LHC-D Top Physics Workshop 2007: Introductory Remarks (Theory)

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Physics Issues:

- Unique opportunity to investigate interactions of a bare quark at $E \sim$ a few 100 GeV
- Dynamics of top production and decay is not explored very precisely so far

- Basic tasks at/for LHC: $\sigma(t\bar{t})$, $\sigma(t)$, $\sigma(\bar{t})$
Profile: mass, charge, spin, decay modes

- New decay modes besides $t \to W + b$? $t \to \tilde{t}$ ..., FCNC decays $t \to c$?
or sizeable FCNC in top production: $pp \to t\bar{c}\,X$?

- Excellent probe of mechanism of electroweak gauge-symmetry breaking,
heavy (Higgs) resonances that strongly couple to top?

- Good probe also for non-SM parity and/or non-SM CP violation
(induced, e.g., by non-standard Higgs bosons)

- Hints of a substructure ?

....

Strong (and electroweak) interactions of top quarks can be reliably predicted – asset!

Top Decays in SM

$$\mathrm{t} \longrightarrow \mathrm{W} + \mathrm{b} \longrightarrow \begin{cases} \ell + \nu_\ell + \mathrm{b} \\ \mathrm{q} + \bar{\mathrm{q}}' + \mathrm{b} \end{cases}$$

Basic issue: determining the structure of the tbW vertex (V-A charged current in SM):

Experiment: W helicity analysis; ℓ, b-jet distributions,...

Theory:
• Predictions for $t \longrightarrow W^+(h_W = -1, 0, +1)$
including QCD & EW corrections (Do et al. (2003))

• Predictions for decay distributions, including QCD corr., of polarized top decay into semileptonic (Czarnecki, Jezabek, Kühn) and non-leptonic (Brandenburg, Si, Uwer) channels

$\longrightarrow$ see talk by J. Körner

QCD radiation in t decay included into MC codes (?) $\longrightarrow$ see talk by S. Gieseke

$t\bar{t}$ Production at Tevatron and LHC:

main reactions (according to SM):

$$\mathrm{p\bar{p}, pp} \longrightarrow \mathrm{t\bar{t}X} \longrightarrow \begin{cases} 2\ell + \mathrm{n} \geq 2 \text{ jets} + \mathrm{P_T^{miss}} \\ \ell + \mathrm{n} \geq 4 \text{ jets} + \mathrm{P_T^{miss}} \\ \mathrm{n} \geq 6 \text{ jets} \end{cases}$$

$t\bar{t}$ production dominated by strong interactions: $q\bar{q} \longrightarrow t\bar{t}$, $gg \longrightarrow t\bar{t}, \cdots$
weak decays of t and $\bar{t}$: $t \longrightarrow b\ell\nu_\ell$ (semileptonic), $t \longrightarrow bq\bar{q}'$ (non-leptonic)
$\mathrm{BR}(2\ell) : \mathrm{BR}(\ell + \mathrm{jets}) : \mathrm{BR}(\mathrm{jets}) \simeq 0.05 : 0.30 : 0.46$ for $\ell = e, \mu$

Tevatron: $\sigma(t\bar{t})_{exp} = 7.3 \pm 0.9$ pb, i.e., $\delta\sigma_{exp} \sim 12\%$

at LHC: $\sigma(t\bar{t}) \sim 800$ pb, experimental goal: $\delta\sigma(t\bar{t})_{exp} \sim 5\%$

Status of Theory:

spin-averaged cross sections $\sigma(pp, p\bar{p} \to t\bar{t}X)$, $d\sigma/dp_T$, ... known to order α_s^3

$+$ resummation of "threshold logarithms" $\alpha_s^3 \left[\frac{\ln(1-z)}{1-z}\right]_+$, $z = Q^2/\hat{s}$

Bonciani et al.; Kidonakis et al.; Cacciari et al.; ...

Predictions for the Tevatron including estimate of PDF and scale uncertainties: $\delta\sigma(t\bar{t})_{th} \sim 10\%$

(Kidonakis, Vogt; Cacciari et al.; ...)

NLO MC generators for $t\bar{t}$ production: MC@NLO, MCFM

Recently: complete calculation of the weak interaction corrections

of order $\alpha_W \alpha_s^2$ to $t\bar{t}$ production (Kühn, Scharf, Uwer; W.B., Fücker, Si)

not important for $\sigma(t\bar{t})$, but relevant for distributions $\longrightarrow$ talk by A. Scharf

With these results:

update of $\sigma(t\bar{t})_{th}$ for LHC to be done!

Does theory uncertainty match expected exp. error?

NNLO QCD corrections necessary? $\longrightarrow$ talk by S. Moch

Role of underlying events in top production?

i.e., collision of the proton remnants with available c.m. energy $(1 - x_1 x_2)s$,

2nd hard collision becomes more likely with increasing s

$\longrightarrow$ talk by S. Gieseke

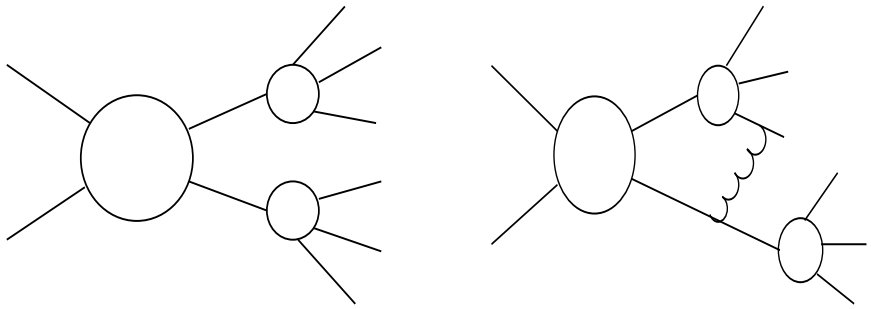
NLO predictions at level of t and $\bar{t}$ decay products, including $t, \bar{t}$ spin d.o.f.

Available for partonic final states:
- factorizable NLO QCD corr. (W.B., Brandenburg, Si, Uwer)
- non-factorizable NLO QCD corr.(Beenakker et al., L. Meyer)
- weak interaction corrections

$\longrightarrow$ predictions for (angular) distributions, correlations,...
in particular distributions due to $t\bar{t}$ spin correlations

parity-violating effects in $t\bar{t}$ production small according to SM,
e.g. longitudinal top polarization
but: definite SM prediction $\longrightarrow$ for non-SM (SUSY) effects see talk by S. Berge

factorizable and non-factorizable corrections



Likewise, for real gluon radiation

Determination of the top mass

experimental goal at LHC: $(\delta m_t)_{exp} \sim 1$ GeV

At present: D0 at Tevatron,
determination of m_t with (tree-level) matrix element method

Determination from invariant-mass distribution of top in $\ell+$ jets channels:

peak of $M_t = \sqrt{(\sum p_i)^2}$ not equal to on-shell mass m_t.
Theory: non-factorizable radiative corrections yield shift.
At NLO QCD (order α_s^3): small shift $|\Delta m_t| < 100$ MeV, but.....

$\rightarrow$ talk by A. Hoang

Futher important issue: p_T, $M_{t\bar{t}}$ distributions

For searches of new physics effects, e.g., heavy resonances that couple to $t\bar{t}$, precise SM predictions of $M_{t\bar{t}}$, p_T spectra are necessary,
especially for $\ell + \ jets$ channels.
Weak interaction corrections sizeable at large $M_{t\bar{t}}$, p_T (Sudakov logs)

Other useful variables: e.g., "transverse mass"

$$M_T = \sqrt{(p_b + p_\ell + p_{\bar{b}} + p_{j_1} + p_{j_2})^2 + (E_T^{miss})^2} + E_T^{miss}$$

Available results are to be put together: p_T, $M_{t\bar{t}}$, M_T distributions including NLO QCD and weak corrections + estimate of scale and PDF uncertainties

Further progress since last meeting:

predictions for $pp \longrightarrow t\bar{t} \; + \; \text{jet}$ to NLO QCD
(Dittmaier, Uwer, Weinzierl)

• important background for Higgs boson production by vector boson fusion:

$$qq \overset{WW,ZZ}{\longrightarrow} qq \; + \; H,$$
$$H \longrightarrow W^+W^- \longrightarrow 4 \; \text{jets}, 2\ell + 2\nu, \ldots$$

precision of $\sim 10\%$ for background required
LO analysis: $t\bar{t}$, $t\bar{t} + n$ jets (n=1,2) (N. Kauer)

• SM "gauge" for the search of new physics contributions to
anomalous chromomagnetic moment of t quark:

$$g_s \frac{a_t}{2m_t} \bar{t} \sigma_{\mu\nu} G^{\mu\nu} t$$

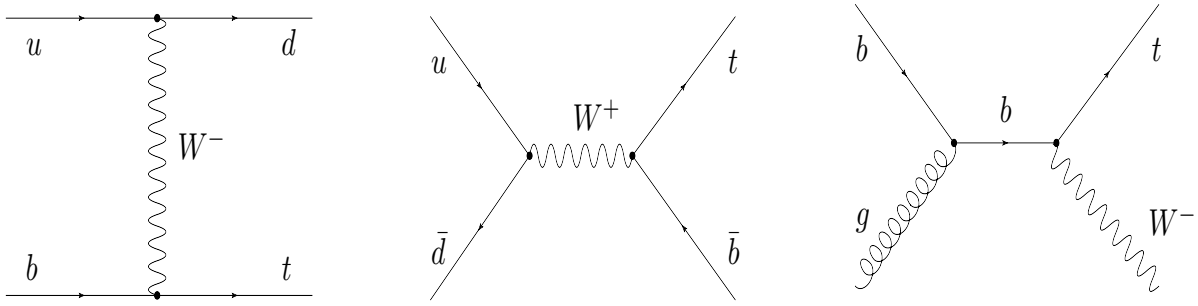
$\delta a_t \sim 0.03$ at LHC
• $t\bar{t} + \gamma$: measurement of el. charge/form factors of t

$\longrightarrow$ see talk by P. Uwer

Single top production:

- weak interactions involved in production; in SM: $\sigma_t \propto |V_{tb}|^2$
- source of polarized tops
- sensitive to non-SM interactions, esp. to FCNC, sizeable production of $t\bar{c}$?

in SM: t channel s channel tW mode



Predictions: Harris et al., Campbell et al.,....(NLO) Kidonakis (NLO + resummed "threshold" logs)

$\sigma_{Tev.}$	1.0 pb	0.44 pb	< 0.1 pb	(NLO QCD)
	1.15(7) pb	0.54(4) pb	0.14(3) pb	(resummed)
σ_{LHC}	154 pb	6.2 pb	~ 30 pb	(NLO QCD)
	150$\pm$ 6 pb	7.8$\pm$0.7 pb	43.5 $\pm$ 4.8 pb	(resummed)
	89 pb ($\bar{t}$)	3.8 pb ($\bar{t}$)	(NLO QCD)	

Recent evidence for single top production at Tevatron: D0 collab. (Dec. 2006)

- $\sigma_{t\,channel} + \sigma_{s\,channel} + c.c.\,modes = 4.9 \pm 1.4$ pb
- $V - A$ coupling $|V_{tb} f_{1,L}| = 1.3 \pm 0.2$

- Predictions for differential cross-section at NLO QCD: (Harris et al. (2002));
- incl. semileptonic t decay and non-factorizable QCD corrections (Campbell et al. (2004))

$\longrightarrow$ incorporated in the MC codes MC@NLO and MCFM

- Weak interaction corrections to single top production also available (Beccaria et al.)

Conclusion: SM predictions for single top production at LHC in reasonably good shape.

But: single t signal clouded by large backgrounds: $W + b\bar{b}$, $W + jets$, $t\bar{t}$, ...

See also recent review on top physics by

A. Quadt, Eur. Phys. Journal C 48, 835 (2006)