Lepton Retuning for Highly Compressed SUSY Cascade Analysis

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Outline

Quick Debrief - adapting our Run 2 analysis for Run 3

Muon Collection

Electron Collection

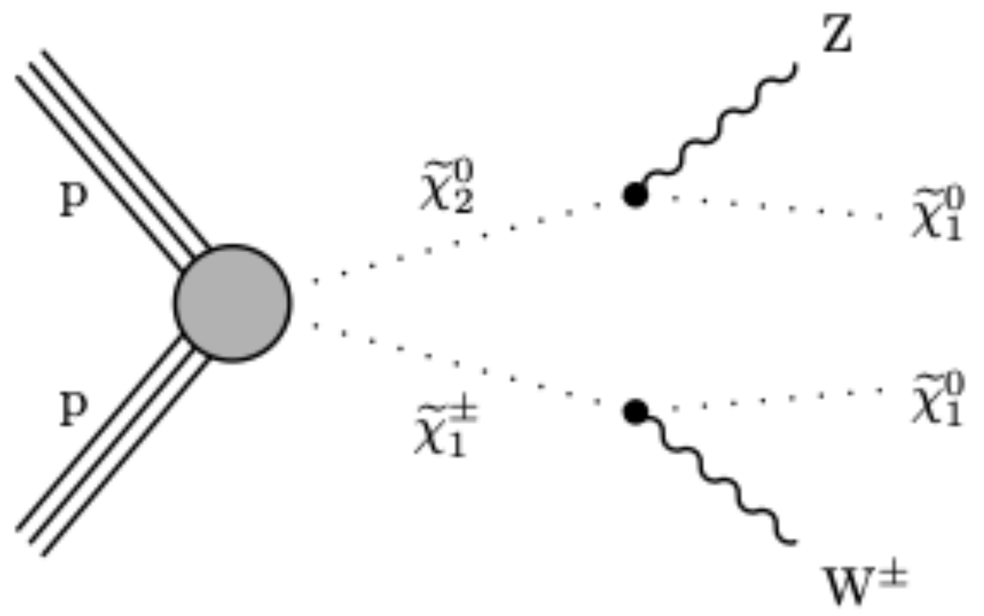
LowPtElectron Collection

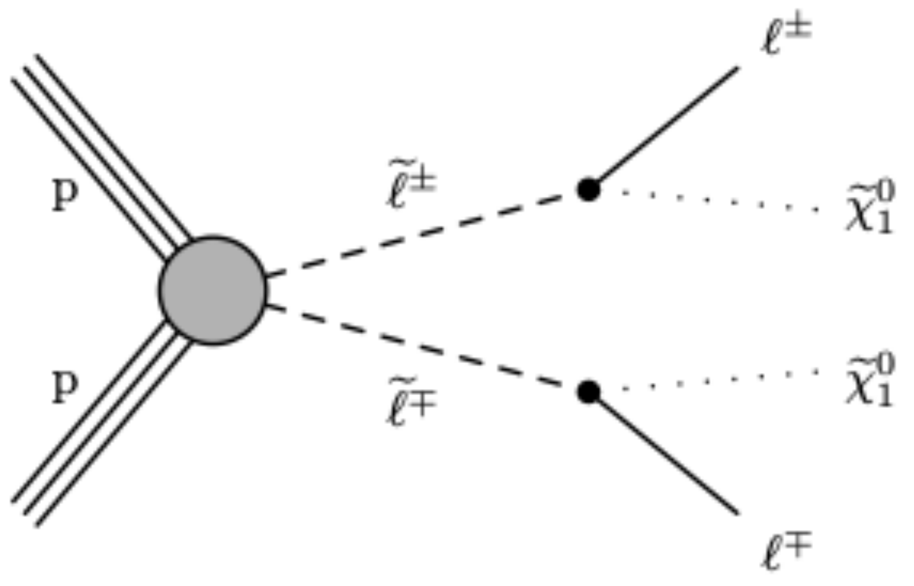
Quick Debrief

Previous Analysis (SUS-23-003) and Current Analysis

Compressed Electroweakinos , $\tilde{\ell}, \tilde{\nu}_\ell$

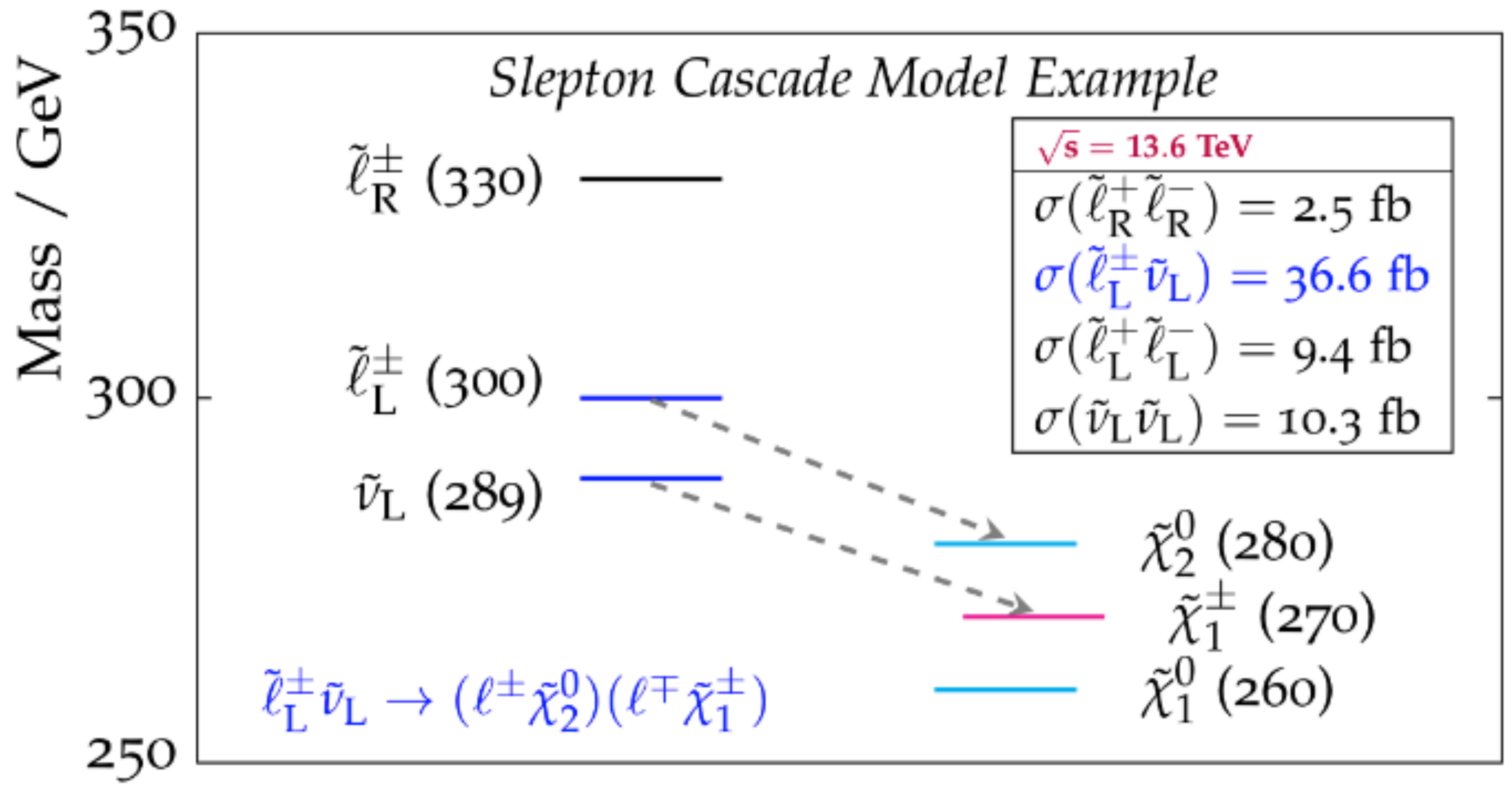
Replace with SlepSnu Diagrams





- **[Previous Analysis (SUS-23-003)]**: general search for *SUSY particles* (stops, sleptons, electroweakinos) with compressed mass spectra in Run 2

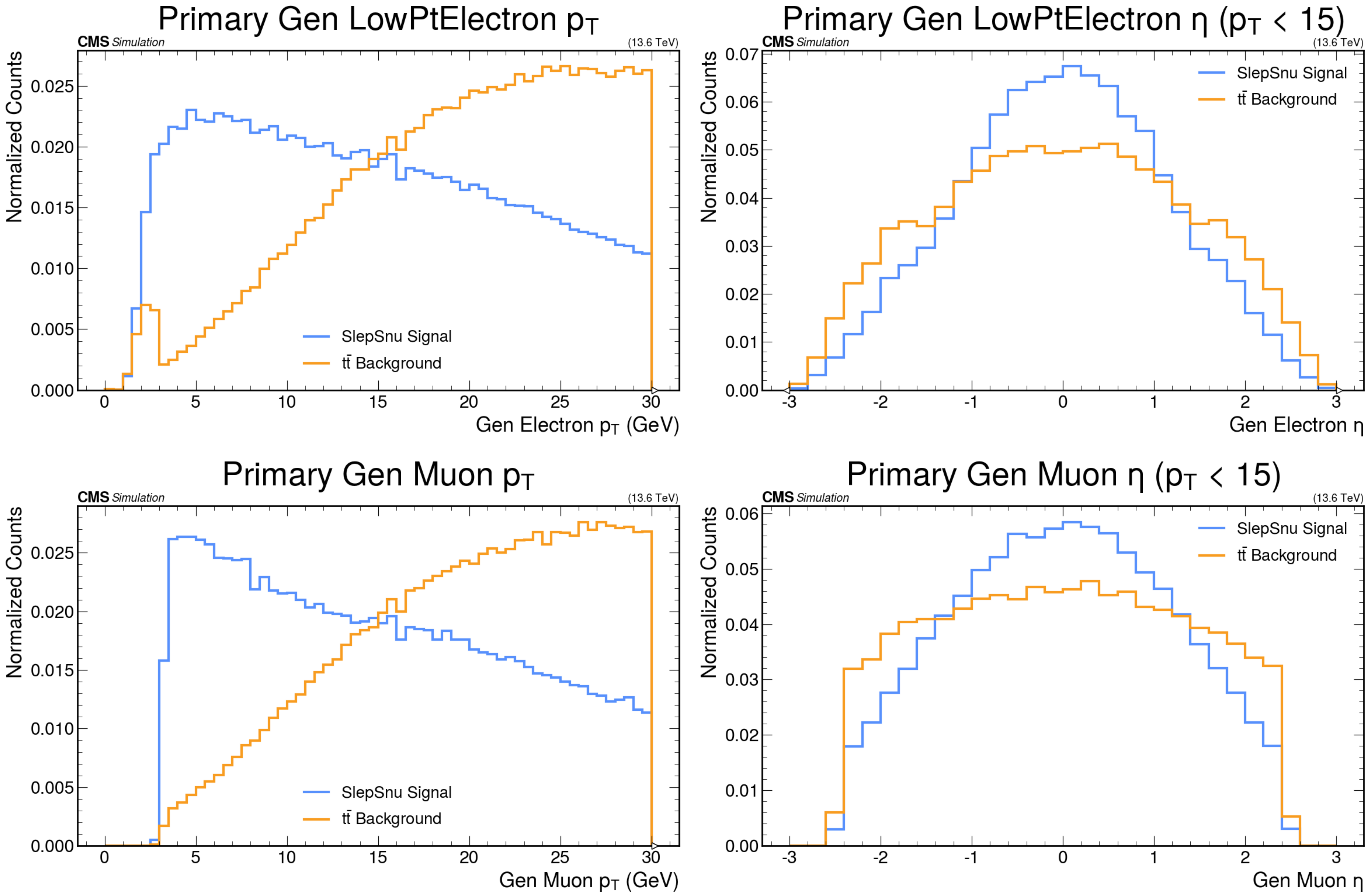
- **[This analysis]**: extensive test of *Electroweakino sector* ($\tilde{\ell}_L^+\tilde{\ell}_L^-, \quad \tilde{\nu}_\ell\tilde{\nu}_\ell^*, \quad \tilde{\ell}_L^+\tilde{\nu}_\ell, \quad \tilde{\ell}_L^-\tilde{\nu}_\ell^*$ for $\ell = e, \mu$.) with compressed mass spectra and *intermediary decays* (Cascade Decays) in Run 3



*Stau's and tau snuetrinos excluded from search

Signal Lepton Characteristics

- **p_T:** Signal Leptons have lower p_T than Background Leps
  - Effect of compression
- **η**: Signal Leptons tend to be more central in η for our signal models (Especially for Electrons)
  - Effect of large (~300 GeV) mass of SUSY particles



#SlepSnu events: 459524 (all available stats) #ttbar events: 1623000

SUS-23-003 Lepton Selection Technique

- Begin with *Baseline cuts*:
  - Very loose custodial cuts on η, PV variables, and isolation variables to clean up mis-reconstructed leps
  - Important note: **Baseline selection** contains *both* **Signal Leptons** and **Background** (fakes, leptons from b's, c's, τ's)
  - Need looser isolation requirements for low p_T leptons

SUS-23-003 Lepton Selection Technique

- Begin with *Baseline cuts*:
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  - Important note: **Baseline selection** contains *both* **Signal Leptons** and **Background** (fakes, leptons from b's, c's, τ's)
  - Need looser isolation requirements for low p_T leptons
- *From Baseline*, define 3 mutually exclusive categories:
  - Gold: Prompt and Isolated (signal-like leptons)
  - Silver: Non-prompt and Isolated (heavy decays)
  - Bronze: Fails ID or Non-isolated (fake leptons)

TO DO:

What work was required?

- Collections/variables have changed between Run 2 and Run 3 (NanoAOD)
    - Must Refresh Baseline Selection THEN redefine Gold/Silver/Bronze categories from that selection
- **LowPtElectron** collection, available in NanoAODv9 UL and newer, provide a way to lower Electron p_T phase space down to 1 GeV (if good efficiency)
- Must tune all selection to optimize signal/background in p_T and η

Muon Collection

NanoAODv12

Muon [back to top]

Object property	Type
Muon_bsConstrainedChi2	Float_t
Muon_bsConstrainedPt	Float_t
Muon_bsConstrainedPtErr	Float_t
Muon_charge	Int_t
Muon_dxy	Float_t
Muon_dxyErr	Float_t
Muon_dxybs	Float_t
Muon_dz	Float_t
Muon_dzErr	Float_t
Muon_eta	Float_t
Muon_fsrPhotonIdx	Short_t(index to Fsrphoton)
Muon_genPartFlav	UChar_t
Muon_genPartIdx	Short_t(index to Genpart)
Muon_highPtId	UChar_t
Muon_highPurity	Bool_t
Muon_inTimeMuon	Bool_t
Muon_ip3d	Float_t
Muon_isGlobal	Bool_t
Muon_isPFcand	Bool_t
Muon_isStandalone	Bool_t
Muon_isTracker	Bool_t
Muon_jetIdx	Short_t(index to Jet)
Muon_jetNDauCharged	UChar_t

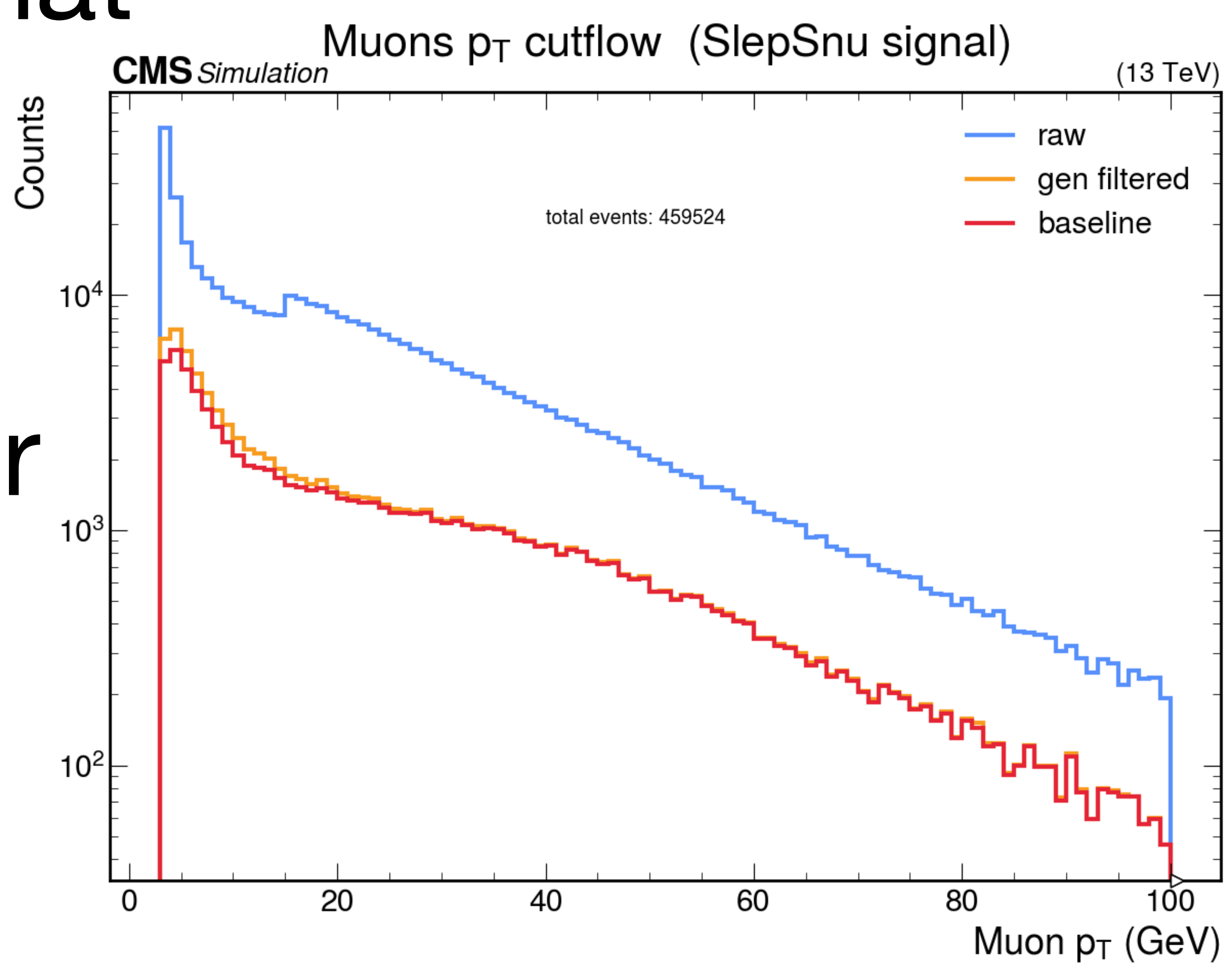
Muon Baseline Cuts

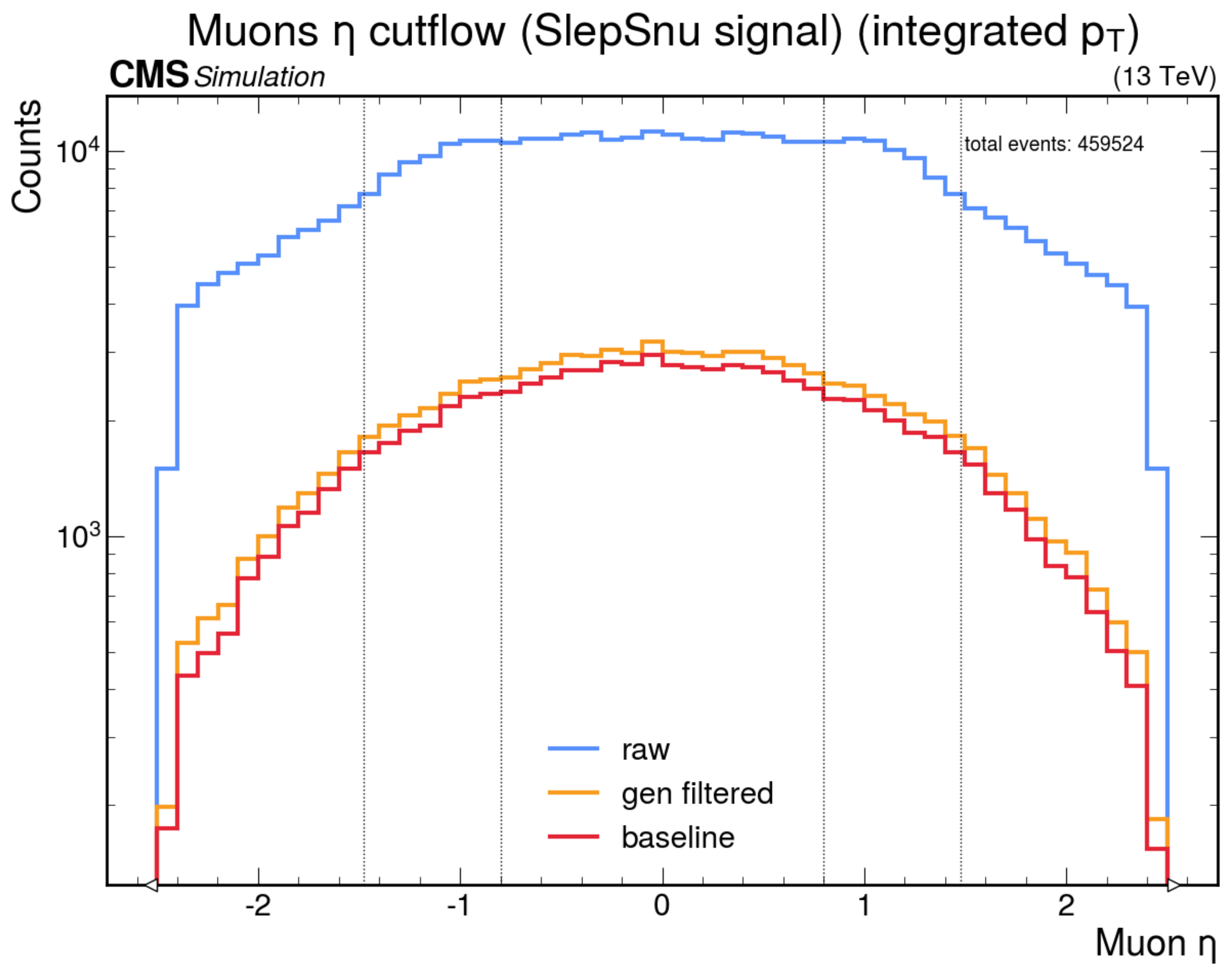
- All variables from Run 2 available in Run 3 for our Baseline selection of Muons

- Verified with iterative cut flows that the baseline selection isn't too aggressive

- From here, we can can parse our what

Muon Baseline Cuts: Previous vs Retuned		
Cut	**Previous**	**Retuned**
p_T	≥ 3 GeV	same
$\lvert\eta\rvert$	< 2.5	same
SIP3D	< 8	same
$\lvert d_{xy}\rvert$	< 0.05 cm	same
$\lvert d_z\rvert$	< 0.1 cm	same
PFRelIso_{03}	$< 20 + \left(\frac{300}{p_T}\right)$ GeV	same
MiniPFRelIso	$< 20 + \left(\frac{300}{p_T}\right)$ GeV	same





Muon GSB Optimization

- Tested Signal/Background efficiencies with cutBased ID variables (Soft, Veto, Medium, Tight)
  - Looked at light fakes (unmatched to PV), heavy decay fakes (c's and b's)
  - Soft, an ID that doesn't rely on PF muons as a starting point, had too many fakes at low p_T
- TIGHT and MEDIUM ID had almost the same efficiency as medium ID at low p_T but the heavy fake and light fake eff. were higher for Medium

Remake, medium vs tight

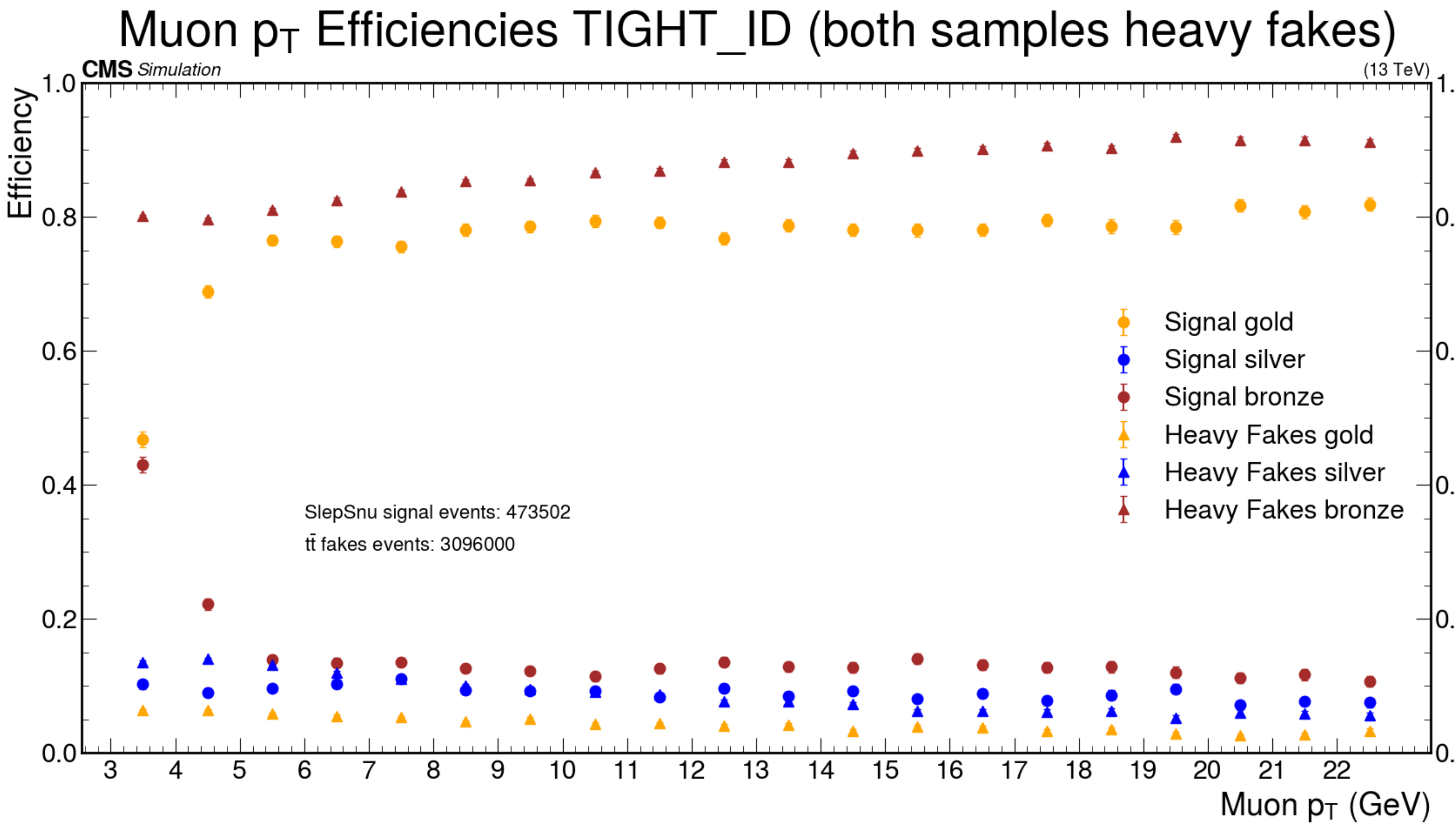
→ Conclusion: Use TIGHT ID

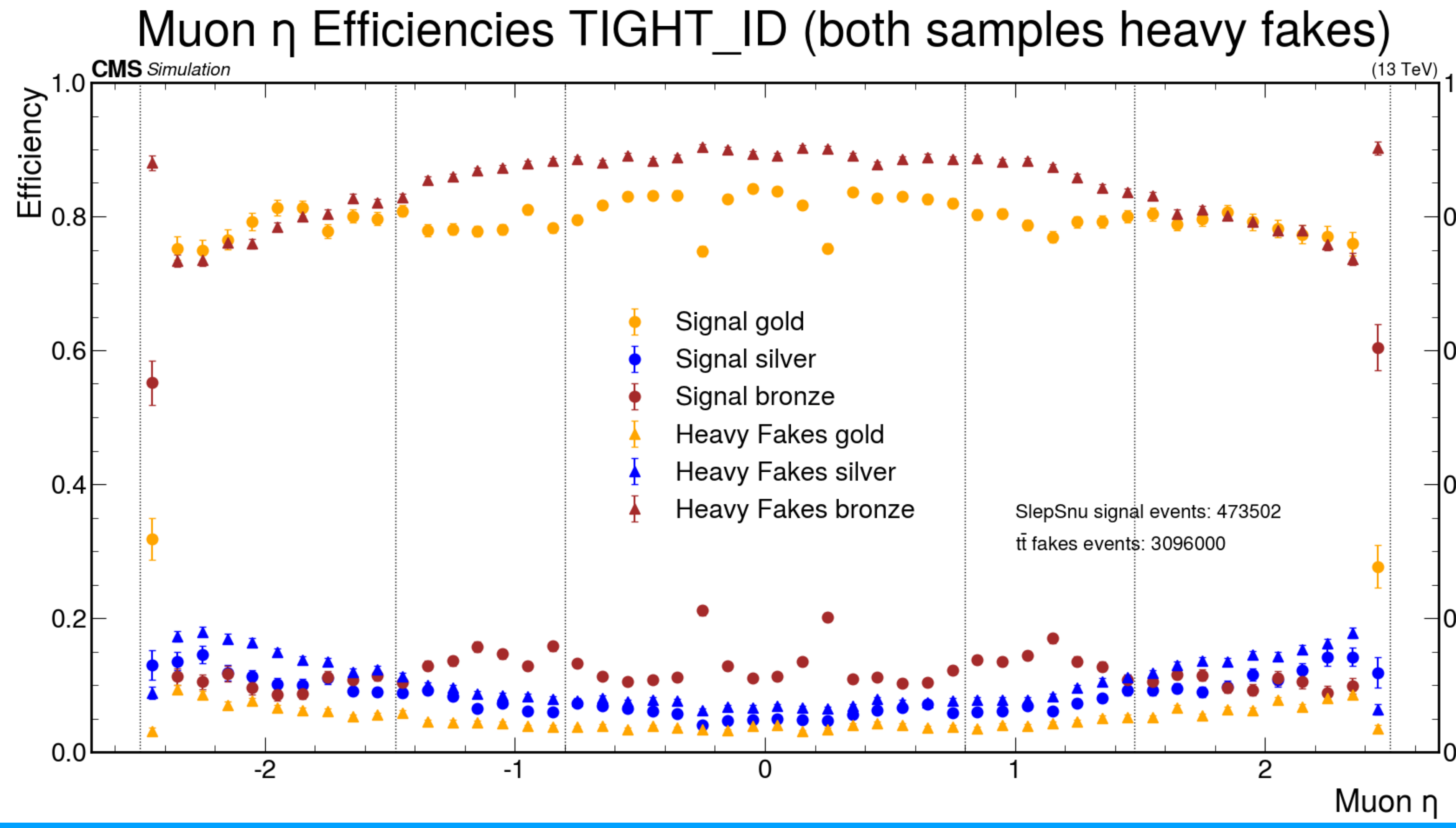
Muon GSB Final Cuts

Muon Category Cuts: Gold vs Silver		
Cut	**Gold**	**Silver**
Baseline selection	✓	✓
Tight ID	✓	✓
SIP3D	< 2	$2 \leq \text{SIP3D} < 8$
$\text{PFRelIso}_{03} \cdot p_T$	≤ 4 GeV	≤ 4 GeV
$\text{MiniPFRelIso} \cdot p_T$	≤ 4 GeV	≤ 4 GeV

Bronze: fails Gold and Silver ID

Gold Silver Bronze Muons vs Heavy Decay Fakes





“Regular” Electron Collection

NanoAODv12

Electron [back to top]

Object property	Type
Electron_charge	Int_t
Electron_convVeto	Bool_t
Electron_cutBased	UChar_t
Electron_cutBased_HEEP	Bool_t
Electron_deltaEtaSC	Float_t
Electron_dr03EcalRecHitSumEt	Float_t
Electron_dr03HcalDepth1TowerSumEt	Float_t
Electron_dr03TkSumPt	Float_t
Electron_dr03TkSumPtHEEP	Float_t
Electron_dxy	Float_t
Electron_dxyErr	Float_t
Electron_dz	Float_t
Electron_dzErr	Float_t
Electron_eInvMinusPInv	Float_t
Electron_energyErr	Float_t
Electron_eta	Float_t
Electron_fsrPhotonIdx	Short_t(ind to Fsrphoto
Electron_genPartFlav	UChar_t
Electron_genPartIdx	Short_t(ind to Genpart)
Electron_hoe	Float_t
Electron_ip3d	Float_t
Electron_isPFcand	Bool_t
Electron_jetIdx	Short_t(ind to Jet)

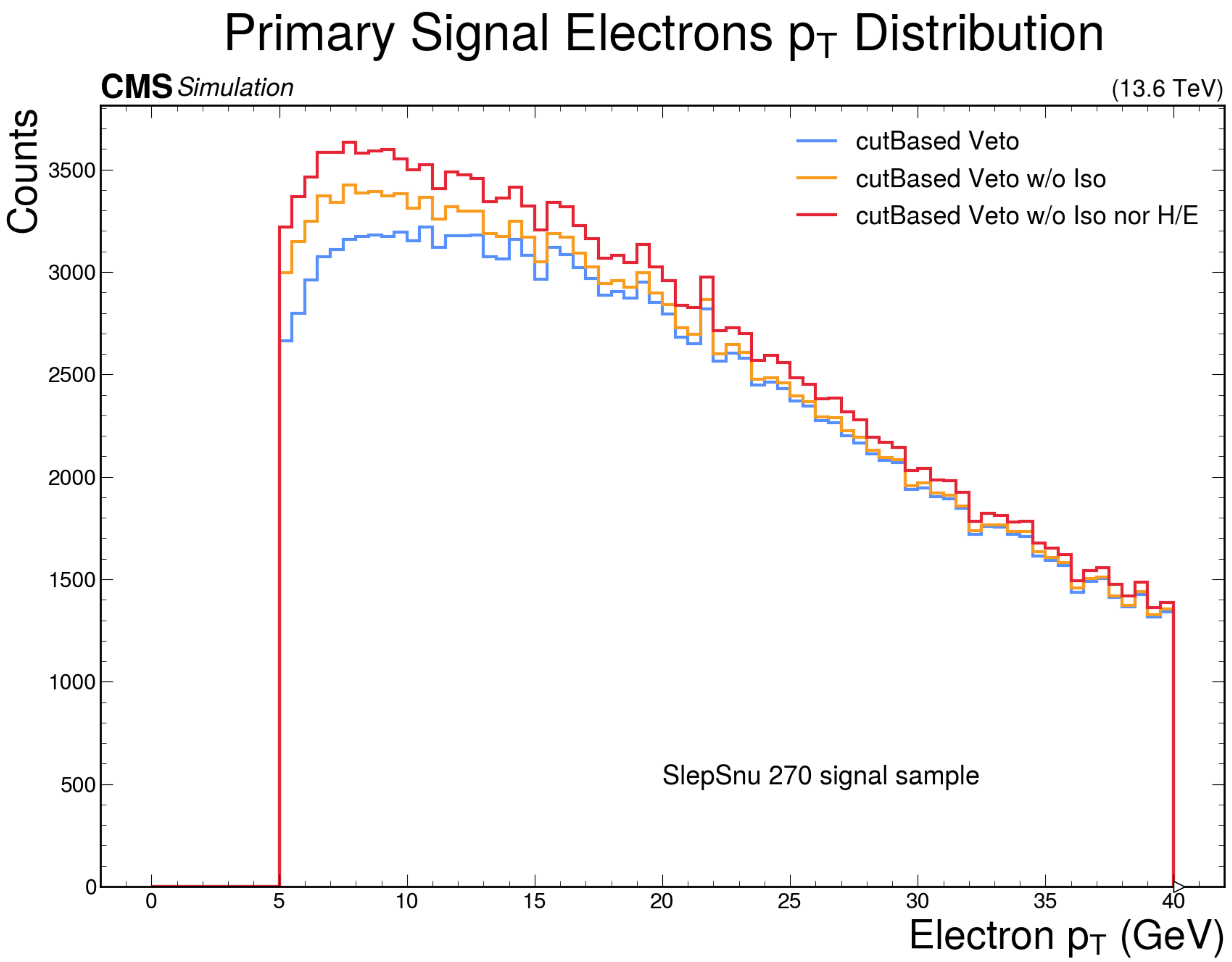
Adapting Baseline Electrons

- "MVA VLooseFO ID" not available in Run 3
  - Run 3 noIso MVA electron ID is bugged in NanoAODv12 (and v11).
- Use cutBased ID (Veto, Loose, Med, Tight)
- **Problem**: cutBased Veto has an isolation cut, may still be *too tight* for our signal electrons
- Must adapt cutBased Veto for our needs

Electron Baseline Cuts: Previous vs Retuned		
Cut	**Previous**	**Retuned**
p_T	≥ 5 GeV	?
$\lvert\eta\rvert$	< 2.5	same
SIP3D	< 8	same
$\lvert d_{xy}\rvert$	< 0.05 cm	same
$\lvert d_z\rvert$	< 0.1 cm	same
PFRelIso_{03}	$< 20 + \left(\frac{300}{p_T}\right)$ GeV	same
MiniPFRelIso	$< 20 + \left(\frac{300}{p_T}\right)$ GeV	same
ID Requirement	MVA VLooseFO ID	?

Motivation for no Iso nor H/E

- Removed isolation and H/E cuts from cutBased Veto
- To create this ID I made use of the **vidNestedWPBitmap** variable in Electron collection
  - Ignore the bits that correspond to "GsfEleHadronicOverEMCut" and "GsfEleEffAreaPFIsoCut"
- **Conclusion**: Recovered Primary Signal Electrons especially at low p_T



Baseline ID for Regular Electrons

- CutBased VETO without H/E, ISO
- With our redefined ID for Electrons, proceed to Gold Silver Bronze
- Will decide on what min p_T for regular Electron collection after we optimize LowPtElectrons

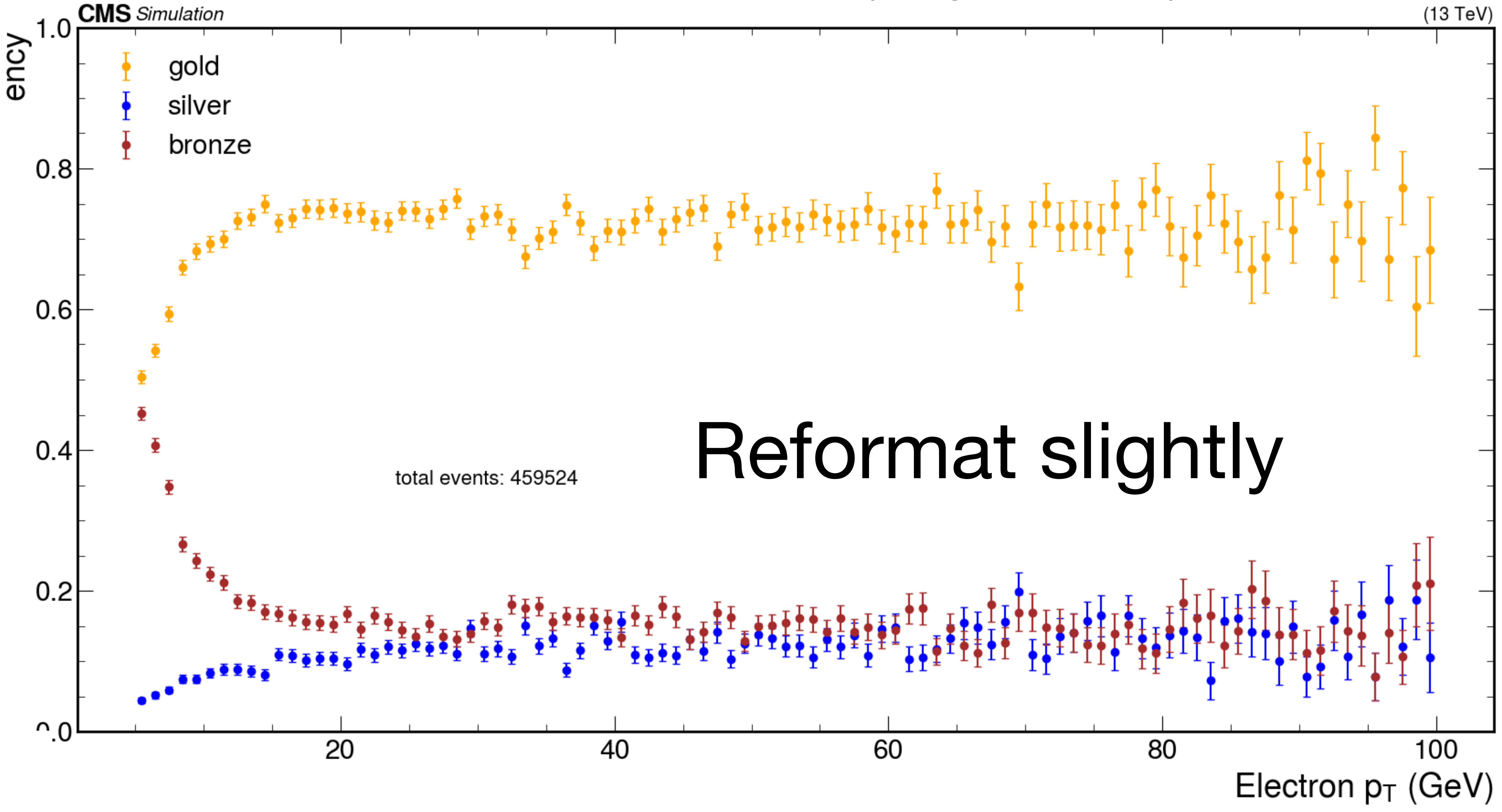
Electron Baseline Cuts: Previous vs Retuned		
Cut	**Previous**	**Retuned**
p_T	≥ 5 GeV	?
$\lvert\eta\rvert$	< 2.5	same
SIP3D	< 8	same
$\lvert d_{xy}\rvert$	< 0.05 cm	same
$\lvert d_z\rvert$	< 0.1 cm	same
PFRelIso_{03}	$< 20 + \left(\frac{300}{p_T}\right)$ GeV	same
MiniPFRelIso	$< 20 + \left(\frac{300}{p_T}\right)$ GeV	same
ID Requirement	MVA VLooseFO ID	CutBased VETO (w/o H/E, Iso)

Regular Electron GSB Selection

Electron Category Cuts: Gold vs Silver		
Cut	**Gold**	**Silver**
Baseline selection	✓	✓
cutBased Veto (no Iso, no H/E)	✓	✓
SIP3D	< 2	$2 \leq$ SIP3D < 8
$\text{PFRelIso}_{03} \cdot p_T$	≤ 4 GeV	≤ 4 GeV
MiniPFRelIso $\cdot p_T$	≤ 4 GeV	≤ 4 GeV

Bronze: fails Gold and Silver ID

Electron Efficiencies (SlepSnu 270)



Reformat slightly

Eta efficiency plot

LowPtElectron Collection

NanoAODv12

LowPtElectron [back to top]

Object property	Type
LowPtElectron_ID	Float_t
LowPtElectron_charge	Int_t
LowPtElectron_convVeto	Bool_t
LowPtElectron_convVtxRadius	Float_t
LowPtElectron_convWP	UChar_t
LowPtElectron_deltaEtaSC	Float_t
LowPtElectron_dxy	Float_t
LowPtElectron_dxyErr	Float_t
LowPtElectron_dz	Float_t
LowPtElectron_dzErr	Float_t
LowPtElectron_eInvMinusPInv	Float_t
LowPtElectron_electronIdx	Short_t(index Electron)
LowPtElectron_energyErr	Float_t
LowPtElectron_eta	Float_t
LowPtElectron_genPartFlav	UChar_t
LowPtElectron_genPartIdx	Short_t(index Genpart)
LowPtElectron_hoe	Float_t
LowPtElectron_lostHits	UChar_t
LowPtElectron_mass	Float_t
LowPtElectron_miniPFRelIso_all	Float_t
LowPtElectron_miniPFRelIso_chg	Float_t
LowPtElectron_pdgId	Int_t
LowPtElectron_phi	Float_t

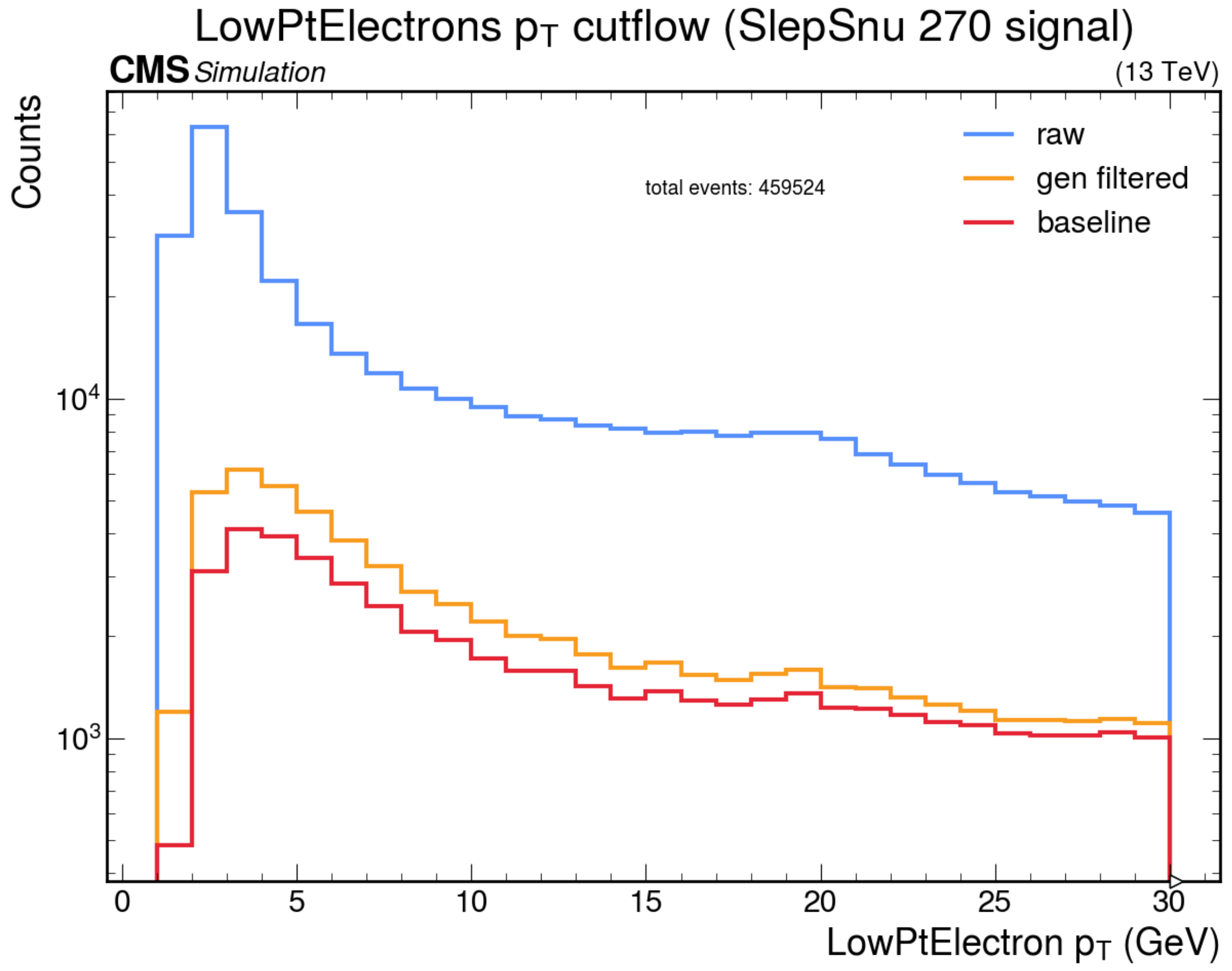
Baseline LowPtElectron Collection

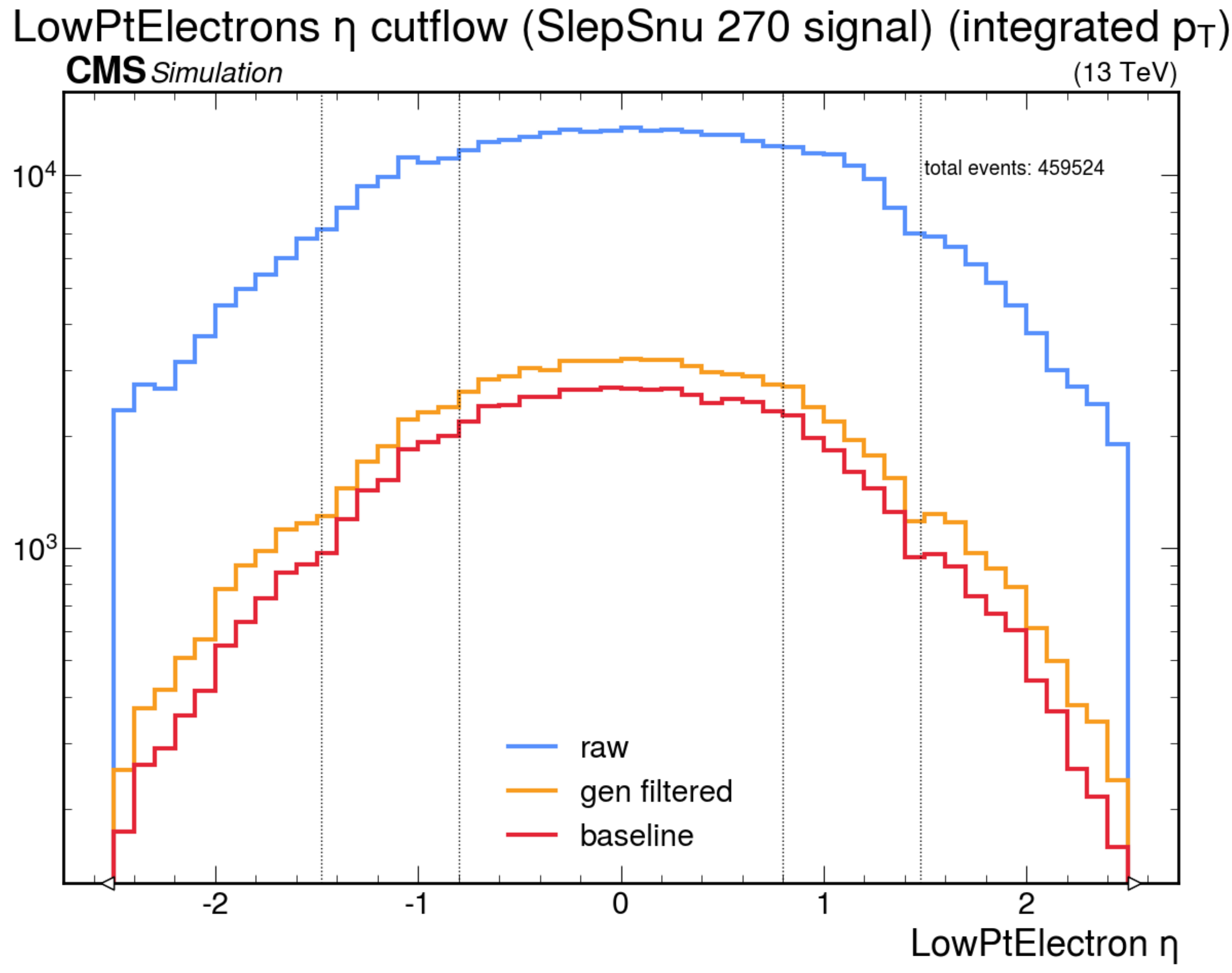
- New collection in NanoAOD, extends pT range of Electrons down to 1 GeV
- A few Electron collection variables unavailable in this collection like:
    - SIP3D
    - cutBased ID's
    - MVA ID's
    - PFRelIso
- For LowPtElectron Baseline we mimicked Electron's Baseline cuts as closely as possible
- p_T of 1-2 GeV has very poor efficiency, omit it

Baseline cuts for LowPtElectrons

Cut	LowPtElectron
p_T	?
$\lvert\eta\rvert$	< 2.5
SIP3D	< 8
$\lvert d_{xy}\rvert$	< 0.05 cm
$\lvert d_z\rvert$	< 0.1 cm
MiniPFRelIso	$< 20 + \left(\frac{300}{p_T}\right)$ GeV
ID	> 1

(Prior work was done to approximate this for LowPtElectrons)



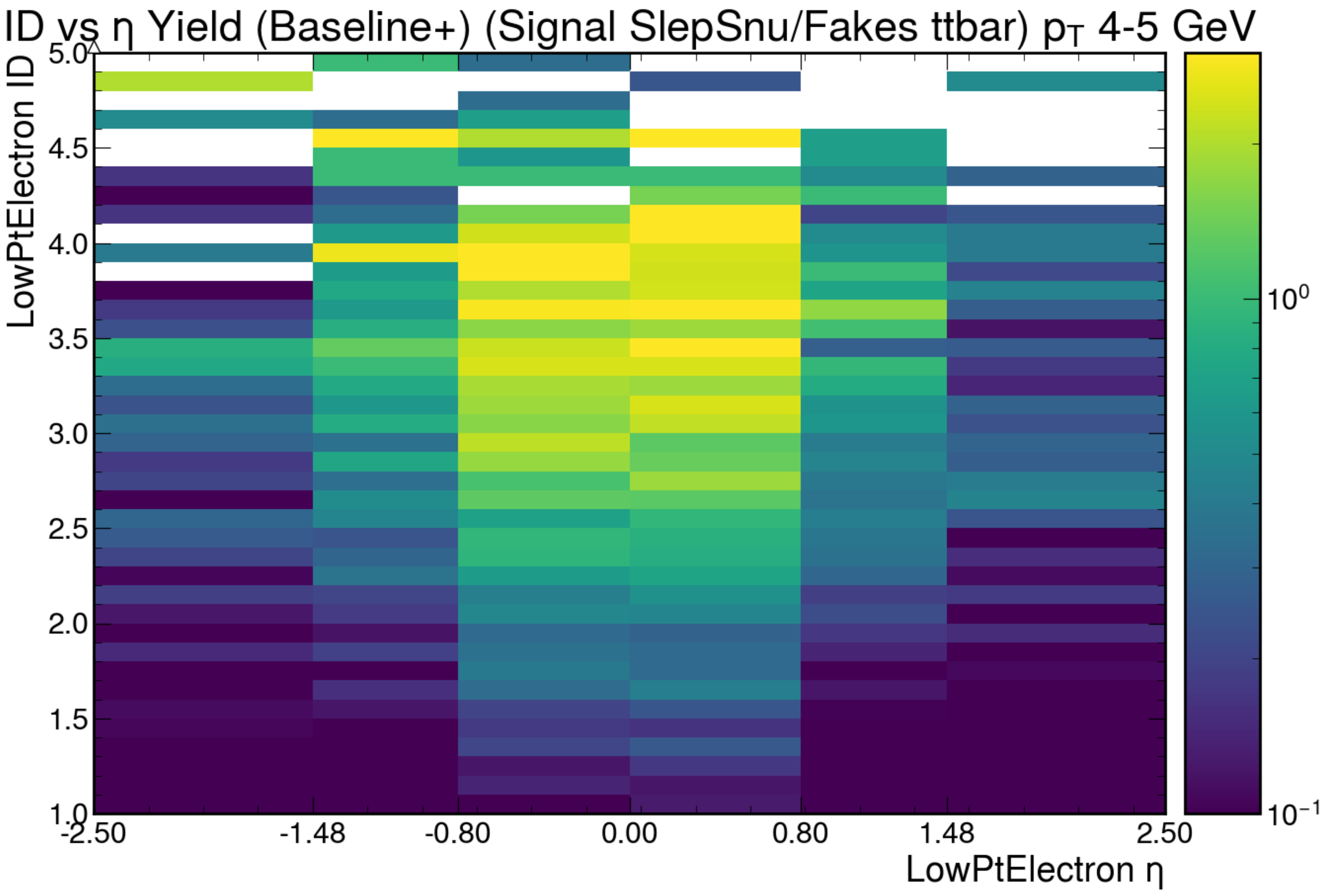


ID’ing Signal LowPtElectrons

- Created our own LowPtElectron ID: η-ID selection
- Motivated by the fact our signal electrons at low pT are predominantly central in η
- Optimized by assessing ID-η yield plots 1 GeV p_T bins

$$\text{Yield} = \frac{n_{Signal}}{n_{Background}}$$

- To properly analyze, look at shape of yield plot

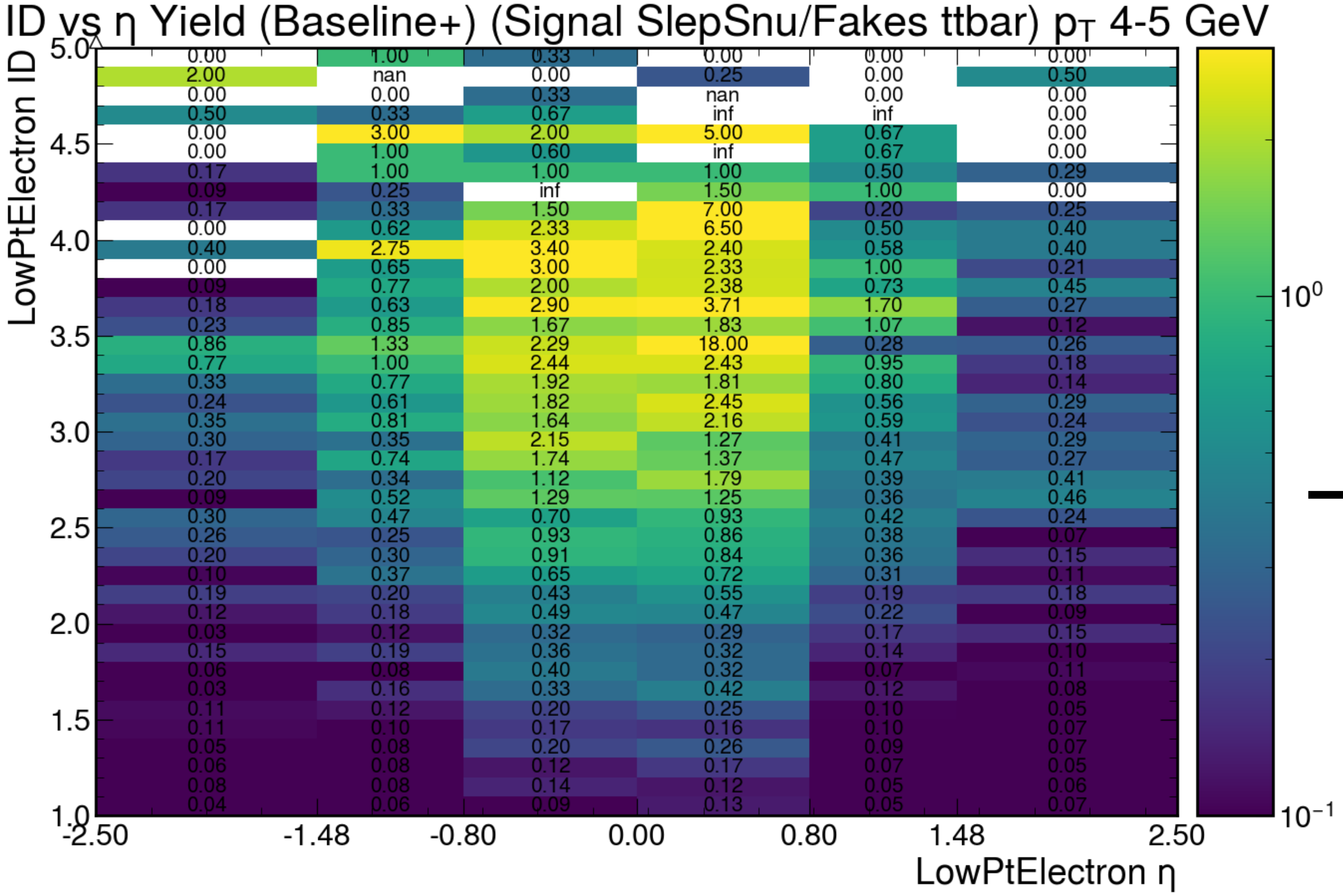


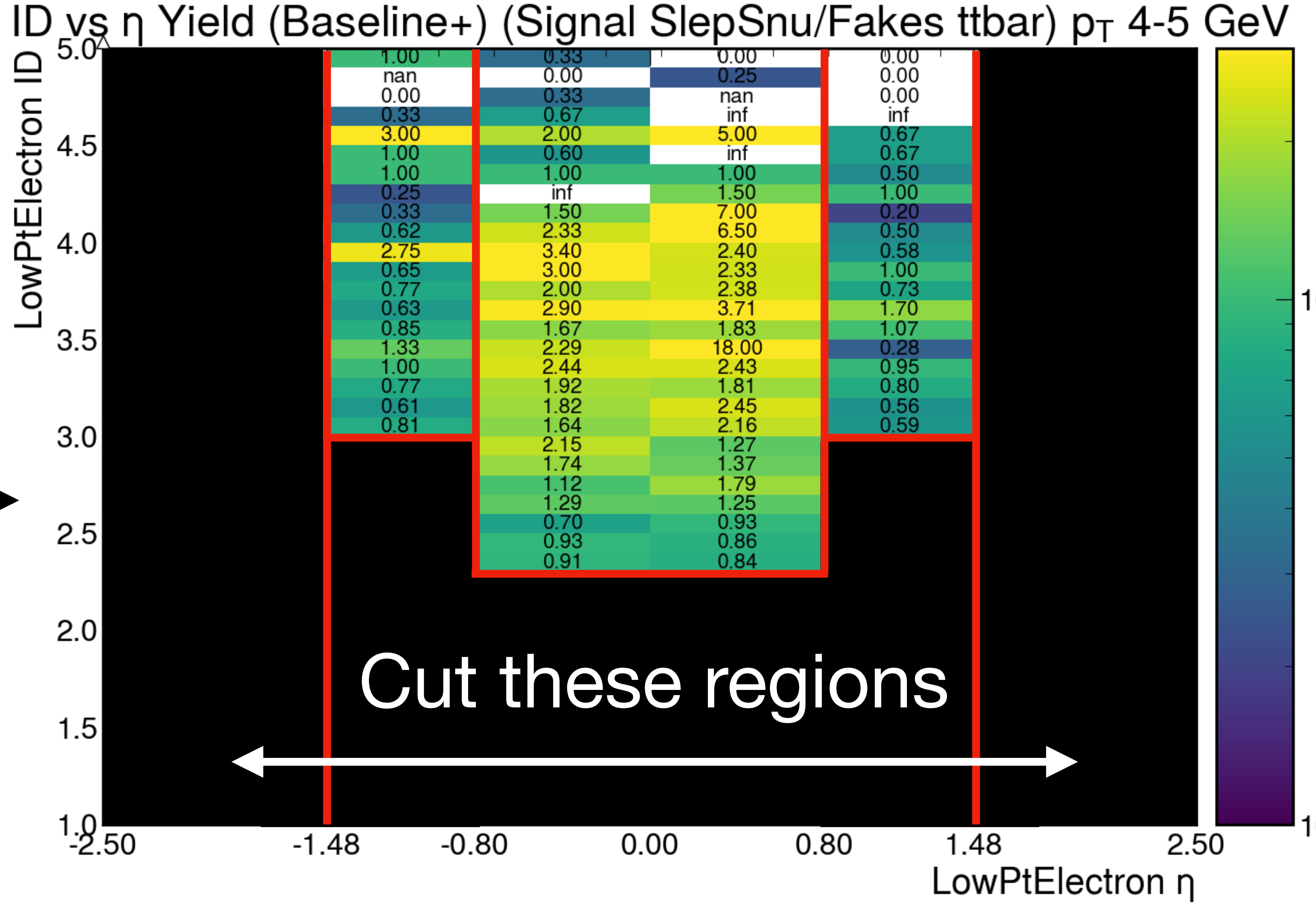
*In these plots, “Baseline+” = Baseline, we used different naming scheme during tuning

LowPtElectron Central η Optimization

First p_T Region

For 2 ≤ pT < 5:



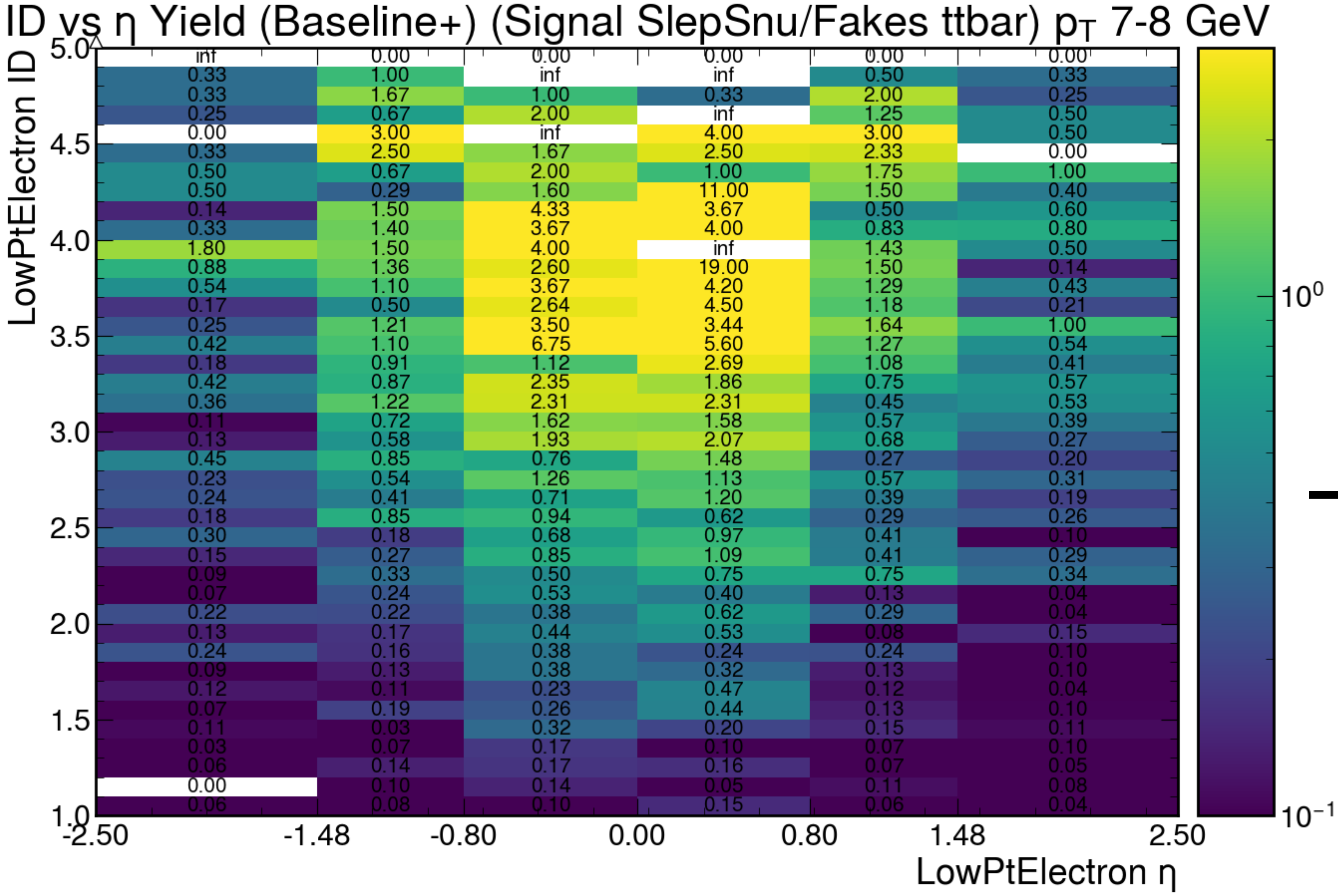


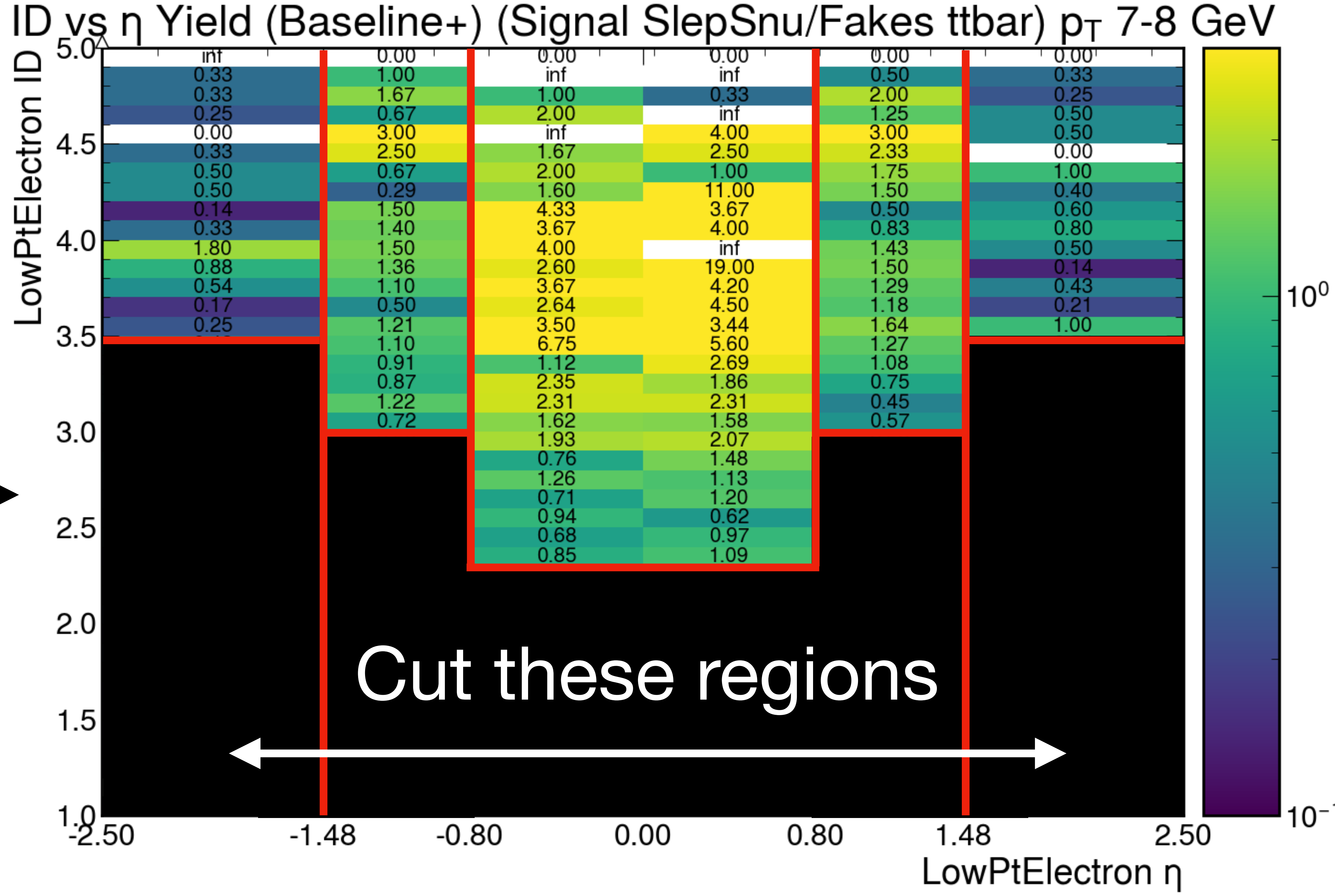
Yield is labeled on each bin

LowPtElectron Central η ID Optimization

Second p_T Region

For 5 ≤ pT < 8:



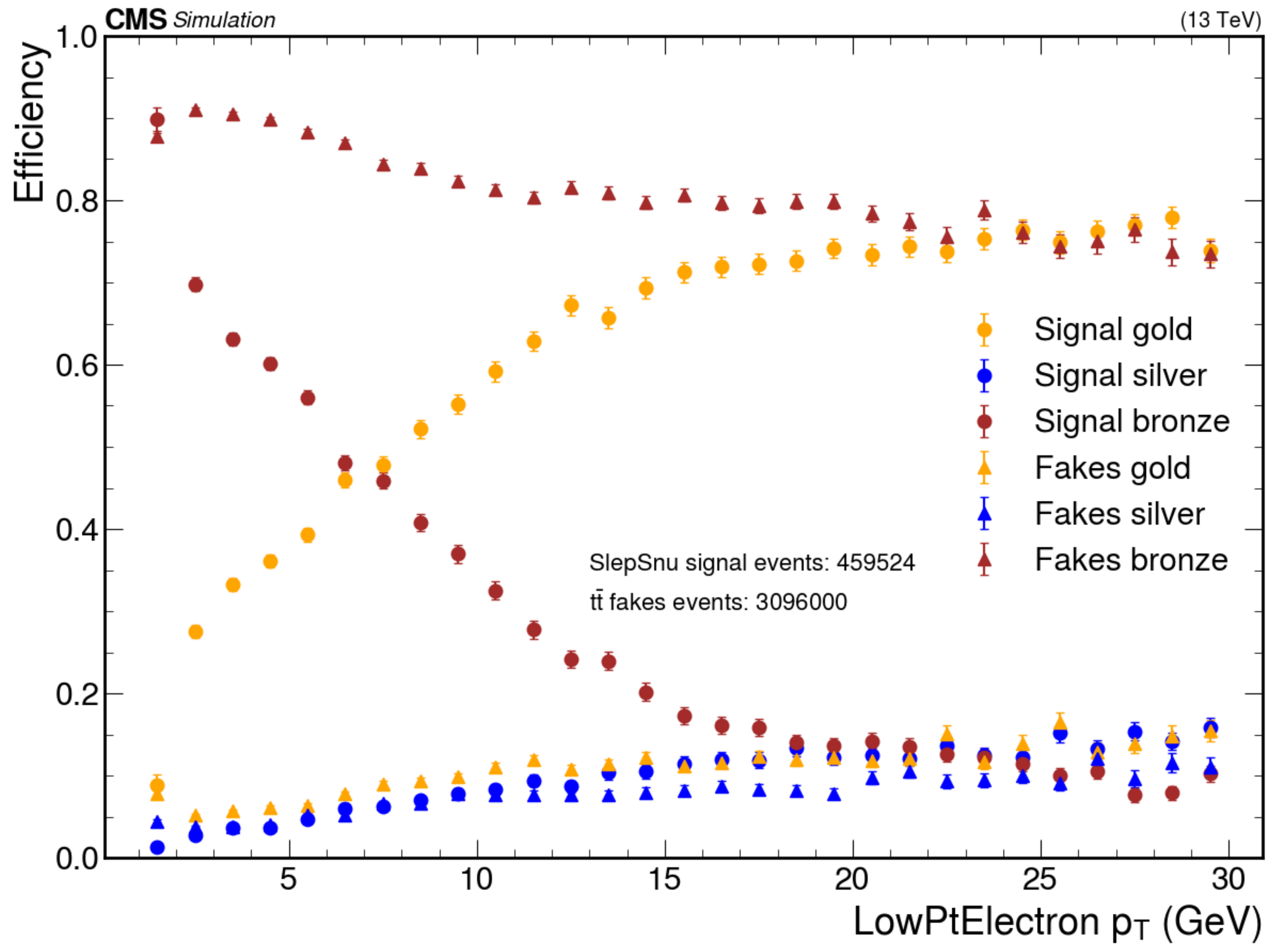


LowPtElectron GSB Final Cuts

LowPtElectron Category Cuts: Gold vs Silver		
Cut	**Gold**	**Silver**
Baseline selection	✓	✓
Central-η ID cuts	✓	✓
SIP3D	< 2	$2 \leq$ SIP3D < 8
MiniPFRelIso $\cdot p_T$	≤ 4 GeV	≤ 4 GeV

Bronze: fails Gold and Silver ID

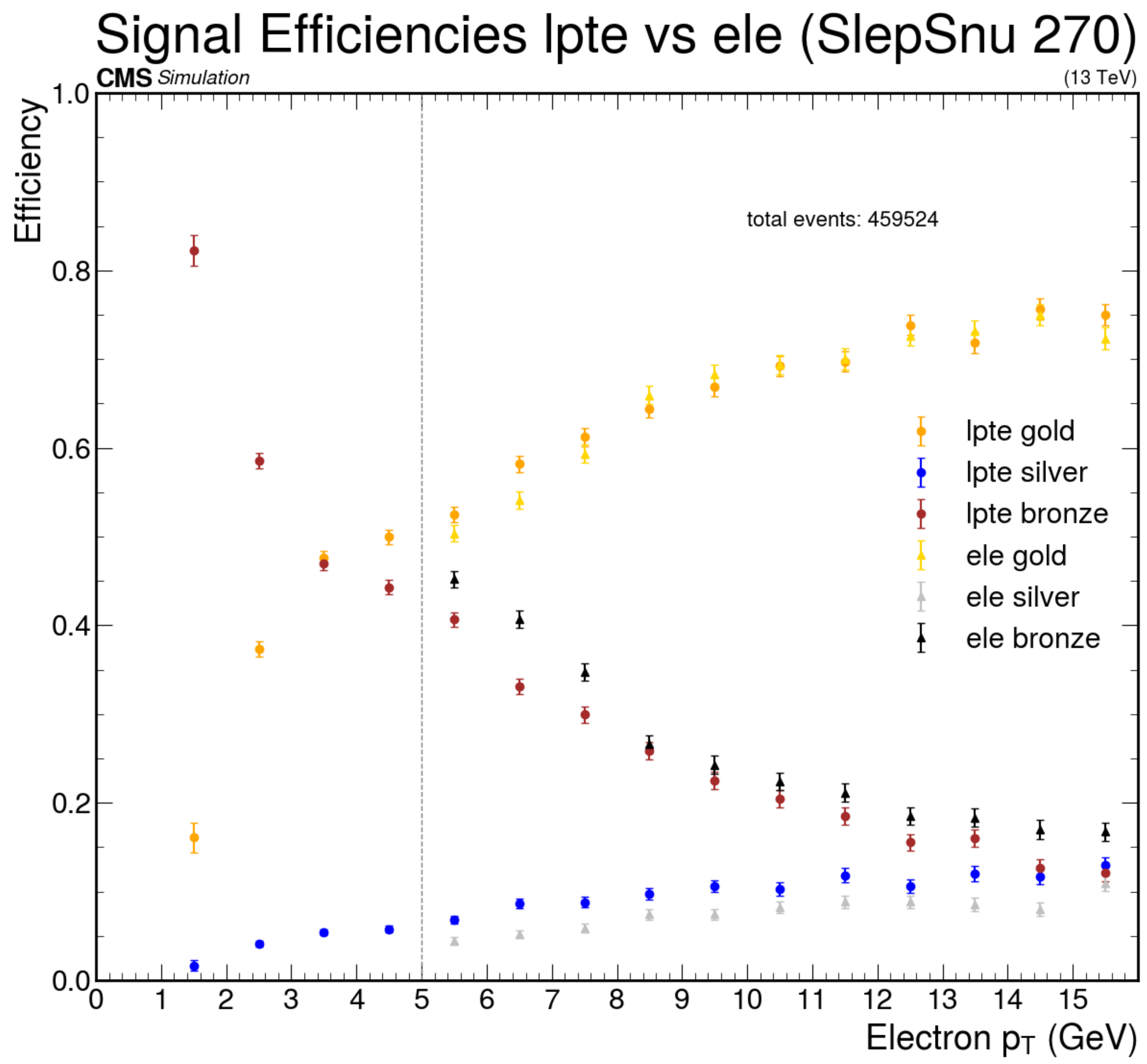
LowPtElectron Efficiencies (both samples)



Eta efficiency plot

LowPtElectrons vs Electrons

- Determine where to use LowPtElectrons based on “efficiency”, but not the ratio
  - Since using different Baseline cuts we cannot directly compare efficiencies (different denominator)
- Look at raw number of signal objects and fakes



*Cannot use this plot to determine which collection is more performant

Compare Raw # electrons for pT 5-10

Gold electrons

- Numbers for the **exact same ttbar events**
- used ttbar sample to have enough statistics
- Use LowPtElectrons up to 8 GeV

pT bins	5-6 GeV	6-7 GeV	7-8 GeV	8-9 GeV	9-10 GeV
LowPtElectron (Signal)	1842	2657	3722	4952	6312
Electron (Signal)	1491	2390	3503	4695	5892
LowPtElectron (Fakes)	622	593	555	486	430
Electron (Fakes)	933	677	491	388	300

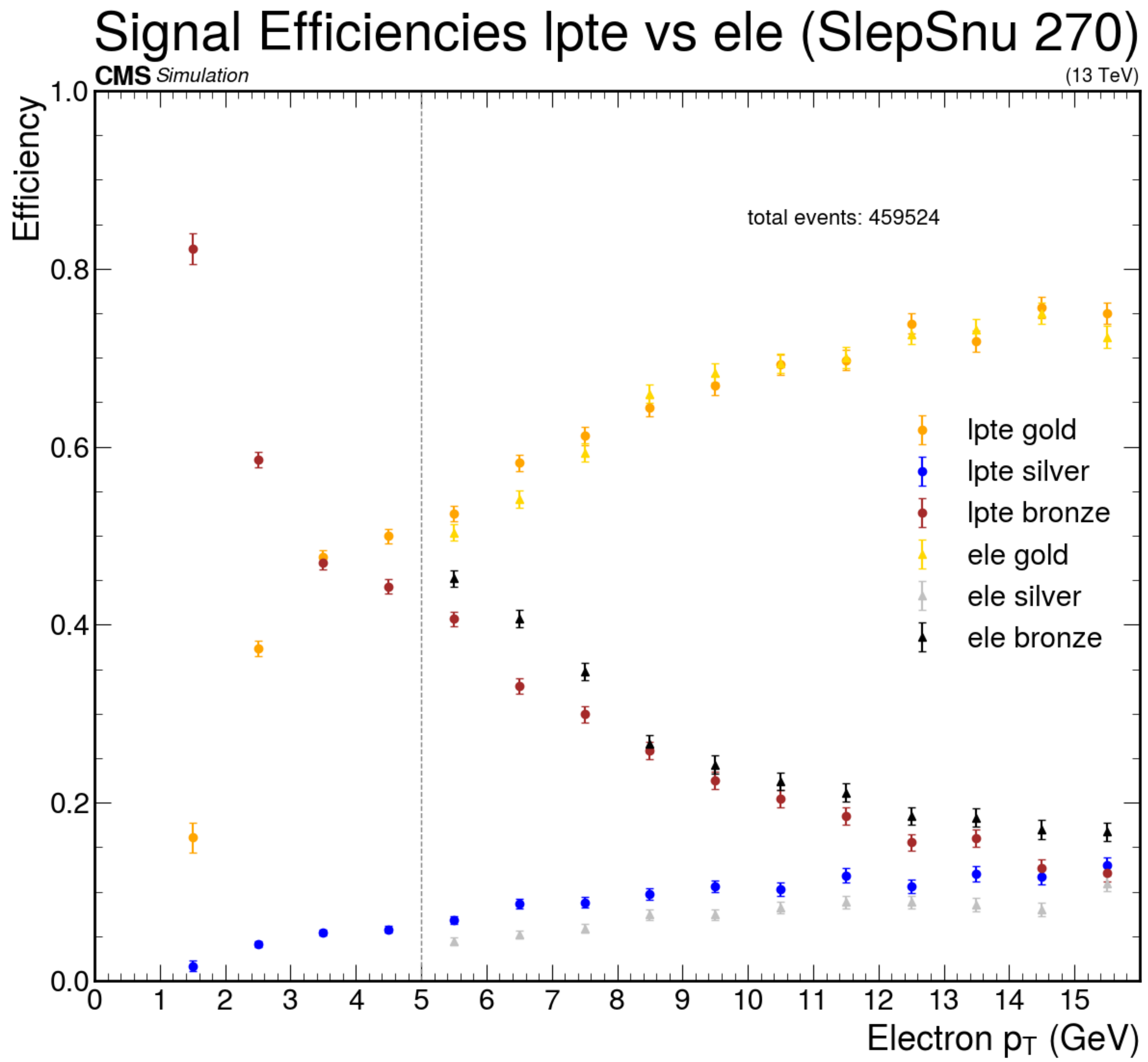
More Signal Electrons

Less Fakes

3,096,000 ttbar events

LowPtElectrons vs Electrons

- LowPtElectrons: between p_T 2-8 GeV
- Electrons: from p_T 8 GeV and above
- Muons: p_T 3 GeV and above
- unable to extend pT range lower unless using NanoAODv14, 2024 samples… Not feasible at the moment



Concluding Remarks

Backup

MC Samples used

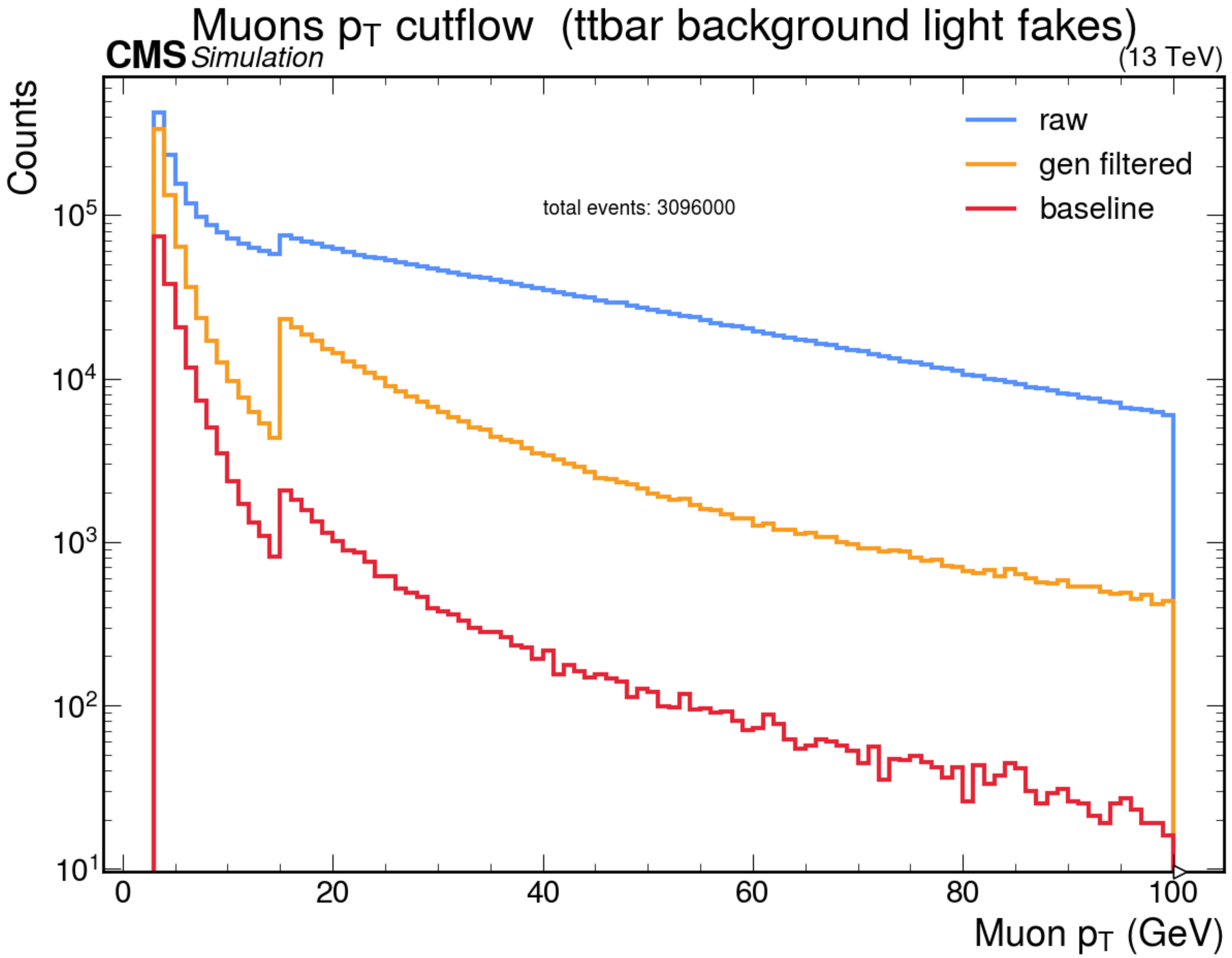
CMS DAS Keys

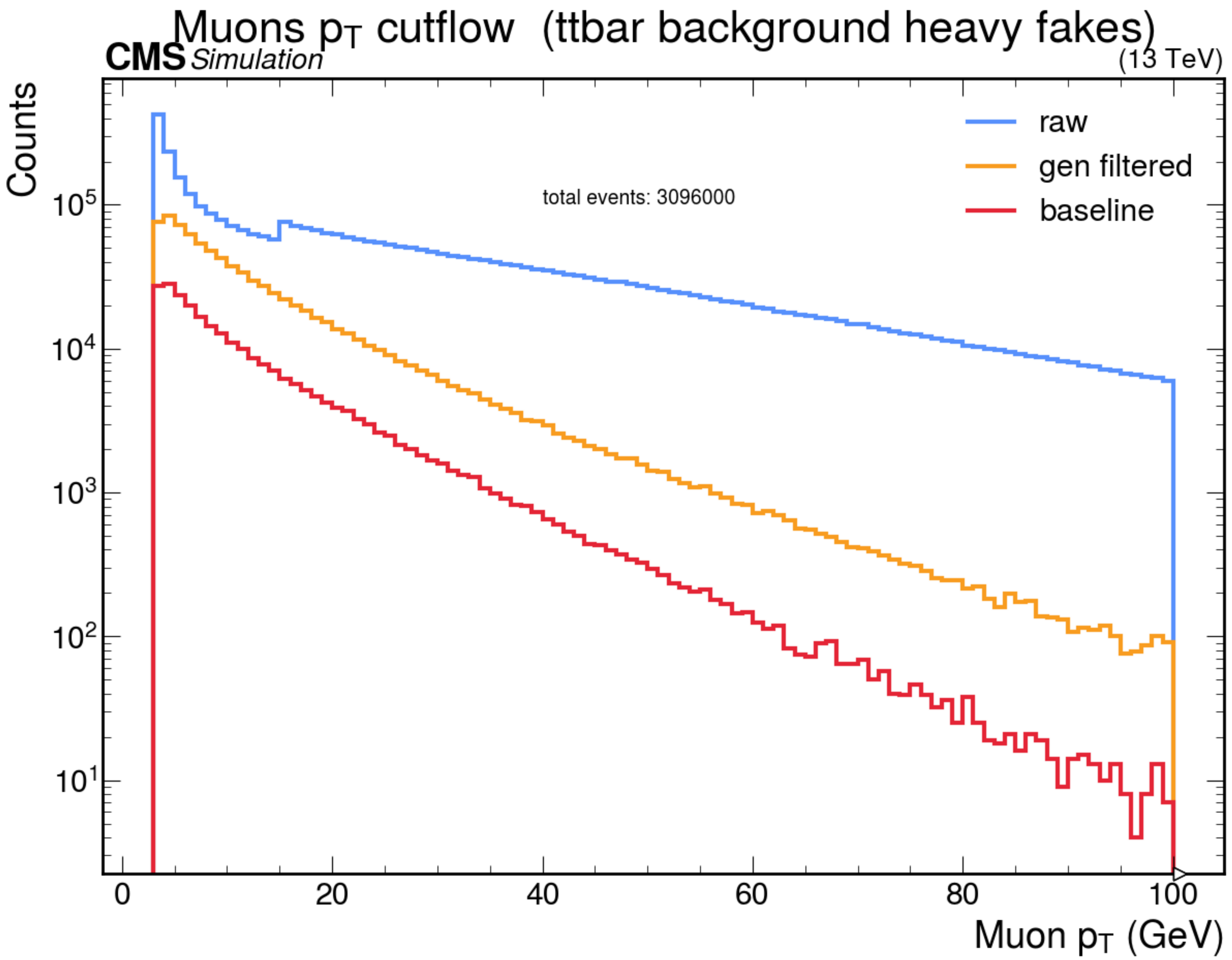
- **ttbarToDiLep_2023:** /TTto2L2Nu_TuneCP5_13p6TeV_powheg-pythia8/Run3Summer23NanoAODv12-130X_mcRun3_2023_realistic_v14-v2/NANOAODSIM

- **SlepSnu270/280:** /SlepSnuCascade_MN1-270_MN2-280_MC1-275_TuneCP5_13p6TeV_madgraphMLM-pythia8/Run3Summer23BPixNanoAODv12-130X_mcRun3_2023_realistic_postBPix_v6-v3/NANOAODSIM

Muon CutFlow ttbar background (Fakes)

p_T

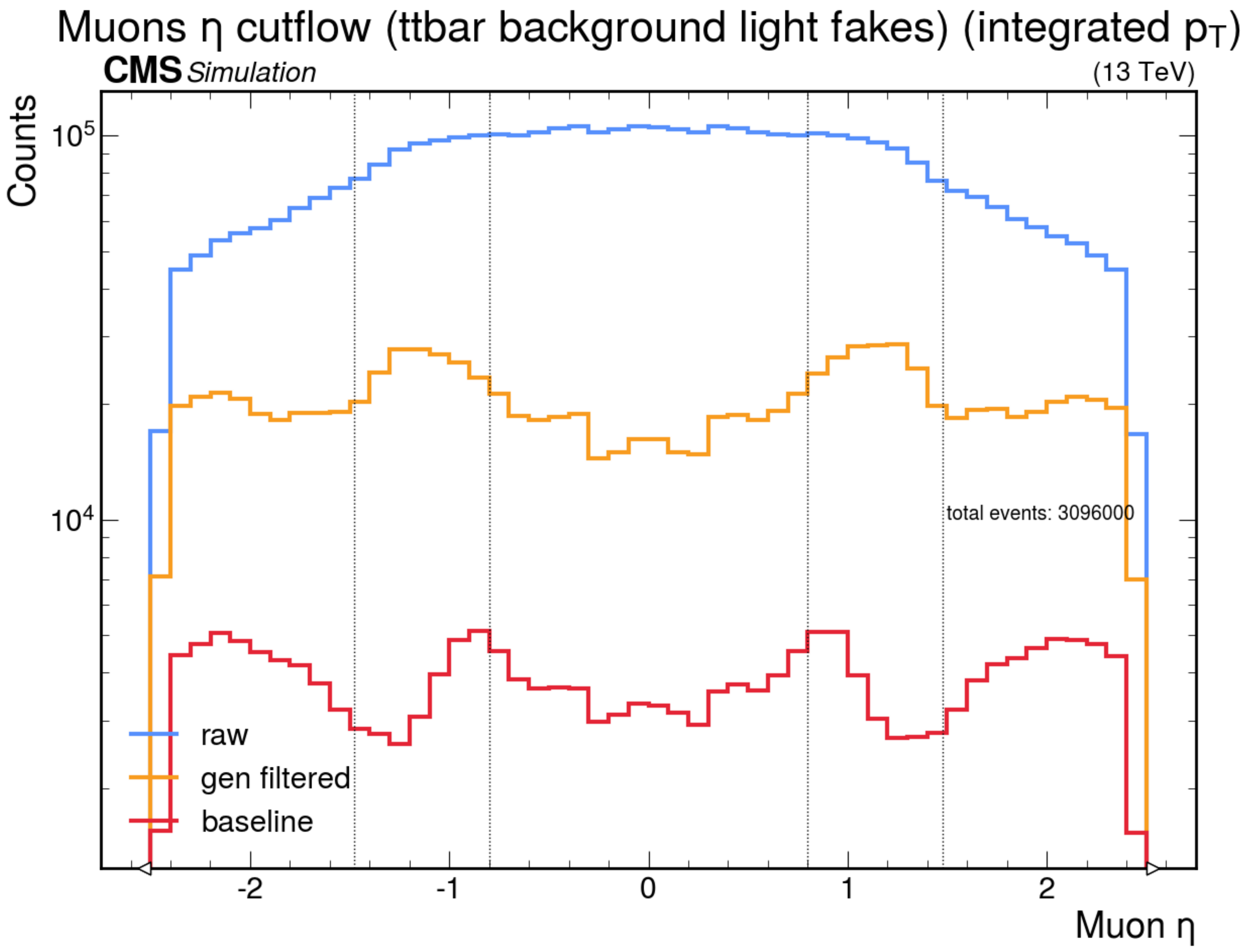


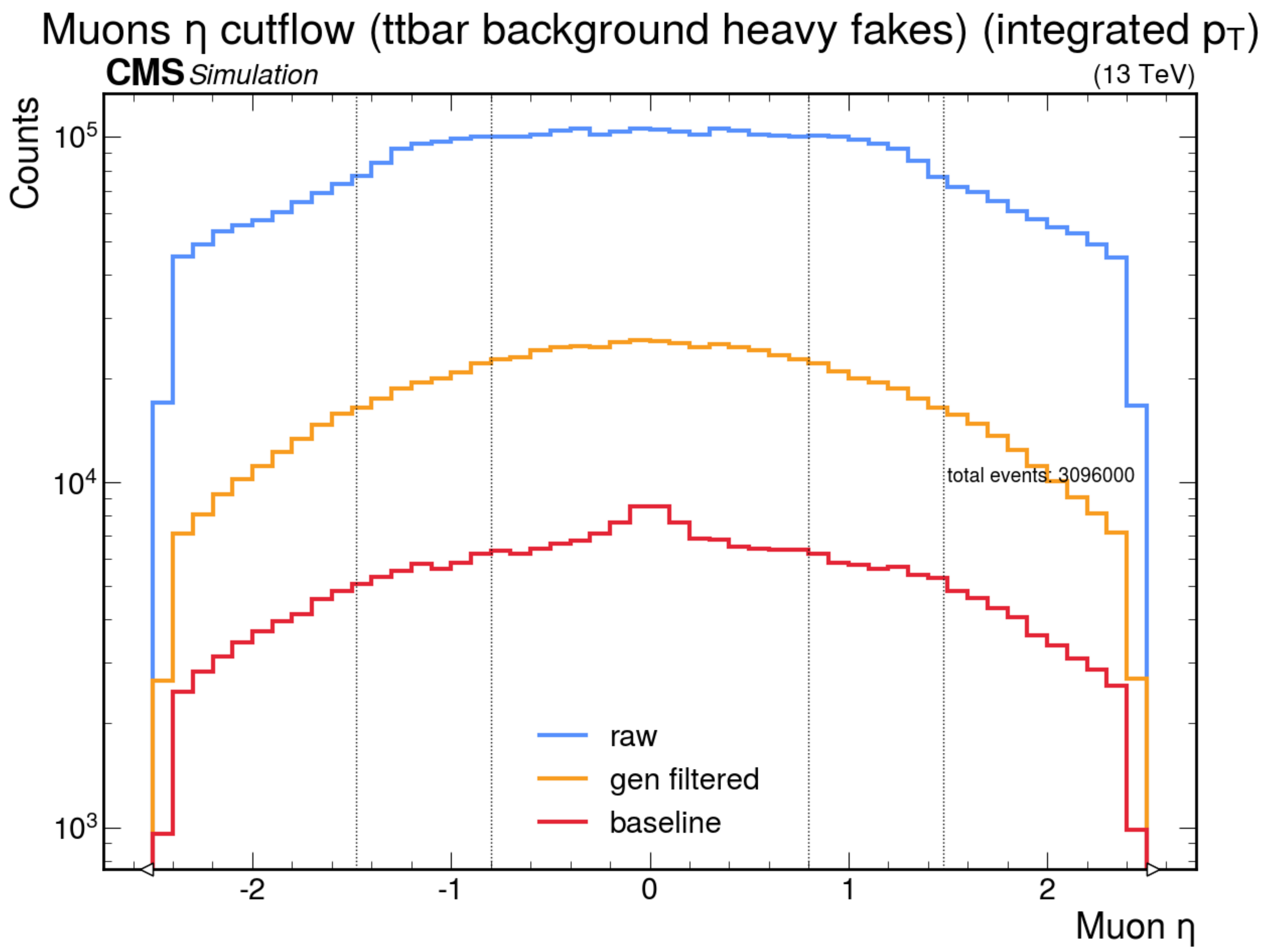


In these plots, blp = baseline,

Muon CutFlow ttbar background (Fakes)

η

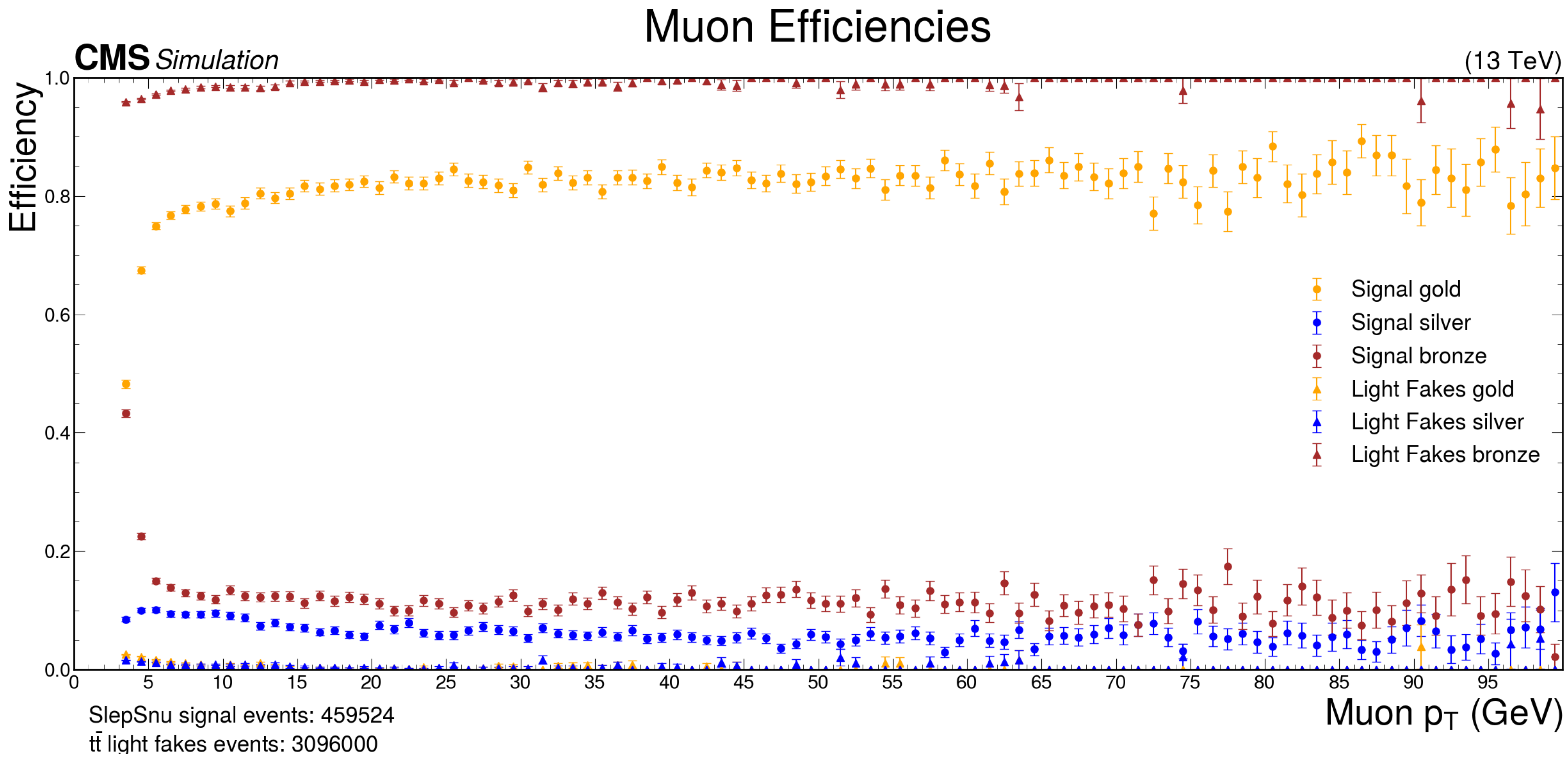




In these plots, blp = baseline,

Muon Efficiciencies (Light Fakes)

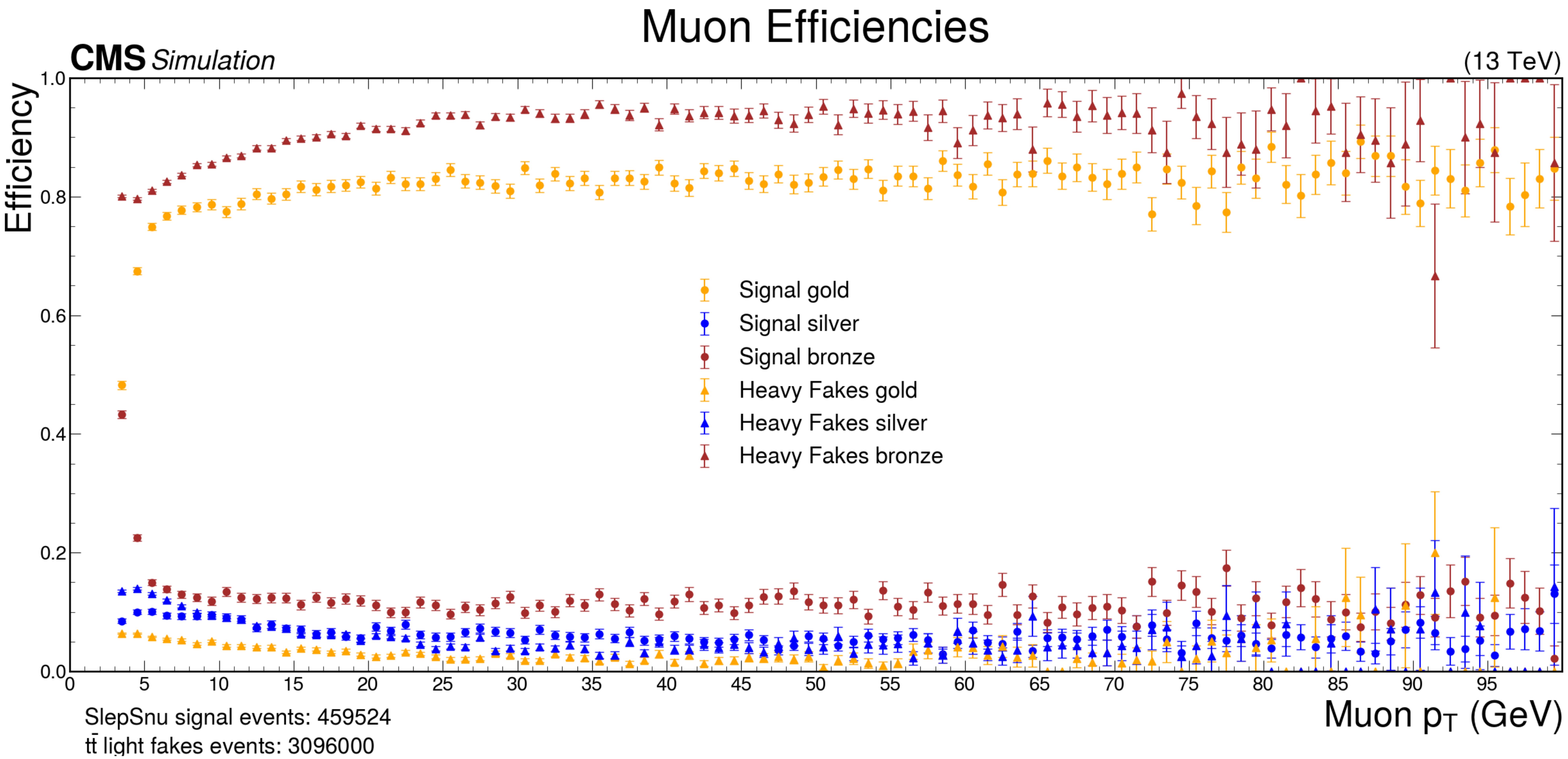
Light Fakes == GenFlav0, unmatched to PV



*Ttbar sample used for fakes

Muon Eficiciencies (Heavy Fakes)

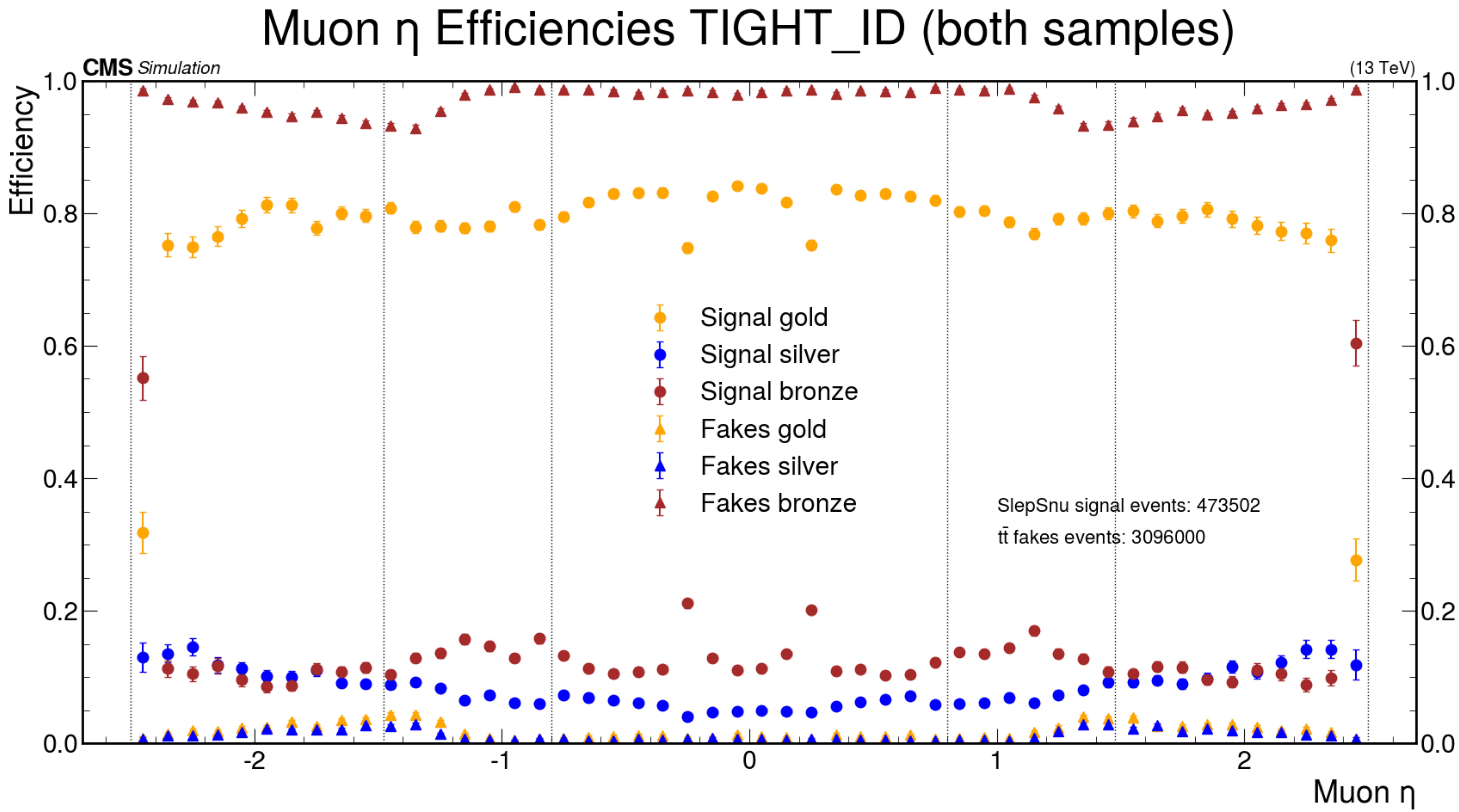
Heavy Fakes == GenFlav4 OR GenFlav5, c's and b's



*Ttbar sample used for fakes

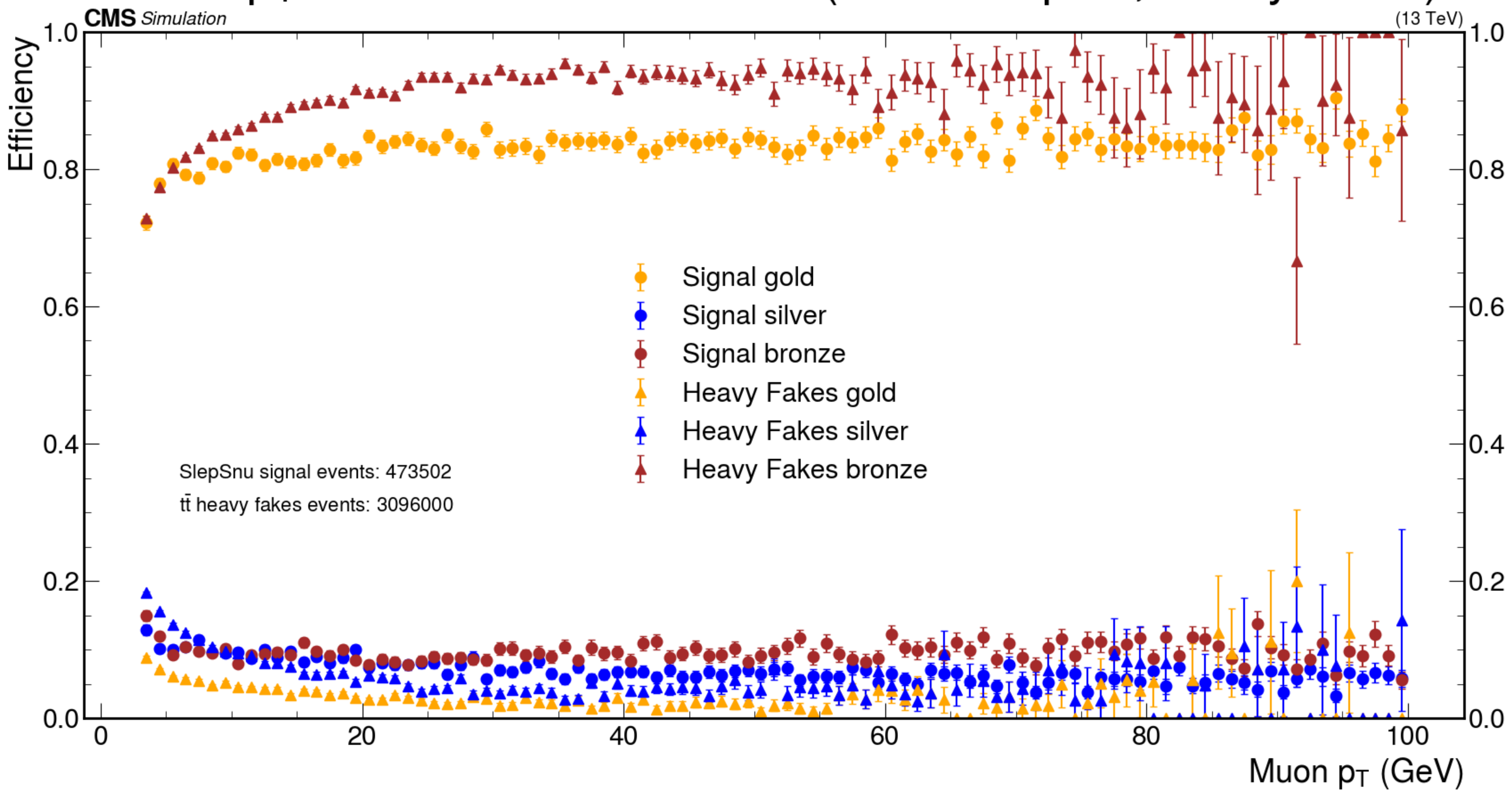
Muon η Efficiencies

SlepSnu Signal and ttbar Light Fakes

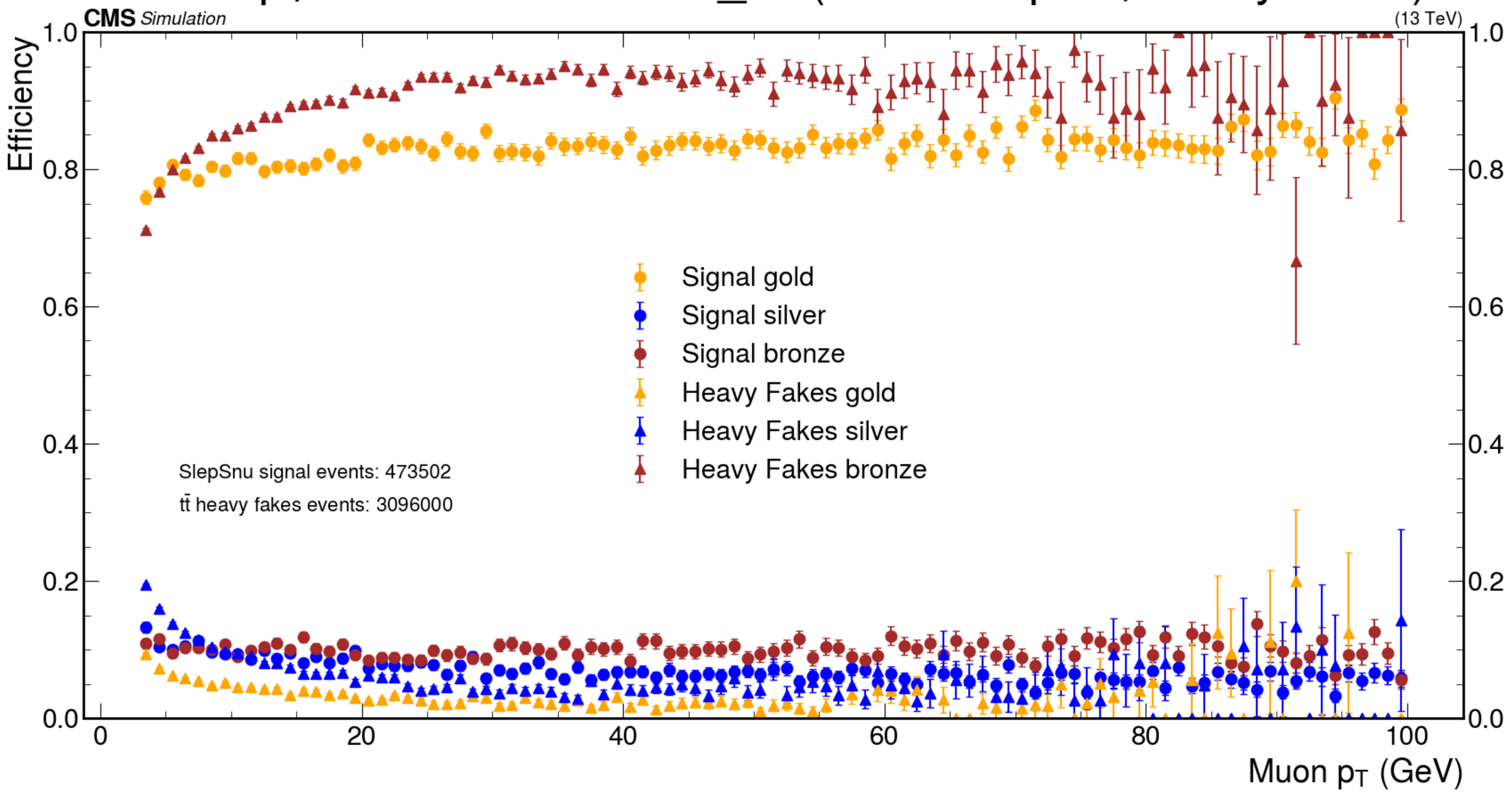


Muon Efficiencies (Heavy Fakes)

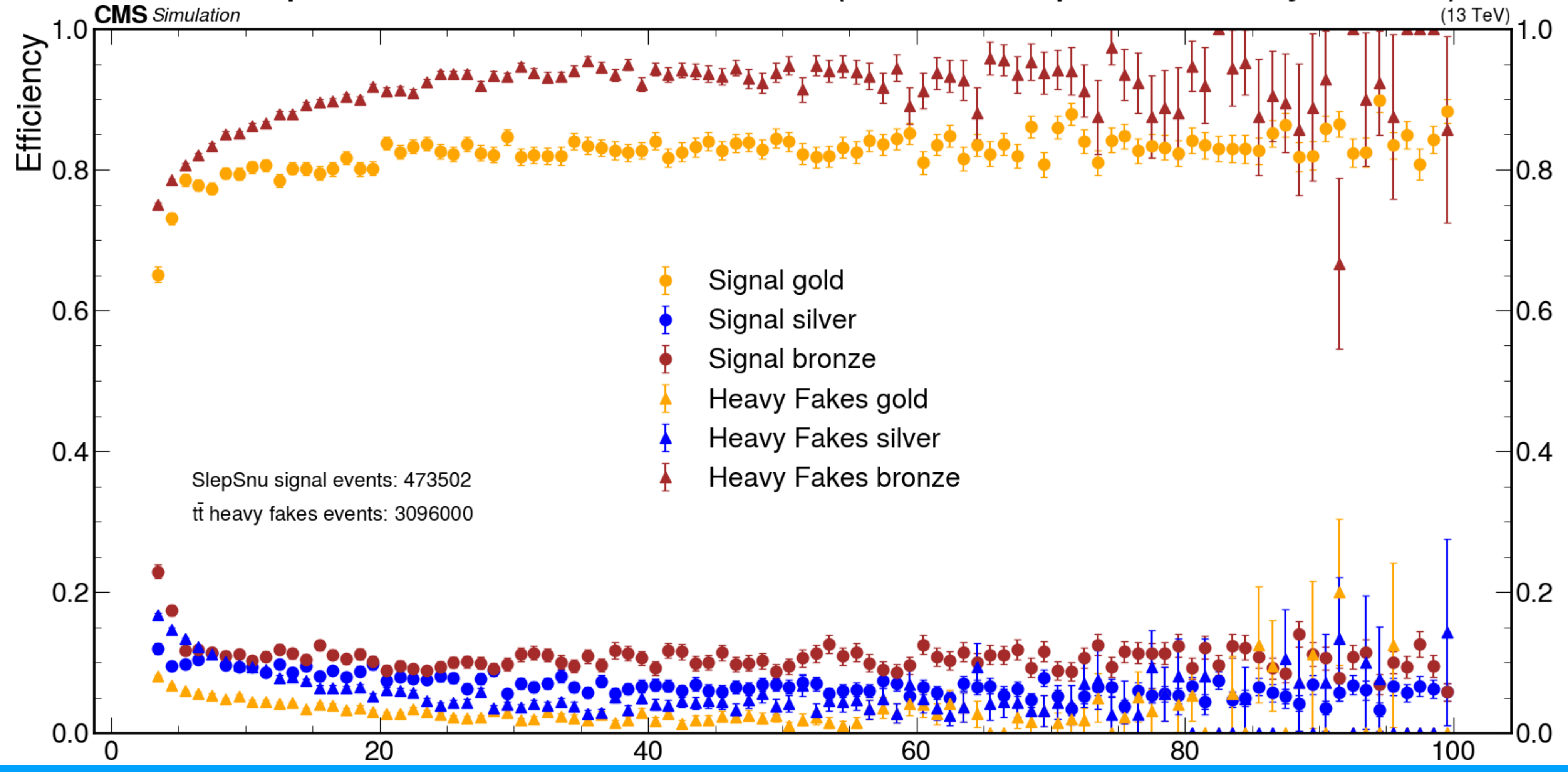
Muon p_T Efficiencies LOOSE ID (both samples, heavy fakes)



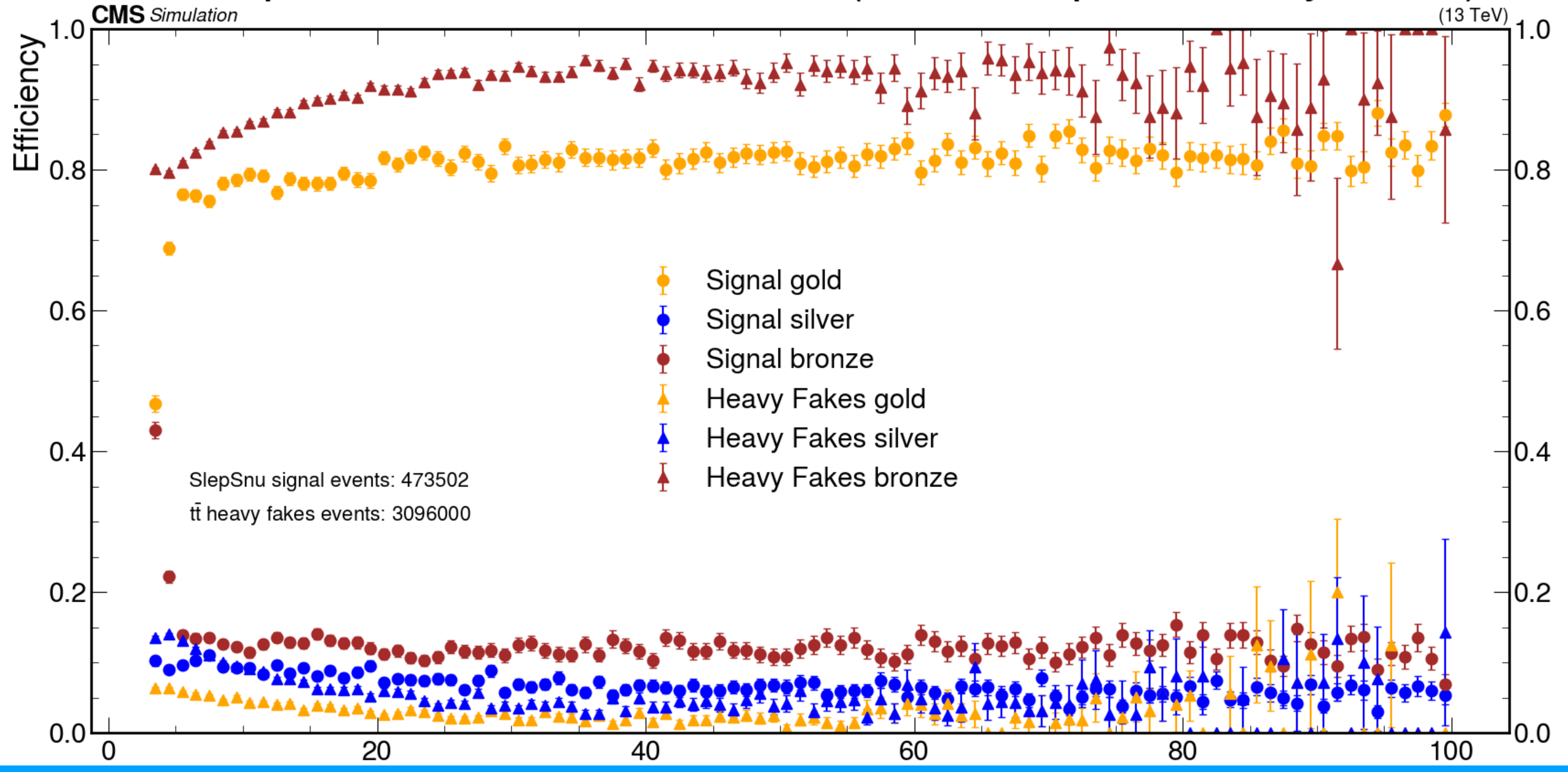
Muon p_T Efficiencies SOFT_ID (both samples, heavy fakes)



Muon p_T Efficiencies MED_ID (both samples, heavy fakes)



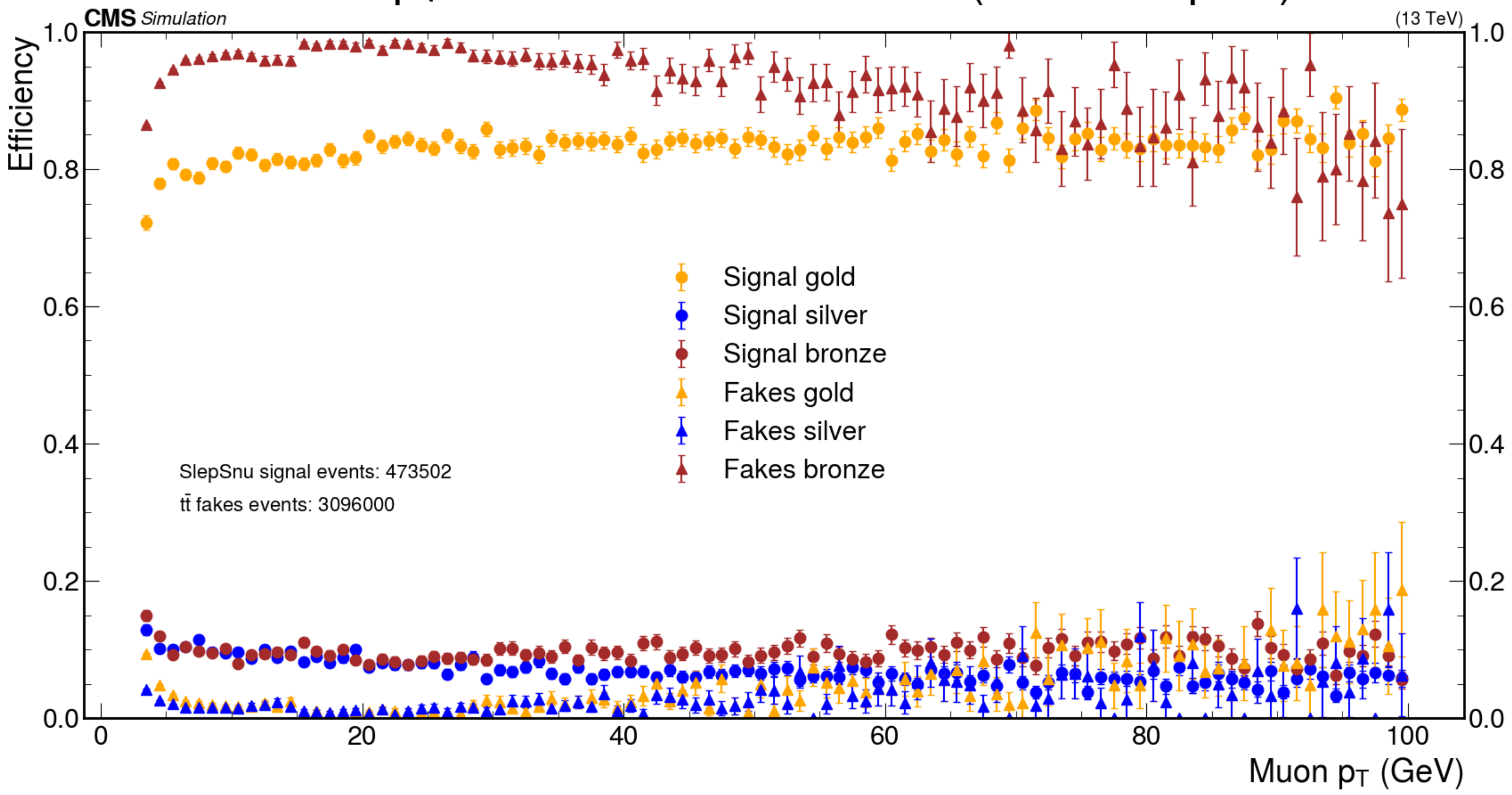
Muon p_T Efficiencies TIGHT_ID (both samples, heavy fakes)



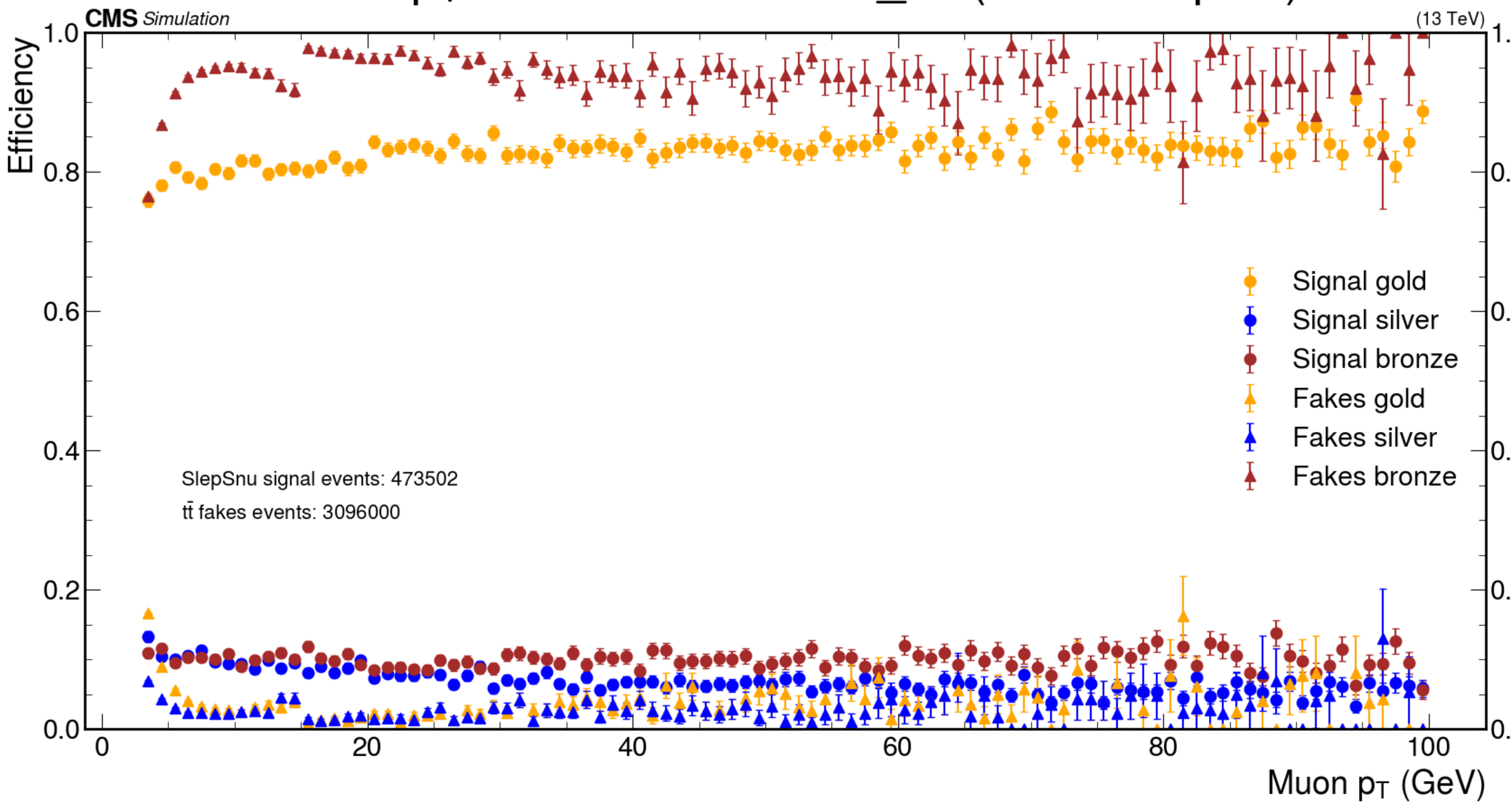
*Ttbar sample used for fakes

Muon Efficiencies (Light Fakes)

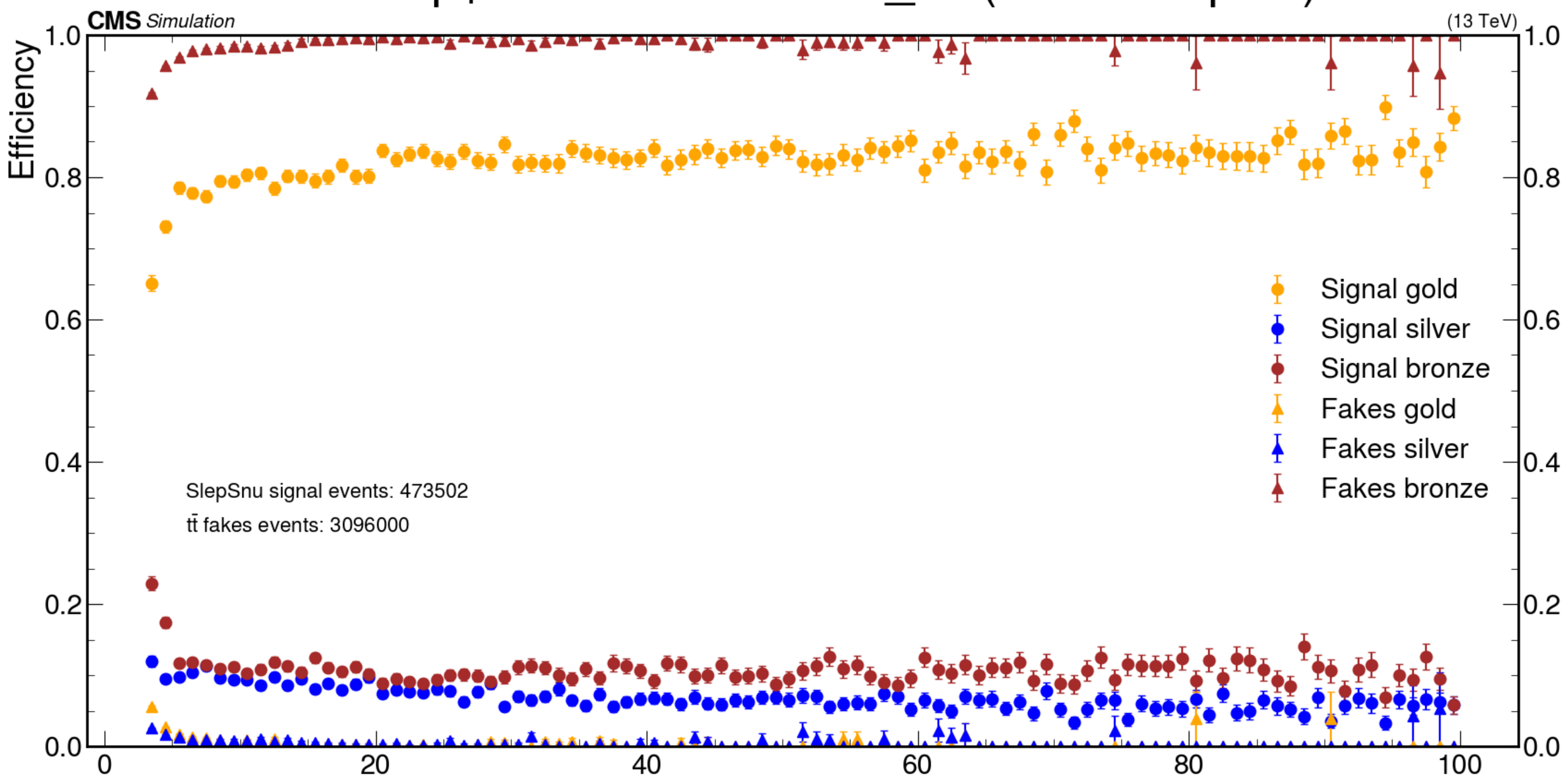
Muon p_T Efficiencies LOOSE ID (both samples)



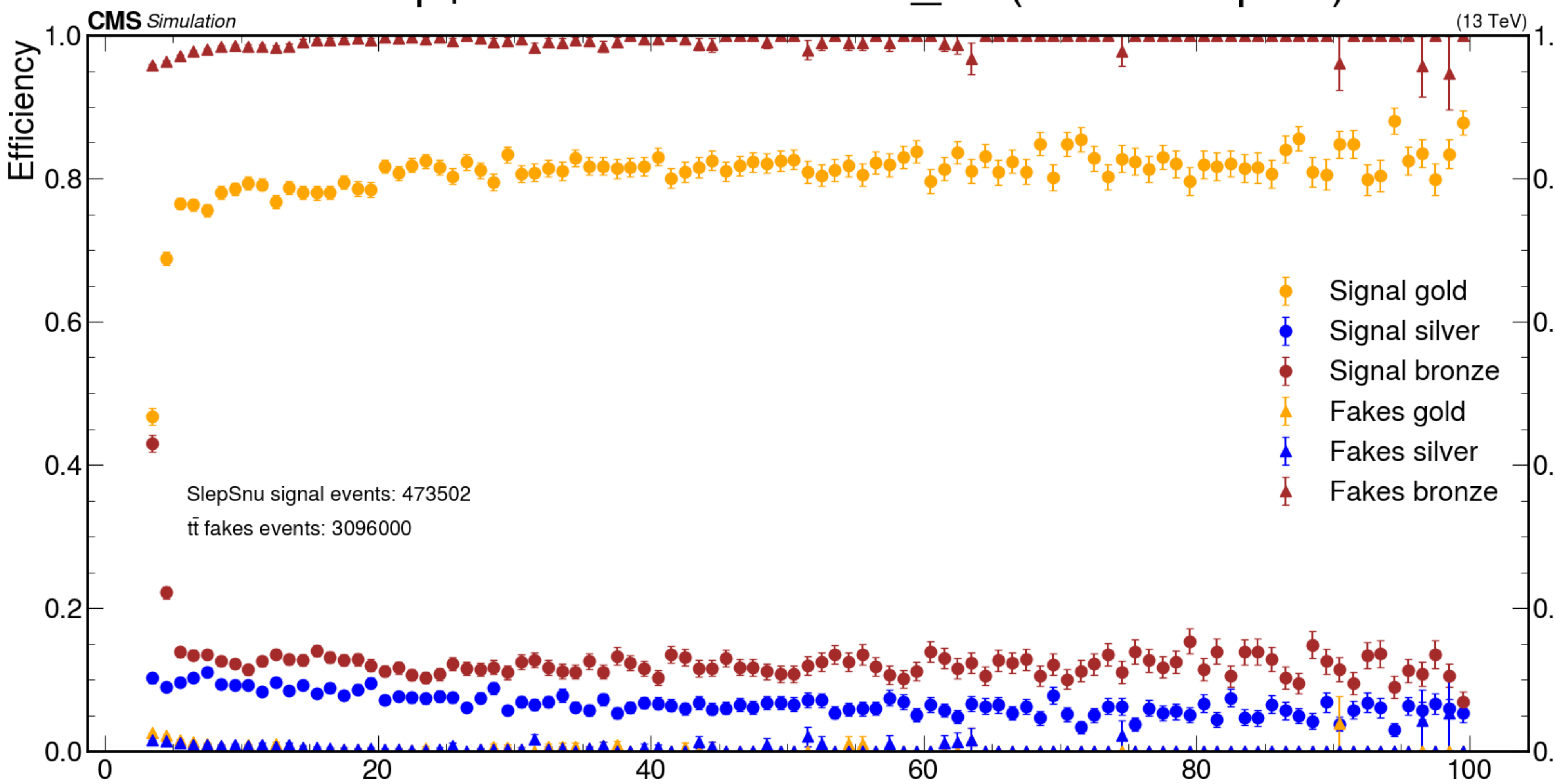
Muon p_T Efficiencies SOFT_ID (both samples)



Muon p_T Efficiencies MED_ID (both samples)



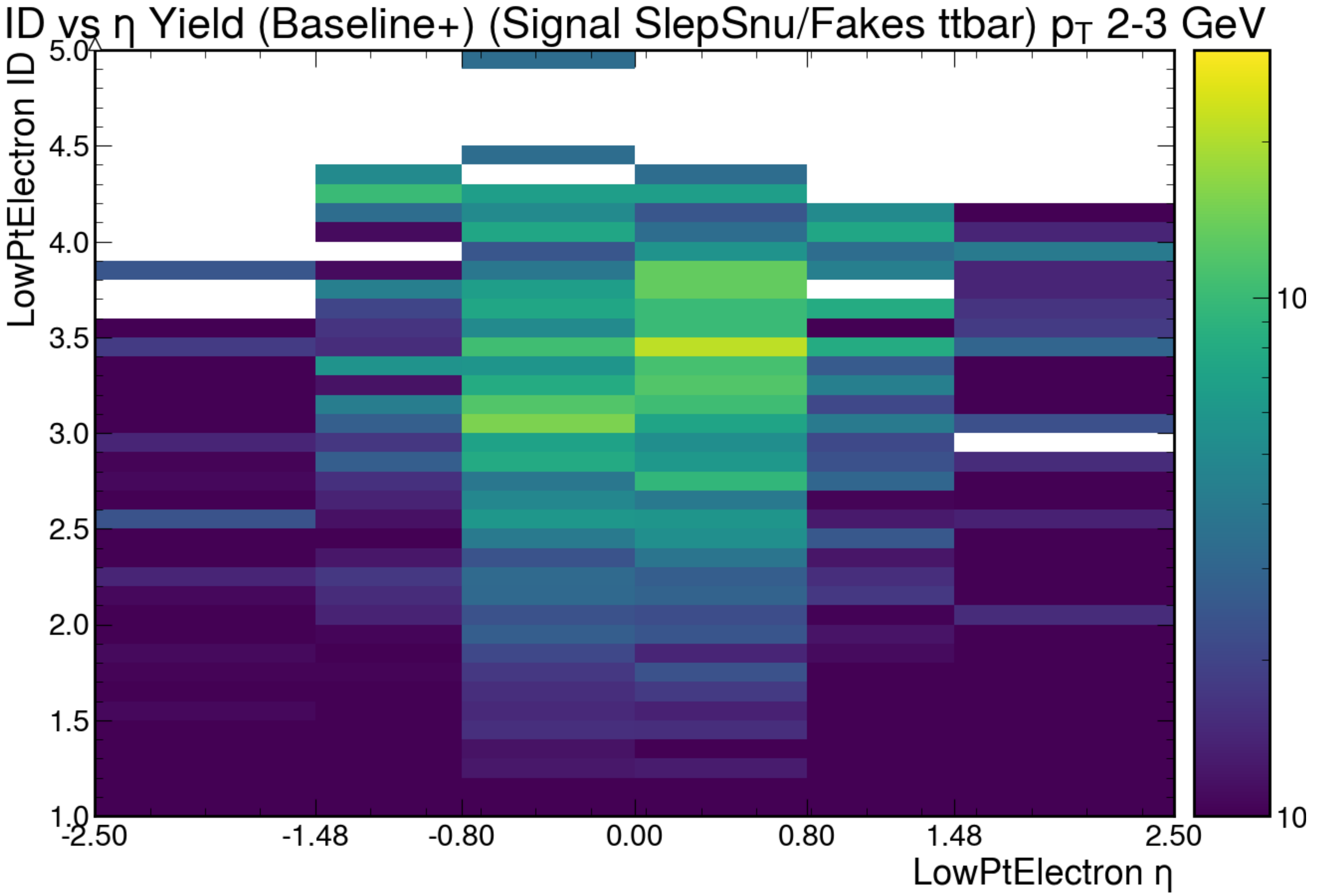
Muon p_T Efficiencies TIGHT_ID (both samples)

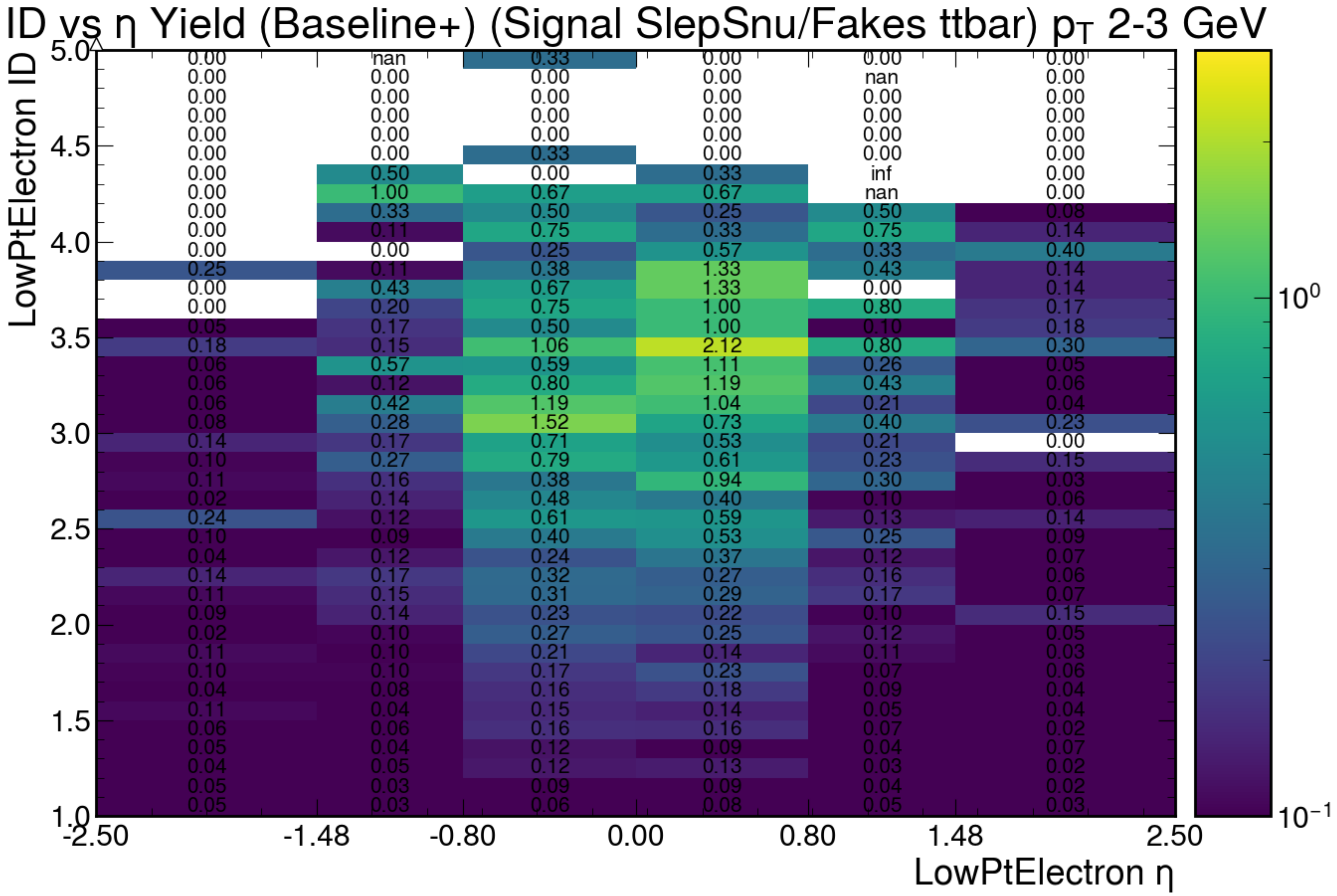


*Ttbar sample used for fakes

η ID Yield p_T 2-3

baseline+ LowPtElectrons

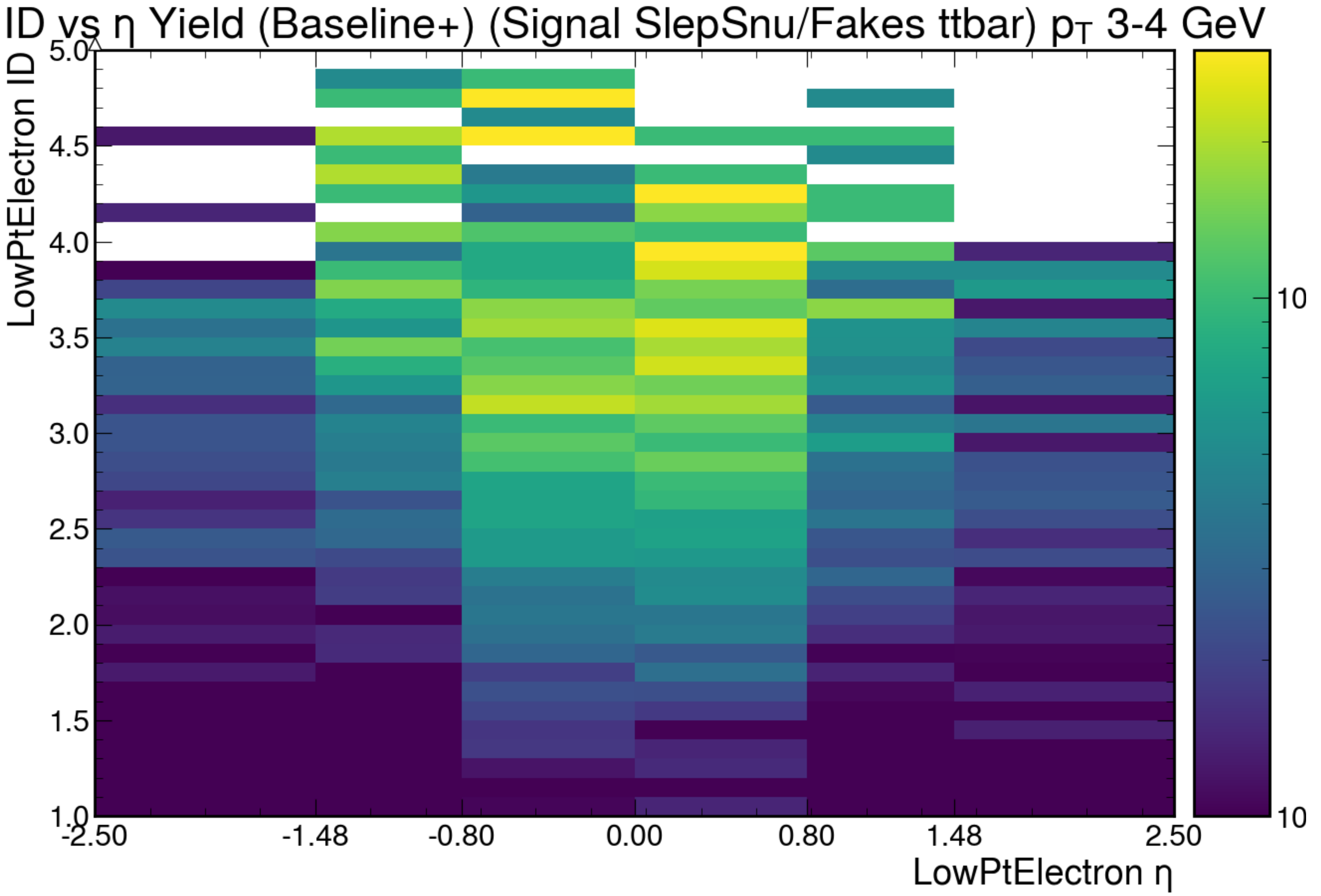


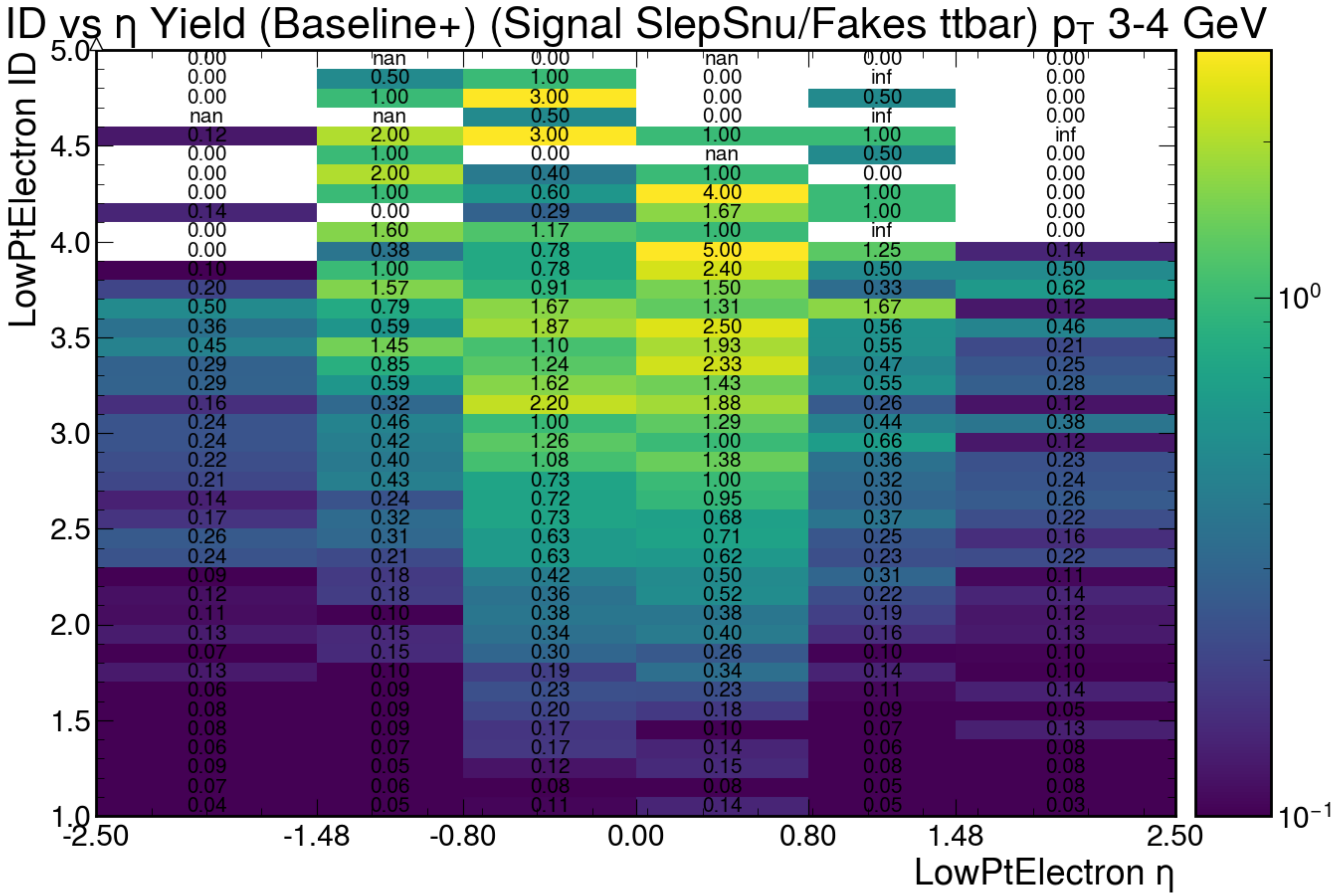


*In these plots, “baseline+” = Baseline, we had different names during tuning

η ID Yield p_T 3-4

baseline+ LowPtElectrons

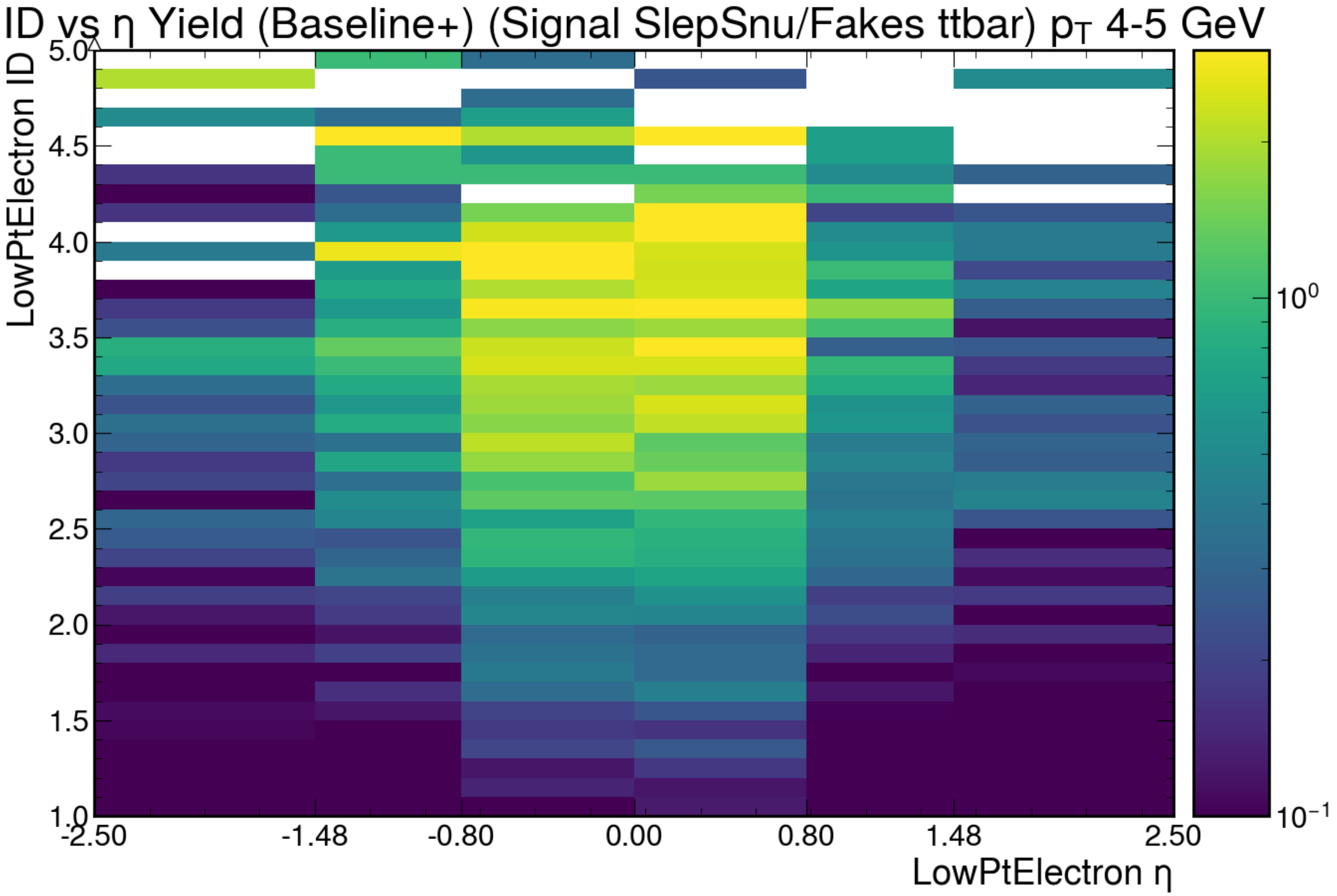


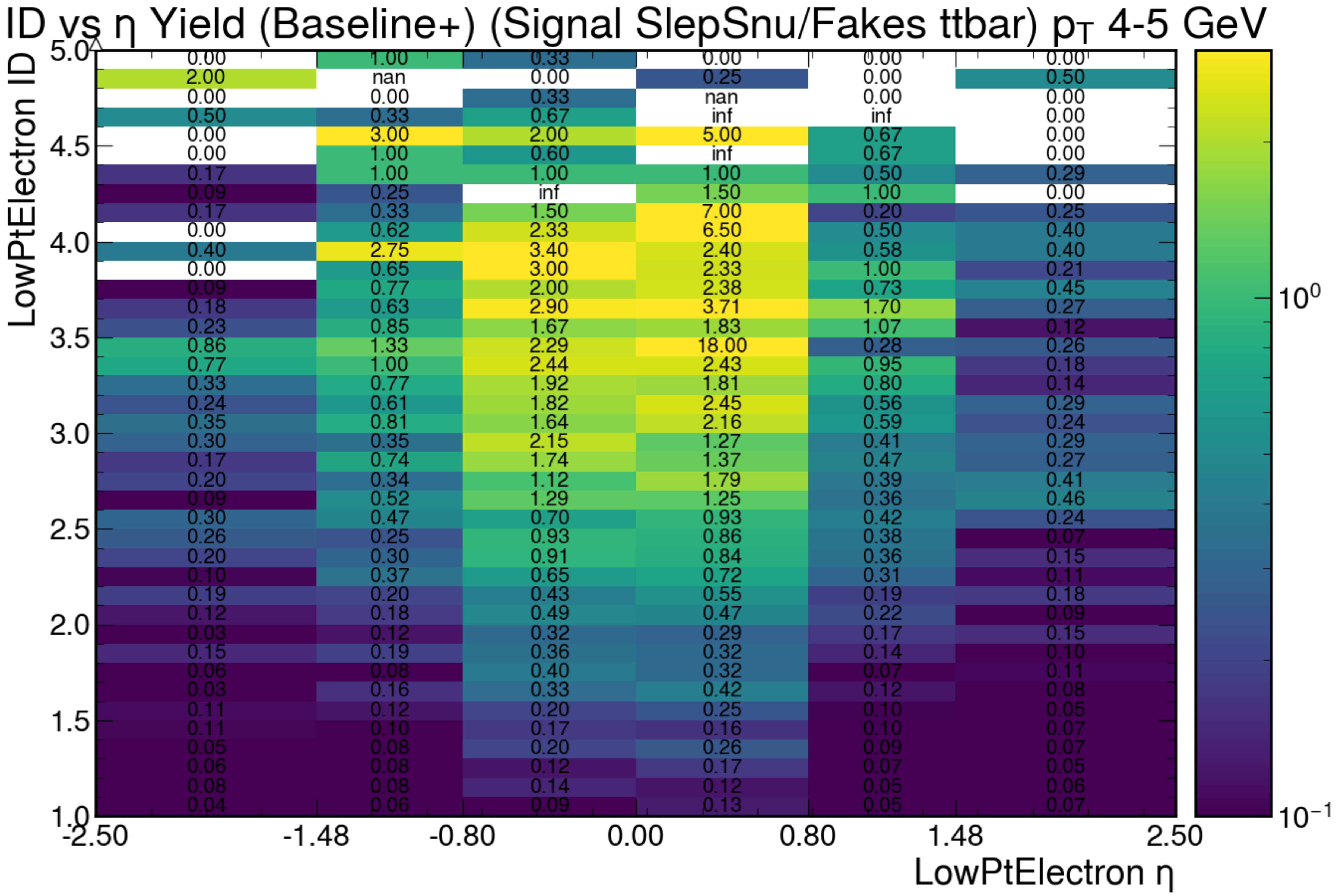


*In these plots, "baseline+" = Baseline, we had different names during tuning

η ID Yield p_T 4-5

baseline+ LowPtElectrons

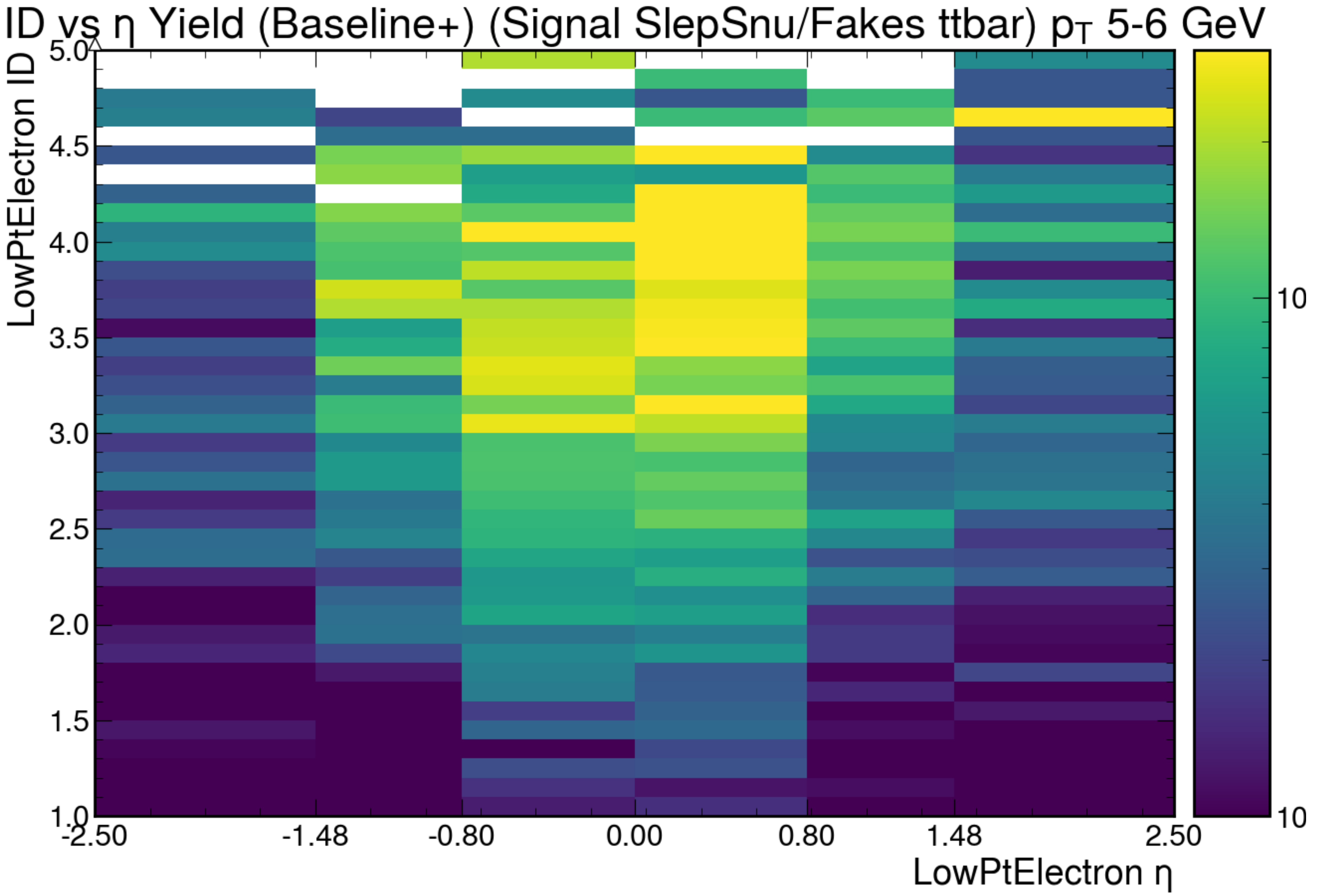


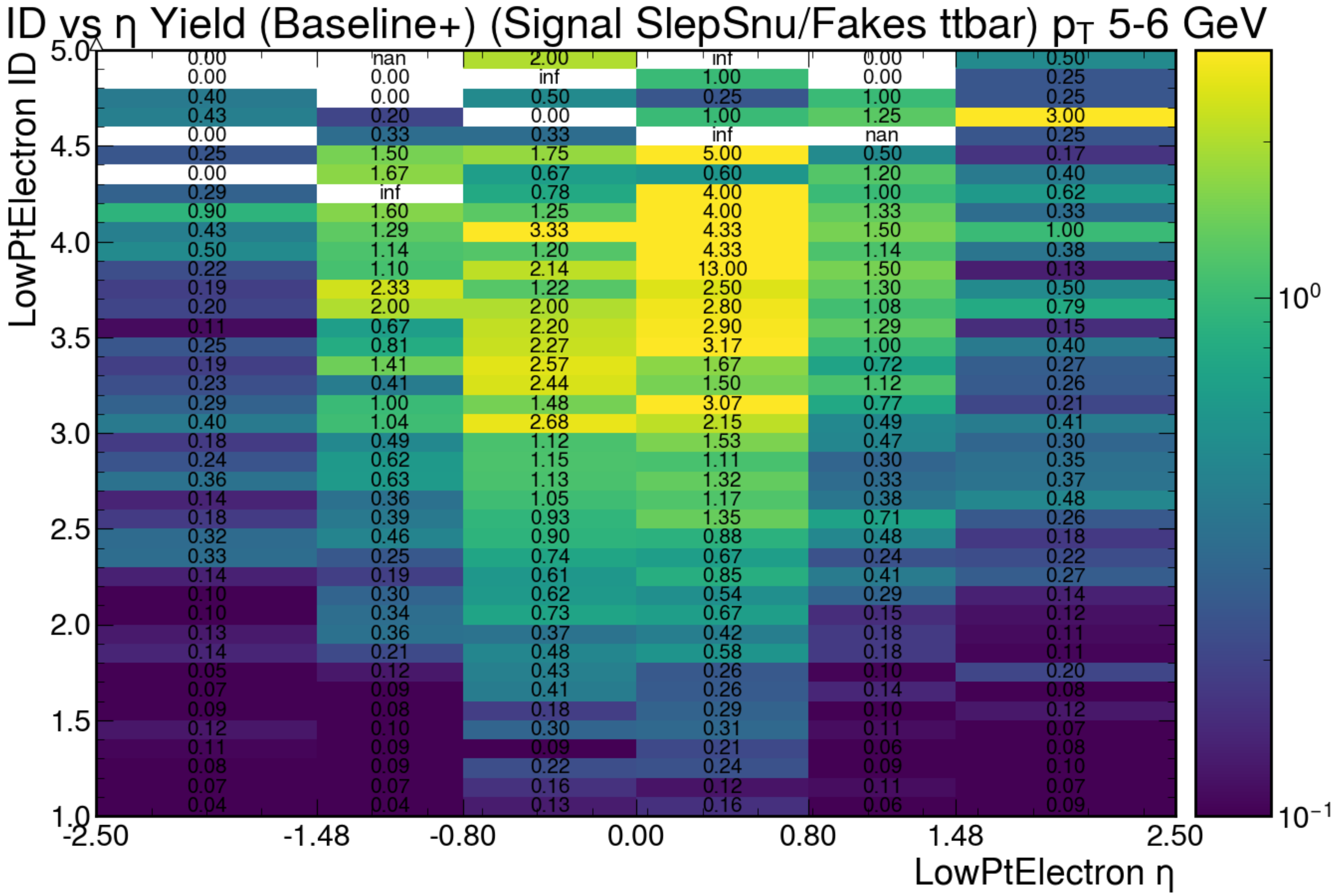


*In these plots, “baseline+” = Baseline, we had different names during tuning

η ID Yield p_T 5-6

baseline+ LowPtElectrons

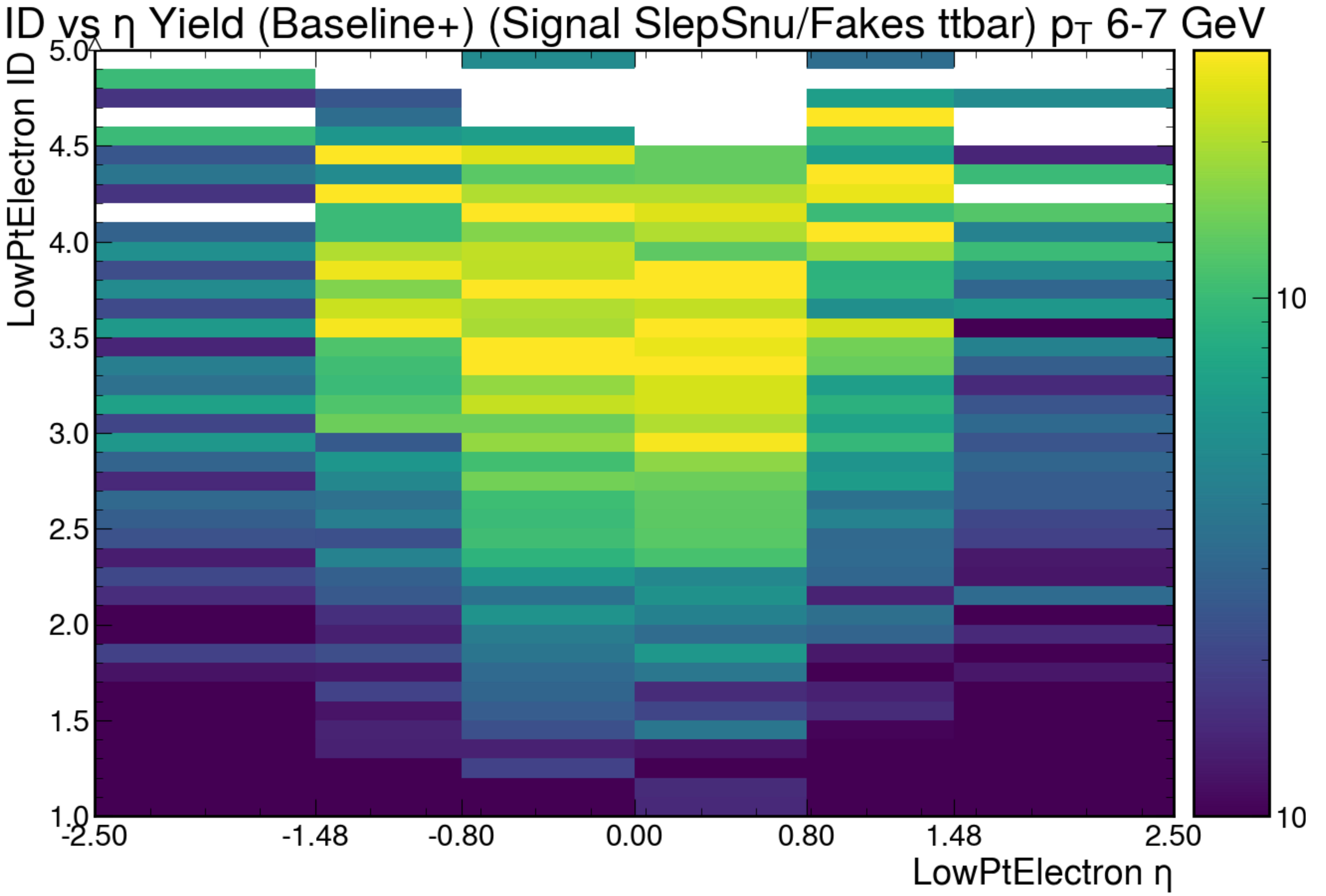


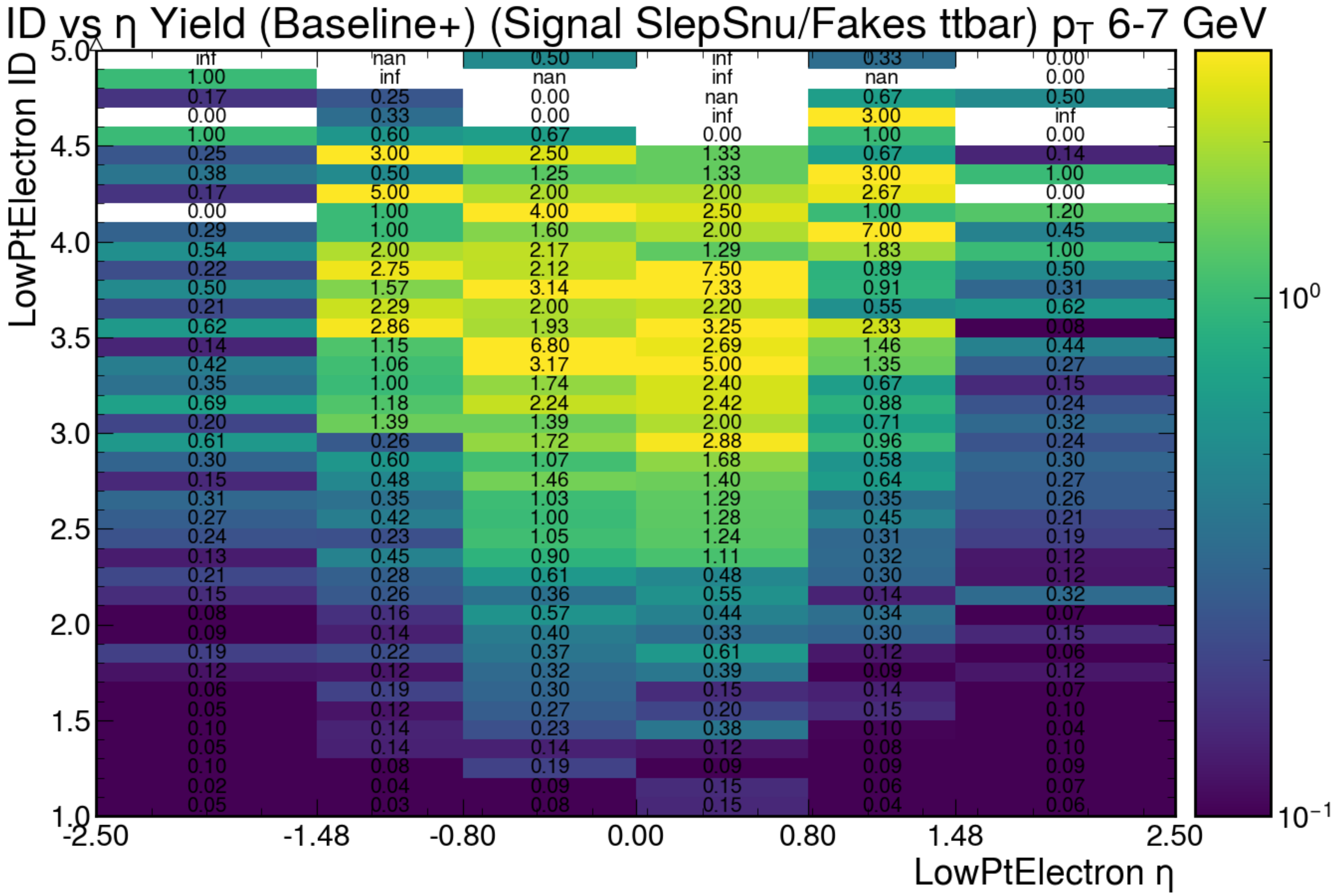


*In these plots, "baseline+" = Baseline, we had different names during tuning

η ID Yield p_T 6-7

baseline+ LowPtElectrons

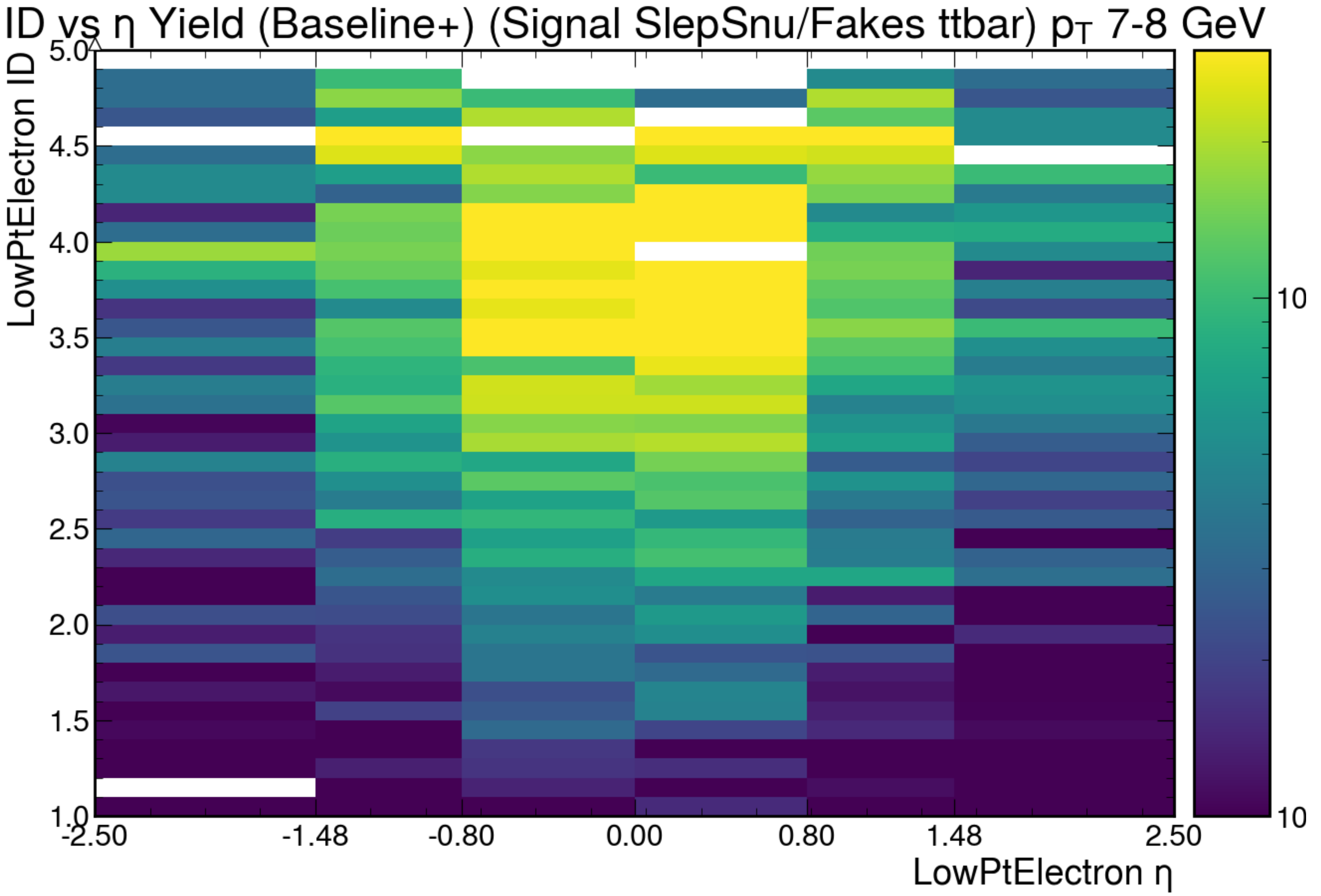


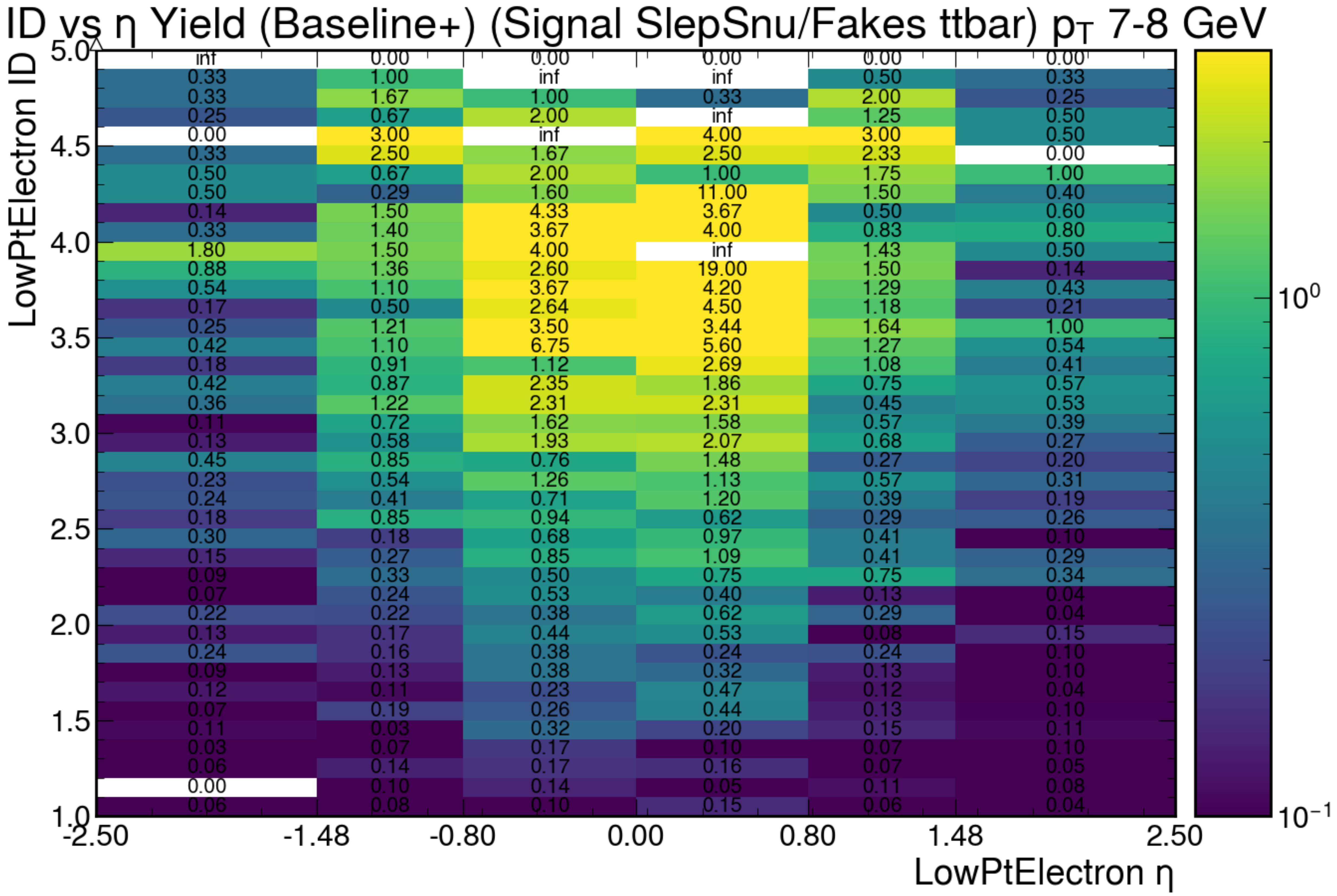


*In these plots, “baseline+” = Baseline, we had different names during tuning

η ID Yield p_T 7-8

baseline+ LowPtElectrons

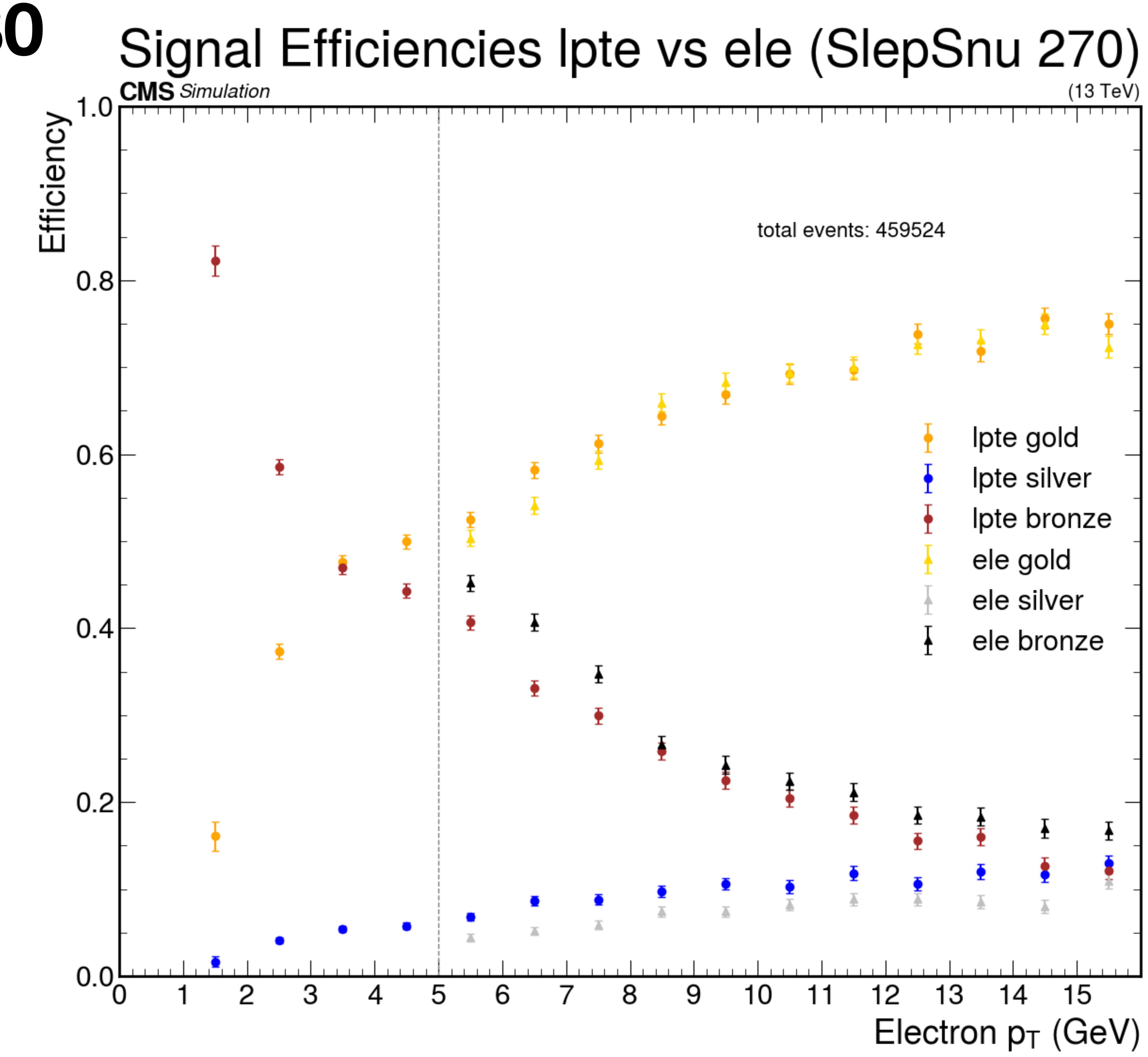




*In these plots, “baseline+” = Baseline, we had different names during tuning

Both Lpte and Ele (signal efficiency)

SlepSnu 270/280



Vertical line at pT = 5 GeV to show where Electron collection begins

Our Approximation for SIP3D

Have to use this for LowPtElectron's since SIP3D does not exist in NanoAOD for their collection

$$\text{SIP}_{3D} = \sqrt{\left(\frac{d_{xy}}{\sigma_{d_{xy}}}\right)^2 + \left(\frac{d_z}{\sigma_{d_z}}\right)^2}$$

Dr. Bean's undergraduate research student, Susan Sukhare, showed that this approximation yields good signal efficiencies for LowPtElectrons in 2017 UL samples when used in lieu of the traditional NanoAOD variable

Efficiencies

Important note

- Calculated relative to Baseline+ (blp):

$$\text{Ele Gold efficiency} = \frac{n_{gold}}{n_{blp}} \qquad \text{lpte Gold efficiency} = \frac{n_{gold}}{n_{blp}}$$

Ele blp ≠ lpte blp

- So, to compare efficiencies, we should really consider #electrons that pass the cuts for the **same exact events**