Vector Boson Scattering at the LHC

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10. October 2012

GEFÖRDERT VOM

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Outline

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Motivation

Theory

- vector boson scattering (VBS) is intimately related to nature of electroweak symmetry breaking (EWSB)
- mechanism of EWSB must regulate $\sigma(V_L V_L \to V_L V_L)$ at high energies
- VBS is sensitive to BSM physics, e.g. anomalous quartic gauge couplings, heavy resonances

Open quests

- VBS not yet observed experimentally

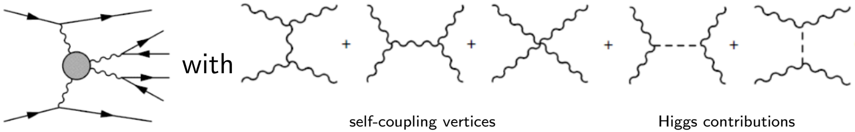
$\Rightarrow$ measure its cross section ($\Rightarrow$ limits on aQGC)

- Is the recently discovered boson the SM Higgs boson?

$\Rightarrow$ check its contribution to VBS

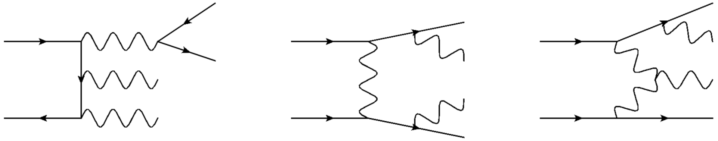
Vector Boson Scattering at the LHC

VBS diagrams



VBS final state is *VVjj*

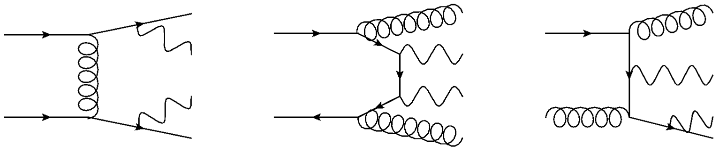
Other pure EW diagrams with same final state



all those diagrams contribute to the final state *VVjj* and are $\mathcal{O}(\alpha_W^4)$

Categorisation of processes with *VVjj* signature

Possible diagrams for *VVjj* final state with QCD vertices



Categories

- VBS and other EW diagrams are not completely separable in a gauge invariant way

$$\left.\begin{array}{c}\text{VBS}\\ \text{other EW}\end{array}\right\} = \mathcal{O}(\alpha_W^4) \quad \text{(referred to as EW processes)}$$

$$\text{QCD} = \mathcal{O}(\alpha_w^2 \alpha_s^2) \quad \text{(referred to as QCD processes)}$$

Why do we pick the same-sign $W^\pm W^\pm$ channel?

- LHC is a hadron collider $\Rightarrow$ consider only leptonic final states

$\Rightarrow$ 5 different final states

final state	VV	σ_{EW} [fb]	σ_{QCD} [fb]
$\ell^\pm \nu \ell'^\pm \nu' jj$	$W^\pm W^\pm$	21	20
$\ell^\mp \nu \ell'^\pm \nu' jj$	$W^\mp W^\pm$	96	1940
$\ell'^\pm \nu' \ell^\pm \ell^\mp jj$	$W^\pm Z$	16	502
$\ell^\pm \ell^\mp \nu \nu jj$	ZZ	5	116
$\ell^\pm \ell^\mp \ell'^\pm \ell'^\mp jj$	ZZ	1	40

- $W^\pm W^\pm$ has best σ_{EW} to σ_{QCD} ratio
- also small background from other SM processes
- $W^\pm Z$ also promising due to even smaller background from other SM processes

What are our goals?

Long-term goals

- establish first significant observation of VBS

$\Rightarrow$ will require combination of several channels

- measurement of σ_{EW}

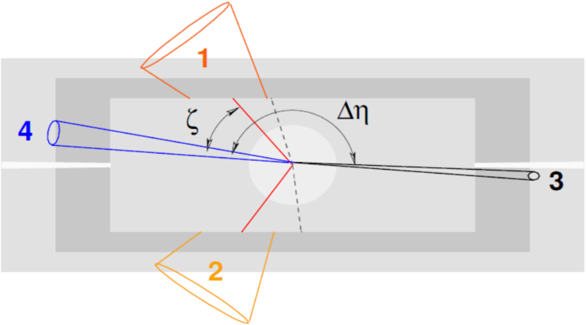
$\Rightarrow$ requires understanding of σ_{QCD} (and interference effects)

- setting limits on BSM physics (anomalous quartic gauge couplings)

Short-term (Moriond 2013)

- measurement of $\sigma_{\mathrm{EW+QCD}}$ in the channels $W^\pm W^\pm$ and $W^\pm Z$
- (interpret the result in terms how significant we observe the EW process)
- (set limits on aQGC)

VBS Event Topology



- two central leptons (1,2)
- two forward jets (3,4) which are separated in η and have large m_{jj}
- missing transverse energy due to the two neutrinos
- $W^{\pm}W^{\pm}$ scattering: leptons carry same electric charge

Backgrounds to the $\ell^\pm\nu\ell'^\pm\nu' jj$ Final State

- no irreducible background due to same-sign lepton pair

$\Rightarrow$ contributions only from detector effects

1. charge mis-reconstruction: $\mathcal{O}(0.3\%)$ for electrons
   $\Rightarrow$ Z+jets, $t\bar{t}$, $W^\pm W^\mp$ scattering
2. mis-identification of jets as leptons
   $\Rightarrow$ W+jets, $t\bar{t}$, single top
3. inefficiencies in lepton identification
   $\Rightarrow$ $W^\pm Z$, ZZ, $Z\gamma^*$
4. asymmetric photon conversions
   $\Rightarrow$ $W\gamma^*$
5. double parton interactions

- most effects are small but due to the tiny signal cross section relevant for this analysis
- can not rely on correct modelling of all detector effects in simulated data $\Rightarrow$ data-driven background estimates (even more) crucial

Plots on Current Status

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Interference between EW and QCD processes

- final goal: measure σ_{EW} for the $VVjj$ final state
- in nature we will always measure the coherent sum of purely electroweak diagrams and diagrams containing QCD vertices

$$\begin{aligned}\sigma_{\mathrm{EW+QCD}} &= \sigma_{\mathrm{EW}} + \sigma_{\mathrm{QCD}} + \sigma_{\mathrm{INT}} \\ &= \sigma_{\mathrm{EW}} + \sigma_{\mathrm{QCD}} \left(1 + \underbrace{\frac{\sigma_{\mathrm{INT}}}{\sigma_{\mathrm{QCD}}}}_{\varepsilon}\right)\end{aligned}$$

- How large is the contribution from the interference to the total cross section?
  - in a general phase space
  - in a VBS enhanced phase space
- How does the interference affect differential distributions?
- Can we absorbe interference contributions in the QCD sample using (simple) scaling factors $(1+\varepsilon)$?

Datasets used

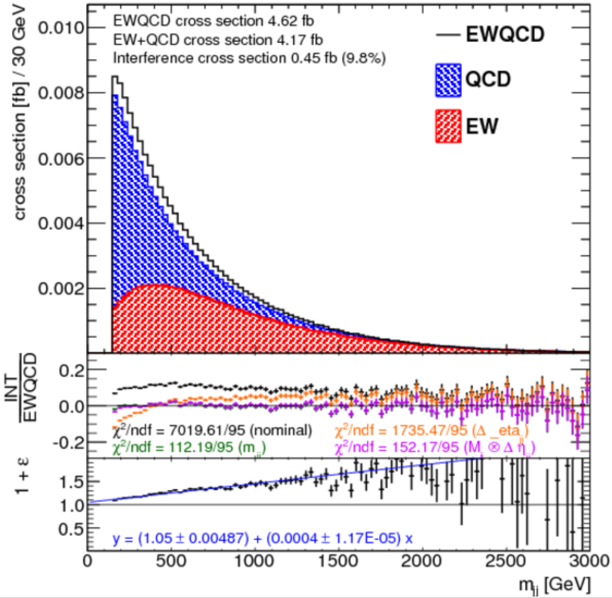
- consider process $pp \to e^+ \nu_e \mu^+ \nu_\mu jj$
- use SHERPA to generate samples for the categories EW, QCD and EW+QCD separately

$\Rightarrow$ $\sigma_{\text{INT}} = \sigma_{\text{EW+QCD}} - \sigma_{\text{EW}} - \sigma_{\text{QCD}}$

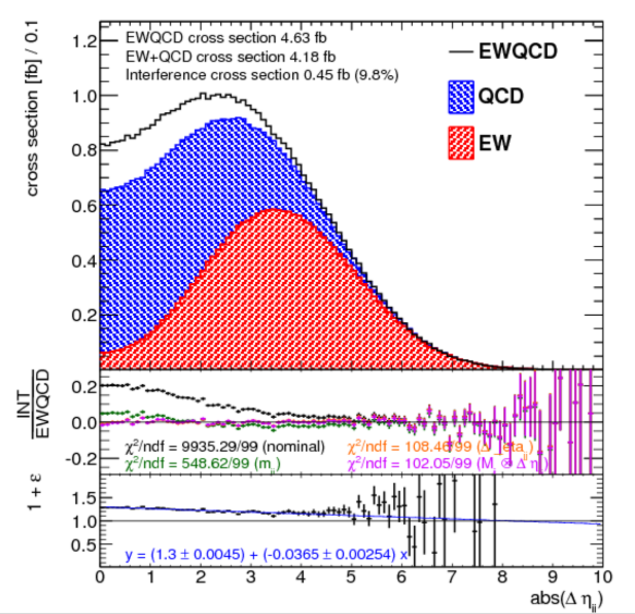
- two different phase space definitions:

	general	VBS
$\lvert\eta_\ell\rvert$	≤ 6	≤ 2.5
$p_{T,\ell}$	$\geq 15\,GeV$	$\geq 20\,GeV$
$\lvert\eta_j\rvert$	≤ 6	≤ 4.5
$p_{T,j}$	$\geq 15\,GeV$	$\geq 30\,GeV$
m_{jj}	$\geq 150\,GeV$	$\geq 500\,GeV$
$\lvert\Delta\eta_{jj}\rvert$	–	≥ 2.4
$\eta_{j1} \times \eta_{j2}$	–	< 0
ζ	–	> -0.5
$E_{T,\text{miss}}$	–	$> 40\,GeV$
$m_{\ell\ell}$	–	$> 20\,GeV$

Invariant Mass of the Two Tagging Jets



η Separation of the Two Tagging Jets



Comparison of Total Cross Sections

σ in *fb*	general	VBS
$\sigma_{\text{EW+QCD}}$	4.63 ± 0.005	0.707 ± 0.002
σ_{EW}	2.21 ± 0.002	0.616 ± 0.001
σ_{QCD}	1.97 ± 0.002	0.062 ± 0.0003
σ_{INT}	0.454 ± 0.006	0.029 ± 0.002
$\sigma_{\text{QCD}} + \sigma_{\text{INT}}$	2.43 ± 0.005	0.091 ± 0.002
$\sigma_{\text{QCD}}(\Delta\eta_{jj})$	2.42 ± 0.002	0.072 ± 0.0004
$\sigma_{\text{QCD}}(m_{jj})$	2.43 ± 0.002	0.087 ± 0.0005
$\sigma_{\text{QCD}}(m_{jj} \otimes \Delta\eta_{jj})$	2.43 ± 0.002	0.081 ± 0.0005

only statistical uncertainties, uncertainty on reweighted QCD samples does NOT include uncertainties from the reweighting

Summary

Conclusion

- observation/measurement of VBS is very important to understand the mechanism of EWSB
- $W^{\pm}W^{\pm}$ most promising for observation of the EW process
- contribution from interference in VBS phase space is $\leq 5\%$

Outlook

- low signal cross sections and difficult background estimation

$\Rightarrow$ expect only sensitivity to $\sigma_{\mathrm{EW+QCD}}$ in the $W^{\pm}W^{\pm}$ and $W^{\pm}Z$ channels for Moriond 2013

$\Rightarrow$ world's first limits on aQGCs

- analysis of/combination with other channels during the shut down

$\Rightarrow$ improve limits on aQGCs, observation of the EW process

Backup

The ATLAS detector