# $t\bar{t}+\gamma$ production cross-section measurement at $\sqrt{s}$=13TeV in the semileptonic channel

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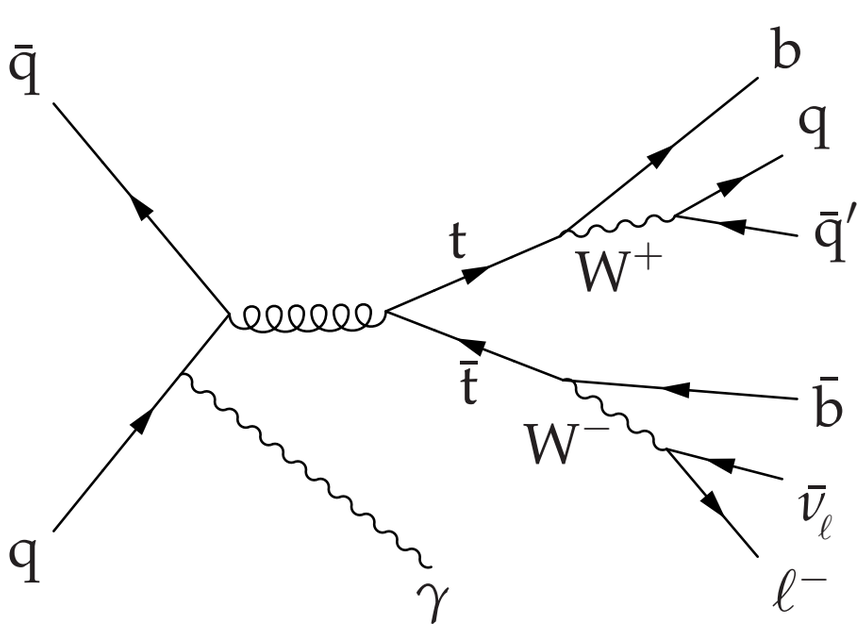
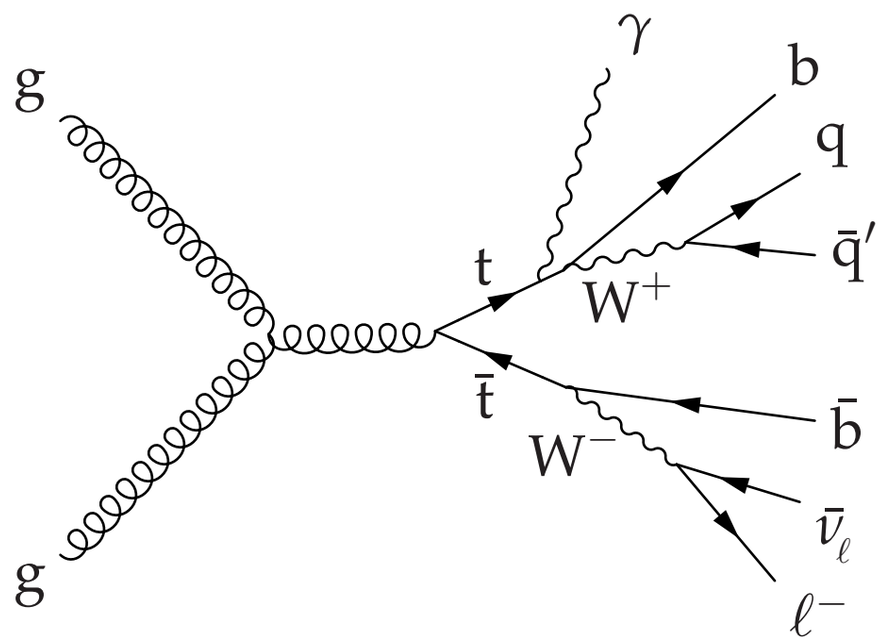
# Introduction and Motivation

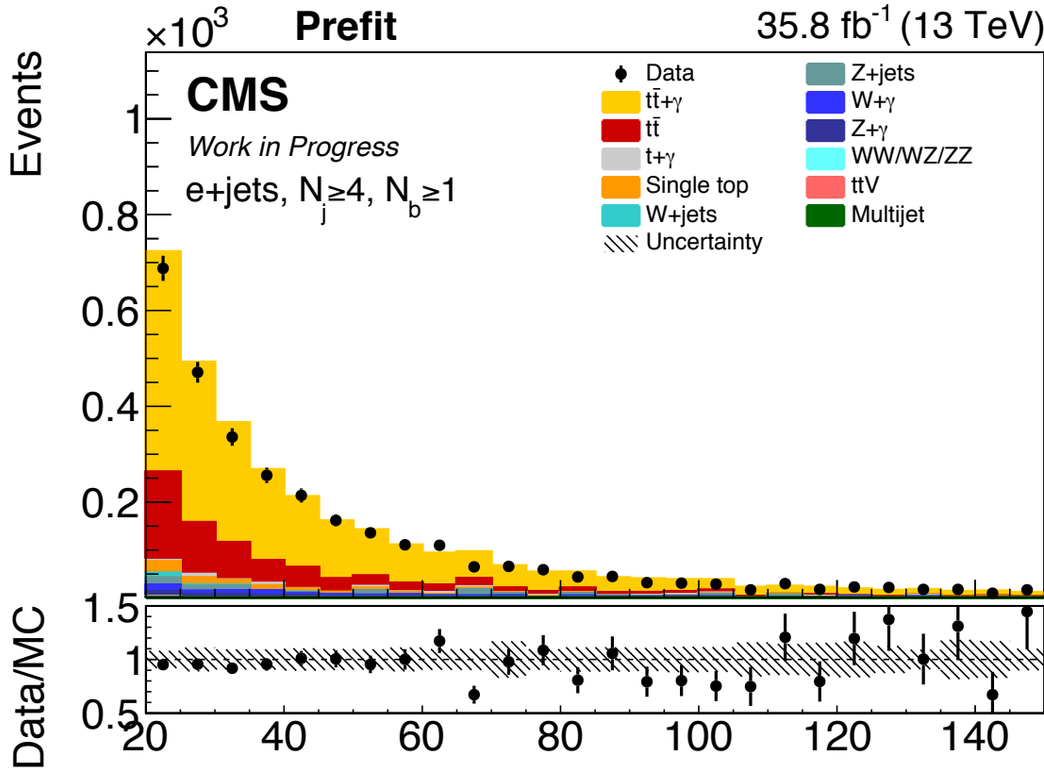
- The top quark being the heaviest quark, the way it interacts with a gauge boson makes an interesting study and can be a window for new physics.
- This measurement can also be used for:
  - **a direct measurement of top quark charge**: $q_t^2 \propto \sigma_{t\bar{t}\gamma}$
  - **top quark electroweak coupling** as $q_t$ and anomalous magnetic moment can be studied through this process.
  - **$t\bar{t}$ charge assymetry** by selecting $t\bar{t}+\gamma$ events.
- $t\bar{t}+\gamma$ : **important background** in many BSM searches and in Higgs analyses.

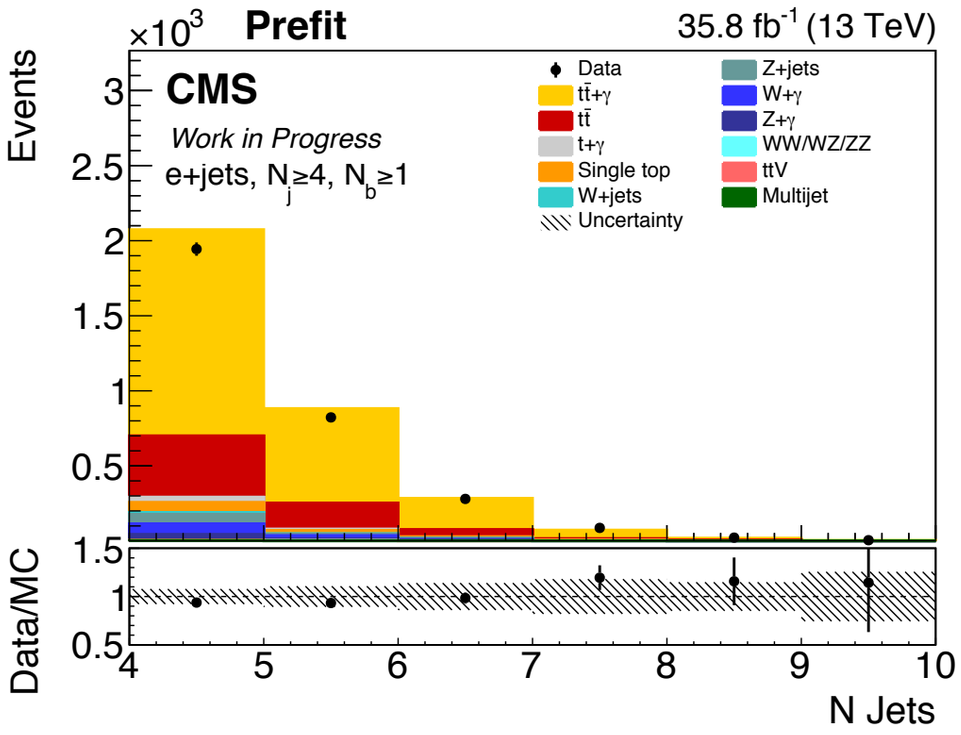


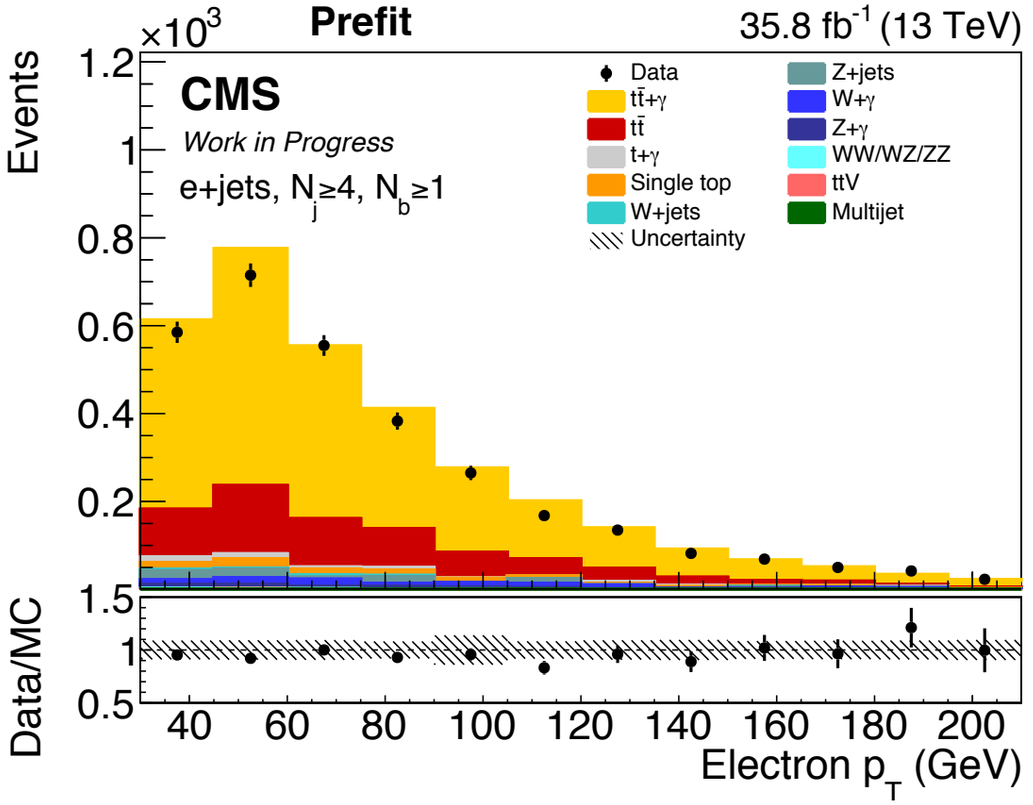



# Event and Object Selection

- **Top quark pair selection**:
  - Lepton Selection : exactly 1 high $P_T$ , isolated lepton
    - Muon $P_T$ > 30 GeV, Ele $P_T$ > 35 GeV
  - >=4 jets ($P_T$ > 30 GeV), at least one btagged
- **Photon Selection**:
  - >=1 isolated photon in barrel, $P_T$ > 20 GeV



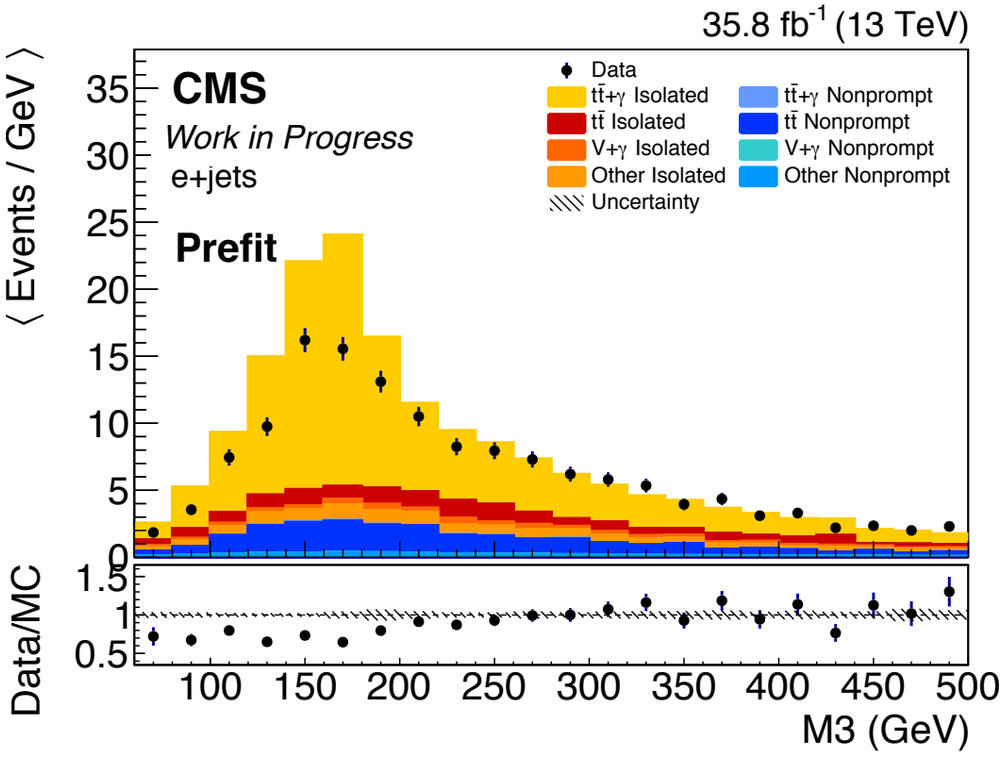



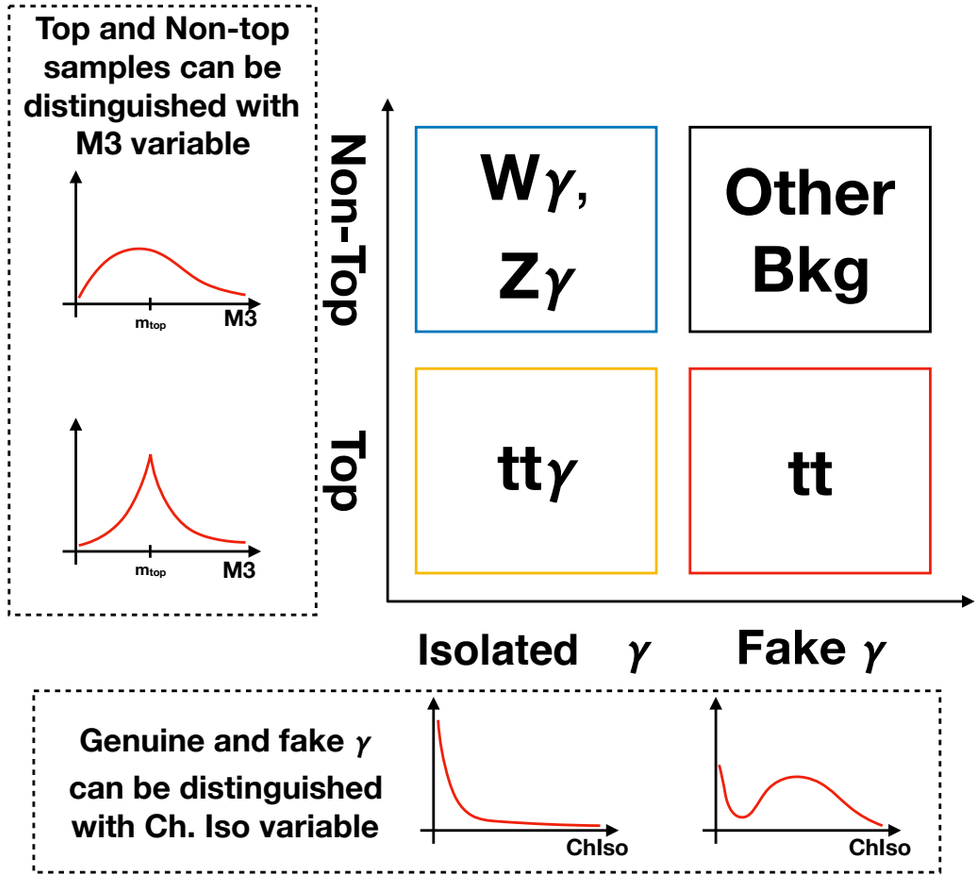
# Analysis Strategy

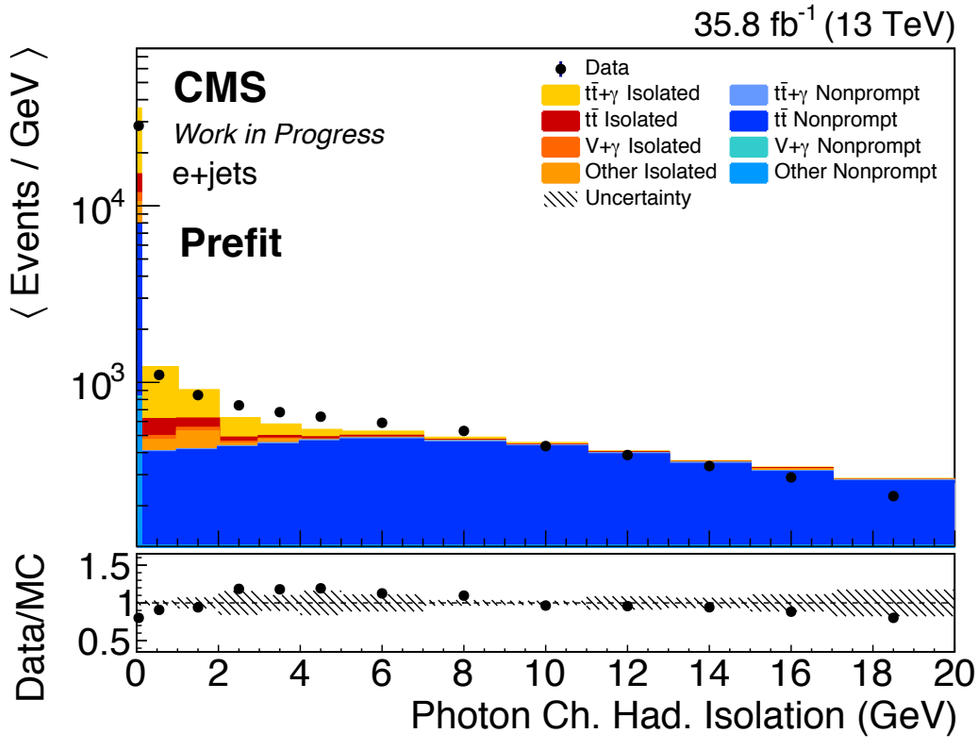
We want to distinguish $t\bar{t}+\gamma$ from background

**M3** - the invariant mass of the three jets with the highest summed pT, expected to reconstruct the top quark mass.




**Charged Hadron Isolation** - sum of the transverse momentum of all charged hadrons in a cone centred around a photon.

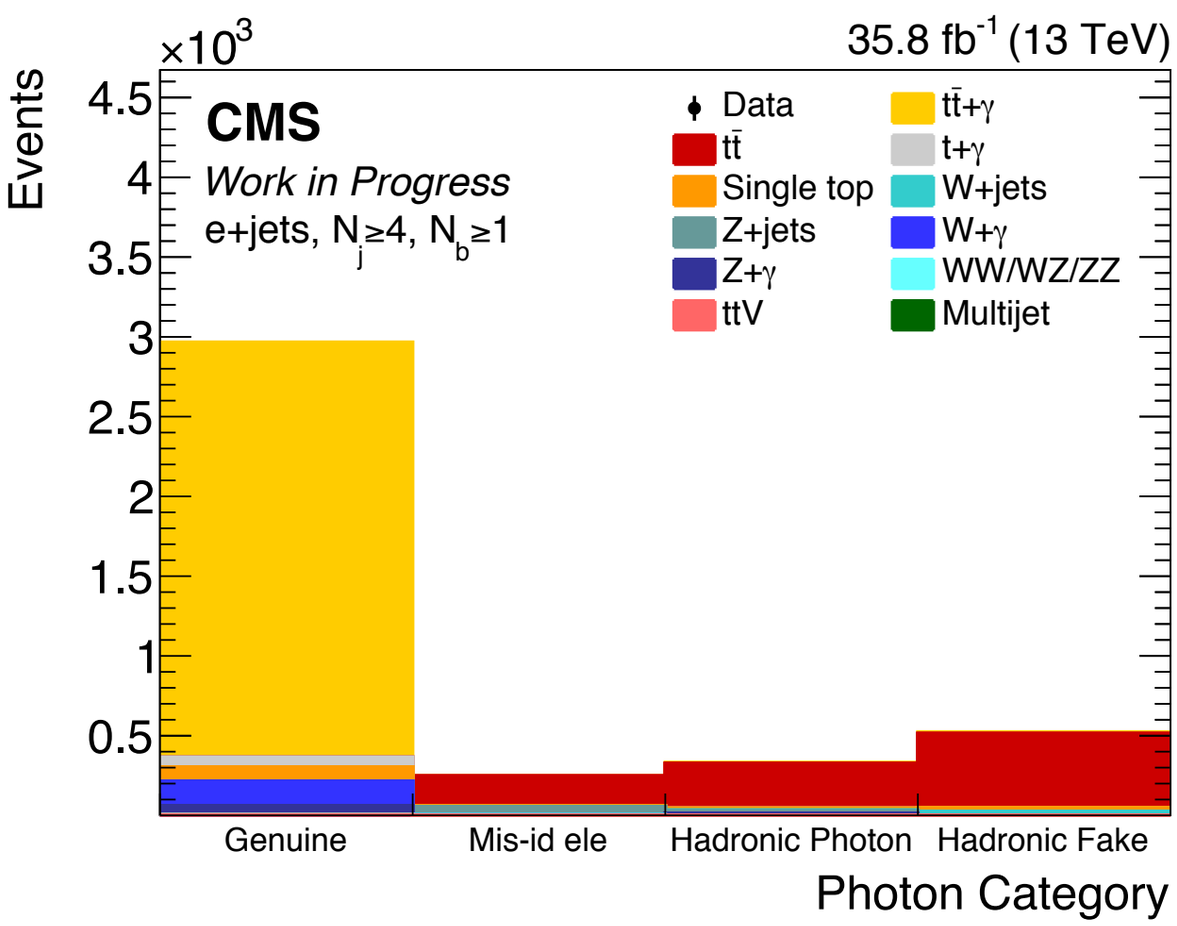


# Photon Categories

Through generator matching we divide our photons into 4 categories based on where it is radiated from.

- **Genuine** : if the photon has a leptonic, bosonic or quark parents
- Photon is actually a **Misidentified electron**
- **Hadronic Photon**: radiated from a hadronic source, example: pion
- **Hadronic Fake**: when the reconstructed photon cannot be matched to a generator level photon.




**Isolated (signal)** photons: Genuine photons and Misidentified electrons

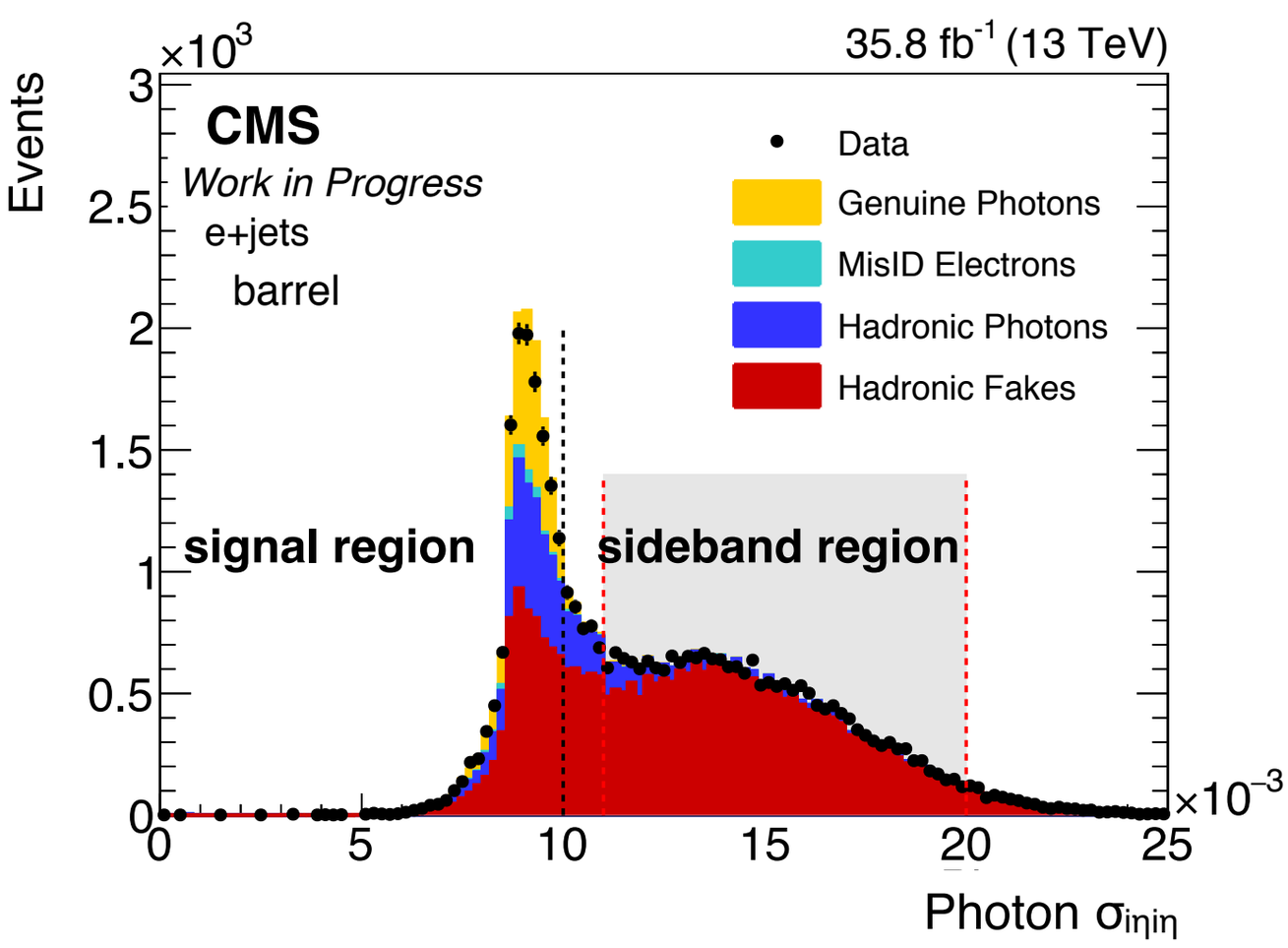
**NonPrompt (background)** photons: Hadronic photons & hadronic fakes:

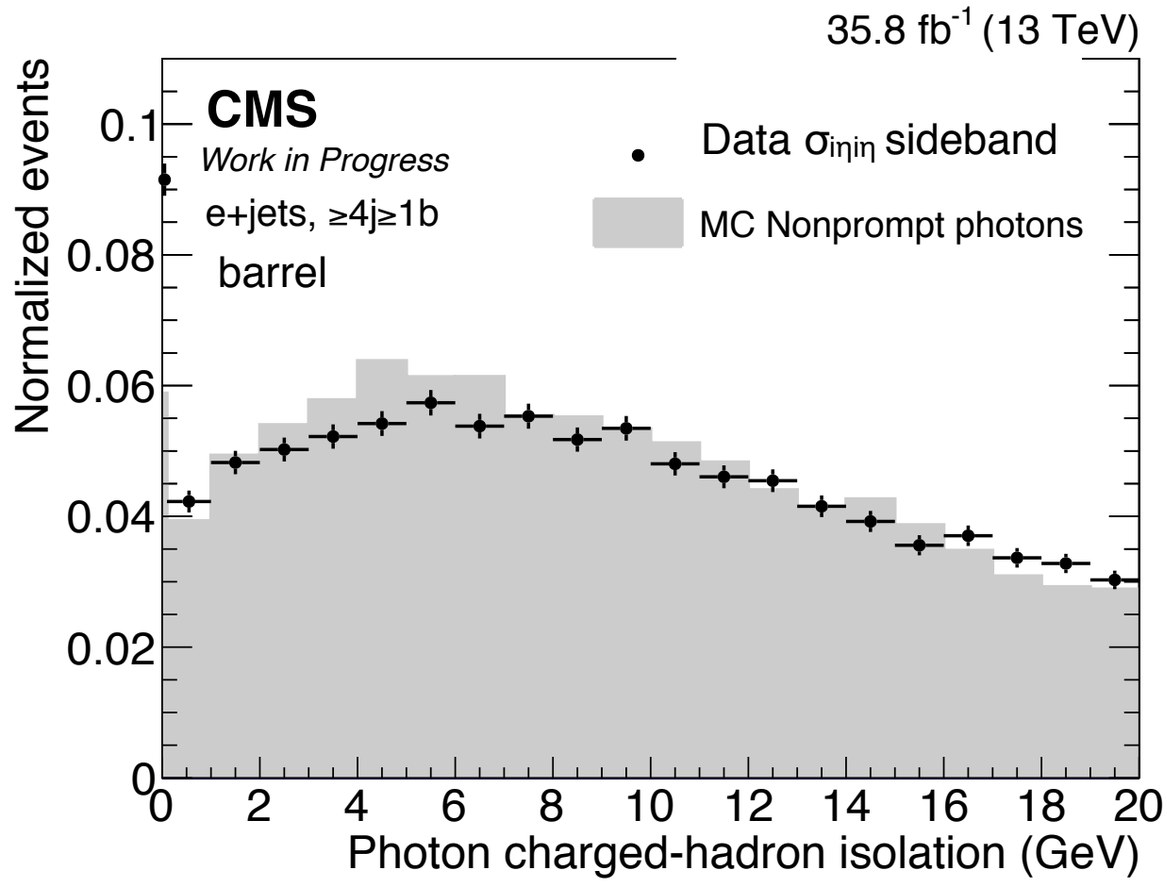
All MC samples are divided into Isolated and NonPrompt templates

# Data based template for Hadronic/Fake photons

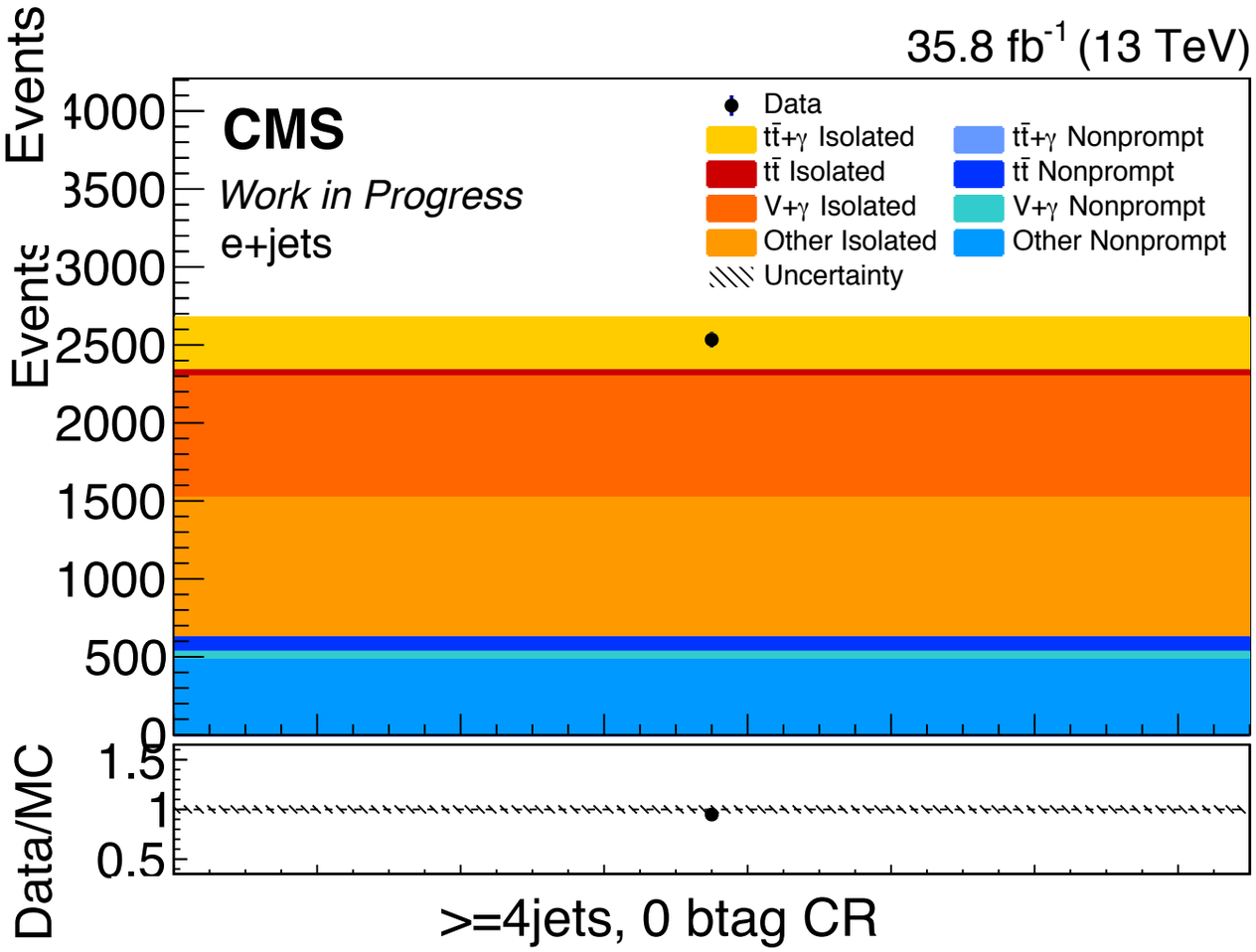
- Data based templates used to avoid any mismodeling in NonPrompt photons

- We extract the shape of these background photons from the $\sigma_{i\eta i\eta}$ **sideband** region of **Charged Hadron Isolation** which is <u>dominated by nonprompt photons.</u>

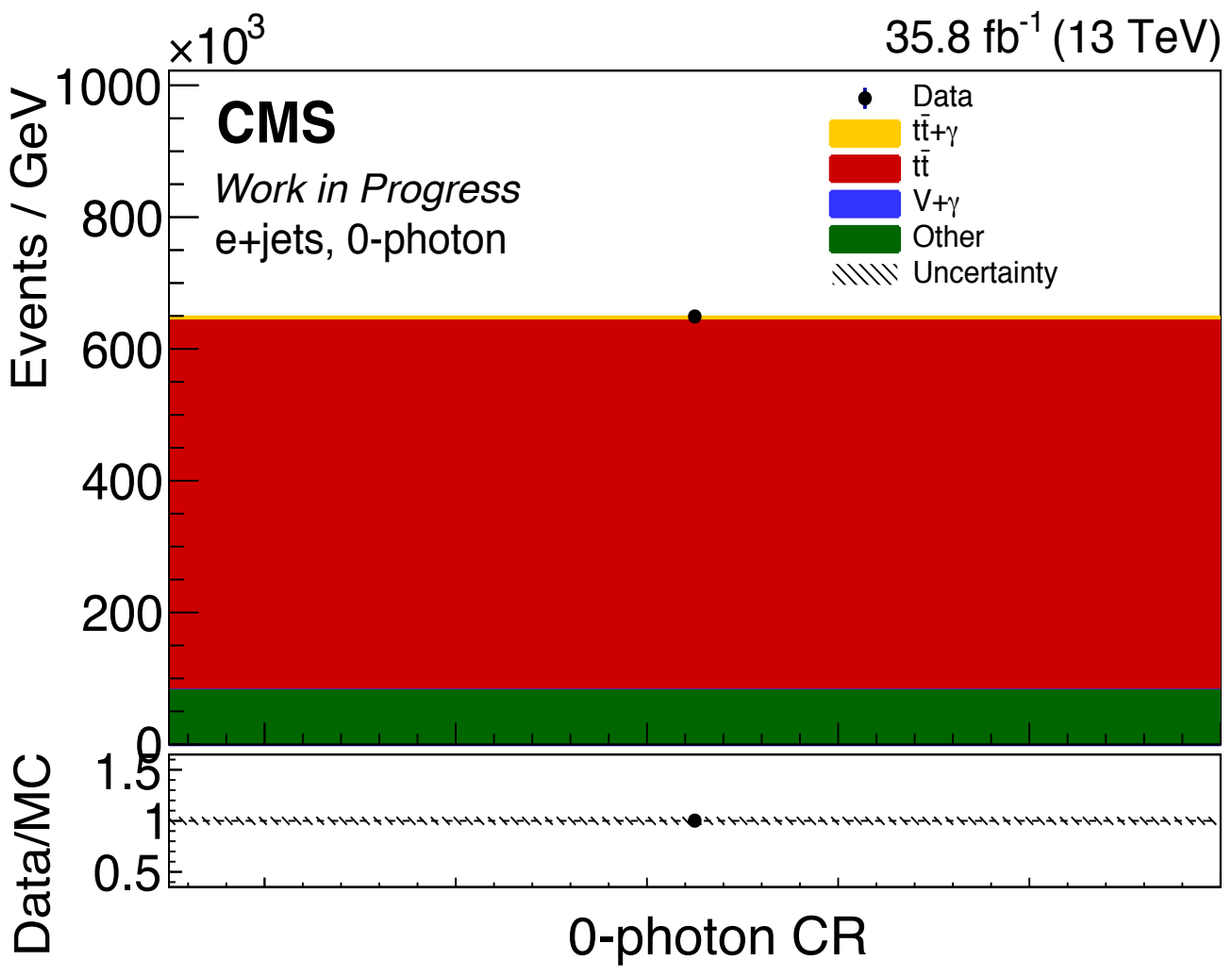


# Control Regions in the Fit



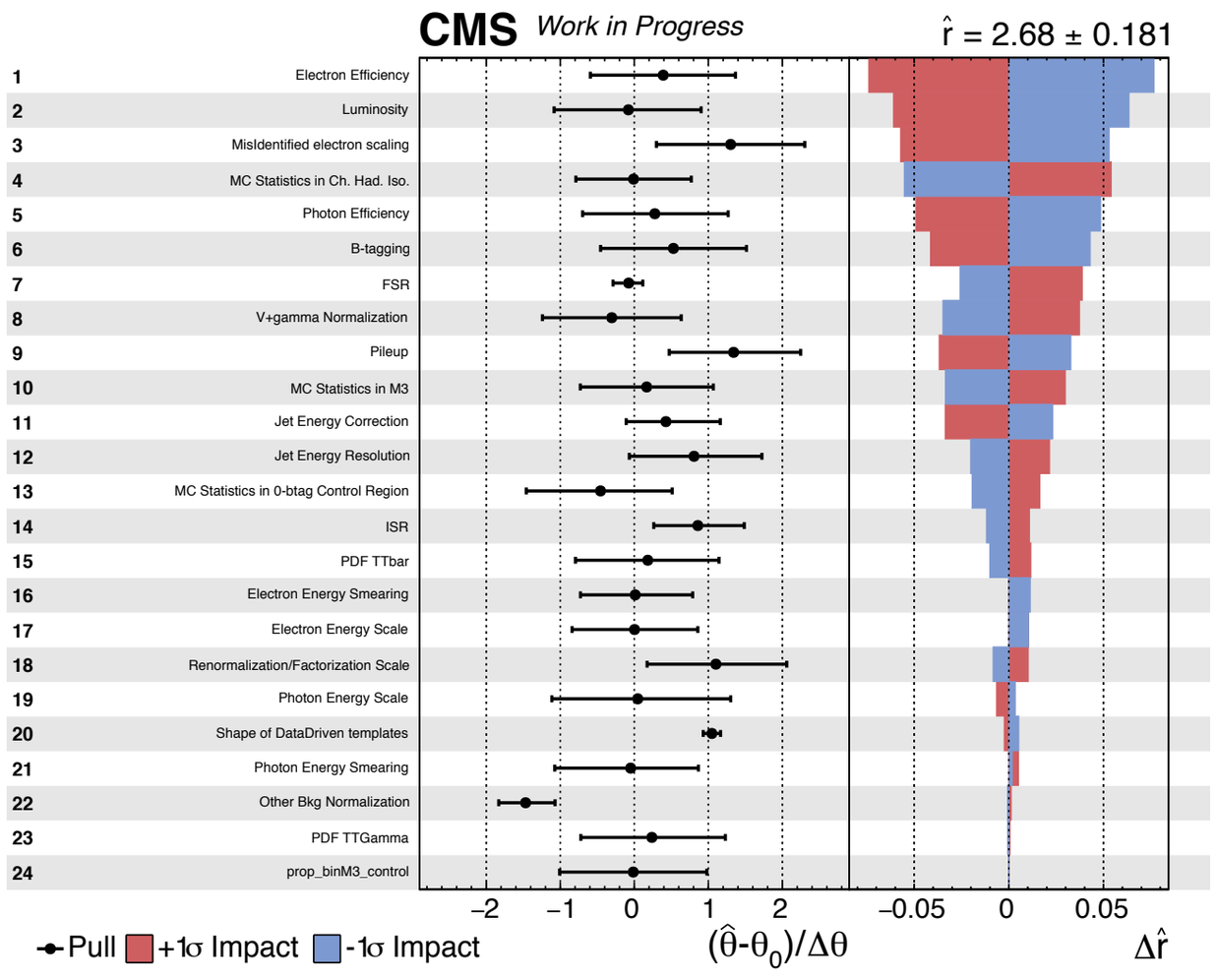

To get a better handle on **W/Z + gamma** process

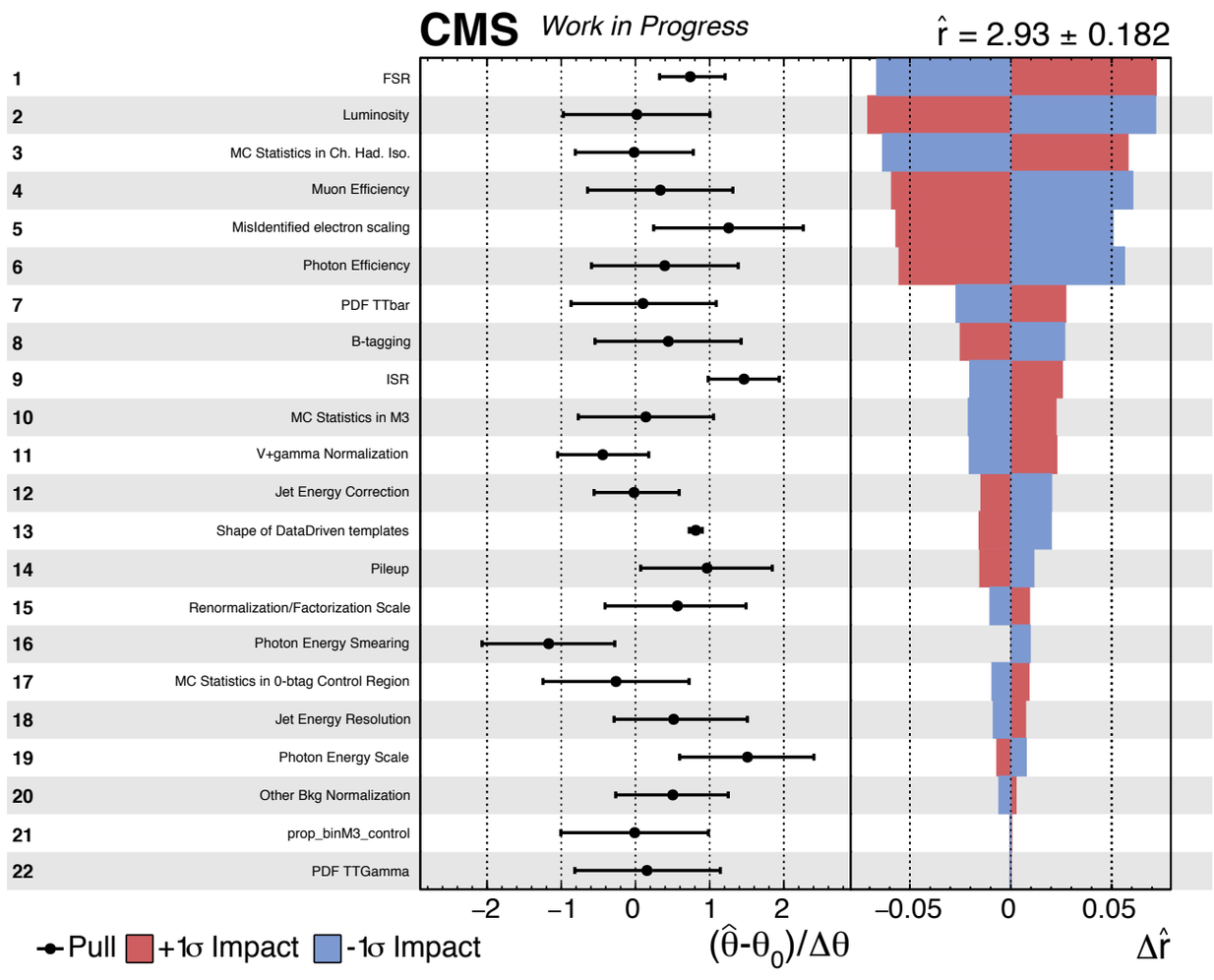



To get a better handle on **ttbar** process

# Fit Results

- Measuring the following:
  - *Fiducial* $\sigma_{t\bar{t}+\gamma}$ : Semileptonic top decay with a photon of PT>20 GeV, in barrel
  - *Inclusive* $\sigma_{t\bar{t}+\gamma}$ : inclusive in top decay and fiducial in photon cuts ($P_T$>20 GeV, in barrel)
  - *NonPrompt photon correction factor* extracted from the fit.
  - *Ratio (R)* of $t\bar{t}+\gamma$ to $t\bar{t}$ cross-section also calculated




Fitting to extract the inclusive cross-section

# Summary

- We get the following preliminary results in the lepton+jets channel:
  - Inclusive cross-section = 2.63 ± 0.14(syst) ± 0.07(stat)pb
  - Ratio = (3.21 ± 0.18(syst) ± 0.06(stat)) × $10^{-3}$
  - Fiducial cross-section being finalised
- Final results coming soon!

# Backup

# Object Selection

## Trigger

- Mu: HLT_IsoMu24_v or HLT_IsoTkMu24_v
- Ele: HLT_Ele32_eta2p1_WPTight_Gsf_v

## Muons

- Tight muon
  - Tight Muon ID
  - $P_T$ > 30 GeV, η < 2.4
  - RelIso < 0.15
- Loose Muon:
  - Loose Muon ID
  - $P_T$ > 15 GeV, η < 2.4
  - RelIso < 0.25

## Photon

- $P_T$ > 20 GeV, η < 2.5 (barrel); 1.4442 > η > 1.566 (endcap)
- Cut Based Medium Photon ID

## Electrons

- Tight electron
  - Tight Electron ID
  - $P_T$ > 35 GeV, η < 2.1
  - Pass gap b/w barrel and endcap
  - Impact parameter cuts : d0< 0.05(barrel), d0< 0.1 (endcap) dz<0.1(barrel), dz<0.2(endcap)
- Veto Electrons:
  - Pass Electron Veto ID
  - $P_T$ > 15 GeV, η < 2.5
  - Pass gap b/w barrel and endcap
  - Impact parameter cuts as above

## Jets

- $P_T$ > 30 GeV, η < 2.4
- Tight JetID
- Remove Jets close to a lepton if dR(jet,lep)< 0.4
- Remove Jets close to a photon if dR(jet,pho)< 0.1
- btagging : deep csv > 0.8484

# Event Selection

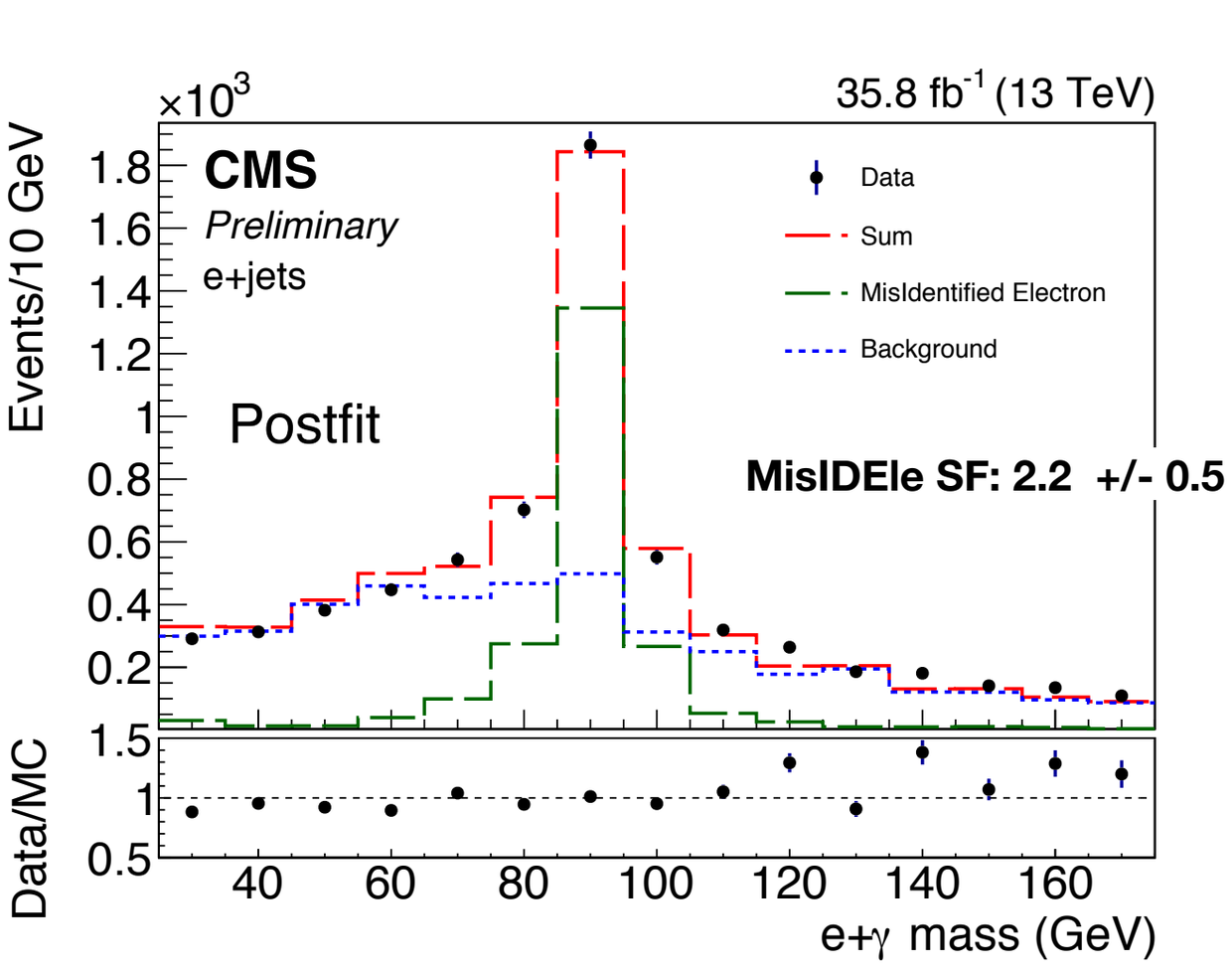
- TTbar selection:
  - Good PV
  - Trigger -
    - Muon: HLT_IsoMu24_v or HLT_IsoTkMu24_v
    - Electron: HLT_Ele32_eta2p1_WPTight_Gsf_v
  - Exactly 1 high $P_T$, isolated lepton
  - No loose leptons
  - >= 4 Jets
  - >= 1 Btagged Jets
  - Overlap removal for the following samples: b/w ttgamma & ttbar, b/w VJets & VGamma, b/w TGJets (t-channel) & ST (t-channel).
- Photon Selection
  - Passes Preselection and has >= 1 photon

# Overlap Removal

- To avoid double counting the same event in two different MC sample overlap removal is used.
- For example in $t\bar{t}+\gamma$ and $t\bar{t}$ sample, the same event maybe duplicated. To avoid counting the same event twice, if an event in $t\bar{t}$ is already present in $t\bar{t}+\gamma$ kinematic phase space, then the event is removed from $t\bar{t}$.
- Overlap removal is based on generator level kinematic cuts of the photon in each sample.
- Overlap removal is performed between :
  - $t\bar{t}+\gamma$ & $t\bar{t}$ (events removed from $t\bar{t}$)
  - $V+\gamma$ & V+jets (events removed from V+jets)
  - $ST+\gamma$ & ST (events removed from ST)

# Corrections to Simulation

- Correcting events with **<u>MisIdentified electrons</u>**
- **Z->e$^+$e$^-$ (e->$\gamma$):** electron is mis-reconstructed as a photon.
  - 3jets, 0btag CR: rich in background processes
  - Fit to invariant mass of e+gamma




the uncertainty in the scale factor comes from:

- statistical uncertainty
- variation between different jet multiplicty regions
- variation due to using a LO ZJets sample vs a NLO ZJets sample (currently using LO ZJets)

# Fit parameters to extract $t\bar{t}+\gamma$ and $t\bar{t}$ cross-section

- Three free floating parameters in this fit: σ($t\bar{t}+\gamma$), NonPrompt photon correction factor, σ(ttbar)

- Backgrounds are floated with a gaussian constraint: V+γ and Other bkg - 30%

| **Sample** | **Isolated Photon** | **NonPrompt Photon** |
|---|---|---|
| $t\bar{t}+\gamma$ | 64.3% | 0.39% |
| $t\bar{t}$ | 4.6% | 18.49% |
| $V+\gamma$ | 4.6% | 0.45% |
| *Other Bkg* | 4.4% | 2.5% |

# Cross-section calculation

$$\sigma_{t\bar{t}\gamma,inlc}(p_T > 20GeV, barrel) = \sigma_{t\bar{t}\gamma,inlc}(p_T > 13GeV, \eta < 2.5) \times A^{\gamma}$$

$$\sigma_{t\bar{t}\gamma,fid}(p_T > 20GeV, barrel) = \sigma_{t\bar{t}\gamma,inlc}(p_T > 20GeV, barrel) \times A^{t\bar{t}}$$

$$A^{\gamma} = \frac{\text{Events with photon in the barrel and } \mathrm{p}_T > 20 \text{ GeV}}{\text{Total events}}$$

$$A^{t\bar{t}} = \frac{\text{Events with top quark pairs in signal phase space}}{\text{Events with photon in the barrel and } \mathrm{p}_T > 20 \text{ GeV}}$$