Search For Leptoquarks at DØ

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Wine & Cheese Seminar

Fermilab

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Outline

- LQ Phenomenology
- LQ Production at HERA
- LQ Production at the Tevatron
- Previous Measurements
- DØ Detector
- First Generation LQ Search at DØ
  - eejj channel
  - eνjj channel
- Second Generation LQ Search
- Third Generation LQ Search
- Conclusions

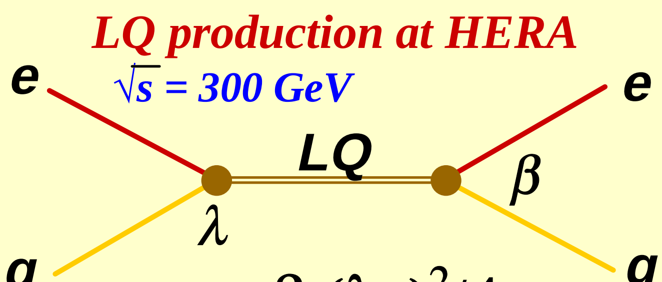
First public presentation of this analysis; to be shown at the HCP '97 tomorrow

LQ Phenomenology

- *Leptoquarks (LQ) are hypothetical particles which appear in many SM extensions to explain symmetry between leptons and quarks*
- *LQ are coupled to both leptons and quarks and carry SU(3) color, fractional electrical charge, baryon (B) and lepton (L) numbers*
- *LQ interactions are entirely fixed by the effective Lagrangian in the assumptions of baryon and lepton number conservation, gauge invariance, renormalizability, and chiral couplings*
- *LQ can have spin 0 (scalar) or 1 (vector)*
- *Scalar LQ can be classified by fermion number (F=3B+L): S-type LQ have F= -2 (3 singlets and one triplet); R-type LQ have F=0 (3 doublets)*
- *LQ appear in 3 generations corresponding to 3 lepton/quark generations; the intergenerational mixing is severely restricted by FCNC data*
- *BR into charged leptons β can be 0, 1/2 or 1 only*

LQ Production at HERA

- ***Both H1 [Z.Phys. C74, 191 (197)] and ZEUS [preprint DESY 97-025, to appear in Z.Phys. C] have recently reported high-Q^2 event excess, which could be explained by the production of the first generation scalar LQ with the mass of around 200 GeV (vector LQ's were already excluded up to much higher mass by DØ)***



$$\sigma \propto \beta\,(\lambda e)^2/4\pi$$

λ=1: *EM coupling*

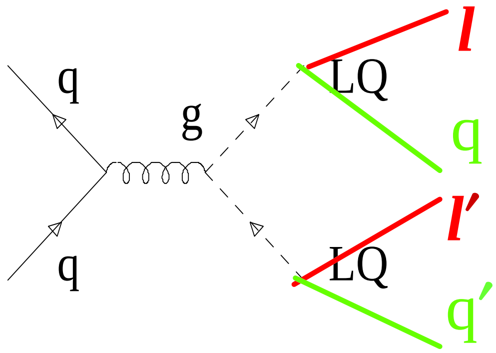
20 pb^{-1} e^+p data:
H1 - 7 events (1.0 bck.)
ZEUS - 4 events (0.9 bck.)
1 pb^{-1} e^-p data:
no excess reported

S-type LQ have much higher production rate in e^-p collisions, so HERA data can be explained within the LQ framework only by R-type LQ with $q = 5/3$. There are two such LQ's and both have $\beta = 1$. HERA data requires $\lambda = 0.04–0.10$.

There is no way to explain HERA data with $\beta \neq 1$ LQ without pushing experimental constraints or adding new terms to the Lagrangian (such as additional fermions). Some attempts to do this appeared recently [J.Hewett,T.Rizzo - private comm.; Babu, Kolda, March-Russell - hep-ph/9705414].

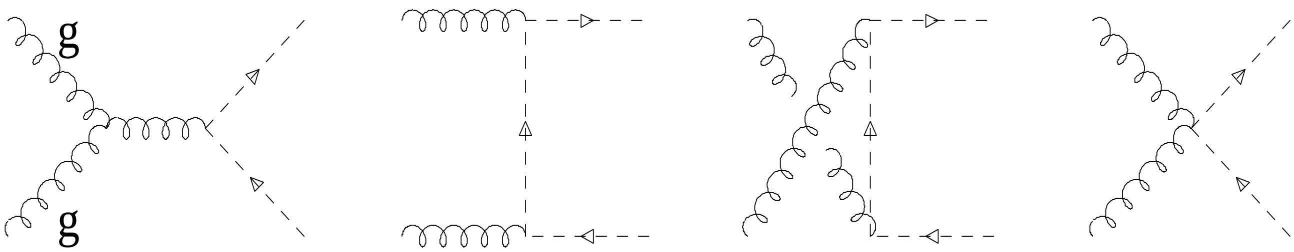
LQ Production at the Tevatron

- *At the Tevatron leptoquark pair production via gluon splitting (strong interactions) dominates*



eejj, eνjj or ννjj channels
Major backgrounds: W/Z+jj, QCD and top production

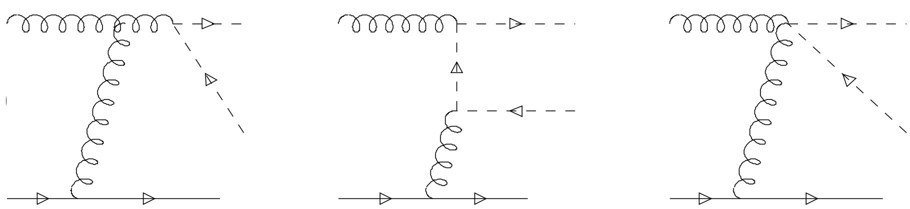
$\beta \equiv B(LQ \to l^{\pm}q)$



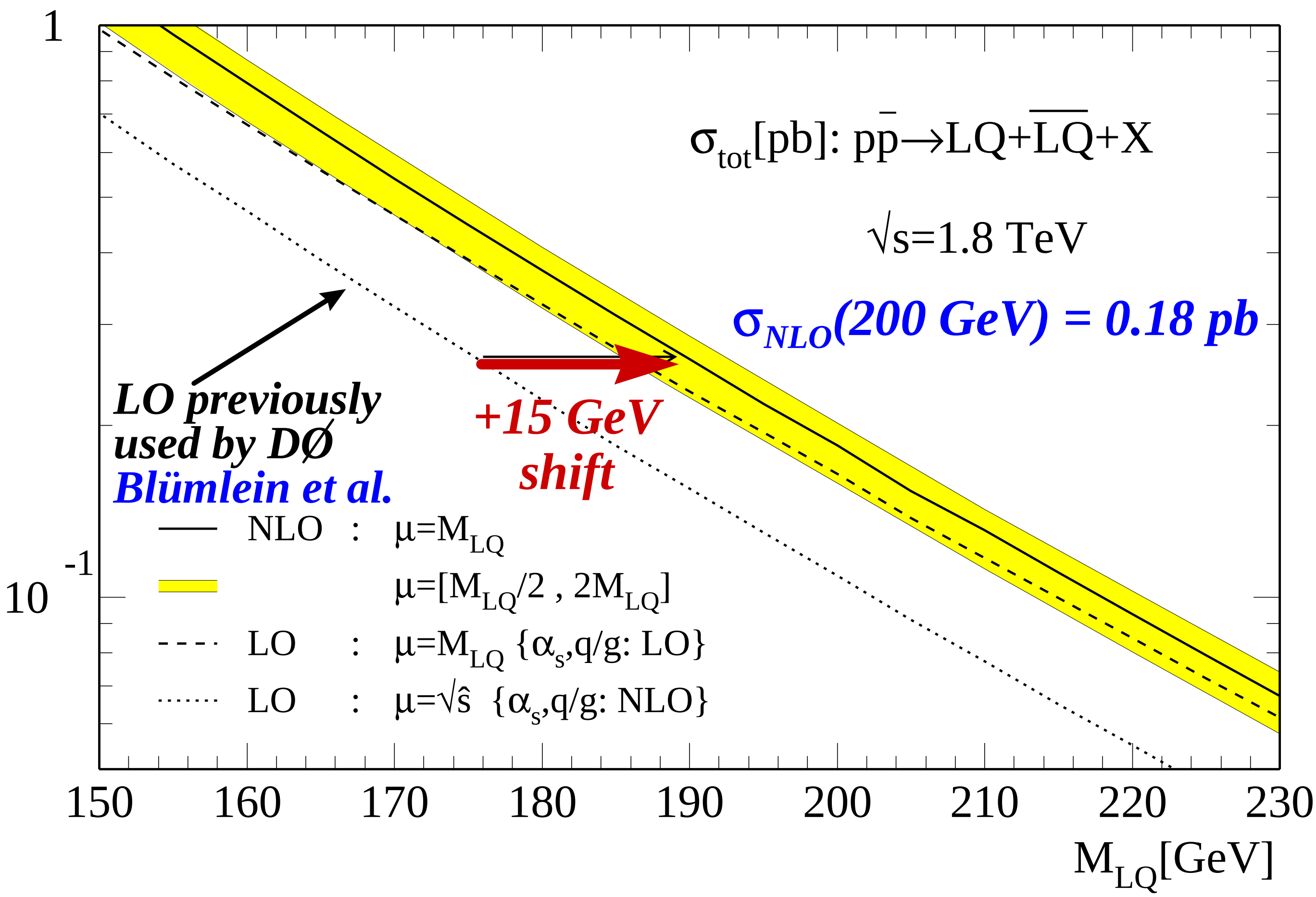
- *Pair production is insensitive to the value of λ since it enters only in the LQ lifetime and for $\lambda > 10^{-12}$ LQ's decay within a collider detector*
- *It depends only on β ($\propto \beta^2$ for eejj, $\propto 2\beta(1-\beta)$ for eνjj and $\propto (1-\beta)^2$ for ννjj)*
- *It has very little model dependence (such as PDF choice, etc.) similar to top pair production*

Next-to-Leading Order Theory

NLO theory - add three diagrams to include α_S^3



Krämer, Plehn, Spira, and Zerwas, hep-ph/9704322



Review of Past Results: 1st Generation

First Generation Limits on M_{LQ}

Published :

CDF

eejj — PR D48, 3939 (1993): 113 GeV for $\beta = 1$
80 GeV for $\beta = 1/2$

DØ

eejj, eνjj — PRL 72, 965 (1994): 130 GeV for $\beta = 1$
116 GeV for $\beta = 0.5$

HERA (H1)

Z.Phys. C64, 545 (1994): 230 GeV for β=0.5
(λ = 1, i.e. EM coupling)

Recently presented:

DØ (red #'s are vector LQ with Y-M couplings)

eejj, eνjj, ννjj — Moriond '97: 175/298 GeV for $\beta = 1$
147/270 GeV for $\beta = 1/2$
81 GeV for $\beta = 0$

CDF (switched to NLO cross section)

eejj — Vanderbilt '97,
Wine & Cheese 5/31/97: 210 GeV for $\beta = 1$

Review of Past Results: 2^{nd} Generation

Second Generation Limits on M_{LQ}

Published:

CDF

μμjj — **PRL 75, 1012 (1995):** **131 GeV for β = 1**
96 GeV for β = 1/2

DØ

μμjj, μνjj — **PRL 75, 3618 (1995):** **119 GeV for β = 1**
97 GeV for β = 1/2

Recently presented:

CDF

μμjj — **Moriond '97:** **197 GeV/c^2 for β = 1**

DØ (using different Q^2-scale for LO c.s.)

μμjj — **Moriond '97:** **167 GeV/c^2 for β = 1**

Review of Past Results: 3^{rd} Generation

Third Generation Limits on M_{LQ}

Published:

CDF (red #s are vector LQ w/ Y-M coupling)

$\tau\tau jj$ — PRL 78, 2906 (1997): 99/225 GeV for q=4/3 or 2/3

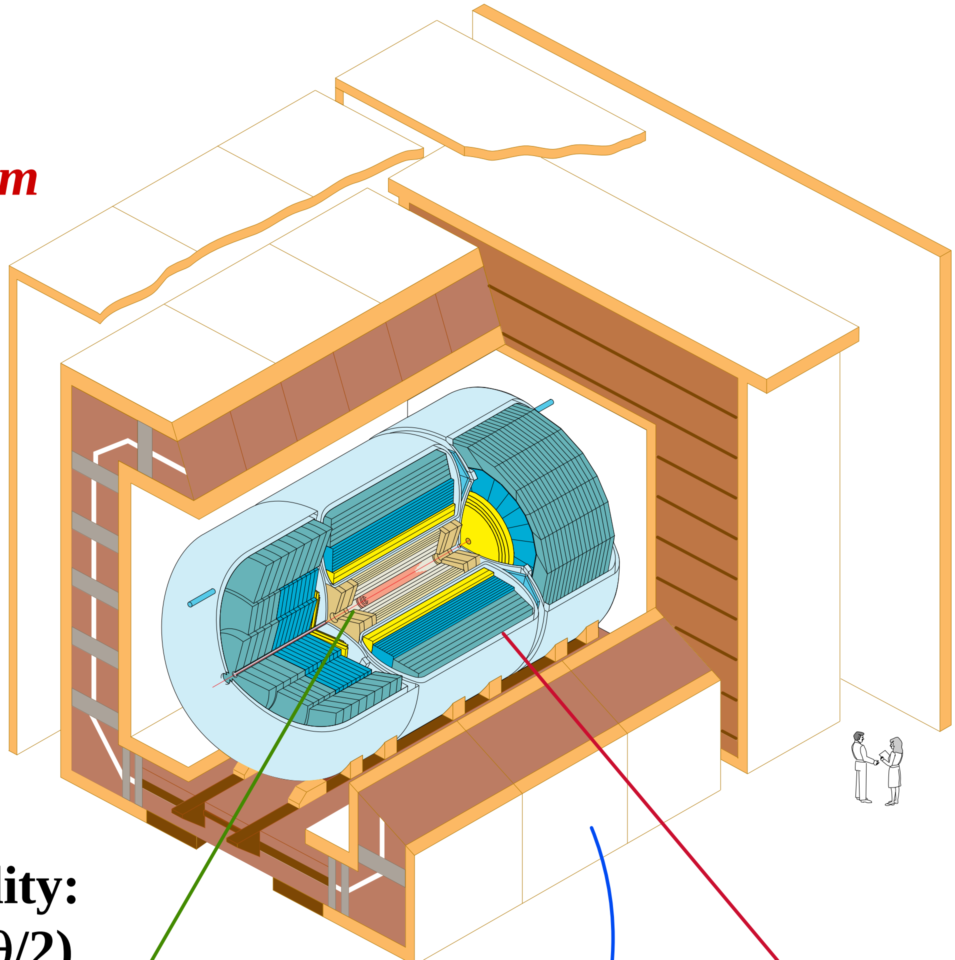
Recently presented:

DØ (using different Q^2-scale for LO c.s.)

$bb\nu_\tau\nu_\tau$ — Moriond ‘97: 80 GeV for q=1/3

DØ Detector

3 Level Trigger System



Pseudorapidity:
$\eta = -\ln \tan(\theta/2)$

DØ Detector

TRACKING

σ(vertex)=6 mm
$\sigma(r\phi)$ = 60 μm (VTX)
= 180 μm (CDC)
= 200 μm (FDC)

MUON

$|\eta| < 3.3$

$\frac{\delta p}{p} = 0.2 \oplus .003p$

CALORIMETRY

$|\eta|<4$
$\Delta\eta \times \Delta\phi = 0.1 \times 0.1$
$\sigma(EM) = 15\%/\sqrt{E}$
$\sigma(HAD) = 50\%/\sqrt{E}$

Search for the First Generation LQ (eejj)

- Since Moriond '97 DØ has carried out an optimized search for the first generation LQ suggested by HERA data
- An improved particle ID developed in DØ over the past 5 years was used in this analysis (including information from the TRD)
- That allowed for the initial cuts applied to the data to be very loose
- Advanced multivariate analysis and cut optimization techniques developed in the course of top analysis were used to optimize the search sensitivity for high masses

Trigger and Data Selection

- Entire Run I statistics (123 pb^{-1})

  1992-1993 - 14.7 pb^{-1} (10,10 GeV EM trigger)

  1994-1995 - 97.8 pb^{-1} (16,20 GeV EM trigger)

  1995-1996 - 10.5 pb^{-1} (16,20 GeV EM trigger)

Trigger is 99.5±0.5% efficient for M_{LQ} = 200 GeV

- Electrons:

$E_T^e > 20$ GeV; $|\eta_e| < 1.1$ (CC) or $1.5 < |\eta_e| < 2.5$ (EC)

Significant EM fraction

  - "Loose":

    Good energy isolation

    Cluster shape typical for the EM object

  - "Tight":

    Matching track

    Combined tracking-TRD-calorimeter info (electron likelihood) consistent with electron

(twice the QCD background rejection for a given efficiency compared to standard ID)

Require exactly 2 electrons; at least 1 "tight"

Trigger and Data Selection (cont'd)

- ***Jets (R = 0.7 cone algorithm; 2 or more):***

  $E_T^j > 15$ GeV; $|\eta^j| < 2.5$

- ***General:***

  M_{ee} far from the Z-peak

  (not in the 82-100 GeV window)

  Electrons well separated from jets

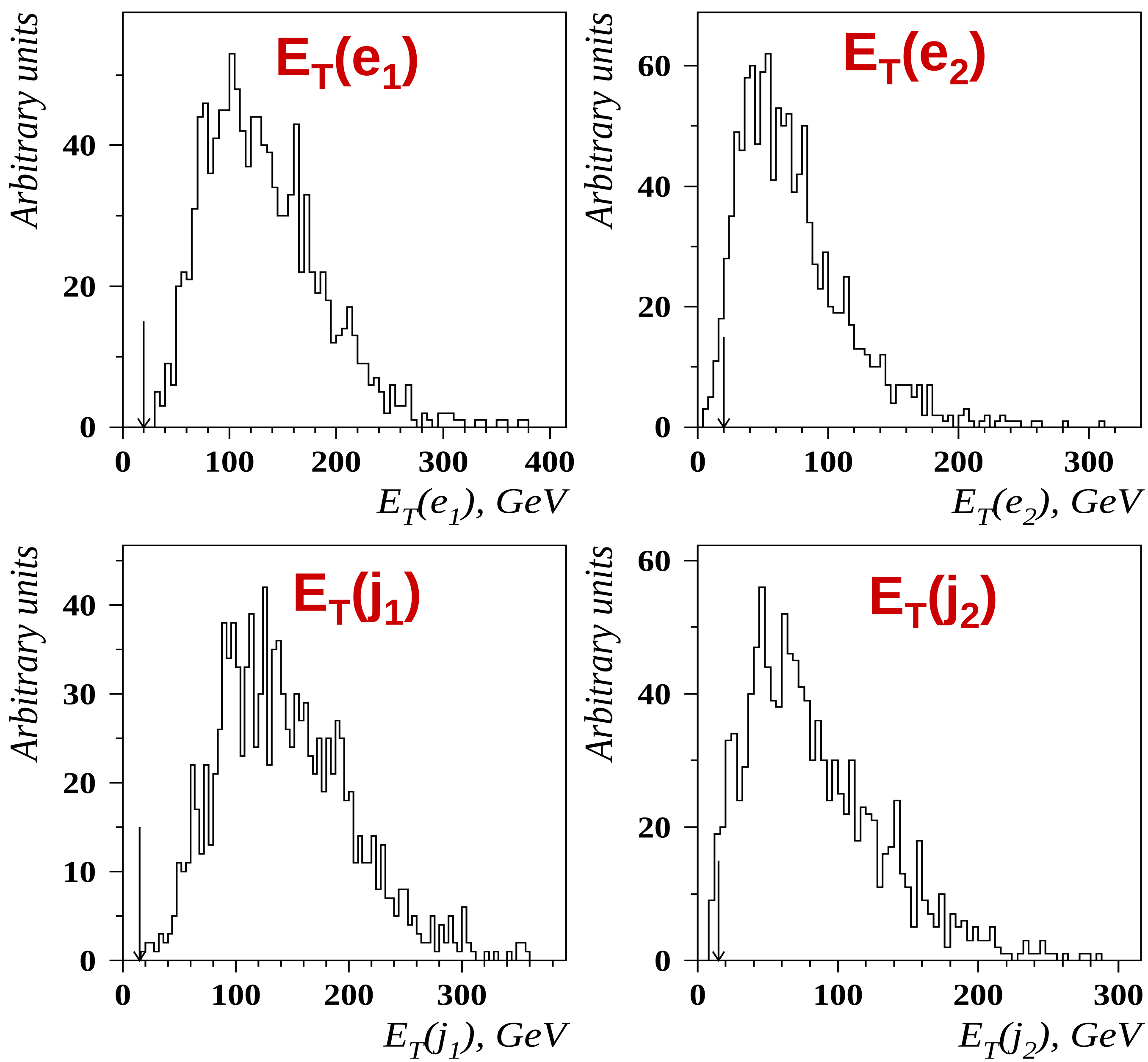
  ($\Delta R^{ej} > 0.7$)

- ***Data selection (101 events)***

Cut	Events
Preselection	9451
Two EM objects	4967
EM in CC/EC, $E_T > 20$ GeV	3880
2 or more jets, $E_T > 15$ GeV	2918
$\Delta R^{ej} > 0.7$	2496
$M_{ee} > 100$ GeV or $M_{ee} < 82$ GeV	1802
At least one "tight" electron	225
"Loose" ID	101

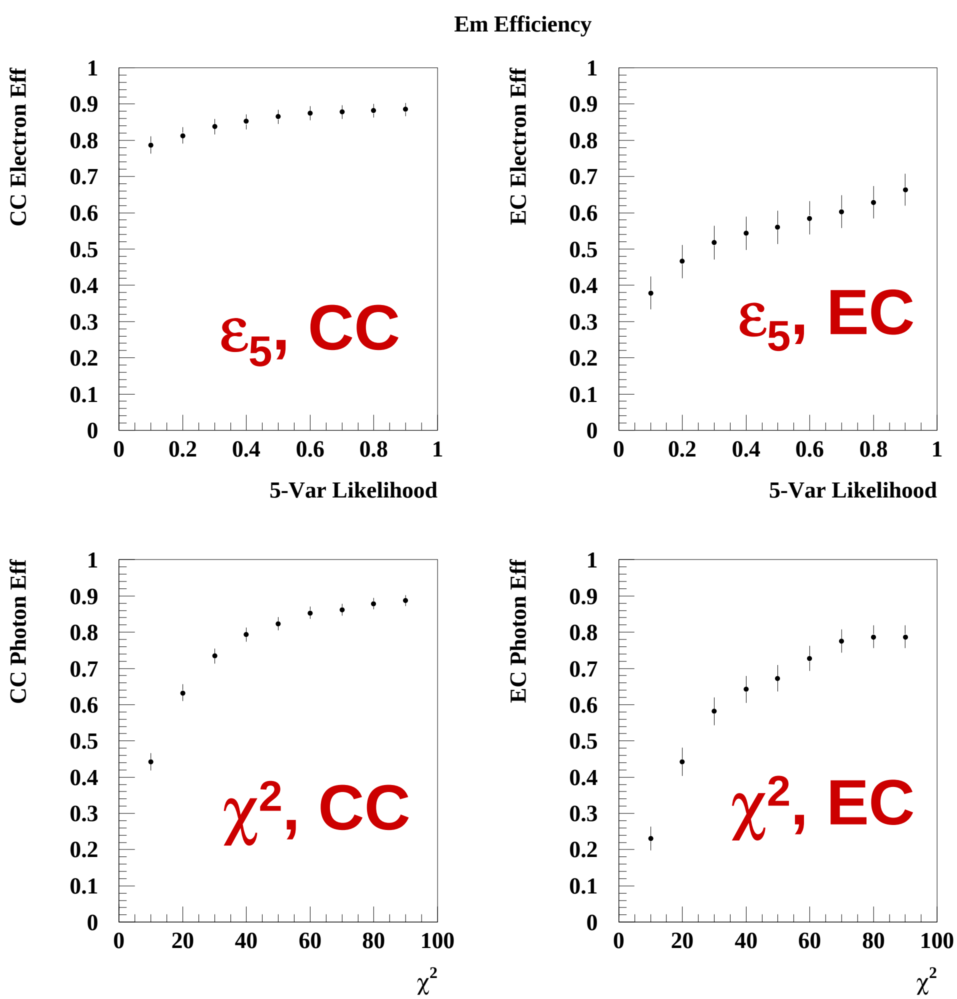
Kinematic Properties of LQ decay

LQ Kinematic properties (M_{LQ} = 225 GeV)



Particle ID Efficiency

- ***Calculate η-dependent efficiency with Z+2j events after background subtraction***
- ***Check efficiency per event against individual "tight" and "loose" electron efficiencies***
- ***Use actual signal η-distribution to calculate overall efficiency***



Z-events:

$\varepsilon_{CC\text{-}CC}$ = 74 ± 3%

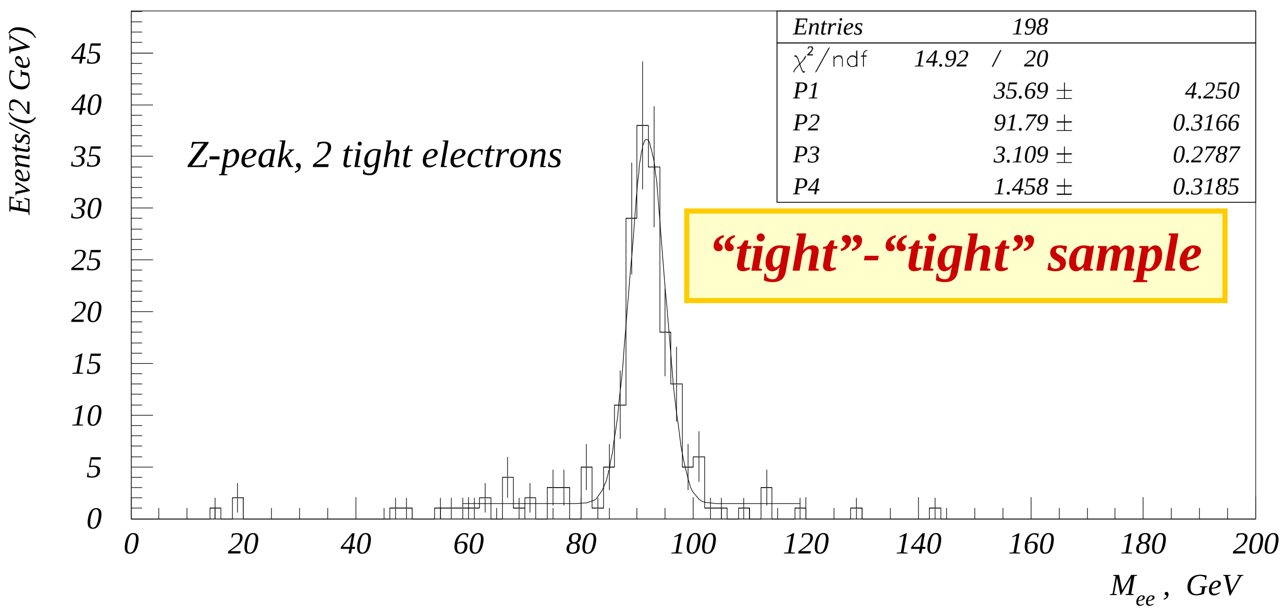
$\varepsilon_{CC\text{-}EC}$ = 66 ± 4%

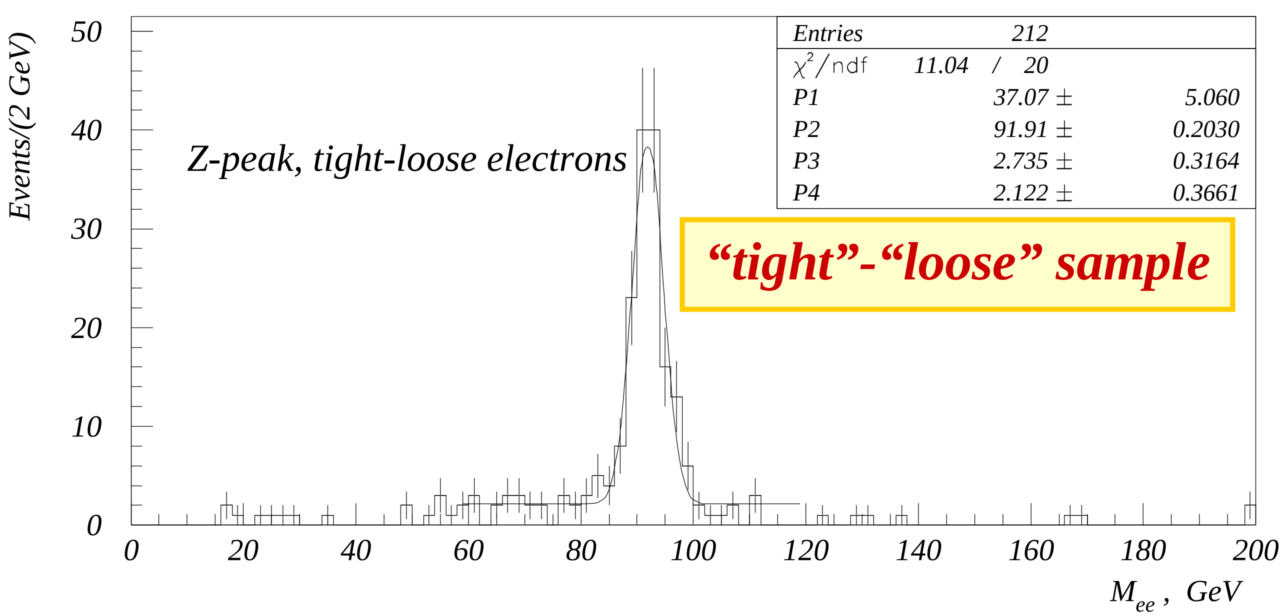
$\varepsilon_{EC\text{-}EC}$ = 68 ± 9%

ε_{LQ}= 73 ± 4%

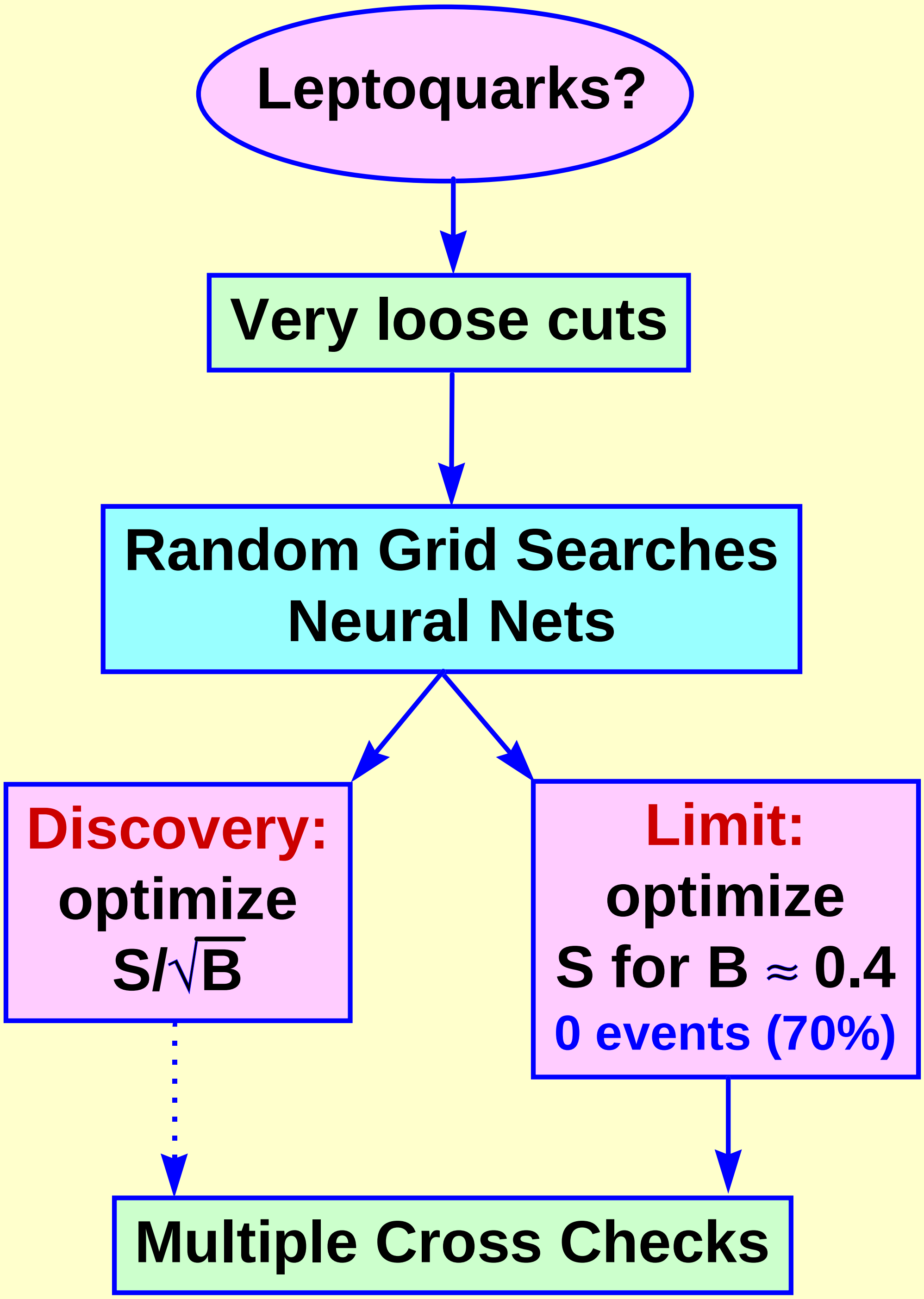
Electron ID Efficiency Improvement

Factor of two improvement in efficiency by using both "tight" and "loose" electrons





Optimization Strategy



Signal & Background Samples

- **Signal:**

  ISAJET v7.22 + GEANT Detector Simulation

  120-260 GeV; 5000 events per mass point

  PYTHIA, 200 GeV; 2000 events (cross checks)

- **Z and Drell-Yan Background:**

  ISAJET v7.22 + GEANT Detector Simulation

  - ***0- 60 GeV; 430K events***
  - ***60-120 GeV; 480K events***
  - ***120-250 GeV; 100K events***
  - ***250-500 GeV; 50K events***

- **Top Quark Background:**

  HERWIG + GEANT Detector Simulation

  M_t = 170 GeV; 100K events

- **QCD Background:**

  Data collected with jjj trigger in 1994-1995

  400K events ($1pb^{-1}$)

Random Grid Searches

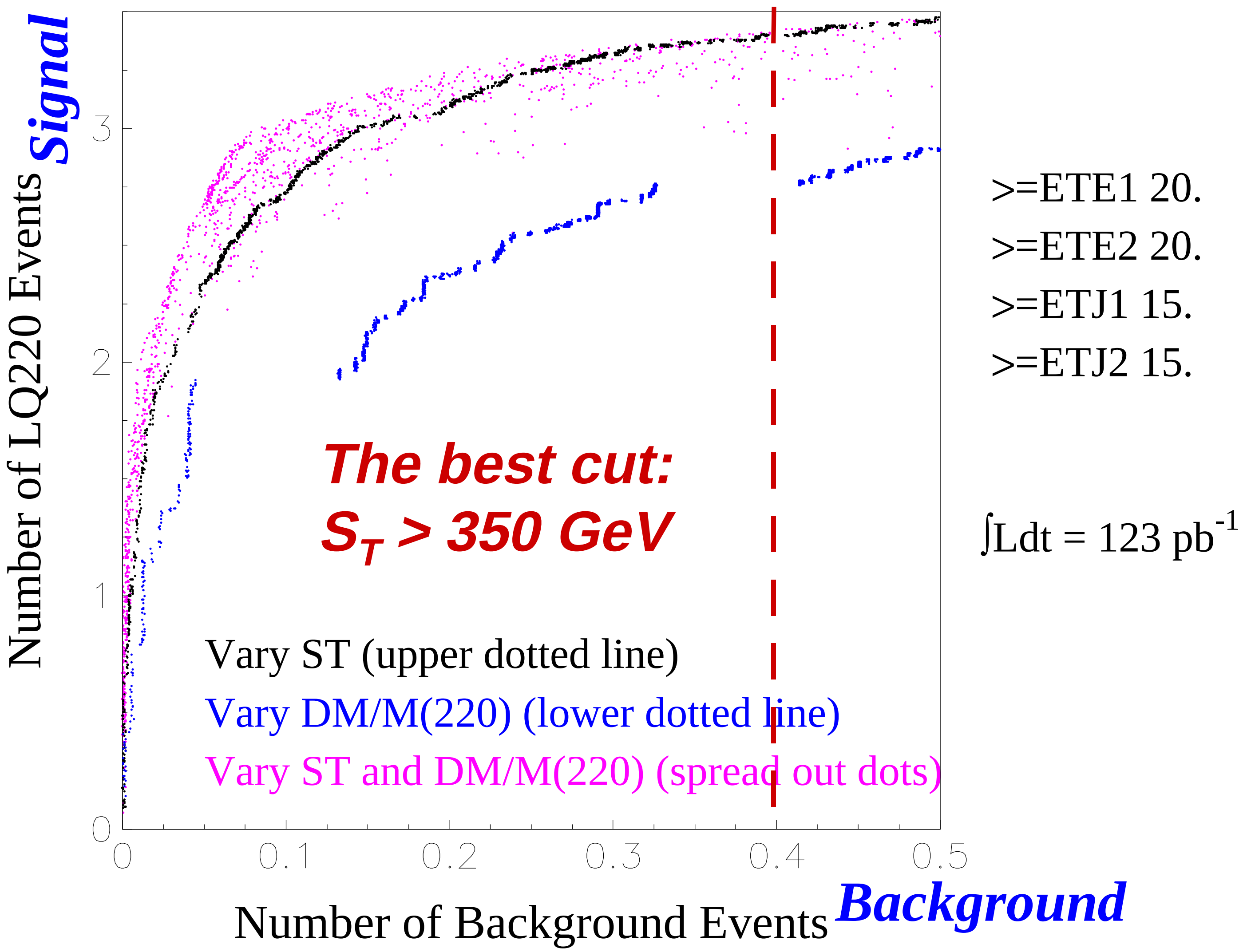
- *Use kinematic parameters of MC events for signal and MC/data events for backgrounds in order to develop optimal set of cuts*
- *Test various combinations of individual object parameters and global parameters of the event*
- *Fix optimal set of cuts and apply it to the data*

A number of variables were tried:

- **Energy variables:**
  - $S_T = \Sigma E_T^e + \Sigma E_T^j$ - scalar E_T
  - $S = \Sigma E^e + \Sigma E^j$
  - $H_T^e = \Sigma E_T^e$, H_T^j, H_T^{j12}, H_T^{j123}
- **Event shape variables:**
  - Centrality = S_T/S, Aplanarity
  - Sphericity, Jet Clustering (η_{RMS})
- **Invariant mass variables:**
  - M_{ee}, pair ej-masses ($M^{e_a j_b}$)
- **Mass difference variables:**
  - $\delta M/M(LQ)$, $\delta M_{12}/\langle M\rangle$, $\delta M_{12}/\sqrt{\langle M\rangle}$

Optimal Cuts

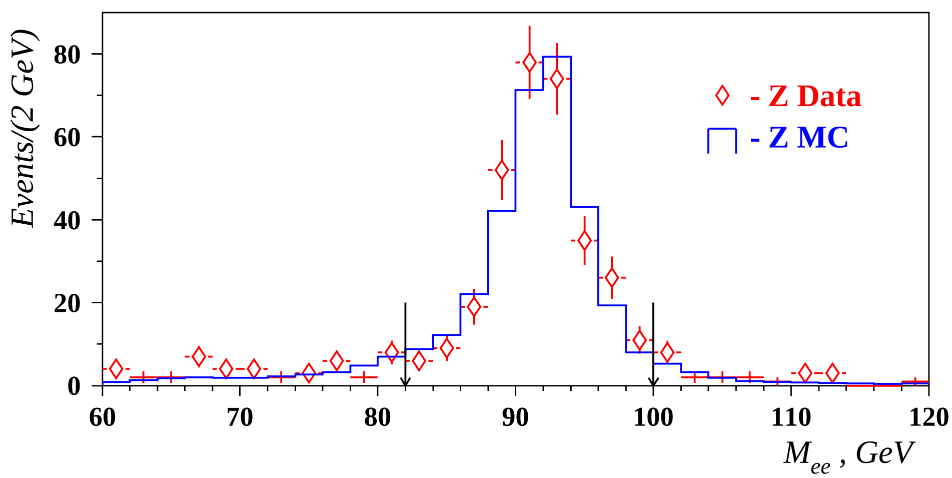
About 50 different combinations of variables were tried. The S_T was shown to be the single most effective variable for backgrounds of about 0.4 events

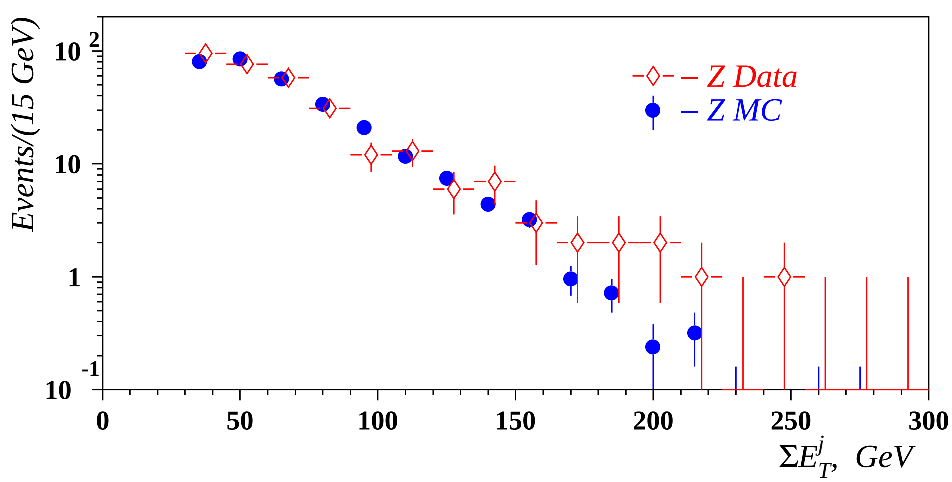


The S_T cut is about 20% more efficient for the signal compared to the $\delta M/M(LQ)$ variable

Drell-Yan Background

- *Normalize integral under the Z-peak to the observed number of Z+2j events*
- *Calculate the background outside the Z-window*





ΣE_T^j

Associated jet production regime equivalent to S_T >350 GeV cut for D-Y background (dominated by high masses) is understood

D-Y Background:

67 ± 13 events for S_T > 0 GeV

0.18 ± 0.04 events for S_T > 350 GeV

(error dominated by jet energy scale)

QCD Background

- **Determine jet faking electron probabilities (including direct photons)**

  Compare number of jets in QCD 3j sample with the number of 2j+e events

  $P(j \rightarrow \text{"tight"}) = (3.5 \pm 0.4)\times 10^{-4}$

  $P(j \rightarrow \text{"loose"}) = (1.3 \pm 0.1)\times 10^{-3}$

  (error covers slight η and E_T^e variations)

- **Calculate the QCD background**

  Two methods:

  - Start with 4j sample and apply faking probabilities twice
  - Start with 3j+e sample and apply faking probabilities once

  Excellent agreement; use the first method for the final numbers due to a better statistics at high S_T

QCD Background:

24 ± 4 events for $S_T > 0$ GeV

0.16 ± 0.02 events for $S_T > 350$ GeV

(error dominated by $P(j \rightarrow e)$ uncertainties)

Top Background

- *Apply all the signal cuts to the $t\bar{t} \rightarrow$ dileptons MC (includes τ-decaying into electrons)*
- *Count the number of events which pass*
- *Calculate background using the top production cross section measured by DØ:*

$$\sigma(p\bar{p} \rightarrow t\bar{t}) = (5.5 \pm 1.8)\ pb$$

and theoretical branching ratio

$$B(t\bar{t} \rightarrow dileptons) = 0.0685$$

- *Studied a possibility to apply a missing E_T cut to reduce top background, but ended up not applying it since the top background is already small*

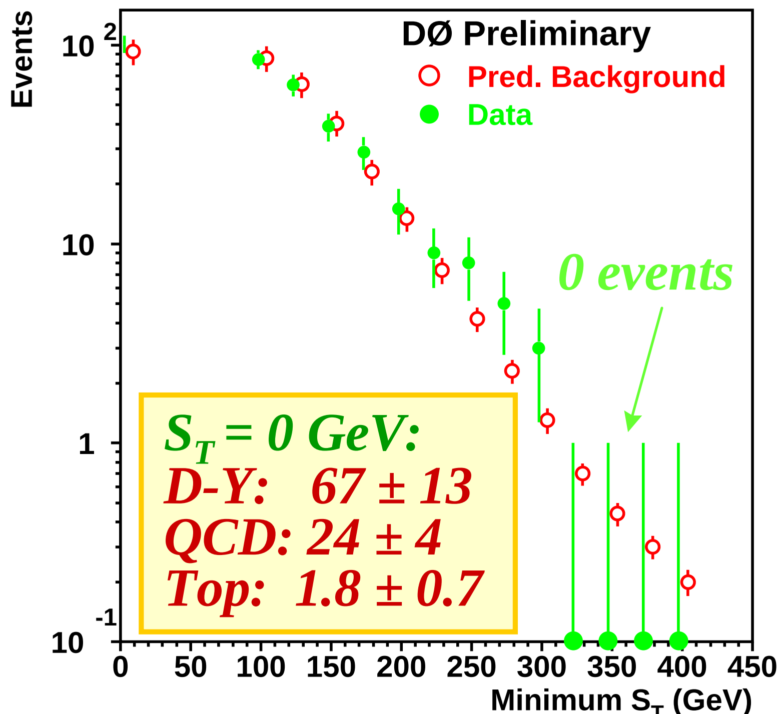
Top Background:

1.8 ± 0.7 events for $S_T > 0$ GeV

0.11 ± 0.04 events for $S_T > 350$ GeV

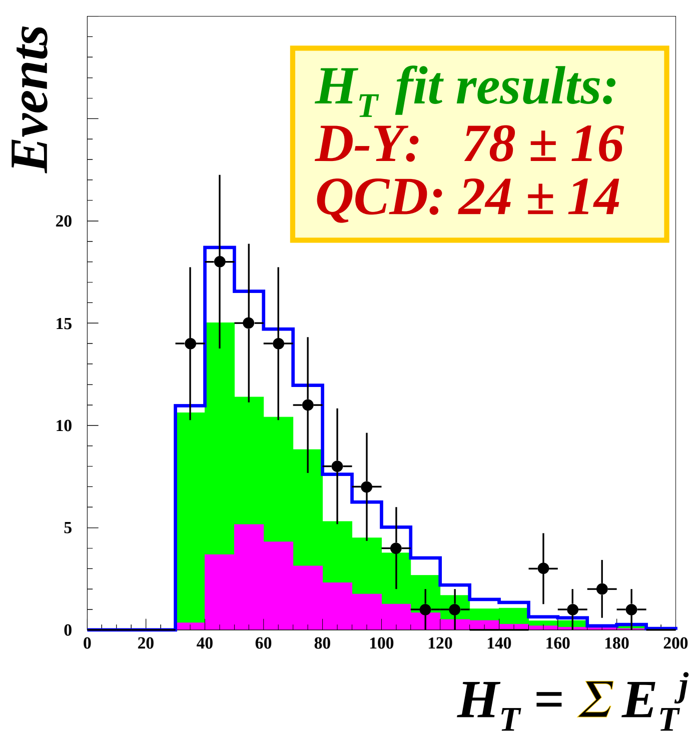
(error dominated by the cross section uncertainty)

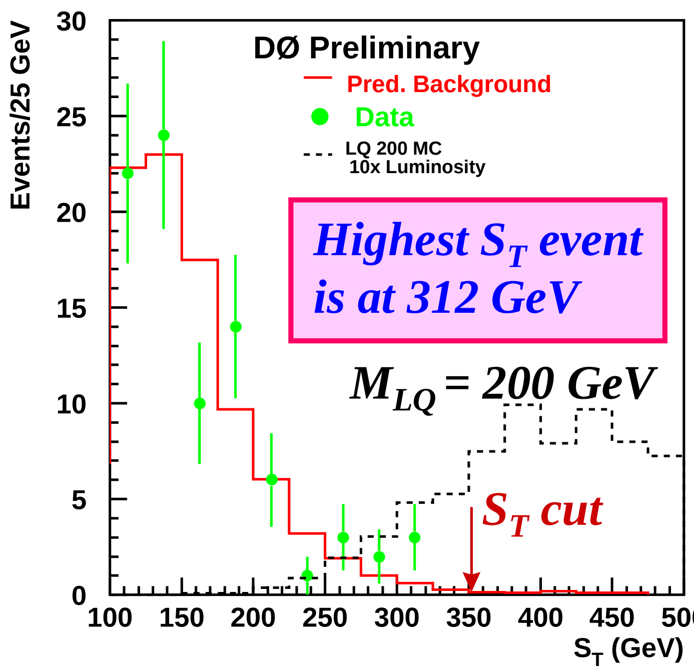
Data vs. Background



S_T Cut (GeV)	Background prediction	Data
0	93 ± 14	101
100	86 ± 13	85
150	41 ± 6	39
200	13 ± 2	15
250	4.2 ± 0.6	8
300	1.4 ± 0.2	3
350	0.44 ± 0.06	0
400	0.20 ± 0.03	0

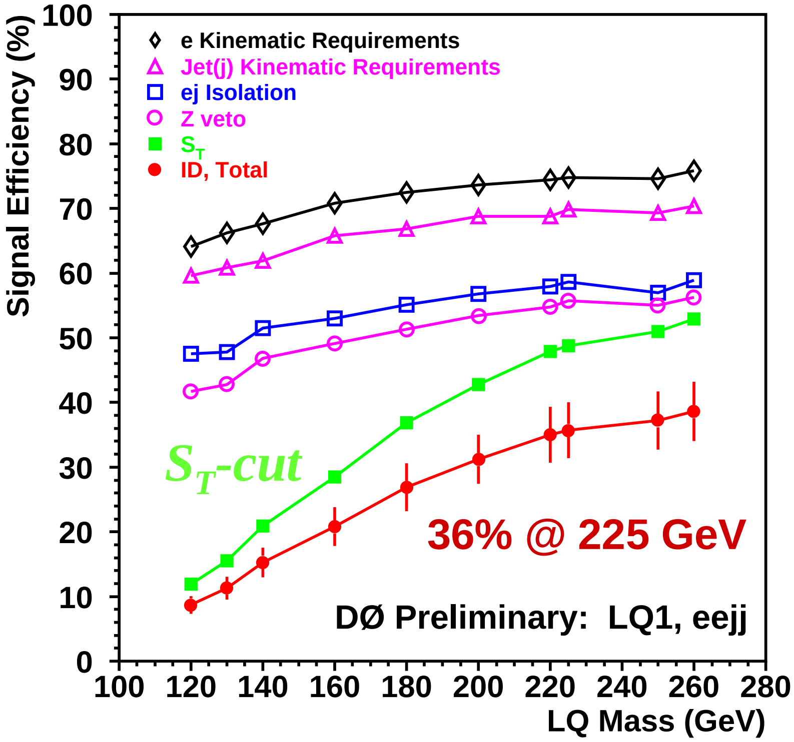
Bayesian Fit to H_Tj Distribution





Acceptance, Efficiency and Systematics

The kinematical/geometrical acceptance is calculated from the LQ MC samples and further corrected for particle ID efficiency as measured with the Z data



Signal Systematics

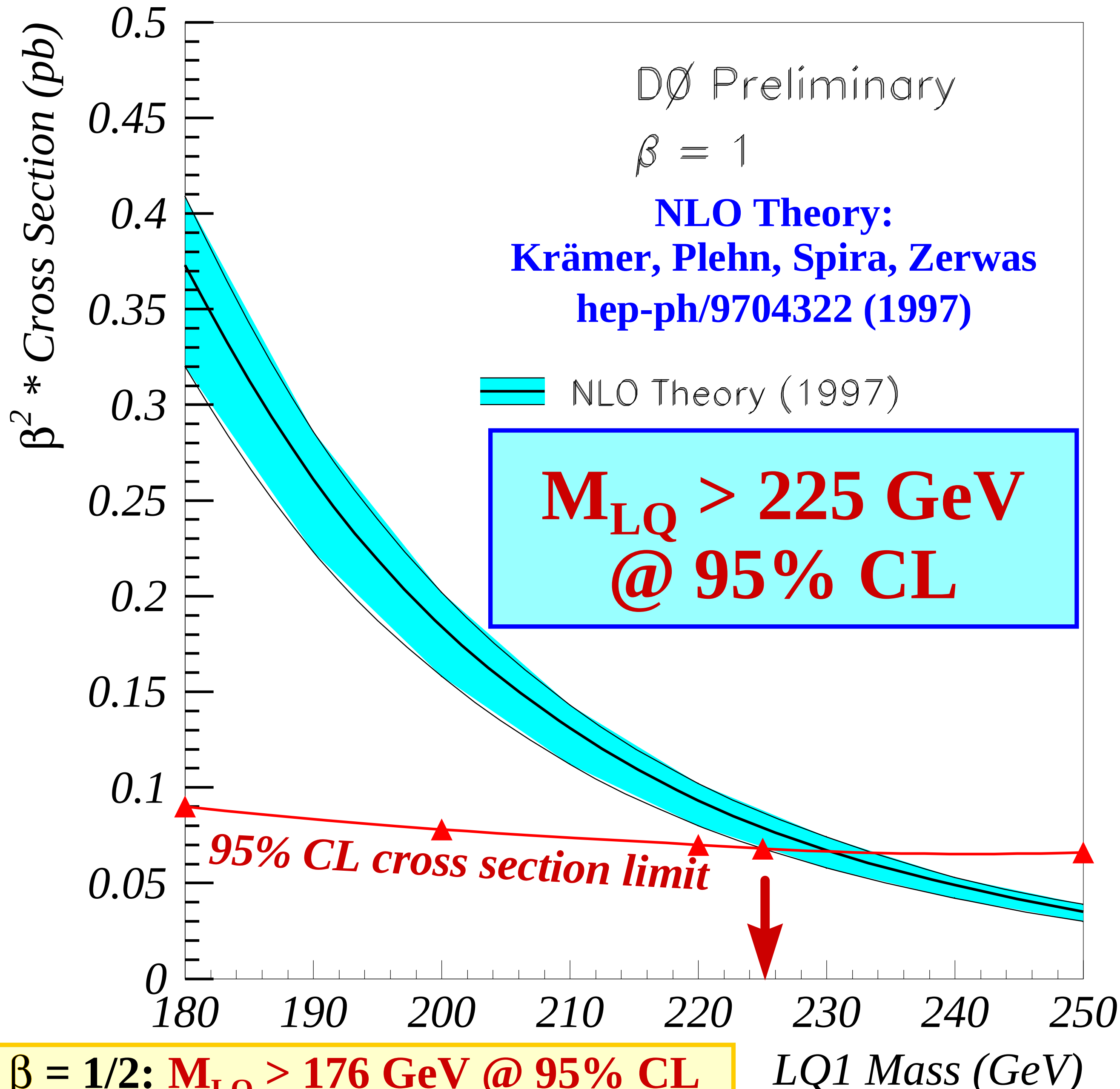
Source of error	*Error*
Particle ID	*5%*
Smearing in the Detector	*3%*
Jet Energy Scale	*2% (260 GeV)* *11% (120 GeV)*
Gluon Radiation	*7%*
PDF and Q^2	*7%*
MC Statistics	*2%*
Luminosity	*5%*
Total	*13% (260 GeV)* *16% (120 GeV)*

Background Systematics

Background	*Systematics*
Drell-Yan	*20% (jet energy scale)*
QCD	*15% (E_T and η dependencies)*
Top	*38% (top cross section)*

Limits on the First Generation LQ

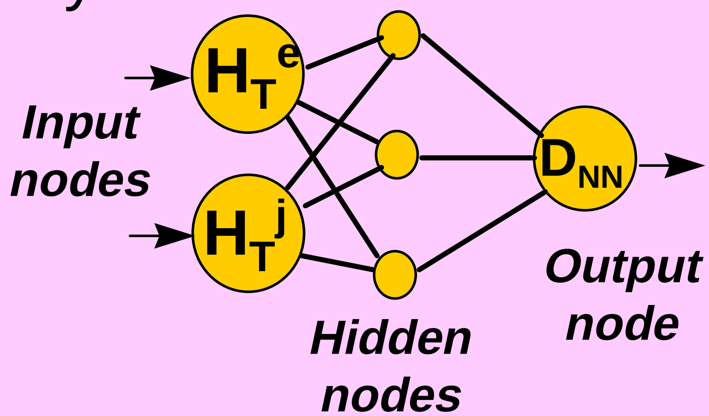
- *No background subtraction (limits are independent of the background and its uncertainty) - PDG method*
- *Account for systematic uncertainty on the signal*



β = 1/2: M_{LQ} > 176 GeV @ 95% CL

Neural Network Analysis

3 layer 2-3-1 feed-forward NN



$H_T^e = \Sigma E_T^e$

$H_T^j = \Sigma E_T^j$

Training:

Signal: LQ(200 GeV) MC

Mixture of QCD, D-Y and Top backgrounds

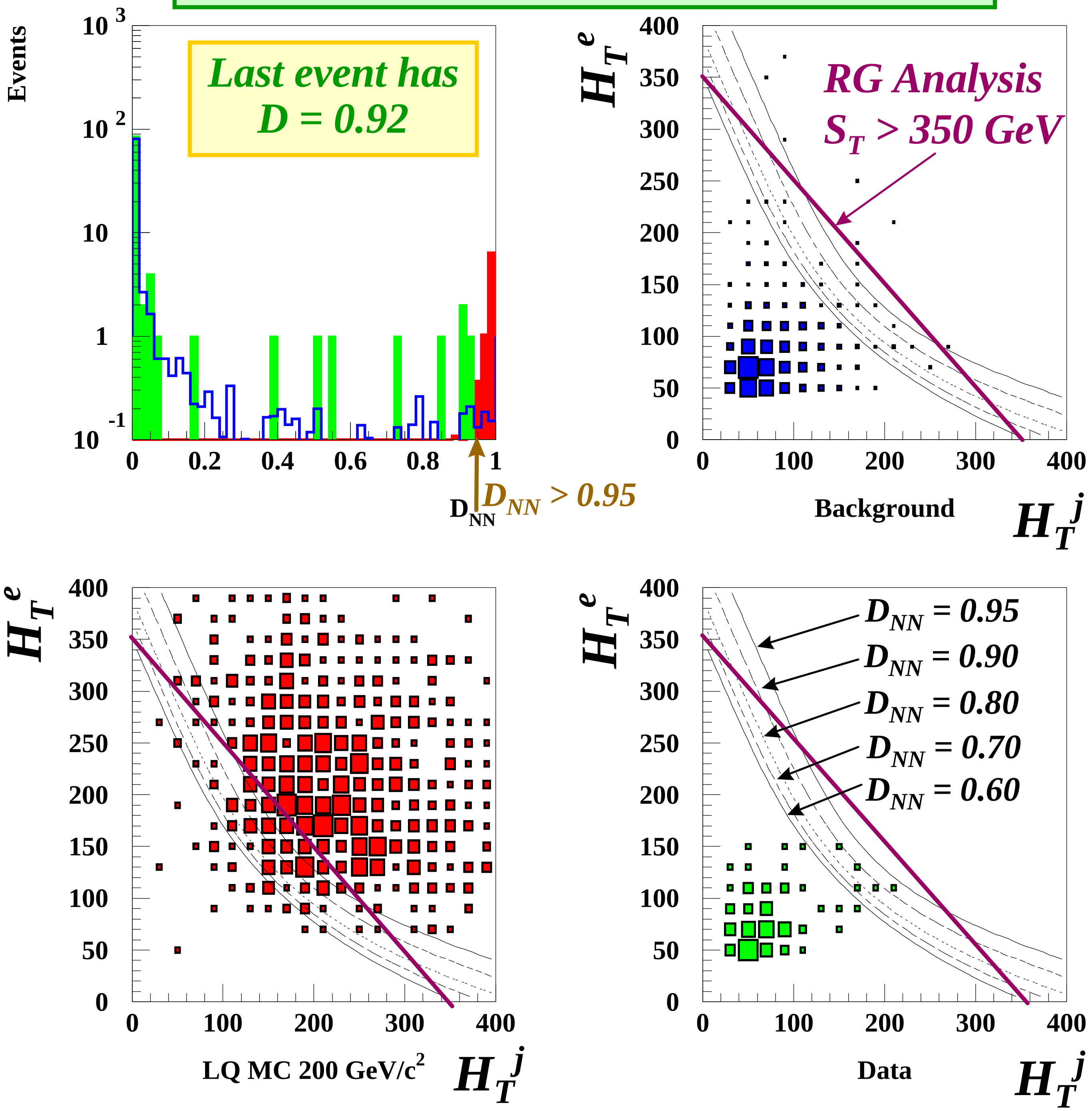
Output:

NN discriminant $0 < D_{NN} < 1$ maximized for the signal

The $D_{NN} > 0.95$ cut corresponds to similar to the RG analysis background. Overall efficiency is slightly better than that of the RG analysis. Both analyses are highly correlated with each other and result in essentially the same LQ mass limits

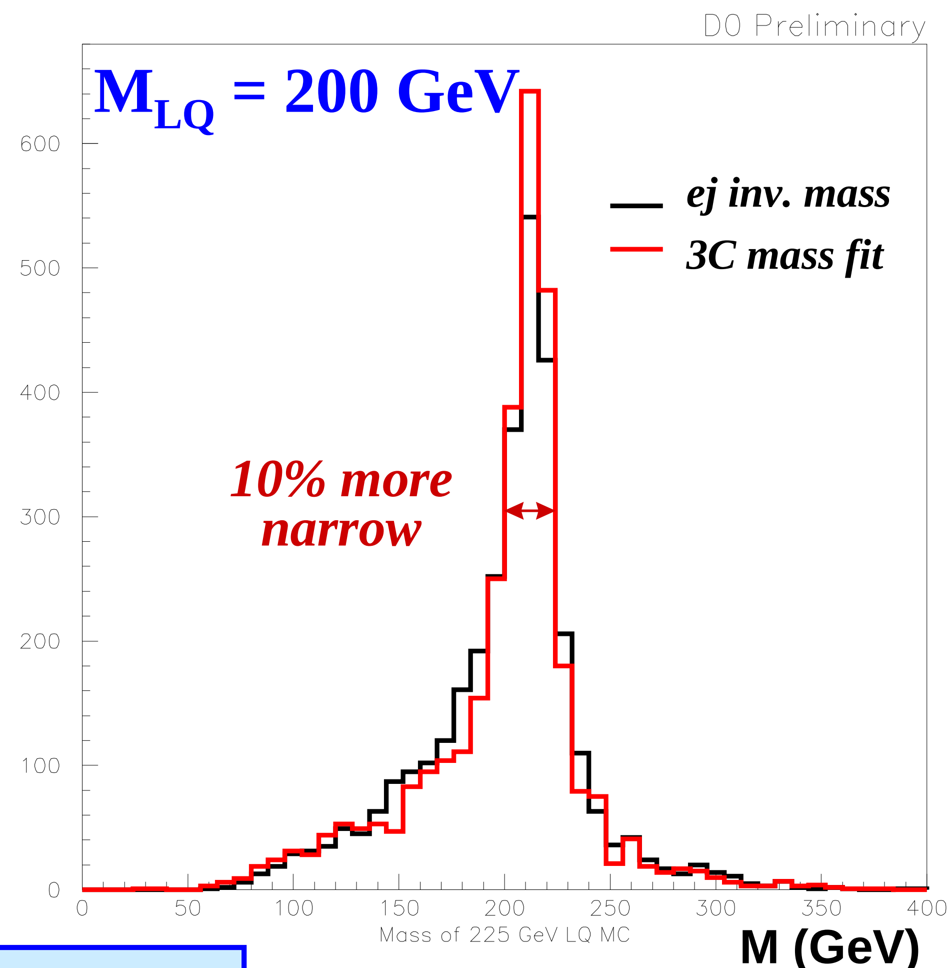
Neural Network Analysis

Results of the NN-based optimization



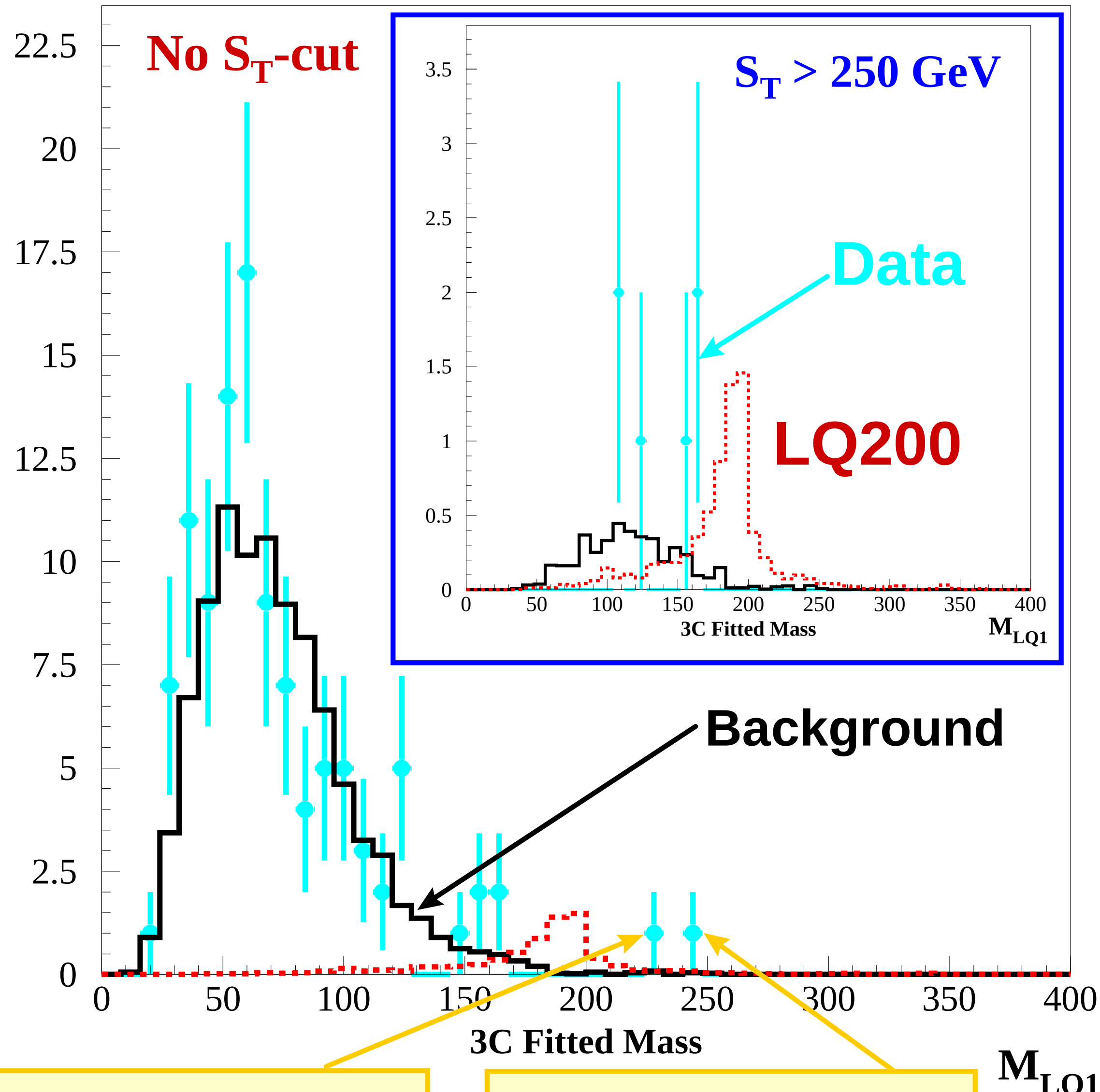
Mass Fit

- *Full-fledged kinematic fitter KFIT (based on SQUAW by O.Dahl) balancing all objects in the event (e, j, unclustered energy)*
- *3C-fitter: fits to the LQ-pair hypothesis with equal mass constraint. Lowest χ^2 solution is kept. Resolution is 10% better than that for pure kinematial calculations.*



Also tried 2C-fitter

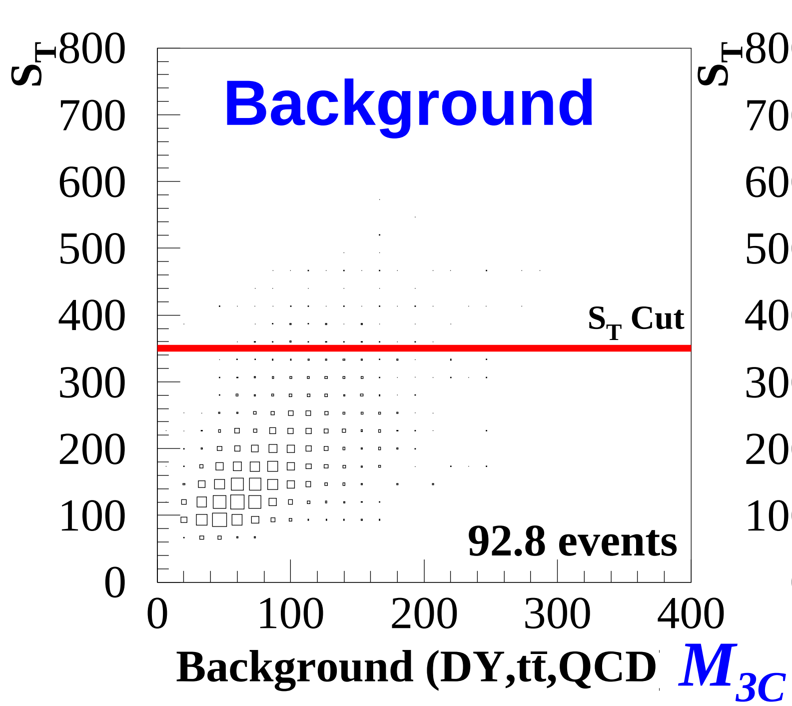
3C-fit Mass Spectra

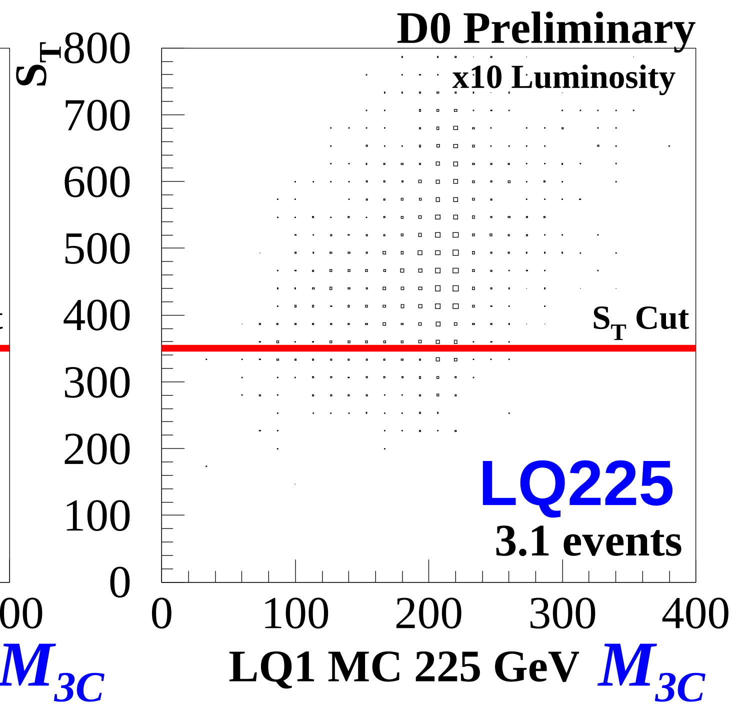


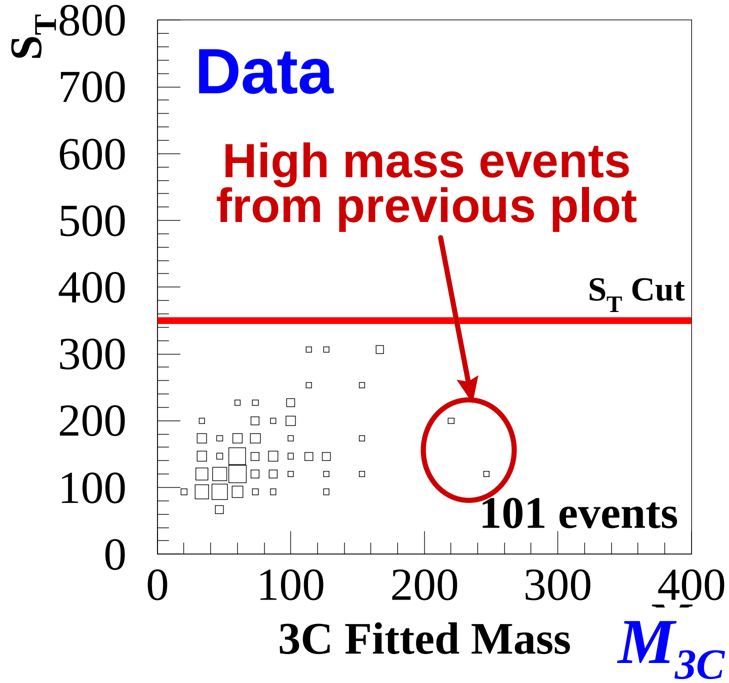
Run 63057, Event 1782
S_T = 121.2 GeV
E_T^{e1} = 29.0 GeV
E_T^{e2} = 25.7 GeV
E_T^{j1} = 36.3 GeV
E_T^{j2} = 30.2 GeV
M_{ee} = 55.3 GeV
M_{3C} = 244.9 GeV
M_{2C} = 269.7/232.7 GeV

Run 90498, Event 13191
S_T = 210.5 GeV
E_T^{e1} = 70.5 GeV
E_T^{e2} = 54.6 GeV
E_T^{j1} = 53.5 GeV
E_T^{j2} = 31.8 GeV
M_{ee} = 129.2 GeV
M_{3C} = 224.7 GeV
M_{2C} = 246.7/217.3 GeV

ST versus 3C-fit Mass





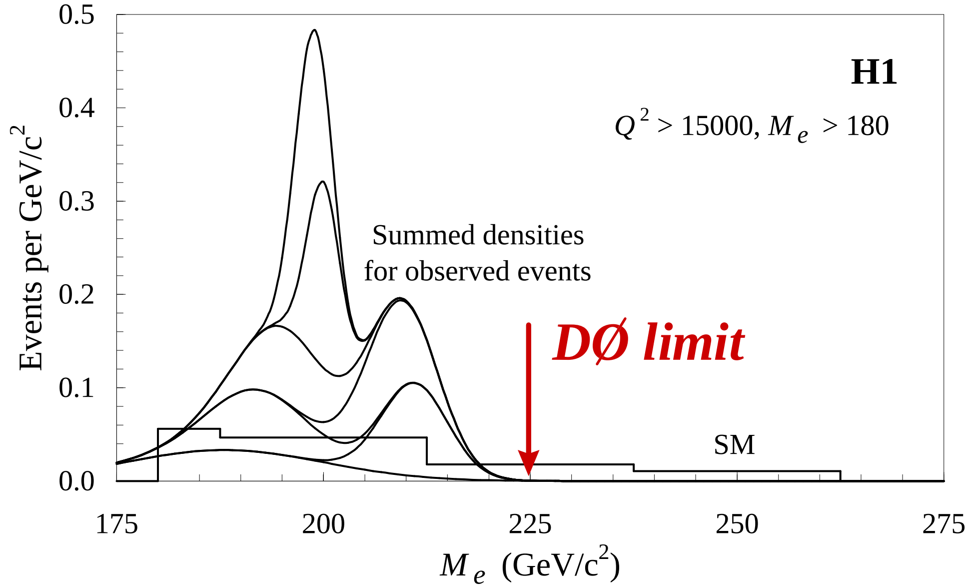


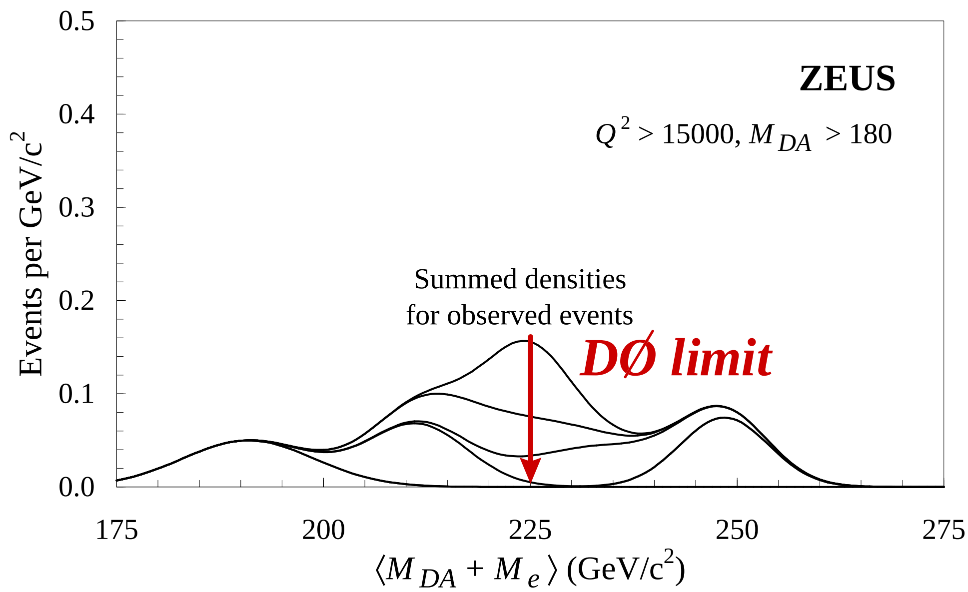
Two events with high mass seen in the 1-dimensional plot are nothing like the LQ signal

No evidences for the LQ signal are seen in the mass analysis as well

D0 on HERA Excess

New DØ result is a single most sensitive search for the β=1 1st generation LQ. It rules out an interpretation of the HERA high Q^2 event excess with 1st generation LQ within general LQ models w/o extra fermions or intergenerational mixing





LQ Searches in the eνjj Channel

- ***Entire Run I statistics:104 pb^{-1} of data***
- ***Event selection:***
  - **1e, $E_T > 25$ GeV, $|\eta| < 1.1$**
  - **2j, $E_T > 25$ GeV, $|\eta| < 1.0$**
  (3rd jet allowed with $|\eta| < 2.5$, $E_T > 25$ GeV)
  - **$\not{E}_T > 40$ GeV**
  (jets and $\not{E}_T$ must have $\Delta\phi, |\pi - \Delta\phi| > 0.25$)
  - **$H_T = \Sigma E_T^j(> 15 \text{ GeV}) + E_T^e > 170$ GeV**
  - **$M_T^{e\nu} > 100$ GeV**
- ***1 event remains***
  (a $t\bar{t}$-candidate with 4j+e topology)

Expected background: 2.5 ± 0.6 events

W+2j: 0.5 ± 0.3
Top: 1.6 ± 0.5
QCD: 0.4 ± 0.2

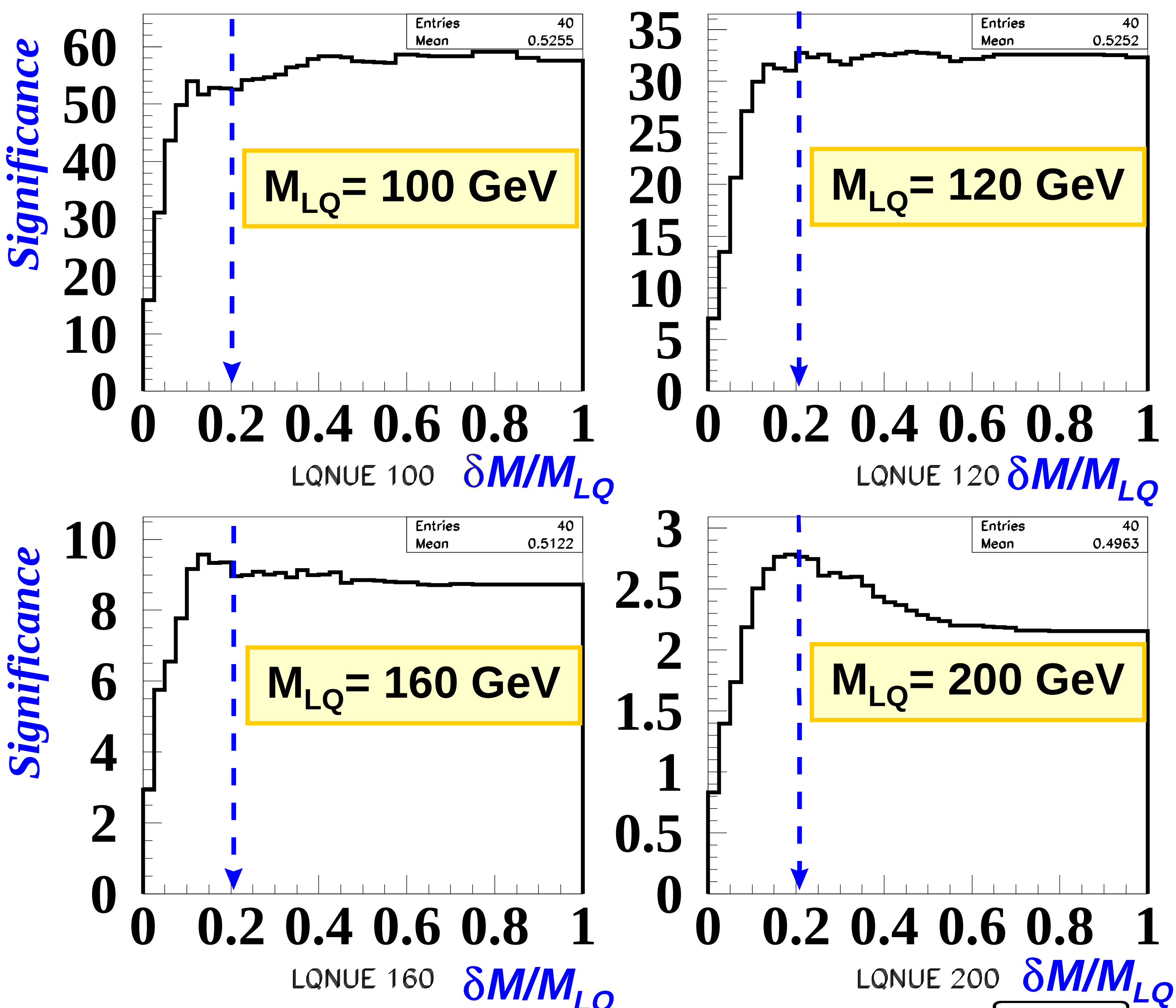
- ***Additional δM/M(LQ) cut on an ej-pair***

$\delta M/M(LQ)$ Cut

$\delta M/M(LQ) = \min(|M_{ej} - M_{LQ}|)/M_{LQ}$

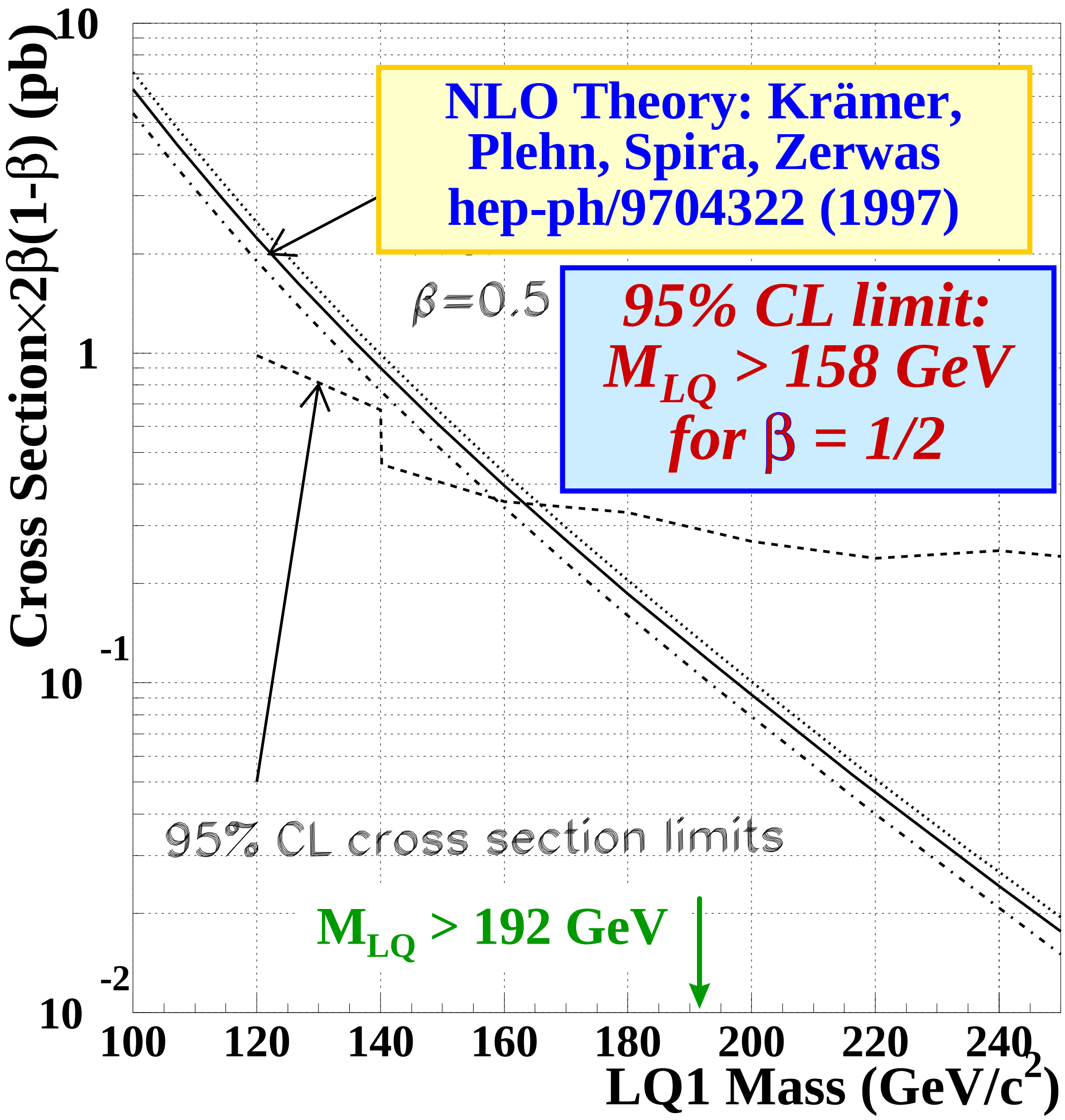
Optimize significance $S/\sqrt{B}$ for typical LQ mass of 160 GeV

$\delta M/M_{LQ} < 0.2$, *no events survive above* $M_{ej} = 140$ *GeV*



β=1/2 LQ Mass Limits

Limit setting procedure and systematic errors are similar to that in the eejj channel



Combined with our eejj analysis the limit is:
M_{LQ} > 192 GeV, for β = 1/2 @ 95% CL

Search for Second Generation LQ

μμjj channel

Data: 1994-1996 Tevatron run (94.4 pb^{-1})

Event Selection:

2 isolated muons:
$p_T^{\mu} > 15$ GeV, $|\eta^{\mu}| < 1.0$,
$\Delta R(\mu, j) > 0.5$

2 jets: $E_T^j > 15$ GeV, $|\eta^j| < 2.5$

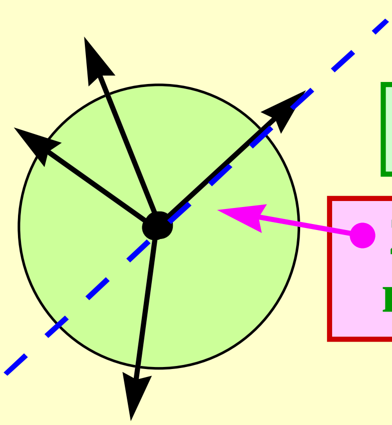
$\Delta\phi(\mu 1, \mu 2) < 160^o$ if
$|\eta_{\mu 1} + \eta_{\mu 2}| < 0.5$

$M_{\mu\mu} > 10$ GeV

$H_T^j > 100$ GeV

Z-kinematic fit $P(\chi^2) < 1\%$

Standard $t\bar{t} \rightarrow$ dimuon selection



2 muons and 2 leading jets are not in the same φ-hemicylinder

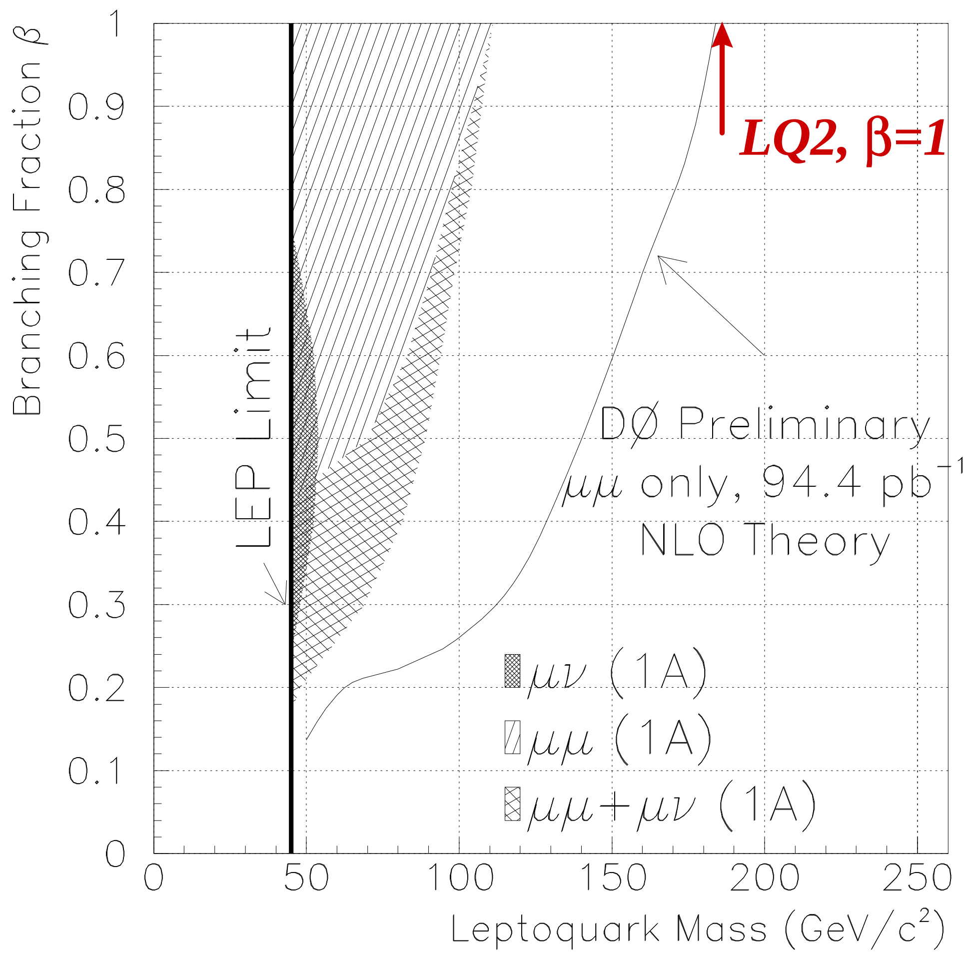
Top rejection

0 events survive

Second Generation LQ Mass Limits

Run 1 Data Sample (94.4 pb^{-1})
Data: 0 events, Exp. Bkgd: 0.9 ± 0.2 events

M_{LQ2} > 184 GeV @ 95% CL for β = 1



NLO Theory: Krämer, Plehn, Spira, Zerwas
hep-ph/9704322 (1997)

Search for Third Generation LQ

q = 1/3 third generation LQ
$\nu\bar{\nu}b\bar{b}$ channel

- $\nu\bar{\nu} \Rightarrow \not{E}_T > 35$ GeV
- 2 jets, at least 1 with muon tag
  - untagged, $E_T^j > 25$ GeV
  - tagged, $E_T^j > 10$ GeV
- topological cuts

Efficiency = 1.9% (M_{LQ3} = 100 GeV/c^2)
(3-5% at higher LQ3 masses)

Major Backgrounds:
$t\bar{t}$, W/Z+2j, QCD multijets

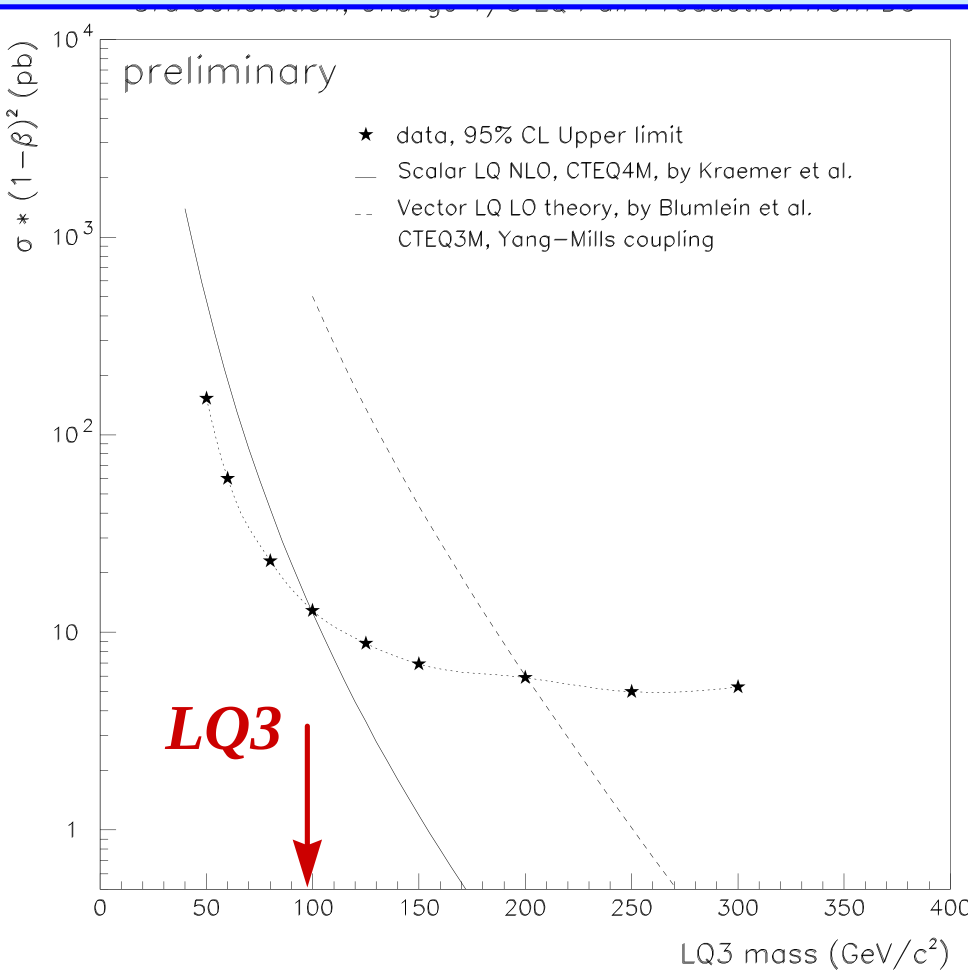
Third Generation LQ Mass Limits

Run 1 Data Sample

Data: 2 events, Exp. bkgd: 3.1± 0.9 events

M_{LQ3} > 98 GeV @ 95% CL for β = 0, q = 1/3

M_{VLQ3} > 201 GeV @ 95% CL for β = 0, q = 1/3



NLO Theory: Krämer, Plehn, Spira, Zerwas
hep-ph/9704322 (1997)

Conclusions

- *The DØ Collaboration has performed a search for scalar LQ and set the following 95% CL lower LQ mass limits based on the NLO theory:*
  - **First Generation:**
    - $\beta = 1$ **225 GeV**
    - $\beta = 1/2$ **192 GeV**
  - **Second Generation:**
    - $\beta = 1$ **184 GeV**
    - $\beta = 1/2$ **140 GeV**
  - **Third Generation:**
    - $\beta = 0$ **98 GeV**

all limits are given @ 95% CL

- *Our measurement in the eejj channel is the single most sensitive Yukawa-coupling-independent search for the first generation LQ. It rules out at 95% CL an interpretation of the HERA data with LQ masses below 225 GeV. This excludes the large class of models which require* $\beta = 1$.

  [see J. Hewett, T. Rizzo - hep-ph/9703337 for discussion]
- *Combined Tevatron results are expected to yield even higher mass limits on the LQ*

A Final Touch

New York Times, February 25, 1997

YORK TIMES SCIENCE TUESDAY, FEBRUARY 25, 1997

Surprising New Particle Appears, Or on the Other Hand, ~~Maybe~~ Not

By DAVID KESTENBAUM

Physicists in Germany may have detected a bizarre hybrid particle called a leptoquark that, if it turns out to be real, could topple the reigning scientific model of how the world is put together.

For two decades, particle physicists have sorted the smallest, apparently indivisible subatomic particles into two exclusive categories, quarks and leptons. Quarks are what protons and neutrons are made of. Leptons are particles like electrons and neutrinos. Together, leptons and quarks make up the atoms that form all of the material world.

The leptoquark — half lepton, half quark — has lived for almost two decades only in the dreams and equations of theoretical physicists as an object that would overturn the Standard Model, a theory that has been dominant for so long that a generation of physicists has known nothing else. The Standard Theory does not predict leptoquarks, but tracks of a leptoquark may now have been seen in a German accelerator.

"A leptoquark would have such enormous consequences for our understanding of physics that I don't dare to dream of it," said Dr. Ralph Eichler, a physicist at the Institut für Teilchenthysik in Switzerland and a spokesman for one of two international teams that reported the leptoquark results on Wednesday at the accelerator, the Deutsches Elektronen-Synchrotron in Hamburg, Germany. Their results were submitted for publication yesterday.

But the DESY physicists are wary of claiming too much. "What we're seeing might just be a random fluctuation," said Dr. Allen Caldwell, a physicist at Columbia University who is the spokesman for the other team, "like getting seven heads in a row when flipping a coin."

The new results, the teams say, could also be evidence for new particles within the quarks, an equally exciting possibility. Dr. Guido Altarelli, a physicist at the CERN laboratory in Switzerland, said the data could also be interpreted as evidence for an even heavier particle, a leptoquark or something else not yet seen.

The Standard Model describes the world from the ground up, from the architecture of atoms to the reactions that power the sun. Although it does not include gravity, it is the closest thing physicists have to a "theory of everything."

"I'm positive the Standard Model is incomplete," said Dr. Joseph Lykken, a physicist at Fermilab in Batavia, Ill., in an interview. "It just leaves too many questions unanswered. I expect we will find a crack in it sometime this decade."

A new particle like the leptoquark would be such a crack. Leptoquarks arise, Dr. Lykken said, in theories that try to unite leptons and quarks into a larger, simpler structure. The Standard Model will not fall so much as it will be consumed by a more complete theory, he predicted.

"If the leptoquark is real," Dr. Lykken said, "it will really be a shock to the whole community."

At the DESY accelerator, a ring of magnets accelerates protons and positrons (the electron's antimatter counterpart) to close to light speed and has them collide. The DESY instrument, the only proton-positron collider in the world, is ideal for making leptoquarks, if they exist.

In most collisions, the positron bounces off the quarks within the proton, which breaks up to form a shower of other particles. The two research teams, which include collaborating groups from 19 countries, monitor the collisions at different points around the four-mile ring, each using a house-sized particle detector weighing thousands of tons. After examining the data from millions of collisions over the last few years, the teams found that some positrons had emerged at surprisingly high energies, a greater number than predicted by the Standard Model. In these events, Dr. Caldwell said, the positron "almost makes a U-turn."

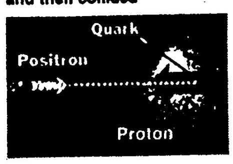
One explanation for that would be the momentary formation of a leptoquark, surviving only a fraction of a second before decaying back into a positron and a quark. Because there were only about 10 of these collisions, the teams said it was impossible to draw definite conclusions about what they might be. The odds that those collisions were produced them by chance, they said, is only about 1 in 300, but this is still well short of the 1-in-10,000 standard usually required to establish firmly that a new particle has been detected.

The two DESY research teams analyzed their data in isolation and did not compare their results until last week, and they were excited to find that they had a lot in common. If the presence of a leptoquark is established, it would be the heaviest subatomic particle yet observed, weighing almost as much as a lead atom. Previous searches had not observed any but could have missed one this heavy. But DESY physicists are choosing their words cautiously, saying leptoquarks are only one possible explanation. DESY will begin collecting more data in March.

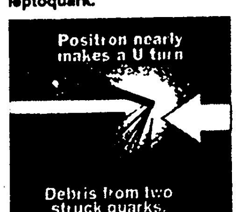
Footprints of a Leptoquark?

At the DESY accelerator in Hamburg, Germany a positron (the electron's antimatter counterpart) collides with a quark. In a few spectacular collisions, the positron nearly makes a U turn. One possible explanation is the momentary creation of a strange new particle called a leptoquark.

Positron and a quark inside a proton are accelerated close to the speed of light and then collided



The high-energy positron nearly reverses direction, possible evidence of a leptoquark.



Source: DESY

The New York Times

Elsevier

...uman chromosomes.

...ler University who re... ...hed a paper on this phe... human cells, said that ...are constantly moving ...forth between states." ...ate between growing and ...in a dynamic equilib... ...le Lange said. ...ariety of species use the ...anism, said Dr. Thomas ...Nobel Prize-winning cell ...the University of Colora... ...r, who published a paper ...telomere length regula... ...t. "The story is consis... ...d. ...il leaves the question ...omeres have any use oth... ...buffer zones. Dr. Black... ...n answer was imminent, ...ers, she said, are about to ...pers showing that telo... ...ssential for nuclear divi... ...ocess of pulling apart the ...es when cells divide. So, ...e telomere story may not ...le one of a few years ago ...ifically, it is a lot more