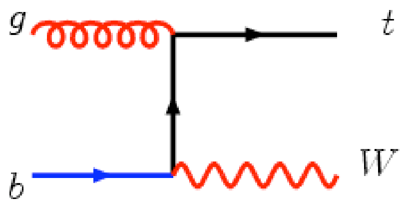
# tW: definition and measurement at the LHC

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work in progress in collaboration with
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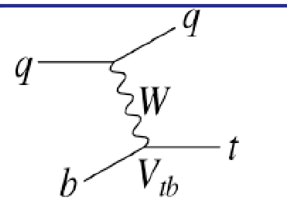
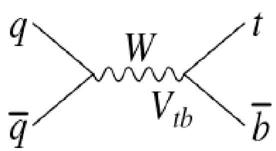
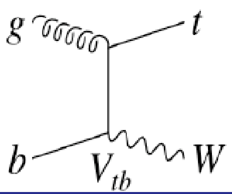
**International Workshop on Top Quark Physics,** Jan 12-15, 2006 Coimbra, Portugal

# Outline

- W-associated production: the cinderella of the single-top processes
- Towards a consistent and practical definition
- Strategies for measurement of $\sigma$ and extraction of $V_{tb}$
- Conclusions and Outlook

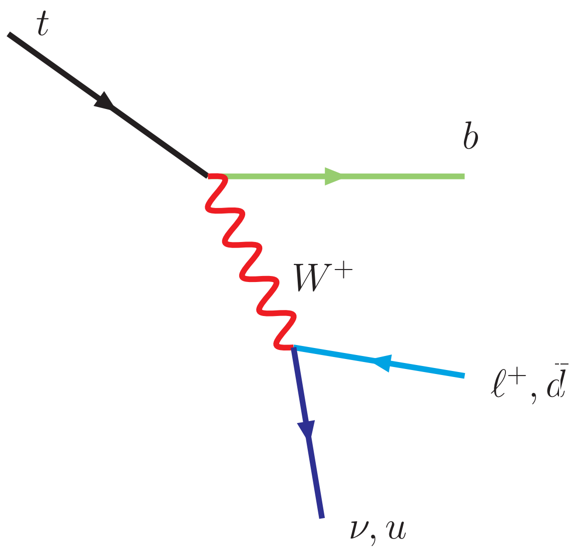
# Single top

| Process | Diagram | Accuracy | CTEQ6M, mt=178 GeV,th err<10% σ (pb) | |
|---|---|---|---|---|
| | | | TeV II | LHC |
| t-channel |  | NLO [Stelzer, Sullivan, Willenbrock. 1997] | 1.85 | 239 |
| s-channel |  | (N)NLO [Smith, Willenbrock. 1996 Chetyrkin, Steinhauser. 2001] | 0.82 | 9.8 |
| tW |  | NLO [Campbell, Tramontano. 2005] | 0.129 | 64 |

All signals available in MCFM (Campbell, Ellis) and t- and s-channel now in MC@NLO (Frixione, Laenen, P. Motylinsky, Webber). Most of the backgrounds are also known at NLO. However, analysis still rely on LO calculations for the heavy-quark fractions in W+jets events (largest background) ⇒ room for improvement.

See A. Giammanco's talk on Saturday

# Top decay: sm br's




Top can decay into a real W ⇒

$\Gamma \approx G_F m_t^3 |V_{tb}|^2 >> \Lambda_{QCD}$ ⇒

Very short life. Top is the only quark that does not feel non perturbative QCD effects! No top-hadrons, no top-spectroscopy but a ``clean'' quark.

In an experiment one is sensitive not to the total width but to the branching ratio:

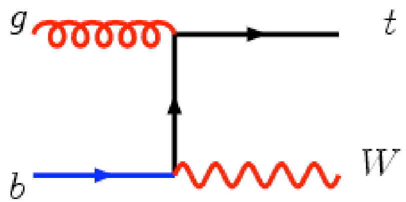
$$R = \frac{\Gamma(t \to Wb)}{\Gamma(t \to Wq)} = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2}$$

CDF has performed such a measurement:
R=0.94 does only tell us that $V_{tb} >> V_{td}, V_{ts}$

# A closer look to tW

The Cinderella of the three channels. Not studied as much as s- and t-channel.

It's the only single top process where we directly see the W.

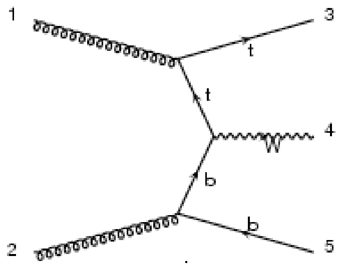



Tiny at the Tevatron, sizeable at the LHC.

With tt, it is an important background for gg→H→WW
(See talk by M. Zanetti on Saturday)

Background to gb>tH+
(See talk by J. Alwall later)

Problem:
Two ways of thinking about it: 4f scheme (gg>tWb) or the 5f scheme (gb>tW). In this second case large logs are resummed into the PDF. Both schemes have to deal with the problem that tW mixes with tt. A consistent and MC friendly solution necessary to avoid double counting and define tW.



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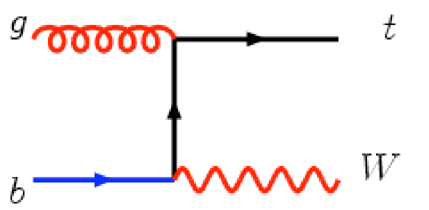


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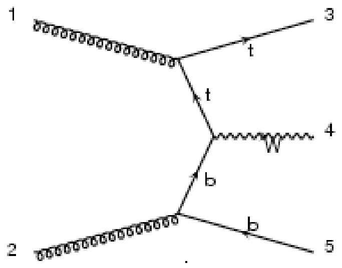
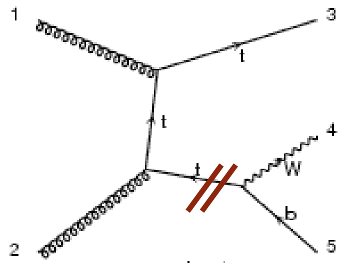
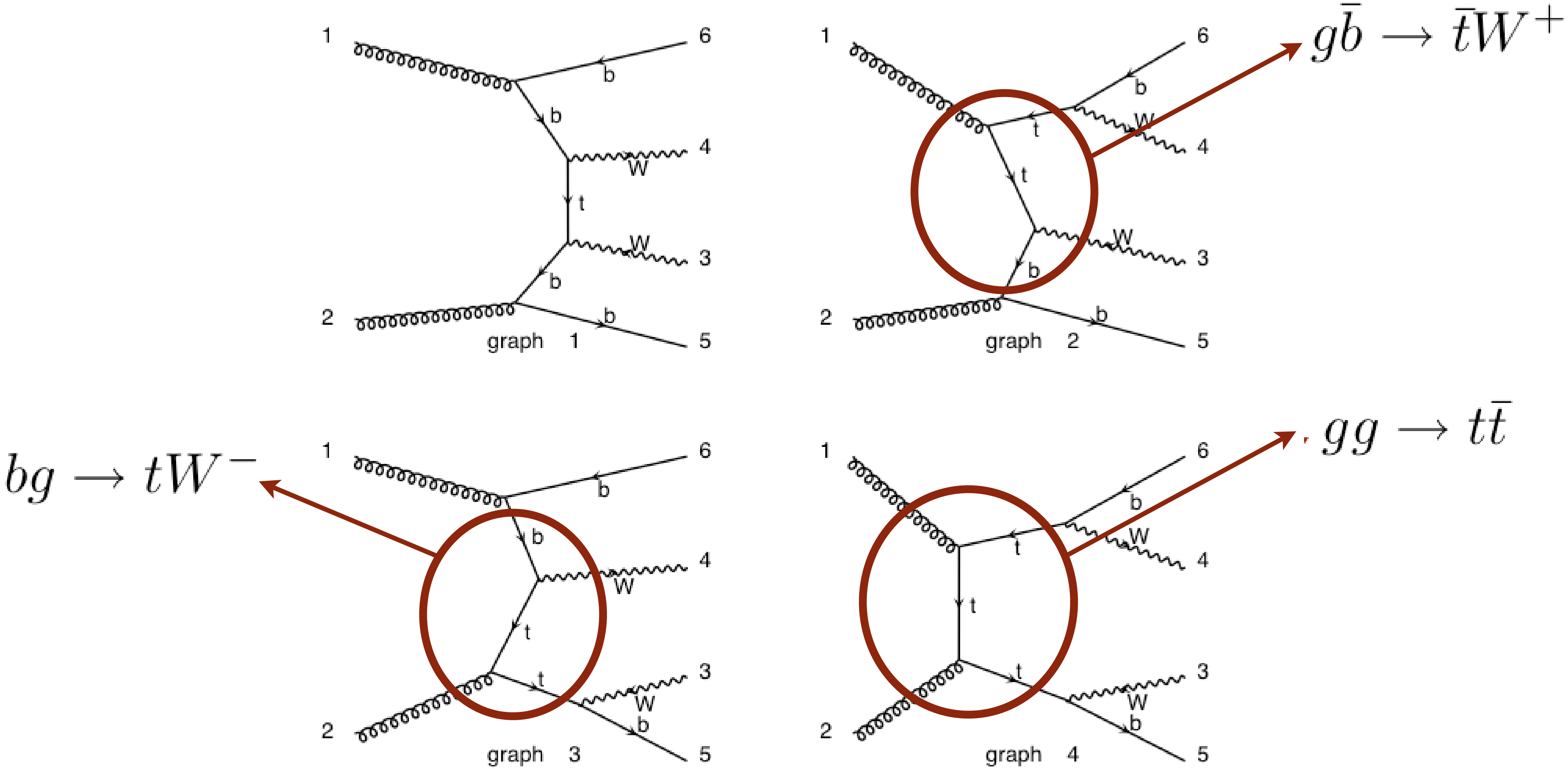


# tW and tt as backgrounds

$$pp \rightarrow W^+W^-b\bar{b}$$



# tW and tt as backgrounds

[Kauer and Zeppenfeld, 2002]

USE: $pp \to W^+W^-b\bar{b}$

- The complete set is gauge invariant (e.g. overall width scheme)
- Double-resonant, single-resonant, non-resonant diagrams are present.
- Interference is correctly included
- tW and tt are "not physical" but just QM amplitudes that interfere (ok only for bkg definition but not for tW as a process on its own).

BUT

☹ Intrinsically LO. Difficult to improve. NLO corrections are not known.

☹ Large logs of M/mb develop when b's are not required at high pt, which spoil the perturbative picture.

# tW signal: available approaches

Aim:
Avoid double counting
1. in a gauge invariant way
2. in a event generator friendly way

Available proposals are not completely satisfactory:

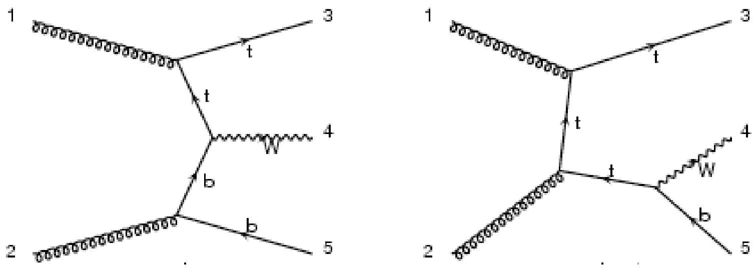
Tait (2000) : zero width limit, analytic approach, gauge invariant:

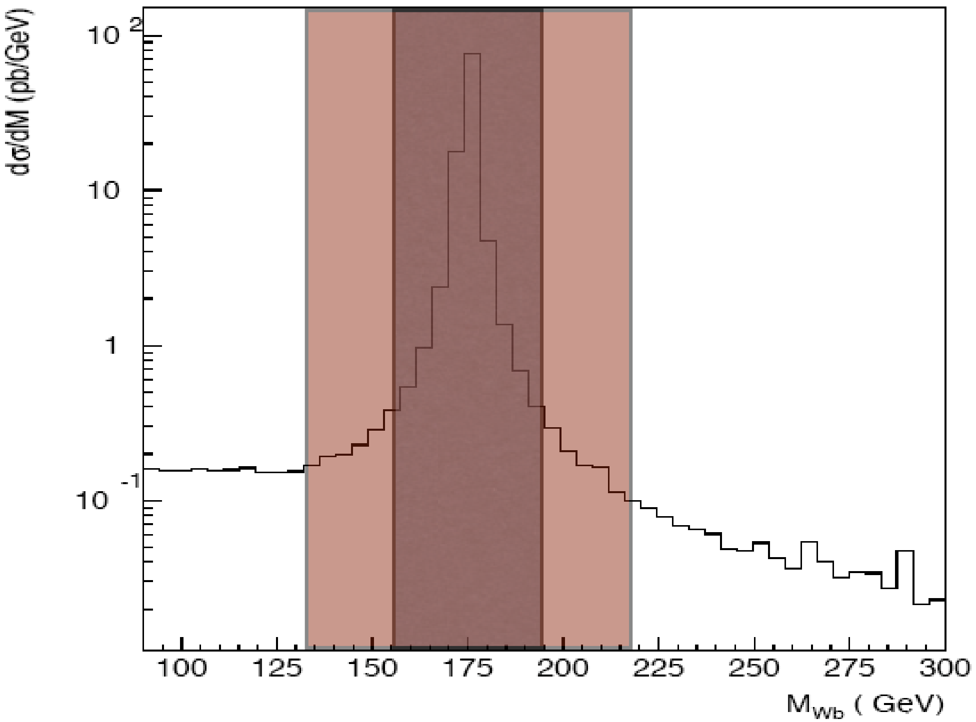
$$\sigma(gg \to tWb)_{singletop} = \sigma(gg \to tWb)_{total} - \sigma(gg \to t\bar{t}) * Br(t \to Wb) - interf[t\bar{t} \otimes tWb],$$

Consistent approach but not useful for
event generators (cross section is not positive definite).

Interference term does not allow a clear separation between tt and tW,
unless can be shown to be negligible

# tW signal: available approaches




Belyaev and Boos (2001)

suggested to use
a mass window of about
12 Γtop so to reproduce the
Tait's zero-width result and
have a generator friendly definition.

The problem is that the size of the window, at fixed width, depends on the interference term leading to a gauge dependence.

The interference term is rouhgly -50% of the tW cross section, even though it is a $\Gamma_t/m_t$ effect.

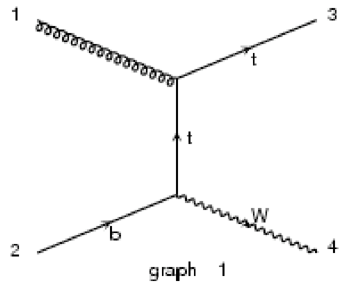
Invariant mass is not a good discriminating variable!

Solution: use the pt of the b's!

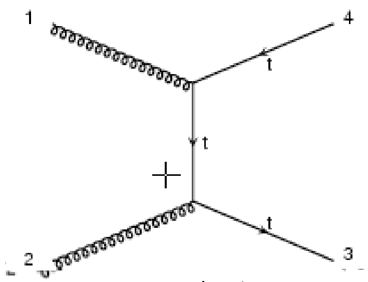
# A simple solution

- Use tt at NLO and gb→tW at NLO, but consistently leave out the $\alpha_S^2 \alpha_W$ terms

IN




+




$\alpha_S^2 \alpha_W \log \dfrac{M}{m_b}$

$\alpha_S^2$

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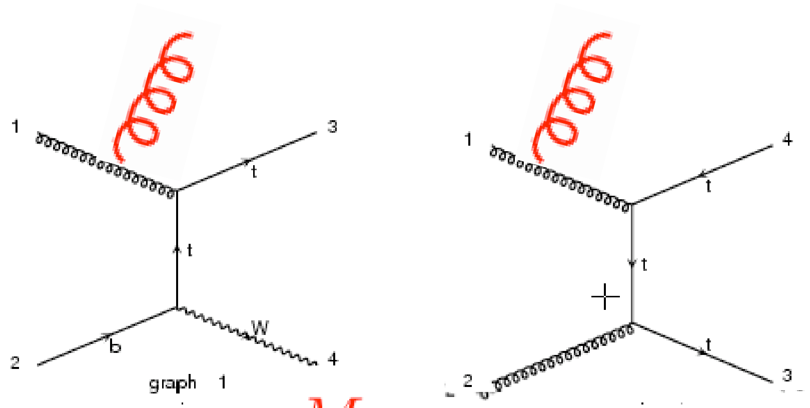


$\alpha_S^2 \alpha_W \log \frac{M}{m_b}$ $\qquad$ $\alpha_S^2$

$+\alpha_S$ corrections

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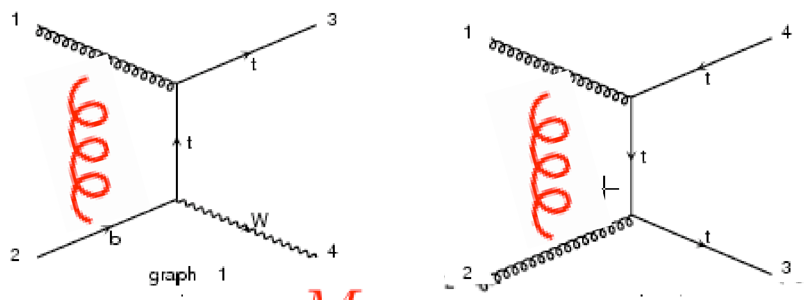


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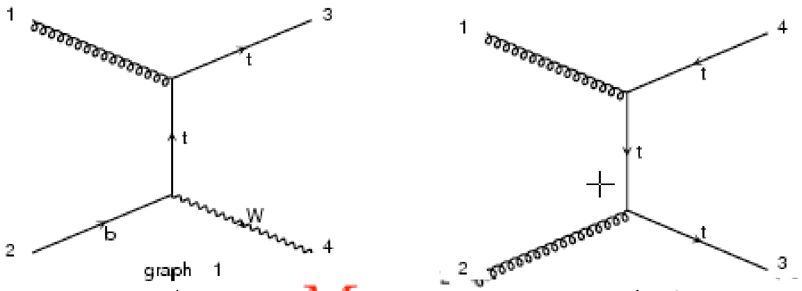


$+\alpha_S$ corrections

$$\alpha_S^2 \alpha_W \log \frac{M}{m_b} \qquad \alpha_S^2$$

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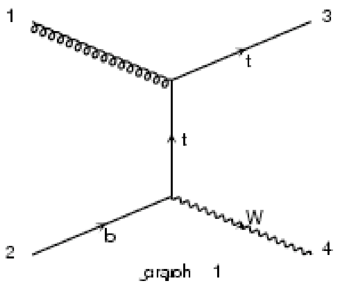
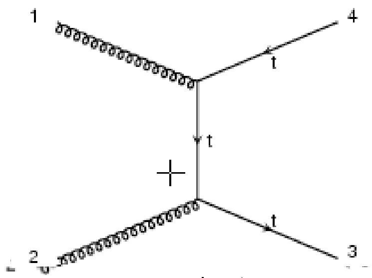


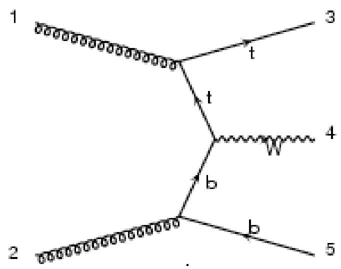



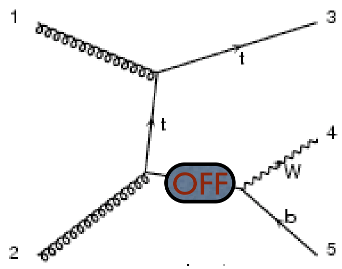

$+\alpha_S$ corrections

$$\alpha_S^2 \alpha_W \log \frac{M}{m_b}$$

$$\alpha_S^2$$

OUT




$$\alpha_S^2 \alpha_W$$

# A simple solution

- Use tt at NLO and gb→tW at NLO, but consistently leave out the $\alpha_S^2\alpha_W$ terms.
- This calculation with $\mu_F \cong p_T$ veto is the NLO

  prediction for the experimental signature of tW where one and only one b-jet is allowed.

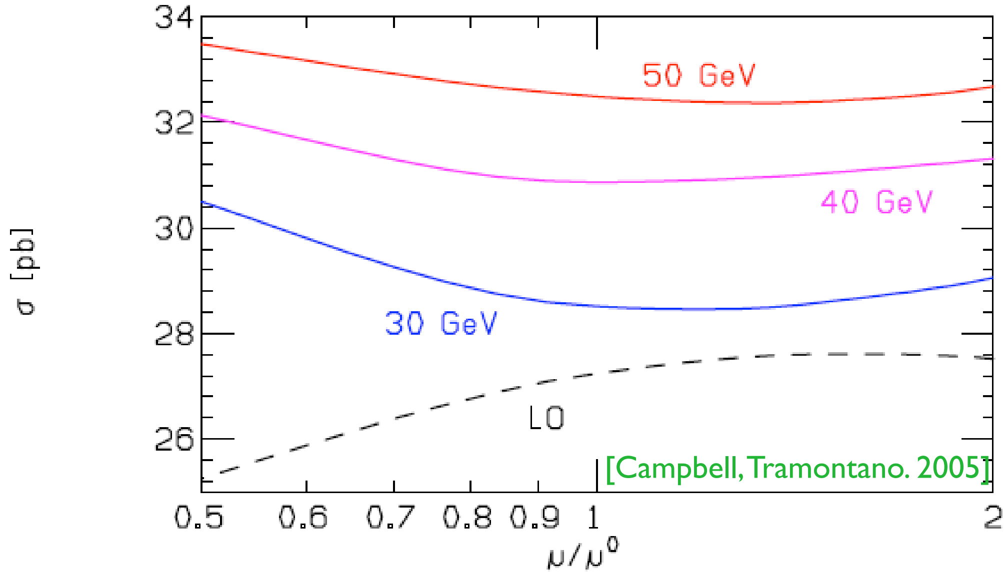
## Advantages

1. Trivial implementation in the NLO calculation
2. Direct physical intepretation (the same as the jet veto)
3. No interference problem
4. No gauge-invariance problem
5. Available

Works equally well for tW as a signal or as a background!

# NLO Results

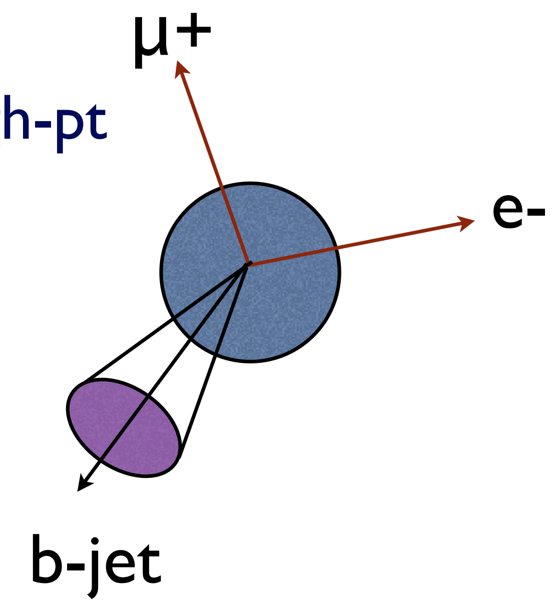
- With a b-jet veto and the right scale choice what is left out is a very small correction
- Check: tW-tt interference is negligible when a b-jet veto is included.
- NLO calculation is stable and predictive




$p_T(b) < pt_{veto}$

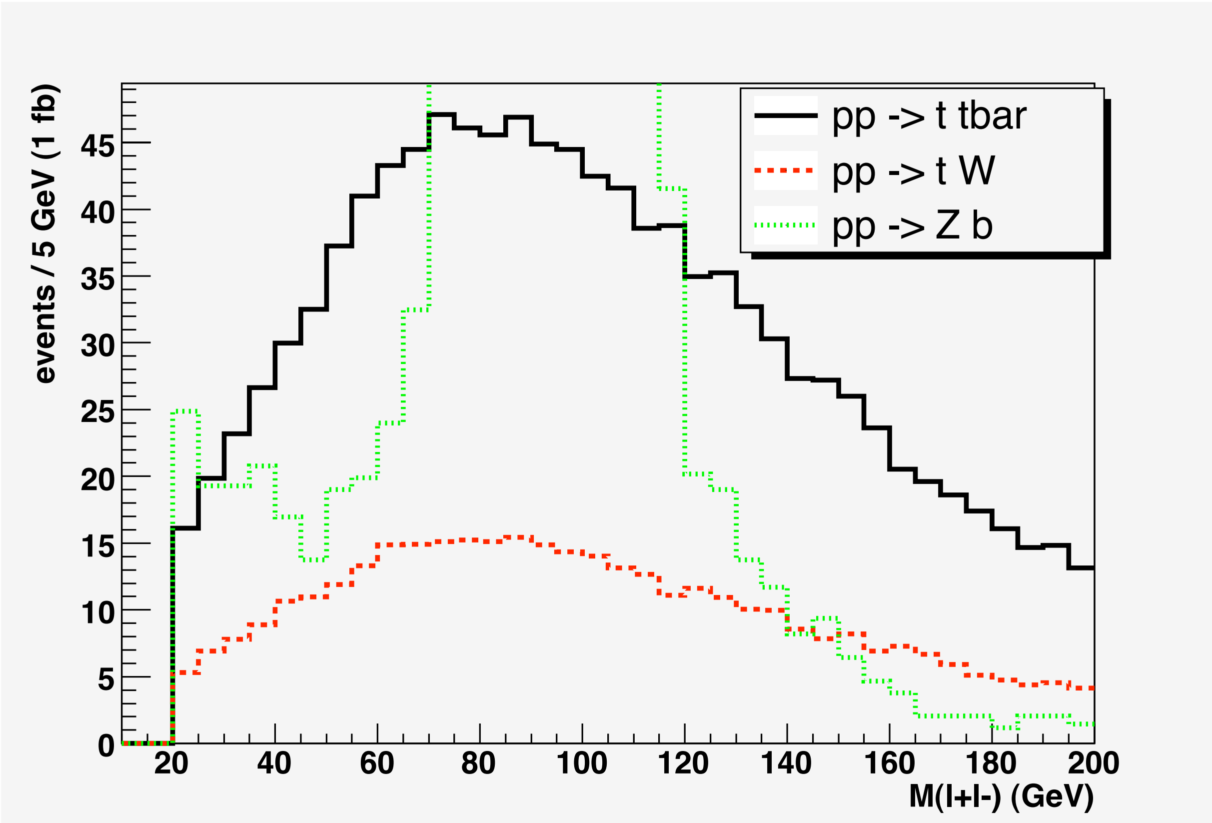
# The strategy in a nutshell

Signal definition:
2 different-flavor opposite-sign leptons at high-pt
+1 and only one b-jet. Inclusive or not (?).




Backgrounds:
tt: dominant
WWb,WWj: negligible
Wbb:reducible when b→e or μ +X

# m(l+l-) distribution




MadGraph+Pythia w/ NLO normalization.
Basic cuts (inclusive: only extra-b's vetoed, see table).
LO and NLO shapes are quite similar (more complete study is on-going).
tW and tt shapes are close: it's a counting experiment!

# The strategy in a nutshell

Signal definition:

2 different-flavor opposite-sign leptons at high-pt
+1 and only one b-jet. Inclusive or not (?).

Backgrounds:

tt: dominant
WWb,WWj: negligible
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Normalization and control samples:

tt: normalized to the 2b-jet sample
Zb: can be used to reduce the PDF uncertaintes, by calculating σ(gb→tW)/σ(gb→bZ). Also study the contamination from b→e or μ +X. This is known at NLO [Campbell, Ellis, FM,.Willenbrock, 2004]
tW: same flavor sample can be included in the analysis by adding an m(ll) cut and/or a missing Et cut.

# Reference numbers

| Process<br>cross sections in fb | LO | NLO<br>exclusive* | NLO<br>inclusive* |
|---|---|---|---|
| tW | 428 | 184 | 420 |
| tt | 1120 | 338 | 1314 |
| Zb | 9440 | 8660 | 12200 |

Both $tW^-$ and $\bar{t}W^+$ included.
Branching ratios to one lepton flavor included.
leptons: pT>20 GeV, |eta|<2.5
b-jet:pT>30 GeV, |eta|<2.5 (one b-jet required)
veto: pT>30 GeV, |eta|<4.5

$S/B \cong 1/3$

$\sqrt{S+B}/S \cong$ 2% with 10 $fb^{-1}$
"theoretical" limit

*one b-jet is always required. In the exclusive case all other jets are vetoed, in the inclusive case only extra b-jets are vetoed.

≥

# Work in progress

- Compare the inclusive and exclusive approaches in detail: theoretical errors assessed.
- In the exclusive case one has to rely on a PS approach to describe soft radiation, leading to normalization and shape dependencies (A MC@NLO approach would be auspicable).
- Systematic comparison of NLO and MadGraph+PS distributions.
- Evaluation and reduction of systematic theoretical errors, such as scales and PDF, by using NLO calculations and reference samples (i.e., tt, with 2 high-pt b's).
- For experimentalists: estimation of the irreducible bakgrounds.

# Conclusions & Outlook

- Single top processes are among the most attractive SM studies at TeV and LHC.
- The only direct access we have to $V_{tb}$.
- W associated production deserves special attention:
  - It is the only single-top process where will we actually "see" the W.
  - Its theoretical definition is delicate: need to be sure that it is consistent and experimentally viable (=physical).
- A new approach has been presented, where NLO corrections can be computed consistently and compared with data.
- Preliminary "theoretical" analysis is in progress and seems very promising.
- More experimental work on tW is certainly welcome...

# Refs and thanks

Tim Tait:
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Phys.Rev. D61 (2000) 034001

A. Belyaev & E. Boos:
"Single Top Quark TW+ X Production At The Lhc: A Closer Look",
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"Finite Width Effects In Top Quark Production At Hadron Colliders",
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"Next-To-Leading Order Corrections To Wt Production And Decay",
Nucl.Phys. B726 (2005) 109

Thanks to the CP3 gang!