NLO QCD and EW corrections to WW+jet production at LHC

李伟华
导师：马文淦
中国科学技术大学
July 24, 2015

Outline

- Introduction
- NLO QCD and EW corrections to WW+jet production
    1. the choice of CKM matrix
    2. quark-to-photon fragmentation function
    3. small Gram determinant problem
- Spin-correlated decay of W boson
- Summary

Introduction

- WW+jet production at LHC can be used to determine the gauge boson couplings
- This process is an important background of new physics
- Significant EW Sudakov effect at high energies

- Current status of WW+jet production

NLO QCD corrections have been calculated in the following papers,

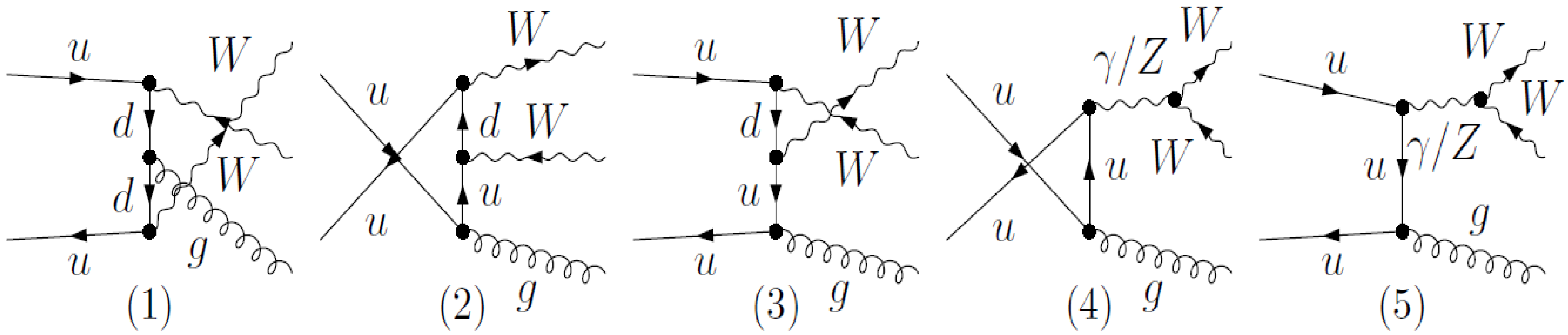
S. Dittmaier, S. Kallweit, and P. Uwer, Phys. Rev. Lett. 100, 062003 (2008).

S. Dittmaier, S. Kallweit, and P. Uwer, Nucl. Phys. **B826**, 18 (2010).

J.M. Campbell, R.K. Ellis, and G. Zanderighi, JHEP 12 (2007) 056.

The NLO EW correction have not been calculated so far!

NLO QCD and EW corrections to WW+jet production



- $\sigma_{NLO} = \boldsymbol{\sigma_{tree}} + \Delta\sigma_{virtual} + \Delta\sigma_{real} + \Delta\sigma_{PDF}$
- two cutoff phase space slicing (TCPSS) method
- G_F-scheme for the calculation of EW corrections

1. The Choice of CKM Matrix

- The fist and second generation quarks do not mix with the third generation

- At LO and EW NLO, due to the unitarity of CKM matrix, the amplitude is independent with CKM matrix.

- At NLO QCD, only part of processes qq->WWqq depends on the explicit entries of the CKM matrix

2. Quark-to-photon fragmentation function

- At QCD NLO, to define collinear-safe observables, the final state jets should be combined by certain jet algorithm.

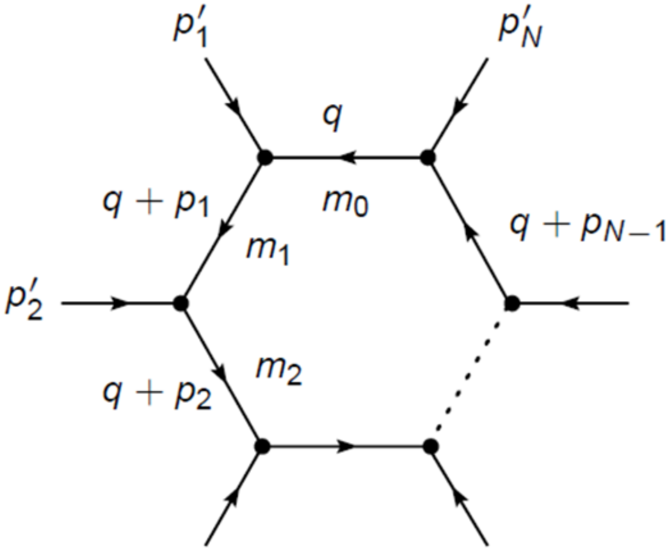
- At EW NLO, the final state jet and photon should also be combined.

  1. Combination of g+γ is not infrared (IR) safe when $E_g \to 0$!!

  2. To solve problem(1), cut on photon energy fraction Z_γ inside a jet.

  3. Combination of q+γ is not IR safe, quark-to-photon fragmentation function is needed to cancel the remained collinear divergence.

3. Small Gram determinant problem



N-point rank-M integral:

$$T^{N}_{\mu_1 \dots \mu_M} = \frac{(2\pi\mu)^{4-D}}{i\pi^2} \int d^D q \, \frac{q_{\mu_1} \dots q_{\mu_M}}{D_1 \dots D_{N-1}}$$

Where $D_i = ((q + p_i)^2 - m_i^2)$

reduced to **scalar integrals** recursively
(Passarino–Veltman method)

In Passarino–Veltman method, the rank-M tensor integral includes the tensor coefficients of the form:

$$T^N_{j_1 \dots j_M} \sim \frac{N(p,m)}{(detG_N)^M}$$

$$G_N = \begin{pmatrix} 2p_1p_1 & \cdots & 2p_1p_{N-1} \\ \vdots & \ddots & \vdots \\ 2p_{N-1}p_1 & \cdots & 2p_{N-1}p_{N-1} \end{pmatrix}$$

vanish $detG_N$,regular $T^N_{j_1 \dots j_M}$

↓

large number cancelations in $N(p,m)$

↓

numerical instability

We developed the library **LoopTools-2.8**, which will use **quadruple precision** automatically when $\det(G_3)$ is small enough ,i.e.

$$\frac{\det(G_3)}{(2p_{max}^2)^3} < 10^{-5}$$

Then any $N \leq 5, M \leq 4$ loop integrals can be calculated numerically and stably.

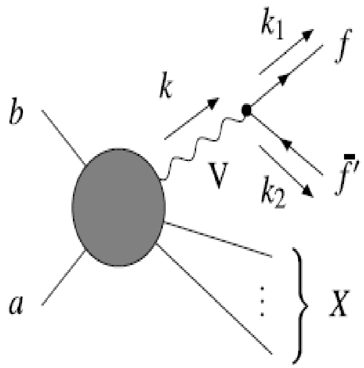
Spin-correlated decay of W boson

Method 1

$$\sigma_{ab\to VX\to f\bar{f}'X} = \frac{1}{2s_{ab}}\int d\Phi_{f\bar{f}'X}\left|\mathcal{M}_{ab\to VX\to f\bar{f}'X}\right|^2$$

$$\sim \frac{1}{2s_{ab}}\int d\Phi_{VX}\sum_{\lambda,\lambda'=0,\pm1}\mathcal{M}_{ab\to VX}(\lambda')^*\,\mathcal{M}_{ab\to VX}(\lambda)$$

$$\times\frac{1}{2M_V\Gamma_V}\int d\Phi_{f\bar{f}'}\left(\hat{k}_1,\hat{k}_2\right)\mathcal{M}_{V\to f\bar{f}'}(\lambda')^*\mathcal{M}_{V\to f\bar{f}'}(\lambda)$$



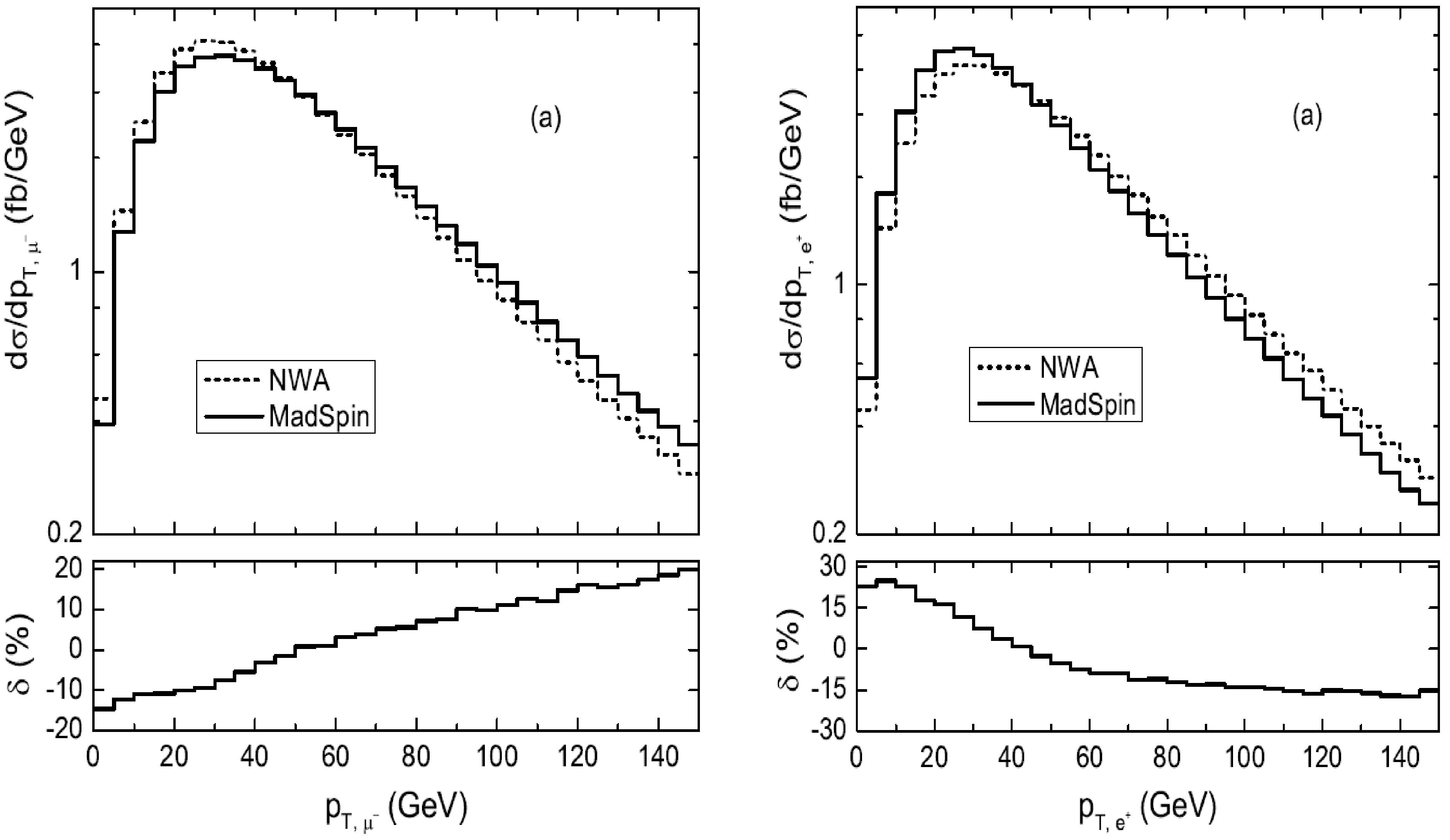
- Method 2

  MadSpin (part of MadGraph5_aMC@NLO)

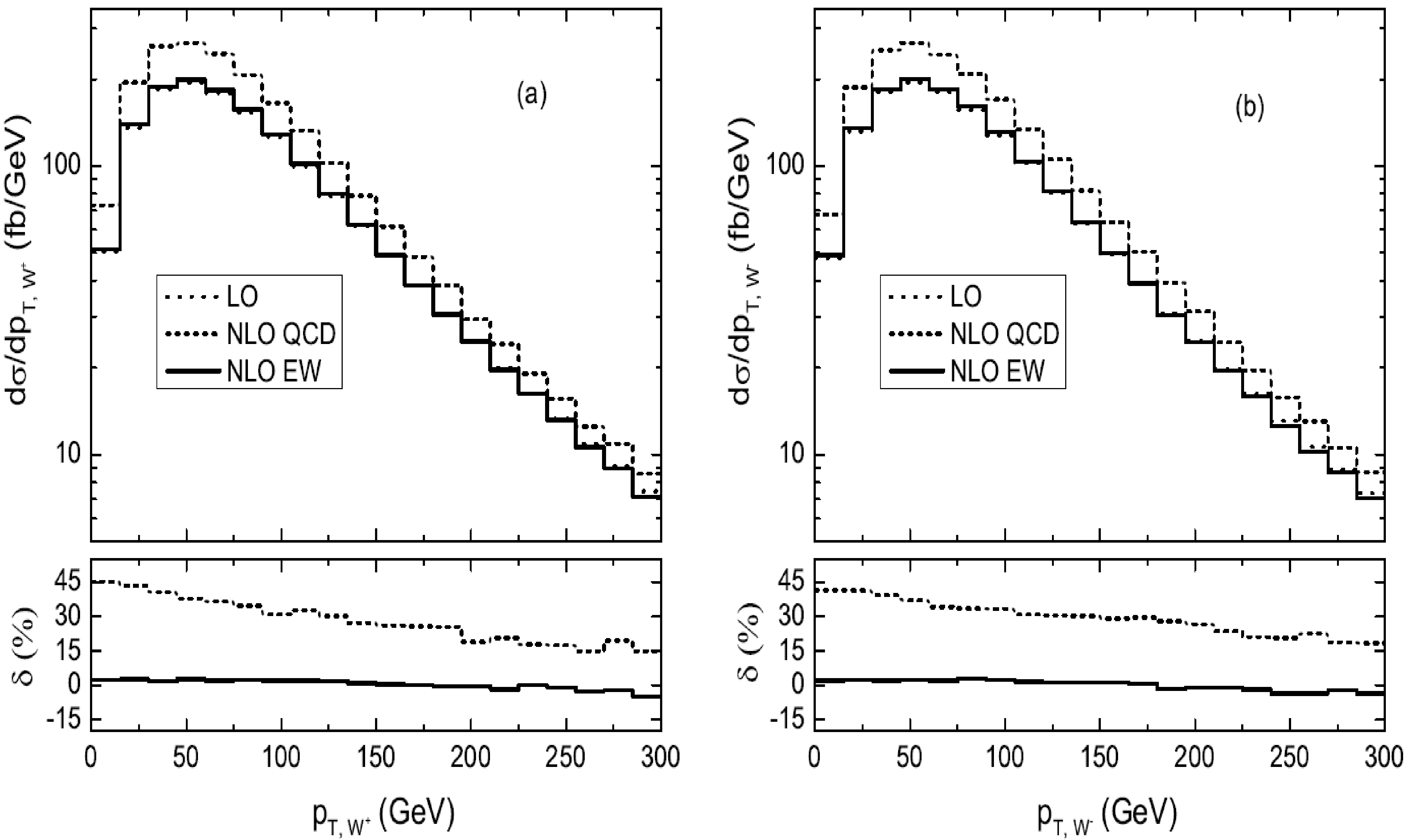
  use an unweighting procedure

S. Frixione, E. Laenen, P. Motylinski, and B.R. Webber, JHEP04 (2007) 081.

P. Artoisenet, R. Frederix, O. Mattelaer, and R. Rietkerk, JHEP03 (2013) 015.



(a)
NWA
MadSpin
$d\sigma/dp_{T,\mu^-}$ (fb/GeV)
δ (%)
p_{T,μ^-} (GeV)
(a)
NWA
MadSpin
$d\sigma/dp_{T,e^+}$ (fb/GeV)
δ (%)
p_{T,e^+} (GeV)



(a)
(b)
dσ/dp_{T, W+} (fb/GeV)
dσ/dp_{T, W-} (fb/GeV)
LO
NLO QCD
NLO EW
δ (%)
p_{T, W+} (GeV)
p_{T, W-} (GeV)

Summary

- We present the complete NLO QCD and EW corrections to WW+jet production at LHC.
- We use the quark-to-photon fragmentation function to define IR safe observables, and use the quadruple floating number to deal with the small Gram determinant problem.
- We use the MadSpin program to include the spin-correlation of W-boson decay.