SINGLE TOP STUDIES WITH MCFM

F. Tramontano

Università di Napoli “Federico II”

and INFN sezione di Napoli

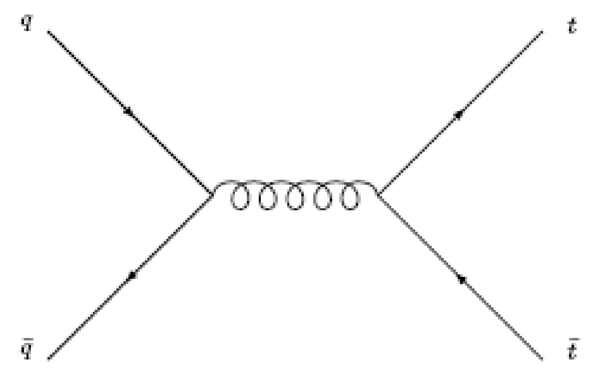
in collaboration with J. Campbell and R.K. Ellis

Munich

DIS 2007

Introduction

- The top quark has been discovered at Tevatron through the strong process of pair creation



6pb at Tevatron

720pb at LHC

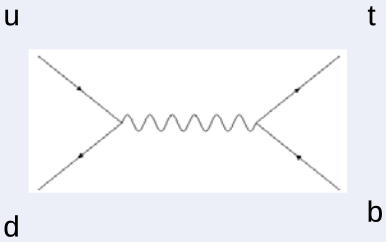
- Single top can be produced only weakly through the W-t-b vertex
- Evidence for single top allows new tests of the Standard Model
- The study of single top events passes from the search for their observation at the Tevatron to their study as a significant source of background events in new physics searches at the LHC

Total cross-sections

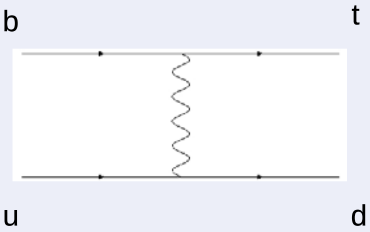
b-pdf dependent

	Tevatron(pb)	LHC(pb)
s-channel	0.89	10
t-channel	1.98	240
top-W associated production	0.14	66

s-channel



t-channel

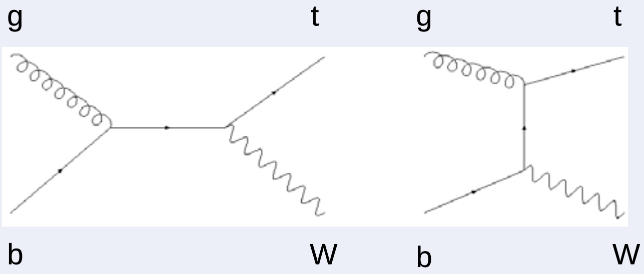


Evidence

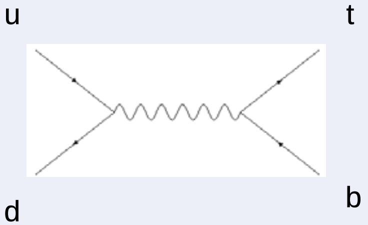
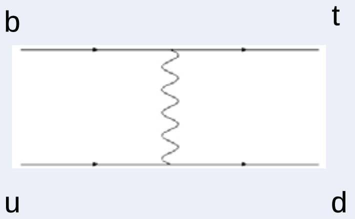
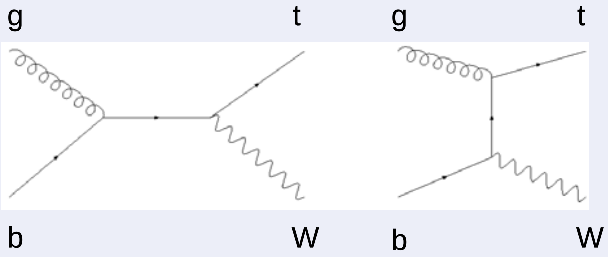
s+t channel

$\sigma = 4.9 \pm 1.4$ pb

top-W associated production

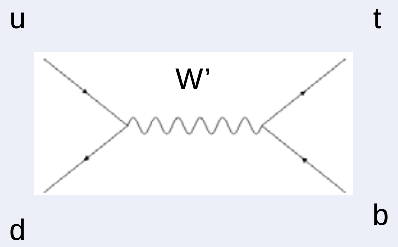


Standard Model physics

	Tevatron	LHC
s-channel  t-channel 	Evidence for the Wtb weak vertex, Direct measurement of Vtb $0.68 < \|V_{tb}\| \leq 1$	backgrounds for HW → b anti-b W
top-W associated production 		Evidence for the Wtb weak vertex, background for H→WW

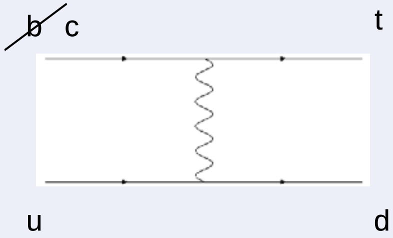
Physics beyond the Standard Model

s-channel



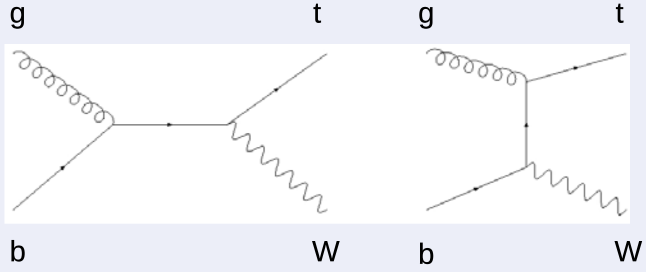
Sensitive to heavy W', charged H, new exotic charged bosons

t-channel



sensitive to FCNC

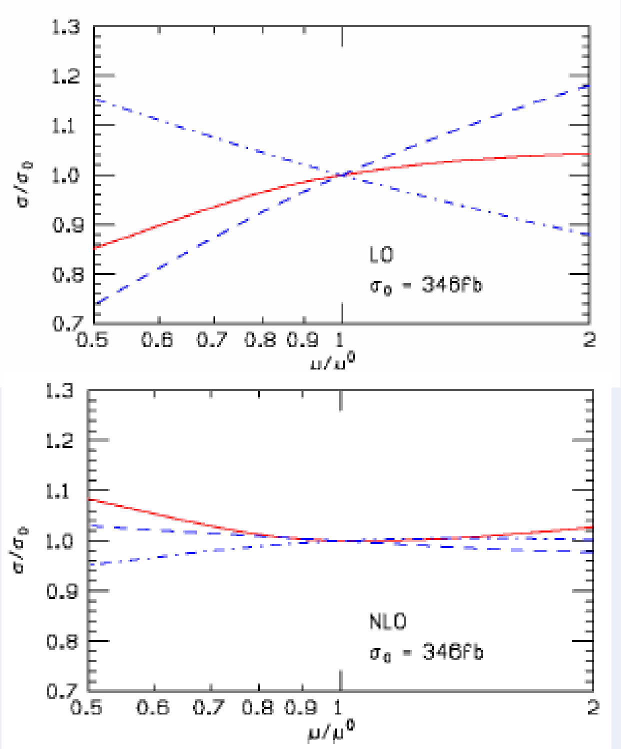
top-W associated production



sensitive to anomalous Wt couplings

Motivation for NLO calculation

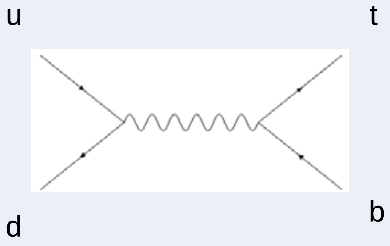
- Although some information can be extracted from Born level calculations, the first serious approximation in QCD is obtained by including $O(\alpha_S)$ radiative corrections
- Only at next to leading order we obtain accurate predictions of event rates that are sensitive to the structure of jets in the final state
- Next to leading order calculation give important information about the choice of factorization (dashed) and renormalization (dot-dashed) scales



Wt

Previous single top NLO results

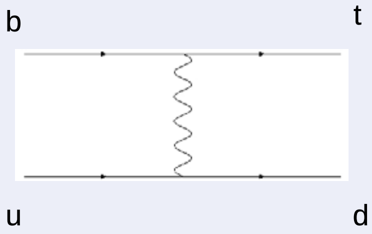
s-channel



Inclusive s-channel:

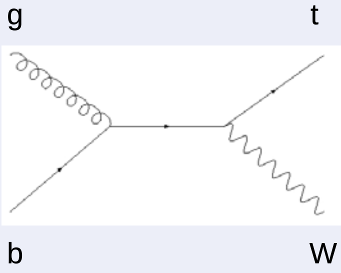
Smith and Willenbrock (1996).

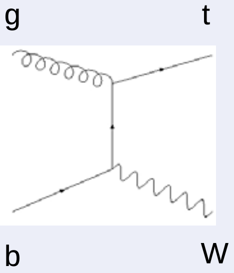
t-channel



Inclusive t-channel:
Bordes, B. van Eijk (1995)
Stelzer, Z. Sullivan, and S.Willenbrock (1997)
Differential:
Harris, Laenen, Phaf, Sullivan and Weinzierl (2002), Sullivan(2004)

top-W associated production





Study of the Wc channel at NLO
(Giele, Keller, Laenen)

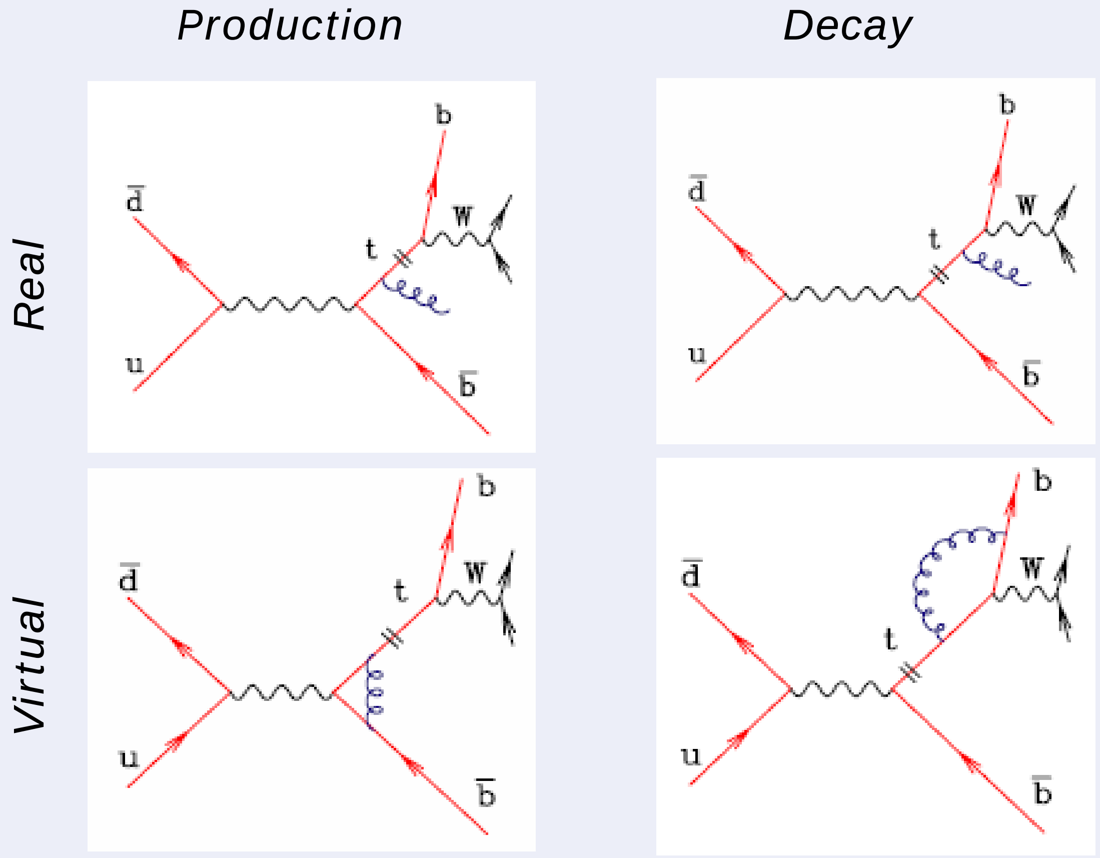
Inclusive Wt:
Zhu, 2002, no decay of W and top and
no program available

Calculation

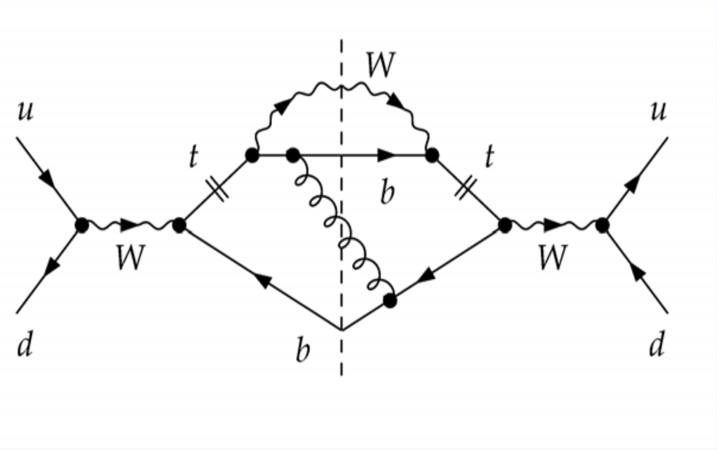
For all the 3 single top channels:

- ❑ We extend the previous program including the leptonic decay of the top quark with full spin correlation
- ❑ We also consider the effect of the gluon radiation in the decay of the top

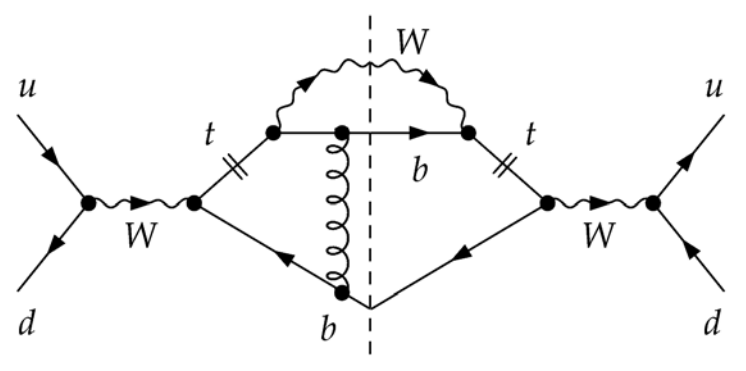
- We work in the on-shell approximation for the top quark: every diagram considered has 1 top quark exactly on its mass shell (double bars)
- Diagrams without an on-shell top quark are suppressed by Γ_t/m_t (~1%)



- Neglect interference between radiation in the production and decay stages



Real interference



Virtual Interference

Physical reason:

- Different characteristic time scales for Production ($1/m_t$) and Decay ($1/\Gamma_t$)
- The two stages are separated by a large time
- The interference average to zero

Caveat

- ❑ Soft gluons potentially dangerous for this argument
  - time scale not confined to a time of order $1/m_t$ -
- ❑ Soft radiation phase space is limited
  - resonant propagator and $E_g < \Gamma_t$ -
- ❑ Because of the cancellation of real and virtual radiation the region of soft radiation is not especially privileged
- ❑ For infra-red safe variables these interference effects are expected to be of order $\alpha_s\Gamma_t/m_t$ (few %)

Fadin, Khoze and Martin (1994), Melnikov and Yakovlev (1994)

Confirmation

- ❑ s-channel process, Pittau (1996)
- ❑ $e^+e^- \rightarrow t\,\overline{t}$ including the sunsequent decay of the top quarks, Macesanu (2002)

In MCFM J. Campbell and R.K.Ellis

- ❑ Cancellation of soft and collinear divergences is performed using the subtraction method with massive quark Catani, Dittmaier, Seymour and Trócsányi (2002)
- ❑ Following Nagy and Trócsányi (massless case) we have introduced a tunable parameter (α) to control the size of the subtraction

$\alpha = 1$ corresponds to the dipole formulas in Catani et al

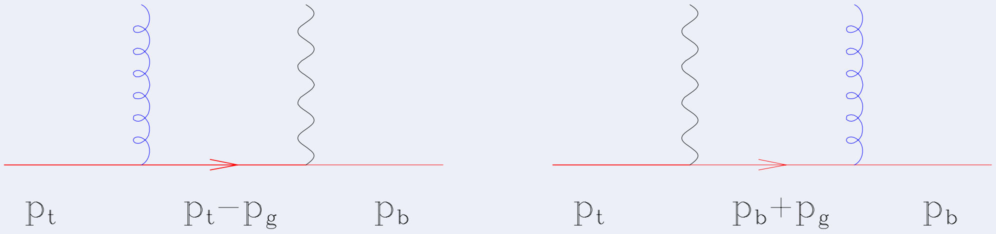
$\alpha < 1$ corresponds to calculate the subtractions into a smaller phase space region around the singularities

1. quicker calculation (subtractions are calculated only where they are needed)
2. independence from α is a valuable check of the implementation
3. reduced mismach between reals and subtractions

- ❑ An extention of the method to all the massive dipole formulas has been performed

Subtraction for radiation in top decay

Real corrections:



- Require a counterterm that has the same soft and collinear singularities as the full matrix element

$$|\mathcal{M}(\cdots p_t, p_W, p_b, p_g)|^2 \to |\mathcal{M}_0(\cdots p_t, \tilde{p}_W, \tilde{p}_b)|^2 D(p_t\cdot p_g, p_b\cdot p_g, m_t^2, M_W^2)$$

- $\tilde{p}_b$ and $\tilde{p}_W$ are defined in such a way to absorb the four-momentum carried away by the gluon

$$p_t = p_b + p_W + p_g = \tilde{p}_b + \tilde{p}_W \qquad \tilde{p}_b{}^2 = 0 \quad \tilde{p}_W{}^2 = p_W{}^2$$

- We define $\tilde{p}_W$ by a Lorentz boost so that the phase space for the subsequent decay of the W is unchanged, and obtain $\tilde{p}_b$ from top momentum conservation above

Usefull for tt also

$$\tilde{p}_W = \alpha\left(p_W - \frac{p_t\cdot p_W}{p_t^2}p_t\right) + \beta p_t$$

$$\alpha = \frac{p_t^2 - p_W^2}{2\sqrt{(p_t\cdot p_W)^2 - p_W^2 p_t^2}} \qquad \beta = \frac{p_t^2 + p_W^2}{2p_t^2}$$

S/B analisys with MCFM

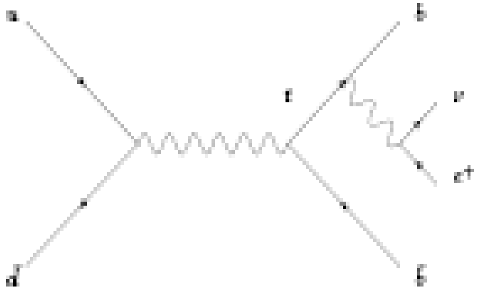
- **Signal** at Tevatron calculated at $\sqrt{s} = 1.98TeV$

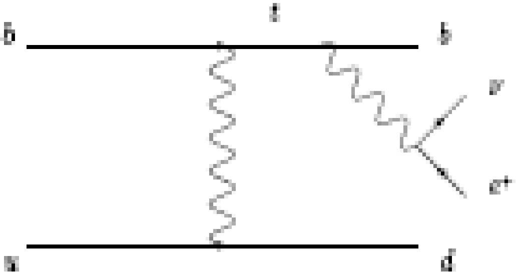
By assuming:

$$p_T^e > 20\,\text{GeV}, \qquad |\eta^e| < 1.1, \qquad \not{E}_T > 20\,\text{GeV}, \qquad \Delta R^{jj} = 1.0,$$

$$p_T^{jet} > 15\,\text{GeV}, \qquad |\eta^{jet}| < 2.8, \qquad 140\,\text{GeV} < m_{bl\nu} < 210\,\text{GeV}$$

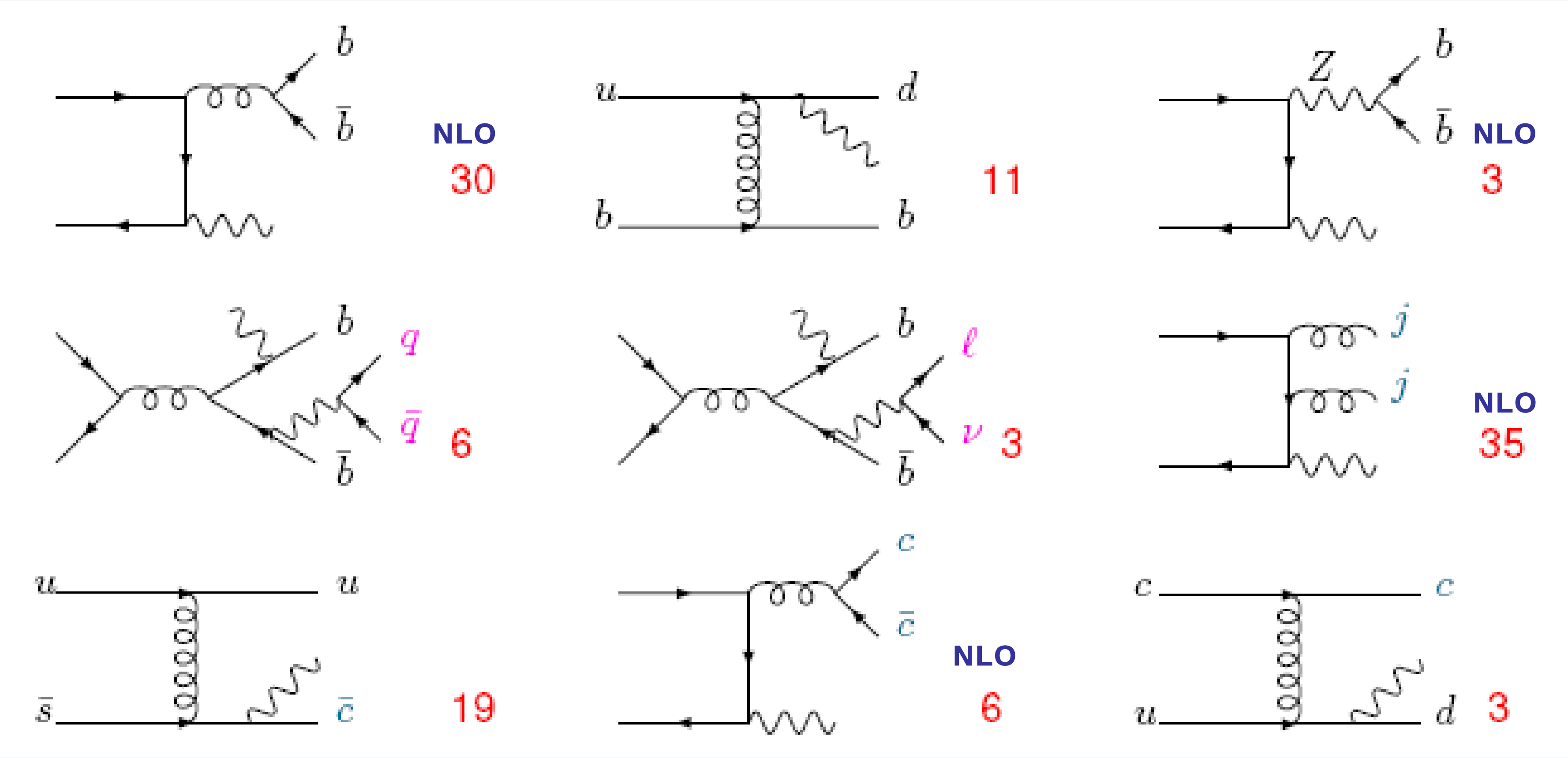
Signal is **18fb** from s-channel (**7fb**) and t-channel (**11fb**)





Backgrounds at Tevatron calculated with MCFM at $\sqrt{s} = 1.98 TeV$

Including nominal tagging efficiencies and fake rates (**fb**)

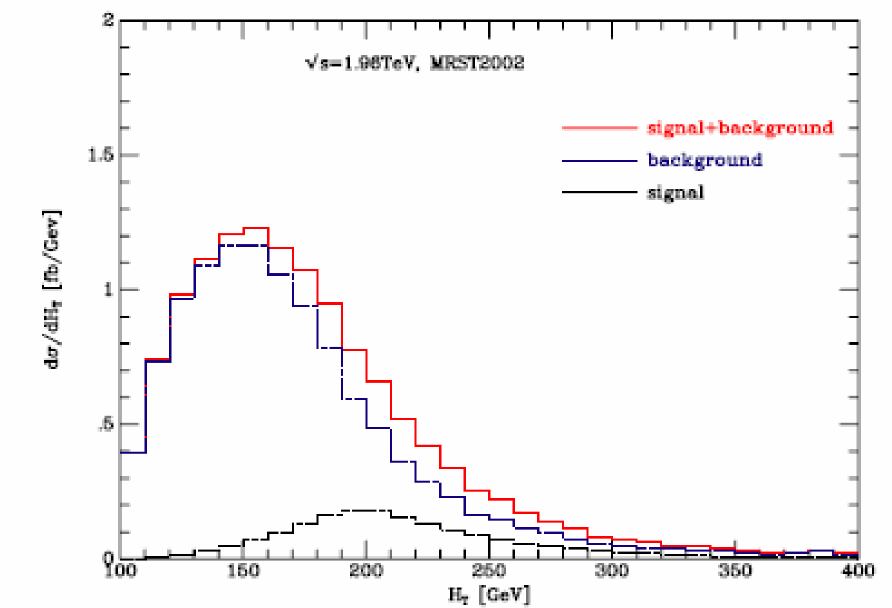


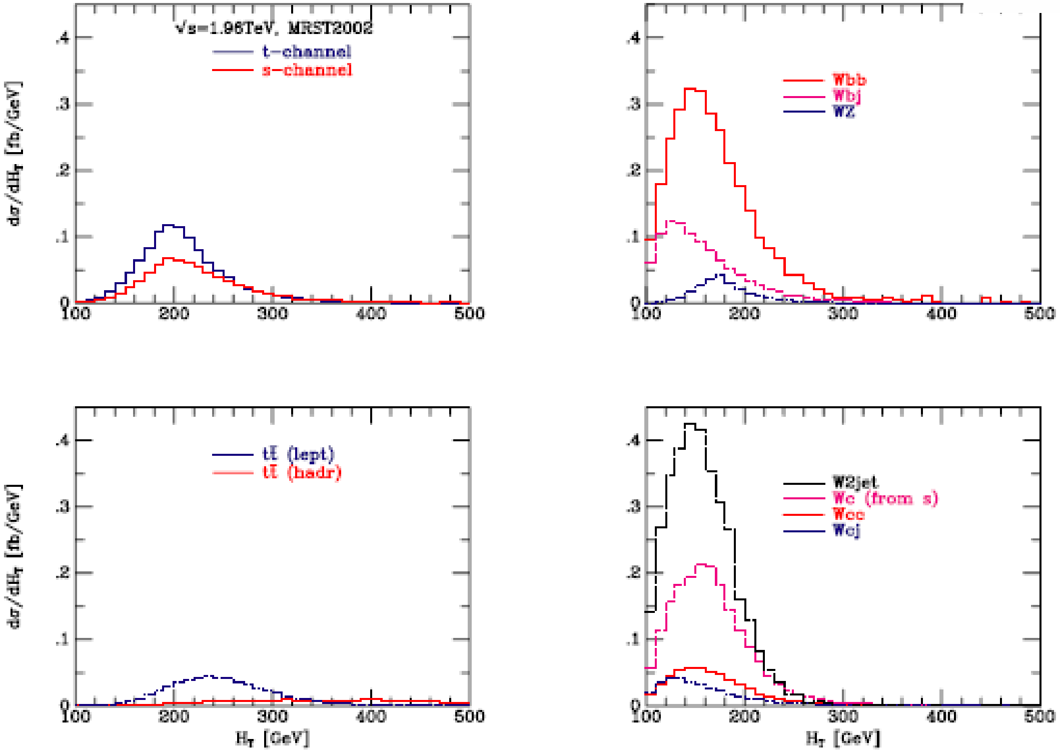
S:B 1:6 with our nominal efficiencies

H_T distrbution:

Scalar sum of jet, lepton and missing E_T

$$H_T = |p_T(\text{lepton})| + |\not{E}_T| + \sum |p_T(\text{jet})|$$



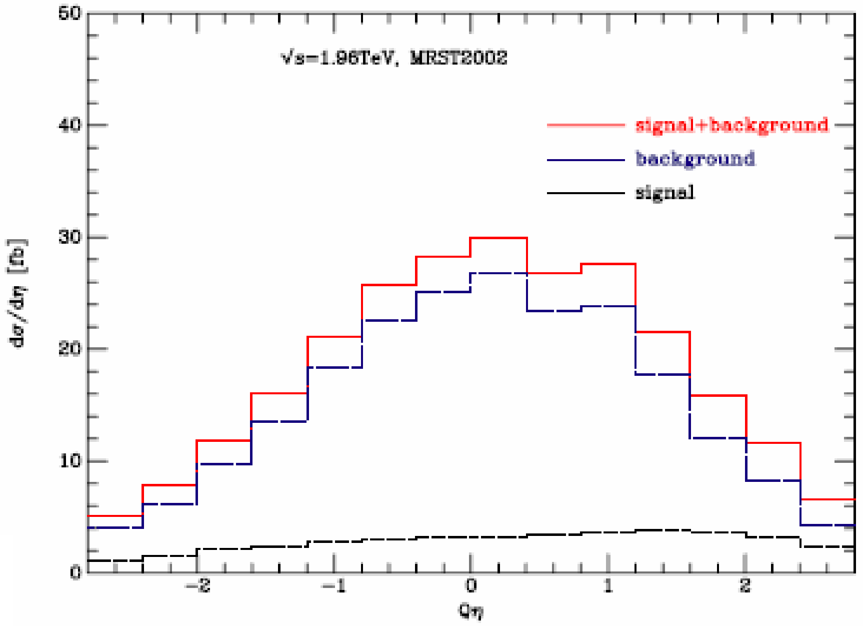


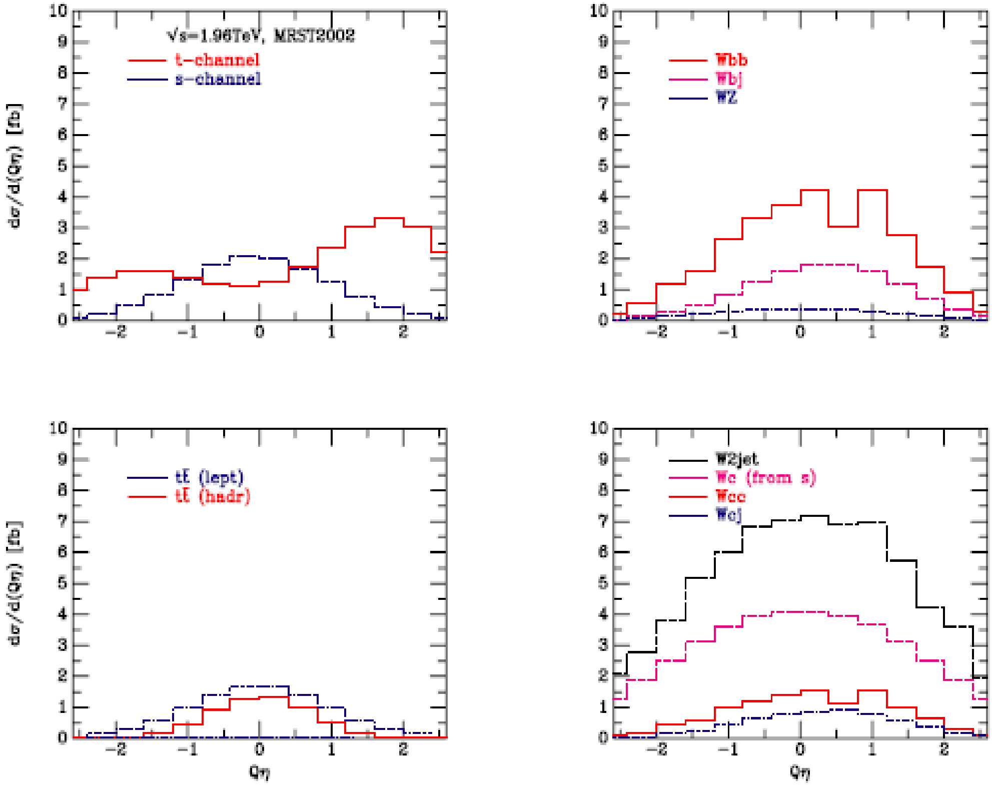
H_T distribution can only be calculated when the momenta of the decay products are known

Tevatron

$Q\eta$ distrbution:

Lepton charge in unit of positron X
pseudorapidity of the untagged jet





Tevatron

Wt production and decay

- The last single top channel has also been implemented in MCFM
- We used helicity amplitudes decomposing the top momentum along the initial gluon and an auxiliary massless momentum t_0

$$u(t)_\uparrow = \frac{(\not{t} + m_t)}{[t_0 g]} |g, -1\rangle, \qquad \bar{u}(t)_\uparrow = \langle g, -1| \frac{(\not{t} + m_t)}{\langle g t_0\rangle}$$

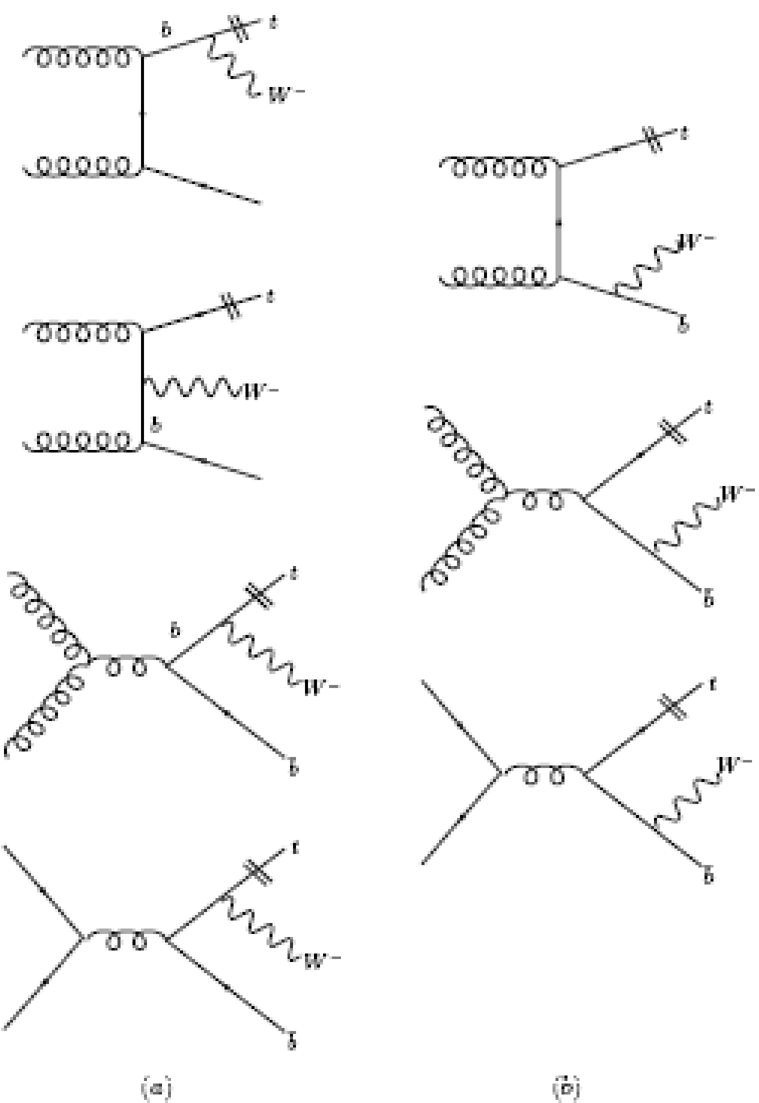
$$u(t)_\downarrow = \frac{(\not{t} + m_t)}{\langle t_0 g\rangle} |g, +1\rangle, \qquad \bar{u}(t)_\downarrow = \langle g, +1| \frac{(\not{t} + m_t)}{[g t_0]}$$

$$t_0^\mu = t^\mu - \frac{m_t^2}{2t \cdot g} g^\mu$$

$$u(t)_\uparrow \bar{u}(t)_\uparrow + u(t)_\downarrow \bar{u}(t)_\downarrow = \not{t} + m_t$$

- We used dimensional regolarization
- Compact expressions are obtained introducing functions that are combination of the usual scalar integrals

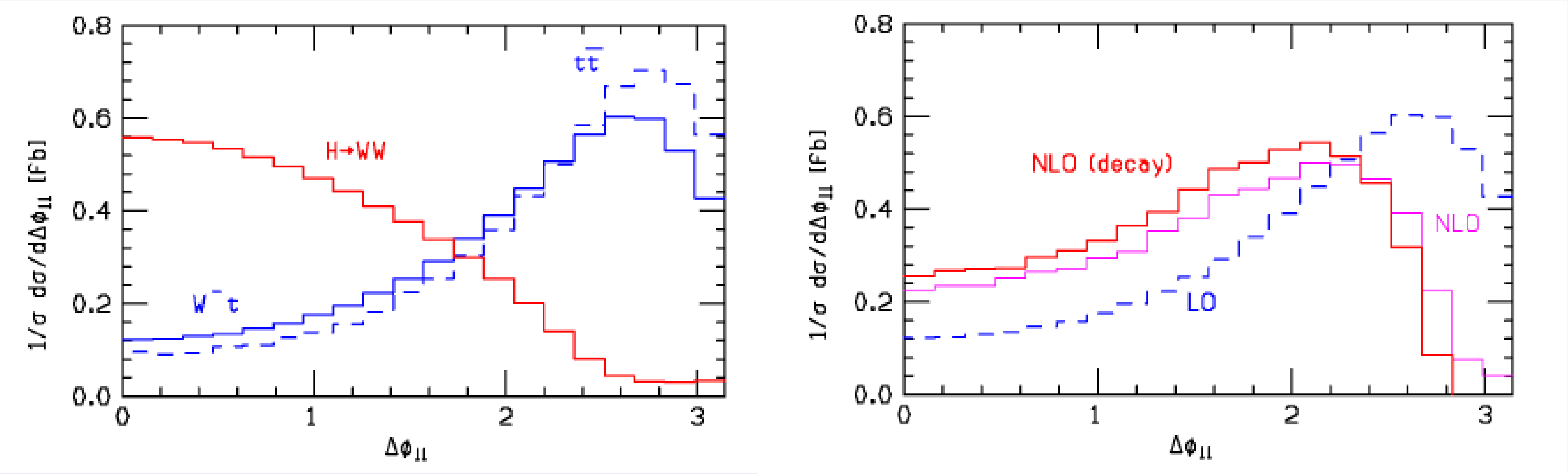
- ☐ For the Reals of the Wt calculation a complication arise due to the presence of double resonant top contribution in the Real corrections with W-t-b in the final state



- ✓ For small p_T of the b quark the contribution from diagrams (a) is in the b-quark pdf (up to μ_F by pdf definition)
- ✓ μ_F is limited by the validity of the collinear approximation $\mu_F \sim (m_t + m_W)/4 \sim 65$ GeV
- ✓ If we consider the b-quark up to a $p_T \sim \mu_F \sim 65$ GeV then tt associated production diagrams (b) give small interference and can be separeted
- ✓ We define single top events with a $\mathbf{p_T}$ veto on the b-jet
- ✓ For higher p_T the tt production gives a better description

- At the LHC the Wt channel has a total rate of 66pb that is larger then the s-channel (10pb)
- For $150 < m_H < 180$ Wt associated production is an important source of background for H→WW* discovery channel
    - WW from the continuum is the main background
    - tt and Wt are large and comparable

Angle between the leptons in the transverse plane



LHC

NLO introduce important modification for this distribution

Approximations

- **We set $m_b = 0$**
  ~1% (from a LO calculation of the s-channel with massive b)

- **We put the top quark on its mass shell**
  ~1% (from a LO calculation with a Breight-Wigner for the top)

- **We neglect interference between radiation emitted in the production and decay stages**
  Expectet to give an $O(\alpha_s \Gamma_t / m_t)$ correction

- **We include no showering and hadronization**
  We have defined a large pseudocone, but a more detailed analysis should await the combination with a parton shower

Conclusion

- Single top evidence at Tevatron makes possible new tests of the Standard Model and the evaluation of important backgrounds to the Higgs search at Tevatron and LHC

- All the 3 single top channels including top decay with full spin correlation have been implemented at NLO in MCFC

- The impelmentation of the subtraction specific for the top decay could also be applied to the decay of the top quarks in the tt associated production process

- Distributions can be generated for single top signal and backgrounds (most at NLO) using MCFM