Leptoquarks at Rome

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Outline

- Why Leptoquarks ?
- Current Results from the TeVatron (who I am...)
- Final Run II results
- ATLAS prototype analyses
- Plans
  - Short term (I just started!)
  - Long(er) term: Rome and beyond
- Conclusions

1st and 2nd generation scalar LQ only!
Lepton signatures!

Theoretical Motivation

- Leptoquarks (LQ) are hypothetical particles which appear in many SM extensions to explain symmetry between leptons and quarks
  - SU(5) GUT model
  - superstring-inspired models
  - 'colour' SU(4) Pati-Salam model
  - composite models
  - technicolor

•LQs are coupled to both leptons and quarks and carry SU(3) color, fractional electric charge, baryon (B) and lepton (L) numbers

•LQs can have:

- spin 0 (scalar)
  - •couplings fixed, i.e., no free parameters
  - •Isotropic decay
- spin 1 (vector)
  - •anomalous magnetic (k_G) and electric quadrupole (λ_G) model-dependent couplings
    - -Yang-Mills coupling: $k_G = \lambda_G = 0$
    - -Minimal coupling: $K_G = 1$, $\lambda_G = 0$
- -Decay amplitude proportional to $(1 + \cos\theta^*)^2$

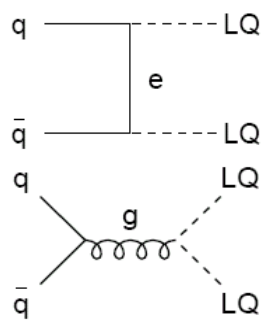
- Experimental evidence searched:
  - indirectly: LQ-induced 4-fermion interactions
  - directly: production cross sections at collider experiments

LQ at Hadron Colliders

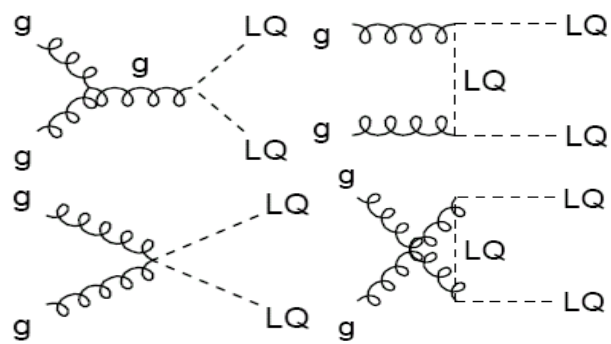
- Pair production
  - Practically independent of Yukawa coupling (only g-LQ-LQ vertex)
  - Depends mainly on LQ mass

- λ dependent process
- does not contribute significantly to 2nd & 3rd generation

$q\bar{q} \rightarrow LQ\ LQ$



$gg \rightarrow LQ\ LQ$



Leptoquark Decay

$\beta = Br(LQ \rightarrow lq)$

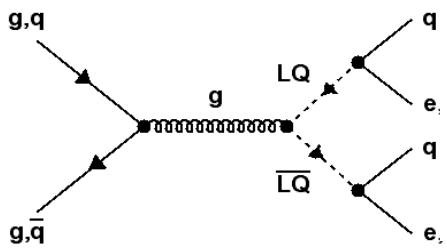
Each generation can decay into 3 final states:

Exclusive to the Hadron Machines

	1st Generation	2nd Generation	3rd Generation
$\beta = 1$	$LQ\,\overline{LQ} \rightarrow e^- e^+ q\bar{q}$	$LQ\,\overline{LQ} \rightarrow \mu^+ \mu^- q\bar{q}$	$LQ\,\overline{LQ} \rightarrow \tau^+ \tau^- q\bar{q}$
$\beta = 0.5$	$LQ\,\overline{LQ} \rightarrow e^{\pm} \nu_e q_i q_j$	$LQ\,\overline{LQ} \rightarrow \mu^{\pm} \nu_\mu q_i q_j$	$LQ\,\overline{LQ} \rightarrow \tau^{\pm} \nu q_i q_j$
$\beta = 0$	$LQ\,\overline{LQ} \rightarrow \nu_e \nu_e q\bar{q}$	$LQ\,\overline{LQ} \rightarrow \nu_\mu \nu_\mu q\bar{q}$	$LQ\,\overline{LQ} \rightarrow \nu_\tau \nu_\tau q\bar{q}$

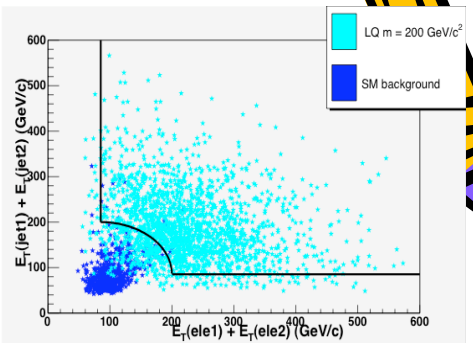
This talk! →	$LQ\,LQ \rightarrow llqq$	2l+2j	$BR = \beta^2$
	$LQ\,LQ \rightarrow l\nu qq$	l+MET+2j	$BR = 2\beta(1-\beta)$
	$LQ\,LQ \rightarrow \nu\nu qq$	MET+2j	$BR = (1-\beta)^2$

Search for LQ in dileptons + jets at CDF



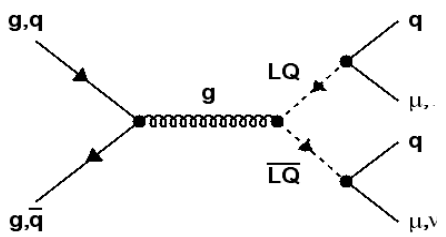
Selection

- ✓ 2 electrons (CC,CF) $E_T > 25$ GeV
- ✓ 2 jets, $E_T(j1) > 30$ GeV, $E_T(j2) > 15$ GeV
- ✓ Z Veto ($76 < M_{\mu\mu} < 110$) GeV
- ✓ Electrons/Jets: $E_T^{j1(e1)} + E_T^{j2(e2)} > 85$ GeV
- ✓ $((E_T(j_1) + E_T(j_2))^2 + (E_T(e_1) + E_T(e_2))^2)^{1/2} > 200$ GeV



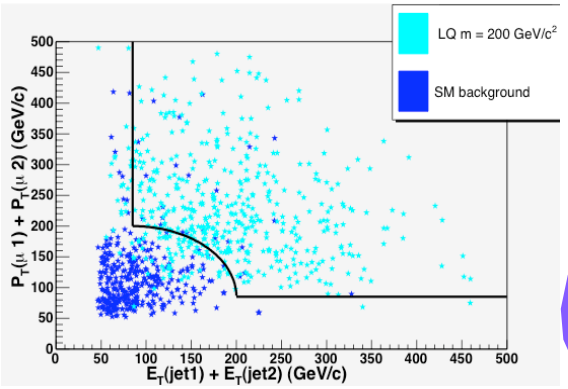
SM background

- Drell-Yan+2jets
- Top ($W \rightarrow e\nu$)
- QCD/Fakes

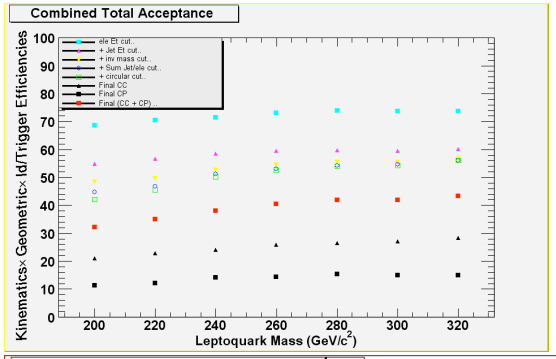


Selection

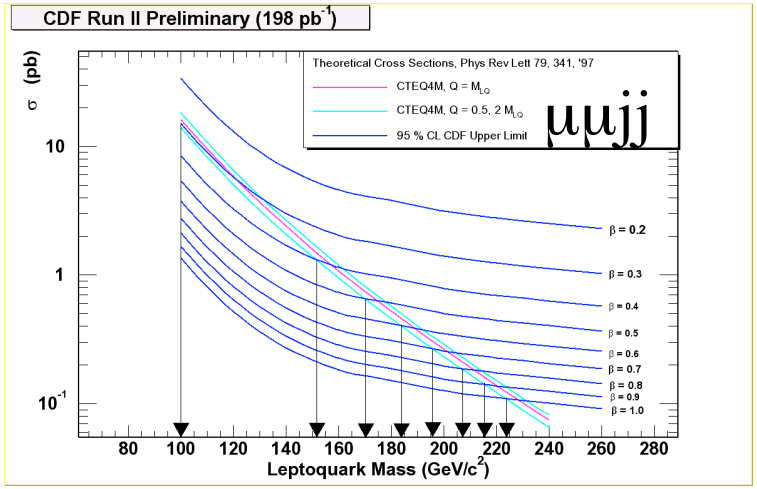
- 2 muons with $P_T > 25$ GeV
- 2 jets with $E_T(j1,j2) > 30,15$ GeV
- Dimuon Mass Veto:
  - $76 < M_{\mu\mu} < 110$, $M_{\mu\mu} < 15$ GeV
- $E_T(j_1) + E_T(j_2) > 85$ GeV and $P_T(\mu_1) + P_T(\mu_2) > 85$ GeV
- $((E_T(j_1) + E_T(j_2))^2 + (P_T(\mu_1) + P_T(\mu_2))^2)^{1/2} > 200$ GeV

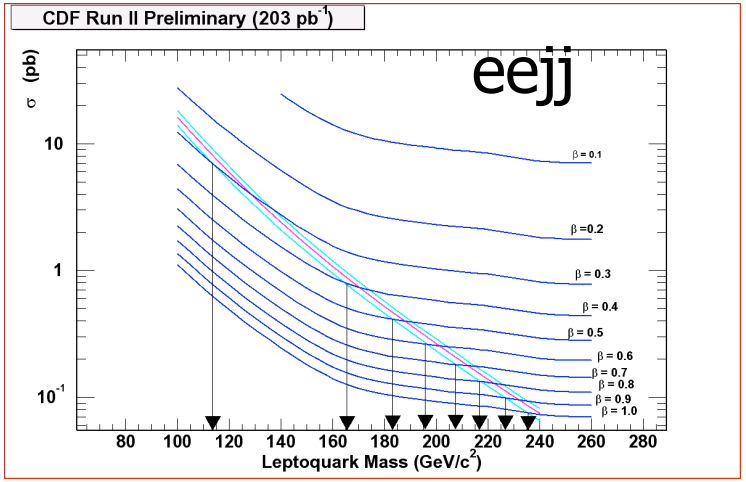


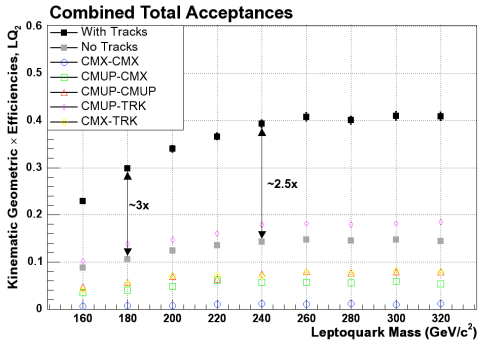
Search for LQ in dileptons + jets (III)



Exclude at 95% CL M_{LQ}<224 GeV/c^2 for β = 1.0

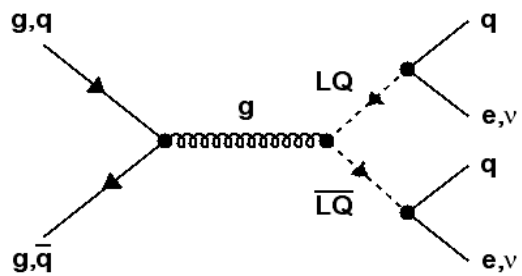






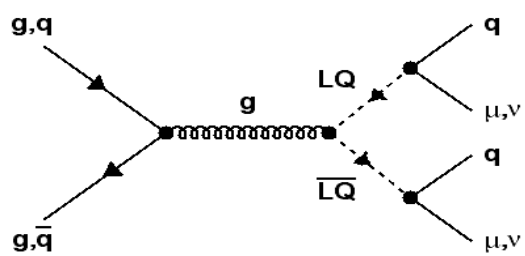
Exclude at 95% CL M_{LQ}<235 GeV/c^2 for β = 1.0

Search for LQ in lepton + MET + jets



SM background

- W +2jets
- Top (l + jets and dilepton)
- QCD/Fakes



Selection

- 1central electrons with E_T > 25 GeV
- MET > 60 GeV
- Veto on 2nd electron, central loose or Plug
- 2 jets with E_T > 30 GeV
- $\Delta\phi$ (MET-jet) > 10°
- $E_T(j1) + E_T(j2)$ > 80 GeV
- $M_T(e\text{-}\nu)$ > 120
- LQ mass combinations

Selection

Z veto (tight/loose pair)

No 2nd muon (CMUP, CMX, or stubless)

$P_T(\mu)$ > 25 GeV

$\not{E}_T$ > 60 GeV

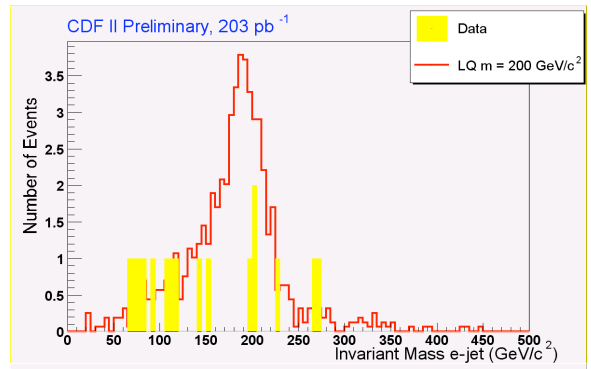
2 jets, @ E_T>30GeV

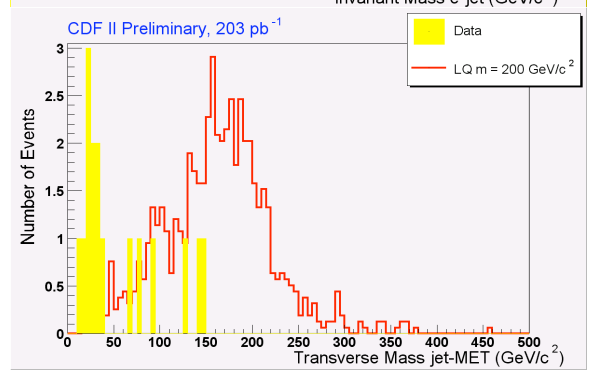
$\Delta\phi(\mu,\not{E}_T)$<175°, $\Delta\phi(\not{E}_T,\text{jets})$>5°

$E_T(\text{jet1})+E_T(\text{jet2})$ > 80 GeV

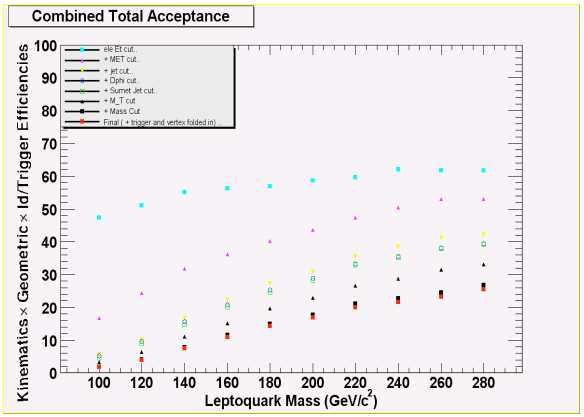
$M_T(\not{E}_T,\text{Muon})$ > 120 GeV/c²

Mass Cut

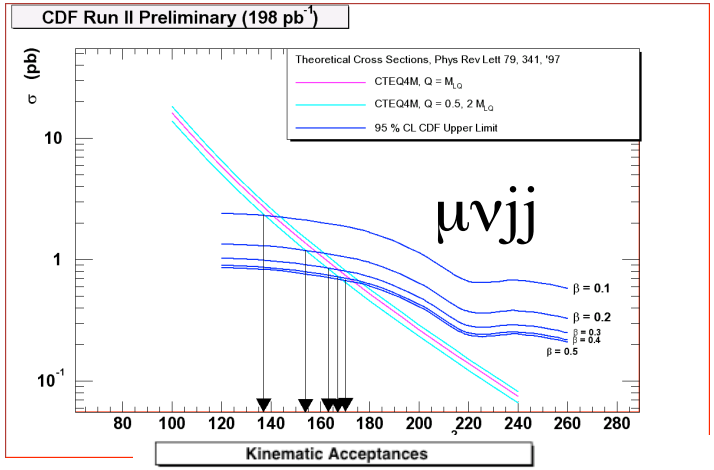


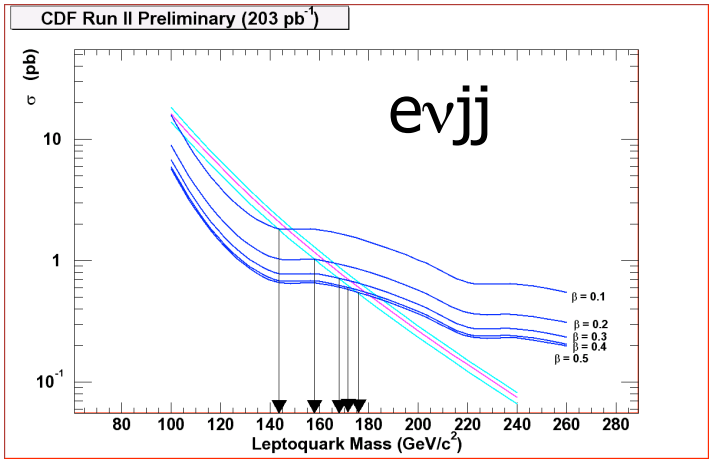


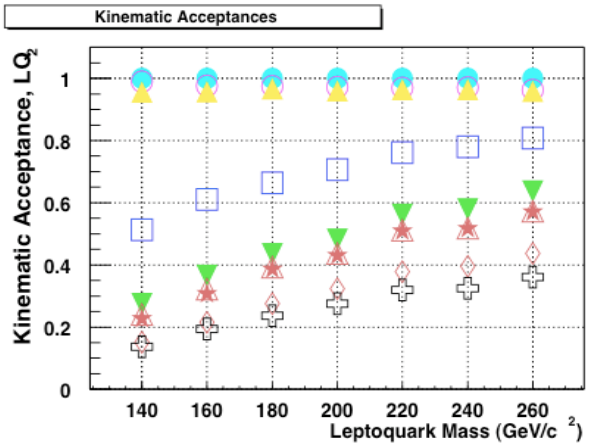
Search for LQ in lepton,MET + jets (III)



Exclude at 95% CL M_{LQ}<170 GeV/c^2 for β = 0.5







Exclude at 95% CL M_{LQ}<176 GeV/c^2 for β = 0.5

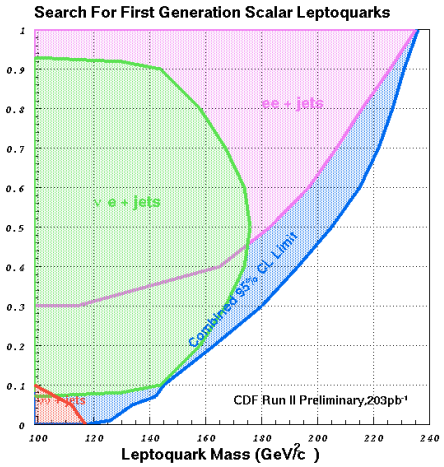
Final Combined Limits

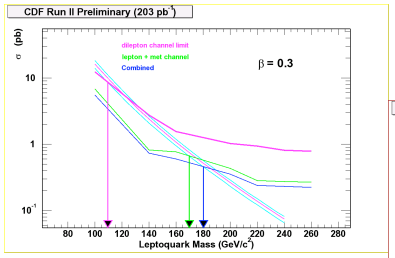
Joint likelihood formed from the product of the individual channels likelihood.
The searches in the dileptons and lepton + MET channels use common criteria and sometime apply the same kind of requirements (for example on lepton identification) so the uncertainties in the acceptances have been considered completely correlated (which gives the most conservative limit).
When calculating the limit combination including also the ννjj channel the uncertainties in the acceptances have been considered uncorrelated.A correlation factor of 0.5 has also been considered (no difference)

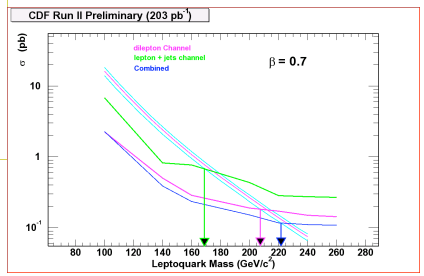
$$\sigma_{LIM} = N_{LIM}/(\varepsilon_{average} \times \mathcal{L})$$

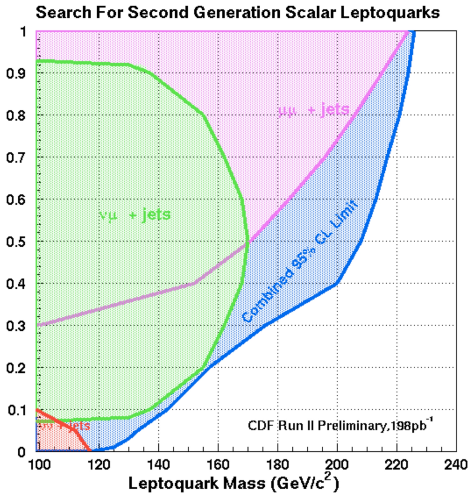
$\varepsilon_{average} = (\beta^2\varepsilon(eejj) + 2\beta(1-\beta)\varepsilon(e\nu jj) + \beta^2\varepsilon(ee \text{ as } e\nu))$ for the 2 channels case and

$\varepsilon_{average} = (\beta^2\varepsilon(eejj) + 2\beta(1-\beta)\varepsilon(e\nu jj) + (1-\beta)^2\varepsilon(\nu\nu jj) + \beta^2\varepsilon(ee \text{ as } e\nu))$ for the 3 channels case









From the TeVatron to LHC

Assumptions:

Same acceptances as now

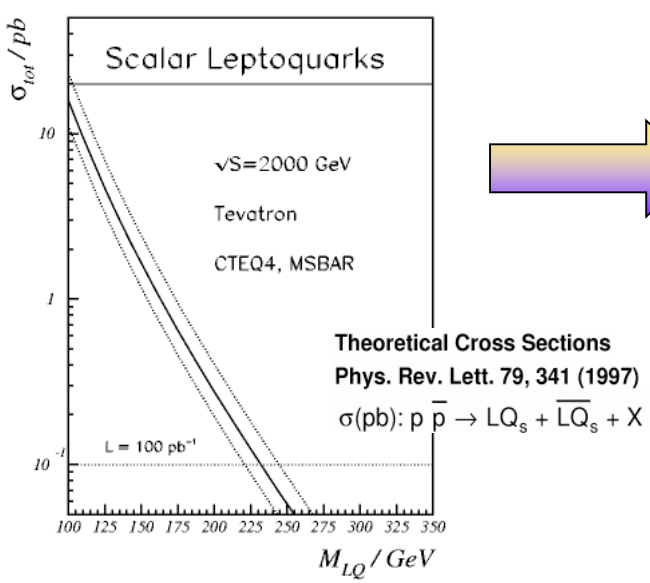
Number of events observed = number of predicted background

Same errors

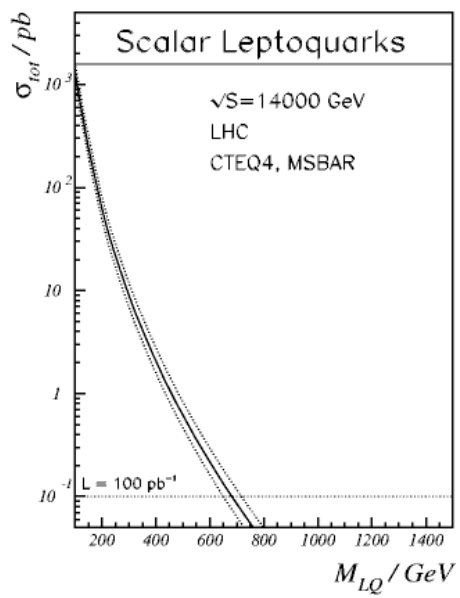
Preliminary

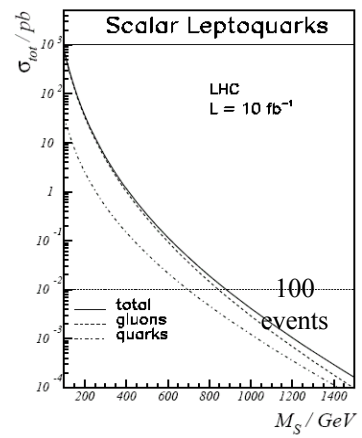
$\beta = 1$ mass limit up to 250-300 GeV/c^2

$\beta = 0.5$ mass limit up to 230-280 GeV/c^2



Theoretical Cross Sections
Phys. Rev. Lett. 79, 341 (1997)
$\sigma(pb)$: $p\,\bar{p} \rightarrow LQ_s + \overline{LQ}_s + X$

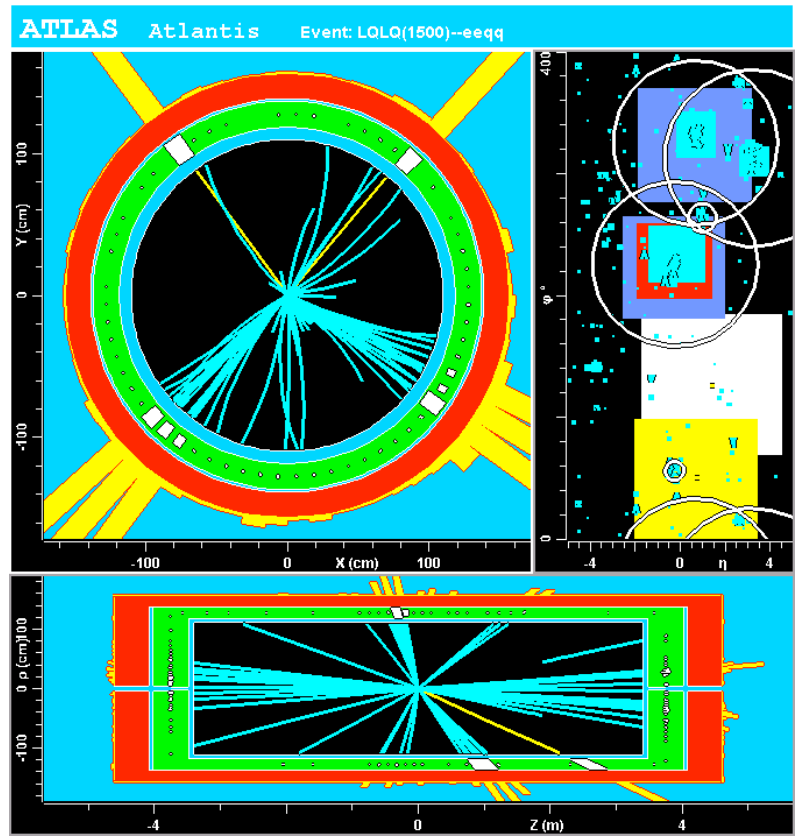




Leptoquarks in ATLAS

V.A. Mitsou, I. Panagoulias, Th. Papadopolou, Physics at LHC, Vienna 2004

- Scalar leptoquarks production studied
- Pair production
  - lljj channel
  - $\nu\nu$ jj channel
- Simulation tools:
  - PYTHIA
    - $qq \rightarrow LQ\ LQ$
    - $gg \rightarrow LQ\ LQ$
  - ATLAS fast simulation *(ATHENA-ATLFAST)*



$LQ\ LQ \rightarrow e^+e^-qq$
m_{LQ}=1500 GeV
(schematic view)

2 leptons + 2 jets topology

Signal

$LQ\ LQ \rightarrow l^+ q l^- q$

1st and 2nd generation LQs

M_{LQ} (TeV)	$\sigma \times \varepsilon$ (fb)
1.0	5.0
1.2	1.3
1.3	0.7
1.5	0.2
1.7	0.07
2.0	0.015

Background

- QCD: huge, but eliminated after high-p_T isolated leptons and high-m_{lj} cuts are applied
- Drell-Yan: eliminated by high-m_{lj} cut

Process	$\sigma \times BR$ (pb)
Zjet (lljj)), $p_T > 20$ GeV	1 380
tt (lνj lνj)	11
ZZ (lljj)	1.2
ZW (lljj)	1.2
WW (lν lν)	3.3

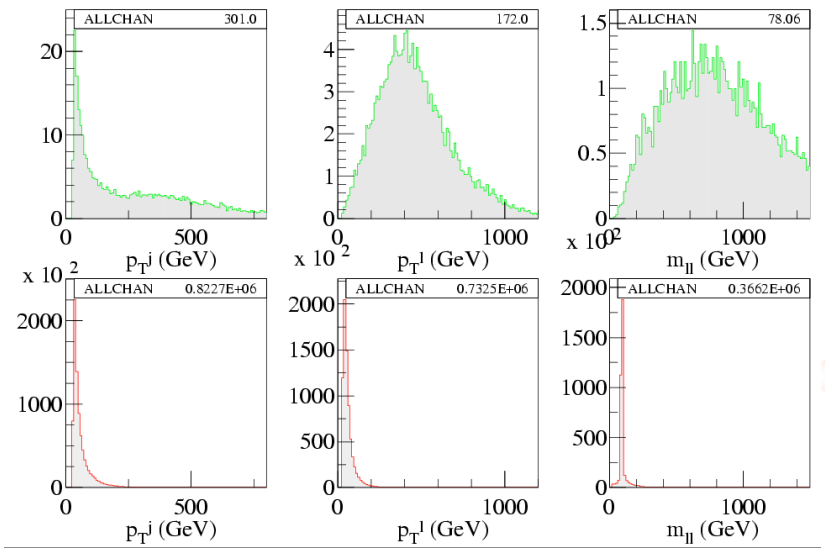
- First level cuts:
  - At least 2 jets with p_T>30 GeV and $|\eta|$<5.0
  - 2 same-flavour, opposite- sign leptons with p_T>30 GeV and $|\eta|$<2.5

2 letpons & 2 jets topology

First level cuts:

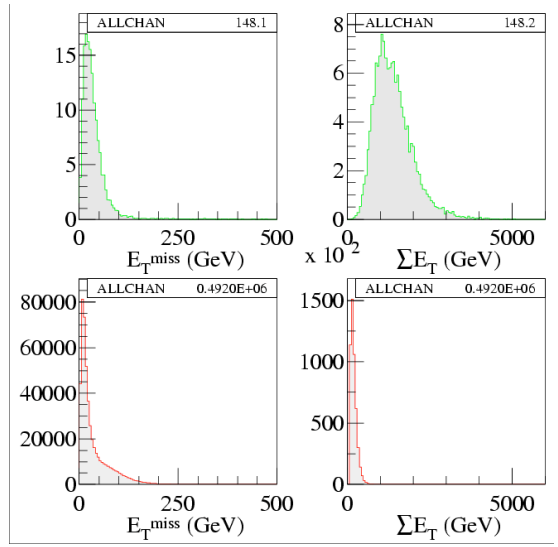
At least 2 jets with p_T>30 GeV and $|\eta|$<5.0

2 same-flavour, opposite- sign leptons with p_T>30 GeV and $|\eta|$ < 2.5



signal

backgrnd

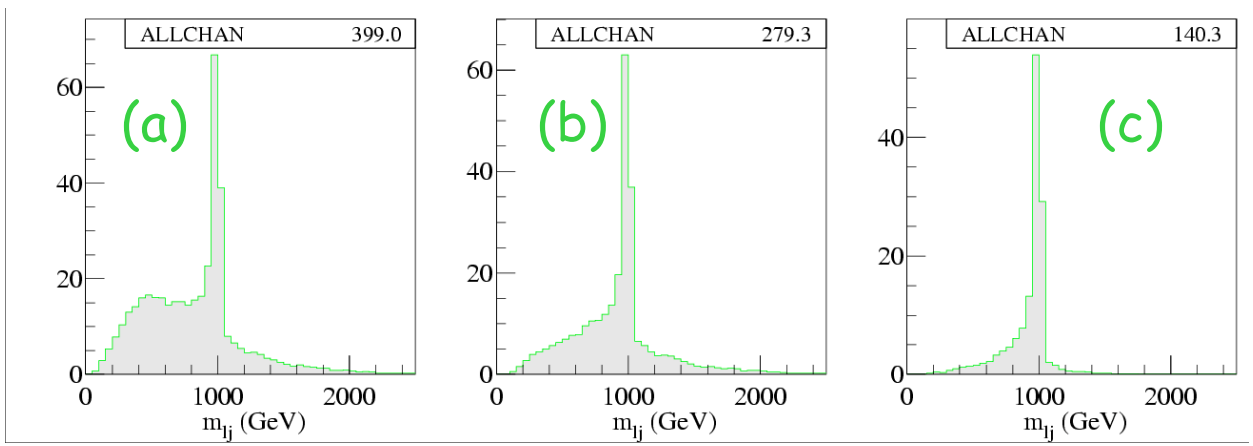


ΣE_T: sum of transverse energy in the calorimeters

M_{lljj} Invariant Mass

m_{lj} combination	$\lvert m_{lj}-m_{LQ}\rvert < 100$ GeV	
	# events	%
(a) all combinations	136/399	35%
(b) two leading jets	126/279	45%
(c) two leading jets; minimum-Δm_{lj} combination	98/140	70%

Provides clearest signal



m_{LQ}=1 TeV

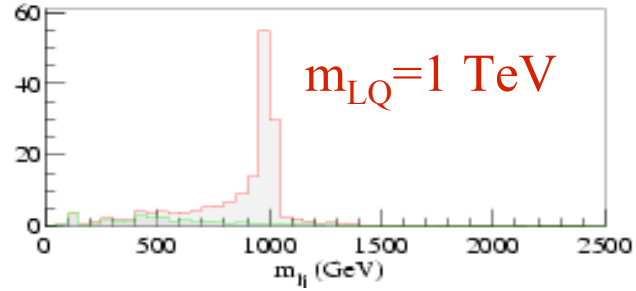
lljj: Selection Cuts

- Similar cuts imposed for both eejj & $\mu\mu$jj channels
- Cuts optimized to maximize significance for all leptoquark masses
  - at least 2 jets with p_T>70 GeV and $|\eta|$<5.0
  - 2 same-flavour, opposite- sign leptons with p_T>100 GeV and $|\eta|$<2.5
  - M_{ll} > 180 GeV *(to remove Z events)*
  - E_T^{miss} < 70 GeV *(for tt background)*
  - ΣE_T > 570 GeV
  - $E_T^{miss}/\Sigma E_T$ < 0.05
  - mass window: $|m_{lj}-m_{LQ}|$ < 100 GeV
  - m_{LQ} reconctructed from two leading jets with minimum-Δm_{lj} combination

Preliminary

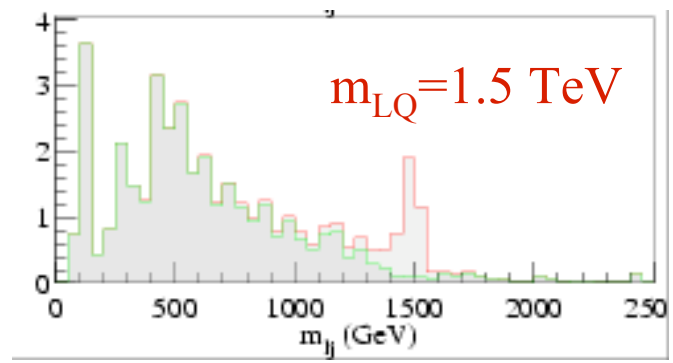
lljj: Expected Significance

- First generation leptoquarks
- Integrated luminosity $\int L = 30\ fb^{-1}$



M_{LQ} (TeV)	Signal	Background	$S/\sqrt{B}$
1.0	126	4.65	58
1.2	27.6	4.14	14
1.3	16.1	3.46	10.7
1.5	4.49	1.86	5.9

Preliminary



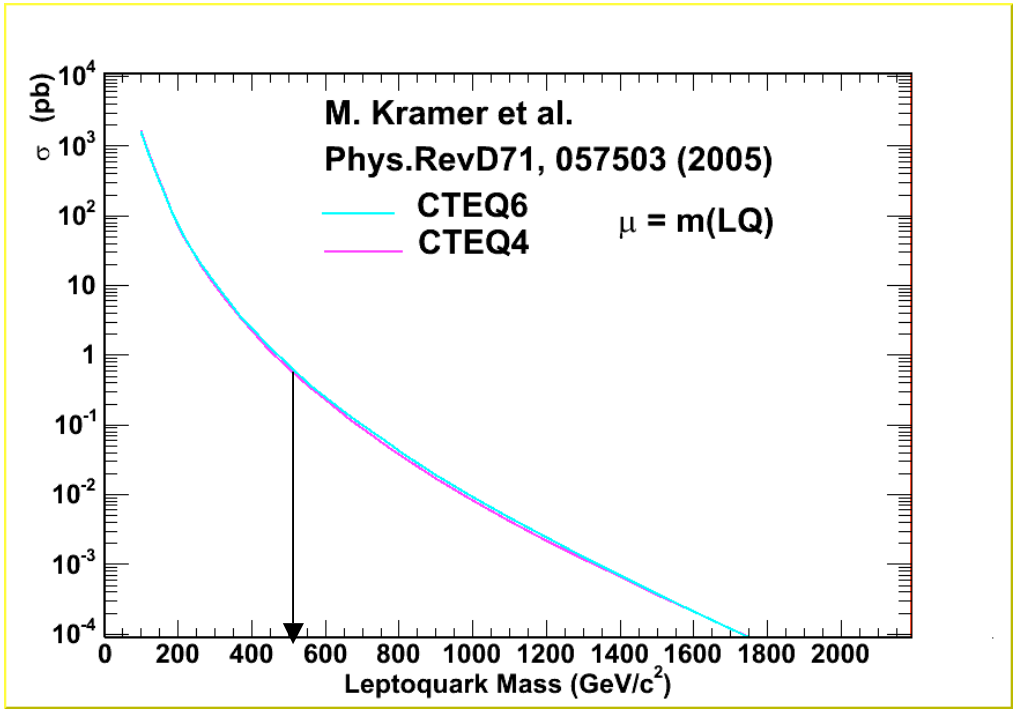
Signal can be clearly observed for m_{LQ} = 1.3 TeV
Similar results obtained for $\mu\mu jj$ channel

Current Status

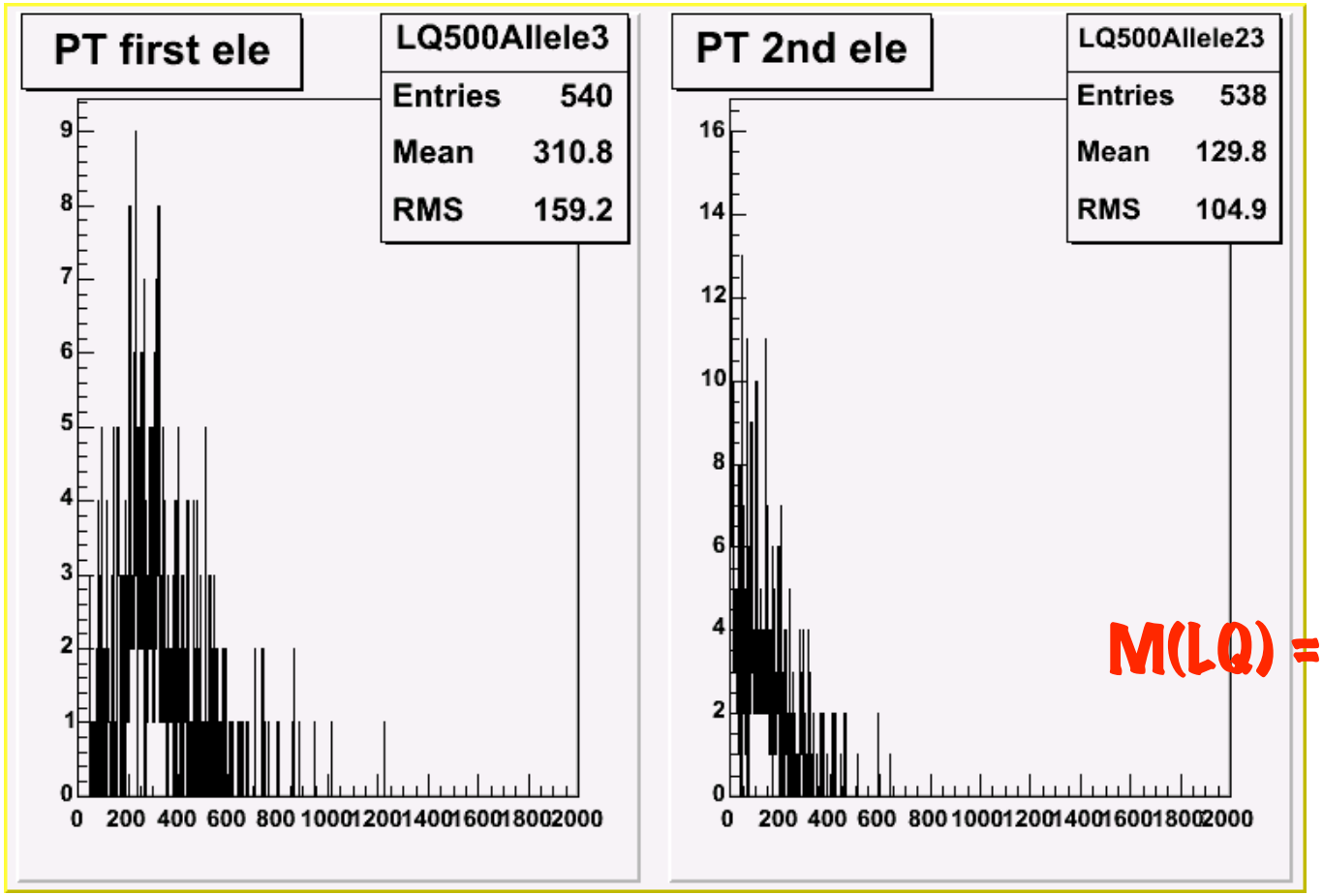
1st Gen, 2 mass points: 0.5 and 1 TeV , β = 1.0:
preliminary AOD and ntuple production

New cross section calculation
(Phys Rev D 71, 2005)

Previous analysis
used Pythia LO



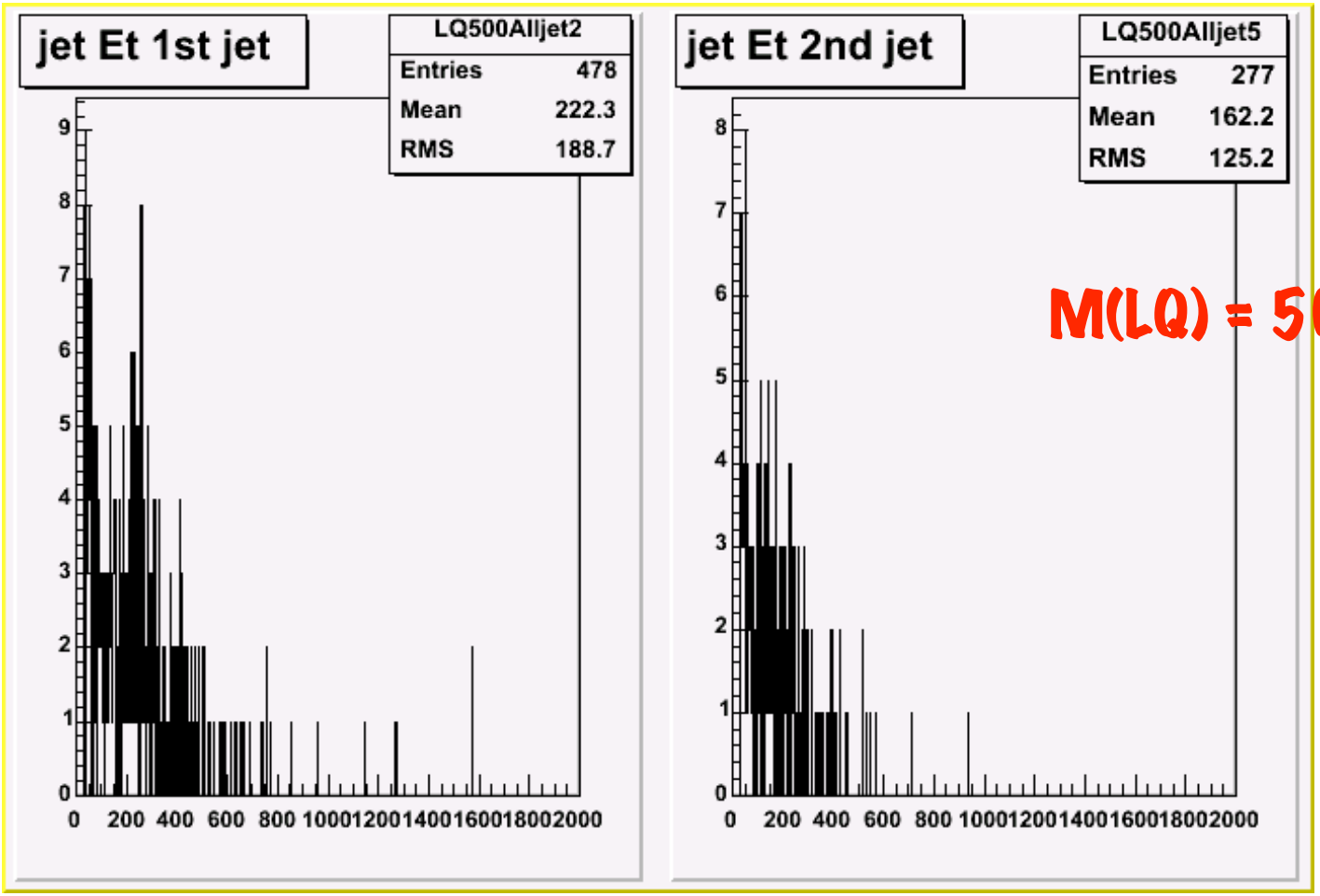
Current Status



2 eles w/
$E_T > 30$ GeV
$\eta < 2.5$

M(LQ) = 500 GeV

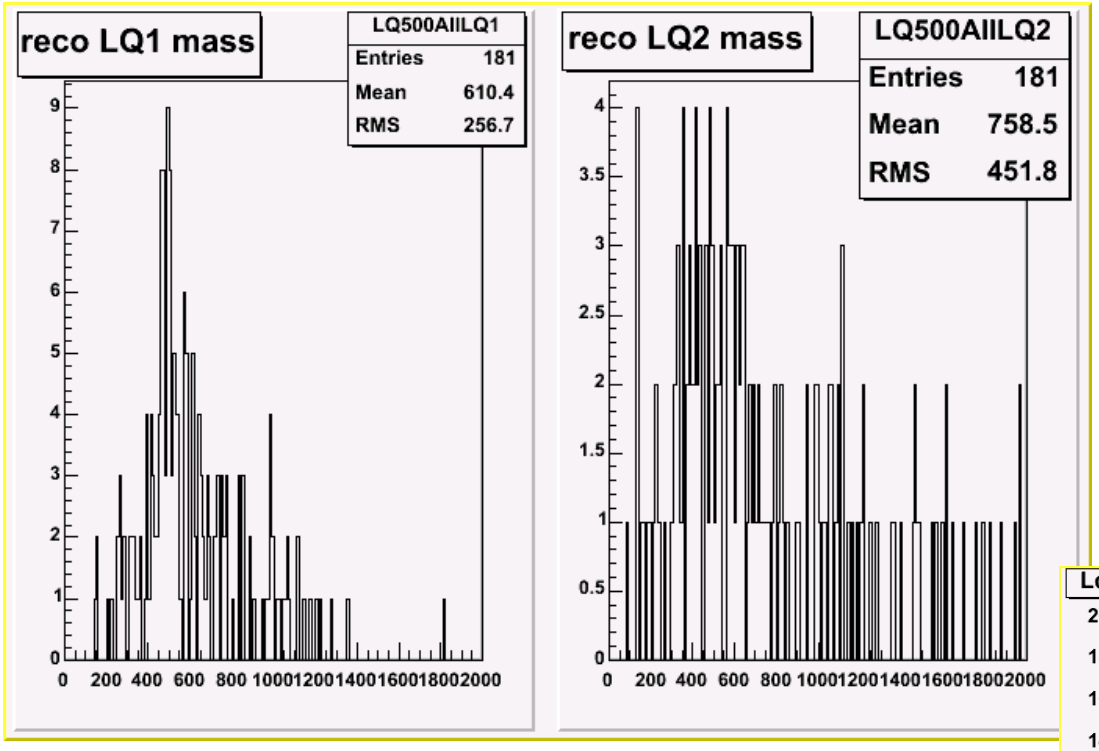
Current Status



M(LQ) = 500 GeV

2 Jets w/
$E_T > 30$ GeV
$\eta < 5.0$

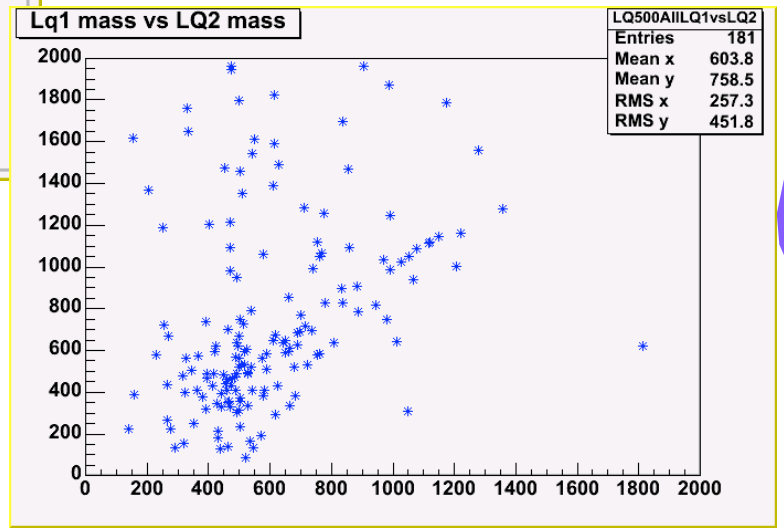
Current Status



The combination chosen is the one minimizing the differences:

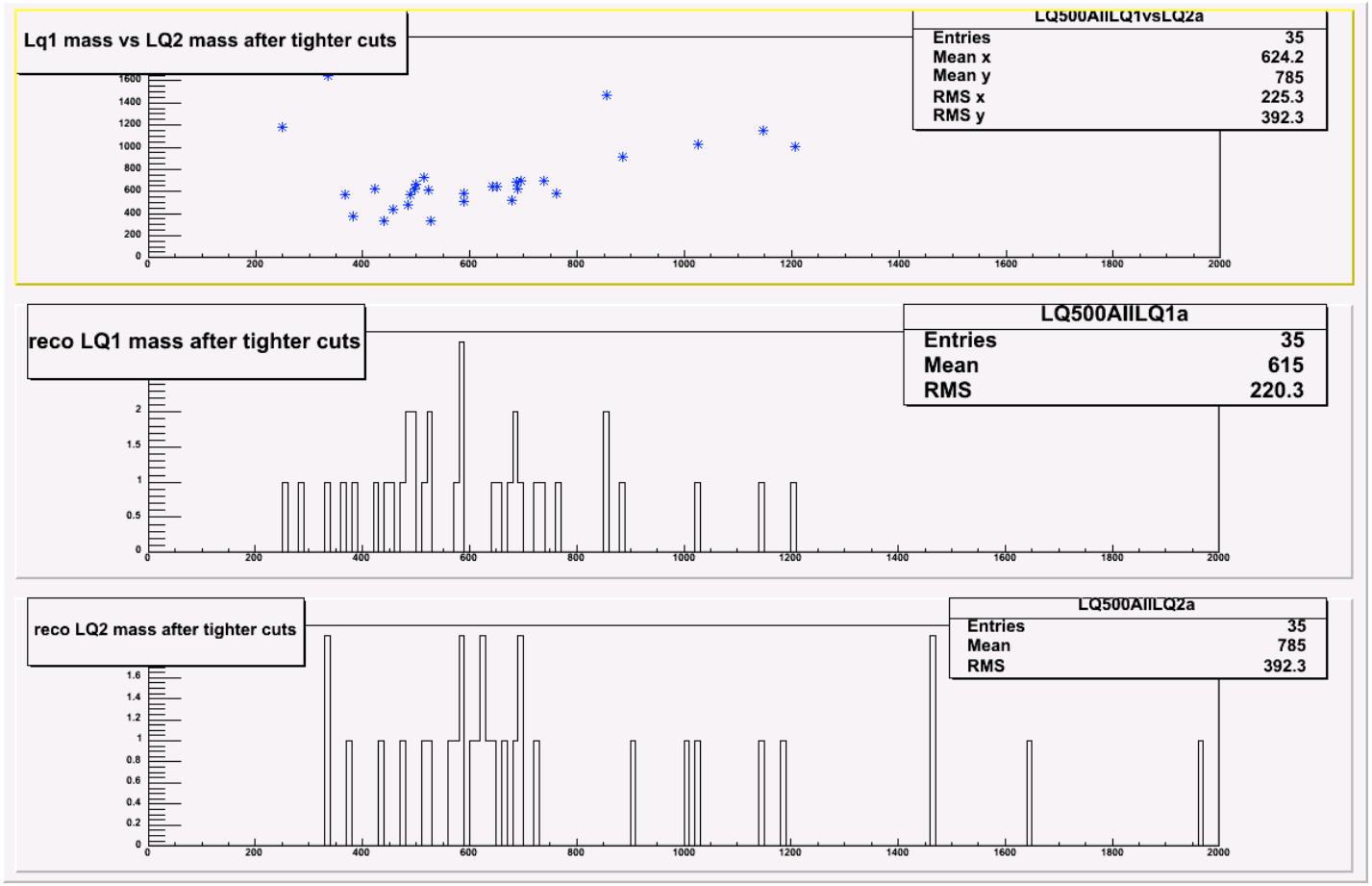
M(l1j1) - M(l2j2)

M(l1j2) - M(l2j1)



M(LQ) = 500 GeV

Current Status



E_T eles > 80
E_T jets > 100

Cuts Efficiency

Number of processed events	540
Number of events with two eles ET> 30 eta < 2.5	538 (0.99)
Number of events with one jet > 30 eta < 5	478 (0.88)
Number of events with two jet> 30 eta < 5	277 (0.51)
Number of events with mass_ee outside Z windows	263 (0.49)
Number of events passing circ cut	263 (0.49)

Number of events expected : $0.51 \times 0.65\text{pb} = 0.33\text{pb}$

Plans

Short term:

Benchmark the 1. TeV point

Signal efficiency for preliminary selection:

2 ele ET > 30, η < 2.5

2 jets ET > 30, η < 5.0

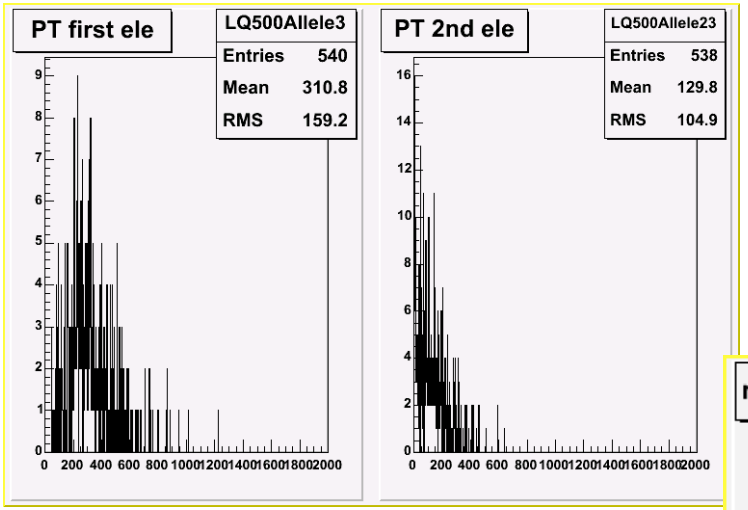
Effective Signal Expected = $\varepsilon \times \sigma$

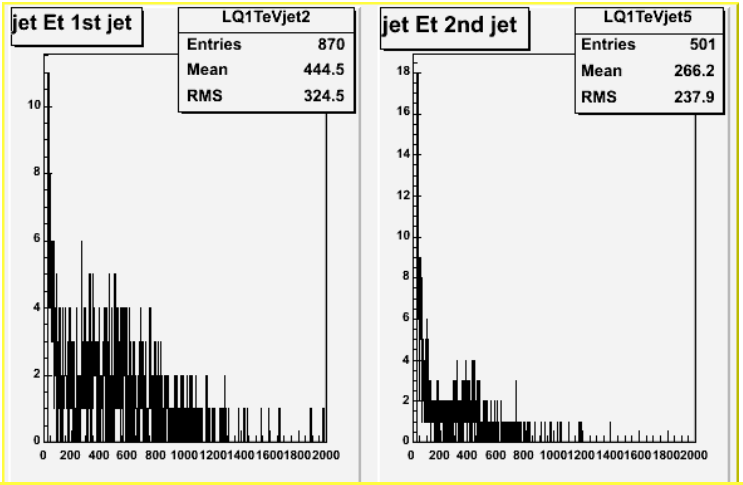
To check efficiency and new cross section effects

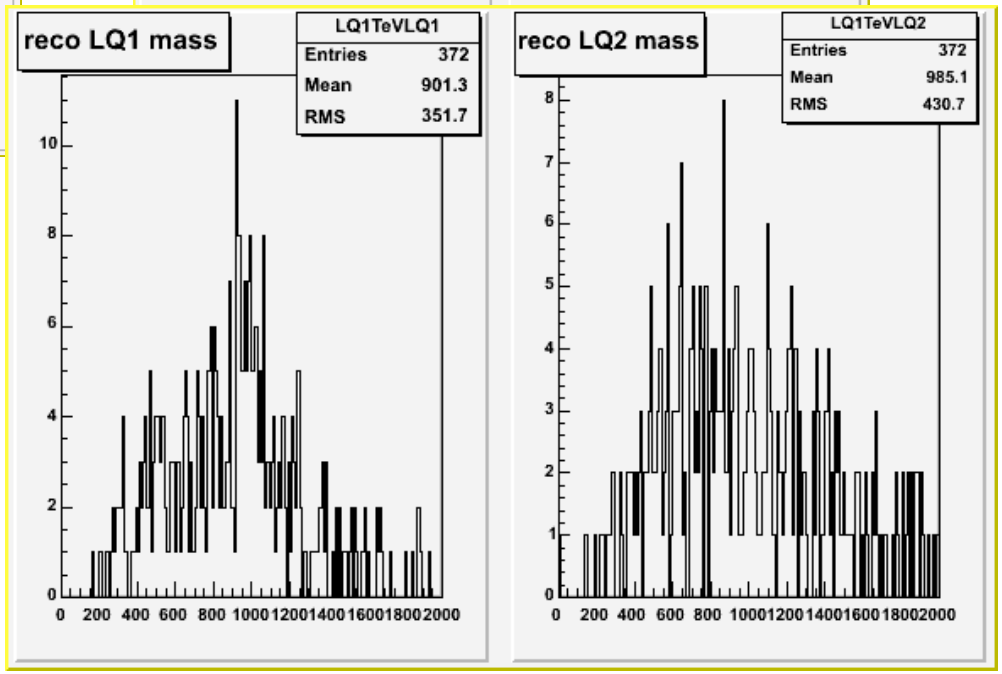
To get familiar with the tools

Expected results in 2 weeks

Plans (II)





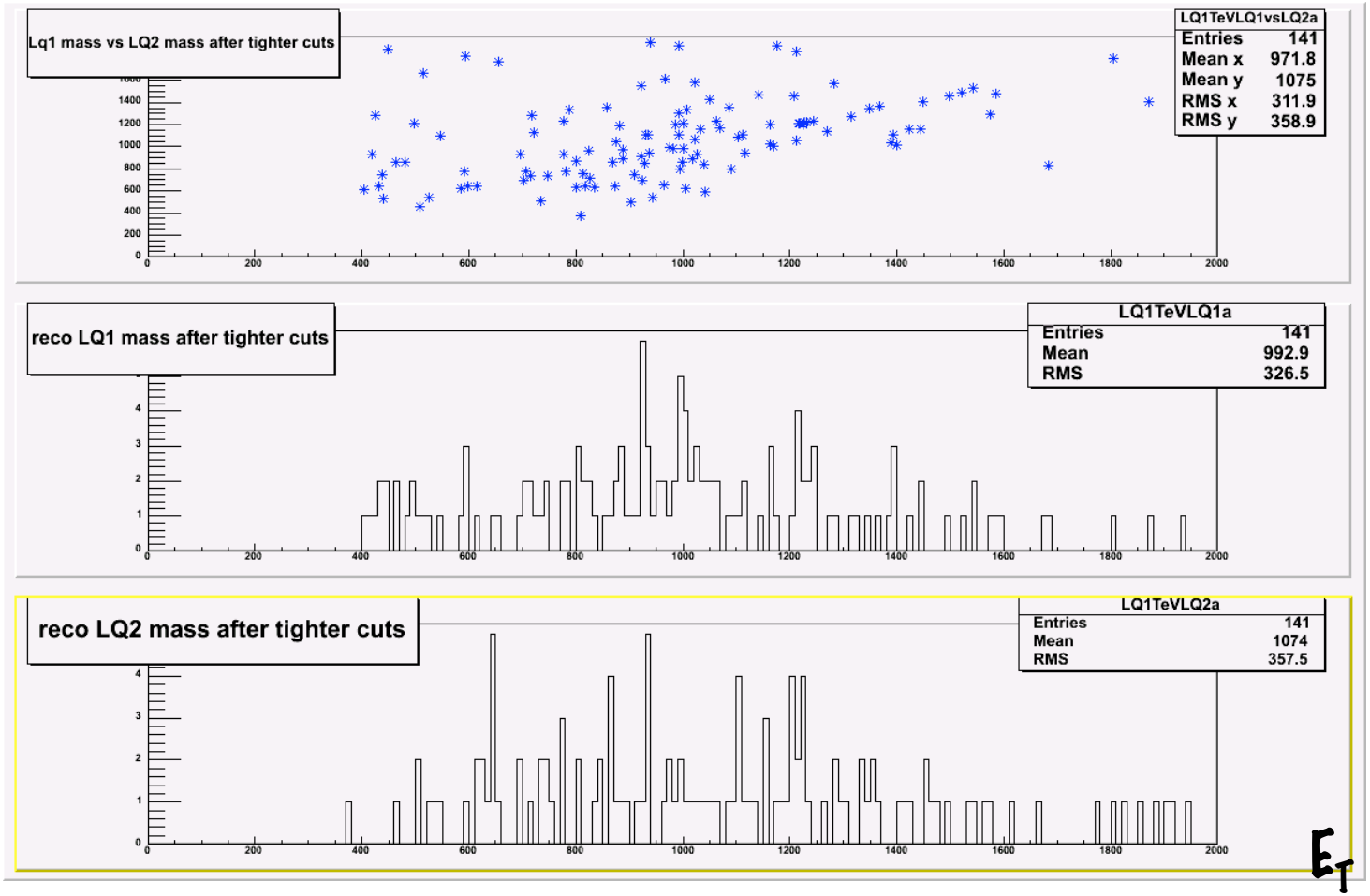


M(LQ) = 1 TeV

evts processed 961
2 eles 30/2.5 960 (0.99)
2 jets 30/5.0 501 (0.50)

X-sec expected : 0.50 × 8.36 fb = 4.2 fb (vs 5)

Plans (III)



E_T eles > 80
E_T jets > 100

Plans II

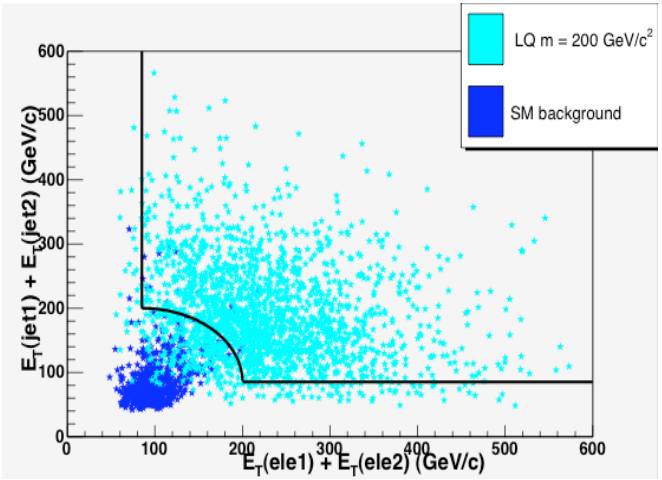
Longer term (Rome and beyond):

Ele selection:

ID cuts (I'm not familiar with them!) -test of the PATs

Beyond the primary selection:

Sumet vs circular cut vs mass cut



Background estimate - optimization

Z + 2 jets

tt

WW

QCD fakes

Expected sensitivity -
expected 95% CL LIMIT....
(need more points)

Plans (III) and Conclusions

Include muons (primary interest)

Include β = 0.5

Possibly include $\nu\nu$jj channel and have the complete β dependence

Extend to a NN approach (M. Wolter)

Help needed

<u>Tools:</u>
Great support from Kamal and Ketevi
(My concern are mostly the ones of a real newcomer, might disappear in a few weeks..)

Still: very difficult to setup the analysis framework -
good tutorial, but sometime not enough
- Terrible code browser...not possible to navigate, very difficult to understand class structures
- Issues with Root (ntuples are not exportable to personal laptop (or FNAL) - necessity to work over network at BNL

<u>Physics:</u> need more mass points, need background samples