$t\bar{t}$+X hadroproduction within the PowHel framework

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and
HELAC group

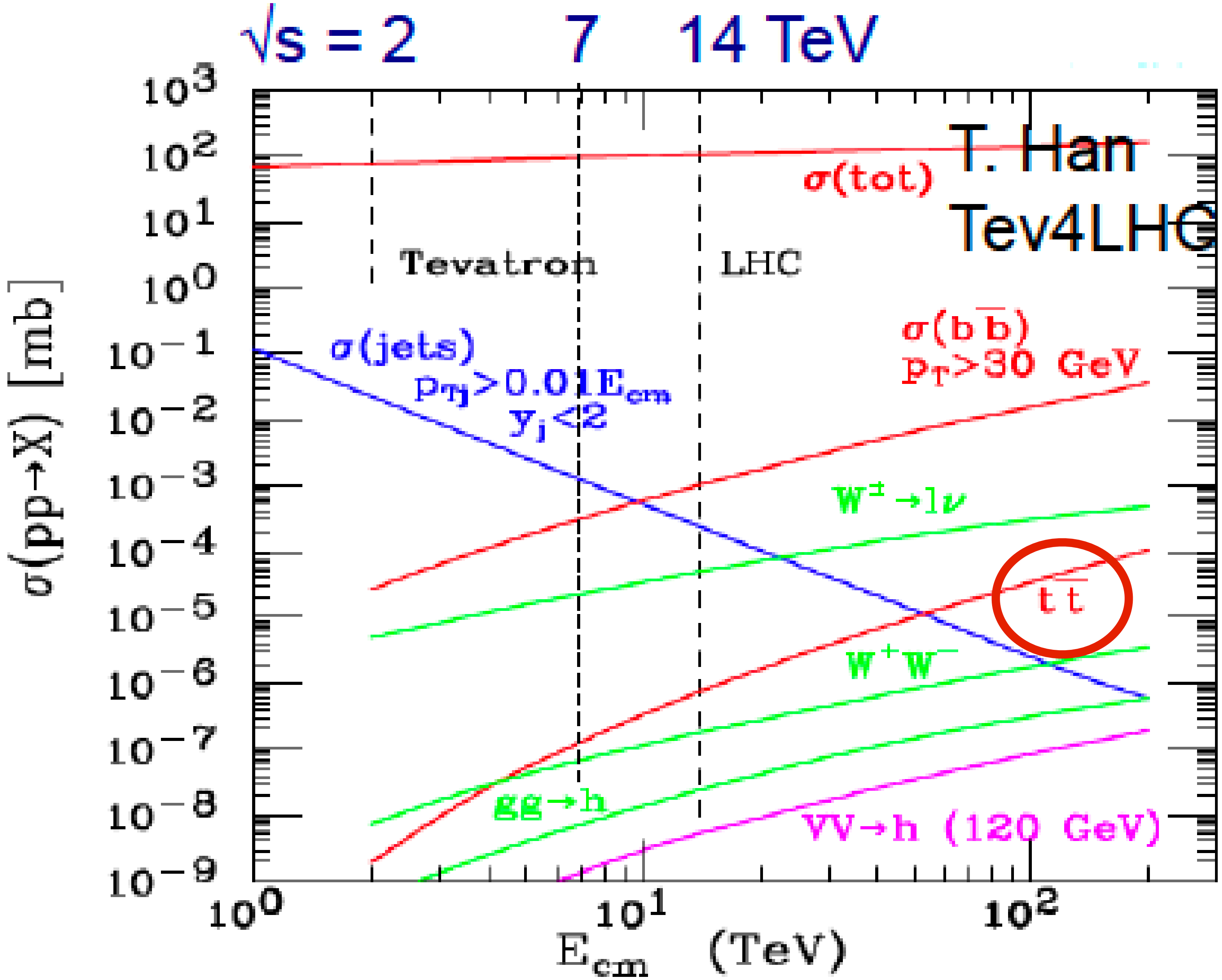
Outline

- Motivation
- Method
- Used frameworks, codes
- Predictions

Motivation

The importance of being top

1. The higher collider energy, the larger weight in total cross section



The importance of being top

1. The higher collider energy, the larger weight in total cross section
2. The t-quark is heavy, Yukawa coupling ~1

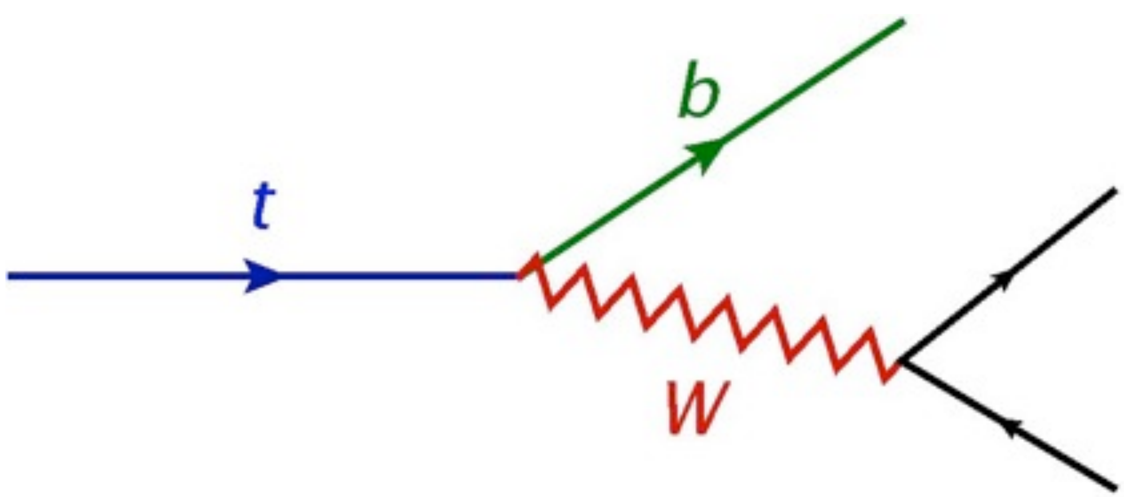
$$m_t = 172.9 \pm 0.6 \pm 0.9(\mathrm{PDG})\,,173.1 \pm 0.6 \pm 1.1(\mathrm{TeVatron})$$

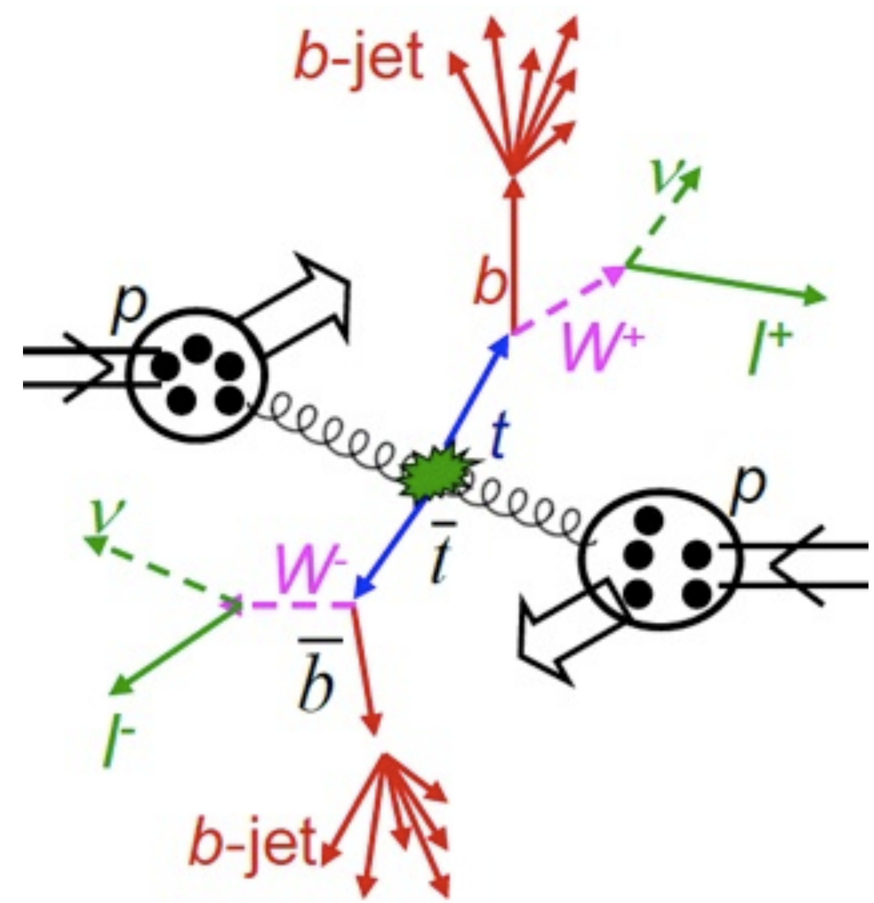
$\Rightarrow$ plays important role in Higgs physics

The importance of being top

1. The higher collider energy, the larger weight in total cross section
2. The t-quark is heavy, Yukawa coupling ~1
3. The t-quark decays before hadronization
   $\Rightarrow$ quantum numbers more accessible than in case of other quarks

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





Top at the LHC

1. Present: precision measurement of quantum numbers, decay rates

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$$\sigma_{\mathrm{NLO}}(pp \to \mathrm{t}\,\bar{\mathrm{t}}) = 806\,\mathrm{pb}$$
$$\sigma_{\mathrm{NLO}}(pp \to \mathrm{t}\,\bar{\mathrm{t}}{+}\mathrm{jet};\ p_{\perp}^{j} > 50\,\mathrm{GeV}) = 376\,\mathrm{pb}$$

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$${\rm t}\,\bar{\rm t}\,{\rm b}\,\bar{\rm b},\; {\rm t}\,\bar{\rm t} + 2\,{\rm jets}$$

These require precise predictions for distributions at hadron level

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(with decays, top is not detected)

Why should we care about NLO + PS?

- Decayed tops (optional)
- Hadrons in final state
- Closer to experiments
- Realistic analysis becomes feasible
- Parton shower can have significant effect (e.g. in Sudakov regions)
- For the user:

  much cheaper, faster than an NLO

Method

From NLO to NLO+PS

Idea: use NLO calculation as hard process as input for the SMC

Bottleneck: how to avoid double counting of first radiation w.r.to Born process

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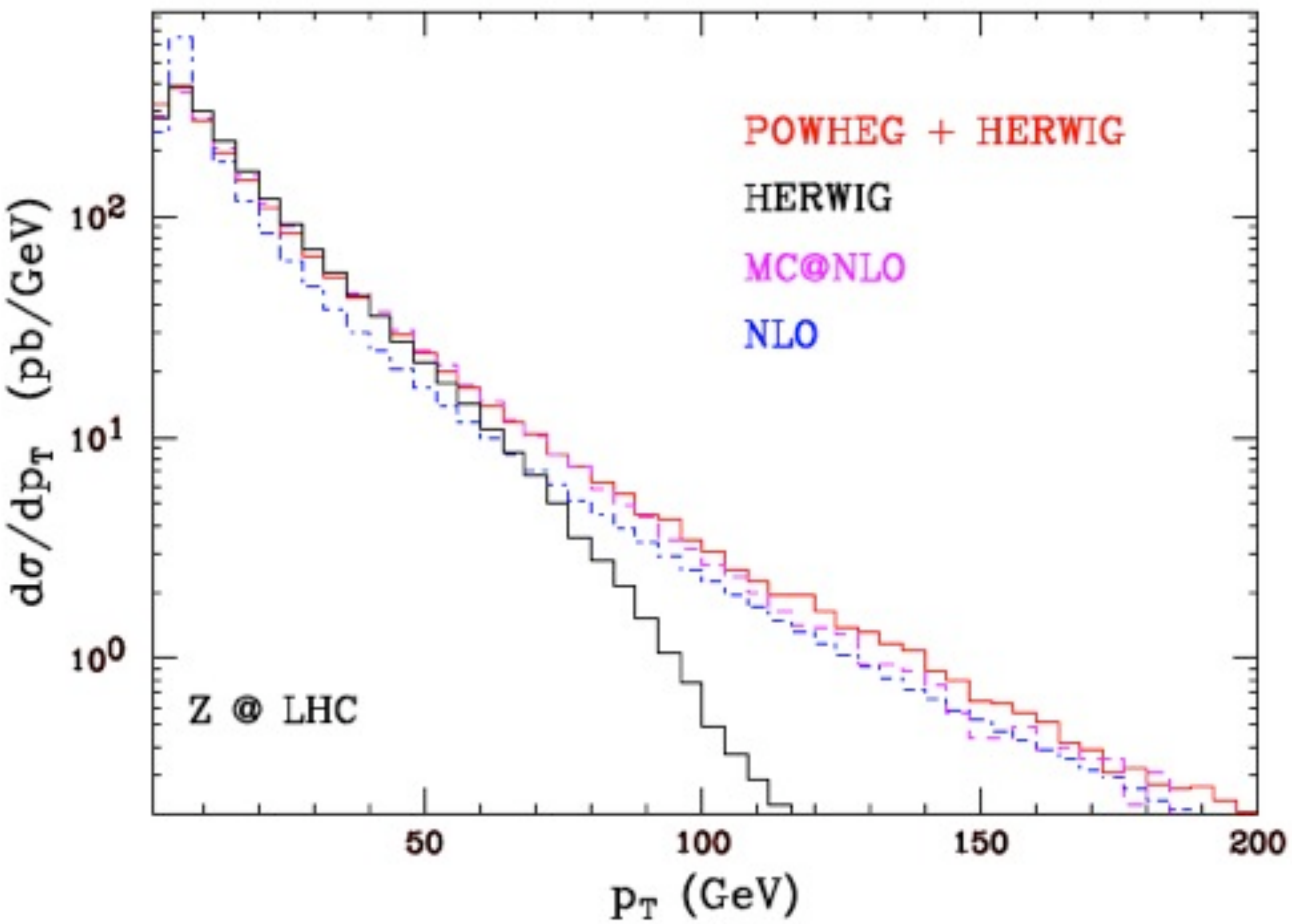
- MCatNLO [Frixione, Webber hep-ph/0204244]
- POWHEG [Nason hep-ph/0409146, Frixione, Nason, Oleari arXiv:0709.2092]

Result: PS events giving distributions exact to NLO in pQCD



Nason, Ridolfi hep-ph/0606275

The POWHEG method

The first radiation in PS approx.:

$$\Delta(t_0) + \Delta(t)\frac{\alpha_\mathrm{S}}{2\pi}\frac{\mathrm{d}t}{t}\frac{\mathrm{d}\phi}{2\pi}\mathrm{d}z P(z,\phi)$$

Only true, if $p_\perp \to 0$

We know, that $\mathrm{d}\Phi_\mathrm{rad}\frac{R}{B} \xrightarrow{p_\perp \to 0} \frac{\alpha_\mathrm{S}}{2\pi}\frac{\mathrm{d}t}{t}\frac{\mathrm{d}\phi}{2\pi}\mathrm{d}z P(z,\phi)$

$$\Rightarrow \Delta(p_{\perp,\mathrm{min}}) + \Delta(p_\perp)\frac{R}{B}\mathrm{d}\Phi_\mathrm{rad}$$

preserves unitarity: $\Delta(p_{\perp,\mathrm{min}}) + \int \mathrm{d}\Phi_\mathrm{rad}\frac{R}{B}\Delta(p_\perp) = 1$

$$\Delta(p_\perp) = \exp\left[-\int \mathrm{d}\Phi_\mathrm{rad}\frac{R}{B}\Theta(p_\perp(\Phi_\mathrm{rad}) - p_\perp)\right]$$

The POWHEG method

Matrix element corrected first emission

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$$\mathrm{d}\sigma = \mathrm{d}\Phi_{\mathrm{B}} B \left[\Delta(p_{\perp,\mathrm{min}}) + \Delta(p_{\perp}) \frac{R}{B} \mathrm{d}\Phi_{\mathrm{rad}} \right]$$

The POWHEG method

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Born

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$$\Rightarrow \int \mathrm{d}\sigma = \sigma_{\mathrm{LO}}$$

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$$d\sigma = d\Phi_B \widetilde{B} \left[\Delta(p_{\perp,\min}) + \Delta(p_\perp) \frac{R}{B} d\Phi_{\rm rad} \right]$$

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$$\widetilde{B}(\Phi_{\mathrm{B}}) = B(\Phi_{\mathrm{B}}) + \tilde{\mathcal{V}}(\Phi_{\mathrm{B}}) + \int \mathrm{d}\Phi_{\mathrm{rad}} \mathcal{R}(\Phi_{\mathrm{B}} \otimes \Phi_{\mathrm{rad}})$$

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$$d\sigma = d\Phi_{\rm B} \widetilde{B} \left[\Delta(p_{\perp,\rm min}) + \Delta(p_\perp)\frac{R}{B} d\Phi_{\rm rad} \right]$$

$$\Rightarrow \int d\sigma = \sigma_{\rm NLO}$$

$$\widetilde{B}(\Phi_{\rm B}) = B(\Phi_{\rm B}) + \tilde{\mathcal{V}}(\Phi_{\rm B}) + \int d\Phi_{\rm rad} \mathcal{R}(\Phi_{\rm B} \otimes \Phi_{\rm rad})$$

Accuracy of an observable

$$\langle O \rangle = \int \mathrm{d}\Phi_{\mathrm{B}} \widetilde{B} \left[\Delta(p_{\perp,\mathrm{min}}) O(\Phi_{\mathrm{B}}) + \int \mathrm{d}\Phi_{\mathrm{rad}} \Delta(p_{\perp}) \frac{R}{B} O(\Phi_{\mathrm{R}}) \right] =$$

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$$= \underbrace{\int d\Phi_B \widetilde{B} \left[\Delta(p_{\perp,\min}) O(\Phi_B) + \int d\Phi_{rad} \Delta(p_\perp) \frac{R}{B} O(\Phi_B) \right]}_{=O(\Phi_B)} +$$

$$+ \int d\Phi_R \Delta(p_\perp) \frac{\widetilde{B}}{B} R \left(O(\Phi_R) - O(\Phi_B) \right) =$$

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$$= \left\{\int d\Phi_B \widetilde{B} O(\Phi_B) + \int d\Phi_R R\left(O(\Phi_R) - O(\Phi_B)\right)\right\}(1 + \mathcal{O}(\alpha_S)) =$$

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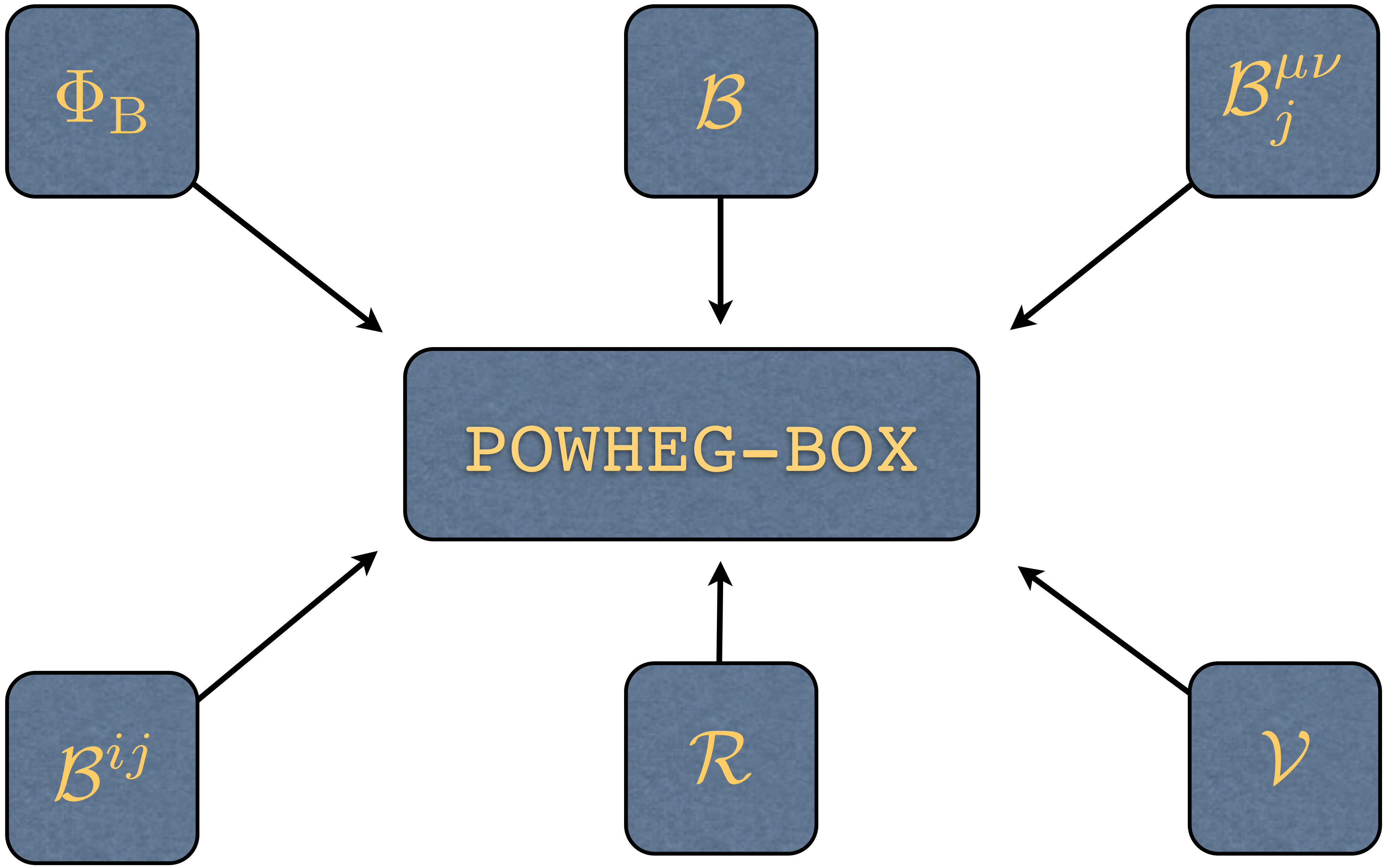
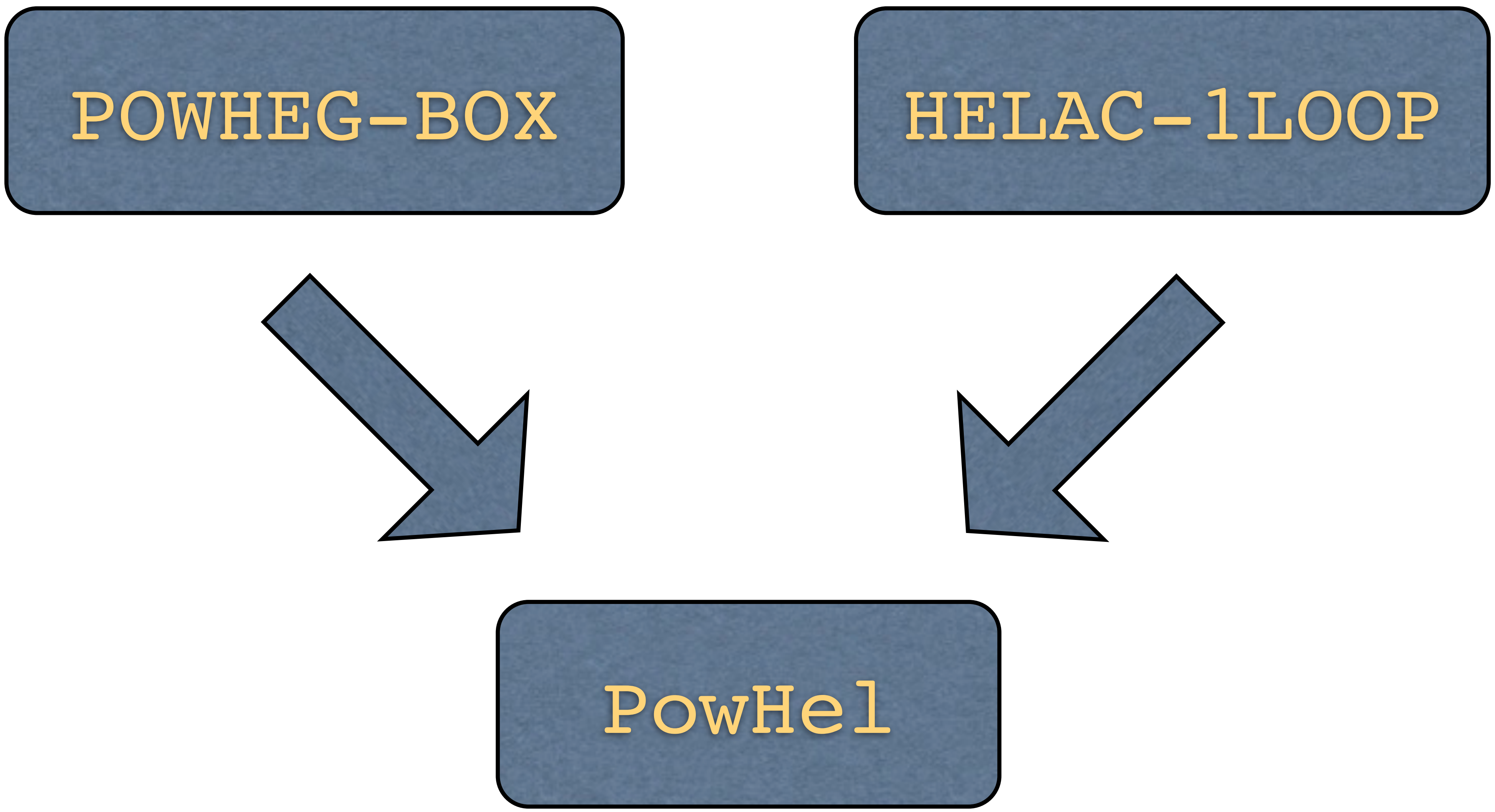
$$= \left\{\int d\Phi_B \left[B+V\right] O(\Phi_B) + \int d\Phi_R R O(\Phi_R)\right\}(1+\mathcal{O}(\alpha_S))$$

NLO accuracy is satisfied, since $\Delta(p_\perp)\frac{\widetilde{B}}{B} = 1+\mathcal{O}(\alpha_S)$

POWHEG-BOX framework



PowHel framework



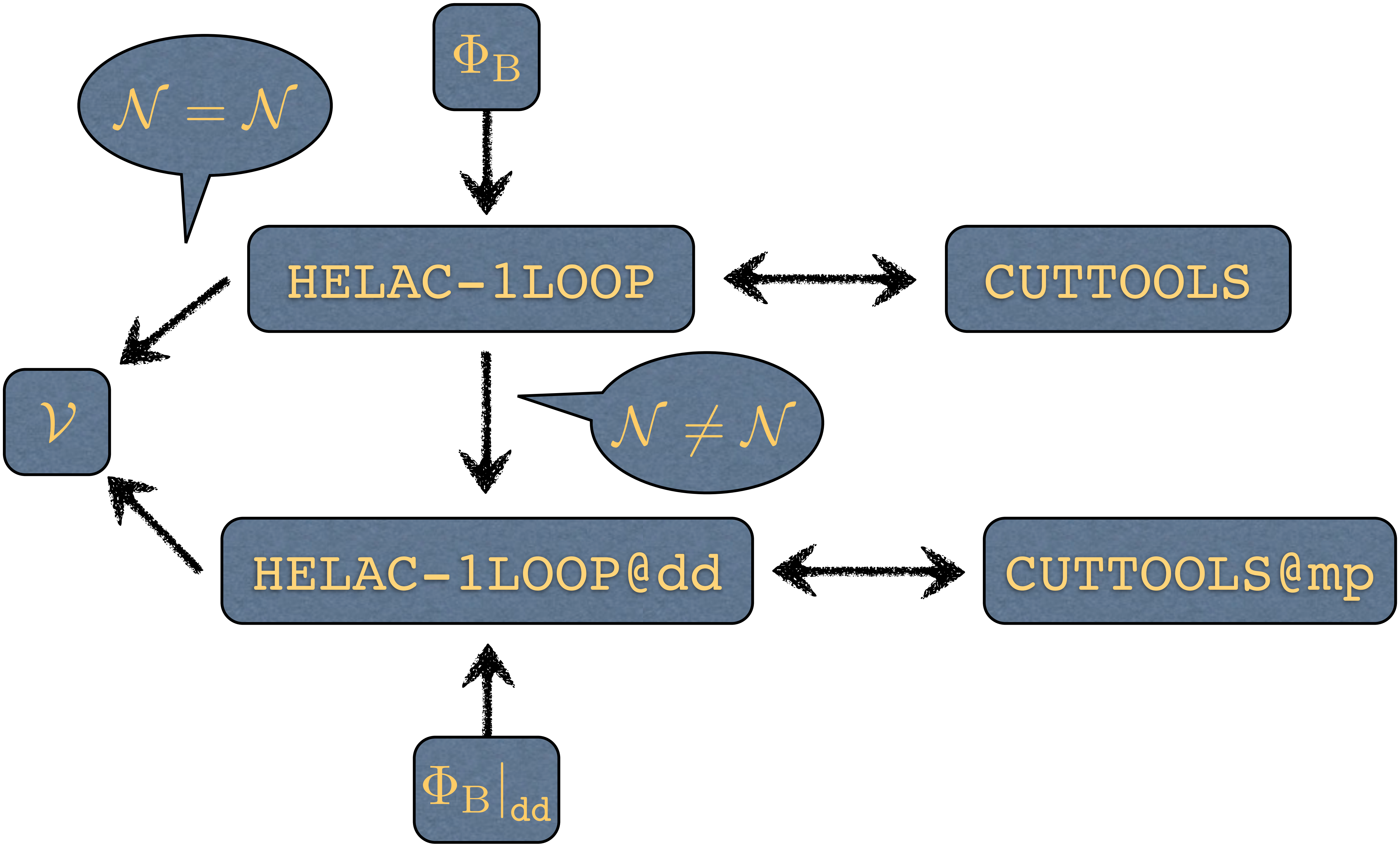
HELAC-1LOOP@dd framework

- Complex processes
- Complicated tensor integrals in the virtual part
- High rank ones with possible numerical instabilities
- Double precision is not enough anymore
  - ➡Higher precision is needed

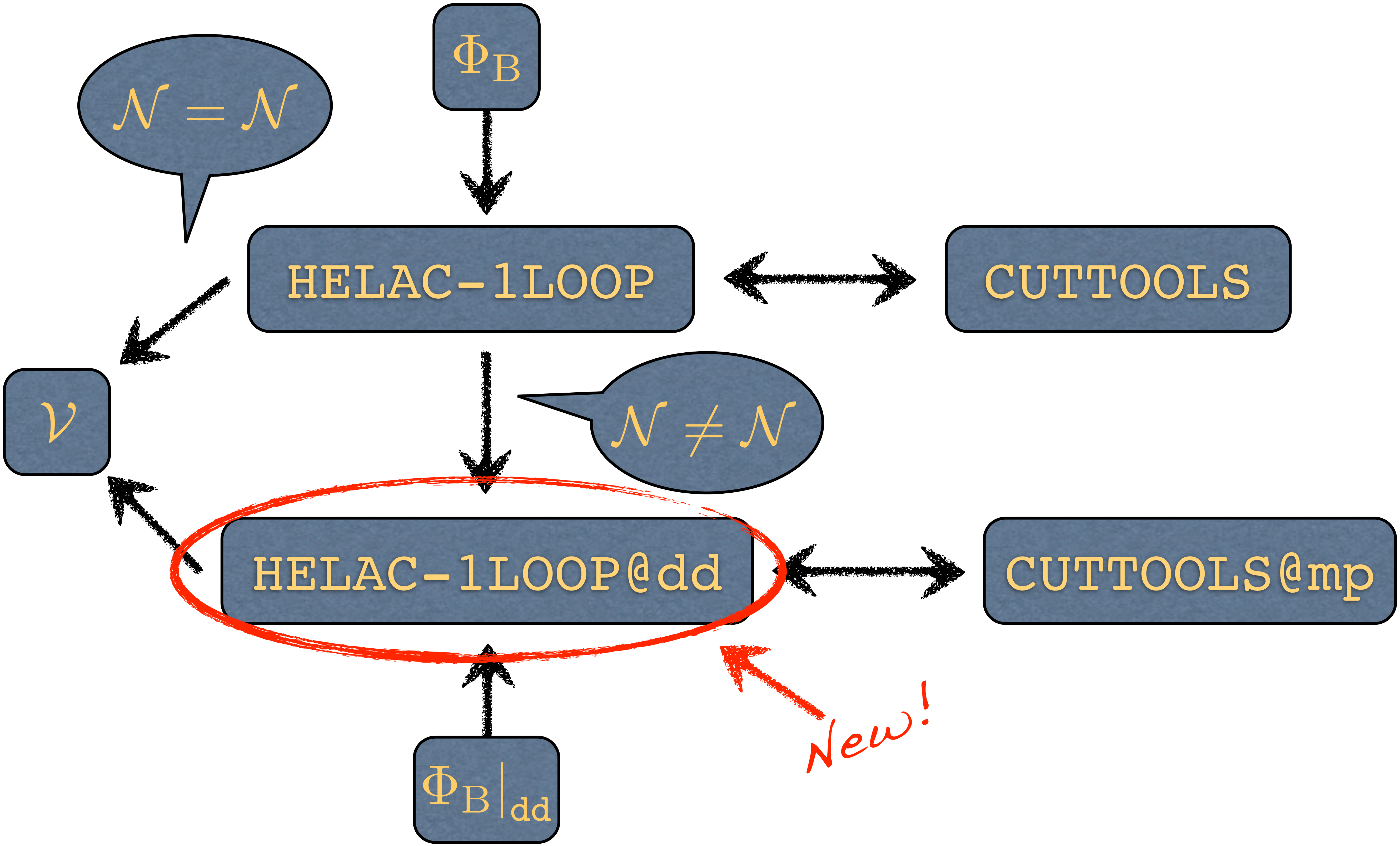
⬇

HELAC-1LOOP@dd

HELAC-1LOOP@dd framework



HELAC-1LOOP@dd framework



How to decay?

- Decay at ME level:
  - Spin correlations
  - CPU time increased
  - Possible different (extra) runs
- Decay at SMC:
  - On-shell heavy objects
  - Easy to evaluate
  - No spin correlations
- Decay with `DECAYER`:
  - Post event-generation run
  - Spin correlations
  - CPU efficient

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-Decay at ME level:

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- Decay at SMC:

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-Decay with DECAYER:

Brand new!

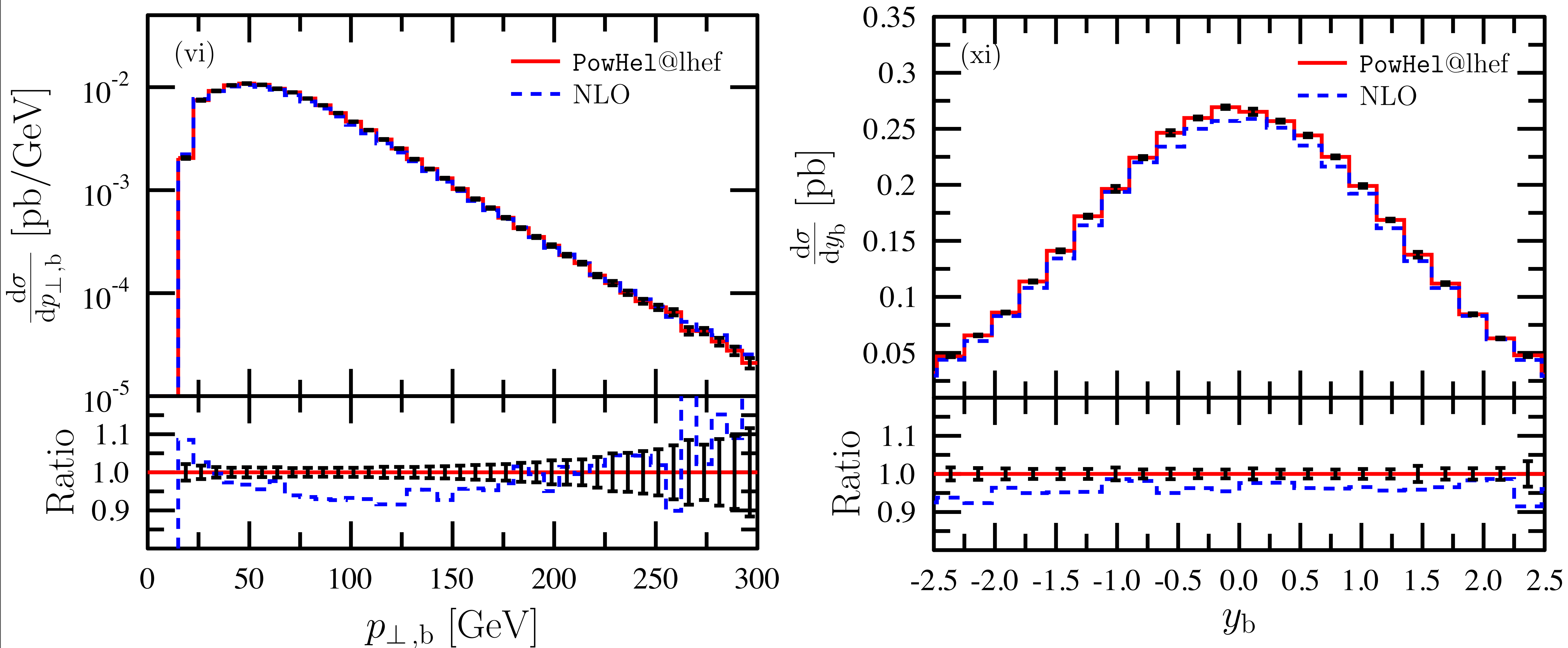
- Post event-generation run
- Spin correlations
- CPU efficient

$W^+ W^- b\bar{b}$ production

$W^+ W^- b \bar{b}$

- Based on the full NLO calculation of the $W^+ W^- b \bar{b}$ (Bevilacqua et. al. arXiv:1012.4230)
- Comparison made for the 7 TeV LHC, with a setup listed in arXiv:1012.4230

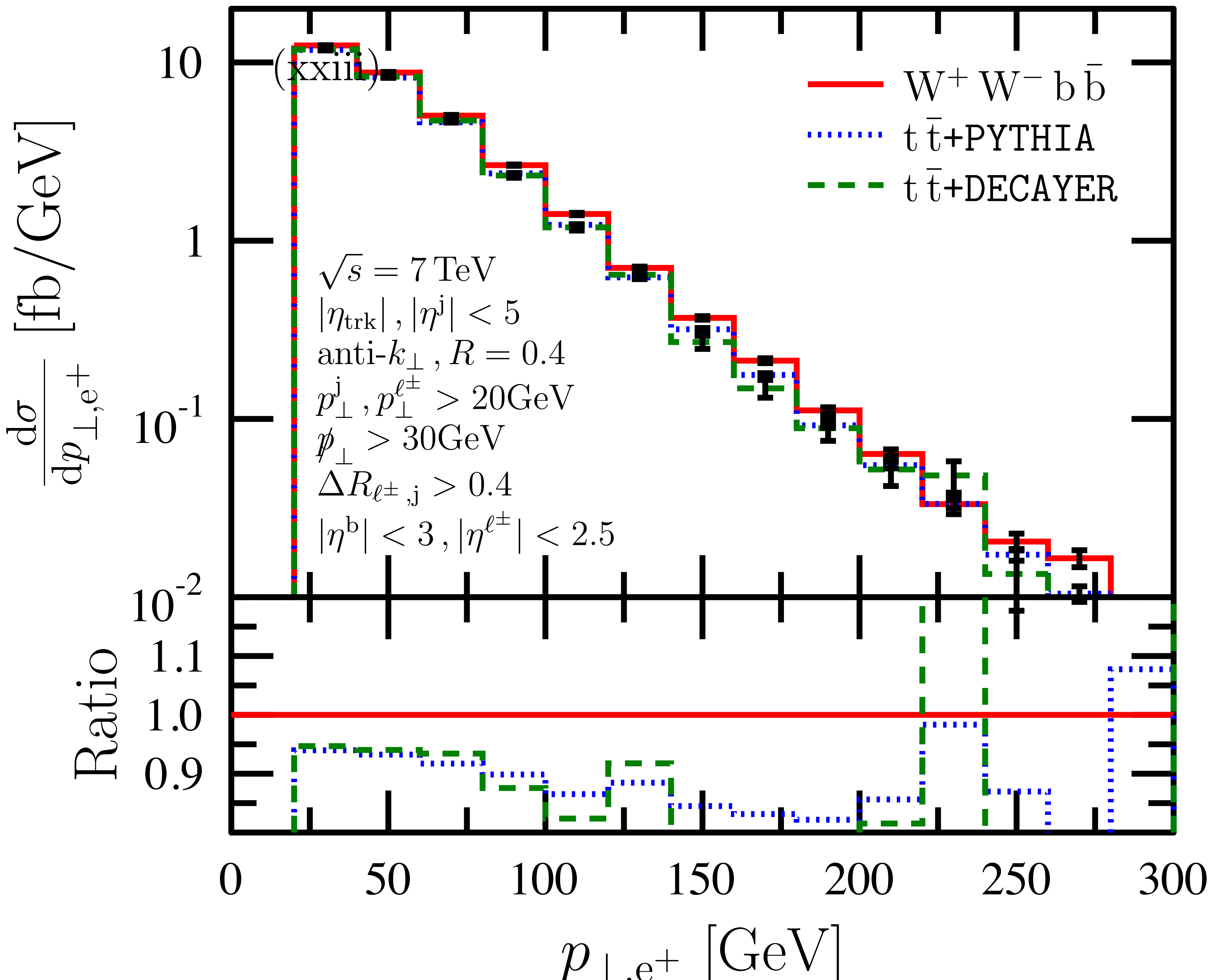
$W^+ W^- b \bar{b}$



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

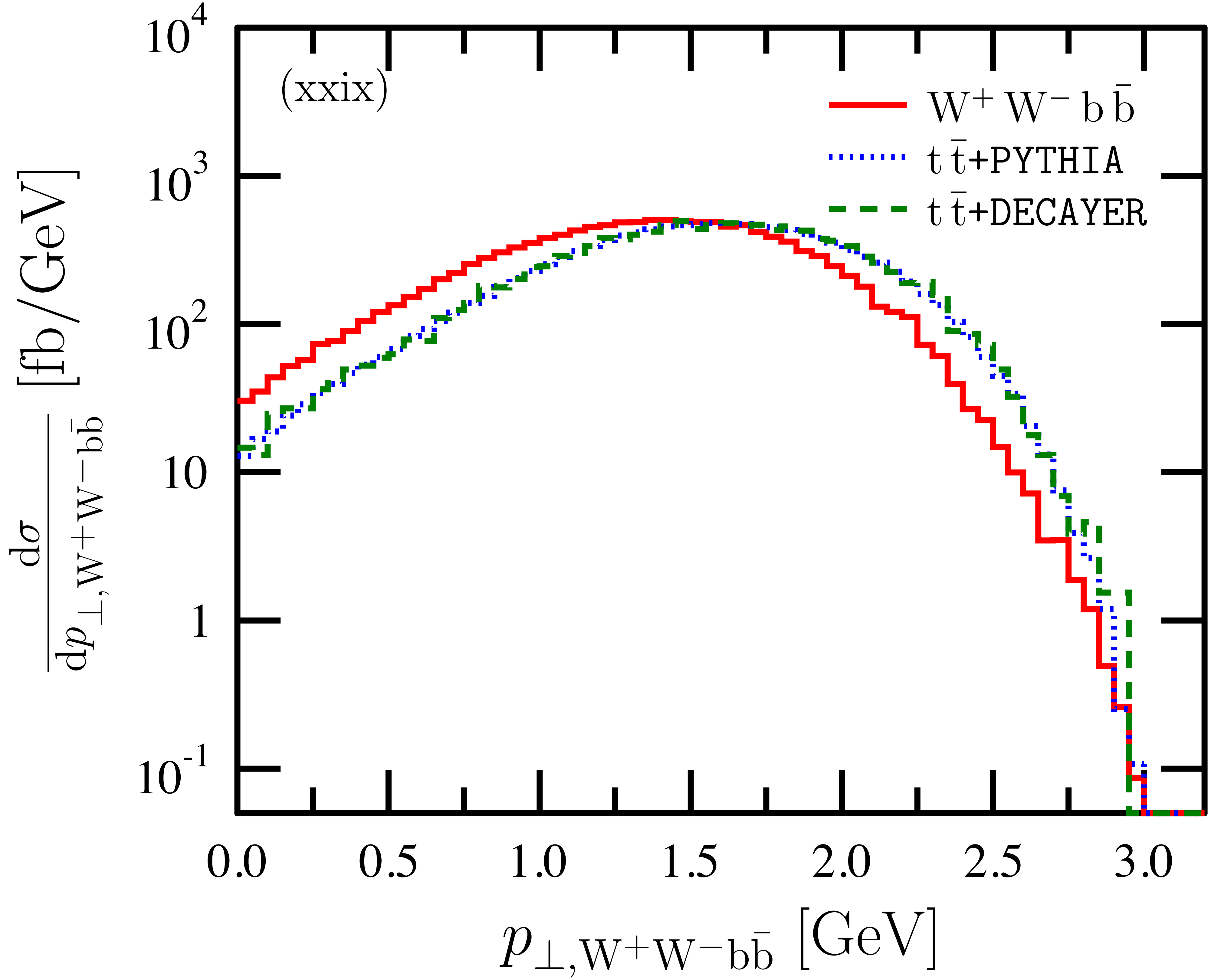
Predictions

$W^+ W^- b \bar{b}$



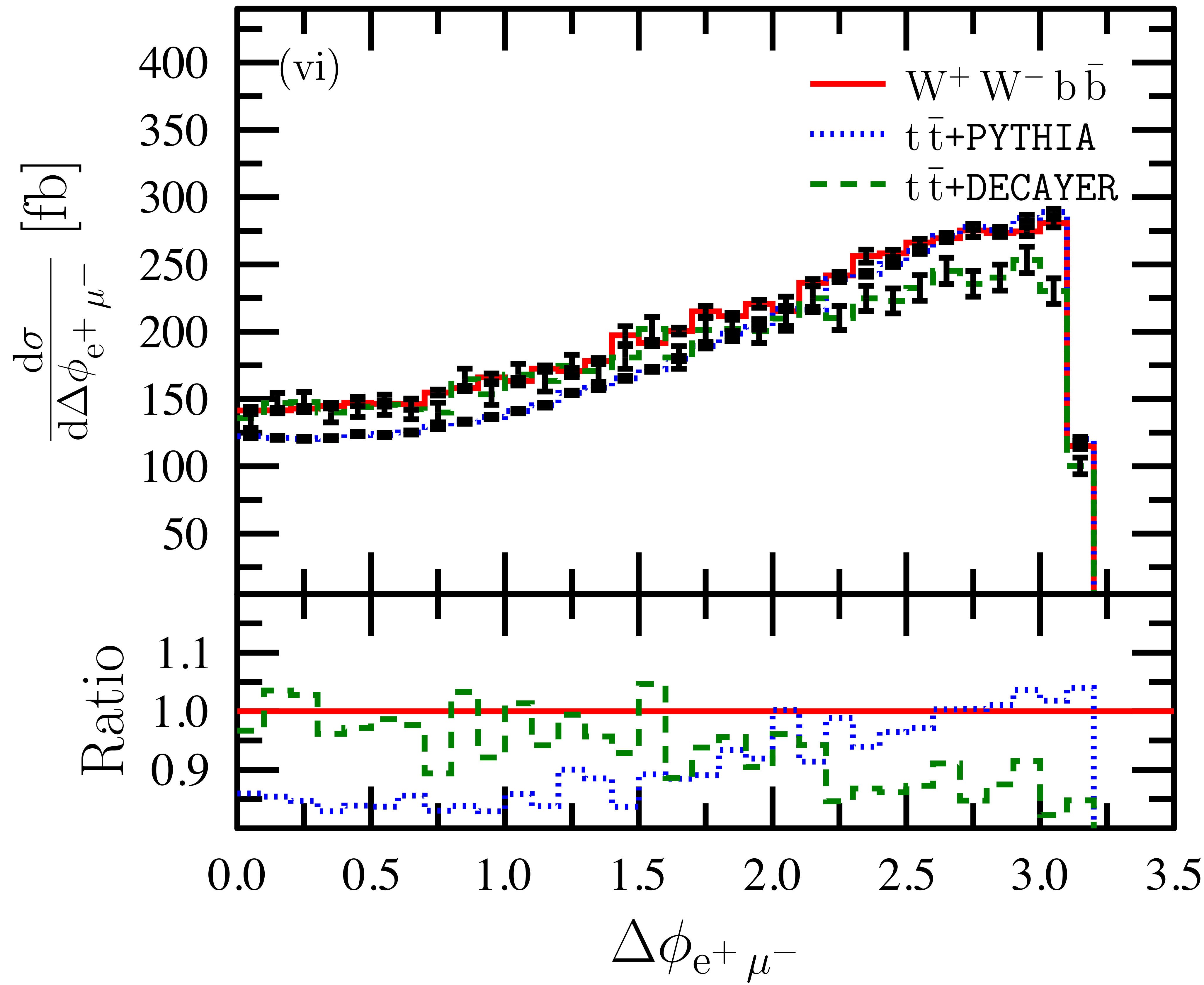
(xxiii)
$W^+ W^- b \bar{b}$
$t \bar{t}$+PYTHIA
$t \bar{t}$+DECAYER
$\sqrt{s} = 7$ TeV
$|\eta_{\rm trk}|, |\eta^{\rm j}| < 5$
anti-$k_\perp$, $R = 0.4$
$p_\perp^{\rm j}, p_\perp^{\ell^\pm} > 20$GeV
$\not{p}_\perp > 30$GeV
$\Delta R_{\ell^\pm, {\rm j}} > 0.4$
$|\eta^{\rm b}| < 3, |\eta^{\ell^\pm}| < 2.5$
$\frac{d\sigma}{dp_{\perp,e^+}}$ [fb/GeV]
10
1
10^{-1}
10^{-2}
Ratio
1.1
1.0
0.9
0
50
100
150
200
250
300
$p_{\perp,e^+}$ [GeV]

$W^+ W^- b \bar{b}$



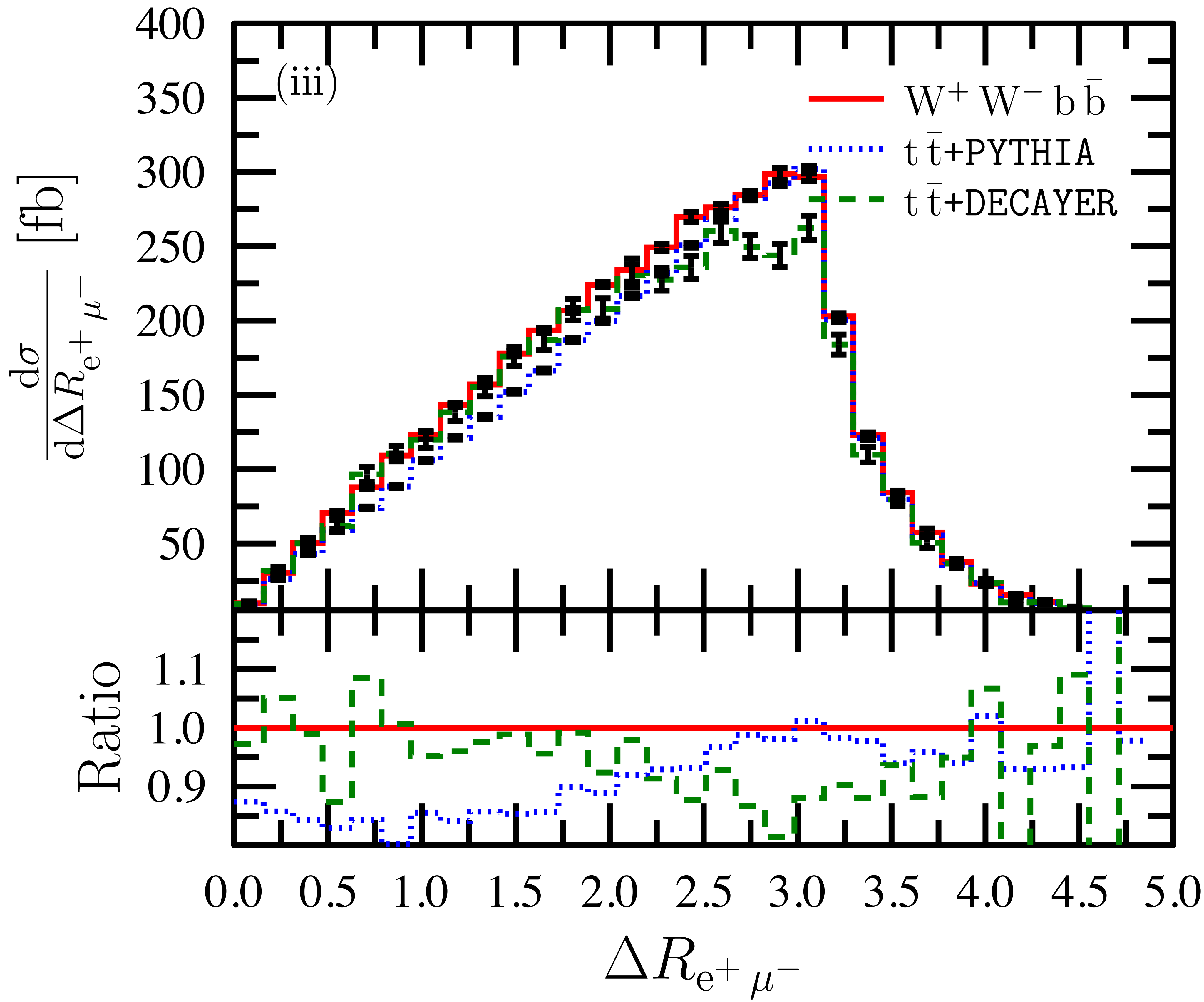
(xxix)
$W^+ W^- b \bar{b}$
$t \bar{t}$+PYTHIA
$t \bar{t}$+DECAYER
10^4
10^3
10^2
10
1
10^{-1}
0.0
0.5
1.0
1.5
2.0
2.5
3.0
$\frac{d\sigma}{dp_{\perp,W^+W^-b\bar{b}}}$ [fb/GeV]
$p_{\perp,W^+W^-b\bar{b}}$ [GeV]

$W^+ W^- b \bar{b}$



(vi)
$W^+ W^- b \bar{b}$
$t \bar{t}$+PYTHIA
$t \bar{t}$+DECAYER
$\frac{d\sigma}{d\Delta\phi_{e^+ \mu^-}}$ [fb]
400
350
300
250
200
150
100
50
Ratio
1.1
1.0
0.9
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
$\Delta\phi_{e^+ \mu^-}$

$W^+ W^- b \bar{b}$



(iii)
W+ W− b b̄
t t̄+PYTHIA
t t̄+DECAYER
dσ/dΔR_{e+ μ−} [fb]
400
350
300
250
200
150
100
50
Ratio
1.1
1.0
0.9
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0
ΔR_{e+ μ−}

Implemented Processes

- t T
- t T + Z (arXiv:1111.0610, 1111.1444)
- t T + H/A (arXiv:1108.0387,1201.3084)
- t T + j (arXiv:1101.2672)
- WWbB (to appear soon)

Implemented Processes

Stay tuned!

The best is yet to come!

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For more fancy plots see the next talk...

Thank you for your attention!