Measurement of CP Asymmetries in $B^0 \to \eta' K^0$ decays

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Motivation

- Most sensitive analysis of $\sin 2\beta^{eff}$ in $b \to q\bar{q}s$ loops
- Belle II published with run1 dataset, now repeat with run1+run2
  - ✅ Use GNN flavor tagger
  - ✅ Include 5 additional modes
  - ✅ Resolve PID and mass window inefficiencies
- Expecting sensitivity on *C* and *S* similar to world's best

$$B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-} K^0_{\pi^+\pi^-}$$
$$B^0 \to \eta'_{\rho\gamma} K^0_{\pi^+\pi^-}$$
$$\boxed{\begin{array}{c} B^0 \to \eta'_{\eta(3\pi)\pi^+\pi^-} K^0_{\pi^+\pi^-} \\ B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-} K^0_{\pi^0\pi^0} \\ B^0 \to \eta'_{\rho\gamma} K^0_{\pi^0\pi^0} \\ B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-} K^0_L \\ B^0 \to \eta'_{\eta(3\pi)\pi^+\pi^-} K^0_L \end{array}}$$

New since run1 Belle II analysis

Belle II Run1 analysis: Phys. Rev. D **110**, 112002

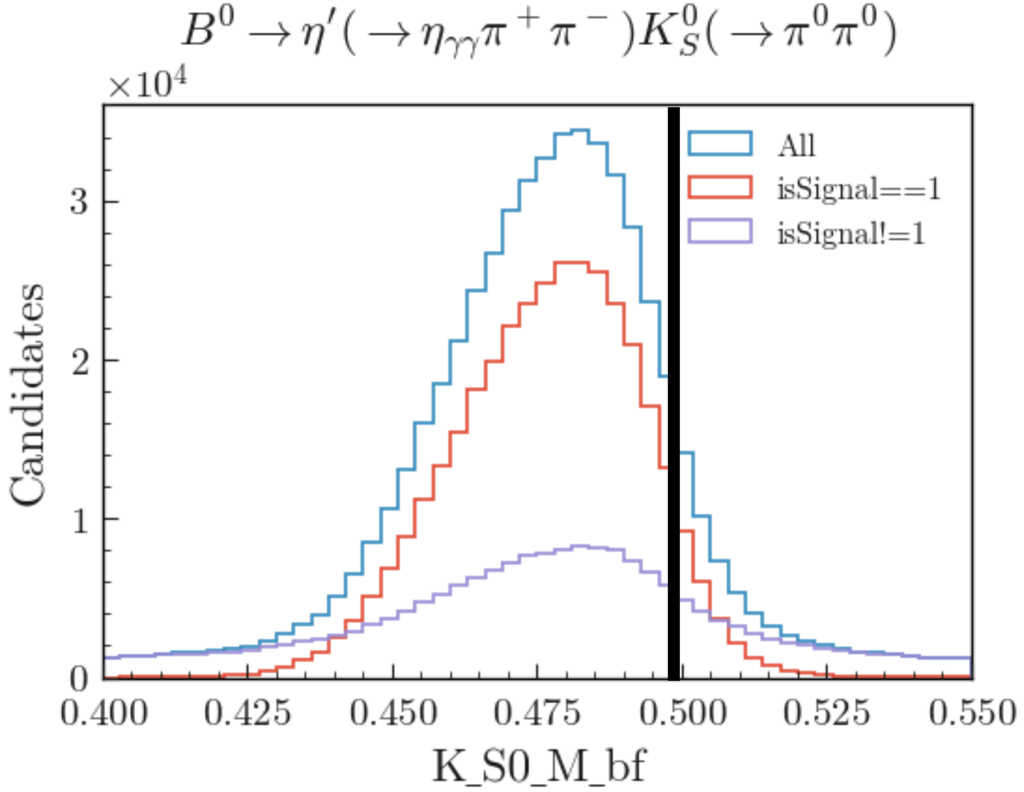
Summary

- Focus on $K_S^0 \to \pi^0\pi^0$ modes
- Reconstruction, selection and signal extraction fit

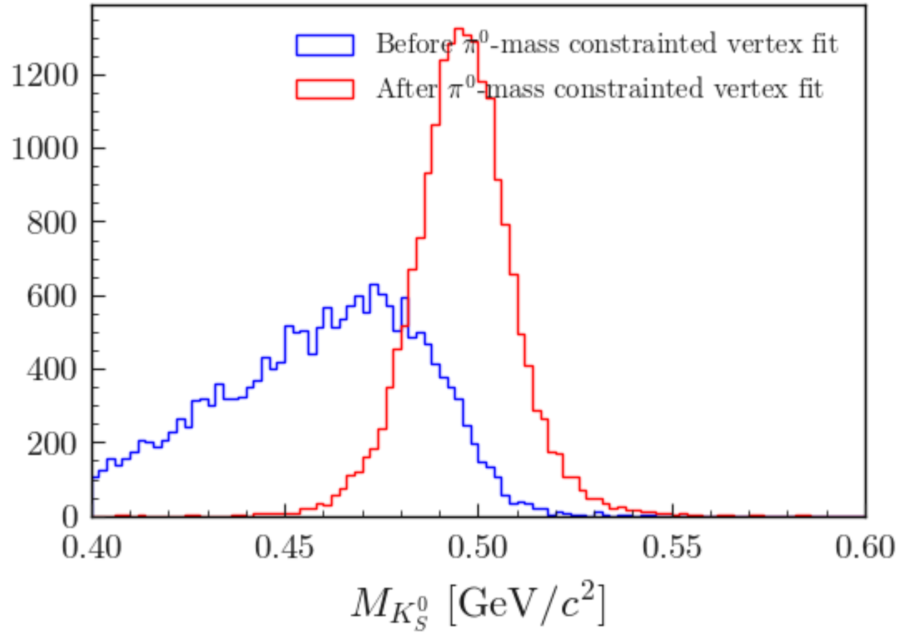
$$B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-} K^0_{\pi^+\pi^-}$$
$$B^0 \to \eta'_{\rho\gamma} K^0_{\pi^+\pi^-}$$
$$B^0 \to \eta'_{\eta(3\pi)\pi^+\pi^-} K^0_{\pi^+\pi^-}$$
$$\boxed{\begin{array}{c} B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-} K^0_{\pi^0\pi^0} \\ B^0 \to \eta'_{\rho\gamma} K^0_{\pi^0\pi^0} \end{array}}$$
$$B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-} K^0_L$$
$$B^0 \to \eta'_{\eta(3\pi)\pi^+\pi^-} K^0_L$$

$K_S^0 \to \pi^0\pi^0$ reconstruction

- Normally, we use the π^0 standard lists
  - Mass windows in the lists are optimized assuming IP production
- For $K_S^0 \to \pi^0\pi^0$, the π^0 is produced away from the IP
- This biases $M(\pi^0)$ and $M(K_S^0)$
  - $|\vec{p}(\gamma)|$ incorrect
  - Combinations of γ to reconstruct π^0, etc. incorrect

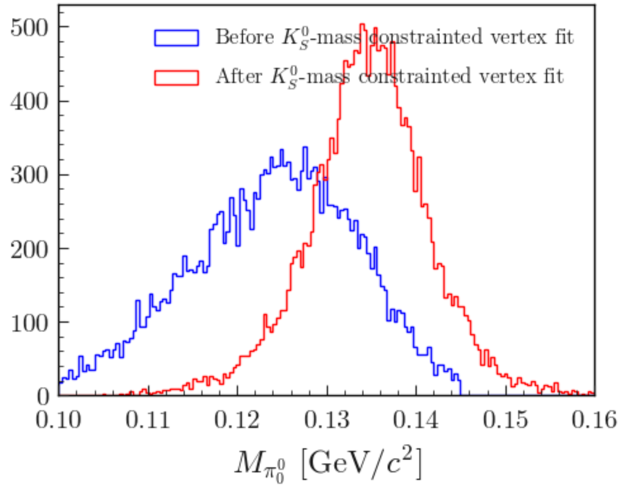


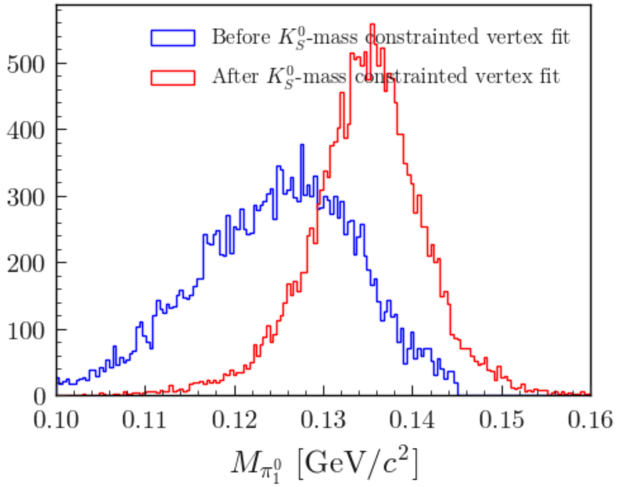
Unbiasing the K_S^0, π^0 mases



1. TreeFit K_S^0 with IP constraint and π^0 mass constraint
   - Must use shifted π^0 mass window initially
   - This unbiases the K_S^0 mass
2. TreeFit B^0 with IP constraint K_S^0 mass constraint
   - This unbiases the π^0 mass
3. TreeFit B^0 with IP constraint and K_S^0 and π^0 mass constraints

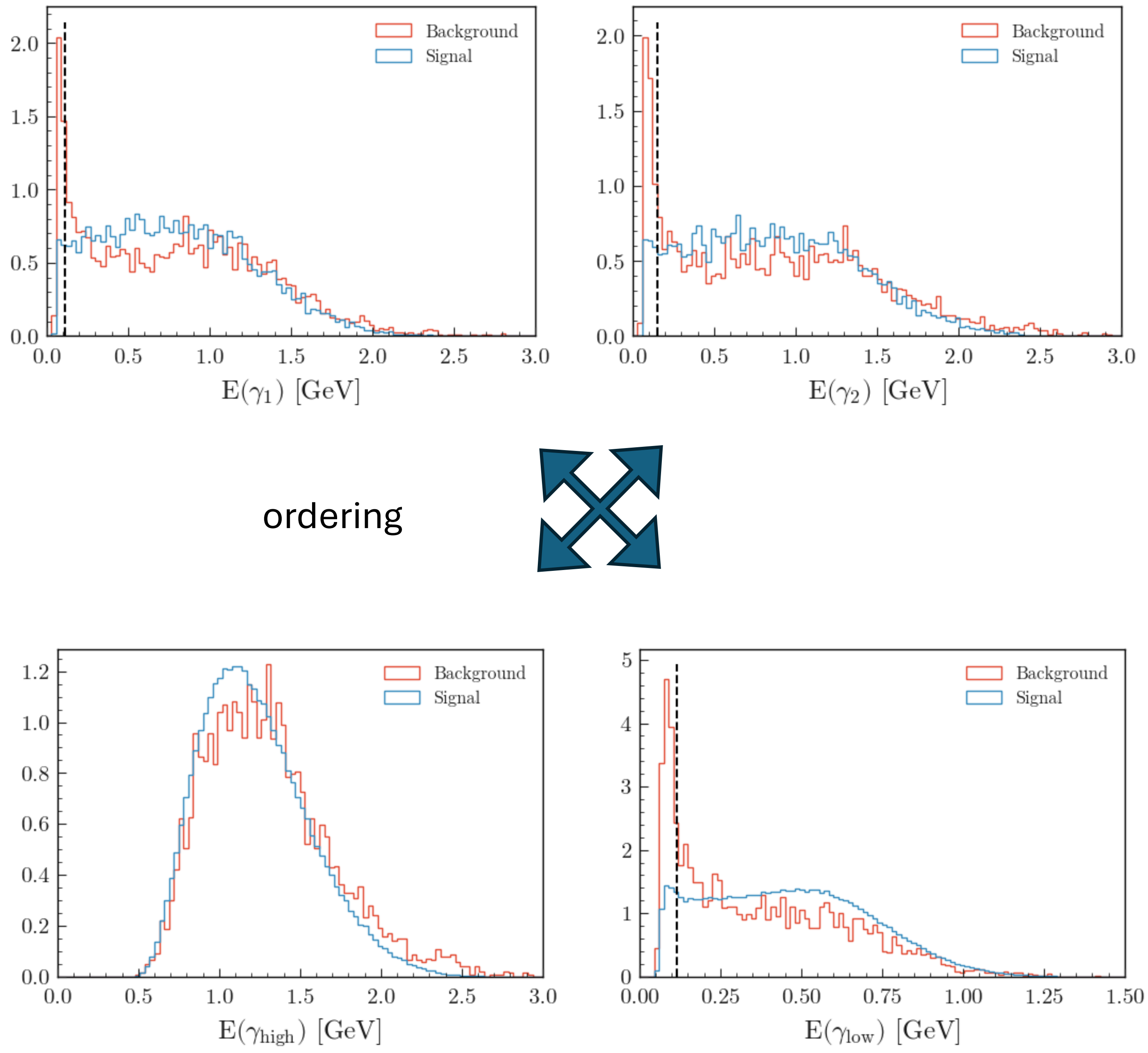
- Then, can apply mass windows on unbiased K_S^0 and π^0 masses





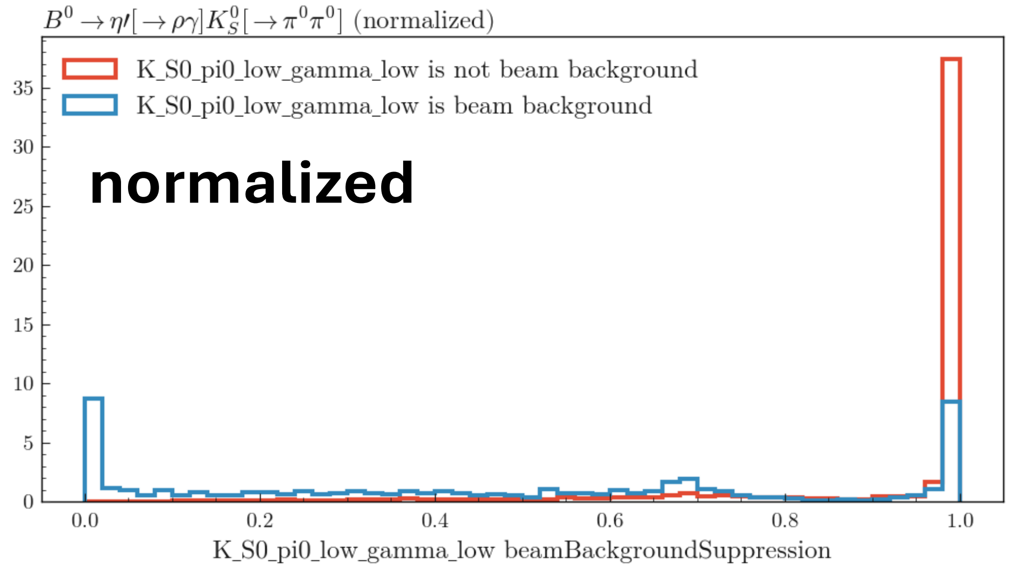
Ordering photons

- $K_S^0 \to \pi^0[\to \gamma\gamma]\pi^0\ [\to \gamma\gamma]$
- $\eta \to \gamma\gamma$
- Order γ, π^0 by energy
- Reduces complexity of optimization
- More intuitive π^0, γ variables



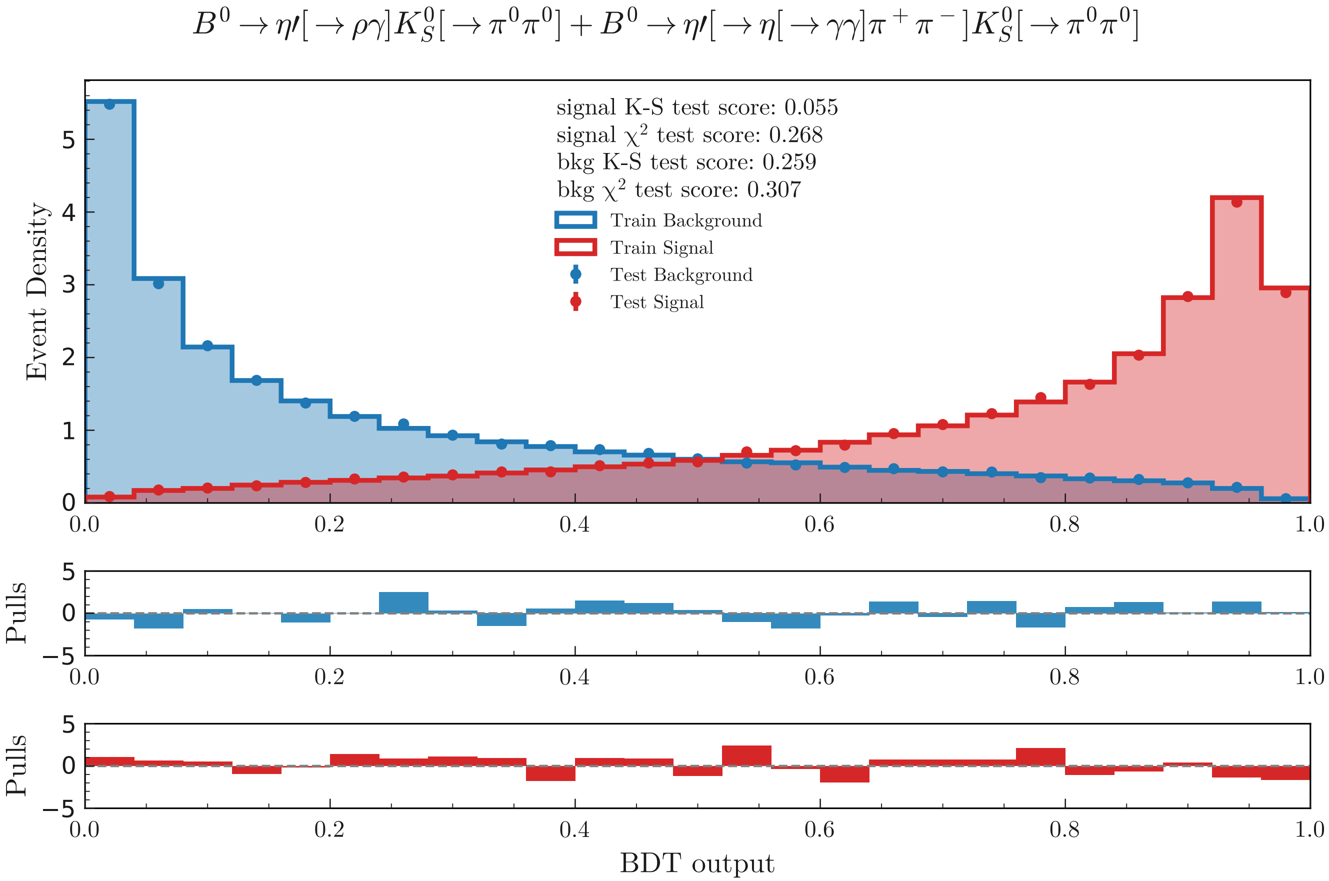
Photon preselection

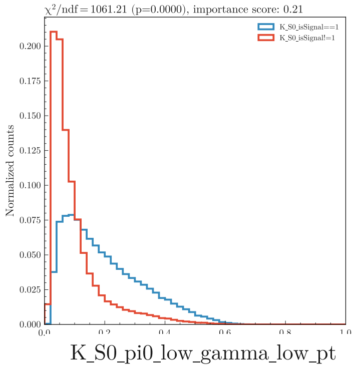
- 34% of K_S0_isSignal!=1 events have at least one beam background photon
- Of the 34%, 79% of them have a beam background photon as the less energetic photon from the less energetic pi0
- Loose cut on photon MVAs (fakePhotonSuppression and beamBackgroundSuppresion) > 0.1
  - 99% sig eff, 18% bkg rej

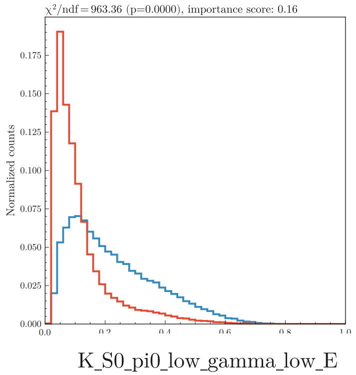


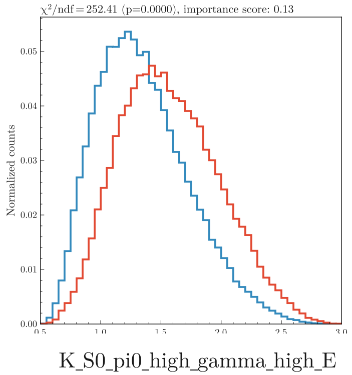
KS00 BDT

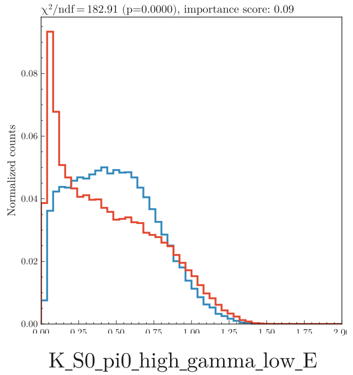
- Train xgboost BDT to select true $K_S^0 \to \pi^0\pi^0$ using K_S^0 and π^0 variables
    - Kinematics, flight distance, etc.
- Signal sample: signal events with truth-matched K_S^0
- Background sample: signal events with no truth-matched K_S^0 (K_S0_isSignal!=1)
- Choose loose cut: 99% signal efficient, 40% bkg rejecting





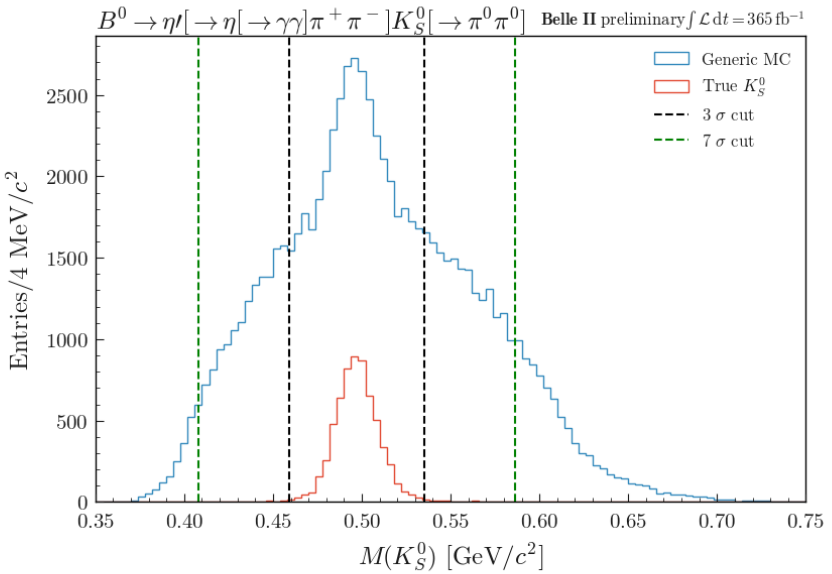




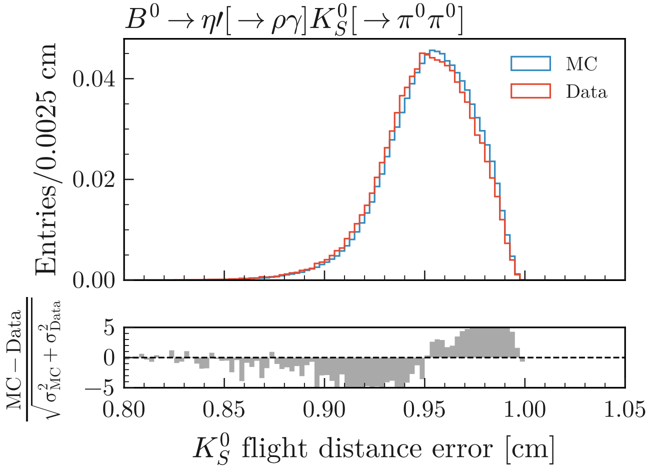


Data/MC comparison in $M\left(K_S^0\right)$ sidebands

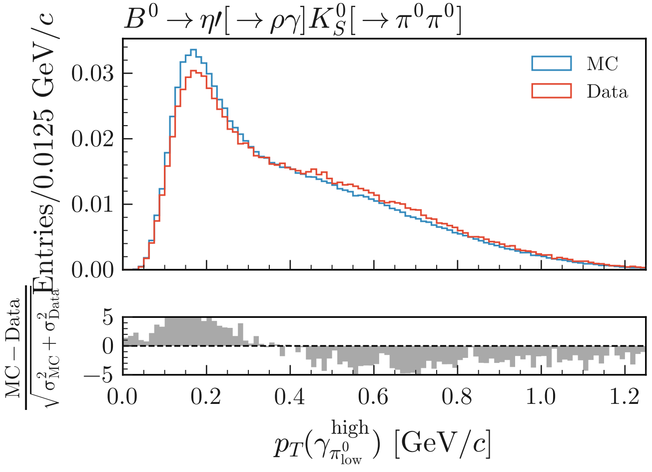
- Validate KS00 BDT variables in $M\left(K_S^0\right)$ sidebands
- Shapes are reasonable



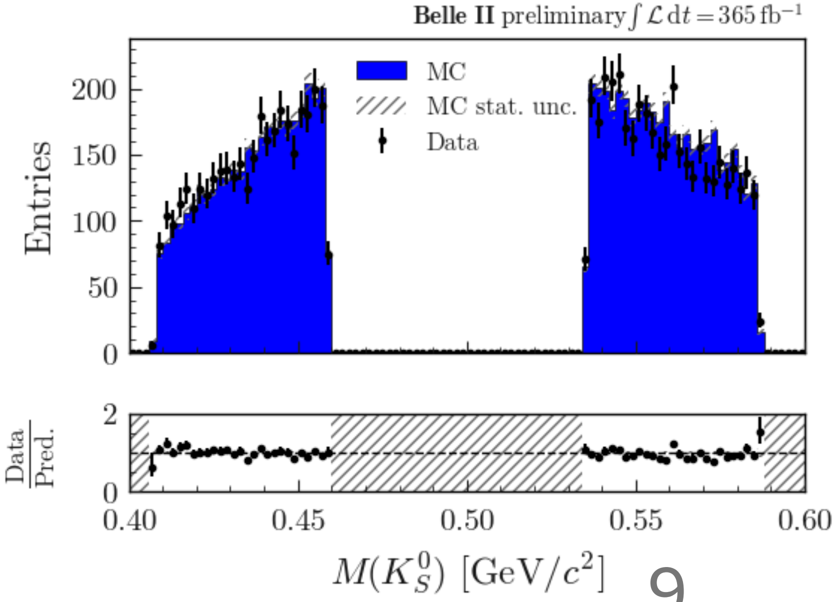
$M(K_S^0)$ sideband



$M(K_S^0)$ sideband



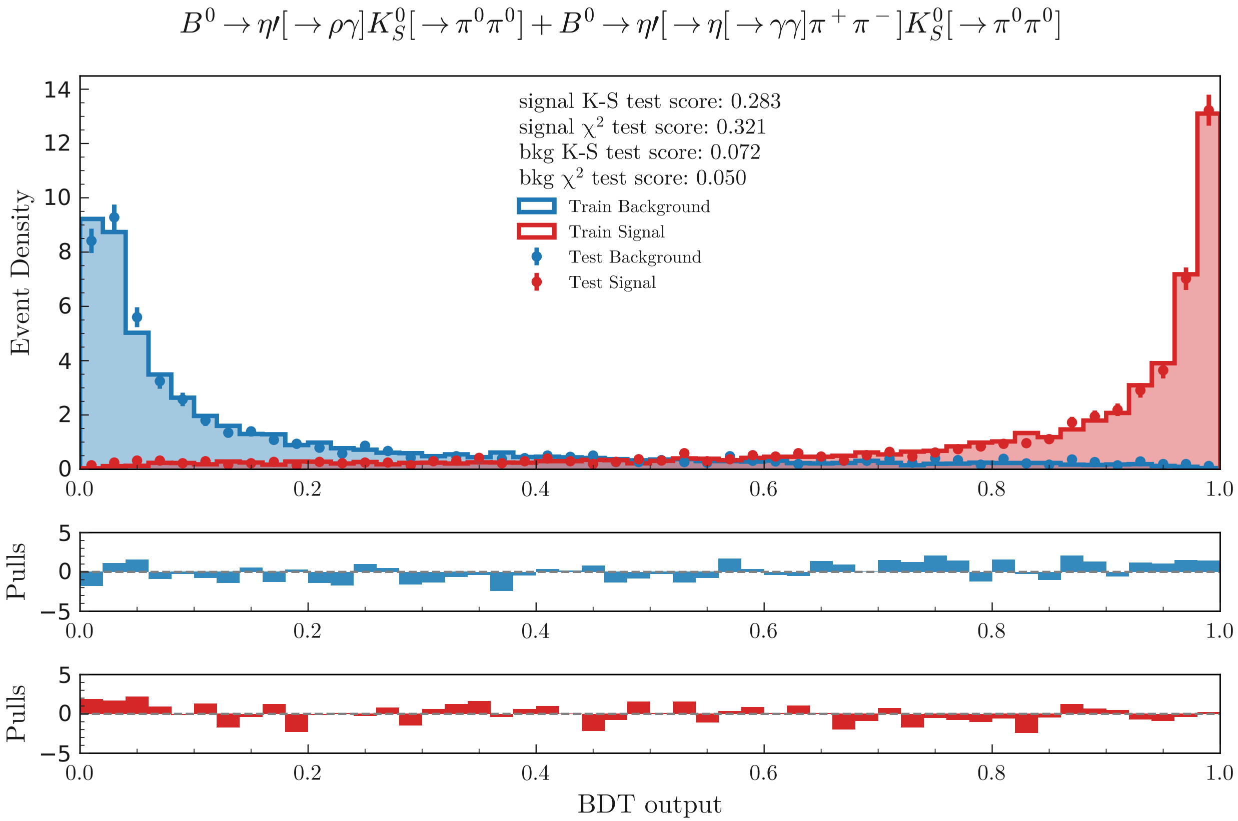
$B^0 \to \eta'[\to \eta[\to \gamma\gamma]\pi^+\pi^-]K_S^0[\to \pi^0\pi^0]$

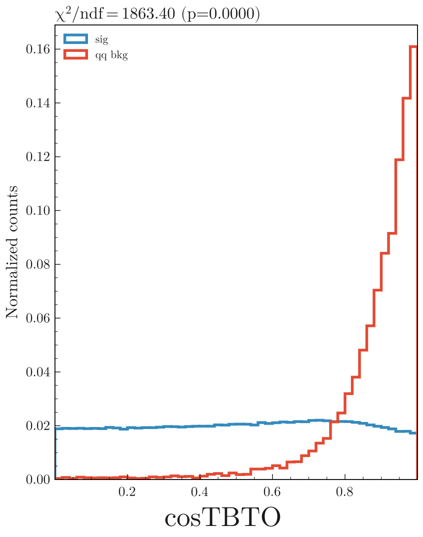


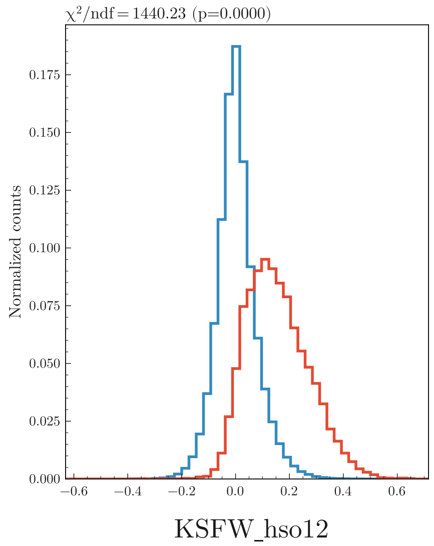
Normalized to area

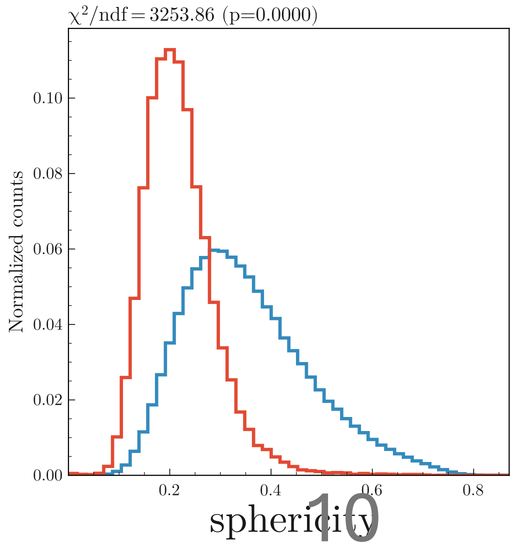
CS BDT

- Dominant background is from continuum
- Train with off resonance data
  - Data/MC and offres/onres agree
- Can train one BDT for both modes
- Signal: TM signal events
- Background: udsct events
- Most important variables:
  - cosTBTO
  - KSFW_hso12
  - sphericity



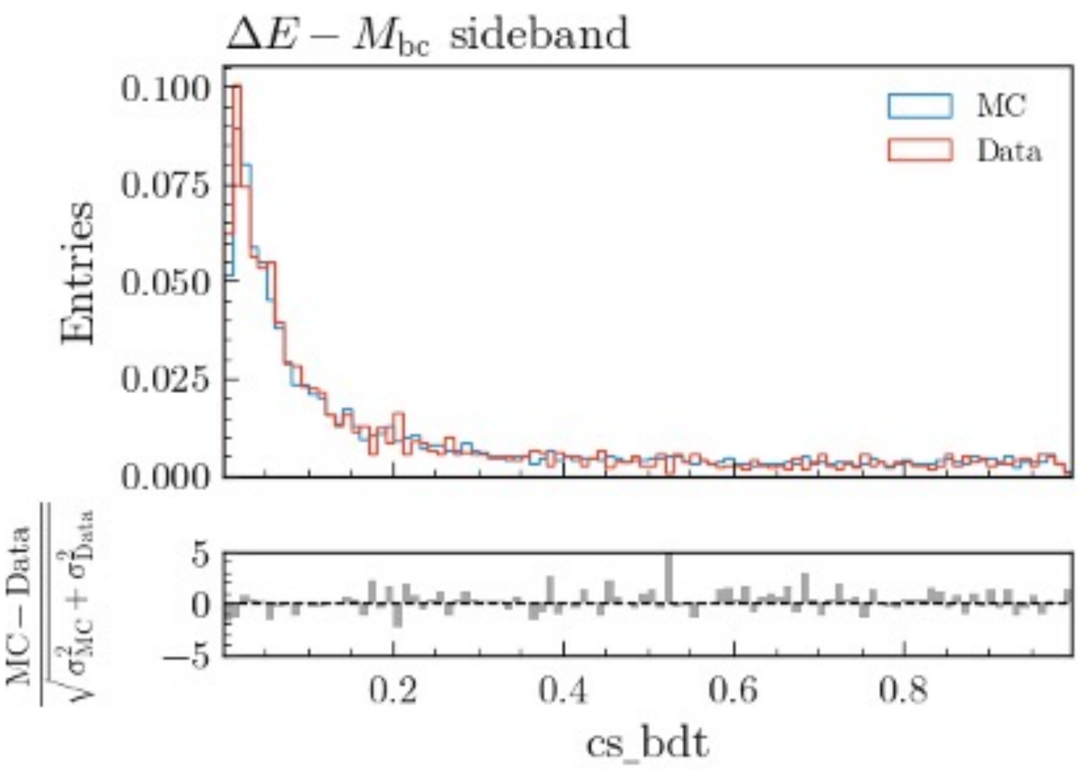




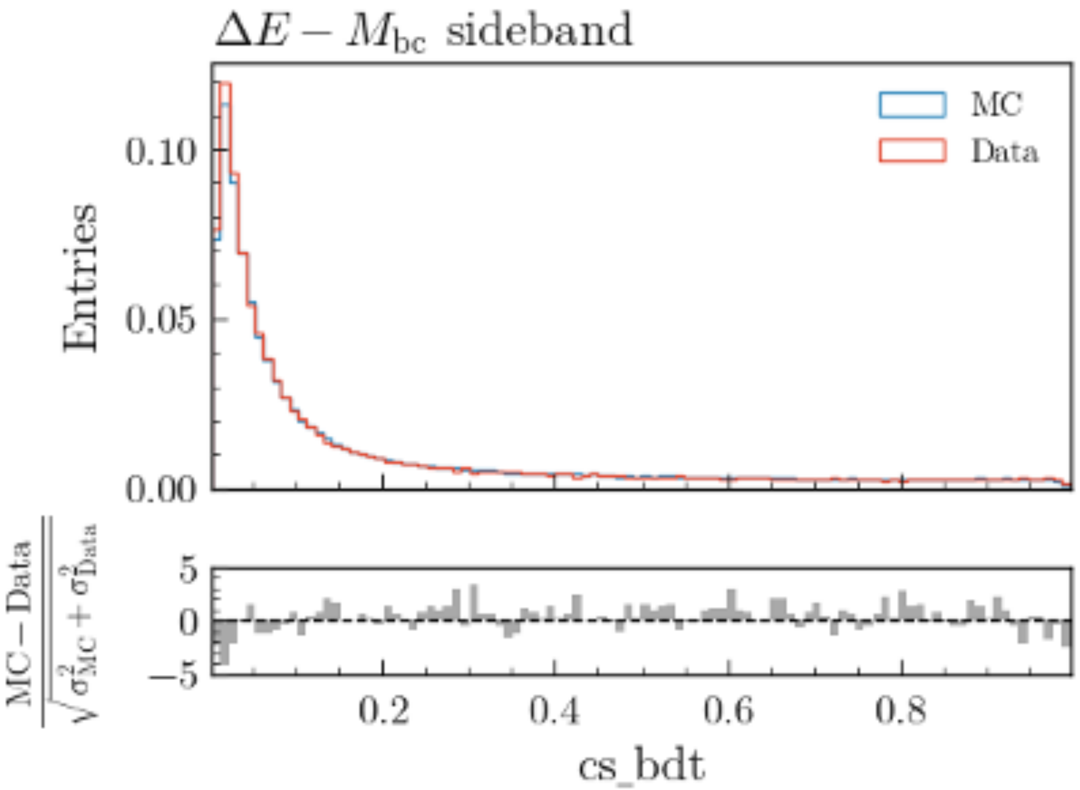


CS output in sidebands

$B^0 \to \eta'[\to \eta[\to \gamma\gamma]\pi^+\pi^-]K_S^0[\to \pi^0\pi^0]$



$B^0 \to \eta'[\to \rho\gamma]K_S^0[\to \pi^0\pi^0]$



Joint optimization

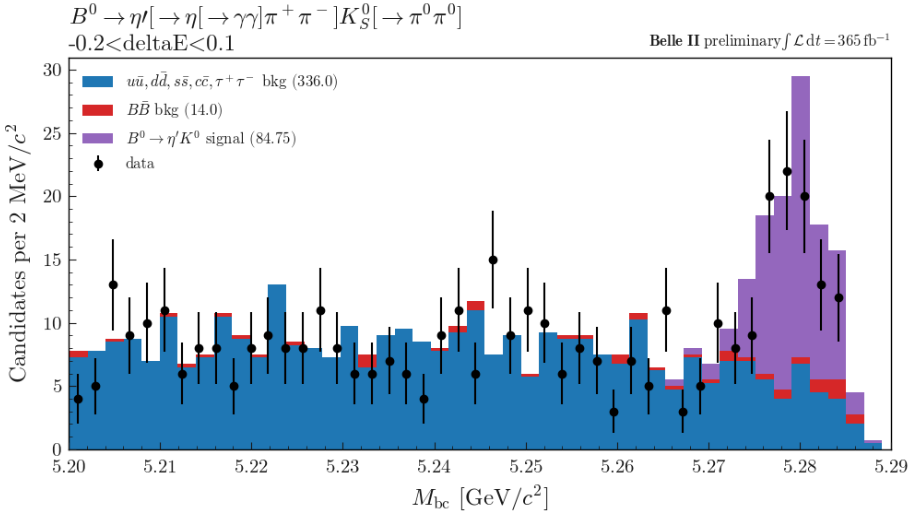
- Optimize mass windows + $E\left(\gamma_{\eta^{(\prime)}}\right)$ + CS BDT simultaneously using optuna
- **Can improve figure of merit by 8.3%, 9.8% for ch4, ch6 respectively compared to standard optimization in series**
- Optimizer favors different window widths*
  - Ch4: $M(\eta)$: $3\ \sigma$, $M(\eta')$: $2.5\ \sigma$, $M\left(K_S^0\right)$: $2.5\ \sigma$
  - Ch6: $M(\rho^0)$: $2\ \sigma$, $M(\eta')$: $1\ \sigma$, $M\left(K_S^0\right)$: $3\ \sigma$

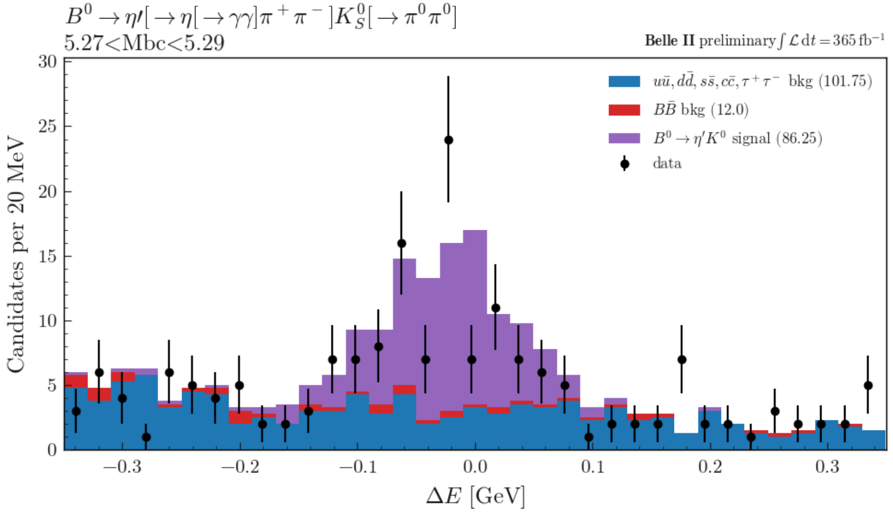
*
- σ is a bit misleading due to large tail
- σ is calculated from weighted average of Gaussians (see backup)

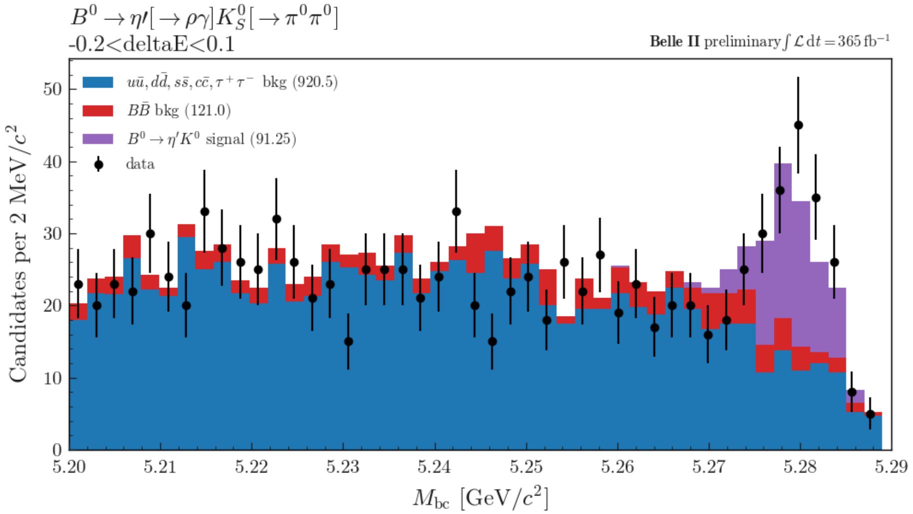
Channel	Change in signal yield in SR [%]	Change in background yield in SR [%]	Change in FOM in SR [%]
ch4	+15.2	+8.1	+8.3
ch6	-2.1	-34.4	+9.8

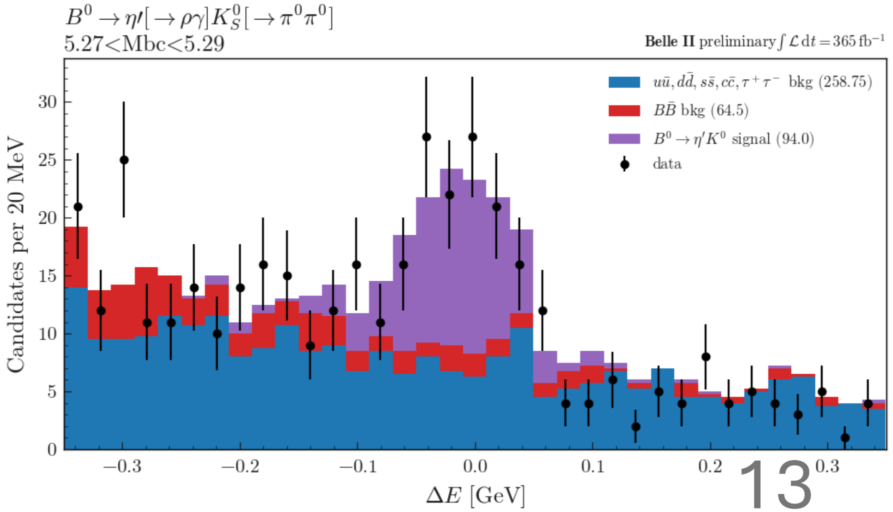
After all selection

- Use KS00 BDT score as BCS
- Yields on par with BaBar for ch4, less for ch6
- Both channels have much better purity than BaBar







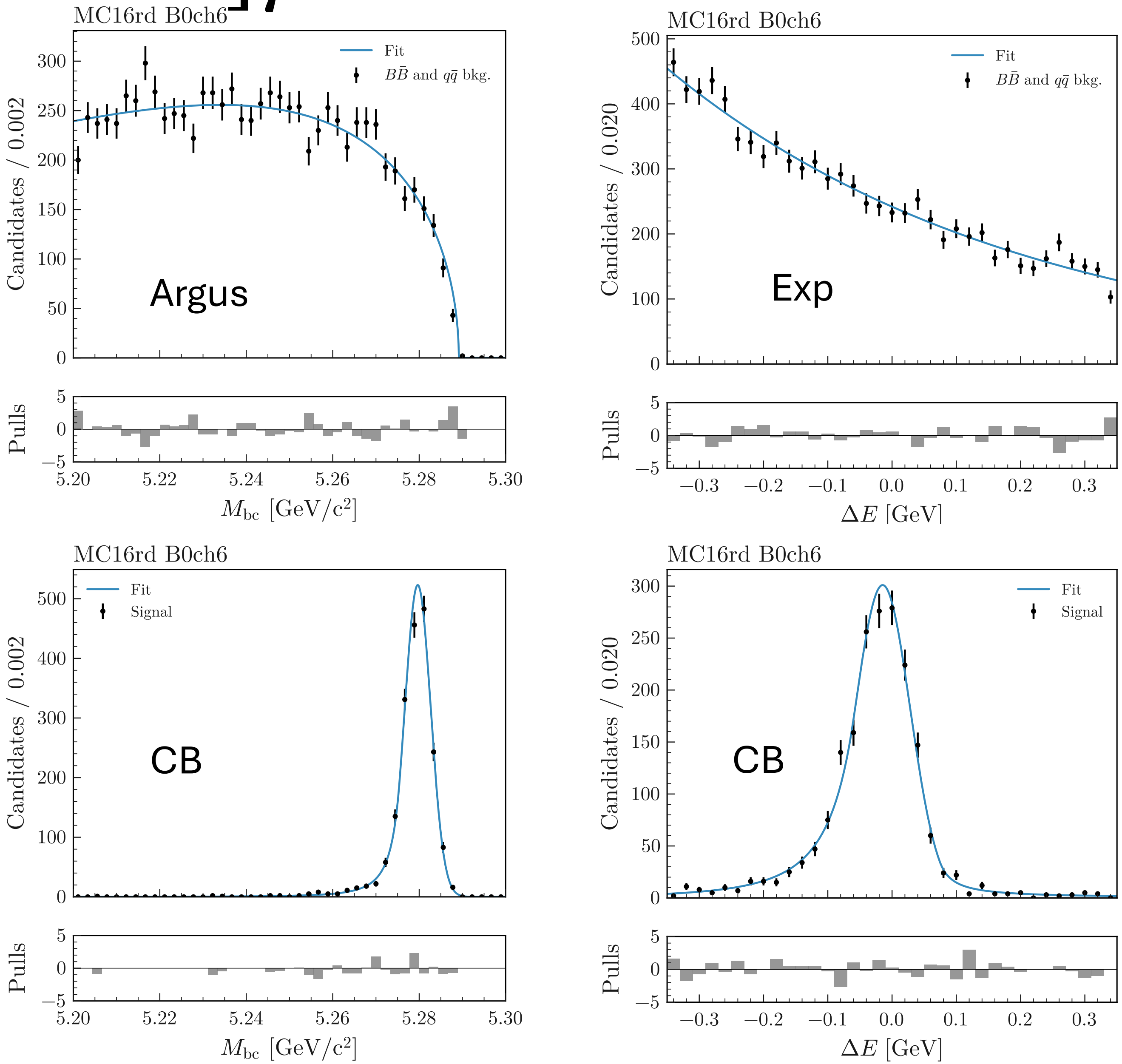


Signal definition

- Consider a candidate from a signal event to be truth-matched if the tracks are truth matched – ignore incorrect clusters
- They don’t improve/diminish the vertex resolution

$\eta' \to \rho^0[\to \pi^+\pi^-]\gamma$

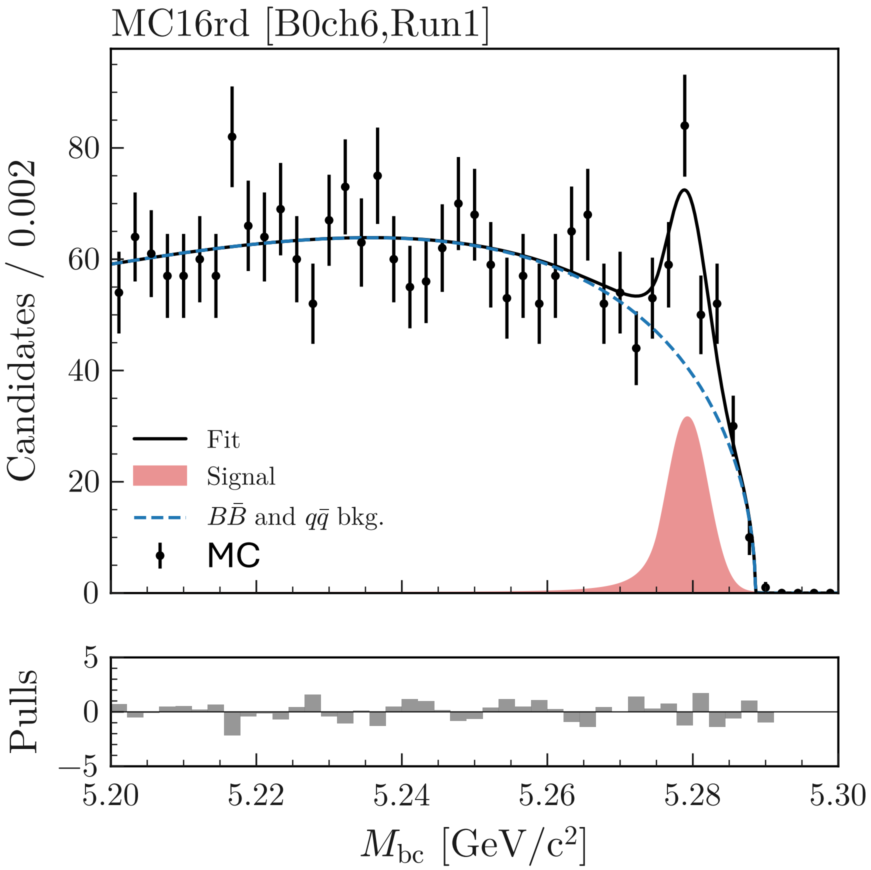
- Model $B\bar{B}$ and $q\bar{q}$ bkg together

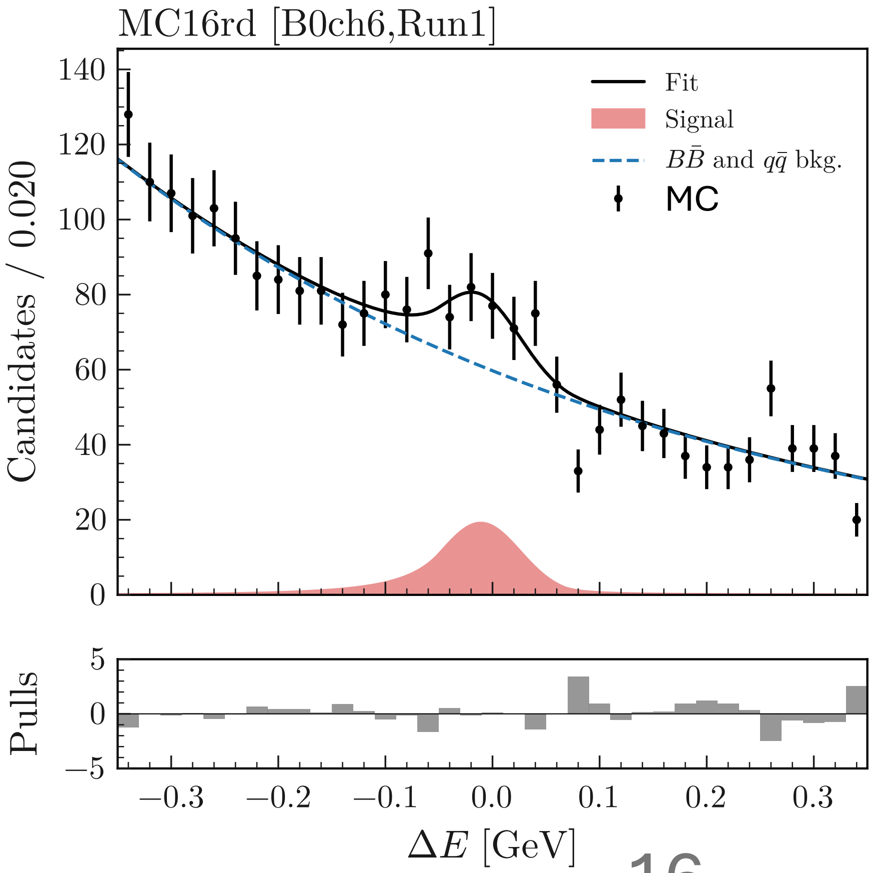


Ch6 ($\eta' \to \rho^0[\to \pi^+\pi^-]\gamma$)

- Fix signal PDF tails
- Validated with pure and bootstrapped toys without significant bias

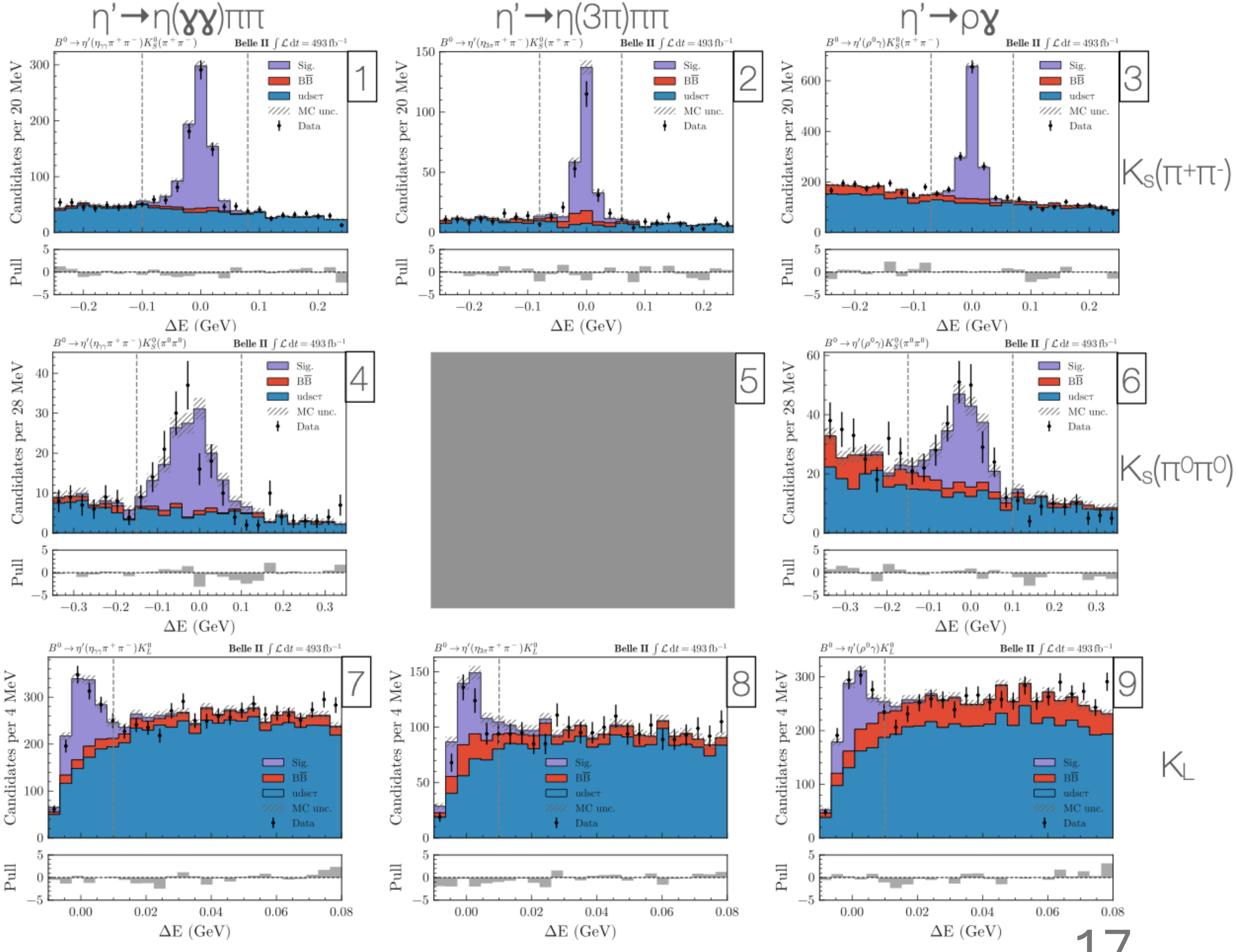
Proc16: 365/fb





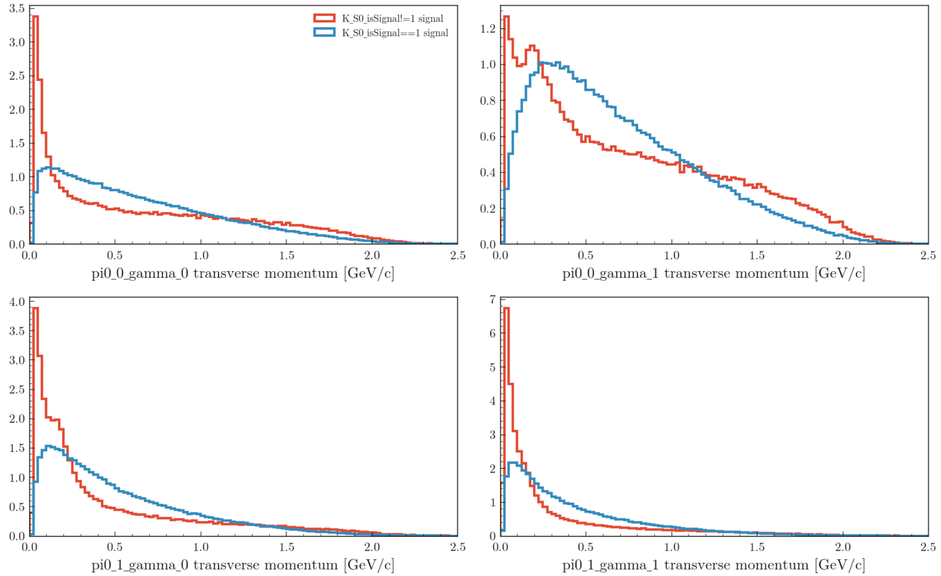
Summary

- Selection of $K_S^0 \to \pi^0\pi^0$ modes optimized
- Other modes selected in parallel
- ~3000 signal events
  - ~3500 in Belle
  - ~2500 in BaBar

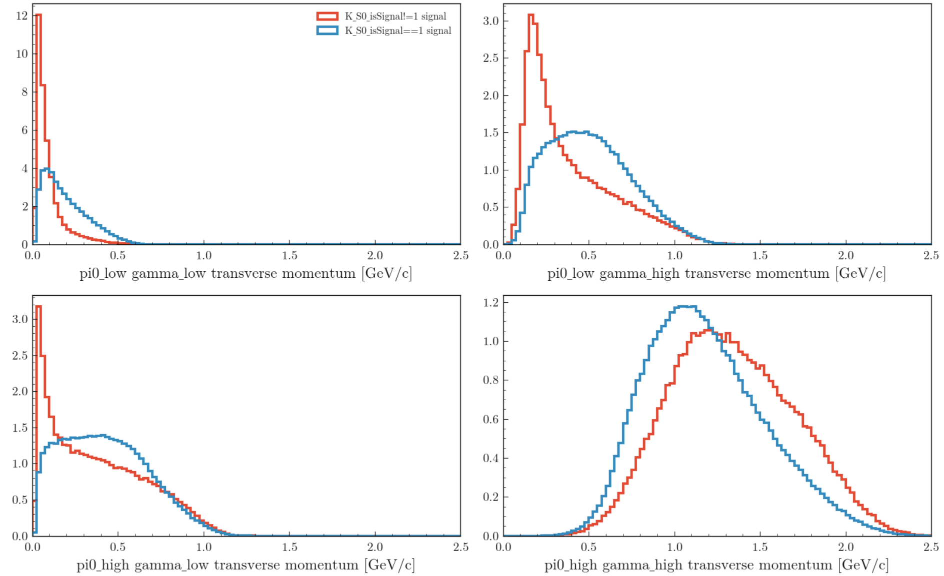


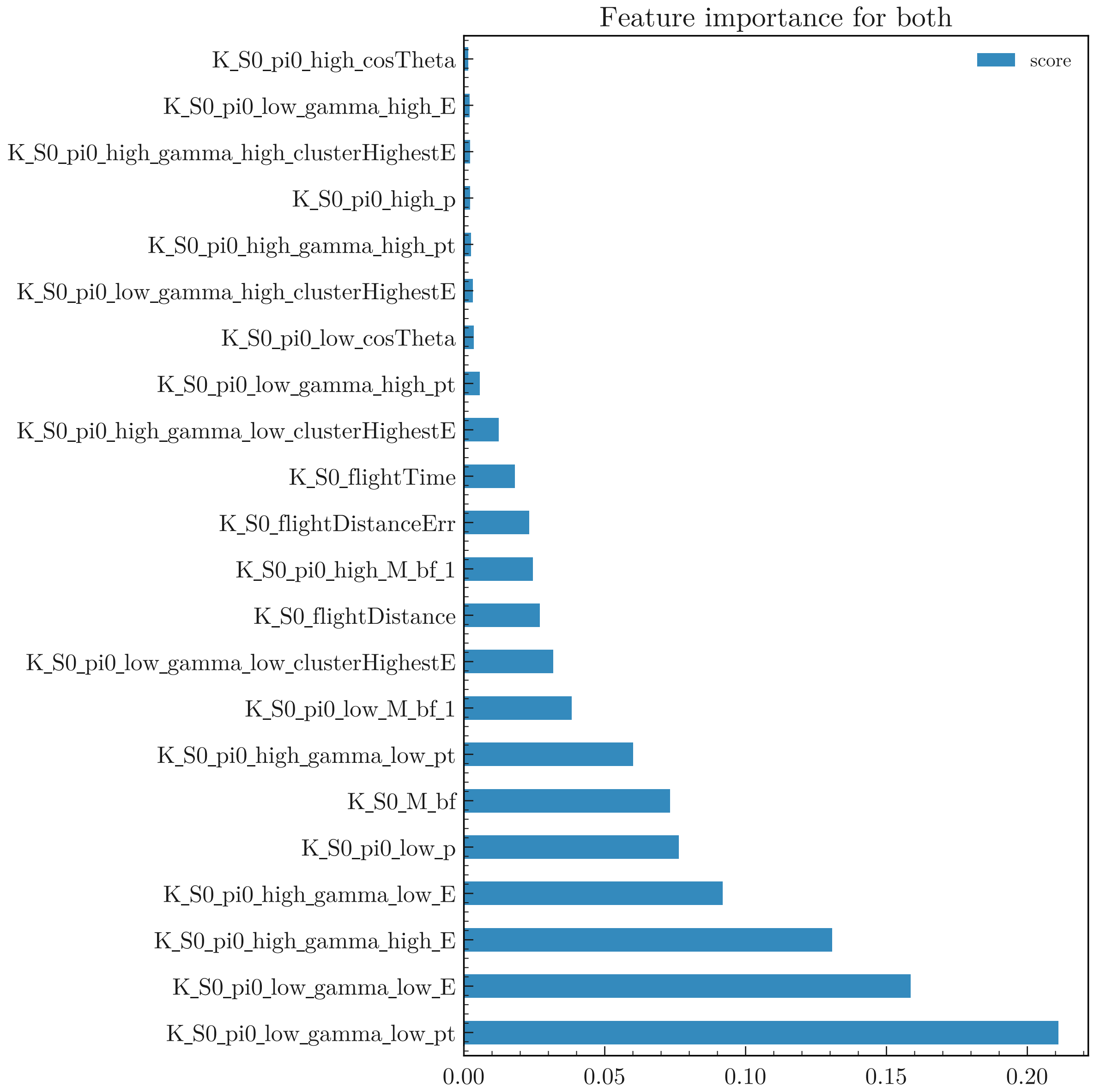
Backup

Photon, pi0 ordering

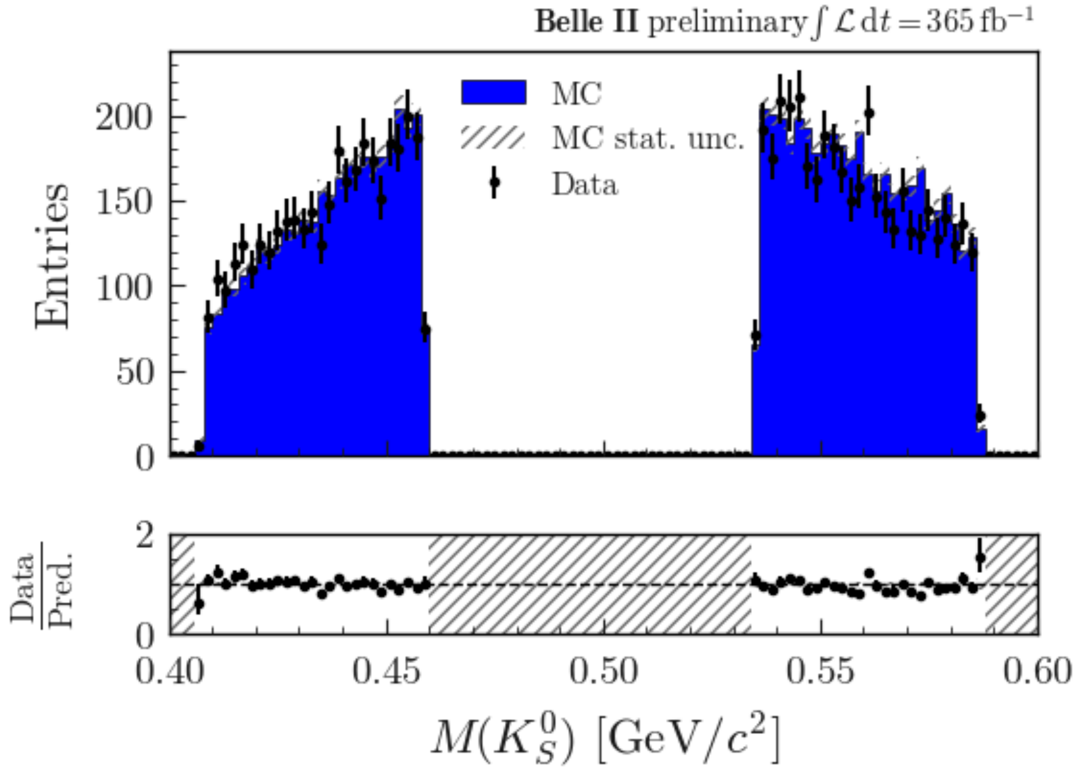


Photon, pi0 ordering

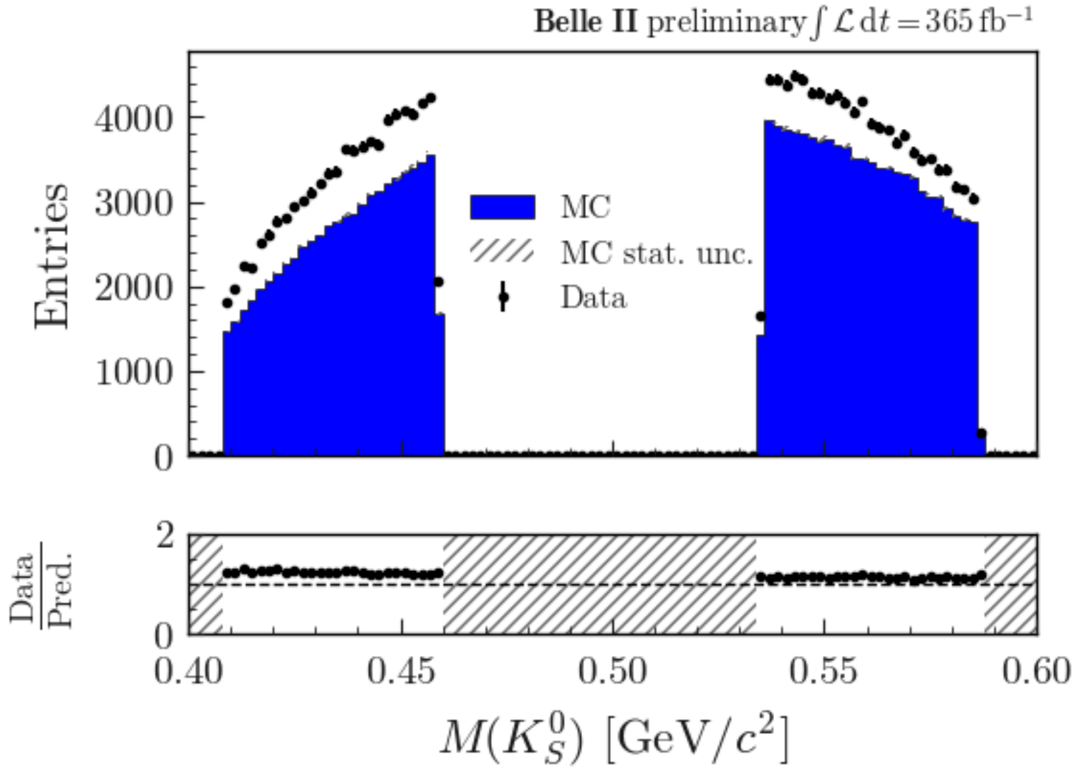



Feature importance for both
score
K_S0_pi0_high_cosTheta
K_S0_pi0_low_gamma_high_E
K_S0_pi0_high_gamma_high_clusterHighestE
K_S0_pi0_high_p
K_S0_pi0_high_gamma_high_pt
K_S0_pi0_low_gamma_high_clusterHighestE
K_S0_pi0_low_cosTheta
K_S0_pi0_low_gamma_high_pt
K_S0_pi0_high_gamma_low_clusterHighestE
K_S0_flightTime
K_S0_flightDistanceErr
K_S0_pi0_high_M_bf_1
K_S0_flightDistance
K_S0_pi0_low_gamma_low_clusterHighestE
K_S0_pi0_low_M_bf_1
K_S0_pi0_high_gamma_low_pt
K_S0_M_bf
K_S0_pi0_low_p
K_S0_pi0_high_gamma_low_E
K_S0_pi0_high_gamma_high_E
K_S0_pi0_low_gamma_low_E
K_S0_pi0_low_gamma_low_pt
0.00
0.05
0.10
0.15
0.20

$B^0 \to \eta'[\to \eta[\to \gamma\gamma]\pi^+\pi^-]K_S^0[\to \pi^0\pi^0]$



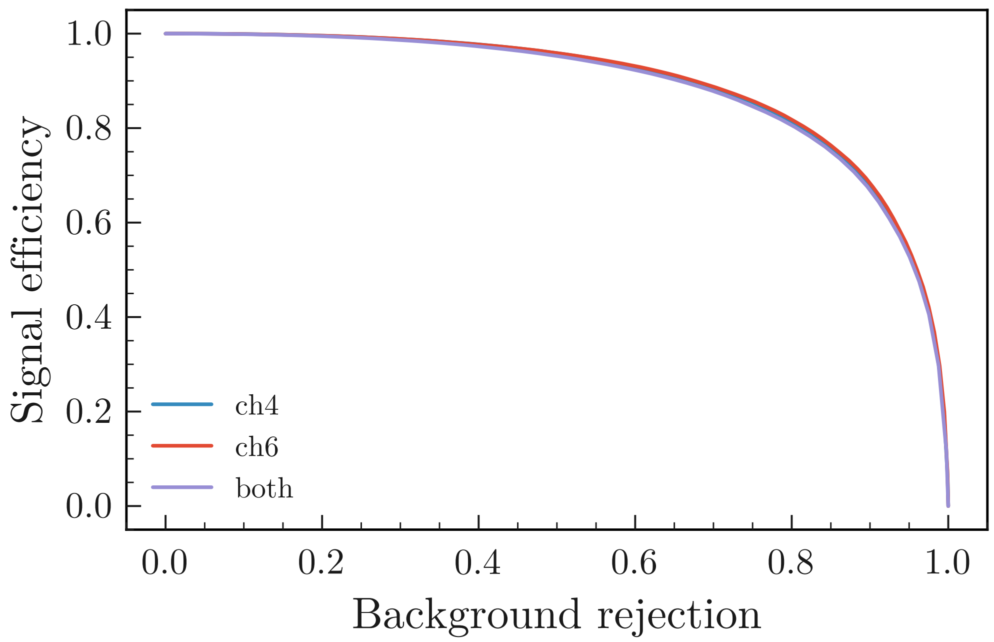
$B^0 \to \eta'[\to \rho\gamma]K_S^0[\to \pi^0\pi^0]$



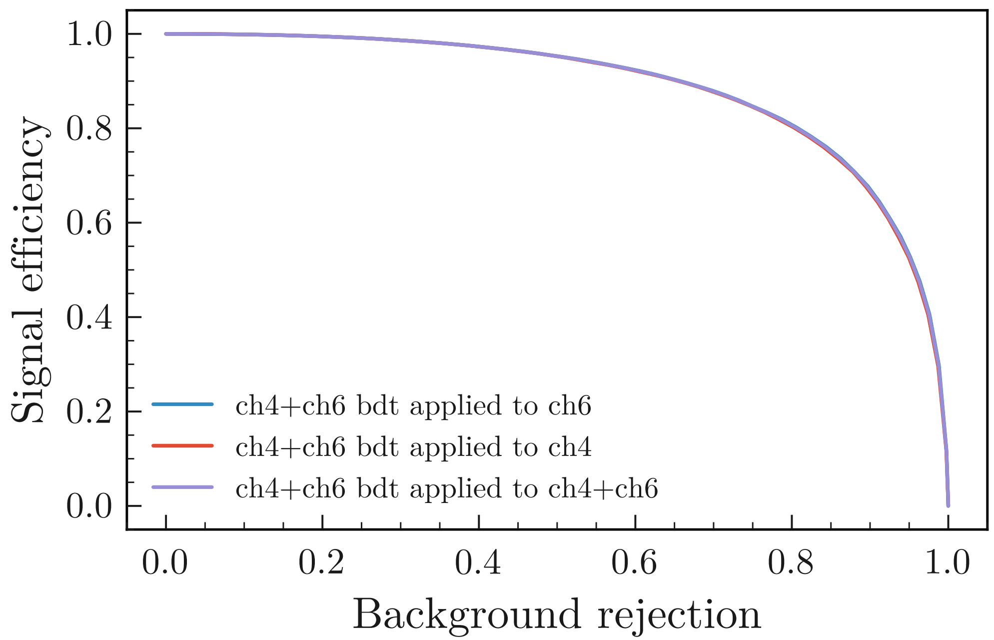
MC scale factor: 0.25

ROC curves for different BDT trainings

ch4 training applied to ch4	ch4 training applied to ch6	ch4 training applied to ch4+ch6
ch6 training applied to ch4	ch6 training applied to ch6	ch6 training applied to ch4+ch6
ch4+ch6 training applied to ch4	ch4+ch6 training applied to ch6	ch4+ch6 training applied to ch4+ch6

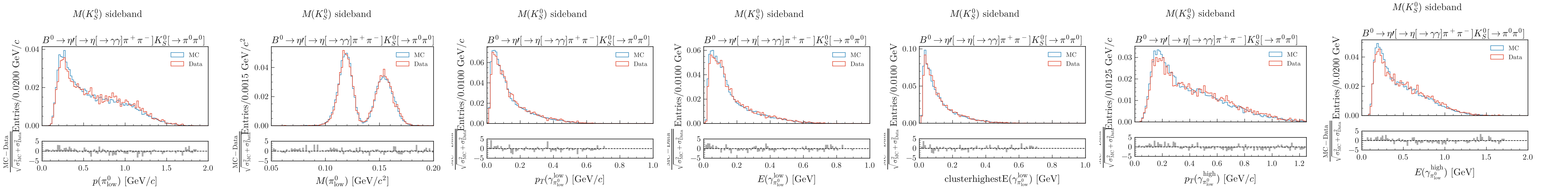


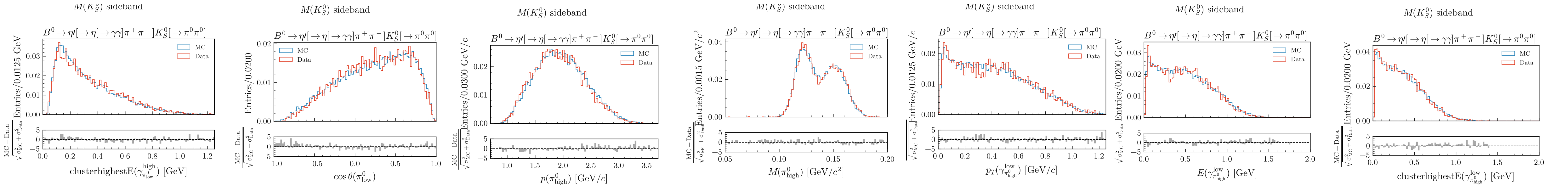
"On diagonal"

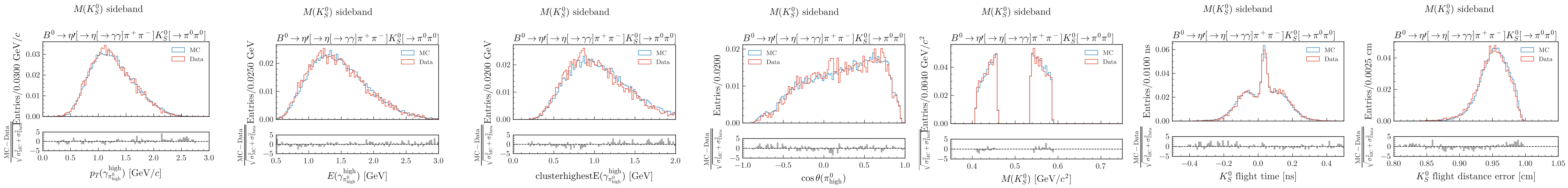


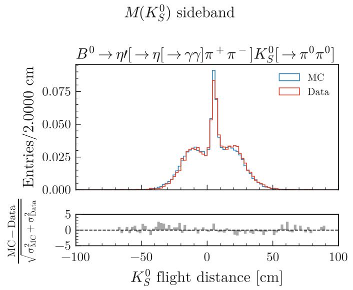
"bottom row"

ch4

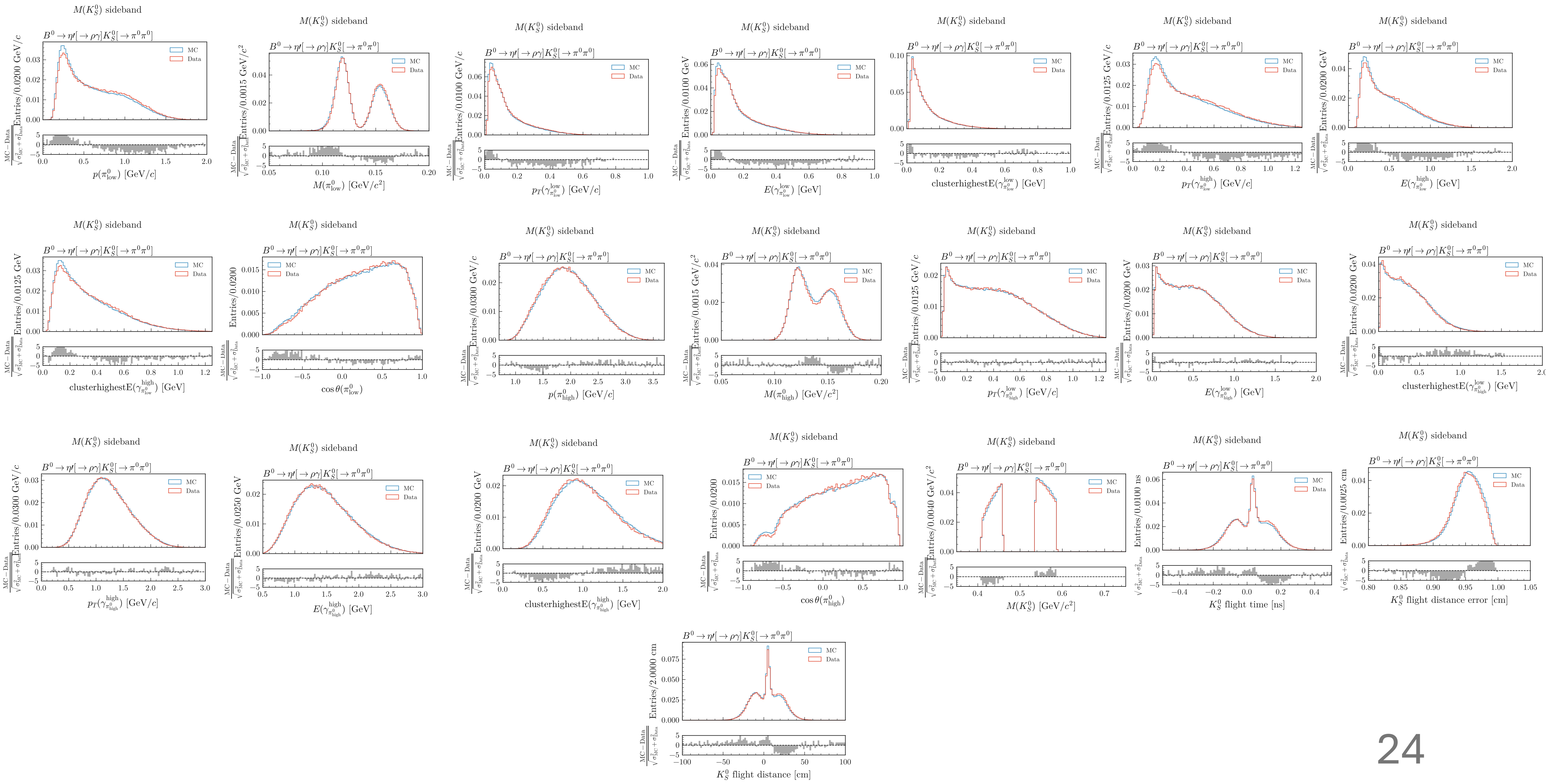

M(K_S^0) sideband
B^0 → η′[→ η[→ γγ]π^+π^−]K_S^0[→ π^0π^0]
MC
Data
p(π^0_low) [GeV/c]
M(π^0_low) [GeV/c^2]
p_T(γ^low_π^0_low) [GeV/c]
E(γ^low_π^0_low) [GeV]
clusterhighestE(γ^low_π^0_low) [GeV]
p_T(γ^high_π^0_low) [GeV/c]
E(γ^high_π^0_low) [GeV]


M(K_S^0) sideband
B^0 → η′[→ η[→ γγ]π^+π^−]K_S^0[→ π^0π^0]
MC
Data
clusterhighestE(γ^high_π^0_low) [GeV]
cos θ(π^0_low)
p(π^0_high) [GeV/c]
M(π^0_high) [GeV/c^2]
p_T(γ^low_π^0_high) [GeV/c]
E(γ^low_π^0_high) [GeV]
clusterhighestE(γ^low_π^0_high) [GeV]


M(K_S^0) sideband
B^0 → η′[→ η[→ γγ]π^+π^−]K_S^0[→ π^0π^0]
MC
Data
p_T(γ^high_π^0_high) [GeV/c]
E(γ^high_π^0_high) [GeV]
clusterhighestE(γ^high_π^0_high) [GeV]
cos θ(π^0_high)
M(K_S^0) [GeV/c^2]
K_S^0 flight time [ns]
K_S^0 flight distance error [cm]

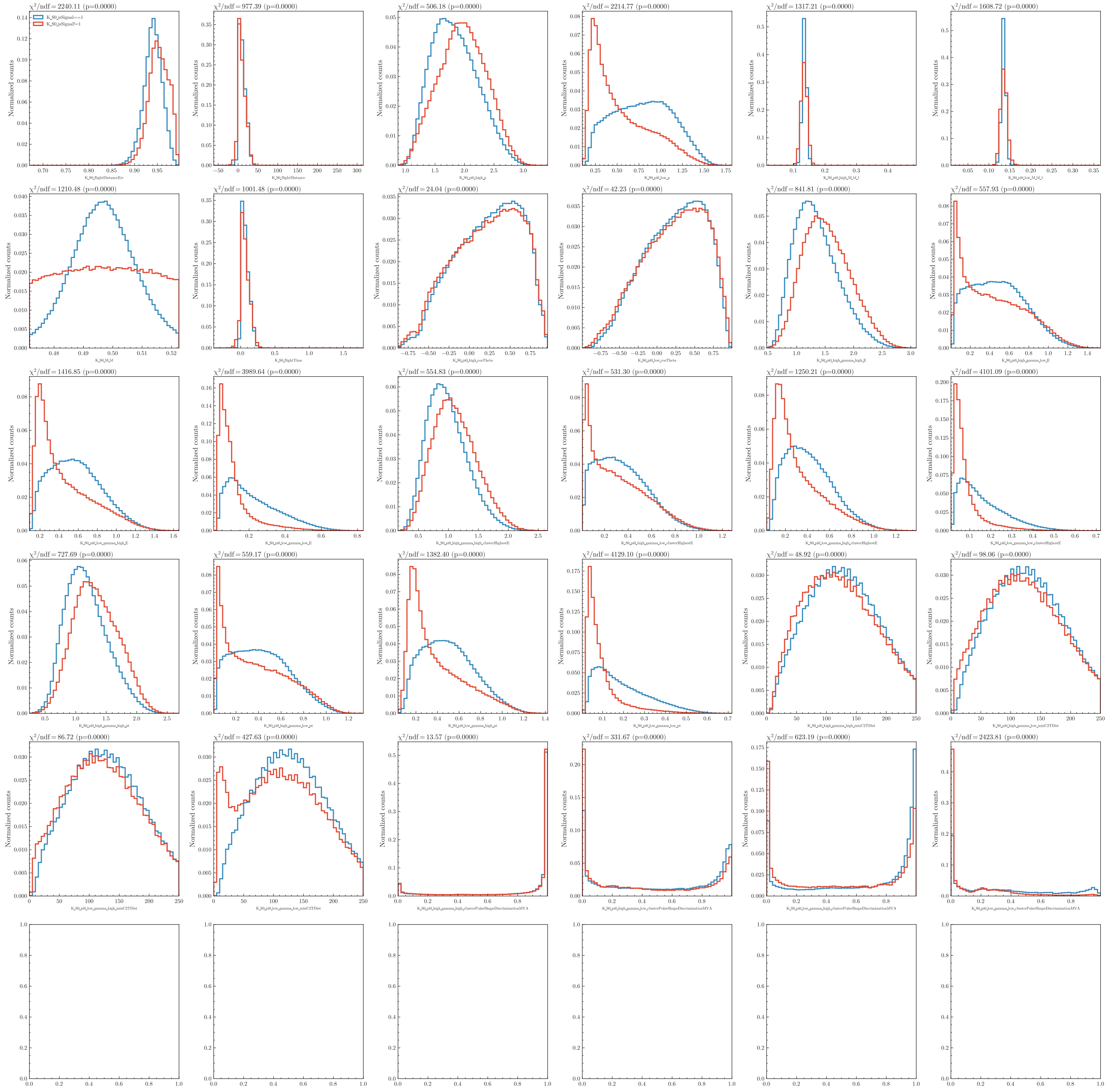

M(K_S^0) sideband
B^0 → η′[→ η[→ γγ]π^+π^−]K_S^0[→ π^0π^0]
MC
Data
K_S^0 flight distance [cm]

ch6



$M(K_S^0)$ sideband
$B^0 \to \eta\prime[\to \rho\gamma]K_S^0[\to \pi^0\pi^0]$
MC
Data
Entries/0.0200 GeV/c
$\frac{\mathrm{MC-Data}}{\sqrt{\sigma^2_{\mathrm{MC}}+\sigma^2_{\mathrm{Data}}}}$
$p(\pi^0_{\mathrm{low}})$ [GeV/c]
Entries/0.0015 GeV/c^2
$M(\pi^0_{\mathrm{low}})$ [GeV/c^2]
Entries/0.0100 GeV/c
$p_T(\gamma^{\mathrm{low}}_{\pi^0_{\mathrm{low}}})$ [GeV/c]
Entries/0.0100 GeV
$E(\gamma^{\mathrm{low}}_{\pi^0_{\mathrm{low}}})$ [GeV]
clusterhighestE($\gamma^{\mathrm{low}}_{\pi^0_{\mathrm{low}}}$) [GeV]
Entries/0.0125 GeV/c
$p_T(\gamma^{\mathrm{high}}_{\pi^0_{\mathrm{low}}})$ [GeV/c]
Entries/0.0200 GeV
$E(\gamma^{\mathrm{high}}_{\pi^0_{\mathrm{low}}})$ [GeV]
Entries/0.0125 GeV
clusterhighestE($\gamma^{\mathrm{high}}_{\pi^0_{\mathrm{low}}}$) [GeV]
Entries/0.0200
$\cos\theta(\pi^0_{\mathrm{low}})$
Entries/0.0300 GeV/c
$p(\pi^0_{\mathrm{high}})$ [GeV/c]
Entries/0.0015 GeV/c^2
$M(\pi^0_{\mathrm{high}})$ [GeV/c^2]
Entries/0.0125 GeV/c
$p_T(\gamma^{\mathrm{low}}_{\pi^0_{\mathrm{high}}})$ [GeV/c]
Entries/0.0200 GeV
$E(\gamma^{\mathrm{low}}_{\pi^0_{\mathrm{high}}})$ [GeV]
Entries/0.0200 GeV
clusterhighestE($\gamma^{\mathrm{low}}_{\pi^0_{\mathrm{high}}}$) [GeV]
Entries/0.0300 GeV/c
$p_T(\gamma^{\mathrm{high}}_{\pi^0_{\mathrm{high}}})$ [GeV/c]
Entries/0.0250 GeV
$E(\gamma^{\mathrm{high}}_{\pi^0_{\mathrm{high}}})$ [GeV]
Entries/0.0200 GeV
clusterhighestE($\gamma^{\mathrm{high}}_{\pi^0_{\mathrm{high}}}$) [GeV]
Entries/0.0200
$\cos\theta(\pi^0_{\mathrm{high}})$
Entries/0.0040 GeV/c^2
$M(K_S^0)$ [GeV/c^2]
Entries/0.0100 ns
K_S^0 flight time [ns]
Entries/0.0025 cm
K_S^0 flight distance error [cm]
Entries/2.0000 cm
K_S^0 flight distance [cm]

ch4+ch6



$B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-} K^0_{\pi^+\pi^-}$

$B^0 \to \eta'_{\rho\gamma} K^0_{\pi^+\pi^-}$

$B^0 \to \eta'_{\eta(3\pi)\pi^+\pi^-} K^0_{\pi^+\pi^-}$

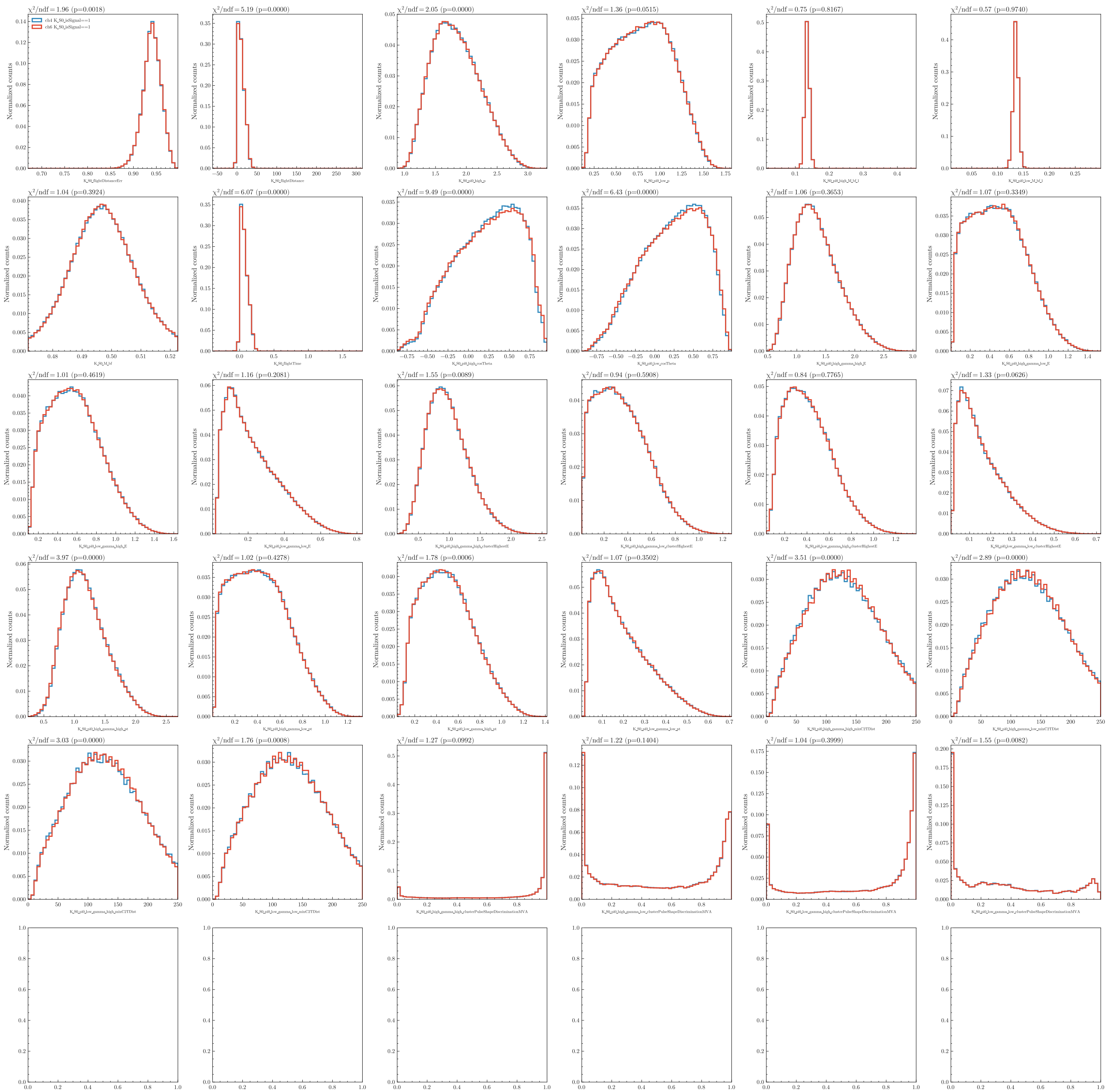
ch4 $B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-} K^0_{\pi^0\pi^0}$

ch6 $B^0 \to \eta'_{\rho\gamma} K^0_{\pi^0\pi^0}$

$B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-} K^0_L$

$B^0 \to \eta'_{\eta(3\pi)\pi^+\pi^-} K^0_L$

ch4 sig vs. ch6 sig



$B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-} K^0_{\pi^+\pi^-}$

$B^0 \to \eta'_{\rho\gamma} K^0_{\pi^+\pi^-}$

$B^0 \to \eta'_{\eta(3\pi)\pi^+\pi^-} K^0_{\pi^+\pi^-}$

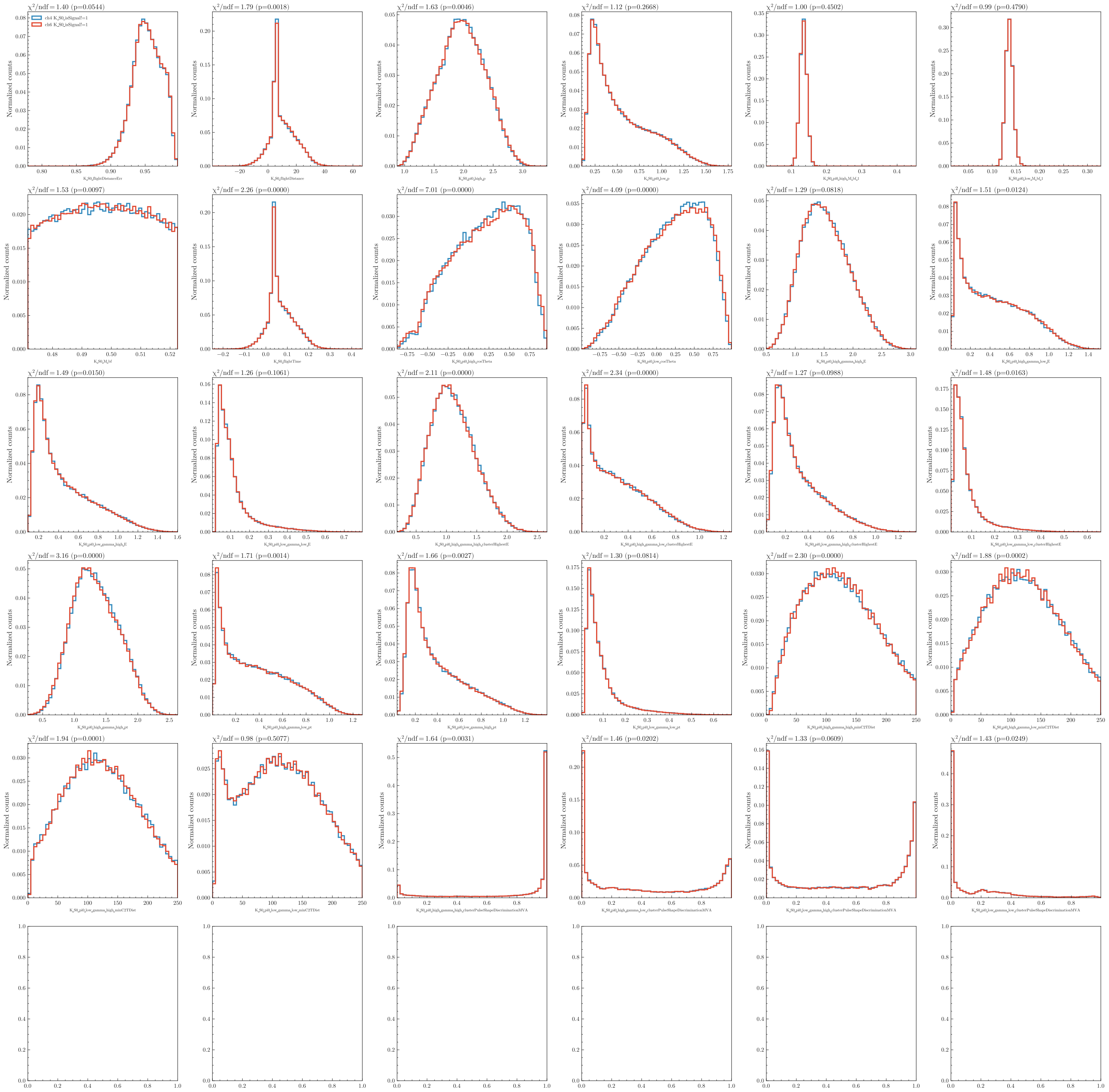
ch4 $B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-} K^0_{\pi^0\pi^0}$

ch6 $B^0 \to \eta'_{\rho\gamma} K^0_{\pi^0\pi^0}$

$B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-} K^0_L$

$B^0 \to \eta'_{\eta(3\pi)\pi^+\pi^-} K^0_L$

ch4 bkg vs. ch6 bkg



$$B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-} K^0_{\pi^+\pi^-}$$

$$B^0 \to \eta'_{\rho\gamma} K^0_{\pi^+\pi^-}$$

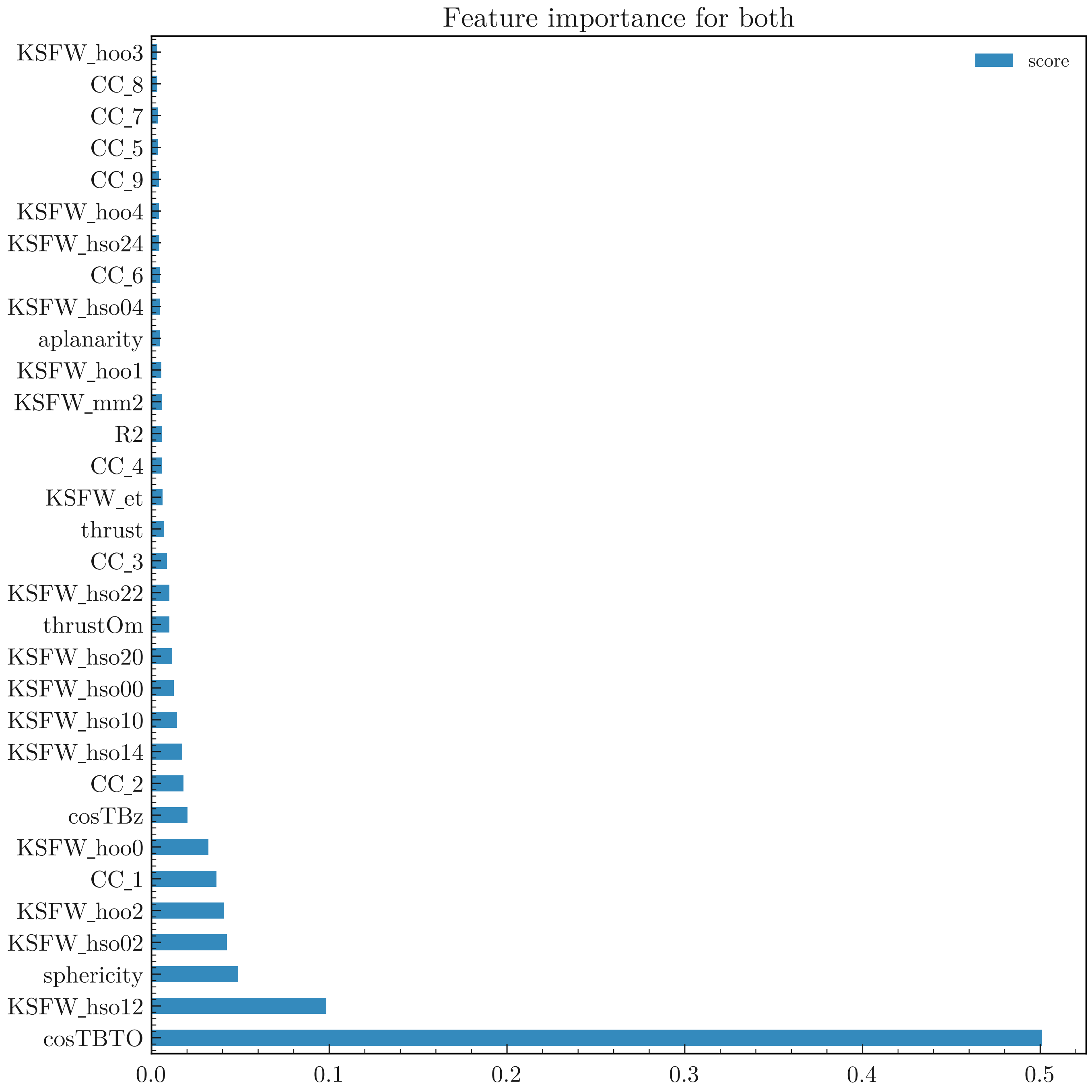
$$B^0 \to \eta'_{\eta(3\pi)\pi^+\pi^-} K^0_{\pi^+\pi^-}$$

ch4 $B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-} K^0_{\pi^0\pi^0}$

ch6 $B^0 \to \eta'_{\rho\gamma} K^0_{\pi^0\pi^0}$

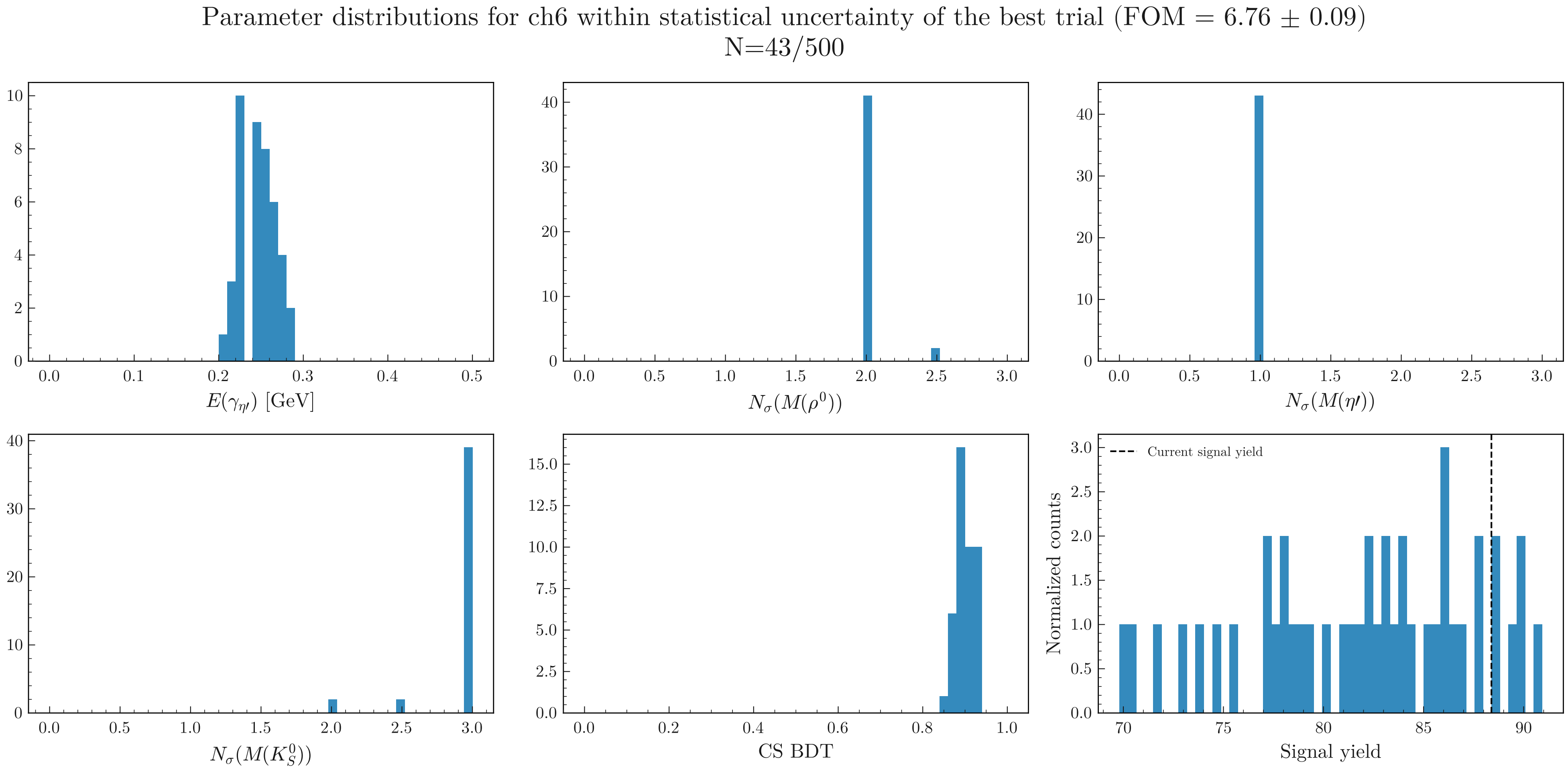
$$B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-} K^0_L$$

$$B^0 \to \eta'_{\eta(3\pi)\pi^+\pi^-} K^0_L$$



Feature importance for both
score
KSFW_hoo3
CC_8
CC_7
CC_5
CC_9
KSFW_hoo4
KSFW_hso24
CC_6
KSFW_hso04
aplanarity
KSFW_hoo1
KSFW_mm2
R2
CC_4
KSFW_et
thrust
CC_3
KSFW_hso22
thrustOm
KSFW_hso20
KSFW_hso00
KSFW_hso10
KSFW_hso14
CC_2
cosTBz
KSFW_hoo0
CC_1
KSFW_hoo2
KSFW_hso02
sphericity
KSFW_hso12
cosTBTO
0.0
0.1
0.2
0.3
0.4
0.5

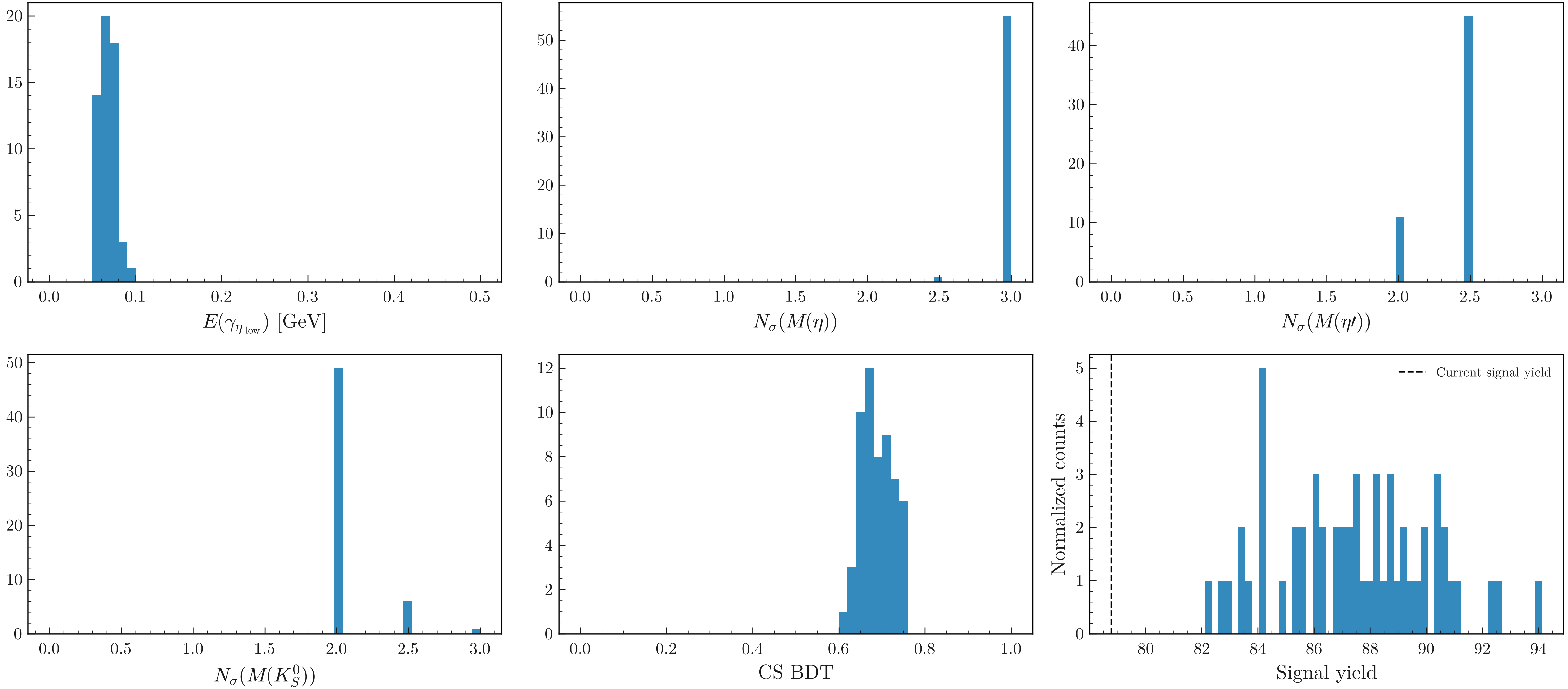
Stability of optimization / similarity in optimized cuts (ch6)



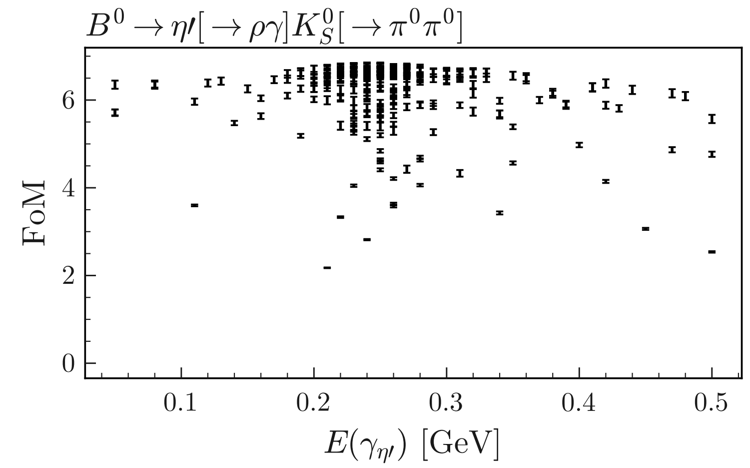
- Check all trials with FOM within statistical uncertainty of maximized FOM
  - 10% of trials (n_trials = 500)
- Plot distribution of cut values

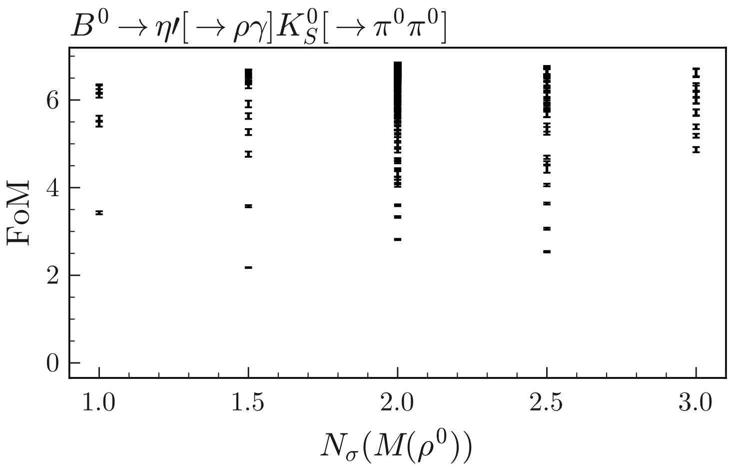
No results within stat. unc. of max FOM with same N_σ for all mass windows

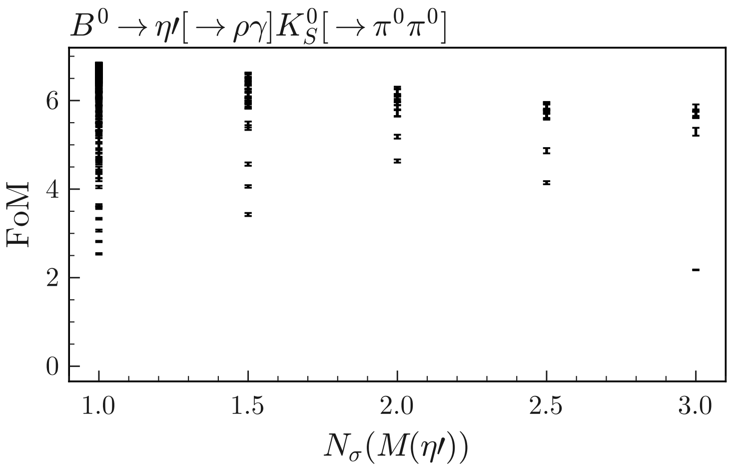
Parameter distributions for ch4 within statistical uncertainty of the best trial (FOM = 8.14 ± 0.10)
N=56/500



Projections of FOM curves (ch6)







$B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-}K^0_{\pi^+\pi^-}$

$B^0 \to \eta'_{\rho\gamma}K^0_{\pi^+\pi^-}$

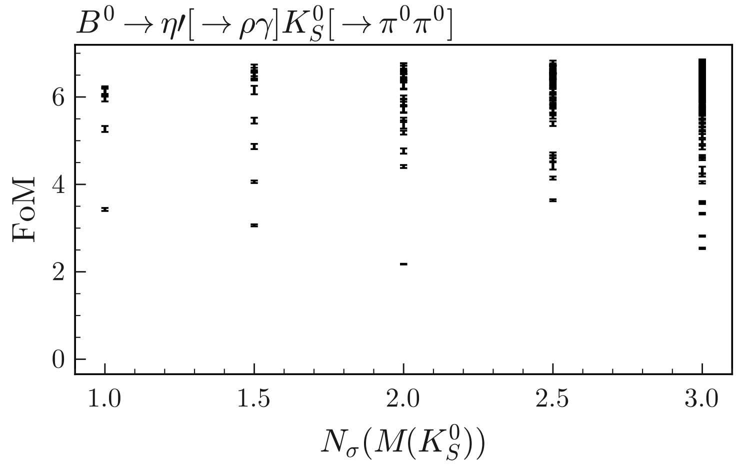
$B^0 \to \eta'_{\eta(3\pi)\pi^+\pi^-}K^0_{\pi^+\pi^-}$

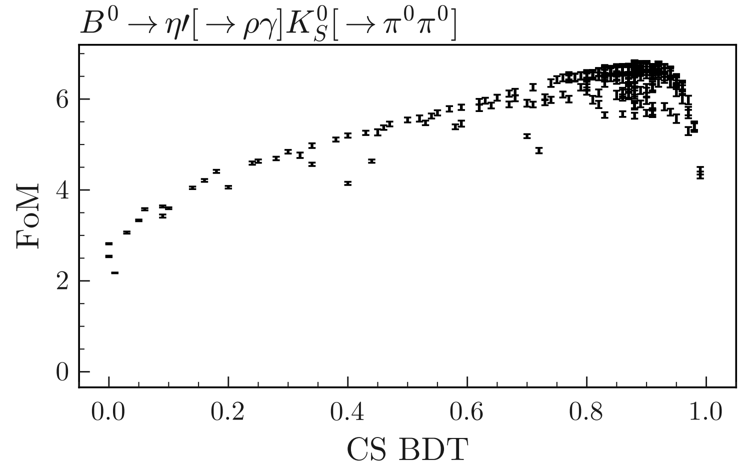
ch4 $B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-}K^0_{\pi^0\pi^0}$

ch6 $B^0 \to \eta'_{\rho\gamma}K^0_{\pi^0\pi^0}$

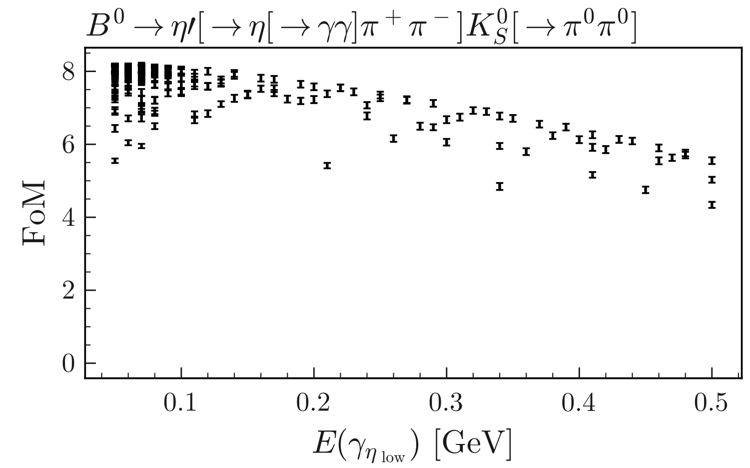
$B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-}K^0_L$

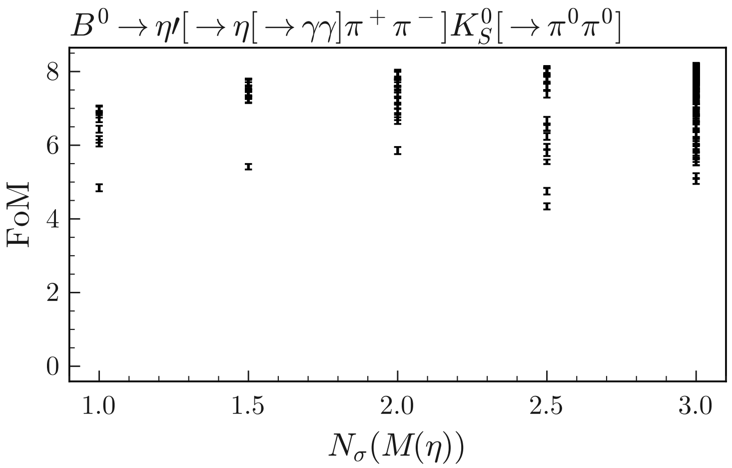
$B^0 \to \eta'_{\eta(3\pi)\pi^+\pi^-}K^0_L$

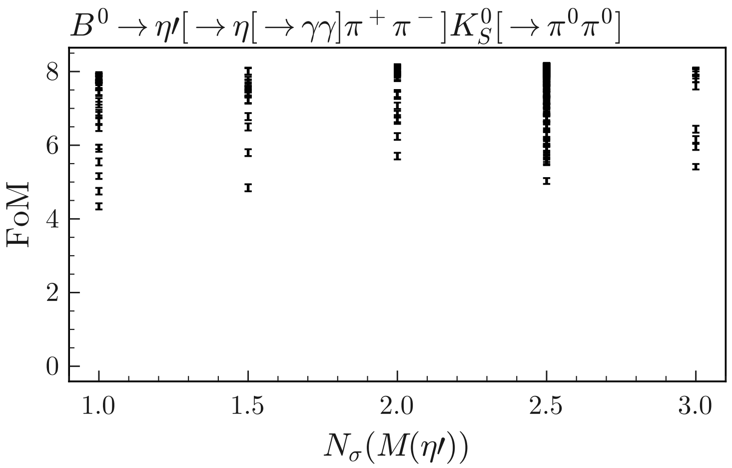




Projections of FOM curves (ch4)







$B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-} K^0_{\pi^+\pi^-}$

$B^0 \to \eta'_{\rho\gamma} K^0_{\pi^+\pi^-}$

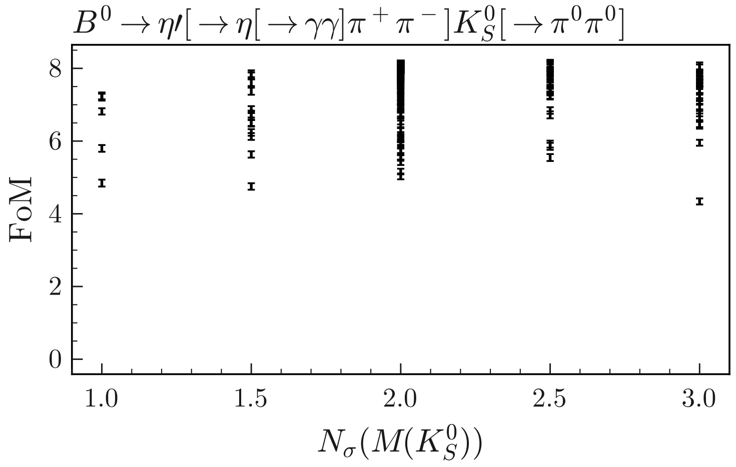
$B^0 \to \eta'_{\eta(3\pi)\pi^+\pi^-} K^0_{\pi^+\pi^-}$

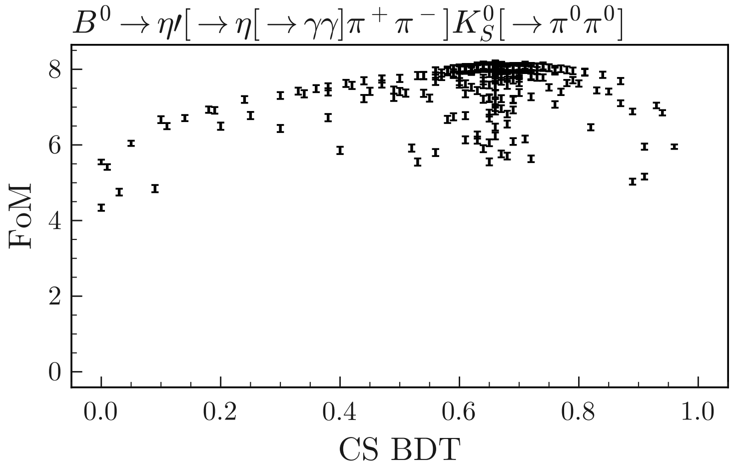
ch4 $B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-} K^0_{\pi^0\pi^0}$

ch6 $B^0 \to \eta'_{\rho\gamma} K^0_{\pi^0\pi^0}$

$B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-} K^0_L$

$B^0 \to \eta'_{\eta(3\pi)\pi^+\pi^-} K^0_L$





Continuum suppression variables comparison between channels

$B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-} K^0_{\pi^+\pi^-}$

ch3 $\boxed{B^0 \to \eta'_{\rho\gamma} K^0_{\pi^+\pi^-}}$

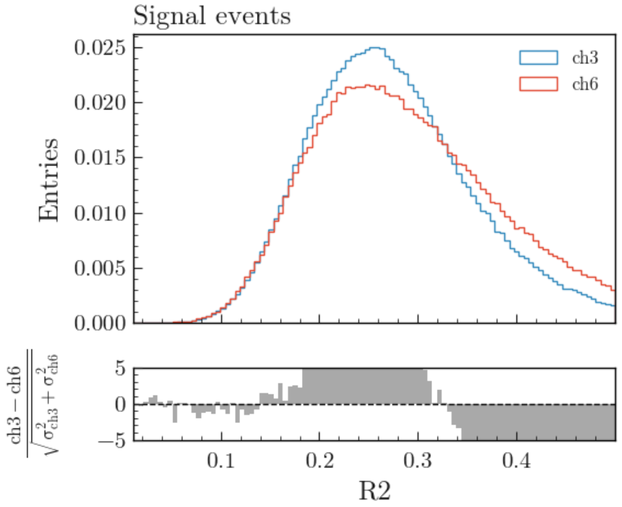
$B^0 \to \eta'_{\eta(3\pi)\pi^+\pi^-} K^0_{\pi^+\pi^-}$

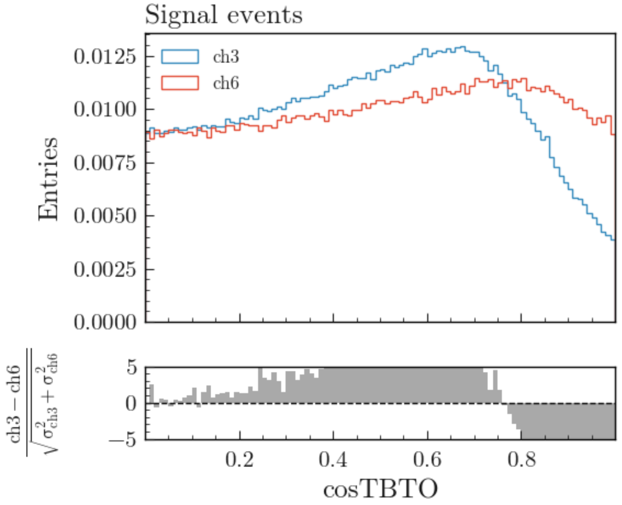
$B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-} K^0_{\pi^0\pi^0}$

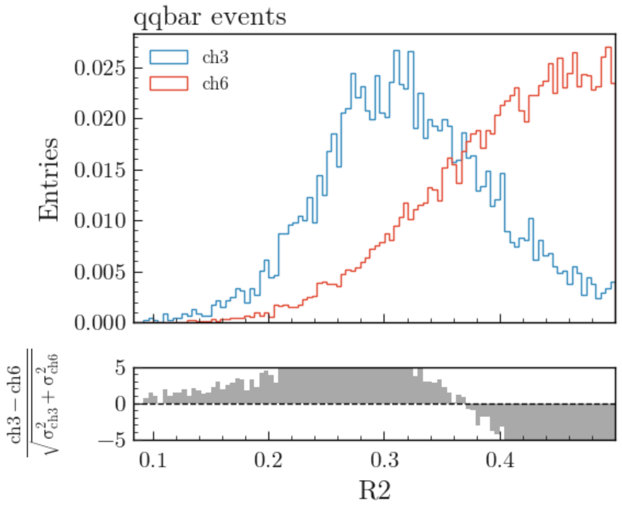
ch6 $\boxed{B^0 \to \eta'_{\rho\gamma} K^0_{\pi^0\pi^0}}$

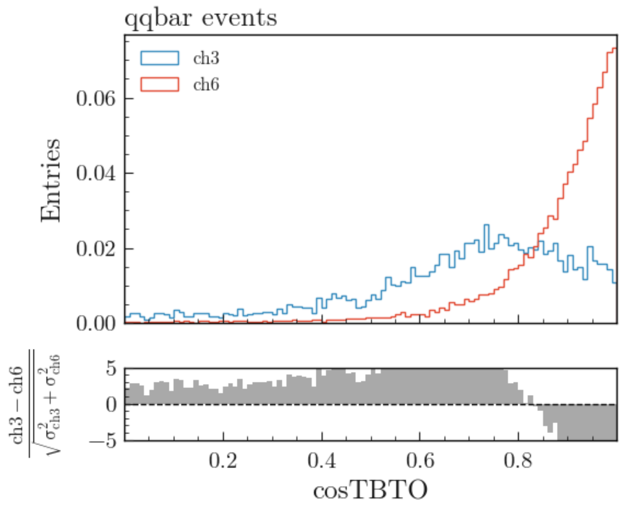
$B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-} K^0_L$

$B^0 \to \eta'_{\eta(3\pi)\pi^+\pi^-} K^0_L$







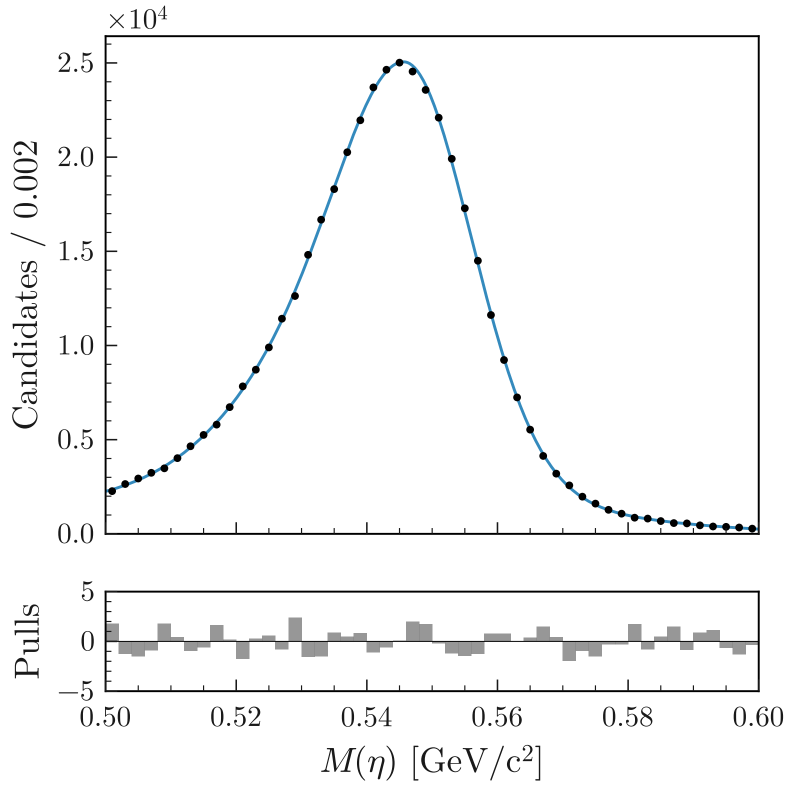


- In signal region $-0.15 < \Delta E < 0.1$ and $M_{\mathrm{bc}} > 5.27$
- Signal is truth matched (B0ch?_etap_tm==1)
- Should we use event shape using the entire event?

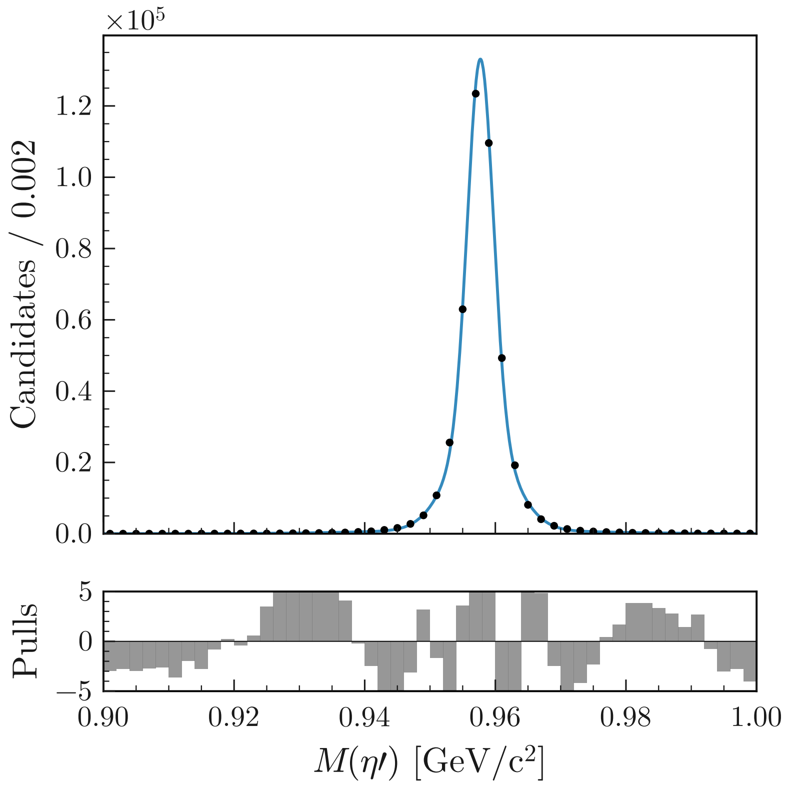
Resonant mass fits

$B^0 \to \eta'_{\eta(\gamma\gamma)\pi^+\pi^-} K^0_{\pi^0\pi^0}$

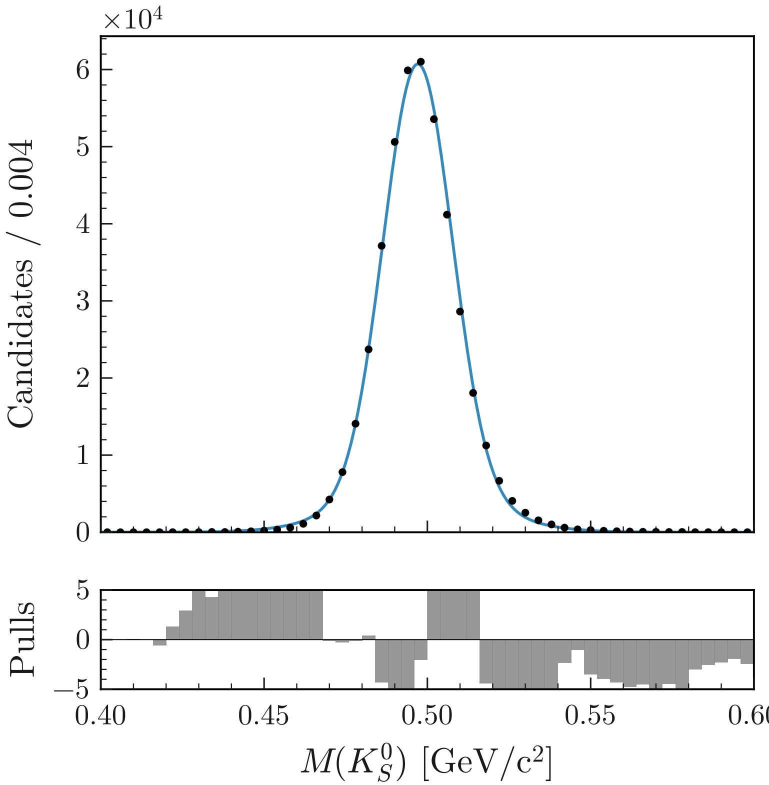
```
cuts:
  'B0 vertex': 'chiProb>=0'
  'TDCPV_qqs skim': 'skim_qqs==1'
  'R2': 'R2<0.5'
  'KS00 mass': '0.459<K_S0_M_bf<0.535'
  'eta mass': '0.516<etap_eta_M_bf<0.575'
  'etap mass': '0.949<etap_M_bf<0.967'
  'photon energy': 'etap_eta_gamma_low_E>0.14'
  'photon MVA': 'K_S0_pi0_high_gamma_high_fakePhotonSuppression>0.1
                 and K_S0_pi0_high_gamma_high_beamBackgroundSuppression>0.1
                 and K_S0_pi0_high_gamma_low_fakePhotonSuppression>0.1
                 and K_S0_pi0_high_gamma_low_beamBackgroundSuppression>0.1
                 and K_S0_pi0_low_gamma_high_fakePhotonSuppression>0.1
                 and K_S0_pi0_low_gamma_high_beamBackgroundSuppression>0.1
                 and K_S0_pi0_low_gamma_low_fakePhotonSuppression>0.1
                 and K_S0_pi0_low_gamma_low_beamBackgroundSuppression>0.1'
```



BifurGauss$_1$+BifurGauss$_2$+Gauss



Gauss$_1$+Gauss$_2$+Gauss$_3$

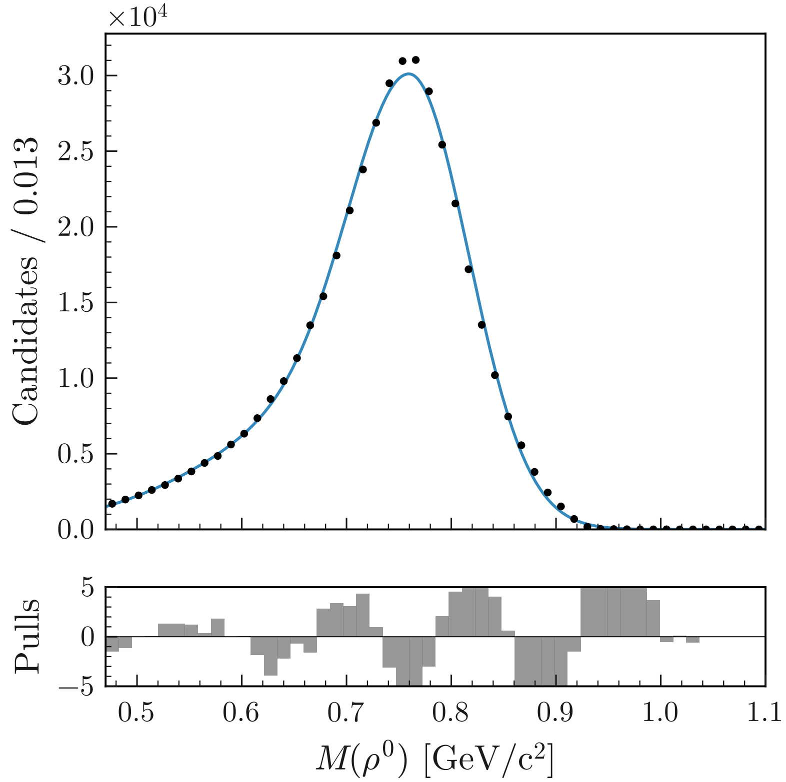


Gauss$_1$+Gauss$_2$

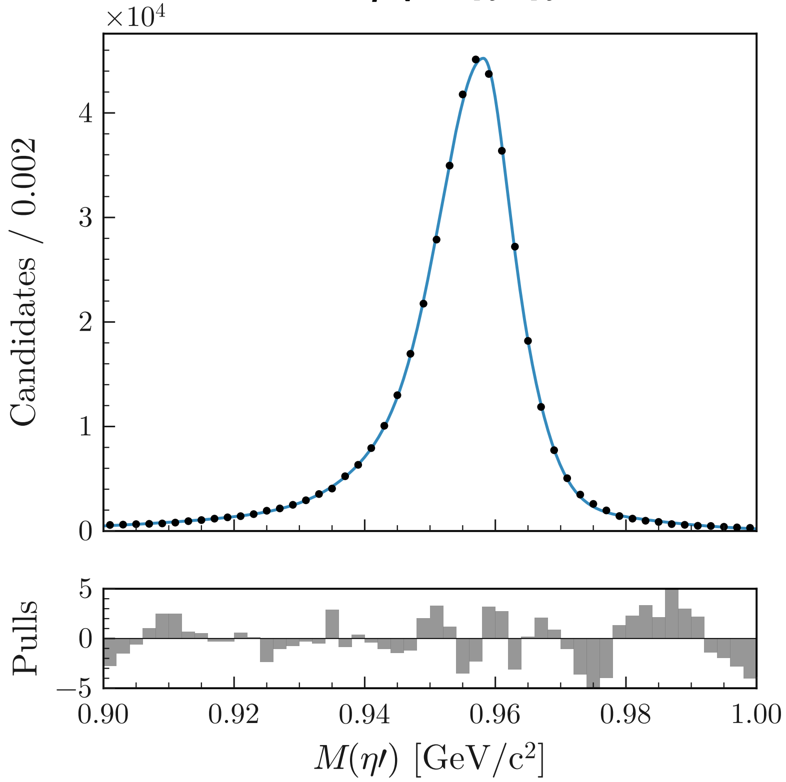
Resonant mass fits

```
cuts:
  'B0 vertex': 'chiProb>=0'
  'TDCPV_qqs skim': 'skim_qqs==1'
  'R2': 'R2<0.5'
  'KS00 mass': '0.459<K_S0_M_bf<0.535'
  'rho0 mass': '0.539<etap_rho0_M_bf<0.874'
  'etap mass': '0.927<etap_M_bf<0.977'
  'photon energy': 'etap_gamma_E>0.23'
  'photon MVA': 'K_S0_pi0_high_gamma_high_fakePhotonSuppression>0.1
    and K_S0_pi0_high_gamma_high_beamBackgroundSuppression>0.1
    and K_S0_pi0_high_gamma_low_fakePhotonSuppression>0.1
    and K_S0_pi0_high_gamma_low_beamBackgroundSuppression>0.1
    and K_S0_pi0_low_gamma_high_fakePhotonSuppression>0.1
    and K_S0_pi0_low_gamma_high_beamBackgroundSuppression>0.1
    and K_S0_pi0_low_gamma_low_fakePhotonSuppression>0.1
    and K_S0_pi0_low_gamma_low_beamBackgroundSuppression>0.1'
```

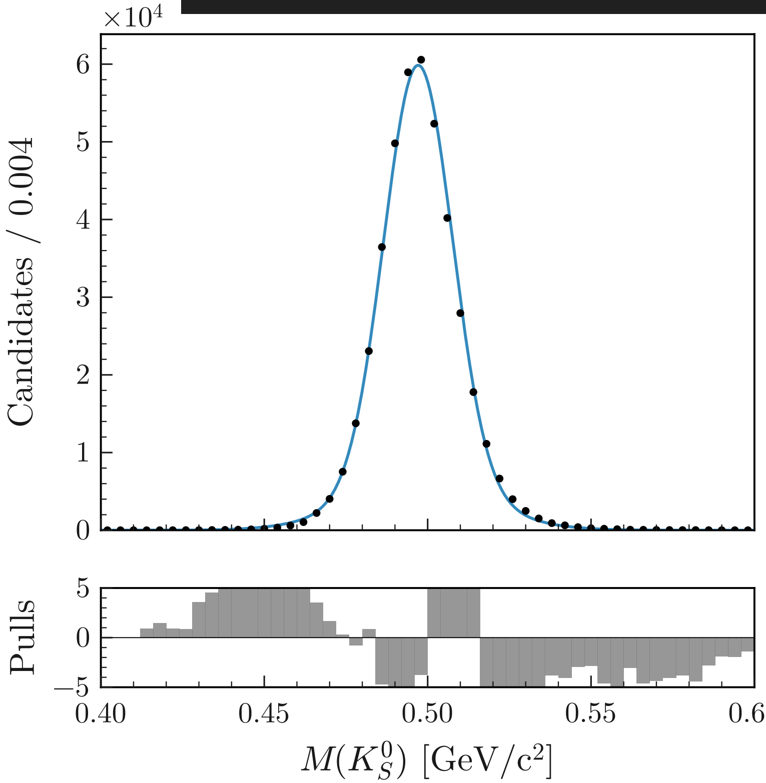
$$B^0 \to \eta'_{\rho\gamma} K^0_{\pi^0\pi^0}$$



BifurGauss+Gauss

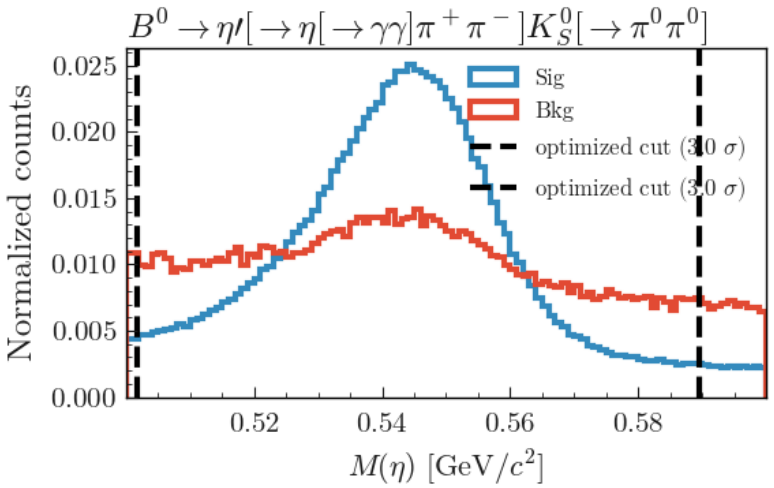


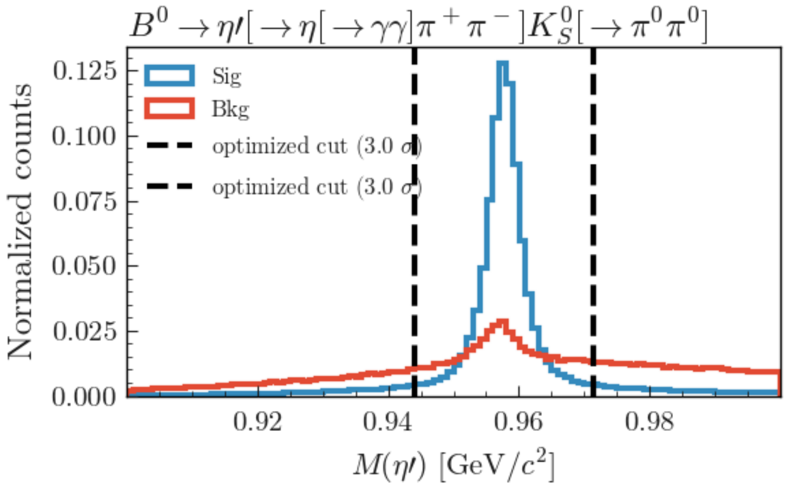
$\text{BifurGauss}_1+\text{BifurGauss}_2+\text{Gauss}$

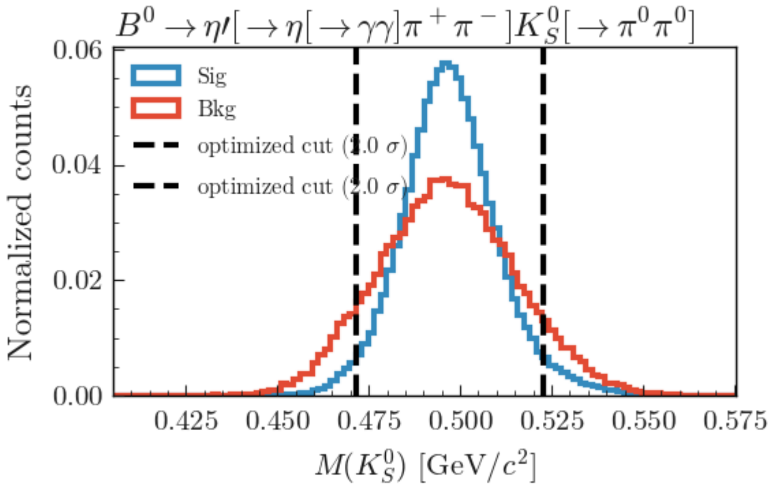


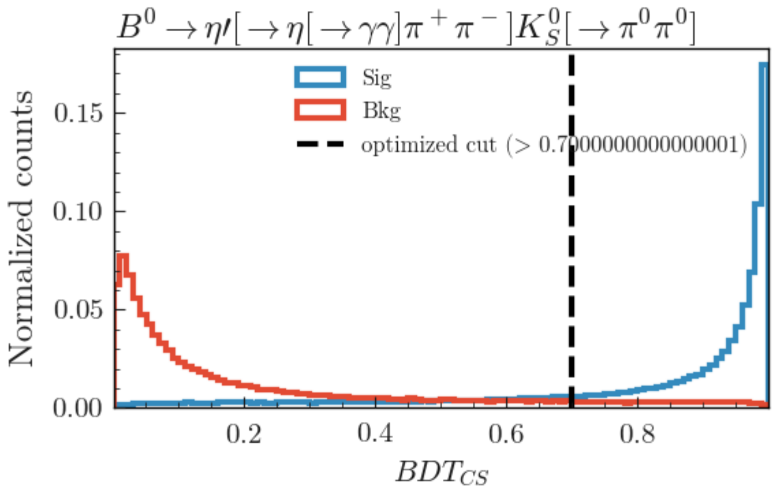
$\text{Gauss}_1+\text{Gauss}_2$

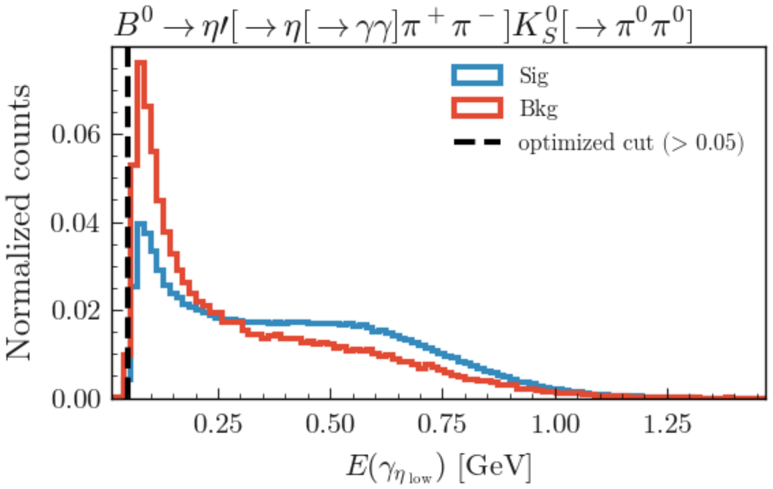
Optuna results ch4



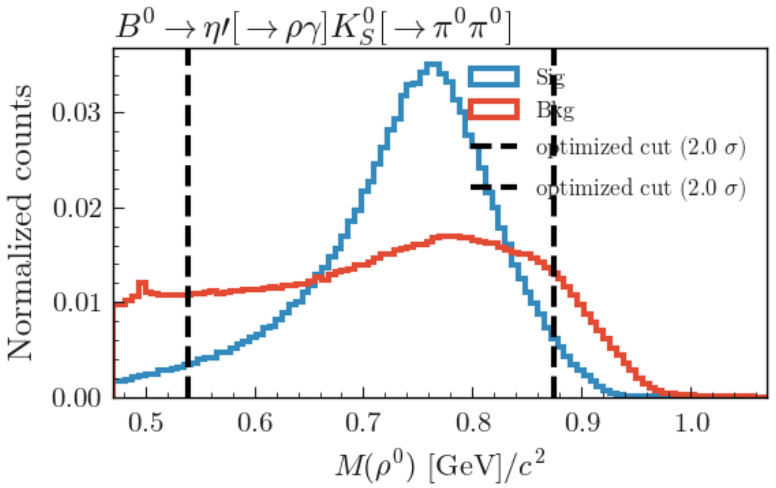


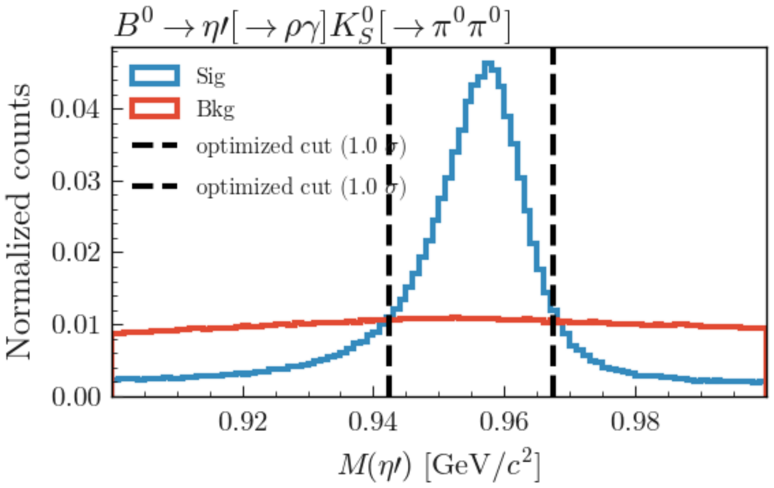


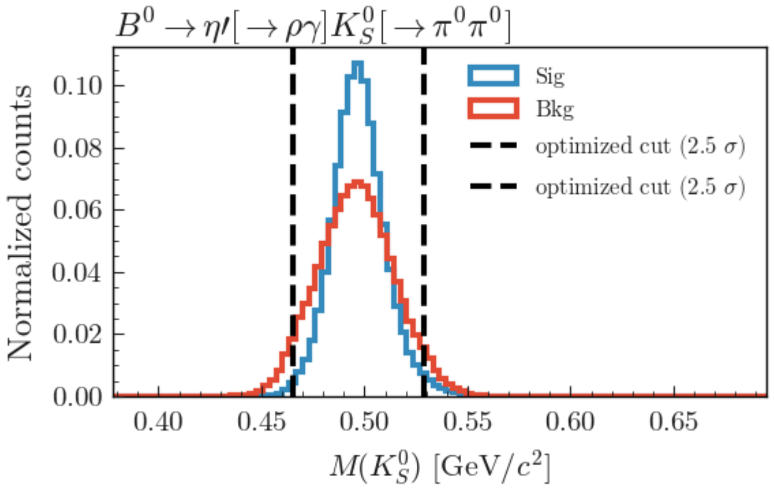


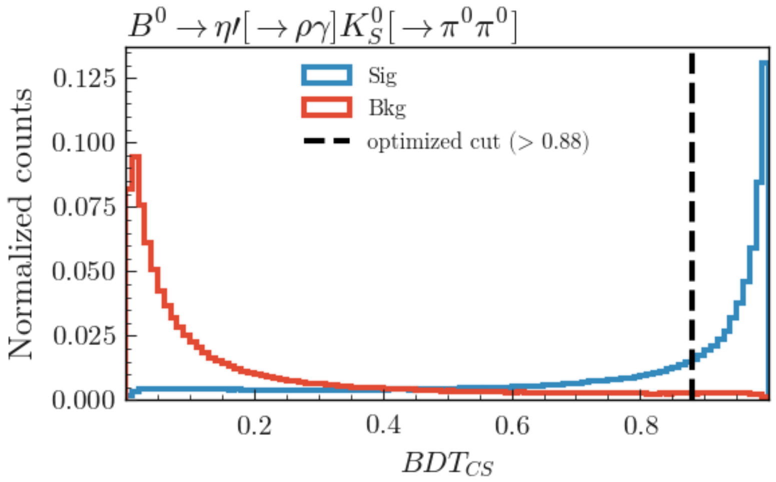


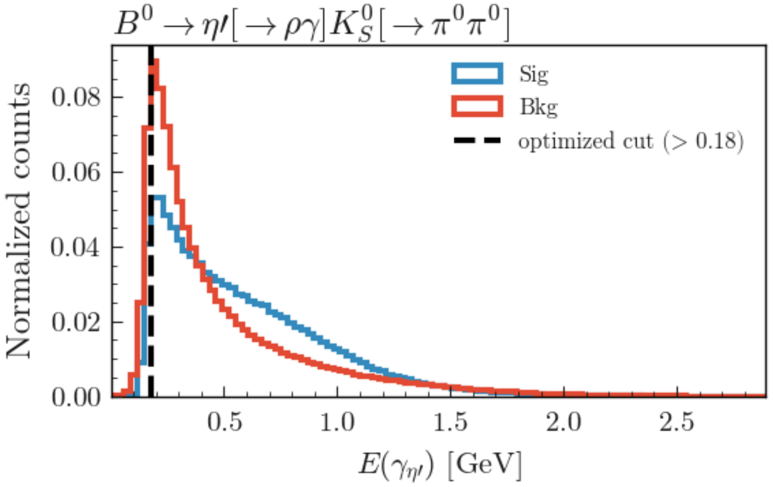
Optuna results ch6











Full picture