Study of Level-1 trigger efficiency of experiment 30

Reporter: Youwen Xue
youwen@mail.nankai.edu.cn

February 19, 2025

Contents

Motivation

1. Motivation

- The Belle II trigger system performs the critical task of reducing the event rate to a manageable level while efficiently retaining events containing interesting physics.
- The correct simulation of trigger in MC samples is crucial for detection efficiency estimation in physical analysis, especially for low multiplicity condition.
- The QED process dimu has a very high cross section, which means high statistics of reconstructed events. (also simple selection)
- In particular, we are interested in CDC trigger efficiency, because there is a potential efficiency decrease in certain specific phi regions during physics run. This study may assist our experts in identifying the reason of the issue.

Strategy

2.1 Definition

- The efficiency of trigger is estimated using orthogonal triggers and calculated by

$$\epsilon_{\text{Trg}} = \frac{N_{\text{Trg}}}{N_{\text{Trg}} \cup N_{\text{Ref}},}$$

  where $N_{\text{Trg}} \cup N_{\text{Ref}}$ is the number of events firing both the trigger to be tested and the reference trigger, and N_{Ref} is the number of events activating the reference trigger.
- The difference is calculated by

$$\text{diff} = \frac{|\epsilon_{\text{DT}} - \epsilon_{\text{MC}}|}{\epsilon_{\text{DT}} + \epsilon_{\text{MC}}},$$

  where ϵ_{DT} and ϵ_{MC} are the efficiencies of data and MC, respectively.
- The weight factor is calculated by $\epsilon_{\text{DT}}/\epsilon_{\text{MC}}$.
- In this slide, the CDC/KLM trigger bit will be tested using the hie trigger bit as a reference, and the ECL trigger bit will be tested using the stt trigger bit for selected events.

2.1 Definition

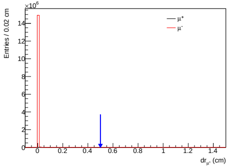
- The main trigger bits:
  - ffy: ≥ 3 2D track, > 0 Neuro 3D track with $|z| < 20\,\text{cm}$.
  - stt: > 0 Neuro 3D track with $p > 0.7\,\text{GeV}/c$ and $|z| < 15\,\text{cm}$, and not an ECL Bhabha.
  - hie: total energy above 1 GeV and not an ECL Bhabha.
  - c4: ≥ 4 isolated clusters with energy above 100 MeV and not an ECL Bhabha.
  - mu_b2b: the KLM track is back-to-back.
  - sttecl: > 0 Neuro 3D track with $p > 0.7\,\text{GeV}/c$ and $|z| < 15\,\text{cm}$, > 0 number of matched CDC track and ECL cluster, and not an ECL Bhabha.
- The variable definitions:
  - $\cos\theta_{\mu^\pm}$: the cosine of polar angle of muon track in lab frame.
  - $\phi_{\mu^\pm}$: the azimuthal angle of muon track in lab frame.
  - $\Delta\phi_{\mu^\pm}$: the difference of azimuthal angle between two muon tracks in lab frame.
  - $\min p_t$: the minimum of transverse momentum between two muon tracks in lab frame.
  - $\cos\theta_{\gamma\text{max}}$: the cosine of polar angle of the most energetic photon in lab frame.
  - $\phi_{\gamma\text{max}}$: the azimuthal angle of the most energetic photon in lab frame.
  - $E_{\gamma\text{max}}$: the energy of the most energetic photon.

2.2 Datasets

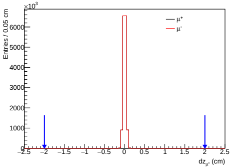
- Data: Exp30 (bucket37 and bucket38).
- MC: MC15rd($\Upsilon(4S)$). It will be replaced with new run-dependent MC in the future.

2.3 Physics analysis

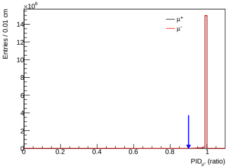
- Event selection.
  - All charged tracks are required to originate from the vicinity of the interaction point; $|dr| < 0.5\,\text{cm}$ and $|dz| < 2\,\text{cm}$.
  - All charged tracks should be in acceptance angle of the CDC, including barrel and endcaps.
  - $R_\mu = \frac{L_\mu}{L_{e^+} + L_\mu + L_\pi + L_K + L_p + L_d} > 0.9$ is required. The L_e, L_μ, L_π, L_K, L_p and L_d are the likelihood for a track to be muon, electron, pion, kaon, proton and deuteron, respectively, calculated based on information from reference subdetectors. The PID for muons does not use the information from the SVD.
  - To identify $\mu^+\mu^-(\gamma)$ events, the invariant mass of the $\mu^+\mu^-$ system is required to be:$M_{\mu^+\mu^-} > 4\,\text{GeV}/c^2$.
  - For the ISR photon, we find the most energetic photon $(E_\gamma > 1\,\text{GeV})$.
  - To remove most of the beam background, the total energy is required to be:$E_{\mu^+\mu^-} + E_\gamma < 11\,\text{GeV}$.



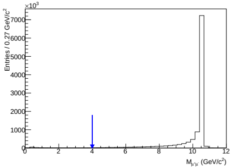
(a)



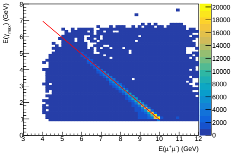
(b)



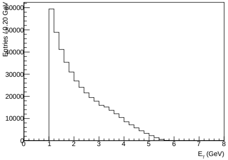
(c)



(d)



(e)



(f)

Figure: The distributions from MC.

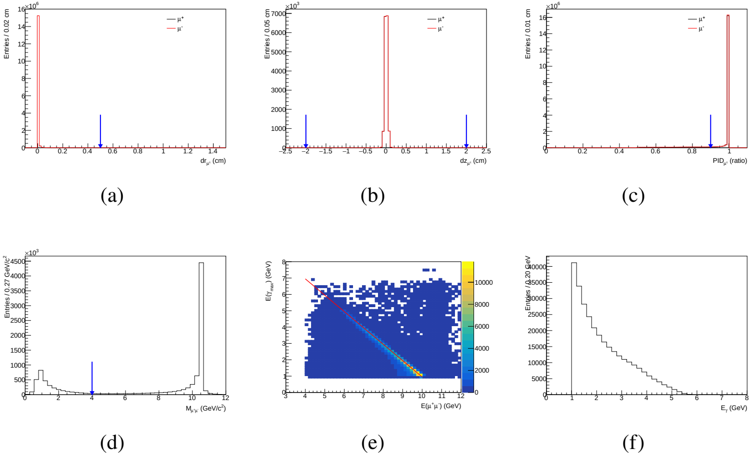


Figure: The distributions from data.

The trigger efficiency of experiment 30

3.1 CDC trigger efficiency

Trigger bit	ϵ_{DT}(PSNM)	ϵ_{MC}(PSNM)	Diff	Factor	ϵ_{DT}(FTDL)	ϵ_{MC}(FTDL)	Diff
Exp30							
~~ffy~~	~~1.86 ± 0.02~~	~~0.09 ± 0.00~~	~~90.30~~	~~19.60 ± 0.64~~	~~1.86 ± 0.02~~	~~0.09 ± 0.00~~	~~90.30~~
fyo	76.26 ± 0.05	72.66 ± 0.04	2.42	1.05 ± 0.00	76.27 ± 0.05	72.66 ± 0.04	2.42
ffo	–	0.35 ± 0.01	–	–	76.49 ± 0.05	72.85 ± 0.04	2.44
fy30	76.76 ± 0.05	73.19 ± 0.04	2.38	1.05 ± 0.00	76.76 ± 0.05	73.19 ± 0.04	2.39
ff30	–	0.36 ± 0.01	–	–	77.02 ± 0.05	73.38 ± 0.04	2.42
stt	92.11 ± 0.03	89.17 ± 0.03	1.62	1.03 ± 0.00	92.11 ± 0.03	89.17 ± 0.03	1.62
syo	0.00 ± 0.00	0.00 ± 0.00	–	–	7.89 ± 0.03	7.10 ± 0.03	5.27
syb	0.00 ± 0.00	0.00 ± 0.00	–	–	4.80 ± 0.03	4.67 ± 0.02	1.43

3.1 CDC trigger efficiency

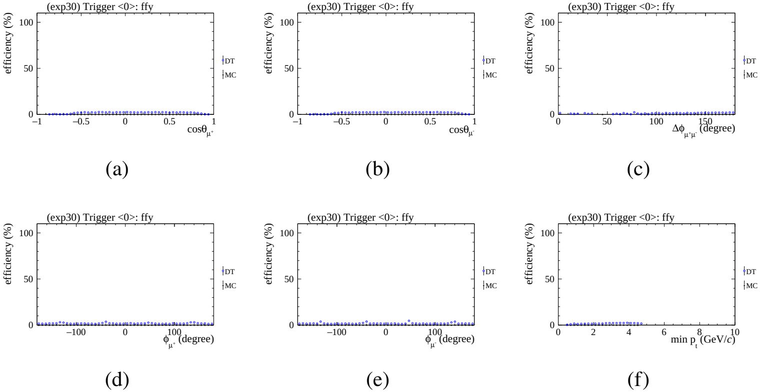


Figure: CDC trigger ”ffy” efficiency with variables after pre-scale. The blue circles with error bars are from data, and the black dots with error bars are from MC samples.

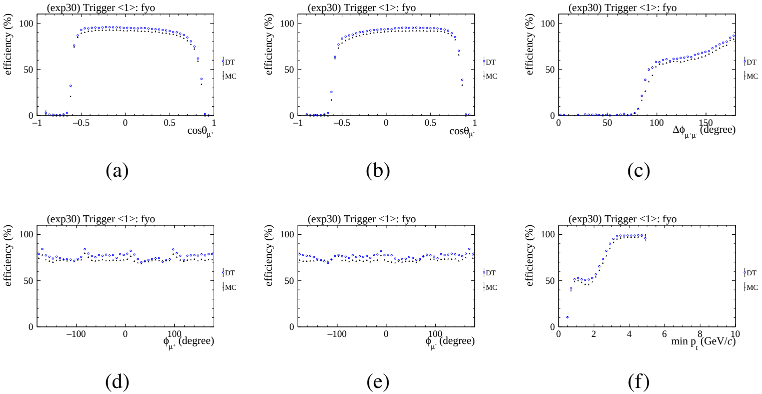


Figure: CDC trigger "fyo" efficiency with variables after pre-scale. The blue circles with error bars are from data, and the black dots with error bars are from MC samples.

3.1 CDC trigger efficiency

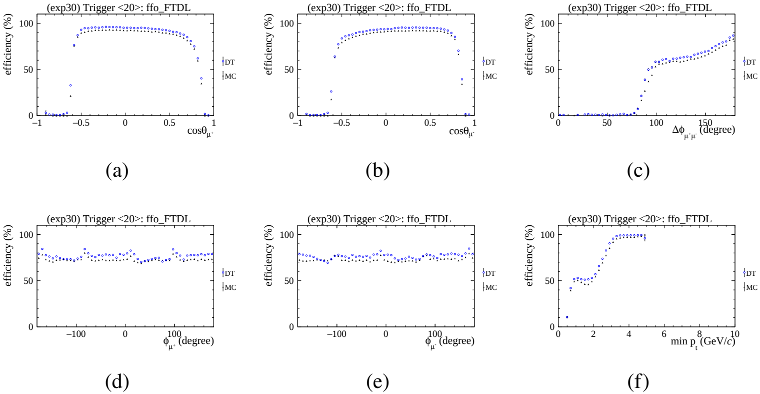


Figure: CDC trigger ”ffo” efficiency with variables before pre-scale. The blue circles with error bars are from data, and the black dots with error bars are from MC samples.

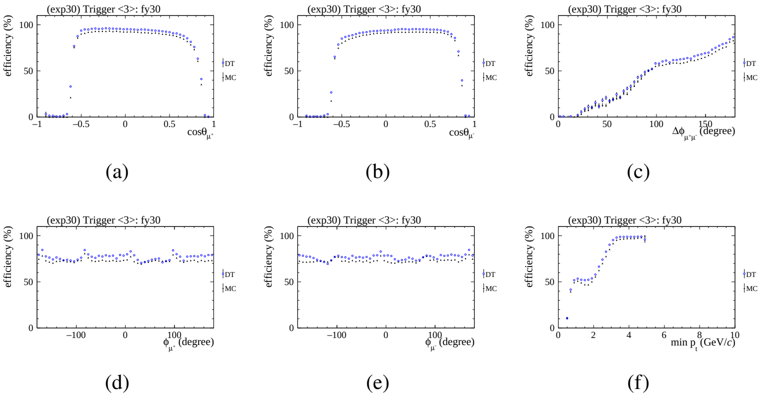
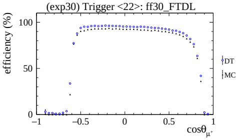
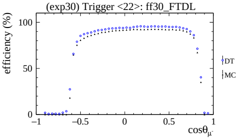


Figure: CDC trigger "fy30" efficiency with variables after pre-scale. The blue circles with error bars are from data, and the black dots with error bars are from MC samples.

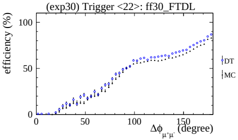
3.1 CDC trigger efficiency



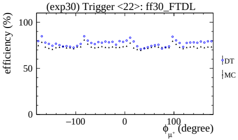
(a)



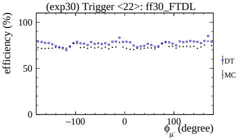
(b)



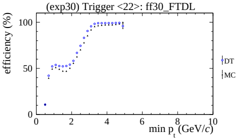
(c)



(d)



(e)



(f)

Figure: CDC trigger ”ff30” efficiency with variables before pre-scale. The blue circles with error bars are from data, and the black dots with error bars are from MC samples.

3.1 CDC trigger efficiency

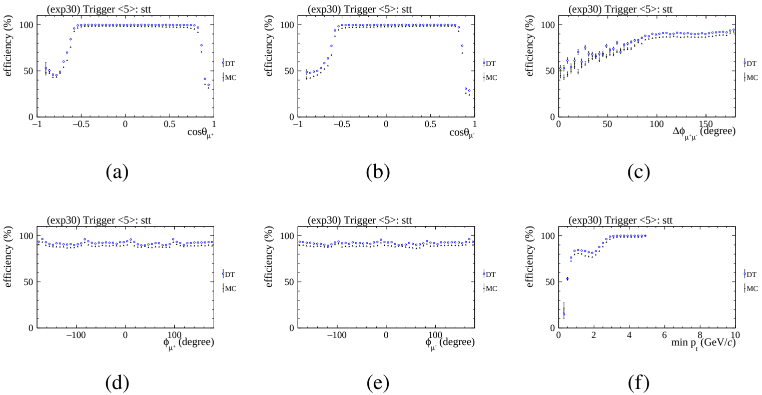


Figure: CDC trigger ”stt” efficiency with variables after pre-scale. The blue circles with error bars are from data, and the black dots with error bars are from MC samples.

3.1 CDC trigger efficiency

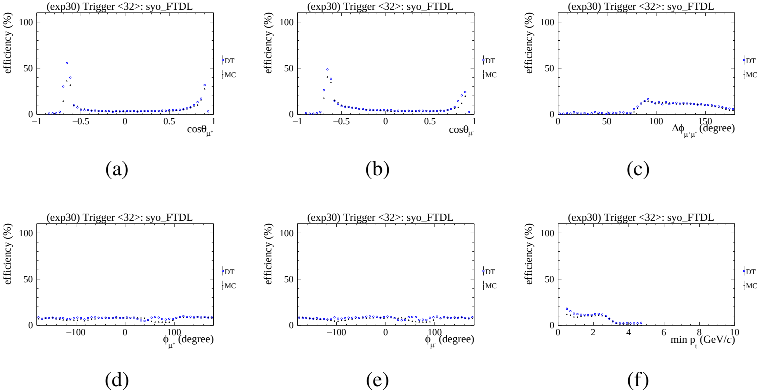


Figure: CDC trigger "syo" efficiency with variables before pre-scale. The blue circles with error bars are from data, and the black dots with error bars are from MC samples.

3.1 CDC trigger efficiency

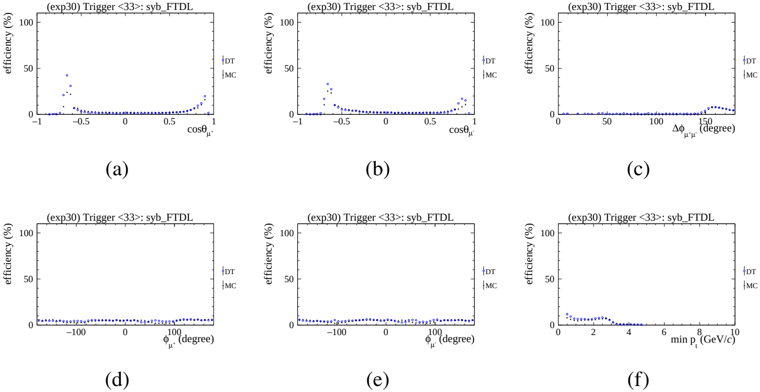


Figure: CDC trigger ”syb” efficiency with variables before pre-scale. The blue circles with error bars are from data, and the black dots with error bars are from MC samples.

3.2 ECL trigger efficiency

Trigger bit	ϵ_{DT}(PSNM)	ϵ_{MC}(PSNM)	Diff	Factor	ϵ_{DT}(FTDL)	ϵ_{MC}(FTDL)	Diff
Exp30							
hie	90.13 ± 0.04	87.65 ± 0.03	1.39	1.03 ± 0.00	90.14 ± 0.04	87.65 ± 0.03	1.40
c4	7.41 ± 0.03	10.66 ± 0.03	18.00	0.69 ± 0.00	7.41 ± 0.03	10.66 ± 0.03	18.00
lml1	17.33 ± 0.04	17.03 ± 0.04	0.86	1.02 ± 0.00	34.45 ± 0.06	34.08 ± 0.05	0.54
lml2	8.97 ± 0.03	9.15 ± 0.03	0.99	0.98 ± 0.00	8.97 ± 0.03	9.15 ± 0.03	0.98
lml4	0.34 ± 0.01	0.38 ± 0.01	5.92	0.89 ± 0.02	3.48 ± 0.02	3.77 ± 0.02	4.07
lml6	55.31 ± 0.06	53.97 ± 0.05	1.22	1.03 ± 0.00	55.31 ± 0.06	53.97 ± 0.05	1.23

3.2 ECL trigger efficiency

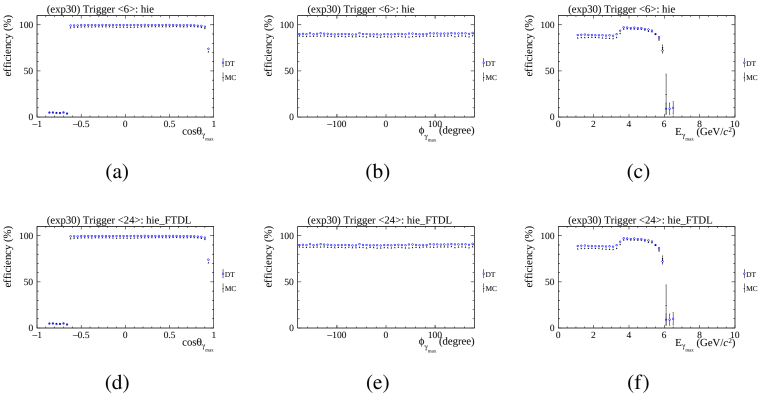


Figure: ECL trigger "hie" efficiency with variables after and before pre-scale. The blue circles with error bars are from data, and the black dots with error bars are from MC samples.

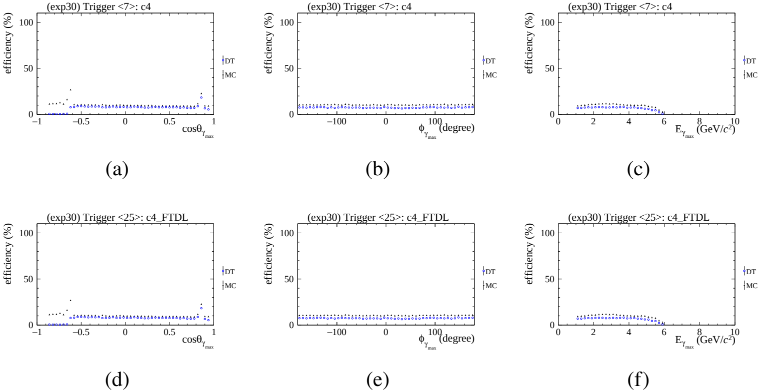


Figure: ECL trigger ”c4” efficiency with variables after and before pre-scale. The blue circles with error bars are from data, and the black dots with error bars are from MC samples.

3.2 ECL trigger efficiency

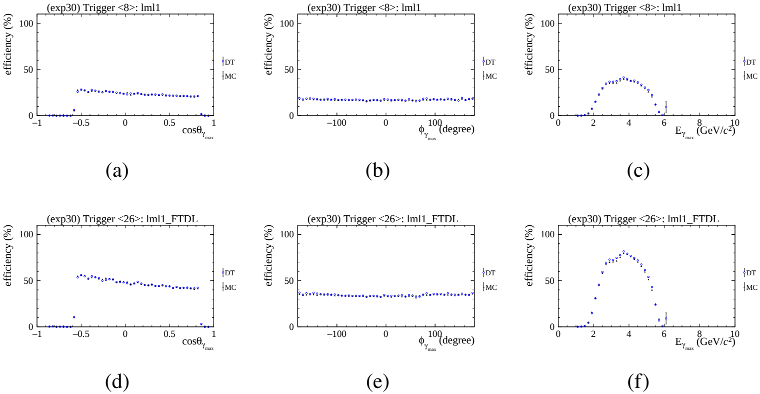


Figure: ECL trigger "lml1" efficiency with variables before and after pre-scale. The blue circles with error bars are from data, and the black dots with error bars are from MC samples.

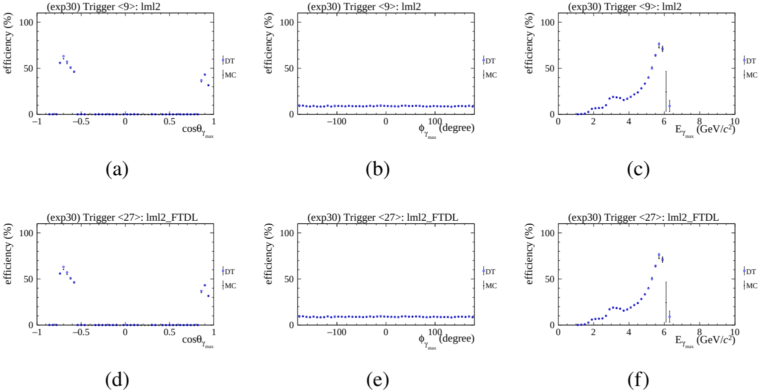


Figure: ECL trigger "lml2" efficiency with variables after and before pre-scale. The blue circles with error bars are from data, and the black dots with error bars are from MC samples.

3.2 ECL trigger efficiency

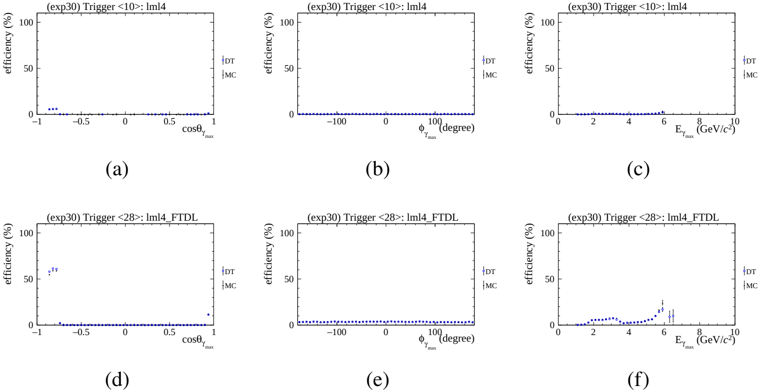


Figure: ECL trigger ”lml4” efficiency with variables after and before pre-scale. The blue circles with error bars are from data, and the black dots with error bars are from MC samples.

3.2 ECL trigger efficiency

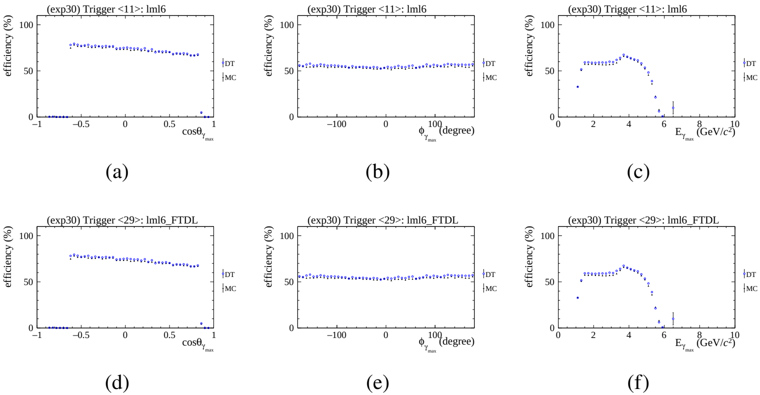


Figure: ECL trigger ”lml6” efficiency with variables after and before pre-scale. The blue circles with error bars are from data, and the black dots with error bars are from MC samples.

3.3 KLM trigger efficiency

Trigger bit	ϵ_{DT}(PSNM)	ϵ_{MC}(PSNM)	Diff	Factor	ϵ_{DT}(FTDL)	ϵ_{MC}(FTDL)	Diff
Exp30							
mu_b2b	45.23 ± 0.06	49.81 ± 0.05	4.83	0.91 ± 0.00	45.23 ± 0.06	49.81 ± 0.05	4.82
cdcklm2	57.92 ± 0.06	58.20 ± 0.05	0.24	0.99 ± 0.00	57.93 ± 0.06	58.20 ± 0.05	0.24
fwd_seklm	3.80 ± 0.02	4.02 ± 0.02	2.78	0.95 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	–
bwd_seklm	4.44 ± 0.02	4.10 ± 0.02	3.96	1.08 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	–

3.3 KLM trigger efficiency

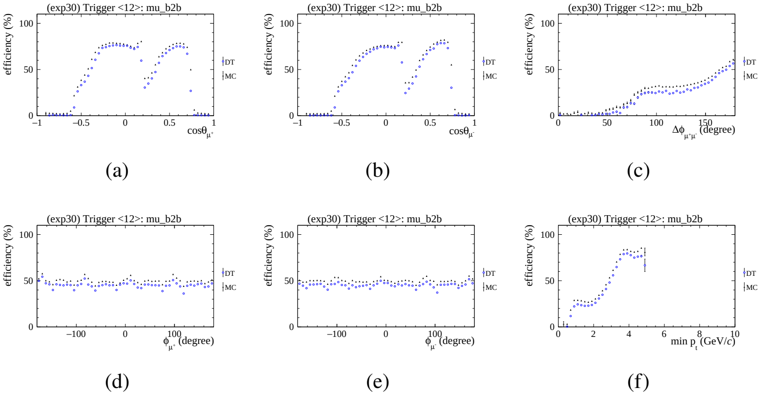


Figure: KLM trigger ”mu_b2b” efficiency with variables after pre-scale. The blue circles with error bars are from data, and the black dots with error bars are from MC samples.

3.3 KLM trigger efficiency

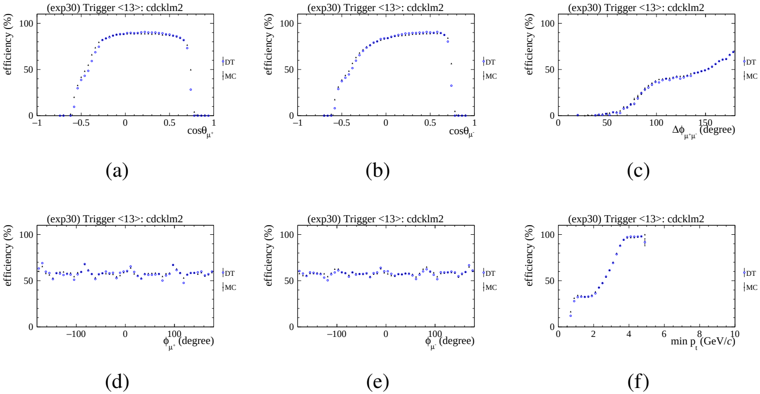


Figure: KLM trigger "cdcklm2" efficiency with variables after pre-scale. The blue circles with error bars are from data, and the black dots with error bars are from MC samples.

3.3 KLM trigger efficiency

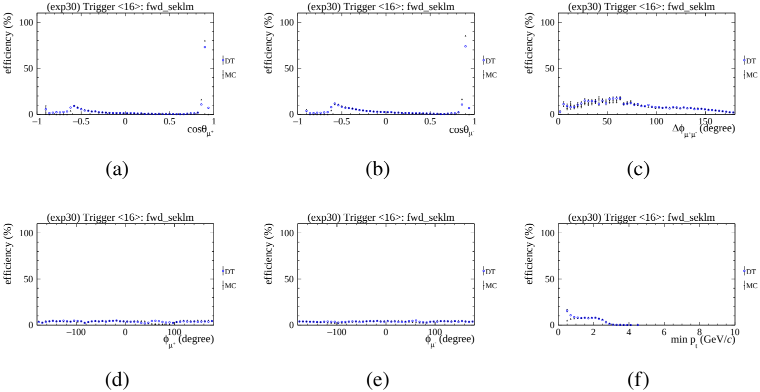


Figure: KLM trigger "fwd_seklm" efficiency with variables after pre-scale. The blue circles with error bars are from data, and the black dots with error bars are from MC samples.

3.3 KLM trigger efficiency

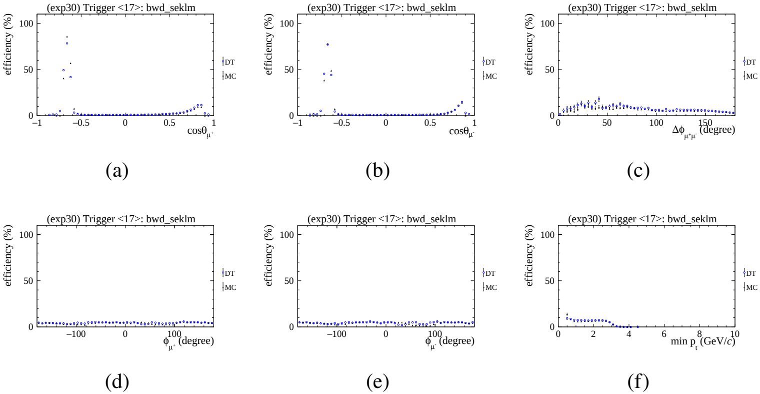


Figure: KLM trigger "bwd_seklm" efficiency with variables after pre-scale. The blue circles with error bars are from data, and the black dots with error bars are from MC samples.

3.4 Check of neural network-based trigger and trigger matching

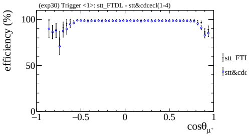
Due to the higher luminosity expected at SuperKEKB in the future, the L1 trigger rate will increase significantly. Many trigger bits will be replaced, otherwise the DAQ and HLT will be saturated. Several strategies have been proposed. One is to expand use of neural network based tracks in CDC triggers, and one is performing CDC-ECL trigger matching.

In this slide, we check the difference of trigger efficiency between standard bit and new one.

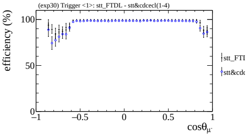
- stt $\rightarrow$ stt & cdcecl(1-4) ϵ (99.91% $\leftrightarrow$ 98.50%)
- f $\rightarrow$ cdcecl(1-4) ϵ (99.96% $\leftrightarrow$ 99.90%)
- syo $\rightarrow$ syo & cdcecl(1-4) ϵ (2.32% $\leftrightarrow$ 2.09%)
- syb $\rightarrow$ syb & cdcecl(1-4) ϵ (0.90% $\leftrightarrow$ 0.78%)
- cdcklm(1-2) $\rightarrow$ ycdcklm(1-2) ϵ (83.94% $\leftrightarrow$ 83.71%)

For the first four items, we select "mu_b2b" as reference trigger. The last one still uses "hie".

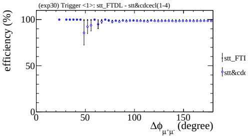
3.4 Check of neural network-based trigger and trigger matching



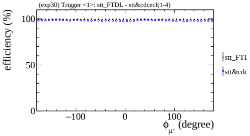
(a)



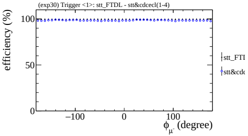
(b)



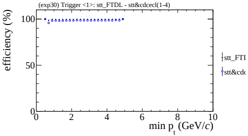
(c)



(d)



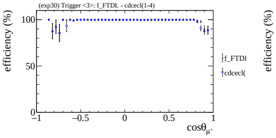
(e)



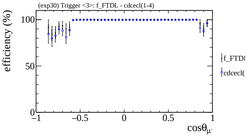
(f)

Figure: The difference of trigger “stt” and “sttecl” efficiency with variables before pre-scale. The efficiency is obtained using “mu_b2b” as reference

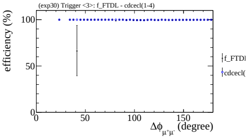
3.4 Check of neural network-based trigger and trigger matching



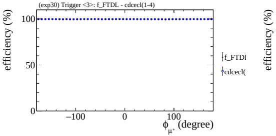
(a)



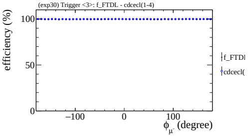
(b)



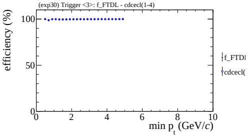
(c)



(d)



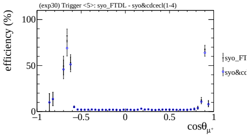
(e)



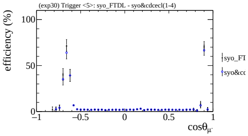
(f)

Figure: The difference of trigger "f" and "cdcecl(1-4)" efficiency with variables before pre-scale. The efficiency is obtained using "mu_b2b" as reference

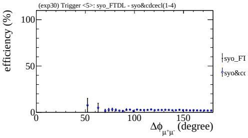
3.4 Check of neural network-based trigger and trigger matching



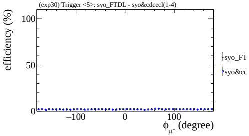
(a)



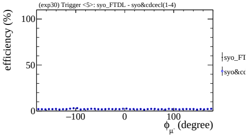
(b)



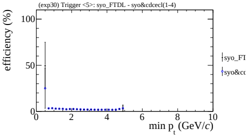
(c)



(d)



(e)



(f)

Figure: The difference of trigger "syo" and "syoecl" efficiency with variables before pre-scale. The efficiency is obtained using "mu_b2b" as reference

3.4 Check of neural network-based trigger and trigger matching

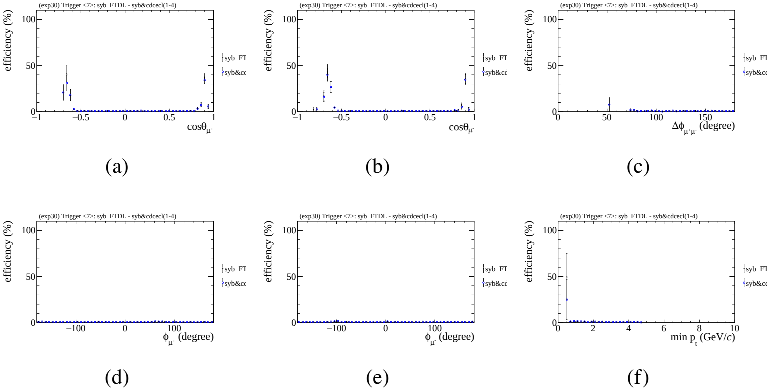


Figure: The difference of trigger “syb” and “sybecl” efficiency with variables before pre-scale. The efficiency is obtained using “mu_b2b” as reference

3.4 Check of neural network-based trigger and trigger matching

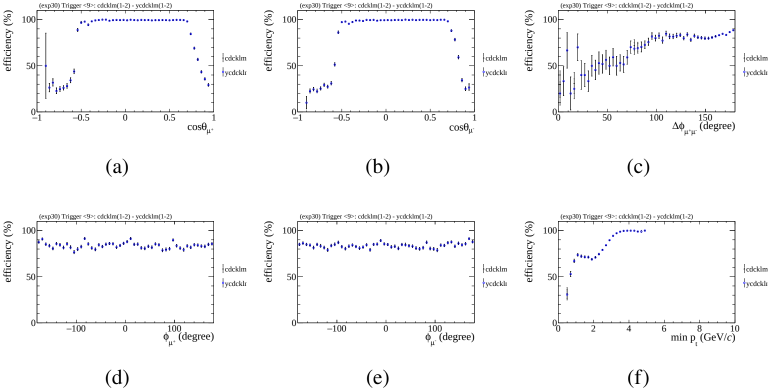


Figure: The difference of trigger “cdcklm(1-2)” and “ycdcklm(1-2)” efficiency with variables before pre-scale. The efficiency is obtained using “hie” as reference

Summary

4. Summary

- The comparison between data and MC samples is important for TSim study in the future, and the calculated weight factor provides information for systematic uncertainty and efficiency correction in physical analysis.
- This slide uses incorrect MC for reference only.
- In CDC trigger efficiency, We don't find efficiency decrease in certain specific phi regions during physics run. (or we should compare it with official MC samples)
- In terms of ffy, the difference between data and MC is significant, so I have excluded it from this slide. I am not sure why this discrepancy exists, and this issue has also been observed in previous experiments.
- For trigger matching, all the trigger bits are consistent after removing the bug from my script.

Thank you for your attention!

What is prescale?
If the prescale value is set to 10： Each time a collision occurs, check if the trigger bit is activated. For the first activation, record it; for the second to the tenth activations, do not record. After the tenth activation, reset the counter. Repeat this operation in a loop. This process effectively seems to reduce the trigger rate by a factor equal to the prescale value.