Trigger Performance for Doubly Charged Higgs

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Higgs Triplet Models

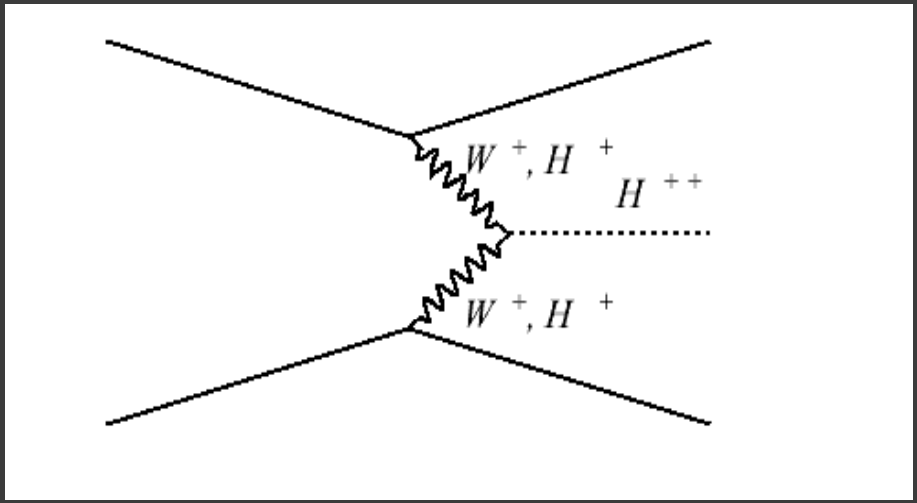
- **Standard Model Higgs**
  - Electroweak symmetry is broken with a complex scalar Isospin doublet (Isospin I = ½ , Hypercharge Y = 1)
  - Explain mass of W and Z boson, quarks and leptons
  - cannot generate neutrino mass
  - Neutrino Oscillation experiment → Neutrinos are not massless

- **Higgs Triplet Models (I = 1, Y = 2)**
  - Higgs Trplet Models are extension of standard model Higgs boson
  - Higgs triplet (H^0,$H^{\pm}$,$H^{\pm\pm}$)
  - Triplet higgs bosons couple to Neutrinos → Neutrinos get mass

- **Doubly charged higgs bosons are a clear signature for this models**

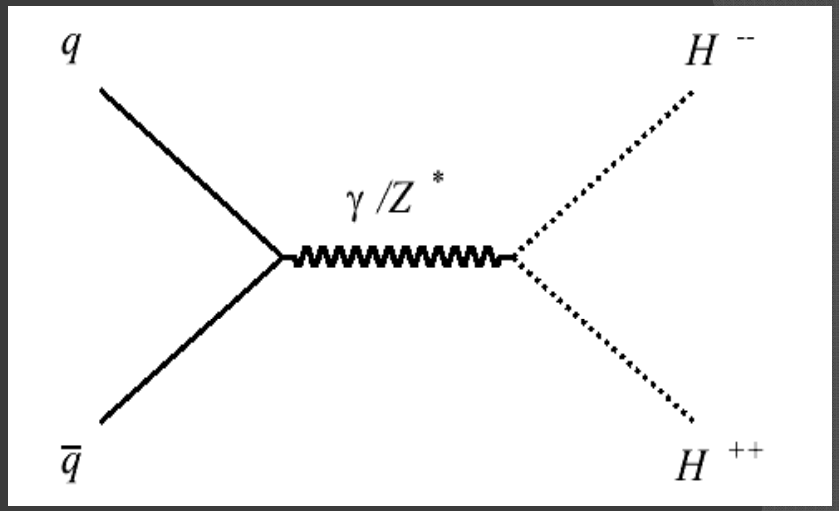
Possible production of doubly charged Higgs at hadron collider

Doubly charged Higgs bosons couple to leptons, W and Z bosons and $H^{\pm}$ bosons



Single production

- by W^+W^+ fusion:
  negligible in most models
- by W^+H^+ or H^+H^+ Fusion:
  cross section is model dependent



Drell-Yan pair production

- cross section
  depends only on $H^{\pm\pm}$ mass

Pair-produced doubly charged Higgs bosons are studied

Decay of doubly charged Higgs bosons

- **Leptonic decays dominate in most models**
- **$H^{\pm\pm}$ decay channels are chosen arbitrarily**
  - *H++H-- → 4mu : Jongseok Lee*
  - *H++H-- → 3mu : Sungeun Lee*
  - *H++H-- → 2mu2e : Junghwan Goh*
- **coupling constant of $H^{\pm\pm}$ to leptons = 0.1 was assumed → forced doubly charged Higgs bosons decay inside the CMS-tracker**

Signal sample generation

decay	gen	# of gen events	Mass (GeV)	CMSSW	Global tag	Energy
H++H-- → 4mu	pythia	10k	130, 150, 170, 200, 300, 600	2_2_6	STARTUP_V9	10 TeV
H++H-- → 2mu2e	pythia	10k	130, 150, 170, 200, 300, 600	3_1_0	MC_31X_V2, STARTUP31X_V2	10 TeV

Background sample

- Used background sample made by H → ZZ group (https://twiki.cern.ch/twiki/bin/view/CMS/HiggsZZMCsamples)

DBS link: GEN samples, DIGI+HLT samples, RECO samples, Skim samples, PAT samples

Bkg	Xsec (fb)	K-factor	Gen Filter eff.	Nb. ev.	Skim eff (glb mu)* / *Nb. ev.	Skim(all mu)* / *Nb. ev.
ttbar	280900	1.46	0.01091	1007062	0.722 / 727618	0.750 / 755314
Zbb	56200	1.66	0.007	1063204	0.642 / 682820	0.664 / 706264
ZZ	189	(1+0.35+0.2)	0.3165	898940	0.870 / 781721	0.88 / 792353

Trigger and skim

- Nicola De Filippis (convenor of H→ZZ group) suggested to use the same trigger and skim as H→ZZ

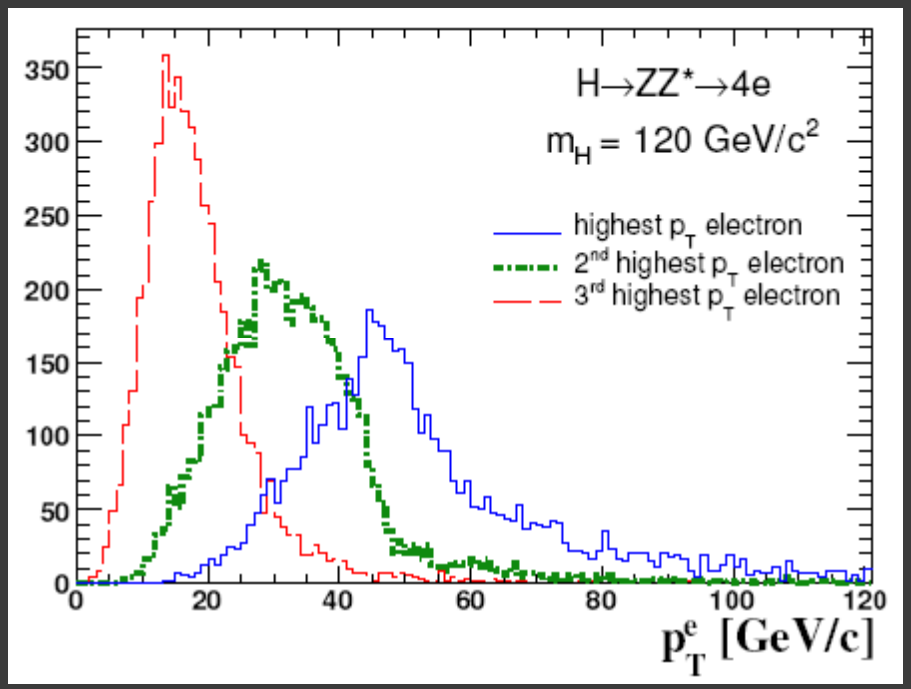
- Skim : 2 leptons with pT > 10 GeV & 1 lepton with pT > 5 GeV

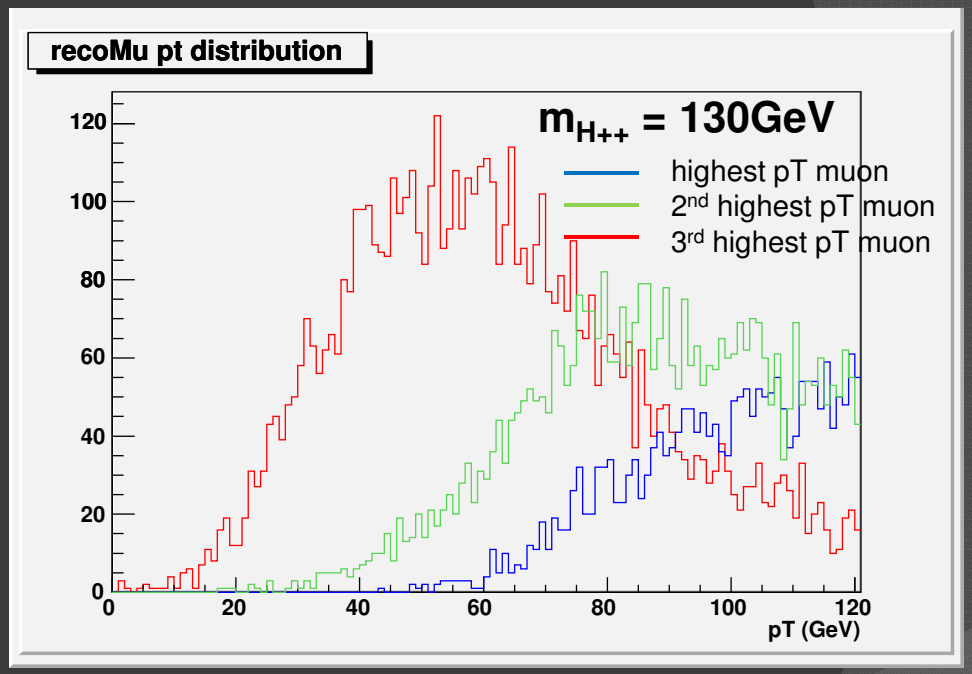
Analysis	8E29 HLT (SARTUP condition)	1E31 HLT (IDEAL condition)
H++H-- → 4mu	HLT_Mu3 HLT_DoubleMu3	HLT_Mu9 HLT_DoubleMu3
H++H-- → 3mu	HLT_Mu3 HLT_DoubleMu3	HLT_Mu9 HLT_DoubleMu3
H++H-- → 2mu2e	HLT_Mu9 HLT_DoubleMu3 HLT_Ele10_LW_EleId_L1R HLT_DoubleEle5_SW__L1R	HLT_Mu9 HLT_DoubleMu3 HLT_Ele15_SW_LooseTrackIso_L1R HLT_DoubleEle10_SW_L1R

Skim


60
40
20
0
0
20
40
60
80
100
120
pT (GeV)

H++H-- → 4 mu


H→ZZ*→4e
m_H = 120 GeV/c²
highest p_T electron
2nd highest p_T electron
3rd highest p_T electron
p_T^e [GeV/c]


recoMu pt distribution
m_H++ = 130GeV
highest pT muon
2nd highest pT muon
3rd highest pT muon
pT (GeV)

H++H-- → 4mu

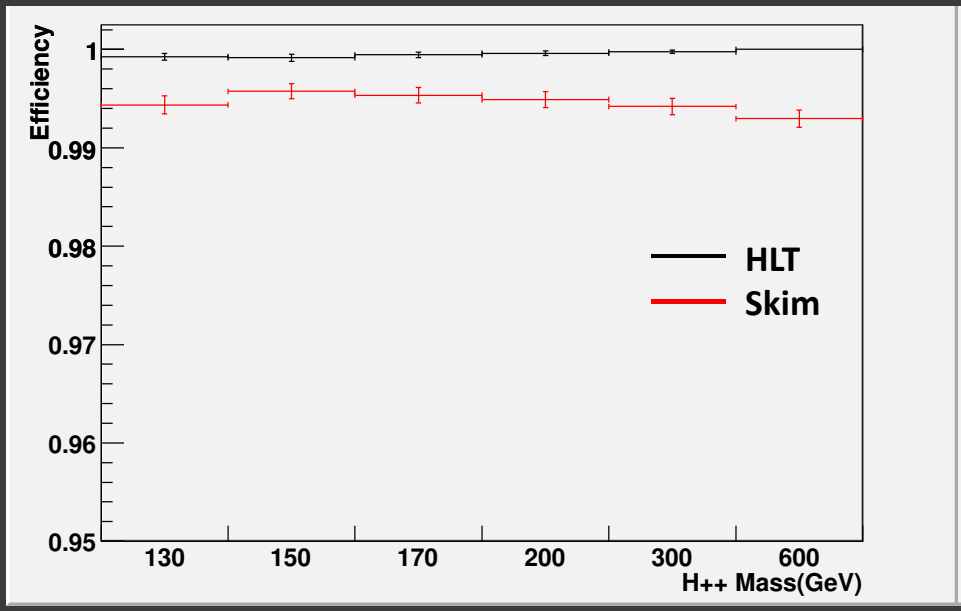
Triggers and Skim used in the analysis

8e29 HLT	1e31 HLT	Skim
'HLT_Mu3' or 'HLT_DoubleMu3'	'HLT_Mu9' or 'HLT_DoubleMu3'	2 muons with pT > 10 GeV & 1 muon with pT > 5 GeV

Efficiency

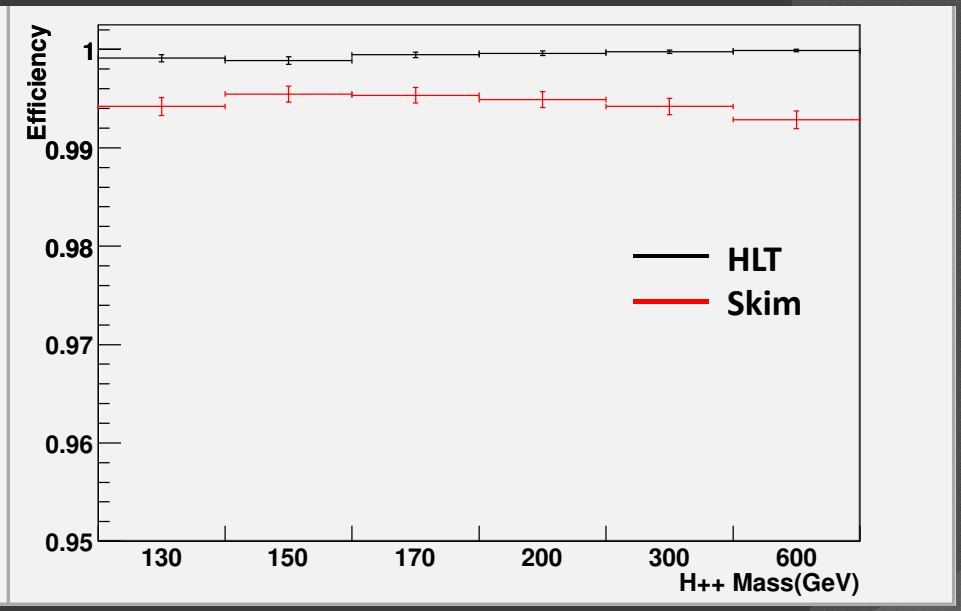
HLT efficiency

8E29 HLT



HLT efficiency

1E31 HLT



Definition of efficiency

$$\varepsilon_{HLT} = \#\, HLT_{events} / N_{gen}$$

$$\varepsilon_{skim} = \#\, HLT_{events} \cap Skim / N_{gen}$$

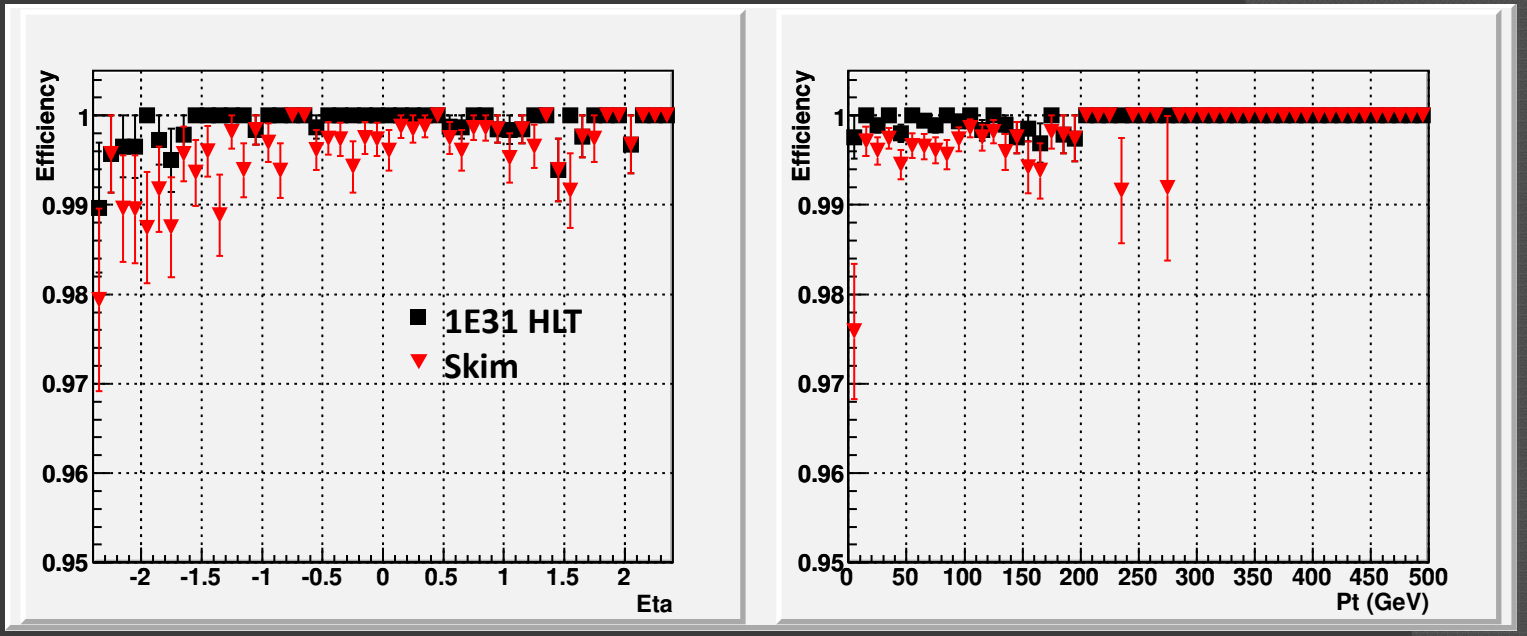
$$\delta\varepsilon = \sqrt{(\varepsilon(1-\varepsilon)) / N_{gen}}$$

Where, N_{gen} is the number of generated events in the sample having four muons of right flavor and charge within detector acceptance (|eta| < 2.4)

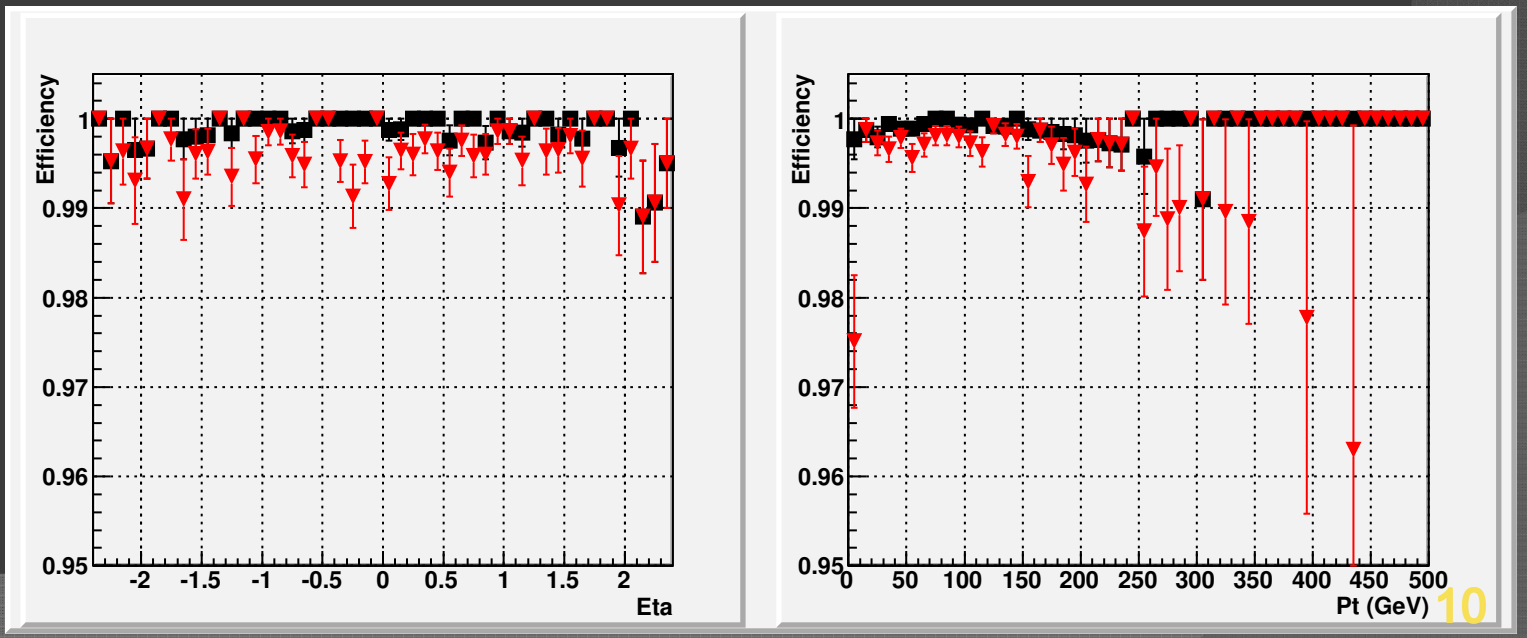
H++H-- → 4mu

Efficiency vs. eta, pT

m_{H++} =130 GeV



m_{H++} =150 GeV



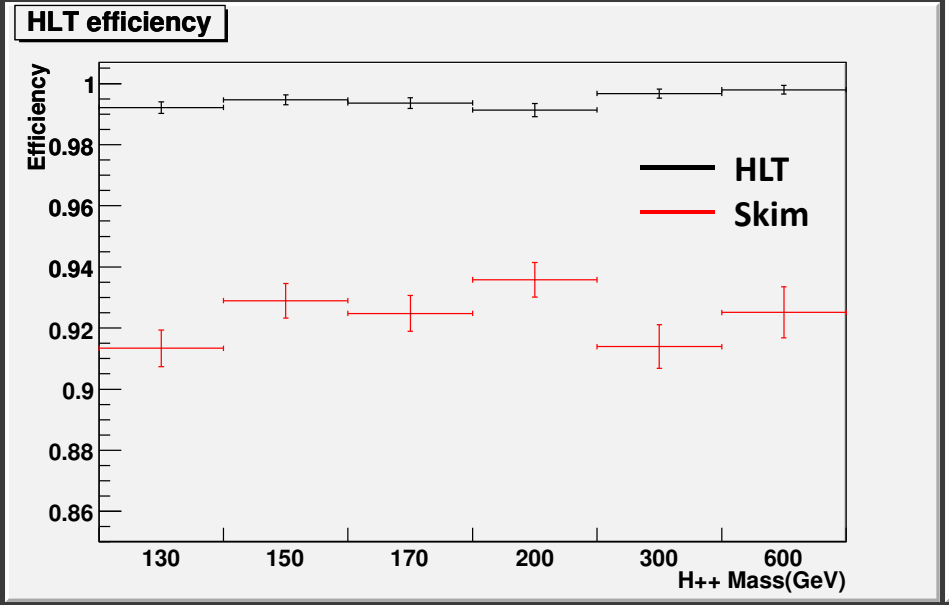
H++H-- → 3mu

Triggers and Skim used in the analysis

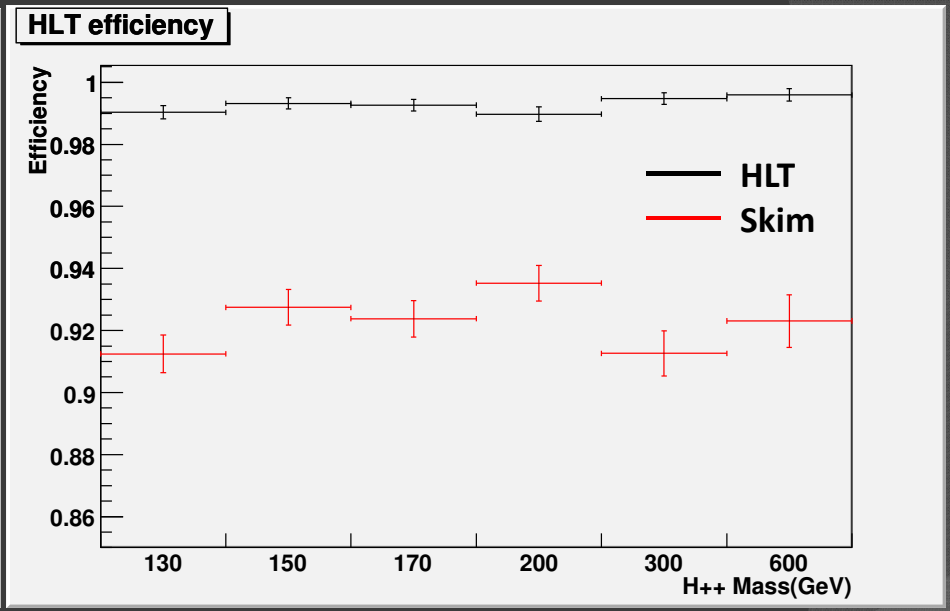
8e29 HLT	1e31 HLT	Skim
'HLT_Mu3' or 'HLT_DoubleMu3'	'HLT_Mu9' or 'HLT_DoubleMu3'	2 muons with pT > 10 GeV & 1 muon with pT > 5 GeV

Efficiency

8E29 HLT



1E31 HLT



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$$\varepsilon_{skim} = \#\, HLT_{events} \cap Skim / N_{gen}$$

$$\delta\varepsilon = \sqrt{(\varepsilon(1-\varepsilon)) / N_{gen}}$$

Where, N_{gen} is the number of generated events in the sample having three muons of right flavor and charge within detector acceptance (|eta| < 2.4)

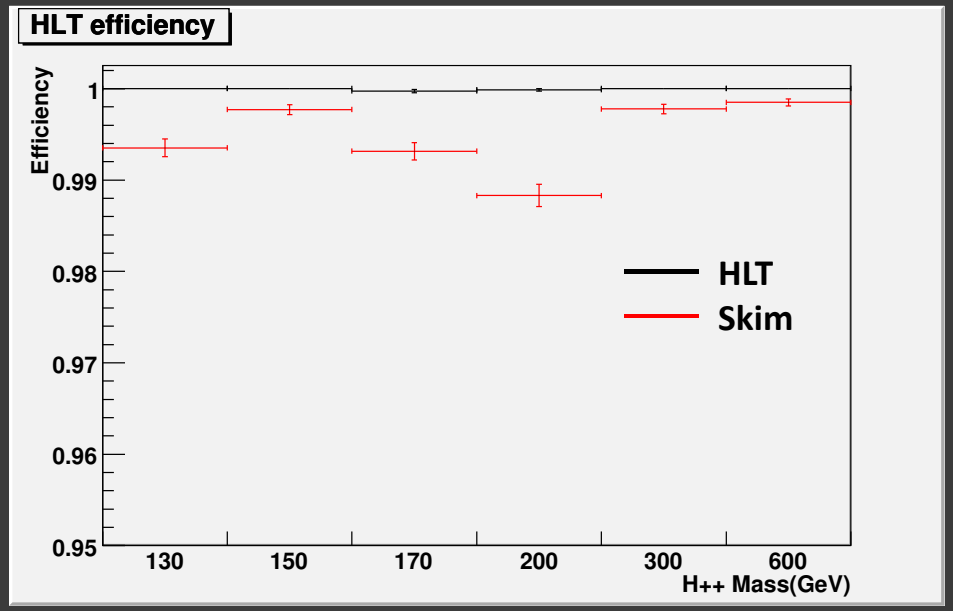
H++H-- → 2e2mu

Triggers and Skim used in the analysis

8e29 HLT	1e31 HLT	Skim
HLT_Mu9 HLT_DoubleMu3 HLT_Ele10_LW_EleId_L1R HLT_DoubleEle5_SW__L1R	HLT_Mu9 HLT_DoubleMu3 HLT_Ele15_SW_LooseTrackIso_L1R HLT_DoubleEle10_SW_L1R	2 leptons with pT > 10 GeV & 1 lepton with pT > 5 GeV

Efficiency

1E31 HLT



Definition of efficiency

$$\varepsilon_{HLT} = \#\, HLT_{events} / N_{gen}$$

$$\varepsilon_{skim} = \#\, HLT_{events} \cap Skim / N_{gen}$$

$$\delta\varepsilon = \sqrt{(\varepsilon(1-\varepsilon)) / N_{gen}}$$

Where, N_{gen} is the number of generated events in the sample having four leptons of right flavor and charge within detector acceptance (|eta| < 2.4)

trigger and skim efficiency for background samples

	ttbar → 4l		Zbb → 4l		zz → 4l	
	# of events	Efficiency	# of events	Efficiency	# of events	Efficiency
Total	170000	-	138000	-	182000	-
4mu, |eta| < 2.4	10173	100.00 %	14225	100.00 %	38241	100.00 %
8E29 HLT 1E31 HLT	10141 10027	99.70 % 98.56 %	14172 14067	99.63 % 98.89 %	38199 38133	99.89 % 99.72 %
8E29 & skim (glb mu) 1E31 & skim (glb mu)	7500 7477	73.72 % 73.50 %	10812 10793	76.01 % 75.87 %	36153 36124	94.54 % 94.46 %

*** Background samples are already filtered at the generation level**

(info from https://twiki.cern.ch/twiki/bin/view/CMS/HiggsZZMCsamples)

	PYTHIA filter	PYTHIA filter efficiency
ttbar → 4l	4(e||mu), pT(e||mu) > 4GeV, |eta(e||mu)| < 2.7	1.09 %
Zbb → 4l	4(e||mu), pT(e||mu) > 4GeV, |eta(e||mu)| < 3.0	0.7 %
zz → 4l	4(e||mu), pT(e||mu) > 4GeV, |eta(e||mu)| < 2.7	31.65 %

Summary

- Trigger and skim efficiency was evaluated for doubly charged Higgs analysis
- The efficiency is close to 100% for H++H-- → 4mu and H++H-- → 2e2mu
  - *we can share the same trigger and skim with H→ZZ group*
- had better modify the skim for H++H-- → 3mu
  - *cannot share the same skim with H→ZZ group*