Diffractive production of top quark(s) in SM and beyond

17 December 2019

Cristian Beldenegro (Kansas), Andrea Bellora (Torino&INFN), Michael Pitt (CERN), Christophe Royon (Kansas)
Outline

Part 1: Exclusive production of top quark pairs

Part 2: Single diffractive events with top quark(s)
Outline

Part 1: Exclusive production of top quark pairs

Part 2: Single diffractive events with top quark(s)

The CEP ttbar studies is a broad effort. Other people also inspire these studies

E.Robutti, S.Tosi, F.Ferro, M.Pisano, R.Mulargia (Genova), A.Bellora, A.Solano (Turin), C. Beldenegro, C.Royon (Kansas), B Ribeiro Lopes, J.Hollar, M.Gallinaro (LIP), D. d’Enteria, M.Pitt, P.da Silva, M.Mulders (CERN)
Central Exclusive production

CEP with tagged protons:

- The main signature of CEP is that the protons remain intact
Central Exclusive production

**CEP with tagged protons:**

- The main signature of CEP is that the protons remain intact

- We can use these protons to tag the CEP events, by measuring them with forward detectors (e.g., AFP or CT-PPS)
Central Exclusive production

CEP with tagged protons:

- The main signature of CEP is that the protons remain intact.

- We can use these protons to tag the CEP events, by measuring them with forward detectors. **For example CMS + CT-PPS:**

Forward protons detected in CT-PPS

Central ttbar event triggered and measured in CMS
Acceptance of forward protons

- Forward detectors usually cover only fraction of momentum loss

V. Petousis, “AFP status and prospects” June 10th, 2019

J. Williams, “PPS physics and prospects” June 10th, 2019

Beam – detector distance: $\xi \geq 2\%$

Collimator settings: $\xi \leq 15\%$

We will follow next acceptance
Central Exclusive production

Photon vs pomeron – initiated

- Acceptance of 2%:
  \[ m_X > 2\% \times 13 \text{TeV} = 260 \text{GeV} \]
- From C. Royon talk yesterday ([link](#)):

\[ \xi \geq 2\% \]

Warning! not the same for quarks. Yet, we will ignore IP contributions for now.
Central Exclusive production

Cross section of CEP at $\sqrt{s} = 13$ TeV

- Apply Forward Detector acceptance (2% $\leq \xi \leq 15\%$):

<table>
<thead>
<tr>
<th>IPROC</th>
<th>Xsec [fb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>WW</td>
<td>14.6</td>
</tr>
<tr>
<td>$\mu\mu$</td>
<td>3.05</td>
</tr>
<tr>
<td>dijet</td>
<td>1.55</td>
</tr>
<tr>
<td>$t\bar{t}$</td>
<td>0.112</td>
</tr>
<tr>
<td>$b\bar{b}$</td>
<td>0.057</td>
</tr>
<tr>
<td>$\gamma\gamma$</td>
<td>0.003</td>
</tr>
</tbody>
</table>
Central Exclusive production

Cross section of CEP at $\sqrt{s} = 13$ TeV

- Apply Forward Detector acceptance ($2\% \leq \xi \leq 15\%$):

- + central detector cuts: $p_T^{jet} > 20\text{GeV}, p_T^{l,\gamma} > 30\text{GeV}, |\eta^{lep,jet,\gamma}| < 2.5$

<table>
<thead>
<tr>
<th>IPROC</th>
<th>Xsec [fb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$WW$</td>
<td>4.54</td>
</tr>
<tr>
<td>$\mu\mu$</td>
<td>0.67</td>
</tr>
<tr>
<td>dijet</td>
<td>0.68</td>
</tr>
<tr>
<td>$t\bar{t}$</td>
<td>0.05</td>
</tr>
<tr>
<td>$b\bar{b}$</td>
<td>0.025</td>
</tr>
<tr>
<td>$\gamma\gamma$</td>
<td>0.0025</td>
</tr>
</tbody>
</table>
Central Exclusive production

Cross section of CEP at $\sqrt{s} = 13$ TeV

- Apply Forward Detector acceptance ($2\% \leq \xi \leq 15\%$):

- + central detector cuts: $p_T^{jet} > 20\text{GeV}, p_T^{l,\gamma} > 30\text{GeV}, |\eta^{lep,jet,\gamma}| < 2.5$

We will focus on $t\bar{t}$ production
Backgrounds in CEP

Background in standard runs (\(<\mu> > 25\))

- With increasing pileup, combinatorial backgrounds of SM \(tt\bar{b}\) + 2 protons from PU is also increasing

Background + 2x

- SM inclusive \(tt\bar{b}\) production
- Single diffractive \(pp\) scattering (PU)
- SM exclusive \(tt\bar{b}\) production
Background rates

- From the fraction of SD and DD events, and the probability that the $\xi$ is within the acceptance, can estimate rate of the SM backgrounds.
- The efficiency of diffractive proton from SD event to be within the acceptance of the forward detector is $\sim23\%$. 

![Graph showing background rates](image-url)
Tagged protons as a measure the $t\bar{t}$bar event

- The mass and the rapidity of the central event can be expressed in terms of proton momentum loss. Hence, from the correlation between the central event and tagged protons, the background can be rejected.

\[ m_{tt} = \sqrt{s \xi_1 \xi_2} \]

\[ Y = \frac{1}{2} \log \left( \frac{\xi_1}{\xi_2} \right) \]
**CEP Event selection with tag. protons**

### Central detector event selection

- Apply basic selection cuts for inclusive ttbar and exclusive ttbar events.
- Divide according to top decay mode and apply corresponding selection.
- Estimated event yields for 300 fb\(^{-1}\) and \(< \mu > = 25\)

<table>
<thead>
<tr>
<th>Cut</th>
<th>Exclusive (signal)</th>
<th>Inclusive (bkg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>proton acceptance</td>
<td>3.05</td>
<td>1.7e+07</td>
</tr>
<tr>
<td>Leptons (n=0,1,\geq2)</td>
<td>2.06</td>
<td>1.4e+07</td>
</tr>
<tr>
<td>Jets (n\geq6,3,1)</td>
<td>1.87</td>
<td>1.1e+07</td>
</tr>
<tr>
<td>b-Jets (n\geq1)</td>
<td>1.65</td>
<td>9.6e+06</td>
</tr>
<tr>
<td>(</td>
<td>m_{pp} - m_{tt}</td>
<td>&amp;</td>
</tr>
</tbody>
</table>

* For signal assume 95%

Further background reduction is possible, this is just a rough estimation.
Sensitivity to CEP ttbar production

Discovery of potential vs pileup and luminosity

- Assuming that after event correlation, we accept 1 of 3600 background events, to achieve 5 sigma we need the following amount of data for given pileup profile:

\[
\frac{s}{\sqrt{b}} (\mu, \mathcal{L}) \propto e^{-p_{\text{hit}} \cdot \mu} \sqrt{\mathcal{L}}
\]

\(p_{\text{hit}}\): probability for a PU proton to hit forward detector (here taken as 0.04)

Pileup has a non-linear relation with integrated luminosity if we desire to achieve the same sensitivity:

\[
\mathcal{L} \propto (\mu e^{p_{\text{hit}} \cdot \mu})^2
\]
Single diffraction in pp

Single diffractive (SD) processes with tagged protons:

- The SD can split into two categories:

  - With tagged proton in one of the forward detectors, we can probe the physics of single diffractive events.
  - High $\xi$ cuts can select pure samples of SD events, yet for pure event sampling low PU event should be considered.

(a) Pomeron exchange    (b) Photoproduction
Single diffractive processes have large Xsec (typically few % from inclusive)
At high pileup hard to identify SD using proton tagging
Single diffractive processes have large Xsec (typically few % from inclusive)

At high pileup hard to identify SD using proton tagging

BUT low – mu runs with ~200pb⁻¹ open window for clean SD measurements

Can be visible with 200 ipb of low mu runs
Single diffractive processes have large Xsec (typically few % from inclusive)
At high pileup hard to identify SD using proton tagging
BUT low – mu runs with ~200pb⁻¹ open window for clean SD measurements

Can be visible with 200 ipb of low mu runs

FPMC Simulation

|S|_{13TeV}|=4%, |S|_{5TeV}|=8%
2% ≤ ξ ≤ 15%, P_T^{MIN}=10GeV

σ_{t\bar{t}}^{13} = 6pb
σ_t^{13} = 0.6pb
SD ttbar events

- Color singlet top quark pairs is challenging to probe within the gluon-gluon production. With SD events we can investigate color flow of ttbar and compare to the inclusive production.
- Top quark are probes the scale/mode of the production through it decay properties – like spin correlations.
- Photoproduction of ttbar can be probed both in pp, pPb and pp data. The measurement can serve as a reference for the pPb runs.

**Figure:**

- The figure illustrates the production of ttbar in photoproduction. The plot shows the cross section as a function of the ttbar invariant mass, with different curves representing different spin correlations and production modes.

**Reference:**

JHEP 1009:034,2010
• Although a low sensitivity to SM exclusive ttbar production, this channel gives a unique opportunity to probe directly the ttyy vertex.

• tty vertex is not constrained as for direct tty measurement, but still might be valid for alternative constrain of tty coupling

• Single top in SD events is sensitive to FCNC coupling from single top photoproduction
Summary

• A new phase-space of SM can be reached using the tagged protons.
• \( \text{ttbar} \) production is not yet visible with LHC data, but it will be good to establish an analysis.
• Single Diffractive SM \( \text{ttbar} \) is visible with LHC data, and it will be interesting to explore this physics.
• The increase of pileup has a way too negative effect on the sensitivity. It would be good in Run3 to have more low pileup runs.
• Single Diffractive SM processes have large potential for probing diffractive physics as well as SM top and EW physics.
Backup