Anomalous Quartic Couplings in Vector Boson Scattering in ATLAS

Jan Schumacher[1], Michael Mertens[2], Michael Kobel[1]
jschumac@physik.uni-bonn.de

[1]Institut für Kern- und Teilchenphysik der Technischen Universität Dresden

[2]Physikalisches Institut der Universität Bonn

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Outline

Motivation – What if there is no SM Higgs?

Assumption: No SM Higgs

- LHC expected to find the SM Higgs boson if it exists
- Assume we see no resonance
- actual EWSB sector possibly beyond our (energy) reach

What needs to be done?

- need another electroweak symmetry breaking (EWSB) mechanism
- need something to unitarize *WW* scattering

Approach here

- generic search for new physics
- parametrize our ignorance with a low energy effective theory
- expect effects vector boson scattering (VBS)

Constructing the Effective Lagrangian

(see e.g. W. Kilian hep-ph/0303015)

Plan

- start using only SM fields
- minimal set necessary to make weak interaction symmetries manifest

Anomalous Couplings

- introduce additional terms to make theory finite at next to leading order
- eleven at dimension four $\mathcal{L}_{1-11}$
- one at dimension two $\mathcal{L}'_{2(W)}$
- higher orders suppressed by factors $O\left(1/16\pi^2\right)$

Anomalous Quartic Couplings α_4, α_5

Assume Custodial Symmetry

$$\frac{M_W^2}{M_Z^2 c_w^2} = \rho,\ \rho \approx 1$$

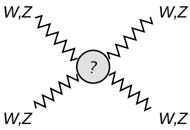
- accidental symmetry
- well fulfilled

$\longrightarrow$ forbid of $\mathcal{L}_{6-11}$ and $\mathcal{L}'_{2(W)}$

Consider what VBS is sensitive to

$$\mathcal{L}_4 = \alpha_4 \left(\mathrm{tr}\left[V_\mu V_\nu\right]\right)^2$$
$$\mathcal{L}_5 = \alpha_5 \left(\mathrm{tr}\left[V_\mu V^\mu\right]\right)^2$$

where V_μ: longitudinal gauge bosons



Monte Carlo Study by M. Mertens

Disclaimer

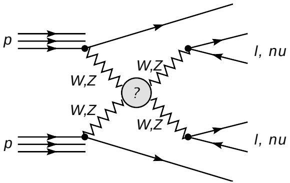
These are not official ATLAS results but findings from Michael Merten's diploma thesis. Please do not quote numbers or plots. All mistakes are mine.

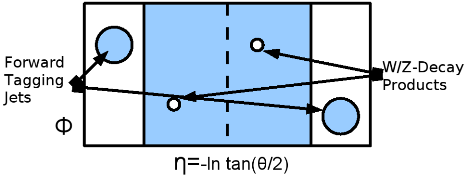
A note is in preparation

- M. Mertens (Bonn)
- J. Große-Knetter (Bonn)
- M. Schumacher (Siegen)
- M. Kobel (Dresden)

Vector Boson Scattering (VBS) Signature

Process



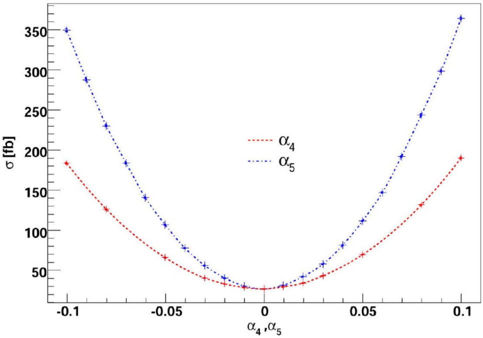


Features

- leptons (here: μ's and ν_μ's, including $\tau \rightarrow \mu\nu_\mu\nu_\tau$)
- missing energy (ν's)
- tagging jets: high p_T, large η-separation
- *WZ* decay products between tagging jets
- little QCD activity: no hard jets in central region

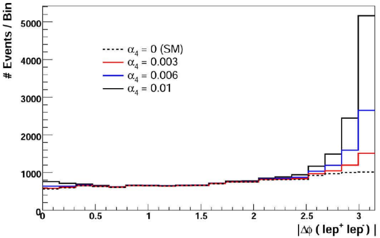
$\alpha_{4,5}$ Sensitive Observables I

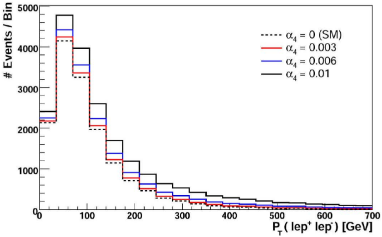
Signal generated using WHIZARD
cross section quadratically dependent on ac's



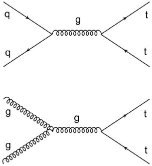
$\alpha_{4,5}$ Sensitive Observables II

polarization states affected by ac's $\rightarrow$ kinematic variables affected, e.g. angular distributions



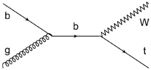


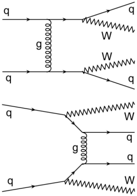
Background processes



ttbar (Pythia)
$t\bar{t} \rightarrow WbWb \rightarrow$ jet jet$\mu^-\bar{\nu}_\mu\mu^+\nu_{mu}$

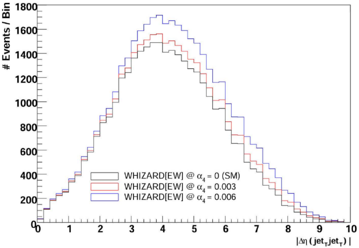
Wt (TopRex)
$Wt \rightarrow WWb \rightarrow$
jet$\mu^-\bar{\nu}_\mu\mu^+\nu_\mu +$ one fake jet

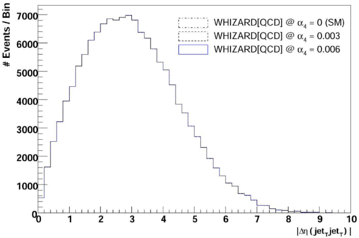




WHIZARD[QCD] irreducible QCD background automatically generated by WHIZARD

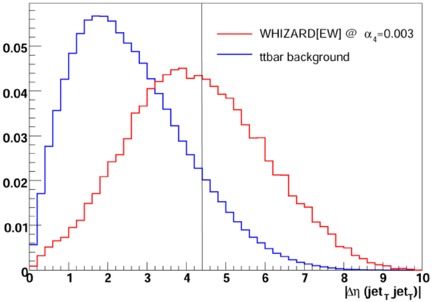
QCD Background from WHIZARD





- irreducible QCD background (WHIZARD[QCD]) contains no information about ac's
  $\rightarrow$ try to cut it away as well
- how to disentangle it?
  - generate events with $\alpha_s = 0$ =: WHIZARD[EW]
  - define: WHIZARD[QCD] := WHIZARD[QCD+EW] - WHIZARD[EW]
  - crosscheck no ac dependence in WHIZARD[QCD]

Strategy for Cut Optimization



- quartic couplings only one subprocess amongst thousands
- try to measure small $\alpha_{4,5} \rightarrow$ interference region with SM
- optimize cuts using signal at $\alpha_4 = 0.003$

Cuts Used

- *Cut 0*: two leptons, two tagging jet candidates, trigger cuts
- *Cut 1*: b jet veto
- *Cut 2a*: $\eta^{\text{min}}_{\text{jet}_T} < \eta_{\text{lep}_{1,2}} < \eta^{\text{max}}_{\text{jet}_T}$
- *Cut 2b*: $\left|\Delta\eta\left(\text{jet}_T\text{jet}_T\right)\right| > 4.4$
- *Cut 3*: $M\left(\text{jet}_T\text{jet}_T\right) > 1200\text{GeV}$
- *Cut 4*: $P_T\left(\text{mini jet}\right) < 26\text{GeV}$
- *Cut 5*: $E\left(\text{jet}_{T_1}\right) > 600\text{GeV}$, $E\left(\text{jet}_{T_2}\right) > 330\text{GeV}$
- *Cut 6*: $P_T\left(\text{jet}_{T_1}\right) > 60\text{GeV}$, $P_T\left(\text{jet}_{T_2}\right) > 25\text{GeV}$
- NB: Few cuts on leptons

Results – Sensitivity Limits for $\mathcal{L}$ =100fb^{-1}

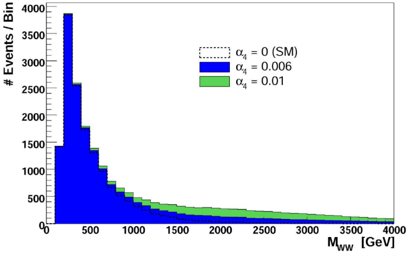
- using binned maximum likelihood
- variables
  - $\Delta\phi\,(\mathrm{lep}^{+}\mathrm{lep}^{-})$
  - $P_T\,(\mathrm{lep}^{+}\mathrm{lep}^{-})$
- fast ATLAS simulation (ATLFAST)
- no systematics studied

coupling	LHC(ATLAS) $\sqrt{s}$ = 14TeV, 100fb^{-1}	ILC $\sqrt{s}$ = 1TeV, 1000fb^{-1}
$\alpha_4\,(1\sigma+)$	0.0047	0.0087
$\alpha_4\,(1\sigma-)$	-0.0043	-0.0089
$\alpha_5\,(1\sigma+)$	0.0030	0.0069
$\alpha_5\,(1\sigma-)$	-0.0032	-0.0073

Comparing to ILC study by *Krstonosic & Mönig*, hep-ph/0508179

Simple Model not Unitarized

- unitarity violated at 1.2TeV
- we have a higher M_{WW} reach than expected



- a lot of WW-pairs heavier than theory is valid for
- cutting difficult and reduces significance
- $\longrightarrow$ need a unitarization scheme

Unitarization Schemes

- different unitarization schemes on the market
- popular ones: Pade, N/D, K-Matrix
- implement distinct features in the high energy limit
- Pade and N/D will generate new resonances
- K-Matrix:
  - project amplitudes $a(s)$ on the Argand circle

$$a_K(s) = a(s)\frac{1 + ia(s)}{1 + a(s)^2}$$

  - does not generate a new resonance (pushes it to ∞)
  - can be seen as a minimal approach
- $\rightarrow$ K-Matrix fits better to the initial assumtion: no resonances seen

Generators

- M. Merten's study done with WHIZARD
- WHIZARD does not have K-Matrix – will hopefully become available
- testing a modified version of PYTHIA from G. Azuelos
- Sherpa being investigated, but unconfirmed

Conclusion / Discussion

Conclusion

- $\alpha_{4,5}$ sensitivity is given
- need some kind of unitarization
- need generator support

Discussion

- Pro/Contra K-Matrix?
- Alternatives?

Thank You!