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Validation note for the CMS same-sign dilepton analysis: CMS_B2G_12_012

Daniele Barducci* and Cédric Delaunay†
LAPTh, Université Savoie Mont Blanc, CNRS, B.P. 110, F-74941 Annecy-le-Vieux, France

This note contains details of the implementation and validation of the CMS *Search for top partners with charge 5/3 in the same-sign dilepton final state* [1] within the `MadAnalysis5` [2–4] framework. This search looks for a signal with two isolated same-sign leptons with $p_T > 30$ GeV and $H_T > 900$ GeV. The implementation has been performed with `MadAnalysis5 v1.2` using the standard version of the `Delphes v3.2.0` [5] package.

I. SIMULATION DETAILS

The CMS collaboration provides several differential distributions, both in the published paper and in the additional material available at [6], together with a summary plot with the expected and observed 95% confidence level (CL) limit for the $X_{5/3}$ QCD pair production cross section times branching fraction in a same-sign dilepton final state. A table with the number of signal events for $m_{X_{5/3}} = 800$ GeV for the three same-sign categories ee, $e\mu$ and $\mu\mu$ separately is also provided. These category are however combined in a unique signal region when computing the exclusion CL. Finally, for a $X_{5/3}$ pair decaying into a same-sign dilepton final state, the signal selection efficiency is claimed to be between 10% and 13% for $m_{X_{5/3}} \in [750, 1000]$ GeV.

The signal process consists in the production of a $X_{5/3}$ pair via QCD interactions. The $X_{5/3}$ is assumed to couple only with the third generation of Standard Model (SM) quarks, and it can therefore only decay via charged current interactions through the process $X_{5/3} \to W^+ t$.

The signal process has been generated with `MG5_aMC v2.3.0` [7] using the model file *Rho resonances in composite Higgs model (including top partners)* which has been implemented in the `UFO` format [8] through the Feynrules package [9], by the authors of [10]. The model is publicly available at the HEPMDB [11] web-page [1] and it has been modified with the inclusion of the QCD interactions for the extra quarks, adding the following lines in the `vertices.py` model file:

```
V_133 = Vertex(name = 'V_133',
particles = [ P.X53__tilde__, P.X53, P.g ],
color = [ 'T(3,2,1)' ],
lorentz = [ L.FFV1 ],
couplings = {(0,0):C.GC_7}).
```

The `MG5_aMC v2.3.0` syntax that has been used to generate the matrix element is:

```
generate p p > X53 X53~ / rho0 rho+ rho- @1
add process p p > X53 X53~ j / rho0 rho+ rho- @2
add process p p > X53 X53~ j j / rho0 rho+ rho- @3
```

and 12 signal samples, corresponding to $m_{X_{5/3}}$ =350, 450, 550, 600, 650, 700, 750, 800, 850, 900, 950 and 1000 GeV, have been generated.

Decays of unstable particles, including the $X_{5/3}$ quark, parton showering and hadronisation have been performed with `PYTHIA v6.4` [12] implemented in `MG5_aMC v2.3.0` through the `pythia-pgs` package. The MLM matching scheme [13, 14] was used to merge the 0, 1 and 2 jets samples. The samples have then been passed through `Delphes v3.2.0` [5] for a fast detector simulation, using a `MadAnalysis5`

* barducci@lapth.cnrs.fr
† delaunay@lapth.cnrs.fr
1 `http://hepmdb.soton.ac.uk/hepmdb:1014.0179`

tuned card. In the `run_card.dat` the value `ickkw` has been fixed to the value of 1, while the value of the jet merging parameter `xqcut` has been tuned according to the ones reported in Tab. I. In the `pythia_card.dat` the flag `showerkt=T` has been added, while the value of `QCUT` has been fixed equal to `xqcut`.

Finally, the QCD pair production cross sections have been normalised to the next-to-next-to-leading-order (NNLO) predictions as reported on the CMS twiki web-page [6]. These values are indicated in Tab. I.

$X_{5/3}$ mass [GeV]	`xqcut` value	σ QCD [fb]
350	75	5.2×10^3
450	75	1.2×10^3
550	75	315.2
600	70	173.8
650	70	100.0
700	70	58.6
750	70	35.0
800	65	21.3
850	65	13.2
900	50	8.3
950	50	5.3
1000	50	3.3

TABLE I. `xqcut` values used in the signal simulation and NNLO cross sections adopted for the signal normalisation for the simulated $X_{5/3}$ masses.

II. VALIDATION

The analysis selection requires isolated leptons, which are defined by computing the scalar sum of the p_T of all neutral and charged reconstructed particles within a cone of size ΔR around the selected lepton. This sum is divided by the p_T of the lepton, which is considered isolated if the ratio is below 0.15 (0.2) in a cone $\Delta R = 0.3$ (0.4) for electrons (muons). A category of loose leptons is also defined, where the ratios are increased to 0.60 (0.40) for electrons (muons). Jets are reconstructed with `FastJet` [15], via an anti-k_T [16] algorithm, with distance parameter 0.5 and are required to have $p_T > 30$ GeV.

In the experimental analysis, jet substructure algorithms to tag boosted jets from top and W decays are also used. Since at the moment this is not a feature implementable in `MadAnalysis5`, we did not use any jet substructure technique for our analysis.

The signal region is then obtained by applying the following set of cuts:

- At least two isolated same-sign leptons as defined above. If more than one same-sign pair is present, the one with the highest leading lepton p_T is considered,

- Dilepton Z boson veto: $M_{ee} < 76$ GeV or $M_{ee} > 106$ GeV,

- Trilepton Z boson veto: $M_{\ell\ell} < 76$ GeV or $M_{\ell\ell} > 106$ GeV, where $M_{\ell\ell}$ is the invariant mass of either one of the selected leptons and any other same flavour opposite sign loose lepton in the event, with $p_T > 15$ GeV,

- $N_C \geq 7$, where N_C is the number of the reconstructed constituents of the event (leptons and jets),

- H_T >900 GeV, where H_T is the scalar sum of the p_T of all the selected jets and leptons in the event.

We now compare the official CMS results with the ones of our simulation. However, since we did not use any jet substructure technique for our analysis, we refrain to compare our jet distributions with the official ones.

A. Published plots

After the signal selection the analysis report 6.8±2.1 background events and 9 observed events. A signal is therefore excluded if it predicts more than 10.1 events in the unique signal region of this search. We obtain a limit on the $X_{5/3}$ mass of 785 GeV, see Fig. 1 (right panel), in good agreement with the official CMS result of 800 GeV.

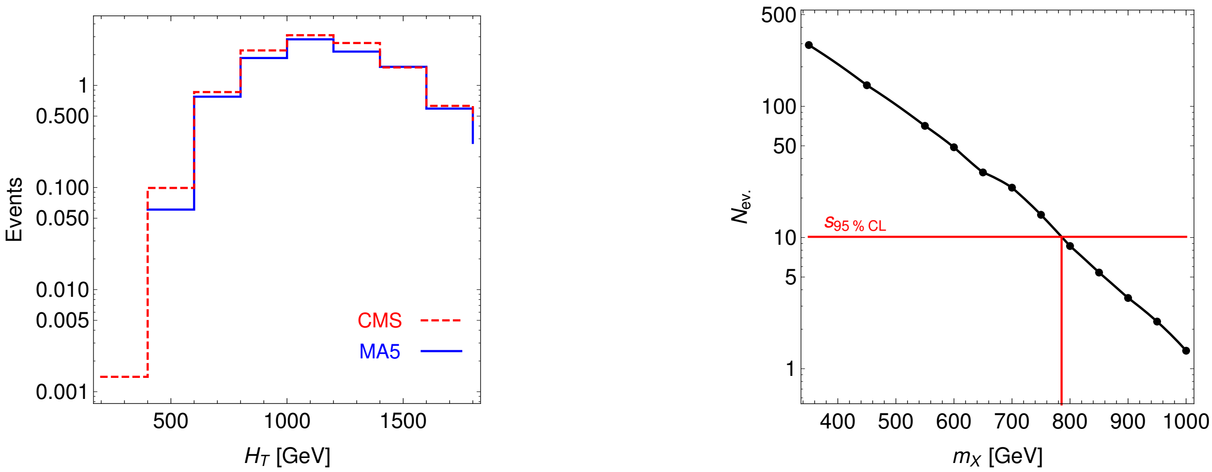

FIG. 1. Distribution of H_T for all channels combined, after the full selection except for the H_T requirement itself for $m_{X_{5/3}} = 800$ GeV (left) and number of signal events in function of the $X_{5/3}$ mass (right). The horizontal red line in the right plot represents the number of signal events excluded at 95% CL, as obtained with the module `exclusion_CLs.py` available within `the MadAnalysis5` package.

Signal Region	CMS official results	MA5 results
ee	2.1	2.3
$\mu\mu$	2.8	2.1
$e\mu$	4.7	4.2

TABLE II. Signal events in the three selection channels for the official CMS results and our simulation for $m_{X_{5/3}} = 800$ GeV.

B. Unpublished plots

In this Section we compare other unpublished plots, publicly available in additional material at on the CMS twiki web-page [6].

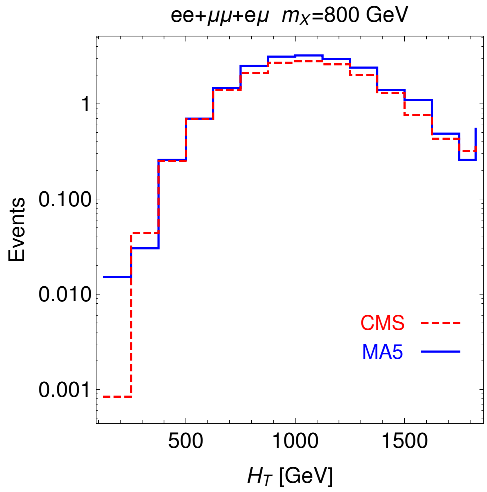

FIG. 2. Distribution of H_T for all channels combined after the same-sign selection, the Z veto and a requirement of at least two jets, for $m_{X_{5/3}}$=800 GeV

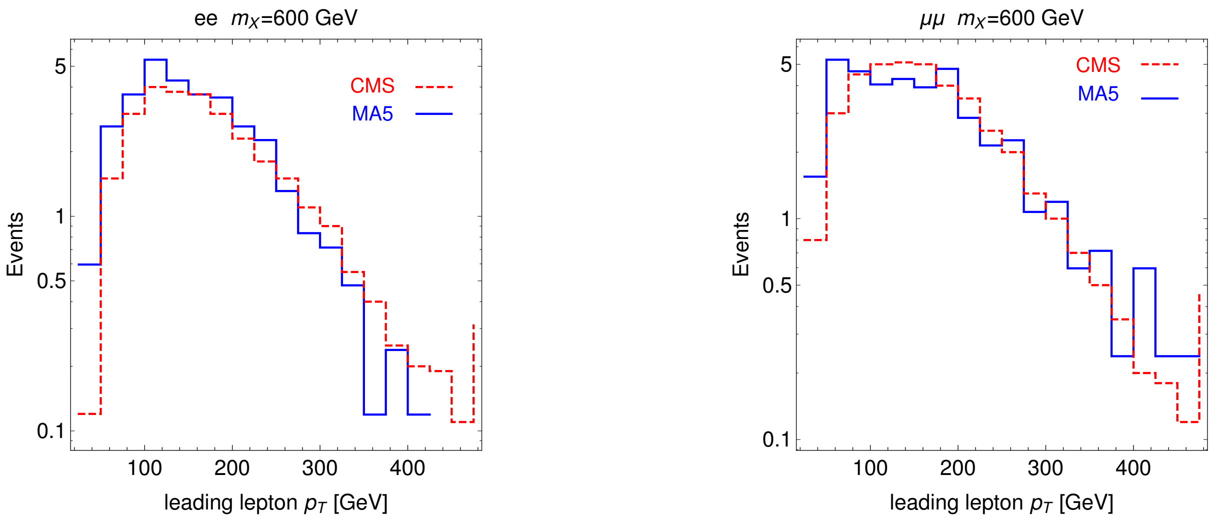

FIG. 3. Distribution of the leading lepton p_T for the ee and $\mu\mu$ selection channels after the same-sign selection, the Z veto and a requirement of at least two jets, for $m_{X_{5/3}} = 600$ GeV

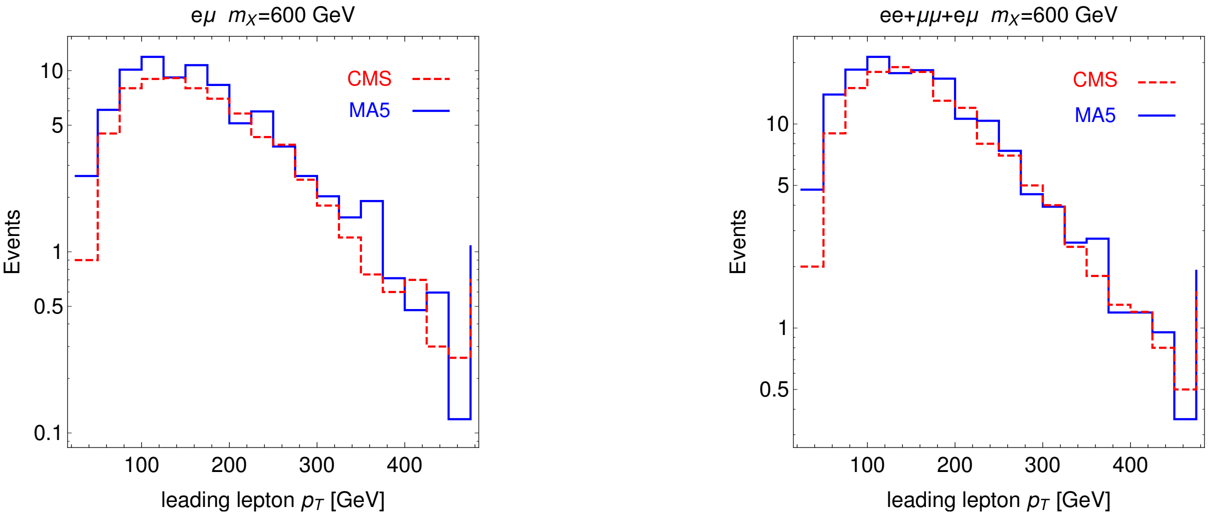

FIG. 4. Distribution of the leading lepton p_T for the $e\mu$ and selection channels and all channels combination after the same-sign selection, the Z veto and a requirement of at least two jets, for $m_{X_{5/3}} = 600$ GeV

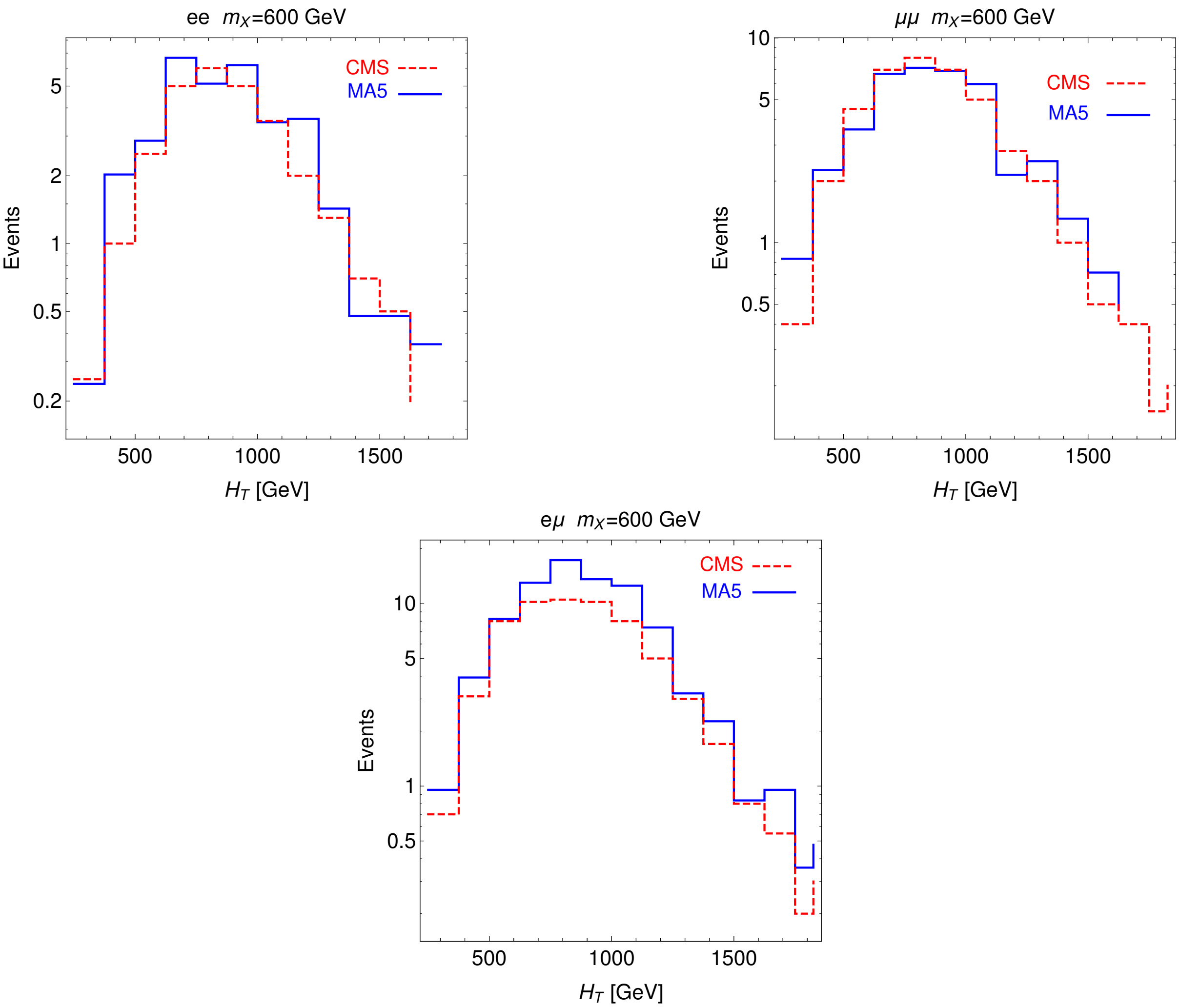

FIG. 5. Distribution of H_T for ee, $\mu\mu$, $e\mu$ selection channels and their combination after the same-sign selection, the Z veto and a requirement of at least two jets, for $m_{X_{5/3}} = 600$ GeV

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