HELEN Report

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August 2006

Abstract

It's given a summary of the activities performed by the student during his HELEN training period at CERN. The main topic is the analysis of the prospects for ttbar diffractive production at CMS/LHC.

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1 Activities overview

During my HELEN training I basically developed activities in analysis groups in CMS. In particular with the diffractive group in CMS (contact Monika Grothe), there has been a strong collaboration towards the completion of the CMS/TOTEM Physics Technical Design Report. I was in charge of the analysis on diffractive production of top pairs, having collaborated further on common topics. The analysis has been performed with resources from both CERN and the T2 HEPGRID BRAZIL Cluster, at UERJ, Brazil. A learning period has been crutial on the CMS detector and software systems and on the computing resources at CERN and the cluster in Brazil, where I was responsible not only for the physics analysis, but also for the installation of the CMS software in the remote site, as well as for the production of datasets. In addition, I was put in contact with the Minimum Bias/Underlying Event group at CMS (contact Paolo Bartalini), having attended several meetings. The main focus was on the production of samples for special run conditions, with non-standard geometry, for very low luminosity, aiming at the design of a trigger at these conditions. Unfortunately changes of plans on the machine have delayed the studies until new samples and software are available.

2 $t\bar{t}$ diffractive production - Executive Summary

Inclusive DPE (Double Pomeron Exchange) production of $t\bar{t}$ pairs (see Fig. 1) was studied for CMS high luminosity running ($2x10^{33}cm^{-2}s^{-1}$), with one top decaying leptonically, with the W further decaying only to muon and a neutrino, and the other to jets. The proccess was simulated with the generator DPEMC v2.4, together with the fast CMS simulation code FAMOS, version 1.4.0. Two theoretical models were used for this analysis, that of Cox & Forshaw and of Boonekamp, Peschanski and Royon (BPR).

As dominant background, we have the overlap of a non-diffractive $t\bar{t}$ event with pile-up events (in average 7) in the same bunch crossing. Since we use RP's (Roman Pots) to tag the diffractive event, uncorrelated diffractive pile-up events generating very forward diffractive protons can fake the non-diffractive event as a diffractive one. For an integrated luminosity of 10 fb^{-1} we obtain a number of events of $\mathcal{O}\,(100)$ for this background, while $\mathcal{O}\,(1)$ to $\mathcal{O}\,(100)$ for the diffractive signal, depending on the theoretical model used.

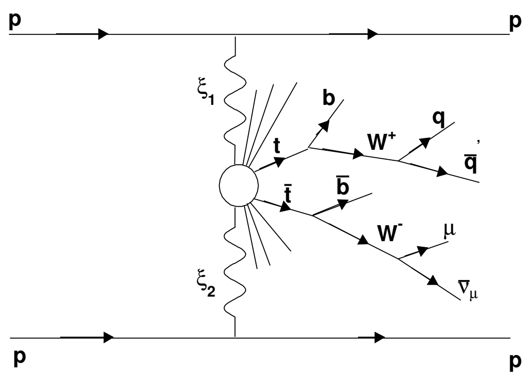

Figure 1: Diagram for inclusive DPE (Double Pomeron Exchange) semileptonic production of $t\bar{t}$.

3 $t\bar{t}$ diffractive production - Detailed analysis description

3.1 Selection Cuts and Reconstruction

Here we describe in a straightforward way our selection cuts and reconstruction methods:

- As we didn't have available the full trigger simulation at hand, we did a simple check on the p_T of the L3 muons, using the *FamosL3MuonReconstructor* in FAMOS and applying the HLT treshold of 19 GeV. This should give an idea of the event yield reduction from the trigger.
- We demand further exactly 1 muon with $E_T > 20$ GeV and $\eta < 2.4$. We also required the muon to be isolated, i.e. that the ratio of the

muon E_T to the E_T of all calorimeter towers (*EcalPlusHcalTower*) in a cone of 0.3 around the muon, plus the muon E_T itself, be at least 0.9. Figure 2 shows both distributions with the cuts indicated.

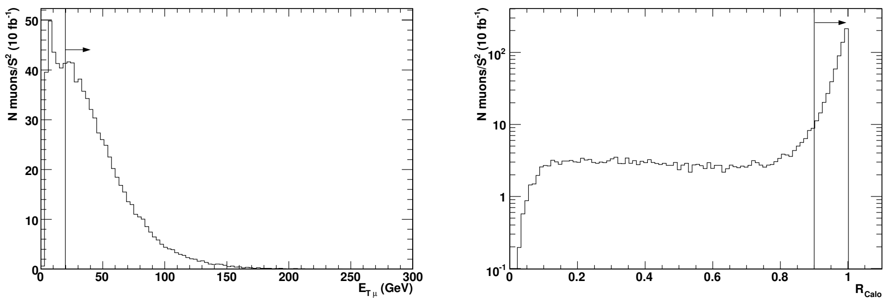

Figure 2: E_T and isolation distributions for muons, normalized to a given luminosity.

- Missing transverse energy ($\not{E}_T$) (using as input objects *EcalPlusHcal-Tower's*) of at least 20 GeV.

- At least 4 jets with $E_T > 30$ GeV and at least two b-tagged also with $E_T > 30$ GeV. To determine which jets are tagged we demand the discriminator variable from the combined b-tag algorithm to be larger than 1.0. These four jets should be the two b ones and those from the hadronically decaying W. In the ideal case, we would have exactly four high E_T jets; however, we demand *at least* four jets, to account for inefficiencies in jet identification. Jets are reconstructed with the standard Iterative Cone algorithm (again with *EcalPlusHcalTower's* as input) with cone size 0.5 with further $\gamma +$jets calibration. Figs. 3 and 4 give, respectively, the jet and b-tagged jet multiplicity distributions and the E_T distributions for non-b jets and b-tagged jets.

- In addition, we demand the detection of at least one proton in both sides of the 220m TOTEM RP's (Roman Pots). This is done by accepting the generated protons (hard event + PU) with a probability given by the acceptance tables from the RP's, as a function of t and ξ. Only protons in the range of $0.02 < \xi < 0.1$ are considered (this is the

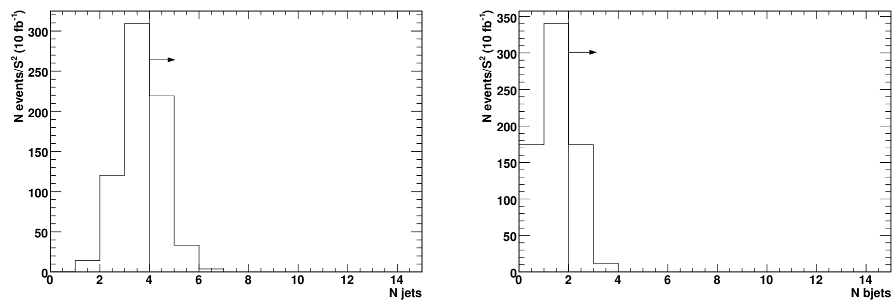

Figure 3: Number of jets and only b-tagged ones with a given E_T cut, normalized to a given luminosity.

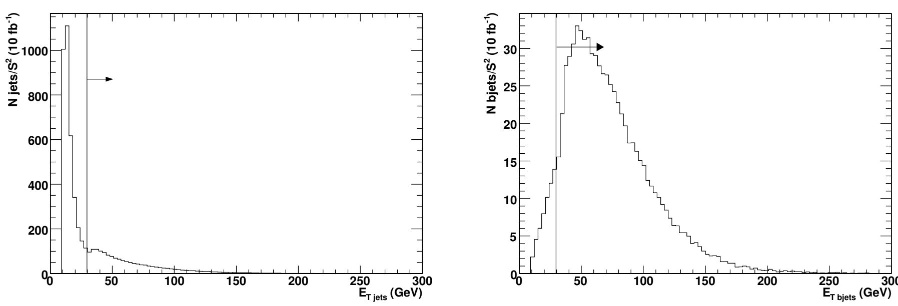

Figure 4: E_T distributions for non-b jets (left) and b-tagged jets (right).

upper limit for diffractive protons at generator level). The situation is described in Fig. 5 where one can see both the proper diffracted protons (cont./blue), showing a rise towards high values of ξ - which is a direct consequence of the kinematical constraint of a high central mass - as well as the uncorrelated protons from the PU (dashed/red), that contaminate the signal and allows for non-diffractive channels to *fake* diffractive ones, as we'll see later.

Both tops were reconstructed, one with the W decaying into jets and the other with the W decaying leptonically:

1. Hadronic top

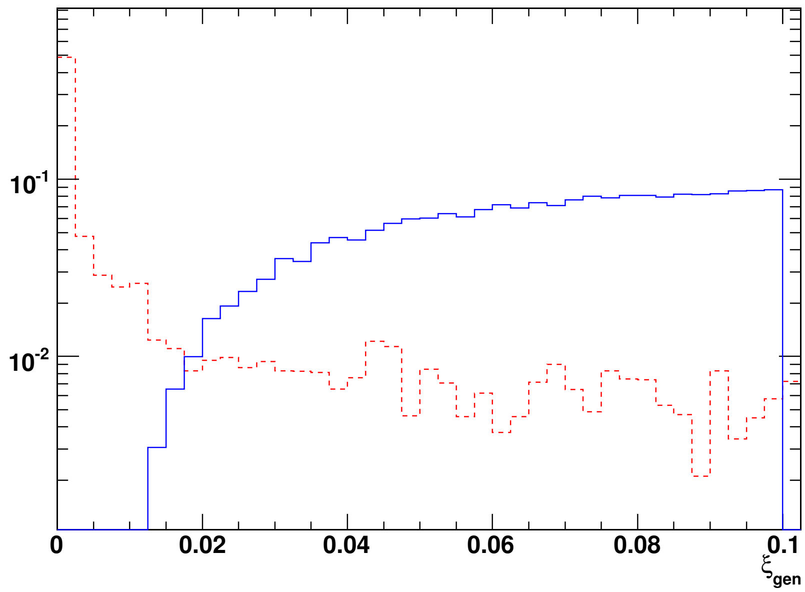

Figure 5: Protons coming from the PU (dashed/red) and diffracted protons (cont./blue) (arbitrary units).

- Step 1: W reconstruction
  - From the non b-tagged jets with the given E_T cut, the pair with invariant mass closest to the nominal W mass was selected.
  - The reconstructed invariant mass of these two jets was required to be between 40 GeV and 120 GeV.
  - The energy of the two selected jets was rescaled such that their invariant mass equals that of the W.
- Step 2: Top reconstruction
  - In order to assign the matching between the b-tagged jets and the W jet, the pair with invariant mass closest to the nominal top mass was chosen.
  - With the b-tagged jet thus selected and the W, one of the two tops can thus be reconstructed.

2. Leptonic top

   - The leptonic W transverse mass was reconstructed using the $\not{E}_T$ and the muon energy. The transverse mass was further required to be less than 120 GeV.
   - The ambiguity due to unmeasured longitudinal component of the neutrino was resolved by minimising the difference between the reconstructed top mass and the nominal one, when looping over the remaining b-tagged jets. If there is no solution for the missing variable (the longitudinal momentum component of the W), the direction of the muon was chosen for the leptonic W.
   - It was futher required that the mass difference between the two top candidates be less then 50 GeV and the cosine of the azimuthal angle between them less then -0.8.

- ξ reconstruction: In principle the ξ from the protons can be obtained from

  $$\xi_{1,2} = \frac{1}{\sqrt{s}} \sum_{\text{particles}} E_T e^{\pm\eta}$$

  where the sum is over all particles in the event.

  We try to reconstruct approximately the ξ. Instead of summing over all the particles, we do it only for the main objects in our event, that is, all the jets, all the muons and the reconstructed neutrino.

  On the other hand we have the ξ from the RP's. We then require the difference between then $\xi_{central} - \xi_{\mathrm{RP}}$ to be less than 0.02. Notice that this difference should be a biased distribution towards negative values, given the approximation used.

  For this, in the case of more then one proton accepted in a given RP, we use the highest ξ one, assuming we know how to discriminate them. Given a full simulation we may decide to change this criteria or even discard these events.

3.2 Efficiencies and Event yields

As the dominant background we have the combined result of non-diffractive top pair events with pile-up events in the same bunch crossing, with protons in the acceptance region. The pile-up effect was simulated at the detector level, using the FAMOS package, combining non-diffractive ttbar (from PYTHIA) with Minimum Bias events, from PHOJET.

The mixing is done inside FAMOS, combining the signal of the hard scale event and a number of pile-up events (also the final state protons) given by a Poisson distribution with mean of 7.0. The same procedure has also been applied to the signal channel and all the diffractive backgrounds.

Table 1 shows the cuts' efficiencies for all the considered diffractive channels, that is, DPE $t\bar{t}$ semileptonic with the W decaying in muon, and with the W decaying in electron, DPE $t\bar{t}$ fully hadronic, di-leptonic (e and μ) and decaying modes including τ leptons. Comparing these efficiencies gives an idea of the behaviour of the $t\bar{t}$ cuts in the analysis. We also considered diffractive $W+$ Jets, which didn't give any suviving events, for the samples considered.

Figure 6 presents the (hadronically decaying) top mass distribution with all the diffractive backgrounds stacked.

Table 2 gives a comparison between the two models considered in the diffractive generator, Cox & Forshaw and BPR, for DPE $t\bar{t}$ production in the semileptonic (muons only) channel. There is a great discrepancy in the numbers for the cross sections, specially if you consider that the Cox & Forshaw number should be further multiplied by a gap survival probability factor, expected to be of the orther of $0.03 - 0.06$ at LHC.

Table 3 gives the comparison of the efficiencies and event yields for the diffractive signal and the before mentioned dominant background of non-diffractive inclusive $t\bar{t}$ mixed with diffractive PU. Here we have a relatively big statistical uncertainty in the final expected number of events surviving the cuts for the inclusive $t\bar{t}$ sample, given a limited sample size, only a fraction of the desired integrated luminosity.

Figure 7 gives the distributions, for signal and non-diffractive $t\bar{t}$, of

Table 1: Efficiencies and event yields for diffractive channels, generated with the Cox & Forshaw model in DPEMC.

Cuts	$t\bar{t} \to b\bar{b}q\bar{q}\mu\nu$	$t\bar{t} \to b\bar{b}q\bar{q}e\nu$	$t\bar{t} \to b\bar{b}q\bar{q}q\bar{q}$	$t\bar{t} \to b\bar{b}\tau$X	$t\bar{t} \to b\bar{b}l\nu l\nu$
L3 pt muon	0.8283	0.0535	0.05422	0.1893	0.6679
1 muon isol.	0.7416	0.0030	0.00334	0.1288	0.4622
4 jets	0.2653	0.0018	0.00240	0.0169	0.0304
2 bjets	0.0977	0.0004	0.00054	0.0061	0.0102
$\not{E}_T$	0.0878	0.0004	0.00025	0.0050	0.0093
lep W $m_\perp$	0.0821	0.0003	0.00025	0.0048	0.0074
had W mass	0.0717	0.0003	0.00021	0.0041	0.0055
Δm_{top} & $\cos\phi$	0.0447	0.0002	0.00006	0.0027	0.0022
RP's acceptance	0.0440	0.0002	0.00006	0.0026	0.0022
$\Delta\xi < 0.02$	0.0394	0.0001	0.00006	0.0023	0.0019
σ/S^2(pb)	0.0701	0.0704	0.2114	0.0996	0.0234
$N/S^2(10\ fb^{-1})$	27.6	0.09	0.12	2.26	0.45

Table 2: Efficiencies and event yields for the signal, generated with both the Cox & Forshaw and the BPR models in DPEMC.

Cuts	$t\bar{t} \to b\bar{b}q\bar{q}\mu\nu$ (Cox & Forshaw)	ϵ_{cuts}	$t\bar{t} \to b\bar{b}q\bar{q}\mu\nu$ (BPR)	ϵ_{cuts}
N total	46559		36406	
L3 pt muon	38563	0.8283	30261	0.8312
1 muon isol.	34526	0.7416	27271	0.7491
4 jets	12354	0.2653	10220	0.2807
2 bjets	4547	0.0977	3782	0.1039
$\not{E}_T$	4088	0.0878	3379	0.0928
lep W $m_\perp$	3822	0.0821	3148	0.0865
had W mass	3338	0.0717	2728	0.0749
Δm_{top} & $\cos\phi$	2082	0.0447	1647	0.0452
RP's acceptance	2048	0.0440	1611	0.0443
$\Delta\xi < 0.02$	1833	0.0394	1444	0.0397
σ(pb)	0.0701 x S^2		0.6886	
N($10\ fb^{-1}$)	27.6 x S^2		273.12	

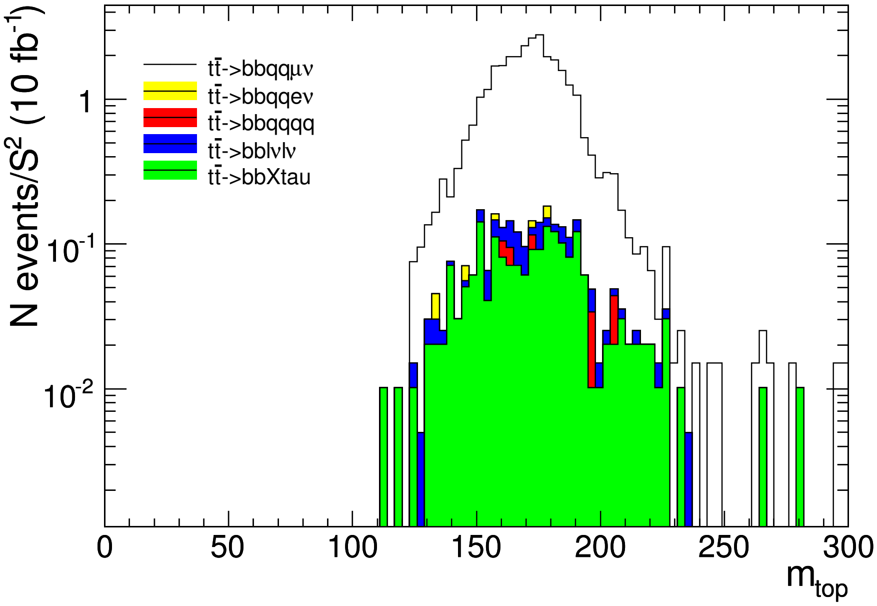

Figure 6: Hadronically decaying top mass distributions with diffractive backgrounds.

$\xi_{central} - \xi_{\rm RP}$, as defined above. Note that the cut shown has to be satisfied for the protons on both sides.

We give, in table 4, a comparison of the RP's cuts behaviour for non-diffractive inclusive $t\bar{t}$, mixed with three different PU samples: PHOJET full MB, PHOJET, excluding DPE process and PYTHIA with diffractive content (which does not include DPE). The numbers for the last two somehow should relate, while the first one should be increased from DPE events combined or not with SD ones. The cuts considered are: fraction of events with at least one proton in both sides in the 220m detectors, independently the fraction of events with at least two protons in one side or the other and both combined, that is, the fraction of accepted events in the RP's in which one has more then one proton in at least one of them. Table 5 gives the same numbers, but now for the diffractive signal. Note that this is the fraction of events that would be discarded with one couldn't treat more than one

Table 3: Raw event selection and efficiencies and further normalization for 10 fb^{-1}.

Cuts	$t\bar{t} \to b\bar{b}q\bar{q}\mu\nu$	ϵ_{cuts}	$qq, gg \to t\bar{t} \oplus$ PHO MB	ϵ_{cuts}
N total	46559		1047609	
L3 pt muon	38563	0.8283	226105	0.2158296
1 muon isol.	34526	0.7416	152761	0.1458187
4 jets	12354	0.2653	57158	0.0545604
2 bjets	4547	0.0977	19808	0.0189078
$\not{E}_T$	4088	0.0878	17653	0.0168508
lep W $m_\perp$	3822	0.0821	15607	0.0148977
had W mass	3338	0.0717	13739	0.0131146
Δm_{top} & $\cos\phi$	2082	0.0447	6416	0.0061244
RP's acceptance	2048	0.0440	67	0.0000640
$\Delta\xi < 0.02$	1833	0.0394	23	0.0000220
σ(pb)	0.0701		488	
N(10 fb^{-1})	27.6		107.14	

proton being detected at once.

Table 4: Fraction of events with at least one proton in each RP, at least 2 protons in one of the RP's and both combined, for inclusive ttbar mixed with different PU samples.

	RP's acceptance	2 protons	Combined
$qq, gg \to t\bar{t} \oplus$ PHO MB	0.0104	0.0077	0.0010
$qq, gg \to t\bar{t} \oplus$ PHO MB no DPE	0.0081	0.0064	0.0010
$qq, gg \to t\bar{t} \oplus$ PY MB	0.0070	0.0064	0.0004

4 Final Remarks

The HELEN programme has given me the possibility to interact and carry on a fruitful collaboration at the CMS Experiment at CERN, being part of analysis groups. I was also able to attend to innumerous meetings, conferences and seminars, that will be invaluable to my formation, and to get to know my future collaborators and colleages in the experiment.

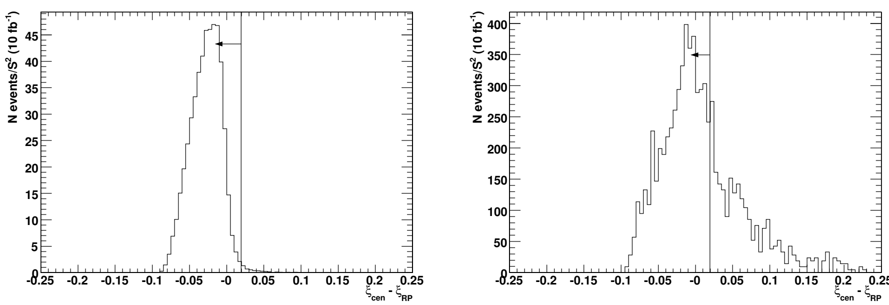

Figure 7: Difference between the ξ calculated from the central detector and from the RP's, for signal (left) and non-diffractive inclusive $t\bar{t}$ (right)

Table 5: Fraction of events with at least one proton in each RP, at least 2 protons in one of the RP's and both combined, for the signal channel.

	$t\bar{t} \to b\bar{b}q\bar{q}l\nu$ (Cox & Forshaw)	$t\bar{t} \to b\bar{b}q\bar{q}l\nu$ (BPR)
RP's acceptance	0.9750	0.9643
2 protons	0.1643	0.1625
Combined	0.1624	0.1596

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