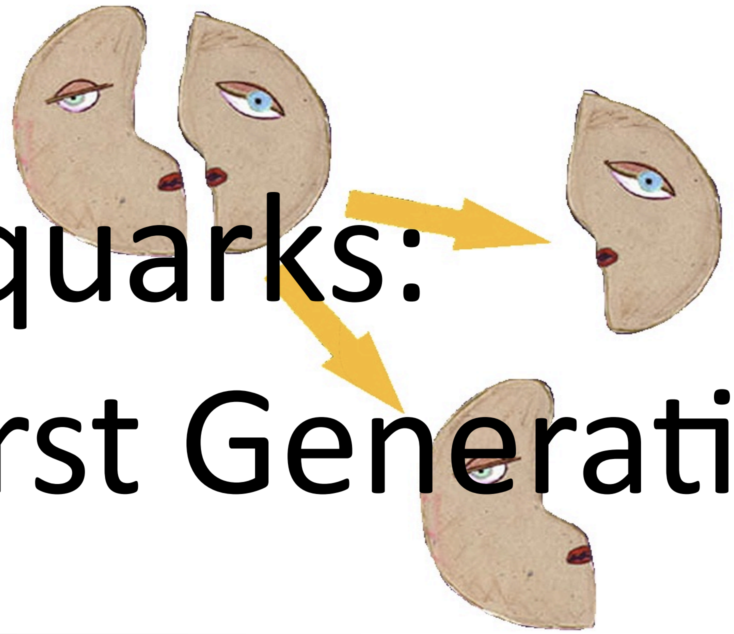
Leptoquarks: The First Generation



R. Caputo

SUNY, Stony Brook

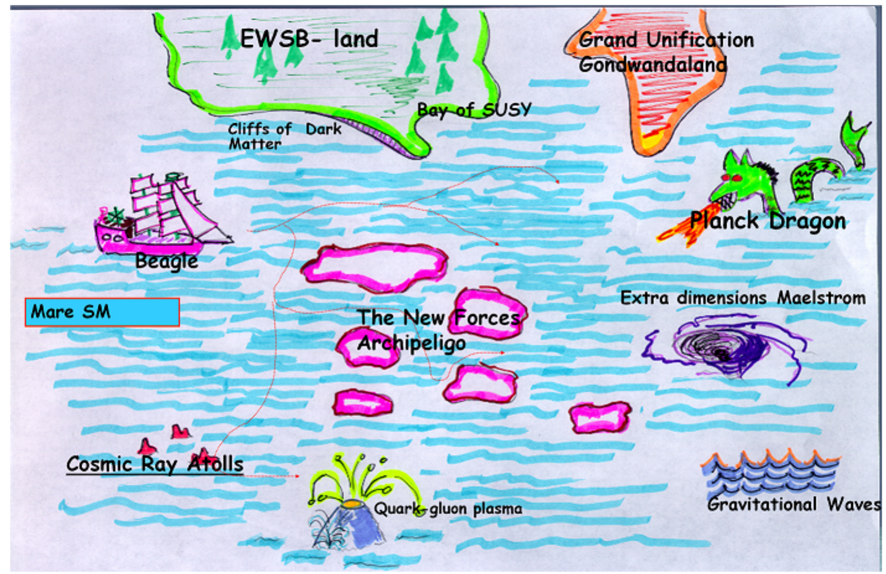
USLUO Meeting

October 30, 2010

On Behalf of the ATLAS Collaboration

Map

- A Brief Introduction to Leptoquarks
- The ATLAS detector
- Backgrounds and Signal
- Results of a W Event Selection
- Shape Comparison for Event Selection
- Optimization
- Conclusions



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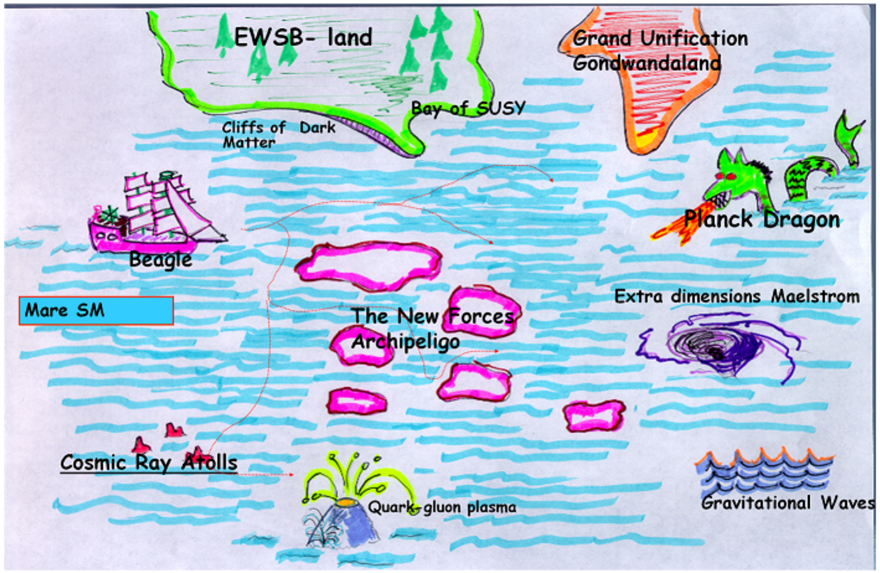
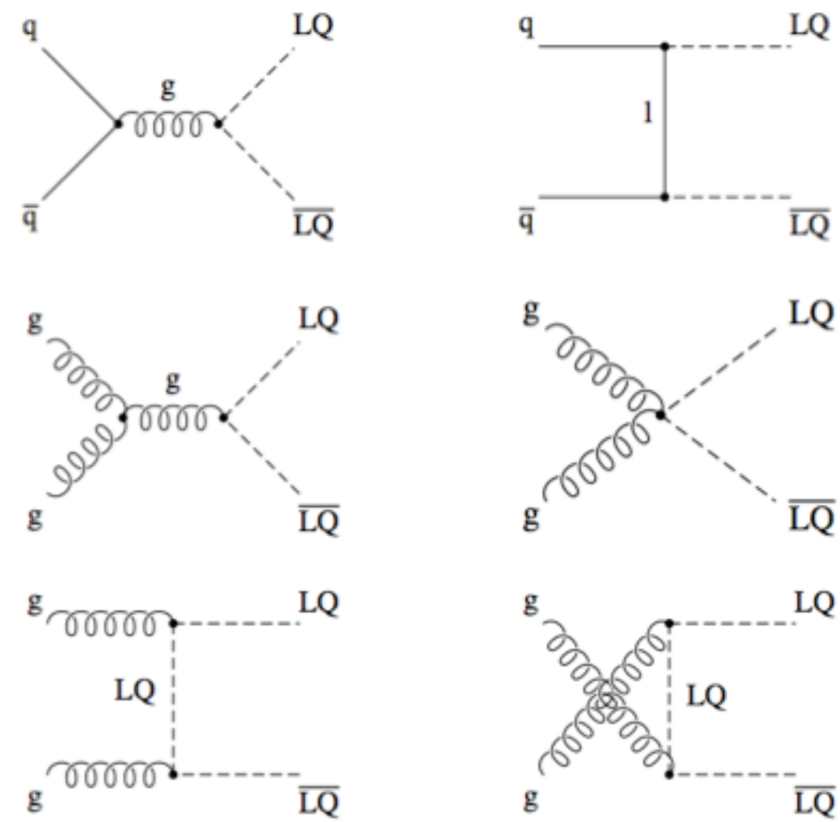


[1]

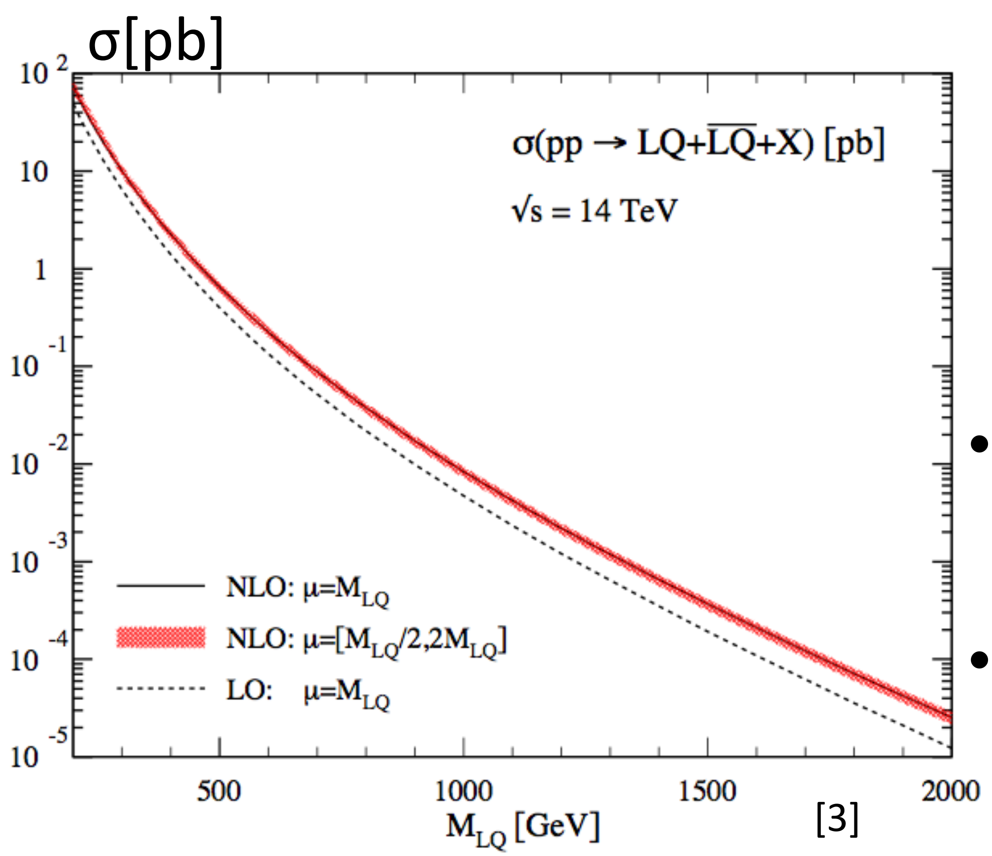
A Brief Introduction

- SM provides no explanation of symmetry between quarks/leptons
- LQs are particles which carry both baryon and lepton number
  - Introduced in many SM extensions
    - quantum numbers vary with theory
    - Pair or single production, scalar or vector
- LQs in effective models must
  - have normalizable interactions
  - obey SM group symmetries
  - couple only to SM fermions and gauge bosons
  - conserve lepton/baryon numbers separately
- LQs decay into $\ell^{\pm}/\nu+q$
  - decay topology parameterized by branching fraction to charged leptons (β)[2]

Born level diagrams for LQ pair production



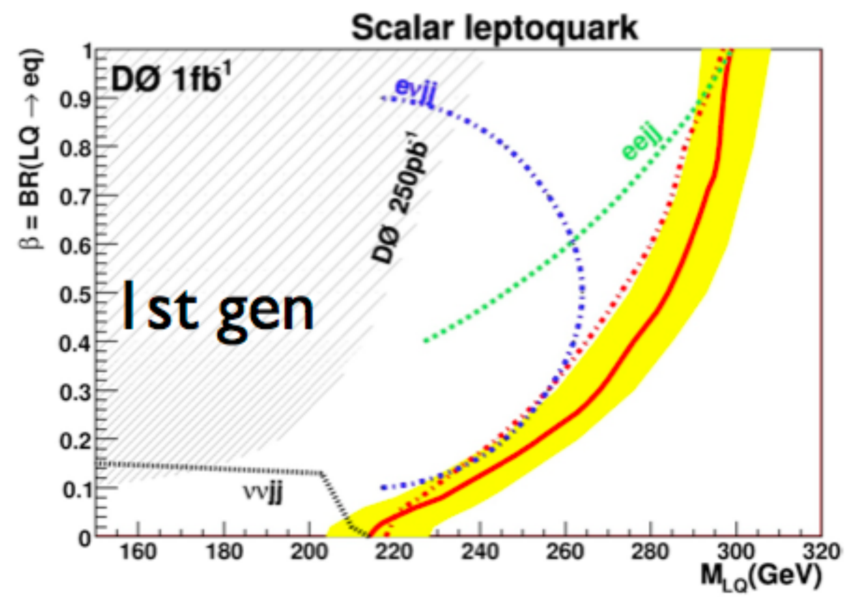
Production Cross Sections



- Leptoquarks are bosons
  - spin-0 scalar
    - 2 couplings: ℓ-q and ν-q
  - spin-1 vector
    - 4 couplings: 2 with λ_G and κ_G (anomolous quadrupole moment and anomalous magnetic moment)
- Use NLO σ for scalar signal [3] and background normalizations
- Discuss scalar LQ pair production
  - LQ interaction relies only on SM α_s which depends LQ mass

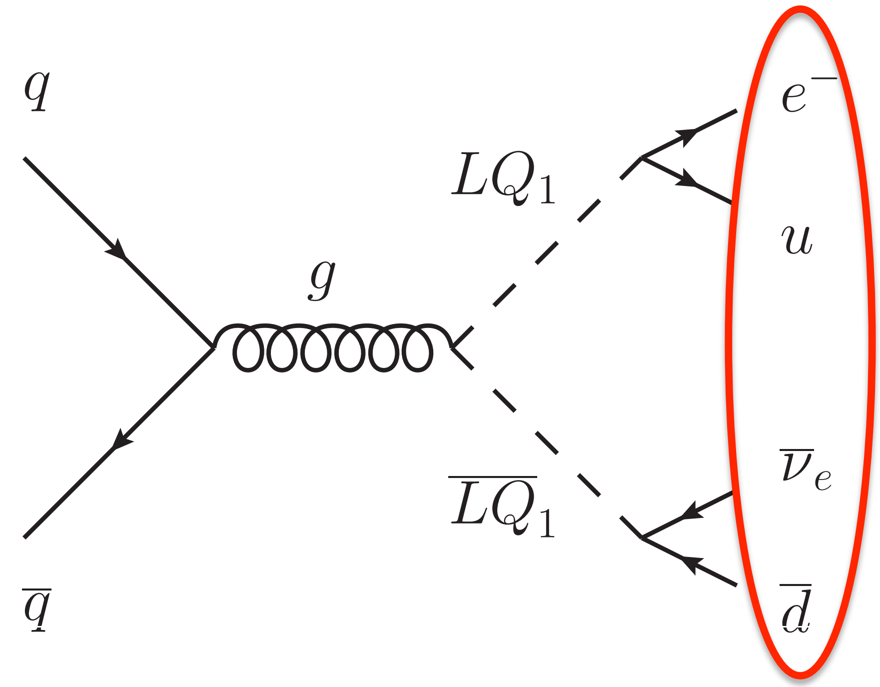
Current Limits: HERA and the Tevatron

- HERA results
  - 1997: H1 and ZEUS observed excess at e+jet mass of 200 GeV (could be single LQ production)
  - ruled out by Tevatron
- Tevatron results
  - D0 limits [4]:
    - 218 GeV (expected), 216 GeV (observed) (β=0.01)
    - 273 GeV (expected), 284 GeV (observed) (β=0.5)
    - 297 GeV (expected), 299 GeV (observed) (β=1)
  - CDF limits [5]:
    - 126 GeV (β=0.01)
    - 205 GeV (β=0.5)
    - 236 GeV (β=1)



Search Model

- LQ pair production
  - decay topology: electron + $\not{E}_T$+ dijet channel
- Not dependent on particular theoretical model
- Color charged so can be produced strongly
  - gg and t-channel process dominant at low LQ mass
  - s-channel dominant at high LQ mass



Signature: high p_T e, high $\not{E}_T$, at least 2 jets

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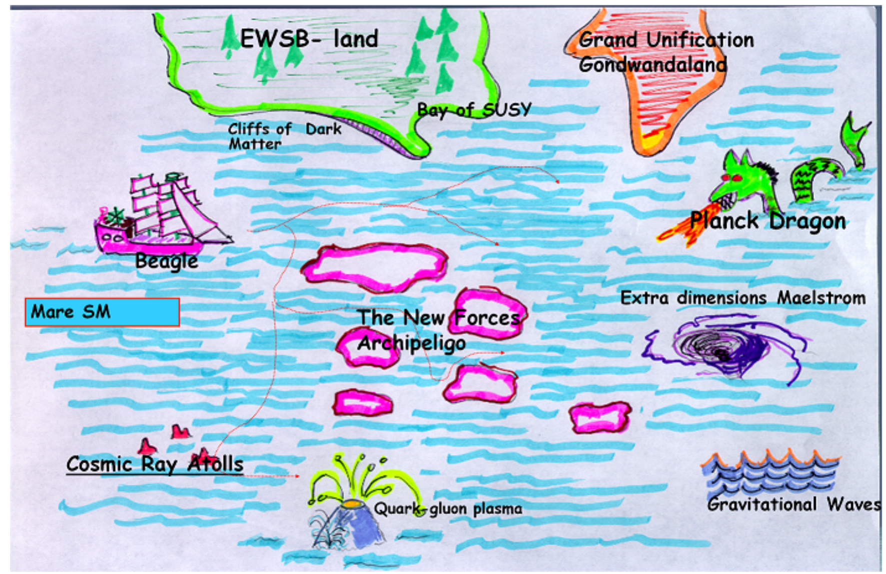
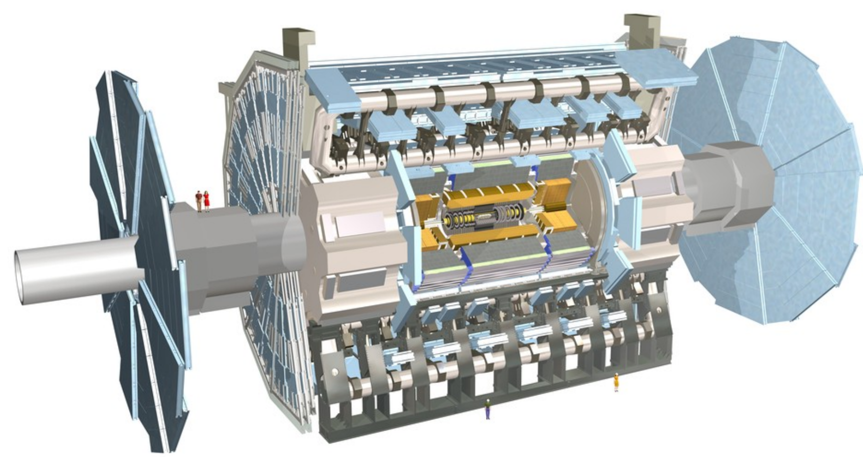


[1]

The ATLAS Detector

- Inner Detector/Tracking
  - Pixel, Silicon Strips, Transition Radiation Tracker
- Calorimeters
  - Electromagnetic
    - LAr Barrel and endcaps
  - Hadronic
    - Tile
    - LAr forward and endcaps
- Magnets
  - Toroid and Solenoid
- Muons
  - Monitored Dtift Tubes (MDT), Thin Gap Chambers (TGC), Cathode Strip Chambers (CSC), Resistive Plate Chambers (RPC)



[6]

The ATLAS Detector

- Inner Detector/Tracking
  - Pixel, Si Strips, Transition Radiation Tracker
  - momentum resolution dependent on η and p_T ($\sim 5\times10^{-4}\ p_T/\mathrm{GeV} \oplus 0.01$)
- Calorimeters
  - Electromagnetic
    - LAr Barrel and endcaps
  - Hadronic
    - Tile
    - LAr forward and endcaps
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  - Toroid and Solenoid
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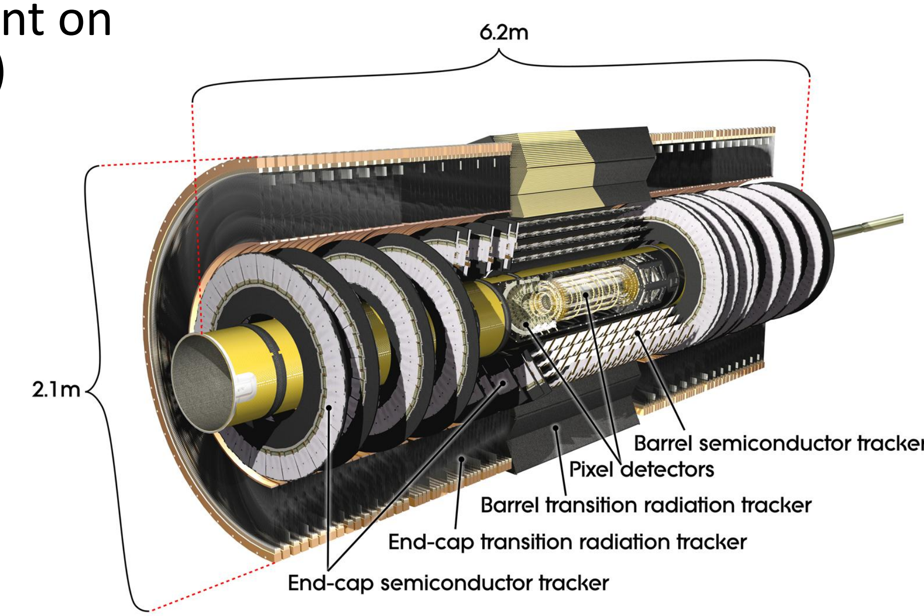
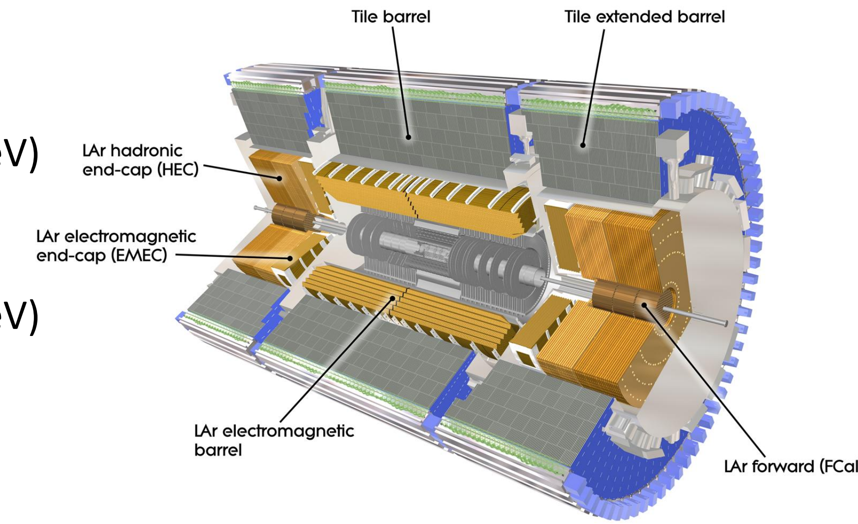


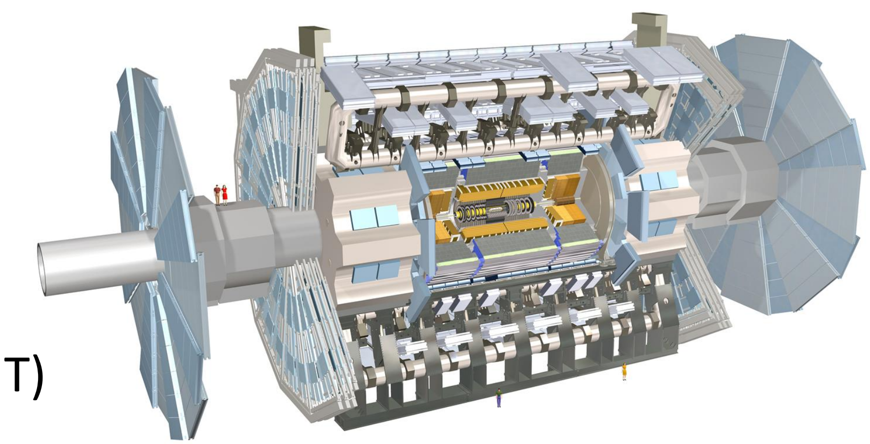
The ATLAS Detector

- Inner Detector/Tracking
  - Pixel, Silicon Strips, Transition Radiation Tracker
- Calorimeters
  - Electromagnetic
    - LAr Barrel, End caps
    - relative energy resolution $\sim 10\%/\sqrt{E/\mathrm{GeV}}$
  - Hadronic
    - Tile, LAr forward and endcaps
    - relative energy resolution $\sim 60\%/\sqrt{E/\mathrm{GeV}} \oplus 0.03$
- Magnets
  - Toroid and Solenoid
- Muons
  - Monitored Dtift Tubes (MDT), Thin Gap Chambers (TGC), Cathode Strip Chambers (CSC), Resistive Plate Chambers (RPC)



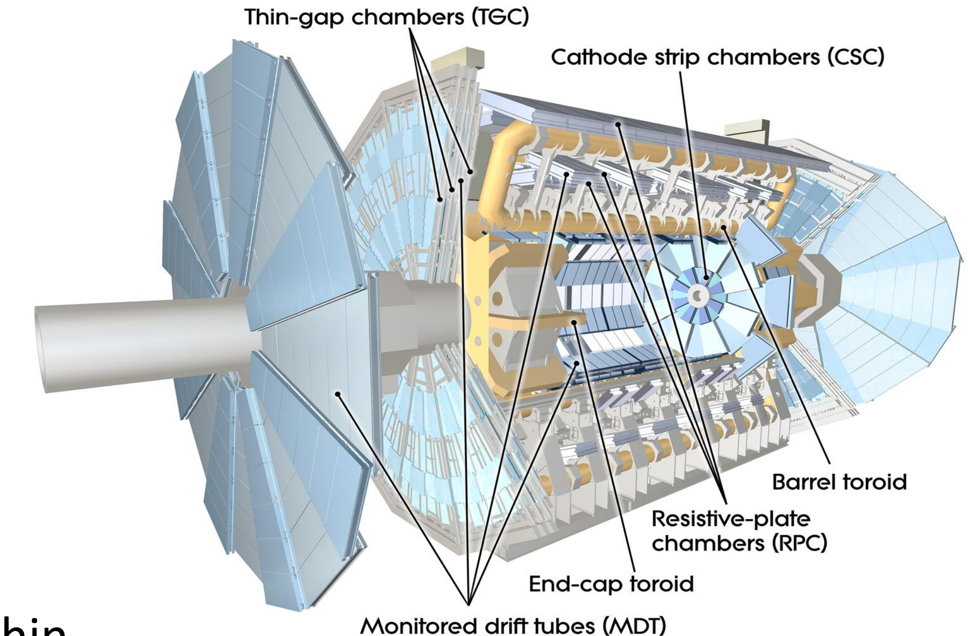
The ATLAS Detector

- Inner Detector/Tracking
  - Pixel, Silicon Strips, Transition Radiation Tracker
- Calorimeters
  - Electromagnetic
    - LAr Barrel and endcaps
  - Hadronic
    - Tile
    - LAr forward and endcaps
- Magnets
  - Toroid - Barrel (3.9 T), End cap (4.1 T)
  - Solenoid - outside of ID (2T)
- Muons
  - Monitored Dtift Tubes (MDT), Thin Gap Chambers (TGC), Cathode Strip Chambers (CSC), Resistive Plate Chambers (RPC)



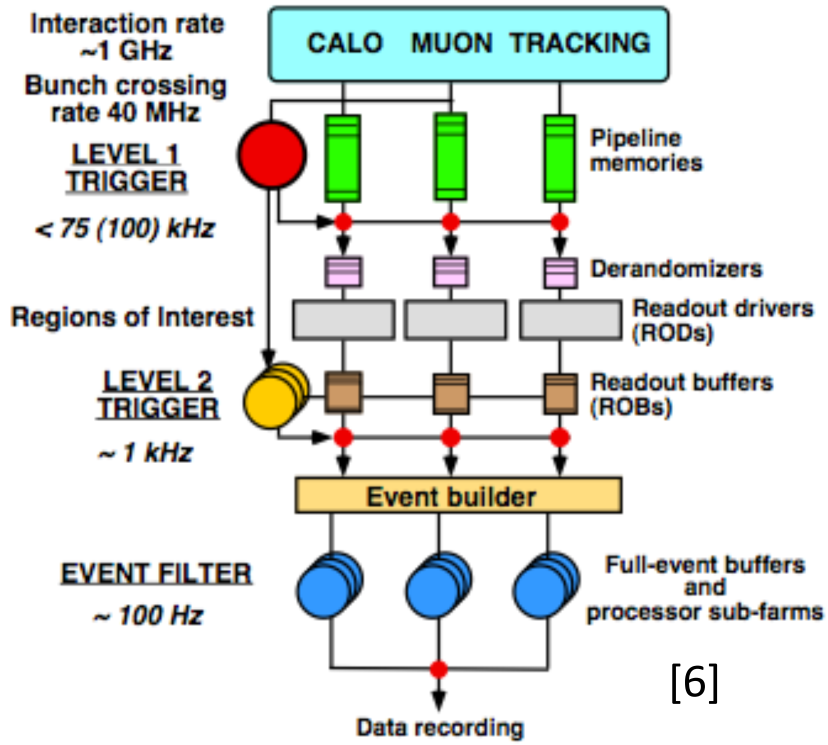
The ATLAS Detector

- Inner Detector/Tracking
  - Pixel, Silicon Strips, Transition Radiation Tracker
- Calorimeters
  - Electromagnetic
    - LAr Barrel and endcaps
  - Hadronic
    - Tile
    - LAr forward and endcaps
- Magnets
  - Toroid and Solenoid
- Muons
  - Monitored Drift Tubes (MDT), Thin Gap Chambers (TGC), Cathode Strip Chambers (CSC), Resistive Plate Chambers (RPC)
  - momentum resolution (~2%)



The ATLAS Detector

- Trigger and Data-Acquisition System
- interaction rate ~10^9 Hz to 100 Hz for recording
- 3 online selection levels
  - level 1 (LVL1) based on reduced granularity from subset of detectors – information held in buffers for level 2
  - level 2 (LVL2) uses region-of-interest (RoI) – position and momentum, selects from buffers
  - level 3 (Event Filter – EF) employs offline algorithms adapted to online environment confirms LVL2



[6]

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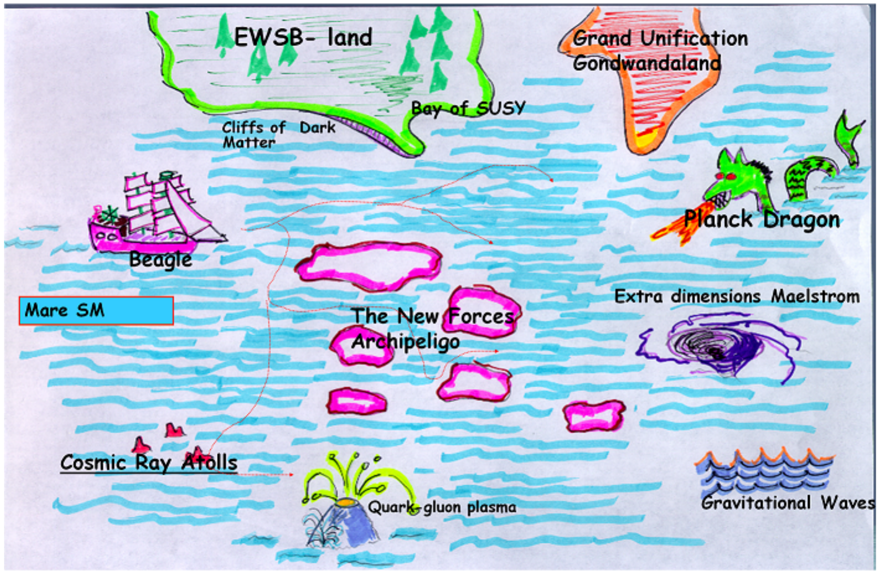


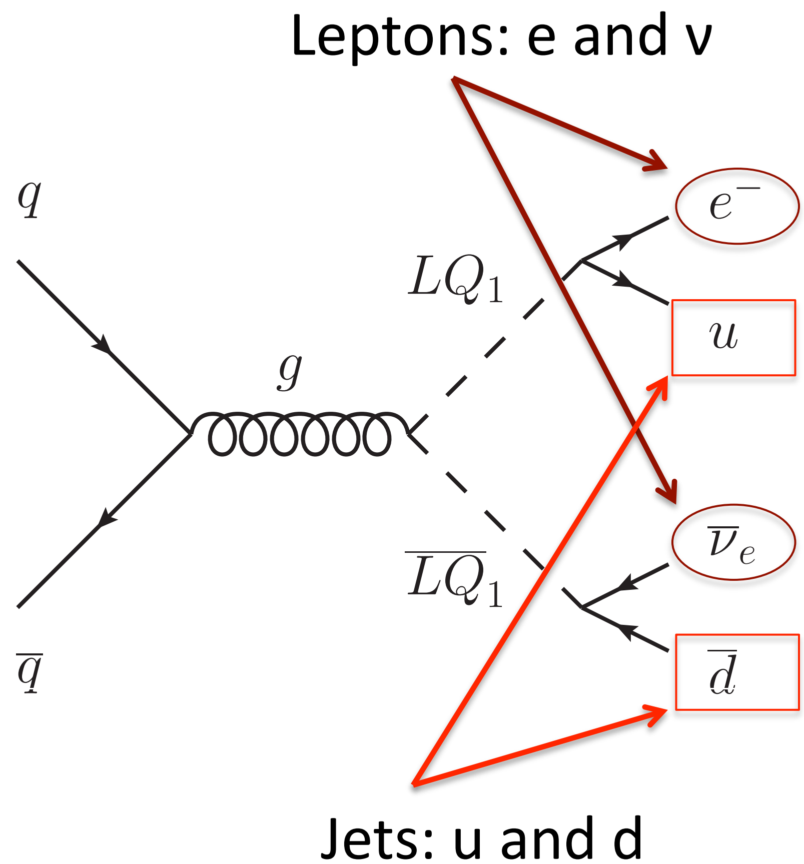
[1]

Backgrounds and Signal

	Approx. Cross Section [pb]
$W \rightarrow e\nu(\tau\nu) + N_{jets}$	10000
$t\bar{t}$	160
single top (eν)	8
diboson (WW/WZ)	27/3
$Z \rightarrow ee(\tau\tau) + N_{jets}$	1000
QCD	(data driven)
$LQ_1\overline{LQ}_1 \rightarrow e\nu qq$ (250 GeV)	3.6
$LQ_1\overline{LQ}_1 \rightarrow e\nu qq$ (300 GeV)	1.2
$LQ_1\overline{LQ}_1 \rightarrow e\nu qq$ (350 GeV)	0.5
$LQ_1\overline{LQ}_1 \rightarrow e\nu qq$ (400 GeV)	0.2

Base Event Selection: The Hunt

- Event Selection – each decay product
  - at least 1 good primary vertex
  - Electrons
    - cluster p_T >20 GeV, $|\eta| < 2.47$ with crack region removed
    - Cluster based with shape requirements and track matched
  - Jets (anti-k_T4, EM scale, topo)
    - p_T >20 GeV, $|\eta| < 2.8$
  - Missing Transverse Energy
    - $\not{E}_T > 25$ GeV
- Event Selection
  - 1 electron
  - no jet requirement for W Selection, ≥ 1 jet required for control region, ≥ 2 for analysis
  - $M_T(e,\not{E}_T) > 40$ GeV

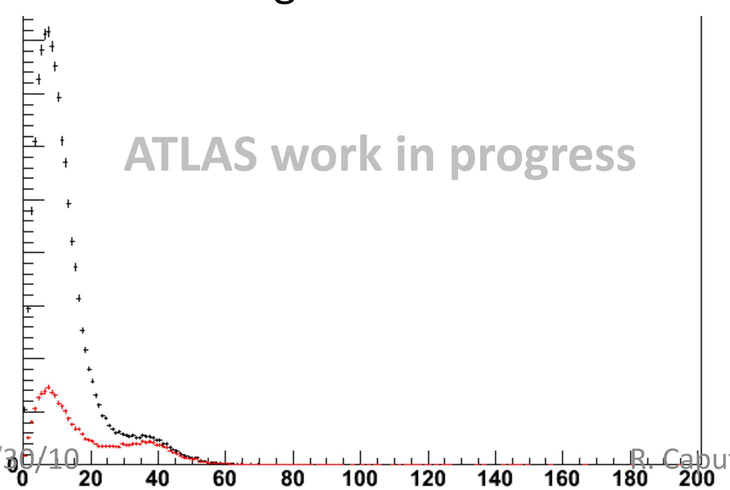


ATLAS work in progress

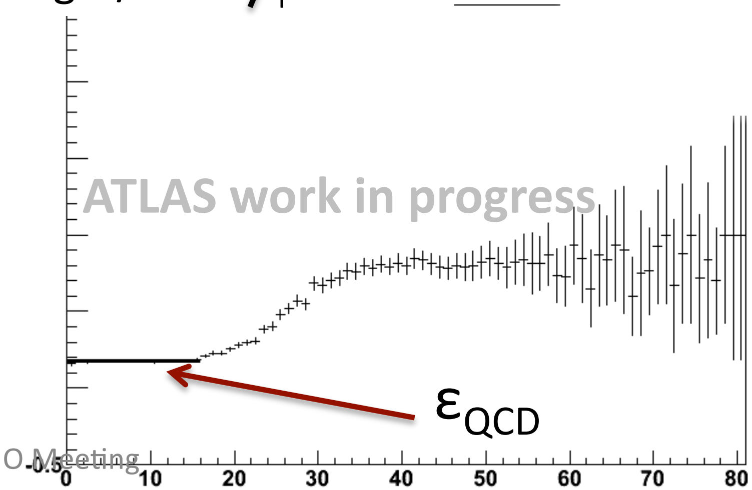
QCD Estimation: Matrix Method

- loose sample w/low real electrons and high QCD
  - $N_l = N_{ele}^{real} + N_{QCD}^{fake}$
- tight sample w/high real electrons and low QCD
  - $N_t = \varepsilon_{ele}^{real} N_{ele}^{real} + \varepsilon_{QCD}^{fake} N_{QCD}^{fake}$
  - ε_{ele}^{real} prob that real electron is tight given loose
  - ε_{QCD}^{fake} prob that fake electron is tight given loose
- Get ε's from analysis, Solve for $\varepsilon_{QCD}^{fake} N_{QCD}^{fake}$

$\not{E}_T$ for loose and tight e's

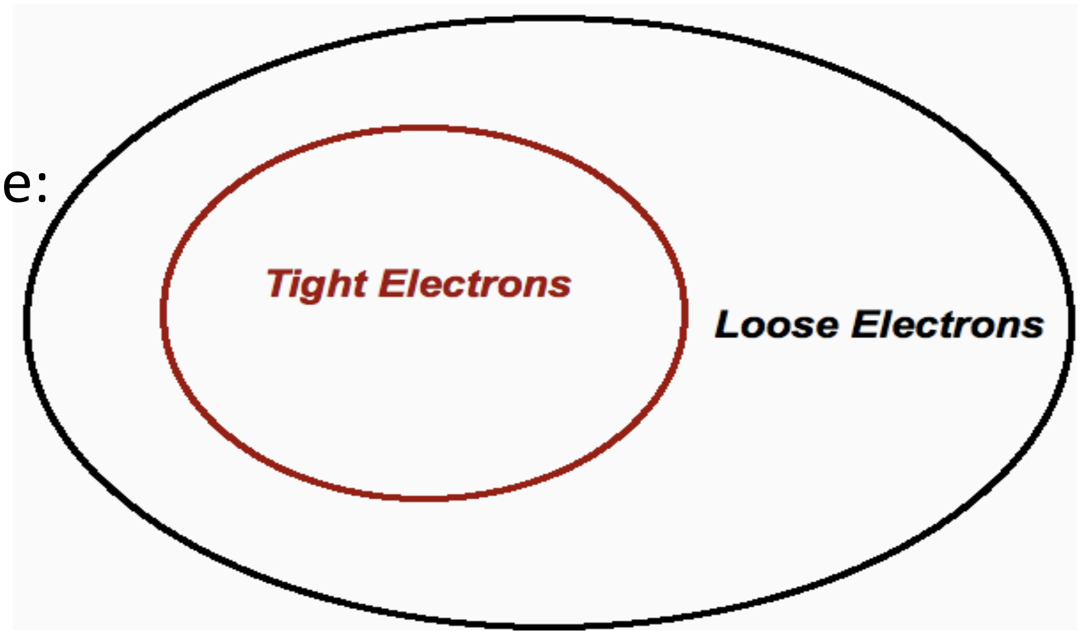


tight/loose $\not{E}_T$ ratio



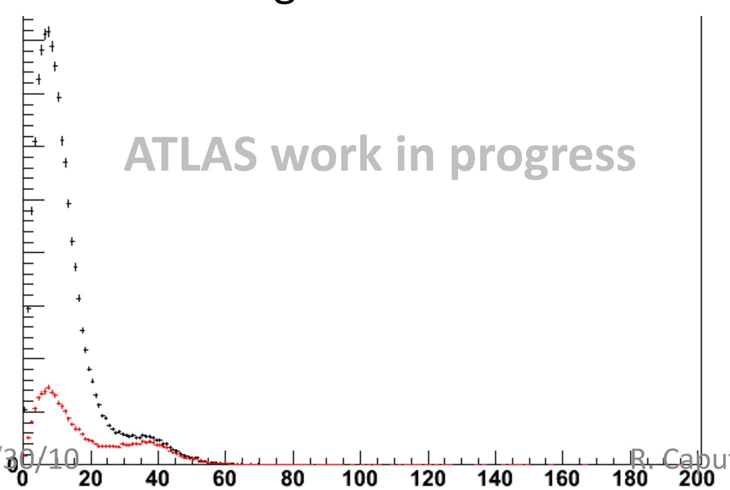
QCD Estimation: Matrix Method

Loose Sample:
Low $\not\!\!E_T$

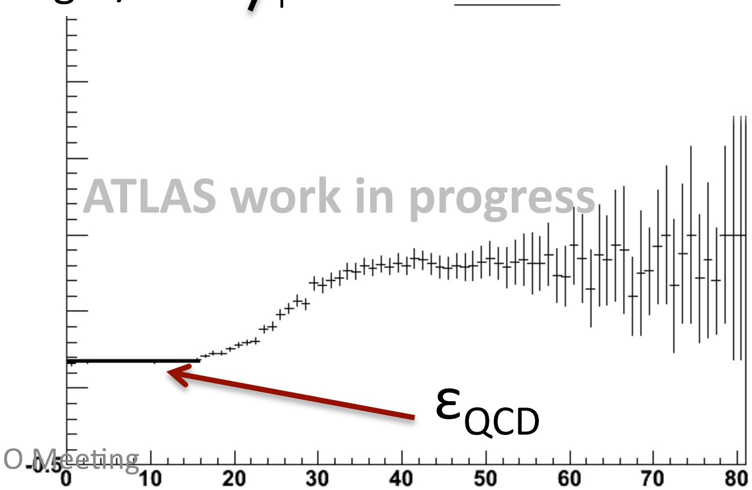


Tight Sample:
2 high p_T
Electrons

$\not\!\!E_T$ for loose and tight e's



tight/loose $\not\!\!E_T$ ratio



Methodology

Bin by Bin

- QCD normalization and shape comes from following:
  - $N_l^i = N_{ele}^{real\ i} + N_{QCD}^{fake\ i}$
  - $N_t^i = \varepsilon_{ele}^{real} N_{ele}^{real\ i} + \varepsilon_{QCD}^{fake} N_{QCD}^{fake\ i}$
  - fill i^{th} bin

$$\varepsilon_{QCD}^{fake} N_{QCD}^{i} = \varepsilon_{QCD}^{fake} \frac{\varepsilon_{ele}^{real} N_l^{\,i} - N_t^{\,i}}{\varepsilon_{ele}^{real} - \varepsilon_{QCD}^{fake}}$$

Reverse Isolation

- shape from loose-tight
- normalization from following:

$$\varepsilon_{QCD}^{fake} N_{QCD} = \varepsilon_{QCD}^{fake} \frac{\varepsilon_{ele}^{real} N_l - N_t}{\varepsilon_{ele}^{real} - \varepsilon_{QCD}^{fake}}$$

- depends on tight/loose definition
- ε_{QCD} ~ 15-20%
- ε_{ele} ~ 75%
  - from Z->ee+N_{jets} MC
  - data/MC correction factor ~1.0

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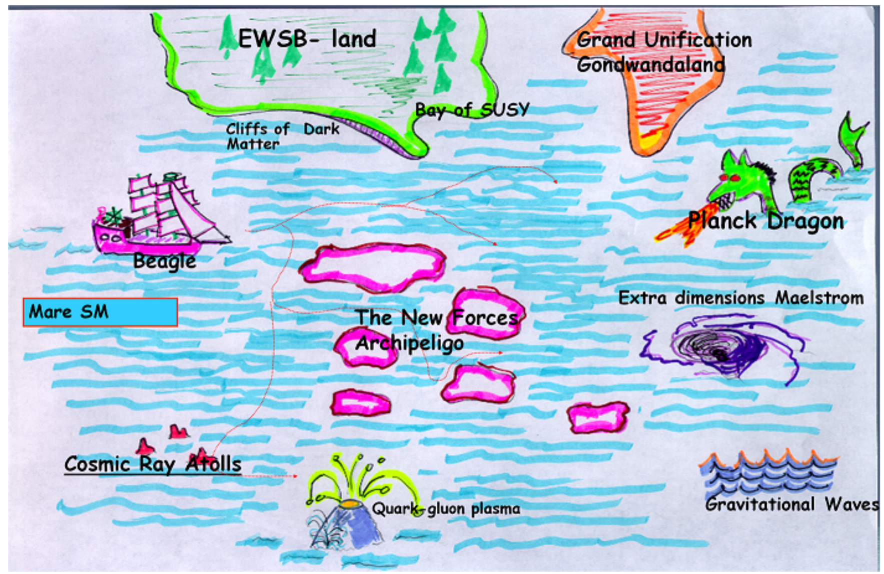
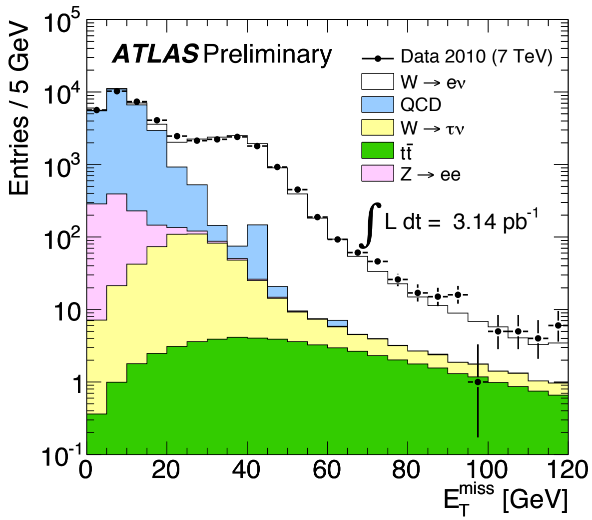


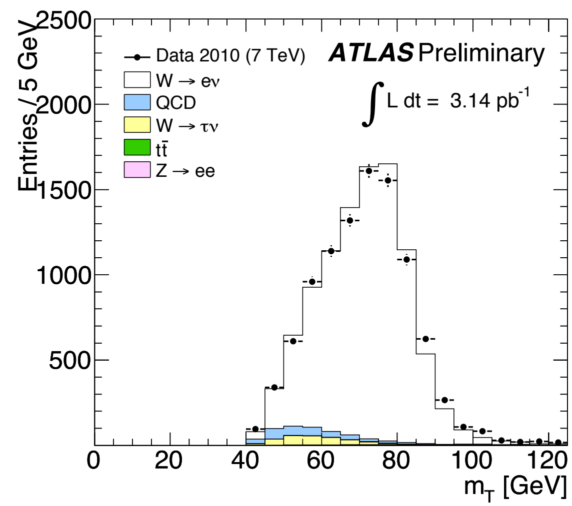
[1]

Base Selection Predicted Yields

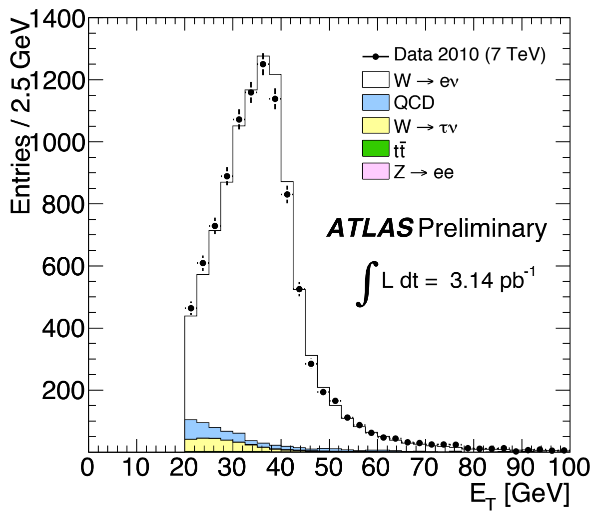
Sample	Pass Base Selection [%]	Approx Predicted Yields 3.1 pb^{-1}
$W \to e\nu + N_{jets}$	8	1900
$W \to \tau\nu + N_{jets}$	0.15	35
$Z \to ee + N_{jets}$	4	13
$Z \to \tau\tau + N_{jets}$	0.14	5
diboson (WW/WZ)	11	7
ttbar (inc)	15	43
single top (ev)	48	14
QCD	--	175
Background Total	--	2200
$LQ_1\overline{LQ}_1 \to e\nu qq$ (250 GeV)	48	6
$LQ_1\overline{LQ}_1 \to e\nu qq$ (300 GeV)	55	2
$LQ_1\overline{LQ}_1 \to e\nu qq$ (350 GeV)	58	0.9

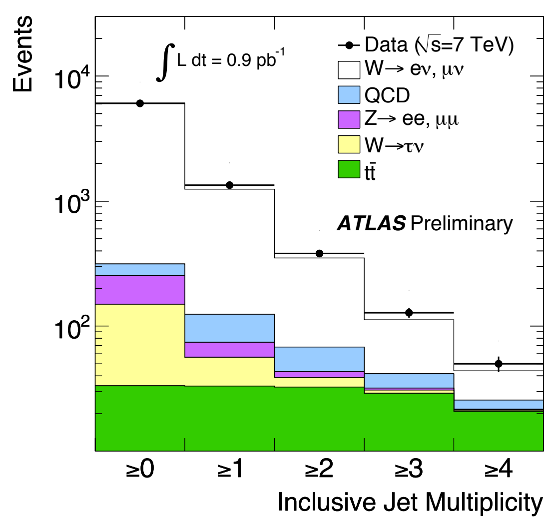
Comparison of W Monte Carlo with Data

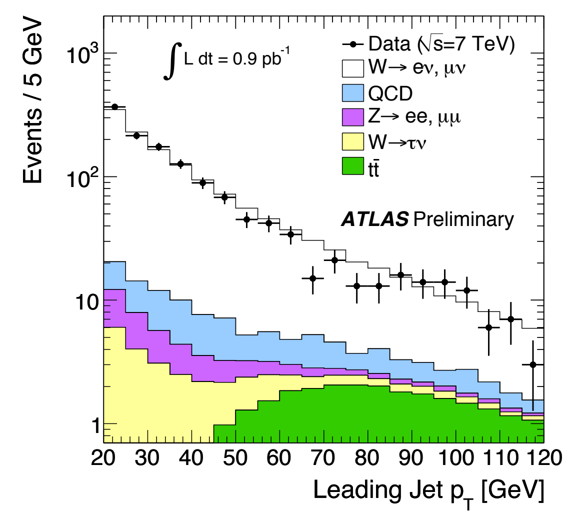




Good agreement between Data and Alpgen Monte Carlo in W reconstruction







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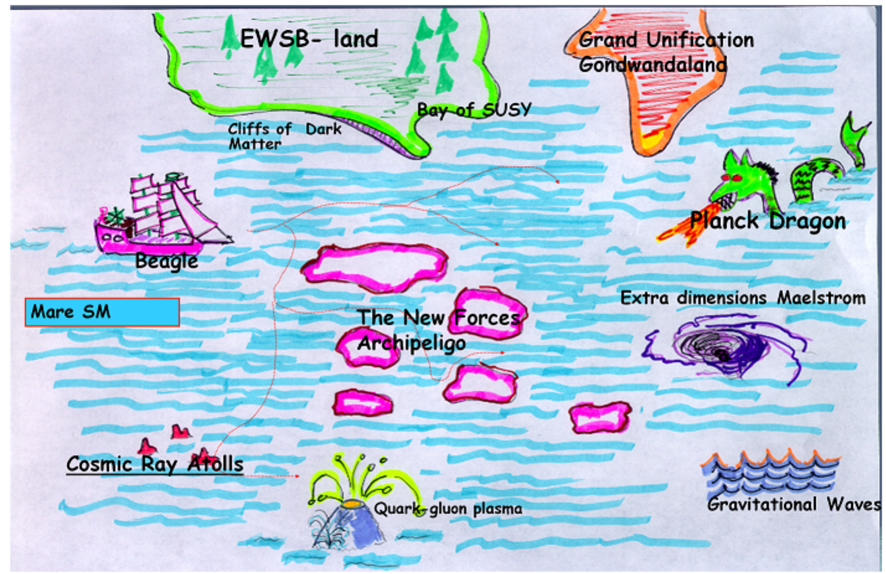
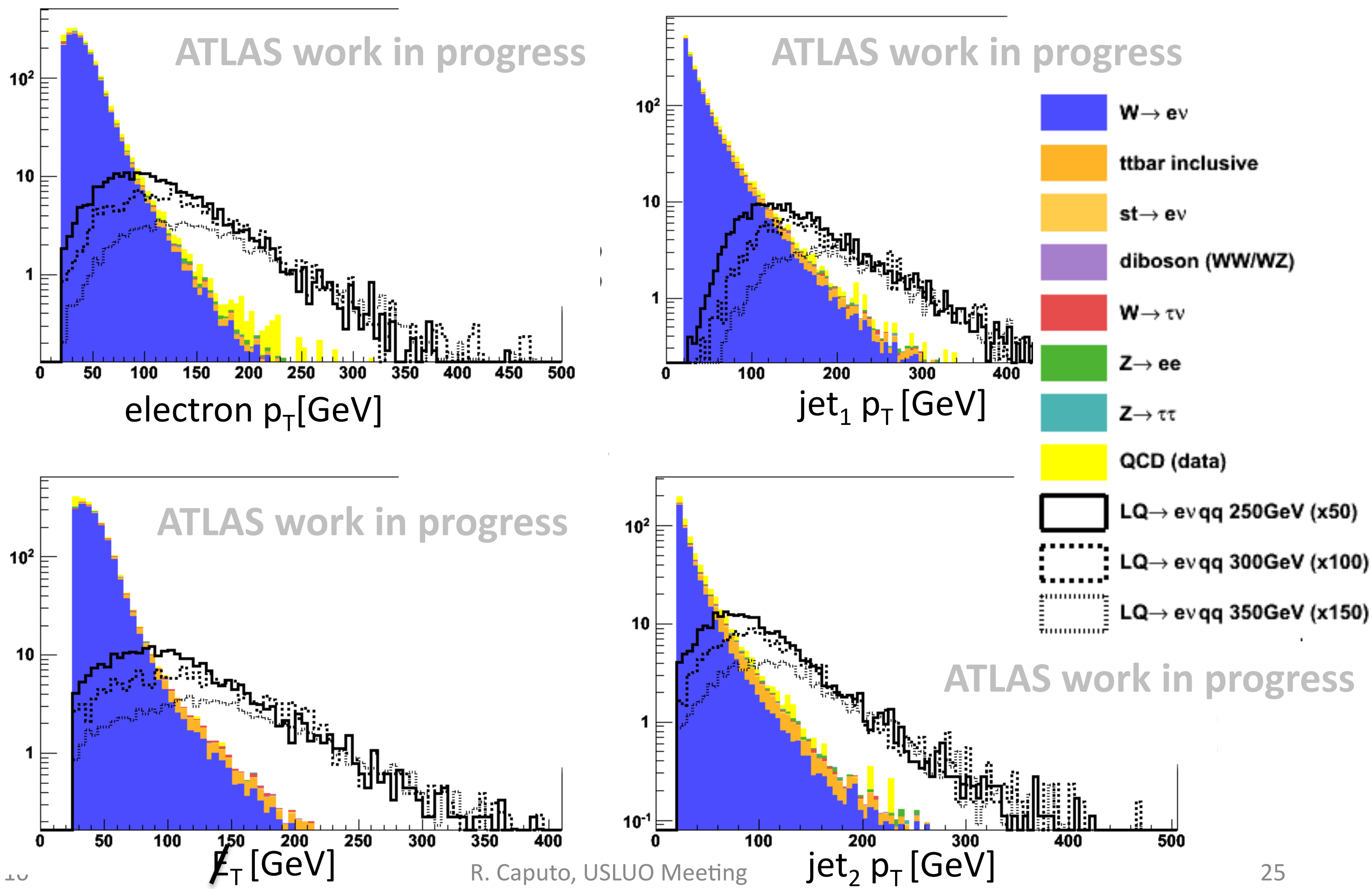


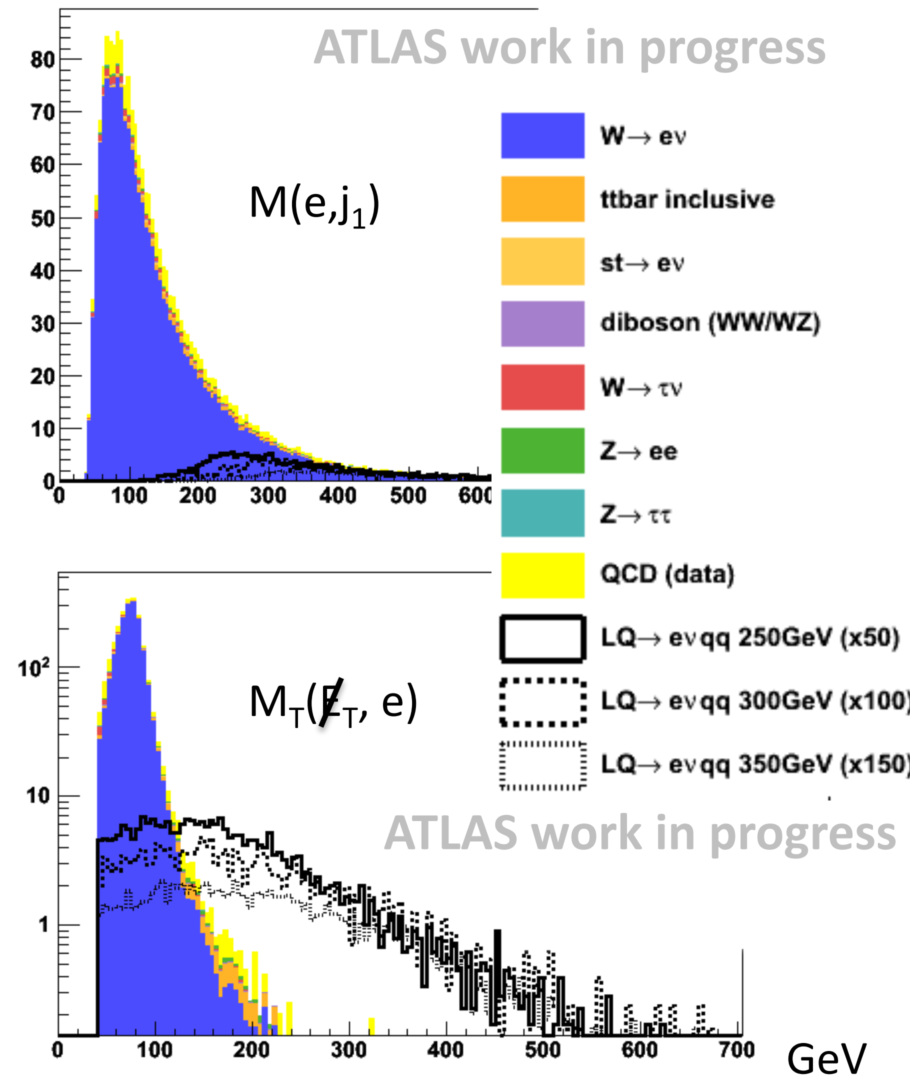
[1]

Background and Signal Shape Comparison

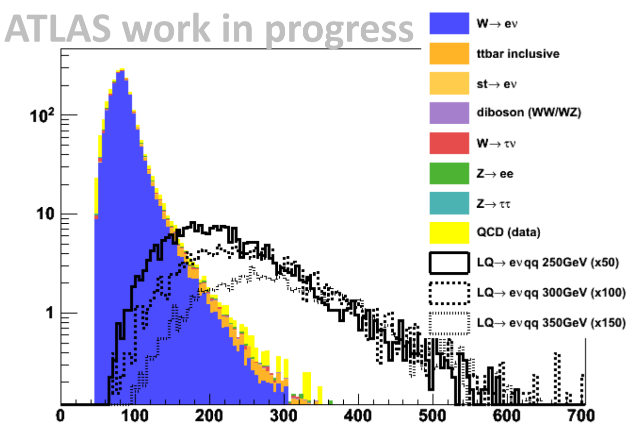


Background and Signal Shape Comparison

- Use plots from control region with 1 jet requirement
- Shape of signal determines best variables to use for optimization
- $M(e,j_1)$ shows clear peak separation, would benefit from background removal
- W dominant background - M_T removal of large W background

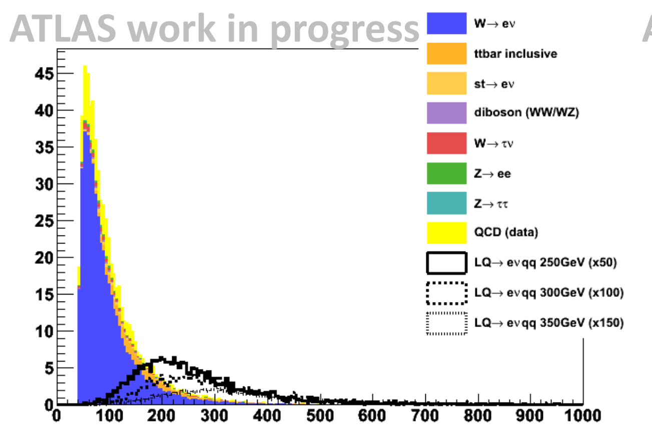


Other Event Variables: L_T, H_T, S_T



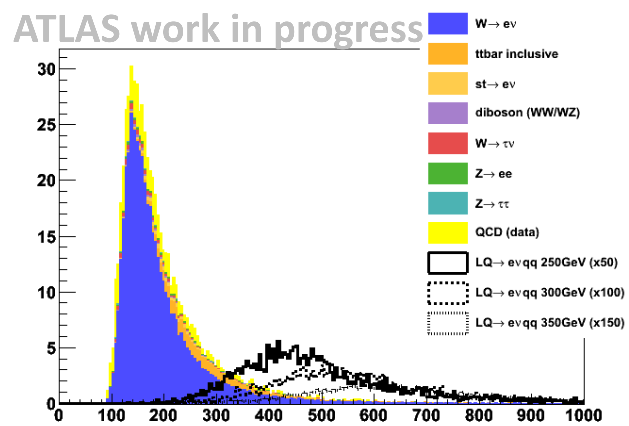
GeV

$L_T = p_T(l) + \not{E}_T$



GeV

$H_T = p_T(j_1) + p_T(j_2)$



GeV

$S_T = H_T + L_T$

This gives an idea of which variables would be the best for optimization

S_T gives very nice signal and background discrimination.

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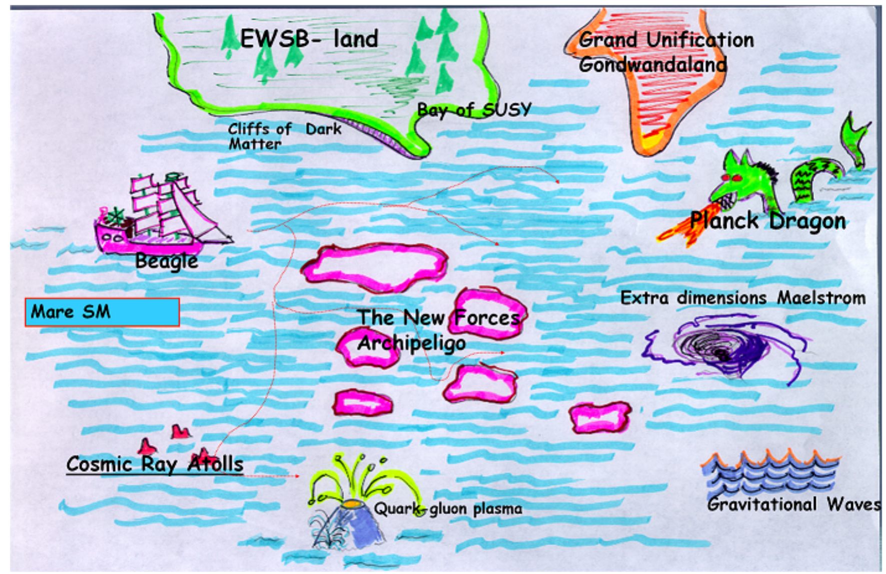


[1]

RGS Optimization

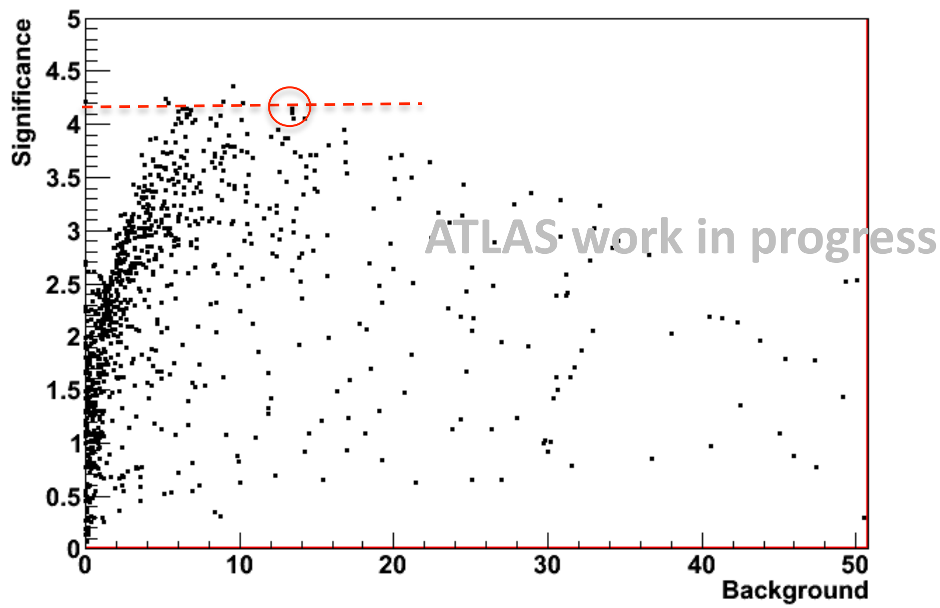
- Random Grid Search - More cut options
  – N-Dimensional
- Each cut choice corresponds to the values in one of the signal events
  – Use every signal event

$$Sig = \frac{S}{\sqrt{B} \oplus 0.1B}$$

- Significance calculated and plotted
  – Matched to each cut
- Compared with simple 1D and 2D calculation
  – over 10% improvement over single variable method
  – allows cross check to not set cuts to an unstable point

Optimization for a 250 GeV LQ

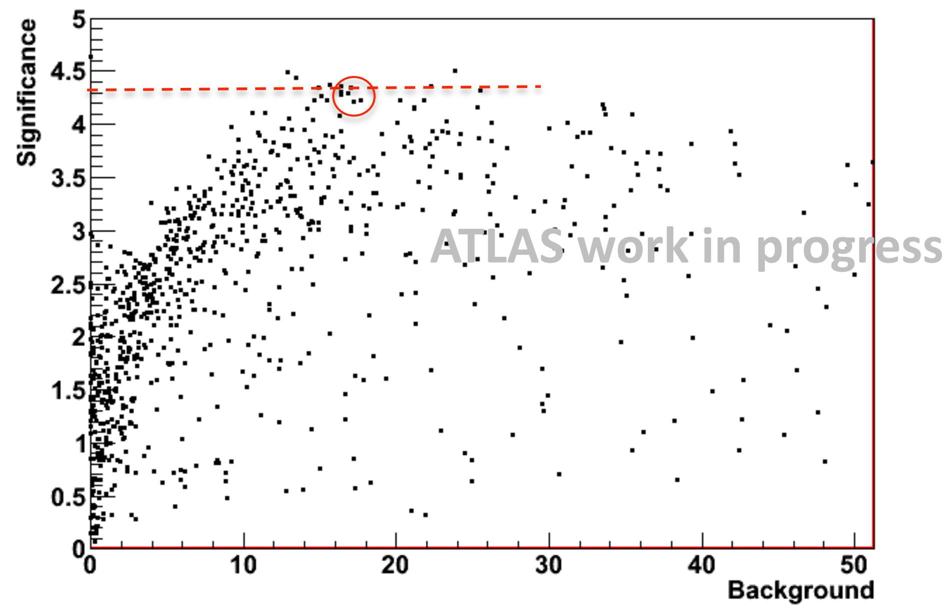
- Where do we have sensitivity?…
- Check near current limit: 250 GeV LQ pairs
  - (assume $\mathcal{L}$ = 20 pb^{-1})
- 4D Grid based on cutting on the following variables:
  - $\not{E}_T$, $M_T(e,\not{E}_T)$, $M(jet_1,e)$, and S_T
- each point represents a set of cuts in the 4-D space



The peak:	M_T – 150 GeV
signal: 14	$\not{E}_T$ - 180 GeV
background: 10	$M(e,j_1)$ – 200 GeV
significance: >4	S_T – 380 GeV

Optimization for a 300 GeV LQ

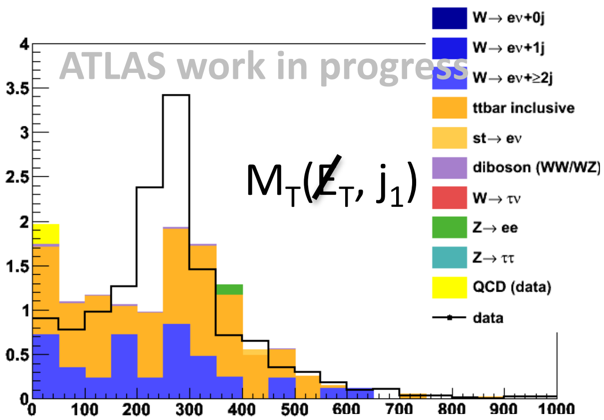
- Boldly going where no experiment has gone before.
- What is our sensitivity in a new region?...
- 300 GeV LQ sample signal first generation
  - ($\mathcal{L}$ = 50 pb^{-1})
- Same 4-D grid space
  - $\not{E}_T$, $M_T(e,\not{E}_T)$, $M(jet_1,e)$, and S_T

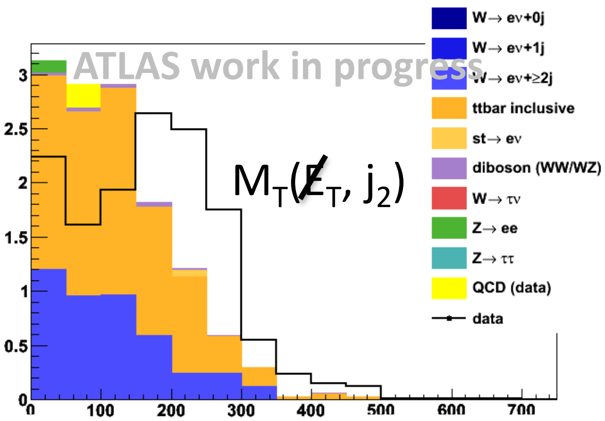


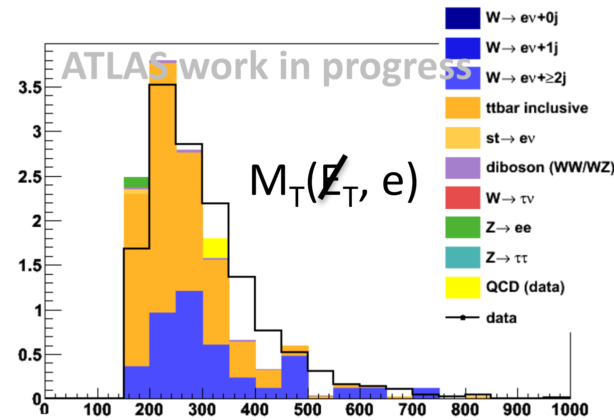
The peak:	M_T – 170 GeV
signal: 18	$\not{E}_T$- 85 GeV
background: 15	$M(e,j_1)$ – 225 GeV
significance: >4	S_T – 400 GeV

Results

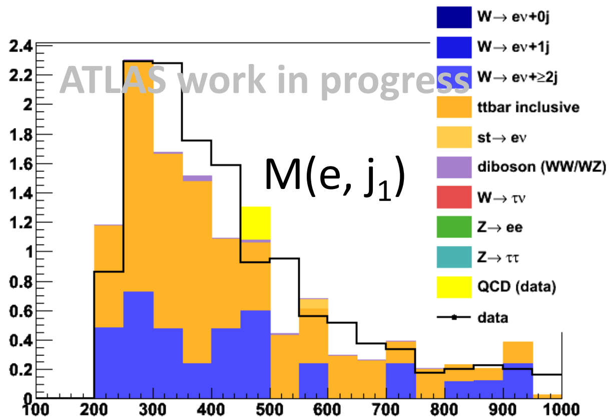
Unscaled Signal

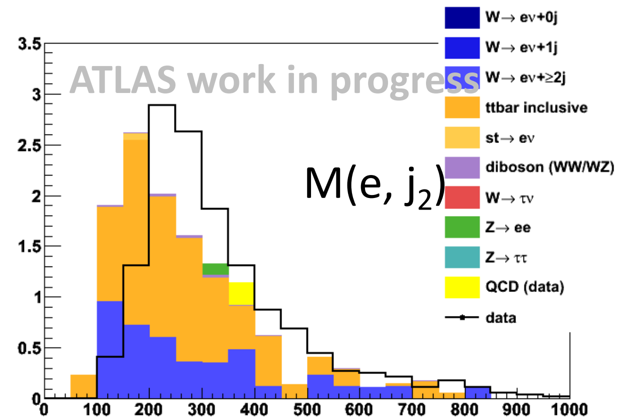




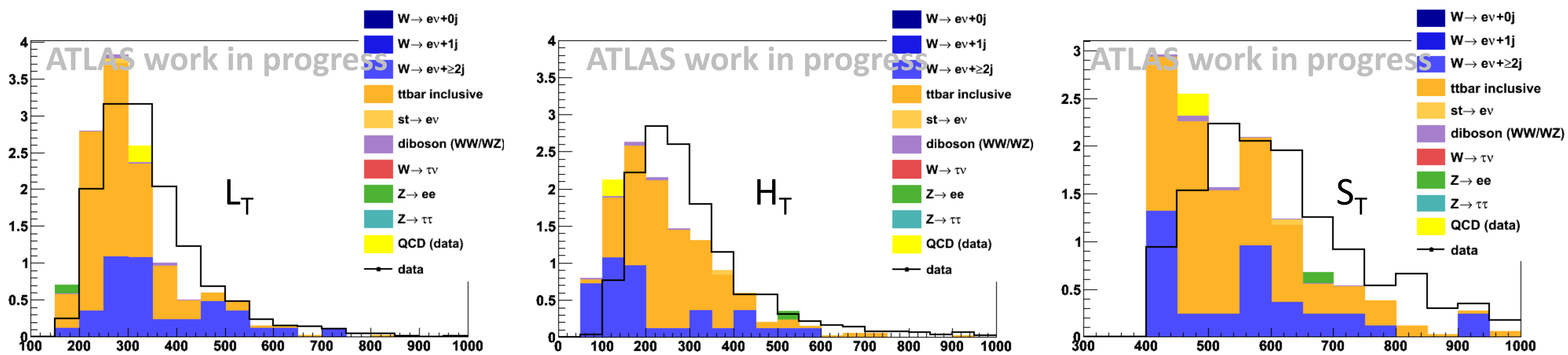


Signal:
300 GeV
$\mathcal{L}$ = 50 pb^{-1}





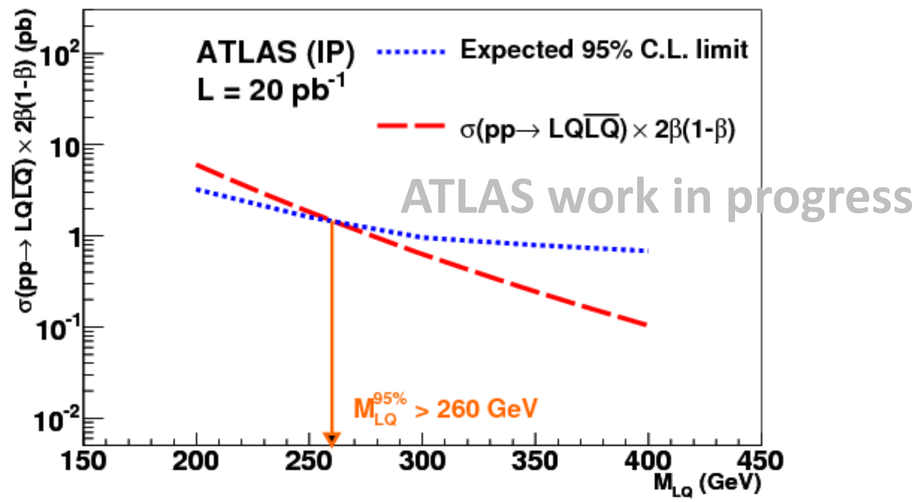
Results

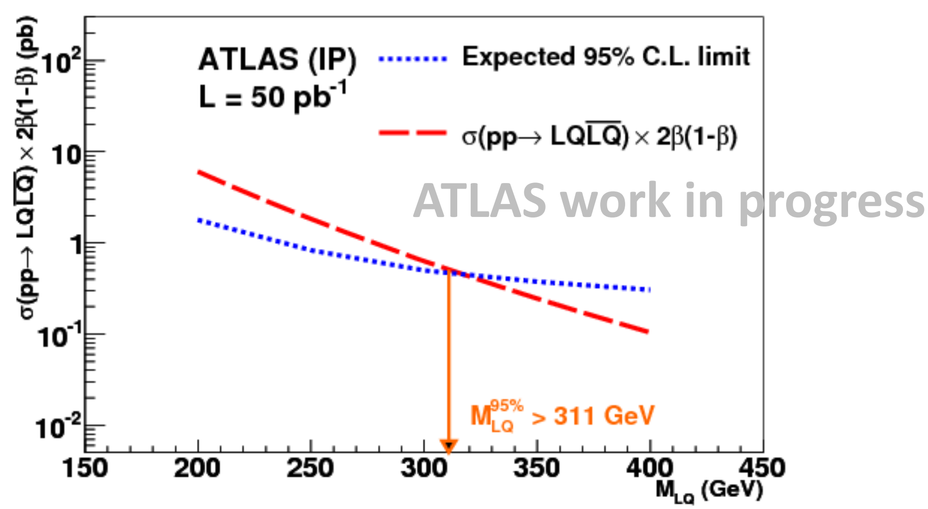


- All this was done with RGS optimization
  - Very loose preselection
  - Investigation of best 4 variables for cuts

Results

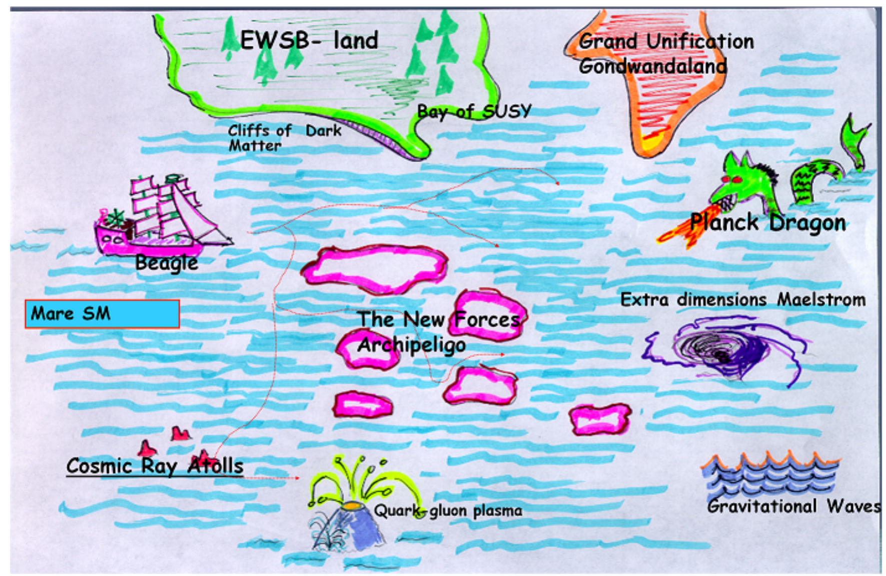
- Promising results using RGS method
  - > 4σ signal significance optimized with 300 GeV LQLQ production
- 95% C.L. limit from RGS method
- Assumes β=0.5
- Limits computed using modified Frequentist approach
- 11% total for systematics 100% correlated between background and signal





Map

- A Brief Introduction to Leptoquarks
- The ATLAS detector
- Backgrounds and Signal
- Results of a W Event Selection
- Shape Comparison for Event Selection
- Optimization
- **Conclusions**

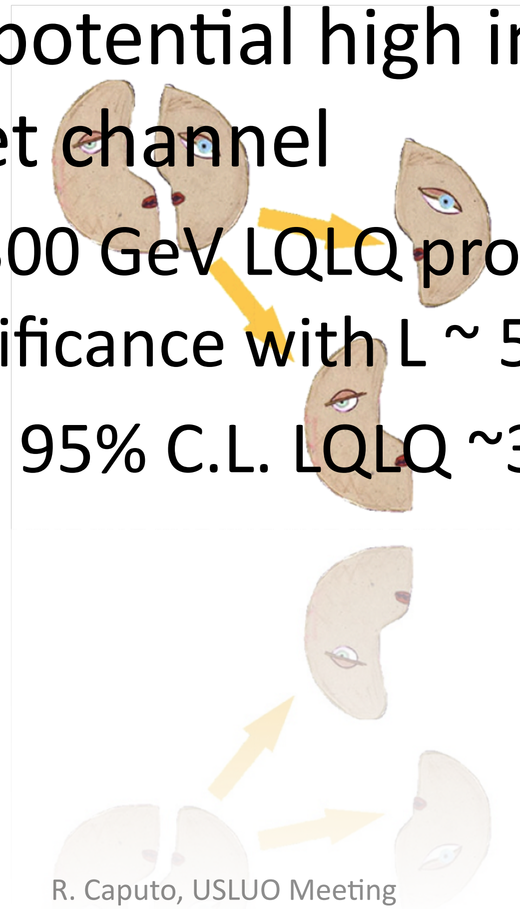


[1]

Conclusions

- Leptoquarks provide a robust set of searches for the new LHC era
- Early discovery potential high in electron+ Missing E_T + dijet channel
  - Discovery: for 300 GeV LQLQ production predicted > 4σ signal significance with L ~ 50 pb^{-1}

    Exclusion: Limit 95% C.L. LQLQ ~310 GeV



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