tT+hard X hadroproduction with PowHel

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in collaboration with
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and
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NEW SZÉCHENYI PLAN

LHCphenOnet

Event Generators and Resummation
May 29 - June 1, 2012
DESY Hamburg

Outline

- Motivation
- Method
- Predictions
- Conclusions and Plans

Garfield knows best!

Motivation

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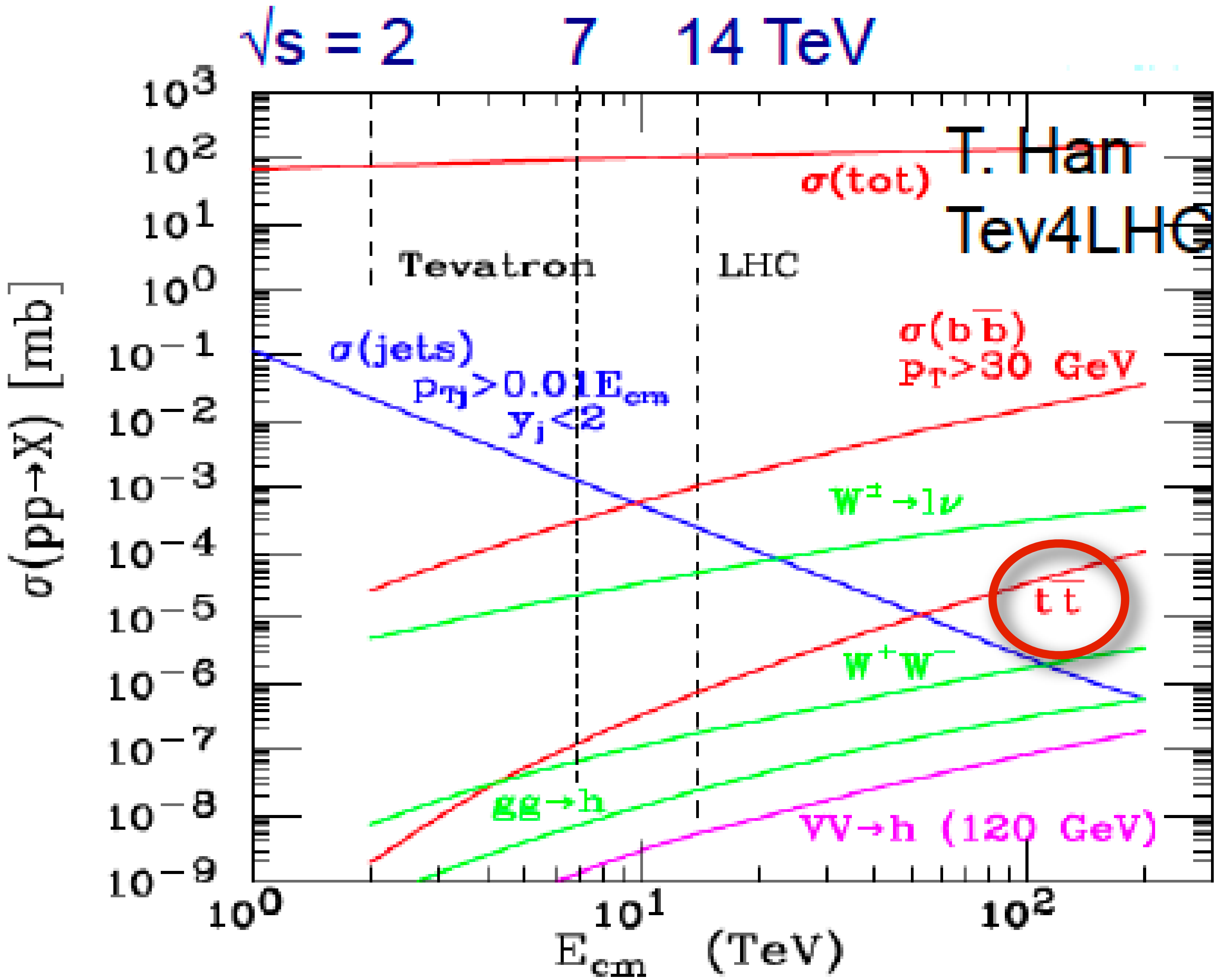
"The t-quark is special"

The importance of being top

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



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2. The t-quark is heavy, Yukawa coupling ~1

   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)

   $172.6 \pm 0.6_{stat} \pm 1.2_{syst}$ (CMS)

   $174.5 \pm 0.6_{stat} \pm 2.3_{syst}$ (ATLAS)

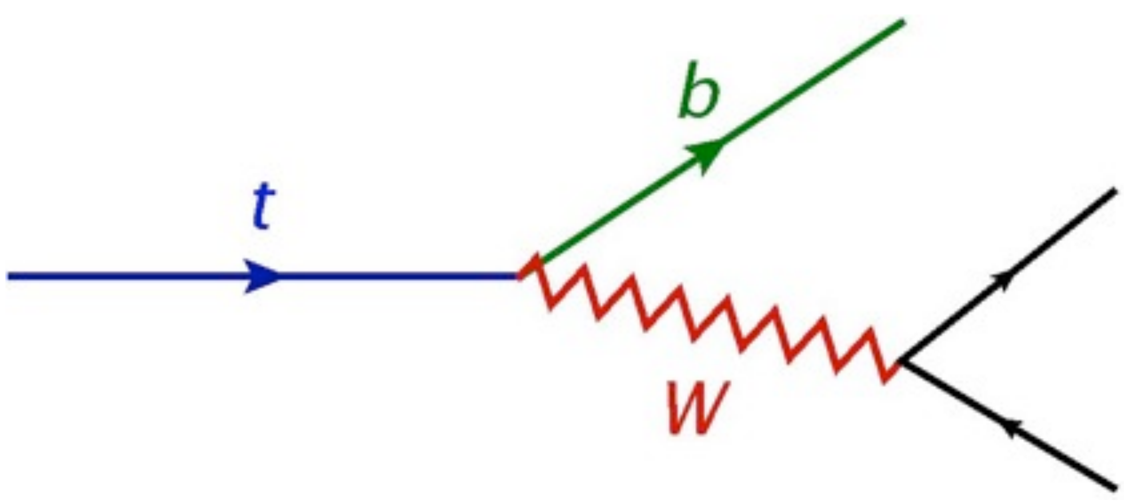
   ($y_t = 1 \Rightarrow 173.9$)

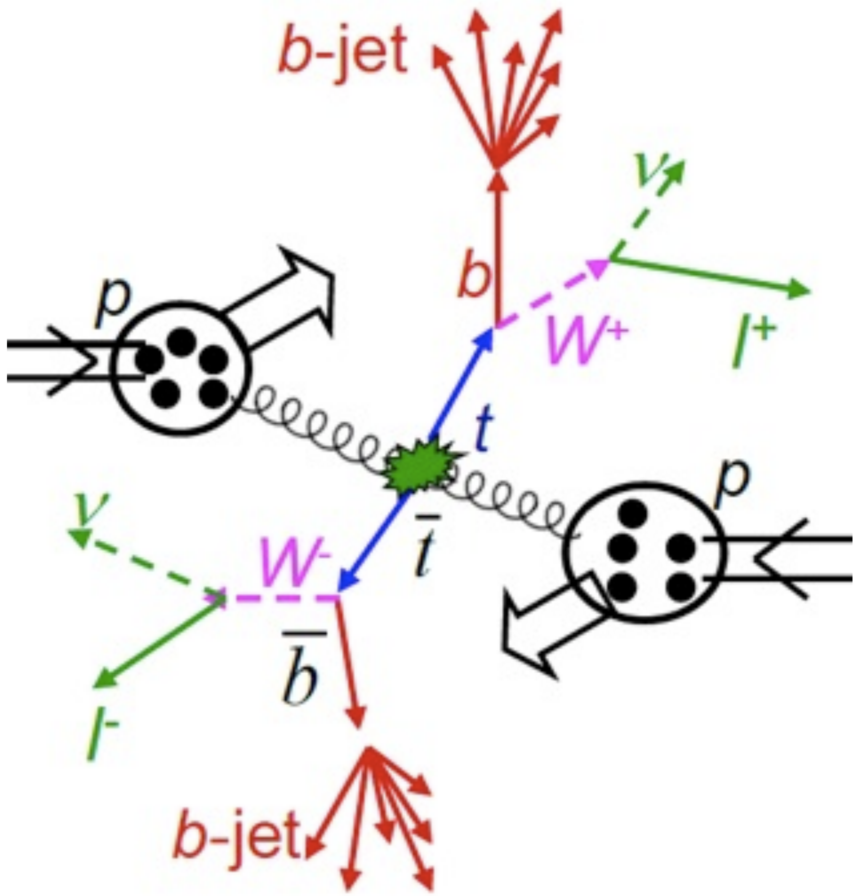
   $\Rightarrow$ plays important role in Higgs physics

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

Present:

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

Future: discovery tool, coupling measurements

These require precise predictions of distributions at hadron level for

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

(with decays, top is not detected)

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...but we deliver the events on request

...to distributions, full of pitfalls & difficulties

There is a long way from matrix elements...

Also covered in Marek's and Simone's talk

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in the next few minutes:

Check your facebook profile!!

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or check the stock market:

NLO subtractions

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- Subtraction method

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

$$\int d\Phi_n B(\Phi_n) = \sigma_{\rm LO}$$

$$V(\Phi_n) = \mathcal{V}(\Phi_n) + \int d\Phi_{\rm rad} A(\Phi_{n+1})$$

$$d\Phi_{n+1} = d\Phi_n \, d\Phi_{\rm rad} \,, \qquad d\Phi_{\rm rad} \propto dt \, dz \, \frac{d\phi}{2\pi}$$

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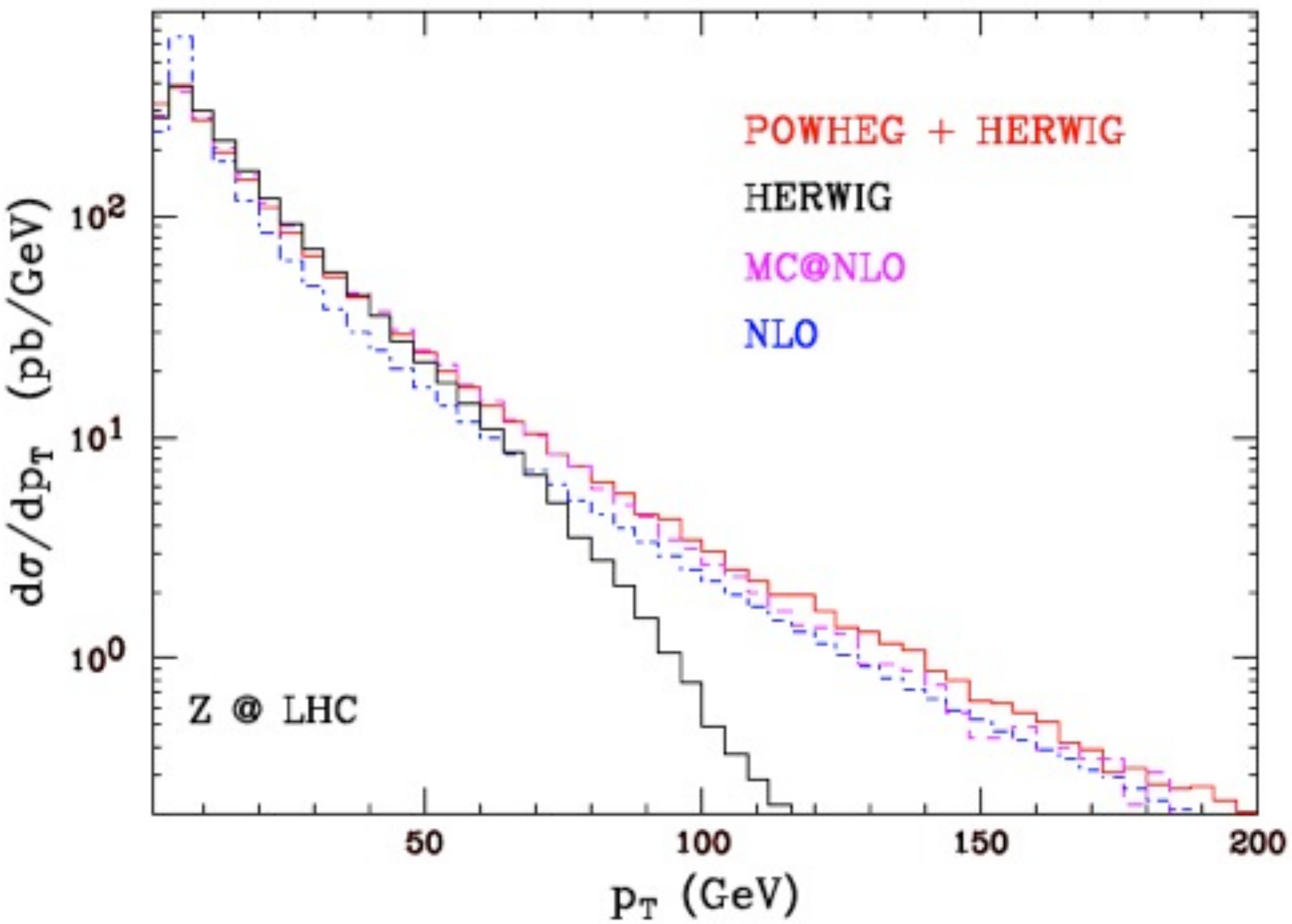
- POWHEG [Nason hep-ph/0409146, Frixione, Nason, Oleari arXiv:0709.2092]

Result: PS events giving distributions exact to NLO in pQCD



[Nason, Ridolfi hep-ph/0606275]

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- tT+... in progress

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$$d\sigma_{\rm SMC} = B(\Phi_n) d\Phi_n \left[\Delta_{\rm SMC}(t_0) + \Delta_{\rm SMC}(t) \underbrace{\frac{\alpha_{\rm s}(t)}{2\pi} \frac{1}{t} P(z)}_{= \lim_{k_\perp \to 0} R(\Phi_{n+1})/B(\Phi_n)} \Theta(t - t_0)\, d\Phi_{\rm rad}^{\rm SMC} \right]$$

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Formal accuracy of the POWHEG MC

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

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$\langle O\rangle_{\rm NLO}$

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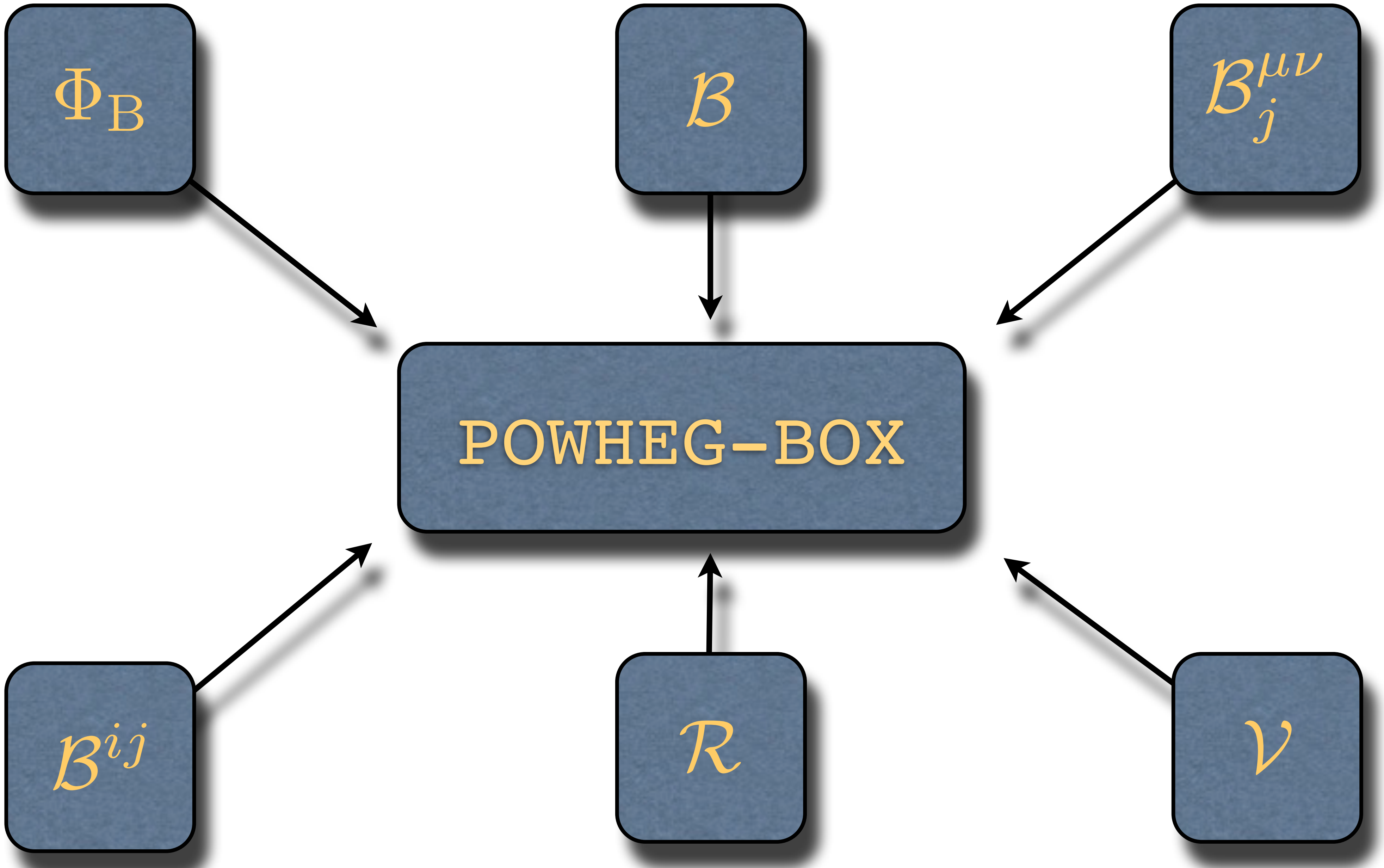
POWHEG-BOX framework



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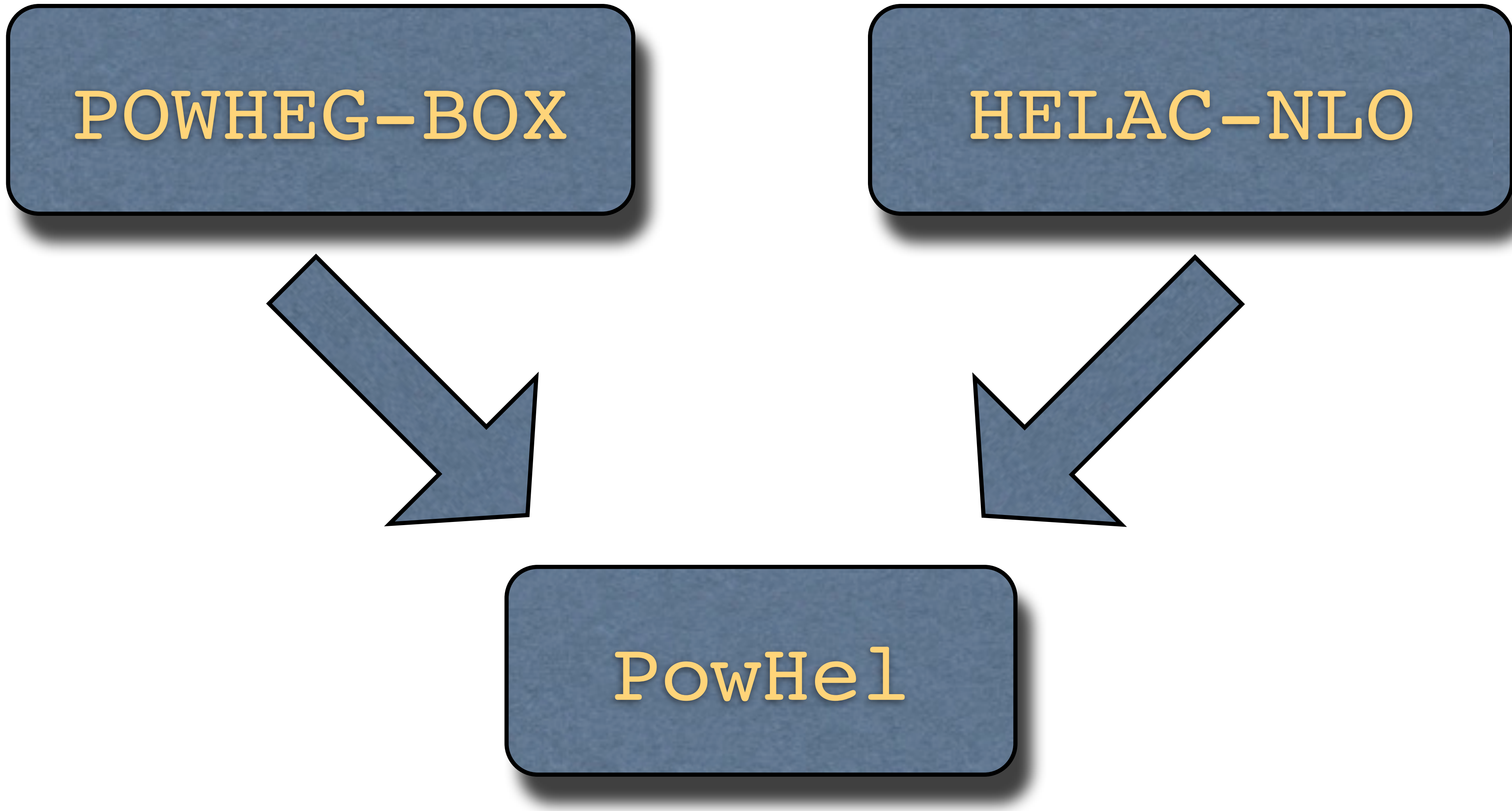

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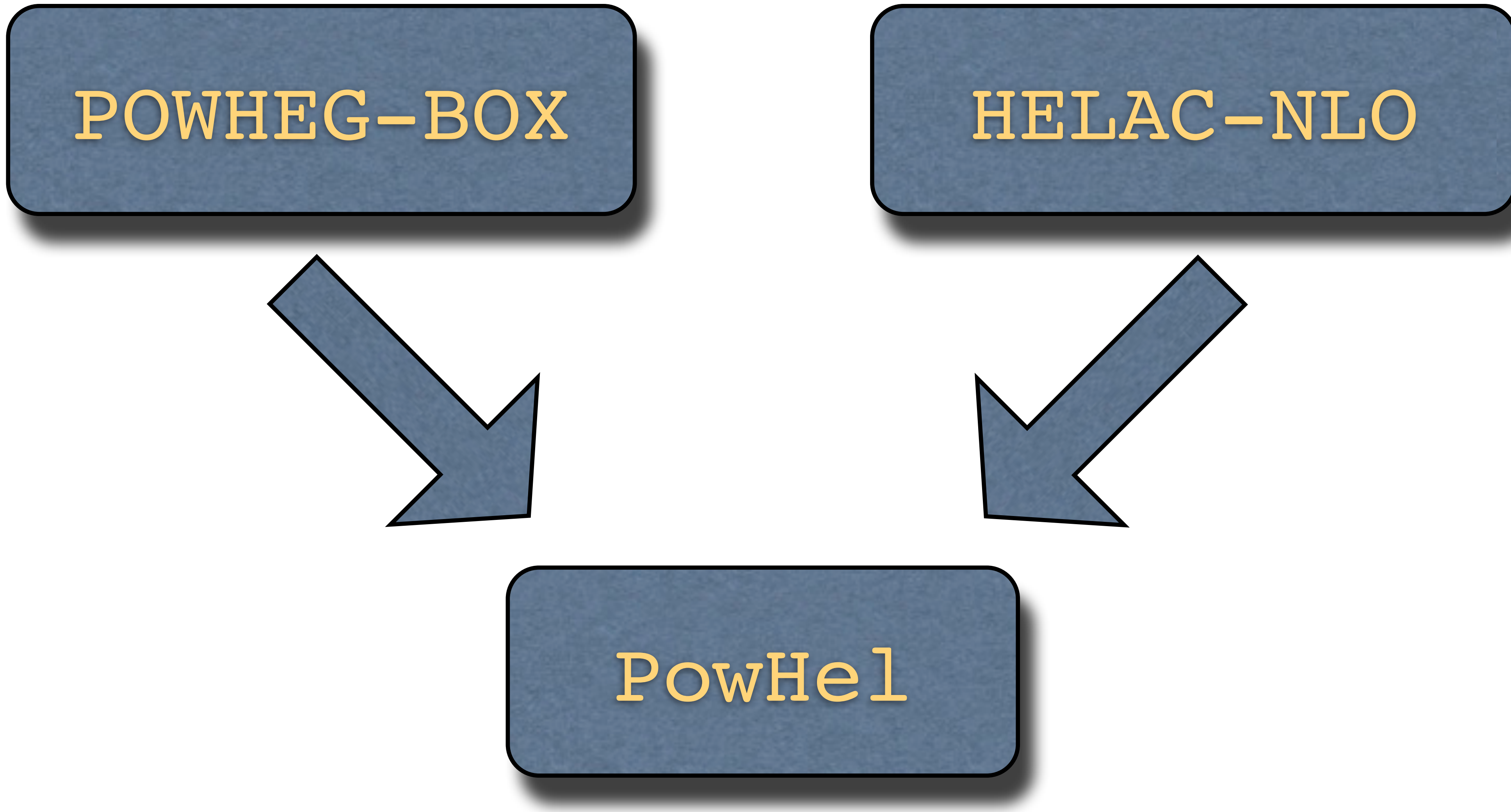

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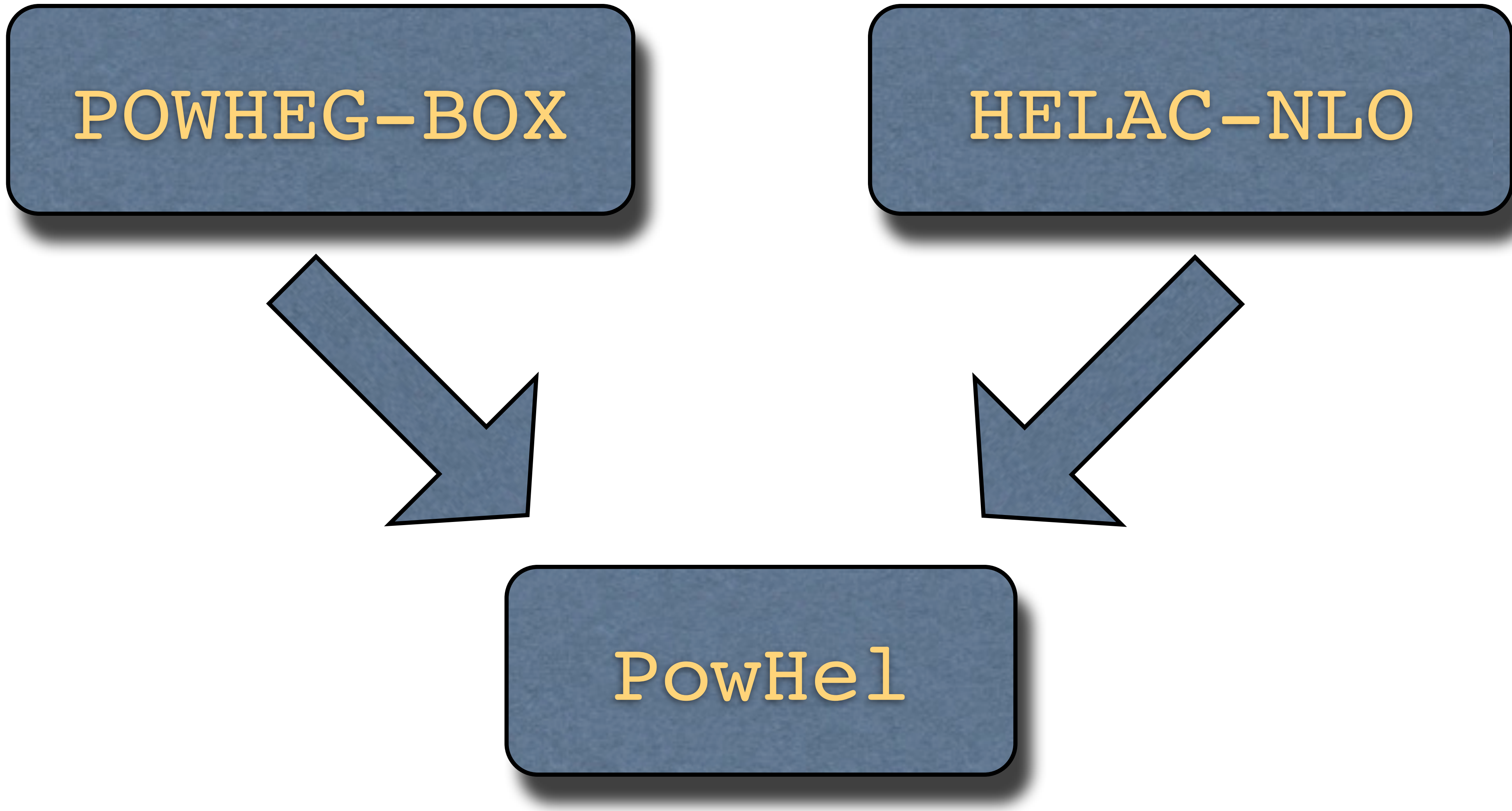

RESULT of PowHel:

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 framework

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

⬇

HELAC-1LOOP@dd

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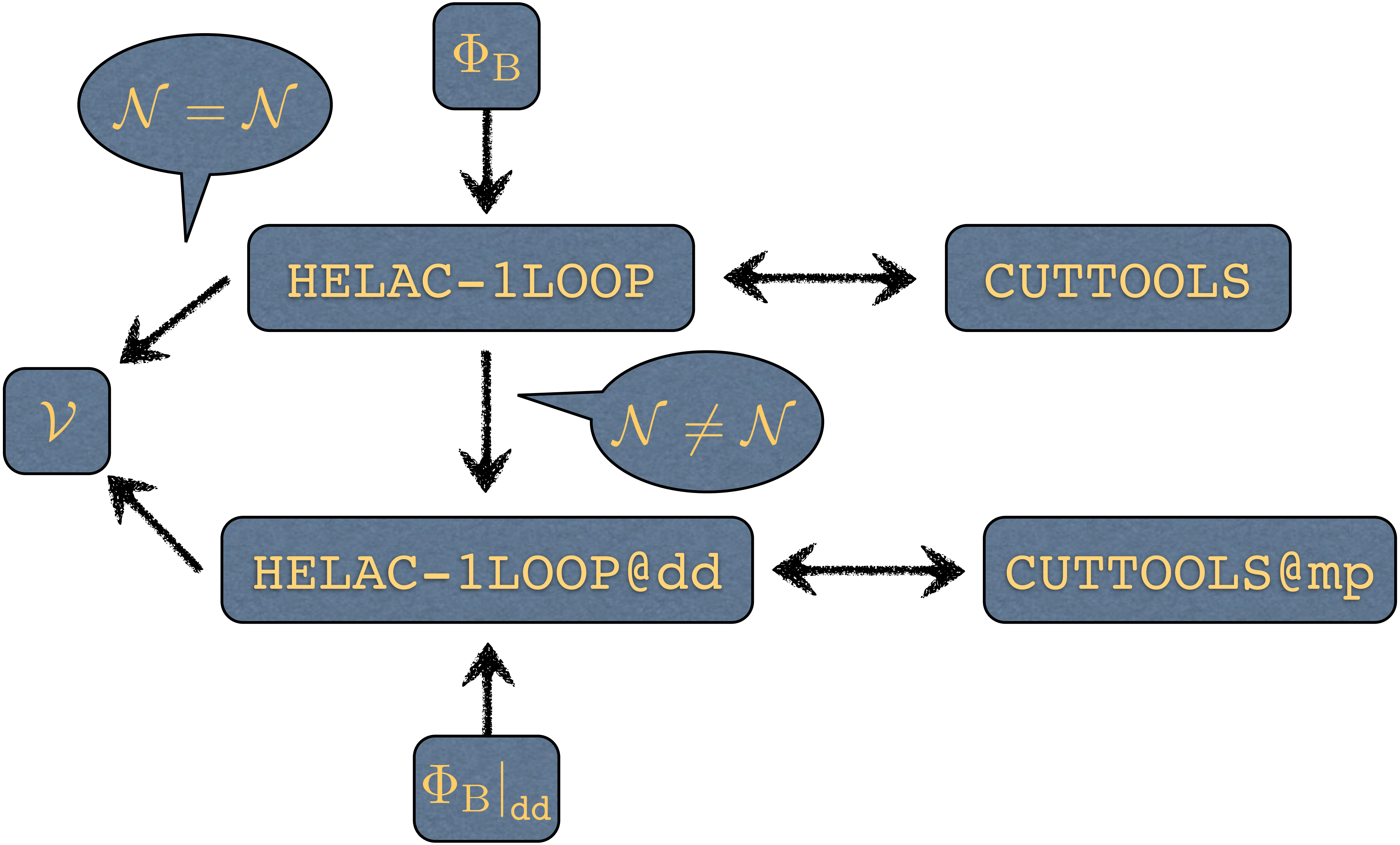

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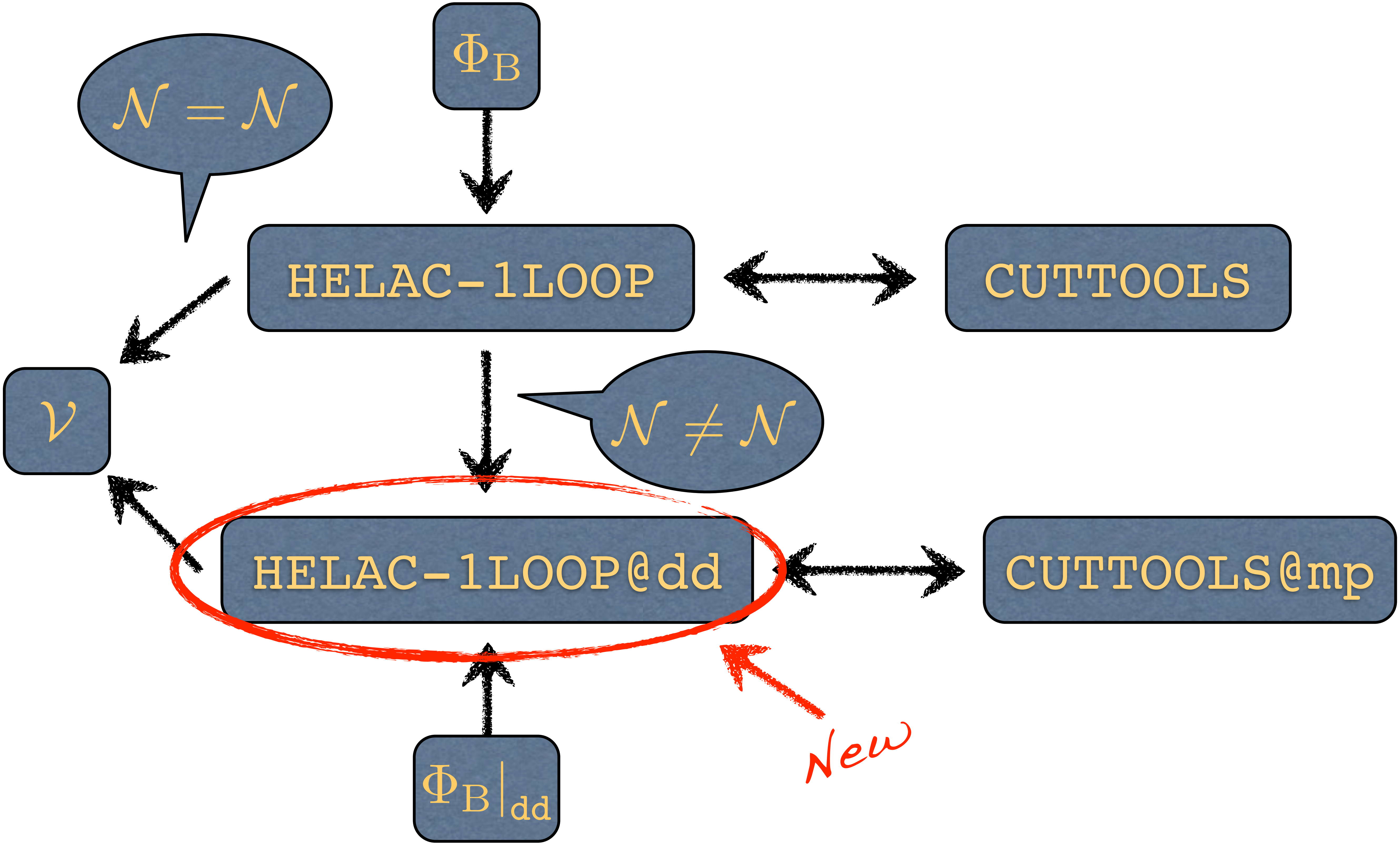

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(see e.g. arXiv: 1111.0610 for $t\bar{t}$ Z production)

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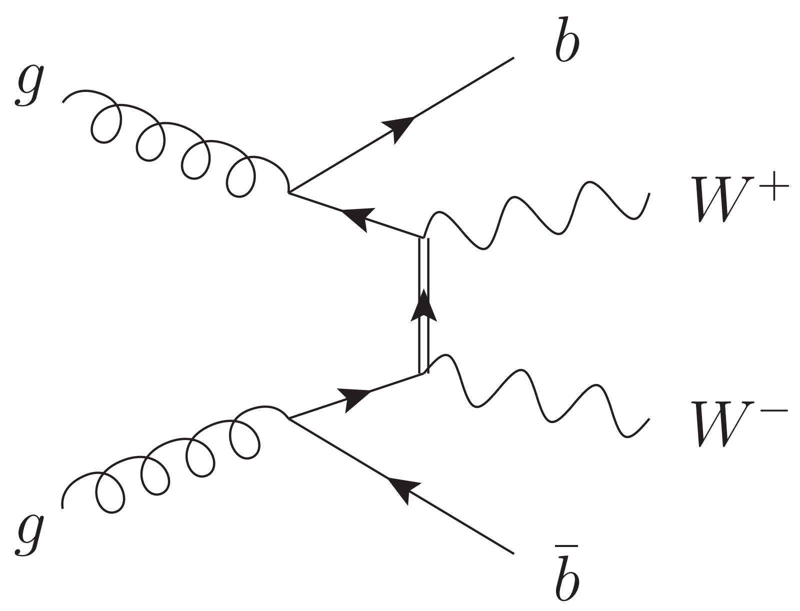
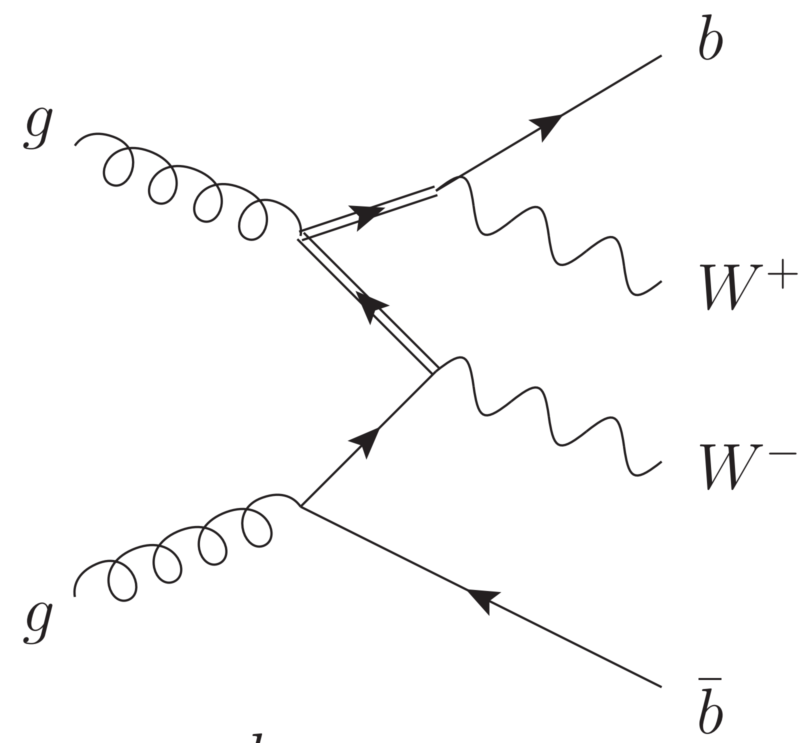
-Decay with DECAYER (NWA): New!

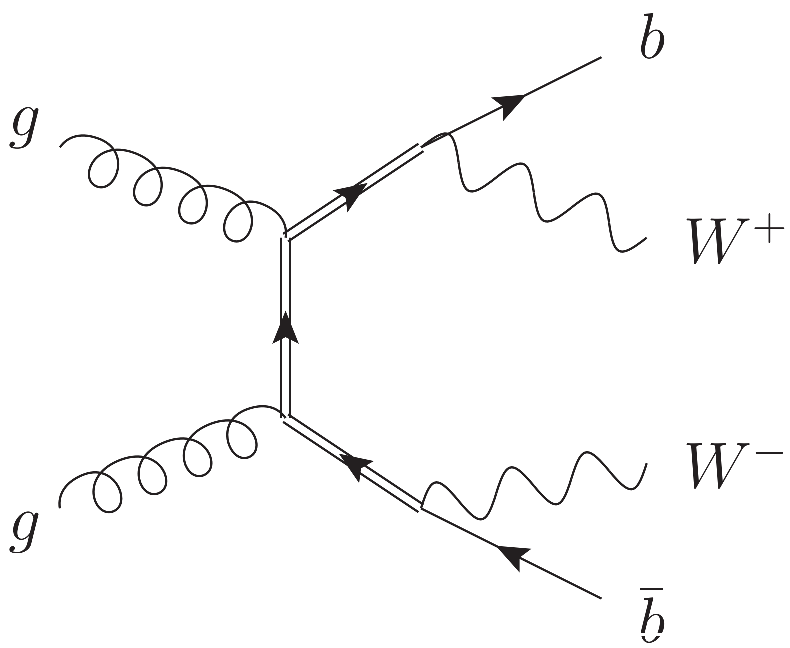
- Post event-generation run
- With spin correlations and off-shell effects
- CPU efficient

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

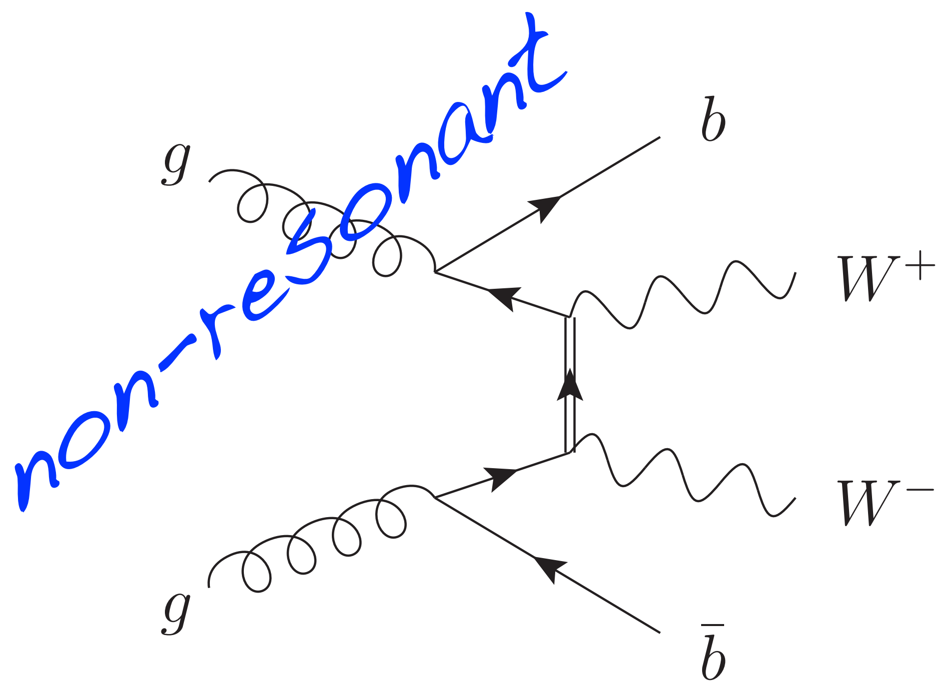
Legs

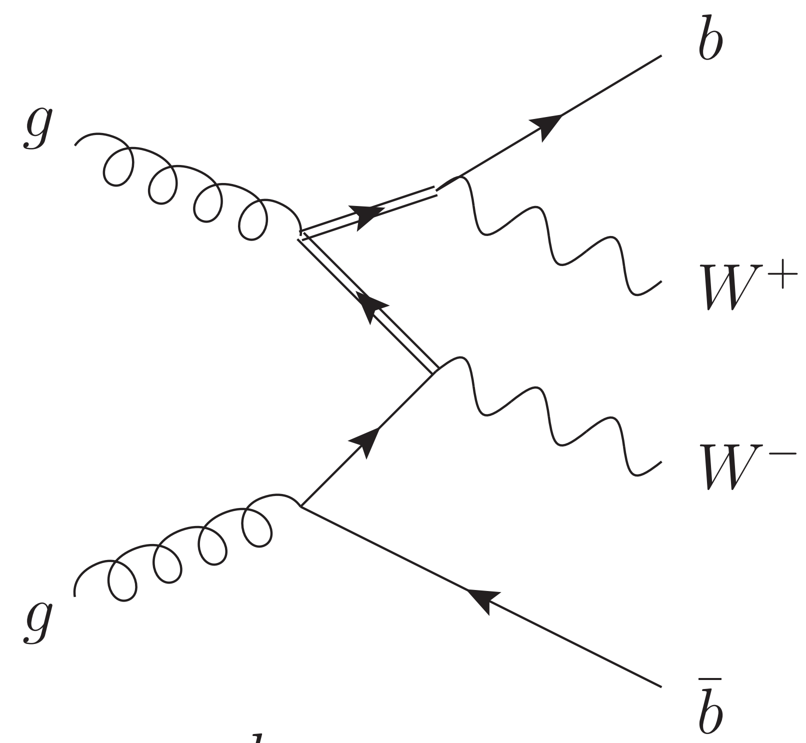


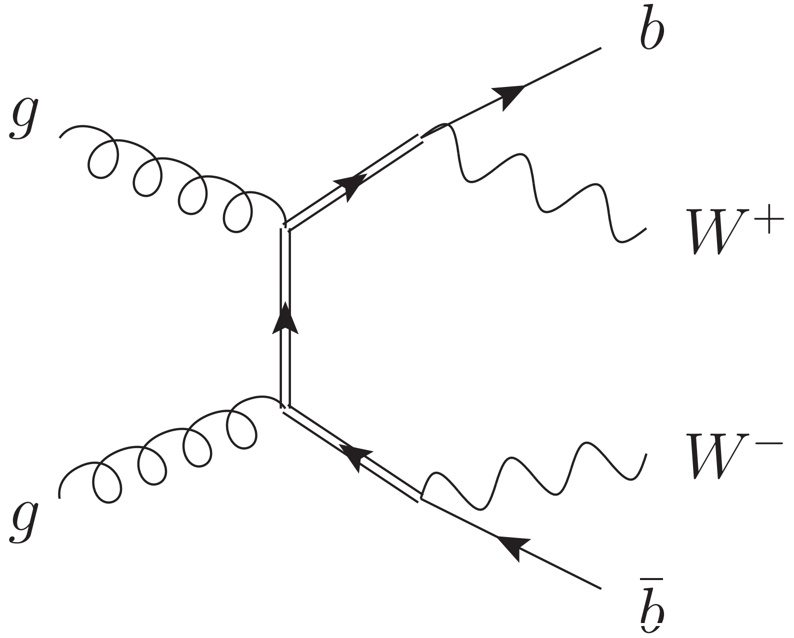




Legs







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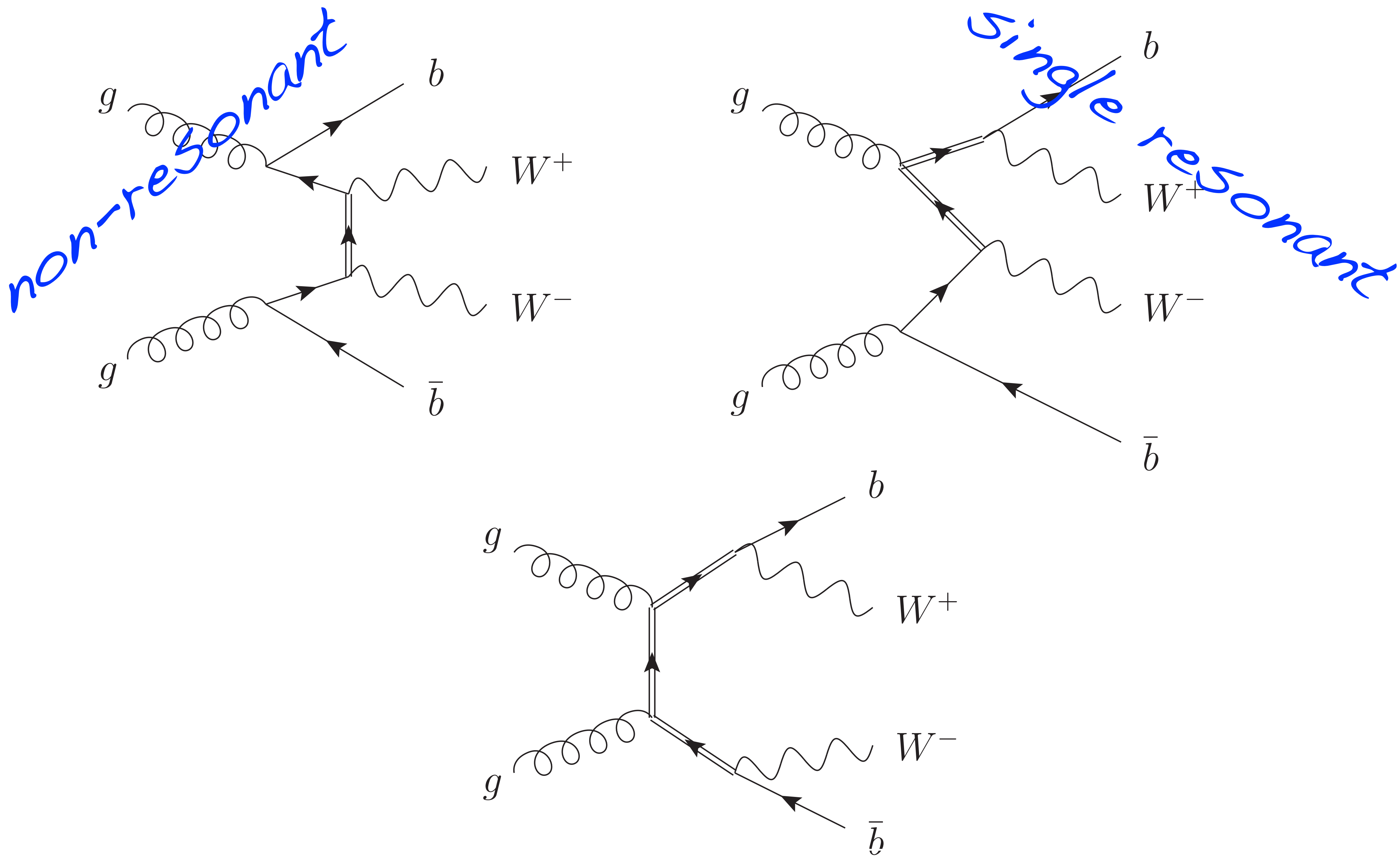
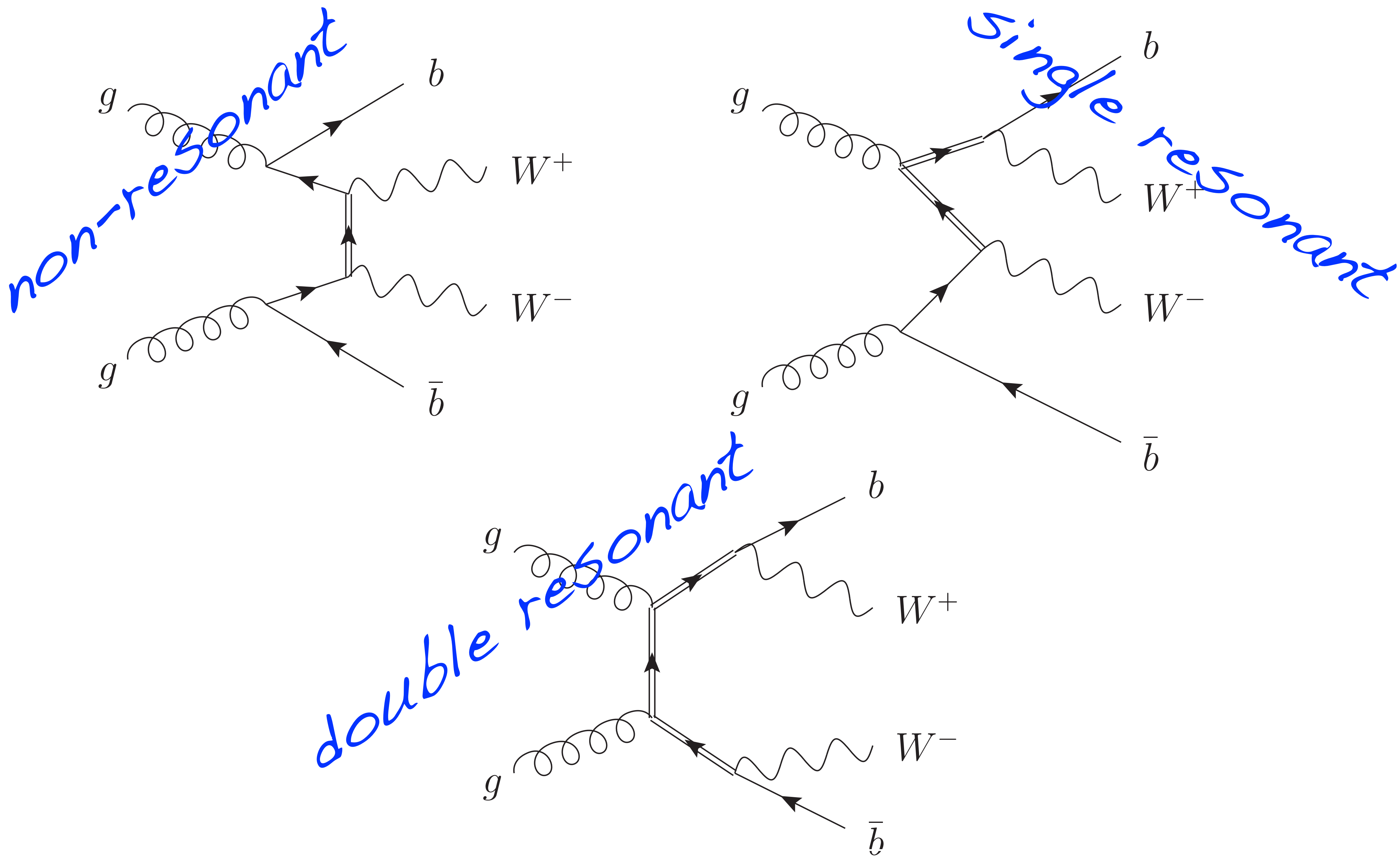
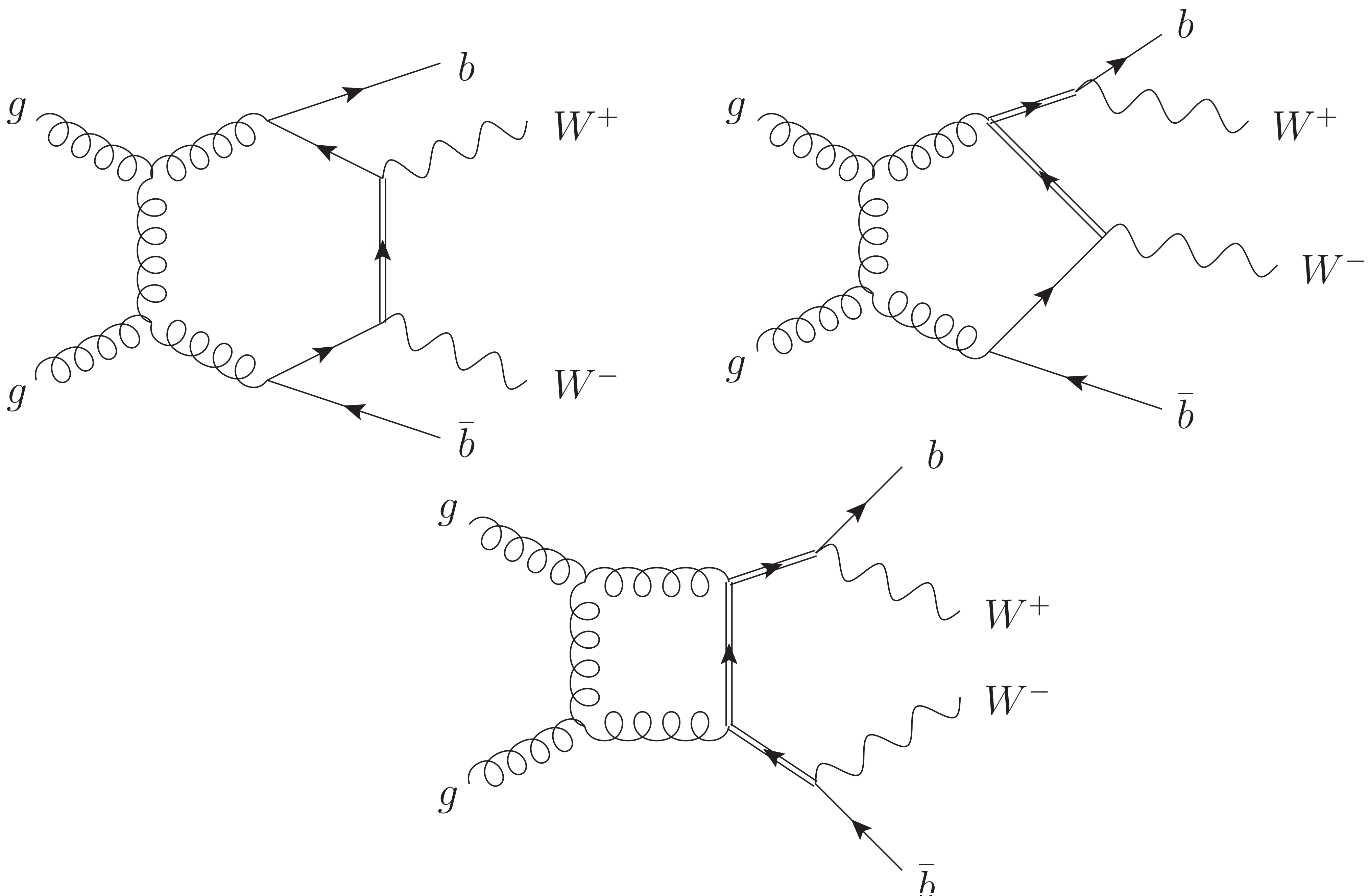


Legs

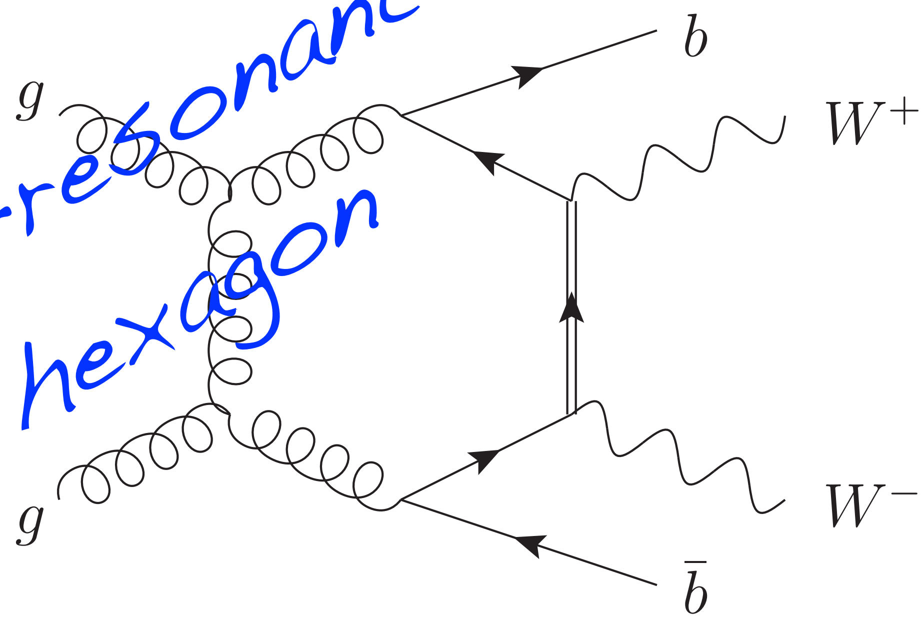

non-resonant
g
g
b
$\bar{b}$
W^+
W^-
single resonant
g
g
b
$\bar{b}$
W^+
W^-
double resonant
g
g
b
$\bar{b}$
W^+
W^-

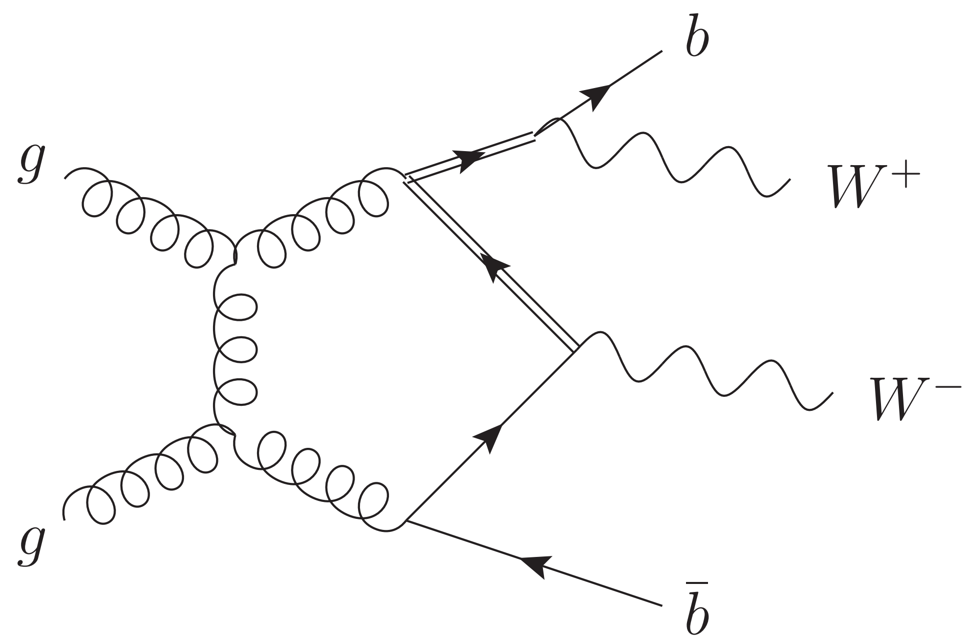
One loop and legs

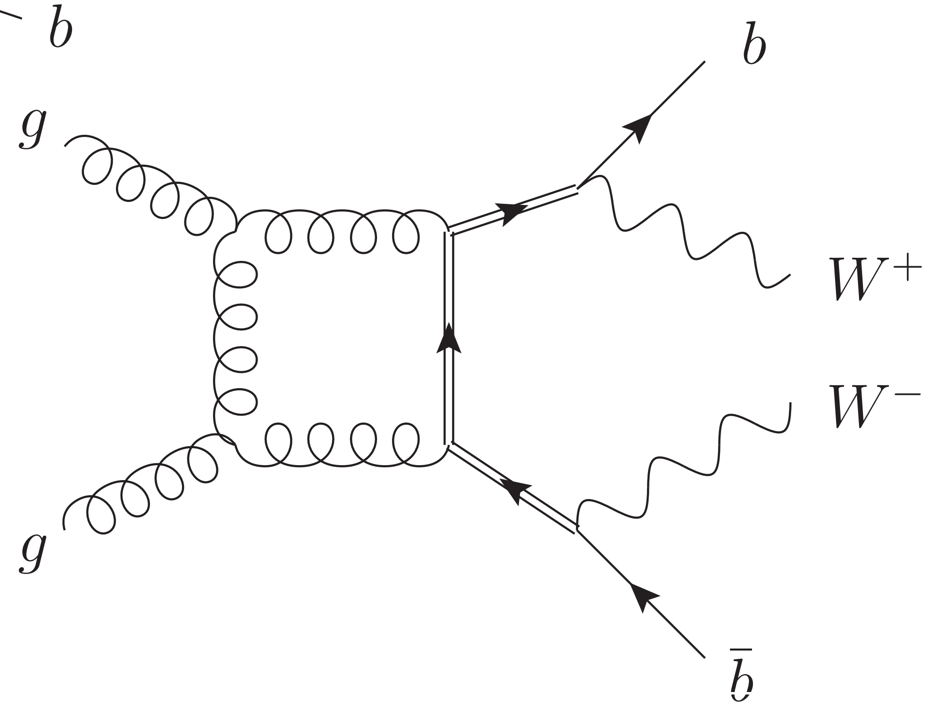


One loop and legs

non-resonant hexagon







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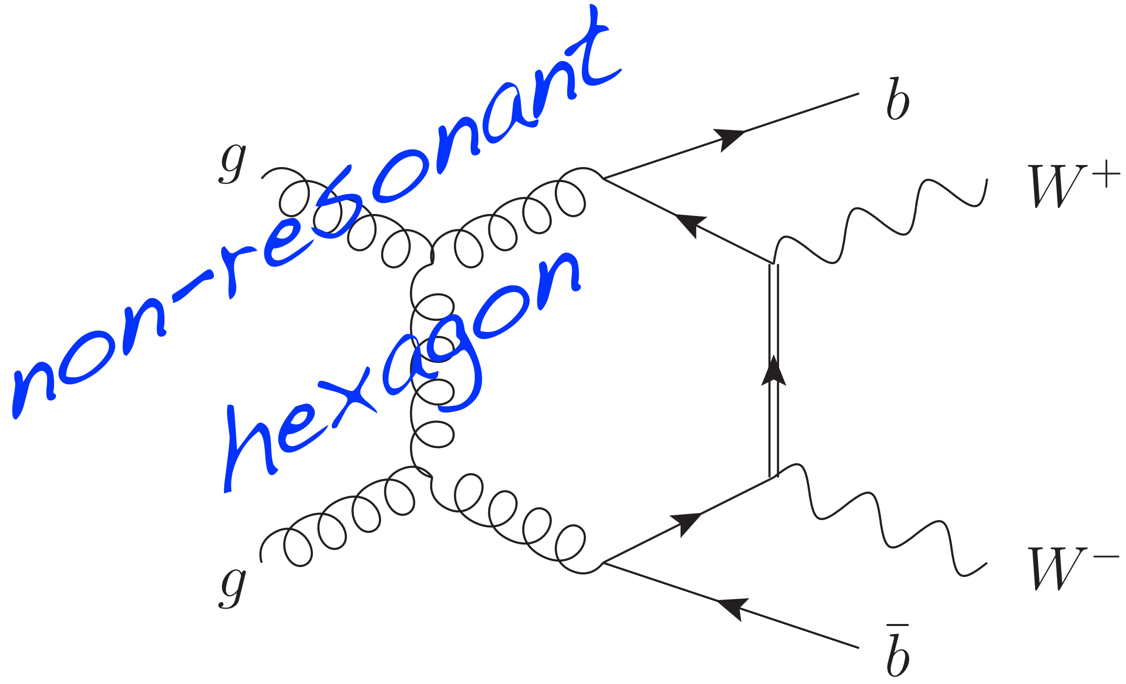

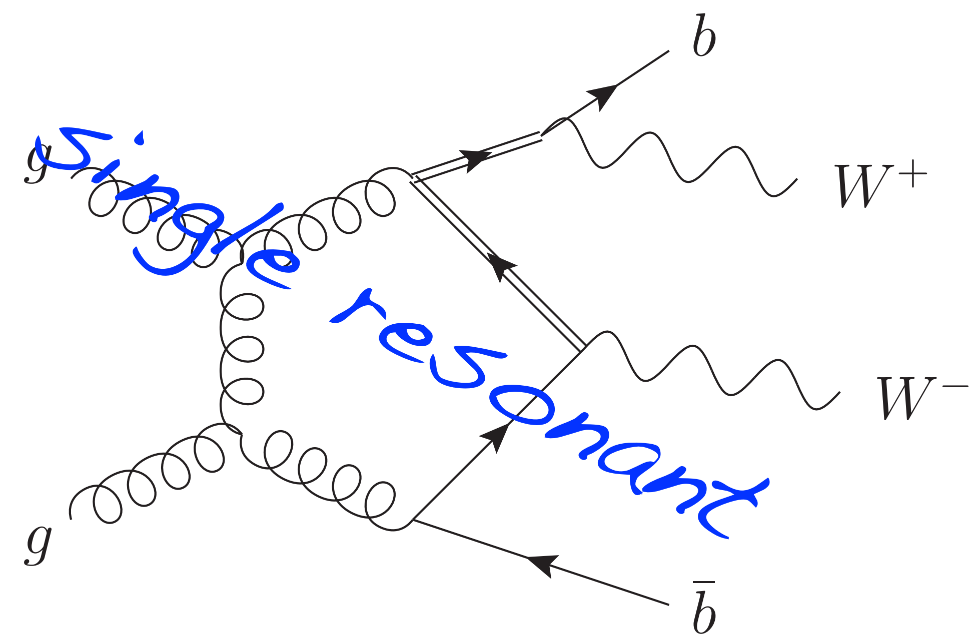

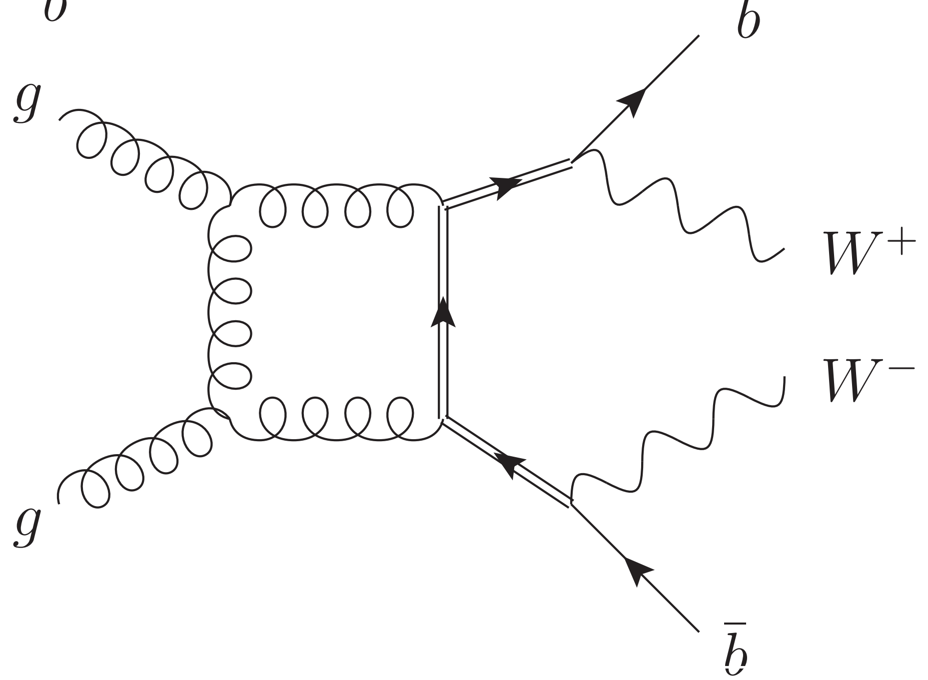

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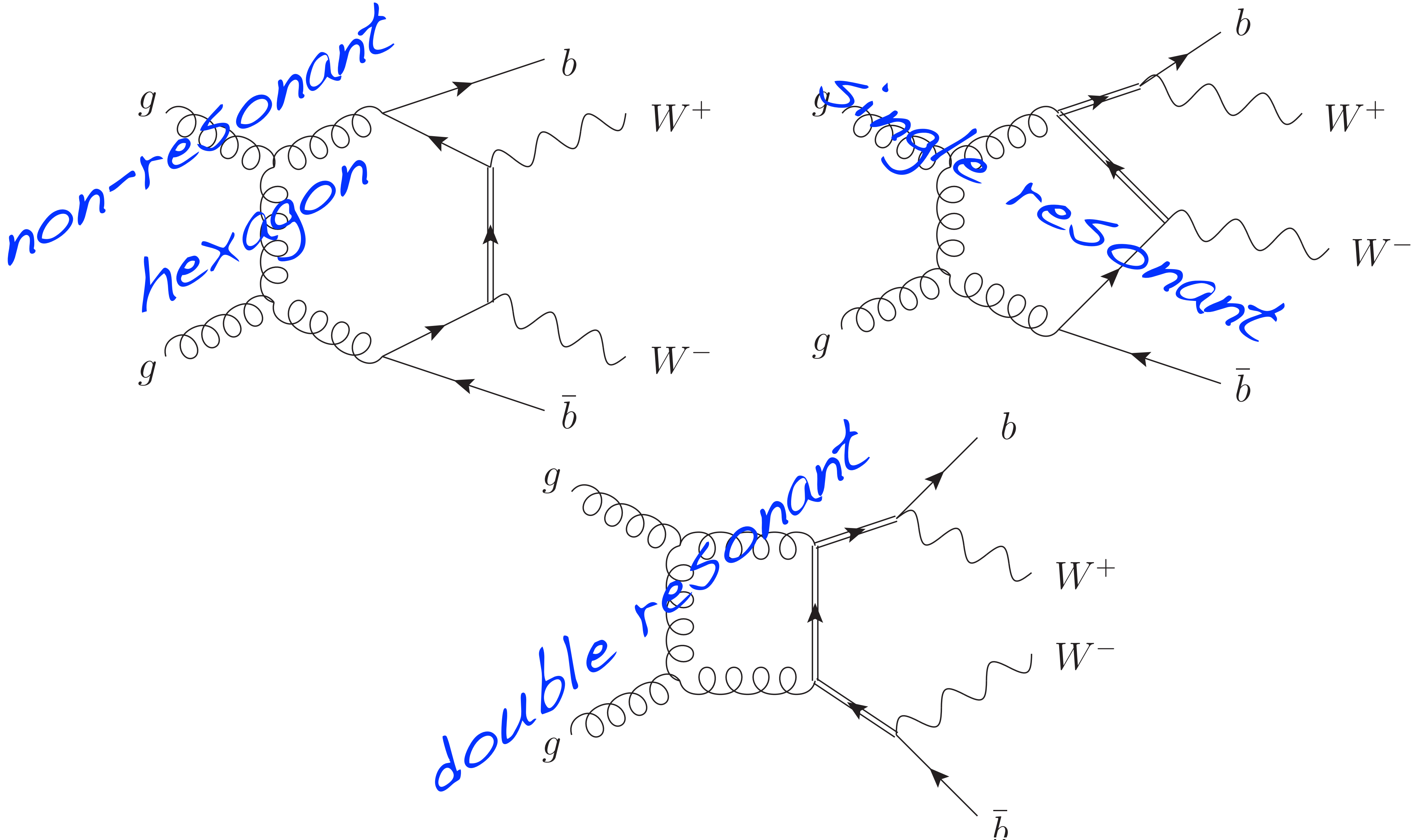
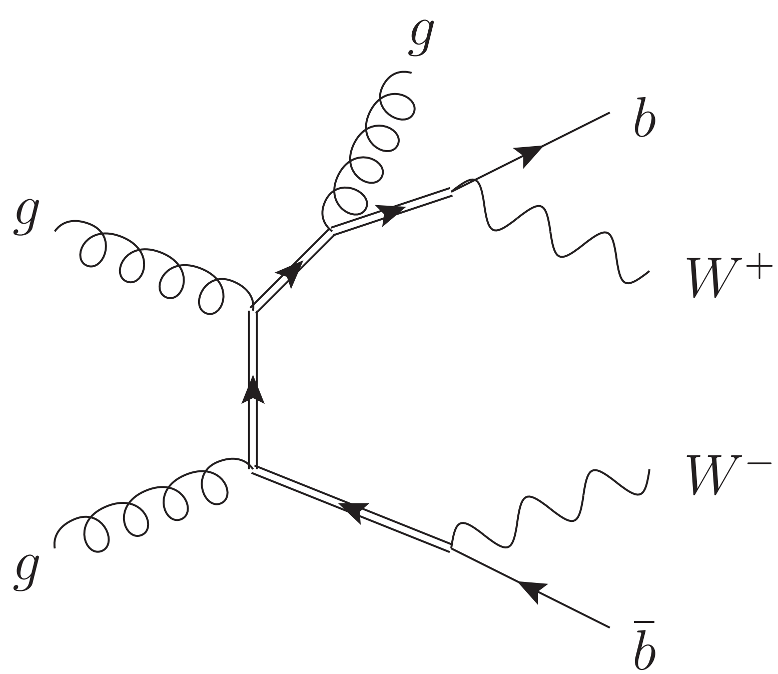
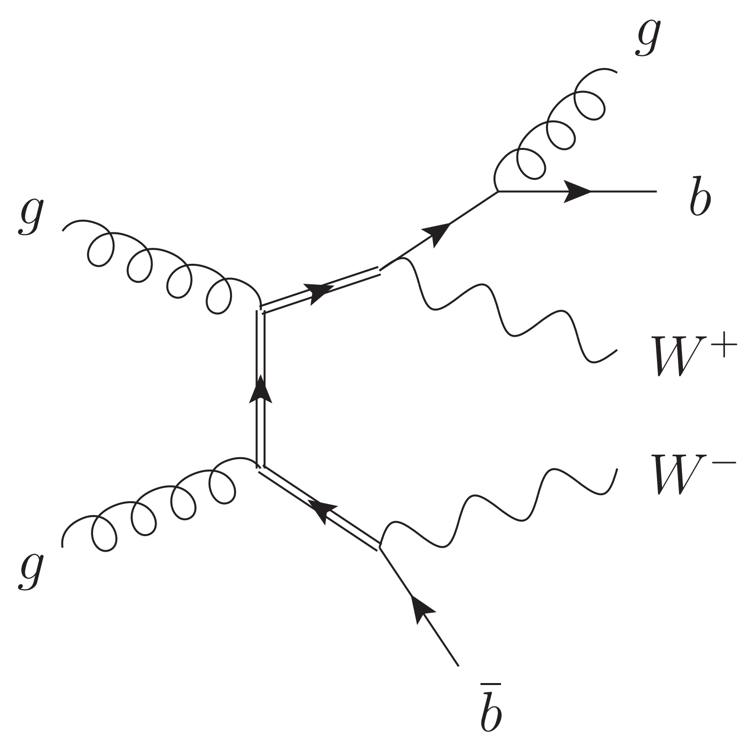
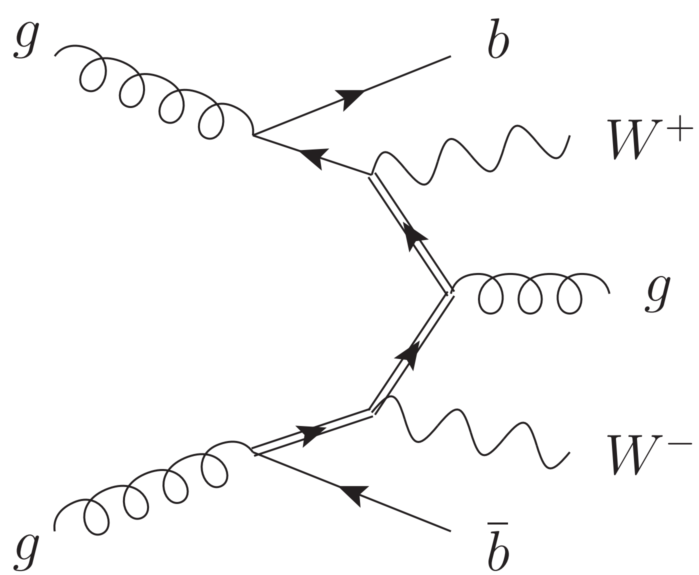
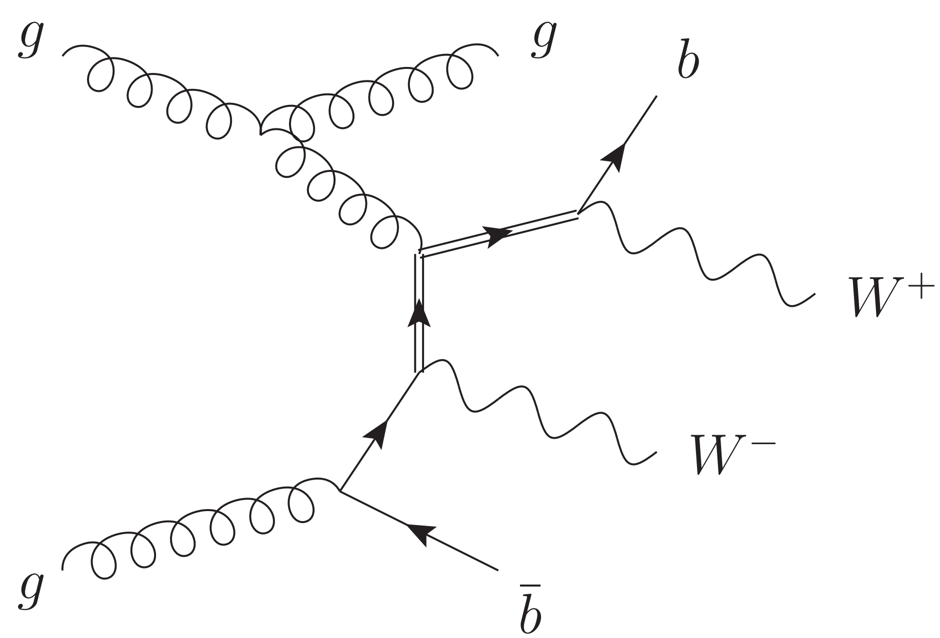


Legs + one more leg









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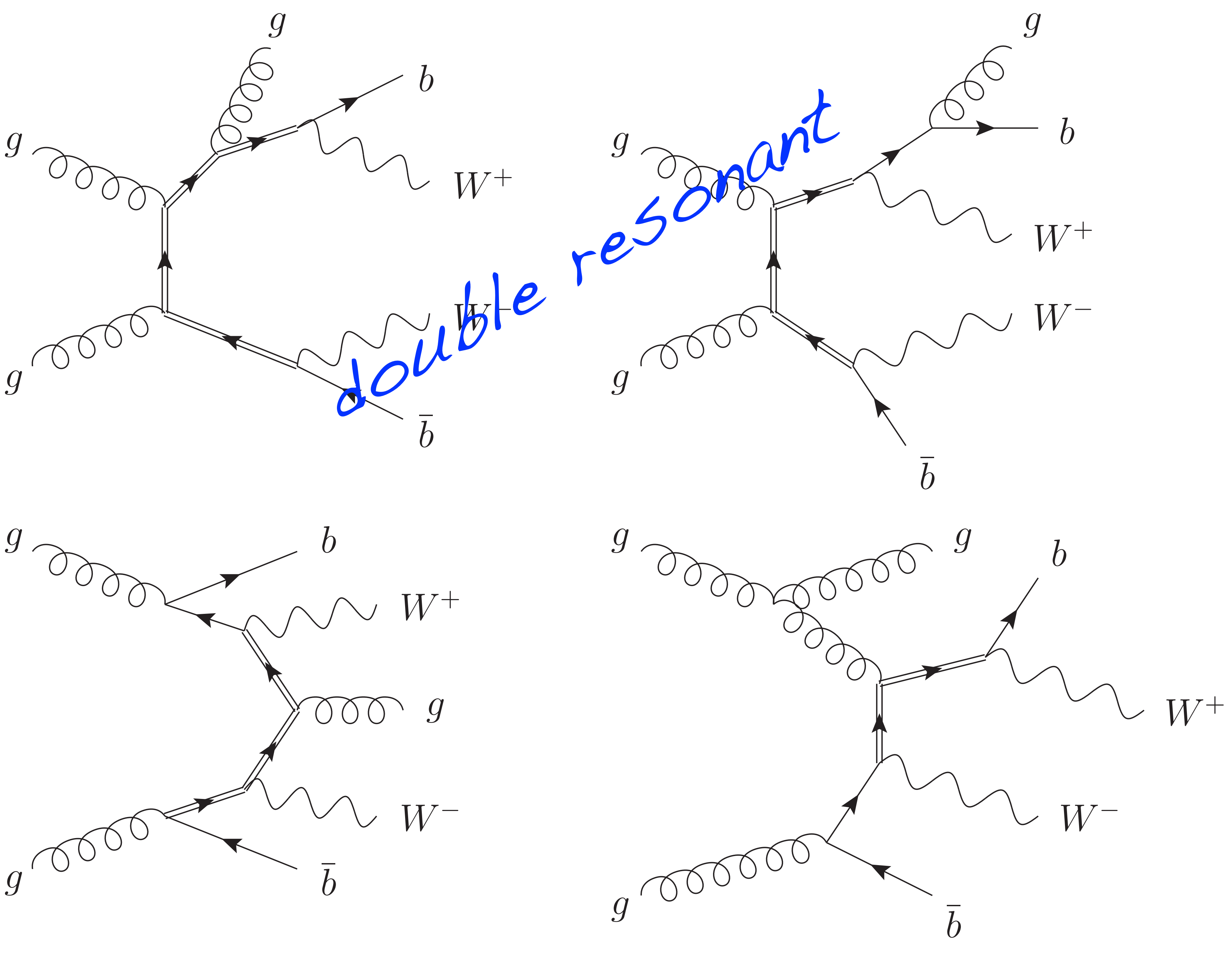
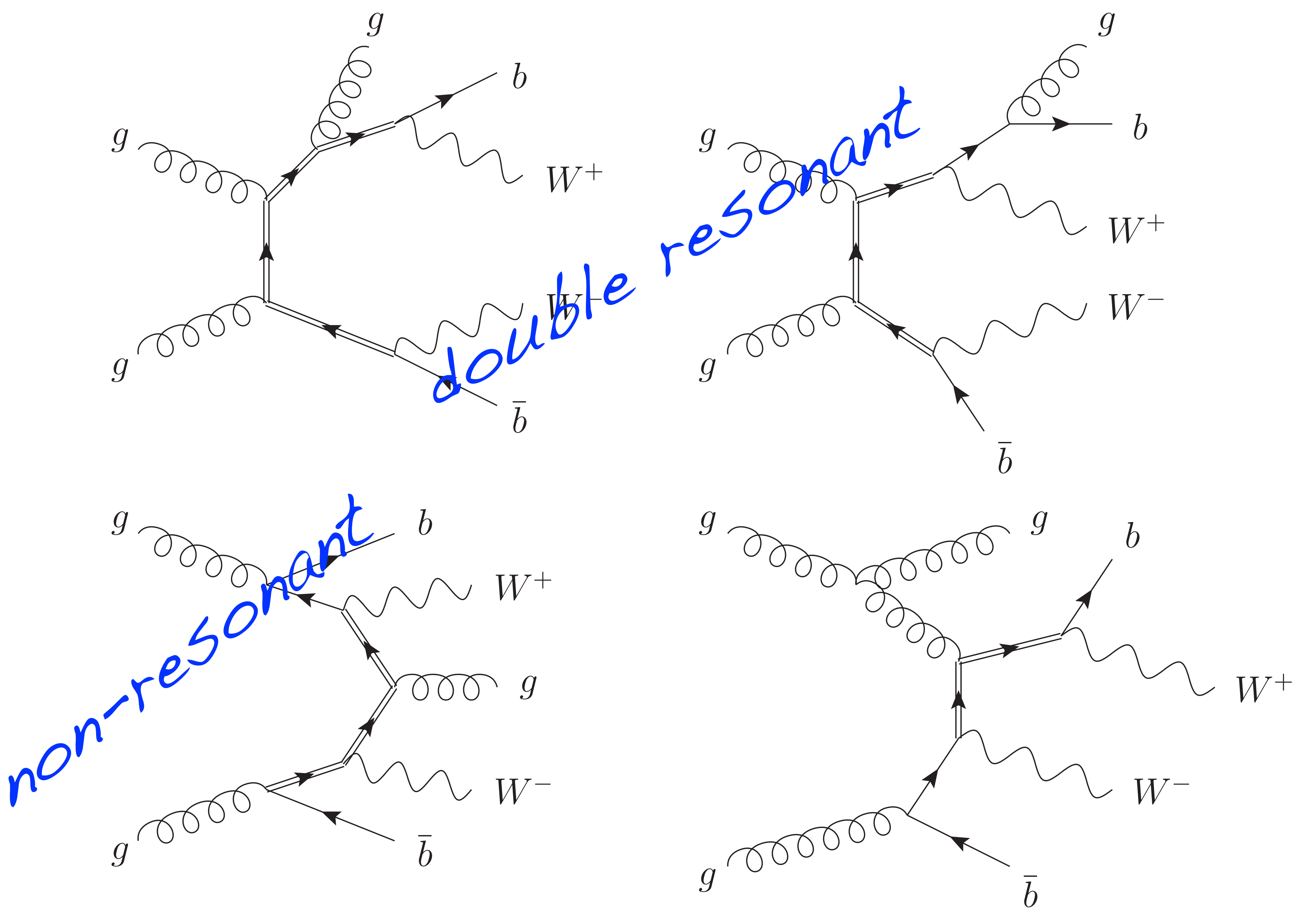
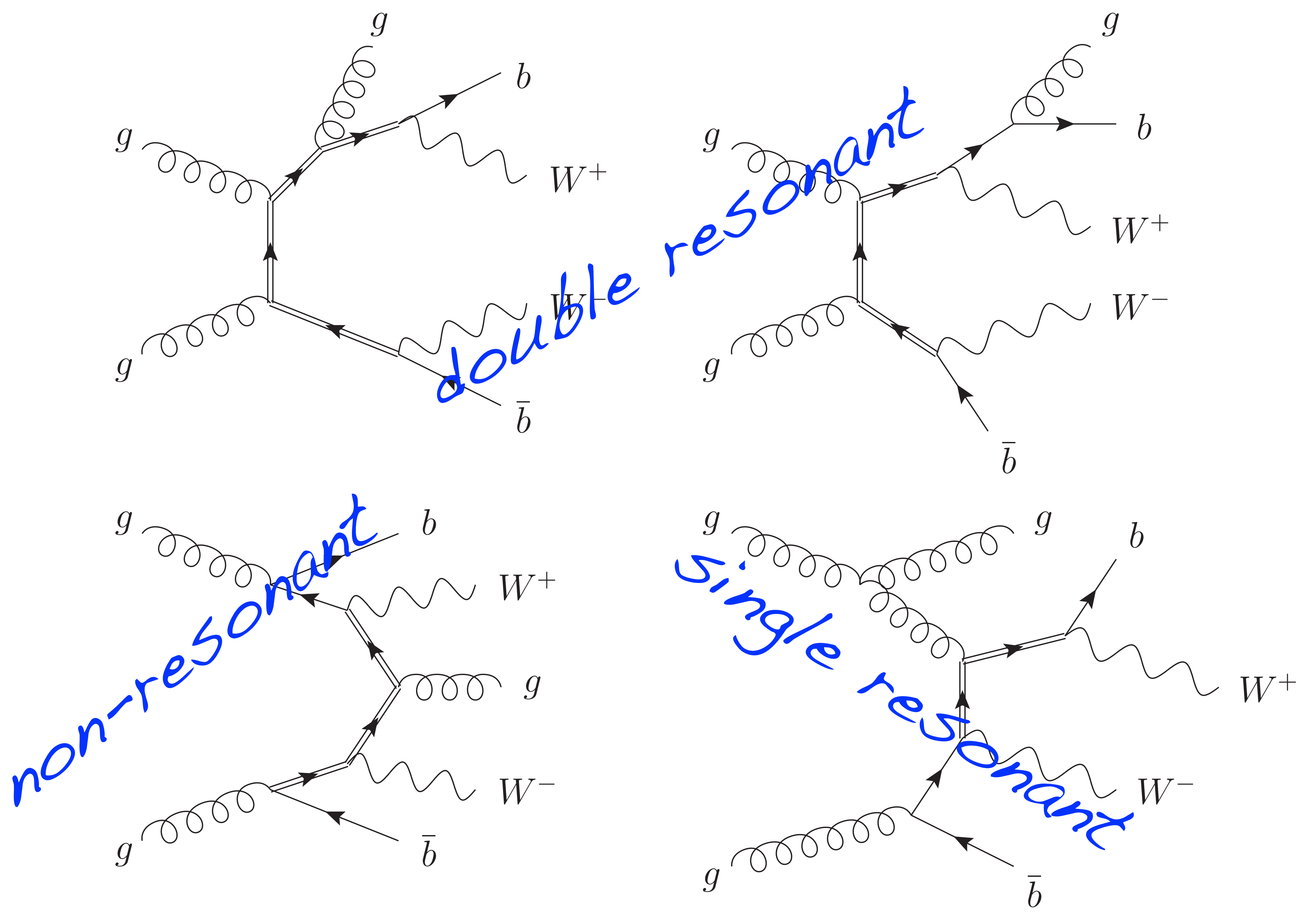


Legs + one more leg



Legs + one more leg



$pp \to e^+ \nu_e \mu^- \bar{\nu}_\mu b\bar{b} + X$

- Based on the full NLO calculation of the $\mathrm{W^+ \, W^- \, b \, \bar{b}}$ [Bevilacqua et. al. arXiv:1012.4230], but new

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- Comparison of LHEF to NLO made for the 7 TeV LHC, with a setup listed in arXiv:1012.4230:
  - fixed scale $\mu = m_t$ and PDG parameters, CTEQ6M

Formal accuracy of the POWHEG MC

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

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Useful for checking

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$\langle O \rangle_{\rm NLO}$

Useful for checking

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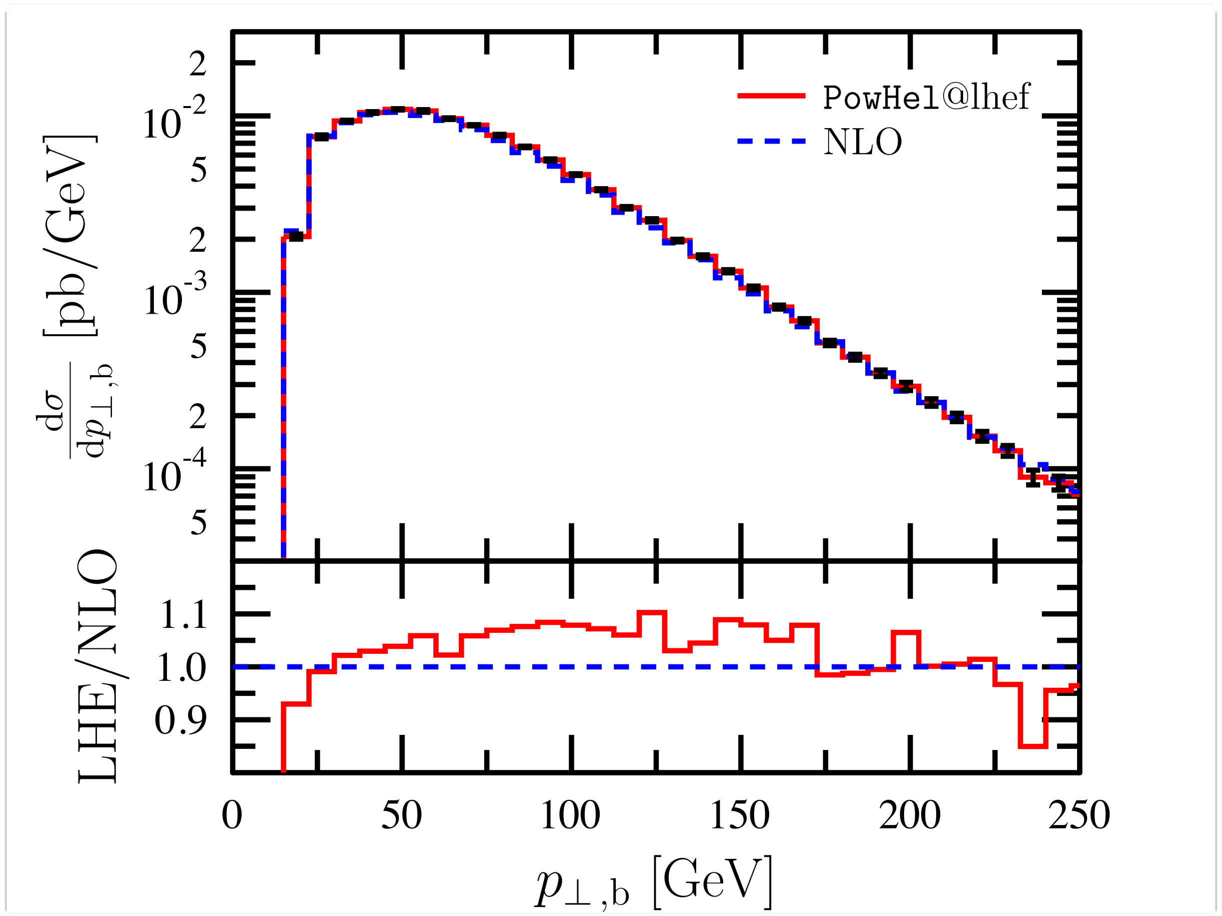
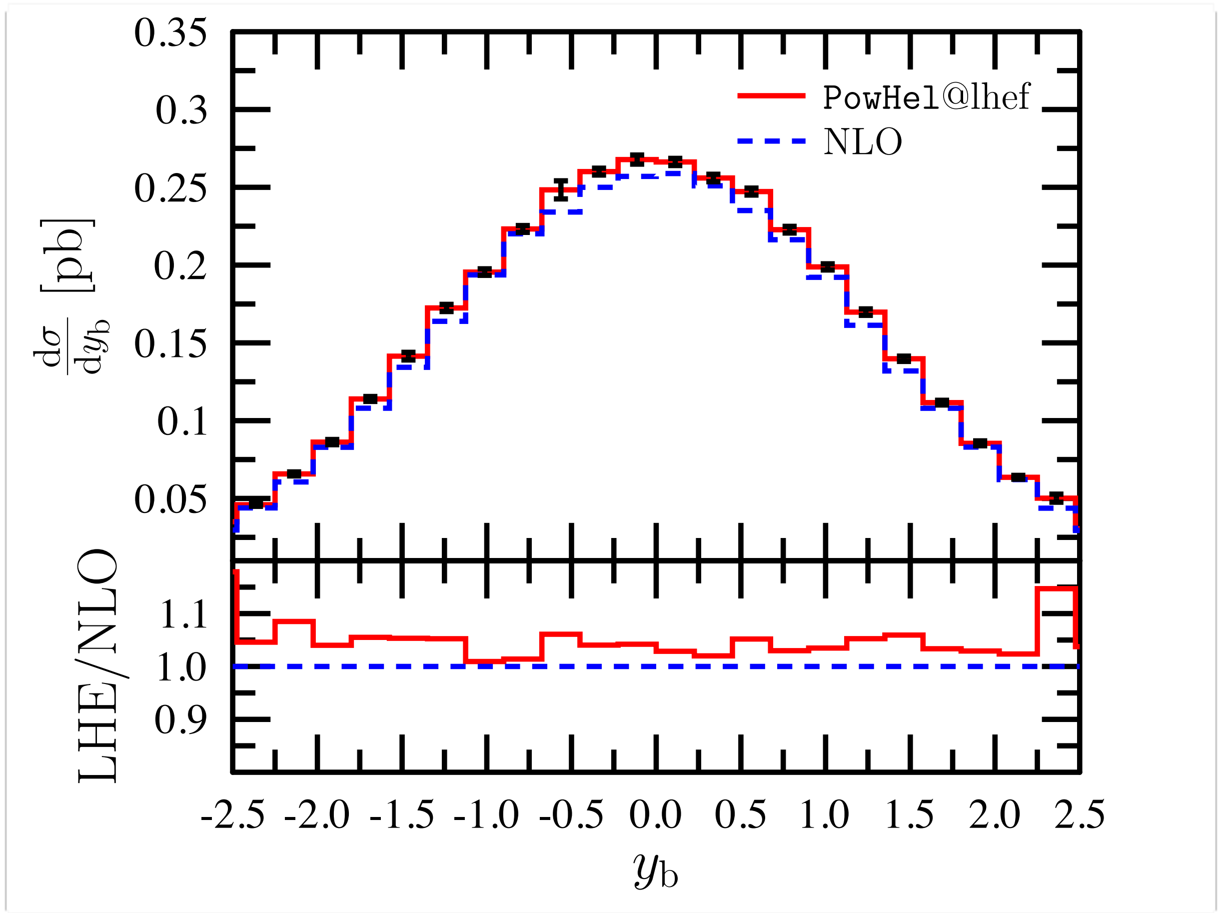


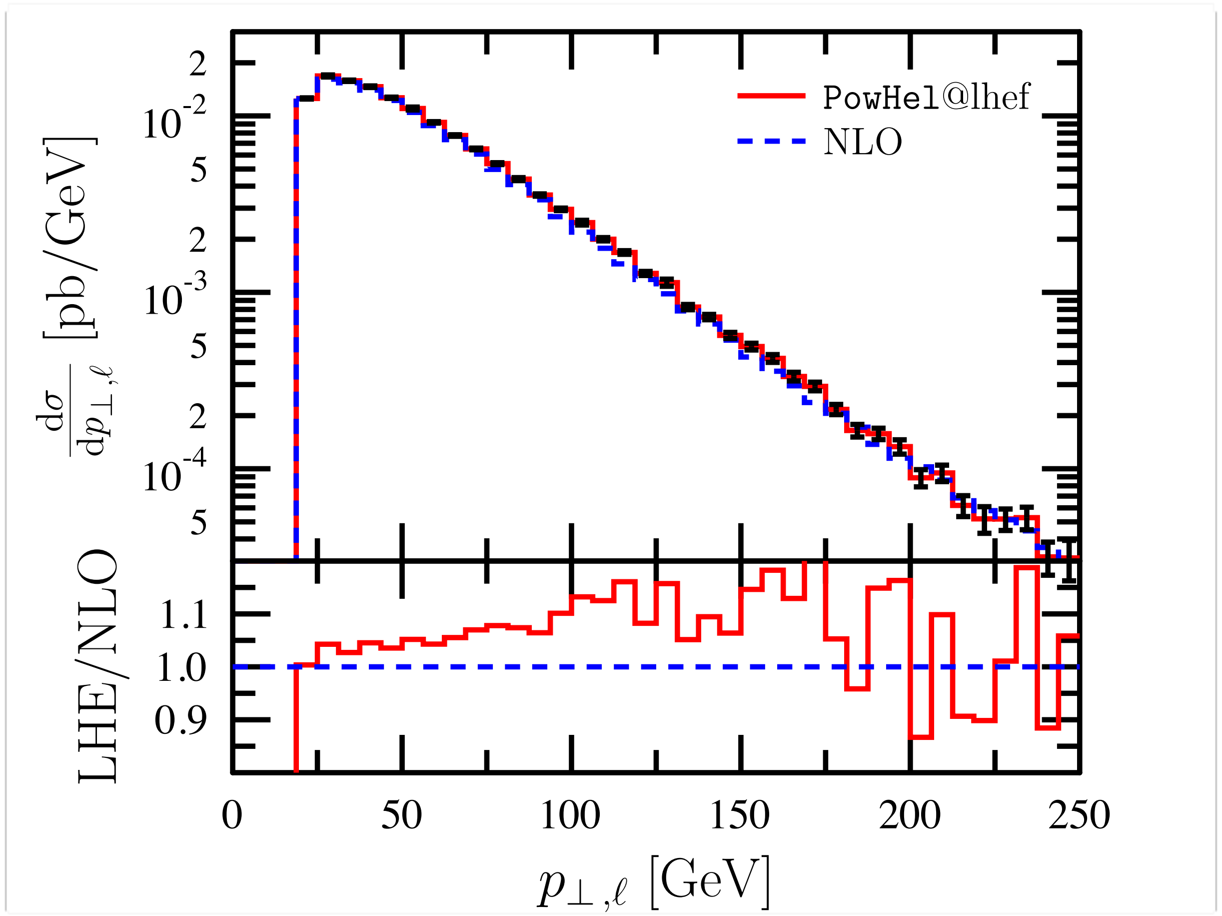


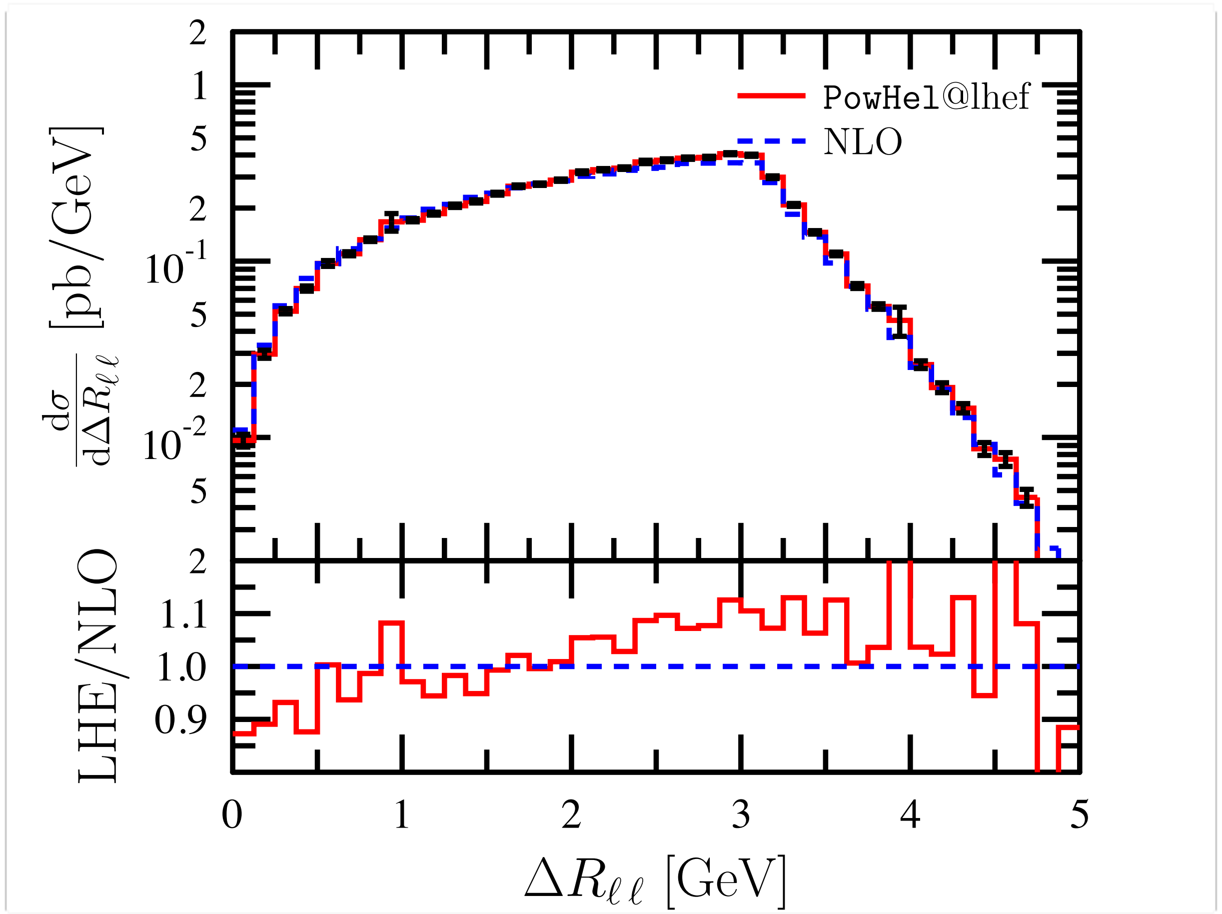
Transverse momentum and rapidity distribution for the b at 7TeV LHC

agreement is within 5%, Remember: $\sigma_{LHE} = \sigma_{NLO}(1+O(\alpha_s))$

[NLO K-factor is large (~1.5)]

$pp \to e^+ \nu_e \mu^- \bar{\nu}_\mu b\bar{b} + X$





Transverse momentum of positron, R-separation of the charged leptons at 7TeV LHC

agreement is within 10%, Remember: $\sigma_{LHE} = \sigma_{NLO}\,(1+O(\alpha_s))$

[NLO K-factor is large (~1.5)]

Predictions

$pp \to e^+\nu_e\mu^-\bar{\nu}_\mu b\bar{b}+X$

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Predictions for LHC at 7 TeV

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to check effect of various approximations to decays and provide reliable predictions at hadron level

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Cuts:

- anti-$k_\perp$, $R=0.4$
- $|\eta_{trk}|$, $|\eta_j| < 5$, $|\eta_{b\text{-}jet}| < 3$, $|\eta_l| < 2.5$
- $p_\perp^j$, $p_\perp^l > 20$ GeV, $\not{p}_\perp > 30$ GeV,
- $\Delta R_{jl} > 0.4$
- at least one anti-b, b-jet, l^+, l^-

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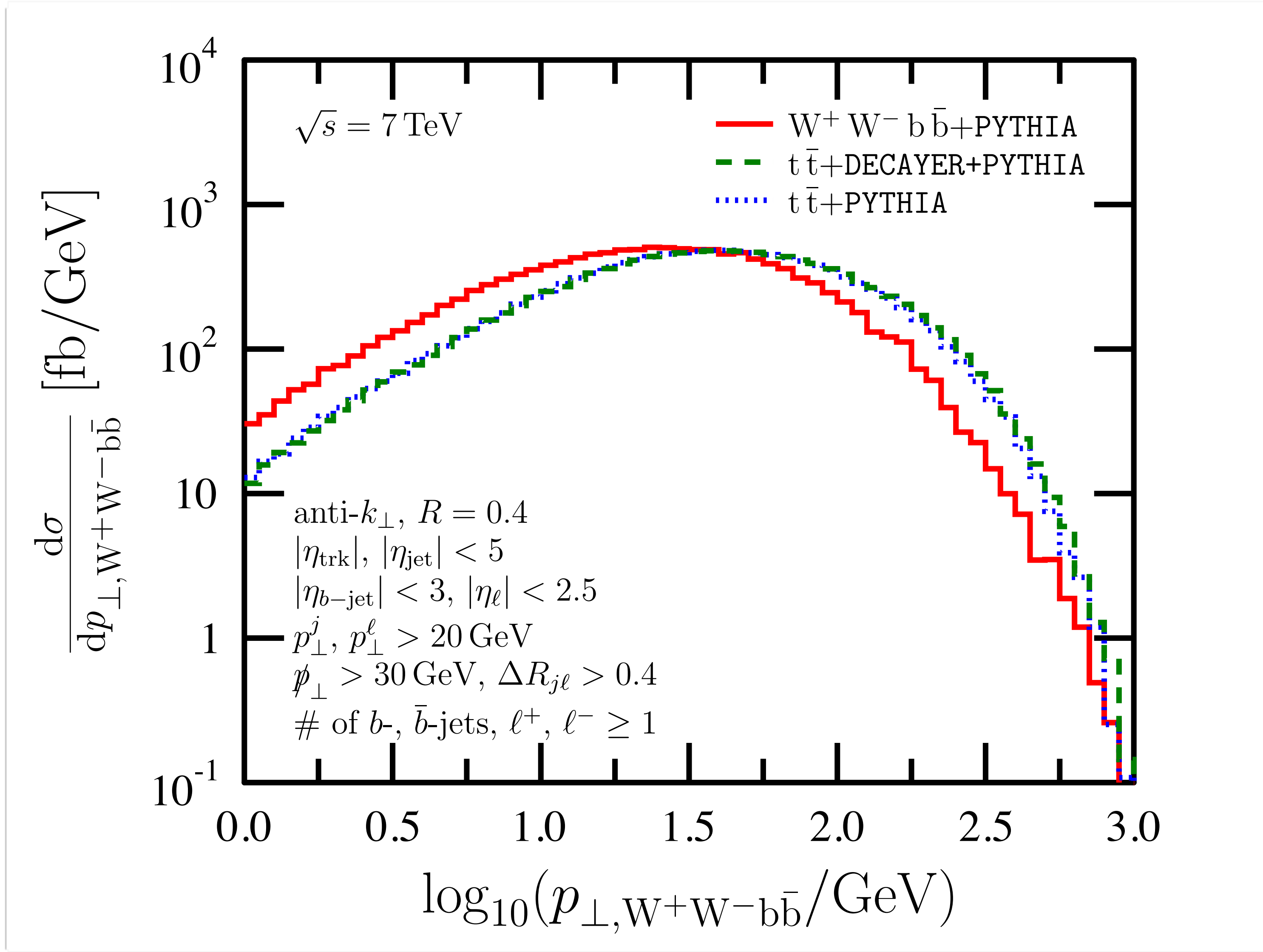
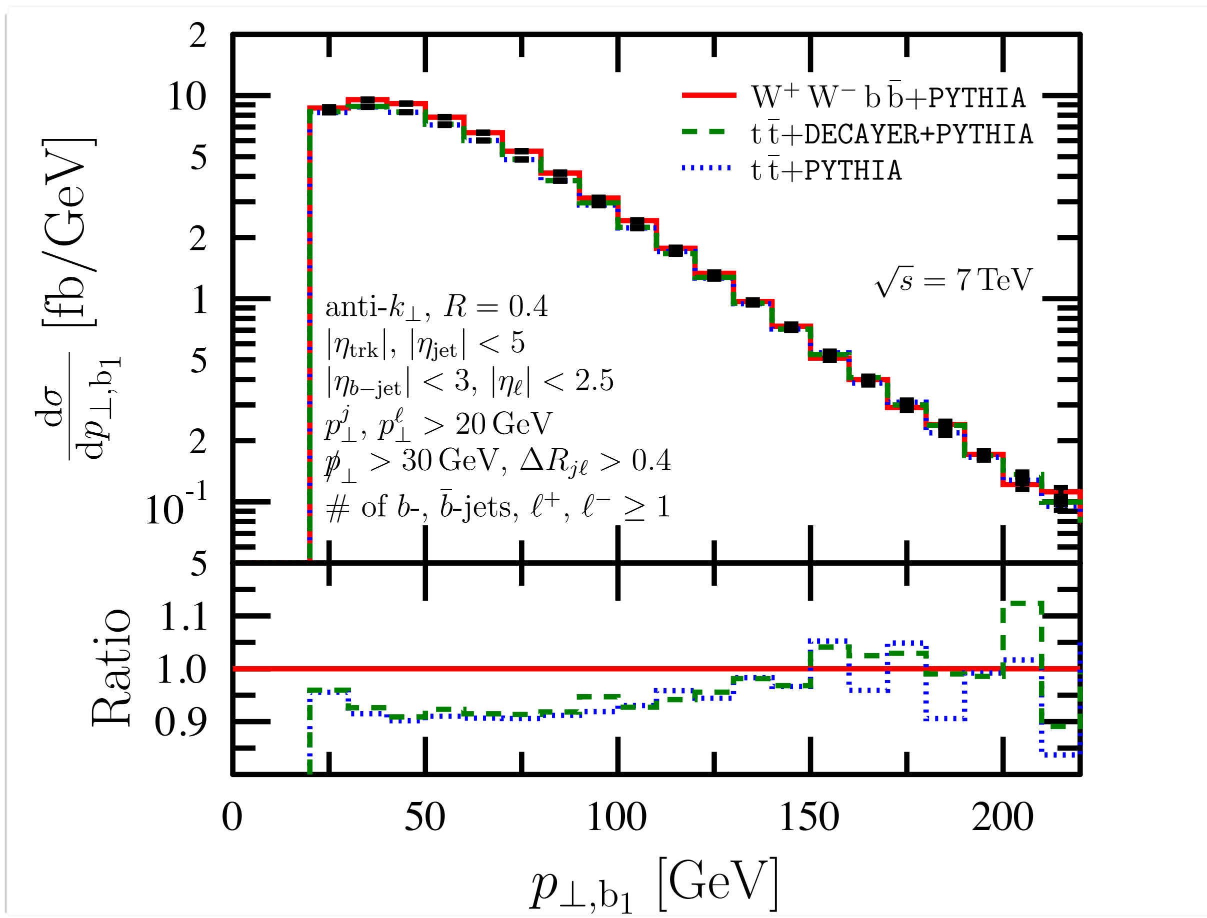
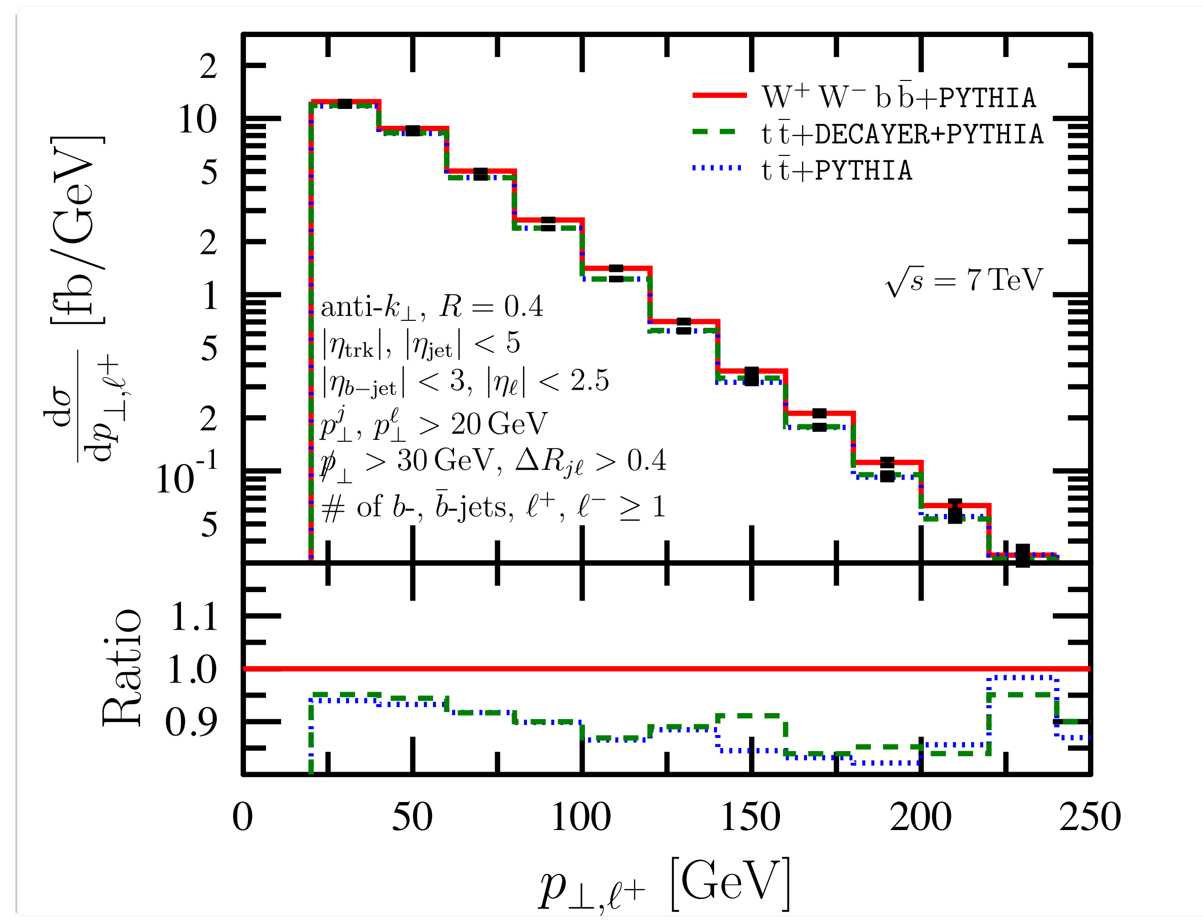


Nice Sudakov suppression at small $p_\perp$, main source of difference is origin of first radiation (in further plots also)

The effect of the shower is ~30% (not shown in these plots)

$pp \to e^+ \nu_e \mu^- \bar{\nu}_\mu b \bar{b} + X$



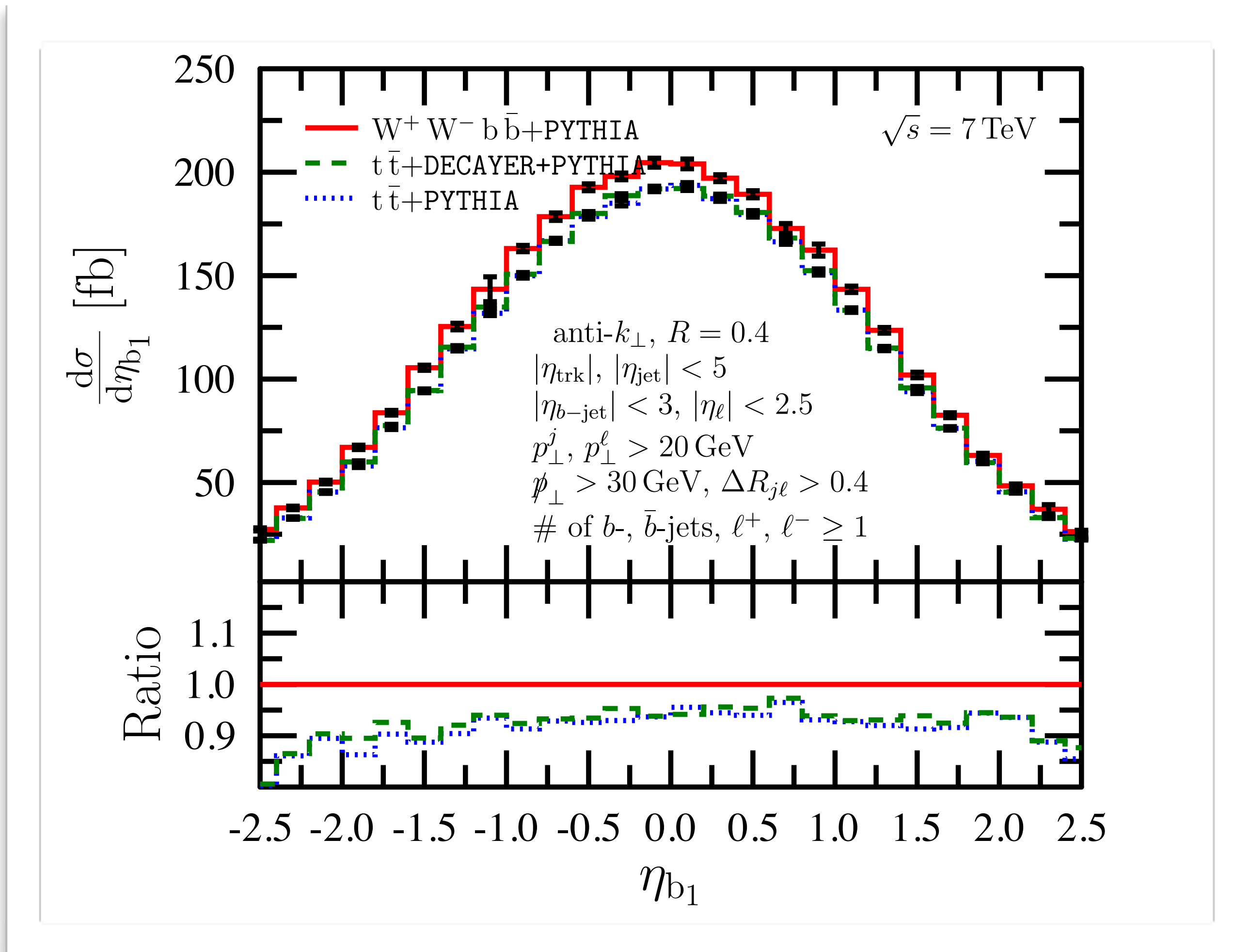


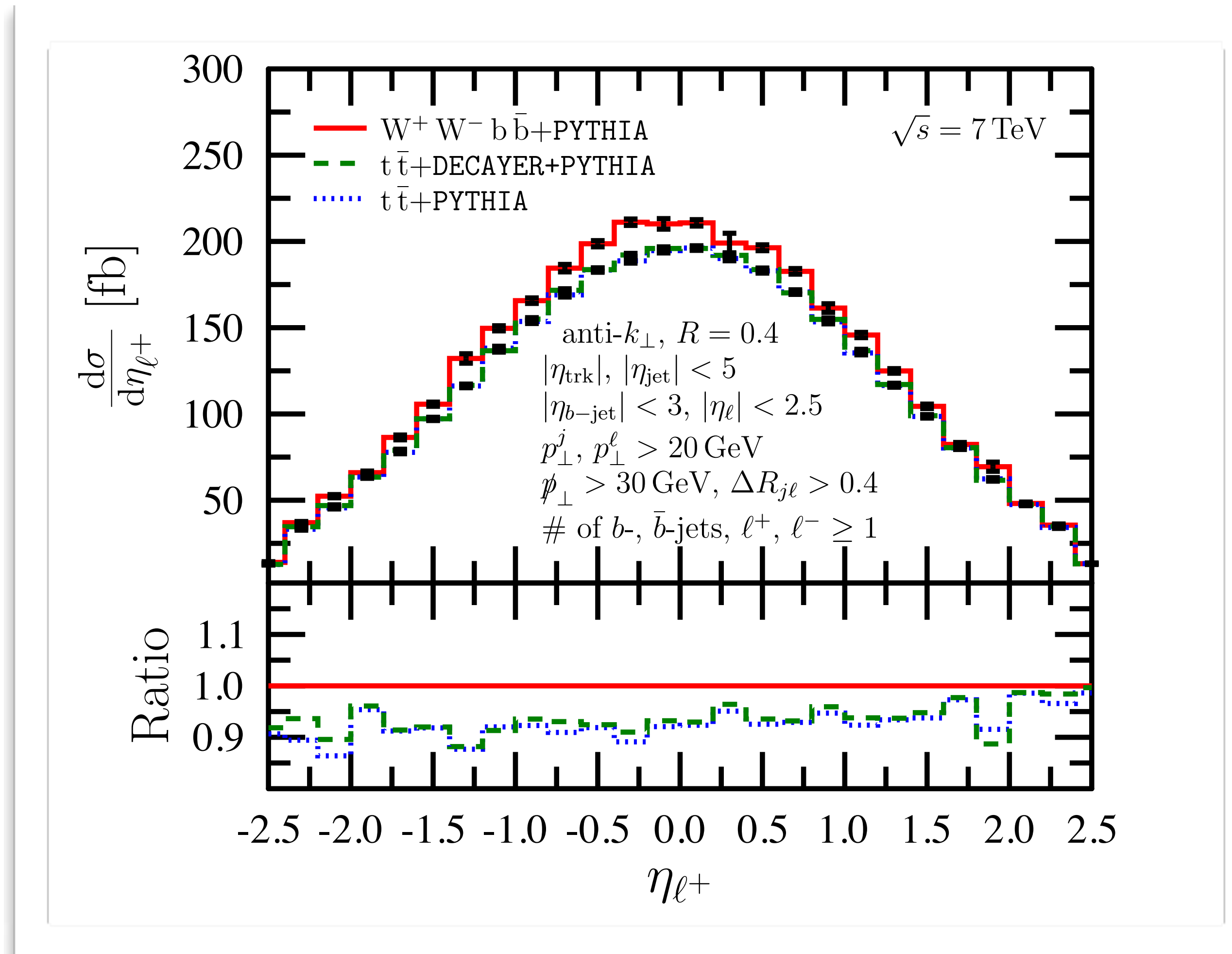
Transverse momentum of b-jet and positron at 7TeV LHC

Effect of NWA vs DCA negligible

full vs NWA small

$pp \to e^+ \nu_e \mu^- \bar{\nu}_\mu b \bar{b} + X$





Rapidity of b-jet and positively charged lepton at 7TeV LHC

Effect of NWA vs DCA negligible

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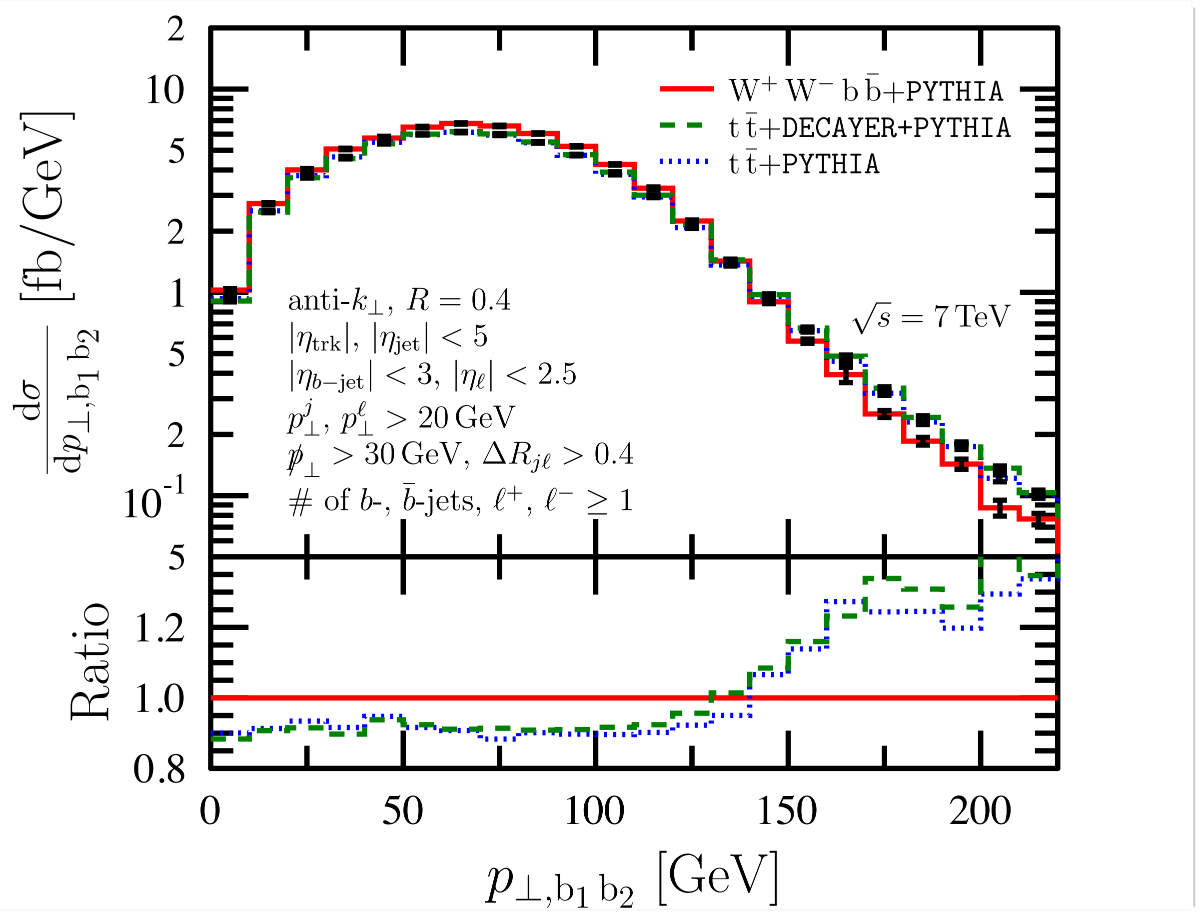
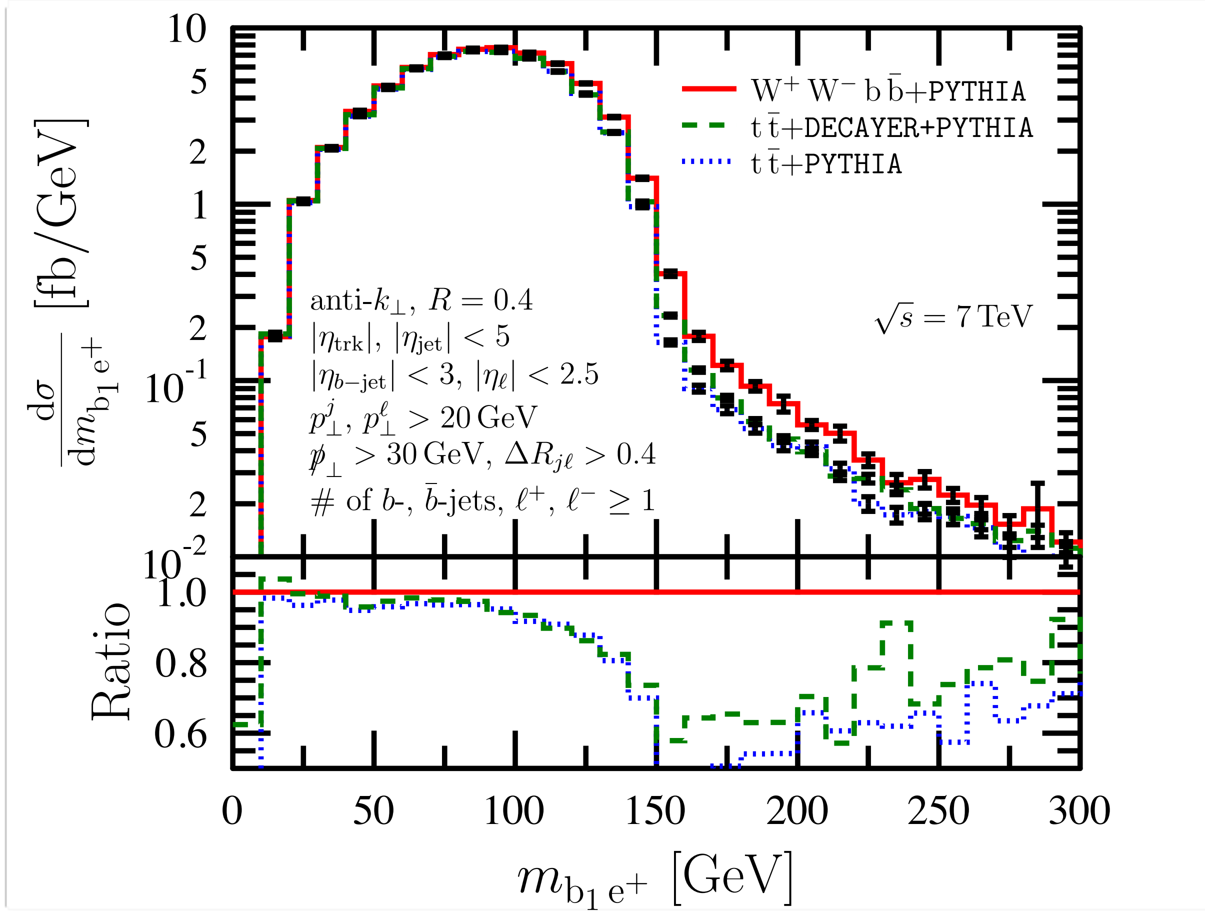


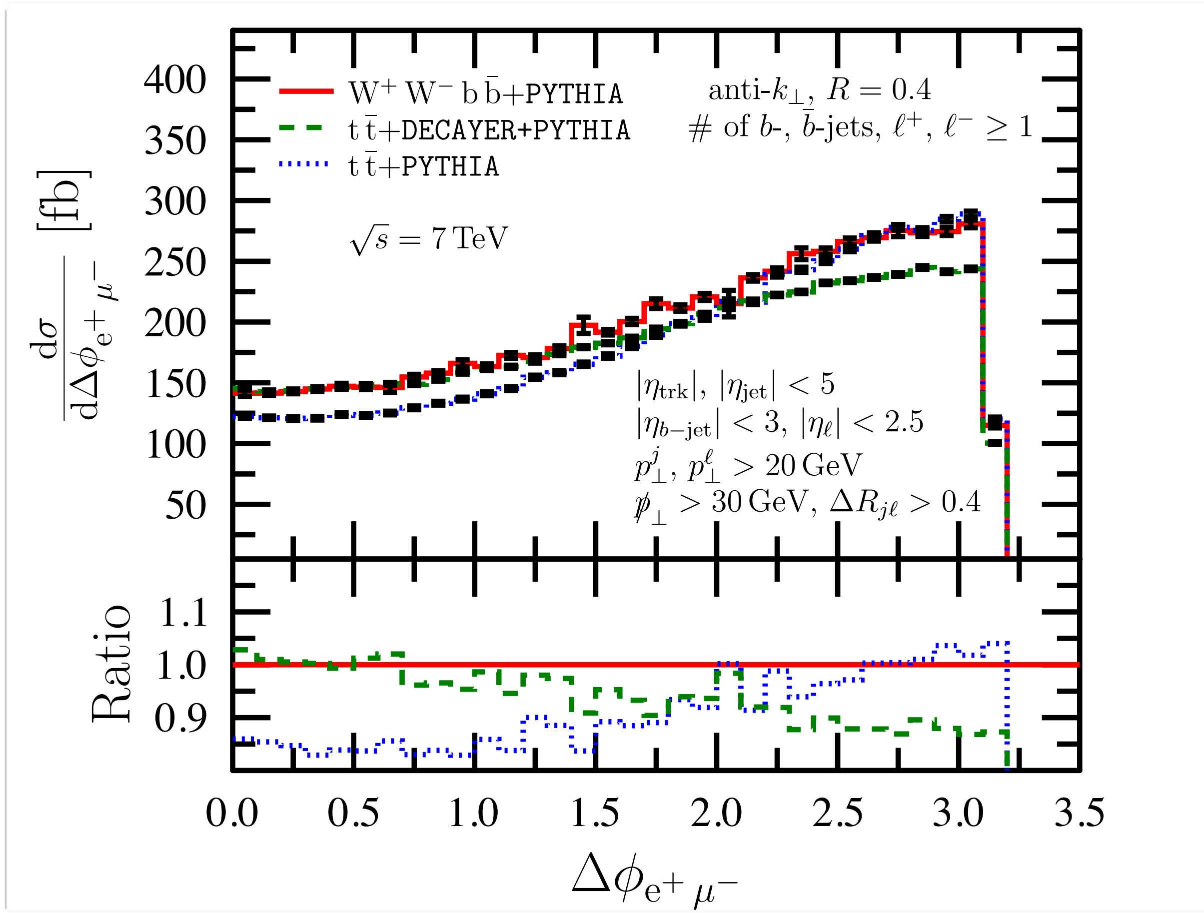


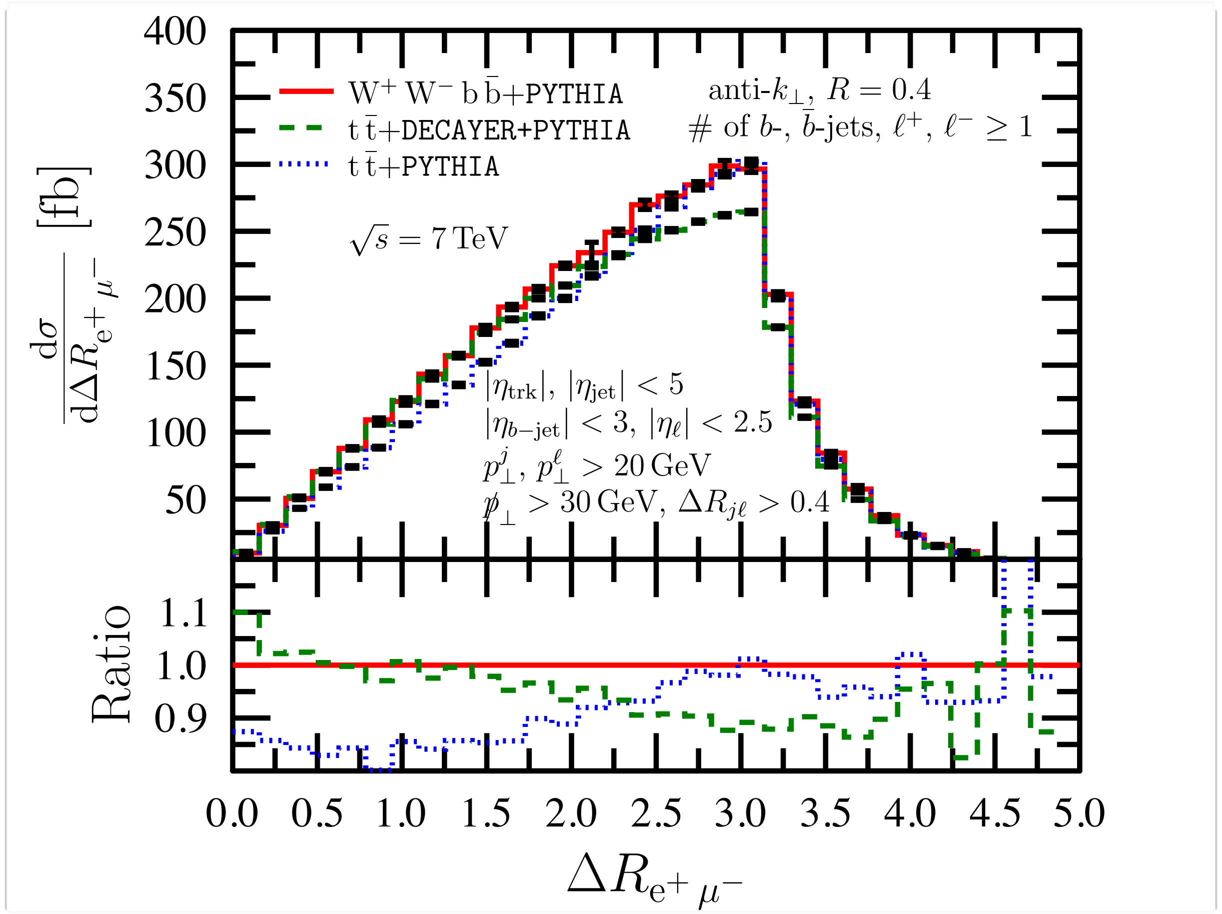
$p_\perp$ of the two b-jets, invariant mass of positron and b-jet at 7TeV LHC

Effect of NWA vs DCA negligible

full vs NWA ~40% above 150 GeV

pp→ $e^+\nu_e\mu^-\bar{\nu}_\mu b\bar{b}$+X





$p_\perp$ of the two b-jets, invariant mass of positron and b-jet at 7TeV LHC

Only distribution where NWA vs DCA differ (among 32)

full - NWA agree below 1.5

Conclusions and outlook

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- ➡ Predictions for LHC with NLO+PS accuracy

Plans

- ➡ Study scale choices and dependences
- ➡ Generation of events on request
- ➡ Comparison to data (in progress)
- ➡ Make codes public
- ➡ Extension to further processes...

Implemented Processes

- ✓ $t\,T$
- ✓ $t\,T + Z$
- ✓ $t\,T + H/A$
- ✓ $t\,T + j$
- ✓ $WWbB$

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- ✓ $t\bar{t} + Z$
- ✓ $t\bar{t} + H/A$
- ✓ $t\bar{t} + j$
- ✓ $WWb\bar{b}$

Implemented Processes

Stay tuned,
More to come!

- ✓ t T
- ✓ t T + Z
- ✓ t T + H/A
- ✓ t T + j
- ✓ WWbB

Thank you for your attention!