Measurement of top quark polarisation in t-channel single top quark production

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Motivation

Top is the only quark that decays before hadronising. Furthermore, SM predicts that only left-handed quarks are produced at the Wtb vertex.
Thus, top quark's decay products retain memory of its spin in their angular distributions, providing a probe to investigate the structure of the Wtb vertex.

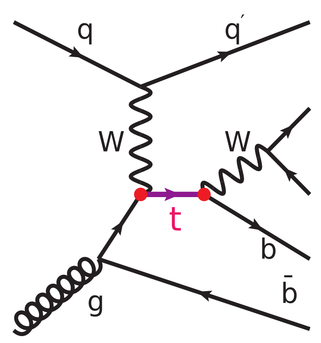
New physics models can lead to a depolarisation in production by altering the coupling structure.
[Aguilar-Saavedra 2008; Aguilar-Saavedra and Bernabeu 2010; Bach and Ohl 2012]
In this way, measuring single top quark polarisation is an important test of SM.

Polarisation and spin asymmetry

$$A_X \equiv \frac{1}{2} \cdot P_t \cdot \alpha_X = \frac{N(\uparrow) - N(\downarrow)}{N(\uparrow) + N(\downarrow)}$$

P_t - top quark polarisation in production
A_X - top quark spin asymmetry
α_X - spin-analysing power of decay product X
$N(\uparrow), N(\downarrow)$ - number of instances X is (anti)aligned with direction of spectator jet

Selecting single top t-channel events

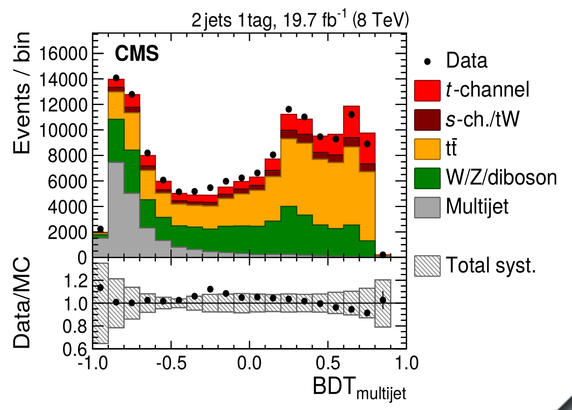


1 light ("spectator") jet
1 muon
missing energy
1 b-jet

second b-jet usually escapes detection

Rejection of multijet background

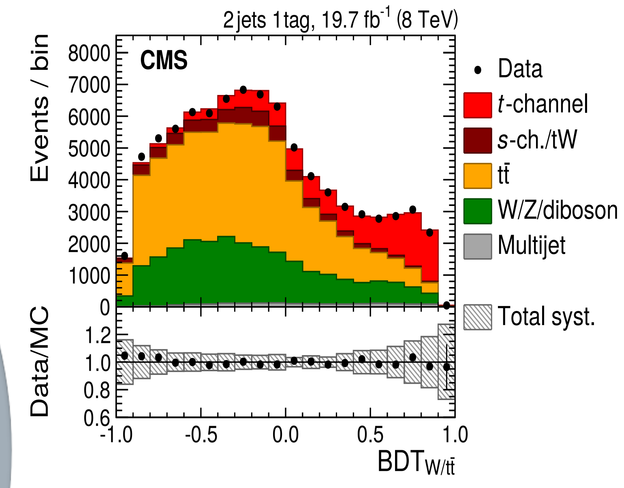
BDT trained to separate signal and multijet background.



Most important variable is transverse mass of W.

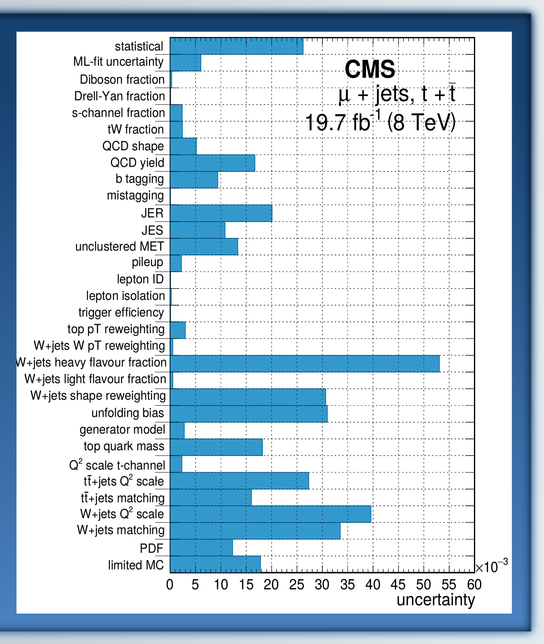
Fit and background rejection

Another BDT is trained for separating out W+jets and $t\bar{t}$ backgrounds.

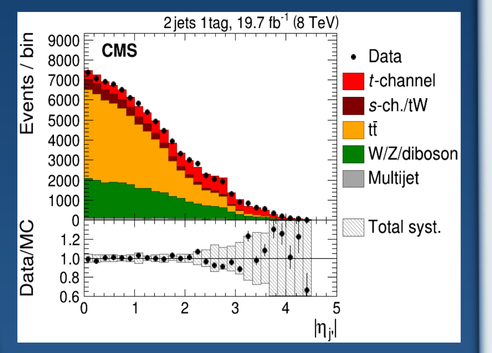


Same distribution is used to fit the contributions of signal and background components.

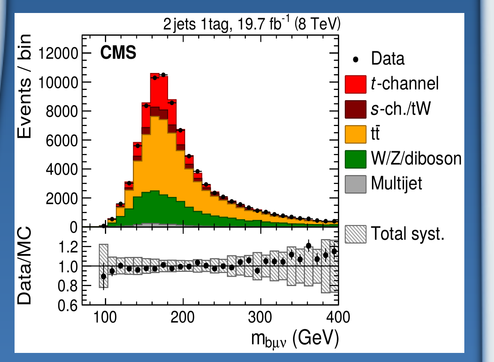
Uncertainties on the measurement



Discriminating variables



The variables having the largest influence on the BDT are pseudorapidity of the light jet and reconstructed top mass.



Measured asymmetry

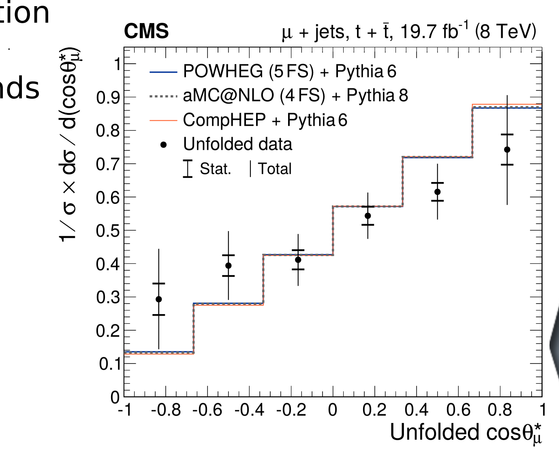
$$A_\mu(t + \bar{t}) = 0.26 \pm 0.03\,(\text{stat.}) \pm 0.10\,(\text{syst.})$$

Compared to the SM prediction of 0.44 by POWHEG at NLO, the result is compatible with a p-value of p (data | SM) = 4.6%.

Unfolding

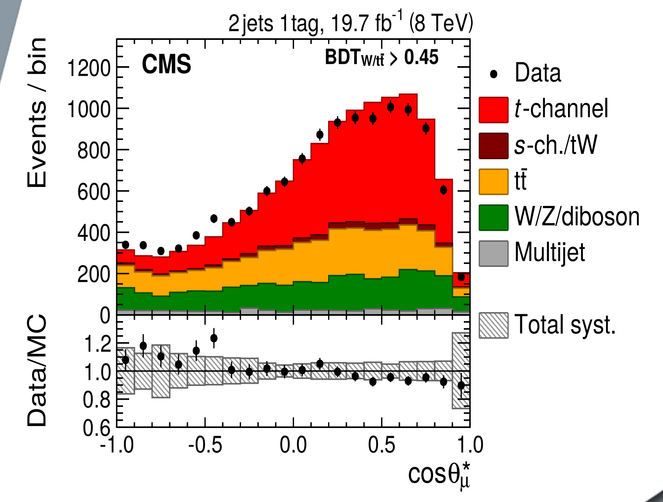
Unfolding distribution to parton level accounts for:
- distortions from detector acceptance
- selection efficiencies
- imperfect top quark reconstruction
- approximation of treating the untagged jet direction as the spectator quark direction

Subtract the backgrounds and unfold using regularised matrix inversion [Blobel 2002]



Value of asymmetry is fitted from unfolded distribution. Tested for bias by injecting anomalous Wtb-coupling events as pseudo-data.

Cos θ^*_μ variable: sensitive to polarisation



Defined as the angle between muon and light ("spectator") jet

Cos θ^*_μ properties

Distributed according to:

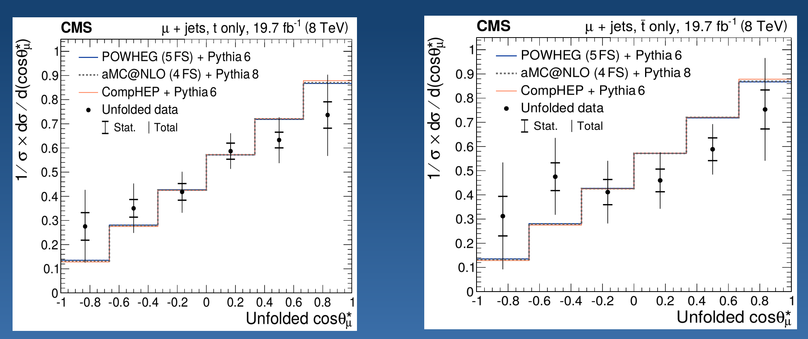
$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*_X} = \frac{1}{2}(1 + P_t^{(\vec{s})}\alpha_X \cos\theta^*_X) = \left(\frac{1}{2} + A_X \cos\theta^*_X\right)$$

Polarisation depends on spin basis $\vec{s}$. The spectator jet basis is one where over 90% of the top quarks are produced in one spin state.
[Mahlon and Parke 2000; Jeżabek and Kühn 1994]

We choose muon as the spin analyser because $\alpha_\mu = 1$ in SM, as well as its high identification efficiency in CMS.

In SM, the top quark spin tends to be aligned with the direction of the spectator quark, so we expect a rising slope. Hence, an excess of antialigned would be a clear indication of an anomalous coupling structure.

Separate results for top quarks and antiquarks



$$A_\mu(t) = 0.29 \pm 0.03\,(\text{stat.}) \pm 0.10\,(\text{syst.})$$
$$A_\mu(\bar{t}) = 0.21 \pm 0.05\,(\text{stat.}) \pm 0.13\,(\text{syst.})$$