Top Quark Physics at DØ in Run II with 500 pb^{-1} of Data

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Top Physics Program

Production

- Top pair cross section
- o Single top cross sections
- ● Couplings: *gtt* *Wtb*
- o Spin correlations
- o $t\bar{t}$ invariant mass spectrum

Decay

- Mass m_{top}
- ● Width Γ_{top}
- ● CKM matrix element $|V_{tb}|$
- ● Gluon radiation
- ● *W* helicities
- ● Branching fractions
- ● p_T spectra
- ● Charge
- o Rare decays

● = new for Run II

o = very much improved for Run II

We think we know about m_{top} and □, but what about …

… All the Other Measurements

Use the reconstructed $t\bar{t}$ and single top with $t \to Wb$ for:

From □, m_{tt} set limits on	anomalous couplings gtt, Wtb Z□, V_8, $\Box_T$ □ $t\bar{t}$; $\tilde{g}$ □ $t\bar{t}$; g □ $\tilde{t}\bar{\tilde{t}}$
Like sign dileptons?	$\tilde{g}$ □ $t\tilde{t}$
Tag rate suppressed?	t □ Ws, Wd $\lvert V_{tb}\rvert$ etc.
Leptonic rate enhanced?	$\tilde{t}$ □ bl□
Leptonic rate suppressed?	t □ $\tilde{t}\Box^0$, $\tilde{t}$ □ $c\Box^0$
Kinematic distribs need $m_{\text{"}\Box\text{"}}$	t □ $\tilde{t}\Box^0$, $\tilde{t}$ □ $b\Box^+$; $\tilde{t}$ □ $b\Box^+$ t □ $\tilde{b}\Box^+$, $\tilde{b}$ □ $b\Box^0$
Angular distributions	production and decay helicities

Extra particles in final state:

g, □, b, l (one or more)	SM radiative decays, plus others

Reconstruct $t\bar{t}$ in different decay modes:

Tau rate enhanced?	t □ H^+b, H^+ □ □□
	t □ $\tilde{t}\Box^0$, $\tilde{t}$ □ □X (high tan□)
Odd stuff	t □ $\Box_T^+b$; t □ $\tilde{t}\tilde{g}$; t □ $\tilde{t}\tilde{G}$
	t □ $\Box^+b$, $\tilde{b}_{\Box}$ (R parity violating)
	t □ $gc, gu, \Box c, \Box u, Zc, Zu$ (FCNC)
	t □ $h^0c, h^0u, \Box_T^0 c, \Box_T^0 u$ (FCNC)

Different modes of single top production:

More odd stuff	$g, Z, \Box$ □ tc, tu ; q □ $Zt, \Box t$

Requires CAREFUL COORDINATION between Top Group and New Phenomena Group so as not to get missed.

Info from Tao Han and Regina Demina

Changes from Run I – Effect on Top

Detector Improvements

Electrons
- measure p_T
- fewer fakes
- use for b tagging

Muons
- better p_T
- lower minimum p_T for tags
- better η coverage
- better triggers

Jets
- charge for jet ID
- b tagging with secondary vertices
- b trigger with STT

Accelerator Improvements

11% higher energy
- 40% increase in $t\bar{t}$ and single top cross sections

5x higher integrated luminosity

Analysis Improvements

- ~25x higher statistics
- better MC models
- better parton distribution function sets
- better analysis tools
- more ways to control systematic errors
- more experience

Data Sets

1. **e or μ + ≥ 1 central jet**
   - + $\not\!\!E_T$ for *l* +*jets/notag* background ($t\bar{t}$ and single top)
   - + $\not\!\!E_T$ + ≥ 2 jets for single top
   - + 'e' or 'μ' + ≥ 2 jets for lepton ID prob (single top)
   - + 'e' or 'μ' + ≥ 3 jets for lepton ID prob ($t\bar{t}$)
   - + e or μ + $\not\!\!E_T$ + ≥ 2 jets for $t\bar{t}$ → *dileptons*, m_{top}
   - (μ) + low $\not\!\!E_T$ + ≥ 2 jets for fake μ backgd ($t\bar{t}$ and single top)
   - + $\not\!\!E_T$ + ≥ 3 jets for $t\bar{t}$ → *lepton+ jets/ tag*
   - + $\not\!\!E_T$ + ≥ 4 jets for $t\bar{t}$ → *lepton+ jets/ notag* , m_{top}

2. **≥ 6 jets (STT or prescaled?)**
   - for $t\bar{t}$ → *alljets* Xsec and m_{top}

3. ***b*-tag + ≥ 2 jets (STT)**
   - Z → $b\bar{b}$ for jet energy scale calibration
   - + ≥ 3 jets to measure secondary vertex tag prob, fake prob (if *b*-tag is in trigger)
   - + ≥ 4 jets for *single top* → *alljets*

4. **≥ 2 jets (≥ 1 central jet; prescaled)**
   - for $b\bar{b}$ continuum subtraction in energy scale calibration
   - + ≥ 3 jets fake electron background in $t\bar{t}$ and single top
   - and measure lepton tag rate functions
   - and measure secondary vertex tag prob, fake prob (if *b*-tag not in trigger)

5. **Various special sets for rare decay searches**

Signal Yields in 500 pb^{-1}

Reconstructed Top Events			
Exclusive Yields (m_{top} = 175 GeV)	Run I 10% tag	Run IIa 500 pb^{-1} 45% tag	65% tag
$t\bar{t} \to ll + \geq 2$ jets	5	39	39
$t\bar{t} \to l + = 3$ jets/ =1 tag		17	16
$t\bar{t} \to l + = 3$ jets/ = 2 tags		9	19
$t\bar{t} \to l + \geq 4$ jets / notags	10	178	71
$t\bar{t} \to l + \geq 4$ jets/ =1 tag	9	145	133
$t\bar{t} \to l + \geq 4$ jets/ =2 tags		70	148
$t\bar{t} \to \geq 6$ jets/ =1 tag	14	252	232
$t\bar{t} \to \geq 6$ jets/ =2 tags	2	124	260
Total $t\bar{t}$ Events	**40**	**834**	**918**
$tb + \bar{t}b \to l + \geq 2$ jets / notags	~0.8	7	3
$tb + \bar{t}b \to l + \geq 2$ jets/ =1 tag	~0.2	11	10
$tb + \bar{t}b \to l + \geq 2$ jets/ = 2 tags		5	10
$tb + \bar{t}b \to \geq 4$ jets/ =1 tag		29	27
$tb + \bar{t}b \to \geq 4$ jets/ =2 tags		12	25
Total s-channel single top	**~1**	**64**	**75**
$tqb + \bar{t}qb \to l + \geq 2$ jets / notags	~2.0	17	7
$tqb + \bar{t}qb \to l + \geq 2$ jets/ =1 tag	~0.3	28	26
$tqb + \bar{t}qb \to l + \geq 2$ jets/ =2 tags		11	23
$tqb + \bar{t}qb \to \geq 4$ jets/ =1 tag		72	66
$tqb + \bar{t}qb \to \geq 4$ jets/ =2 tags		29	61
Total t-channel single top	**~2.3**	**157**	**183**

How to Improve the Analyses

Reduce the Errors

More statistics ... the following errors will go down by $1/\sqrt{N}$:

Electron ID efficiency	5 % (CC), 7 % (EC)
Fake electron probability	10 % (CC), 8 % (EC)
Muon ID efficiency	10 % (CF), 3 % (EF)
Fake muon probability	5 % (CF), 30 % (EF)
Tag muon ID efficiency	5 % (CF), 3 % (EF)

The following errors need more work to make them go down :

Integrated luminosity	5 %
Tag rate functions	8 %
Modeling tagging muons	10 %
PDF model of proton	1 – 10 %
Jet energy scale	1 – 10 %
Multiple interactions	3 – 10 %
Modeling jets	5 – 14 %

Increase the Efficiencies / Reduce the Fake Rates

Electron ID	strongly dependent on jet multiplicity 61 % (CC), 54 % (EC), for ≥2 jet events
Fake e probability	0.01 % (CC), 0.05 % (EC)
Muon ID	~ 45 %
Fake μ probability	7 – 16 % (CF), 45 – 63 % (EF)
Jet ID	kT jets for high efficiency at low E_T ?
b-tag efficiency	10 % / jet —> 40 % – 70 % / jet ?
Fake tag prob	~ 0.4 % / jet

Improve the MC Models

Jet Modeling

$t\bar{t}$ Signal

HERWIG 5.7 and 5.9 used in Run I

Version 5.9 had a bug in the *b* parton showering
—> Too much gluon radiation at large angles. Fixed in 6.0

Version 6.1 replaces the parton showering algorithms in top decay (FSR) with NLO matrix element calculations
—> Energy radiated ~same, angular distribution different

NLO matrix elements will be in top production (ISR) soon

Single Top Signal

Get NLO generator from Laenen (extension of DYTAG)

W+Jets Background

CompHEP could replace VECBOS
—> Quark masses are included (changes pT for *b* jets)

b-Decay Modeling

Get the latest CLEO model of *b* and *c* decays for HERWIG

PDFs

Update from CTEQ3M to CTEQ6M and/or MRS98

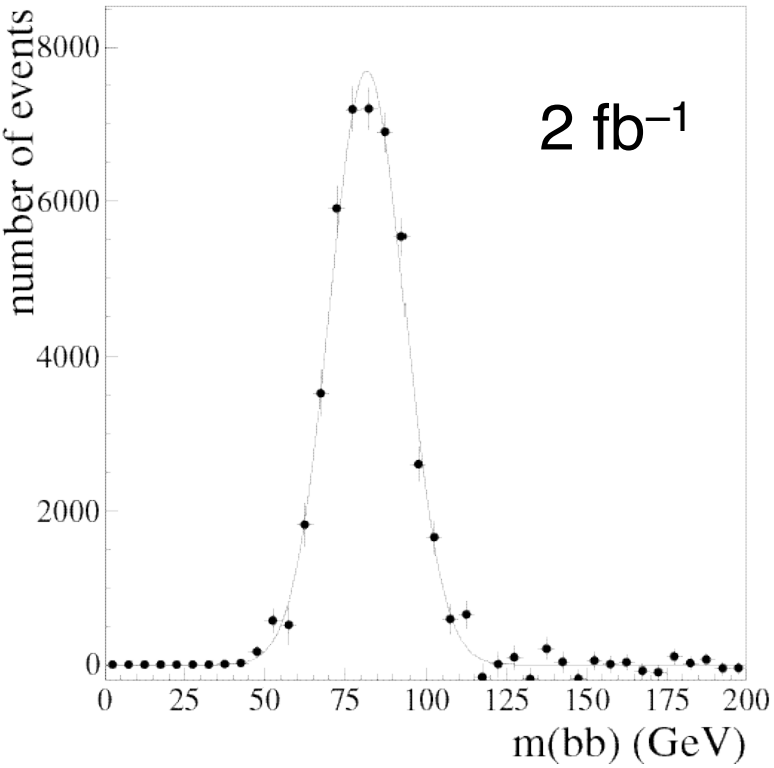
Improve the Jet Energy Scale Calibration

Narain and Heintz DØ Note 3604

Use STT with >= 2 jet events, at 20% efficiency
Able to reconstruct $Z \to b\bar{b}$ peak above 2 jet continuum

p_T balancing with dijet and $\gamma + jet$ events limited to ~1.5%
$Z \to b\bar{b}$ will reduce this to ~0.3% (Full Run II)

In 500 pb^{-1}, reconstruct ~10,000 $Z \to b\bar{b}$ on a ~140,000 $g \to b\bar{b}$ continuum



Try to do this with lepton-tagged jets too ?
Might need to if no STT. Calibrate lepton-correction to jet

Improve *b*-Tagging of Jets

Bookkeeping Problem

Run I Separate analyses for untagged and tagged events in cross section measurement
Separate treatment for untagged, single-tagged, and double-tagged events in mass measurement

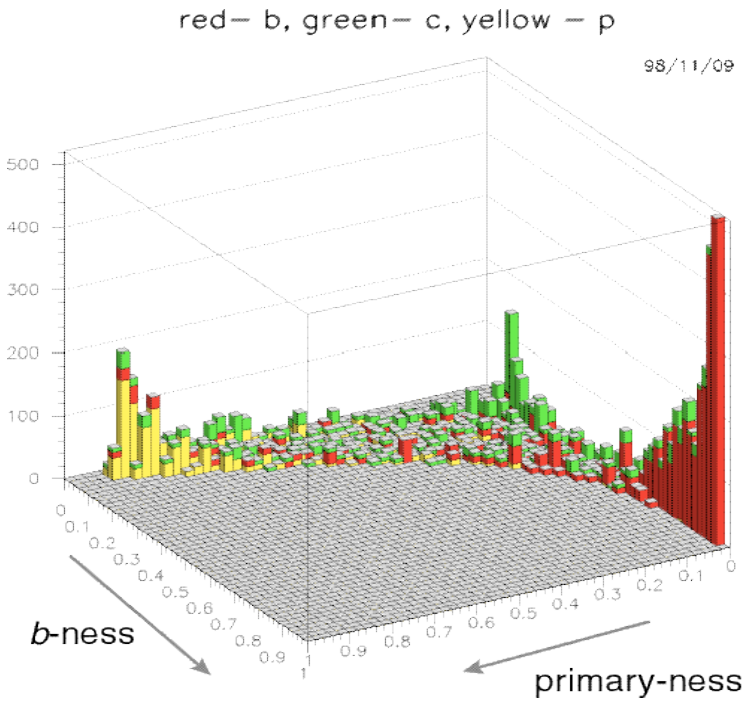
Run II Each jet can have:

(SMT) (*e*) (*μ*)
(SMT+*e*) (SMT+*μ*) (*e*+*μ*) (*e*+*e*?) (*μ*+*μ*)
(SMT+*e*+*μ*) (SMT+*e*+*e*?) (SMT+*μ*+*μ*)

Up to two combs / event — how many analyses?

Losing Information

If the SMT, *e* and *μ* tags are just yes/no information, then much is lost – must combine all available information in NN
CDF have developed a NN with 8 inputs and 3 outputs (*b, c, p*)



(D. Amidei, R. Demina
D. Wolinski)

We must do this too!
Optimized for DØ, better!

Summary of Key Issues

~ 900	$t\bar{t}$ pair events	S:B 5:1 (*ll*)	3:1 (*l*+*jets*) ?
~ 240	single top events	S:B 1:4 ?	

Yields are critically dependent on:

- keeping trigger efficiencies at Run I levels
- improving *e* ID efficiency in high occupancy environment
- improving μ ID efficiency
- using the STT for single top –> alljets

Signal:Background will be determined by:

- lowering fake rates for *e*, μ, *b*-tag
- getting high *b*-tagging efficiency

Highest quality measurements depend on:

- improving the jet energy scale calibration
- using better MC tools for modeling
- using neural networks wherever possible

Summary of Top Physics with 500 pb^{-1}

We should publish papers (PRL and/or PRD) of the following measurements:

Major:

1. top quark mass
2. $t\bar{t}$ pair production cross section
3. s-channel and t-channel single top cross sections

Production:

4. anomalous coupling limits (from cross sections)
5. gluon radiation studies
6. high mass resonance search in m_{tt}
7. spin correlations

Decay:

8. W helicities
9. branching fractions
10. p_T spectra (perhaps with 5.)

11.–15. rare searches (several)

Combined:

16. $|V_{tb}|$ and top width from single top cross section and $t\bar{t}$ decay branching fractions