Prospects for early discoveries in final states with di-leptons, jets and no missing energy: LRSM and Leptoquarks…

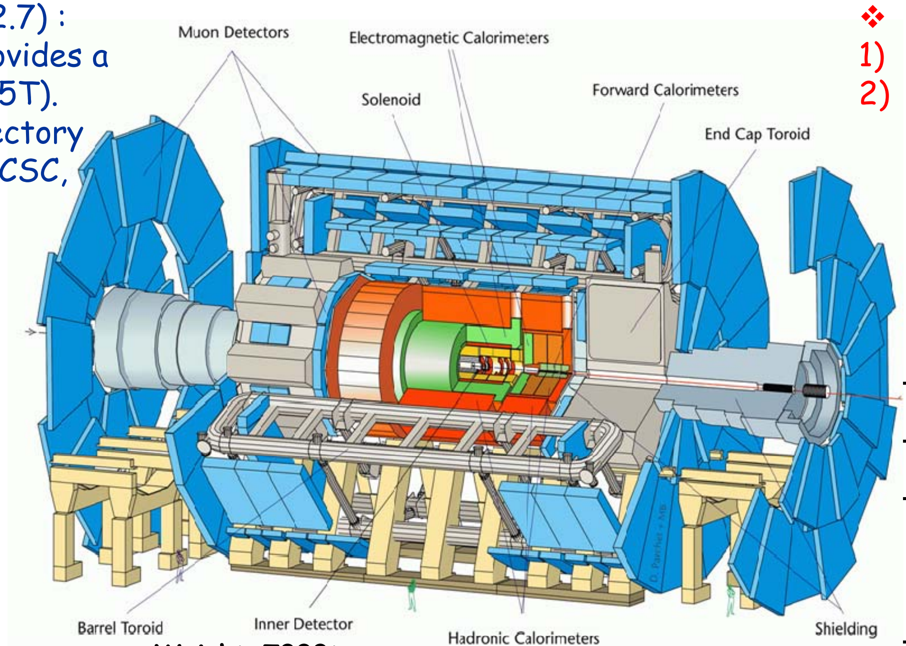
Chaouki Boulahouache
University Of Pittsburgh
On behalf of the ATLAS Collaboration

- The ATLAS detector
- Motivation
- Current Limits and Monte-Carlo Studies
- Event Selection and Reconstruction
- Background Studies/Suppression
- Systematic Uncertainties
- Discovery potential
- Summary

ATLAS Detector

❖ Calorimeter (|η|<5):
1) EM : Pb-LAr
2) HAD: Fe/scintillator (central), Cu/W-LAr (fwd).

❖ Muon Spectrometer (|η|<2.7) :
1) Air-core toroids which provides a toroidal magnetic field (0.5T).
2) Muon momentum and trajectory are measured using MDT, CSC, RPC and TGC chambers



Weight~7000tons
Dimensions: length=55m. width=32m. height=35m.

❖ Inner detector (|η|<2.5, B=2T)
1) Si pixels and strips
2) Transition Radiation Detector (e/π separation).

E, pT (GeV)	Resolution
Inner Det.	$\sigma/pT \sim 5\times10^{-4} + 0.01$
EM-Calo	$\sigma/E \sim 0.1/\sqrt{E} + 0.007$
HAD-Calo	
--Barrel	$\sigma/E \sim 0.5/\sqrt{E} + 0.03$
--forward	$\sigma/E \sim 1.0/\sqrt{E} + 0.1$
Muon	$\sigma/pT \sim 0.07$ at 1TeV.

➢ There are three trigger levels, namely L1, L2 and EF.
❖ Each trigger level is uncorrelated with the other two.
❖ A candidate event is considered if it passes all three trigger levels.
❖ For the analyses to be shown in this talk, we rely on single lepton trigger streams with relatively low thresholds in order to obtain high overall trigger efficiencies.

Motivation for LQs…

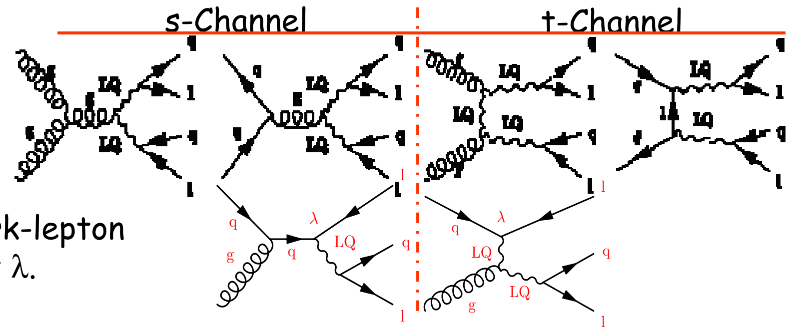
- Do leptons and quarks interact? Why such interaction is needed?
- Hypothesize an unusual colored boson (called "Leptoquark"), can be either scalar or vector.
- Couples to leptons and quarks, carries baryon and lepton numbers, color and fractional electric charge[1].
- Provides an explanation for the symmetry between leptons and quarks.
- Three generations: favored by experimental limits from lepton number violation, flavor-changing neutral currents, and proton decay.

[1]Pati and Salam 'Lepton number as the fourth "color". ' Phys. Rev. D10 (1974).

How Leptoquarks are produced at Hadron colliders?

In pairs via the strong interaction.

In association with a lepton via the leptoquark-quark-lepton coupling, where the coupling constant is denoted by λ.



Experimental signature for a LQ pair is: two high pT leptons and two high pT jets. (since LQs are relatively heavy objects).

LQs: Current Limits and Signal Simulation…

- Latest experimental limits are coming from Tevatron experiments (D0 & CDF), for β=1 (branching ratio of a leptoquark decaying to a charged lepton and a quark), the 95%CL limits are:

1) First generation scalar LQ(eq), m_{LQ1}>256GeV and m_{LQ1}>236GeV, from D0[1] and CDF[2] based on integrated ppbar luminosities of ~ 250pb^{-1} and 200pb^{-1} respectively.
2) Second generation scalar LQ(μq), m_{LQ2} >251GeV and m_{LQ2} >226GeV, were obtained with 300 pb^{-1} and 200 pb^{-1} by the D0[3] and CDF[4] experiments, respectively.

[1]Abazov, V. M. et al "Search for first-generation scalar leptoquarks in P Anti-P Collisions at √s =1.96-TeV", Phys. Rev. D71 (2005).
[2]Darin E. Acosta et al "Search for first-generation scalar leptoquarks in p anti-p collisions at s**(1/2) = 1.96-TeV", Phys. Rev. D72 (2005).
[3]V.M. Abazov et al, "Search for pair production of second generation scalar leptoquarks in p anti-p collisions at s**(1/2) = 1.96-TeV". Phys.Lett.B636 (2006).
[4]A. Abulencia et al, "Search for second-generation scalar leptoquarks in p anti-p collisions at s**(1/2) = 1.96-TeV". Phys.Rev.D73 (2006).

- MC generator Pythia was used to simulate 1st and 2nd generation scalar leptoquarks. (4 mass points)

M(LQ) (GeV)	σ(pp→LQ LQ) (NLO) (pb)
300	10.1±1.5
400	2.24±0.376
600	0.225±0.048
800	0.0378±0.0105

Motivation for LRSMs…

❑Why do neutrinos need right handed partners?

➢In Standard Model neutrinos are massless, but neutrinos are proven to oscillate (Super-K, Phys. Rev. Lett. 81 (1998)), therefore they should have mass ➔ direct indication for new physics beyond SM.

➢In many models M_N appears naturally, most attractive one is LR Symmetric Models ($SU(3)_C X SU(2)_L X SU(2)_R X U(1)_{B-L}$).

❑Will this explain parity violation?

➢Left-right models were introduced in 1974-1975 (R. N. M., Pati, Senjanovic) mainly to understand the origin of P-violation, but later interesting properties emerged:

✓Generate Majorana neutrino states N_l (partners of light neutrinos) ($l=e, \mu, \tau$), together with new gauge bosons W_R and Z'.

✓Neutrino masses generated via "See-Saw" mechanism (**M_N~0.1- 1** TeV).

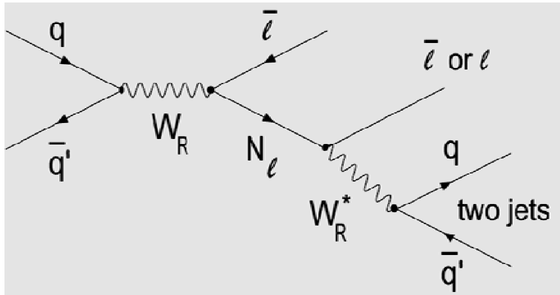
✓Parity violation is generated naturally.

✓Baryogenesis via Leptogenesis (B-L conservation).

How W_R and N_R are produced at Hadron colliders?

➢W_R is produced via quark-antiquark interaction.

➢Majorana neutrino produced through the W_R decay.



➢Experimental signature is two high pT leptons and two high pT jets. (Since W_R is a heavy object)

LRSM: Current Limits and Signal Simulation…

- Indirect limit: K_L-K_S mass difference[1] which implies $M(W_R)>(1.6^{+1.2}_{-0.7})$TeV.
- Latest experimental limits from D0[2] experiment, a lower mass for the W_R limit of 739GeV assuming it decays to both lepton pairs and quark pairs and 768GeV assuming the W_R would decay to quark pairs.

[1] G. Barenboim, J. Bernabeu, J. Prades, M. Raidal PRD55,1997
[2]Abazov, V. M. et al, arXiv:0803.3256v1 (2008).

- Signals have been simulated using MC generator Pythia.
- Two mass points have been simulated namely: LRSM_18_3=(W_R=1800GeV & N_R=300GeV) and LRSM_15_5=(W_R=1500GeV & N_R=500GeV), where the LO cross-section is 24.8pb and 47.0pb respectively.
- Assumptions:
  1. The SM axial and vector couplings.
  2. The CKM matrix for the quark sector.
  3. No mixing between the new and SM intermediate vector bosons.
  4. Phase space isotropic decays of Majorana neutrinos.
- The Majorana nature of the new heavy neutrinos allows for same-sign and opposite-sign di-leptons. The same-sign di-leptons will be used to make a low background cross-check.

Basic Object/Event Selection And Reconstruction…

Basic Selection Criteria

- Electron candidates are identified as:
  1) Energy clusters reconstructed in the EM calorimeter matched to tracks in the inner detector.
  2) Satisfy various shower-shape and track-quality cuts.
  3) $pT > 20$ GeV.
  4) $|\eta| < 2.5$.

- Muons candidates are identified as:
  1) Tracks in the inner tracking detector matched with tracks in the muon spectrometer and satisfy muon energy isolation in the calorimeter
  2) $pT > 20$ GeV.
  3) $|\eta| < 2.5$.

- Jets are identified as:
  1) Energy clusters reconstructed in the calorimeters using a $\Delta R=0.4$ cone algorithm.
  2) $pT > 20$ GeV
  3) $|\eta| < 4.5$
  4) ΔR (between a jet and any electron candidate) ≥ 0.1 (to avoid electrons being misidentified as jets).

❖ Event selection: require at least two leptons (where M(ll) > 70GeV) and at least two jets.

❖ For LQs: Require that the two leptons are oppositely charged.

- LQs reconstruction:
  1) Combine any of the two high pT jets with any of the two high pT leptons.
  2) Accept only the two combinations that have the smallest difference.

- N_R reconstruction:
  1) Combine the two high pT jets with either of the two high pT leptons
  2) Accept only the combination that gives the smaller invariant mass (99% correct).
  3) For dielectron-channel: cases where $0.1 < \Delta R$ (electron, jet) < 0.4, only jets are used to avoid double counting (cases where $M(W_R) \geq 2 * M(N_R)$). The diμ-channel does not have such problem.
- W_R reconstruction: Combine the above result with the remaining high pT lepton.

- Overall offline trigger efficiency for di-lepton events that satisfy all selection criteria exceeds 95%.

MC Study: Background Contribution/Suppression

- The main sources of background are:

1) TTbar
2) Z/DY+jets
3) Di-Bosons (WW, WZ, ZZ) → Small contribution
4) Multi-jet production → No contribution to the diμ-channel, but affects the dielectron-channel
5) Other potential background sources, such as single-top production, were studied and found to be insignificant.

- The kinematics property of the new physics events (large expected masses) implies simple background selection criteria.
- Variables used for background suppression, in both analyses:
  1) $S_T=(pT_{jet1}+pT_{jet2}+pT_{lep1}+pT_{lep2})$
  2) Dilepton mass: M(ll)

> Cuts have been optimized for both searches and for each lepton channel (see next slides).

- For LQ,
  1) M(lepton+jet): For the dielectron-channel, background due to jets misidentified as electrons is greatly reduced by requiring each M(e+jet) to be close to the tested LQ mass. However, this is not used in the diμ-channel but a requirement that the average mass is consistent with the tested LQ mass.
  2) Charge correlation: Lepton charge correlation was used for LQs in the event selection.

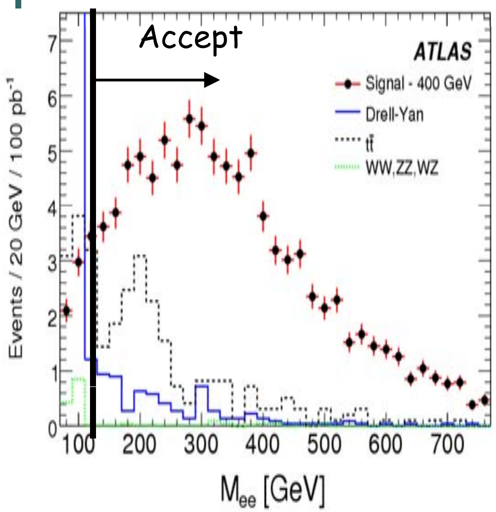
> The background suppression criteria were optimized for 5σ discovery at the lowest possible luminosity. But special care was taken to make sure we do not bias against relatively low masses.

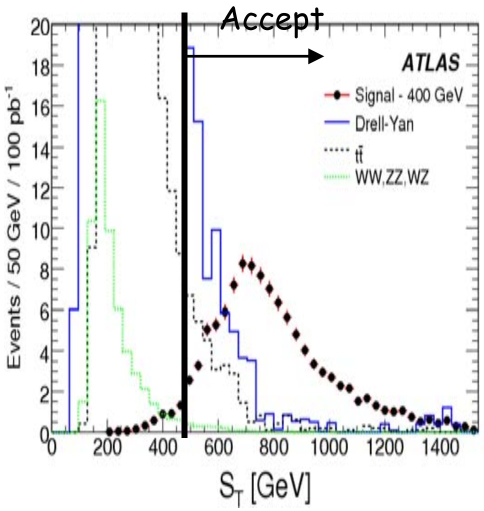
Preliminary

Background Suppression: LQ (dielectron-channel) (e.g.:400GeV Case)

❖ Distribution background suppression variables.

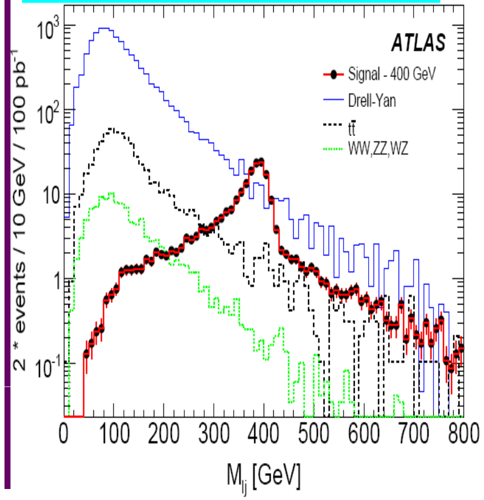
Dilepton invariant mass | **S_T:pT scalar sum**



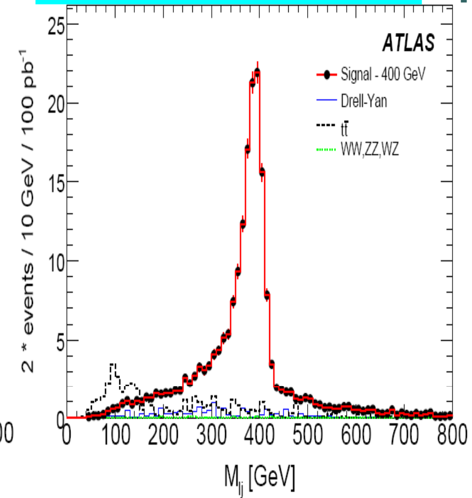


❖ Lepton+jet Invariant mass distribution

After basic selection but before background suppression



After basic selection and after background suppression



- The background is dominated by ttbar for relatively light Leptoquarks and will be dominated by Z/DY for higher masses.
- Reconstruction efficiency after background suppression ~24% for 400GeV goes down to 20% for the 800GeV case.

❖ Remaining partial cross section after each cut.

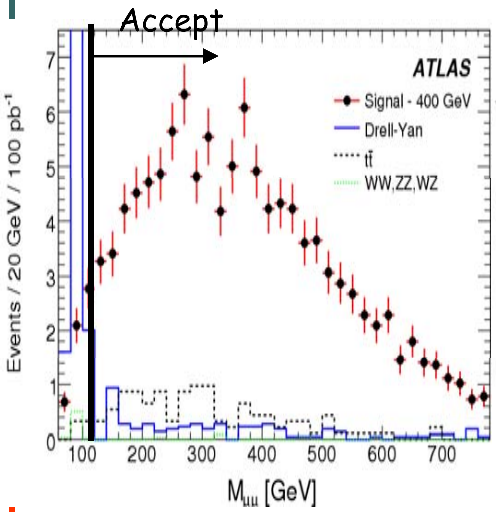
Physics sample	Before selection	Baseline selection	S_T ≥ 490 GeV	M_{ee} ≥ 120 GeV	M^1_{lj} - M^2_{lj} mass window in GeV [320 - 480] - [320 - 480]	[700 - 900] - [700 - 900]
LQ (400 GeV)	2.24	1.12	1.07	1.00	0.534	-
LQ (800 GeV)	0.0378	0.0177	0.0177	0.0174	-	0.0075
$Z/DY \geq 60$ GeV	1808.	49.77	0.722	0.0664	0.0036	0.00045
$t\bar{t}$	450.	3.23	0.298	0.215	0.0144	0.0
VB pairs	60.94	0.583	0.0154	0.0036	0.00048	0.0
Multijet	10^8	20.51	0.229	0.184	0.0	0.0

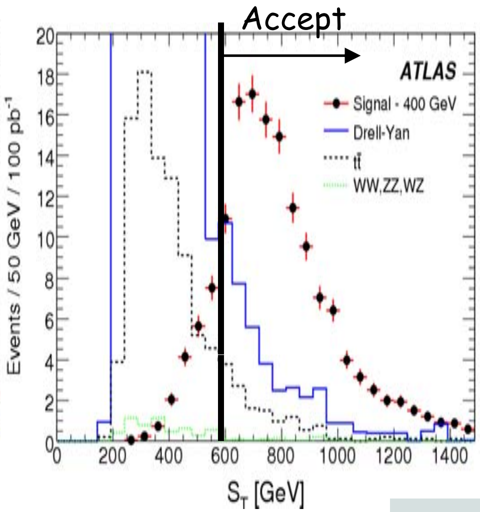
Background Suppression: LQ (diμ-channel) (e.g.:400GeV Case)

Preliminary

❖ Distribution background suppression variables.

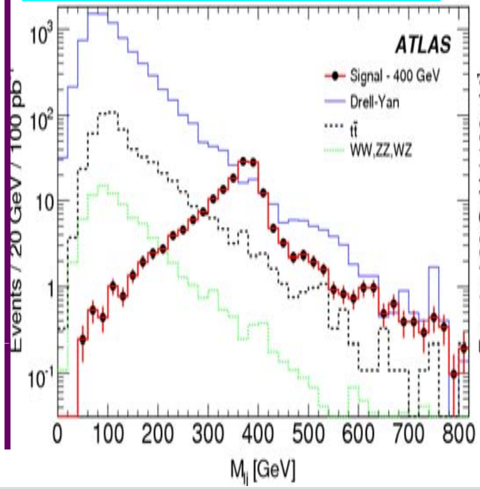
Dilepton invariant mass | **S_T:pT scalar sum**



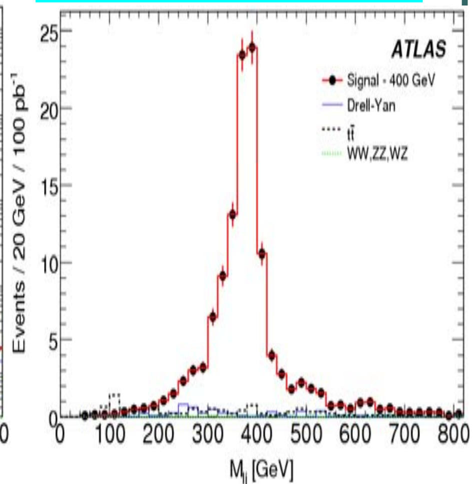


❖ Lepton+jet Invariant mass distribution

After basic selection but before background suppression



After basic selection and after background suppression



- The background is dominated by Z/DY processes and ttbar for relatively light Leptoquarks but for higher masses, Z/DY will be the dominating source.
- No Multi-jet contribution.
- Reconstruction efficiency after background suppression ~44% for 400GeV goes up to 57% for the 800GeV case.

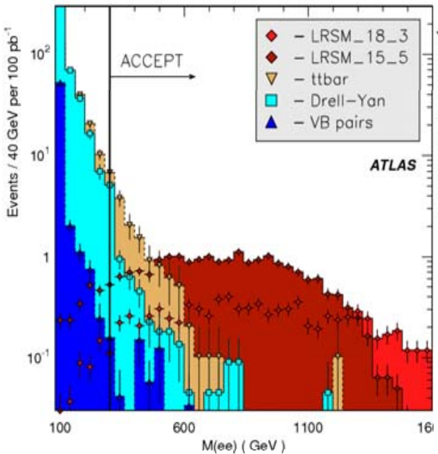
❖ Remaining partial cross section after each cut.

Physics sample	Before selection	Baseline selection	$p_T^{\mu}\geq 60$ GeV $p_T^{jet}\geq 25$ GeV	S_T ≥ 600 GeV	$M(\mu\mu)$ ≥ 110 GeV	M_{lj} mass window in GeV [300 - 500]	[600 - 1000]
LQ (400 GeV)	2.24	1.70	1.53	1.27	1.23	0.974	-
LQ (800 GeV)	0.0378	0.0313	0.0306	0.0304	0.030	-	0.0217
$Z/DY \geq 60$ GeV	1808.	79.99	2.975	0.338	0.0611	0.021	0.014
$t\bar{t}$	450.	4.17	0.698	0.0791	0.0758	0.0271	0.0065
VB pairs	60.94	0.824	0.0628	0.00846	0.00308	0.00205	0.000758
Multijet	10^8	0.0	0.0	0.0	0.0	0.0	0.0

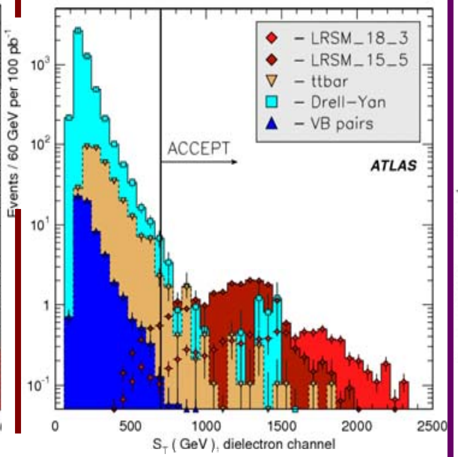
Background Suppression: LRSM (dielectron-channel).

Preliminary

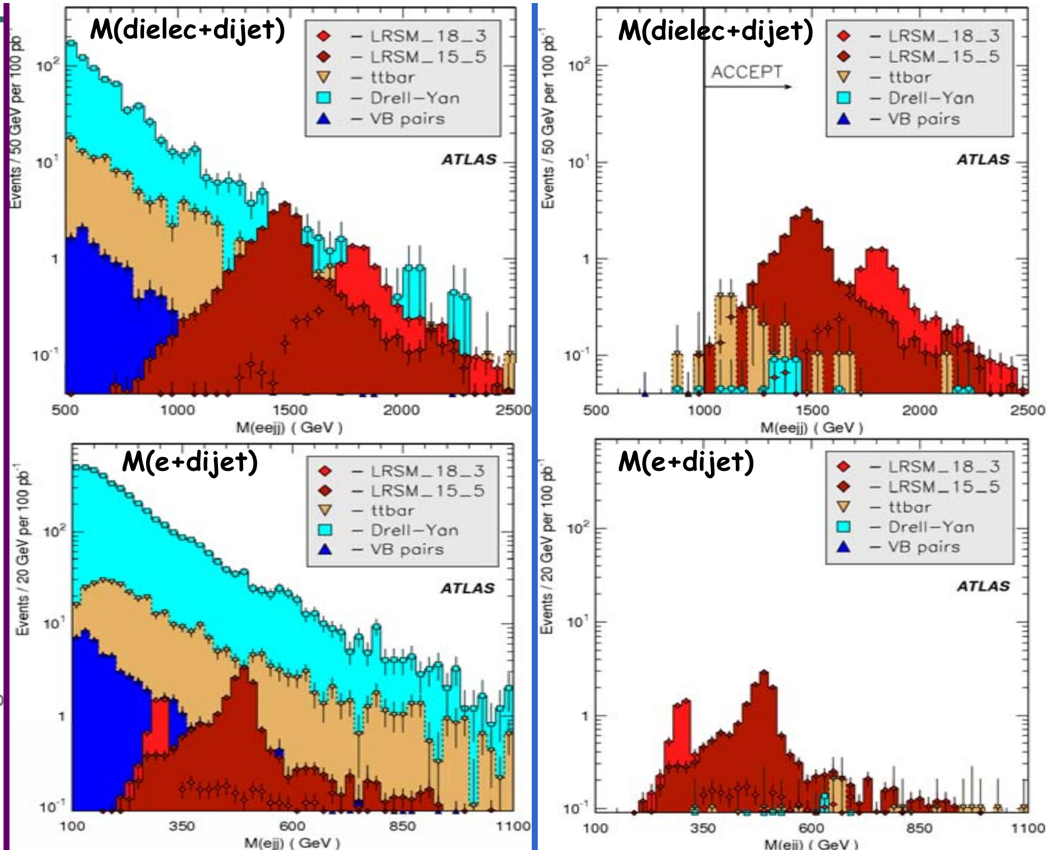
Di-elec. invariant mass



S_T:pT scalar sum



❖ Distribution background suppression variables.



After basic selection but before background suppression

After basic selection and after background suppression

- The background is dominated by ttbar.
- Multi-jets do not contribute to the signal region.
- Reconstruction efficiency after background suppression ~32% for LRSM_18_3 goes up to 39% for the LRSM_15_5.

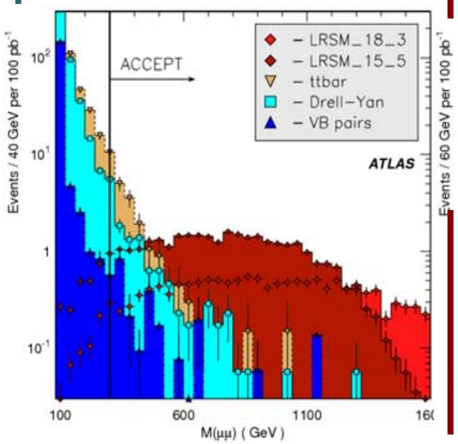
❖ Remaining partial cross section after each cut.

Physics sample	Before selection	Baseline selection	$M(ejj) \geq 100$ GeV	$M(eejj) \geq 1000$ GeV	$M(ee) \geq 300$ GeV	$S_T \geq 700$ GeV
LRSM_18_3	0.248	0.0882	0.0882	0.0861	0.0828	0.0786
LRSM_15_5	0.470	0.220	0.220	0.215	0.196	0.184
$Z/DY \geq 60$ GeV	1808.	49.77	43.36	0.801	0.0132	0.0064
$t\bar{t}$	450.	3.23	3.13	0.215	0.0422	0.0165
VB pairs	60.94	0.583	0.522	0.0160	0.0016	0.0002
Multijet	10^8	20.51	19.67	0.0490	0.0444	0.0444

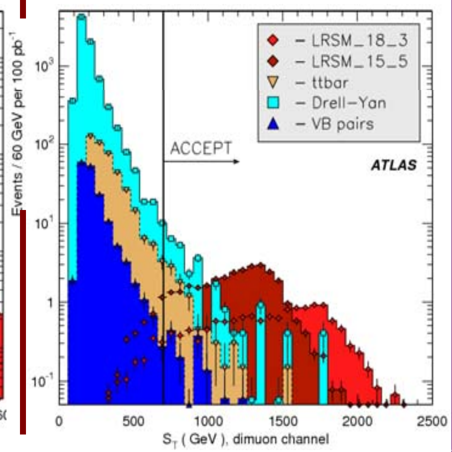
Background Suppression: LRSM (diμ-channel).

Preliminary

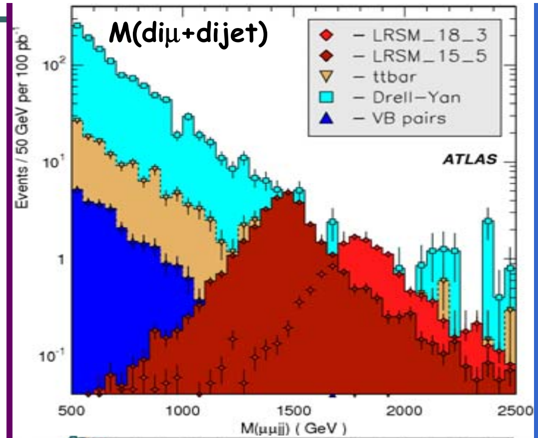
Di-μ invariant mass

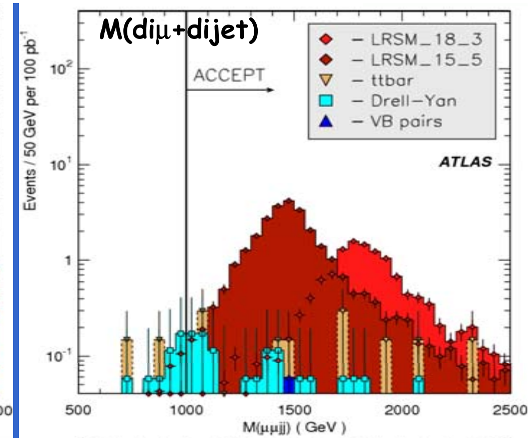


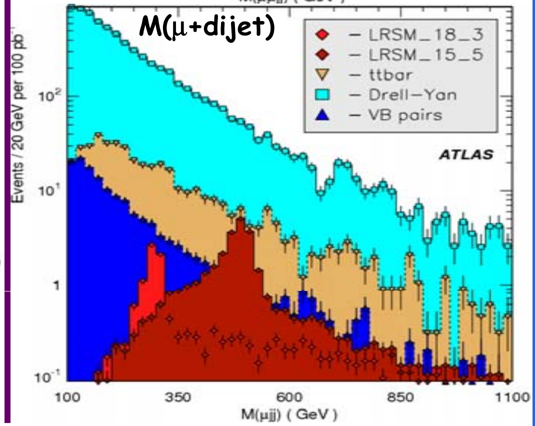
S_T:pT scalar sum

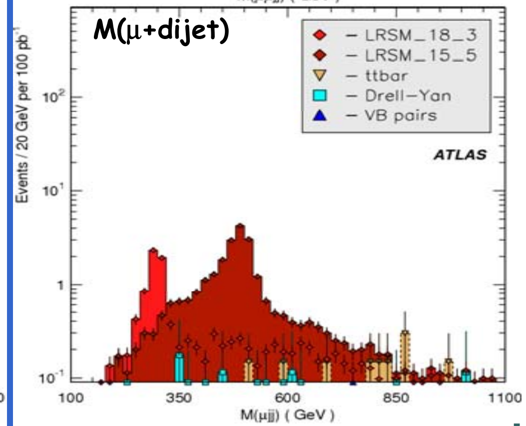


❖ Distribution background suppression variables.









After basic selection but before background suppression

After basic selection and after background suppression

- ➢The reconstruction efficiency is higher in the μ-channel than in the e-channel due to the cut on the angular distance between electrons-jets though the peak resolution is wider in the μ-channel (mainly because of worsening in the muon pt measurement resolution).
- ➢The background is dominated by Z/DY processes and ttbar.
- ➢ No Multi-jet contribution.
- ➢Reconstruction efficiency after background suppression ~52% for LRSM_18_3 goes up to 58% for the LRSM_15_5.

❖ Remaining partial cross section after each cut.

Physics sample	Before selection	Baseline selection	$M(\mu jj) \geq 100$ GeV	$M(\mu\mu jj) \geq 1000$ GeV	$M(\mu\mu) \geq 300$ GeV	$S_T \geq 700$ GeV
LRSM_18_3	0.248	0.145	0.145	0.141	0.136	0.128
LRSM_15_5	0.470	0.328	0.328	0.319	0.295	0.274
$Z/DY \geq 60$ GeV	1808.	79.99	69.13	1.46	0.0231	0.0127
$t\bar{t}$	450.	4.17	4.11	0.275	0.0527	0.0161
VB pairs	60.94	0.824	0.775	0.0242	0.0044	0.0014
Multijet	10^8	0.0	0.0	0.0	0.0	0.0

Preliminary Systematic Studies…

Preliminary

- A preliminary estimation of systematic uncertainties is summarized (conservative estimate for early data based on ~ 100pb^{-1}):

1) Luminosity: 20%.
2) Lepton identification, trigger and reconstruction efficiencies: electron (2%), muon(5%).
3) Lepton energy scale: 1%
4) Lepton resolution (pT (GeV)): electron($0.66*(0.1/\sqrt{pT}+0.007)$) and muon ($0.011/pT+0.00017$).
5) Jet energy scale: 10% for $|\eta|\leq 3.2$ and 20% for $|\eta|>3.2$
6) Jet energy resolution a trade off between pessimistic and optimistic estimates (E(GeV)): $[0.6,0.75]/\sqrt{E} + [0.05,0.07]$ for $|\eta|\leq 3.2$ and $[0.9,1.10]/\sqrt{E} + [0.07,0.10]$ for $|\eta|>3.2$
7) Ttbar (DY) cross-section: 12% (10%).

Total Syst. effects	for signal events		for background events	
	di-elec	di-μ	di-elec	di-μ
LQ	±27%	±29%	±53%	±51%
W_R	±23%	±25%	±45%	±40%

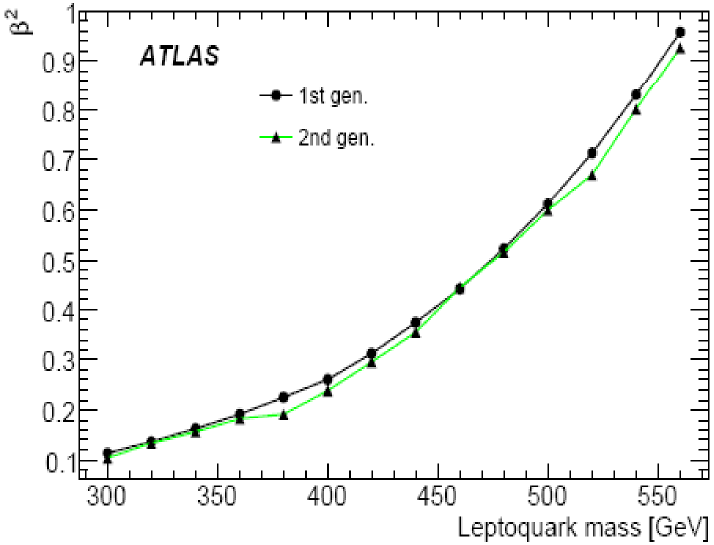
- The systematic effects are dominated by uncertainty in integrated pp luminosity (20%), the jet energy scale (16%-35%), jet resolution (6%-28%), and the limited statistics of background MC samples (15%-30%).

Discovery Potential for Leptoquarks…

Preliminary

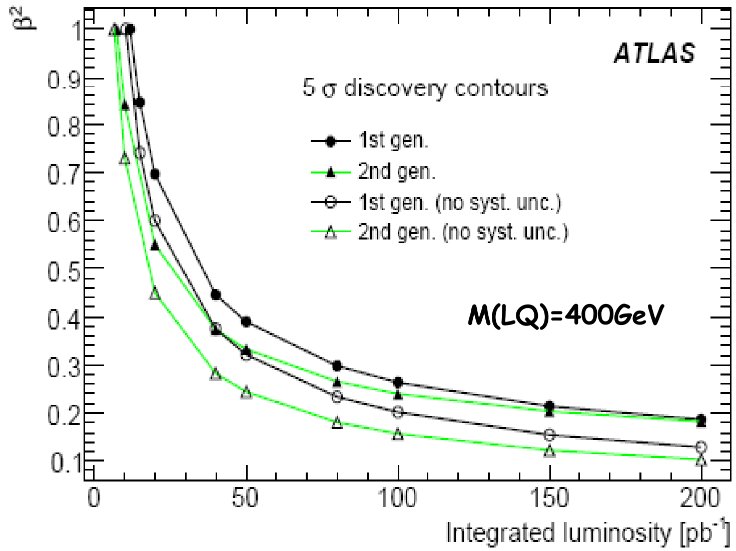
➢Minimum β^2 of scalar leptoquark needed for a 5σ discovery at 100 pb^{-1} of total integrated pp luminosity (background systematic uncertainty included):

β^2 Vs. LQ mass



➢5σ discovery plot for 1st and 2nd generation scalar LQs:

β^2 Vs. total integrated luminosity

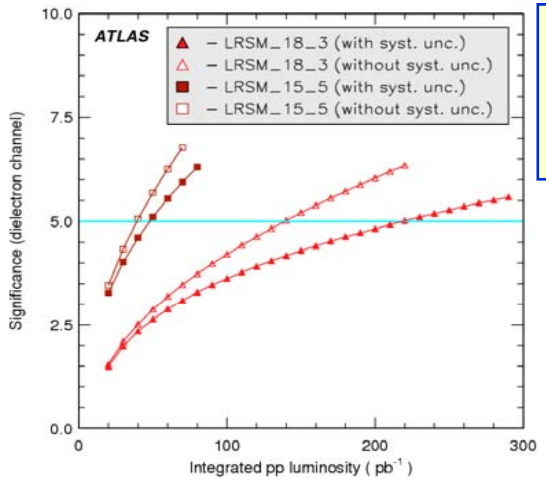


➢ If we take the case where M(LQ) < 500GeV and branching ratio into a charged lepton and a quark is 100%, the discovery can be made with the first 100pb^{-1} of integrated pp luminosity.

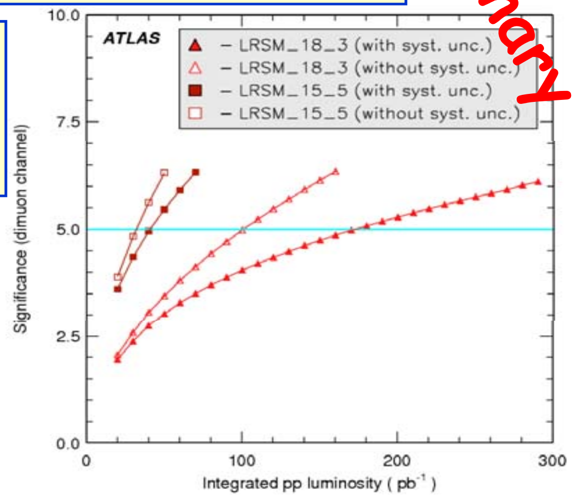
Discovery Potential for W_R and N_R…

Preliminary

➢Discovery plot for W_R.: "electron channel"
Significance Vs. total integrated luminosity

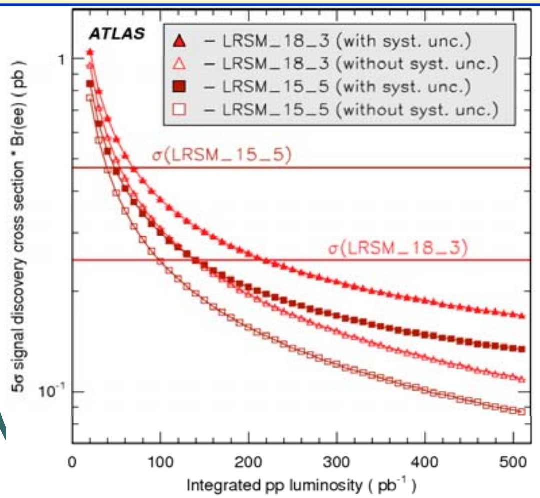


➢Discovery plot for W_R.: "muon channel"
Significance Vs. total integrated luminosity



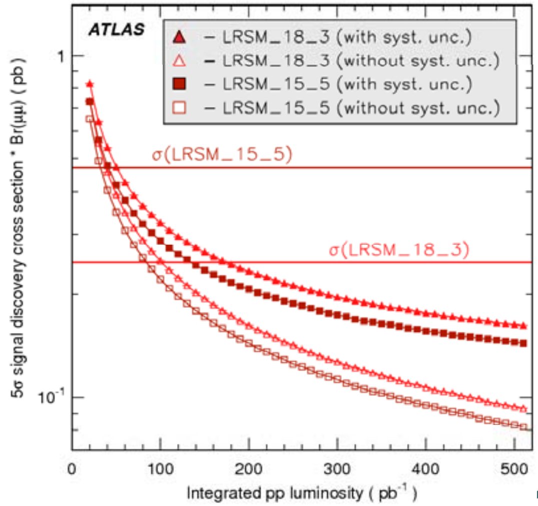
➢ Discovery at the two mass points namely LRSM_15_5 and LRSM_18_3 would require integrated pp luminosities of 40pb^{-1} and 150pb^{-1} respectively.

➢ 5σ discovery partial cross-section vs. luminosity ("di-electron channel")



➢ The lower is the "real" cross-section, the higher is the total integrated luminosity needed to make a discovery.

➢ 5σ discovery partial cross-section vs. luminosity ("di-muon channel")



Summary/Conclusion…

- Studies of the detection possibilities of Leptoquarks, Majorana Neutrinos and Heavy right handed W-bosons have been studied at great length with the ATLAS detector. The signature considered is two high pT leptons (electrons, μ's) and two high pT jets.
- We have used common basic lepton and jet selections for both analyses and have achieved a better understanding of the event topology and the corresponding reconstruction.
- Evaluated the background contribution to both analyses and found that ttbar and Z/DY backgrounds have the most important contribution with some variation depending on the lepton channel of the decay and event topology.
- The background contribution and trigger efficiencies will be measured/checked using real data.
- Calculated the systematic uncertainties and were used to evaluate the discovery potential for Leptoquarks, N_R and W_R.
- A discovery potential for Leptoquarks, W_R (hence N_R) is possible within the first 200pb^{-1} of integrated luminosity.

ATLAS status: CLOSED…
Looking forward for the first collisions to happen….