tT+V hadroproduction at NLO accuracy matched with SMC

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in collaboration with
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and
HELAC group

LHCPhenonet midterm meeting, Ravello, Italy
September 20, 2012

NEW SZÉCHENYI PLAN

LHCphenonet

Outline

- Motivation
- PowHel
- Predictions
- Conclusions

Motivation

The t-quark is special

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m_t [GeV]=$172.9 \pm 0.6_{stat} \pm 0.9_{syst}$ (PDG),

$173.2 \pm 0.6_{stat} \pm 0.8_{syst}$ (TeVatron)

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$\Rightarrow$ plays important role in Higgs physics and searches

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production cross section, mass, width, t-T mass difference, spin correlations, W helicity/ polarization, Vtb, charge, charge asymmetry, anomalous couplings, FCNC, jet veto in tT

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Future:

discovery tool, coupling measurements

These require precise predictions of distributions at hadron level for

pp $\rightarrow$tT+hard X, X = H, A, W, Z, γ , j, bB, 2j...

(with decays, top is not detected)

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  - match to shower Monte Carlo (SMC) programs

We pursue both within Phenonet

this talk

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NLO subtractions

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$$\begin{aligned}\mathrm{d}\sigma_{\mathrm{NLO}} &= \left[B(\Phi_n) + \mathcal{V}(\Phi_n) + R(\Phi_{n+1})\mathrm{d}\Phi_{\mathrm{rad}}\right]\mathrm{d}\Phi_n \\ &= \left[B(\Phi_n) + V(\Phi_n) + \left(R(\Phi_{n+1}) - A(\Phi_{n+1})\right)\mathrm{d}\Phi_{\mathrm{rad}}\right]\mathrm{d}\Phi_n\end{aligned}$$

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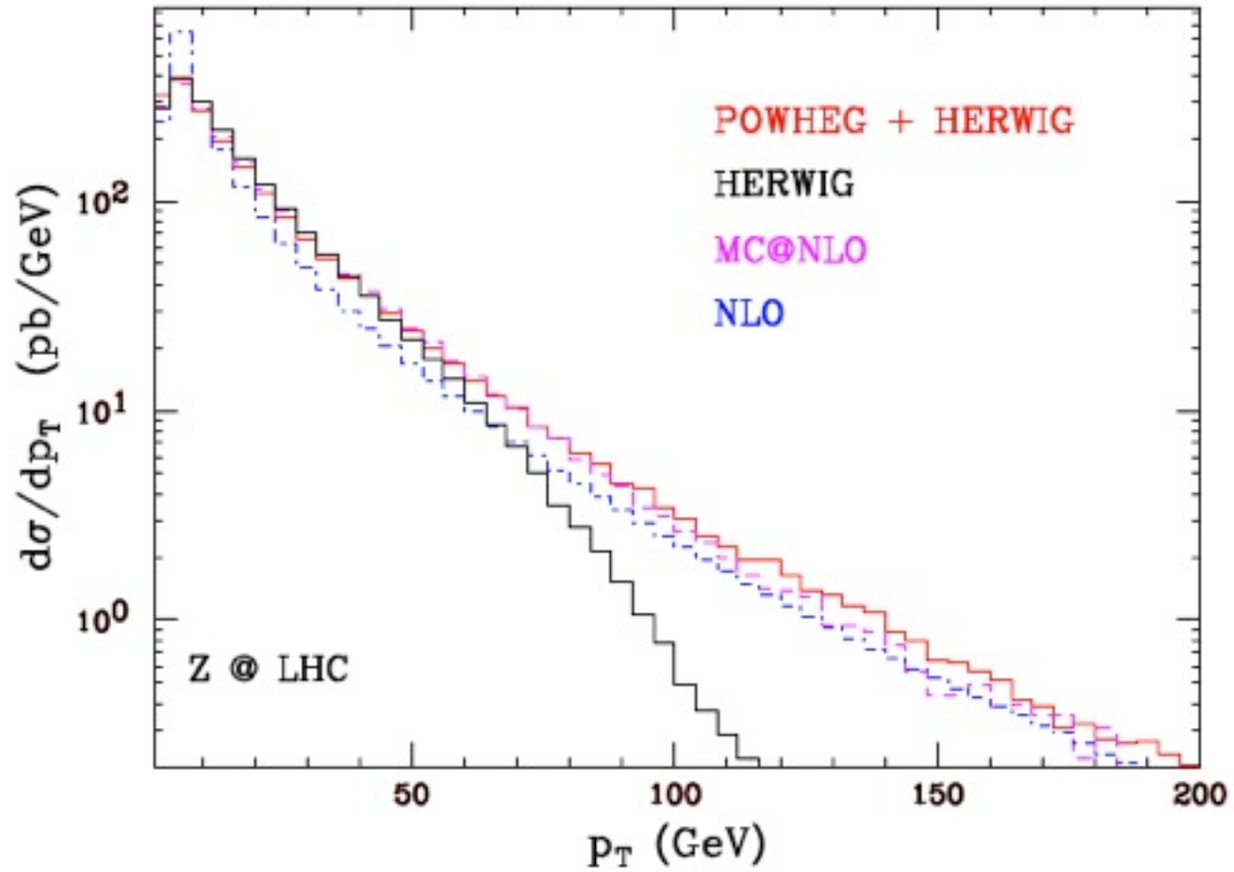
Solutions:

- MCatNLO [Frixione, Webber hep-ph/0204244]
- POWHEG [Nason hep-ph/0409146, Frixione, Nason, Oleari arXiv:0709.2092]

Result: PS events giving distributions exact to NLO in pQCD



[Nason, Ridolfi hep-ph/0606275]

Accuracy of the POWHEG cross section

$$\frac{\mathrm{d}\sigma_{\mathrm{LHE}}}{\mathrm{d}O} = \frac{\mathrm{d}\sigma_{\mathrm{NLO}}}{\mathrm{d}O} + \mathrm{O}(\alpha_{\mathrm{s}}) \int \mathrm{d}\Phi_R R(\Phi_R) \Big[\delta(O(\Phi_R) - O) - \delta(O(\Phi_B) - O) \Big]$$

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Used: $\Delta\Big(\Phi_B, k_\perp(\Phi_R)\Big) \dfrac{\tilde{B}(\Phi_B)}{B(\Phi_B)} = 1 + \mathrm{O}(\alpha_s)$

Difference scales with the NLO K-factor

Our choice: POWHEG-BOX with HELAC-NLO for tT+hard X

PowHel

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- HELAC-NLO is a collection of codes (HELAC-Phegas, HELAC-1loop, HELAC-Dipoles) to compute LO and NLO partonic cross sections for $2 \to 2, 3, 4, 5$ processes

[Bevilaqua et al, arXiv: 1110.1499]

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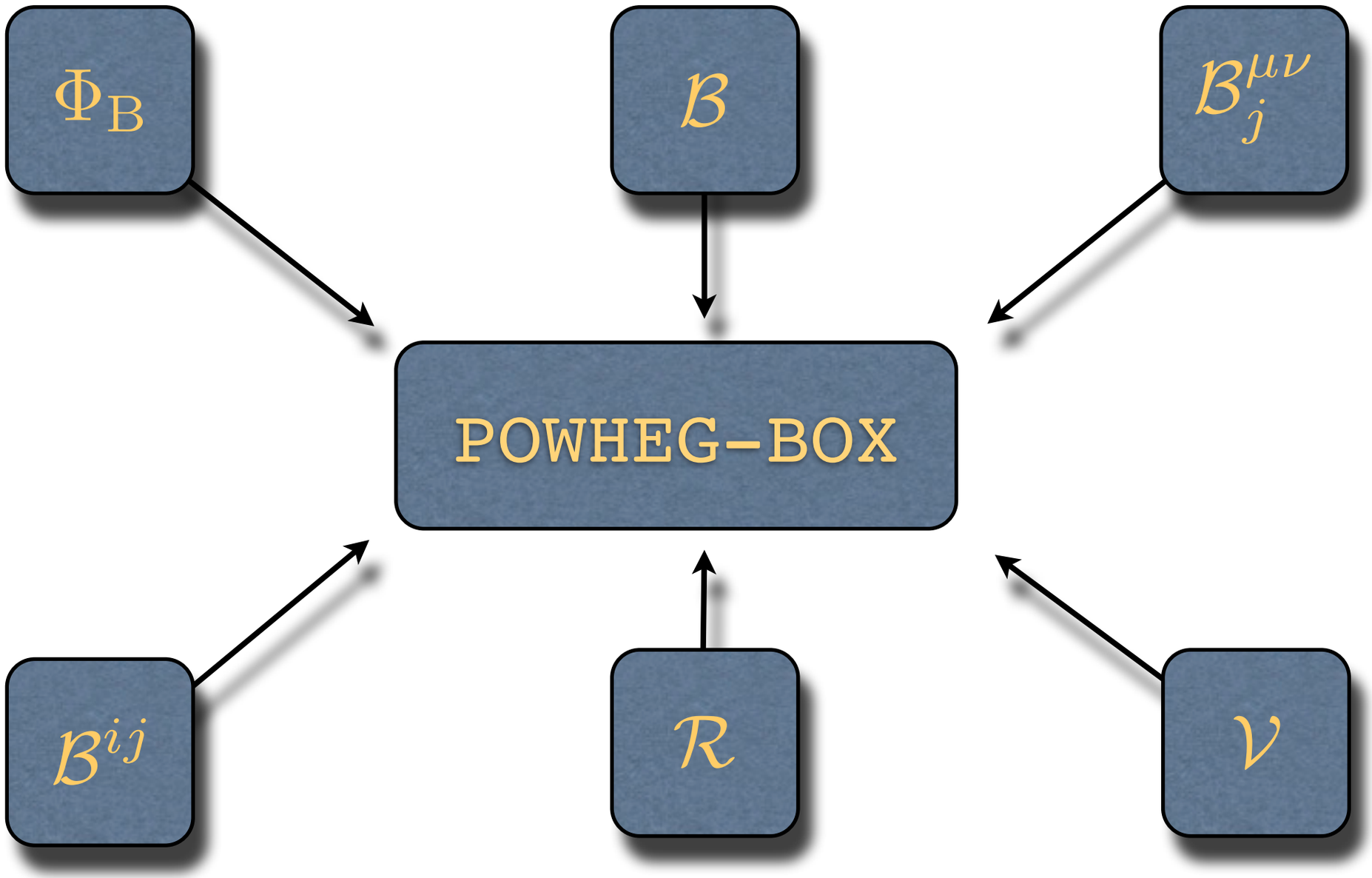
- It provides tree and 1loop ME for us
- Both are publicly available:

http://helac-phegas.web.cern.ch/helac-phegas/
http://powhegbox.mib.infn.it/

POWHEG-BOX framework



PowHel framework

POWHEG-BOX

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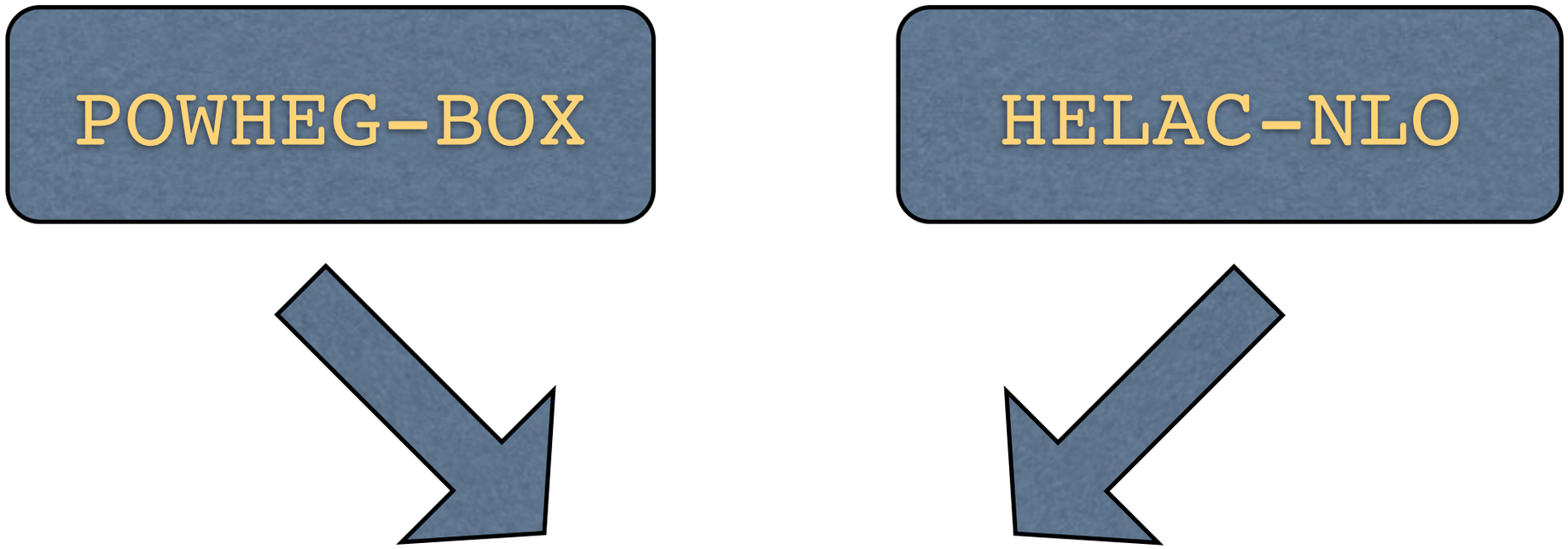


PowHel

RESULT of PowHel:

PowHel framework

POWHEG-BOX

HELAC-NLO

PowHel

RESULT of PowHel:

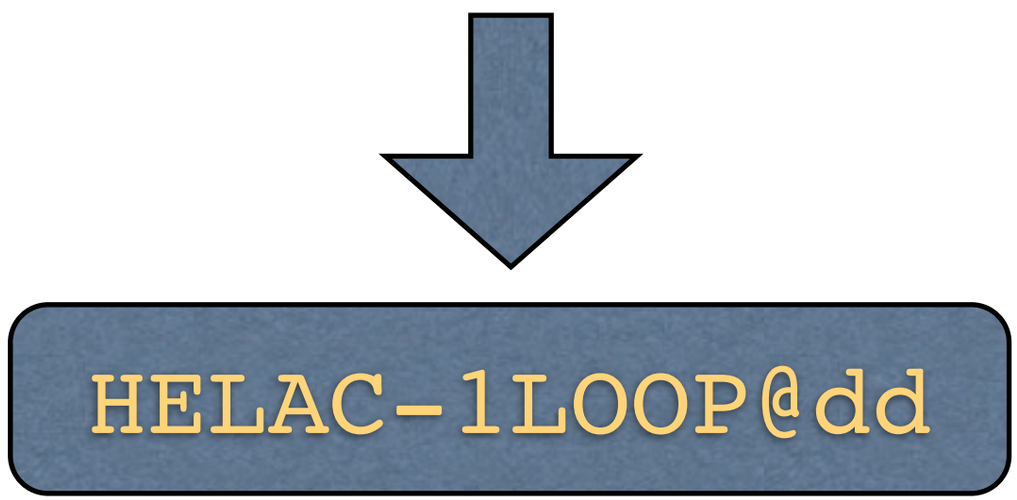
Les Houches file of Born and Born+1st radiation events (LHE) ready for processing with SMC followed by almost arbitrary experimental analysis

HELAC-1LOOP@dd

Processes with more than 2 particles in final state

- Complicated tensor integrals in 1-loop amplitudes
- High rank ones with possible numerical instabilities
- If double precision is not enough (check)

➡ use double-double precision



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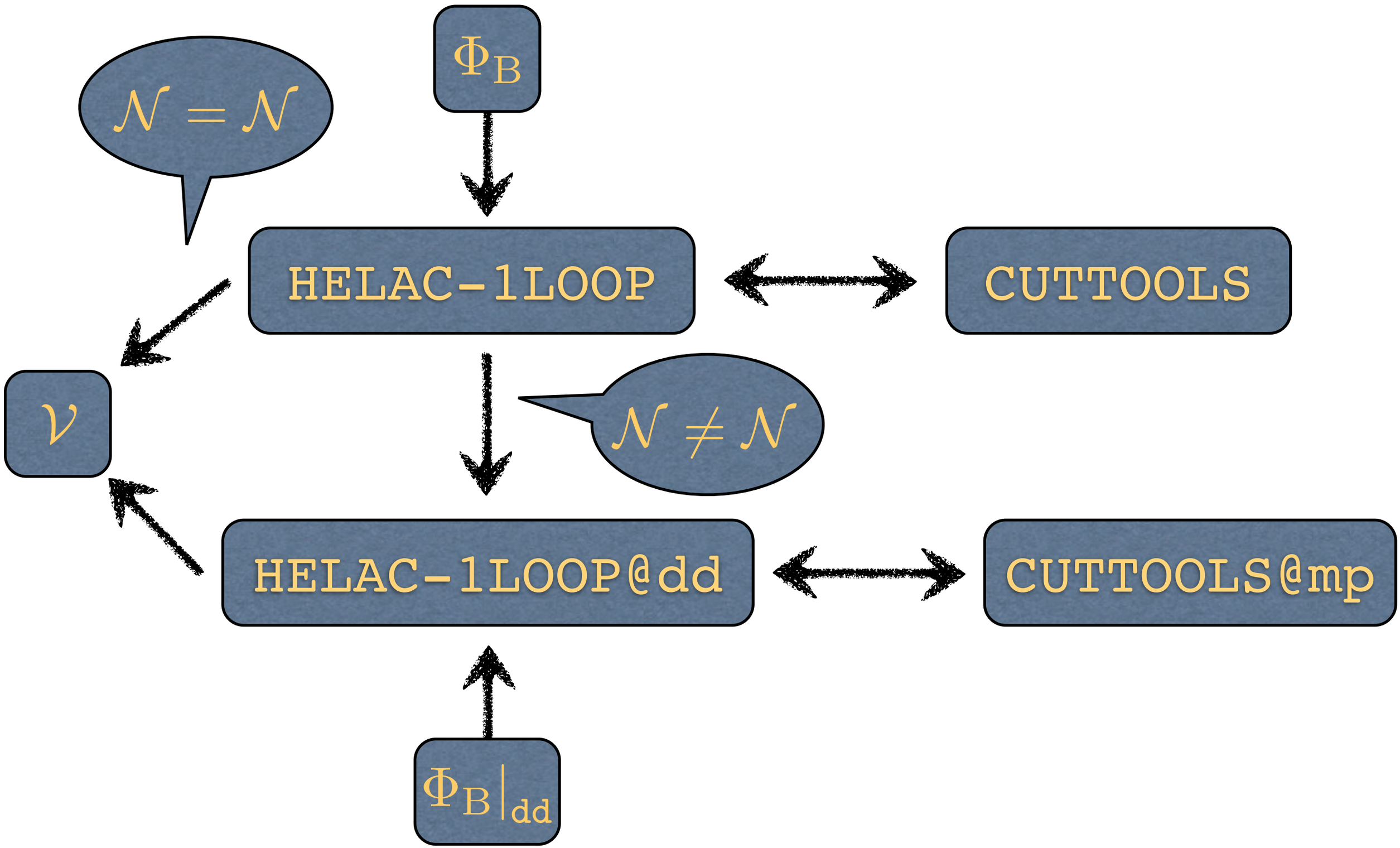
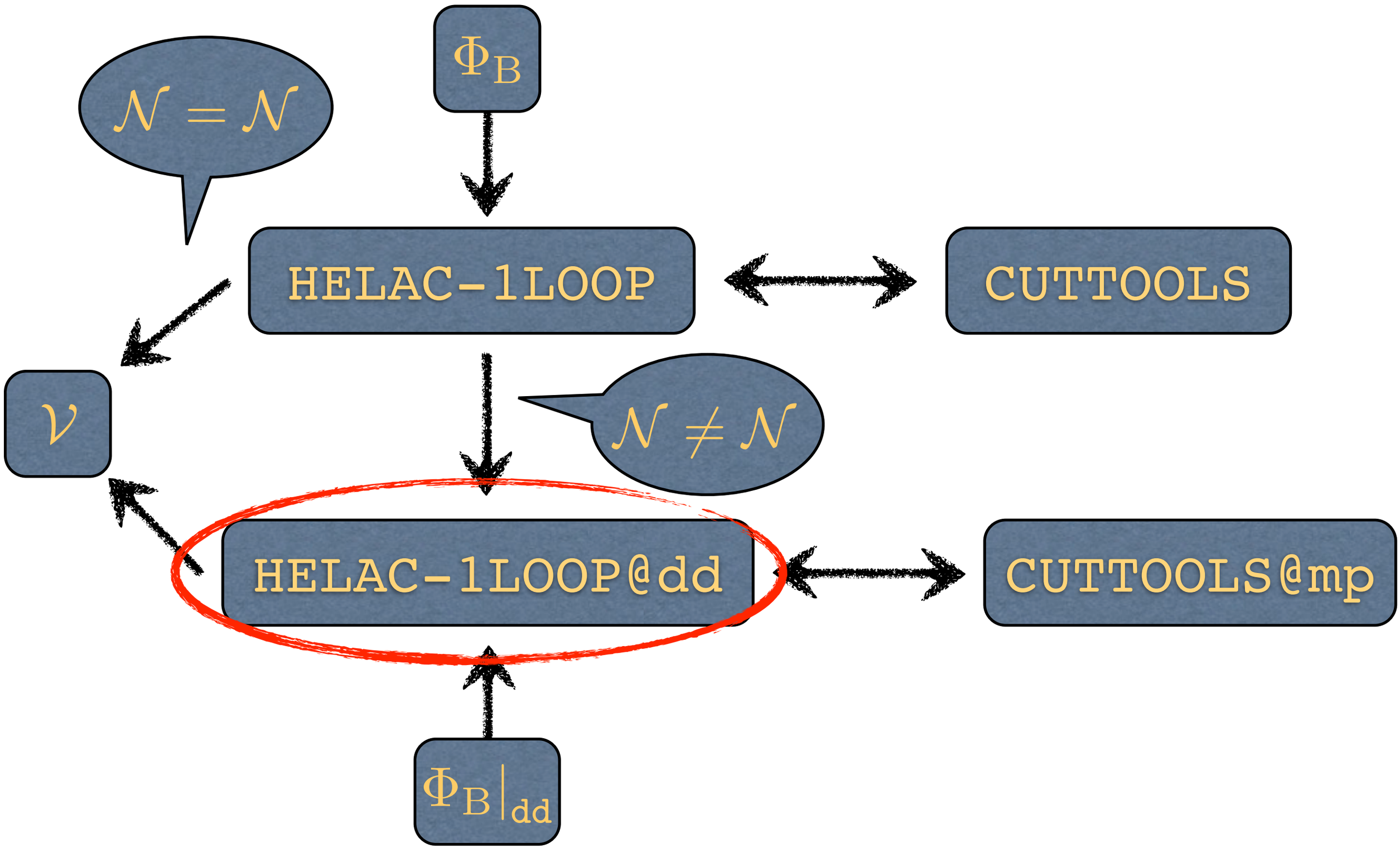


HELAC-1LOOP@dd



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

TWiki > DbTheory Web > TtjProd (2011-07-15, AdamKardos)

Top quark pair production in association with a jet

This page contains those event files which concern top quark pair production with a jet. The used code can be found here: ttj.tgz.

TeVatron @ 1.96 TeV

1. m_t = 172 GeV , \mu = \mu_R = \mu_F = m_t, CTEQ6M PDF, 2-loop running \alpha_s, p_{\bot,\mathrm{min}} = 5 GeV . This set was taken for comparison with Melnikov and Schulze(arXiv:1004.3284). ttj-tev-01.tgz (315 Mb)
2. m_t = 174 GeV , \mu = \mu_R = \mu_F = m_t, CTEQ6M PDF, 2-loop running \alpha_s, p_{\bot,\mathrm{min}} = 5 GeV . This set was taken for comparison with Dittmaier, Uwer and Weinzierl(arXiv:0810.0452). ttj-tev-02.tgz (152 Mb)

LHC @ 7 TeV

1. m_t = 172 GeV , \mu = \mu_R = \mu_F = m_t, CTEQ6M PDF, 2-loop running \alpha_s, p_{\bot,\mathrm{min}} = 5 GeV . To reproduce the predictions of arXiv:1101.2672. ttj-lhc-01.tgz (410 Mb)
2. m_t = 172 GeV , \mu = \mu_R = \mu_F = m_\bot (for a precise definition please see arXiv:1101.2672), CTEQ6M PDF, 2-loop running \alpha_s, p_{\bot,\mathrm{min}} = 5 GeV . To reproduce the predictions of arXiv:1101.2672. ttj-lhc-02.tgz (397 Mb)

Processes in PowHel

by Garzelli, Kardos, Papadopoulos, ZT

✓ $t\bar{t}$ and $W^+W^-b\bar{b}$ [to appear]

✓ $t\bar{t}$+H/A [arXiv: 1108.0387 and 1201.3084]

✓ $t\bar{t}$+Z [arXiv: 1111.0610 and 1208.2665]

✓ $t\bar{t}$+jet [arXiv: 1101.2672]

✓ $t\bar{t}$+$W^{\pm}$ [arXiv: 1208.2665]

• $t\bar{t}$+X [in preparation]

Checks of the NLO computation

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- ✓ Check (implementation of) real emission squared matrix elements in POWHEG-BOX to those from HELAC-PHEGAS/MADGRAPH in randomly chosen phase space points

- ✓ Check (implementation of) virtual correction in POWHEG-BOX to those from HELAC-1Loop/GOSAM/MADLOOP in randomly chosen phase space points

- ✓ Check the ratio of soft and collinear limits to real emission matrix elements tends to 1 in randomly chosen kinematically degenerate phase space points

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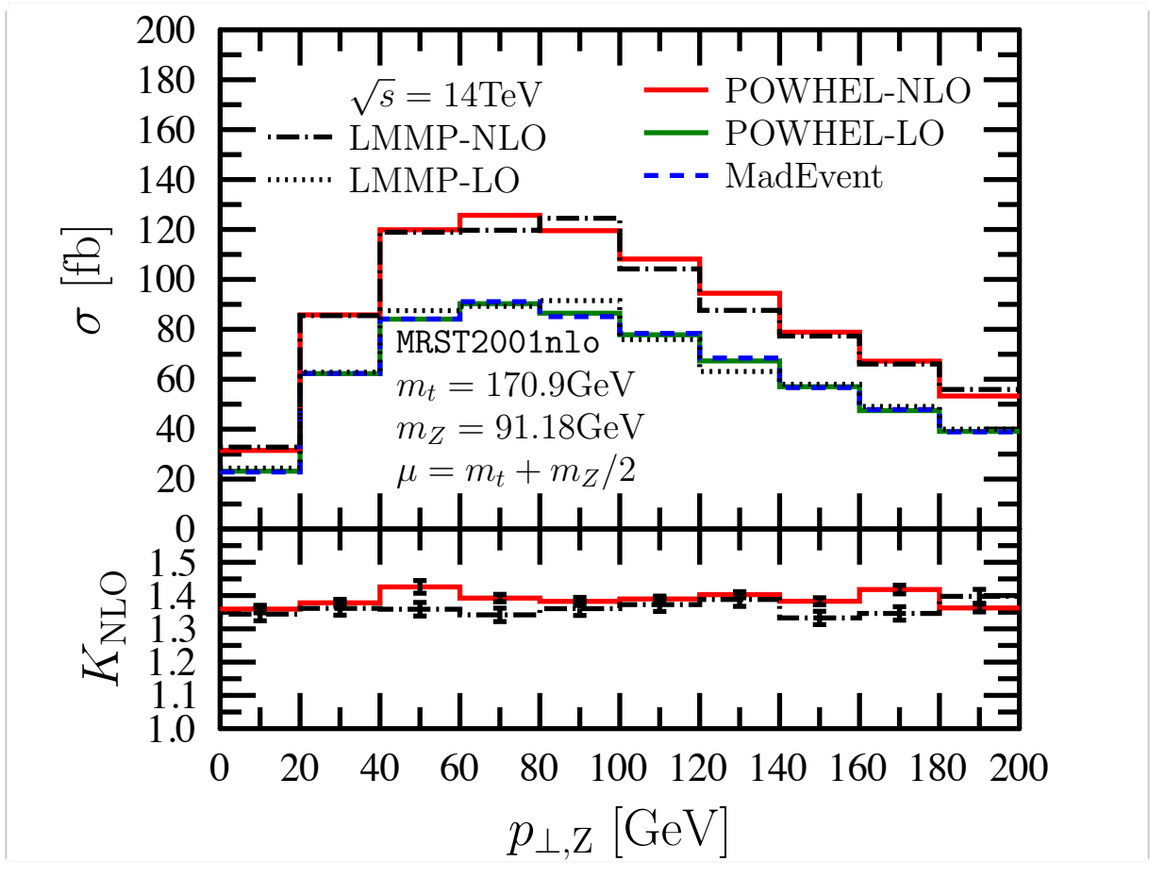
Each PowHel computation is an independent one of other NLO predictions for the process

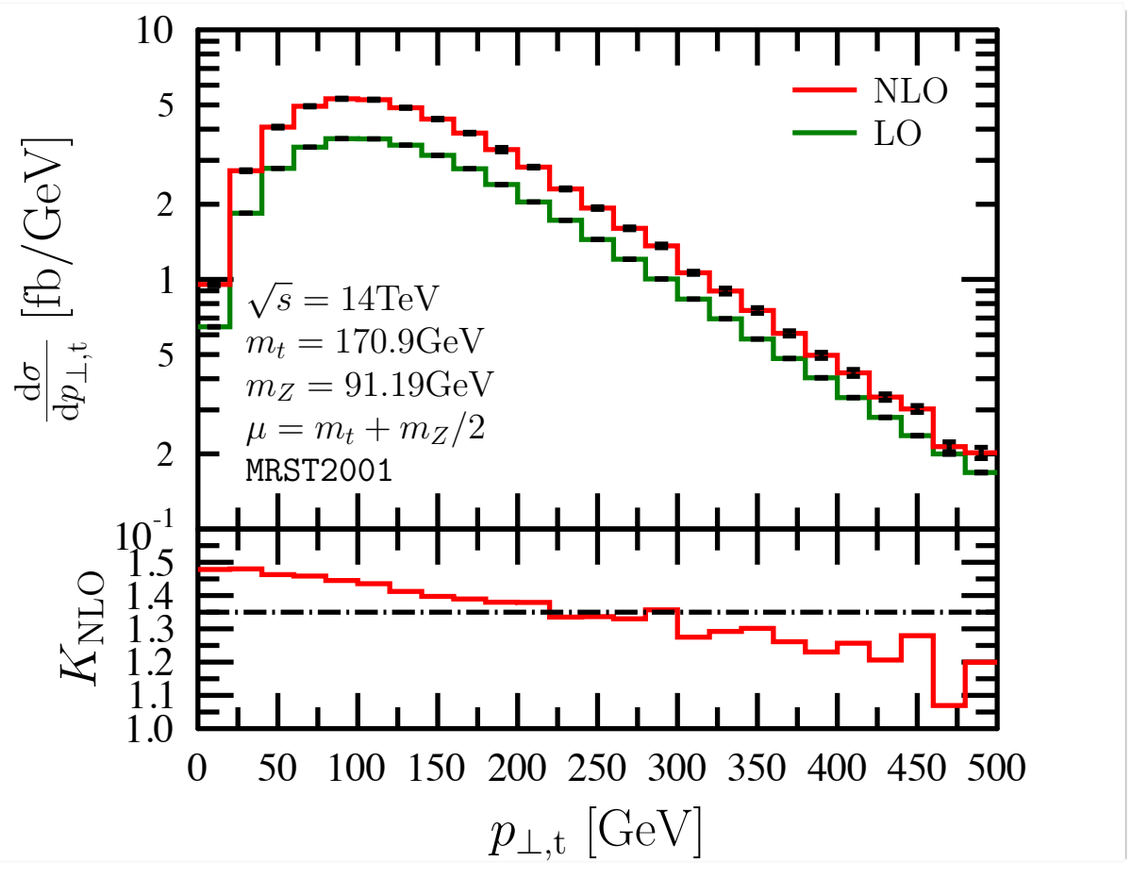
(see e.g. arXiv: 1111.0610 for tT Z production)

tTV-production (V=Z,W±)

$pp \to t\bar{t}+V$ checks

- NLO predictions for tTW^+ and tTW^- agree with those by J. Campbell and K. Ellis,
JHEP 1207 (2012) 052 [arXiv:1204.5678]
- NLO predictions for ttZ a bit larger than those by A. Lazopoulos, T. McElmurry, K. Melnikov, F. Petriello,
Phys. Lett. B666 (2008) 62 [arXiv:0804.2220]





pp→ tt̄+V checks

$pp \to t\bar{t}+V$ checks

- Comparison of LHEF to NLO made for the 7 TeV LHC

  - fixed scale $\mu = m_t + m_W/2$ and PDG parameters, CTEQ6M

Accuracy of the POWHEG cross section

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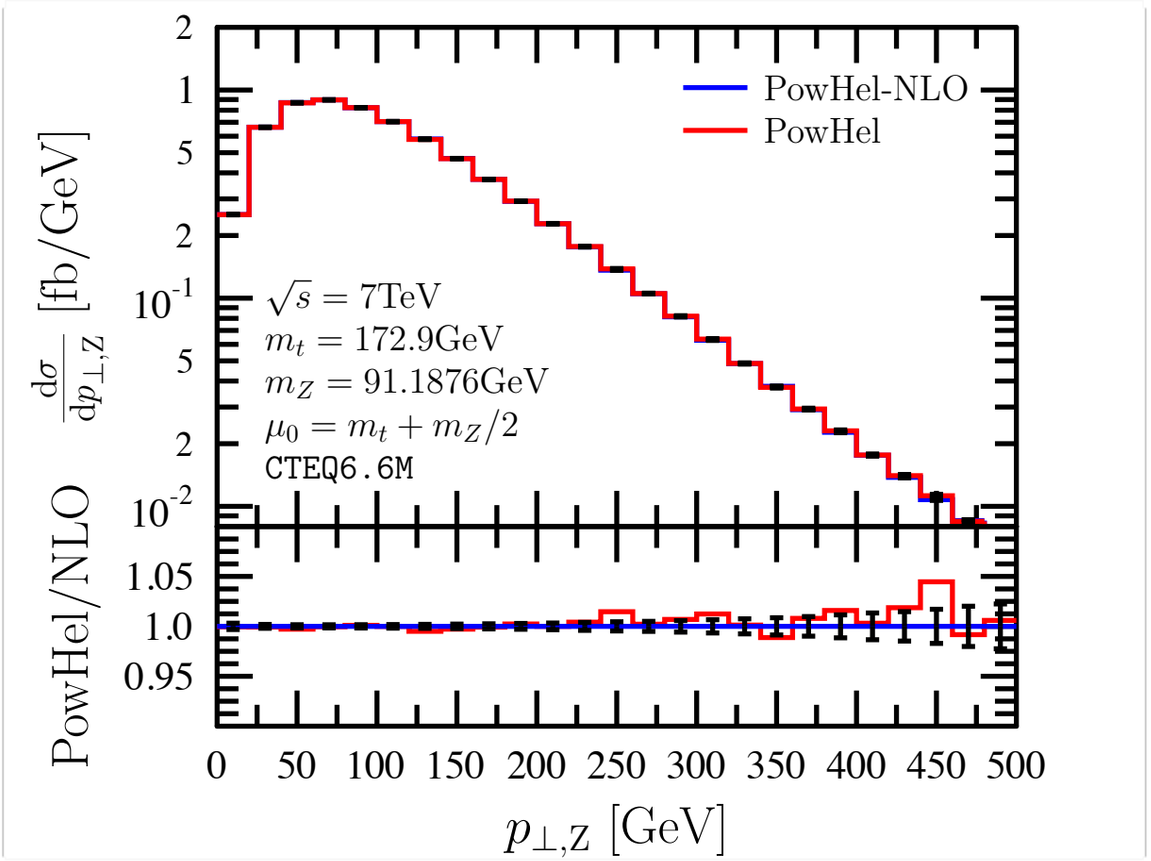
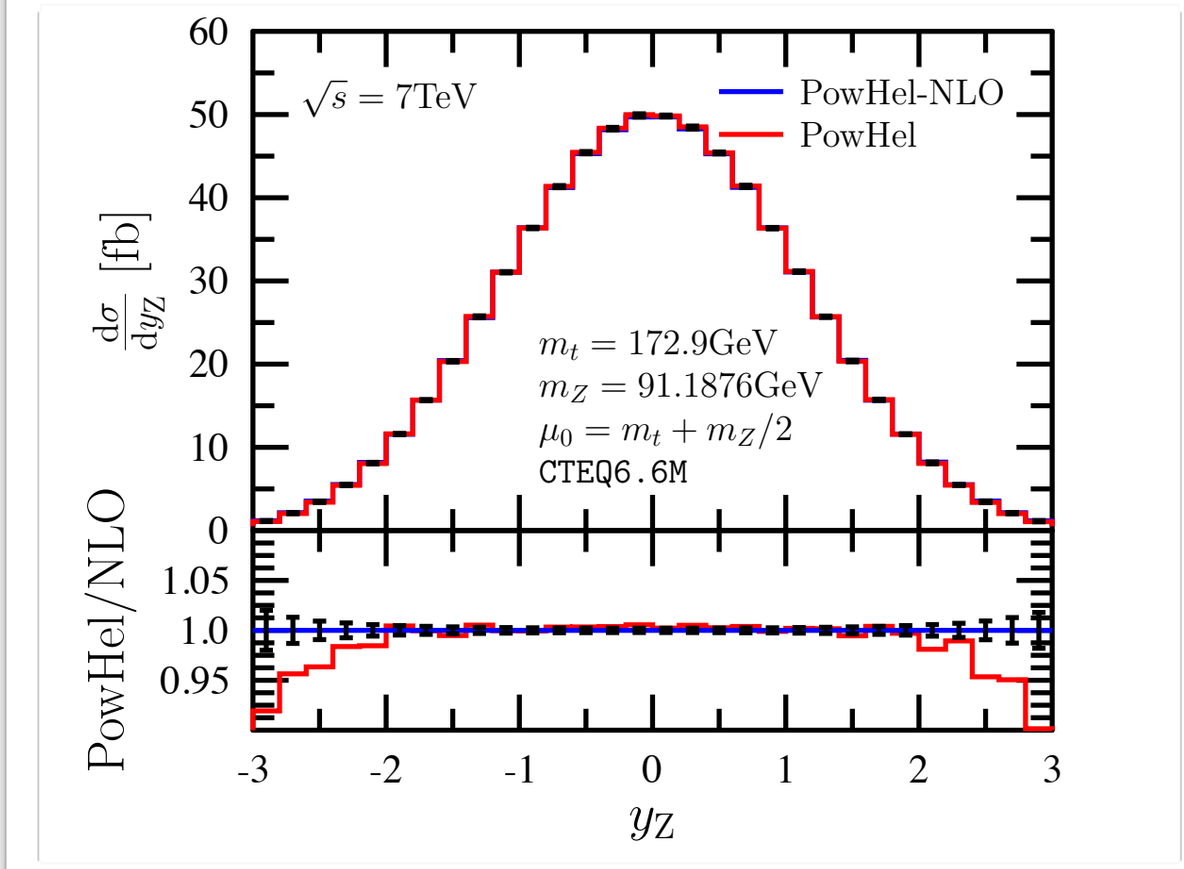
Difference scales with the NLO K-factor

pp→ t$\bar{t}$+Z: LHE vs NLO



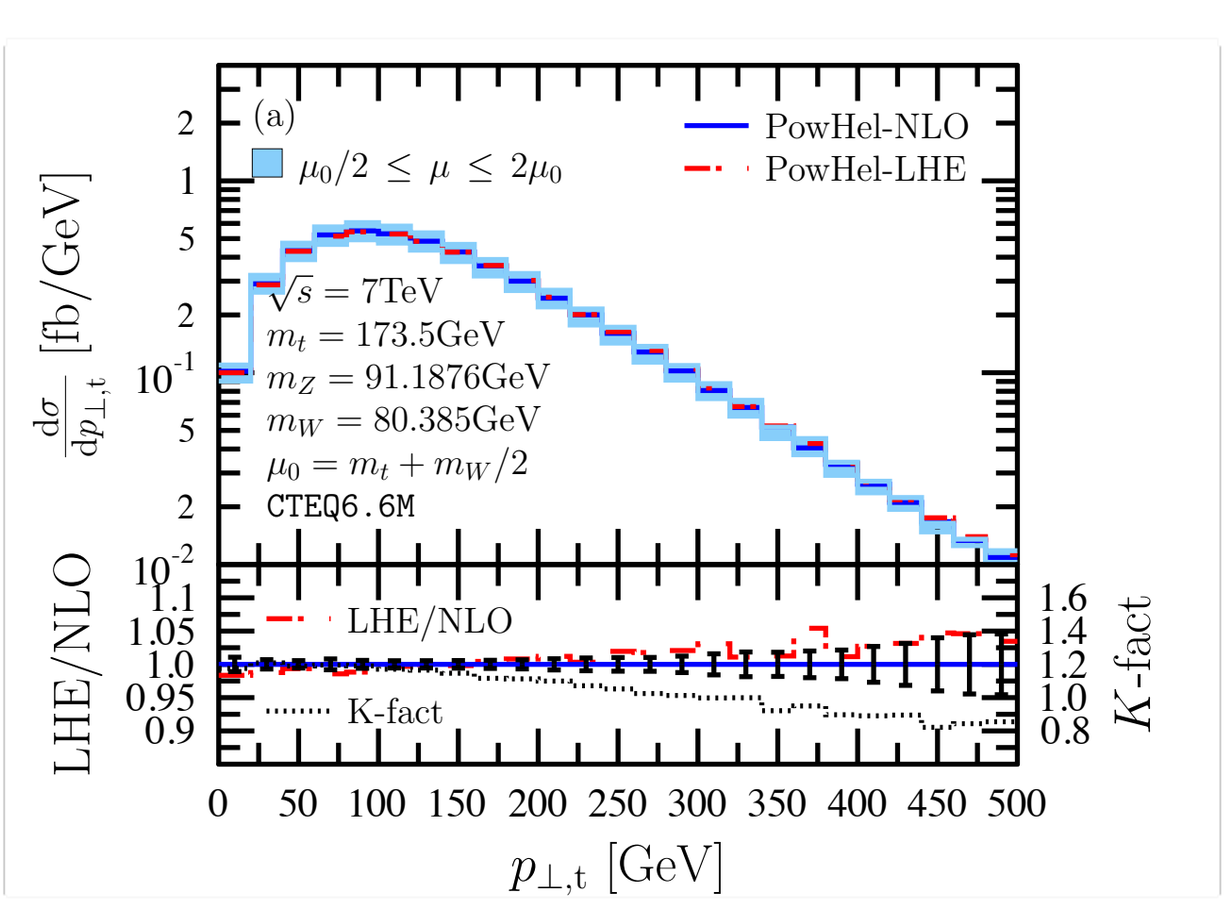


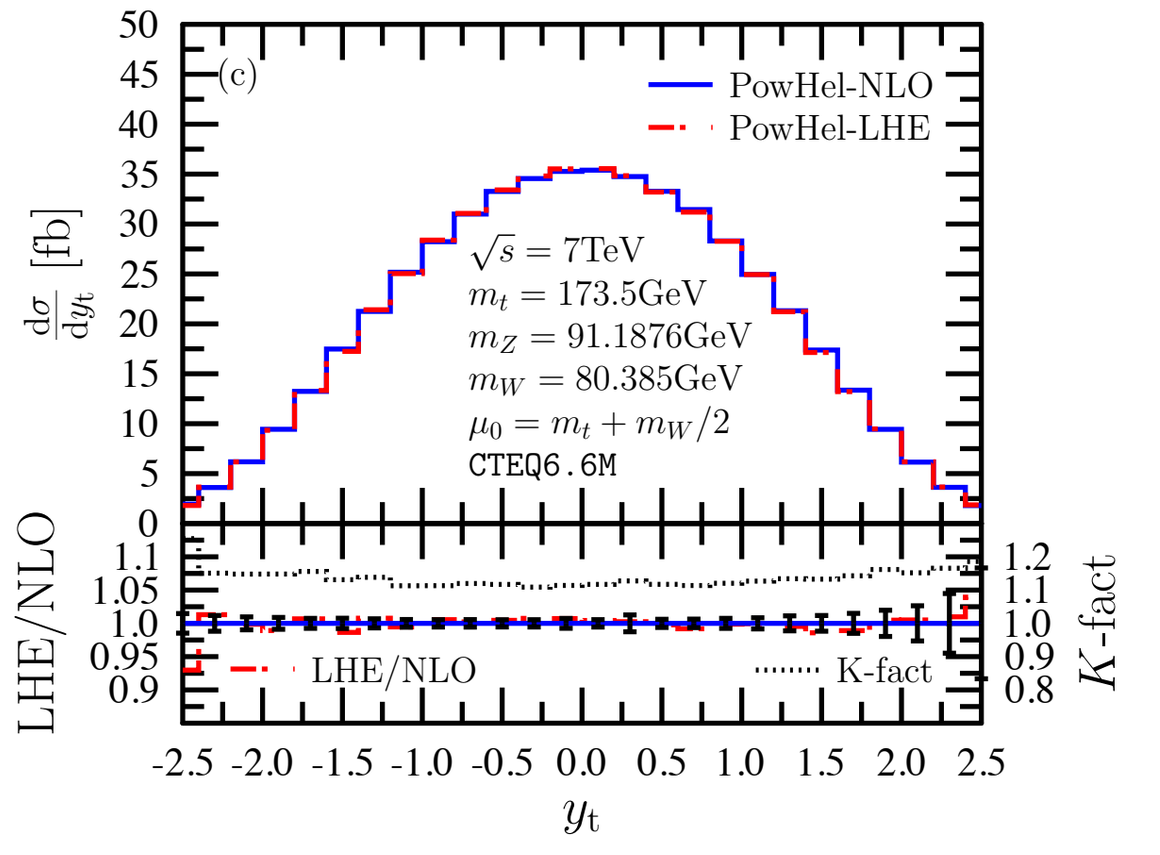
Transverse momentum and rapidity distribution for the Z at 7TeV LHC

agreement is within 1%, Remember: $\sigma_{LHE} = \sigma_{NLO} + O(\alpha_s)$ Finite

[inclusive NLO K-factor is ~1.4]

pp→ tt̄+W⁺: LHE vs NLO





Transverse momentum and rapidity distribution for the t at 7TeV LHC

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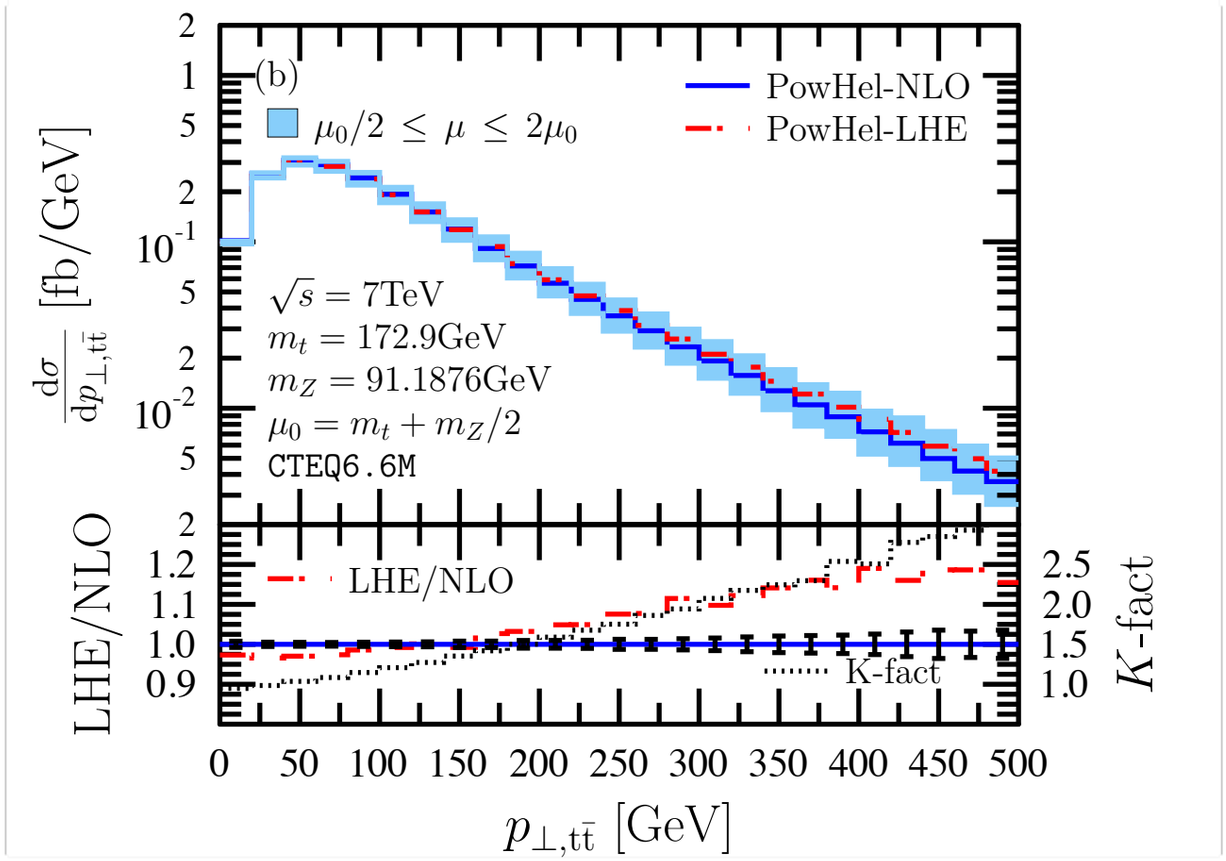
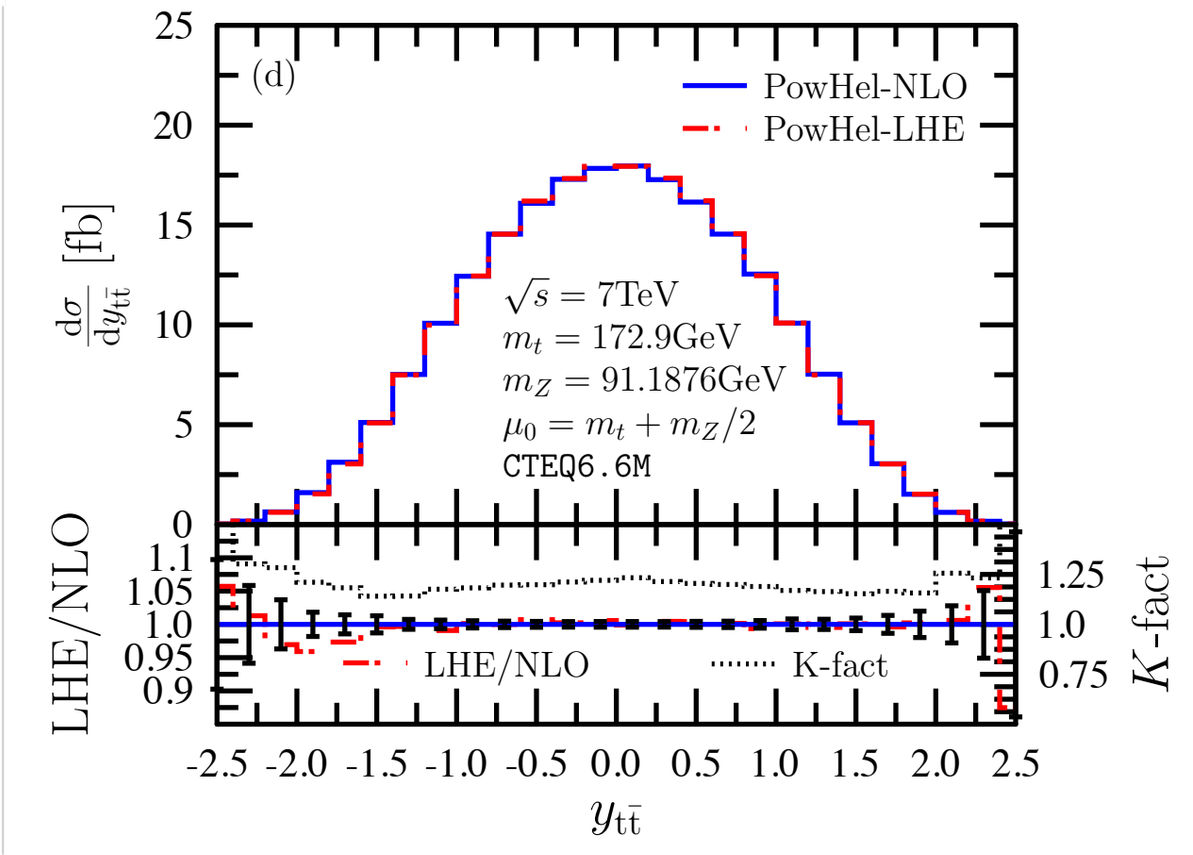
pp→ tt̄+W⁺: LHE vs NLO





Transverse momentum and rapidity distribution for the tT-pair at 7TeV LHC

difference correlates with K-factor,

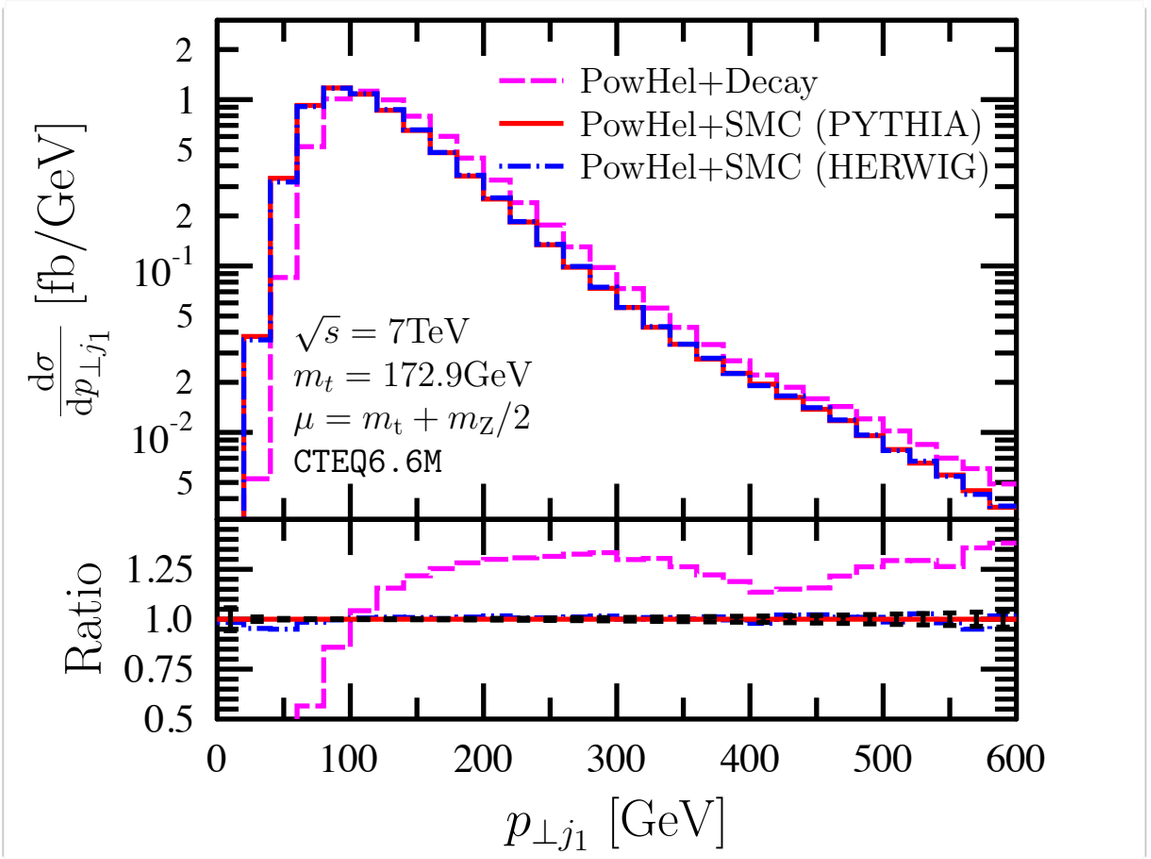
Remember: $\sigma_{LHE} = \sigma_{NLO} + O(\alpha_s)$ Finite

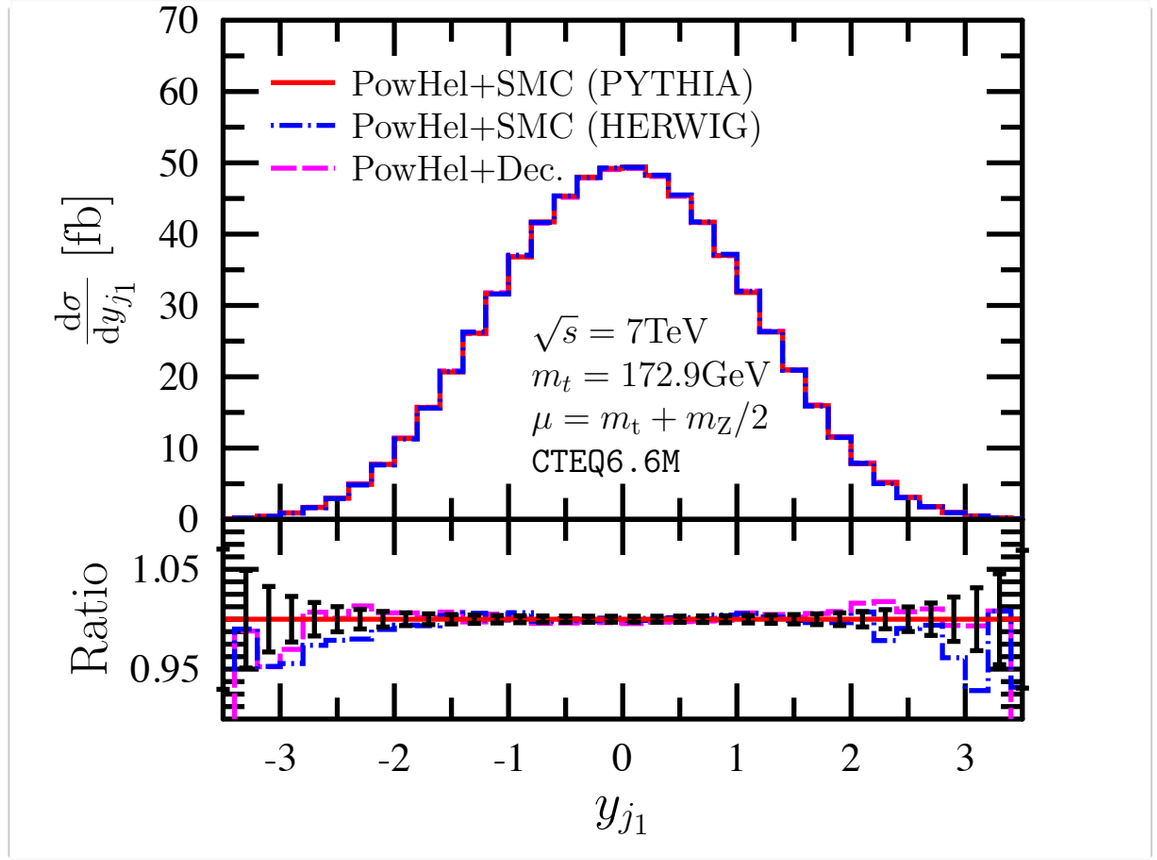
$pp \to t\bar{t}$, $WWbb\bar{b}$, $t\bar{t}+H, A$, jet

...similar agreement between NLO and LHE (discussed elsewhere)

Predictions

pp→ tt̄+Z: effect of the SMC

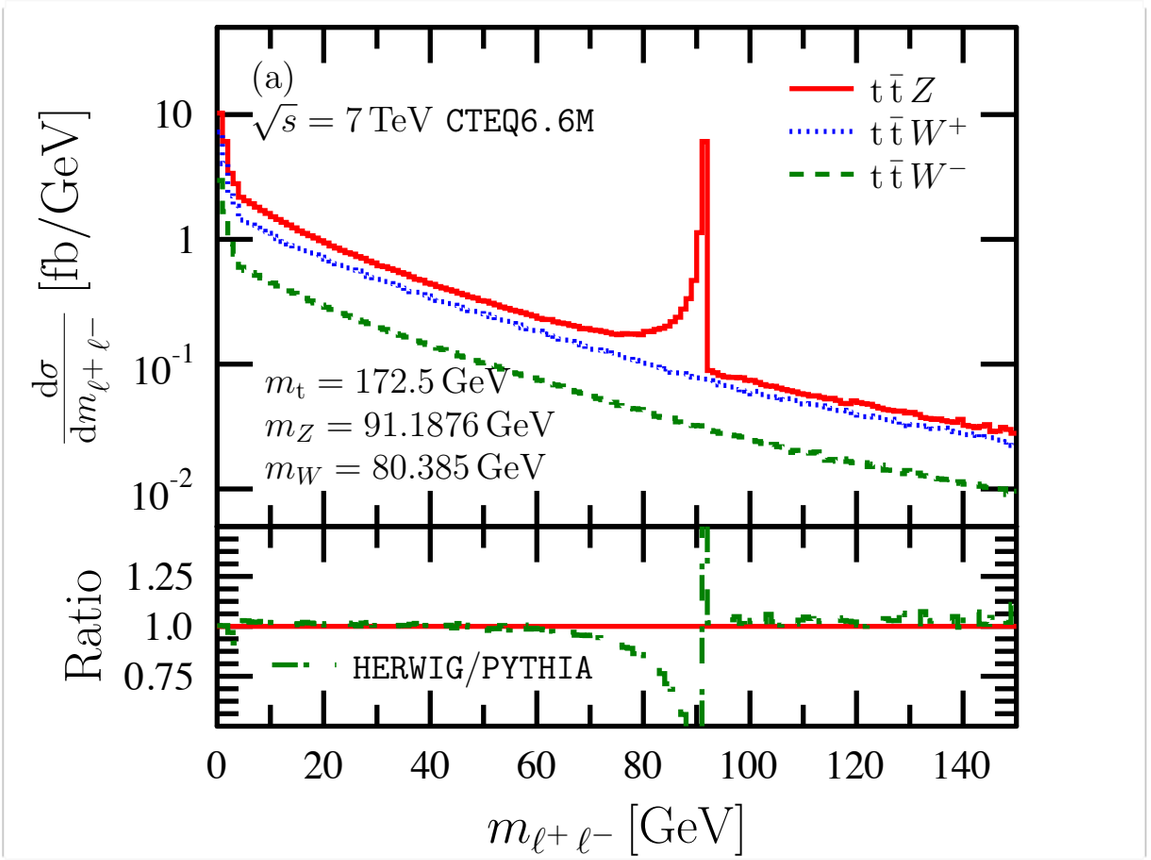


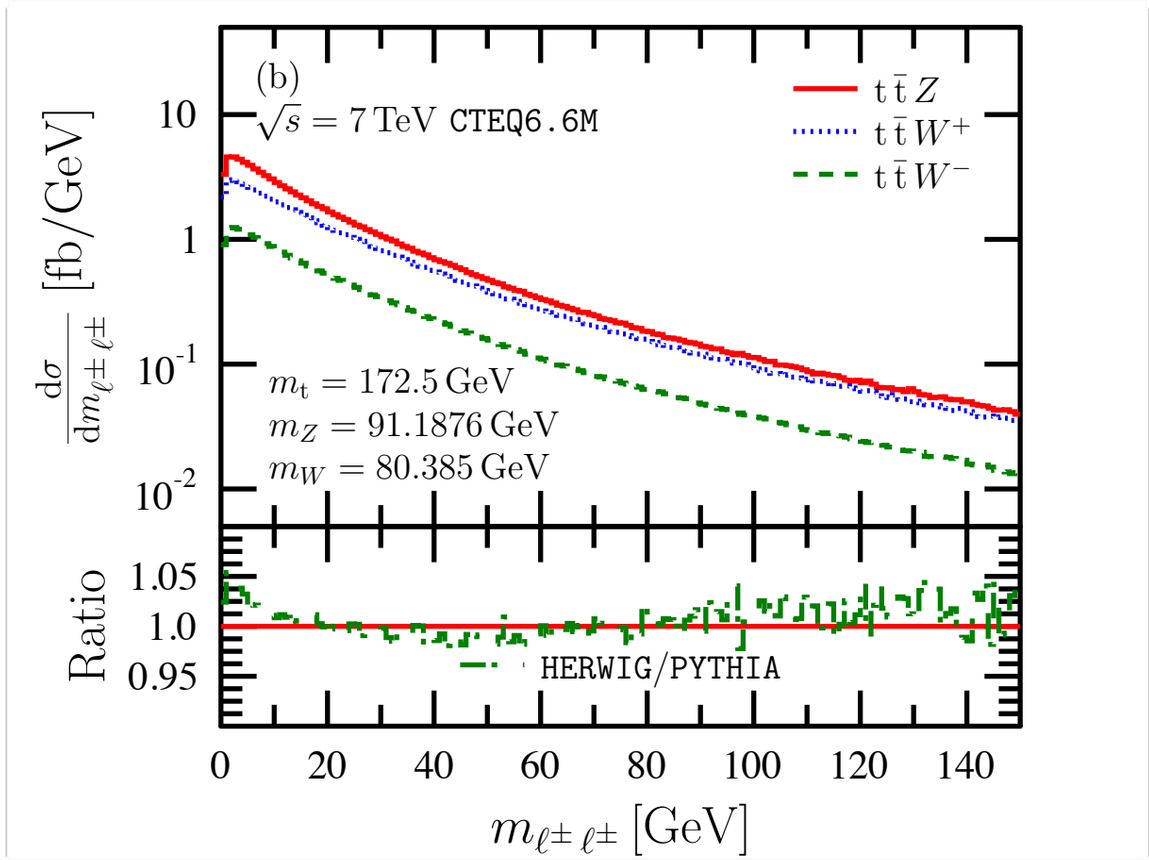


Transverse momentum and rapidity distribution for the hardest jet at 7TeV LHC

PS softens the $p_\perp$-spectrum, rapidity is hardly affected

pp→ tt̄+V: after PS, no cuts





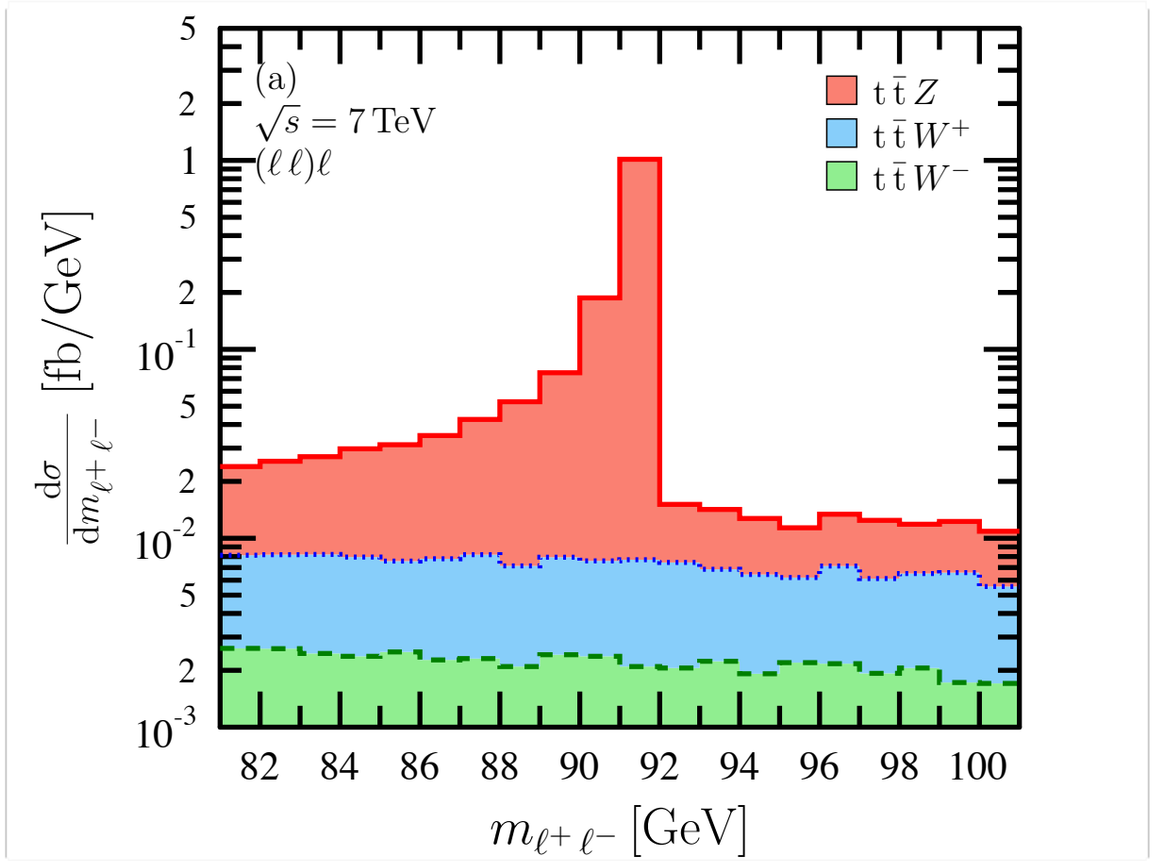
Invariant mass of all same flavour lepton-antilepton pairs and same-sign lepton and antilepton pairs at 7TeV LHC

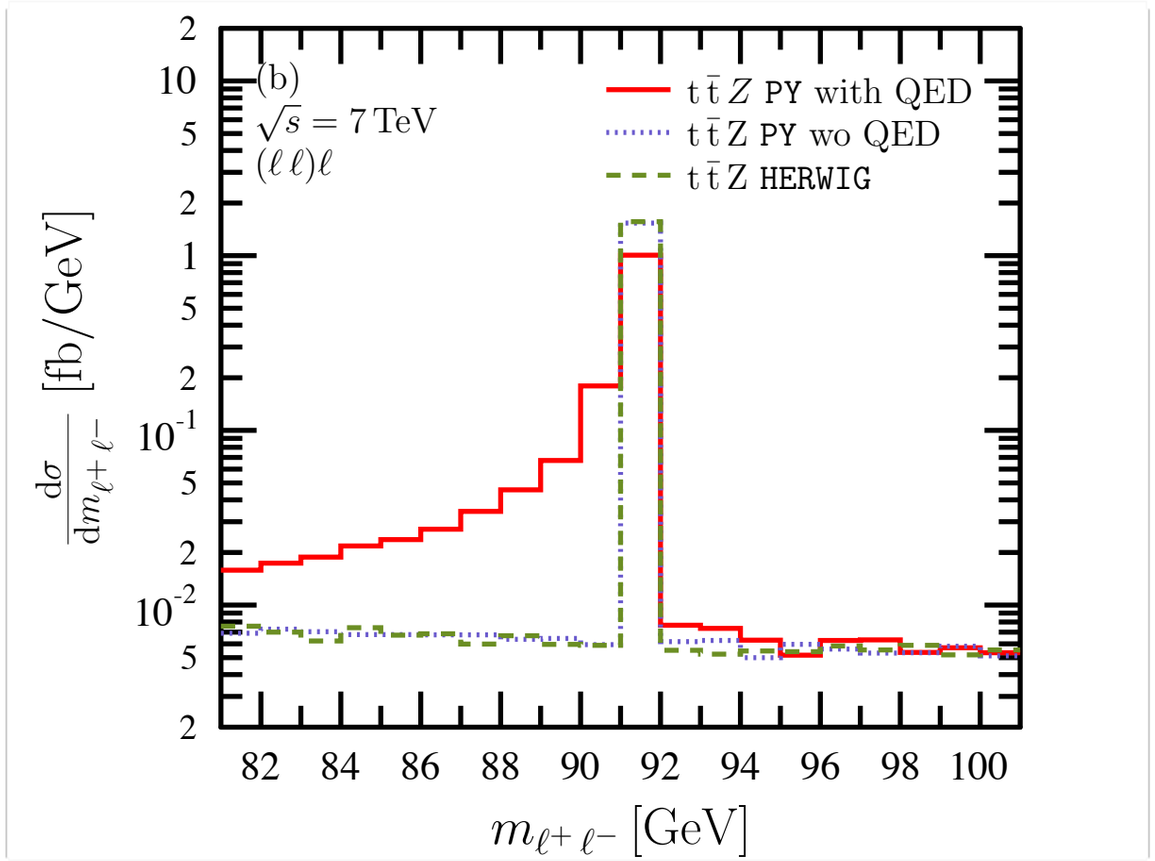
Selection of peak region used in trilepton analysis below

pp→ tt̄+V: trilepton channel

- Following experimental analysis done by CMS [CMS PAS TOP-12-014]
- Cuts favouring semileptonic decay of the tT-pair and same-flavour, opposite-sign lepton pairs from Z
- tTW contributions suppressed

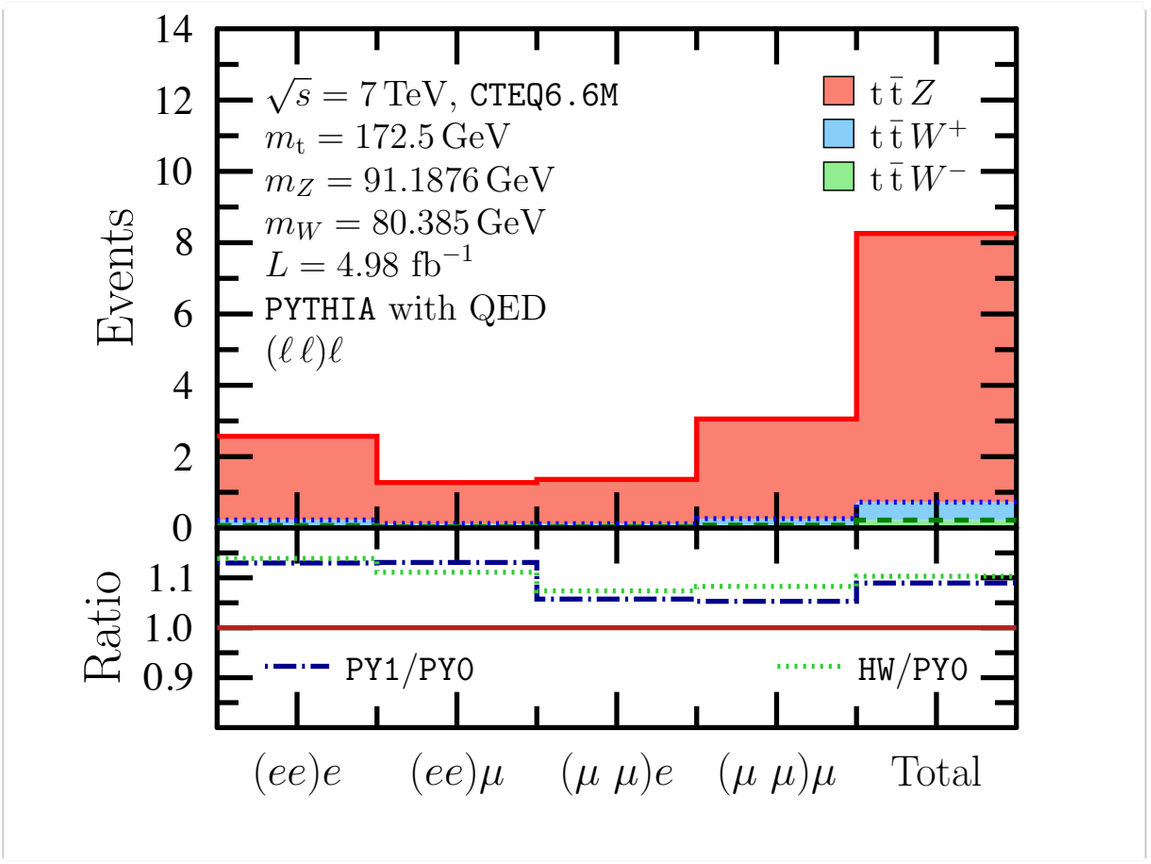
pp→ tt̄+V: trilepton channel





Invariant mass of reconstructed Z from same flavour lepton pairs at 7TeV LHC:
a) different channels accumulated b) different SMC

pp→ tt̄+V: trilepton channel



channel	prediction #of events	measured #of events
(e,e)e	2.57±0.02	$1^{+2.4}_{-0.8}$
(e,e)μ	1.27±0.02	$2^{+2.7}_{-1.2}$
(μ, μ)e	1.36±0.02	$2^{+2.7}_{-1.2}$
(μ, μ) μ	3.05±0.02	$4^{+3.2}_{-2.0}$
total	8.26±0.02	$9^{+4.1}_{-3.0}$

- Background from Z+jets, tT, diboson production is not included in prediction, estimated 2.9±0.8 events by CMS
- Largest difference in (e,e)e channel is related to e-reconstruction in the experiment (assumed 100% in prediction)
- b-tagging is by MCTRUTH in prediction

$pp \to t\bar{t}+V$: trilepton channel

channel	σ [fb] at 7 TeV	σ [fb] at 8 TeV	ratio
(e,e)e	0.516	0.762	1.52
(e,e)μ	0.255	0.388	1.52
(μ, μ)e	0.273	0.420	1.54
(μ, μ) μ	0.613	0.934	1.52
total	1.658	2.524	1.52

- At 8 TeV the cross section is 52% larger (in all channels)
- Differential distributions can be rescaled by a factor 1.52 with good appriximation
- Total of 50 events are predicted for integrated luminosity L=20 fb^{-1} (by the end of 2012)

$pp \to t\bar{t} + H, A, \text{jet}, W\,W\,b\,\bar{b}$

...are also done within LHCPhenonet,

but discussed elsewhere

Conclusions and outlook

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- ➡ Predictions for LHC with NLO+PS accuracy

Implemented Processes

✓t T and WWbB

✓t T + Z

✓t T + H/A

✓t T + j

✓t T + W

✳t T + … (not yet public)

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The end