Event Selection Of Semileptonic $t\bar{t}$ Events

$t\bar{t} \rightarrow \mu + jets$

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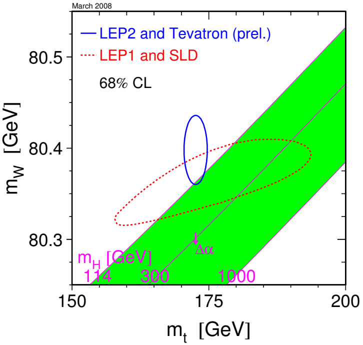
Overview

Motivation – Role inside SM and beyond

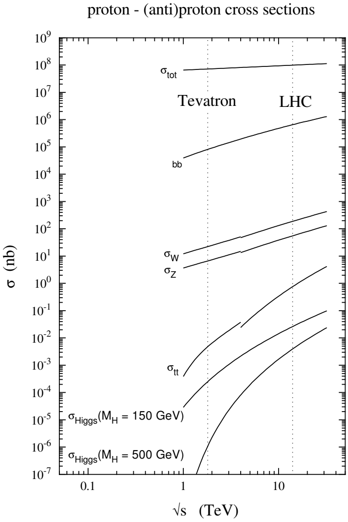
- connection to Higgs mechanism
  - Yukawa-coupling
  - indirect mass constraint
- (mass) limit of current knowledge
- powerful test of
  - detector
  - reconstruction
- proof of understanding
- important cornerstone



most important Standard Model parameters:

- mass
- (differential) cross sections

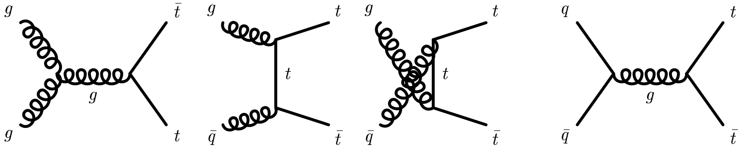
Selection Efficiency is fundamental to credibility



- huge hadronic backgrounds
- leptons are the key
- proper identification needed
- especially electrons
- muons are relatively easy

Production and decay

QCD production in leading order:



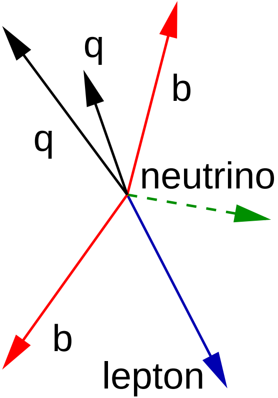
weak decay: $t \longrightarrow Wb \approx 100\%$

Fully hadronic decays	$t\bar{t} \longrightarrow bbqqqq$	46.2%	
Semileptonic decays	$t\bar{t} \longrightarrow bbqq\ell\nu$	43.5%	(29%)
Dileptonic decays	$t\bar{t} \longrightarrow bb\ell\nu\ell\nu$	10.3%	(5.1%)

- NOTE: omission of τ final states
- today only $t\bar{t} \longrightarrow bbqq\mu\nu$ – (14.5%)

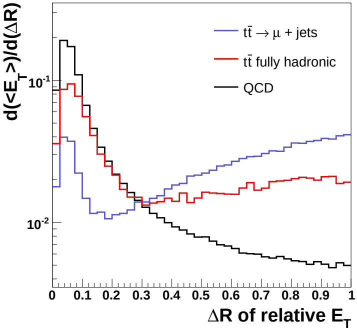
General Preselection

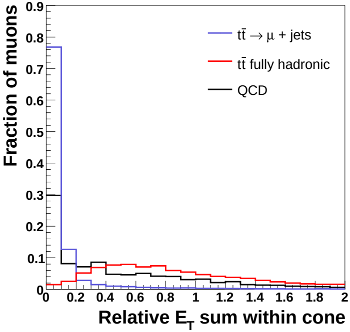
- reduce data volume
- ensure that event is reconstructable
- straightforward cut approach
- single lepton cut
- jet multiplicity cut
- simple variables



Muon Isolation

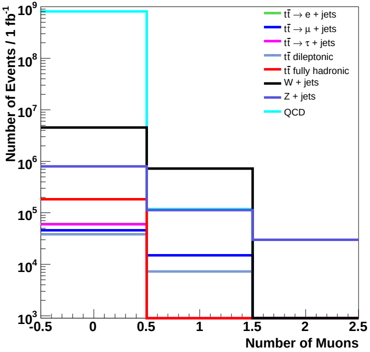
- very important for background suppression!
- define isolation scheme and cut values



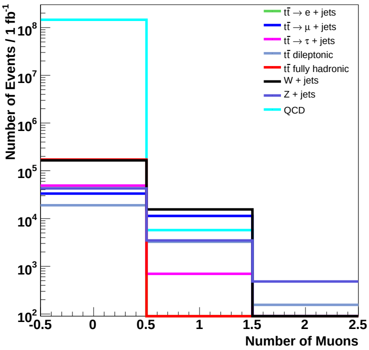


Lepton Preselection

- cut on exactly one isolated muon with $p_T \geq 30\,\text{GeV}$, $|\eta| \leq 2.4$



before cut



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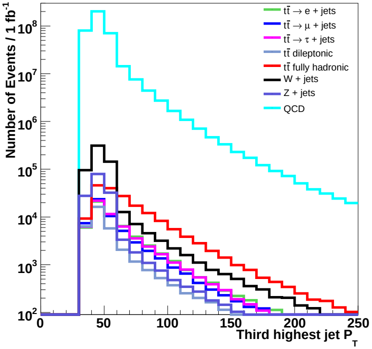
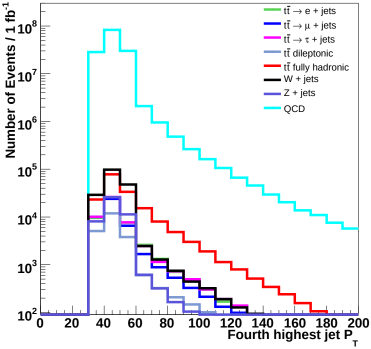
Jet Preselection

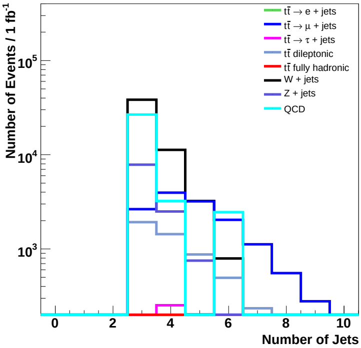
- jets will prove to be very difficult to master
- most sensitive is cut on third/fourth highest jet E_T



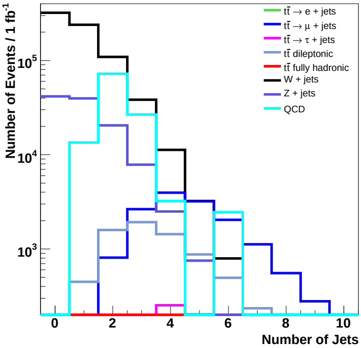


Jet Preselection 2

- cut on fourth highest jet E_T after muon preselection cut



30 GeV



40 GeV

Preselection Results

	Before	After	Efficiency
$t\bar{t} \rightarrow e + jets$	60828	1	$1.6 \cdot 10^{-5}$
$t\bar{t} \rightarrow \mu + jets$	60926	11122	0.183
$t\bar{t} \rightarrow \tau + jets$	60692	685	0.011
$t\bar{t} \rightarrow$ dileptonic	46035	3224	0.070
$t\bar{t} \rightarrow$ hadronic	183384	9	$4.9 \cdot 10^{-5}$
$W + jets$	5266k	13991	$2.7 \cdot 10^{-3}$
$Z + jets$	938k	3160	$3.4 \cdot 10^{-5}$
QCD	811326k	3286	$4.1 \cdot 10^{-6}$

$$S/B = \frac{11122}{(3919) + (17151) + (3286)} = \frac{1}{2.2}$$

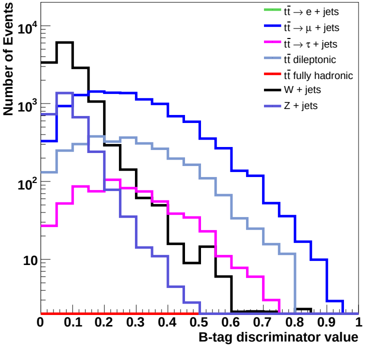
Event Selection

- now complex computations possible
- include partial or total event reconstruction
- use unique features of $t\bar{t}$ events
- different observables:
  1. identify particles
  2. shape variables
  3. kinematic content of event
- from now on omitted: QCD

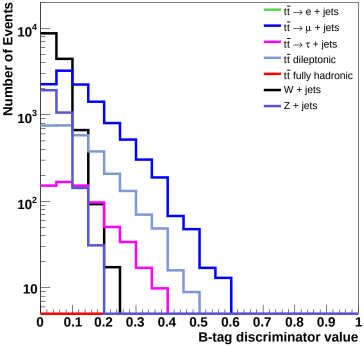
BTagging

- almost unique signature:
  - one isolated lepton
  - at least four jets
  - two b-jets
- use impact parameter significance:
  - determine 2D/3D track impact parameter
  - use measurement accuracy as weight
  - multivariate method to calculate the probability for compatibility with primary vertex
  - use of this probability as discriminant
- one false btag possible
- two high discriminant values unlikely

B Discriminator Distributions

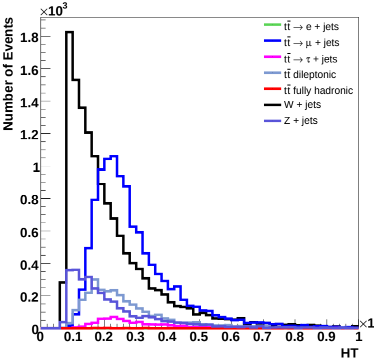


highest btag value

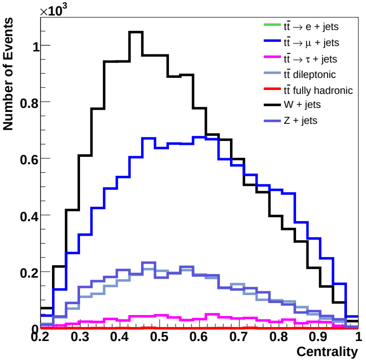


second highest btag value

Event Shapes: Ht and Centrality



scalar sum of 4 highest E_T jets



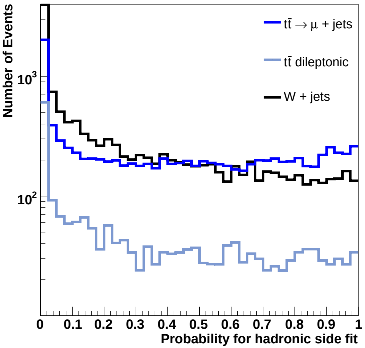
centrality

Kinematic Fit

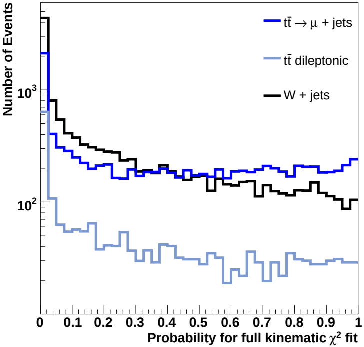
- use event *template* for χ^2 fit on particles
- χ^2 value after fit can be interpreted as goodness of fit
- in principle: indicator of semileptonic $t\bar{t}$ decay
- technical:
  - use four (five) highest E_T jets
  - use lepton and neutrino
  - imply mass constraints
  - two W masses (leptonic and hadronic side)
  - two top masses (leptonic and hadronic side)
  - leave neutrino η (or p_z free)
- use best χ^2 values from combinatorics
- different fits possible

Kinematic Fit Results

- use *Fit probability* of events with converged fits



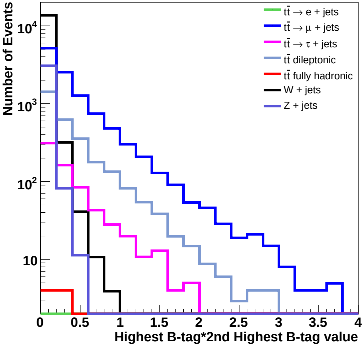
hadronic leg



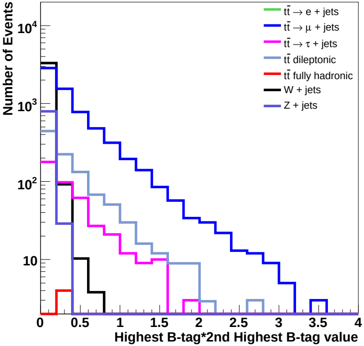
whole event at once

Cut Selection: BTagging

- cut on product of highest and second highest discriminator value



before cuts



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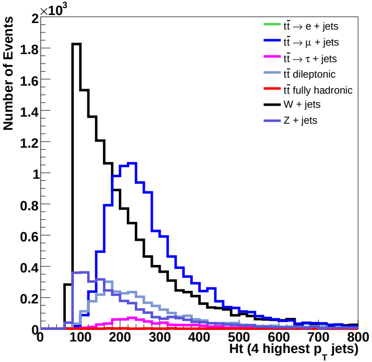
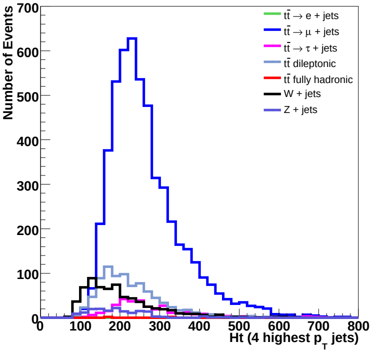
Cut Selection: Event Shapes

- only Ht is suited for a cut selection



before cuts



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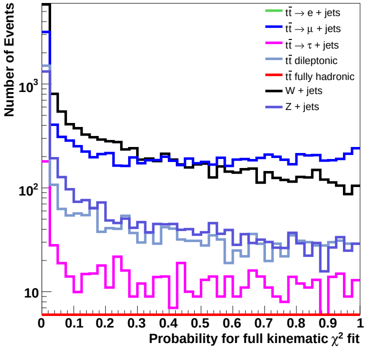
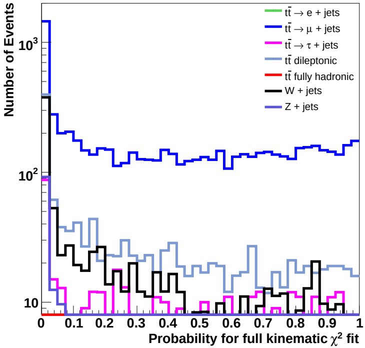
Cut Selection: Event Fit *Probability*

- only probability for whole event fit is shown



before cuts



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Results of cut based approach

	Before	After	Efficiency
$t\bar{t} \rightarrow e + jets$	60828	0	0
$t\bar{t} \rightarrow \mu + jets$	60926	4981	0.082
$t\bar{t} \rightarrow \tau + jets$	60692	322	0.005
$t\bar{t} \rightarrow$ dileptonic	46035	745	0.016
$t\bar{t} \rightarrow$ hadronic	183384	4	$2.2 \cdot 10^{-5}$
$W + jets$	5266k	435	$8.2 \cdot 10^{-5}$
$Z + jets$	938k	120	$1.3 \cdot 10^{-4}$

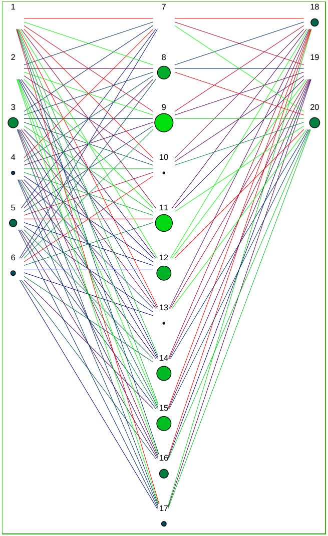
$$S/B = \frac{4981}{(1072) + (555)} = \frac{3.1}{1}$$

Neural Network

- simple cut values can be combined more effectively
- multivariate technique: Neural Network
- high generalisation power
- correlations are taken into account
- technique:
  - create subsets of data (training and validation)
  - train network with certain layout
  - test against validation sample (and additional tests)
  - encode trained network into function
  - evaluate final variable and cut value
- use same variables as before (plus Centrality)

Simple Network layout

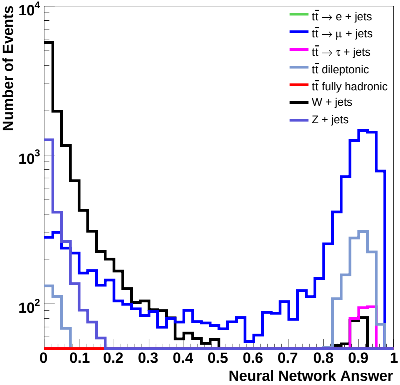
- simple network
- six input nodes
- eleven hidden nodes
- three output nodes
- use 1/5 of data



Final Selection Variable

- combine output node values n_i into final variable

$$\kappa = \frac{n_1}{n_2 + n_3} \Big/ \left(\frac{n_2}{n_1 + n_3} + \frac{n_3}{n_1 + n_2} \right) \qquad \in [0, 1]$$



Result of multivariate approach

	Before	After	Efficiency
$t\bar{t} \rightarrow e + jets$	60828	1	$1.6 \cdot 10^{-5}$
$t\bar{t} \rightarrow \mu + jets$	60926	7711	0.127
$t\bar{t} \rightarrow \tau + jets$	60692	482	$7.9 \cdot 10^{-4}$
$t\bar{t} \rightarrow$ dileptonic	46035	1469	0.03
$t\bar{t} \rightarrow$ hadronic	183384	4	$2.2 \cdot 10^{-5}$
$W + jets$	5266k	1022	$1.9 \cdot 10^{-4}$
$Z + jets$	938k	269	$2.9 \cdot 10^{-4}$

$$S/B = \frac{7711}{(1956) + (1026)} = \frac{2.6}{1}$$

Summary and Outlook

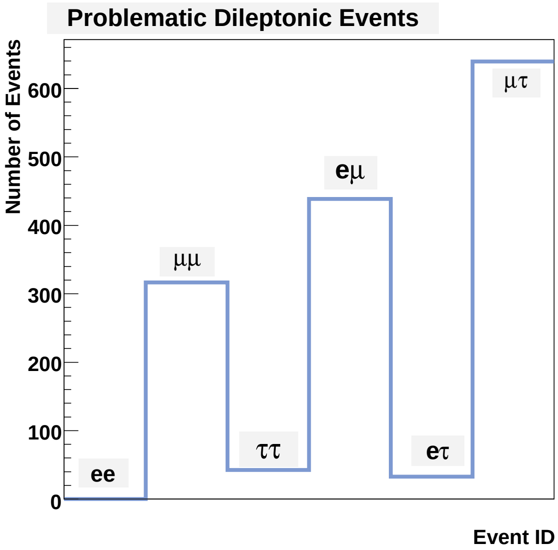
Summary

- successful selection possible
- credibility of cross section is ensured with efficiencies $\simeq 10\%$
- straightforward cut based approach possible
- Neural Network approach very promising
- largest background is (dileptonic) $t\bar{t}$

Outlook

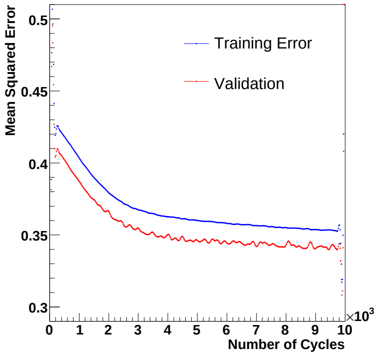
- check systematic influences on differential cross sections
- think about methods for QCD extrapolation

Backup 1

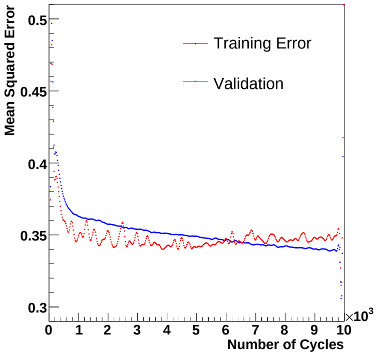

Problematic Dileptonic Events
Number of Events
0
100
200
300
400
500
600
ee
μμ
ττ
eμ
eτ
μτ
Event ID

Backup 2 – NN Training

- Overtraining avoided



simple network
no danger of overtraining



complex network
overtraining possible

Backup 3 – NN weights/correlations