Reconstruction of $M(t\bar{t})$ invariant mass in the all-jet top decays using the longitudinally-invariant KT algorithm

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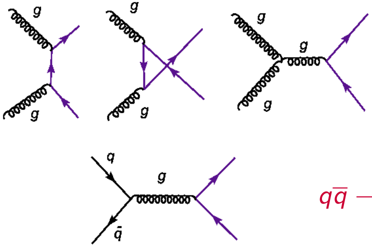
Outline

Tops at LHC

- Decay before hadronisation
- Large mass, intriguingly close to the scale of electroweak symmetry breaking
- Unique place to search physics beyond the SM
- Produced in pairs by strong forces. Decay as bare quarks before hadronisation
- Production mostly by gluon fusion ($gg \to t\bar{t}$, 87%)



$q\overline{q} \to t\bar{t}$, 13%

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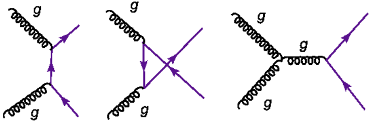

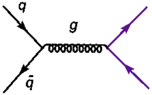

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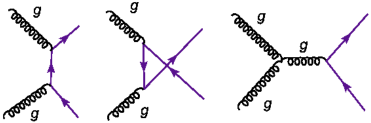

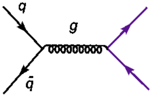

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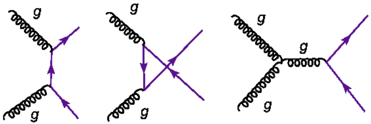

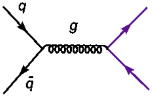

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Searches for new physics

- Top quark production can be sensitive to new physics near the TeV scale. Consider a generic heavy state "X" decaying as:

$$pp \longrightarrow X \longrightarrow t\bar{t}$$

- Several exotic models predict such resonance:
  - Models for extra dimensions (i.e. a lowest excited graviton)
  - In the Higgs sector, look at CP violation signals
  - Technicolor models, a leptophobic Z' boson
  - etc.
- Should be seen as a narrow bump on smoothly falling $t\bar{t}$ invariant-mass distribution $M(t\bar{t})$

Fully hadronic top decays

- In the SM, the top quarks decay as t $\longrightarrow$ W b
- When $W \rightarrow q\bar{q}$, 6 jets should be observed:

$$pp \longrightarrow t\bar{t} \longrightarrow WbW\bar{b} \longrightarrow q\bar{q}q\bar{q}b\bar{b}$$

- Kinematics can be fully reconstructed
- Largest branching ratio (46% of all top decays)
- Huge QCD multijet background:
  - $\sigma(t\bar{t}) \sim 240$ pb^{-1} vs $\sigma(QCD) \sim 690000$ pb^{-1} for $E_T^{min} = 120$ GeV
- Large $S/B \sim 1/9$ even with b-tagging (J.D'Hondt, HCP06, Durham)

Goals

- Maximize top signal while reducing QCD multijet background
- Find appropriate kinematic range, cuts, filters etc.
- Estimate contribution to $M(t\bar{t})$ from QCD multijet background

MC simulation

- PYTHIA 6.4 $P_T^{min} = 120$ GeV (CKIN(3)) to increase efficiency
- Generate 5 fb^{-1} for $t\bar{t}$, inclusive QCD, $b\bar{b}$ processes (separately)
- Fast simulation based on ATLfast:
  - Calorimeter cells/jets smeared in accordance with resolutions;
  - pileup option is included
  - simulate 60% efficiency for *b*-tagging

Jet definition

- Use the longitudinally-invariant K_T algorithm
  - based on pairwise merging, nearest, lowest p_T first
  - simple definition
  - infrared safe
  - mimics QCD branching sequence
  - better mass reconstruction
  - widespread adoption at HERA
- FastJet K_T algorithm by Cacciari and Salam (speed: $\sim N \ln N$ since only recalculates nearest neighbors)
- Jet reconstruction algorithm is run on input clusters

Warning:

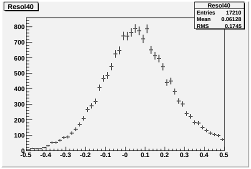
- $k_T$jet resolution could be worse than for the cone with $R = 0.4$ (small signals with large fluctuations pulled in by algorithm)
- Pile-up events contribute stronger than for the cone with R=0.4

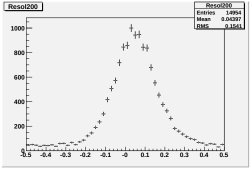
(see, for example, talks by: P.Loch, TeV4LHC, Feb 2005, BNL I.Vivarelli, HCP2005)

k_T algorithm

While the situation with the k_T algorithm needs to be clarified, at this moment one assumes:
k_T algorithm resolution is as bad as for the cone with R=0.7 and with the pile-up option included to the cone resolution

- k_T algorithm is run on the input calorimeter clusters (after initial resolution smearing)
- Apply additional smearing for k_T jets until the jet resolution becomes similar to that of the cone algorithm with pile-up contribution
- Verify this procedure using W mass reconstructed with the cone algorithm

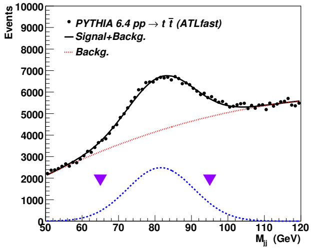




resolutions for 40 and 200 GeV k_T jets

Reconstruction using a simple cut-based method

- 6 jets with $E_T > 40$ GeV and $\mid \eta \mid < 3$. Highest E_T jet > 140 GeV.
- b-tagging jets with $\mid \eta \mid < 2.5$
- Combine any 2 jets without b-tags
- Exactly two W candidates in the mass range 65-95 GeV (low efficiency!)
- Calibrate jet energy using the W peak position
- Recalculate W energies using the PDG mass to improve the mass resolution
- Combine W momenta with b-tagged jets
- Reconstruct exactly 2 top candidates (range 150 and 200 GeV)
- Angular separation between two top quarks > 0.4 rad and $P_T^{min} = 50$ GeV.
- Optionally, top mass can be fixed for $M(t\bar{t})$.

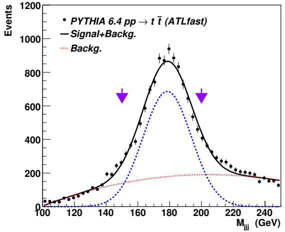


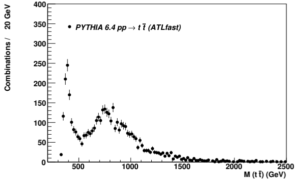
Dijet invariant mass from light-flavored jets ($\sigma = 9$ GeV)

Other techniques based on likelihood, neural network, decision trees can be tried in future

$t\bar{t}$ invariant mass for 5 fb^{-1}

- 4500 $t\bar{t} \rightarrow 6jets$ reconstructed events
- Efficiency: 1.2% (4500 / N(gen) x 0.46)
  - cut on M_{jj} is very inefficient
- Almost Gaussian signal
- Peak at 178.5 ± 0.1 GeV, $\sigma = 15$ GeV

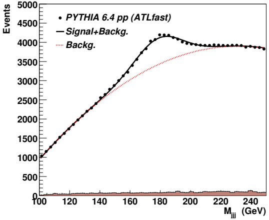




Background from combinatorics and semileptonic top decays feature small angular separations between misreconstructed objects which lead to an enhancement near the mass threshold of $t\bar{t}$

Contribution of multijet background

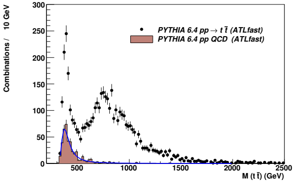
- Inclusive pp events were generated for 130 pb^{-1} with $E_T^{min} = 120$ GeV (90 M events, 2.5 weeks on 2.0 Ghz PC)
- Events passed through the same fast simulation and reconstruction
- Background shape was fitted with P3
- Extrapolated to 5 fb^{-1} with the factor 39



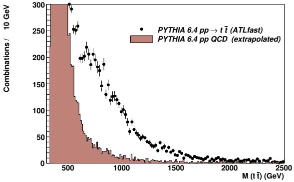
Background from QCD multijet events leads to S/B=1/5

Contribution to $M(t\bar{t})$ from QCD multijets

- QCD background added to $M(t\bar{t})$
- Background shape fitted with a Landau function
- Background extrapolated to 5 fb^{-1}

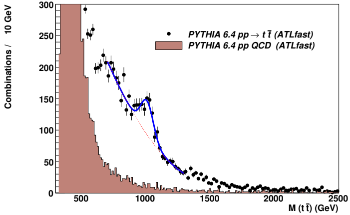


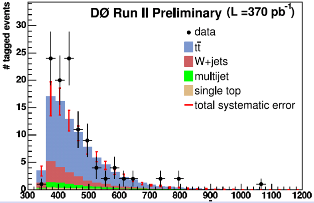
- Background from QCD multijet events feature small angular separations between misreconstructed objects
- Lead to an enhancement near the $t\bar{t}$ mass threshold
- $M(t\bar{t})$ almost unaffected by QCD background for > 700 GeV (purity $\sim 80\%$)



Prospects for searches

- Assume a genetic narrow resonance to $X \rightarrow t\bar{t}$
- Set its mass to 1 TeV (''graviton'' from PYTHIA)
- Reconstruct 380 events to establish it with 6σ confidence level (using a Gaussian+P2 fit)
- Requires 30k generated $X \rightarrow t\bar{t}$ events
- Efficiency: $\sim$ 3% (380 / 30k * 0.46)
- $\sigma(X)\mathrm{BR}(X \rightarrow t\bar{t}) > 6\,\mathrm{pb}$ is needed for a discovery of "X" state using the all-hadronic decay channel and $5\,\mathrm{fb}^{-1}$
- Expected mass resolution $\sim$ 9 GeV

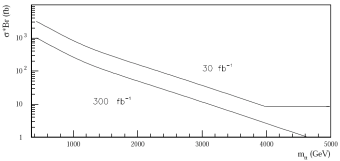




6σ discovery potential for a narrow resonance $\sim 6pb$ with $L = 5\ \mathrm{fb}^{-1}$ using the all-hadronic $t\bar{t}$ decay channel

Comparison with semileptonic decay topology

- Single-lepton decay topology was studied previously (S.Bentvelsen, hep-ph/0408111)
- $\sigma(X)\mathrm{BR}(X \to t\bar{t}) \simeq 1\,\mathrm{pb}$ for 6σ discovery with $L = 30\ \mathrm{fb}^{-1}$ (for mass 1 TeV)
- Scaling down this result to $L = 5\ \mathrm{fb}^{-1}$ used in this analysis, the all-hadronic top channel should be as promising as the semileptonic one (even for the simple reconstruction procedure used in this study)



Summary

- Reconstruction of all-hadronic top decays was investigated using a fast simulation and the longitudinally-invariant k_T algorithm.
- QCD multijet background is significant, but it is mostly concentrated at low $M(t\bar{t})$ region (low angular separation between t and $\bar{t}$ candidates)
- $M(t\bar{t})$ spectrum has relatively high purity $\sim 80\%$ for > 700 GeV, i.e. $M(t\bar{t})$ is almost unaffected by QCD multijet events.
- $\sigma(X)\mathrm{BR}(X \to t\bar{t}) \simeq 6\,\mathrm{pb}$ is required for a discovery of a narrow resonance using only this decay channel and $L = 5\,\mathrm{fb}^{-1}$
- Conclusion: the all-hadronic $t\bar{t}$ decays is rather competitive channel for searches