Vector boson scattering with WHIZARD and SHERPA

Ulrike Schnoor
Michael Kobel, Philipp Anger
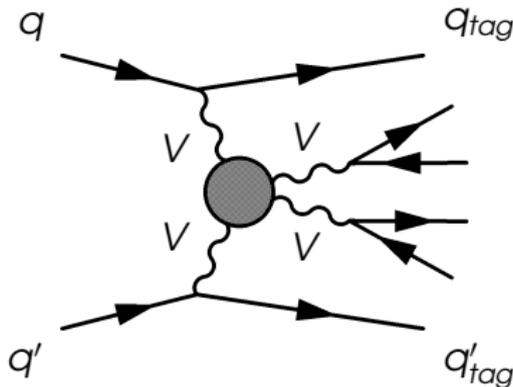IKTP TU DRESDEN

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Vector Boson Scattering

- Signal $qq' \rightarrow q_{tag}q'_{tag}VV$ (V = W or Z)

- "blob" contains all **VV scattering** diagrams
- same final state also possible via many non-VV-scattering channels
- meaningful signal definition: gauge invariantly separable subprocess containing the scattering diagrams
- Kinematic VBS cuts suppress non-VV-scattering contributions

Definition of Sub-Processes: EW, QCD, EWQCD

Signal = purely EW processes: $\alpha_s = 0 \to \mathcal{O}(\alpha_w^4)$

EW w/ VBS topology   **+ EW w/o VBS topology**
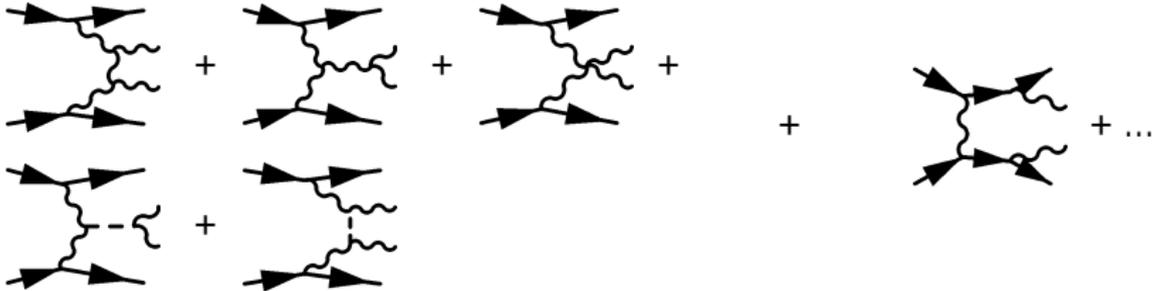
triple/quartic gauge vertices + Higgs channels   + other EW processes

Signal+BG = EWQCD: $\alpha_s \neq 0 \to \mathcal{O}(\alpha_w^2)\mathcal{O}(\alpha_s^2) \oplus \mathcal{O}(\alpha_w^4)$

- EWQCD = EW + QCD
  (separate production of QCD not possible in WHIZARD)
- QCD to be reduced by topological cuts

3 / 13

Monte Carlo Generation

Generate events using WHIZARD 2.0 and SHERPA 1.3.1 with the following settings

WHIZARD : http://projects.hepforge.org/whizard/
SHERPA : http://www.sherpa-mc.de/

Generator level cuts and settings

- Kinematic cuts on generator level
  - charged leptons $p_T > 15$ GeV
  - jets $p_T > 15$ GeV
  - leptons invariant mass $M_{ll} > 20$ GeV to prevent $\gamma^* \to ll$ divergences
  - $\Delta R(j,j) > 1.0$ between the jets
- PDF set: cteq6l

Scales

- factorization, renormalization scale $\mu_F = \mu_R = M_Z$
- fixed scales to ensure consistency between the generators

Monte Carlo Generation

Electroweak parameters and Higgs properties

Electroweak coupling affects cross sections of EW ($\sim \alpha_W^4$) and QCD($\sim \alpha_W^2$)

G_F **scheme** (WHIZARD default)

ensures unitarity in VBS in LO electroweak

$$\alpha_{QED} = \frac{e^2}{4\pi}$$

with $e = 2 \sin\theta_W \frac{m_W}{v}$; $\sin^2\theta_W = 1 - \frac{m_W^2}{m_Z^2}$; $v = \frac{1}{\sqrt{\sqrt{2}G_F}}$

- $\Rightarrow \alpha_{QED}$ = 1/132.5049

Higgs mass and width affect cross sections and kinematic distributions

- Higgs mass for validation samples: $m_H = 120$ GeV
- Width of Higgs resonance highly depends on Higgs mass
  $\rightarrow$ use HDECAY to calculate corresponding width

Discrepancies between the generators

Investigation of exclusive Processes

Process	VV	EW		EWQCD	
		SHERPA	WHIZARD	SHERPA	WHIZARD
$uu \to dd e^+ \mu^+ \nu_e \nu_\mu$	W^+W^+	0.69	0.71	2.0	2.0
$ud \to ud e^+ e^- \nu_e \bar{\nu}_e$	W^+W^-/ZZ	1.07	4.67	4.5	4.5
$ud \to ud e^+ \mu^- \nu_e \bar{\nu}_\mu$	W^+W^-	1.0	0.7	4.2	4.0
$ud \to ud e^+ e^- \nu_\mu \bar{\nu}_\mu$	ZZ	0.07	0.07	0.27	0.27

(cross-sections in fb)

- reason found after Paris meeting
- off-shell $H/Z \to WW^*$ (and $H \to ZZ^*$) missing in WHIZARD 2.0.6 phase space integration

Distribution of $l\nu$ invariant mass:
(for $ud \to ud e^+ e^- \nu_e \bar{\nu}_e$)

- Higgs mass $m_H = 120$ GeV
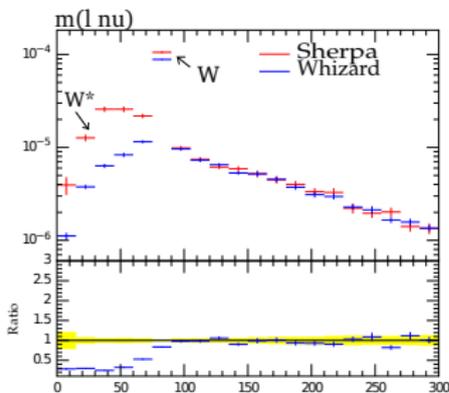
New version: WHIZARD 2.0.7 (since 19.03.2012)
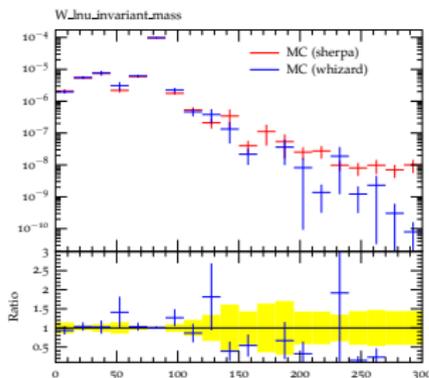
- new version WHIZARD 2.0.7 released: problem is **fixed**
- off-shell $H/Z \to WW^*$ (and $H \to ZZ^*$) found

on the left: Distribution of $l\nu$ invariant mass for $ud \to ude^+e^-\nu_e\bar{\nu}_e$ with WHIZARD version **2.0.7**

- 2.0.6: integration unstable; (too) many iterations in phase space integration needed for correct result
- 2.0.7: fewer iterations sufficient

Example: Cross section vs. Higgs width for $ud \to ud\mathbf{H} \to ude^+\nu_e\mu^-\bar{\nu}_\mu$ for different numbers of iterations
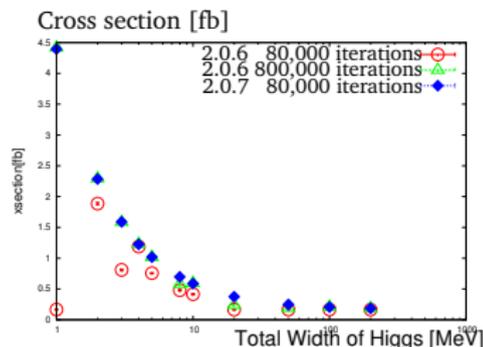
New WHIZARD version 2.0.7: very good agreement with SHERPA

Investigation of exclusive Processes

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$ud \to ude^+e^-\nu_\mu\bar{\nu}_\mu$	ZZ	0.07	0.07	0.27	0.27

(cross-sections in fb; Generation errors < 2 %)

- Opposite sign processes also under control now

- next slides: distributions for inclusive same sign process $pp \to jjl^+l'^+\nu_l\nu_{l'}$

  □ same generator settings as above, except:
  □ pdfset = cteq6l1; $\mu = \mu_F = \mu_R = 2m_W$

VBS Event kinematics
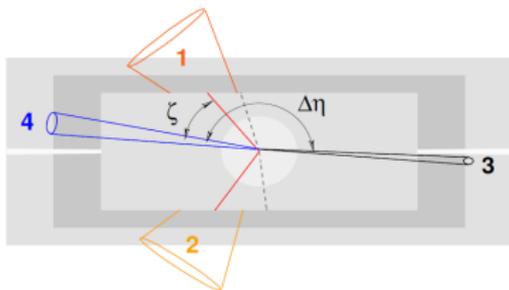
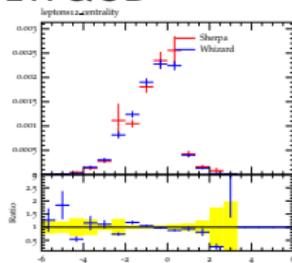- forward tagging jets
- central W decay products

Lepton centrality ζ

$\zeta := \min\{\min\{\eta_{l1}, \eta_{l2}\} - \min\{\eta_{j1}, \eta_{j2}\}, \max\{\eta_{j1}, \eta_{j2}\} - \max\{\eta_{l1}, \eta_{l2}\}\}$
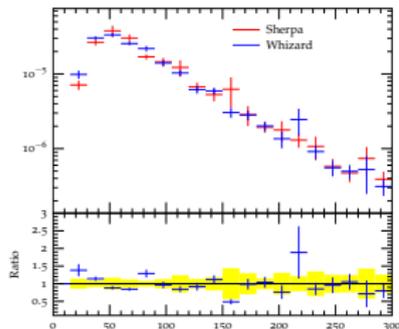
EW
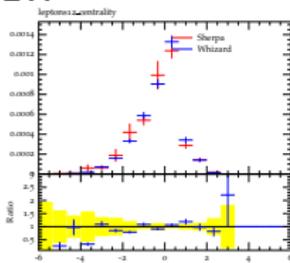
EWQCD

- both leptons in η between tagging jets: $\zeta > 0$ (VBS topology)
- one or both leptons at larger $|\eta|$ than closest jet: $\zeta < 0$
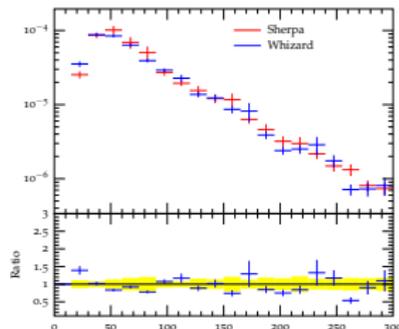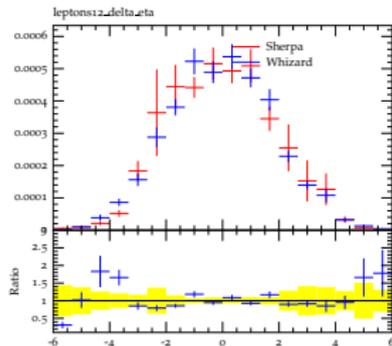- EW tends to have more positive ζ than EWQCD

Comparison of kinematic distributions

Same sign process $pp \rightarrow jjl^{\pm}\nu l^{\pm}\nu$

EW

p_T of the first lepton

EWQCD

EW
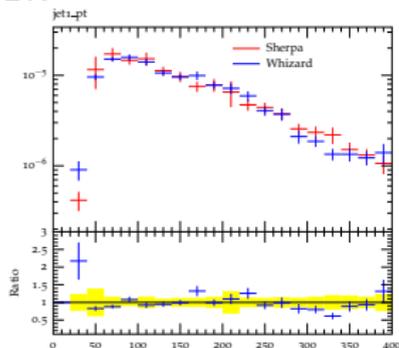
p_T of the first jet

EWQCD
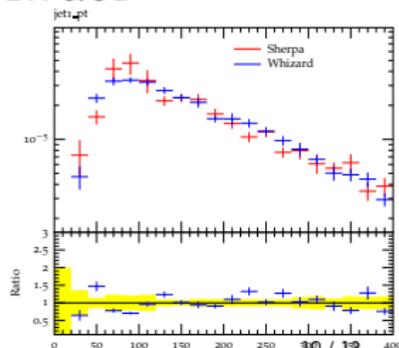
Ulrike Schnoor: Vector boson scattering with WHIZARD and SHERPA

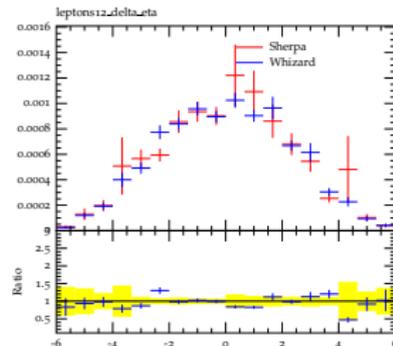# Comparison of kinematic distributions

Same sign process $pp \to jjl^{\pm}\nu l^{\pm}\nu$

EW

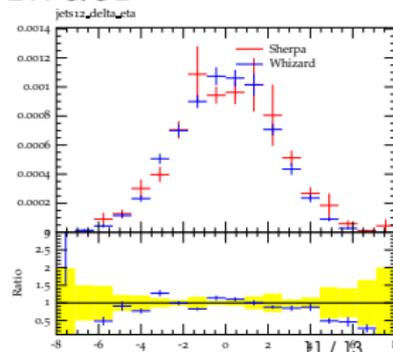
EWQCD

$\Delta\eta$ of the leptons

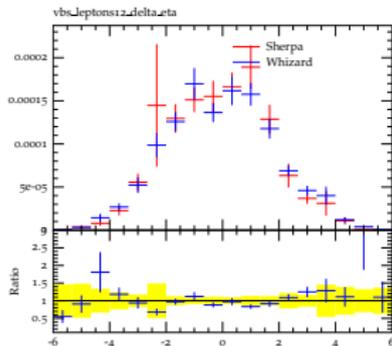EW
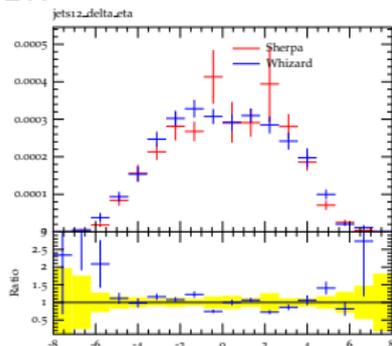
EWQCD

$\Delta\eta$ of the jets

Comparison of kinematic distributions

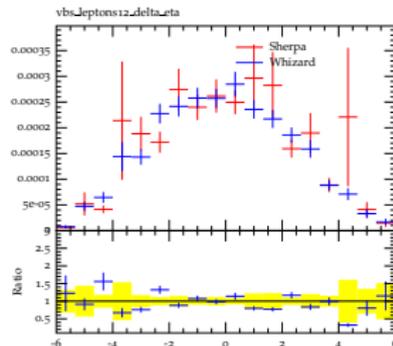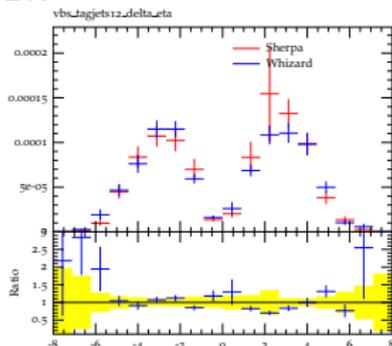**Same sign process** $pp \rightarrow jjl^{\pm}\nu l^{\pm}\nu$

EW

after opposite hemisphere cut:

$\eta_{j1} \cdot \eta_{j2} < 0$
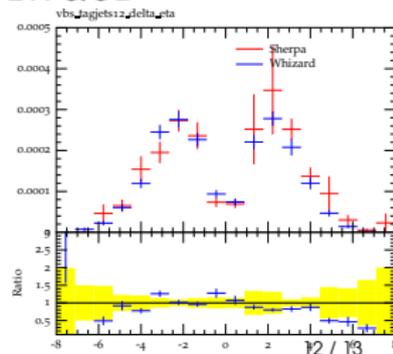
$\Delta\eta$ of the leptons

EWQCD

EW

after opposite hemisphere cut:

$\eta_{j1} \cdot \eta_{j2} < 0$

$\Delta\eta$ of the jets

EWQCD

Summary and Outlook

- Monte Carlo Generators WHIZARD and SHERPA validated for LO Vector Boson Scattering
- Problem finding resonance in $H/Z \to WW^*$ (and $H \to ZZ^*$) **solved in** WHIZARD **2.0.7**
- ATLAS event generation plans for data analysis in NLO
  - QCD: SHERPA (only real) & POWHEGBox (real and virtual)
  - EW: SHERPA (only real) & VBF@NLO (real and virtual)
  - BSM resonances: WHIZARD (at LO)
- VBS: important channel **to be measured at the LHC** to probe EWSB