$$B^0 \rightarrow K_S^0 \tau^{\pm} \ell^{\mp} \text{ analysis with } Hadronic\ B \text{ tagging}$$

$$Hands\ on\ section\ update$$

Meihong Liu, Karim Trabelsi

Dec. 2nd 2022 @ Valencia

The previous report is in backup

minC2TDist in Belle II Software

- Build a BDT used to reject the gamma background in π^0 reconstruction ($\tau \to \rho \to \pi^0$)
- minC2TDist is available in Belle II (always 0 in Belle after B2BII)

```cpp
double minDist(10000);
TVector3 cryCenter;
cryCenter.SetMagThetaPhi(shower.getR(), shower.getTheta(), shower.getPhi());
Const::ChargedStable hypothesis = Const::pion;
int pdgCode = abs(hypothesis.getPDGCode());
for (const auto& track : tracks) {
  TVector3 trkpos(0, 0, 0);
  for (const auto& extHit : track.getRelationsTo<ExtHit>()) {
    if (abs(extHit.getPdgCode()) != pdgCode) continue;
    if ((extHit.getDetectorID() !=  Const::EDetector::ECL) continue
    if (extHit.getCopyID() == -1) continue;
    trkpos = extHit.getPositionTVector3();
    double distance = (cryCenter - trkpos).Mag();
    if (distance < minDist) {
      trackID = track.getArrayIndex();
      minDist = distance;
    }
  }
}
if (minDist > 9999) minDist = -1;
return minDist;
}
```


necessary for minC2TDist
- crystal centre (R, Theta, Phi)
- extrapolated hits relation (ExtHits in basf2)

5

Why it doesn't work in Belle?

necessary for minC2TDist

- crystal centre (R, Theta, Phi)
- extrapolated hits relation (ExtHits in basf2)

Further conversion

The CDC hit pattern information is not yet converted, although it is crucial in specific analyses. However, the SVD hit pattern information is converted.

In release-04-00 and release-04-01 the ExtHits and ECLHits are converted. These features have been removed again to allow B2BII to be used in light releases.

If anyone is interested in either of the above, please contact @Chia-Ling Hsu .

What we did:
Copy ExtHits in B2BII Release-04 and implement in local Release-06

Why it doesn't work in Belle?

necessary for minC2TDist
- crystal centre (R, Theta, Phi)
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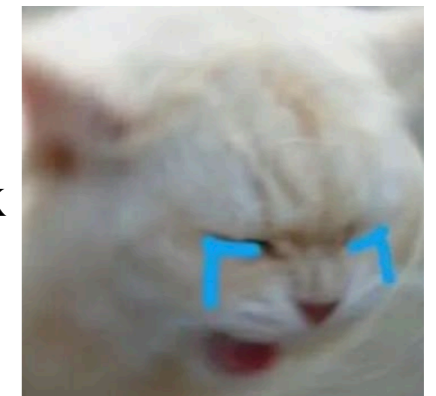
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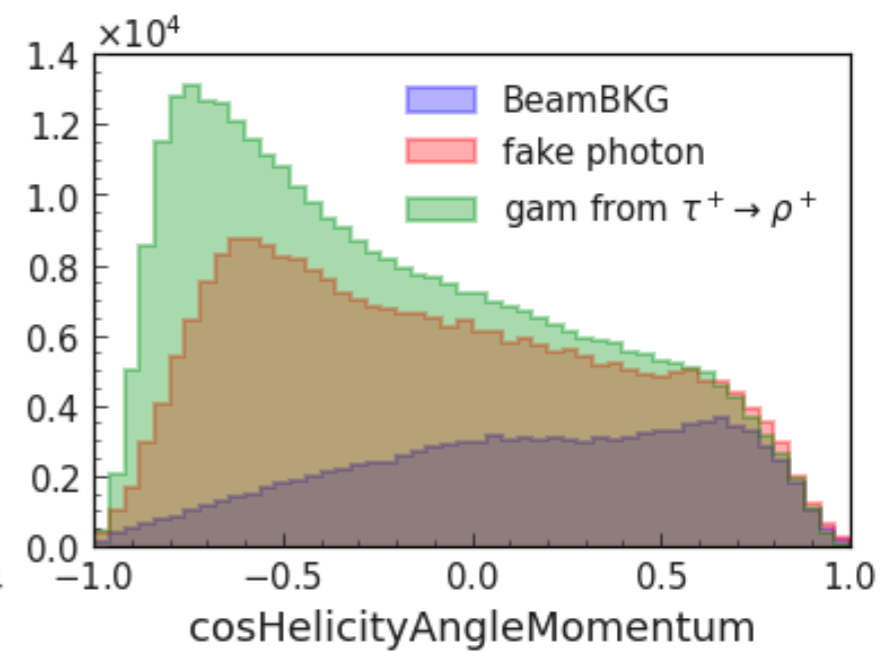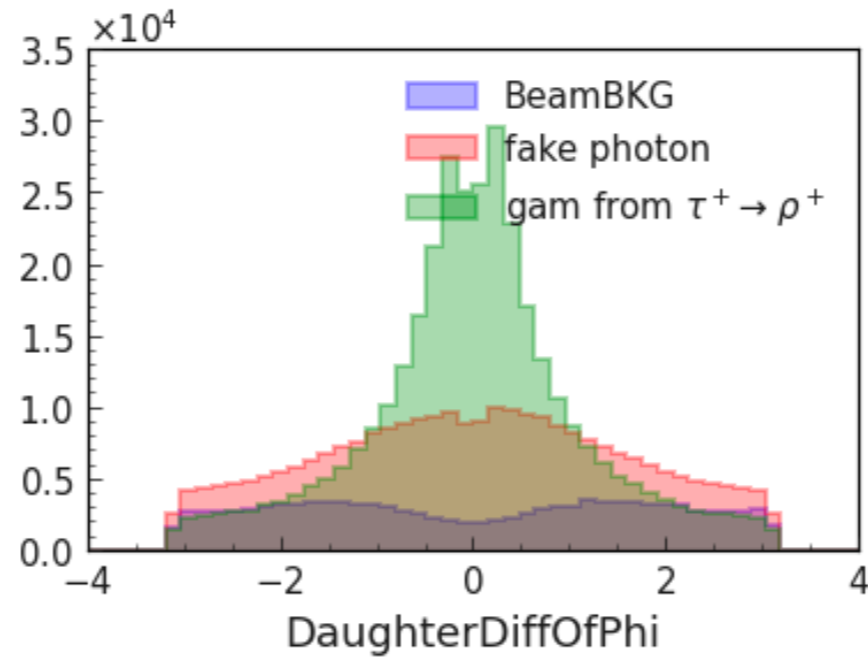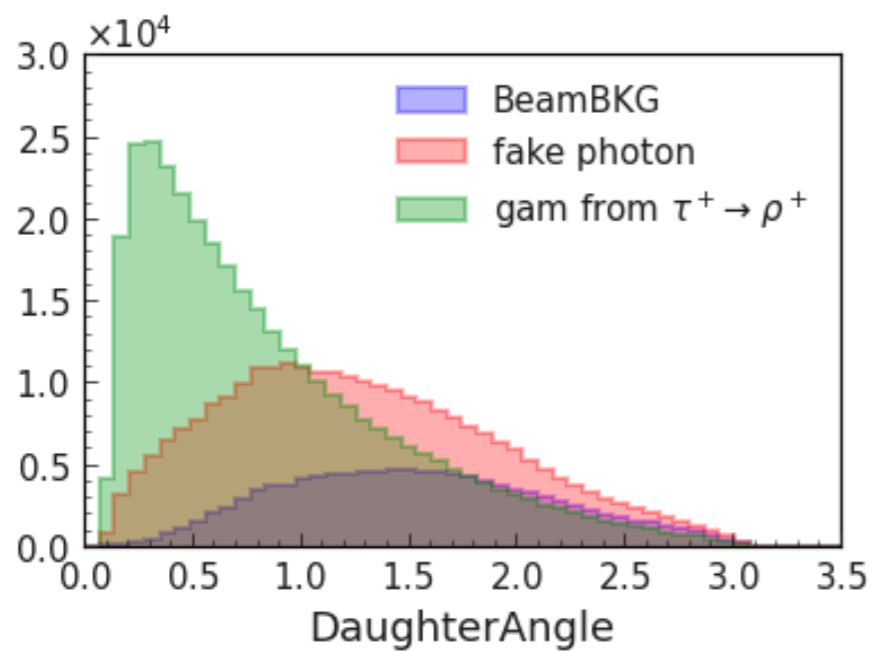
Still doesn't work

Next steps:

      Contact B2BII and software experts to ask if there is some other information we lost

More ideas to reject gamma background

Clusters (gamma) level $\longrightarrow$ **?** $\longrightarrow$ π^0 level

Put some light cuts and do the training for clusters

After physics week in Valencia...

Try to finish and fix the cluster BDT (the minC2TDist) in one month

(Also will work hard for Belle II B^0 FEI in this month....🙇‍♀️)

Thanks for the organizers❤️
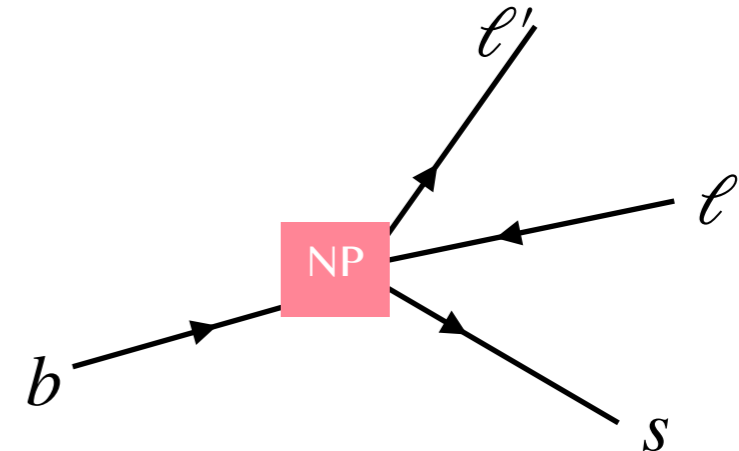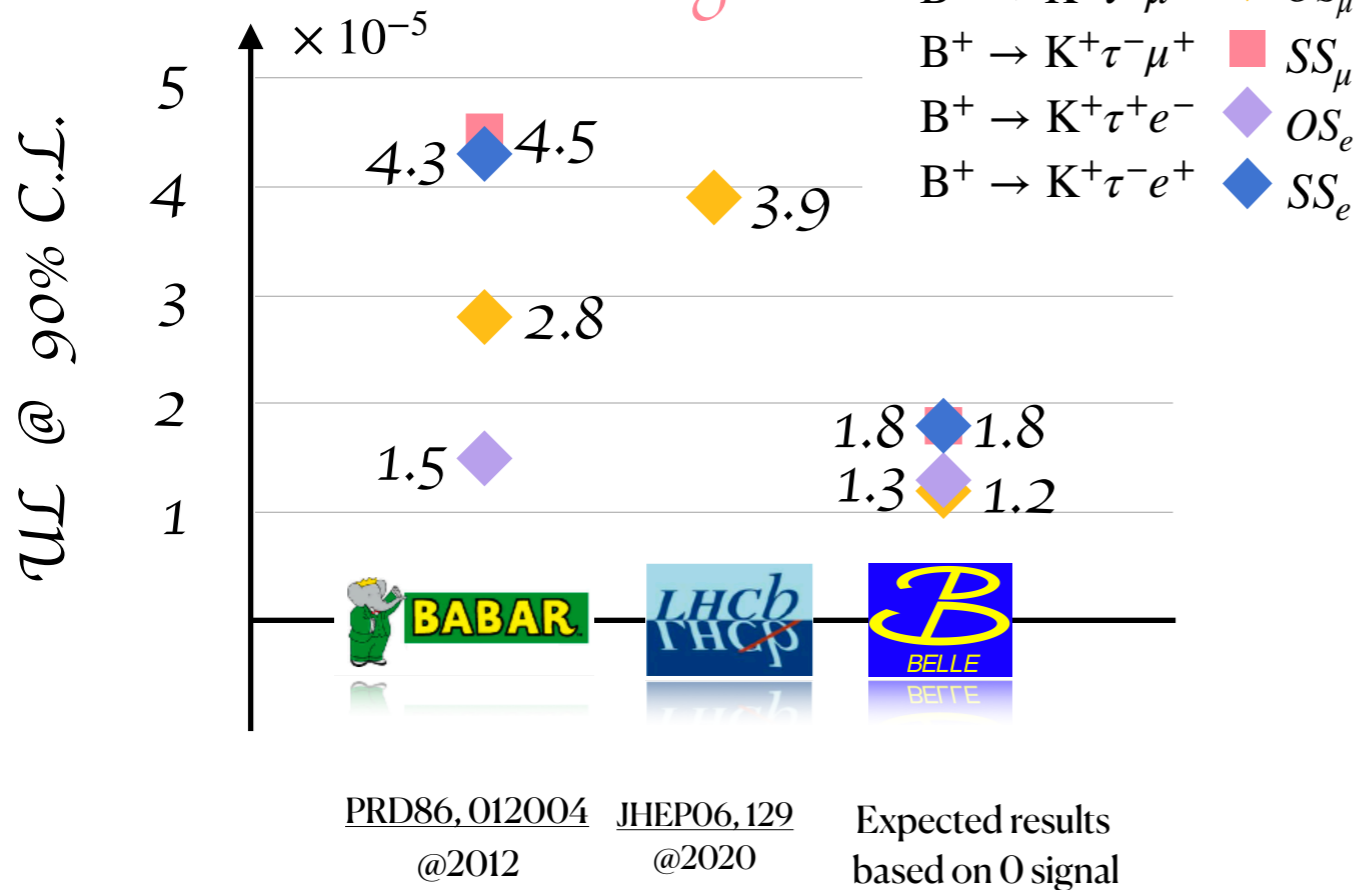Thanks for help from Nirarika, Pavel, Jakub, Sebastiano.....

Backup

$b \to s\tau\ell$ 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 $B^0 \to K_S^0 \tau^\pm \ell^\mp$.

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

$\mathcal{UL}$ @ 90% C.L.

$\times 10^{-5}$

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

4.3 4.5
3.9
2.8
1.5
1.8 1.8
1.3 1.2

BABAR   LHCb   BELLE

PRD86, 012004   JHEP06, 129   Expected results
@2012   @2020   based on 0 signal

ℓ'

NP

b

ℓ

s

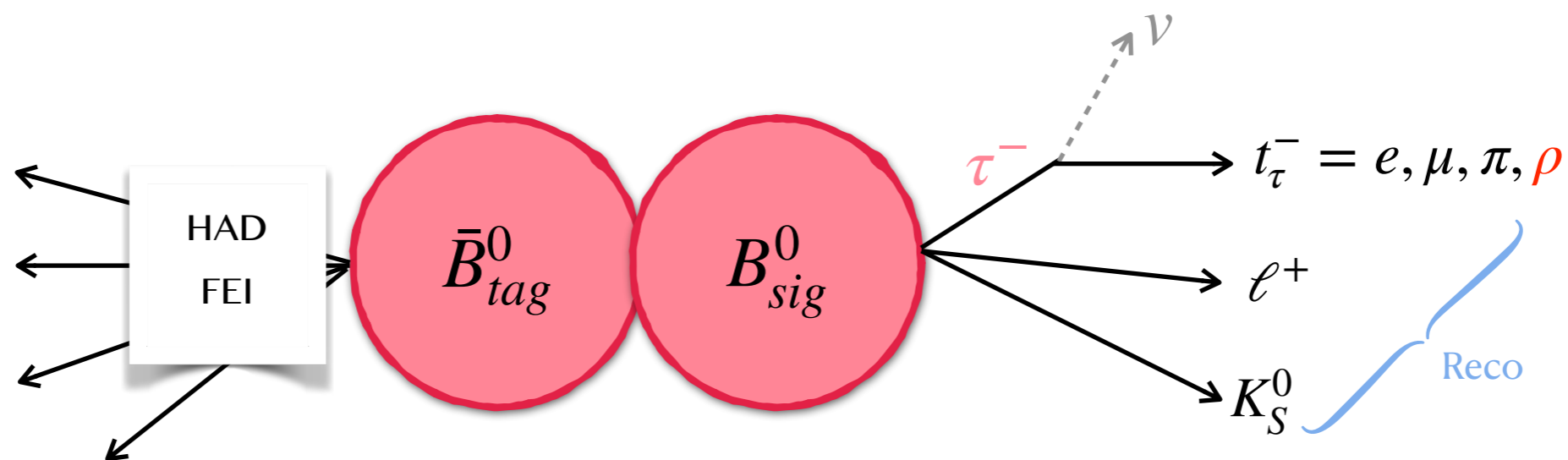$b \to s\tau\ell$ search in neutral B

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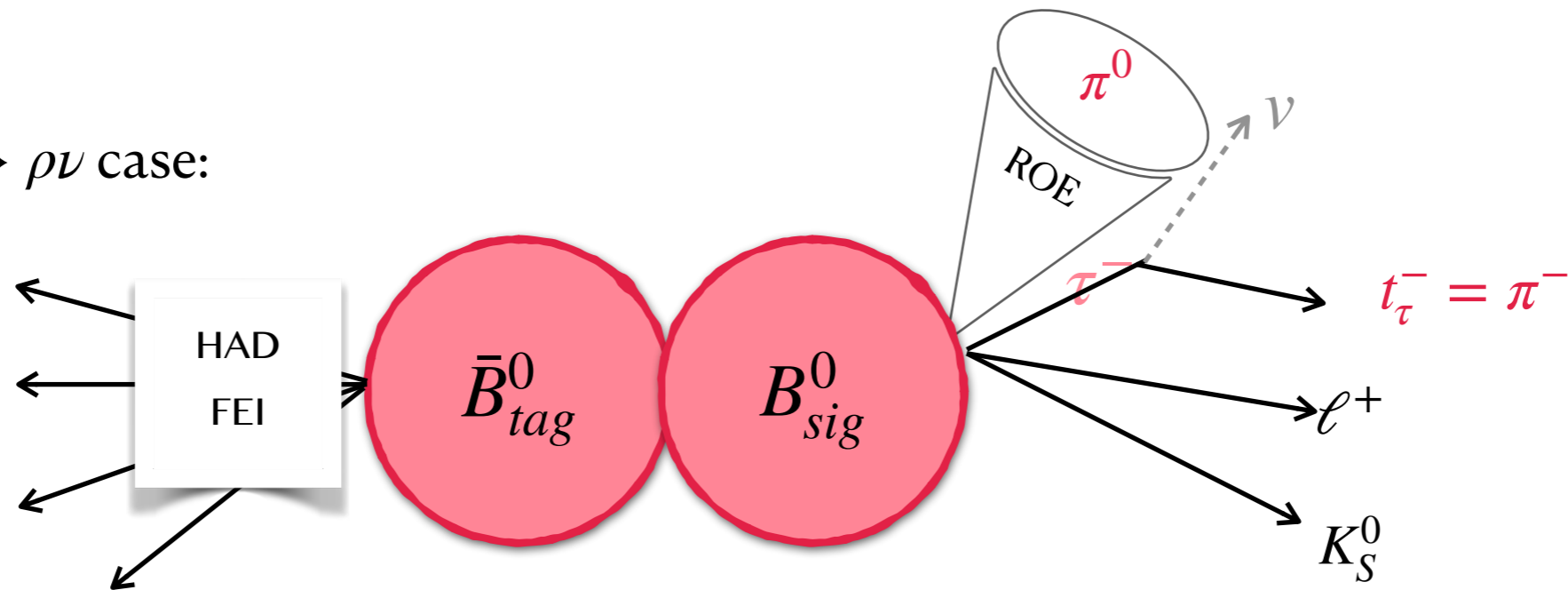
(ab^{-1} @ Belle II ~ fb^{-1} @ LHCb)

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

	$B^+ \to K^+ \tau^\pm l^\mp$	$B^0 \to K_S^0 \tau^\pm l^\mp$
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 $K_S^0 t_\tau^- l^+$** •K_S^0 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 $B^0 \to K_S^0 \tau^\pm \ell^\mp$ and $B^+ \to K^+ \tau^\pm \ell^\mp$

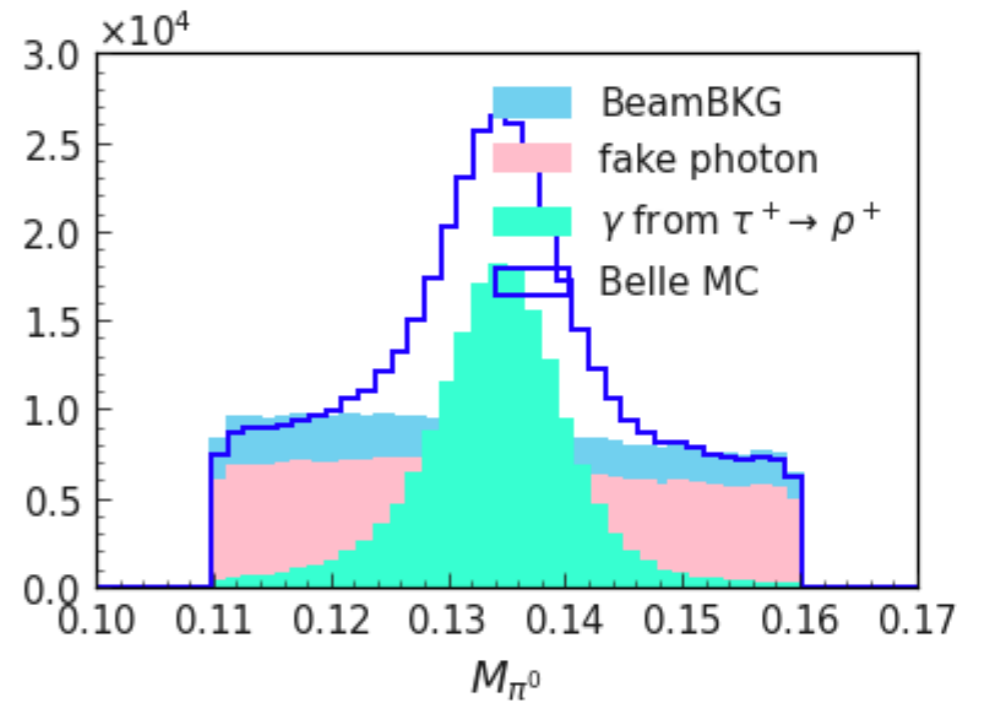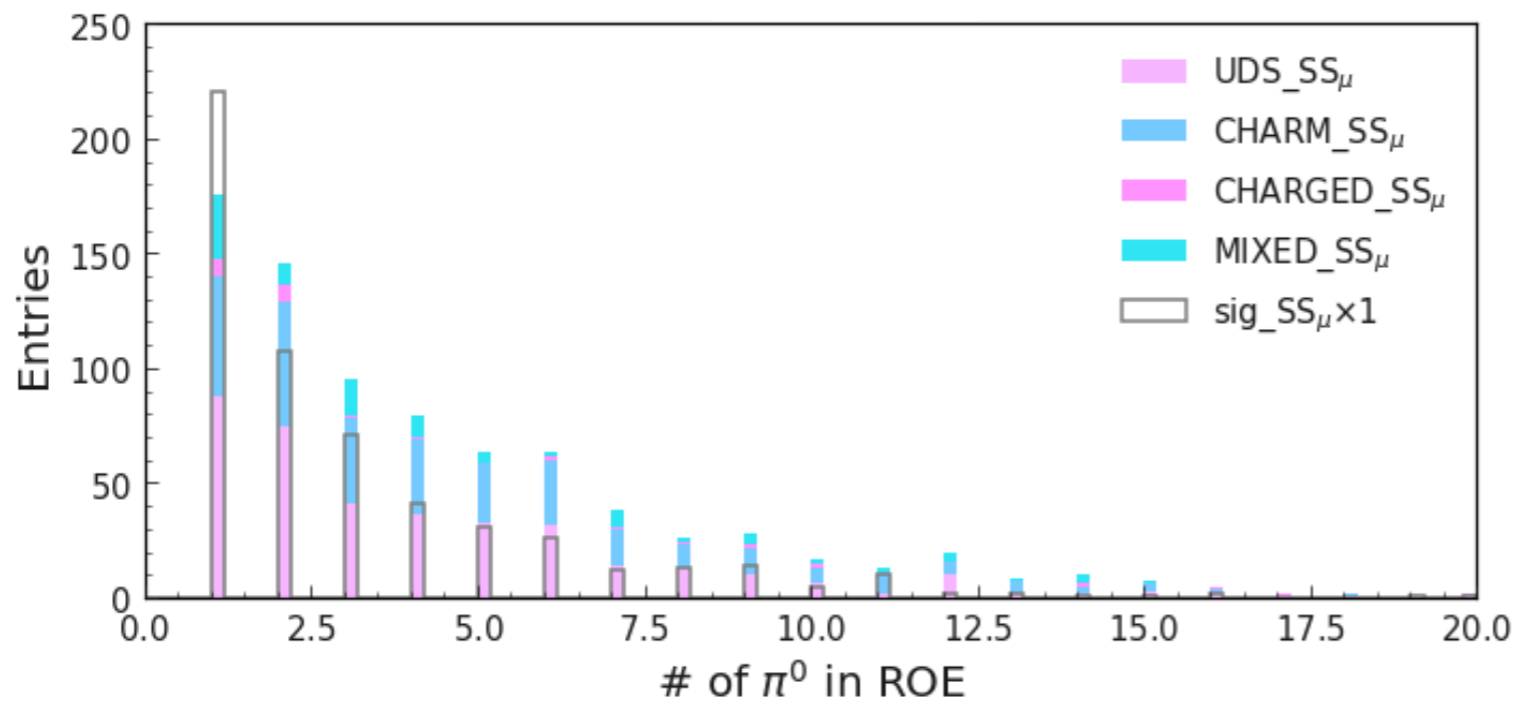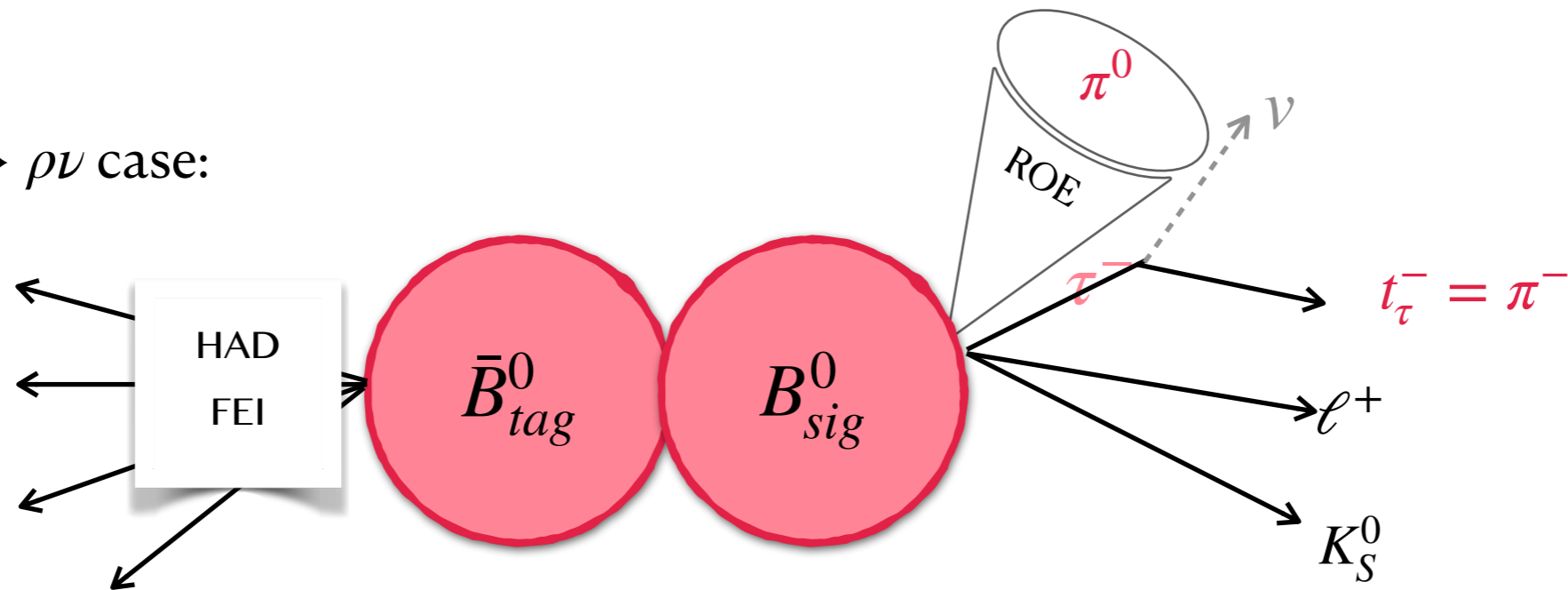In $\tau \to \rho\nu$ case:

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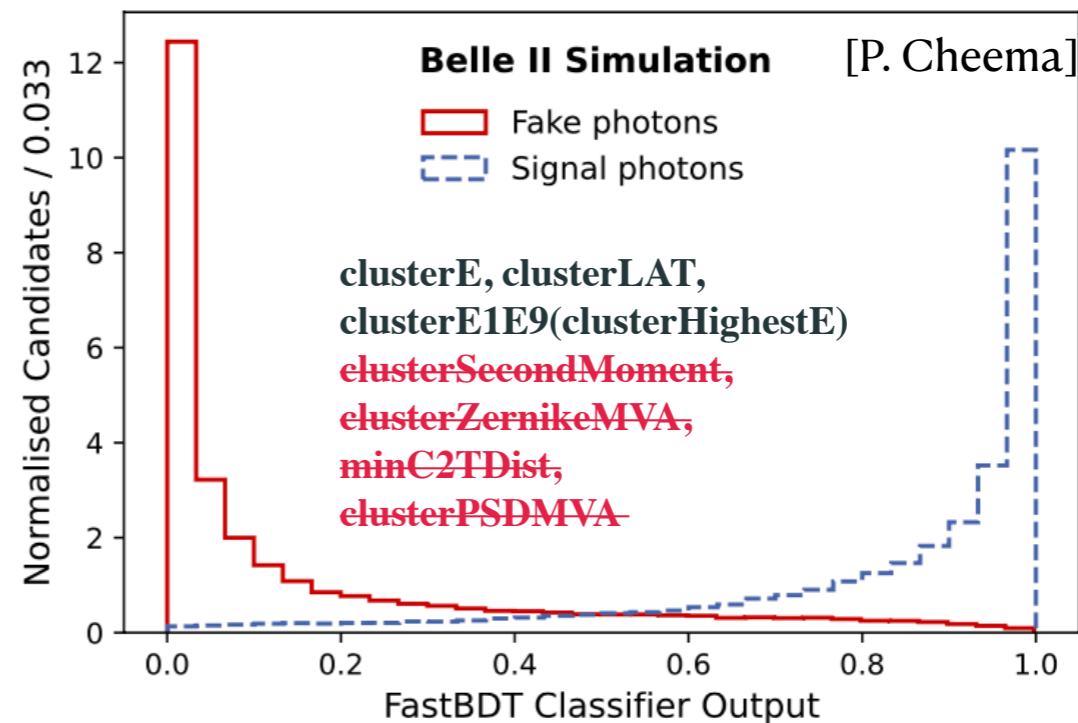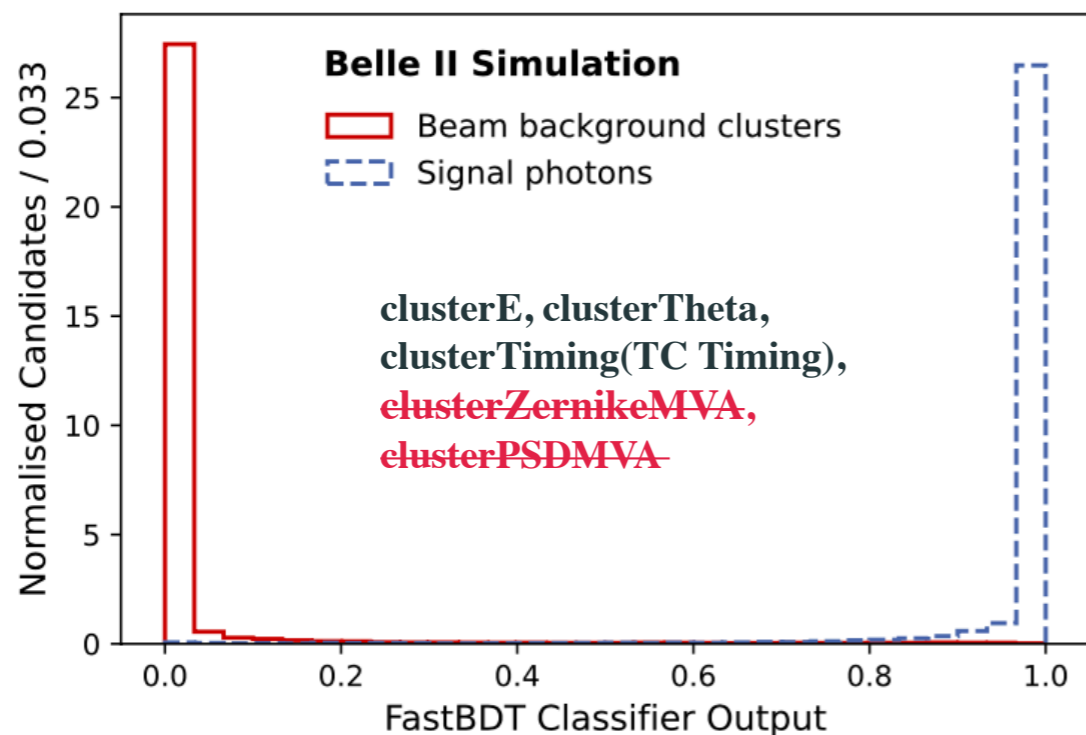# Comparison of $B^0 \to K_S^0 \tau^\pm \ell^\mp$ and $B^+ \to K^+ \tau^\pm \ell^\mp$

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

π^0

ROE

ν

HAD FEI

$\bar{B}^0_{tag}$

B^0_{sig}

τ^-

$t_\tau^- = \pi^-$

ℓ^+

K_S^0

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

[P. Cheema]
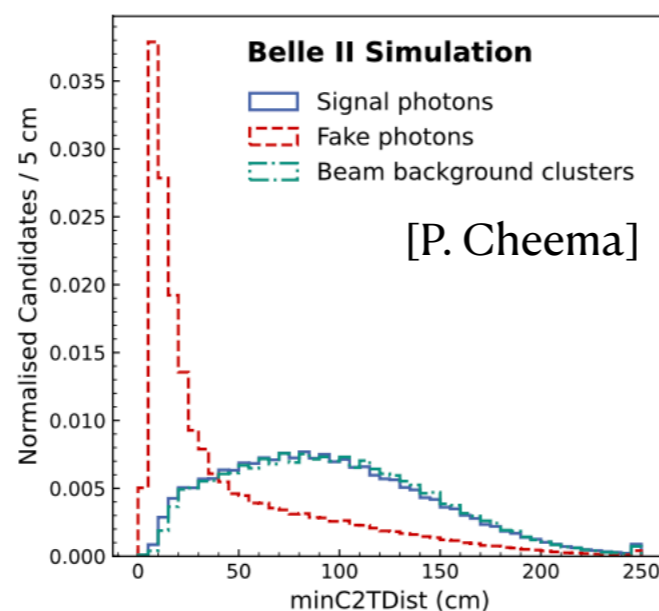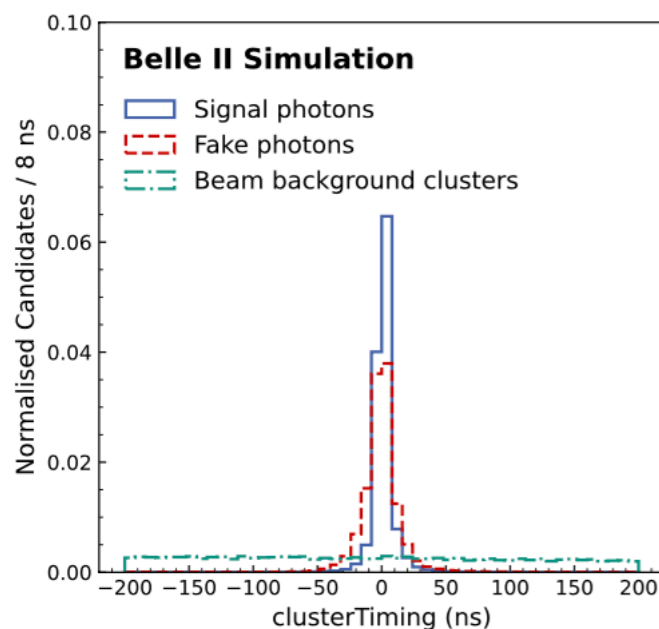
clusterTiming: TC timing - Event t_0.
- Powerful for Beam BKG rejection.
- In Belle, the alternative of clusterTiming is TC timing, which is only available in data after exp30.
- Available but not properly implemented in B2BII.

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.

3

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

Belle MC
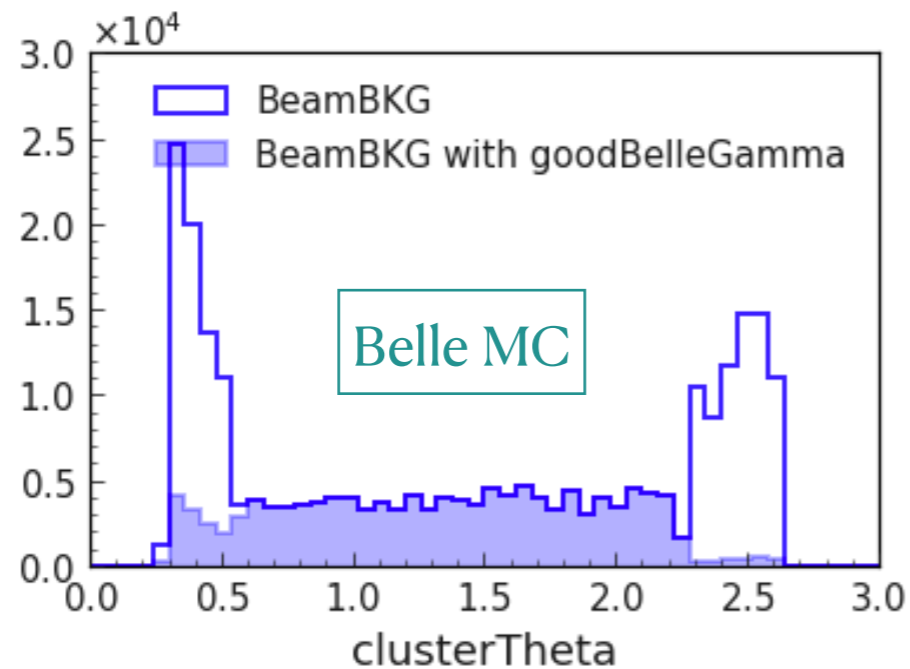
goodBellegamma can kill 2/3 of the total Beam BKG

$$E > 50 \text{ MeV; barrel}$$
$$E > 100 \text{ MeV; forward endcap}$$
$$E > 150 \text{ MeV; backward endcap}$$

Check in exp39
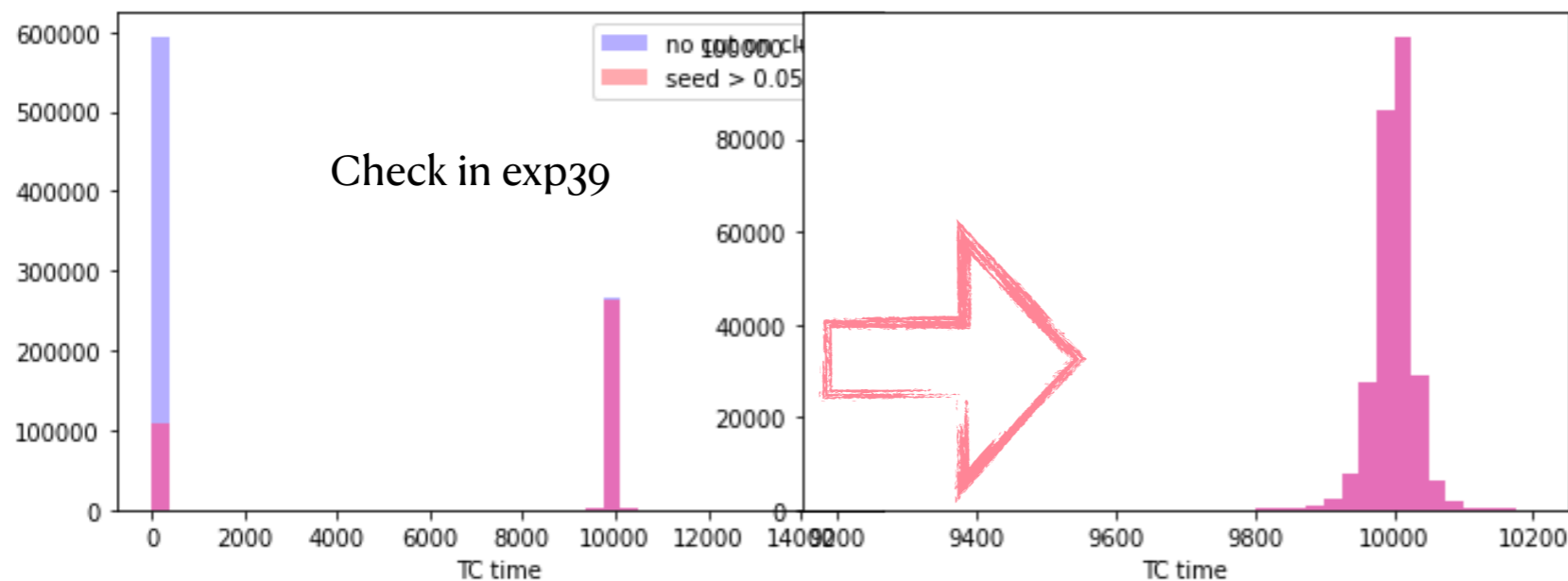
TC Timing is also useful to reject the Beam background by easily required: TC timing>0;

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

BDT score for fake photon

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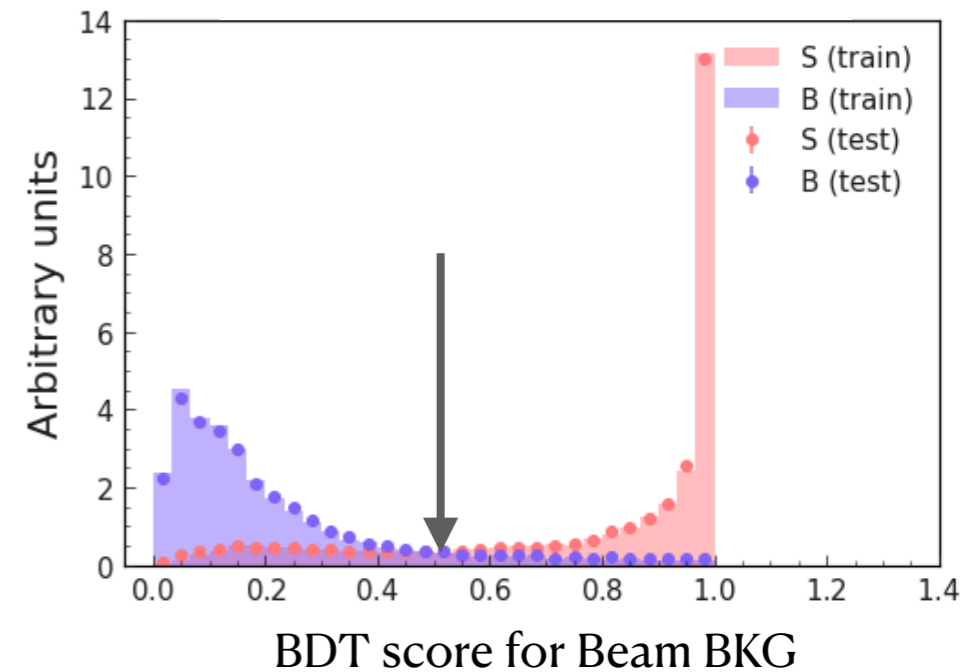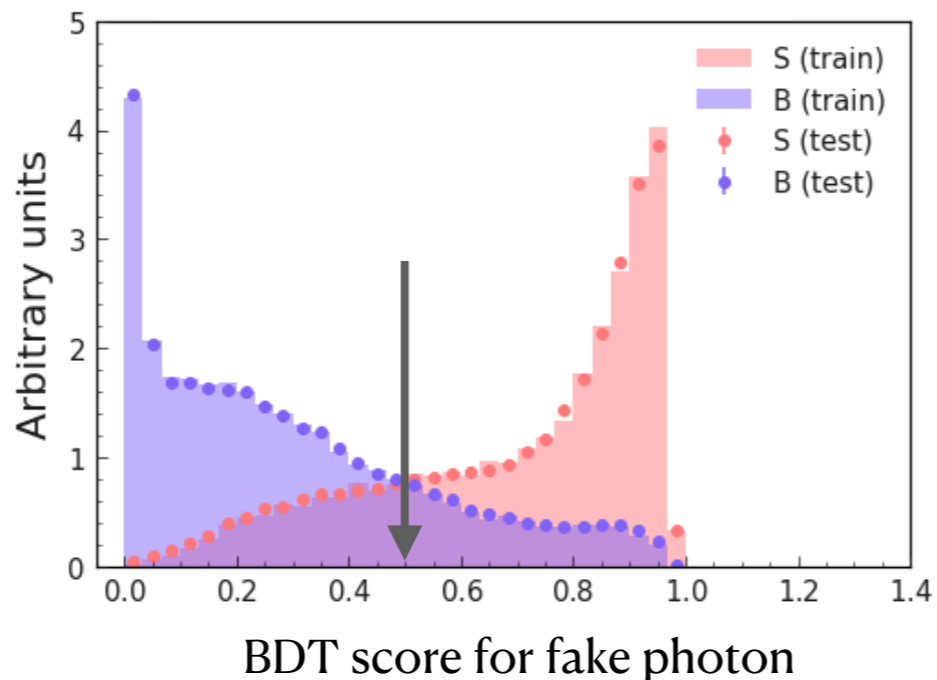
- We can identify clearly π^0 in $\tau \to \rho\nu$ reconstruction and separate $\rho\nu$ events from $\pi\nu$;
- γ background is significantly reduced, but our signal efficiency is also affected （-45%）.
- The separation for fake photon is not that good, more powerful variable for fake photon training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

Belle MC
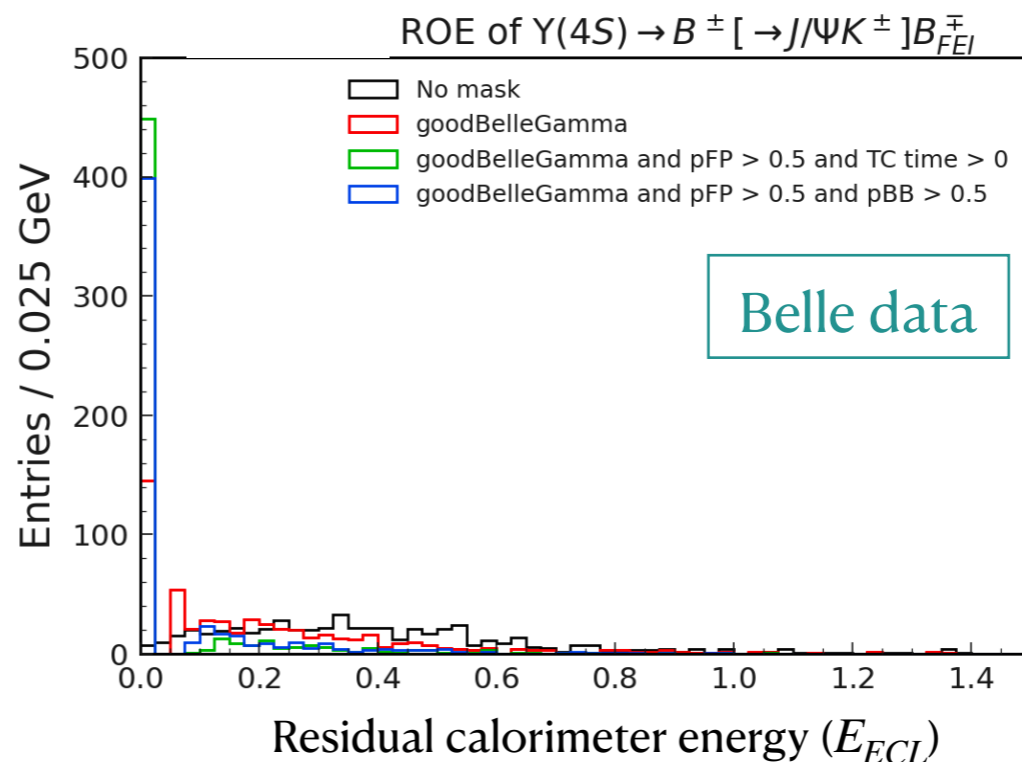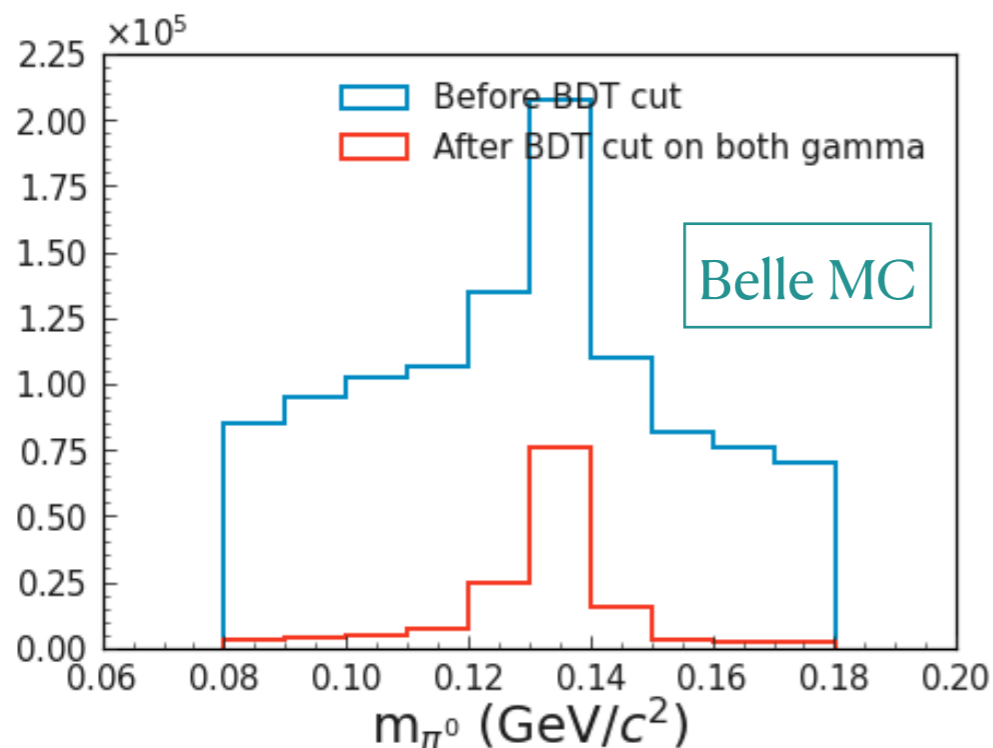
Belle data

Validation in Belle data
[V. Vobbilisetti]