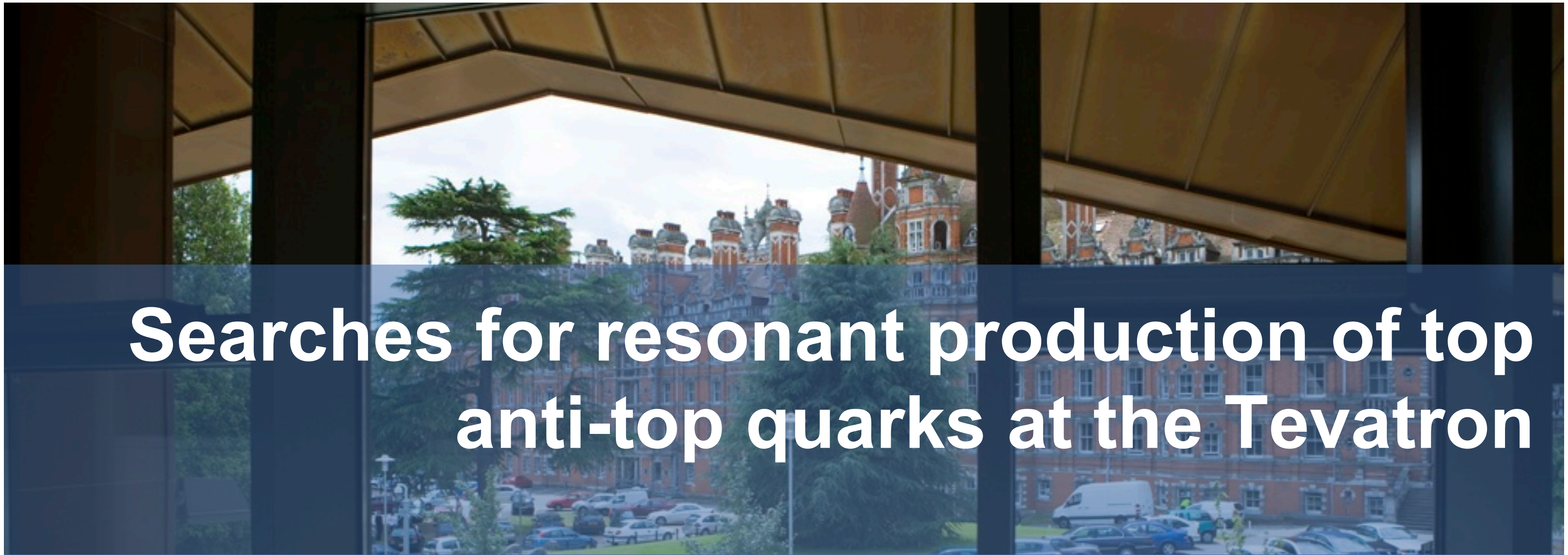

Searches for resonant production of top anti-top quarks at the Tevatron

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for the CDF and D0 Collaborations

TOP 2011 Sant Feliu de Guixols, 27th September

University of Rochester

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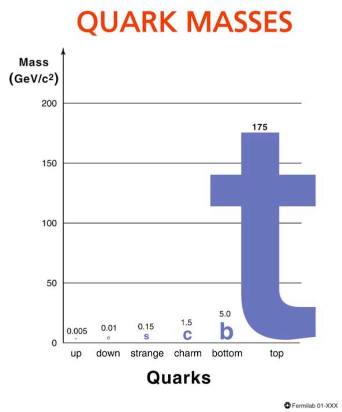
Motivation for searching for resonant ttbar production

- Top mass is so large…
  - Involved in EWSB
  - And in BSM scenarios
- Large radiative correction to the Higgs:
  - Need to cancel
  - Involves new particles:
    - Top partners (SUSY)
    - Fermions (Little Higgs)
    - Extra Dimensions
  - In those models: gauge interactions with enhanced coupling to the top
    - KK excitations of the graviton
    - Weak and strong gauge bosons
    - ➔resonance in ttbar production and not in di-jet or di-lepton due to their small couplings to light particles



Motivation for searching for resonant ttbar production

- Can group models according to the spin of the object, its color content and CP parity:
  - Spin 0, 1, 2
  - Color singlet or color octet
  - Parity even or odd (scalar vs pseudo-scalar, vector vs axial-vector)
- There can be non-trivial interference effects between new resonances and SM ttbar
- Experimentally: Look at the M_{tt} spectrum to see any deviation over the SM ttbar

Spin	color	parity $(1, \gamma_5)$	some examples/Ref.
0	0	(1,0)	SM/MSSM/2HDM, Ref. [51, 52, 53]
0	0	(0,1)	MSSM/2HDM, Ref. [52, 53]
0	8	(1,0)	Ref. [54, 55]
0	8	(0,1)	Ref. [54, 55]
1	0	(SM,SM)	Z'
1	0	(1,0)	vector
1	0	(0,1)	axial vector
1	0	(1,1)	vector-left
1	0	(1,-1)	vector-right
1	8	(1,0)	coloron/KK gluon, Ref. [56, 57, 58]
1	8	(0,1)	axigluon, Ref. [57]
2	0	–	graviton "continuum", Ref. [17]
2	0	–	graviton resonances, Ref. [18]

Table 1: The BSM particles included in the topBSM "model".

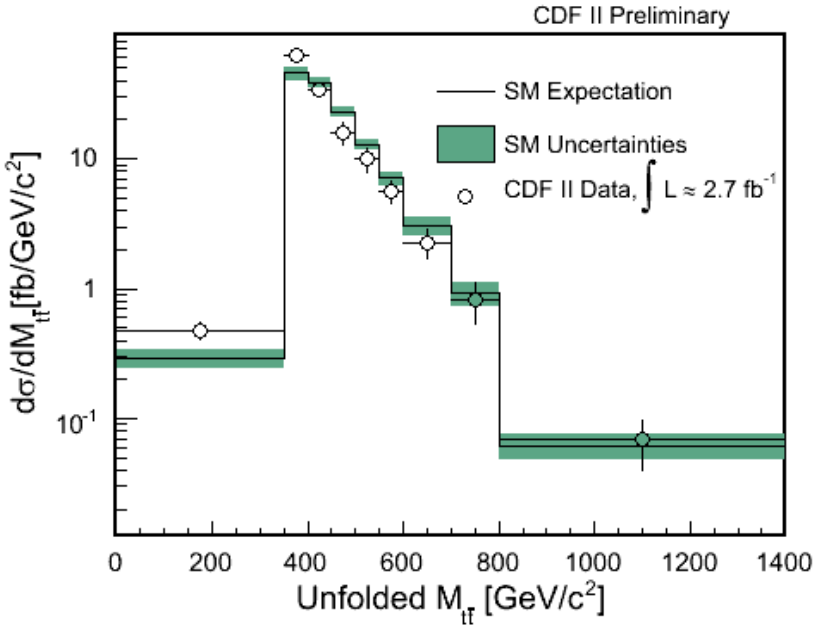
Frederix, Maltoni: hep-ph/0712.2355v3

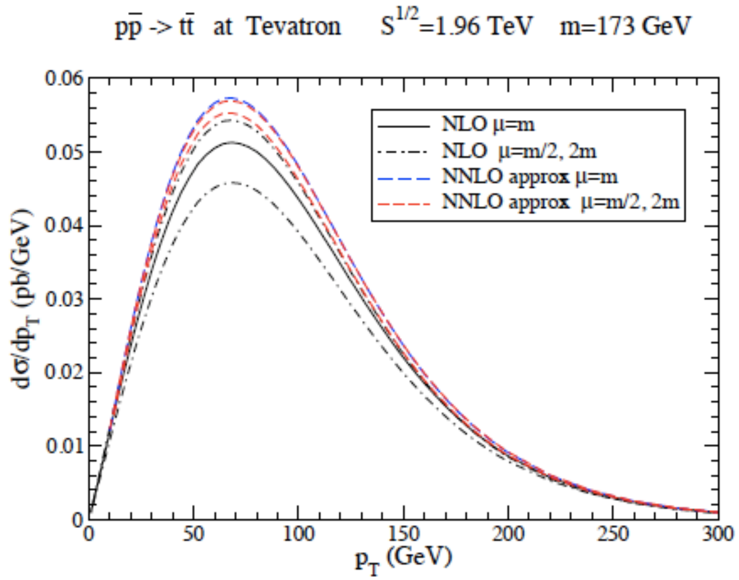
Most results extract limits for topcolor leptophobic Z' of narrow width

Massive gluon G

SM non-resonant ttbar production

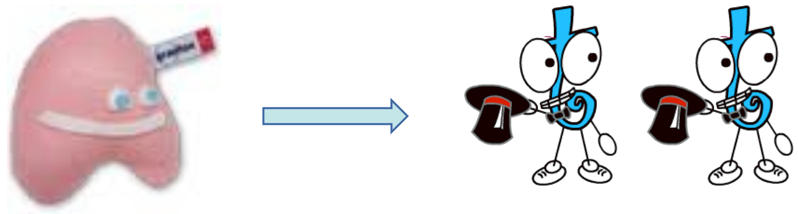
- Very few events at very high M_{tt}
- See Jung's talk earlier
- Tevatron resonant searches focused on non-boosted topology so far
  - ➔ less efficient at very high mass
- Current precision on the total σ_{tt} leaves open the possibility of non-SM contributing to tt production





N. Kidonakis, Phys. Rev. D 82, 114030 (2010)

Content: 5 Tevatron results



- (1:G): CDF: Search for New Color-Octet Vector Particle Decaying to tt using 1.9fb^{-1} (L+J) (PLB 691 183)
- (2:D0): D0: Search for tt Resonances in the L+J using 3.6fb^{-1} (D0 note: 5882-CONF)
- (3:Z'ME): CDF: Search for resonant production of tt pairs in 4.8fb^{-1} (L+J) (CDF note: CDFR/10468)

- CDF: Search for resonant production of tt decaying to jets using 2.8fb^{-1} (AllHad) (arXiv:1108.4755)

- CDF: A Search for Boosted Top Quarks using 5.95fb^{-1} (AllHad, L+J) (CDF note: CDFR/10234)

Reconstructing the M_{tt}

Decay products

χ^2 kinematic fit

CDF $1fb^{-1}$

No kinematic fit, use M_W for ν

D0 $3.6fb^{-1}$

Matrix Elements (+Templates)

CDF L+J $4.8fb^{-1}$

CDF AllHad $2.8fb^{-1}$

DLM with no tt production Matrix

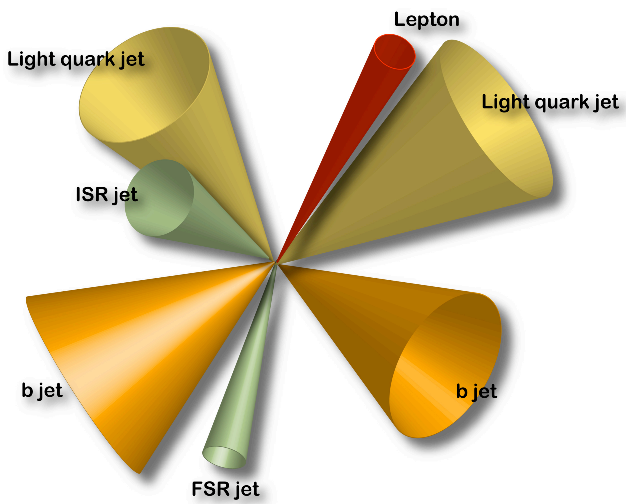
CDF $1.9fb^{-1}$

Lepton + Jets Event Selection

Trigger:
CDF: e: E_T >18 GeV
μ: p_T>18GeV
D0: e(μ)+jet

Isolated Leptons
CDF: e: E_T>20GeV
μ: p_T>20GeV
D0: : e: E_T>20GeV
μ: p_T>25GeV $|\eta|<2.0$

Jets
Topological clusters
CDF: Anti-k_T (R=0.4)
(1:G): =4j E_T>20GeV
(3:Z'ME): ≥4 j $|\eta|<2.0$, E_T>20GeV
D0: Cone algorithm with R=0.5
≥3 j $|\eta|<2.5$, p_T>20GeV, 1 j p_T>40GeV



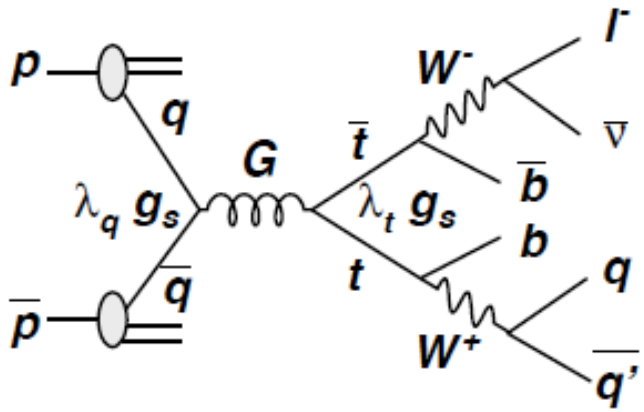
ME_T
Vector sum of calo energy deposits
Corrected for identified objects
CDF: ME_T>20GeV
D0: e: ME_T>20GeV
μ: ME_T>25GeV

b-jets
CDF: Displaced vertex (SECVTX), ε_b: 50%, ε_l: 2%
D0: NN (d_0, m_{tvx}, sig. displ., N_{trks} within sec. vtx.) >0.65, ε_b: 55%, ε_l<1%

Event Cleaning
Good run conditions
Z0 vtx < 60cm
veto: l+track within Z mass
Cosmic veto

CDF: Search for New Color-Octet Vector Particle, 1.9fb^{-1}

- Searching for massive generic gluon G
- Assume coupling massive-massless gluon is 0
- Interference between G and SM qq➔g➔tt
- Coupling of G to quarks is assumed to be parity-conserving
- SM gg➔tt is background
- L+J Backgrounds (treatment same as for σ measuremen
  - W+Jets (HF, LF) (get tag rate, etc)
  - QCD (data driven)
  - EWK (diboson, single top)



$$\lambda \equiv \lambda_q \lambda_t$$

Source	Expected number of events
Electroweak	9.9 ± 0.5
W + bottom	16.5 ± 6.7
W + charm	12.9 ± 5.2
Mistags	16.7 ± 3.6
non-W	13.6 ± 11.7
SM $gg \to t\bar{t}$	48.2 ± 15.6
Total Background ($n_b^{\mathrm{exp}} \pm \sigma_b^{\mathrm{exp}}$)	117.8 ± 19.8
SM $q\bar{q} \to t\bar{t}$ ($\sigma = 5.6$ pb)	211.7 ± 29.3
Data	371

tt/non-tt:1.8
Data/Bkg:1.1

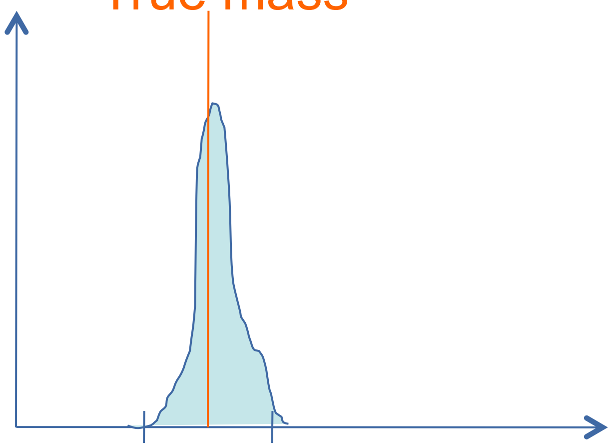
Reconstructing M_{tt} and statistical treatment

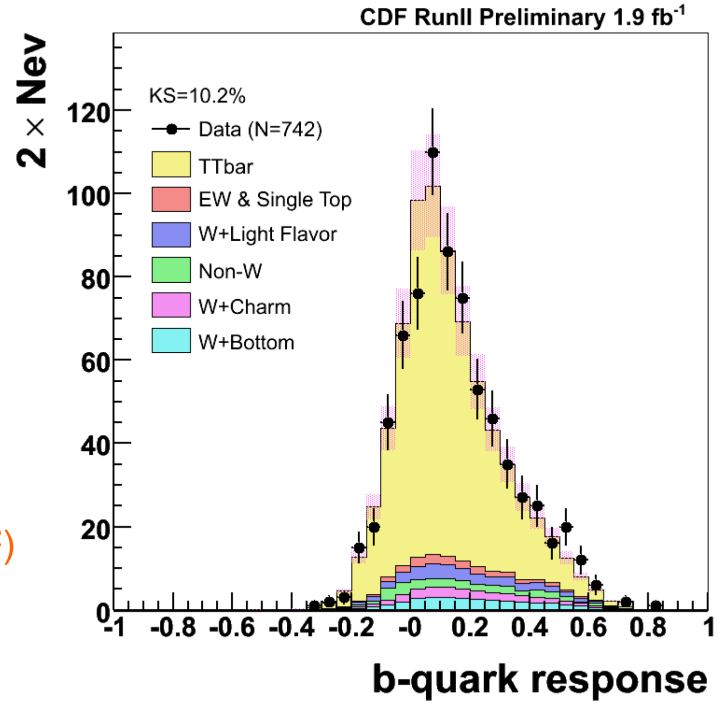
- Reconstruct parton level momenta event by event using Dynamical Likelihood Method (DLM) (used for Top mass)
  - Likelikood: $$L_{path}(x_i;y_j) \equiv N\frac{d\sigma}{d\Phi}(x_i)w(x_i,y_j)$$

Transfer Function: pdf from observed to parton kinematics

  - Each event: average over all the possible paths

True mass





Assume that TF ind. of tt production matrix
At reco: remove from L: No bias toward SM tt production

Reconstructing M_{tt} and statistical treatment

- Signal g+G pdf is:

$$p_s[\sqrt{\hat{s}_r};\boldsymbol{\alpha}] \equiv N(\boldsymbol{\alpha}) \int \left[\frac{d\sigma}{d\sqrt{\hat{s}_p}}\right]^*_{SM:q\bar{q}\to t\bar{t}} R(\sqrt{\hat{s}_p};\boldsymbol{\alpha}) f(\sqrt{\hat{s}_r}-\sqrt{\hat{s}_p};\sqrt{\hat{s}_p}) d\sqrt{\hat{s}_p}$$

$$\boldsymbol{\alpha} \equiv (\lambda, M, \Gamma)$$

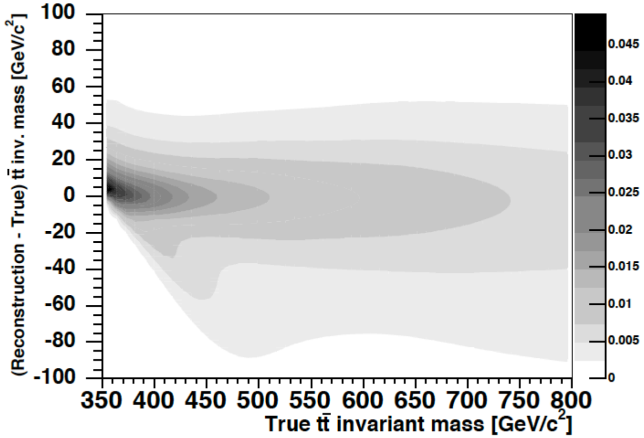
After cuts

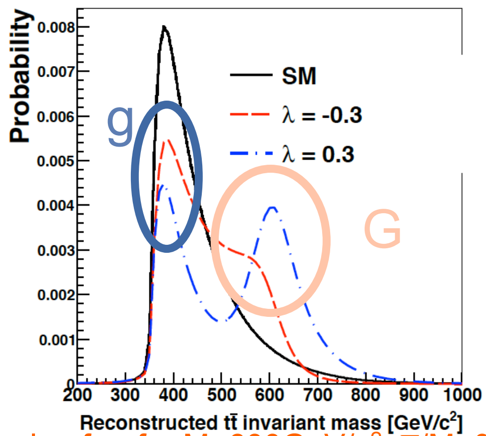
Reconstructed M_{tt}

True M_{tt}

•Ratio of g+G to SM tt production:
- PDF, top propagators, decay ME and final state densities for g+G and tt cancel out
- •Allows to generate g+G events from SM tt MC

Resolution function which translates $\sqrt{\hat{s}_p}$ to $\sqrt{\hat{s}_r}$



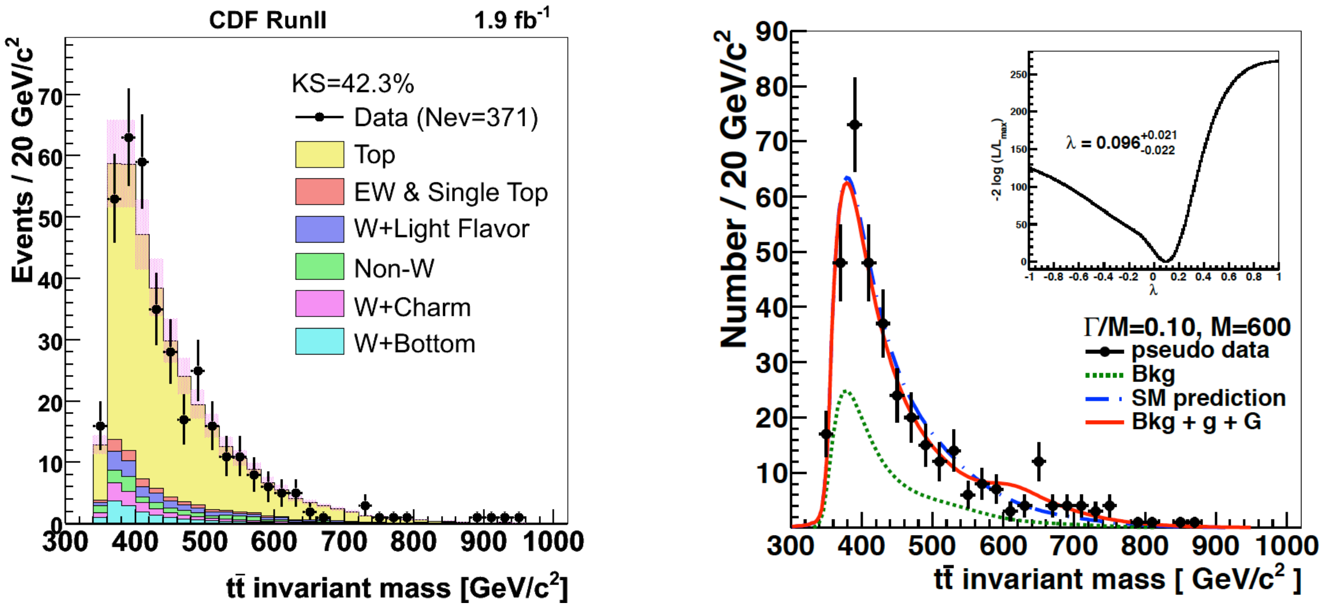


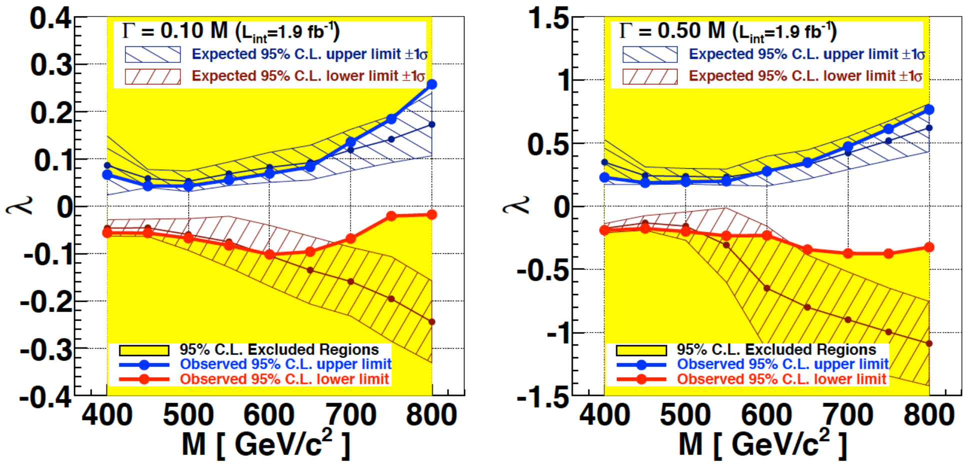
Example of p_s for M=600GeV/c², Γ/M=0.10, $\lambda=\pm0.3$

- Unbinned Maximum Likelihood:

$$L\left(\lambda, n_s, n_b | M, \frac{\Gamma}{M}\right) \equiv G(n_b; n_b^{\exp}, \sigma_b^{\exp}) P(N;n) \prod_{i=1}^{N} \frac{n_s p_s(\sqrt{\hat{s}_r}(i);\boldsymbol{\alpha}) + n_b p_b(\sqrt{\hat{s}_r}(i))}{n}$$

Results





No significant indication of a massive Gluon with |λ|>0.5 is observed

D0: Search for tt Resonances in the L+J using 3.6fb^{-1}

- After L+J event selection:

$A \cdot \varepsilon \cdot BR =$

$SM\,tt : 3j : 3.4\%, \geq 4j : 4.4\%$

$650 GeV/c^2 Z' : 3j : 2.8\%, \geq 4j : 3.9\%$

- Backgrounds:
  - W+jets:pretagxevent tag P
  - QCD: MM b-tag sample, shape: lepton failing iso cuts
- Get M_{tt} from using up to 4 leading jets, and use

$$M_W^2 = (p^\ell + p^\nu)^2$$

  - For $p_{z\nu}$
    - If 2 solutions: smallest $|p_z|$
    - If 0 real solutions: $p_z=0$
    - Better sensitivity at high M than using kinematic fit

	3 jets	$\geq$ 4 jets
$t\bar{t}$	624	721
Single top	47	13
Diboson	32	8
W+jets	592	129
Z+jets	85	26
Multijet	84	22
Total background	1464	919
Data	1411	934

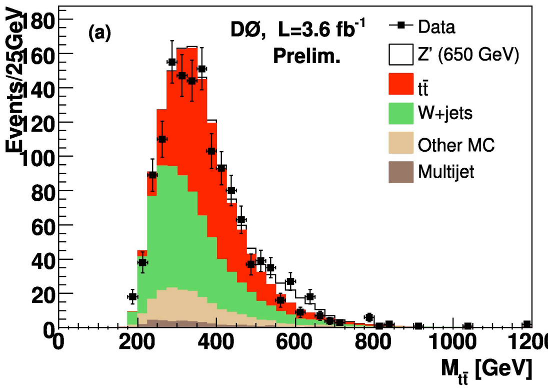
tt/non-tt:1.3
Data/Bkg:0.98

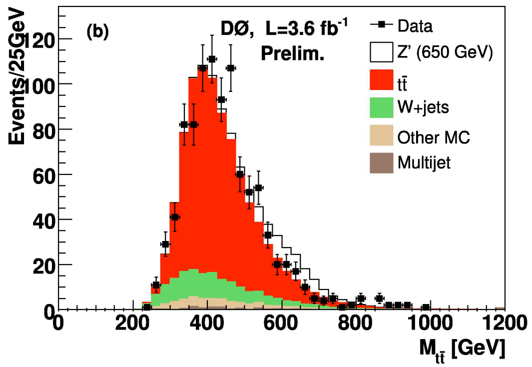
D0: Search for tt Resonances in the L+J using 3.6fb-1

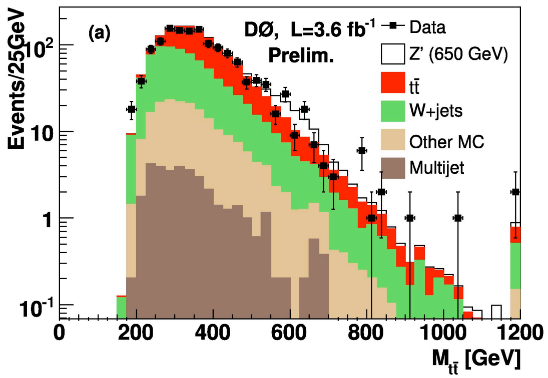
- Get limit using Bayesian approach with a Poisson probability for the number of events in each bin, and a flat prior for σB
- Systematics:
  - Some analyses: integrated over as nuisance parameters
  - Some systematics change the normalization and others change both the shape of M_{tt} and the normalization
  - Normalization:
    - σ_{tt} uncertainty, integrated luminosity, various ε (eg lepton)
  - Shape:
    - JES, ISR/FSR, PDF

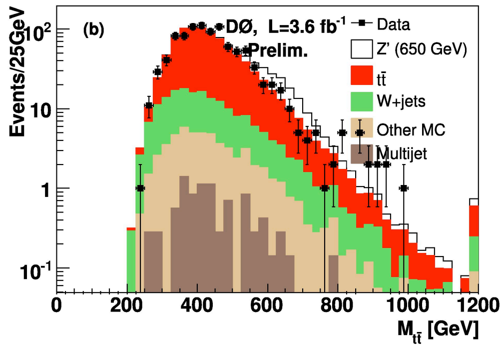
source	rel. sys. uncertainty (%)							
	Standard Model processes				Resonance $M_X = 650\,\text{GeV}$			
	3 jets		≥4 jets		3 jets		≥4 jets	
	σ^+	σ^-	σ^+	σ^-	σ^+	σ^-	σ^+	σ^-
Jet energy calibration	−0.4	0.2	−0.2	−0.3	−2.0	1.3	3.2	−2.7
Jet energy resolution	−0.2	−0.1	−0.2	−0.2	−0.1	0.2	0.0	0.1
Jet identification	−0.4	0.4	−0.4	0.4	1.2	−1.2	−2.2	2.2
$\sigma_{t\bar{t}}(m_t = 170\,\text{GeV})$	2.3	−2.3	4.0	−4.0	–	–	–	–
W+jets (heavy flavor)	1.7	−1.6	0.7	−0.6	–	–	–	–
b fragmentation	0.1	–	0.1	–	0.8	–	1.3	–
Multijet lepton fake rate	0.6	−0.6	−0.2	0.1	–	–	–	–
Luminosity	2.6	−2.4	4.1	−3.8	6.0	−5.8	6.1	−5.8
Top quark mass	1.5	2.2	0.5	1.2	–	–	–	–
Selection efficiencies	1.8	−1.8	2.9	−2.9	3.6	−3.7	3.6	−3.6
b-tagging	3.1	−3.1	3.2	−3.3	3.9	−4.1	3.5	−3.7

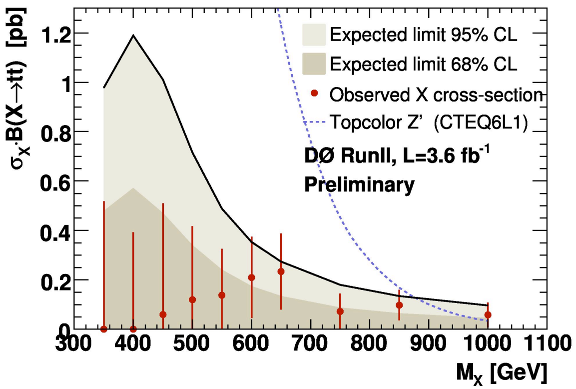
Results

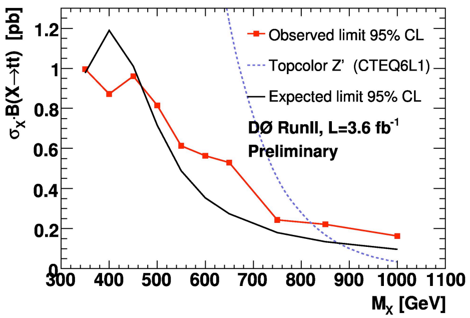


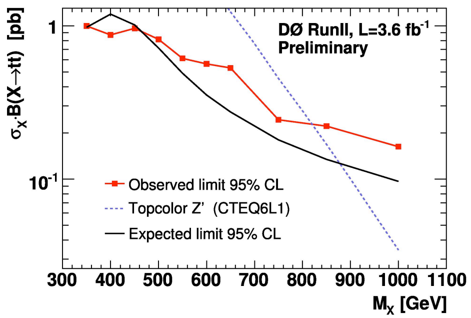












3 jets

≥ 4 jets

A topcolor leptophobic Z' is excluded at 95%CL below 820 GeV/c^2

CDF: Search for resonant production of tt pairs in 4.8fb-1

- For each event: apply tt hypothesis: observed event kinematics mapped to parton level using the Matrix Element for tt production and decay

- L+J Backgrounds (treatment same as for σ measurements)
  - W+Jets (HF, LF) (get tag rate, etc)
  - QCD (data driven)
  - EWK (diboson, single top)

component	4 jets	≥ 5 jets
non-W	46.1 ± 35.7	15.7 ± 12.2
Z+light flavor	6.4 ± 0.5	1.6 ± 0.1
W+light flavor	32.9 ± 8.5	7.4 ± 3.1
$Wb\bar{b}$	51.5 ± 12.6	12.4 ± 3.7
$Wc\bar{c}$	27.7 ± 6.6	7.3 ± 2.1
Wcj	14.0 ± 3.3	3.0 ± 0.9
single top	8.9 ± 0.4	1.4 ± 0.0
diboson	9.1 ± 0.6	2.4 ± 0.1
total non–$t\bar{t}$	196.6 ± 39.5	51.2 ± 13.3
SM $t\bar{t}$	667.1 ± 61.8	225.2 ± 21.0

Data: 996 370

tt/non-tt:3.6
Data/Bkg:1.2

Reconstructing M_{tt} and Statistical treatment

- Then construct a pdf representing M_{tt}:

$$\rho(x) \equiv \int \sum_k \pi(p_k|m_t) W(j|p_k) \delta(x - \mathbb{M}(p_k)) \mathrm{d}p_k.$$

M_{tt} given parton p_k

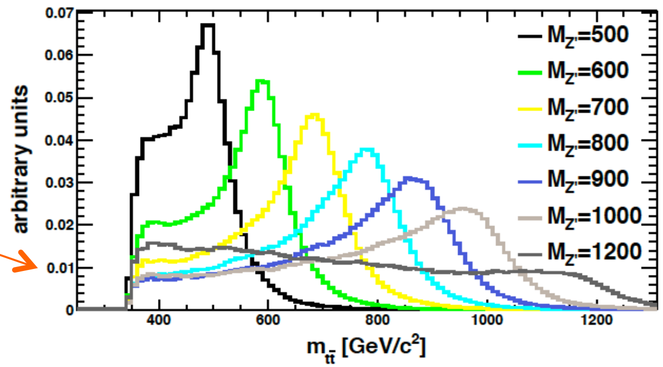
Sum over jet-parton assignments

- Transfer Function mapping jets to partons:
  - from MC ΔR(jets, p)<0.15 and no other jets or partons within ΔR<0.6
  - 10 bins in jet E_T
  - 5 bins in jet η

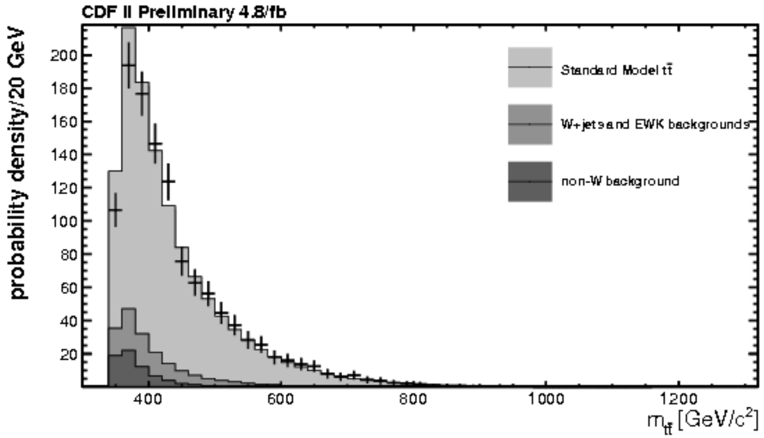
- Probability for an event in sample i goes into the likelihood:

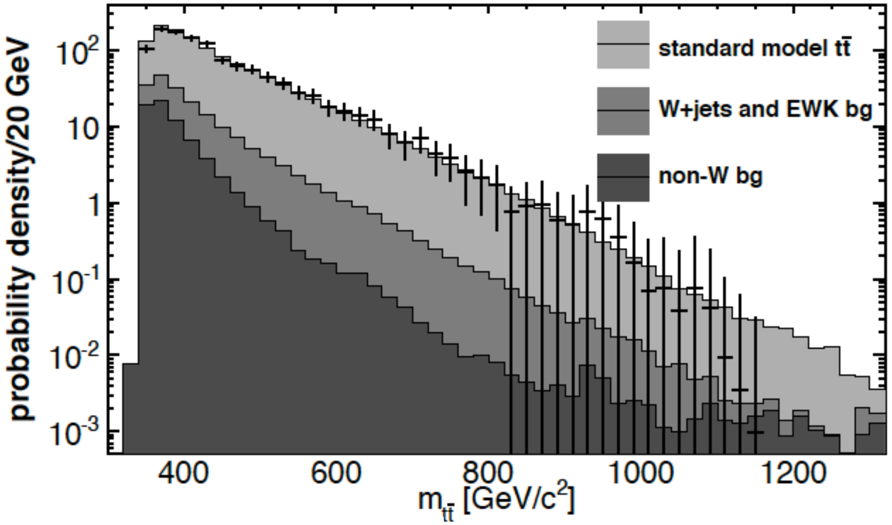
$$P_i(f_{\text{sig}}) = f_{\text{sig}} P_{\text{sig},i} + (1 - f_{\text{sig}}) P_{\text{bg},i}$$

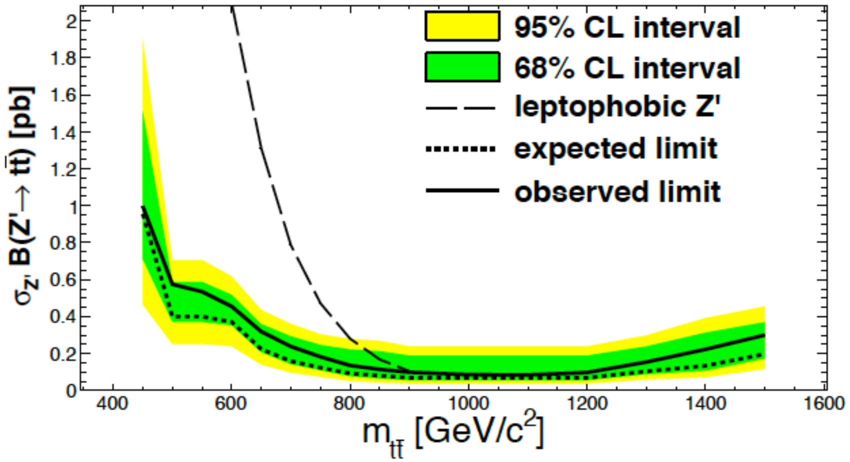
templates



Results







A topcolor leptophobic Z’ is excluded at 95%CL below 900 GeV/c^2

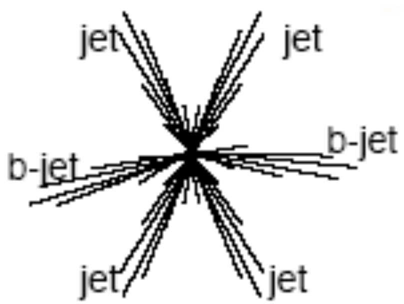
All Hadronic Event Selection

Trigger:
Jet Trigger: ≥4 jets
E_T>10GeV, ε: 80%

Veto Leptons

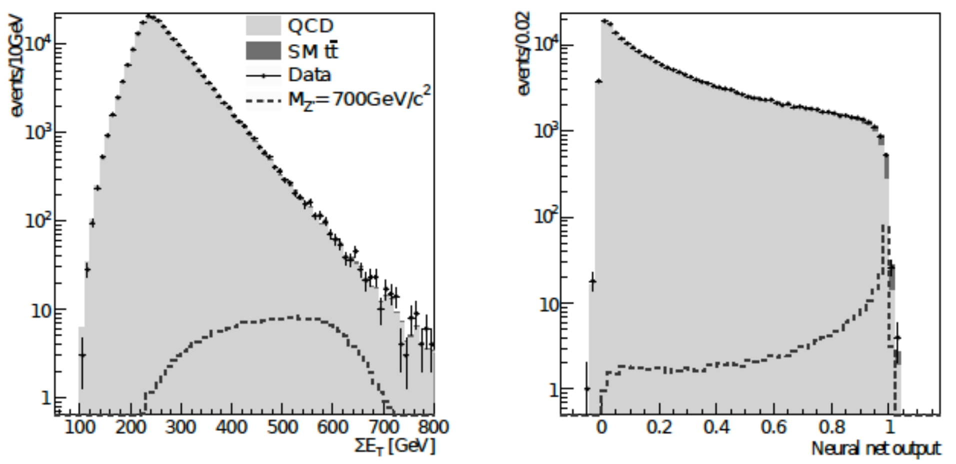
Veto ME_T

Jets
Topological clusters
Anti-k_T (R=0.4)
6 or 7 jets |η|<2.0, E_T>15GeV



Neural Net to reduce QCD background
10 variables used
Multijet data used as training sample
SM tt used as signal
NN>0.93

b-jets
Displaced vertex (SECVTX), ε_b: 50%, ε_l: 2%



CDF: Search for resonant production of tt decaying to jets

- Advantages of All hadronic channel:
  - High BR
  - good mass resolution
  - Complementary result
- AllHad:
  - QCD: get tag rate matrix from 4 or 5 jet sample and test on various control samples:
    - NN<0.25, 0.25<NN<0.75, 0.75<NN<0.93
- Likelihood calculated by integrating signal ME:
  - to calculate M_{tt} (sum over combinations)
  - Suppress the background

$M_{Z'}(\mathrm{GeV}/c^2)$	σ[pb]	$\epsilon \pm \delta\epsilon$
SM $t\bar{t}$	6.7	3.8 ± 0.5
450	8.96	4.2 ± 0.5
500	5.66	4.7 ± 0.5
550	3.40	5.3 ± 0.5
600	2.09	5.7 ± 0.5
650	1.31	5.8 ± 0.4
700	0.78	5.6 ± 0.4
750	0.47	5.2 ± 0.3
800	0.28	4.6 ± 0.3
850	0.16	4.0 ± 0.2
900	0.10	3.6 ± 0.2

Reconstructing M_{tt} and Statistical treatment

TF are used as functions of E and η
To set limits: Likelihood is used
within Bayes theorem

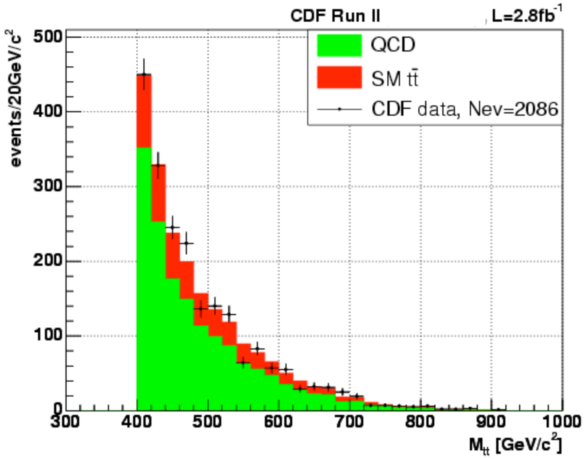
$$L(\vec{n}|\sigma,\vec{\nu}) = \prod_i e^{-\mu_i}\frac{\mu_i^{n_i}}{n_i!}$$

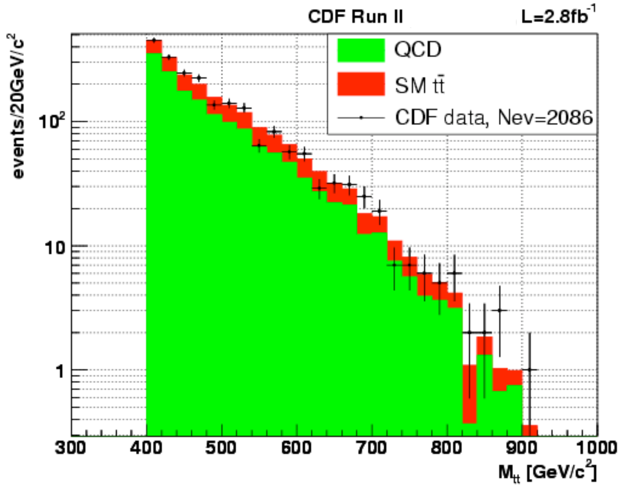
$$\mu_i = \sigma_s(A_s - A_s^{cont})T_s^i + \sigma_{tt}(A_{tt} - A_{tt}^{cont})T_{tt}^i + N_{QCD}T_{QCD}^i$$

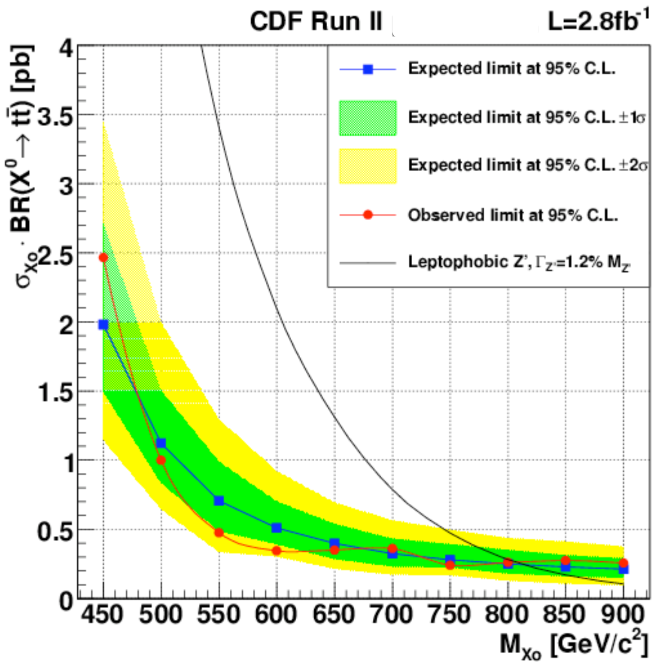
Contamination of signal
and tt events in QCD
data sample

i=mass bin
T^i: fraction of
evts in bin i

Results







A topcolor leptophobic Z' is excluded at 95%CL below 805 GeV/c^2

A search for boosted top quarks at CDF using 5.95fb-1

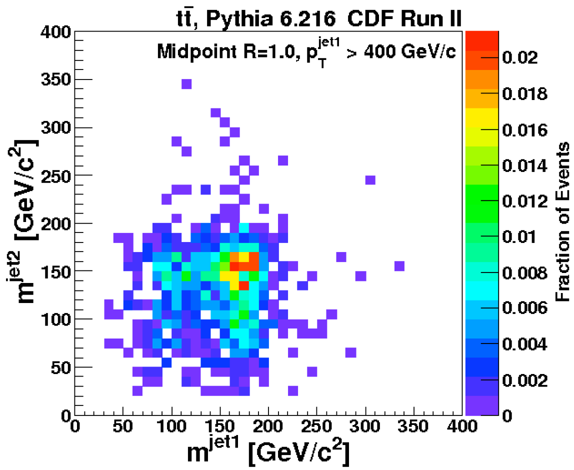
- Observation of massive collimated jets:
  - Test of perturbative QCD
  - Tune the MC event generators
  - Gives insight into the parton showering mechanism
  - No data available for top quark with $p_T > 400$GeV/c
  - $\gamma > 3$: top decay products collimate into single massive jet

- Event selection:
  - Trigger: ≥1 jet with $E_T > 100$GeV: 7.58×10^7 evts
  - Jets: Midpoint alg R=1.0, calorimeter towers ➔ 4-vec: "E-scheme"
    - Then correct using JES
    - Then correct for MI
  - ≥1 jet $p_T > 400$GeV/c $|\eta| < 0.7$
    - Typical JES f=1.12 (3% unc)
  - $$S_{MET} \equiv \frac{\not{E}_T}{\sqrt{\sum E_T}} < 10$$
  - Nevts = 4230

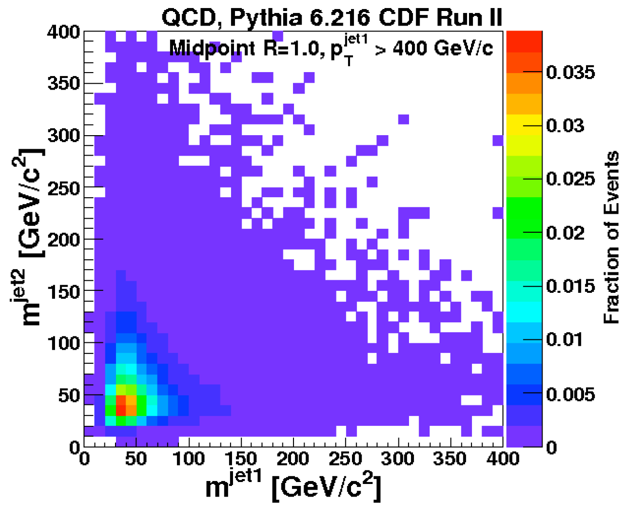
A search for boosted top quarks at CDF using 5.95fb-1

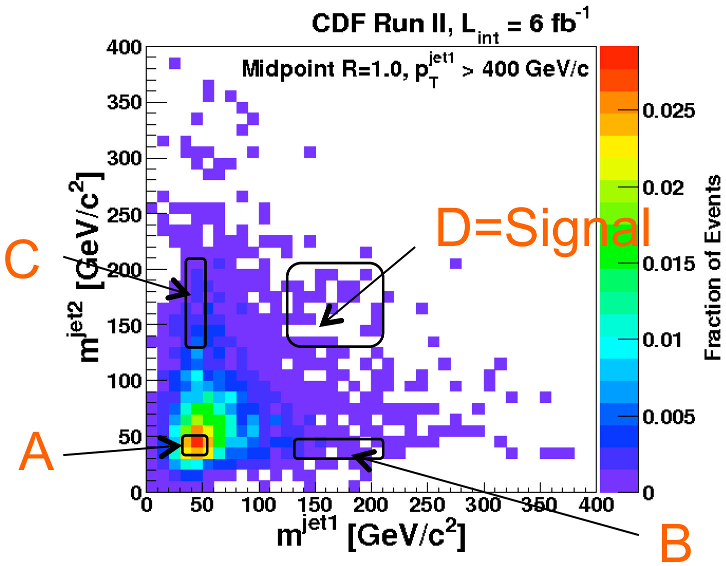
- Expect (based on recent NNLO calculation by N. Kidonakis):
- or f=5.58x10^{-4}
- AllHad channel: use m^{jet1} and m^{jet2} (slight correlation) and expect no ME_T:

$$\sigma_{ttp_T > 400\,GeV/c} = 4.55^{+0.50}_{-0.41}\, fb$$



S_{MET}<4





$$R_{mass} = \frac{N_B N_C}{N_A N_D}$$

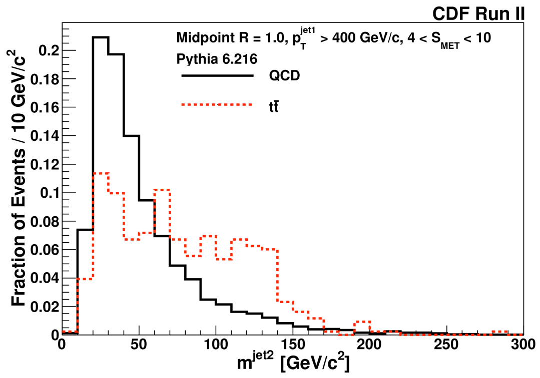
$$R_{mass} = 0.89 \pm 0.03(stat) \pm 0.03(syst)$$

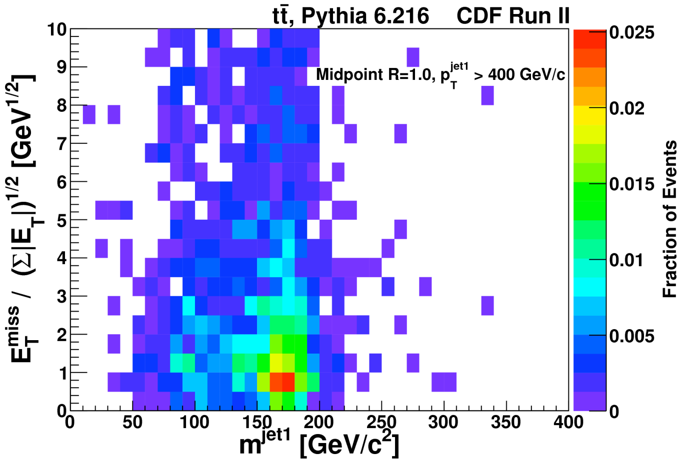
All Hadronic CDF, L_{int} = 6 fb^{-1}

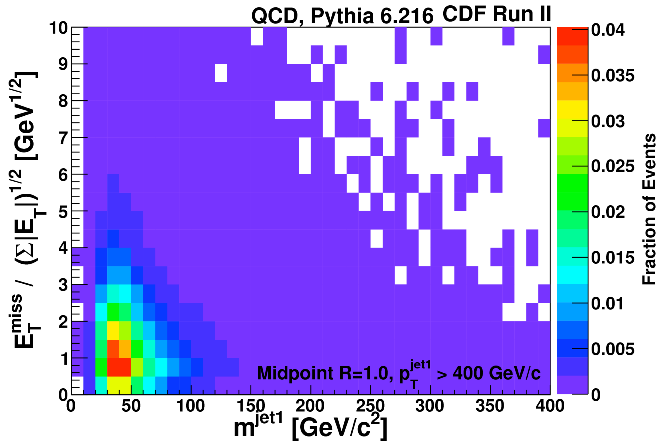
Region	m^{jet1} (GeV/c²)	m^{jet2} (GeV/c²)	Data (events)	ttbar MC (events)
A	(30, 50)	(30, 50)	370	0.00
B	(130, 210)	(30, 50)	47	0.08
C	(30, 50)	(130, 210)	102	0.01
D (signal)	(130, 210)	(130, 210)	31	3.03
Predicted QCD in D	14.6±2.76			

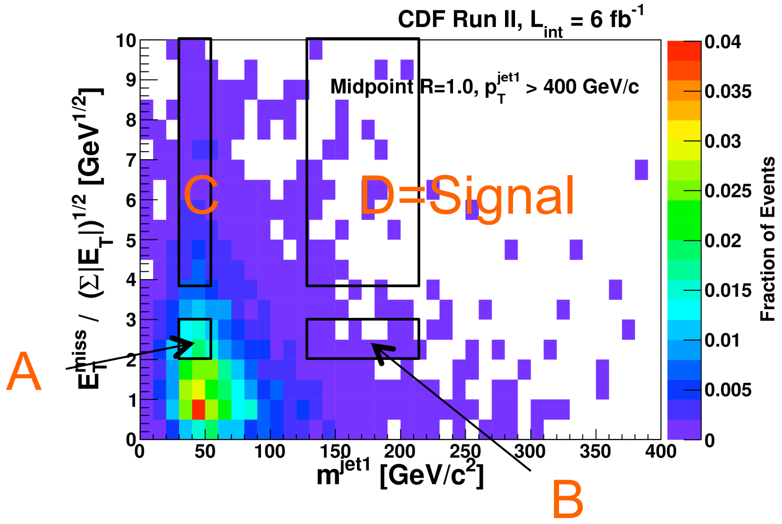
A search for boosted top quarks at CDF using 5.95fb-1

- For L+J channel: $4<S_{MET}<10$: effective for evts where recoil jet does not contain all the decay products
- M^{jet2} no longer discriminating between QCD and tt









$$\frac{N_A}{N_B} = \frac{N_C}{N_D}$$

Semileptonic — CDF, L_{int} = 6 fb^{-1}

Region	m^{jet1} (GeV/c²)	S_{MET} (GeV$^{1/2}$)	Data (events)	ttbar MC (events)
A	(30, 50)	(2, 3)	256	0.01
B	(130, 210)	(2, 3)	42	1.07
C	(30, 50)	(4, 10)	191	0.03
D (signal)	(130, 210)	(4, 10)	26	1.90
Predicted QCD in D	31.3±8.1			

A search for boosted top quarks at CDF using 5.95fb-1

- Combining AllHad+L+J:
  - data: 57 vs tt+QCD: 46±8.5(stat)±13.8(syst)
  - Calculate UL on $\sigma_{boostedtop}$
  - Use Bayesian with flat prior
    - Syst are nuisance parameters
    - ε_{tt}=0.182
- Expected limit: σ<33fb at 95%CL
- Observed limit: σ<38fb at 95%CL
  - Order of magnitude larger than SM prediction, dominated by background
- Can use allhad channel to put limit on resonant production:
  - tt is now background
  - X σ < 20fb at 95%CL

Uncertainties — CDF, L_{int} = 6 fb^{-1}

Source	±%
Jet Mass Scale	30
Luminosity	6
Background (statistical)	19
JES on ttbar	25
Top Quark Mass	0.3
R_{mass} (statistical)	3
R_{mass} (systematic)	3
Total (added in quadrature)	**44.2**

Conclusions:

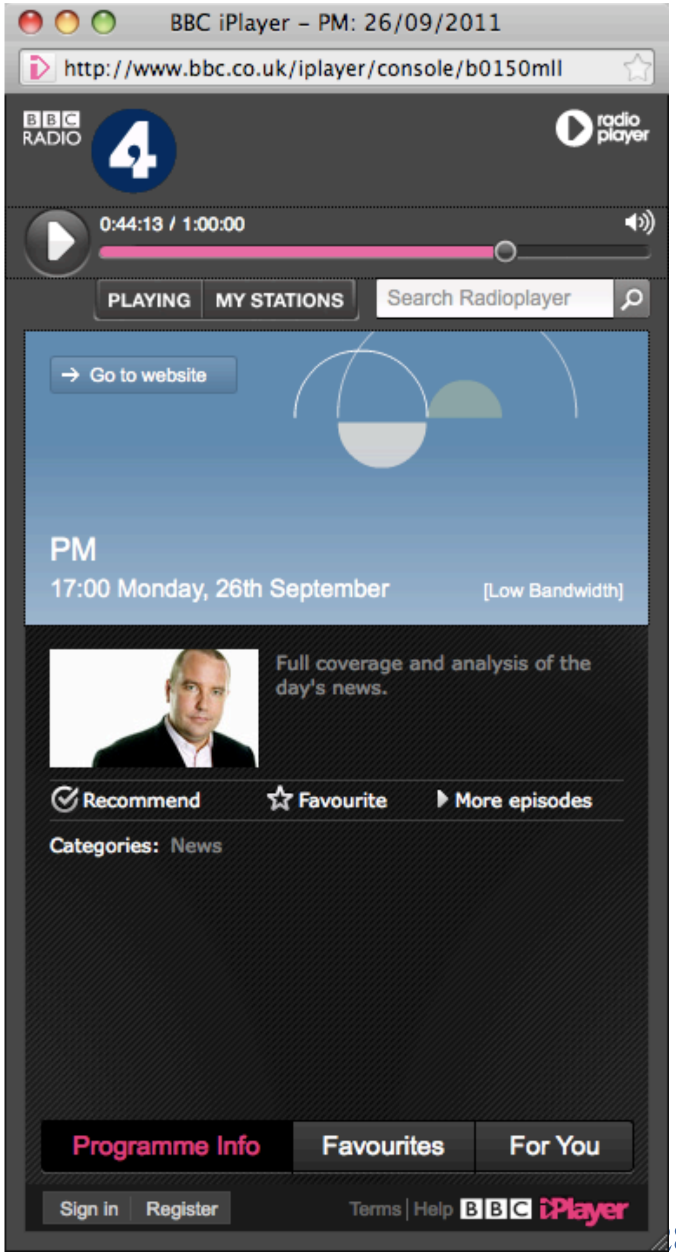
- Reported on tt resonant production results from the Tevatron
  - Non boosted regime:
    - AllHad and L+J in various techniques
      - If a topcolor leptophobic Z' exists it probably has $M_{Z'} > 900 GeV/c^2$
        - » STILL BEST LIMIT! (for Γ=1.2%)
      - If a massive gluon exists its coupling is probably less than 0.5
        - » This massive G is generic, but assumes parity-conservation, ATLAS/CMS look specifically at the KKgluon model, hard to compare results
  - Boosted regime:
    - X σ<20fb at 95%CL
- Also reported on first Tevatron boosted analysis
  - $\sigma_{toppt>400GeV} < 38fb$ at 95%CL
    - Most stringent limit on boosted top quark σ

Advertisement 1

The Tevatron:
28 years of discovery and innovation

Advertisement 2

- Yesterday I did some “publicity” for our workshop and top physics on national radio in the UK
- Go to minute 43 of: http://www.bbc.co.uk/iplayer/console/b0150mll

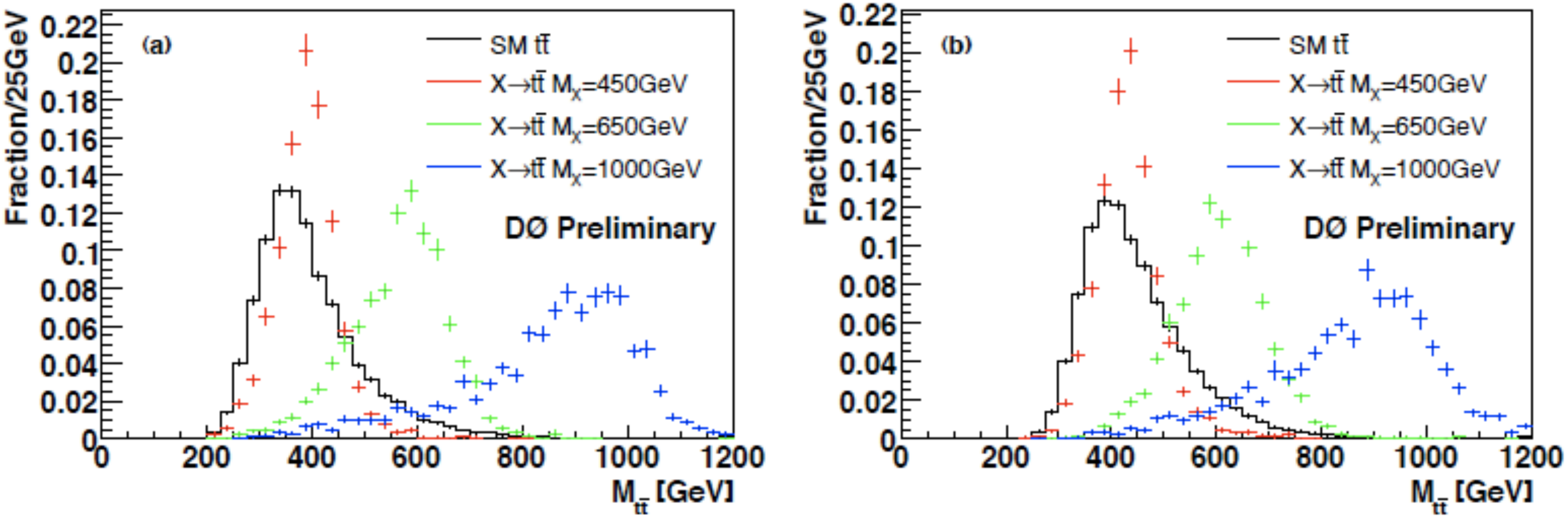


Backups: massive G

Table 2: Expected and observed 95% C.L. lower/upper limits on λ. Expected limits are in parentheses.

	$\Gamma/M = 0.05$	$\Gamma/M = 0.10$	$\Gamma/M = 0.20$	$\Gamma/M = 0.30$	$\Gamma/M = 0.40$	$\Gamma/M = 0.50$
M=400	(-0.036 / 0.042)	(-0.046 / 0.086)	(-0.074 / 0.156)	(-0.11 / 0.26)	(-0.15 / 0.30)	(-0.17 / 0.35)
	-0.043 / 0.040	-0.056 / 0.067	-0.089 / 0.11	-0.12 / 0.18	-0.16 / 0.20	-0.19 / 0.23
M=450	(-0.038 / 0.040)	(-0.046 / 0.058)	(-0.065 / 0.087)	(-0.087 / 0.13)	(-0.12 / 0.19)	(-0.13 / 0.24)
	-0.045 / 0.027	-0.057 / 0.042	-0.086 / 0.06	-0.12 / 0.09	-0.15 / 0.14	-0.18 / 0.19
M=500	(-0.051 / 0.038)	(-0.060 / 0.053)	(-0.083 / 0.087)	(-0.12 / 0.13)	(-0.13 / 0.18)	(-0.16 / 0.24)
	-0.059 / 0.034	-0.067 / 0.043	-0.10 / 0.06	-0.14 / 0.10	-0.17 / 0.14	-0.20 / 0.19
M=550	(-0.058 / 0.049)	(-0.075 / 0.069)	(-0.13 / 0.10)	(-0.15 / 0.15)	(-0.20 / 0.20)	(-0.31 / 0.23)
	-0.064 / 0.039	-0.083 / 0.055	-0.12 / 0.08	-0.16 / 0.13	-0.19 / 0.18	-0.23 / 0.20
M=600	(-0.074 / 0.058)	(-0.10 / 0.082)	(-0.19 / 0.12)	(-0.21 / 0.18)	(-0.35 / 0.22)	(-0.65 / 0.28)
	-0.073 / 0.048	-0.10 / 0.069	-0.16 / 0.10	-0.15 / 0.16	-0.22 / 0.20	-0.23 / 0.28
M=650	(-0.098 / 0.077)	(-0.14 / 0.092)	(-0.24 / 0.15)	(-0.36 / 0.20)	(-0.58 / 0.27)	(-0.80 / 0.33)
	-0.081 / 0.069	-0.096 / 0.083	-0.13 / 0.15	-0.16 / 0.20	-0.26 / 0.29	-0.34 / 0.35
M=700	(-0.11 / 0.082)	(-0.16 / 0.12)	(-0.27 / 0.17)	(-0.44 / 0.25)	(-0.68 / 0.32)	(-0.90 / 0.42)
	-0.070 / 0.091	-0.068 / 0.14	-0.091 / 0.19	-0.13 / 0.29	-0.31 / 0.37	-0.37 / 0.47
M=750	(-0.14 / 0.11)	(-0.20 / 0.14)	(-0.33 / 0.21)	(-0.50 / 0.31)	(-0.71 / 0.39)	(-1.00 / 0.52)
	-0.020 / 0.13	-0.021 / 0.18	-0.033 / 0.26	-0.03 / 0.38	-0.06 / 0.47	-0.37 / 0.61
M=800	(-0.16 / 0.12)	(-0.24 / 0.17)	(-0.39 / 0.27)	(-0.59 / 0.37)	(-0.80 / 0.49)	(-1.09 / 0.62)
	-0.011 / 0.18	-0.017 / 0.26	0.017 / 0.37	-0.04 / 0.50	-0.01 / 0.63	-0.33 / 0.76

Backups: D0 L+J



M_X [GeV]	exp. limit [pb]	obs. limit [pb]
350	0.98	1.00
400	1.19	0.87
450	1.01	0.96
500	0.72	0.81
550	0.49	0.61
600	0.35	0.56
650	0.27	0.53
750	0.18	0.24
850	0.13	0.22
1000	0.10	0.16

source	rel. sys. uncertainty (%) Standard Model processes				Resonance $M_X = 650\,\mathrm{GeV}$			
	3 jets		≥4 jets		3 jets		≥4 jets	
	σ^+	σ^-	σ^+	σ^-	σ^+	σ^-	σ^+	σ^-
Jet energy calibration	−1.2	1.3	2.8	−2.7	−1.7	1.1	3.6	−3.6
Jet energy resolution	−3.2	1.7	0.5	−0.6	−2.2	0.8	1.7	−1.1
Jet identification	0.1	−0.1	−1.2	1.2	0.2	−0.2	−1.6	1.6
$\sigma_{t\bar{t}}(m_t = 170\,\mathrm{GeV})$	2.6	−3.3	4.8	−6.1	–	–	–	–
W+jets (heavy flavor)	1.0	0.0	0.4	−0.2	–	–	–	–
b fragmentation	−7.0	–	−6.0	–	−6.7	–	−6.1	–
Multijet lepton fake rate	−0.2	0.2	−0.1	0.1	–	–	–	–
Luminosity	2.1	−2.0	3.9	−3.7	6.1	−5.8	6.1	−5.8
Top quark mass	−1.0	1.2	−1.4	2.0	–	–	–	–
Selection efficiencies	1.4	−1.4	2.3	−2.3	3.6	−3.6	3.6	−3.6
b-tagging	5.4	−9.9	5.7	−8.7	7.2	−9.8	6.5	−8.9

Backups: CDF ME

	CEM	CMUP	CMX
4 jets, 1 tag	480	221	131
4 jets, ≥ 2 tags	110	33	21
≥ 5 jets, 1 tag	164	81	41
≥ 5 jets, ≥ 2 tags	47	21	16

$m_{Z'}$ [GeV/c^2]	Expected limit	Observed limit
450	0.954	1.05
500	0.400	0.49
550	0.400	0.46
600	0.371	0.40
650	0.224	0.26
700	0.159	0.20
750	0.123	0.15
800	0.092	0.11
850	0.080	0.10
900	0.068	0.09
950	0.069	0.08
1000	0.069	0.07
1100	0.069	0.07
1200	0.070	0.08
1300	0.104	0.13
1400	0.134	0.18
1500	0.197	0.24

Z' pole mass [GeV]	$\Delta\sigma$ [pb]
450	0.210
500	0.183
550	0.155
600	0.153
650	0.087
700	0.058
750	0.044
800	0.030
850	0.025
900	0.020
950	0.012
1000	0.014
1100	0.016
1200	0.011
1300	0.029
1400	0.036
1500	0.065

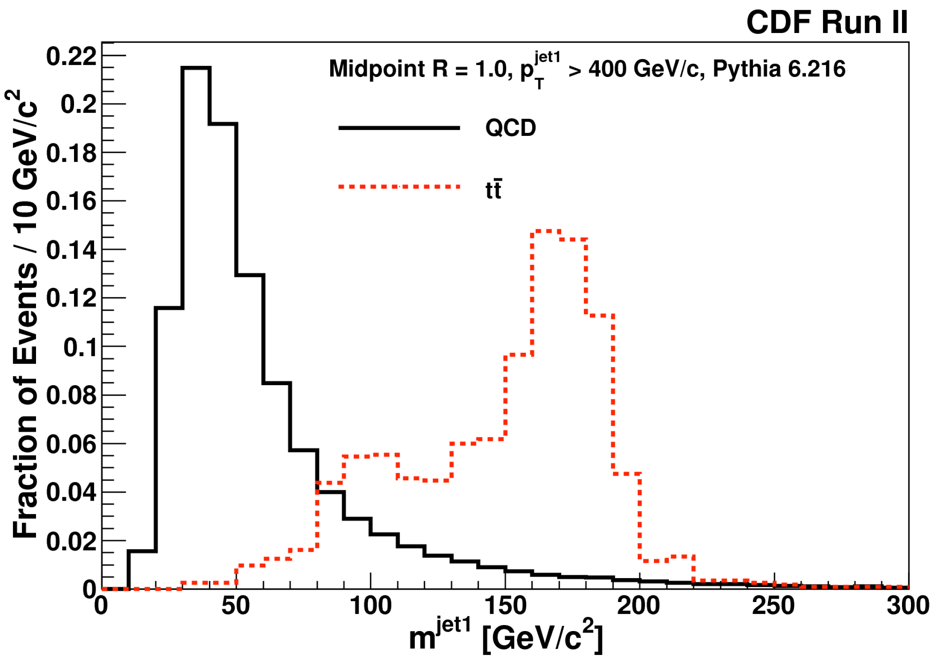
Backups: CDF: all had

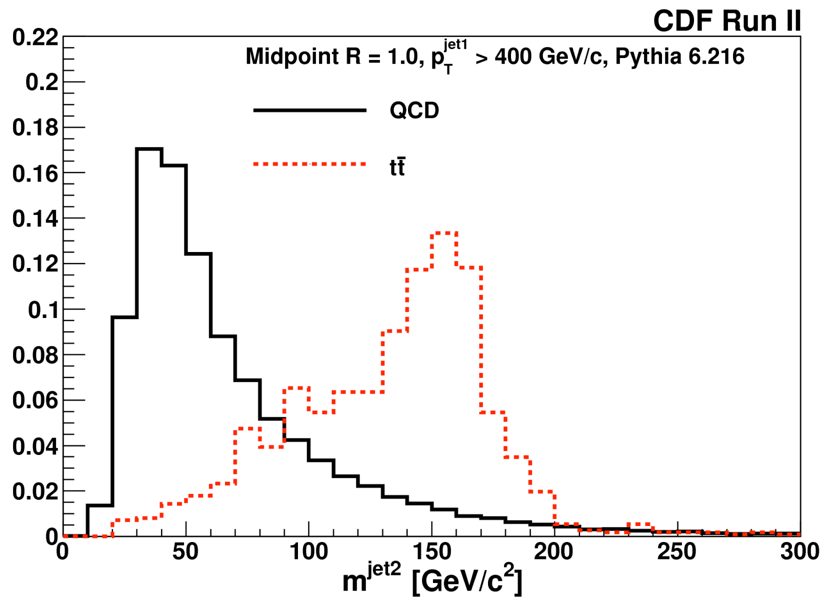
Variable	Description
$\sum E_T$	Scalar sum of all jet E_T
$\sum_3 E_T$	As above, excluding two highest E_T jets
C	Centrality, defined in text
A	Aplanarity, defined in text
$M_{2j}^{\min}$	Minimum dijet invariant mass
$M_{2j}^{\max}$	Maximum dijet invariant mass
$M_{3j}^{\min}$	Minimum trijet invariant mass
$M_{3j}^{\max}$	Maximum trijet invariant mass
$E_T^{\star,1}$	$E_T \sin^2\theta^\star$ for the highest E_T jet
$\langle E_T^\star \rangle$	Geometric mean of E_T of remaining $N-2$
MED	Constructed from matrix element

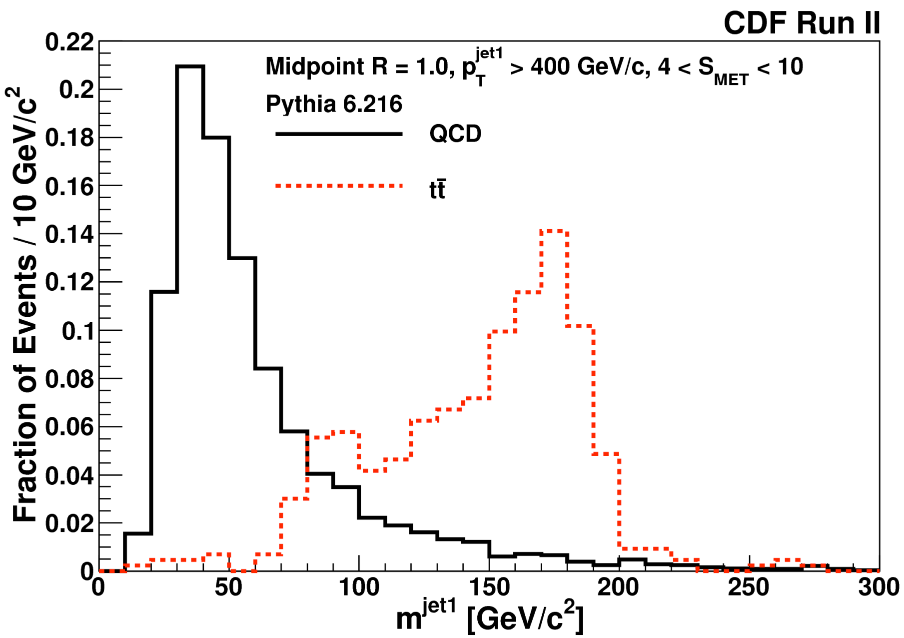
ity is $C = \frac{\sum E_T}{\sqrt{\hat{s}}}$, where $\sqrt{\hat{s}}$ is the invariant mass of the multijet system. The aplanarity is defined as $A = \frac{3}{2}Q_1$, where Q_1 is the smallest of the three normalized eigenvalues of the sphericity tensor, $M^{ab} = \sum_j P_j^a P_j^b$, calculated in the center of mass system of all jets, where a and b refer to the spatial components of the jet four-momentum

P_j. In Table I, $\theta^\star$ is a jet emission direction, represented by the angle between the jet direction, measured in the center of mass frame of all jets, and the proton beam axis. For the last variable, MED (matrix element discriminant), we exploit the broad set of information from the event about its production and decay through the SM $t\bar{t}$ matrix element. For each event we calculate 'the minus log probability' of Eq. (1) at 9 different top mass points, $m_t = 155, 160...195$ GeV$/c^2$, and use their sum as the final discriminator.

Backups: boosted top







$$\chi^2 = \sum_{i=\ell,4jets} \frac{(\hat{p}_T^i - p_T^i)^2}{\sigma_i^2} + \sum_{j=x,y} \frac{(\hat{p}_j^{UE} - p_j^{UE})^2}{\sigma_j^2}$$
$$+ \frac{(m_{jj} - m_W)^2}{\Gamma_W^2} + \frac{(m_{\ell\nu} - m_W)^2}{\Gamma_W^2} + \frac{(m_{bjj} - m_t)^2}{\Gamma_t^2} + \frac{(m_{b\ell\nu} - m_t)^2}{\Gamma_t^2}$$