

My Work as a Grad Student

Searching for Single Top Quark Production

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Simon Fraser University

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Acknowledgements

Dugan O'Neil, Yann Coadou, Mike Vetterli (SFU)

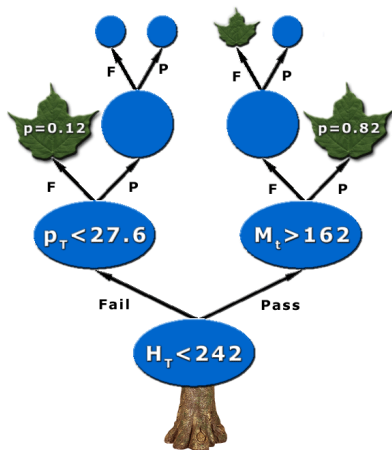
Reinhard Schwienhorst, Aran Garcia-Bellido, Ann Heinson
(Single top conveners)

Aurelio Juste, Michele Weber, Darien Woods (DØ)

Zhiyi Liu, Jorge Armando Benitez, Monica Pangilinan
& Marco Bieri
(Fellow grad students)

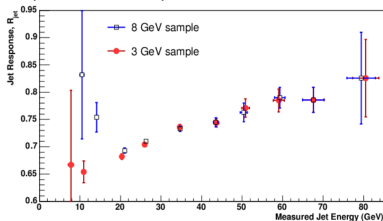
Outline

- 1 Masters Thesis (2004) – Jet Response
- 2 Evidence for Single Top Quark Production
- 3 Ph.D. Year One
- 4 Ph.D. Year Two – Evidence for Single Top
- 5 Ph.D. Year Three & Four (now)

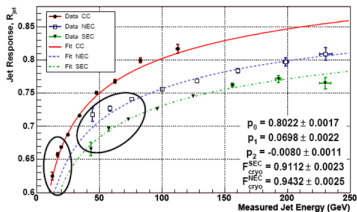


My Masters Thesis (2004) – Jet Response

Jet response in CC with different jet reconstruction thresholds



SFU Jet Response Measurement

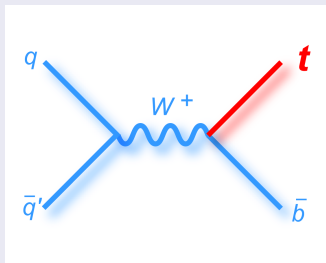


- 1 Did my Masters' course work → 2003 in Lund, Sweden
- 2 Came to SFU as an exchange student and did my Masters Thesis for Dugan O'Neil (Jan 2004–Dec 2004)
A Study of Jet Response in the $D\bar{O}$ Calorimeters
- 3 Developed a new method to better measure low energy jets
- 4 Added the nine circled data points to the jet response measurement curve
- 5 Worked in the JES group, with γ +jets(+ $\cancel{E}_T$) data & MC

Electroweak single top production

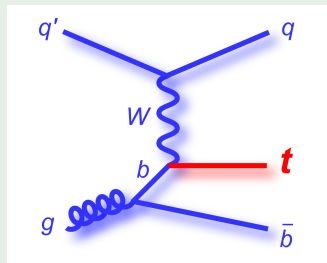
- Never observed before
- Dominant production channels at the Tevatron:

s-channel (tb)



$$\sigma_{\text{NLO}} = 0.88 \pm 0.11 \text{ pb (*)}$$

t-channel (tqb)



$$\sigma_{\text{NLO}} = 1.98 \pm 0.25 \text{ pb(*)}$$

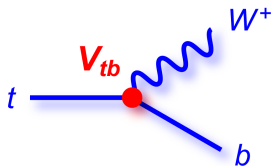
(*) $m_t = 175 \text{ GeV}$, Phys.Rev. D70 (2004) 114012

- Total SM cross section: $\sigma_{s+t} = 2.9 \text{ pb}$

Motivation

1. Predicted but not observed before
2. **Study the Wtb coupling**

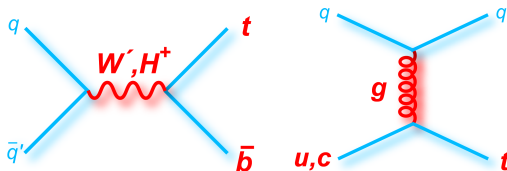
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & \mathbf{V_{tb}} \end{pmatrix}$$



- Direct measurement of $|V_{tb}|$ (more later)
 - Unitarity test of CKM matrix
 - Anomalous Wtb couplings
3. Measurement of top quark properties:
polarization, decay width, lifetime, mass...

4. New physics, example:

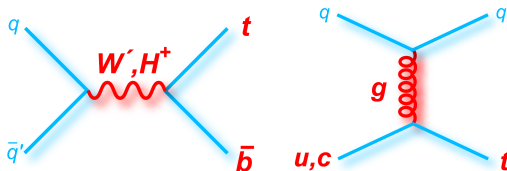
- s -channel: resonances like heavy W' , charged Higgs
- t -channel: Flavour-changing neutral currents
- 4-th quark generation?



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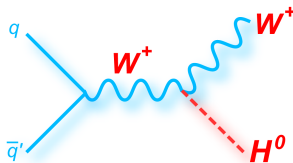
- s-channel: resonances like heavy W' , charged Higgs
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5. Very similar to SM Higgs production

- Same final state and bkg as

$$WH \rightarrow l\nu b\bar{b}$$

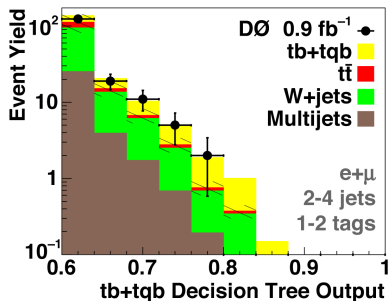
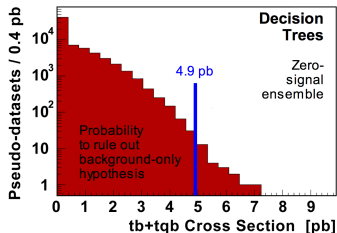
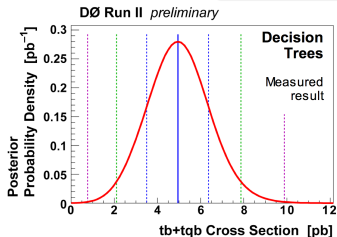


6. Test of advanced separation techniques

Boosted decision tree observed results

$\sigma_{s+t} = 4.9 \pm 1.4 \text{ pb}$
 $p\text{-value} = 0.035\% (3.4\sigma)$
SM compatibility: 11% (1.3σ)

Evidence!



PRL 98, 181802

Ph.D. Year One, 2005 – The arrival of p17

DØ was undergoing some major changes late 2004–2005

- New data format/software release (p17)
- New calorimeter calibration, vertex reconstruction, etc.
- New [Common Analysis Framework](#) (CAF)

I was one of the first people to start working full-time on developing and testing this format

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Main contributions

- 1 Helped with the new Jet Energy Scale – did JES Closure Tests
- 2 Created the (CAF-based) software package [top_cafe](#), containing tools for **top quark analysis**
- 3 Helped develop other software packages, especially:
 - cafe – CAF base package
 - caf_util – official object selection/treatment
 - caf_mc_util – official MC tools

- A set of utilities for CAF-based top analyses
- Developed this package (from scratch)
- Depends on many other lower level packages – much time was spent collaborating with other package authors, suggesting improvements, etc.

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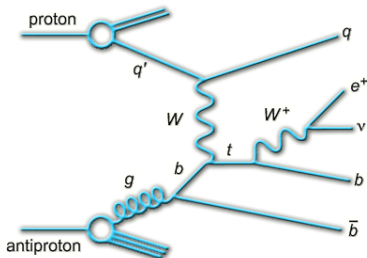
What top_cafe is

- 1 Contains the analysis configuration files – the full analysis chain: event selection, object correction, calculation of topological variables, etc.
- 2 Knows where the “best” available data and MC samples are and their properties
- 3 Knows how to properly apply jet corrections (JES, smearing, etc.) and how to calculate the E_T , apply muon and electron smearing, etc.

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- 4 It became a success!
Heavily used – not only by the top group.



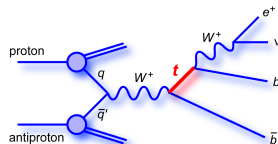
First half of the year

- Produced p17 data and MC samples
- Implemented the single top selection analysis in `top_cafe`
- Spent lots of time improving our understanding and scaling of our background samples – after a few months work we saw a nice agreement between the observed data and our simulated background

Signal and backgrounds samples

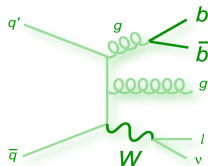
Single top signal, MC

- COMPHEP-SINGLETOP



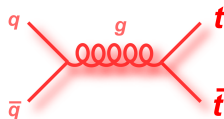
W+jets, MC

- Most difficult background
- Shapes from ALPGEN
- Normalization and heavy flavour fraction from data



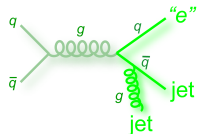
$t\bar{t}$, MC

- ALPGEN
- Normalized to $\sigma_{NNLO} = 6.8$ pb



Multijet events, from data

- misidentified lepton



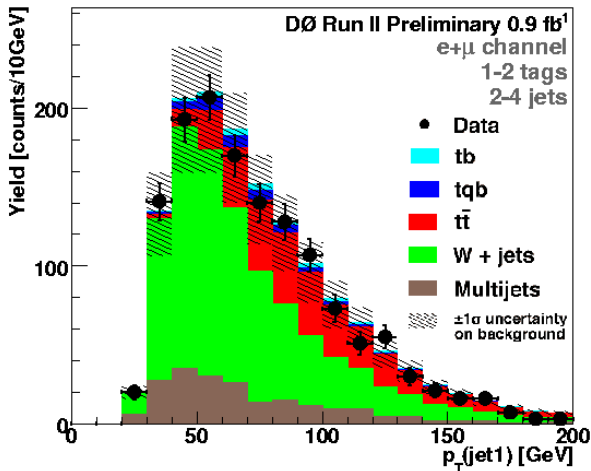
Background modelling

Expected N_{events}

$s + t$ signal	62
$t\bar{t}$	348
Wjj	174
Wbb & Wcc	675
multijet	201

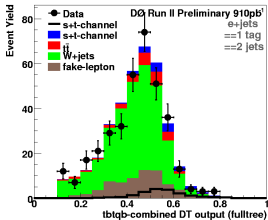
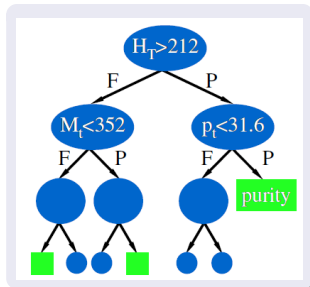
data/bkg N_{events}

signal	62
background	1399
data	1398



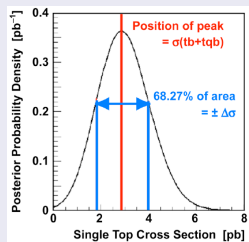
The Decision Tree Analysis

- Single top signal sample trained against our background samples
- Idea: recover events that fail criteria in cut-based analysis
- Separate training per $(l_{ep}, N_{tag}, N_{jet})$ -bin
- **Boosting** – give mis-classified events higher weight and re-train! (20 times)



Decision Tree Output

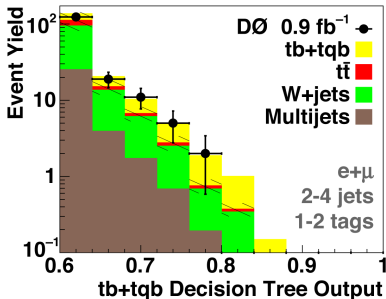
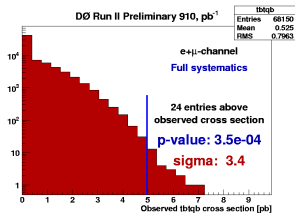
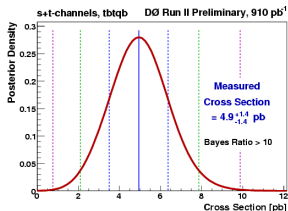
Build posterior $P(\sigma|D) \propto \int_{a,b} P(D|\sigma, a, b) \text{Prior}(\sigma) \text{Prior}(a, b)$



Bayesian posterior

Boosted Decision Tree Found Evidence

$\sigma_{s+t} = 4.9 \pm 1.4 \text{ pb}$
 $p\text{-value} = 0.035\% (3.4\sigma)$ ← Evidence!
SM compatibility: 11% (1.3σ)



RunIIb detector upgrade → higher inst. lum, better tracking
(added new silicon layer) → new data format again (p20)

- 1 Helped with the data production using WestGrid
- 2 Presented last years result at different conferences
(Lake Louise, CAP Saskatoon, Fermilab Users' Meeting)
- 3 Wrote Decision Tree part of the single top PRD, also public
webpage of the Decision Tree result

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- ③ Wrote Decision Tree part of the single top PRD, also public
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- ④ Main author of **vjets_cafe** – same idea as top_cafe, but
extended:

Works with both the new and the old data format (p17&p20)

Used by all electroweak analyses at DØ (Higgs, top, W/Z)

This is what we use for the current single top analysis

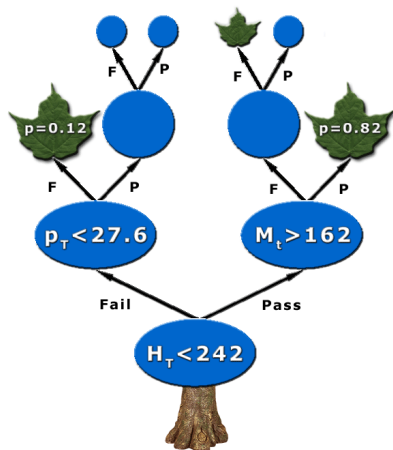
- Last time we had 0.9 fb^{-1} of data, currently we have 2.2 fb^{-1}
- Chance to reach **discovery** (5σ) if we do a good job with the analysis

Single top analysis improvements and problems

- Looser event selection → **higher signal acceptance**, but also **more background** (lower s/b)
- Higher luminosity → **more noise** & need to re-weight MC samples to match observed luminosity profile
- More statistics → problems with MC samples now evident (ALPGEN jet 2 η distribution not wide enough)
- New b -tagging approach
- **Improved Decision Tree analysis** – lots of improvements introduced, working on this right now

Summary

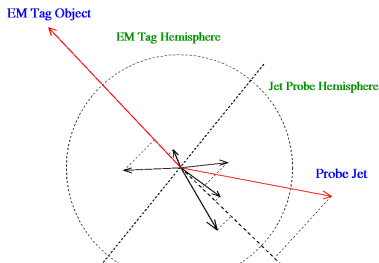
- 1 Background modelling of real data – esp. W +jets, QCD and $t\bar{t}$
- 2 Data-background separation using Boosted Decision Tree
- 3 Analysis software development and coordination



BACKUP SLIDES

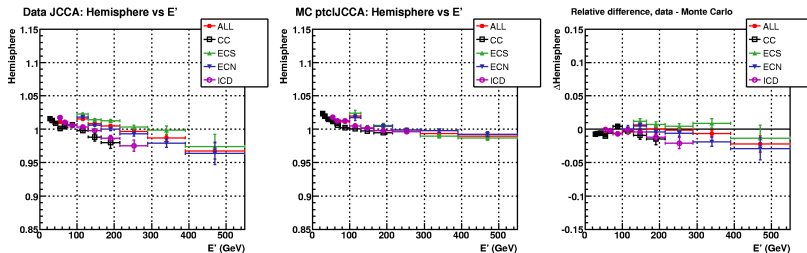
- Joint Undergrad-Masters Physics Engineering Science Program, Lund Institute of Technology, Sweden, 1998-2005
- SFU Exchange Year, 2003-04
- Master's Thesis: "A Study of Jet Response in the DØ Calorimeters"
SFU Thesis Supervisor: Dr. Dugan O'Neil
Lund University Thesis Support: Dr. Paula Eerola
- Defended in Lund, Sweden December 2004 examined by:
Dr. Per Kristiansson, Nuclear Physics Division, Lund Institute of Technology

- Worked on Closure Tests of the first jet energy scale measurement using p17 data
- For closure tests, we compute the imbalance in $\gamma + \text{jet(s)}$ events.
- There are several ways to compute these imbalances, one of the most useful is, the Hemisphere Balance:



$$\mathcal{H} \equiv \frac{\sum_{\text{Probe hemi}} |\vec{p}_T \cdot \vec{n}_{\text{EM}}|}{\sum_{\text{Tag hemi}} |\vec{p}_T \cdot \vec{n}_{\text{EM}}|}$$

- JES Closure results for the 2005 JES



- We see the Hemisphere Balance versus E' – an estimation of the true jet energy
- Left we have data after JES correction, in the middle particle level jets from Monte Carlo, to the right the relative difference.
- Larger cones sizes (0.7) seem to perform better than smaller (0.5).

Second half of the year

- Worked on signal/background separation using Boosted Decision Trees
- Already had experience at SFU (through Yann) using this multivariate technique → got started fairly quickly once we had good data/bkg agreement

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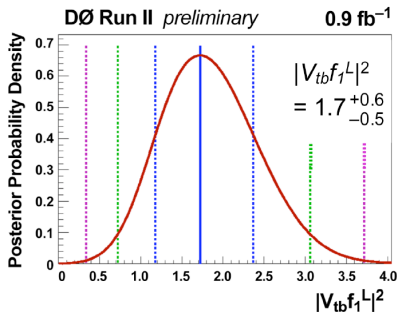
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- Worked on deriving the systematic uncertainties
- Worked on the cross section code (Bayesian approach)
- Worked on ensemble generation – to derive the significance of our result
- Worked on rescaling our background (we had bugs in the generation of our $W + jets$ samples)

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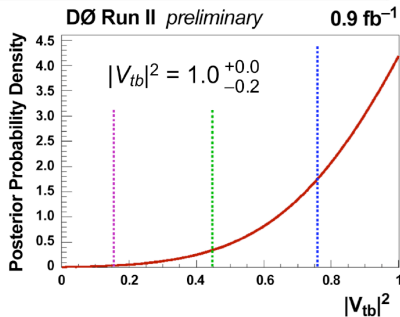
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- Worked on rescaling our background (we had bugs in the generation of our $W + jets$ samples)
- All 3 of us worked night and day, but it paid off in the end... :)

First direct measurement of $|V_{tb}|$

- Assuming $V_{td}^2 + V_{ts}^2 \ll V_{tb}^2$ and pure $V-A$ and CP-conserving Wtb interaction



$$|V_{tb} f_1^L| = 1.3 \pm 0.2$$



$$0.68 < |V_{tb}| \leq 1 \text{ @ 95\% CL}$$

(assuming $f_1^L = 1$,
flat prior in $[0,1]$)

- No assumption about number of quark families or CKM unitarity

First direct measurement of $|V_{tb}|$

■ General form of Wtb vertex:

$$\Gamma_{Wtb}^{\mu} = -\frac{g}{\sqrt{2}} \left(V_{tb} \right) \left\{ \gamma^{\mu} \left[f_1^L P_L + f_1^R P_R \right] - \frac{i\sigma^{\mu\nu}}{M_W} (p_t - p_b)_{\nu} \left[f_2^L P_L + f_2^R P_R \right] \right\}$$

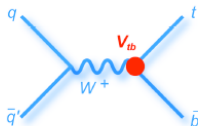
■ Assume

- SM top quark decay : $V_{td}^2 + V_{ts}^2 \ll V_{tb}^2$
- Pure V-A : $f_1^R = 0$
- CP conservation : $f_2^L = f_2^R = 0$

■ No need to assume only three quark families or CKM matrix unitarity

(unlike for previous measurements using $t\bar{t}$ decays)

- Measure the strength of the V-A coupling, $|V_{tb} f_1^L|$, which can be > 1



Additional theoretical uncertainties

	tb	tqb
Top mass	13 %	8.5 %
Scale	5.4 %	4.0 %
PDF	4.3 %	10 %
α_s	1.4 %	0.01 %