$B^0 \to K^0_S \tau^\pm \ell^\mp$ analysis with Hadronic B tagging

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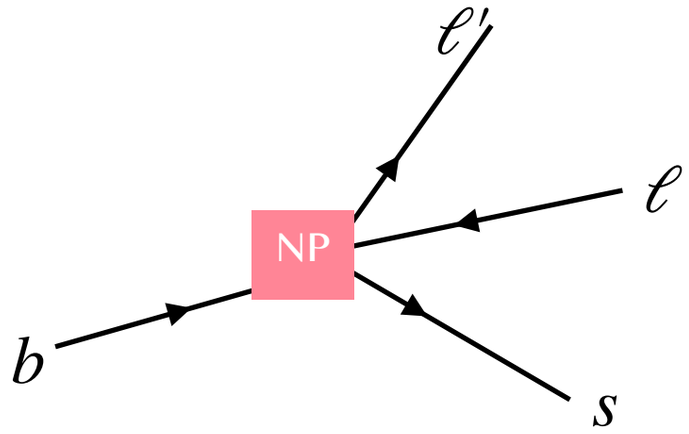
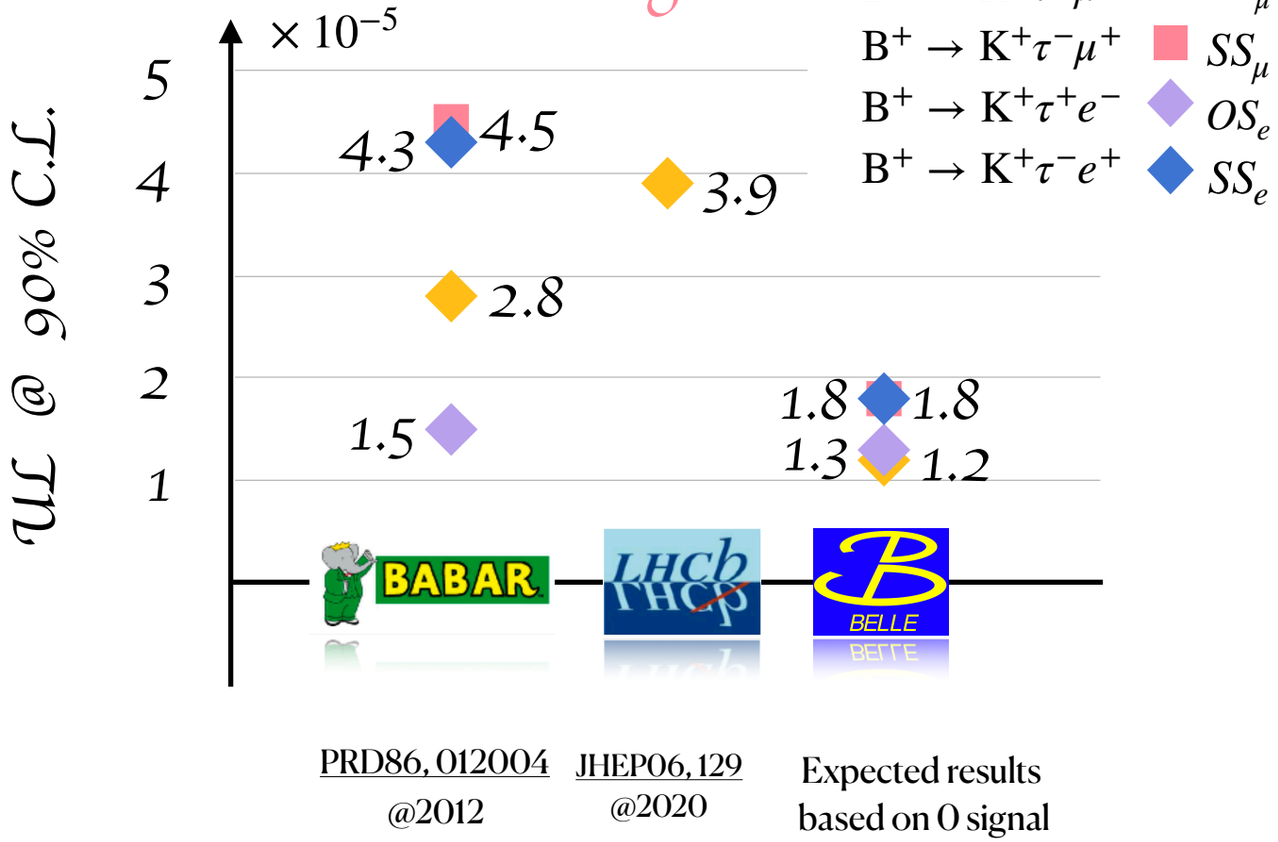
$b \to s\tau\ell$ search in B decays

- B-anomalies hits can be found in $R_{K^{(*)}} = \dfrac{\Gamma\left(B \to K^{(*)}\mu^+\mu^-\right)}{\Gamma\left(B \to K^{(*)}e^+e^-\right)}$ and $R_{D^{(*)}} = \dfrac{\Gamma\left(B \to D^{(*)}\tau\nu\right)}{\Gamma\left(B \to D^{(*)}\mu\nu\right)}$;
- LFV, especially with τ lepton, may arise together with LFUV, which will enhance the branching fraction and can be explained by some NP (leptoquarks, Z'..);
- Search LFV in $b \to s\tau\ell$;
- First measurement in $B^0 \to K^0_S\tau^\pm\ell^\mp$.



$b \to s\tau\ell$ search in charged B



$B^+ \to K^+\tau^+\mu^-$ OS_μ
$B^+ \to K^+\tau^-\mu^+$ SS_μ
$B^+ \to K^+\tau^+e^-$ OS_e
$B^+ \to K^+\tau^-e^+$ SS_e

$b \to s\tau\ell$ search in neutral B

LHCb with 9 fb^{-1} data, shown at ICHEP 2022

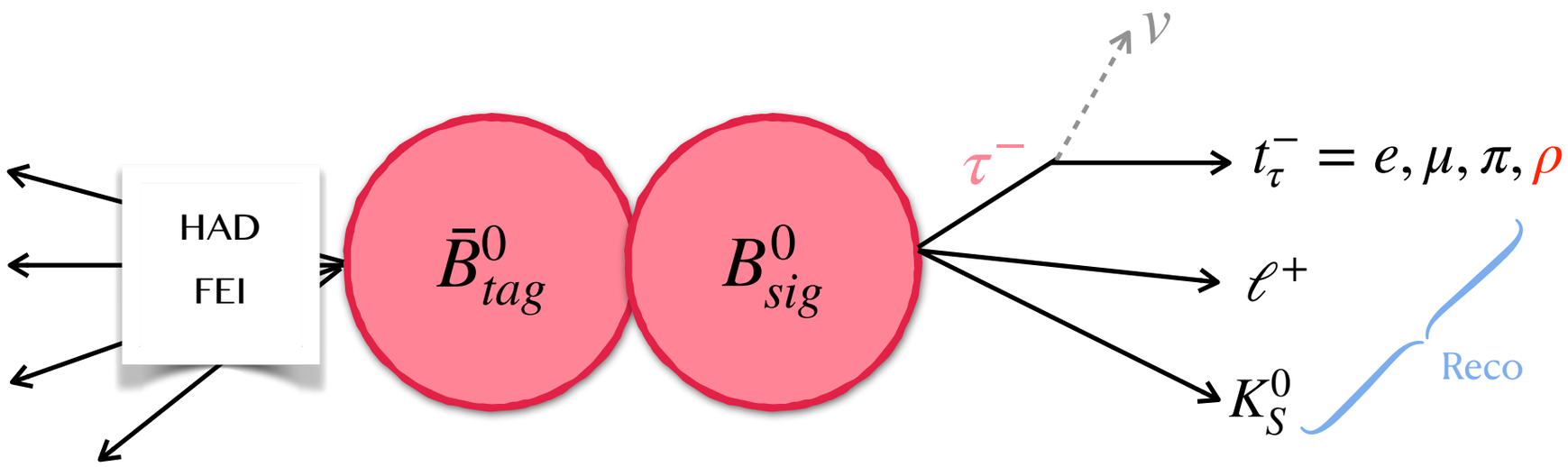
$B^0 \to K^{*0}\tau^+\mu^- : 1.0 \times 10^{-5}$

$B^0 \to K^{*0}\tau^-\mu^+ : 8.2 \times 10^{-6}$

Belle is competitive with less than 1 ab^{-1} against 9 fb^{-1} of LHCb!!

(ab^{-1}@ Belle II ~ fb^{-1} @ LHCb)

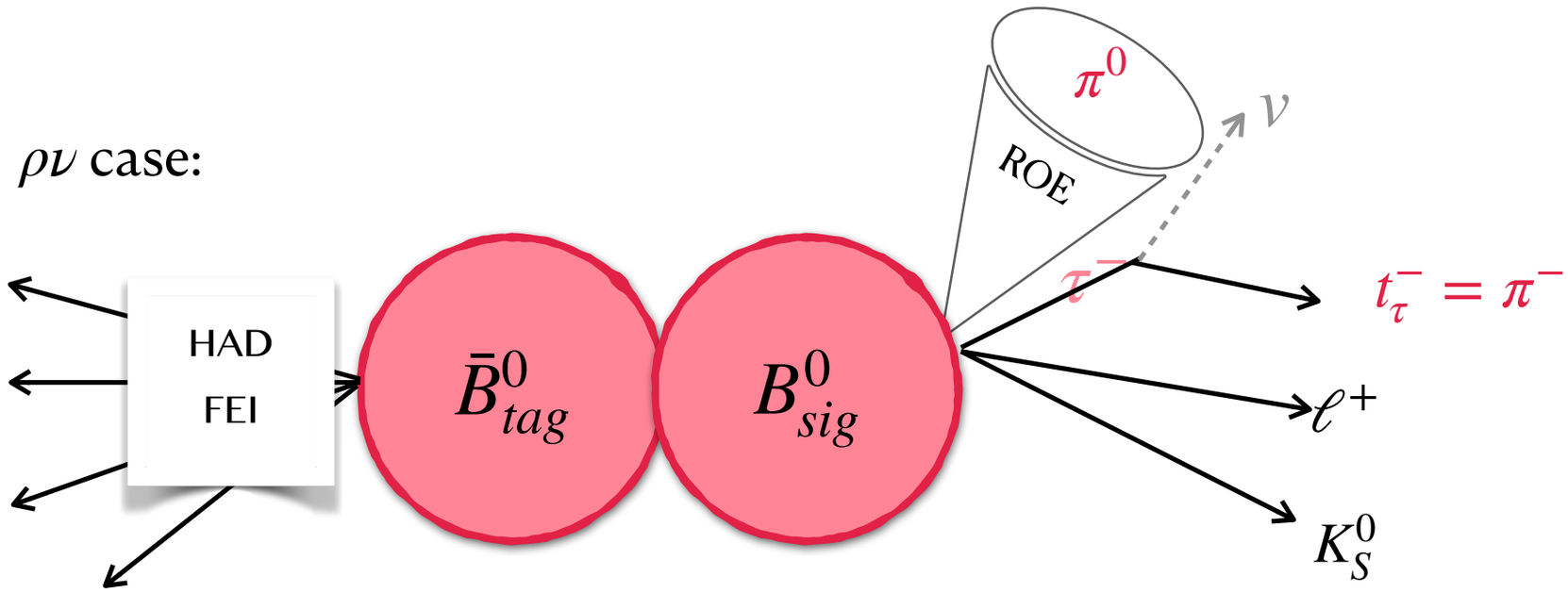
Comparison of $B^0 \to K^0_S \tau^\pm \ell^\mp$ and $B^+ \to K^+ \tau^\pm \ell^\mp$



	$B^+ \to K^+ \tau^\pm l^\mp$	$B^0 \to K^0_S \tau^\pm l^\mp$
Data sample	Belle ($711\ fb^{-1}$) only	Belle ($711\ fb^{-1}$) +Belle II ($400\ fb^{-1}$)
B tag	**B^+ hadronic FEI**	**B^0 hadronic FEI** • Tighter cut for ΔE (0.05GeV)
B sig	**Reco $K^+ t^-_\tau l^+$** •Mis-id between K^+ and π^+ •BDT training	**Reco $K^0_S\ t^-_\tau l^+$** •K^0_S reconstruction is good •Cut-based BDT training
	$t_\tau = e/\mu/\pi$ • $t_\tau = \pi$ also includes $\tau \to \rho$	**$t_\tau = e/\mu/\pi/\rho$** •BR($\tau \to \rho\nu$) is about 25% (π:10%, μ/e: 17%) •Reconstruct $\rho^+ \to \pi^+ \pi^0$ first, then those which can not reconstruct as ρ will be part of $\tau \to \pi$

Comparison of $B^0 \to K^0_S \tau^\pm \ell^\mp$ and $B^+ \to K^+ \tau^\pm \ell^\mp$

In $\tau \to \rho\nu$ case:



	$B^+ \to K^+ \tau^\pm l^\mp$	$B^0 \to K^0_S \tau^\pm l^\mp$
Data sample	Belle (711 fb^{-1}) only	Belle (711 fb^{-1}) +Belle II (400 fb^{-1})
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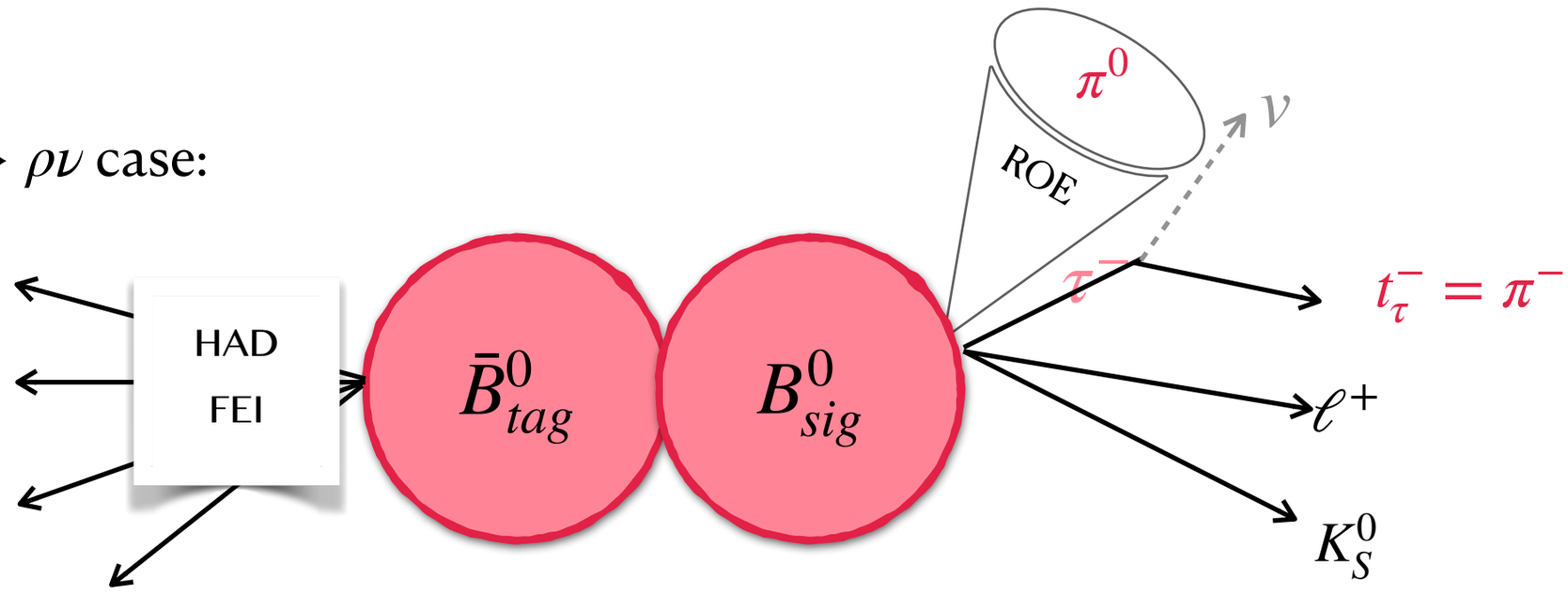
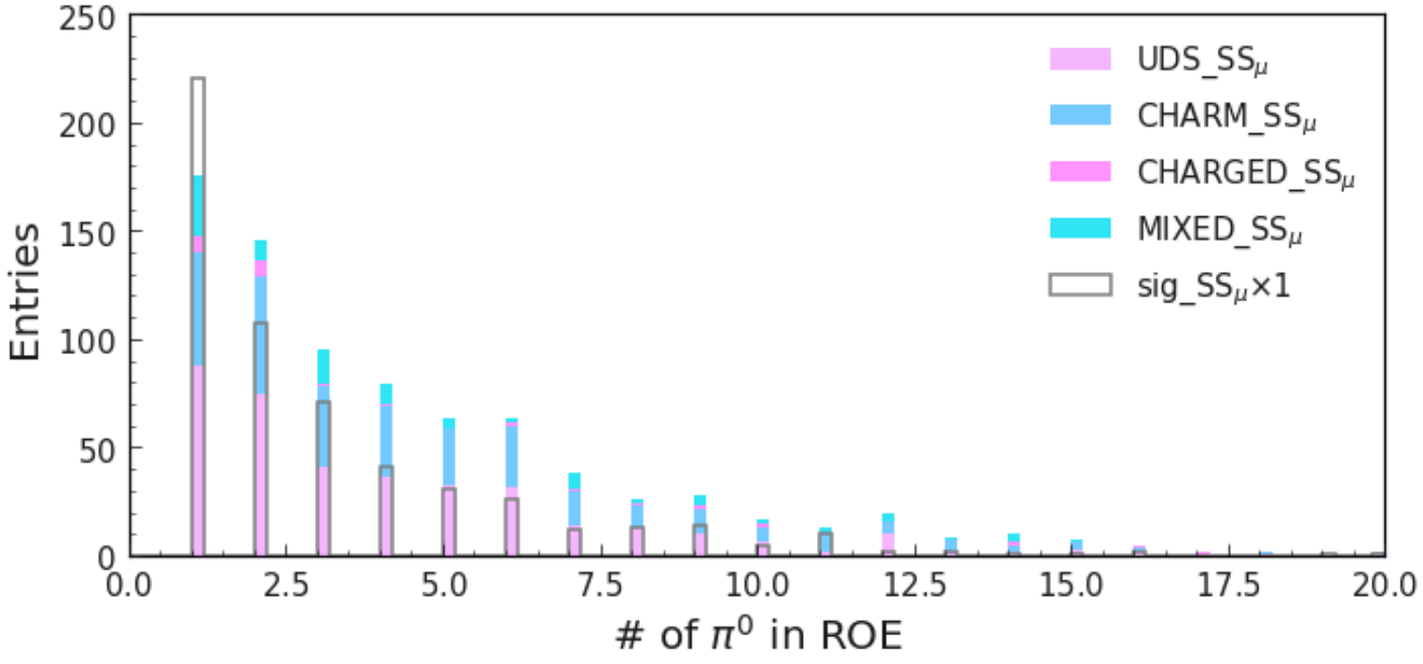
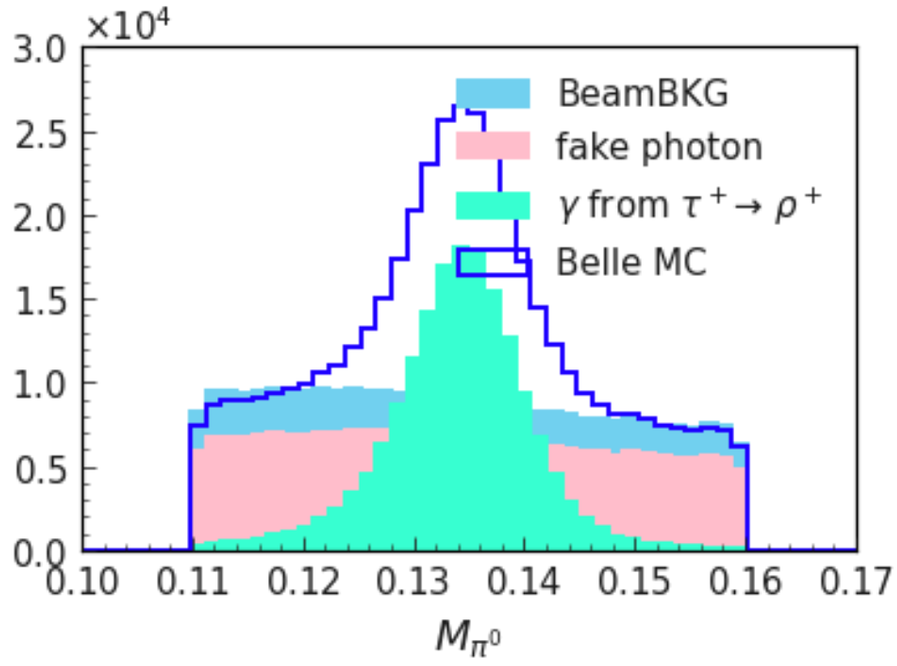
Comparison of $B^0 \to K_S^0 \tau^\pm \ell^\mp$ and $B^+ \to K^+ \tau^\pm \ell^\mp$

In $\tau \to \rho\nu$ case:



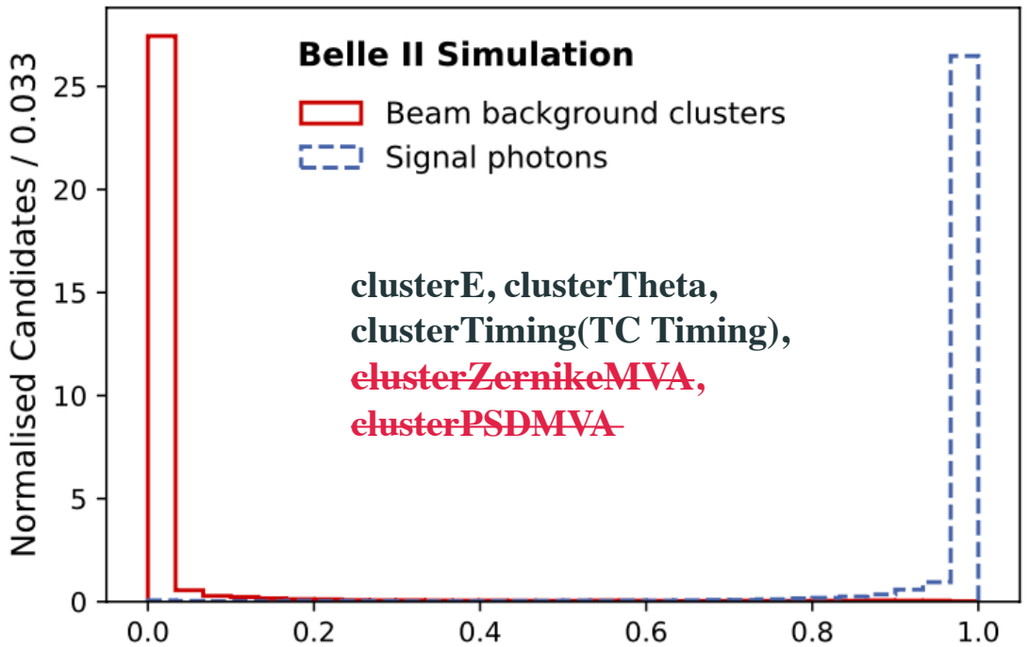


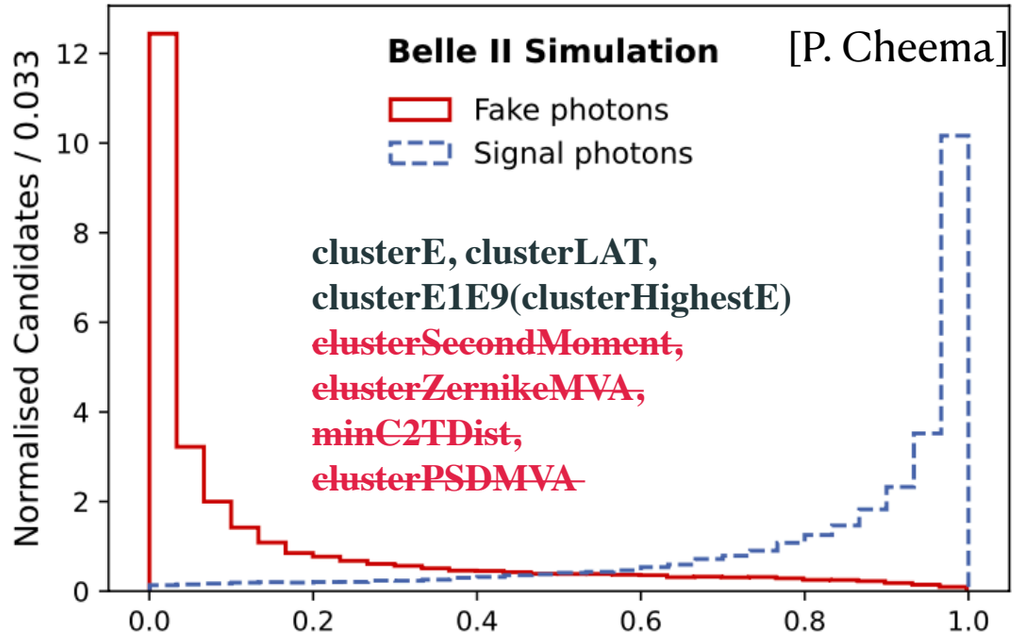


Many π^0 candidates exist in ROE, because of the fake photon and beam background photons

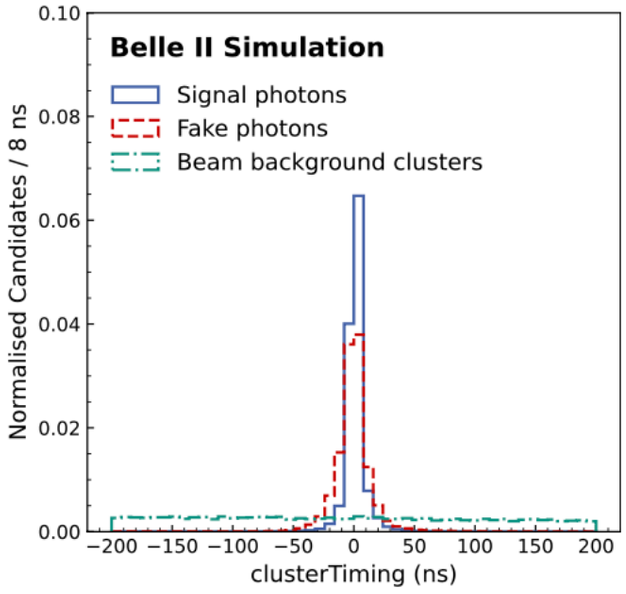
How to reconstruct a clean pi0?

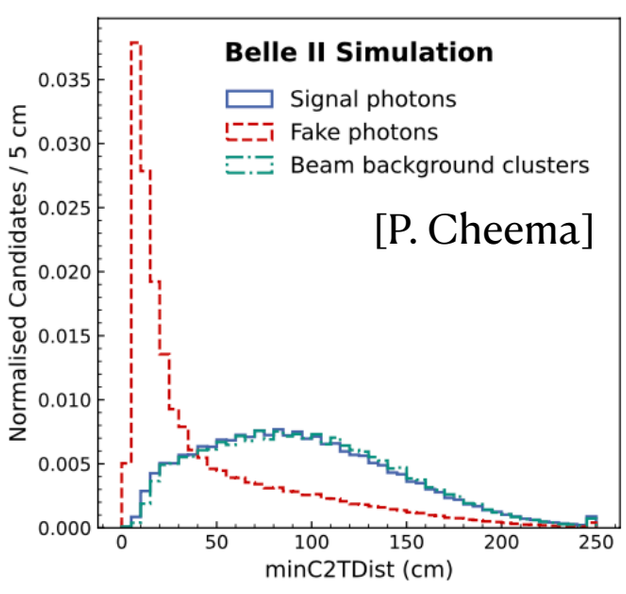
In Belle II, BDT classifiers are built to separate true γ from beam background photon (beamBackgroundSuppression) and fake photon (hadronicSplitOffSuppression)





We will use the similar strategy for Belle and Belle II, but some of the features for Belle II are not available in Belle





clusterTiming: TC timing - Event t_0.

- Powerful for Beam BKG rejection.
- In Belle, the alternative of clusterTiming is TC timing, which is only available in data after exp30.
- Available but not properly implemented in B2BII.

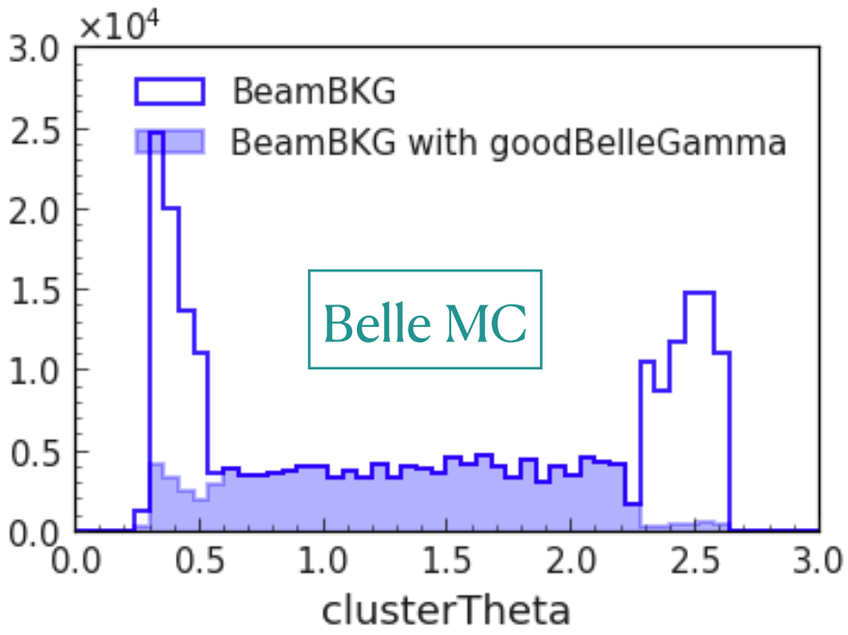
minC2TDist: distance between ECL cluster and nearest track hitting the ECL.

- Powerful for fake photon rejection.
- We ask P. Cheema how to access this variable in Belle.

Classifier of cluster in Belle

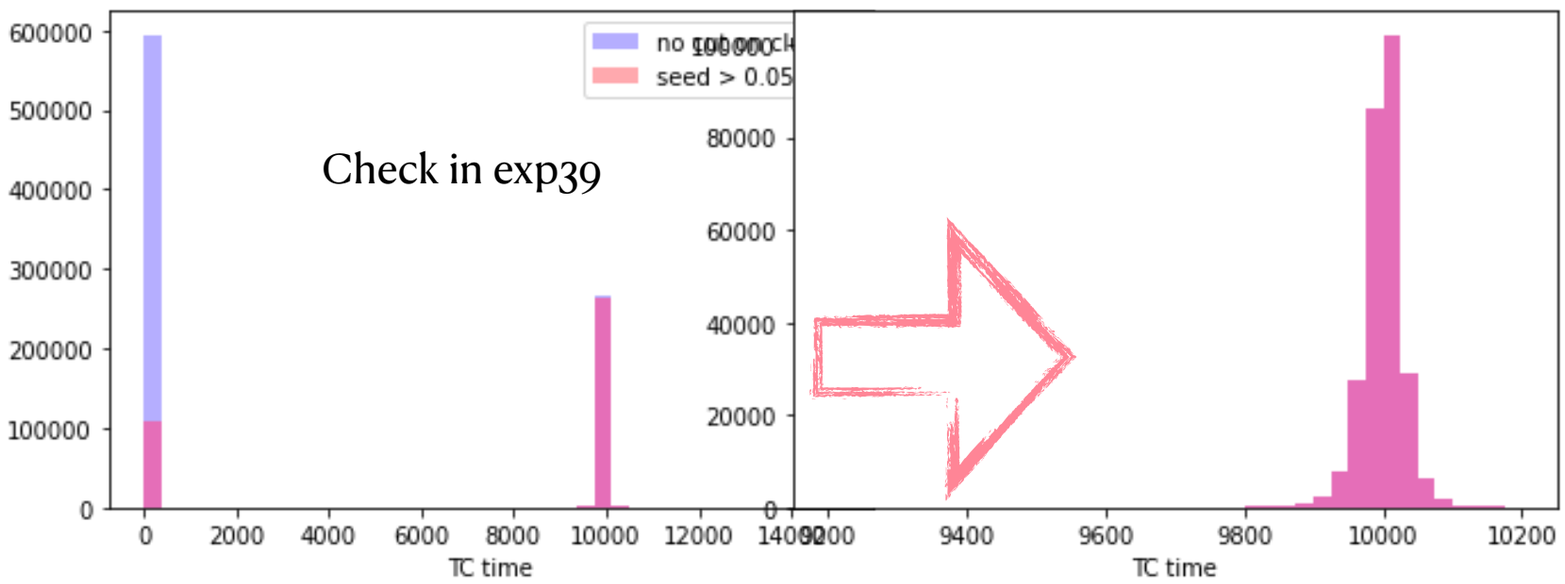
- In Belle, take the advantage of mcPDG=911 for Beam BKG, we have the gamma category as follows:

- **Real γ from $\tau \to \rho \to \pi^0$**: mcPDG ==22 && mcmoth==111 && abs(mcgmoth)==213 &&abs(mcggmoth)==15
- **Fake photon**: mcPDG!=22 && mcPDG!=911
- **Beam background**: mcPDG==911



goodBellegamma can kill 2/3 of the total Beam BKG

$E > 50$ MeV; barrel
$E > 100$ MeV; forward endcap
$E > 150$ MeV; backward endcap

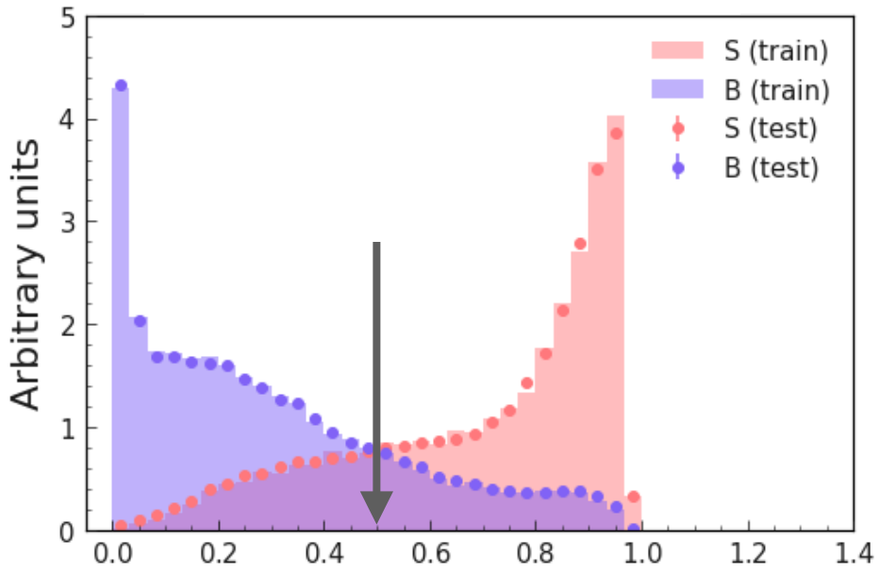


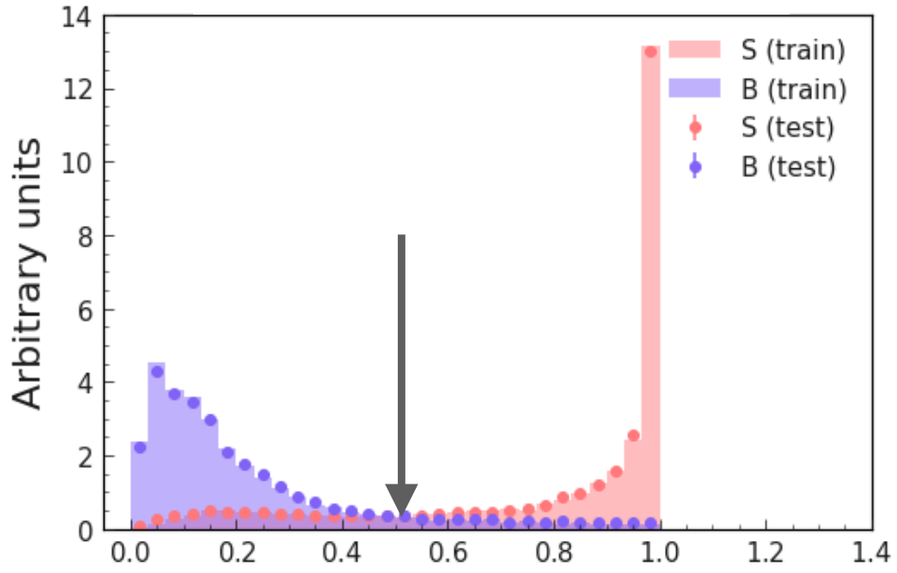
TC Timing is also useful to reject the Beam background by easily required: TC timing>0;

Or even tighter requirement like 9000 < TC timing < 11000 ns.

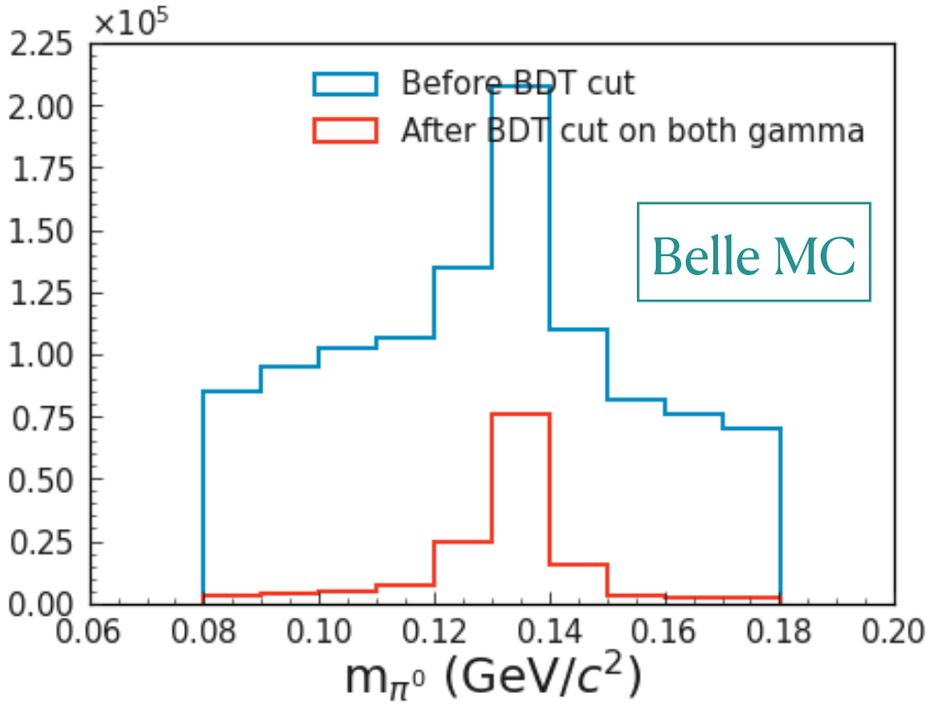
Gamma classifier BDT training In Belle

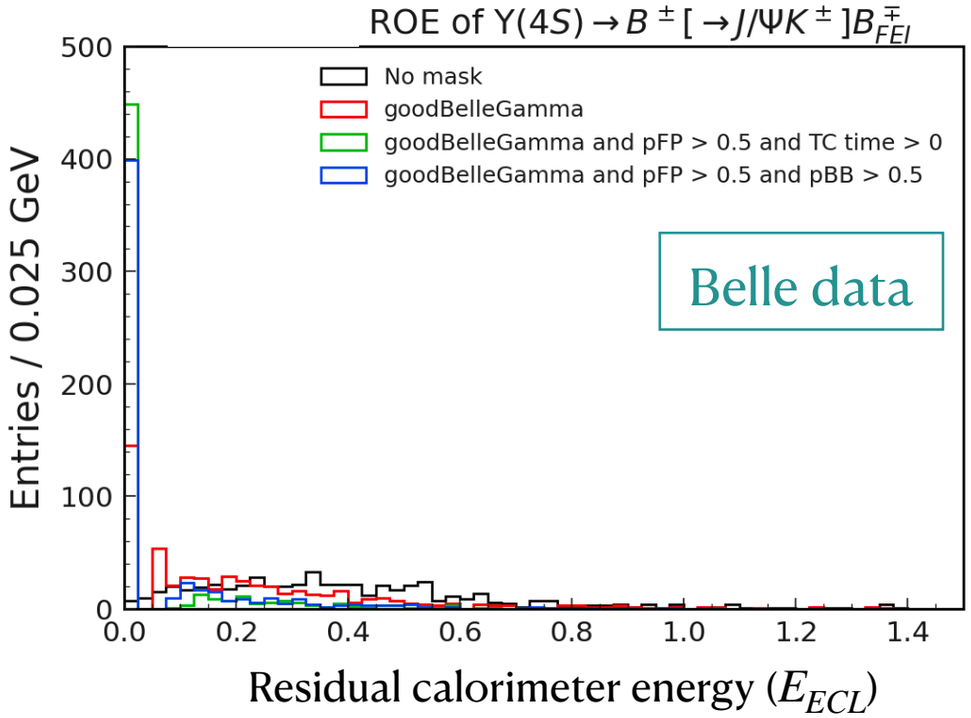
Features for BDT:
clusterE,
clusterHighestE,
clusterNHits,
clusterTheta,
clusterLAT,
clusterE9E25





- We can identify clearly π^0 in $\tau \to \rho\nu$ reconstruction and separate $\rho\nu$ events from $\pi\nu$;
- γ background is significantly reduced, but our signal efficiency is also affected （-45%）.
- The separation for fake photon is not that good, more powerful variable for fake photon training like **minC2TDist** is needed....Or optimize the BDT cuts...?





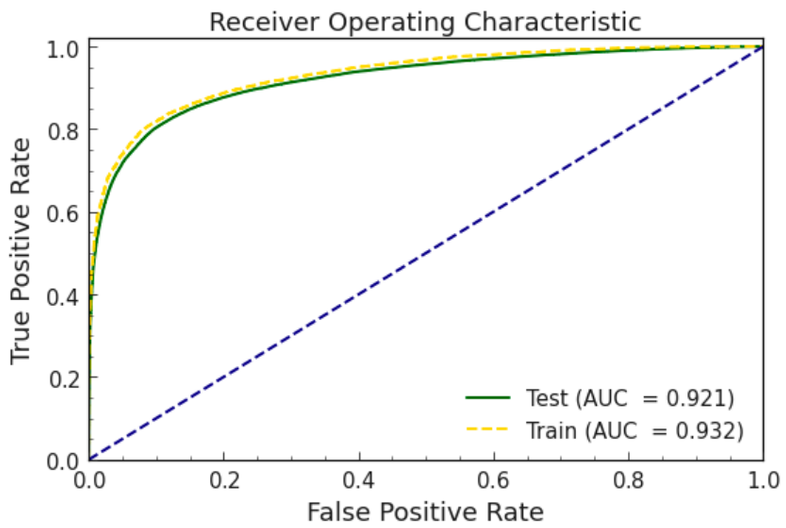
Validation in Belle data
[V. Vobbilisetti]

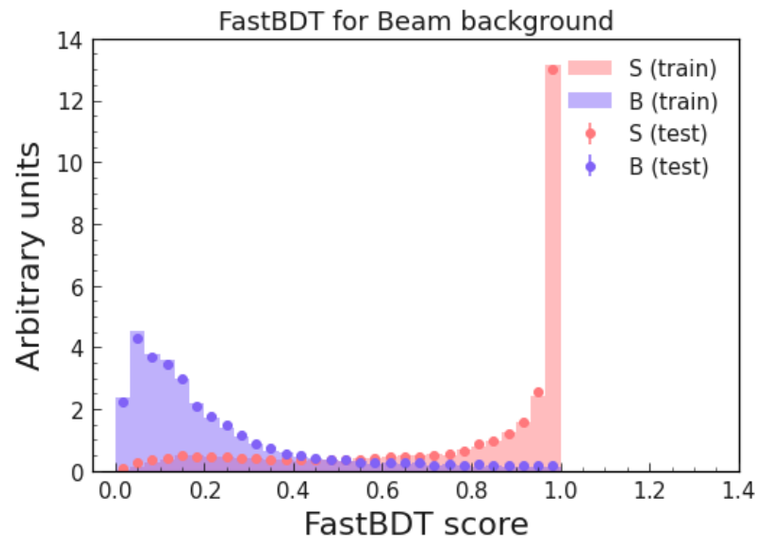
Backup

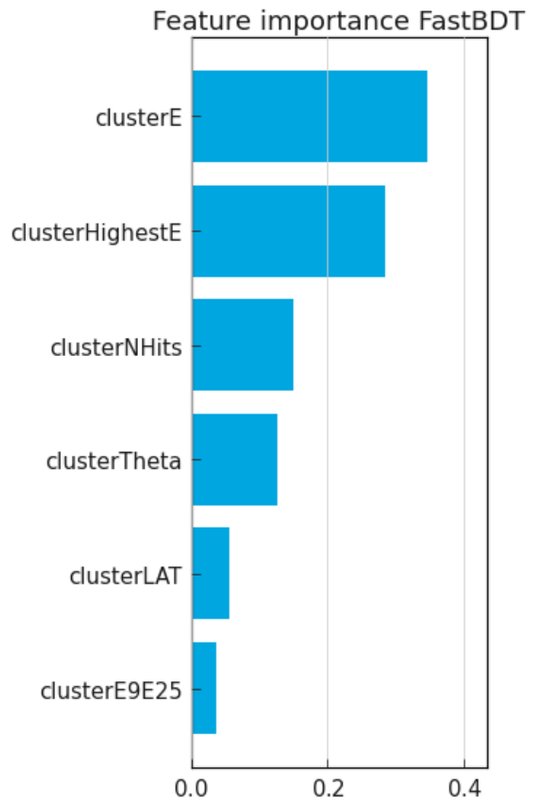
BDT training result

Beam background

NTrees	NLevels	shrinkage	#training (#sig=#bkg)	#test
200	3	0.1	113215*0.9	113215*0.1

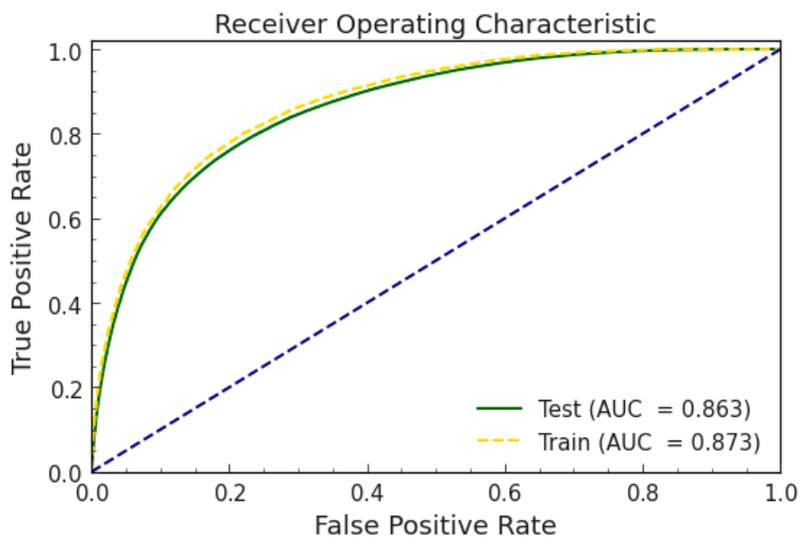


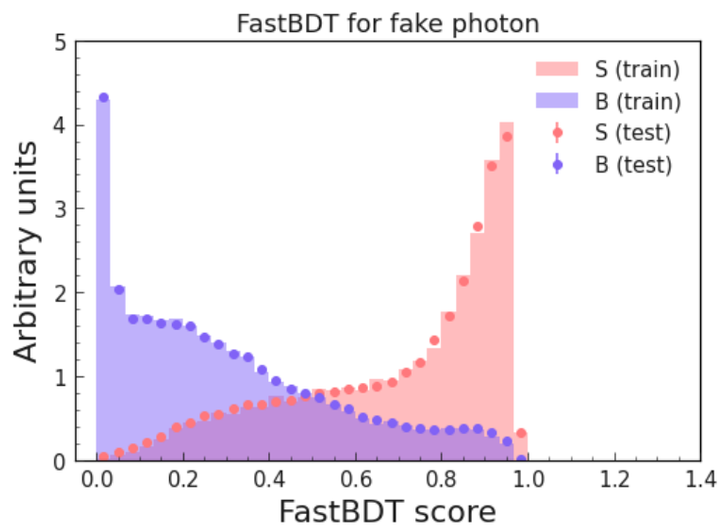


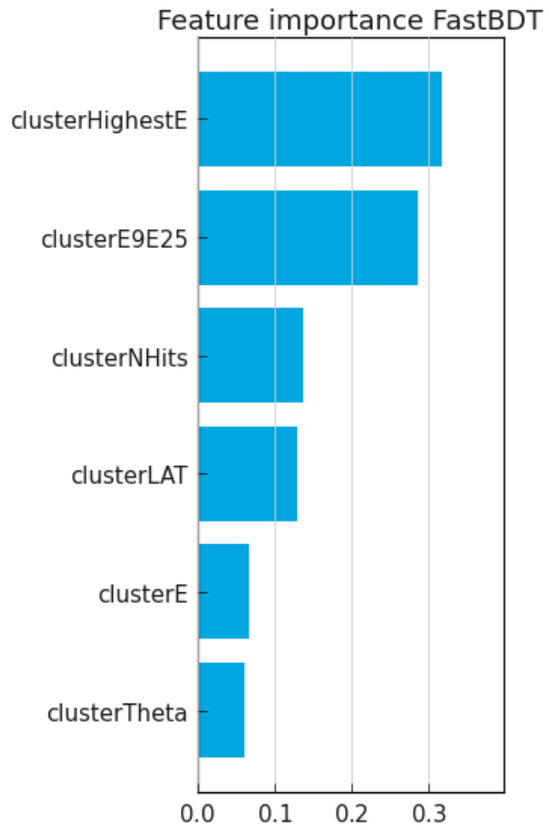


Fake photon

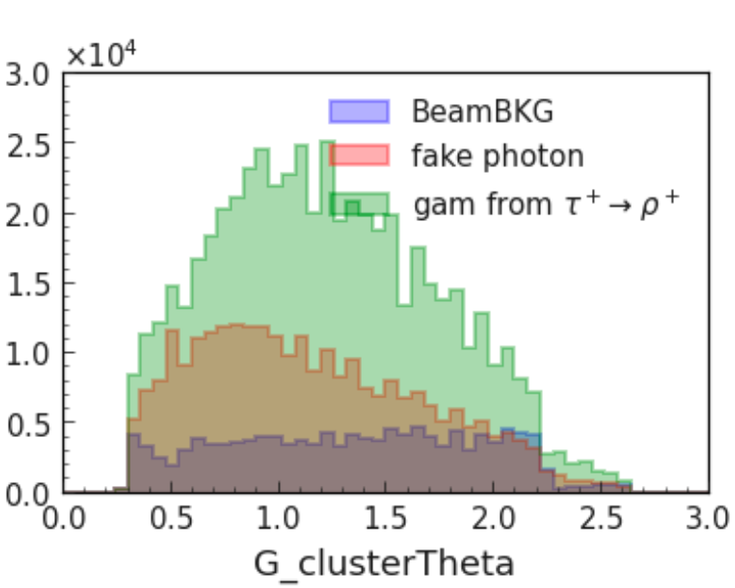
NTrees	NLevels	shrinkage	#training (#sig=#bkg)	#test
300	3	0.1	258205*0.9	258205*0.1

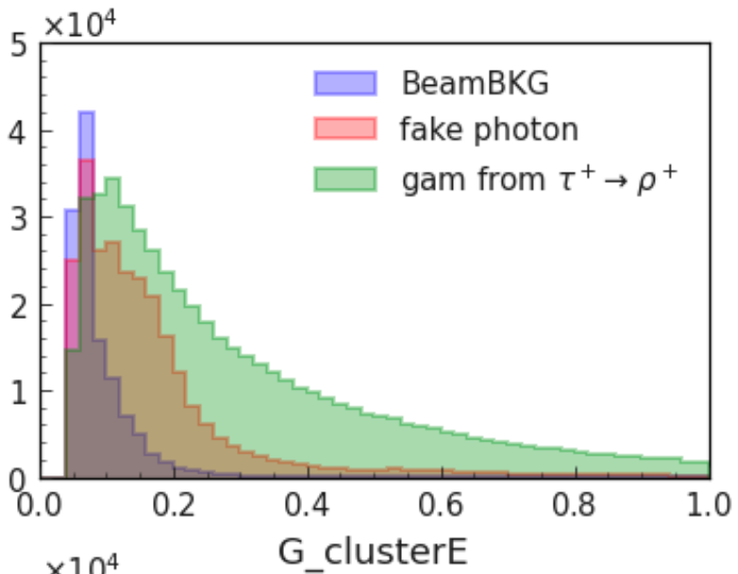


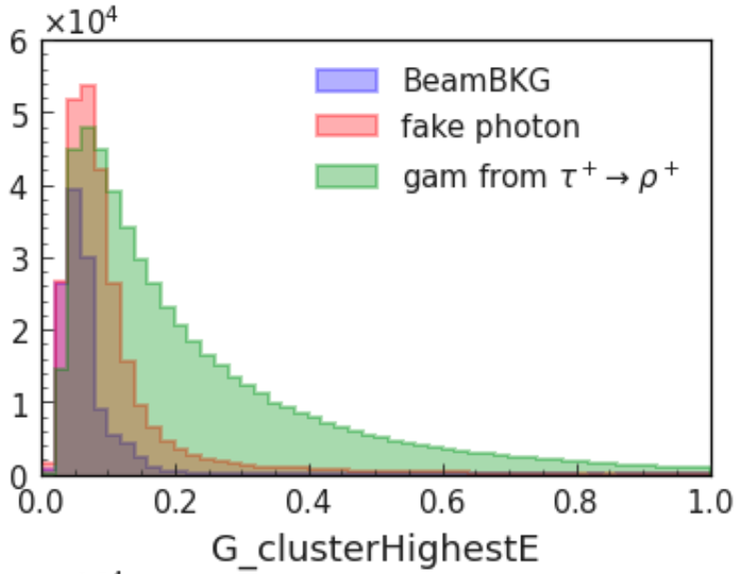


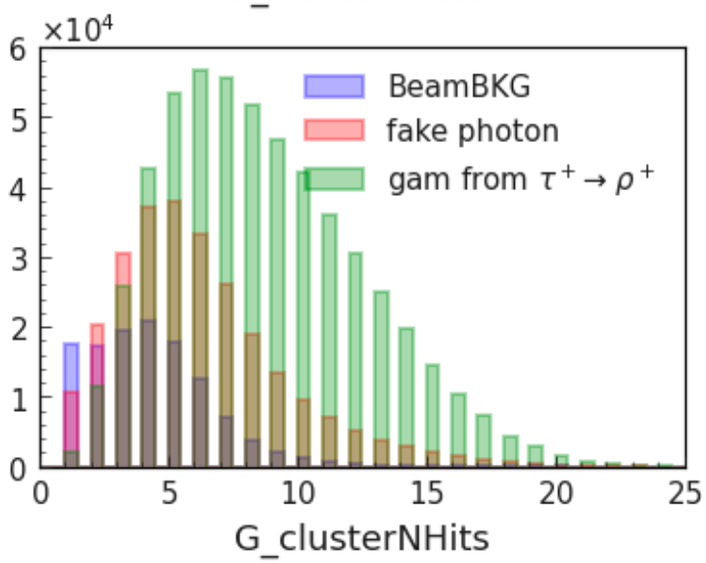


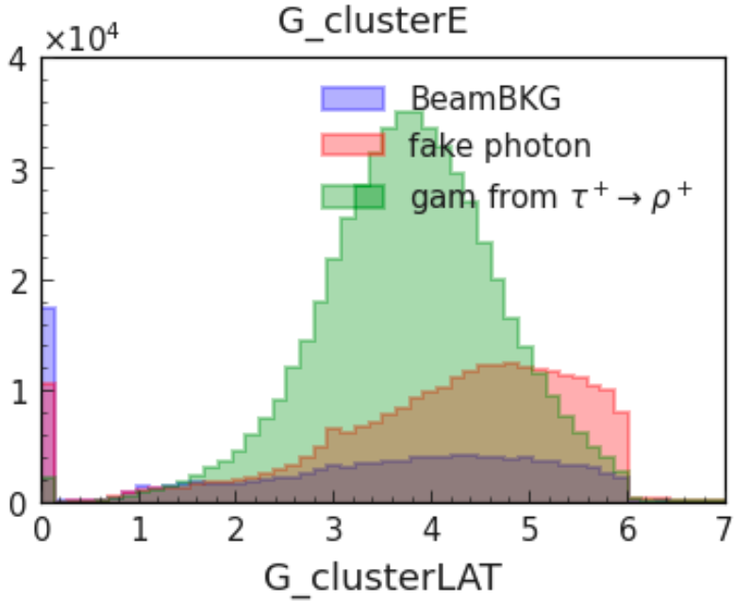
Distributions of clusters with goodBelleGamma in Belle

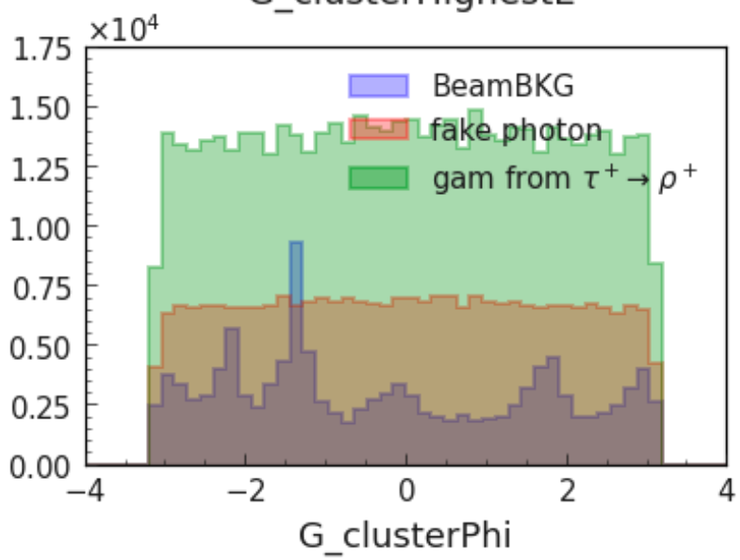


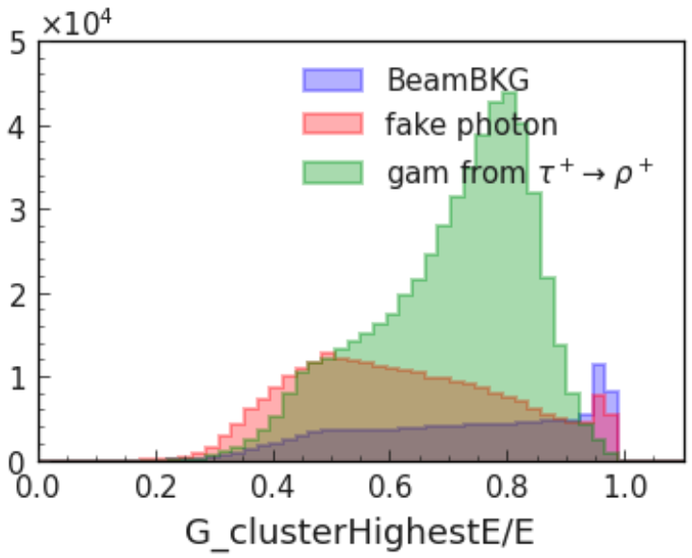












- The variables with goodBelleGamma selection will be put into BDT training
- Some variables show good separation like clusterLAT, clusterHighestE...
- The distribution clusterHighestE/clusterE shows interesting separation, which a bit like the E1/E9 or called E_highest/E_clustershape