NLO QCD + Shower MC effects on multiparticle hadroproduction processes including a $\mathrm{t\bar{t}}$ pair

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mostly on the basis of [arXiv:1111.1444], [arXiv:1208.2665]

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Outline

- Introduction
- The PowHel + SMC framework
- Selected results of our latest simulations:
  the $t\bar{t}V$ processes, with V = heavy gauge boson
- Conclusions

How to go beyond σ^{NLO} ?

$*$ So far σ^{NLO} has been computed for several $2 \to 2, 3, 4$ processes of interest for collider physics (see the Les Houches 2005, 2007, 2009, 2011 "wish-lists") and very recently for the first $2 \to 5$ processes.

$*$ The complexity of the computation increases with the number of external legs (virtual corrections and real subtractions are both CPU time consuming).

$*$ σ^{NLO} allows for accounting for configurations with at most one more external leg (real radiation emission) with respect to the considered process.

$*$ On the other hand, at LHC much more complex events appear, with several jets in the final states!

$*$ Two possibilities to fill the gap:
- going beyond NLO, by computing NNLO, etc....(but this is complex, especially for multiparticle production processes!),
- interfacing NLO hard scattering computations at the parton level to Parton Shower approaches.

Two complementary approaches

$*$ Fixed-order scattering matrix elements (LO, NLO, NNLO)
describe hard emission processes, i.e. large angle/high energy emissions
$\Rightarrow$ results at the parton level, at an high-energy scale.

$*$ Parton Shower approaches
resum leading logarithmic soft and collinear emissions at all orders in P.T.
$\Rightarrow$ system evolution by subsequent emissions down to a low energy scale where P.T. breaks, non-perturbative QCD has to be used and hadronization takes place.

Matching Fixed Order (NLO) to PS approaches

⇒ to get the benefit of both approaches, suited to different kinematical regions.

⇒ Problems:
- dead regions: each phase space configuration should be covered by one (and only one) of the two approaches,
- double counting: NLO real radiation should not be recomputed as a first PS emission from the underlying Born configuration,
- smooth transition between the two kinds of emissions (NLO/PS "borders") should be ensured.

Specific matching algorithms for NLO+PS have been designed: the most popular ones are MC@NLO and POWHEG.

[S. Frixione, B.R. Webber, hep-ph/0204244]

[P. Nason, hep-ph/0409146], [S. Frixione, P. Nason, C. Oleari, arXiv:0709.2092]

⇒ Towards automation: the MC@NLO and POWHEG-BOX codes, implementing in numeric programs the corresponding matching algorithms.

[S. Alioli, P. Nason, C. Oleari and E. Re, arXiv:1002.2581]

[S. Frixione, F. Stoeckli, P. Torrielli, et al., arXiv:1010.0819]

PowHel = HELAC-NLO + POWHEG-BOX

* We use codes included in the HELAC-NLO package to provide input for POWHEG-BOX.

* HELAC-NLO is a set of codes (Helac-Phegas / Helac-1loop / Helac-Dipoles) to compute respectively LO and NLO parton level cross-sections for multiparticle production processes (so far $2 \to 2, 3, 4, (5)$ external legs @ NLO) for pp, e^+e^-, $p\bar{p}$ initial states.

* Both HELAC-NLO codes and POWHEG-BOX are publicly available on the web, but their interface not yet (it is process dependent!).

`http://helac-phegas.web.cern.ch/helac-phegas/`

[G. Bevilacqua, M. Czakon, M.V.G., A. van Hameren, A. Kardos, C.G. Papadopoulos, R. Pittau, M. Worek, arXiv:1110.1499 [hep-ph]]

`http://powhegbox.mib.infn.it/`

[S. Alioli, P. Nason, C. Oleari and E. Re, JHEP 1006 (2010) 043, arXiv:1002.2581]

Processes at NLO QCD + PS accuracy studied so far by PowHel

- $pp \to \mathrm{t\bar{t}}$
- $pp \to \mathrm{t\bar{t}}$+jet [arXiv:1101.2672]
- $pp \to \mathrm{t\bar{t}}H/\mathrm{t\bar{t}}A$ [arXiv:1108.0387], further in [arXiv:1201.3084]
- $pp \to \mathrm{t\bar{t}}Z$ [arXiv:1111.1444], [arXiv:1208.2665]
- $pp \to \mathrm{t\bar{t}}W^+, \mathrm{t\bar{t}}W^-$ [arXiv:1208.2665]
- $pp \to (\mathrm{t\bar{t}} \to W^+W^-b\bar{b}) \to e^+\nu_e\mu^-\bar{\nu}_\mu b\bar{b}$ in preparation

All these processes involve the production of a $\mathrm{t\bar{t}}$ pair.

Top quarks

∗ Discovered ∼ 15 years ago at Tevatron

∗ Exact properties (mass/coupling constants) still prone to relatively large uncertainties

∗ Heavy: $m_t \sim 173$ GeV

∗ Decay width ($\Gamma_t \sim 1.4$ GeV) > hadronization energy scale ($\Lambda \sim \Gamma_t/5$)
⇒ t decays before hadronizing: t → bW (with 99% B.R.)

∗ From the experimental point of view it has to be reconstructed from decay products:

- 3 jets
- 1 b-jet + 1 lepton + missing energy

∗ ⇒ $t\bar{t} \rightarrow W^+W^-b\bar{b}$ (top mostly emitted as $t\bar{t}$ pairs):

- fully hadronic channel
- semileptonic channel
- dileptonic channel

∗ $t\bar{t}$ asymmetries studies (FB asymmetry at the Tevatron and charge asymmetry at LHC) corresponding to preferred phase-space configurations for $t\bar{t}$ emissions

∗ Possible background for BSM physics:
− t' production directly decaying in bW: cuts for mass reconstruction ($m_{t'} > m_t$), can help in disentangling the signal from t background,
− stop production, further decaying in top + LSP, down to $t\bar{t}$ + MET:
cut on MET helps reducing SM backgrounds

PowHel input for $t\bar{t}Z/t\bar{t}W^+/t\bar{t}W^-$

* `POWHEG-BOX` input:

+ phase-space corresponding to 3 massive particles in the final state

+ all ME's provided by HELAC-NLO codes:

- Born squared ME's for the $\mathrm{q\ \bar{q}'\ t\ \bar{t}\ W^{\pm} \to 0}$, $\mathrm{q\ \bar{q}\ t\ \bar{t}\ Z \to 0}$, $\mathrm{g\,g\,t\ \bar{t}\ Z \to 0}$ processes
- spin and color correlated Born amplitudes
- real emission squared ME's corresponding to $\mathrm{q\ \bar{q}'\ t\ \bar{t}\ W^{\pm}\ g \to 0}$, $\mathrm{q\ \bar{q}\ t\ \bar{t}\ Z\ g\ \to 0}$, $\mathrm{g\ g\ t\ \bar{t}\ Z\ g\ \to 0}$, $\mathrm{q\ g\ t\ \bar{t}\ Z\ q\ \to 0}$, $\mathrm{\bar{q}\ g\ t\ \bar{t}\ Z\ \bar{q}\ \to 0}$
- finite part of the virtual emission amplitudes for the $\mathrm{q\ \bar{q}'\ t\ \bar{t}\ W^{\pm} \to 0}$, $\mathrm{q\ \bar{q}\ t\ \bar{t}\ Z \to 0}$, $\mathrm{g\ g\ t\ \bar{t}\ Z \to 0}$ processes

* Once specified the flavour structures above, `POWHEG-BOX` finds automatically the singular regions for real radiation, and computes the counterterms necessary for the cancellation of the virtual IR divergences according to the FKS subtraction scheme.

PowHel output

* Total and differential NLO cross-sections

* LHE's: events at the first radiation emission level in the Les Houches format stored in files available at our web-site:

http://grid.kfki.hu/twiki/bin/view/DbTheory/

* Link between the two kinds of output:
according to the POWHEG method, $\sigma_{LHE} = \sigma_{NLO}$ by construction, whereas, for differential distributions,

$$d\sigma_{LHE} = d\sigma_{NLO} + \text{formally higher order corrections}\,.$$

* Further showering by SMC codes: PYTHIA and HERWIG.

LO and NLO total $t\bar{t}V$ cross-sections: PowHel predictions

	$\sqrt{s}$ (TeV)	μ	$\sigma^{\rm LO}$ (fb)	$\sigma^{\rm NLO}$ (fb)	$\mathcal{K}$-fact.
$t\bar{t}W^+$	7	$\mu_0/2$	121.8(1)	114.3(1)	1.13
		μ_0	93.1(1)	104.7(1)	
		$2\mu_0$	72.7(1)	93.8(1)	
	8	$\mu_0/2$	159.3(1)	156.2(2)	1.16
		μ_0	122.9(1)	142.6(2)	
		$2\mu_0$	96.7(1)	127.5(1)	
$t\bar{t}W^-$	7	$\mu_0/2$	46.7(1)	46.9(1)	1.20
		μ_0	35.6(1)	42.6(1)	
		$2\mu_0$	27.8(1)	38.0(1)	
	8	$\mu_0/2$	64.1(1)	67.1(1)	1.23
		μ_0	49.4(1)	60.5(1)	
		$2\mu_0$	38.9(1)	53.9(1)	
$t\bar{t}Z$	7	$\mu_0/2$	141.6(1)	149.4(2)	1.32
		μ_0	103.5(1)	136.9(1)	
		$2\mu_0$	77.8(1)	120.8(1)	
	8	$\mu_0/2$	209.5(1)	224.9(4)	1.34
		μ_0	153.9(1)	205.7(2)	
		$2\mu_0$	116.2(1)	181.7(2)	

Table: PowHel predictions for the inclusive $t\bar{t}W^+$, $t\bar{t}W^-$ and $t\bar{t}Z$ cross-sections at LO and NLO QCD accuracy at LHC for $\sqrt{s} = 7$ and 8 TeV, for various static scale choices, centered around $\mu_0 = m_t + m_V/2$, with V = W for the $t\bar{t}W$ cases and Z for the $t\bar{t}Z$ one. The statistical uncertainties of our simulations are shown in parentheses. Parameters adopted for NLO computation: the CTEQ6.6M PDF set with a 2-loop running α_S and 5 active flavours, $m_{\rm b} = 0$, PDG heavy particle masses $m_{\rm t} = 173.5$ GeV, $m_W = 80.385$ GeV and $m_Z = 91.1876$ GeV, non-diagonal CKM-matrix in the first two families, with $\sin^2\theta_C = 4.9284 \cdot 10^{-2}$. $\mu_R = \mu_F = \mu_0$.

NLO total $t\bar{t}V$ cross-sections: comparison with other existing predictions

$*$ As for $\mathrm{t\bar{t}}W^+$ and $\mathrm{t\bar{t}}W^-$ we made comparisons with the MCFM predictions by [J. Campbell and K. Ellis, JHEP 1207 (2012) 052] and we found agreement within our statistical uncertainties.

$*$ However we prefer the $\mu_0 = m_t + m_V/2$ to the $\mu_0 = m_t$ central scale choice adopted in that paper, because the scale uncertainties in the $[\mu_0/2,\ 2\mu_0]$ interval are reduced.

$*$ As for $\mathrm{t\bar{t}}Z$ we made comparisons with the predictions by [A. Lazopoulos, T. McElmurry, K. Melnikov and F. Petriello, Phys. Lett. B 666, 62 (2008)] finding slightly larger total cross-section.

Predictions at NLO + PS accuracy

$*$ $t\bar{t}Z$, $t\bar{t}W^+$, $t\bar{t}W^-$: no-cut analysis (possible since the Born cross-section is finite)

$*$ $t\bar{t}Z$, with $t\bar{t}$ pairs decaying fully hadronically

$*$ $t\bar{t}Z$ / $t\bar{t}W^+$ / $t\bar{t}W^-$, with $t\bar{t}$ pairs decaying semi-leptonically.

$t\bar{t}Z$, no-cut analysis: LHEF level vs NLO level

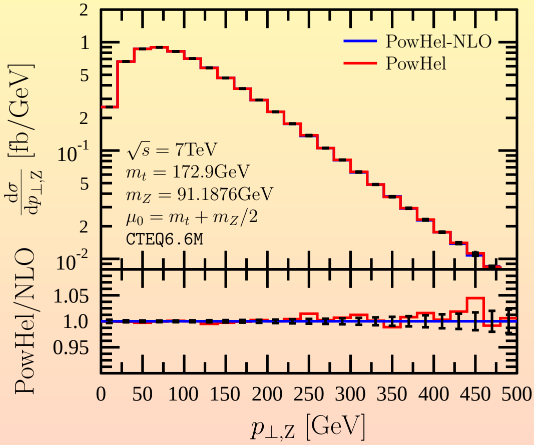

Figure: Inclusive transverse momentum of the Z boson at NLO and LHEF level. The lower panels show the ratio of the predictions with combined statistical uncertainties. [from arXiv:1111.1444]

$t\bar{t}Z$, no-cut analysis: shower + hadronization level vs. decay level

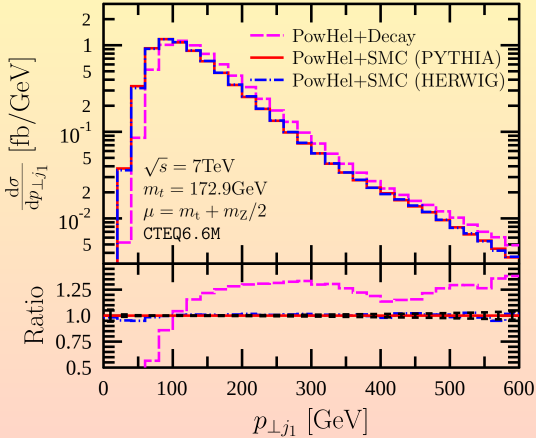

Figure: Inclusive transverse momentum distribution of the hardest jet after decay (simulated by means of PYTHIA) and after full SMC, by considering both PYTHIA and HERWIG. The lower panels show the ratio of all predictions to PowHel+SMC using PYTHIA. [from arXiv:1111.1444]

$t\bar{t}Z/t\bar{t}W^+/t\bar{t}W^-$ no-cut analysis: shower level

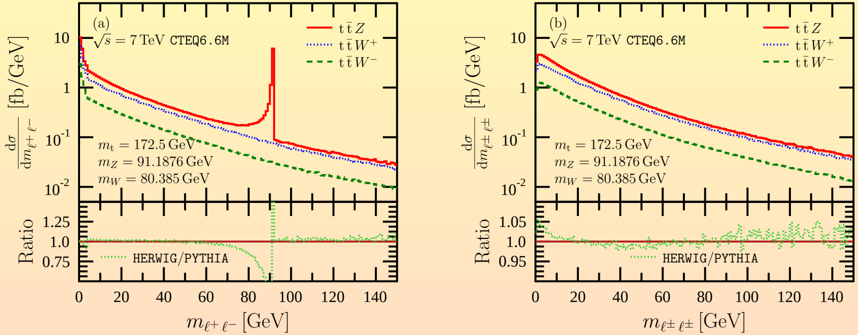

Figure: Invariant mass of a) all (ℓ^+, ℓ^-) same-flavour lepton-antilepton pairs and b) all (ℓ, ℓ) same-sign lepton and anti-lepton pairs from all events in the inclusive analysis, as obtained by PowHel + PYTHIA at the $\sqrt{s} = 7$ TeV LHC. Predictions for the three processes $t\bar{t}Z$, $t\bar{t}W^+$, and $t\bar{t}W^-$ are shown separately. In the lower panel, the ratio between the cumulative predictions of PowHel + HERWIG and PowHel + PYTHIA is also shown. [from arXiv:1208.2665]

$t\bar{t}Z/t\bar{t}W^+/t\bar{t}W^-$ no-cut analysis: shower level

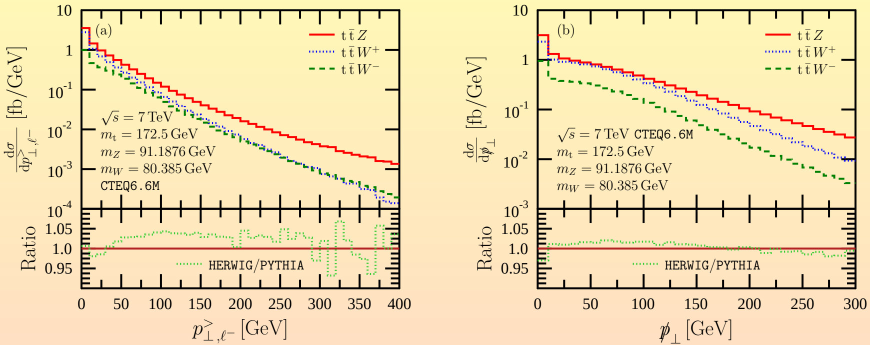

Figure: Distributions of a) the transverse momentum of the hardest lepton and b) the missing transverse momentum due to all neutrinos from all events in the no-cut analysis, as obtained by PowHel + PYTHIA at the $\sqrt{s} = 7$ TeV LHC. Predictions for the three processes $t\bar{t}Z$, $t\bar{t}W^+$, and $t\bar{t}W^-$ are shown separately. In the lower panel, the ratio between the cumulative predictions of PowHel + HERWIG and PowHel + PYTHIA is also shown.
[from arXiv:1208.2665]

$t\bar{t}Z$ in the fully hadronic channel

∗ $t\bar{t}Z \rightarrow$ 2 b-jets + 4 light jets + missing energy

∗ Set of cuts originally proposed in a parton level study [U. Baur et al., arXiv:hep-ph/0512262] extended to the hadron level.

∗ $t\bar{t}$ reconstruction through invariant mass: a χ^2 minimization is introduced to best-fit at the same time m_{W^+}, m_{W^-}, m_t, $m_{\bar{t}}$ out of all possible combinations of six jets:

$$\chi^2(b_1 j_1 j_2; \bar{b}_2 j_3 j_4) = \frac{(m_{j_1 j_2} - m_{W^+})^2}{\sigma_W^2} + \frac{(m_{j_3 j_4} - m_{W^-})^2}{\sigma_W^2} + \frac{(m_{b_1 j_1 j_2} - m_t)^2}{\sigma_{\mathrm{t}}^2} + \frac{(m_{\bar{b}_2 j_3 j_4} - m_{\bar{t}})^2}{\sigma_{\mathrm{t}}^2},$$

$t\bar{t}$-quark pair invariant mass: $t\bar{t}Z$ vs. $t\bar{t}j$

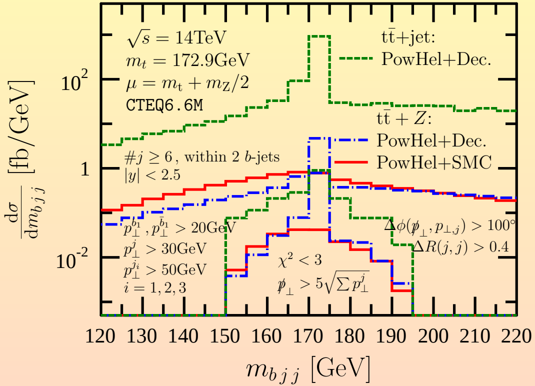

Figure: Invariant mass distribution of the t-quark reconstructed from the decay products at both decay (blue dash-dotted lines) and full SMC (red solid lines) levels, for the $t\bar{t}Z$ signal and, at the decay level, for one background ($t\bar{t}$+jet) (green dashed lines) after selection cuts (1–8) (wider distributions in abscissa values) and after selection cuts (1–10) (narrower distributions).
[from arXiv:1111.1444]

$t\bar{t}Z/t\bar{t}W^+/t\bar{t}W^-$ in the trilepton decay channel

∗ Set of cuts aimed at favouring the

$$(\text{semileptonic decay of } \mathrm{t\bar{t}} \text{ pair}) \quad + \quad (Z \to \ell^+ + \ell^-)$$

∗ Analysis proposed by the CMS collaboration in the [CMS PAS TOP-12-014 technical report] and applied to the $\sqrt{s} = 7$ TeV LHC data.

∗ $\mathrm{t\bar{t}}W^+/\mathrm{t\bar{t}}W^-$ contributions highly suppressed by Z reconstruction requirements, in particular $81\,\mathrm{GeV}/c^2 < m_{\ell\ell} < 101\,\mathrm{GeV}/c^2$

PowHel + SMC predictions in the dilepton channel @ 7 TeV

in the same format as in the experiment

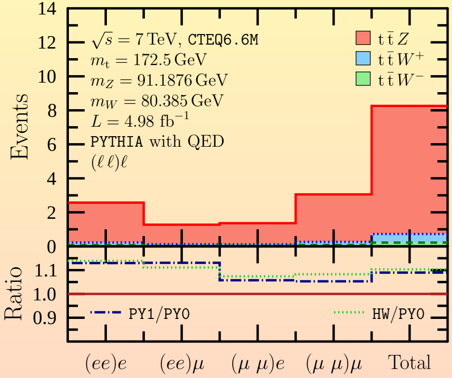

Figure: Number of events in the trilepton channels at the $\sqrt{s} = 7\,\mathrm{TeV}$ LHC, as predicted by PowHel + PYTHIA, for an integrated luminosity amounting to $L = 4.98\,\mathrm{fb}^{-1}$. The contributions due to $t\bar{t}Z$, $t\bar{t}W^+$ and $t\bar{t}W^-$ are cumulated one over the other. To be compared with the experimental data in Fig. 4 of the CMS PAS TOP-12-014 technical report. In the lower inset the ratios between cumulative results using different SMC (HERWIG/PYTHIA) and between cumulative results obtained by neglecting and including photon bremsstrahlung from leptons (PYTHIA-no-brem/PYTHIA) are also shown.

Z invariant mass reconstruction in the trilepton channel

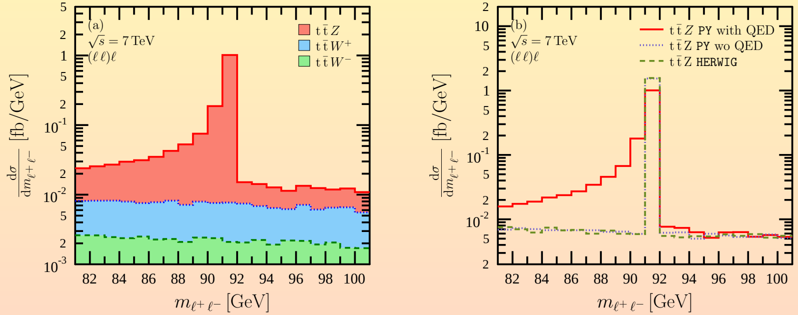

Figure: Invariant mass of the Z reconstructed from same-flavour (ℓ^+, ℓ^-) pairs after the trilepton analysis, as obtained by PowHel+ PYTHIA at the $\sqrt{s} = 7$ TeV LHC.
a) Predictions corresponding to the different processes $t\bar{t}Z$, $t\bar{t}W^+$ and $t\bar{t}W^-$ cumulated one over the other, b) distributions obtained by using different SMC (PYTHIA, HERWIG and PYTHIA without photon bremmstrahlung from leptons) are also shown, limited to $t\bar{t}Z$-production.

Comparison with the experimental data at 7 TeV, for $L = 4.98\,\mathbf{fb}^{-1}$

channel	theory (# $t\bar{t}V$ events)	experiment (# events)
$(e,e)e$	2.57 ± 0.02	1 + 2.4 - 0.8
$(e,e)\mu$	1.27 ± 0.02	2 + 2.7 - 1.2
$(\mu,\mu)e$	1.36 ± 0.02	2 + 2.7 - 1.2
$(\mu,\mu)\mu$	3.05 ± 0.03	4 + 3.2 - 2.0
total	8.26 ± 0.04	9 + 4.1 - 3.0

∗ background contribution (Z + jets, $t\bar{t}$, diboson production) is not yet included in the theoretical simulation, but present in the experimental data (CMS estimate of the total background: 2.9 ± 0.8 events).

∗ the uncertainties on the theoretical predictions are statistical only.

∗ largest discrepancies in the (e,e) channel, related to lepton reconstruction: our detection efficiencies are assumed to be 100% in all $(\ell,\ell)\ell$ channels, differently from the experiment (where the reconstruction of electrons is more problematic).

∗ theoretical b-jet tagging on the basis of the SMC `MCTRUTH` different from the experimental one.

PowHel predictions at 8 TeV in the trilepton channel

channel	theory 7 TeV (fb)	theory 8 TeV (fb)	theory 8 TeV / 7 TeV
$(e,e)e$	0.516	0.782	1.515
$(e,e)\mu$	0.255	0.388	1.521
$(\mu,\mu)e$	0.273	0.420	1.538
$(\mu,\mu)\mu$	0.613	0.934	1.523
total	1.658	2.524	1.522

$*$ The ratio between the cross-sections at 8 and 7 TeV is almost the same in all channels (maximum difference $< 1.5\%$)

$*$ Differential distributions at 7 TeV can be rescaled to 8 TeV by multiplying for a ~ 1.52 factor, with good approximation.

$*$ A total of ~ 50 events is predicted by PowHel at 8 TeV for an integrated luminosity $L = 20\ \mathrm{fb}^{-1}$, as expected by the end of this year.

$t\bar{t}Z/t\bar{t}W^+/t\bar{t}W^-$ in the dilepton decay channel

$*$ Set of cuts aimed at favouring the

$$\text{(semileptonic decay of } \mathrm{t\bar{t}} \text{ pair)} \quad + \quad (Z \to \ell^+ + \ell^-)$$
$$\text{(semileptonic decay of } \mathrm{t\bar{t}} \text{ pair)} \quad + \quad (W \to \ell \nu_\ell),$$

globally leading to a pair of same sign leptons.

$*$ Analysis proposed by the CMS collaboration in the [CMS PAS TOP-12-014 technical report] and applied to the $\sqrt{s} = 7$ TeV LHC data.

$*$ trilepton veto: events passing the trilepton analysis are discarded in this one.

$*$ inspired by supersymmetry searches, but different since we do not include any cut on $\not{p}_\perp$, usually required to disentangle new physics signals.

PowHel + SMC predictions in the dilepton channel @ 7 TeV

in the same format as in the experiment

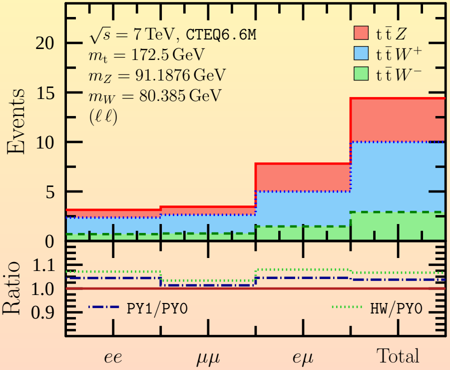

Figure: Number of events in the dilepton channel at $\sqrt{s} = 7\,\mathrm{TeV}$ LHC, as predicted by PowHel + PYTHIA, for an integrated luminosity $L = 4.98\,\mathrm{fb}^{-1}$. The contribution in the $(e,\, e)$, $(\mu,\, \mu)$, $(e,\, \mu)$ channels are shown separately, as well as their sum in the last bin. The contributions due to $t\bar{t}Z$, $t\bar{t}W^+$ and $t\bar{t}W^-$ are cumulated one over the other. In the lower inset the ratios between cumulative results using different SMC HERWIG and PYTHIA (HW/PY0) and between cumulative results obtained by neglecting and including photon bremsstrahlung from leptons in PYTHIA (PY1/PY0) are also shown.

Some interpretation

$*$ $t\bar{t}W^+$ total contribution enhanced with respect to the $t\bar{t}Z$ one because of selection cuts + the trilepton veto.

$*$ $\sigma(t\bar{t}W^+)$ / $\sigma(t\bar{t}W^-)$ ratio almost unchanged before and after cuts.

$*$ For both $t\bar{t}W^+$ and $t\bar{t}W^-$, $\sigma(e,\mu) \sim \sigma(e,e) + \sigma(\mu,\mu)$,
as expected on the basis of combinatorics.

$*$ For $t\bar{t}Z$ $\sigma(e,\mu) > \sigma(e,e) + \sigma(\mu,\mu)$, because of the trilepton veto.

$*$ HERWIG predictions $\sim$ 8% larger than the PYTHIA ones, as a net result of two effects with opposite trend: on the one hand, the absence in HERWIG of lepton bremsstrahlung by γ emissions allows more leptons to pass the cuts with respect to PYTHIA, on the other, the trilepton veto is more severe for HERWIG than for PYTHIA.

$\not{p}_\perp$ distribution in the dilepton channel @ 7 TeV

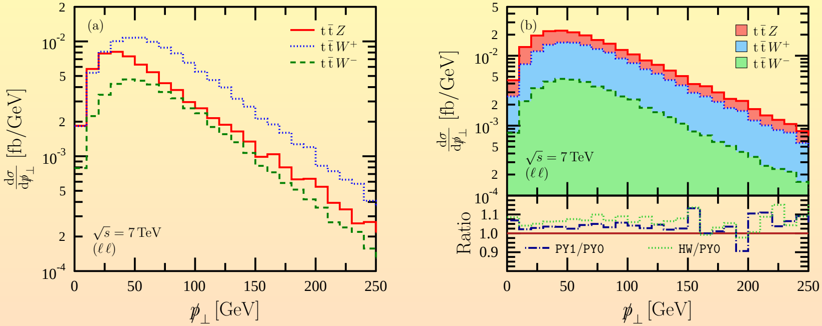

Figure: Missing transverse momentum distribution at $\sqrt{s} = 7$ TeV LHC, as predicted by `PowHel` + PYTHIA after the dilepton analysis. a) distributions for the $t\bar{t}Z$ $t\bar{t}W^+$ and $t\bar{t}W^-$ processes are shown separately. b) these different contributions are added one over the other in a cumulative way. In the lower inset the ratios between cumulative results using different SMC HERWIG and PYTHIA (`HW`/`PY0`) and between cumulative results obtained by neglecting and including photon bremsstrahlung from leptons in PYTHIA (`PY1`/`PY0`) are also shown.

$\not{p}_\perp$ suppressed in the first bins even without the explicit presence of a $\not{p}_\perp$ cut.

$\not{p}_\perp >$ 50 GeV cut $\rightarrow$ reduction from $\sim$ 14 to $\sim$ 10 events

$\not{p}_\perp >$ 100 GeV cut $\rightarrow$ reduction from $\sim$ 14 to $\sim$ 6 events

PowHel+PYTHIA predictions in the dilepton channel @ 8 TeV

channel	theory 7 TeV (fb)	theory 8 TeV (fb)	theory 8 TeV / 7 TeV
(e, e)	0.631	0.907	1.437
(μ, μ)	0.694	0.991	1.428
(e, μ)	1.569	2.289	1.459
total	2.894	4.187	1.446

$*$ The ratio between the cross-sections at 8 and 7 TeV is almost the same in all channels (maximum difference $< 2.3\%$).

$*$ A total of > 80 events is predicted by PowHel+PYTHIA at 8 TeV for an integrated luminosity $L = 20$ fb^{-1}, as expected by the end of this year.

Conclusions

$*$ After $2-3$ years of development, PowHel+ SMC is a robust framework for predictions at both NLO QCD and NLO QCD + PS accuracy.

$*$ So far, we have concentrated on multiparticle production processes including a $t\bar{t}$ pair.

$*$ Examples given in this talk as for $t\bar{t}Z/t\bar{t}W^+/t\bar{t}W^-$, also recently studied by the experimental collaborations at LHC under the same systems of cuts.

$*$ Our analyses are just examples of how the produced events can be used. More realistic phenomenological analyses (accounting for detector acceptance and capabilities) can be carried out by the experimental collaborations (with or without our collaboration...).

$*$ LHEF for $t\bar{t}$+jet, $t\bar{t}H$, $t\bar{t}A$, $t\bar{t}Z$, $t\bar{t}W^+$, $t\bar{t}W^-$at NLO QCD + PS accuracy, available on the web to everybody. http://grid.kfki.hu/twiki/bin/view/DbTheory/

$*$ Further configurations: production of events on request.

Thank you for your attention!