Top precision at the LHC

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University of Zürich

Based on:
TJ, Nason [arXiv:1509.09071]
TJ, Lindert, Nason, Oleari, Pozzorini [arXiv:1607.04538]

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Universität Zürich[UZH]

Fyzikální ústav
Akademie věd ČR, v. v. i.

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[†] Wikipedia

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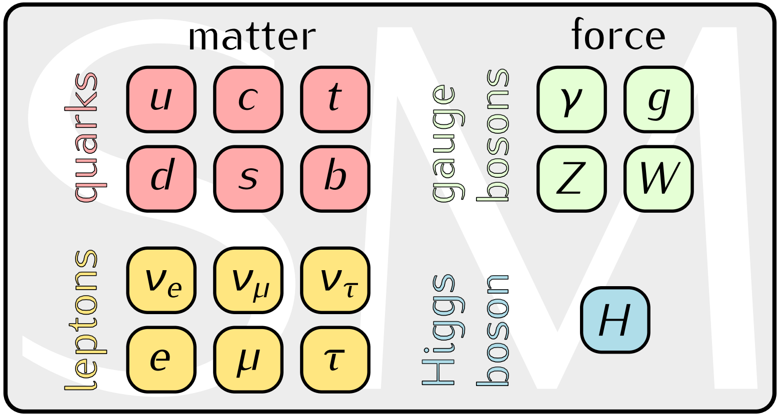
Top quark trivia

- 3^{rd} family up-type quark



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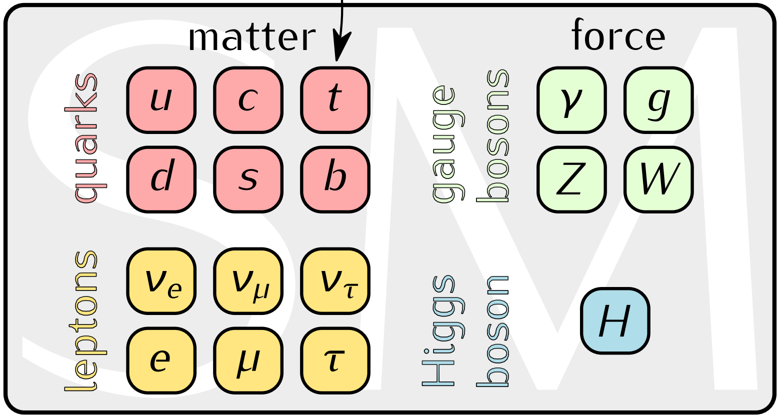

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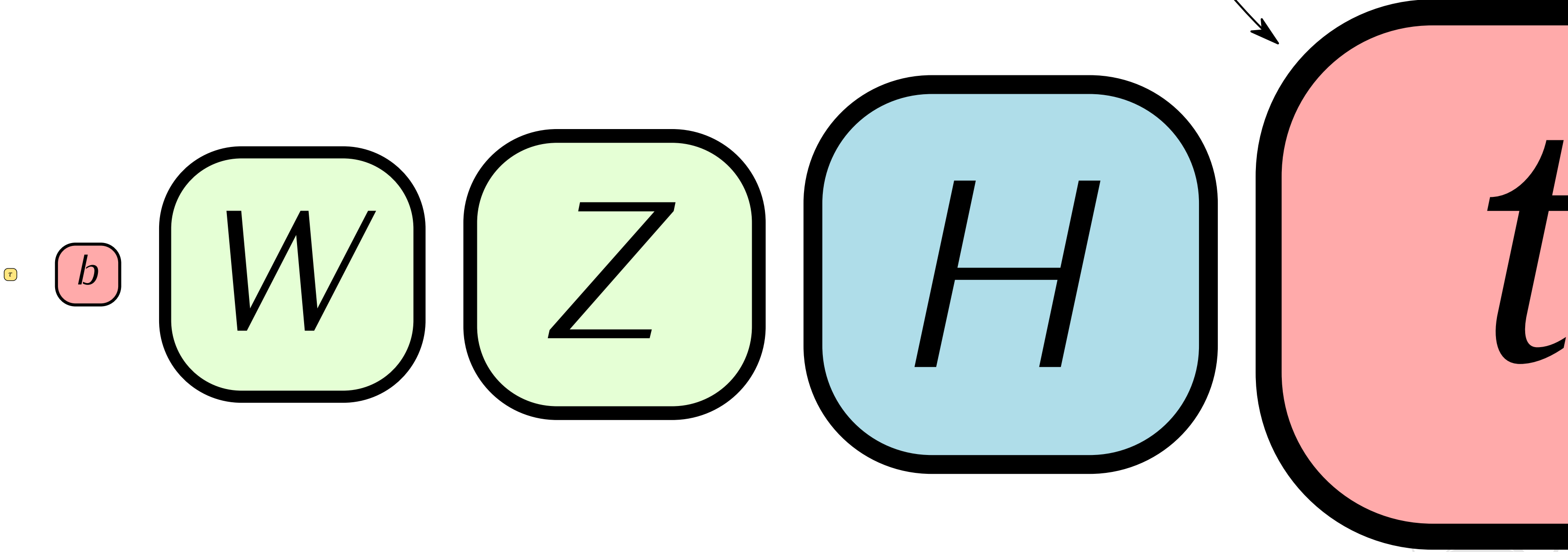

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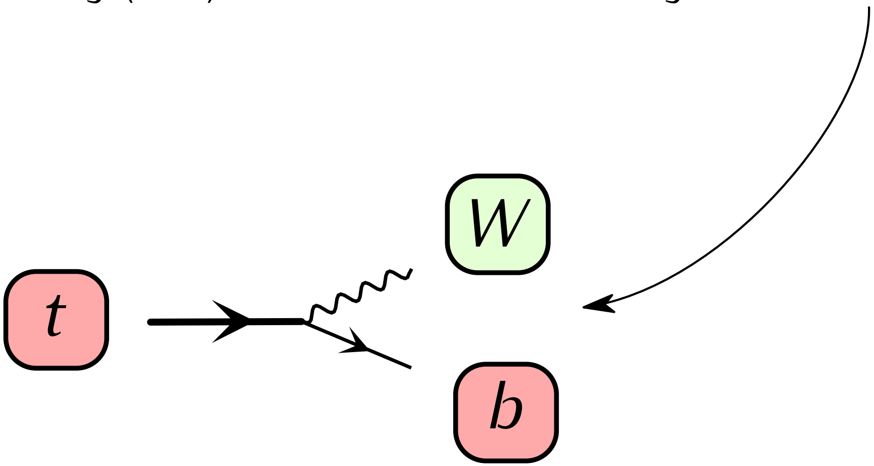
- 3^{rd} family up-type quark
- heaviest elementary particle so far, $m_t \sim 173$ GeV
- is very short lived, $\Gamma_t \sim 1.4$ GeV
  - relatively narrow resonance, $\Gamma_t/m_t \sim 0.8\%$
  - decays before it gets a chance to hadronize, unlike any other quark
  - decays electroweakly (EW) and almost exclusively as $t \to W + b$



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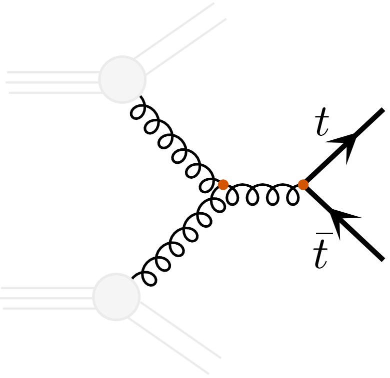

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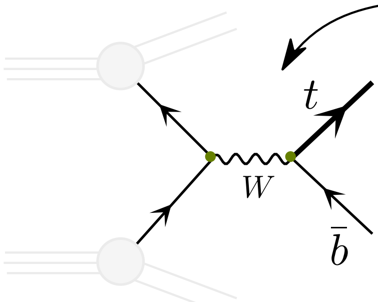

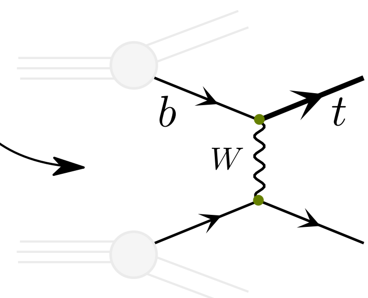

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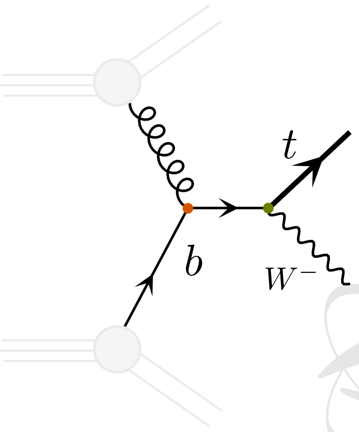
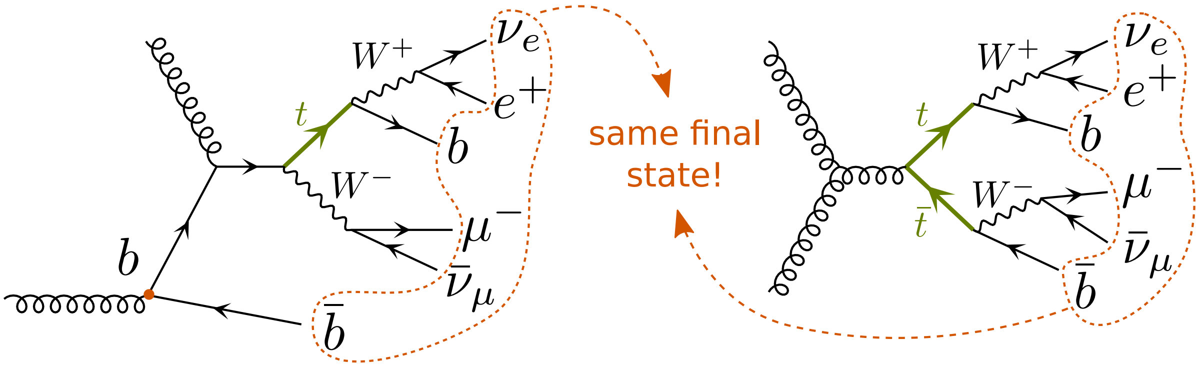


Top quark trivia

tW associated production @ NLO $\quad$ $t\bar{t}$ production @ LO



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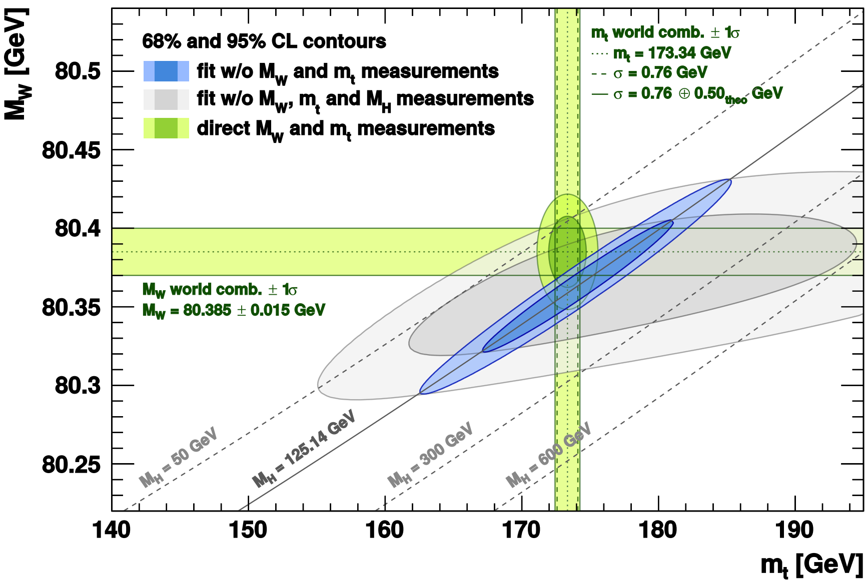
goes out the window!

Top quark mass

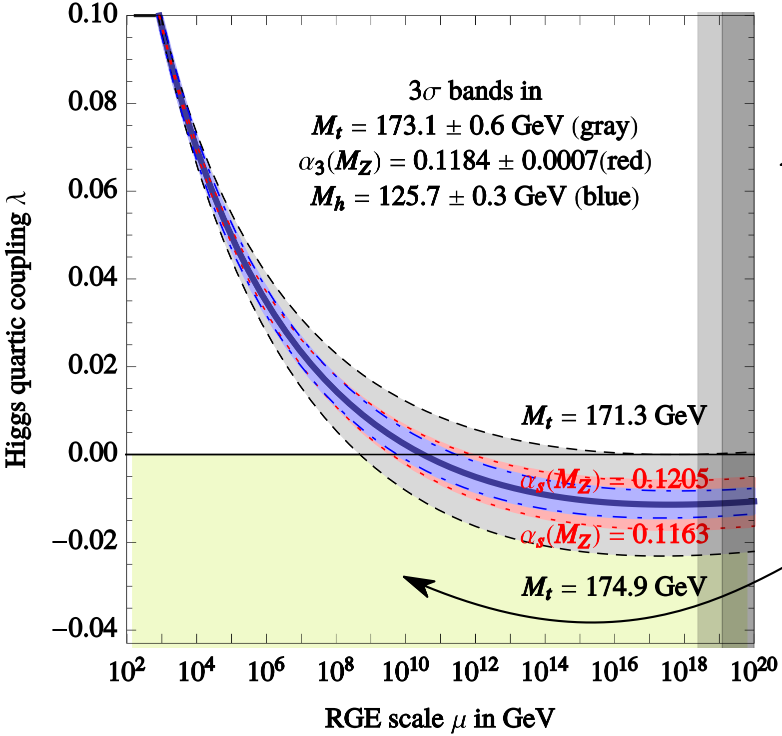
- m_H, m_W and m_T correlated in the SM
  - Accurate knowledge of m_T constitutes a precision test of the SM



Global fit to electroweak precision observables [arXiv:1407.3792]

Top quark mass

- Due to its large mass top couples to the Higgs boson rather strongly
  - RG flow of the Higgs quartic sensitive to the value of m_T



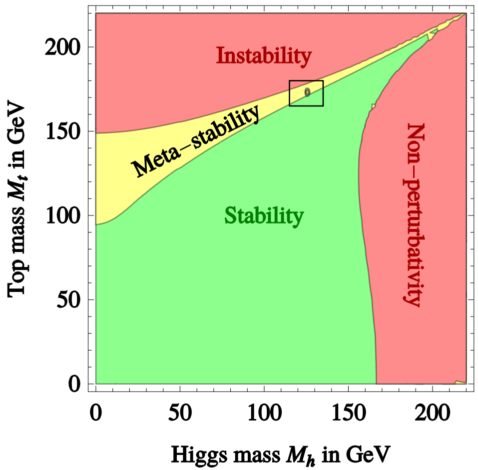
RG flow of the Higgs quartic coupling for $m_H = 125.7$ GeV [arXiv:1512.01222]

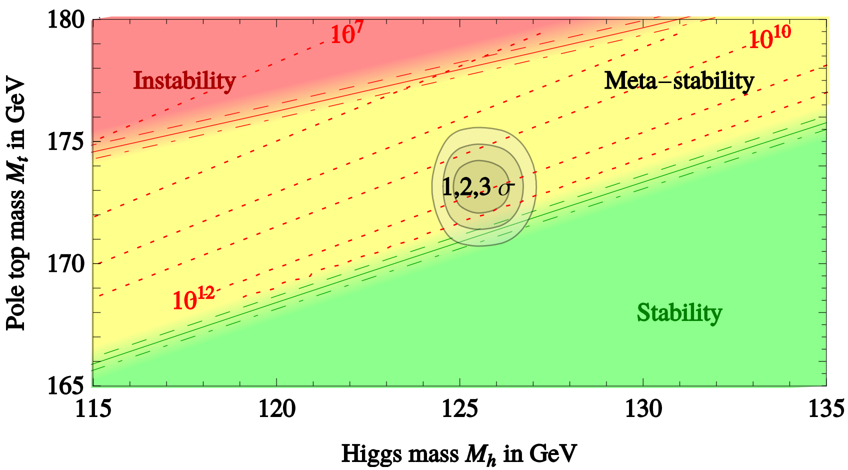
Higgs potential has no minimum for $\lambda < 0$!

Top quark mass

- Due to its large mass top couples to the Higgs boson rather strongly
  - Current values of m_H and m_t suggest the vacuum is metastable

[arXiv:1205.6497]





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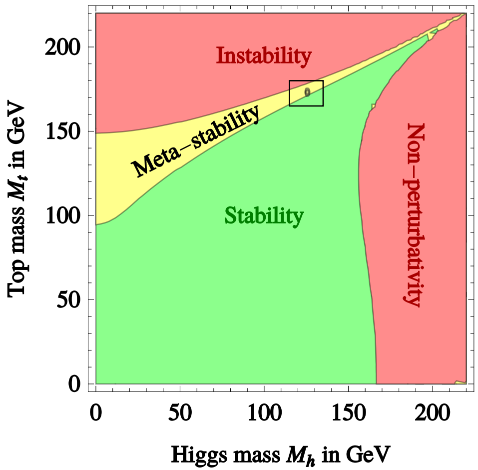

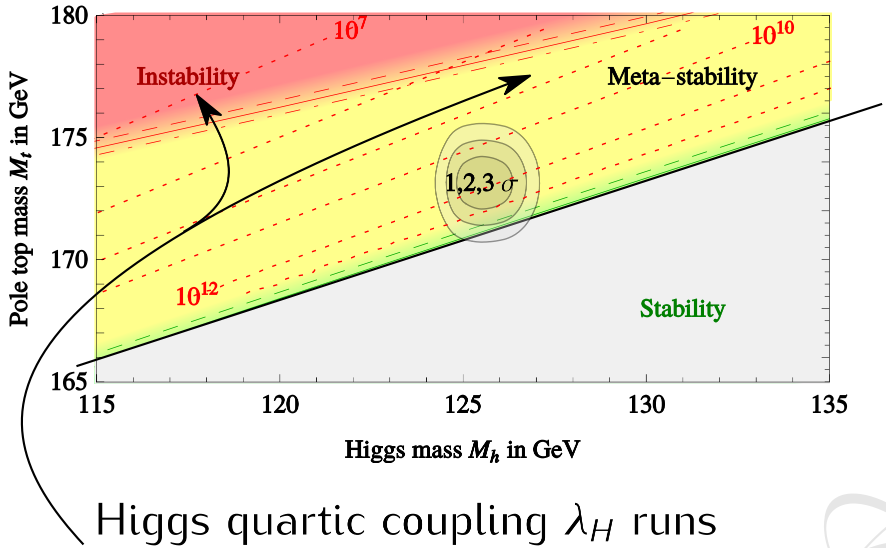

Higgs quartic coupling λ_H runs
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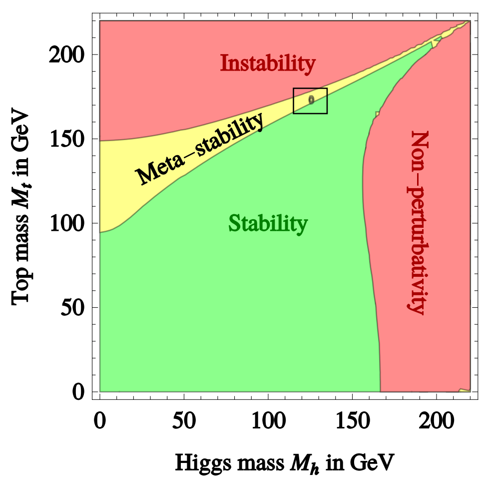
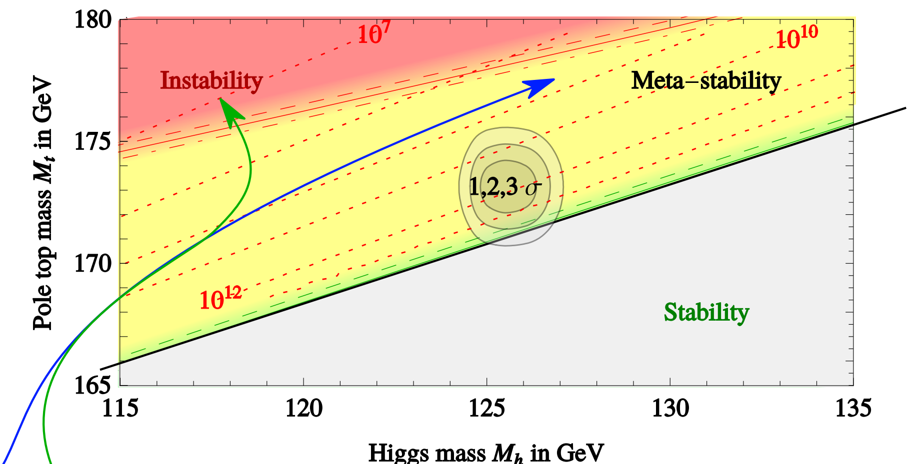


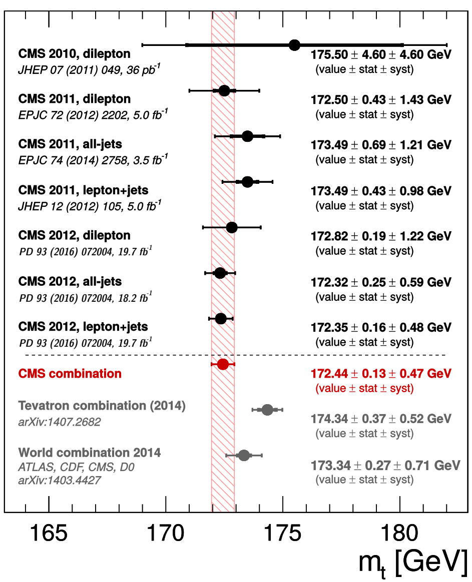


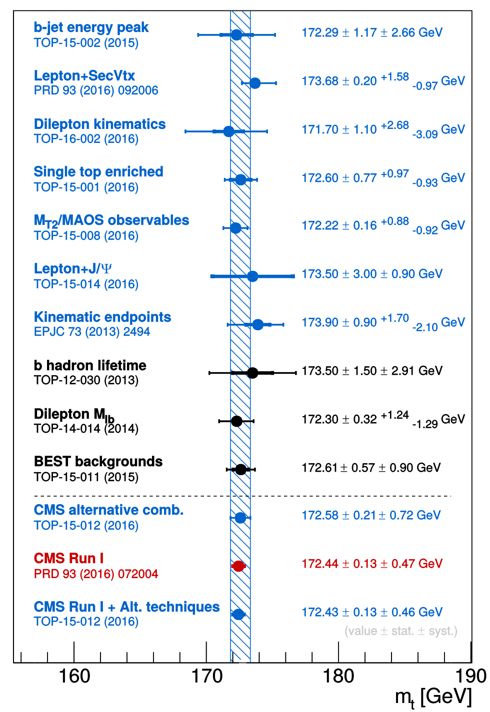
The vaccum life-time is long enough

Higgs quartic coupling λ_H runs to negative values at Planck scale

Top quark mass

- m_T measurement at the LHC
  - Plethora of methods for m_t determination
  - Most precise ones rely on top reconstruction from its decay products
  - Top-quarks abuntantly produced at the LHC





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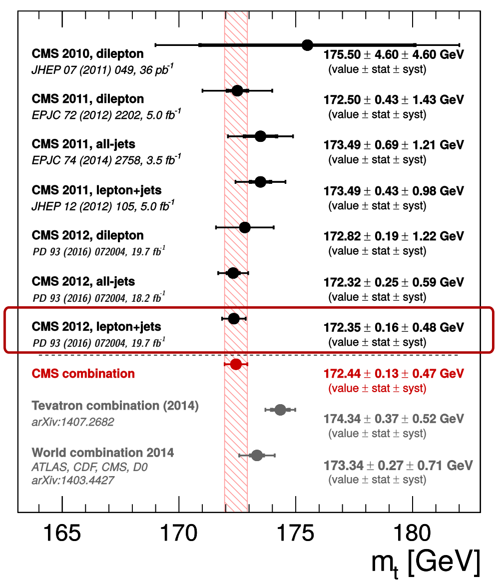

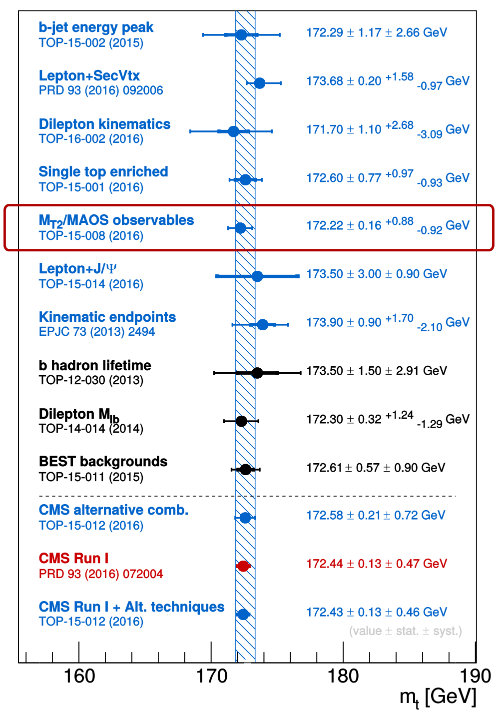

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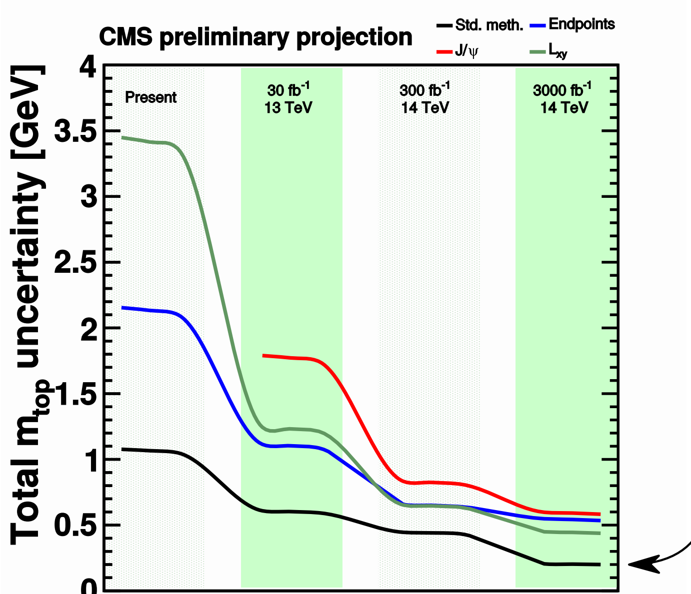

[arXiv:1404.1013]

0.2 GeV?

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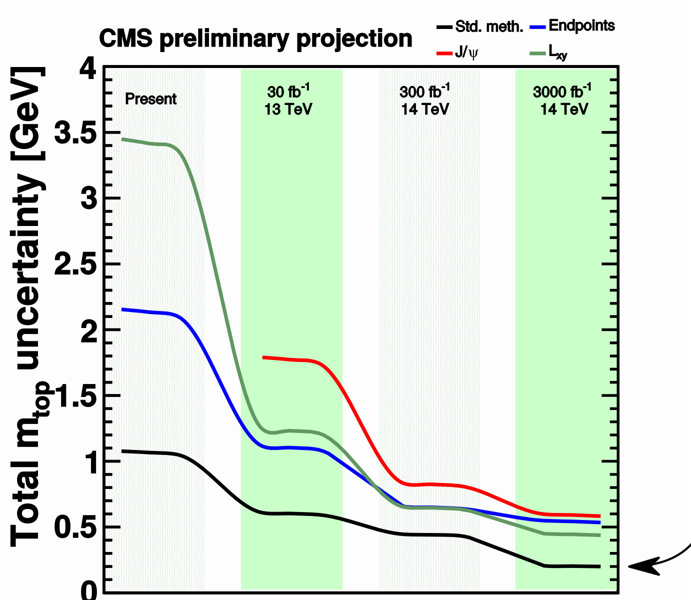

[arXiv:1404.1013]

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Are the theoretical predictions for top mass determinations precise enough?

Top quark

arXiv id	observable	top backgrounds
1712.02758	Higgs and Z to $\varphi\gamma$, $\rho\gamma$	———————————–
1712.02118	long lived charginos	$t\bar{t}$
1712.02304	$H \to ZZ^* \to 4l$	$t\bar{t}$, $t\bar{t}+Z$, $t\bar{t}+H$
1712.02332	squarks and gluinos	$t\bar{t}$, Wt, ST, $t\bar{t}+W/Z/WW$
1712.01602	$d\sigma_{tW}$	duh
1711.11520	top-squark pair	$t\bar{t}$, Wt, ST, $t\bar{t}+Z$
1711.08341	soft-drop jet mass	———————————–
1711.03301	dark matter, other NP	$t\bar{t}$, ST (small contrs)
1711.03296	$\sigma_{W^+}/\sigma_{W^-}$ and $d\sigma_W$	$t\bar{t}$, ST
1711.02692	$\sigma_{\text{(di)jet}}$	———————————–
1711.01901	Supersymmetry	$t\bar{t}$, ST, Wt
1710.11412	dark matter + b/t quarks	$t\bar{t}$, ST, $t\bar{t}+W/Z/\gamma/H$, $t\bar{t}+WW/t\bar{t}$, ...
1710.09560	σ isolated-γ + h.f. jet	———————————–
1710.09748	H^{++}	$t\bar{t}$, ST, $t\bar{t}W/Z/\gamma/H$
1710.07235	WW/WZ resonances	$t\bar{t}$, ST
1710.07171	pair-produced resonances	$t\bar{t}$
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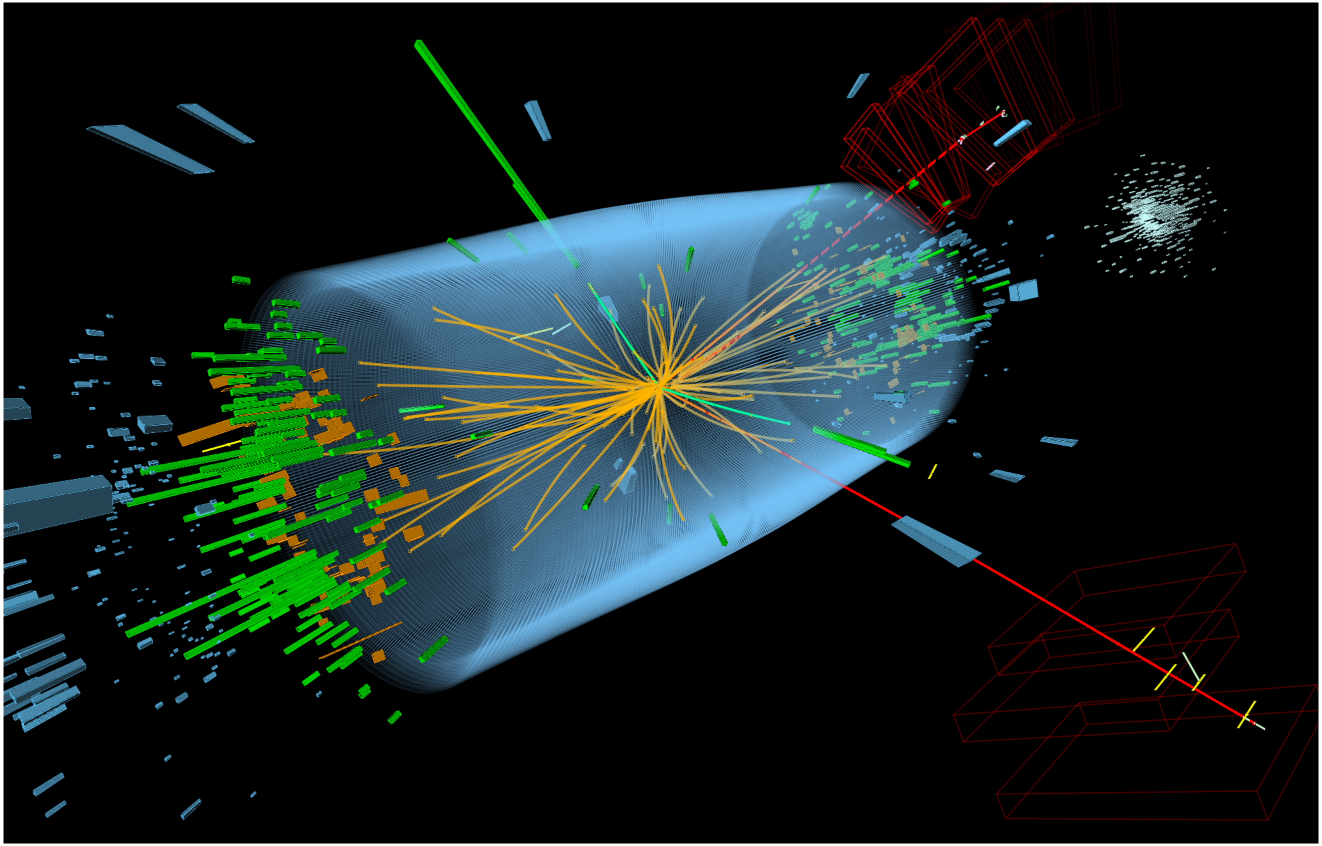
12/16 require reliable simulation of $t\bar{t}$!

Hadronic collisions

- An example of a proton-proton collision



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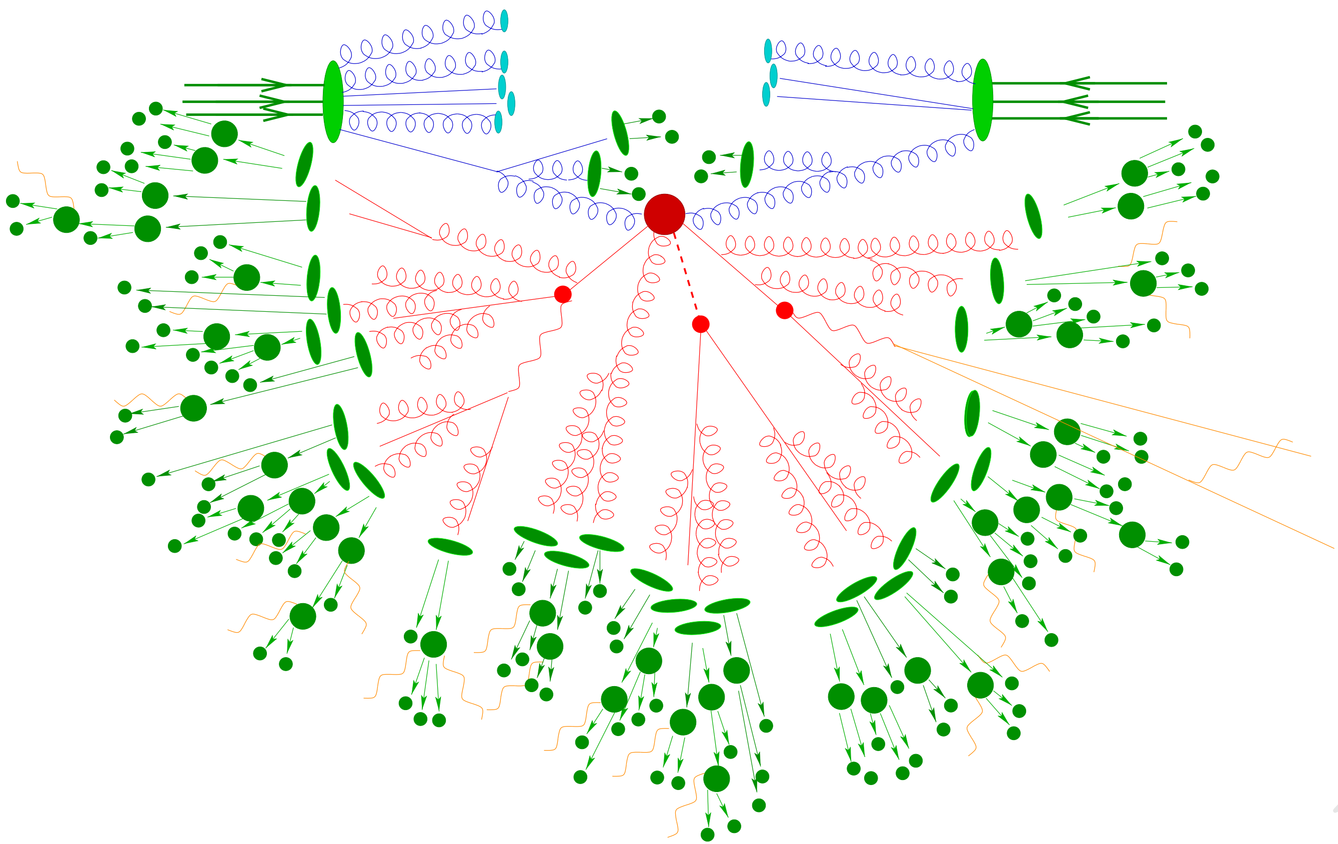

† drawing by Sherpa

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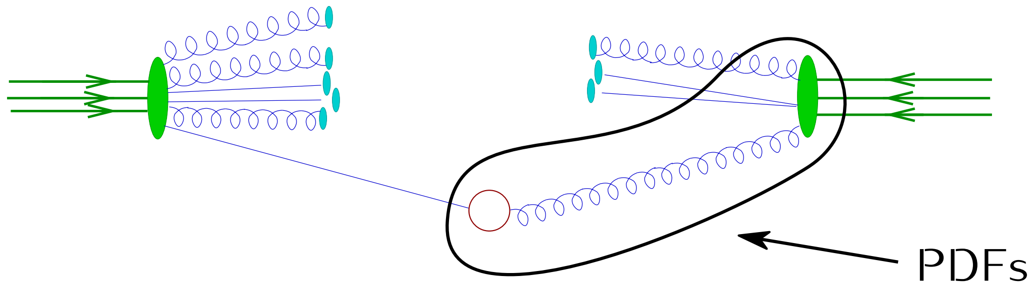

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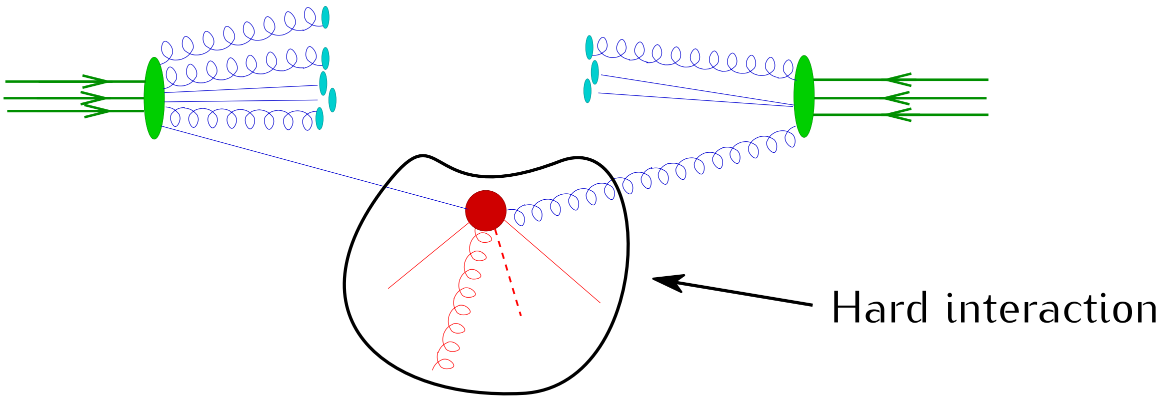

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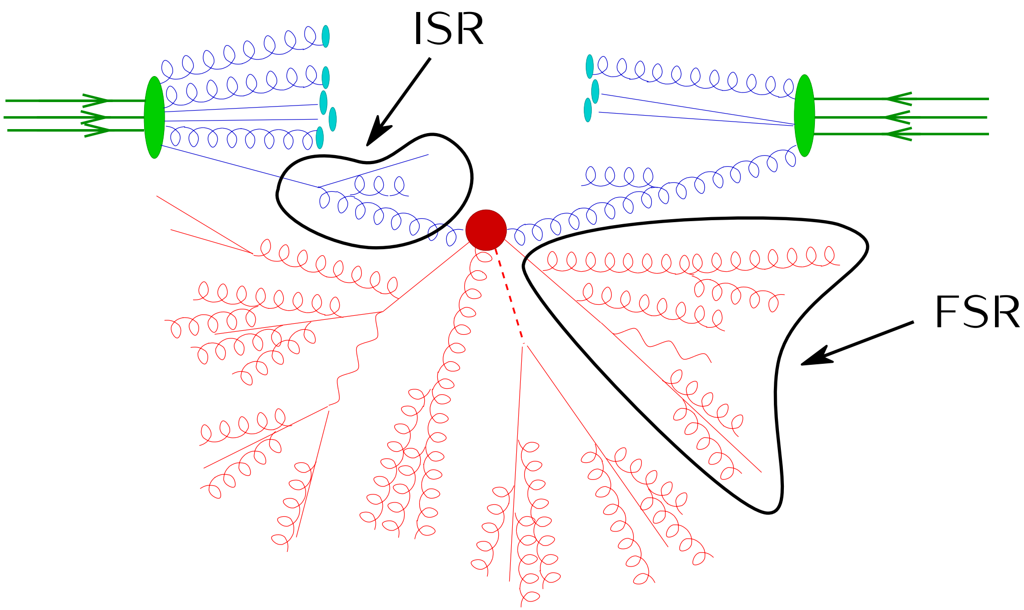

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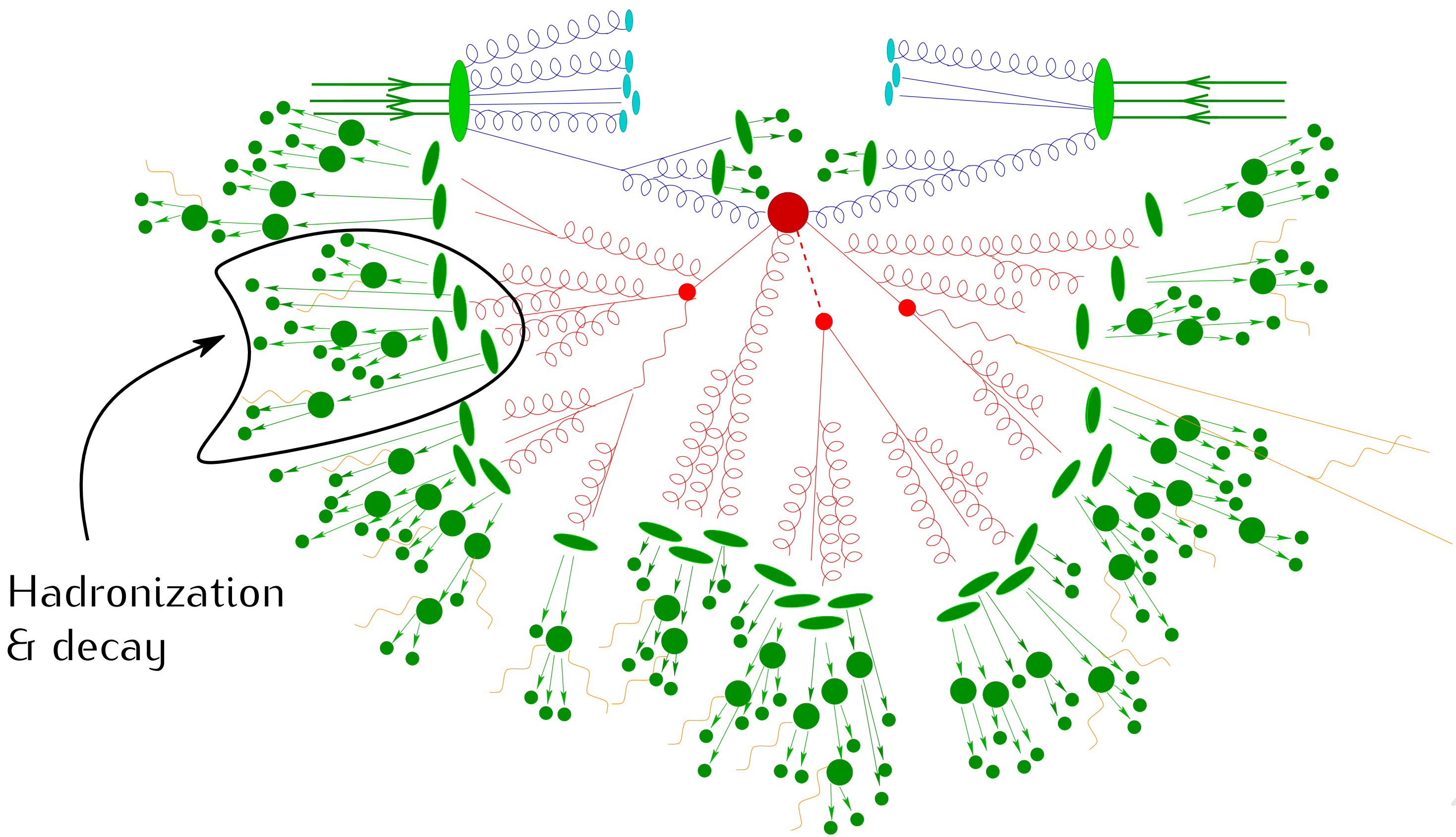

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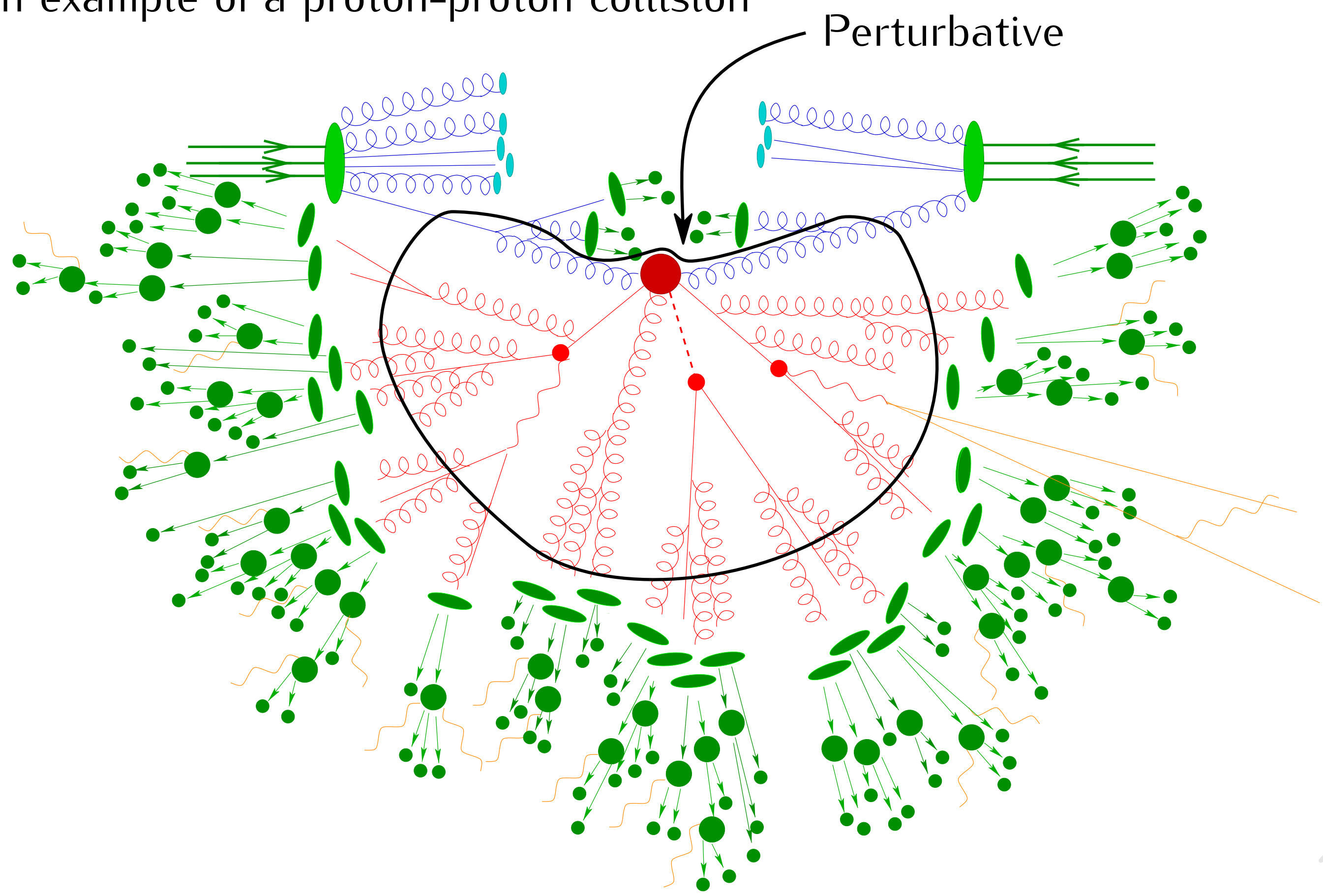

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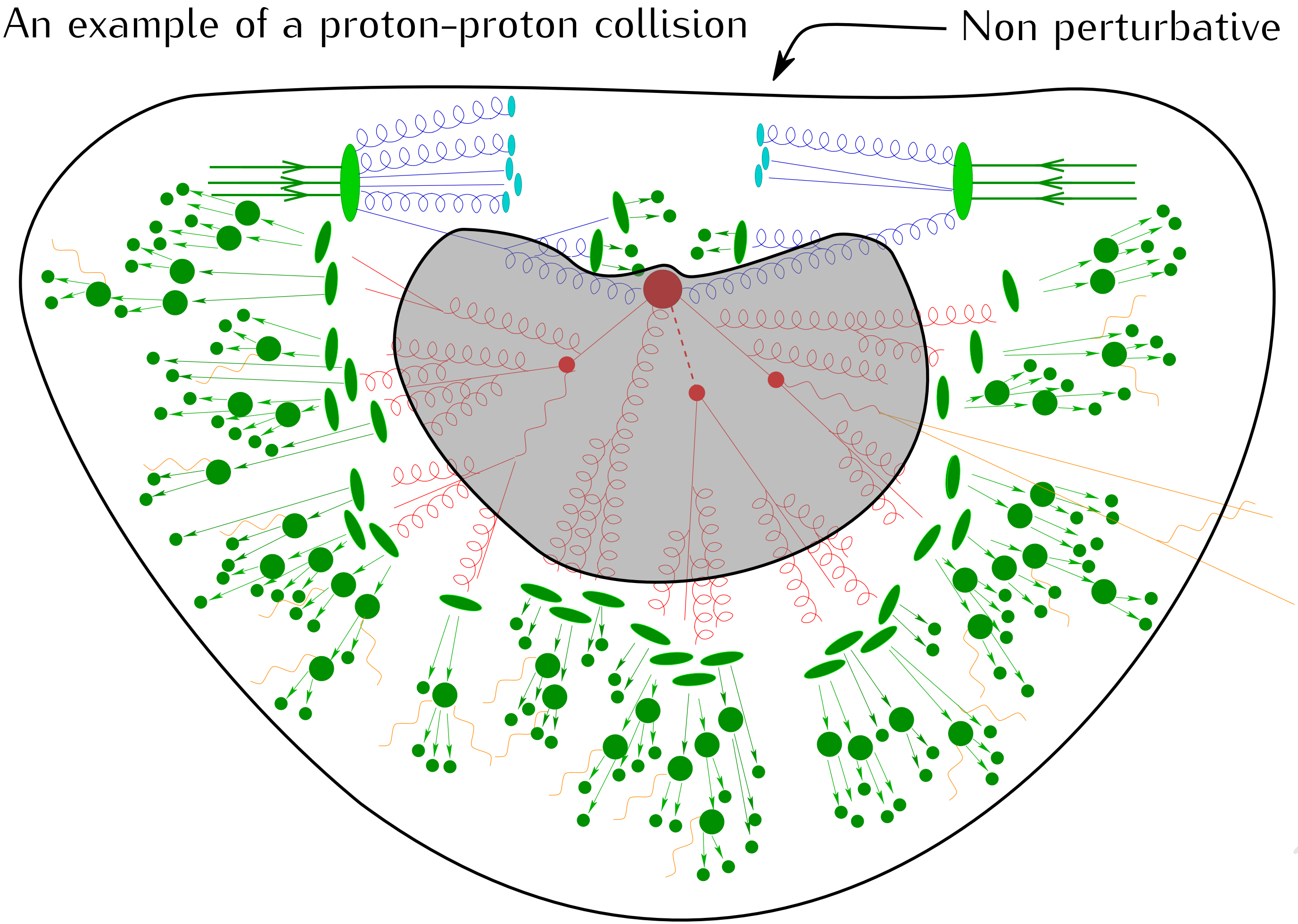

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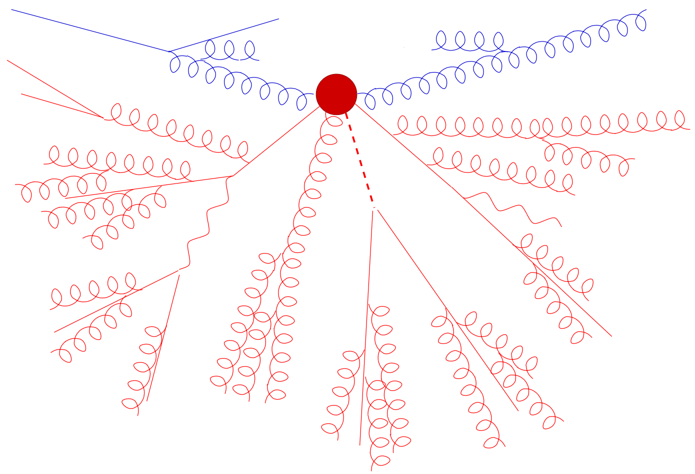
  - in particular: interplay of fixed order NLO calculations and PS



PS = Parton Shower
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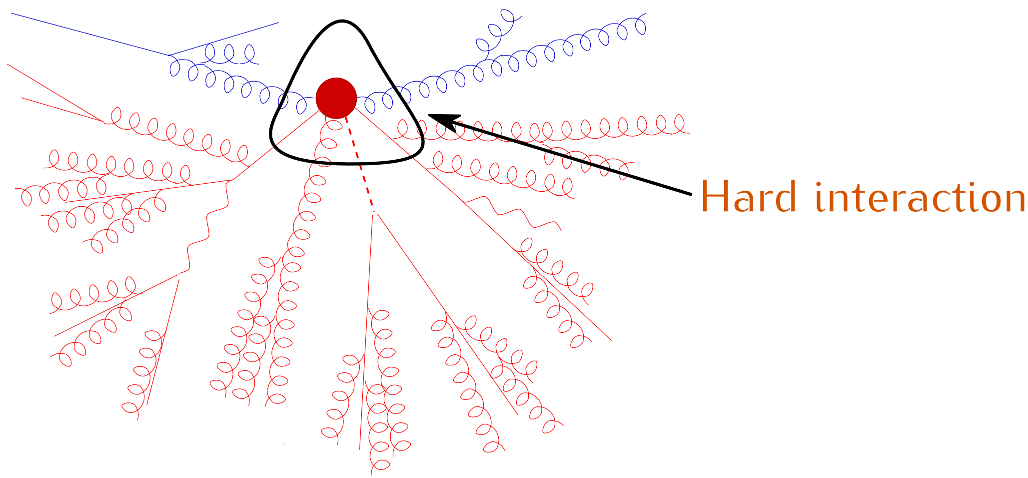

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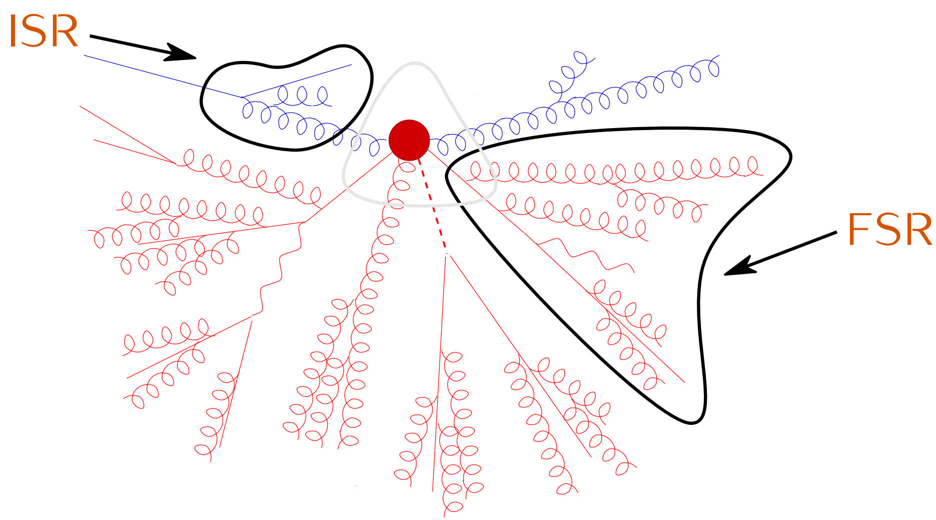

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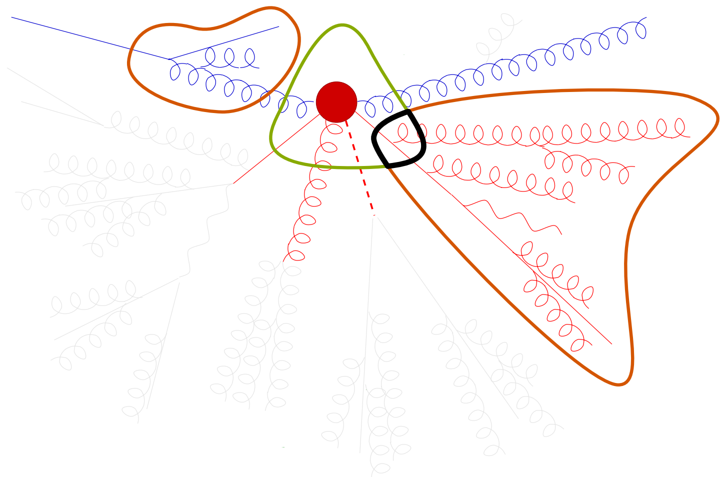

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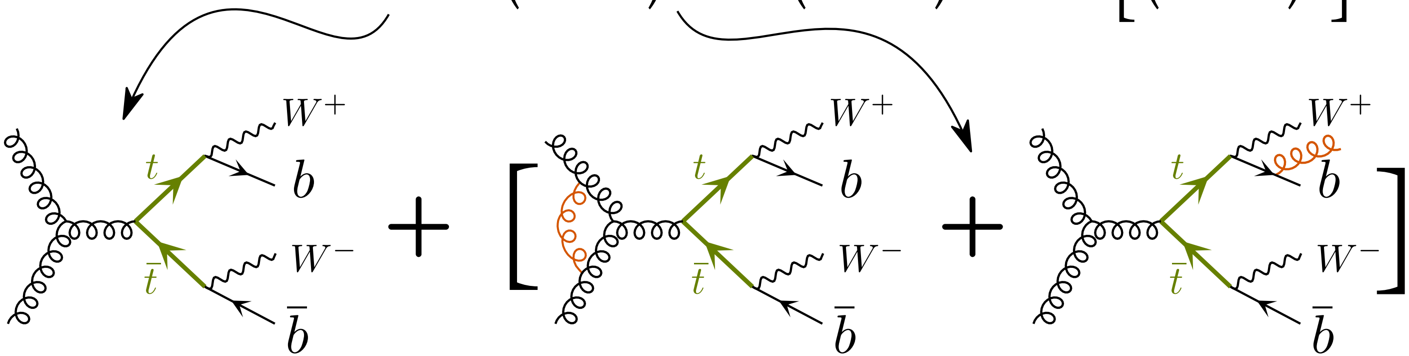
Precise calculations for colliders

- Perturbative expansion in coupling constants:

$$\sigma(\mu_r) = \frac{\alpha(\mu_r)}{\pi}\hat{\sigma}_1 + \left(\frac{\alpha(\mu_r)}{\pi}\right)^2 \hat{\sigma}_2 + \left(\frac{\alpha(\mu_r)}{\pi}\right)^3 \hat{\sigma}_3 + \mathcal{O}\left[\left(\frac{\alpha(\mu_r)}{\pi}\right)^4\right] \quad ^\dagger$$



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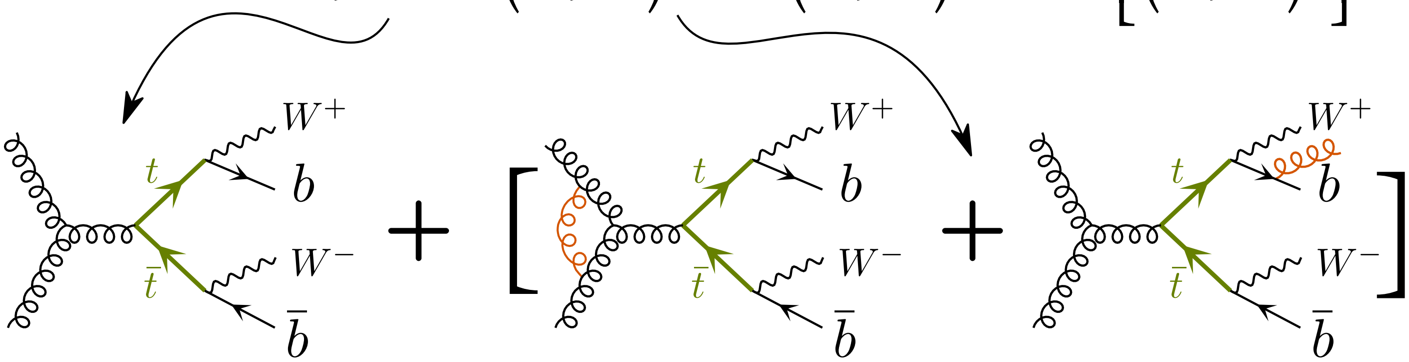

precise = including terms beyond the leading order

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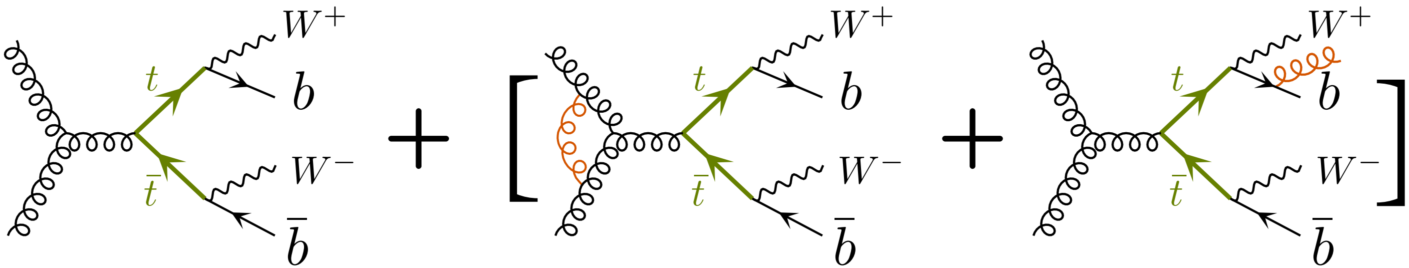

- State of the art for top-pair and single top production:
    - Single top, top pair NNLO QCD [arXiv:1404.7116,1511.00549]
    - Top pair NNLO QCD + NLO EW [arXiv:1511.00549]

    - Single top × decay in NWA at approximate NNLO QCD [arXiv:1708.09405]
    - Top pair × decay in NWA at approximate NNLO QCD [arXiv:1705.08903]

    - Single top full off-shell leptonic NLO QCD [arXiv:1305.7088]
    - Top pair full off-shell leptonic NLO QCD [arXiv:1312.0546]
    - Top pair full off-shell leptonic NLO EW [arXiv:1607.05571]
    - Top pair full off-shell semileptonic NLO mixed [arXiv:1711.10359]

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- All order resummation:
    - In most calculations logarithms of scale ratios appear
    - When the scales are widely separated, the logs become large spoiling the convergence
    - Resummation: "The art of constructing, from a subset of terms in a finite order perturbation series, an all-orders expression whose expansion gives at least those terms back."
    - Universal numeric approach exists, known as Parton Shower, resuming leading logarithms
    - Analytic process dependend calculations with higher accuracy available†

† heavily underrepresented in this talk

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- All or
  - spoiling
  - rms in a finite order perturbation series, an all-orders expression whose expansion gives at least those terms back."
  - Universal numeric approach exists, known as Parton Shower, resuming leading logarithms
  - Analytic process dependend calculations with higher accuracy available[†]

- Stacking PS on top of LO calculations trivial
- General framework for matching PS to NLO calculations known
- Some NNLO+PS calculations available

[†] heavily underrepresented in this talk

Precise calculations for colliders

- Perturbative expansion in coupling constants:

$$\sigma(\mu_r) = \frac{\alpha(\mu_r)}{\pi}\hat{\sigma}_1 + \left(\frac{\alpha(\mu_r)}{\pi}\right)^2 \hat{\sigma}_2 + \left(\frac{\alpha(\mu_r)}{\pi}\right)^3 \hat{\sigma}_3 + \mathcal{O}\left[\left(\frac{\alpha(\mu_r)}{\pi}\right)^4\right]$$

- All o

- Stacking PS on top of LO calculations trivial
- General framework for matching PS to NLO calculations known
- Some NNLO+PS calculations available

spoiling

rms in a finite order perturbation series, an all-orders expression whose expansion gives at least those terms back."

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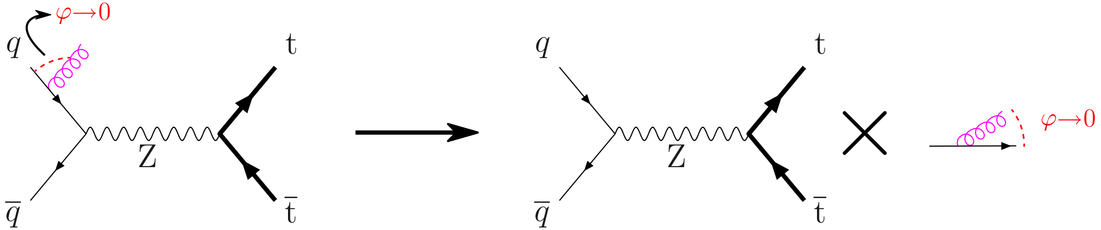
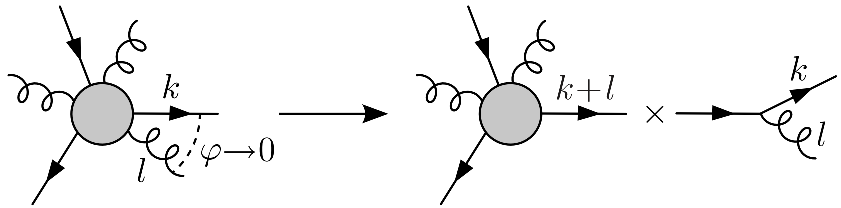
Parton Shower

- In the collinear limit:



Parton Shower

- In the collinear limit:



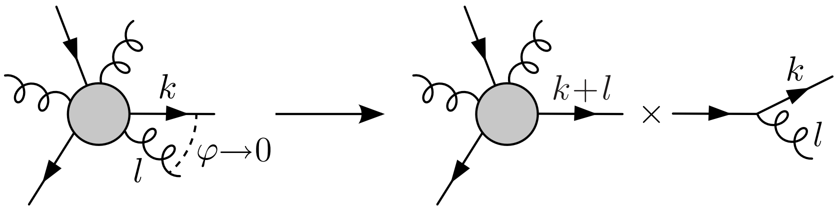
$$|\mathcal{M}_{n+1}|^2 d\Phi_{n+1} \to |\mathcal{M}_n|^2 d\Phi_n \times \frac{\alpha_S}{2\pi}\frac{dt}{t} P_{q,qg}(z) dz \frac{d\phi}{2\pi}$$

  - t hardness measure ($\to 0$), z momentum fraction, ϕ azimuthal angle
  - $P_{q,qg}(z)$ Altarelli-Parisi splitting for $q \to qg$

- Can be applied recursively: n splittings naively correspond to real corrections at N^{n}NLO

Parton Shower

- In the collinear limit:



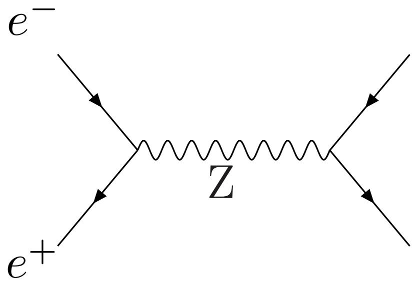
$$|\mathcal{M}_{n+1}|^2 d\Phi_{n+1} \to |\mathcal{M}_n|^2 d\Phi_n \times \frac{\alpha_S}{2\pi}\frac{dt}{t} P_{q,qg}(z) dz \frac{d\phi}{2\pi}$$

- Virtual corrections taken into account via Sudakov form factor

$$dP(t, t+dt) = \frac{\alpha_S}{2\pi}\frac{dt}{t}\int\frac{d\phi}{2\pi}\int P_{i,jl}(z) dz$$

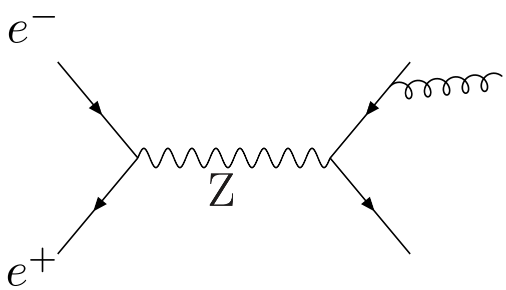
  - dP probability of $i \to jl$ splitting in $[t, t+dt]$
  - $1 - dP$ probability of no emission, equivalent of virtual correction

Parton Shower



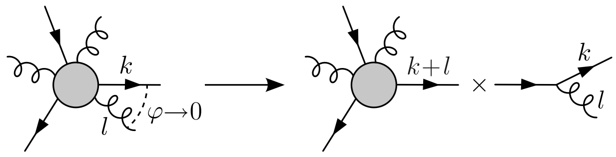
$$W = W_B$$

Parton Shower



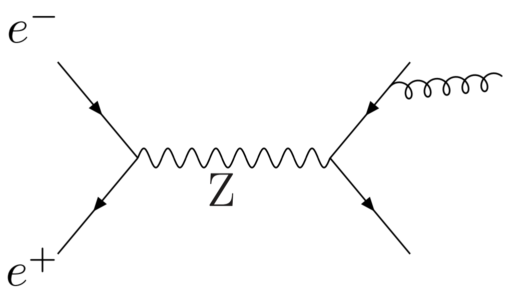
$$W = W_B \times V$$

- Real corrections in collinear approximation:



$$|\mathcal{M}_{n+1}|^2 d\Phi_{n+1} \to |\mathcal{M}_n|^2 d\Phi_n \times \underbrace{\frac{\alpha_S}{2\pi} \frac{dt}{t} P_{q,qg}(z) dz \frac{d\phi}{2\pi}}_{V}$$

Parton Shower



$$W = W_B \times V \times \Delta$$

- Virtual corrections in collinear approximation:

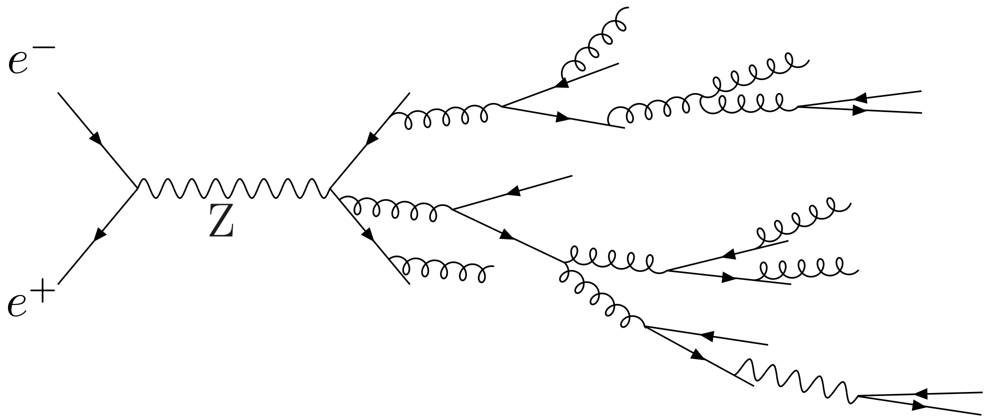
Δ

$$dP(t, t + dt) = \frac{\alpha_S}{2\pi}\frac{dt}{t}\int\frac{d\phi}{2\pi}\int P_{i,jl}(z)dz$$

  - dP probability of $i \to jl$ splitting in $[t, t + dt]$
  - $1 - dP$ probability of no emission, equivalent of virtual correction

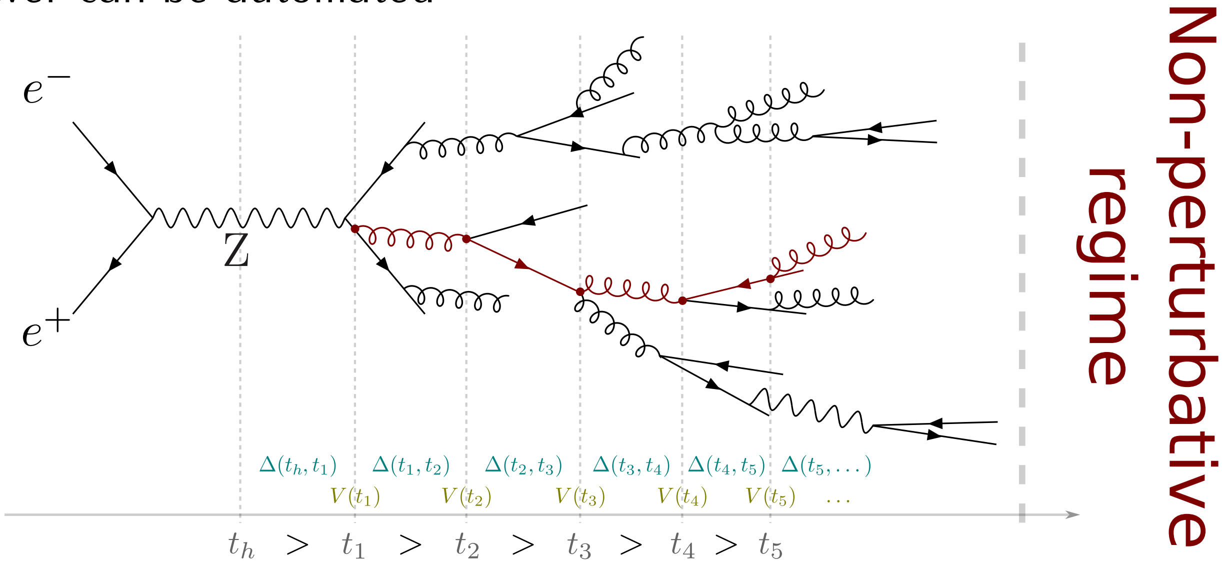
Parton Shower

- Parton Shower can be automated



Parton Shower

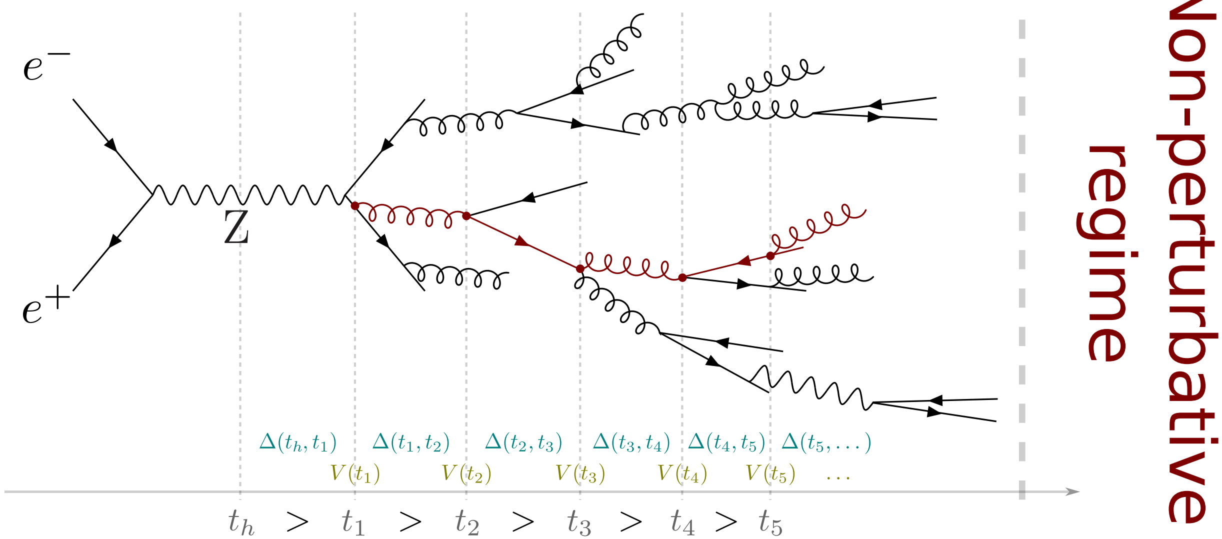
- Parton Shower can be automated



  - Variable t measures hardness
    - Vanishes in the collinear limit
  - Weight of the event is the Born weight times the splitting and Sudakov factors
  - The ordering ensures equivalence to leading-logarithmic resummation

Parton Shower

- Parton Shower can be automated

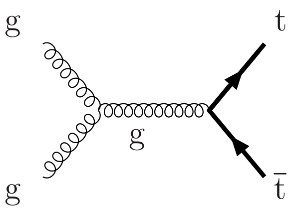


  - With the purpose of:
    - Resumming leading-logarithms
    - Generating final state multiplicities unfeasible at FO
    - Modelling of clustering, hadronization, multi-parton scattering, . . .
  - Two well known Shower Monte Carlos (SMCs): `Pythia`, `Herwig`

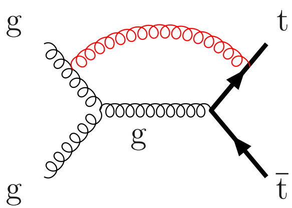
NLO & PS

- Fixed order calculation @ NLO

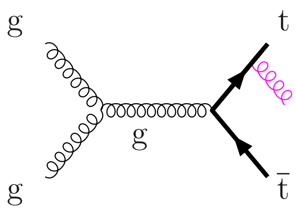
Born



virtual



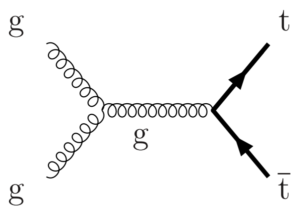
real



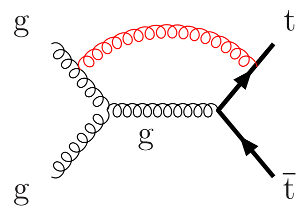
NLO & PS

- Fixed order calculation @ NLO

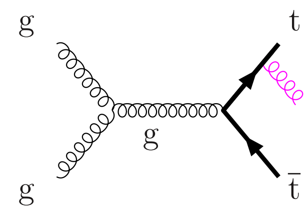
Born



virtual

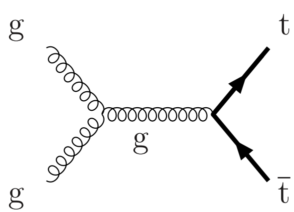


real

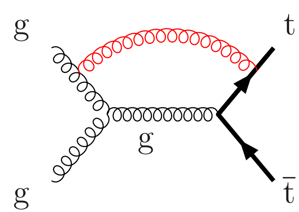


- Parton Shower

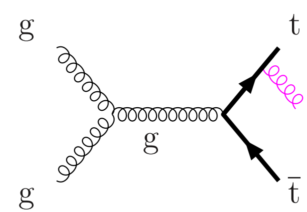
Born



Δ



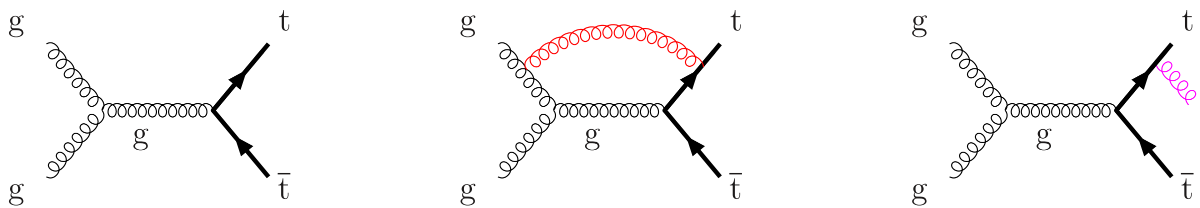
V



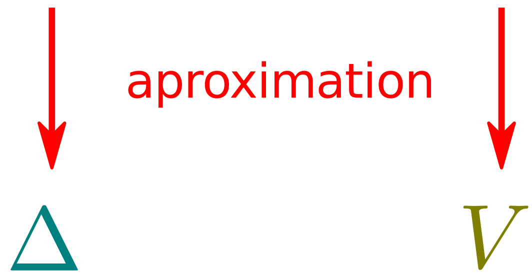
NLO & PS

- Fixed order calculation @ NLO

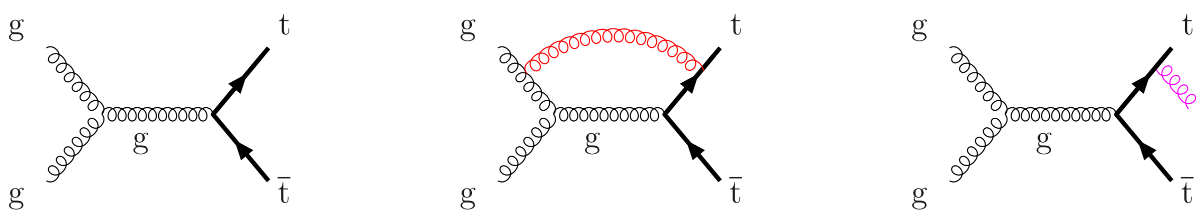
Born virtual real



- Parton Shower



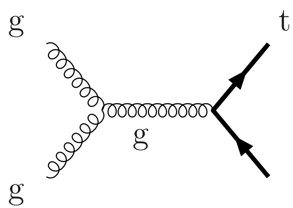
Born



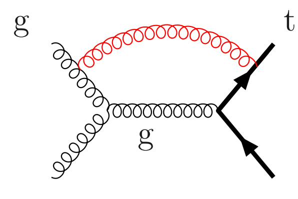
NLO+PS

- NLO matched with PS

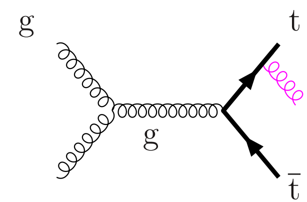
Born



virtual



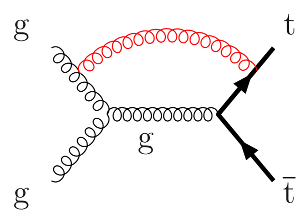
real



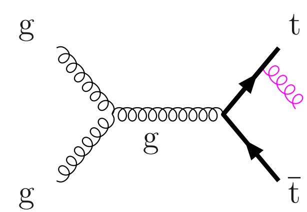
Leads to overcounting!

Δ and V counted twice!

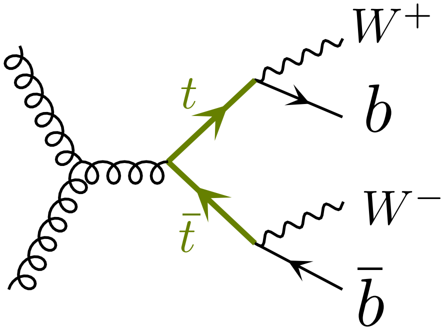
Δ



V



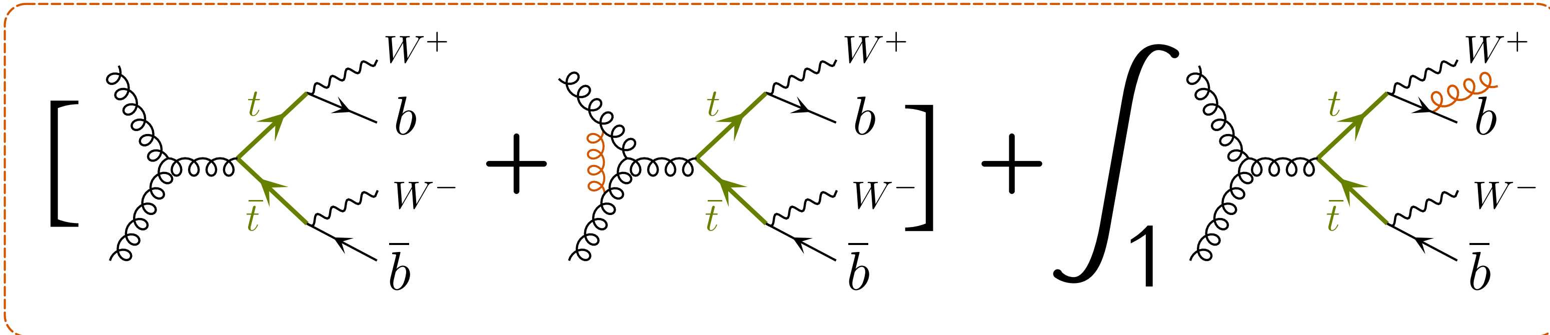
NLO+PS à la POWHEG



$$d\sigma = \overline{B}(\Phi_B)\, d\Phi_B \left[\Delta(q_{\text{cut}}) + \sum_\alpha \Delta(k_T^\alpha) \frac{R_\alpha(\Phi_\alpha(\Phi_B, \Phi_{\text{rad}}))}{B(\Phi_B)}\, d\Phi_{\text{rad}}\right]$$

$$\text{with } \Delta(k_T^\alpha) = \exp\left[-\int_{k_T^\alpha > q_{\text{cut}}} \frac{R_\alpha(\Phi_\alpha(\Phi_B, \Phi_{\text{rad}}))}{B(\Phi_B)}\, d\Phi_{\text{rad}}\right]$$

NLO+PS à la POWHEG



$$\mathrm{d}\,\sigma = \overline{B}(\Phi_B)\,\mathrm{d}\,\Phi_B \left[\Delta(q_{\mathrm{cut}}) + \sum_{\alpha} \Delta(k_T^{\alpha}) \frac{R_{\alpha}(\Phi_{\alpha}(\Phi_B, \Phi_{\mathrm{rad}}))}{B(\Phi_B)}\,\mathrm{d}\,\Phi_{\mathrm{rad}} \right]$$

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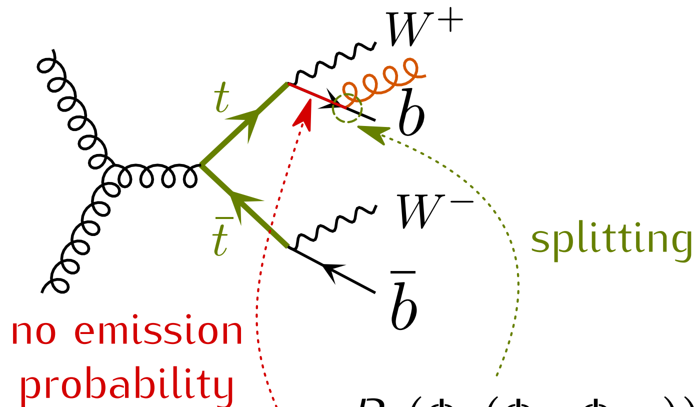
NLO+PS à la POWHEG



$$d\sigma = \overline{B}(\Phi_B)\, d\Phi_B \left[\Delta(q_{\text{cut}}) + \sum_\alpha \Delta(k_T^\alpha) \frac{R_\alpha(\Phi_\alpha(\Phi_B, \Phi_{\text{rad}}))}{B(\Phi_B)}\, d\Phi_{\text{rad}} \right]$$

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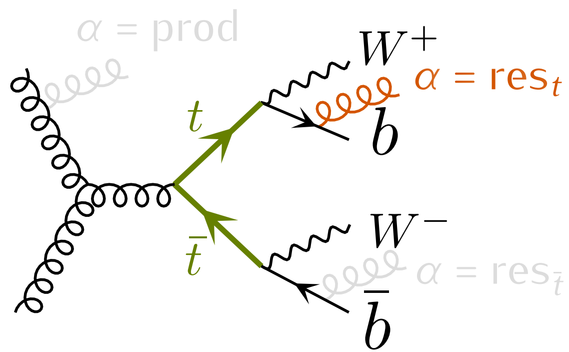
- Such a NLO calculation can be resummed using the standard formulation of the Parton Shower supplemented by a p_T veto

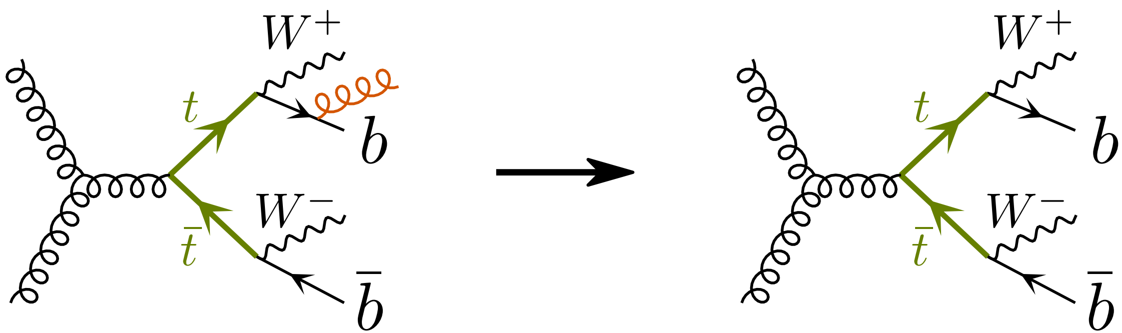
NLO+PS à la POWHEG



$$
\mathrm{d}\,\sigma = \overline{B}(\Phi_B)\,\mathrm{d}\,\Phi_B\left[\Delta(q_{\mathrm{cut}}) + \sum_{\alpha}\Delta(k_T^{\alpha})\frac{R_{\alpha}(\Phi_{\alpha}(\Phi_B,\Phi_{\mathrm{rad}}))}{B(\Phi_B)}\,\mathrm{d}\,\Phi_{\mathrm{rad}}\right]
$$

$$
\text{with } \Delta(k_T^{\alpha}) = \exp\left[-\int_{k_T^{\alpha}>q_{\mathrm{cut}}}\frac{R_{\alpha}(\Phi_{\alpha}(\Phi_B,\Phi_{\mathrm{rad}}))}{B(\Phi_B)}\,\mathrm{d}\,\Phi_{\mathrm{rad}}\right]
$$

NLO+PS à la POWHEG



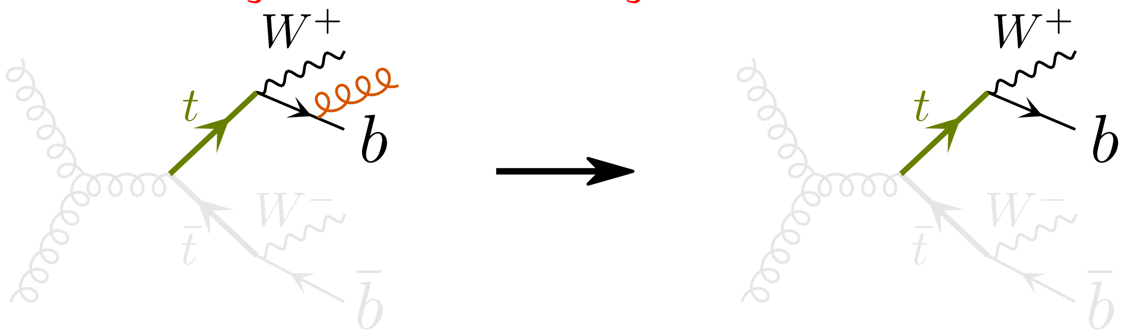
$$\mathrm{d}\,\sigma = \overline{B}(\Phi_B)\,\mathrm{d}\,\Phi_B \left[\Delta(q_{\mathrm{cut}}) + \sum_{\alpha} \Delta(k_T^{\alpha}) \frac{R_\alpha(\Phi_\alpha(\Phi_B, \Phi_{\mathrm{rad}}))}{B(\Phi_B)}\,\mathrm{d}\,\Phi_{\mathrm{rad}} \right]$$

$$\text{with } \Delta(k_T^{\alpha}) = \exp\left[-\int_{k_T^{\alpha} > q_{\mathrm{cut}}} \frac{R_\alpha(\Phi_\alpha(\Phi_B, \Phi_{\mathrm{rad}}))}{B(\Phi_B)}\,\mathrm{d}\,\Phi_{\mathrm{rad}} \right]$$

- In standard formulation of the POWHEG method:
  - $n+1 \leftrightarrow n$ mapping doesn't preserve top virtuality
  - Leading to unphysical suppression away from collinear singularities
  - Only one hardest emission is kept

NLO+PS à la POWHEG

Only radiation in decay is concerned!



$$d\sigma = \overline{B}(\Phi_B)\, d\Phi_B \left[\Delta(q_{\text{cut}}) + \sum_\alpha \Delta(k_T^\alpha) \frac{R_\alpha(\Phi_\alpha(\Phi_B, \Phi_{\text{rad}}))}{B(\Phi_B)}\, d\Phi_{\text{rad}}\right]$$

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- In standard formulation of the POWHEG method:
  - $n+1 \leftrightarrow n$ mapping doesn't preserve top virtuality
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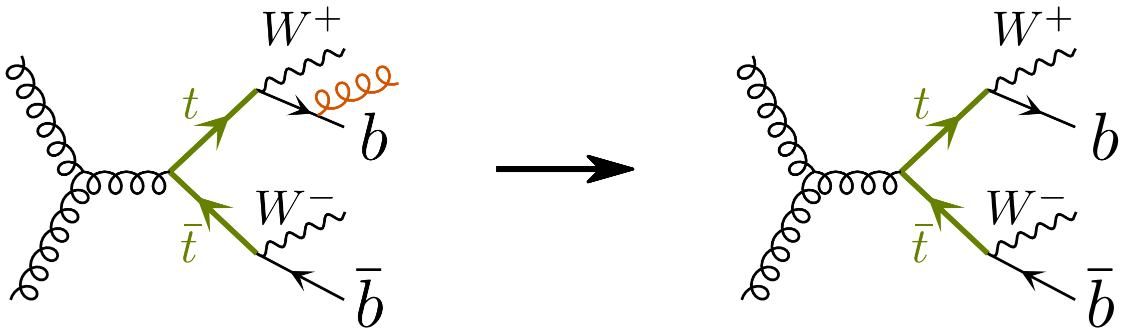
NLO+PS à la POWHEG RES

[TJ, P. Nason 2015]



$$\mathrm{d}\,\sigma = \overline{B}(\Phi_B)\,\mathrm{d}\,\Phi_B \left[\Delta(q_{\mathrm{cut}}) + \sum_{\alpha} \Delta(k_T^{\alpha}) \frac{R_\alpha(\Phi_\alpha(\Phi_B, \Phi_{\mathrm{rad}}))}{B(\Phi_B)} \,\mathrm{d}\,\Phi_{\mathrm{rad}} \right]$$

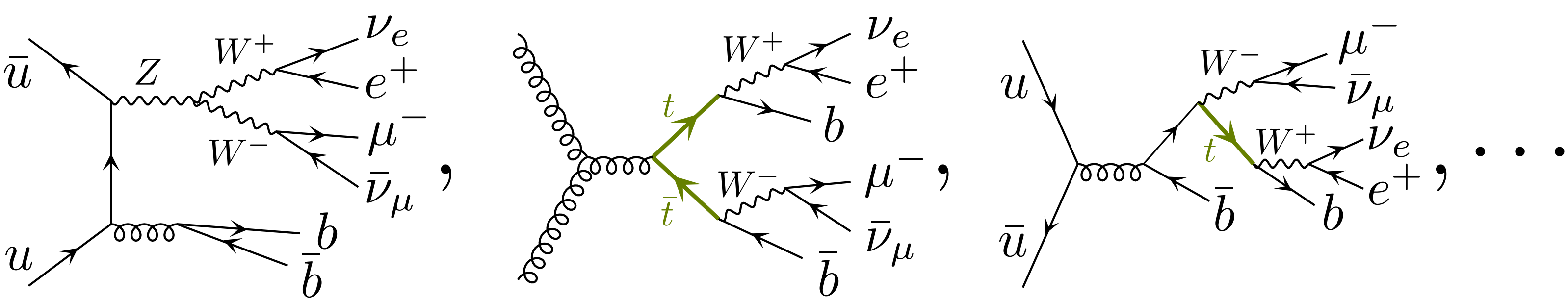
$$\text{with } \Delta(k_T^{\alpha}) = \exp\left[- \int_{k_T^{\alpha} > q_{\mathrm{cut}}} \frac{R_\alpha(\Phi_\alpha(\Phi_B, \Phi_{\mathrm{rad}}))}{B(\Phi_B)} \,\mathrm{d}\,\Phi_{\mathrm{rad}} \right]$$

- In new “resonance-aware” formulation of the POWHEG method:
  - $n+1 \leftrightarrow n$ mapping preserves top virtuality
  - No unphysical distortions of the top line shape
  - Keeps multiple emissions: from production and each resonance

bb41

[TJ, Lindert, Nason, Pozzorini, Oleari 2016]

- Process
  - $pp \to \ell^+ \nu_\ell l^- \bar{\nu}_l b \bar{b}$@ NLO QCD ($pp \to W^+ b W^- \bar{b}$, $W \to$ leptons)

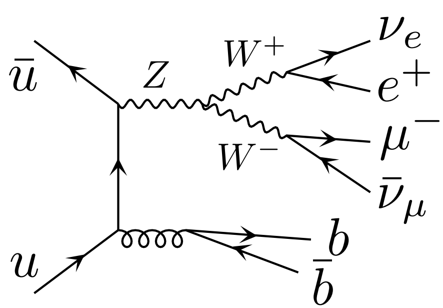


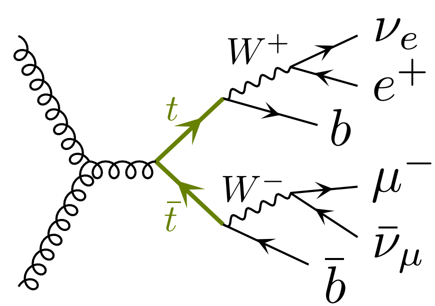
  - Born, real and virtual matrix elements by `OpenLoops`
  - 4 flavour number scheme
    - Unified description of $t\bar{t}$ and Wt production
    - Effects of b-quark mass included
    - Phase space with unresolved b-quarks accessible

bb41

[TJ, Lindert, Nason, Pozzorini, Oleari 2016]

- Process
  - $pp \to \ell^+ \nu_\ell \, l^- \bar{\nu}_l \, b \, \bar{b}$@ NLO QCD ($pp \to W^+ b W^- \bar{b}$, $W \to$ leptons)
  - Born, real and virtual matrix elements by `OpenLoops`
  - 4 flavour number scheme
    - Unified description of $t\bar{t}$ and Wt production
    - Effects of b-quark mass included
    - Phase space with unresolved b-quarks accessible
- NLO+PS generator
  - Implements resonance aware `POWHEG` method
  - Employs 2 resonance histories





bb4l

[TJ, Lindert, Nason, Pozzorini, Oleari 2016]

UZH

- Process
  - $pp \to \ell^+ \nu_\ell l^- \bar{\nu}_l b \bar{b}$@ NLO QCD ($pp \to W^+ b W^- \bar{b}$, $W \to$ leptons)
  - Born, real and virtual matrix elements by OpenLoops
  - 4 flavour number scheme (unified $t\bar{t}$ & Wt, b mass effects, ...)
- NLO+PS generator
  - Implements resonance aware POWHEG method
  - Employs 2 resonance histories $(t(W^+b)\bar{t}(W^-\bar{b}), Z(W^+W^-)b\bar{b})$
- Shower Monte Carlo
  - Standard LHE interface not sufficient (separate `scalup` required for production and each resonance)
  - `Pythia8`: `PowhegHooksBB4L` class publicly available (compatible with `PowhegHooks`)
  - `Herwig7`: coming soon

bb4l

[TJ, Lindert, Nason, Pozzorini, Oleari 2016]

- Process
  - $pp \to \ell^+\nu_\ell l^-\bar{\nu}_l b\bar{b}$@ NLO QCD ($pp \to W^+bW^-\bar{b}$, $W \to$ leptons)
  - Born, real and virtual matrix elements by OpenLoops
  - 4 flavour number scheme (unified $t\bar{t}$ & Wt, b mass effects, ...)
- NLO+PS generator
  - Implements resonance aware POWHEG method
  - Employs 2 resonance histories $(t(W^+b)\bar{t}(W^-\bar{b}), Z(W^+W^-)b\bar{b})$
- Shower Monte Carlo
  - Pythia8 interface available, Herwig7 coming soon
- Implementation
  - Resonance aware POWHEG method: POWHEG BOX RES
  - Process implementation: b_bbar_4l or $b\bar{b}4l$
  - Publicly available http://powhegbox.mib.infn.it/

Results

- Compare $t\bar{t}$ & tW generators
  - Generators:
    - `hvq + ST_wtch_DR` and `hvq + ST_wtch_DS`
    - `ttb_NLO_dec` (tW contribution only at LO)
    - `bb4l`
  - Observables:
    - Shapes of m_{Wj_B} and m_{lj_B}
  - Setup:
    - LHC 8TeV
    - Anti-k_T jets, $R = 0.5$
    - The $b/\bar{b}$ jet is the jet with the hardest $b/\bar{b}$ flavoured hadron
    - W's fully reconstructed
    - Shower with `Pythia 8.2`

$t\bar{t}$ & tW generators in POWHEG BOX

- hvq [Frixione, Nason, Ridolfi, 2007], ST_wtch_DR(S) [Re, 2010]
  - Production at NLO
  - Decays at LO
  - Radiation from FS b's only with PS
  - Includes hadronic W decays
- ttb_NLO_dec [Campbell, Ellis, Nason, Re, 2014]
  - Production at NLO
  - Decays at NLO
  - Radiation from FS b's with ME (thanks to allrad)
  - Includes hadronic W decays, Wt contribution at LO
- bb4l [TJ, Lindert, Nason, Oleari, Pozzorini, 2016]
  - $pp \to \ell^+ \nu_\ell \, l^- \bar{\nu}_l \, b \, \bar{b}$ production at NLO (production and decay at NLO)
  - Radiation from FS b's with ME (thanks to allrad)
  - No hadronic W decays, Includes Wt contribution

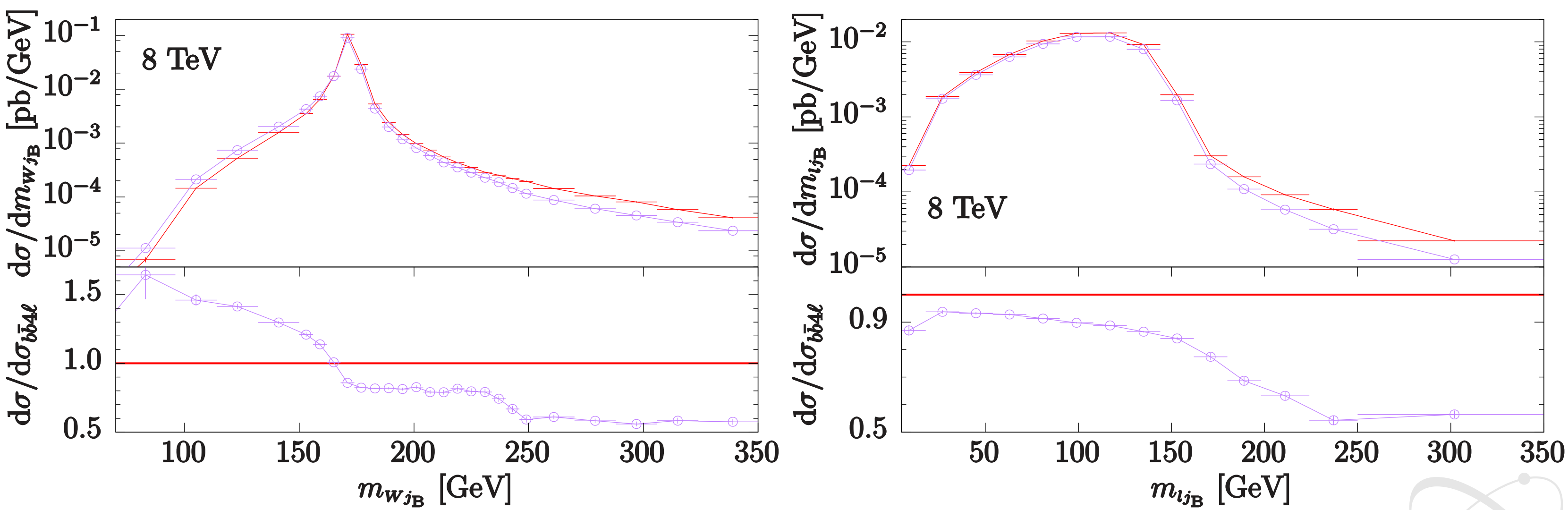
$t\bar{t}$ & tW generators in POWHEG BOX

- `hvq` [Frixione, Nason, Ridolfi, 2007], `ST_wtch_DR(S)` [Re, 2010]
  - Production at NLO
  - Decays at LO
  - Radiation from FS b's only with PS
  - Includes hadronic W decays
- `ttb_NLO_dec` [Campbell, Ellis, Nason, Re, 2014]
  - Production at NLO
  - Decays at NLO
  - Radiation from FS b's with ME (thanks to `allrad`)
  - Includes hadronic W decays, Wt contribution at LO
- `bb4l` [TJ, Lindert, Nason, Oleari, Pozzorini, 2016]
  - $pp \to \ell^+ \nu_\ell \, l^- \bar{\nu}_l \, b \, \bar{b}$ production at NLO (production and decay at NLO)
  - Radiation from FS b's with ME (thanks to `allrad`)
  - No hadronic W decays, Includes Wt contribution

`POWHEG-BOX-V2`

Impact of radiative corrections in top decays

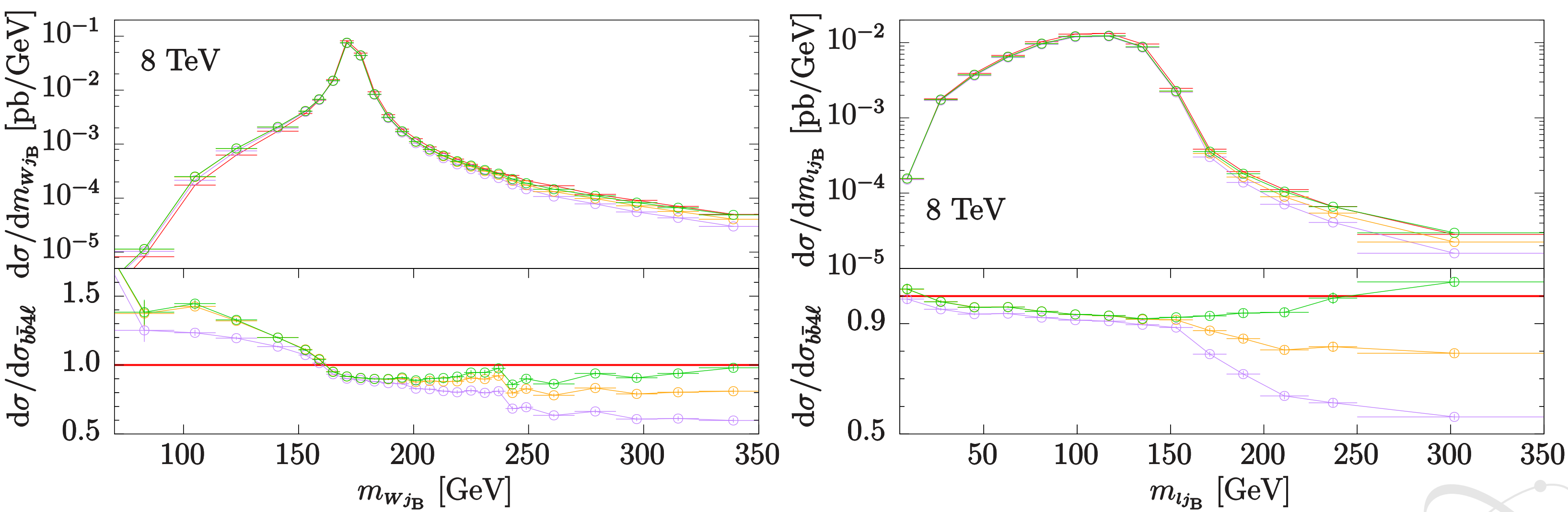
- $W j_B$ and $l j_B$ mass
  - b_bbar_4l: $pp \to \ell^+ \nu_\ell l^- \bar{\nu}_l b \bar{b}$@NLO, allrad scheme
  - hvq: $t\bar{t}$ @NLO, decay @LO, no Wt contribution



we observe a dramatic difference, even a shift in the reconstructed top mass peak

Impact of radiative corrections in top decays

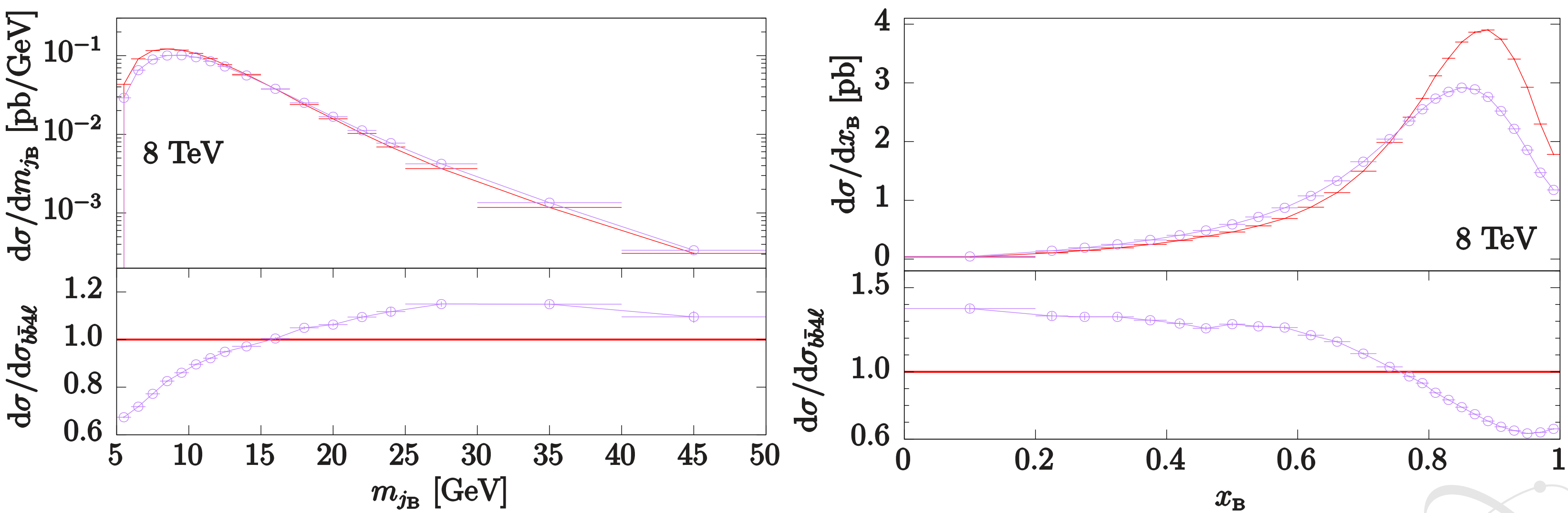
- $W j_B$ and $l j_B$ mass
  - `b_bbar_4l`: $pp \to \ell^+ \nu_\ell \, l^- \bar{\nu}_l \, b \, \bar{b}$@NLO, `allrad` scheme
  - `hvq`: $t\bar{t}$ @NLO, decay @LO, no Wt contribution
  - `hvq + ST_wtch_DS`: tt & Wt @NLO, t decay @LO
  - `hvq + ST_wtch_DR`: tt & Wt @NLO, t decay @LO



adding `ST_wtch` to `hvq` improves the agreement,
most notably in the tails

Impact of radiative corrections in top decays

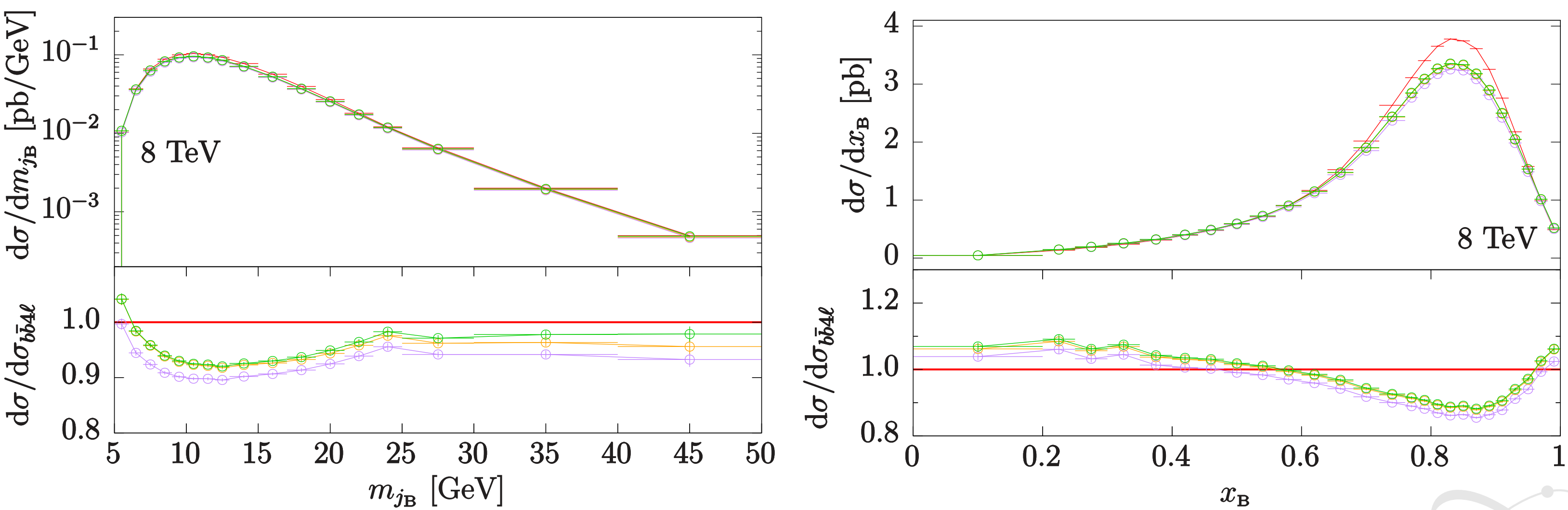
- j_B mass and B fragmentation function
  - b_bbar_4l: $pp \to \ell^+ \nu_\ell l^- \bar{\nu}_l b \bar{b}$@NLO, allrad scheme
  - hvq: $t\bar{t}$ @NLO, decay @LO, no Wt contribution



hvq predicts narrower b-jets and softer B fragmentation function

Impact of radiative corrections in top decays

- j_B mass and B fragmentation function
  - b_bbar_4l: $pp \to \ell^+ \nu_\ell l^- \bar{\nu}_l b \bar{b}$@NLO, allrad scheme
  - hvq: $t\bar{t}$ @NLO, decay @LO, no Wt contribution
  - hvq + ST_wtch_DS: tt & Wt @NLO, t decay @LO
  - hvq + ST_wtch_DR: tt & Wt @NLO, t decay @LO

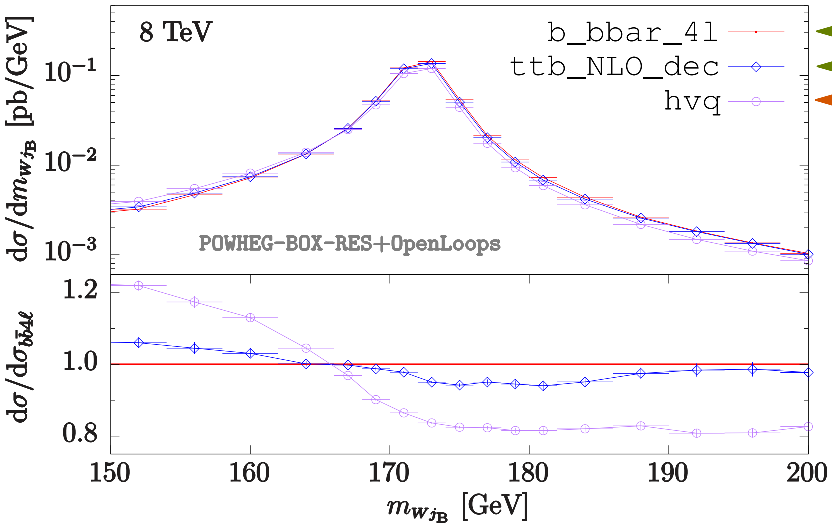


adding ST_wtch to hvq does not affect the shape

† difference with respect to previous slide due to MPI

Impact of radiative corrections in top decays

- In conclusion:
  - Radiative corrections in top decays have dramatic impact on b-jet description

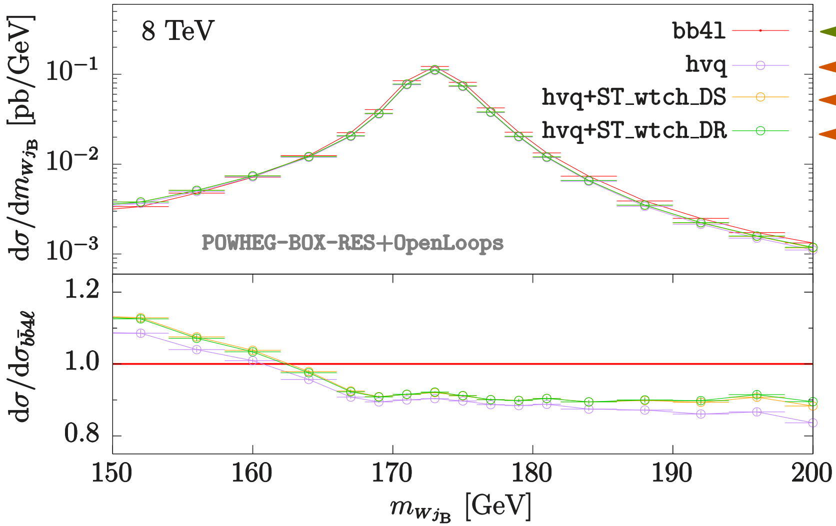


hardest emission from b governed by POWHEG

radiation from b fully governed by SMC

Impact of radiative corrections in top decays

- In conclusion:
  - Radiative corrections in top decays have dramatic impact on b-jet description



hardest emission from b governed by POWHEG

radiation from b fully governed by SMC

the difference in the shape around the peak due to treatment of hardest emission off b's (adding `ST_wtch` to `hvq` does not help)

Summary and outlook

- Top quark plays a prominent part in the LHC physics program
  - Heaviesr particle of the SM, playing crucial role in EWSB
  - Precise knowledge of m_T important for SM precision tests
  - Accurate Monte Carlos for top quark simulation indispensable
- Recent years saw tremendous progress:
  - In FO calculations reaching NNLO QCD + NLO EW precision in production, NNLO QCD in decay in NWA
  - First NLO QCD full off-shell calculations with top decay now also available
  - This culminated in NLO+PS matched Monte Carlo for top-pair and tW production including leptonic decay
- Comparisons with previous generation show:
  - Considerable differences in b-jet description
  - May this have an impact on top mass determination?