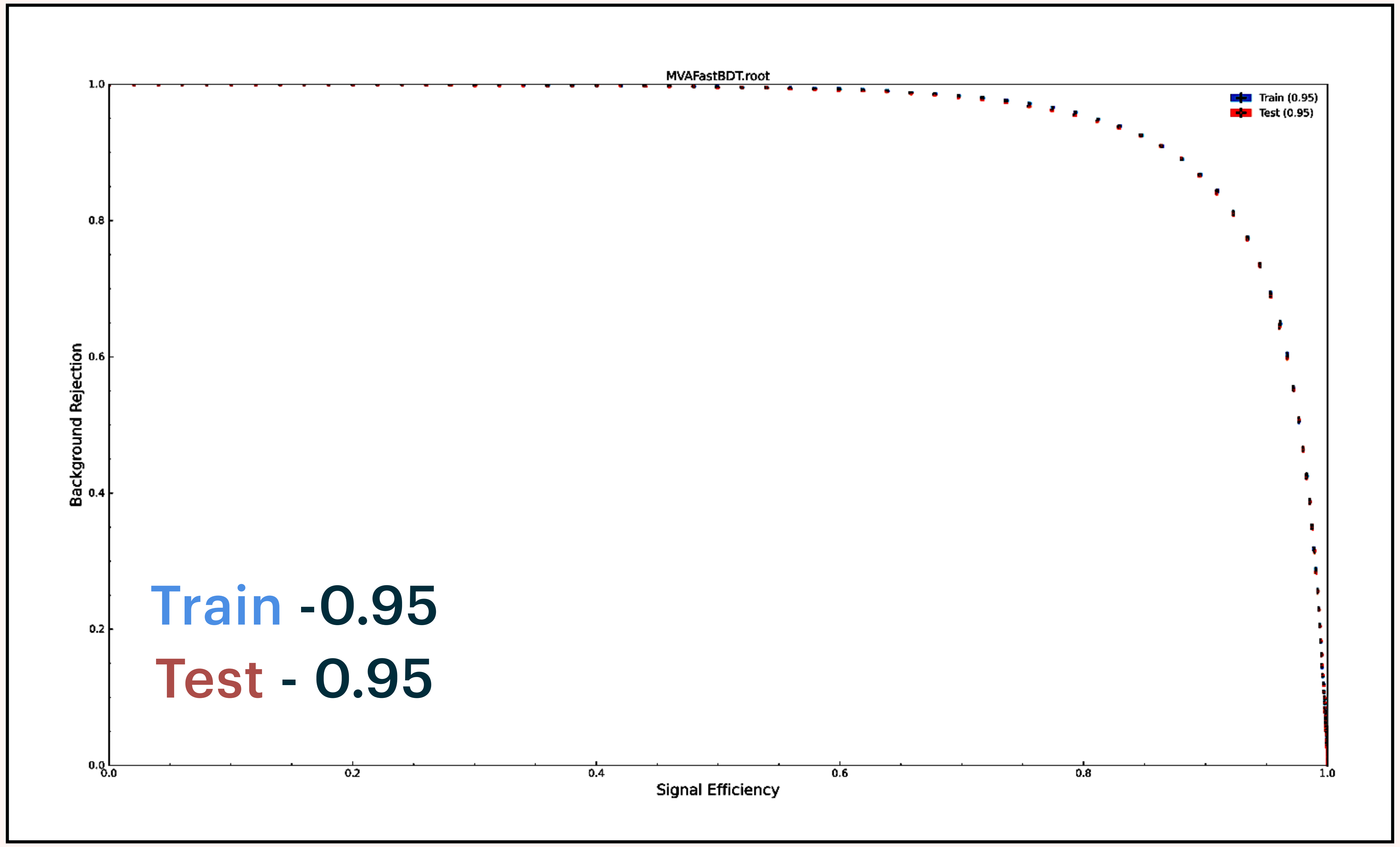


ROC plot of pi0 for Tight Cut

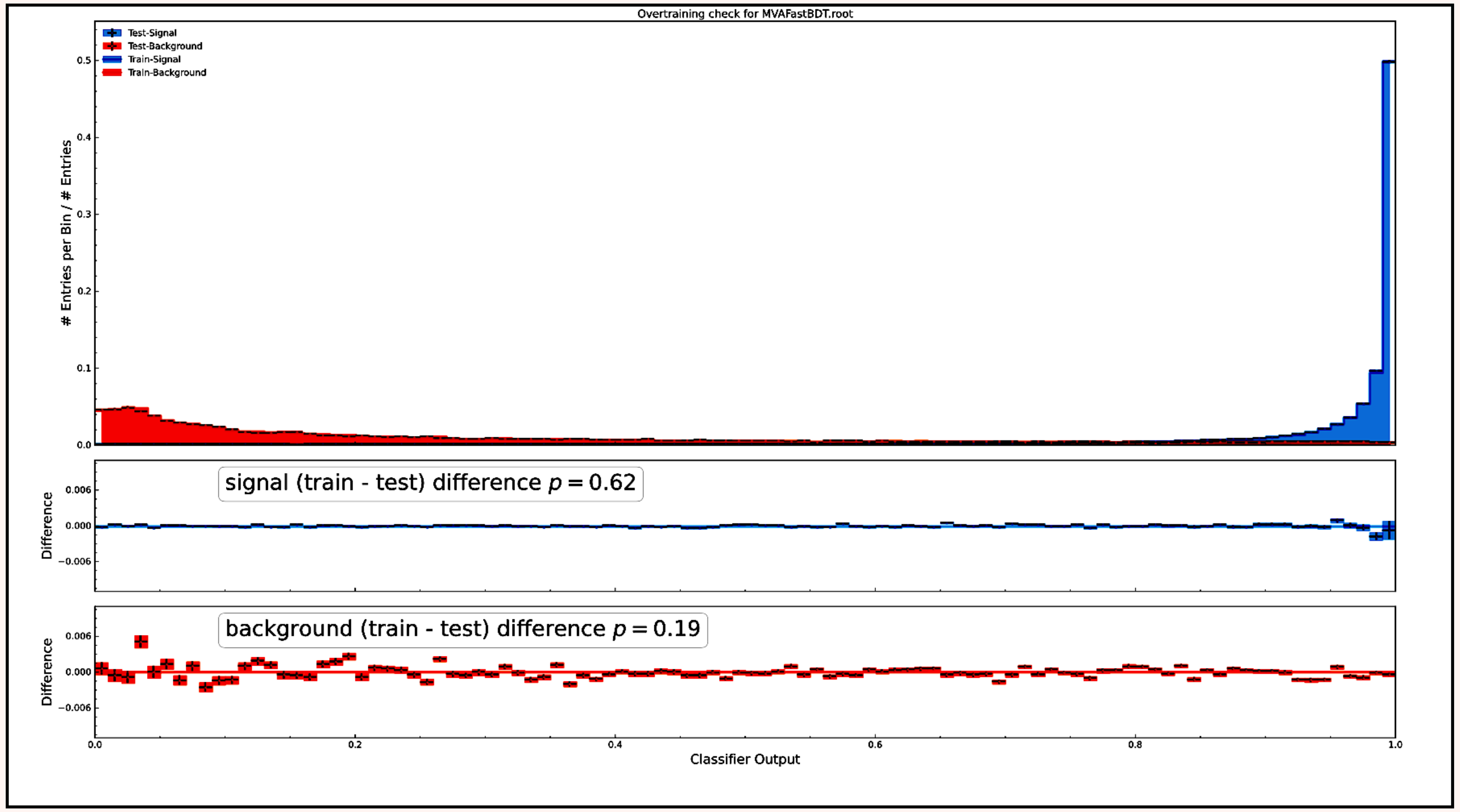


Ks probability plot of pi0 for Tight Cut

ROC CURVE AND KS PLOT FOR CLUSTER CUT

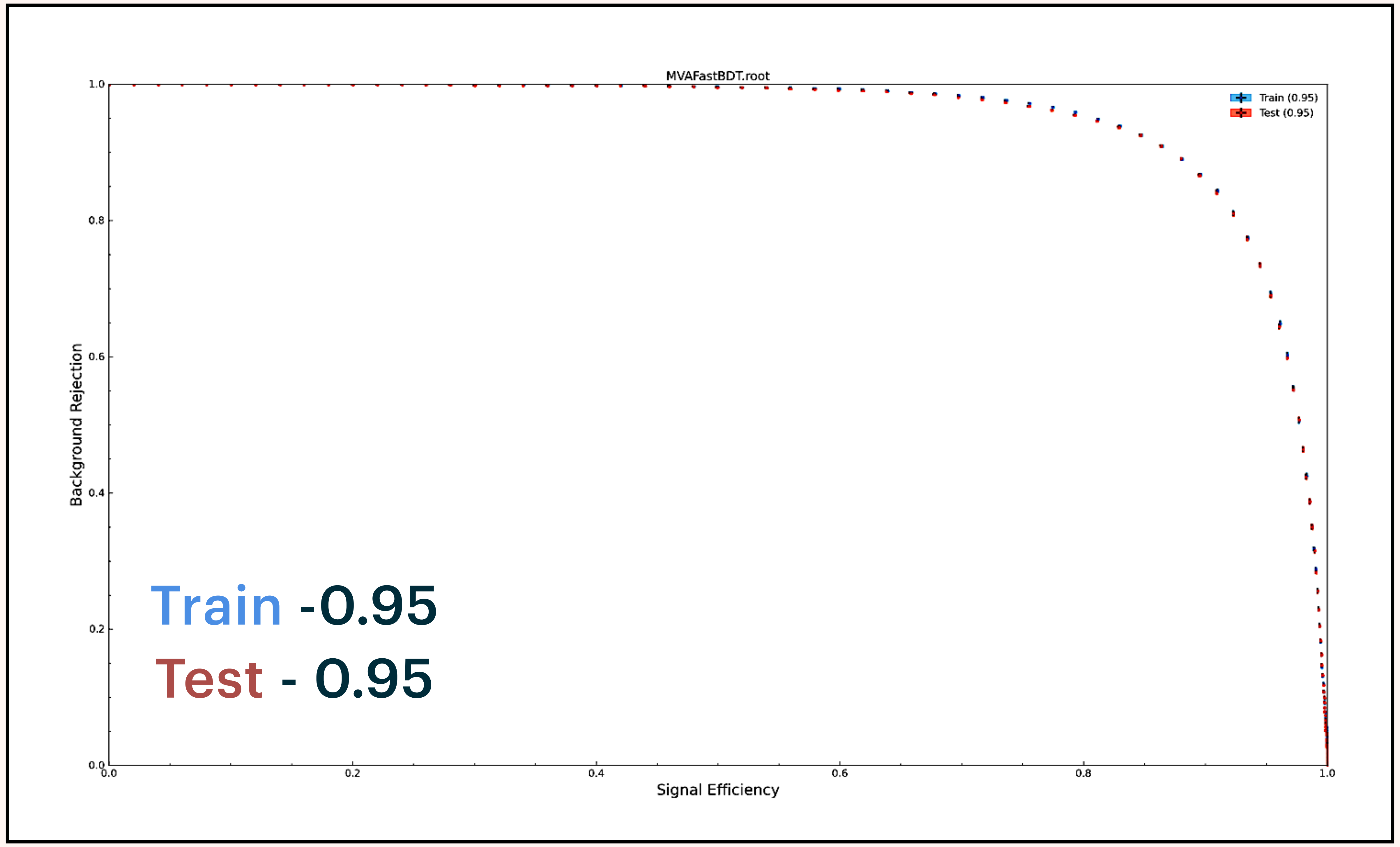


ROC plot of pi0 for Cluster Cut

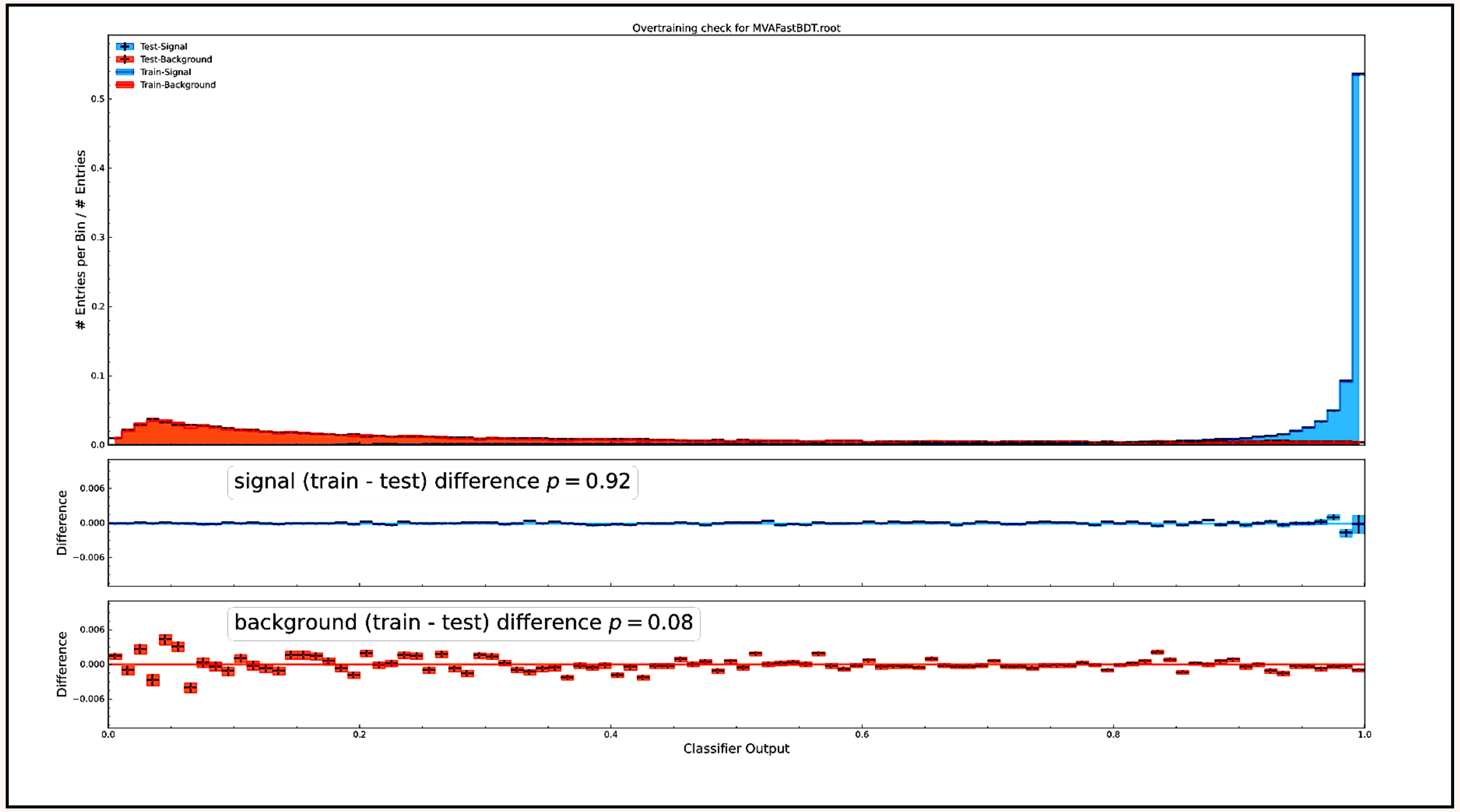


Ks probability plot of pi0 for Cluster Cut

ROC CURVE AND KS PLOT FOR BOTH CUT



ROC plot of pi0 for Both Cut



Ks probability plot of pi0 for Both Cut

CUT FLOW TABLE FOR ROC AND KS

	Train	Test
Loose	0.95	0.95
Standard	0.95	0.95
Tight	0.96	0.95
Cluster	0.95	0.95
Both	0.95	0.95

ROC TABLE

	P_sig	P_bkg
Loose	0.48	0.43
Standard	0.63	0.02
Tight	0.74	0.08
Cluster	0.62	0.19
Both	0.92	0.08

KS PROBABILITY TABLE

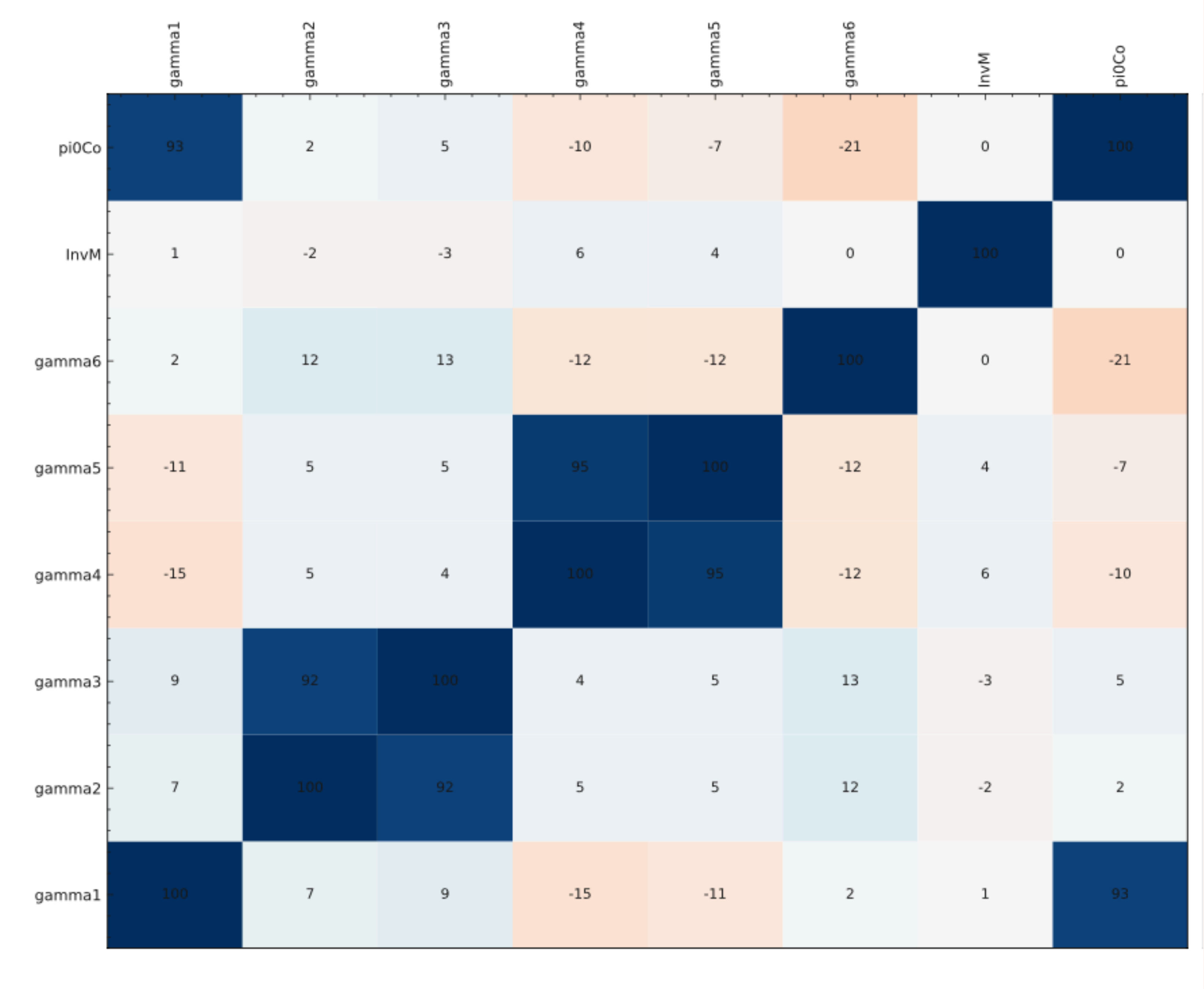
KS FOR DIFFERENT VARIABLES

KS Probability plot	P_Signal	P_Bkg
pi0CosHel	0.0369	0.62
InvM	0.008	0.529
gamma_soft_E	0.8185	0.5438
gamma_soft_minC2TDist	0.588	0.603
gamma_soft_ZernikeMVA	0.639	0.433
gamma_soft_clusterTheta	0.618	0.534

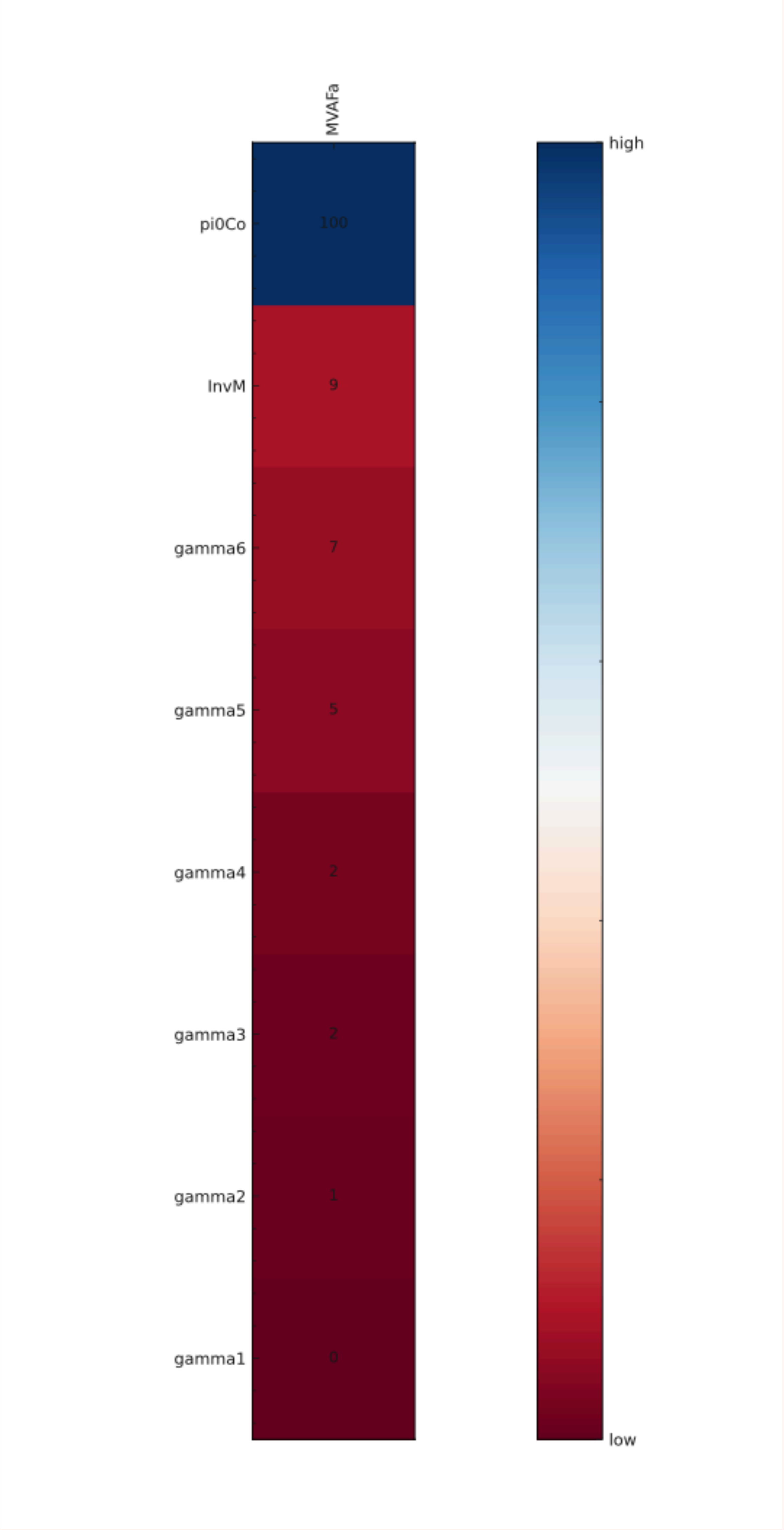
Table for KS Probability plot for different variable

VARIABLE IMPORTANCE

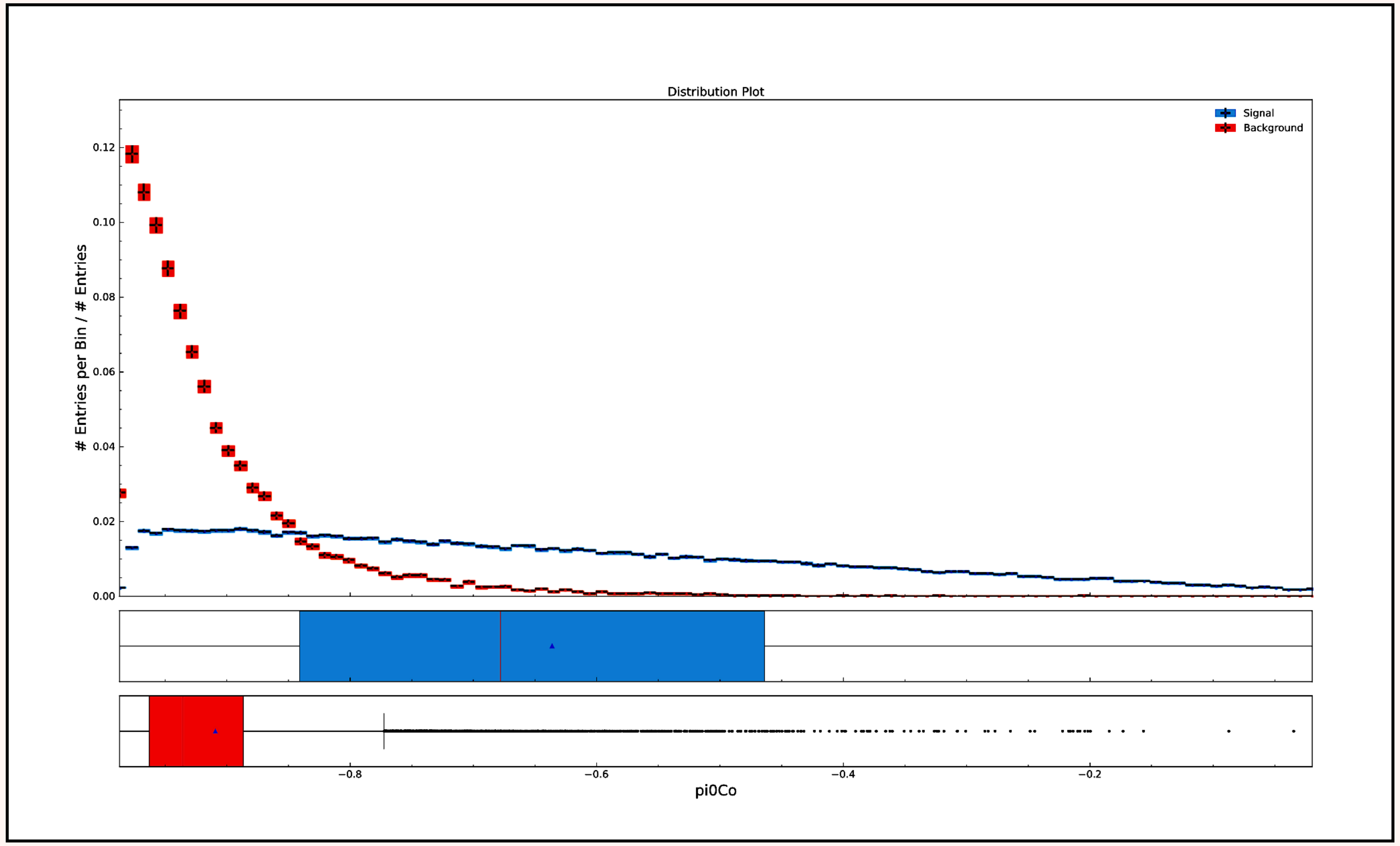
- **pi0CosHel > InvM > gamma_hard_E > gamma_hard_clusterTheta > gamma_soft_clusterTheta > gamma_hard_minC2TDist > gamma_soft_minC2TDist > gamma_soft_E**



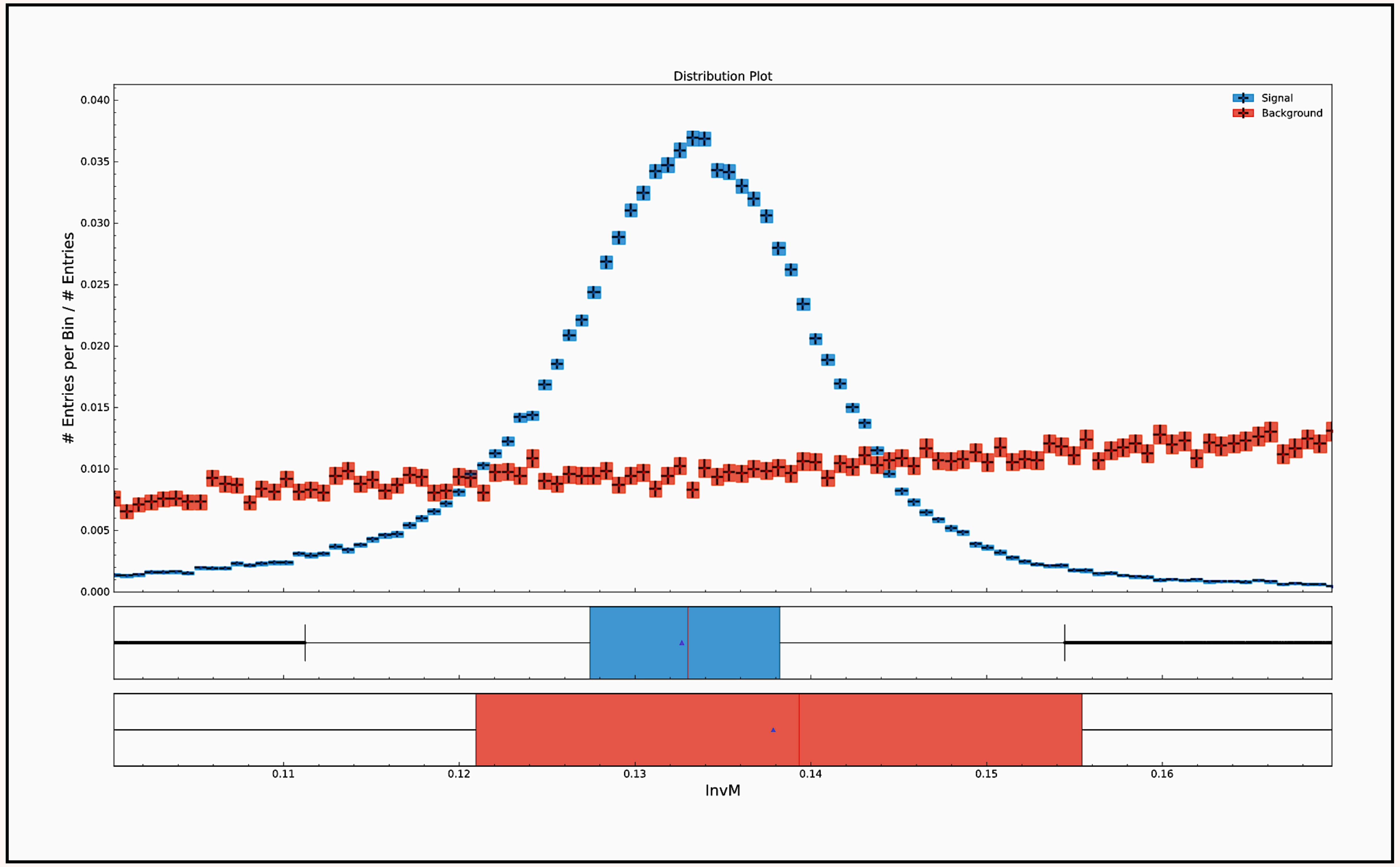
Variable	Abbreviation
gamma_soft_E	gamma1
gamma_soft_minC2TDist	gamma2
gamma_hard_minC2TDist	gamma3
gamma_soft_clusterTheta	gamma4
gamma_hard_clusterTheta	gamma5
gamma_hard_E	gamma6
InvM	InvM
pi0CosHel	pi0Co



PI0_COSHEL AND INVM SIG BKG



Pi0_cosHel



InvM

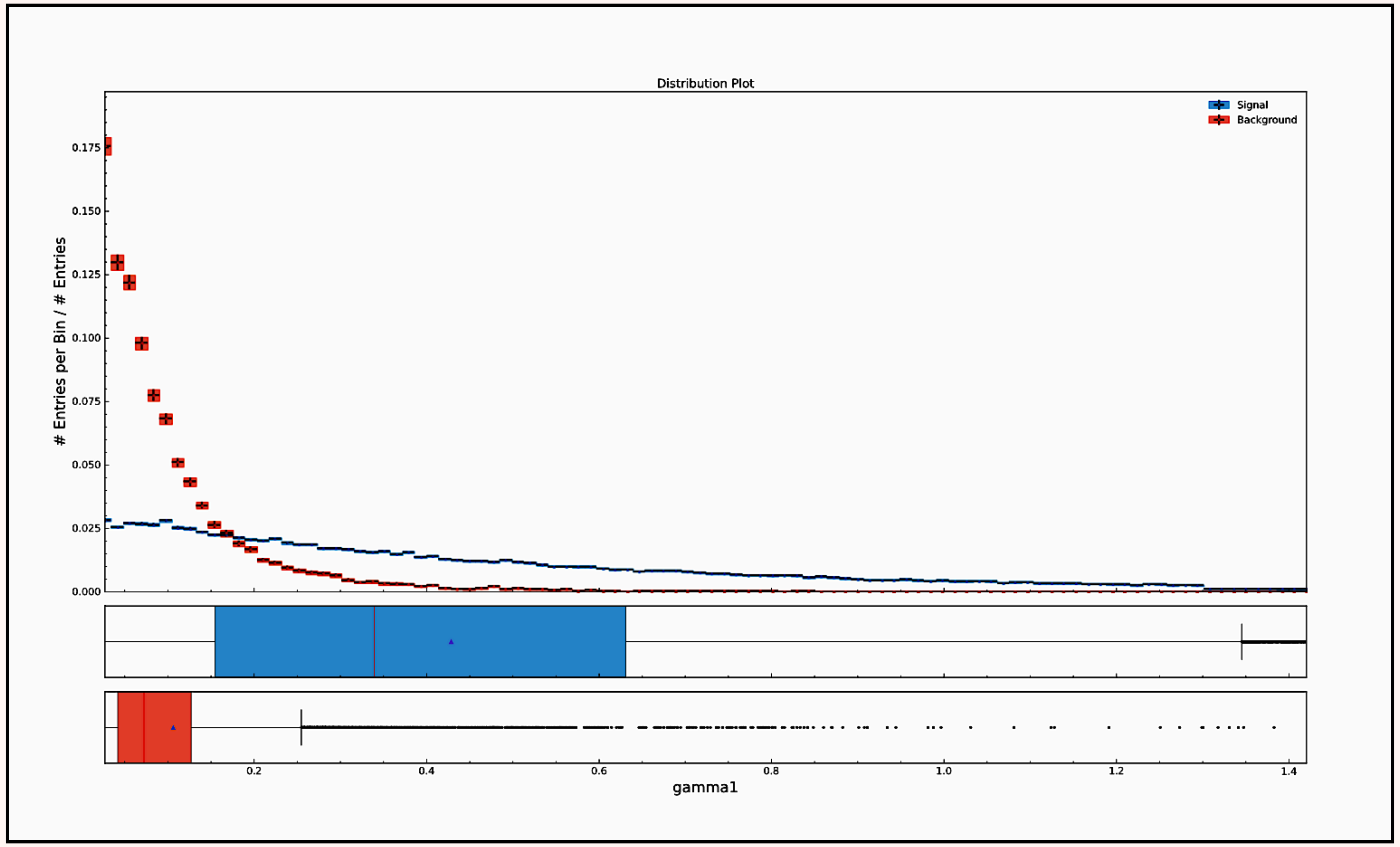
Background Signal

Sig= correctly reconstructed $B \rightarrow X\gamma$

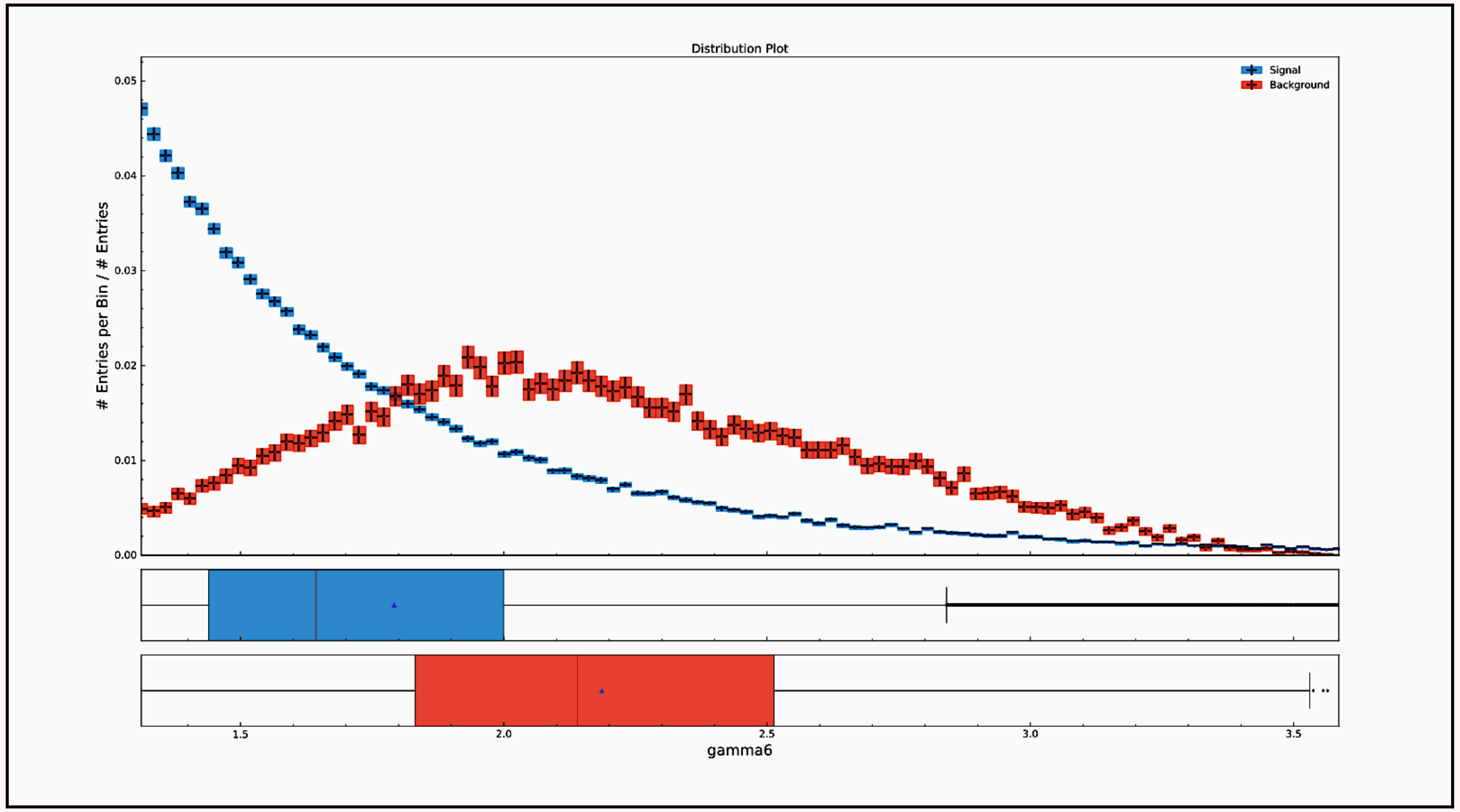
Bkg = correctly reconstructed $\pi^0 \rightarrow \gamma\gamma$

The distributions are normed for signal and background separately, and only the region +- 3 sigma around the mean is shown.

GAMMA_SOFT_E AND GAMMA_HARD_E



gamma_soft_E



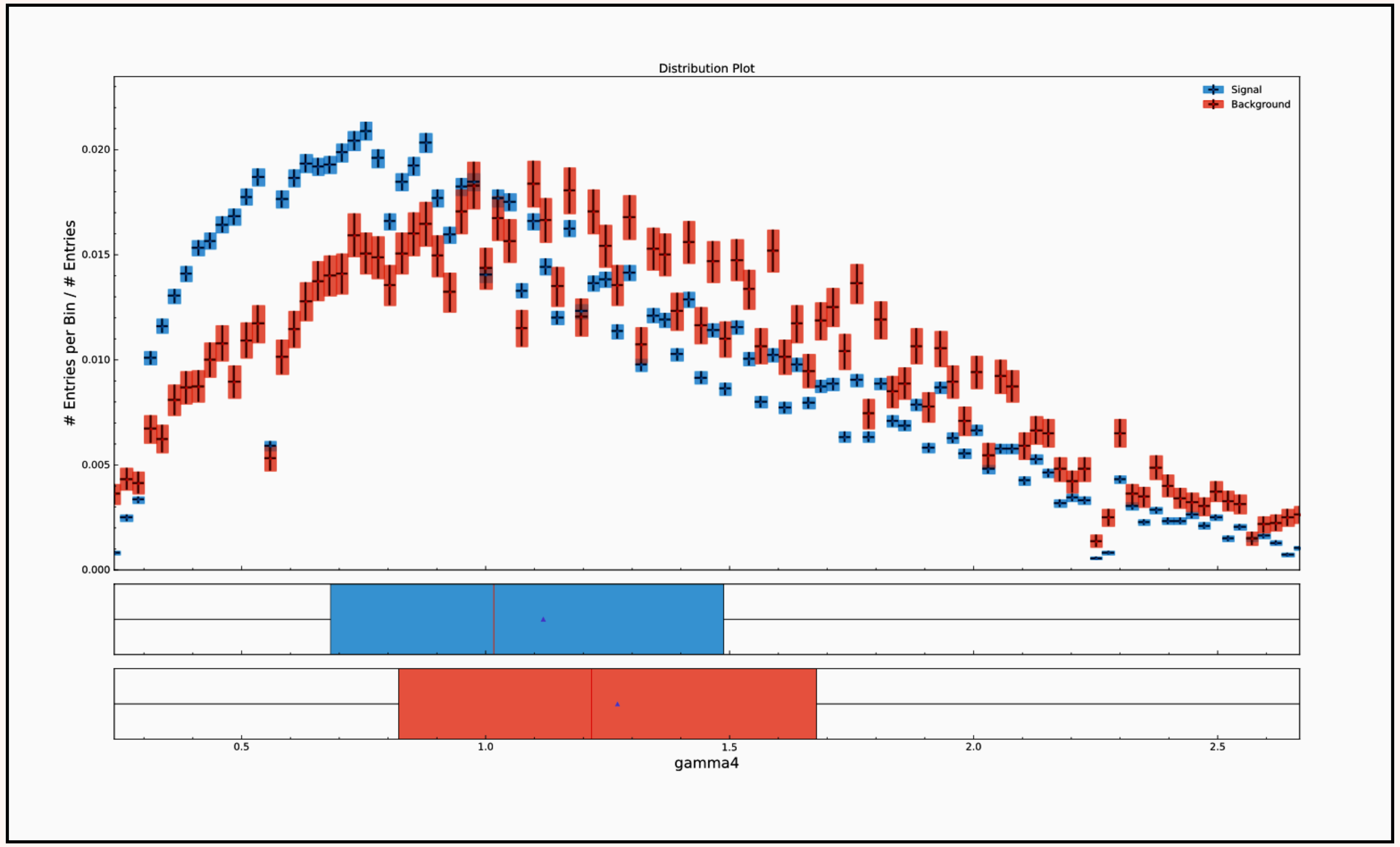
gamma_Hard_E

Sig= correctly reconstructed $B \to X\gamma$

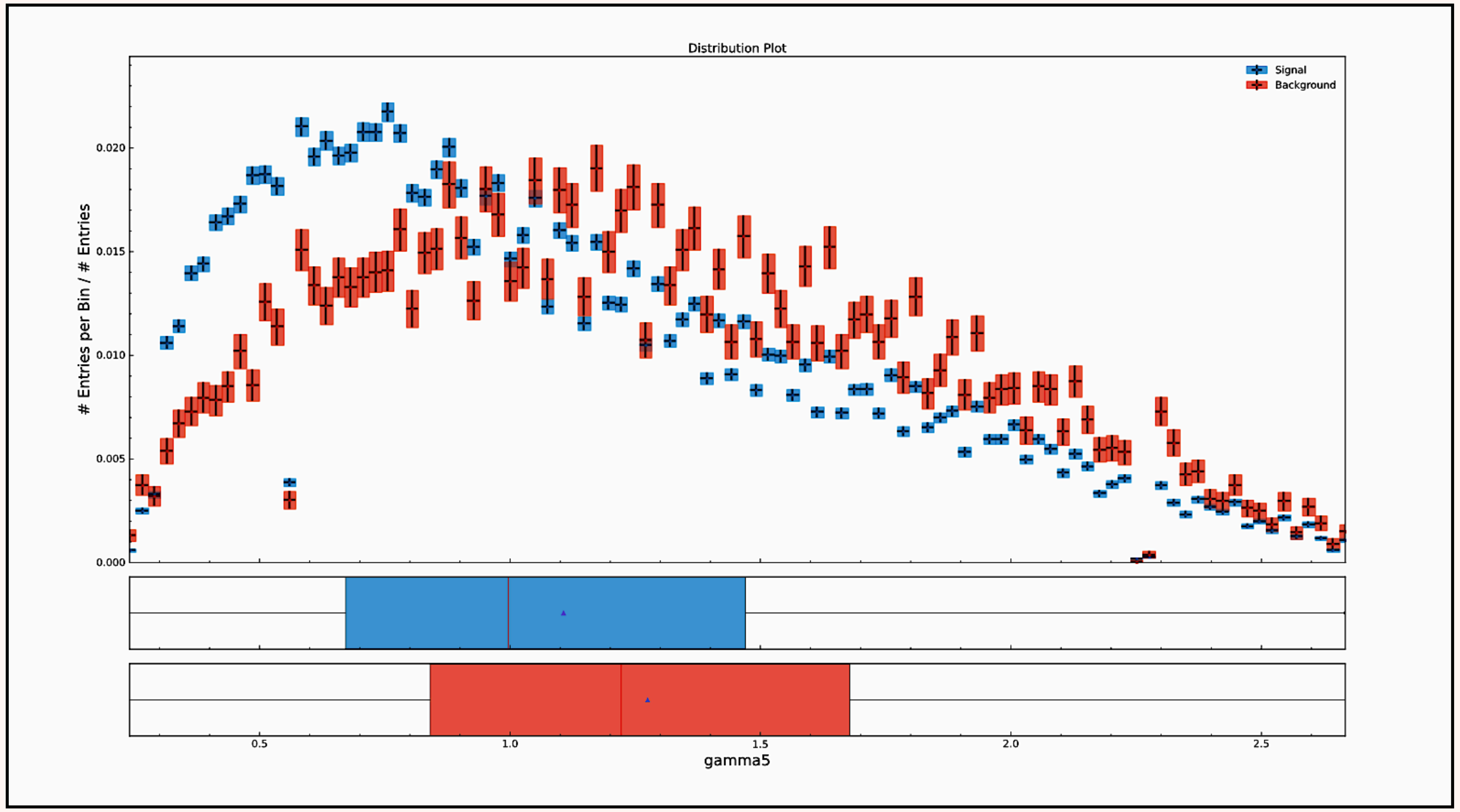
Bkg = correctly reconstructed $\pi^0 \to \gamma\gamma$

Background Signal

GAMMA_SOFT_CLUSTERTHETA AND GAMMA_HARD_CLUSTERTHETA



gamma_soft_clusterTheta



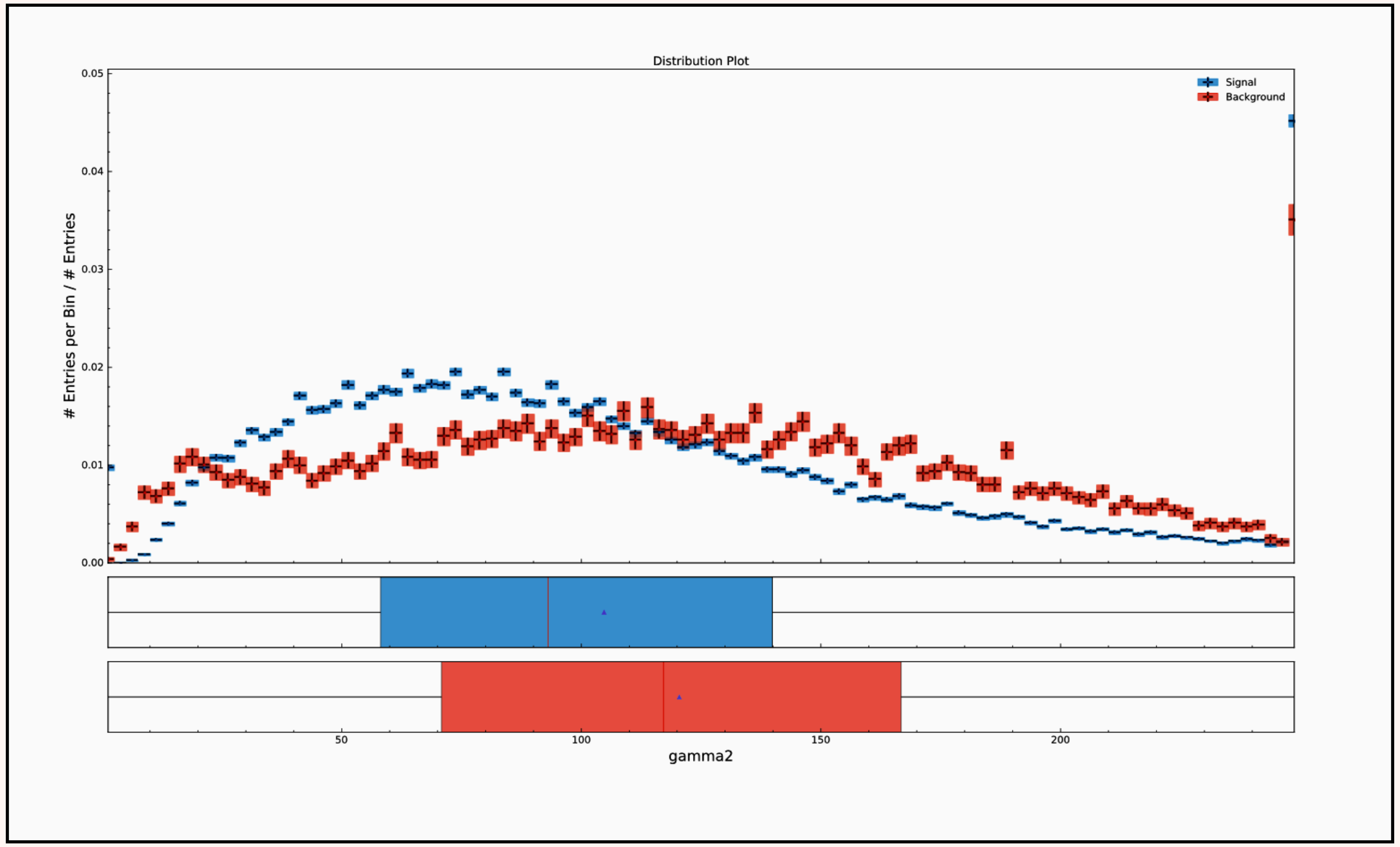
gamma_Hard_clusterTheta

Sig= correctly reconstructed $B \to X\gamma$

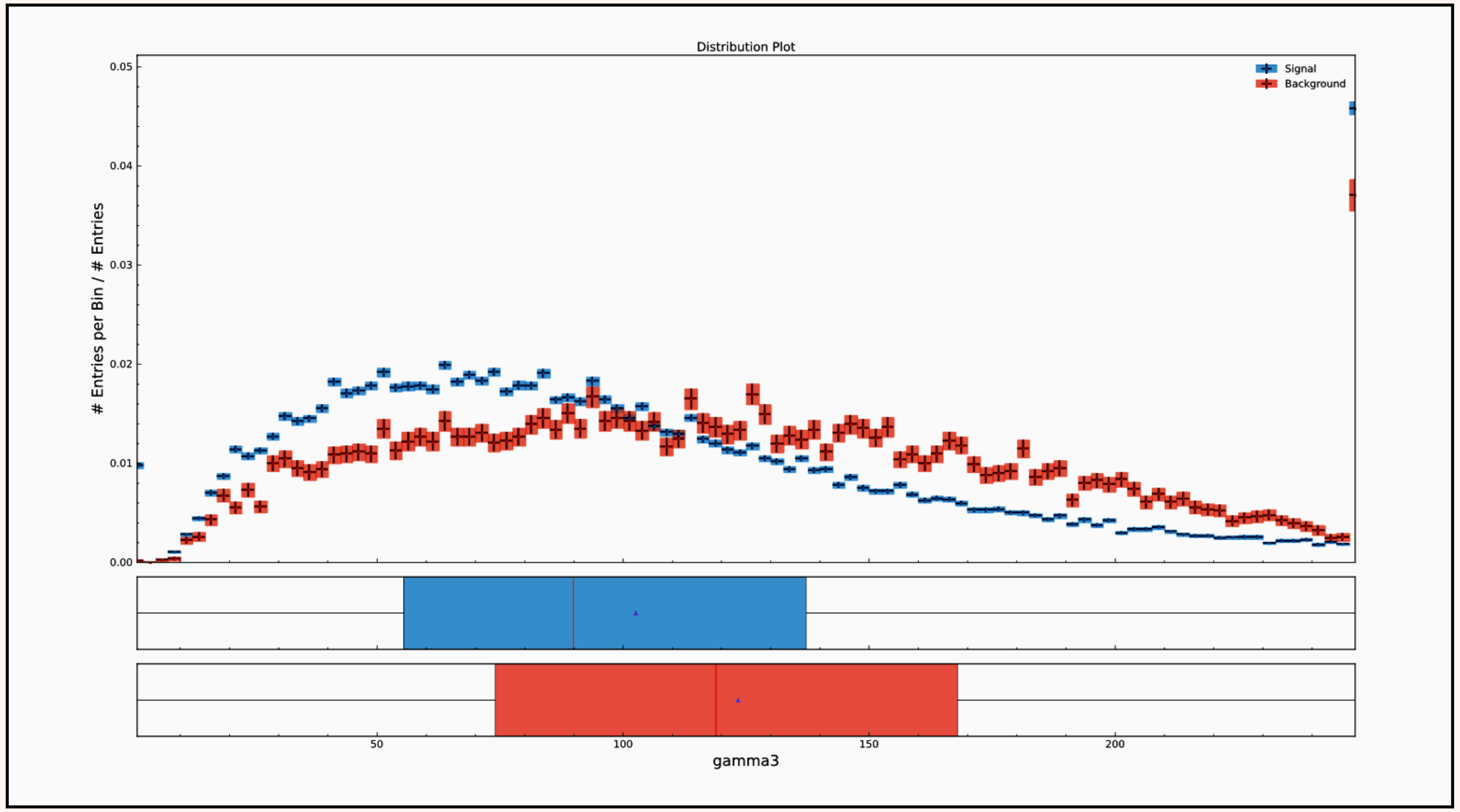
Bkg = correctly reconstructed $\pi^0 \to \gamma\gamma$

Background Signal

GAMMA_SOFT_MINC2TDIST AND GAMMA_HARD_MINC2TDIST



gamma_soft_minC2Tdist



gamma_Hard_minC2Tdist

Sig= correctly reconstructed $B \to X\gamma$

Bkg = correctly reconstructed $\pi^0 \to \gamma\gamma$

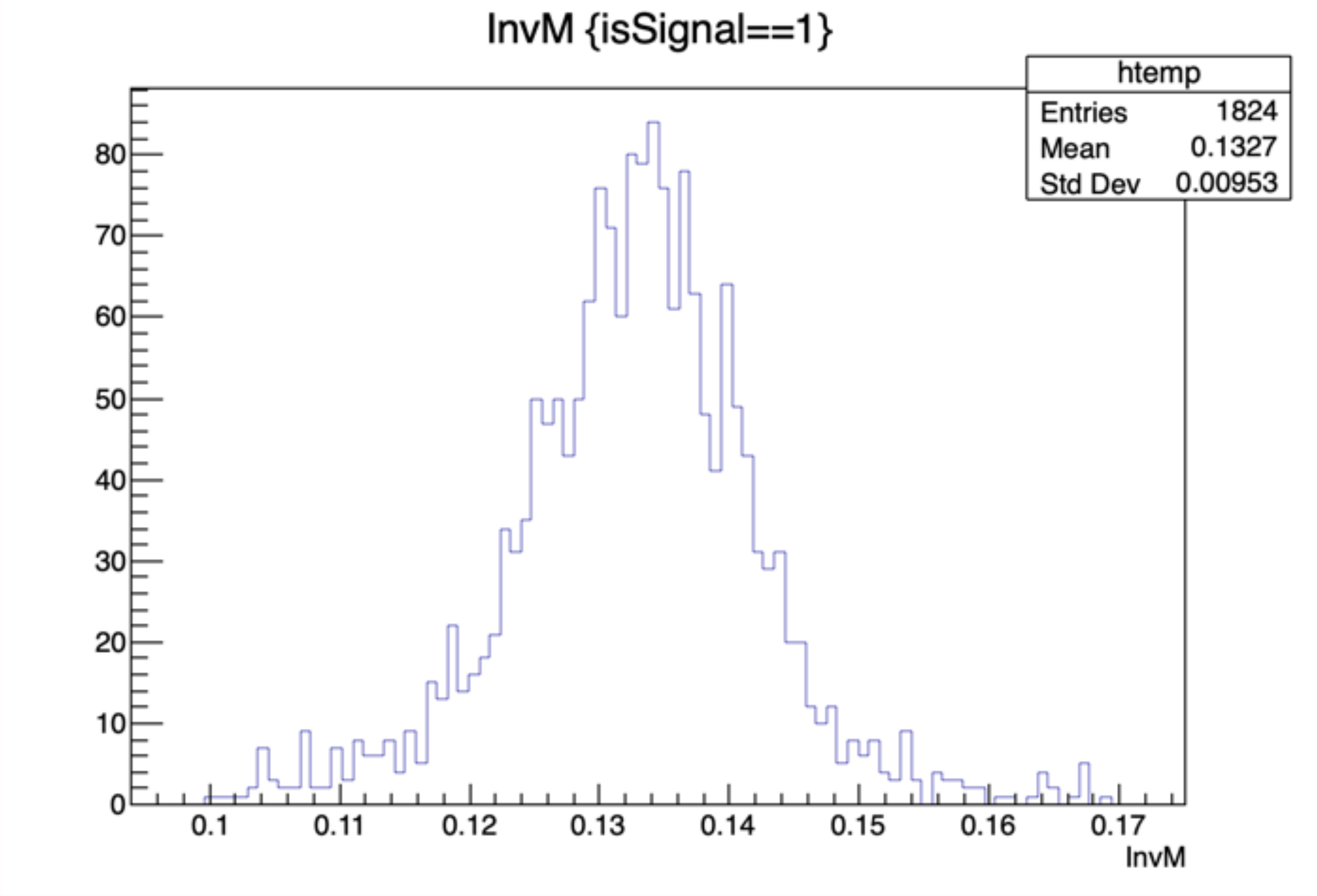
Background Signal

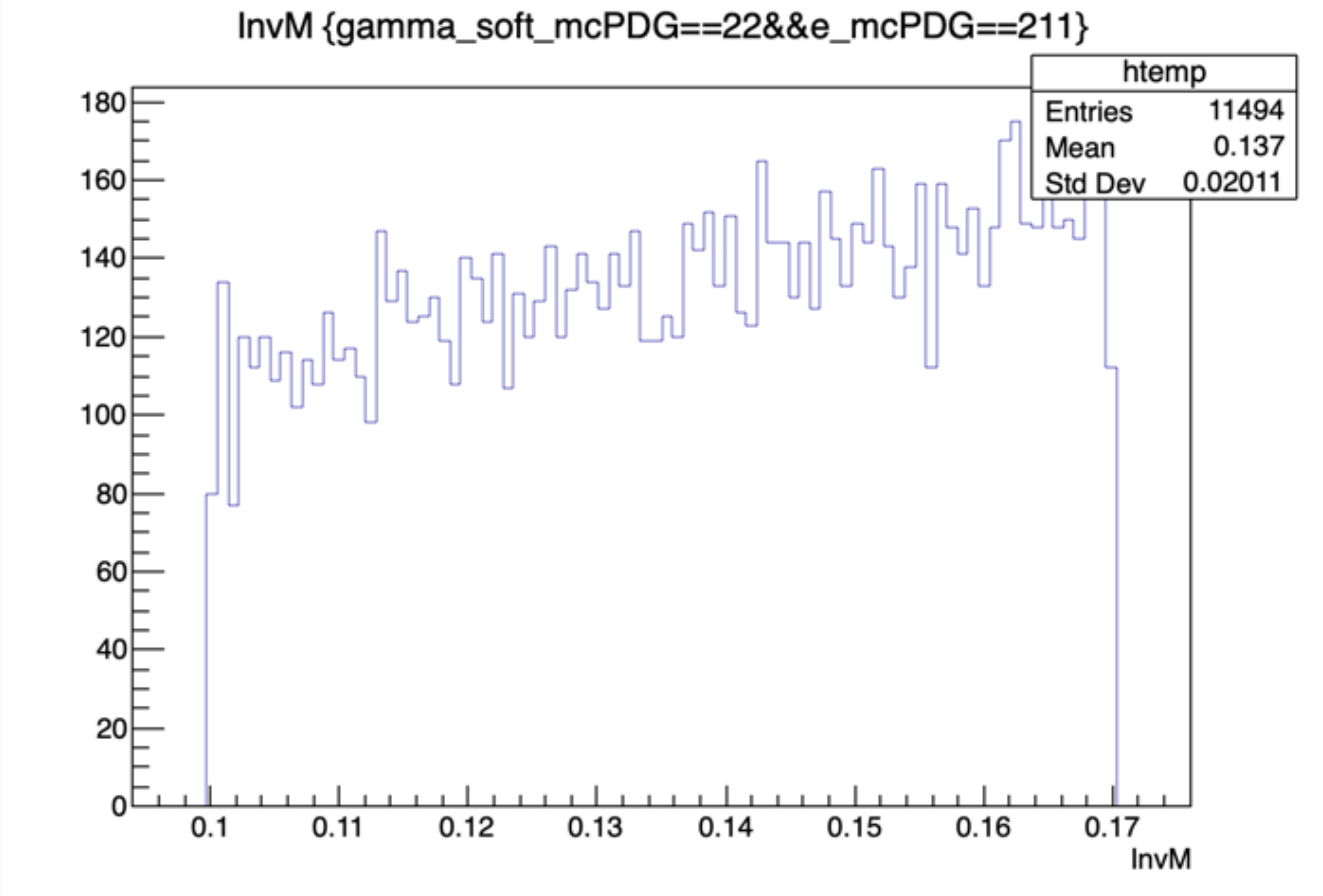
Var-1

INV_M COMPARISONS

TM- gamma_soft_mcPDG==22 && e_mcPDG==211

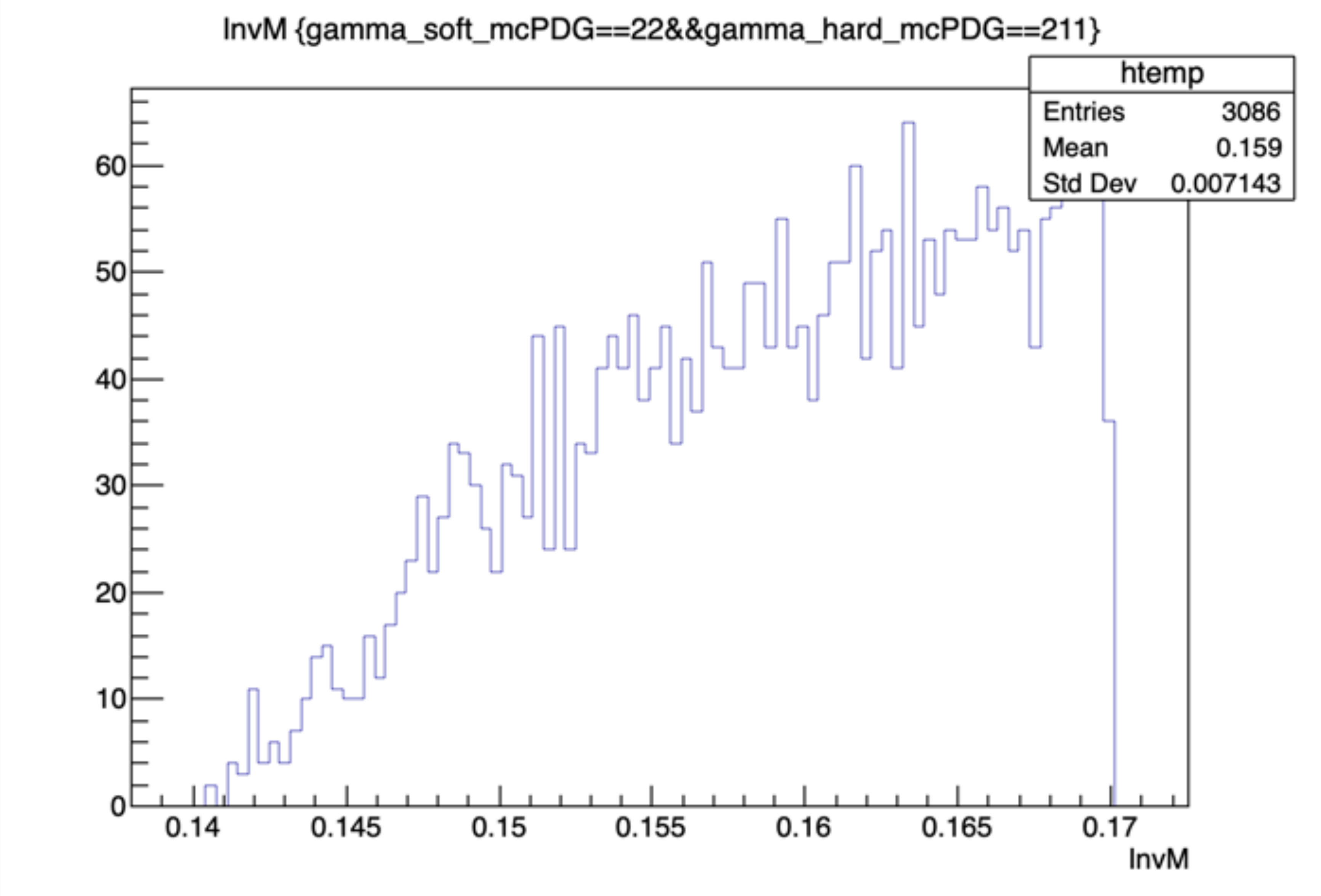
$\pi^0 \to \gamma\gamma$

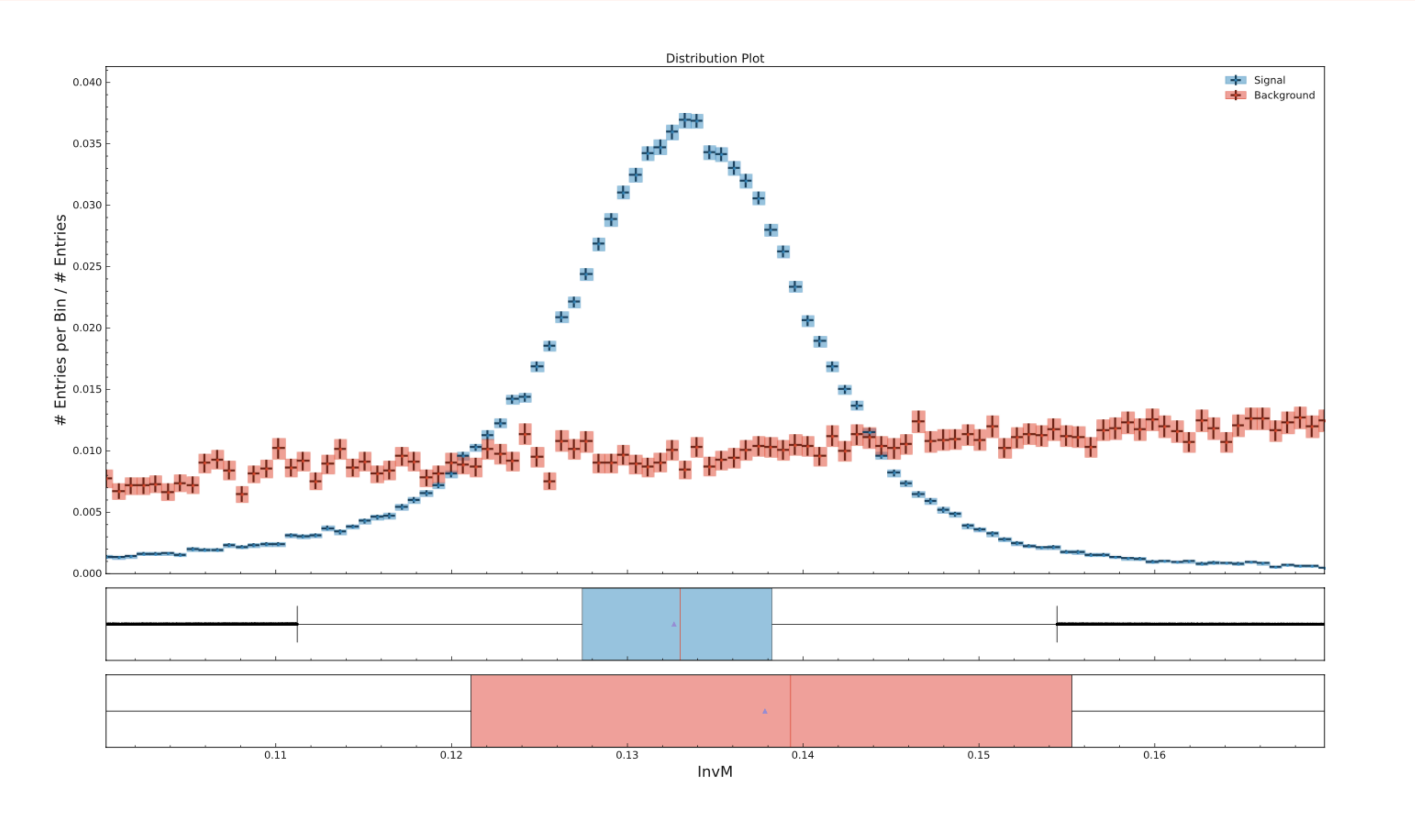




$\pi^0 \to e^-\gamma$

$\pi^0 \to \pi^+\gamma$



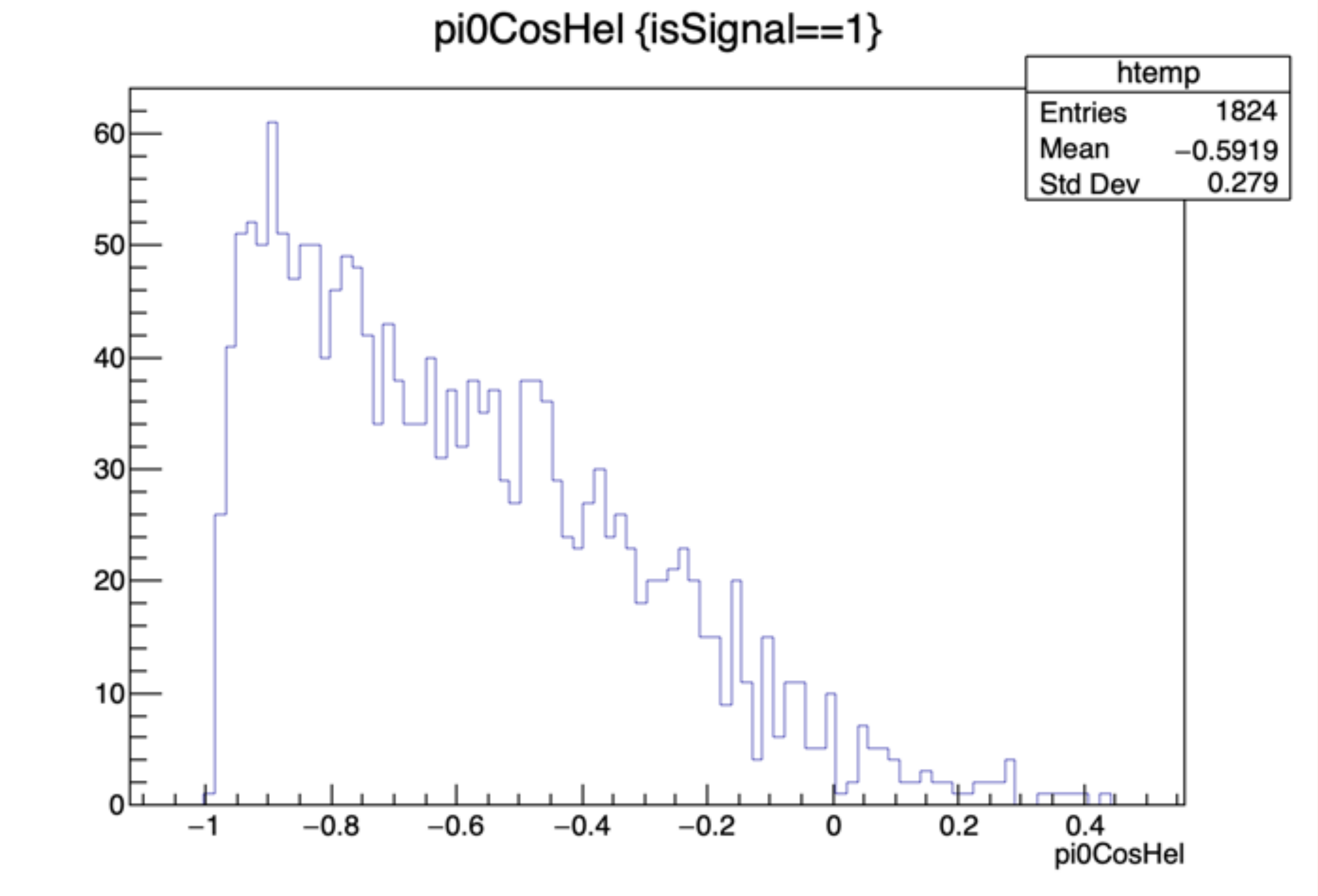


InvM B->Xγ

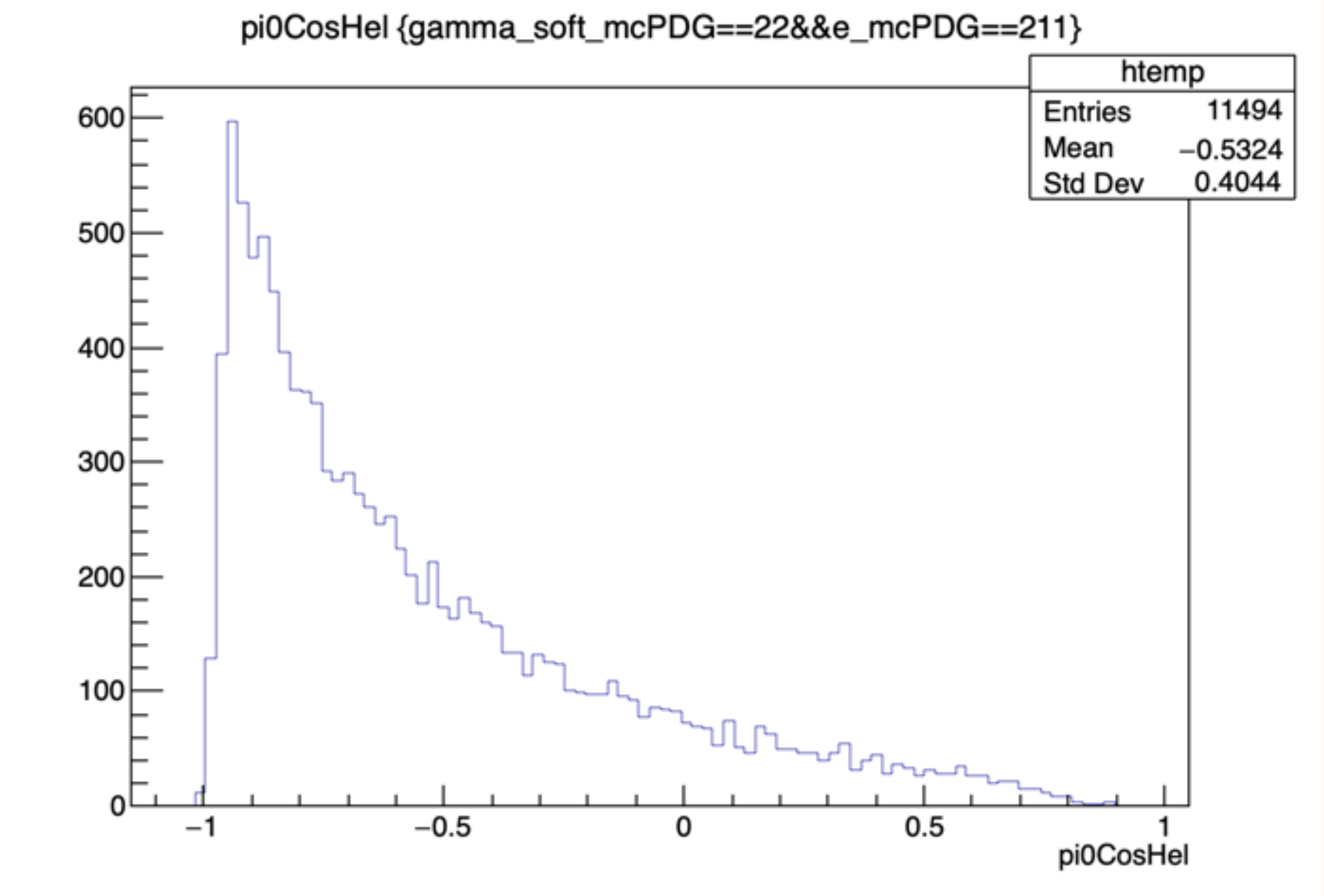
PIOCOSHEL COMPARISONS

TM- gamma_soft_mcPDG==22 && e_mcPDG==211

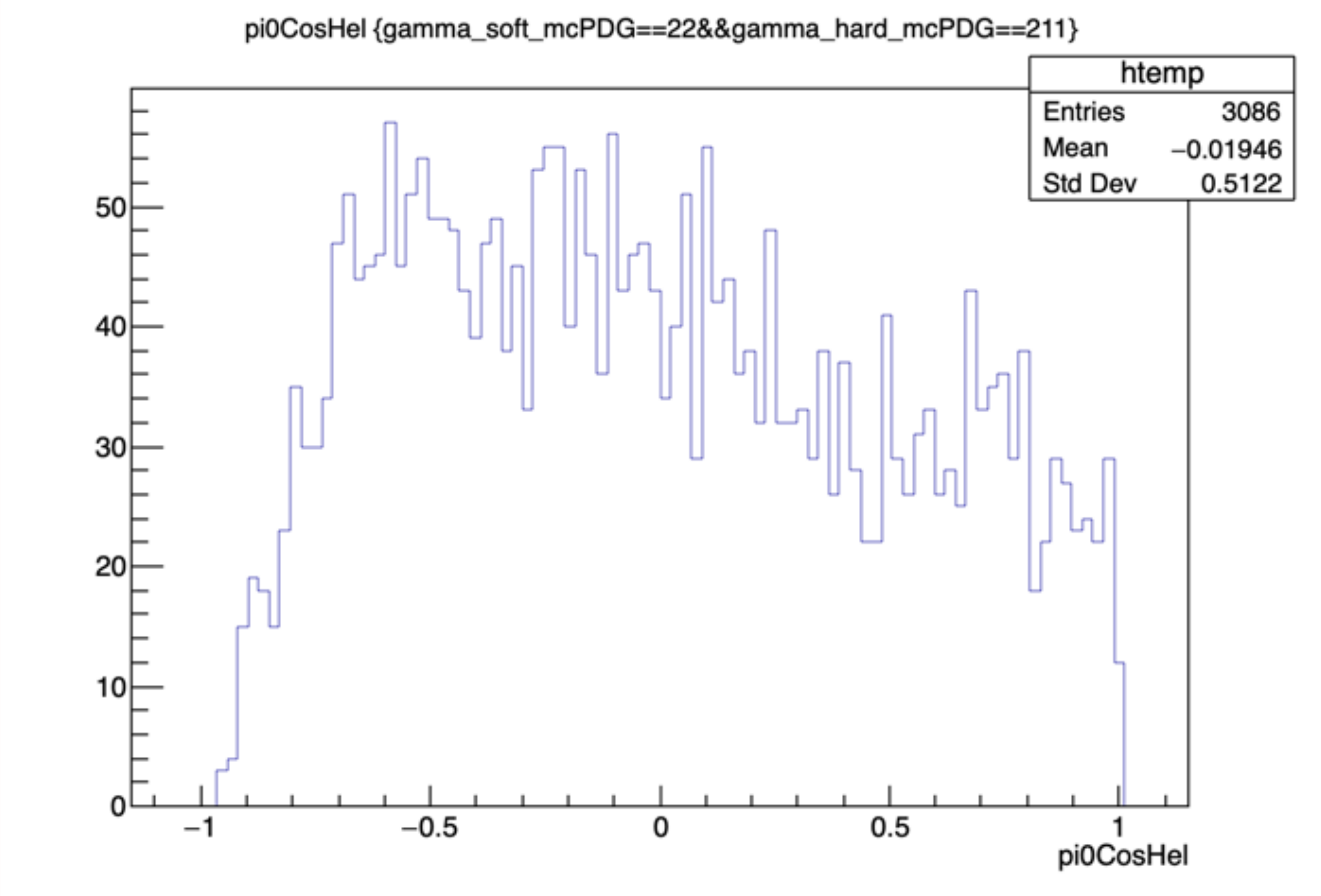
$\pi^0 \rightarrow \gamma\gamma$

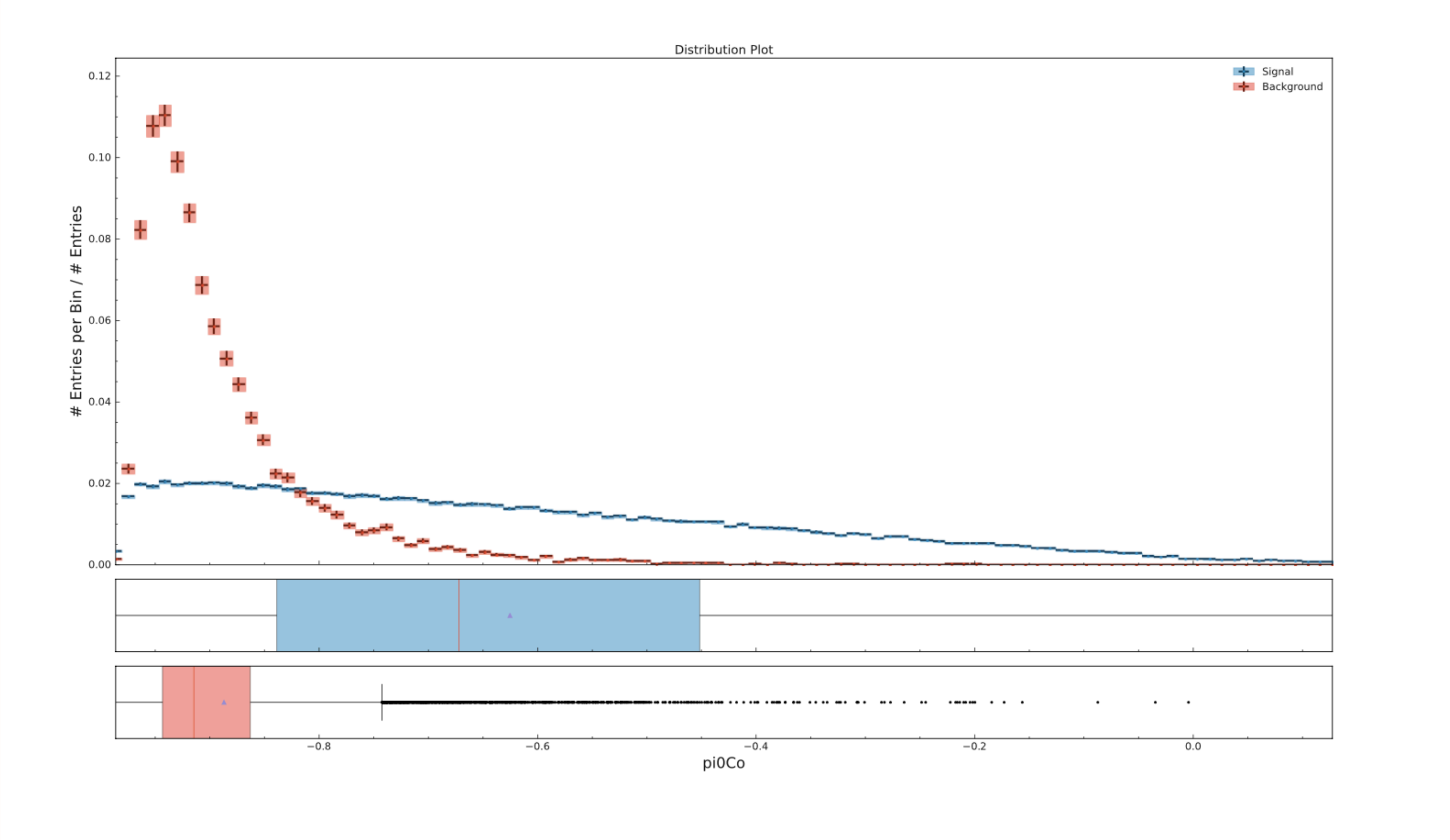


$\pi^0 \rightarrow e^-\gamma$



$\pi^0 \rightarrow \pi^+\gamma$





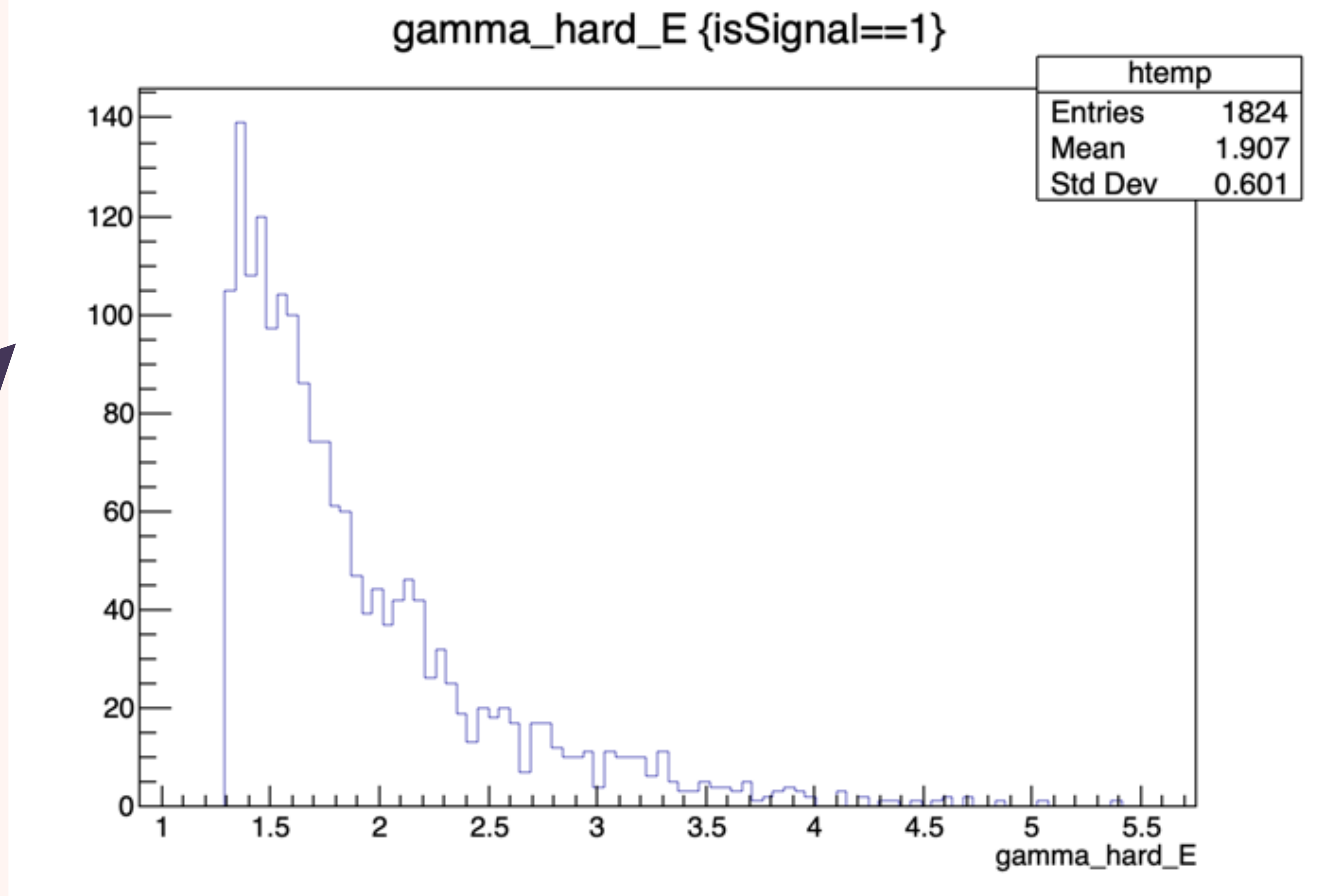
piOCosHel B->Xγ

Var-3

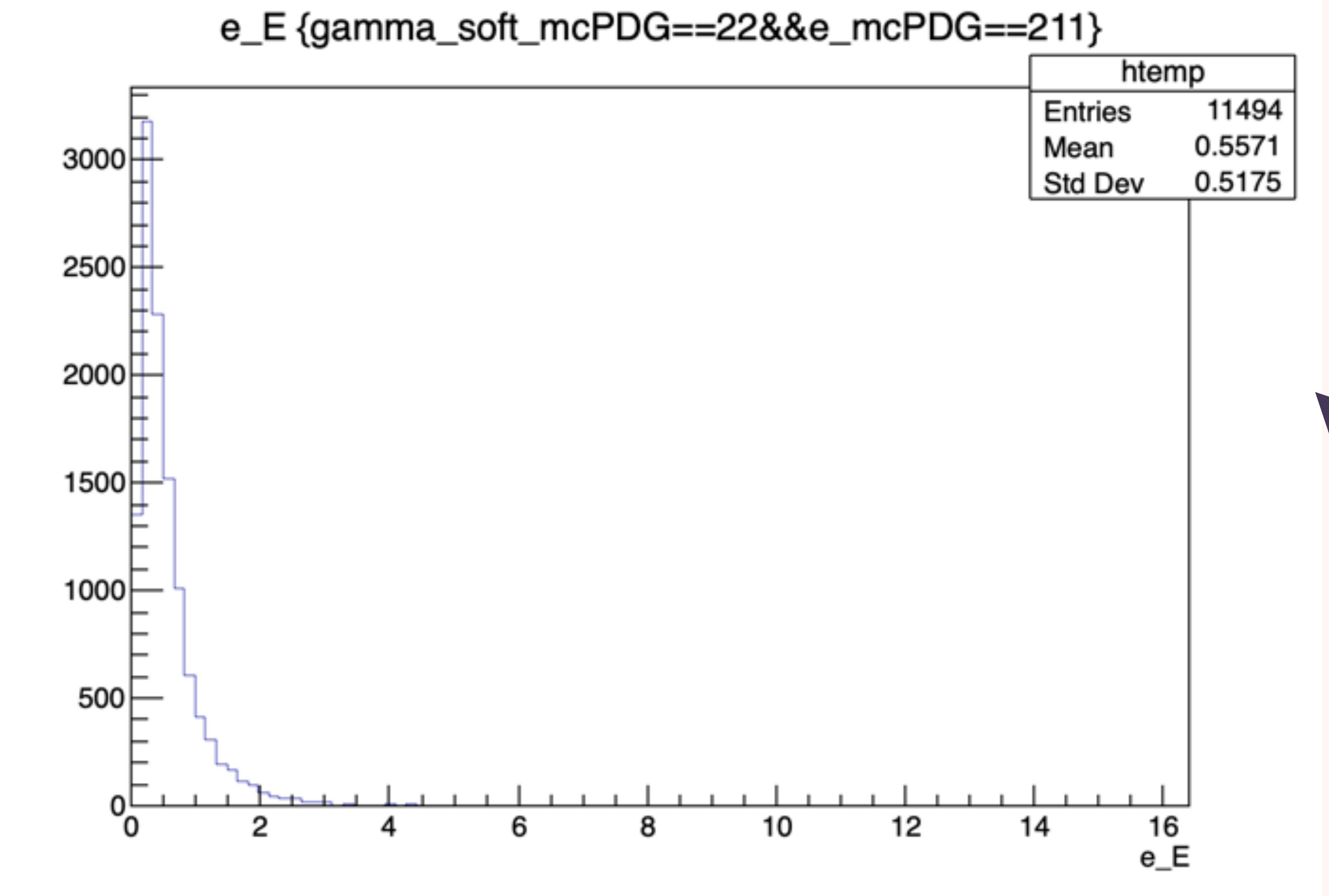
GAMMA_HARD_E/$\pi^+ E$/$e^- E$ COMPARISONS

TM-gamma_soft_mcPDG==22 &&e_mcPDG==211

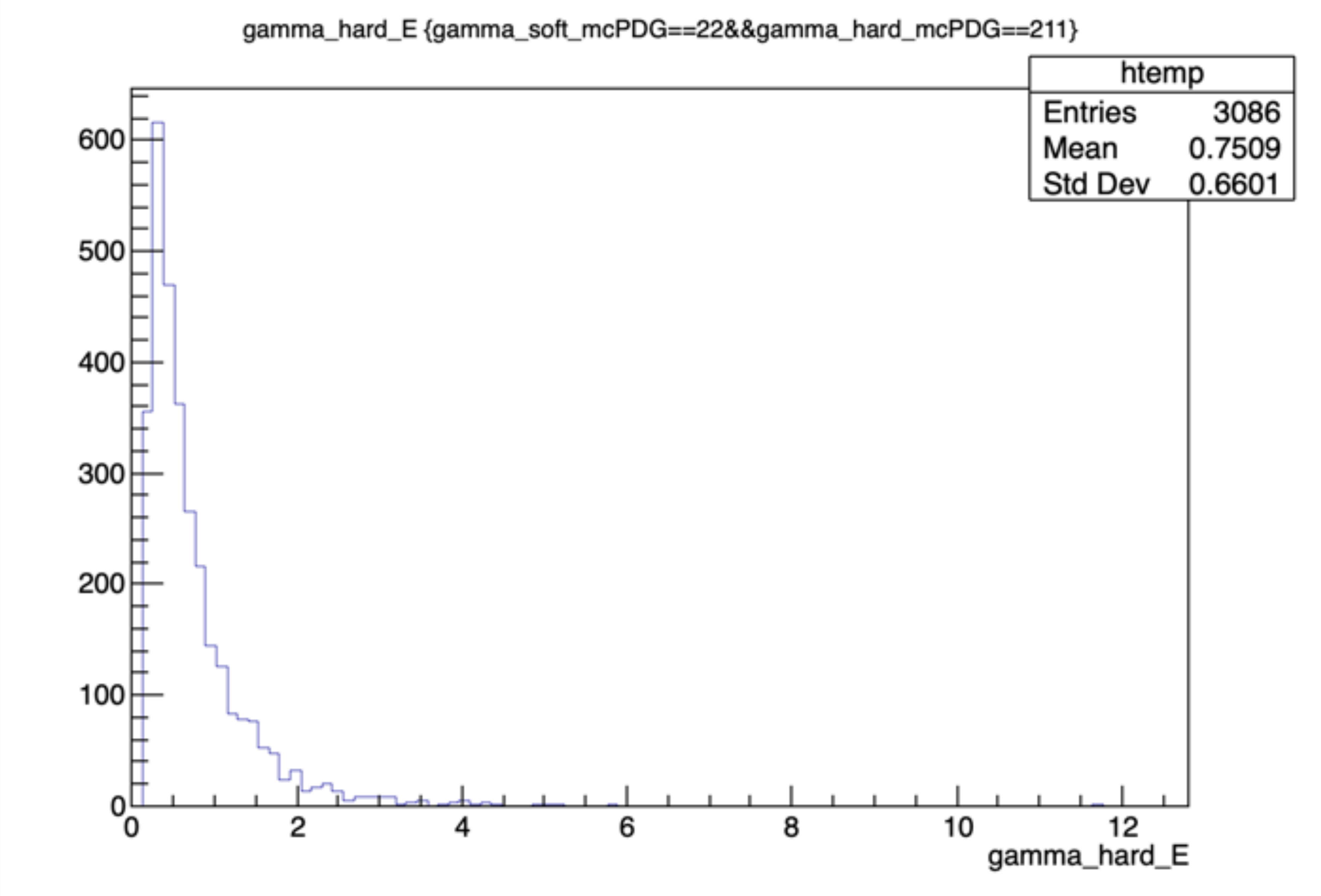
$\pi^0 \to \gamma\gamma$

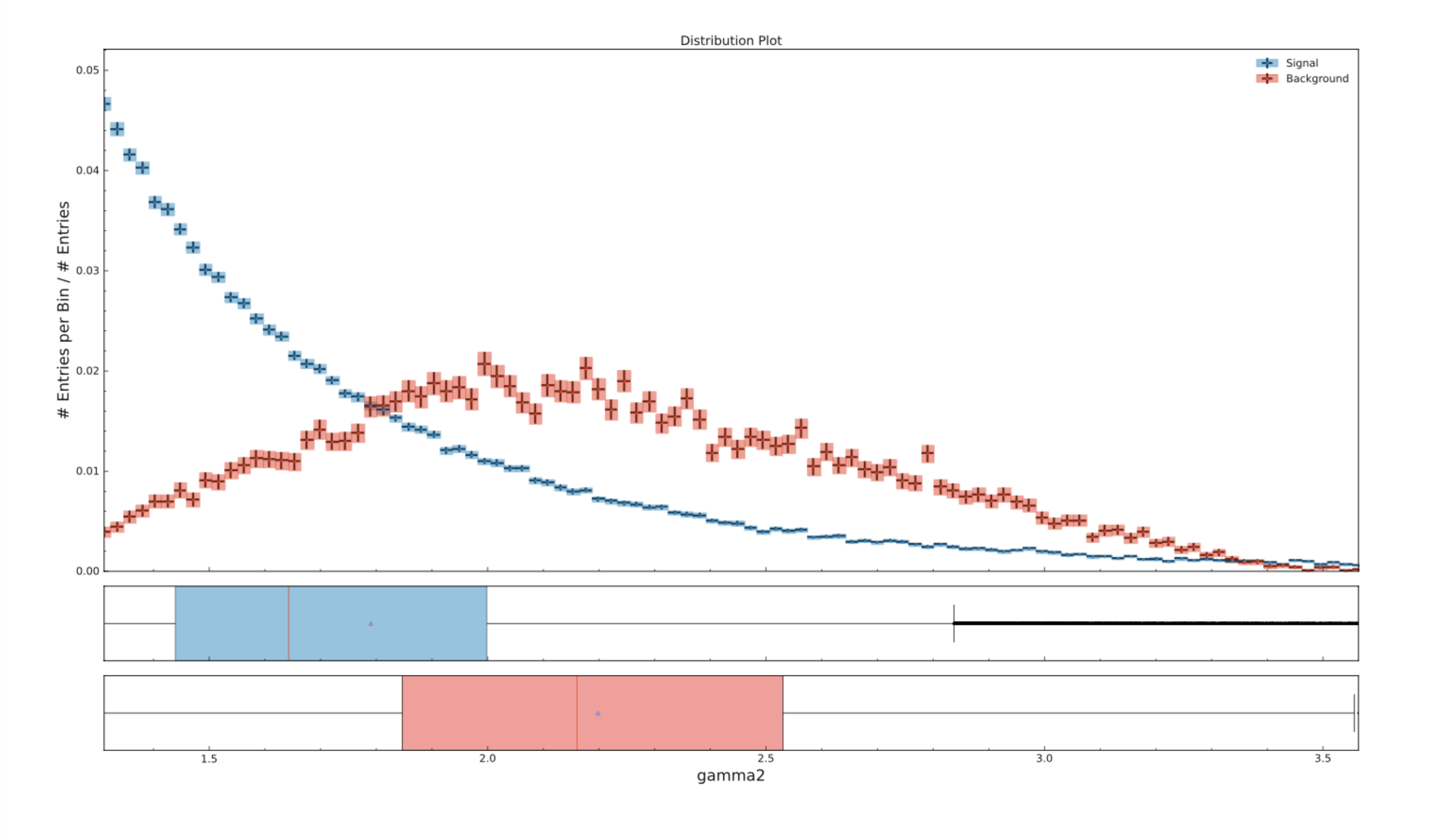


$\pi^0 \to e^-\gamma$



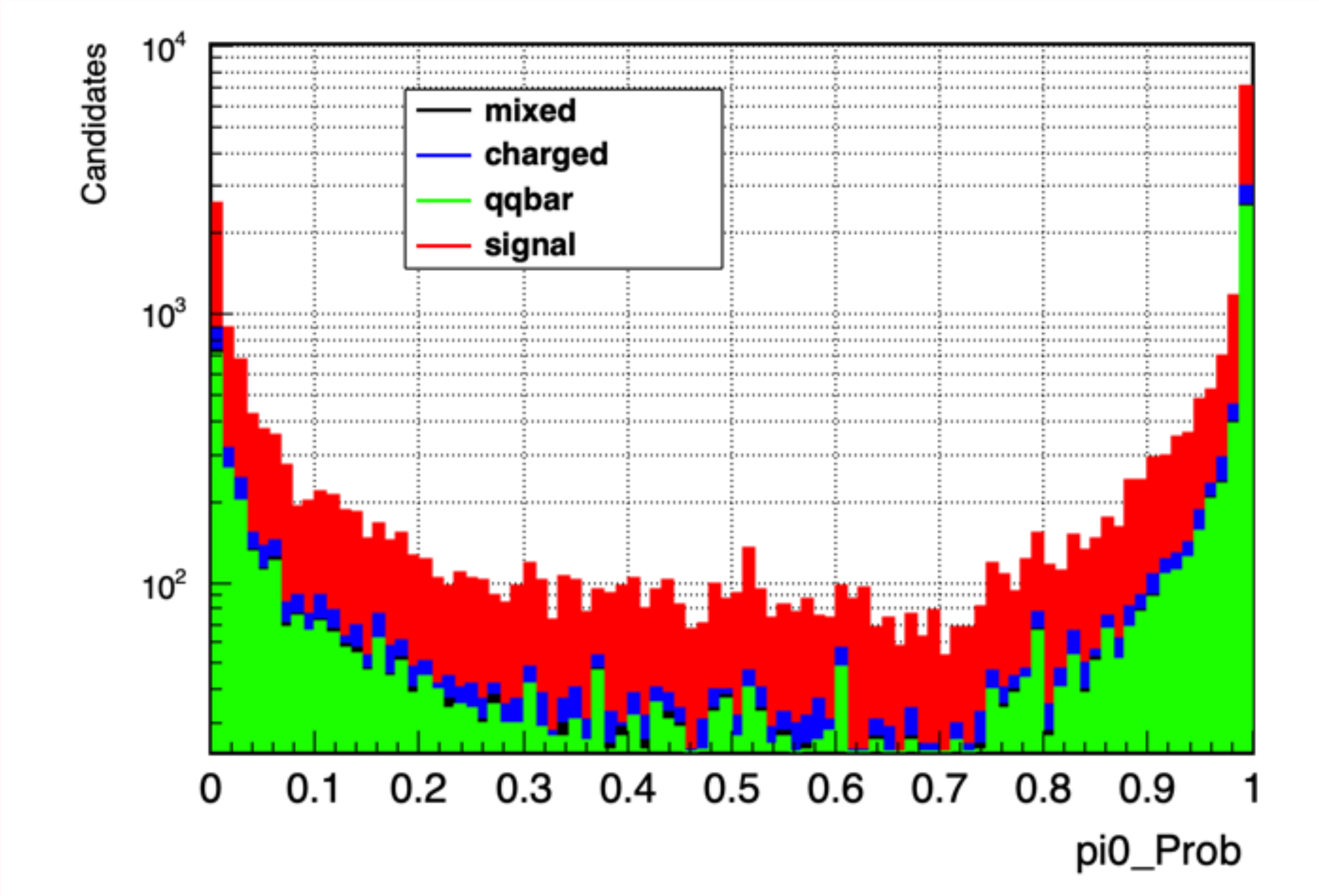
$\pi^0 \to \pi^+\gamma$



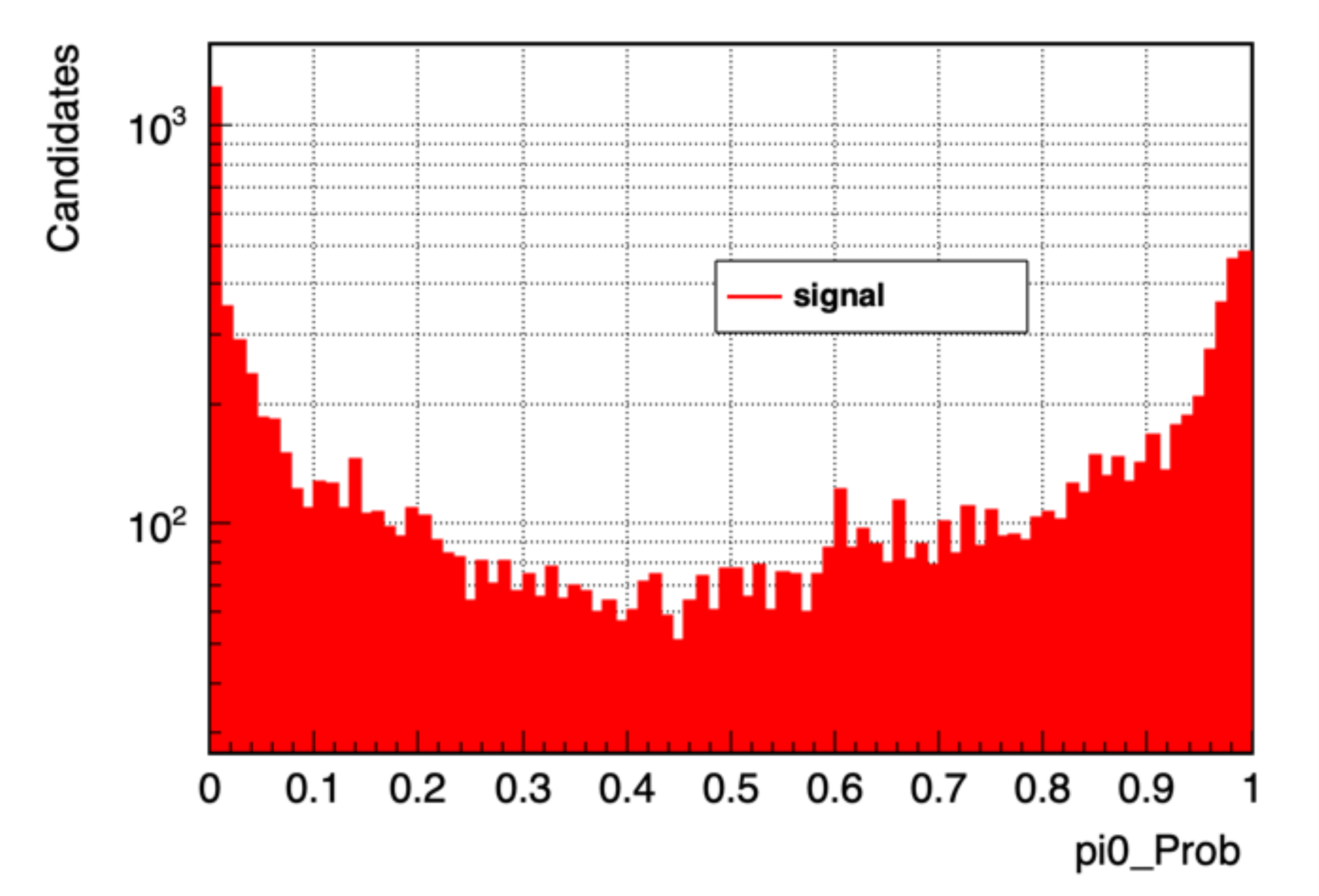


gamma_hard_E B->Xγ

π^0 PROBABILITY PLOT COMPARISON



π^0 probability plot in log scale for pion mass hypothesis

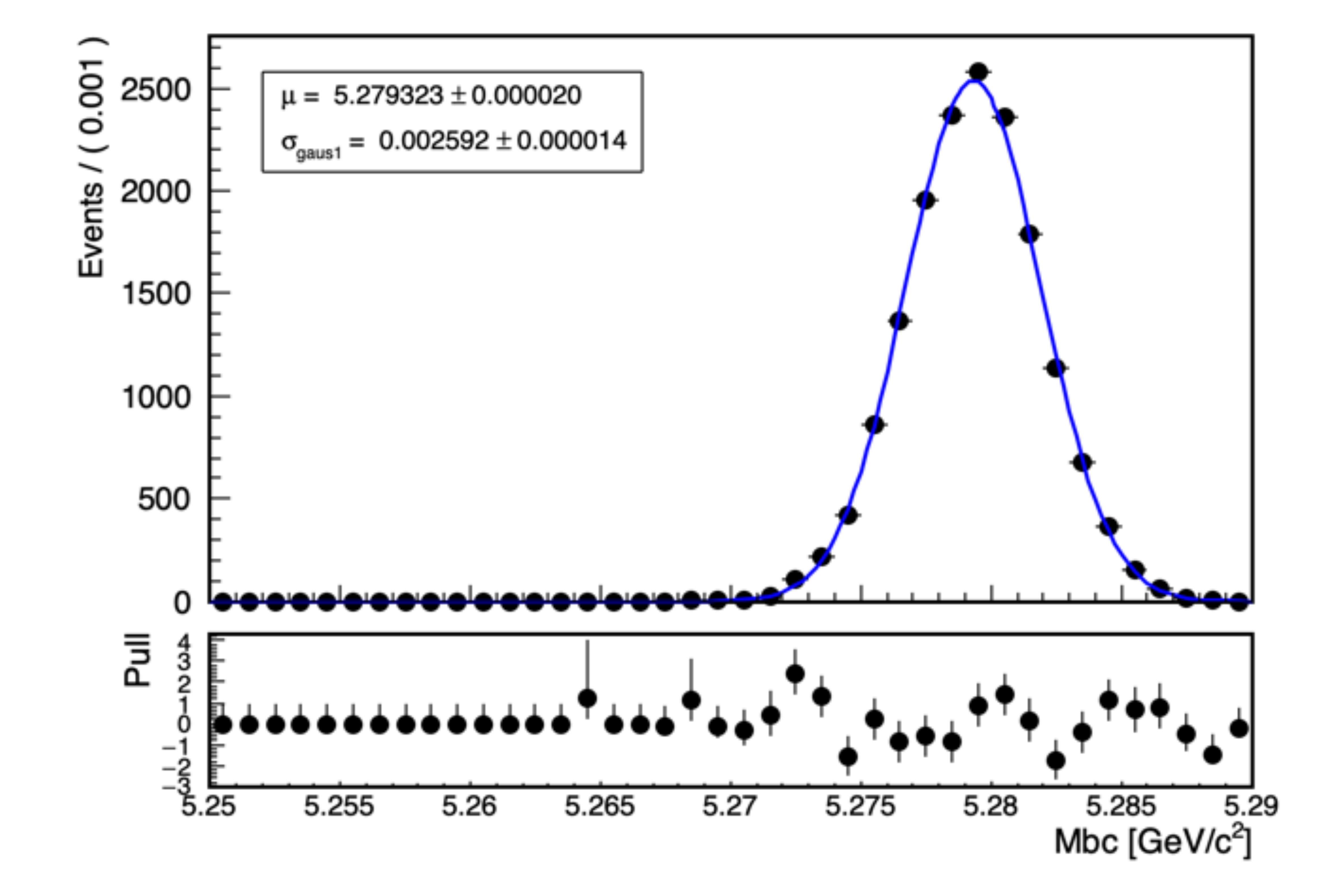


π^0 probability plot in log scale for B- decay channel for electron mass hypothesis

- **Signal** represents the correctly reconstructed $B^- \rightarrow D^0[K^-\pi^+]\pi^-$channel (isSignal==1)

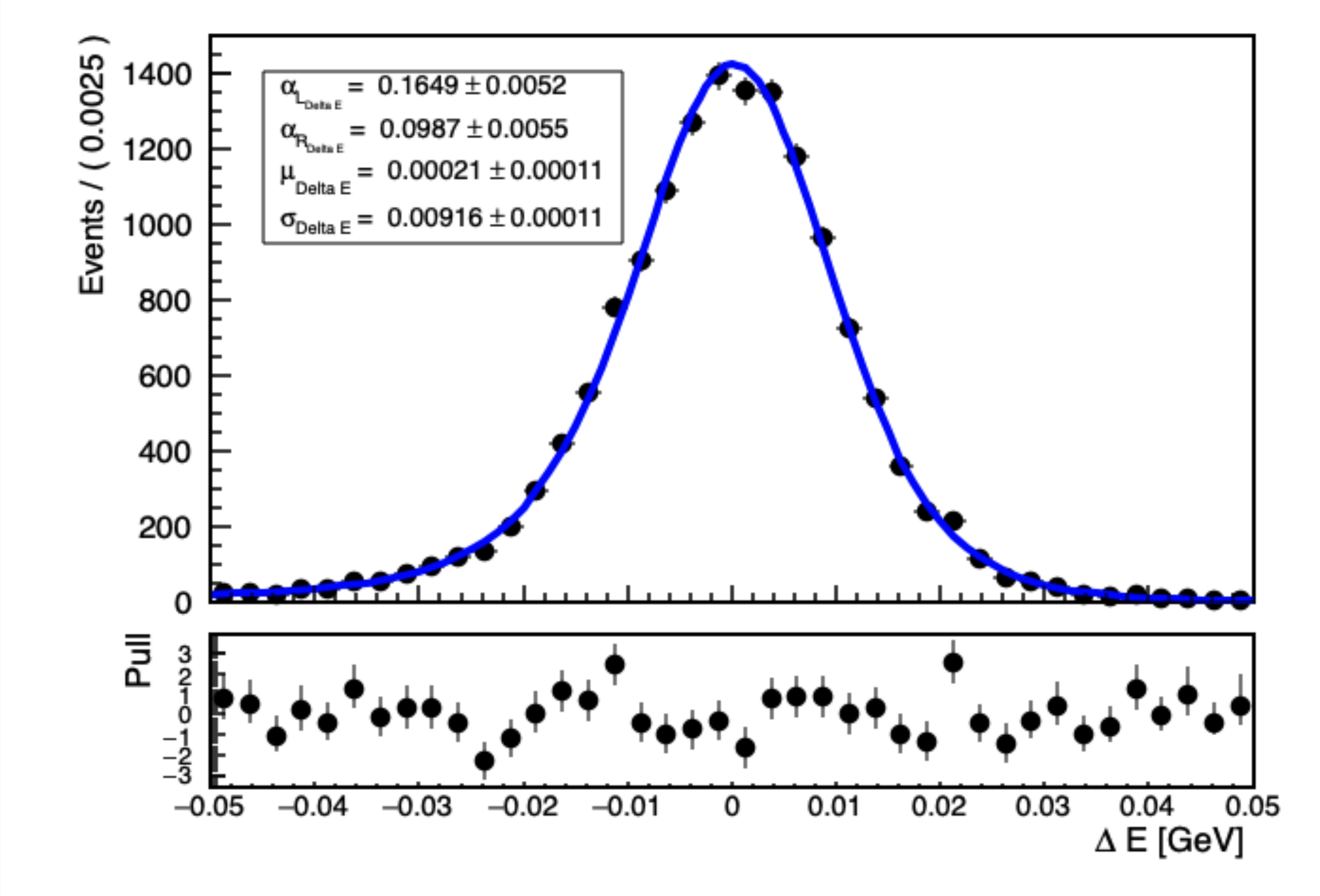
- **Signal** represents the correctly reconstructed $B^- \rightarrow D^0[K^-\pi^+]e^-$channel

1D-$M_{bc}\Delta E$ SIGNAL FIT WITH ALL THE CUT



1D-Signal M_{bc} Fit with Single Gaussian

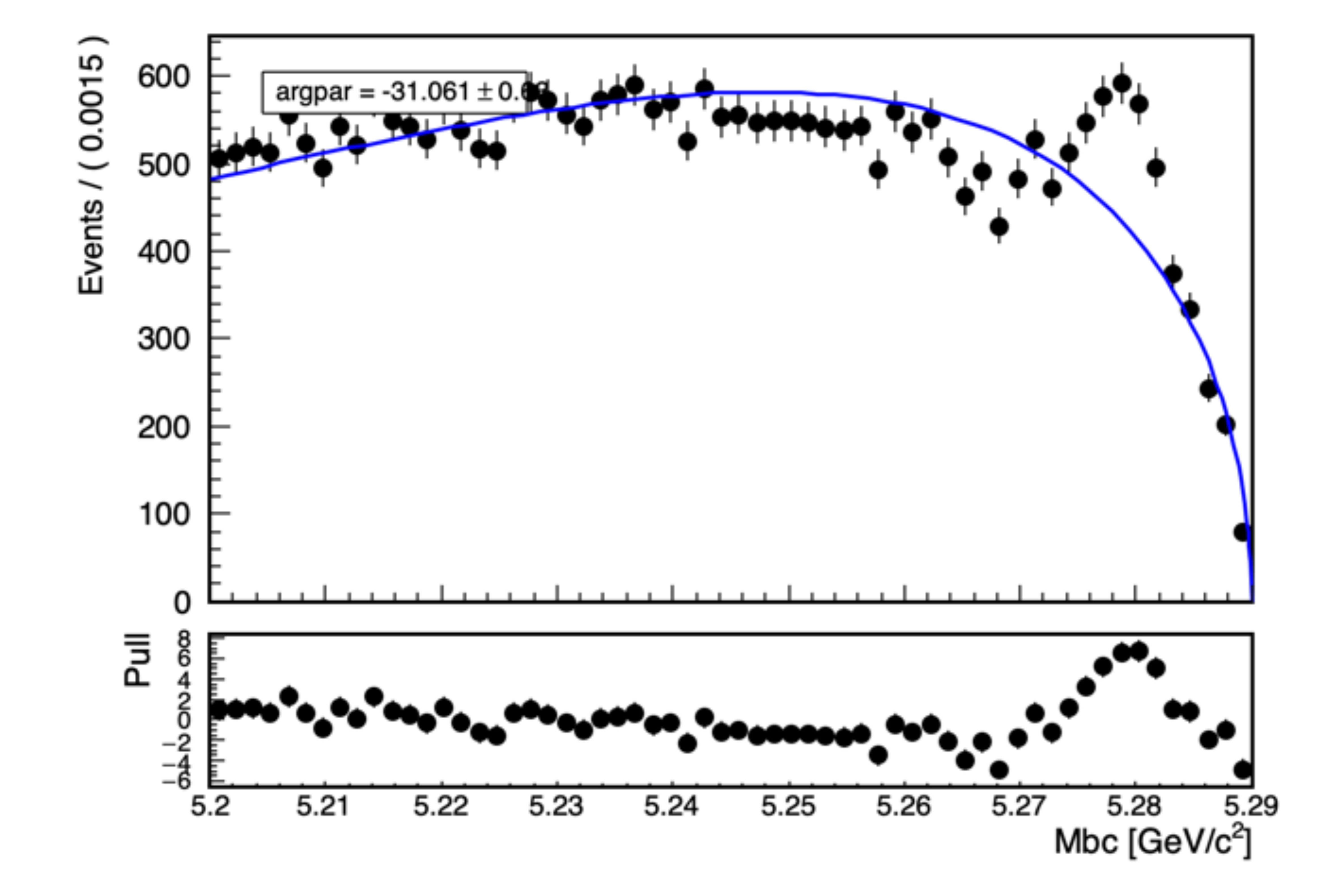
- σ_{Mbc} refers to the sigma of Gaussian
- μ_{Mbc} refers the mean



1D-Signal ΔE Fit with Cruijff Function

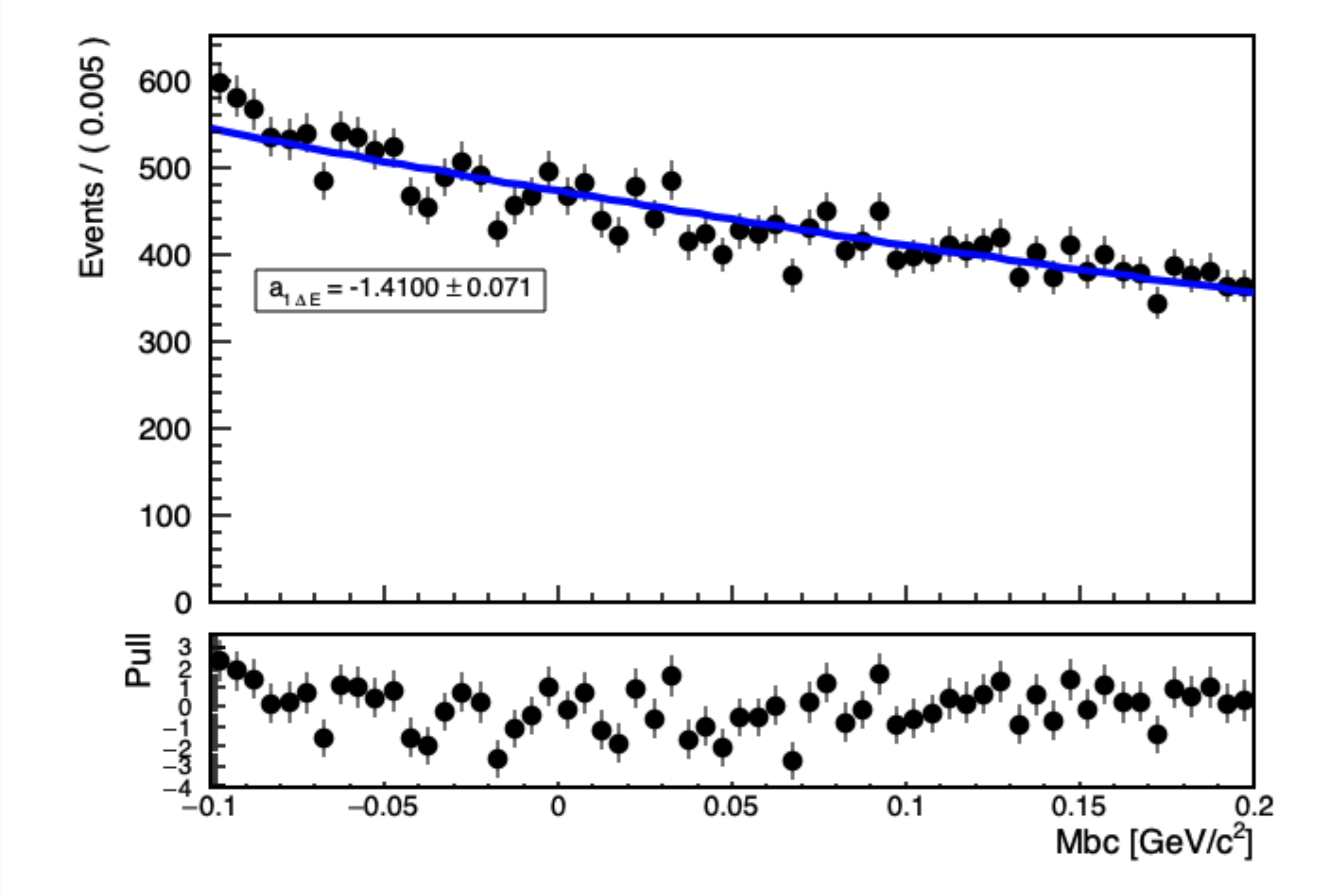
- $\sigma_{\Delta E}$ refers to the sigma of Gaussian
- $\mu_{\Delta E}$ refers the mean
- σ_L, σ_R refers to the sigma of Cruijff
- α_L, α_Rrefers to the Constant of Cruijff

1D-$M_{bc}\Delta E$ BKG FIT WITH ALL THE CUT



1D-Background M_{bc} Fit with Argus Function

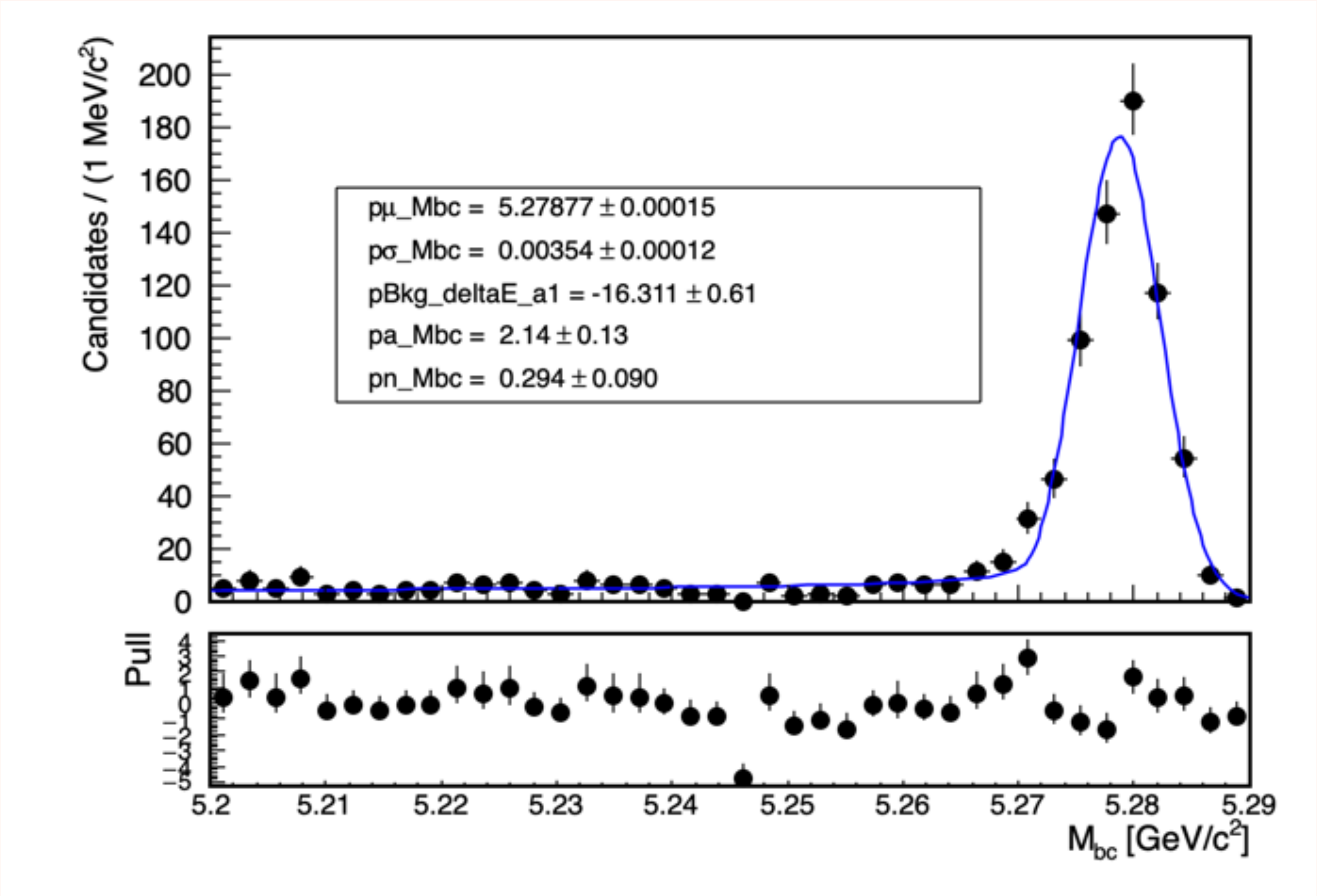
- Argpar refers to argus constant



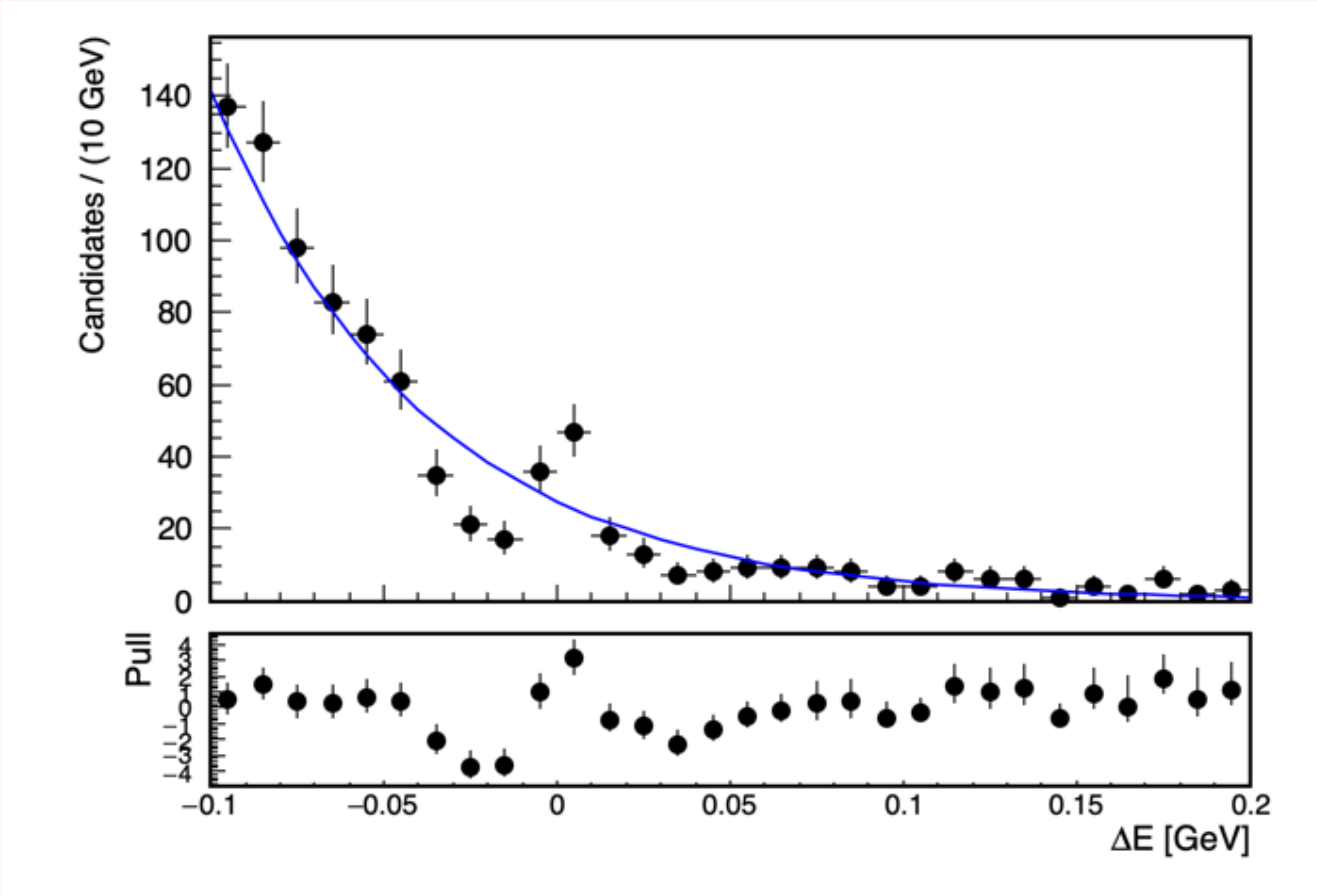
1D-Background ΔE Fit with Exponential Function

- $a_{1\Delta E}$ refers the constant of exponential

2D $B\bar{B}$ BACKGROUND FIT



Signal $B\bar{B}$ Fit with Single crystal Ball



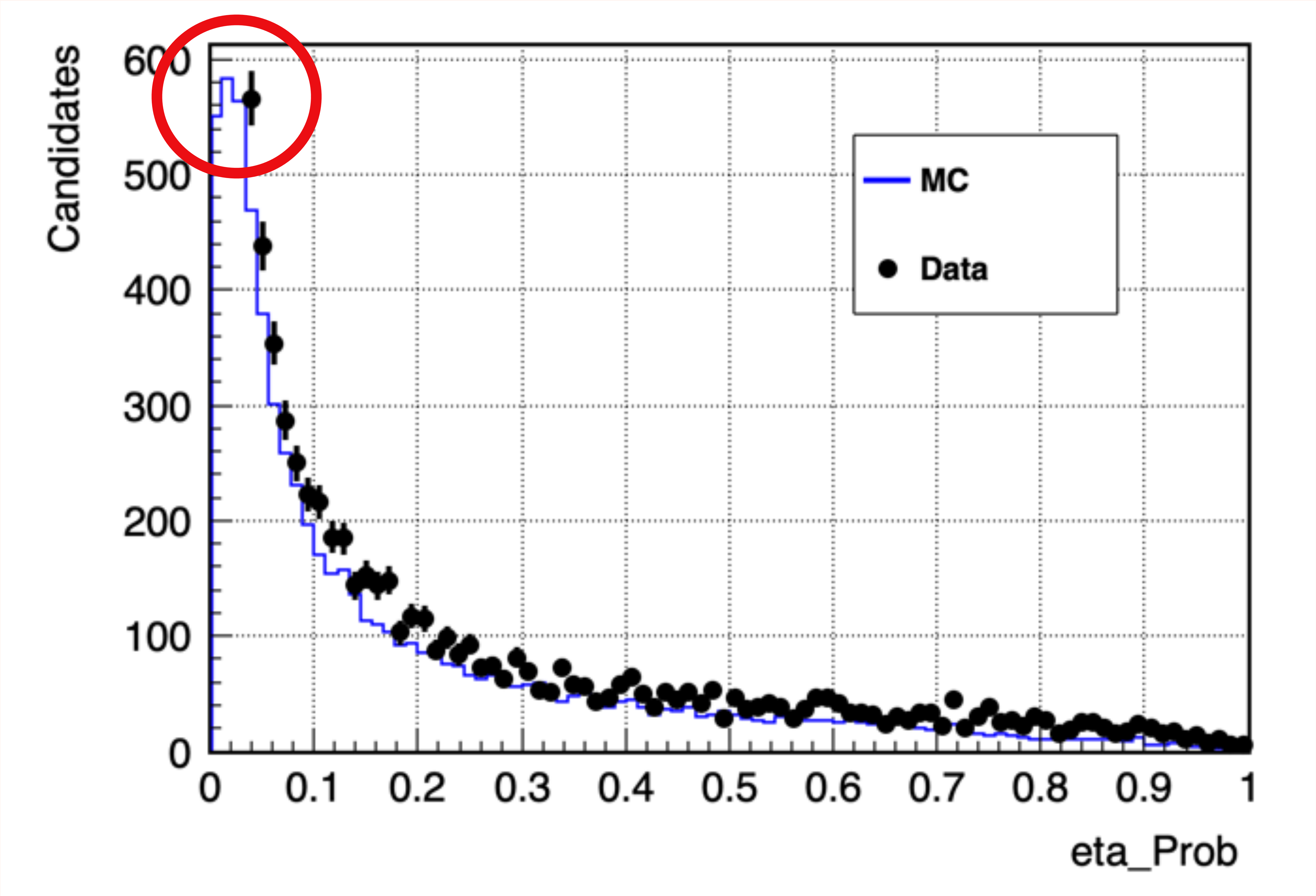
Background $B\bar{B}$ Fit with Exponential Fit

- $p\sigma_{Mbc}$ refers to the sigma of crystal ball
- Pn_{Mbc} and pa_{Mbc} constant for Crystal Ball

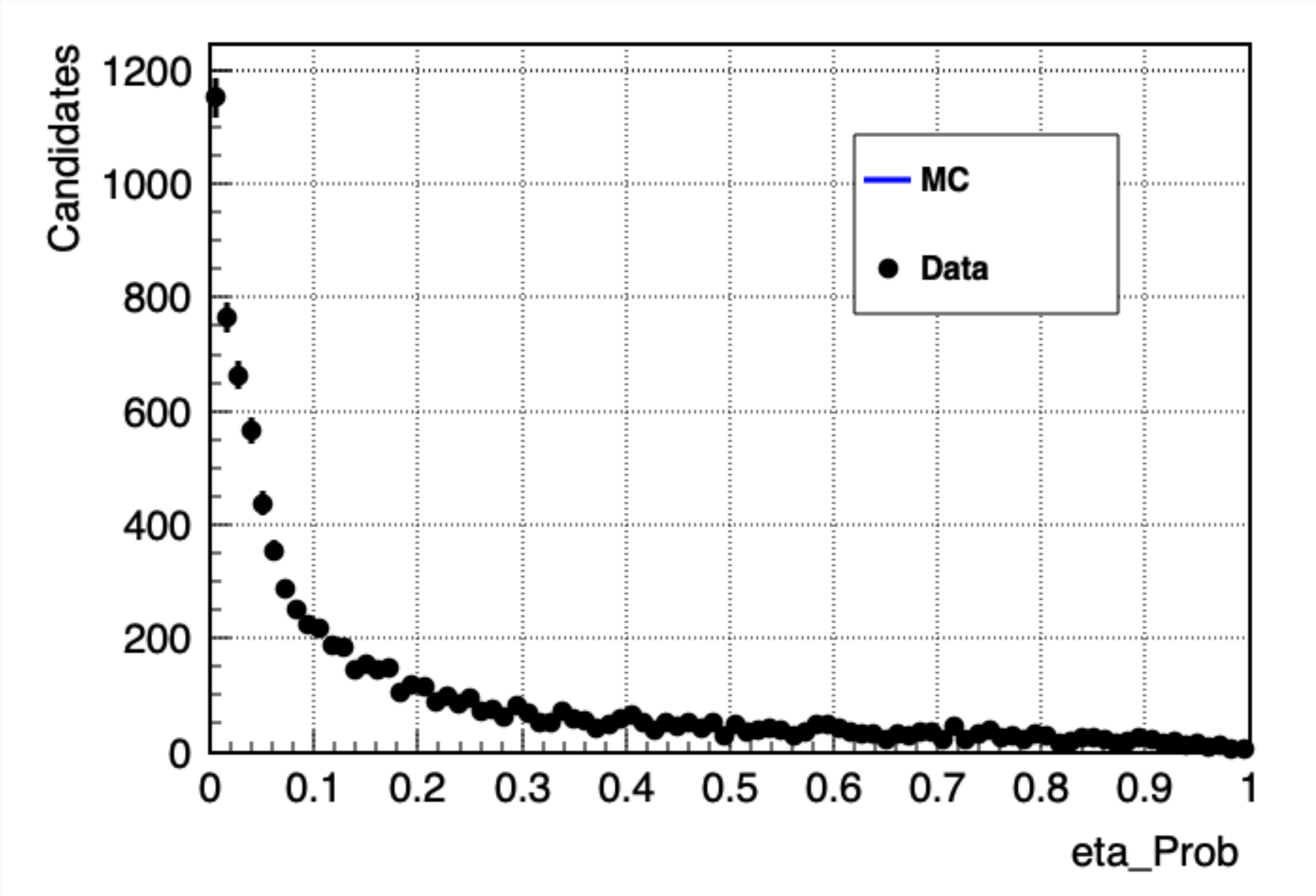
Background yield- 863

- pBkg_deltaE exponential constant for Bkg

DATA-MC AGREEMENT OF η PROB



Data-MC agreement of η Prob plot (Data and MC)



Data-MC agreement of η Prob plot (only Data)

All the MC and the Data points in the plot are scaled.

- **BLUE indicates the MC events**
- **Black indicates the data with error bars.**

SIGNAL EVENTS IN THETA MOMENTUM BINNING

Total Signal in MC-1

	p1	P2	P3	P4
Theta1 (fwd)	0+0=0	0+0=0	1+0=1	637+19=656
Theta2 (bar)	0+0=0	0+7=7	878+26=904	2326+43=2369
Theta3 (bar)	224+10=234	2142+124=2266	2516+101=2617	531+14=545
Theta 4 (bar)	2894+166=3060	1253+42=1295	44+1=45	0+0=0
Theta 5 (bwd)	265+17=282	0+0=0	0+0=0	0+0=0

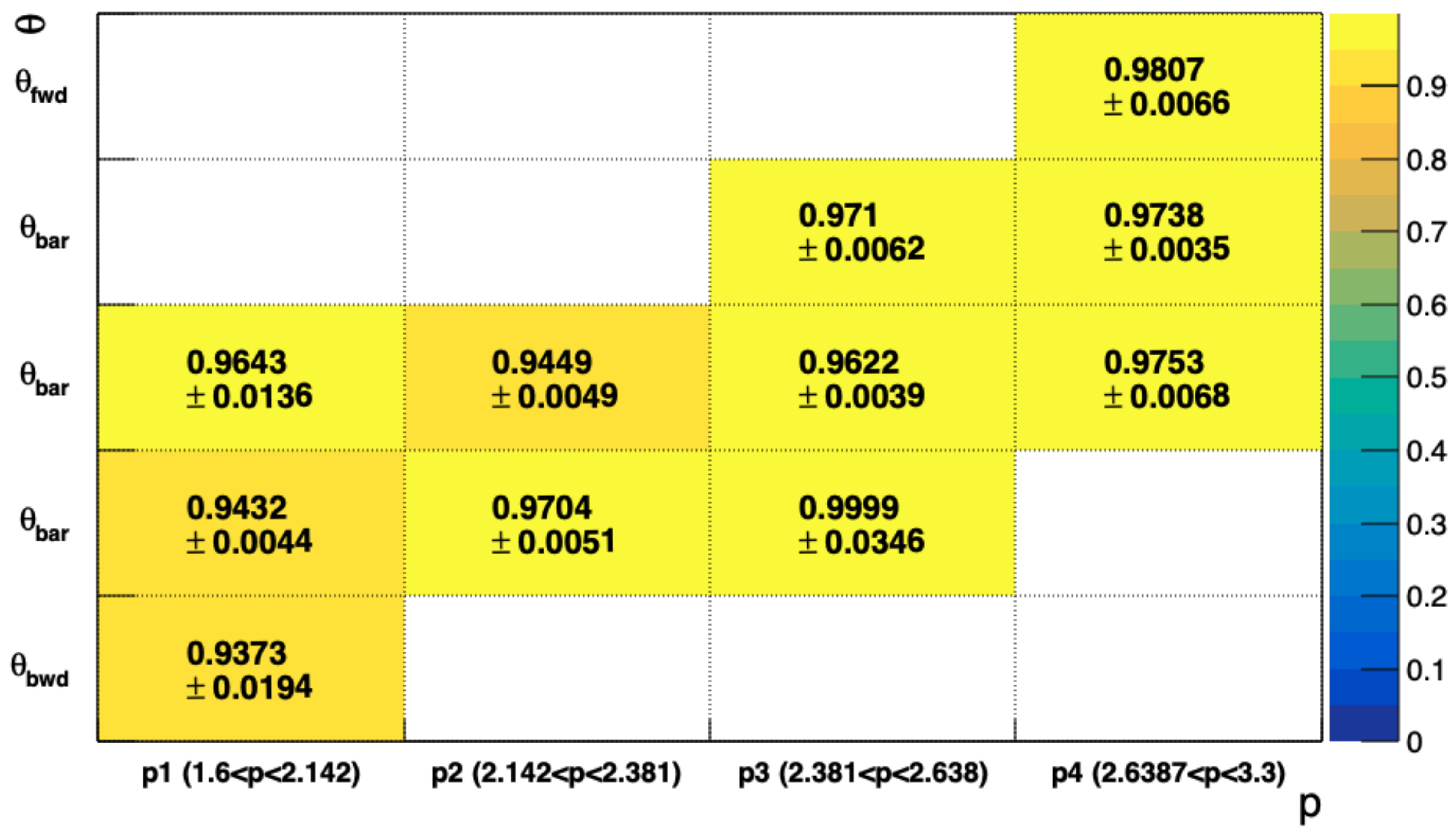
Eta_Prob<0.68 + Eta_Prob>0.68 = Total signal event (for the particular bin)

MOMENTUM THETA BINNING SYSTEMATICS

ϵ_{MC} Pbin Theta distribution

	P_1 (1.6 < p < 2.142)	P_2 (2.142) < p < 2.381))	P_3 (2.381 < p < 2.638)	P_4 (2.638 < p < 3.3)
Theta1 (fwd)				0.9807 ± 0.0066
Theta2 (bar)			0.9710 ± 0.0062	0.9738 ± 0.0035
Theta2 (bar)	0.9643 ± 0.0136	0.9449 ± 0.0049	0.9622 ± 0.0039	0.9753 ± 0.0068
Theta 4 (bar)	0.9432 ± 0.0044	0.9704 ± 0.0051	0.9999 ± 0.0346	
Theta 5 (bwd)	0.9373 ± 0.0194			

ϵ_{Mc} Tabular Distribution



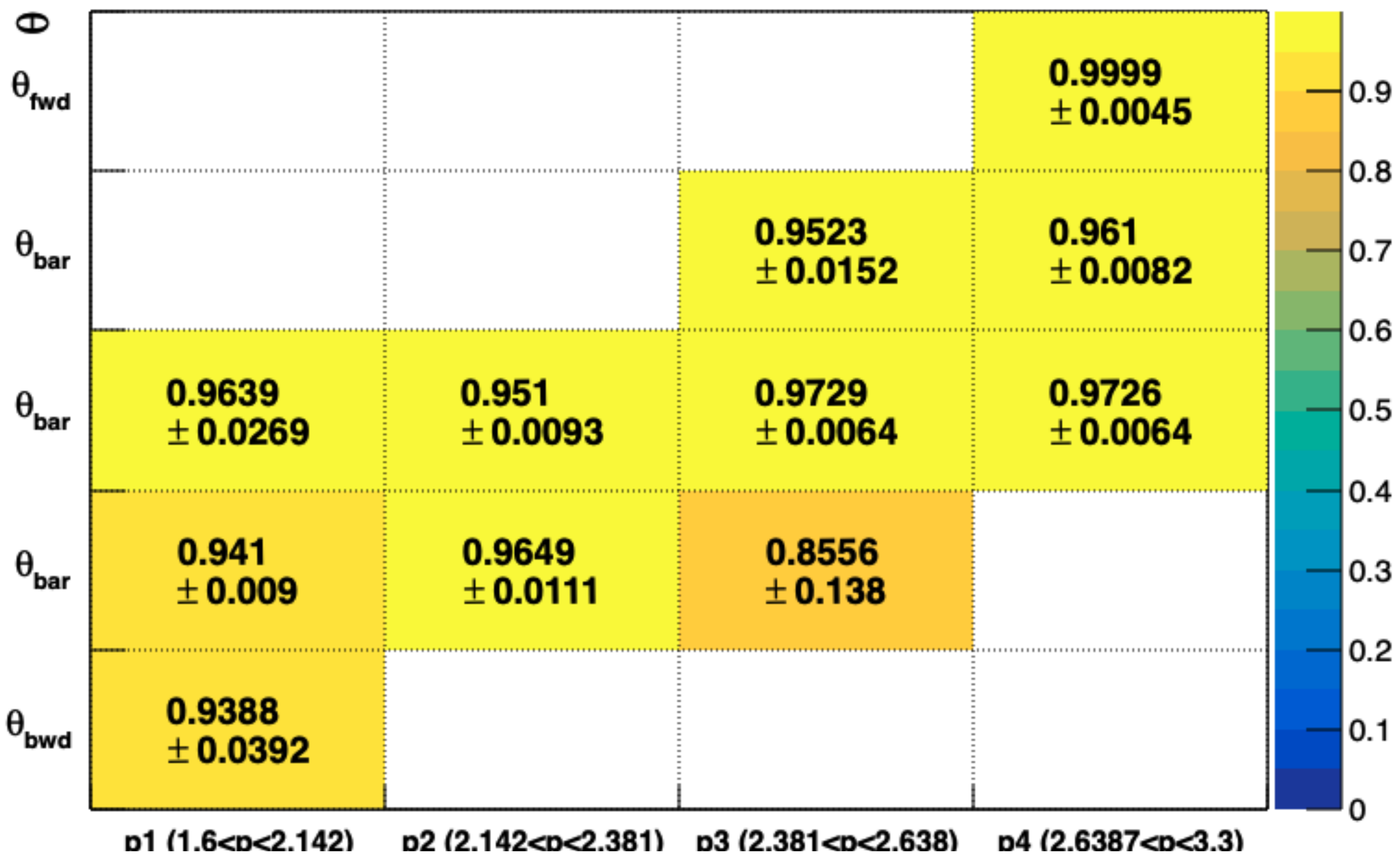
ϵ_{MC} colz 2D Distribution

MOMENTUM THETA BINNING SYSTEMATICS

ϵ_{DATA}

	P_1 (1.6 < p < 2.142)	P_2 (2.142) < p < 2.381))	P_3 (2.381 < p < 2.638)	P_4 (2.638 < p < 3.3)
Theta1 (fwd)				0.9999 ± 0.0045
Theta2 (bar)			0.9523 ± 0.0152	0.9610 ± 0.0082
Theta2 (bar)	0.9639 ± 0.0269	0.9510 ± 0.0093	0.9729 ± 0.0064	0.9726 ± 0.0064
Theta 4 (bar)	0.9410 ± 0.0090	0.9649 ± 0.0111	0.8556 ± 0.1380	
Theta 5 (bwd)	0.9388 ± 0.0392			

ϵ_{Data} Tabular Distribution



ϵ_{Data} colz 2D Distribution