



Searches for Excited and New Leptons and Quarks at the Tevatron

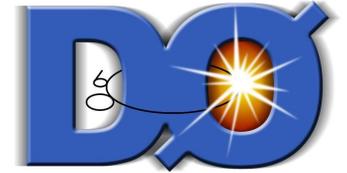
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Moscow, Russia

Herbert Greenlee
Fermilab

For the CDF and D0 Collaborations
July 29, 2006

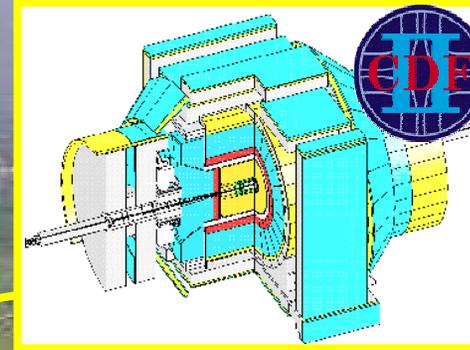


Outline

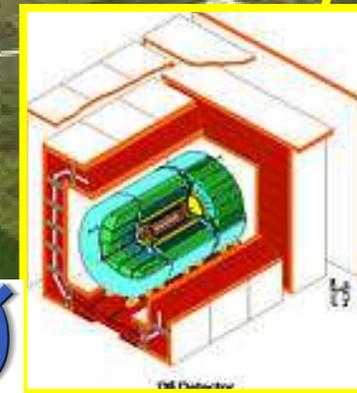


- Tevatron.
- Excited Leptons and Quarks.
 - μ^* (CDF & D0).
 - q^* (D0).
- New Quarks.
 - High p_T dileptons (CDF).
 - High p_T Z 's (CDF).

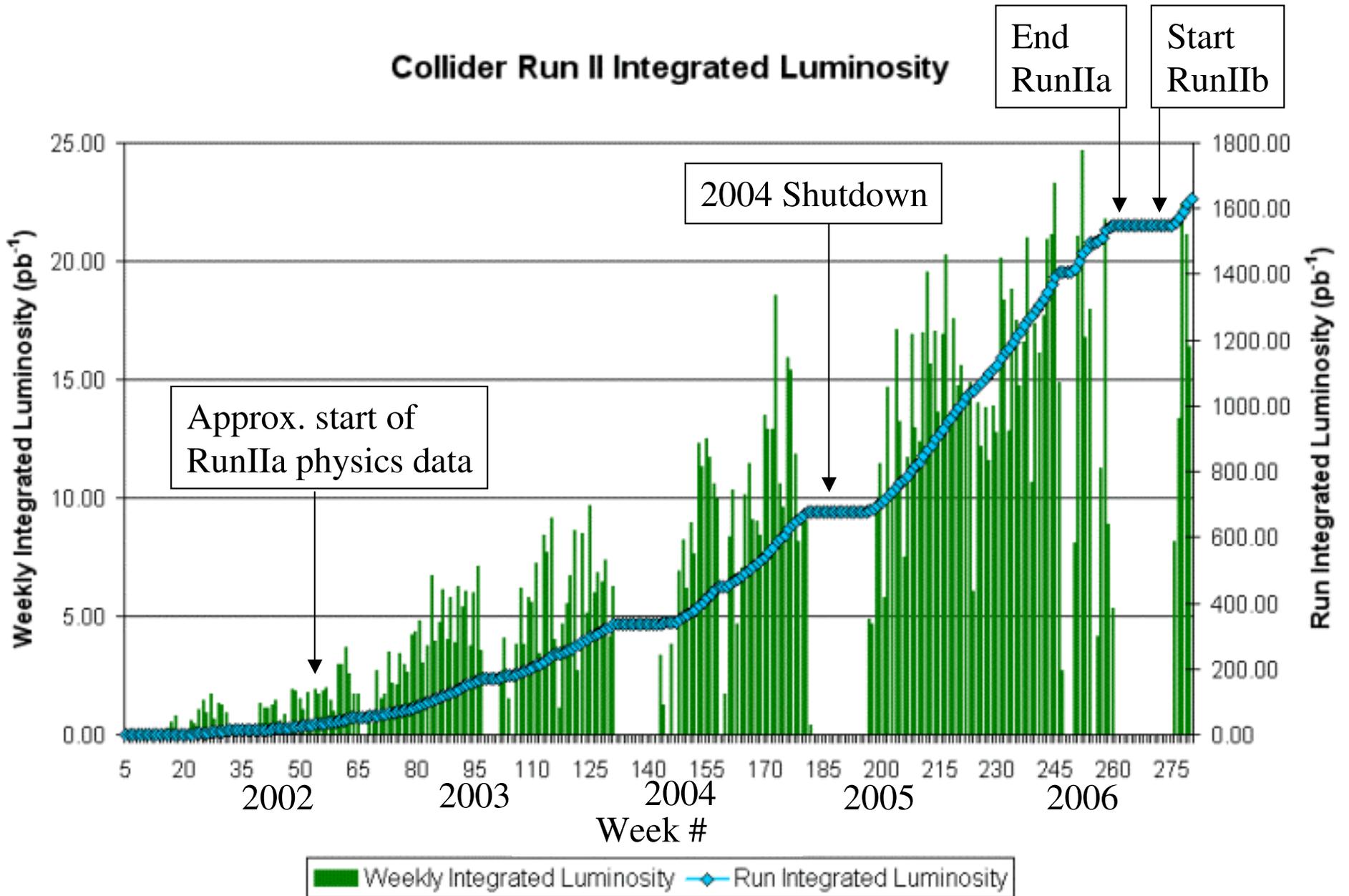
The Fermilab Tevatron



$p\bar{p}$ collisions
 $\sqrt{s} = 1.96 \text{ TeV}$
Run IIa $\sim 1 \text{ fb}^{-1}$
Run IIb started 6/2006 ($4\text{--}8 \text{ fb}^{-1}$)



Collider Run II Integrated Luminosity

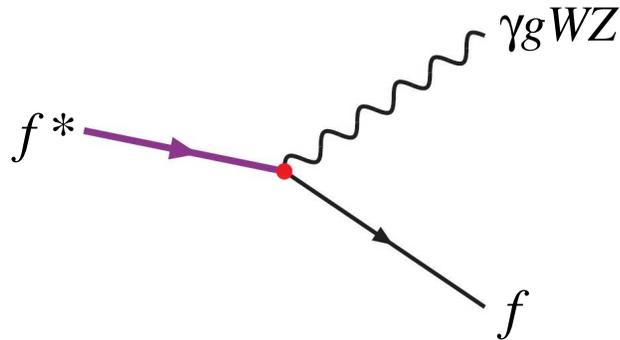


Theoretical Overview

- Excited leptons and quarks —
 - Have the same quantum numbers as known leptons or quarks.
 - Occur in compositeness models where the known fermions are bound states of more fundamental particles which are bound together by a new strong interaction.
 - Have novel interactions due to residual effects of binding force (as do the known fermions in compositeness models).
- New leptons and quarks —
 - Have different or new flavor quantum numbers than known fermions.
 - May have only ordinary gauge interactions.
 - Occur in a variety of theoretical models.

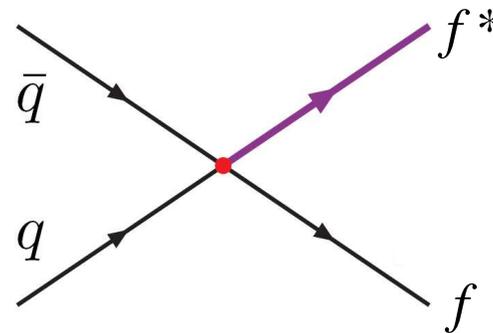
Compositeness Models

- Results in the talk (by both experiments) are interpreted in terms of the compositeness model of Baur, Spira, & Zerwas (PRD 42, 815, (1990)).
- Compositeness models includes the following novel effective interactions.



Gauge boson magnetic transitions
(analogous to $\Sigma^0 \rightarrow \Lambda \gamma$)

Strength $1/\Lambda$



Four-fermion contact interactions

Strength $4\pi/\Lambda^2$

Λ = Compositeness scale.

Additional dimensionless coupling constants are generically of order one
(this is assumed in following model dependent results).

Excited Muon Search

- Associated production of μ^* and μ occurs dominantly via contact interaction followed by decay of μ^* via photon transition.

$$q\bar{q} \rightarrow \mu^* \mu \rightarrow \mu \mu \gamma$$

Production occurs can occur via either contact interaction or gauge interaction (generally contact interaction dominates).

Very clean signature with low background.

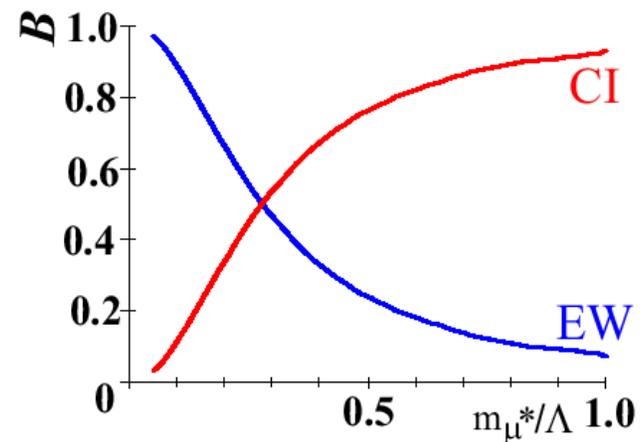
Main background is Drell-Yan:

$Z/\gamma \rightarrow \mu\mu$ with radiated γ (ISR, FSR).

Other backgrounds:

fake γ , diboson (WZ, ZZ)

Decay via gauge boson competes with decay via contact interaction depending on mass of μ^* .



Excited Muon Search (D0)

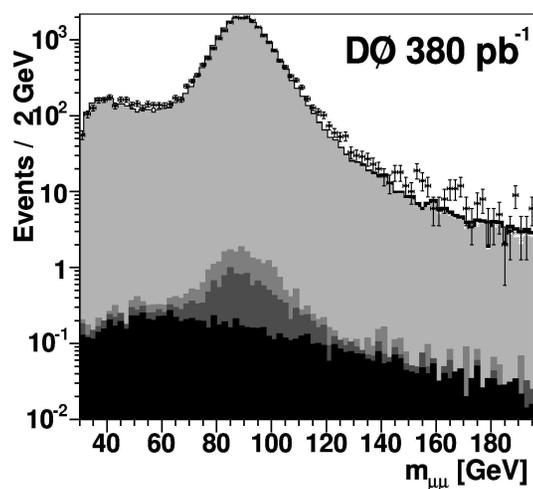


Event selection:

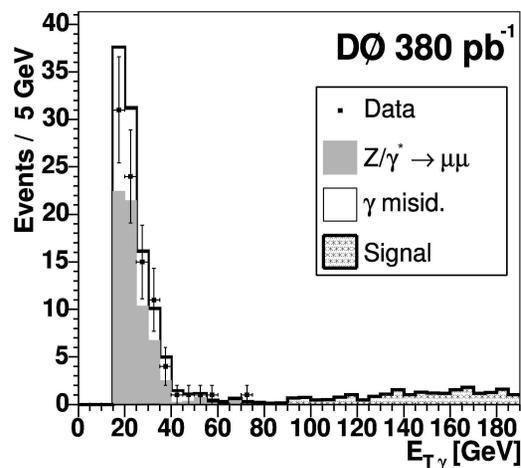
- Two high- p_T isolated muons ($p_T > 15$ GeV).
- One high- p_T isolated photon ($p_T > 27$ GeV).
- $M_{\mu\gamma} > 200$ GeV (varies with μ^* mass hypothesis).

Data Events	SM Background
0	0.17 ± 0.13

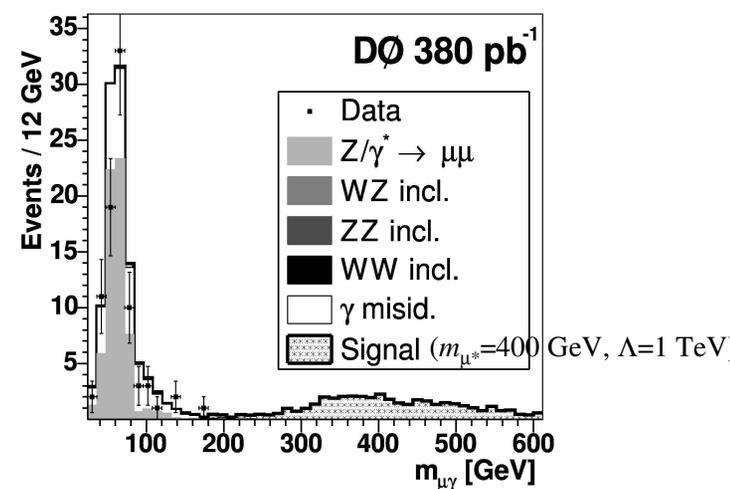
$\mu\mu$ Invariant Mass



Photon E_T

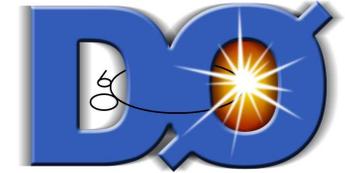


$M_{\mu\gamma}$ ($E_{T\gamma} > 16$ GeV)



No excess events over SM background

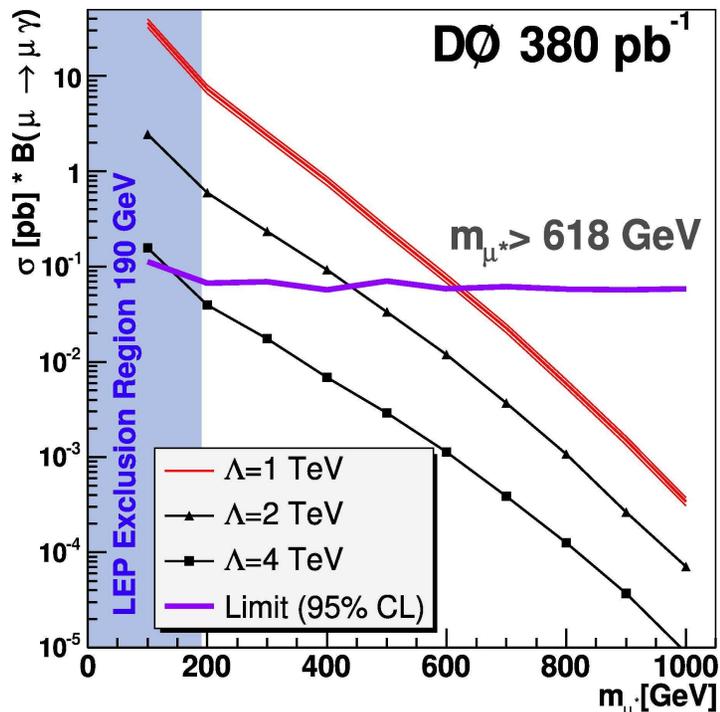
Excited Muon Search (D0)



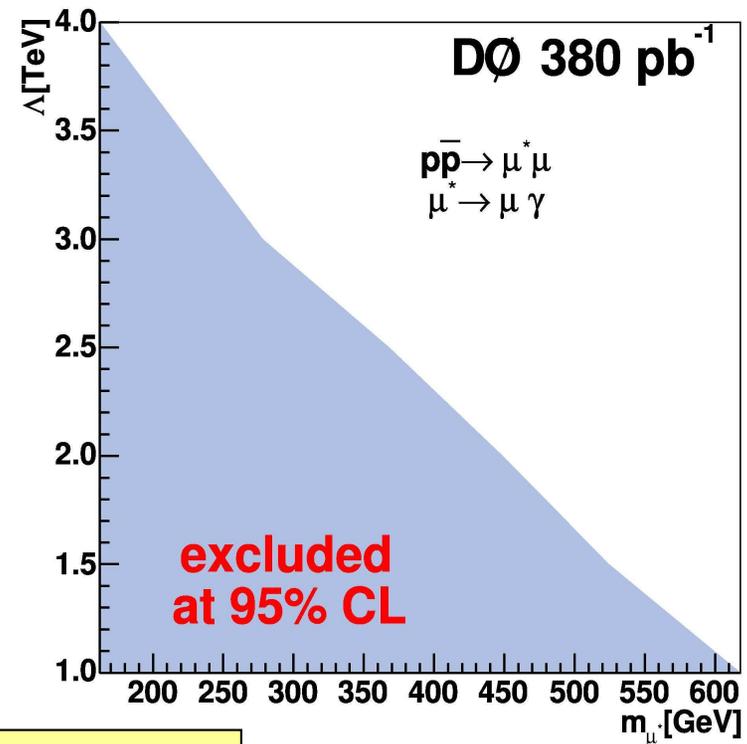
Model Assumptions:

- Contact Interaction and Gauge Boson terms both contribute to production and decay (CI dominates production).

Cross Section Limit

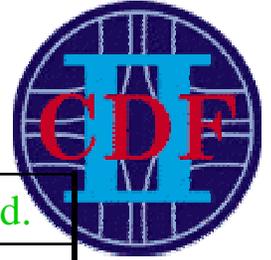


Excluded Region



$m_{\mu^*} > 688 \text{ GeV}$ if $\Lambda = m_{\mu^*}$

Excited Muon Search (CDF)

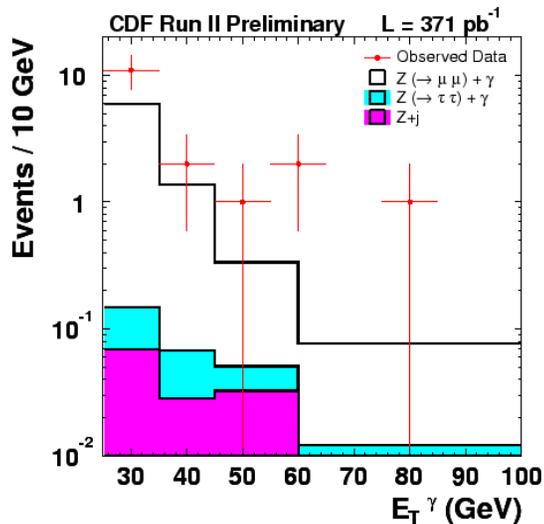


Event selection:

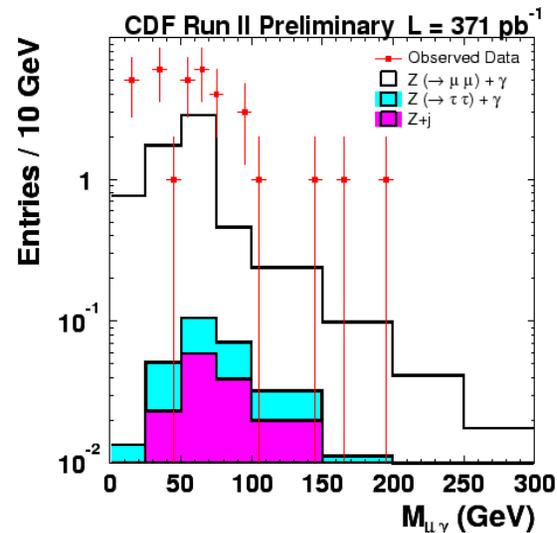
- Two high- p_T isolated muons ($p_T > 20$ GeV).
- One high- p_T isolated photon ($p_T > 25$ GeV).
- $M_{\mu\mu} < 81$ GeV or $M_{\mu\mu} > 101$ GeV
- $M_{\mu\gamma}$ (3σ window, depending in μ^* mass hypothesis)

$m_{\mu\gamma}$ (GeV)	Data	SM Bkgd.
>0	34	16.6 ± 1.8
>50	22	10.4 ± 1.1
>100	4	2.1 ± 0.3
>150	2	0.89 ± 0.14
>200	0	0.37 ± 0.07

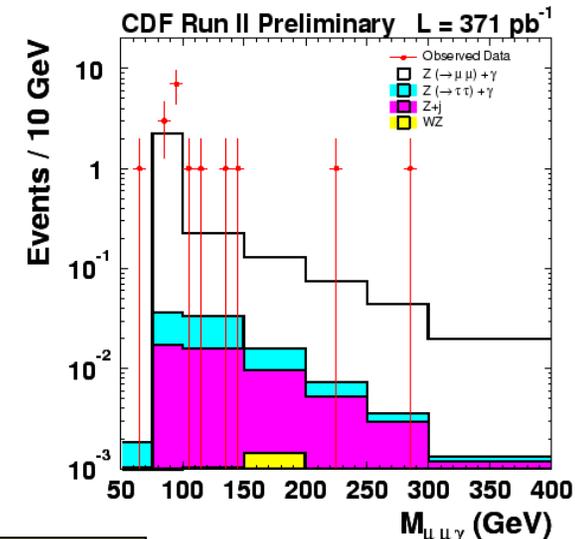
Photon E_T



$\mu\gamma$ Invariant Mass



$\mu\mu\gamma$ Invariant Mass



No excess events over SM background

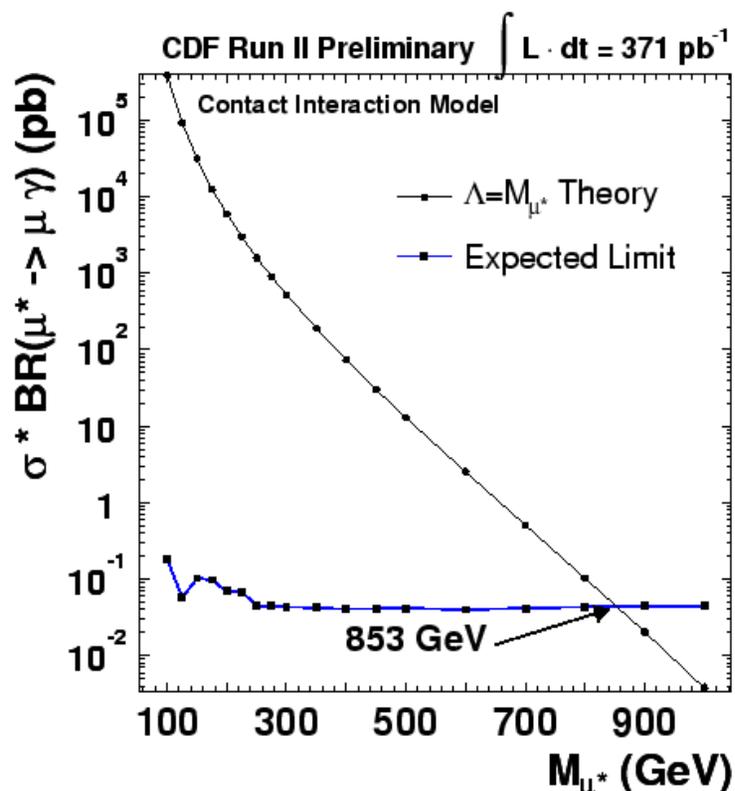


Excited Muon Search (CDF)

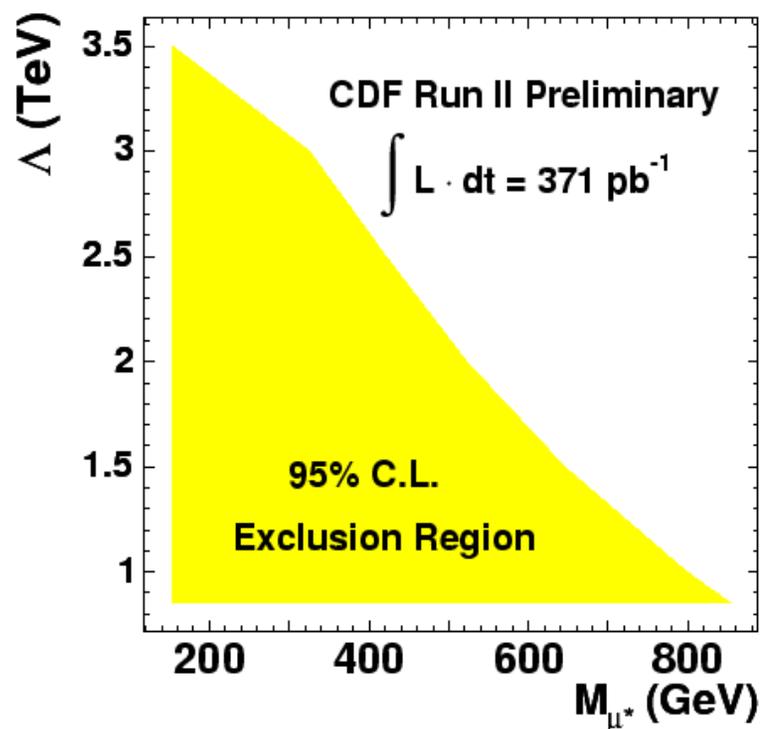
Model Assumptions:

- Production via Contact Interaction, decay via gauge interaction.

Cross Section Limit

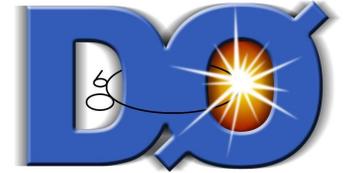


Excluded Region



$m_{\mu^*} > 696 \text{ GeV}$ if $\Lambda = m_{\mu^*}$ and decays via CI are allowed.

Excited Quark Search (D0)



- Resonant production of excited quark via gluon-quark fusion, followed by decay to quark and Z boson and $Z \rightarrow ee$.

$$qg \rightarrow q^* \rightarrow qZ (\rightarrow ee)$$

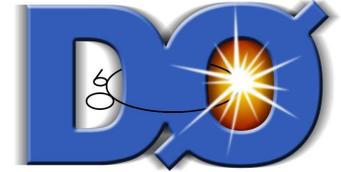
Event Selection:

- Two high p_T isolated electrons ($E_T > 30, 25$ GeV)
- One jet ($E_T > 20$ GeV)
- $80 \text{ GeV} < M_{ee} < 102 \text{ GeV}$
- Final selection using $M_{Z\text{jet}}$ and p_{TZ}
(cuts depend on M_{q^*} and Γ_{q^*} hypothesis).

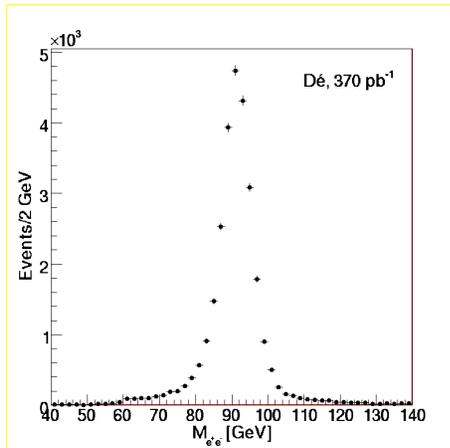
Background:

- Main background by far is SM Z+jet production.
- Instrumental backgrounds (fake electrons) are very small.

Excited Quark Search Results

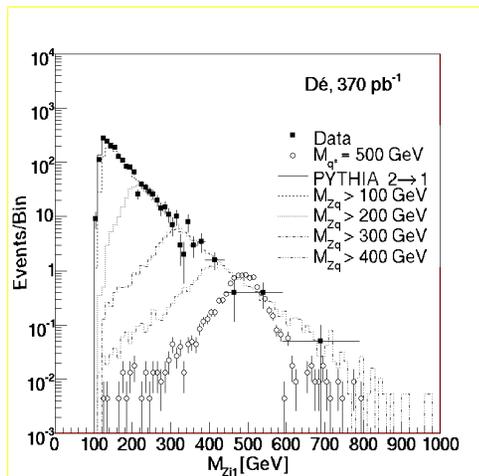


ee Invariant Mass

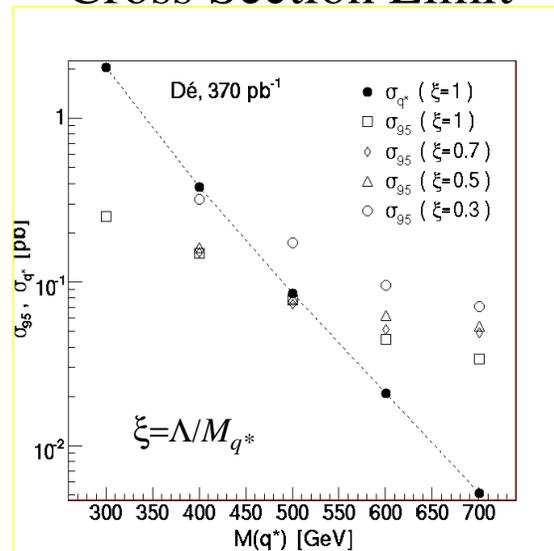


M_{q^*} (GeV)	Data Events	Expected background	σ limit (pb, 95%CL)
300	31	32.8 ± 2.9	0.25
400	9	7.5 ± 0.8	0.15
500	3	2.9 ± 0.8	0.08
600	1	1.6 ± 0.6	0.05
700	0	0.64 ± 0.06	0.03

Z-jet Invariant Mass



Cross Section Limit



No excess events above expected background

Model limit:

$M_{q^*} < 510$ GeV

assuming $\Lambda = M_{q^*}$

New Quark Searches (CDF)



- New heavy quarks are assumed to have standard flavor quantum numbers and be pair-produced by the strong interaction.

$$q\bar{q} \rightarrow Q\bar{Q}$$

- Scenarios are considered where new heavy quarks decay into normal quark and EW bosons.

$$Q \rightarrow q + W, Z, \text{ or } H$$

- More specifically, CDF has searched for departures from SM expectations in the following generic signatures (signature-based searches).
 - High p_T Z 's.
 - Dileptons ($ee, \mu\mu, e\mu$).

BPT Model Quarks

- For concreteness, results are interpreted in terms of the model of Bjorken, Pakvasa, and Tuan (BPT), PRD, 66 (053008), 2002.
- This model includes three additional down-type isosinglet right-handed heavy quarks (D, S, B) that mix with and decay into the corresponding right-handed light quarks, plus W , Z , and H .
- For the purposes of these analyses, BPT quarks can be thought of as down-type quarks that decay into $W:Z:H$ with ratios 2:1:1.



High p_T Z Search (CDF)

Event Selection:

- Two high p_T leptons (ee or $\mu\mu$).
- $66 \text{ GeV} < M_{ll} < 116 \text{ GeV}$

SM sources of high- p_T Z 's

- Z +jets (major source).
- Dibosons (WW , WZ , ZZ).

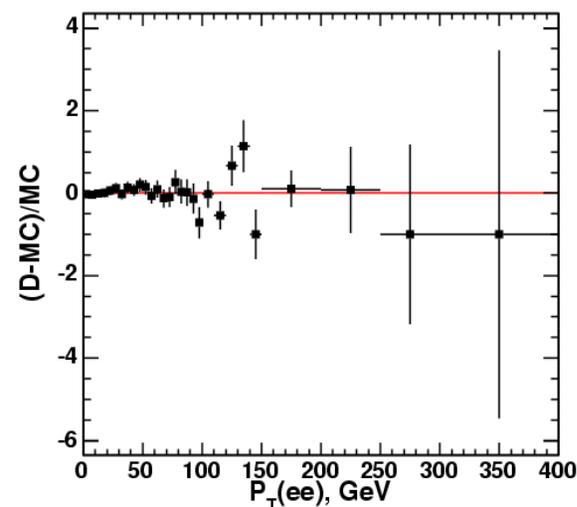
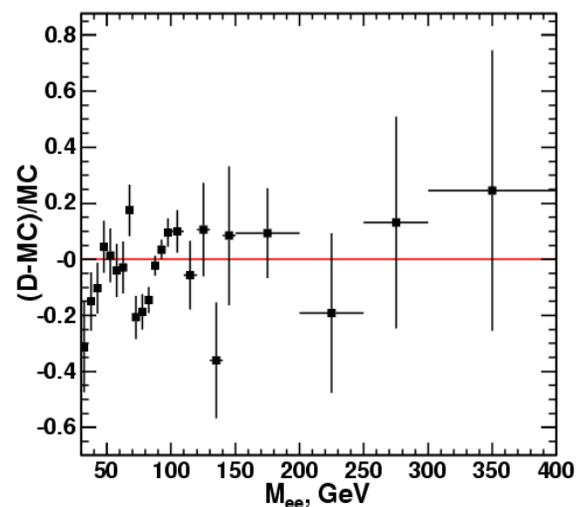
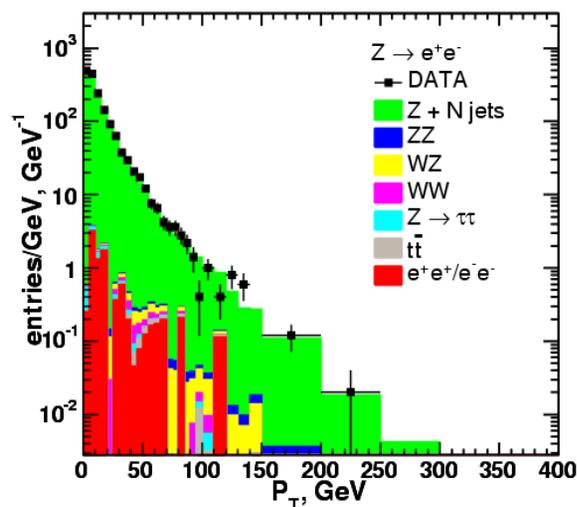
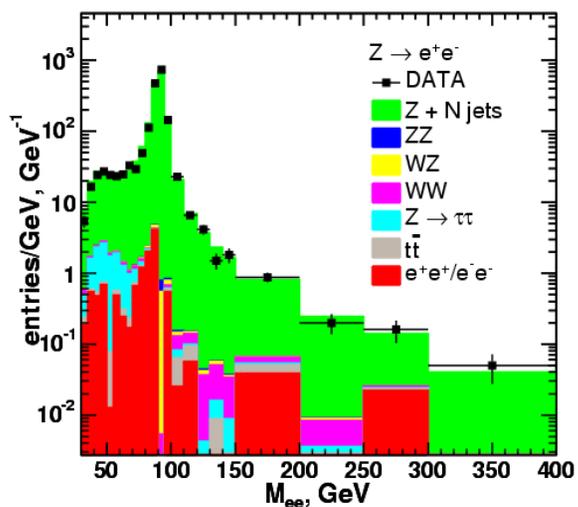
Background:

- $t\bar{t}$
- Fakes



High p_T Z Search (Electrons)

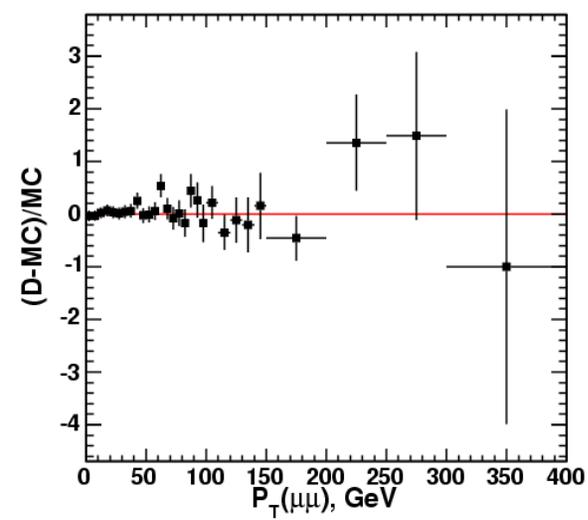
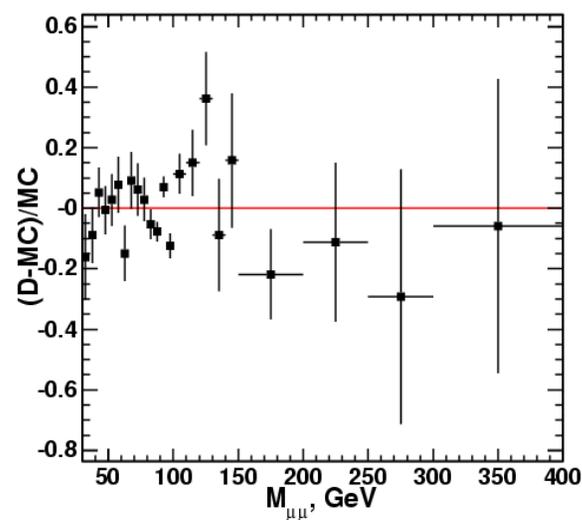
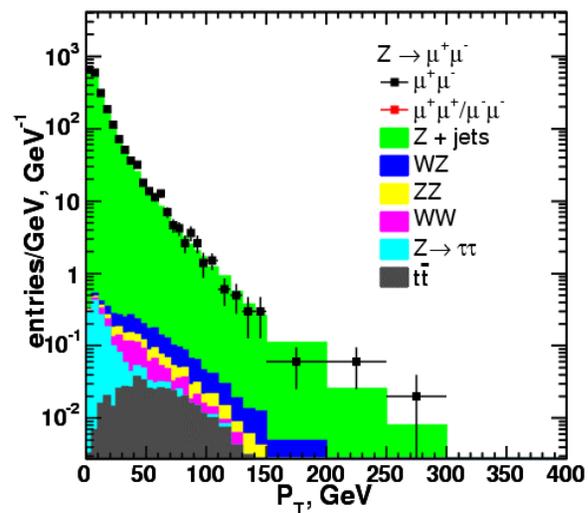
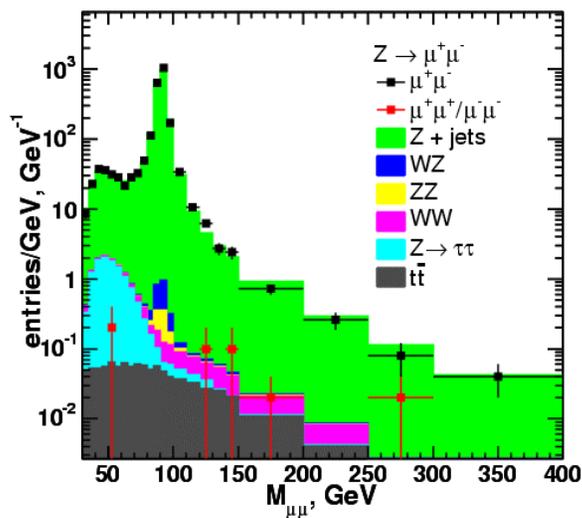
CDF Run II Preliminary (305 pb⁻¹)





High p_T Z Search (Muons)

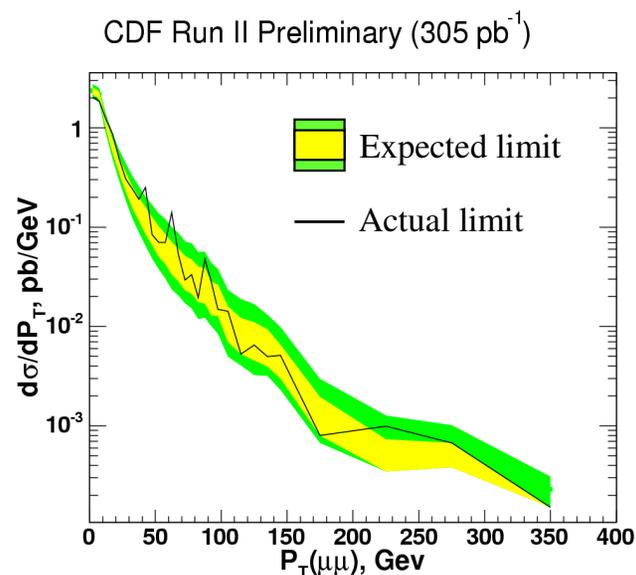
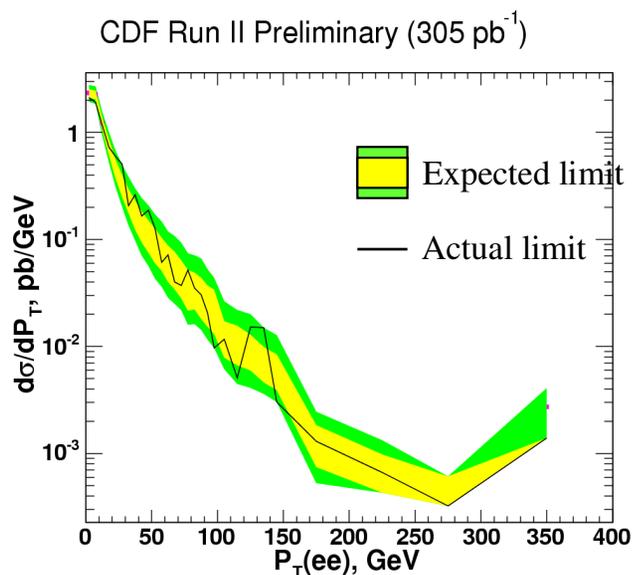
CDF Run II Preliminary (305 pb⁻¹)





High p_T Z Search Results

- No excess high p_T Z' s over SM expectations. Put upper limit on anomalous Z cross section.



BPT Model Results

$$\sigma_{Q\bar{Q}} < 0.35 \text{ pb for } M_Q = 300 \text{ GeV}$$



Dilepton Search (CDF)

Event Selection:

- Two high p_T isolated leptons ($e\mu$ or same-sign ee , $\mu\mu$).
- Two jets ($p_T > 50$ GeV).
- $H_T > 400$ GeV (control region $H_T < 200$ GeV).

Backgrounds:

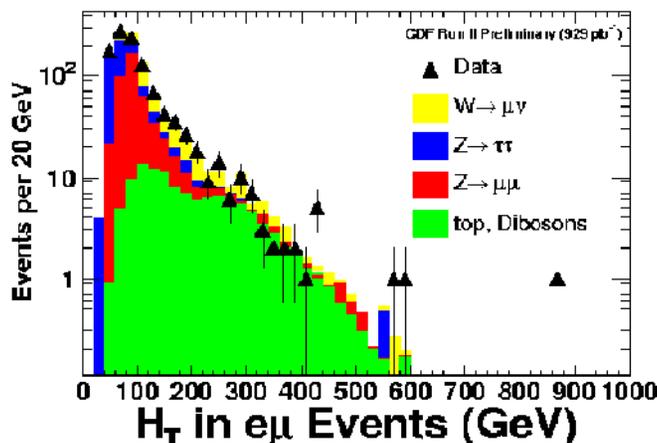
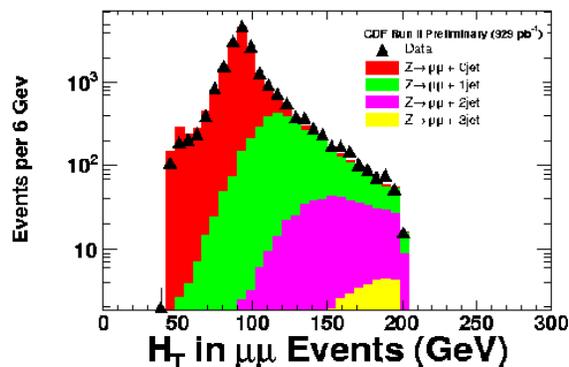
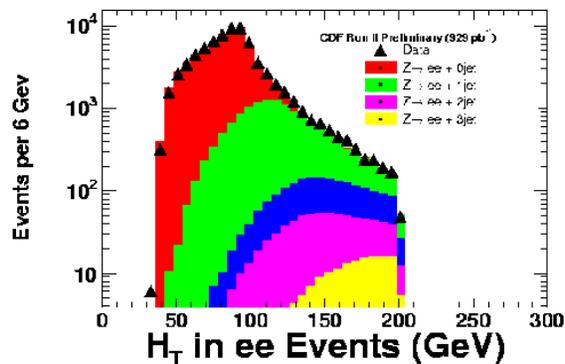
- Fakes.
- Z +jets (ee , $\mu\mu$).
- $Z \rightarrow \tau\tau$ (em).
- tt
- Dibosons.



Dilepton Search

$L=929 \text{ pb}^{-1}$

(Control region plots)



Channel	SM Bkgd	Signal (300 GeV BPT quark)	Data
$e\mu$	2.9 ± 1.5	1.9 ± 0.2	2
SS $ee, \mu\mu$	1.5 ± 0.75	0.9 ± 0.09	0

$\sigma_{\mathcal{O}\mathcal{O}} < 0.40 \text{ pb (90\% CL)}$

Summary

- Results presented for the following searches.
 - Associated production of excited muons ($\mu^* \rightarrow \mu\gamma$).
 - Resonant production of excited quarks ($q^* \rightarrow qZ$).
 - Excess high- p_T Z 's (BPT quarks).
 - Excess dileptons (BPT quarks).
- No evidence for non-SM fermions is seen. Limits have been reported on $\sigma \times BR$, as well as model-dependent excluded regions.
- Both Tevatron experiments have $\sim 1 \text{ fb}^{-1}$ of data on tape. New more sensitive results based on these data will be reported soon.
- Data taking has started for Run I Ib, which is going very well so far. Expect 4–8 fb^{-1} of data by 2009.