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

USLUA meeting, October, 2018

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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 asymmetry 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
  - $\geq 4$ jets ($P_T > 30$ GeV), at least one btagged

- **Photon Selection:**
  - $\geq 1$ isolated photon in barrel, $P_T > 20$ GeV
We want to distinguish $t\bar{t}+\gamma$ from background.

**Analysis Strategy**

**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 templates 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 $\sigma_{i\eta i}$ sideband region of Charged Hadron Isolation which is dominated by nonprompt photons.
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 \( P_T > 20 \) 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
• We get the following preliminary results in the lepton+jets channel:
  • Inclusive cross-section = 2.63 ± 0.14(syst) ± 0.07(stat)pb
  • Ratio = \((3.21 ± 0.18(syst) ± 0.06(stat)) \times 10^{-3}\)
  • 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
  - \( p_T > 30 \text{ GeV}, \eta < 2.4 \)
  - RelIso < 0.15
- **Loose Muon**
  - Loose Muon ID
  - \( p_T > 15 \text{ GeV}, \eta < 2.4 \)
  - RelIso < 0.25

### Electrons
- **Tight electron**
  - Tight Electron ID
  - \( p_T > 35 \text{ GeV}, \eta < 2.1 \)
  - 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
  - \( p_T > 15 \text{ GeV}, \eta < 2.5 \)
  - Pass gap b/w barrel and endcap
  - Impact parameter cuts as above

### Jets
- \( p_T > 30 \text{ GeV}, \eta < 2.4 \)
- 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

### Photon
- \( p_T > 20 \text{ GeV}, \eta < 2.5 \) (barrel);
  \( 1.4442 > \eta > 1.566 \) (endcap)
- Cut Based Medium Photon ID
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
  - $\geq 4$ Jets
  - $\geq 1$ 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 $\geq 1$ 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 **MisIdentified electrons**

- \( Z \rightarrow e^+e^- (e \rightarrow \gamma) \): electron is mis-reconstructed as a photon.

- 3jets, 0btag CR: rich in background processes

- Fit to invariant mass of e+gamma

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The uncertainty in the scale factor comes from:

- statistical uncertainty
- variation between different jet multiplicity 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: $\sigma(t\bar{t}+\gamma)$, NonPrompt photon correction factor, $\sigma(tt\bar{bar})$

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

<table>
<thead>
<tr>
<th>Sample</th>
<th>Isolated Photon</th>
<th>NonPrompt Photon</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t\bar{t}+\gamma$</td>
<td>64.3%</td>
<td>0.39%</td>
</tr>
<tr>
<td>$t\bar{t}$</td>
<td>4.6%</td>
<td>18.49%</td>
</tr>
<tr>
<td>$V+\gamma$</td>
<td>4.6%</td>
<td>0.45%</td>
</tr>
<tr>
<td>Other Bkg</td>
<td>4.4%</td>
<td>2.5%</td>
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</tbody>
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Cross-section calculation

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

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

\[A^\gamma = \frac{\text{Events with photon in the barrel and } p_T > 20 \text{ GeV}}{\text{Total events}}\]

\[A^{t\bar{t}} = \frac{\text{Events with top quark pairs in signal phase space}}{\text{Events with photon in the barrel and } p_T > 20 \text{ GeV}}\]