Strong WW scattering at LHC *

D. R. Wood
Northeastern University, Boston, MA, 02115

ABSTRACT

A summary is given of the prospects for observing strong electroweak symmetry breaking (SESB) at LHC though strong scattering of EW gauge bosons. Sensitivity to SESB signals are summarized along with possible ways to distinguish different models for SESB. Some of the significant issues for detecting the signatures of SESB at LHC are discussed.

I. OBSERVING STRONG SCATTERING AT LHC

The prospects for observing strong WW scattering at LHC have been examined by both the ATLAS[1, 2] and CMS[3, 4] collaborations as well as by many phenomenologists[5, 6, 7, 8]. The final results of some of these studies are summarized in Table I. The results are shown for three different models: 1 TeV Standard Model Higgs scalar, a 2.5 GeV vector resonance ("ρ"), and Low Energy Effective theory (LET). The numbers have all been rescaled to correspond to 200 fb^{-1}, which might represent the combined data from CMS and ATLAS in one year.

There are some variations in the event selection criteria used by different groups, but several features are common:

- Two isolated central ($|\eta_\ell| \lesssim 2.5$) same-sign leptons of at least moderate p_T ($p_T > 25$ GeV).
- Large invariant mass of lepton pair ($m(\ell^\pm\ell^\pm) \gtrsim 100$ GeV), and large ϕ separation ($\Delta\phi_{\ell\ell} \gtrsim 90°$).
- Rejection of events with opposite-sign leptons consistent with a Z decay.
- Rejection of events with high-p_T central jets ($p_T \gtrsim 40$GeV).

The third requirement suppresses the background from $pp \to WZ + X$, while the fourth is very important in reducing the backgrounds from $t\bar{t}$ and $Wt\bar{t}$ production.

An important additional signature of $qq' \to W^+W^+qq'$ is the presence of "tagging" jets from the quarks in the forward and backward regions of the detector ($2 \lesssim |\eta| \lesssim 5$)[9]. Some groups have required tags in both the forward and backward regions[1, 3, 2, 4], while others have used a single tag with a hight p_T threshold[6] ($p_T(\mathrm{tag}) \gtrsim 40$ GeV) along with higher lepton p_T cuts ($p_{T\ell} \gtrsim 70$ GeV).

In any case, from the significances quoted in Table I, one can conclude that strong coupling, if present, should be detectable at LHC in the W^+W^+ channel. The event rates are low, however, so that it might take several years to observed the signal. Consequently, by the time these analyses have adequate statistics, more information should be available about the presence or absence of light Higgs particles. These constraints might narrow the search for strong coupling.

II. CHANNEL COMPARISONS

If strong scattering is observed at LHC, we will then want to learn more about the actual model for strong symmetry breaking. Some models can be distinguished by comparing the event rates in different VV channels. (Here, "V" means either a W or a Z.) Some comparisons of different channels are given in Table II. One sees, for example, that the rate in the $ZZ \to \ell\ell jj$ channel might be useful to distinguish a scalar Higgs type coupling from a "ρ" vector coupling.

In addition, there is the possibility that the kinematic features of the events (e.g. the η and p_T distributions of the leptons and their correlations) might yield additional discrimination power. This has begun to be explored in the ZZ channel[10], and it might prove useful in other channels as well.

III. EXPERIMENTAL ISSUES

In this workshop, three areas were identified where certain aspects of detector performance have a large influence on the study of W^+W^+ strong scattering:

Lepton efficiency: This related more to background rejection than to signal acceptance. There is a large potential background from $WZ \to \ell^+\nu\ell'^+\ell'^-$. The ℓ'^- is normally used to veto the event, but if it goes undetected then the event is difficult to distinguish from $W^+W^+ \to \ell^+\nu\ell'^+\nu'$. Both CMS and ATLAS studies conclude that this background is manageable if the additional information from the forward/backward jet tags is used to suppress the Standard Model WZ production.

Sign Mismeasurement: The production of W^+W^- pairs exceeds the production of W^+W^+ pairs to such an extent that even as small probability of charge misidentification could cause the W^+W^- events to overwhelm the signal. If the probability for incorrect charge assignment is less that 10^{-5} for $p_{T\ell} = 100$ GeV and less that 10^{-3} for $p_{T\ell} = 500$ GeV[11] then the unlike-sign background should be easily suppressed. This is a very modest demand on the tracking resolution if it is assumed to be Gaussian in inverse momentum. In practice, however, the charge misidentification probability can be dominated by non-Gaussian tails of the tracking resolution. These effects were studies in detail for the proposed SDC experiment at the SSC[11] and for ATLAS[1]. Background from charge misidentification

* Work supported by the National Science Foundation through grant PHY/9514950

Table I: A summary of signal and background estimates for like-sign W pairs. All results are rescaled to an exposure of 200 fb^{-1}(1 year $\times$ 2 detectors). Signal and background are given in number of events passing final selections.

Model	Detector	W^+W^+ signal (S)	background (B)	significance ($S/\sqrt{B}$)	ref.
1.0 TeV SM	CMS	60	152	4.9	[4]
1.0 TeV SM	ATLAS	46	92	4.8	[1]
1.0 TeV SM	Generic	11	7.4	4.1	[6]
2.5 TeV ρ	ATLAS	50	152	4.1	[1]
2.5 TeV ρ	Generic	32	7.4	12	[6]
LET	ATLAS	78	152	6.3	[1]
LET-K	Generic	26	7.4	9.6	[6]

Table II: A summary of signal and background estimates for some VV channels other than. like-sign W pairs. All results are rescaled to an exposure of 200 fb^{-1}.

Channel	Model	S	B	$S/\sqrt{B}$	ref.
W^+W^-	1.0 TeV SM	114	38	18	[1]
	1.0 TeV SM	54	24	11	[6]
	2.5 TeV ρ	11	24	2.2	[6]
	LET-K	9.2	24	1.9	[6]
WZ	1.0 TeV SM	80	132	7	[8]
	1.0 TeV SM	2.4	9.8	0.8	[6]
	2.5 TeV ρ	6.6	9.8	2.1	[6]
	LET-K	6.0	9.8	1.9	[6]
$ZZ \to 4\ell$	1.0 TeV SM	28	38	4.5	[8]
	1.0 TeV SM	18	1.4	15	[6]
	2.5 TeV ρ	2.6	1.4	2.2	[6]
	LET-K	2.8	1.4	2.4	[6]
$ZZ \to \ell\ell jj$	1.0 TeV SM	18	7.8	6.5	[1]
	1.0 TeV SM	58	3.6	31	[6]
	2.5 TeV ρ	8.8	3.6	4.6	[6]
	LET-K	9.0	3.6	4.7	[6]

was taken into account in both the ATLAS and CMS studies, and the tracking performance was found to be adequate.

Forward/Backward Jet Tagging: Studies have shown[1, 3, 2, 4] that the significance of the strong WW scattering signal can be improved with a tag on both the forward and the backward tag jet. The p_T of these jets tends to be quite modest, ($\sim M_W/2$), so this double tag is efficient only if the transverse momentum threshold on the tag jets can be set quite low ($p_T(\min) \approx 15$ GeV). The experimental challenge is to distinguish these jets from clusters of energy that could arise from underlying events and pile-up in the calorimeters.

The Monte Carlo simulations have been done for the ATLAS experiment[1] which compare the rate of tag jets from strong WW scattering to those from background and pile-up. The instantaneous luminosity used in these studies was $\mathcal{L}$=$1.0 \cdot 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. The best results were achieved with a minimum cell threshold of $E_T > 3$ GeV and a jet threshold of $E_T > 15$ GeV. With these requirements, the overall probability of double tags for background events was estimated to be around 0.6%, which was actually dominated by true jets rather than pile-up.

IV. CONCLUSION

Strong symmetry breaking, if it exists, should be observable at LHC after a few years of running. Good lepton acceptance, correct charge identification and the efficient detection of forward tagging jets are important requirements for this search. Additional studies would be useful to find ways to discriminate different models of strong symmetry breaking using VV data from LHC.

V. REFERENCES

[1] ATLAS Collaboration, Technical Proposal, CERN/LHCC/94-43, LHCC/P2, Dec., 1994.

[2] G. Azuelos, C. Leroy, and R. Tafirout, "Observation of Like-Sign W boson Pairs at LHC," ATLAS Internal Note PHY-NO-033, Dec. 1993; Addendum-1, Apr. 1995.

[3] CMS Collaboration, Technical Proposal, CERN/LHCC 94-38, LHCC/P1, Dec., 1994.

[4] J.R. Smith, "Strong Interacting WW Scattering in CMS", CMS TN/95-179, May 1996.

[5] M.S. Chanowitz and W. Kilgore, Phys. Lett. **B322**, 147 (1994); Phys. Lett. **B347**, 387 (1995).

[6] J. Bagger, *et al.*, Phys. Rev. D **52**, 3878 (1995).

[7] M. Golden, T. Han and G. Valencia, "Strongly-Interacting Electroweak Sector: Model Independent Approaches," UCD-95-32, ISU-HET-95-6, Oct. 1995.

[8] Dobado, et al., Phys. Lett. **B352**, 400 (1995).

[9] R.H. Cahn, S.D. Ellis and W.J. Stirling, Phys. Rev. D **35**, 1626 (1987).

[10] M.H. Reno, these proceedings.

[11] Solenoidal Detector Collaboration, Technical Design Report, SDC-92-201, SSCL-SR-1215, Apr. 1992.