Electroweak corrections for $W/Z + n$ jet production

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1. Motivation

We consider in general processes at the LHC with $\sqrt{s} = 8$ TeV. Generic Features

- High center of mass energy
- $\alpha_{\text{ew}} \ln^2[M^2_{W/Z}/s]$ potentially large

$\Rightarrow$ Electroweak corrections become important

Interesting processes are e.g.

1. $W/Z + n$ jet
2. Gauge boson pair production

Especially the first one is important

- Testing environment for pQCD calculations
- New physics searches
- Huge and irreducible SM background

$\Rightarrow$ Need a thorough understanding

A lot of effort has been put in QCD calculations. Electroweak corrections are as important as some of the known QCD corrections.

- High complexity $\Rightarrow$ Monte Carlo generators

$\Rightarrow$ Need a framework to automatically provide NLL corrections to various processes

2. Setup of the Theory

1. Match full SM $SU(3)_C \otimes SU(2)_W \otimes U(1)_Y$ onto soft collinear effective theory, still with the unbroken SM
2. Run down to scale of EW symmetry breaking

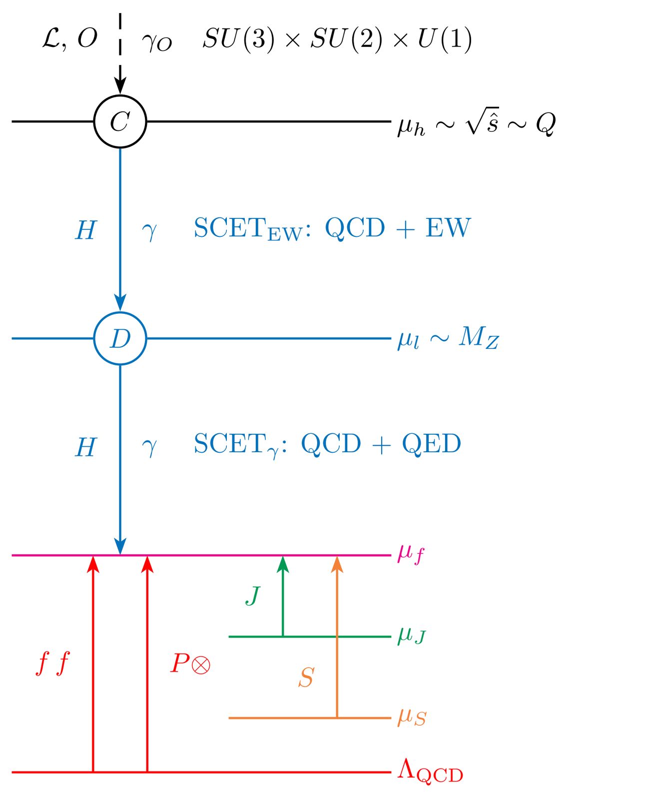

Figure 1: Schematical overview of the EFT

1. Fields are described by colinear and soft Wilson lines $\Rightarrow$ valid for energetic particles
2. Regulator choice:

$\Rightarrow$ Factorizes soft and colinear calculations

Ingredients for the Calculation

1. Collinear corrections
   - Depends on field, only
   - Matching accounts for symmetry breaking effects, e.g. $\gamma - Z$ mixing, $M_W \neq M_Z$
2. Soft corrections
   - Depends on gauge structure, only
   - Matching accounts for blow up of operator basis $\Rightarrow$ Electroweak symmetry breaking

Master Formula

$$\mathbf{C}_{\text{low}} = \mathcal{M}_{\text{low}}\,\mathcal{M}_{\text{col}}\,\mathcal{M}_{\text{soft}}\,\mathbf{C}_{\text{high}}\,\mathcal{M}^{\mathsf{T}}_{SU(3)}$$

with the individual matrices below (Special case $SU(3)$: Separate gauge space, only running)
For the electroweak matrices we have, where R is a running and M a matching matrix

$$\mathcal{M}_{\text{low}} = \exp\left[\int_{\mu}^{M_z} \frac{d\mu}{\mu} R^{\text{soft+col}}_{U(1)_{\text{EM}}}\right]$$

$$\mathcal{M}_{\text{col}} = \exp\left[M^{\text{col}}_{U(1)_Y\otimes SU(2)_W}\right] \times \exp\left[\int_{M_z}^{\sqrt{s}} \frac{d\mu}{\mu} R^{\text{col}}_{U(1)_Y\otimes SU(2)_W}\right]$$

$$\mathcal{M}_{\text{soft}} = \exp\left[\int_{M_z}^{\sqrt{s}} \frac{d\mu}{\mu} R^{\text{soft}}_{U(1)_Y}\right] M^{\text{break}}_{SU(2)} \times \exp\left[\int_{M_z}^{\sqrt{s}} \frac{d\mu}{\mu} R^{\text{soft}}_{SU(2)_W}\right]$$

$\Rightarrow$ Wilson Coefficient

- Columns: Different $SU(3)_C$ Op.
- Rows: Different $SU(2)_W \otimes U(1)_Y$ Op.

Operators

- High Scale

$$\mathcal{O} = \bar{Q}_L \tau^a T^A Q_L W^a G^A$$

- Low scale

$$\mathcal{O}_1 = \bar{U}_L T^a D_L W^- G^a$$
$$\mathcal{O}_2 = \bar{D}_L T^a U_L W^+ G^a$$
$$\mathcal{O}_{3-6} = \text{Involving Z and } \gamma$$

$\Rightarrow$ Non-square matrices

Parton Distribution Functions (PDF)

- Partons inside proton collide

$\Rightarrow$ Match onto non-perturbative set of PDFs

- We use CTEQ5 for the plots

Phase-Space

- Two additional variables x_A and x_B

$\Rightarrow$ Accounts for momentum distribution of partons within the protons

- Use special parameterisation: Factorization of single final state plus extra radiation
- Bar components: Defined in 1 particle PS

$$d\phi_2 = d\bar{\phi}_1 d\phi_{\text{rad}}$$
$$d\bar{\Phi}_1 = d\bar{x}_A d\bar{x}_B \widetilde{d\bar{k}_V} (2\pi)^4 \delta^4(\bar{k}_A + \bar{k}_B - \bar{k}_V) = \frac{2\pi}{S} d\bar{Y}$$
$$d\Phi_{\text{rad}} = \frac{s}{(4\pi)^3} \frac{\xi}{1-\xi} \theta(\xi - \xi_{\max}) d\xi dy d\phi$$

1. $|\bar{Y}| \le \log \frac{\sqrt{S}}{M}$: Rapidity of vector boson
2. $0 \le \xi \le \xi_{\max}$: Energy fraction of the jet
3. $y = \cos\theta \in [-1, 1]$ of radiated parton
4. $\phi \in [0, 2\pi]$ is the azimuthal angle

3. Observables

$\mathbf{pp \to W^{\pm} j}$

- In total 16 subprocesses contribute
- $W^+ \leftrightarrow W^-$: up and down quarks change role
- Taking into account the first and second generation as well as CKM factors

1. $\bar{q}_u q_d \to W^+ G$ and $1 \leftrightarrow 2$
2. $q_u G \to W^+ q_d$ and $1 \leftrightarrow 2$
3. $\bar{q}_d G \to W^+ \bar{q}_u$ and $1 \leftrightarrow 2$

- Investigate p_T spectrum of gauge boson

$\Rightarrow$ Effectively we resum $\alpha_{\text{ew}} \ln^2[M^2_{W/Z}/p^2_{T_{W/Z}}]$

Plots (Preliminary!)

- Statistical error only (4M events)
- p_T binning: 25 GeV
- Corrections are colored as
  1. Black: Tree
  2. Red[Light]: LL[with QCD corrections]
  3. Blue[Light] : NLL[with QCD corrections]
- $pp \to W^- j$

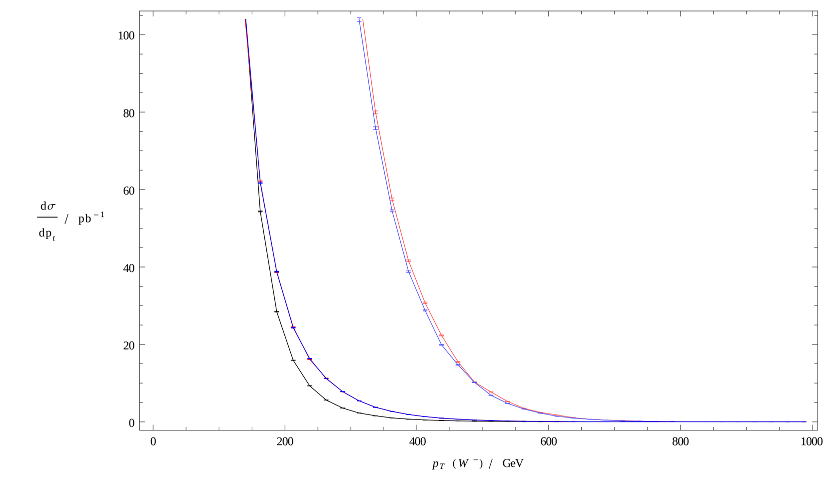

Figure 2: No real Gluon emission considered!

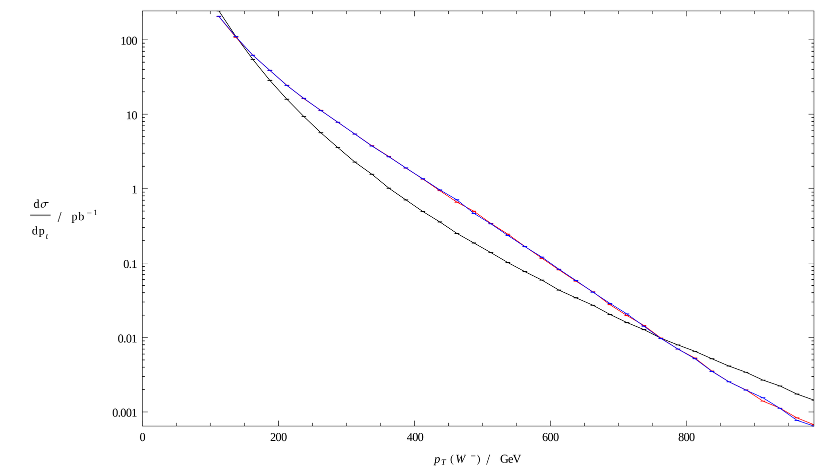

Figure 3: No real infrared divergence

- $pp \to W^+ j$

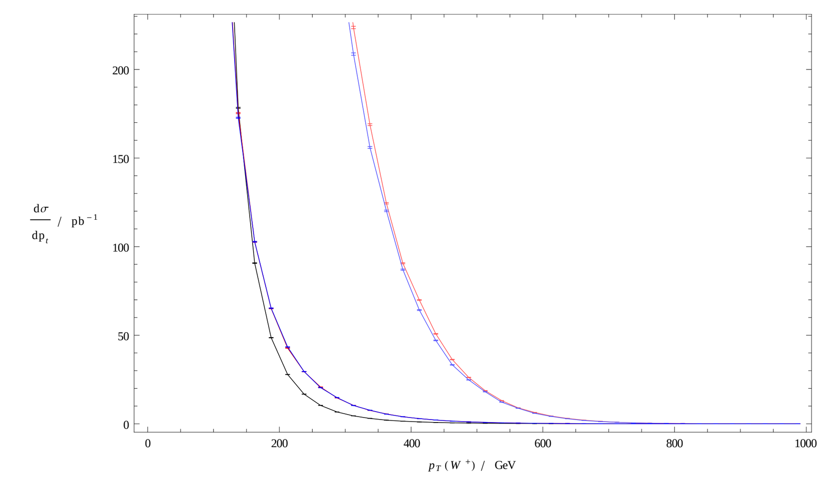

Figure 4: No real Gluon emission considered!

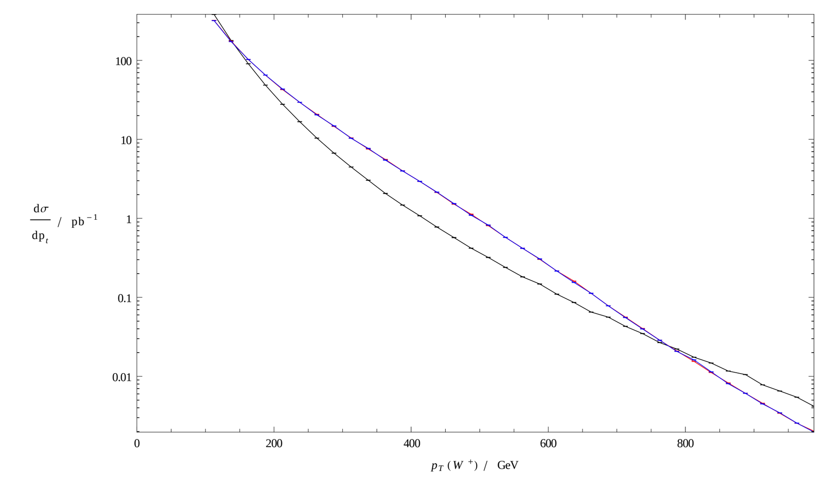

Figure 5: No real infrared divergence

- Combined

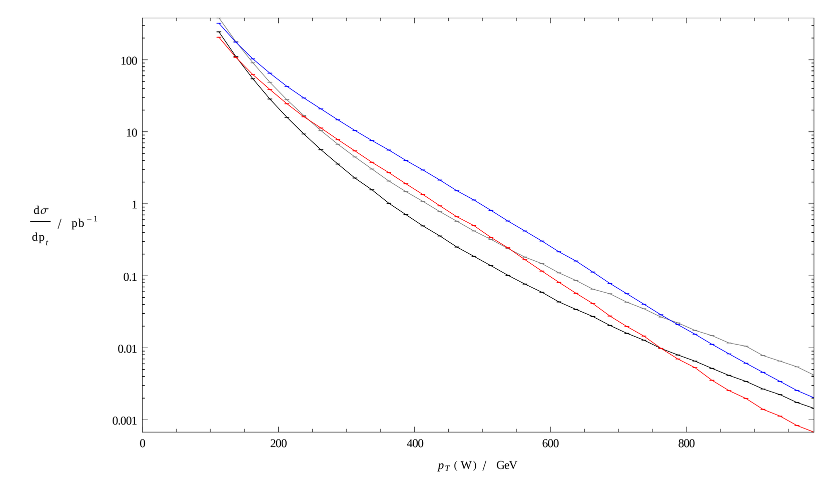

Figure 6: Black[Gray]: Tree $W^-[W^+]$, Red[Blue]: NLL w/o QCD $W^-[W^+]$

References

[1] J. -y. Chiu, F. Golf, R. Kelley and A. V. Manohar, Phys. Rev. Lett. **100** (2008) 021802 [arXiv:0709.2377 [hep-ph]].

[2] J. -y. Chiu, F. Golf, R. Kelley and A. V. Manohar, Phys. Rev. D **77** (2008) 053004 [arXiv:0712.0396 [hep-ph]].

[3] J. -y. Chiu, A. Fuhrer, R. Kelley and A. V. Manohar, Phys. Rev. D **81** (2010) 014023 [arXiv:0909.0947 [hep-ph]].