Simultaneous $t\gamma q + t\bar{t}\gamma$ measurement

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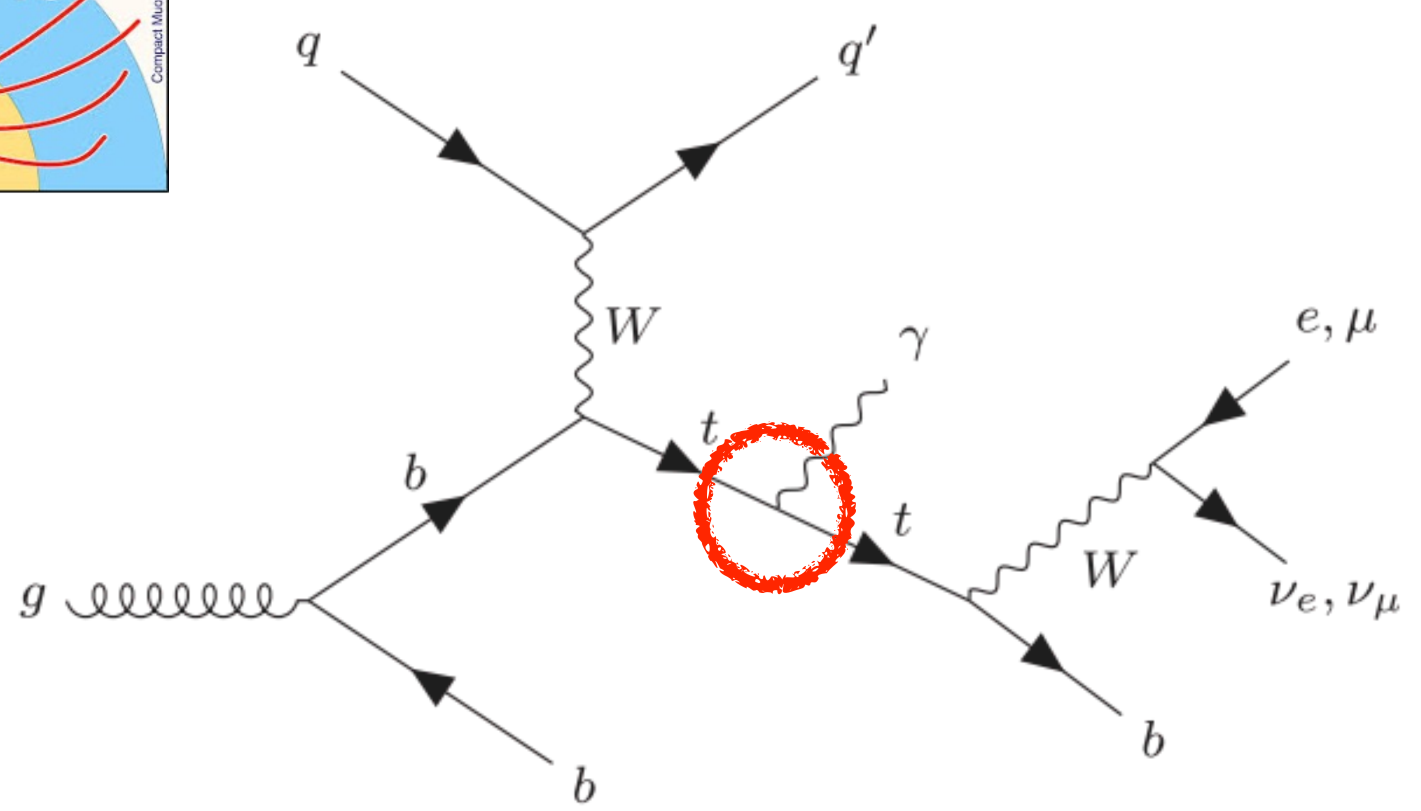
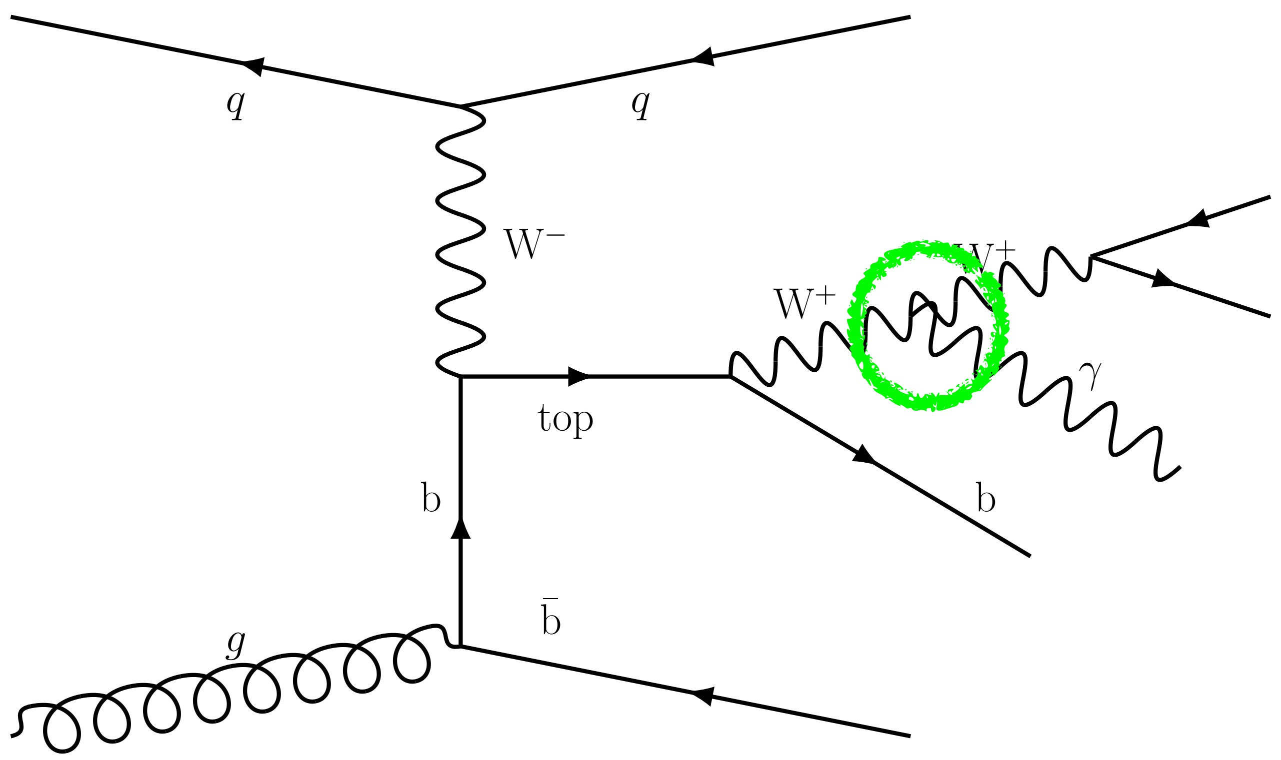
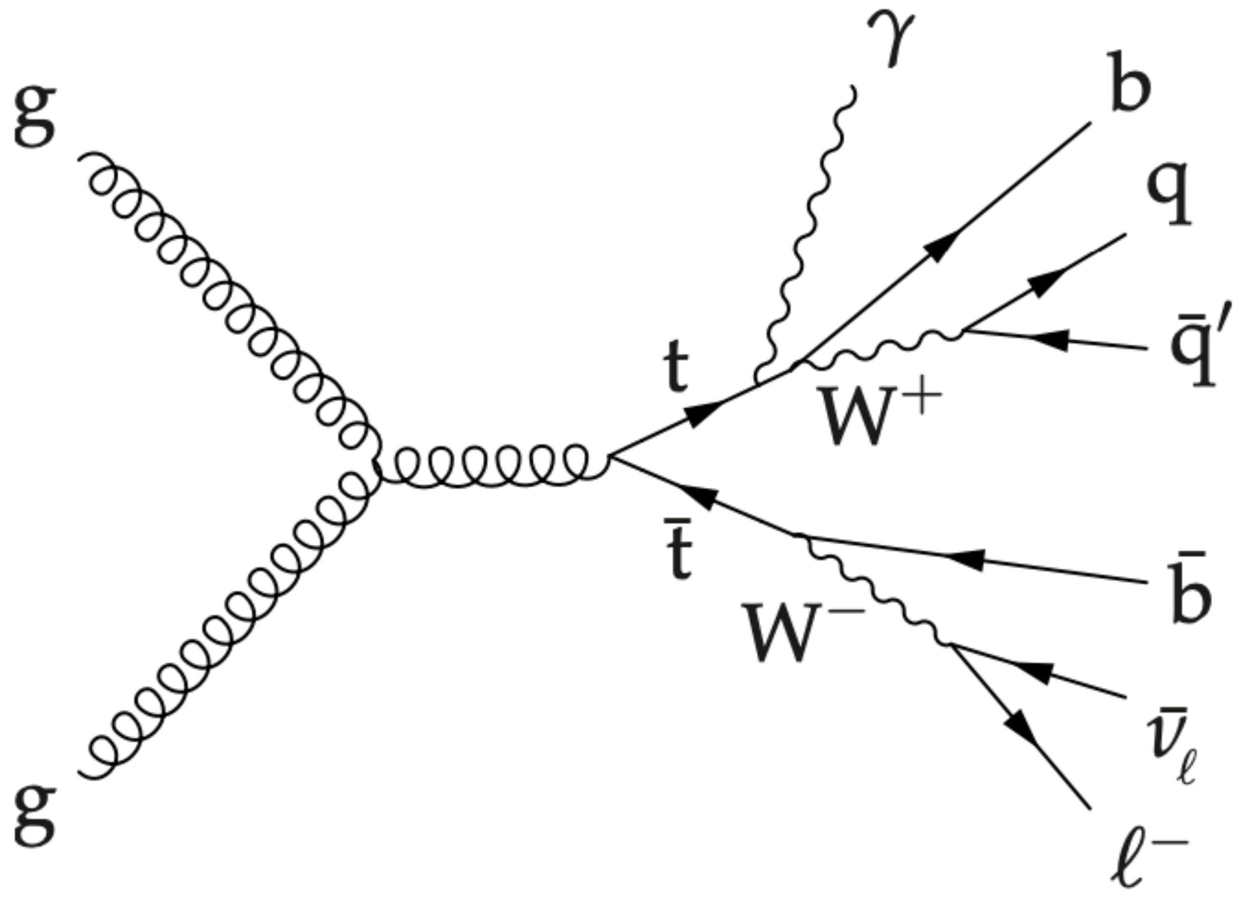
CMS TOP PAG meeting

8 Oct 2024

Motivation







- The $t\gamma q$ process is observed by ATLAS. CMS has the evidence paper with partial data. No differential cross section results to date
- This process represents a direct probe of the top-photon coupling
  - Anomalous top-photon electroweak coupling via EFT fit to tγq+ttγ

Simultaneous measurement of the tγq+ttγ

- Inclusive and first-ever differential cross sections
- Full set of correlations between the two processes
- Possible for a more straightforward EFT interpretation
- High precision ttγ results

Previous updates:

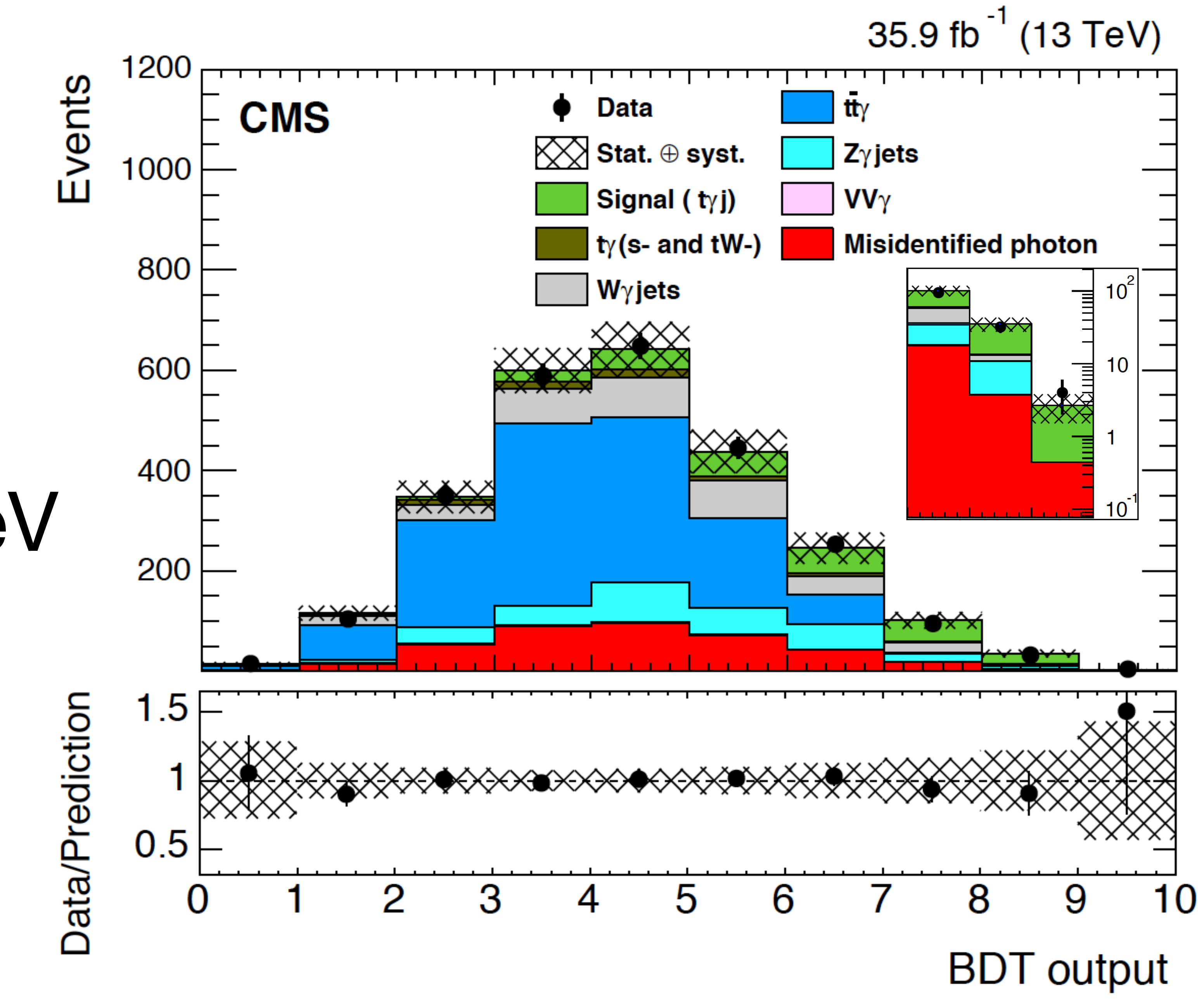
- tX+ttX talk on April 23
- tX talk on May 29

Overview

CMS result:

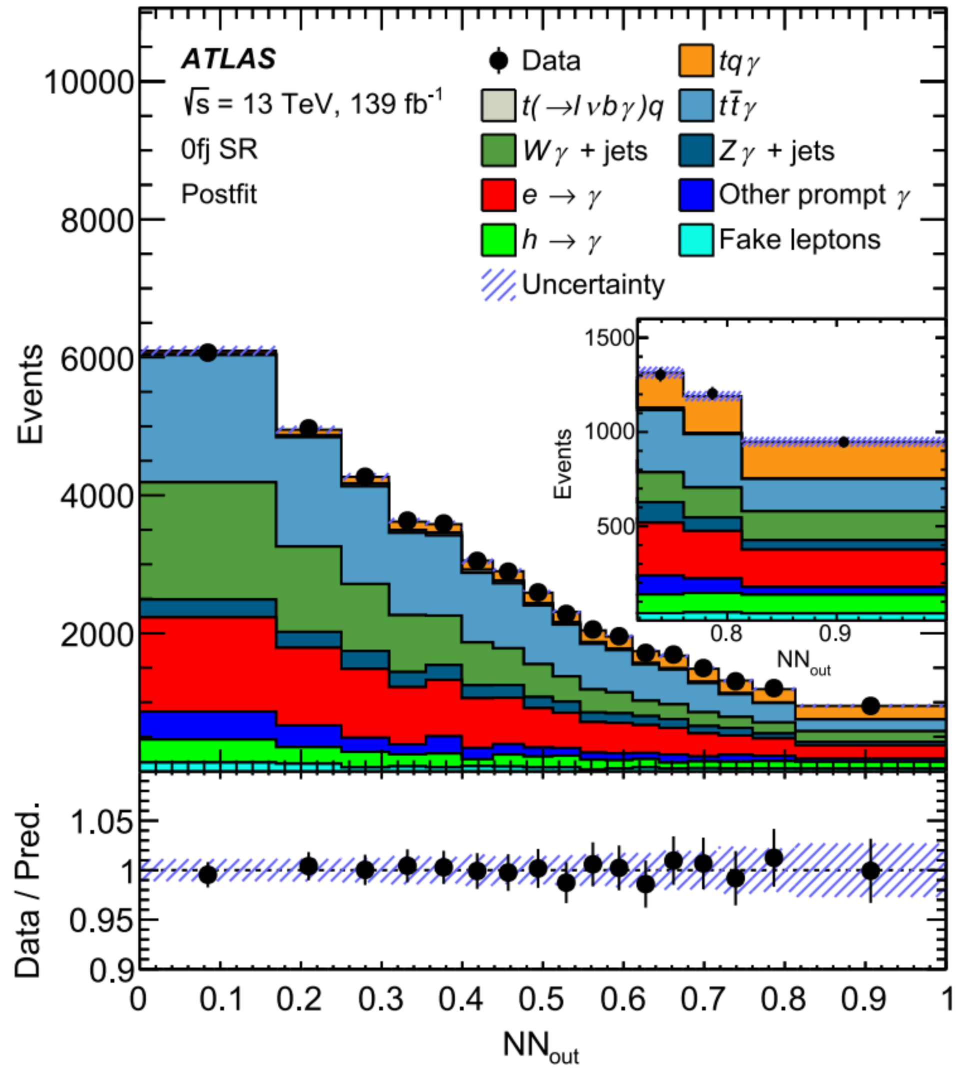
- μ channel 2016 data only
  - Signal is with exactly 1γ, 1μ, 1b-jet, ≥1j, and satisfy MET > 30 GeV
- BDT is trained for tγq signal against the main background $t\bar{t}\gamma$
- Observed (Expected) significance **4.4 (3) σ**

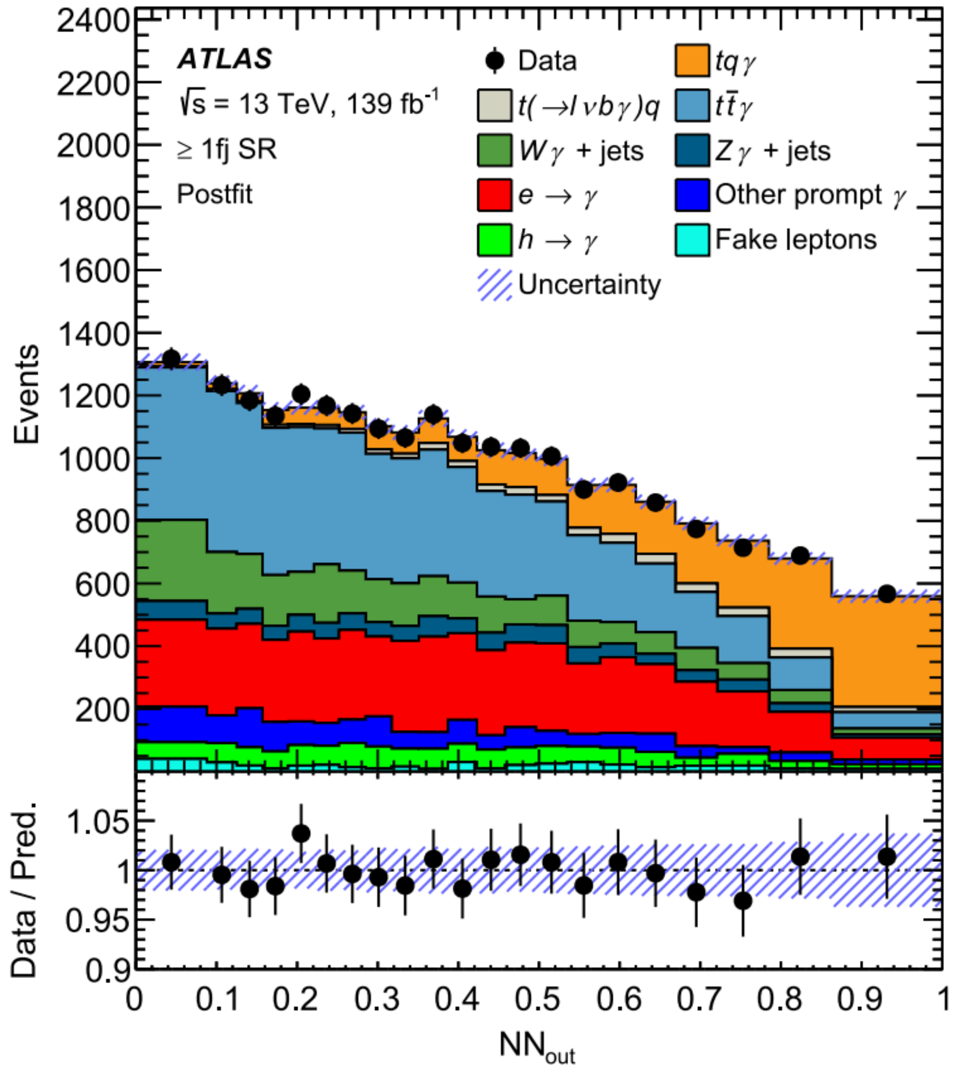
◆ Ongoing inclusive tγq measurement using full run 2 data by IPM



ATLAS result:

- Both the μ and e channel with full run 2 data
  - Exactly 1γ, 1ℓ, 1b-jet, and MET > 30 GeV
  - Categorise signal to 0fj and ≥1fj (number of forward jets)
- NNs are trained in the SRs
- Observed (Expected) significance **9.3 (6.8) σ**





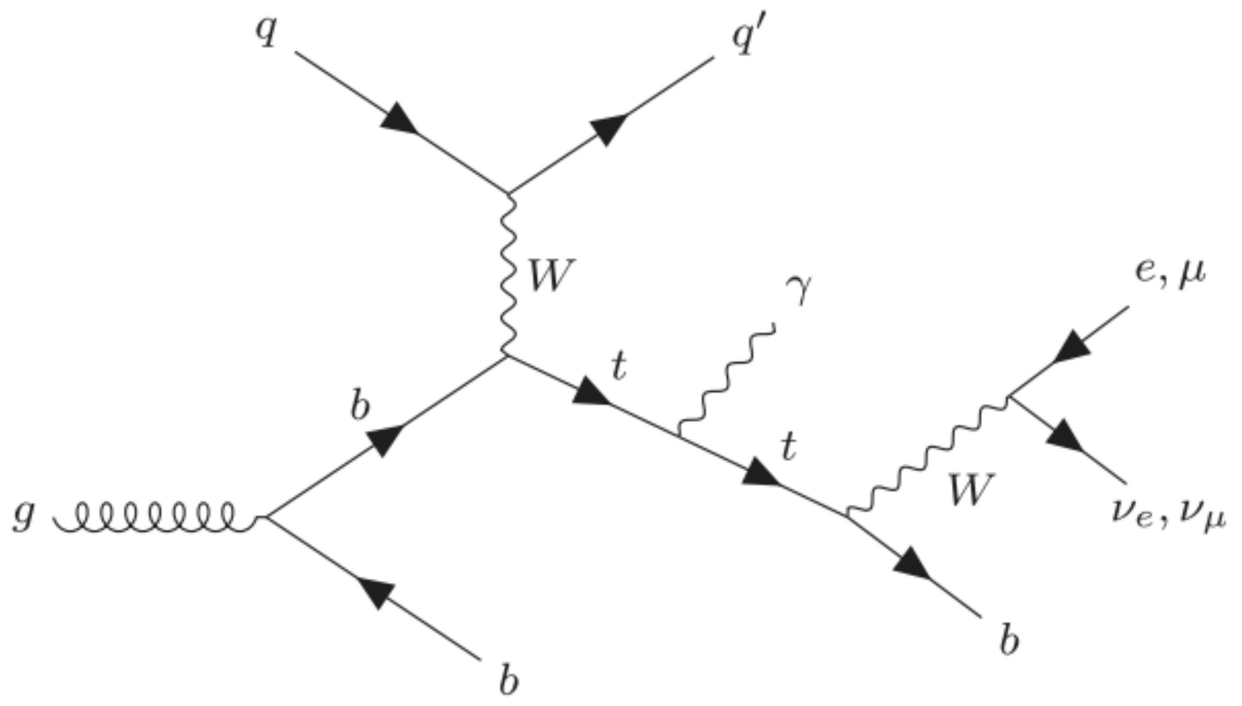
Goal and strategy

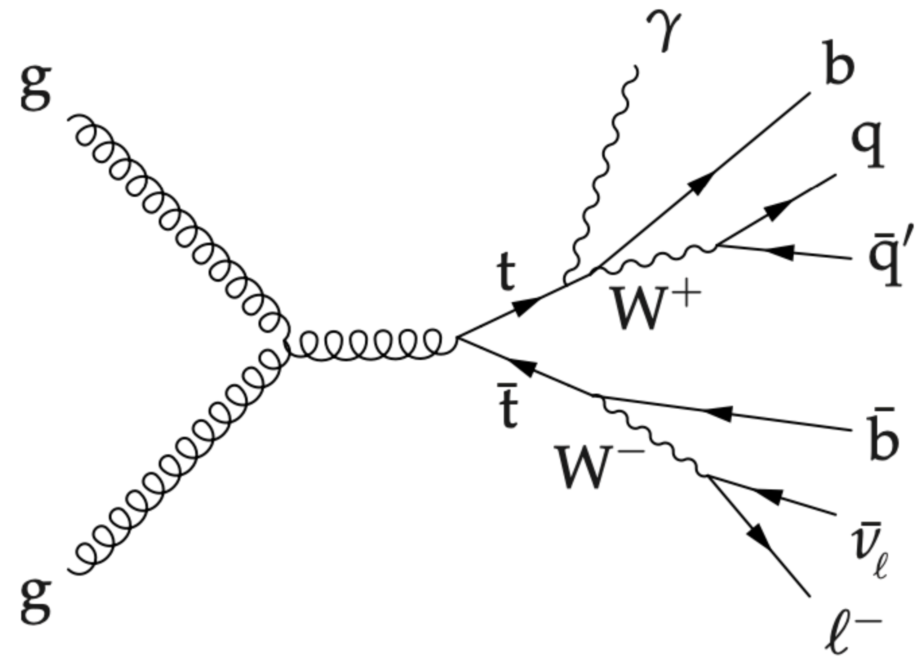
Separate signal and background

- Train **BDT** to separate tγq, $t\bar{t}\gamma$ and others

Background estimation/constraint (<u>$t\bar{t}\gamma$ as signal</u>):

- Simulation: $t\bar{t}$, V+Jets/Vγ+Jets, tW/tWγ, TTV, VV
- Data-Driven backgrounds:
  - j→γ (nonprompt γ), j→ℓ (nonprompt ℓ), e→γ (mainly in e channel)
- Define proper control regions
  - Constrain main and data-driven background normalisations





Signal events (**N_ℓ=1, N_γ ≥1, N_j≥2, N_b≥1):** *exactly 1 lepton, at least 1 photon, at least 2 jets, of which at least 1 is b-jet*

- tγq+$t\bar{t}\gamma$ inclusive/differential cross sections
- Possible tγq+$t\bar{t}\gamma$ EFT interpretation

Data and MC

- Analysis is based on the NanoAOD v9 UL campaign
- Data: Full Run-II dataset SingleMuon and SingleElectron (EGamma)
- Trigger: Single electron and muon trigger → SFs are ready for these HLT paths

✦ Full MC sample list can be found in backup

✦ Phase space overlap removal of samples w/ and w/o simulated Madgraph γ (details can be seen from previous talk)

✦ Signal MCs are at NLO either in MG5 or Powheg

✦ TGJets_leptonDecays_TuneCP5_13TeV-amcatnlo-pythia8

✦ TTGJets_TuneCP5_13TeV-amcatnloFXFX-madspin-pythia8

✦ TTToSemiLeptonic_TuneCP5_13TeV-powheg-pythia8

✦ TTTo2L2Nu_TuneCP5_13TeV-powheg-pythia8

Selection & correction

Signal requirements:

- Event ≥ 1 good PV and pass MET Filters and pass high-level trigger
- Exactly one lepton
  - Reject events containing extra ℓ with veto lepton requirement
- At least one photon
- At least two jet with one at least one being b-jet
- $\Delta R(\ell,\gamma) > 0.4, \Delta R(\ell,j) > 0.4, \Delta R(\gamma,j) > 0.4$
- MET $p_T > 20$ GeV

Applied correction:

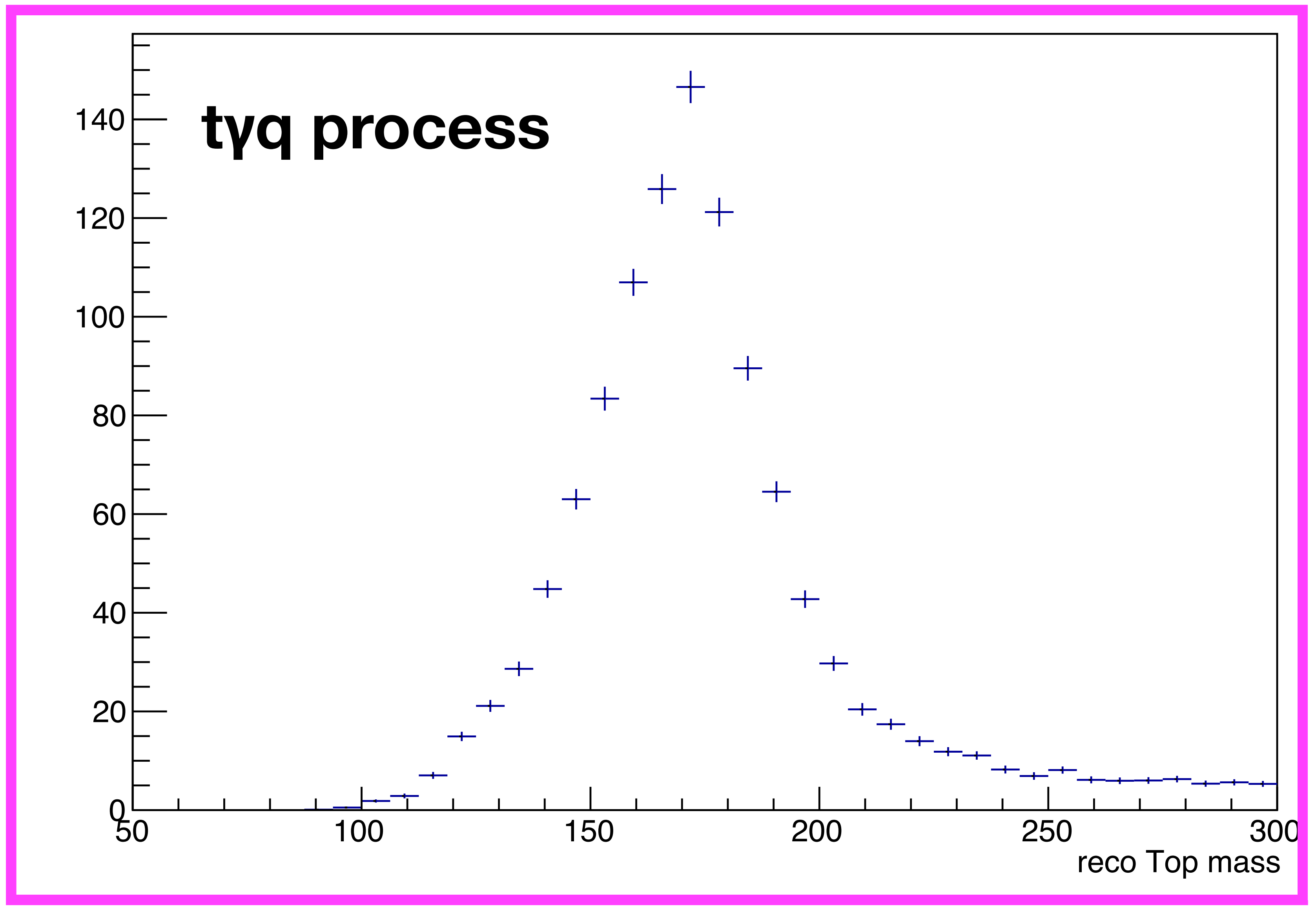
- Pileup reweighting
- L1 prefiring (2016 and 2017 MCs)
- Lepton energy correction
- Lepton ID/ISO/RECO/HLT scale factors
- e/γPhoton energy scale/smearing
- Photon ID/Pixel Seed Veto scale factors
- Jet energy correction
- Jet pileup ID scale factors
- b-jet ID scale factors

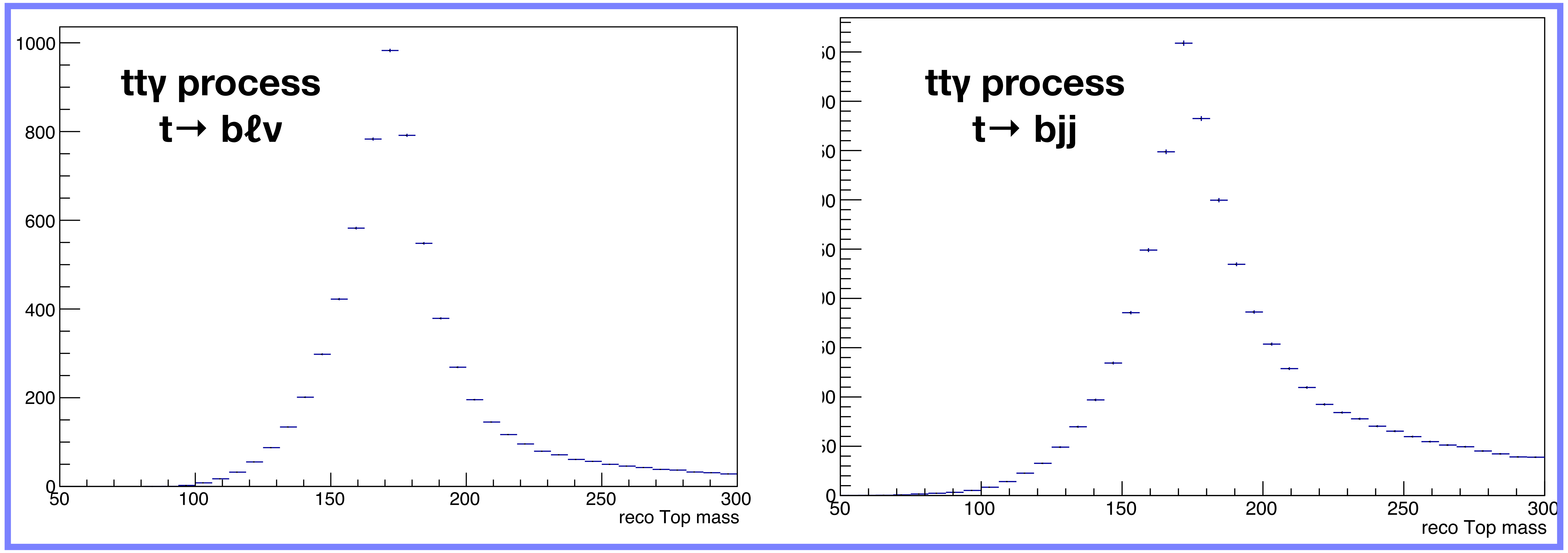
Details of the object selection are in backup

Top reconstruction

- Chi-square minimisation is performed
- Leptonic and hadronic top quarks are reconstructed depending on the the available objects (details in backup)
- If the reconstruction is not possible, give a default value -10

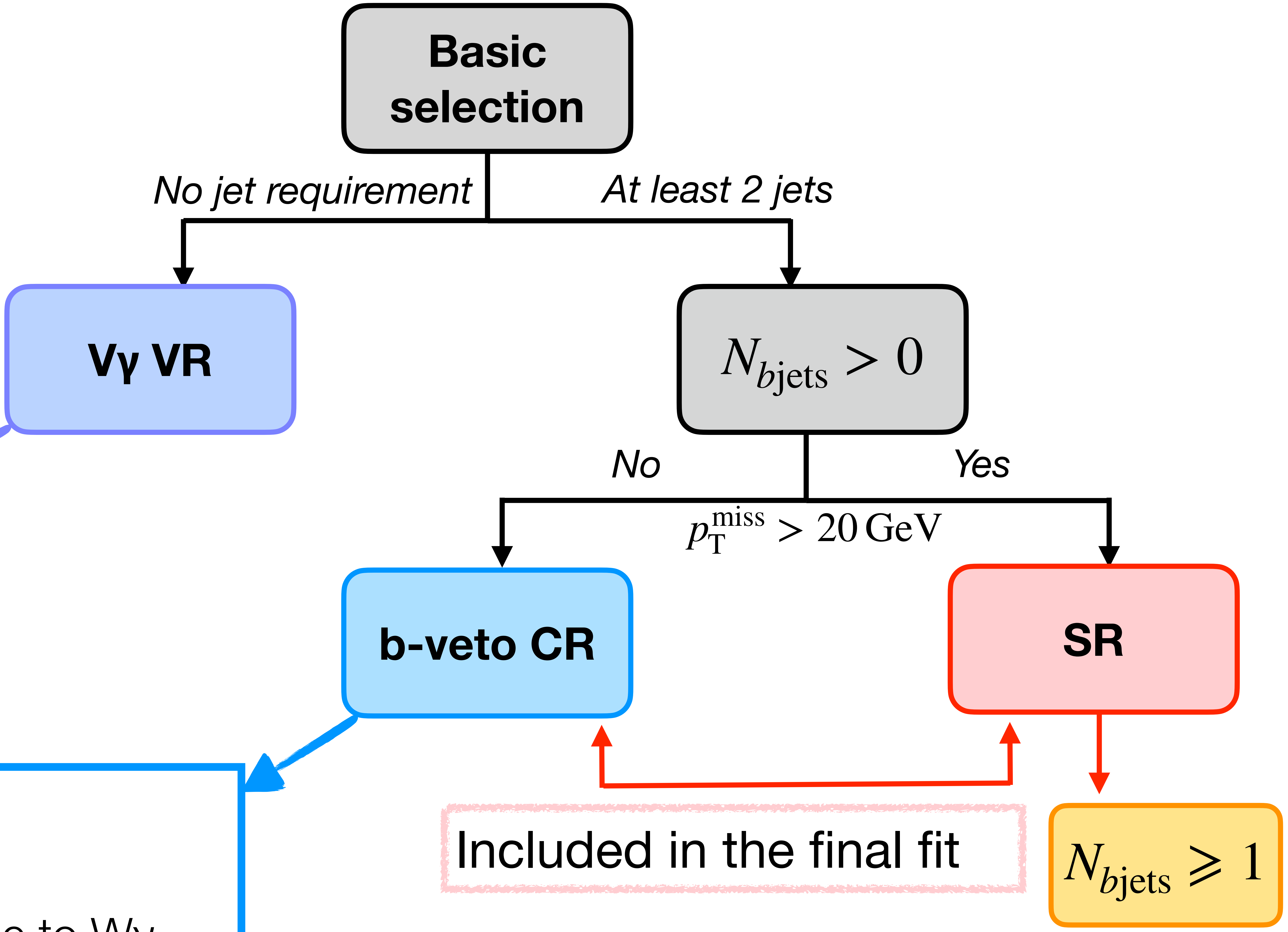
$$\chi^2_{\mathrm{t,lep}} = \left(\frac{m_{\ell\nu\mathrm{b}} - m_{\mathrm{t}}}{\sigma_{\mathrm{t,lep}}}\right)^2 \qquad \chi^2_{\mathrm{t,had}} = \left(\frac{m_{\mathrm{bjj}} - m_{\mathrm{t}}}{\sigma_{\mathrm{t,had}}}\right)^2 \qquad \chi^2_{\mathrm{t}} = \left(\frac{m_{\ell\nu\mathrm{b}} - m_{\mathrm{t}}}{\sigma_{\mathrm{t,lep}}}\right)^2 + \left(\frac{m_{\mathrm{bjj}} - m_{\mathrm{t}}}{\sigma_{\mathrm{t,had}}}\right)^2$$





Event categorisation

Baseline selection	A. Exactly one lepton with $p_T^{\mu/e}$> 30 (35) GeV, $\lvert\eta\rvert < 2.4$ (2.5) B. Pass single e(μ) HLT paths C. At least one photon with p_T^{γ}> 20 GeV in the barrel or endcap



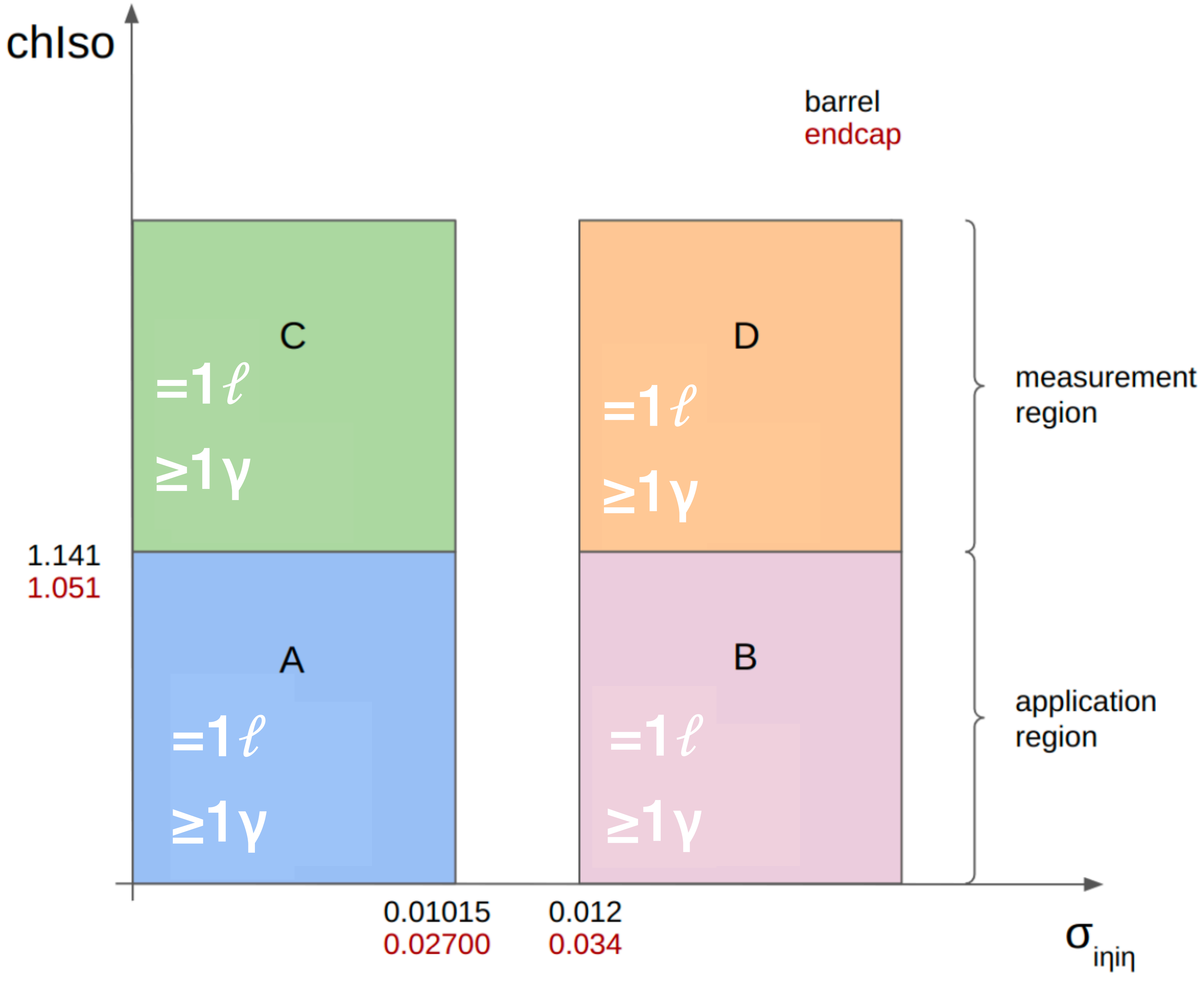
Vγ enriched region
- Nonprompt γ contribution is comparable
- Very large statistics is helpful to validate corresponding background normalisation

Wγ enriched region
- Nonprompt ℓ contribution is visible
- Nonprompt γ contribution is comparable to Wγ
- Constrain the corresponding background normalisation by correlating the same systematic uncertainty in the SR

Events are further separated to **e channel** and **μ channel**

Background estimation — Nonprompt γ

- Under the selection of exactly one lepton and at least one photon $N_{\ell}=1$, $N_{\gamma} \geq 1$
- The ABCD regions are built by varying the charge isolation or $\sigma_{i\eta i\eta}$
- Assuming the nonprompt photon performance in C and D is similar with in A and B, the nonprompt photon fake rate can be estimated and corrected by the following equations

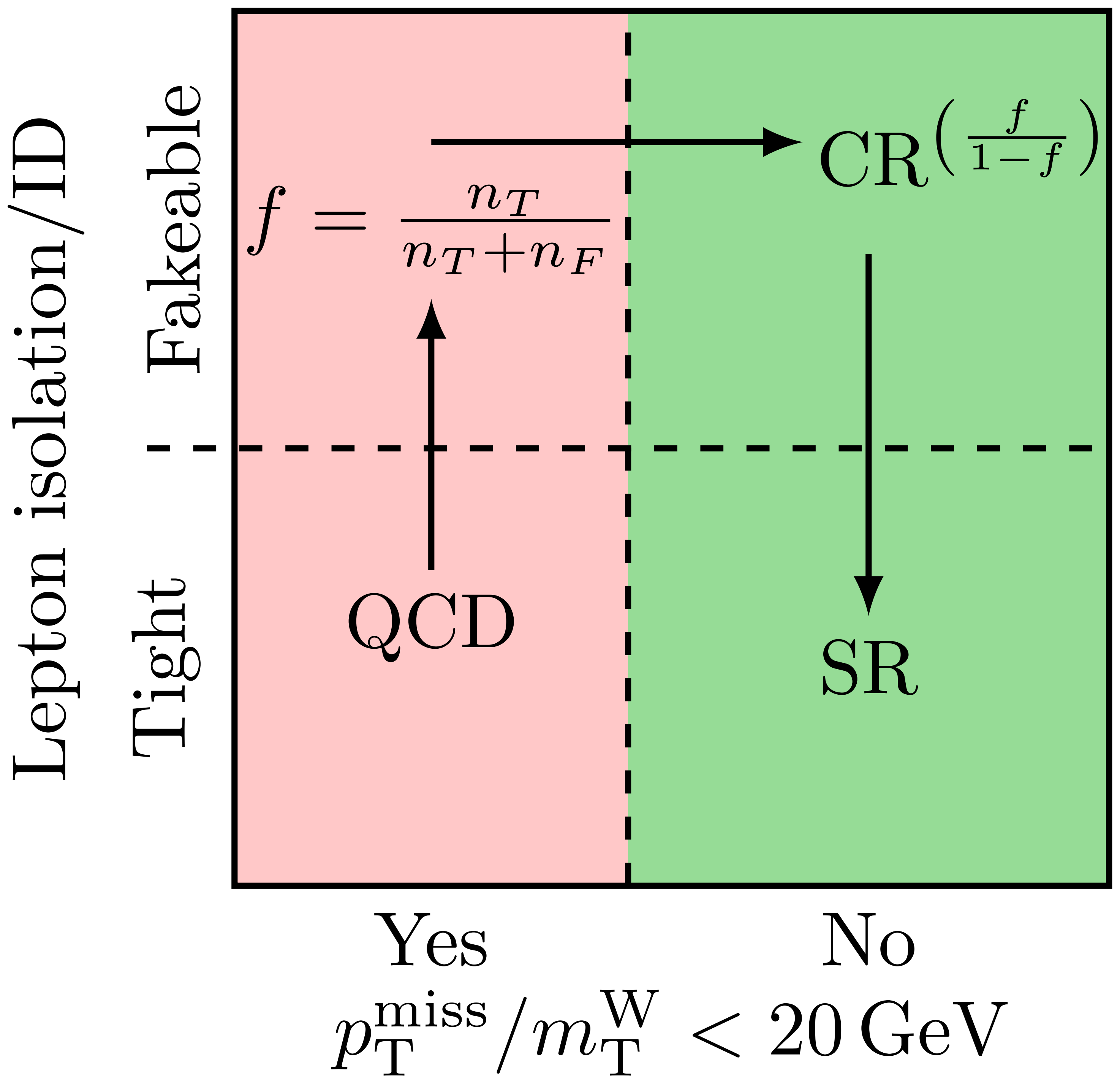


$$\text{fake rate}^{ij} = \frac{\text{Data}_C^{ij} - (\text{prompt} + \text{ele mis.})\,\text{MC}_C^{ij}}{\text{Data}_D^{ij} - (\text{prompt} + \text{ele mis.})\,\text{MC}_D^{ij}}$$

$$k_{\text{MC}}^{ij} = \frac{\text{nonprompt MC}_A^{ij}}{\text{nonprompt MC}_B^{ij}} \div \frac{\text{nonprompt MC}_C^{ij}}{\text{nonprompt MC}_D^{ij}}$$

$$\text{nonprompt contribution} = \sum_{ij} (\text{data}_B^{ij} \times \text{fake rate}^{ij} \times k_{\text{MC}}^{ij}) - \sum_{ij} ((\text{prompt} + \text{ele mis.})\,\text{MC}_B^{ij} \times \text{fake rate}^{ij} \times k_{\text{MC}}^{ij})$$

Background estimation — Nonprompt ℓ

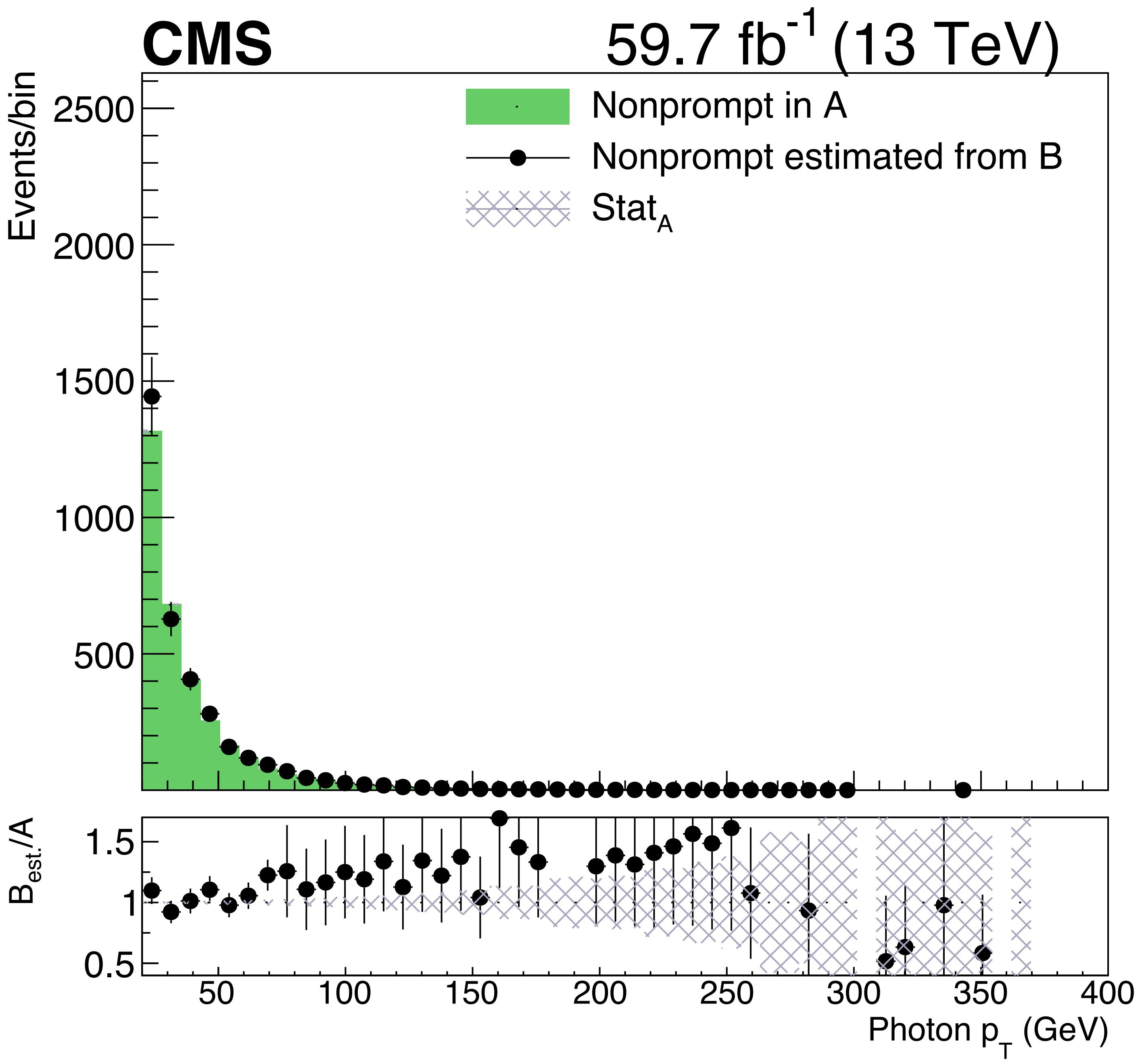


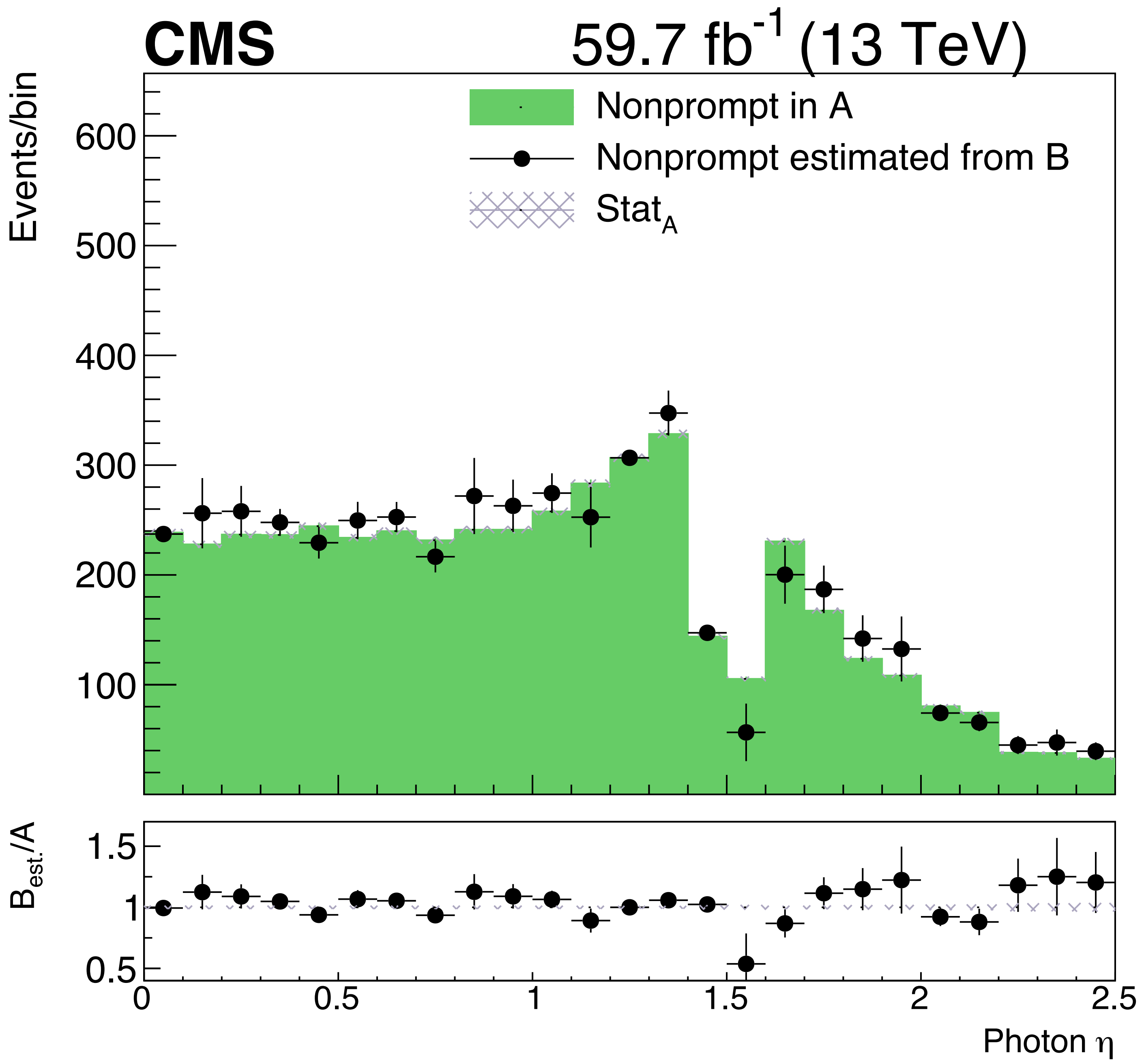
1. Build QCD jet-enriched region with requirements of
   - Exactly one lepton
   - $p_{\mathrm{T}}^{\mathrm{miss}} < 20$ GeV and $m_{\mathrm{T}}^{\mathrm{W}} < 20$ GeV
   - At least one jet with $p_T > 30$ GeV and $\Delta R(\ell, j) > 0.4$
2. Measure the tight-to-loose rate $f = \dfrac{n_T}{n_T + n_F}$
   - n_T the number of leptons passing tight ℓ ID in QCD jet-enriched region
   - n_F the number of leptons passing fakeable ℓ ID in QCD jet-enriched region
3. Build nonprompt ℓ data-driven CR with fakeable ℓ ID and apply to SR with weights $f/(1-f)$

$$n^{\mathrm{SR}}_{\mathrm{nonprompt}\,\ell} = \sum_{\mathrm{ij}} (\mathrm{data}^{\mathrm{ij}}_{\mathrm{CR}} \times \frac{f^{\mathrm{ij}}}{1-f^{\mathrm{ij}}}) - \sum_{\mathrm{ij}} (\mathrm{prompt}\,\ell\ \mathrm{MC}^{\mathrm{ij}}_{\mathrm{CR}} \times \frac{f^{\mathrm{ij}}}{1-f^{\mathrm{ij}}})$$

Background estimation — Closure for nonprompt

$$\text{nonprompt contribution}^{t\bar{t}}_{A} = \sum_{ij} (t\bar{t}^{ij}_{B_{\text{nonprompt}}} \times \text{fake rate}^{ij}_{t\bar{t}} \times k^{ij}_{t\bar{t}})$$

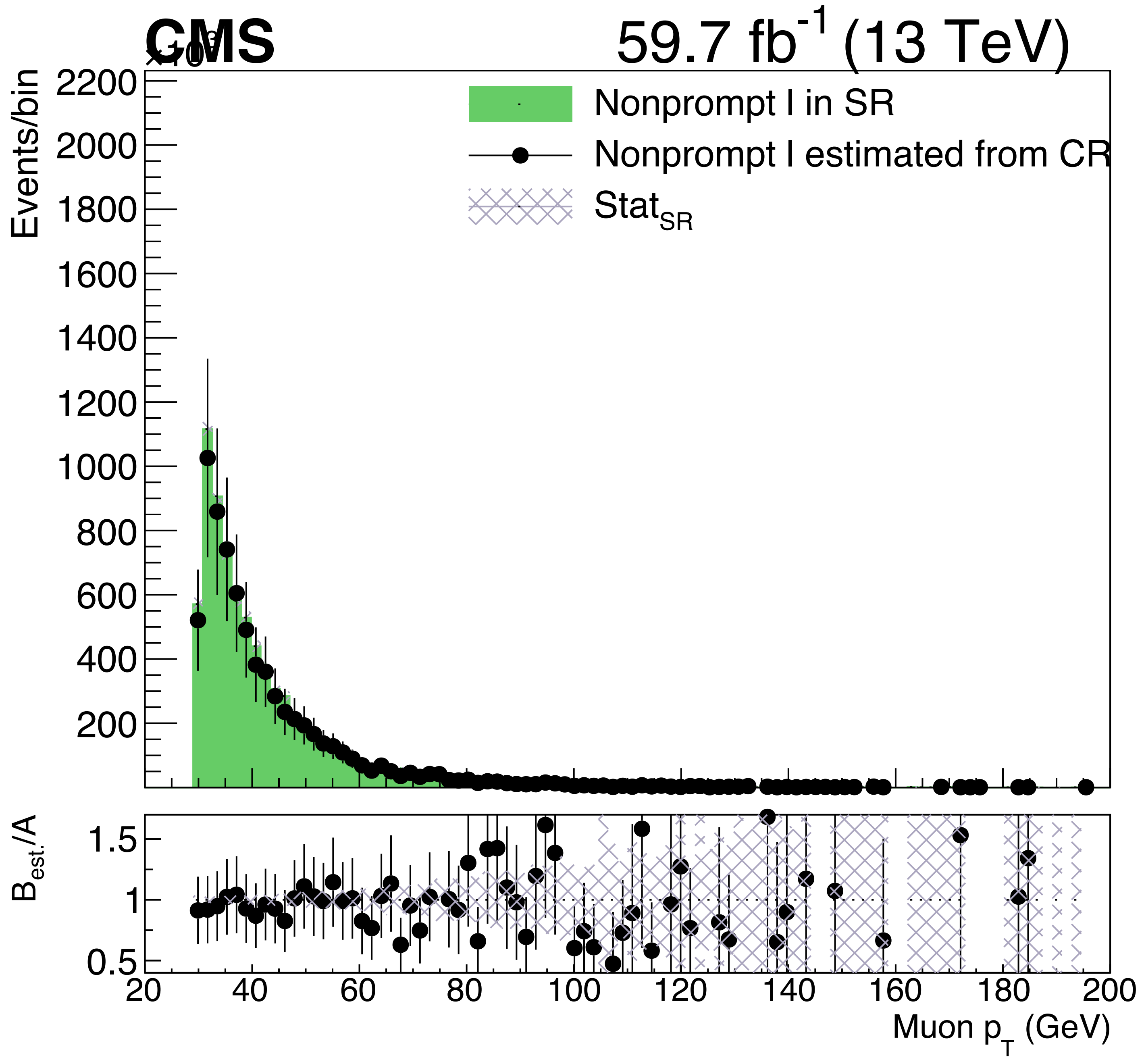




Assigned 10% flat uncertainty and 30% for events based on photon pT < 80 GeV or not

Cases in 2016 and 2017 are the similar

$$n^{SR}_{\text{nonprompt}\,\ell} = \sum_{ij} \left(QCD^{ij}_{CR_{\text{nonprompt}}} \times \frac{f^{ij}_{QCD}}{1-f^{ij}_{QCD}}\right)$$



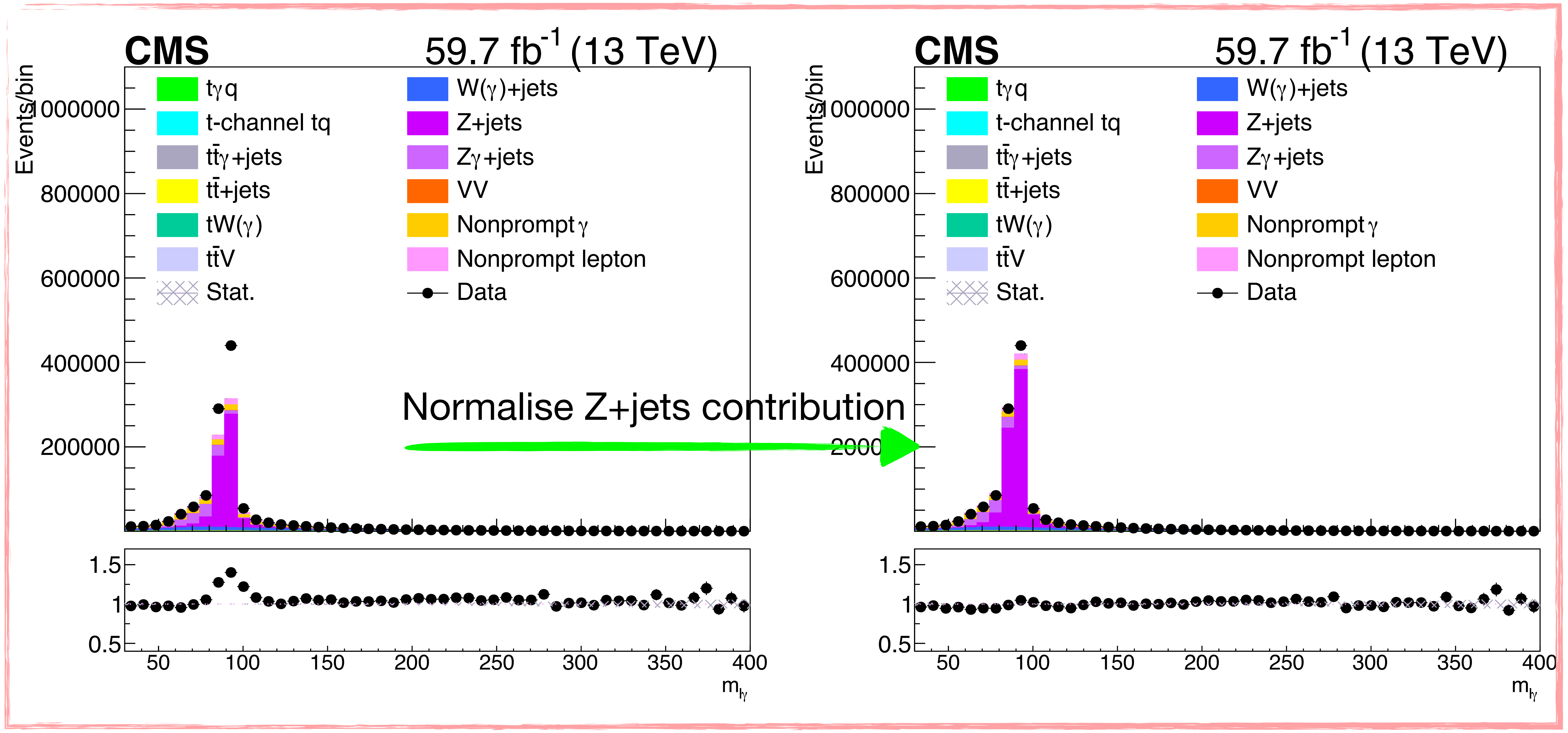
Assigned 30% flat uncertainty

Cases in 2016 and 2017 are the similar

Background estimation — ele mis. γ

From checking $m_{\ell\gamma}$ distribution in the Vγ control region in the electron channel:

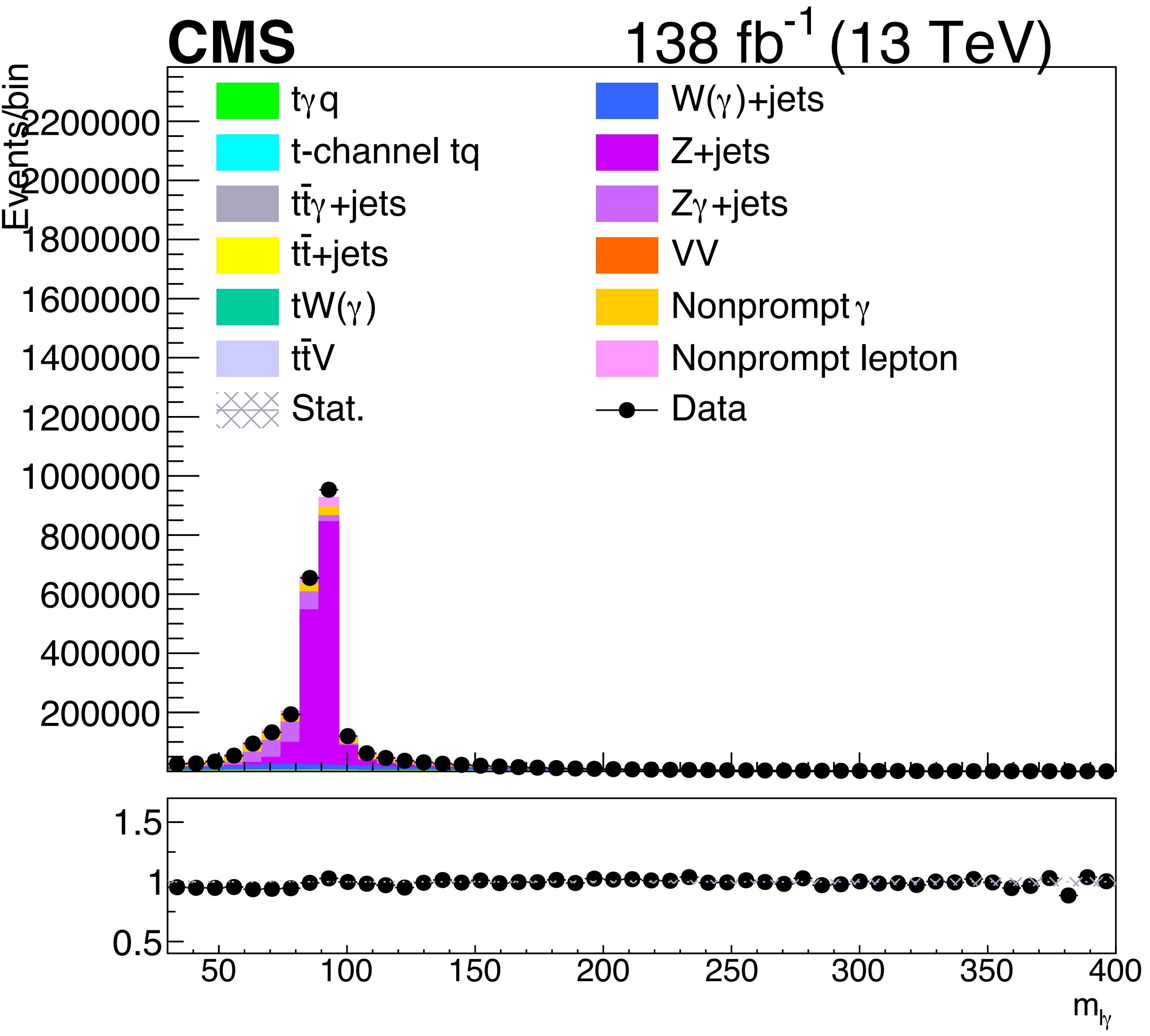
- The ele mis. γ contribution is from Z+jet -> can be cured by the ***normalisation factor***
- The normalisation factor derived in this Vγ region for different years are a bit different

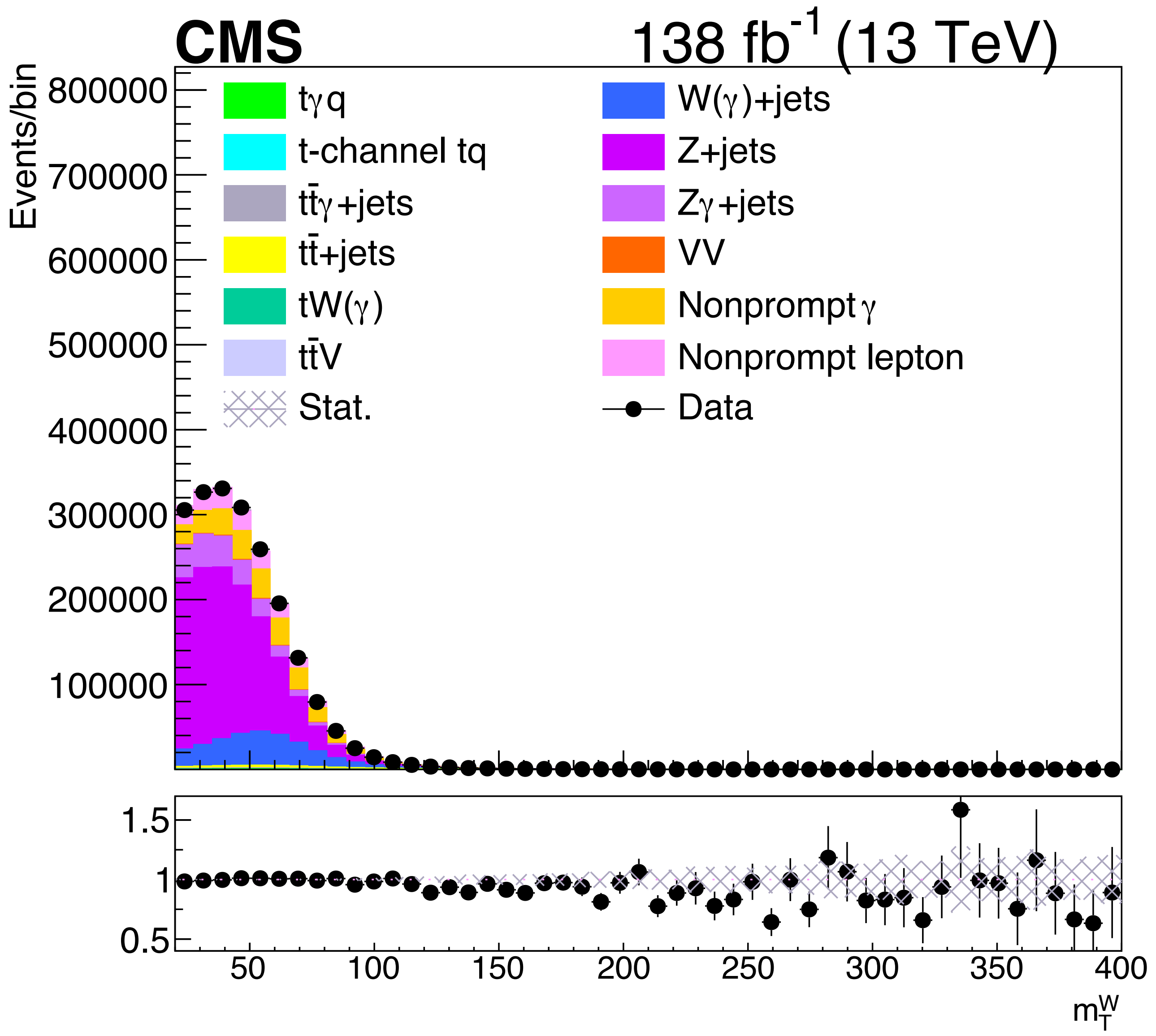


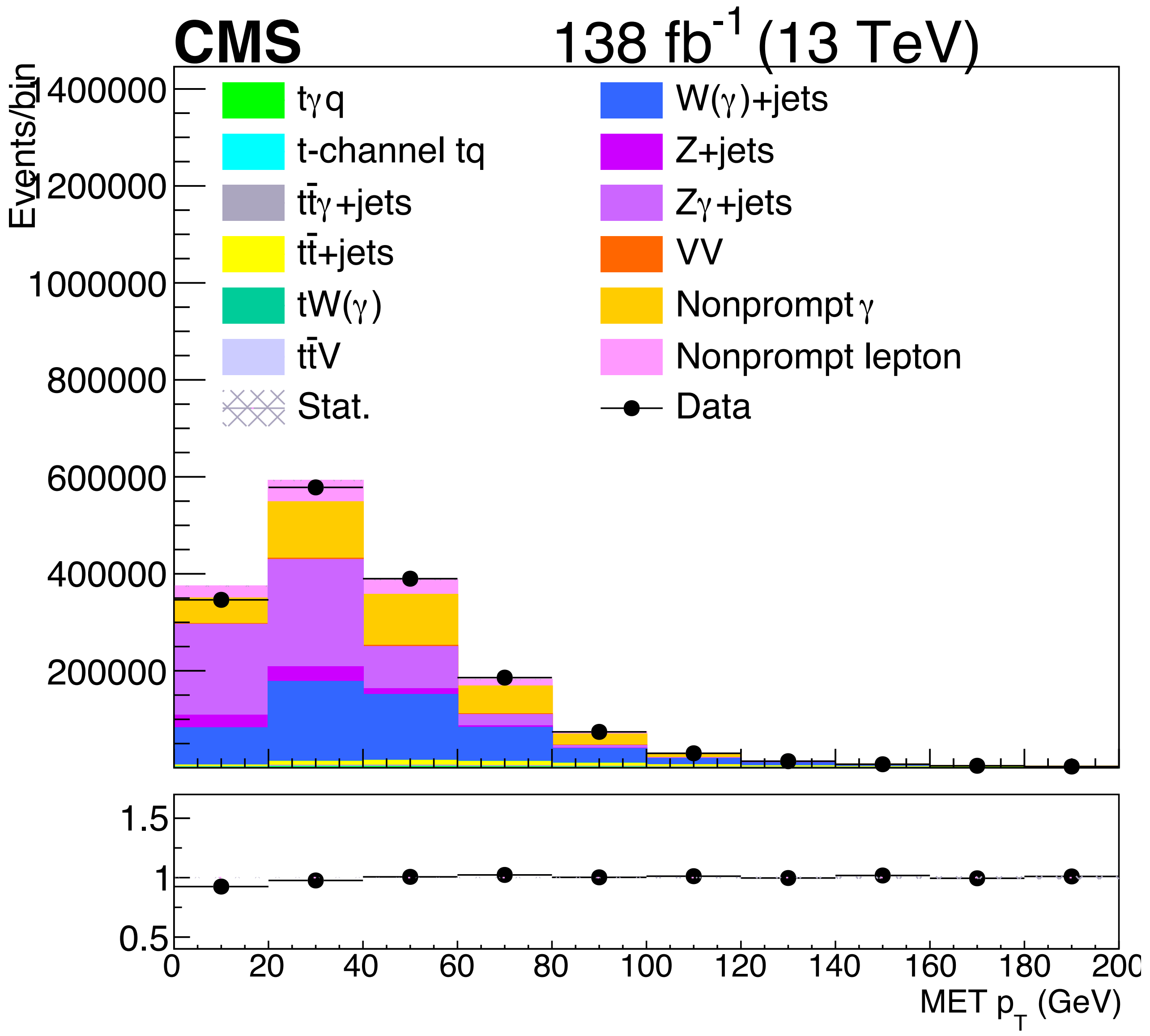
The estimation in the final fit:

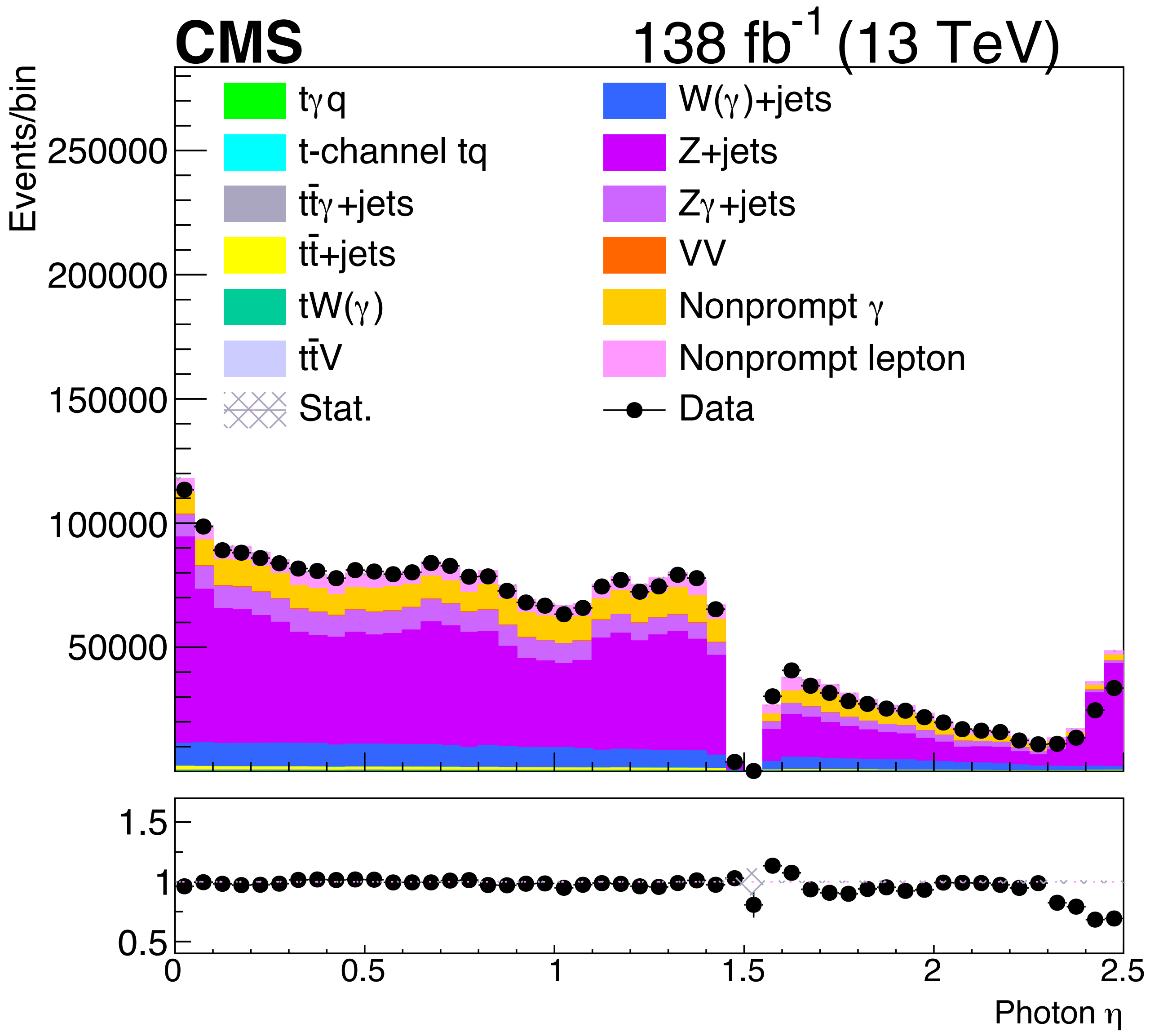
- Float the Z+jets normalisation in the fit as rateParam
- This rateParam is uncorrelated between years

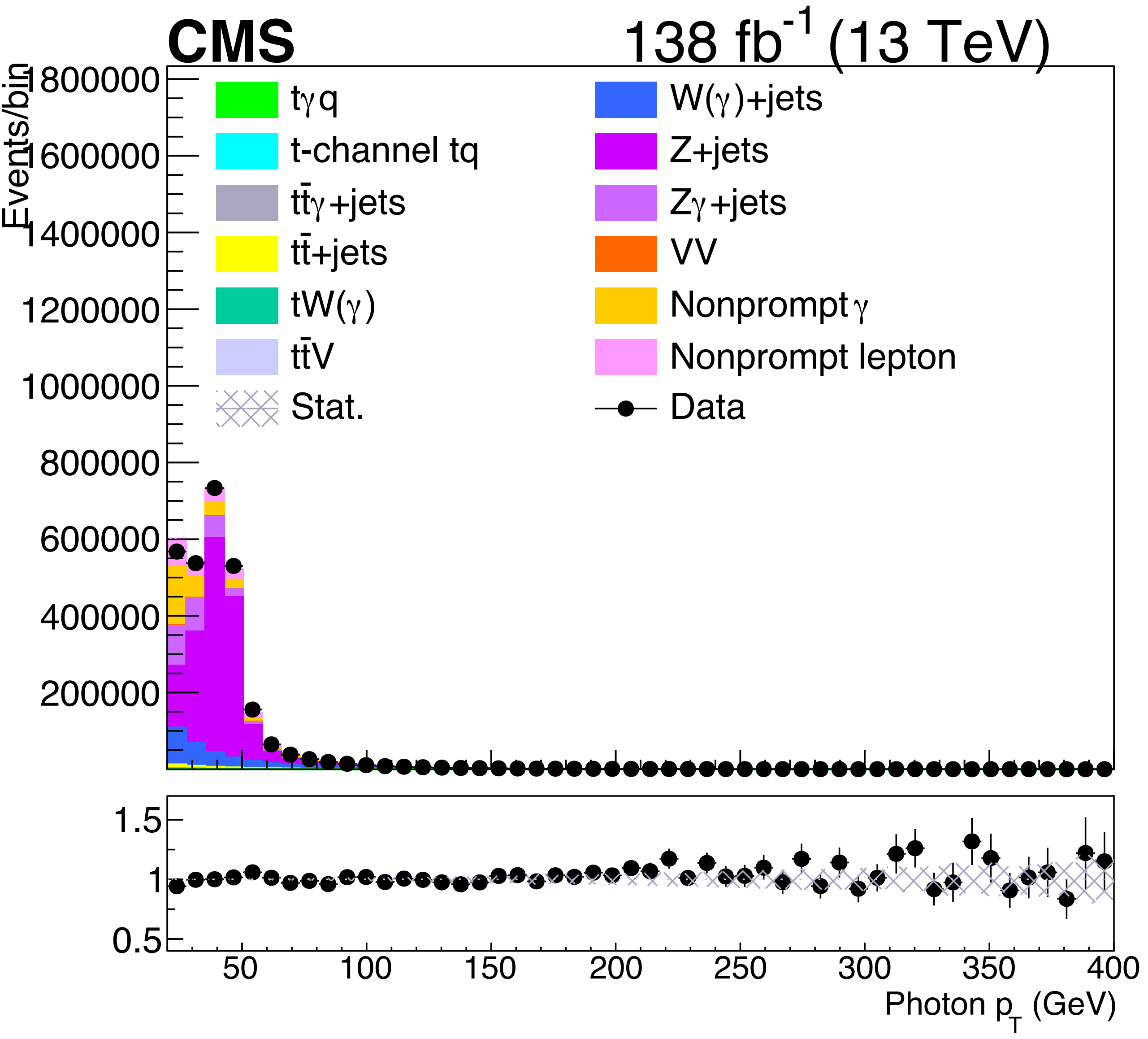
Control plots — Vγ VR (e)

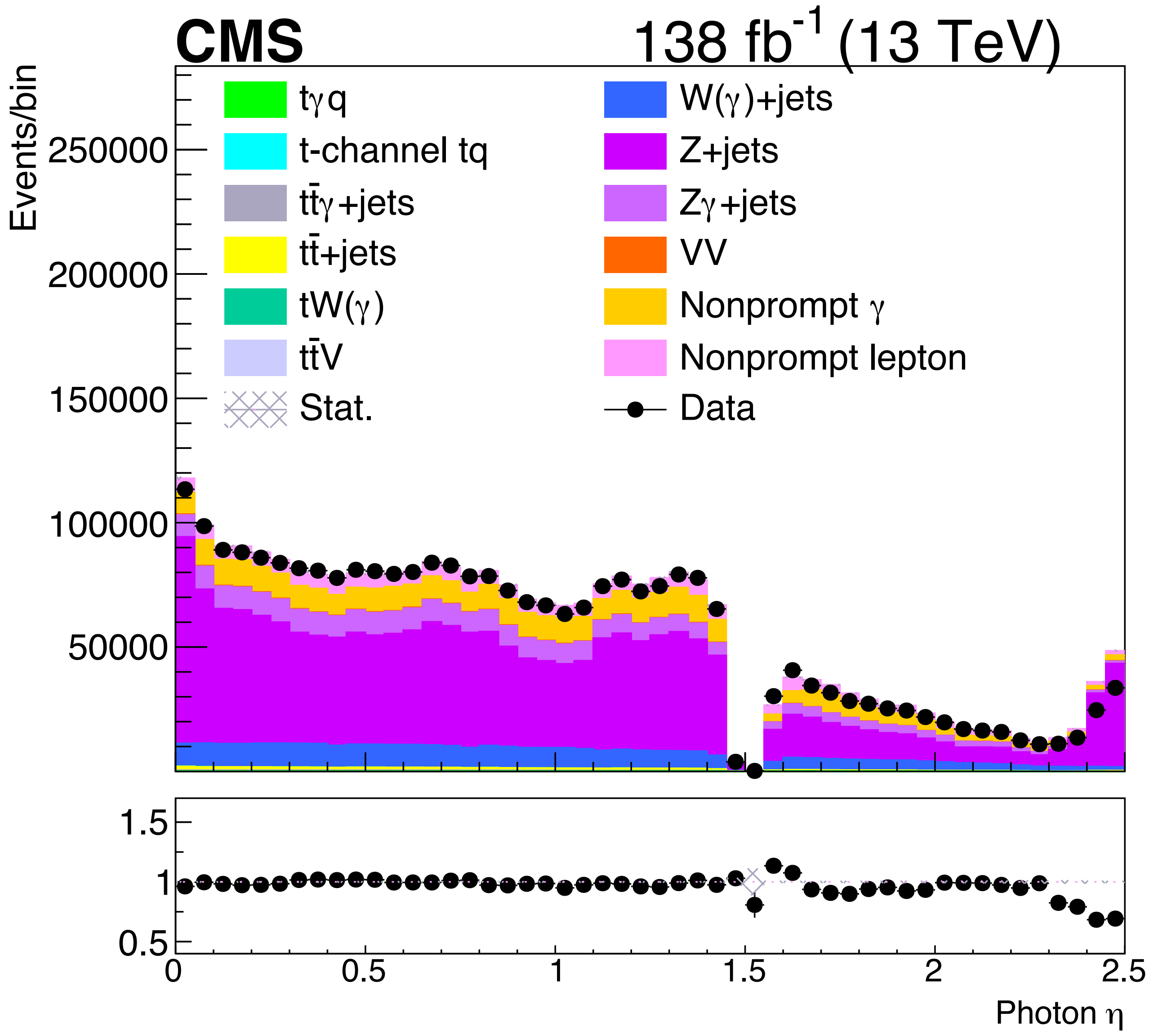








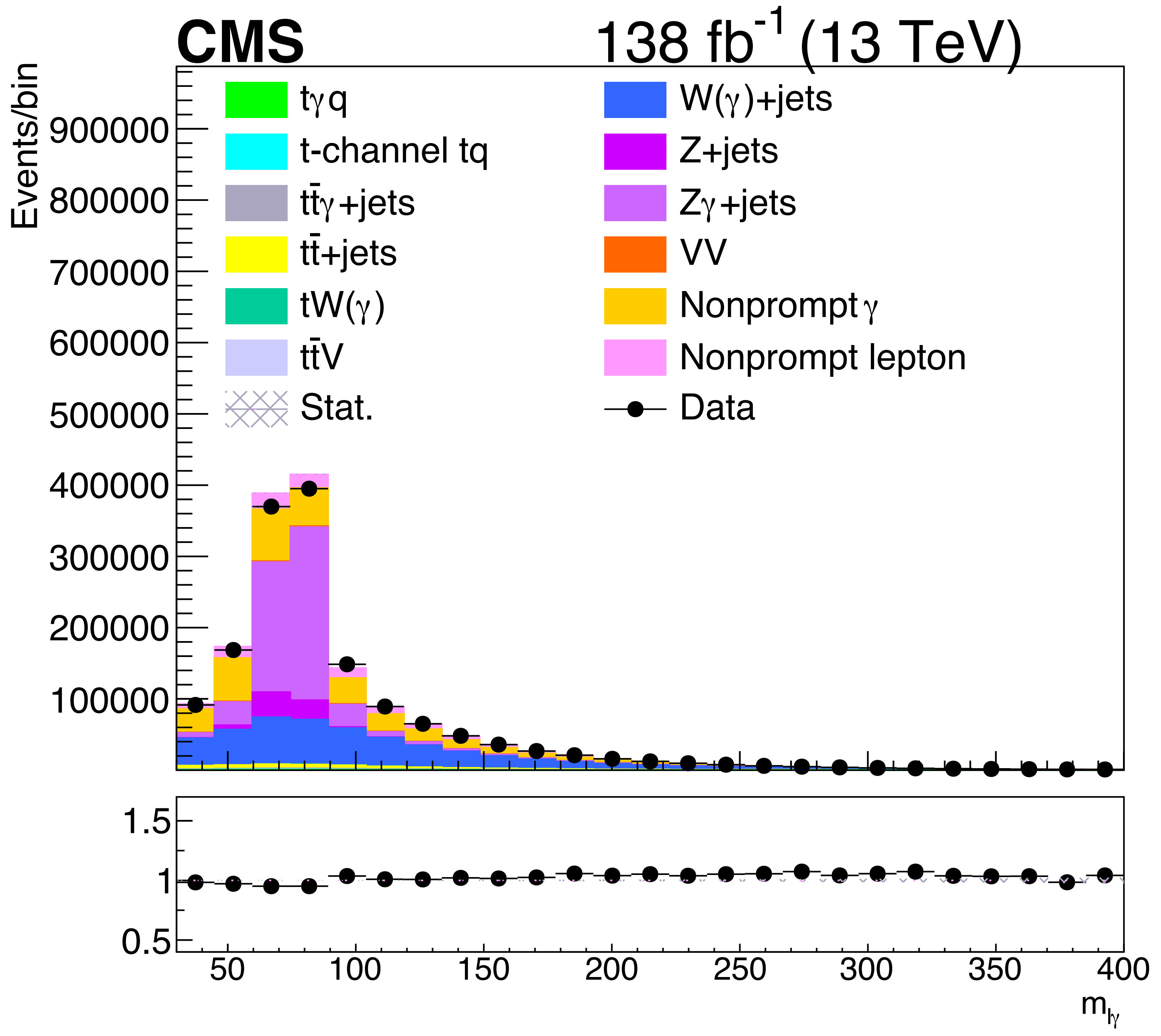


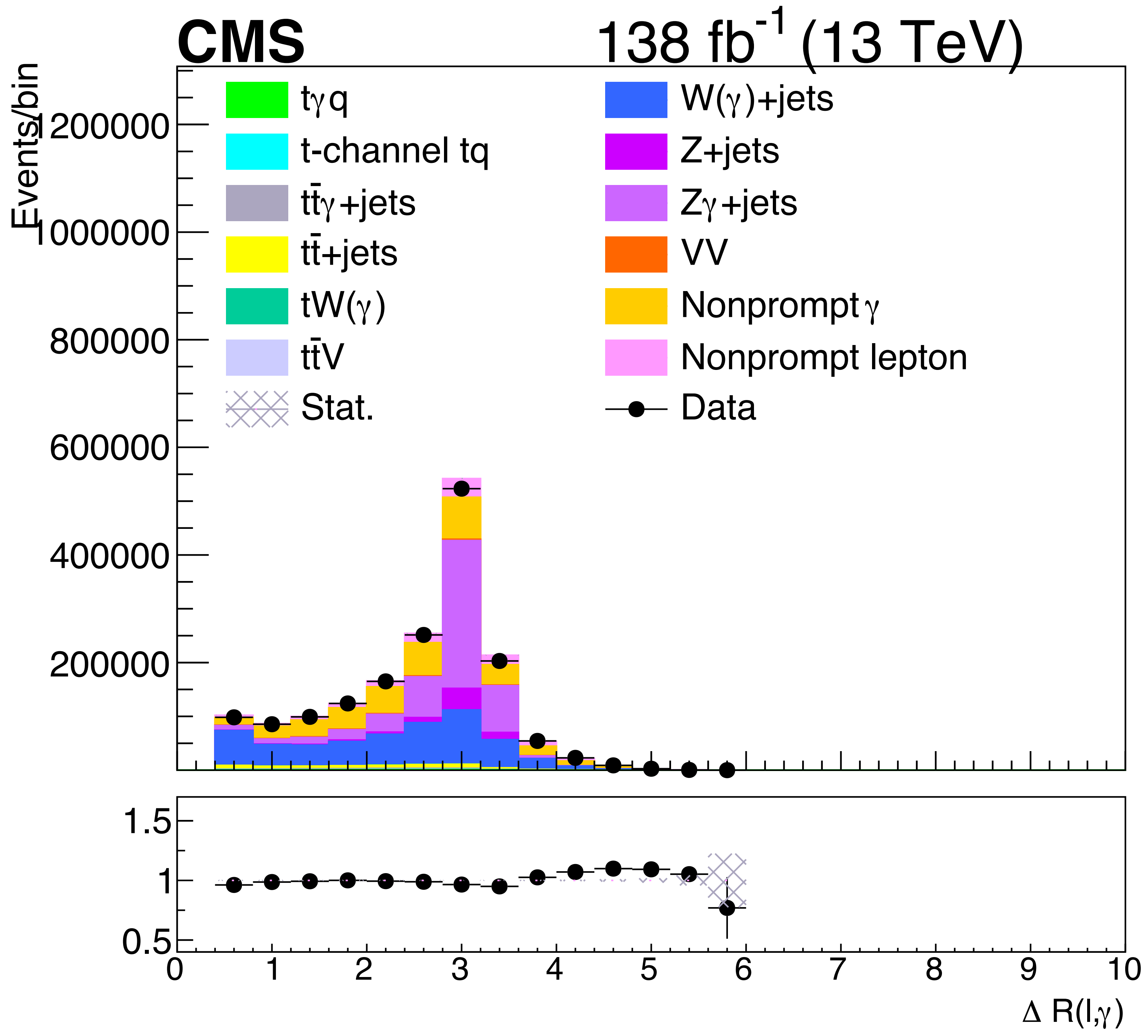


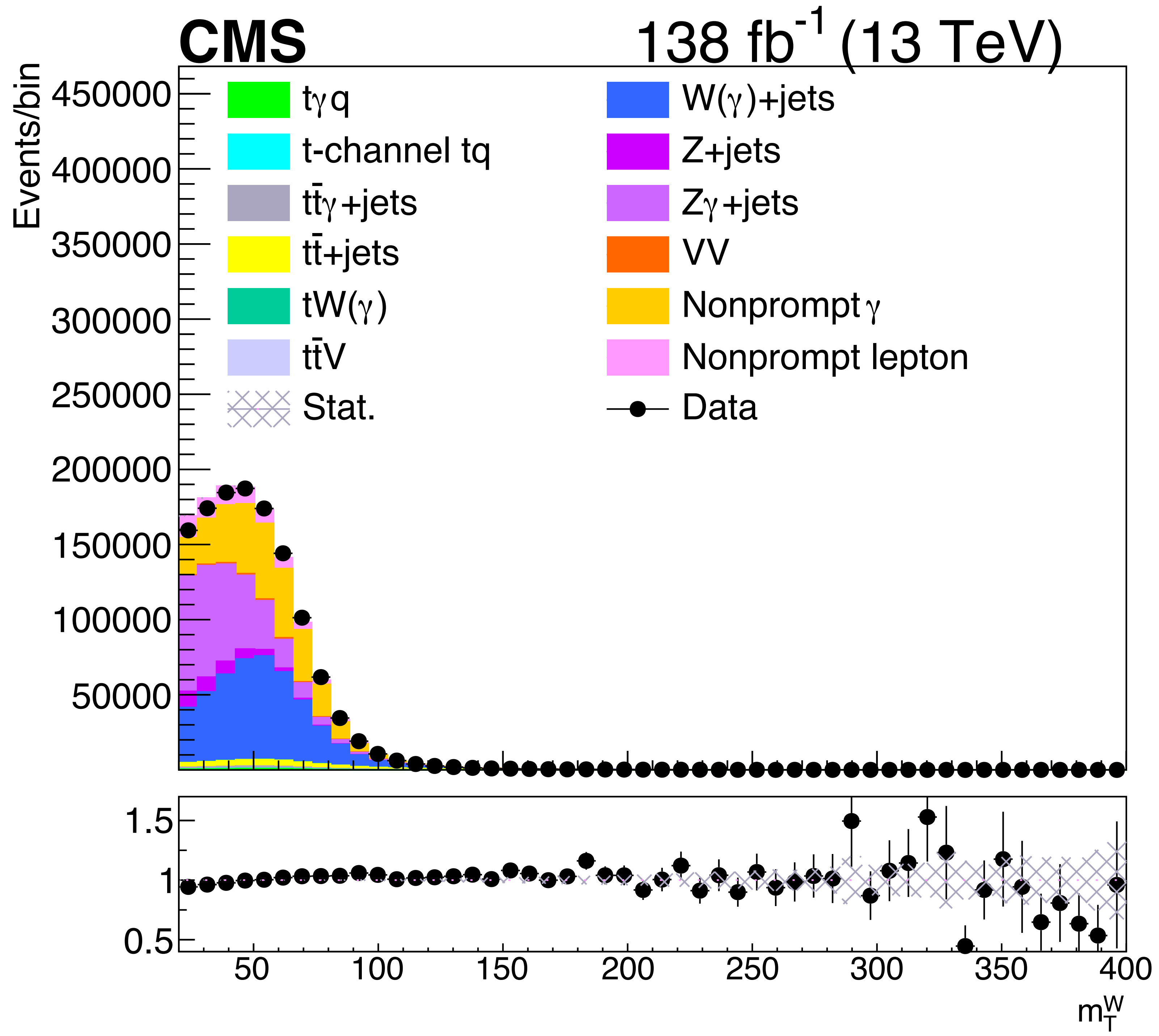
- The Z+jets contribution is normalised by a factor estimated in $m_{\ell\gamma}$ distribution
- The factors are bit different for different years
  - 1.6, 1.7, 1.4, and 1.4 are used from 2016pre to 2018

The method works well for estimating the ele mis. γ contribution

Control plots — Vγ VR (μ)

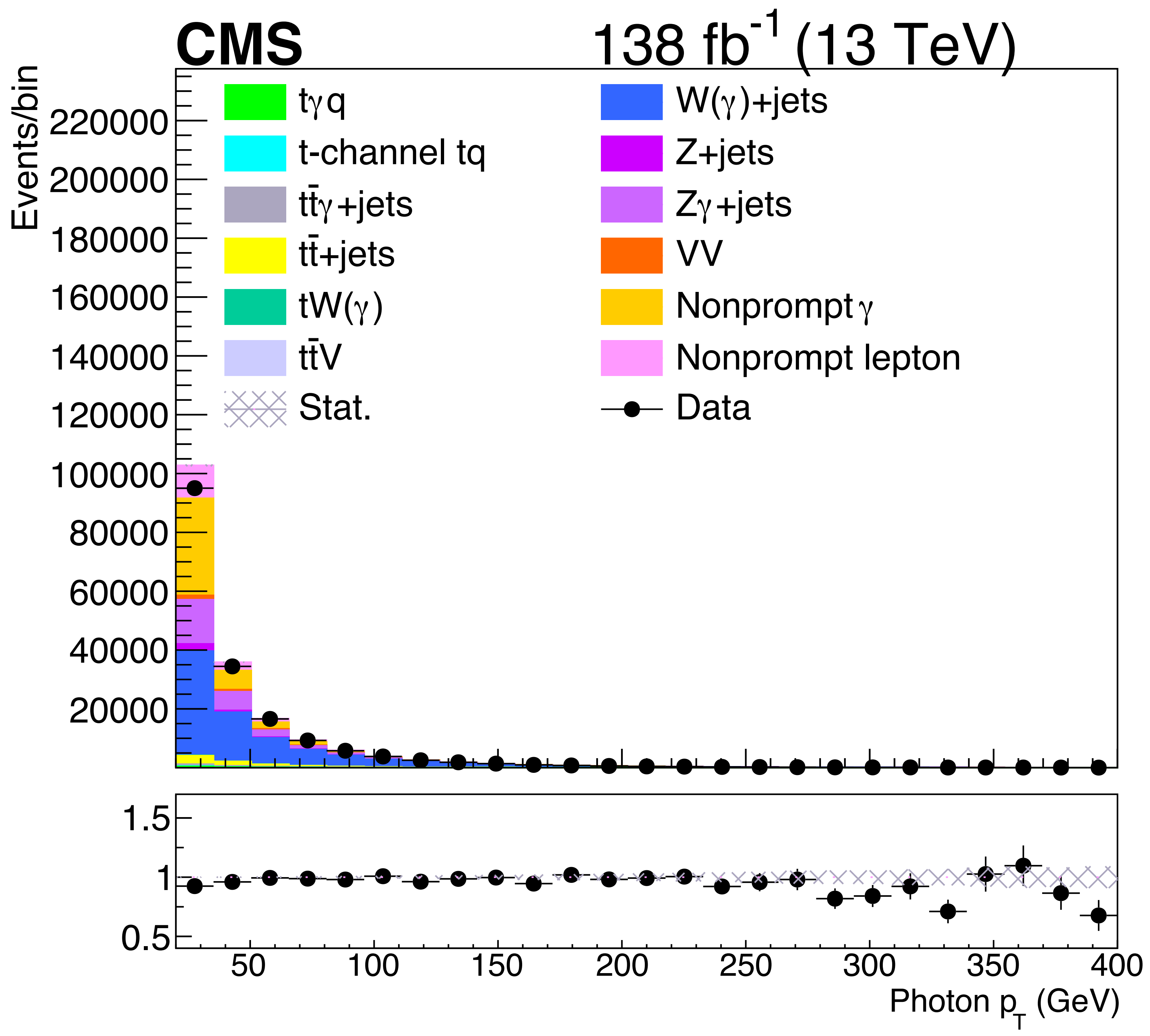


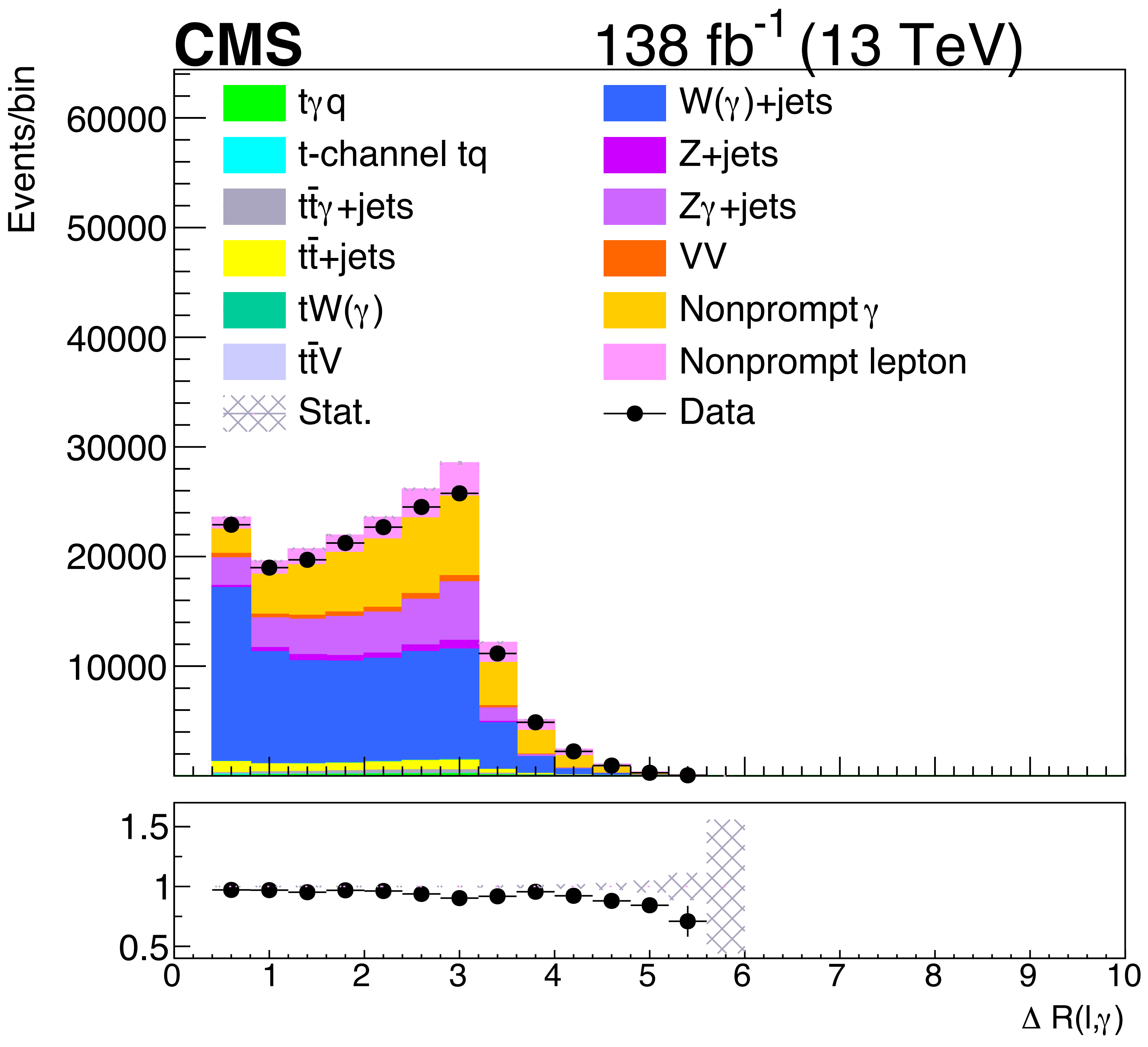


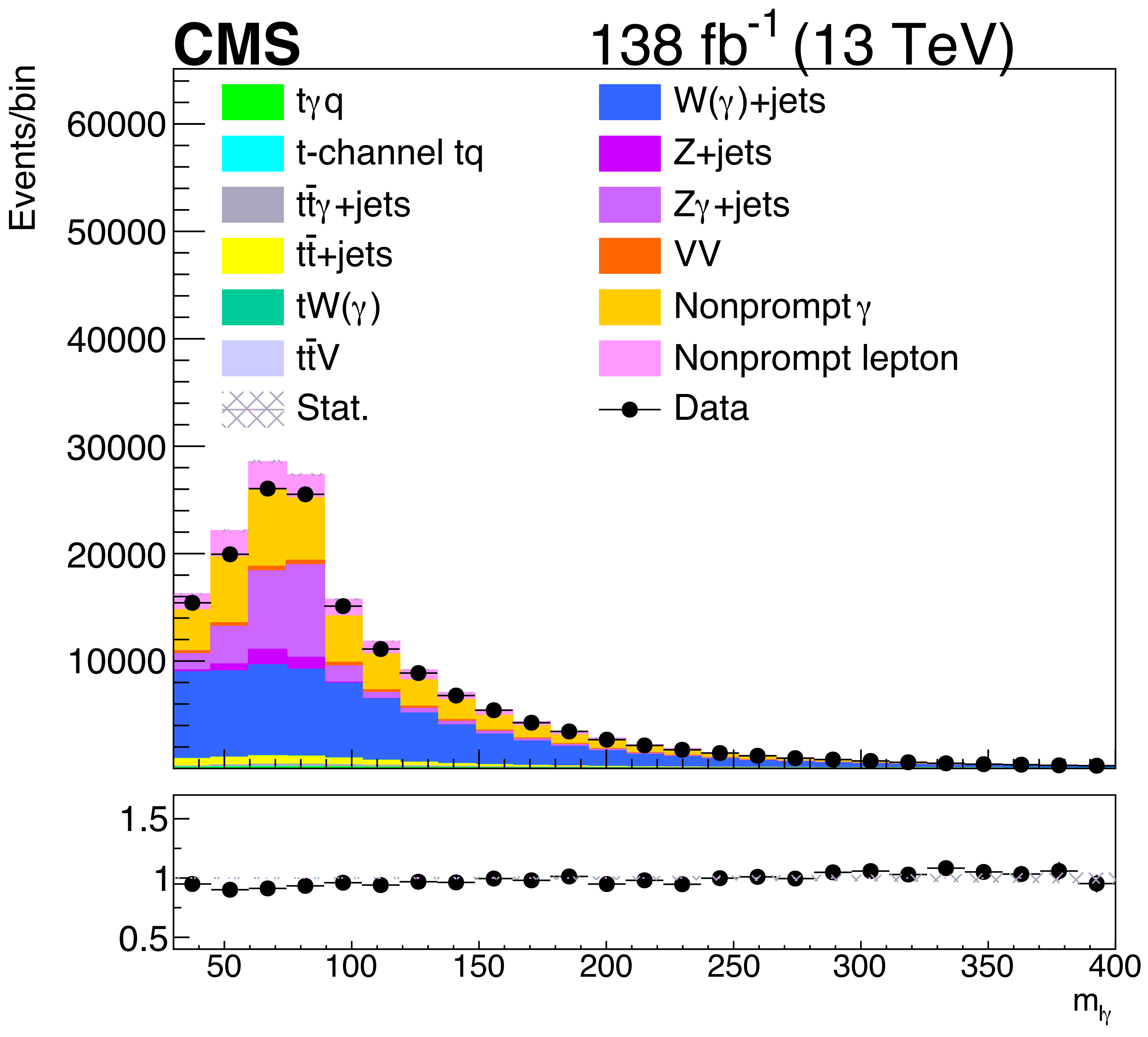


No need to consider the ele mis. γ contributions, agreement is reasonable with current background estimation (simulation and nonprompt from data)

Control plots — b-veto CR (μ)



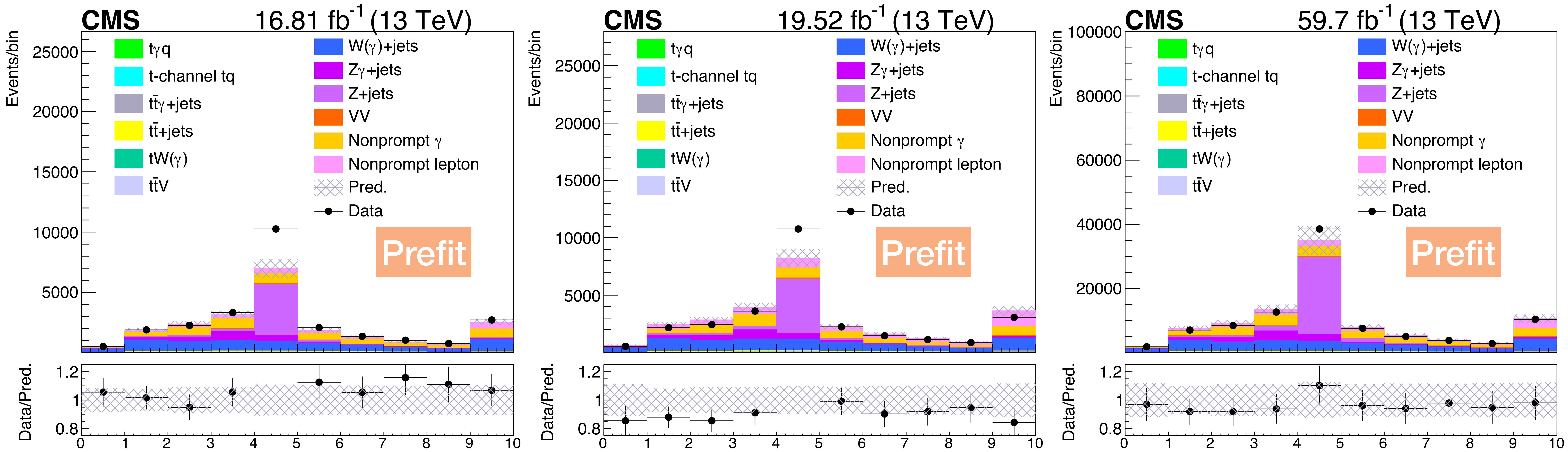


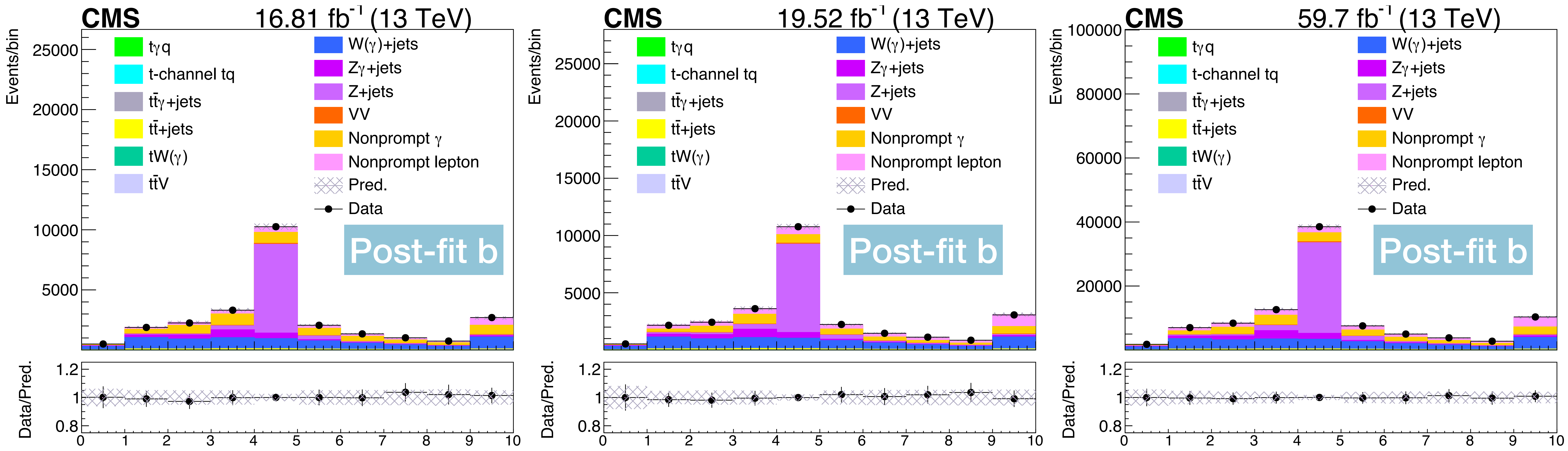


No need to consider the ele mis. γ contributions, agreement is reasonable with current background estimation (simulation and nonprompt from data)

Control plots — b-veto CR (e)

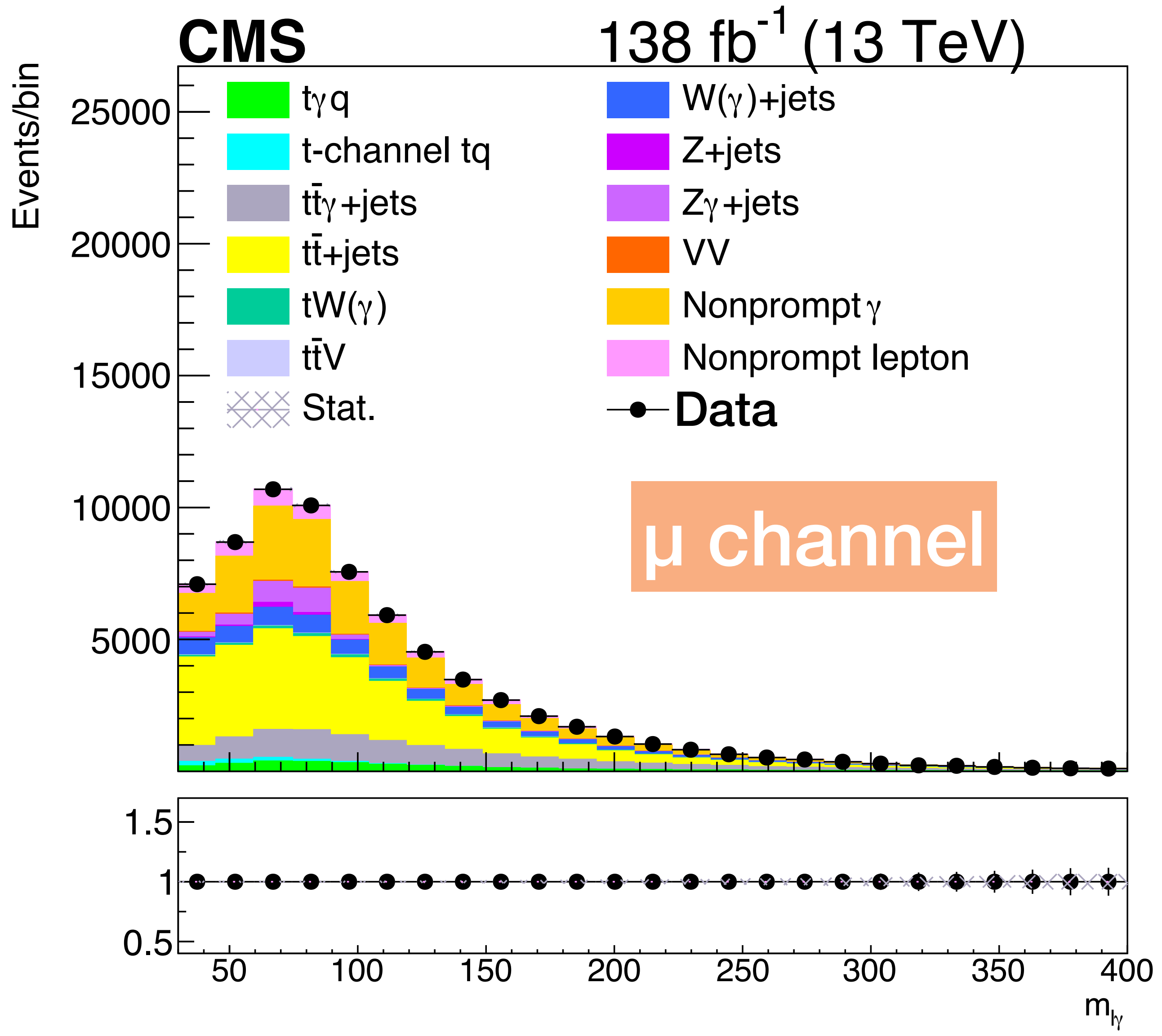
- $m_{\ell\gamma}$ distribution after a CR-only fit

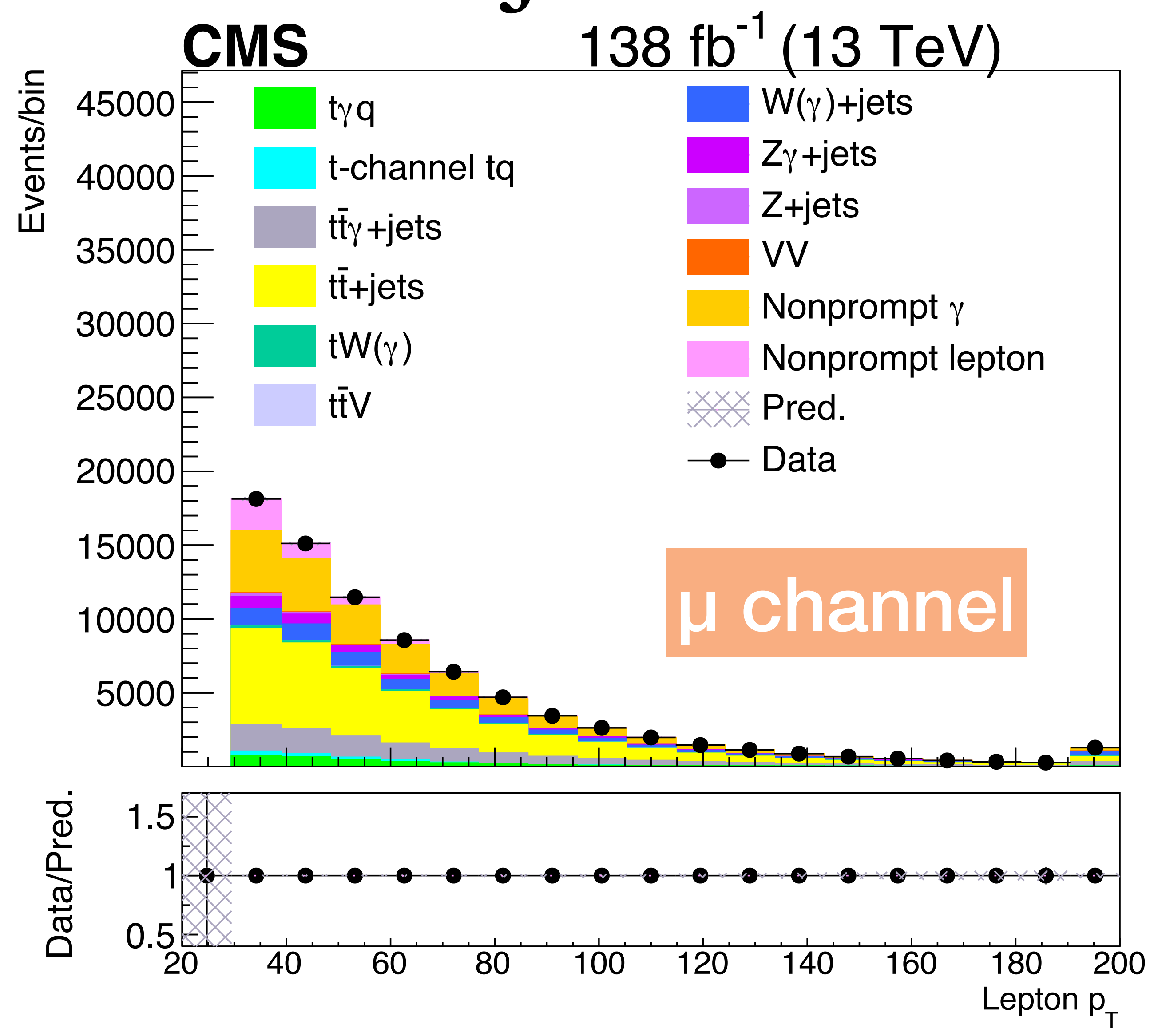


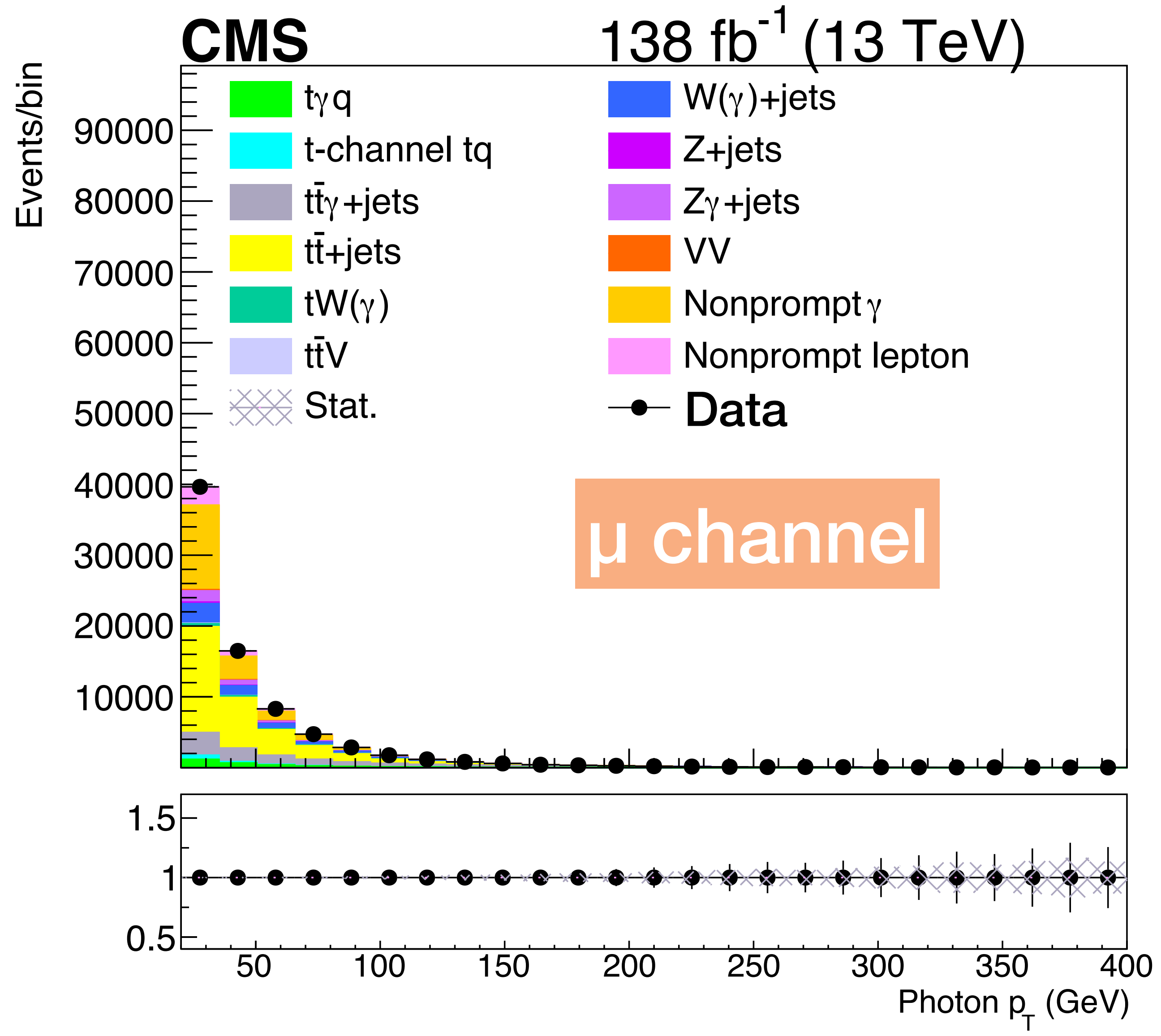


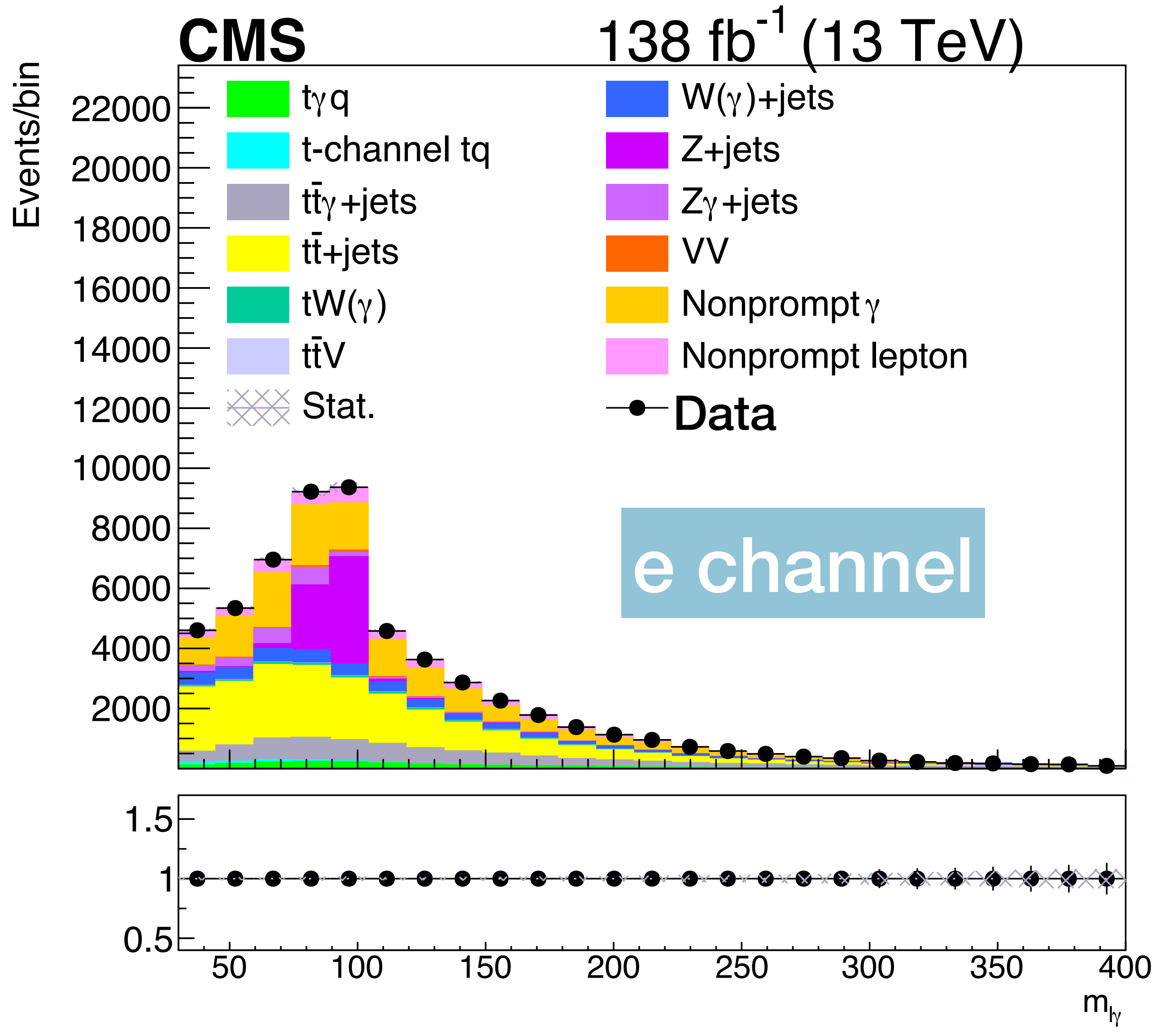
fit of the data with signal strength set to zero

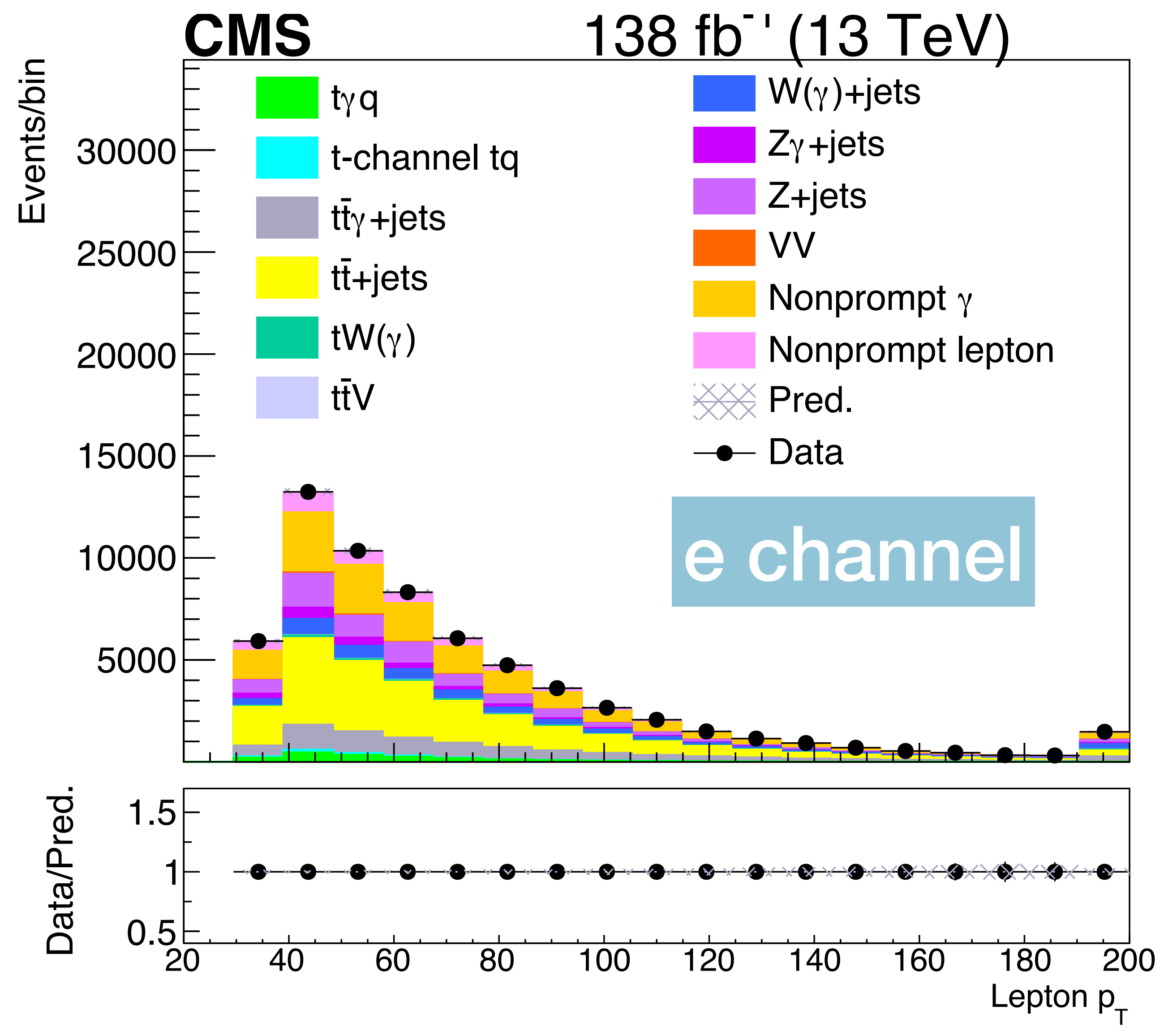
SR plots — $N_{\mathrm{j}} \geq 2\ \ N_{\mathrm{b-jets}} \geq 1$

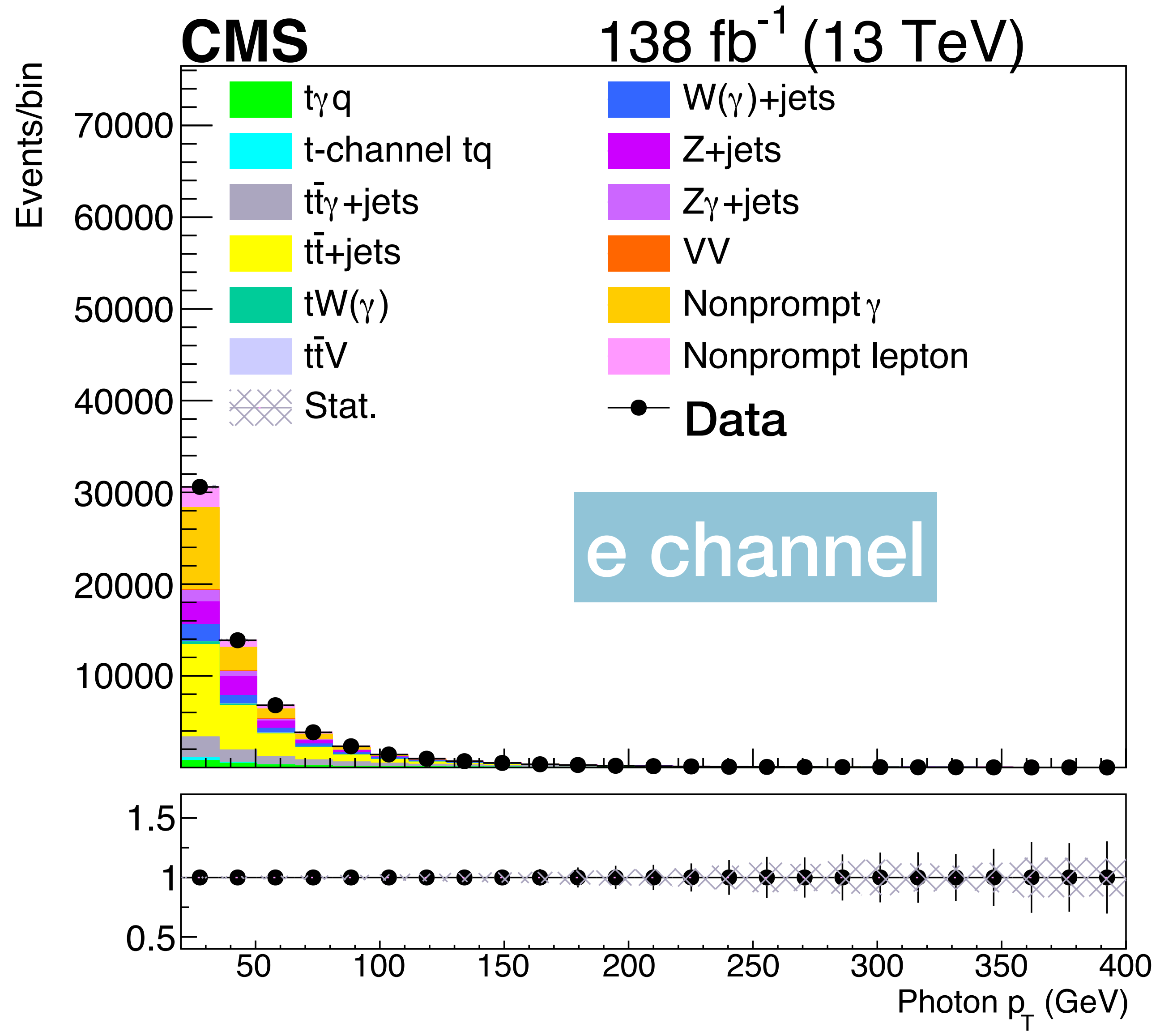




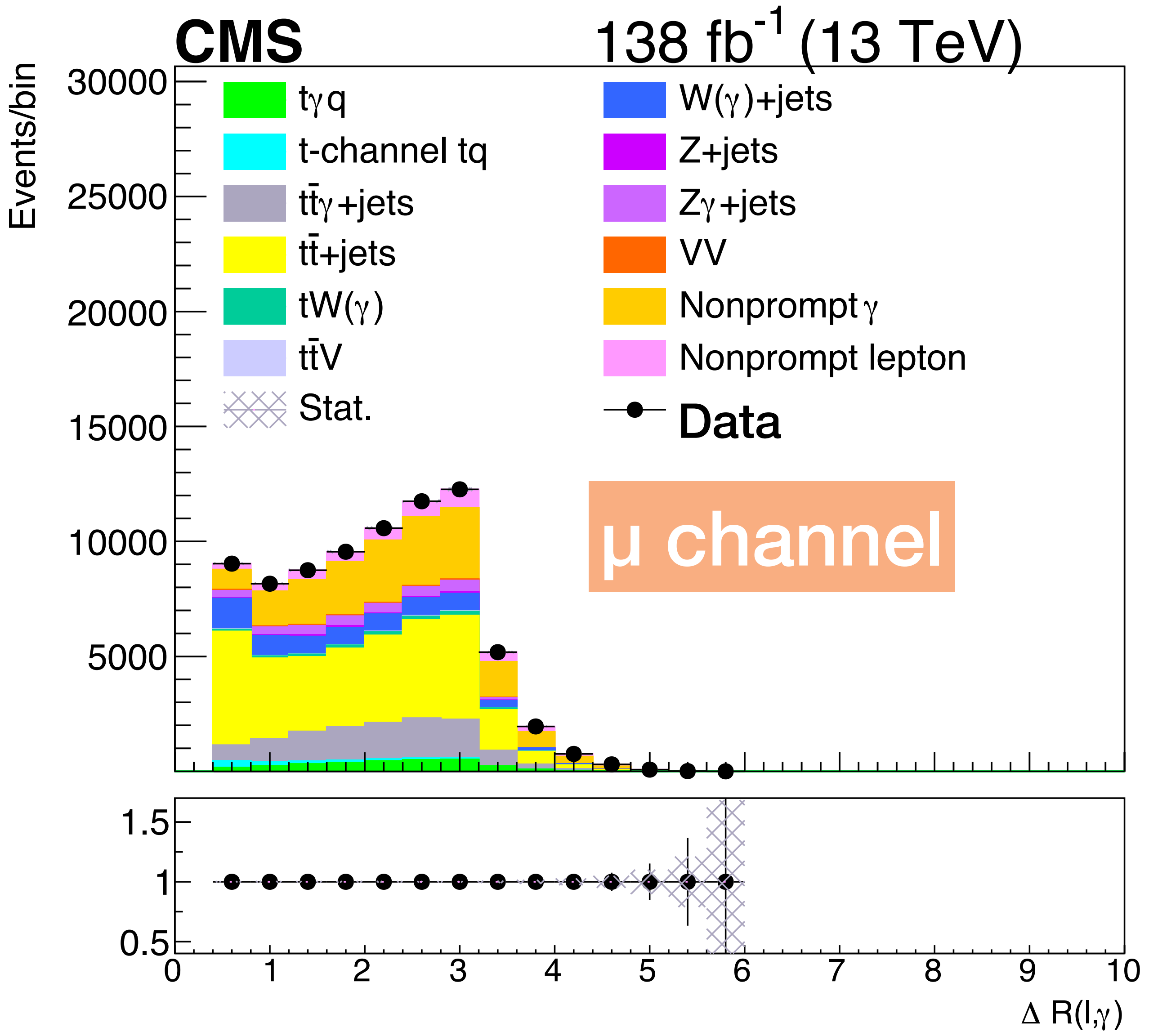


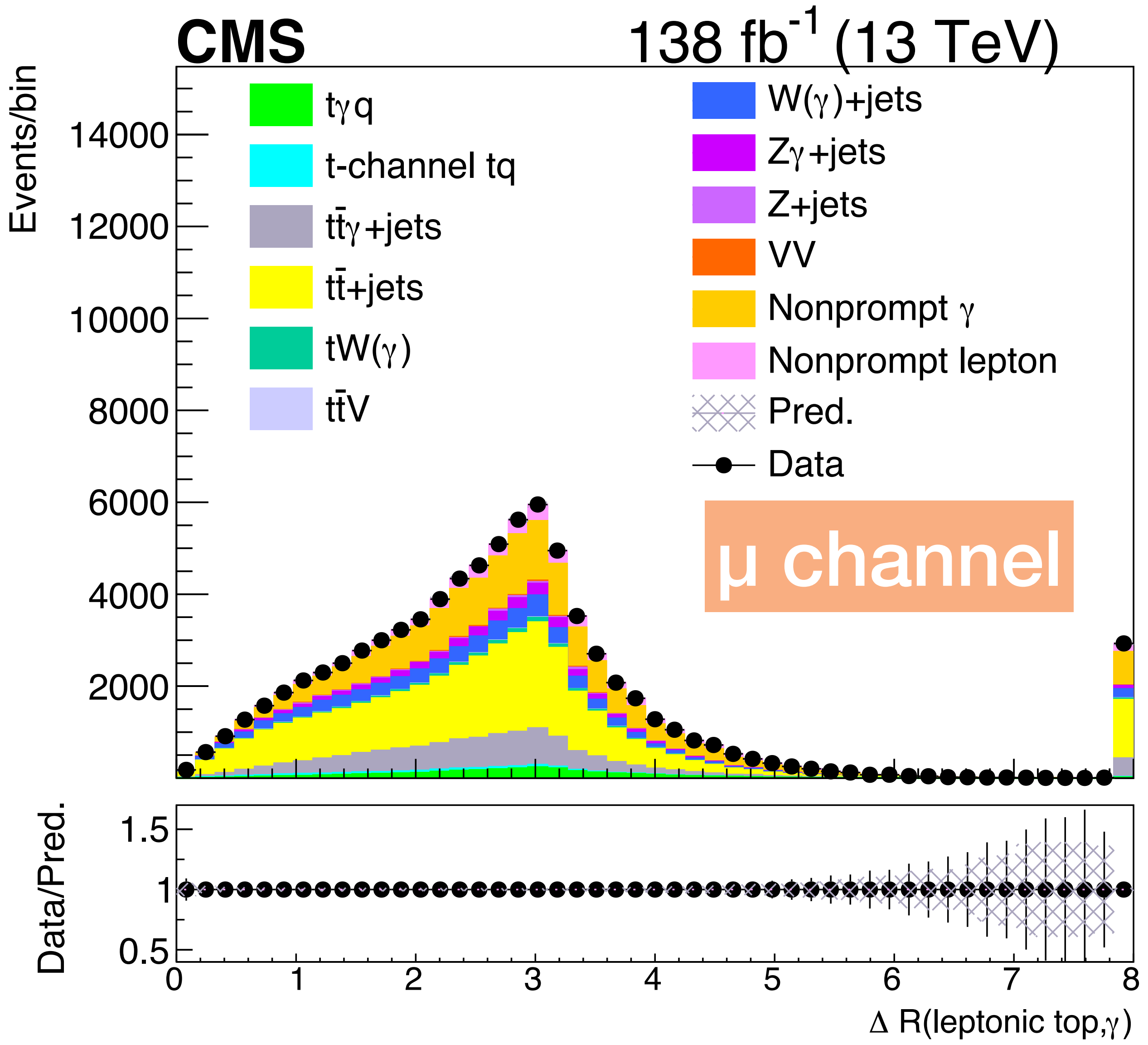


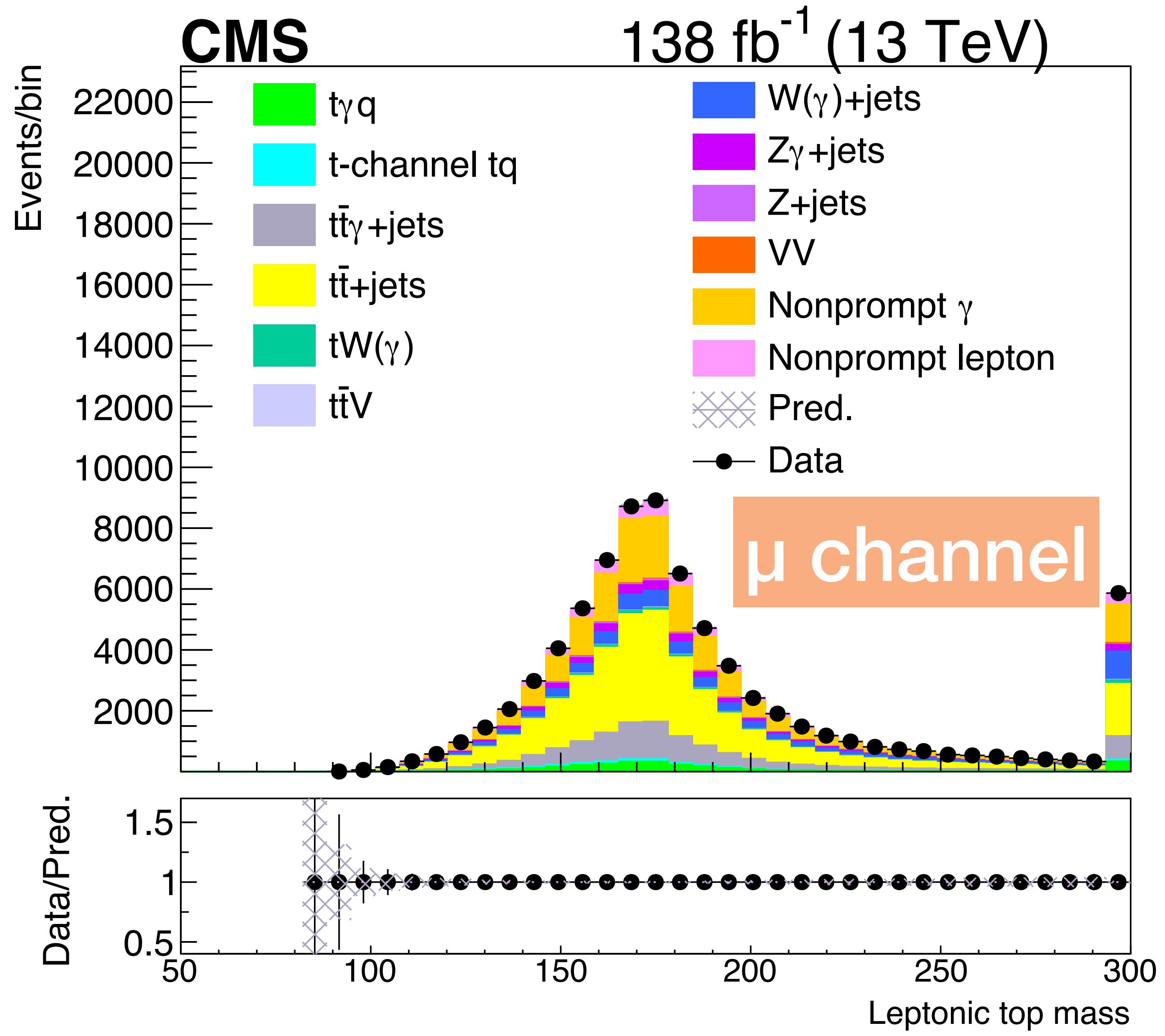


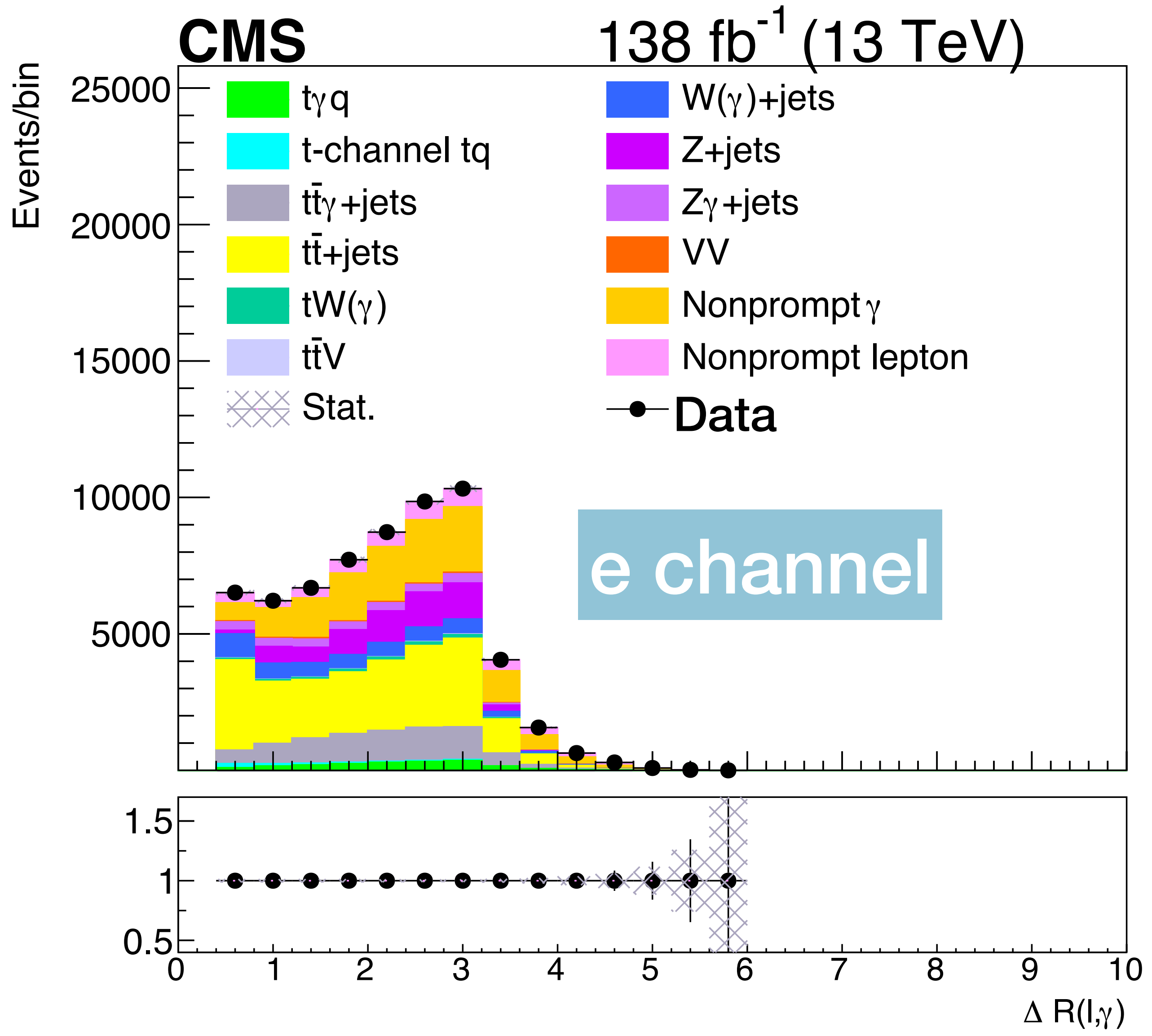


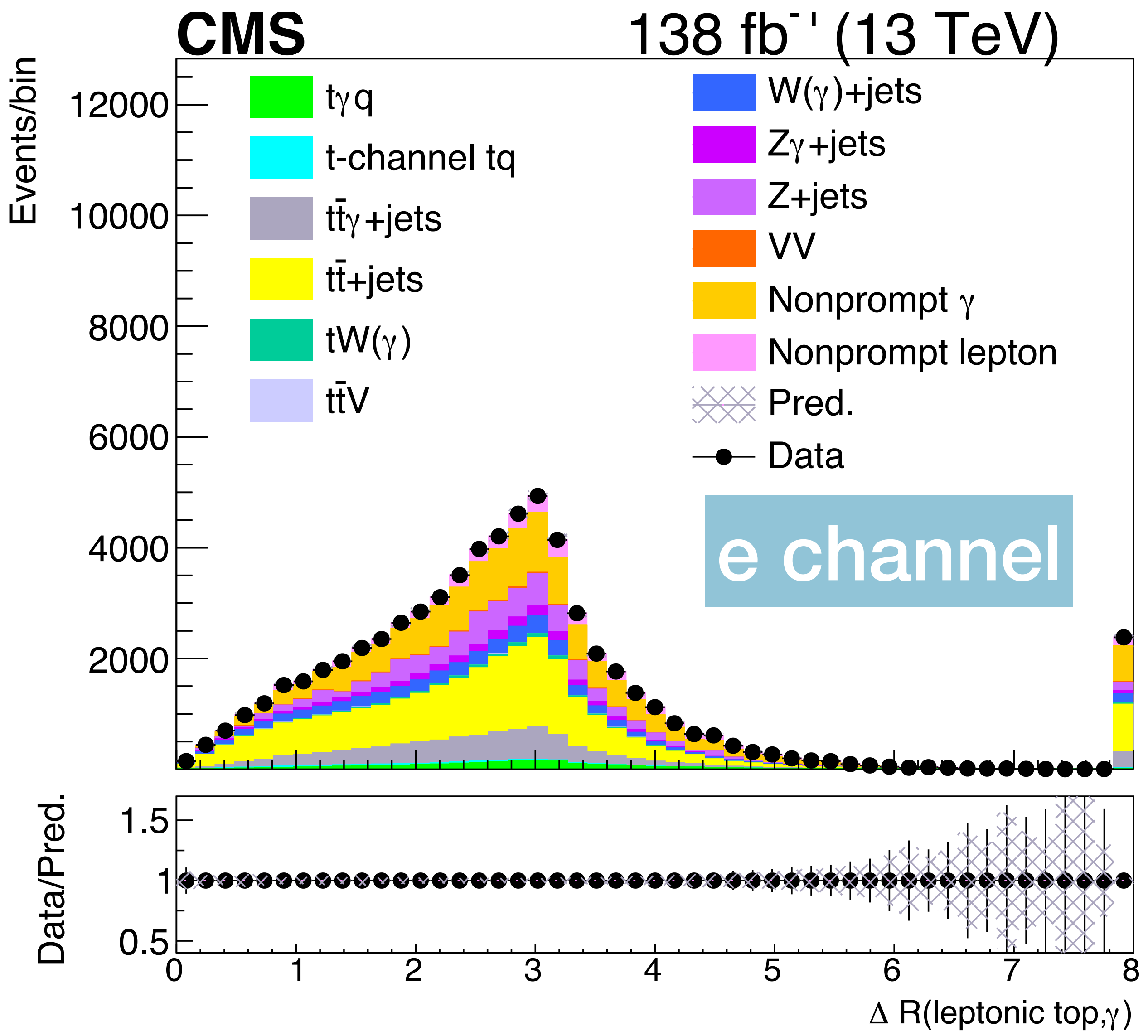
SR plots — $N_j \geq 2$ $N_{b-jets} \geq 1$

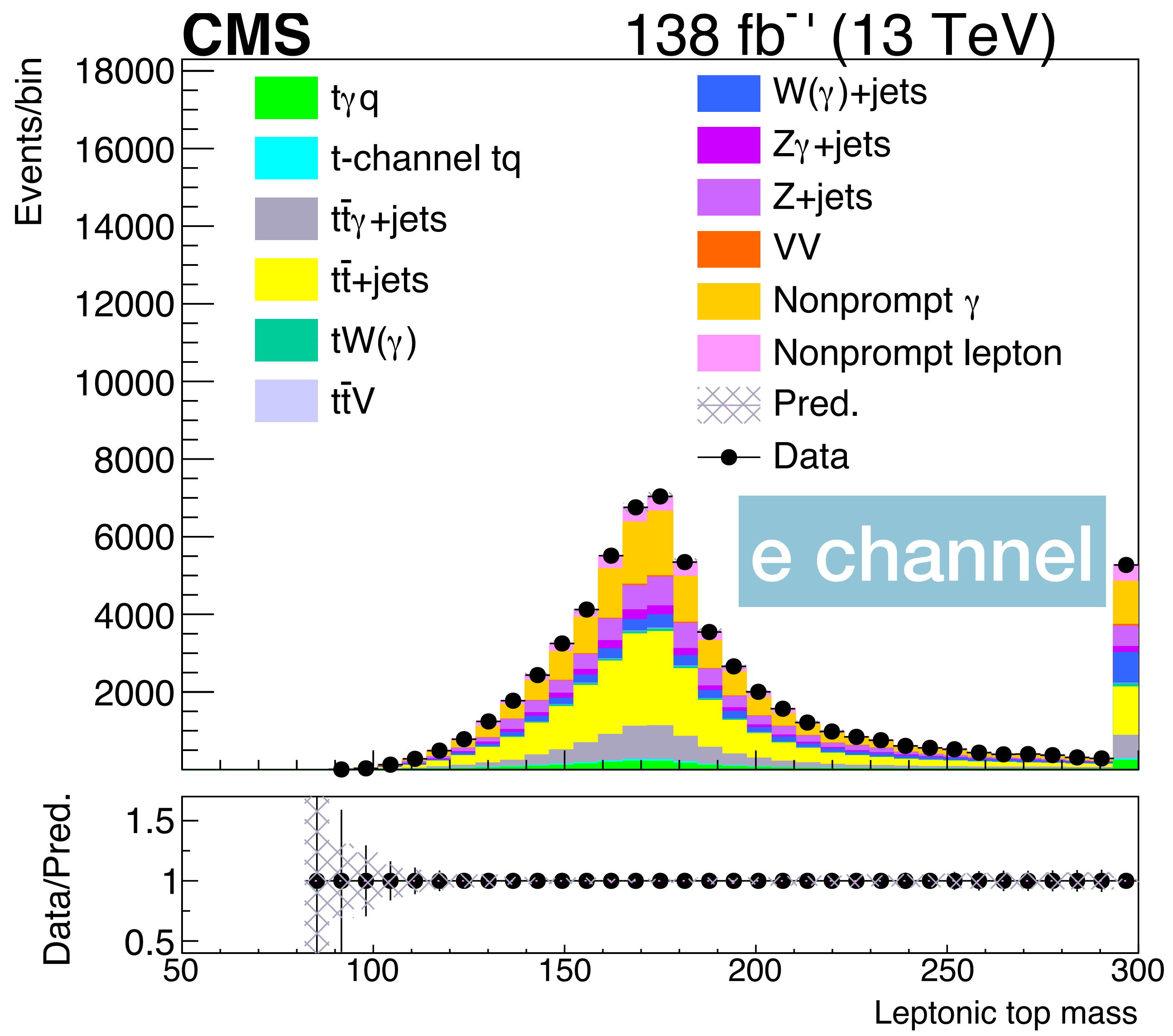








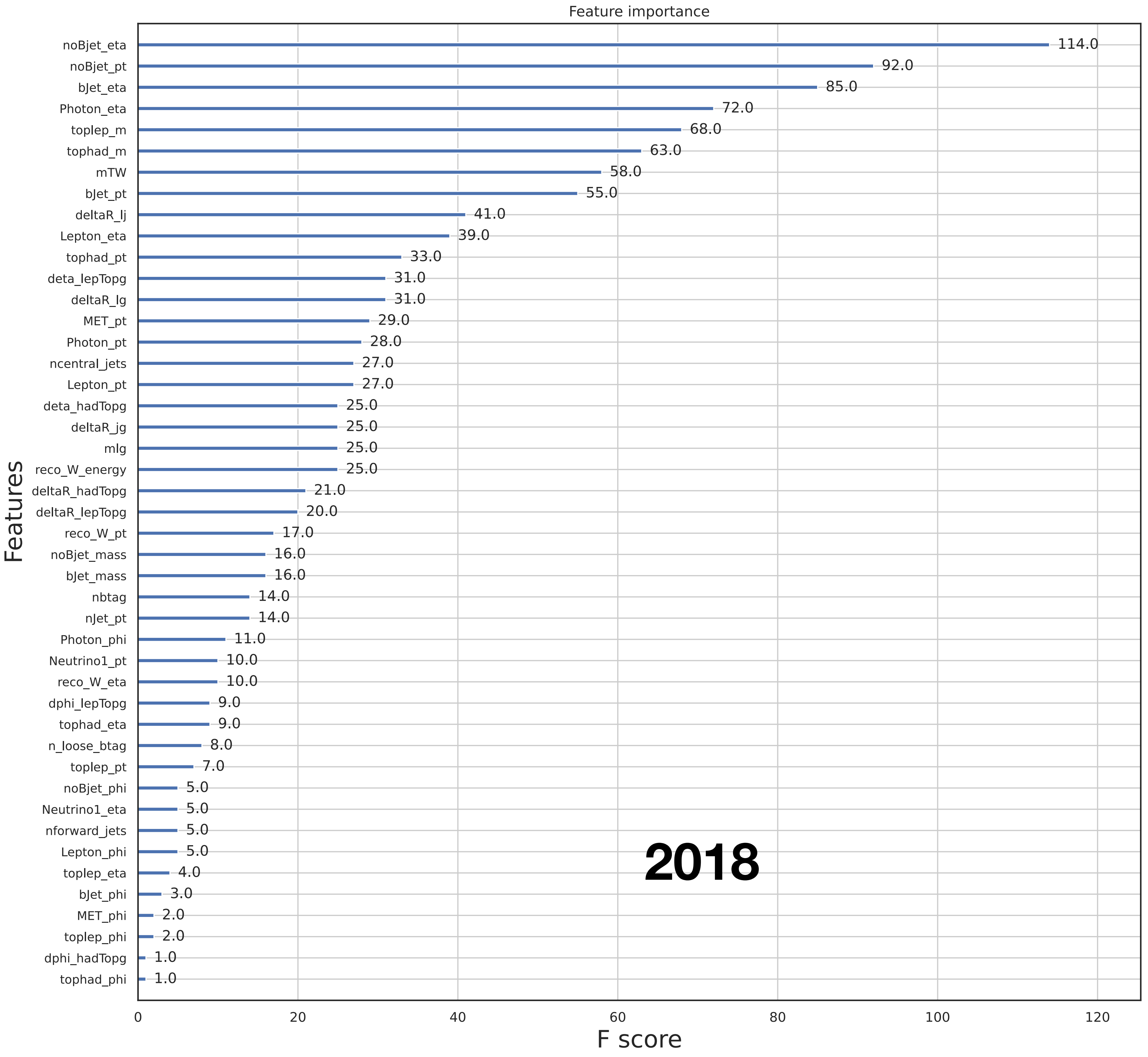


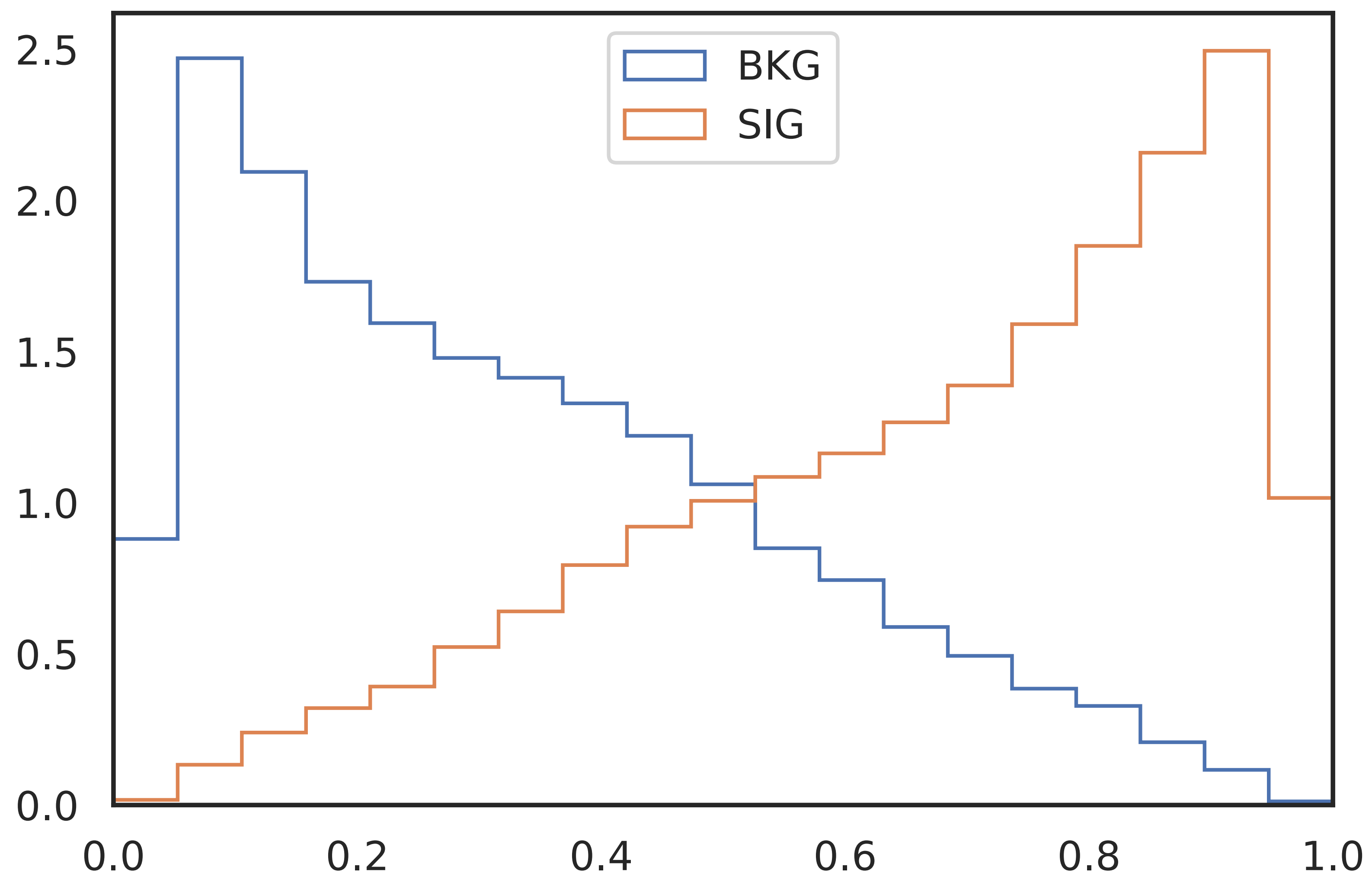


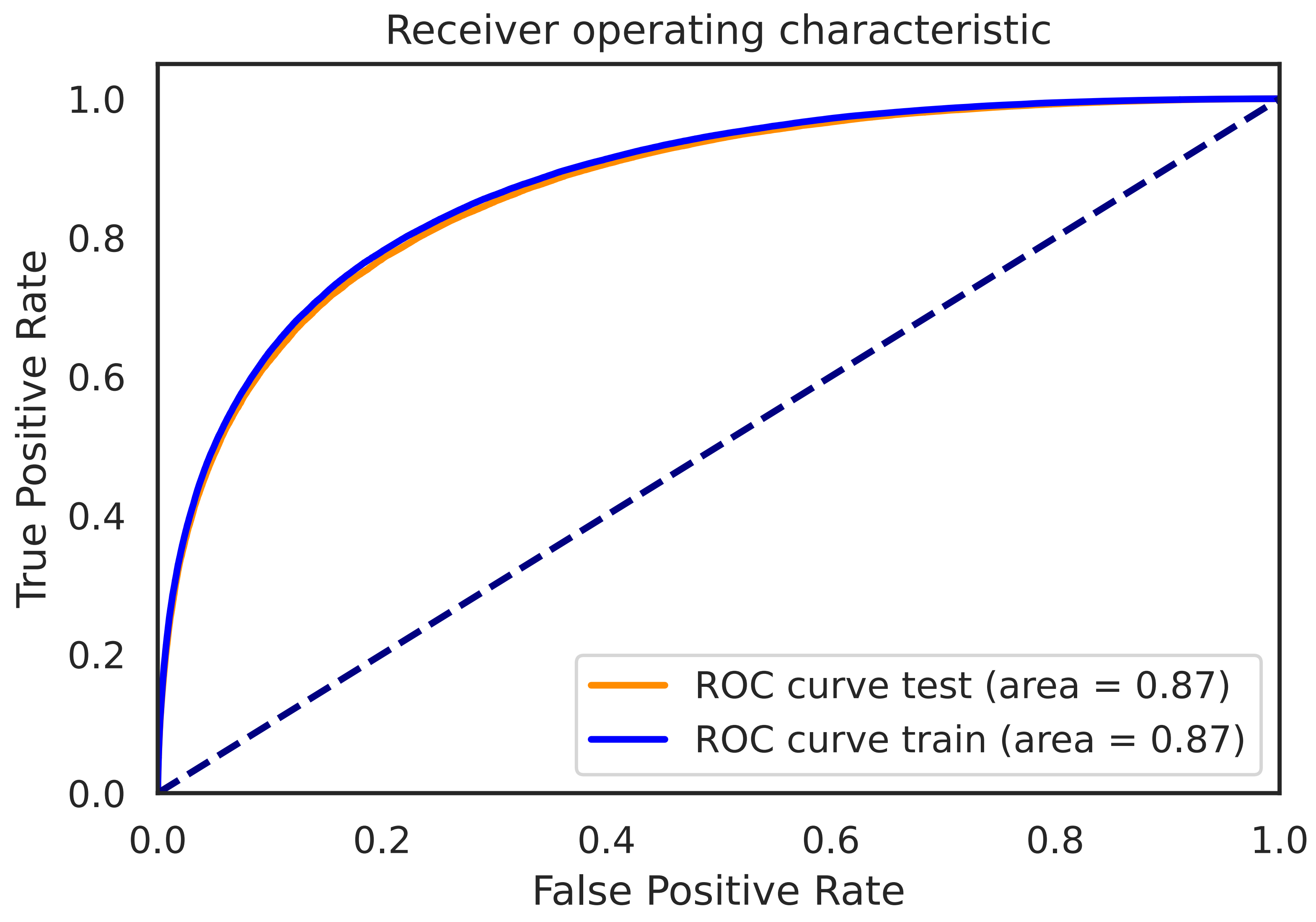
BDT training

A BDT is trained in the signal region with tγq as signal and $t\bar{t}\gamma$+others as backgrounds

- Includes both muon and electron events
- Backgrounds are simulation estimation
- **Trained separately for different years**







- Train and test matched well ~ 86%
- Similar separation power between years
- Similar feature importance ranking between years

Systematic uncertainties

Theoretical uncertainties:

- Renormalisation and factorisation
- PDF → splited
- Parton shower (FSR, ISR)

Experimental uncertainties:

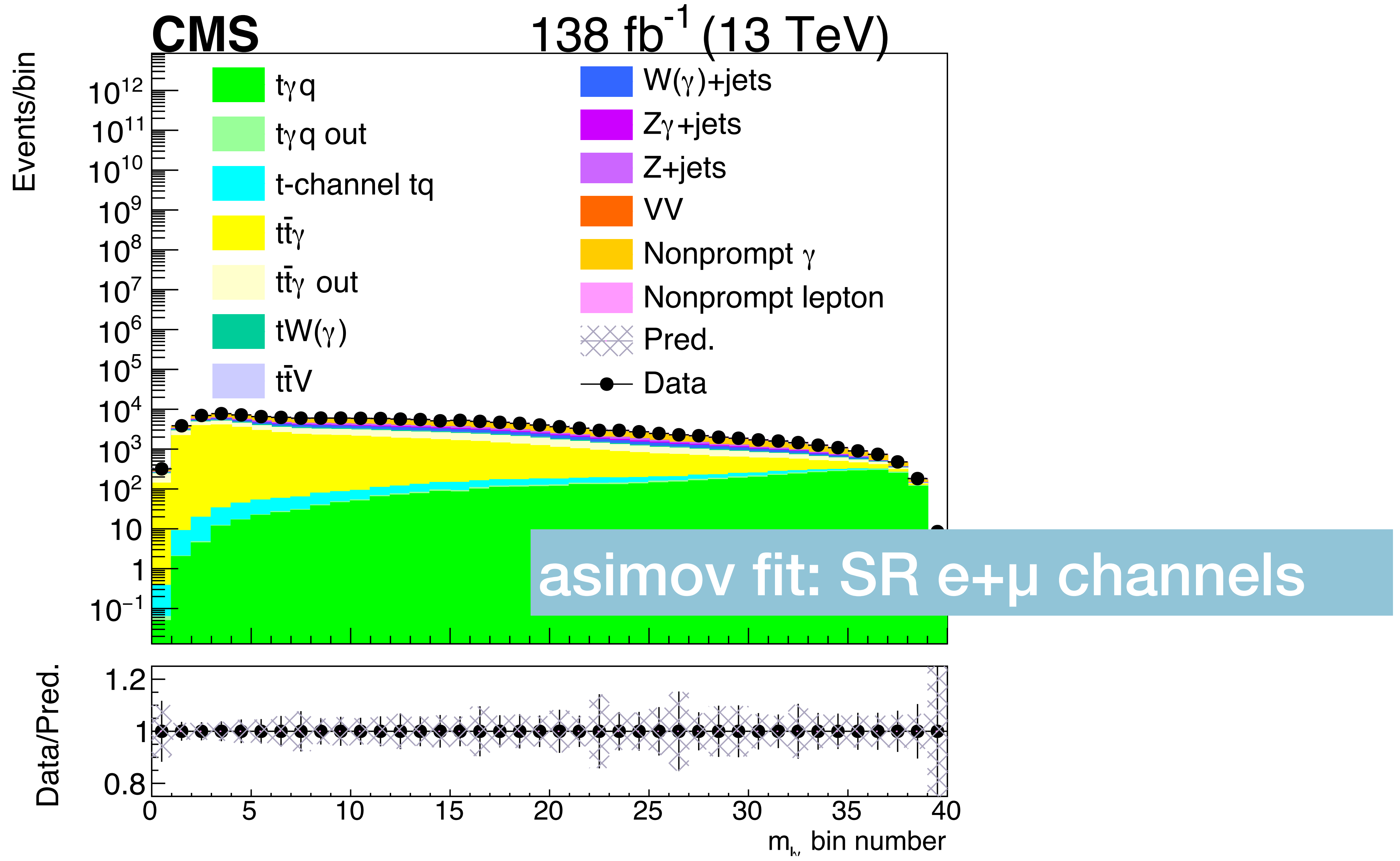
- Luminosity, PU, L1 pre-firing (2016 and 2017)
- Lepton ID/ISO/reco/HLT
- Photon ID/veto scale factors
- Pileup Jet ID/Btagging SFs
- Jet energy scale and resolution → split JES
- Uncluster MET energy
- Nonprompt photon/lepton estimation
- **rateParam for Z+jets in the electron channel** → uncorrelated between years

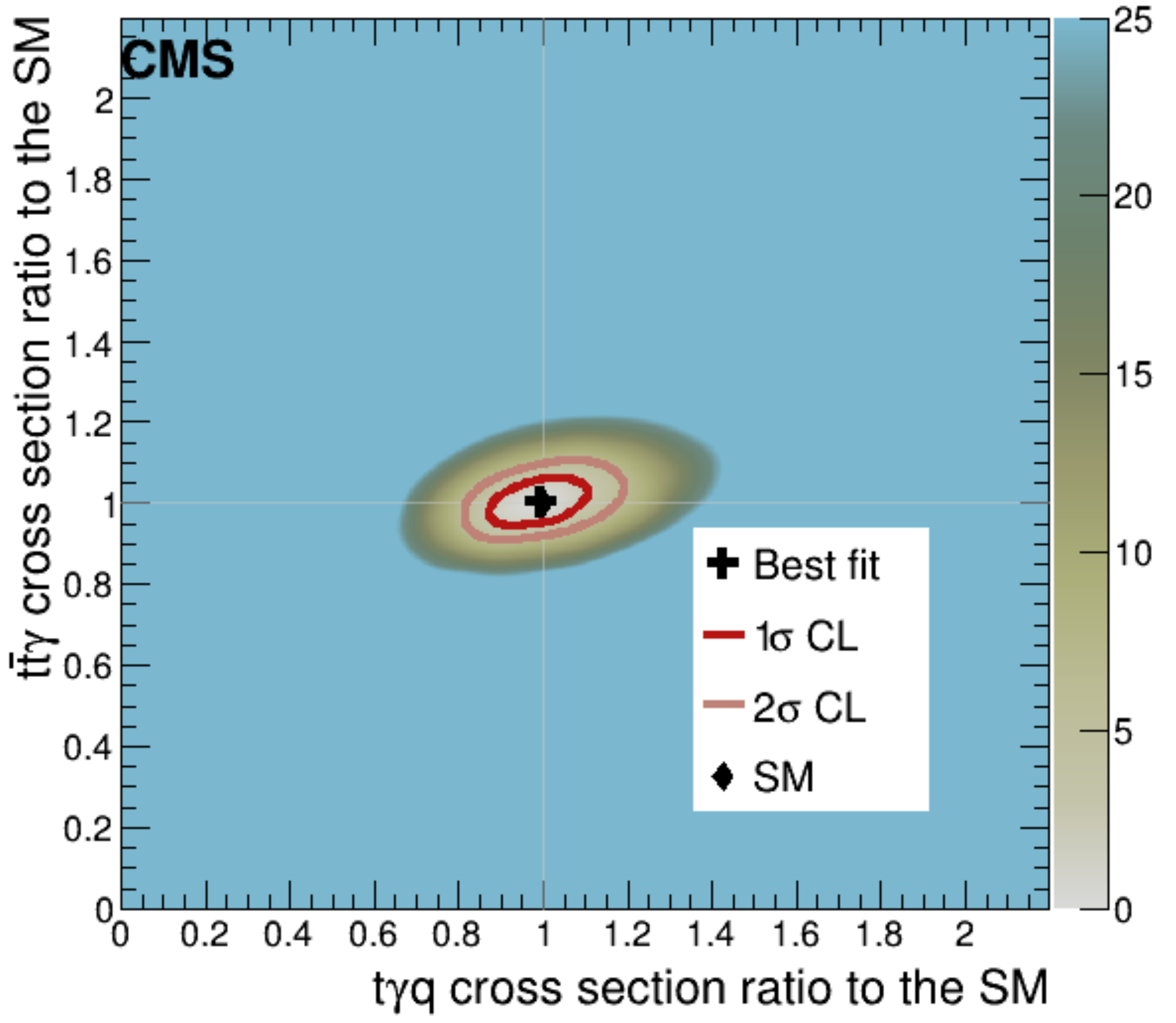
Shape style in data card:
Both shape and normalisation are considered

Simultaneous inclusive fit

- Perform a simultaneous fit for events in the **signal** and **b-veto control regions**
  - The signal region uses the BDT distribution
  - The control region uses the $m_{\ell\gamma}$ distribution
- POIs are signal strengths of $t\gamma q$ and $t\bar{t}\gamma$ (prod.+decay)
  - *Signal events out of fiducial are regarded as backgrounds but have same uncertainties as the real signal events*
- All systematic uncertainties are considered
- rateParam for Z+jets in the electron channel

Selection	gen-lepton	gen-photon	gen-Jet	gen-bJet
p_T/GeV	> 30	> 15	> 30	> 30
|η|	< 2.5	< 2.5	< 4.7	< 2.5
status	1	1	—	—
|pdgID|	13/11	22	—	—
Others	No meson mother	• No meson mother • Isolated • ΔR(ℓ,γ) > 0.1	• ΔR(ℓ,j) > 0.4 • ΔR(ℓ,γ) > 0.1	• |partonFlavour| = 5 • ΔR(ℓ,j) > 0.4 • ΔR(ℓ,γ) > 0.1





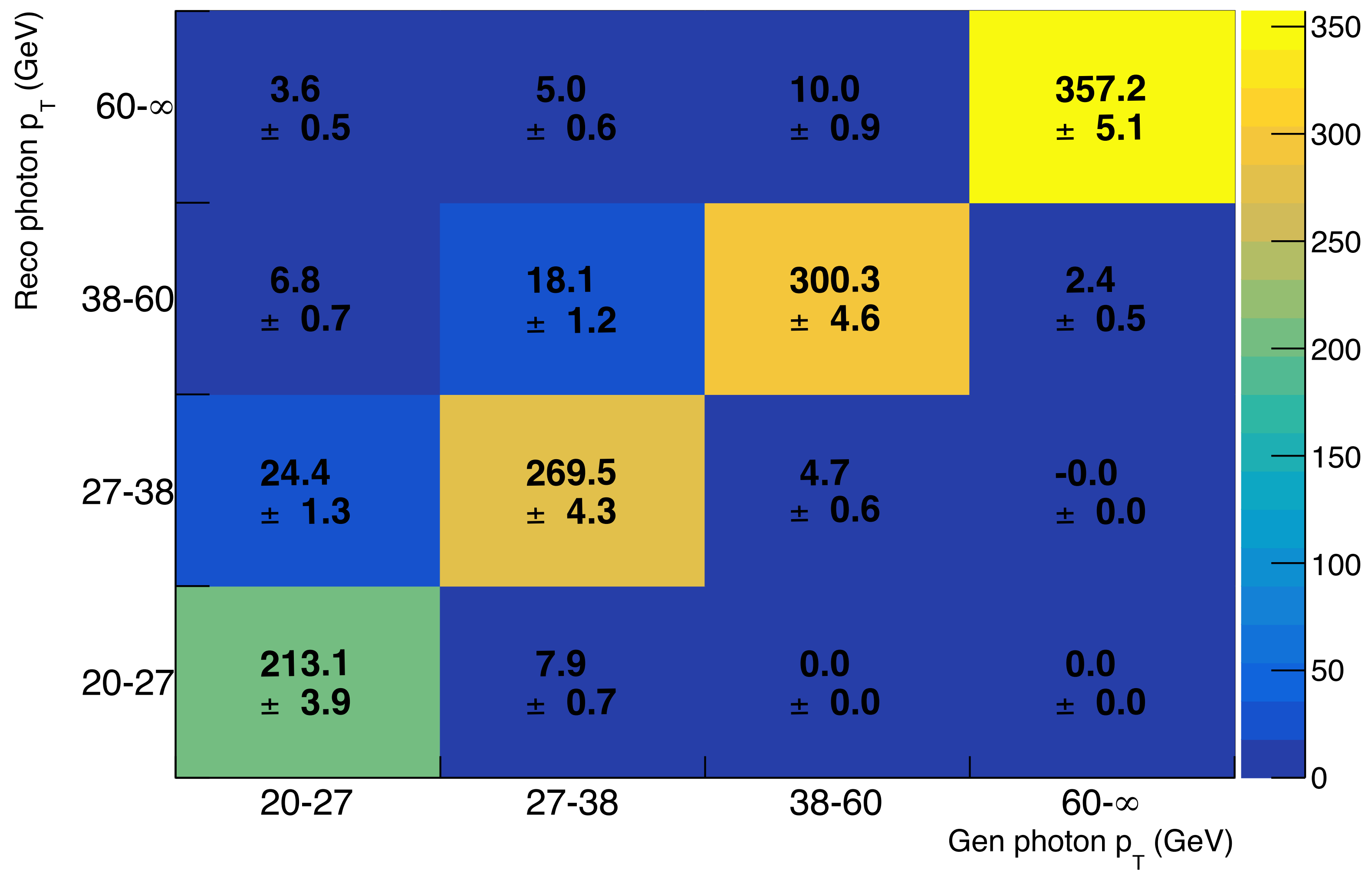
$r_{t\gamma q} = 1.0^{+0.077}_{-0.077}$

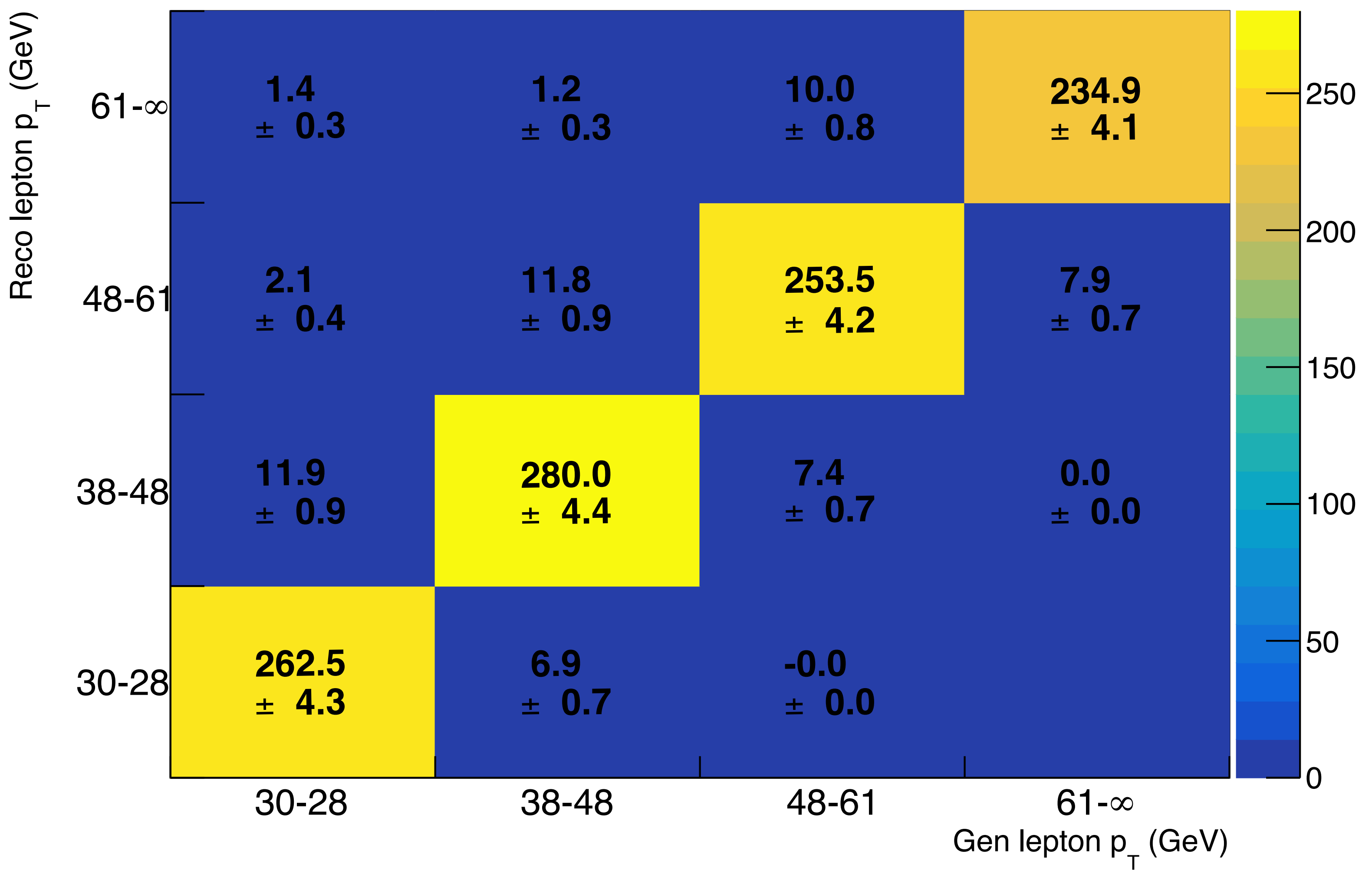
$r_{t\bar{t}\gamma} = 1.0^{+0.040}_{-0.041}$

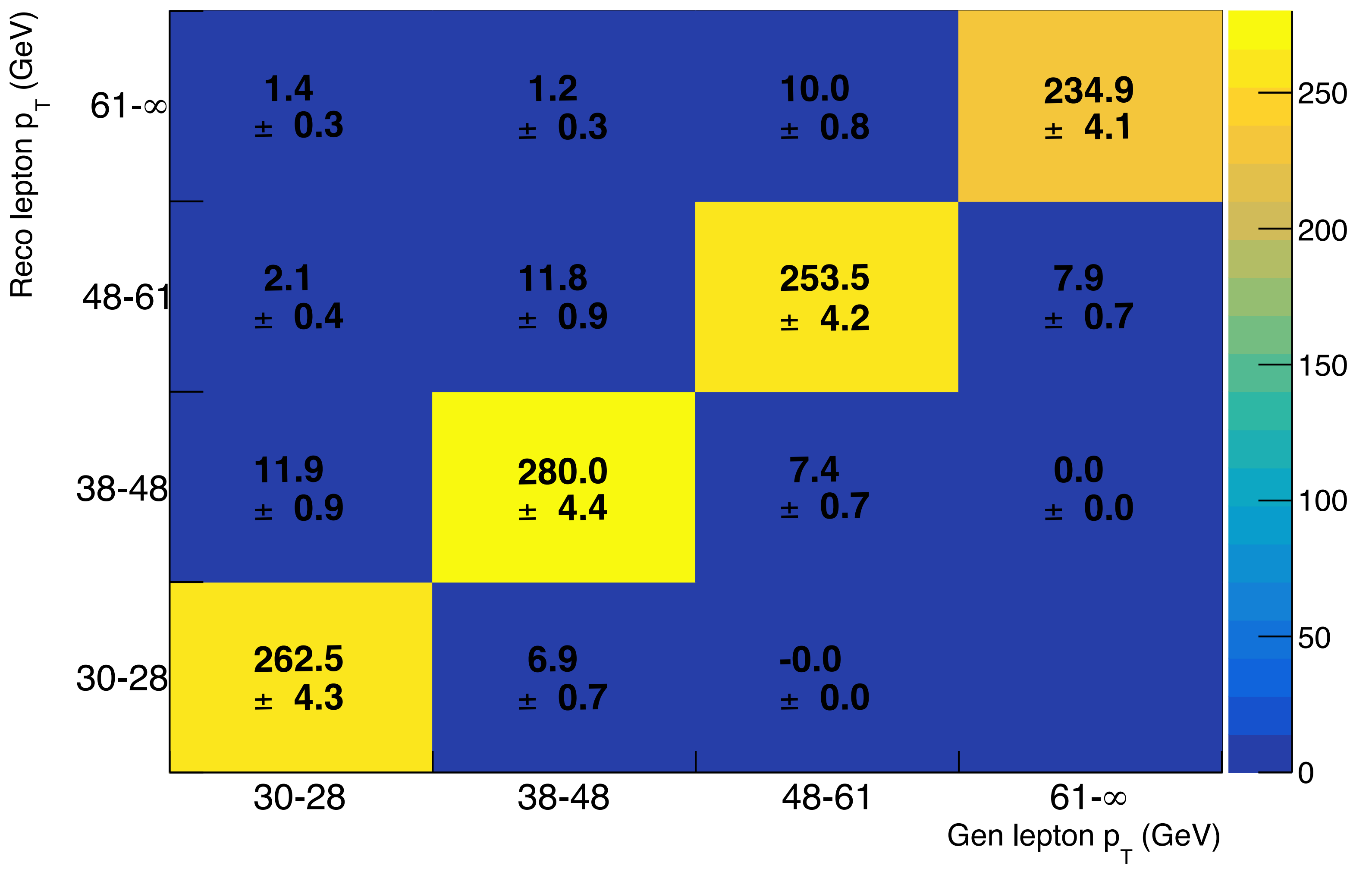
TOP-18-010:
$r = 1.0 \pm 0.009\,\mathrm{stat}$
$\pm 0.062\,\mathrm{syst}$

Simultanesous differential fit

- Maximum-likelihood unfolding using BDT
  - $t\gamma q$ SR → BDT > 0.5
  - $t\bar{t}\gamma$ SR → BDT < 0.5
- Photon p_T, lepton p_T, and $m_{\ell\gamma}$ are measured → not important in the BDT training
- Very diagonal response matrix, no regularisation

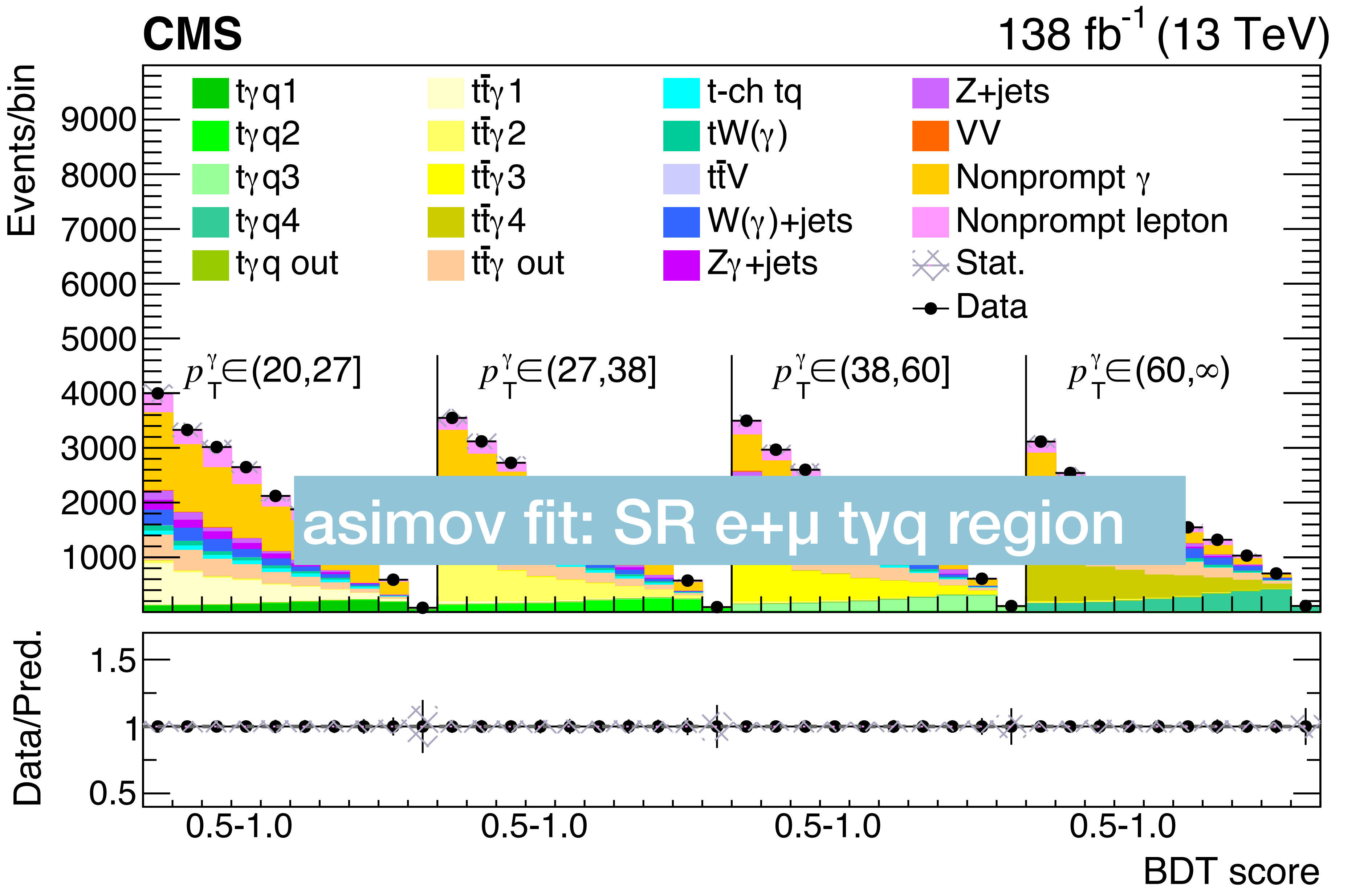


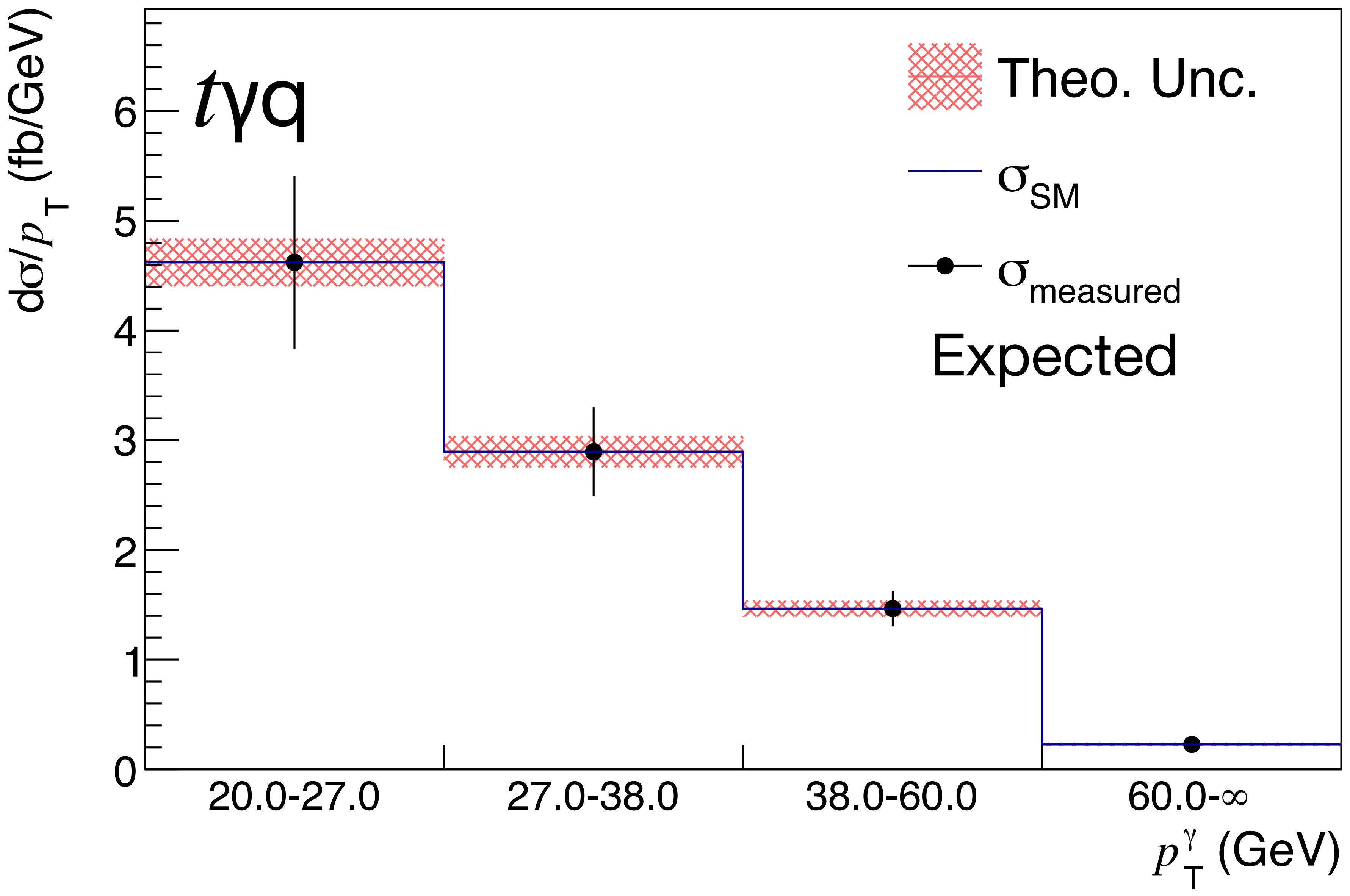




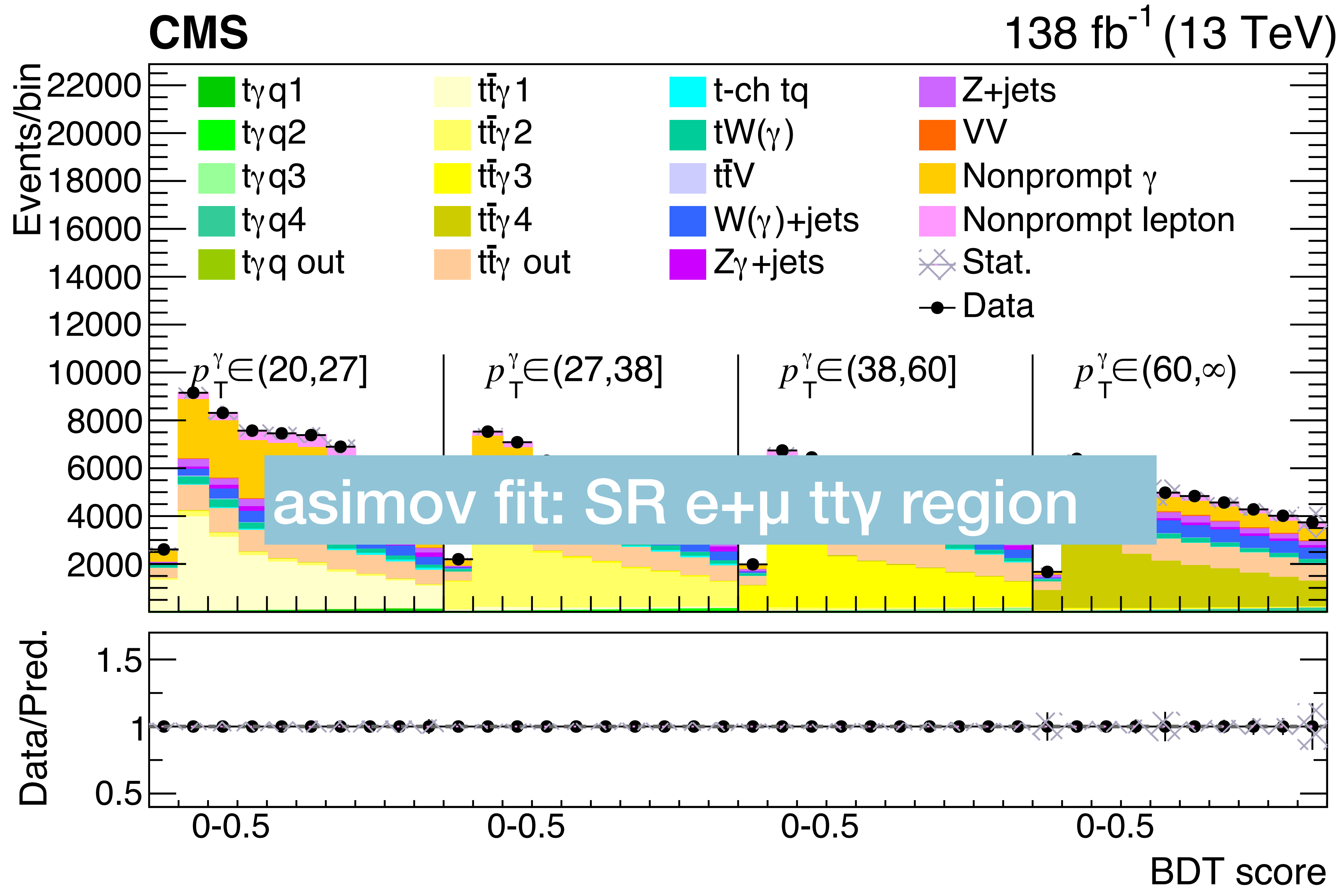
Similar performance between years

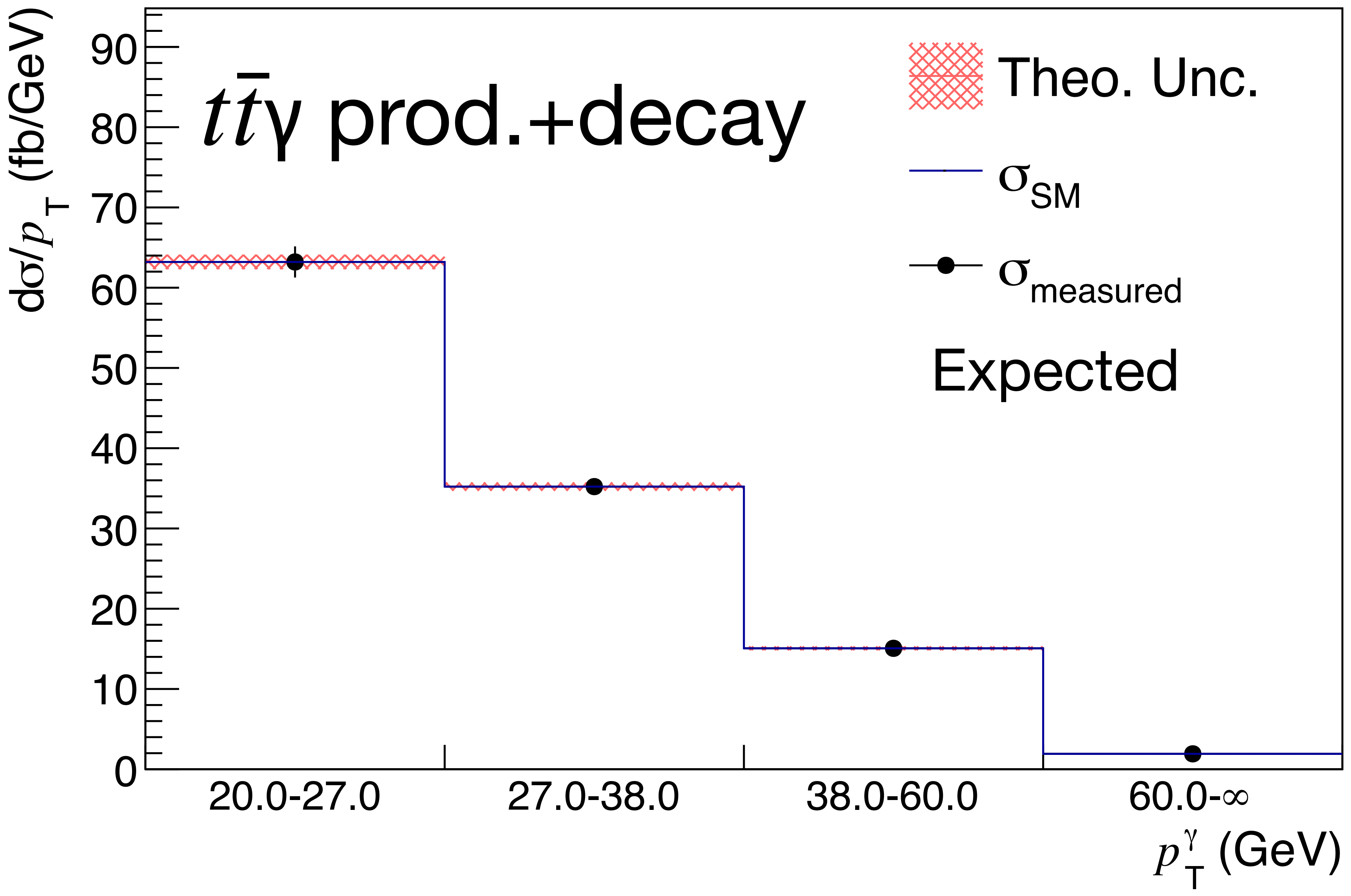
Simultanesous differential fit — p_T^γ





Variable	p_T^γ
r_1	1.0 ± 0.17
r_2	1.0 ± 0.14
r_3	1.0 ± 0.11
r_4	1.0 ± 0.09



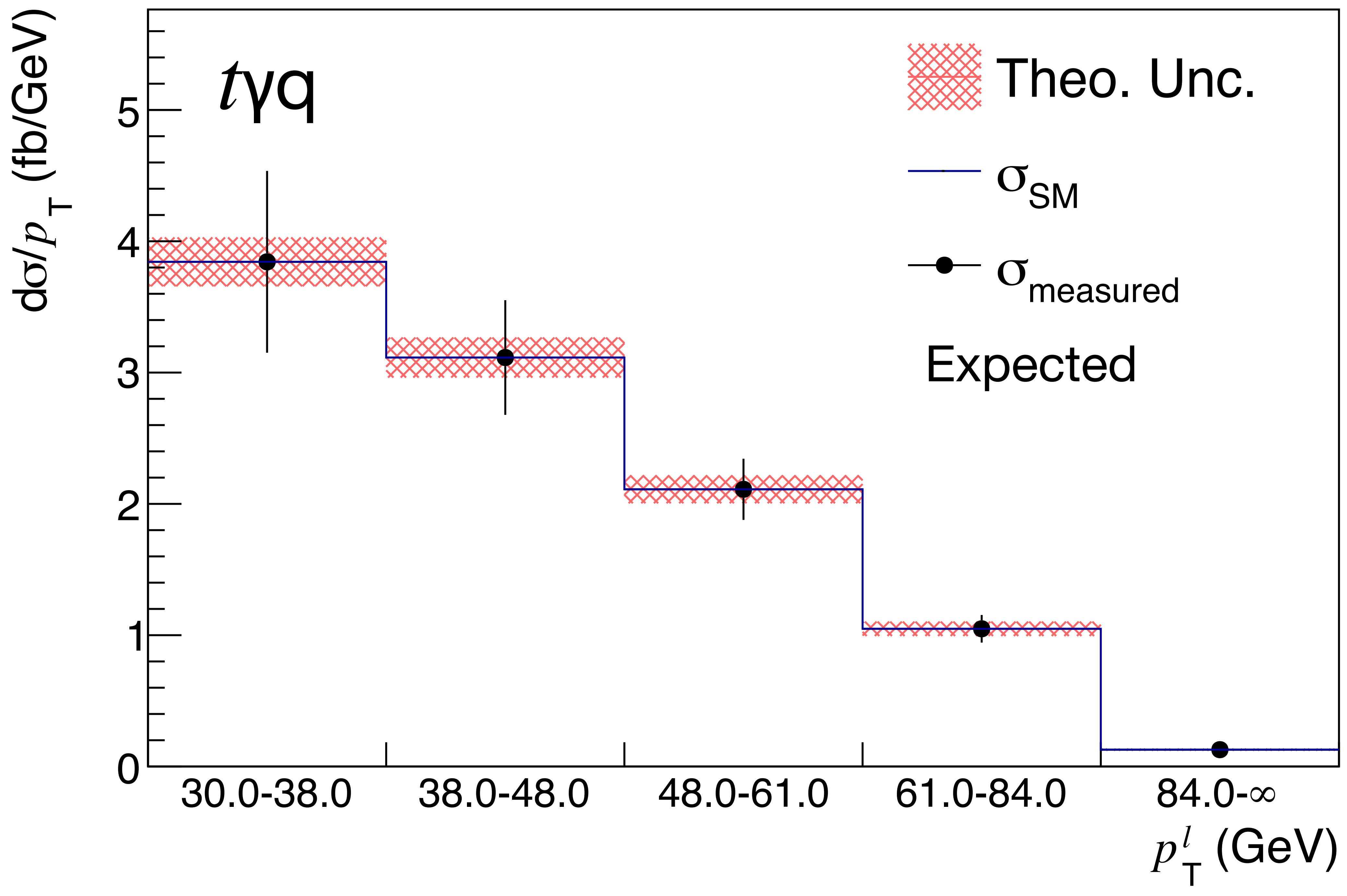


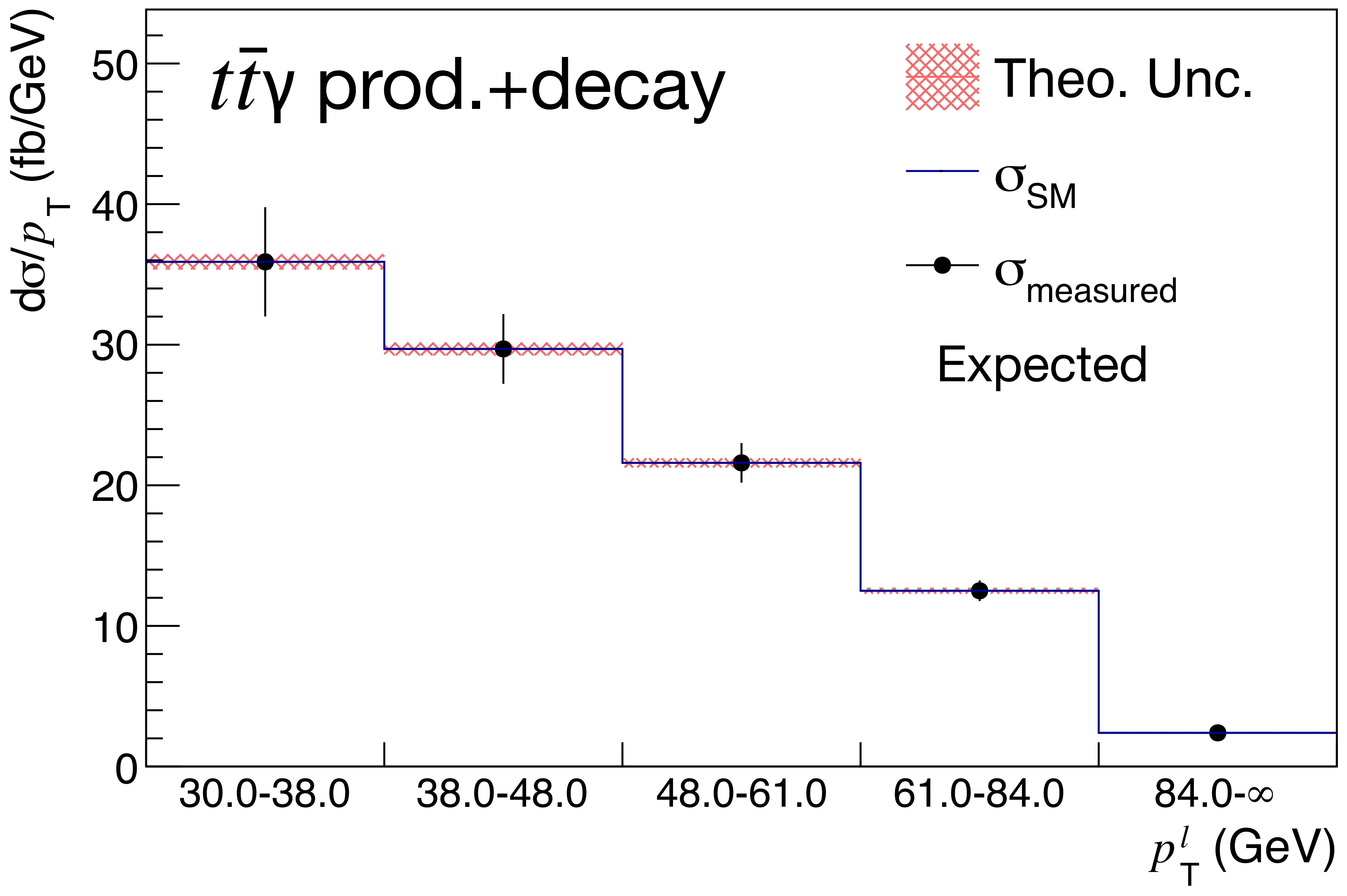
Variable	p_T^γ
r_1	1.0 ± 0.05
r_2	1.0 ± 0.04
r_3	1.0 ± 0.34
r_4	1.0 ± 0.04

Simultanesous differential fit — p_T^ℓ

Variable	r_1	r_2	r_3	r_4	r_5
p_T^ℓ (tγq)	1.0 ± 0.14	1.0 ± 0.12	1.0 ± 0.12	1.0 ± 0.12	1.0 ± 0.15

Variable	r_1	r_2	r_3	r_4	r_5
p_T^ℓ (ttγ+tt)	1.0 ± 0.05	1.0 ± 0.04	1.0 ± 0.04	1.0 ± 0.04	1.0 ± 0.05

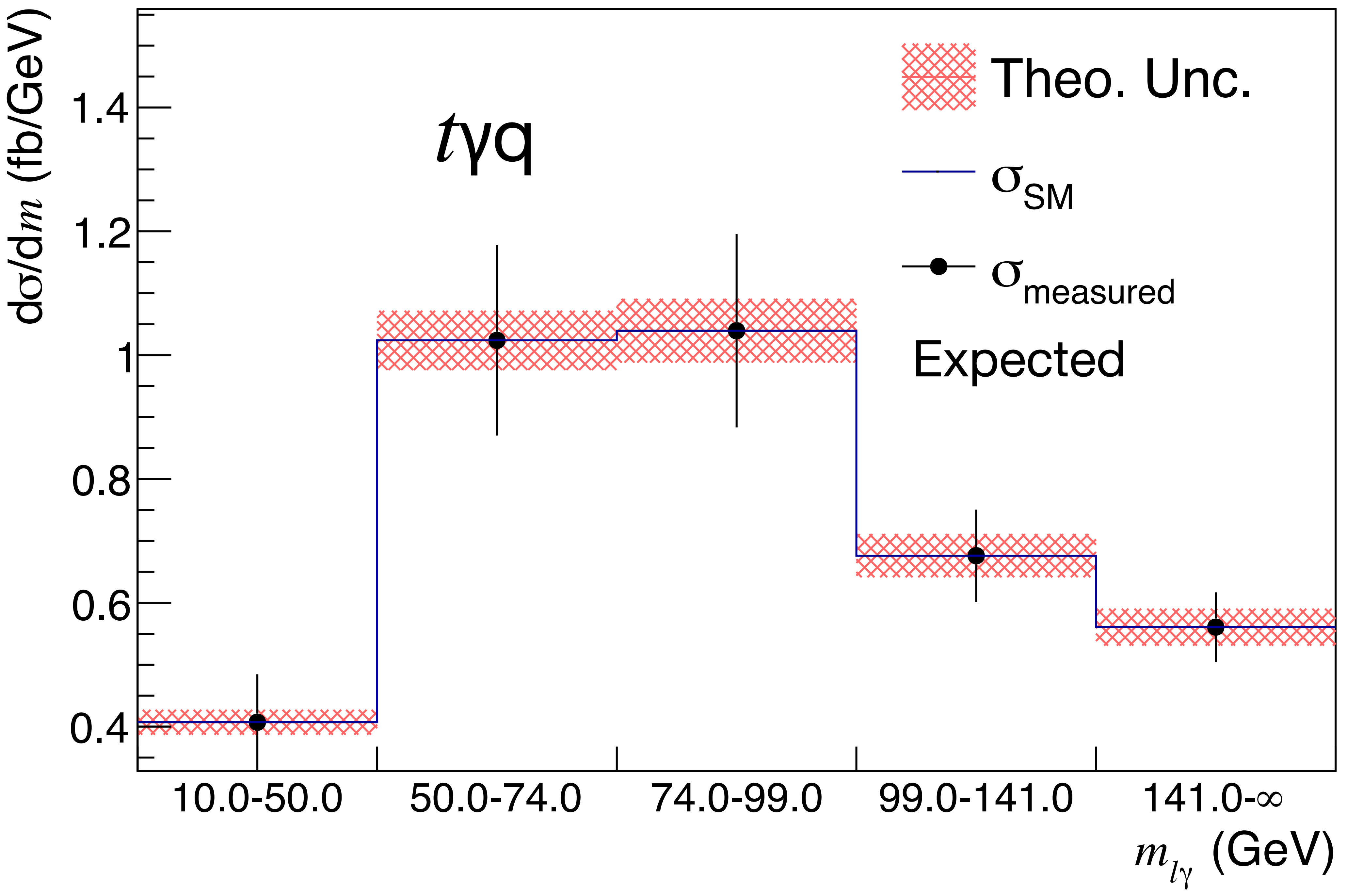


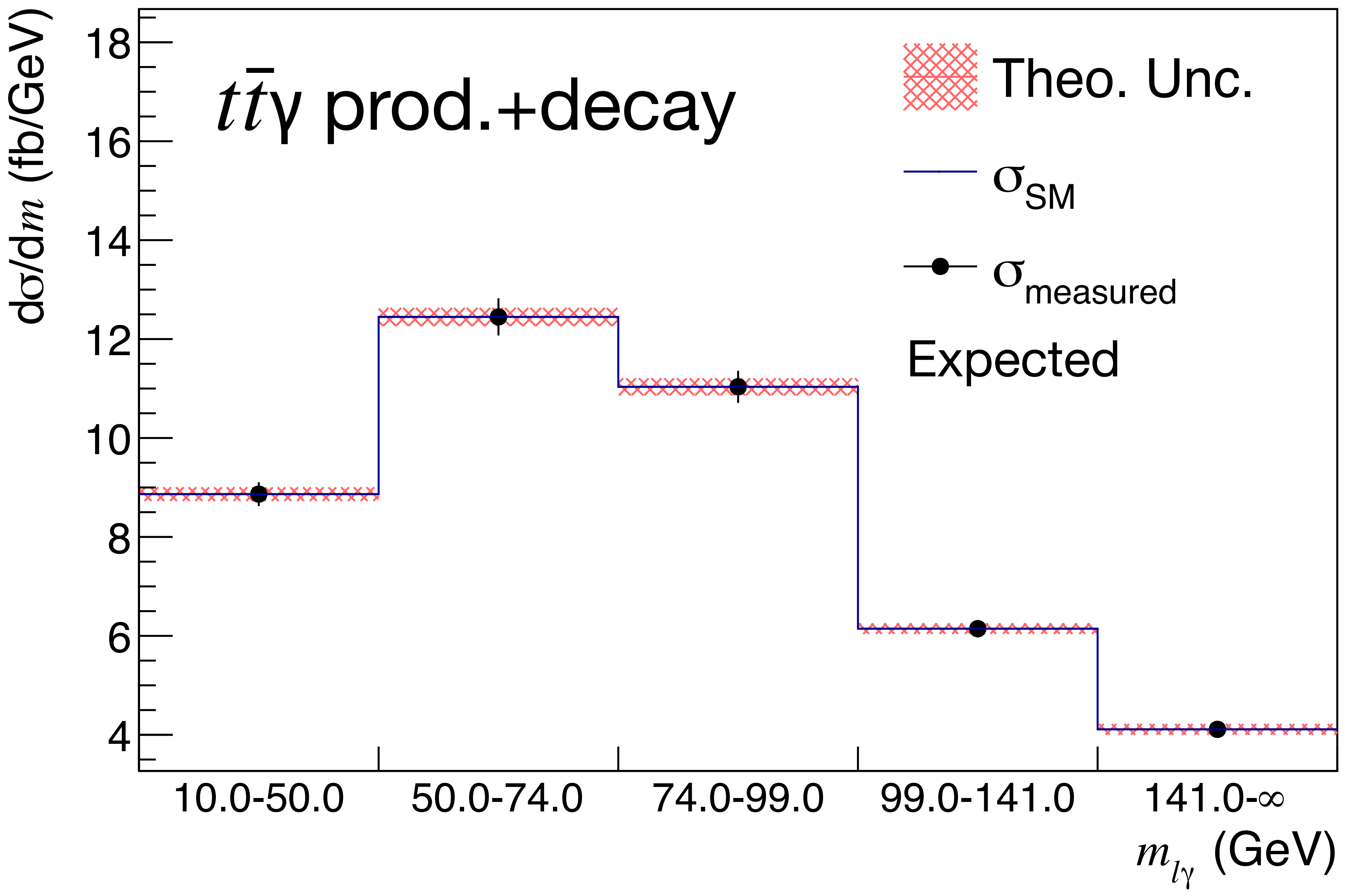


Simultanesous differential fit — $m_{\ell\gamma}$

Variable	r_1	r_2	r_3	r_4	r_5
$m_{\ell\gamma}$ (tγq)	1.0 ± 0.19	1.0 ± 0.15	1.0 ± 0.15	1.0 ± 0.11	1.0 ± 0.10

Variable	r_1	r_2	r_3	r_4	r_5
$m_{\ell\gamma}$ (ttγ+tt)	1.0 ± 0.04	1.0 ± 0.05	1.0 ± 0.05	1.0 ± 0.05	1.0 ± 0.05





EFT interpretation

SMEFT Parameter — Wilson Coefficients

- Productions of tγq+tt̄γ are expected to be sensitive to several EFT operators coupling to the weak hypercharge and isospin gauge bosons, C_{tB}, C_{tW}.

$$C^{Z}_{2,\mathrm{V}} = \frac{v^2 m_t}{\sqrt{2} c_w s_w m_Z \Lambda^2} \Re\left[C_{tZ}\right], \quad C^{Z}_{2,\mathrm{A}} = \frac{v^2 m_t}{\sqrt{2} c_w s_w m_Z \Lambda^2} \Im\left[C_{tZ}\right],$$

$$C^{\gamma}_{2,\mathrm{V}} = \frac{\sqrt{2} v m_t}{e \Lambda^2} \Re\left[C_{t\gamma}\right], \quad C^{\gamma}_{2,\mathrm{A}} = \frac{\sqrt{2} v m_t}{e \Lambda^2} \Im\left[C_{t\gamma}\right],$$

$$C_{tZ} = c_w \cdot C_{tW} - s_w \cdot C_{tB},$$

$$C_{t\gamma} = s_w \cdot C_{tW} + c_w \cdot C_{tB}.$$

where s_w (c_w) is the sine (cosine) of the Weinberg angle, m_Z is the Z boson mass and $C_{t\gamma}$ and C_{tZ} are the EFT operators, which are linear combinations of the dipole operators C_{tB}, C_{tW}

Two-heavy ($9+6$ CPV d.o.f.)

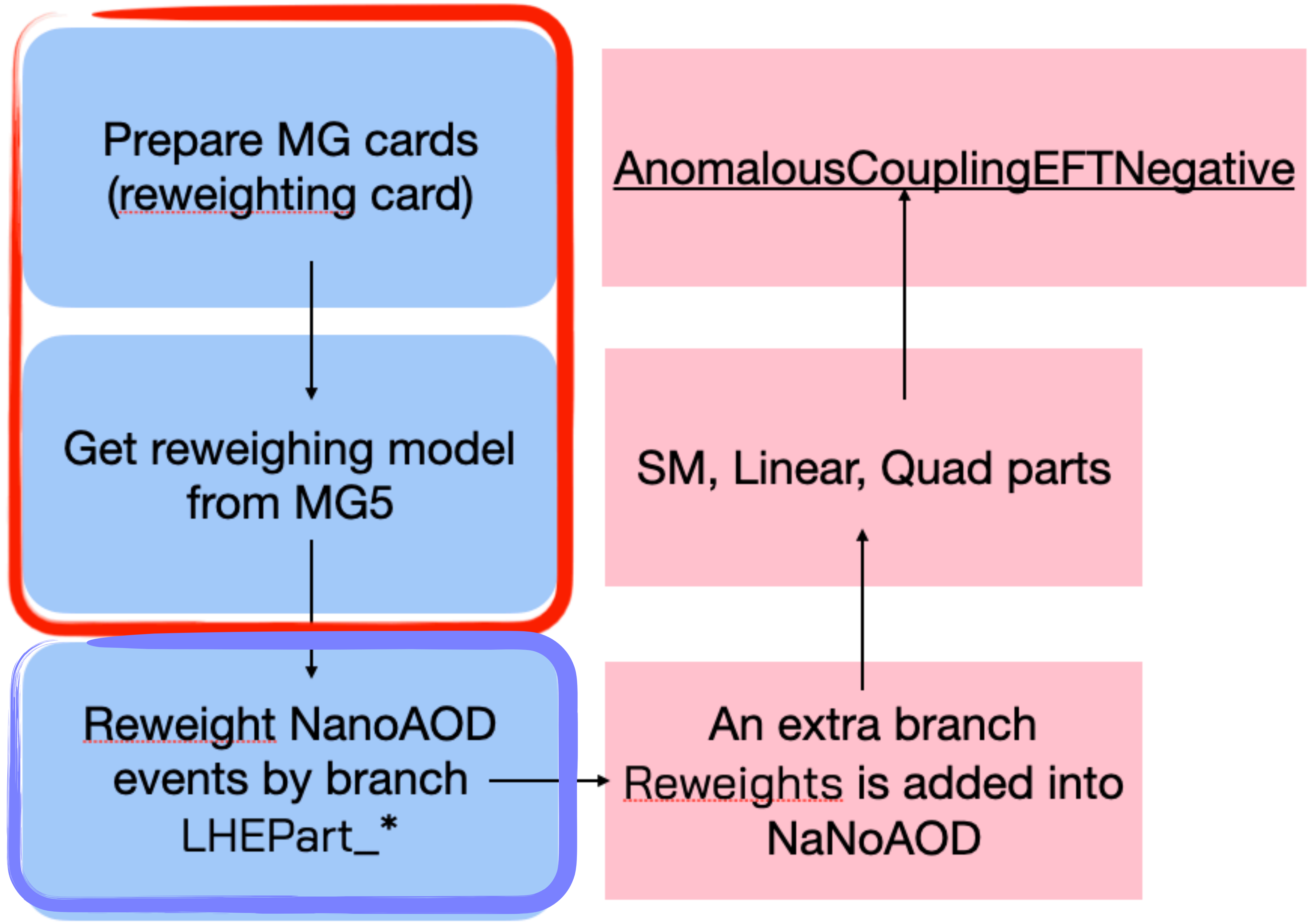
$c^{[I]}_{t\varphi}$	$\equiv {}^{[\mathrm{Im}]}_{\mathrm{Re}}\{C^{(33)}_{u\varphi}\}$	
$c^{-}_{\varphi q}$	$\equiv C^{1(33)}_{\varphi q} - C^{3(33)}_{\varphi q}$	$c^{1}_{\varphi q}$ $[-3.1, 3.1]$ [45], $[-8.3, 8.6]$ [46]
$c^{3}_{\varphi Q}$	$\equiv C^{3(33)}_{\varphi q}$	$[-4.1, 2.0]$ [45], $[-8.6, 8.3]$ [46]
$c_{\varphi t}$	$\equiv C^{(33)}_{\varphi u}$	$[-9.7, 8.3]$ [45], $[-9.1, 9.1]$ [46]
$c^{[I]}_{\varphi tb}$	$\equiv {}^{[\mathrm{Im}]}_{\mathrm{Re}}\{C^{(33)}_{\varphi ud}\}$	
$c^{[I]}_{tW}$	$\equiv {}^{[\mathrm{Im}]}_{\mathrm{Re}}\{C^{(33)}_{uW}\}$	c_{tW} $[-4.0, 3.5]$ [45], $[-4.1, 4.1]$ [46]
$c^{[I]}_{tZ}$	$\equiv {}^{[\mathrm{Im}]}_{\mathrm{Re}}\{-s_W C^{(33)}_{uB} + c_W C^{(33)}_{uW}\}$	c_{tB} $[-6.9, 4.6]$ [45], $[-7.6, 7.6]$ [46]
$c^{[I]}_{bW}$	$\equiv {}^{[\mathrm{Im}]}_{\mathrm{Re}}\{C^{(33)}_{dW}\}$	
$c^{[I]}_{tG}$	$\equiv {}^{[\mathrm{Im}]}_{\mathrm{Re}}\{C^{(33)}_{uG}\}$	c_{tG} $[-1.32, 1.24]$ [45]

Two-heavy-two-lepton ($8+3$ CPV d.o.f. $\times 3$ lepton flavours)

https://arxiv.org/pdf/1802.07237

- SMEFTsim (2012.11343): only LO mode
  - $\Re c_{tG}$, $\Re c_{tW}$, $\Re c_{tB}$ are selected to do reweighting

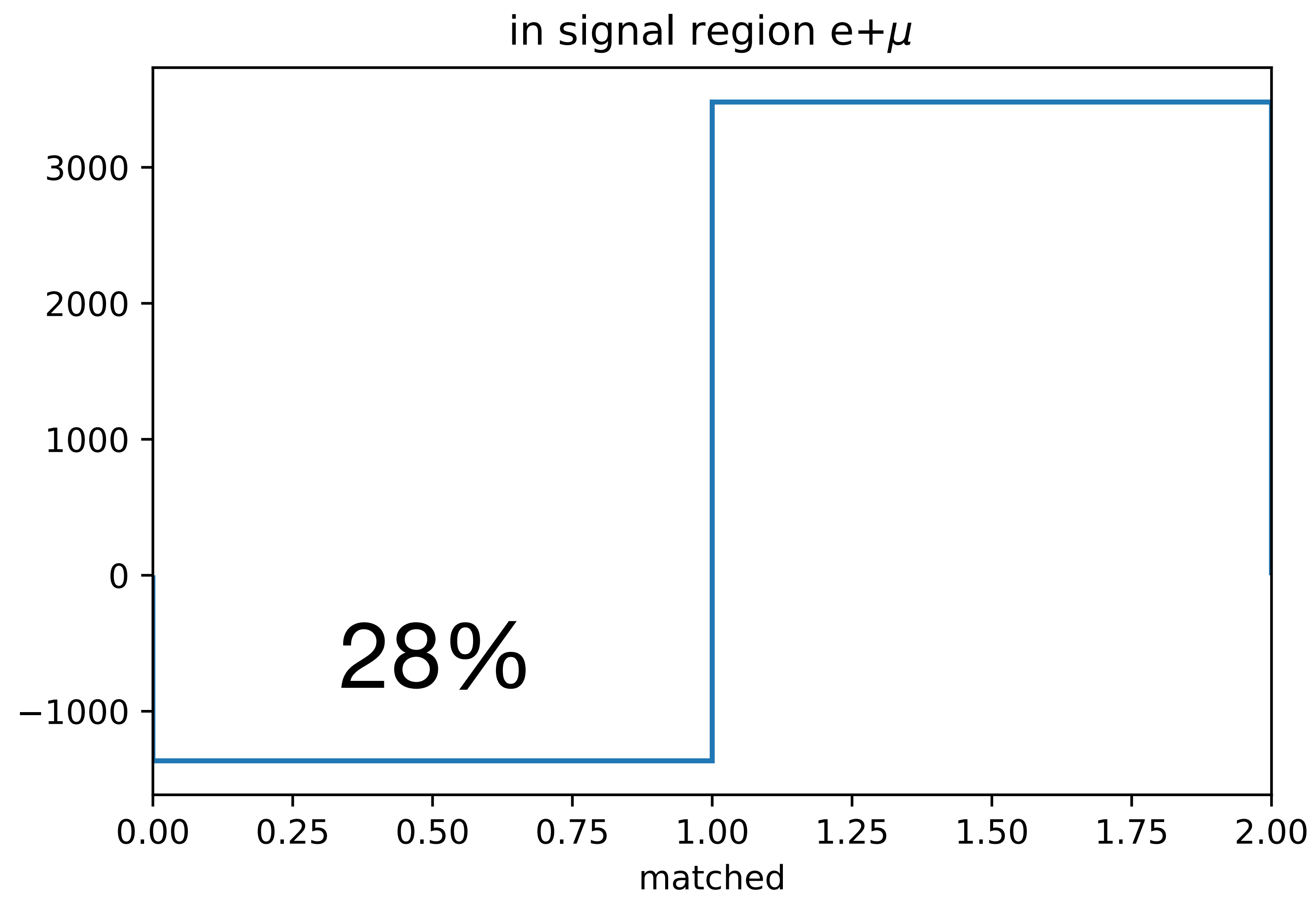
EFT sample



- Use the EFT2Obs and reweight nanoAOD
- The signal samples used in our SM measurement are both NLO sample for tγq+tt̄γ → Private LO SM gridpacks are produced to validate our EFT sample (LHE validation plots in backup)

It's doing a mapping from a PDG list got from MG5 production to NanoAOD LHEPart:

1. If the NanoAOD LHE event can be matched to the PDG list, we get the reweight $= w_{ori}^{NLO} \times \dfrac{w_i^{LO}}{w_{sm}^{LO}}$
2. If the NanoAOD LHE events can't be matched to the PDG list, the Reweights are just same as the generator weight

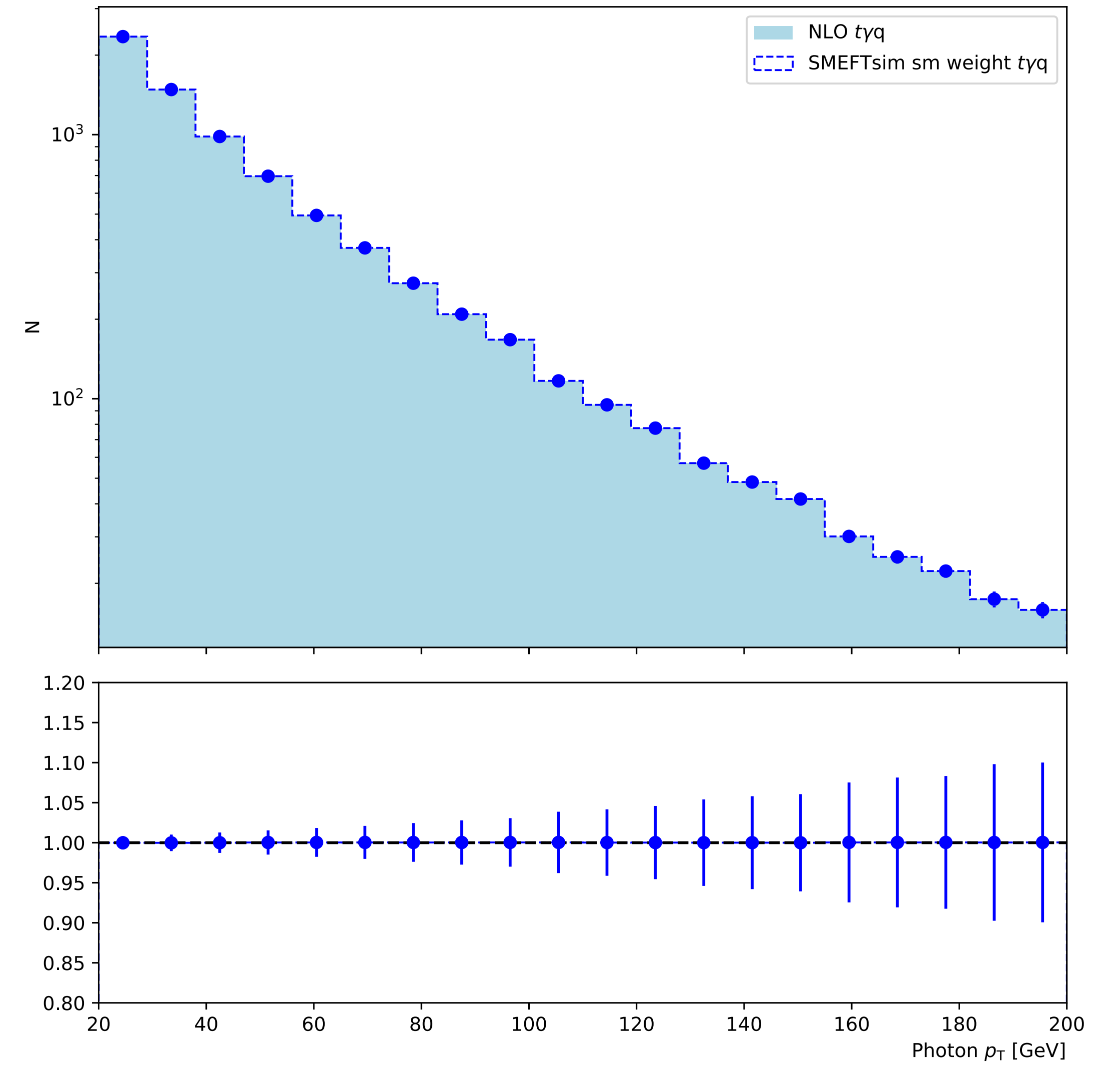


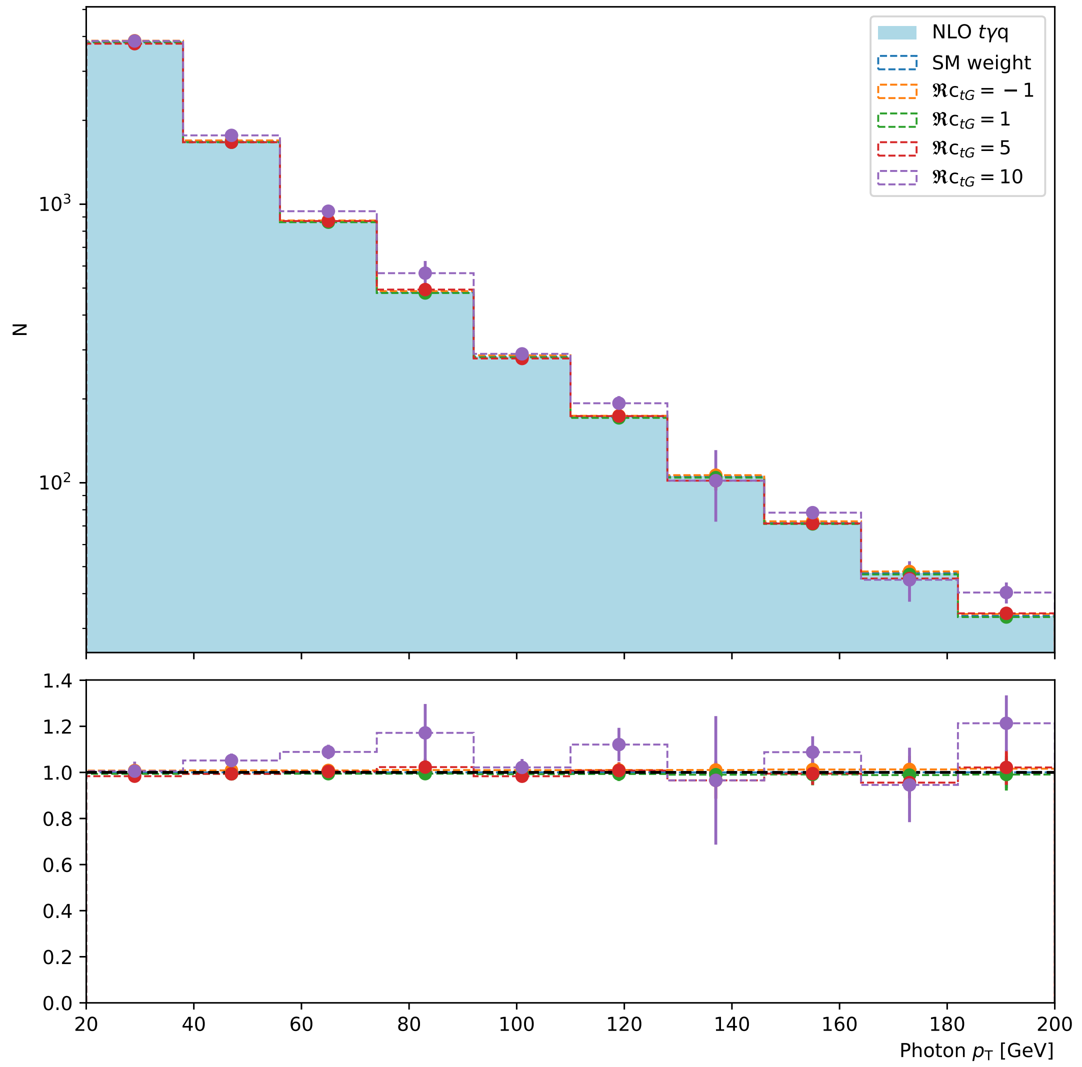
This is a bool variable distribution:

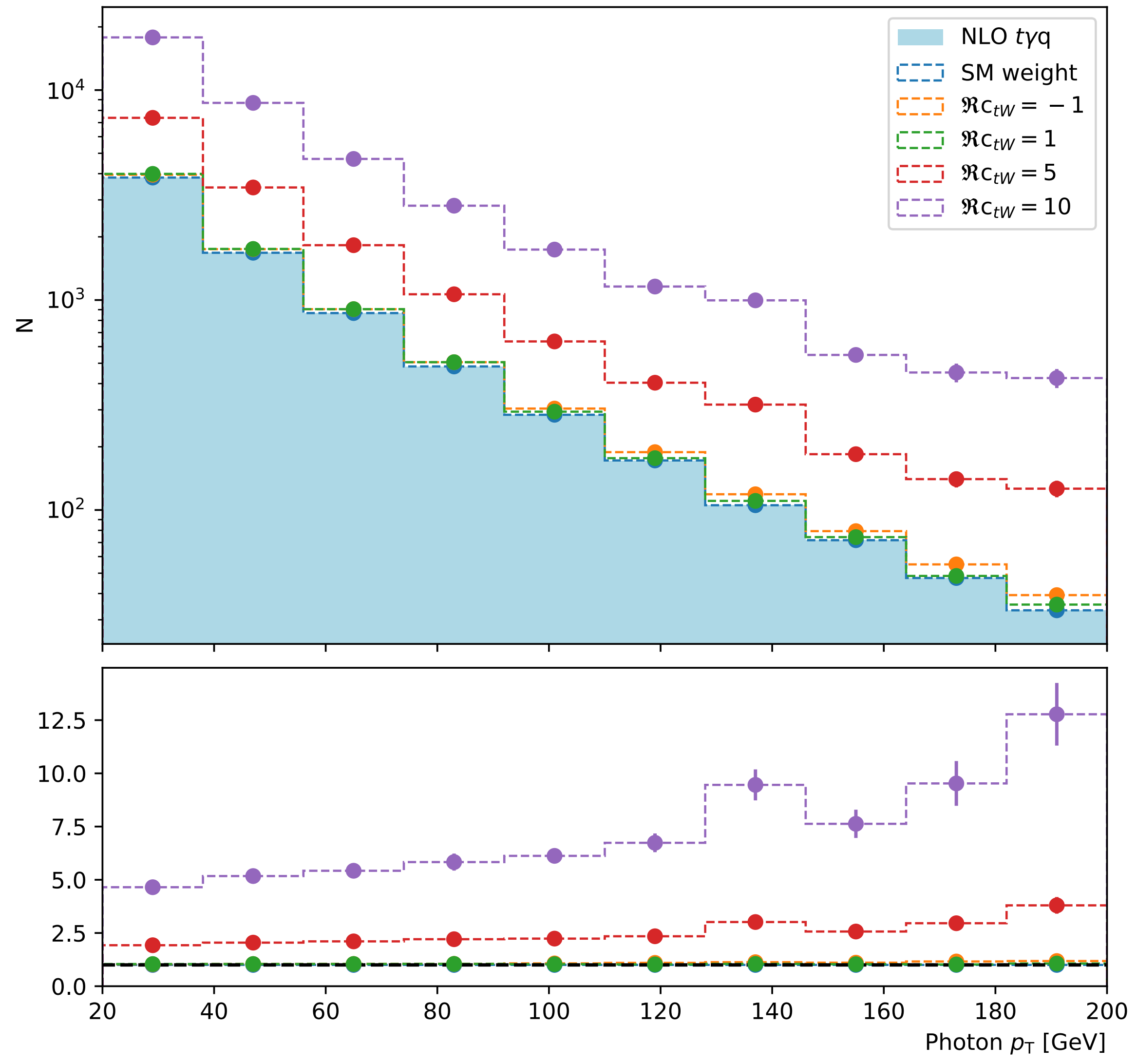
- Almost unmatched events are with negative genweight
- The percent of unmatched to total is 28% less or more before or after selection

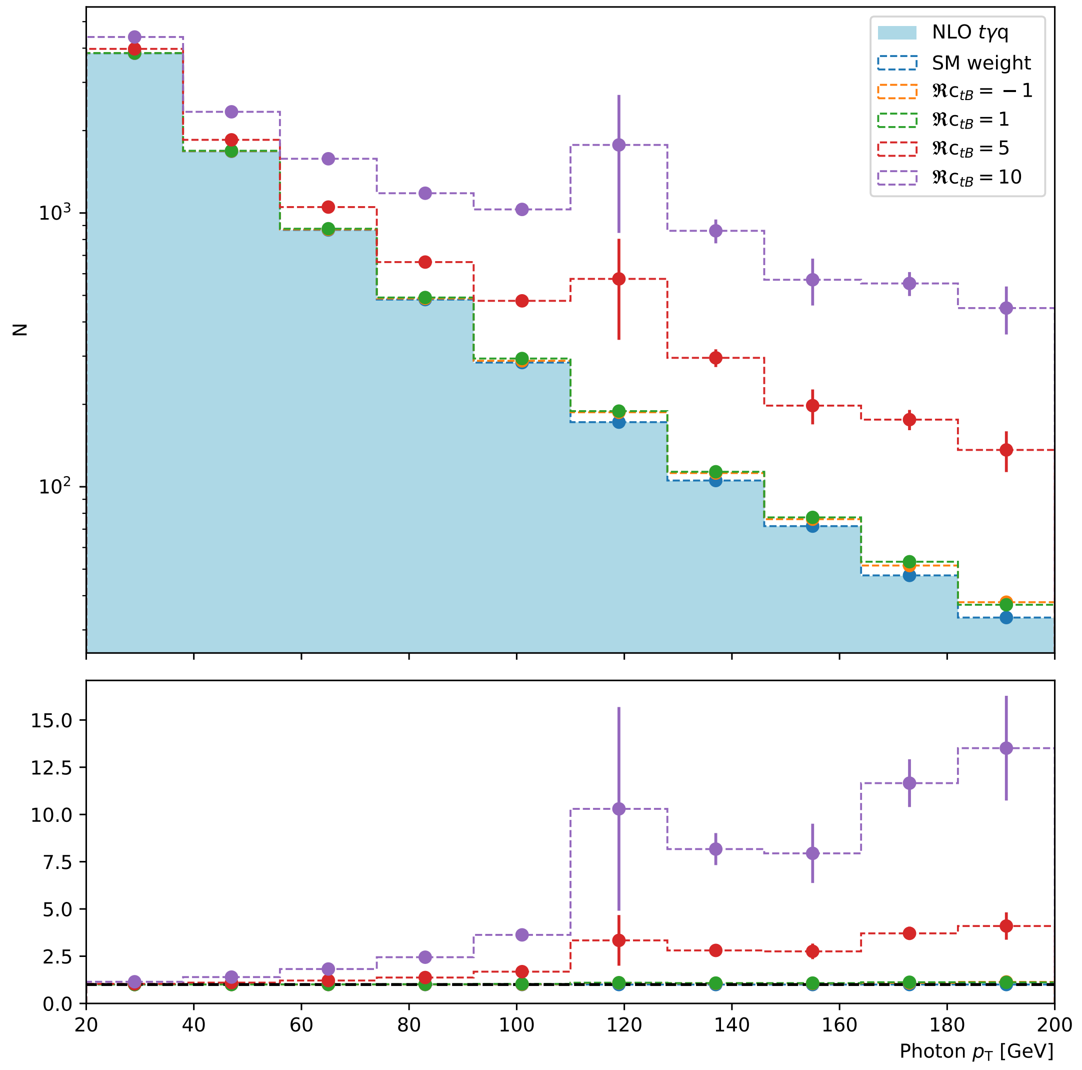
Gen/Reco-level distributions

e+μ channels under gen fiducial region

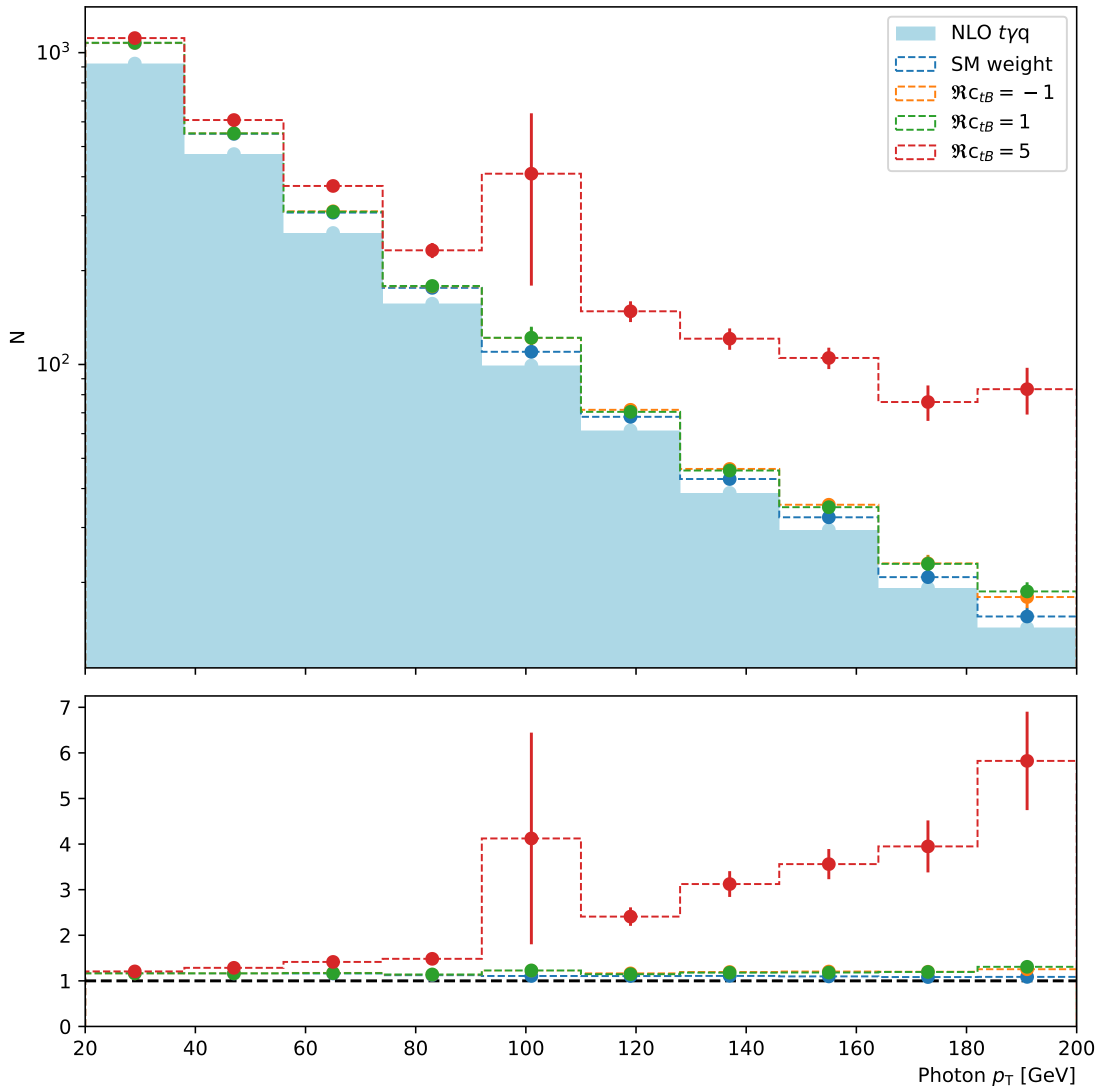


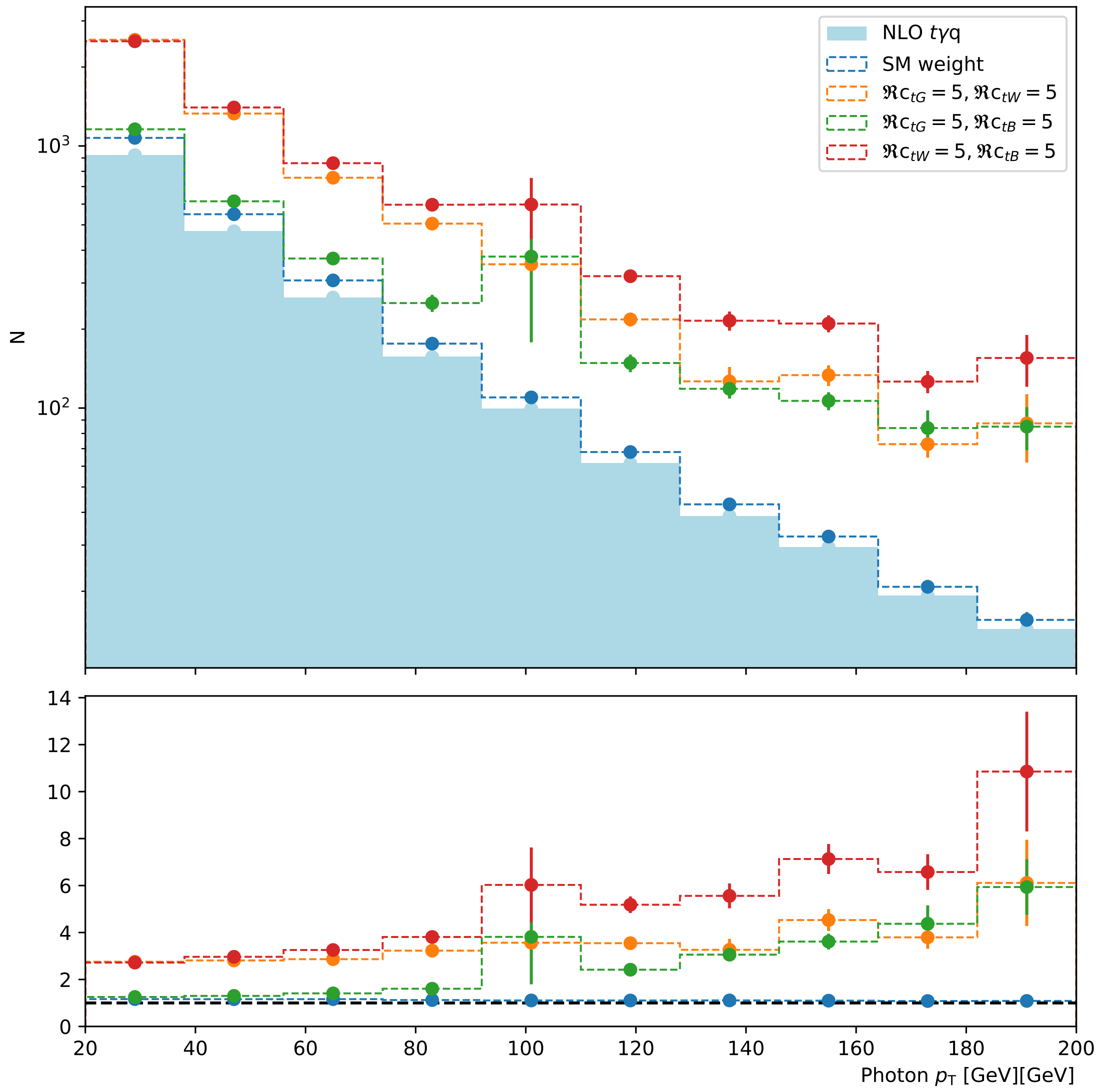


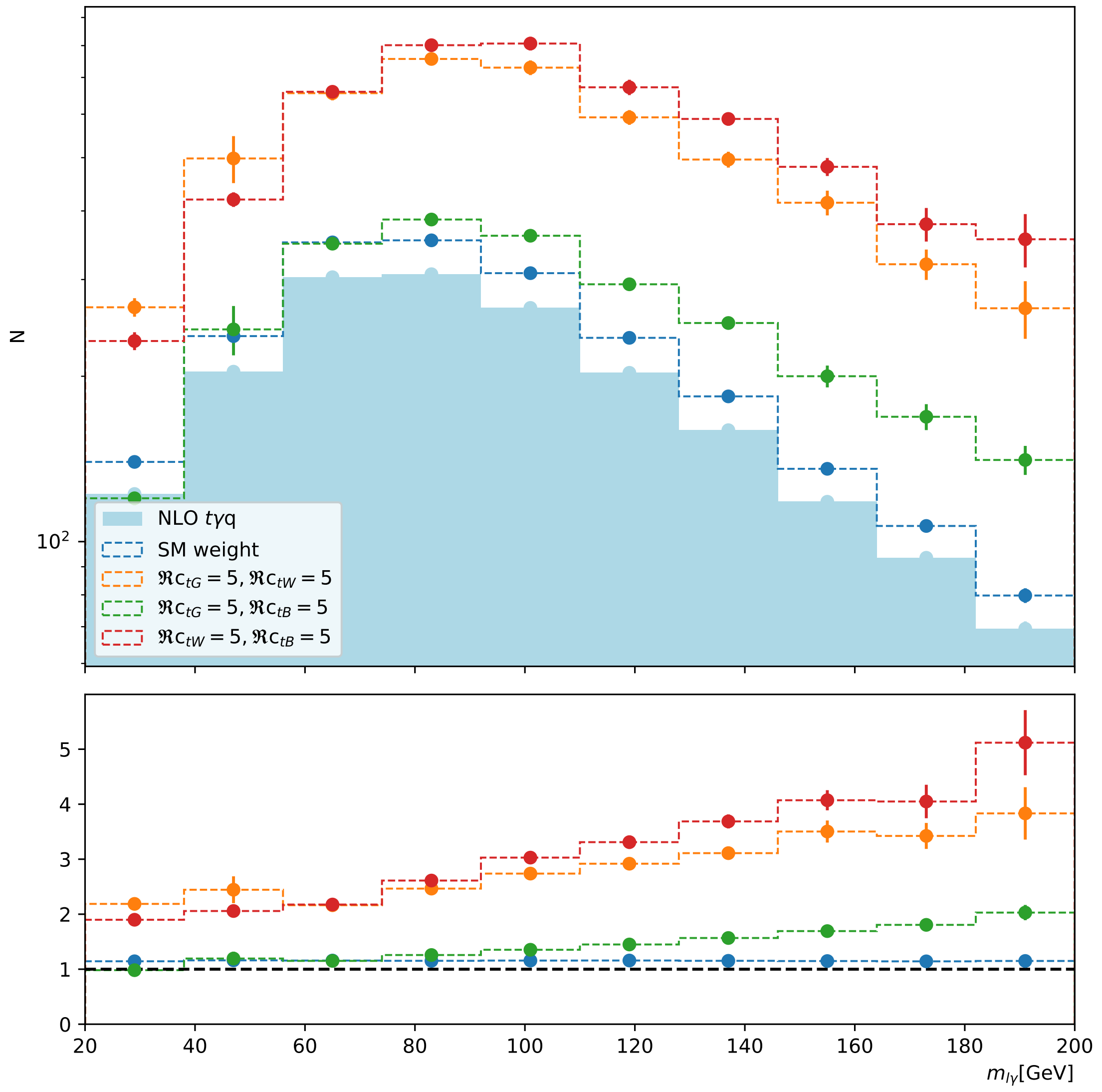


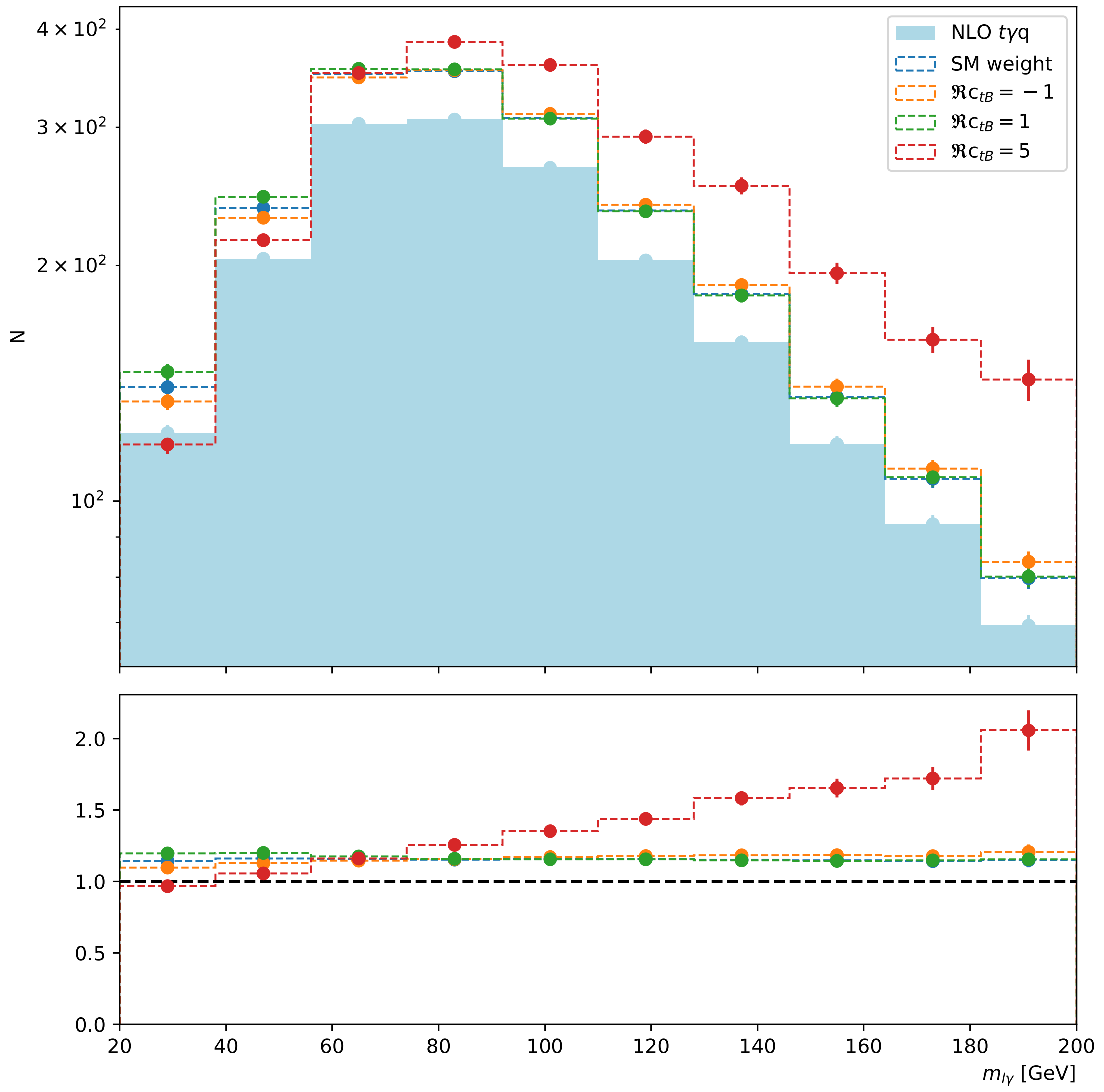


e+μ channels under Reco signal region



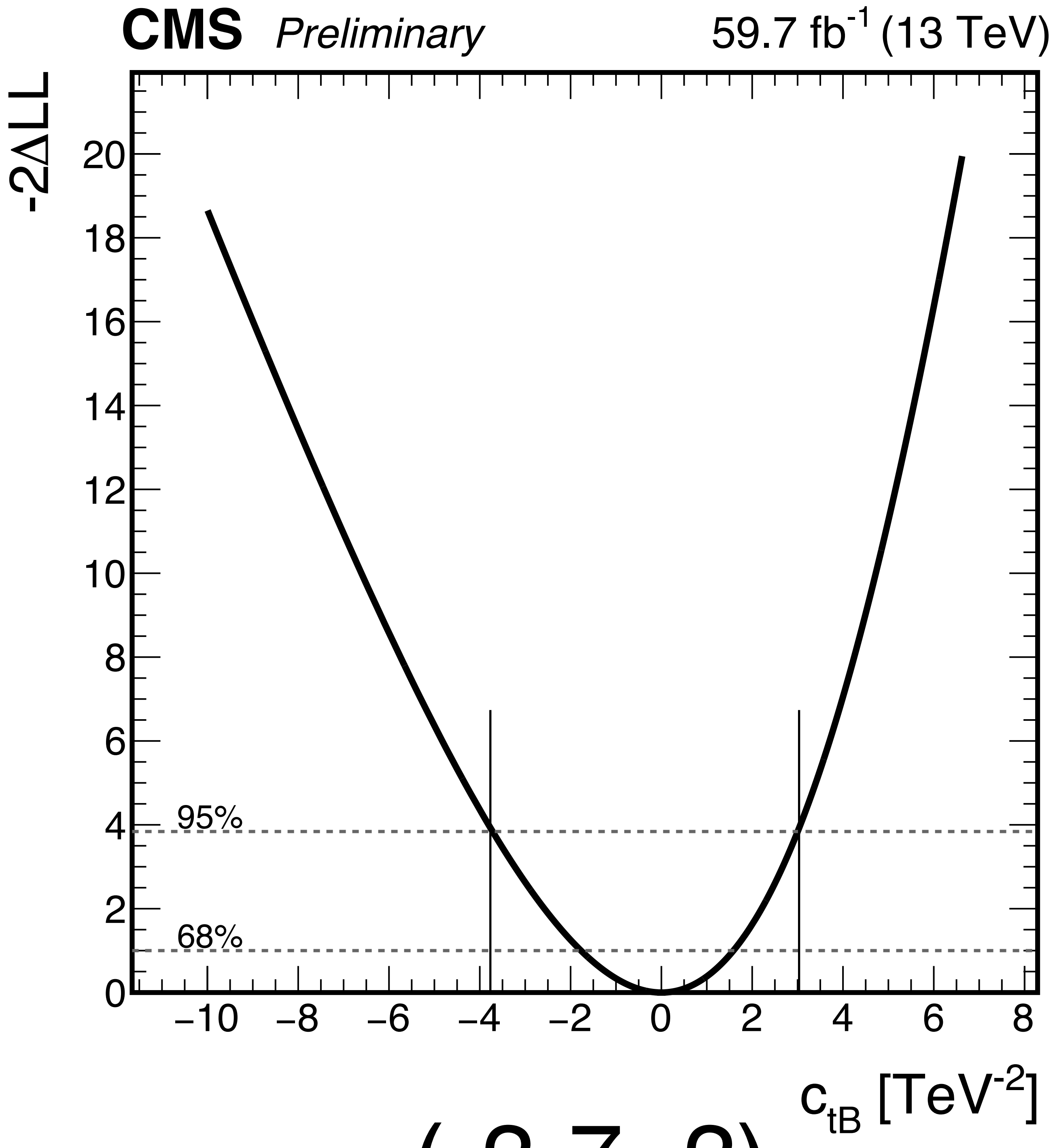




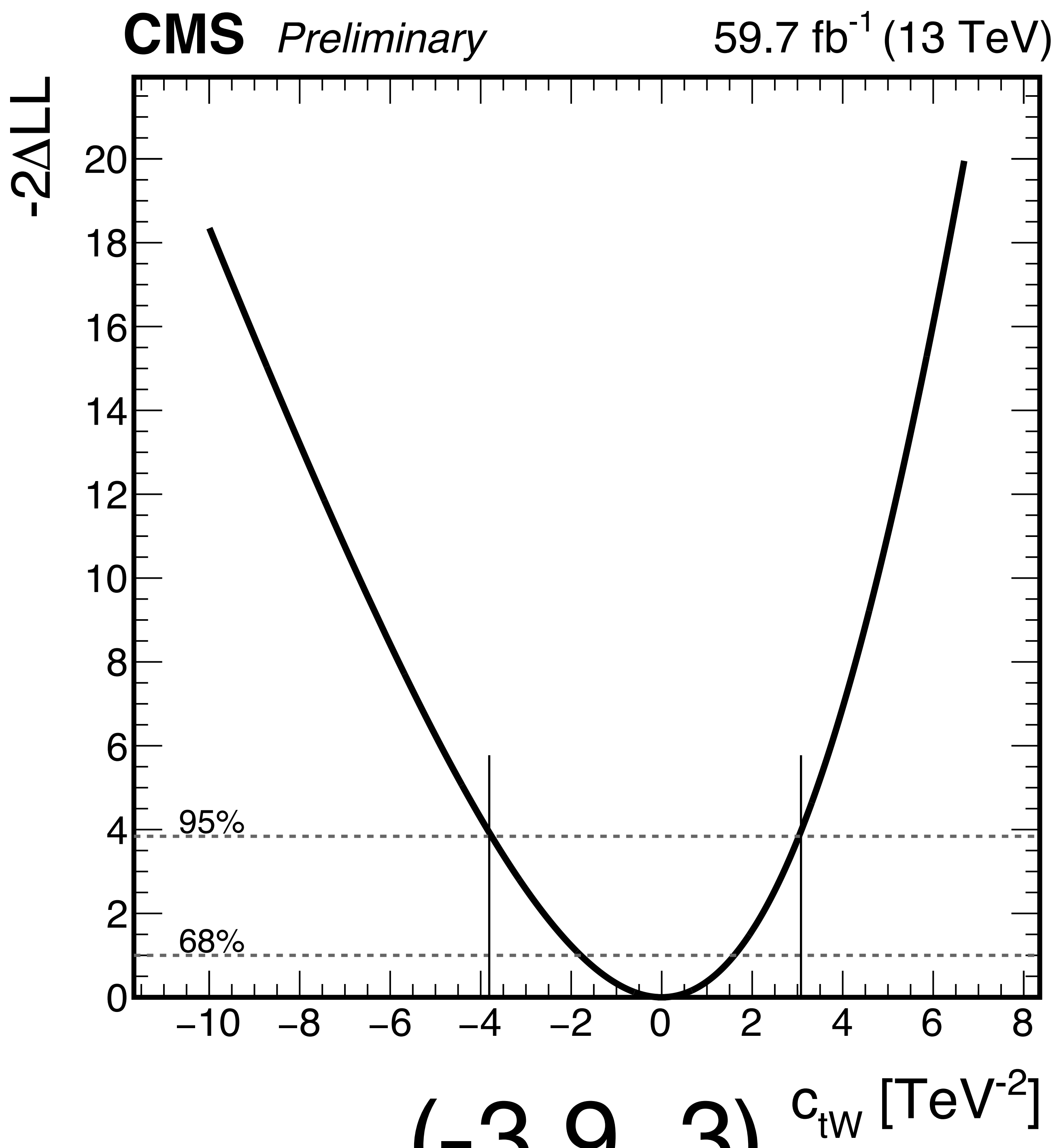


EFT fit result

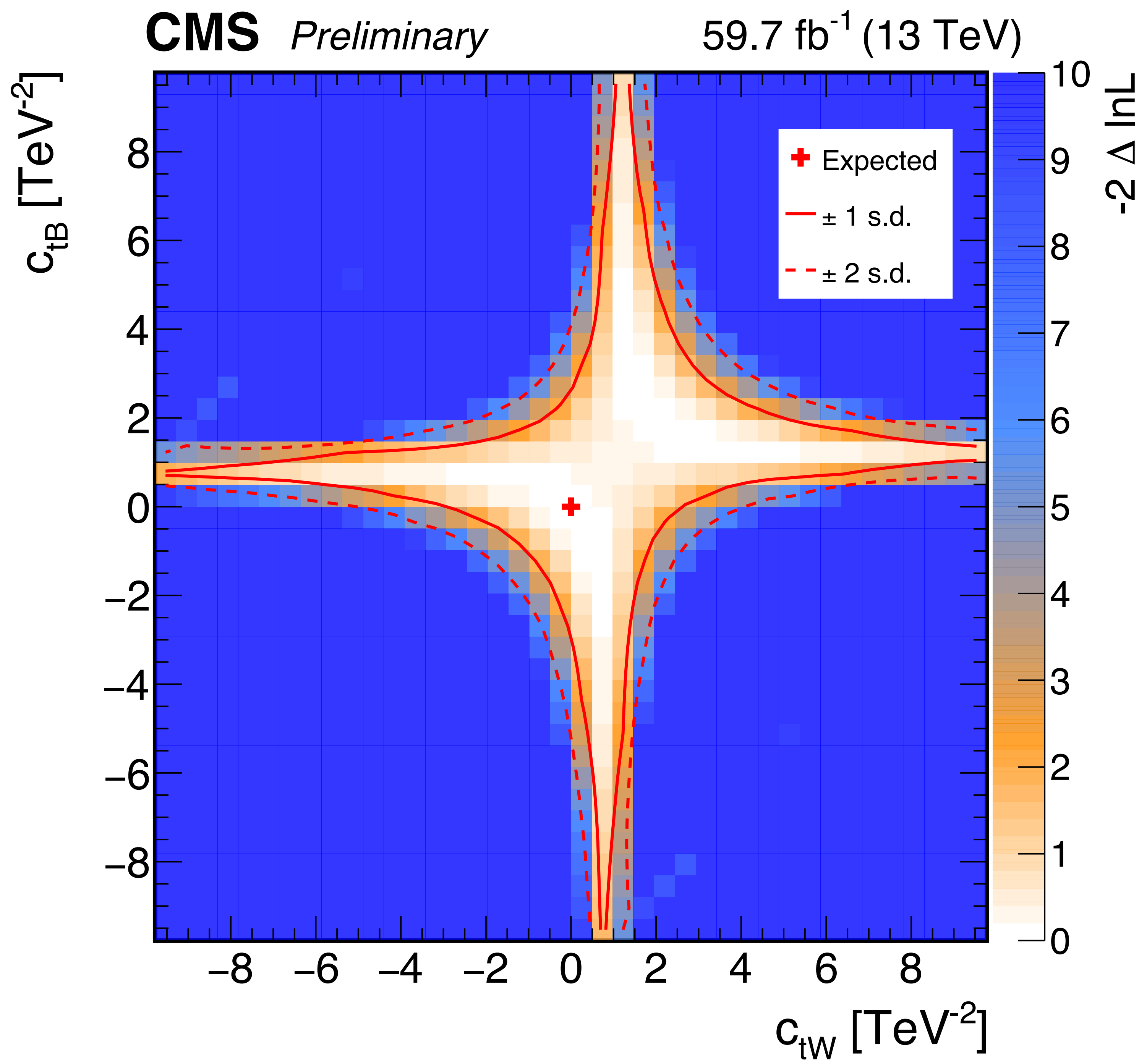
- POIs: the value of the coefficients
- Fit signal region ($N_j \geq 2$, $N_b \geq 1$) in photon p_T distributions
- All uncertainties considered but in lnN style uncertainties → to be update to shape
- Currently the fit is for tγq in 2018 data and MC muon channel



(-3.7, 3)



(-3.9, 3)



Summary

- Present the full run2 simultaneous inclusive tγq+ttγ results
- Present the full run2 simultaneous differential tγq+ttγ results
  - Photon p_T, lepton p_T, and $m_{\ell\gamma}$
- Present the EFT framework for doing the EFT interpretation

  Produce private gridpacks by SM and SMEFTsim models

  Using reweighting approach to add EFT weights into NanoAOD

  Preliminary EFT limits for operators $\Re c_{tG}$, $\Re c_{tW}$, $\Re c_{tB}$ (2018 muon channel)

- Open question for EFT:
  - EFT model: The current model SMEFTsim_topU3l_MwScheme_UFO somehow is not allowed to modify the cpv coefficient aka. the imaginary part
  - Unmatched event: How handle these events? Is that fine to just leave them there?

Discussion

- Timeline: aiming for Moriond25
- Documentation of AN note is in good shape
  → could start the analysis review soon

Available on the CMS information server **CMS AN-23-188**

CMS Draft Analysis Note

The content of this note is intended for CMS internal use and distribution only

2024/10/02
Archive Hash: untracked
Archive Date: 2024/10/02

Differential cross section measurements of single top and $t\bar{t}$ in association with a photon production

Ying An[1], Maria Aldaya[1], Hugo Alberto Becerril Gonzalez[1], Abideh Jafari[2], and Andreas Meyer[1]

[1] DESY, Hamburg, Germany
[2] Isfahan University of Technology, Isfahan, Iran

Abstract

This note presents the study of measuring $t\bar{t}$ and single top in association with a photon simultaneously. Both the inclusive and differential cross sections are measured in proton-proton (pp) collisions at a center-of-mass energy of $\sqrt{s} = 13\,\text{TeV}$, based on the data recorded by the CMS experiment, corresponding to an integrated luminosity of $138\,\text{fb}^{-1}$. Measurements are performed in events with a well-isolated, highly energetic lepton (electron and muon), at least two jets from the hadronization of quarks, and an isolated photon. The photon emitted from initial state radiation, top quark, and top quark decay products, are simulated in separated samples. Differential cross sections as functions of the leading photon transverse momentum, the leading lepton transverse momentum, the number of forward jet transverse momentum, and ΔR of some particles including reconstructed top are presented. The measurement is also carried out differentially in several kinematic observables and interpreted in the context of effective field theories.

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PDFAuthor:	Ying AN, Maria Aldaya, Hugo Becerril, Abideh Jafari, Andreas Meyer
PDFTitle:	Differential cross-section measurements of single top and ttbar in association with a photon production
PDFSubject:	CMS
PDFKeywords:	CMS, single top, top-photon coupling

Please also verify that the abstract does not use any user defined symbols

Backup

Object selection

backup

Electron	Good
p_T/GeV	> 35
|η|	< 2.5 not in ECAL gap
ID	cut-based medium ID
Others	Impact (d_{xy},d_z)

Muon	Good
p_T/GeV	> 30
|η|	< 2.4
ID	cut-based tight ID
Iso	Tight Iso (<0.15)

Photon	Good
p_T/GeV	> 20
|η|	< 2.5 not in ECAL gap
ID	cut-based medium ID
Electron-veto	pixel seed veto

JetMET	Jet	b-jet	MET
p_T/GeV	> 30	> 30	> 20
|η|	< 4.7	< 2.5	—
Type	AK4CHS	AK4CHS	PFMET
ID	tight jet ID Pileup ID (jet p_T<50)	medium deepjet ID	—

- Pileup reweighting
- Lepton energy correction
- Lepton ID/ISO/RECO/HLT scale factors
- e/γPhoton energy scale/smearing
- Photon ID/Pixel Seed Veto scale factors
- Jet energy correction
- Jet pileup ID scale factors (**New**)
- b-jet ID scale factors (**New**)

All corrections are considered

Events of interest: $\mathbf{N_\ell=1, N_\gamma \geq 1, N_j \geq 2, N_b \geq 1}$

- Event ≥ 1 good PV and pass MET Filters and pass high-level trigger
- Exactly one lepton
  - Reject events containing extra ℓ with veto lepton requirement
- At least one photon
- At least two jet with one at least one being b-jet
- $\Delta R(\ell,\gamma) > 0.4, \Delta R(\ell,j) > 0.4, \Delta R(\gamma,j) > 0.4$
- MET p_T > 20 GeV

Significance

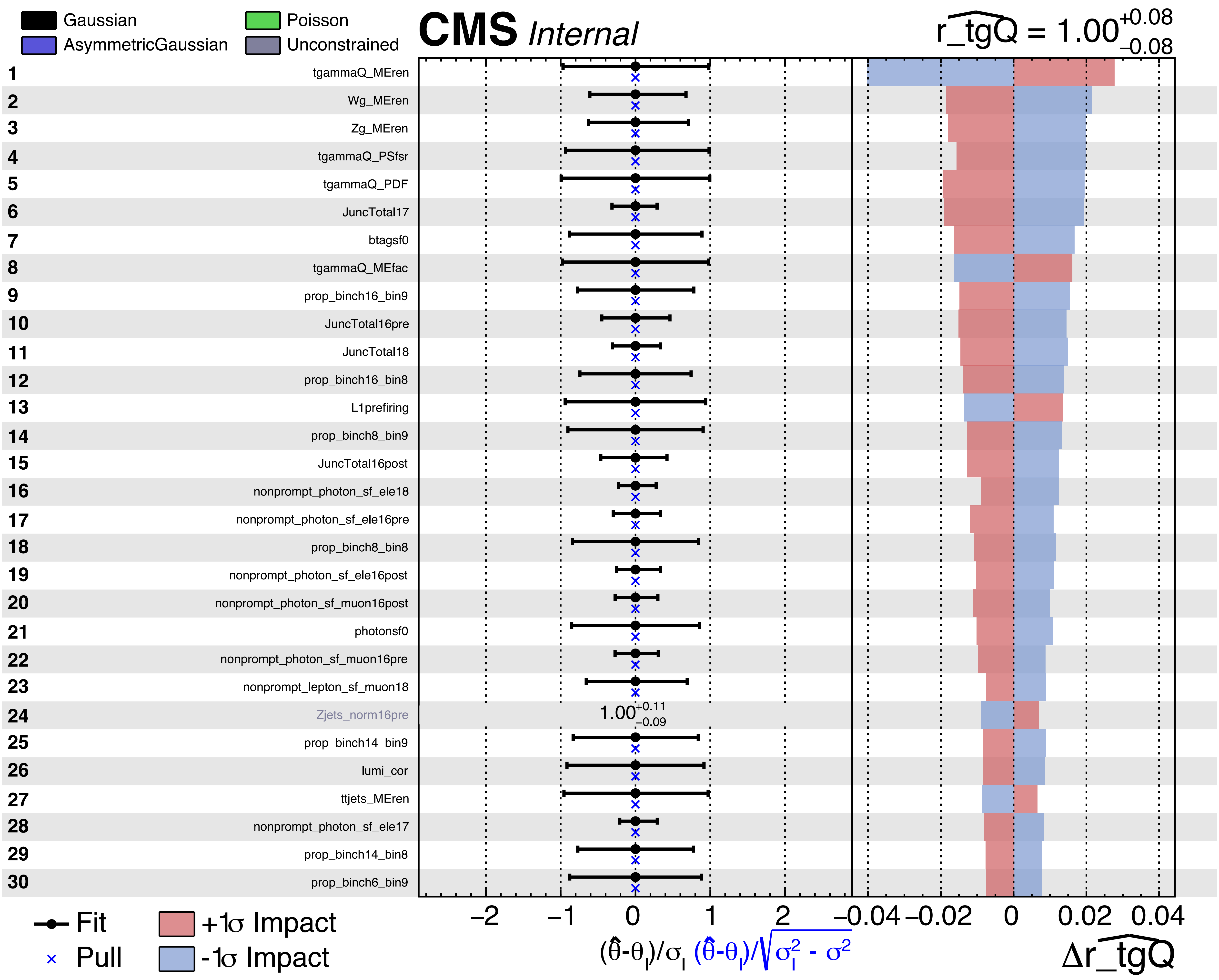
- Perform a simultaneous fit for events in the **signal** and **b-veto control regions**
  - The signal region uses the BDT distribution
  - The control region uses the $m_{\ell\gamma}$ distribution
- POI is signal strengths of $t\gamma$q
- All systematical uncertainties are considered
- rateParam for Z+jets in the electron channel

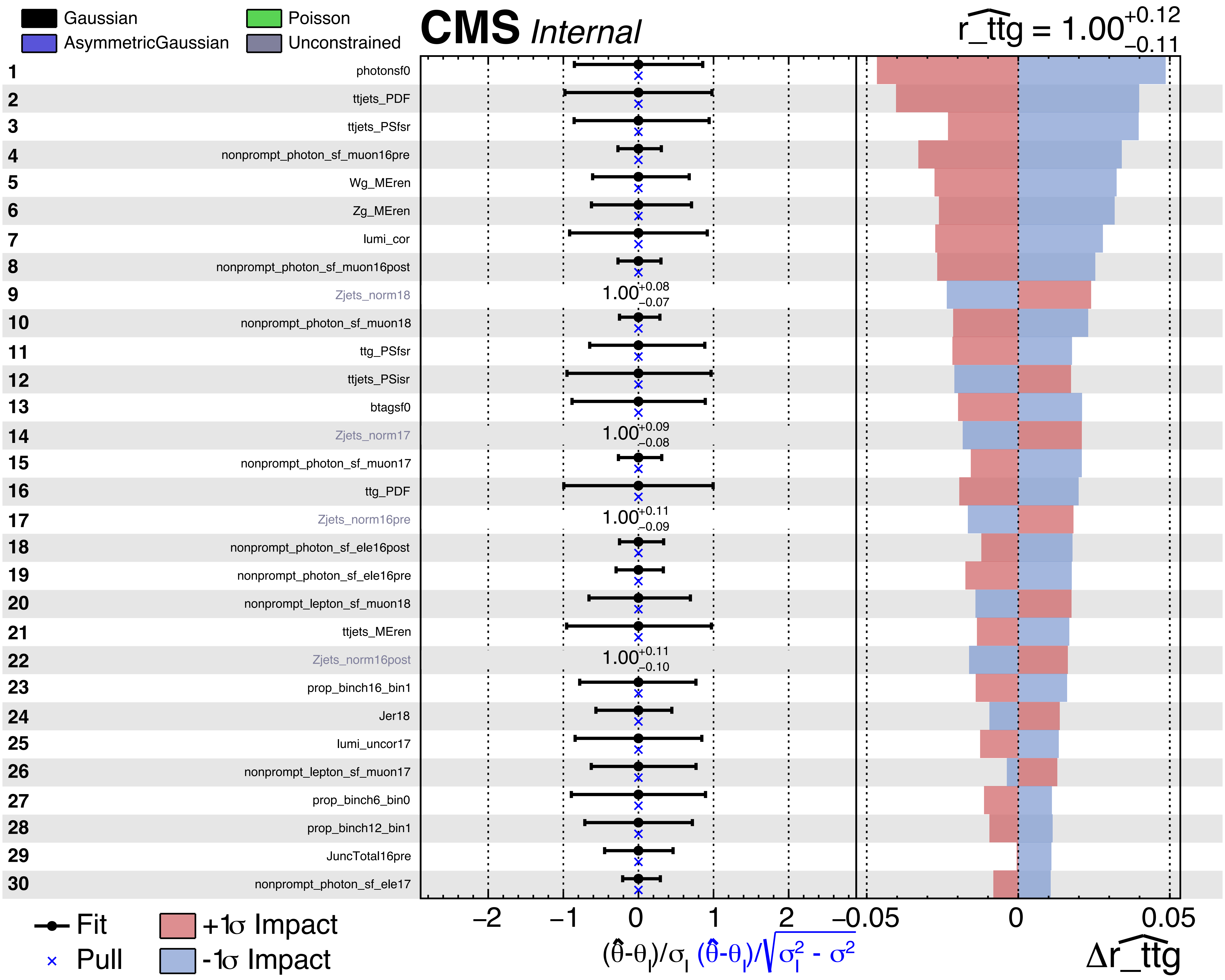
```
combine -M Significance ws_significance_run2.root -t -1 --expectSignal=1

- Significance --

Significance: 19.158
```

Simultaneous inclusive fit — impact





SMEFT model

- SMEFTsim (2012.11343): only LO mode

    SMEFTsim_topU3l_MwScheme_UFO: A case with a $U(2)^3$ symmetry in the quark sector and a $U(3)^2$ symmetry in the lepton sector

    Wilson coefficients expressed in terms of their real and imaginary parts, rather than absolute values, correspond to CP conserving (violating)

    $\Re c_{tG}$, $\Re c_{tW}$, $\Re c_{tB}$ are selected to do reweighting

[1] https://feynrules.irmp.ucl.ac.be/wiki/SMEFT#no1

Workflow

Prepare MG cards (reweighting card)

Get reweighing model from MG5

Reweight NanoAOD events by branch LHEPart_*

An extra branch Reweights is added into NaNoAOD

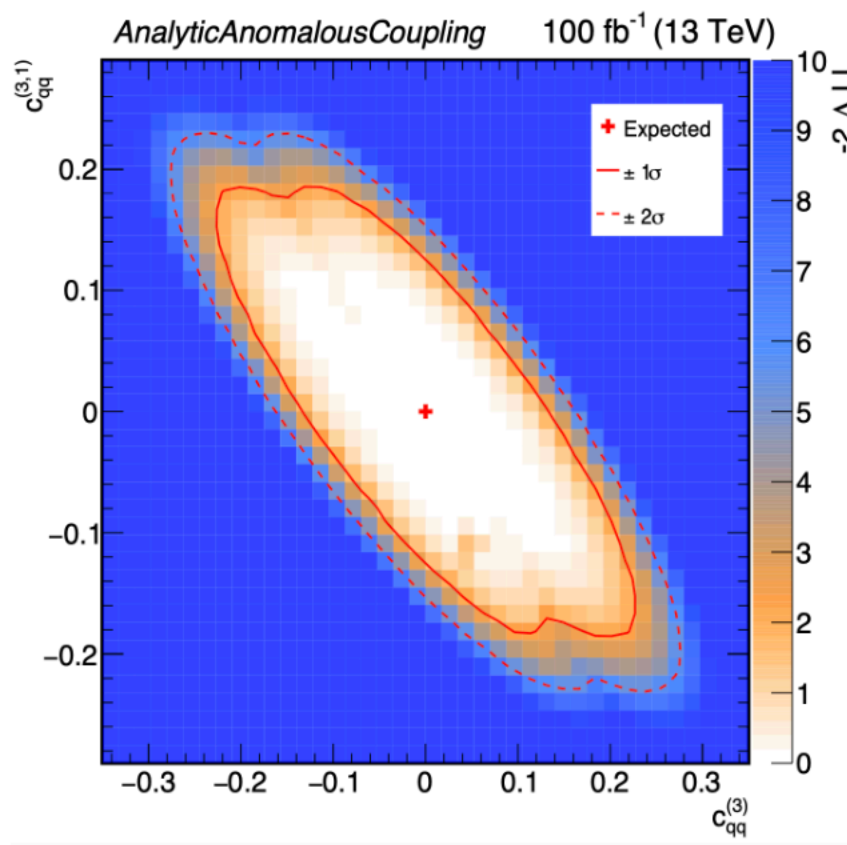
SM, Linear, Quad parts

AnomalousCouplingEFTNegative

```
## Shape input card
imax 1 number of channels
jmax * number of background
kmax * number of nuisance parameters
-----------------------------------------------------------------------------------------------------
bin         inWW_cW
observation 0
shapes  *          * shapes/histos_inWW_cW.root     histo_$PROCESS histo_$PROCESS_$SYSTEMATIC
shapes  data_obs         * shapes/histos_inWW_cW.root      histo_Data
bin              inWW_cW                       inWW_cW                       inWW_cW
process          sm                            sm_lin_quad_cW                quad_cW
process          1                             2                             3
rate             30611.7690                    34426.6029                    3957.9833
-----------------------------------------------------------------------------------------------------
lumi  lnN        1.02                          1.02                          1.02
-----------------------------------------------------------------------------------------------------
```

$$
\begin{cases}
\omega_{\text{Quad}} = 0.5 \cdot \left[\omega(k=1) + \omega(k=-1) - 2 \cdot \omega(k=0)\right] \\
\omega_{\text{SM}} = \omega(k=0) \\
\omega_{\text{Lin}} = 0.5 \cdot \left[\omega(k=1) - \omega(k=-1)\right]
\end{cases}
$$

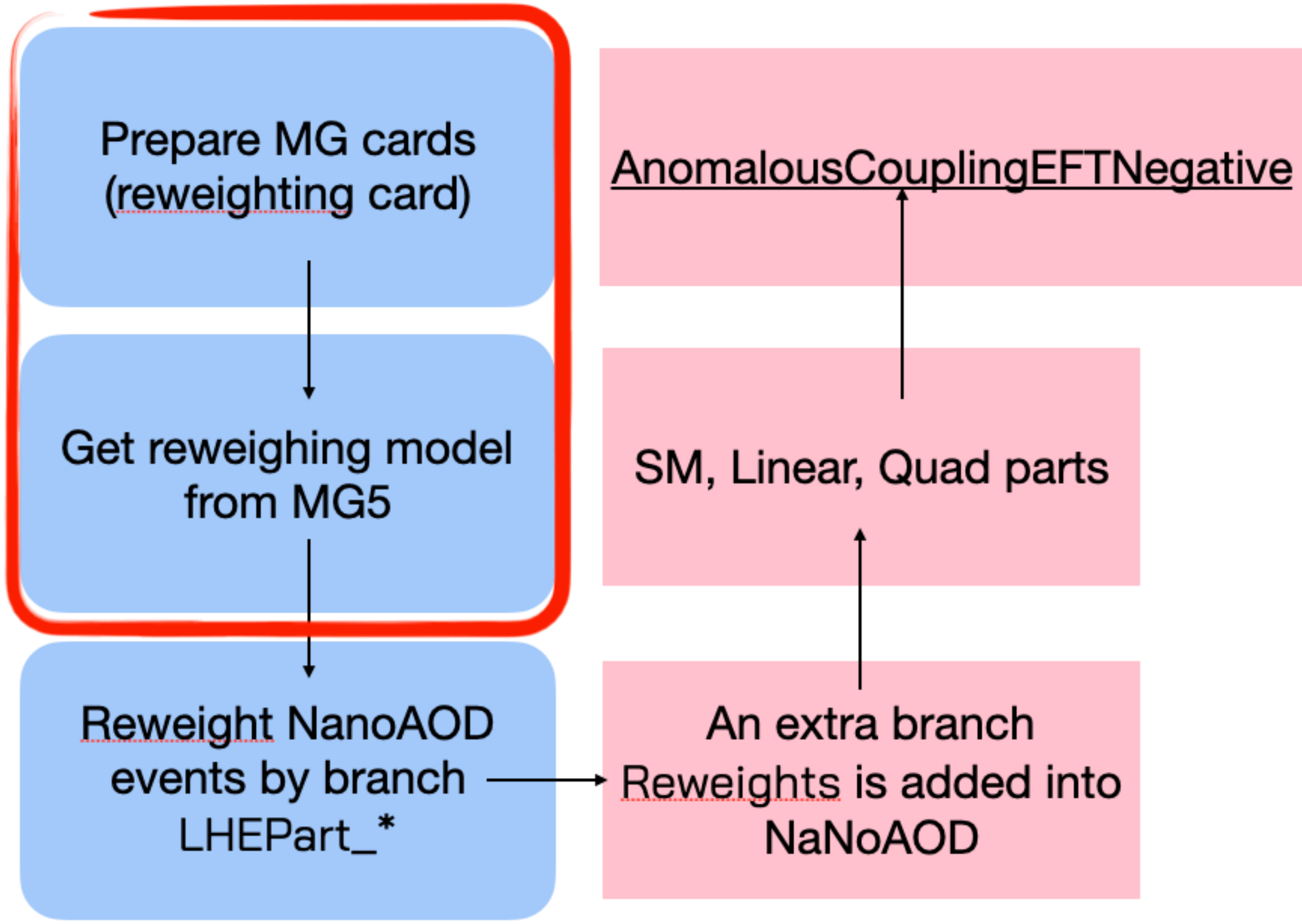
$$
\omega_{\text{Mix}} = \omega(1,1) + \omega(0,0) - \omega(1,0) - \omega(0,1)
$$



EFT sample

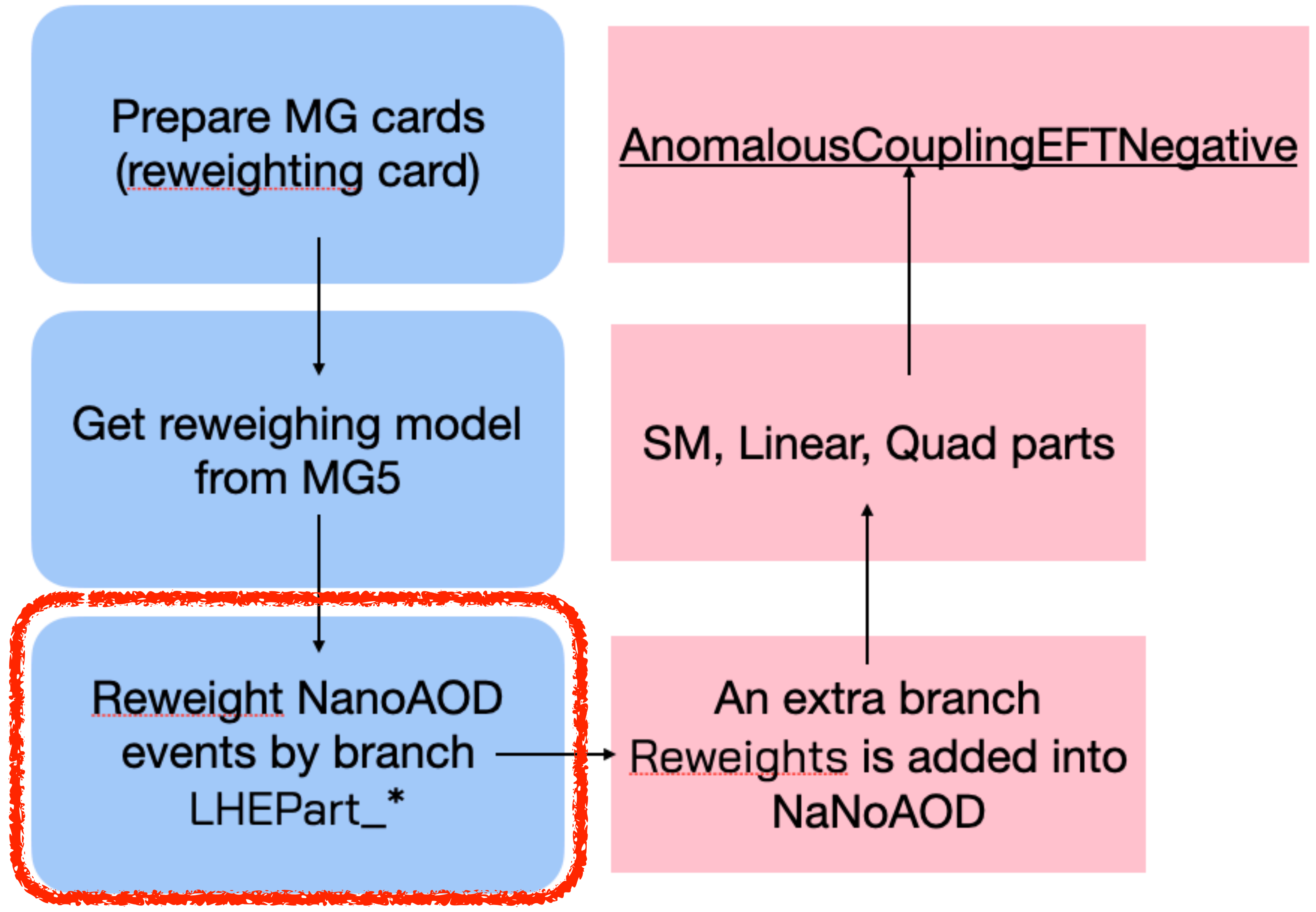
- ✳ Official SM NLO tγq production with 4f scheme (no FSR)
- ✳ Private SM LO tγq production with 4f scheme (no FSR)
- ✳ Private SMEFTsim LO tγq production with 4f scheme (no FSR)

- ✦ Official SM NLO $t\bar{t}\gamma$ production with 5f scheme (no FSR)
- ✦ Official SM LO $t\bar{t}\gamma$ production with 4f scheme
- ✦ Private SM LO $t\bar{t}\gamma$ production with 4f scheme (no FSR)
- ✦ Private SMEFTsim LO $t\bar{t}\gamma$ production with 4f scheme (no FSR)



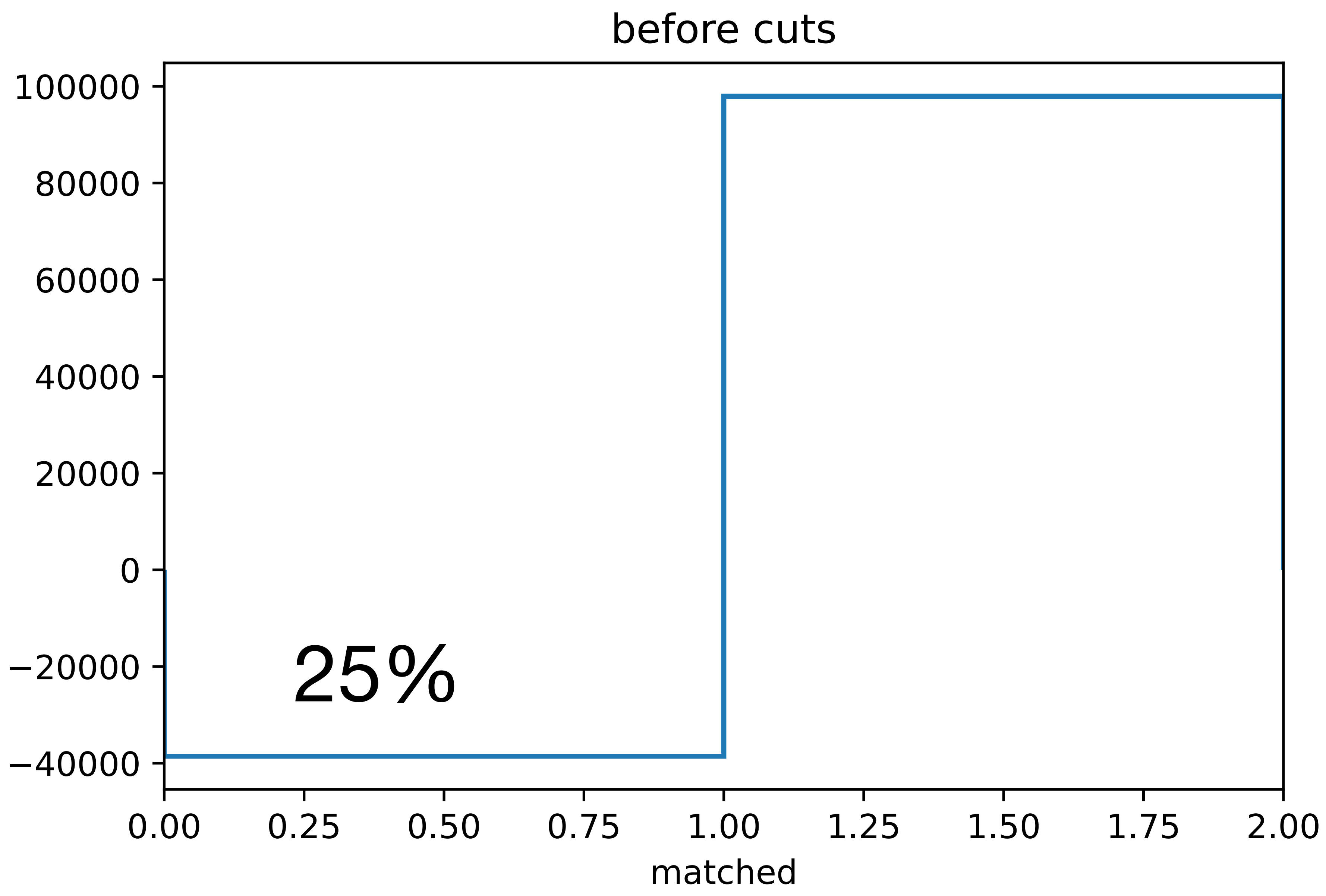
The signal samples used in our SM measurement are both NLO sample for tγq+ $t\bar{t}\gamma$, so a private LO SM gridpacks are produced to validate our EFT sample

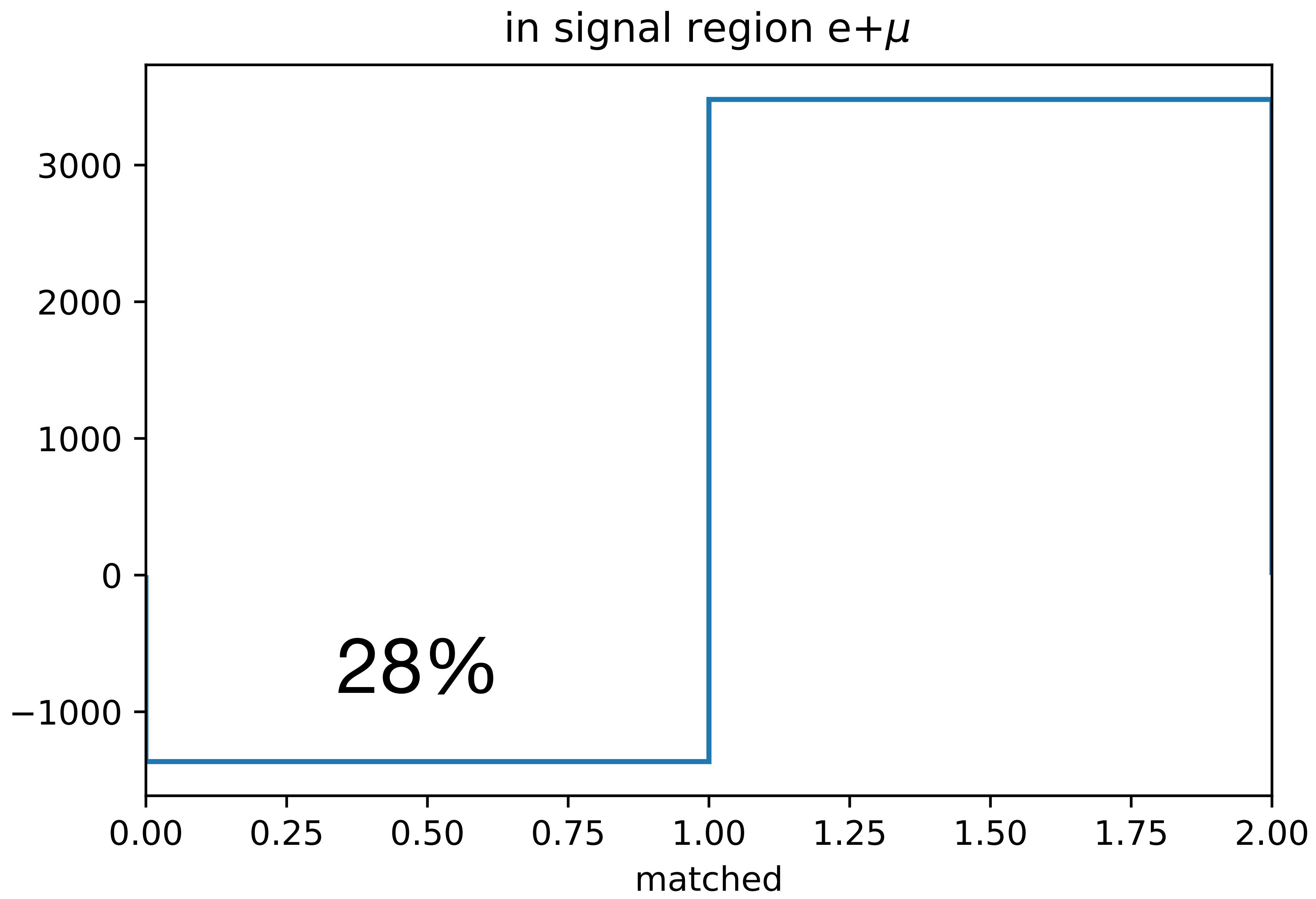
Reweight to NanoAOD



It's doing a mapping from a PDG list got from MG5 production to NanoAOD LHEPart:

1. If the NanoAOD LHE event can be matched to the PDG list, we get the reweight $= w_{\text{ori}}^{\text{NLO}} \times \dfrac{w_i^{\text{LO}}}{w_{sm}^{\text{LO}}}$
2. If the NanoAOD LHE events can't be matched to the PDG list, the Reweights are just same as the generator weight





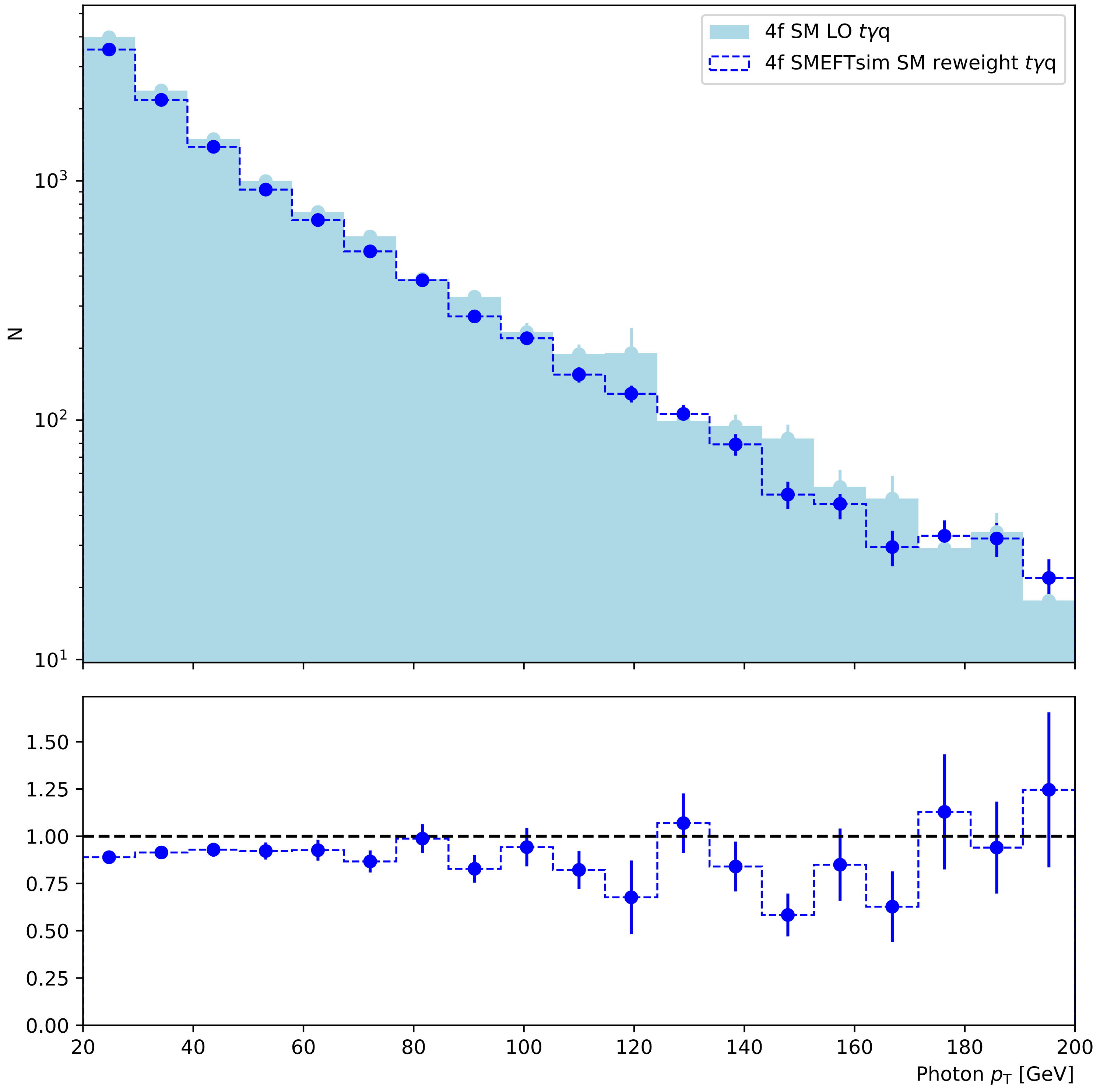
This is a bool variable distribution:

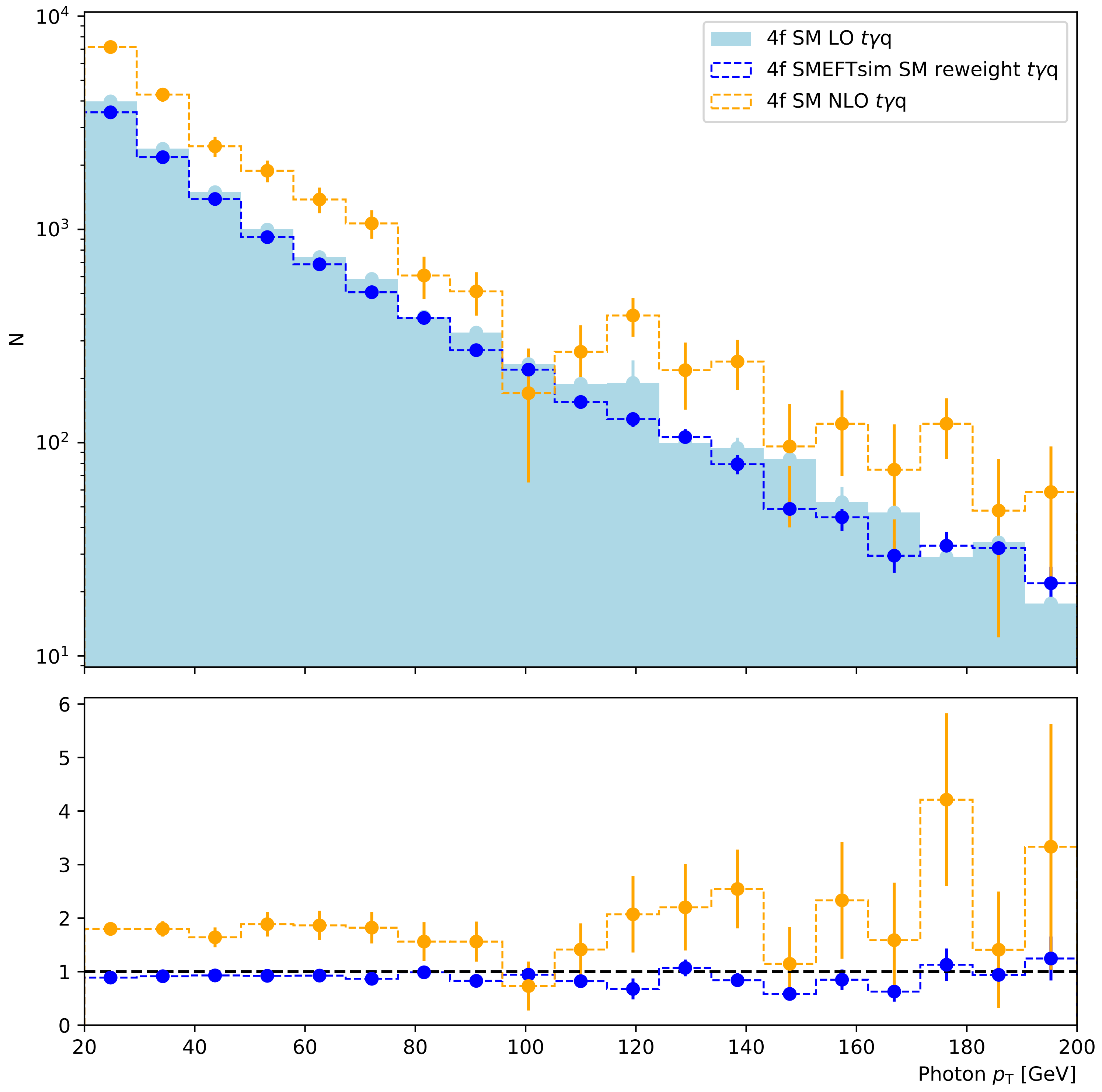
- Almost unmatched events are with negative genweight
- The percent of unmatched to total is 28% less or more before or after selection

EFT sample validation — tγq

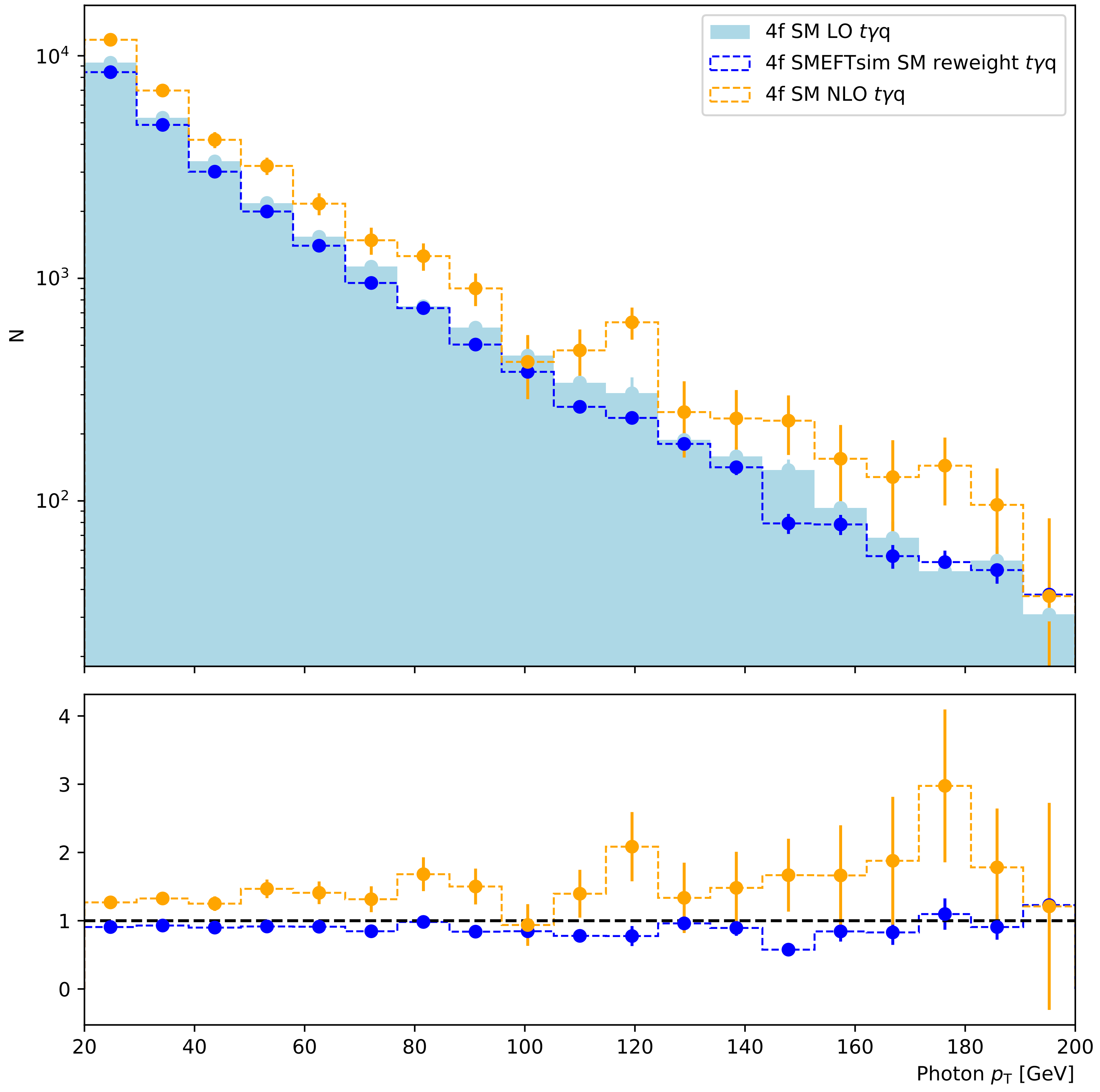
LHE level

Selection: **N$_\ell$=1, N$_\gamma$ ≥1, N$_j$≥1, N$_b$≥1** with p_T > 20, 20, and 30 GeV





Without any selection

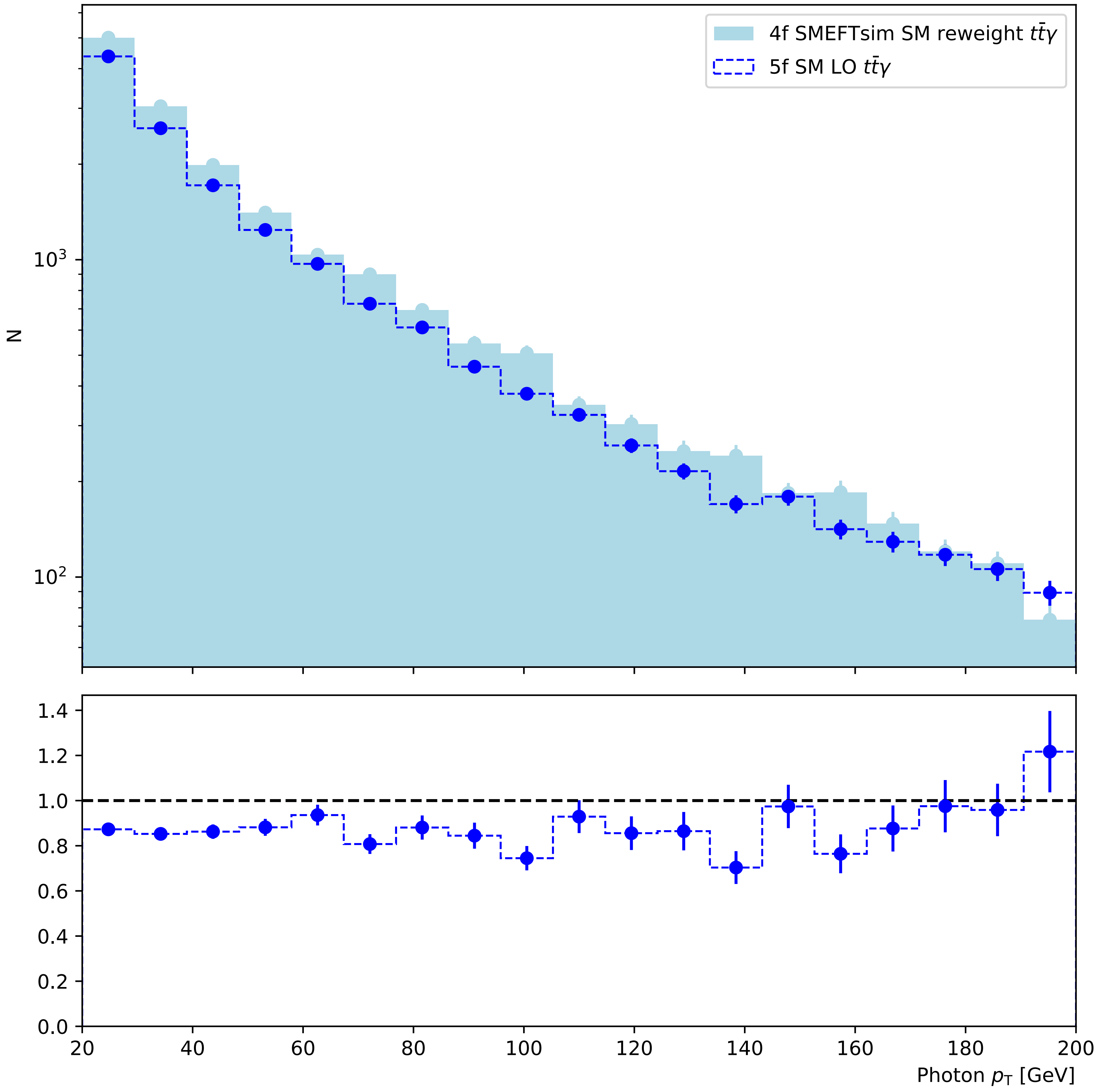


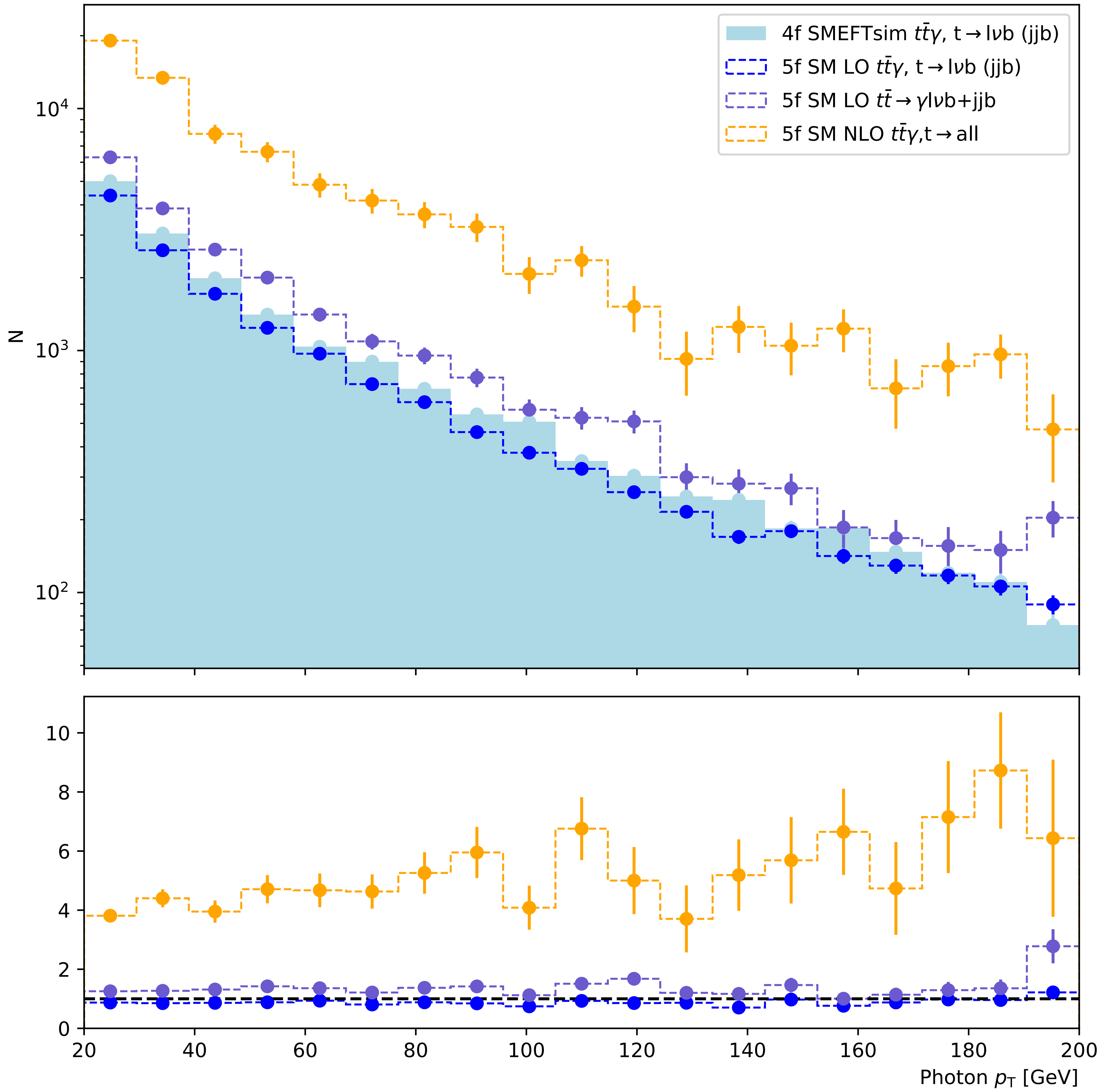
The agreement between EFT sample with SM reweight and SM LO sample looks reasonable in shape.
The difference in normalisation should come from the cross section values.

XS/process	NLO tγq	LO tγq	EFT tγq with SM
Cross section/pb	0.992 +- 0.004	0.72 +- 0.003	0.82 +- 0.1

EFT sample validation — ttγ

LHE level   Selection: **$N_\ell \geq 1$, $N_\gamma \geq 1$, $N_j \geq 1$** with p_T > 20, 20, and 30 GeV



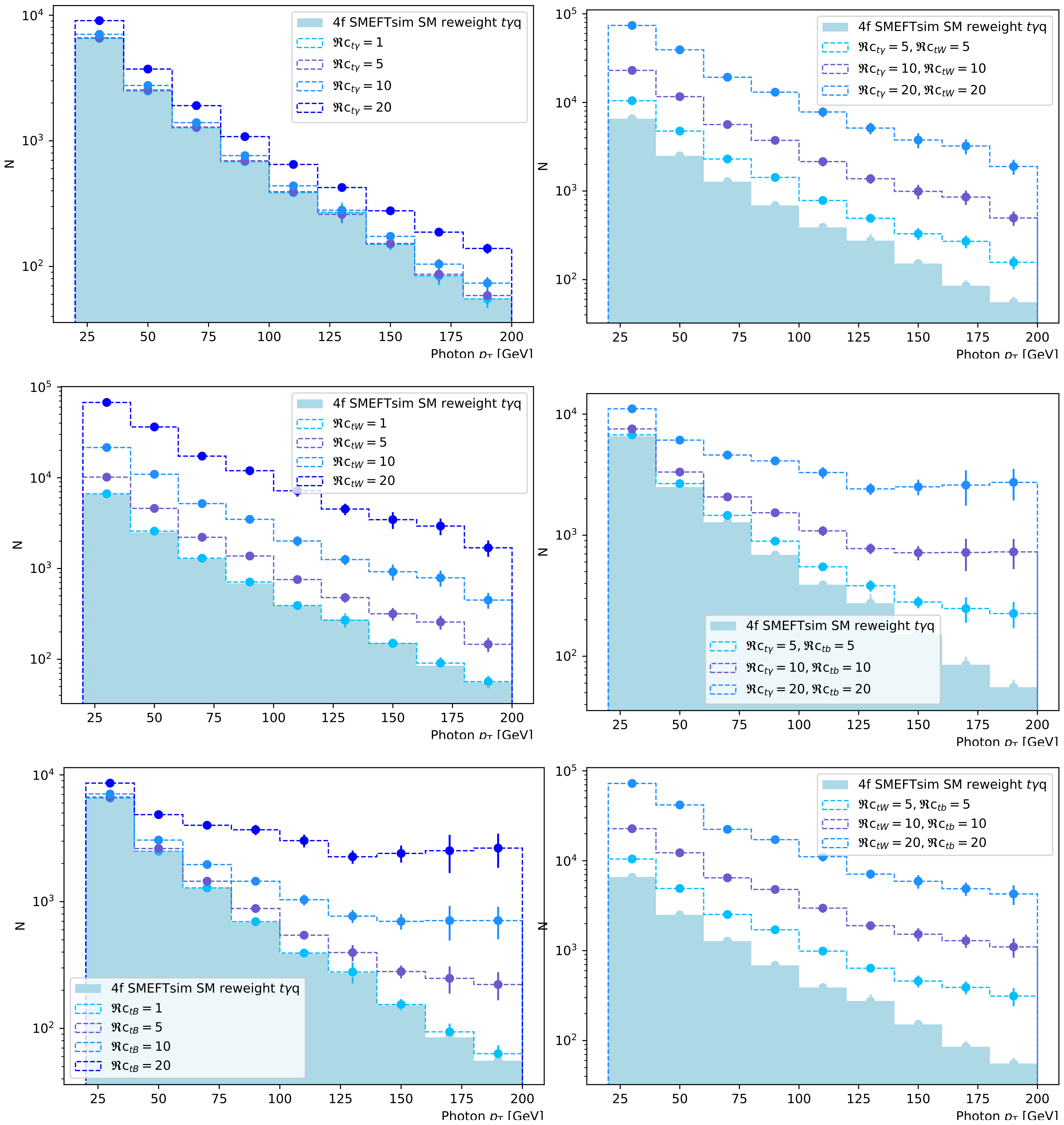


Similar case that no shape effect. But the normalisation difference between LO and NLO is really large.

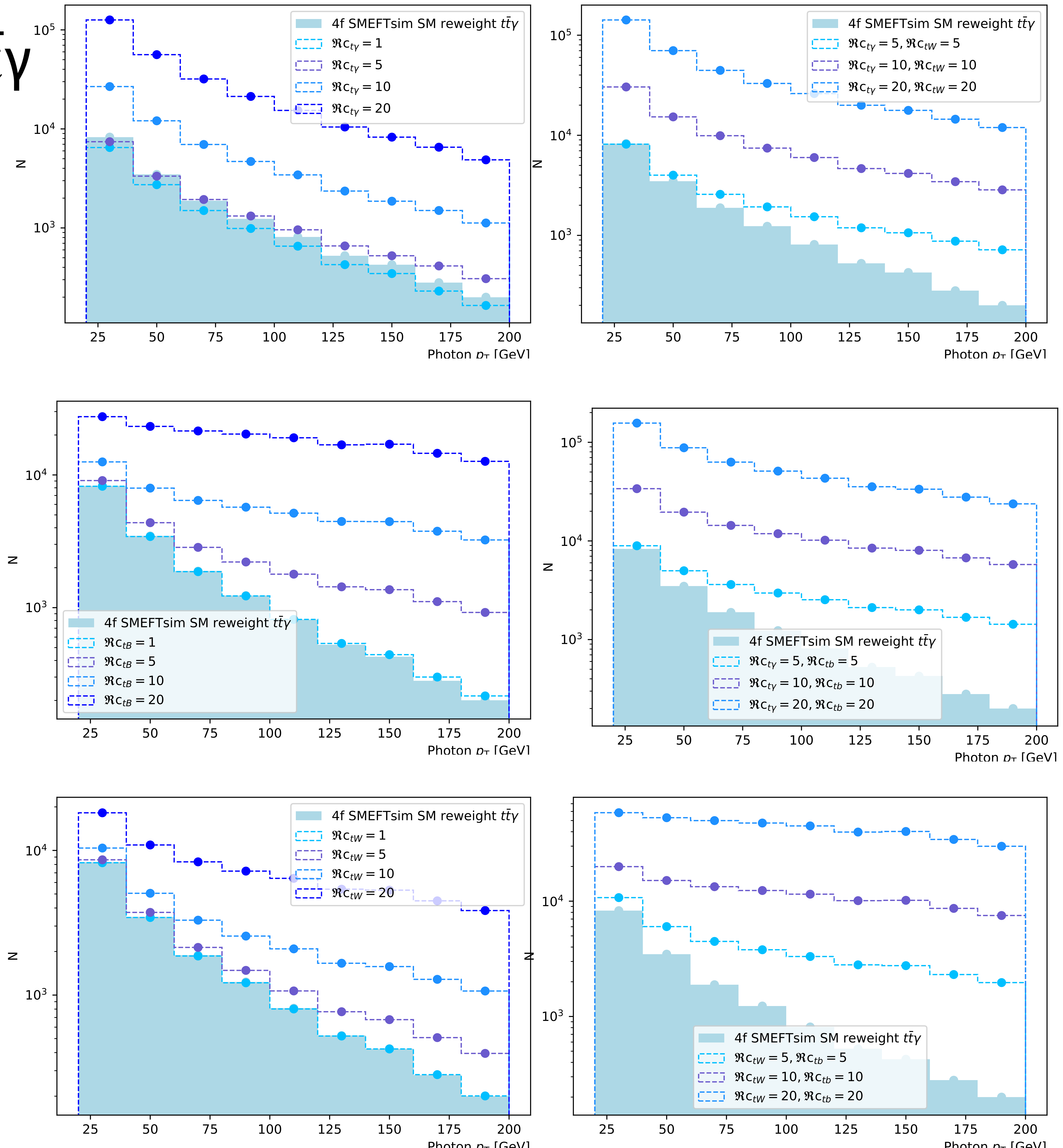
XS/process	NLO ttγ	LO ttγ (with FSR)	LO ttγ	EFT ttγ with SM weight
Cross section/pb	2.58 +- 0.005	5.121 +- 0.004	0.6145 +- 0.002	0.73 +- 0.08

Photon p_T distributions — LHE-level

tγq

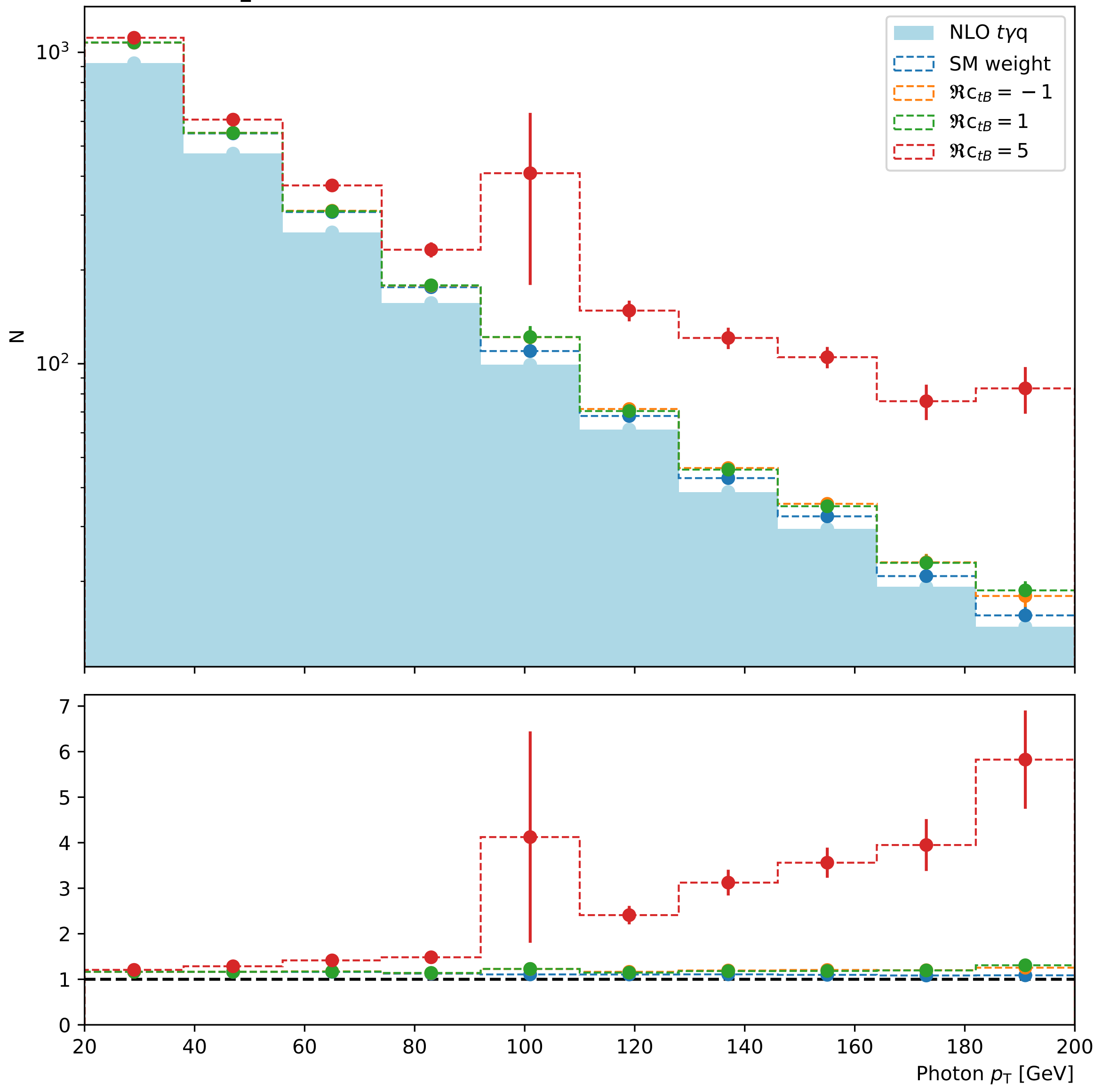


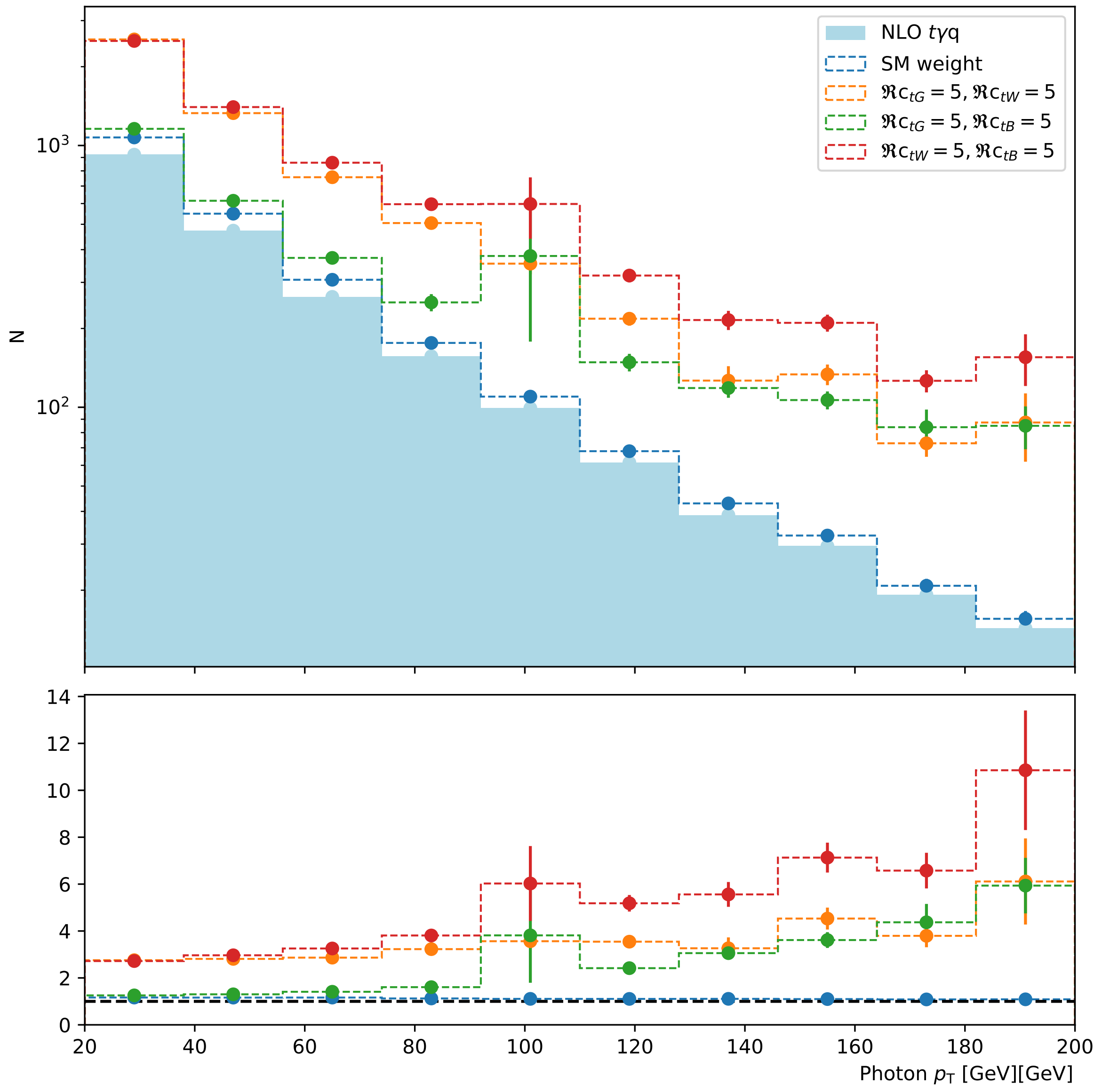
$t\bar{t}\gamma$

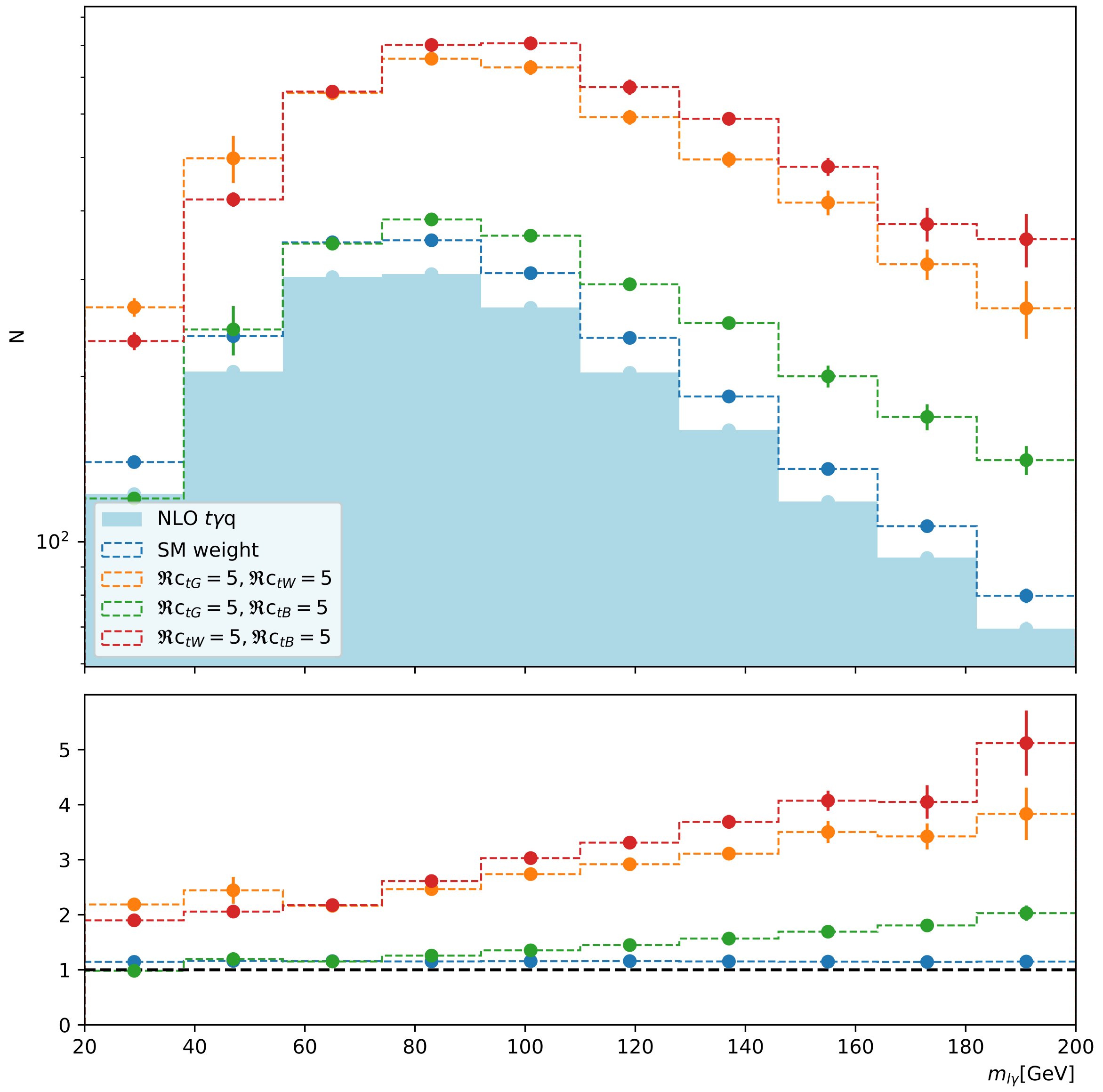


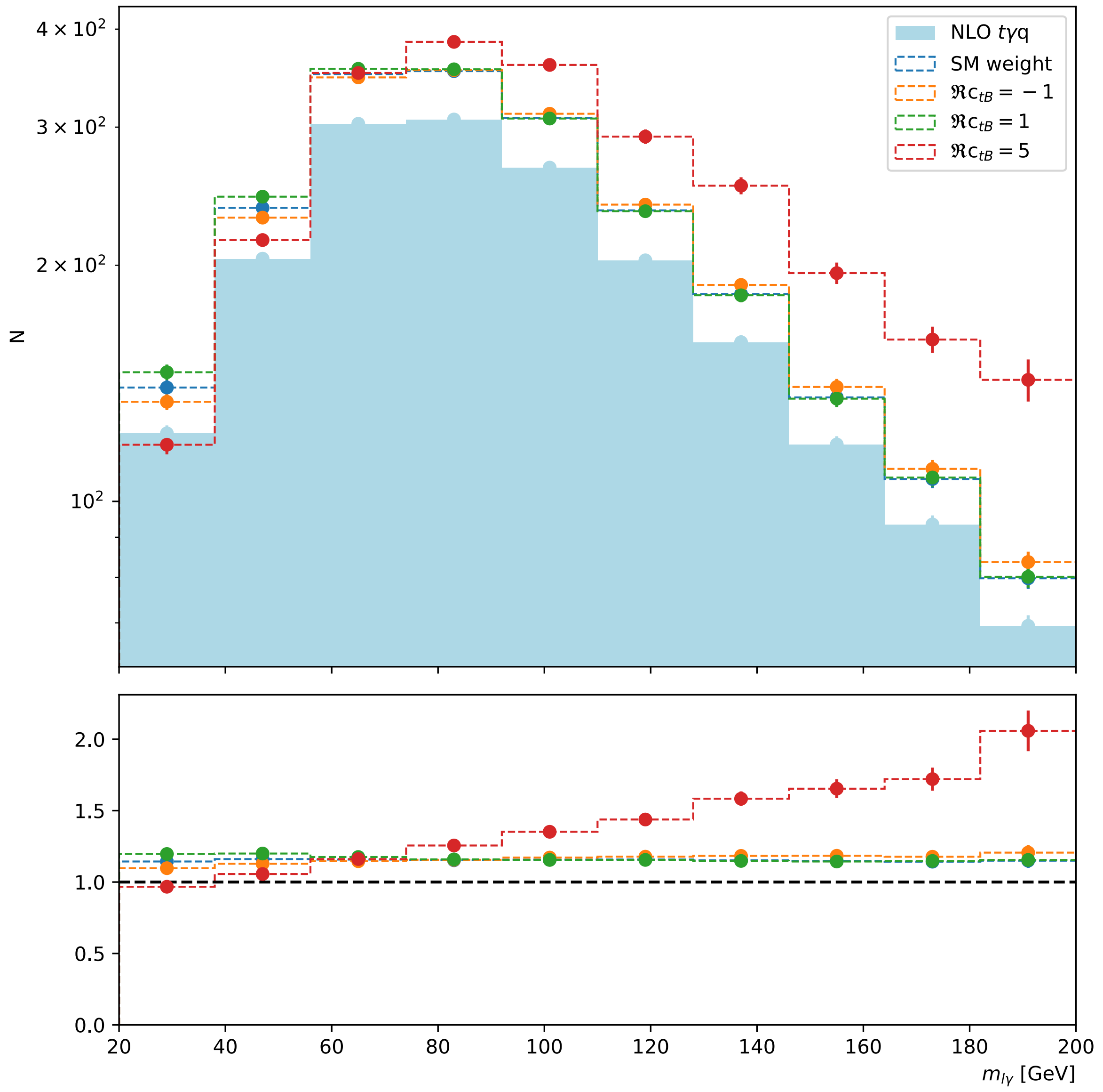
Reco-level distributions

e+μ channels









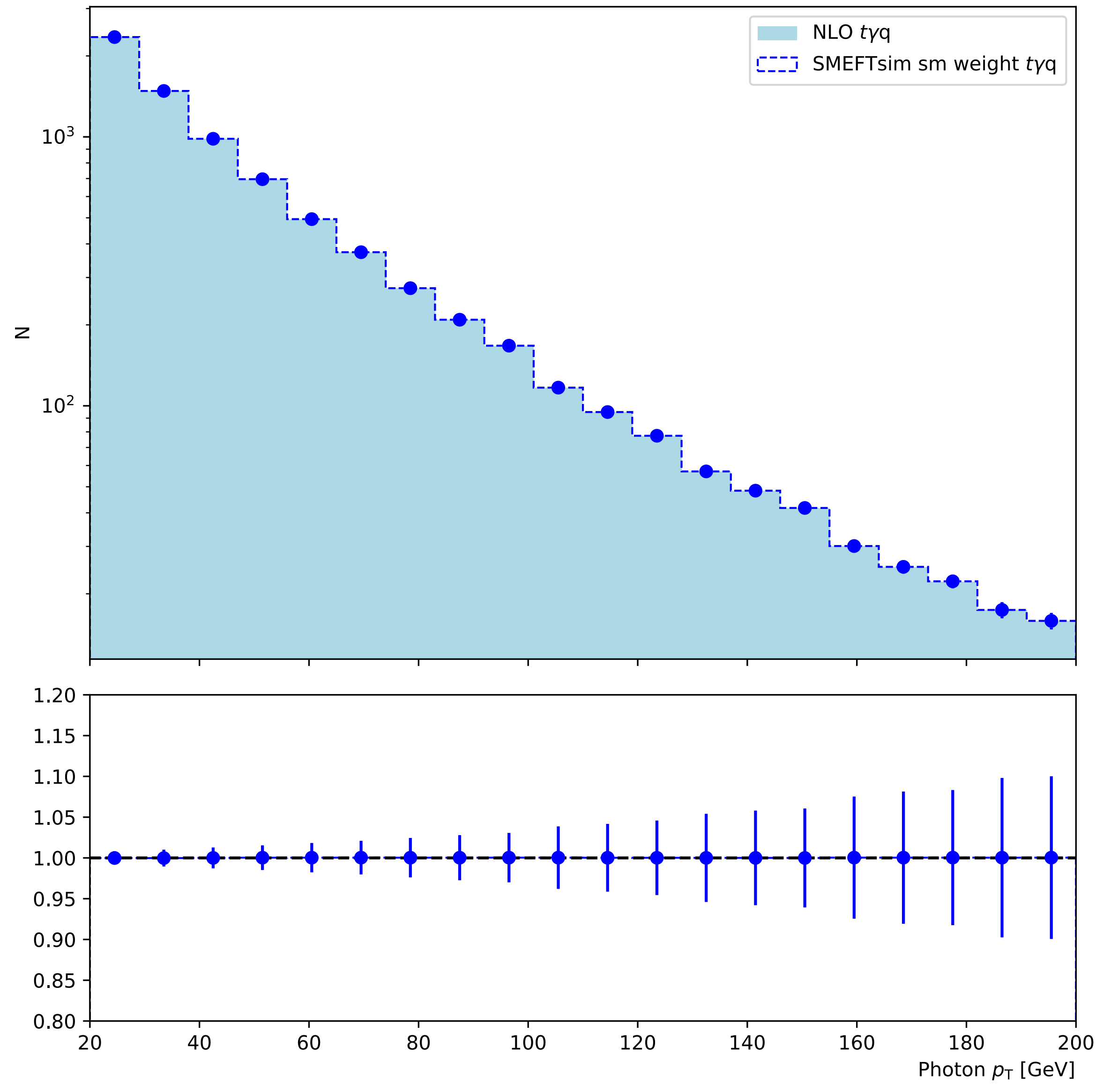
Selection: **N_ℓ=1, N_γ ≥1, N_j≥1, N_b≥1**

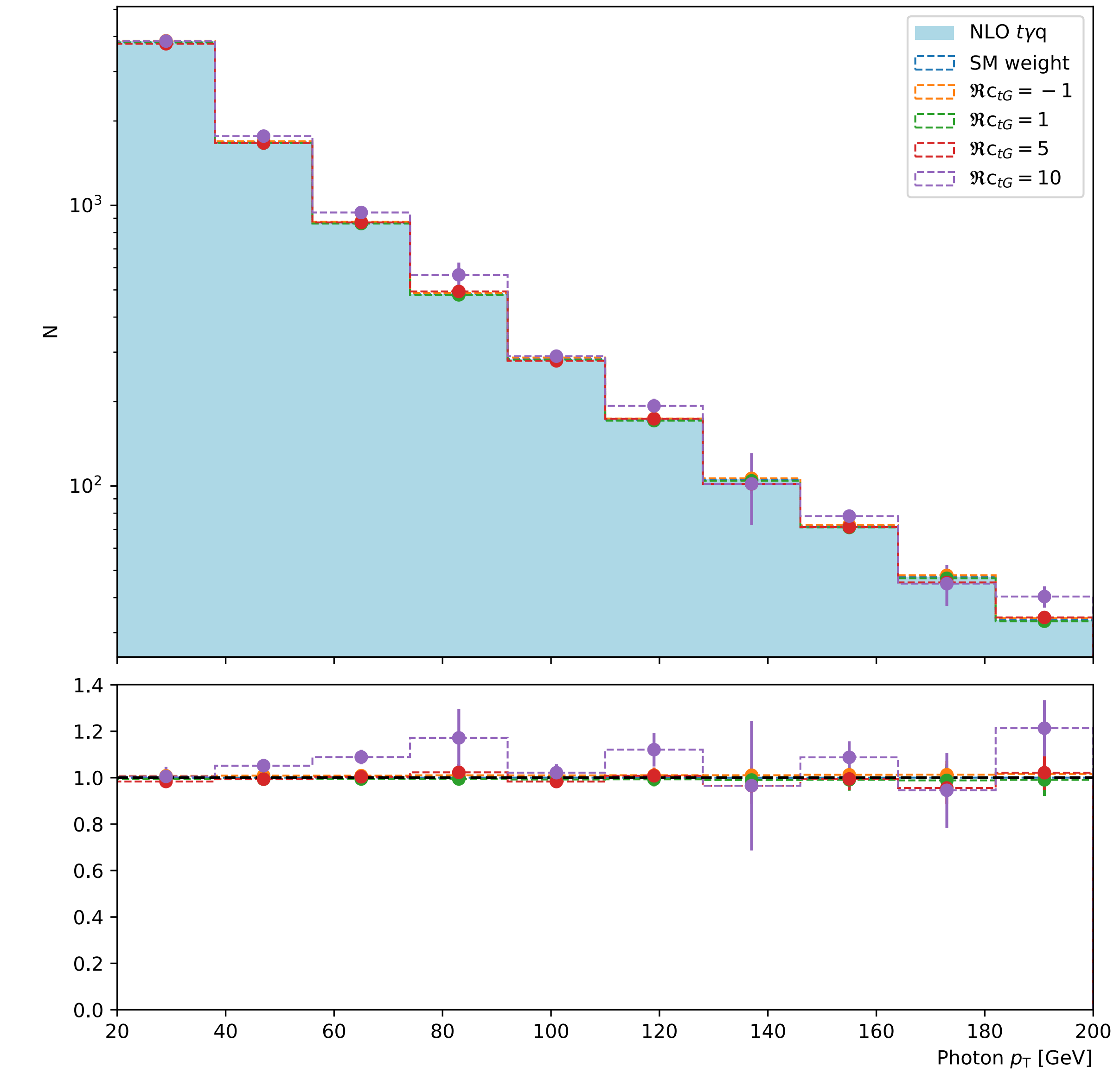
- Event ≥ 1 good PV and pass MET Filters and pass high-level trigger
- Exactly one lepton
  - Reject events containing extra ℓ with veto lepton requirement
- At least one photon
- At least two jet with one at least one being b-jet
- $\Delta R(\ell,\gamma) > 0.4, \Delta R(\ell,j) > 0.4, \Delta R(\gamma,j) > 0.4$
- MET $p_T > 20$ GeV

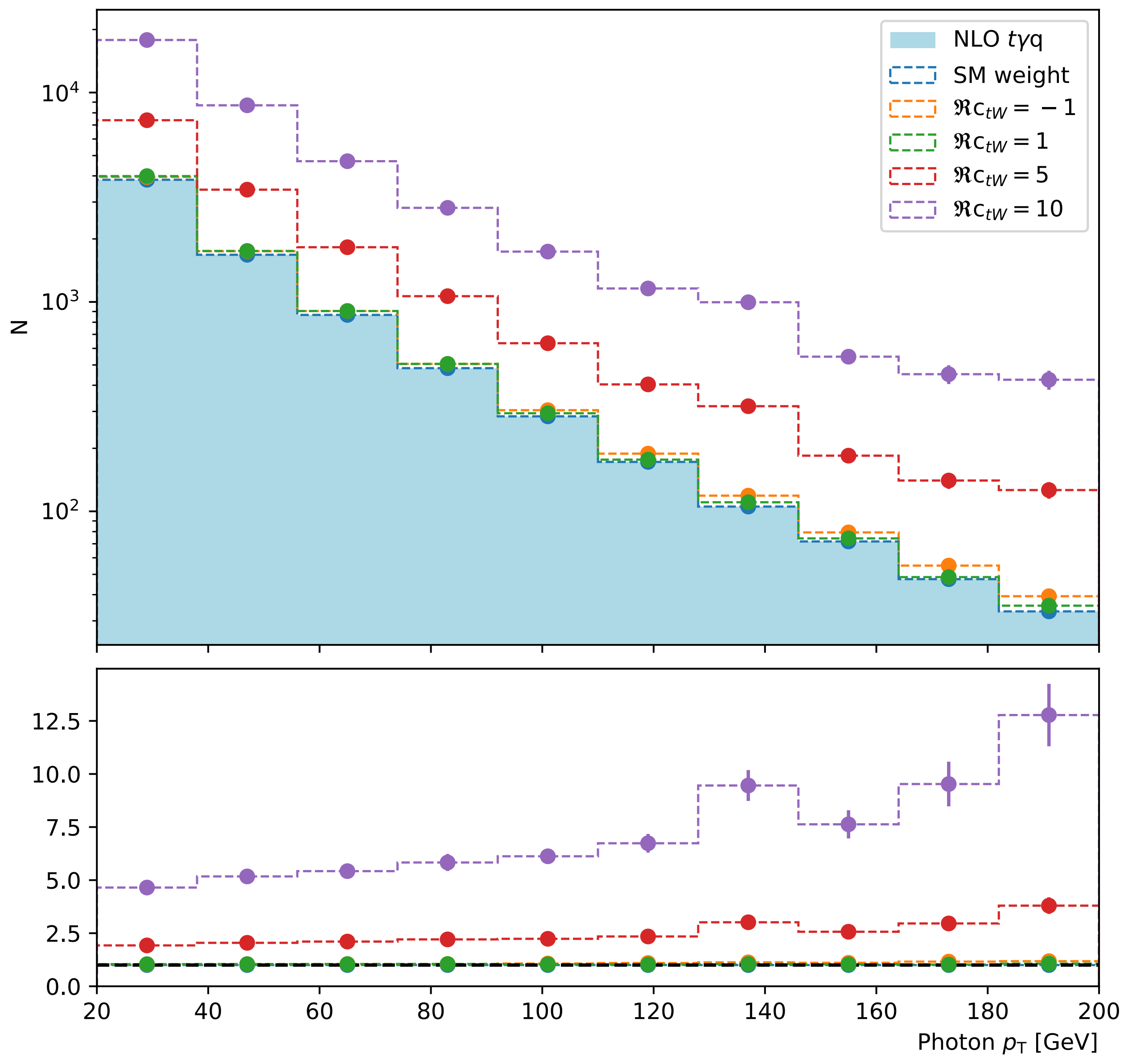
Here, the SM reweight values (blue hist) without reweigting and scale factors for all objects. If they are included, the agreement should be fine.

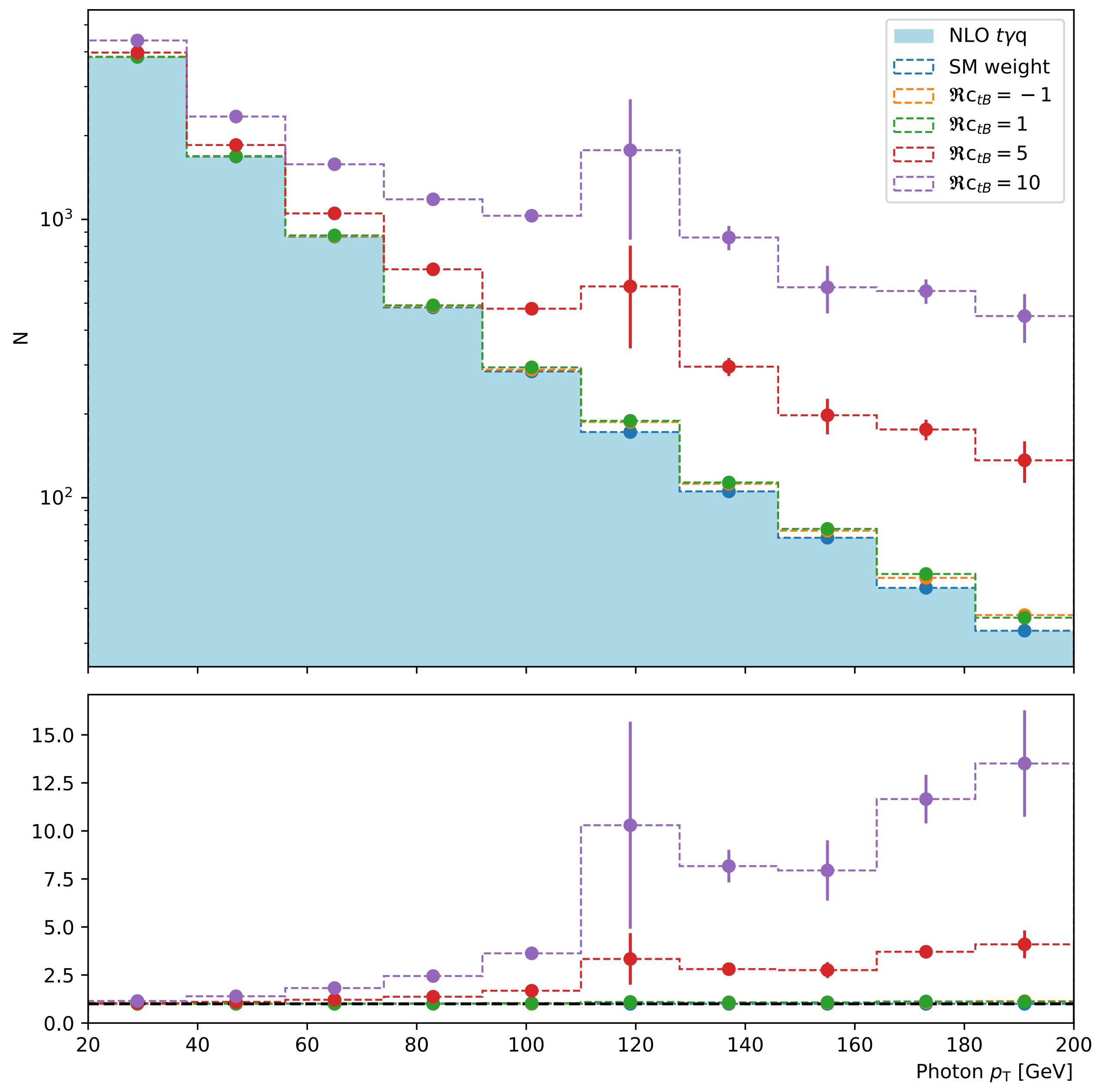
Gen-level distributions

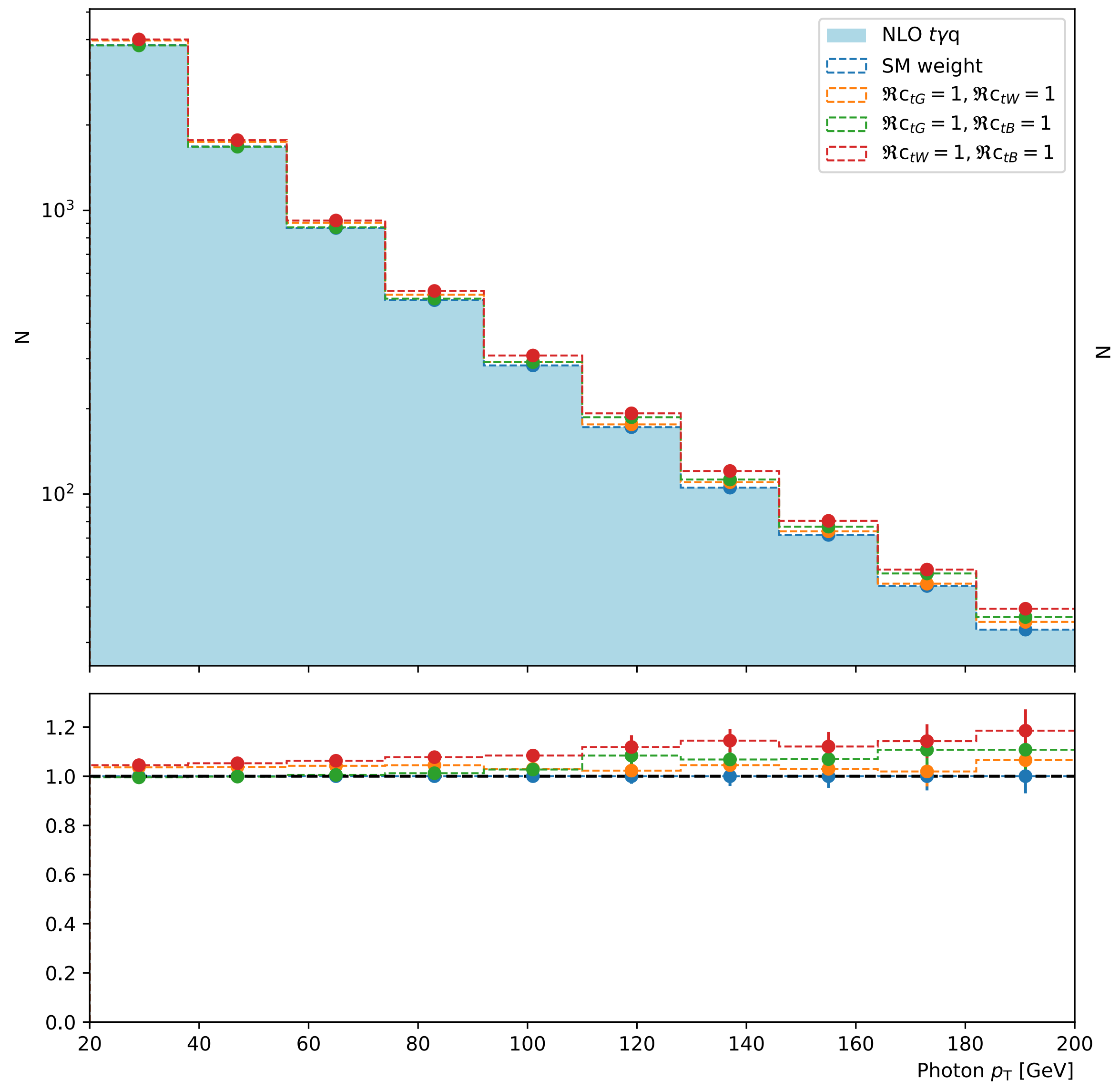
e+μ channels

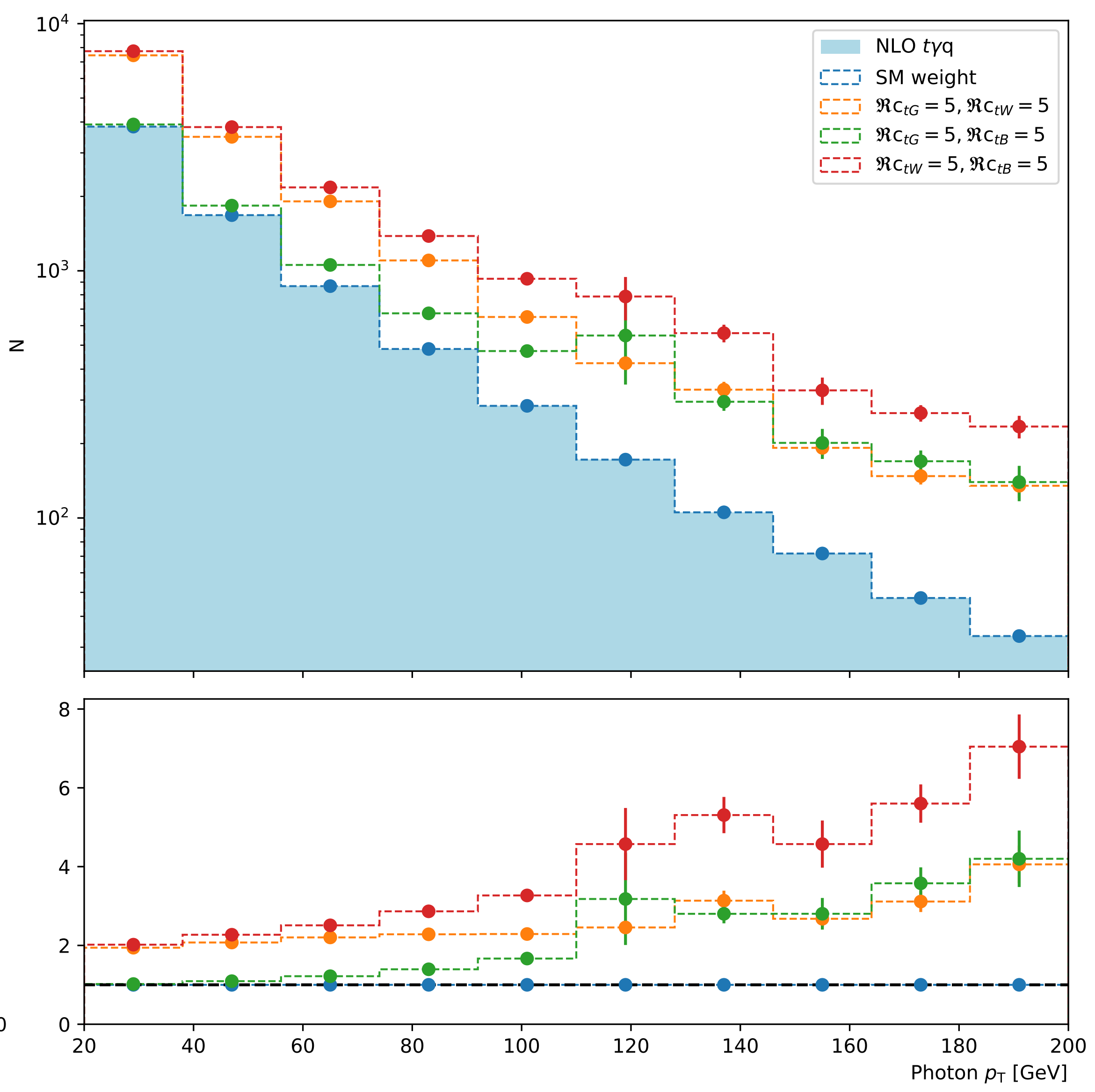








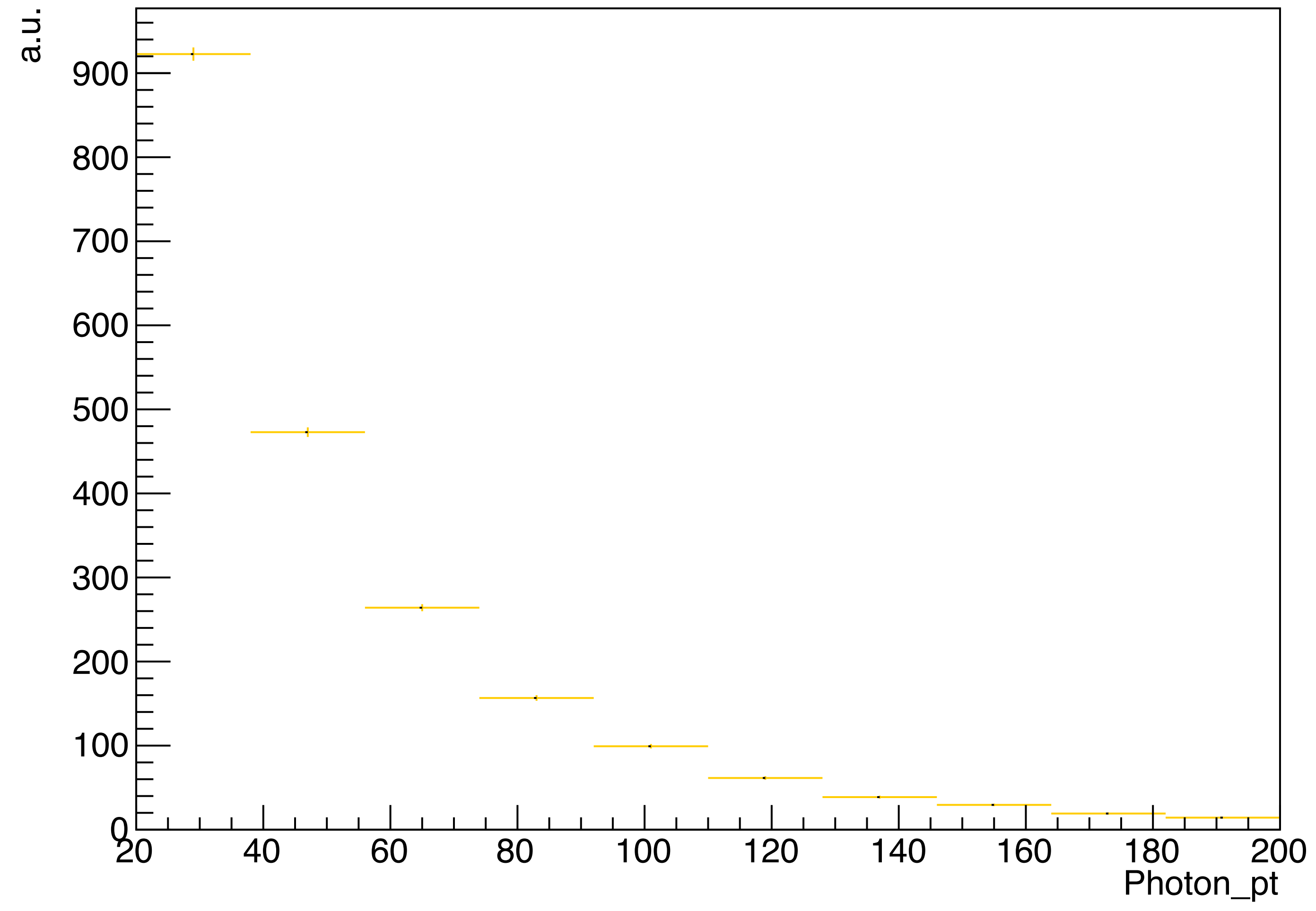




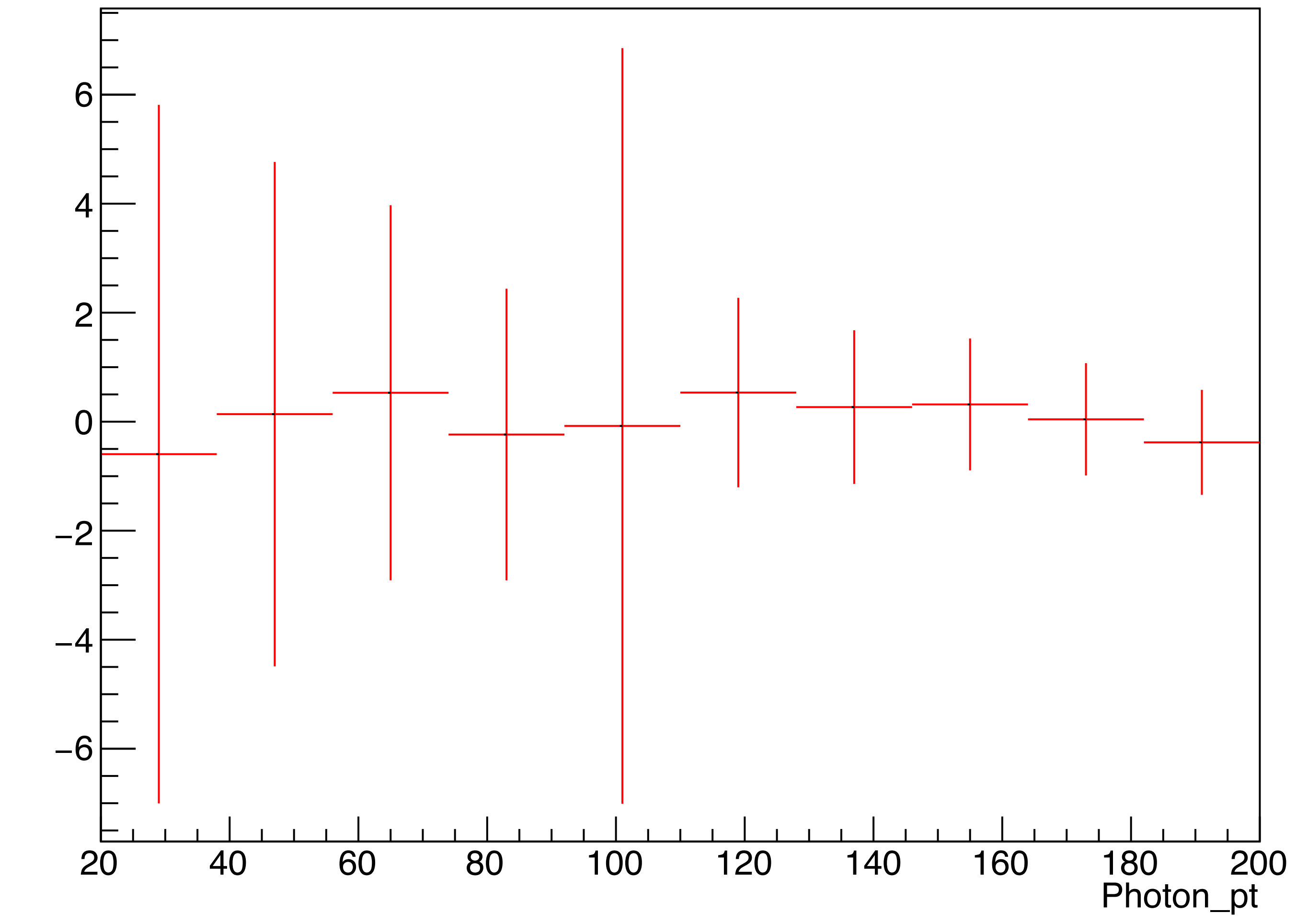
Selection	gen-ℓ	gen-γ	gen-j	gen-b
p_T/GeV	> 30	> 15	> 30	> 30
|η|	< 2.5	< 2.5	< 4.7	< 2.5
status	1	1	—	—
|pdgID|	13/11	22	—	—
Others	No meson mother	• No meson mother • Isolated • ΔR(ℓ,γ) > 0.1	• ΔR(ℓ,j) > 0.4 • ΔR(ℓ,γ) > 0.1	• |partonFlavour| = 5 • ΔR(ℓ,j) > 0.4 • ΔR(ℓ,γ) > 0.1

EFT decomposition

SM parts



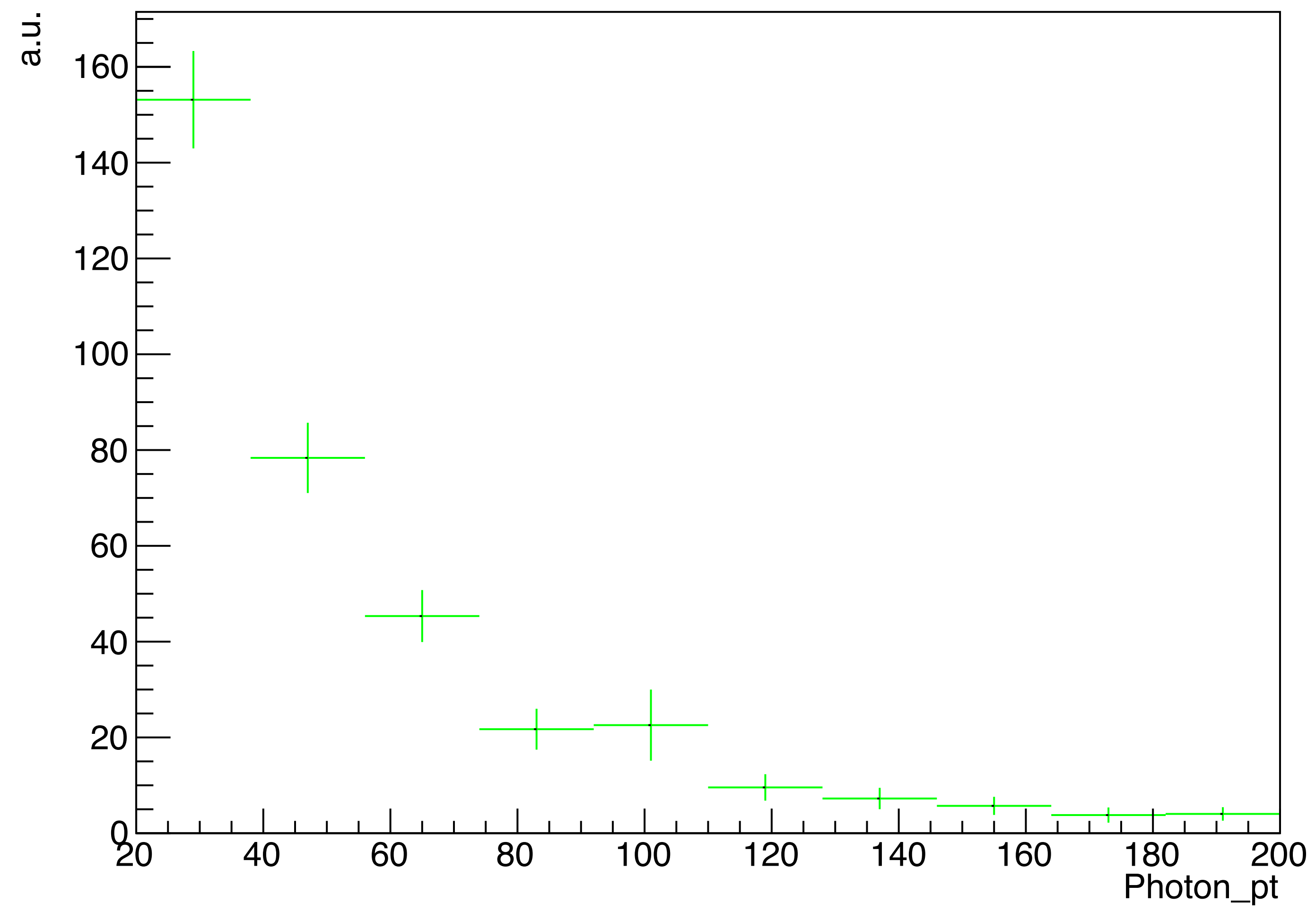
Linear parts c_{tB}



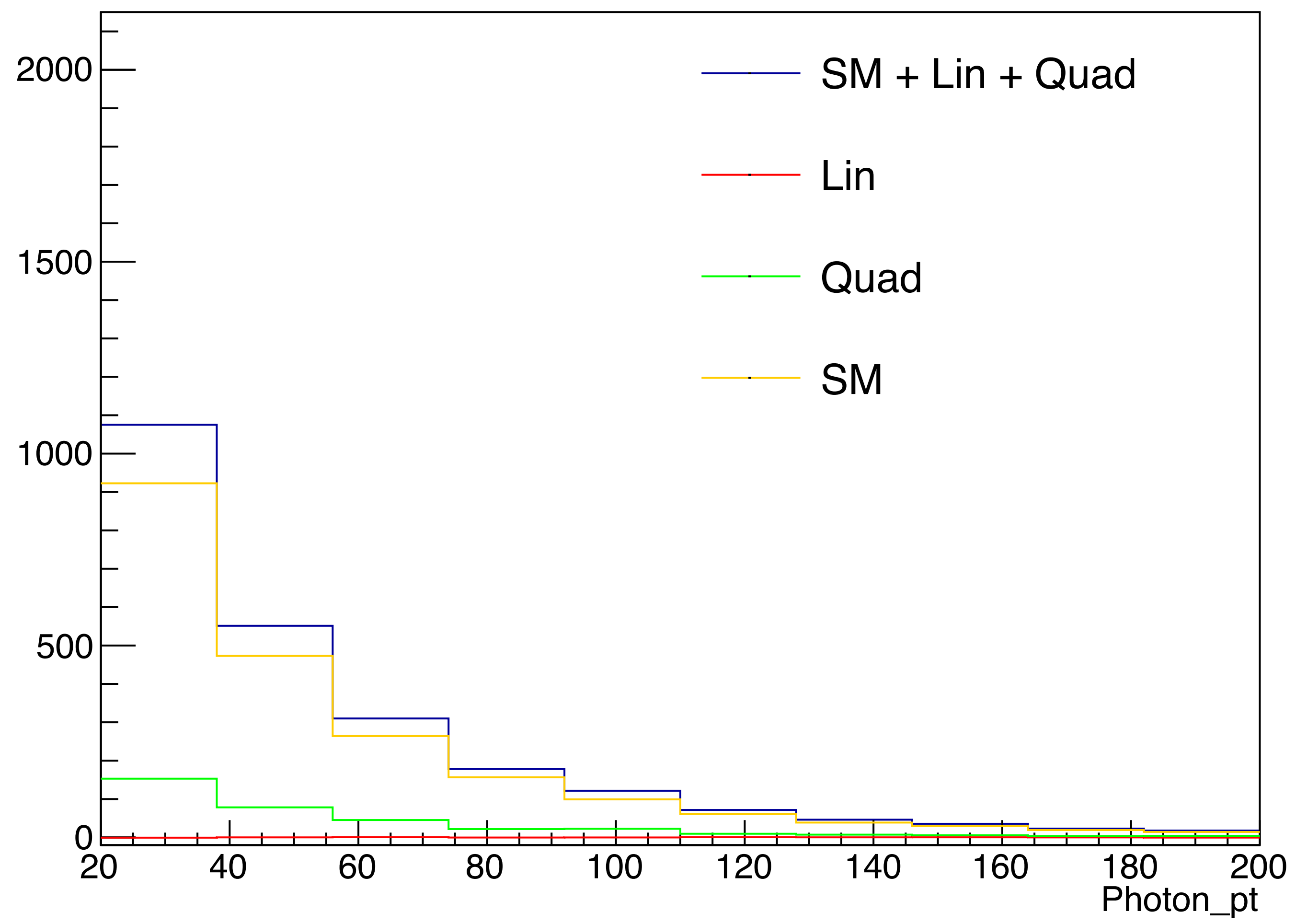
$$
\begin{cases}
\omega_{\text{Quad}} = 0.5 \cdot \left[\omega(k=1) + \omega(k=-1) - 2 \cdot \omega(k=0)\right] \\
\omega_{\text{SM}} = \omega(k=0) \\
\omega_{\text{Lin}} = 0.5 \cdot \left[\omega(k=1) - \omega(k=-1)\right]
\end{cases}
$$

$$\omega_{\text{Mix}} = \omega(1,1) + \omega(0,0) - \omega(1,0) - \omega(0,1)$$

Quad parts c_{tB}



SM + Lin + Quad c_{tB}



SM + Lin + Quad c_{tB}