Electroweak Symmetry Breaking without Higgs Boson.

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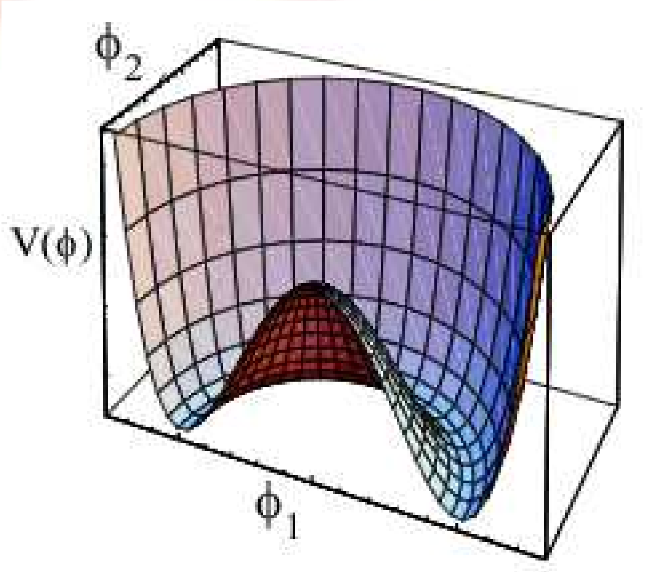
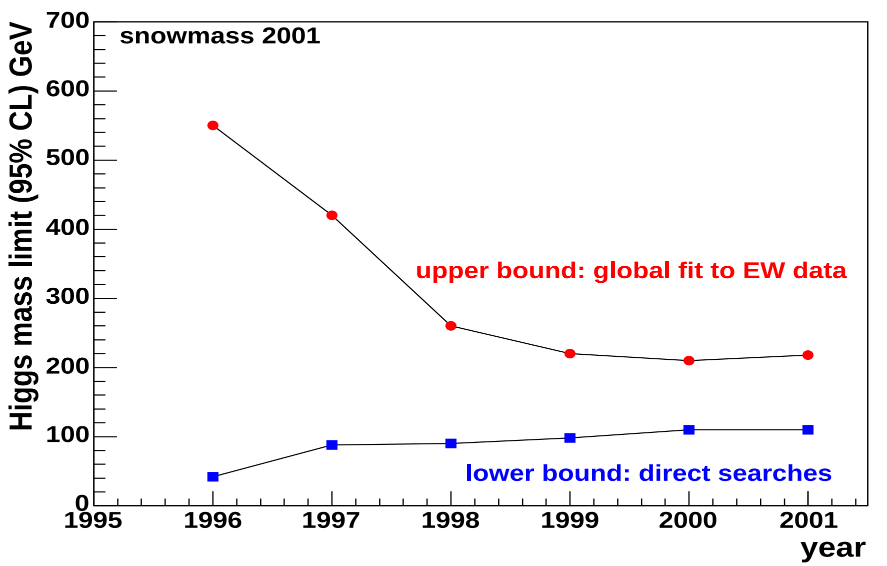
Outline

- **The Electroweak Chiral Langrangian (EWChL): Why and How.**
- **Application of the EWChL in the $V_L V_L$ scattering to probe new physics.**
- **Few scenarios for the new physics.**
- **Performance studies of the ATLAS Detector at the LHC.**
  - **$W_L W_L$ with no resonances (Continuum)** by J.M. Butterworth, P. Sherwood, S. Stefanidis.
  - **$W_L W_L$ with resonances** by S.E. Allwood, J.M. Butterworth, B.E. Cox.
  - **$W_L Z_L$ with resonances** by G. Azuelos, P-A. Delsart, J. Idárraga, A. Myagkov.
- **Summary.**

- Standard Model: A very good model satisfying theorists and experimentalists.
- It explains the **Electroweak Symmetry Breaking(EWSB)** by introducing the **Higgs** boson.





- However, any assumptions and any mass limits are **model dependent.**
- Enhanced production of **longitudinal** vector boson pairs ($V_L V_L$) is one of the most characteristic signals of the new physics.

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- Describes the low energy effects of different strongly interacting models of the EWSB sector.
- The differences among underlying theories appear through the values of the effective chiral couplings.
- It includes operators up to order of s^2 ($\equiv E^4$).
- The analytical complete form can be found in *Dobado et al., Phys.Rev.D**62**,055011*, but terms of major importance are:

$$\mathcal{L}_{EWCh} = \mathcal{L}^{(2)} + \mathcal{L}^{(4)} + ... = \frac{u^2}{4} Tr\{D_\mu U D^\mu U^\dagger\} + \alpha_4 \left(Tr\{D_\mu U D^\mu U^\dagger\}\right)^2 + \alpha_5 \left(Tr\{D_\mu U D^\nu U^\dagger\}\right)^2 \quad (1)$$

where the $SU(2)_L \bigotimes U(1)_Y$ covariant derivative of U is defined as:

$$D_\mu U \equiv \partial_\mu U + ig\frac{\tau^\alpha}{2} W_\mu^\alpha U - ig' U \frac{\tau^3}{2} B_\mu \quad (2)$$

where τ^α ($\alpha = 1, 2, 3$) are the Pauli matrices , ω are the three Goldstone bosons and $u = 246$ GeV.

- The α_4, α_5 are expected to be in the range [-0.01,0.01] *(Belyaev et al., Phys.Rev.D**59**,015022)*.
- **Different choices for the magnitude and the sign of α_4 and α_5 would correspond to different choices for the underlying (unknown) theory.**

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- For the $V_L^a V_L^b \to V_L^c V_L^d$ in the weak isospin space ($V_L^i = W_L^+, W_L^-, Z_L^o$):

$$\mathcal{M}(V_L^a V_L^b \to V_L^c V_L^d) \equiv A(s,t,u)\delta^{ab}\delta^{cd} + A(t,s,u)\delta^{ac}\delta^{bd} + A(u,t,s)\delta^{ad}\delta^{bc} \quad (3)$$

where the key amplitude $A(s,t,u)$ is:

$$\begin{aligned} A(s,t,u) &= \frac{s}{u^2} + \frac{1}{4\pi u^4}\left(2\alpha_4 s^2 + \alpha_5(t^2+u^2)\right) + \\ &+ \frac{1}{16\pi^2 u^4}\left(-\frac{t}{6}(s+2t)\log\left(-\frac{t}{\mu^2}\right) - \frac{u}{6}(s+2u)\log\left(-\frac{u}{\mu^2}\right) - \frac{s^2}{2}\log\left(-\frac{s}{\mu^2}\right)\right) \end{aligned} \quad (4)$$

- **Precise measurement of the $V_L V_L \to V_L V_L$ scattering cross-section would allow the extraction of the α_4 and α_5 parameters.**

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- The usual EWChL approach doesn't respect **unitarity**.
- Unitarity is restored by applying different **unitarization protocols**, for example: **Inverse Amplitude Method (Padé)**, N/D protocol etc.
- Unitarization procedure $\rightsquigarrow$ **Resonances.**
- The **position** and the **nature** of the resonances **depend strongly** upon the unitarisation procedure. (see *Butterworth et al., Phys.Rev.D**65**,096014* for comparison between the Padé and the N/D protocols.)
- Using the Padé protocol, we obtain the following mass and width of the resonances:

$$M_V^2 = \frac{u^2}{4(\alpha_4 - 2\alpha_5) + \frac{1}{144\pi^2}}, \qquad \Gamma_V = \frac{M_V^3}{96\pi u^2} \tag{5}$$

$$M_S^2 = \frac{12u^2}{16(11\alpha_5 + 7\alpha_4) + \frac{101}{48\pi^2}}, \qquad \Gamma_S = \frac{M_S^3}{16\pi u^2} \tag{6}$$

- For equal masses, scalar resonances would be **6 times wider** than vector resonances.

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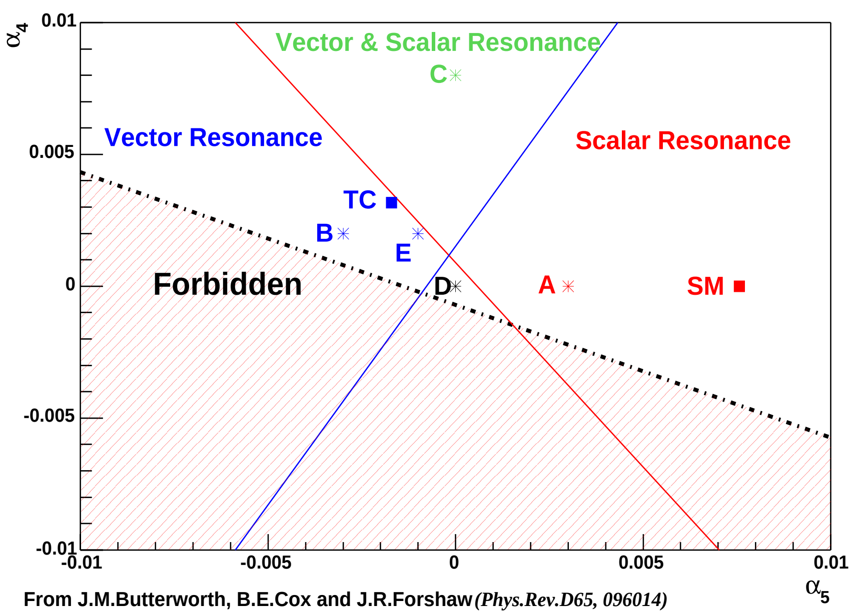
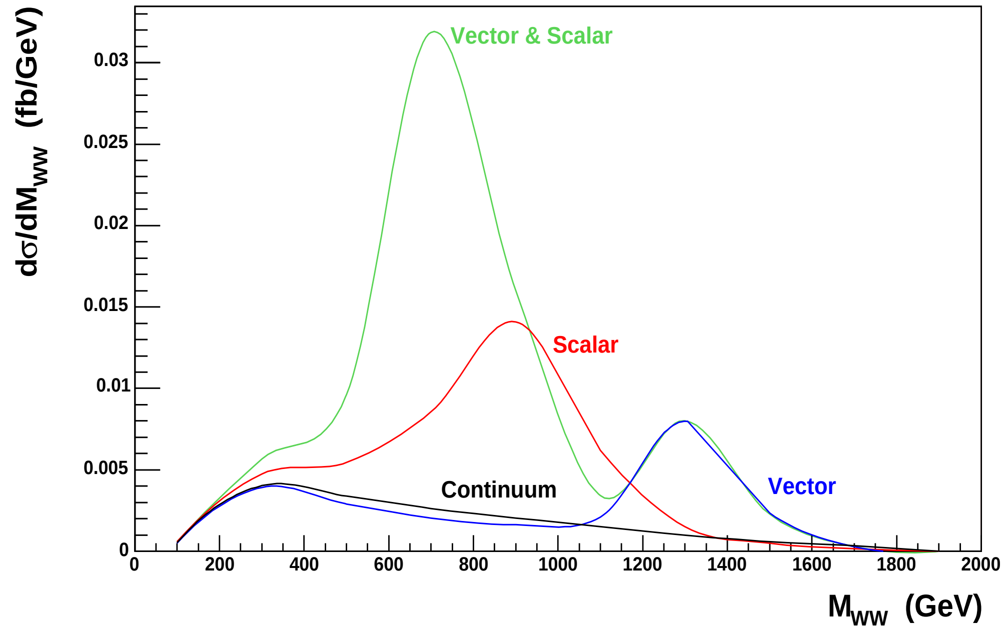


From J.M.Butterworth, B.E.Cox and J.R.Forshaw *(Phys.Rev.D65, 096014)*



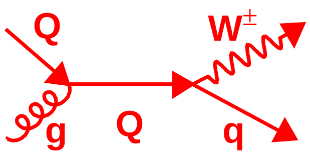
Scenario	α_4	α_5	Resonance Mass (GeV)
Scalar(A)	0.0	0.003	989.8
Vector(B)	0.002	-0.003	1360.3
Scalar + Vector (C)	0.008	0.0	809.6 + 1360.3
Continuum (D)	**0.0**	**0.0**	**NA**

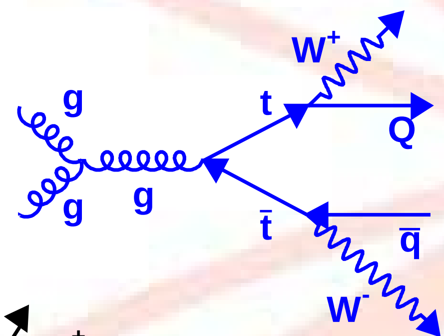
- PYTHIA has been modified to include the EWChL and to produce the resonances for different parameters.

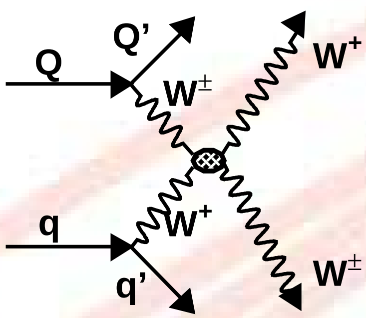
Signal and Background Processes at LHC - Data Samples

For all processes:

- **PYTHIA** was used as a generator.
- **Rome Tuning** for the Underlying Events.
- **MRST2001E** (central value) as PDF.
- Allowed **all the decays** of the Ws.







- Signal:
  - Continuum ; $W_L^{\pm}W_L^{\pm} \rightarrow W_L^{\pm}W_L^{\pm}(\rightarrow \ell\nu jj)$.
  - $\sigma = 44\ fb$.
- $t\bar{t}$ Background:
  - $\hat{p}_{\perp}\ >\ 300\ GeV$
  - $\sigma = 15640\ fb$.
- W+jets Background:
  - $\hat{p}_{\perp}\ >\ 250\ GeV$
  - $\sigma = 62600\ fb$.

The generated events were then simulated using the **Fast Simulation** package for the ATLAS Detector.

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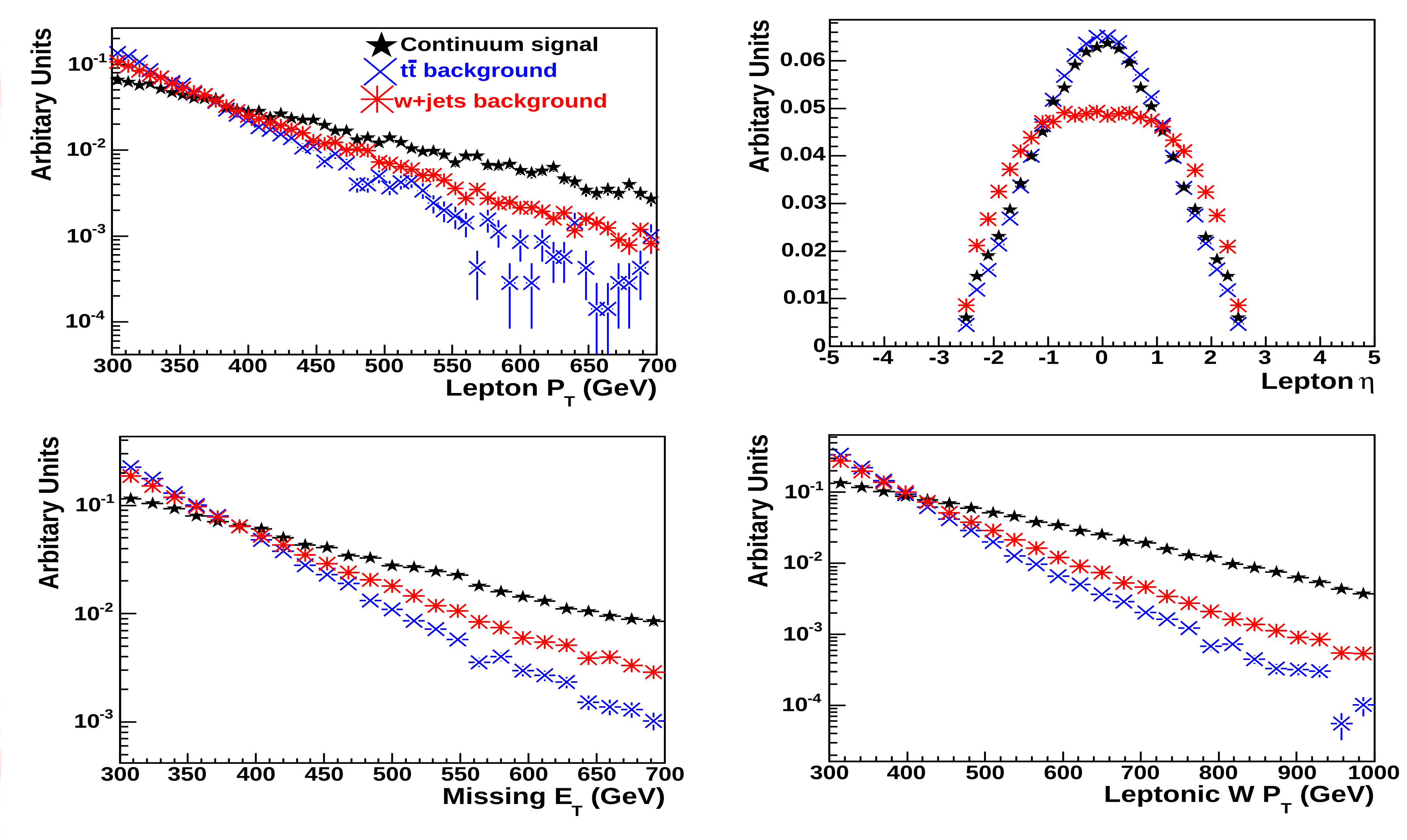
Initial Distributions: The Leptonic sector



- **Applied Cuts:** $P_T^{W_{lept}} > 320\ GeV$

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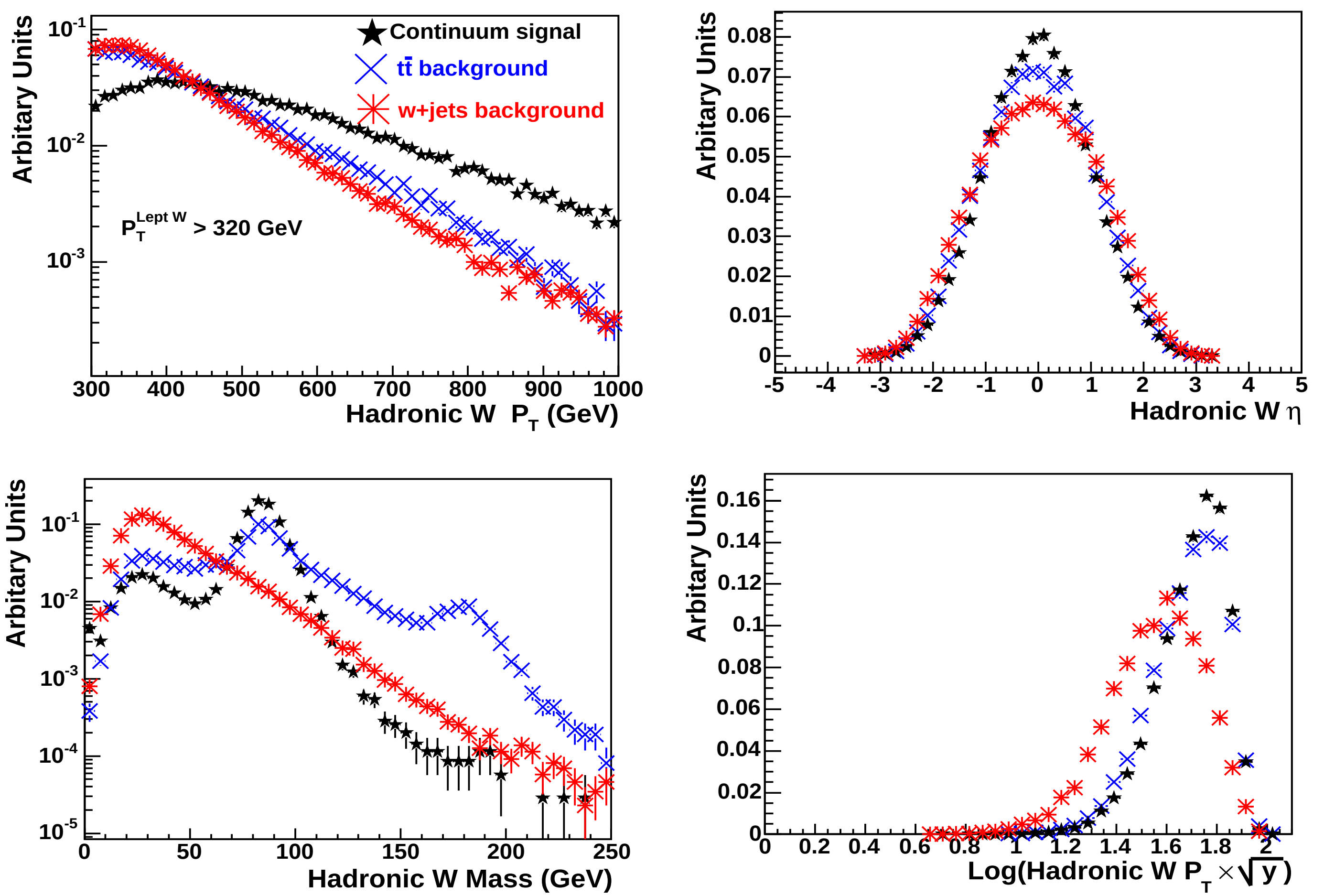

Applied Cuts:

- $P_T^{W_{had}} > 320\ GeV$
- $|\eta_{W_{had}}| < 2$
- $66\ GeV < M_{W_{had}} < 102\ GeV$
- $1.55 < \log(P_T \times \sqrt{y}) < 2$

Important Keys:

- Reconstruct the Hadronic W as **1 jet** since the Ws are **highly boosted**.
- **Subjet Analysis** with the $k_\perp$ (see *hep-ph/0210022*)
  - For the leading jet, re-run the $k_\perp$ algorithm to find its structure.
  - $P_T \times \sqrt{y}$: scale at which the jet is resolved into 2 subjets $\sim \mathcal{O}(M_W)$

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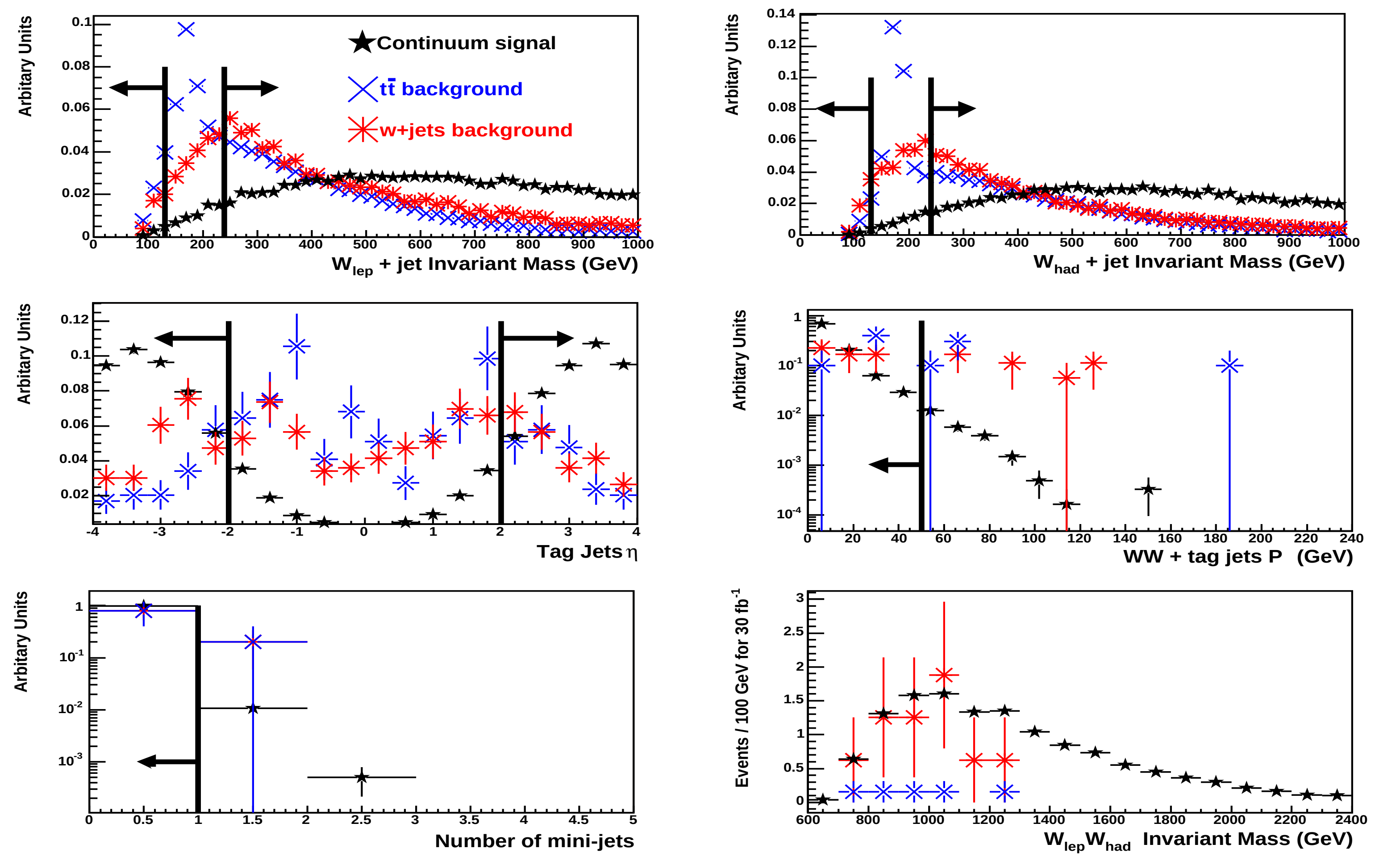
After applying the kinematics cuts, we investigate the features of the hadronic environment:



Applied Cuts:

- **Top Veto:** $130\ GeV < M_{W+jet} < 240\ GeV$
- **Tag Jets:** $P_T > 20\ GeV;\ \ E > 300\ GeV;\ \ |\eta| > 2.0$
- **Hard Scatter P_T:** $P_T^{WW+tagJets} < 50\ GeV$
- **MiniJets:** Number of miniJets $<\ 1$

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Cross-section σ (fb)	Signal	$t\bar{t}$	W+jets	Significance† for $L = 30\ fb^{-1}$
Generated	44	15640	62600	0.88
Cuts				
P_T Leptonic W	3.31±0.01	422.81±1.46	2889.37±7.58	0.33
P_T Hadronic W	2.59±0.01	191.96±0.99	1816.92±6.07	0.33
η Hadronic W	2.59±0.01	191.96±0.99	1816.92±6.07	0.33
Mass Hadronic W	2.04±0.01	88.80±0.68	209.29±2.09	0.66
Y Scale	1.74±0.01	72.29±0.61	113.95±1.54	0.71
Top Veto	1.57±0.01	4.10±0.15	53.13±1.05	1.15
P_T, E, η Tag Jets	0.45±0.01	0.05±0.02	0.38±0.09	3.73
P_T hard scatter	0.44±0.01	0.03±0.01	0.21±0.07	4.93
Number of Mini-jets	**0.44±0.01**	**0.03±0.01**‡	**0.21±0.07**‡	**4.93**

† Only the average value used.

‡Although statistical errors for the background processes must be reduced, other studies give the same order for the average value.

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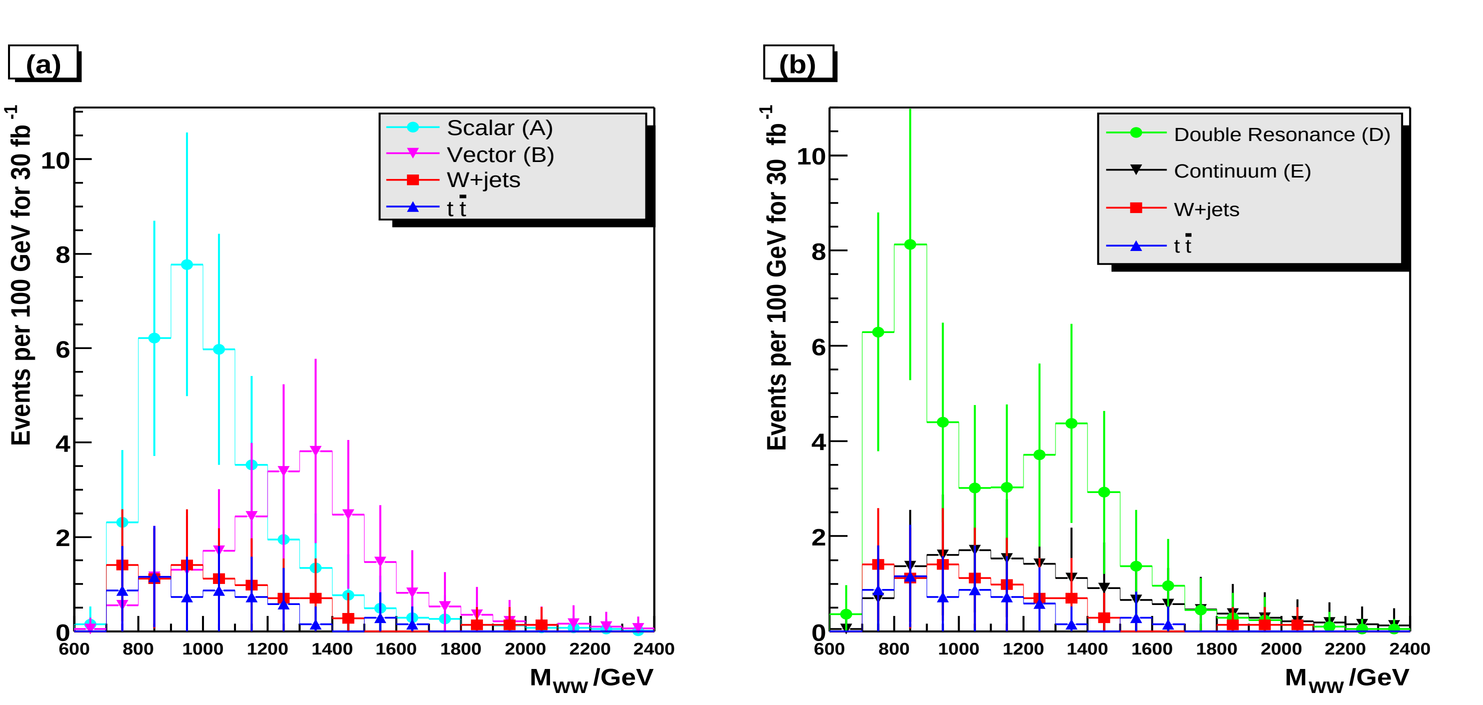
This report is for $W_L W_L$ scattering using the EWChL parameters for different scenarios which include **Scalar, Vector** and **Scalar+Vector** Resonances (work done by S.E. Allwood).



Final cross-section σ (fb)	Signal	$t\bar{t}$	W+jets	Significance for $L = 30\ fb^{-1}$
Scenario				
1 TeV Scalar Resonance	1.05	0.04	0.28	**10.17**
1.4 TeV Vector Resonance	0.70	0.04	0.28	**6.78**
Double Resonance	1.33	0.04	0.28	**12.88**
Continuum	0.44	0.03	0.21	**4.93**

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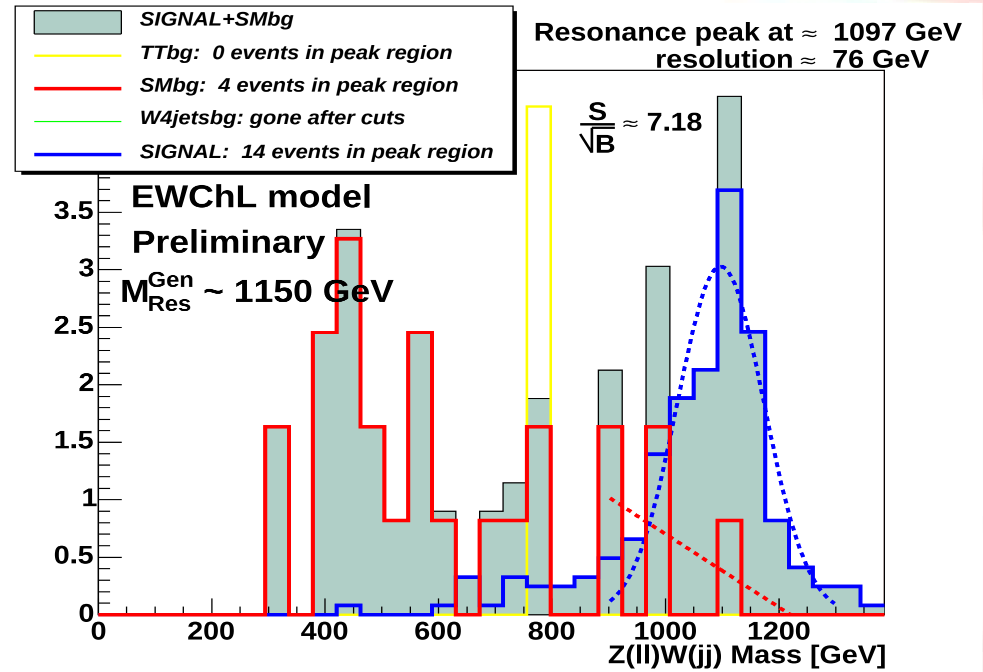
- A complete list of notes on the Dynamical EWSB can be found under the Exotics Group at:

http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/EXOTICS/

- This report is from: **G.Azuelos,P-A.Delsart,J.Idárraga** (Montreal) and **A.Myagkov** (Protvino):
  - Study of the **EWChL** and the **higgsless** (see *Csaki et al., Phys.Rev.Lett.**92**,101802*) models.
  - Full simulation/reconstruction under the DC2 production.
  - Signal Processes: $qqWZ \to qqjj\ell\ell$; $qqWZ \to qq\ell\nu\ell\ell$; $qqWZ \to qq\ell\nu jj$
  - Background Processes: SM $qqWZ$ production ; $t\bar{t}$ (MC@NLO) ; W+4jets (ALPGEN)



- For both models, $qqWZ \to qqjj\ell\ell$ can provide discovery with 100 fb^{-1}.
- $qqWZ \to qq\ell\nu\ell\ell$ is very clean but with low cross section. Must wait till 300 fb^{-1}.
- $qqWZ \to qq\ell\nu jj$ can also give good sensitivity with 100 fb^{-1}.

- The motivation and the functionality of the **EWChL** have been presented for the $V_L V_L \rightarrow V_L V_L$ scattering.
- Detailed analysis using the **Continuum spectrum** for the $\boldsymbol{W_L W_L}$ scattering results in a $\boldsymbol{5\sigma}$ significance, for the most pessimistic scenario.
- Recent analyses are based on both the **full** and **fast** simulation of the ATLAS Detector.
- Though restricted by the statistics, we are confident that ATLAS will be able to see new signatures even **with 30** $\boldsymbol{fb^{-1}}$ of data.

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