Method to observe Spin Correlations in top quark pair events

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- Top quark spin correlations
- Description of the method
- Top event production
- Code Development
- Analysis strategy

Angular Distribution

Top quark is extremely short lived:

$$\Gamma_t = 1.48 \text{ GeV} \rightarrow \tau_t = 0.44 \times 10^{-24} < \tau_{QCD} \approx 3 \times 10^{-24}$$

The spin information is not diluted by hadronization but transferred to the decay products.

- Top and anti-top produced at hadron colliders are unpolarized, but their spins are *Correlated !!!*
- the spin of the top quark is reflected by its decay products

Angular distribution of the daughter particle:

$$\frac{1}{\Gamma}\frac{d\Gamma}{d(\cos\theta_\pm)} = \frac{1}{2}(1 + \kappa_f \cos\theta_\pm)$$

θ = angle between the direction of motion of the daughter particle and the chosen spin axis.

κ = spin analyzer quality of top quark daughter defined as the degree to which the daughter is correlated to the top spin.

Top quark spin correlation

The spin correlation of top quark pairs:

$$A = \frac{N_{\parallel} - N_X}{N_{\parallel} + N_X} = \frac{N(t_L \bar{t}_L + t_R \bar{t}_R) - N(t_L \bar{t}_R + t_R \bar{t}_L)}{N(t_L \bar{t}_L + t_R \bar{t}_R) + N(t_L \bar{t}_R + t_R \bar{t}_L)}$$

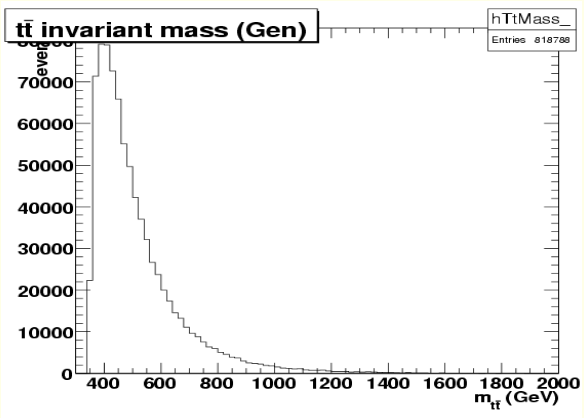
$N_{\parallel}$ N_x = number of events with parallel and anti-parallel top quark spin

The spin correlation in the semileptonic decay channel can be measured in terms of double differential distribution:

$$\frac{1}{N}\frac{d^2N}{d\cos\theta_l \, d\cos\theta_q} = \frac{1}{4}(1 - A\kappa_l\kappa_q \cos\theta_l \cos\theta_q)$$

θ_l / θ_q = angle between the decay particle momentum in its parent (anti) top quark rest frame and the (anti) top quark momentum in the ttbar quark pair rest frame.

Method to observe the SC



The double differential distribution is fitted in several bins of m_{ttbar} to obtain the magnitude of the spin correlations A:

$$f = 1/N\,(1 - \kappa_l\,\kappa_q\,A\cos\theta_l\cos\theta_q)$$

- For low masses m_{ttbar} the spin correlations are enhanced, while for higher masses they are depleted.
- The inclusive sample can be divided into two subsamples with a threshold of $m_{ttbar} = 500\ GeV/c^2$
- The spin correlation magnitude A can be obtained from the fit
- The effect of non-zero spin correlations becomes visible making the ratio between two exclusive distributions.

Estimation of the spin correlations

The fit function becomes:

$$f = R\,(1 - kl\ k_q\ A^+ \cos\theta_l \cos\theta_q) / (1 - k_l\ k_q\ A^- \cos\theta_l \cos\theta_q)$$

The values A^+ and A^- have a well determined relation in the SM. It can be used as a constraint on the fit function.

The difference of A+ and A- is visible as an offset of the correlation axis with respect to the origin of the two dimensional plane (A+, A-).
This offset becomes measurable and can be compared with SM prediction.

It's needed to find a method to estimate the "real" value of the spin correlations starting from the measured one, taking into account the effects of the events selection and of the residual background. The method could be tested by varying the spin correlations value in the generator or by weighting the samples without spin correlations and comparing it with the obtained result.

MC event production

Currently there aren't MC datasets available containing the Spin Correlations information:

- **MadGraph: in order to include the correlations between the tops it's needed to use a 2 →6 matrix element. The Decay routine (used while producing the events) does include the correlations in the decay products, but not between the two tops.**
- **Pythia is not supposed to take into account the spin correlations between the two tops.**
- **Alpgen generates the spin correlations but no samples available.**

I'm producing my private Pythia TTbar samples.

Pythia sample production

2M TTbar inclusive events → 280.000 semileptonic muon events.

Pythia – FastSimulation production (CMSSW_2_2_6): FastSim AOD published in DBS:

/CMSSW226_Pythia_TTbar_10TeVFastsim/villella-CMSSW226_Pythia_TTbar_10TeVFastsim-c901d69ccfcf82f248152bed34c6919f/USER

PATLayer1 + TtGenEvent (CMSSW_2_2_7): crab jobs failed!!!!

I made a small test production (50.000 events) to check that the whole production chain was working:

- AODFastSim
- PAtLayer1 + TtGenEvent
- SanityChecker
- TopTree

NB: it's not possible to produce exclusive ttbar semileptonic events using Pythia as generator!!!!

Code Development

TopTree → Spin Correlations variables: the angular distributions both at TtGen and at Reco level (up to now the TtGen level is available).

Analysis Code → reads the tree variables (gen and reco level), makes the important histo's and fits for the analysis (e.g.:double differential distributions and fits, A vs Mtt plot, Enhanced/Depleated plot…..)

It fills the histo's and computes the fits for each cut divided in separate directory in the root file by adding a few lines in the Code.

Analysis strategy

- TTbar samples without spin correlations: the analysis selection applied on those samples it's important to evaluate the effect of the cuts on the distributions and the fit values;
- Background: estimate the effect of the residual background on the distributions.
- Events selection: the cuts can be tuned taking into account the shape of the residual background and the effect of the cuts on the distributions.

Future plan

As soon as I have some samples:

- Study the effect of the cuts at Gen and Reco Level;
- Find a robust method to fit the double differential distributions (very important!!!);
- Decide the event selection.

In the mean time:

- Finish to develop the code (reco level in the TopTree and in the analysis code).