Z-boson pair + 1-jet production at NLO QCD

Nikolas Kauer

Centre for Particle Physics

Royal Holloway, University of London

in collaboration with

T. Binoth, S. Karg and G. Sanguinetti

Physics at TeV Colliders Workshop

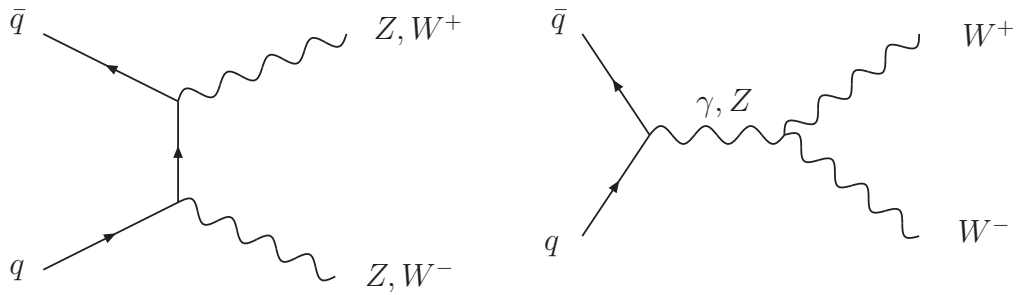
Les Houches

June 10, 2009

Outline

- Vector-boson pair (+ jets) production
- Importance for LHC physics
- NLO QCD calculation for ZZ + jet
- Partial results
- Summary

Predictions for vector-boson pair production



- $e^+e^-, pp, p\bar{p} \to ZZ, WW$ at LO (and decays)

Brown, Mikaelian (1979); Stirling, Kleiss, S. Ellis (1985); Gunion, Kunszt (1986); Muta, Najima, Wakaizumi (1986); Berends, Kleiss, Pittau (1994) [$e^+e^- \to f_1\bar{f}_2 f_3\bar{f}_4$ at LO]

- $pp, p\bar{p} \to ZZ, WW, WZ$ at NLO QCD (with leptonic decays)

Ohnemus (1991); Mele, Nason, Ridolfi (1991); Ohnemus, Owens (1991); Frixione (1993); Ohnemus (1994); Dixon, Kunszt, Signer (1998, 1999); Campbell, K. Ellis (1999) [$pp, p\bar{p} \to \ell\bar{\ell}\ell'\bar{\ell}'$ at NLO QCD]

- $gg \to ZZ, WW$ (with leptonic decays), (1-loop)^2 NNLO QCD correction

Dicus, Kao, Repko (1987); Glover, van der Bij (1989); Kao, Dicus (1991); Matsuura, v.d. Bij (1991); Zecher, Matsuura, v.d. Bij (1994); Dührssen, Jakobs, v.d. Bij, Marquard (2005); Binoth, Ciccolini, NK, Krämer (2005, 2006); Binoth, NK, Mertsch (2008)

- 2-loop-virtual–Born interference for $q\bar{q} \to WW \longrightarrow$ NNLO QCD correction

Chachamis, Czakon, Eiras (2008)

Predictions for vector-boson pair + jets production

- $pp, p\bar{p} \to WW$ + jet at NLO QCD (with leptonic decays)

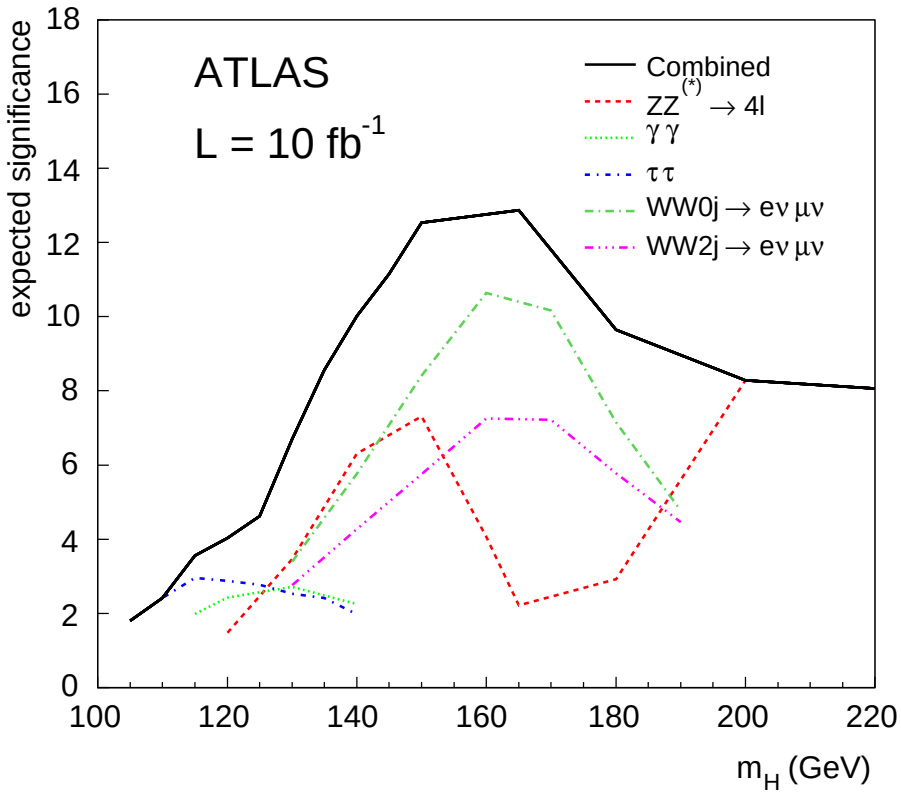
Dittmaier, Kallweit, Uwer (2007); Campbell, K. Ellis, Zanderighi (2007)

- Vector boson fusion contribution to $pp \to WW$ + 2 jets, ZZ + 2 jets, WZ + 2 jets at NLO QCD with leptonic decays

B. Jäger, Oleari, Zeppenfeld (2006); Bozzi, B. Jäger, Oleari, Zeppenfeld (2007)

Importance for LHC physics

- $H \to VV$ searches: dominant irreducible background is VV (+ jets) $\quad VV = ZZ, WW$
- background to new physics searches with multi-lepton (+ jets) signatures (SUSY, ...)



High activity level on experimental side!

$\longrightarrow$ strong interest in improved theoretical predictions

ATLAS: Dührssen, Mellado, Mir, Quayle, Rebuzzi, Rosati, Solfaroli, ... **CMS**: Davatz, Dissertori, Drollinger, Giolo-Nicollerat, Giordano, Lowette, Nikitenko, Stöckli, Zanetti, ...

NLO QCD calculation for ZZ + jet

Virtual correction: GOLEM tensor reduction approach

Binoth, Heinrich (2004); Binoth, Guillet, Heinrich, Pilon, Schubert (2005)

6 distinct subprocesses (u,d sep.), ~ 200 Feynman graphs, 36 helicity combinations, 't Hooft-Veltman and $\overline{\text{MS}}$ schemes

$\longrightarrow$ LoopFest talk by S. Karg

$2 \to 3$ status: complete and cross checked except for collinear term

Real correction: Catani-Seymour dipole subtraction

Catani, Seymour (1996); Catani, Dittmaier, Seymour, Trocsanyi (2002)

$p_1 p_2 \to ZZ p_3 p_4$: 21 subprocesses, on avg. 6 dipoles per subprocess, ~ 1200 Feynman graphs in total

Amplitude and subtraction terms:
MadGraph Stelzer et al. (1994), MadDipole Frederix, Gehrmann, Greiner (2008)
Cross check: Sherpa dipoles Gleisberg, Krauss (2007) ✓ and Helac dipoles Czakon, Papadopoulos, Worek (2009) ✓

$2 \to 4$ status: complete, 9 digit agreement for $|\mathcal{M}_R|^2$ and all dipoles ✓, not yet cross checked: multi-channel PS

Partial results

Input parameters/settings:

$N_F = 5$ ($M_q = 0$)

$M_Z = 91.188$ GeV

$\alpha(M_Z) = 0.00755391226$

PDF: CTEQ6L1 (LO), CTEQ6M (NLO) Pumplin et al. (2002)

$\sin^2 \theta_W = 0.222247$

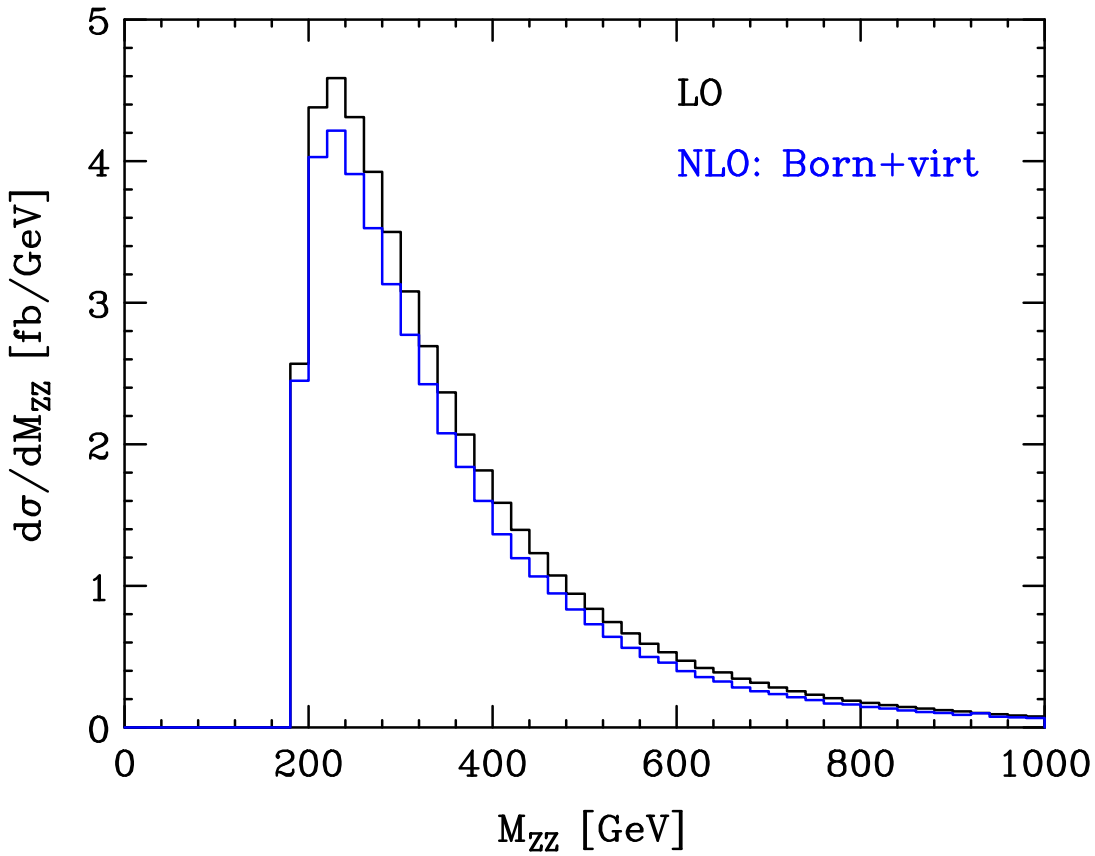
central scale choice: $\mu_R = \mu_F = M_Z$

$\sigma(pp \to ZZj)$ [fb]			
$\mu = \mu_R = \mu_F$	$M_Z/2$	M_Z	$2M_Z$
LO	1156	1006	874
NLO: Born+virt	836	899	909
NLO: real	117	88	67

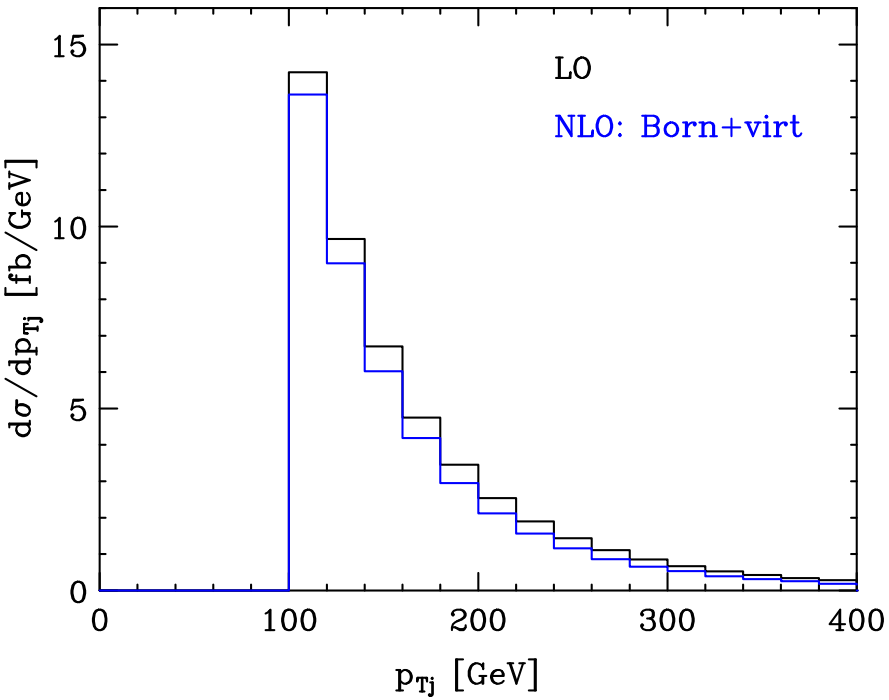
cuts: $p_{T3,4} > 100$ GeV, $\Delta R_{34} > 0.4$

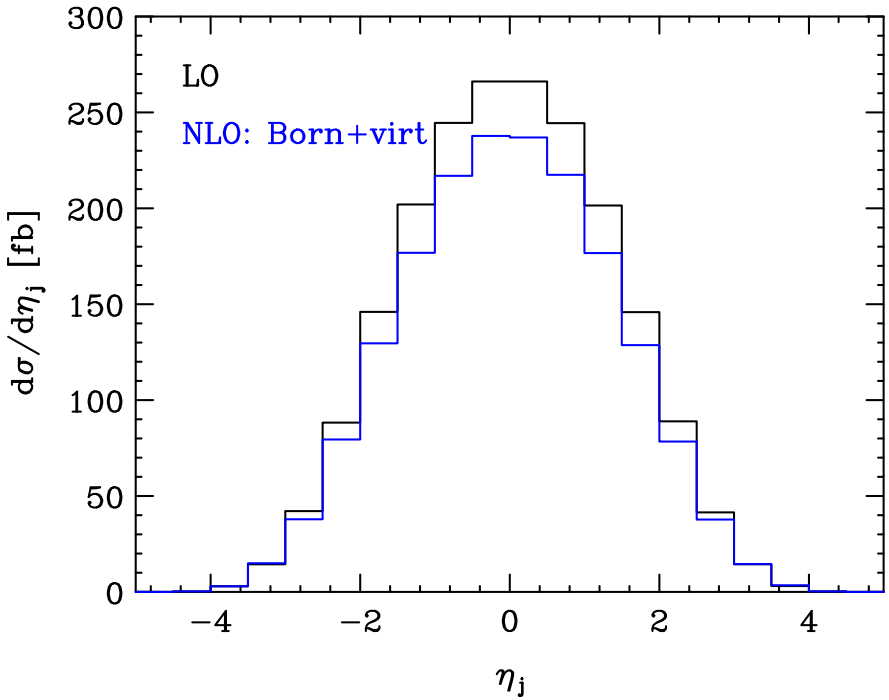
Distributions

ZZ invariant mass distribution

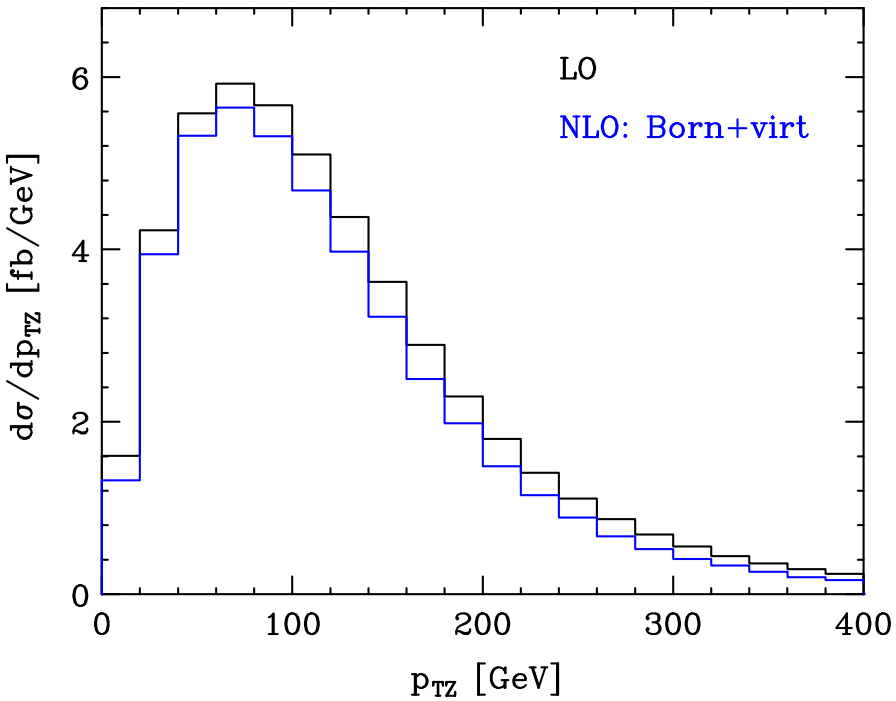


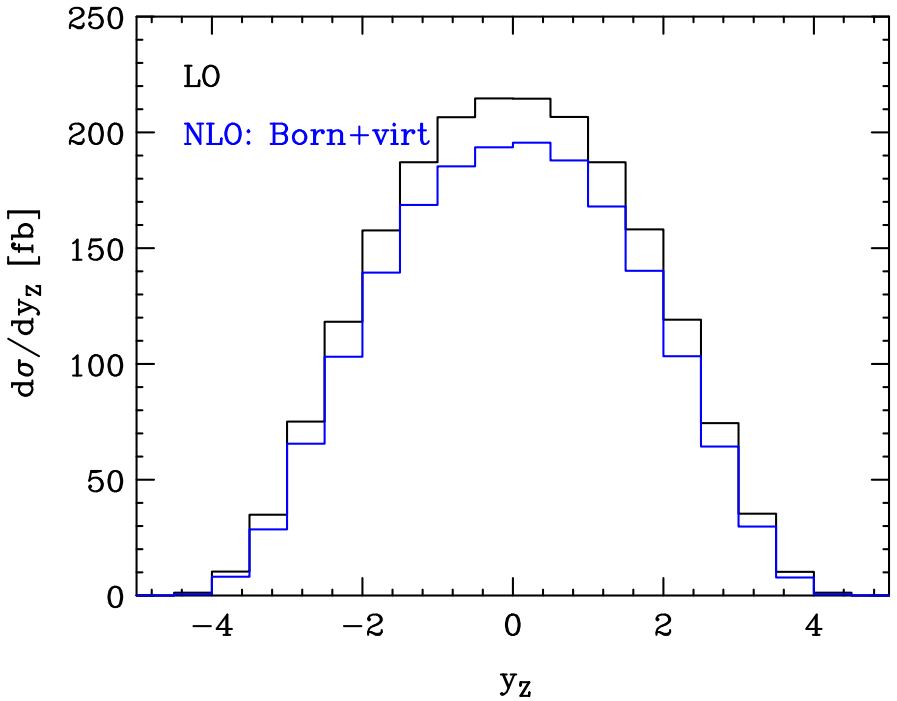
p_T(jet) and jet pseudorapidity distributions



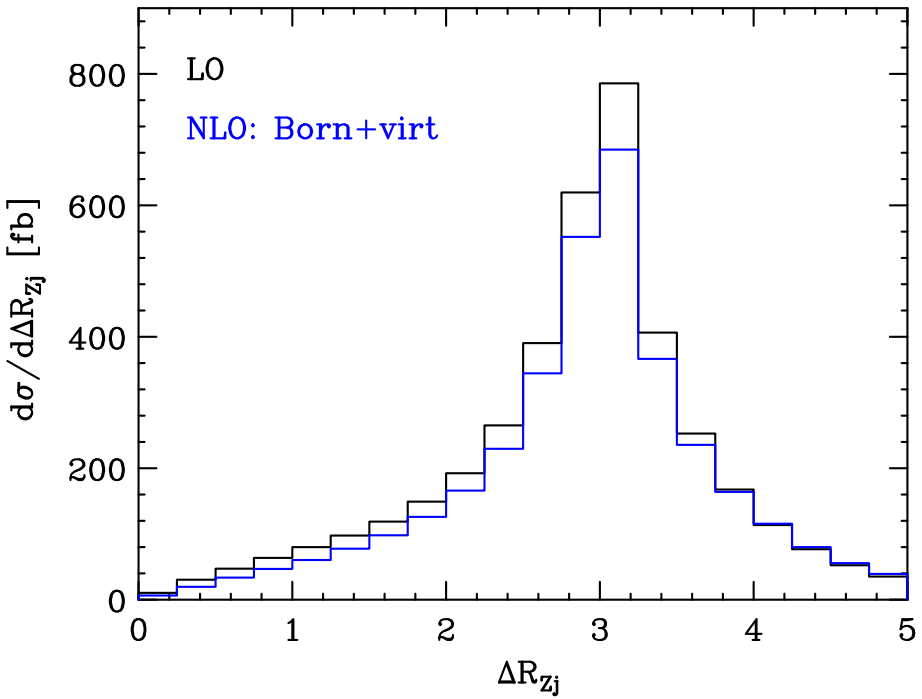


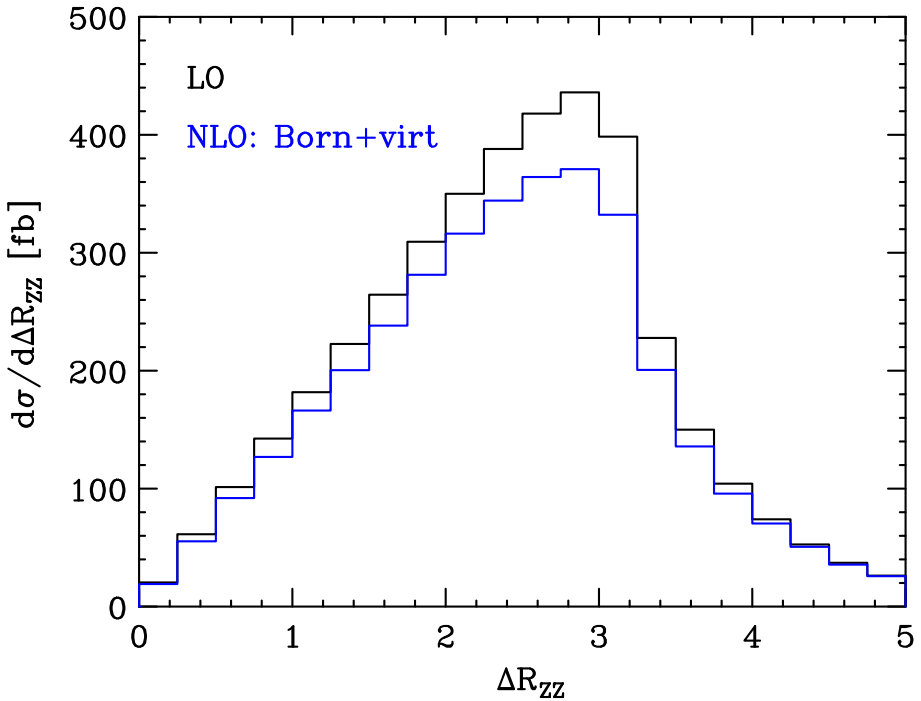
$p_T(Z)$ and Z rapidity distributions





$\Delta R(Z, \text{jet})$ and $\Delta R(Z, Z)$ distributions





Summary

- $pp \to ZZ$ + jet @ NLO needed to predict ZZ (+ jet) LHC backgrounds and control theoretical uncertainty
- $pp \to ZZ$ + jet @ NLO is component of $pp \to ZZ$ @ NNLO
- NLO for $2 \to 3$ hadron collider processes now clearly feasible, but still tedious
- our calculation is well advanced
- working hard to finish it