$K\tau\tau$ status

18/03/2024

UL

Lepton global PID > 0.9

	$K\ell\ell$	$K\ell\pi$ charge inclusive	$K^+\ell^+\pi^-$ opposite charge	$K^+\pi^+\ell^-$ same charge
Cut-based	Eff: 1.4×10^{-5} Bkg: 4 UL: 0.92×10^{-3}	Eff: 3.2×10^{-5} Bkg: 80 UL: 1.7×10^{-3}	Eff: 1.2×10^{-5} Bkg: 28 UL: 2.8×10^{-3}	Eff: 2.5×10^{-5} Bkg: 67 UL: 2.1×10^{-3}
BDT-based	Eff: 2.2×10^{-5} Bkg: 11 UL: 0.96×10^{-3}	Eff: 2.8×10^{-4} Bkg: 4904 UL: 1.5×10^{-3}	Eff: 1.6×10^{-4} Bkg: 3574 UL: 2.2×10^{-3}	Eff: 1.7×10^{-4} Bkg: 2577 UL: 1.7×10^{-3}

BDT input variables: $\mathrm{M}^2_{\mathrm{miss}}$, $p^*_{\ell^+}$, $m(K^+h^-)$, q^2, cosTBTO

Caveat for BDT:

- Background normalisation is approximated to 0.7 based on previous studies
- No K-folding performed for selecting the optimisation point

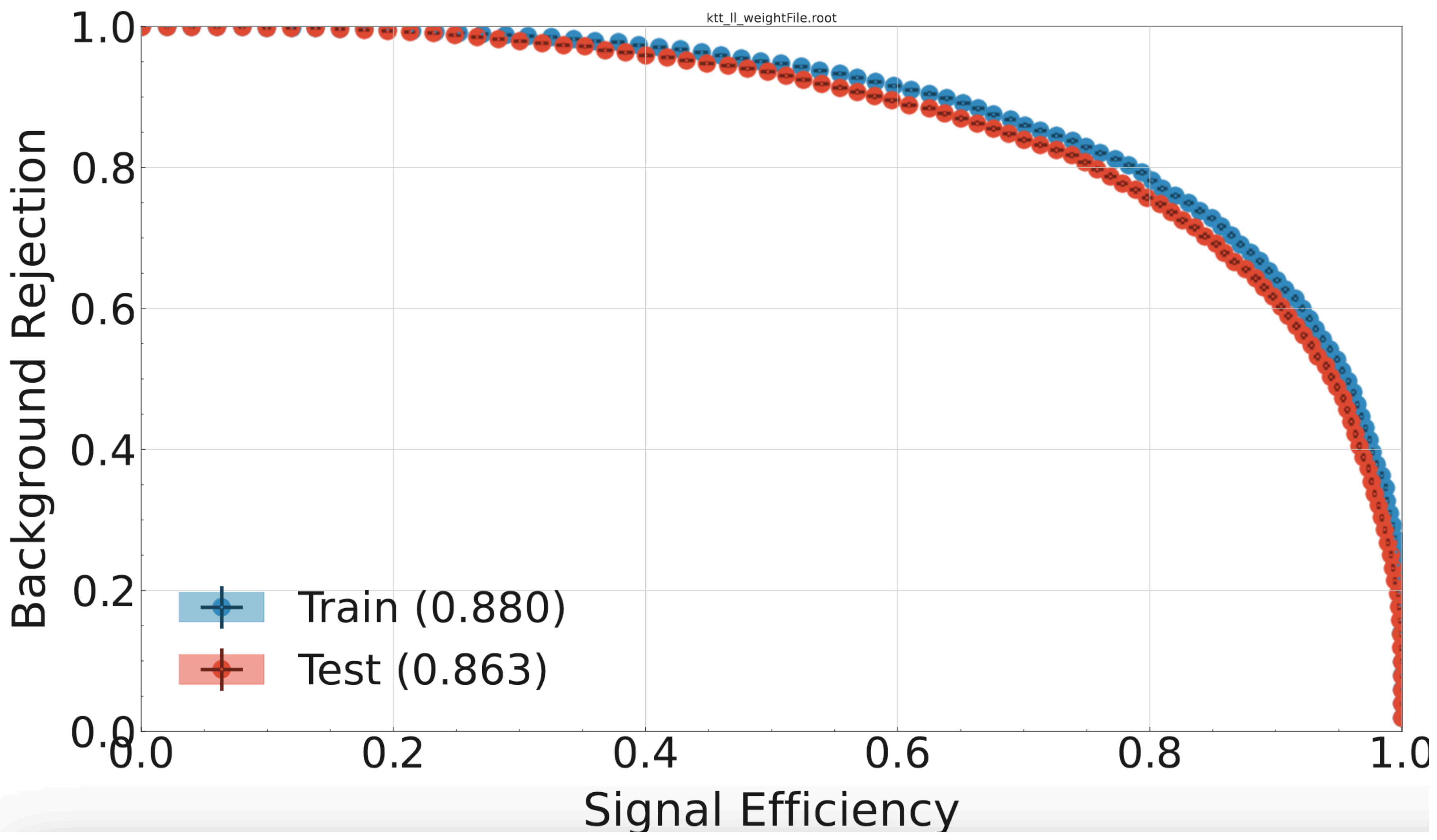
Optimizated cuts

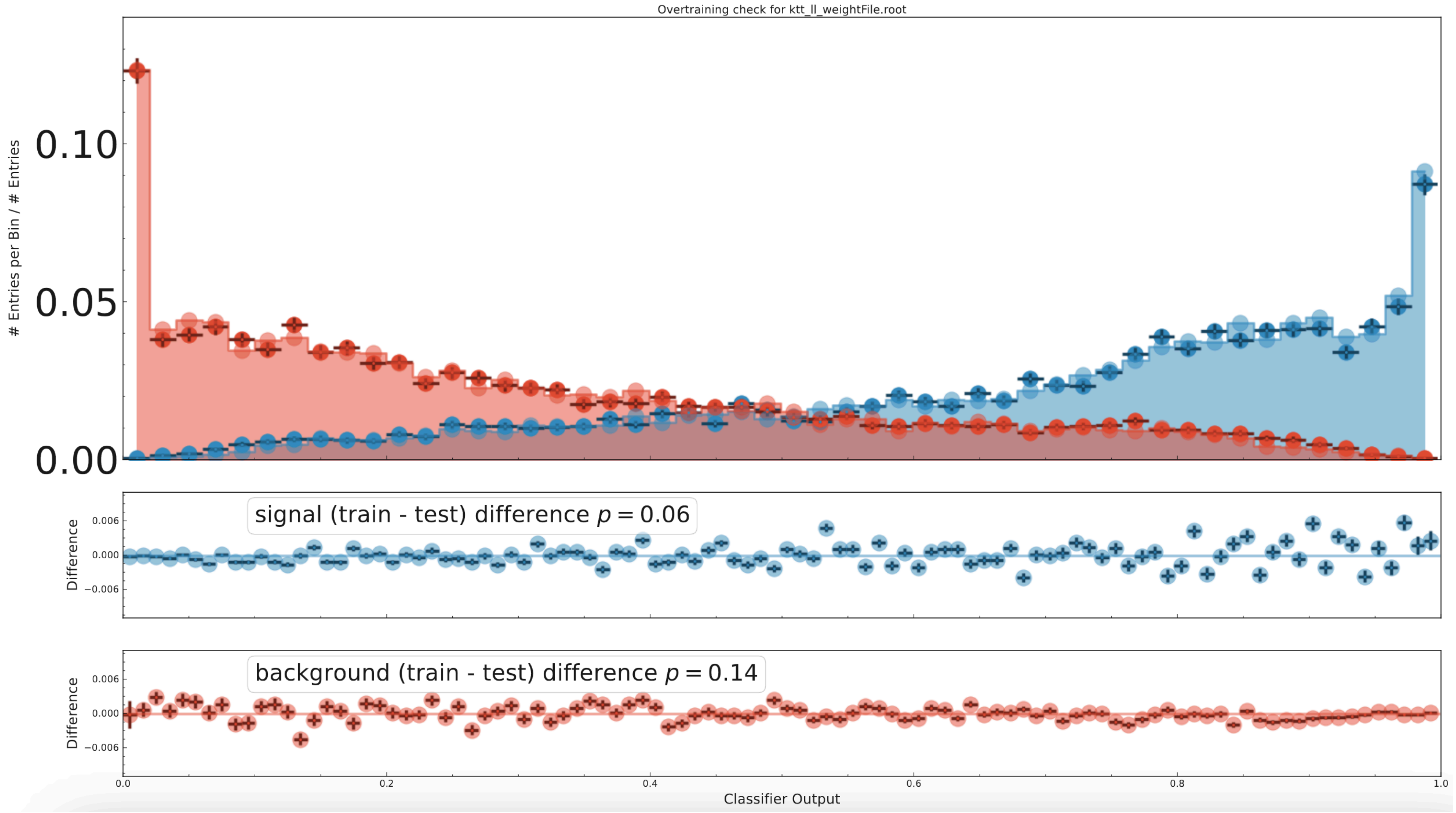
Lepton global PID > 0.9

	$K\ell\ell$	$K\ell\pi$ charge inclusive	$K^+\ell^+\pi^-$ opposite charge	$K^+\pi^+\ell^-$ same charge
Cut-based	$\mathrm{M}^2_{\mathrm{miss}} > 1.4\,\mathrm{GeV}^2/c^4$ $p^*_{\ell^+} > 0.6\,\mathrm{GeV}/c$ $\mathrm{E}_{\mathrm{ECL}} < 250\,\mathrm{MeV}$	$\mathrm{M}^2_{\mathrm{miss}} > 1\,\mathrm{GeV}^2/c^4$ $p^*_{\ell^+} > 0.45\,\mathrm{GeV}/c$ $\mathrm{E}_{\mathrm{ECL}} < 450\,\mathrm{MeV}$ pion global ID > 0.05	$\mathrm{M}^2_{\mathrm{miss}} > 1.5\,\mathrm{GeV}^2/c^4$ $p^*_{\ell^+} > 0.4\,\mathrm{GeV}/c$ $\mathrm{E}_{\mathrm{ECL}} < 400\,\mathrm{MeV}$ pion global ID > 0.05	$\mathrm{M}^2_{\mathrm{miss}} > 0.5\,\mathrm{GeV}^2/c^4$ $p^*_{\ell^+} > 0.45\,\mathrm{GeV}/c$ $\mathrm{E}_{\mathrm{ECL}} < 600\,\mathrm{MeV}$ pion global ID > 0.05
BDT-based	BDT > 0.97 $\mathrm{E}_{\mathrm{ECL}} < 660\,\mathrm{MeV}$	BDT > 0.7 $\mathrm{E}_{\mathrm{ECL}} < 1120\,\mathrm{MeV}$	BDT > 0.7 $\mathrm{E}_{\mathrm{ECL}} < 1310\,\mathrm{MeV}$	BDT > 0.58 $\mathrm{E}_{\mathrm{ECL}} < 1120\,\mathrm{MeV}$

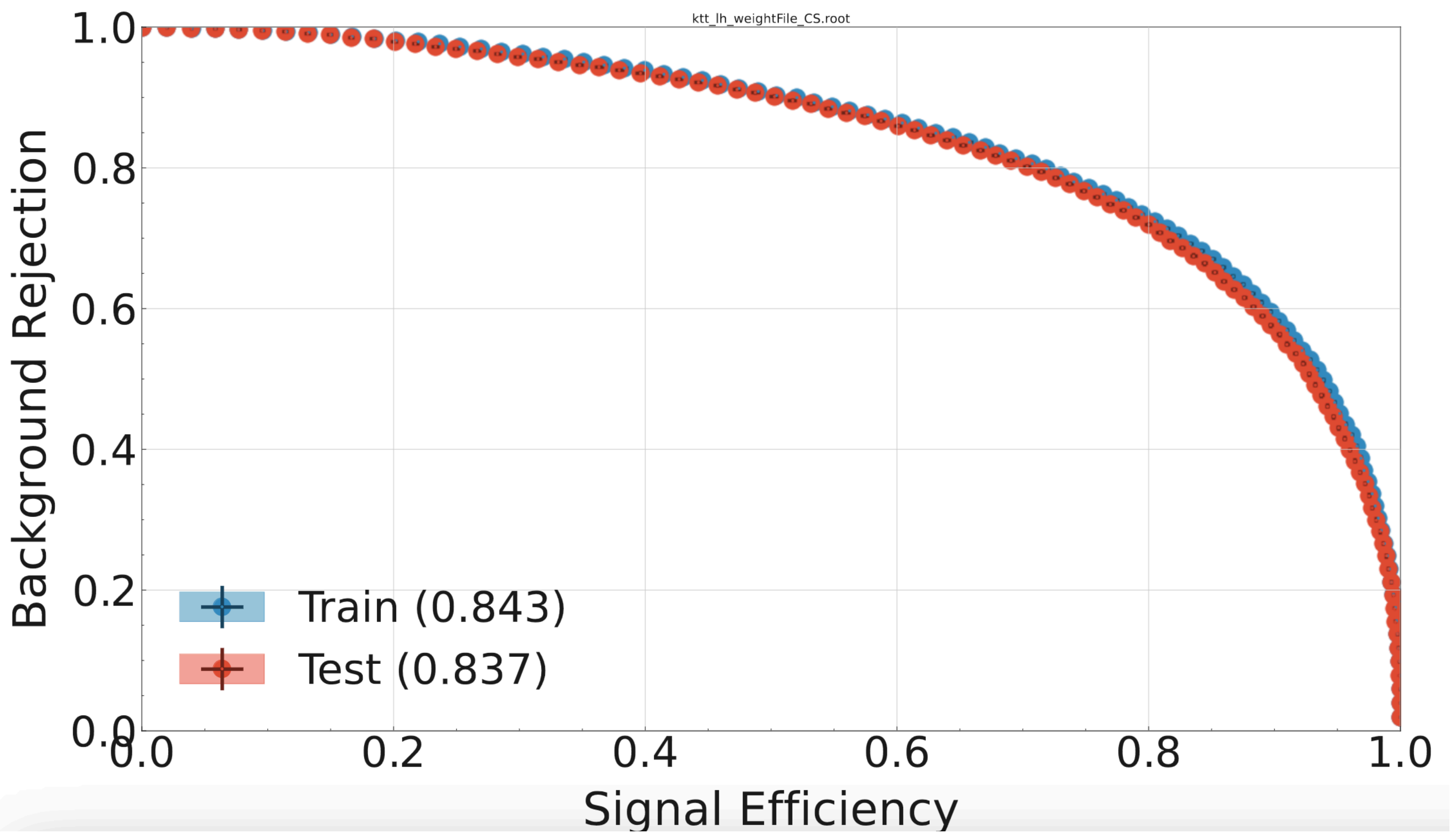
BDT performance

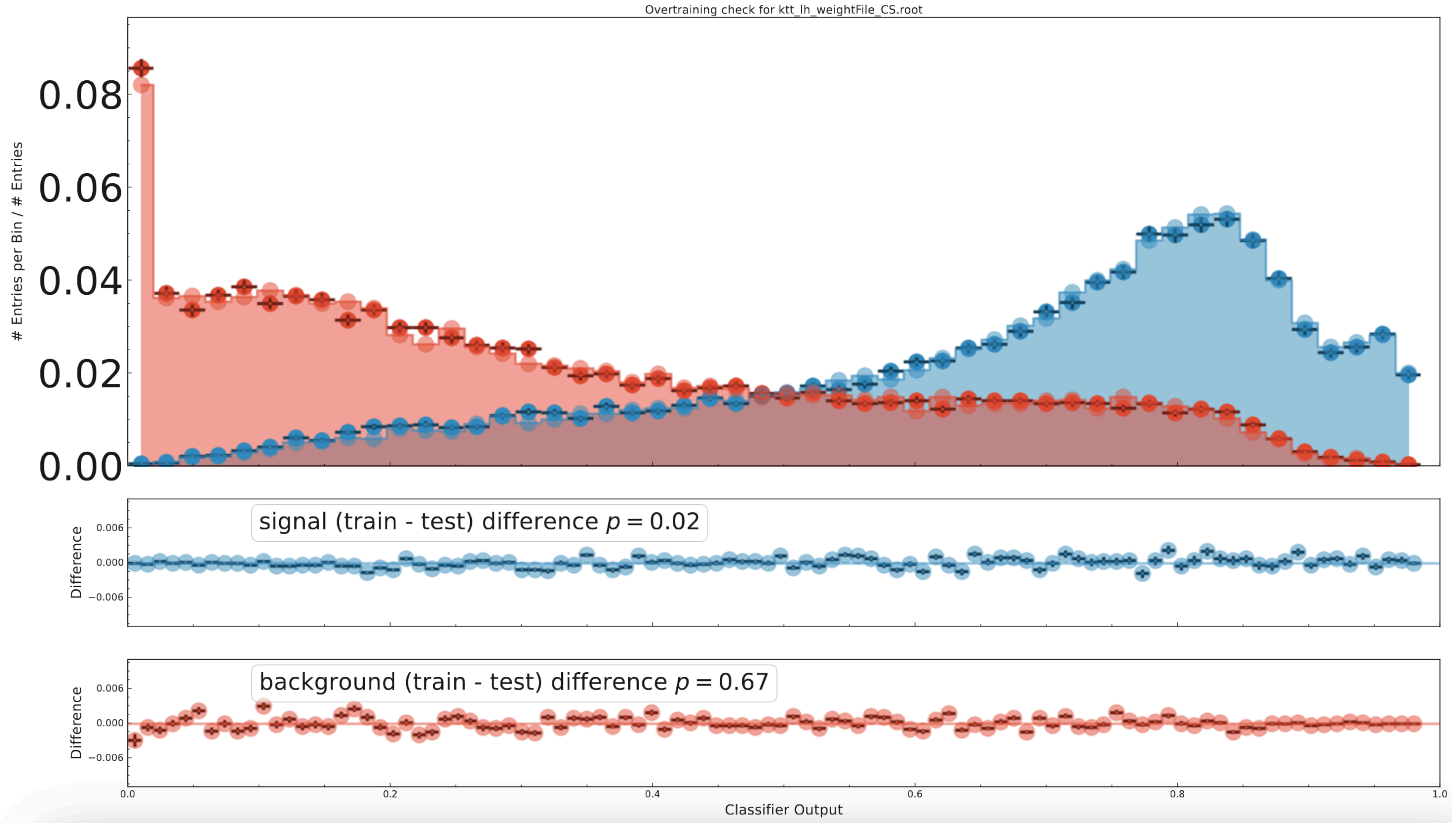
Kll





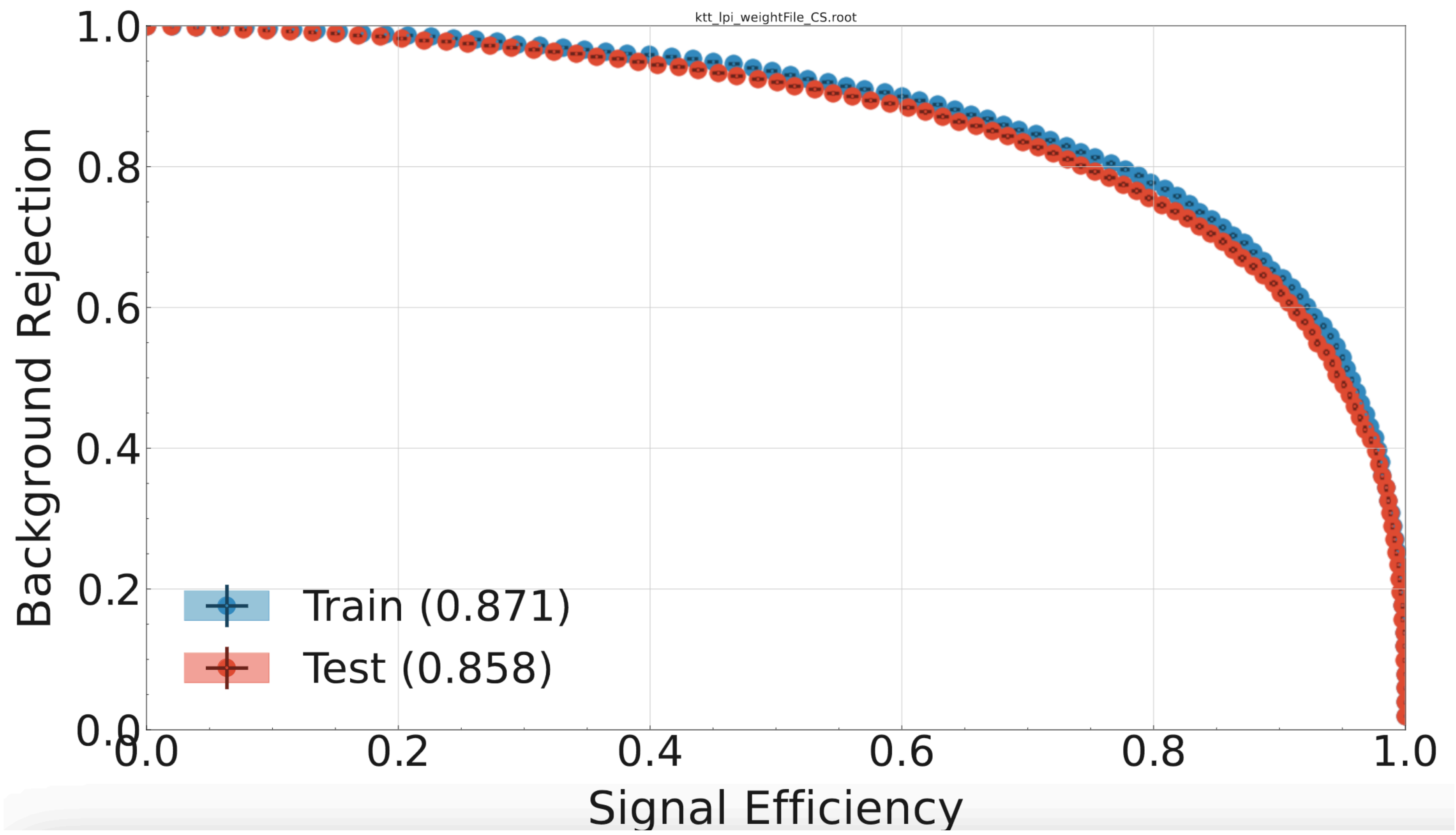
Klh: inclusive

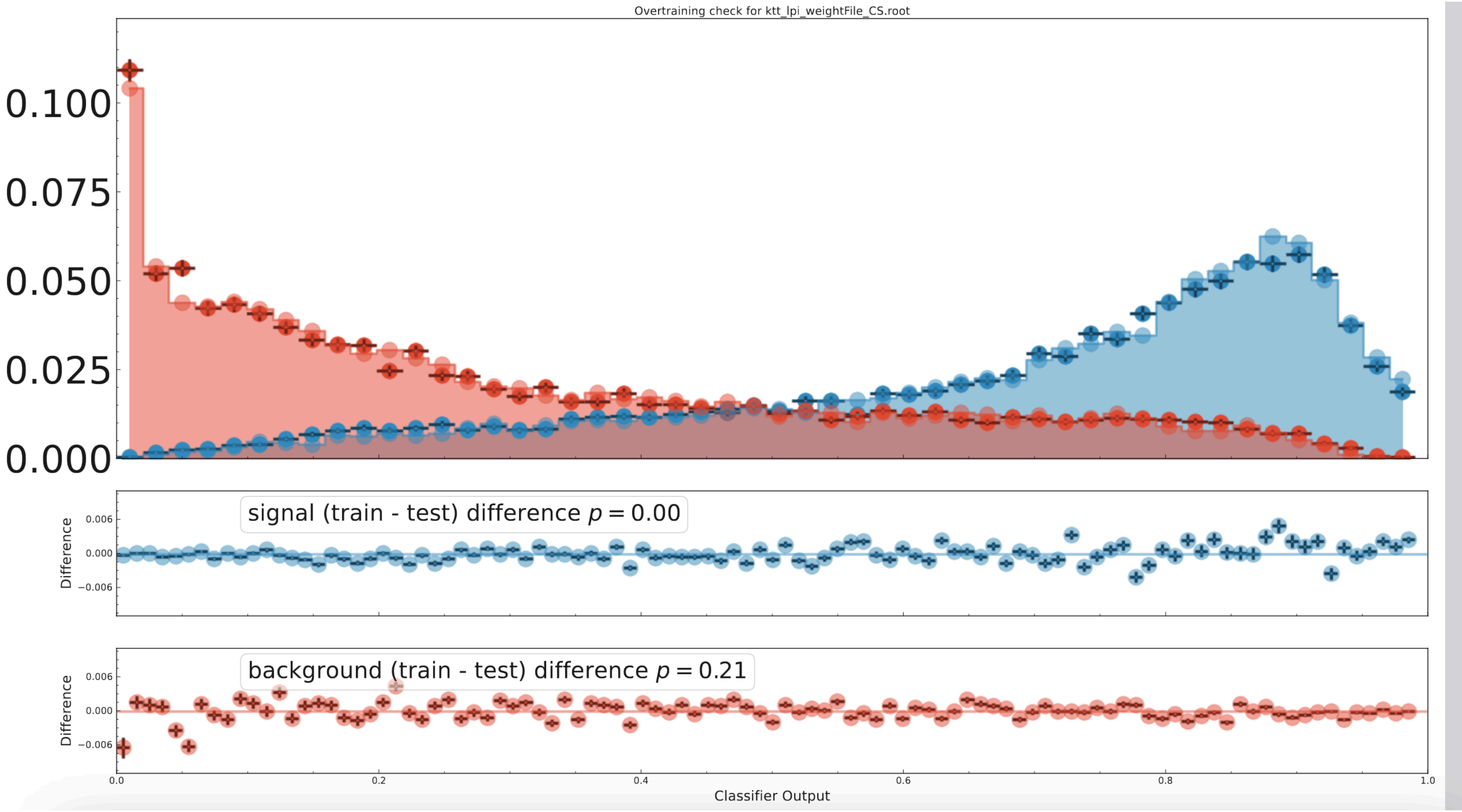




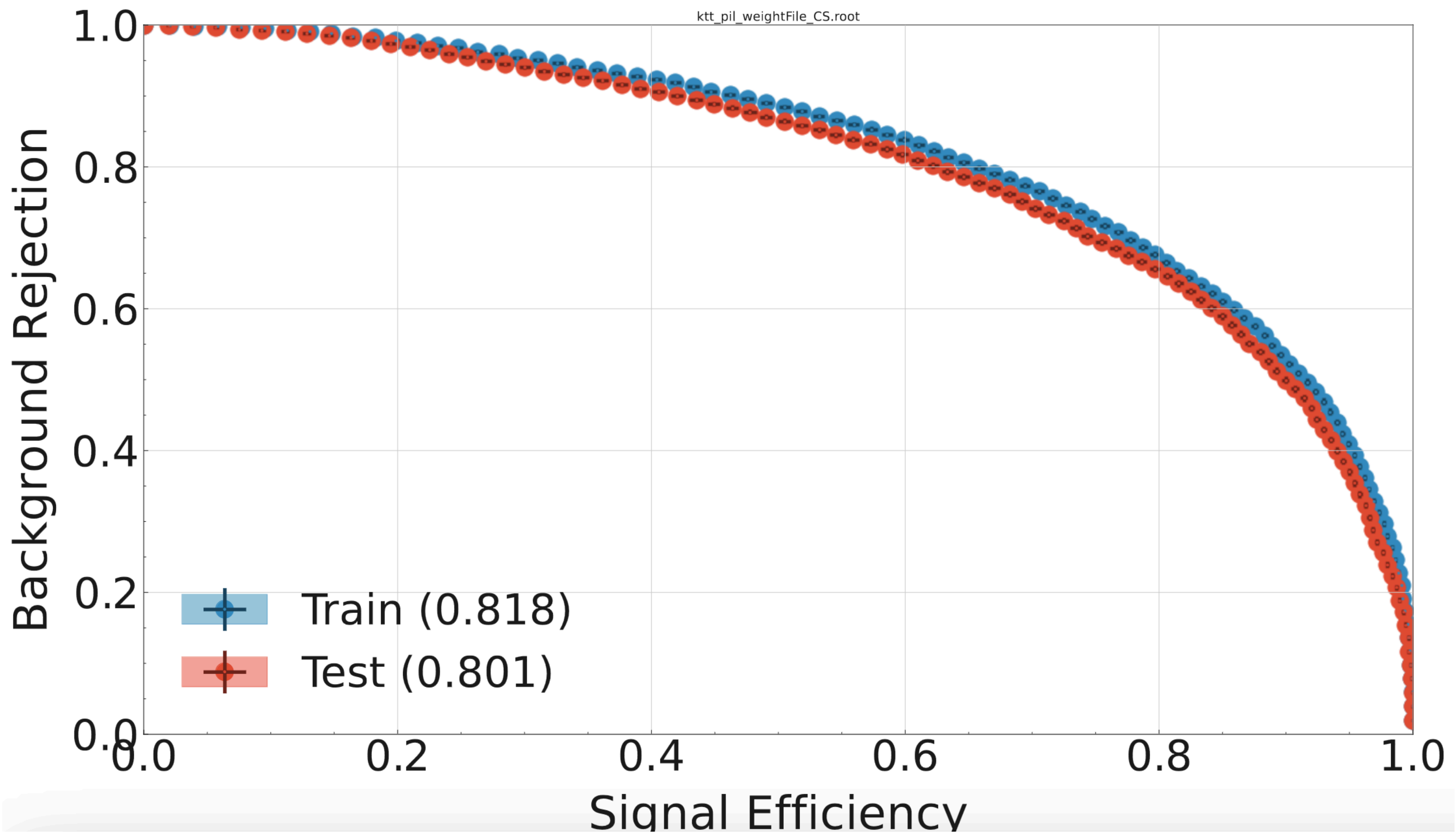
BDT performance

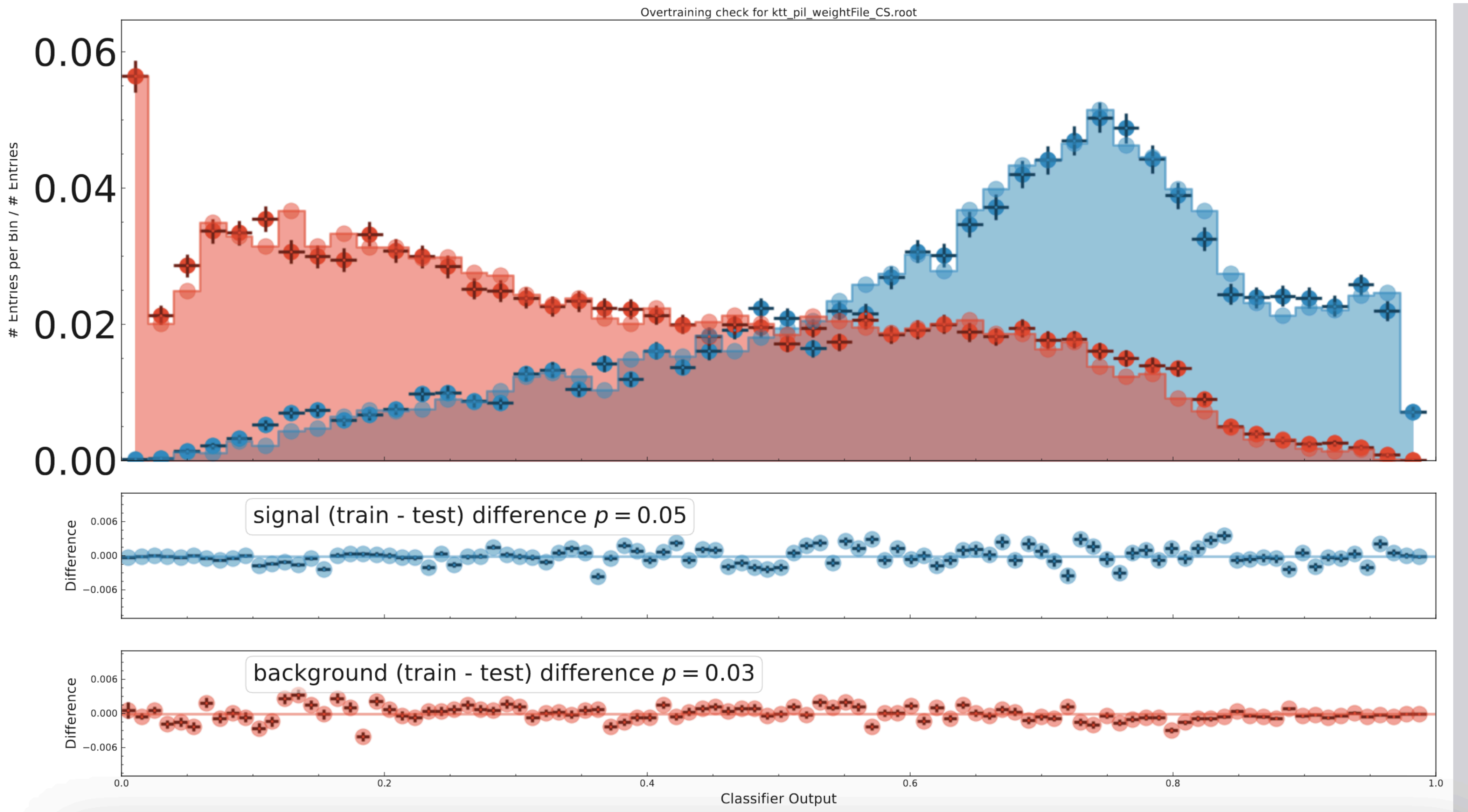
$K^+l^+\pi^-$





$K^+\pi^+l^-$





BDT: separation variables

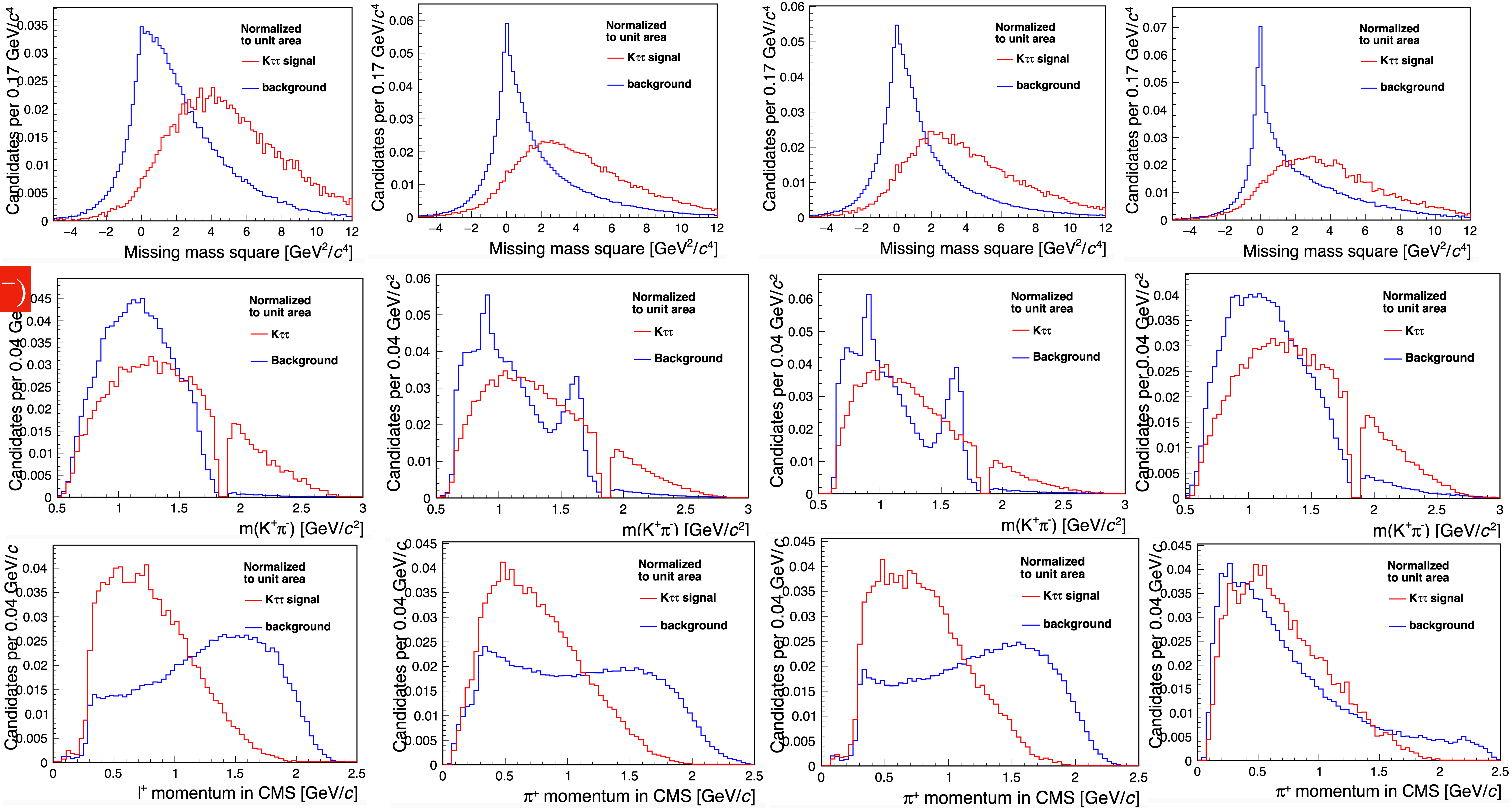
e ID > 0.9; μ ID > 0.9

$K\ell\ell$ | $K\ell\pi$:charge inclusive | opposite charge | same charge

$\mathrm{M}^2_{\mathrm{miss}}$

$m(K^+h^-)$

$p^*_{h^+}$



BDT: separation variables

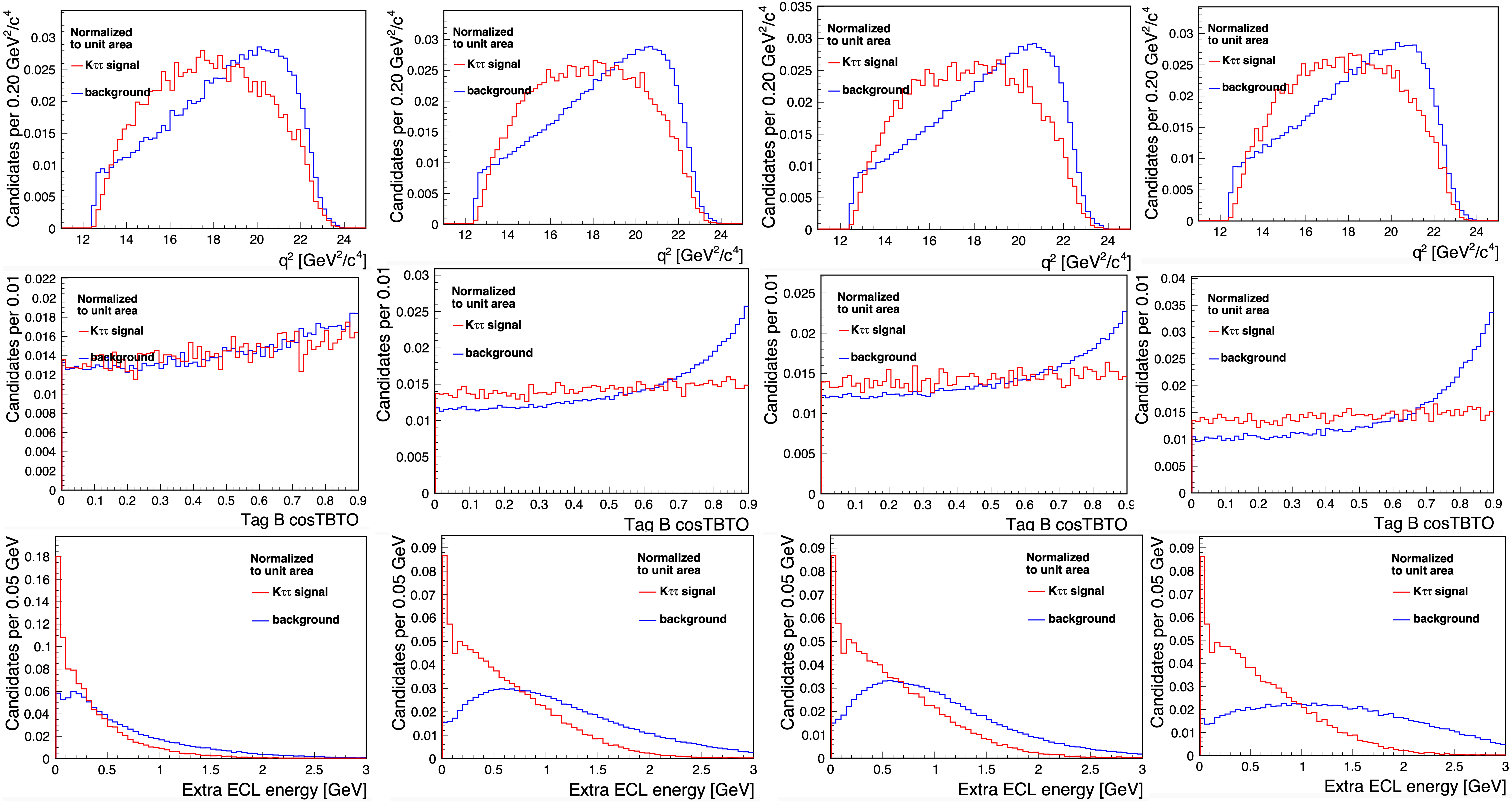
e ID > 0.9; μ ID > 0.9

$K\ell\ell$ | $K\ell\pi$:charge inclusive | opposite charge | same charge

q^2

$\cos\theta_T$

E_{ECL}

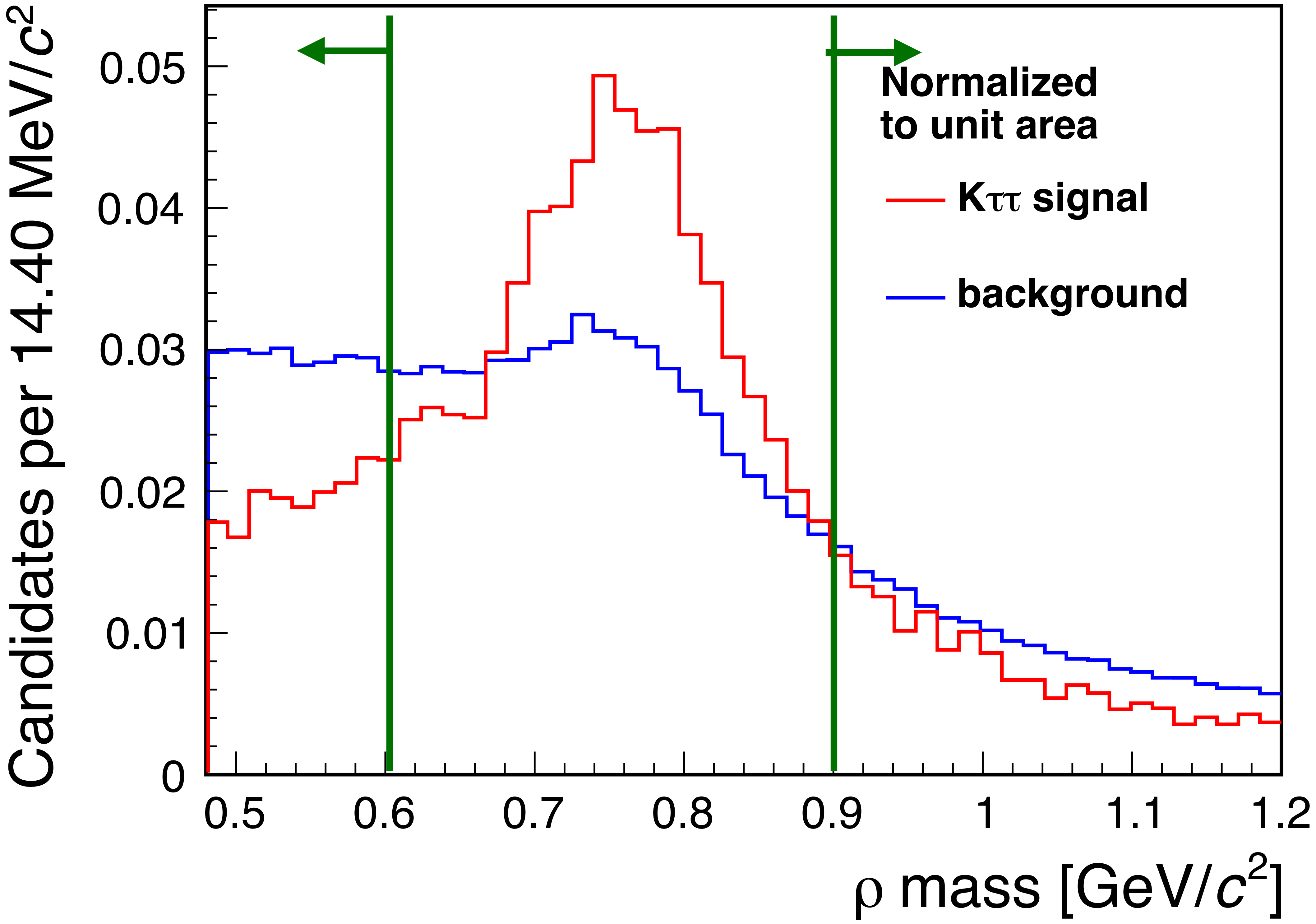


ρ veto

ρ reconstruction

- Check whether ρ veto can improve sensitivity in $K\ell\pi$
- Our π^0 veto: remove events with $m(\gamma\gamma)$ within $0.131 < m(\pi^+\pi^0) < 0.138$ GeV/c^2
- Selection of $\rho^+ \to \pi^+\pi^0$:
  - π^+ from signal τ
  - π^0 in ROE of tag B
    - same γ selection as in E_{ECL}
    - $120 < m(\gamma\gamma) < 150$ MeV/c^2
    - $p > 200$ MeV/c
    - daughter $|\Delta\phi| < 2.2$
    - mass constraint
  - ρ mass: $0.480 < m(\pi^+\pi^0) < 1.2$ GeV/c^2

$K\ell\pi$:charge inclusive



ρ veto: remove events with ρ mass within $0.6 < m(\pi^+\pi^0) < 0.9$ GeV/c^2

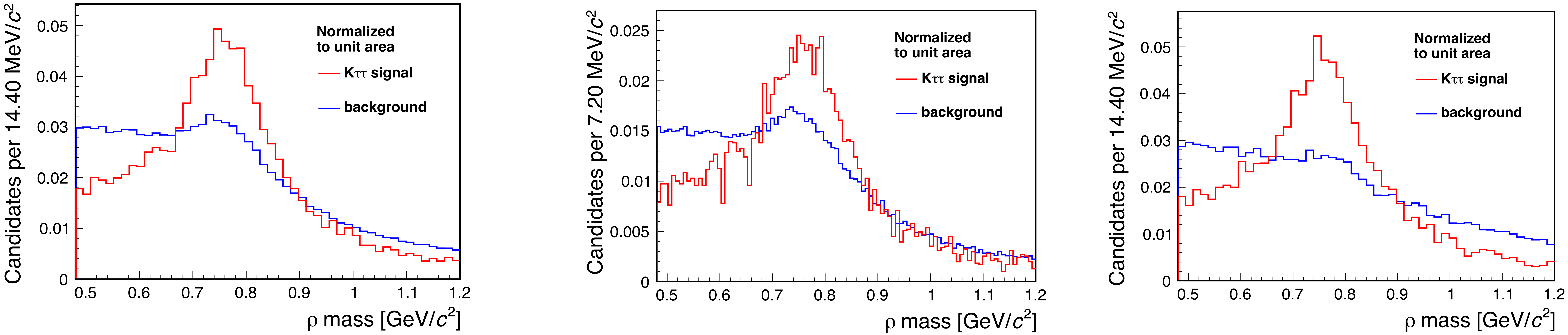
ρ mass

$K\ell\pi$:charge inclusive

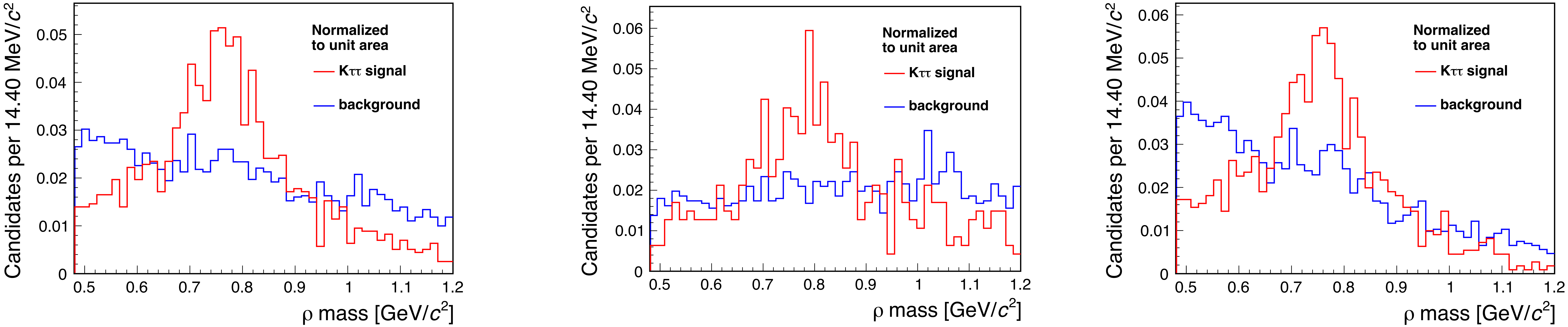
opposite charge

same charge

no $m(K^+h^-)$ cut



$m(K^+h^-) > 1.9$ GeV/c^2



Signal has more ρ peak shape than background. Same veto cut for all cases

ρ veto: reduction rate

no $m(K^+h^-)$ cut

	Charge inclusive	**Opposite charge pion**	**Same charge pion**
Signal	18%	18%	18%
Background	23%	23%	23%

$m(K^+h^-) > 1.9$ GeV/c^2

	Charge inclusive	**Opposite charge pion**	**Same charge pion**
Signal	14%	11%	16%
Background	17%	15%	18%

Won't change sensitivity. Either improve ρ reconstruction or don't apply ρ veto

Backup

Strategy

- Divide into two independent samples ($K\ell\ell$ and $K\ell\pi$) based on electron PID and muon PID.
- Highest preference to $K\ell\ell$ in best candidate selection: pick randomly $K\ell\ell$ candidate; if there is no $K\ell\ell$ then randomly choose a $K\ell\pi$ candidate
- Optimize the cuts on separation variable or on BDT (easier to check in cut-based first) in both cases to find the best expected limit. In pion, we will add pion global PID into the optimization on top of inverse lepton PID cuts
- K-folding with 5 samples to mitigate the fluctuation
- We repeat this process with different leptonID selections

Cut-based: separation variables

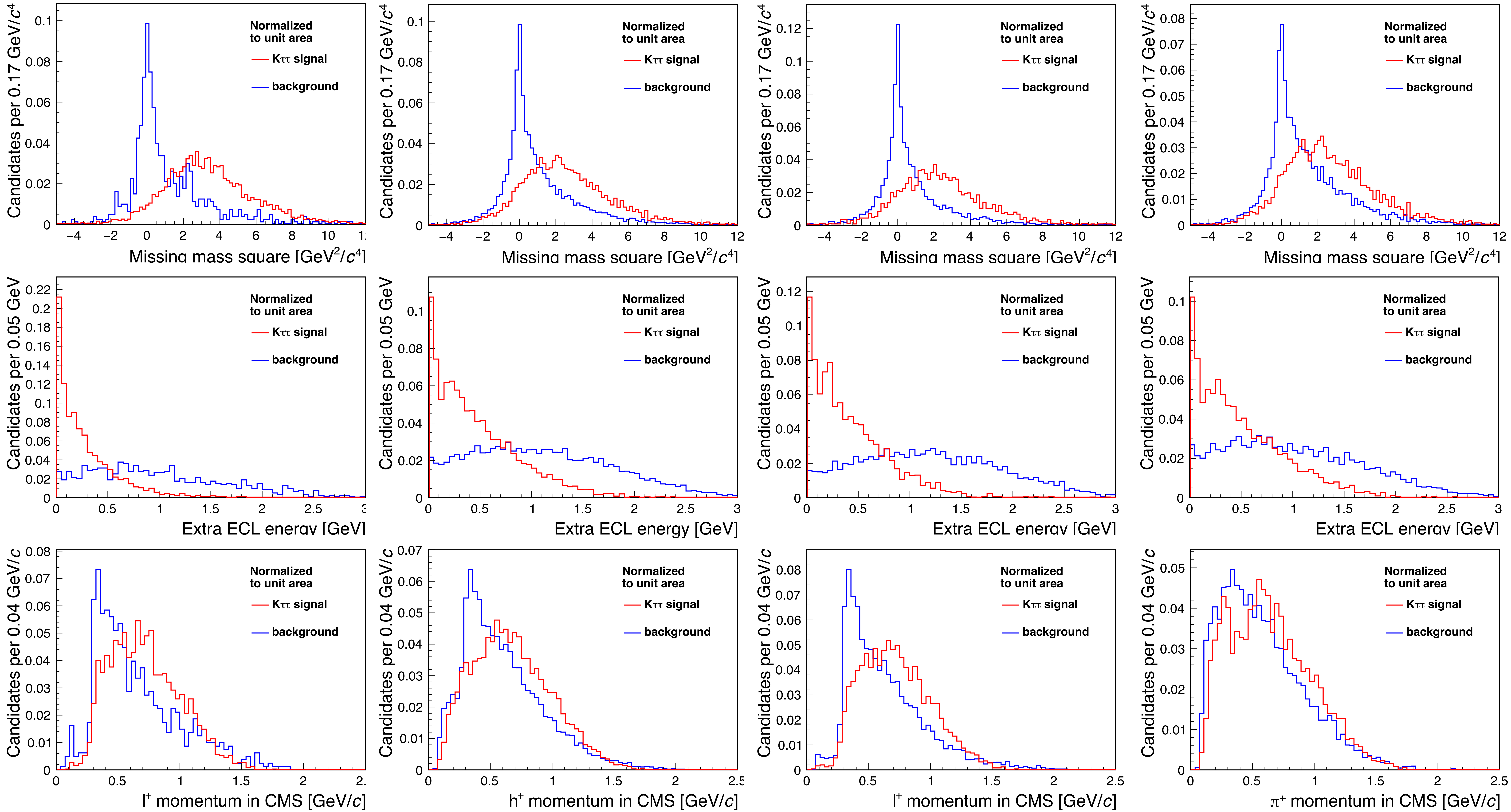
e ID > 0.9; μ ID > 0.9

$K\ell\ell$ | $K\ell\pi$:charge inclusive | opposite charge | same charge

M^2_{miss}

E_{ECL}

$p^*_{h^+}$



Cut-based UL

Lepton global PID	$K\ell\ell$	$K\ell\pi$ charge inclusive	$K^+\ell^+\pi^-$ opposite charge	$K^+\pi^+\ell^-$ same charge
e ID > 0.7 μ ID > 0.7	Eff: 1.5×10^{-5} Bkg: 5 UL: 0.98×10^{-3}	Eff: 3.5×10^{-5} Bkg: 107 UL: 1.8×10^{-3}	Eff: 1.3×10^{-5} Bkg: 39 UL: 2.9×10^{-3}	Eff: 2.0×10^{-5} Bkg: 54 UL: 2.3×10^{-3}
e ID > 0.8 μ ID > 0.8	Eff: 1.2×10^{-5} Bkg: 2 UL: 0.85×10^{-3}	Eff: 4.1×10^{-5} Bkg: 137 UL: 1.8×10^{-3}	Eff: 1.3×10^{-5} Bkg: 36 UL: 2.9×10^{-3}	Eff: 2.5×10^{-5} Bkg: 72 UL: 2.1×10^{-3}
e ID > 0.9 μ ID > 0.9	Eff: 1.4×10^{-5} Bkg: 4 UL: 0.92×10^{-3}	Eff: 3.2×10^{-5} Bkg: 80 UL: 1.7×10^{-3}	Eff: 1.2×10^{-5} Bkg: 28 UL: 2.8×10^{-3}	Eff: 2.5×10^{-5} Bkg: 67 UL: 2.1×10^{-3}

Similar performance on different lepton PID choices. UL of $K\ell\pi$ is twice as $K\ell\ell$.
We want to see if BDT can reduce this differences.

Cut-based UL: optimized cuts

Lepton global PID	$K\ell\ell$	$K\ell\pi$ charge inclusive	$K^+\ell^+\pi^-$ opposite charge	$K^+\pi^+\ell^-$ same charge
e ID > 0.7 μ ID > 0.7	$\mathrm{M}^2_{\mathrm{miss}} > 2.375\,\mathrm{GeV}^2/c^4$ $p^*_{\ell^+} > 0.5\,\mathrm{GeV}/c$ $\mathrm{E}_{\mathrm{ECL}} < 250\,\mathrm{MeV}$	$\mathrm{M}^2_{\mathrm{miss}} > 1\,\mathrm{GeV}^2/c^4$ $p^*_{\ell^+} > 0.45\,\mathrm{GeV}/c$ $\mathrm{E}_{\mathrm{ECL}} < 550\,\mathrm{MeV}$ pion global ID > 0.05	$\mathrm{M}^2_{\mathrm{miss}} > 1.125\,\mathrm{GeV}^2/c^4$ $p^*_{\ell^+} > 0.3\,\mathrm{GeV}/c$ $\mathrm{E}_{\mathrm{ECL}} < 350\,\mathrm{MeV}$ pion global ID > 0.05	$\mathrm{M}^2_{\mathrm{miss}} > 0.5\,\mathrm{GeV}^2/c^4$ $p^*_{\ell^+} > 0.45\,\mathrm{GeV}/c$ $\mathrm{E}_{\mathrm{ECL}} < 450\,\mathrm{MeV}$ pion global ID > 0.25
e ID > 0.8 μ ID > 0.8	$\mathrm{M}^2_{\mathrm{miss}} > 2.25\,\mathrm{GeV}^2/c^4$ $p^*_{\ell^+} > 0.5\,\mathrm{GeV}/c$ $\mathrm{E}_{\mathrm{ECL}} < 150\,\mathrm{MeV}$	$\mathrm{M}^2_{\mathrm{miss}} > 0.5\,\mathrm{GeV}^2/c^4$ $p^*_{\ell^+} > 0.45\,\mathrm{GeV}/c$ $\mathrm{E}_{\mathrm{ECL}} < 600\,\mathrm{MeV}$ pion global ID > 0.05	$\mathrm{M}^2_{\mathrm{miss}} > 1.125\,\mathrm{GeV}^2/c^4$ $p^*_{\ell^+} > 0.35\,\mathrm{GeV}/c$ $\mathrm{E}_{\mathrm{ECL}} < 350\,\mathrm{MeV}$ pion global ID > 0.05	$\mathrm{M}^2_{\mathrm{miss}} > 0.375\,\mathrm{GeV}^2/c^4$ $p^*_{\ell^+} > 0.45\,\mathrm{GeV}/c$ $\mathrm{E}_{\mathrm{ECL}} < 600\,\mathrm{MeV}$ pion global ID > 0.15
e ID > 0.9 μ ID > 0.9	$\mathrm{M}^2_{\mathrm{miss}} > 1.4\,\mathrm{GeV}^2/c^4$ $p^*_{\ell^+} > 0.6\,\mathrm{GeV}/c$ $\mathrm{E}_{\mathrm{ECL}} < 250\,\mathrm{MeV}$	$\mathrm{M}^2_{\mathrm{miss}} > 1\,\mathrm{GeV}^2/c^4$ $p^*_{\ell^+} > 0.45\,\mathrm{GeV}/c$ $\mathrm{E}_{\mathrm{ECL}} < 450\,\mathrm{MeV}$ pion global ID > 0.05	$\mathrm{M}^2_{\mathrm{miss}} > 1.5\,\mathrm{GeV}^2/c^4$ $p^*_{\ell^+} > 0.4\,\mathrm{GeV}/c$ $\mathrm{E}_{\mathrm{ECL}} < 400\,\mathrm{MeV}$ pion global ID > 0.05	$\mathrm{M}^2_{\mathrm{miss}} > 0.5\,\mathrm{GeV}^2/c^4$ $p^*_{\ell^+} > 0.45\,\mathrm{GeV}/c$ $\mathrm{E}_{\mathrm{ECL}} < 600\,\mathrm{MeV}$ pion global ID > 0.05

Cut-based: background composition

Before optimization

$E_{ECL} < 600\,\mathrm{MeV}$

Lepton global PID	$K\ell\ell$	$K\ell\pi$ charge inclusive	$K^+\ell^+\pi^-$ opposite charge	$K^+\pi^+\ell^-$ same charge
e ID > 0.7 μ ID > 0.7	Total: 384 B^+B^-: 63% $B^0\bar{B}^0$: 19% $c\bar{c}$: 9% uds : 9%	Total: 3535 B^+B^-: 62% $B^0\bar{B}^0$: 10% $c\bar{c}$: 11% uds : 20%	Total: 1527 B^+B^-: 46% $B^0\bar{B}^0$: 7% $c\bar{c}$: 17% uds : 31%	Total: 2008 B^+B^-: 68% $B^0\bar{B}^0$: 13% $c\bar{c}$: 7% uds : 12%
e ID > 0.8 μ ID > 0.8	Total: 320 B^+B^-: 64% $B^0\bar{B}^0$: 18% $c\bar{c}$: 9% uds : 9%	Total: 3317 B^+B^-: 60% $B^0\bar{B}^0$: 10% $c\bar{c}$: 11% uds : 19%	Total: 1336 B^+B^-: 48% $B^0\bar{B}^0$: 6% $c\bar{c}$: 17% uds : 30%	Total: 1981 B^+B^-: 68% $B^0\bar{B}^0$: 13% $c\bar{c}$: 7% uds : 11%
e ID > 0.9 μ ID > 0.9	Total: 251 B^+B^-: 68% $B^0\bar{B}^0$: 18% $c\bar{c}$: 7% uds : 7%	Total: 3099 B^+B^-: 62% $B^0\bar{B}^0$: 11% $c\bar{c}$: 10% uds : 17%	Total: 1188 B^+B^-: 50% $B^0\bar{B}^0$: 6% $c\bar{c}$: 16% uds : 27%	Total: 1911 B^+B^-: 69% $B^0\bar{B}^0$: 14% $c\bar{c}$: 7% uds : 10%

Cut-based: background composition

After optimization

Lepton global PID	$K\ell\ell$	$K\ell\pi$ charge inclusive	$K^+\ell^+\pi^-$ opposite charge	$K^+\pi^+\ell^-$ same charge
e ID > 0.7 μ ID > 0.7	Total: 26 B^+B^-: 62% $B^0\bar{B}^0$: 23% $c\bar{c}$: 4% uds : 12%	Total: 654 B^+B^-: 54% $B^0\bar{B}^0$: 9% $c\bar{c}$: 13% uds : 34%	Total: 213 B^+B^-: 45% $B^0\bar{B}^0$: 9% $c\bar{c}$: 15% uds : 31%	Total: 328 B^+B^-: 63% $B^0\bar{B}^0$: 11% $c\bar{c}$: 7% uds : 19%
e ID > 0.8 μ ID > 0.8	Total: 13 B^+B^-: 54% $B^0\bar{B}^0$: 23% $c\bar{c}$: 15% uds : 8%	Total: 832 B^+B^-: 54% $B^0\bar{B}^0$: 9% $c\bar{c}$: 13% uds : 24%	Total: 182 B^+B^-: 44% $B^0\bar{B}^0$: 10% $c\bar{c}$: 15% uds : 31%	Total: 468 B^+B^-: 63% $B^0\bar{B}^0$: 10% $c\bar{c}$: 10% uds : 17%
e ID > 0.9 μ ID > 0.9	Total: 21 B^+B^-: 57% $B^0\bar{B}^0$: 29% $c\bar{c}$: 10% uds : 5%	Total: 478 B^+B^-: 57% $B^0\bar{B}^0$: 11% $c\bar{c}$: 10% uds : 22%	Total: 144 B^+B^-: 47% $B^0\bar{B}^0$: 12% $c\bar{c}$: 13% uds : 28%	Total: 444 B^+B^-: 63% $B^0\bar{B}^0$: 11% $c\bar{c}$: 10% uds : 16%

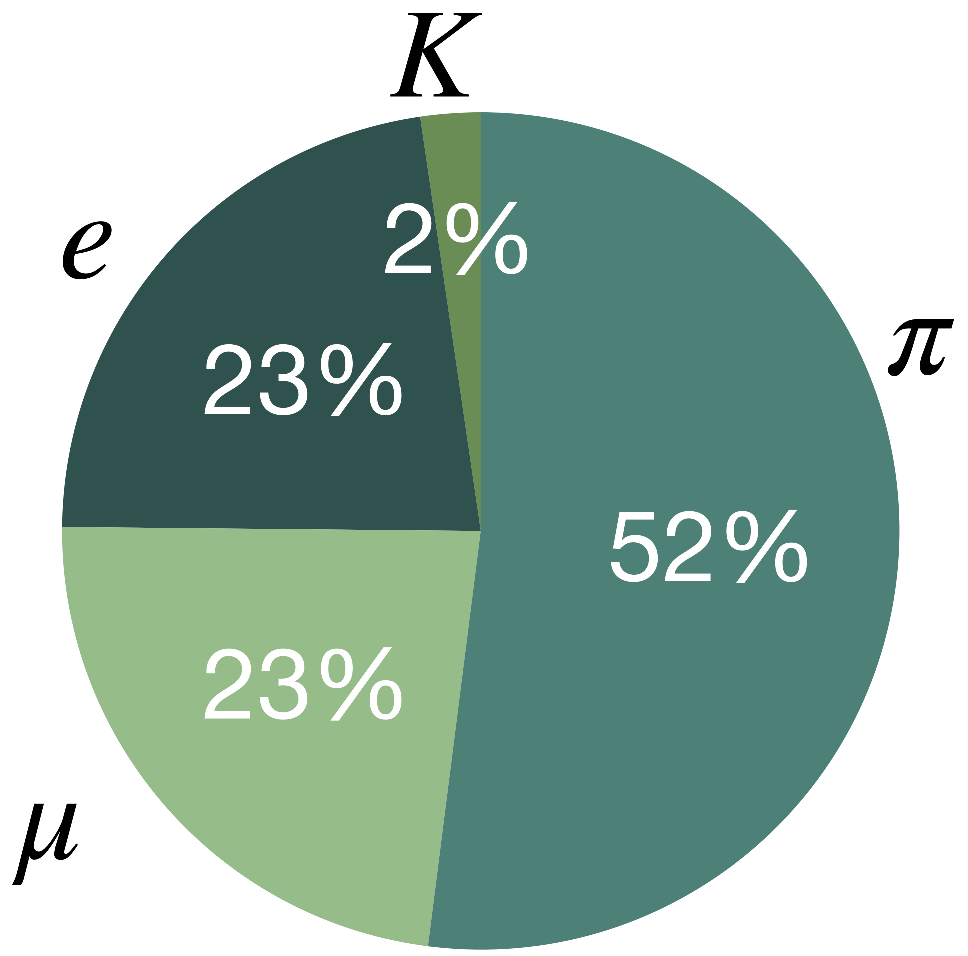
Cut-based: background normalization

Lepton global PID	$K\ell\ell$	$K\ell\pi$ charge inclusive	$K^+\ell^+\pi^-$ opposite charge	$K^+\pi^+\ell^-$ same charge
e ID > 0.7 μ ID > 0.7	0.64 ± 0.27 $\mathrm{E_{ECL}} > 300$ MeV	0.67 ± 0.07 $\mathrm{E_{ECL}} > 600$ MeV	0.78 ± 0.09 $\mathrm{E_{ECL}} > 600$ MeV	0.64 ± 0.08 $\mathrm{E_{ECL}} > 600$ MeV
e ID > 0.8 μ ID > 0.8	0.59 ± 0.23 $\mathrm{E_{ECL}} > 200$ MeV	0.68 ± 0.06 $\mathrm{E_{ECL}} > 600$ MeV	0.75 ± 0.10 $\mathrm{E_{ECL}} > 600$ MeV	0.64 ± 0.08 $\mathrm{E_{ECL}} > 600$ MeV
e ID > 0.9 μ ID > 0.9	0.70 ± 0.08 $\mathrm{E_{ECL}} > 300$ MeV	0.66 ± 0.09 $\mathrm{E_{ECL}} > 600$ MeV	0.71 ± 0.13 $\mathrm{E_{ECL}} > 600$ MeV	0.62 ± 0.08 $\mathrm{E_{ECL}} > 600$ MeV

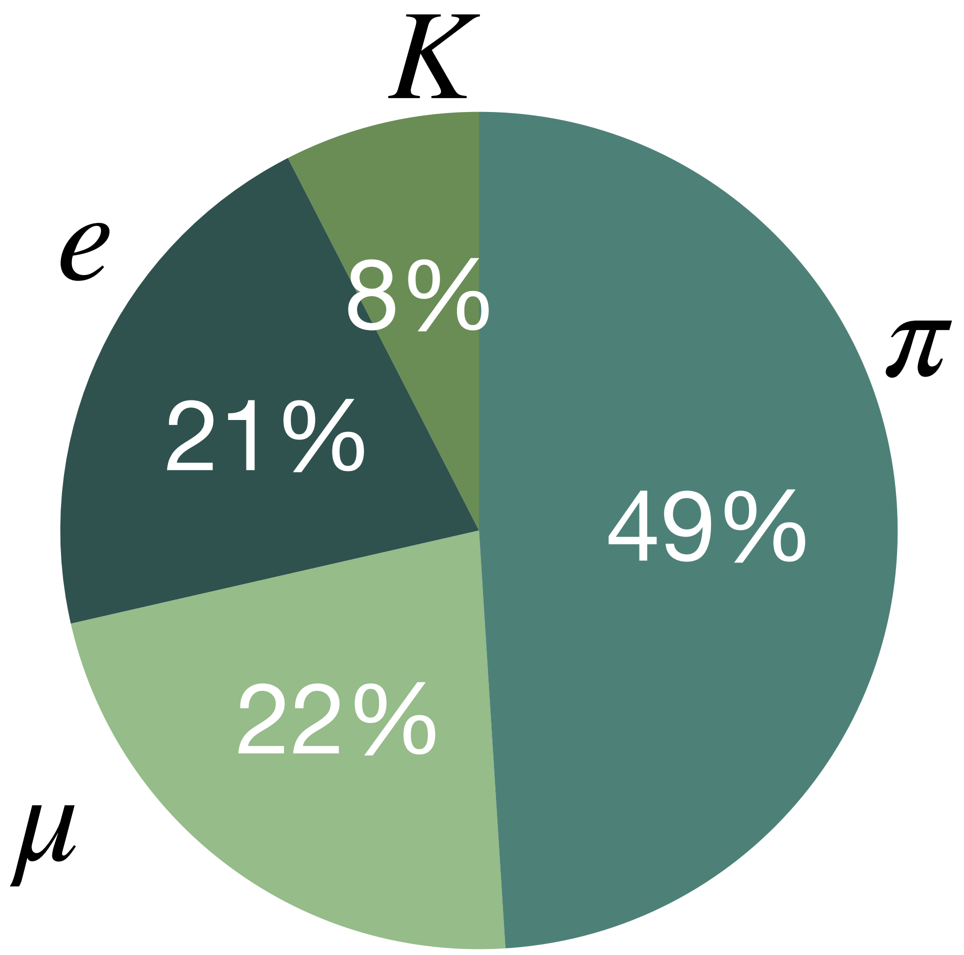
Particle composition on pion track in signal

- No PID selection applied on pion

Opposite charged pion in $K^+\ell^+\pi^-$



Same charged pion in $K^+\pi^+\ell^-$

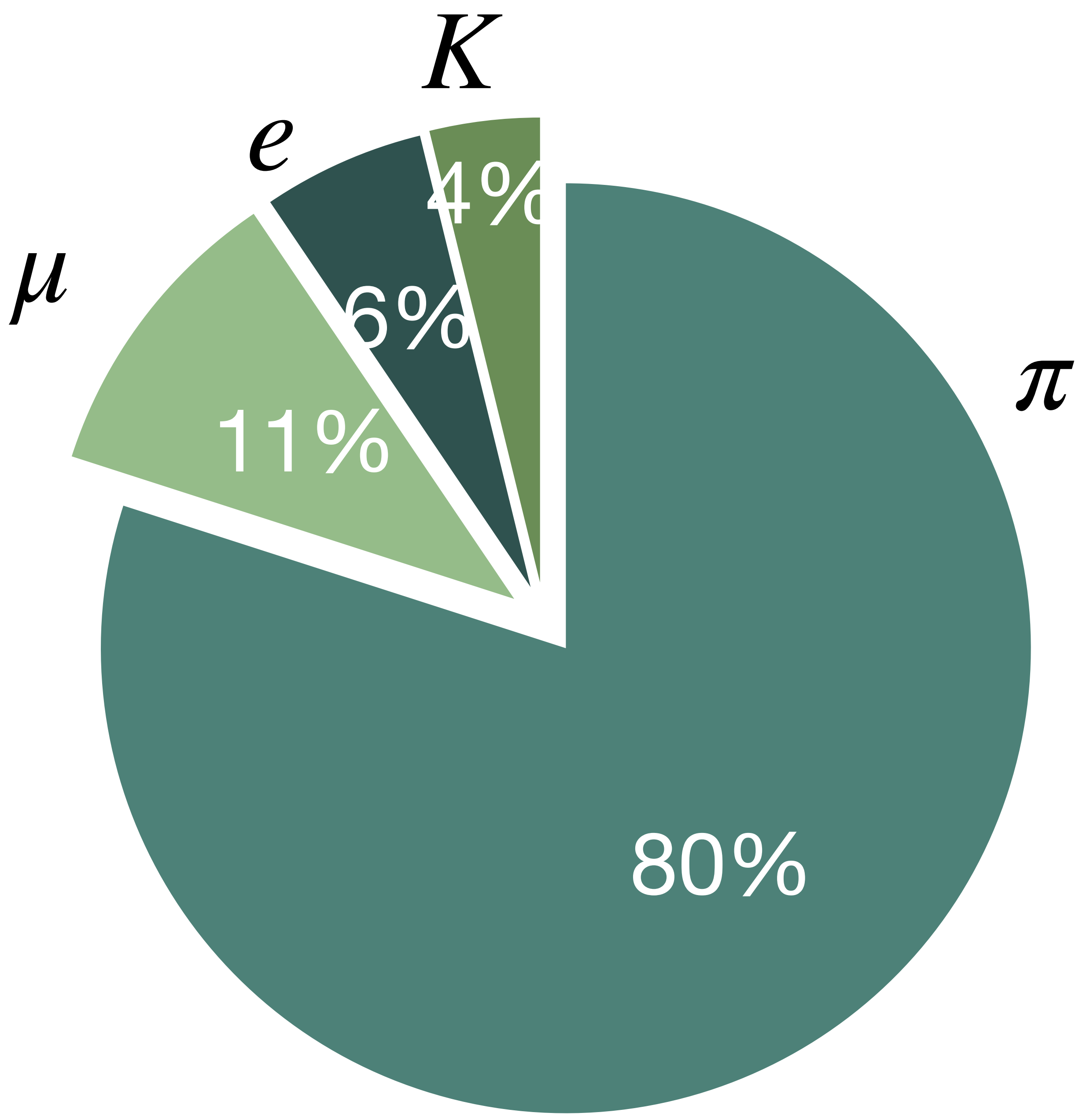


Fakes dominate from both electron and muon

Composition in signal in pion track

$\mathscr{L}(e) < 0.9$ and
$\mathscr{L}(\mu) < 0.9$

Opposite charged pion in $K^+\ell^+\pi^-$



Same charged pion in $K^+\pi^+\ell^-$