New New-Phenomena Results from DØ

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for the DØ Collaboration

Hunting for supersymmetry in $\gamma \not{E}_T$+jets events

Search for energetic $\gamma\gamma$ events

An update on Leptoquarks

Les Rencontres de Physique de la Vallee d'Aoste

March 4, 1998, La Thuile, Italy

The DØ Detector

Tracking Detector

Vertex Detector
Transition Radiation Detector
Central and Forward Drift Chambers

LAr Calorimeter

Projective geometry, 4 E.M. layers and 4-5 hadronic layers
E.M. calorimeter: 21 radiation lengths
$\Delta\eta\times\Delta\phi=0.1\times0.1$ (0.05×0.05 for E.M. layer 3)

$\Delta E/E \sim 15\%/\sqrt{E} \oplus 0.4\%$ for e/γ

$\Delta E/E \sim 80\%/\sqrt{E}$ for jets

Muon Spectrometer

Three layers of proportional drift tubes
with magnetized iron toroids with B=1.9T
$\Delta p/p \sim 20\%/p \oplus 0.8\%$

$\not{E}_T$ Resolution

$\sim 1+0.02\ \Sigma E_T$ (GeV)

Special Features

No central magnetic field
Two beam pipes, One wanted, one unwanted

Minimal Supersymmetric Standard Model

Supersymmetry predicts a supersymmetric particle for every Standard Model particle

Under R-parity conservation supersymmetric particles are pair produced

The lightest supersymmetric particle (LSP) is stable and weakly interacting escaping detection $\Rightarrow \not{E}_T$

MSSM is the minimal extension of the Standard Model

(1) add an extra Higgs doublet of opposite hypercharge

(2) supersymmetrization of the gauge theory

In the framework of MSSM

The Gaugino-Higgsino sector is parameterized by four parameters: M_1, M_2, μ, $\tan\beta$

Gauge/Higgs Bosons: γ, Z^0, $W^\pm$, h^0, H^0, A^0, $H^\pm$, g

Neutralinos/Charginos: $\tilde{\chi}^0_1$, $\tilde{\chi}^0_2$, $\tilde{\chi}^0_3$, $\tilde{\chi}^0_4$, $\tilde{\chi}^\pm_1$, $\tilde{\chi}^\pm_2$, $\tilde{g}$

The scalar sector is parameterized by many mass parameters

lepton/quark $(\nu,e)_L$ e_R $(u,d)_L$ u_R d_R

slepton/squark $(\tilde{\nu},\tilde{e})_L$ $\tilde{e}_R$ $(\tilde{u},\tilde{d})_L$ $\tilde{u}_R$ $\tilde{d}_R$

Different SUSY breaking leads to different class of models

Models with Dominant $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 + \gamma$ Decay

To explain a recent CDF $ee\gamma\gamma\not{E}_T$ event,
it has been suggested (Kane et al. PRL 76, 3498 (1996))

$\tilde{e} \to e + \tilde{\chi}_2^0$ and $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 + \gamma$

$\tilde{\chi}_1^0$ is mostly higgsino, $\tilde{\chi}_2^0$ is mostly gaugino
only possible if $M_1 \sim M_2$, $\tan\beta \sim 1$ and $|\mu| < M_2$ in MSSM
No gaugino mass unification

Furthermore, the event kinematics and rate suggest

$m(\tilde{\chi}_2^0) - m(\tilde{\chi}_1^0) > 20$ GeV/c^2

$Br(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 + \gamma) = 100\%$

Processes $p\bar{p} \to \tilde{e}\tilde{e}$, $\tilde{\nu}\tilde{\nu}$, $\tilde{\chi}_2^0\tilde{\chi}_2^0$
will result $\gamma\gamma\not{E}_T$ events at Tevatron
Clean signature, but small cross section......

Processes $p\bar{p} \to (\tilde{q}, \tilde{g}, \tilde{\chi}_2^0) \to \tilde{\chi}_2^0 + X$
will result $\gamma\not{E}_T$ events with multijets at Tevatron
Large cross section, large backgrounds......

Search for $\gamma\gamma\not{E}_T$ Events

Using the event selection and the background estimation of our published $\gamma\gamma\not{E}_T$ analysis (PRL 80, 442 (1998))

$E_T^{\gamma1}$>20 GeV, $E_T^{\gamma2}$>12 GeV, $|\eta^\gamma|$<1.2 or 1.5<$|\eta^\gamma|$<2.0, $\not{E}_T$>25 GeV

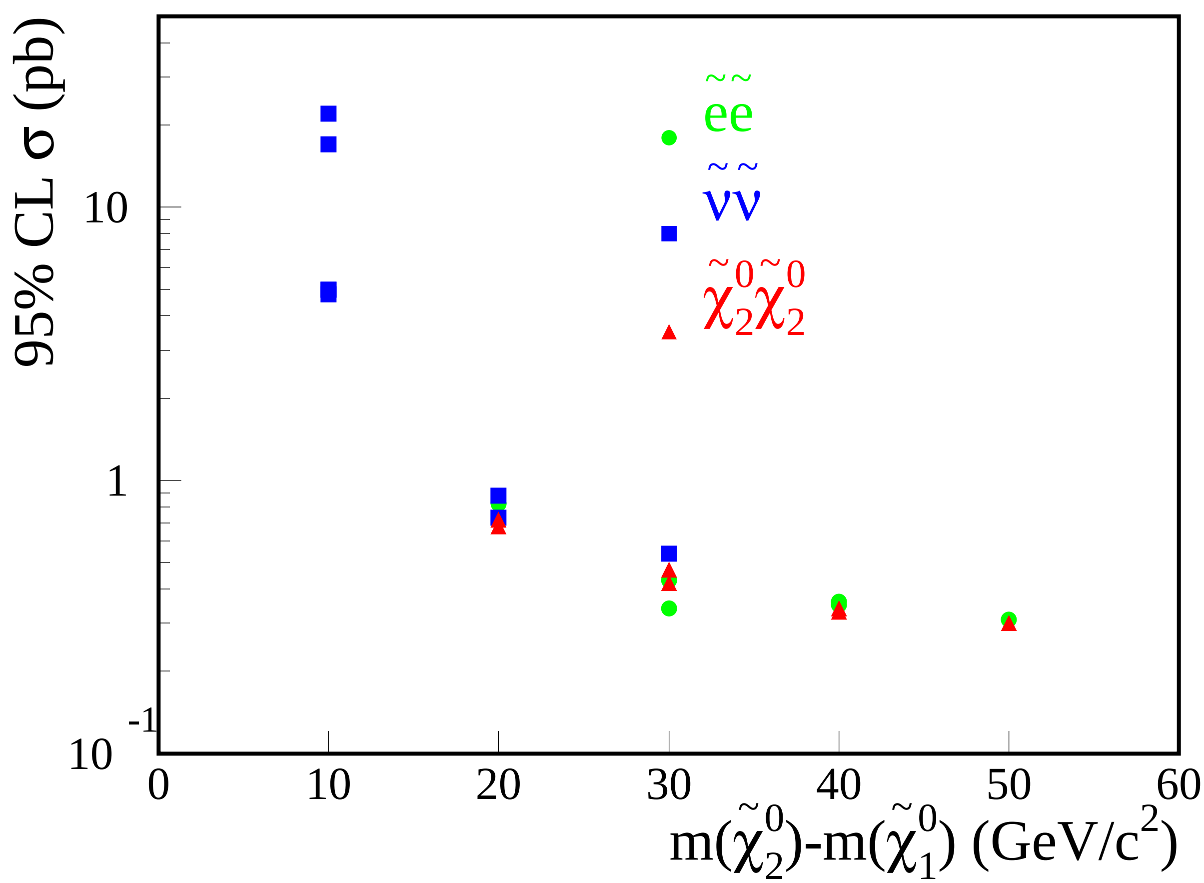
2 events observed and 2.3±0.9 background events expected

we can set 95% CL upper limits on

$\sigma(p\bar{p} \to \tilde{e}\tilde{e}, \tilde{\nu}\tilde{\nu}, \tilde{\chi}_2^0\tilde{\chi}_2^0 + X)$

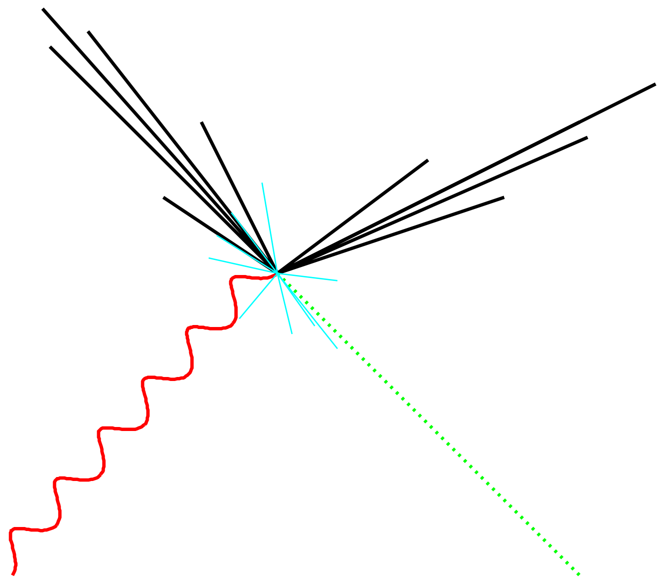
All these limits are well above the theoretical cross sections

No sensitivity to the models



Search for $\gamma \not{E}_T$+≥2-Jets Events

Signature and Backgrounds



One high E_T photon, two or more jets
Large missing transverse energy

There is almost no Standard Model backgrounds at parton-level

But there are important instrumental backgrounds
(1) multijet, direct photon events
(2) e+jets (W+jets, $t\bar{t}$,...) and ν+jets events

Search for $\gamma \not{E}_T$+≥2-Jets Events

Selection of Base Sample

(1) E_T^{γ}>20 GeV, |η|<1.2 or 1.5<|η|<2.0

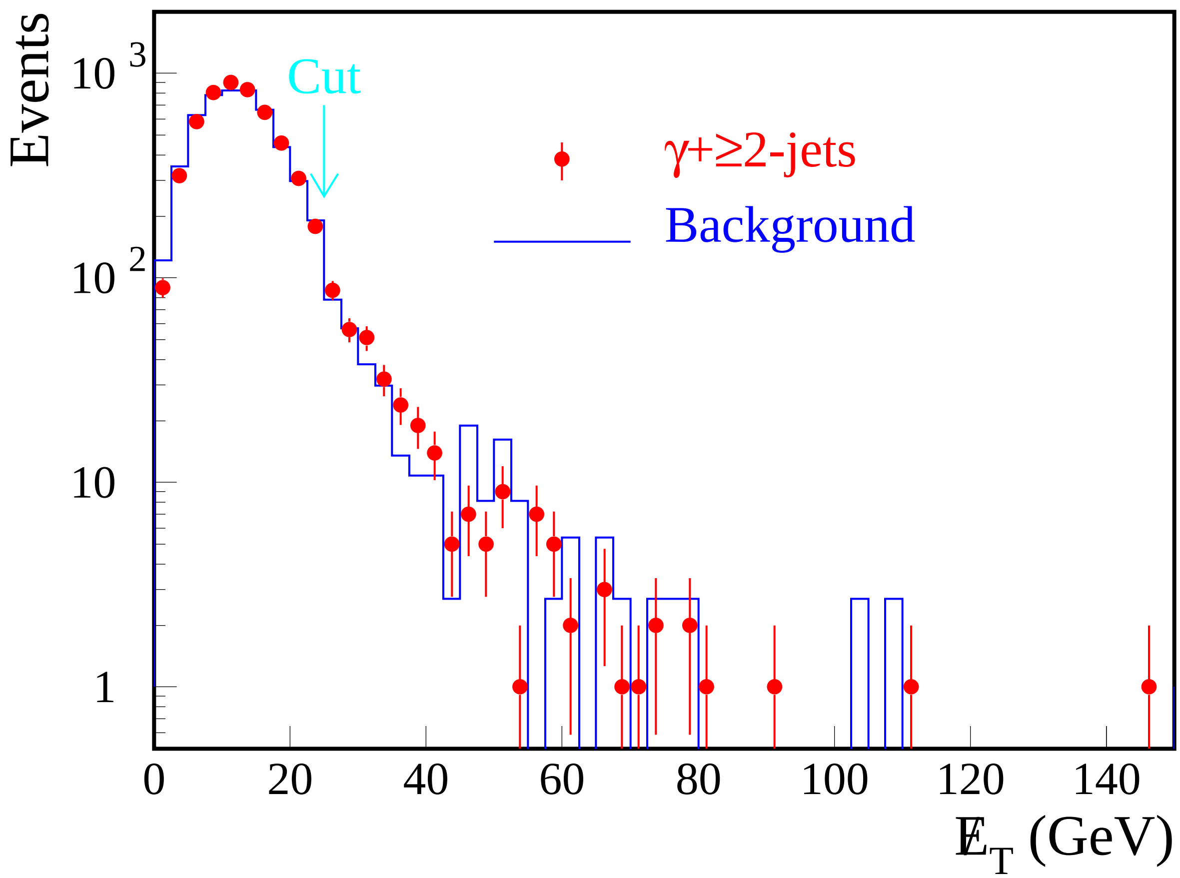
(2) Two or more jets with E_T^{j}>20 GeV, |η|<2.0

(3) $\not{E}_T$>25 GeV

A total of 378 events are selected

(74 events with ≥3-jets and 10 events with ≥4-jets)

from a data sample of $\int L dt = 99.4 \pm 5.4\ pb^{-1}$



Search for $\gamma \not{E}_T$+≥2-Jets Events

Multijet Backgrounds

Multijet (with misidentified photon)
and direct photon events with mismeasured $\not{E}_T$
will fake $\gamma \not{E}_T$+≥2-jets events

$\not{E}_T$ mismeasurement can be modeled using
multijet events with photon-like clusters

The estimated multijet background is
370.3±35.7 events

e/ν+jets Backgrounds

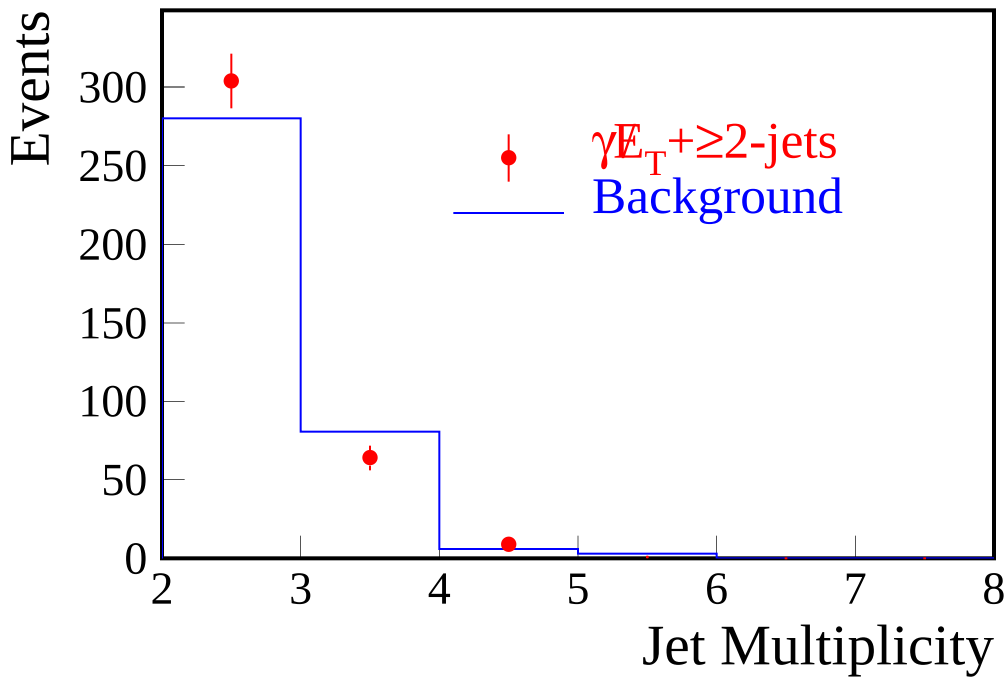
Events with genuine $\not{E}_T$ such as those from
W(→eν)+jets and Z(→νν)+jets would fake $\gamma \not{E}_T$+≥2-jets
events if the electrons or jets were misidentified as photons

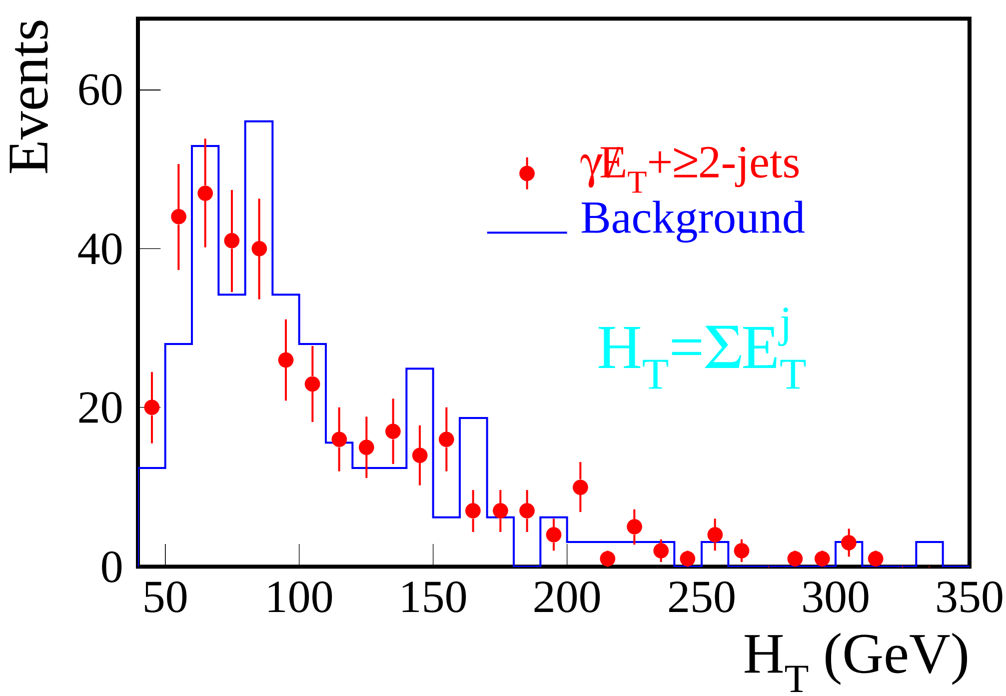
We estimate their contributions using the fake
P(e→γ) and P(jet→γ) probabilities

The estimated e/ν+jets background is 5.3±0.8 events

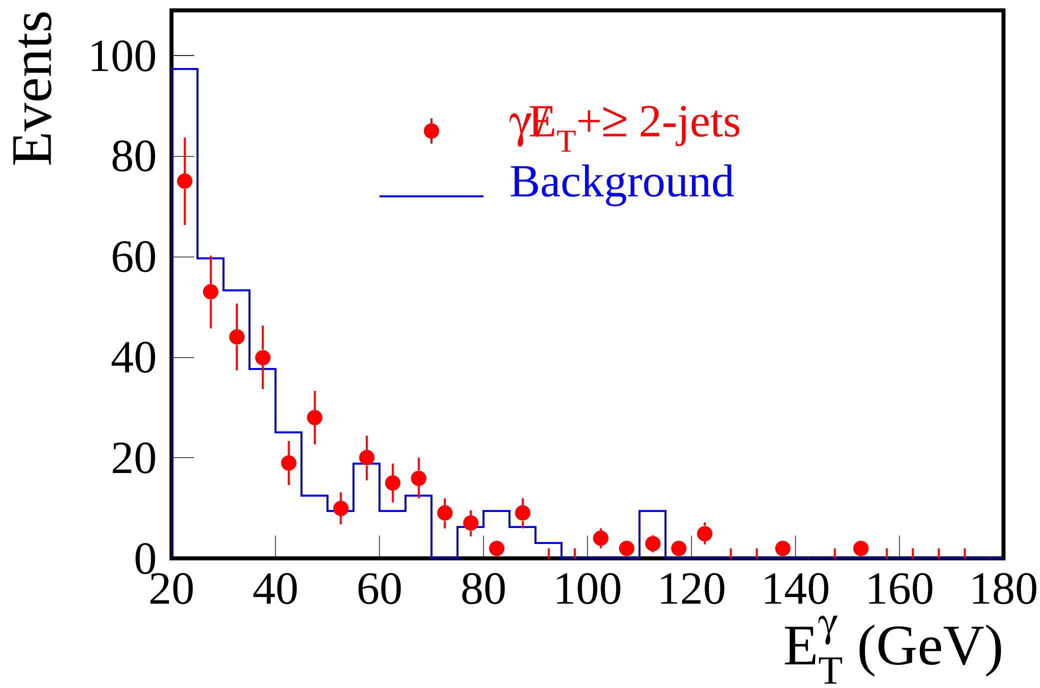
Total background 375.6±35.7

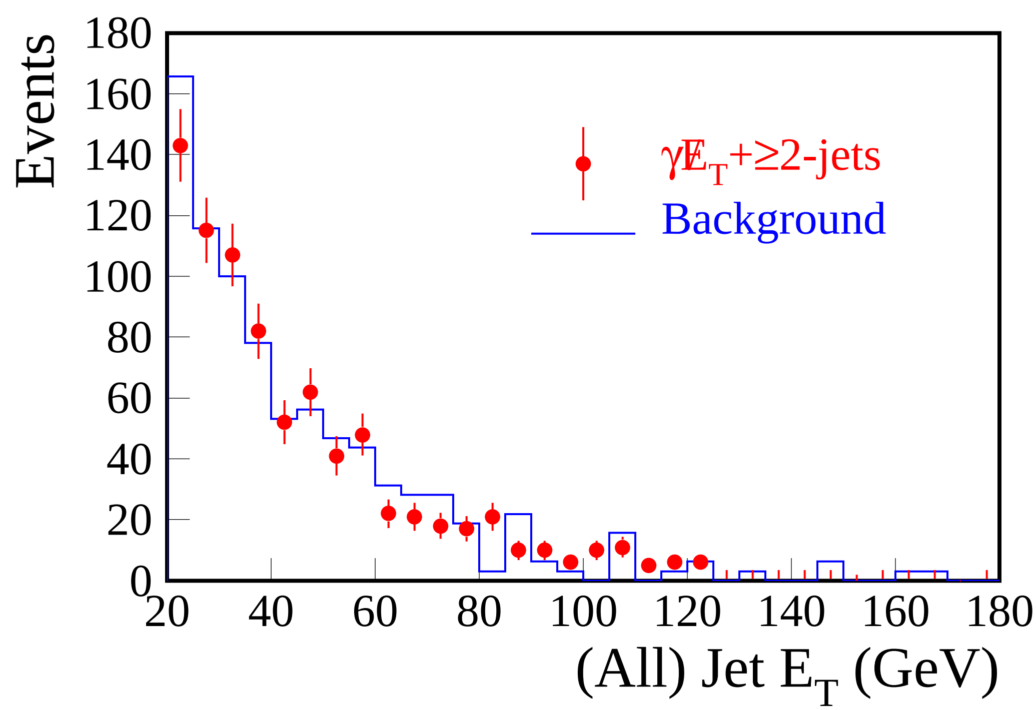
Search for $\gamma\not{E}_T$+≥2-Jets Events





Search for $\gamma \not{E}_T + \geq 2$-Jets Events





Search for $\gamma\not{E}_T$+≥2-Jets Events

Signal Simulation

The production of $p\bar{p}\rightarrow(\tilde{q}, \tilde{g}, \tilde{\chi}^0_2) \rightarrow\tilde{\chi}^0_2$+X and decays of sparticles are modeled using SPYTHIA program

The MSSM parameters (M_1, M_2, μ and $\tan\beta$) are varied within the constraints

$m(\tilde{\chi}^0_2)-m(\tilde{\chi}^0_1)>20$ GeV/c^2

$Br(\tilde{\chi}^0_2\rightarrow\tilde{\chi}^0_1+\gamma)=100\%$

Sleptons are assumed to be heavy so they do not affect decays of other sparticles

All stop productions (direct or indirect) are ignored

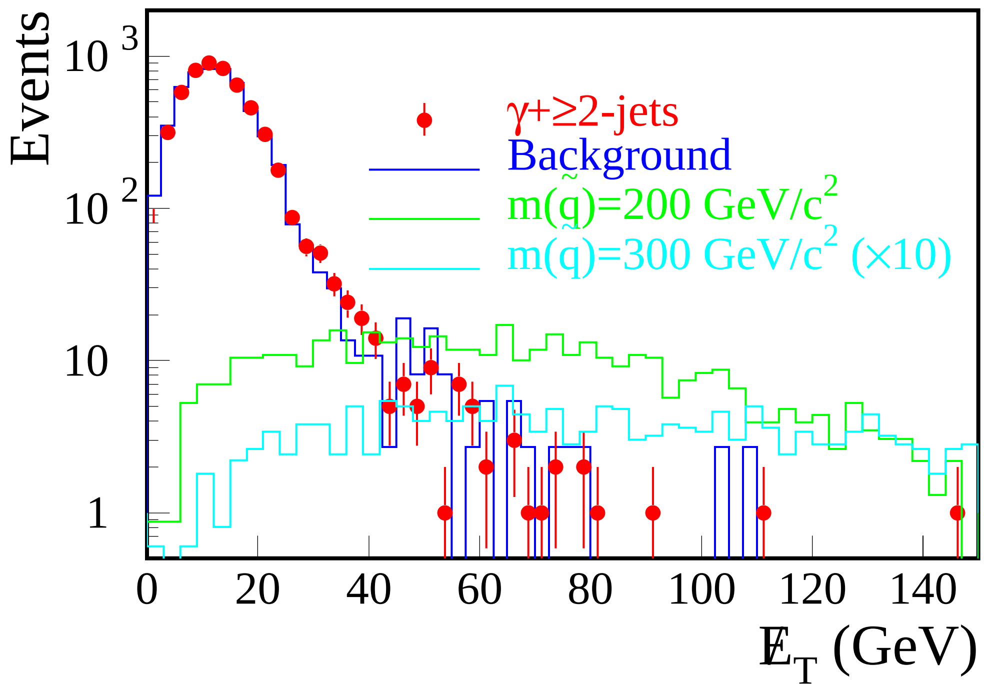
We study three different cases

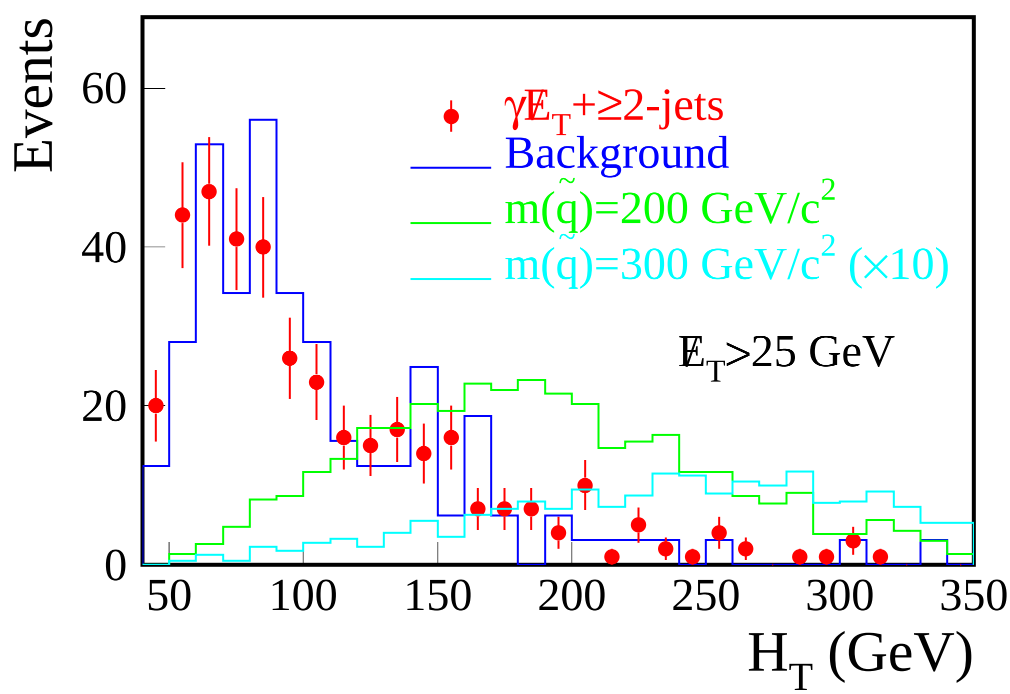
1) $m(\tilde{q})=m(\tilde{g})$ — equal squark/gluino mass
2) $m(\tilde{q})\gg m(\tilde{g})$ — heavy squarks/light gluinos
3) $m(\tilde{q})\ll m(\tilde{g})$ — heavy gluinos/light squarks

For the case $m(\tilde{q})=m(\tilde{g})$, the expected numbers of events are 351 for $m(\tilde{q})$=200 GeV/c^2 and 19 for $m(\tilde{q})$=300 GeV/c^2 in the base sample

Search for $\gamma \not{E}_T$+≥2-Jets Events

$m(\tilde{q})=m(\tilde{g})$





Search for $\gamma \not{E}_T + \geq 2$-Jets Events

Selection Optimization

The number of observed events (378) agrees well
with 375.6±35.7 events expected from background sources
(For $\gamma \not{E}_T + \geq 3$-jet events, 74 observed compared with 75.8±16.2 expected)

The base sample is dominated by multijet backgrounds
The background events and events expected from supersymmetry
have very different $\not{E}_T$ and H_T distributions

To increase sensitivity to supersymmetry, we optimize
the event selection in $\not{E}_T$-H_T plane

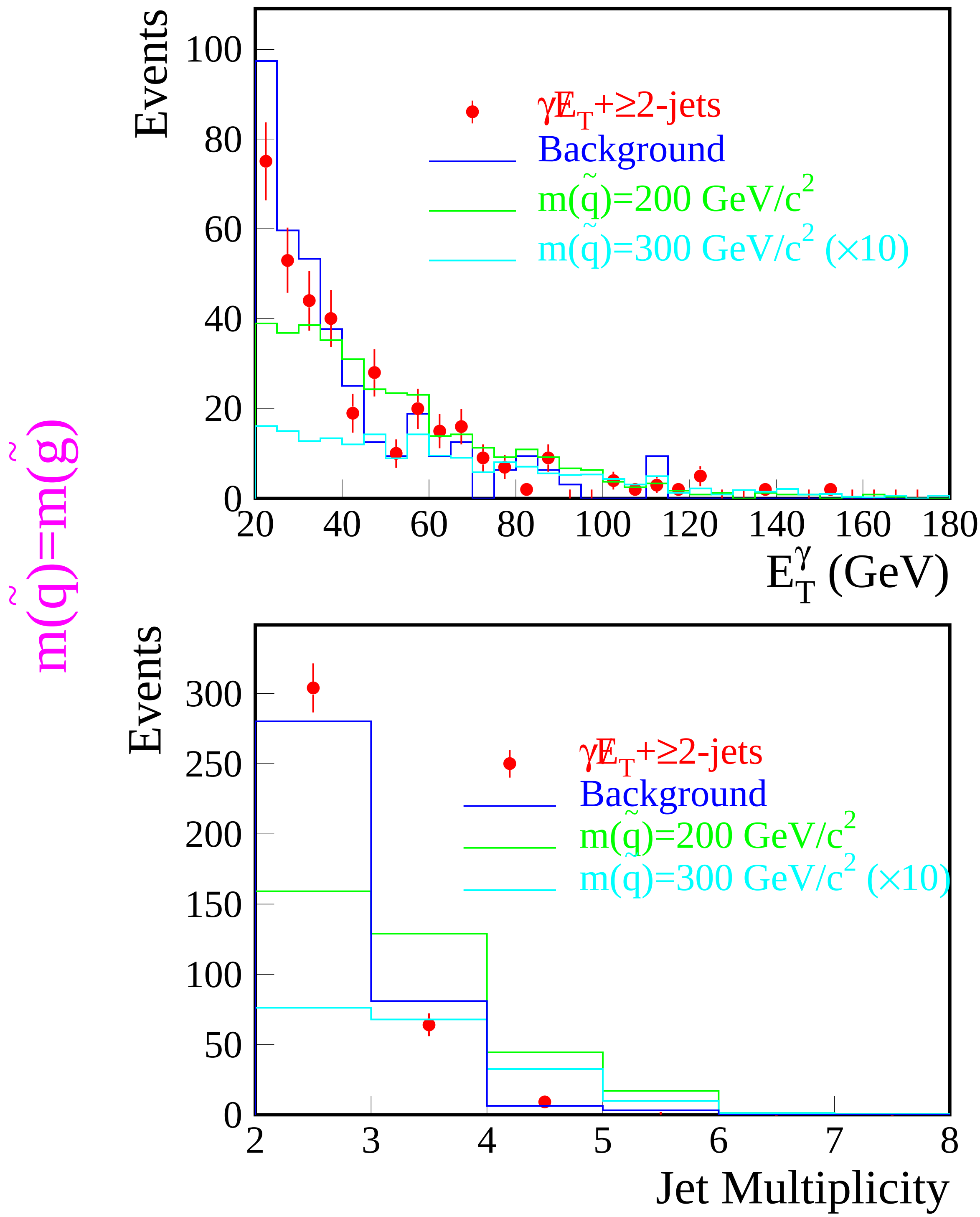
$\not{E}_T$ and H_T cuts are varied to maximize the ratio
ε/σ_b for $m(\tilde{q})=m(\tilde{g})=300$ GeV/c^2,

The optimized cuts are
$\not{E}_T>45$ GeV and $H_T>220$ GeV

For the optimized cuts, we observe
5 data events while 8.1±5.8 background events are expected

For $m(\tilde{q})=m(\tilde{g})=300$ GeV/c^2
the detecting efficiency for the signal is (21.5±1.0±1.9)%
and 11.3 events are expected

Search for $\gamma \not{E}_T$+≥2-Jets Events



Search for $\gamma \not{E}_T + \geq 2$-Jets Events

Interpretations of the Results

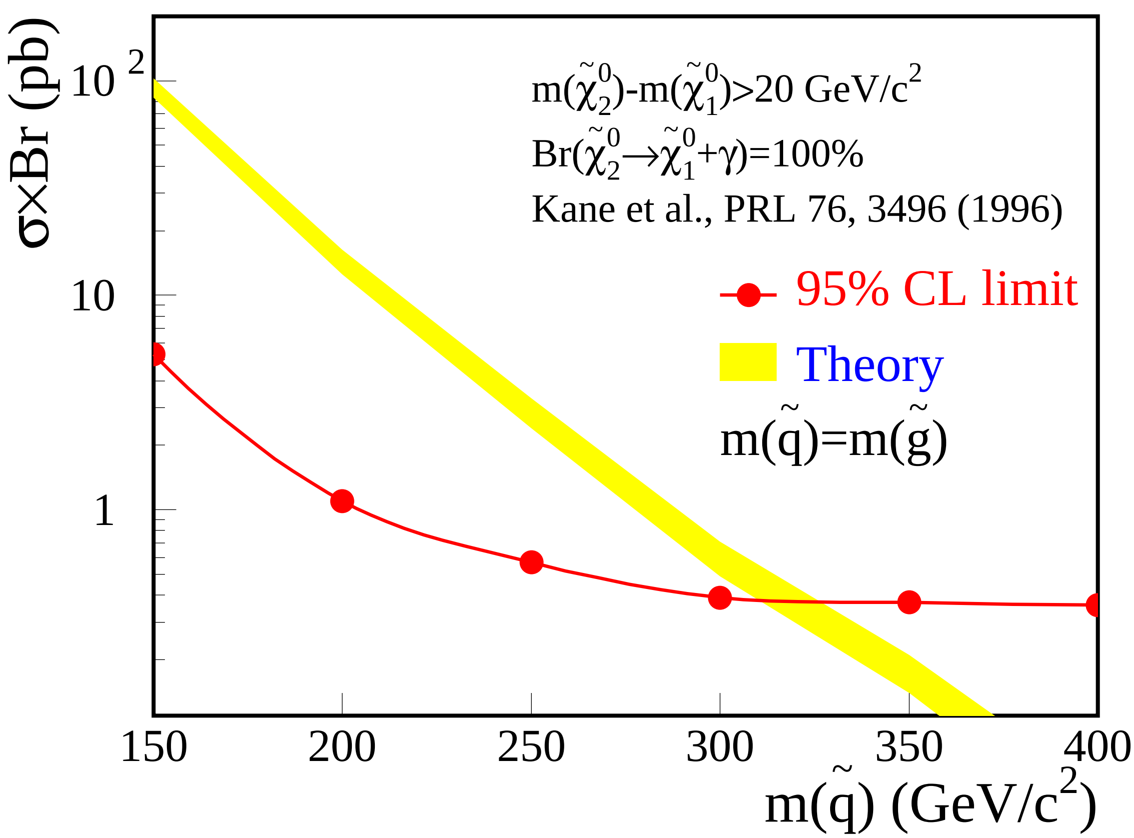
With 5 candidates and 8.1±5.8 events expected
we observe no excess of events

We set a 95% CL low mass limit of 311 GeV/c^2 for
equal squark/gluino mass in models with

$m(\tilde{\chi}_2^0)-m(\tilde{\chi}_1^0)>20$ GeV/c^2

$Br(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0+\gamma)=100\%$

and heavy sleptons



Search for $\gamma \not\!\!E_T$+≥2-Jets Events

Interpreations of the Results

If squarks are heavy and gluinos are light
$m(\tilde{g})>233\ \mathrm{GeV}/c^2$

If squarks are light and gluinos are heavy
$m(\tilde{q})>219\ \mathrm{GeV}/c^2$

The $\sigma(p\bar{p}\rightarrow\tilde{\chi}_2^0+X)$ is higher if sleptons are light
and is lower if stop is light
Consequently, the mass limits vary about 10 GeV/c^2

No sign of the models of Kane et al.
But the models are NOT ruled out if the squarks/gluinos are heavy

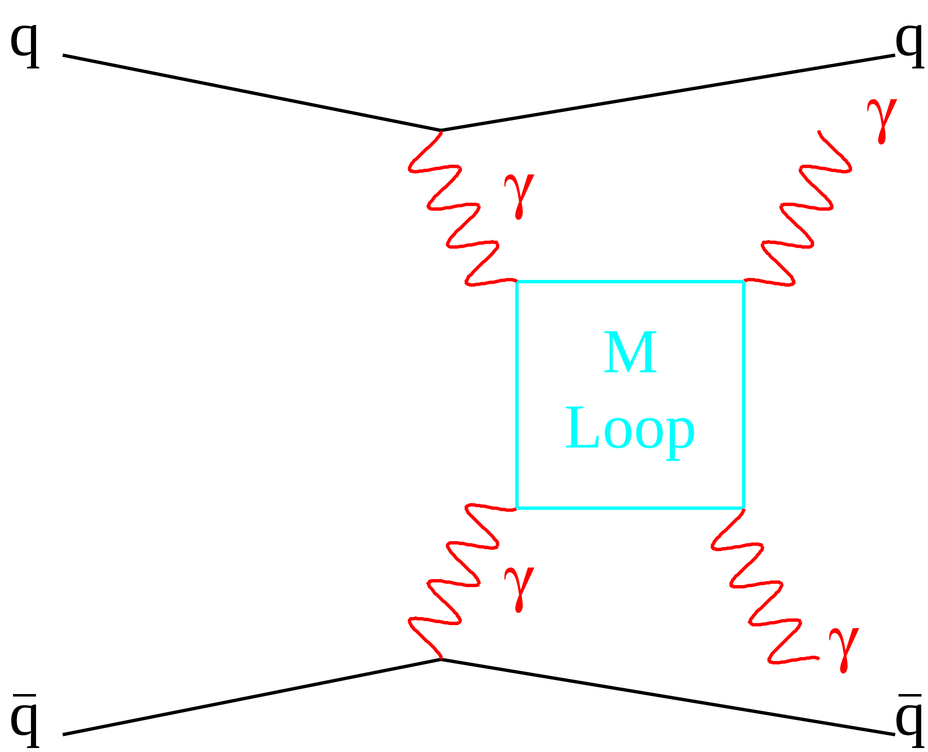
Search for Energetic γγ Events

Introduction

We have searched for possible excess
beyond the expected backgrounds in
γγ+jets and γγ+$\not{E}_T$ final states and found nothing

But how about energetic γγ events?

In fact, the existence of the monopole will result in
anomalous γγ→γγ scattering at Tevatron



Magnetic coupling, low Q^2 production
resulting large σ(pp̄→γγ+X) cross section

Search for Energetic $\gamma\gamma$ Events

The Monopole Theory

The monopole was introduced by Dirac and
late further developed by Schwinger

It symmetrizes electricity and magnetism
and explains quantization of electric charge

$$g = \frac{2\pi n}{e} \qquad n = \pm 1, \pm 2, \ldots$$

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

The relic monopoles have been searched for extensively
Their flux is strongly constrained
However, these experiments are insensitive to the monopole mass

Accelerator experiments complement the flux experiments
and are unique in exploring monopole mass reach

The L3 experiment sets a mass limit
$M > 510\ \mathrm{GeV}/c^2$
by studying the $Z^0 \rightarrow \gamma\gamma\gamma$ rate

Search for Energetic $\gamma\gamma$ Events

Selection of Base Sample

1) Two photons with E_T^{γ}>40 GeV and $|\eta^{\gamma}|$<1.1
2) No jet with E_T^{j}>15 GeV and $|\eta^{j}|$<2.5
3) No significant $\not\!\!E_T$, $\not\!\!E_T$<25 GeV

90 candidate events selected

Background Processes

Physics backgrounds due to similar loop diagrams with other particles are negligible

The QCD backgrounds due to dijets (jj), direct photons (jγ) and diphotons ($\gamma\gamma$) with jets misidentified as photons are estimated to be 25±9 events

The Drell-Yan backgrounds due to dielectron production with electrons misidentified as photons are estimated to be 63±7 events

The total estimated background events: 88±12, in good agreement with the 90 observed candidates

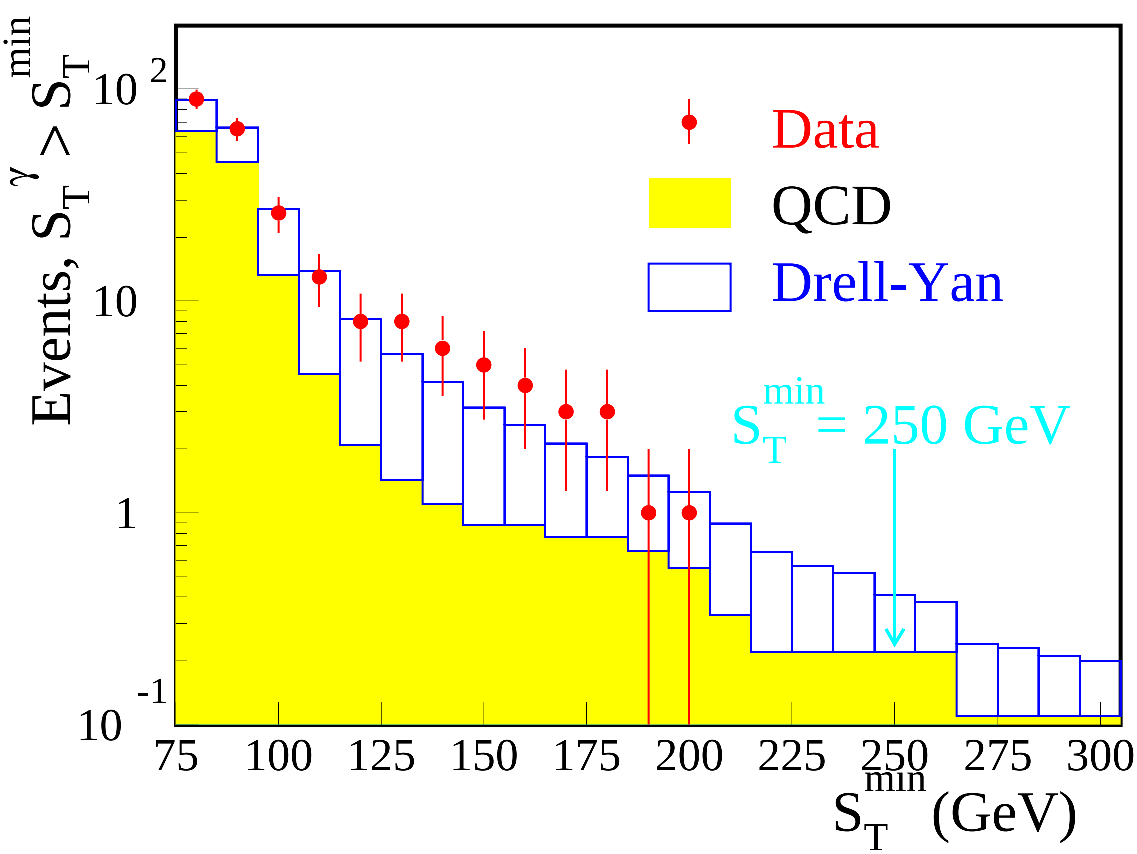
Search for Energetic γγ Events

Selection Optimization

To optimize the sensitivity to the monopole contribution we apply a cut on $S_T = \Sigma E_T^\gamma$

We vary the S_T cut threshold (S_T^{min}) to achieve an expected background of 0.4 events

The S_T^{min}=250 GeV cut corresponds to a background of 0.41±0.11 events with no data events



Search for Energetic $\gamma\gamma$ Events

Cross Section Limit

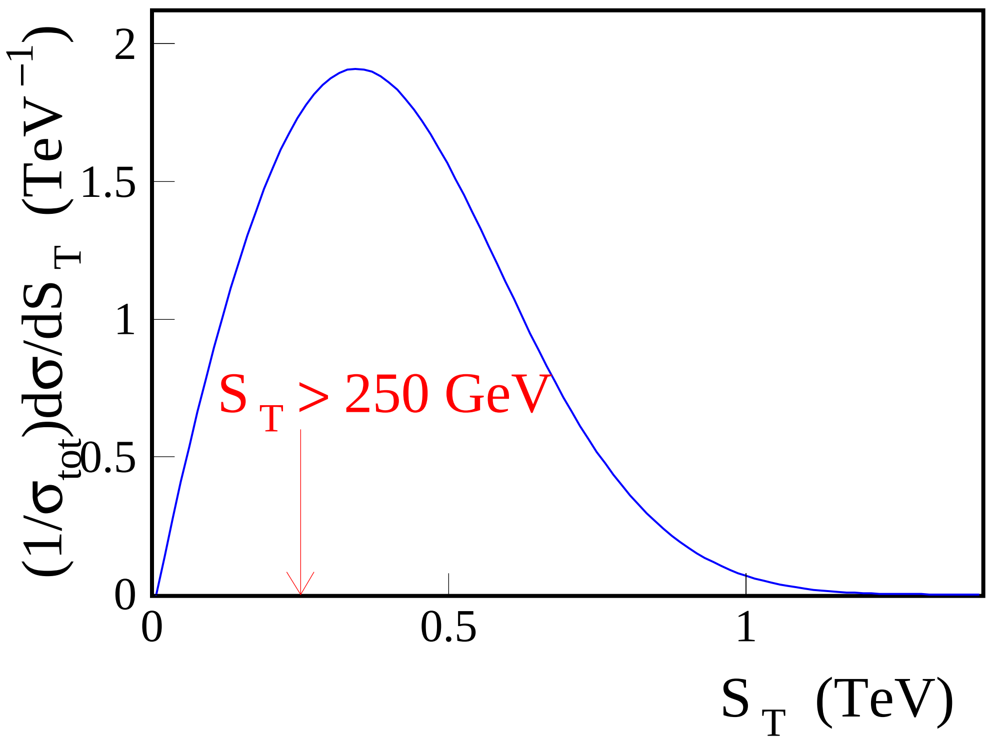
The photon identification efficiency is 73%
the overall efficiency for selecting $\gamma\gamma$ events with
$\Sigma E_T^{\gamma}>250$ GeV and $|\eta^{\gamma}|<1.1$ is
$(52.8\pm1.4)\%$

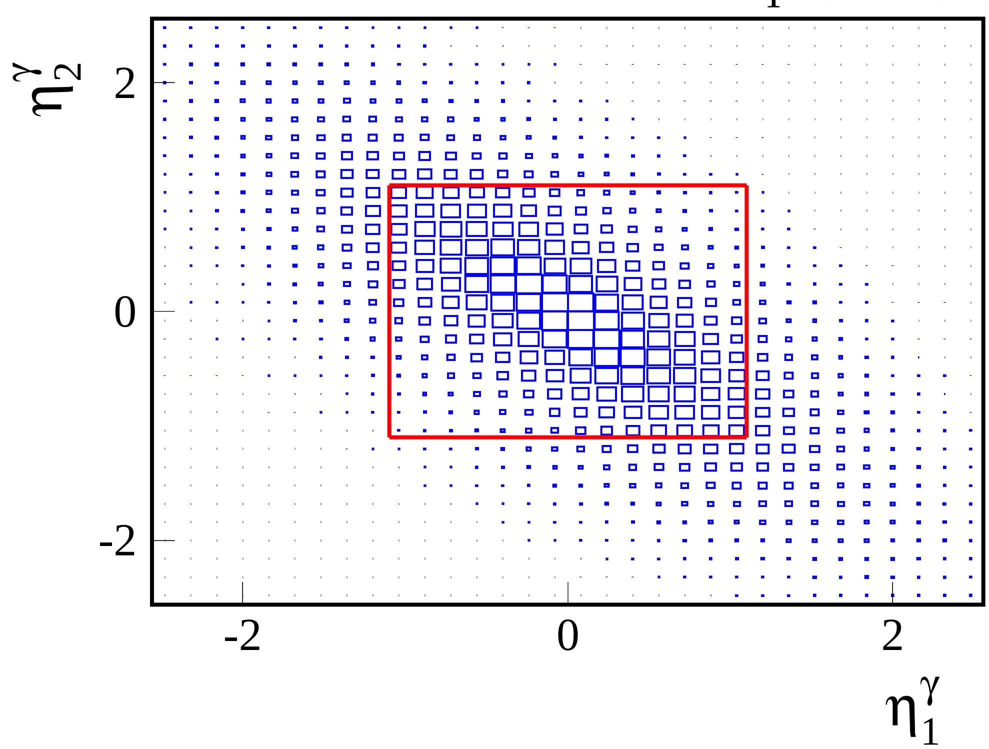
The analysis is based on a sample of
69.5 ± 3.7 pb^{-1}, the trigger did not require
the presence of an inelastic collision and therefore
was efficient for low Q^2 process

We set 95% CL upper cross section limit on the production of
two or more photons with $\Sigma E_T^{\gamma}>250$ GeV and $|\eta^{\gamma}|<1.1$

$$\sigma(p\bar{p}\rightarrow\gamma\gamma+X)<0.083 \text{ pb}$$

Search for Energetic γγ Events





Search for Energetic γγ Events

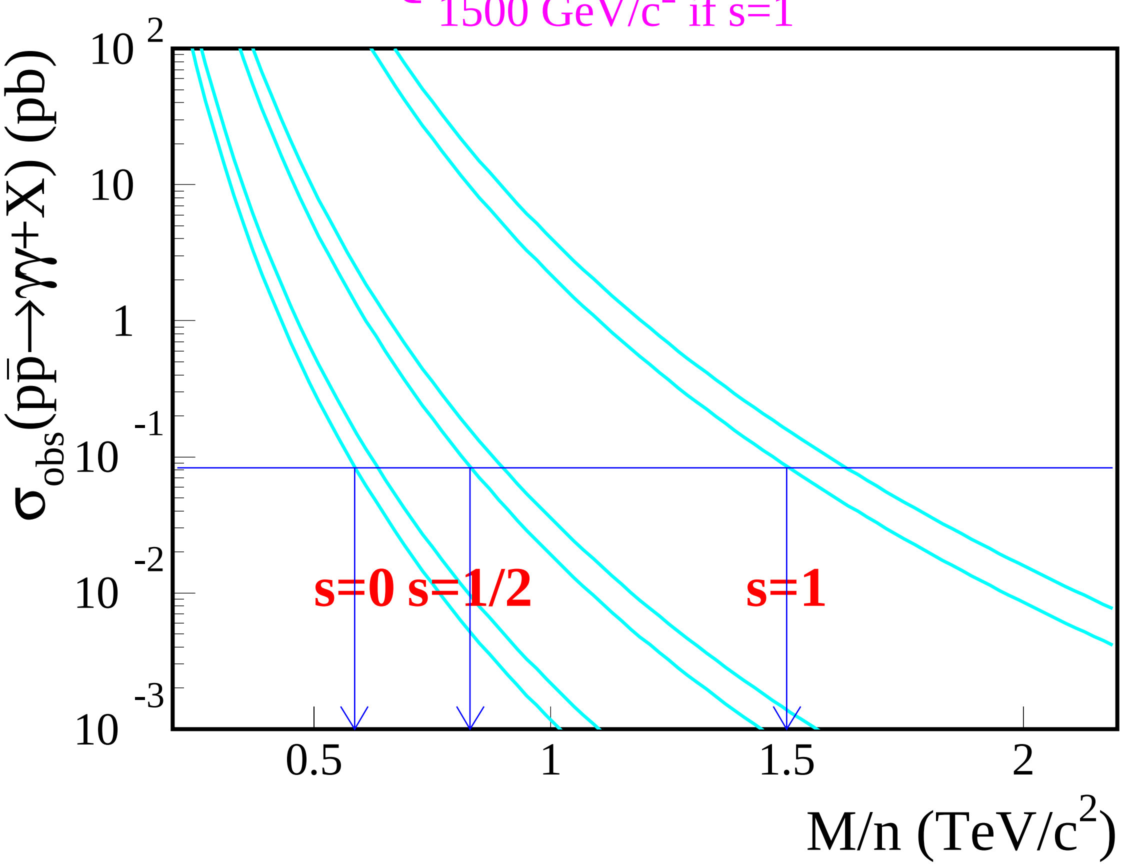
Monopole Interpretation

If we take the $p\bar{p}\to\gamma\gamma+X$ cross section recently calculated by I.F. Ginzburg and A. Schiller (hep-ph/9802310)

$$\sigma(p\bar{p}\to\gamma\gamma+X) = 0.040\, P(s) \left(\frac{n}{M\,(\mathrm{TeV})}\right)^8 \mathrm{pb}$$

We set 95% CL limits on monopole mass M/n

$$M/n > \begin{cases} 585\ \mathrm{GeV}/c^2 & \text{if } s=0 \\ 830\ \mathrm{GeV}/c^2 & \text{if } s=1/2 \\ 1500\ \mathrm{GeV}/c^2 & \text{if } s=1 \end{cases}$$



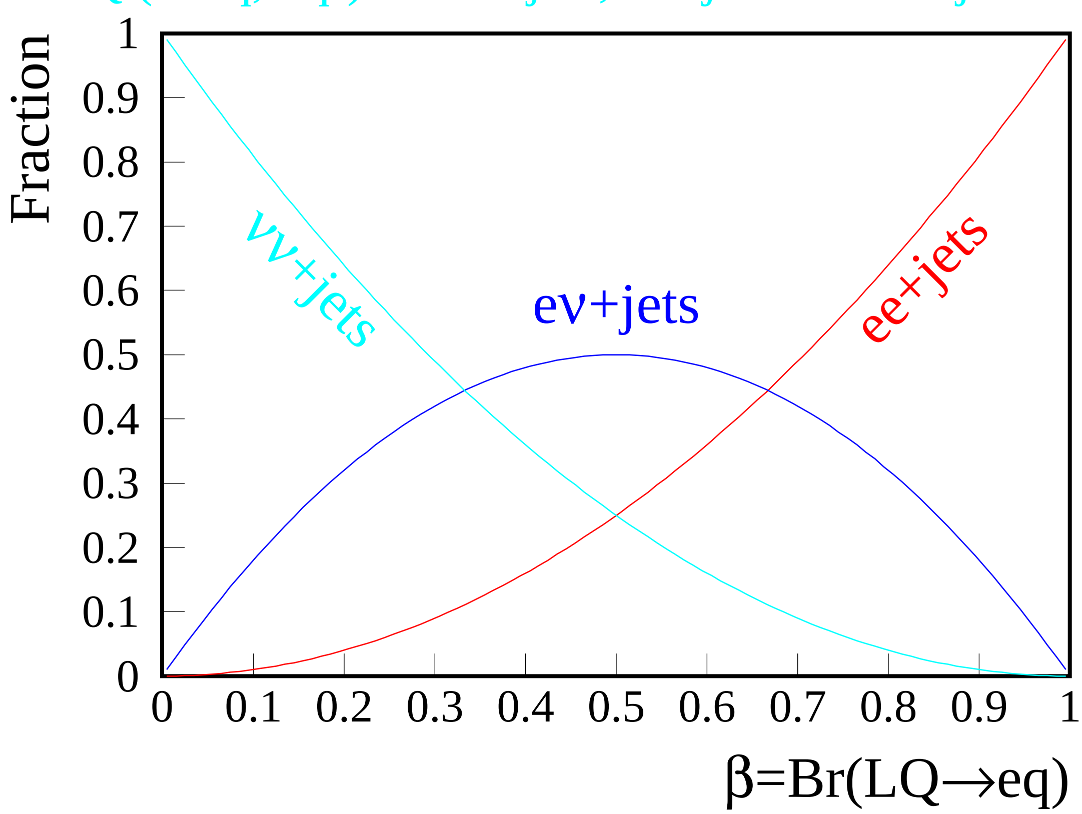
Update on Leptoquark Searches

Introduction

Leptoquarks (LQ) are hypothesized exotic color-triplet bosons which couple to both quarks and leptons, LQ are expected to couple to leptons/quarks within a single generation

Thanks to H1 and ZEUS experiments at HERA
The 1st generation LQ received much publicity in 1997

Leptoquarks would be dominantly pair produced via strong interactions at Tevatron. The signatures for the 1st generation LQ ($\rightarrow$eq, νq') are ee+jets, eν+jets and $\nu\nu$+jets



Update on Leptoquark Searches

ee+jets Analysis

1) Two electrons with $E_T>20$ GeV, $|\eta|<1.1$ or $1.5<|\eta|<2.5$
2) Two jets with $E_T>15$ GeV, $|\eta|<2.5$
3) $82<M_{ee}<100$ GeV/c^2
4) $S_T(\equiv E_T^{e1}+E_T^{e2}+\Sigma E_T^{j}) > 350$ GeV

No candidate was observed
with the estimated 0.45±0.06 background events

Update on Leptoquark Searches

$e\nu$+jets Analysis

1) One electron with E_T>20 GeV, $|\eta|$<1.1 or 1.5<$|\eta|$<2.5
2) Two jets with E_T>20 GeV, $|\eta|$<2.5
3) $\not{E}_T$>30 GeV and point away from jets
4) NN (based on S_T and mass variables) cut optimzed
for each assumed LQ mass for M_{LQ}>120 GeV/c^2
$S_T(\equiv E_T^e + E_T^{j1} + E_T^{j2} + \not{E}_T)$>400 GeV for M_{LQ}<120 GeV/c^2

No candidate observed with the expected background events ranging from 0.3 to 0.6 depending on the NN cut

Update on Leptoquark Searches

Interpretation of the Results

No excess of ee+jets and eν+jets events were observed

Combined with our νν+jets results for the stop search,
we exclude the first generation scalar LQ of mass less than
225, 204, and 79 GeV/c^2 for β=1, 0.5, and 0, respectively

These results rule out a leptoquark interpretation of the excess
of high Q^2 events at HERA within chiral models

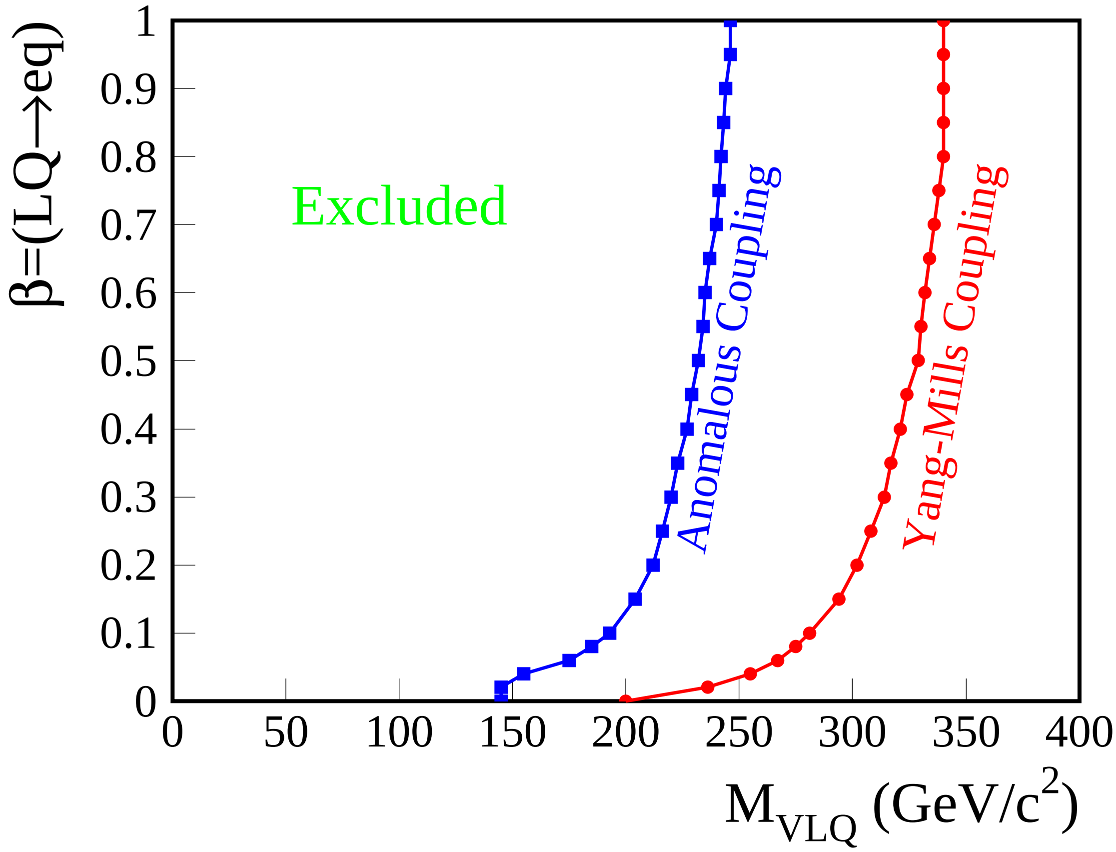
Update on Leptoquark Searches

Vector Leptoquark

LQ can be either scalar or vector particles
Vector LQ has the same signatures as the scalar LQ

The ee+jets, eν+jets and νν+jets analyses
for the scalar LQ are applied to
the vector LQ search with small modifications

For Yang-Mills coupling, the lower limits on the vector LQ mass are 340, 329 and 200 GeV/c^2 for β=1, 0.5 and 0, respectively



If supersymmetry is around the corner,
then we still are trying to find out where the corner is...

Monopoles are cool,
but we have not had any luck so far

Leptoquarks are getting cold...

Supersymmetry, monopoles and leptoquarks
are interesting,

we will take whatever God gives...