Search for Exotics at DØ

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Outline

- LeptoQuark (LQ) Phenomenology
- LQ at HERA and Tevatron
- DØ Detector
- First Generation LQ Search at DØ
  - ee+jets channel
  - eν+jets channel
  - νν+jets channel
- Search for Other LQ Generations
- LQ Conclusions
- Theory of Magnetic Monopoles
- Effects of Virtual Monopoles
- Heavy Monopole Search at DØ
- Monopole Conclusions
- Search for Fermiophobic Higgs
- Conclusions: Future of DØ

100 Years of Particle Physics

1897 - Discovery of Electron (J.J.Thompson)

↓

Symmetries

↓

1995 - Discovery of t-quark (CDF and DØ)

Symmetries → Groups → Transformations (e.g., SO(3) - three-dimensional rotations)

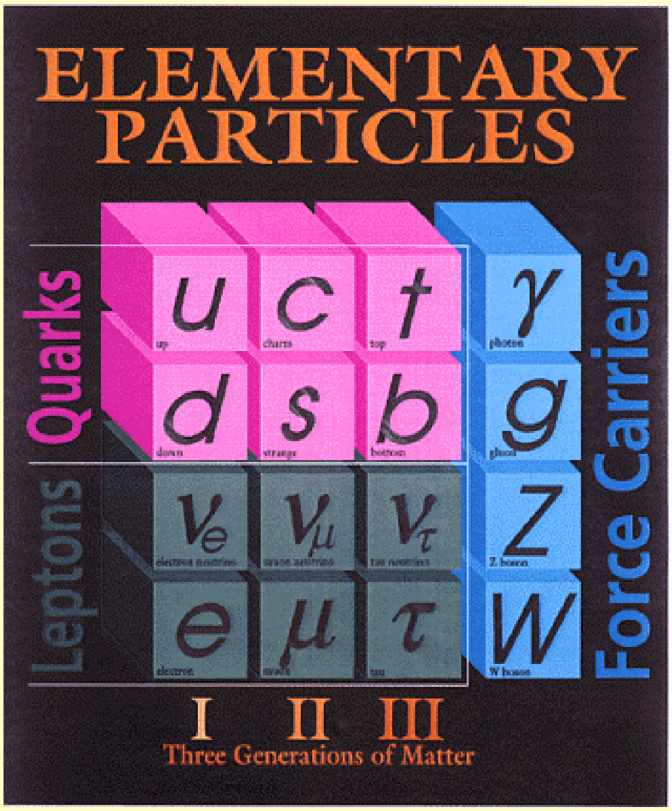
↓ ***Noether's Theorem:***

Symmetries → Invariance → Conservation Laws

↓ ***Higgs Mechanism:***

Symmetries → Approximate Symmetries → Broken Symmetries → Masses

Mysterious Symmetry of Generations



3 COLORS

u +2/3	u +2/3	u +2/3
d -1/3	d -1/3	d -1/3

e -1
ν_e 0

Colorless

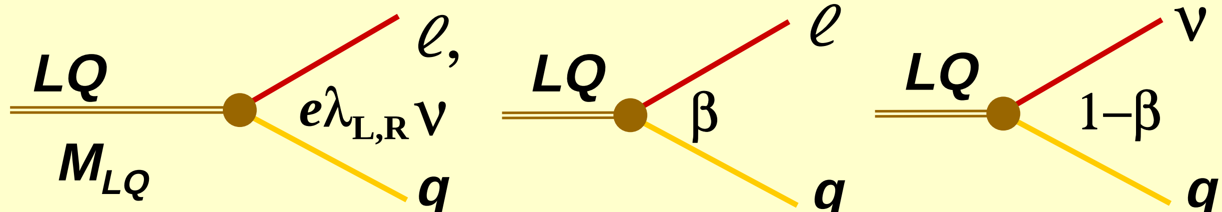
$\Sigma Q = 0$!

One of the ways to solve the mystery of generations is to introduce the LEPTOQUARKS - exotics objects which have properties of both leptons and quarks and let them know of each other's presence via ℓ-q-LQ interaction

First introduced by J.C.Pati and A.Salam in 1973 (SU(4) model), these particles became popular in many extensions of the SM, especially in Grand Unified Theories and composite models

LQ Phenomenology

- LQ come in 3 generations and 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 $SU(3)_C \times SU(2)_L \times U(1)_Y$ assuming baryon/lepton number conservation, EGI, renormalizability, and chiral couplings:



- BR into charged leptons β can be 0, 1/2, or 1 only, if no extra fermions are added to the model
- LQ can have spin 0 (scalar) or 1 (vector)
- LQ interactions can be classified by the fermion number ($F=3B+L$): $\mathcal{L} = \mathcal{L}_{F=-2} + \mathcal{L}_{F=0}$
  - S-type scalar LQ have F= -2 (3 singlets and 1 triplet)
  - R-type scalar LQ have F=0 (3 doublets)
  - V-type vector LQ have F= -2 (3 doublets)
  - U-type vector LQ have F=0 (3 singlets and 1 triplet)

Low Energy Limits

- *Intergenerational mixing of LQ is severely restricted by FCNC data and other low energy phenomena:*
  - $K \to \pi e^+ e^-, \pi\mu^+\mu^-$ ($\bar{s}d\bar{\ell}\ell$ vertex)
  - $B \to \bar{\ell}\ell X$
  - $K \to \mu e$ *decay would receive a large contribution from LQ coupled to the first and second families*
- *Chirality of the couplings is ensured from tight limits on the* $\pi \to e\bar{\nu}$ *decay and from* g_μ*-2 measurements*
- *Limits on the LQ mass from low energy data (atomic parity violation, quark-lepton universa-lity, etc.):*
  - $M_{LQ}/\lambda > 500\text{-}2000$ GeV
- *Previous HERA measurements:*
  - $M_{LQ} > 230\text{-}250$ GeV *for* $\lambda = 1$
- *LEP searches for* $Z \to \mathrm{LQ}\,\overline{\mathrm{LQ}}$ *set coupling-independent mass limits (as long as couplings are strong enough to ensure short LQ lifetime):*
  - $M_{LQ} > 44$ GeV

Why is (was) it so Exciting?

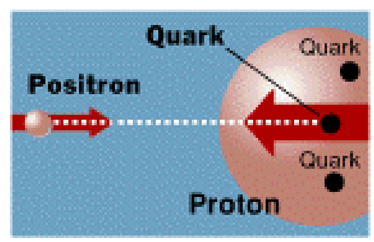
HERA at DESY (Hamburg)

New York Times February 25, 1997

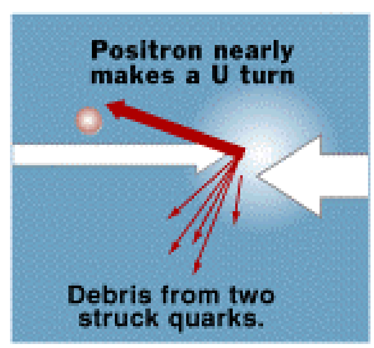
Footprints of a Leptoquark?

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.

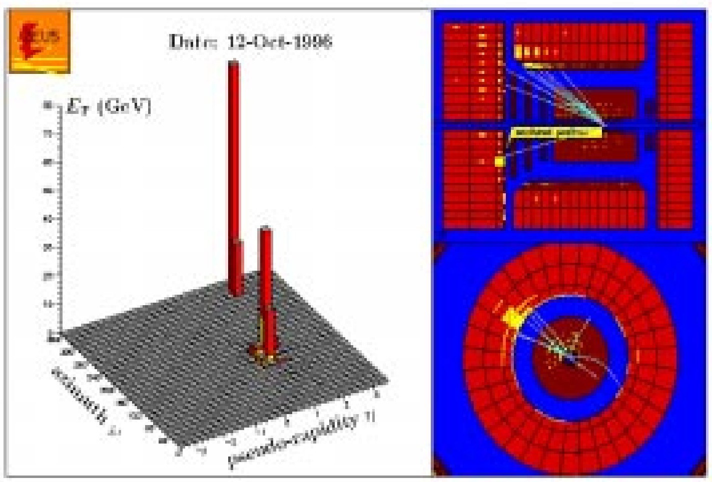
Positron and a quark inside a proton are accelerated close to the speed of light and then collided



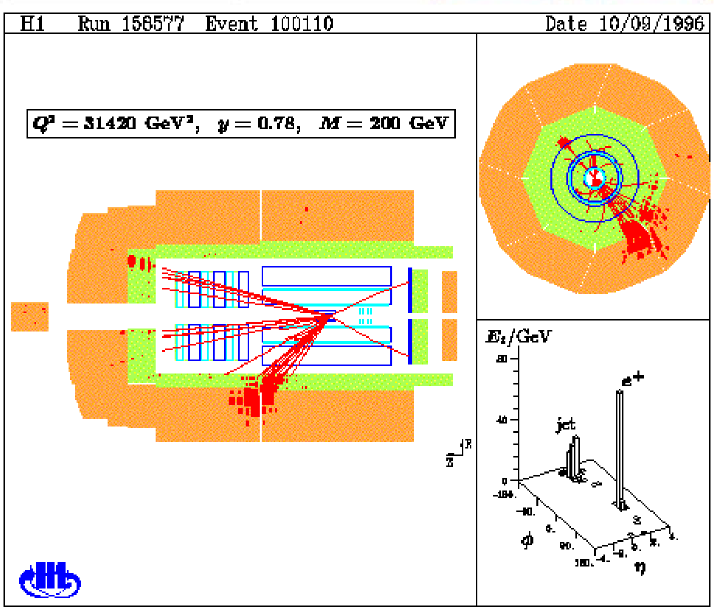
The high-energy positron nearly reverses direction, possible evidence of a leptoquark.



High Q^2 events in 20 pb^{-1} of e^+p data



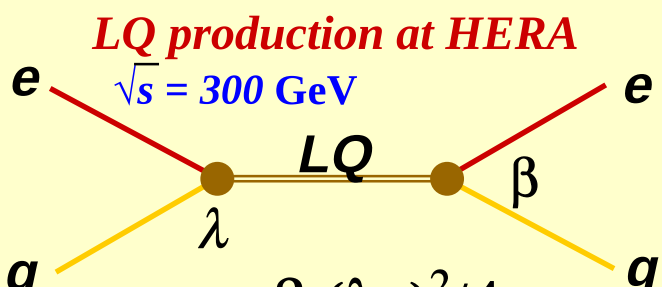
ZEUS: 4 events (SM: 0.9)



H1: 7 events (SM: 1.0)

LQ Production at HERA

Both H1 [Z.Phys. C74, 191 (197)] and ZEUS [Z.Phys. C74, 207 (1997)] 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 were already excluded up to much higher mass by DØ)



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

$\lambda=1$: *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:

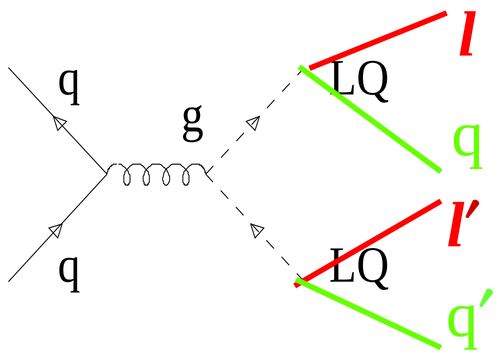
no excess reported

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 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 so appeared recently [J.Hewett,T.Rizzo - hep-ph/9708419; Babu, Kolda, March-Russell - Phys. Lett. B408 (1997) 261].

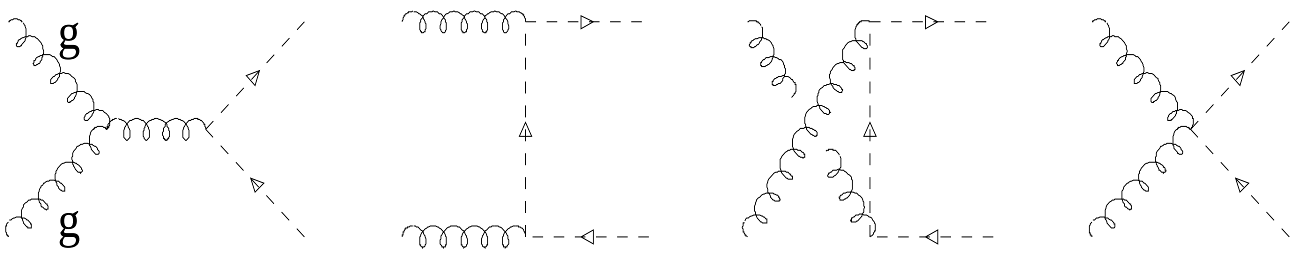
LQ Production at the Tevatron

- *At the Tevatron leptoquark pair production via gluon exchange (strong interaction) dominates*



eejj, eνjj or ννjj channels
Major backgrounds: W/Z+jj, QCD and $t\bar{t}$ production

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

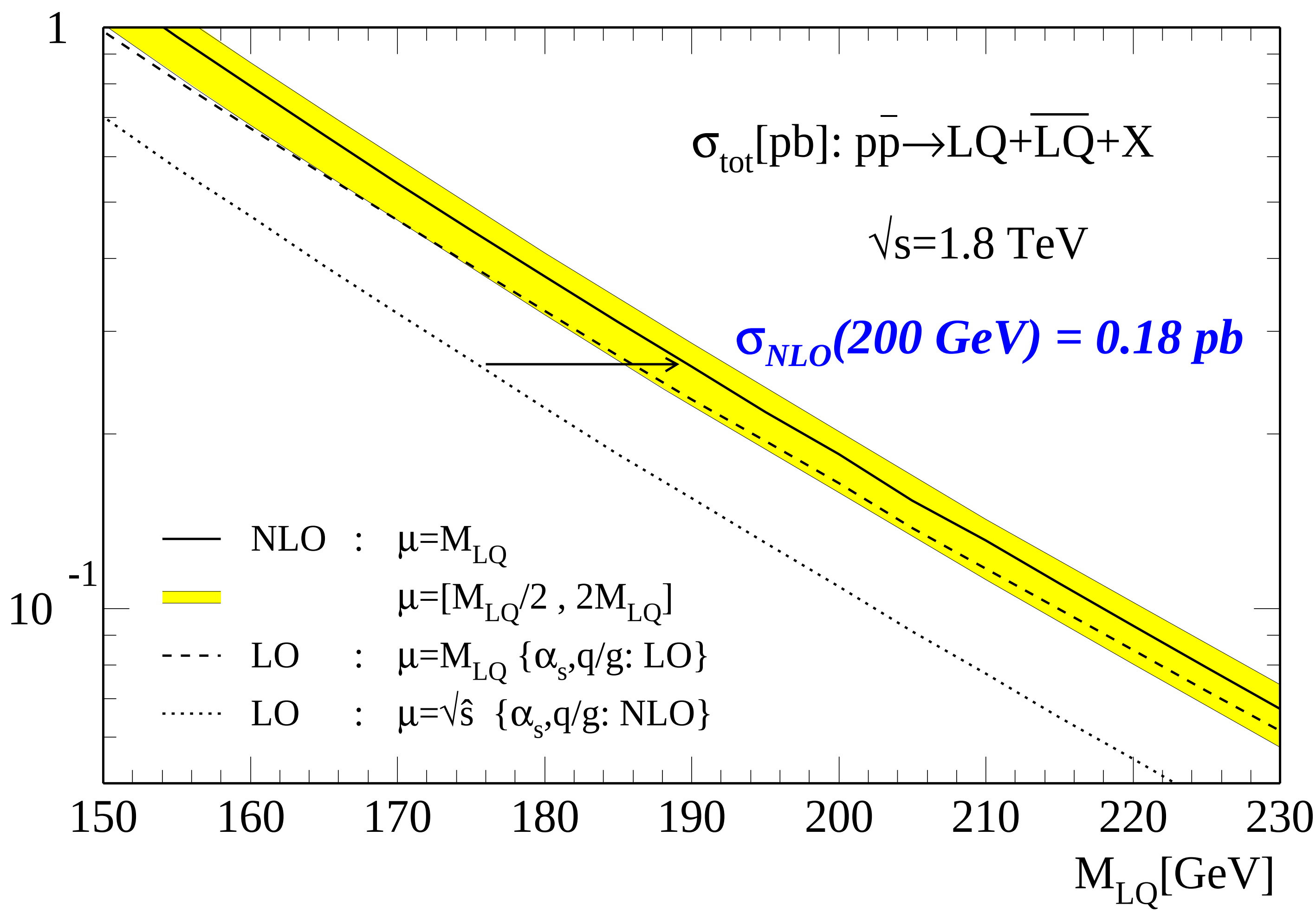


- *Pair production is insensitive to the value of λ since it enters only in the LQ lifetime and for $\lambda > 10^{-12}$ LQ decay within a collider detector*
- *It depends only on β ($\propto \beta^2$ for eejj, $\propto 2\beta(1-\beta)$ for eνjj and $\propto (1-\beta)^2$ for ννjj)*
- *It has very little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

Next-to-Leading Order Theory

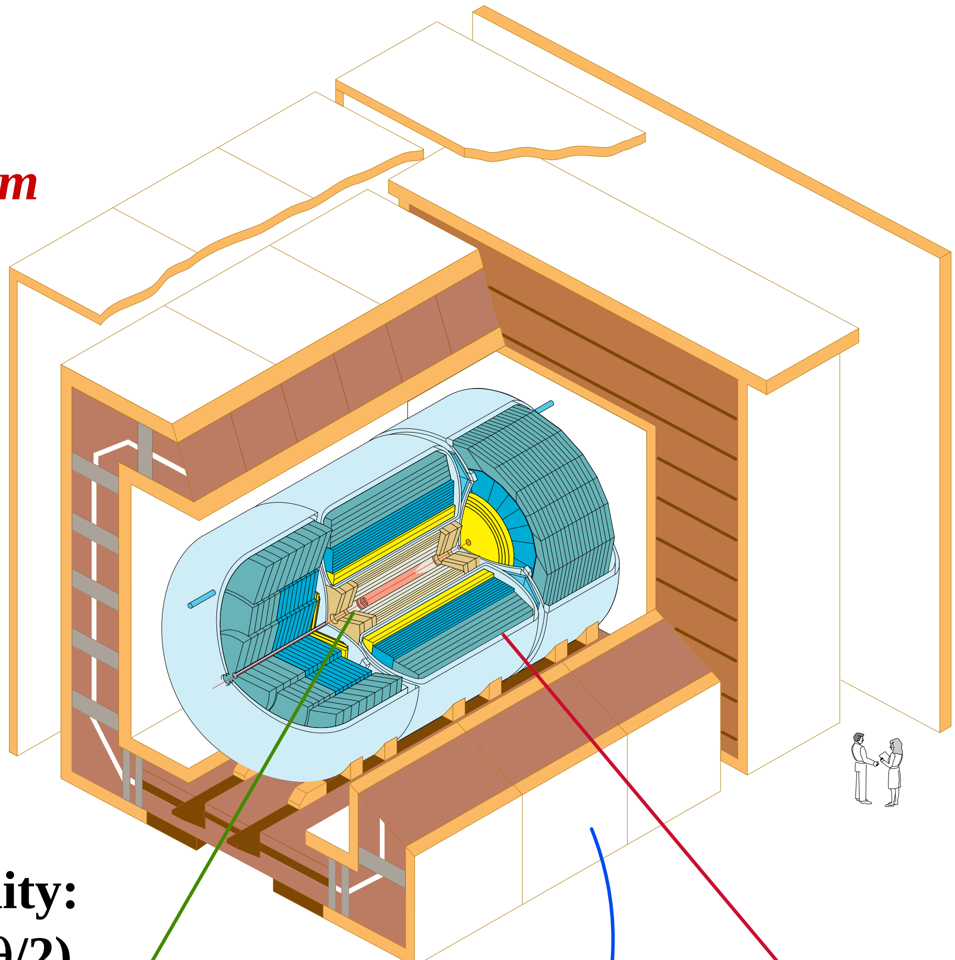
NLO theory – calculate ~100 additional diagrams to include $O(\alpha_S^3)$ effects

M.Krämer, T.Plehn, M.Spira, and P.M.Zerwas, Phys.Rev.Lett. **79**, 341 (1997)



DØ Detector

3 Level Trigger System



DØ Detector

Pseudorapidity:

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

TRACKING

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

MUON

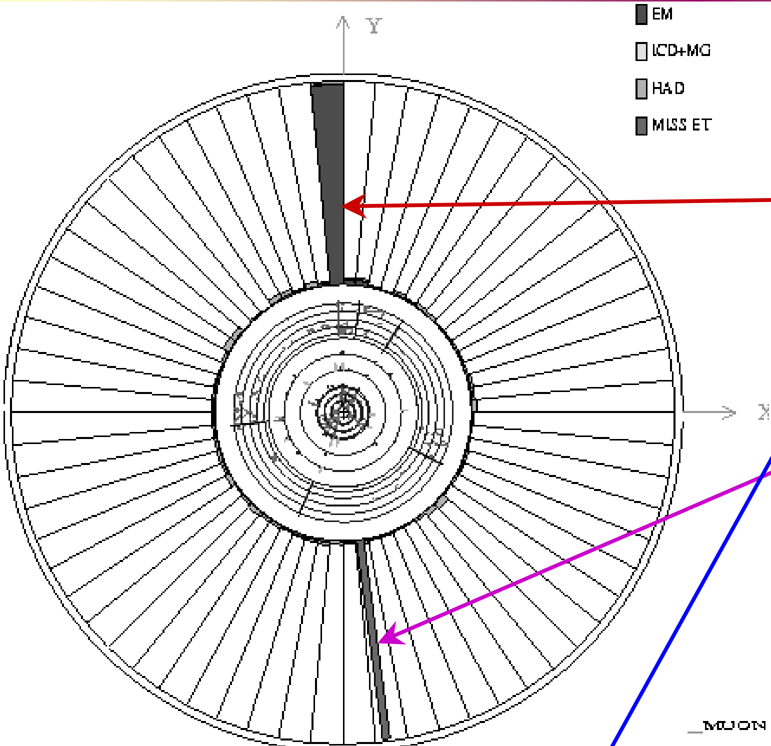
$|\eta| < 3.3$

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

CALORIMETRY

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

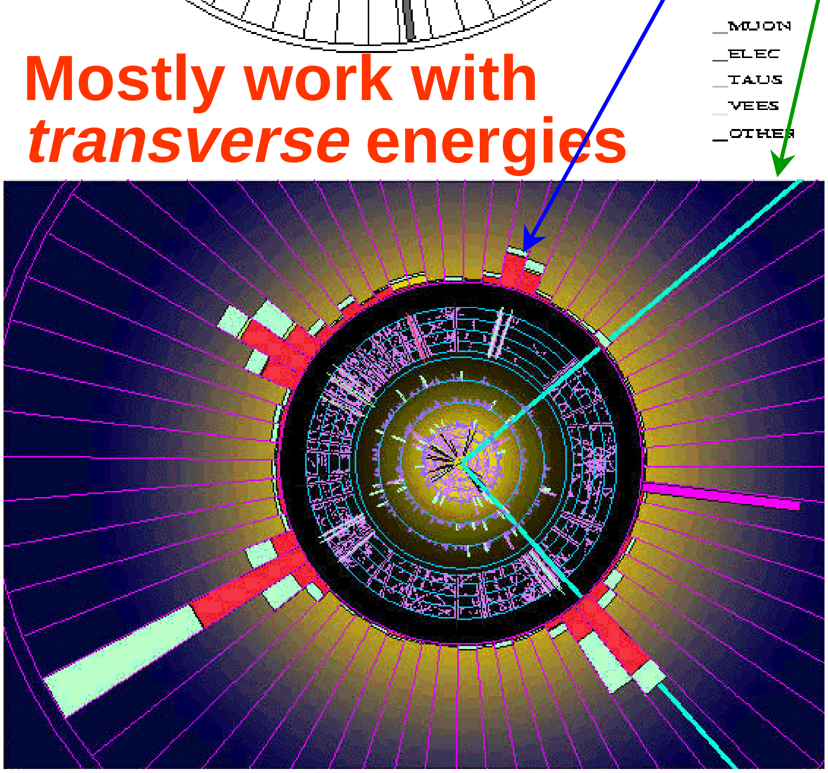
Particle Identification

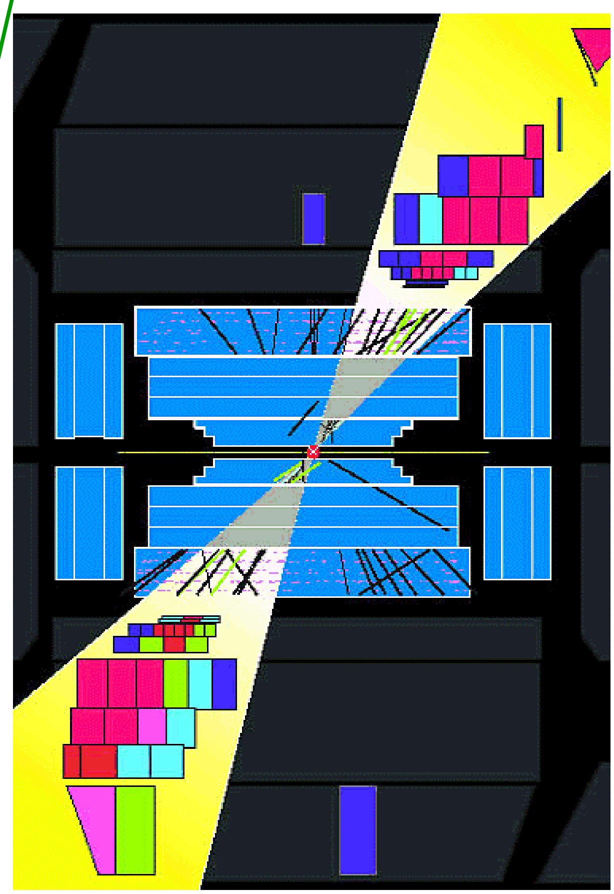


DØ is perfectly suited for identification of:

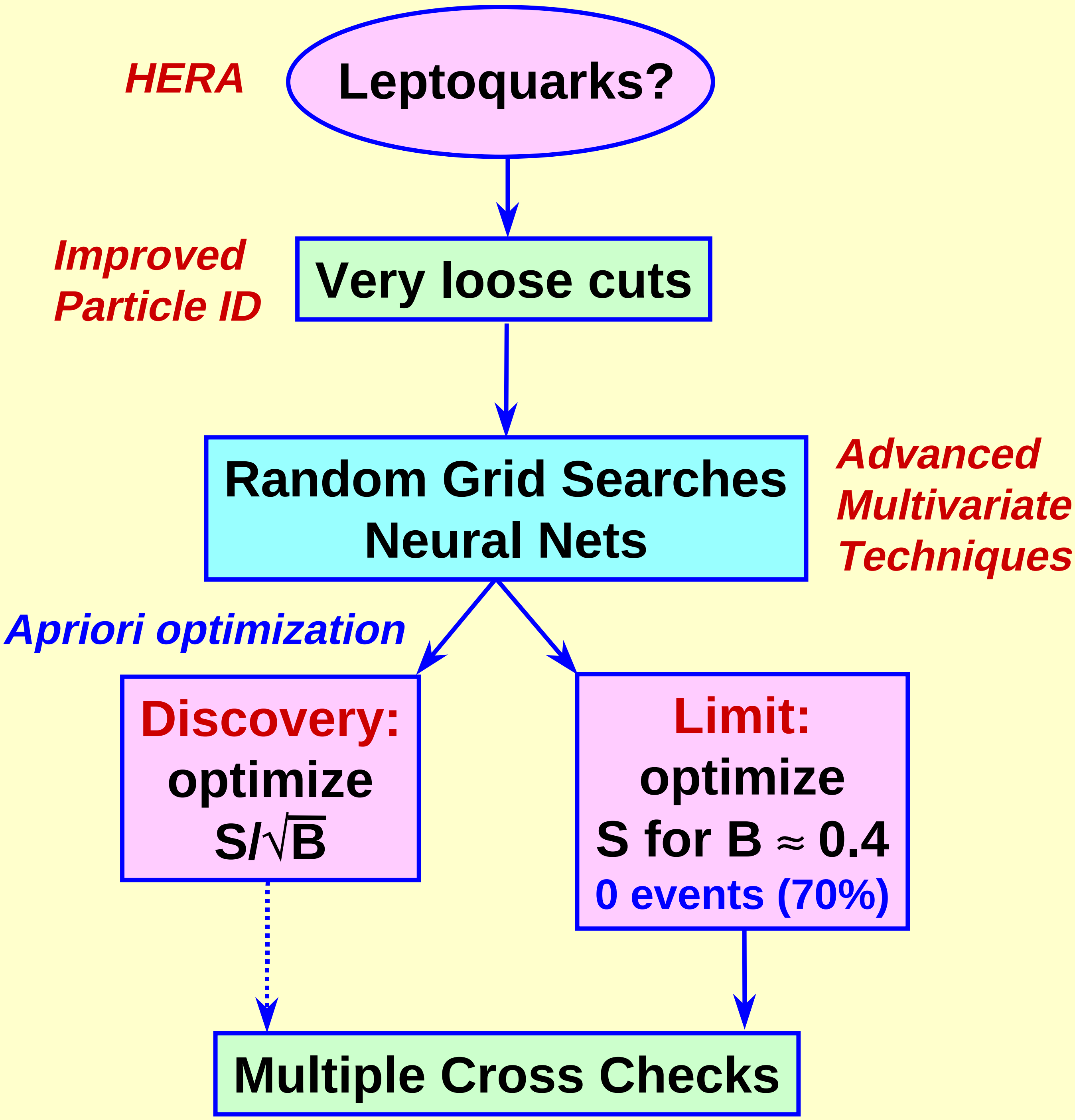
- *Electrons/Photons*
- *Jets*
- *Muons*
- *Neutrinos (Missing Transverse Energy)*

Mostly work with *transverse* energies





Search for LQ at DØ: Optimization Strategy

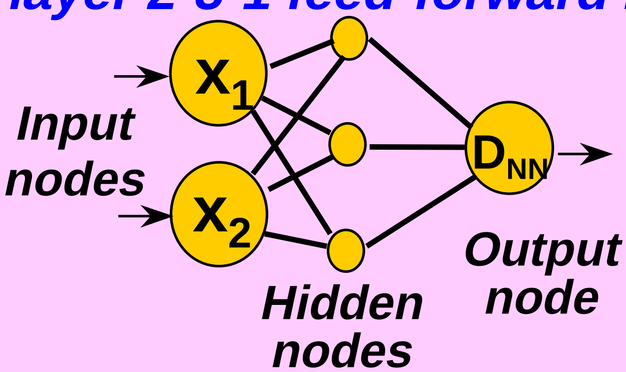


Random Grid and Neural Net Searches

Random Grid Search:

Use kinematic parameters of MC events for signal and MC or data events for backgrounds in order to find the optimal cuts

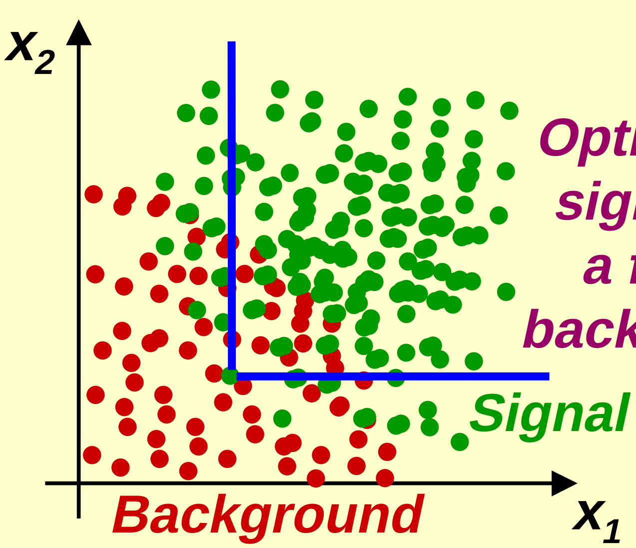
3 layer 2-3-1 feed-forward NN



Neural Net Search:

Train the net on a mixture of signal and background, so that $D_{NN} \approx 1$ for signal and $D_{NN} \approx 0$ for background

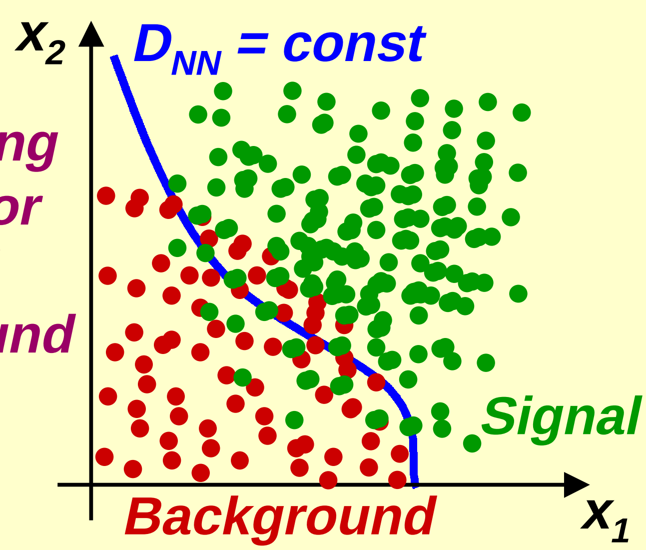
Random Grid Search



Simpler cut, lower S/B

Optimizing signal for a fixed background

Neural Net Search



Sophisticated cut, best possible S/B

Data Selection in ee+jets Channel

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

  EM trigger; >99% efficient for offline cuts

- 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

  N.B. twice the QCD background rejection compared to standard ID

- Require exactly 2 electrons; at least 1 "tight"

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

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

Data Selection in ee+jets Channel, cont'd

- **General:**

  M_{ee} far from the Z-peak

  (not in the 82-100 GeV window)

  Electrons well separated from jets

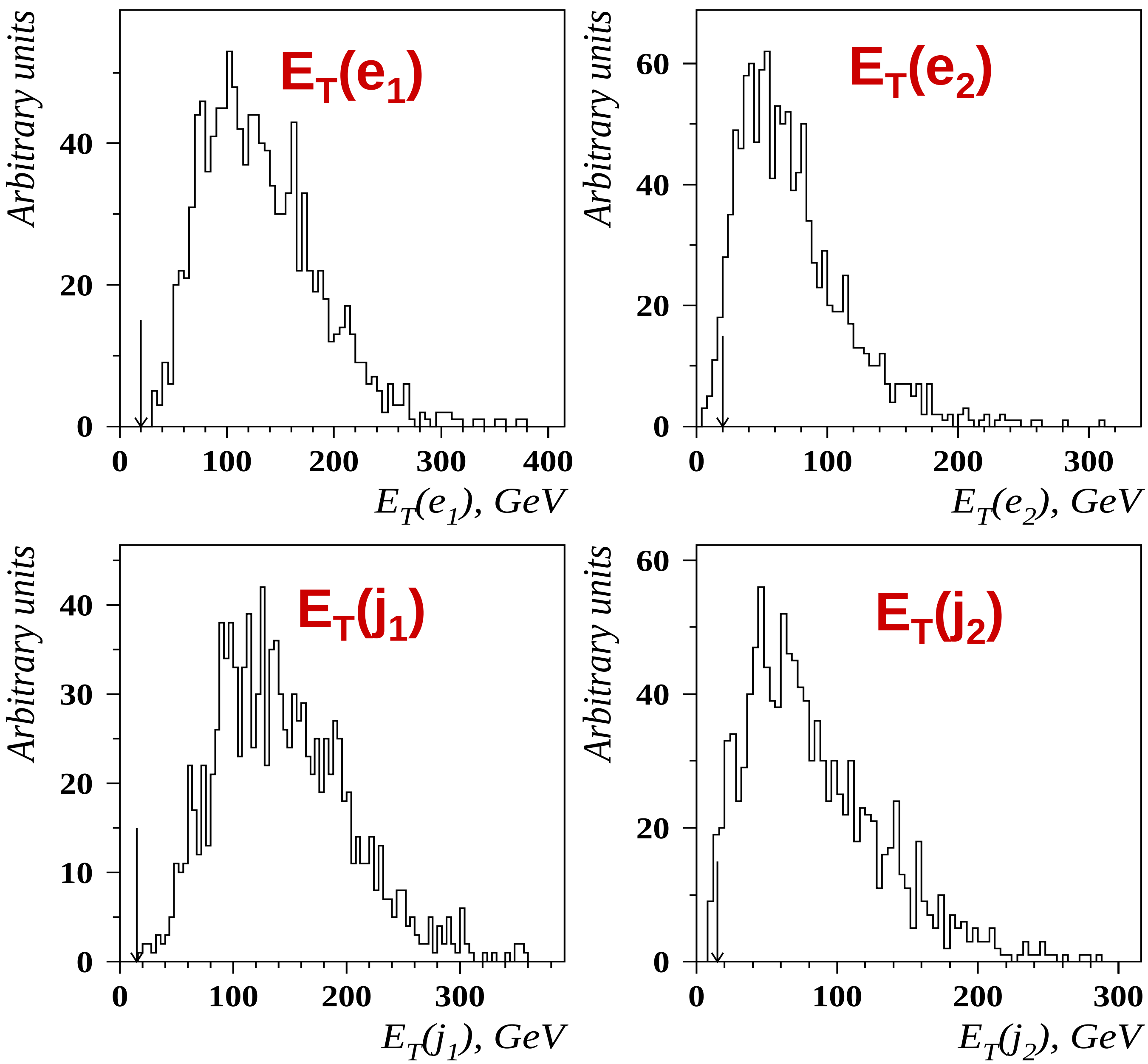
  ($\Delta R^{ej} > 0.7$)

- **Base sample: 101 events**

Cut	Events
Preselection	9,451
Two EM objects	4,967
EM in CC/EC, $E_T > 20$ GeV	3,880
2 or more jets, $E_T > 15$ GeV	2,918
$\Delta R^{ej} > 0.7$	2,496
$M_{ee} > 100$ GeV or $M_{ee} < 82$ GeV	1,802
At least one "tight" electron	225
"Loose" ID	101

Kinematic Properties of LQ decay

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



Random Grid Searches

- *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

  $S_T^{12} = \Sigma E_T^e + E_T^{j1} + E_T^{j2}$ - scalar E_T^{12}

  $S = \Sigma E^e + \Sigma E^j$

  $H_T^e = \Sigma E_T^e$, H_T^j, H_T^{j12}, H_T^{j123}

- **Event shape variables:**

  Centrality = S_T/S, Aplanarity

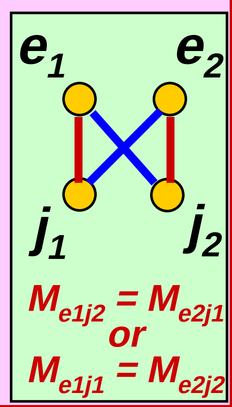
  Sphericity, Jet Clustering (η_{RMS})

- **Invariant mass variables:**

  M_{ee}, pair ej-masses ($M^{e_a j_b}$)

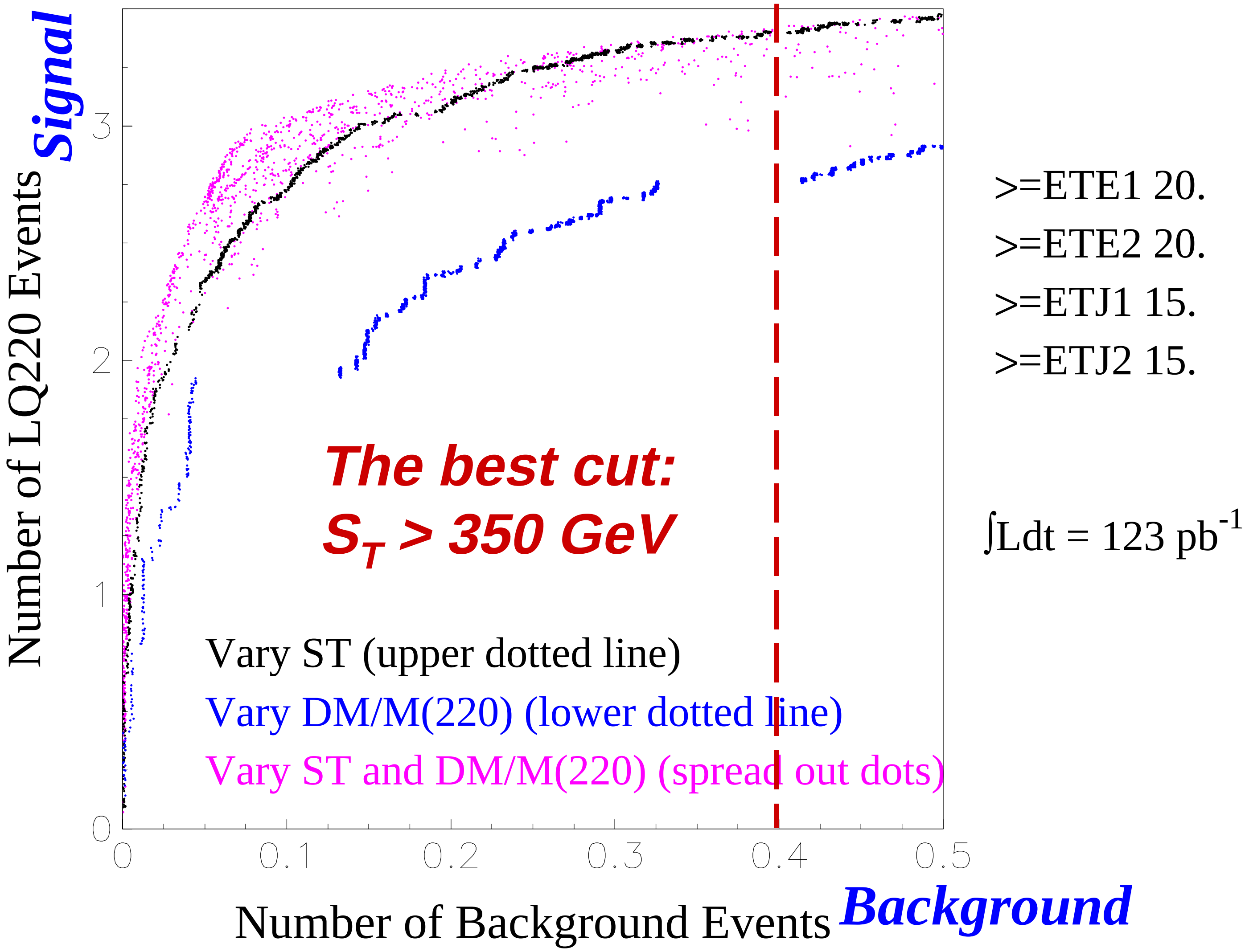
- **Mass difference variables:**

  $\delta M_{min}/M_{LQ}$, $\delta M_{min}/\langle M\rangle$, $\delta M_{min}/\sqrt{\langle M\rangle}$



Optimal Cuts

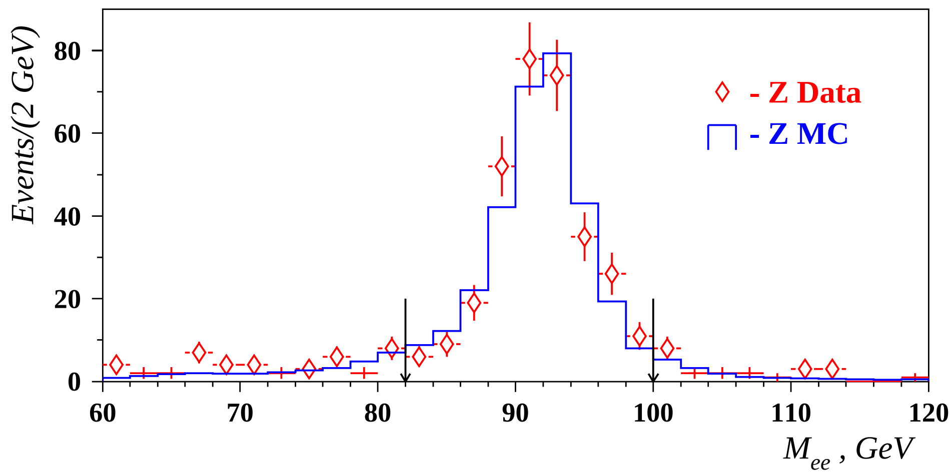
About 50 different combinations of variables were tried. The S_T was shown to be the single most effective variable for backgrounds of about 0.4 events

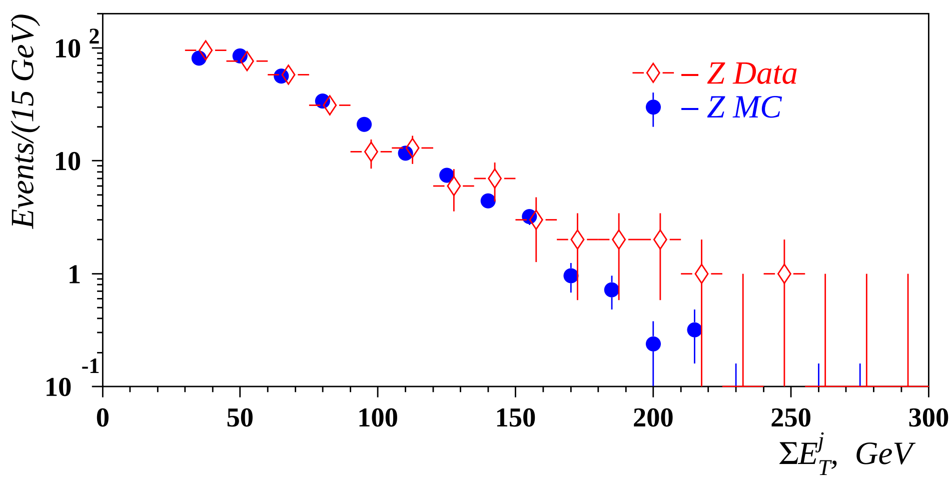


The S_T cut is about 20% more efficient for the signal compared to the $\delta M_{min}/M_{LQ}$ cut

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

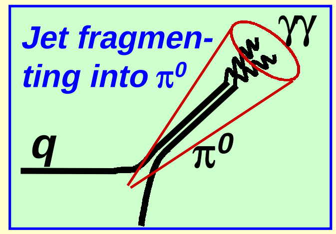
0.18 ± 0.04 events for S_T > 350 GeV

(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 signal cuts to the $t\bar{t} \rightarrow \ell\ell' +$ jets 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

$$B(t\bar{t} \rightarrow \ell\ell' + jets) = 0.0685$$

- 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 uncertainty in the cross section)

Data vs. Background

Main backgrounds:

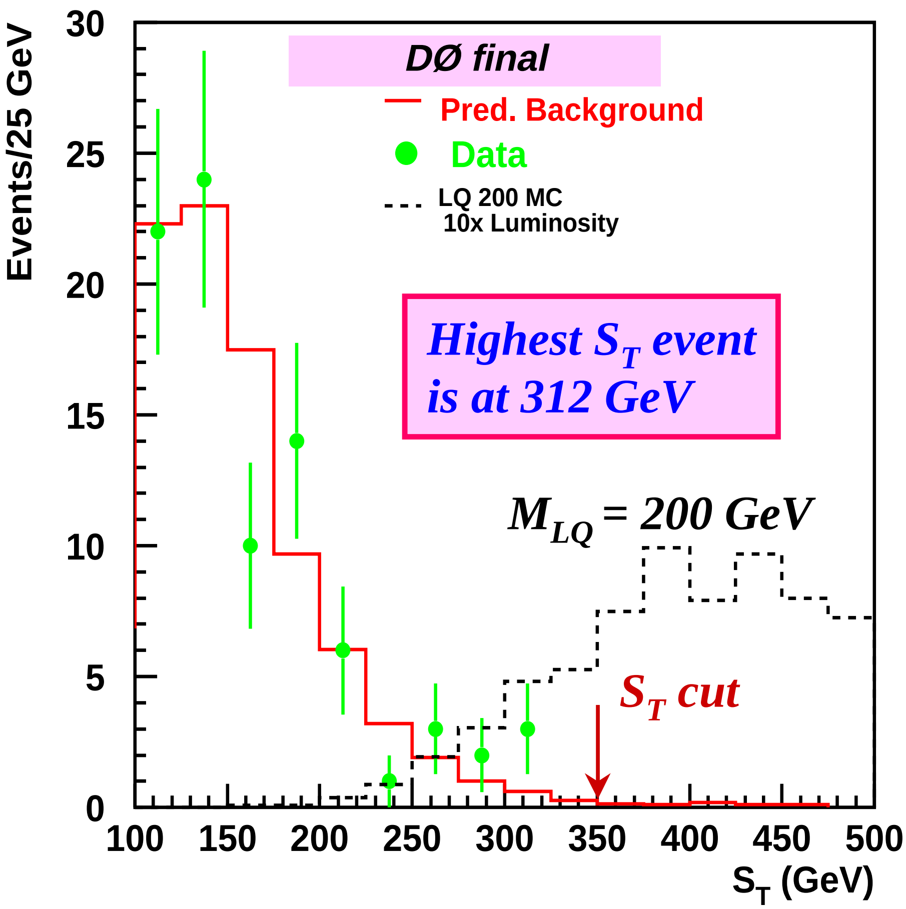
Drell-Yan + jets

QCD Multijet fakes

Top production *(used to be a signal 3 years ago)*

$S_T = 0$ GeV:
D-Y: 67 ± 13
QCD: 24 ± 4
Top: 1.8 ± 0.7

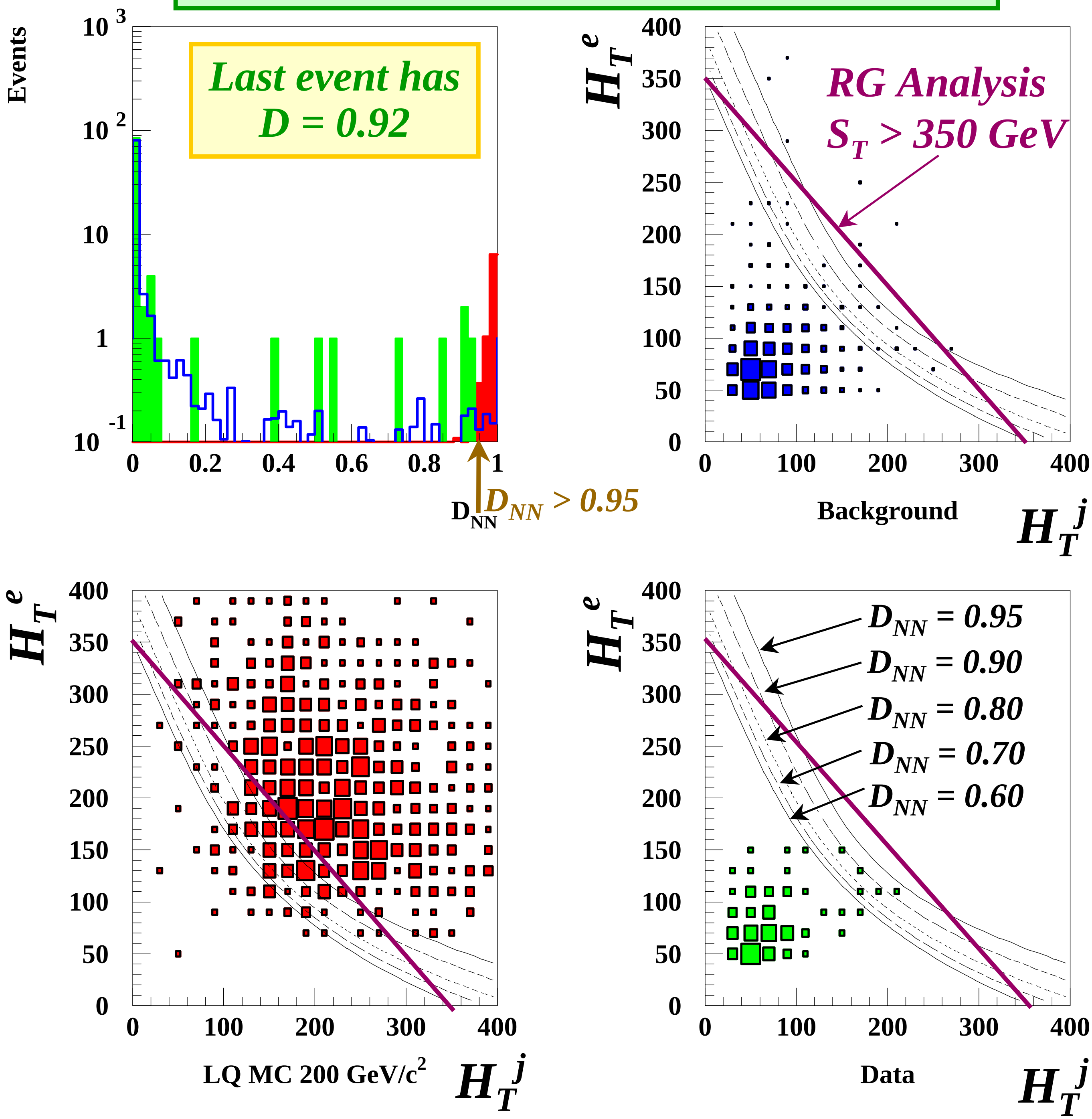
$S_T = 350$ GeV:
D-Y: 0.18 ± 0.06
QCD: 0.16 ± 0.02
Top: 0.11 ± 0.04



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

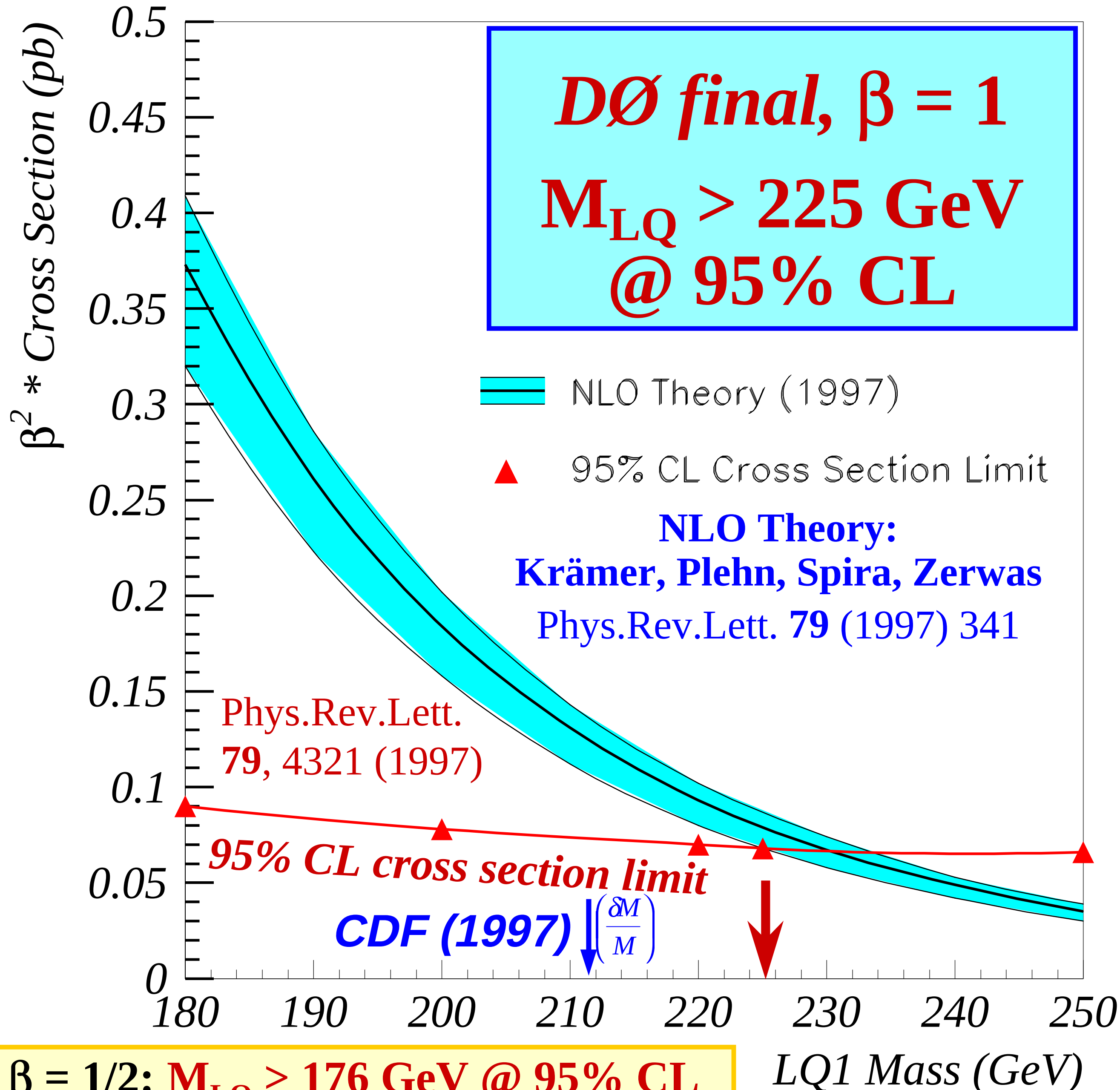
Neural Network Analysis

Results of the NN-based optimization



Limits on the First Generation LQ

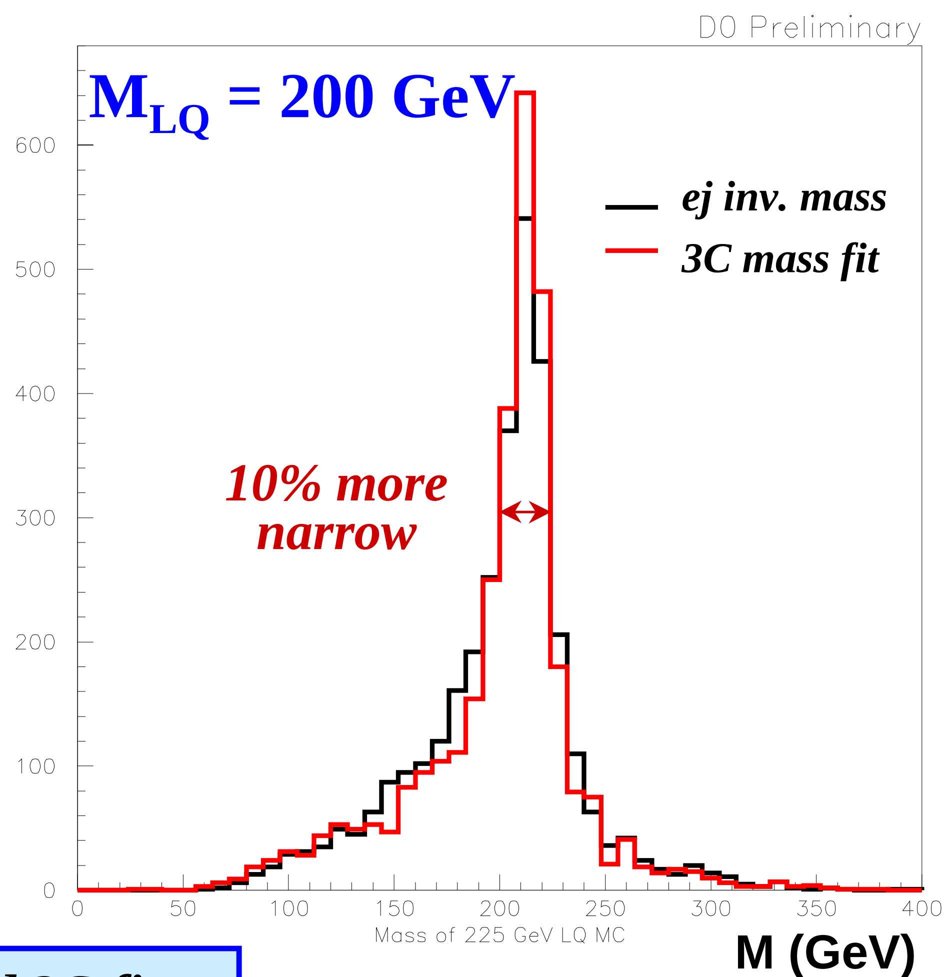
- *No background subtraction (limits are independent of the background and its uncertainty)*
- *Account for systematic uncertainty on the signal*



$\beta = 1/2$: $M_{LQ} > 176$ GeV @ 95% CL

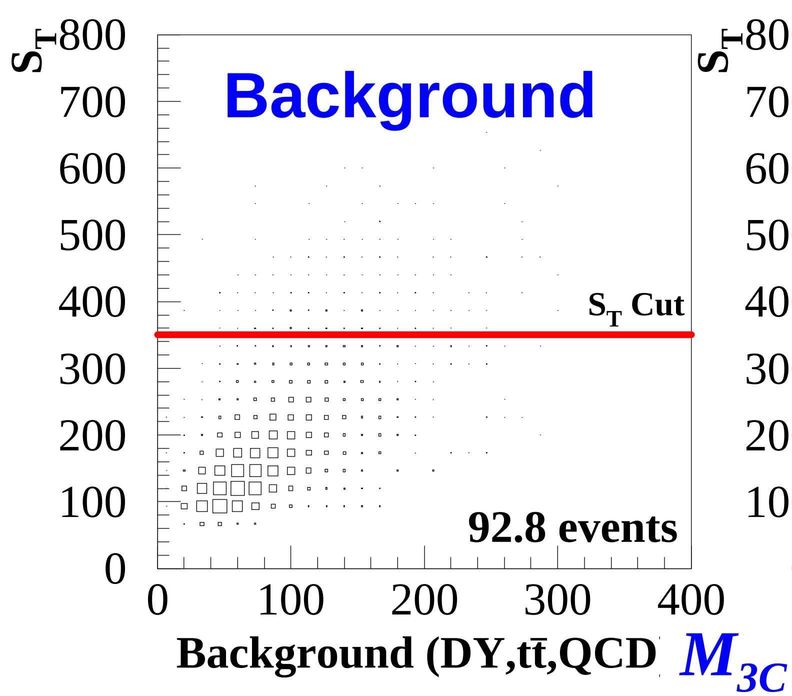
Mass Fit

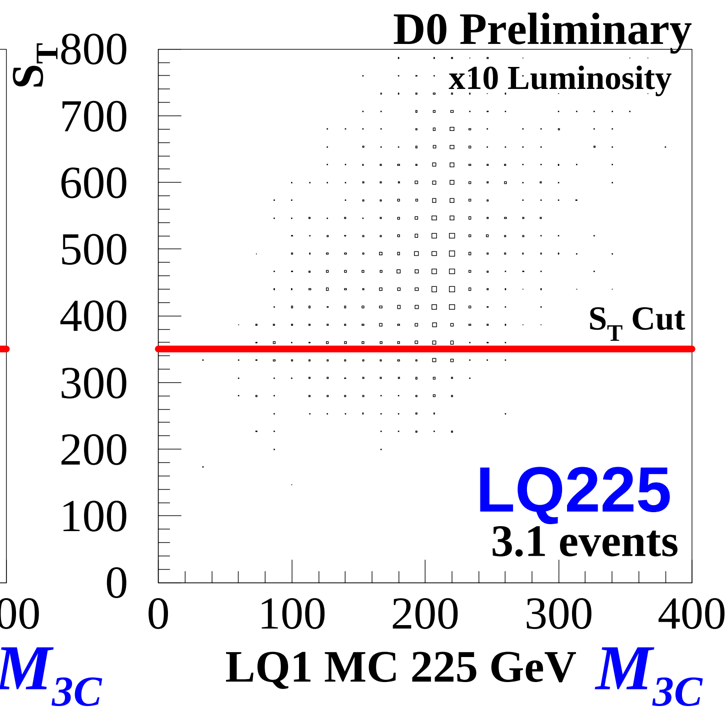
- *Full-fledged kinematic fitter KFIT (based on SQUAW by O.Dahl) balancing all objects in the event (e, j, unclustered energy)*
- *3C-fitter: fits to the LQ-pair hypothesis with equal mass constraint. Lowest χ^2 solution is kept. Resolution is 10% better than that for pure kinematical calculations.*

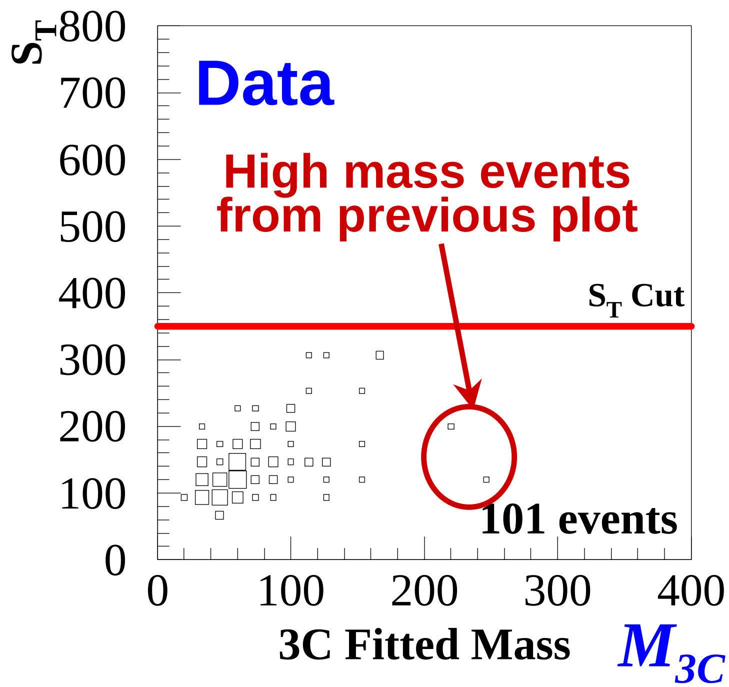


Also tried 2C-fitter

S_T versus 3C-fit Mass







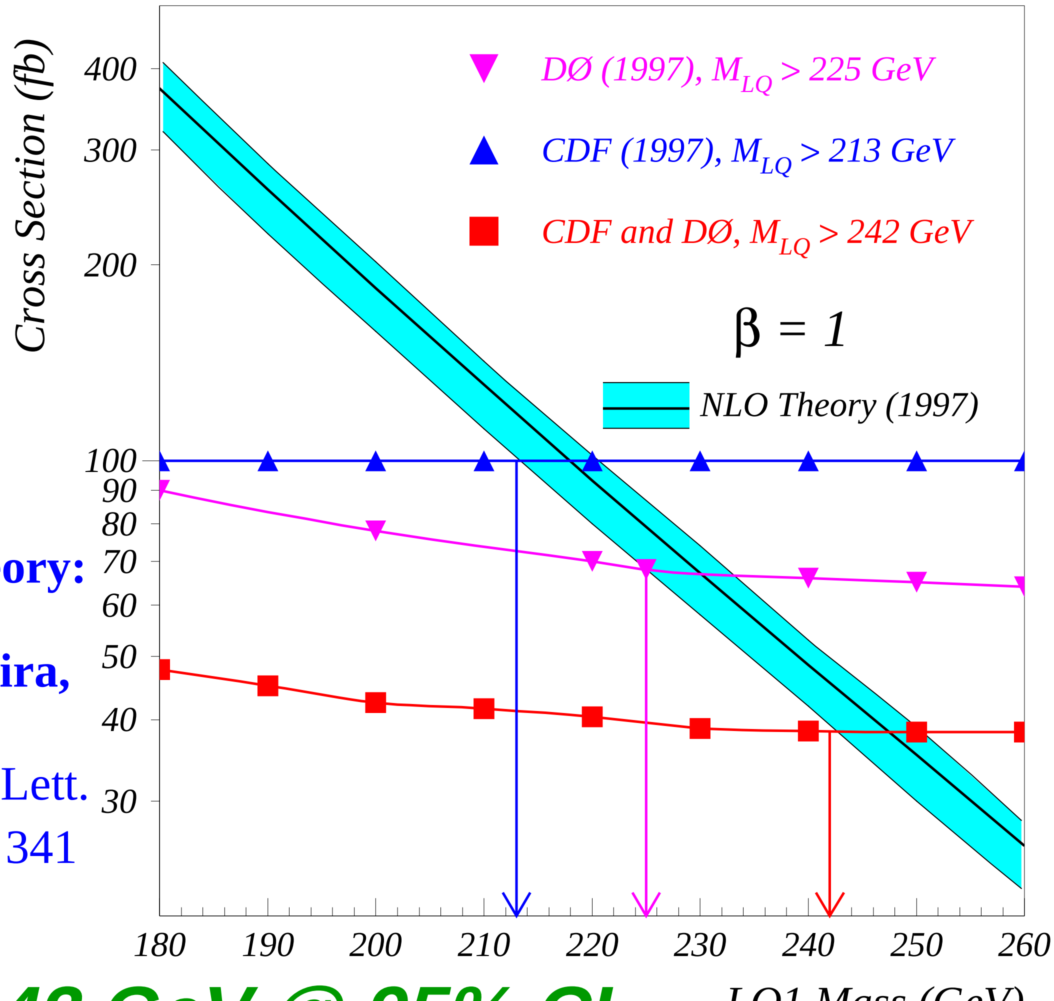
Two events with high mass seen in the 1-dimensional plot are nothing like the LQ signal

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

Combination of the CDF and DØ Results

CDF has performed an analogous analysis based on the δM/M variable and set lower limit on first generation leptoquark mass of ***213 GeV*** *for β = 1 [PRL* ***79*** *(1997) 4327].*

We combined the two null results taking into account correlated systematic errors.

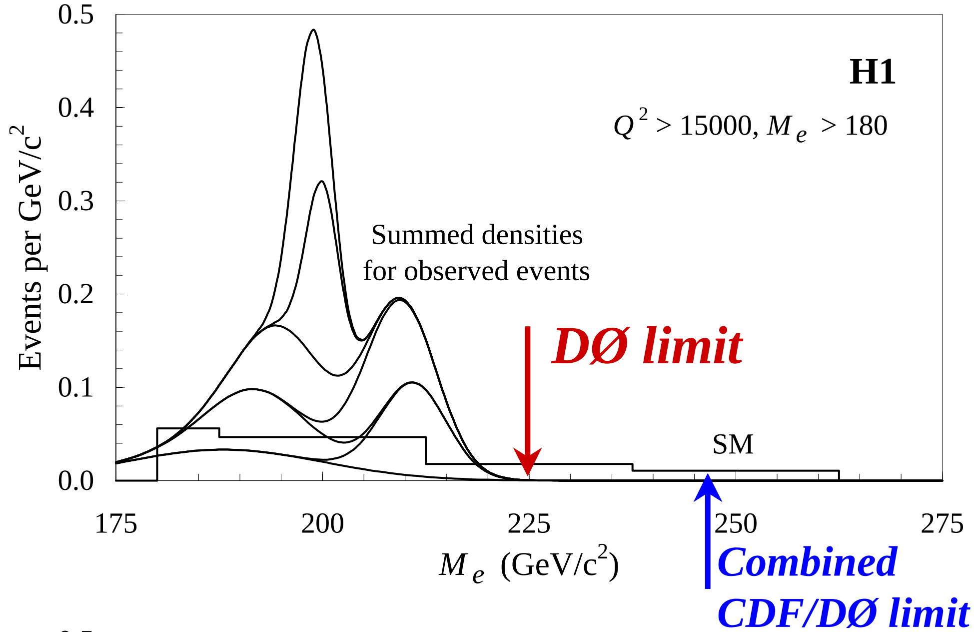


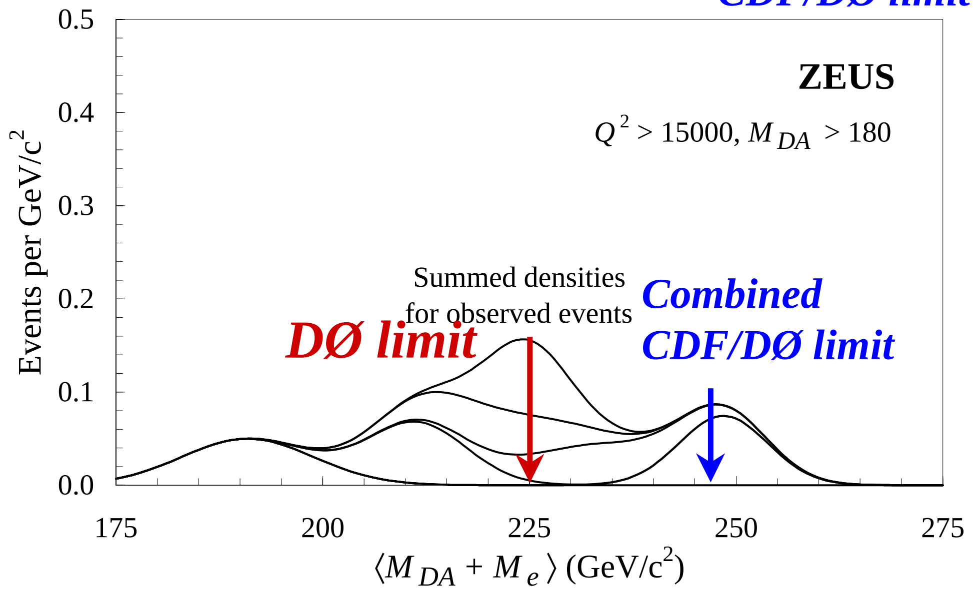
NLO Theory: Krämer, Plehn, Spira, Zerwas
Phys.Rev.Lett. **79** (1997) 341

M > 242 GeV @ 95% CL

Tevatron 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





Data Selection in $e\nu$+jets Channel

- **Entire Run I statistics (115 pb^{-1})**

  EM [+$\not{E}_T$ [+ jets]] triggers; >99% efficient for offline cuts

- **Electron:**

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

  - Significant EM fraction
  - Matching track
  - Combined tracking-TRD-calorimeter info (electron likelihood) consistent with electron

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

  $E_T^j > 20$ GeV; $|\eta^j| < 2.5$

- **Missing Transverse Energy:**

  $\not{E}_T > 30$ GeV; $\min(\Delta\phi(j,\not{E}_T)) > 0.25$ for $\not{E}_T < 120$ GeV

- **General:**

  Muon veto (reduces top background)

  $M_T(e\nu) > 110$ GeV (suppress W+jets background)

Data Selection in $e\nu$+jets Channel, cont'd

- *Base sample: 14 events*

Cut	*Events*
Preselection	*95,383*
One EM object	*22,649*
EM in CC/EC, E_T > 20 GeV	*18,683*
2 or more jets, E_T > 20 GeV	*8,925*
Electron ID	*3,091*
Muon veto	*2,963*
$\not{E}_T$-cuts	*1,094*
$M_T(e\nu)$ > 110 GeV	*14*

Total Background:
17.8 ± 2.1 events (see below)

QCD Background

- ***Use jet faking electron probability from the ee+jets analysis :***

  $P(j \to \text{electron}) = (3.5 \pm 0.4) \times 10^{-4}$

  (error covers slight η and E_T^e variations)

- ***Calculate the QCD background***
  - *Select single interaction events to ensure correct vertex (important for $\not{E}_T$)*
  - *Start with 3j+$\not{E}_T$ sample with all other cuts applied and multiply the number of combinations passing jet and electron fiducial cuts by electron faking probability*
  - *Correct for single interaction requirement inefficiency (50% ± 5%)*

QCD Background:

75 ± 15 events before $M_T(e\nu)$ cut

4.1 ± 0.9 events in the base sample

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

Top Background

- Apply all signal cuts to the $t\bar{t} \to \ell + jets$ MC (includes dilepton contribution)
- Correct for muon veto (suppression factor of 1.9 ± 0.1)
- Count the number of events which pass
- Calculate background using the top production cross section measured by DØ:

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

and theoretical branching ratio

$$B(t\bar{t} \to \ell + jets) = 0.456$$

Top Background:

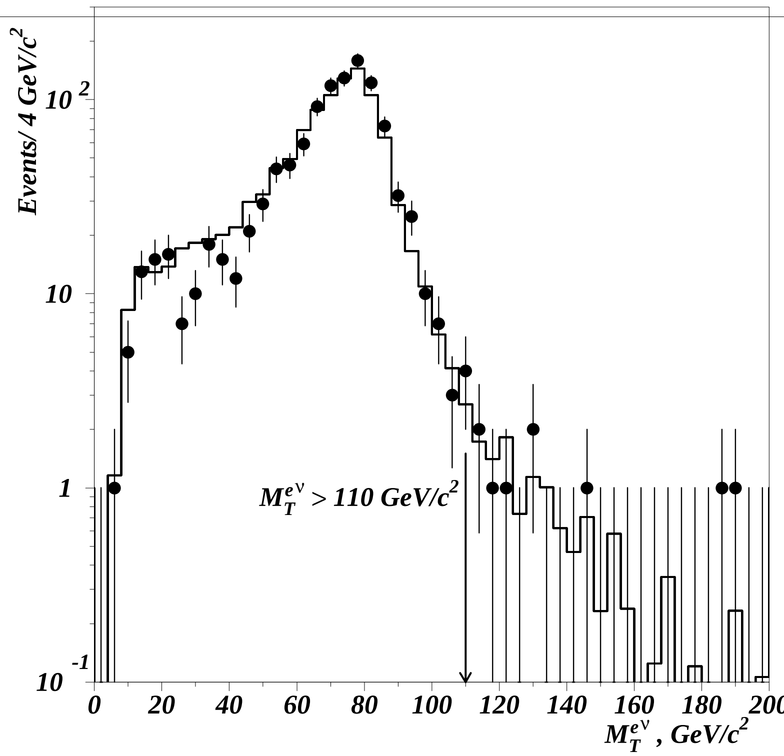
12 ± 4 events before $M_T(e\nu)$ cut

2.0 ± 0.7 events in the base sample

(error dominated by uncertainty in the cross section)

W+jets Background

- ***Normalize the W+jets MC sample with all cuts except for $M_T(e\nu)$ applied and the estimated QCD and $t\bar{t}$ backgrounds added to the data for $M_T(e\nu) < 110$ GeV***



W+jets Background:

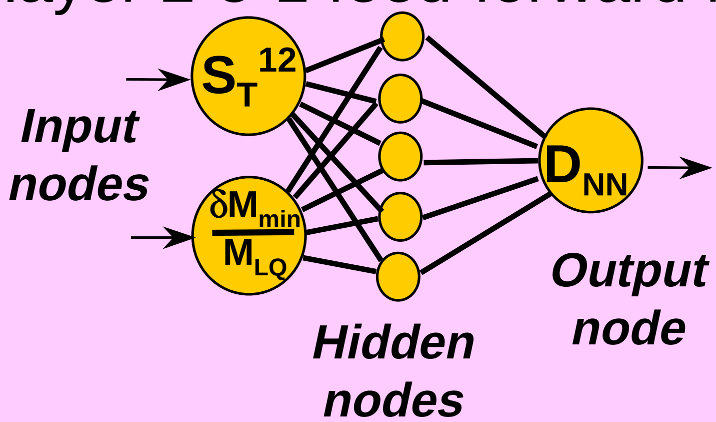
1010 ± 70 events before $M_T(e\nu)$ cut

11.7 ± 1.8 events in the base sample

(error dominated by the uncertainties in jet energy scale and MC statistics)

Neural Network Analysis in eνjj Channel

3 layer 2-5-1 feed-forward NN



M_{LQ} =
140 GeV
160 GeV
180 GeV
200 GeV
220 GeV

$S_T^{12} = E_T^e + \not{E}_T + E_T^{j1} + E_T^{j2}$

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

Reduced gluon radiation systematics (for $E_T^{j1} + E_T^{j2}$)

Essential against the $t\bar{t}$ background

Training:

Signal: LQ(M_{LQ}) MC

Mixture of QCD, W+jets and Top backgrounds

Output:

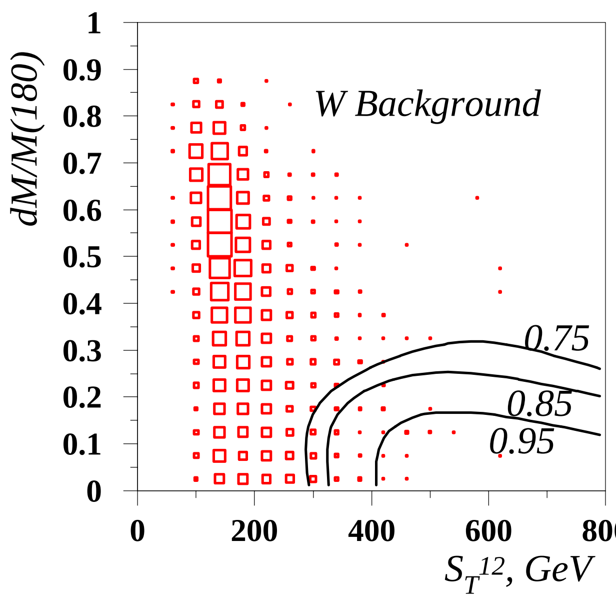
NN discriminant $0 < D_{NN} < 1$ maximized for the signal

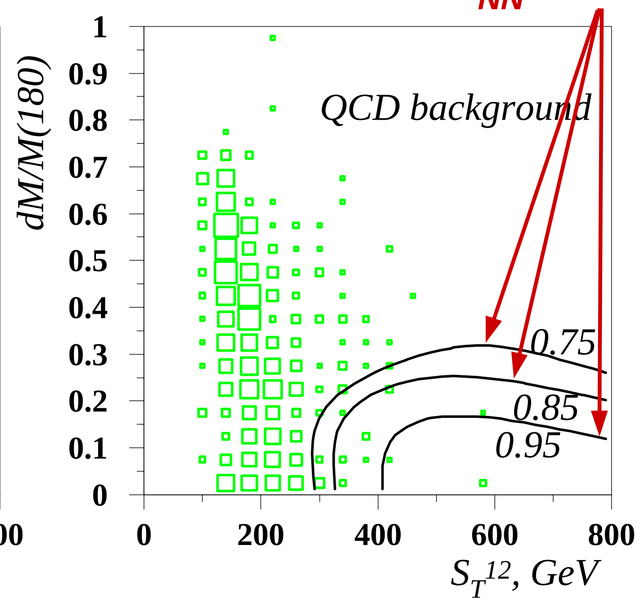
For $M_{LQ} < 120$ GeV where top background is not an issue used straight ee+jets-like $S_T^{12} > 400$ GeV cut:

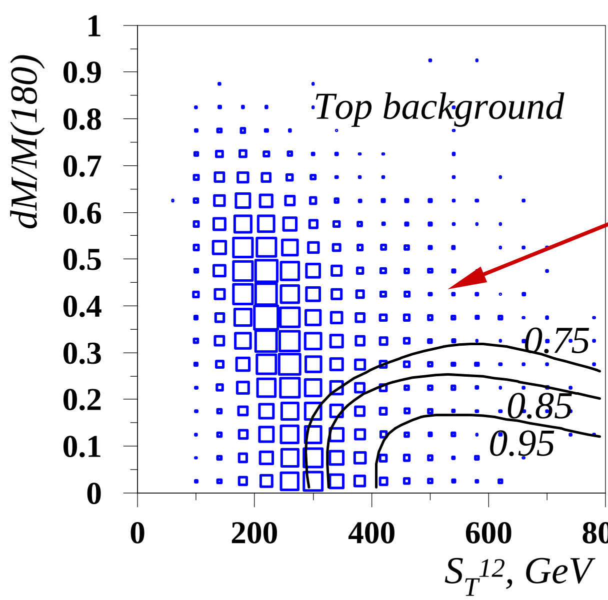
NN Optimization, M_{LQ} = 180 GeV

Constant D_{NN} contours for backgrounds, loose cuts

Constant D_{NN} contours



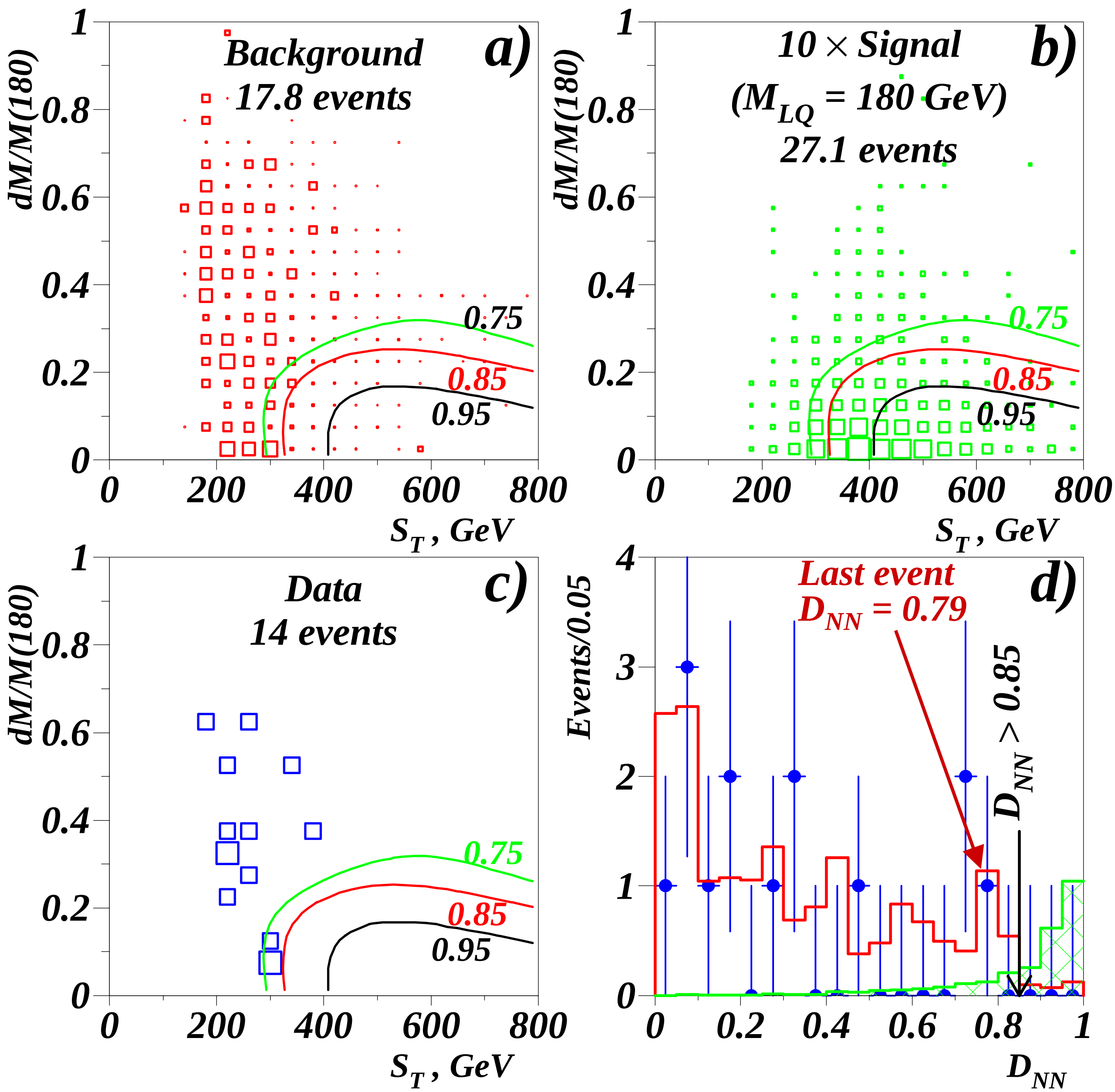




That's why we need $\delta M/M_{LQ}$ variable in the eν+jets channel

NN Results
M_{LQ} = 180 GeV

Background for D_{NN} > 0.85 cut is 0.29 ± 0.25 events



Data are consistent with the background hypothesis

Background and Efficiency

We vary the D_{NN}-cut (in 0.05 steps) and S_T^{12}-cut (in 50 GeV steps) and fix it to give the background value closest to the desired level of 0.4 events (with the background uncertainties taken into account). As a result, no events pass the chosen cut for any of the networks or S_T^{12} cut.

Background and efficiency

M_{LQ} (GeV)	Background prediction	Signal efficiency
80	0.60 ± 0.27	0.003 ± 0.001
100	0.60 ± 0.27	0.012 ± 0.002
120	0.60 ± 0.27	0.025 ± 0.003
140	0.54 ± 0.25	0.067 ± 0.010
160	0.61 ± 0.27	0.109 ± 0.012
180	0.29 ± 0.25	0.147 ± 0.012
200	0.43 ± 0.27	0.194 ± 0.017
220	0.41 ± 0.27	0.215 ± 0.017

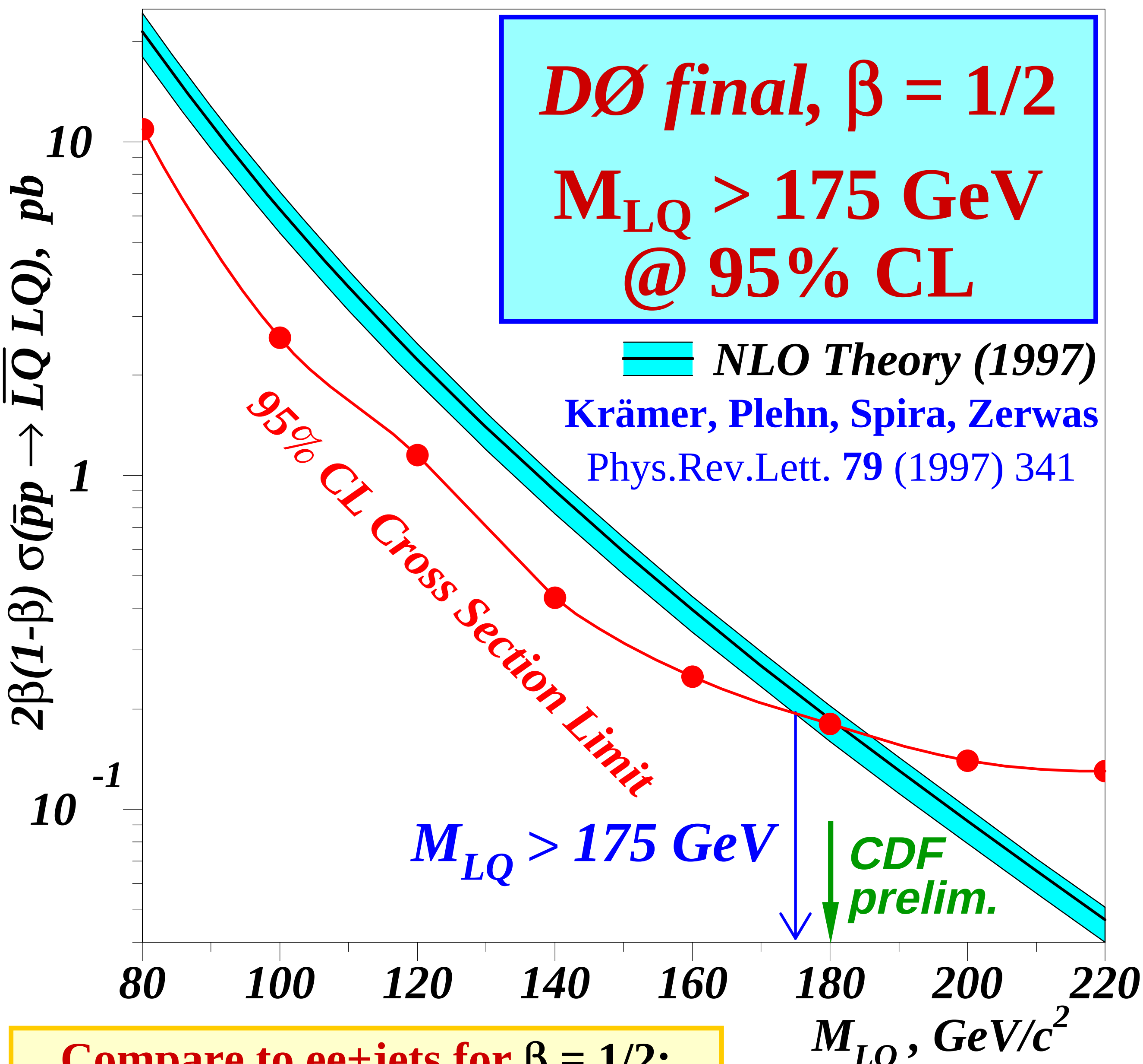
Signal Systematics

Source of error	Error
Particle ID	5%
Smearing in the Detector	3%
Jet Energy Scale	2% -10%
Gluon Radiation	4%
PDF and Q^2	5%
MC Statistics	3-25%
Luminosity	5%
Total	8%-25

Data are consistent with the background hypothesis; no evidences for leptoquarks are found

Mass Limits in eν+jets Channel

[PRL **80** (1998) 2051]



Compare to ee+jets for β = 1/2:
M_{LQ} > 176 GeV @ 95% CL

Data Selection in $\not\!\!E_T$+jets Channel

- *Use our published analysis [PRL **76**, 2222 (1996)]: search for stop pair production in*

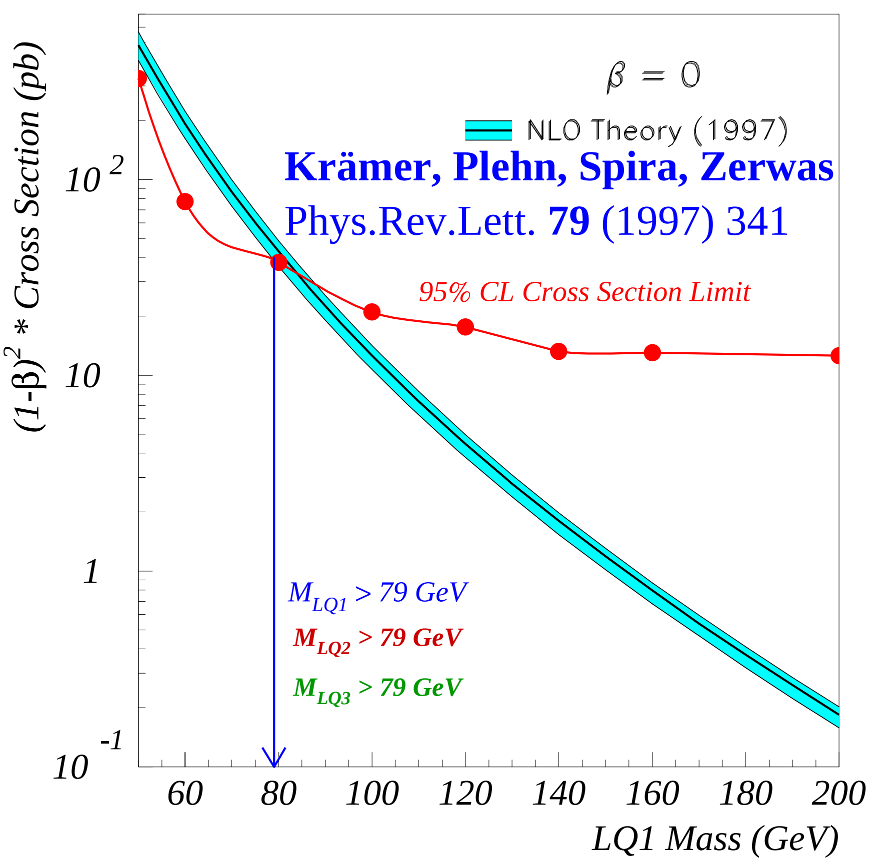
$$p\bar{p} \to \tilde{t}_1\bar{\tilde{t}}_1 + X \to c\chi_1^0 c\chi_1^0 + X \to \not\!\!E_T + jets$$

- *This analysis is not optimized for LQ searches; it also uses only a small fraction of available statistics; still it is useful to extend LQ mass limits to β=0*
- *Data set:*
  - **7.4 pb^{-1}, collected with $\not\!\!E_T$ trigger in the 1992-1994 run**
- *Selection Cuts:*
  - **$\not\!\!E_T > 40$ GeV, $E_T^j > 30$ GeV**
  - **$90^o < \Delta\phi(j_1,j_2) < 165^o$**
  - **$10^o < \Delta\phi(j_{1,2},\not\!\!E_T) < 125^o$; $10^o < \Delta\phi(j_{>2},\not\!\!E_T)$**
  - **electron/muon veto**
- *Observed 3 candidate events*

Results in $\not\!E_T$+jets channel

- **Backgrounds:**
  - W(eν,μν,τν)+jets ***(2.98 ± 1.14 events)***
  - Z(μμ,ττ) [+jets] ***(0.51 ± 0.27 events)***
  - ***Total: 3.49 ± 1.17 events vs. 3 candidates***
- **Signal efficiency:**

From: 0.45% ± 0.10% + 0.00% - 0.05% (M_{LQ}=50 GeV)
To: 6.36% ± 0.35% + 0.04% - 0.06% (M_{LQ}=200 GeV)



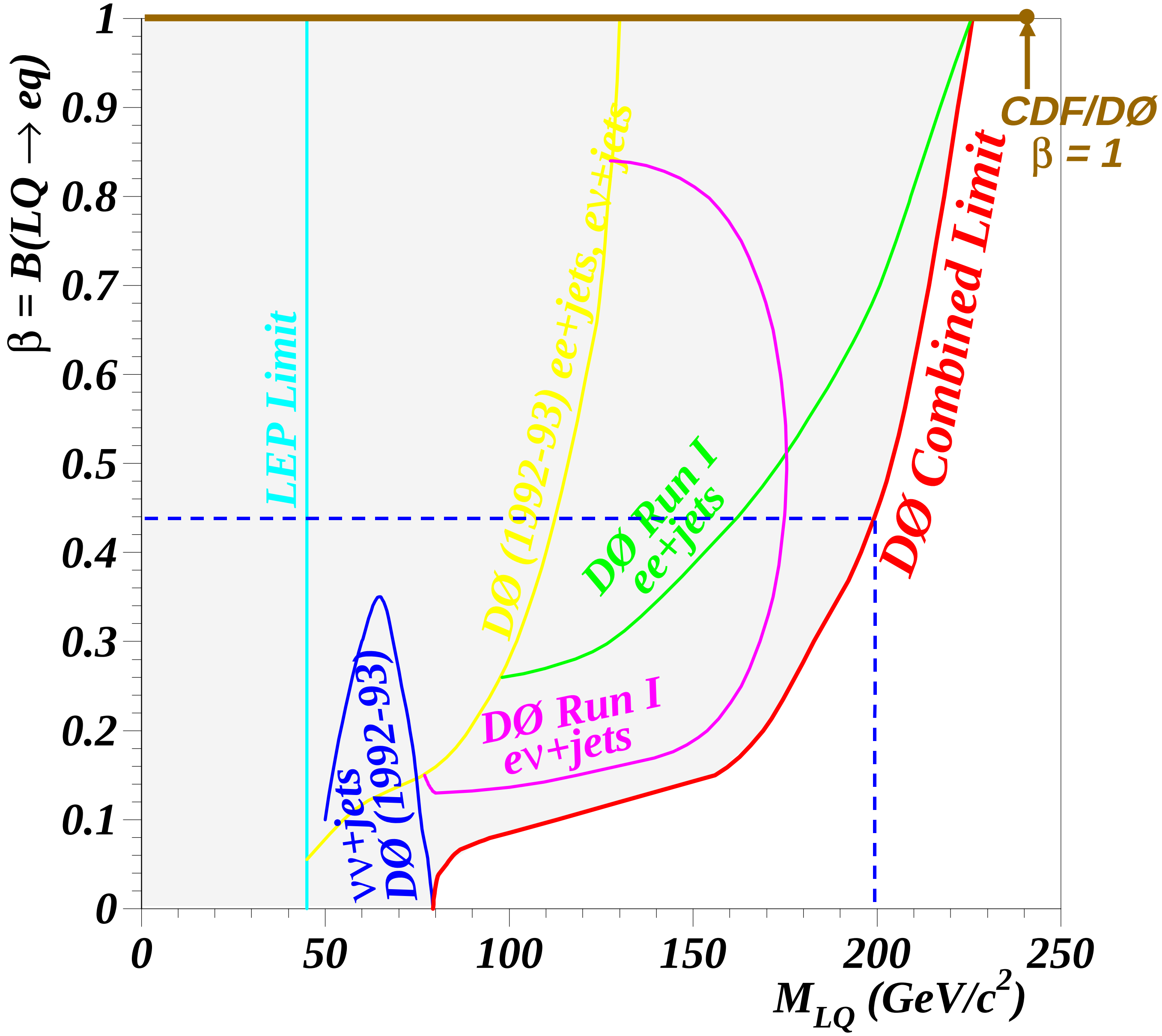
DØ final, β = 0
M_{LQ} > 79 GeV @ 95% CL

Unique measurement sensitive to β = 0; generation-independent

Combined Limits on First Generation LQ

First Generation Scalar Leptoquarks are excluded by DØ at 95% CL for β > 0.4. This closes HERA LQ saga.

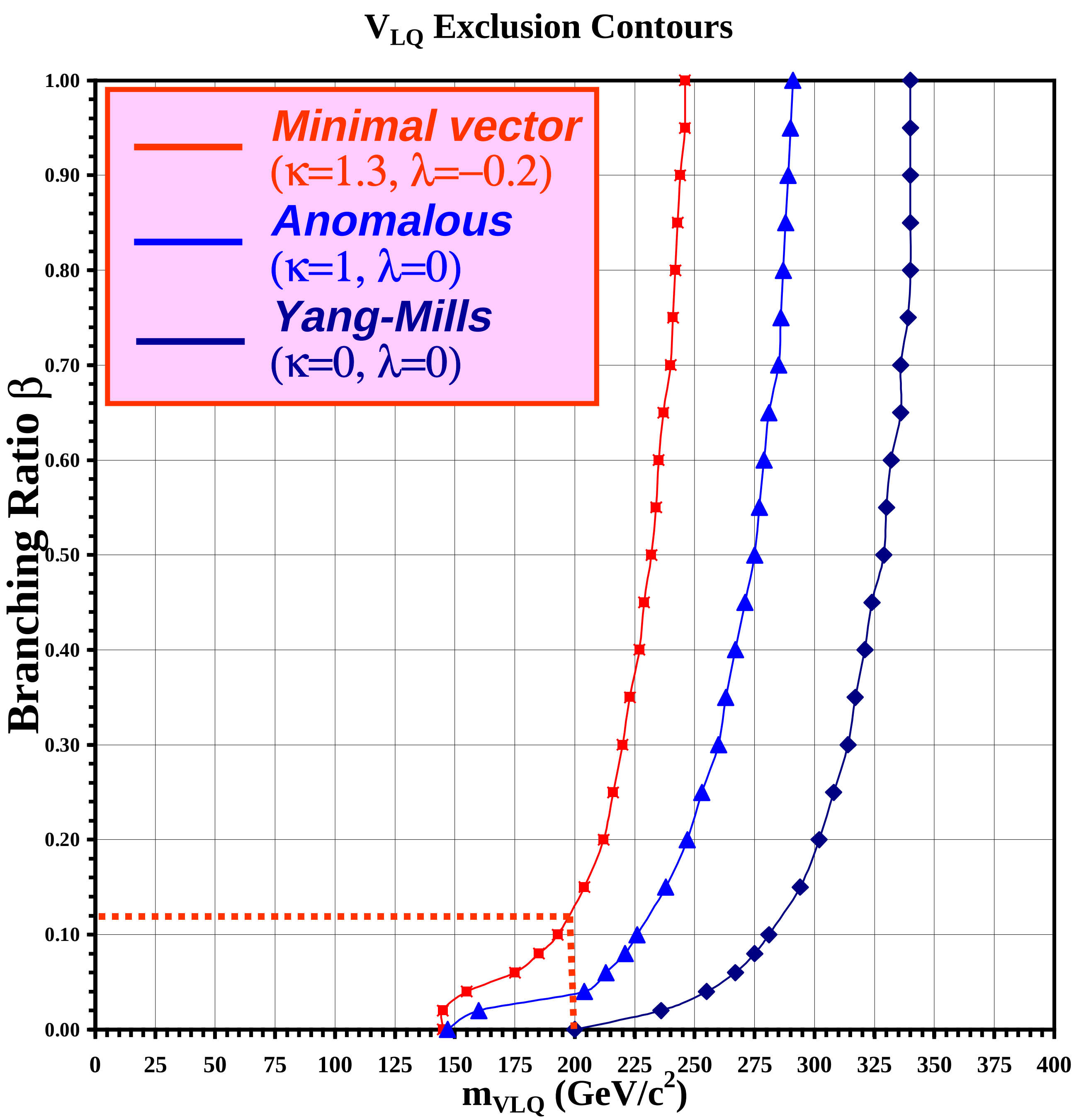
For β = 1.0, M_{SLQ} > 225 GeV



For β = 0.5, M_{SLQ} > 204 GeV

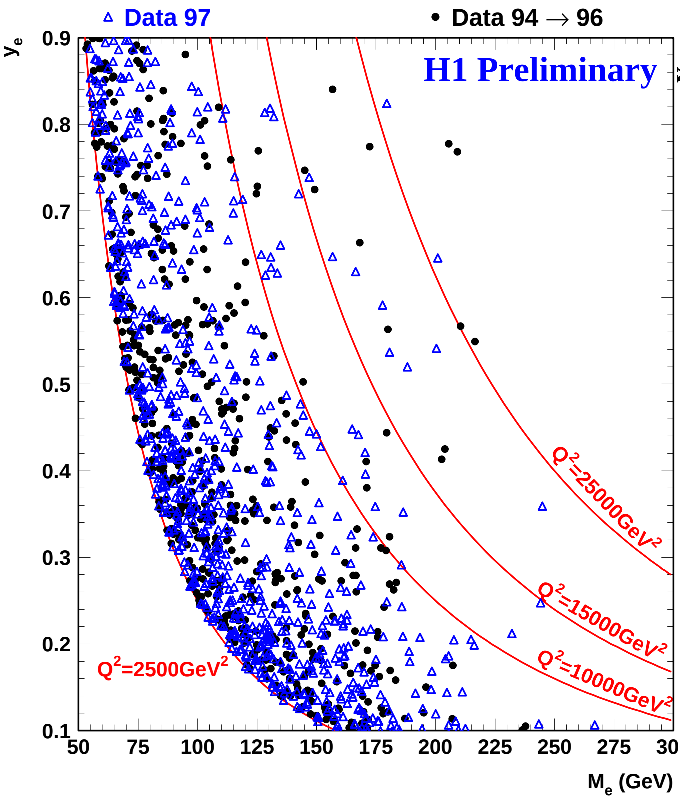
Combined Limits on Vector LQ

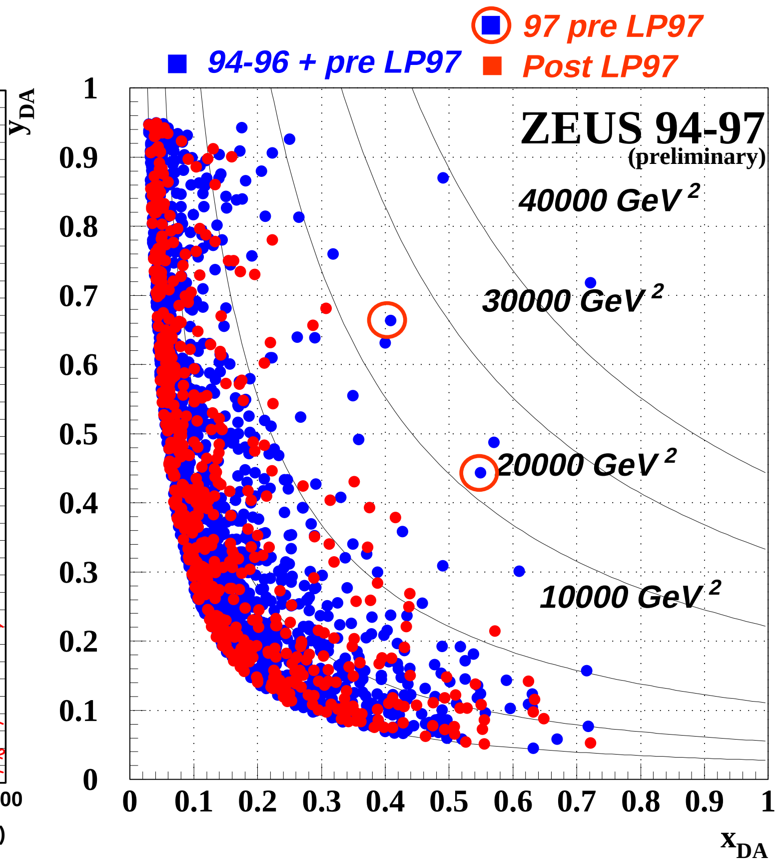
Vector LQ are excluded up to much higher masses



The Aftershock

- ***After analyzing 1997 data set the significance of HERA excess did not improve. In fact, 1997 data alone does not exhibit any significant excess of high Q^2 events***



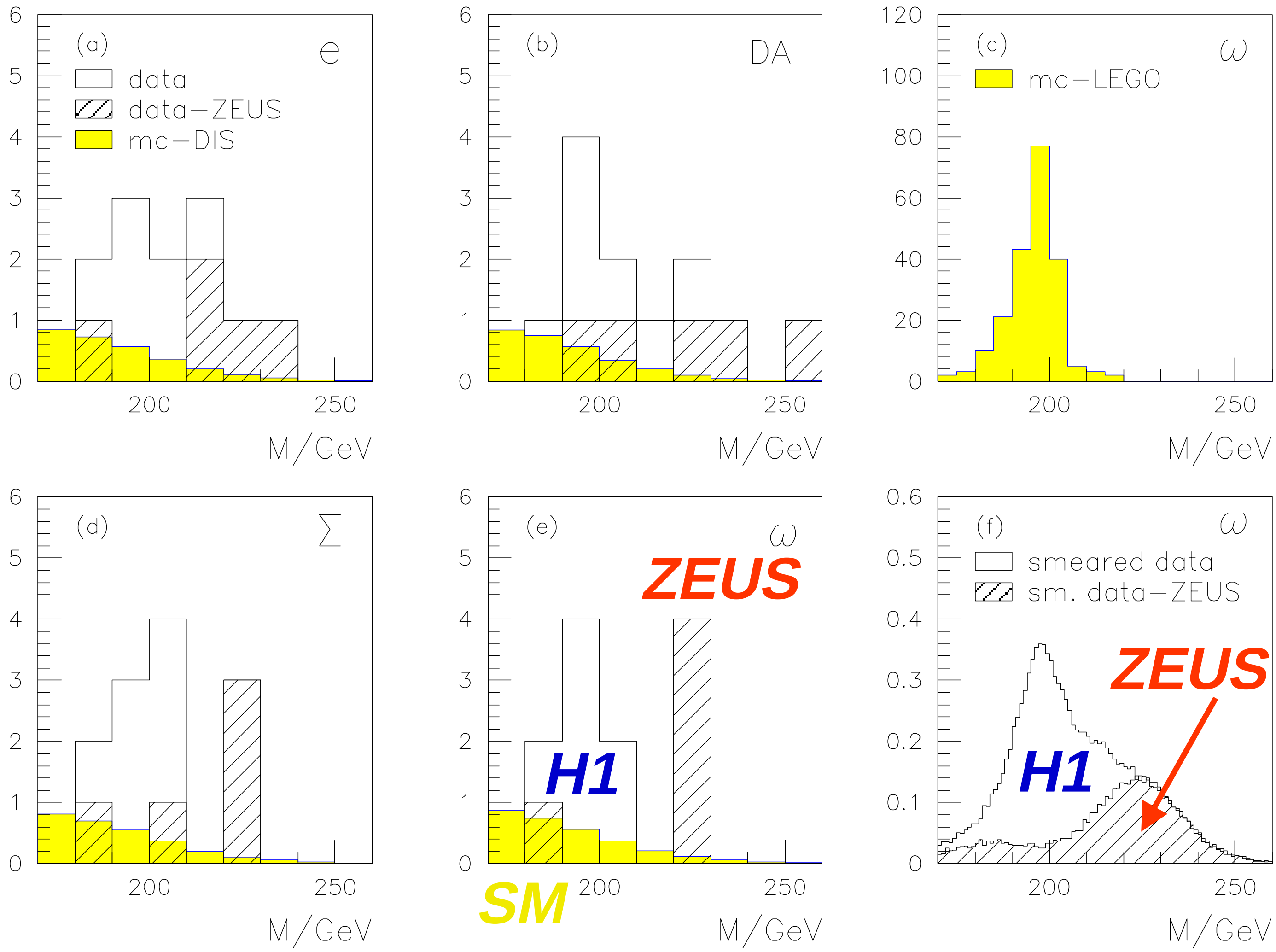


	H1, 1997			H1, 1994-1997			ZEUS, 1997		ZEUS, 1994-1997		
Q^2, GeV^2	N	SM bck.	P	N	SM bck.	P	N	SM bck	N	SM bck	P
10000	31	32.7 ± 3.8	59%	51	55.0 ± 6.4	60.0%	33	27.8 ± 2.0	66	60 ± 4	
15000	10	8.8 ± 1.3	38%	22	14.8 ± 2.1	5.9%	8	8.3 ± 0.7	20	17 ± 2	
20000	4	2.6 ± 0.4	27%	10	4.4 ± 0.7	1.8%	2		7		
25000	2	0.9 ± 0.2	24%	6	1.6 ± 0.3	0.6%	0		3		
35000							0	0.14 ± 0.01	2	0.29 ± 0.02	0.04

Aftershock, cont'd

- ***Moreover, a joint analysis of the H1/ZEUS data does not support an explanation of the HERA results with a single narrow resonance:***

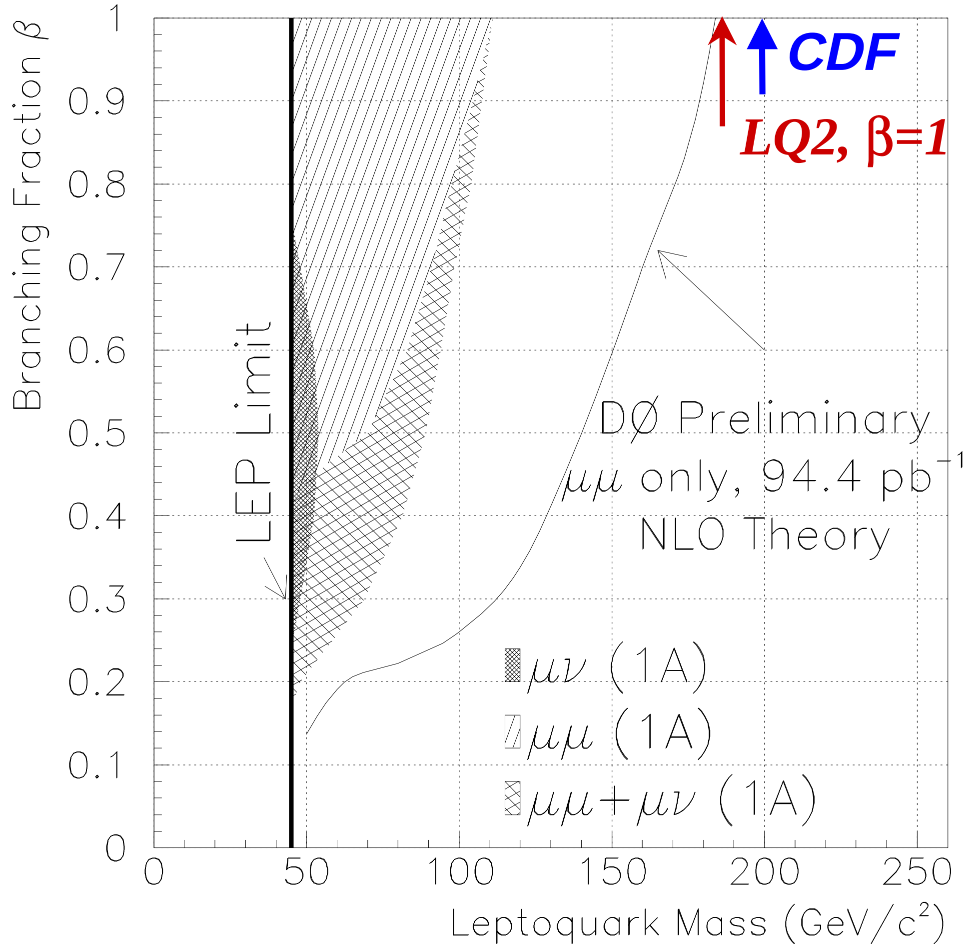
[U.Bassler, G.Bernardi, *Z.Phys.* ***C76****, 223 (1997)****]***



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



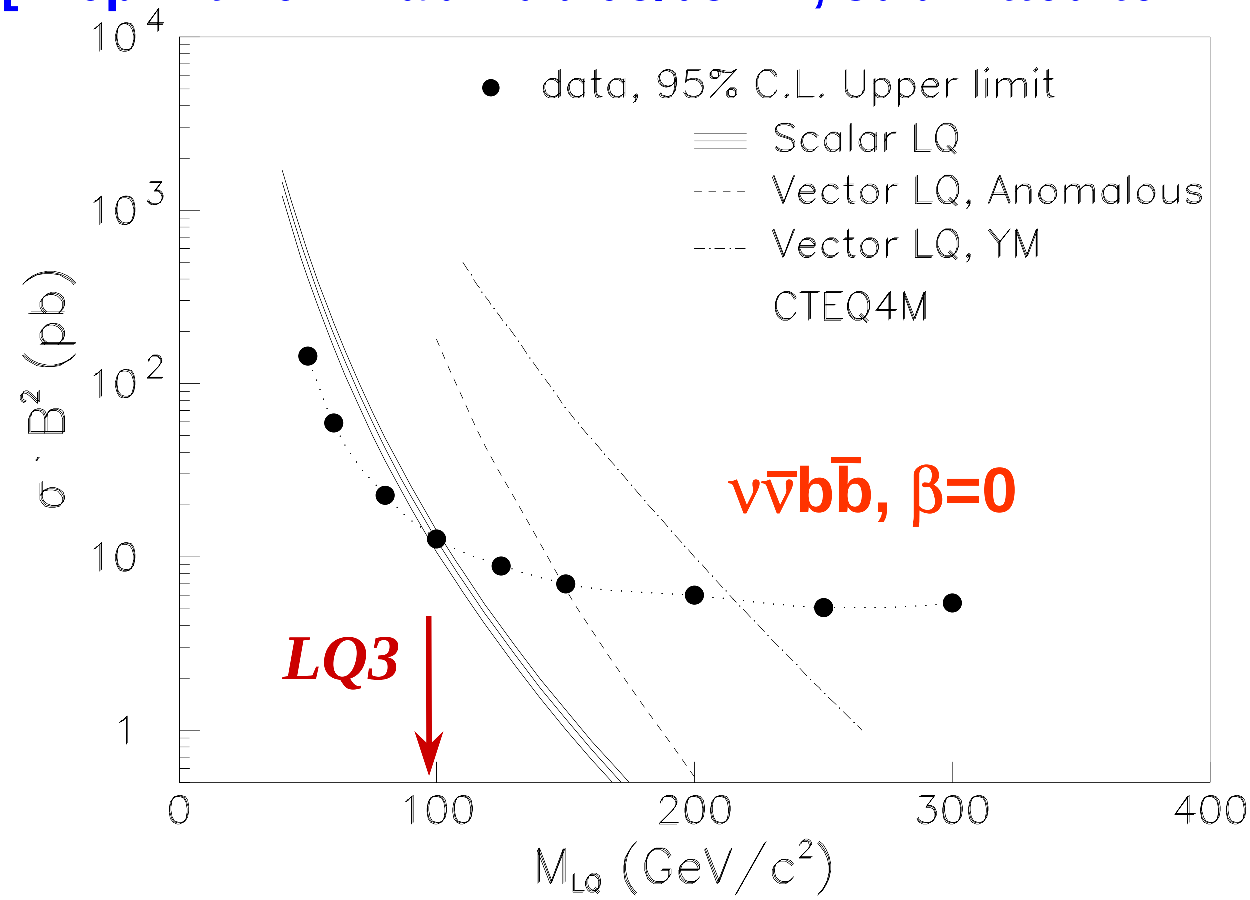
NLO Theory: Krämer, Plehn, Spira, Zerwas
Phys.Rev.Lett. **79** (1997) 341

Third Generation LQ Mass Limits

Run 1 Data Sample
Data: 2 events, Exp. Bkgd: 3.1± 0.9 events

M_{LQ3} > 94 GeV @ 95% CL for β = 0, q = 1/3
M_{VLQ3} > 216 GeV @ 95% CL for β = 0, q = 1/3

[Preprint Fermilab-Pub-98/081-E, submitted to PRL]



NLO Theory: Krämer, Plehn, Spira, Zerwas
Phys.Rev.Lett. **79** (1997) 341

Leptoquark Searches 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**
    - $\beta = 1/2$ **204 GeV**
    - $\beta = 0$ **79 GeV**
  - **Second Generation:**
    - $\beta = 1$ **184 GeV**
    - $\beta = 1/2$ **140 GeV**
    - $\beta = 0$ **79 GeV**
  - **Third Generation:**
    - $\beta = 0$ **94 GeV**

all limits are given @ 95% CL

- *Our search for first generation LQ is the single most sensitive Yukawa-coupling-independent measurement. It rules out at 95% CL an interpretation of the HERA data with LQ with masses below 200 GeV and $\beta > 0.4$. This excludes a very broad class of models.*
- *Combined Tevatron results are expected to yield even higher mass limits on the LQ (242 GeV, β=1)*

A Final Touch

New York Times, February 25, 1997

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Elsevier

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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 Teilchenphysik 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 there by chance, they said, is only about 1 in 100, 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.

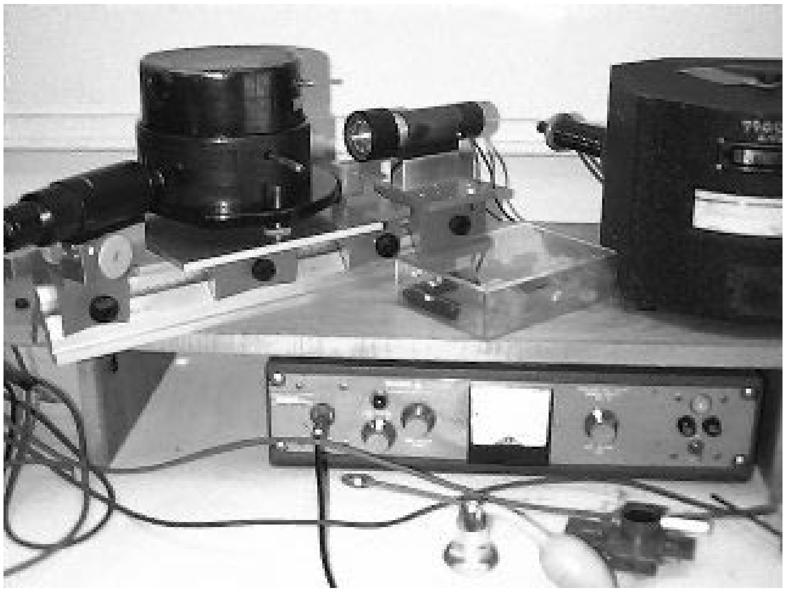
Positron and a quark inside a proton are accelerated close to the speed of light and then collided

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

Source: DESY

The New York Times

Quantization of the Electric Charge



R.Millikan oil drop experiment (1909):

Electric charge is quantized; the elementary free charge is that of the electron

$e = 1.6\times10^{-19}$ C

We think that fractional electric charge of e/3 exists (quarks), but multiple experiments similar to the original Millikan experiment show that it seems to be always confined

One way to explain mysterious quantization of the electric charge is to postulate the existence of a free magnetic charge - a MONOPOLE. First introduced by Paul Dirac in 1931 and later developed by J.Schwinger, G.'t Hooft and other founders of QED, they remain hypothetical particles despite numerous attempts to find them

Theory of Magnetic Monopoles

- **Magnetic monopoles restore the symmetry of Maxwell equations:**

$$\left.\begin{aligned}\partial_\nu F^{\mu\nu} &= -j^\mu \\ \partial_\nu \tilde{F}^{\mu\nu} &= 0\end{aligned}\right\} \rightarrow \left\{\begin{aligned}\partial_\nu F^{\mu\nu} &= -j^\mu \\ \partial_\nu \tilde{F}^{\mu\nu} &= -k^\mu\end{aligned}\right.$$

$$\left\{\begin{aligned}F^{\mu\nu} &\rightarrow \tilde{F}^{\mu\nu} \\ \tilde{F}^{\mu\nu} &\rightarrow -F^{\mu\nu}\end{aligned}\right. \quad \left(\begin{array}{c}\textit{symmetric under} \\ \textit{duality transformation}\end{array}\right)$$

- **They also explain quantization of the electric charge via famous Dirac quantization rule:**

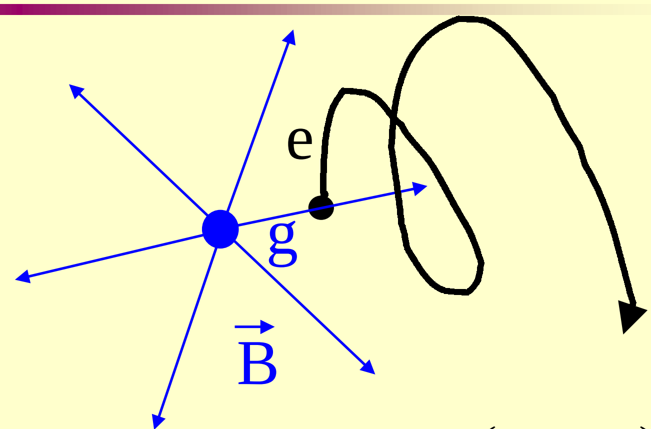
$$\frac{eg}{4\pi} = \frac{1}{2}n$$

(in ħ=c=1 units)

Simple Derivation of Dirac Quantization

$$\vec{B} = \frac{g}{4\pi r^3}\vec{r},$$

$\hbar = c = 1$



$$m\ddot{\vec{r}} = e\dot{\vec{r}} \times \vec{B}, \quad \vec{L} = \vec{r} \times m\dot{\vec{r}}$$

$$\frac{d\vec{L}}{dt} = \frac{d}{dt}(\vec{r} \times m\dot{\vec{r}}) = \vec{r} \times m\ddot{\vec{r}} = \frac{eg}{4\pi r^3}\vec{r} \times \left(\dot{\vec{r}} \times \vec{r}\right) = \frac{d}{dt}\left(\frac{eg}{4\pi r}\vec{r}\right)$$

$$\vec{J} = \vec{r} \times m\dot{\vec{r}} - \frac{eg}{4\pi r}\vec{r}$$

Total angular momentum is the sum of the particle angular momentum and the angular momentum of the EM field

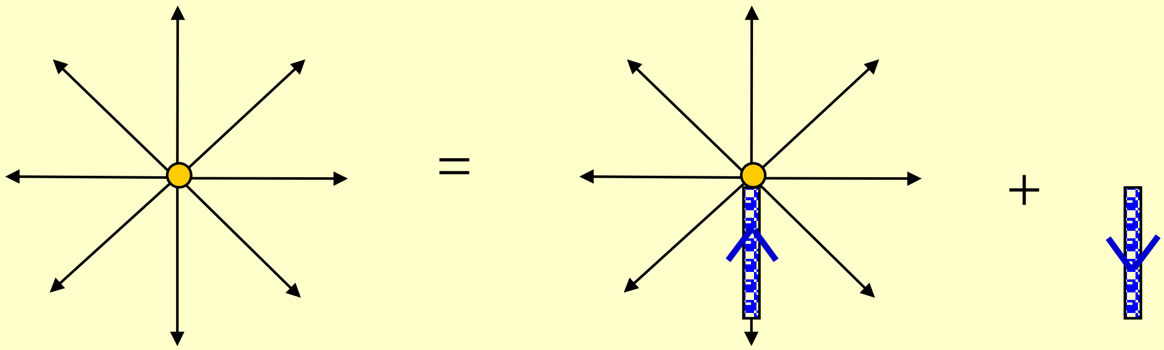
$$\frac{eg}{4\pi} = \frac{1}{2}n$$

Total angular momentum is quantized, hence, second component is quantized!

$$g = \frac{2\pi n}{e}, n = \pm 1, \pm 2, \ldots \text{ (in Schwinger theory } n = \pm 2, \pm 4, \ldots)$$

$$\alpha = \frac{e^2}{4\pi} \approx \frac{1}{137} \Rightarrow \alpha_g = \frac{g^2}{4\pi} = \frac{n^2}{4\alpha} \approx 34n^2$$

Dirac String (Quantum Approach)

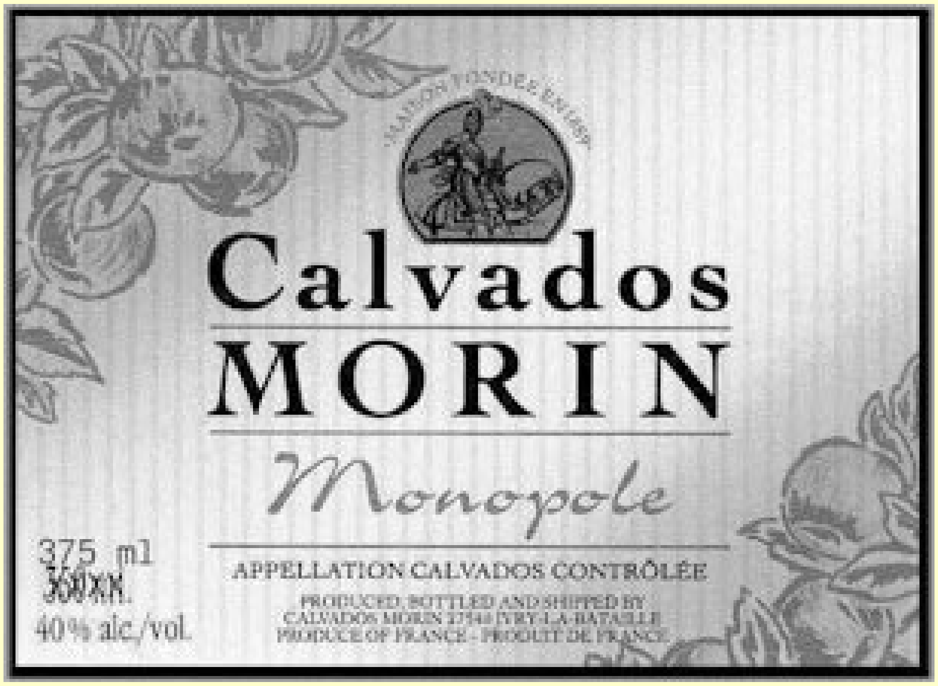


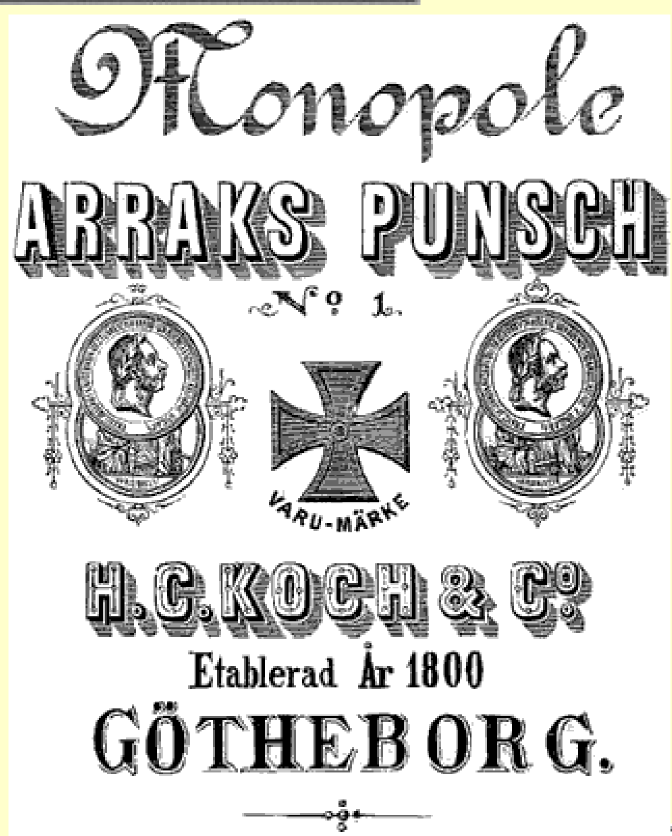
- **Need a singularity (Dirac String) to describe the QED in presence of static magnetic charges (otherwise gauge invariance is violated)**
- **Dirac string can not be observed since it is a mathematical, rather than a physical object (e.g., Aharonov-Bhom effect is absent exactly due to Dirac quantization rule)**
- **Dirac string is a necessary artifact of gauge invariance requirement**

Problems with the Monopole Theory

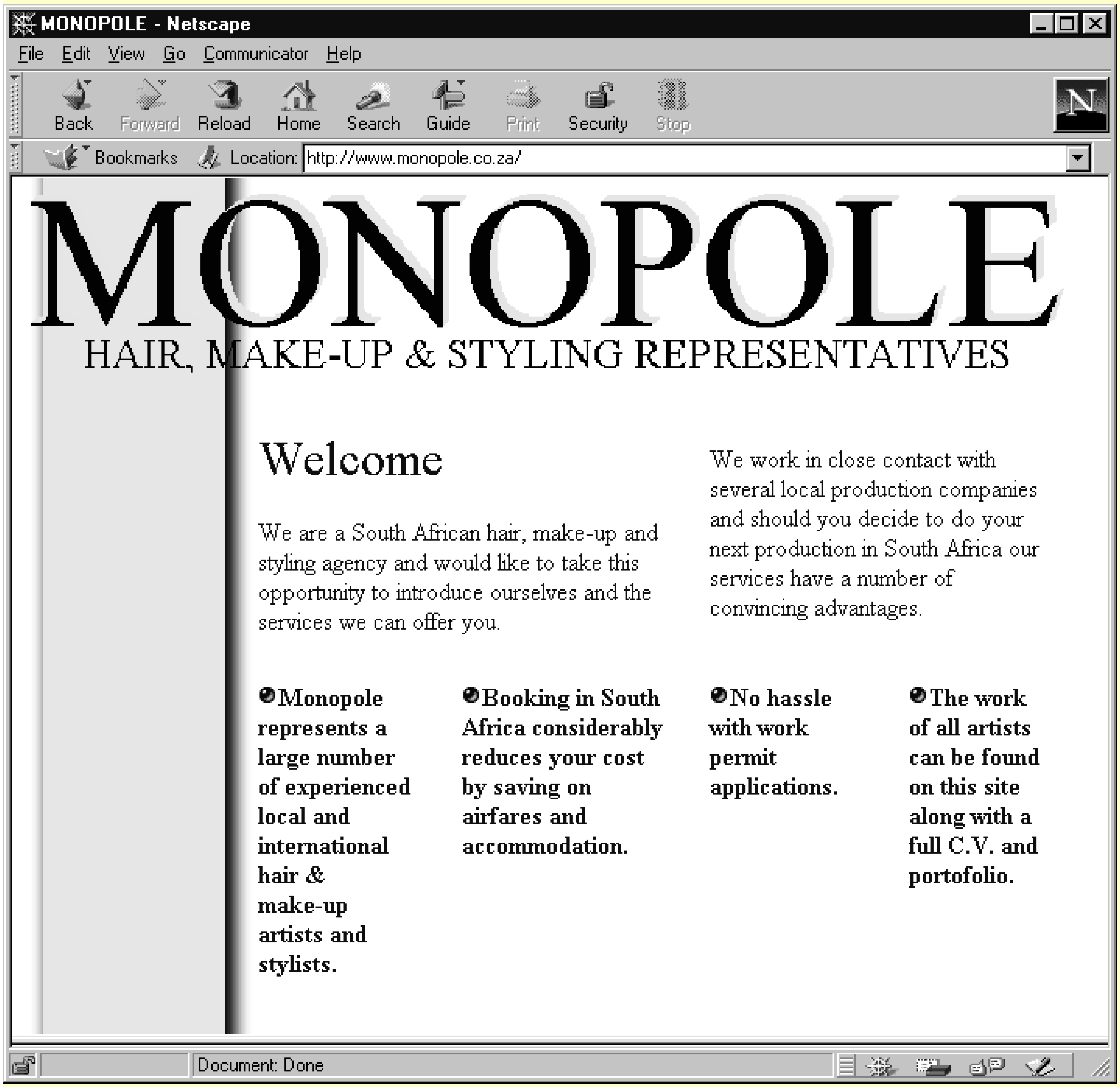
- At the current level of theory we do not know if one can write a fully renormalizable description of magnetic poles: it was never proved either right or wrong
- There are arguments that monopole theory could violate local U(1) or that monopoles have to be heavy (~10^4 TeV) in order not to violate unitarity
- One needs a theory with a Dirac string or its surrogate to describe QED with monopoles
- Definitely more theoretical work on this subject is welcome

Searches for Monopoles





Searches for Monopoles



Searches for Monopoles

monopole_prices - Netscape

Location: file:///J|/My Documents/Monopoles/monopole_prices.htm

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Monopoles: Dominating monstrosities

Idon't want Fairfax County to be dominated by monopoles. I don't want Virginia's natural beauty to be dominated by monopoles.

Go up to New Jersey, a state that is ``wired." The central feature of the New Jersey landscape is the hideous and dominating monopole. There is a monopole every mile, and five above even small towns.

Residents of Fairfax County and Virginia should wake up to what is beginning to happen here. Do we want these ugly intrusions on the beauty of our environment? Do we want to take the health risk living under these monstrosities?

Go and see the one at Lee Highway and Harrison Street in Arlington. If that ugly monopole is the best technology can come up with, I say get back to the drawing board.

EMILIE BRZEZINSKI

McLean

Document: Done

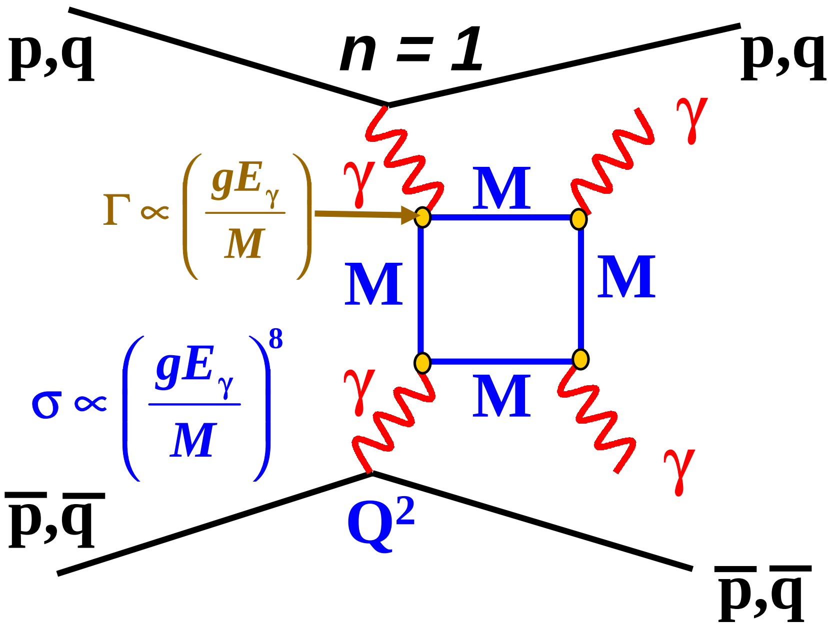
Real Searches for Monopoles

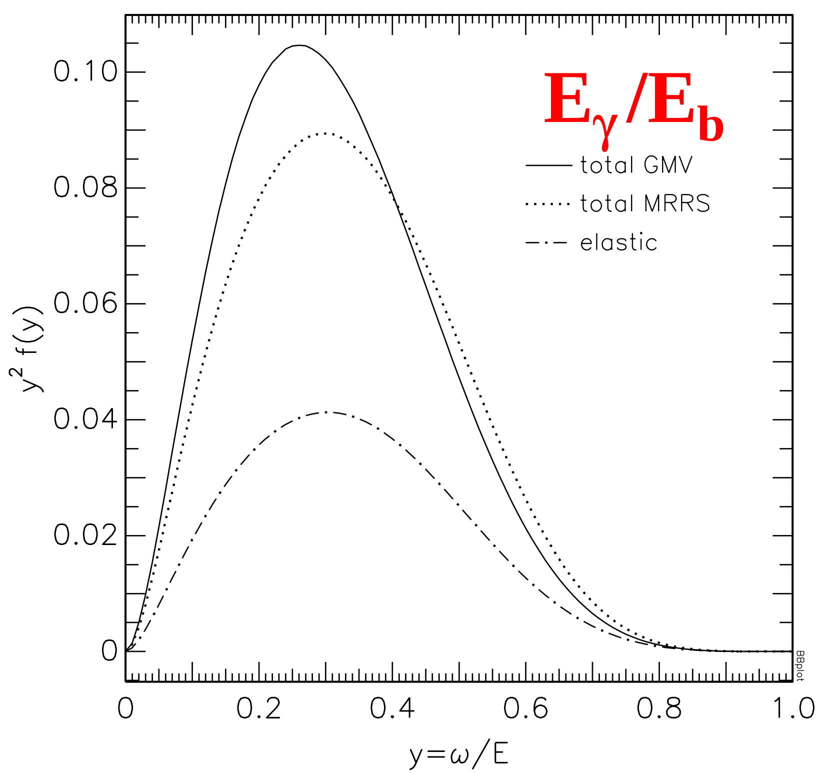
- **Flux measurement experiments:**
  - *Always set limits on the flux of the relic monopoles travelling through the universe*
  - *EM induction in superconducting coils*
  - *Scanning materials for ionization traces (minerals, meteorites, moon rocks, huge detector volumes)*
- **Accelerator experiments:**
  - *Can set limits on monopole mass*
  - *Production of monopoles in the lab: mass reach is inherently restricted by the machine energy*
- **Current limits:**
  - *c.s.< 200 pb for M < 850 GeV (EØ)*
  - *M > 510 GeV (L3, 1995, $Z \to \gamma\gamma\gamma$, based on a similar idea)*

Effects of the Virtual Monopoles

I.F.Ginzburg, A.Schiller, PRD 57 (1998) 6599

(original idea by I.F.Ginzburg, S.L.Panfil, 1982)





Production features:

- *Low Q^2 of the beams ("γγ-collider")*
- *Roughly isotropic scattering angle in the CM frame, ergo central photons*
- *Energetic photons: $\langle E \rangle \approx 0.3E_b$*
- *Cross section drops as the monopole mass to the 8th power - no thorough optimization is required*
- *About a third of the cross section is due to the elastic collisions*

Theoretical Assumptions

- *Theory is applicable to local, or pointlike, monopoles and not Polyakov-`t Hooft GUT monopoles*
- *Calculations are based on the perturbation theory with the effective parameter* $g_{eff} \sim E^{\gamma}/M$ *and are valid for* $g_{eff} < 1$
- *Theory assumes under-threshold production of monopoles, which is equivalent to perturbativity assumption*
- *Unitarity requirement is automatically satisfied in the perturbative region*

Production Cross Section

At the Tevatron operating at $\sqrt{s}$ = 1.8 TeV the cross section is given by:

$$\sigma(p\bar{p} \to \gamma\gamma X) = 57 \cdot P\left(\frac{n}{M[\mathrm{TeV}]}\right)^8 \mathrm{fb}$$

Significant spin dependence!

$$P = \begin{cases} 0.085, & S = 0 \\ 1.39, & S = 1/2 \\ 159, & S = 1 \end{cases}$$

M = 1 TeV, n = 1:

σ = 4.8 fb (S = 0)

σ = 79 fb (S = 1/2)

σ = 9.1 pb (S = 1)

Differential cross section under the assumption of $E_T(\gamma_1) = E_T(\gamma_2)$ is given by:

$$\frac{d^3\sigma}{d\eta_3 d\eta_4 dE_T} = 2E_T\left(\frac{\alpha_e}{\pi}\right)^2 y_1^2 f(y_1) y_2^2 f(y_2) \frac{5RE_b^4}{112}\Phi$$

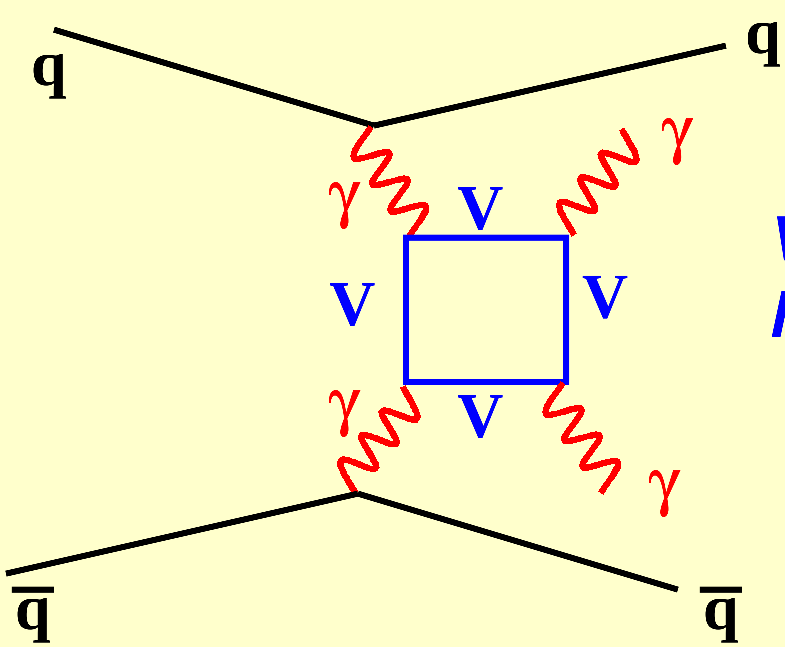
observables (refers to $d\eta_3 d\eta_4 dE_T$)

$$\Phi = \left(4 - \frac{1}{\cosh^2\left(\frac{\eta_3 - \eta_4}{2}\right)}\right)^2, \; y_{1,2} = \frac{E_T}{2E_b}\left(e^{\pm\eta_3} + e^{\pm\eta_4}\right)$$

$$R = \frac{28P}{405\pi}\left(\frac{n}{2\sqrt{\alpha_e}M}\right)^8$$

Diphoton Backgrounds

(1) *Other γγ-scattering diagrams:*



V=W has the highest contribution

Negligible
*[Jikia,Tkabaladze PL **B323** (1994) 453]*

(2) *QCD (jj/jγ/γγ)*

(3) *DØ-specific: Drell-Yan (ee → "γγ")*

Data Selection

- **Data Sample:**
  - *Entire Run I data taken with an inclusive single photon trigger with NO inelastic collision requirement (70 ± 4 pb^{-1})*
- **Data Selection:**
  - *≥ 2 photons (with $E_T^\gamma > 40$ GeV):*

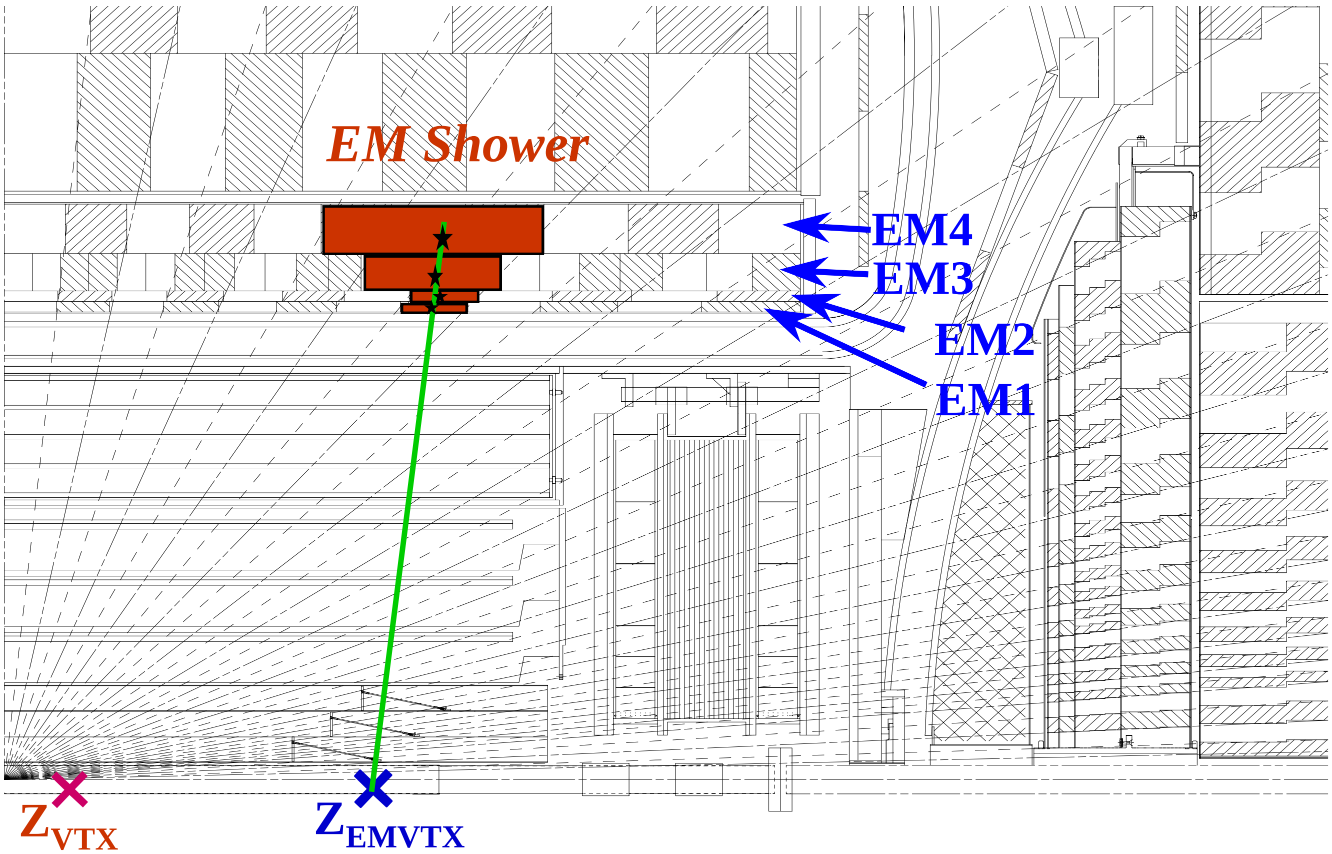
$|\eta_\gamma| < 1.1$	**$\chi^2 < 100$**
ISO < 0.10	**EMF > 0.95**

  - *Jet veto (to select low Q^2 interact.):*

    No jets with $|\eta_j| < 2.5$ and $E_T > 15$ GeV
  - *Transverse Energy Conservation:*

    $\not{E}_T < 25$ GeV
- **Problem:**
  - *What to do about misvertexing?*

EM-Cluster Projection Technique



4-point fit (EM1-EM4): Z_{EMVTX} - calorimeter-based Z-position of the vertex. Typical resolution in RZ per photon is:

$\sigma_{RZ} \sim$ 20 cm (energy and rapidity dependent)

With two photons vertex is known to ~ 14 cm for $Z \rightarrow ee$ events (better for higher E_T^{EM})

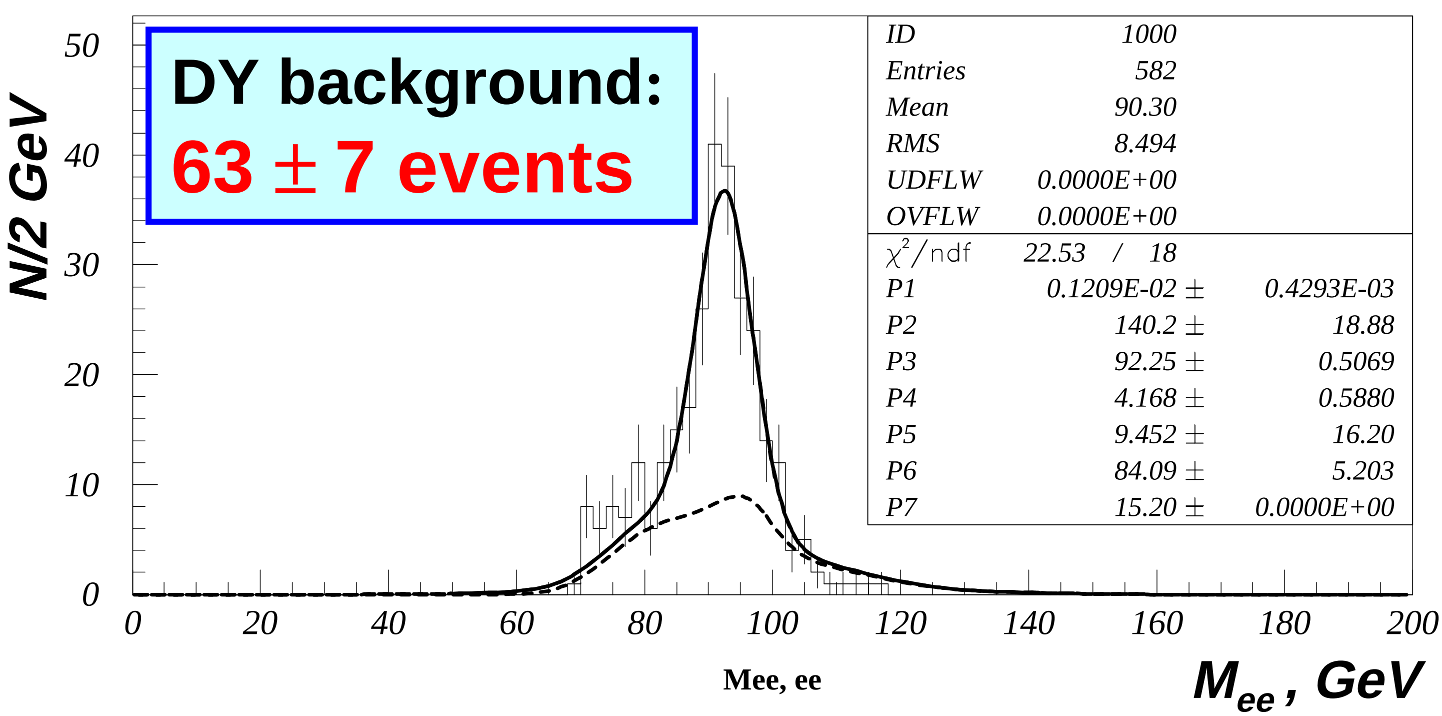
QCD Background

90 candidate events pass basic cuts

- *Start with jγ sample collected with the same trigger to calculate QCD background*
- *Use PYTHIA to obtain fractions of jj/jγ/γγ events as a function of E_T^γ (do not use cross sections, just the shapes!)*
- $$B_{\gamma\gamma} = N_{jj}P_\gamma^{\ 2} + N_{j\gamma}P_\gamma\varepsilon_\gamma + N_{\gamma\gamma}\varepsilon_\gamma^{\ 2}$$
  $$B_{j\gamma} = 2N_{jj}P_\gamma + N_{j\gamma}\varepsilon_\gamma$$
- **$P(j\rightarrow\gamma) = (10.5 \pm 1.4)\times 10^{-4}$**
- **QCD background: 25 ± 8 events**

Drell-Yan Background

- Fit the diphoton mass spectrum for $70 < S_T < 100$ GeV with the sum of a Gaussian and a fixed shape for the QCD background
- Let the two normalizations float
- $P(ee \to \text{“}\gamma\gamma\text{”}) = 0.110 \pm 0.012$
- Use dielectron sample with similar cuts to obtain DY background

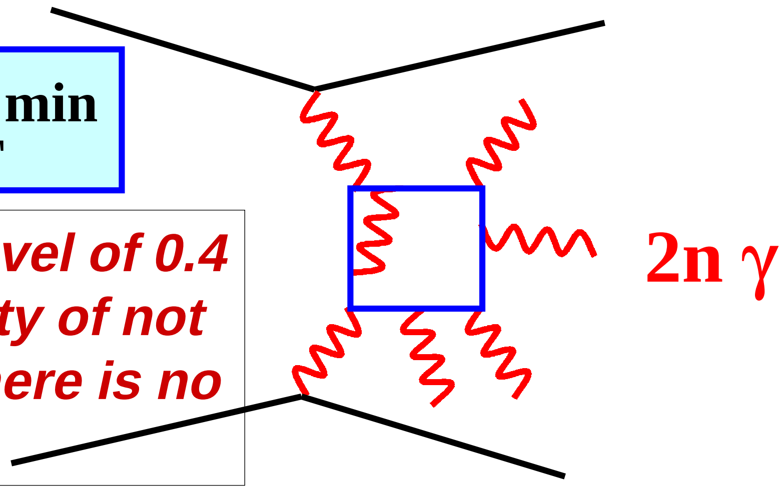


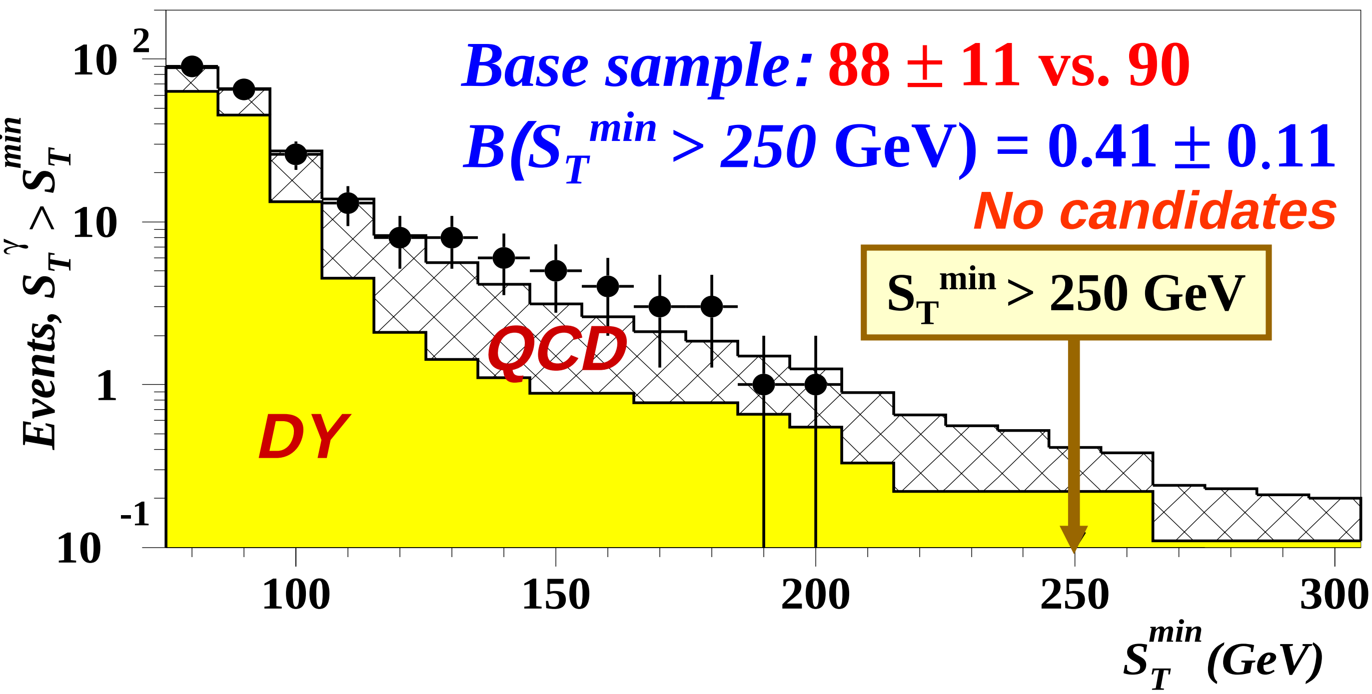
S_T Analysis

S_T approach takes care of possible NLO QED effects which result in partial cross section "leak" into the final states with higher photon multiplicity:

$$S_T = \sum E_T^{\gamma} > S_T^{min}$$

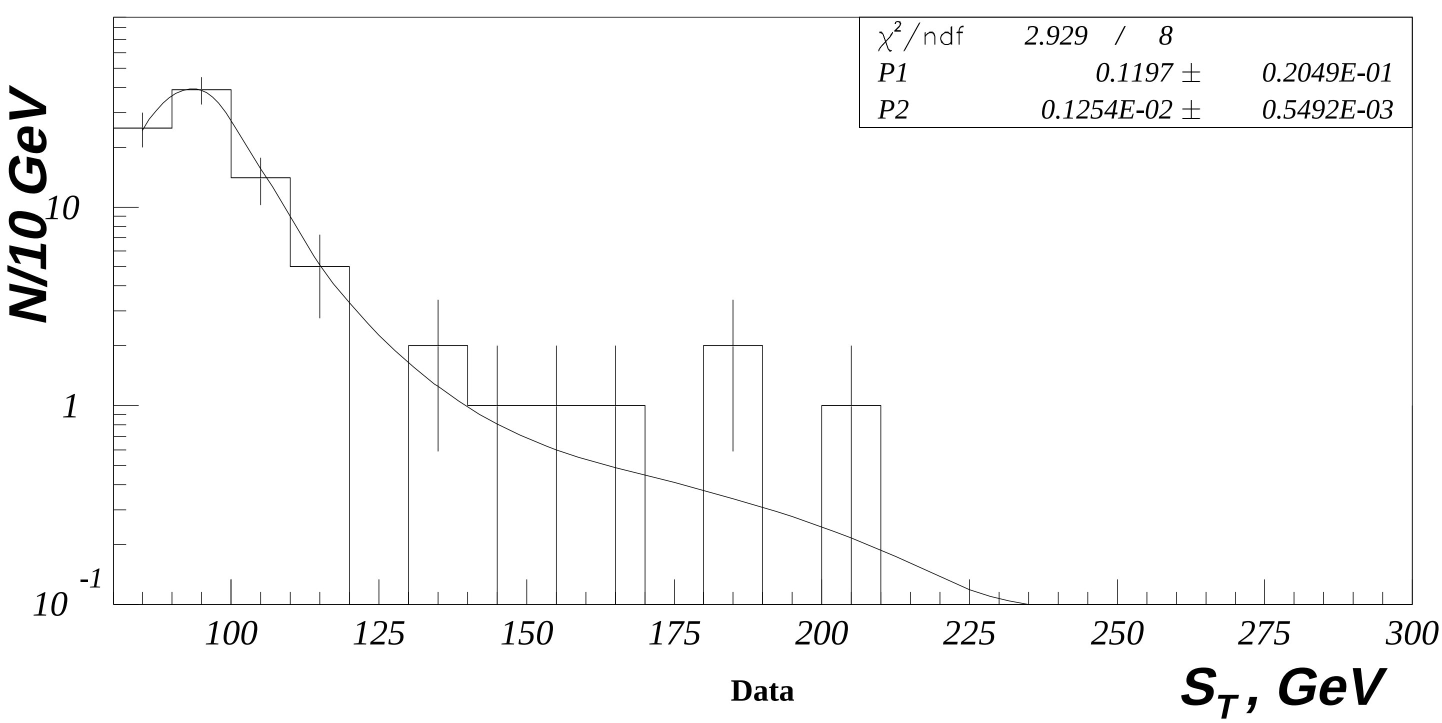
Choose background level of 0.4 events (70% probability of not seeing any events if there is no signal)





S_T-Distribution Fit

- *A cross check was done by fitting the differential S_T distribution with the sum of two backgrounds with the two misidentification probabilities as fit parameters*
- *Excellent agreement with the direct method*



Efficiency and Cross Section Limit

Chosen cut: $S_T > 250$ GeV
Background: 0.41 ± 0.11 events
Candidates: None
Efficiency:

Cut	Efficiency	
ISO < 0.10:	0.93 ± 0.01	per photon
EMF > 0.95:	0.99 ± 0.01	per photon
$\chi^2 < 100$:	0.95 ± 0.01	per photon
No tracks:	0.91 ± 0.01	per photon
No convrsns:	0.92 ± 0.01	per photon
Total:	**0.73 ± 0.01 (per photon)**	
$\not{E}_T < 25$ GeV:	0.99 ± 0.01	per event
Overall:	**0.53 ± 0.01 (per event)**	

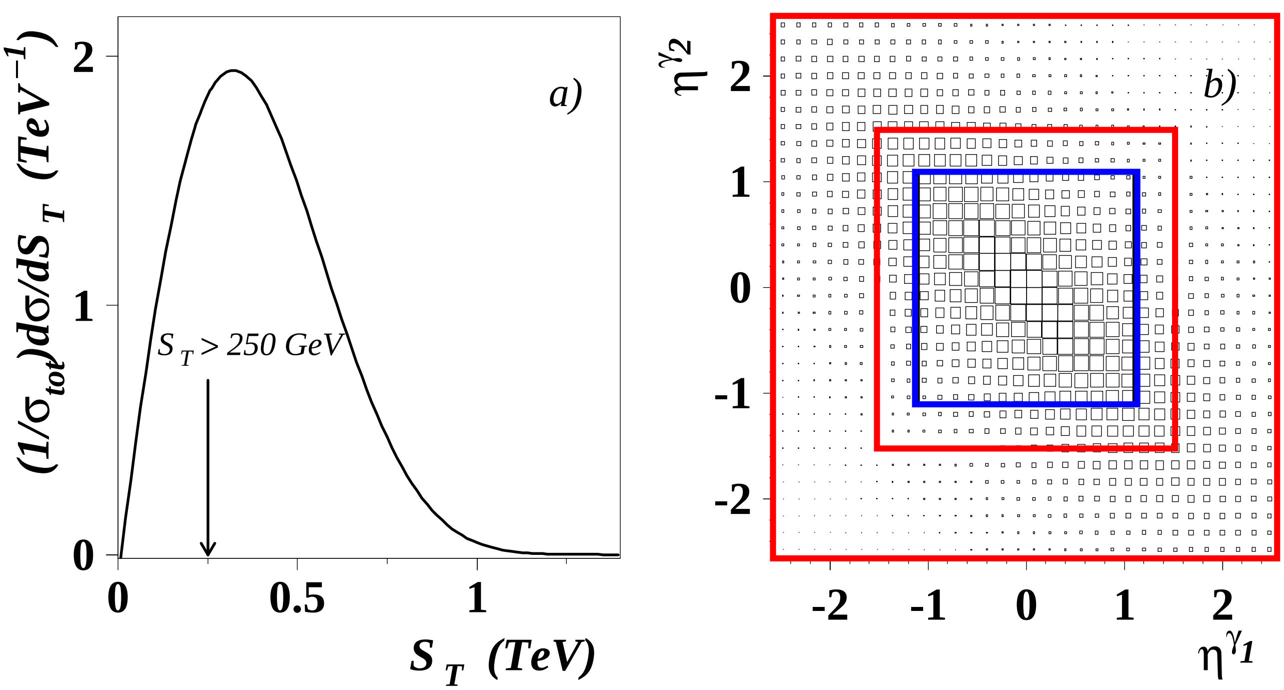
95% CL upper cross section limit: 83 fb
(includes systematic errors on the efficiency and integrated luminosity)

Monopole Parametric Monte Carlo

Includes:

- *Interaction point smearing σ = 30 cm*
- *Vertex position resolution*
- *EM energy smearing*
- *Detector acceptance*
- *Photon flux via p.d.f. (CTEQ4L, GRV)*

A = 0.50 ± 0.01



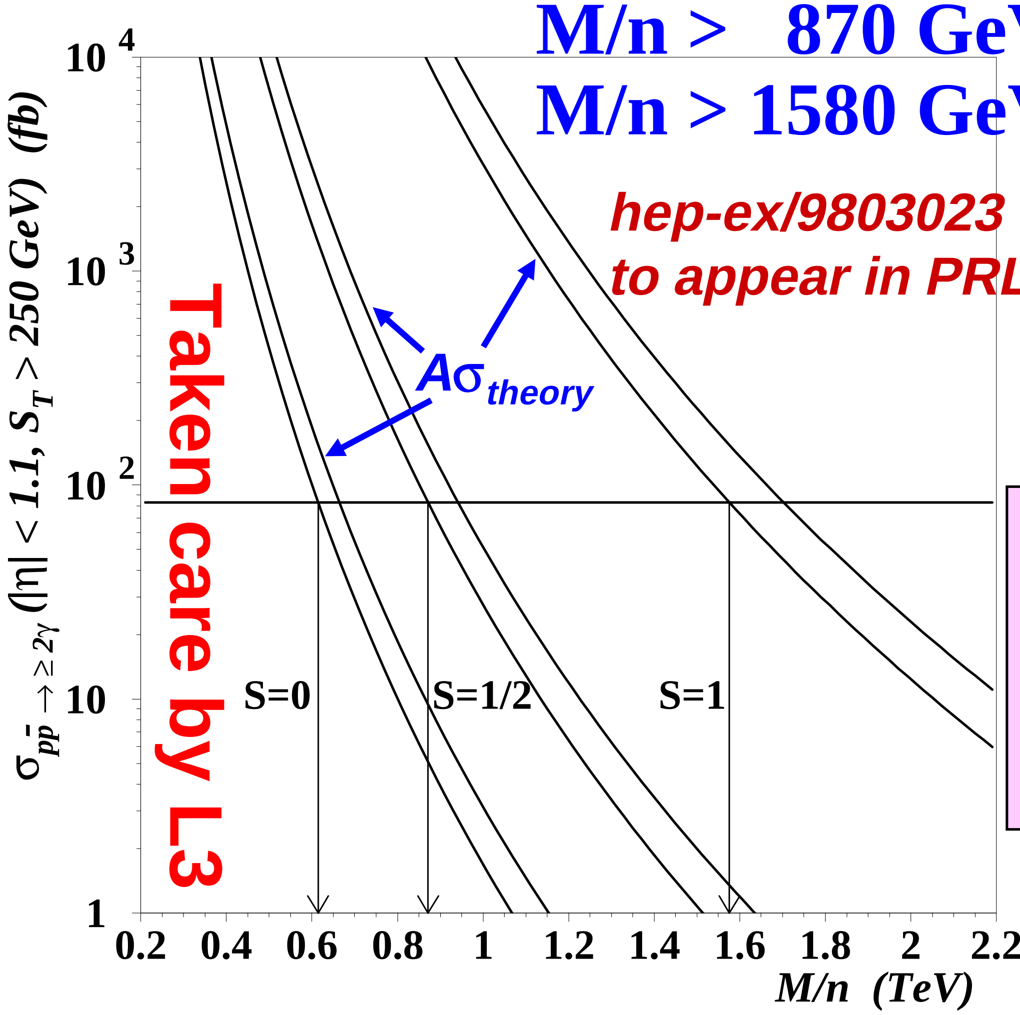
N.B. max A = 0.56 ± 0.01 (less than 2% in limits)!

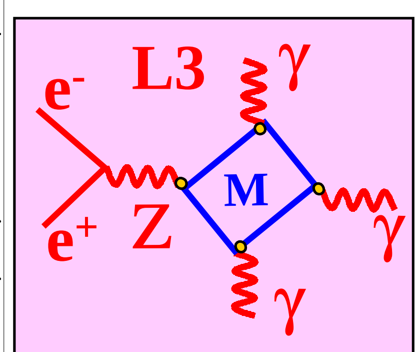
Limits on Heavy Monopole Mass

- **Bayesian approach with flat prior and Gaussian uncertainties on the efficiency, integrated luminosity and acceptance**
- **30% uncertainty on the theory; use low theory band**

M/n > 610 GeV for S=0
M/n > 870 GeV for S=1/2
M/n > 1580 GeV for S=1

hep-ex/9803023
to appear in PRL 81 (1998)

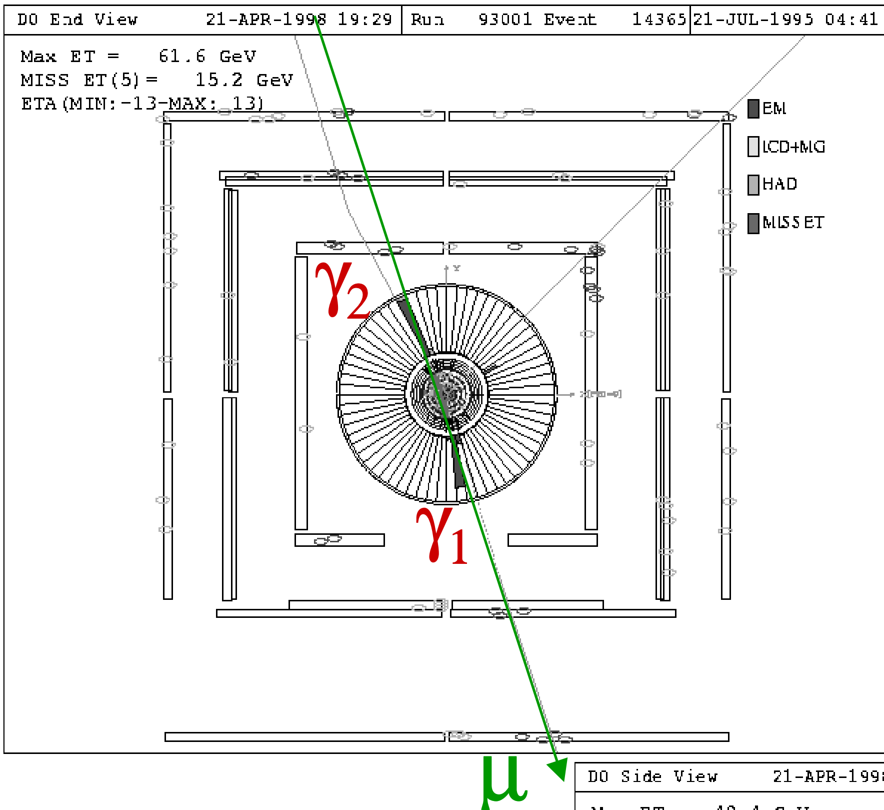




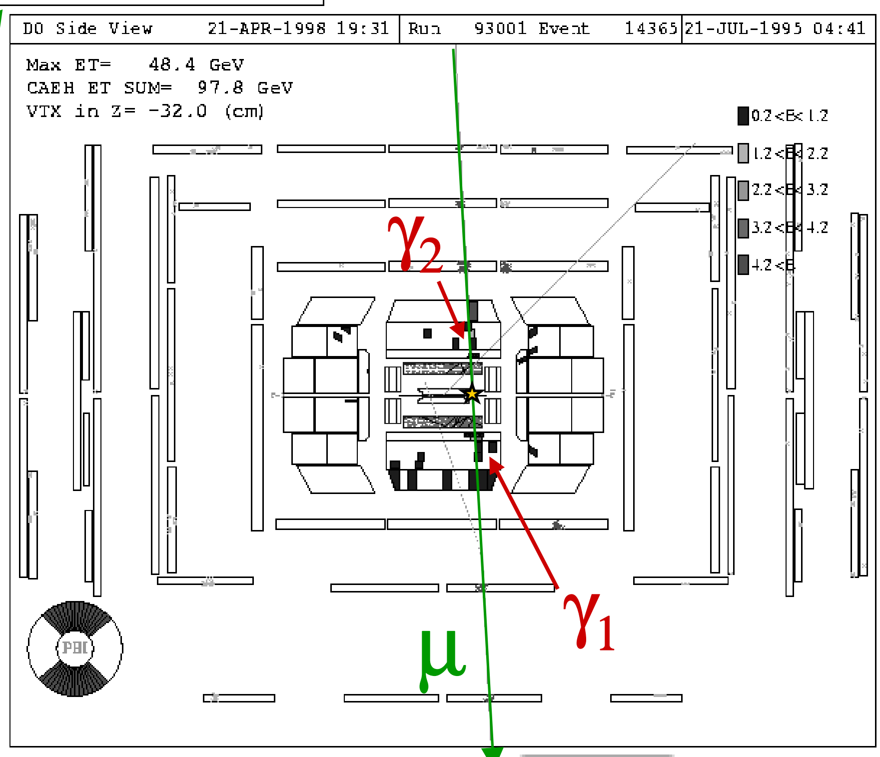
Elastic Analysis

- An alternative analysis can be done by noting that about 50% of the cross section for the monopole loop is due to (nearly) elastic collisions
- DØ is equipped with luminosity monitors (Level 0 trigger) which can be used as an inelastic collision veto
- Such a veto corresponds to virtually background-free environment: $B = 1.8 \pm 0.4$ events (dominated by the diffractive Drell-Yan) and only one candidate (consistent with $Z \rightarrow ee$)
- For $S_T > 100$ GeV cut, background is 0.4 events; no candidate events pass this cut
- We use this only as a cross check since the acceptance is small due to multiple interactions effects and additional elasticity requirement

Double Cosmic Bremsstrahlung



Extremely rare double cosmic bremsstrahlung event (fails the missing E_T cut)



E_{γ_1} = 96 GeV

E_{γ_2} = 93 GeV

Z^{γ}_{vtx} = 45 cm

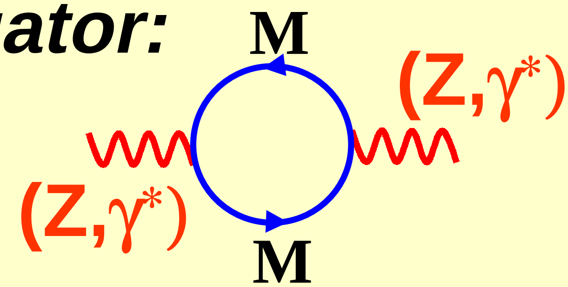
no Level 0 hits

Validity of the Theory

- ***Strictly speaking theory is valid only for under the threshold production, i.e.*** $\langle E_\gamma \rangle < M$
- ***Hence, our limits are valid for M above a few hundred GeV. L3 results cover lower masses.***
- ***If the effective parameter of the perturbation theory*** ($g_{eff} \sim E_\gamma/M$) ***is »1, extra photons will be emitted, but our*** S_T ***analysis accounts for that***
- ***When (and if) the higher order theory is available DØ results could be easily used to set updated limits***

Comparison with Other Indirect Limits

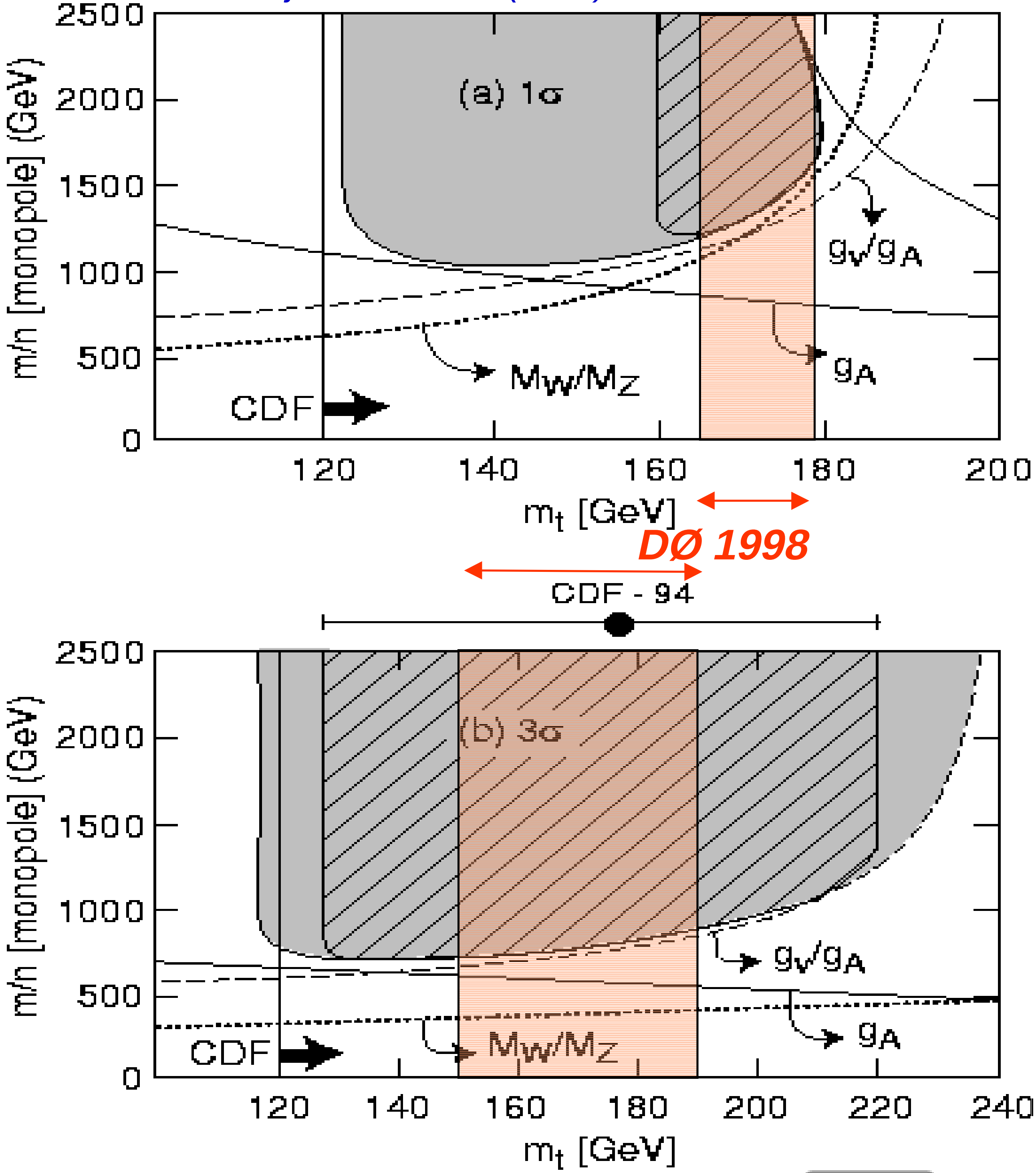
- ***Indirect limits on the monopole mass can be derived from loop corrections to the (Z,γ) propagator:***



- ***The variables most sensitive to this loop diagram are:*** g_V/g_A, g_A, ***and*** M_Z/M_W
- ***Corrections were calculated by DeRujula [****Nucl. Phys.* ***B435*** *(1995) 257****] and were shown to give mass limit of about 0.8 TeV for spin 1/2 monopoles, which is somewhat worse than the new DØ limits***
- ***Updated LEP results make these indirect limits slightly less restrictive***

Monopole Mass Limits from EW Results

A.De Rujula, NP ***B435*** *(1995) 257*



Monopole Search Summary

- **Experimental upper cross section limit:**

$\sigma(pp \rightarrow \geq 2\gamma + X, S_T > 250$ GeV, $|\eta_\gamma| < 1.1) < 83$ fb (at the 95% CL)

- ***Monopole lower mass limits:***

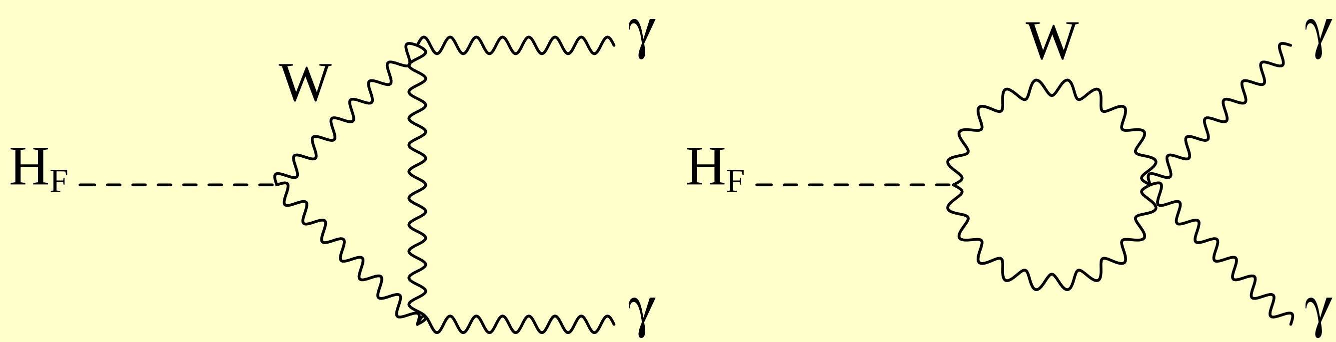
M/n > 610 GeV for S = 0
M/n > 870 GeV for S = 1/2
M/n > 1580 GeV for S = 1

these are the most restrictive mass limits on heavy pointlike Dirac monopoles

- ***Multiple cross checks show that the results are very stable***
- ***Results to appear in Phys. Rev. Lett. 81 (1998)***

Fermiophobic Higgs Phenomenology

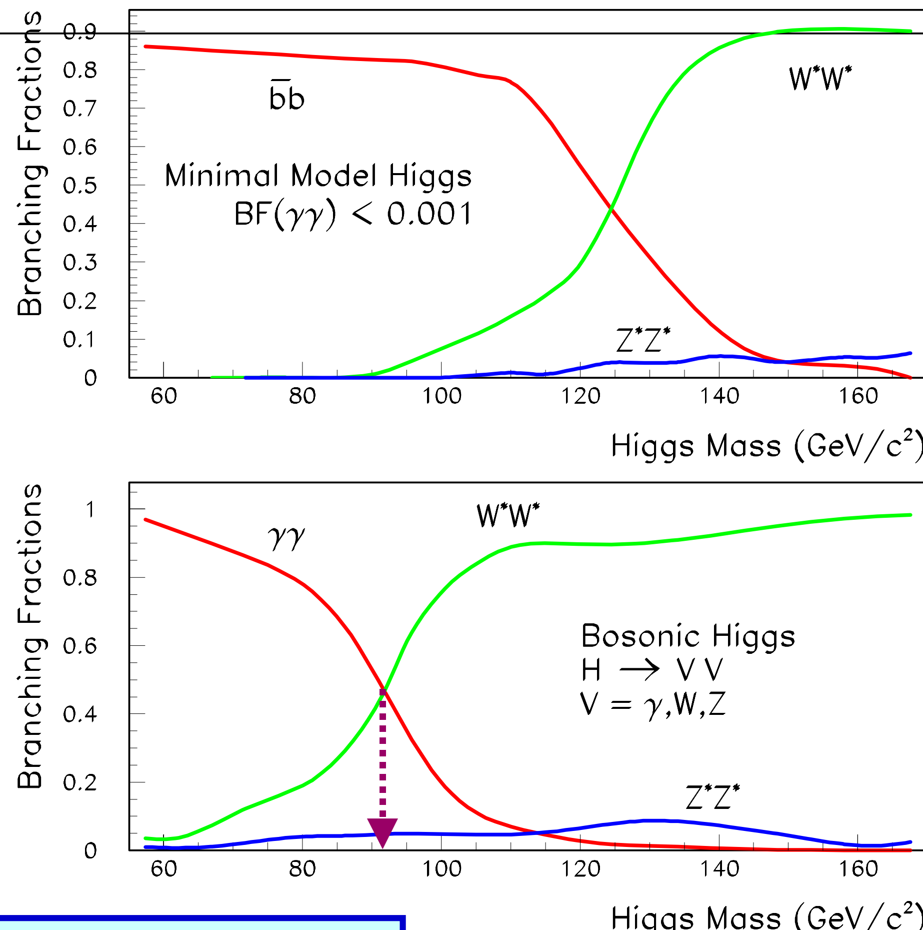
- *Several SM extensions allow for an additional light neutral Higgs boson with suppressed coupling to fermions [A.G.Akeroyd, PL B **353** (1996) 89]*
- *Existence of such a fermiophobic or bosonic Higgs boson would be an evidence against MSSM*
- *Such a Higgs boson would have a suppressed $b\bar{b}$ decay mode at low masses and an enhanced $\gamma\gamma$ decay mode through a a virtual W-loop:*



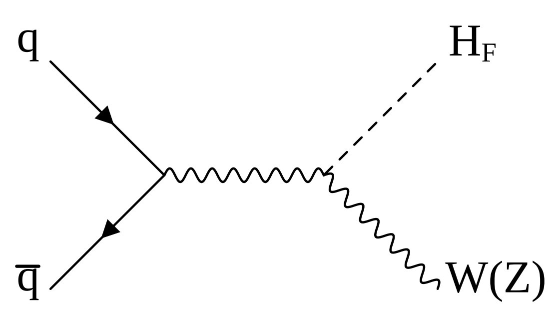
- *This decay mode dominates for bosonic Higgs masses below about 90 GeV*

Fermiophobic Higgs Production and Decay

- MSSM and fermiophobic Higgs decay modes:



At the Tevatron an associated production mechanism dominates. We focus on the dijet W/Z decay mode and diphoton fermiophobic Higgs decays



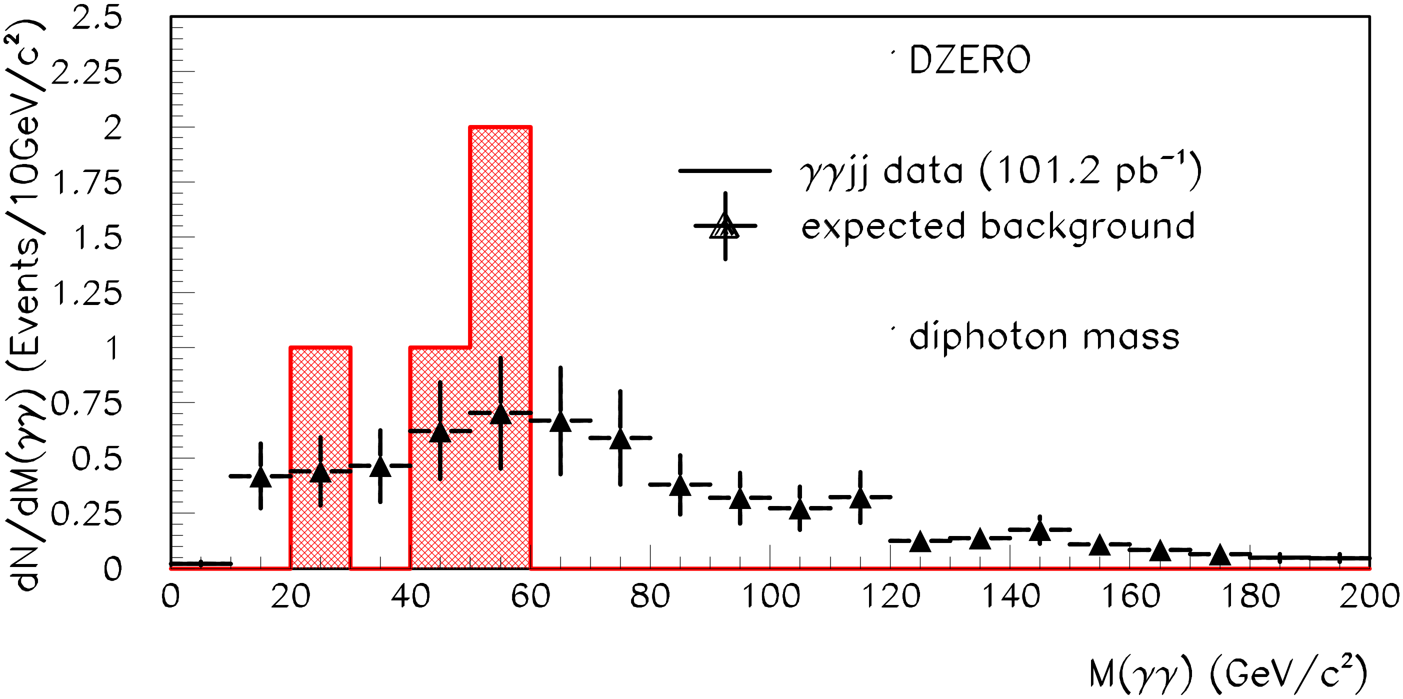
Data Selection

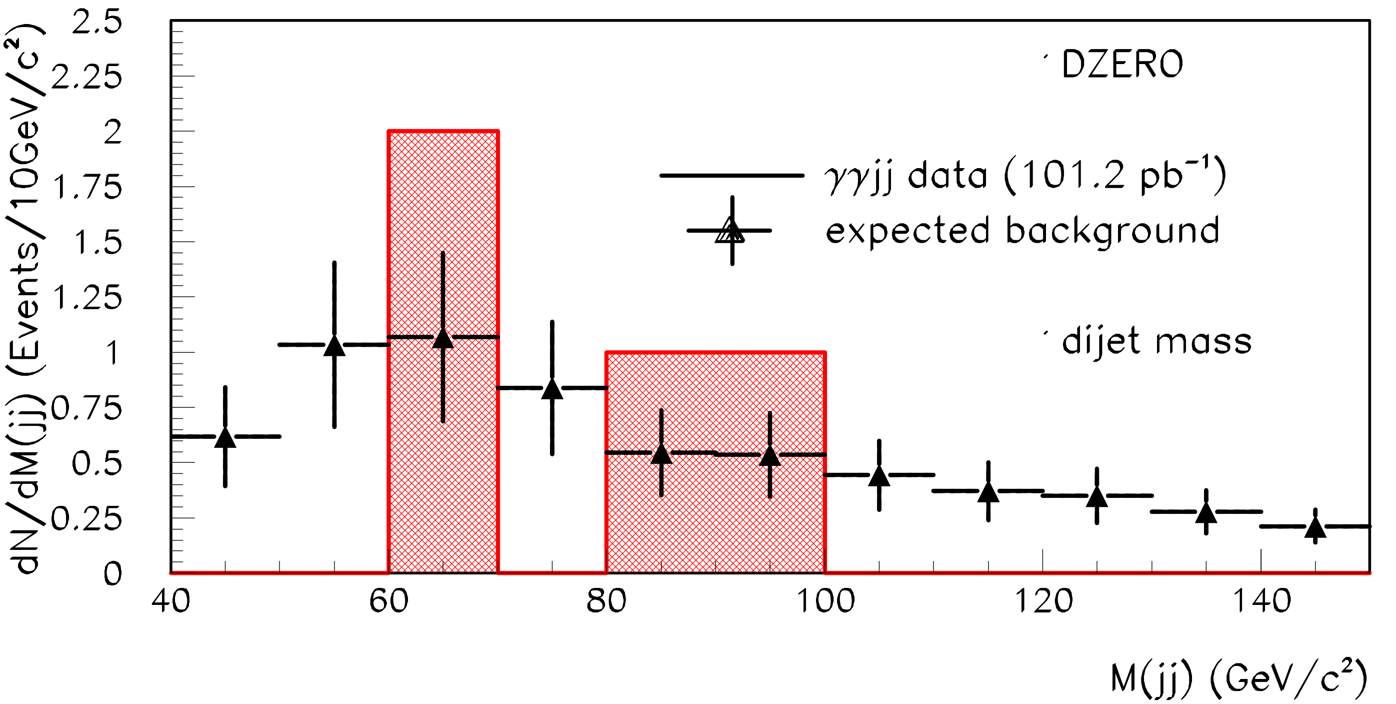
- **Data Sample:**
  - *Entire Run I data taken with an inclusive diphoton photon trigger (101 ± 5 pb^{-1})*
- **Data Selection:**
  - *≥2 photons (with E_T^γ > 30/15 GeV):*
    $|\eta_\gamma|$ < 1.1 or 1.5 < $|\eta_\gamma|$ < 2.0/2.25
    ISO < 0.10; χ^2 < 100; EMF > 0.96
    no tracks or hits in the tracker
  - *≥2 jets (R=0.7, with E_T^j > 30/15 GeV):*
    $|\eta_j|$ < 2.0/2.25
  - *Additional cuts:*
    40 GeV < M_{jj} < 150 GeV (select W/Z)
    $\Delta R^{j\gamma}$ > 0.7
- **Candidate events:**
  - *4 $jj\gamma\gamma$ events pass these cuts; highest $M_{\gamma\gamma}$ in the sample is 55 GeV*

Backgrounds

- Major background is due to QCD multijet production with jets faking photons. Estimated from jj "$\gamma\gamma$" sample with photons failing quality cuts by normalizing to the data for $M_{\gamma\gamma} < 60$ GeV where the bosonic Higgs is excluded by LEP: **4.0 ± 1.5 events**
- Other important background is due to direct photon production. Estimated from PYTHIA by applying jet-faking-photon probability of **$(4.3 \pm 1.0)\times10^{-4}$: 2.0 ± 0.6 events**
- Other considered backgrounds: Wγ + jets, Z + jets, tt $\rightarrow$ ee + jets are less than 0.01 event
- **Overall background is 6.0 ± 2.1 events, consistent with the observed four candidates**

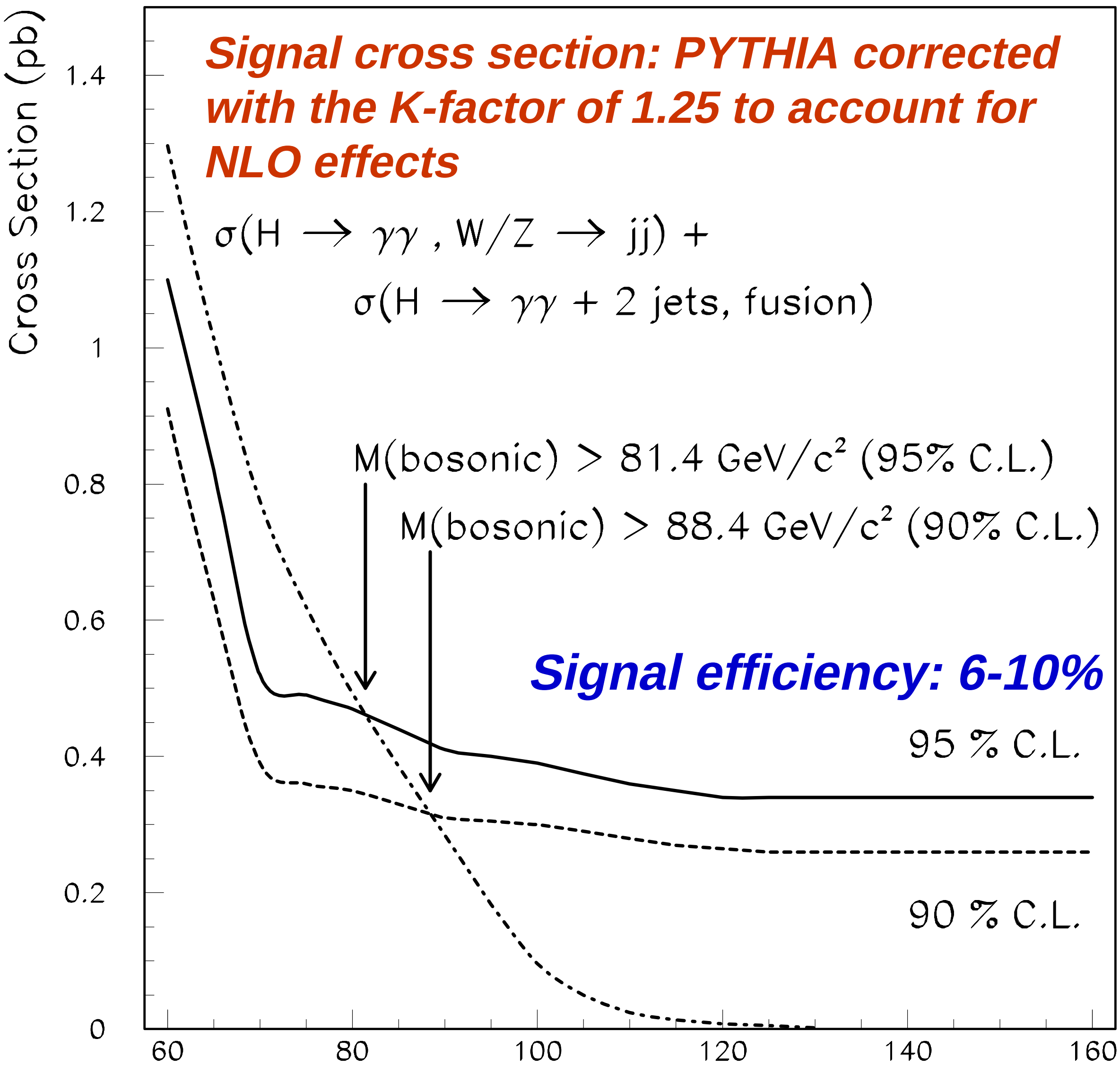
Data vs. Background





Limits on Fermiophobic Higgs

- Since data agrees with the background we proceed with setting limits on fermiophobic Higgs mass:



$M_H > 81.4$ GeV @ 95% CL

Conclusions: Future of DØ

- ***So far we have not found any exotics, but we tried hard...***
- ***Currently, the DØ detector is undergoing a major upgrade***
- ***We expect to accumulate at least 20 times more data in the next Run scheduled to start in the year 2000***
- ***The upgraded DØ detector with improved strengths will be well suited for searches for unknown in the next millenium***
- ***After all, the main reason to do particle physics is to either find something new or prove that it is not there…***
- ***And we hope to find it!***