Study of $B^0 \to K^+ K^- \pi^0$ at Belle and Belle II

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BHadronic

Content

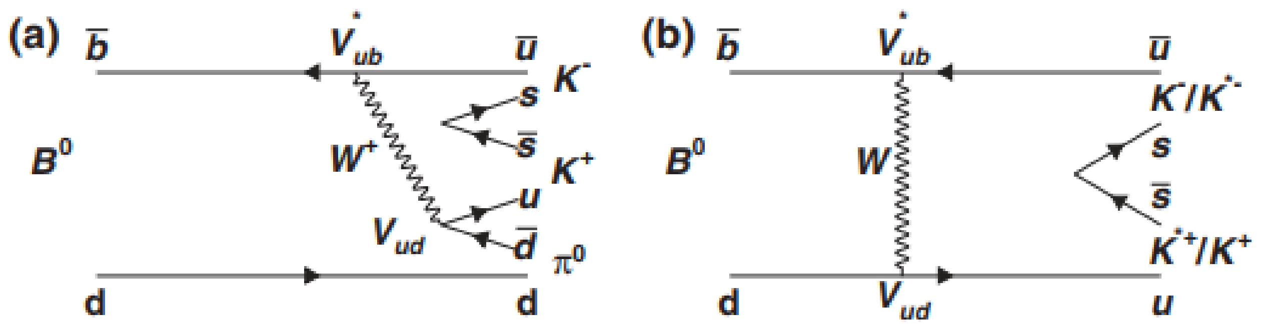
Update log

- Update Belle II analysis using **MCrd** instead of **MCri**
- Add Belle analysis

Motivation

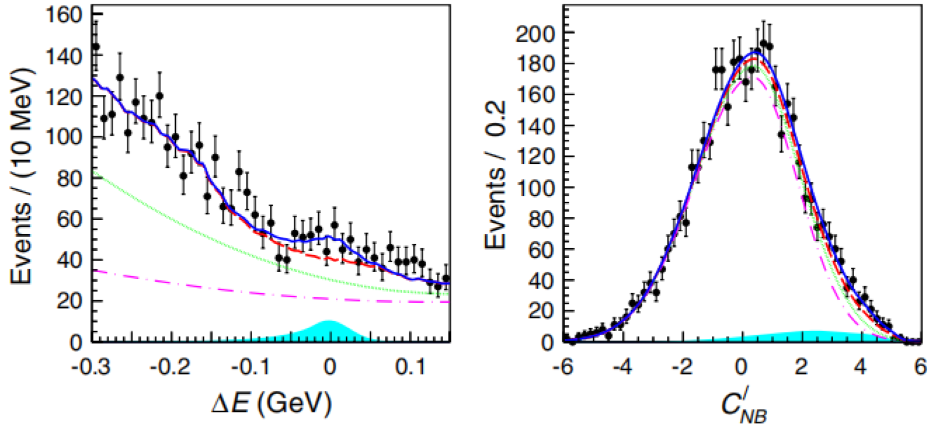
- $B^0 \to K^+K^-\pi^0$ suppressed in standard model (SM)
  - Charmless three-body decay
  - Sensitive probe of new physics
  - Potential intermidiate states ...

- Dominant decay amplitude : $b \to u$ tree
- Internal W exchange diagram
  - $B^0 \to K^{*\pm}K^{\mp}$ with $K^{*\pm} \to K^{\pm}\pi^0$



Typical Feynman diagrams that contribute to the decay $B^0 \to K^+K^-\pi^0$: (a) $b \to u$ tree and (b) internal W exchange [1]

- Belle
  - ✓ Evidence with significance of 3.5σ [1]
  - ✓ $\mathcal{B}(B^0 \to K^+K^-\pi^0) = [2.17 \pm 0.60(\text{ stat }) \pm 0.24(\text{ syst })] \times 10^{-6}$
  - ✓ 711 fb^{-1} data sample contains 772×10^6 $B\bar{B}$ pairs



Evidence for the decay $B^0 \to K^+K^-\pi^0$ [1]

- Belle & Belle II
  - ☐ 711 fb^{-1} + 365 fb^{-1} data sample to reach higher signal significance (Goal > 5σ)
  - ☐ CP asymmetry measurement and Amplitude analysis ...

[1] V. Gaur et al. (Belle Collaboration) Phys. Rev. D **87**, 091101(R)

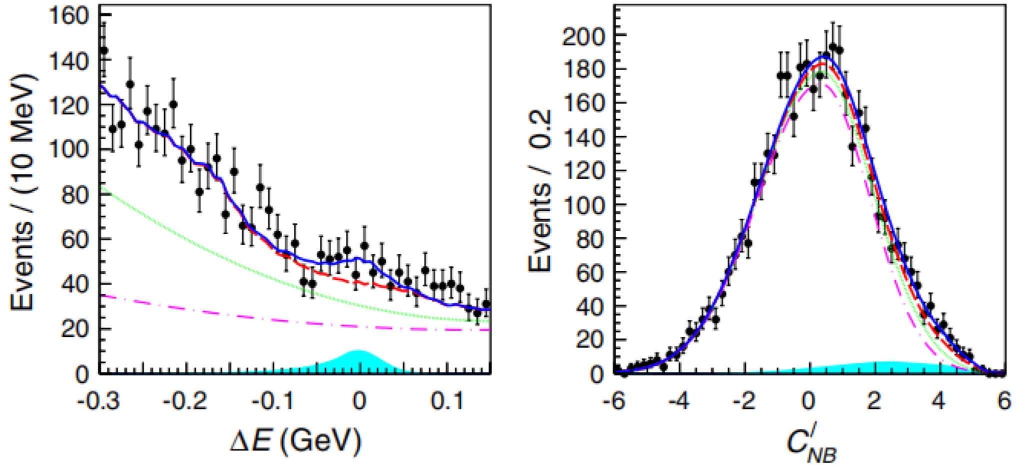
Research Method

- Select $B^0 \to K^+K^-\pi^0$ candidates
- Extract signal yields using an unbinned maximum likelihood fit to the variables:

  ΔE and transformed CS (apply tight cut on M_{bc})

Major analysis steps

- ☐ Event reconstruction & Basic event selection
- ☐ Selection optimization
- ☐ Background study
- ☐ Signal yield extraction
- ☐ Fitter validation
- ☐ Control channel study
- ☐ Systematic uncertainties
- ☐ Fit the data



Evidence for the decay $B^0 \to K^+K^-\pi^0$ [1]

[1] V. Gaur et al. (Belle Collaboration) Phys. Rev. D **87**, 091101(R)

Belle II

Dataset

Dataset		Version
Signal MC	2M (**MC15rd**) (decayfile) : https://gitlab.desy.de/belle2/software/basf2/-/blob/main/decfiles/dec/1110021003.dec	light-2409-toyger
Generic MC	1.4 ab^{-1} qqbar (**MC15rd**) 1.4 ab^{-1} mixed & charged (**MC15rd**)	
Data	365 fb^{-1} $\Upsilon(4S)$ on-resonance data 42.7 fb^{-1} off-resonance data	

Baseline Selection

- $B^0 \to K^+K^-\pi^0$

➢ basf2 default final-state particle list builder functions

- **Tracks**
  - dr < 0.5 cm & |dz| < 2 cm
  - thetaInCDCAcceptance
  - nTracks > 2
- B^0
  - 5.25 $< M_{bc} <$ 5.289 GeV/c^2
  - -0.3 GeV $< \Delta E <$ 0.15 GeV
  - treefit
- $K^\pm$
  - No PID requirement

- $\pi^0 \to \gamma\gamma$
  - StdPi0 (eff50_May2020)
    - 0.105 < InvM <0.150 GeV/c^2
  - kFit
  - γ
    - StdPhoton (eff50_May2020)
      - ClusterNHits > 1.5
      - 0.2967 < ClusterTheta < 2.6180
      - Cluster E in different area:
        - E_γ in forward endcap > 0.025 GeV
        - E_γ in barrel > 0.025 GeV
        - E_γ in backforward endcap > 0.04 GeV
    - |ClusterTiming| < 200 ns

Selection Optimization

- $B^0 \to K^+K^-\pi^0\ (\pi^0 \to \gamma\gamma)$

Variable	Description
γ relevant variable	
clusterE	ECL cluster's energy corrected for leakage and background
beamBackgroundSuppressionScore	The output of an MVA classifier that uses shower-related variables to distinguish true photon clusters from beam background clusters (**Belle II**)
fakePhotonSuppressionScore	The output of an MVA classifier that uses shower-related variables to distinguish true photon clusters from fake photon clusters (**Belle II**)
π^0 relevant variable	
$\chi^2_{\pi^0}$	χ^2 of π^0 mass constraint fit
daughterAngle	The three dimensional angle between the two clusters used for π^0 reconstruction
cosHelicityAngleMomentum	Cosine of the angle between the line defined by the momentum difference of two photons in the frame of π^0 and the momentum of π^0 in the lab frame
InvM	The invariant mass of diphoton used to reconstruct π^0
Charged kaon relevant variable	
atcPIDBelle_3_2	The kaon likelihood against pion $\mathcal{L}(K/\pi)$. (**Belle**)
kaonIDNN	The kaon identification probability calculated from the PID neutral network. (**Belle II**)

➢ Selection optimized based on

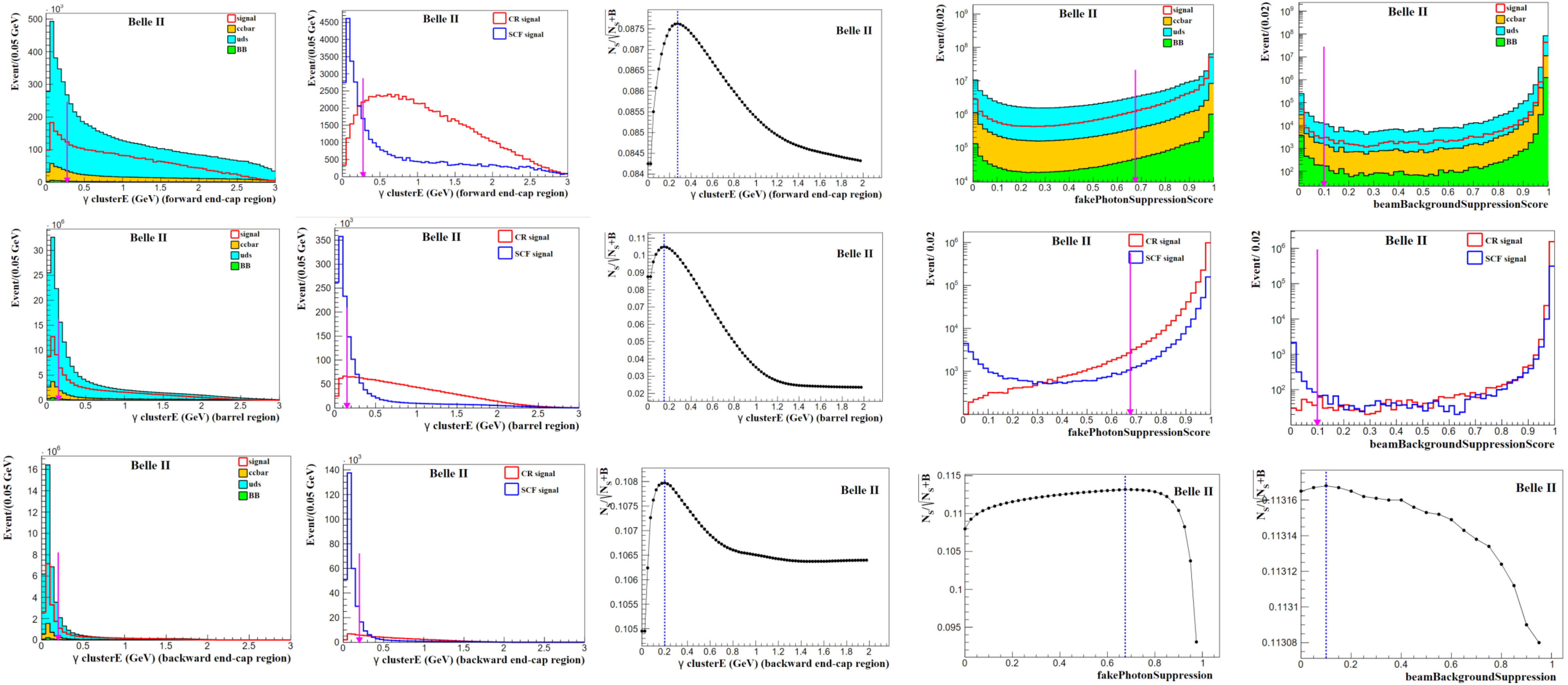
$$\text{Figure of Merit (FOM)} = \frac{N_S}{\sqrt{N_S+N_B}}$$

- N_S : expected signal events in the experimental data estimated by assuming the branching ratio to be $\mathcal{B}(B^0 \to K^+K^-\pi^0) = 2.17 \times 10^{-6}$ [1]
- N_B : background events scaled to the luminosity of the experimental data

[1] V. Gaur et al. (Belle Collaboration) Phys. Rev. D **87**, 091101(R)

γ relevant variable

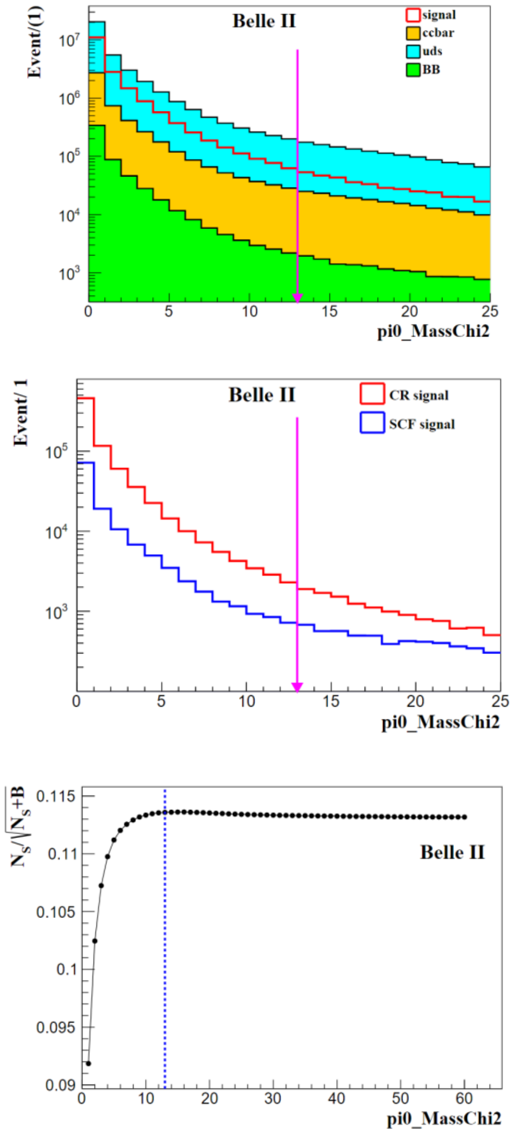
- $B^0 \to K^+K^-\pi^0\ (\pi^0 \to \gamma\gamma)$
  - ➢ clusterE (forward end-cap region) > 0.275 GeV
  - ➢ clusterE (barrel region) > 0.15 GeV
  - ➢ clusterE (backward end-cap region) > 0.2 GeV
  - ➢ fakePhotonSuppressionScore > 0.675
  - ➢ beamBackgroundSuppressionScore > 0.1



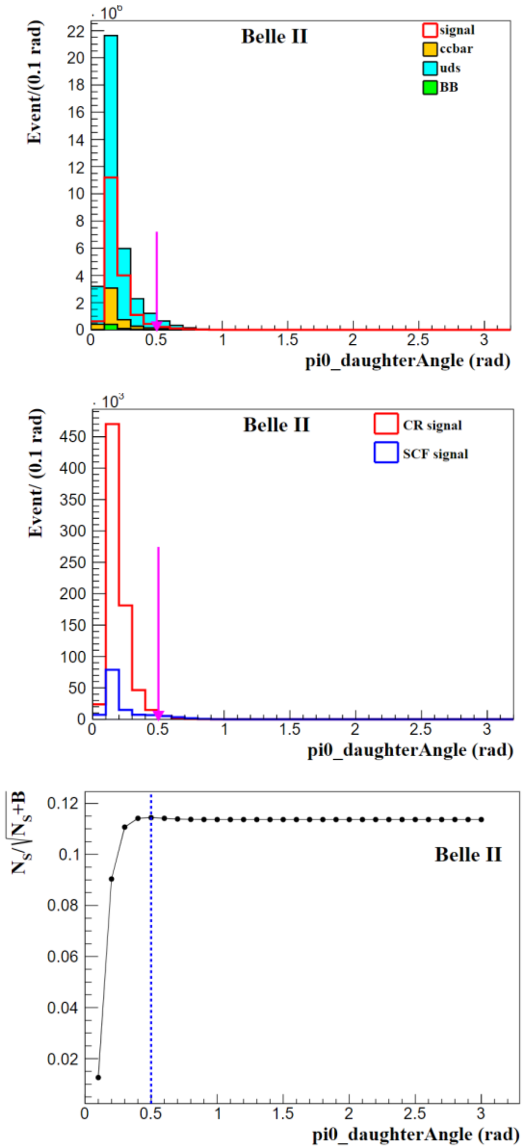
π^0 relevant variable

- $B^0 \to K^+K^-\pi^0$ $(\pi^0 \to \gamma\gamma)$

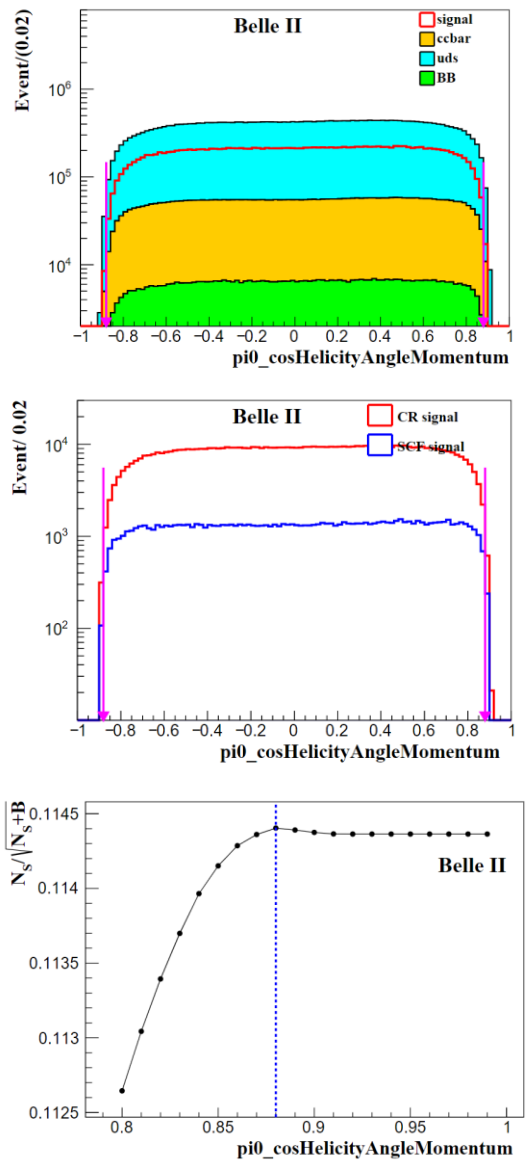
  - $\chi^2_{\pi^0} < 13$



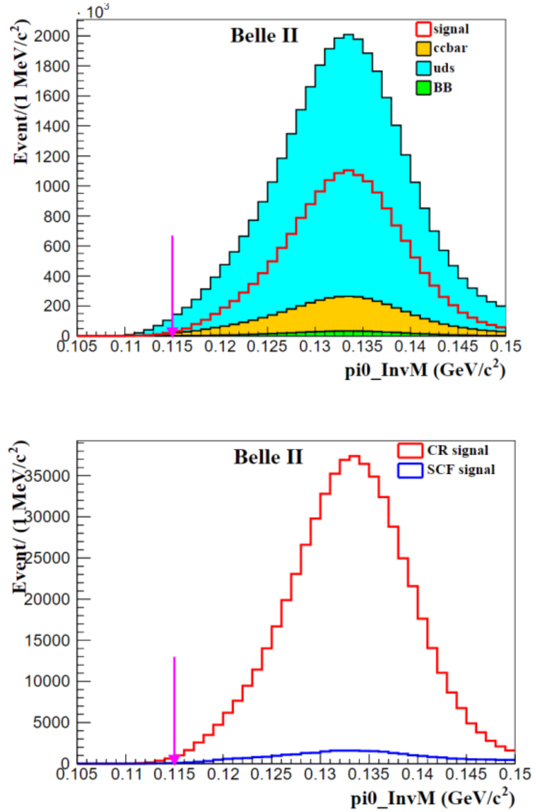
  - pi0_daughterAngle < 0.5



  - |pi0_cosHelicityAngleMomentum| < 0.88

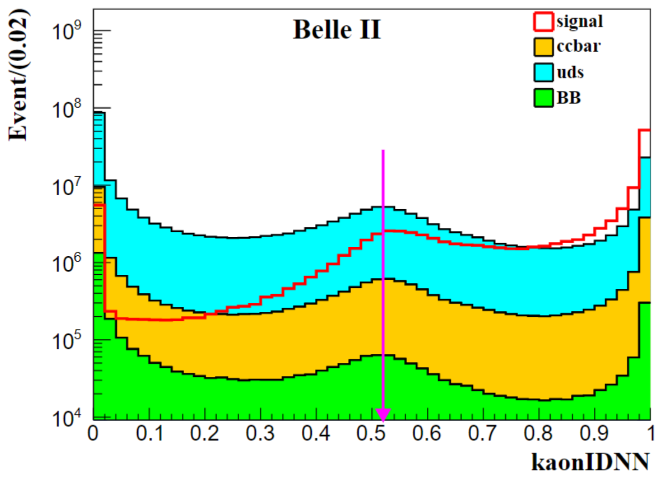


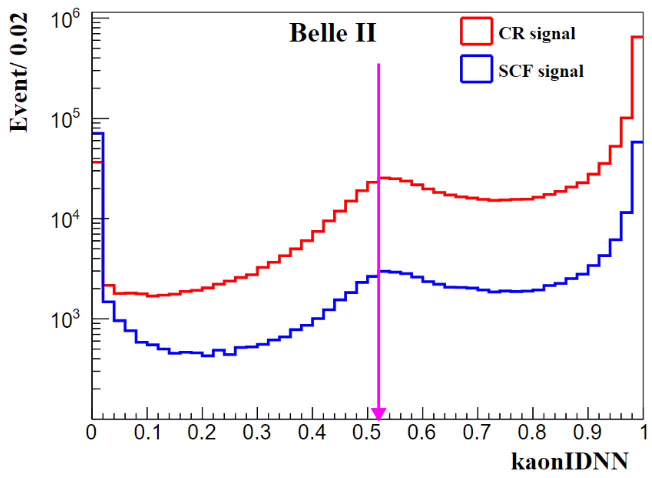
  - 0.115 GeV < pi0_InvM < 0.150 GeV
  - Corresponding to $[-2.5\,\sigma, +2.0\,\sigma]$ range centered at the known π^0 mass

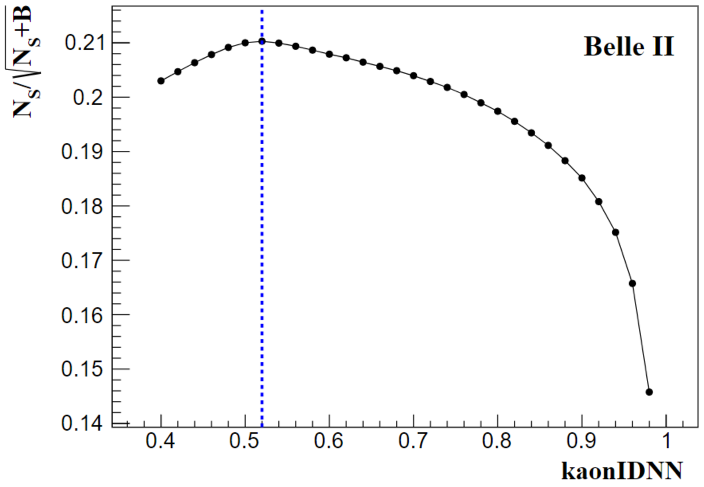


Charged kaon relevant variable

- $B^0 \to K^+K^-\pi^0$ $(\pi^0 \to \gamma\gamma)$
  - ➢ kaonIDNN > 0.52







Cutflow

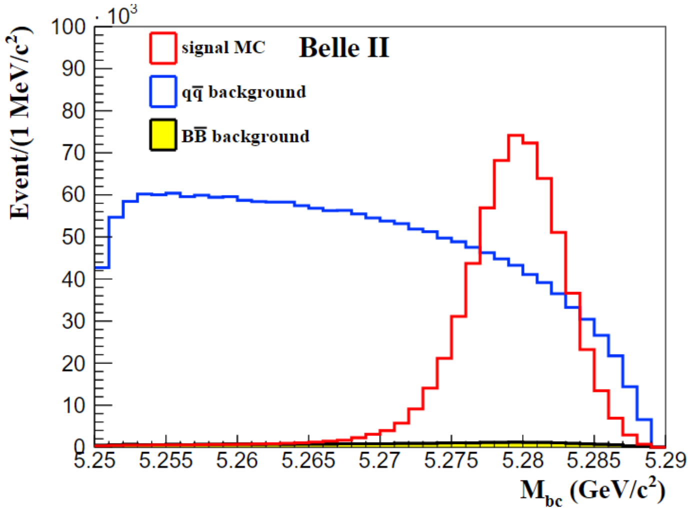
- Summary of the optimized selection

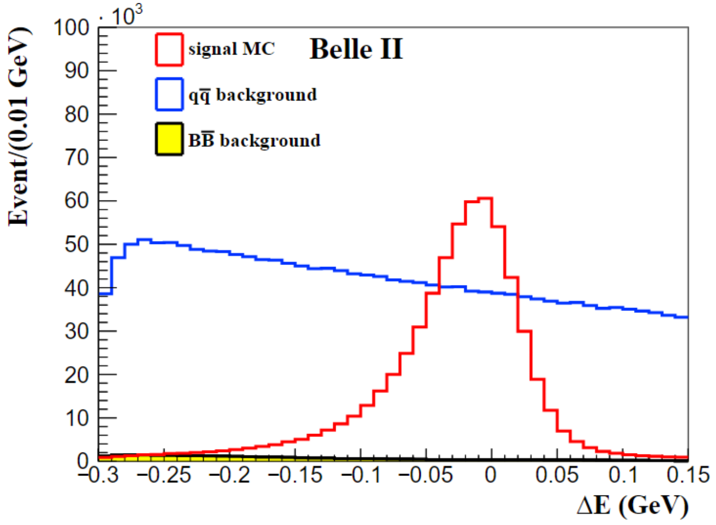
$$\varepsilon = \frac{N_S^{\mathrm{cor}}}{N_{\mathrm{gen}}}, \quad SCF = \frac{N_S^{\mathrm{mis}}}{N_S^{\mathrm{cor}} + N_S^{\mathrm{mis}}},$$

- $\varepsilon = 28.55 \pm 0.04\%$ SCF = 4.35 ± 0.04%

Target	Selection	Signal efficiency [%]	SCF [%]
	Baseline Selection	48.25	45.07
γ	clusterE (forward end-cap region) > 0.275 MeV	47.25	41.47
	clusterE (barrel region) > 0.15 MeV	39.82	18.05
	clusterE (backward end-cap region) > 0.2 MeV	39.22	15.49
	fakePhotonSuppressionScore > 0.675	37.91	13.75
	beamBackgroundSuppressionScore > 0.1	37.91	13.74
π^0	$\chi^2_{\pi^0} < 13$	37.07	13.16
	daughterAngle < 0.5	36.68	12.29
	|cosHelicityAngleMomentum| < 0.88	36.63	12.27
	$0.115 < \mathrm{InvM} < 0.150$ MeV/c^2	36.56	12.25
$K^{\pm}$	kaonIDNN > 0.52	28.55	4.35

$$M_{bc} = \sqrt{E_{beam}^2 - p_B^2},$$
$$\Delta E = E_B - E_{beam},$$





Modified M_{bc}

- $B^0 \to K^+K^-\pi^0\ (\pi^0 \to \gamma\gamma)$

$$M'_{bc} = \sqrt{E^{*2}_{beam} - p^{*\prime 2}_{B}} \qquad p^{*\prime}_{B} = p^{*2}_{K^+} + p^{*2}_{K^-} + p^{*\prime}_{\pi^0}$$

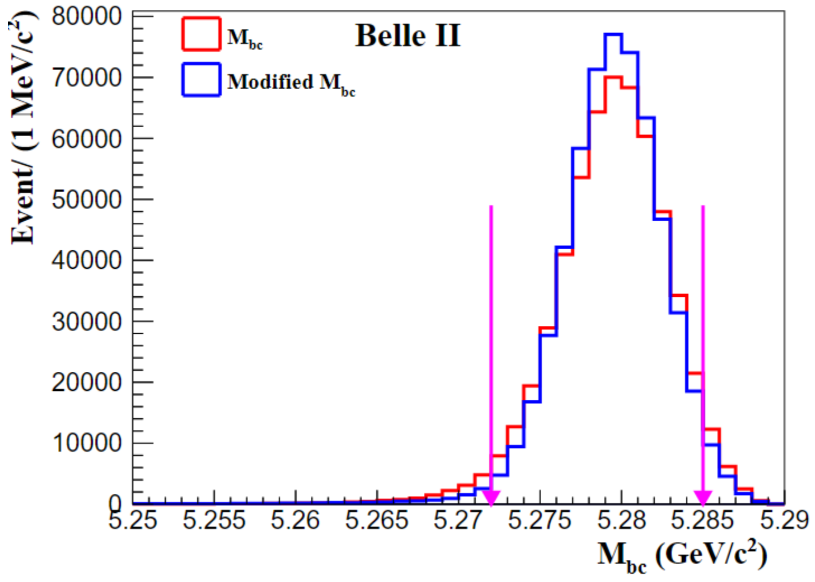
$$p^{*\prime}_{\pi^0} = \sqrt{\left(E^*_{beam} - E^*_{K^+} - E^*_{K^-}\right)^2 - m^2_{\pi^0}} \times \frac{p^*_{\pi^0}}{|p^*_{\pi^0}|}$$

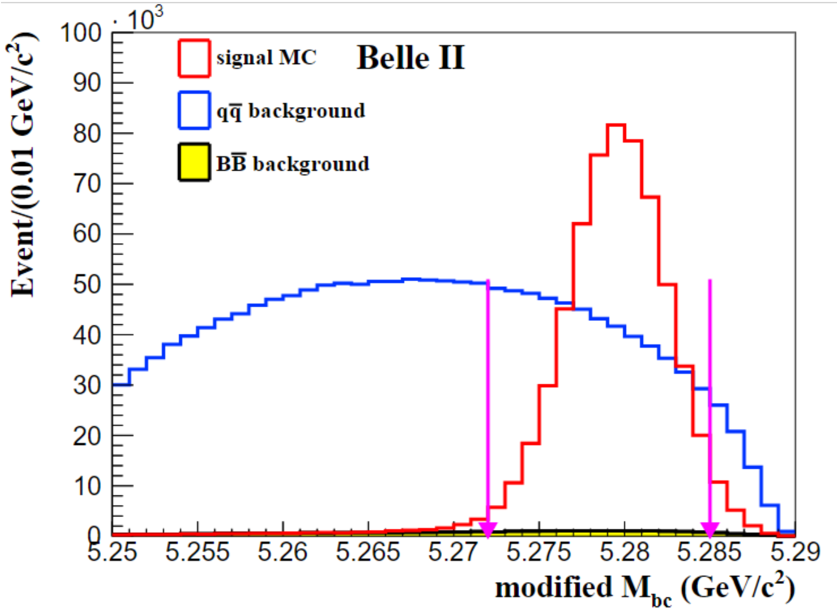
Tight cut on M'_{bc}

- $5.272 < M'_{bc} < 5.285$ GeV/c^2

Fitting region

- $-0.25 < \Delta E < 0.15$ GeV

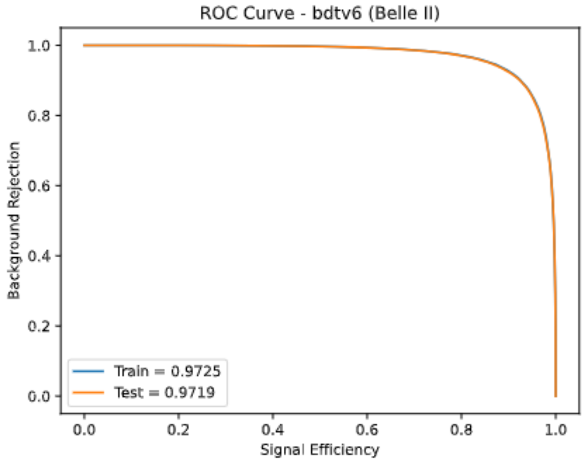


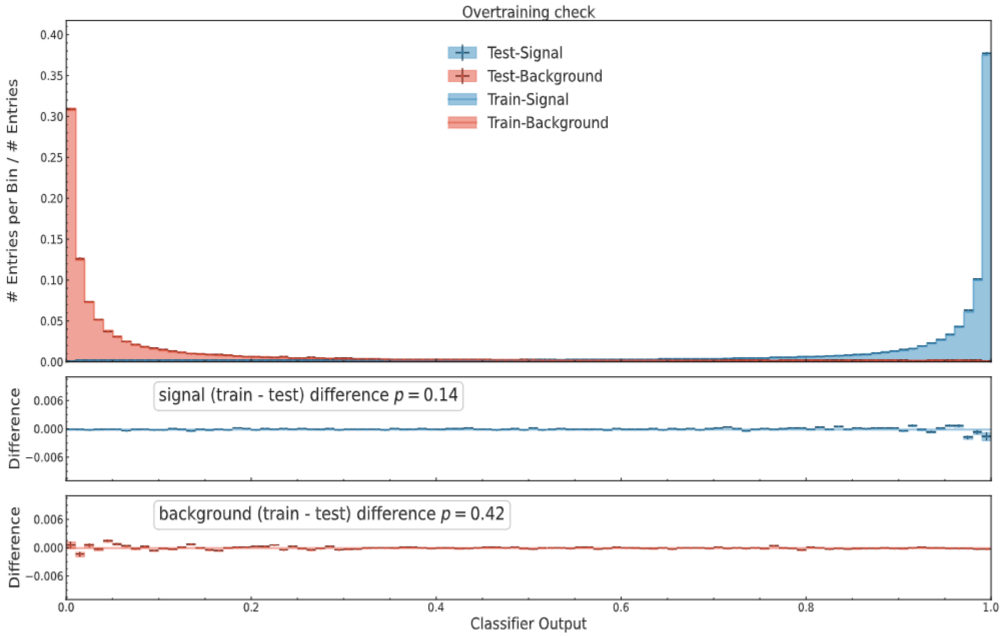


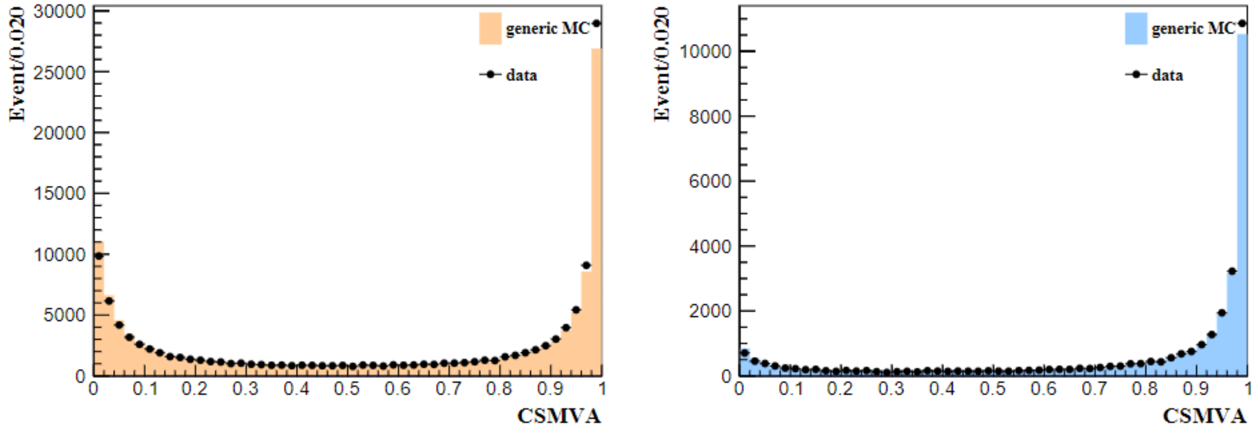
Continuum Suppression

- **Continuum suppression**

- Total 15 variables used in FBDT training
  - Event shape variables
  - Vertex fit variables







Data-simultaion comparison of the FBDT output on (left) background-enhanced and (right) signal-enhanced $\boldsymbol{B^+ \to \bar{D}^0(\to K^+\pi^-\pi^0)\pi^+}$ candidates. MC is normalized to the total number of data events for better comparison

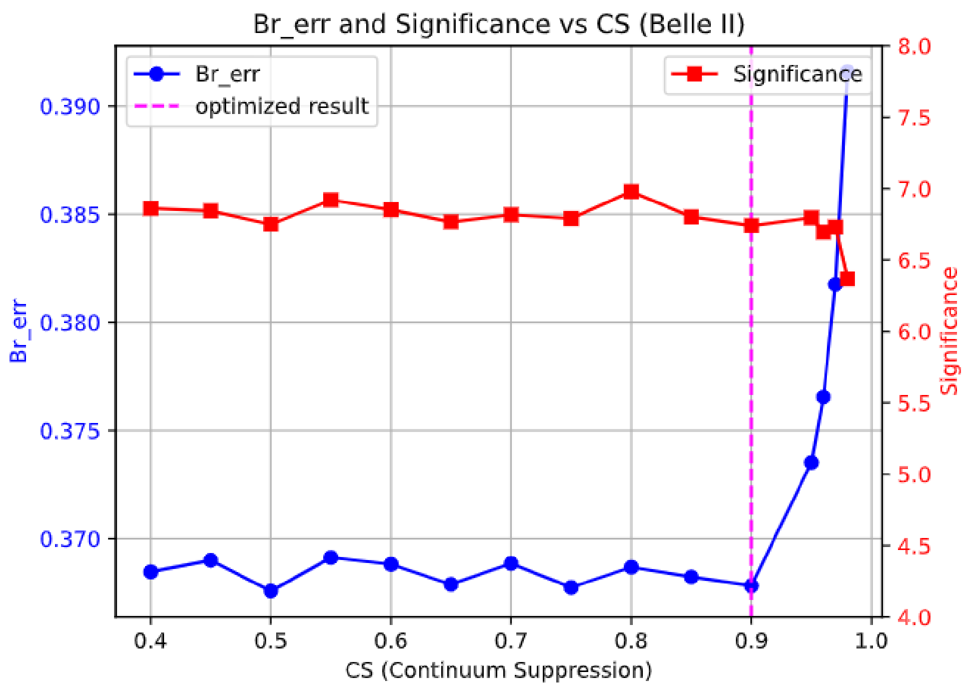
Continuum Suppression optimization

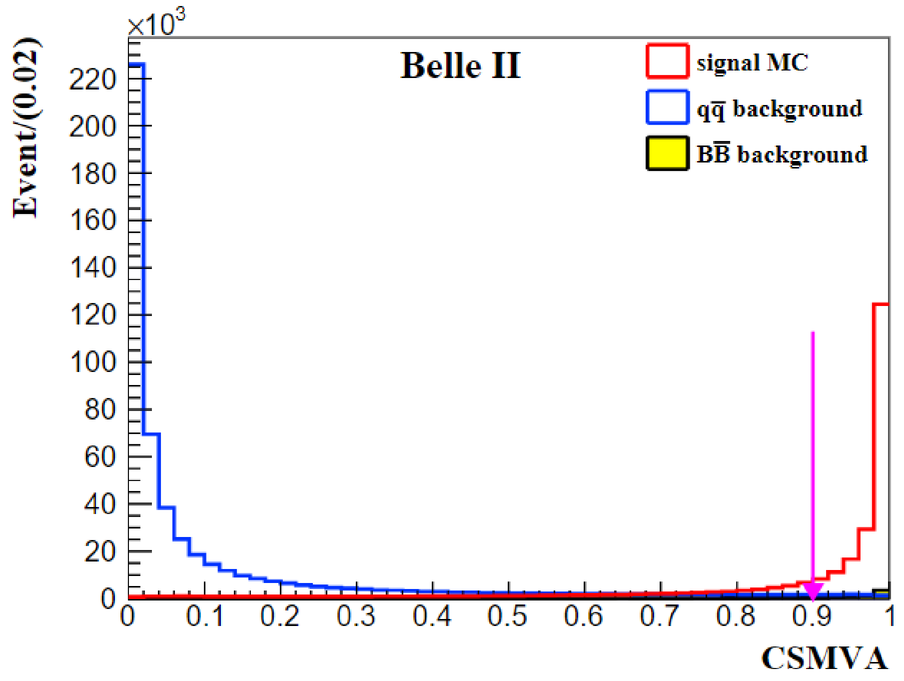
- **Continuum suppression optimization**
  - 1000 ToyMC for each requirement
  - PDFs extracted from MC shape

➢ CSMVA > 0.9 (The most stringent threshold)

To minimize possible systematic uncertainties proportional to background contamination

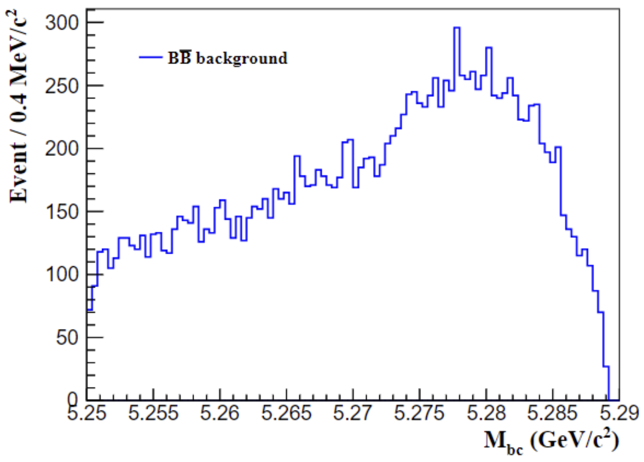
➢ Reject 98.52% continuum background and preserve 71.53% signal events

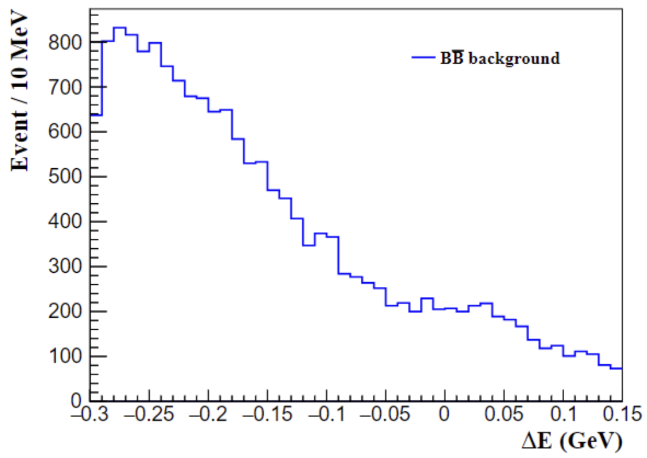




$B\bar{B}$ Background

- ***B* decays background**





- M_{bc} strongly peaks around 5.279 GeV/c^2 and a potential peak appears in the range from -50 MeV to 50 MeV in ΔE distribution

➢ $D \to KK$ & $D \to K\pi$ decay

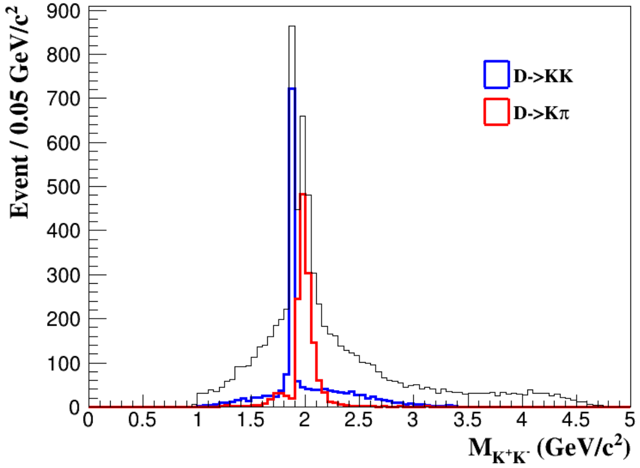
➢ Topoana ($B \to K\pi\pi$: Main peaking background)

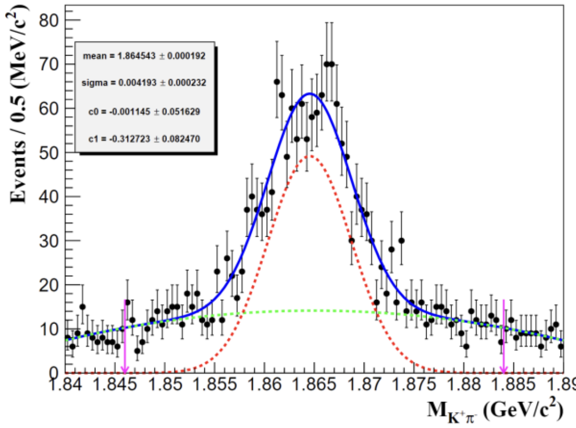
$$M_{KK} = \sqrt{(E_{K^+} + E_{K^-})^2 - (\boldsymbol{p}_{K^+} + \boldsymbol{p}_{K^-})^2}$$

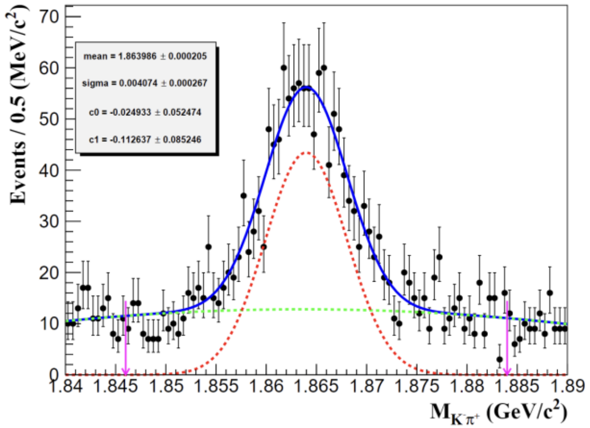
$$M_{K\pi} = \sqrt{(E_K + E_\pi)^2 - (\boldsymbol{p}_K + \boldsymbol{p}_\pi)^2}$$

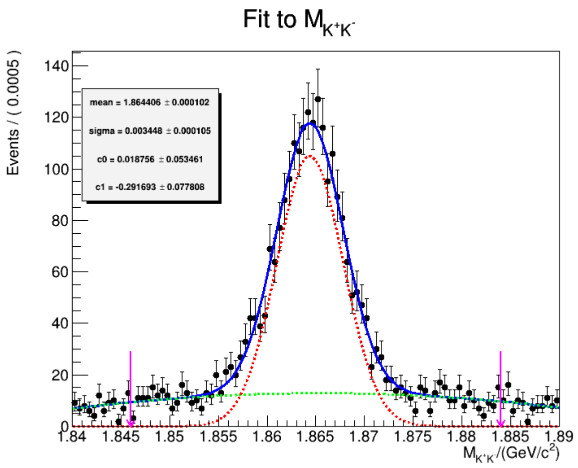
$$E_K = \sqrt{\boldsymbol{p}_K{}^2 + m_K{}^2}$$

$$E_\pi = \sqrt{\boldsymbol{p}_\pi{}^2 + m_\pi{}^2}$$ (use the pion mass from PDG)







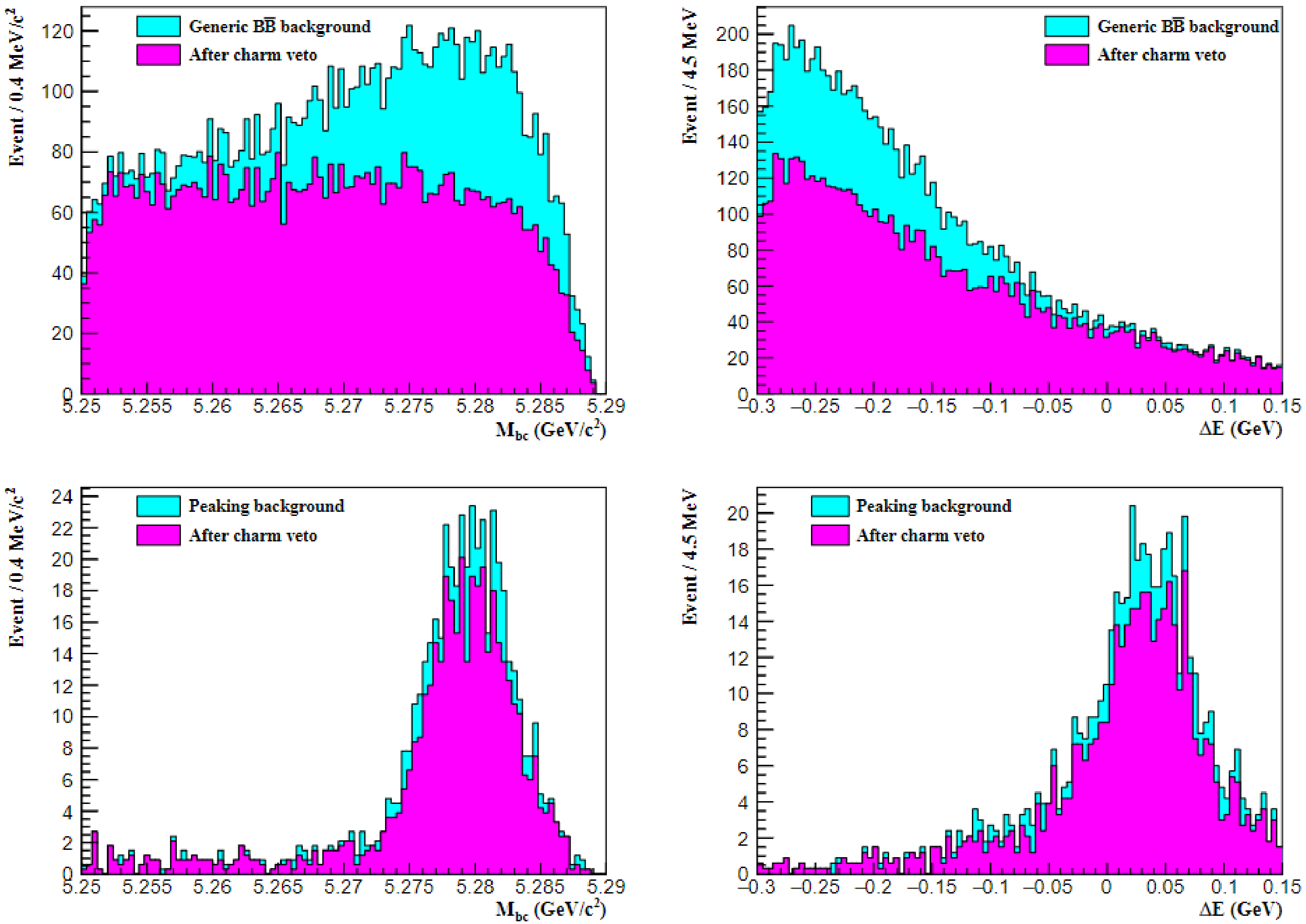


Peak from D decay ($D \to KK$ & $D \to K\pi$)

Charm veto : $1.846 < \boldsymbol{M_{K^\pm\pi^\mp}}$, $\boldsymbol{M_{KK}} < 1.884$ GeV/c^2

$B\bar{B}$ Background

- ***B* decays background**
  - **Peaking background:** $B \to K\pi\pi$
  - **Generic $B\bar{B}$ background:**
    The remain $B\bar{B}$ background after removing peaking background
  - Charm veto :
    $1.846 < M_{K^{\pm}\pi^{\mp}}, M_{K^{+}K^{-}} < 1.884\ \mathrm{GeV}/c^2$



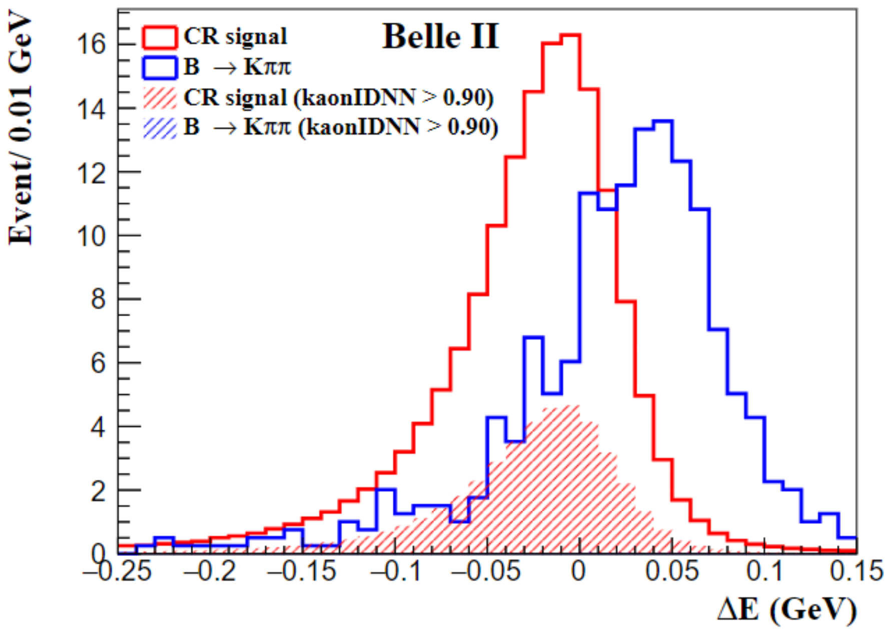
Peaking Background

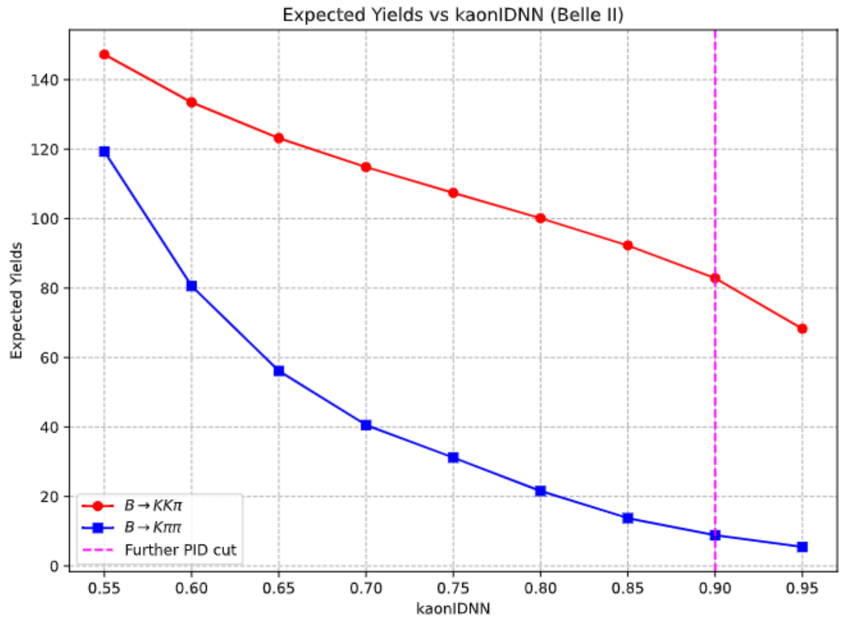
- **Peaking background**

$\mathcal{B}(B^0 \to K^+K^-\pi^0) = (2.17 \pm 0.6) \times 10^{-6}$

$\mathcal{B}(B^0 \to K^+\pi^-\pi^0) = (37.8 \pm 3.2) \times 10^{-6}$

➢ Require further cut on PID: kaonIDNN > 0.9

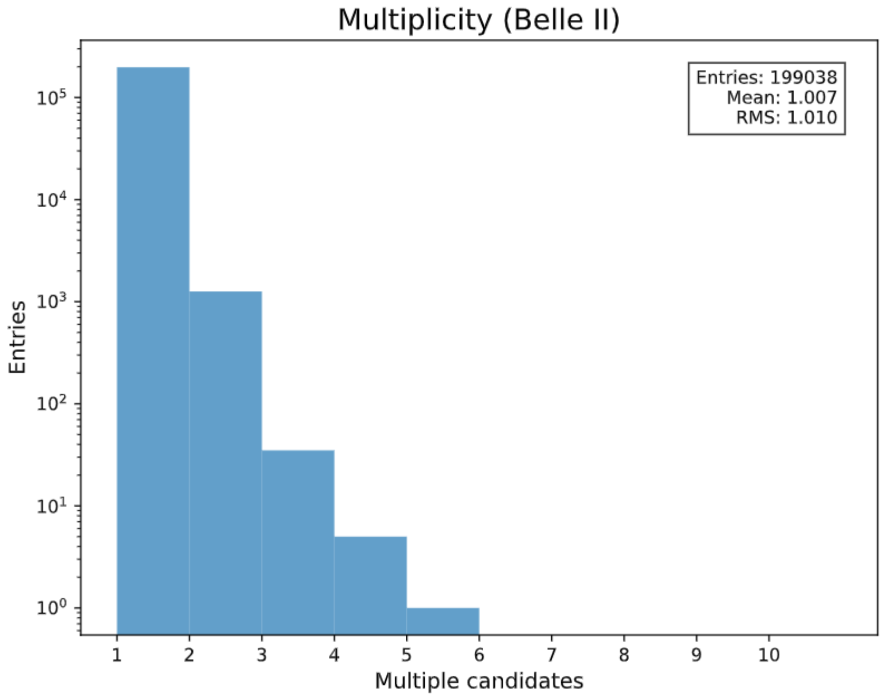




- The event number of the two components are scaled to the expected yields corresponding to the integrated luminosity of the real data

Candidate Multiplicity and Final Selection

- $B^0 \to K^+K^-\pi^0$
  - Mutiplicity: 1.007
  - Best candidate selection
    - ➢ Lowest π^0 mass-constrained χ^2
    - ➢ Then lowest B^0 vertex fit χ^2



- Final selection

Target	Selection	Signal efficiency [%]	SCF [%]
	Baseline and Optimized Selection	28.55	4.35
signal Region	$5.272 < M'_{bc} < 5.285$ GeV/c^2	27.19	2.39
	$-0.25 < \Delta E < 0.15$ GeV	27.05	2.23
Continuum Suppression	CSMVA > 0.9	19.35	1.71
Charm veto window	$1.846 < M_{K^\pm K^\mp} < 1.884$ GeV/c^2	19.16	1.71
	$1.846 < M_{K^\pm \pi^\mp} < 1.884$ GeV/c^2	18.76	1.71
Further PID requirement	kaonIDNN > 0.9	9.91	1.49
Best candidate selection		9.89	1.04

- $\varepsilon = 9.89 \pm 0.02\%$ SCF $= 1.04 \pm 0.02\%$

- Sample composition
  - ➢ Signal (Correctly reconstructed and self-crossfeed signal)
  - ➢ Continuum background
  - ➢ Generic $B\bar{B}$ background
  - ➢ Peaking background

Signal yield extraction

- **Fitter for $B^0 \to K^+K^-\pi^0$**
  - tight cut on M_{bc}
  - 2D Fit on ΔE and transformed CS (C') **(μ-transformation)**
  - Probability density function (PDF) of each event category j: $\mathcal{P}_j^i = \mathcal{P}_j(\Delta E^i)\mathcal{P}(C'^i),$
  - Extended likelihood function: $\mathcal{L} = \exp(-\sum_j n_j) \times \prod_i [\sum_j n_j \mathcal{P}_j^i]$

PDF used to model each event category

Event category	ΔE	C'
CR signal	Double CB	Flat
SCF signal	2D histogram	
Continuum Background	Poly1	2Exp
Generic $B\bar{B}$ Background	Double G	Poly2
Peaking Background	2D KDE	

- The CR signal and SCF signal are considered distinct and their combined PDF is : $n_{\text{sig}} \times [(1-f)\mathcal{P}_{CR} + f\mathcal{P}_{SCF}]$

- Parameters fixed
  - SCF fraction
  - PDF parameters (except 2 parameters of $q\bar{q}$ bkg)
  - The yield of peaking background
- Parameters floated :
  - The yield for each event category except for peaking background (n_{sig} includes CR and SCF signal)
  - Continuum background PDF parameters (2 parameters are floated, coefficient p_0 and the fraction of two exponential function)

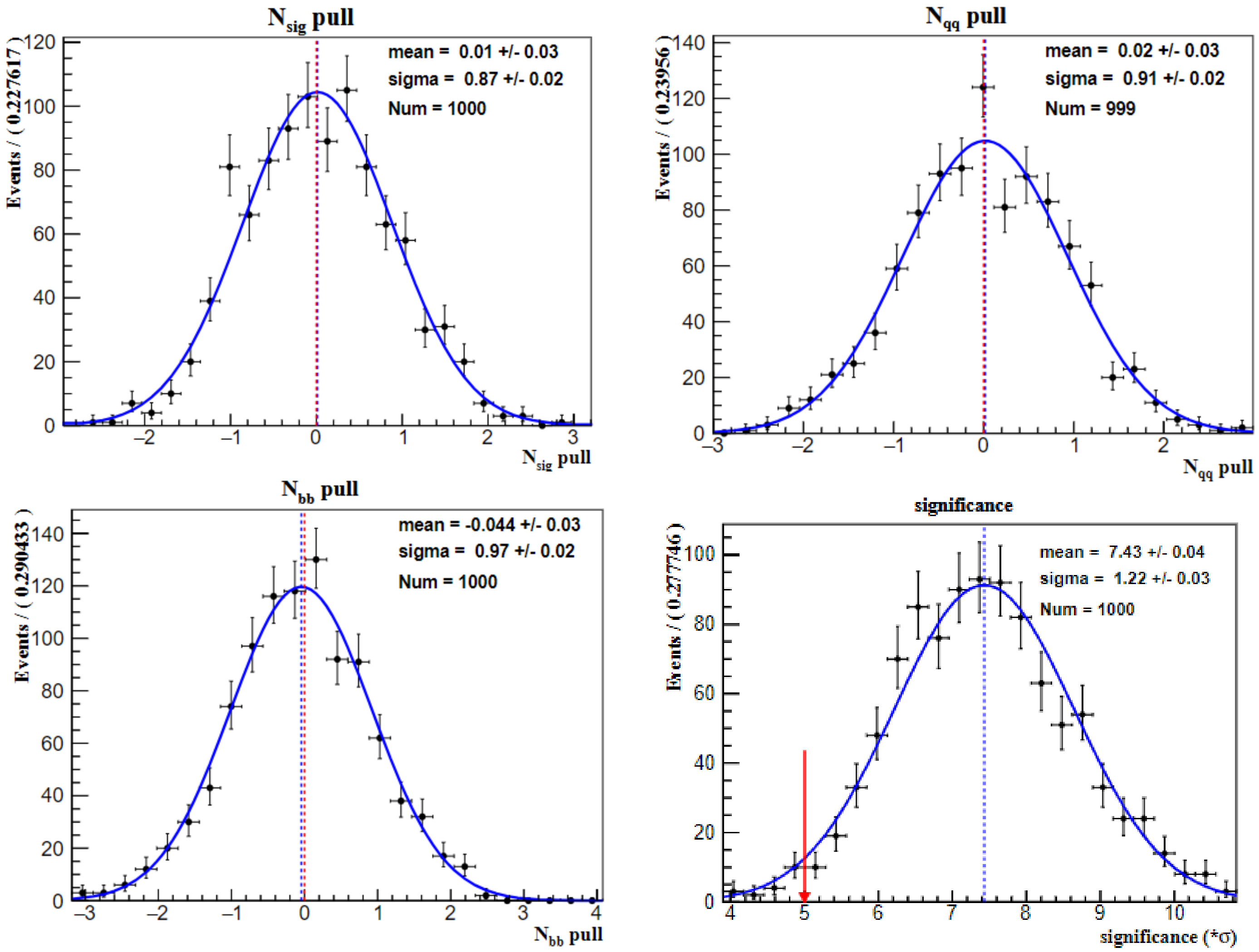
Event estimation

- Signal Events : estimated by assuming the branching ratio to be $\mathcal{B}(B^0 \to K^+K^-\pi^0) = 2.17 \times 10^{-6}$
  - $N_{sig}^{exp} = N_{B\bar{B}} \times \mathcal{B}(B^0 \to K^+K^-\pi^0) \times \varepsilon_{sig}^{rec}$
- Continuum bkg & Generic BB bkg : scaled to the integrated luminosity of experimental data
- Peaking bkg : calculated by
  - $N_{peak}^{exp} = N_{B\bar{B}} \times \mathcal{B}(B^0 \to K^+\pi^-\pi^0) \times \varepsilon_{peak}^{rec}$

	Expected Yield
Signal	84
Continuum background	431
Generic BB background	201
Peaking background	9

Fitter validation

- **GSIM** (1000 samples)
  - Yield of each component fluctuated drawing from a Poisson distribution around their nominal expected value



$$\text{pull} = \frac{x_{fit} - x_{true}}{\sigma_x}$$

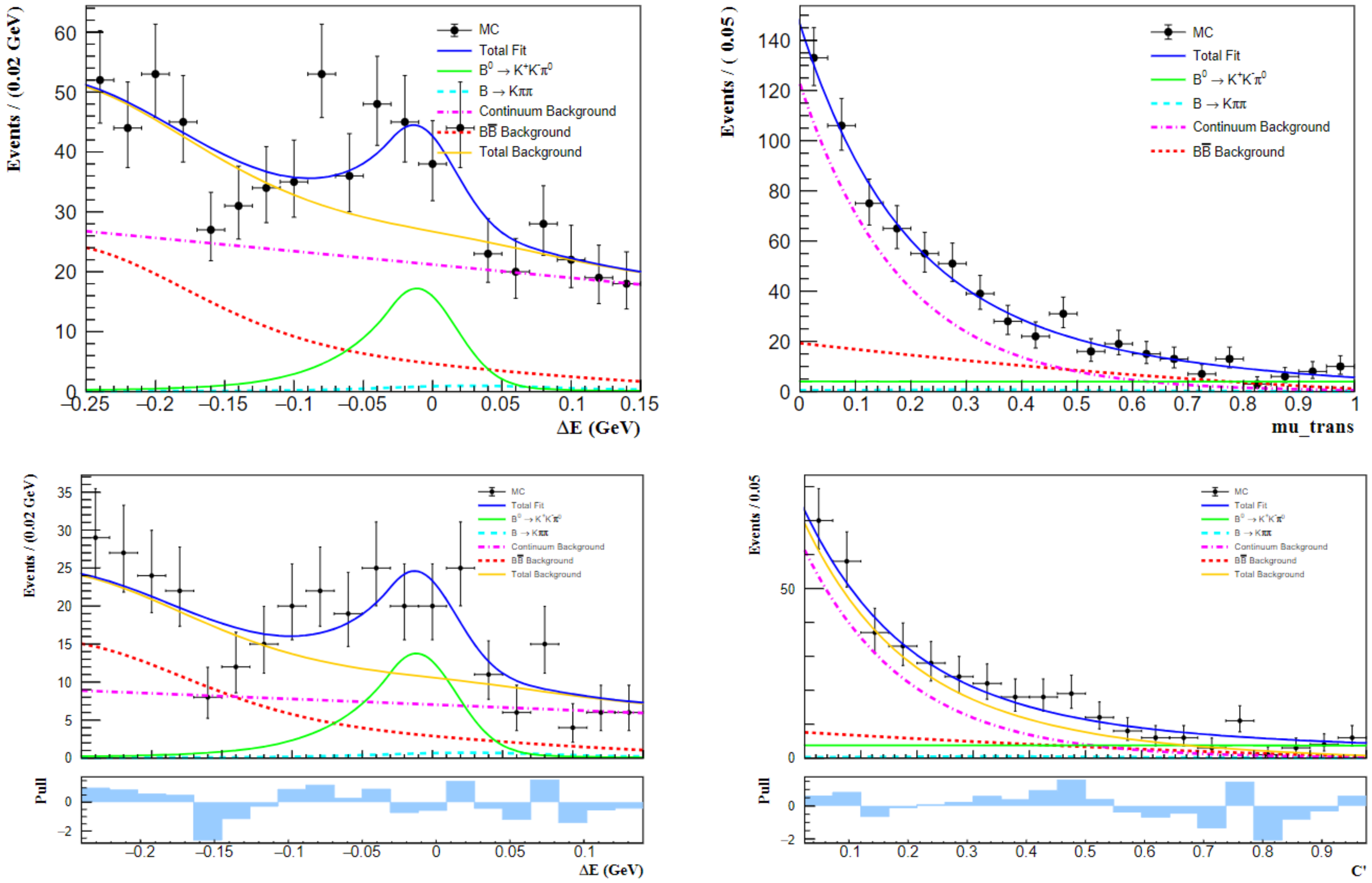
Significance : $\sqrt{2 * (NLL - NLL_{min})}$

Fitter validation

- **GSIM** (1000 samples)

  - Fit Range
    - ΔE [-0.25, 0.15] GeV
    - C' [0, 1]

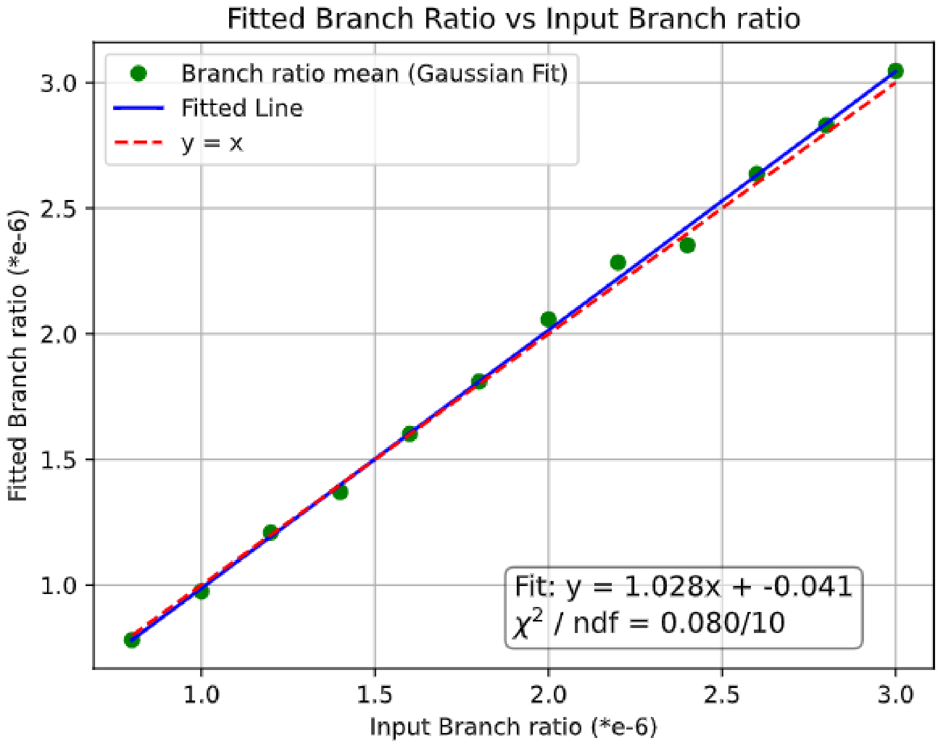
  - Projection Plot
    - $-0.15 < \Delta E < 0.05$ GeV, and
    - C' > 0.2

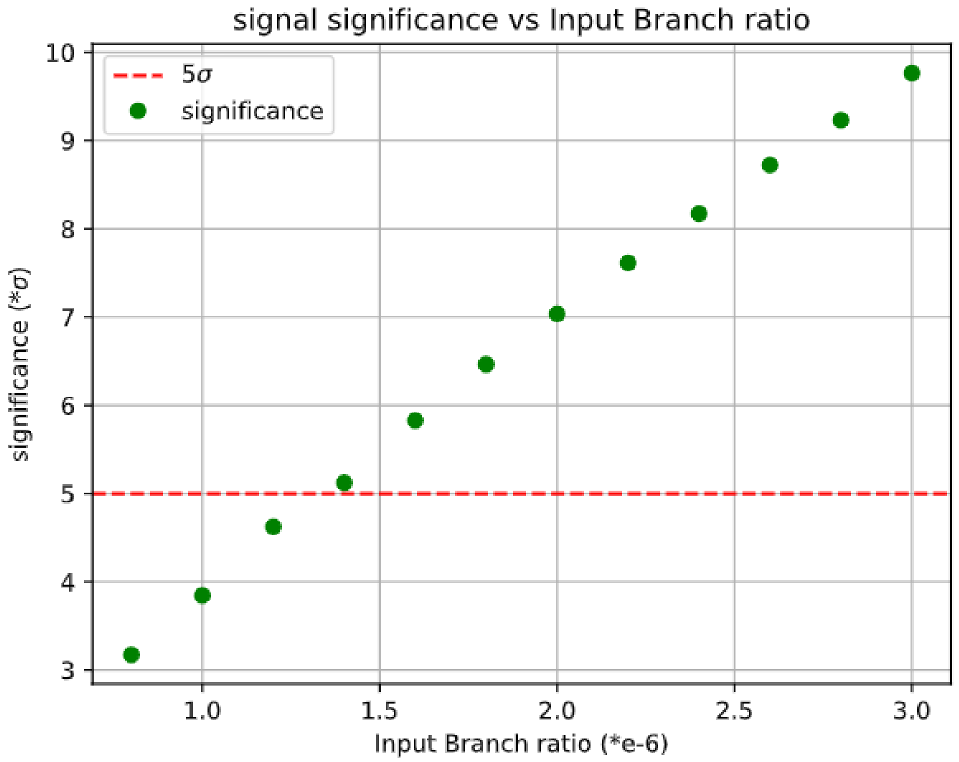


Fitting results for one of the GSIM samples

Fitter Validation

- Linearity test (Branching ratio varies from 0.8×10^{-6} to 3.0×10^{-6})
- 1000 GSIM samples for each input)





Belle

Dataset

<table>
<tr><th>Belle Dataset</th><th colspan="3"></th><th>Version</th></tr>
<tr><td>Signal MC</td><td colspan="3">2M</td><td rowspan="5">light-2409-toyger</td></tr>
<tr><td rowspan="4">Background MC</td><td>type</td><td>Numbers of streams</td><td>Experiments</td></tr>
<tr><td>$q\bar{q}$ uds + charm</td><td>1</td><td>7 - 65</td></tr>
<tr><td>Generic $B\bar{B}$ charged + mixed</td><td>5</td><td>7 - 65</td></tr>
<tr><td>Rare $B\bar{B}$ charged + mixed</td><td>50</td><td>7 - 65</td></tr>
<tr><td>Data</td><td colspan="3">711 fb^{-1} $\Upsilon(4S)$ on-resonance data
89.5 fb^{-1} off-resonance data</td><td></td></tr>
</table>

Baseline Selection

- $B^0 \to K^+K^-\pi^0$

  - **Tracks**
    - dr < 0.5 cm & |dz| < 2 cm
    - thetaInCDCAcceptance
    - nTracks > 2
  - B^0
    - $5.25 < M_{bc} < 5.289$ GeV/c^2
    - -0.3 GeV < ΔE < 0.15 GeV
    - treefit
  - $K^\pm$
    - No PID requirement
  - $\pi^0 \to \gamma\gamma$
    - 0.105 < InvM <0.160 GeV/c^2
    - kFit
  - γ
    - **GoodBelleGamma**
    - Cluster E in different area:
      - E_γ in forward endcap > 0.10 GeV
      - E_γ in barrel > 0.05 GeV
      - E_γ in backforward endcap > 0.15 GeV

Selection Optimization

- $B^0 \to K^+K^-\pi^0\ (\pi^0 \to \gamma\gamma)$

Variable	Description
γ relevant variable	
clusterE	ECL cluster's energy corrected for leakage and background
beamBackgroundSuppressionScore	The output of an MVA classifier that uses shower-related variables to distinguish true photon clusters from beam background clusters (**Belle II**)
fakePhotonSuppressionScore	The output of an MVA classifier that uses shower-related variables to distinguish true photon clusters from fake photon clusters (**Belle II**)
π^0 relevant variable	
$\chi^2_{\pi^0}$	χ^2 of π^0 mass constraint fit
daughterAngle	The three dimensional angle between the two clusters used for π^0 reconstruction
cosHelicityAngleMomentum	Cosine of the angle between the line defined by the momentum difference of two photons in the frame of π^0 and the momentum of π^0 in the lab frame
InvM	The invariant mass of diphoton used to reconstruct π^0
Charged kaon relevant variable	
atcPIDBelle_3_2	The kaon likelihood against pion $\mathcal{L}(K/\pi)$. (**Belle**)
kaonIDNN	The kaon identification probability calculated from the PID neutral network. (**Belle II**)

➢ Selection optimized based on

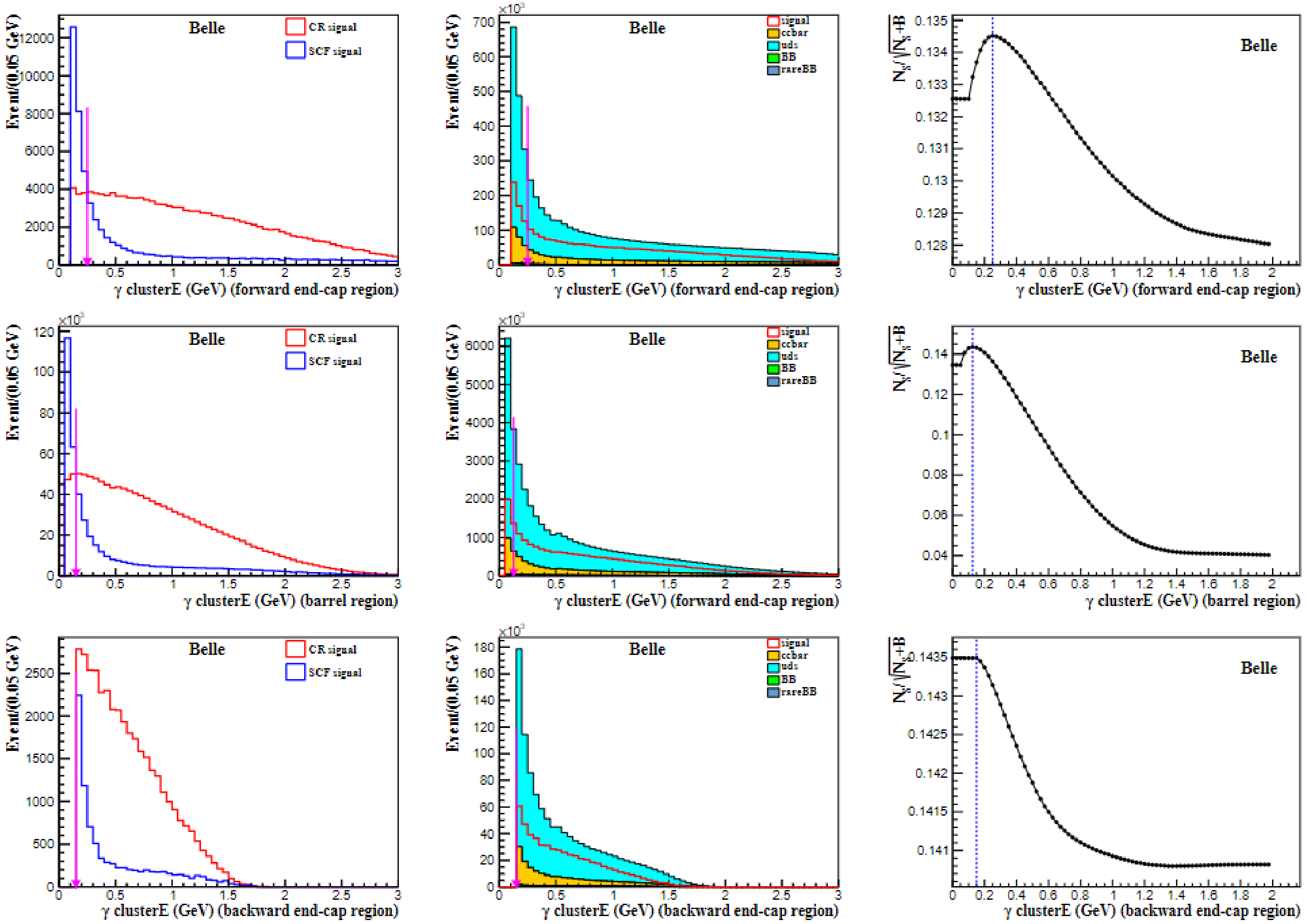
$$\text{Figure of Merit (FOM)} = \frac{N_S}{\sqrt{N_S+N_B}}$$

- N_S : expected signal events in the experimental data estimated by assuming the branching ratio to be $\mathcal{B}(B^0 \to K^+K^-\pi^0) = 2.17 \times 10^{-6}$ [1]
- N_B : background events scaled to the luminosity of the experimental data

[1] V. Gaur et al. (Belle Collaboration) Phys. Rev. D **87**, 091101(R)

γ relevant variable

- $B^0 \to K^+K^-\pi^0\ (\pi^0 \to \gamma\gamma)$
  - clusterE (forward end-cap region) > 0.25 GeV
  - clusterE (backward end-cap region) > 0.15 GeV
  - clusterE (barrel region) > 0.125 GeV



π^0 relevant variable

- $B^0 \rightarrow K^+K^-\pi^0$ ($\pi^0 \rightarrow \gamma\gamma$)

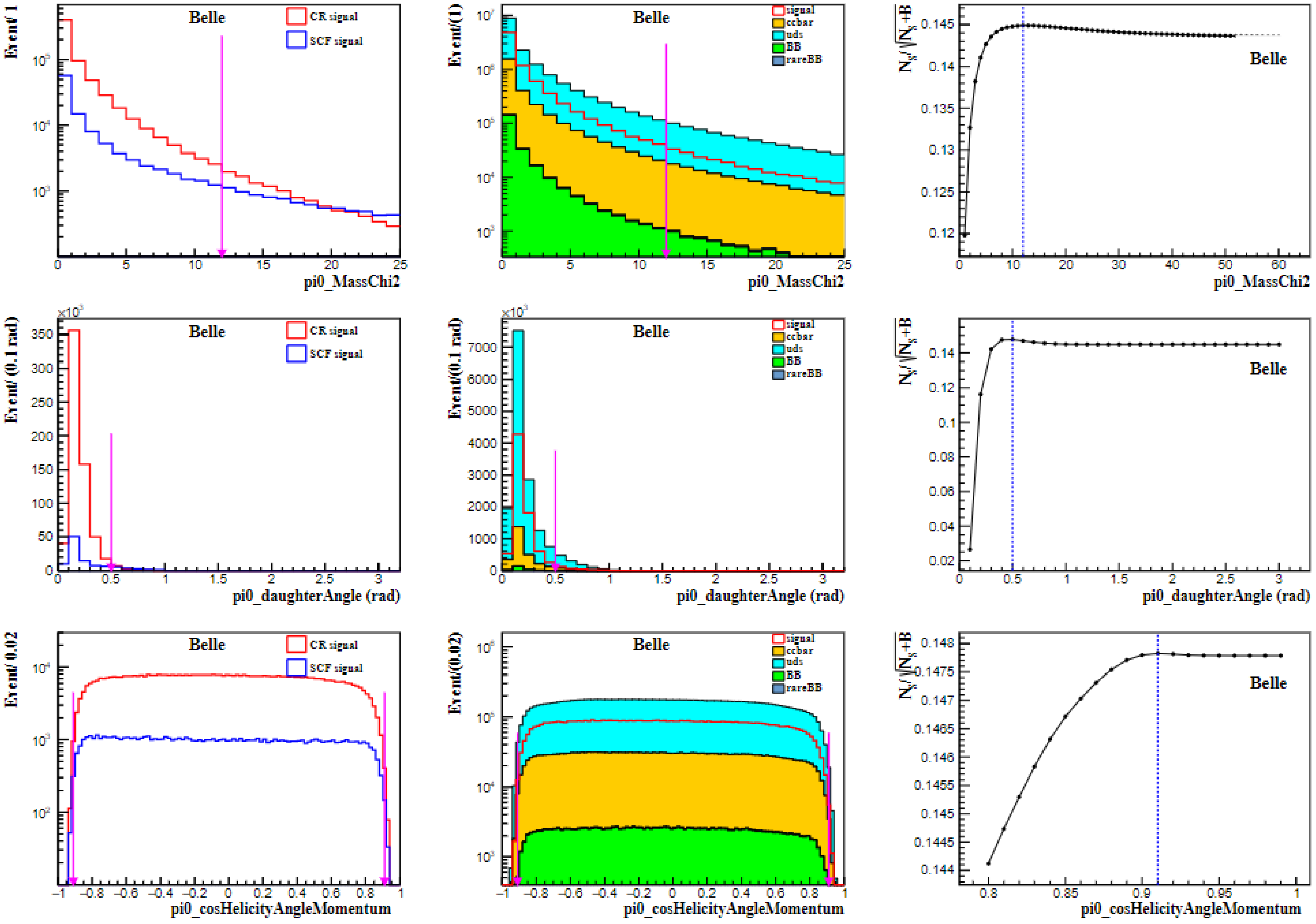
➢ $\chi^2_{\pi^0} < 12$

➢ pi0_daughterAngle < 0.5

➢ |pi0_cosHelicityAngleMomentum| < 0.91

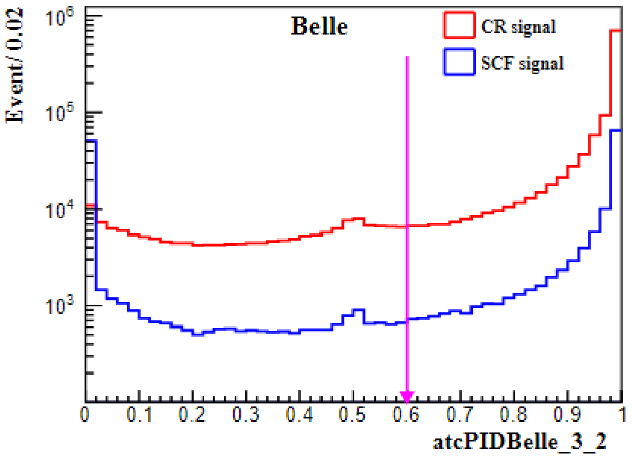
➢ 0.114 GeV < pi0_InvM < 0.152 GeV

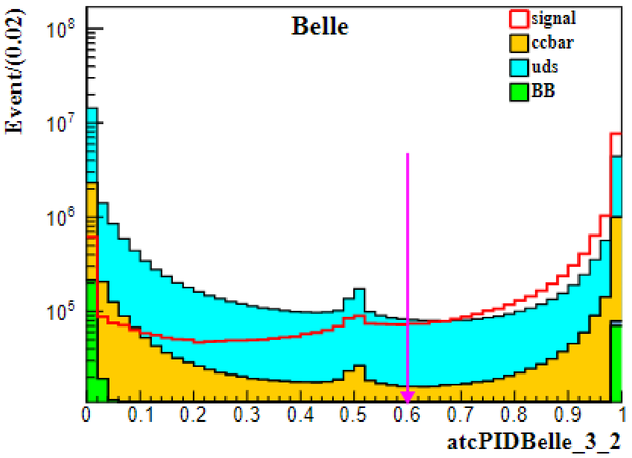
➢ Corresponding to $[-3\,\sigma, +3\,\sigma]$ range centered at the known π^0 mass

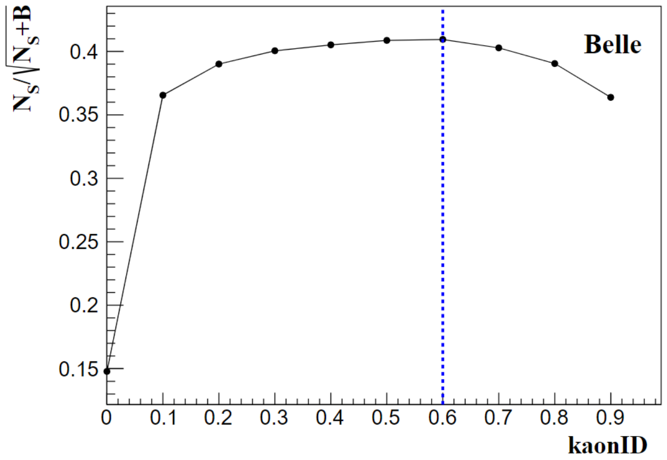


Charged kaon relevant variable

- $B^0 \to K^+K^-\pi^0\ (\pi^0 \to \gamma\gamma)$
  - ➢ atcPIDBelle_3_2 > 0.60







Cutflow

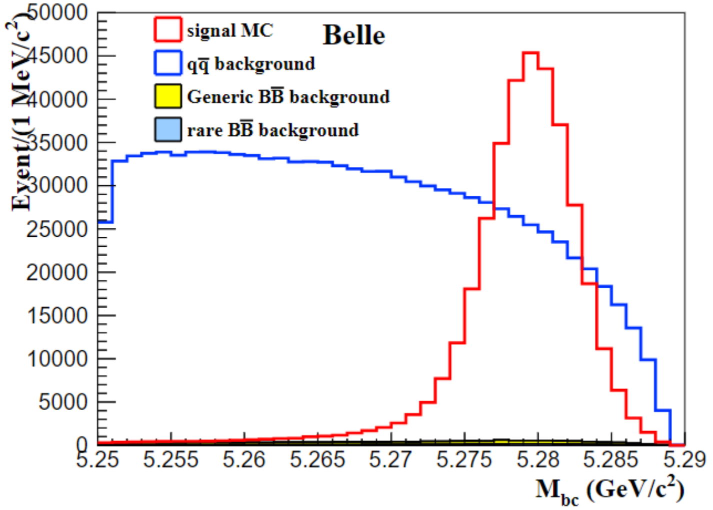
➢ Summary of the optimized selection

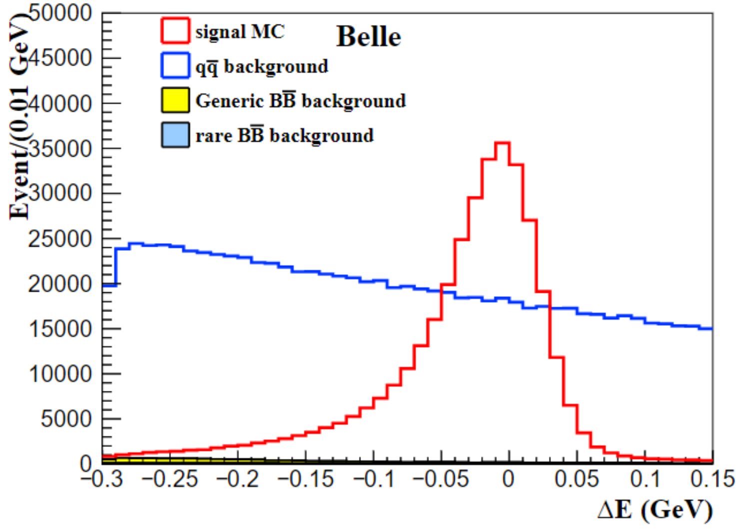
$$\varepsilon = \frac{N_S^{\rm cor}}{N_{\rm gen}}, \quad SCF = \frac{N_S^{\rm mis}}{N_S^{\rm cor} + N_S^{\rm mis}},$$

- $\varepsilon = 23.09 \pm 0.03\%$ SCF = 4.45 ± 0.03%

Target	Selection	Signal efficiency [%]	SCF [%]
	Baseline Selection	38.72	35.37
γ	clusterE (forward end-cap region) > 0.25 MeV	38.05	33.07
	clusterE (barrel region) > 0.125 MeV	34.15	18.05
	clusterE (backward end-cap region) > 0.15 MeV	34.15	18.05
π^0	$\chi^2_{\pi^0} < 12$	31.75	12.74
	daughterAngle < 0.5	31.17	11.31
	|cosHelicityAngleMomentum| < 0.91	31.13	11.29
	$0.114 <$ InvM < 0.152 MeV/c^2	30.88	11.19
$K^\pm$	$\mathcal{L}(K/\pi) > 0.6$	23.09	4.45

$$M_{bc} = \sqrt{E_{beam}^2 - p_B^2},$$
$$\Delta E = E_B - E_{beam},$$





Modified M_{bc}

- $B^0 \to K^+K^-\pi^0\ (\pi^0 \to \gamma\gamma)$

$$M'_{bc} = \sqrt{E^{*2}_{beam} - p^{*\prime 2}_{B}} \qquad p^{*\prime}_{B} = p^{*2}_{K^+} + p^{*2}_{K^-} + p^{*\prime}_{\pi^0}$$

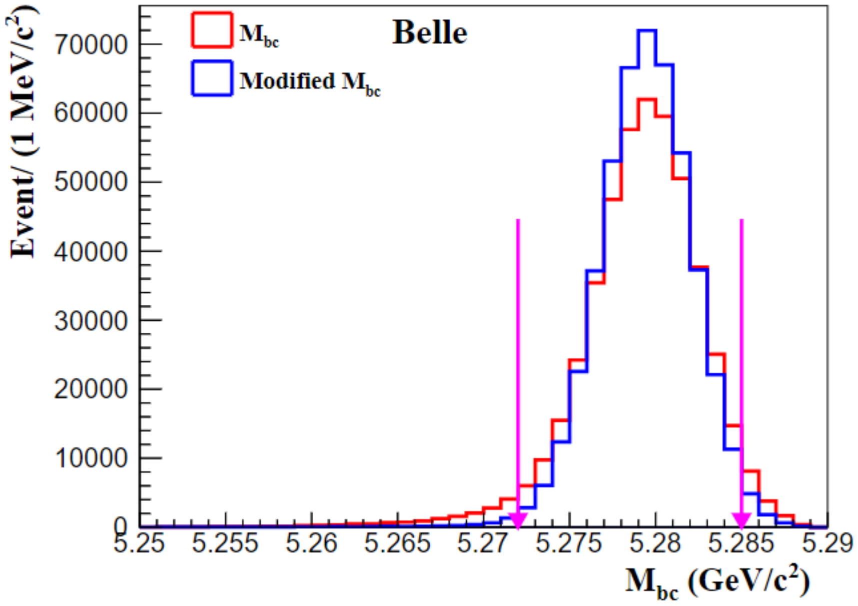
$$p^{*\prime}_{\pi^0} = \sqrt{\left(E^{*}_{beam} - E^{*}_{K^+} - E^{*}_{K^-}\right)^2 - m^2_{\pi^0}} \times \frac{p^{*}_{\pi^0}}{|p^{*}_{\pi^0}|}$$

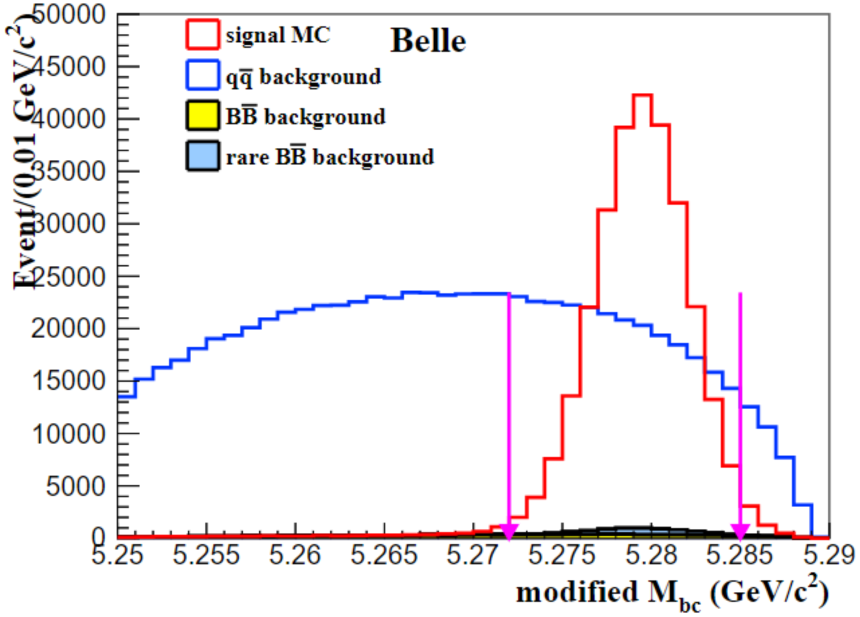
Tight cut on M'_{bc}

- $5.272 < M'_{bc} < 5.285$ GeV/c^2

Fitting region

- $-0.25 < \Delta E < 0.15$ GeV

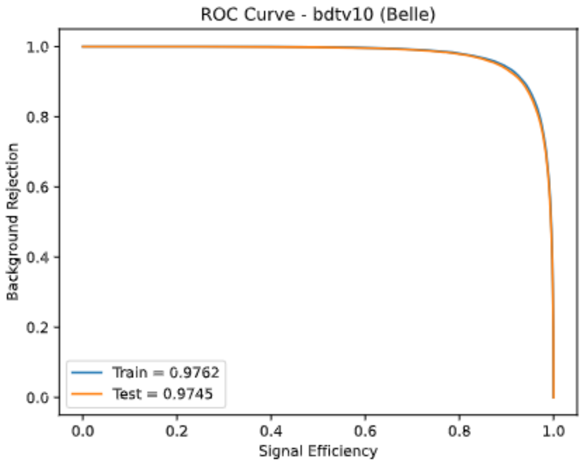


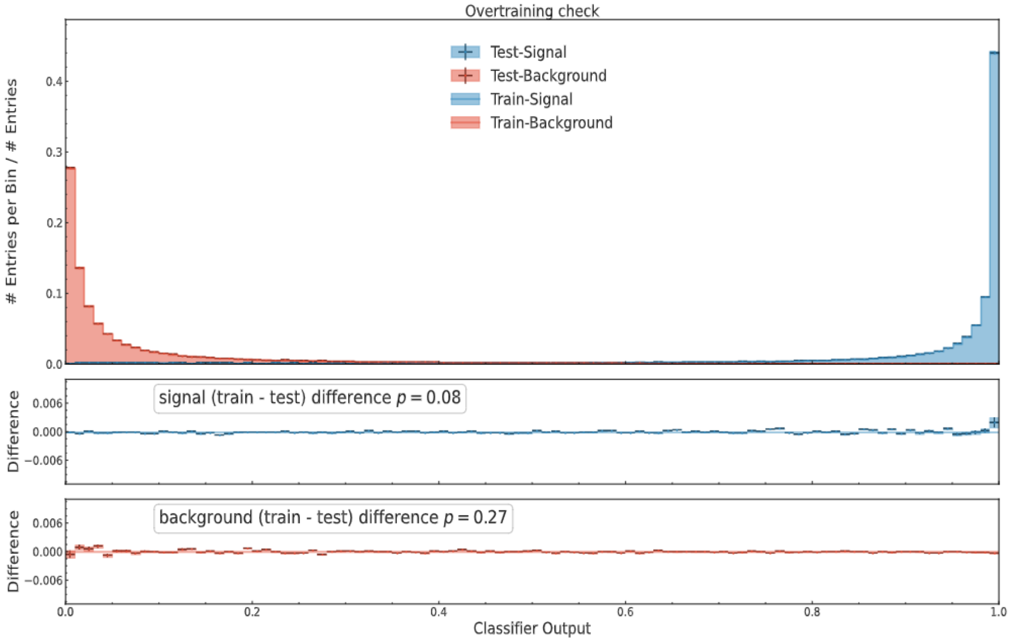


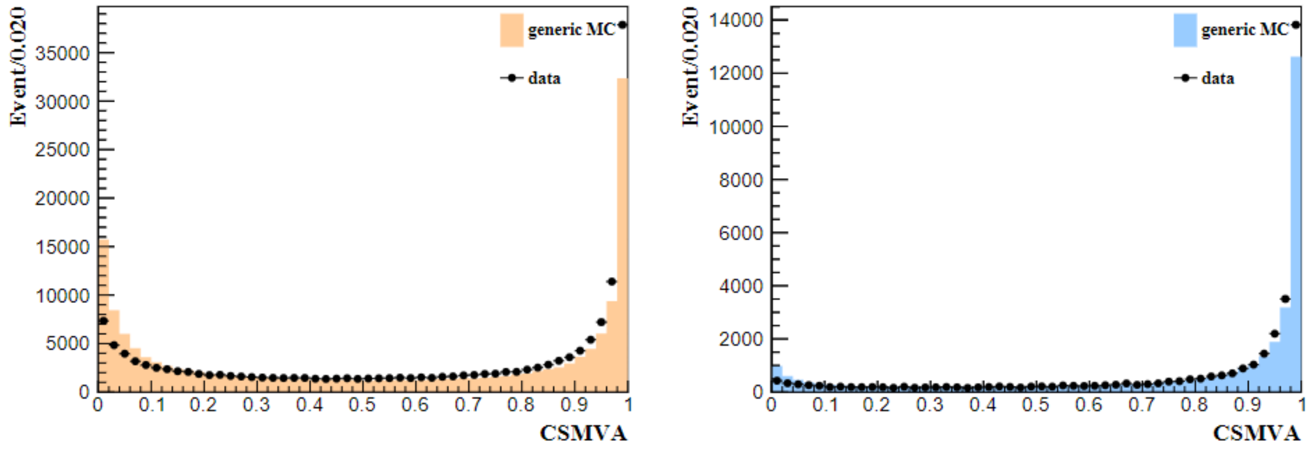
Continuum Suppression

- **Continuum suppression**

- Total 22 variables used in FBDT training
  - Event shape variables
  - Vertex fit variables







Data-simultaion comparison of the FBDT output on (left) background-enhanced and (right) signal-enhanced $\boldsymbol{B^+ \to \bar{D}^0(\to K^+\pi^-\pi^0)\pi^+}$ candidates. MC is normalized to the total number of data events for better comparison

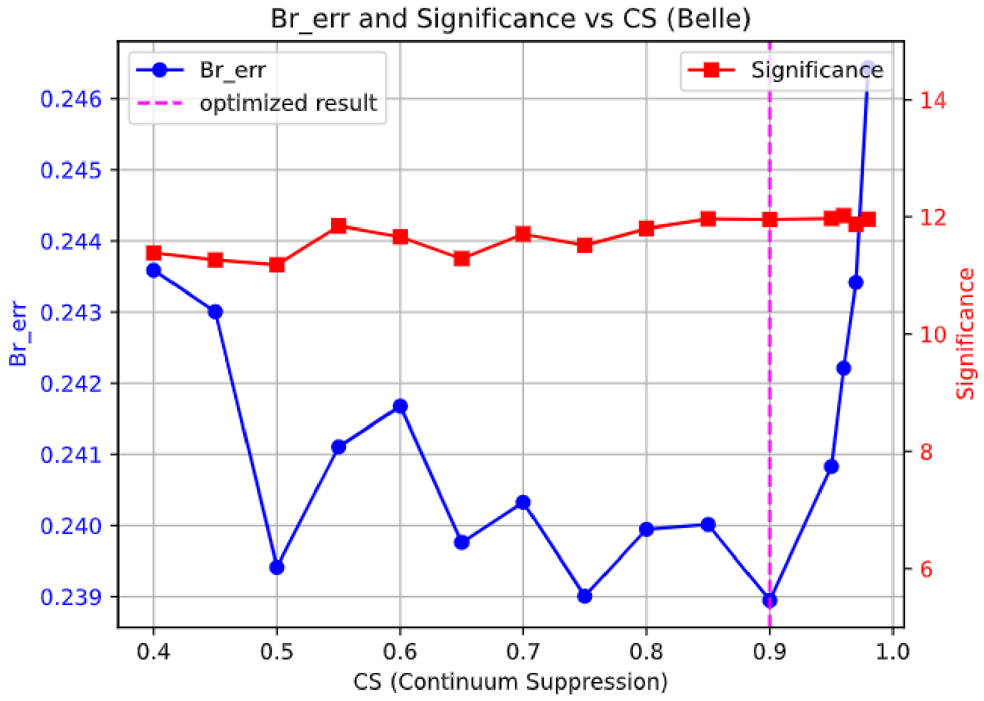
Continuum Suppression optimization

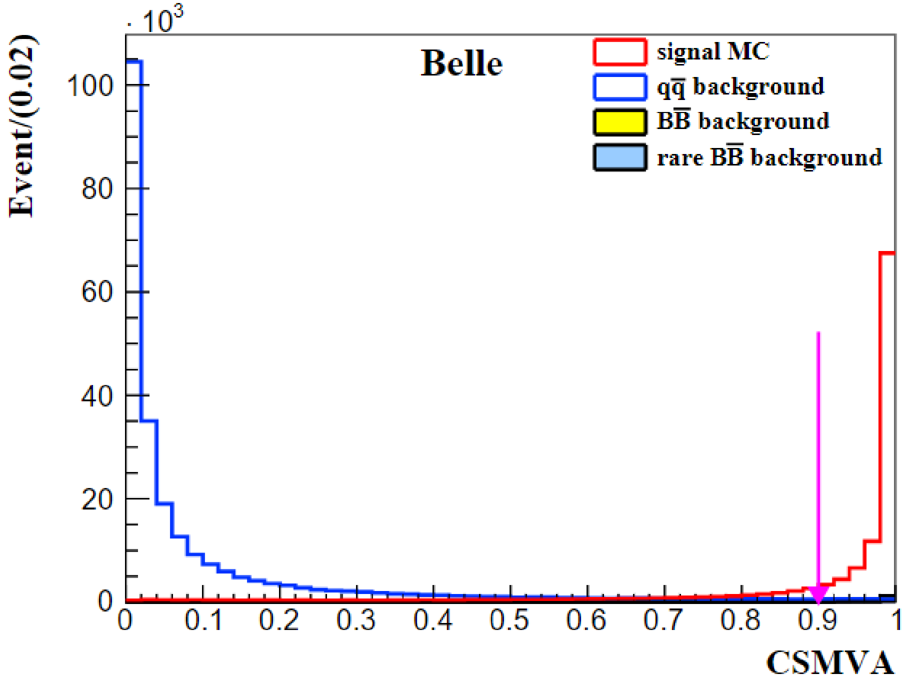
- **Continuum suppression optimization**
  - 1000 ToyMC for each requirement
  - PDFs extracted from MC shape

➢ CSMVA > 0.9 (The most stringent threshold)

To minimize possible systematic uncertainties proportional to background contamination

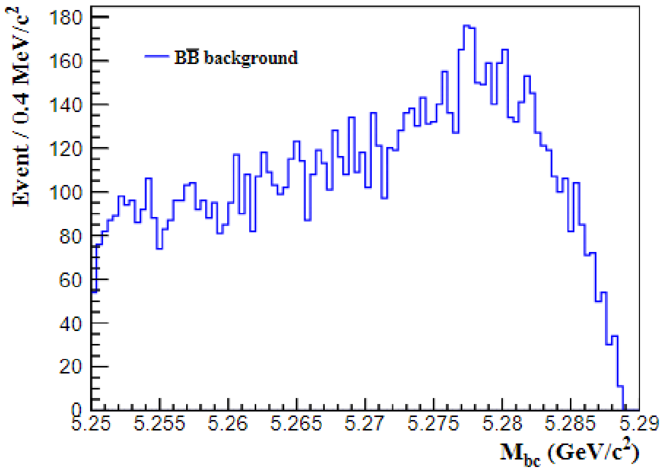
➢ Reject 98.69% continuum background and preserve 74.45% signal events

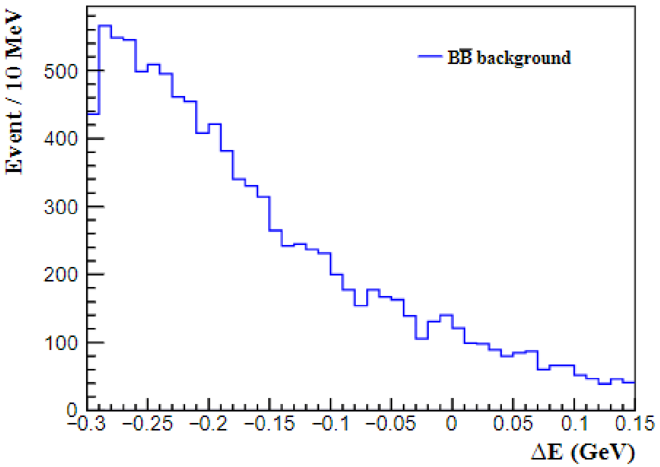




$B\bar{B}$ Background

- **Generic $B\bar{B}$ background ($b \rightarrow c$ decays)**





- M_{bc} strongly peaks around 5.279 GeV/c^2

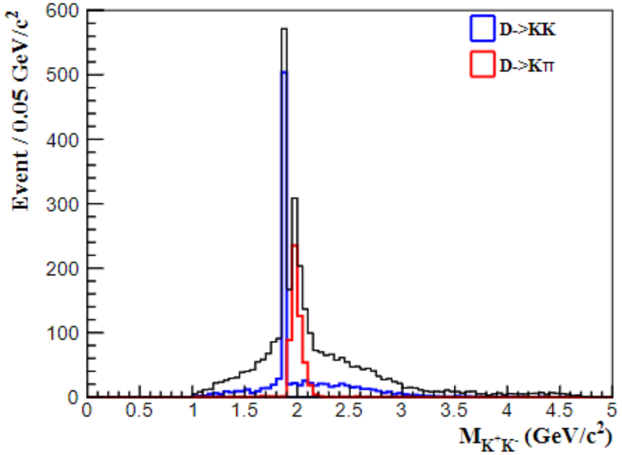
➢ $D \rightarrow KK$ & $D \rightarrow K\pi$ decay

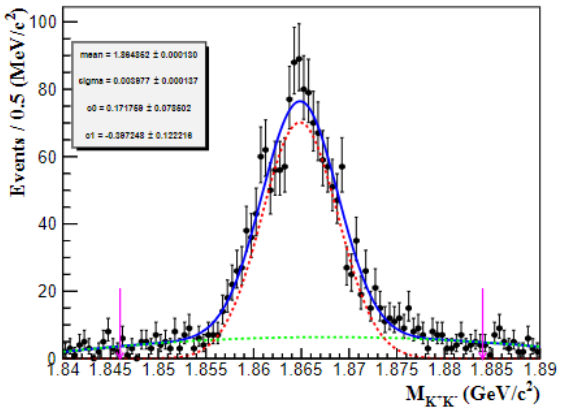
$$M_{KK} = \sqrt{(E_{K^+} + E_{K^-})^2 - (\boldsymbol{p}_{K^+} + \boldsymbol{p}_{K^-})^2}$$

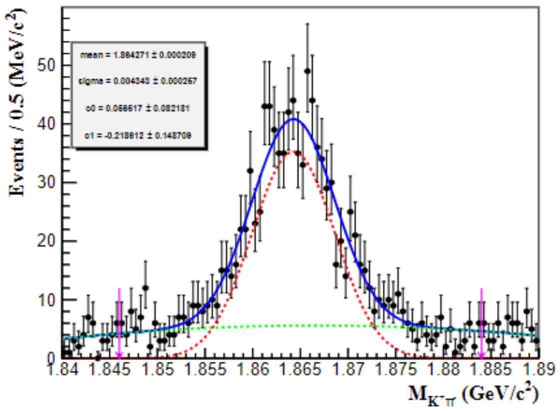
$$M_{K\pi} = \sqrt{(E_K + E_\pi)^2 - (\boldsymbol{p}_K + \boldsymbol{p}_\pi)^2}$$

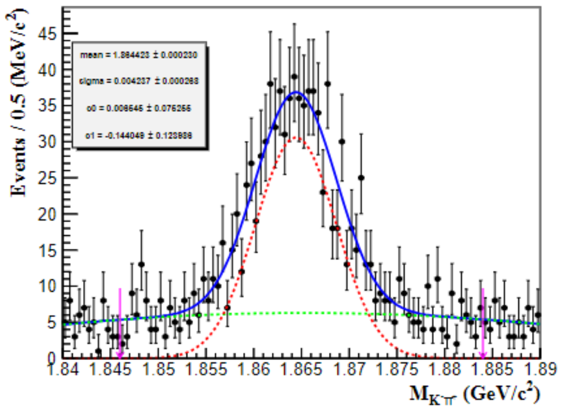
$$E_K = \sqrt{\boldsymbol{p}_K{}^2 + m_K{}^2}$$

$$E_\pi = \sqrt{\boldsymbol{p}_\pi{}^2 + m_\pi{}^2}$$ (use the pion mass from PDG)







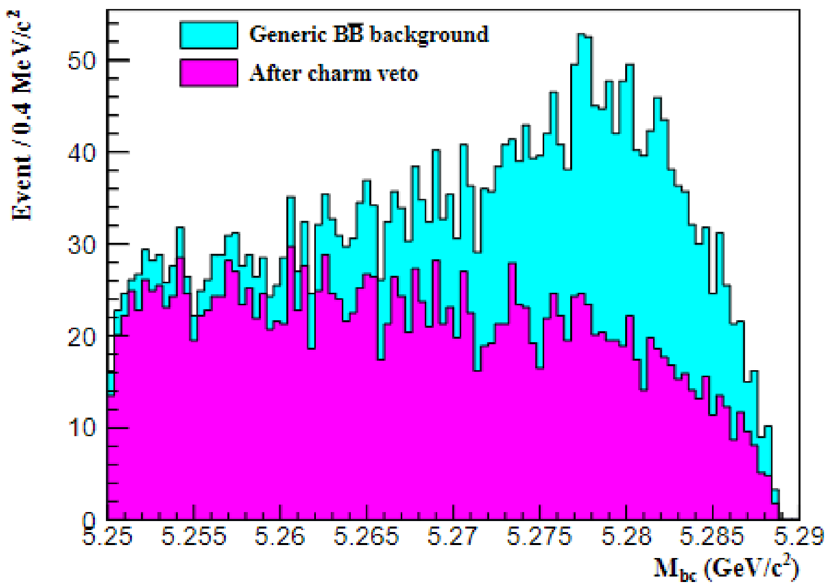


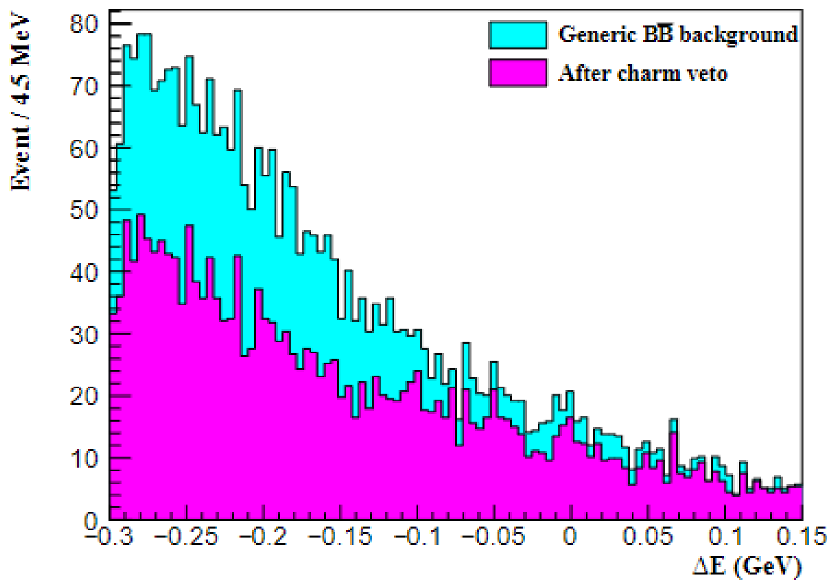
Peak from D decay ($D \rightarrow KK$ & $D \rightarrow K\pi$)

Charm veto : $1.846 < \boldsymbol{M_{K^\pm\pi^\mp}}$, $\boldsymbol{M_{KK}} < 1.884$ GeV$/c^2$

$B\bar{B}$ Background

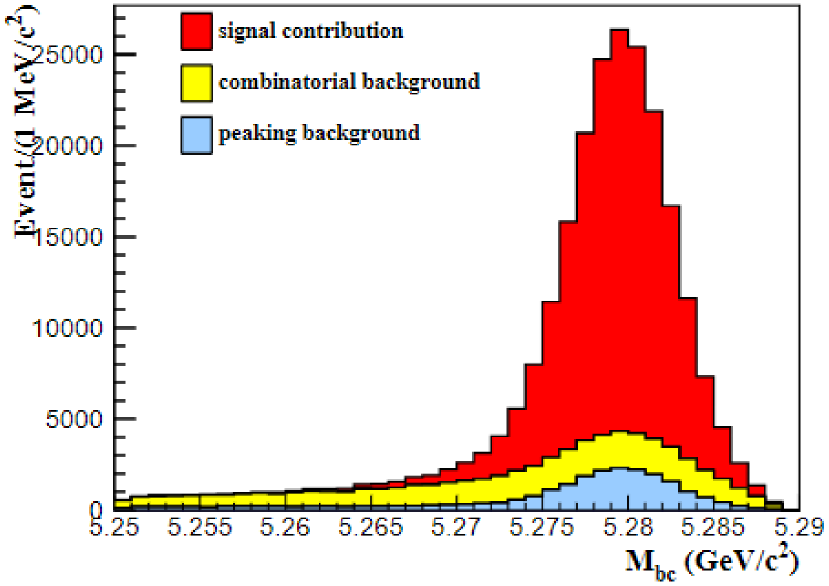
- **Generic $B\bar{B}$ background ($b \to c$ decays)**
  - Charm veto :
    $1.846 < M_{K^{\pm}\pi^{\mp}}\ , M_{K^{+}K^{-}} < 1.884\ \mathrm{GeV}/c^2$

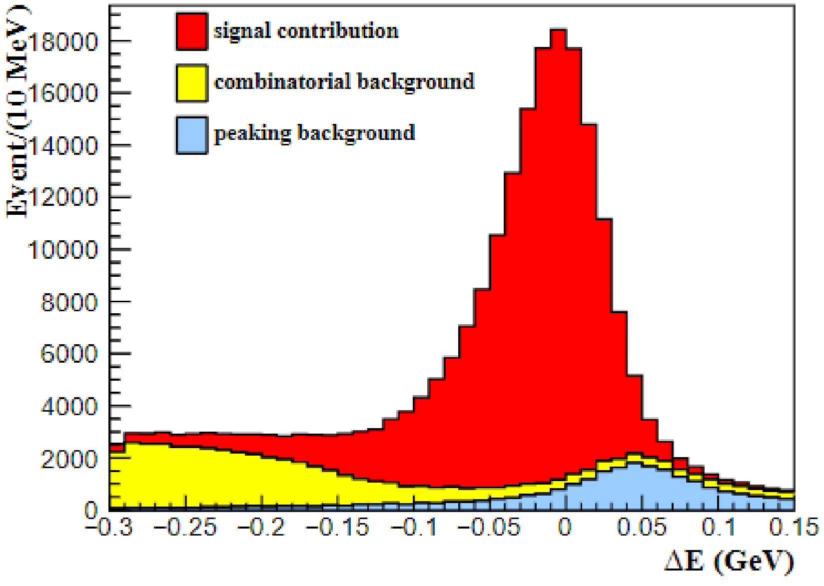




$B\bar{B}$ Background

- **rare $B\bar{B}$ background**
  - **Combinatorial $B\bar{B}$ background:**
    The remain rare $B\bar{B}$ background after removing peaking background
  - **Peaking background:** $B \to K\pi\pi$



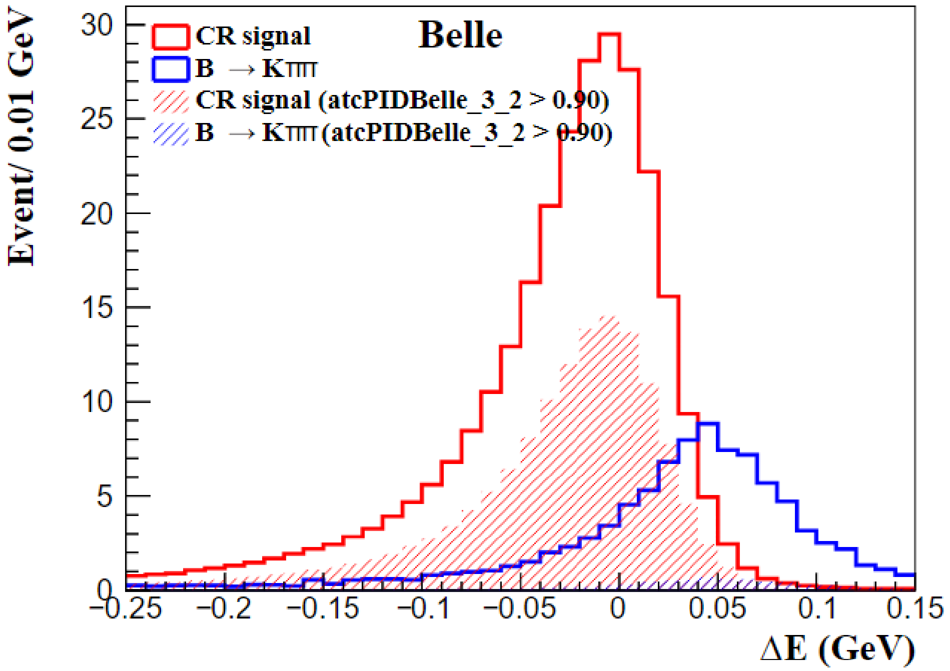


Peaking Background

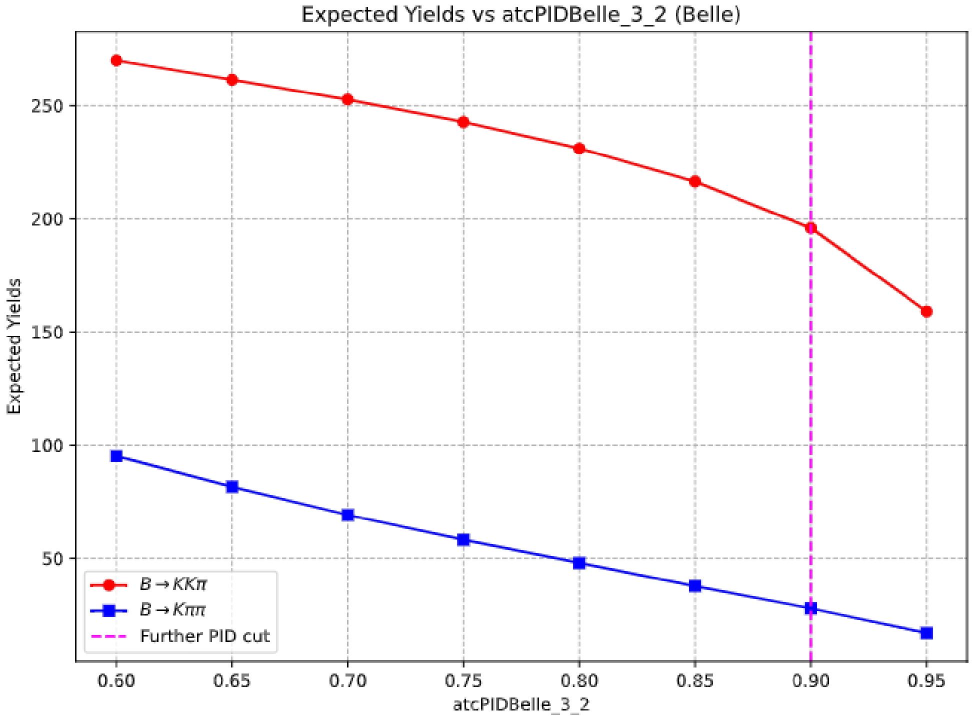
- **Peaking background**

$$\mathcal{B}(B^0 \to K^+K^-\pi^0) = (2.17 \pm 0.6) \times 10^{-6}$$

$$\mathcal{B}(B^0 \to K^+\pi^-\pi^0) = (37.8 \pm 3.2) \times 10^{-6}$$



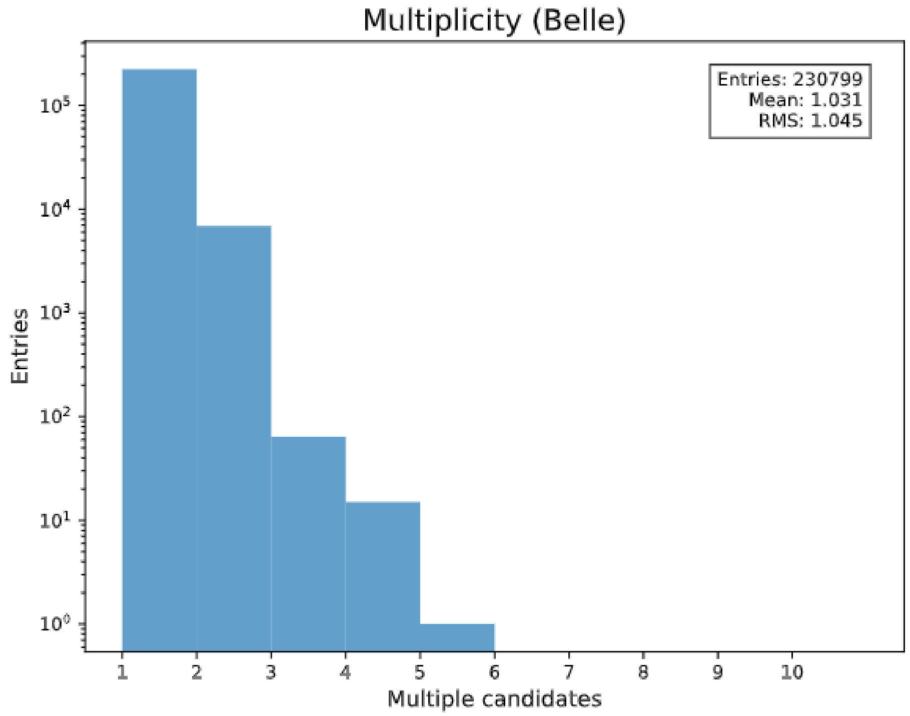
➢ Require further cut on PID: kaonID > 0.9



- The event number of the two components are scaled to the expected yields corresponding to the integrated luminosity of the real data

Candidate Multiplicity and Final Selection

- $B^0 \to K^+K^-\pi^0$
  - Mutiplicity: 1.031
  - Best candidate selection
    - ➢ Lowest π^0 mass-constrained χ^2
    - ➢ Then lowest B^0 vertex fit χ^2



- Final selection

Target	Selection	Signal efficiency [%]	SCF [%]
	Baseline and Optimized Selection	23.09	4.45
signal Region	$5.272 < M'_{bc} < 5.285$ GeV/c^2	22.53	2.50
	$-0.25 < \Delta E < 0.15$ GeV	22.28	2.32
Continuum Suppression	CSMVA > 0.9	16.59	1.67
Charm veto window	$1.846 < M_{K^\pm K^\mp} < 1.884$ GeV/c^2	16.43	1.68
	$1.846 < M_{K^\pm \pi^\mp} < 1.884$ GeV/c^2	16.11	1.69
Further PID requirement	$\mathcal{L}(K/\pi) > 0.9$	11.70	1.64
Best candidate selection		11.41	1.13

- $\varepsilon = 11.41 \pm 0.02\%$ SCF $= 1.13 \pm 0.02\%$

- Sample composition
  - ➢ Signal (Correctly reconstructed and self-crossfeed signal)
  - ➢ Continuum background
  - ➢ Generic $B\bar{B}$ background
  - ➢ Combinatorial $B\bar{B}$ background
  - ➢ Peaking background

Signal yield extraction

- **Fitter for $B^0 \to K^+K^-\pi^0$**
  - tight cut on M_{bc}
  - 2D Fit on ΔE and transformed CS (C') (**μ-transformation)**
  - Probability density function (PDF) of each event category j: $\mathcal{P}_j^i = \mathcal{P}_j(\Delta E^i)\mathcal{P}(C'^i),$
  - Extended likelihood function: $\mathcal{L} = \exp(-\sum_j n_j) \times \prod_i [\sum_j n_j \mathcal{P}_j^i]$

PDF used to model each event category

Event category	ΔE	C'
CR signal	Double CB	Flat
SCF signal	2D histogram	
Continuum Background	Poly1	2Exp
Generic $B\bar{B}$ Background	Double G	KDE
Combinatorial $B\bar{B}$ Background	Double G	Poly2
Peaking Background	2D KDE	

- The CR signal and SCF signal are considered distinct and their combined PDF is : $n_{\text{sig}} \times [(1-f)\mathcal{P}_{CR} + f\mathcal{P}_{SCF}]$
- The combined PDF of generic $B\bar{B}$ background and combinatorial $B\bar{B}$ background is : $n_{\text{B}\bar{\text{B}}} \times [(1-f_{gbb})\mathcal{P}_{combinatorial} + f_{gbb}\mathcal{P}_{generic}],$

$$f_{gbb} = \frac{n_{\text{generic}}}{n_{\text{generic}} + n_{\text{combinatorial}}},$$

- Parameters fixed
  - SCF fraction
  - PDF parameters (except 2 parameters of $q\bar{q}$ bkg)
  - The yield of peaking background
- Parameters floated :
  - The yield for each event category except for peaking background (n_{sig} includes CR and SCF signal)
  - Continuum background PDF parameters (2 parameters are floated, coefficient p_0 and the fraction of two exponential function)
  - The fraction of generic $B\bar{B}$ background (f_{gbb})

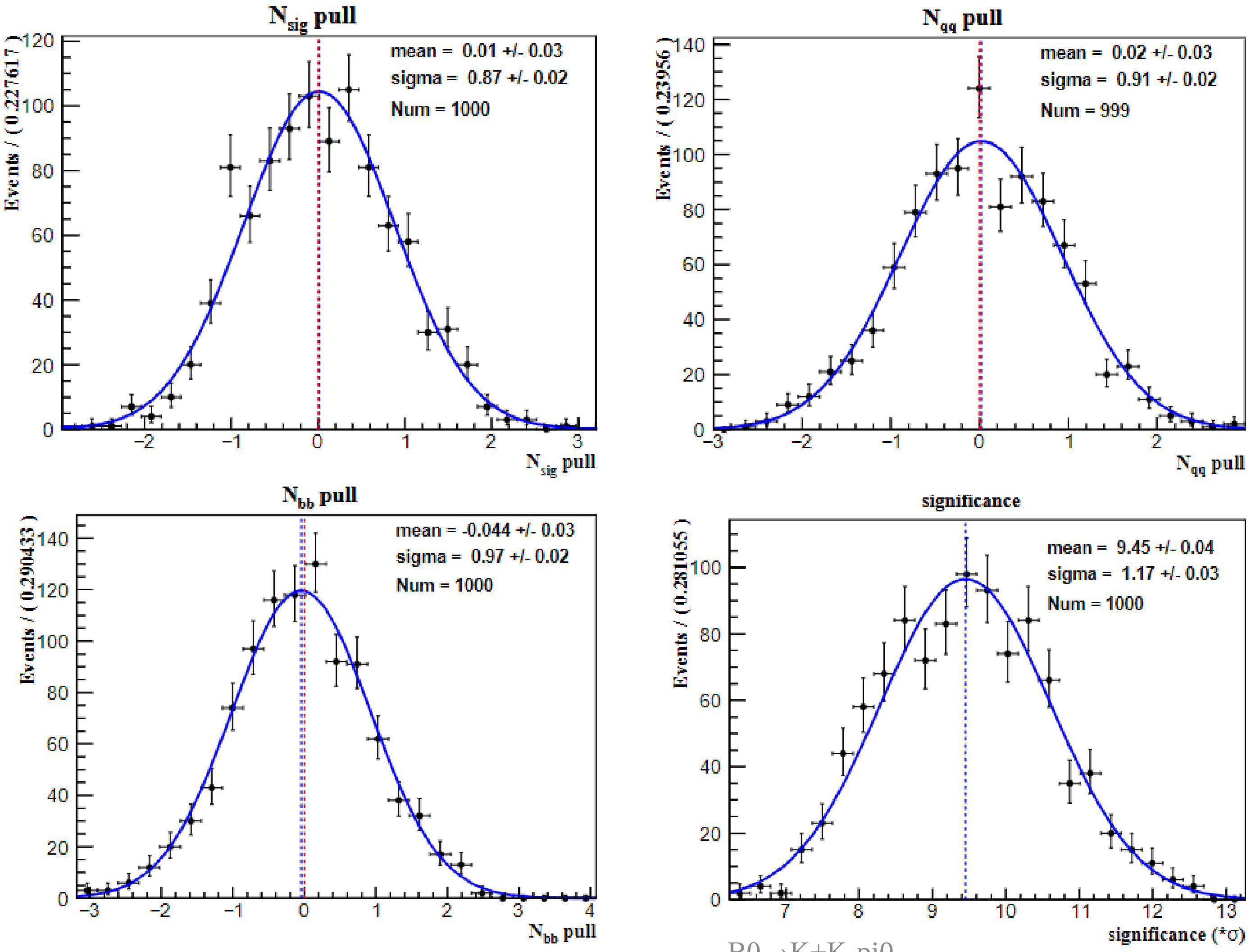
Event estimation

- Signal Events : estimated by assuming the branching ratio to be $\mathcal{B}(B^0 \to K^+K^-\pi^0) = 2.17 \times 10^{-6}$
  - $N_{sig}^{exp} = N_{B\bar{B}} \times \mathcal{B}(B^0 \to K^+K^-\pi^0) \times \varepsilon_{sig}^{rec}$
- Continuum bkg & Generic BB bkg : scaled to the integrated luminosity of experimental data
- Peaking bkg : calculated by
  - $N_{peak}^{exp} = N_{B\bar{B}} \times \mathcal{B}(B^0 \to K^+\pi^-\pi^0) \times \varepsilon_{peak}^{rec}$

	Expected Yield
Signal	193
Continuum background	1760
BB background	502
Peaking background	28

Fitter validation

- **GSIM** (1000 samples)
  - Yield of each component fluctuated drawing from a Poisson distribution around their nominal expected value



$$\text{pull} = \frac{x_{fit} - x_{true}}{\sigma_x}$$

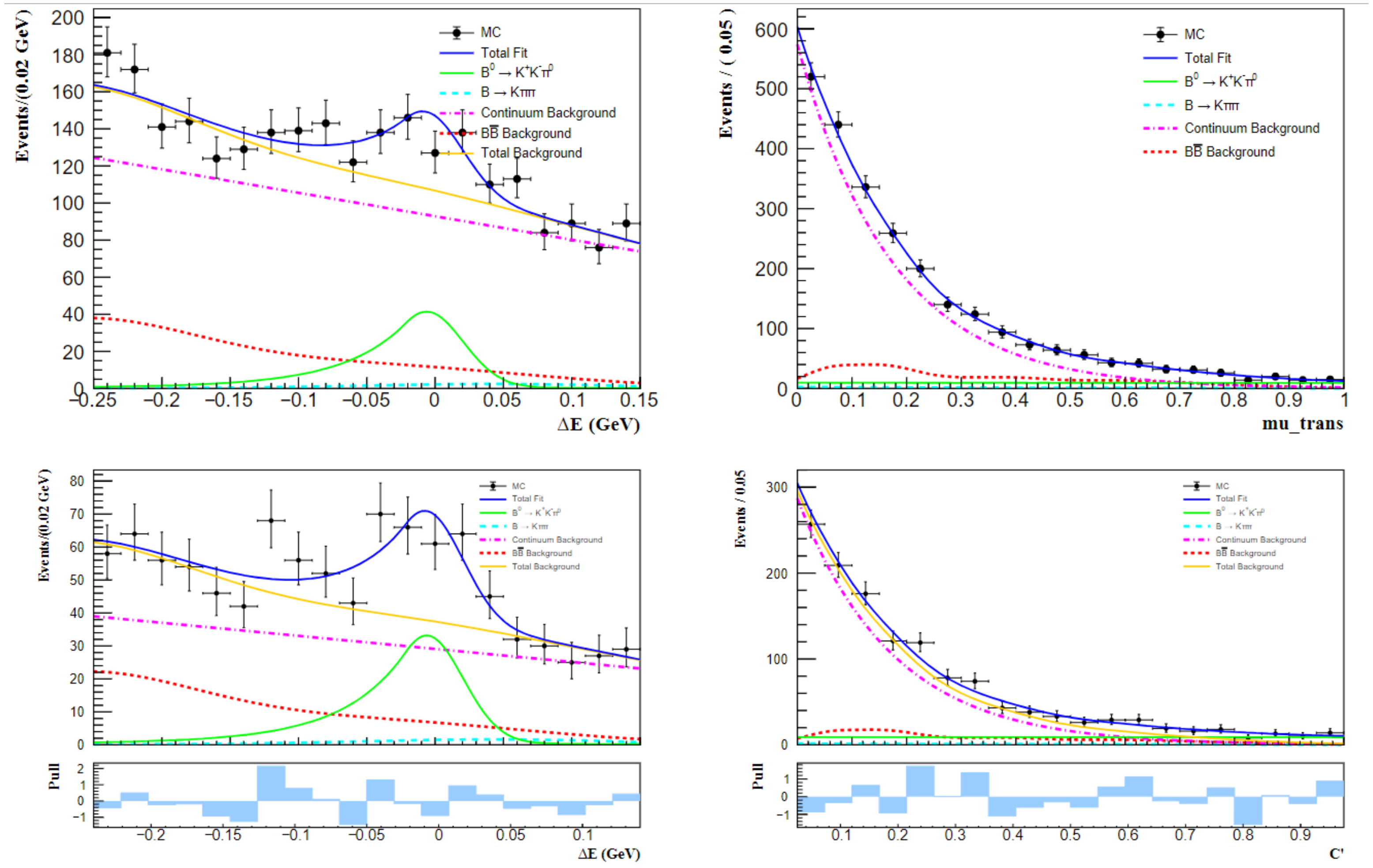
Significance : $\sqrt{2 * (NLL - NLL_{min})}$

Fitter validation

- **GSIM** (1000 samples)

  - Fit Range
    - ΔE [-0.25, 0.15] GeV
    - C' [0, 1]

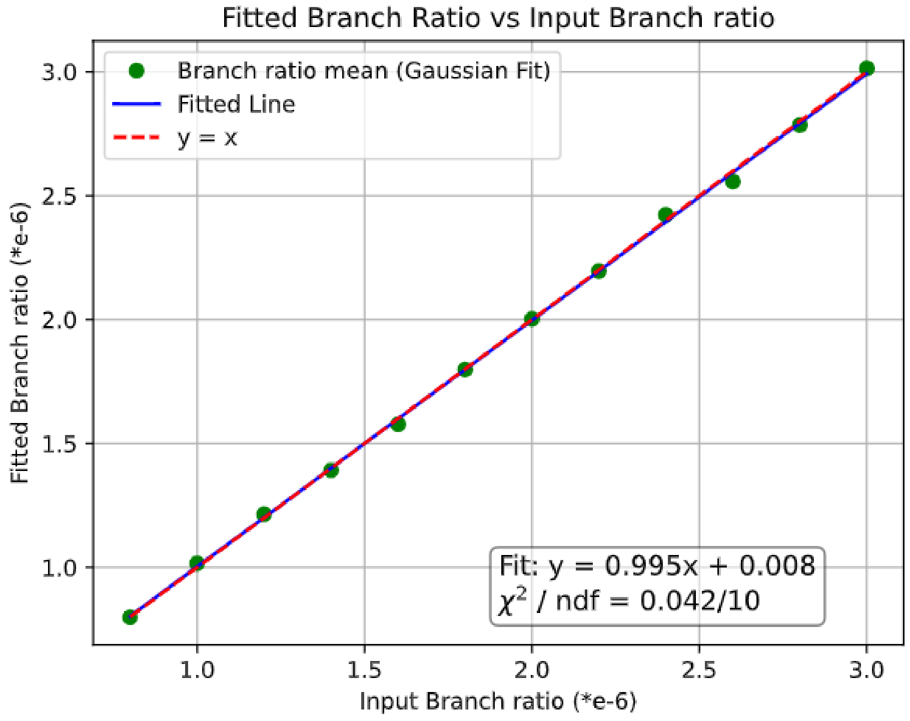
  - Projection Plot
    - $-0.15 < \Delta E < 0.05$ GeV, and
    - C' > 0.2

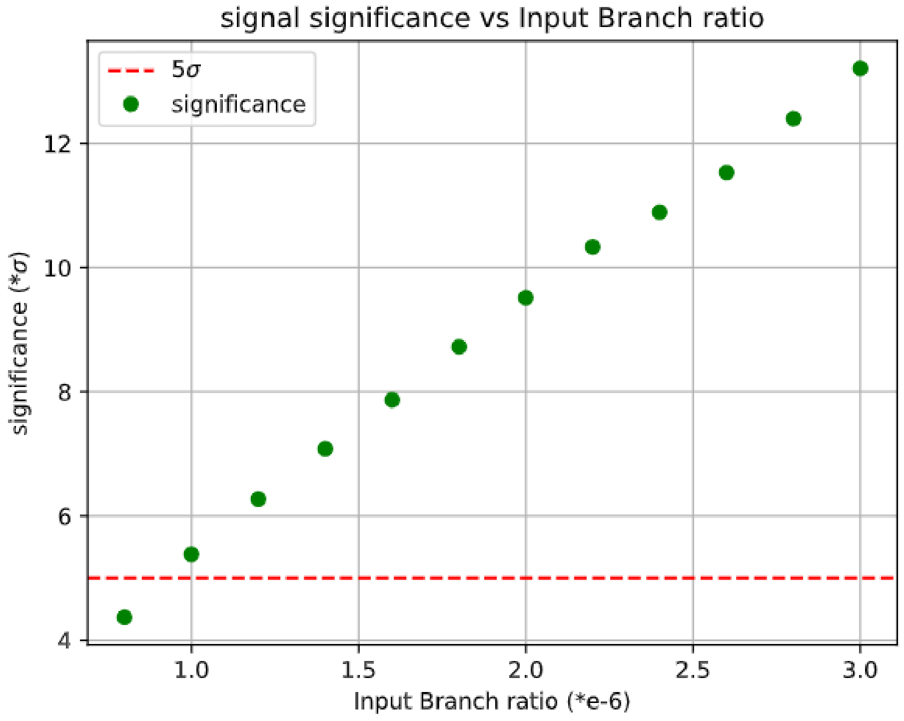


Fitting results for one of the GSIM samples

Fitter Validation

- Linearity test (Branching ratio varies from 0.8×10^{-6} to 3.0×10^{-6})
- 1000 GSIM samples for each input)





Control Channel

Control Channel

$B^+ \to \bar{D}^0(\to K^+\pi^-\pi^0)\pi^+$

- To extract calibration parameter (shift and scale factor)
- To assess possible differences in the CS efficiency between data and MC

The selection criteria for $B^+ \to \bar{D}^0(\to K^+\pi^-\pi^0)\pi^+$ (Belle)

Target	Selection
charged tracks	$\|dz\| < 2$ cm $dr < 0.5$ cm theta in CDC acceptance
γ	forward > 25 MeV, barrel > 125 MeV, backward > 150 MeV
π^0	$115 < M_{\gamma\gamma} < 150$ MeV/c^2 $\chi^2_{\pi^0} < 12$ daughterAngle < 0.5 |cosHelicityAngleMomentum| < 0.91
K/π	atcBellePID_3_2 > 0.9 for selecting kaons atcBellePID_3_2 < 0.1 for selecting pions
$\bar{D}^0$	$1.826 <$ InvM < 1.893 GeV/c^2
B^+	$5.272 < M'_{bc} < 5.285$ GeV/c^2 $-0.25 < \Delta E < 0.15$ GeV
CSMVA	CSMVA > 0.9

The selection criteria for $B^+ \to \bar{D}^0(\to K^+\pi^-\pi^0)\pi^+$ (Belle II)

Target	Selection
charged tracks	$\|dz\| < 2$ cm $dr < 0.5$ cm theta in CDC acceptance
γ	$0.2976 < \theta < 2.6180$ rad clusterNHits > 1.5 |clusterTiming| < 200 ns forward > 275 MeV, barrel > 150 MeV, backward > 200 MeV beamBackgroundSuppressionScore > 0.1 fakePhotonSuppressionScore > 0.675
π^0	$115 < M_{\gamma\gamma} < 150$ MeV/c^2 $\chi^2_{\pi^0} < 13$ daughterAngle < 0.5 |cosHelicityAngleMomentum| < 0.88
K/π	kaonIDNN > 0.9 for selecting kaons, rest considered pions
$\bar{D}^0$	$1.826 <$ InvM < 1.893 GeV/c^2
B^+	$5.272 < M'_{bc} < 5.285$ GeV/c^2 $-0.25 < \Delta E < 0.15$ GeV
CSMVA	CSMVA > 0.9

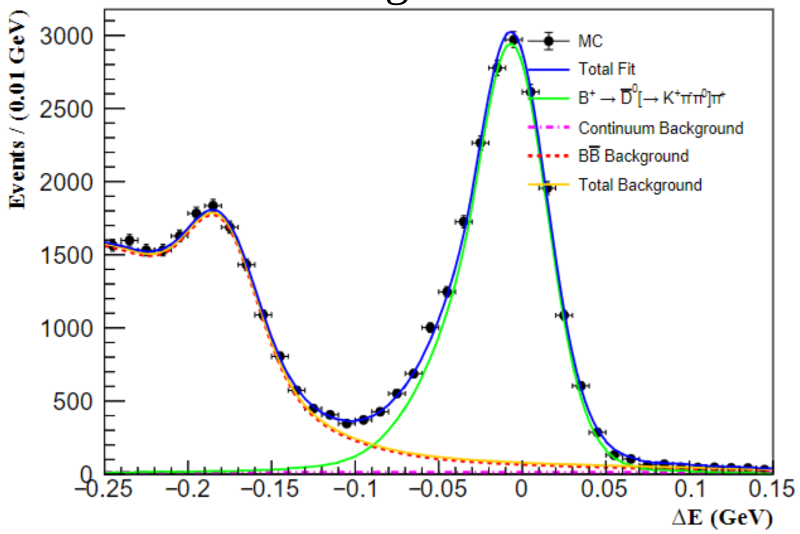
Control Channel

$B^+ \to \bar{D}^0(\to K^+\pi^-\pi^0)\pi^+$

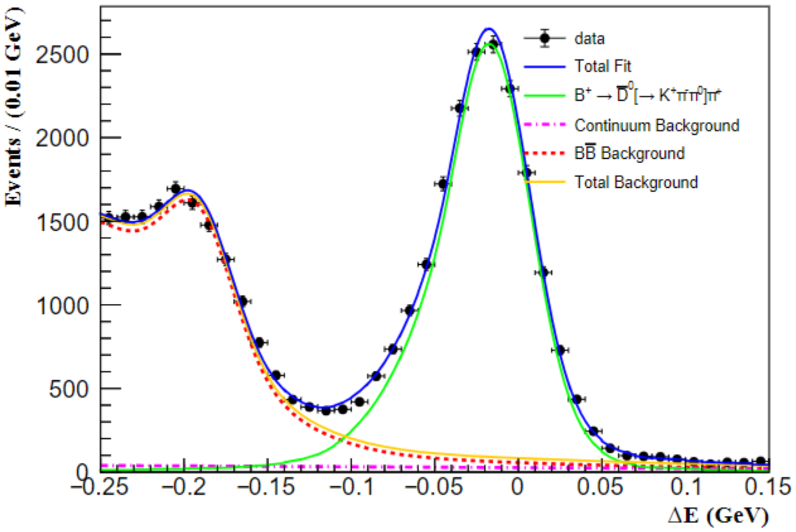
Summary of the calibration values

	Calibration Value
ΔE mean (GeV) (Belle)	$-(1.046 \pm 0.028) \times 10^{-2}$
ΔE sigma (GeV) (Belle)	1.123 ± 0.011
ΔE mean (GeV) (Belle II)	$-(2.576 \pm 0.411) \times 10^{-3}$
ΔE sigma (GeV) (Belle II)	1.088 ± 0.018

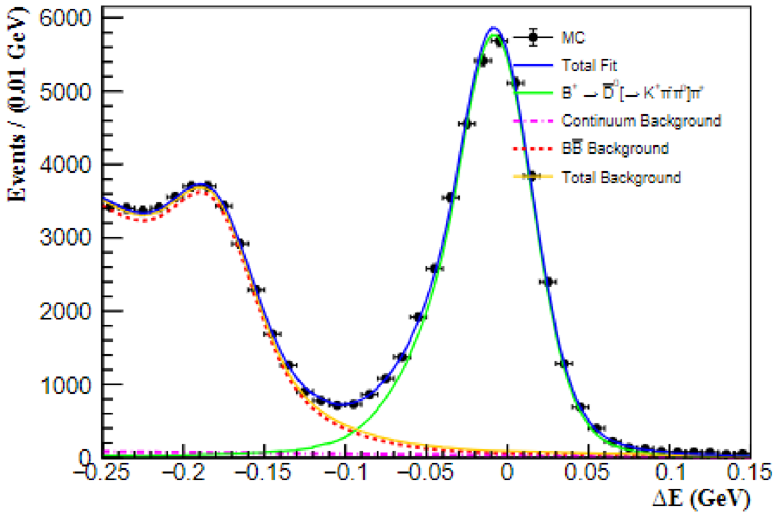
Belle generic MC



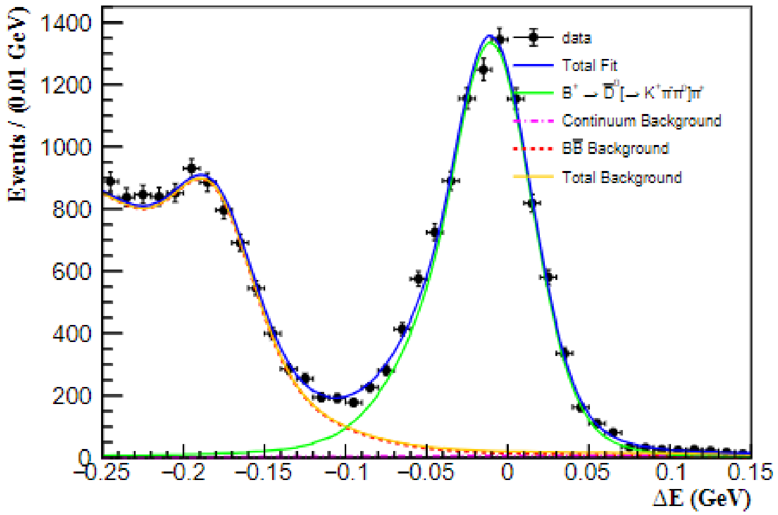
Belle data



Belle II generic MC



Belle II data



Summary

- ➢ Update Belle II analysis using MCrd samples
- ➢ Add Belle analysis

- Next to do
  - ➢ PID correction
  - ➢ Systematic uncertainties
  - ➢ Complete Belle2Note …

Thanks for your attention!

Back up

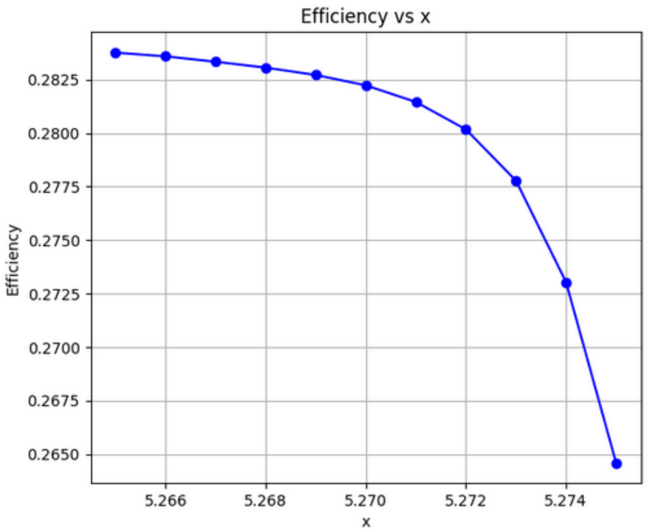
photonMVA

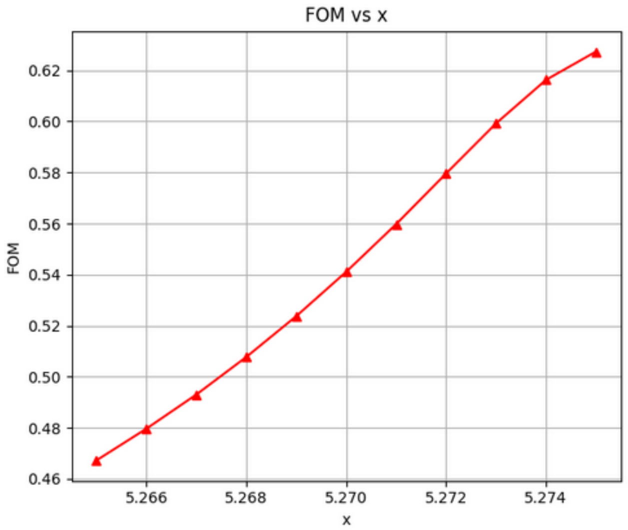
γ relevant variable	
beamBackgroundSuppressionScore	The output of an MVA classifier that uses shower-related variables to distinguish true photon clusters from beam background clusters
fakePhotonSuppressionScore	The output of an MVA classifier that uses shower-related variables to distinguish true photon clusters from fake photon clusters

https://confluence.desy.de/display/BI/Neutrals+Performance

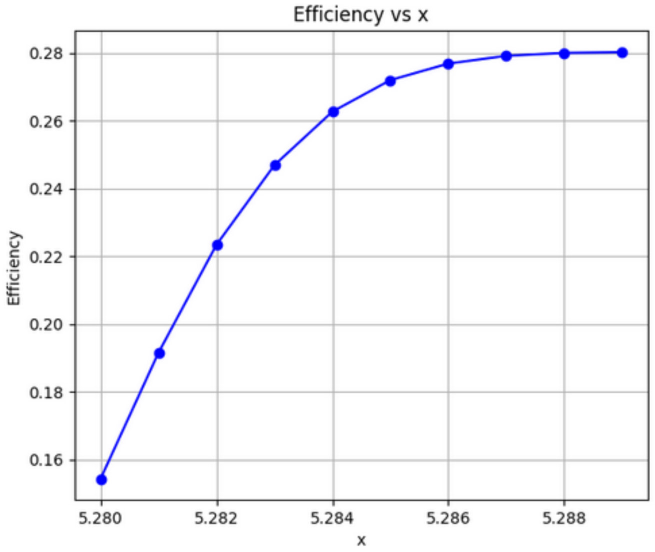
Modified M_{bc}

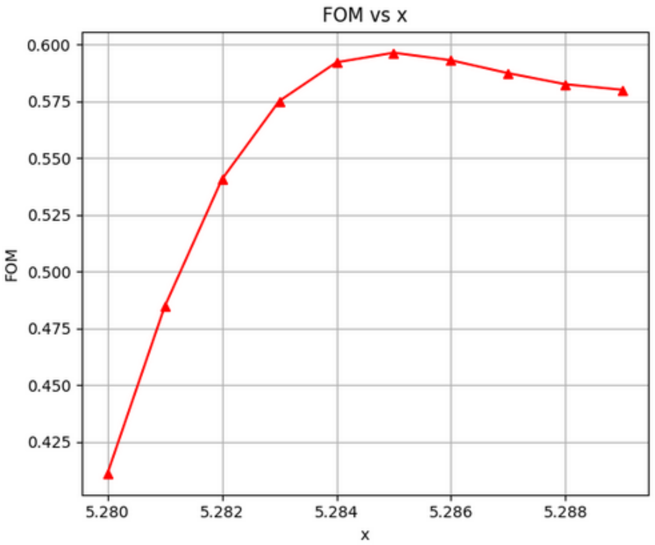
Left





Right

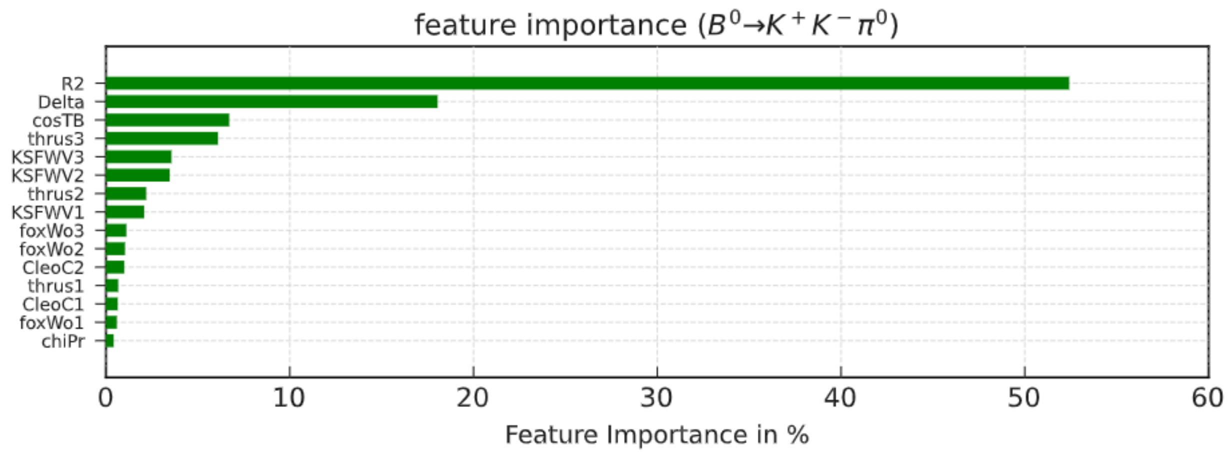


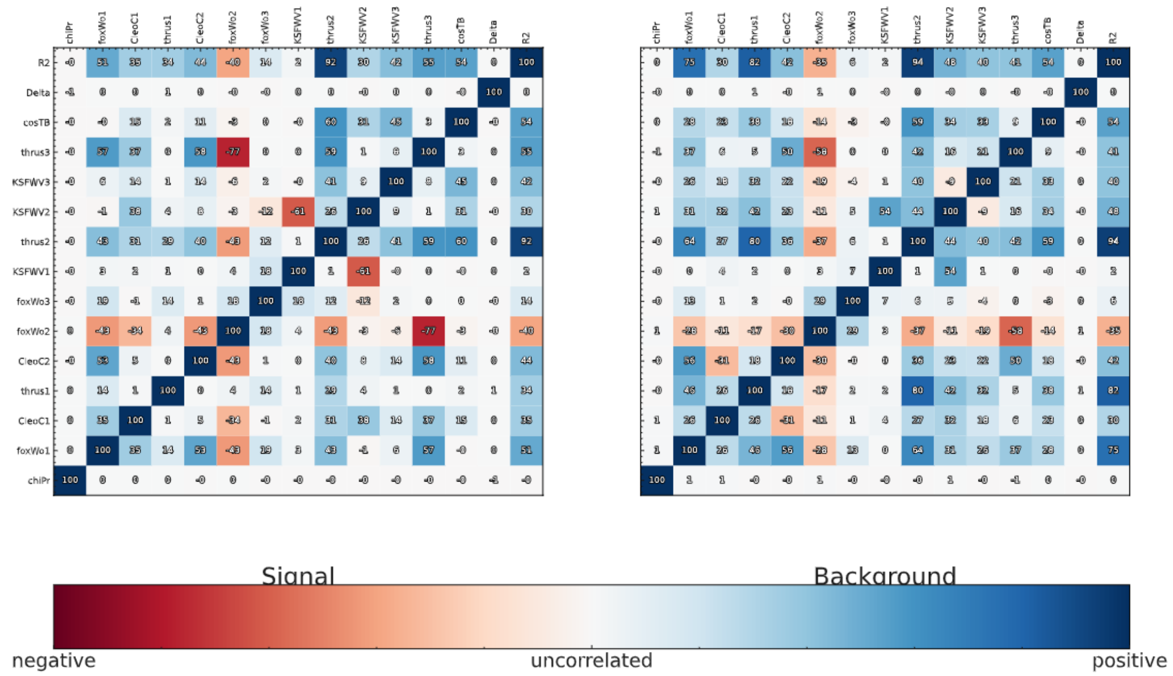


Variables used in CS training (Belle II)

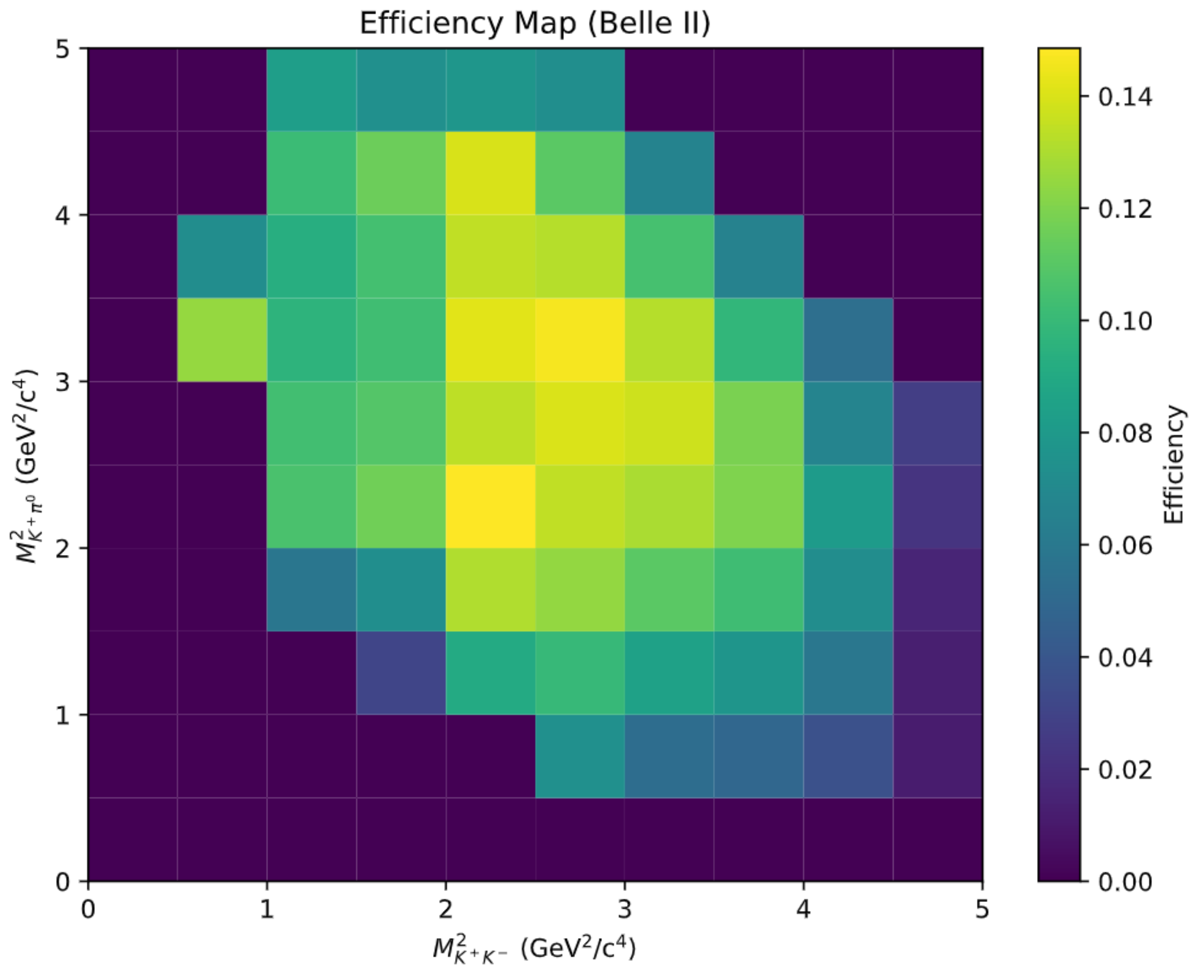
TABLE XVIII. Variables used in FBDT training (BelleII)

Variable	Abbreviation	Variable	Abbreviation
R2	R2	DeltaZ	Delta
cosTBTO	cosTB	thrustBm	thrust3
KSFWVariableshso12	KSFWV3	KSFWVariableshso02	KSFWV2
thrust	thrust2	KSFWVariableshoo0	KSFWV1
foxWolframR3	foxWo3	foxWolframR1	foxWo2
CleoConeCS1	CleoC2	thrustOm	thrus1
CleoConeCS2	CleoC1	foxWolframR4	foxWo1
chiProb	chiPr		

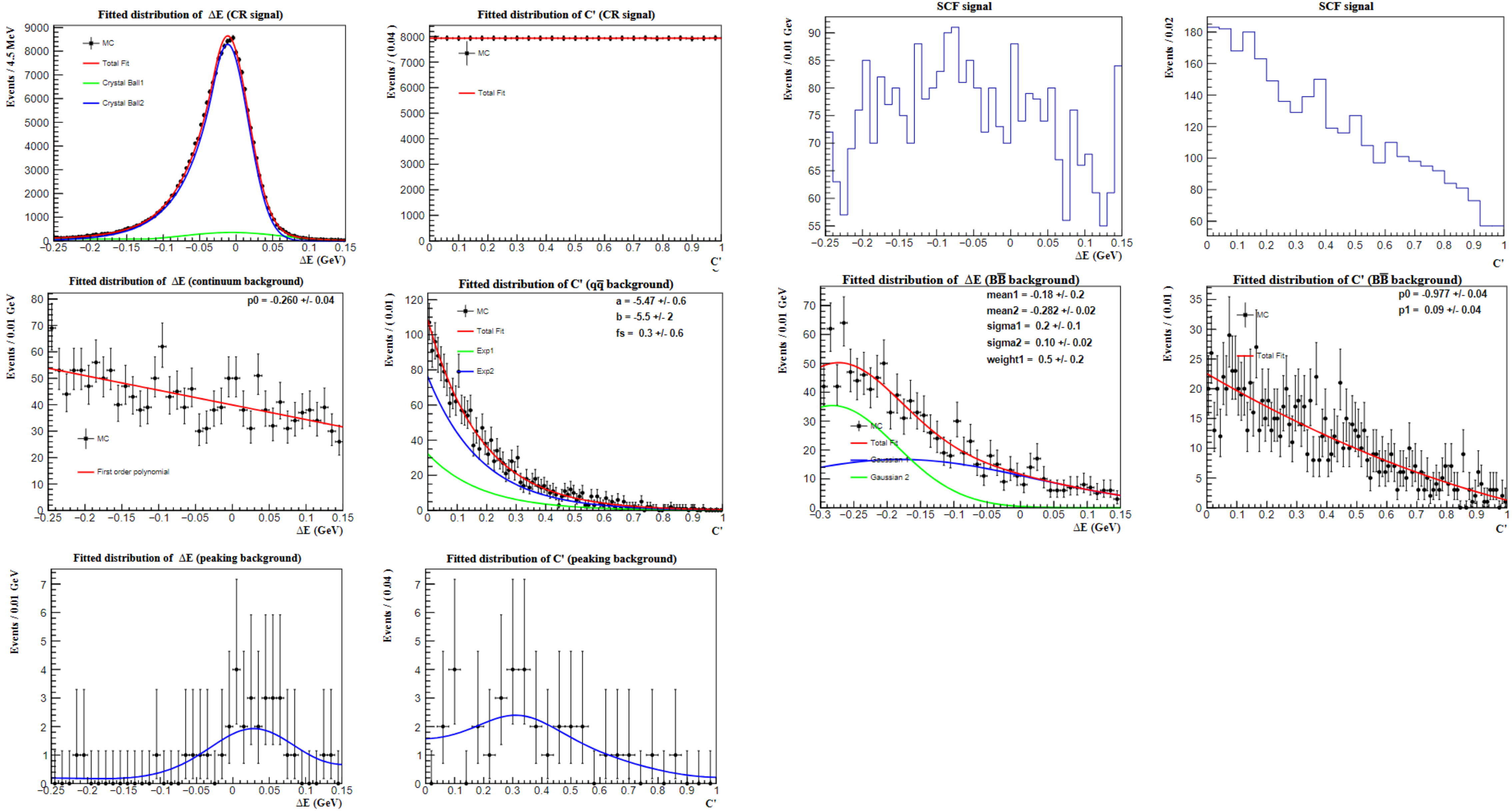




Efficiency map (Belle II)

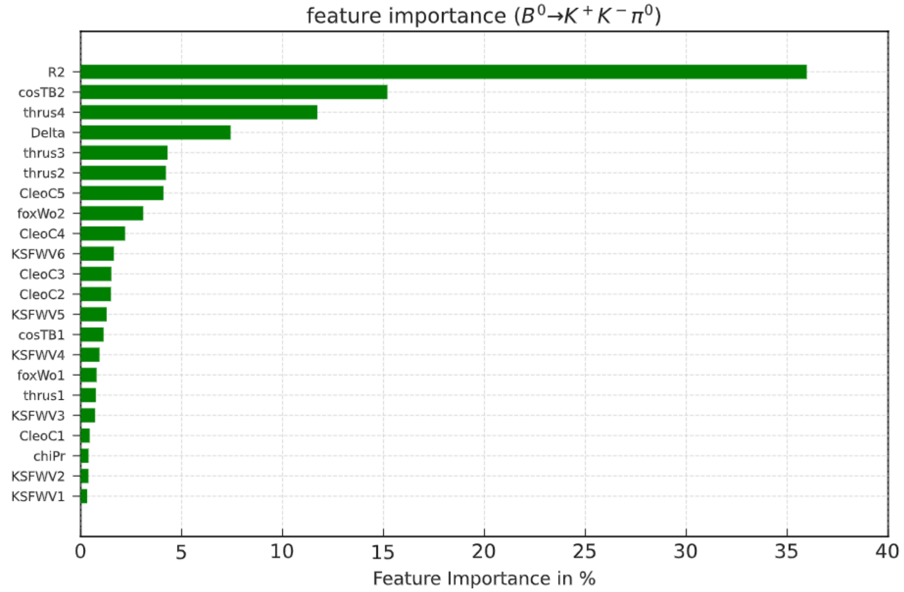


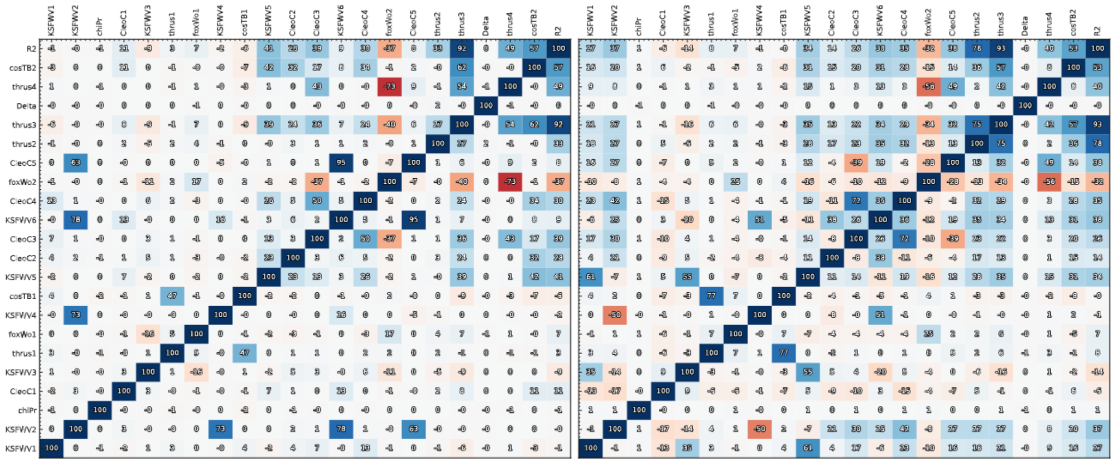
PDFs (Belle II)



Variables used in CS training (Belle)

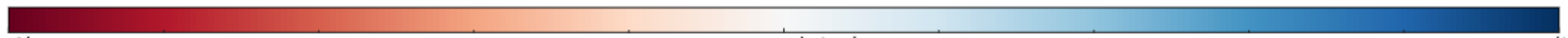
Variable	Abbreviation	Variable	Abbreviation
R2	R2	cosTBTO	cosTB2
thrustBm	thrus4	DeltaZ	Delta
thrust	thrus3	thrustOm	thrus2
CleoConeCS1	CleoC5	foxWolframR3	foxWo2
CleoConeCS2ROE	CleoC4	KSFWVariableshso02	KSFWV6
CleoConeCS2	CleoC3	CleoConeCS3ROE	CleoC2
KSFWVariableshso12	KSFWV5	KSFWV5	cosTB1
KSFWVariablesmm2	KSFWV4	foxWolframR1	foxWo1
thrustAxisCosTheta	thrus1	KSFWVariableshso10FS1	KSFWV3
CleoConeCS4ROE	CleoC1	chiProb	chiPr
KSFWVariableshso04FS1	KSFWV2	KSFWVariableshso14FS1	KSFWV1



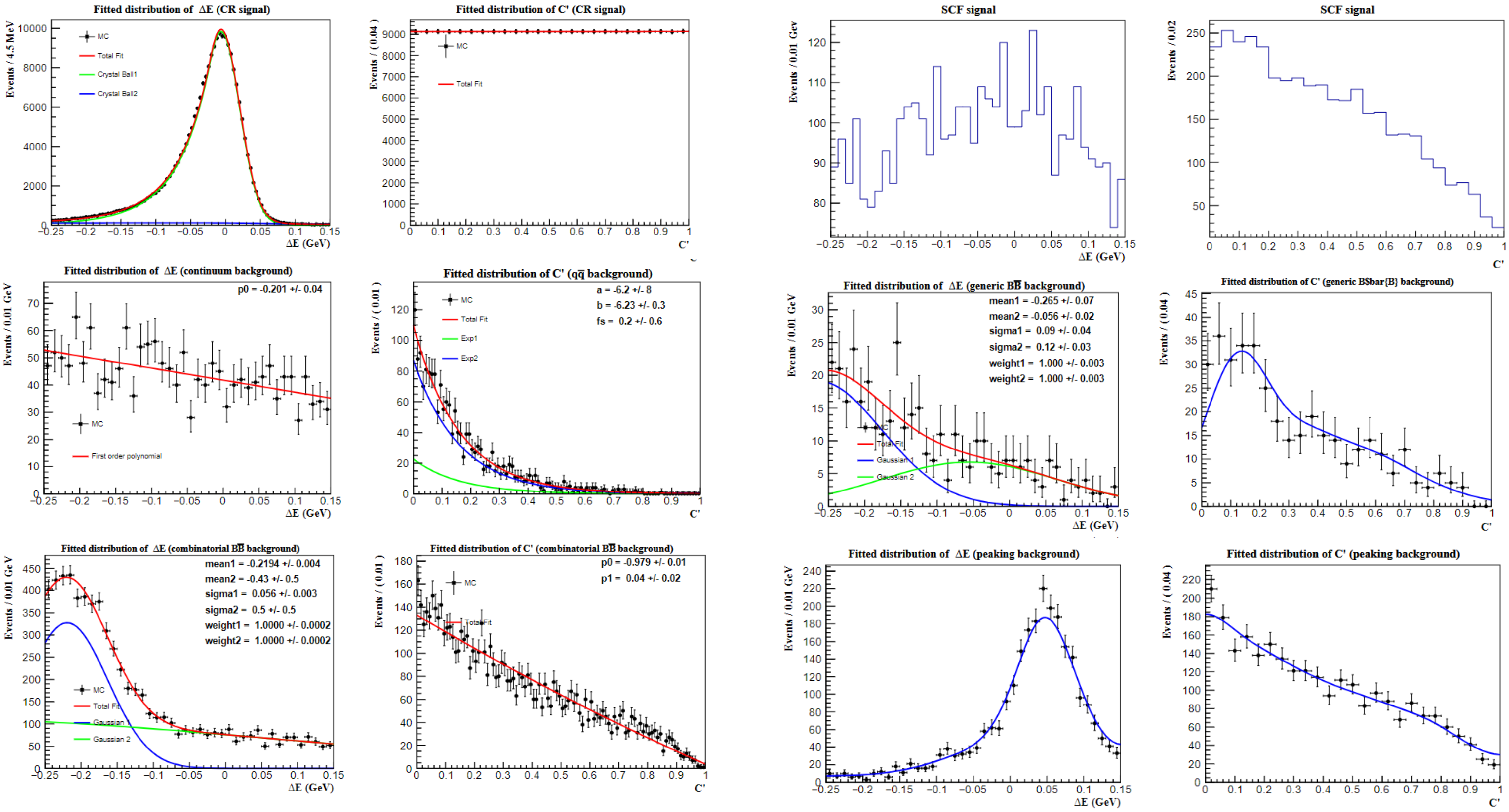


Signal

Background



PDFs (Belle)



Fitted distribution of ΔE (CR signal)
MC
Total Fit
Crystal Ball1
Crystal Ball2
Events / 4.5 MeV
ΔE (GeV)
Fitted distribution of C' (CR signal)
Events / (0.04)
C'
SCF signal
Events / 0.01 Gev
ΔE (GeV)
SCF signal
Events / 0.02
C'
Fitted distribution of ΔE (continuum background)
p0 = -0.201 +/- 0.04
First order polynomial
Events / 0.01 GeV
Fitted distribution of C' (qq̄ background)
a = -6.2 +/- 8
b = -6.23 +/- 0.3
fs = 0.2 +/- 0.6
Exp1
Exp2
Events / (0.01)
Fitted distribution of ΔE (generic BB̄ background)
mean1 = -0.265 +/- 0.07
mean2 = -0.056 +/- 0.02
sigma1 = 0.09 +/- 0.04
sigma2 = 0.12 +/- 0.03
weight1 = 1.000 +/- 0.003
weight2 = 1.000 +/- 0.003
Gaussian 1
Gaussian 2
Fitted distribution of C' (generic B$bar{B} background)
Events / (0.04)
Fitted distribution of ΔE (combinatorial BB̄ background)
mean1 = -0.2194 +/- 0.004
mean2 = -0.43 +/- 0.5
sigma1 = 0.056 +/- 0.003
sigma2 = 0.5 +/- 0.5
weight1 = 1.0000 +/- 0.0002
weight2 = 1.0000 +/- 0.0002
Fitted distribution of C' (combinatorial BB̄ background)
p0 = -0.979 +/- 0.01
p1 = 0.04 +/- 0.02
Fitted distribution of ΔE (peaking background)
Fitted distribution of C' (peaking background)