State of the art POWHEG generators for Top Mass Measurements at the LHC

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University of Zürich

In collaboration with:
S. Ferrario Ravasio, P. Nason and C. Oleari
based on [arXiv:1801.03944]

Universität Zürich[UZH]

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- Top mass measurements
  - Mass determinations based on the top quark reconstructed from its decay products in di-leptonic channel
- POWHEG generators
  - NLO+PS top-pair generators available in `POWHEG BOX` that implement top decay at different levels of accuracy
- State of the art
  - In experimental analyses: `POWHEG-BOX-V2`/hvq (2007)
  - In theory: $b\bar{b}4l$ (2016)
- Goal
  - Explore the potential impact of an upgrade of the top-pair generator on top mass extractions

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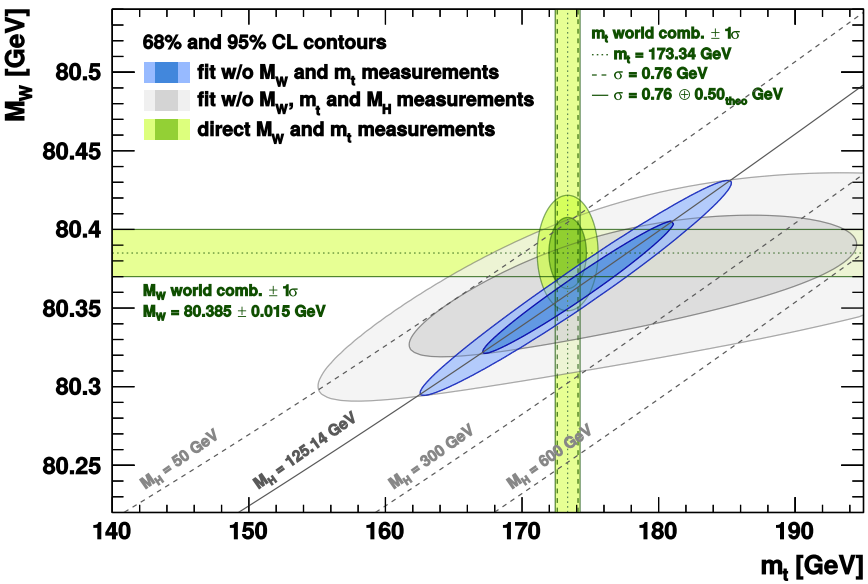
m_T: theory

- Accurate knowledge of m_T useful for
  - Precision tests of the SM
    - m_H, m_W and m_T correlated



Global fit to electroweak precision observables [arXiv:1407.3792]

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- Accurate knowledge of m_T useful for
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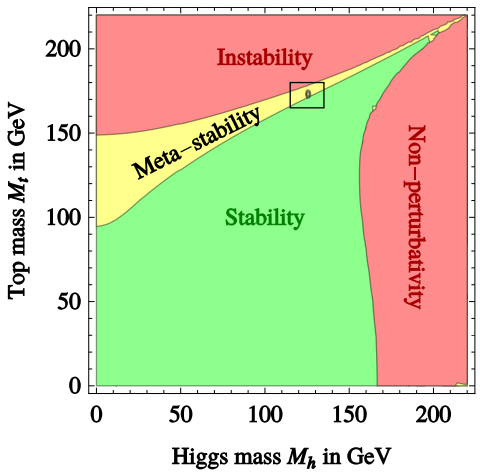
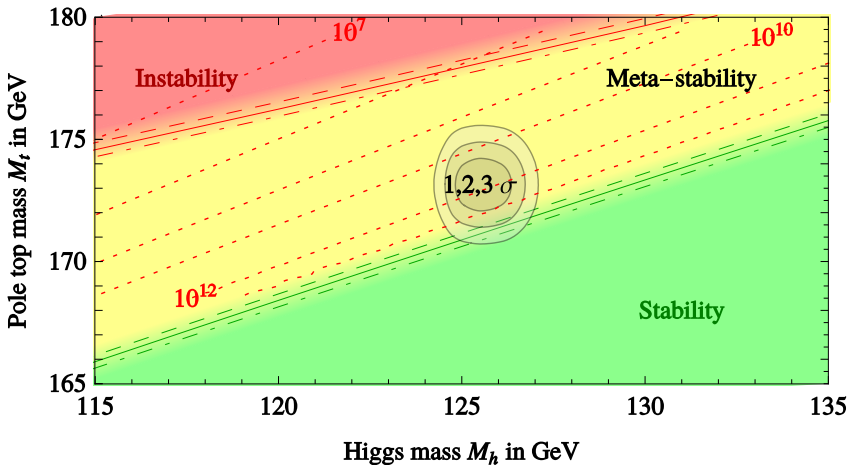
  - Addressing the issue of vacuum stability
    - Current values of m_H and m_t suggest the vacuum is metastable

[arXiv:1205.6497]





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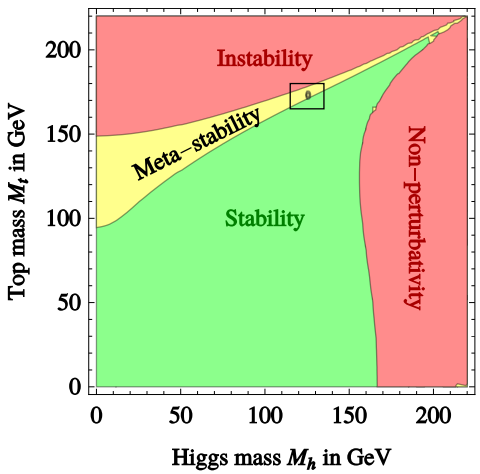

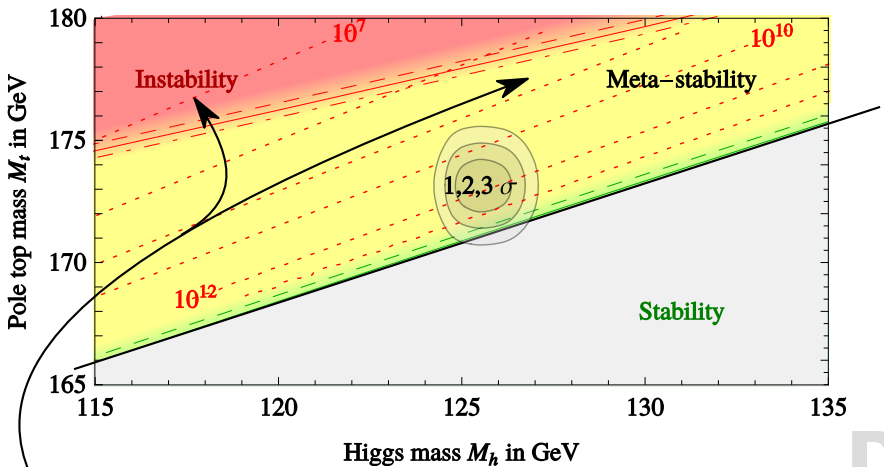

Higgs quartic coupling λ_H runs to negative values at Planck scale

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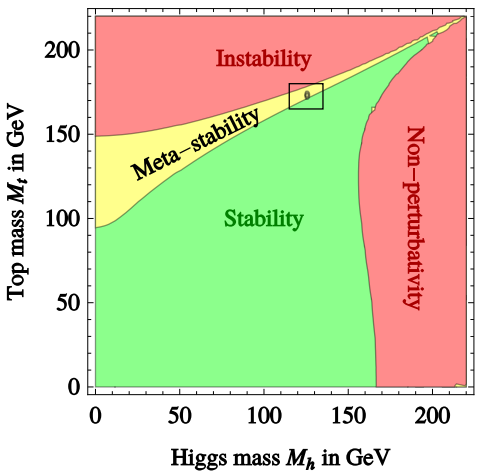

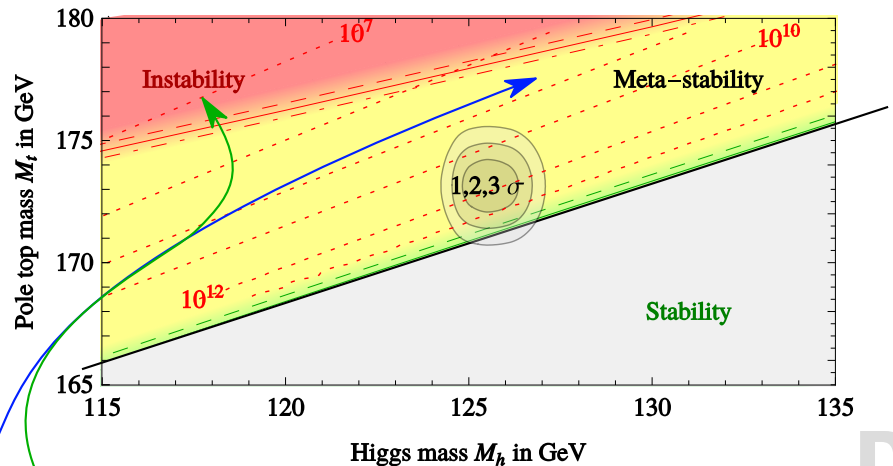

The vaccum life-time is long enough

Higgs quartic coupling λ_H runs to negative values at Planck scale

m_T: experiment

- m_T measurement at the LHC
  - Plethora of methods for m_t determination
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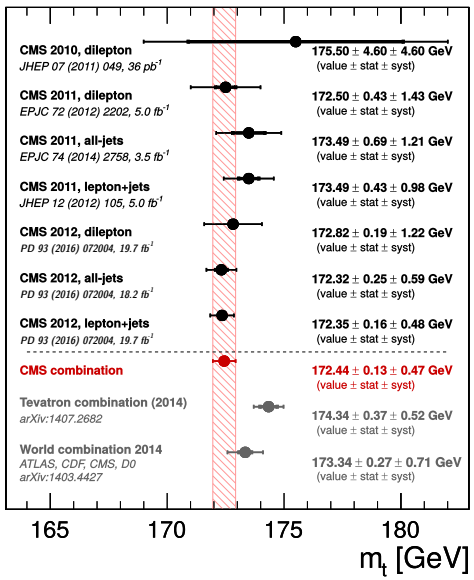

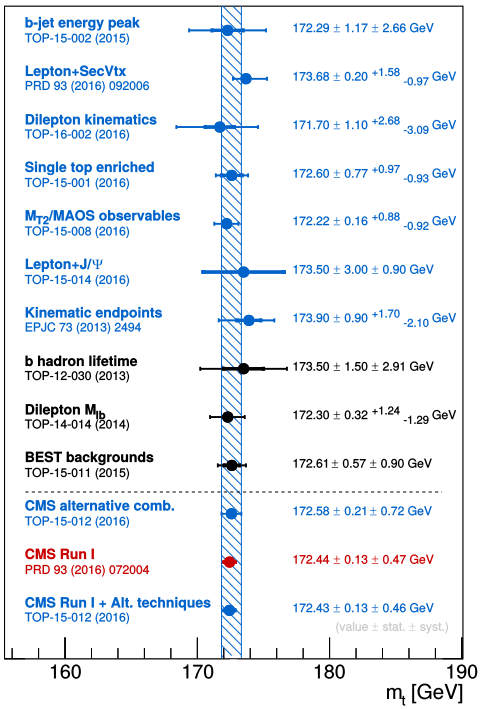

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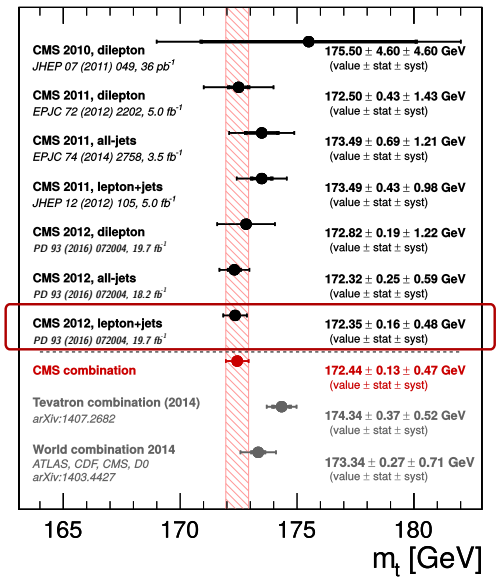

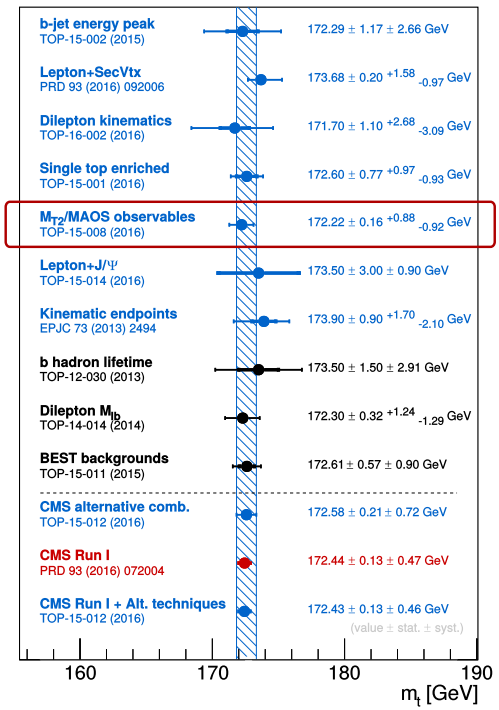

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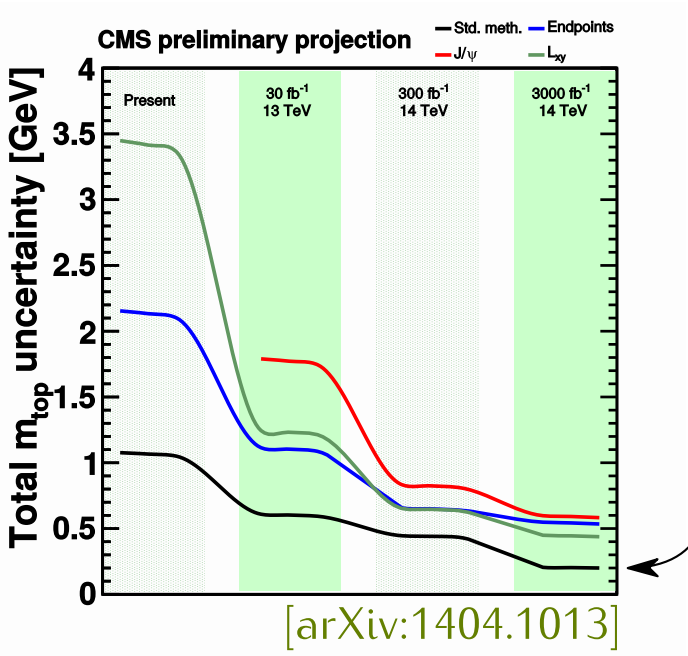

[arXiv:1404.1013]

0.2 GeV?

m_T: summary

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  - Top-quark reconstruction heavily relies on Monte Carlo generators
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  - Is uncertainity due to modelling properly taken into account?

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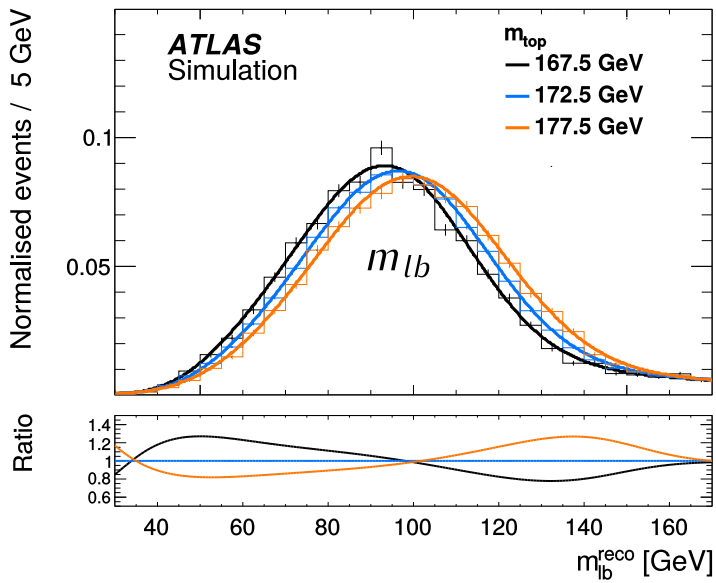

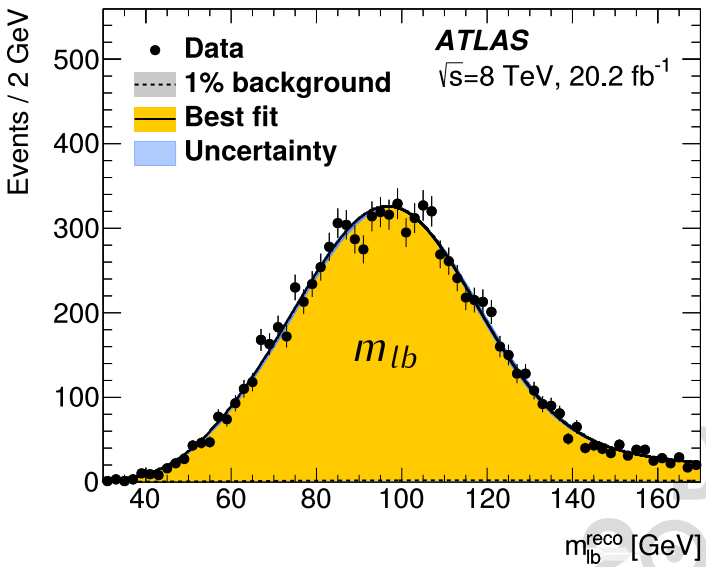

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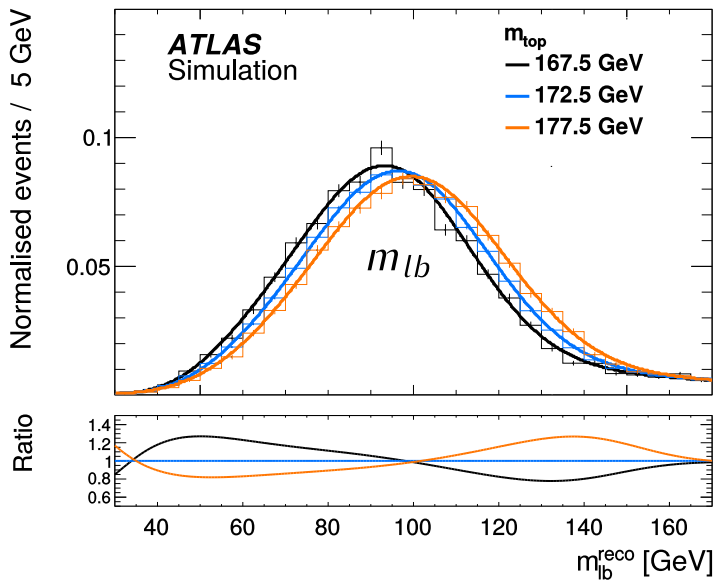
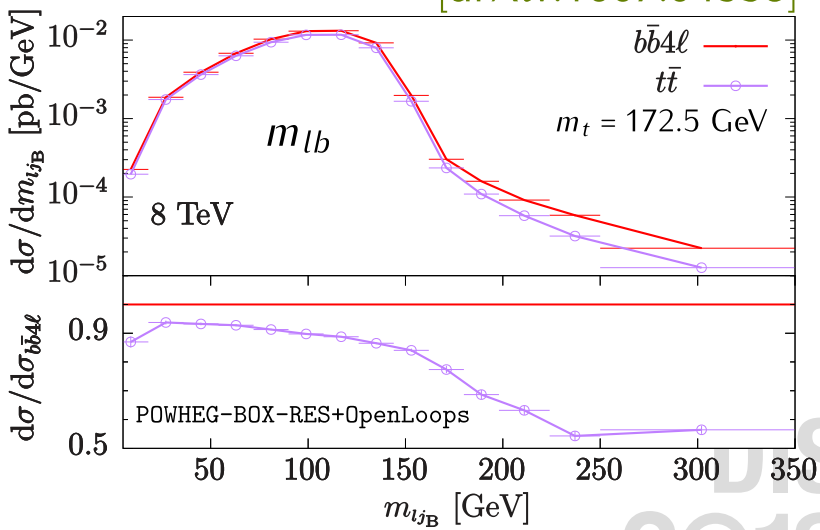


[arXiv:1607.04538]



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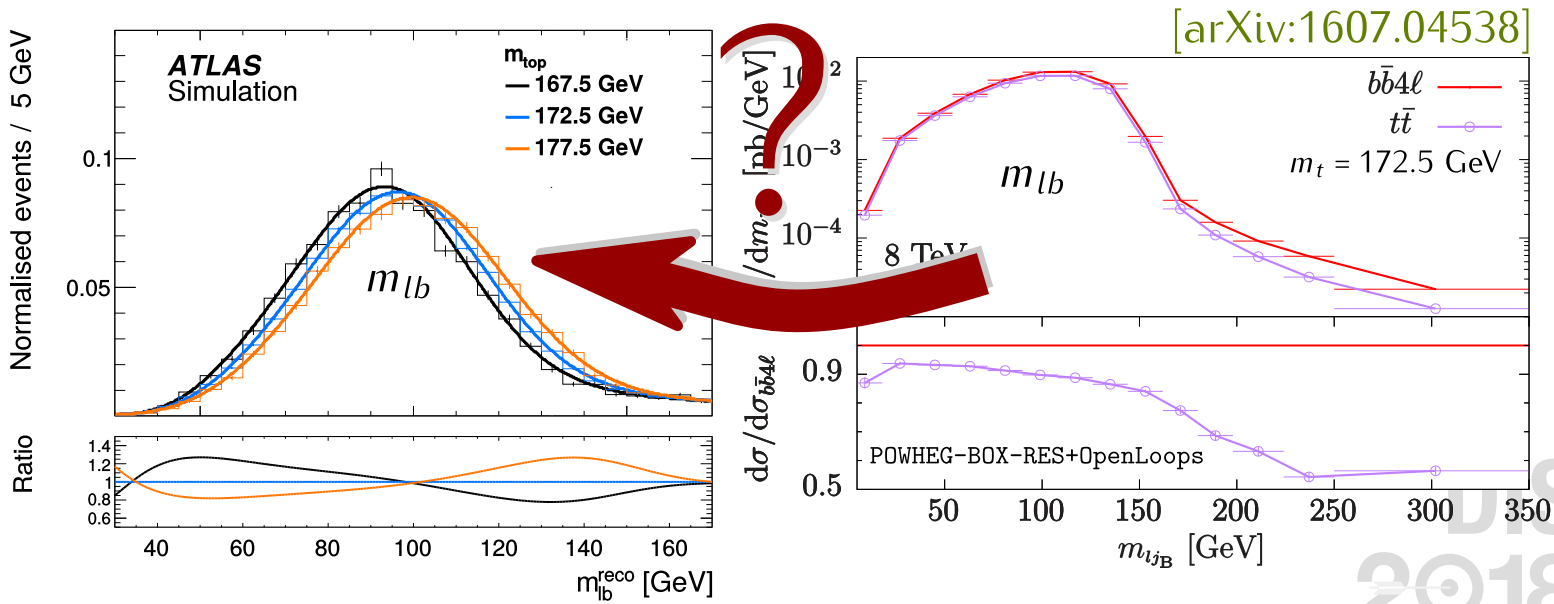

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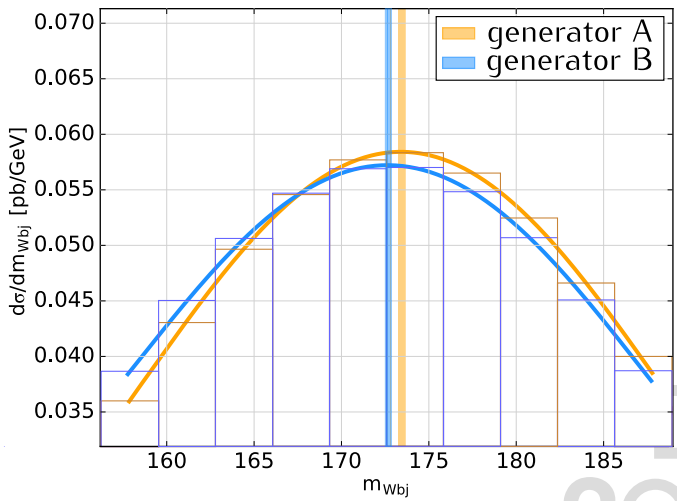
- Let's see:
  - Take Wb-jet system mass
  - Make a prediction with two generators (A and B) with $m_{\text{in}}^{\text{A}} = m_{\text{in}}^{\text{B}}$
  - Find the peaks at $m_{\text{out}}^{\text{A}}$, $m_{\text{out}}^{\text{B}}$ (e.g. using a polynomial fit)
  - Uncertainity: $|m_{\text{out}}^{\text{A}} - m_{\text{out}}^{\text{B}}|$



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- Let's see:
  - Take another observable
  - Generate pseudo data with generator A with m_{in}^{A}
  - Prepare templates with generator B for many m_{in}^{B}
  - Find the template B describing the pseudo data with $m_{\text{fit}}^{\text{B}}$
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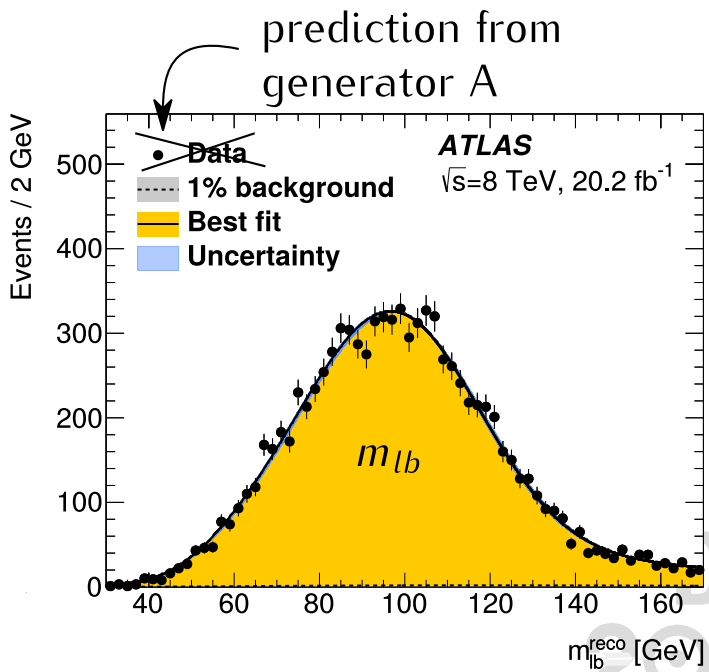

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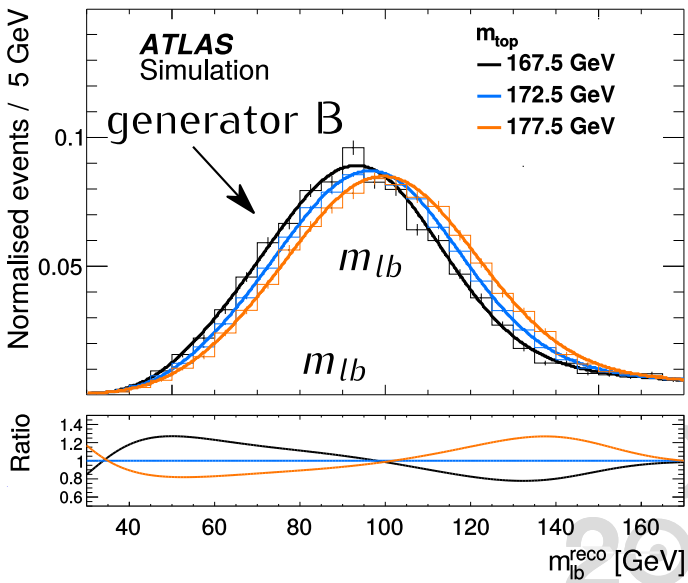

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- In the search for an answer we look at in [arXiv:1801.03944]:
  - Three generators implementing an increasingly precise treatment of $t\bar{t}$ production and decay in the di-leptonic channel
  - Two SMCs: Pythia8.2 [Sjöstrand et al. 2014], Herwig7.1 [Bellm et al. 2015]
  - Observables:
    - Peak position of the Wb-jet system mass specturm
    - b-jet energy spectrum [Agashe et al. 2016]
    - Mellin moments of lepton spectra [Frixione et al. 2014]

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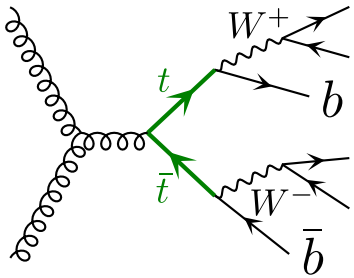
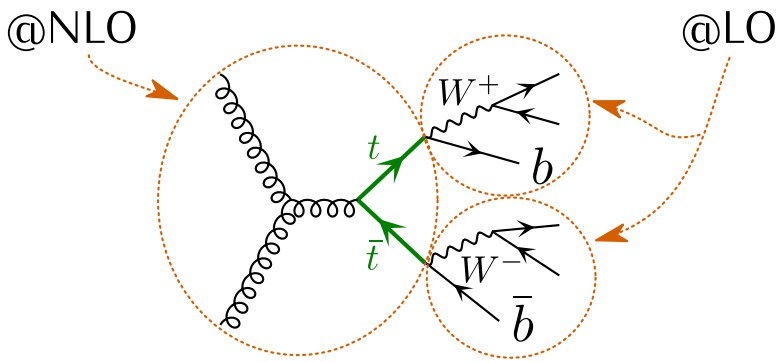
POWHEG $t\bar{t}$ NLO+PS generators

- POWHEG-BOX/hvq or hvq [Frixione, Nason, Ridolfi, 2007]



POWHEG $t\bar{t}$ NLO+PS generators

- `POWHEG-BOX/hvq` or *hvq* [Frixione, Nason, Ridolfi, 2007]



  - $t\bar{t}$ production at NLO
  - No NLO corrections in decays (radiation from b only by PS)
  - Spin correlations and off shell effects approximate
  - Includes hadronic W decays

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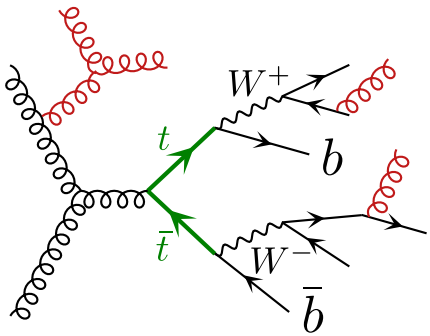

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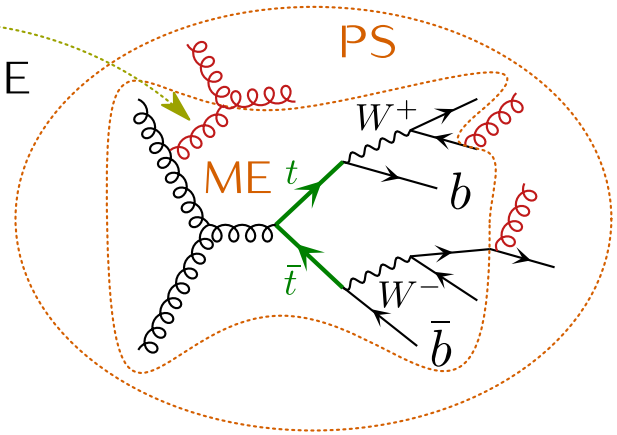
Only ISR with ME



Rest by PS

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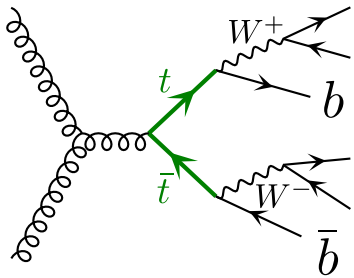
POWHEG $t\bar{t}$ NLO+PS generators

- `POWHEG-BOX/ttb_NLO_dec` or $t\bar{t}dec$ [Campbell, Ellis, Nason, Re, 2014]



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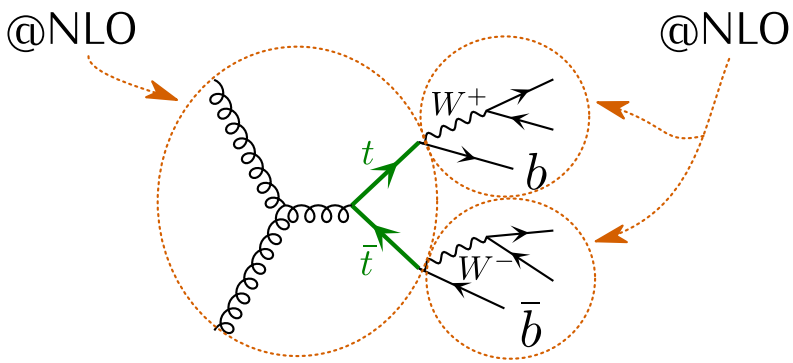

  - $t\bar{t}$ production at NLO
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  - Exact spin correlations and LO exact off shell effects
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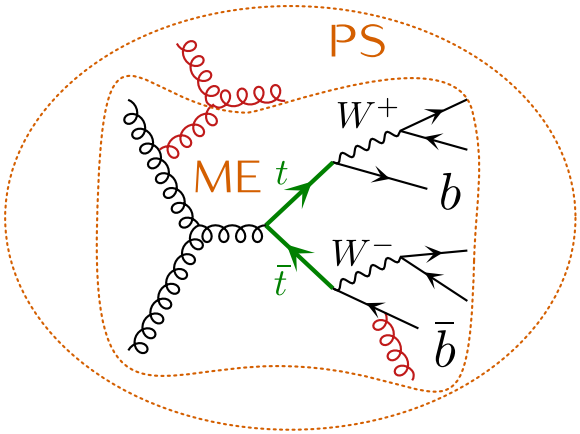

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  - Makes radiation both from production and resonances possible (`allrad`)

POWHEG $t\bar{t}$ NLO+PS generators

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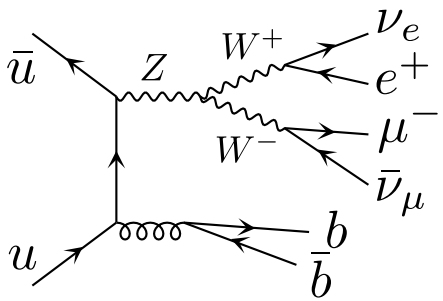

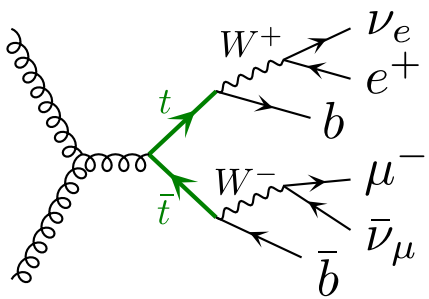

- $pp \to \ell^+ \nu_\ell \, l^- \bar{\nu}_l \, b \, \bar{b}$ production at NLO
- Exact spin correlations* and exact off shell effects
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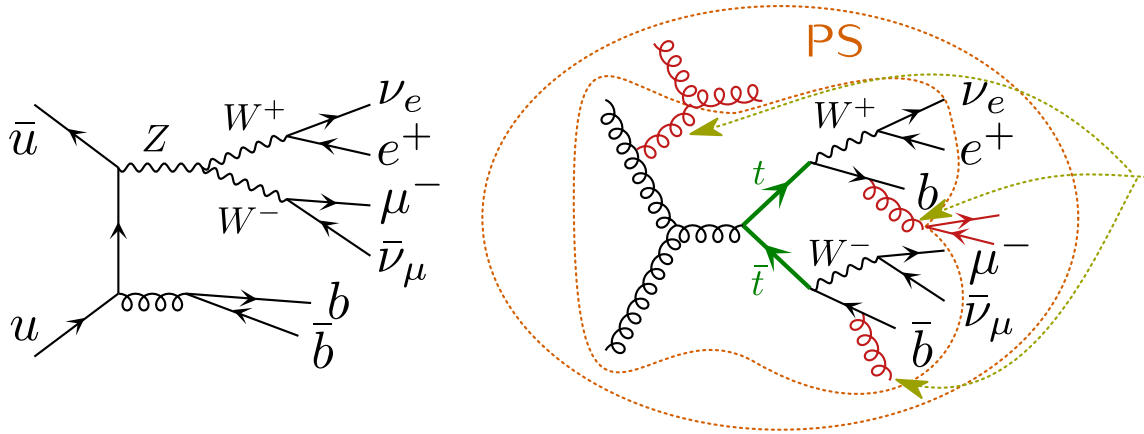

Keeps radiation in production and decay

- $pp \to \ell^+ \nu_\ell \, l^- \bar{\nu}_l \, b \, \bar{b}$ production at NLO
- Exact spin correlations* and exact off shell effects
- Includes interference of radiation from production and decay
- Makes radiation both from production and resonances possible (`allrad`)

POWHEG $t\bar{t}$ NLO+PS generators

	hvq	$t\bar{t}dec$	$b\bar{b}4l$
NLO in production	yes	yes	yes
NLO in decay	no	yes	yes
Radiation off b-quarks from tops	SMC	ME	ME
Spin correlations	approximate	yes	yes
Off shell effects	approximate	LO	yes
Production/decay interference	no	no	yes
Hadronic W decays	yes	yes	no

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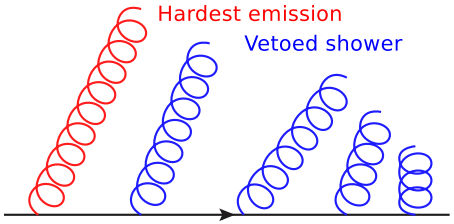
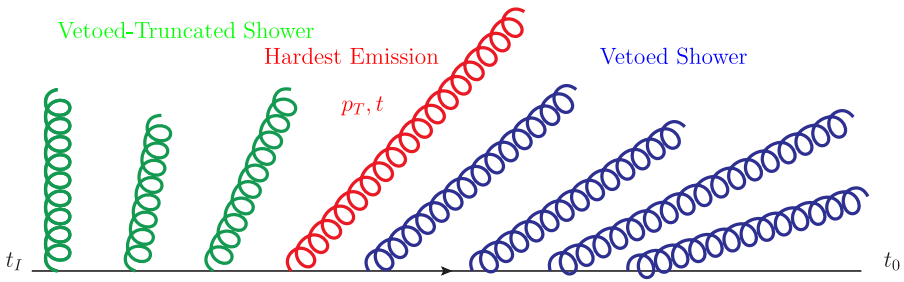
POWHEG-BOX-V2 $t\bar{t}$

Shower Monte Carlo programs

- `Pythia8.2`: $k_\perp$-ordered shower, natural for matching with POWHEG



- `Herwig7.1`: angular-ordered shower, in principle requiring truncated showers

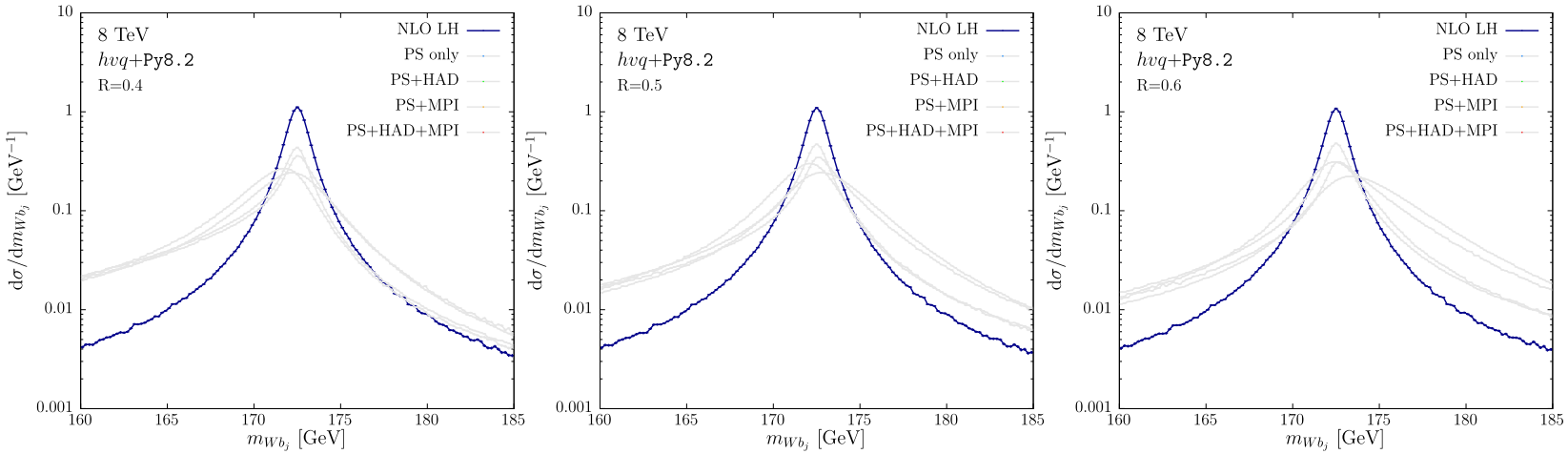


- Both require a custom interface to allow vetoing with multiple scales
  - `Pythia8.2`: `UserHooks::doVetoFSREmissions`
  - `Herwig7.1`: `FullShowerVeto::vetoShower`, `ShowerVeto::vetoTimeLike`

Results

- Our goal is to assess compatibility of the generators in terms of Wb-jet mass distribution peak position shifts with respect to the most precise one ($b\bar{b}4l$)
- Comparing generators we can learn whether:
  - Modelling of radiation from the b jet by SMCs is adequate
  - Interference effects in radiation from production and decay play a relevant role
- Peak positions are obtained through:
  - a.) ideal detector: a fit to a skewed Lorentzian
  - b.) including "detector effects": a fit of the distribution smeared by a Gaussian $\Delta = 15$ GeV to a skewed Lorentzian
- We also vary the perturbative scales, PDFs and the value of α_S: 7 point μ_r and μ_f variation, 30 PDF4LHC eigenvectors, PDFs with different values of α_S, respectively
- And compare the peak positions for different SMCs

Anatomy of the m_{Wj_B} peak



- Radiative corrections in decay (PS) enhance low-mass region
- Hadronization further enhance low-mass region and smear the peak
- MPI fills the high-mass tail
- Behaviour of each component is R dependent

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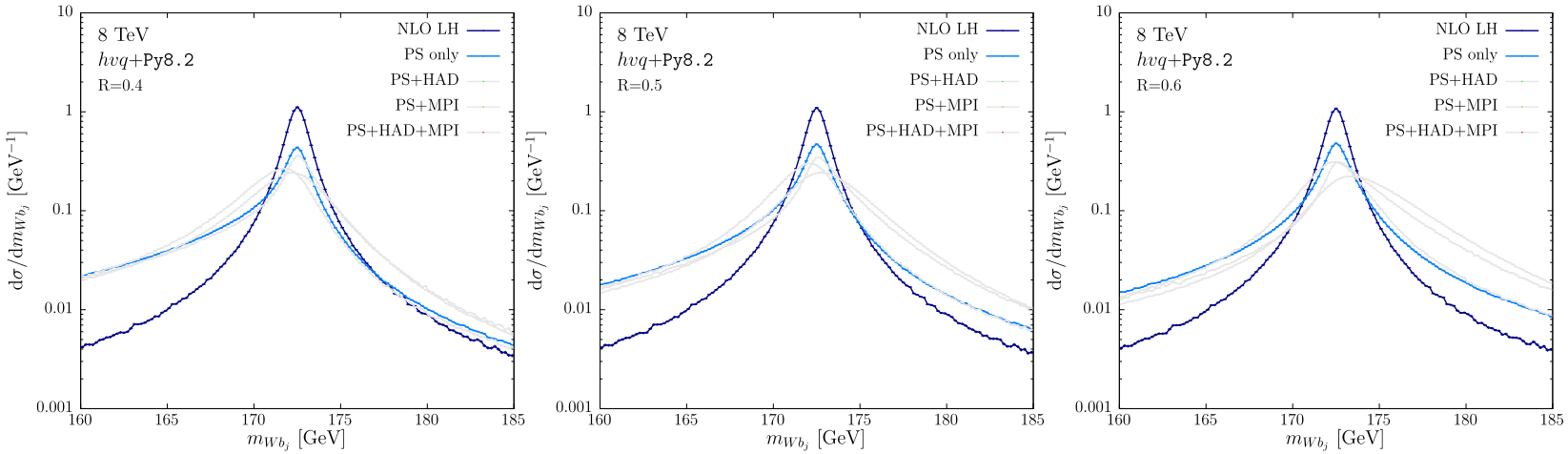

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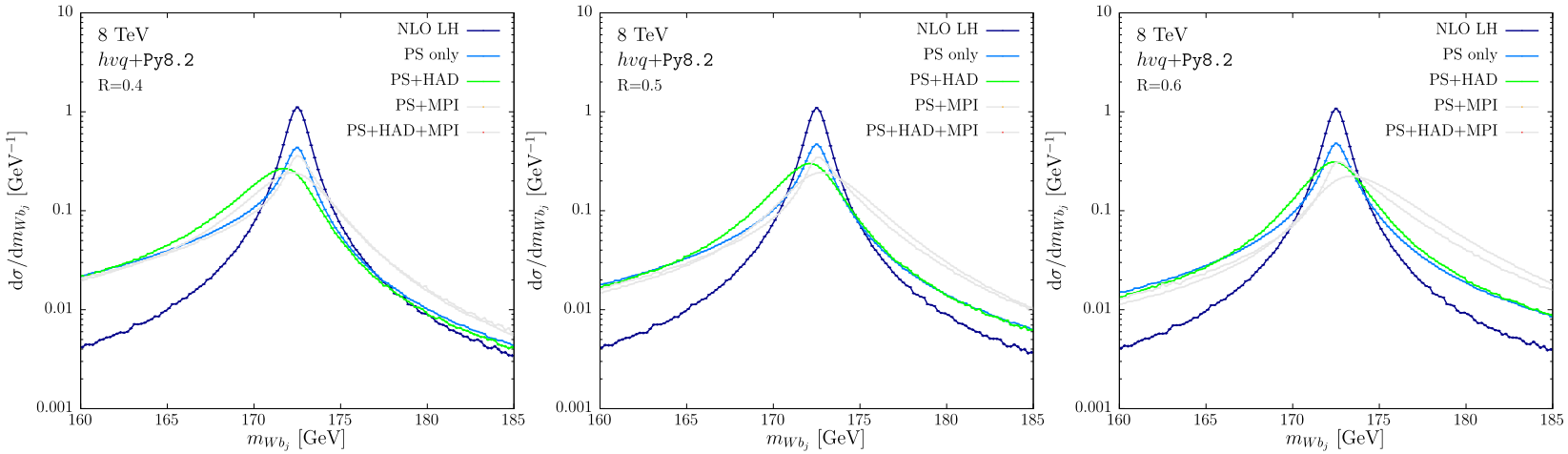

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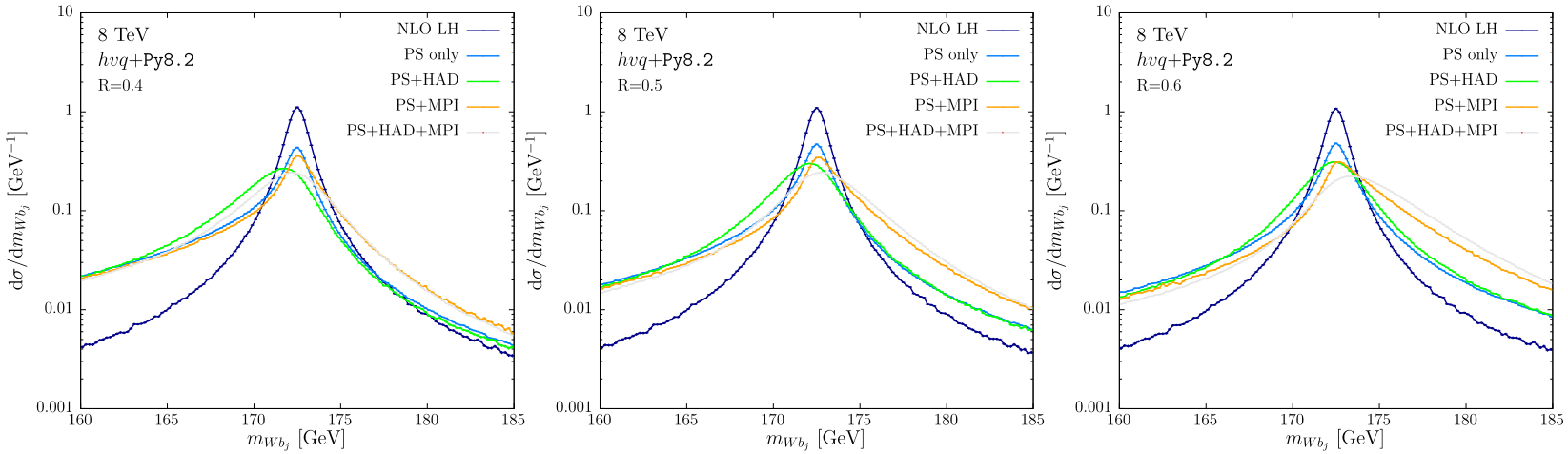

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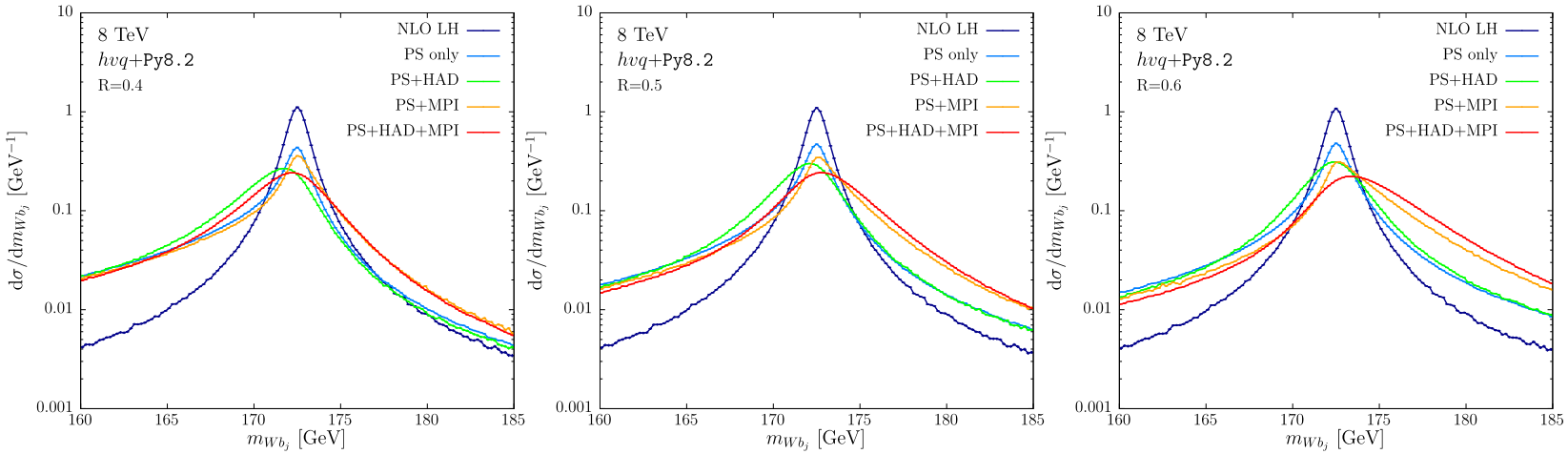

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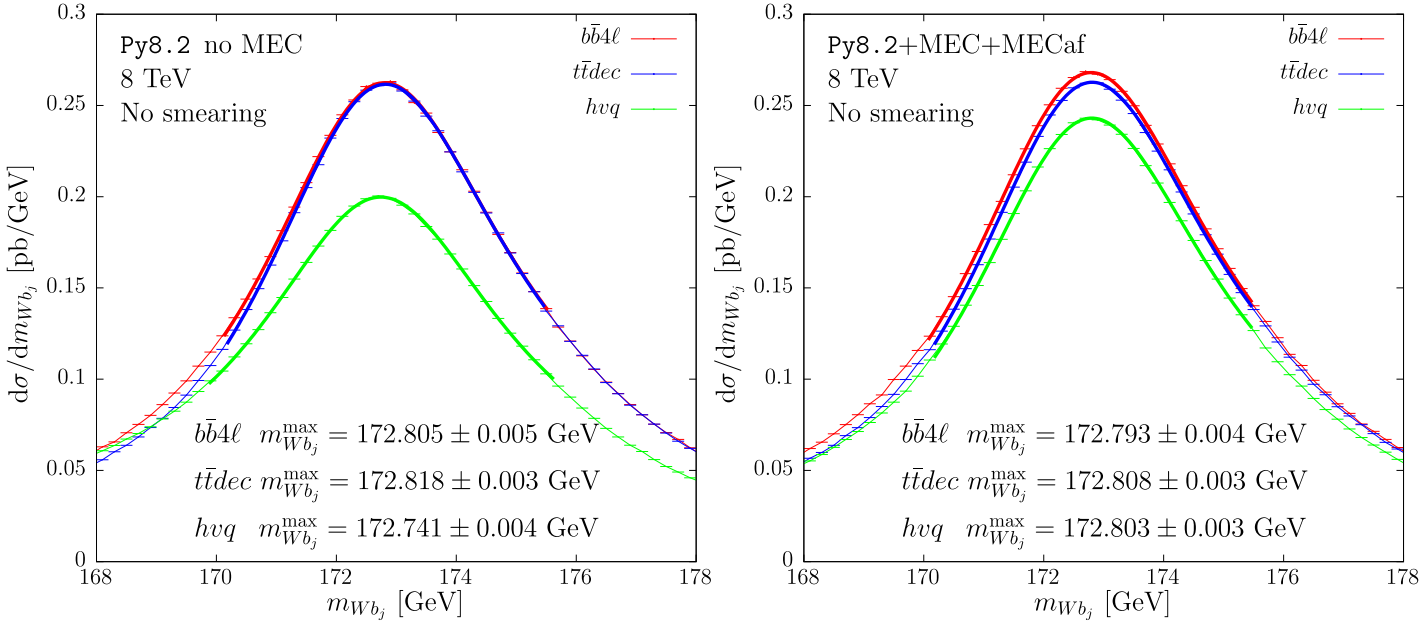
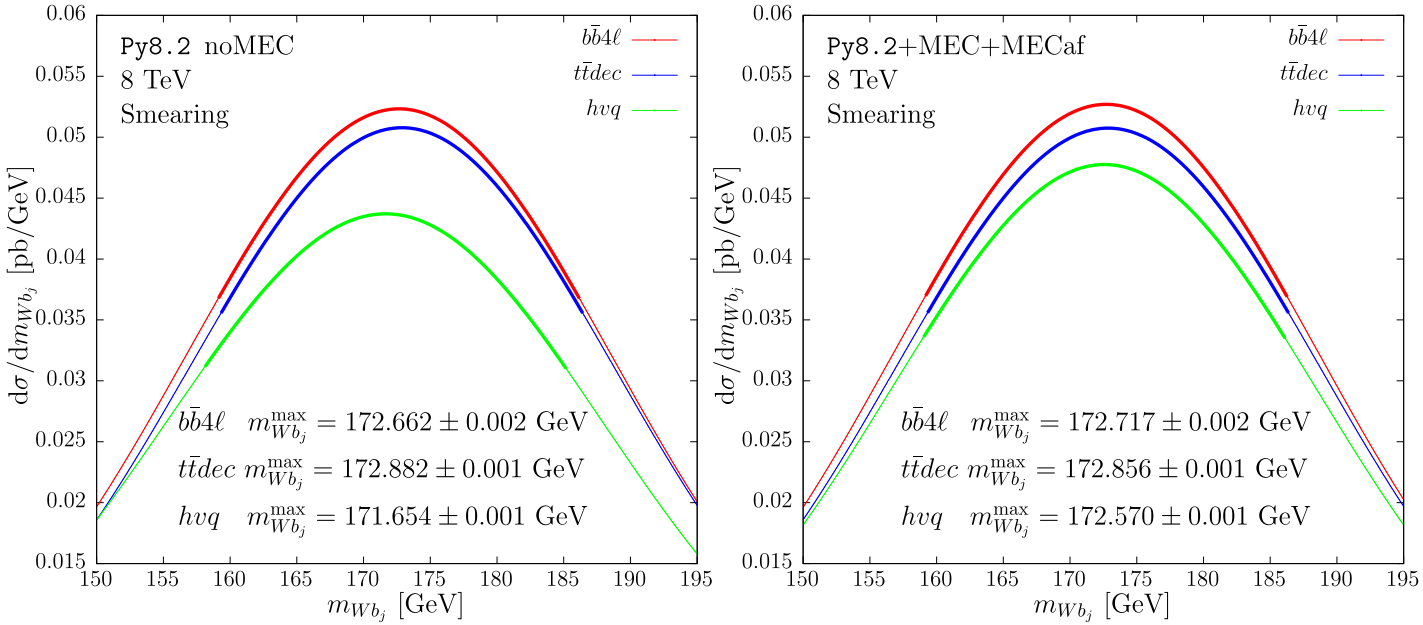
m_{Wj_B}: ideal detector



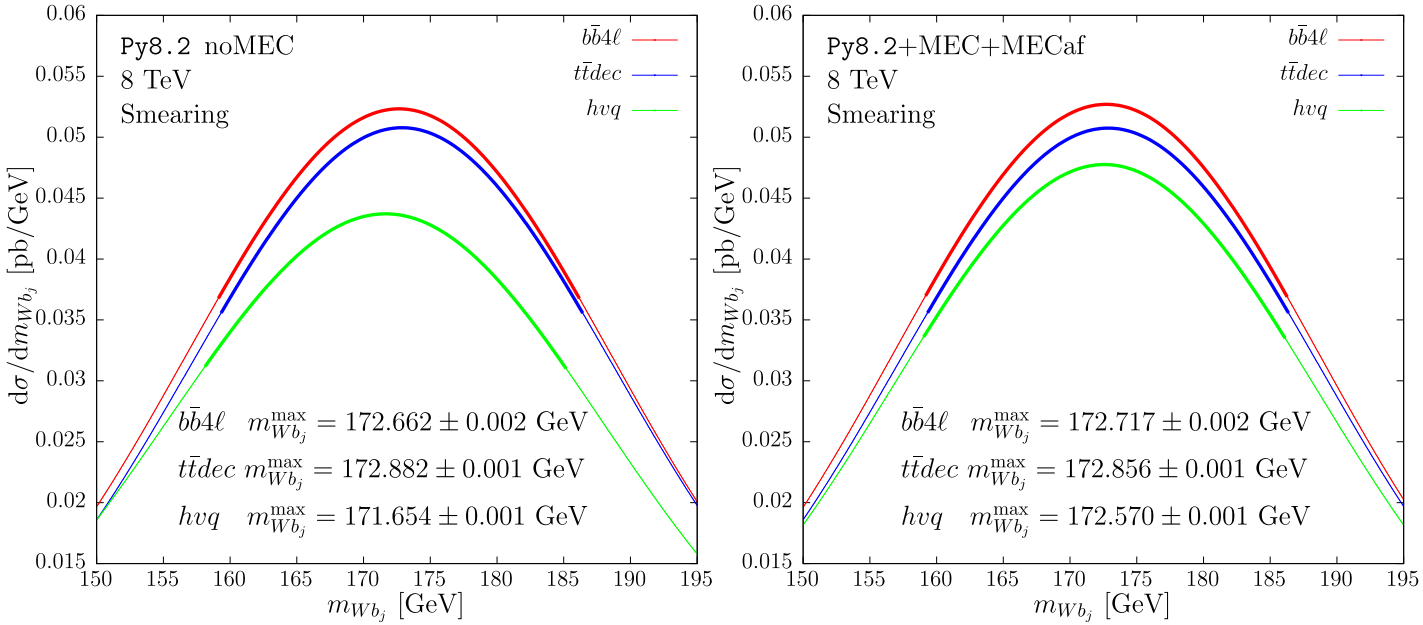
- A fit to skewed Lorentzian reveals:
  - Remarkable consistency between $b\bar{b}4l$ and $t\bar{t}dec$
  - Gentle shift of the hvq peak, of $\sim 60MeV$, without MEC
  - MEC brings hvq impressively close to $b\bar{b}4l$
  - Consistency check: stability of $b\bar{b}4l$ and $t\bar{t}dec$ with respect to MEC

m_{Wj_B}: with "detector effects"



- A fit of the smeared m_{Wj_B} to a skewed Lorentzian reveals:
  - $t\bar{t}dec$ shift to $b\bar{b}4l$ of +140 MeV
  - hvq shift to $b\bar{b}4l$ of −147 MeV
  - All generators consistent with each other given current experimental precision

m_{Wj_B}: with "detector effects"

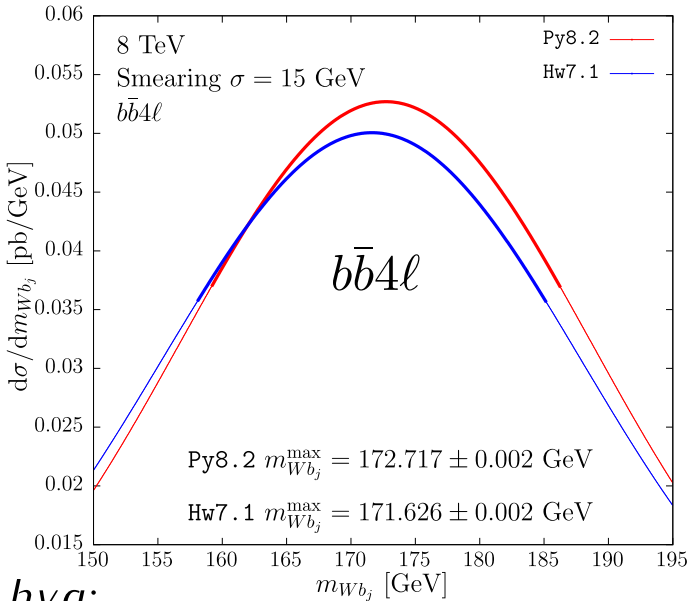


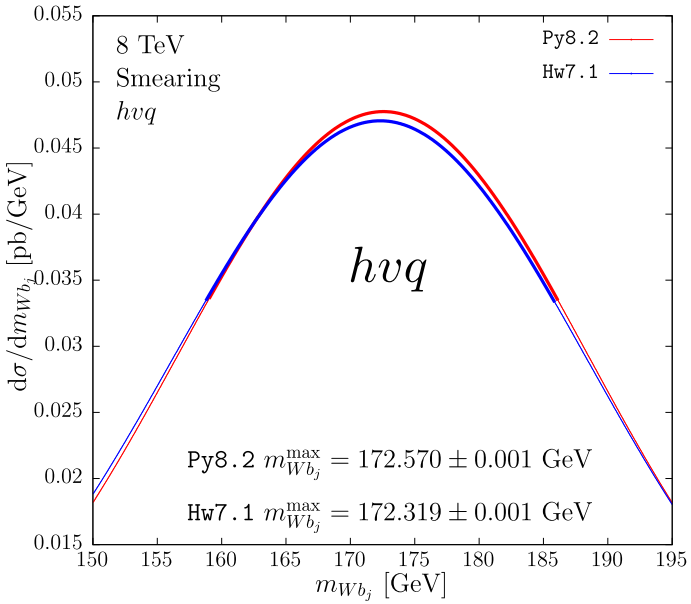
- Furthermore:

	% − $b\bar{b}4\ell$	(μ_R, μ_F)	PDF	α_S
$b\bar{b}4\ell$	+0 MeV	$^{+86}_{-53}$ MeV	-	±64 MeV
$t\bar{t}dec$	**+140 MeV**	$^{+6}_{-6}$ MeV	-	±54 MeV
hvq	**−147 MeV**	$^{+7}_{-7}$ MeV	±5 MeV	±9 MeV

  - Only $b\bar{b}4l$ provides realistic scale variation uncertainity

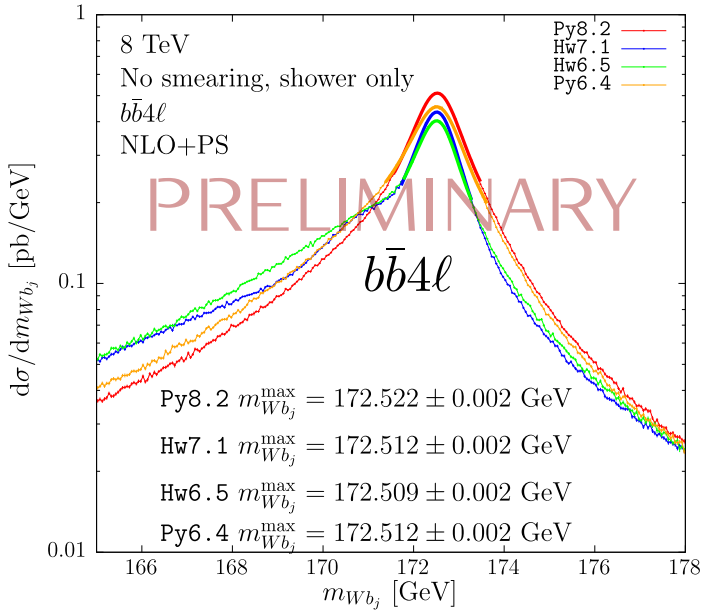
m_{Wj_B}: SMC comparison

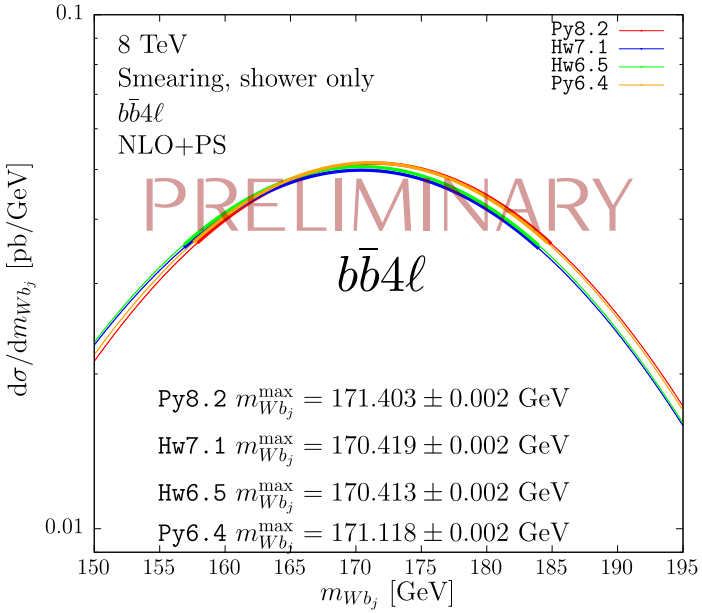




- hvq:
  - ~ 250 GeV shift, predictions consistent
  - description of radiation in decays by SMC (PS+MEC)
- $b\bar{b}4l$:
  - ~ 1 GeV shift
  - description of radiation in decays by ME

m_{Wj_B}: SMC comparison





- Note that the disagreement shows up at the PS level already
- Comparisons with "the older siblings":
  - Exhibit similar behaviour
  - `Pythia8.2`: $k_\perp$ dipole, `Pythia6`: $k_\perp$, `Herwig7.1/6`: angular

Summary

- Are our theory predictions accurate enough?
  - YES, if only using `Pythia8.2`
    - Wb-jet mass peak shifts under 200 MeV, even with smearing
    - `Pythia8.2` MEC do a great job eliminating a ~ 1 GeV shift
  - NO?, once `Herwig7.1` considered
    - hvq: predictions consistent, ~ 250 MeV shift
    - $b\bar{b}4l$ and $t\bar{t}dec$: dramatic shifts observed
- Do we understand the difference between `Pythia8.2` and `Herwig7.1`?
  - Both include MEC, we tried all available options in `Herwig7.1`
  - Angular ordered showers in princple require truncated shower but Seymour's prescription makes the agreement worse
  - Dipole shower kinematics (`Pythia8.2`) more reshuffling-stable than the angular shower ones (`Herwig7.1`)
  - Comparisons against `Pythia6`, `Herwig6` show the same trend
- Many more interesting results in [arXiv:1801.03944]