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$t\bar{t}$ mass difference project

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Outline

Theory and project goal

Nature appears to assure us with CPT symmetry, and in particular a full symmetry between the mass of particle and mass of anti-particle. This theory was measured precisely a lot of times for all the particles, but in this paper, we will show analysis made for the first time on run 2 dataset for top quarks.

The project goal is to measure precisely a mass difference (0 or larger) for the top quark and anti-top quark.

Obtaining data, selection rule

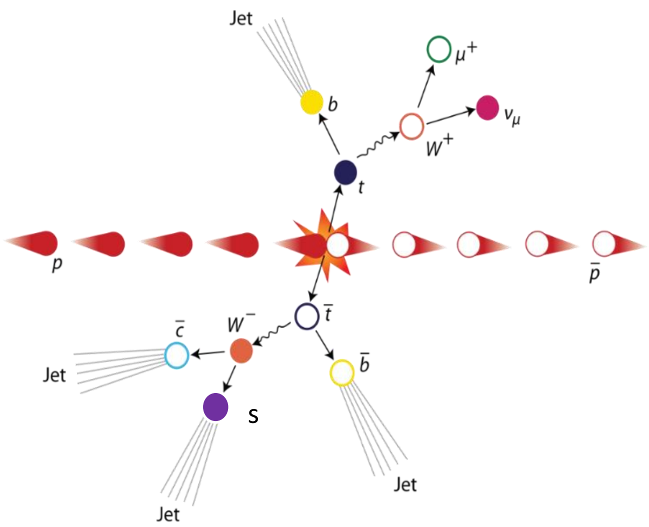


Figure 1: $t\bar{t}$ event

We are looking for $t\bar{t}$ events, specifically at lepton+jets topology.
the selection for the events we are interested in is: at least 4 jets->at least 2 b jets. Then looking at the charge of the lepton-if its positive, μ^+,then we look at a top quark otherwise at anti-top quark.

The quantity we are interested in is M(l,b) -the invariant mass between the lepton and the b jet. This quantity is highly sensitive to the top quark mass, therefore we can use it to get a strong indication about the mass difference of top quark and anti-top quark.

Getting Chi-square value method

To determine goodness of fit we are calculating chi-square values in the next method:

Calculating ratio between data and simulation (sum of $t\bar{t}$ $and\ background$)

Fitting a line to the central area of the ratio and calculating chi-square

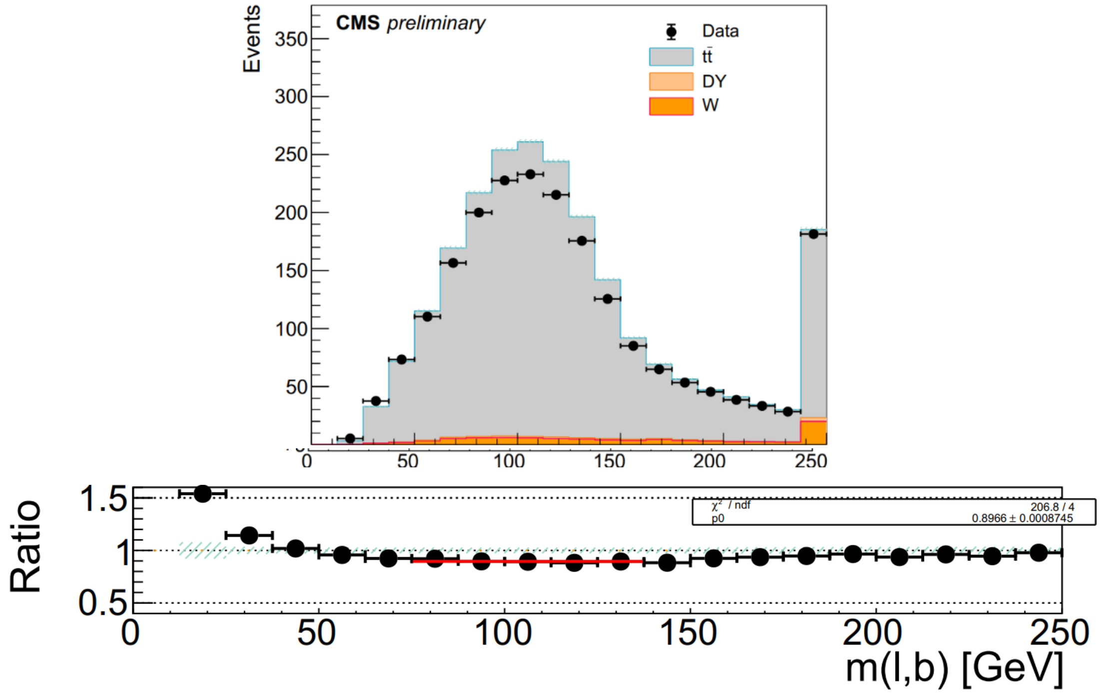


Figure 2: method of extractin chi-square out of fit

Correcting background

To improve the fit between simulation and data we need to correct the background. the need to correct comes from the fact that the simulation might simulate the background in a wrong way. In this project we corrected two errors: W background and $t\bar{t}$ background normalization.

W correction is done by creating a control region.in this control region the selection rule is: no b tags. The m(l,b) plot of a control region is shown in next figure (3).than we calculate the ratio between simulation and data in control region. We get a constant and a function that change the number and the shape of the W background. we multiply these numbers by the simulation and get a better fit overall. The equation of the constant is :

$$\alpha_W = \frac{N_W^{CR}}{N_W^{exp,CR}} \quad (1)$$

Another correction we apply is a normalization for the $t\bar{t}$ part of the simulation. This is also done by calculating the ratio between data to simulation and multiplying by a constant. The equation of simulation with corrections is :

$$N^{SR} = \alpha_W N_W^{SR} + \mu_{tt} N_{tt}^{SR} \quad (2)$$

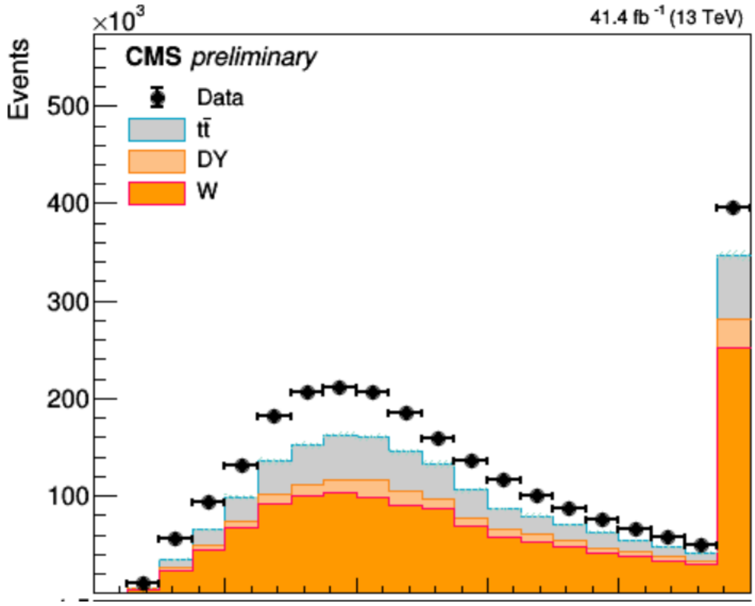


Figure 3: m(l,b) in control region

Checking simulation-injecting simulated mass, measure simulation mass

In order to check that the simulation is not biased to a different average mass of top or anti-top quark we ran a simulation injecting different "data" with different mass difference between top and anti-top quark. The difference injected are (2GeV,1.5GeV,1GeV,0.5GeV,0GeV). then we measured the mass difference and checked if the difference measured fits the injected one.in figure 4 we can see an example for the result with mass difference of 0 injected. We can see that the program measures perfectly a difference of 0GeV, meaning there is no bias in the simulation.

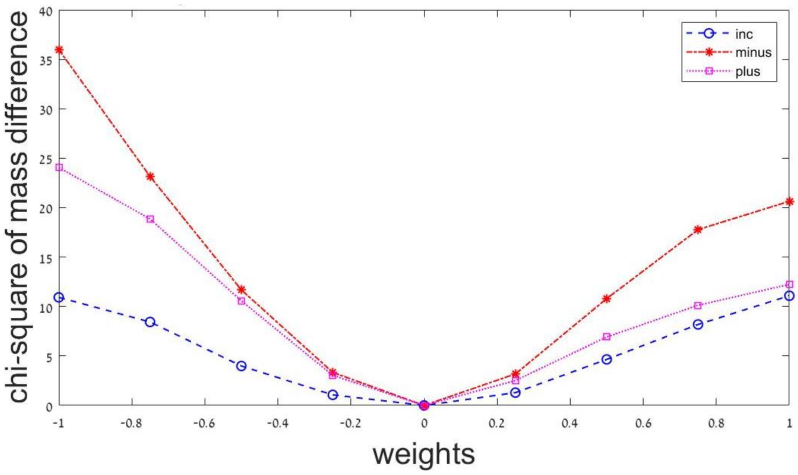


Figure 4:measured mass vs. injected mass

In figure 5 we can see a linear fit of all these measurements, the error bars are calculated by a square root of number of data bins. The errors we got are ~200MeV which is not worse than previous results made in CMS. We believe that with more analysis these errors will be smaller 😊

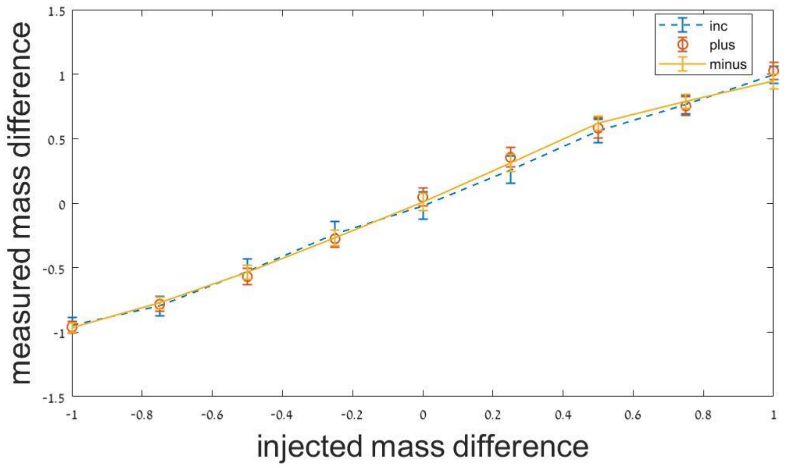


Figure 5:measured mass vs. injected mass for all mass diff's

Fitting to data- simulation with correction

Now after we corrected the background and checked the simulation, we can proceed to fit the simulation to the data. In the next figures (6-8) we look at $ml^{+}b, ml^{-}b, inclusive\ mlb$. We can see that the fitting looks really good, comparing to figure 2 for example. Under every figure there's a table with chi-square values for different simulation corrections.

$\underline{ml^{+}b}$

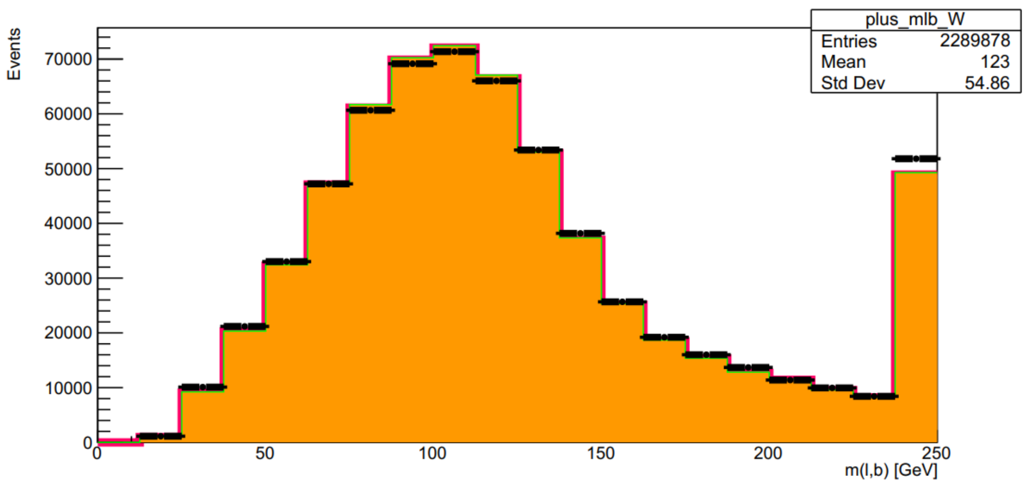


Figure 6: simulation(orange) and data(black) after simulation corrections

Correction on simulation	No corrections	Only α_W correction	Both α_W norm and shape	$t\bar{t}$ scaled correction
$\chi^2 value$	162.27	64.015	50.28	18.73

Table 1: chi square values for ml^+b

$\underline{inclusive\ mlb}$

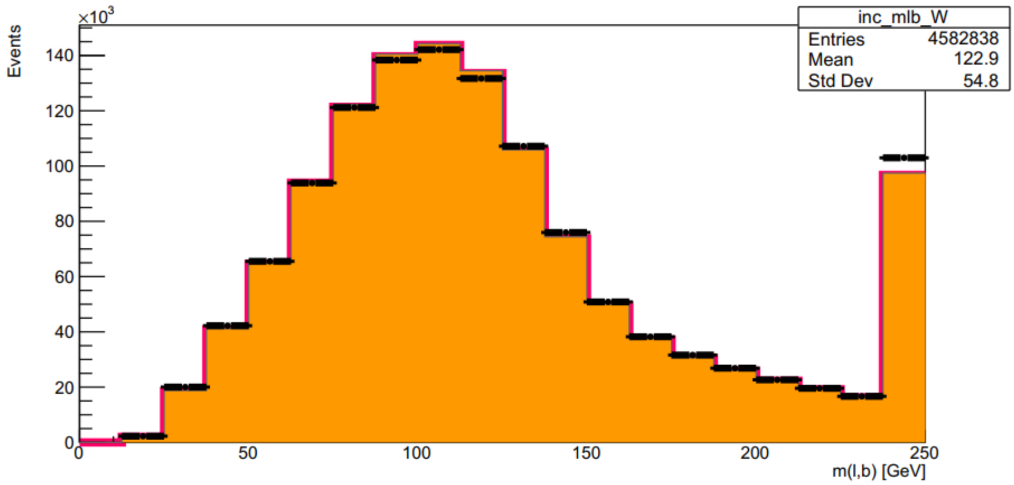


Figure 7: simulation(orange) and data(black) after simulation corrections

Correction on simulation	No corrections	Only α_W correction	Both α_W norm and shape	$t\bar{t}$ scaled correction
$\chi^2 value$	324.96	118.715	87.6	37.21

Table 2: chi square values for inclusive mlb

$ml^{-}b$

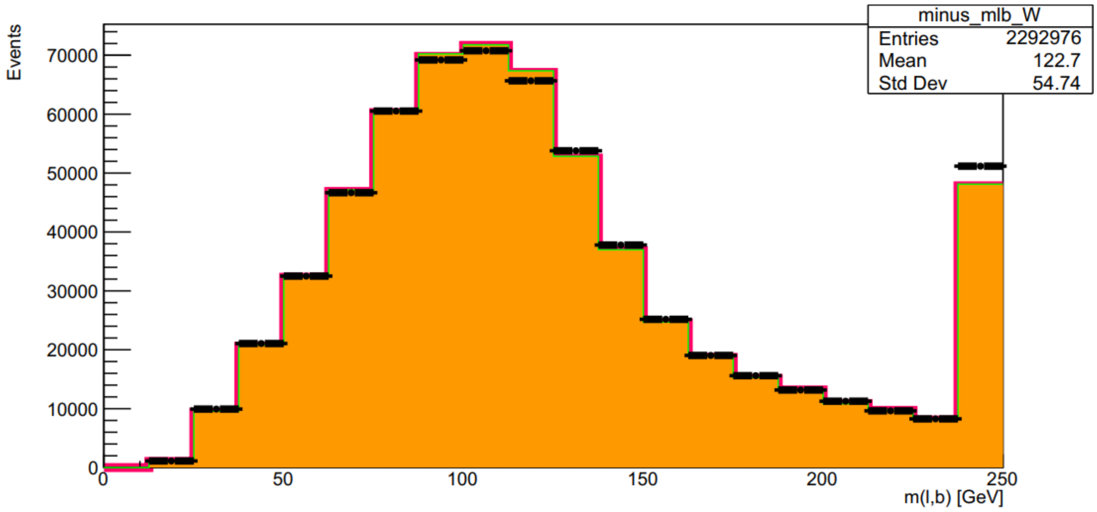


Figure 8: simulation(orange) and data(black) after simulation corrections

Correction on simulation	No corrections	Only α_W correction	Both α_W norm and shape	$t\bar{t}$ scaled correction
$\chi^2 value$	193.84	75.02	58.21	30.77

Table 3: chi square values for $ml^{-}b$

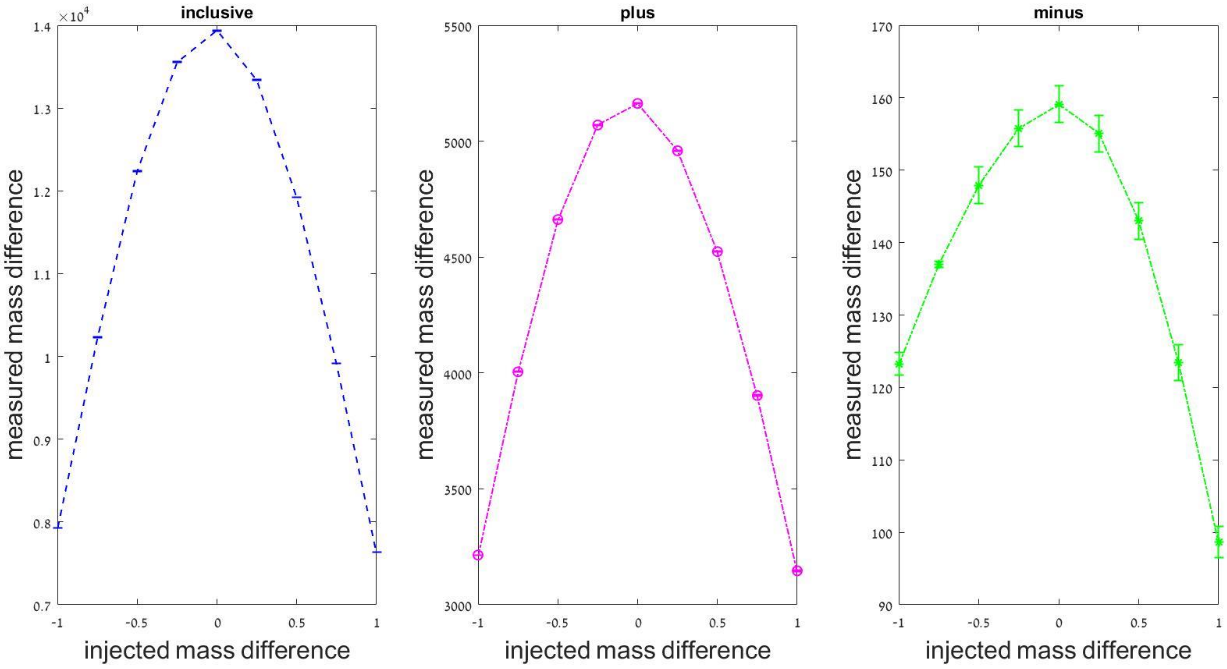
we can see that the χ^2 improves and gets smaller by 6-10 time

the one with no corrections at all! With more corrections we will get even better results, something to look for in the future 😊

Results-looking for mass difference, comparing with data

The result we want to achieve is to measure precisely the mass difference between top quark and anti-top quark. We expect a figure similar to figure 4- a "happy" parabola with minimum around zero. This will indicate on 0 mass difference between top and anti-top as the CPT theory predicts.

The result we can see in the figure below:



We can see that we didn't get a happy parabola, but a sad one! This might happen due to several reasons; we suspect that it is because the average mass of the top and anti-top quark is not exactly 172.5GeV and this creates an unpredicted behavior for this measurement.

Hence from these results we can't conclude anything about the question if there's a mass difference and CPT violation or not, more corrections and analysis needs to be done to achieve this result.

Conclusions

- The fitting method is unbiased on simulation
- Promises statistical precision of ~200MeV on mass difference, probably will get better with more analysis and corrections
- Background corrections improved agreement between data and simulation
- No conclusion about CPT violation …. YET

Future work & improvement

Possible problems in the process-require improvement:

- B jet selection process is not perfect-for every lepton, choosing both jets to create data when in real life only one b-jet is the "right" one. This process needs to be optimized.
- Calculating chi-square by fitting only the central area. This area might be more prone to systematic errors, so maybe its better to calculate the fit for a different area in the ratio between data and simulation.
- Calculating average mass by a 2-dimensional scan of mass differences. The average mass of top and anti-top quark might be different then 172.5GeV and this will cause the results to be unpredictable.

Figure list

thanks

Thank you to my supervisors Martijn Mulders and Pedro Silva for a great project!