$B \rightarrow X_s \gamma$ study

with hadronic tagging method in the *Belle* collaboration

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INTRODUCTION

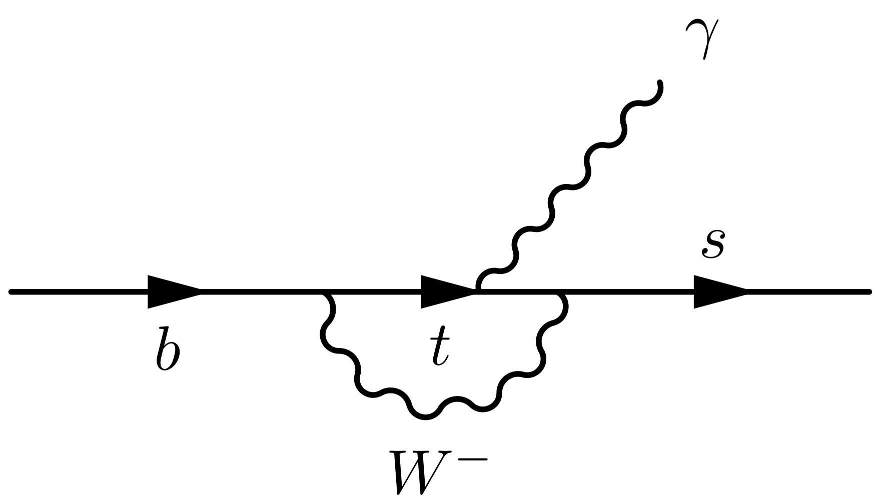


Figure 1: FCNC process of $b \to s\gamma$ decay

As for the tree level decay of b→s**γ** is forbidden in the Standard Model, the decay takes place at least at the loop level with FCNC as a leading order penguin diagram as Figure 1.

(The virtual W might be replaced by $H^{\pm}$ or non-SM particles, which leads to enhanced or suppressed branching fraction.)

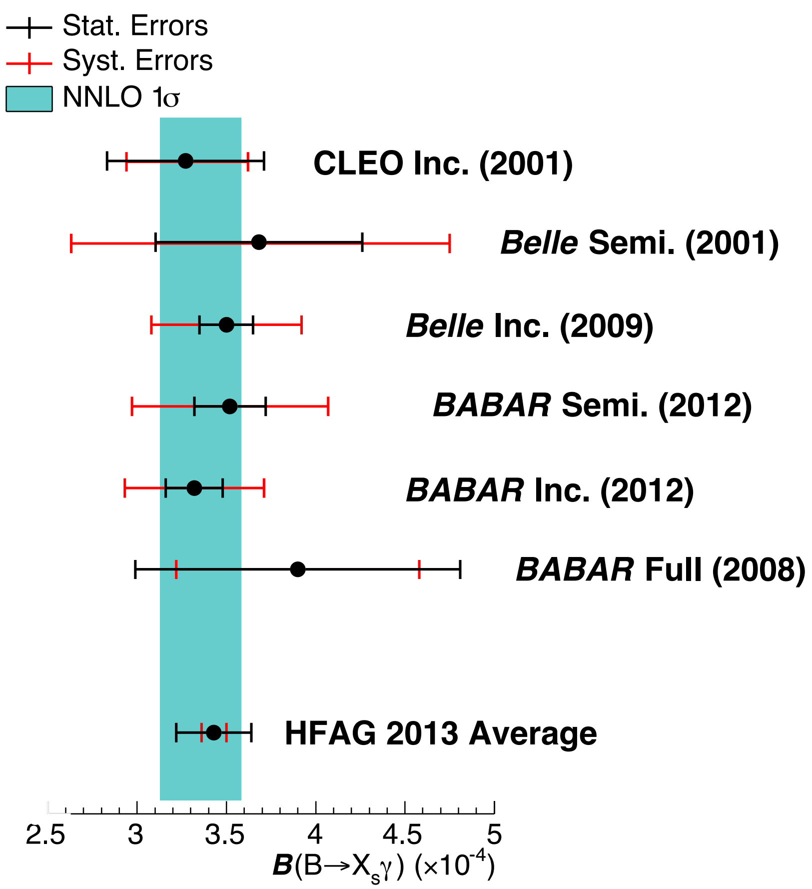
The most recent NNLO result

$$\mathcal{B}(B \to X_s\gamma)_{NNLO} = (3.36 \pm 0.23) \times 10^{-4}$$

The most recent HFAG average

$$\mathcal{B}(B \to X_s\gamma)_{\mathrm{HFAG}} = (3.43 \pm 0.21 \pm 0.07) \times 10^{-4}$$

The current experimental average agrees well on the recent NNLO result with ~0.3σ deviation.



INTRODUCTION

Through this analysis, we will be able to obtain ..

B.F, the CP asymmetry, A_{CP} and the **isospin asymmetry** Δ_{0-} of $b \to s\gamma$.

Current PDG

$$A_{CP} = -0.008 \pm 0.029$$

$$\Delta_{0-}(B(B \to X_s\gamma)) = -0.01 \pm 0.06$$

Especially, provided the info. of the charge of B-meson by *the hadronic tagging method*, we can ***directly*** obtain the isospin asymmetry.

EKP fullrecon module fully reconstructs one of B-mesons (B_{tag}) in an event via hadronic decay channels (e.g. $B \to D\pi$) providing the info. on ***p***, ***E***, ***q***, etc. from which we can derive the info. of the other B meson (B_{sig}) directly. (The crucial concept of the hadronic tagging method !)

QUALITY CONTROL VARIABLES

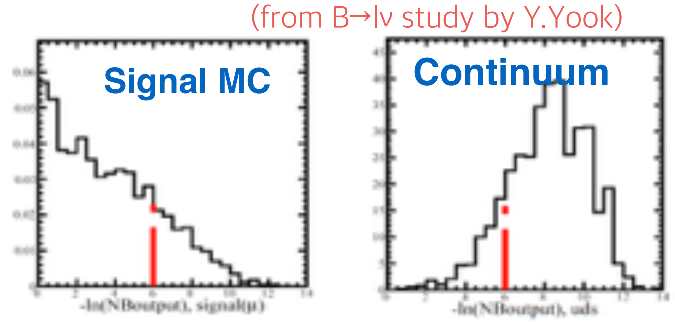
$$M_{bc} = \sqrt{((E_{CM}/2)^2 - |p_{tag}|^2}$$

$$\Delta E = E_{B_{tag}} - E_{CM}/2$$

E_{CM} : (2 x Beam energy) in CM frame
p_{tag} : The momentum of B_{tag} in CM frame
E_{Btag} : The energy of B_{tag} in CM frame

NB_{out} : Neuro-bayse Output

(from B→lν study by Y.Yook)



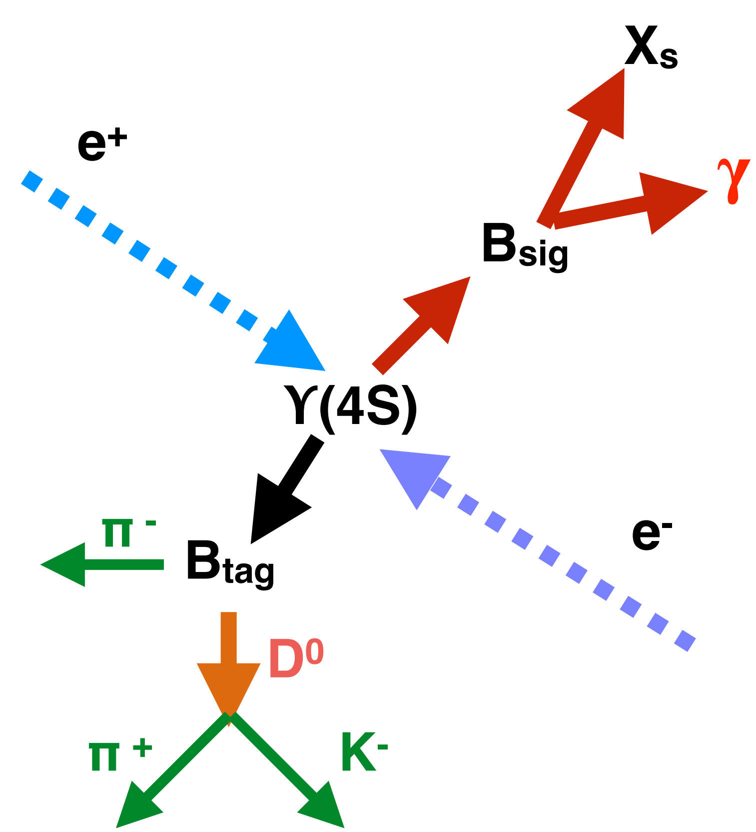


Figure 3. A schematic view of the hadronic tagging method via *B→Dπ channel*

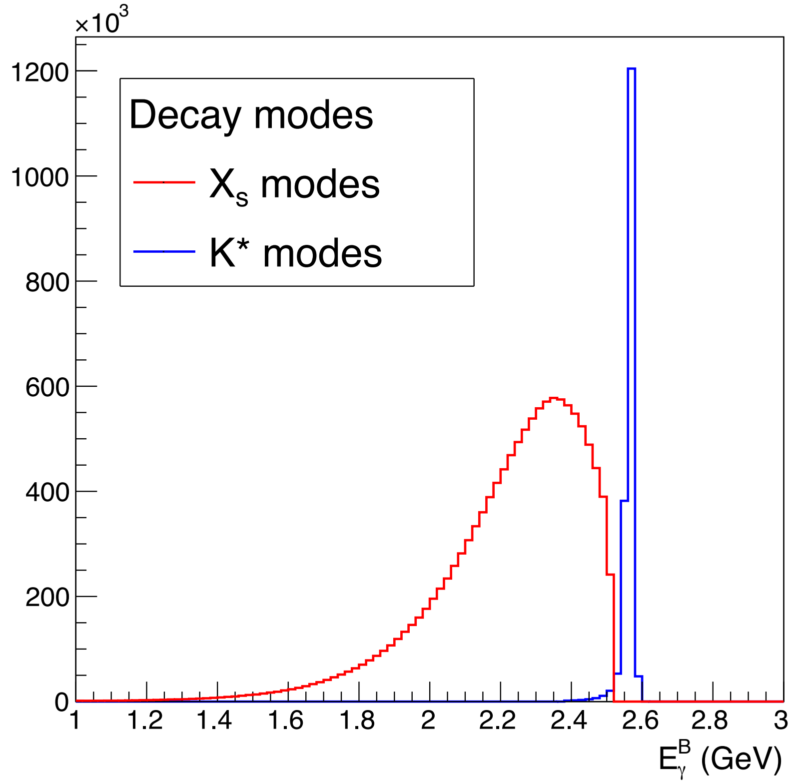
Introduction

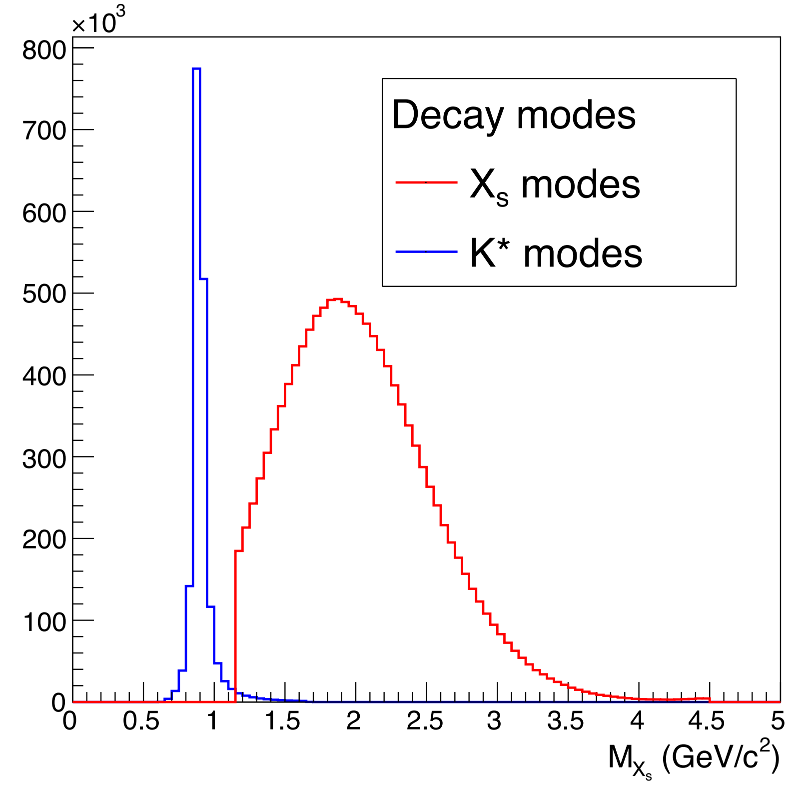
Signal MC

Kagan-Neubert model shaped with heavy quark parameters employed for signal modeling.

Current HFAG global fit for the heavy quark parameters

$$m_b = 4.541 \pm 0.023 \text{ GeV} \qquad \mu_\pi^2 = 0.414 \pm 0.078 \text{ GeV}^2$$





$B \rightarrow K^*\gamma$ channels are separately generated for more realistic modeling.

Events as ~25 times as many $N_{expected}$ in Data was generated

Selection Criteria

EKP fullrecon

Best B_{tag} Selection

(For the B_{tag} with the highest o_{tag})

$$o_{tag} > 0.1$$

$$5.24 < M_{bc}^{tag} < 5.29\mathrm{GeV}$$

$$|\Delta E| < 0.06\mathrm{GeV}$$

Contiuum Suppression

NeuroBayes
with event shape variables

Signal Candidate Selection

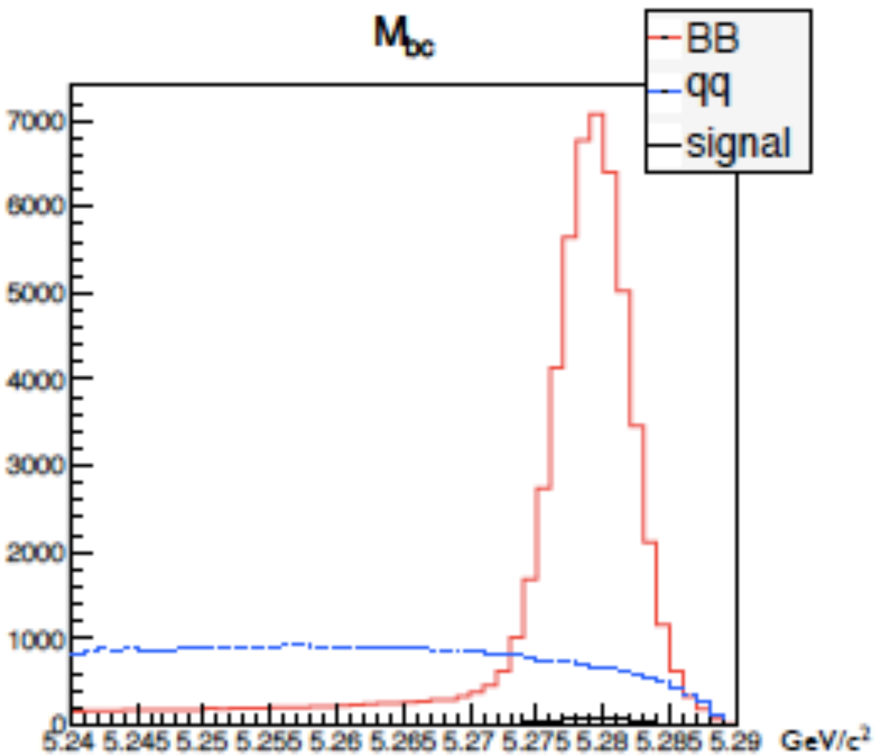
Most energetic (in B rest frame) gamma
among sig-side gammas.

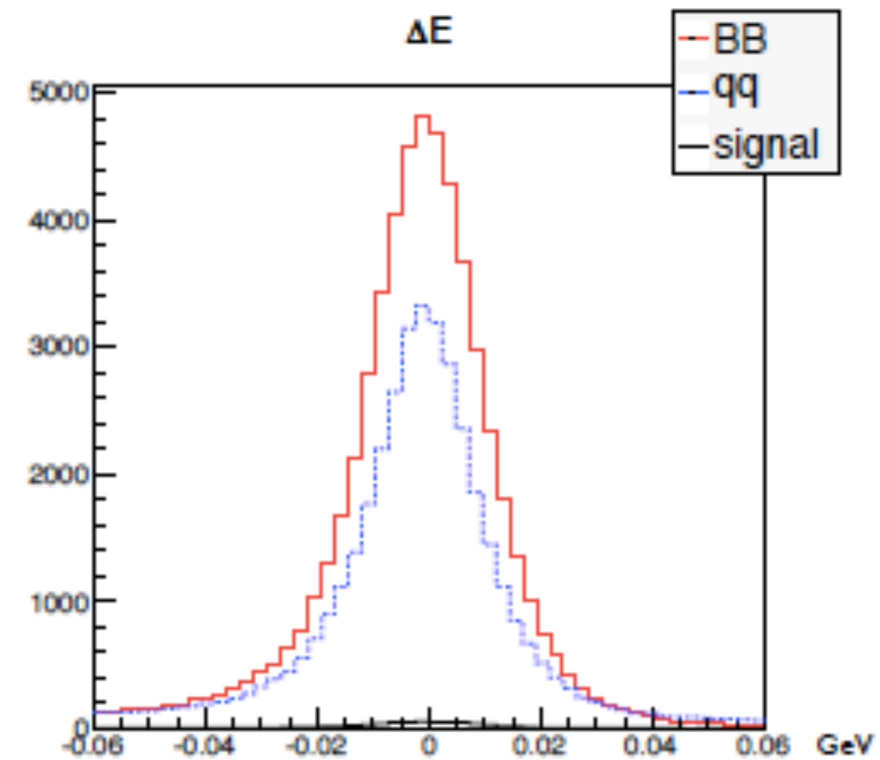
$$E_{\mathrm{candi.}\gamma}^{B} > 1.3\mathrm{GeV}$$

Signal Isolations

1. TDC off-timing veto
   - to suppress beam backgrounds
2. π^0 & η veto
   - based on P. Koppenburg's study
3. E9/E25 (photon purity)
4. electron radiation veto
   - Reject photons too close to electron track

Best B Selection





	Simulated	After fullrecon & pre-selection	Efficiency
Signal	1.45E+07	2.11E+04	0.15%
Generic	3.86E+09	1.21E+07	0.31%
Continuum	1.16E+10	5.32E+06	0.05%

Table. The number of event before/after the fullrecon & pre-selection of sig/Generic/Continuum.

All MC available in KEKCC are employed

< Multipliers to corresponding # of events in DATA>

10x generic $B\bar{B}$

6x continuum

50x Rare B decay set

20x Ulnu decay set

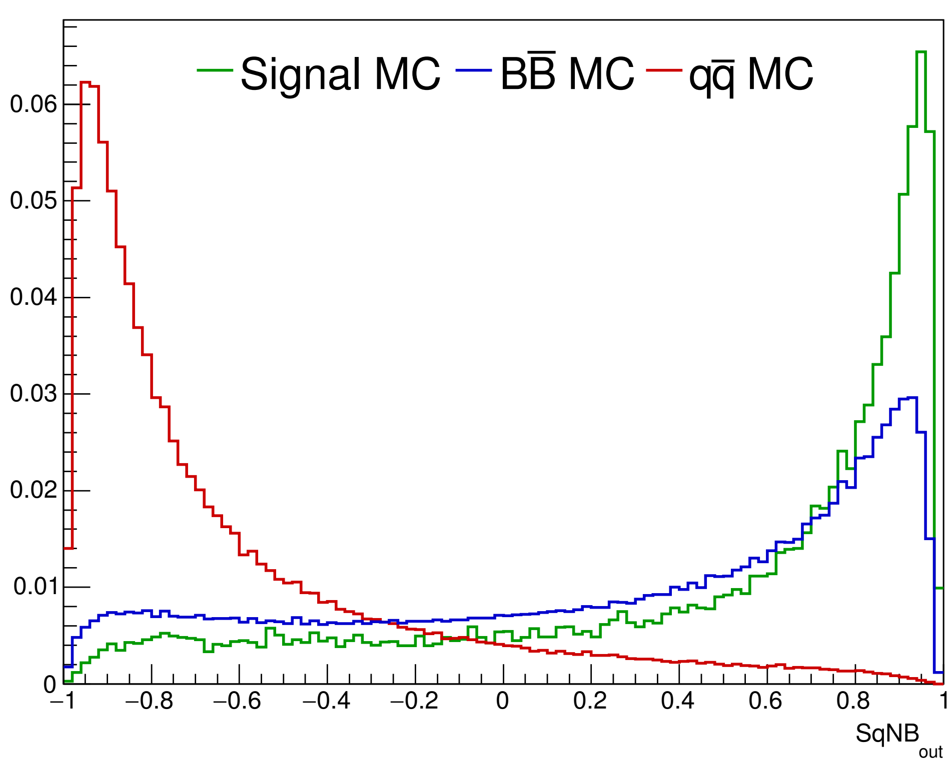
Continuum Suppression using NeuroBayes

- Test Input Variables - Event Shape Variables

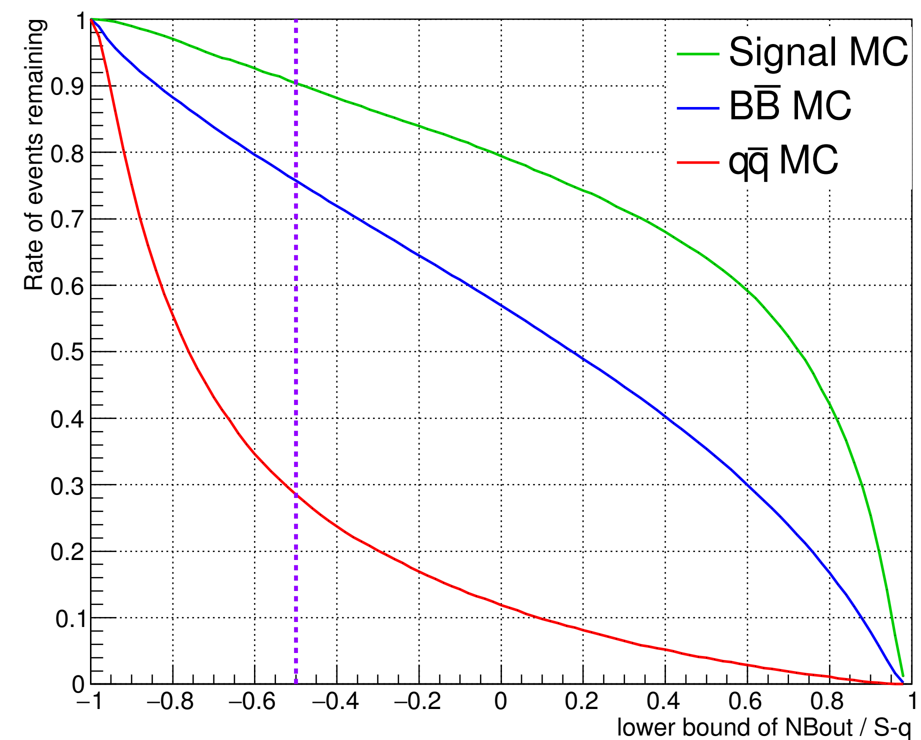
O_{tag}, $|\cos\theta_{thrust}|$, Missing M^2, E_T, Super-Fox-Wolfram moments, Sphericity, Aplanarity, and $\cos\theta_B$

- NB output distributions & performance

NB output



Eff. for NB output > x



$SqNB_{out}$ > -0.5 is required

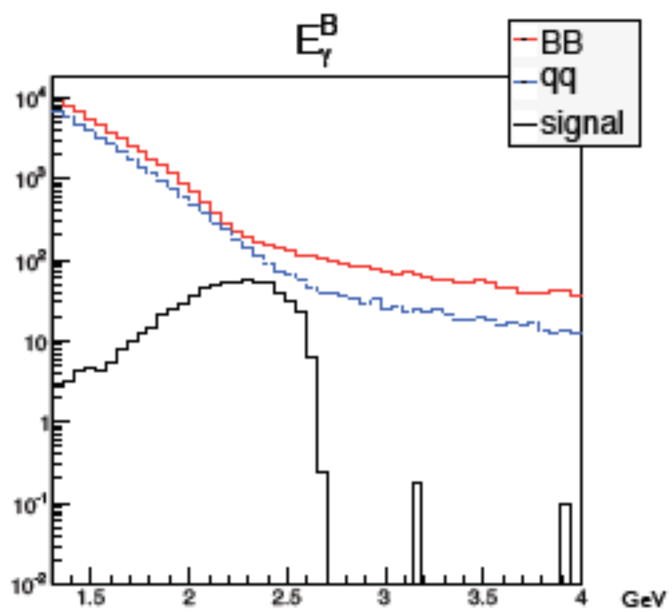
90% of signal events are reserved while rejecting 70% of the continuum events

Selection Criteria

Signal Candidate Selection

The most energetic (in B rest frame) photon among sig-side gammas.

$E_{\gamma}{}^{B}{}_{candi}$ > 1.3 GeV required



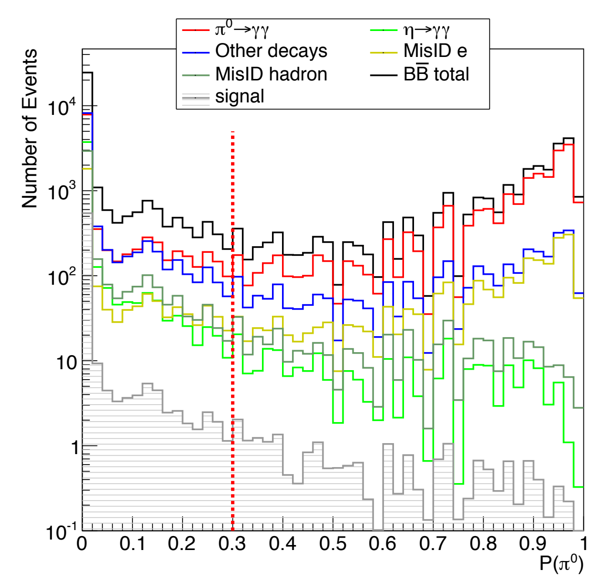
Signal Isolations

1. Beam background rejection

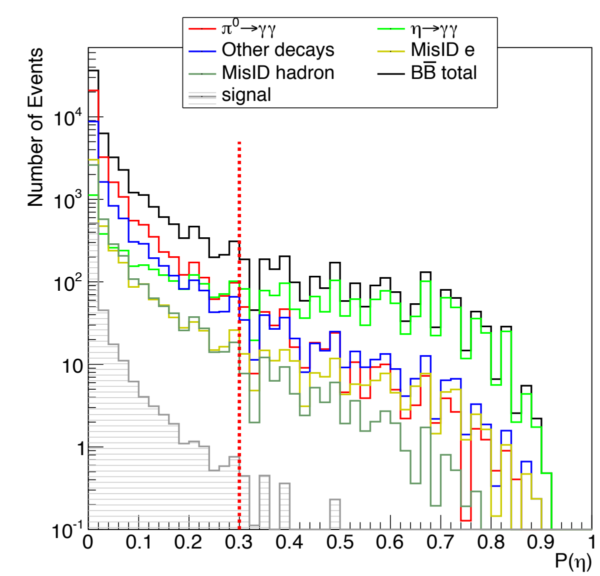
Using ECL trigger timing information

2. $\pi^0/\eta \rightarrow \gamma\gamma$ rejection

Using probability distribution obtained by control samples in the mass & photon energy

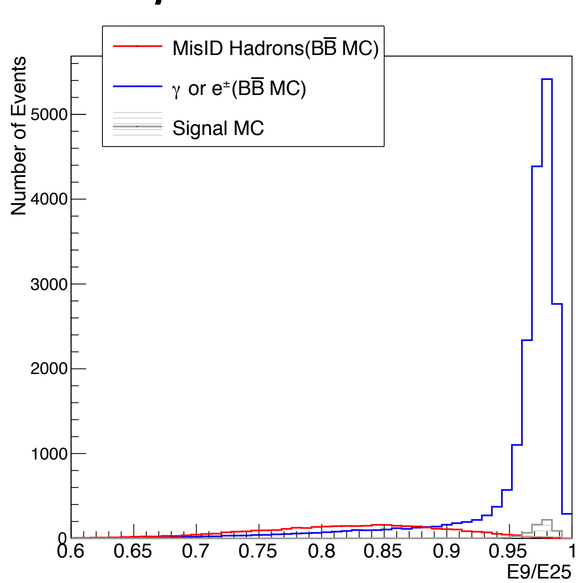


Red($\pi^0\rightarrow\gamma\gamma$) peak around 1



GR($\eta\rightarrow\gamma\gamma$) shows high prob.

3. E9/E25 > 0.95



E9 : E deposited in 3X3 ECL cluster

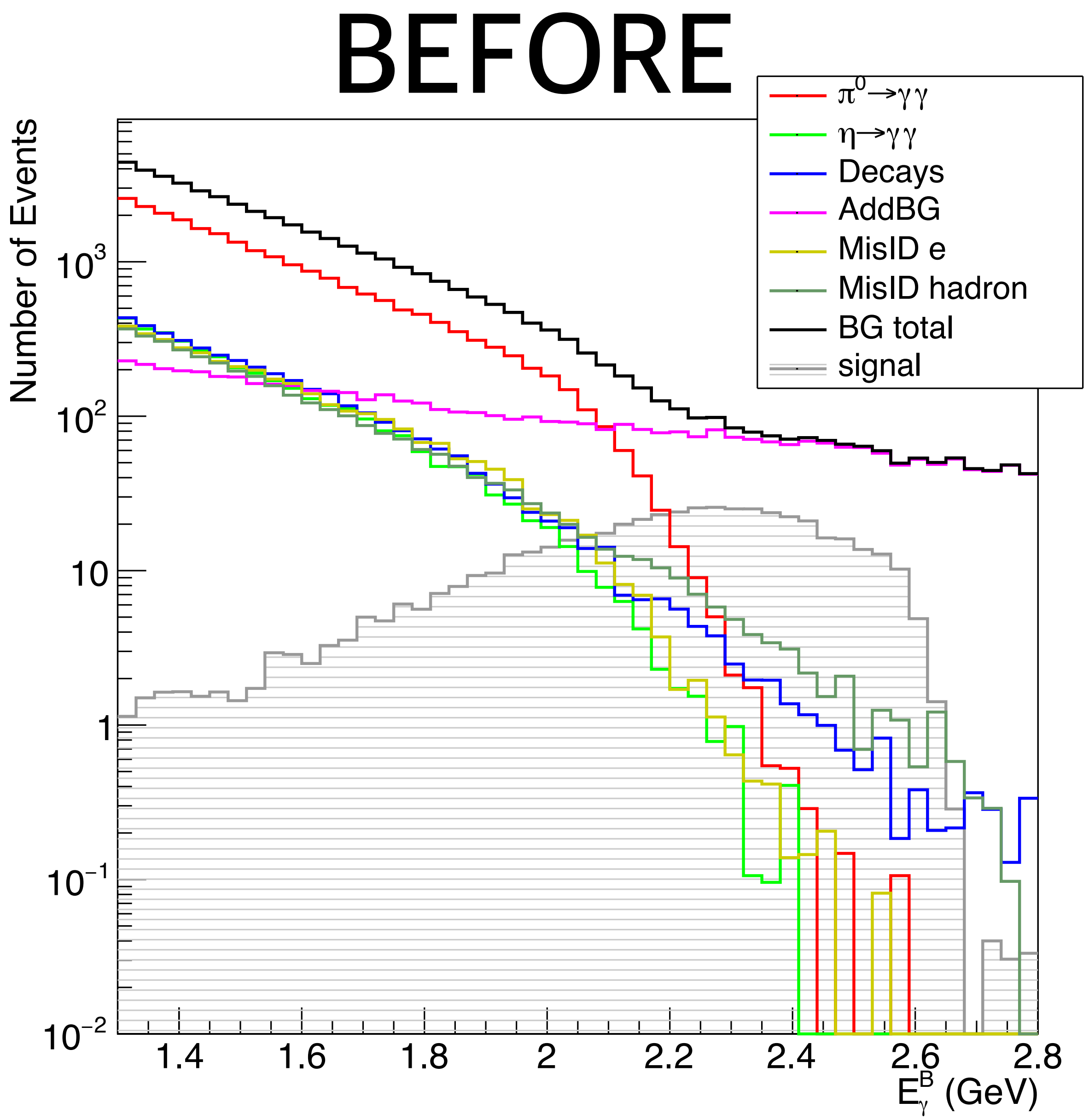
E25 : E deposited in 5X5 ECL cluster

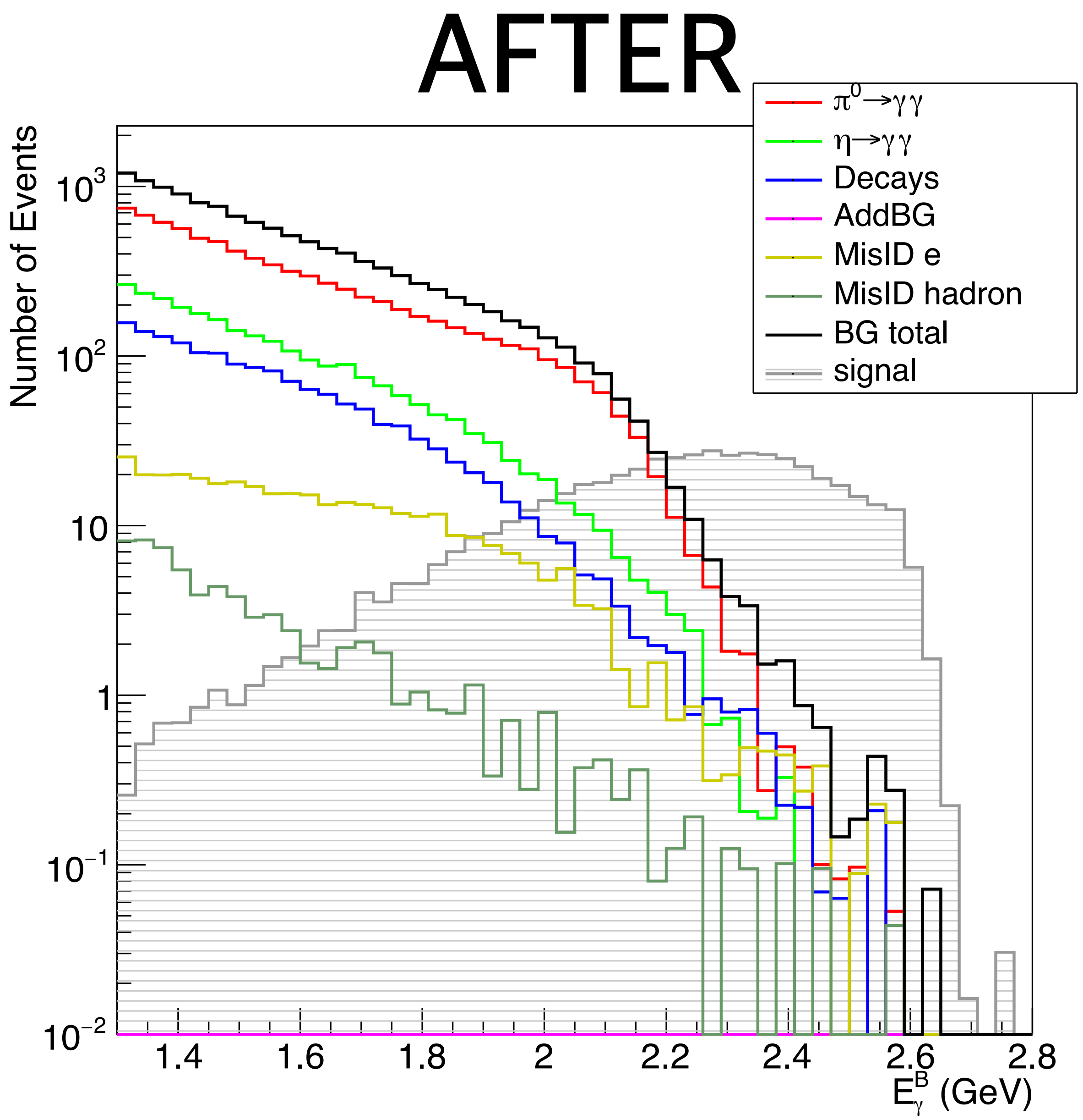
We can reject a lot of bkg mis-identified as photon, especially most of hadron showers

4. e radiation veto

Angle btw. candidate gamma & the closest electron was tested to veto the events oriented by electron's emission. $e\rightarrow e\gamma$ events have a peak around $\cos\theta_e = 1$

Selection Criteria





Each requirements were optimized to show the possible- highest significance in the target region, $1.8 < E_\gamma < 2.0$ GeV

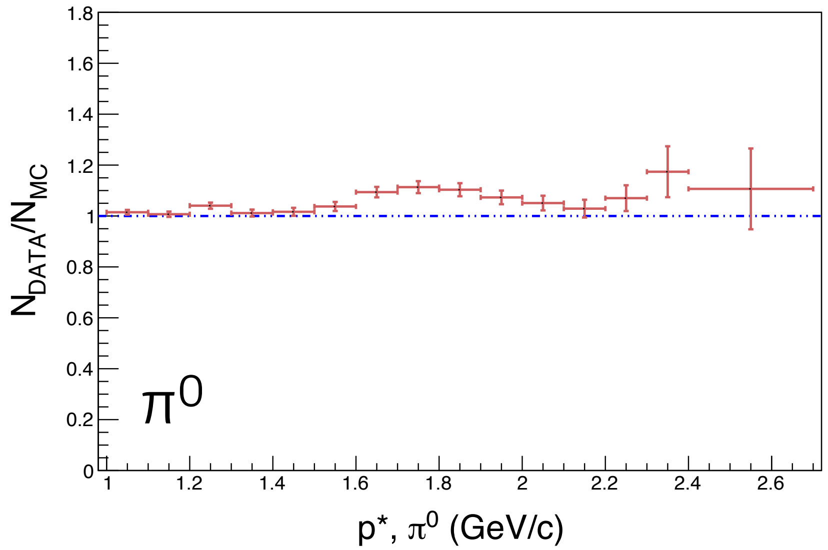
Overall gaussian significance improved from 2.1 to 3.9

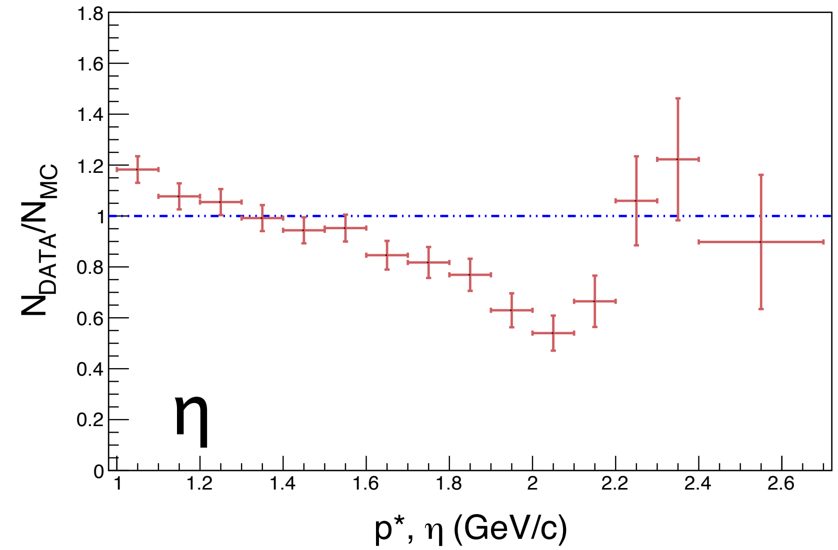
Many π^0 & η originated bkg still remaining

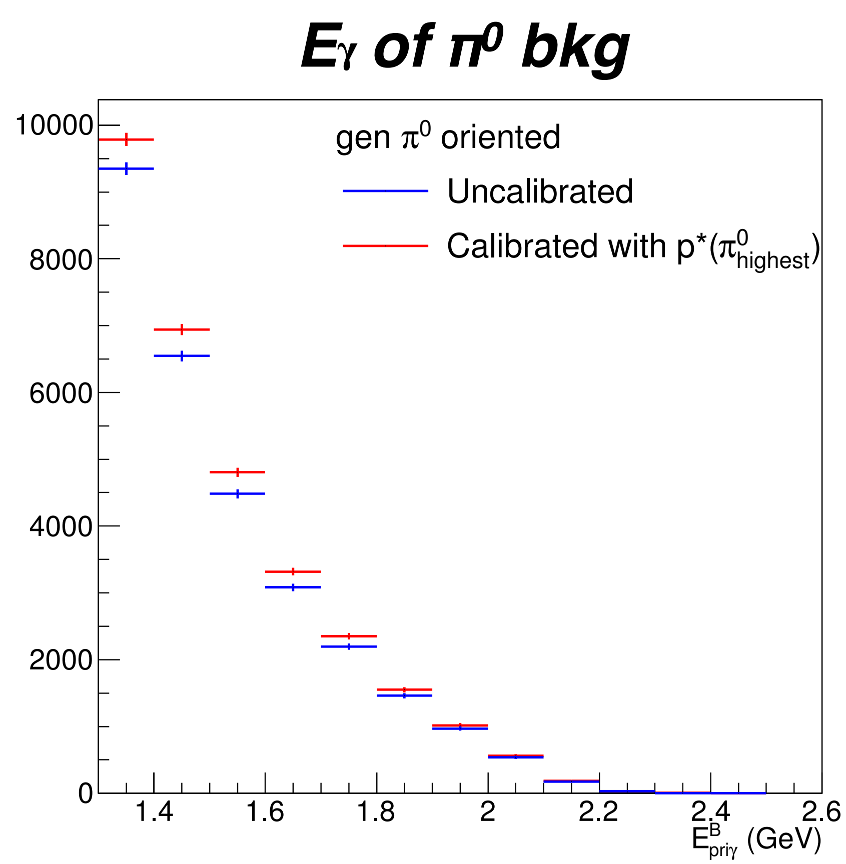
π^0/η Background Calibration

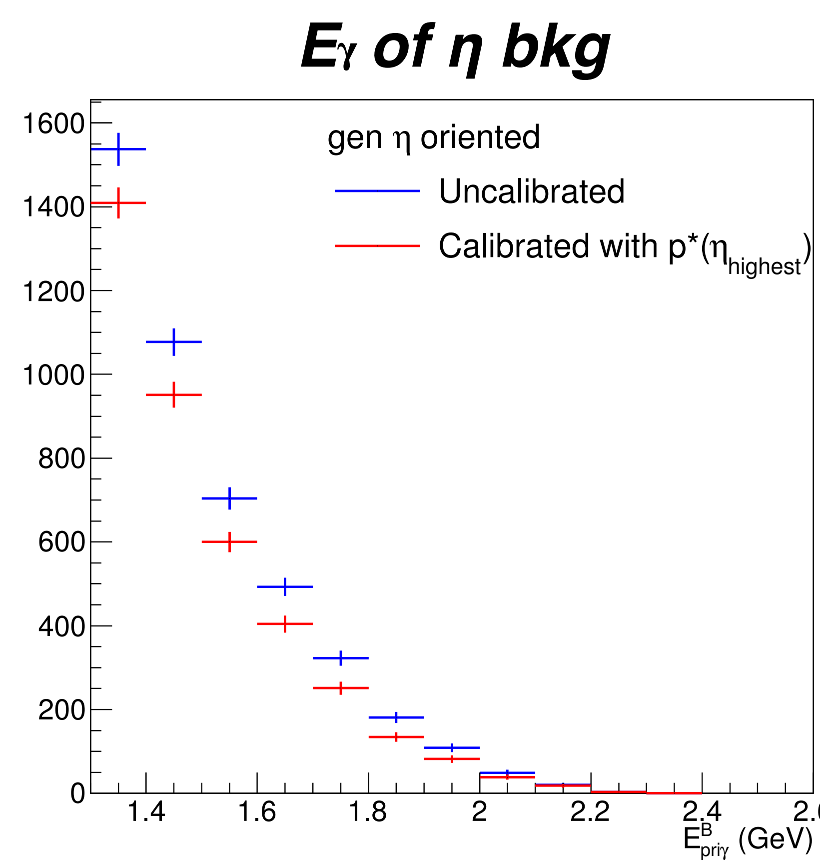
- To correct the absolute rate of π^0 & η background, the calibration factors are obtained using a large-sized set of M($\gamma\gamma$) control samples

Errors are only statistical at the moment









Signal Efficiency

$$\epsilon_i = N^{fit}_{recon-i} / N^{gen}_{gen-i}$$

Measured in **recon**. Egam

Measured in **gen.** Egam

Currently we *do not* consider off-diagonal contributions between recon. & gen. Egam

The B.F. measurement should be affected little.

Unfolding (by like SVD method) *is not* considered because
it can be another source of huge systematic uncertainty

Simultaneous Fitting Method

Egam range of interest : $1.6 < E^B_\gamma < 2.6$ GeV (10 of 0.1GeV-wide bins)

$$PDF_i(\theta) = PDF_i(\theta(E_\gamma); E_\gamma)$$

We fit all 10 bins simultaneously

PDF Parameters are parameterised as polynomials of Egam

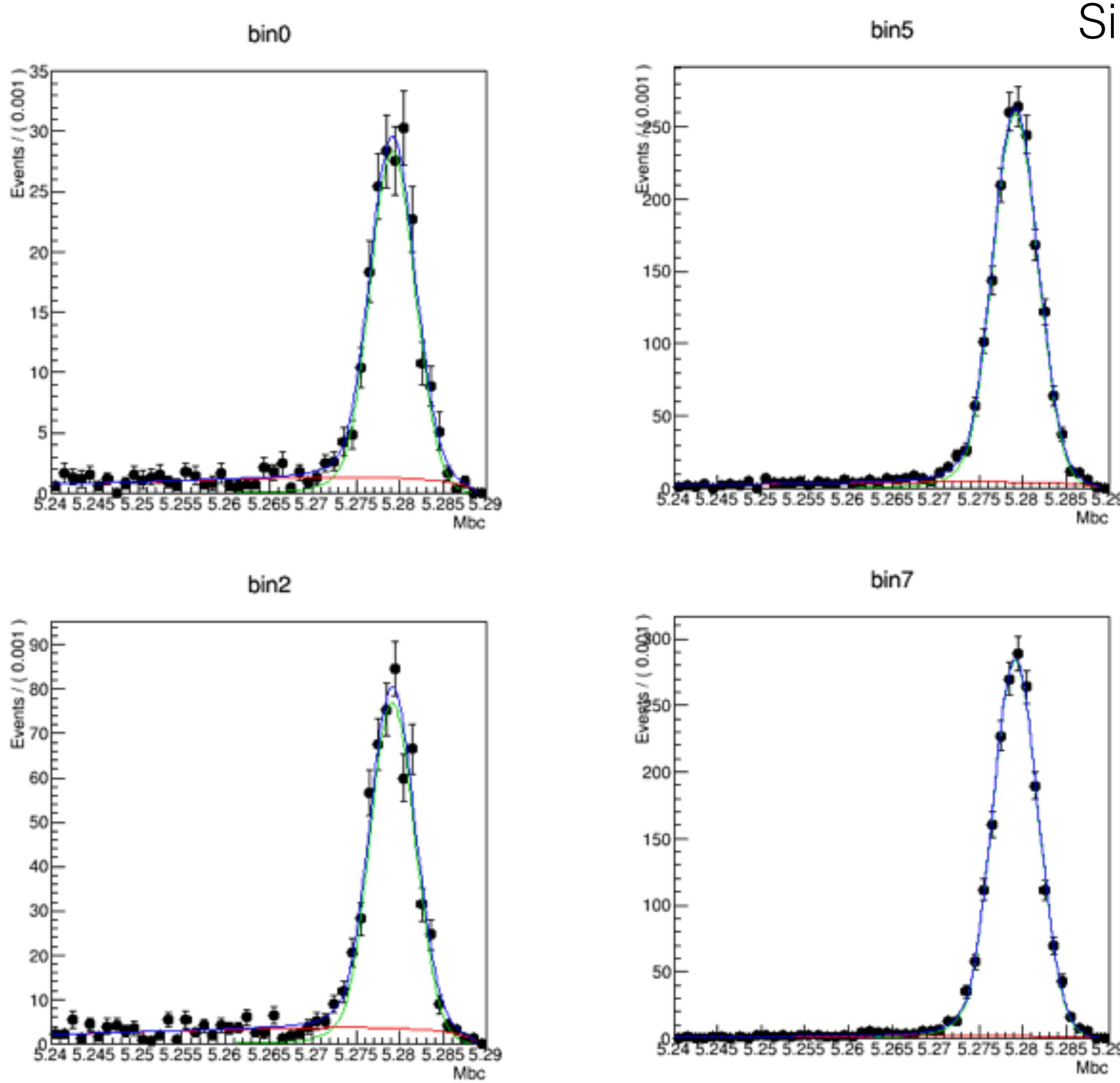
The order of each polynomials are adjusted to have the lowest-possible order

Signal Yield Estimation

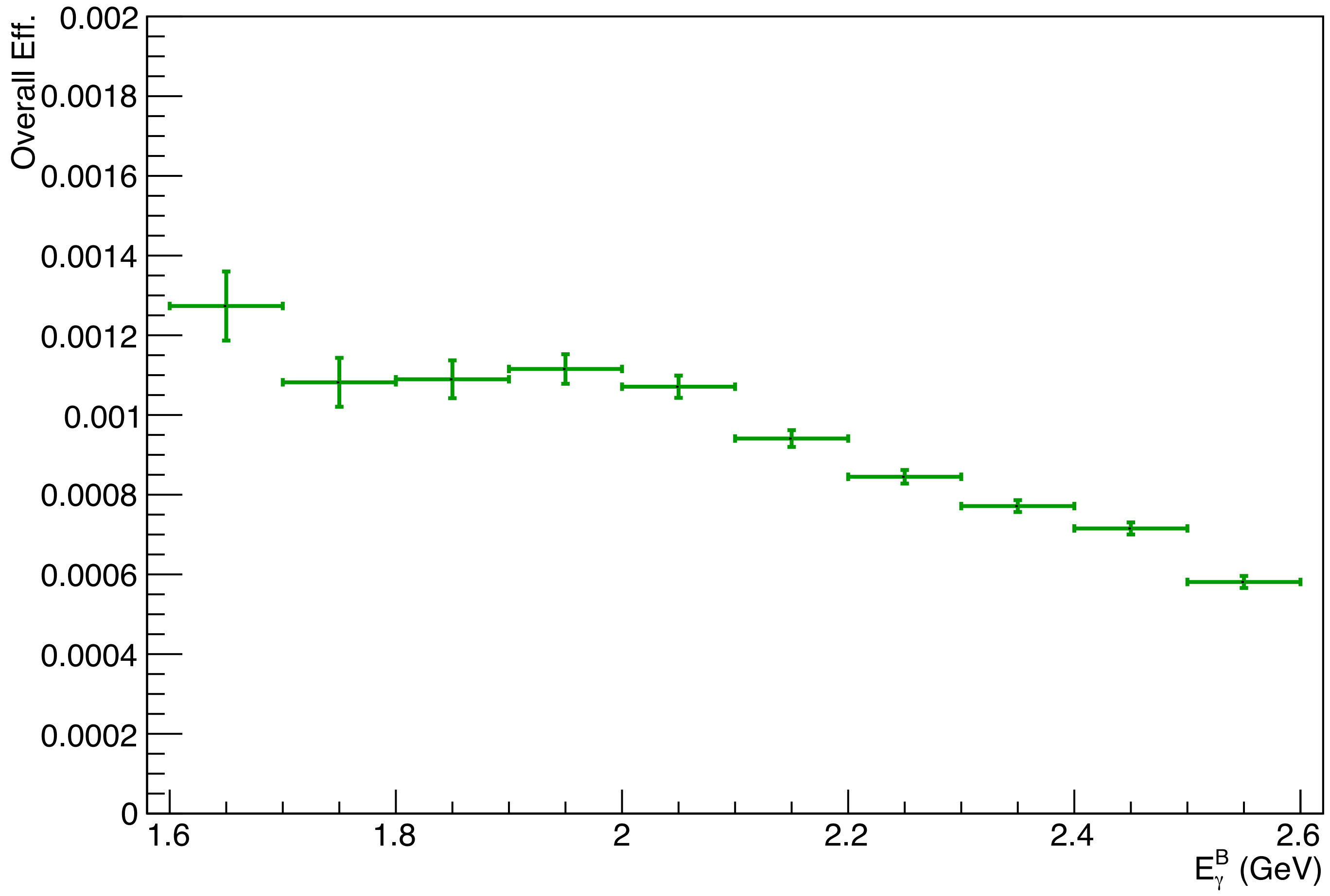
Simultaneous Fitting Method

EXAMPLE

Signal (Xs Only) MC



Signal Efficiency



bin	from	to	eff
0	1.6	1.7	1.3E-03
1	1.7	1.8	1.2E-03
2	1.8	1.9	1.2E-03
3	1.9	2.0	1.1E-03
4	2.0	2.1	1.1E-03
5	2.1	2.2	9.4E-04
6	2.2	2.3	8.2E-04
7	2.3	2.4	7.6E-04
8	2.4	2.5	7.7E-04
9	2.5	2.6	5.6E-04

Systematic Uncertainties

- Possible sources of systematic uncertainties
- Note most of them will be canceled out in asymmetry calculations

1. General
   1.1. Binning effect
   1.2. N_{BB} uncertainty
   1.3. Tagging efficiency bias

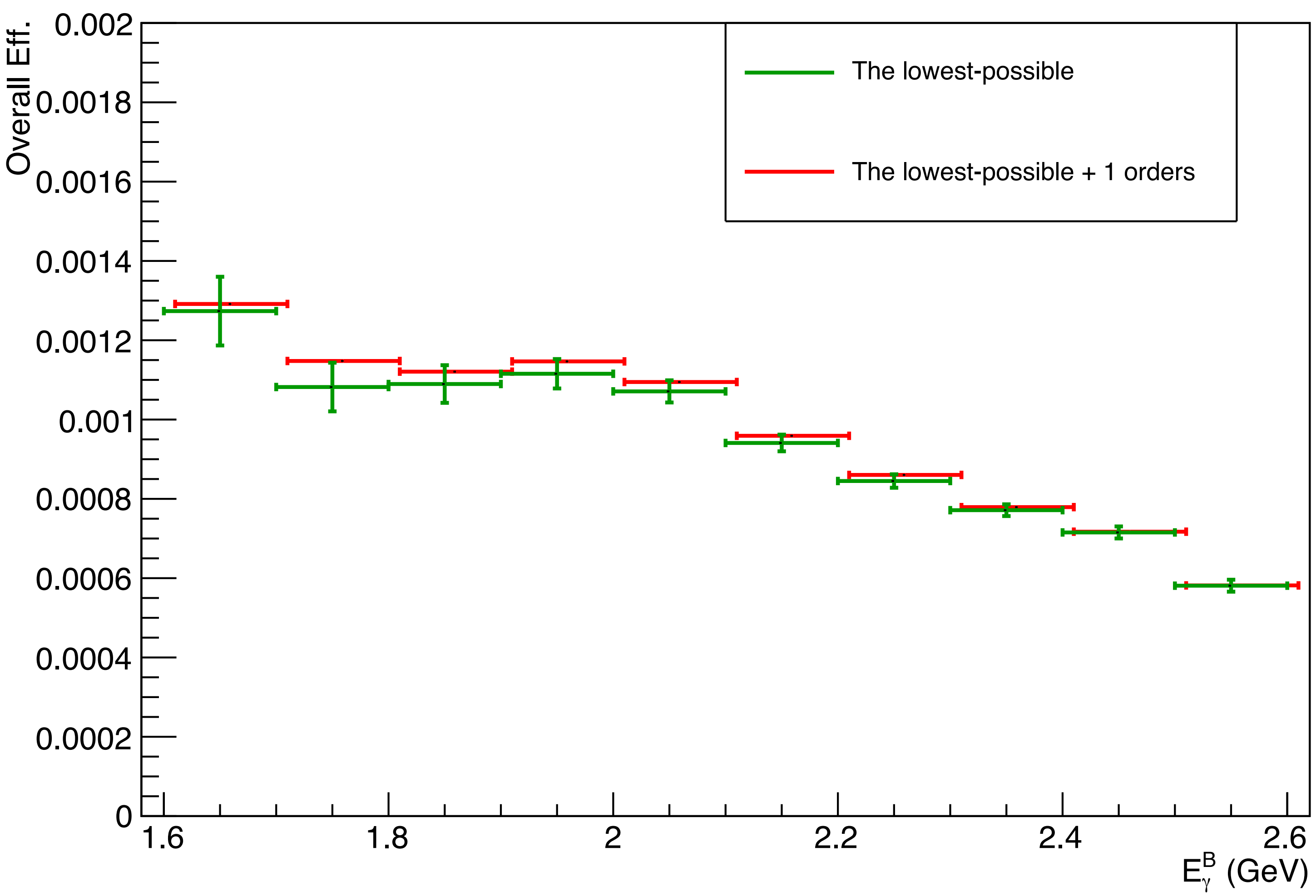
2. Signal Efficiency
   2.1. HFAG BF uncertainty
   2.2. BF($b \rightarrow d\gamma$) uncertainty
   2.3. Heavy quark parameters' uncertainties
   2.4. Extrapolation factor uncertainty
   2.5. High E photon detection rate

3. Background Yield
   3.1. Correction factors
   3.2. Selection criteria

Systematic Uncertainty Associated the Signal Efficiencies

PDF parameterisation

Estimation was performed by measuring the deviation obtained when we give an additional d.o.f to each PDF parameters

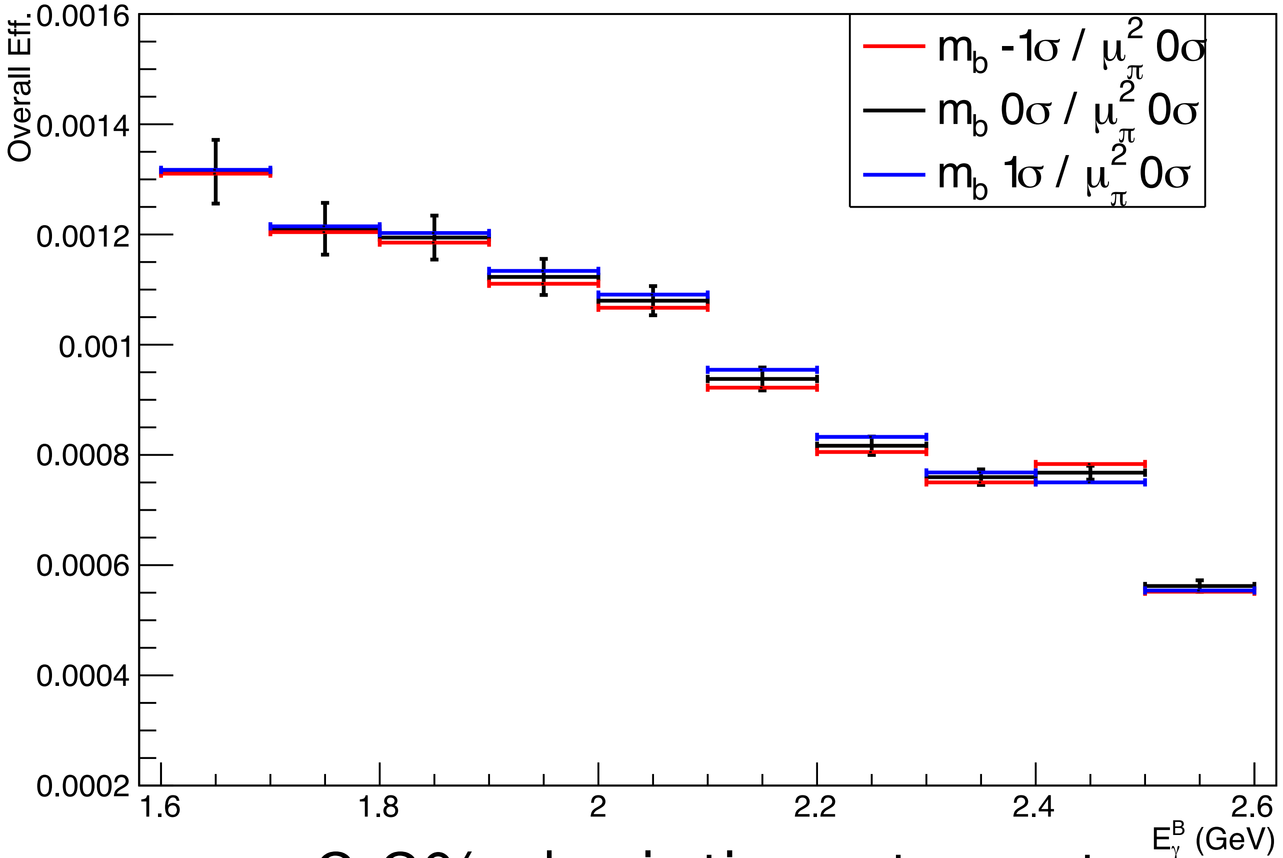


bin	from	to	eff	DEV.	in %
0	1.6	1.7	1.3E-03	1.8E-05	1.4%
1	1.7	1.8	1.2E-03	6.6E-05	5.4%
2	1.8	1.9	1.2E-03	3.1E-05	2.6%
3	1.9	2.0	1.1E-03	3.1E-05	2.8%
4	2.0	2.1	1.1E-03	2.4E-05	2.2%
5	2.1	2.2	9.4E-04	1.8E-05	1.9%
6	2.2	2.3	8.2E-04	1.5E-05	1.9%
7	2.3	2.4	7.6E-04	7.7E-06	1.0%
8	2.4	2.5	7.7E-04	1.9E-06	0.2%
9	2.5	2.6	5.6E-04	7.0E-07	0.1%

Systematic Uncertainty Associated the Signal Efficiencies

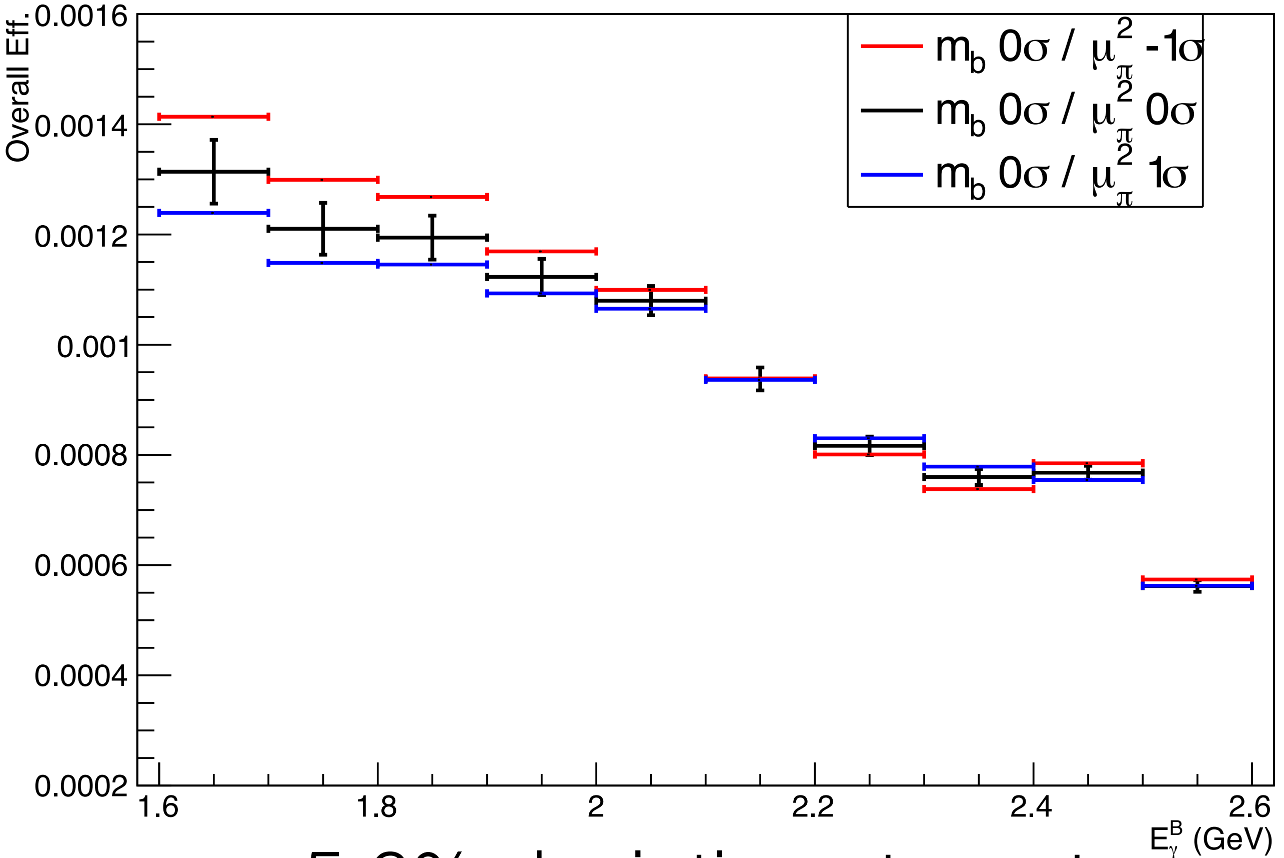
Shape parameter systematic uncertainty (Delta Method)

$m_b \pm 1\sigma$ variation



2.2% deviation at most
(bin 2.4-2.5GeV)

$\mu_\pi^2 \pm 1\sigma$ variation



5.6% deviation at most
(bin 1.6-1.7GeV)

delta method with definition;

$$\sigma_\epsilon^2 = (\partial_{m_b}\epsilon)^2\sigma_{m_b}^2 + (\partial_{\mu_\pi^2}\epsilon)^2\sigma_{\mu_\pi^2}^2 + (\partial_{m_b}\epsilon)(\partial_{\mu_\pi^2}\epsilon)\mathrm{Cov}(m_b, \mu_\pi^2)$$

Systematic Uncertainty
Associated the Signal Efficiencies

Shape parameter systematic uncertainty (Delta Method)

Result summary

bin	from	to	eff	PDF shape	Shape parameter	quad sum	rate
bin0	1.6	1.7	1.3E-03	1.8E-05	9.9E-05	1.0E-04	7.69%
bin1	1.7	1.8	1.2E-03	6.6E-05	8.8E-05	1.1E-04	9.09%
bin2	1.8	1.9	1.2E-03	3.1E-05	7.3E-05	7.9E-05	6.65%
bin3	1.9	2.0	1.1E-03	3.1E-05	4.7E-05	5.6E-05	4.99%
bin4	2.0	2.1	1.1E-03	2.4E-05	2.2E-05	3.2E-05	3.00%
bin5	2.1	2.2	9.4E-04	1.8E-05	1.7E-05	2.4E-05	2.61%
bin6	2.2	2.3	8.2E-04	1.5E-05	2.1E-05	2.6E-05	3.21%
bin7	2.3	2.4	7.6E-04	7.7E-06	2.3E-05	2.4E-05	3.17%
bin8	2.4	2.5	7.7E-04	1.9E-06	2.3E-05	2.3E-05	3.01%
bin9	2.5	2.6	5.6E-04	7.0E-07	1.5E-05	1.5E-05	2.62%

Other sources of the systematic associated with the B.F measurement.

N_{BB} uncertainty

N_{bkg} (summarised in back-up)

$B \to X_d \gamma$ subtraction $(4.0 \pm 0.4)\%$ (Babar fullrecon, CKMfitter)

Photon detection efficiency ~2% (P. Koppenburg)

Summary and Plan

Most part necessary for B.F. measurements has been studied

On the way to **opening the box** !

Please stay tuned!

Need further study on systematic uncertainties
for measuring the *asymmetries*

Followings will be studied to validate the study before
B.F. measurement..

Linearity test
NBout sideband study
..

BACKUP

NeuroBayes for the Continuum Suppression

Suggested by Dr. Ishikawa

- In the current BN1355..

Continuum events are suppressed by the requirement, $|\cos\theta_{thrust}| < 0.8$, only.

(for $E\gamma$>1.9 GeV) qq MC rejection ~ 70% while reserving ~80% of signal and BB MC

Maybe we could reject the continuum events more efficiently by using NeuroBayes.

- Pre-selection

Best B selection - $O_{tag} > 0.1$, $5.24 < M_{bc} < 5.29$, $|\Delta E| < 0.06$ (The same as in BN1355 v1.5)

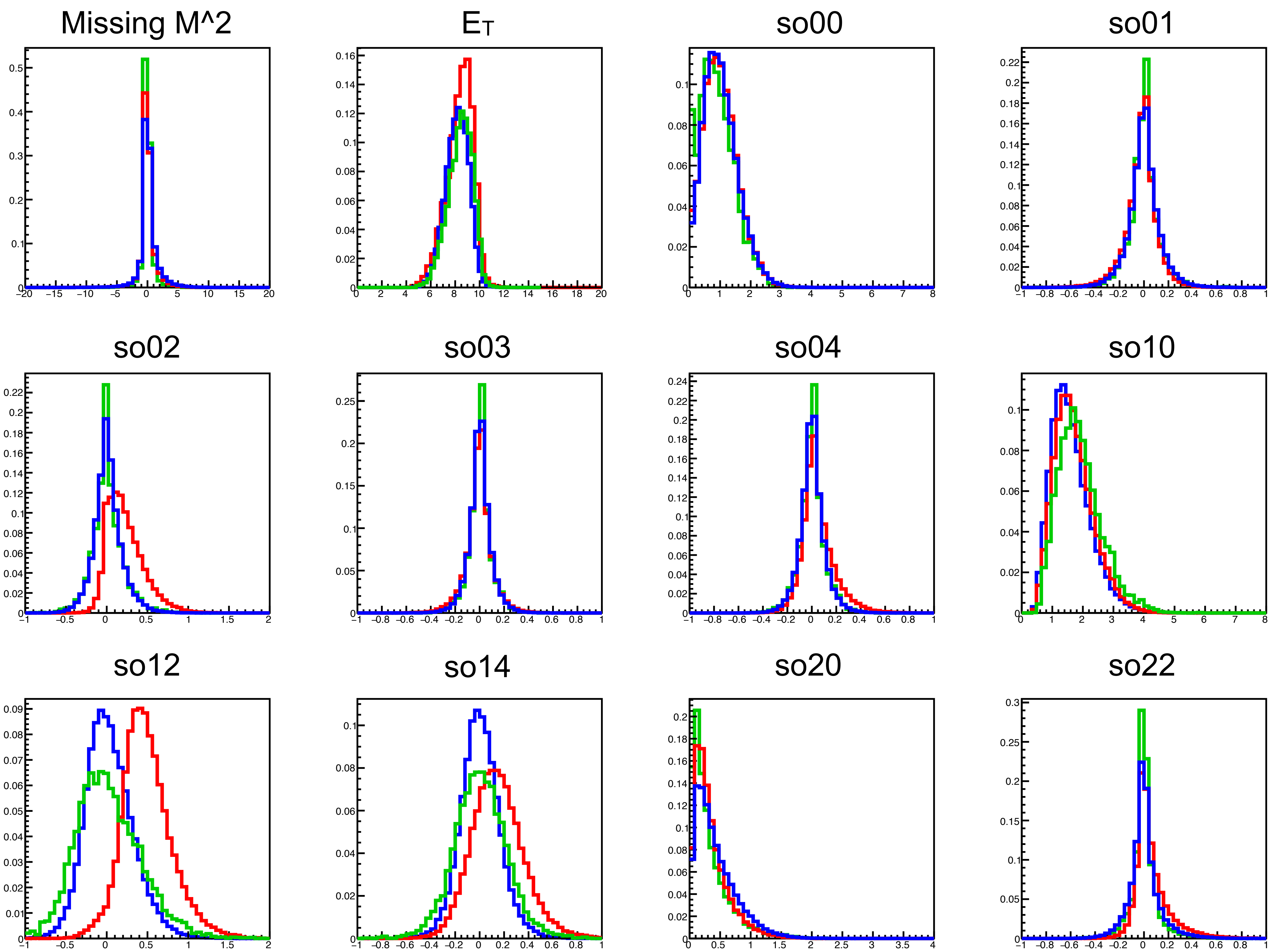
- Test Input Variables - Event Shape Variables

O_{tag}, $|\cos\theta_{thrust}|$, Missing M^2, E_T, Super-Fox-Wolfram moments, Sphericity, Aplanarity, and $\cos\theta_B$

- Correlation test with the primary E_{gam} in Bsig rest frame (for signal MC)

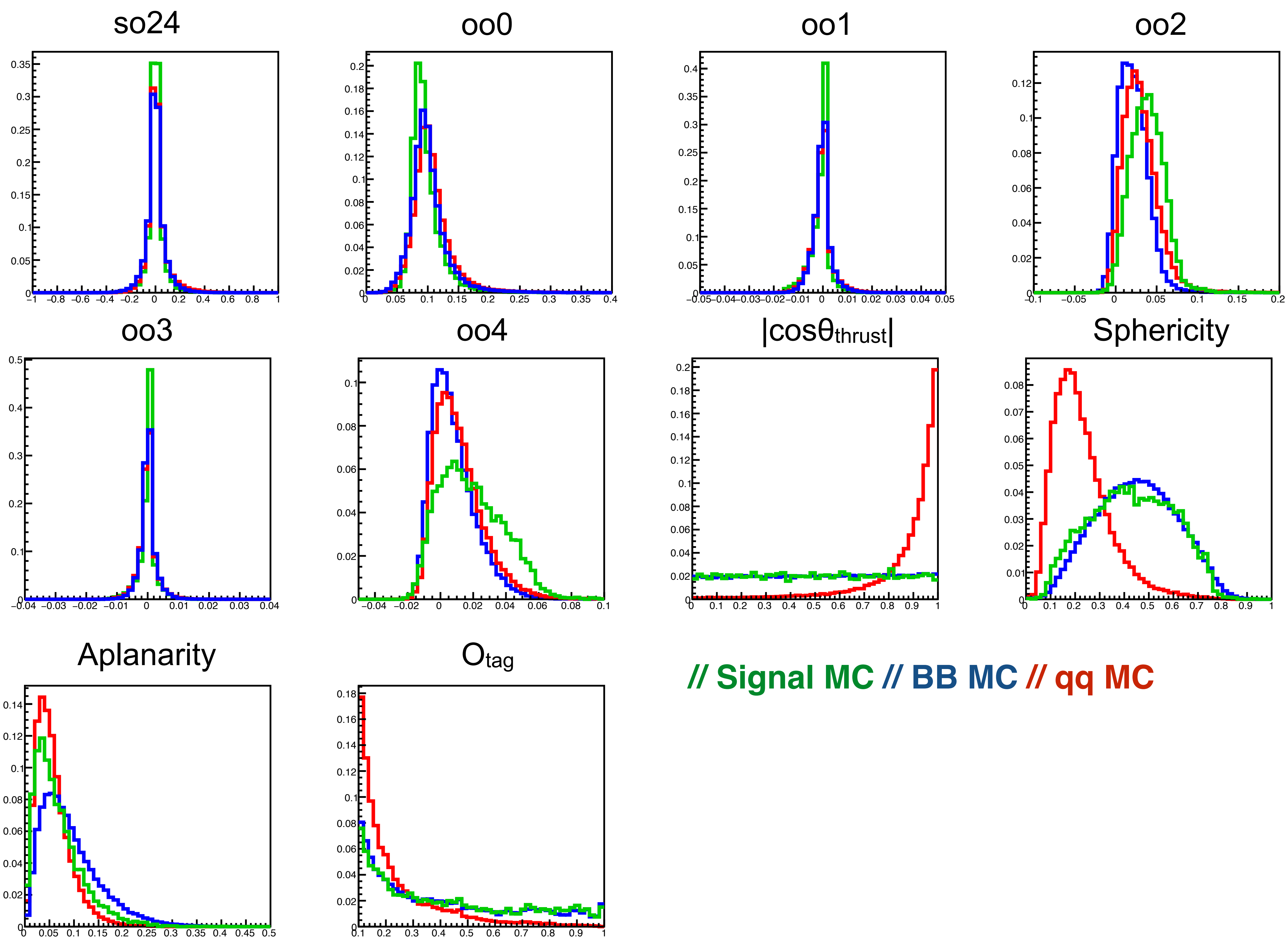
Variables which show obvious correlation (numerically, C>=0.15) with E_{gam}(>1.3 GeV) in 2D scatter plot are excluded from the input variable set.

Continuum suppression using NeuroBayes



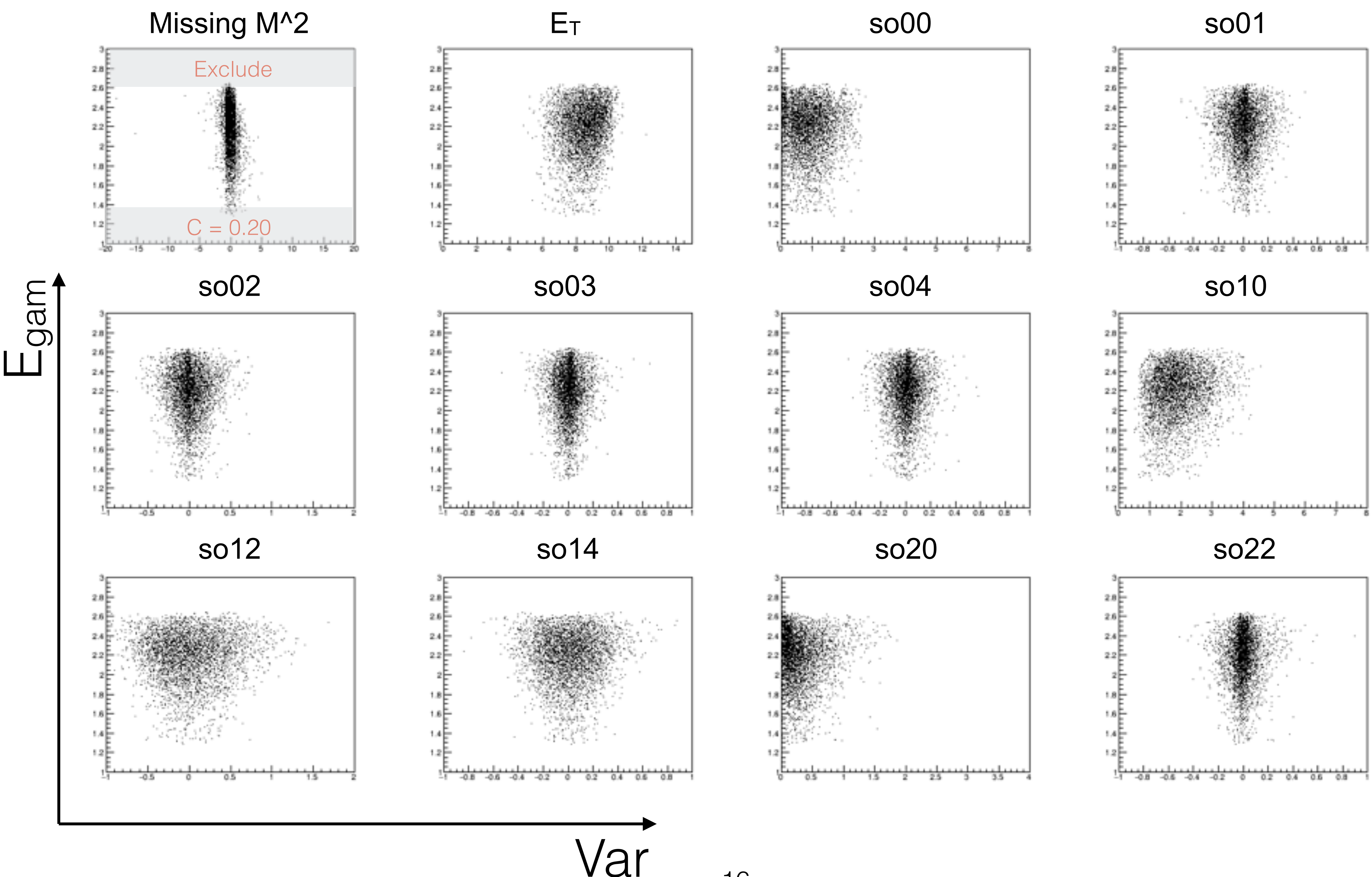
// Signal MC // BB MC // qq MC

Continuum suppression using NeuroBayes



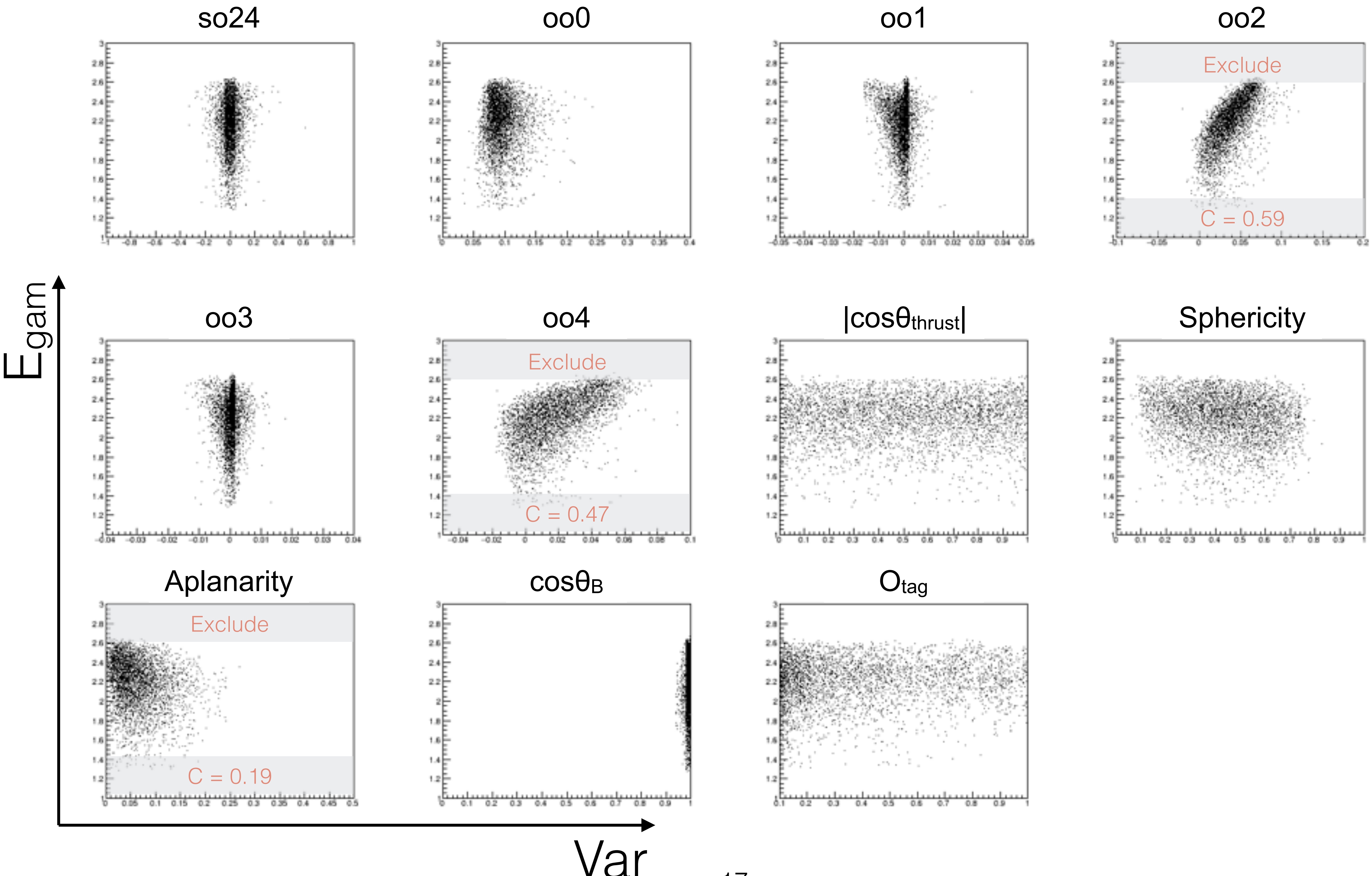
Continuum suppression using NeuroBayes

- Correlation test with the primary E_{gam} in Bsig rest frame (for signal MC)



Continuum suppression using NeuroBayes

- Correlation test with the primary E_{gam} in Bsig rest frame (for signal MC)



NeuroBayes for the Continuum Suppression

- Input Variables - 19 events shape variables

- Training Samples

  signal MC - ~7700 events

  BB MC - events from exp65 in str0

  qq MC - events from exp65 in str0

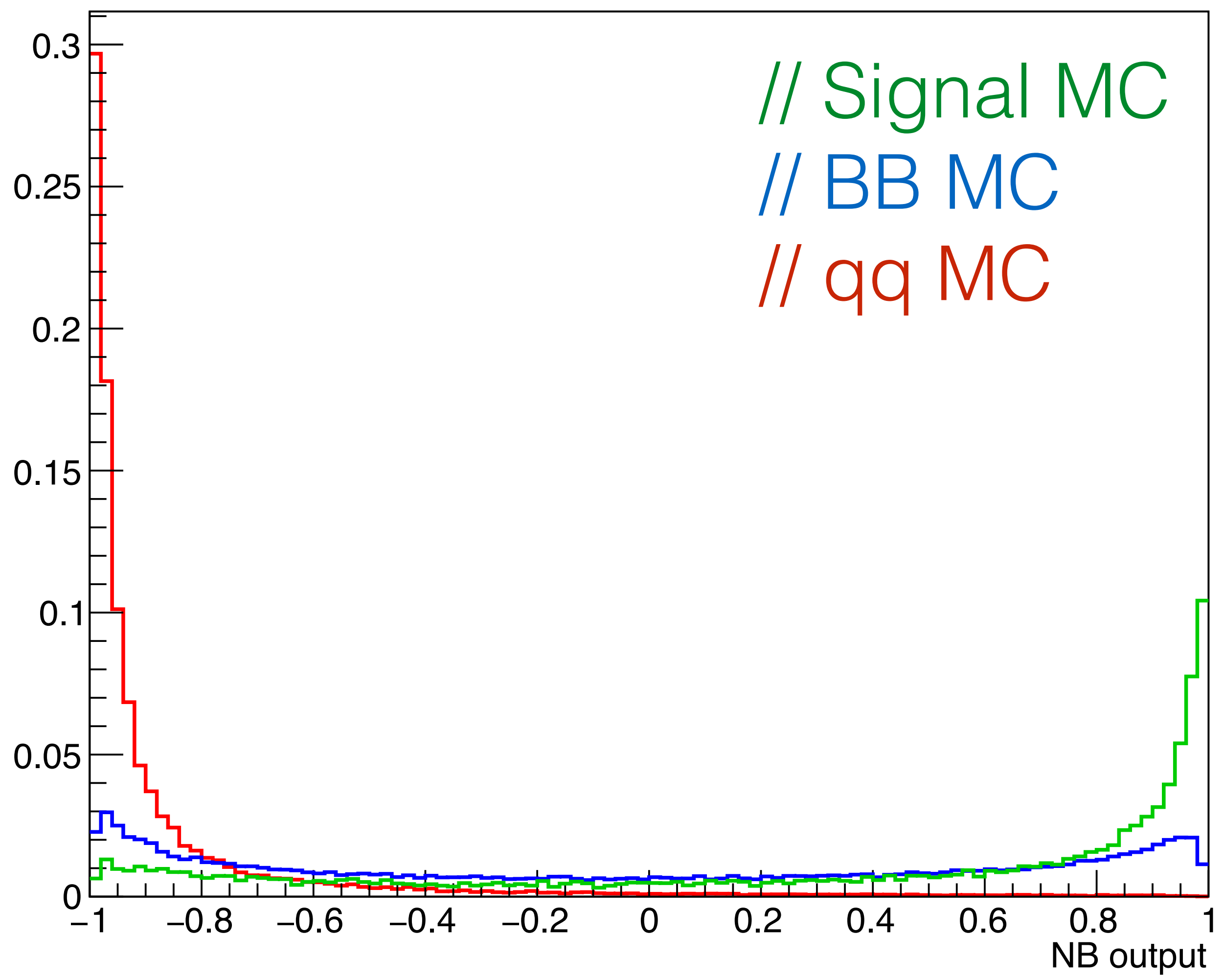
- Training Setup

  Binary problem between signal MC and the continuum MC

  (Other problem setup was also tested, check the backup for the details)

NeuroBayes for the Continuum Suppression

- NB output distributions

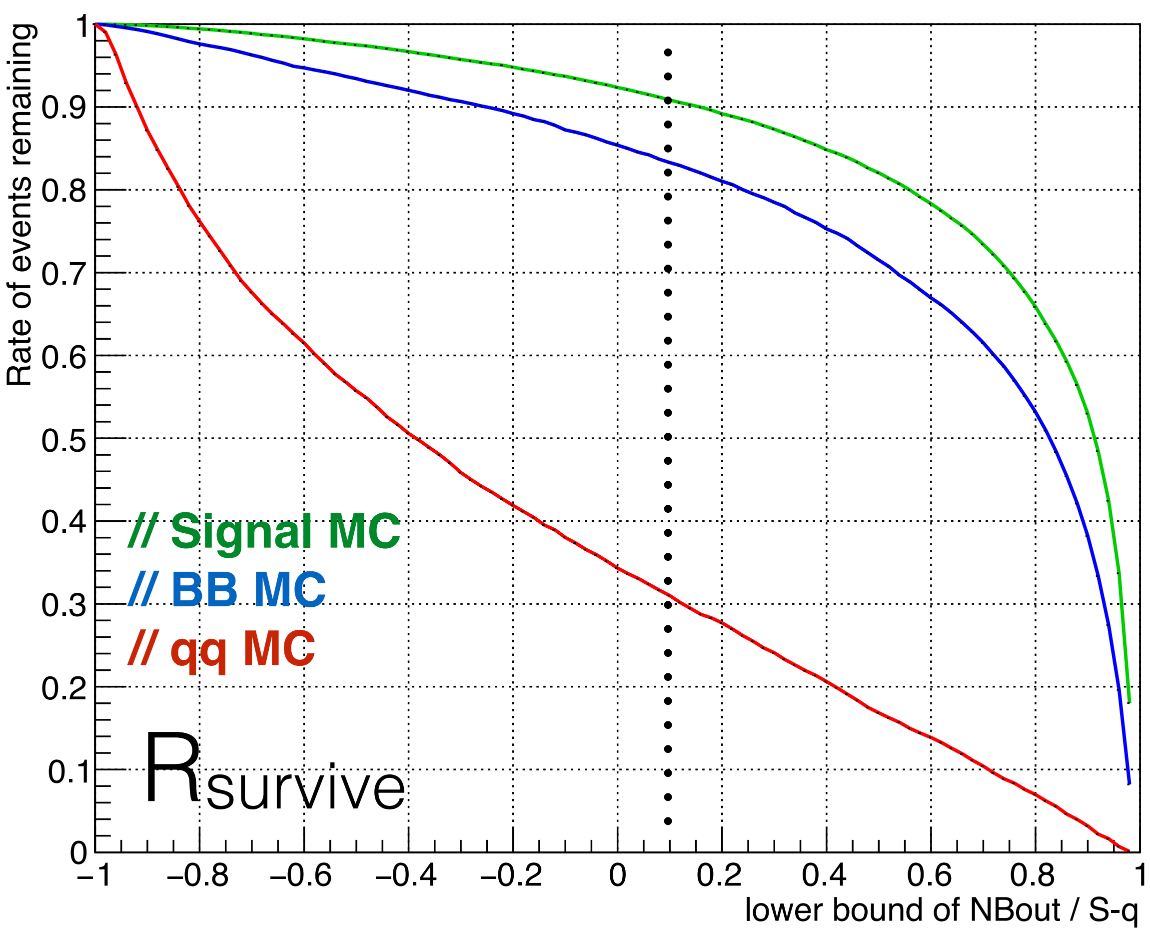


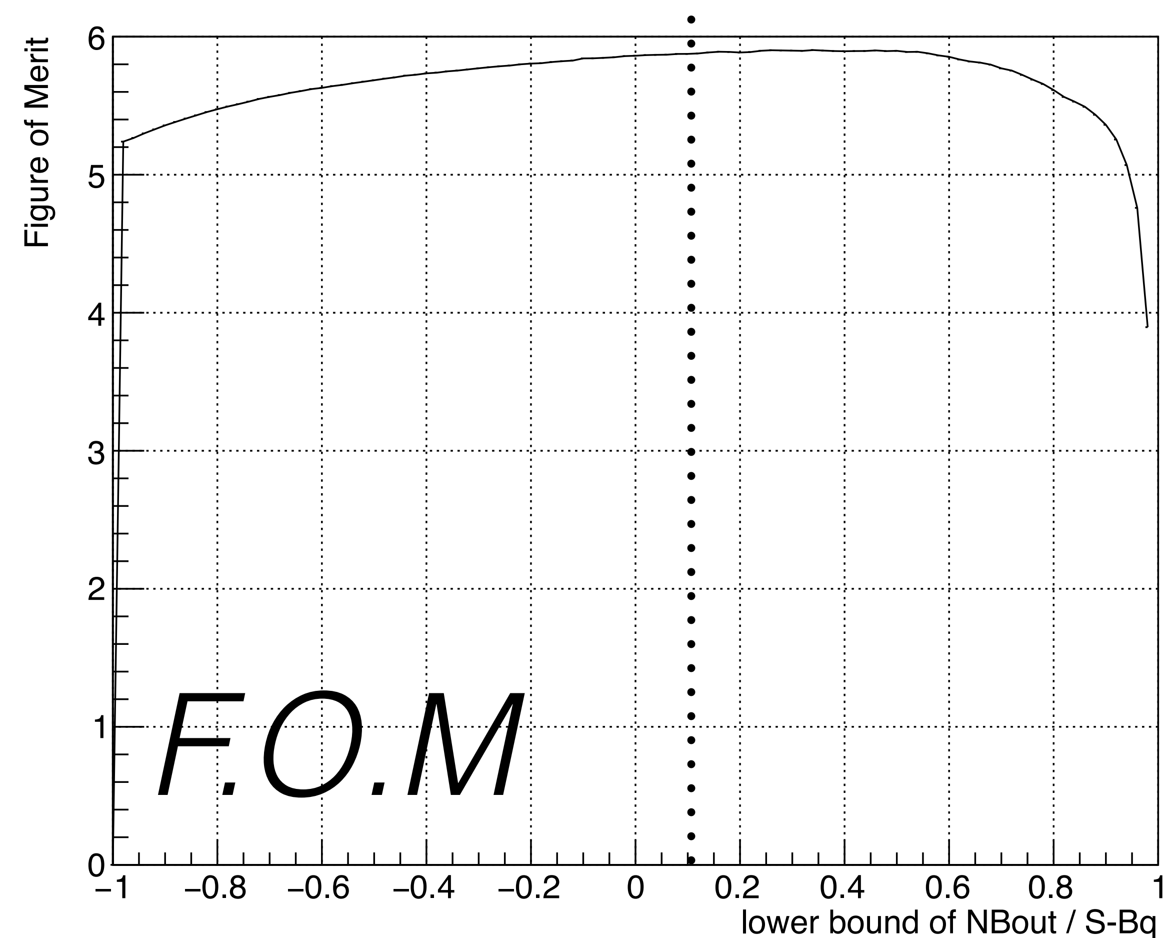
(for $E_\gamma > 1.3$ GeV)

NeuroBayes for the Continuum Suppression

- Requirement Decision : $R_{survive}$ curve & F.O.M.

For signal E_γ > 1.9 Region





$SqNB_{out} > 0.1$

For the same rejection as $|\cos\theta_{thrust}|$, about 10% more signal events survive the continuum suppression.

New Selection Criteria

EKP fullrecon

Best B_{tag} Selection

(For the B_{tag} with the highest o_{tag})

$$o_{tag} > 0.1$$

$$5.24 < M_{bc}^{tag} < 5.29\text{GeV}$$

$$|\Delta E| < 0.06\text{GeV}$$

Contiuum Suppression

$SqNB_{out} > 0.1$

Signal Candidate Selection

Most energetic (in B rest frame) gamma among sig-side gammas.

$$E_{\text{candi.}\gamma}^{B} > 1.3\text{GeV}$$

Signal Isolations

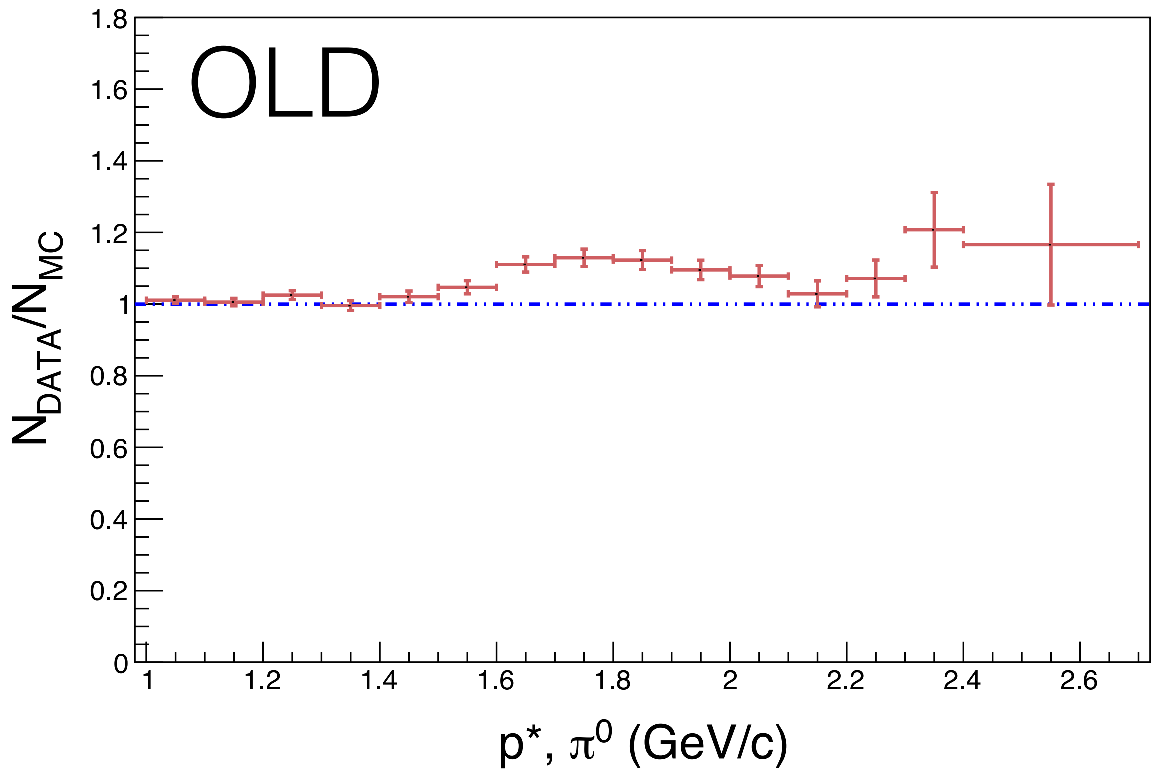
1. TDC off-timing veto
   - to suppress beam backgrounds
2. π^0 & η veto
   - based on P. Koppenburg's study
3. **E9/E25 > 0.95** (no TMVA anymore)
4. electron radiation veto
   - Reject photons too close to electron track

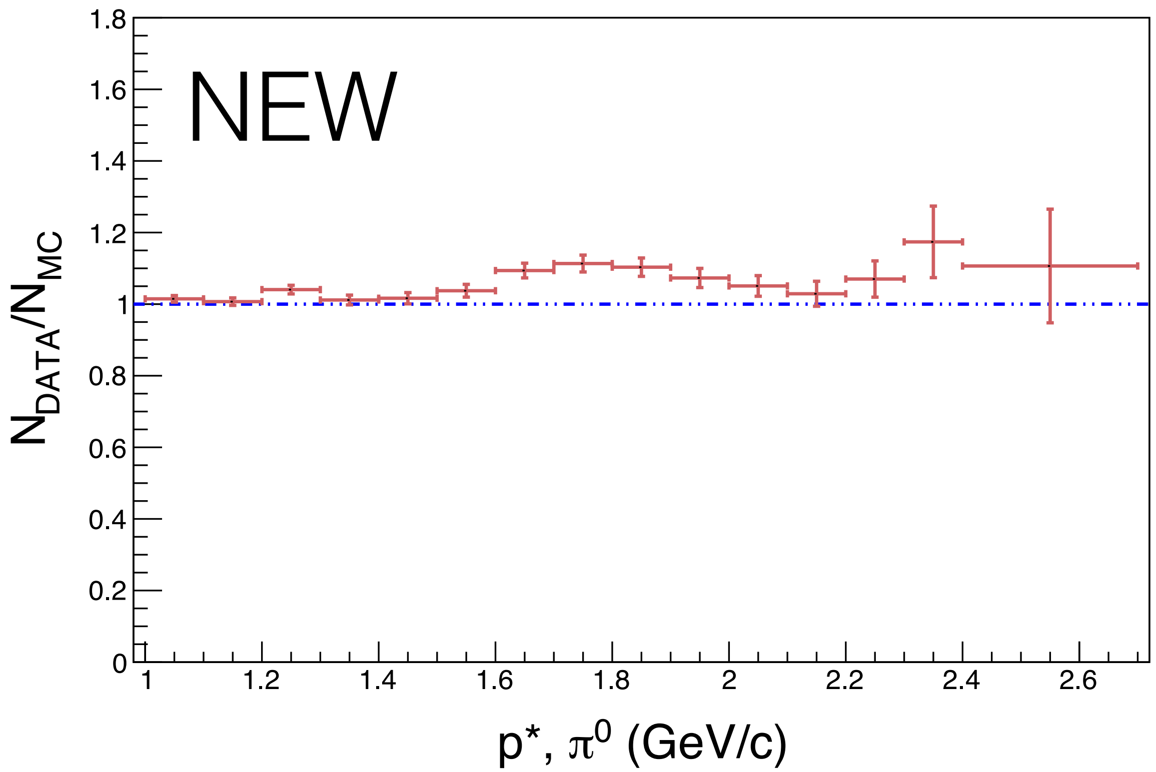
Calibration Factors with the new continuum suppression

As $|\cos\theta_{thrust}| < 0.8$ was applied for pi0/eta calibration,

we recalculated pi0/eta calibration factors with new $SqNB_{out}$ condition.

pi0 calibration factors

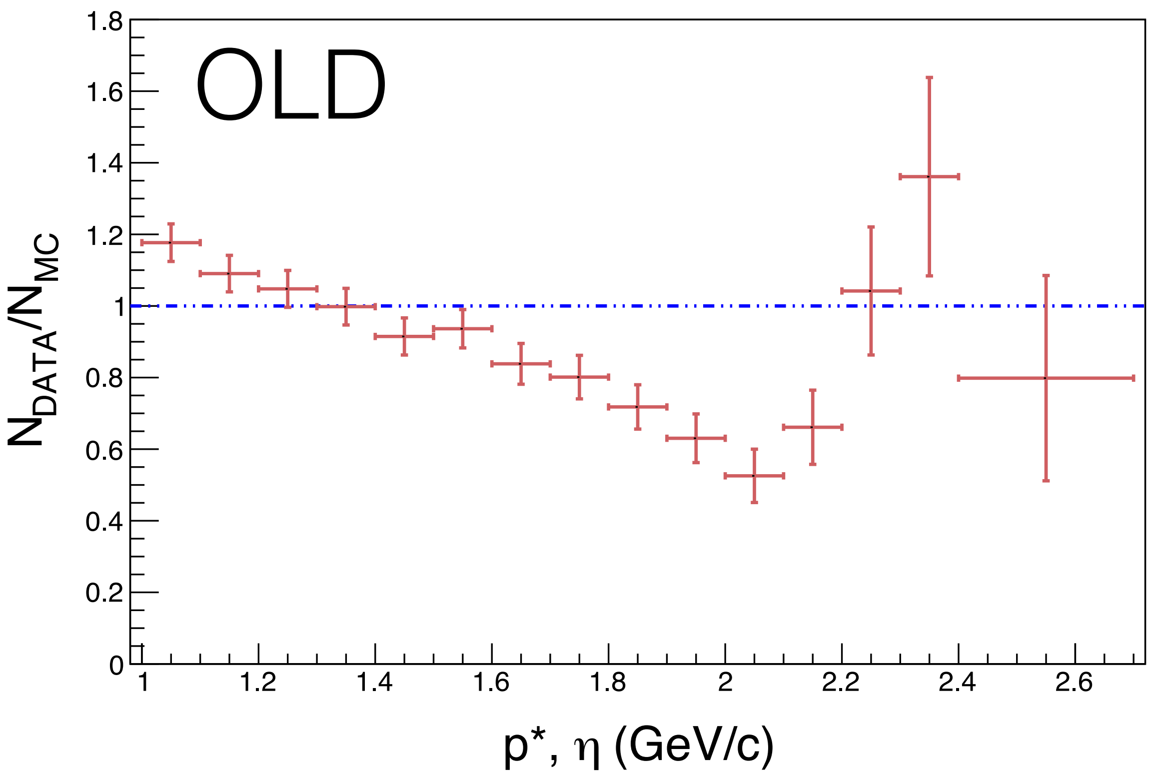


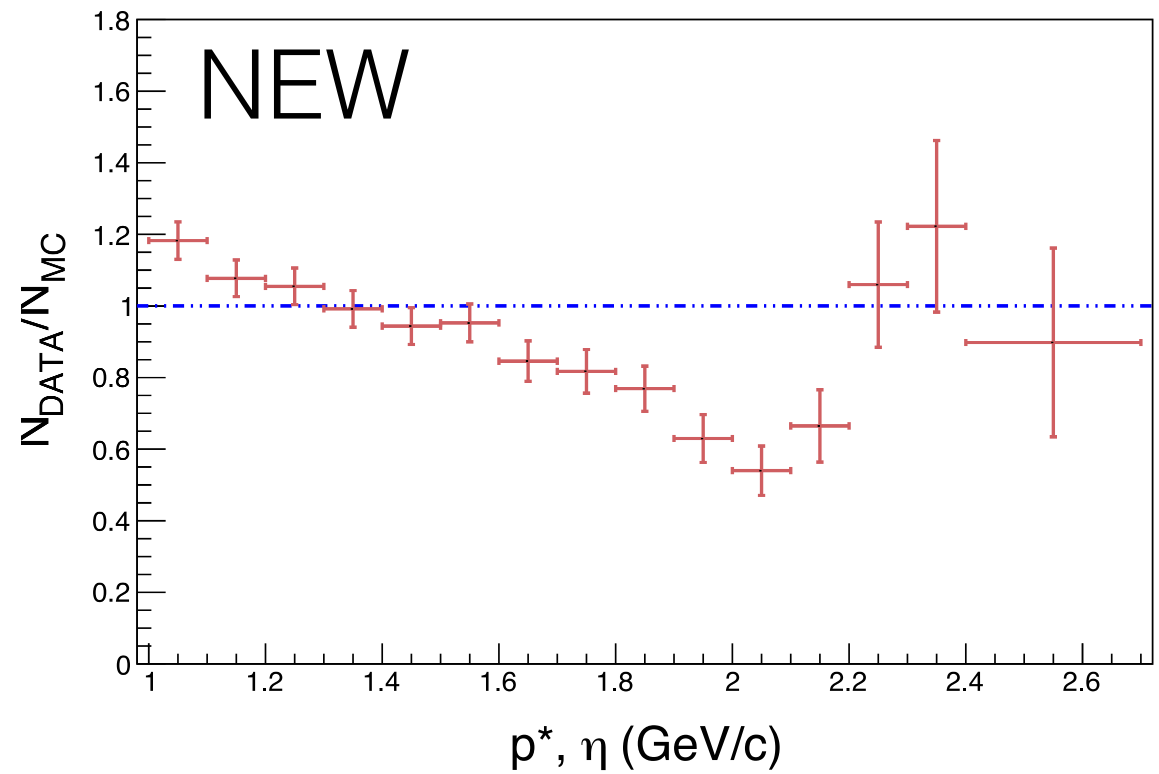


Difference within error bars (mostly statistical).

Calibration Factors with the new continuum suppression

eta calibration factors





Difference within error bars (mostly statistical).

Pi0/Eta calibration factors are stable.

Systematic Uncertainty from the yields of backgrounds

Samples	Percent in E_γ>1.8 (# of events)	Systematic uncertainty
Signal	16.9%	Not used in the measurement
continuum	18.0%	excluded from M_{bc} fitting
$\pi^0 \to \gamma\gamma$ (scaled)	48.4%	1st-order correction factors varied
$\eta \to \gamma\gamma$ (scaled)	7.8%	1st-order correction factors varied
misID e	2.6%	20% uncertainty on its yield will be assigned. (taken from Koppenburg, Louis' work)
misID had	0.4%	50% uncertainty on its yield will be assigned. (taken from Koppenburg, Louis' work)
Other decays	3.6%	Including PHOTOS uncertainty, 20% uncertainty on its yield will be assigned. (taken from Koppenburg, Louis' work)
Bremsstrahlung	2.3%	20% uncertainty on it yield will be assigned. (taken from Koppenburg's work)

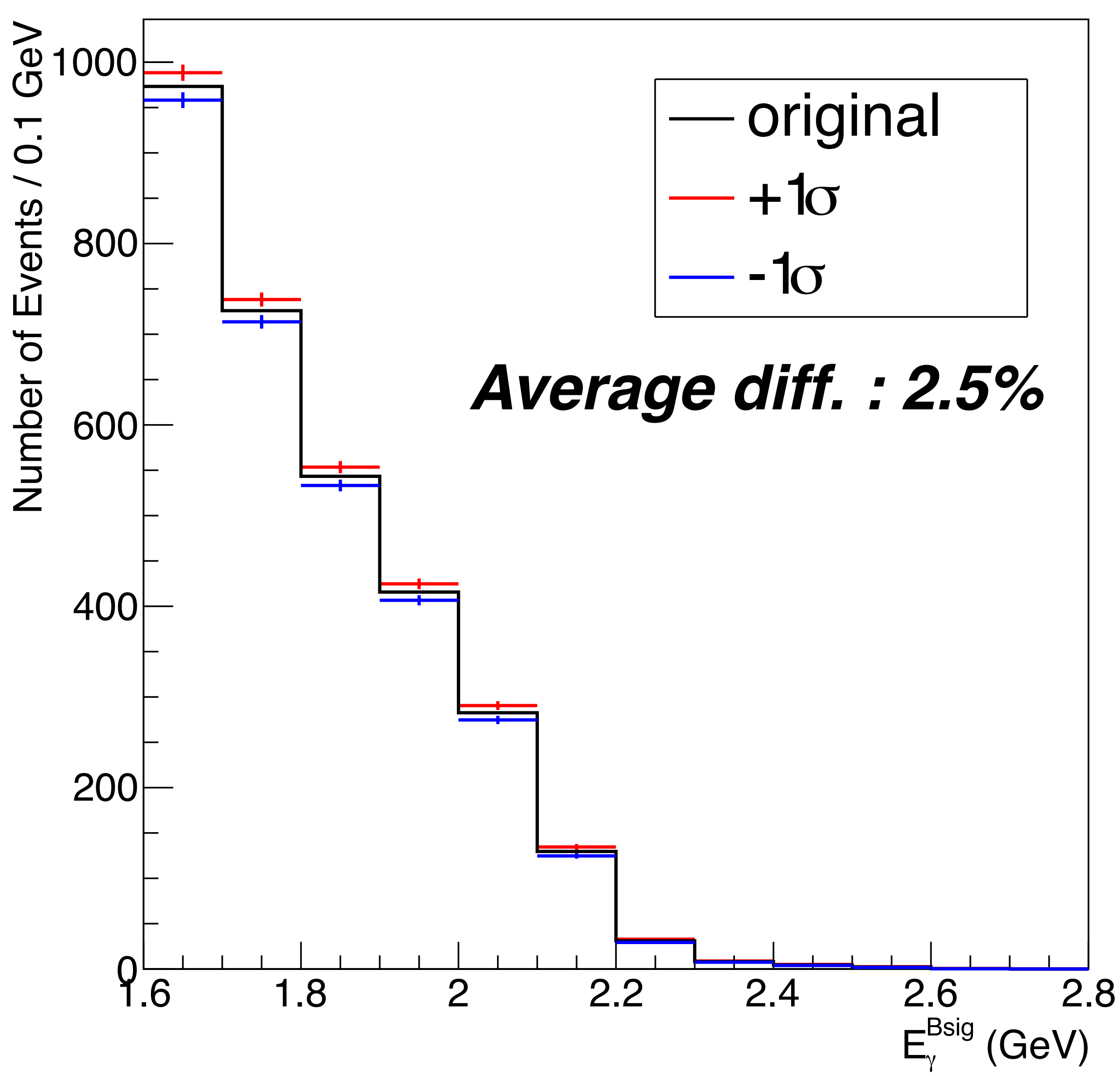
Each uncertainties (except corrected samples) should contain the C_{tag} uncertainty

π^0/η yield with varied calib. factors

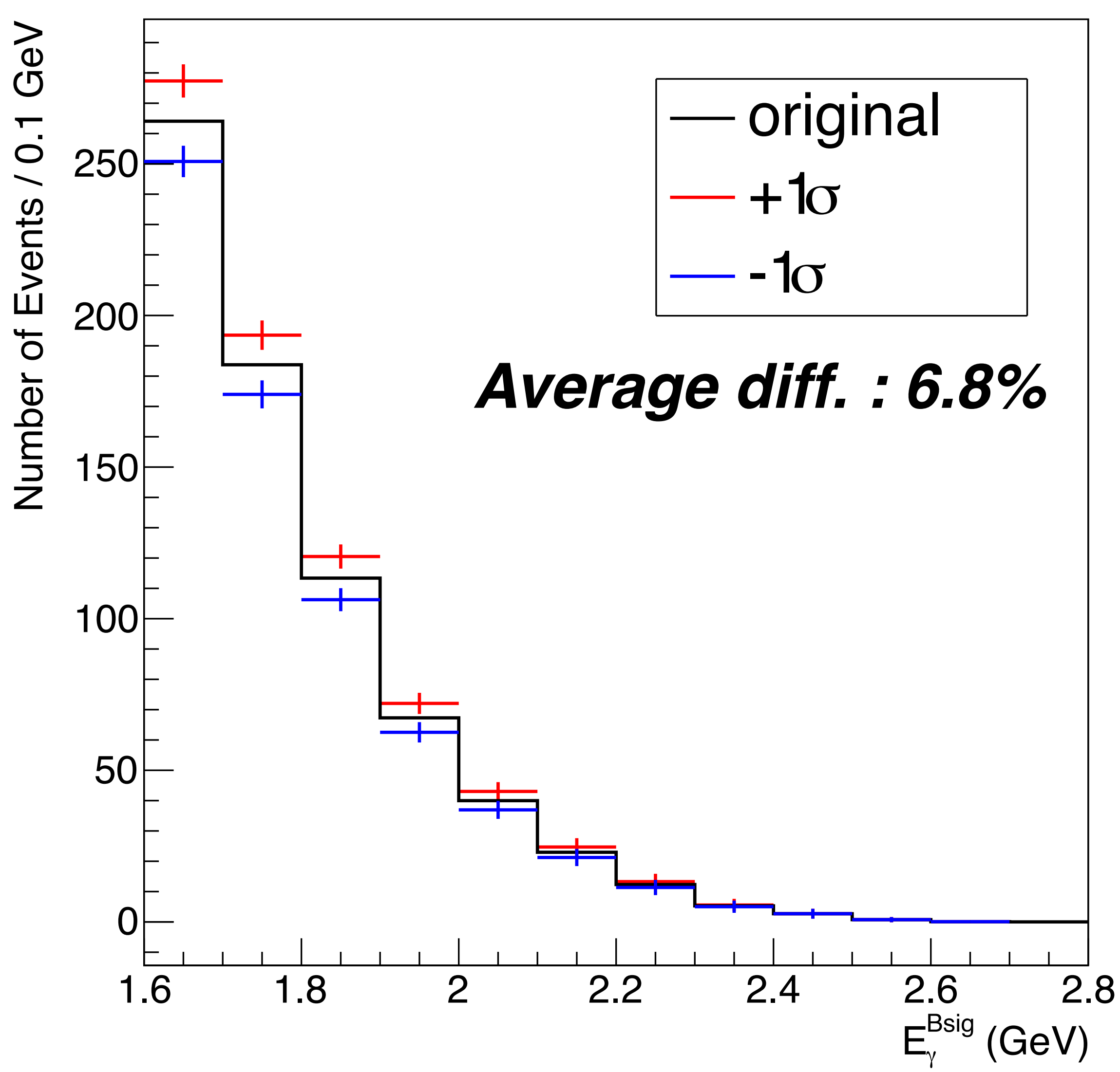
The whole calibration factors are varied by $\pm 1\sigma_{stat}$,
the statistical uncertainties of the factors for each E_γ bin.

The difference on their yields in each E_γ bin will be taken as systematic uncertainties of π^0/η bkg.

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

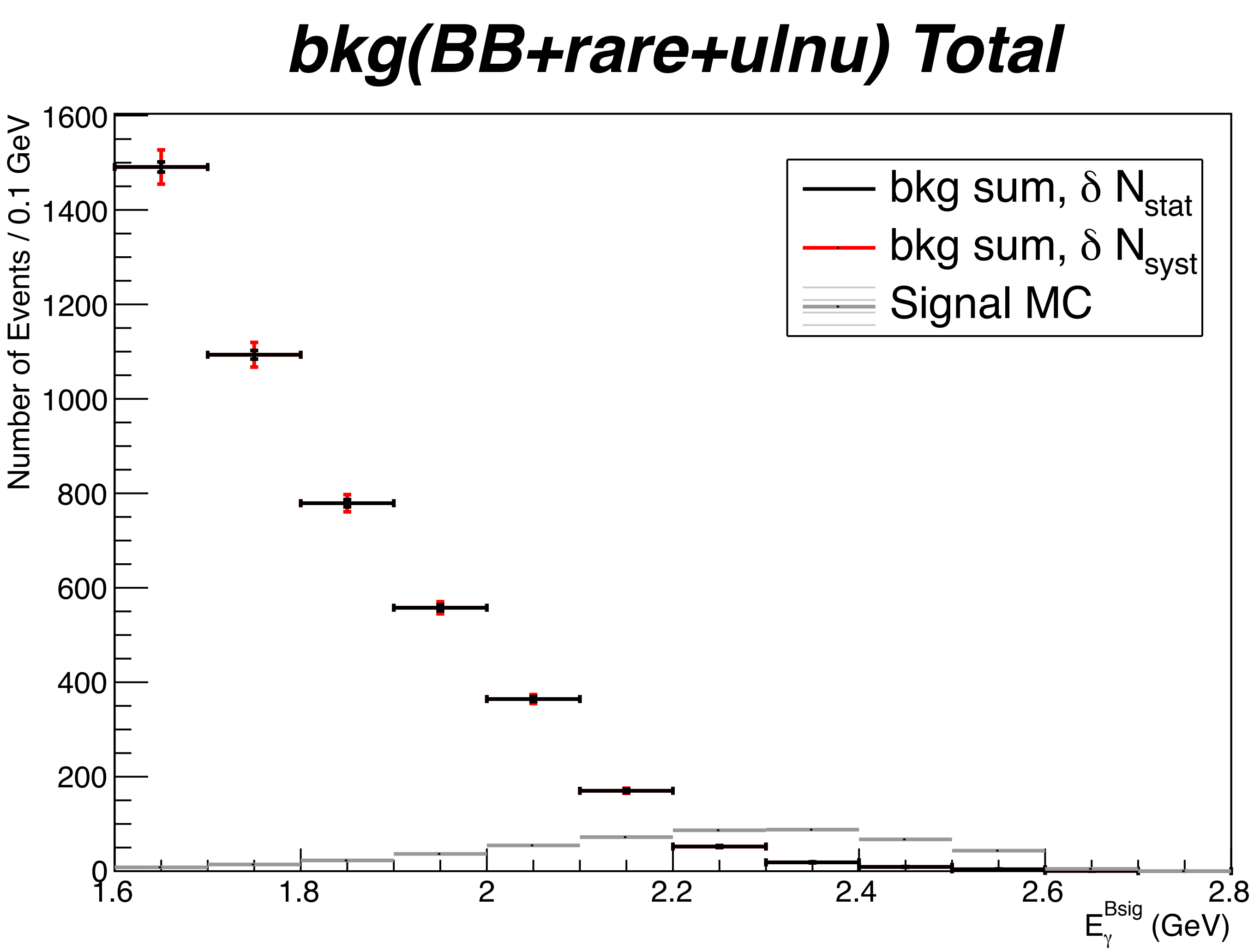


$\eta \to \gamma\gamma$



Background yields systematic uncertainty

Errors associated with each sample are summed quadratically



bin begins	bin ends	# of events	δN_{syst}	rate
1.6	**1.7**	1491	36.19	2.4%
1.7	**1.8**	1093	26.09	2.4%
1.8	**1.9**	779.1	18.20	2.3%
1.9	**2.0**	557.8	12.82	2.3%
2.0	**2.1**	364.4	9.40	2.6%
2.1	**2.2**	170.2	5.33	3.1%
2.2	**2.3**	52.17	2.15	4.1%
2.3	**2.4**	18.67	1.06	5.7%
2.4	**2.5**	9.07	0.73	8.0%
2.5	**2.6**	4.02	0.40	9.9%
2.6	**2.7**	0.56	0.16	28.2%
2.7	**2.8**	0.02	0.002	14.5%
Sum		**4540.3**	**51.1**	**1.1%**

Bkg(BB+rare+ulnu), ***N***evt Summary

bin begins	bin ends	$N_{BBbkgMC}$	$\delta N_{BBbkg,stat}$	rate	$\delta N_{BBbkg,syst}$	rate	Error sum	rate
1.6	**1.7**	1491	10.7	0.7%	36.2	2.4%	37.7	2.5%
1.7	**1.8**	1093	9.11	0.8%	26.1	2.4%	27.6	2.5%
1.8	**1.9**	779.1	7.67	1.0%	18.2	2.3%	19.7	2.5%
1.9	**2.0**	557.8	6.47	1.2%	12.8	2.3%	14.4	2.6%
2.0	**2.1**	364.4	5.24	1.4%	9.4	2.6%	10.8	3.0%
2.1	**2.2**	170.2	3.53	2.1%	5.3	3.1%	6.4	3.8%
2.2	**2.3**	52.2	1.82	3.5%	2.2	4.1%	2.8	5.4%
2.3	**2.4**	18.7	0.96	5.2%	1.1	5.7%	1.4	7.6%
2.4	**2.5**	9.07	0.56	6.2%	0.73	8.0%	0.9	10.1%
2.5	**2.6**	4.02	0.37	9.2%	0.40	9.9%	0.5	13.5%
2.6	**2.7**	0.56	0.12	21.0%	0.16	28.2%	0.2	35.1%
2.7	**2.8**	0.02	0.02	100.0%	0.002	14.5%	0.02	101.0%
Sum		4540.0	18.5	0.4%	51.1	1.1%	54.3	1.2%

(Note these numbers are based on the number of events,
fitting shape uncertainties should be added)

Other sources of the systematic uncertainty

1. General
    1.1. Photon detection efficiency (±2.3%, from BN669)
2. Signal efficiency
    2.1. MC Modeling (the HFAG hevay-quark parameters)
    2.2. HFAG branching fraction
    2.3. Tag correction efficiency (6.5% from BN1190, provisionally)
    2.4. Fitting shape parameter’s uncertainty (2.5% from BN669, provisionally)
    2.5. SVD matrix modelling uncertainty (need further study)

Comments on the missing sources are welcome.

Summary & Plan

- Using Nerubayes improved the performance of the continuum suppression.
- The systematic uncertainties associated with the yields of background samples are investigated.
- BN1355 will be updated will be updated.
- The systematic uncertainty associated with the signal efficiency will be studied.
- SVD for unfolding the spectrum is to be studied.

Back up

pi0 yields

bin begins	bin ends	org	+1sig	dff	-1sig	dff
1.8	**1.9**	543.34	553.45	1.86%	533.23	-1.86%
1.9	**2.0**	415.69	424.75	2.18%	406.64	-2.18%
2.0	**2.1**	282.58	290.49	2.80%	274.67	-2.80%
2.1	**2.2**	129.62	134.54	3.80%	124.70	-3.80%
2.2	**2.3**	31.07	32.86	5.75%	29.28	-5.75%
2.3	**2.4**	8.13	8.79	8.08%	7.48	-8.08%
2.4	**2.5**	4.42	4.98	12.82%	3.85	-12.82%
2.5	**2.6**	2.15	2.55	18.95%	1.74	-18.95%
2.6	**2.7**	0.39	0.59	48.96%	0.20	-48.96%
2.7	**2.8**	0.02	0.02	14.49%	0.01	-14.49%
	sum	1417.41	1453.03	2.51%	1381.80	-2.51%

eta yields

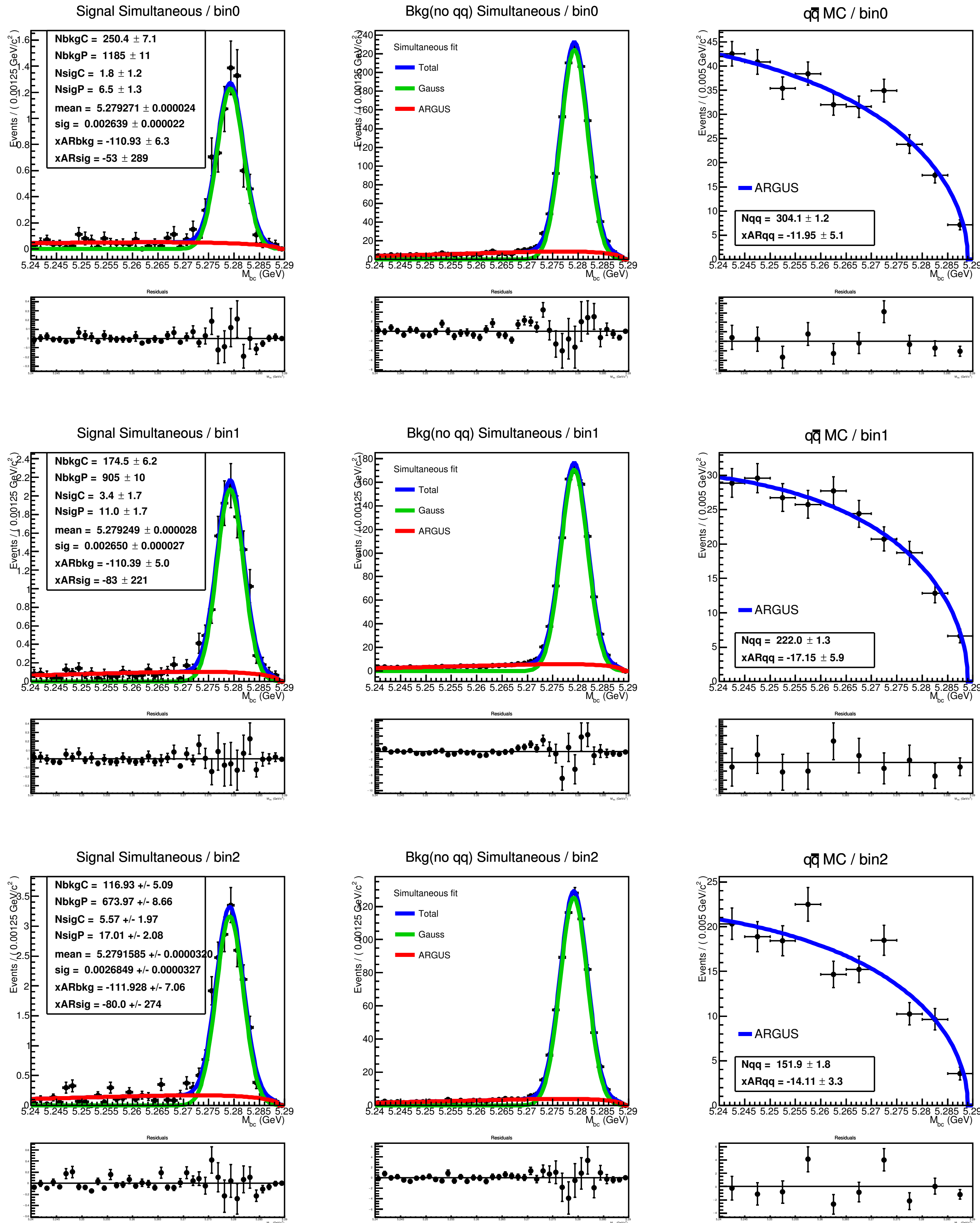
bin begins	bin ends	org	+1sig	dff	-1sig	dff
1.8	**1.9**	113.38	120.50	6.28%	106.26	-6.28%
1.9	**2.0**	67.30	72.06	7.09%	62.53	-7.09%
2	**2.1**	39.99	43.03	7.60%	36.95	-7.60%
2.1	**2.2**	22.97	24.69	7.51%	21.24	-7.51%
2.2	**2.3**	12.32	13.28	7.82%	11.36	-7.82%
2.3	**2.4**	5.29	5.56	5.24%	5.01	-5.24%
2.4	**2.5**	2.69	2.69	0.00%	2.69	0.00%
2.5	**2.6**	0.74	0.74	0.00%	0.74	0.00%
2.6	**2.7**	0.07	0.07	0.00%	0.07	0.00%
2.7	**2.8**	0.00	0.00		0.00	
	sum	264.74	282.63	6.76%	246.84	-6.76%

Rough expectation of the significance

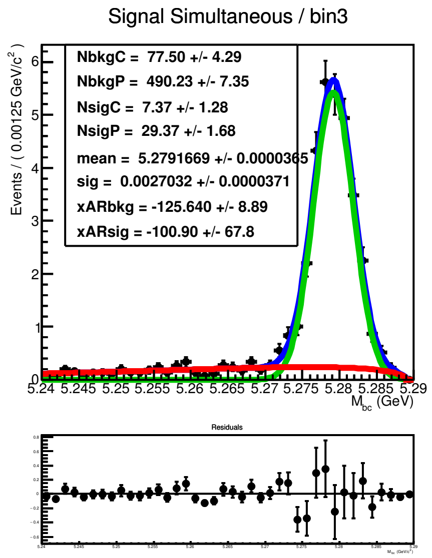
bin begins	bin ends	$N_{BBbkgMC}$	$\delta N_{BBbkg,stat}$	$\delta N_{BBbkg,syst}$	N_{sigMC}	N_{Sum} [Σ(S+BB)]	δN_{Sum} ($\sqrt{N_{Sum}}$)	$\delta N_{subtraction}$ $\sqrt{(\delta N_{Sum}^2+\Sigma\delta N_{BBbkg}^2)}$	Significance (N_{sig} / $\delta N_{subtraction}$)
1.6	**1.7**	1491	10.65	36.19	8.115	1499.115	38.72	54.1	0.2
1.7	**1.8**	1093	9.113	26.09	14.15	1107.15	33.27	43.3	0.3
1.8	**1.9**	779.1	7.666	18.20	22.79	801.89	28.32	34.5	0.7
1.9	**2.0**	557.8	6.467	12.82	36.59	594.39	24.38	28.3	1.3
2.0	**2.1**	364.4	5.244	9.40	54.54	418.94	20.47	23.1	2.4
2.1	**2.2**	170.2	3.531	5.33	72.09	242.29	15.57	16.8	4.3
2.2	**2.3**	52.17	1.823	2.15	86.61	138.78	11.78	12.1	7.2
2.3	**2.4**	18.67	0.9617	1.06	87.96	106.63	10.33	10.4	8.4
2.4	**2.5**	9.066	0.5612	0.73	67.3	76.366	8.74	8.8	7.7
2.5	**2.6**	4.019	0.3692	0.40	43.43	47.449	6.89	6.9	6.3
2.6	**2.7**	0.5649	0.1184	0.16	4.801	5.3659	2.32	2.3	2.1
2.7	**2.8**	0.01721	0.01721	0.00	0.03055	0.04776	0.22	0.2	0.1
Sum		4540.0	18.5	51.1	498.4	5038.4	71.0	89.4	5.6

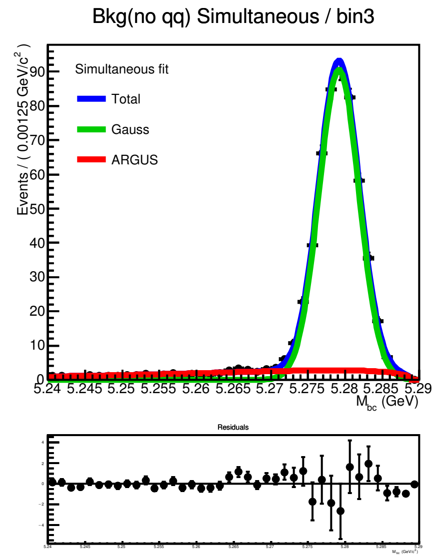
(Note these numbers are based on the number of events)

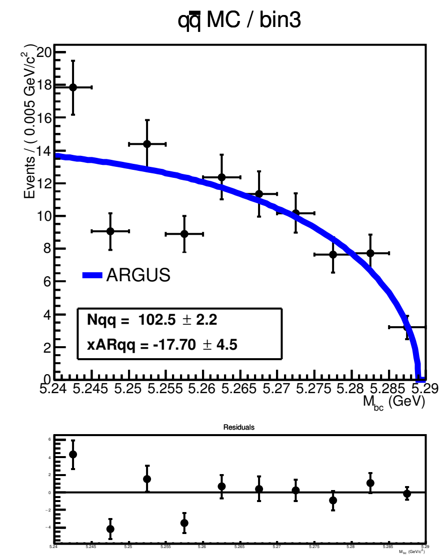
toyMC bkg subtracted yield

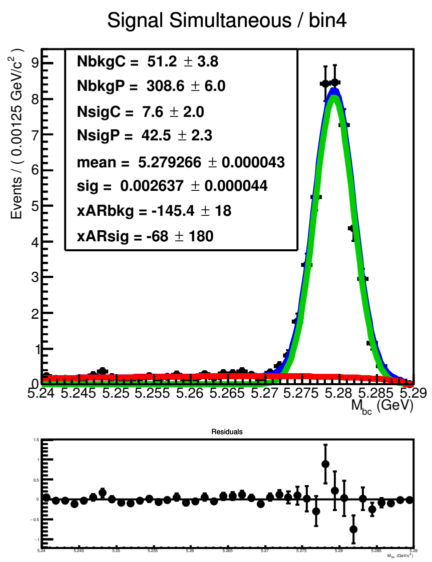


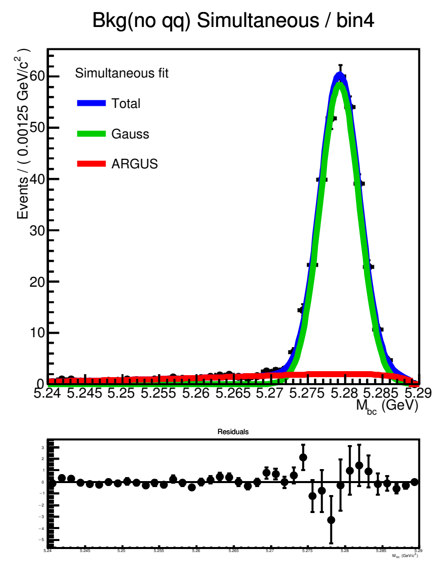
Signal Simultaneous / bin0
NbkgC = 250.4 ± 7.1
NbkgP = 1185 ± 11
NsigC = 1.8 ± 1.2
NsigP = 6.5 ± 1.3
mean = 5.279271 ± 0.000024
sig = 0.002639 ± 0.000022
xARbkg = -110.93 ± 6.3
xARsig = -53 ± 289
Bkg(no qq) Simultaneous / bin0
Simultaneous fit
Total
Gauss
ARGUS
qq̄ MC / bin0
ARGUS
Nqq = 304.1 ± 1.2
xARqq = -11.95 ± 5.1
Signal Simultaneous / bin1
NbkgC = 174.5 ± 6.2
NbkgP = 905 ± 10
NsigC = 3.4 ± 1.7
NsigP = 11.0 ± 1.7
mean = 5.279249 ± 0.000028
sig = 0.002650 ± 0.000027
xARbkg = -110.39 ± 5.0
xARsig = -83 ± 221
Bkg(no qq) Simultaneous / bin1
Simultaneous fit
Total
Gauss
ARGUS
qq̄ MC / bin1
ARGUS
Nqq = 222.0 ± 1.3
xARqq = -17.15 ± 5.9
Signal Simultaneous / bin2
NbkgC = 116.93 +/- 5.09
NbkgP = 673.97 +/- 8.66
NsigC = 5.57 +/- 1.97
NsigP = 17.01 +/- 2.08
mean = 5.2791585 +/- 0.0000320
sig = 0.0026849 +/- 0.0000327
xARbkg = -111.928 +/- 7.06
xARsig = -80.0 +/- 274
Bkg(no qq) Simultaneous / bin2
Simultaneous fit
Total
Gauss
ARGUS
qq̄ MC / bin2
ARGUS
Nqq = 151.9 ± 1.8
xARqq = -14.11 ± 3.3
Events / (0.00125 GeV/c^2)
Events / (0.005 GeV/c^2)
M_{bc} (GeV)
Residuals

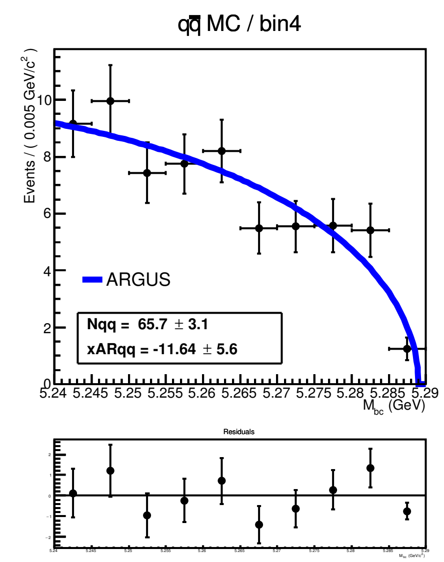


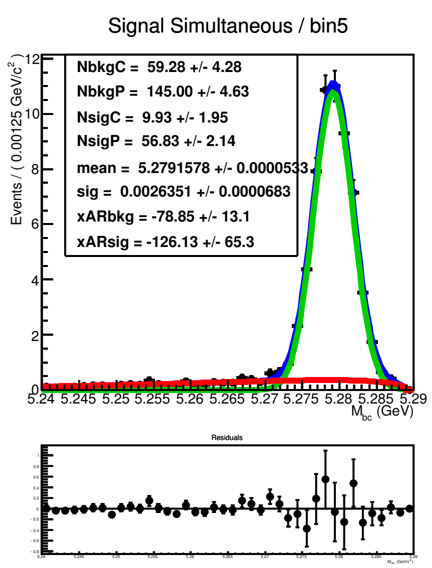


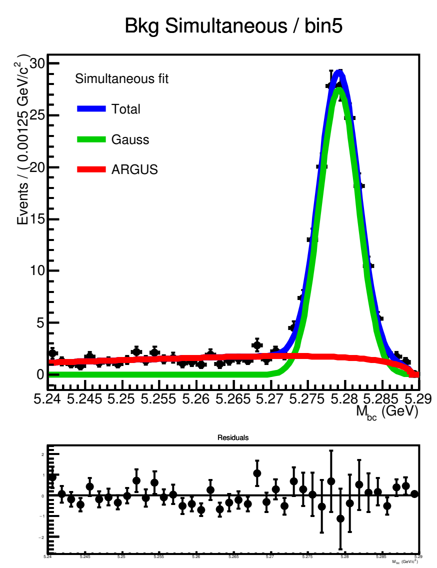




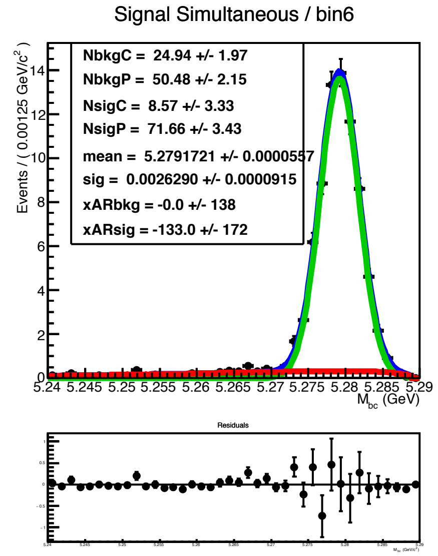


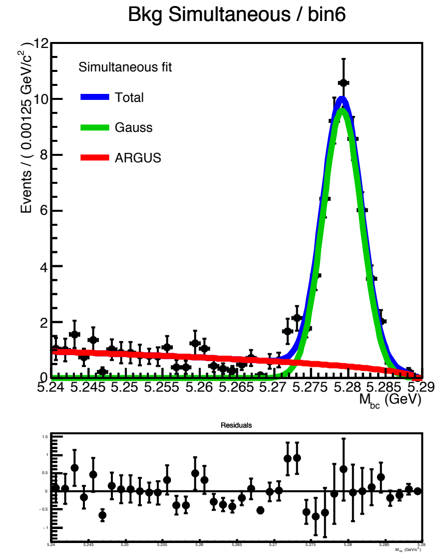




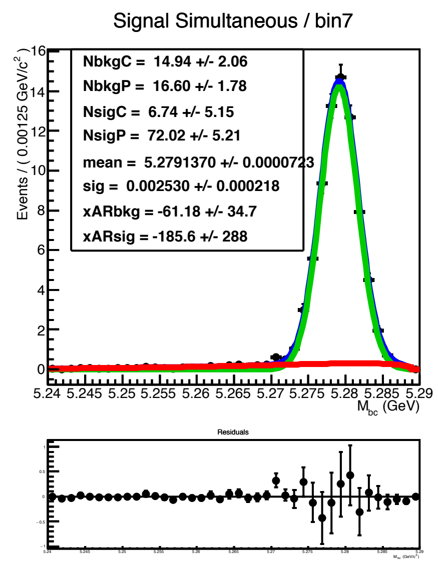


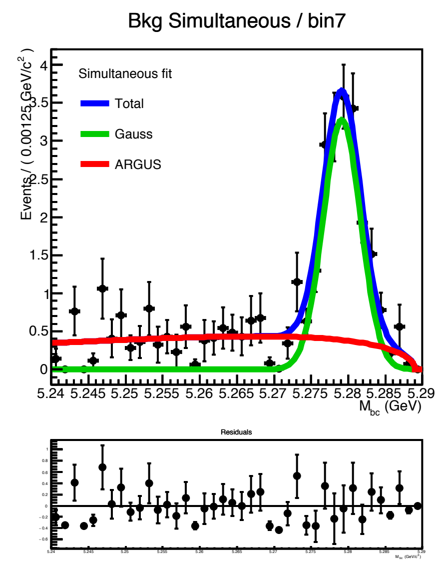
qq̄ included in bkg fit



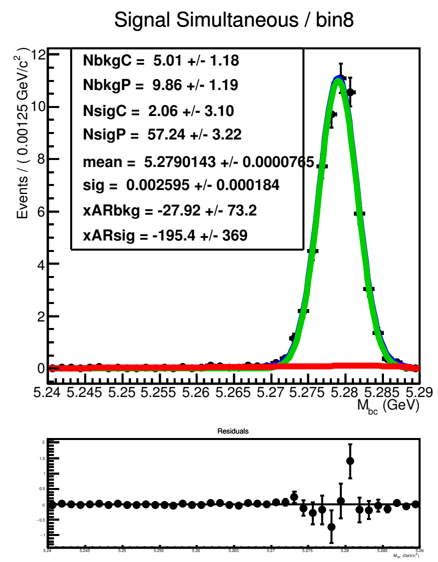


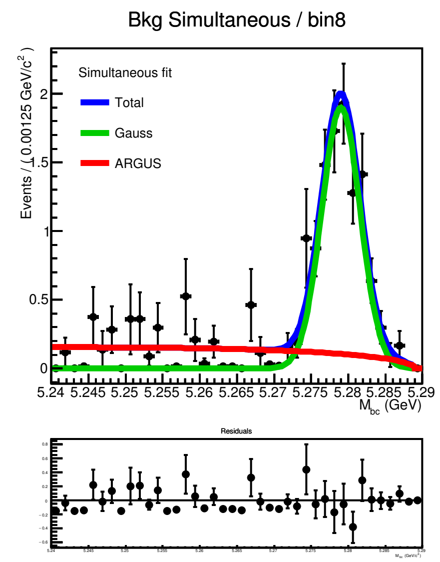
$q\bar{q}$ included in bkg fit



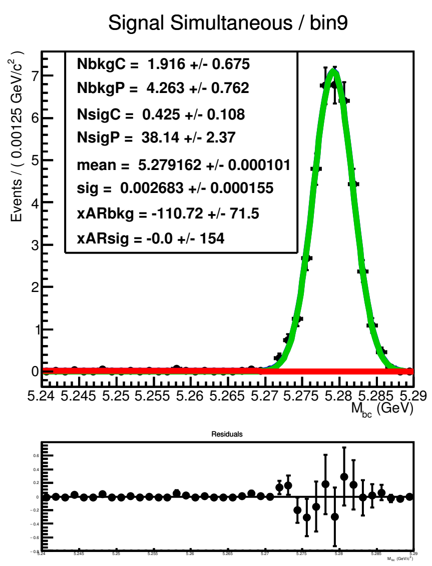


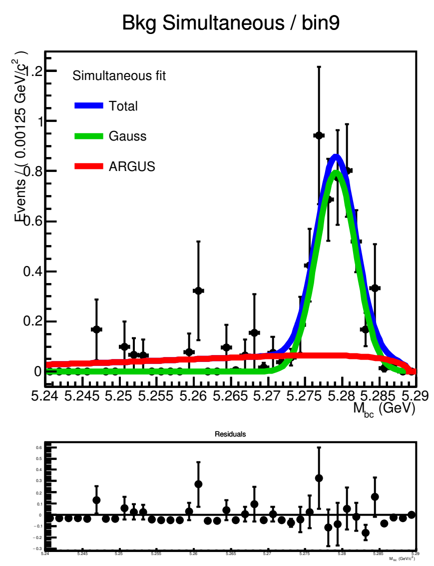
$q\bar{q}$ included in bkg fit



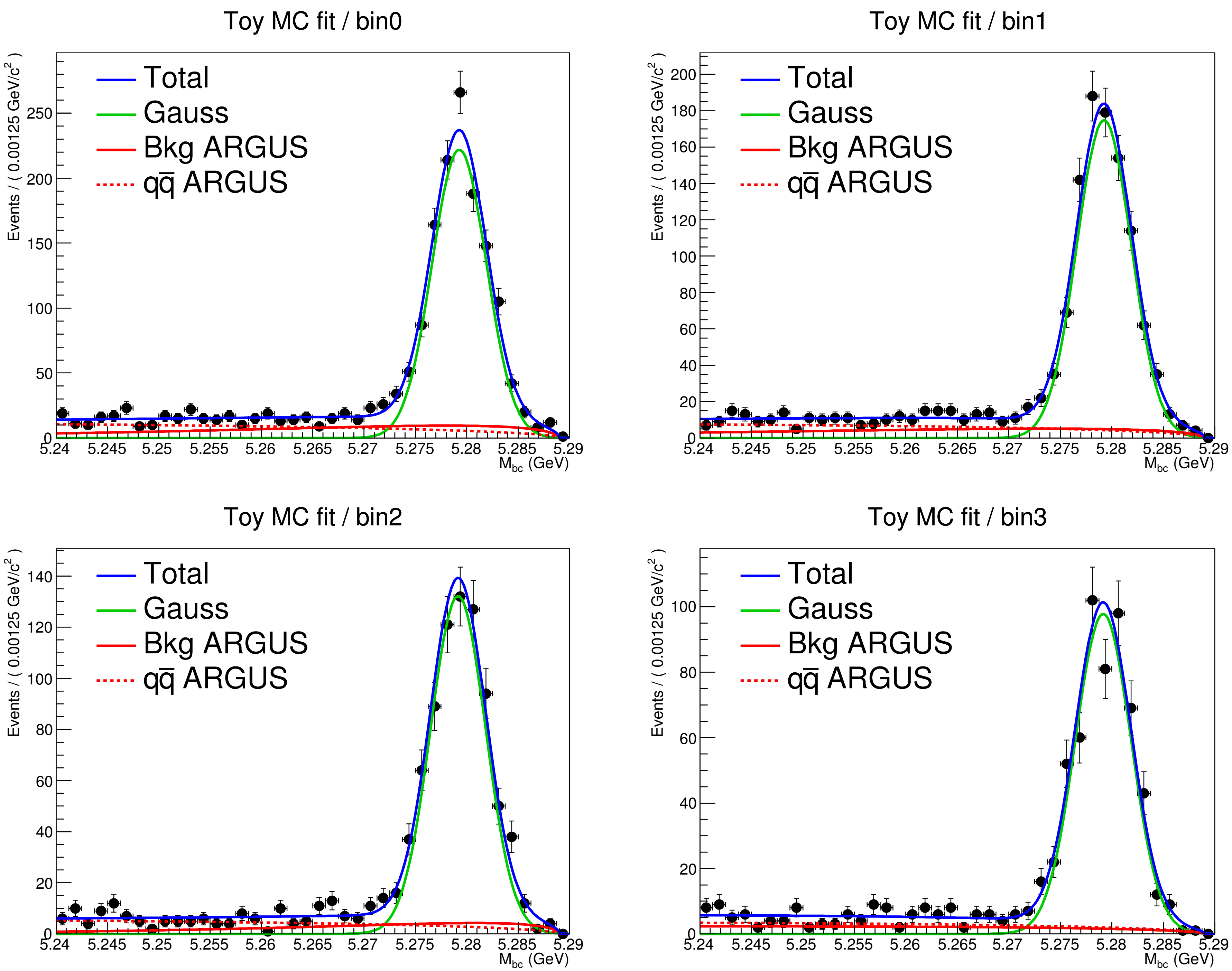


$q\bar{q}$ included in bkg fit

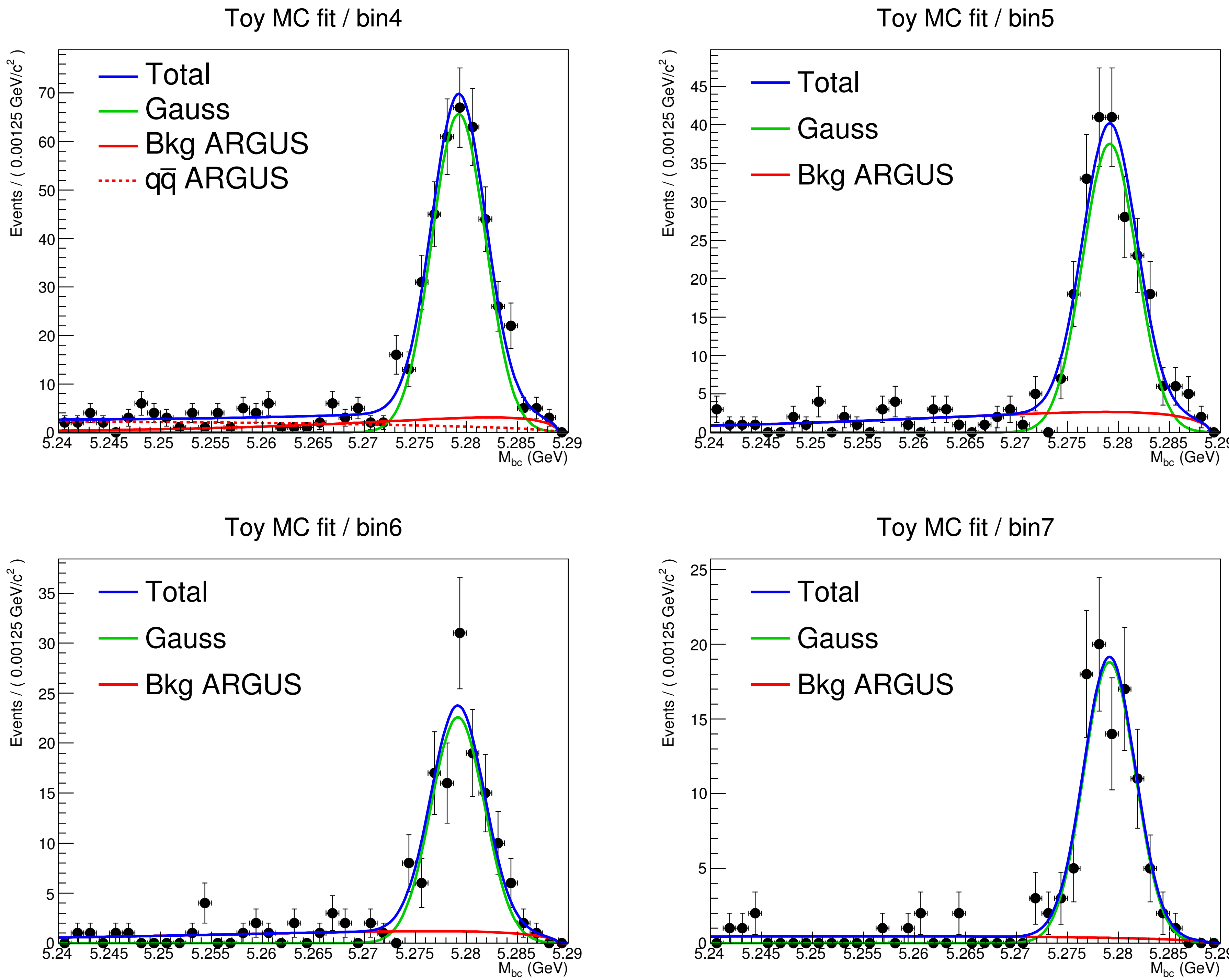


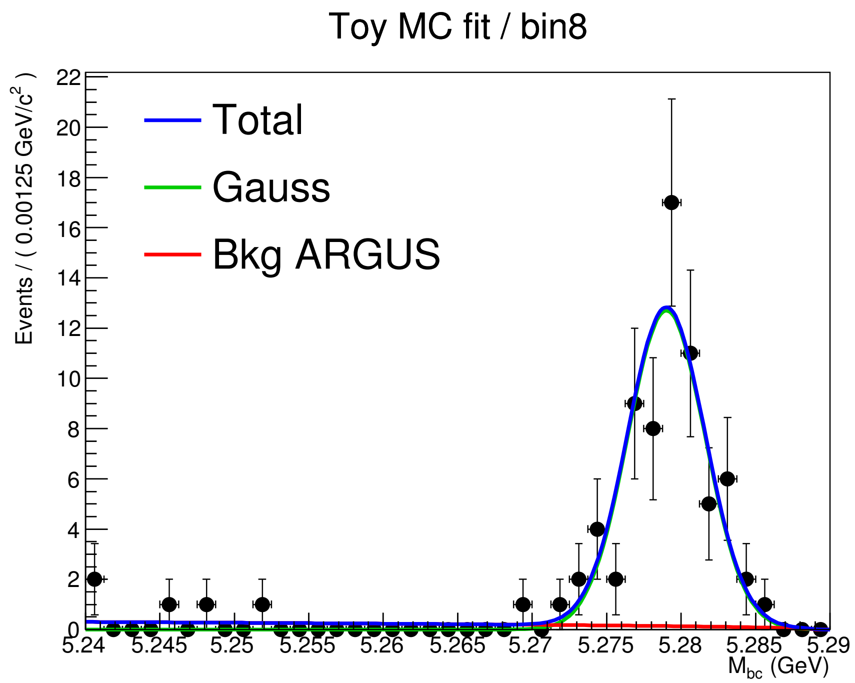


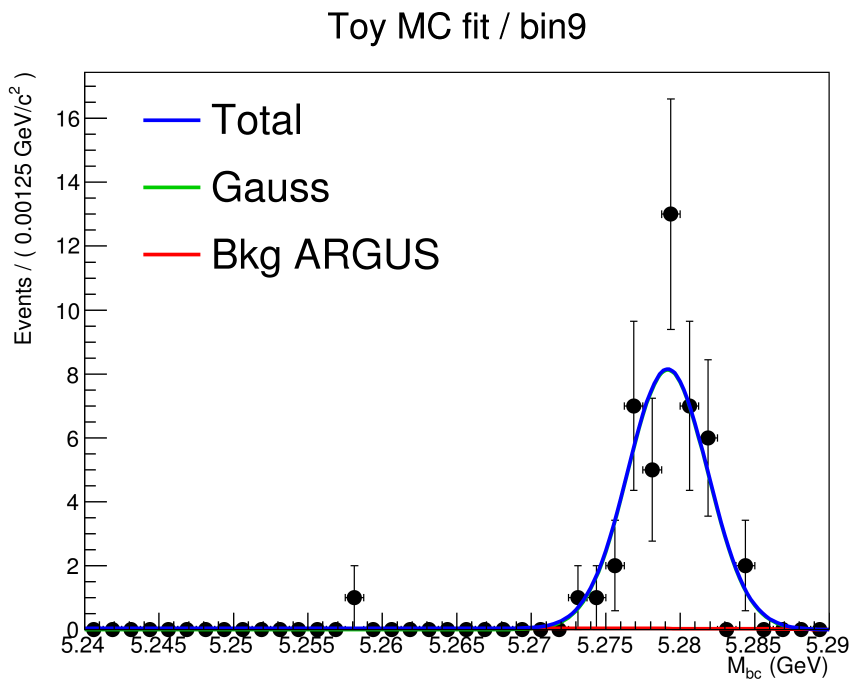
qq̄ included in bkg fit



Toy MC fit / bin0
Toy MC fit / bin1
Toy MC fit / bin2
Toy MC fit / bin3
Total
Gauss
Bkg ARGUS
qq̄ ARGUS
Events / (0.00125 GeV/c^2)
M_{bc} (GeV)


Toy MC fit / bin4
Total
Gauss
Bkg ARGUS
$q\bar{q}$ ARGUS
Events / (0.00125 GeV/c^2)
M_{bc} (GeV)
Toy MC fit / bin5
Total
Gauss
Bkg ARGUS
Events / (0.00125 GeV/c^2)
M_{bc} (GeV)
Toy MC fit / bin6
Total
Gauss
Bkg ARGUS
Events / (0.00125 GeV/c^2)
M_{bc} (GeV)
Toy MC fit / bin7
Total
Gauss
Bkg ARGUS
Events / (0.00125 GeV/c^2)
M_{bc} (GeV)


Toy MC fit / bin8
Total
Gauss
Bkg ARGUS
Events / (0.00125 GeV/c^2)
M_{bc} (GeV)

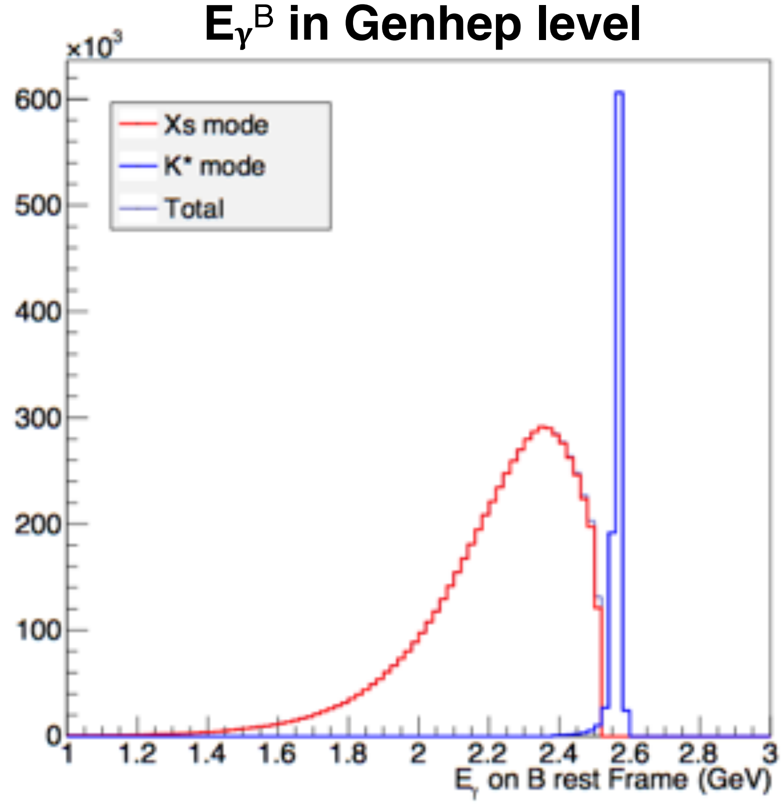

Toy MC fit / bin9
Total
Gauss
Bkg ARGUS
Events / (0.00125 GeV/c^2)
M_{bc} (GeV)

bkg calibration

2. SIMULATION

(1) Signal MC generation

E_γ^B in Genhep level



M(Xs) in Genhep level

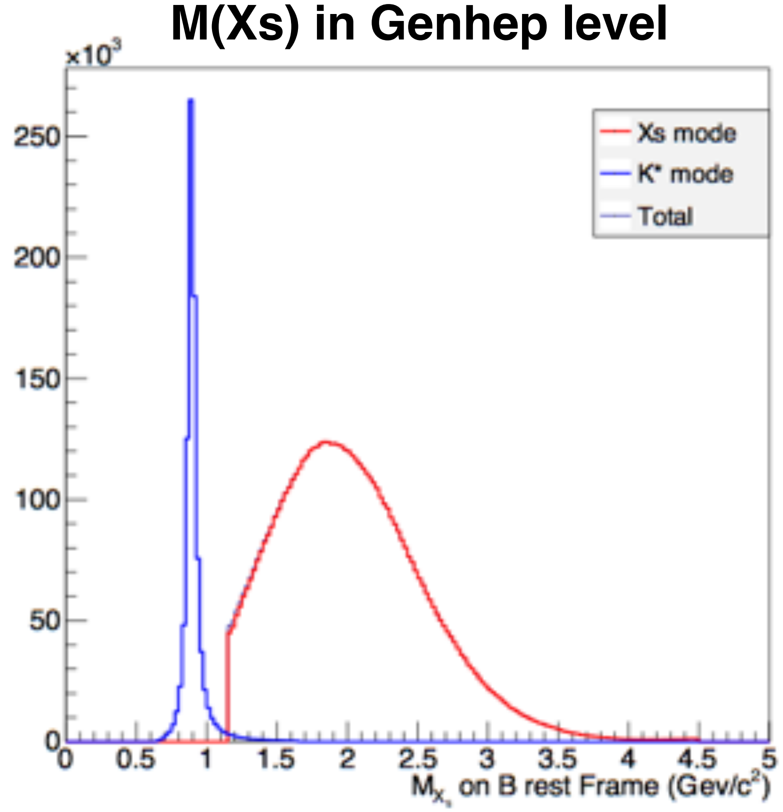


Figure 1. Signal event generation results

(1)24 mil. of events was generated using Evtgen and simulated using Gsim

(2)$B \to X_s \gamma$ MC samples go through the random selection defined by the Kagan-Neubert model[1]

Heavy Quark Parameters are used for the K-N dist. parameters.

HFAG values m_b=4.574 GeV, μ_π^2=0.459 GeV²

(3)$B \to K^* \gamma$ MC samples are generated according to the ratio Xs : K* = 88 : 12, and simulated.

Generation Results

		Gen & Gsim	Random selection	Eff.
Xs modes	Mixed	12 mil.	6369933	53.08%
	Charged	12 mil.	6370224	53.09%
K* modes	Mixed	868632		
	Charged	868674		

~33 times of events expected from DATA

Table 1. The number of signal MC events

[1] A. L. Kagan and M. Neubert, Eur. Phys. J. C7, 5 (1999), hep-ph/9805303.

2. SIMULATION

(2) Signal & Bkg. MC simulation, and Pre-selection

Pre-selection

Best-B_{tag} Selection

NBRank = 1
(if ∃ multiple choices, the one with higher NBout is chosen.)
$5.24 < M_{bc} < 5.29$ GeV/c^2
$|\Delta E| < 0.06$ GeV
NBout > 0.1

Candidate Selection

Most energetic (in B rest frame) gamma among sig-side gammas.
$E_{\gamma}^{B}{}_{candi} > 1.3$ GeV

Table 2. Pre-selection criteria

	Simulated	After fullrecon & pre-selection	Efficiency
Signal	14477463	25287	0.17%
Generic	5 streams	414812	
Continuum	5 streams	266364	

Table 3. The number of event before/after the fullrecon & pre-selection of sig/Generic/Continuum.

5 Streams of Generic & Continuum MC
50 streams of RareB, **20 streams** of Ulnu MC employed.

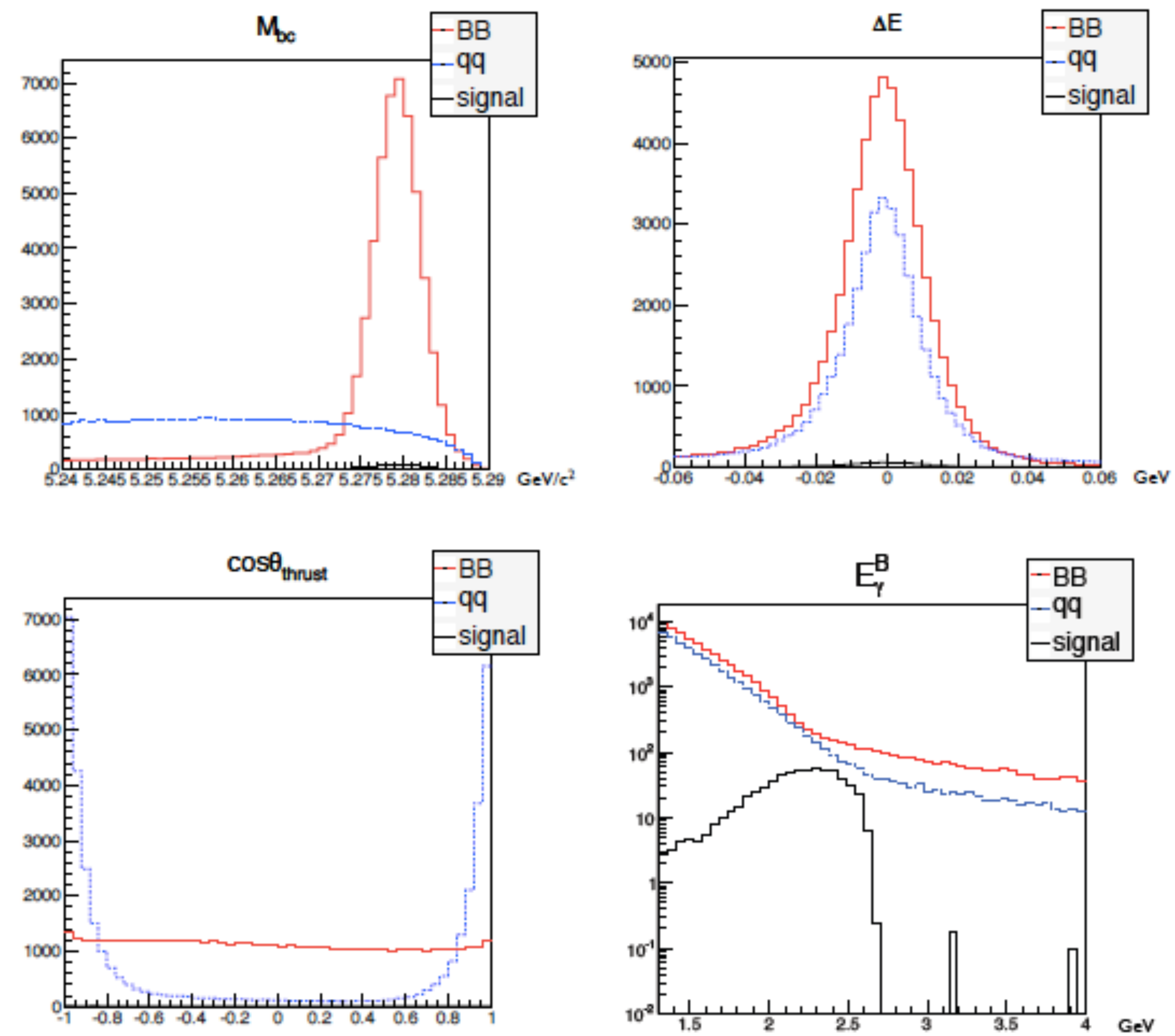
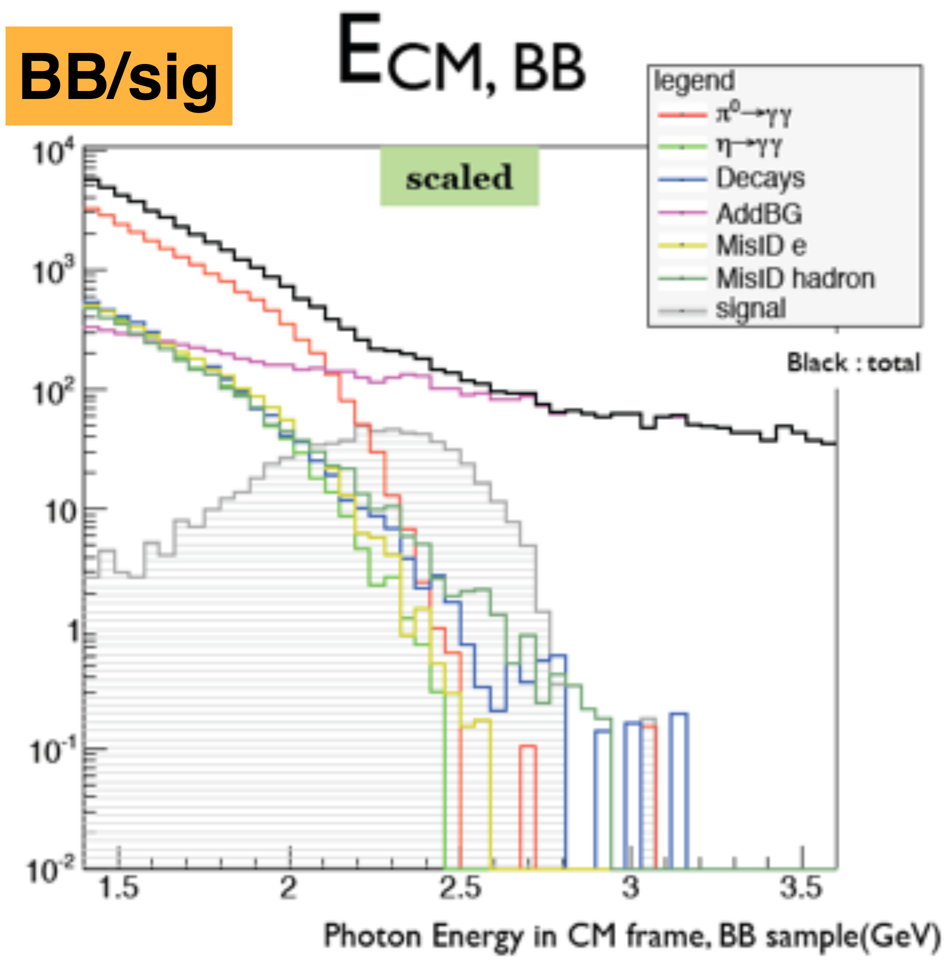


Figure 2. sig/bkg. simulation & pre-cut results

3. EVENT SELECTION

Selection Criteria



π^0&η and addbg(911, off-timing) particles are dominant.

Selection Criteria

1. idhep ≠ 911 for MC, off-timing for DATA
   - to veto off-timing particles
2. $P(\pi^0)<0.3$ & $P(\eta)<0.3$
   - to suppress π^0&η
3. $|\cos\theta_{thrust}| < 0.8$
   - to suppress the remaining continuum events
4. $PDERS_{ecl} > 0.2$
   - to suppress the hadronic shower events.
5. $\cos\theta e < 0.8$
   - to suppress the electron's radiative events.

✻ In each step, tag-correction is applied.

Analysis Regions

Region I : $1.3 < E_\gamma^B < 1.8$ GeV

Region II : $1.8 < E_\gamma^B < 2.0$ GeV (Optimization regions)

Region III : 2.0 GeV $< E_\gamma^B < 2.8$ GeV

3. EVENT SELECTION

(1) Off-timing veto

911(addbg) particles in MC correspond to the off-timing events, overlay beam backgrounds(QED bkg) in DATA.
All the MC candidates with idhep=911 (isthep= -91) are vetoed.
All the off-timing on Triger Count is vetoed in the case of DATA.

(2) $P(\pi^0)<0.3$ & $P(\eta)<0.3$ Cut

Probability of the candidates to be a daughter of π^0 or η was calculated, according to the distribution of the mass combined by the candidate gamma paired with another gamma.
(Only signal-side pairs were considered since there was not a significant advantage in using the others)

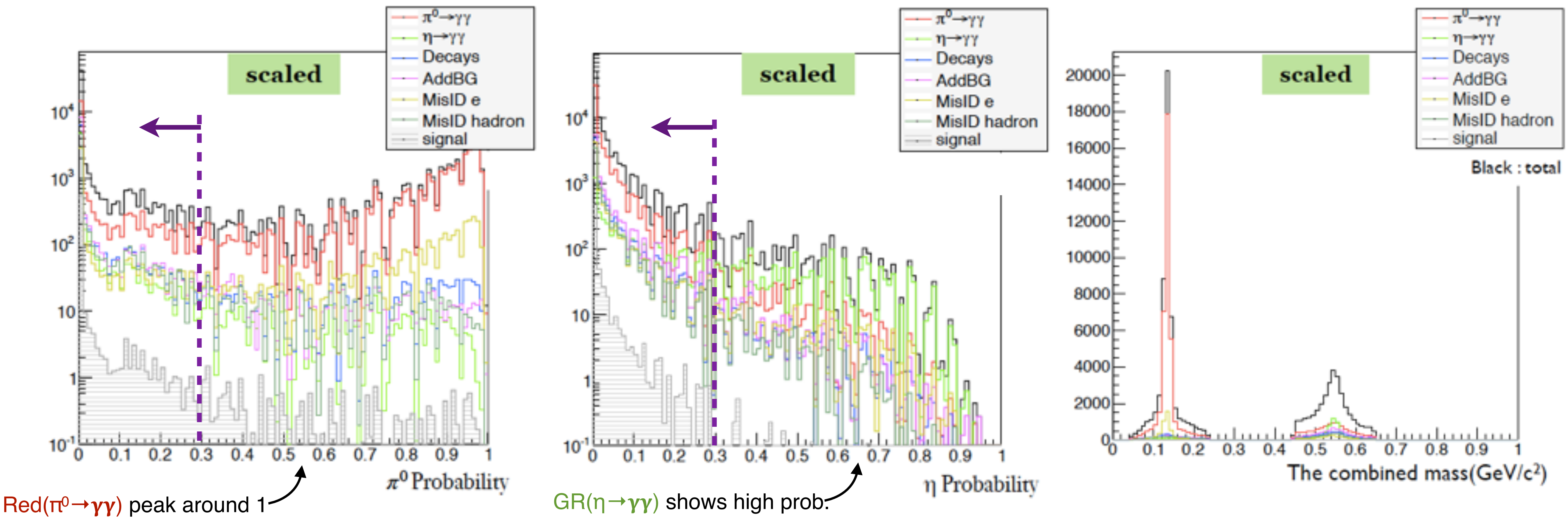


Fig 4. The related distributions to $P(\pi^0)<0.3$ & $P(\eta)<0.3$ *Cut*

3. EVENT SELECTION

(3) $|\cos\theta_{thrust}| < 0.8$ Cut

To suppress the continuum events, thrust angle cut was employed.

$$\text{Thrust Axis} = \frac{\sum \vec{p}_i^{\,\text{longitude}}}{\vec{p}_i}$$

Angle btw. two thrust axis of sig-side and tag-side was calculated.

$$\cos\theta_{\text{thrust}} = \vec{A}_{\text{sig}} \cdot \vec{A}_{\text{tag}}$$

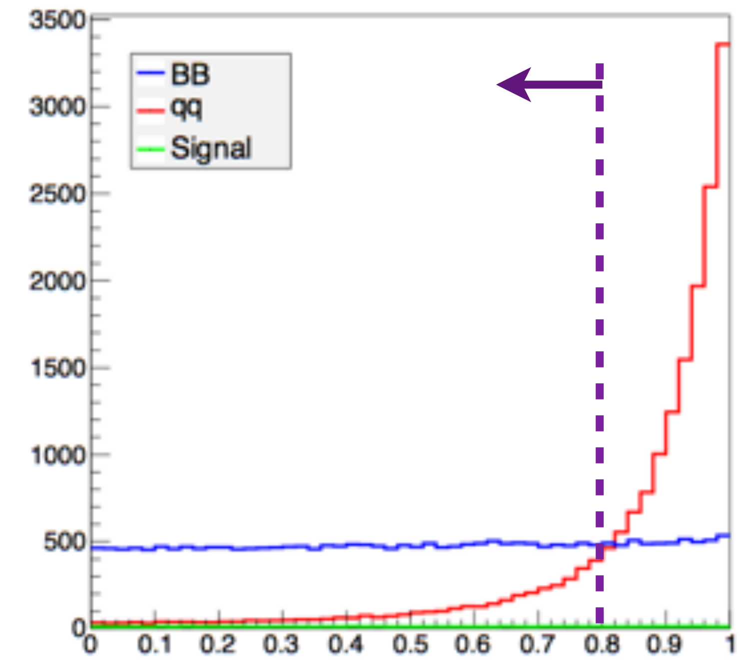


Fig 5. $|\cos\theta_{thrust}|$ distribution of sig/BB/qq

(4) ECL variables, MVA

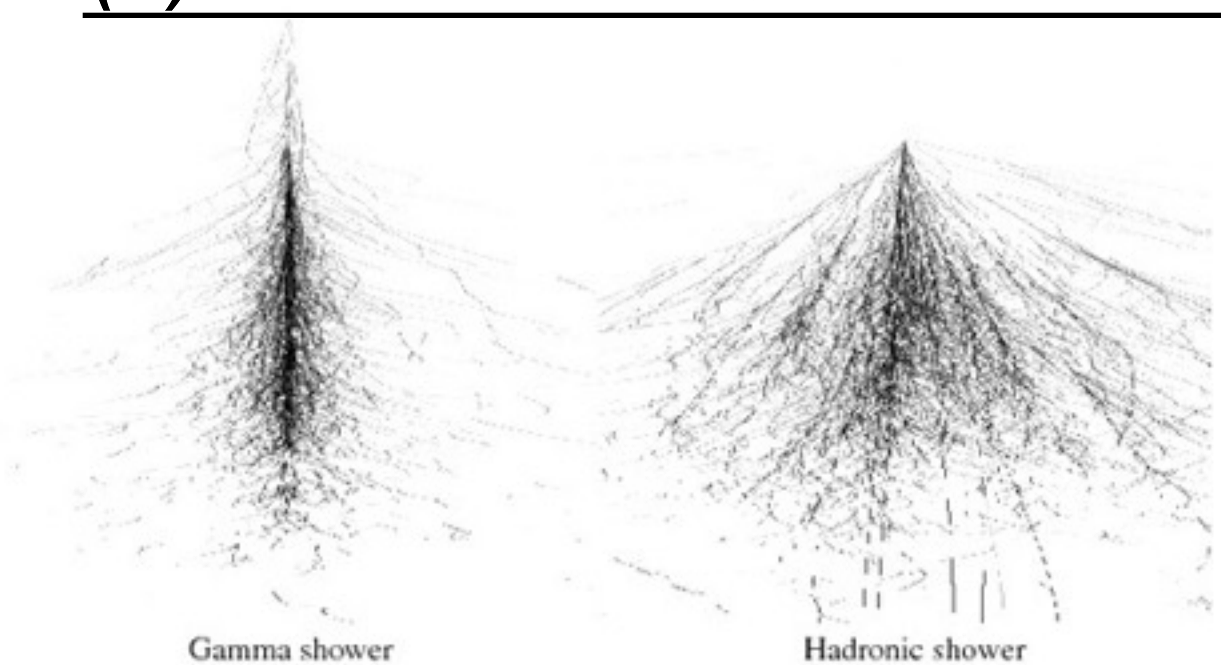


Fig 6. The different character of gamma showers and hadronic showers. (from K. Bernlöhr, Imaging very high energy gamma-ray telescopes)

Hadronic shower (e.g. anti-n, anti-p) shows widely spread shower shape compared to the real gamma shower inside calorimeters.
So we decided to make use of **ECL shower parameters** to veto hadronic shower events.

ECL shower parameters
- Shower width : The RMS width of shower shape
- Shower mass : The combined mass of showers
- E9/E25 : (E Deposited in 3X3 ECL cluster) / (E Deposited in 5X5 ECL cluster)

3. EVENT SELECTION

(4) ECL variables, MVA

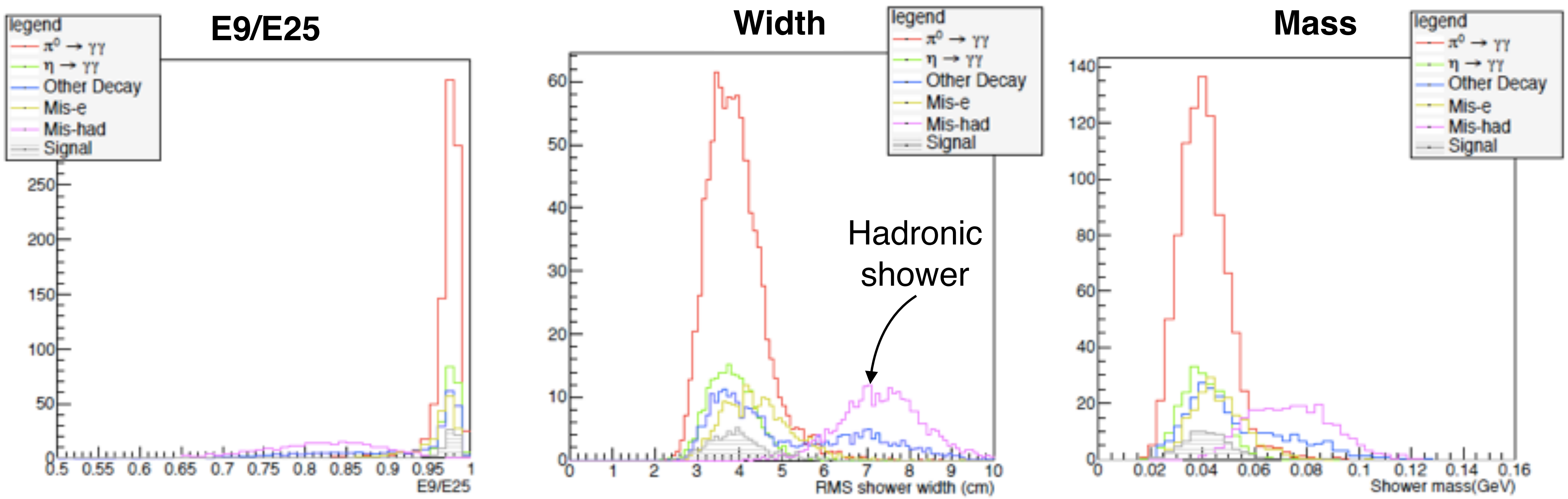


Fig 6. ECL shower parameters in Optimization region, SIG/BB (1.8~2.0 GeV)

These variables are correlated (correlation matrix in back-up), we tried Multi-Variate Analysis (MVA) using TMVA, the root built-in tool for MVA.

Training Set : 6 mil. of Signal / 1 stream of BB&qq

Tested method : Rectangular Cuts, Fisher(Linear) Discriminant, Multi-dimensional Likelihood(PDERS)

PDERS **shows a better ROC in general.**

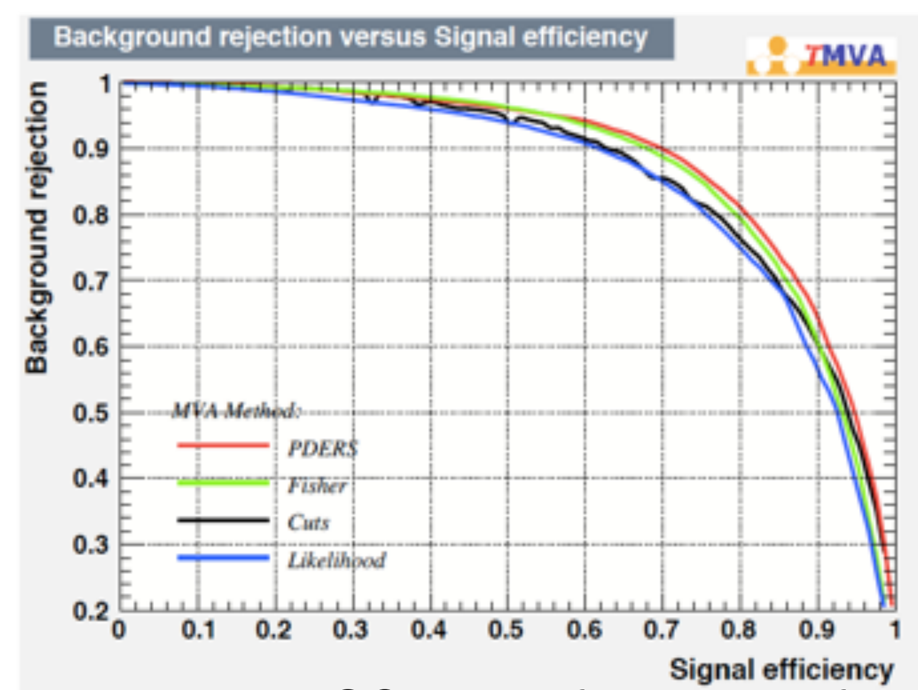


Fig 7. ROC curve of a various of methods

3. EVENT SELECTION

(4) ECL variables, MVA

After overtraining test and FoM test for optimization region, we decided the cut at PDERS > 0.2. (Details are shown in the BACK-UP)

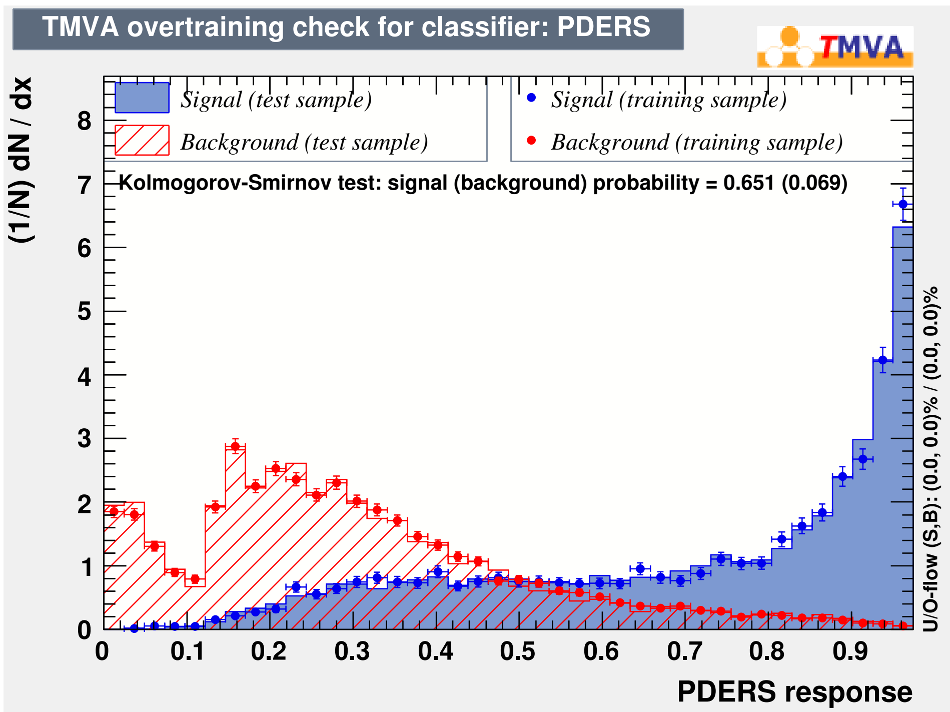


Fig 8. Overtraining test

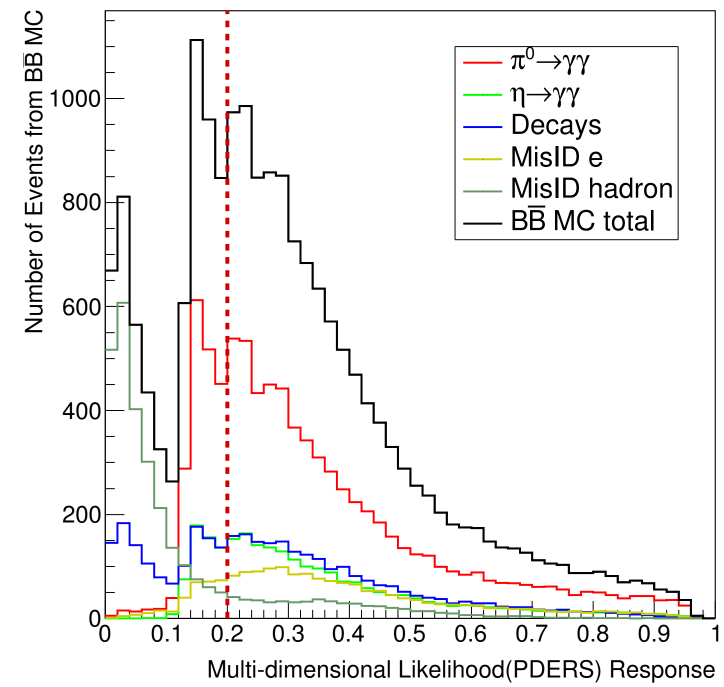


Fig 9. PDERS normalized dist. of specific bkg.

(5) $\cos\theta_e < 0.8$ cut

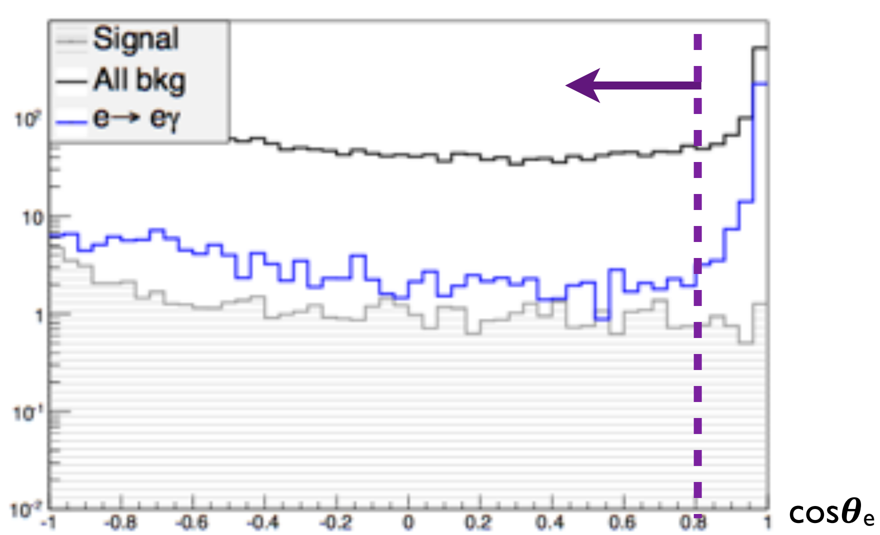


Fig 10. $\cos\theta_e$ dist. of specific bkg.

Angle btw. candidate gamma & the closest electron was tested to veto the events oriented by electron's emission. $e \rightarrow e\gamma$ events have a peak around $\cos\theta_e = 1$

3. EVENT SELECTION

(6) Selection Efficiency

Region 1 , 1.3 < $E\gamma^B$ < 1.8 GeV

Region I	Sig	BB	qq	FoM
911 veto	99.48%	93.02%	95.74%	0.21
P(π0)&P(η)	87.10%	48.59%	50.32%	0.26
|cosθthrust|	80.27%	79.01%	22.79%	0.29
PDERS	86.56%	63.59%	64.22%	0.31
cosθe	97.46%	93.01%	96.24%	0.31
tot-efficiency	59%	21.12%	6.79%	
tot-cutoff	41%	78.88%	93.21%	

Region 2 , 1.8 < $E\gamma^B$ < 2.0 GeV

Region II	Sig	BB	qq	FoM
911 veto	99.48%	83.22%	89.16%	1.01
P(π0)&P(η)	95.17%	54.79%	59.68%	1.27
|cosθthrust|	77.35%	79.43%	20.45%	1.32
PDERS	96.87%	79.9%	79.13%	1.43
cosθe	99.17%	96.22%	97.38%	1.44
tot-efficiency	70.64%	27.84%	8.39%	
tot-cutoff	29.65%	72.16%	91.61%	

Region 3 , 2.0 < $E\gamma^B$ < 2.8 GeV

Region III	Sig	BB	qq	FoM
911 veto	99.48%	38.81%	62.94%	8.71
P(π0)&P(η)	97.78%	69.4%	68.35%	10.00
|cosθthrust|	79.27%	80.03%	18.43%	10.61
PDERS	99.39%	77.25%	80.67%	11.43
cosθe	99.26%	97.76%	97.78%	11.45
tot-efficiency	76.07%	16.28%	6.25%	
tot-cutoff	23.93%	83.72%	93.75%	

Table4. Signal Efficiency of selection criteria

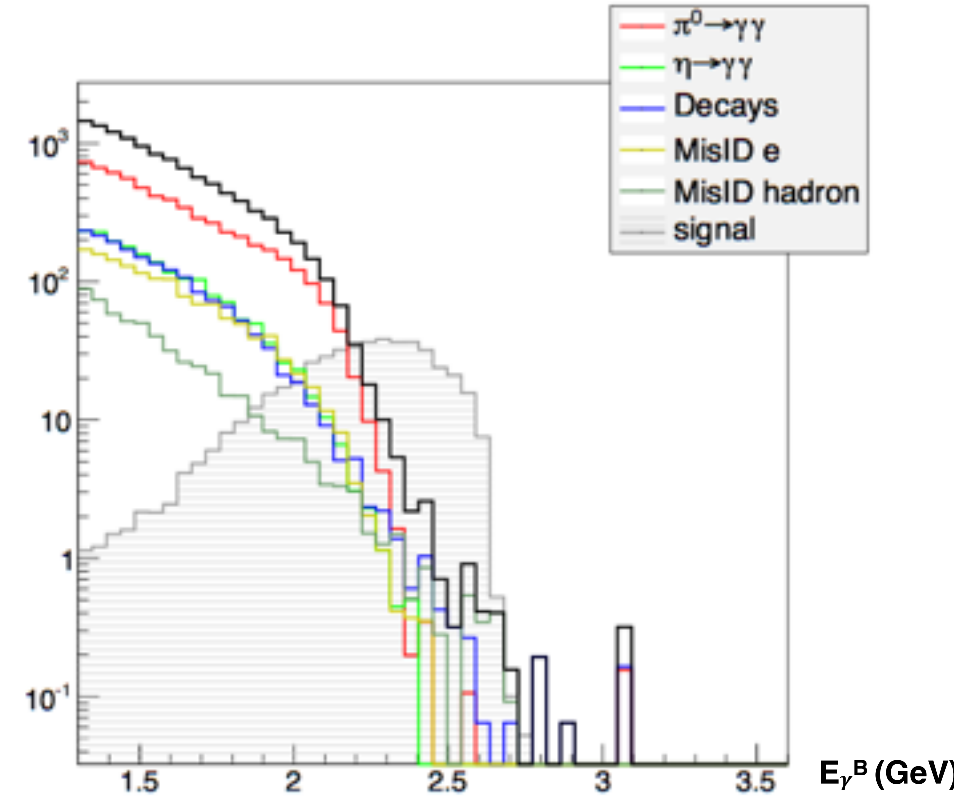
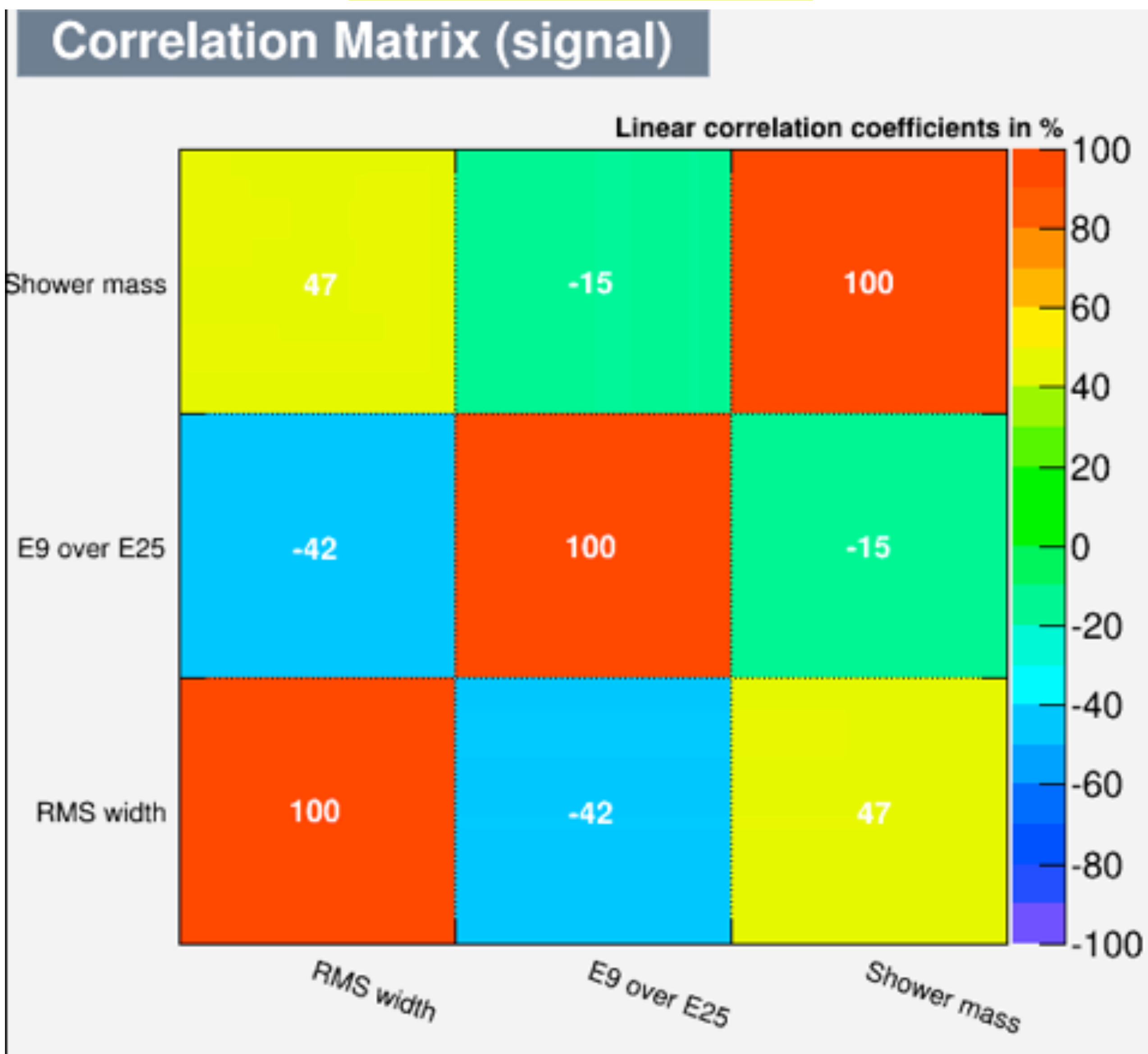


Fig 11. E_γ^B distribution after selection (sig/BB)

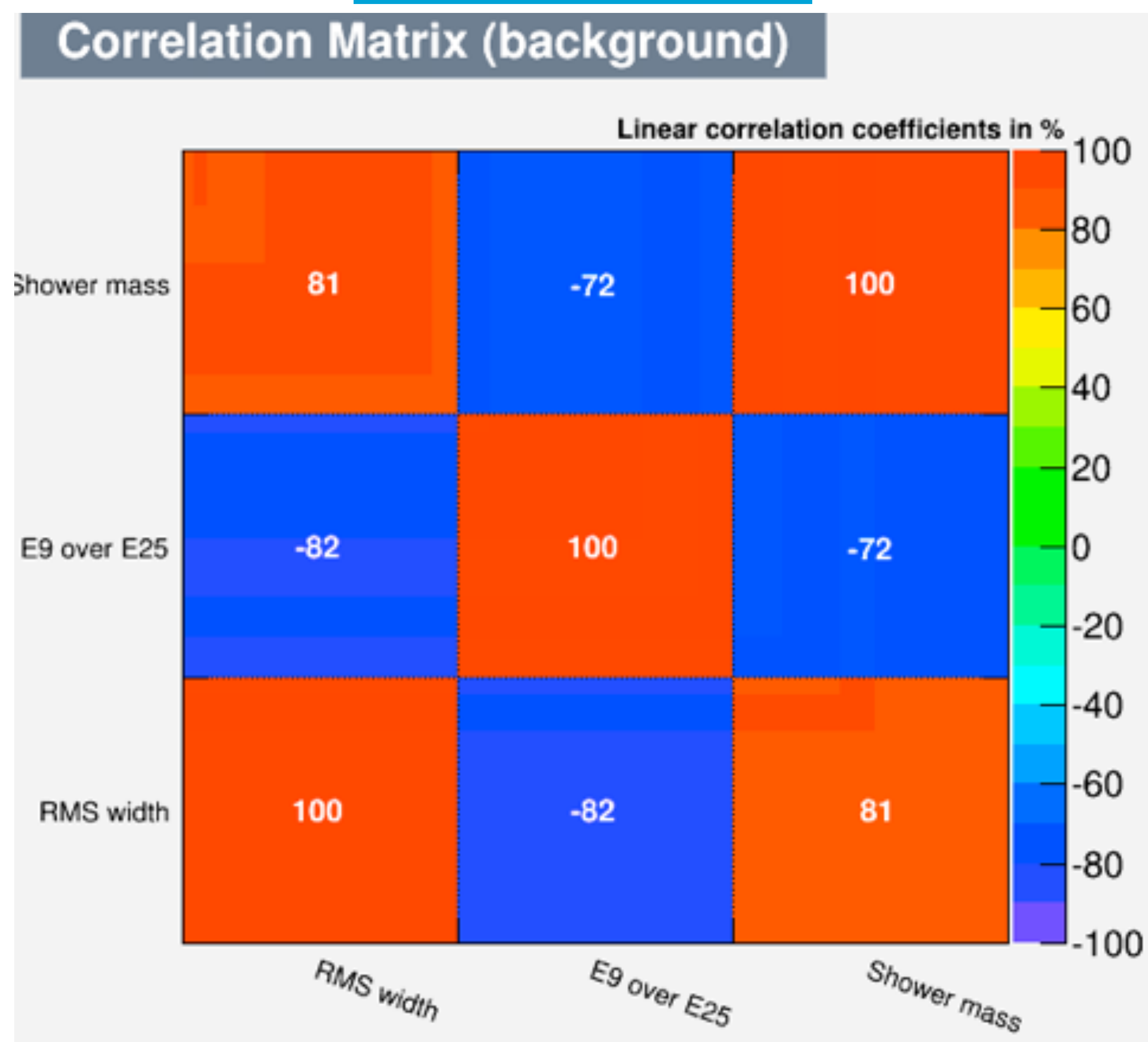
ECL variables

OK, apparently, it seems hard to generally apply MVA(distances, $\cos\theta_e$) cut to my samples of interest. (But I want to use this MVA somehow!)
So I checked the linear correlations btw ECL variables again, but this time, the whole MC samples were considered. (I only used samples in 1.8 ~ 2.0 GeV region in the last time)

Linearity(signal)

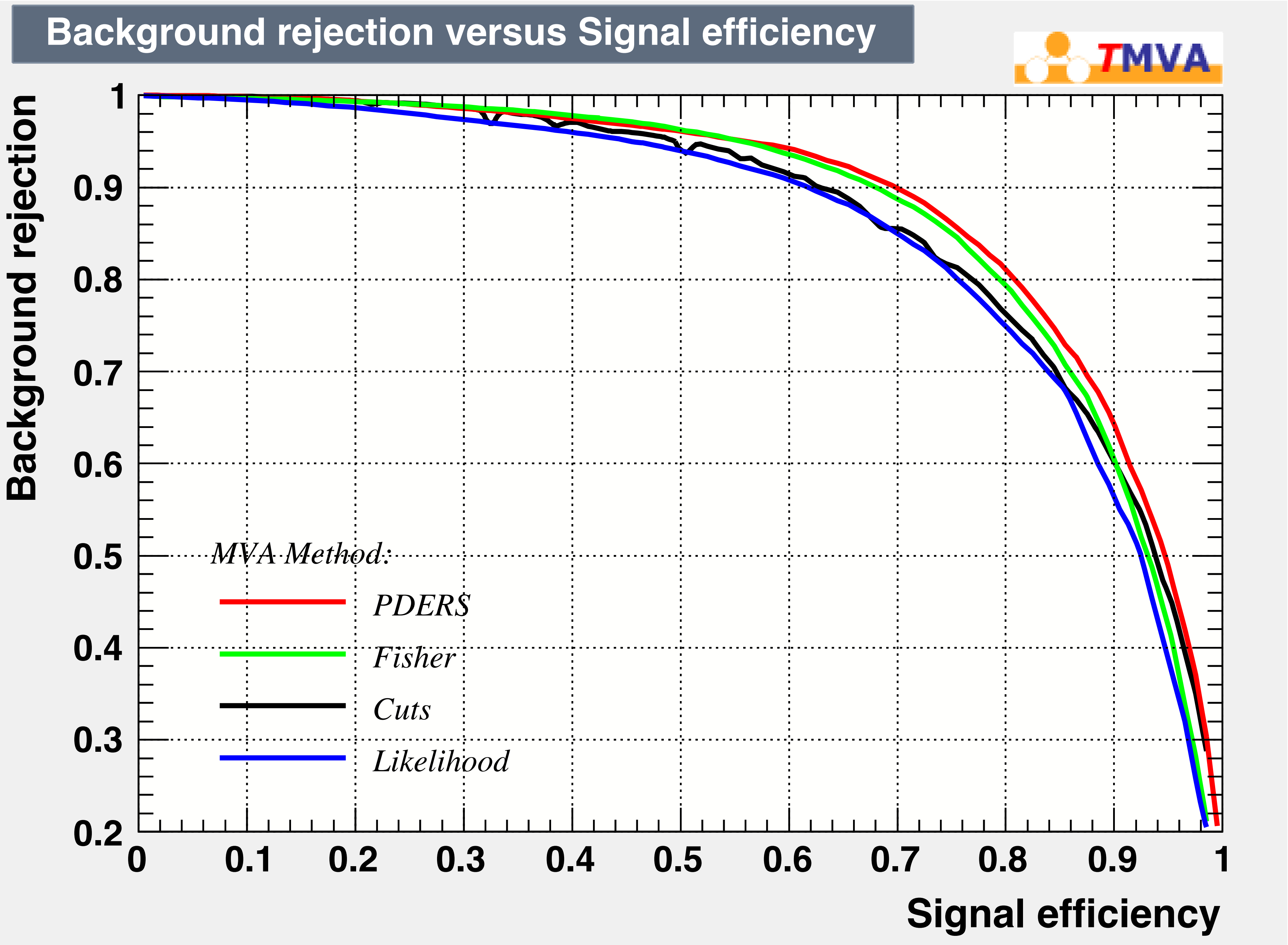


Linearity(BB+qq)



Wow, it seems hopeful!

ECL variables - MVA results



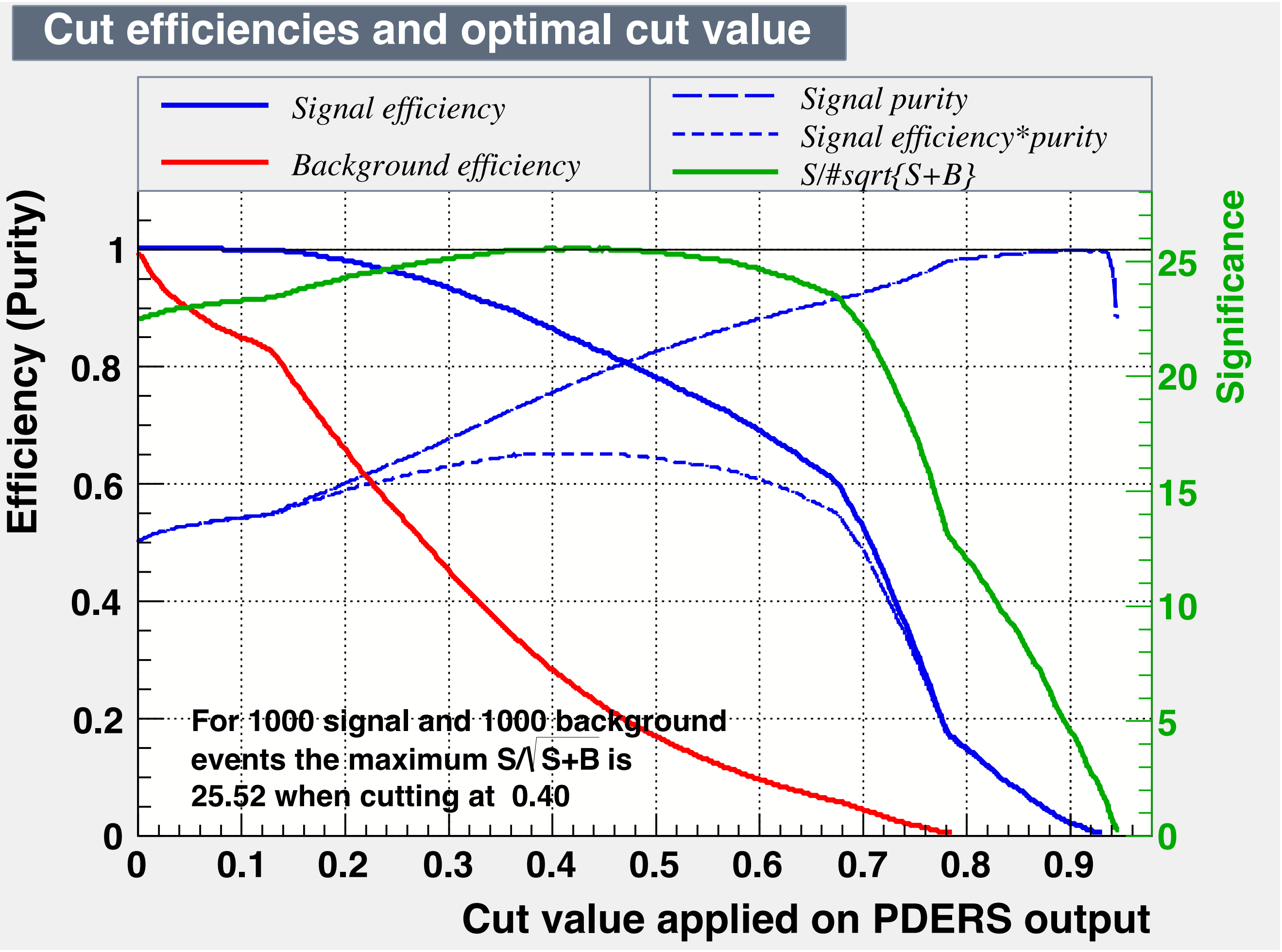
Fisher(linear discriminant) & PDERS(Multi-dimensional Likelihood) are generally better than just Rectangular Cuts.
And MVA can be a good choice for the optimization of rectangular cuts only.

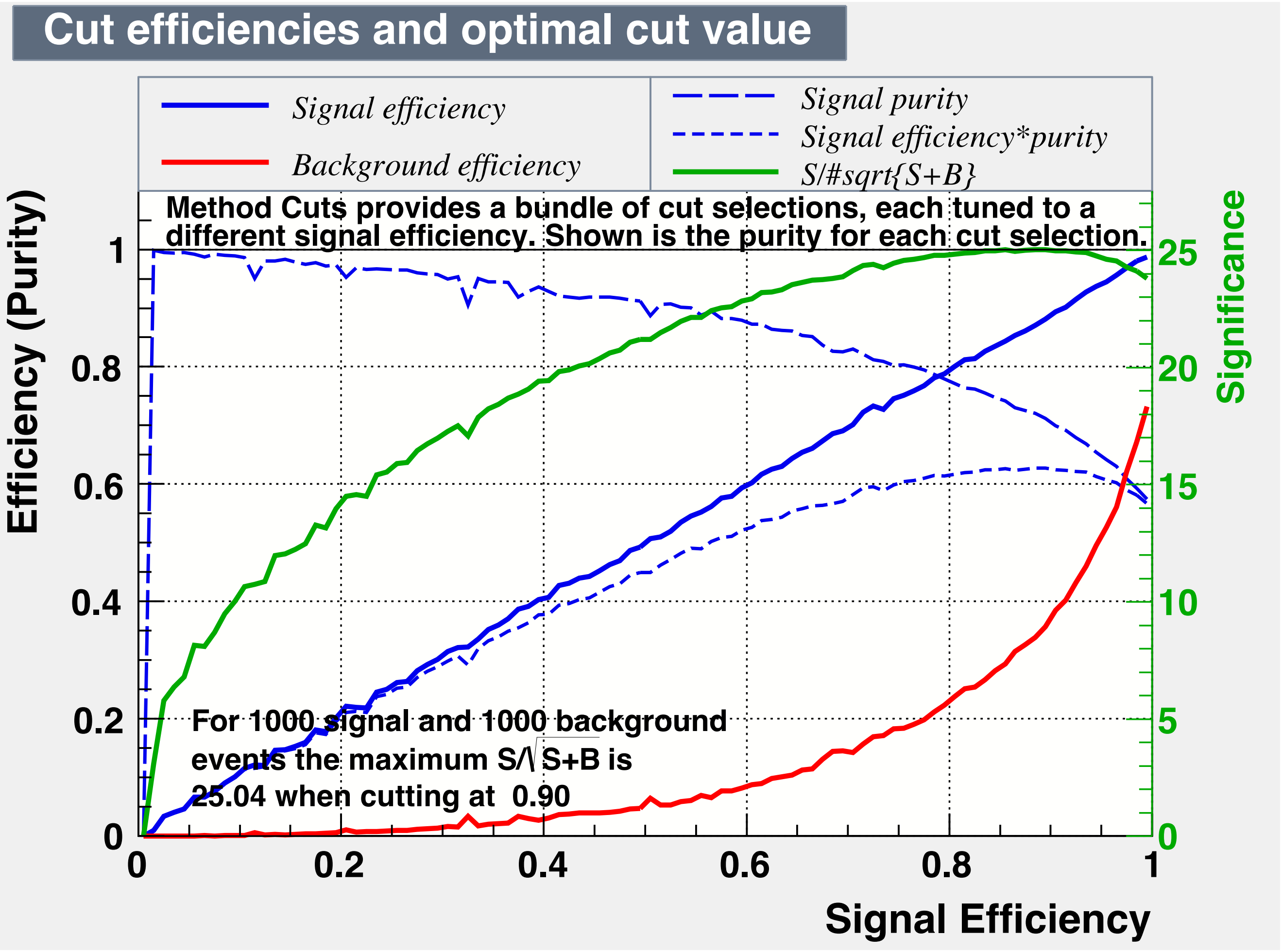
Fisher = -0.602*(width) -0.104*(e9/e25) - 0.534*(mass) +12.38

ECL variables - MVA results

FoM Comparison with Rectangular Cut

of random test set (# of sig , # of bkg) = (1000, 1000)



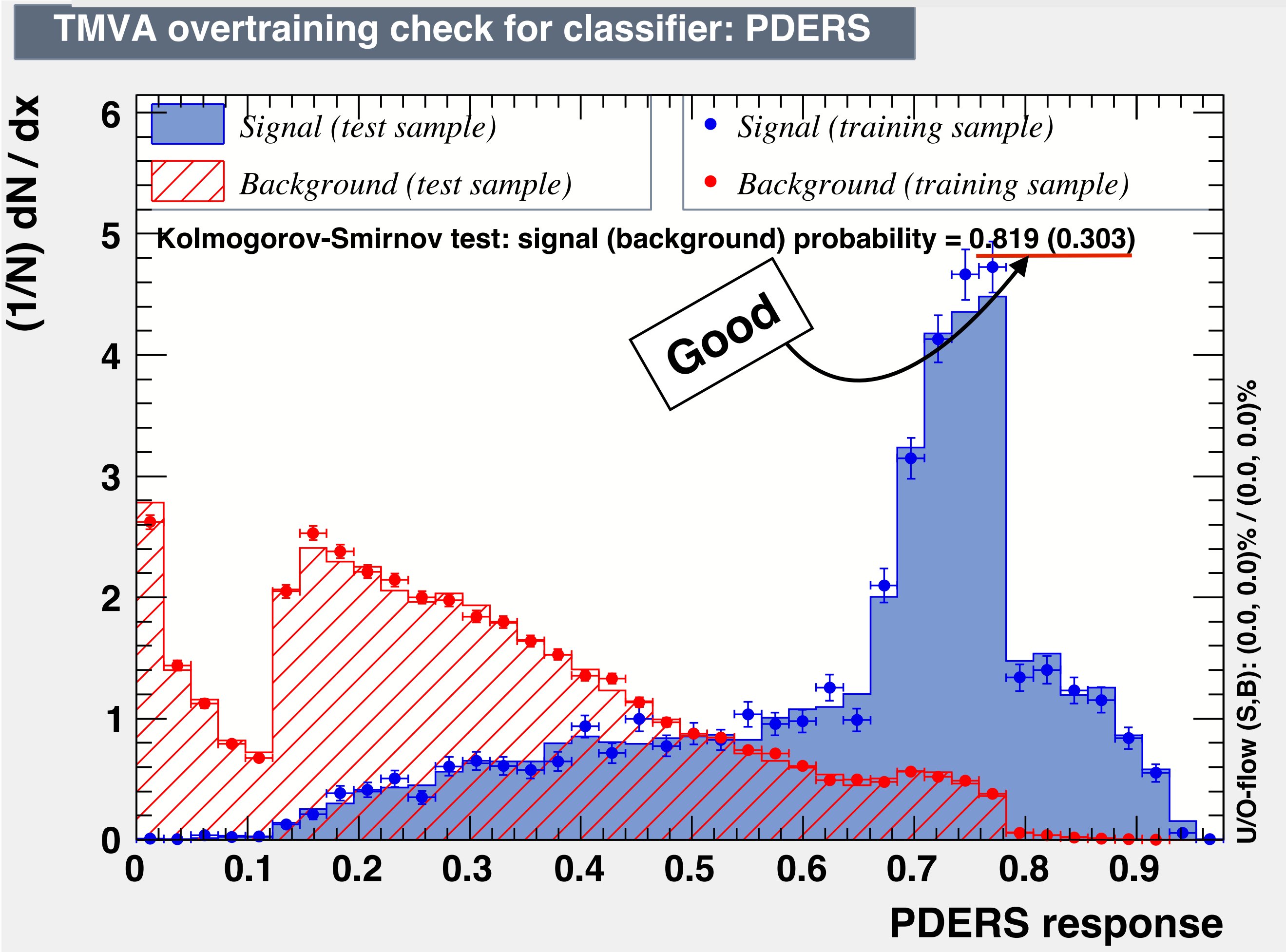


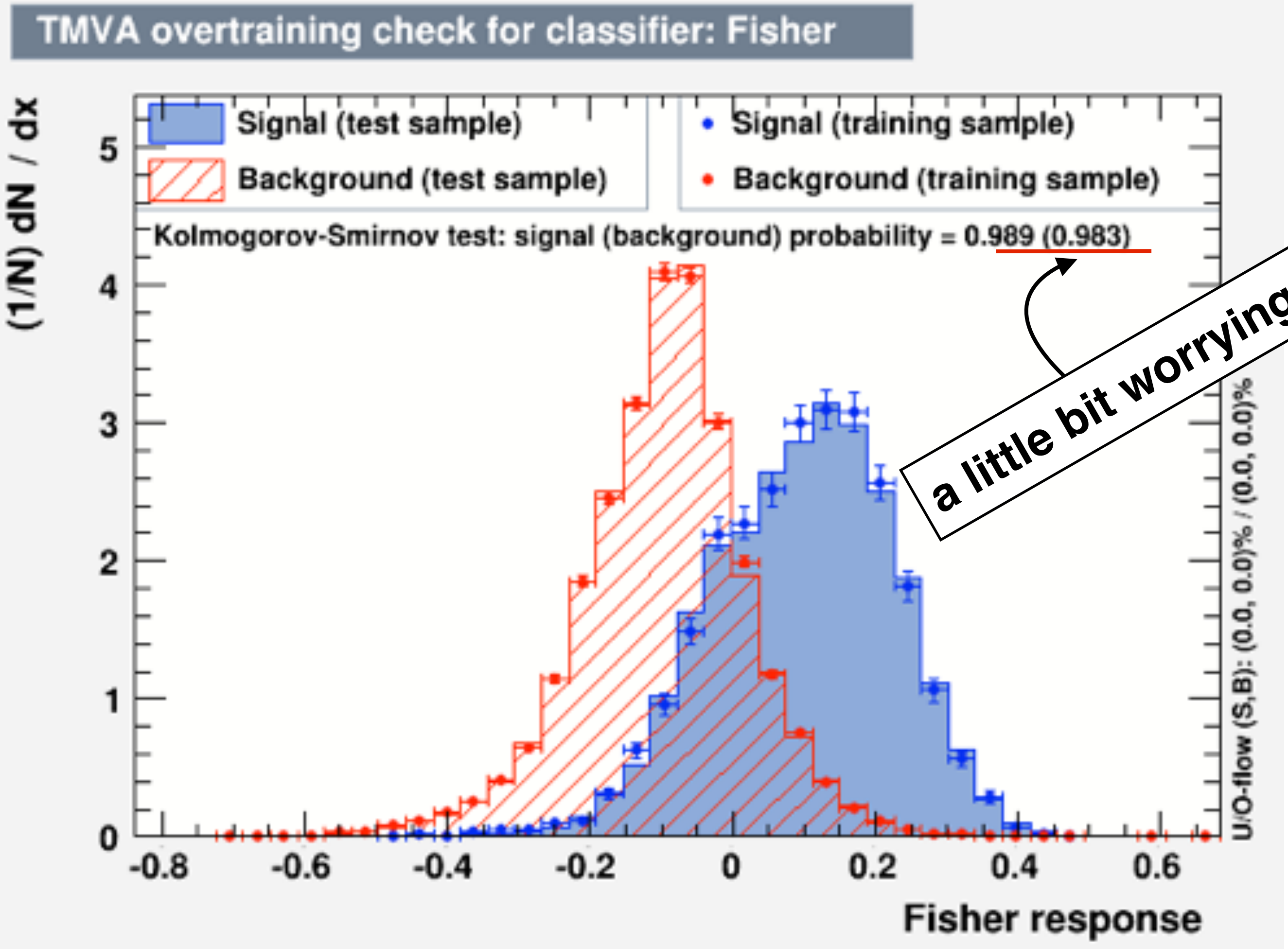
		PDERS	Rect. Cuts	Improvement(PDERS to Cuts)
FoM_{MAX}		25.5169	25.0428	1.89%
at FoM_{MAX}	Sig eff.	0.8641	0.8814	-1.96%
	Bkg Cut-off	0.7173	0.6426	11.62%

ECL variables - MVA results

Overtraining Check - Training Samples vs Testing Samples

(TMVA guide) Proper training and validation requires three statistically independent data sets: one for the parameter optimi- sation, another one for the overtraining detection, and the last one for the performance validation. In TMVA, the last two samples have been merged to increase statistics. <u>The (usually insignificant) bias introduced by this on the evaluation results does not affect the analysis as far as classification cut efficiencies or the regression resolution are independently validated with data.</u>





Kolmogorov-Smirnov test : A sort of comparison like χ^2 btw H_0(trained PDF) & H_1(testing PDF)
almost 1 : the same PDF(overtrained), almost 0 : no meaning of training, 0.1~0.9 : usual expectation

PDERS can be a better choice according to K-S test

π^0 Calibration

Fitting Process - Modeling

We employed the 2D fitting method to obtain the yield of TRUE π^0 from the data.
We found that we need to introduce a new P.D.F to model TRUE π^0 appropriately.

TRUE π^0, $M(\pi^0)$ Model

Bifurcated Crystal Ball

$$B.C.B.(x\,;\,m_0,\sigma_L,\sigma_R,\alpha_L,\alpha_R,n_L,n_R) = N\cdot\begin{cases} A_L\cdot(B_L-\frac{x-m_0}{\sigma_L})^n & \text{for } \frac{x-m_0}{\sigma_L}\le-\alpha_L \\ exp(-\frac{(x-m_0)^2}{2\sigma_L^2}) & \text{for } \frac{x-m_0}{\sigma_L}>-\alpha_L \\ exp(-\frac{(x-m_0)^2}{2\sigma_R^2}) & \text{for } \frac{x-m_0}{\sigma_R}<\alpha_R \\ A_R\cdot(B_R+\frac{x-m_0}{\sigma_R})^n & \text{for } \frac{x-m_0}{\sigma_R}\ge\alpha_R \end{cases}$$

Tail sides of 2 CB are merged !

$$A_S = (\frac{n}{|\alpha_S|})^n\cdot exp(-\frac{|\alpha_S|^2}{2})$$

$$B_S = \frac{n}{|\alpha_S|}-|\alpha_S|$$

p*(1.0 - 1.1 GeV)

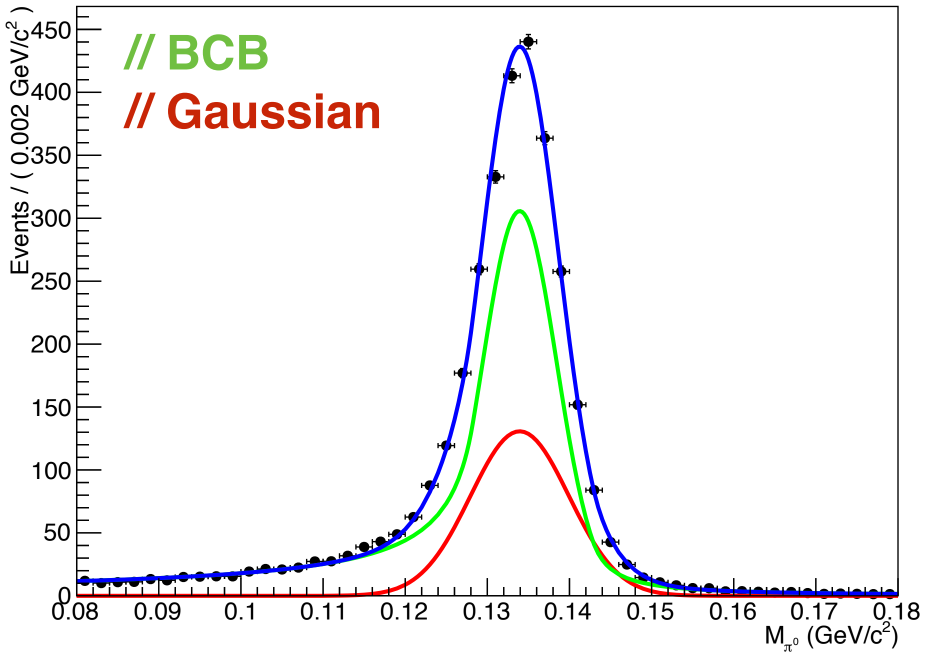


Fig 8. Example of true π^0 model

$$P.D.F_{true} = f\times BCB(x;m_0,\sigma,\sigma,\alpha_L,\alpha_R,n_L,n_R) + (1-f)\times Gauss(x;m_0,\sigma)$$

π^0 Calibration

Fitting Process - Modeling

Momentum binning; *to check the momentum dependence*

Region 1. 10 bins 100 MeV wide spanning $1.0 \leq p_{cm} < 2.0$ GeV (10 bins)
Region 2. 2 bins 200 MeV wide spanning $2.0 \leq p_{cm} < 2.4$ GeV (2 bins)
Region 3. 1 bins 300 MeV wide spanning $2.4 \leq p_{cm} < 2.7$ GeV (1 bins)

※ For the last bin (2.4-2.7 GeV), the $M(\pi^0)$ P.D.F was obtained from BB MC + Rare B MC.

Models Summary

	True	Random
$M(\pi^0)$	1 BCB + 1Gaussian (obtained from BB MC)	3rd-order Chebychev (obtained from BB MC)
M_{bc}	1 CB + 1 ARGUS (obtained from BB MC)	1 ARGUS (obtained from off DATA/ qqMC)

→

2D uncorrelated product	$M(\pi^0)_{true}$	$M(\pi^0)_{rndm}$
True M_{bc}	$P_{TP, TB}$	$P_{RP, TB}$
Rndm M_{bc}	$P_{TP, RB}$	$P_{RP, RB}$

※ ***TP*** : True Pi0, ***TB*** : True B, ***RP*** : Random Pi0, ***RB*** : Random B

π^0 Calibration

Fitting Process - Modeling

P.D.Fs for True/Rndm π^0 are obtained from $M(\pi^0)$ dist. of **BB MC**

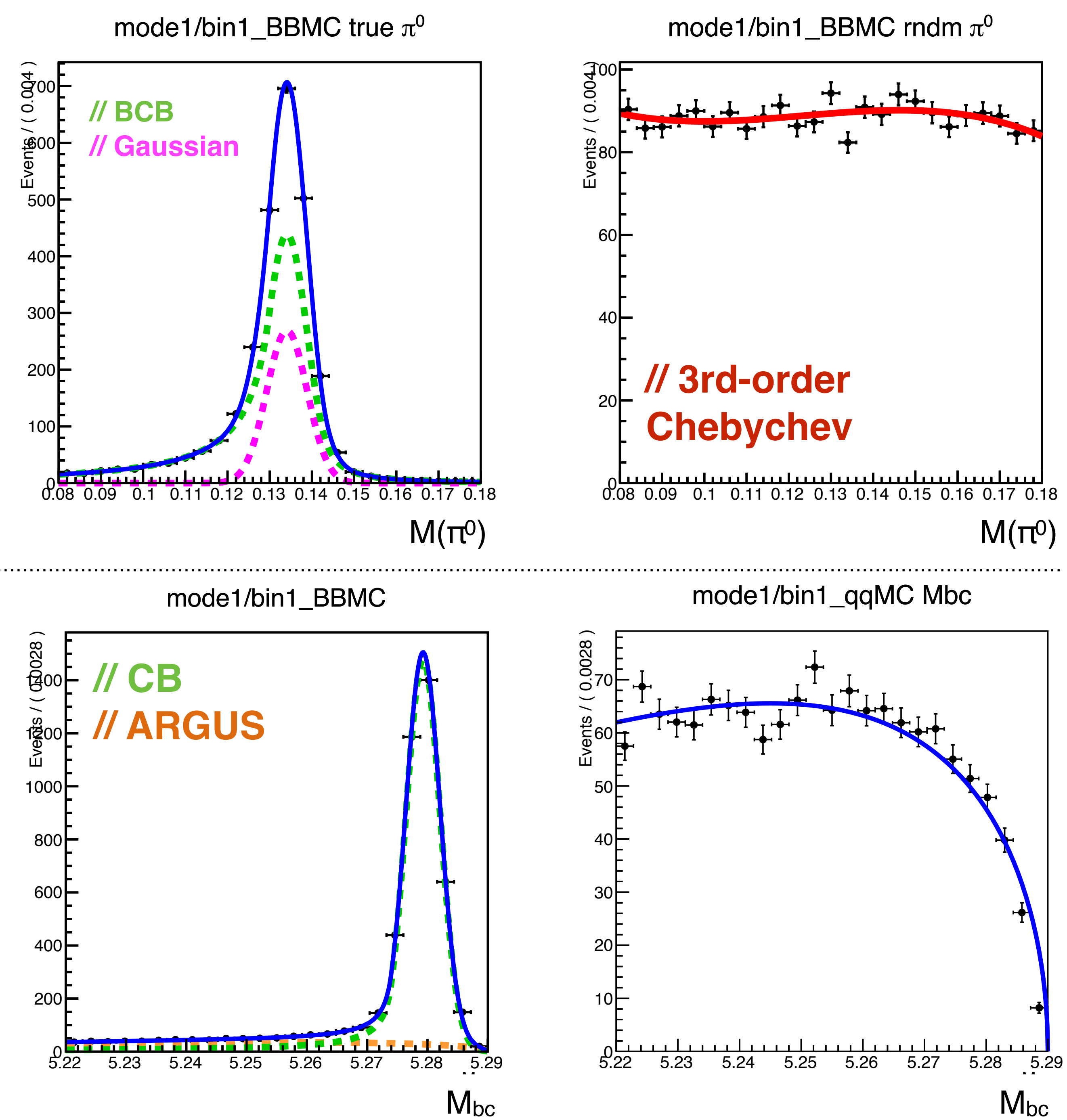
※ For the last bin (2.4-2.7 GeV), the $M(\pi^0)$ P.D.F was obtained from BB MC + Rare B MC.

P.D.Fs for True B are obtained from M_{bc} dist. of **BB MC**

P.D.Fs for Rndm B are obtained from M_{bc} dist. of **scaled off-DATA/qq MC**

※ For the last bin (2.4-2.7 GeV), the trueB M_{bc} P.D.F was obtained from BB MC + Rare B MC.

Bin 1, p*(1.0 - 1.1 GeV)



< Fig 9 > Modeling result

The results for the other bins are in the backup (p23)

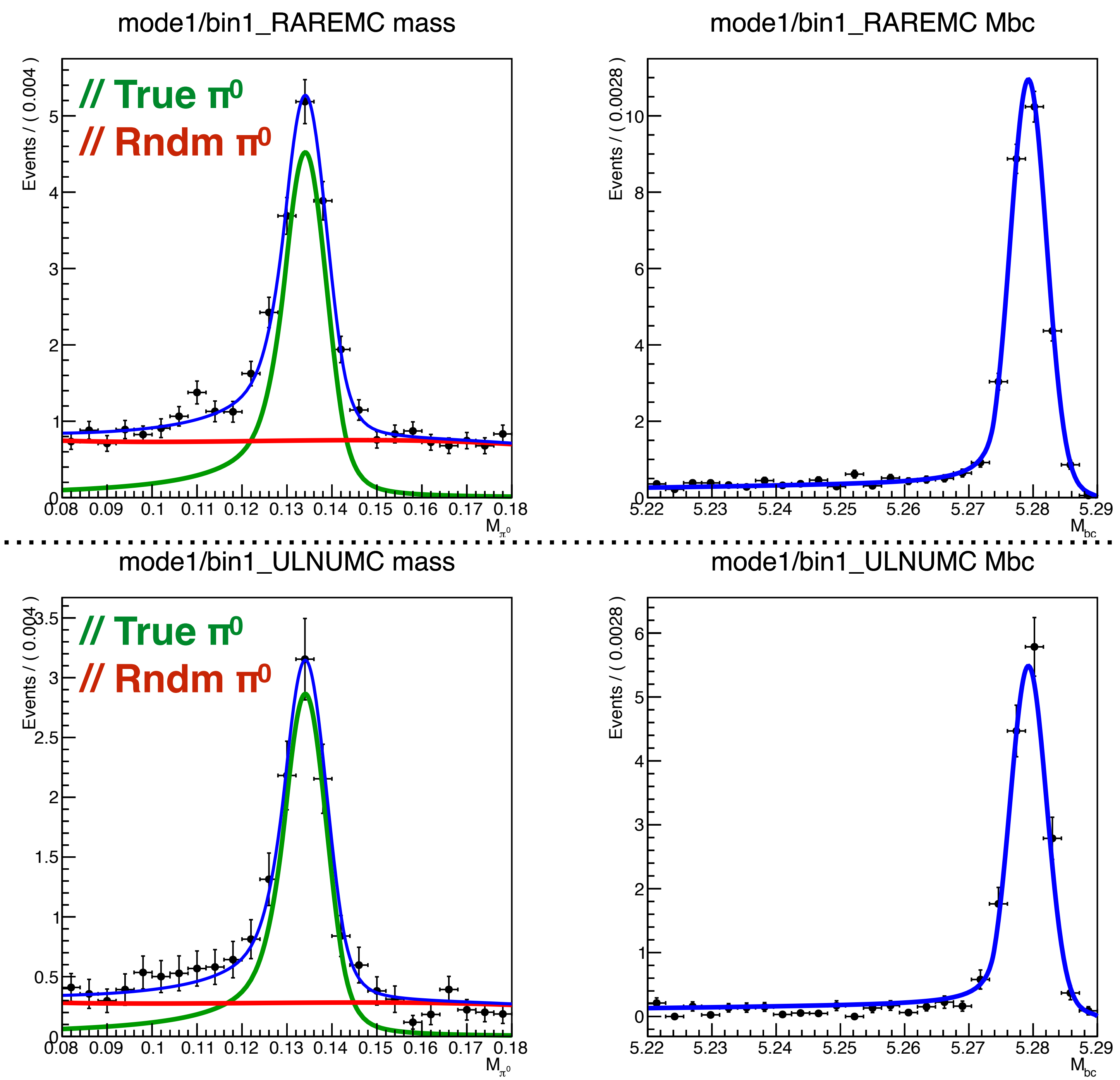
π^0 Calibration

Fitting Process

PDFs(True π^0, Rndm π^0, True B) obtained from BB MC were fixed to fit the other true B MC; Rare B & Ulnu MC.

PDFs represent them pretty well.

Bin 1, p*(1.0 - 1.1 GeV)



< Fig 10> Fitting result of each True B MC samples

The results for the other bins are in the backup (p25)

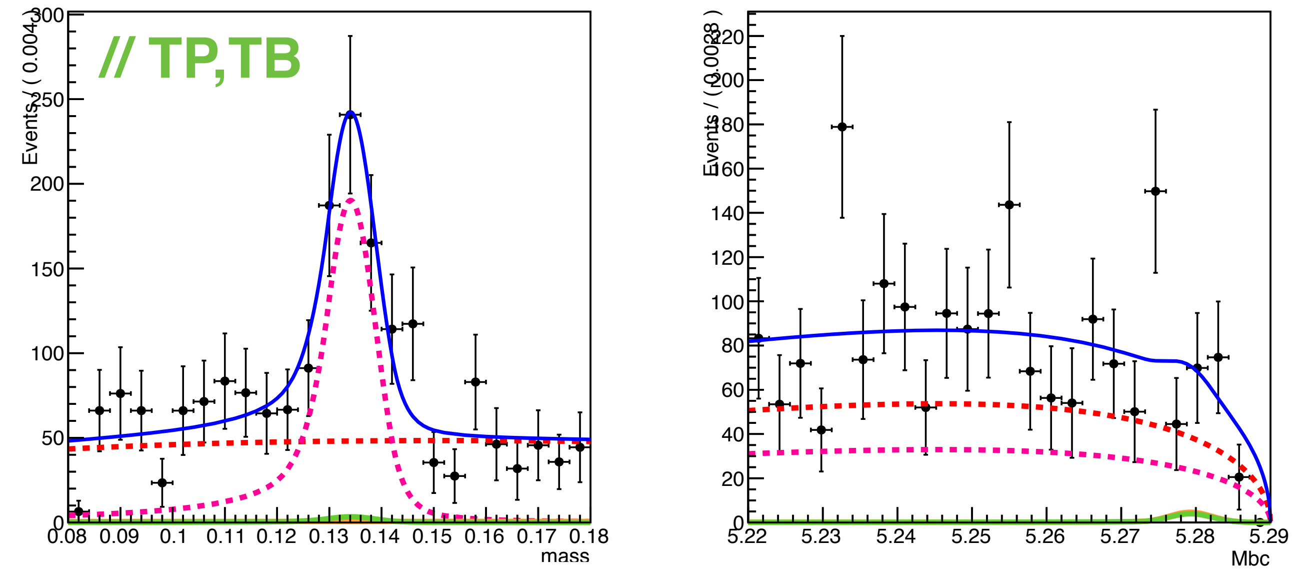
π^0 Calibration

Fitting Process - Continuum Samples

Since using qq MC could be beneficial when appropriate, we tested the yield of true π^0 oriented from true B decay(***N_{TPTB}***) inside the continuum samples using 2D fitting method.

Scaled Off-resonance DATA

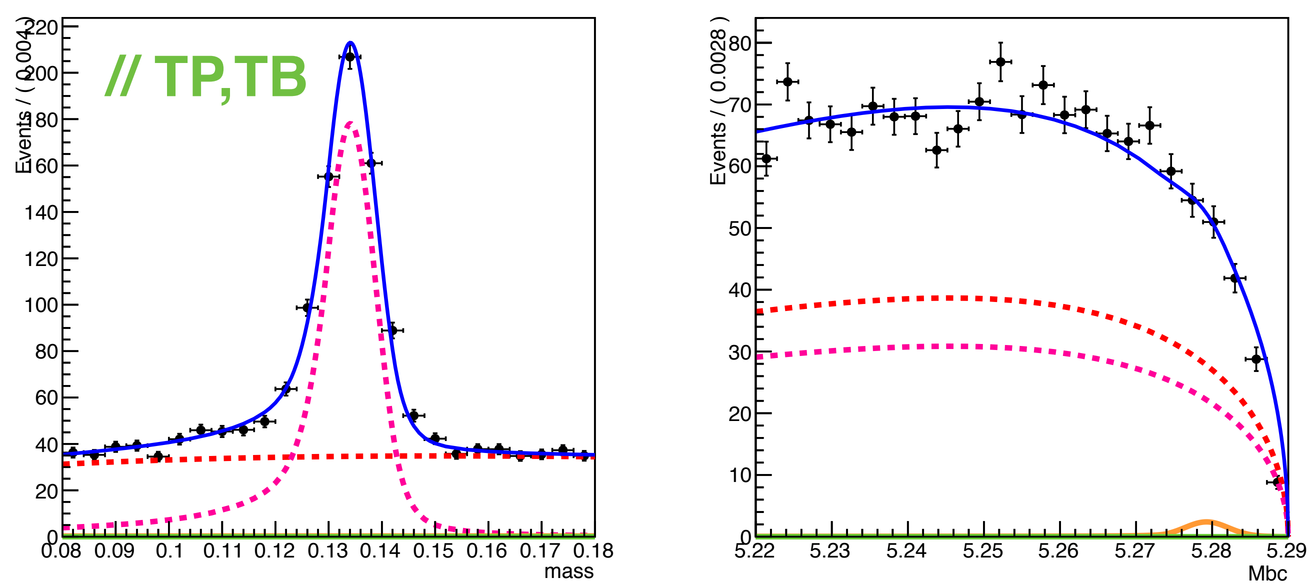
Yield	True B	Rndm B
True π^0	12.86±61.89	724.2±132.1
Rndm π^0	15.11±85.69	1180±157.9



Bin 1, p*(1.0 - 1.1 GeV)

On-resonance qq MC

Yield	True B	Rndm B
True π^0	0.01440±0.8486	678.0±14.07
Rndm π^0	7.846±3.076	849.7±122.9



N_{TPTB} consistent to ZERO for both cases

< Fig 11 > 2D fitting result of scaled off-data and qq MC

π^0 Calibration

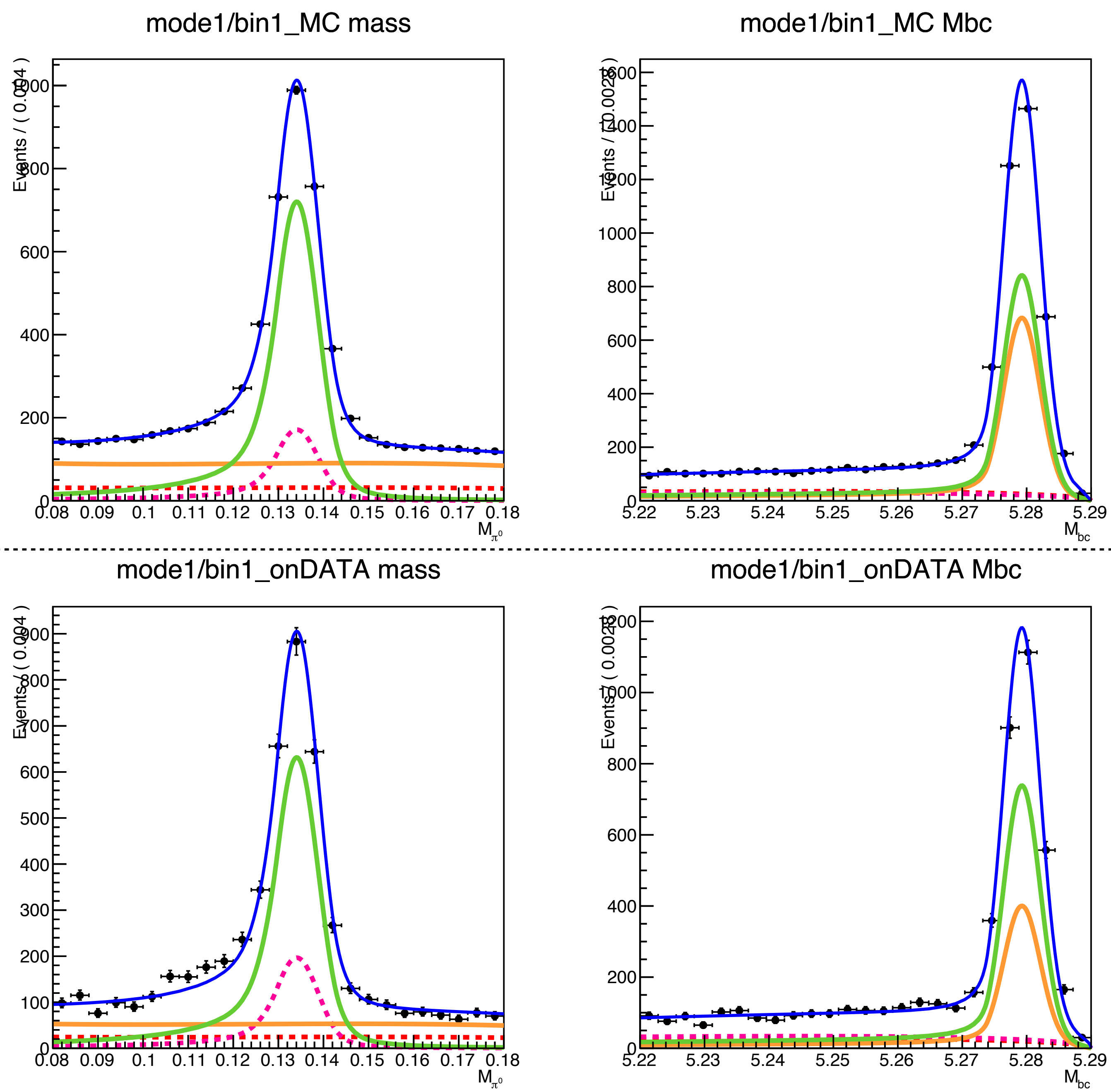
Fitting Process

Using 2D fitting method as in p.12, we obtained N_{TPTB} from the whole MC and on-resonance DATA.

// TP,TB
// RP, TB
// TP, RB
// RP, RB

MC

DATA



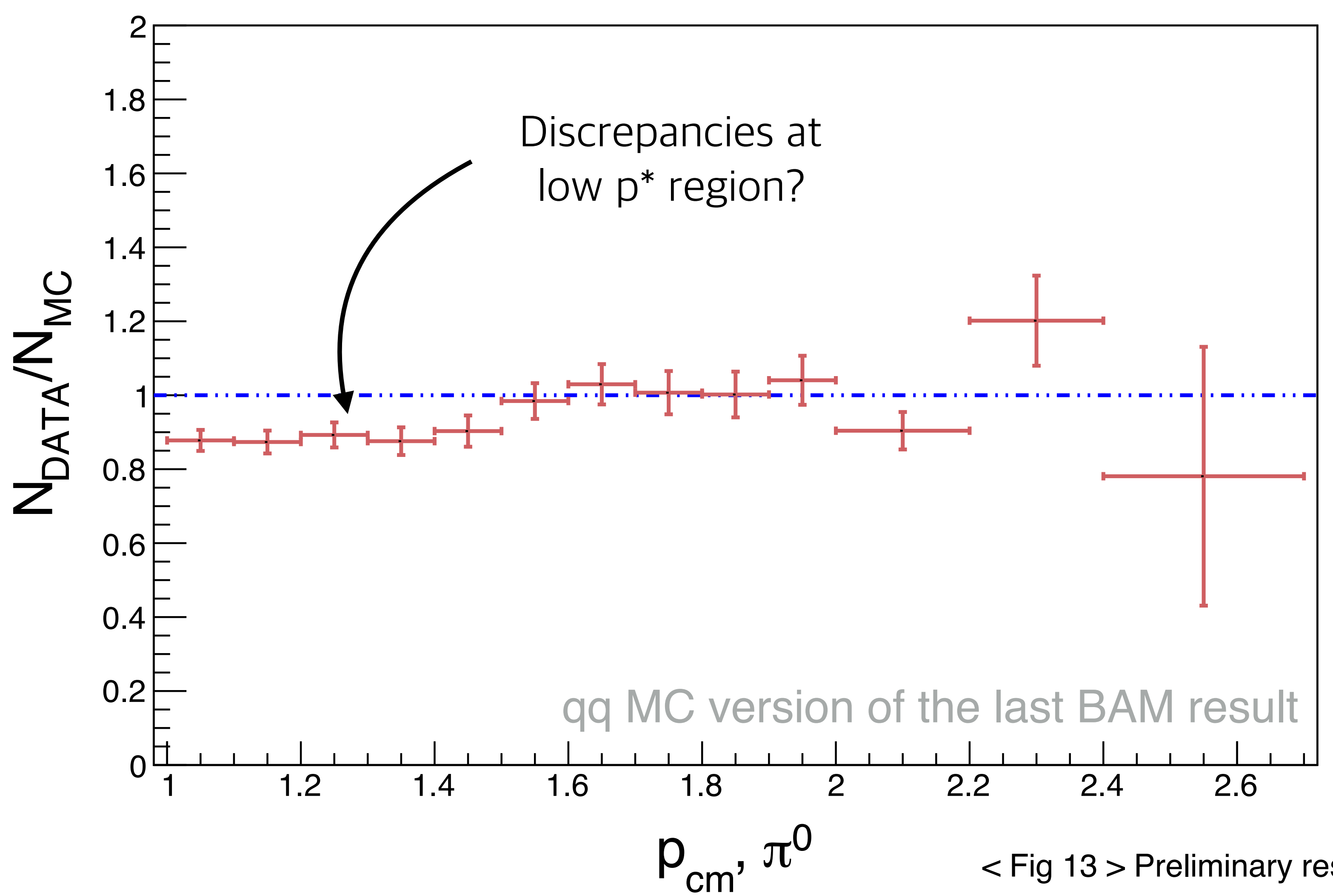
< Fig 12 > $M(\pi^0)$-M_{bc} 2D fitting results of the whole MC and on-DATA, for bin 1

The results for the other bins are in the backup (p29)

π^0 Calibration

Calibration Factors

Since we have considered tagging efficiency correction all the time, we can simply obtain the calibration factors as $N_{TPTB,DATA}/N_{TPTB,MC}$



< Fig 13 > Preliminary result of pi0 calibration factors

Suspicious discrepancies emerged

π^0 Calibration

Calibration Factors - Discrepancies?

Suspicious : TC Timing of photons (Off-timing veto)
There has been a couple of report on TC timing noting that its equivalent MC simulation is not guaranteed at low energy region.

Test #1 : Full Off-timing Veto (The result on p.14)
→ ∄ specific Eγ threshold for applying Off-timing veto

Test #2 : Eγ>1.0 GeV → Off-timing Veto
→ Only photons with E>1.0 GeV are subjected to Off-timing veto

Test #3 : $E_{asym} < 0.8$, (Substitution for purity control of photons)
→

$$E_{asym} = \frac{E_{\gamma,1} - E_{\gamma,2}}{E_{\gamma,1} + E_{\gamma,2}}$$

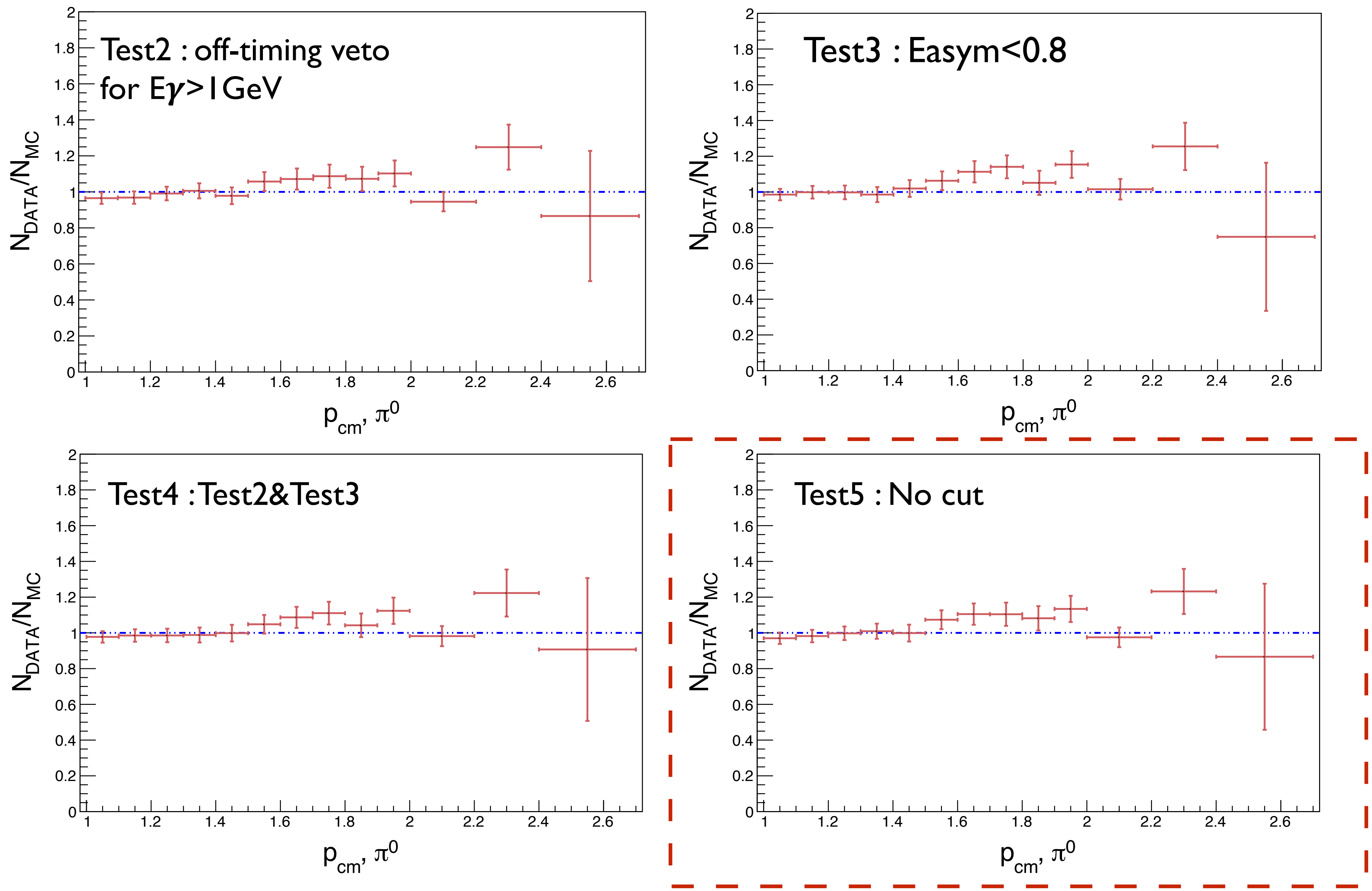
$E_{\gamma,1}, E_{\gamma,2}$: E of the daughter gammas

Test #4 : Combination of Test #2 & Test #3
→ The most pure π^0 samples are given

Test #5 : No such Cut

π^0 Calibration

Calibration Factors - Discrepancies?



< Fig 14 > Results of tests on the pi0 calibration factors

No discrepancy at the low p* region.

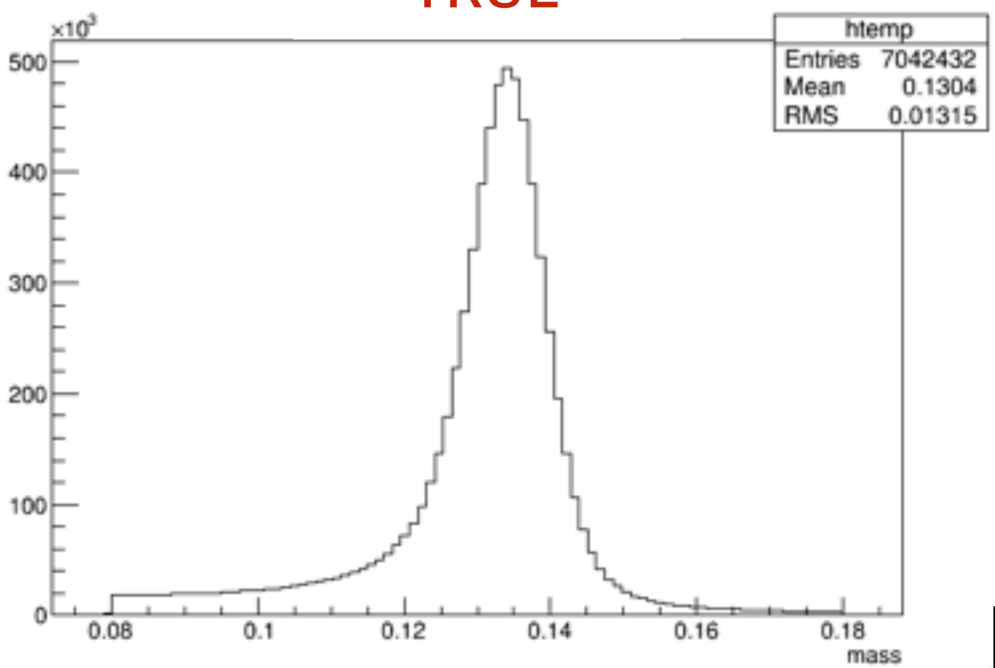
Hard to tell the difference among Test #2-5 → Go with Test #5

2. π^0 calibration

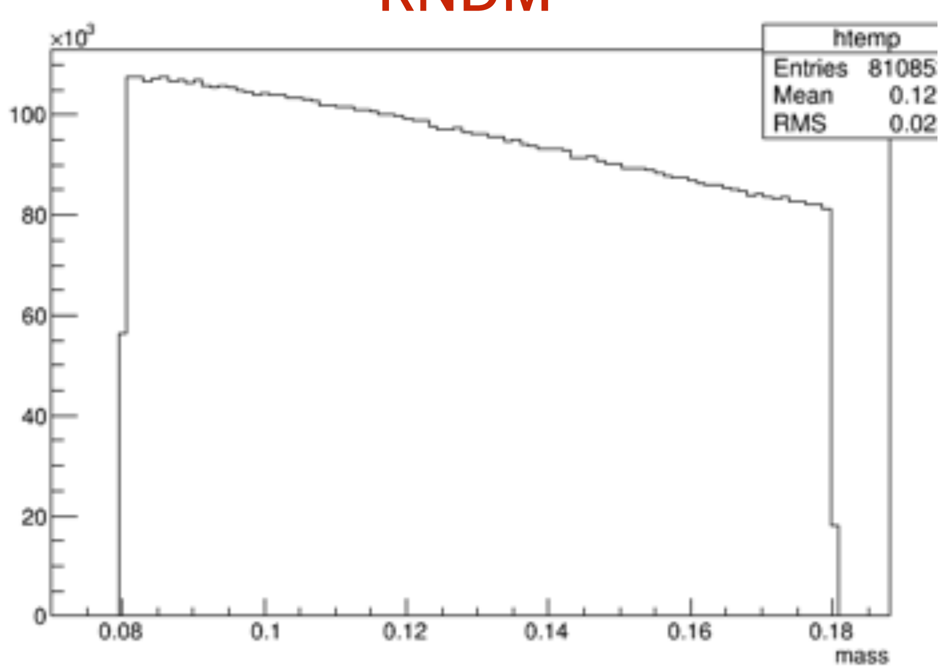
(2) Issue of EKP fullrecon on π^0 mass distribution

BEFORE fullrecon

TRUE

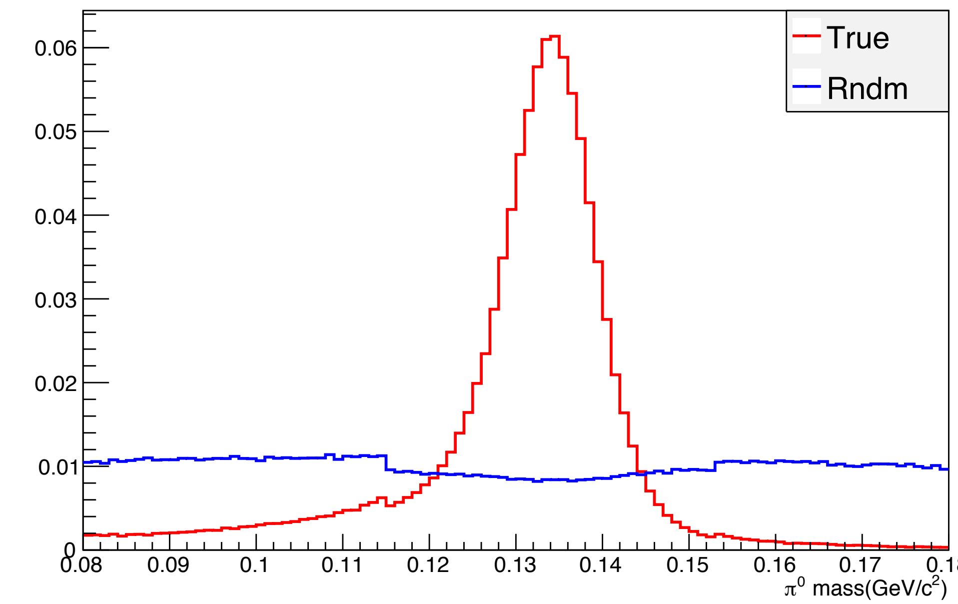


RNDM

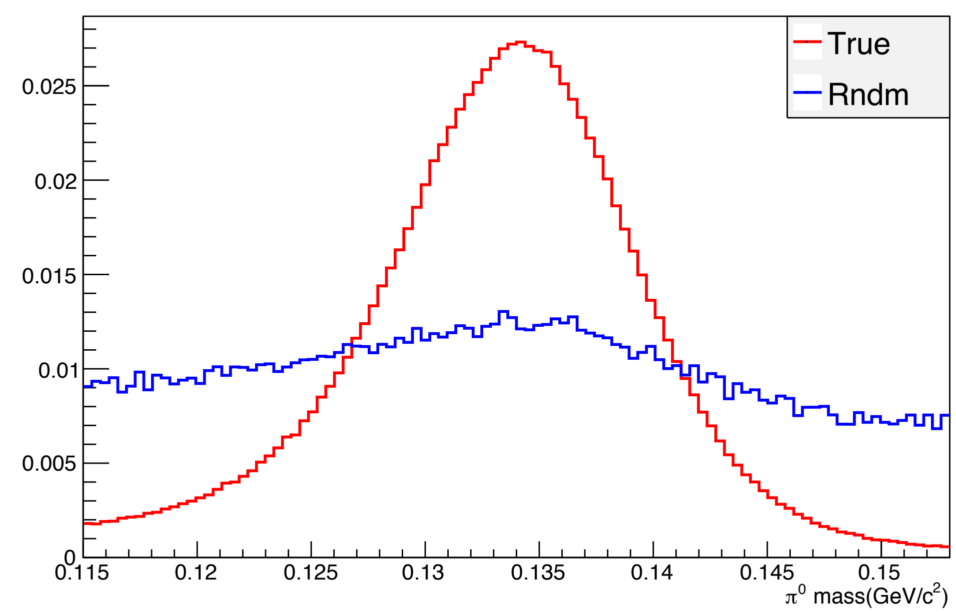


AFTER fullrecon

Non-tagged π^0, Normalized



Tagged-Normalized



2. π^0 calibration

(2) Issue of EKP fullrecon on π^0 mass distribution

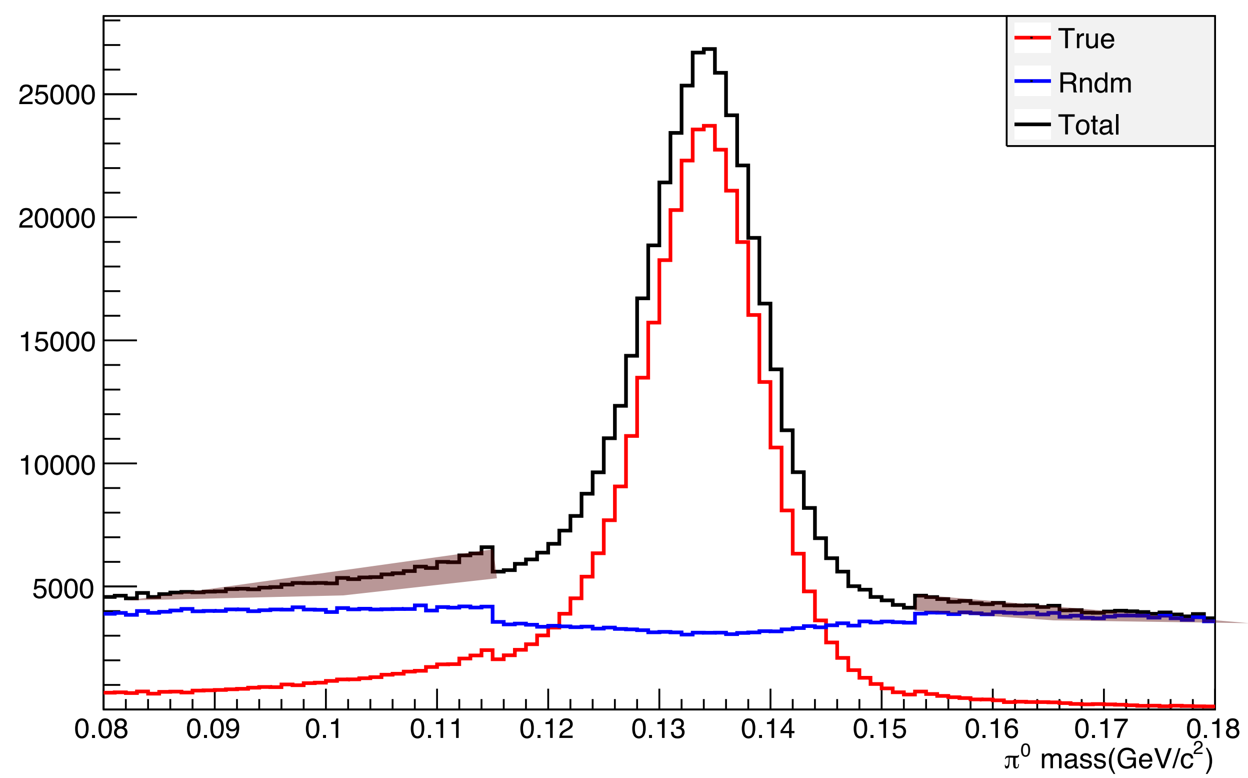
BEFORE fullrecon

TRUE

AFTER fullrecon

Non-tagged π^0, Normalized

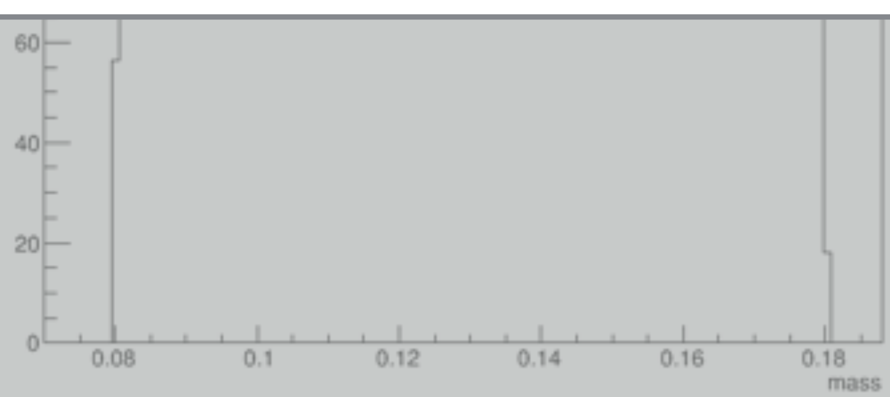
Non-tagged π^0, Normalized

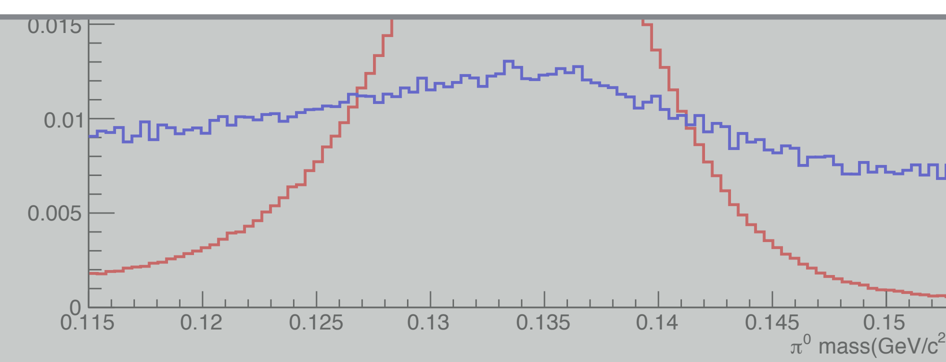


This is a result of π^0 mass cut required inside EKPfullrecon

(0.115 < π^0 mass < 0.153 GeV)

***Colored part** might have been tagged if there were no mass cut*





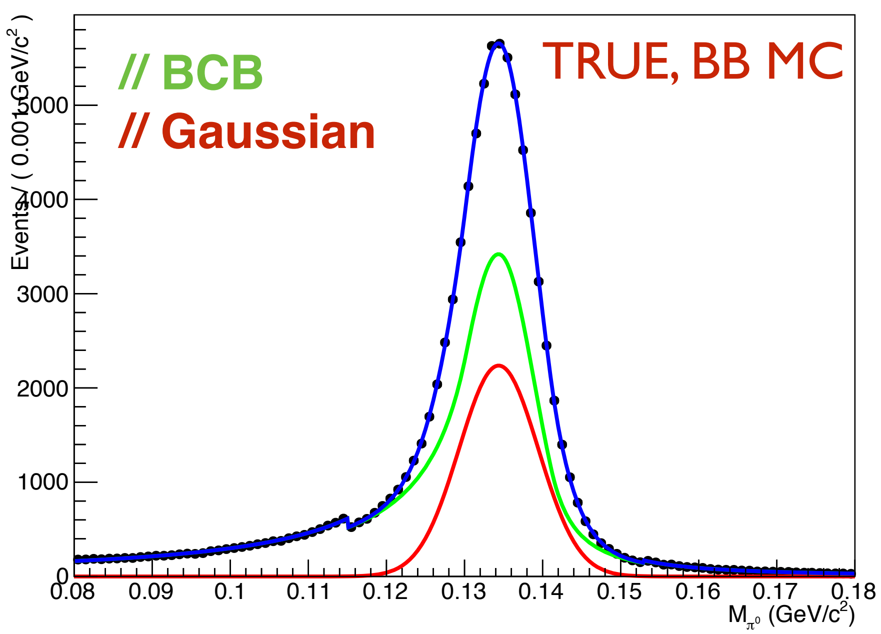
2. π^0 calibration

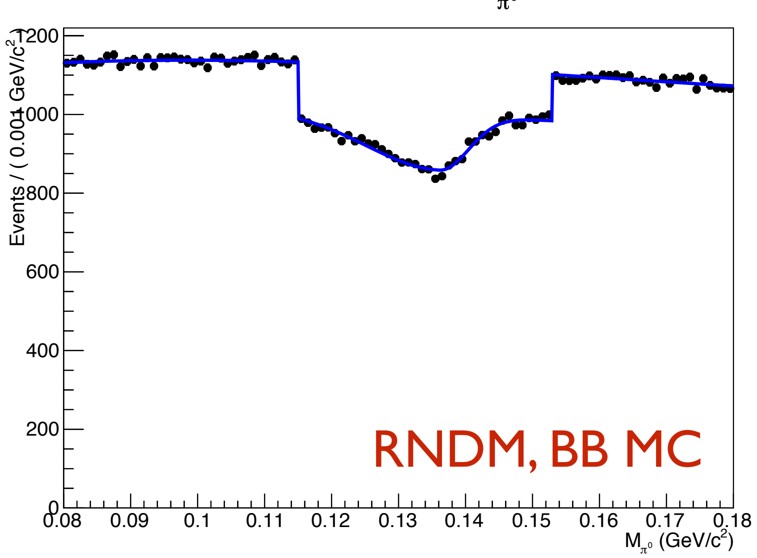
(3) Fitting, Yield Estimations

Momentum binning; to check the momentum dependence

Region 1. 10 bins 100 MeV wide spanning $1.0 \leq p_{cm} < 2.0$ GeV (10 bins)
Region 2. 2 bins 200 MeV wide spanning $2.0 \leq p_{cm} < 2.4$ GeV (2 bins)
Region 3. 1 bins 300 MeV wide spanning $2.4 \leq p_{cm} < 2.7$ GeV (1 bins)

1.0 - 1.1 GeV





New PDF introduced

Bifurcated Crystal Ball (B.C.B)

Tails on both sides of a Bifurcated Gaussian

π^0 Mass dist. of true π^0 can be described by
1 BCB + 1 Gaussian

Rndm can be described by
3rd-order Chebychev - Bifurecated Gaussian

The height of kink can be controlled by multiplying an *step function* to the original PDF.

See p.20 - p.27 for the other bins