$t\bar{t}$ decay into 6-jets at the LHC

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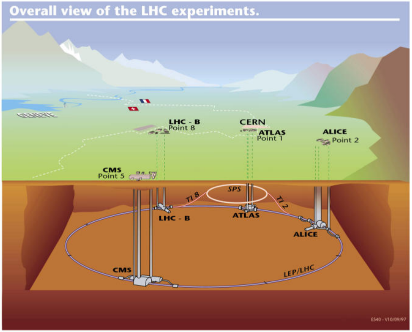
overview

motivation

- analysis of the properties of top quarks is one of the main topics at LHC – LHC is a top quark factory.
- good test of pertubative QCD which predicts $t\bar{t}$ cross section.
- top quark mass and its decay properties allow test of standard model and Higgs sector.
- top quark events are dominant background in many searches for new physics at TeV scale. extraction of new physics requires detailed measurements and understanding of production rates and properties of top quarks.
- hadronic decays ($W \rightarrow qq$) provide in situ calibration source for calometry at LHC.

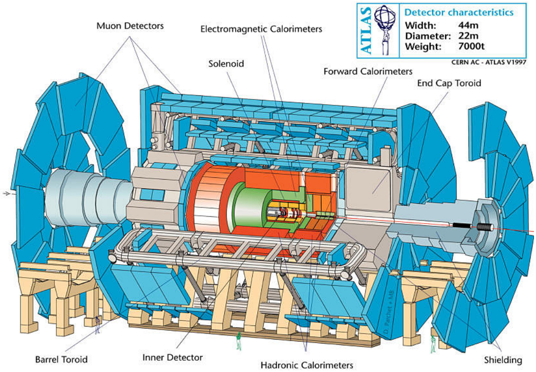
LHC and the ATLAS detector

- the **L**arge **H**adron **C**ollider is currently being built at CERN.
- head-on collisions of 2 separate beams of protons up to an energy of 7 TeV
- four large experiments: ATLAS, CMS, LHCb and ALICE



the ATLAS Detector

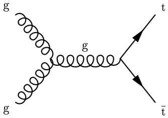
- inner tracker
- calorimeter
- muon spectrometer
- magnetic system

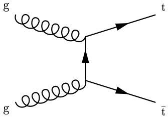


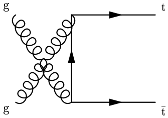
$t\bar{t}$ production at LHC

main process:

$gg \rightarrow t\bar{t}$ $\quad$ ($\approx$ 87 % at LHC)

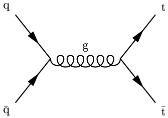






in addition:

$q\bar{q} \rightarrow t\bar{t}$ $\quad$ ($\approx$ 13 % at LHC)



expected $t\bar{t}$ cross section at LHC:
$\sigma(pp \to t\bar{t}) \approx 833\ \mathrm{pb}$ (NLO)

this corresponds to:
$8 \cdot 10^6\ t\bar{t}$ events per year at $\int L\, dt = 10\ \mathrm{fb}^{-1}$

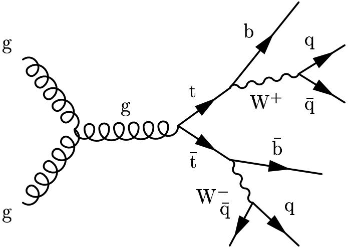
$\rightarrow$ LHC is a real top quark factory.
$\rightarrow$ study of properties of the top in great detail.
$\rightarrow$ test predictions of standard model for top quarks.

$t\bar{t}$ decay at LHC

according to the SM, the top quark decays almost exclusively to $W + b$.
hence the final state topology depends on the decay modes of the W bosons.

- hadronic decay:
  $t\bar{t} \rightarrow W^+W^-b\bar{b} \rightarrow q\bar{q}'q\bar{q}'b\bar{b}$
  6 final jets, 44 % of all $t\bar{t}$ events
- leptonic decay:
  $t\bar{t} \rightarrow W^+W^-b\bar{b} \rightarrow l\nu l^-\nu b\bar{b}$
  2 final jets, 2 leptons, 2 $\not{E}_T$, 26 % of all $t\bar{t}$ events
- semileptonic decay:
  $t\bar{t} \rightarrow W^+W^-b\bar{b} \rightarrow l\nu q\bar{q}b\bar{b}$
  4 final jets, 1 lepton, $\not{E}_T$, 30 % of all $t\bar{t}$ events

hadronic decay

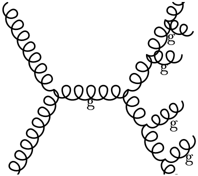


most common top decay

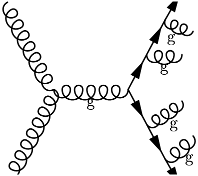
branching ratio of 44 % corresponds to $3.7 \cdot 10^6$ multijet events for $\int L\ dt = 10\ \mathrm{fb}^{-1}$

huge QCD multijet background

QCD background



jets in the QCD multijet background originate predominantly from gluon radiation.



presumed QCD multijet cross-section for $\mathrm{p_T} > 100\ \mathrm{GeV}$ (hard processes):
$\sigma_{QCD} = 1.4\ \mu\mathrm{b}$ (2 to 6 jets)
$\sigma_{QCD} = 0.3\ \mu\mathrm{b}$ (5 and 6 jets)

in comparison to:
$\sigma(pp \rightarrow t\bar{t}) \approx 833\ \mathrm{pb}$ (NLO)

signal selection

event shapes:

- $t\bar{t}$ event: $t\bar{t} \rightarrow W^+W^-b\bar{b} \rightarrow q\bar{q}'q\bar{q}'b\bar{b}$
  big difference in mass in the decay levels
  $t \rightarrow Wb$ and $W \rightarrow q\bar{q}$. leads to large angles between decay particles.
  $\Rightarrow$ spherical structure of event

- background event: $g \rightarrow g + g + g$
  dominated by collinear and infrared singularities. leads to small angles between the jets.
  $\Rightarrow$ flat structure of event

a) sphericity: defines how spherical an event is.

$$\boxed{0 \leq \mathrm{S} \leq 1}$$

b) aplanarity: defines how the jets in an event are placed with respect to a plane.
measure of the transverse momentum component out of the event plane.

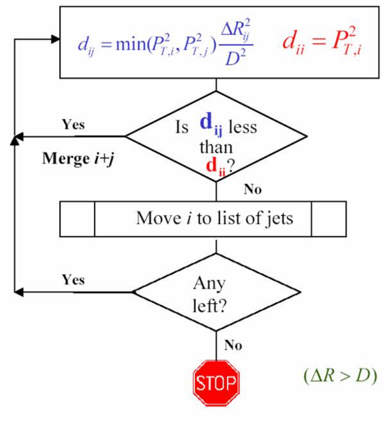
$$\boxed{0 \leq \mathrm{A} \leq 0.5}$$

$t\bar{t}$ events tend to have higher aplanarity and higher sphericity than background.

more options for signal selection:

- $|\eta| < 3$ and $|\eta| < 2.5$ for b-jets (pseudorapidity $\eta = -ln\ tan(\frac{\theta}{2})$)
- scalar sum of jets $\mathrm{p_T} \geq 125\ \mathrm{GeV}$ (reconstructed value)
- b-tagging: identify secondary vertex in event
- selection of dijet pairs from jets, which were not classified as b-jets
  $\Rightarrow$ $W \rightarrow q\bar{q}$ candidates
- calculation of invariant mass: $|m_{q\bar{q}} - m_W|$

jet reconstruction: the $\mathrm{k_T}$ algorithm

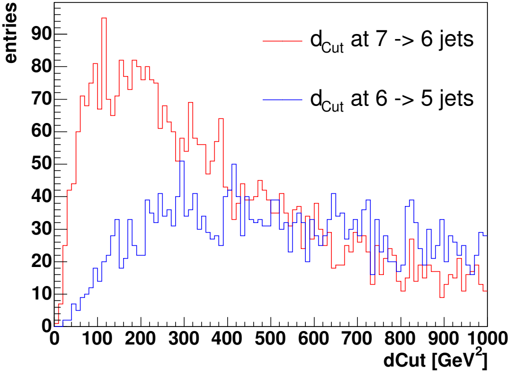


- $R_{ij} = (\eta_i - \eta_j)^2 + (\Phi_i - \Phi_j)^2$
- D is specified parameter (scaling parameter)
- $\mathrm{d_{Cut}}$: cut-off parameter defines hard scale of event $\Lambda^2_{QCD} \ll \mathrm{d_{Cut}} \leq s$
- $\mathrm{d_{min}} > \mathrm{d_{Cut}}$: all remaining objects are classified as jets
- size of jets is dynamic, no overlapping jets

first results

- $t\bar{t}$ events ($\sim \alpha_s$) are produced with the LO generator PYTHIA.
- QCD background has to be generated with help of MC generators using calculations of higher order in α_s, i.e. ALPGEN, which can produce up to six final state jets ($\sim \alpha_s^6$) at LO.
  1) weighted events with 3, 4, 5 and 6 jets in final state are generated with ALPGEN.
  2) events are unweighted in second ALPGEN run.
  3) unweighted events are run in PYTHIA (exclusive mode), where parton shower, CKKW matching and jet algorithm are applied to the events.
  4) events are scaled to the same luminosity: $L_{t\bar{t},PYTHIA} = 0.545\ fb^{-1}$

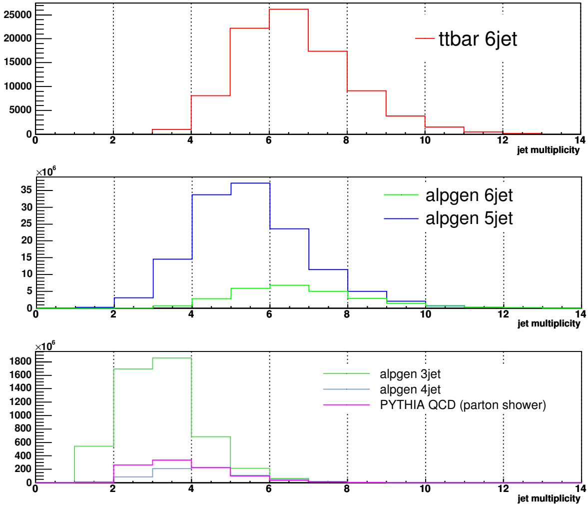
- determination of cut-off parameter $\mathrm{d_{Cut}}$



distribution of $\mathrm{d_{Cut}}$ at jet merging 7 $\rightarrow$ 6 jets and 6 $\rightarrow$ 5 jets.
best $\mathrm{d_{Cut}}$ for generating events with six jets in final state:

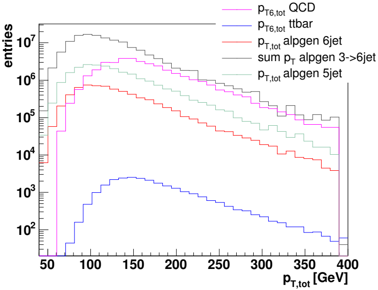
$$\boxed{400 - 500\ \mathrm{GeV}^2}$$

- jet multiplicity for $t\bar{t} \rightarrow$ 6-jet (PYTHIA), QCD multijet (only parton shower in PYTHIA) and ALPGEN 3,4,5 and 6 jet events on hadron level for $\mathrm{d}_{\mathrm{Cut}} = 450\ \mathrm{GeV}^2$



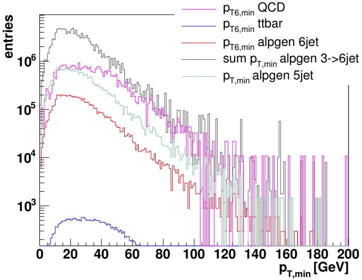
$\Rightarrow$ require ≥ 5 jets

- $\mathrm{p_T}$ of $t\bar{t}$ and background events on hadron level



total transverse momentum in event

$\Rightarrow$ require $p_{T,tot} \geq 125$ GeV

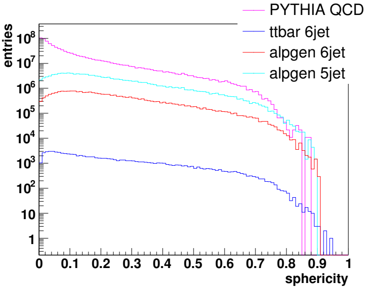


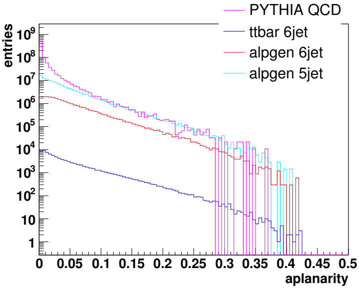
minimum transverse momentum of jet in event

$\Rightarrow$ require

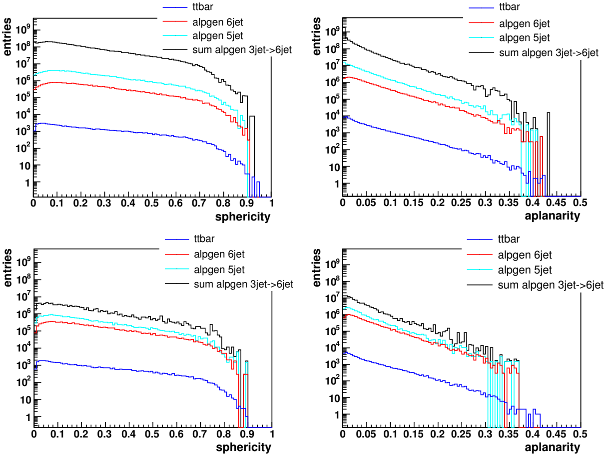
$10 \text{ GeV} \leq p_{T,min} \leq 70 \text{ GeV}$

- sphericity and aplanarity of $t\bar{t} \rightarrow$ 6-jet, PYTHIA QCD and ALPGEN events on hadron level





- sphericity and aplanarity of $t\bar{t} \rightarrow$ 6-jet, PYTHIA QCD and ALPGEN events on hadron level for first selection cuts



cut 1: number of jets ≥ 5

cut 2: $p_{T6,tot} \geq 125$ GeV

cut 3: $10 \text{ GeV} \leq p_{T6,min} \leq 70 \text{ GeV}$

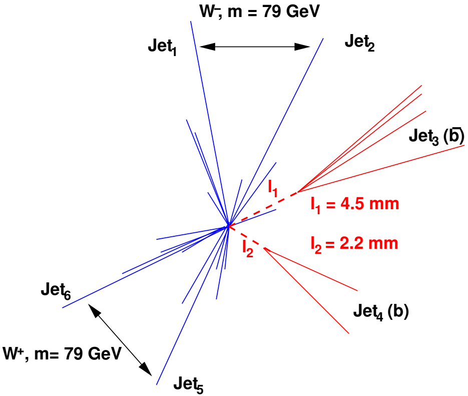
summary and outlook

- at LHC the largest source of top quarks is from $gg \to t\bar{t}$ production.
- the largest sample of $t\bar{t}$ events consists of 6-jet events from fully hadronic decay.
- isolation of the top signal by using kinematic cuts and cuts on the number of jets.

next steps:

- implement and study further selection variables.
- use ATLAS software (Athena) to generate “more realistic“ $t\bar{t}$ events including detector simulation.

b-tagging



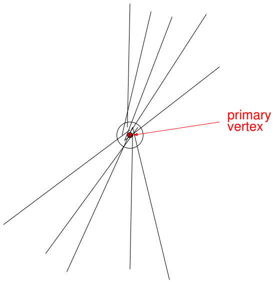
$\tau(t) = 0.5 \cdot 10^{-24}$ s
$\Rightarrow$ no hadronization

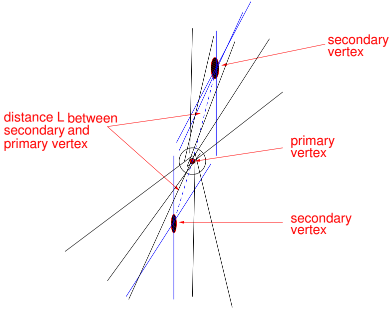
$\tau(b) = 1.5 \cdot 10^{-12}$ s
$\Rightarrow$ b decays a few mm off primary vertex

$$\boxed{\epsilon_{b-tag} = 50 - 60\ \%}$$

b-tagging labels a jet as b-jet if a b-quark of $p_T > 5$ GeV is found in a given cone $\Delta R = 0.2$ around the reconstructed jet for jets with $|\eta| < 2.5$

how to find a secondary vertex





- identify primary vertex
- find crossing tracks off primary vertex
- crossing position indicates secondary vertex
- $\frac{L}{\delta Vertex} > 3 \Rightarrow$ secondary vertex in event

the $\mathrm{k_T}$ algorithm

at most hadron colliders the cone algorithm is used for the reconstruction of jets. The cone algorithm clusters particles to a jet when they are within a radius of $R = \sqrt{(\Delta\eta^2 + \Delta\phi^2)}$.
$\Rightarrow$ overlapping jets.
the $\mathrm{k_T}$ algorithm combines particles with similar p_T^2 to one jet.
maximum distance between the particles: $\mathrm{d_{Cut}}$