COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

US ATLAS

Prospects for the Search for a Doubly Charged Higgs with ATLAS

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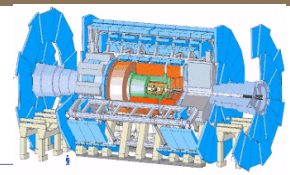
Summary

Physics Motivation



L-R symmetric model would be a natural extension of the SM

- $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$
- predicts new fermions:
  heavy Majorana neutrino
- predicts new gauge bosons:
  W_R
- predicts new Higgs sector

$\Delta_R = (\Delta_R^0, \ \Delta_R^+, \ \Delta_R^{++})$

$\Delta_L = (\Delta_L^0, \ \Delta_L^+, \ \Delta_L^{++})$ (if Lagrangian is invariant under $L \leftrightarrow R$ symmetry)

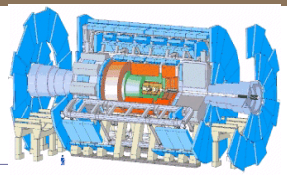
$\phi_{1,2}^0, \ \phi_{1,2}^{\pm}$

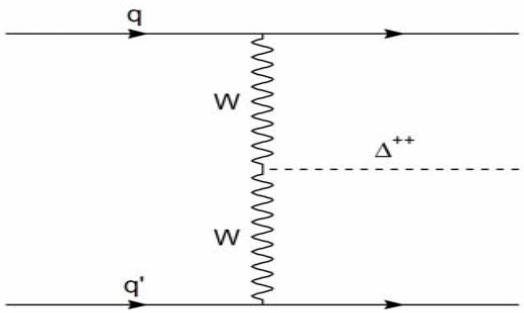
Parameters: $k_1 \quad k_2 \quad v_L \quad v_R \quad k = \sqrt{k_1^2 + k_2^2} \sim 250 GeV$

$$\rho = \frac{M_{W_L}^2}{\cos^2\theta_W M_{z1}^2} \sim \frac{1 + 2v_L^2/k^2}{1 + 4v_L^2/k^2} \quad \Rightarrow \quad v_L \leq 9 \ GeV$$

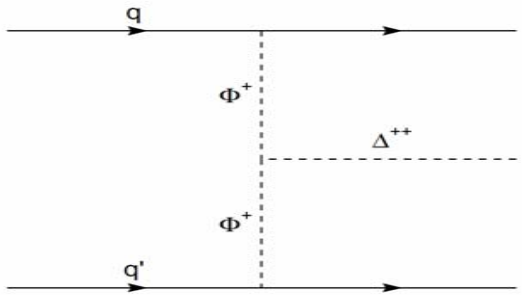
$$m_{W_R}^2 = g_R^2 v_R^2 / 2, \qquad g_R = g_L \approx 0.64$$

DCH Production at LHC

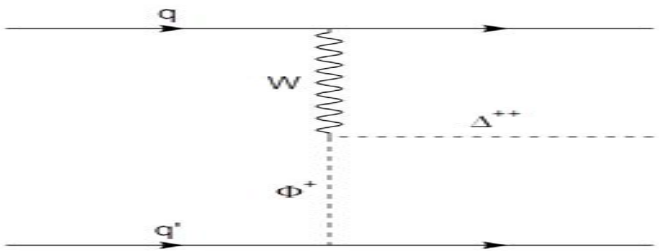




$$\frac{1}{\sqrt{2}} g_R^2 v_R W_R^- W_R^- \Delta_R^{++}$$



$$\frac{1}{\sqrt{2}} v_L \Delta_R^{++} (\beta_1 \Phi_1^- \Phi_2^- - \beta_2 \Phi_1^- \Phi_1^- - \beta_3 \Phi_2^- \Phi_2^-)$$



$$i g_R W_{R\mu}^- (\Delta_R^- \partial^\mu \Delta_R^{++} - \Delta_R^{++} \partial^\mu \Delta_R^-)$$

β's are small in realistic models
Yukawa couplings (to quarks) is
<< gauge coupling

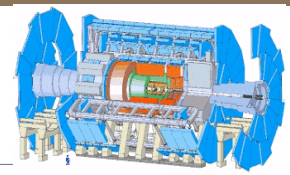
$$v_L << v_R$$

$$v_L \leq 9 GeV$$

$$g_R \sim g_L$$

$$M_{w_R}^2 \sim g_R^2 (2 v_R^2 + k_1^2)$$

DCH Decay Modes



In lowest order the doubly charged scalar can decay via the following channels:

$$\Delta^{++}_{R,L} \rightarrow l^{+} l^{'+}$$

$$\Delta^{++}_{R,L} \rightarrow W^{+}_{R,L} W^{+}_{R,L}$$

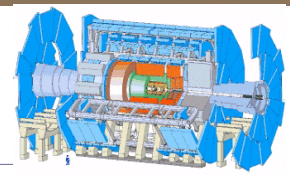
$$W^{+}_{R,L} W^{+}_{R,L} \delta^{0}$$

$$h^{+} h^{+} \delta^{0}$$

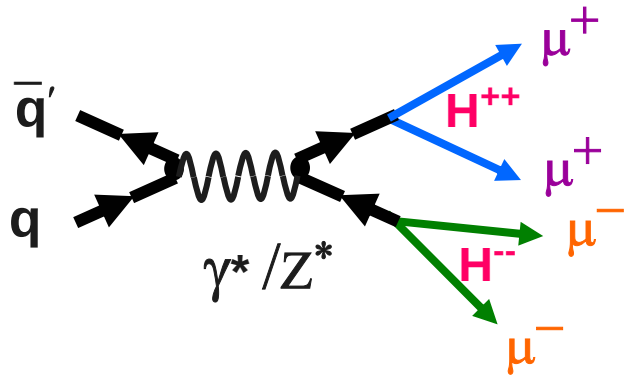
$$h^{+} h^{+} h^{0}$$

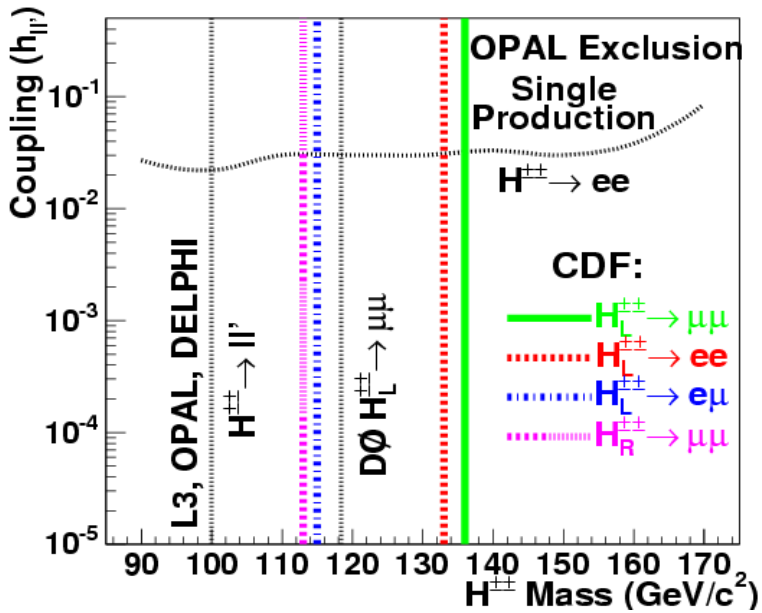
} Kinematically Suppressed or disallowed

Experimental Status

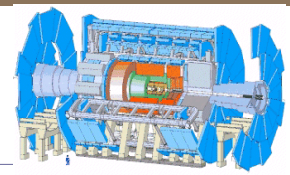


- Tevatron Results:
  - **Limits on L-handed Higgs have gone up to ~ 130 GeV**
  - **Limits on R-handed Higgs have gone up to ~ 113 GeV**
- LEP Results
  - **Mass Limit ~ 100 GeV**





Analysis Description



Parameters:

$$M_{H_L^{++}} = 300, 400, 500, 600, 700, 800 GeV$$

$$v_L = 5,9\ GeV$$

Leptonic coupling:

e	μ	τ
1	0	0
0	1	0
0	0	0

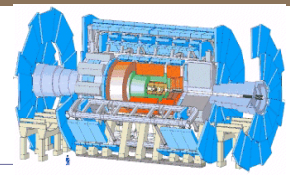
e	μ	τ
0	0	0
0	0	0
0	0	1

Signals:

$\Delta_L^{++} \to \ell^+\ell^+$ $\quad l = e, \mu$ $\qquad \Delta_L^{++} \to \tau^+\tau^+$, $\tau \to l\nu\nu$

Background: $Wt\bar{t}$, $W^+W^+(QCD)$, $W^+W^+(EW)$, $WZqq$, $t\bar{t}$

Cross Section Summary



Signal cross section: Δ_L^{++}

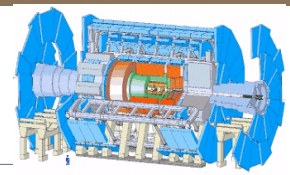
$Mass_{\Delta^{++}}$ (GeV)	σ (fb) for ν_L=5GeV	σ (fb) for ν_L=9GeV
300	1.75	5.68
400	1.14	3.69
500	0.77	2.50
600	0.56	1.82
700	0.42	1.33
800	0.32	1.02

Backgrounds cross section:

Background	Number of Events	$\sigma \times BR$ (fb)
$pp \rightarrow W\bar{t}\bar{t}$	200 000	23
$qq \rightarrow W^+W^+qq$	100 000	37
$qq \rightarrow WZqq$	27 000	28.6
$qq \rightarrow t\bar{t}$ P_t 10-200 GeV	8 000 000	90 800
$qq \rightarrow t\bar{t}$ P_t 200 GeV-∞	2 000 000	14 100

The gauge bosons were required to decay leptonically

$\Delta_L^{++} \rightarrow l^+ l^+$



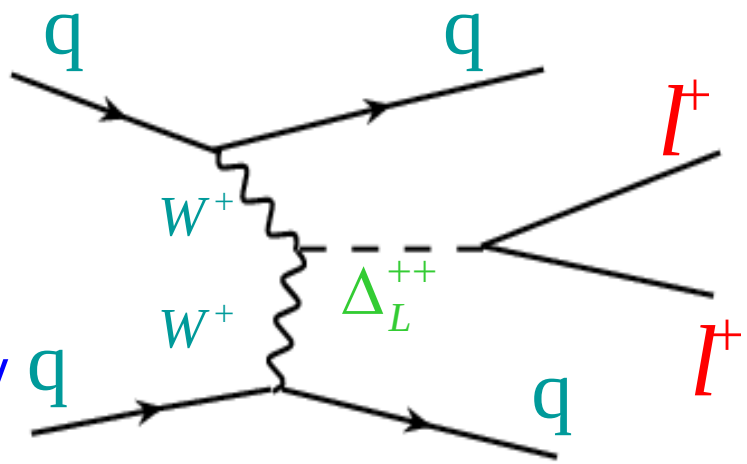
Signal : consider $\Delta_L^{++} \rightarrow \ell^+ \ell^+$, only e or μ
(cannot decay to quark pair because of charge conservation)

Backgrounds : $Wt\bar{t}$, $W^+W^+(QCD)$, $W^+W^+(EW)$, $WZqq$, $t\bar{t}$

$$nlep = 2$$

$$\Delta\phi_{ll} > 2.5$$

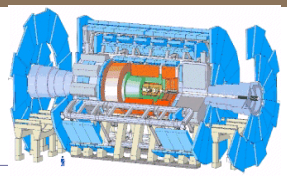
$$\Delta P_T^{ll} = f(M_{ll})$$

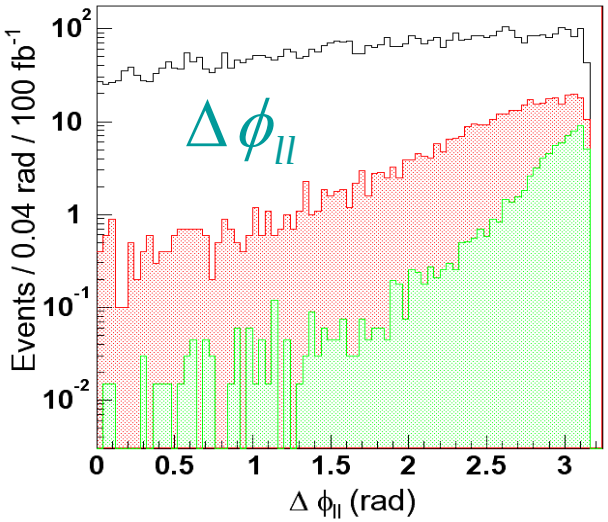


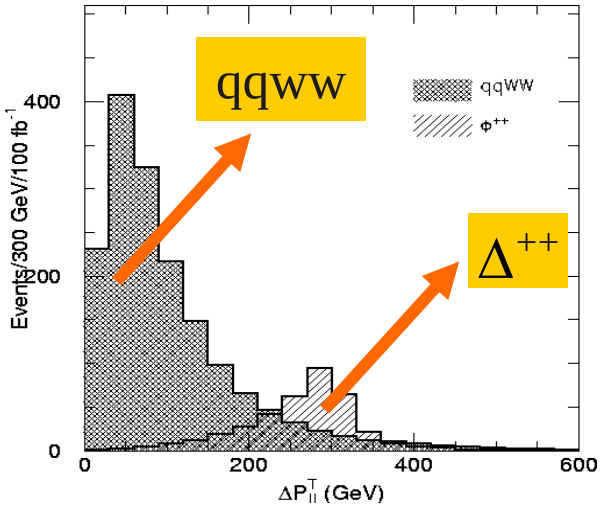
Forward jets tagging:
E_j1>200 GeV, E_j1>200 GeV
well separated in eta

Missing transverse momentum cut

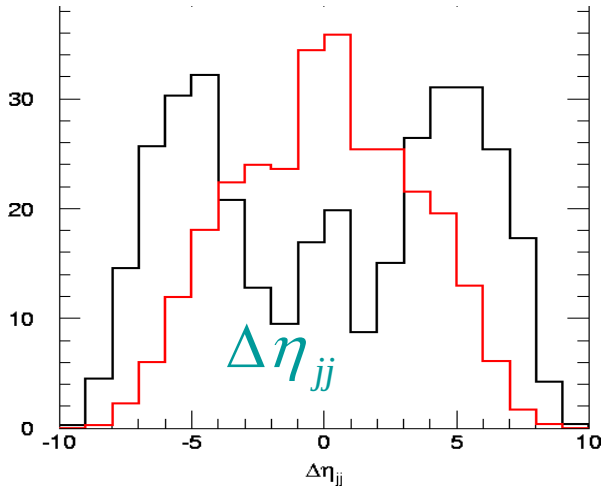
$\Delta_L^{++} \rightarrow l^+ l^+$

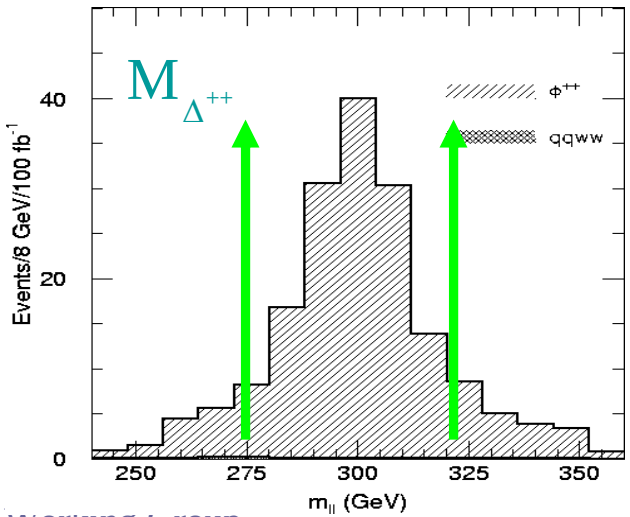




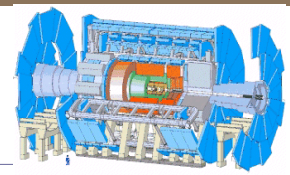


Δp_T^{ll}

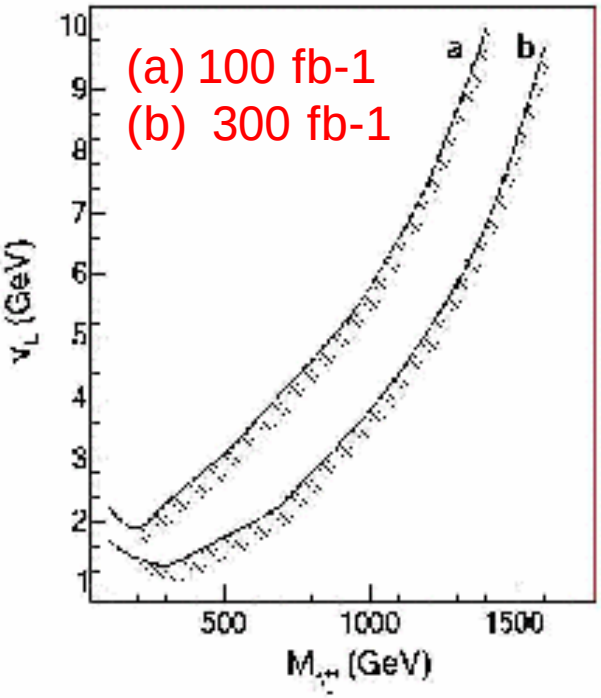




Results



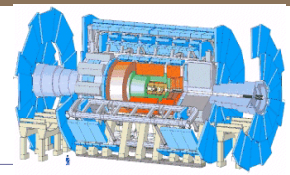
100 fb-1	Δ^{++} 300 GeV	Δ^{++} 800 GeV	total backg
Isolated leptons	330 (384)	59 (69)	133/13
$\lvert\Delta\phi_{ll}\rvert > 2.5$	253 (289)	56 (65)	75/8.3
$\Delta_{P_T^{ll}} > (\frac{M_{ll}}{2}+50)$	220 (260)	50 (59)	37/2.5
Fwd Jet tagging	156(185)	40 (47)	17/1.4
pt miss	152(180)	34 (40)	3.0/0.1



Nb of Events after each cut

Discovery reach

$\Delta_L^{++} \rightarrow \tau^+\tau^+$



Signal : consider $\Delta_L^{++} \rightarrow \tau^+\tau^+ \rightarrow l^+ l^+ P_{miss}^T + X$

Backgrounds : $W\,t\bar{t}$, W^+W^+qq, $WZqq$, $t\bar{t}$

Leptons Cuts:

$nlep = 2$

$P_T^{lep} > 25\,GeV$

$M_{l_1 l_2} > 30\,GeV$

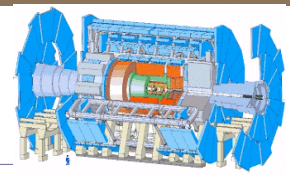
$0 < x_{l_1}, x_{l_2} < 1$

Jets Cuts:

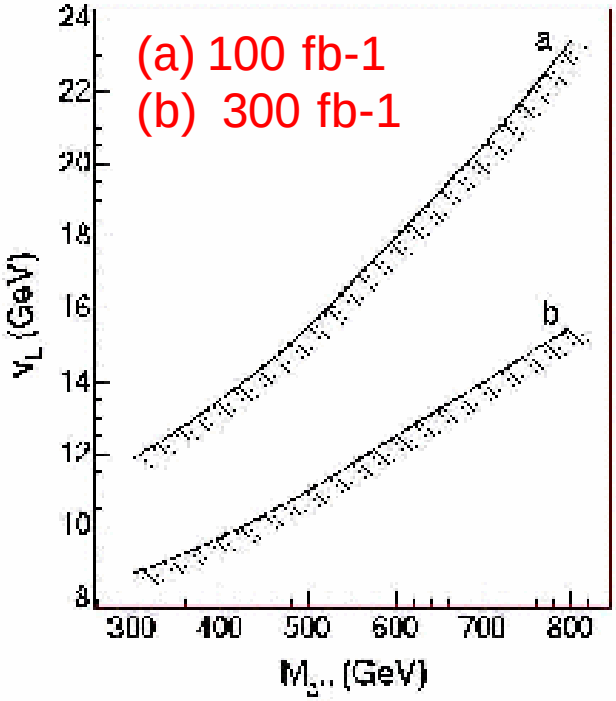
- b-jet Veto
- Forward Jet Tagging

$$m^2_{\tau^+\tau^+} \approx \frac{2\ p_{l_1} \cdot p_{l_2}}{x_{l_1}\ x_{l_2}}$$

Results



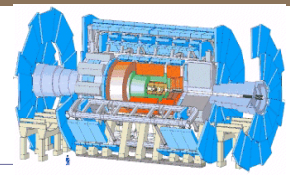
100 fb-1	Δ^{++} 300 GeV	Δ^{++} 800 GeV	total backg
Isolated leptons	42 (54)	10.1(13.4)	707/299
$0 < x_1,\ x_2 < 1$	40 (47)	9.6 (12.0)	480/222
no b jet	38 (46)	9.1 (11.5)	158/100
Fwd Jet tagging	18 (22)	4.3 (5.8)	33/23
$M_{ll} > 30$ GeV	15 (16.3)	3.8 (4.8)	23/16



Nb of Events after each cuts

Discovery reach

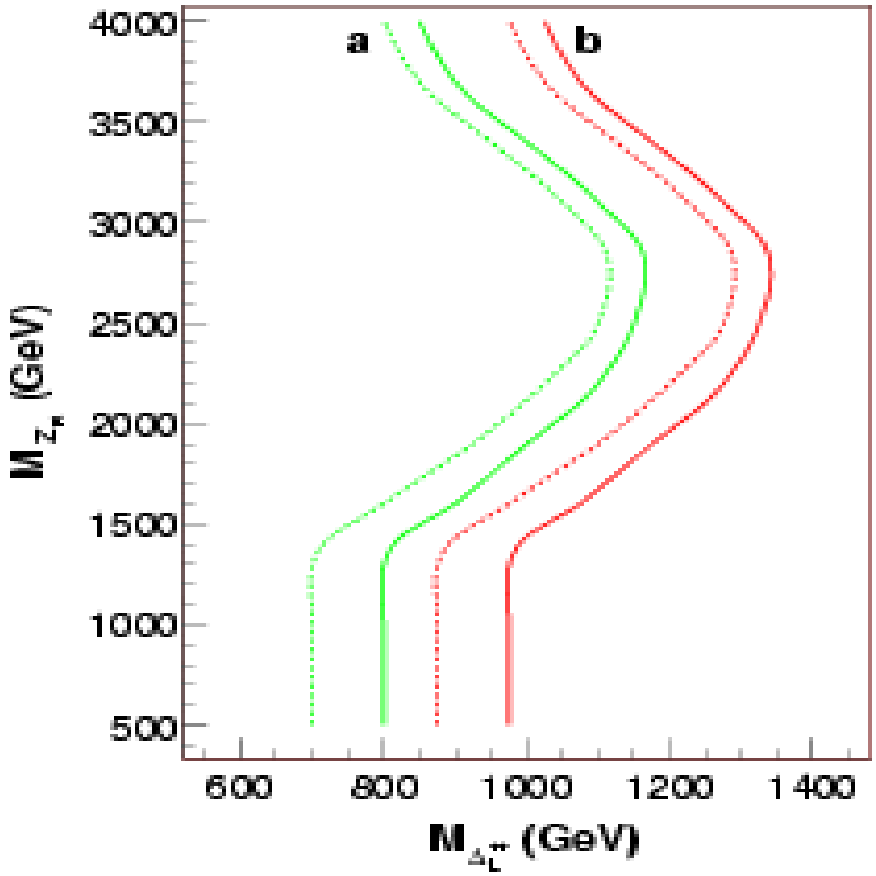
$\Delta_L^{++}\Delta_L^{--} \rightarrow l^+l^+l^-l^-$



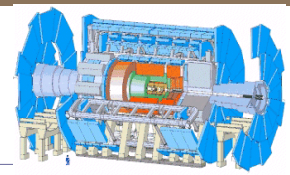
(a) 100 fb-1
(b) 300 fb-1

Full = 3 leptons are observed

Dashed = 4 leptons are observed



Right Handed DCH



Signal cross section:

$M(W_R^+)$	$M(\Delta_R^{++})$				
	300	500	800	1000	1500
650	7.9	4.6	2.2	1.4	0.45
750	4.7	2.8	1.4	0.87	0.31
850	2.9	1.8	0.90	0.58	0.21
950	1.9	1.2	0.61	0.40	0.15
1000	1.6	0.98	0.50	0.33	0.12
1050	1.3	0.81	0.42	0.28	0.11
1500	0.30	0.20	0.11	0.074	0.029

(1)

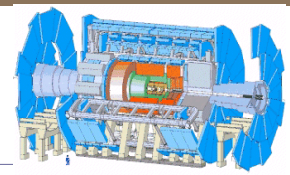
Backgrounds cross section:

Background	Number of Events	$\sigma \times BR$ (fb)
$pp \to W\bar{t}t$	200 000	23
$qq \to W^+W^+\,qq$	100 000	37
$qq \to WZqq$	27 000	28.6
$qq \to t\bar{t}$ P_t 10-200 GeV	8 000 000	90 800
$qq \to t\bar{t}$ P_t 200 GeV-∞	2 000 000	14 100

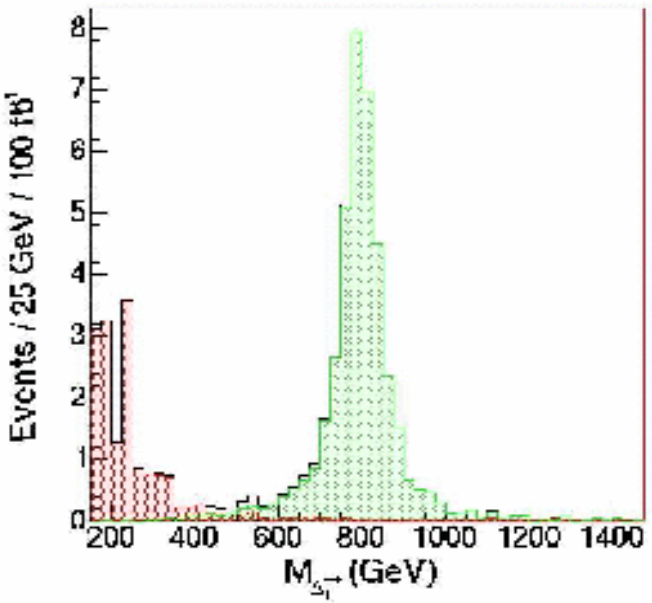
(2)

The gauge bosons were required to decay leptonically

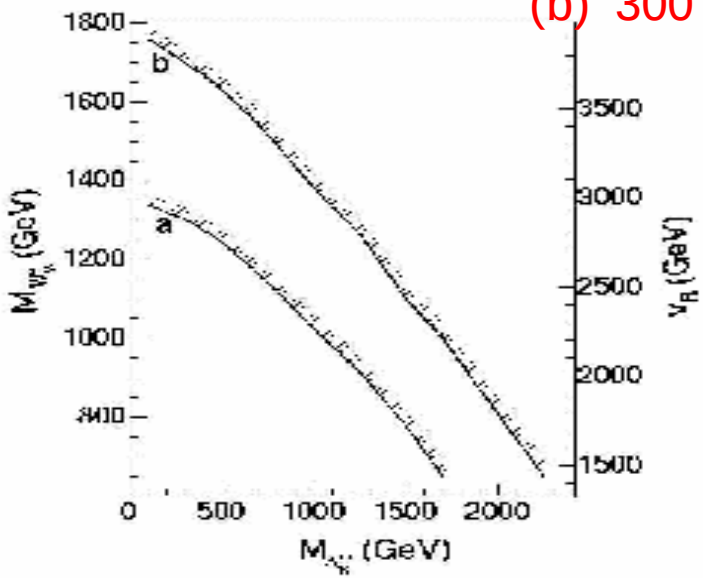
$\Delta_R^{++} \rightarrow l^+ l^+$



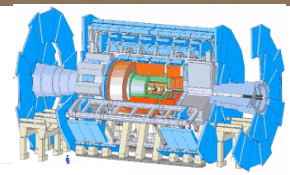
	Δ^{++} 300 GeV	Δ^{++} 800 GeV	$W^+W^+\,qq$	$W\,t\bar{t}$	$WZqq$	$t\bar{t}$	total backg
Isolated leptons	278 (327)	63 (95)	109/12	7.6/0.6	0/0.8	17/0	133/13
Lepton P_T	256 (301)	63 (94)	63/11	5.9/0.5	0/0.8	1.1/0	70/12
$2.4(P_T^{l_1}+P_T^{l_2})-M_{ll}>480$	191(227)	59(85)	10/2.1	1.3/0.3	0	0	12/2.4
Fwd Jet tagging	156(186)	56(74)	6.0/1.3	0.1/0	0	0	6/1.3
ptmiss	154(181)	56(68)	3.0/0.3	0/0	0	0	3.1/0.3



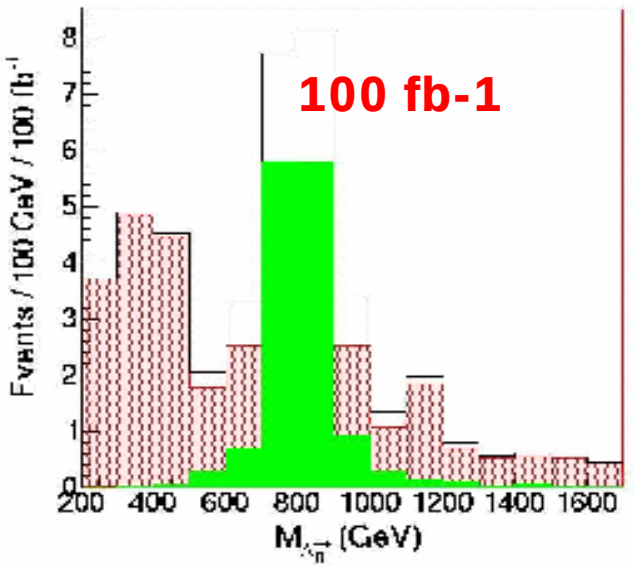
(a) 100 fb-1
(b) 300 fb-1



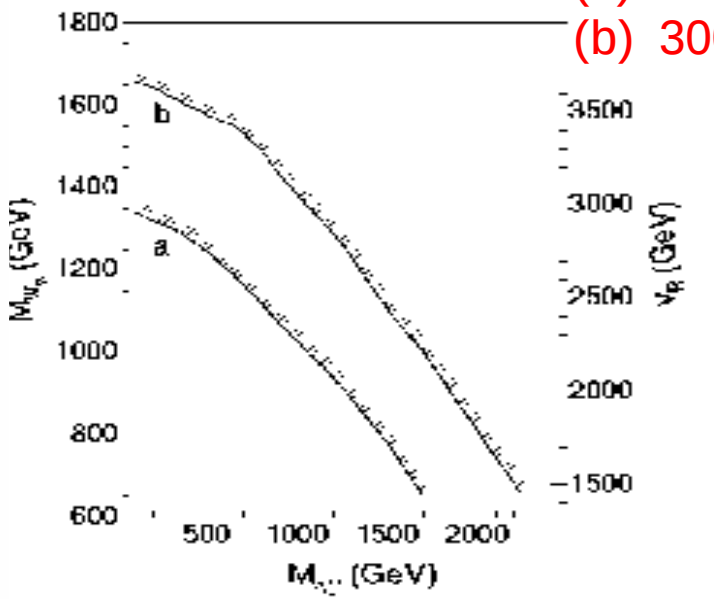
$\Delta_R^{++} \rightarrow \tau^+\tau^+$



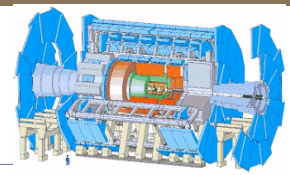
	Δ^{++} 300 GeV	Δ^{++} 800 GeV	W^+W^+qq	$W t\bar{t}$	$WZqq$	$t\bar{t}$	total backg
Isolated leptons	~~44~~ (~~49~~)	20 (23)	153/80	13/5.1	12/0.7	~~486~~/137	707/234
$0 < x_{\tau 1},\ x_{\tau 2} < 1$	~~44~~ (~~46~~)	20 (21)	~~84~~/60	6.~~4~~/3.3	8.0/0.7	360/101	~~480~~/171
no b-jet	~~42~~ (~~44~~)	18(21)	~~84~~/59	0.2/0.2	7.2/0.7	62/16	175/83
Fwd Jet tagging	36 (~~34~~)	16 (18)	21/15	0/0	2.3/0	20/7.~~4~~	~~45~~/23
$E_T^{miss} > 150$ GeV	23 (25)	13 (15)	5.2/7.2	0/0	0.8/0	2.5/2.1	8.6/9.3



(a) 100 fb-1
(b) 300 fb-1



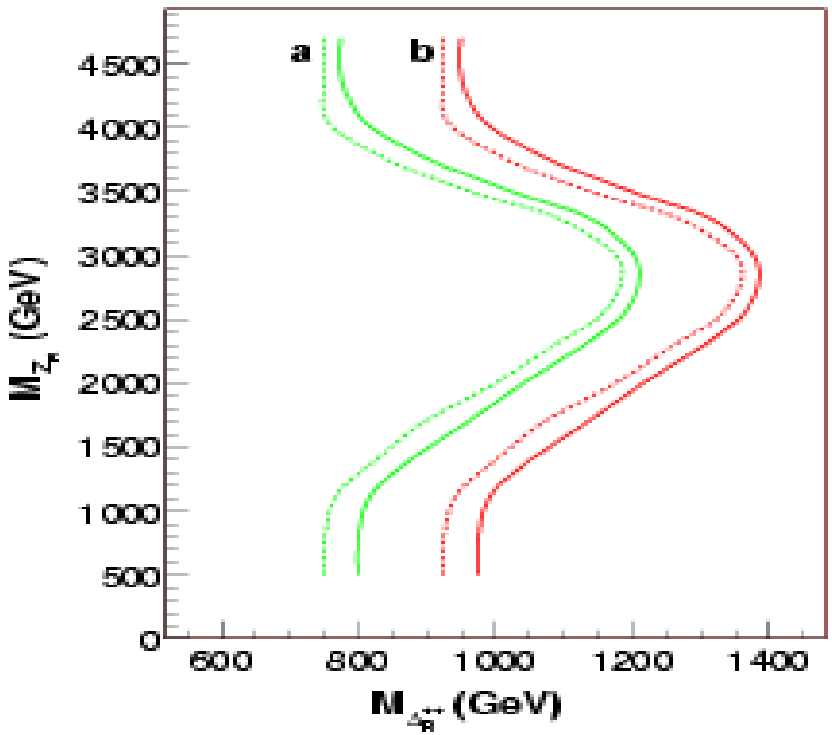
$\Delta_R^{++}\Delta_R^{--} \rightarrow l^+l^+l^-l^-$



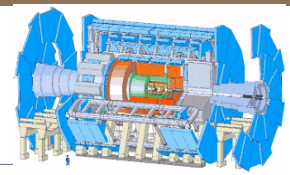
Dashed = 4 leptons are observed

Full = only 3 leptons are observed

(a) 100 fb-
(b) 300 fb



Summary



- ✓ DCH predicted in the LR Symmetric Model should yield a striking signature at LHC
- ✓ LHC will be able to probe a large region of unexplored parameter space in the triplet Higgs sector
- ✓ Validation of the present analysis using full simulation has already started.

Full Simulation Studies

Signal:

$M(\Delta_L^{++}) = 500\ GeV;\ \Delta^{++} \rightarrow e^+ e^+$

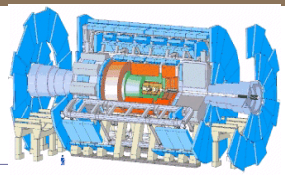
Backgrounds :

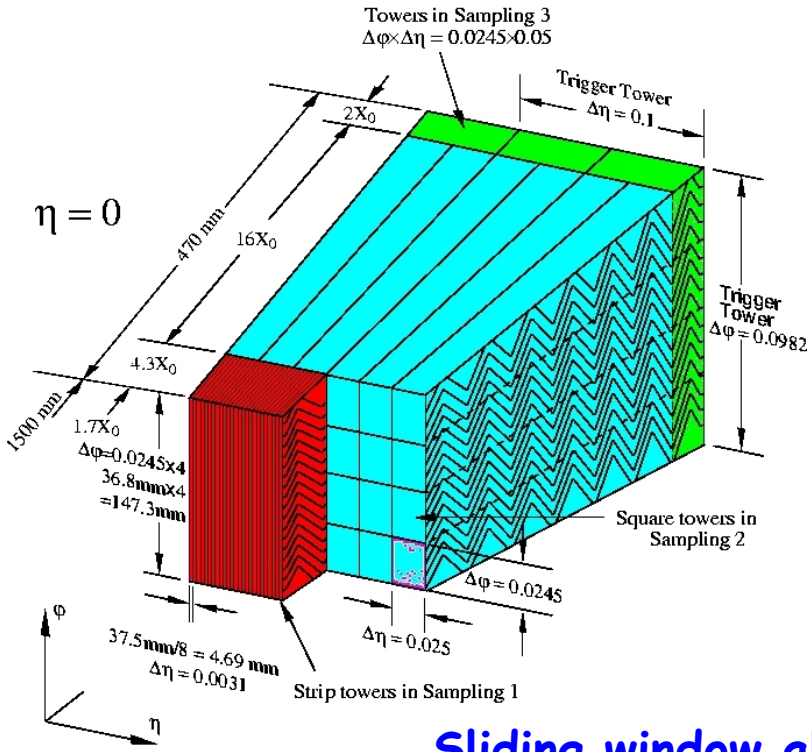
qqww with leptonic decays of both w's

Event Selection:

Two same signe high Pt electrons

H. Pt Electrons reconstruction at ATLAS





3 longitudinal samplings

Fine granularity:

- sampling 1 : ~ 6 X0, $\Delta\eta \times \Delta\varphi \sim 0.003 \times 0.1$
- sampling 2 : ~ 18 X0 $\Delta\eta \times \Delta\varphi \sim 0.025 \times 0.025$
- sampling 3 : ~ 6 X0 $\Delta\eta \times \Delta\varphi \sim 0.05 \times 0.025$

good energy resolution

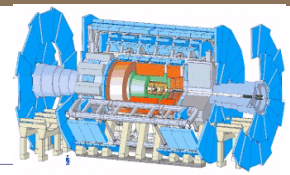
$$\sigma(E)/E \sim 10\%/\sqrt{E} \oplus 0.7\%$$

excellent angular/position resolution and particle identification capability

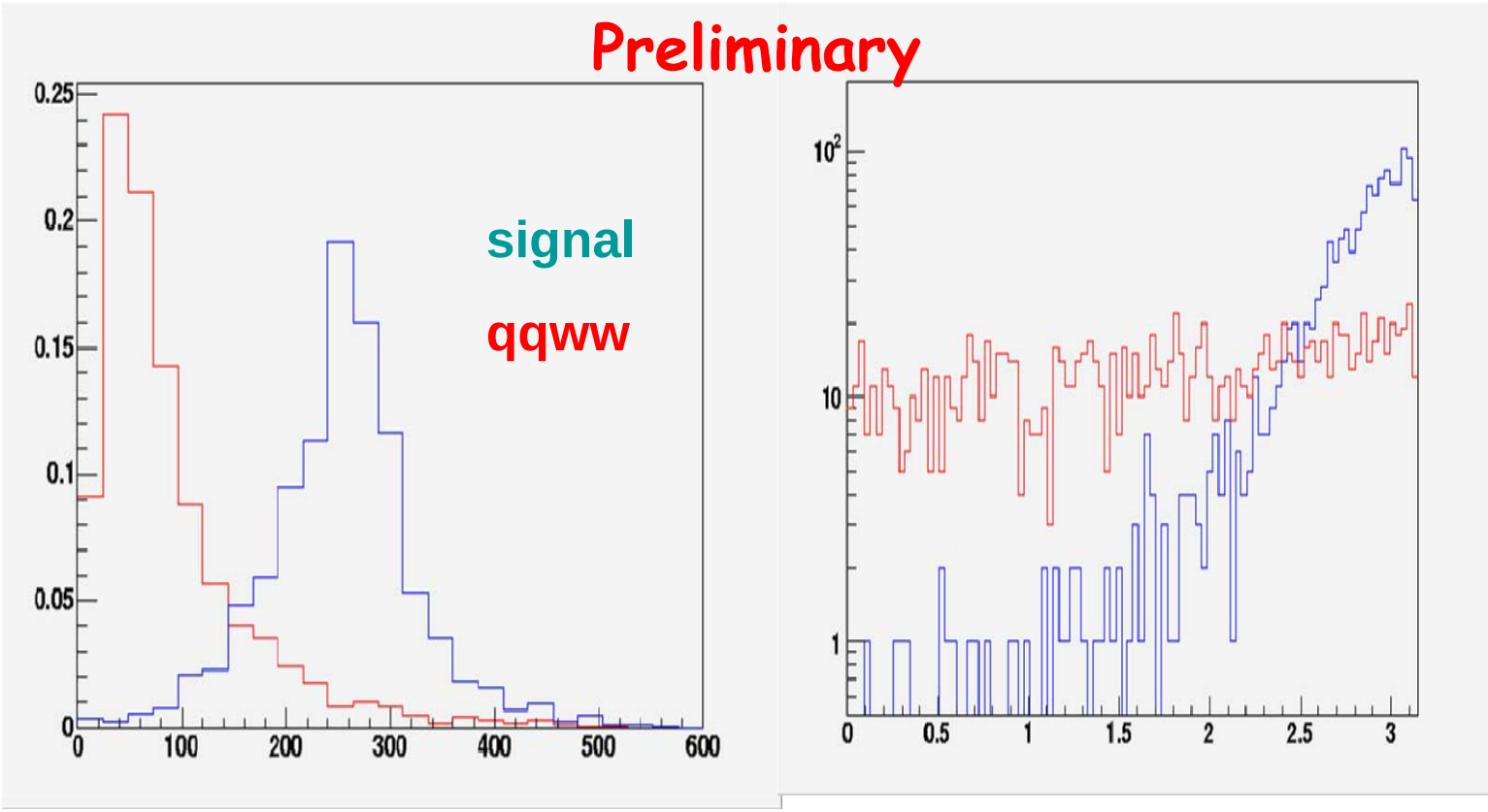
Sliding window algorithm. For each cluster the best ID track is searched for within a given E/P range.

Cuts: Had. Leakage, shower shape, first samp.

Full Simulation Studies (I)



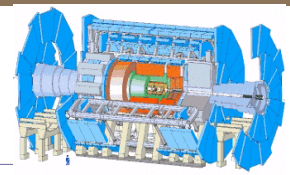
Preliminary



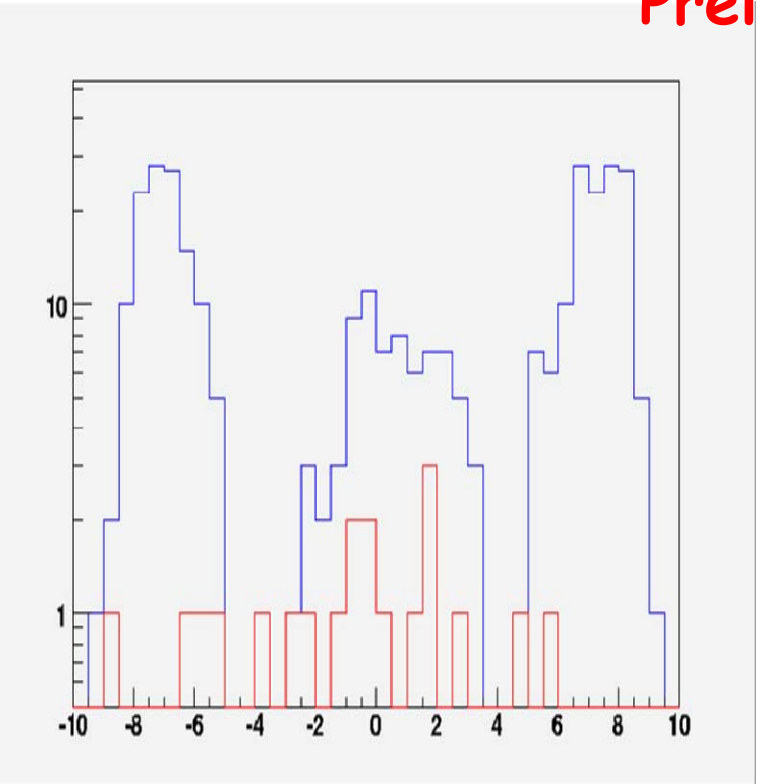
P_l^T

$\Delta\phi_{ll}$

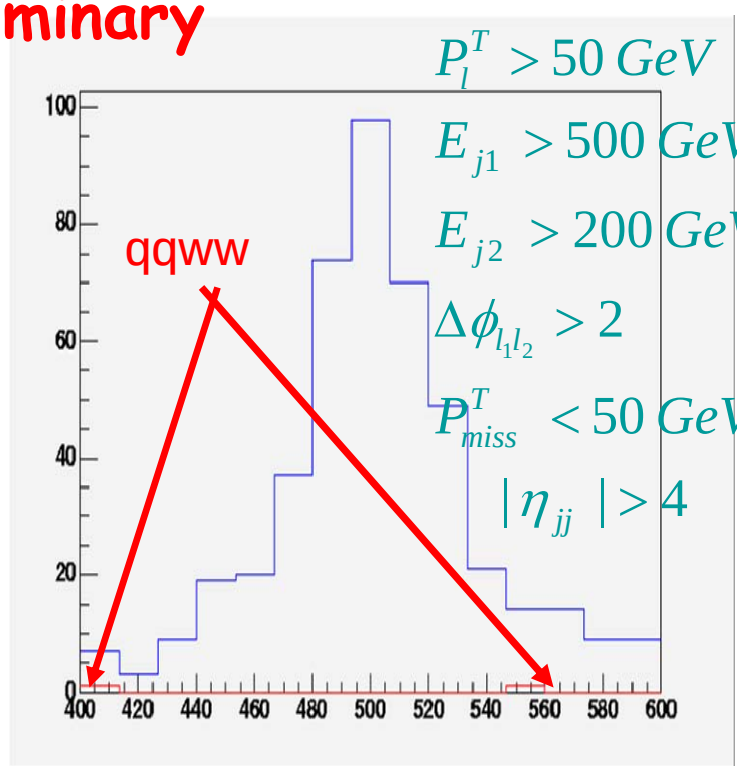
Full Simulation Studies (II)



Preliminary

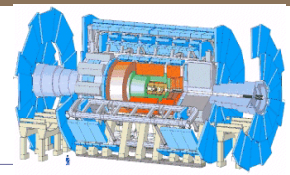


$\Delta\eta_{jj}$

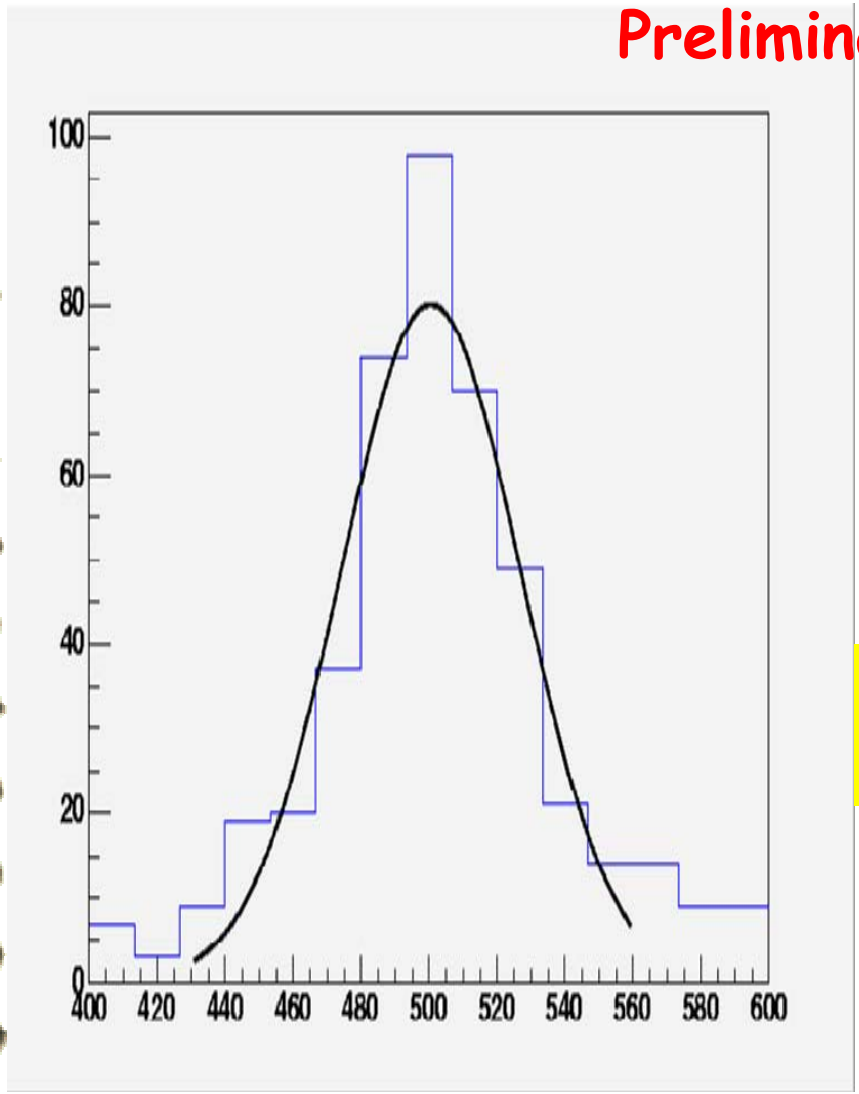


M_{ll}

Full Simulation Studies (III)



Preliminary



Full Simulation:

$\mu = 500 .5 \pm 1.41\ GeV$

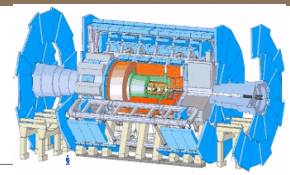
$\sigma = 26 .5 \pm 1.6\ GeV$

ATLFAST

$\mu = 499 \pm 0 .8\ GeV$

$\sigma = 27 \pm 0 .9\ GeV$

Other Possible Triplet at ATLAS



$\tilde{H}^{\pm\pm}$

- Signatures depends on NLSP
- Need to implement and validate MC generators