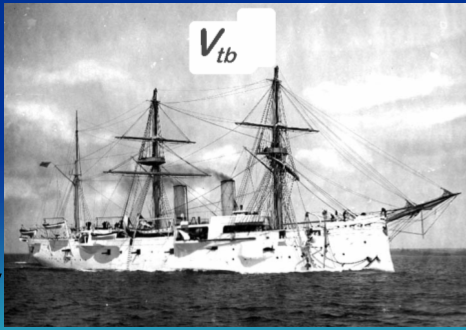
Tevatron Connection

Single-top-quark production

Flagship measurement of Run II



Zack Sullivan

Fermi National Accelerator Laboratory

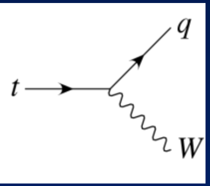
Learning about the *Wtq* vertex

- Measuring $B(t\to Wb)$ only tells us $V_{tb} \gg V_{td}, V_{ts}$

$$\frac{BR(t\to Wb)}{BR(t\to Wq)} = \frac{|V_{tb}|^2}{|V_{td}|^2+|V_{ts}|^2+|V_{tb}|^2} = 0.94^{+0.31}_{-0.24}$$

CDF, PRL 86 (01) 3233

$$\frac{-ig}{\sqrt{2}} V_{tq} \gamma^{\mu} \tfrac{1}{2}(1-\gamma_5)$$



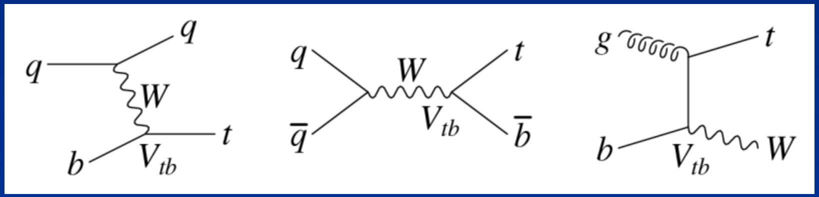
See polarization of top at production (~5 fb^{-1})

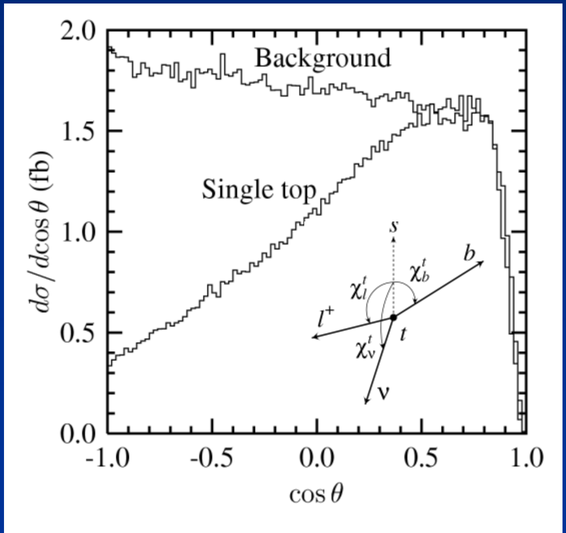
- In the SM $V_{tb} = 0.9991 \pm 0.0001$ (PDG 2004)

Relax Unitarity of CKM matrix

$$\begin{pmatrix} 0.9730-0.9796 & 0.2174-0.2241 & 0.0030-0.0044 \\ 0.213-0.226 & 0.968-0.975 & 0.039-0.044 \\ 0-0.08 & 0-0.11 & 0.07-0.9993 \end{pmatrix}$$

V_{tb}



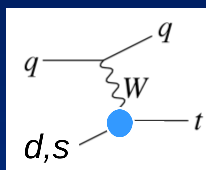


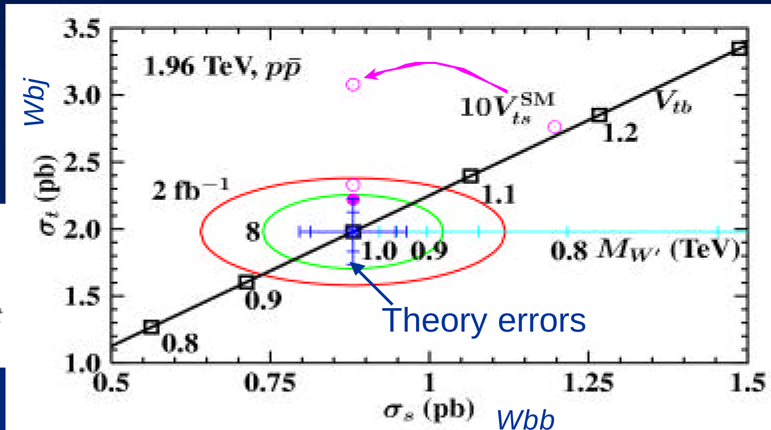
Stelzer, ZS, Willenbrock, PRD 58 (98) 094021

- Single-top cross section proportional to $|V_{tb}|^2$
  - Measure $B(t\to Wb)$ in $t\bar{t}$, extract $\delta V_{tb} \sim \delta\sigma_t/2$ in each channel

Learning about new physics

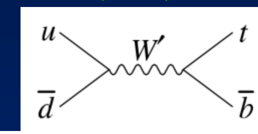
FCNC, V_{td}, V_{ts}

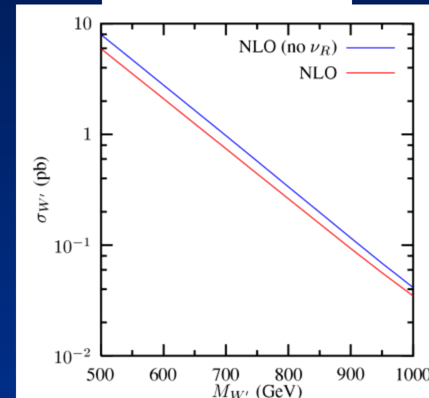


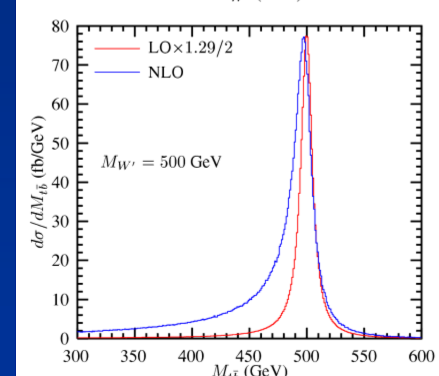


W', π^+_T, W_{KK}, ~~R_p~~ $\tilde{t}$

Simmons; Tait, Yuan (97)



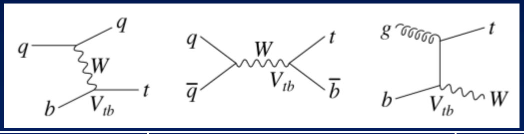




ZS, PRD 66 (02) 075011

- Fully differential NLO W' for arbitrary V, A couplings ZS, PRD 66 (02) 075011
  - CDF Run I: $M_{W'}$>550 GeV (was 420 GeV) PRL 90 (03) 081802
  - Look for resonant peak in *Wbb* invariant mass – same rate for L/R-handed
  - Use spin correlations to tell if W' has left or right-handed interactions
- Run II can reach 800-900 GeV (2 fb^{-1})

Single-top-quark production



	Tevatron Run I	Tevatron Run II	LHC	Dominant Uncertainties
σ_t (NLO)[1]	1.45±0.20 pb	1.98±0.28 pb	247±12 pb	PDFs, δM_t
σ_s (NLO)[1]	0.75±0.10 pb	0.88±0.12 pb	10.7±1.1 pb	$\pm 2.5\% \times \delta M_t$
σ_{tW} (LL)[2]	0.06±0.01 pb	0.09±0.02 pb	56±8 pb	PDFs & scale
Total	**2.26±0.25 pb**	**2.95±0.33 pb**	**314±15 pb**	

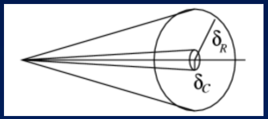
For details see
ZS, hep-ph/0408049

- *s*-/*t*-channel now known fully differentially[1]
  - If M_t = 178.0±4.3 GeV $\rightarrow \sigma_t$ = 1.88±0.27 pb; σ_s = 0.82±0.11 pb
  - First honest PDF uncertainties included above:
    - $\delta\sigma_t = +11\ -8\ \%$; $\delta\sigma_s = +4.7\ -3.9\ \%$

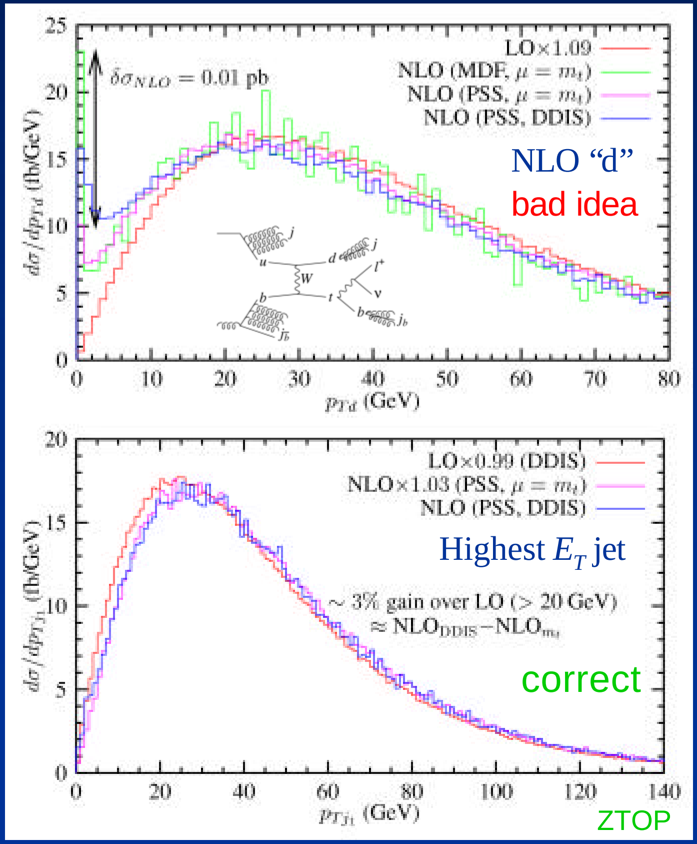
[1] Harris, Laenen, Phaf, ZS, Weinzierl, PRD 66 (02) 054024
[2] Tait, PRD 61 (00) 034001; Belyaev, Boos, PRD 63 (01) 034012

Paradigm of “jet calculations”

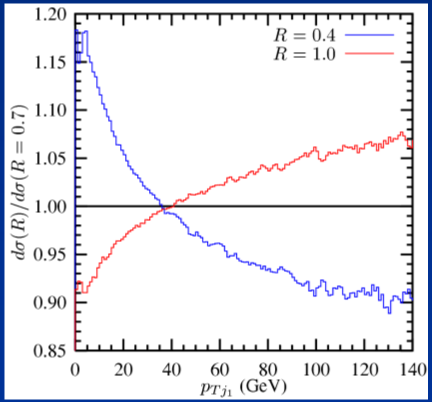
How do we interpret fully differential NLO?



- We are calculating jets <u>not</u> partons
  - Calculations are not well defined w/o a jet definition
- “Bad things” happen if you treat jets as partons



- Choice of jet definition can have a larger effect than all theory uncertainties combined.



Exclusive t +1 jet at NLO

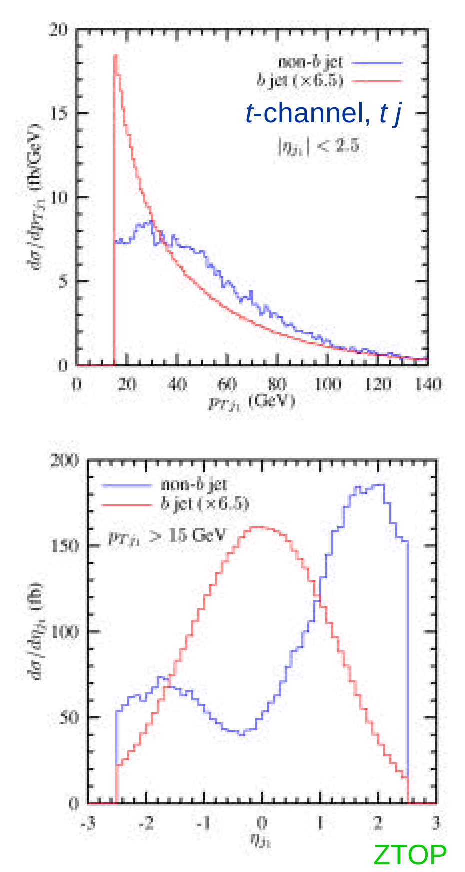
ZS, hep-ph/0408049

# b-jets		$t\,j$ $(W\,j\,j)$	$t\,j\,j$ $(W\,j\,j\,j)$
s-channel	= 2	0.620 pb $^{+13}_{-11}\%$	0.168 pb $^{+24}_{-19}\%$
	= 1	0.022 pb $^{+24}_{-19}\%$	(NNLO)
t-channel	= 1	0.950 pb $^{+16}_{-15}\%$	0.152 pb $^{+17}_{-14}\%$
	= 2	0.146 pb $^{+21}_{-16}\%$	0.278 pb $^{+21}_{-16}\%$

Cuts: E_{Tj}>15 GeV, $|\eta_j|$<2.5, no cuts on t

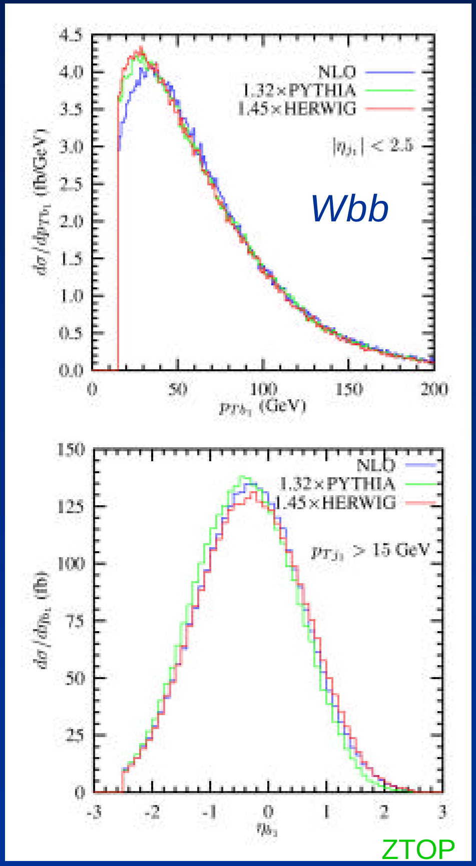
- Cross sections & uncertainties depend on cuts
- Shapes are stable, only normalizations vary
  - s-channel, $t\,b_{\mathrm{NLO}} = 1.54 \times t\,b_{\mathrm{LO}}$
  - t-channel, $t\,j_{\mathrm{NLO}} = t\,j_{\mathrm{LO}}$ if using $m_l = Q^2$, $m_h = Q^2 + m_t^2$

b-jets/non-*b* jets have different distributions

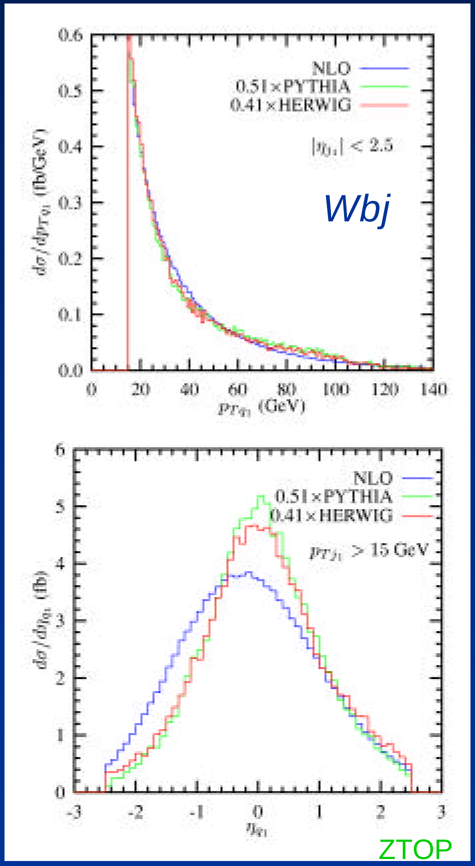


NLO *s*-channel vs. HERWIG/PYTHIA

- LO × 1.54 great approx. for *Wbb*, using $\mu = M_{tb}$



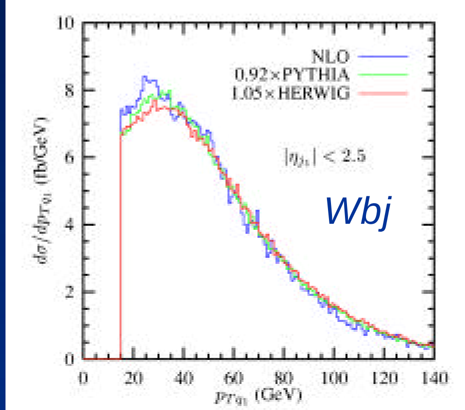
- HERWIG/PYTHIA use too small a scale ($< M_W$)
  - too much radiation
  - *Wbb* underestimated by factor of 1.4
  - *Wbj* and *W+3j* over-estimated by factor of 2
  - Background to *W*-Higgs ×1.4 as well
- Feed LO events from MadEvent/CompHEP into HERWIG/PYTHIA and normalize to NLO

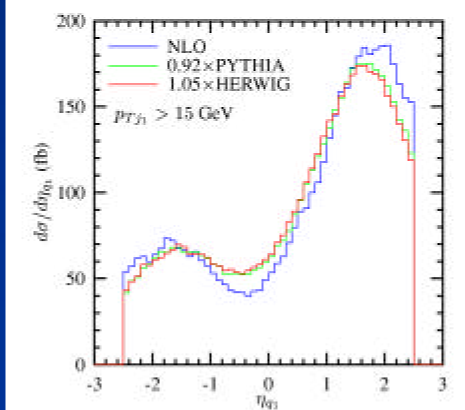


ZS, hep-ph/0408049

NLO *t*-channel vs. HERWIG/PYTHIA

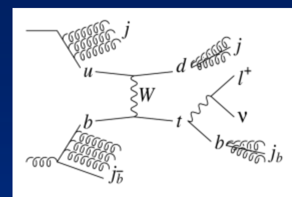
- LO ≈ NLO, using $\mu_l = Q^2$, $\mu_h = Q^2 + m_t^2$ (double-DIS)



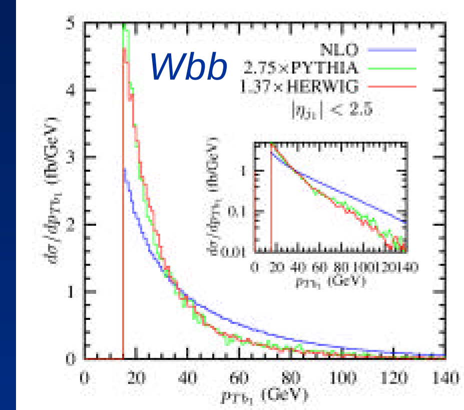


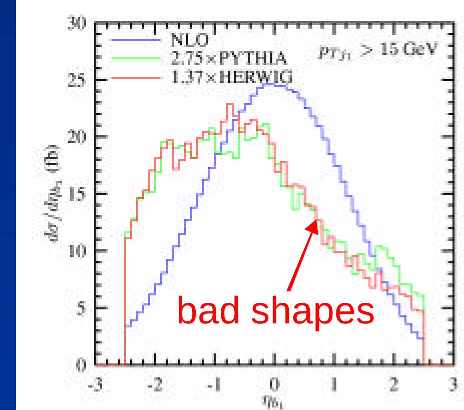
- HERWIG/PYTHIA *Wbb* 1/3 of LO prediction

Both use



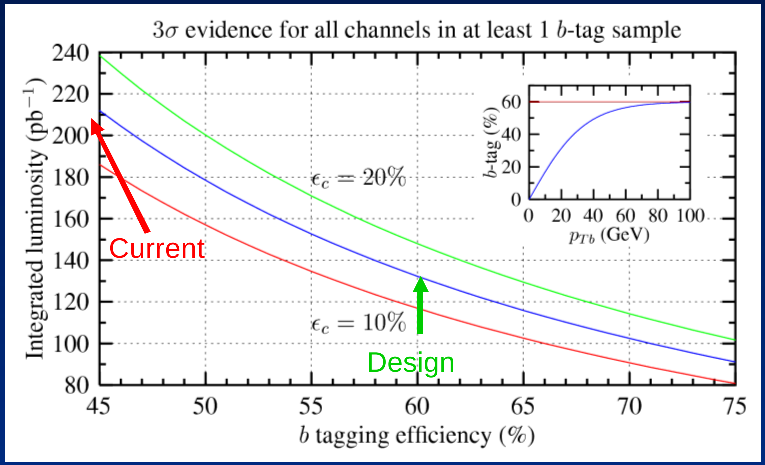
  - IS radiation is too soft and forward, miss hard *b*
  - Background to *W*-Higgs ~3 times larger as well
- Feed LO events from MadEvent/CompHEP into HERWIG/PYTHIA and normalize to NLO *tj, tb, tjj, tbj* samples.





ZS, hep-ph/0408049

Phenomenological Observations



- Lower E_{Tj} thresholds from 20-30 GeV → 15 GeV.
  - 1.5x improvement in signal
- $|\eta_{e,\mu}| < 1 \rightarrow |\eta_{e,\mu}| < 2$
  - 1.5x improvement in signal
  - Is there a clever way to improve range in $|\eta_\mu|$ for CDF?
- *b*-tagging has room to grow: 30-40%/*b* → 60%/*b*
  - 2.5x improvement in signal
  - This is central to finding new physics: *H, SUSY, W′, Z′*, …
  - Remember single-top is a large component of the *Wbb* background
- Jet-energy resolution limits cut on $M_t(bl^+\nu)$, currently ±35 GeV → ±20 GeV
  - 1.8x drop in *Wjj* background
  - Hurts MET from calorimeter
  - A larger cone size may lower out-of-cone uncertainties, and increase signal.

Conclusions

- Single-top-quark theory is in great shape
  - A description of NLO kinematic distributions, uncertainties, and matching to HERWIG/PYTHIA is in ZS, hep-ph/0408049
    - δM_t dominates uncertainties right now, PDFs are right behind
    - If M_t = 178.0±4.3 GeV $\rightarrow \sigma_t$ = 1.88±0.27 pb; σ_s = 0.82±0.11 pb
    - If Run II design goals met , we will know V_{tb} ~±7-9% with 2-4 fb^{-1}
  - Computational tools:
    - ZTOP (spin-averaged NLO based on PRD 66 (02) 054024)
    - HERWIG/PYTHIA (use MadEvent/CompHEP as inputs, match to NLO)
    - MCFM (will add on-shell top decay code, available ~ Oct.)
    - ONETOP (LO + threshold resum, D0 version ≠ Mrenna/Yuan)
- Twice as much data is on tape waiting to be analyzed — push for discovery, not limits!
- What else can we do to help?