High p_t top-jet production at the LHC

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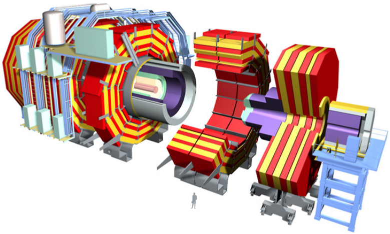
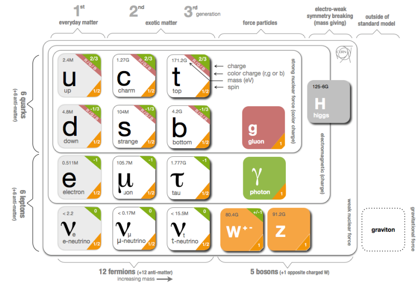
Outline

- Introduction to top physics.
- Motivation for boosted top regime.
- $t\bar{t}$ cross section measurements at 13 TeV with CMS detector.
- Phenomenological studies on hadron level definition of top jets.
- Theory predictions for $\Delta\phi$ observable.
- Summary.

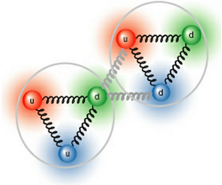


The Standard Model explains how the basic building blocks of matter interact, governed by four fundamental forces.

- Elementary particles grouped in fermions and bosons
- Fermions interact through the exchange of a gauge boson
- Mass of particles acquired via interaction with Higgs field



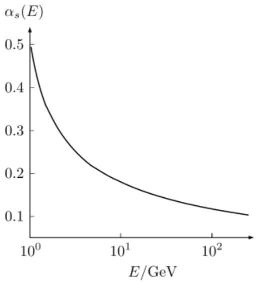
We will focus in strong interactions described by QCD!



Protons are made of quarks and gluons continuously emitted and absorbed through strong interaction

Quarks and gluons carry colour

High Energy: asymptotic freedom.
Low Energy: colour confinement.



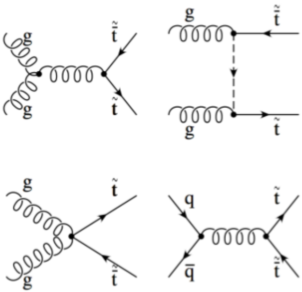
Quarks and gluons can not be observed freely in nature!

Introduction

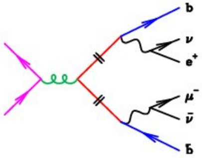
Top Quark production

What is special about Top quark?

- It is the heaviest particle in the Standard Model (173GeV), which implies very short lifetime ($5 \cdot 10^{-25} s$).
- Unique possibility of studying bare quarks (decay faster than the hadronization process takes place).



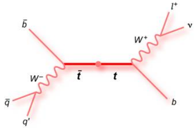
- At Tevatron $q\bar{q} \rightarrow t\bar{t}$ is the dominant channel , while at LHC is $gg \rightarrow t\bar{t}$, and only at highest pt, $q\bar{q} \rightarrow t\bar{t}$ becomes important.
- The top quark decays almost exclusively to an on-shell W boson and a b quark. ($t\bar{t} \rightarrow Wb$)

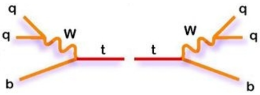


Dileptonic channel: both W decaying in lepton and neutrino ($\Gamma \sim 1/9$)

Missing energy due to the neutrino.

Semileptonic channel: one W decaying hadronically, and the other leptonically ($\Gamma \sim 4/9$)

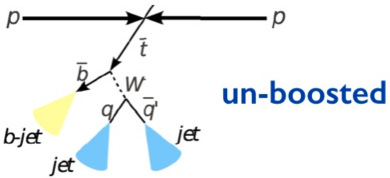


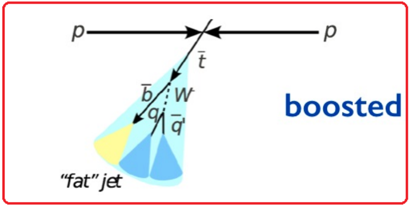


Hadronic channel: both W decaying hadronically ($\Gamma \sim 4/9$)

No missing energy, better p_t resolution

- Regime of boosted topologies because of high p_{T}^{Top}.
- Main problem to deal with: huge background coming from QCD multijet production

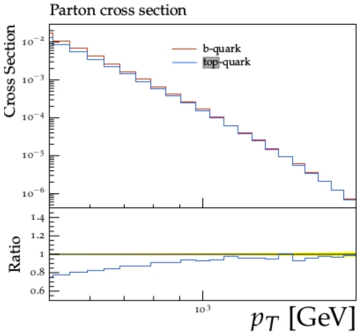




Motivation

Why boosted top topologies?

- Demonstrate the flavour-blindness of QCD: at high pt the $b\bar{b}$ is expected to be the same as $t\bar{t}$ production.
- Higher p_t implies scenarios closer to the back to back configuration, where QCD resummation effect can be studied.
- Higher p_t regime will allow us also to study QCD radiation effects of the top before decaying.



High p_t top measurements.

- Top p_t measured in boosted topologies in all-jets decay channels
- 2015 Data used with an integrated luminosity of 2.53 fb^{-1}

TOP-16-013

 CMS PAS TOP-16-013

CMS Physics Analysis Summary

Contact: cms-pag-conveners-top@cern.ch

2016/06/15

Measurement of the $t\bar{t}$ production cross section at 13 TeV in the all-jets final state

The CMS Collaboration

Abstract

The top quark pair production cross section is measured in the all-jets decay channel using pp collisions at a centre-of-mass energy of 13 TeV at the LHC with the CMS detector. The data sample corresponds to an integrated luminosity of 2.53 fb^{-1} recorded in 2015. The inclusive $t\bar{t}$ production cross section is measured to be $834 \pm 25(\text{stat})^{+118}_{-104}(\text{syst}) \pm 23(\text{lumi})$ pb. Differential cross sections at detector level are measured as a function of the leading top quark transverse momentum, p_T, and are compared to predictions from quantum chromodynamics. The spectrum is constructed by combining two distinct reconstruction approaches, targeting the low p_T (resolved top quark decay products), and the high p_T (boosted top quark decay products) regions. Finally, the cross sections are also reported at parton level, extrapolated to the full phase space. In all cases, the measured top quark p_T spectrum is found to be significantly softer than the theory predictions.

Event Selection

At least two jets with $p_t > 200\text{GeV}$, $\eta < 2.4$.

Leading jet with $p_t > 450\text{GeV}$.

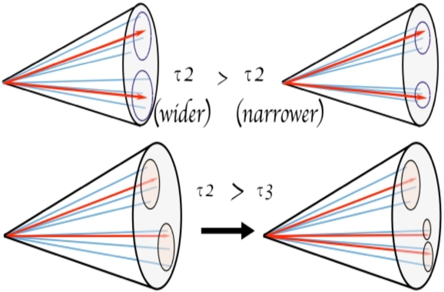
Both leading jets with at least one sub-jet b-tagged.

Multivariate Analysis (MVA) with n-subjetness variables.

Mass (soft drop mass) of the leading jet in the top mass window (150GeV,200GeV)

N-subjetness variables

$$\tau_N = \frac{\Sigma_i^n p_{(t,i)} min(\Delta R_{(i,1)}, \Delta R_{(i,2)} \ldots \Delta R_{(i,n)})}{\Sigma_i^n p_{(t,i)} R}$$

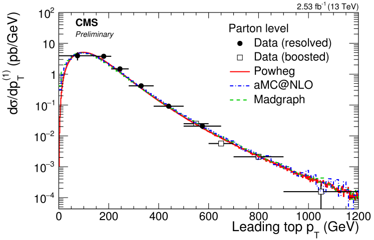


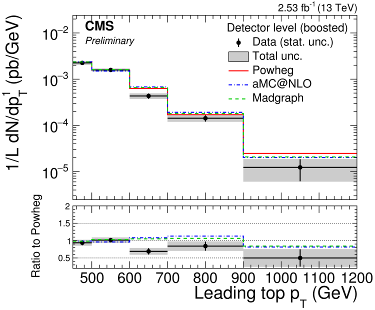
$$\tau_{ij} = \tau_i / \tau_j$$

MVA Variables

τ_{32} ,τ_{31}

- Absolute diff. $\sigma_{t\bar{t}}$ at parton and Detector level
- Boosted regime
- Measured p_T spectrum softer than predictions.

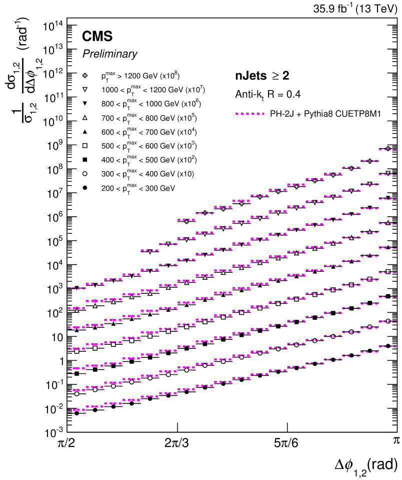




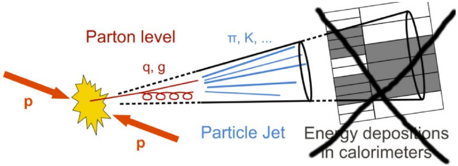
Main Motivation to go for more phenomenological studies:

hadron level definition of top jet.

- Model dependence affecting uncertainties at parton level.
- Direct comparison with dijet measurements (i.e. $\Delta\phi$ between leading jets at high p_t, SMP-16-014)



Motivation for Phenomenological studies at Hadron level



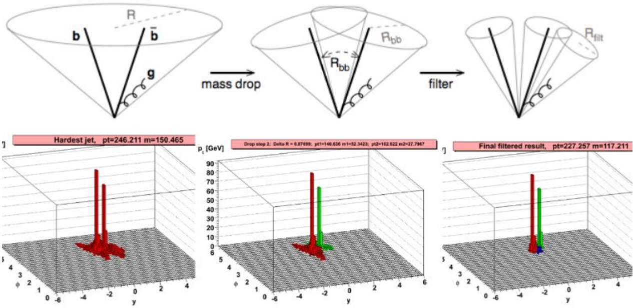
Removal of detector effects (unfolding)
→ Results at hadron level

Having a hadron level definition (theory prediction) will allow us directly compare with unfolded data

Better accuracy expected in comparison with theory predictions at parton level.

We use Anti-kt algorithm (Radius 0.8) to cluster the fat jet, and the Cambridge-Aachen algorithm to decluster the fat jet

Soft radiation is removed (soft drop mass mechanism)



Cluster with a large R

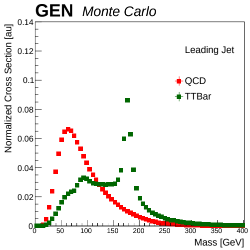
Undo the clustering into subjets, until a large asymmetry/mass drop is observed: tagging step

Re-cluster with smaller R, and keep only 3 hardest jets: grooming step

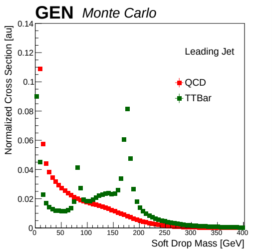
Mass Distributions

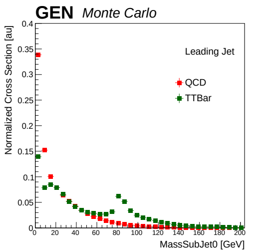
The two leading jets are the top jets candidates.

Signal: the leading jets have a pronounced peak on the top mass window, which corroborate the assumption that the top decays products are cluster inside the fat jet!



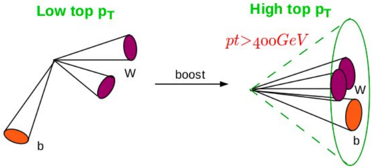
After declustering and removing soft radiation





Hadron Level definition

At least two jets with
$p_t > 400$GeV and $\mid \eta \mid < 2.4$.



B-hadron Requirement

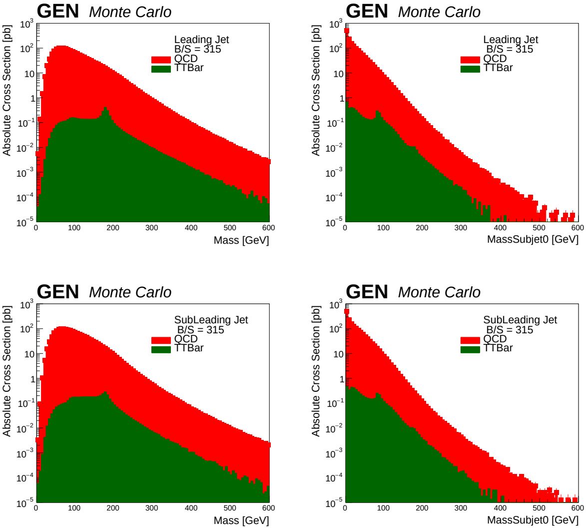
- Requiring one b-Hadron inside the fat jet.
- Soft Drop Mass of the two leading jets larger than 50GeV.

Selection Criteria

- Both leading jets with 150GeV$< Mass <$ 200GeV.
- Mass of the first sub-jet in the both leading jets larger than 30GeV.

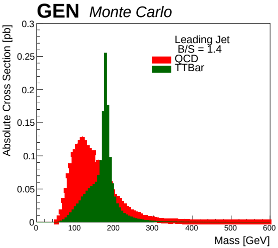
$S/B \sim 3.45$ with an efficiency of $\sim 7.7\%$ (with respect of the dijet boosted events)

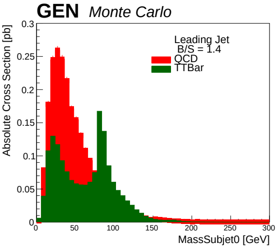
Top dijet boosted topologies

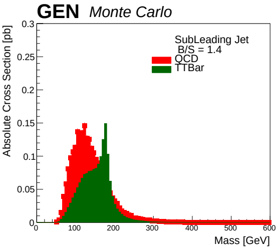


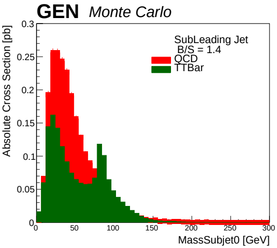
- Two jets with $p_t > 400\text{GeV}$ and $\eta < 2.4$
- Ratio $B/S \sim 315$

B-Hadron requirement



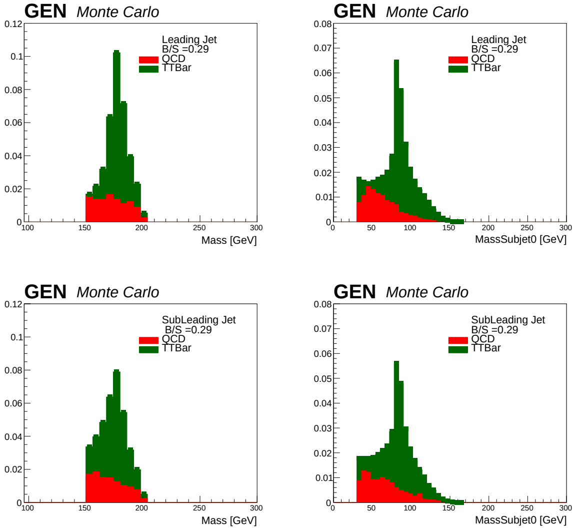






- Two Jets with $p_t > 400\text{GeV}$ and $\eta < 2.4$ + extra requirement of a B-hadron inside the fat jet.
- Ratio $B/S \sim 1.4$
- **Signal Acceptance:**33% *Background rejection:* 99.83% (with respect of high pt dijet events).

Mass Cuts selection criteria



- Two Jets with $p_t > 400\text{GeV}$ and $\eta < 2.4$ + a B-hadron inside the fat jet + **mass cuts**.
- Ratio $B/S \sim 0.29$
- **Signal Acceptance:**7.7%, *Background rejection:* 99.99% (with respect of high pt dijet events).

Theory Predictions:

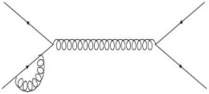
$\Delta\phi$ between the two leading jets.

p_t distribution of the leading and subleading jets

Monte Carlo vs Theory prediction

Leading order process

Real correction



Virtual correction

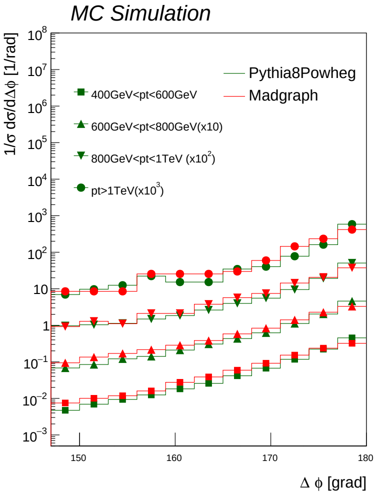
Powheg

- NLO predictions: leading order process + real correction + virtual corrections
- $t\bar{t} + 1jet$ from ME
- Parton Shower starting form the first emission

Madgraph

- NLO predictions: leading order process + real correction + virtual corrections
- $t\bar{t} + 2jet$ from ME
- Parton Shower starting form the third emission

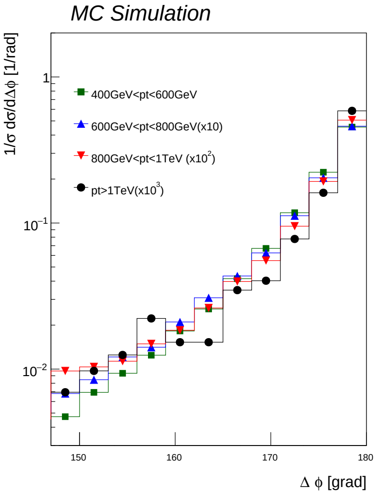
$\Delta\phi$ between the two leading top jets using different Monte Carlos prediction is compared



For the most to back to back configuration predictions are higher order are more required (NLO,NNLO...)

Powheg predictions lead to most back to more configuration than NLO predictions.

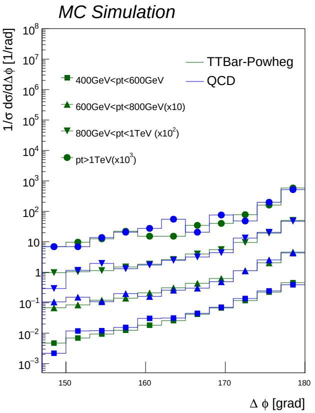
It is compared $\Delta\phi$ between the two leading top jets using different Monte Carlos prediction



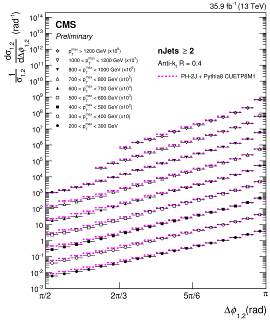
Higher p_t scenarios lead to more back to back configuration.

Theory prediction
$\Delta\phi$ observable

$\Delta\phi$ between the two leading top jets and the dijet case in QCD is compared.



Results from QCD dijet events



Main goal: Reproduce $\Delta\phi$ analysis from QCD measurements.

Summary and Outlook

- Boosted object reconstruction is a relatively new subject that has been recognized as crucial at the most recent LHC energies, specially in $t\bar{t}$ production.
- Top jets at hadron level are defined in order to compare theory predictions with data
- High p_t top jets in the back to back region ($\Delta\phi \sim \pi$) can be used to study resumation effects and compare with light quarks jets (QCD).