

Jožef Stefan Institute
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$f^{\pm}/f^{00}$ ($R^{\pm 00}$) from inclusive di-leptonic events

Measurement of the Branching Ratio and Direct CP Asymmetry of $B^+ \to K^+\eta$, $B^+ \to \pi^+\eta$, $B^0 \to K_S^0\eta$

F9 Strategic Meeting 2026

Aljaž Hvala

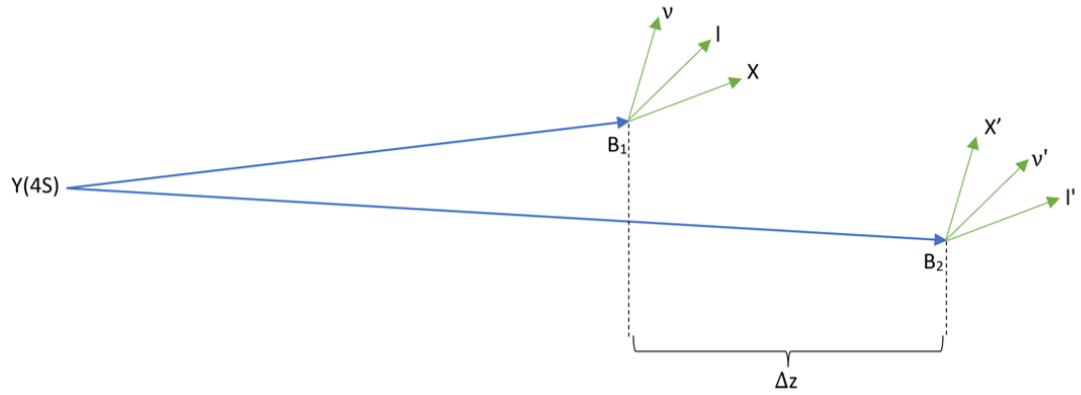
September 30, 2026

$f^{\pm}/f^{00}$ ($R^{\pm 00}$) from inclusive di-leptonic events

- We would like to measure $R^{\pm/00} = \frac{f^{\pm}}{f^{00}} = \frac{\Gamma(\Upsilon(4S)\to B^{+}B^{-})}{\Gamma(\Upsilon(4S)\to B^{0}\bar{B}^{0})}$
- HFLAV world average: $f^{\pm}/f^{00} = 1.054 \pm 0.038$

arXiv:2411.18639v1

- We consider events where both B mesons decay semi-leptonically



$B^{+} \to l^{+}\nu X;\ B^{-} \to l^{-}\bar{\nu}X'$ Chg
$B^{0} \to l^{+}\nu X;\ \overline{B^{0}} \to l^{-}\bar{\nu}X'$ Unm
} OS

$B^{0} \to l^{+}\nu X;\ B^{0} \to l^{+}\nu X'$
$\overline{B^{0}} \to l^{-}\bar{\nu}X;\ \overline{B^{0}} \to l^{-}\bar{\nu}X'$
} Mix (SS)

$$N^{OS} = N^{chg} + N^{unm} = N^{\pm} + (1-\chi_d)N^{00}$$
$$N^{SS} = \chi_d N^{00}$$

- Ratio $R^{\pm 00}$ can be determined from N^{chg}/N^{unm} or more reliably from N^{OS}/N^{SS}

$$R^{\pm 00} = \left(\frac{\tau_{B^0}}{\tau_{B^+}}\right)^2 \frac{N^{\pm}}{N^{00}} = \left(\frac{\tau_{B^+}}{\tau_{B^0}}\right)^2 (\chi_d\left(1+\frac{N^{OS}}{N^{SS}}\right) - 1)$$

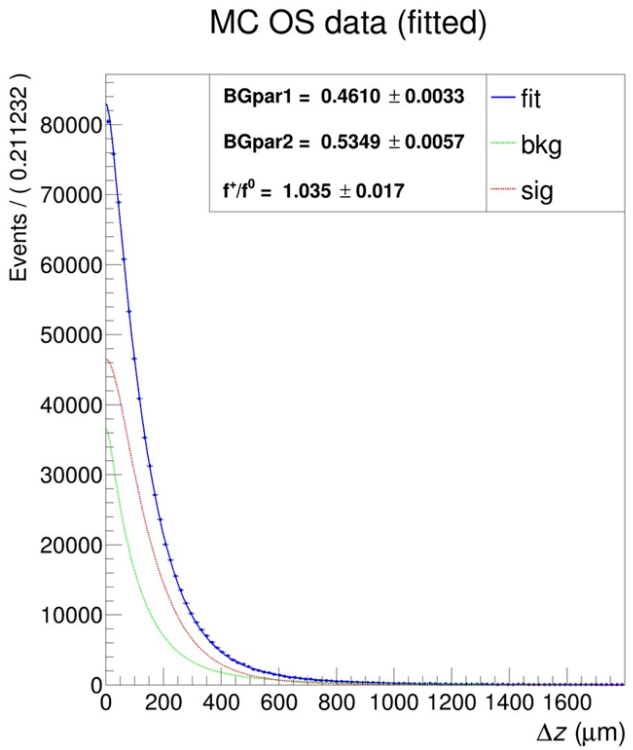
$$R^{\pm 00} = \left(\frac{\tau_{B^0}}{\tau_{B^+}}\right)^2 (1-\chi_d)\left(\frac{N^{chg}}{N^{unm}}\right)$$

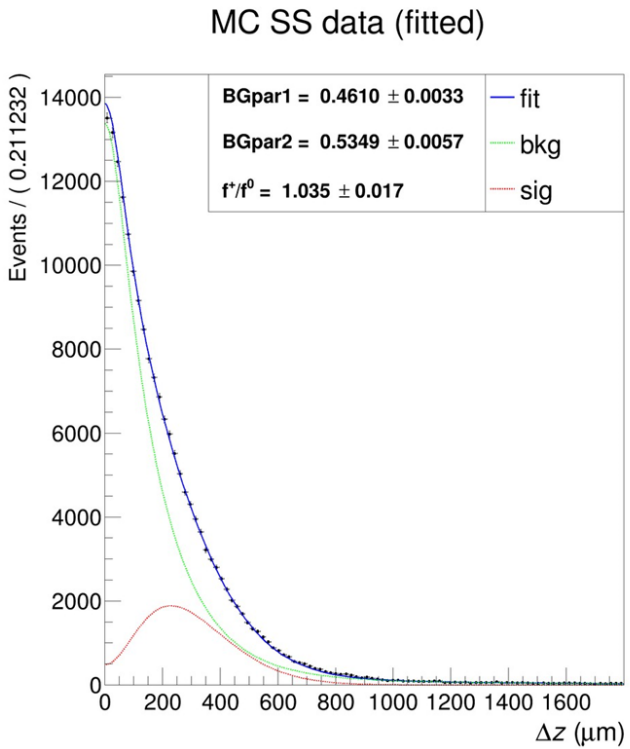
- Known theoretical signal distribution in respect to Δz used to separate signal/background:

$$PDF(unmix) \propto e^{-\frac{|\Delta t|}{\tau_{B^0}}}(1+\cos(\Delta m_d \Delta t))$$

$$PDF(mix) \propto e^{-\frac{|\Delta t|}{\tau_{B^0}}}(1-\cos(\Delta m_d \Delta t))$$

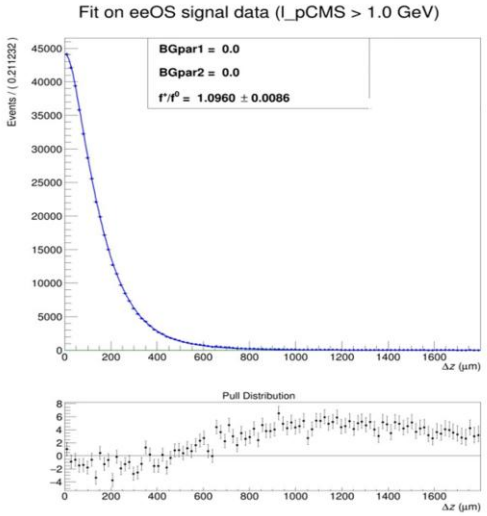
$$PDF(chg) \propto e^{-\frac{|\Delta t|}{\tau_{B^+}}}$$

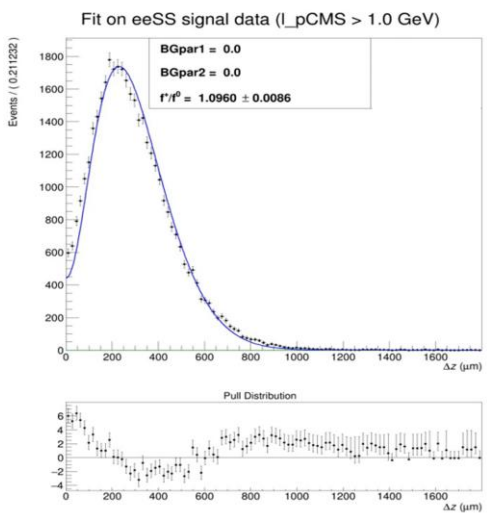


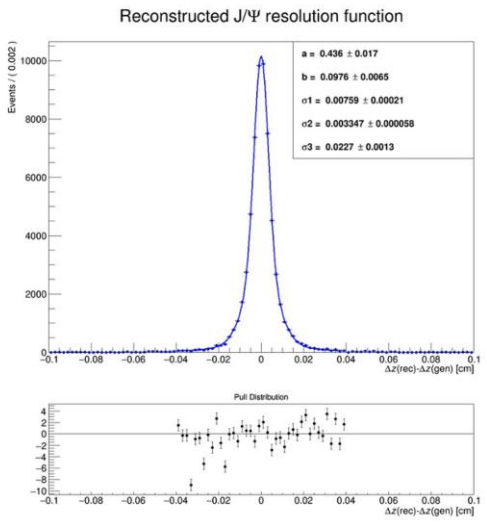


Resolution function (Δt(gen) → Δz(rec))

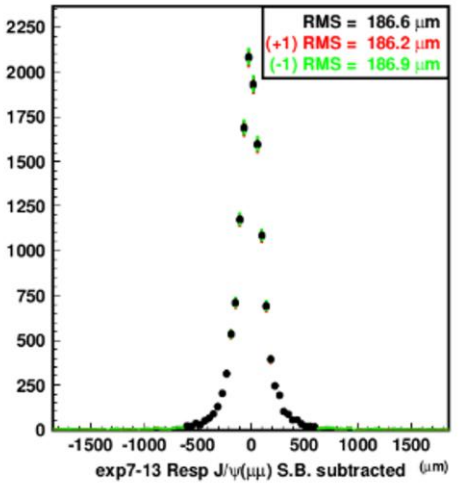
- J/ψ **approach:**
  - In $J/\psi \rightarrow l^{+}l^{-}$ leptons share the same decay vertex
  - Residuals $\Delta z = l_1_z$ - l_2_z are histogramed, fitted with 3 Gaussians, signal distributions are convoluted with this resolution model





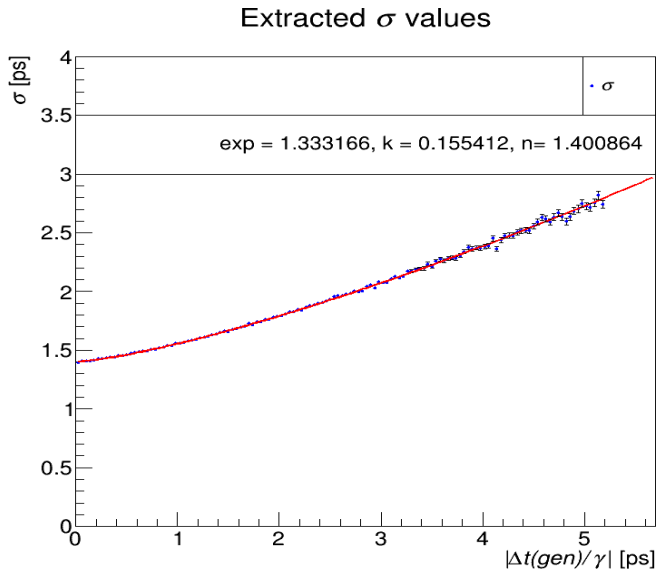


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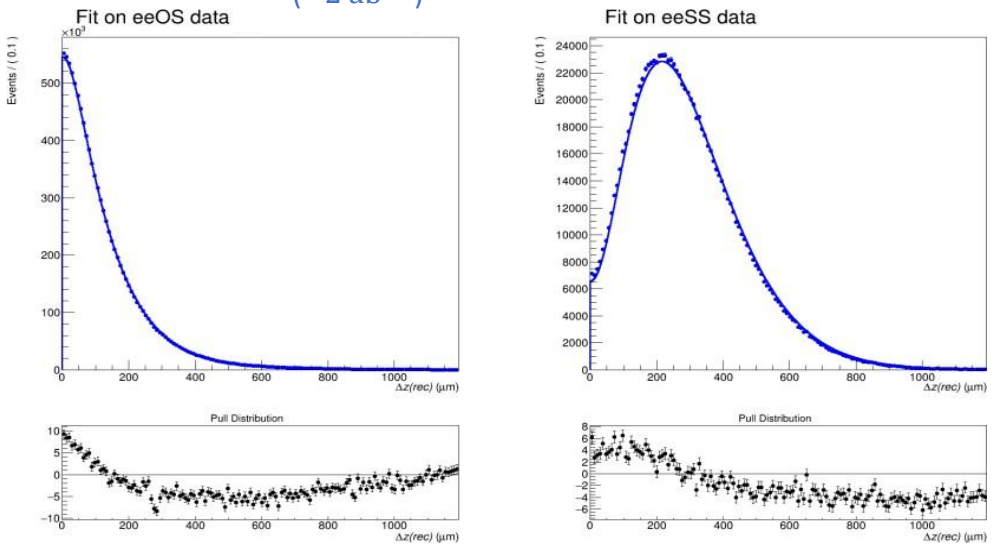


- **Accounting for the dependace on $\Delta t(gen)$:**
  - Performing a fit on $\Delta z(rec) - \Delta t(gen)$ distributions in different $\Delta t(gen)$ bins to construct a resolution with $\Delta t(gen)$ dependent σ
  - $\Delta t(gen)$ times resolution is integrated over $\Delta t(gen)$

$$F(x) = \int_{-\infty}^{\infty} f(x') e^{-\frac{(x-x')^2}{2(kx'+n)^2}} dx' \qquad x = \Delta z(rec),\ x' = \Delta t(gen)$$



11 million generated signal $\mu\mu$ events (~2 ab^{-1})



$B \to K^+/\pi^+/K_S^0\eta$ fit procedure

- Measurement of branching fractions and partial rate asymmetries for:

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

$B^+ \to \eta(\to \pi^+\pi^-\pi^0)\pi^+$

$B^0 \to \eta(\to \pi^+\pi^-\pi^0)K_S^0$

$B^+ \to \eta(\to \gamma\gamma)K^+$

$B^+ \to \eta(\to \gamma\gamma)\pi^+$

$B^0 \to \eta(\to \gamma\gamma)K_S^0$

- Fits determine sample composition (signal, feed-across $\bar{q}q$ bkg, $\bar{B}B$ bkg) using observables:

  → $M_{bc} = \sqrt{(\sqrt{s}/2)^2 - |\boldsymbol{p}_B^*|^2}$

  → $\Delta E = E^* - \sqrt{s}/2$

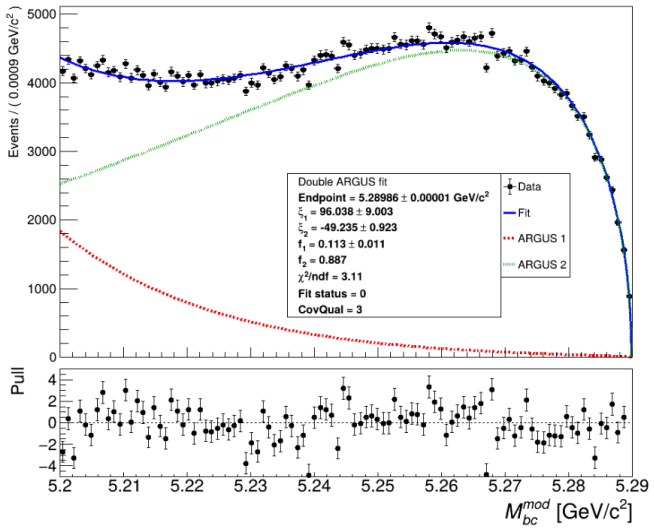
  → transformed continuum suppression classifier variable calculated using boosted decision tree (BDT)

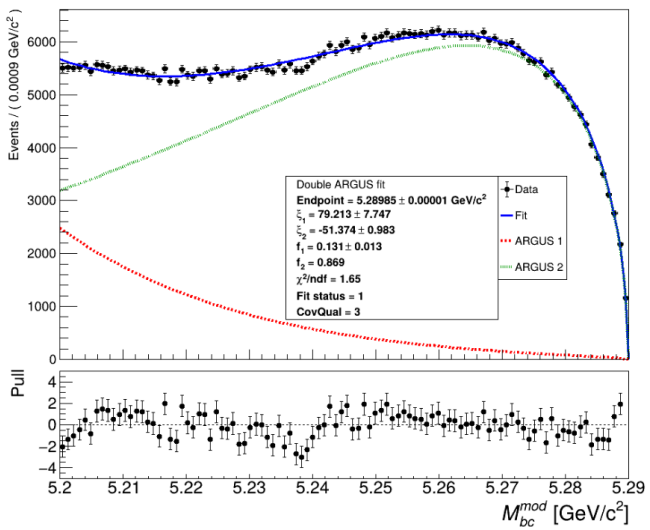
- Shapes of distributions for different components are fixed from simulated data

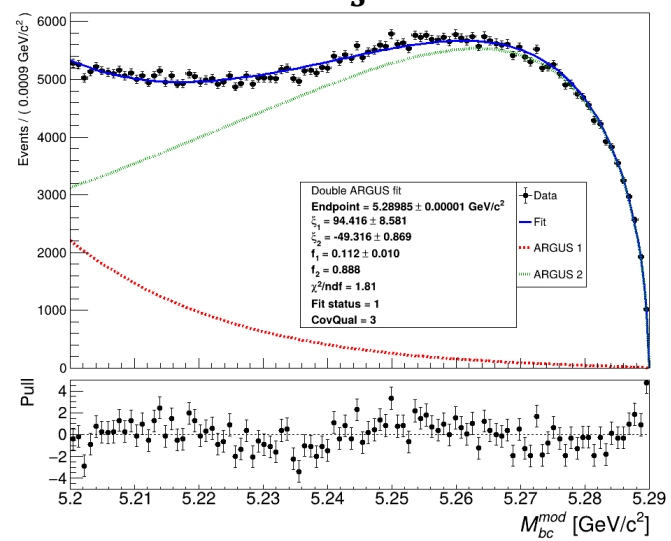
Continuum background - Modified M_{bc}

K^+ | π^+ | K_S^0

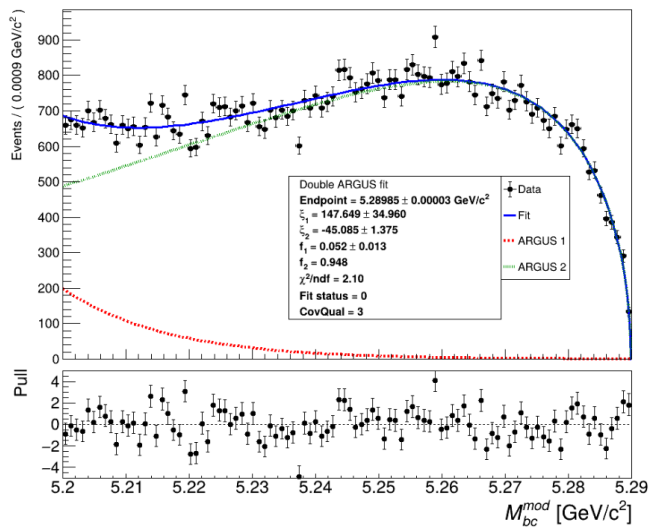
$\eta \to \gamma\gamma$

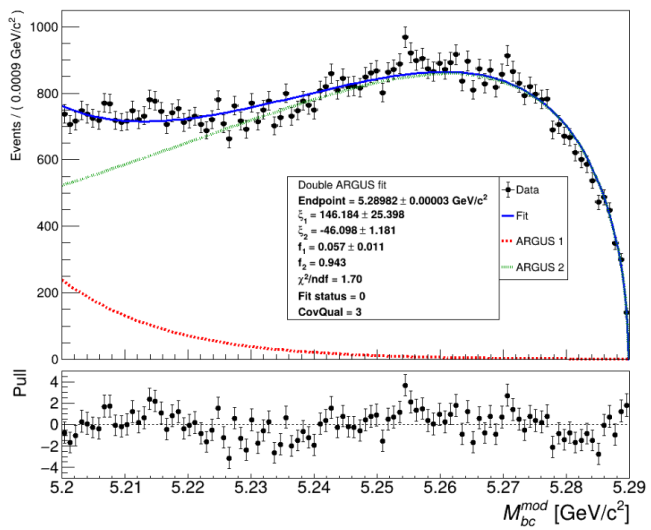


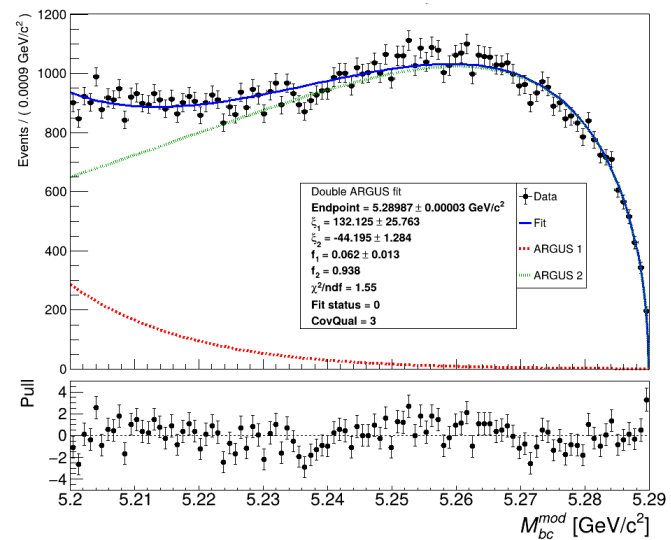




$\eta \to 3\pi$



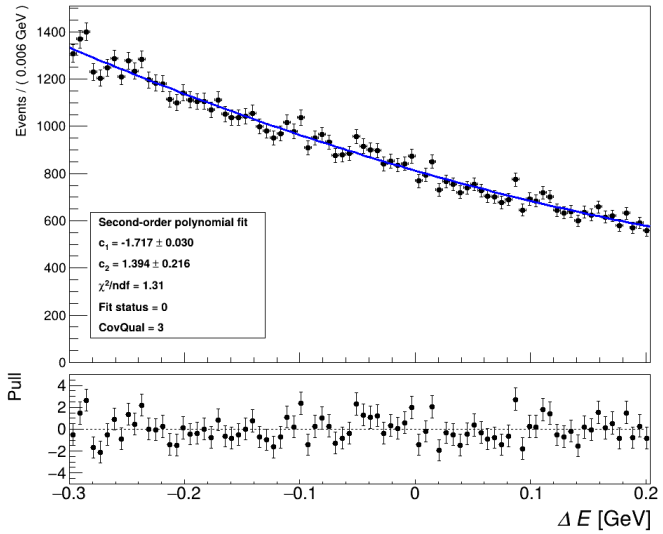


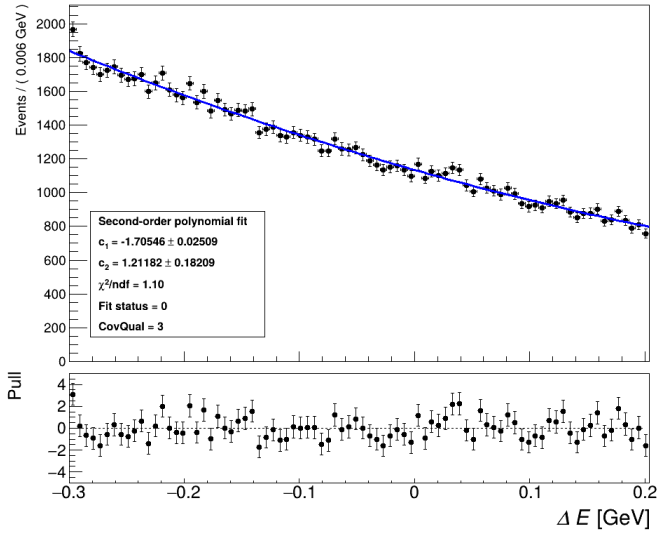


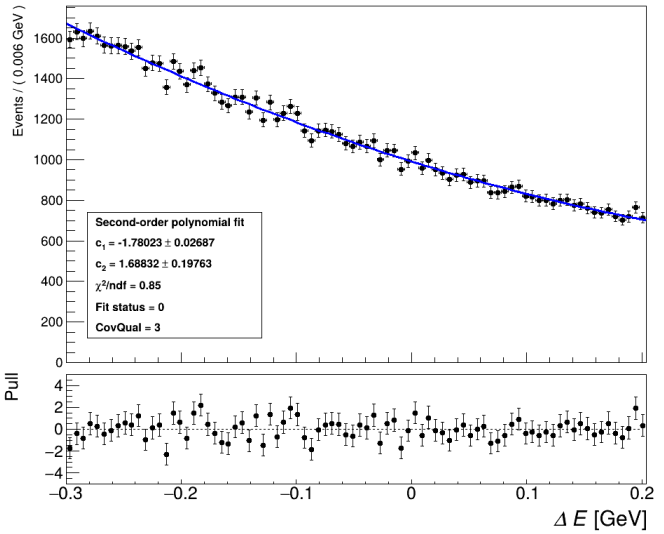
Continuum background - ΔE

K^+ π^+ K_S^0

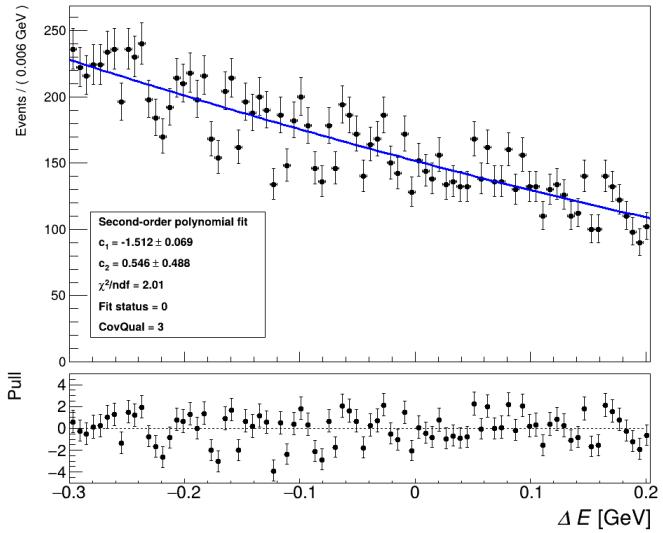
$\eta \to \gamma\gamma$

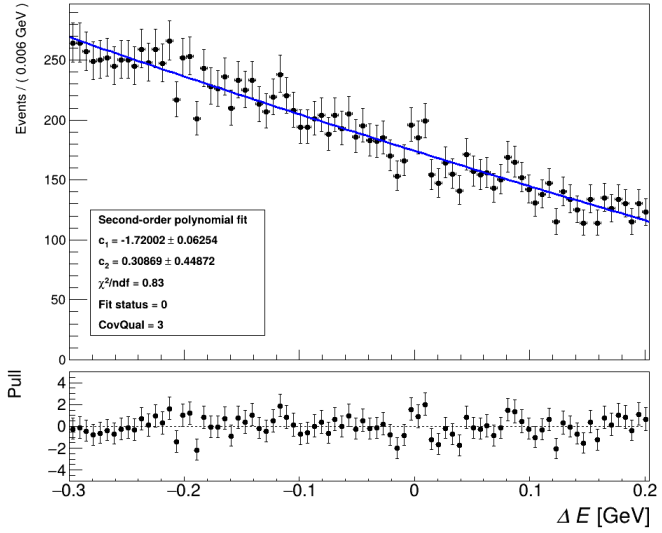


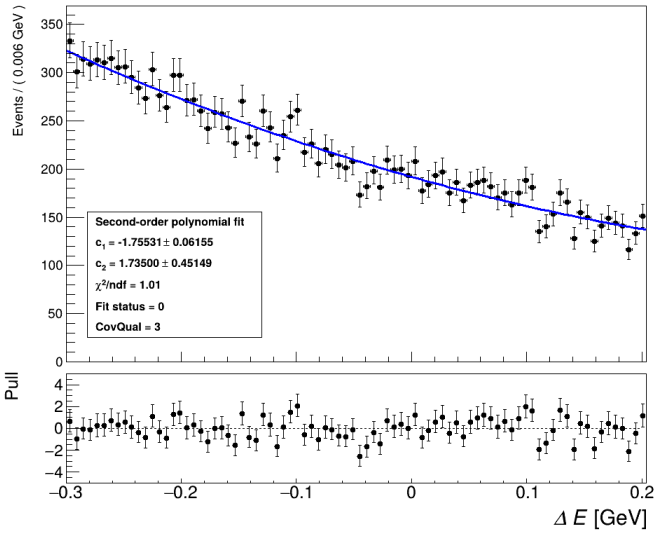




$\eta \to 3\pi$



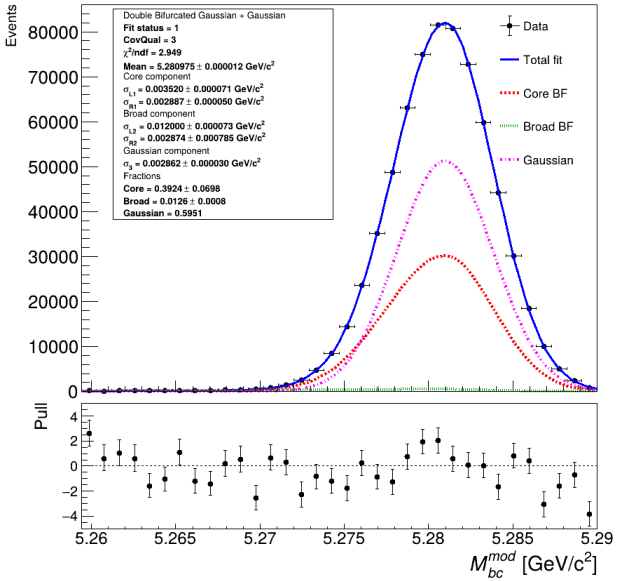


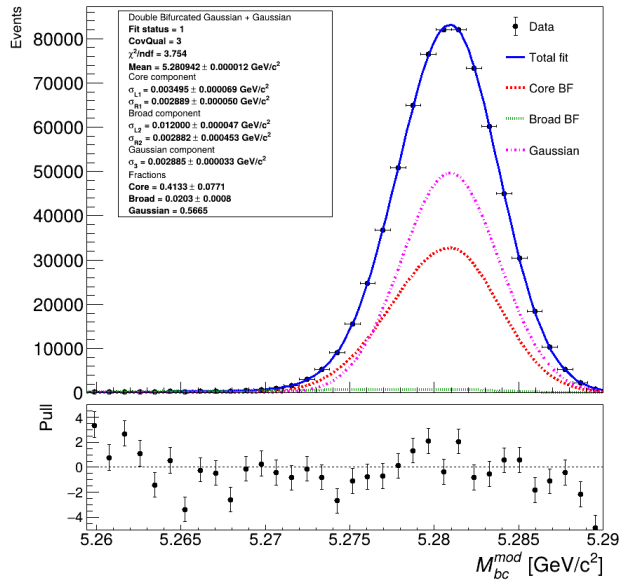


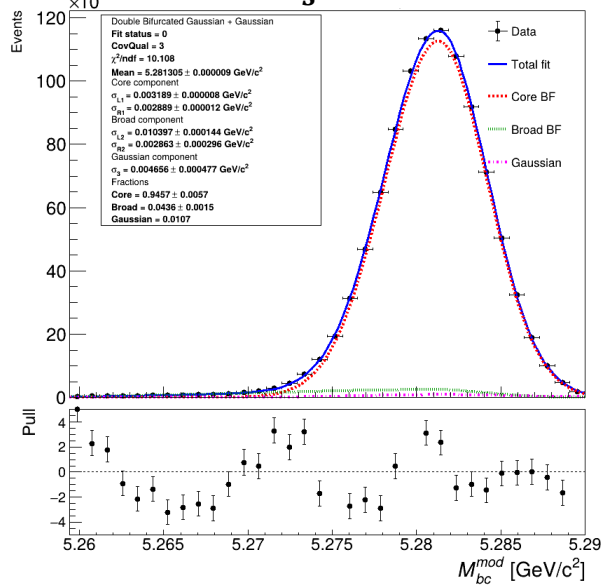
Signal - Modified M_{bc}

K^+ π^+ K_S^0

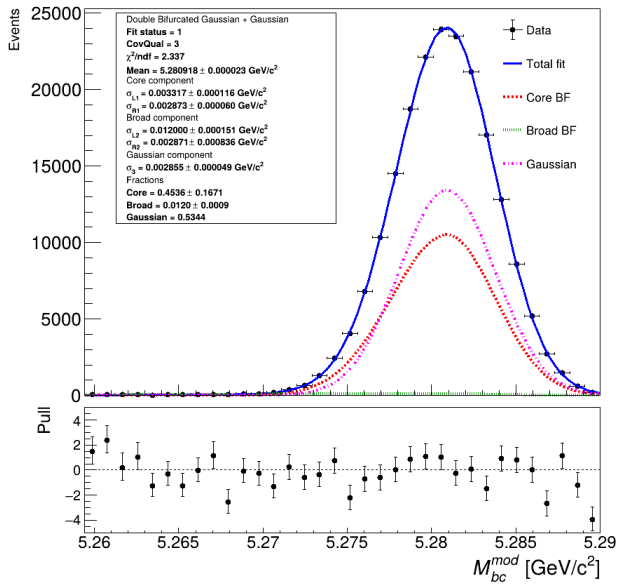
$\eta \to \gamma\gamma$

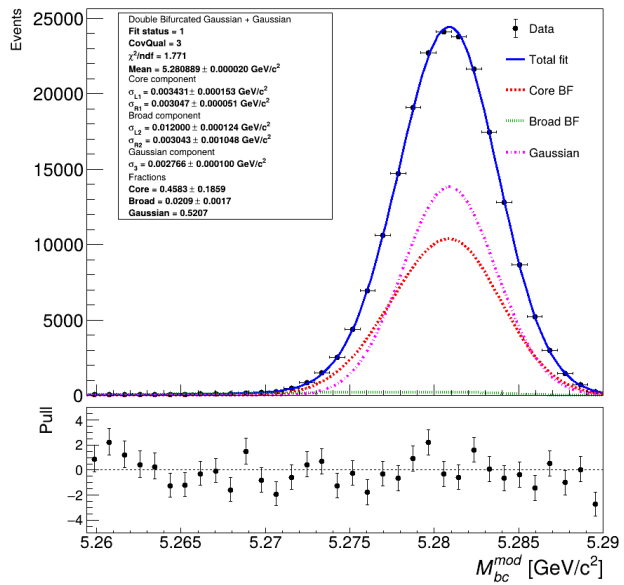


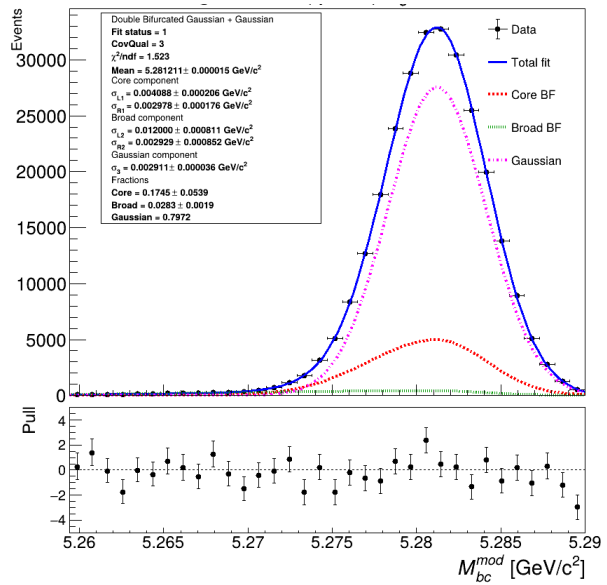




$\eta \to 3\pi$



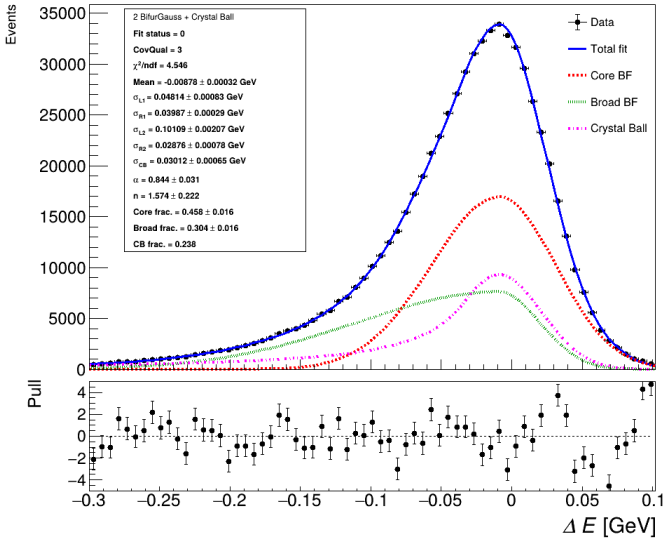


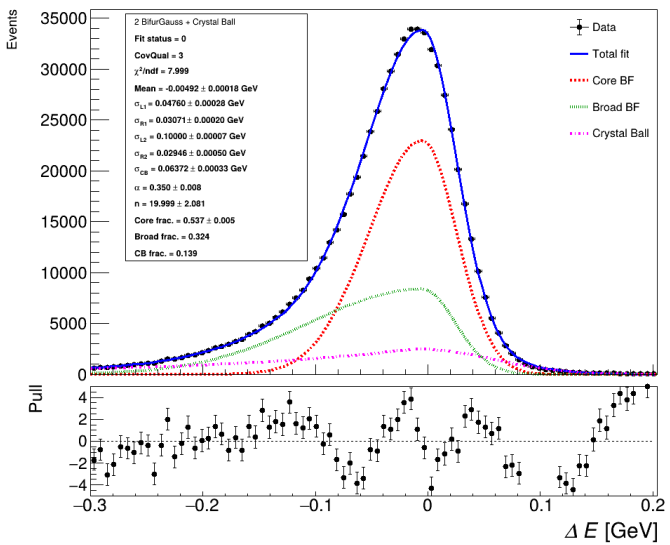


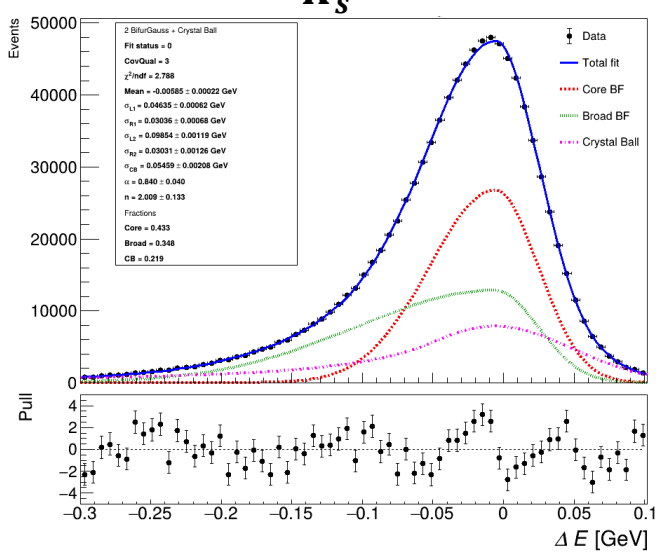
Signal - ΔE

K^+ π^+ K_S^0

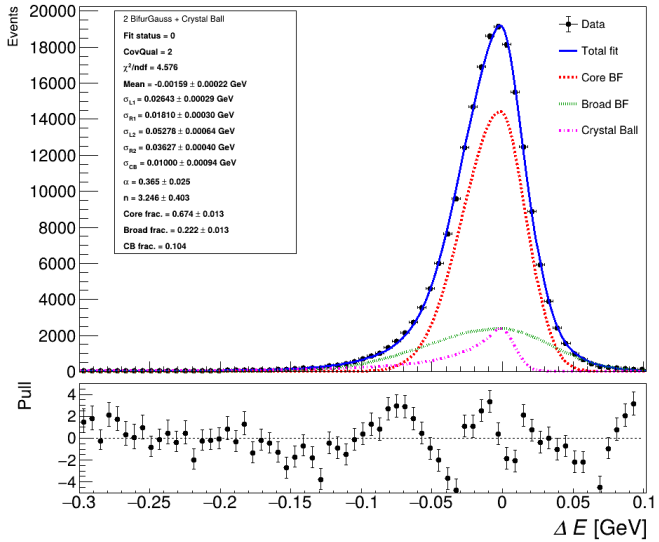
$\eta \to \gamma\gamma$

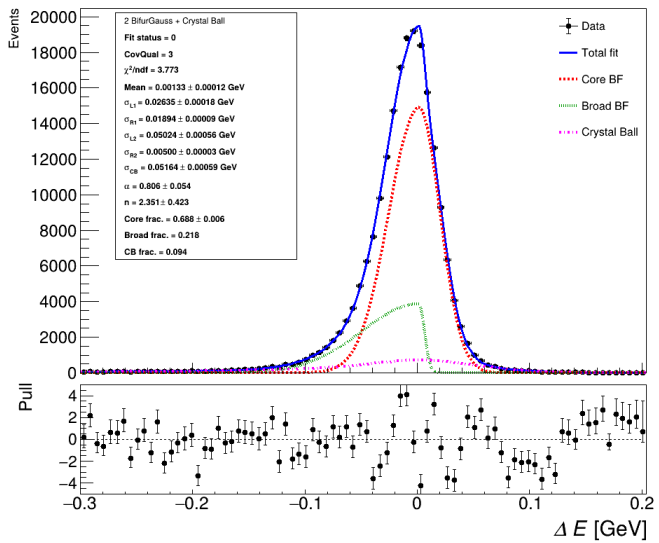


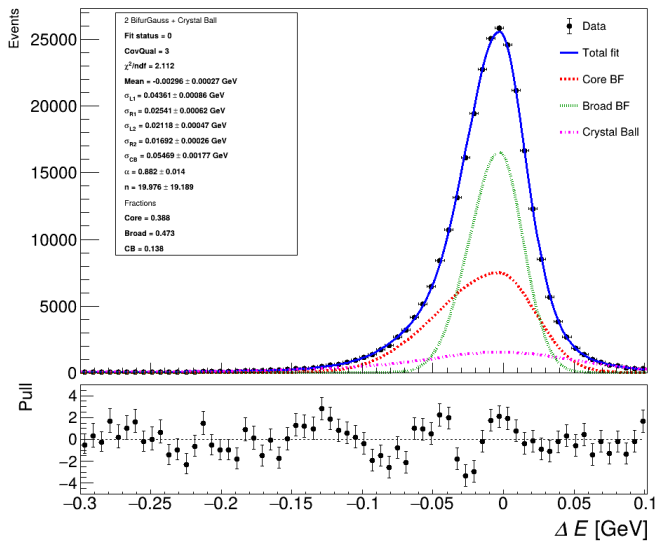




$\eta \to 3\pi$



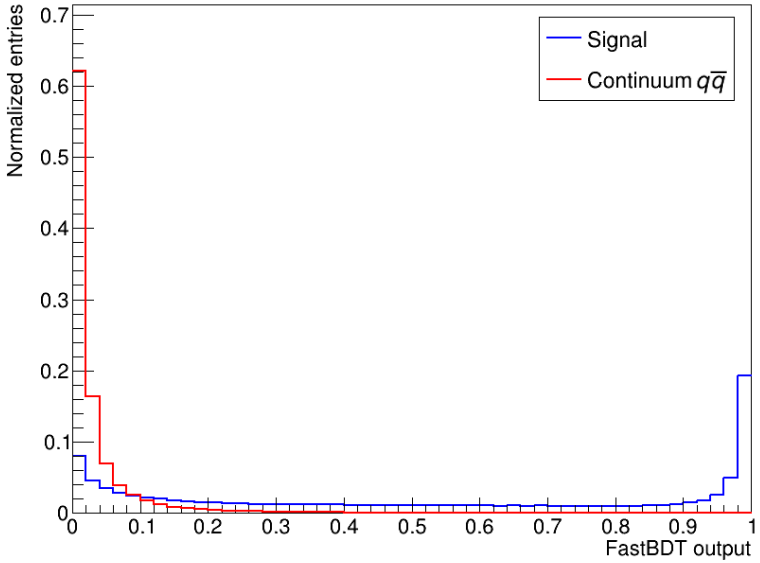




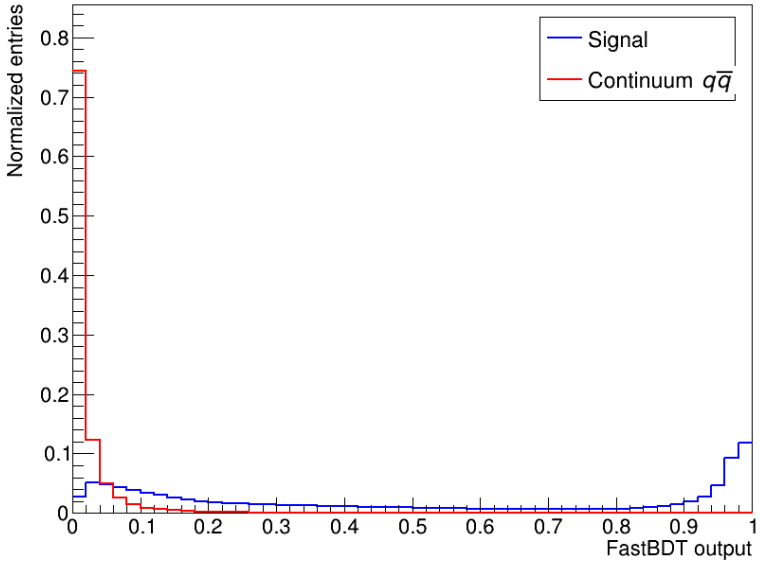
Continuum suppression using BDT

- Using 30 input variables – $cosTBTO$, R_2, $thrustBm$, $thrustOm$

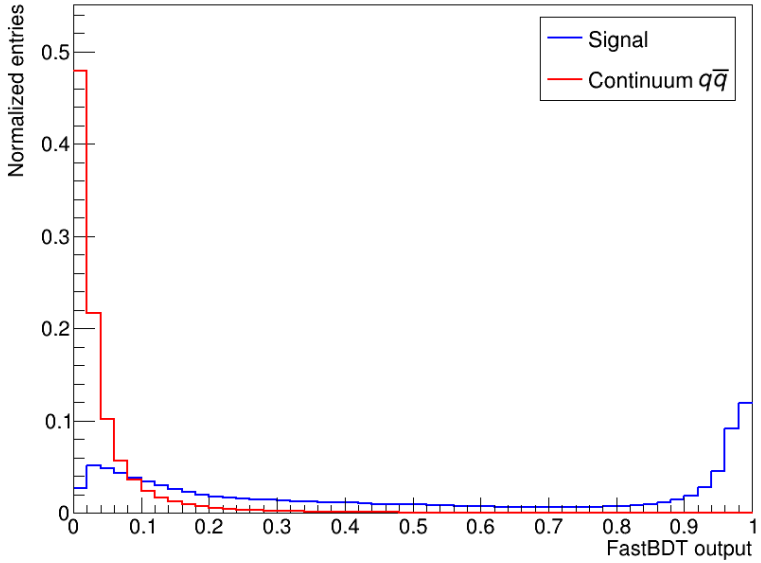
$B^+ \to K^+\eta$



$B^+ \to \pi^+\eta$



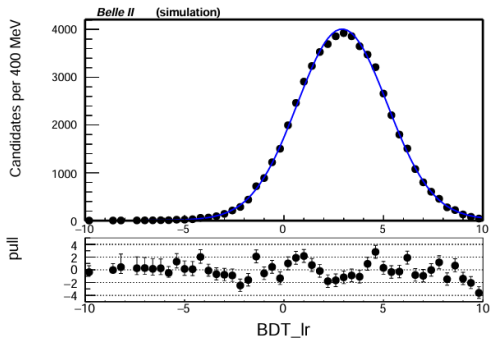
$B^0 \to K^0_S\eta$



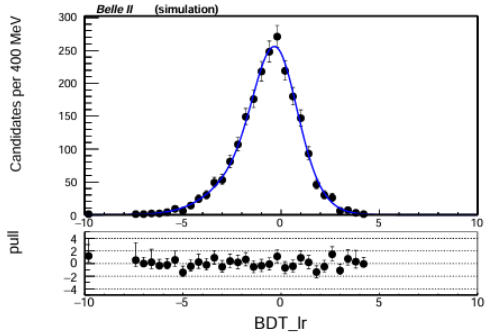
- BDT output is transfored into $\mathrm{BDT_lr} = log\frac{\mathrm{BDT} - \mathrm{BDT_{cut\text{-}off}}}{\mathrm{BDT_{Max}} - \mathrm{BDT}}$ and the distributions are fitted (3D dimension of the fit)

Plan

- Perform a fit $\mathrm{BDT_lr} = log\frac{\mathrm{BDT} - \mathrm{BDT_{cut\text{-}off}}}{\mathrm{BDT_{Max}} - \mathrm{BDT}}$ to extract the shape



Signal



$q\bar{q}$

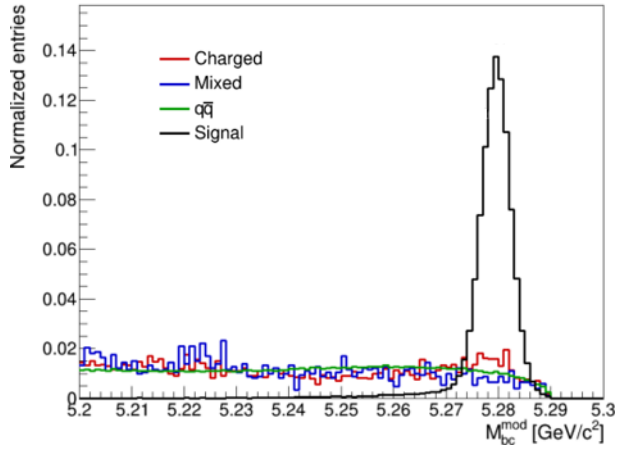
BELLE2-NOTE-PH-2024-015

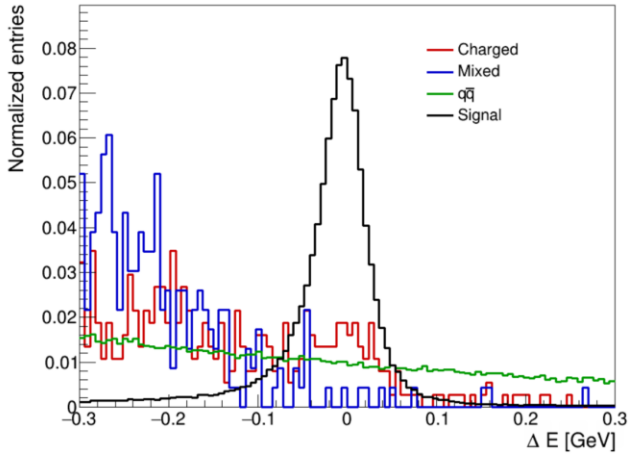
- Construct a 3D fitter to fit the $B^0 \to K_S^0(\eta \to \gamma\gamma/3\pi)$ and $B^+ \to K^+/\pi^+(\eta \to \gamma\gamma/3\pi)$ generic MC data samples and extract the branching fractions

Backup

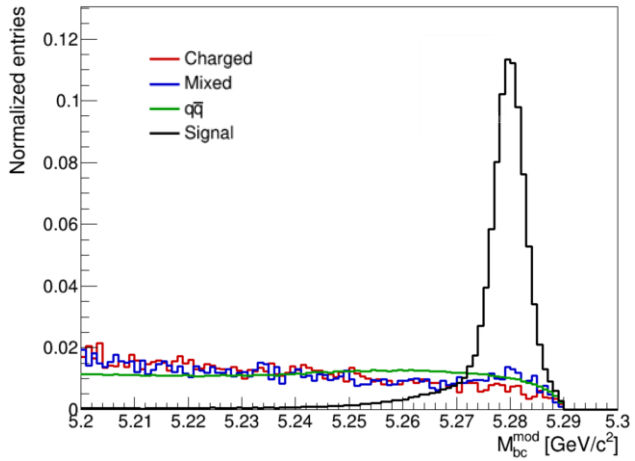
Generic MC16ri and signal MC comparison

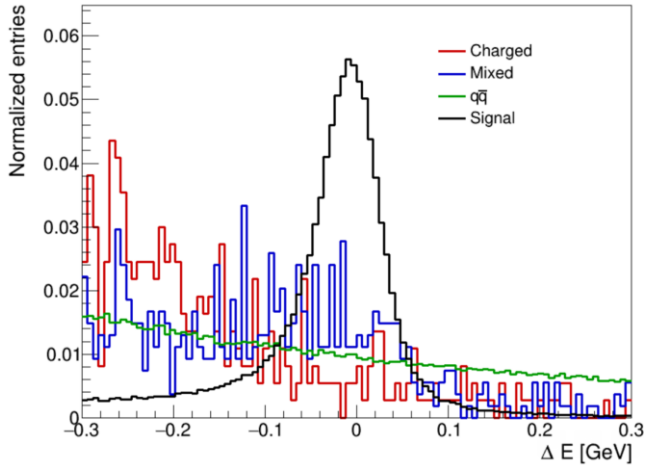
$B^+ \to K^+\eta$





$B^0 \to K_S^0\eta$





$B^+ \to \pi^+\eta$

