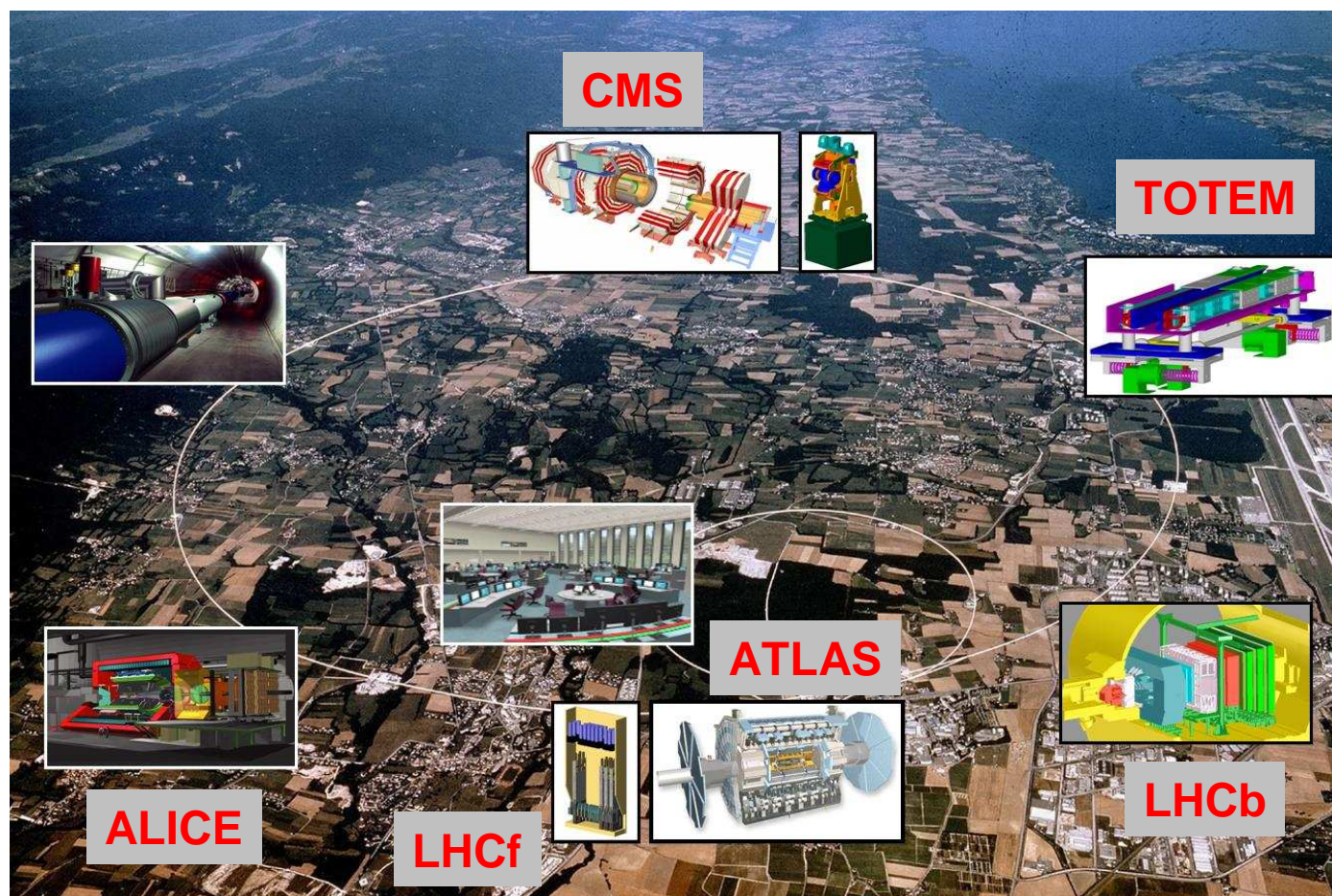# Sensitivity to Leptoquarks and Majorana Neutrinos with Early ATLAS Data
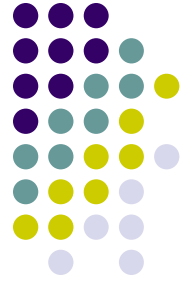## Studies of Final States with High p_T Dileptons and Jets

Shanti Wendler, University of Pittsburgh
ATLAS Collaboration

Leptoquarks

- Leptoquarks appear naturally in GUTs
  - Remarkable symmetry between leptons and quarks
- Leptoquarks have:
  - Color
  - Fractional electric charge
  - Lepton and baryon numbers
  - Can be vector or scalar
  - 3 generations favored by observed limits on lepton-number violation and flavor-changing neutral currents
- Constrained by established limits on proton decay
  - If LQ cannot couple to diquark, proton is stable
  - LQ discovery possible in the first 100pb^{-1} of data
    - with $\beta=1$ for LQ $\rightarrow \ell + q$ and $m_{LQ} < 550$ GeV
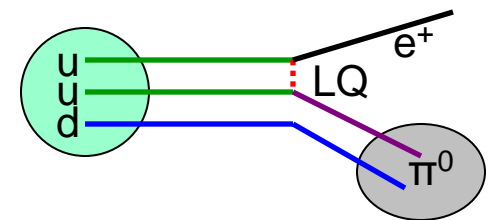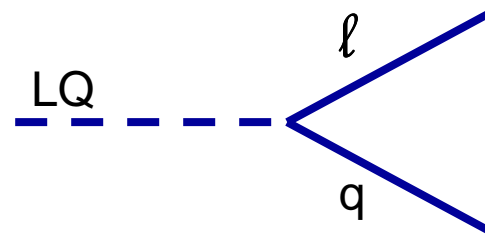
Leptoquarks
Tevatron Limits
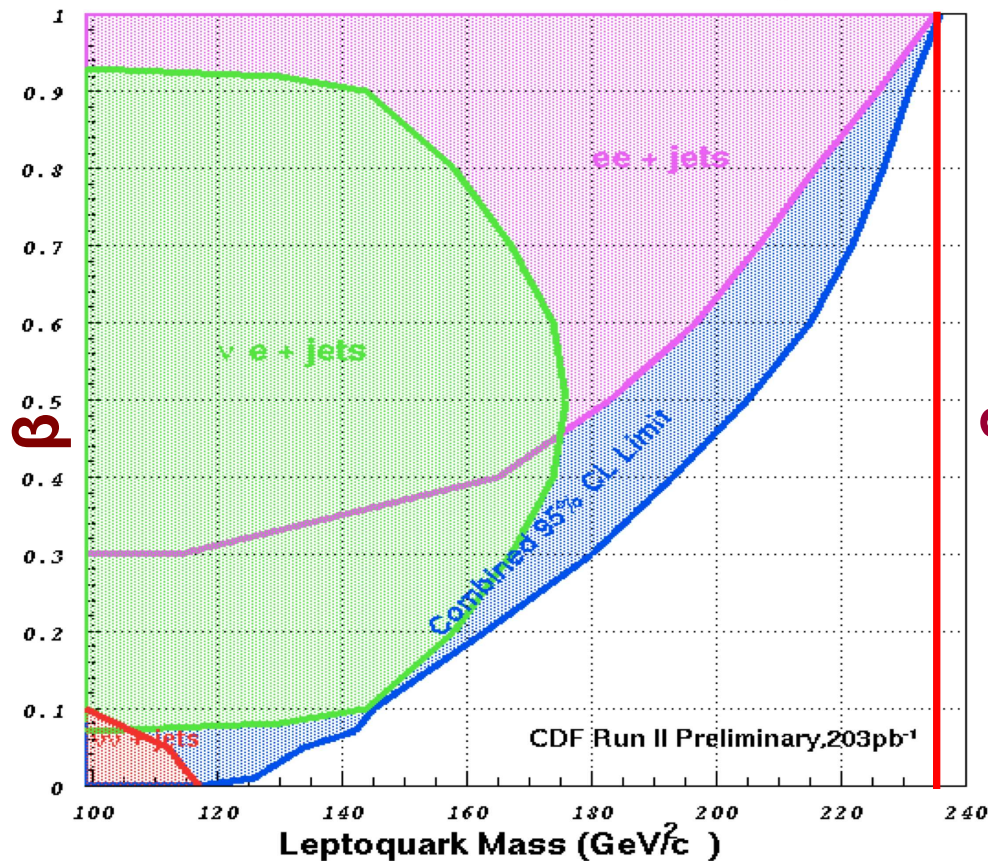
Mass Limits (LQ→eq w/ β=1)

DØ: m_{LQe} > 292 GeV at 1 fb^{-1}

CDF: m_{LQe} > 236 GeV at 200 pb^{-1}

Mass Limits (LQ→μq w/ β=1)

DØ: $m_{LQ\mu}$ > 316 GeV at 1 fb^{-1}

CDF: $m_{LQ\mu}$ > 226 GeV at 200 pb^{-1}

Search For First Generation Scalar Leptoquarks

ee + jets

ν e + jets

Combined 95% CL Limit

CDF Run II Preliminary,203pb^{-1}

β

Leptoquark Mass (GeV/c^2)

Search For Second Generation Scalar Leptoquarks

μμ + jets

νμ + jets

Combined 95% CL Limit

CDF Run II Preliminary,198 pb^{-1}

β

Leptoquark Mass (GeV/c^2)
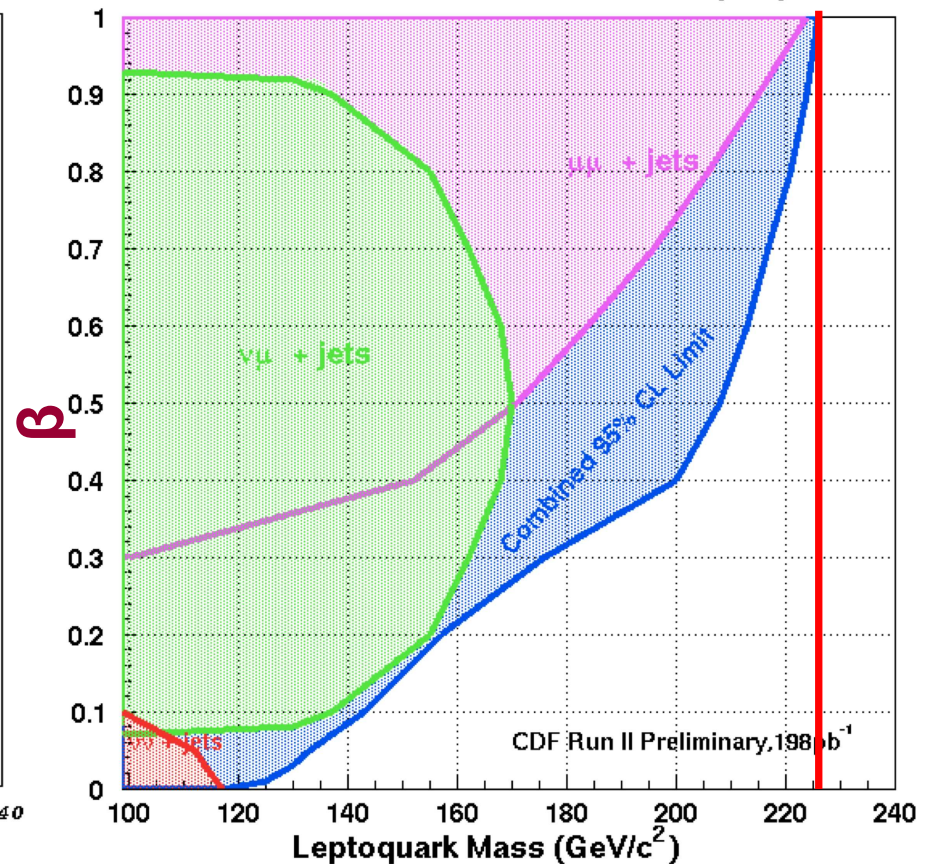
A. Abulencia et al., The CDF Collaboration, Phys. Rev. D73, 051102 (2006)
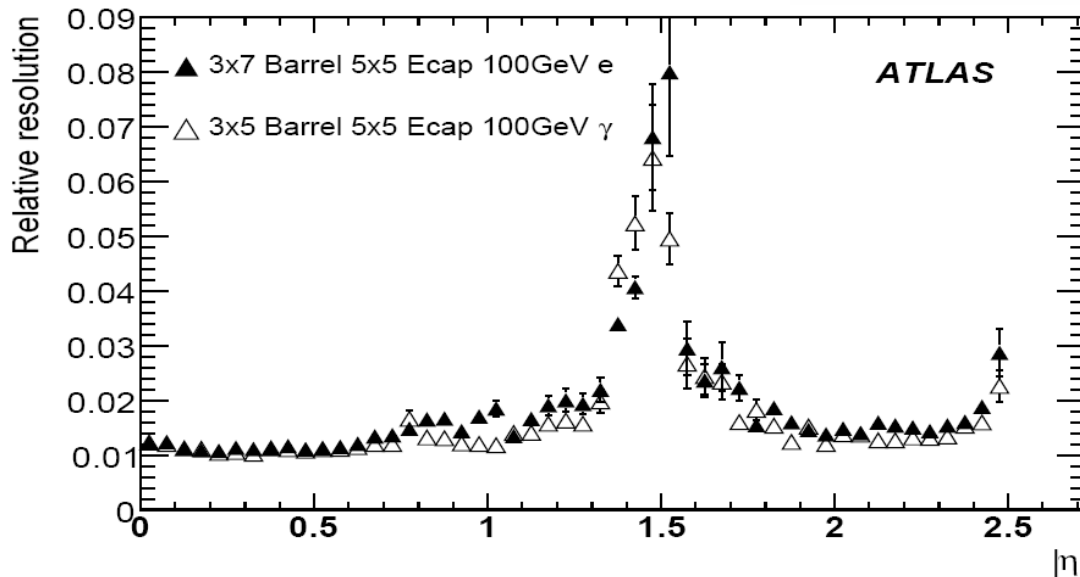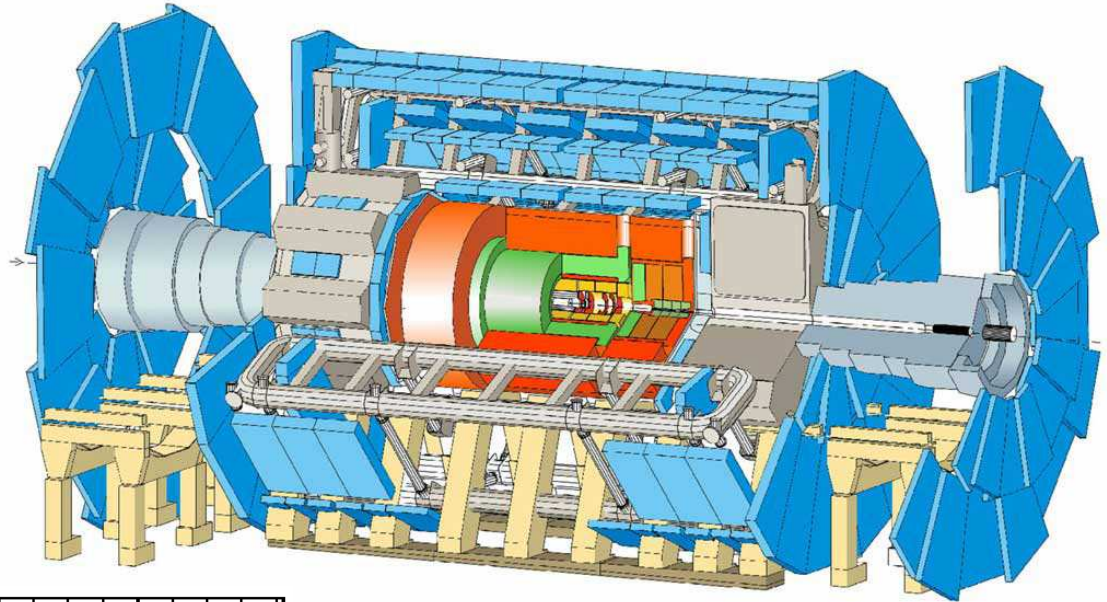D. Acosta et al., The CDF Collaboration, Phys. Rev. D72, 051107 (2005).
V.M. Abazov et al., The DØ Collaboration, arXiv:/0808.4023 [hep-ex] (2008)
DØ Collaboration Search for First-Generation Leptoquarks in the dielectron channel with the DØ
Detector in pp Collisions at ps = 1:96 TeV, DØ Note 5644-CONF (2008)

Shanti Wendler, University of Pittsburgh, LHC2008 pg 3

ATLAS Detector
Resolution, Particle ID, Fakes

Subdetector	Resolution
Inner Det.	$\sigma/p_T \sim 5 \times 10^{-4}$
EM Cal	$\sigma/E \sim .1/\sqrt{E} + .005$
Had Cal	$\sigma/E \sim .5/\sqrt{E} + .03$
Muon	$\sigma/p_T \sim .1$ at 1 TeV

▲ 3x7 Barrel 5x5 Ecap 100GeV e
△ 3x5 Barrel 5x5 Ecap 100GeV γ

ATLAS

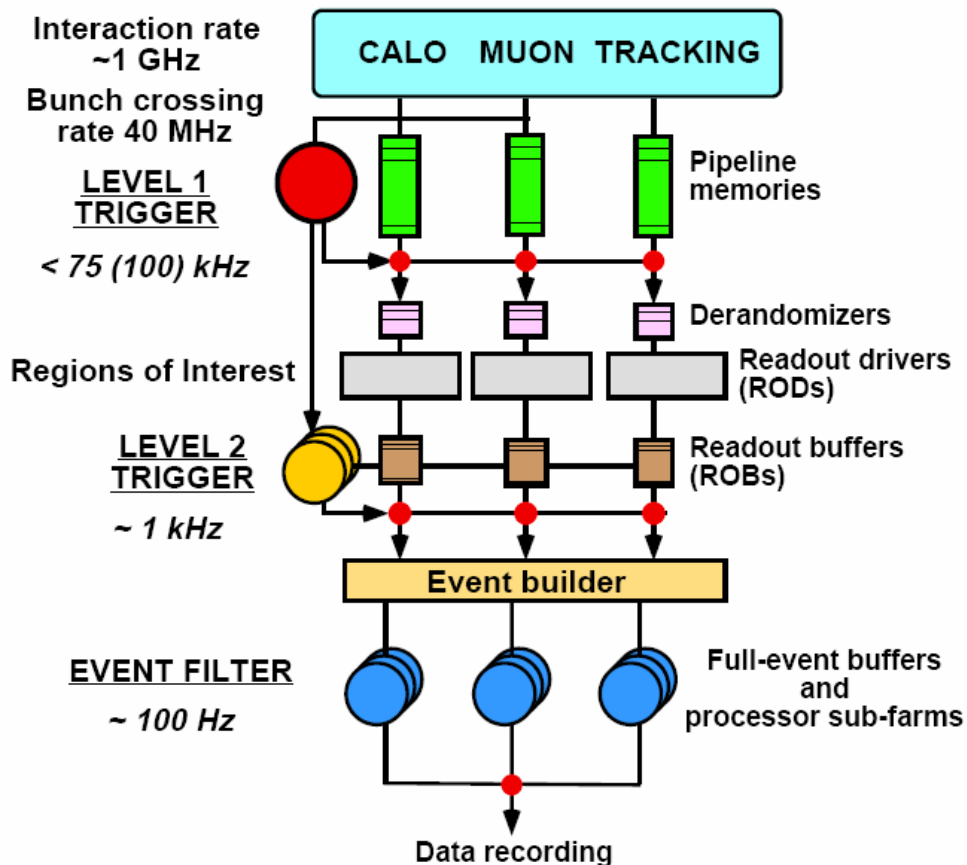| Systematic Uncertainty	
Luminosity	20%
Jet Energy Scale	16-35%
Jet Energy Resolution	6-28%
Limited MC Statistics	15-30%

(Conservative Estimates for Early Data)

ATLAS Detector

Trigger Efficiencies

Single Reconstructed Particle
LVL1 Trigger Efficiencies
Muon   ~ 78% at p_T > 20GeV
Electron ~100% at p_T > 20GeV

Interaction rate
~1 GHz
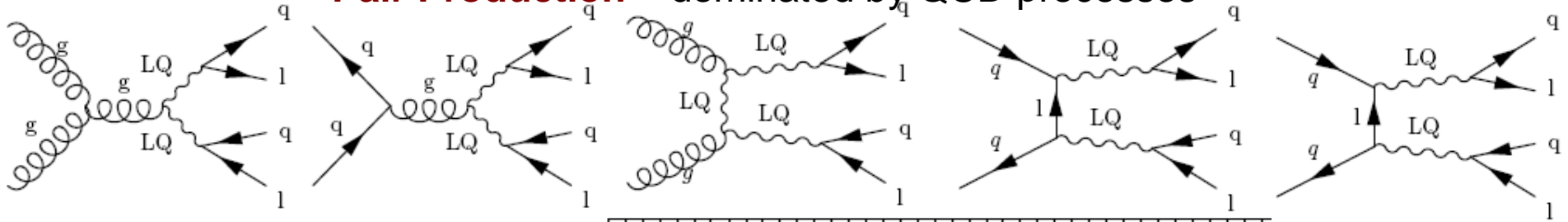
Bunch crossing
rate 40 MHz

**LEVEL 1
TRIGGER**

< 75 (100) kHz

Regions of Interest

**LEVEL 2
TRIGGER**

~ 1 kHz

EVENT FILTER

~ 100 Hz

CALO   MUON   TRACKING

Pipeline
memories

Derandomizers

Readout drivers
(RODs)

Readout buffers
(ROBs)

Event builder

Full-event buffers
and
processor sub-farms

Data recording

Holes in Muon LVL1 Geometric Acceptance

Toroid
ribs

Support Legs

φ / η

Signal Event Decision

Physics Channel	Level 1 Evt. Dec.	Full Chain Evt. Dec.
1st gen. LQ m_{LQ} = 400 GeV	**100%**	**97%**
2nd Gen LQ m_{LQ} = 400 GeV	**97.7%**	**96.5%**
LRSM (ee) m_{WR} = 1800 GeV, m_{Ne} = 300 GeV	**100%**	**96.4%**
LRSM (μμ) m_{WR} = 1800 GeV, $m_{N\mu}$ = 300 GeV	**96.8%**	**94.5%**

Leptoquark Production with LHC
Signal and Background

Pair Production – dominated by QCD processes

LQ
DY
ttbar
WW, ZZ, WZ

Dielectron

First generation

ATLAS

Signal - 400 GeV
Drell-Yan
$t\bar{t}$
WW,ZZ,WZ

$2 * $ events / 10 GeV / 100 pb^{-1}

M_{lj} [GeV]

Dimuon

Events / 20 GeV / 100 pb^{-1}

M_{lj} [GeV]
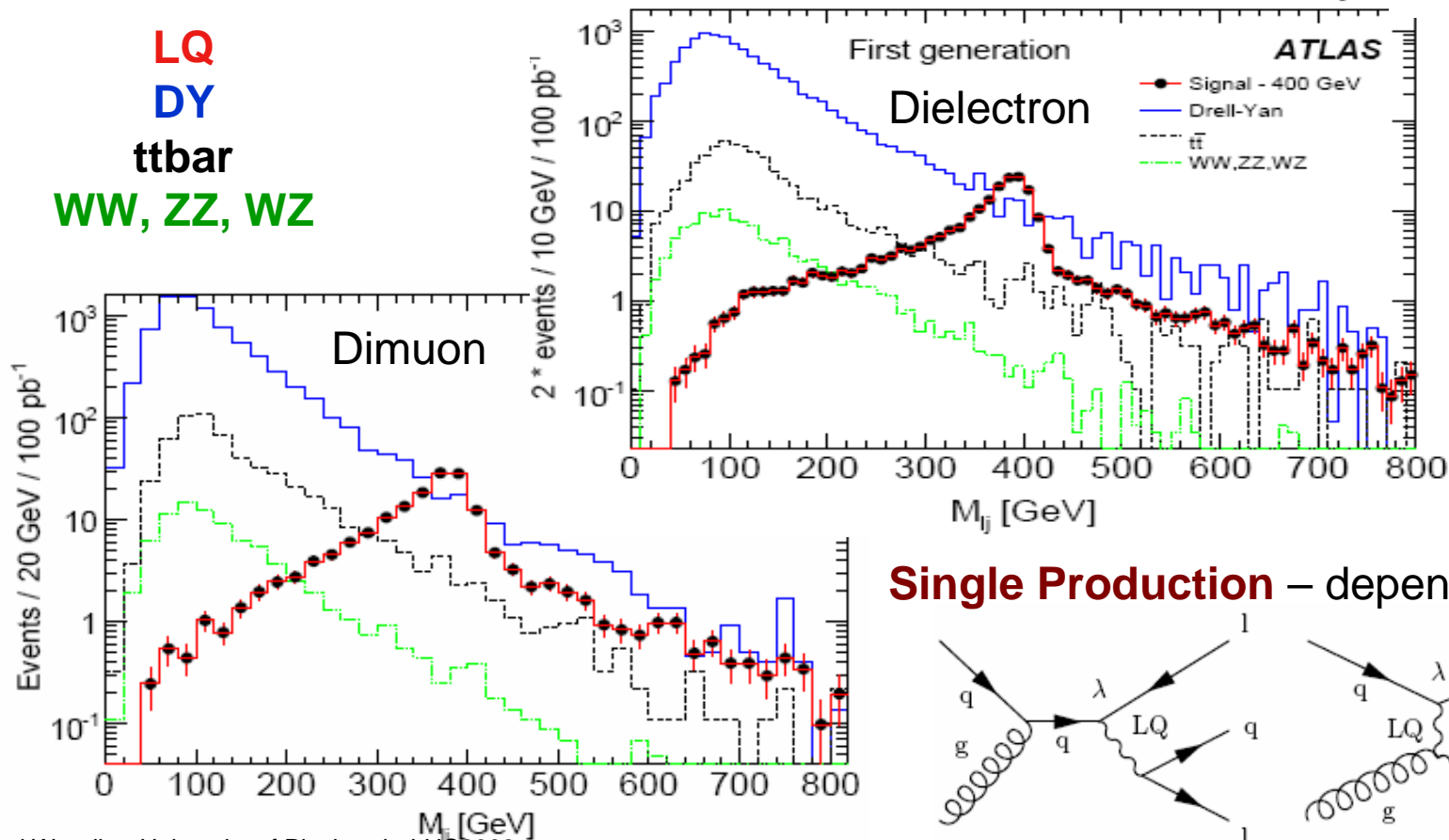
Single Production – dependent on λ

pg 6

Shanti Wendler, University of Pittsburgh, LHC2008
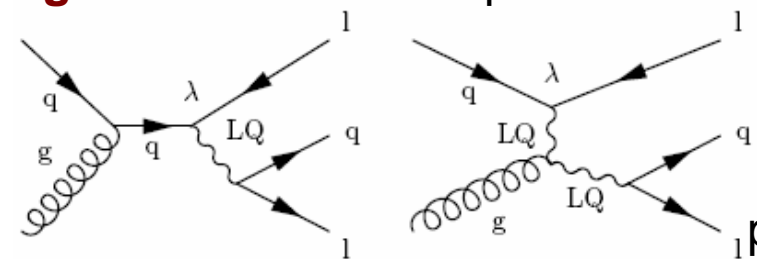
LQ Background Suppression

Dilepton Mass and $S_T = |p_{Tjet1}| + |p_{Tjet2}| + |p_{T\ell1}| + |p_{T\ell2}|$

1st Gen.

2nd Gen.

$m_{LQ}=400\text{GeV}$

LQ
DY
ttbar
WW, ZZ, WZ

$S_T = \sum |p_T|$
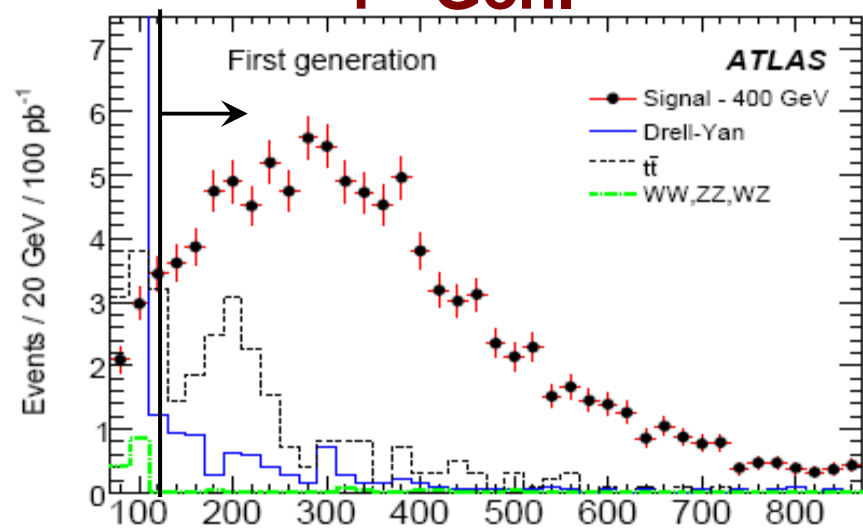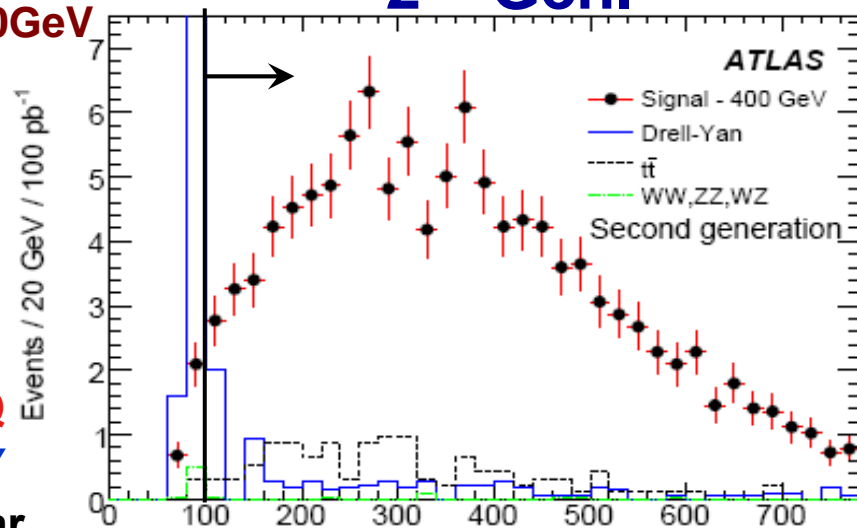
$M_{ee} > 120$ GeV

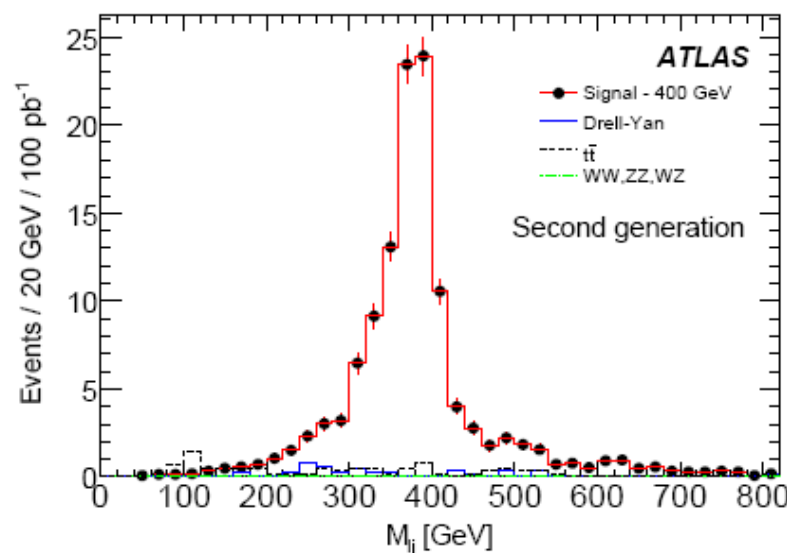$M_{\mu\mu} > 110$ GeV
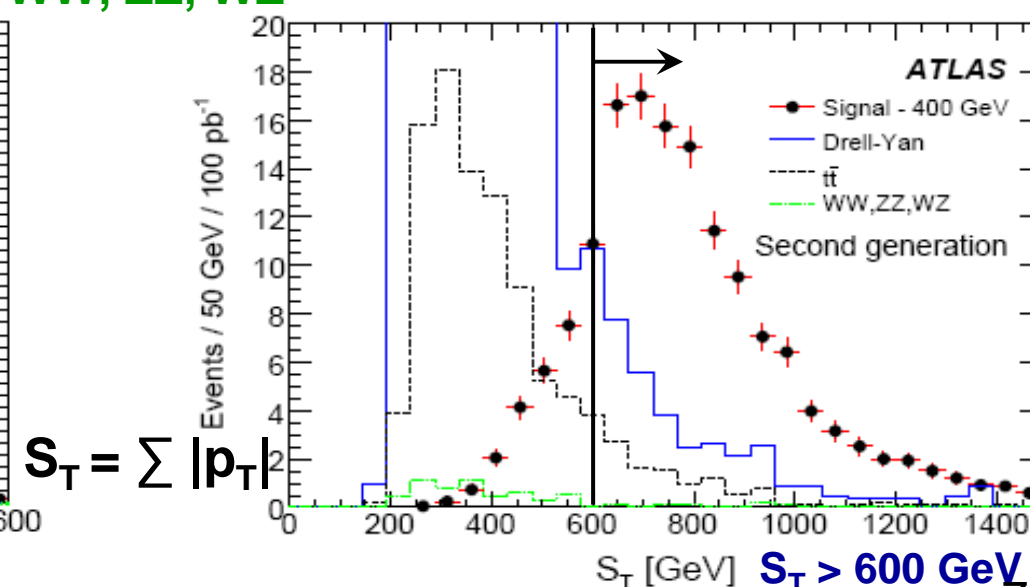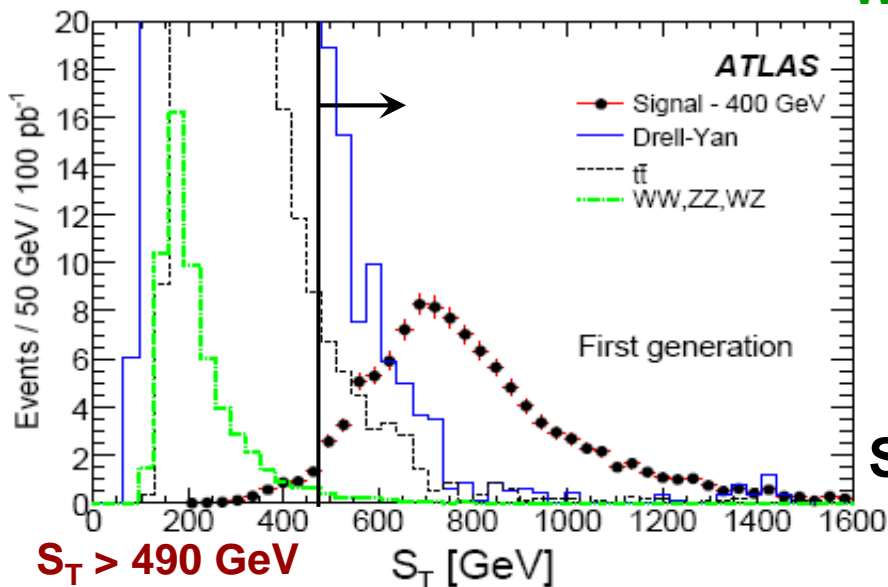
$S_T > 490$ GeV

$S_T > 600$ GeV

LQ mass
Before and After Background Suppression

m$_{LQ}$=400GeV

Dielectron

Dimuon

Shanti Wendler, University of Pittsburgh, LHC2008
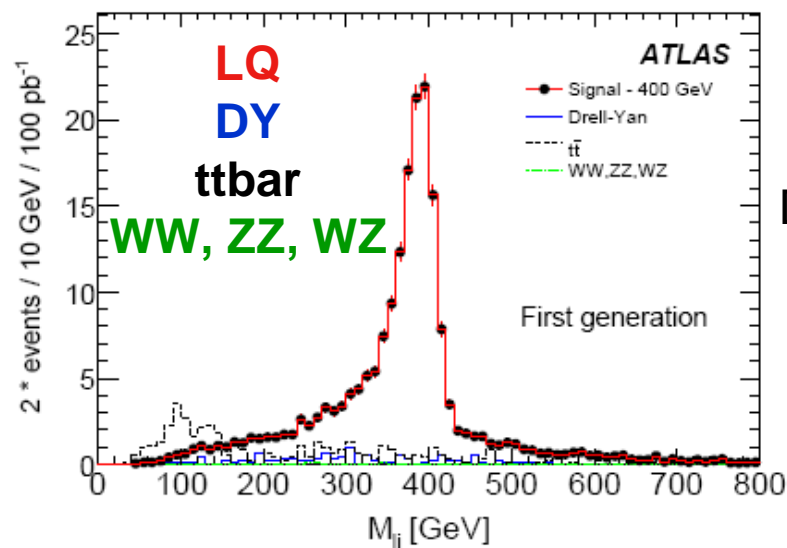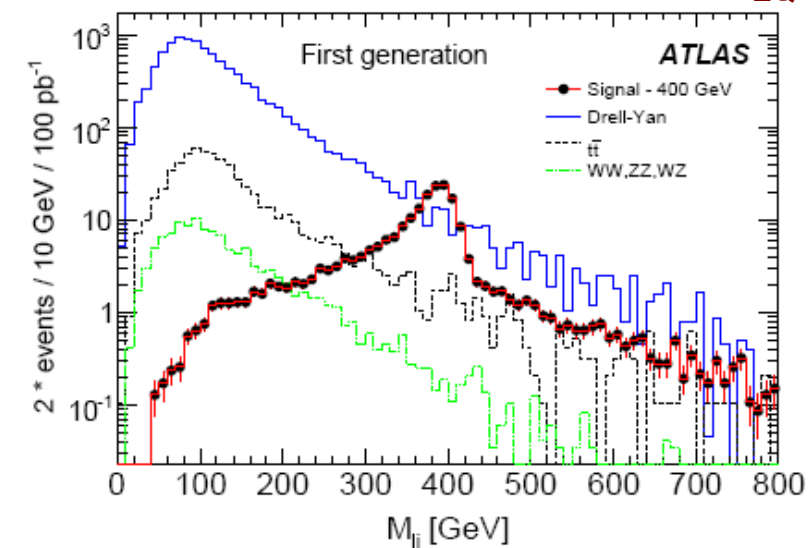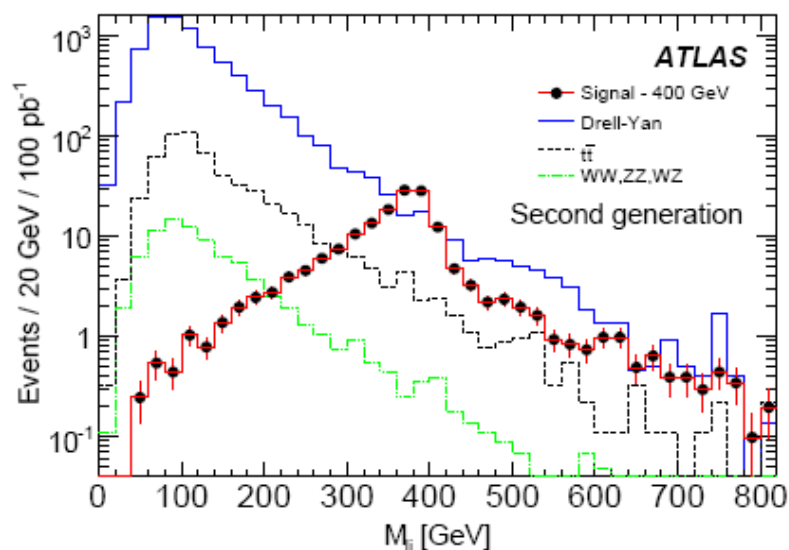
LQ Discovery Potential
5σ Significance

Mass	1st Gen	2nd Gen
300 GeV	2.8 pb^{-1}	1.6 pb^{-1}
400 GeV	11.8 pb^{-1}	7.7 pb^{-1}
600 GeV	123 pb^{-1}	103 pb^{-1}
800 GeV	1094 pb^{-1}	664 pb^{-1}

100 pb^{-1}

ATLAS
- 1st gen.
- 2nd gen.

β^2

Leptoquark mass [GeV]

5 σ discovery contours
- 1st gen.
- 2nd gen.
- 1st gen. (no syst. unc.)
- 2nd gen. (no syst. unc.)

m$_{LQ}$=400GeV

β^2

Integrated luminosity [pb^{-1}]
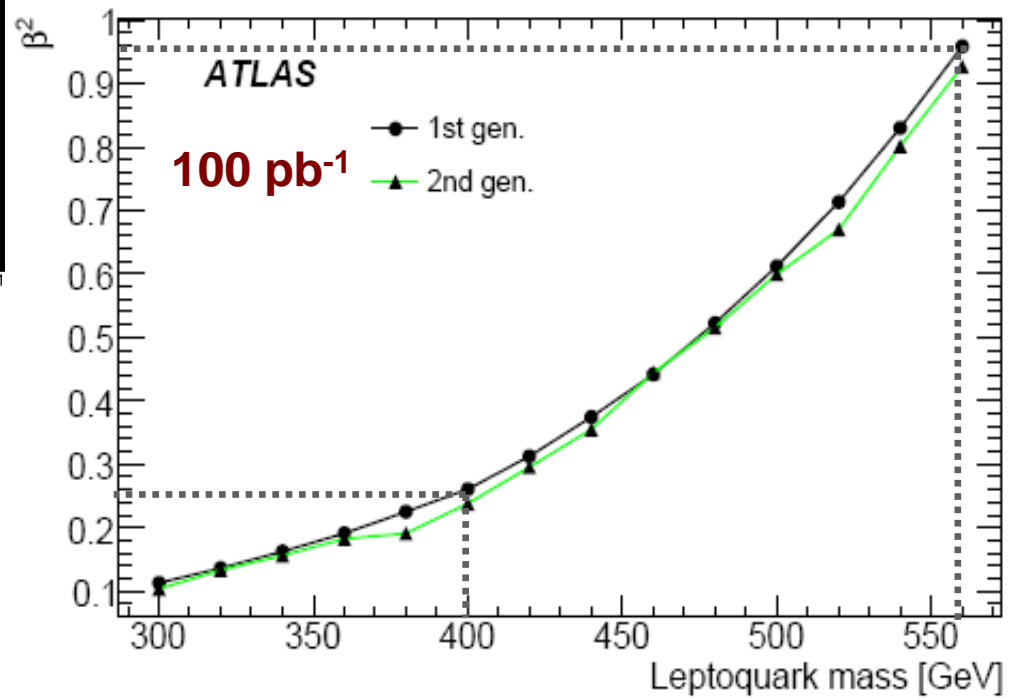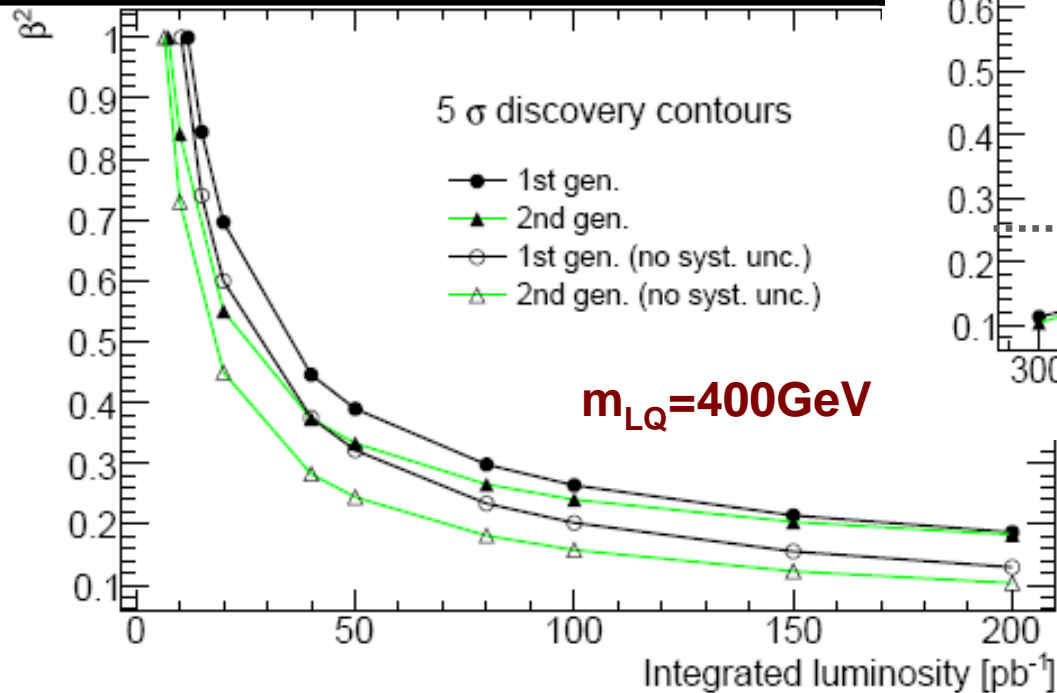
Left-Right Symmetric Models

- Introduces Majorana Neutrinos, generating light neutrino masses via the sea-saw mechanism
- Majorana Neutrinos allow Baryogenesis via Leptogenesis
  - Majorana decays do not conserve lepton number
    - Same sign dilepton signal with negligible background
    - CP violation gives leptonic matter/antimatter asymmetry
  - Leptons converted to baryons via (non-perturbative) sphaleron interactions
    - Leptonic asymmetry is converted to baryonic asymmetry
  - LSP stable
- Parity is an exact symmetry at high energies
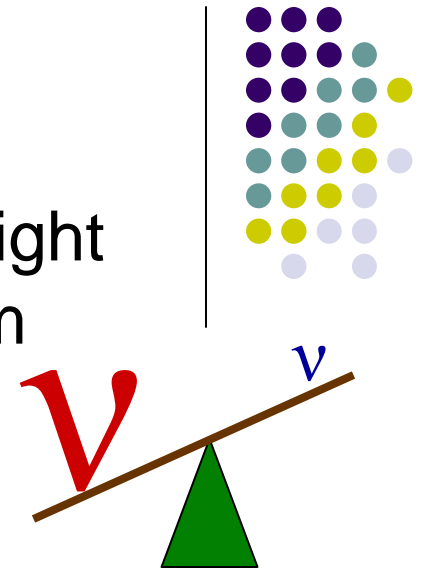
LRSM Current Limits

DØ Direct Limits: m_{WR} > 739 GeV for g'=g_W g'/g_W < .72 for m_{WR} = 600 GeV at .9 fb^{-1}
CDF Direct Limits: m_{WR} > 800 GeV for g'=g_W g'/g_W < .65 for m_{WR} = 600 GeV at 1.9 fb^{-1}

CDF Limits
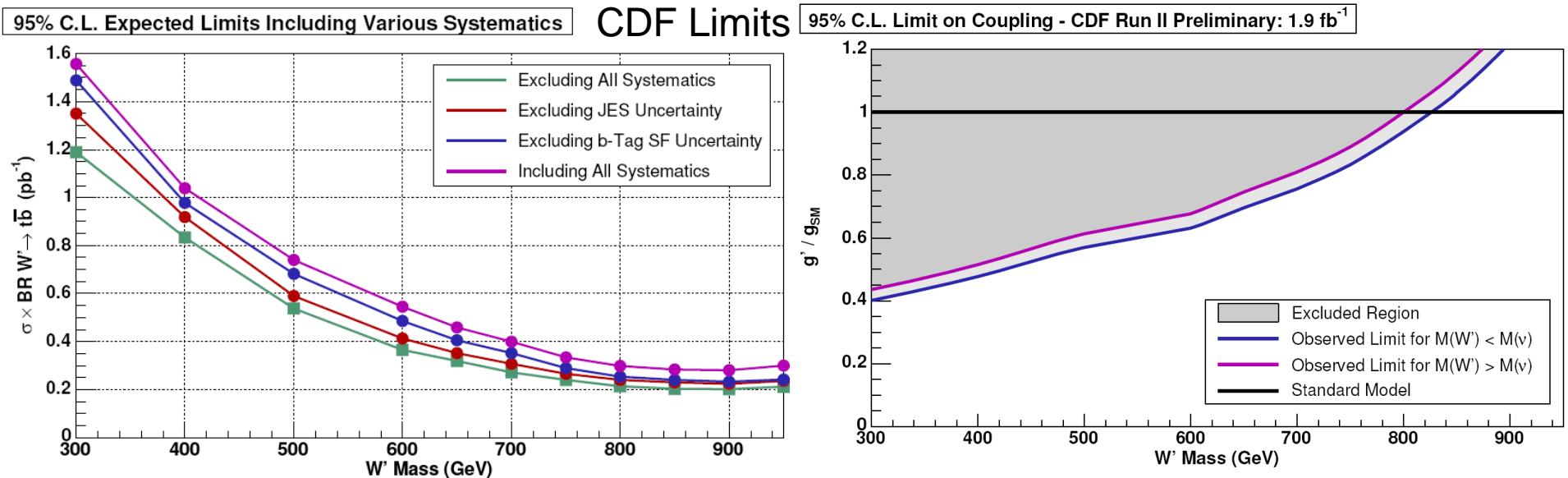
Note: These Tevatron studies were not done with $\ell \ell$ j j final states

Indirect limits on K_L -K_S mass difference indicate M_{WR} > 1.6 (+1.2, -0.7) TeV.

V.M. Abazov et al., The DØ Collaboration, Phys. Rev. Lett. 100, 211803 (2008)
Shanti Wendler, University of Pittsburgh, LHC2008   D. Amidei et al., W'-like Resonances in the tb Decay Channel with 1.9 fb-1, CDF Note 9150 (2008)

LRSM Signatures with ATLAS

Signal and Background
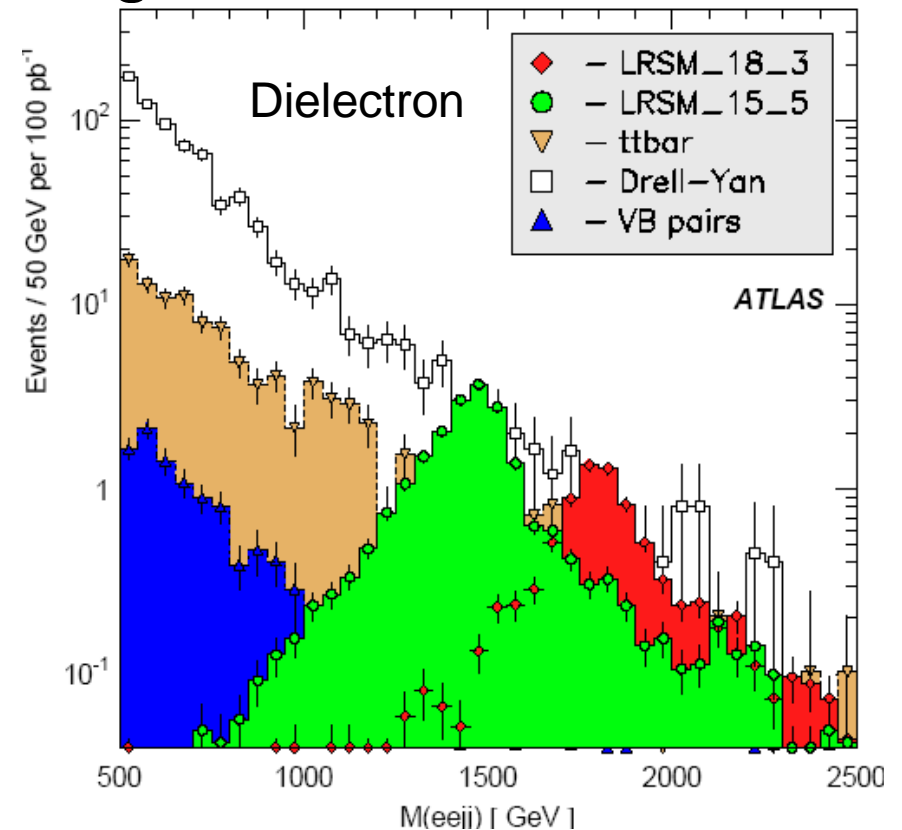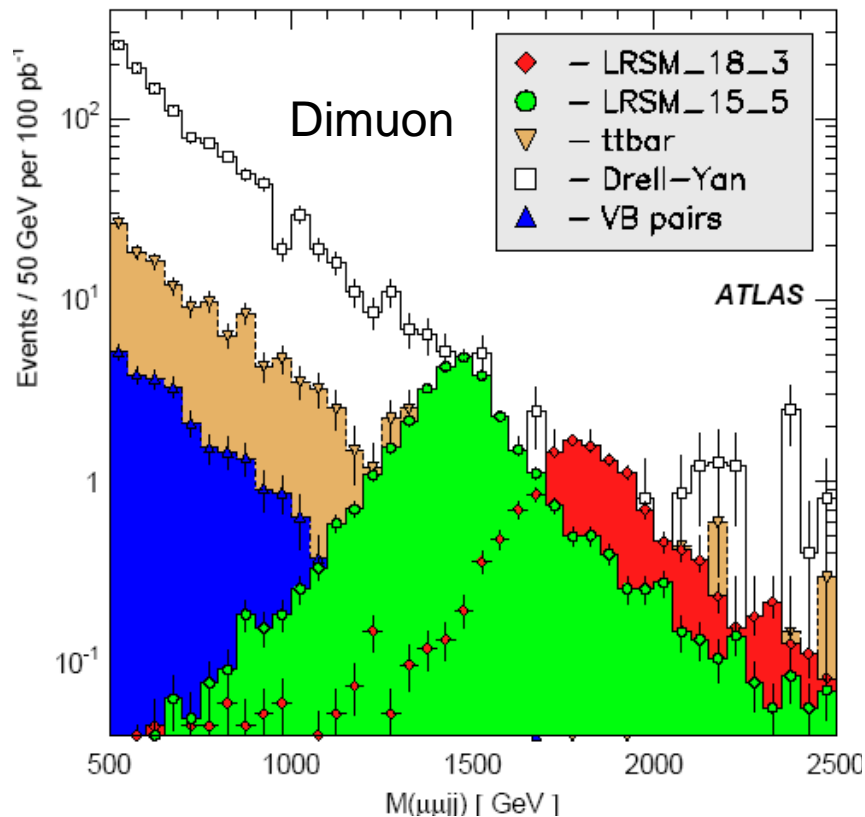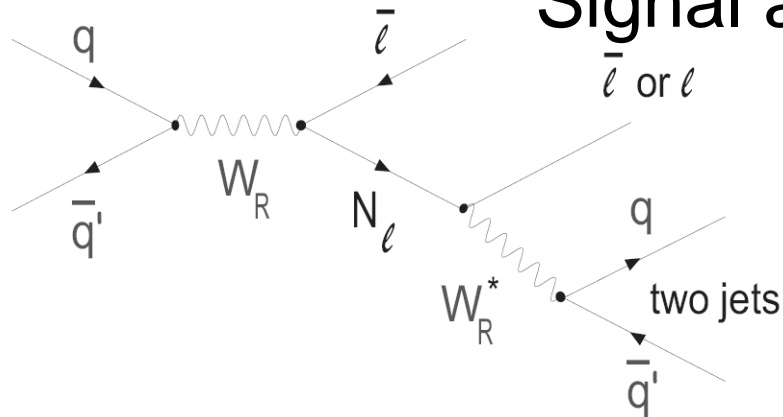
LRSM (m$_{WR}$=1800GeV, m$_N$=300GeV)
LRSM (m$_{WR}$=1500GeV, m$_N$=500GeV)
DY(white)
ttbar
WW, ZZ, WZ

LRSM Background Suppression

Dilepton Mass and $S_T = |p_{Tjet1}| + |p_{Tjet2}| + |p_{T\ell1}| + |p_{T\ell2}|$
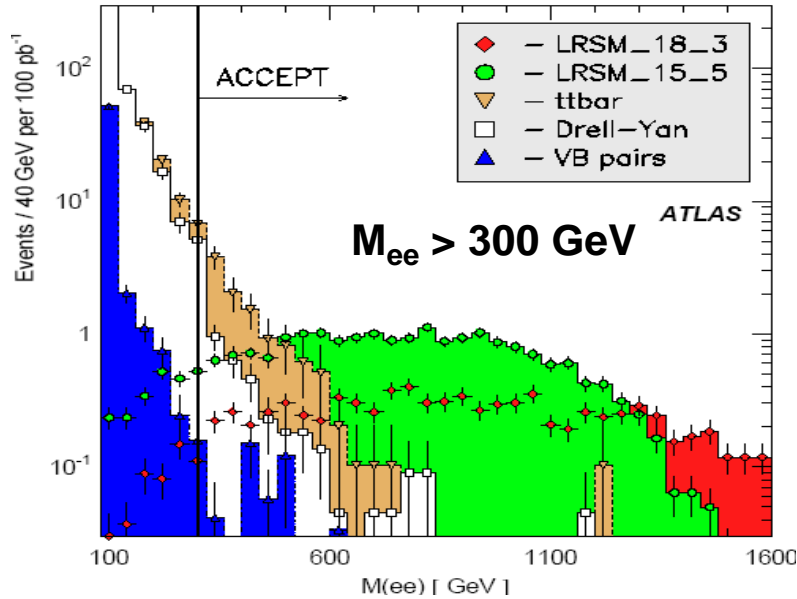
$m_{WR}=1800GeV$
$m_N=300GeV$
$m_{WR}=1500GeV$
$m_N=500GeV$
DY(white)
ttbar
WW, ZZ, WZ
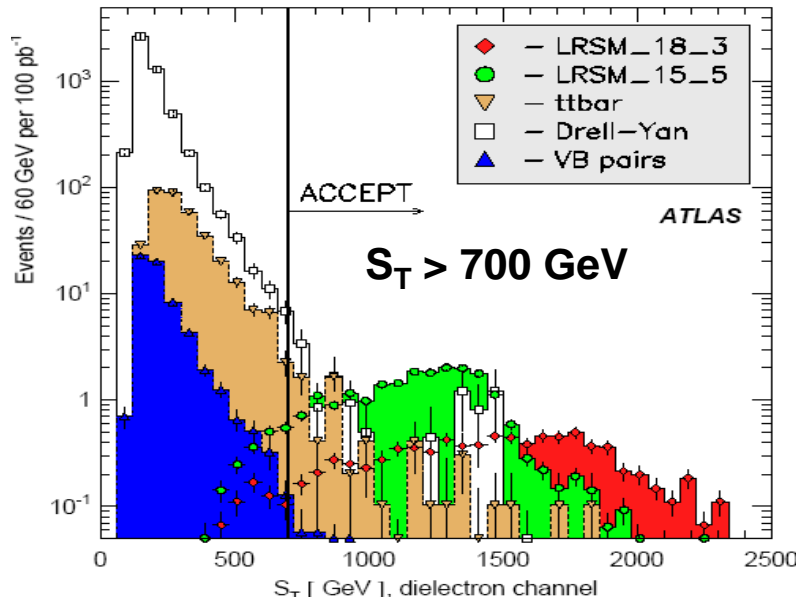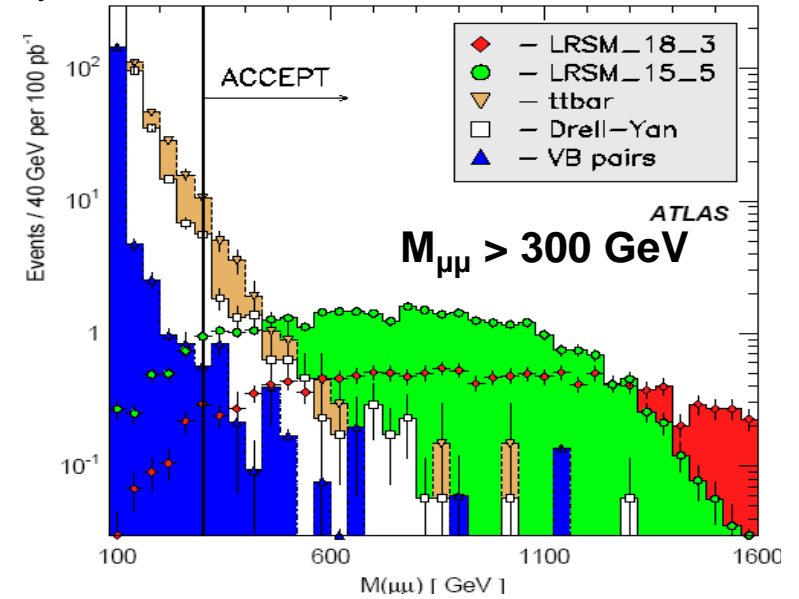
$S_T = \sum p_T$
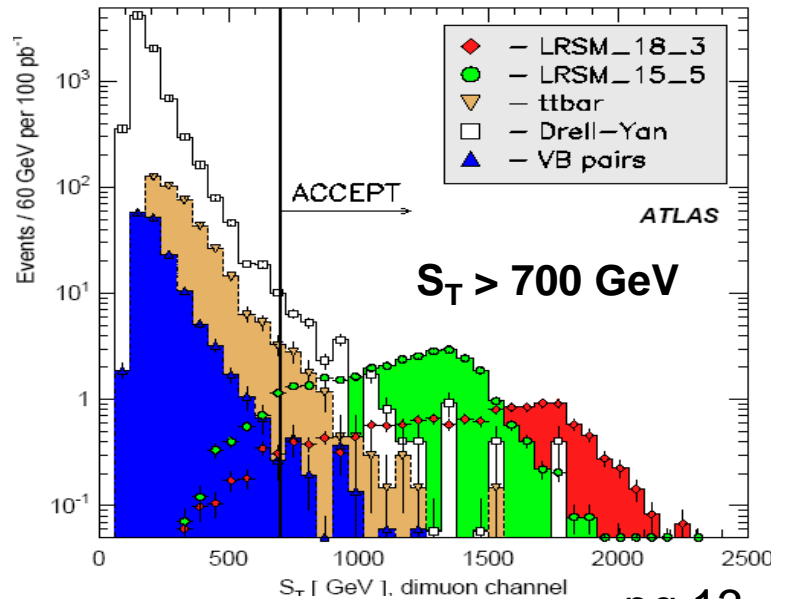
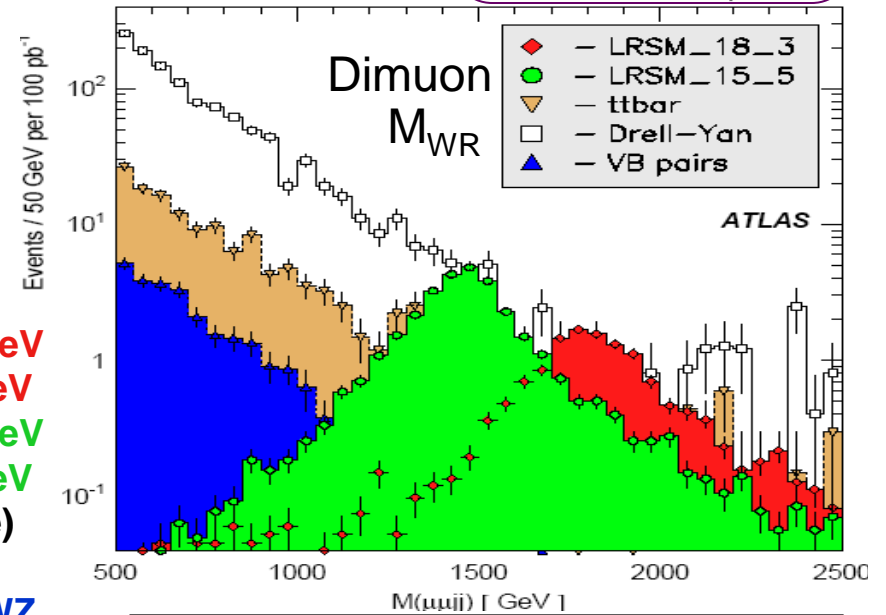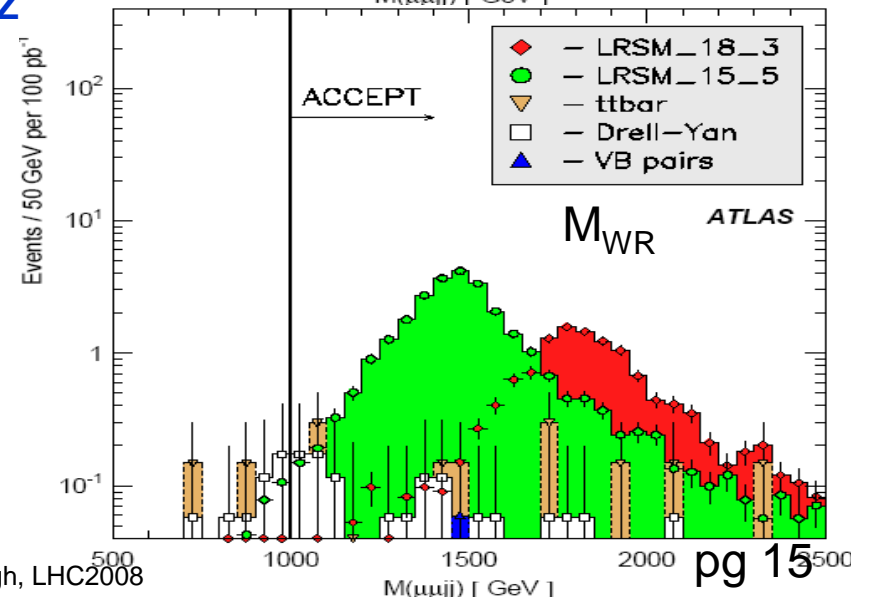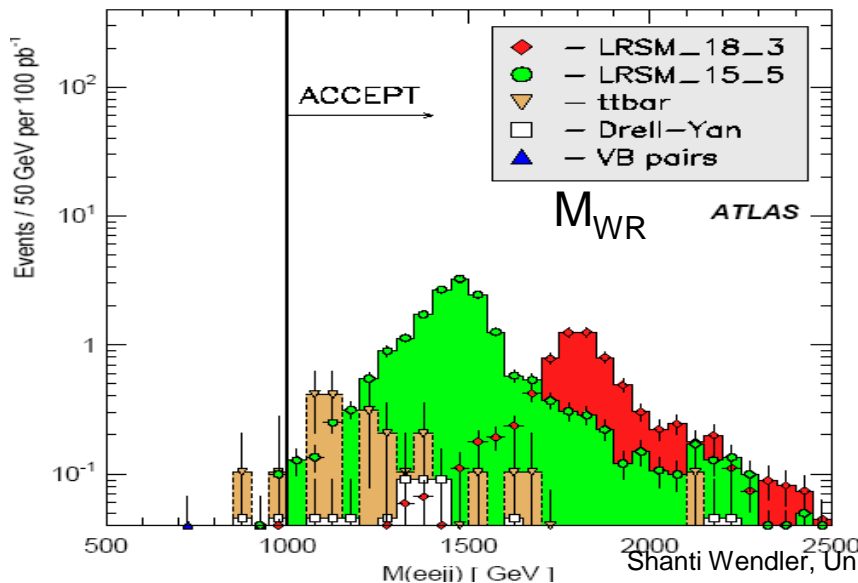# Majorana Neutrino mass
Before and After Background Suppression

m_WR=1800GeV
m_N=300GeV
m_WR=1500GeV
m_N=500GeV
DY(white)
ttbar
WW, ZZ, WZ

$m_{WR}=1800GeV$
$m_N=300GeV$
$m_{WR}=1500GeV$
$m_N=500GeV$

Shanti Wendler, University of Pittsburgh, LHC2008
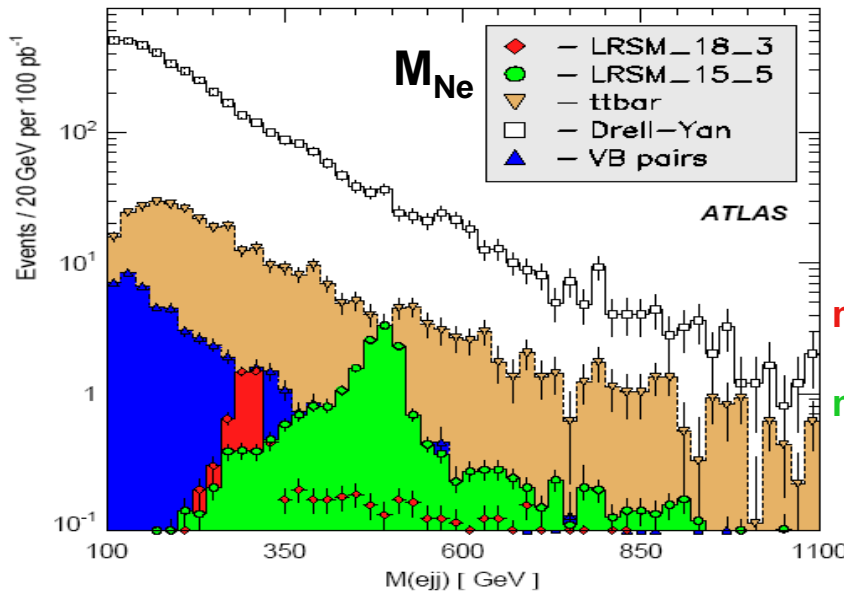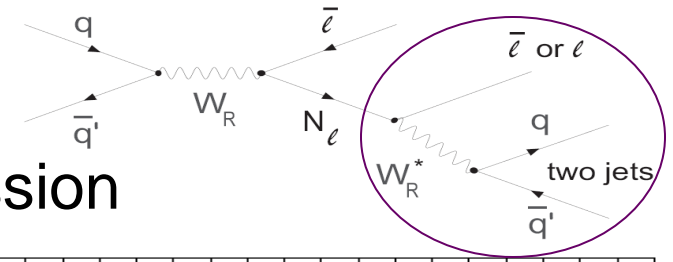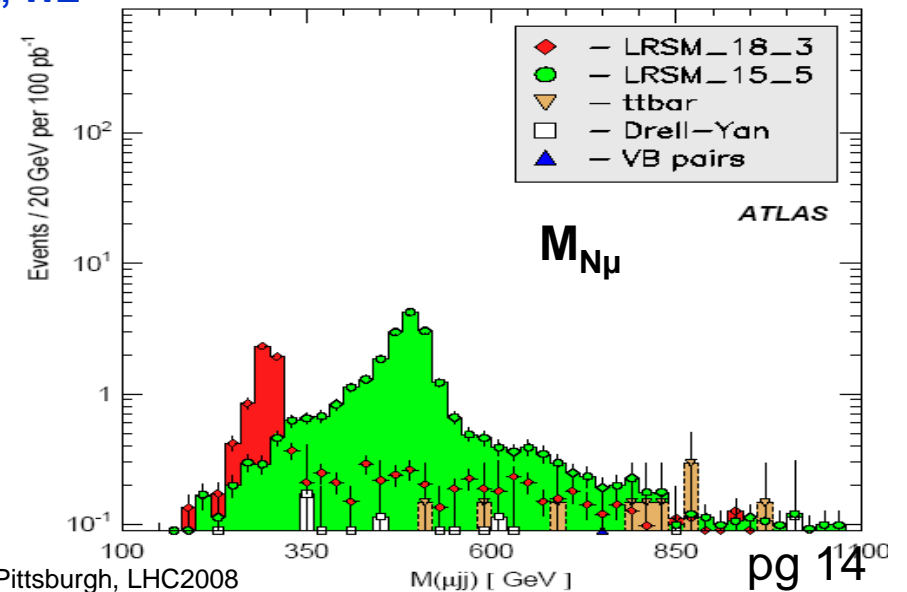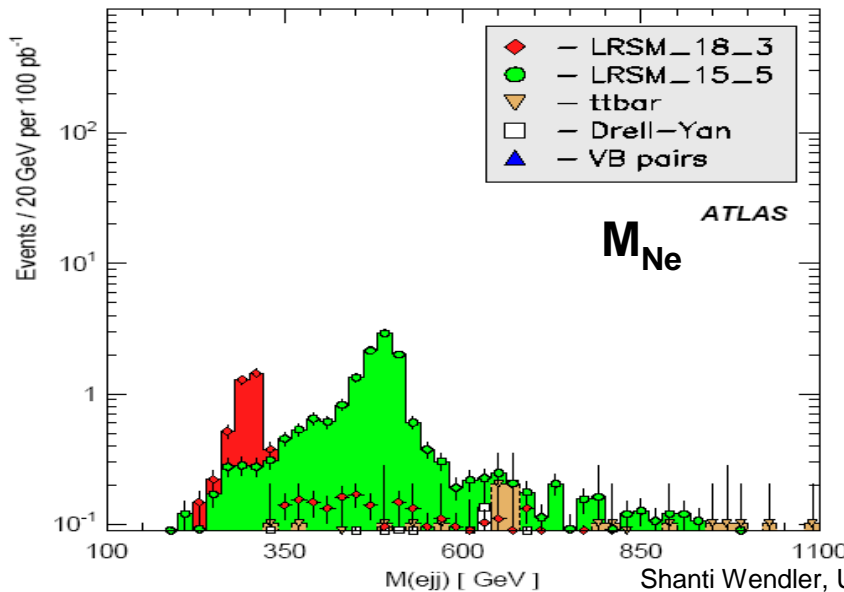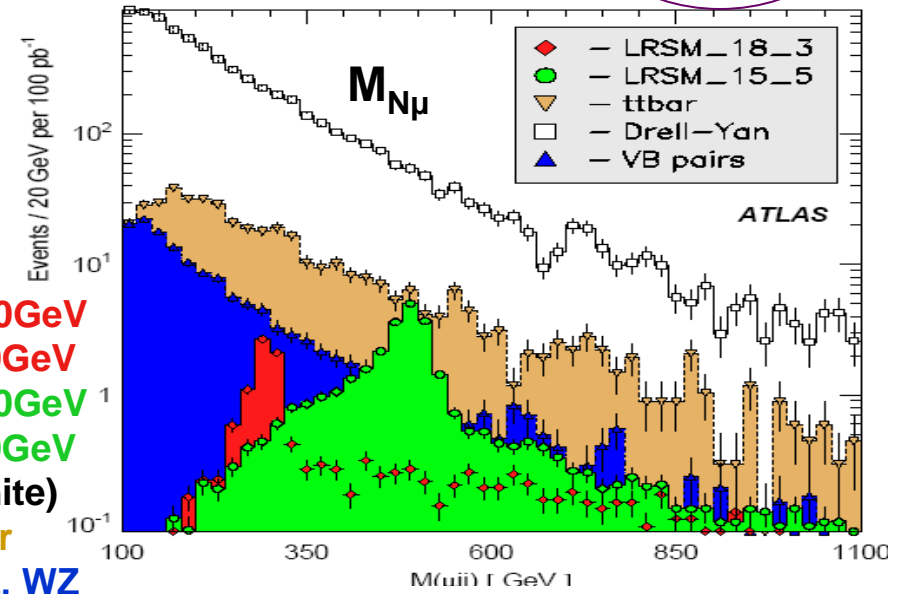
W_R mass
Before and After Background Suppression
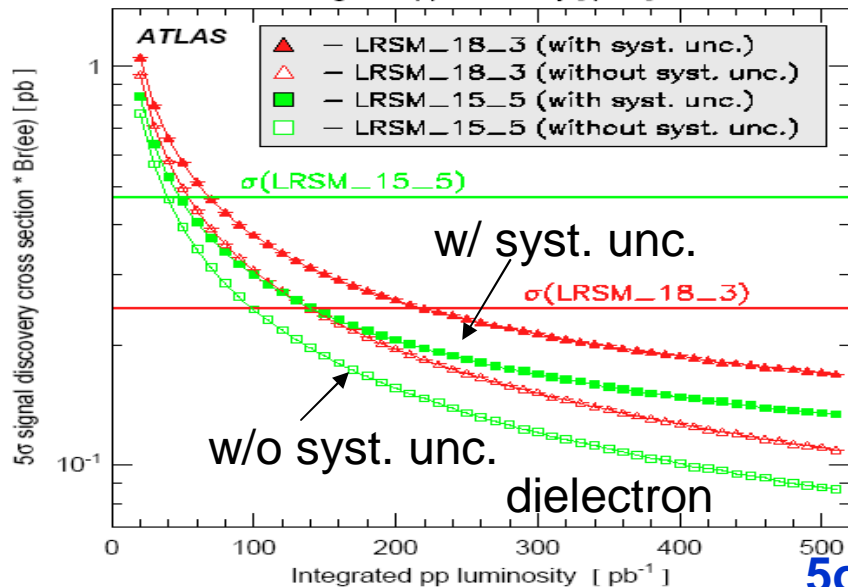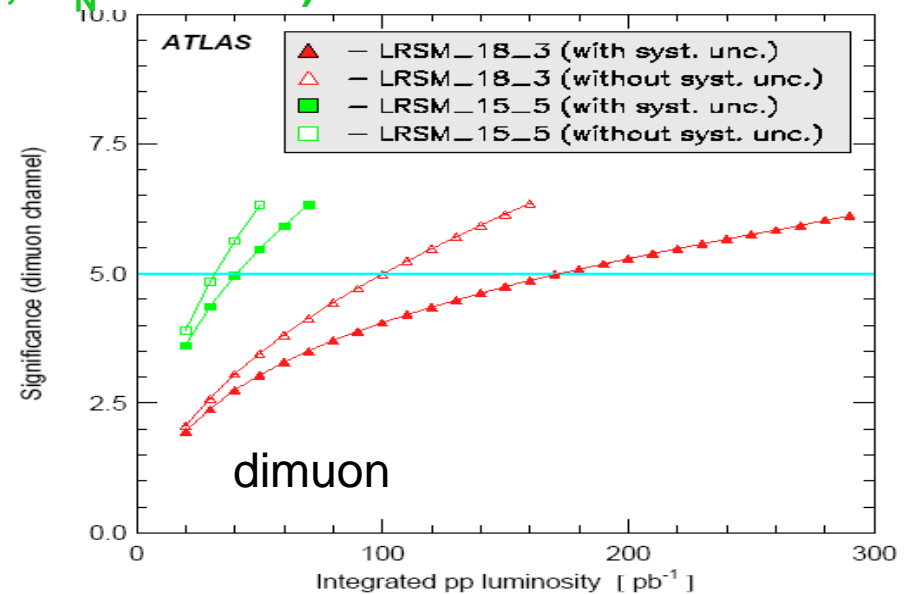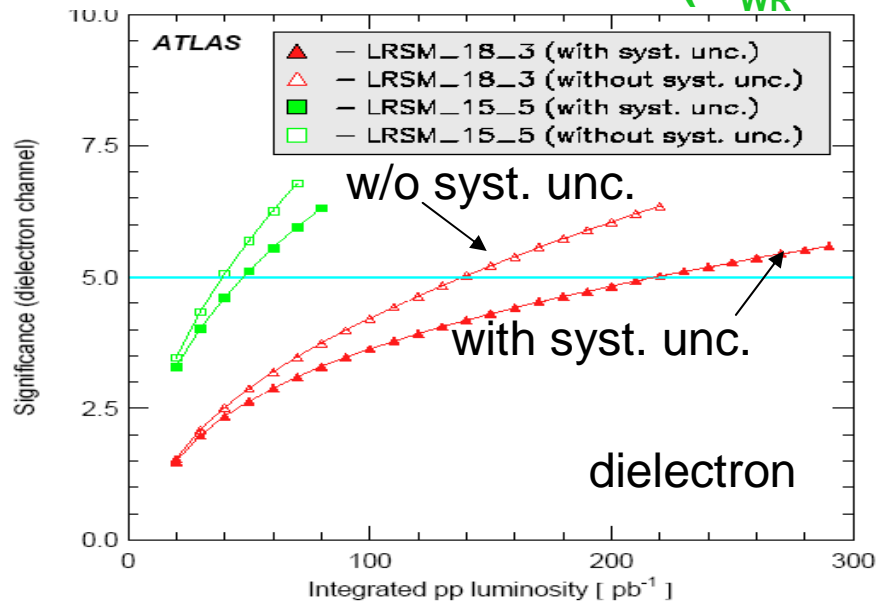

$m_{WR}=1800GeV$
$m_N=300GeV$

$m_{WR}=1500GeV$
$m_N=500GeV$

DY(white)
ttbar
WW, ZZ, WZ

pg 15
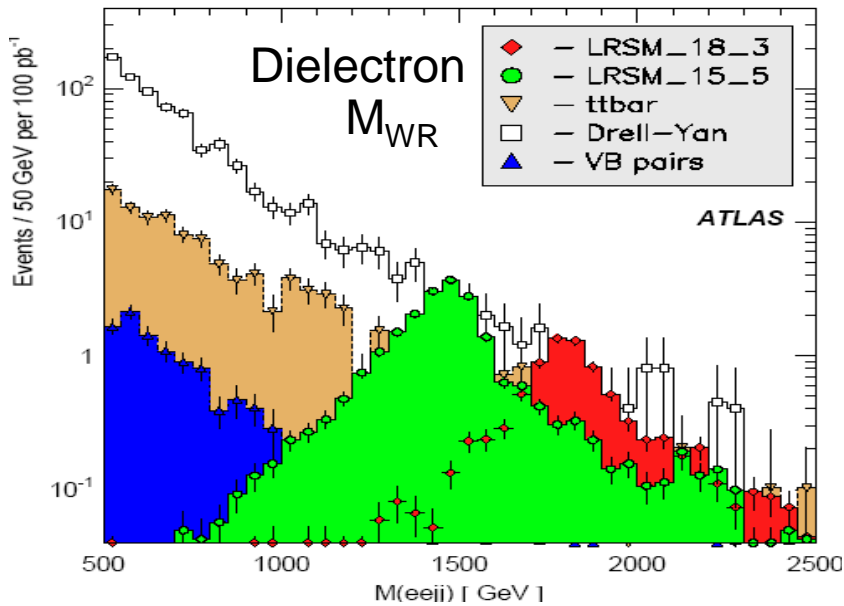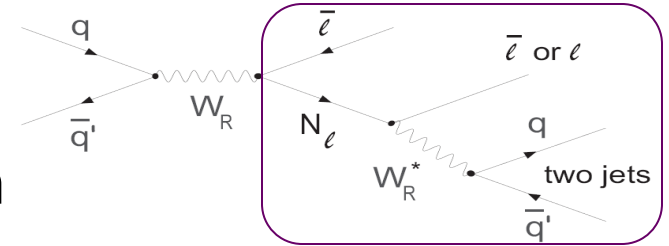
LRSM Discovery Potential

LRSM (m_{WR}=1800GeV, m_N=300GeV)
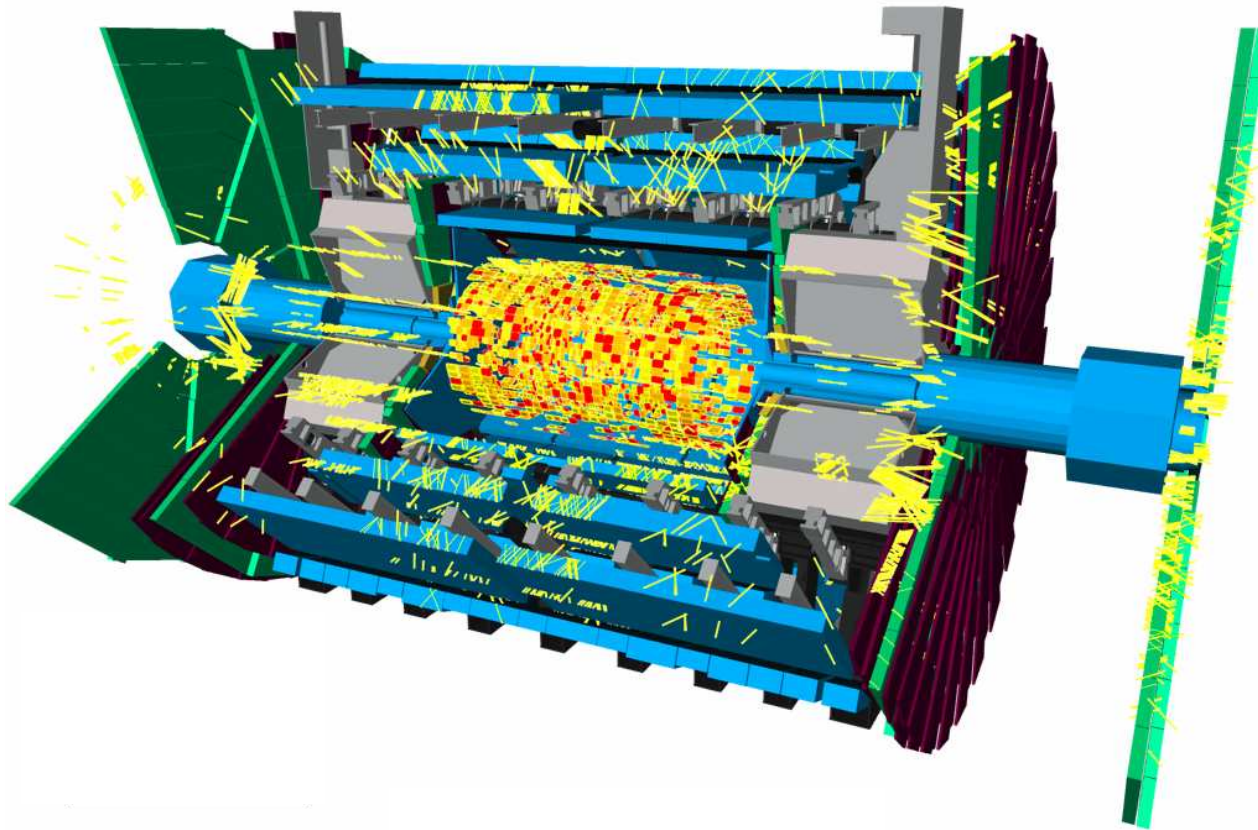## LRSM (m_{WR}=1500GeV, m_N=500GeV)
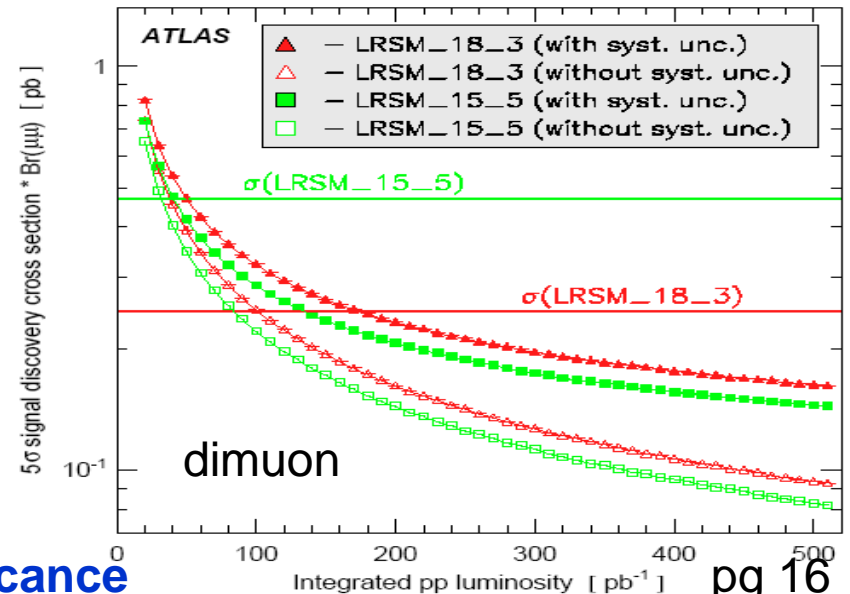
5σ Significance

Summary

- LRSM and LQ channels have great potential for results with early data

- Working to understand detector response with beam events, cosmic data

- Extending analyses to include single LQ production, Z'$\rightarrow$NN, and other channels

**ATLAS Collaboration, Expected Performance of the ATLAS Experiment,
Detector, Trigger and Physics, CERN-OPEN-2008-020, Geneva, 2008, to appear.**