Hadroproduction of a charged vector boson pair in association with a b-quark pair at NLO accuracy matched with PS

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Motivation

“The t-quark is special”

t-quark: potential tool for discovery

- The t-quark is heavy, Yukawa coupling ~1
  m_t [GeV]=173.34±0.64 (LHC+TeVatron, 2014)
  (⇒ y_t=0.997±0.003, $m_t\, m_Z$ = $(125.7\pm0.3)^2$ GeV^2)
- measuring its mass is important as it has direct implications on the Higgs sector of the SM and its extrapolation to high energies

Stability bound of the SM vacuum:

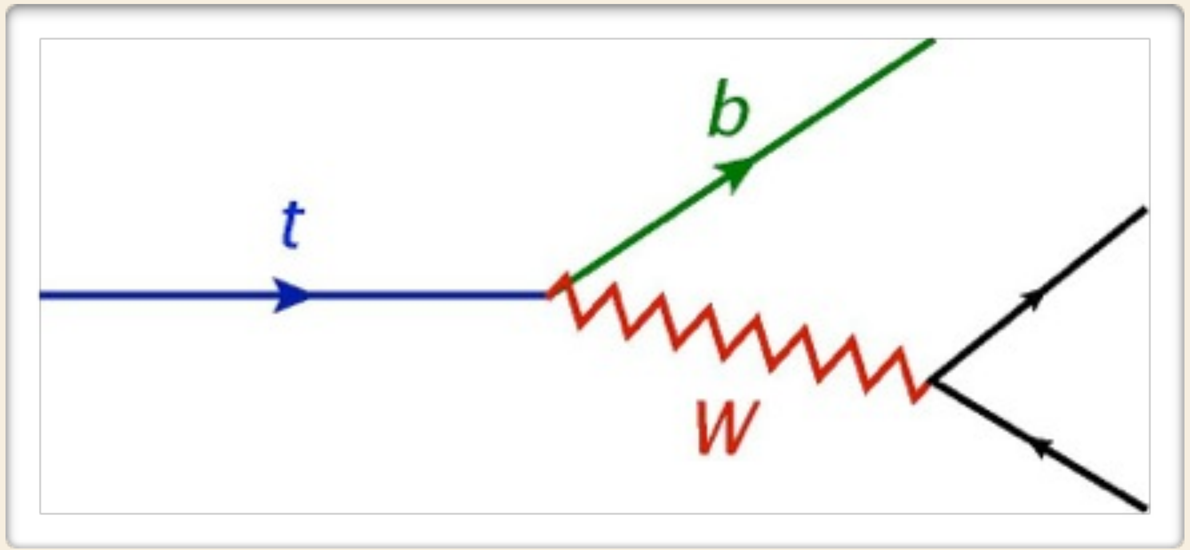
$$M_h > 129.6\,\mathrm{GeV} + 2.0(M_t - 173.34\,\mathrm{GeV}) - 0.5\,\mathrm{GeV}\,\frac{\alpha_3(M_Z) - 0.1184}{0.0007} \pm 0.3\,\mathrm{GeV}$$

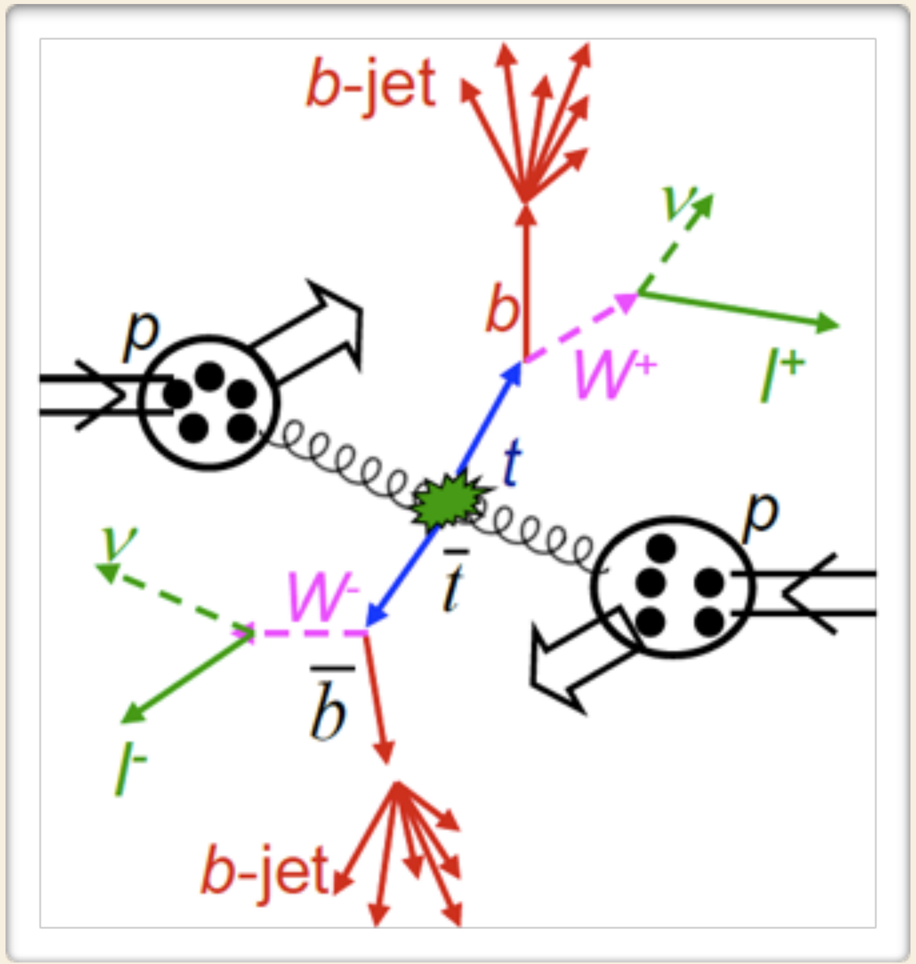
[Buttazzo et al:1307.3536]

t-quark decays before hadronization

...almost exclusively into W^+b

$$|V_{tb}|^2 \gg |V_{ts}|^2, |V_{td}|^2$$





the t-quark has to be reconstructed from its decay products rendering measurement of m_t highly non-trivial

$m_{\ell b}$ method for measuring m_t

$$m_{\rm est}^2 = m_W^2 + \frac{2\langle m_{\ell\, b}^2\rangle}{1-\langle\cos\theta_{\ell\, b}\rangle}$$

at LO in QCD:

$$\langle m_{\ell\, b}^2\rangle = \frac{m_{\rm t}^2 - m_W^2}{2}\Big(1-\langle\cos\theta_{\ell\, b}\rangle\Big)$$

$\Rightarrow$ $m_{\rm est} = m_{\rm t}$ ($\theta_{\ell b}$ is measured in the rest frame of W)

violated by several effects

- higher order radiation in production and decay
- finite width effects
- imperfect pairing of charged lepton and b-quark
- acceptance cuts on leptons, jets and missing energy
- experimental issues (e.g. mis-identification)

} can be studied in QCD

QCD studies beyond LO

- NLO production with NLO decay in narrow width approximation

  [Biswas, Melnikov, Schulze arXiv:1006.0910, Campbell, Ellis arXiv:1204.1513]

- WWbB production at NLO accuracy

  [Denner, Dittmaier, Kallweit, Pozzorini arXiv:1012.3975, 1207.5018, Bevilacqua, Czakon, van Hammeren, Papadopoluos, Worek arXiv:1012.4230, Heinrich, Maier, Nisius, Winter arXiv:1312.6659]

- WWbB production at NLO accuracy including single top channel (with finite m_b)

  [Frederix: 1311.4893, Cascioli, Kallweit, Maierhofer, Pozzorini arXiv:1312.0546]

Conclusion:

Apart from few observables
NLO production and decay
combined in NWA is a robust
prediction at fixed order

further corrections are several percent

How about

parton shower, decay and hadronization?

[Garzelli, Kardos and Trócsányi, arXiv: 1406.2324, Campbell, Ellis, Nason and Re, arXiv: 1412.1828]

PowHel framework

HELAC-NLO

[Bevilacqua et al, arXiv: 1110.1499]

POWHEG-BOX

[Alioli, Nason, Oleari, Re, arXiv: 1002.2581]

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

Three approximations

1. Complete at given order in PT: both resonant and non-resonant diagrams
2. Narrow-width approximation (NWA): only resonant contributions (spin correlations kept)
3. Decay-chain approximation (DCA): on-shell production times decay (off-shell and spin-correlation effects are lost)

"3" implemented naturally in NLO+SMC

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increasing complexity ↑

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decreasing precision ↓

"3" implemented naturally in NLO+SMC

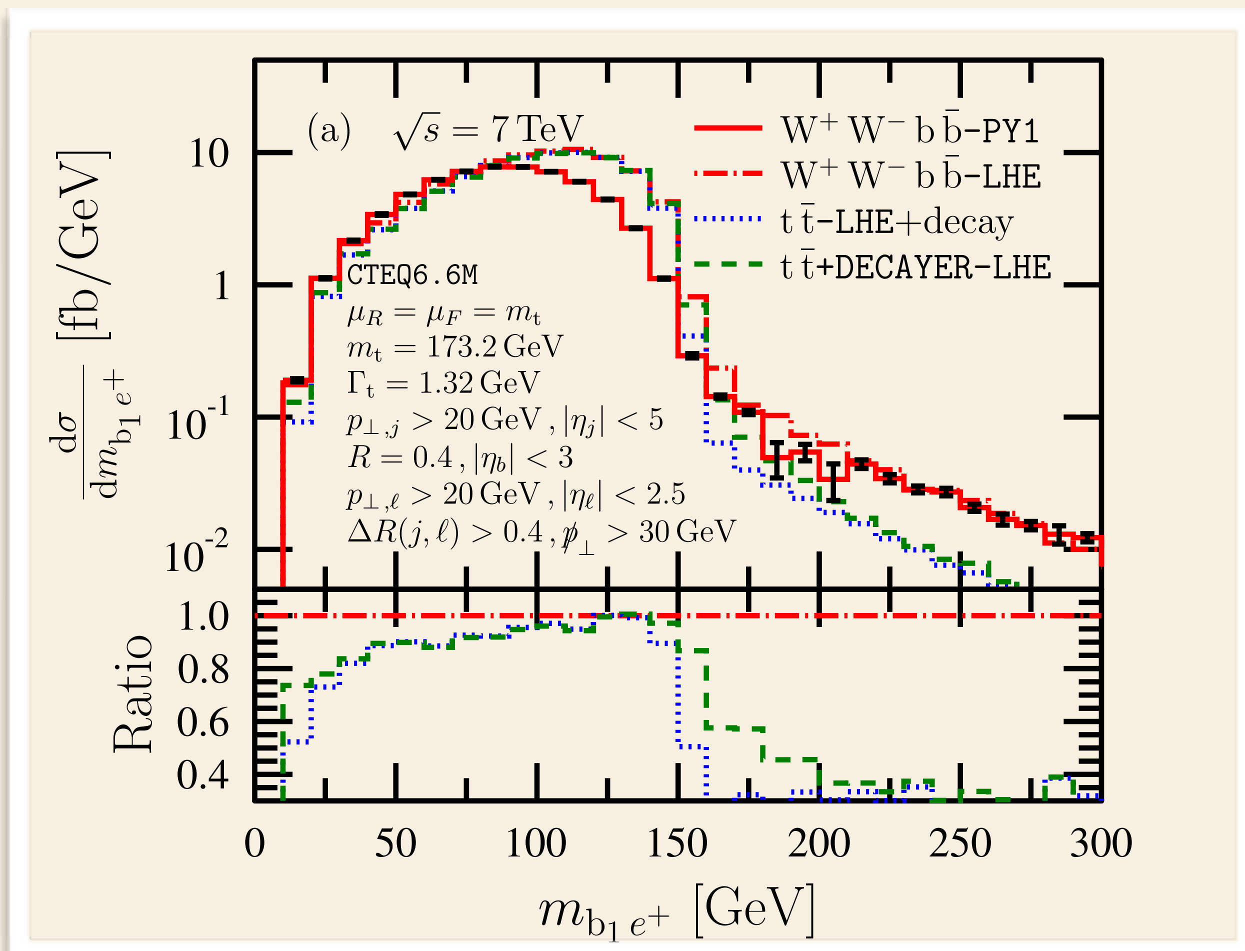
QCD studies beyond LO

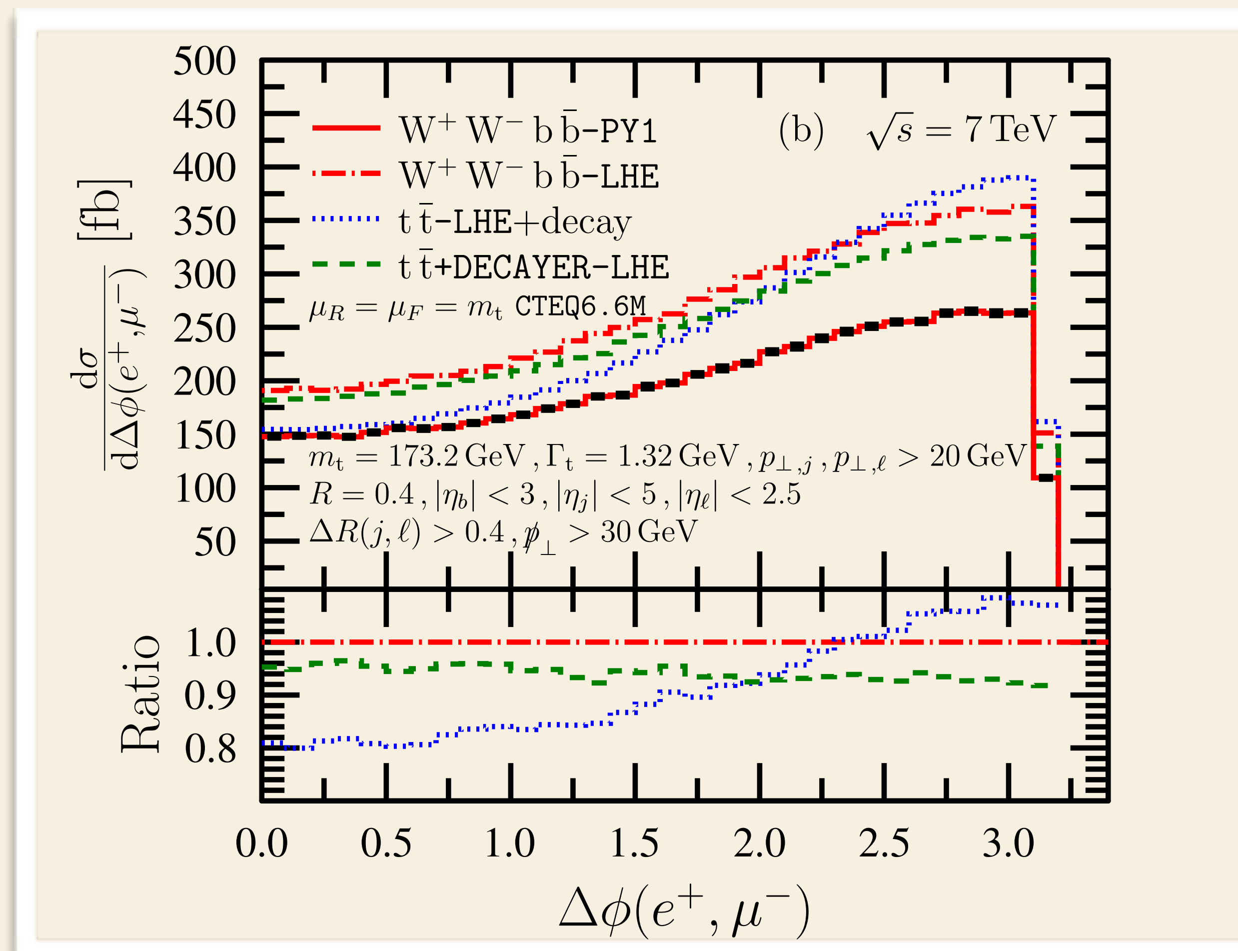
- Decay at ME level:
  - resonant, non-resonant graphs with spin correlations and finite width effects, complex mass scheme
  - large CPU time
- Decay in SMC (DCA):
  - on-shell heavy objects
  - easy to evaluate
  - no spin correlations, no off-shell effects
- Decay with DECAYER (NWA):
  - post event-generation run
  - with spin correlations and finite width effects
  - CPU efficient

sample distributions with most interesting changes

a) invariant mass of the hardest *b*-jet and hardest isolated positron
b) azimuthal separation between the hardest isolated positron and muon

Effect of different approximations on pre-showered events



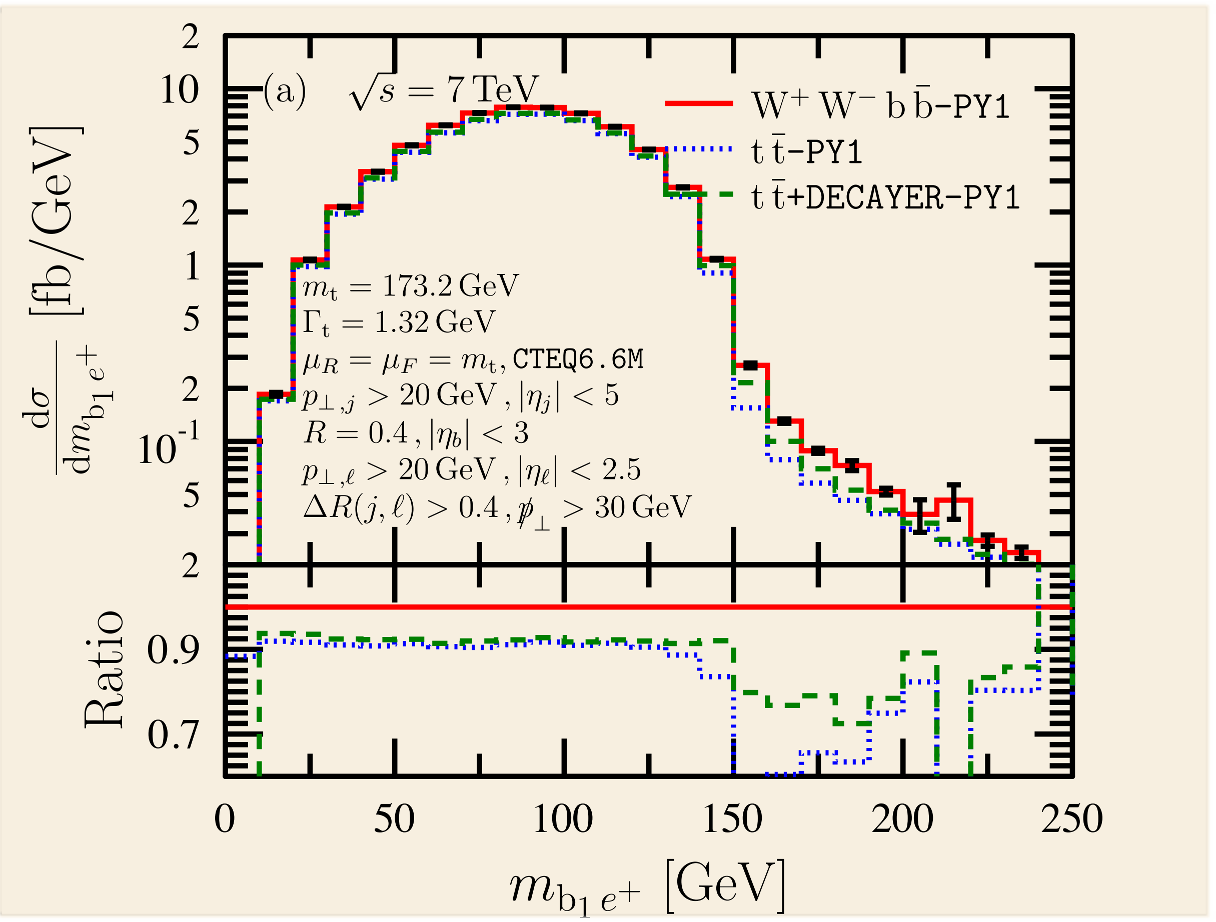


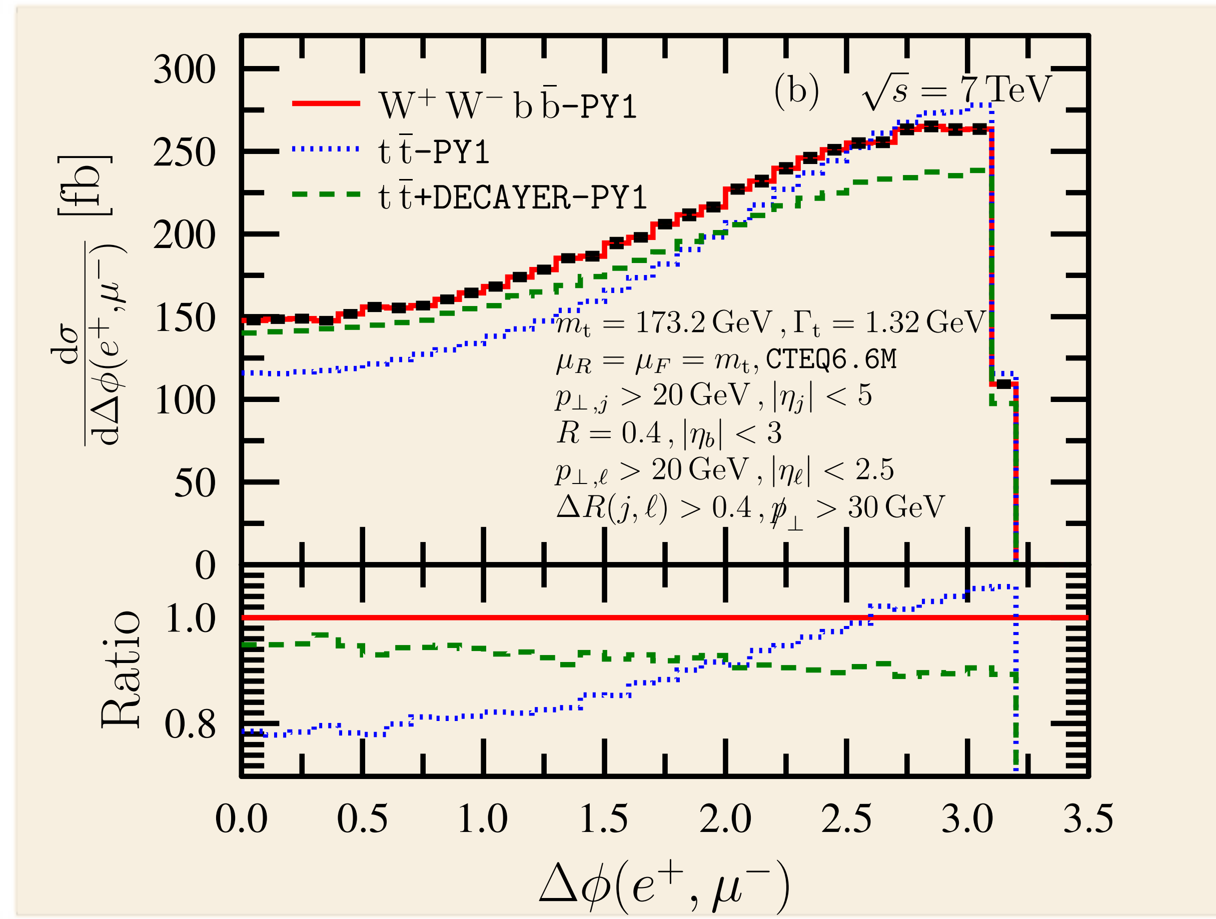
at LO: $m_t^2 = p_t^2 = m_{W^+}^2 + 2p_{e^+}p_b + 2p_{\nu_e}p_b$; $m_{e^+b} \leq \sqrt{m_t^2 - m_W^2 - m_{\nu_e b}^2} \simeq 153\,\mathrm{GeV}$,

a) large increase above LO threshold in WWbB, all three give very similar xsections near peak

b) DECAYER catches spin correlations well

Effect of different approximations after full SMC

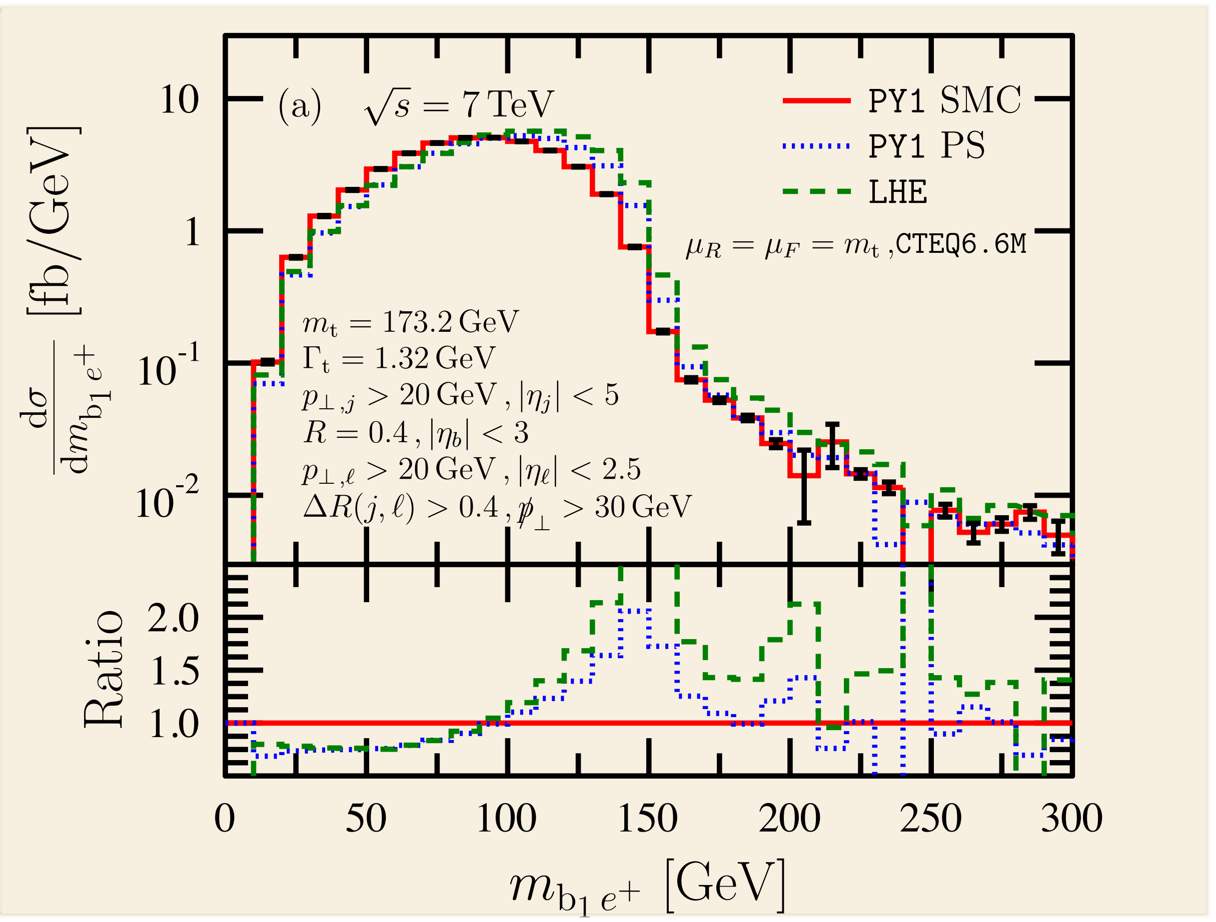


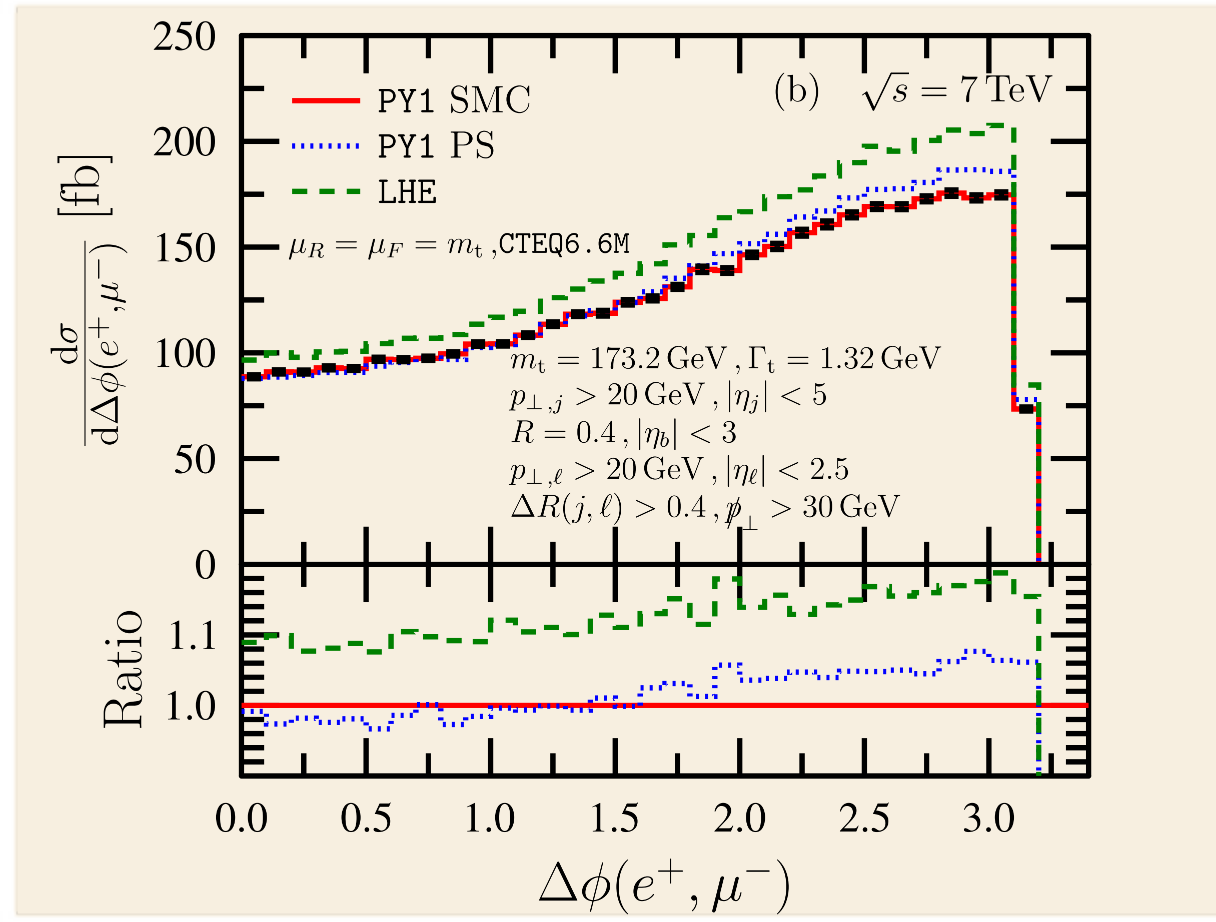


a) uniform increase in WWbB below LO threshold

b) SMC does not change the picture seen on LHEs

Effect of the parton shower on full WWbB final state





a) PS has small effect, hadronization has larger

b) PS means a uniform decrease of 10%

(caveat: B hadrons were not kept stable)

Conclusions

- Predictions presented for hadroproduction of WWbB final states
- Predictions presented for hadroproduction of tT final states followed by decay of t-quarks in the
  - decay chain approximation
  - narrow width approximation
- Effects of PS are small except specific regions and observables
- Events are available on request or at http://grid.kfki.hu/twiki/bin/view/DbTheory/

Processes available in PowHel

✓ tT	[Kardos et al, arXiv:
✓ tT + Z	1111.0610,1111.1444,
✓ tT + W	1208.2665,
✓ tT + H/A	1108.0387,
✓ tT + j	1101.2672,
✓ WWbB	1405.5659,
✓ tT + bB	1303.6291, 1408.0266
✓ tT, W + γ	1406.2324 Thursday 17:42
✓ tT + γ γ	1408.0278]

The end

Extra slides

Technical cuts for WWbB production

1. Minimum transverse momentum of b- and anti b quarks, $p_\perp > 2$ GeV

2. Minimum b anti-b invariant mass, $m_{b\,b} > 1$GeV.

Selection cuts in the dilepton channel

1. Each jet is required to have transverse momentum $p_{\perp,\mathrm{j}} > 20$ GeV and pseudorapidity $|\eta_{\mathrm{j}}| < 5$, otherwise it is not counted among the jets.
2. Each of the jets satisfying the 1st condition, to be classified as a *b*- or anti *b*-jet, is required to be b-tagged and have $|\eta_b| < 3$, due to the geometry of the tracking system.
3. We require at least one *b*-jet and one anti *b*-jet.
4. Each charged lepton is required to have $p_{\perp,\ell} > 20$ GeV and $|\eta_\ell| < 2.5$, otherwise it is not counted among the leptons.
5. We require at least one charged lepton and one charged anti-lepton, that are isolated from all jets by requiring $\Delta R(\ell, \mathrm{j}) > 0.4$ in the azimuthal angle-pseudorapidity plane. If there are more leptons that pass cut 4, those are kept without isolation from the jets.
6. We require a minimum missing transverse momentum $\mathrm{p}_{\perp,\mathrm{miss}} > 30$ GeV.