



Non-SUSY searches at the TeVatron

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On behalf of CDF and D0 collaborations

Models and Final States

- Go beyond the Standard Model without introducing SUSY

	Models	Final States
<i>Lepton-quark substructure</i>	<i>compositeness</i> <i>excited fermions</i> <i>Leptoquarks</i>	$e e, \gamma \gamma, \mu \mu$ $\mu \mu \gamma, e e j$ $e e j j, \mu \mu j j, e v j j, \mu v j j, v v j j, v v b b$
<i>EWSB without Higgses</i>	<i>technicolor</i>	$b b, b b c$
<i>New Heavy gauge bosons</i>	Z' W'	$e e, \mu \mu, \tau \tau$ $e v, b b l v$
<i>Hierarchy problem</i> ($M_{Planck} >> M_{EW}$)	<i>Extra Dimensions:</i> <i>Large Extra Dimensions (ADD LED)</i> <i>Randall-Sundrum gravitons (RS gravitons)</i>	$e e, \gamma \gamma, \mu \mu$ (resonant or not) $j e t + M E_T$ (monojet)

→ Three final states: leptons/photons , leptons+jets (+ $M E_T$) , jets+ $M E_T$



Non-SUSY searches at the TeVatron

Final state: Leptons/photons

*ADD -LED
RS gravitons
 Z'
 W'
excited muons*



Dilepton/Diphoton



dielectron/diphoton

- $E_T > 15-25 \text{ GeV}$
 - isolated, fraction EM
 - EM shower shape
 - Track match (ee) → Tracker
- EMid: $\epsilon \sim 80$ to 90%
- Main background:
 - Drell-Yan $\rightarrow ee, \gamma\gamma$
 - Fakes: QCD multijet events and direct photon events \rightarrow estimated from data
 - syst signal: ~9% (cross section, EMid, acceptance, e/γ)

dimuon

- $P_T > 15 \text{ GeV}$
 - Isolated
 - Track quality req. (hits...)
 - Cosmic ray bkgd cuts
- μ id: $\epsilon \sim 80$ to 90%
- Main background:
 - Drell-Yan $\rightarrow \mu\mu$
 - syst signal: 8% (acceptance)

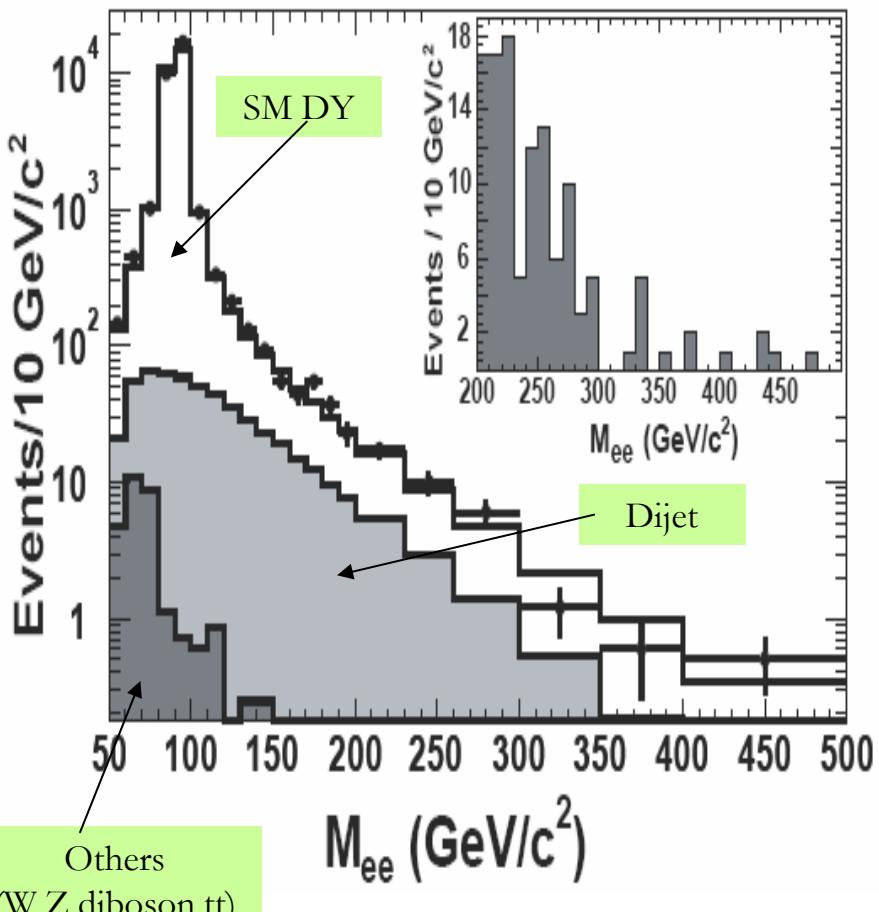
syst SM background: 9 to 13% (efficiency, momentum smearing, PDF,...)

→ Direct search (mass peak: Z', RS graviton) and indirect search (LED, compositeness)

$Z' \rightarrow ee$

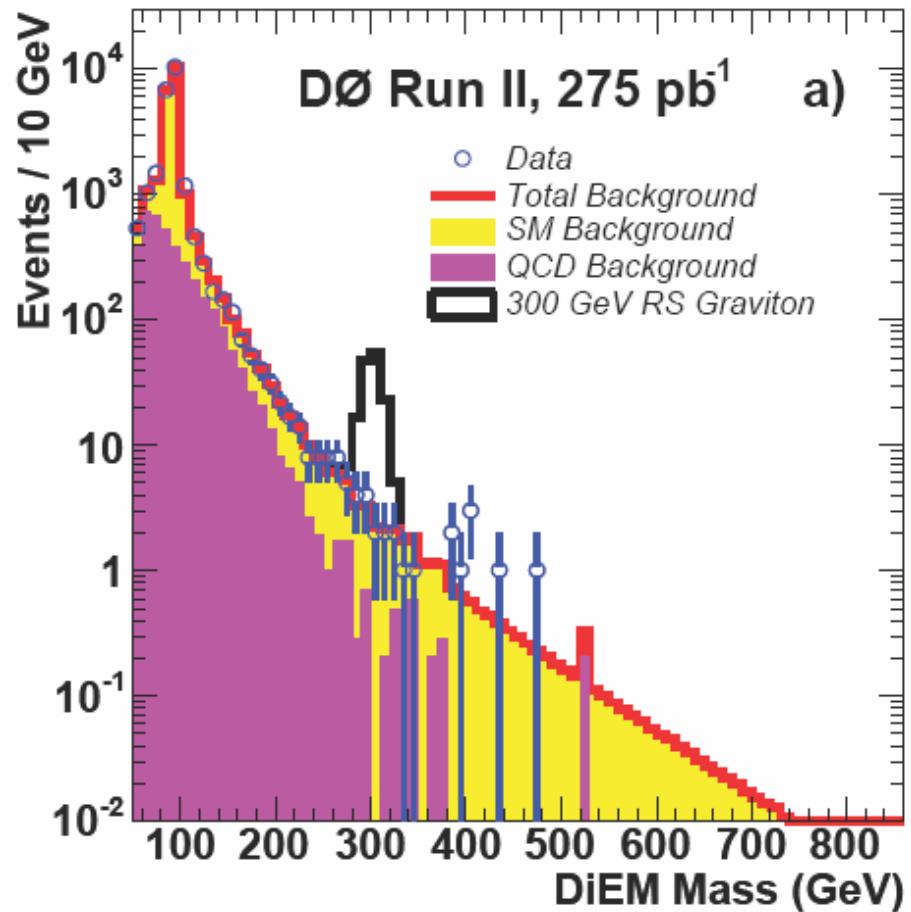


$\mathcal{L} \sim 450 \text{ pb}^{-1}$



RS graviton – ee, $\gamma\gamma$

DØ Run II, 275 pb^{-1} a)





Dilepton



- No excess wrt SM -> limits (95% CL) on the models

Compositeness: ee, $\mu\mu$

$$L_{ql} = \frac{g_0^2}{\Lambda^2} \{ \eta_{LL} (\bar{q}_L \gamma^\mu q_L) (\bar{\mu}_L \gamma_\mu \mu_L) + \eta_{LR} (\bar{q}_L \gamma^\mu q_L) (\bar{\mu}_R \gamma_\mu \mu_R) \\ + \eta_{RL} (\bar{u}_R \gamma_\mu u_R) (\bar{\mu}_L \gamma^\mu \mu_L) + \eta_{RR} (\bar{d}_R \gamma_\mu d_R) (\bar{\mu}_R \gamma^\mu \mu_R) \\ + \eta_{RR} (\bar{u}_R \gamma^\mu u_R) (\bar{\mu}_R \gamma_\mu \mu_R) + \eta_{RR} (\bar{d}_R \gamma^\mu d_R) (\bar{\mu}_R \gamma_\mu \mu_R) \}$$

$\mu\mu$
250 pb⁻¹

Λ : compositeness scale(TeV)

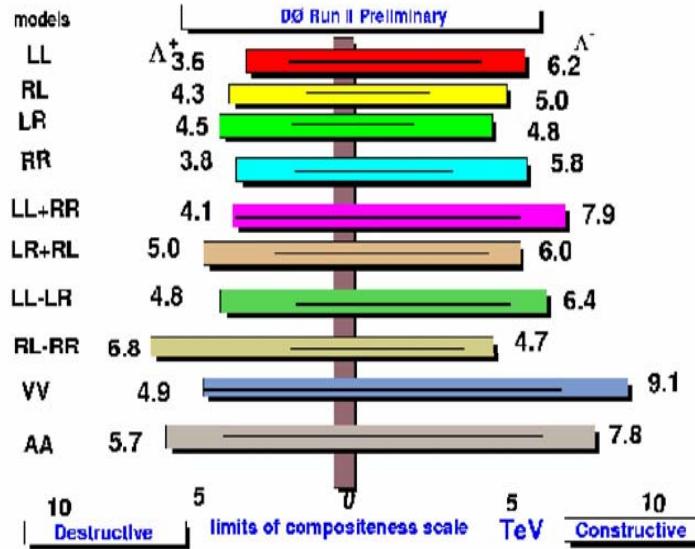
Z'->ee CDF 450 pb⁻¹

Z' Model	Z_{SM}	Z_χ	Z_ψ	Z_η
Exp. limit (GeV/c ²)	860	735	725	745
Obs. limit (GeV/c ²)	850	740	725	745

$m_{Z'_SM} > 850$ GeV @95% CL

Model	Λ^+ (TeV)	Λ^- (TeV)
LL	4.19	6.98
RR	4.15	6.74
LR	5.32	5.10
RL	5.31	5.17
LL+RR	5.05	9.05
LR+RL	6.45	6.12
LL-LR	4.87	7.74
RL-RR	5.07	7.41
VV	6.88	9.81
AA	5.48	9.76

ee
200 pb⁻¹



ADD LED

cross section: $\sigma = f(\eta_G, \eta_G^2)$

parameter: $\eta_G = \mathcal{F}/M_S$

M_S : fundamental Planck scale

$\mathcal{F} \sim 1$: model dependent

\mathcal{L} (pb $^{-1}$)	Final state	GRW [1]	HLZ[2]						Hewett[3] $\Lambda=+1/\lambda=-1$
			n=2	n=3	n=4	n=5	n=6	n=7	
200 CDF	ee	1.10	-	1.31	1.10	0.999	0.929	0.879	0.987/0.959
246 D0	$\mu\mu$	1.07	1.09	1.27	1.07	0.97	0.90	0.85	0.96/0.93
275 D0	ee+ $\gamma\gamma$	1.48	1.74	1.76	1.48	1.33	1.24	1.17	1.32/1.21

RunI+RunII

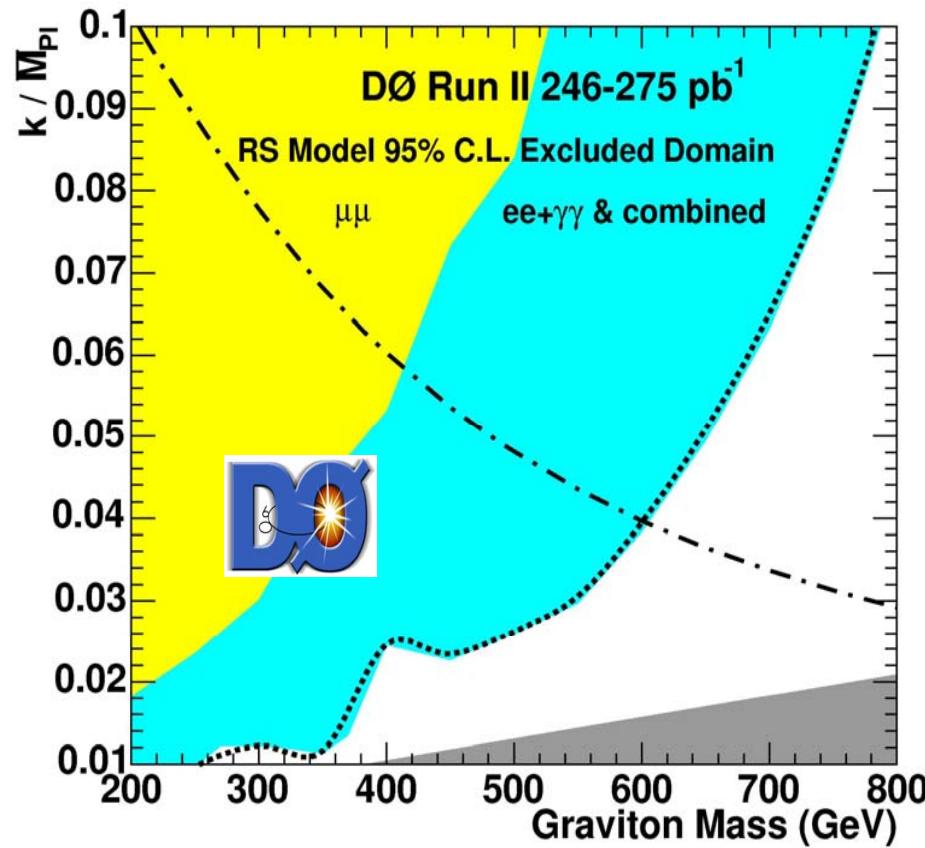
World Best Limit

RS graviton: ee, $\gamma\gamma$, $\mu\mu$ combined

parameters:

-graviton mass

- k/M_{Pl} : coupling to the SM fields



[1] Giudice, Rattazzi, Wells NPB 544,3 (1999)

[2] Han, Lykken, Zhang PRD59,105006 (1999)

[3] Hewett PRL 82, 4765 (1999)



Lepton/photon(s)+X

Signature of excited particles which decay to $l/\gamma+X$

$\gamma\gamma+X$

diphoton trigger: $E_T > 12$ (isolated), $E_T > 18$ GeV
2 central photons $|\eta| < 1$ $E_T > 13$ GeV

$\gamma\gamma+e,\mu$
 $\mathcal{L} \sim 683 \text{ pb}^{-1}$

one electron $E_T > 20$ GeV
one muon $p_T > 20$ GeV

$\gamma\gamma+\gamma$
 $\mathcal{L} \sim 1020 \text{ pb}^{-1}$

A third photon

1 fb⁻¹

Source	electron	muon
$Z\gamma\gamma$	$0.535 \pm 0.014 \pm 0.049$	$0.307 \pm 0.011 \pm 0.028$
$W\gamma\gamma$	$0.117 \pm 0.008 \pm 0.011$	$0.048 \pm 0.005 \pm 0.004$
Fake $l+\gamma\gamma$	$0.093 \pm 0.004 \pm 0.038$	$0.006 \pm 0.005 \pm 0.003$
$l\gamma + \text{jet} \rightarrow \gamma$	$0.386 \pm 0.021 \pm 0.220$	$0.093 \pm 0.011 \pm 0.114$
$l\gamma + e \rightarrow \gamma$	$3.363 \pm 0.272 \pm 0.760$	$0.017 \pm 0.017 \pm 0.004$
Total	4.49 ± 0.84	0.47 ± 0.12
Data	2	0

$l\gamma\gamma$

High Luminosity

$\gamma\gamma\gamma$: exp: 1.9 ± 0.6 observ: 4

$\gamma l+X$

One isolated $\gamma E_T > 25$ GeV
One isolated « tight » central lepton $E_T > 25$ GeV

$l\gamma+ME_T$
 $\mathcal{L} \sim 307 \text{ pb}^{-1}$

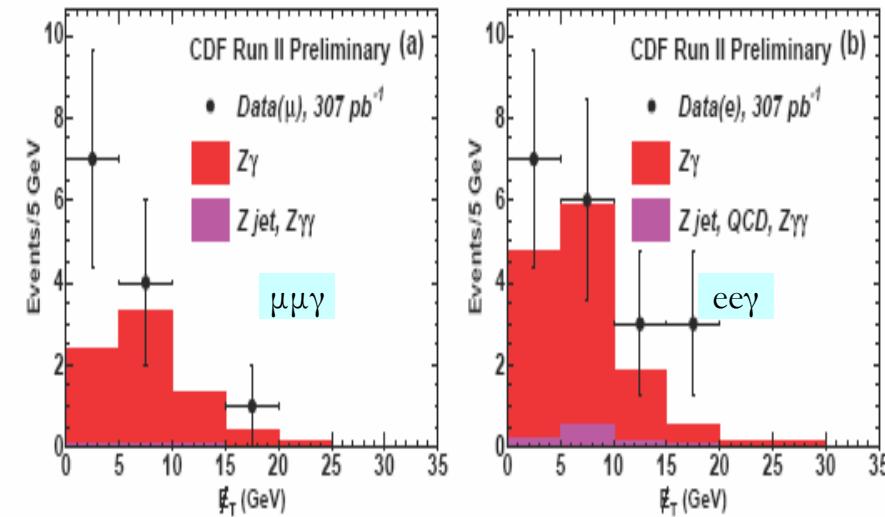
$ME_T > 25$ GeV

Obs: 43 Exp: 35.1 ± 5.3

$l\gamma+l$
 $\mathcal{L} \sim 307 \text{ pb}^{-1}$

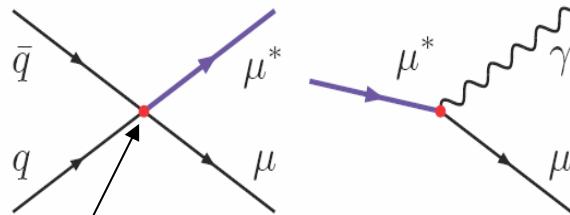
Loose lepton $E_T > 25$ GeV

Obs: 31 Exp: 21.2 ± 4



No excess wrt SM

Excited muons



Contact Interaction (CI)

Main background:
 $Z\gamma, WZ, ZZ$
 $Z + \text{jet (fakes)}$

	CDF L=371 pb ⁻¹	D0 L=377 pb ⁻¹
2 isolated muons	$p_T > 20 \text{ GeV}$	$p_T > 15 \text{ GeV}$
1 isolated photon	$E_T > 25 \text{ GeV}$	$E_T > 16 \text{ GeV}$

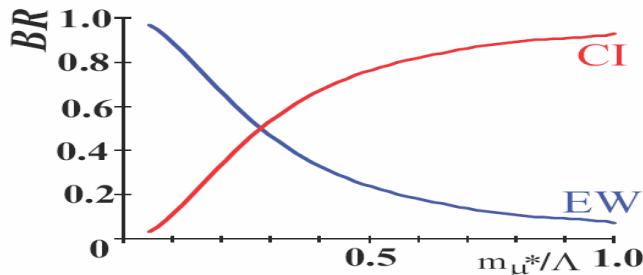
Systematics:
fakes(jet misid as photon)

Compositeness models:
Quarks and leptons are composed of a scalar and a spin 1/2 particles
Large spectrum of excited states



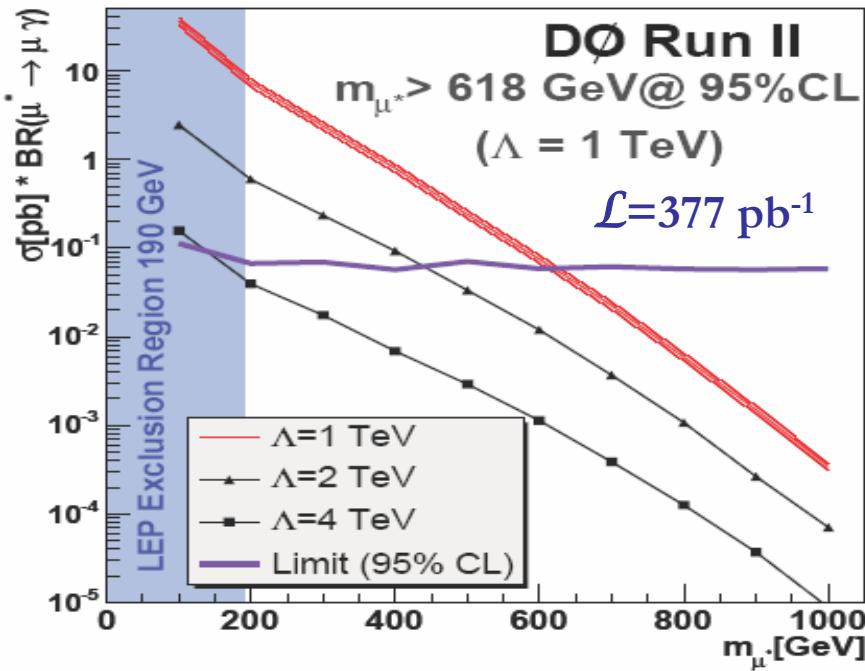
$E_T^\gamma > 27 \text{ GeV} + M_{\mu\gamma}$ mass cut

m_{μ^*} [GeV]	$m_{\mu\gamma}$ cut [GeV]	Data	SM expectation	Signal eff. [%]
100	200	0	0.170 ± 0.126	7.5 ± 1.0
200	200	0	0.170 ± 0.126	12.5 ± 1.5
300	280	0	0.041 ± 0.023	12.1 ± 1.5
400	330	0	0.016 ± 0.011	14.7 ± 1.8
500	440	0	0.003 ± 0.001	11.9 ± 1.5
600	440	0	0.003 ± 0.001	14.4 ± 1.8
700	440	0	0.003 ± 0.001	13.6 ± 1.7
800	440	0	0.003 ± 0.001	14.5 ± 1.8
900	440	0	0.003 ± 0.001	14.7 ± 1.8
1000	440	0	0.003 ± 0.001	14.4 ± 1.8



EW decays: $\mu^* \rightarrow \mu + \text{gauge boson}$
 CI decays: $\mu^* \rightarrow \mu + \text{ff}$

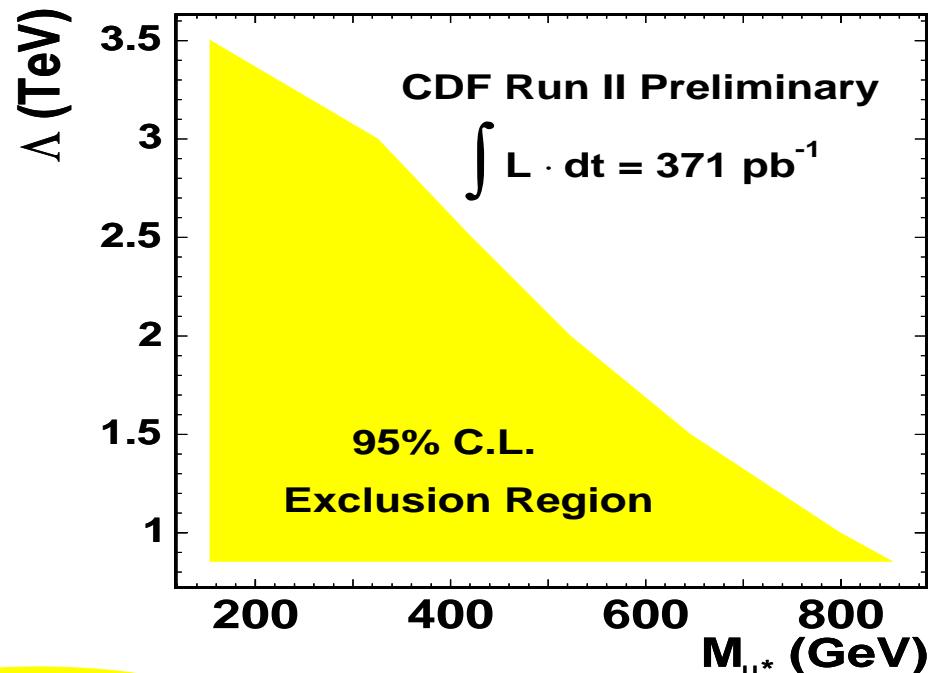
Three parameters:
 - m_{μ^*}
 - $\text{BR}(\mu^* \rightarrow \mu\gamma)$
 - Λ : compositeness scale



$m_{\mu^*} > 618 \text{ GeV } \Lambda=1 \text{ TeV}$

World Best Limit

$m_{\mu^*} > 800 \text{ GeV } \Lambda=1 \text{ TeV}$



Only EW decays

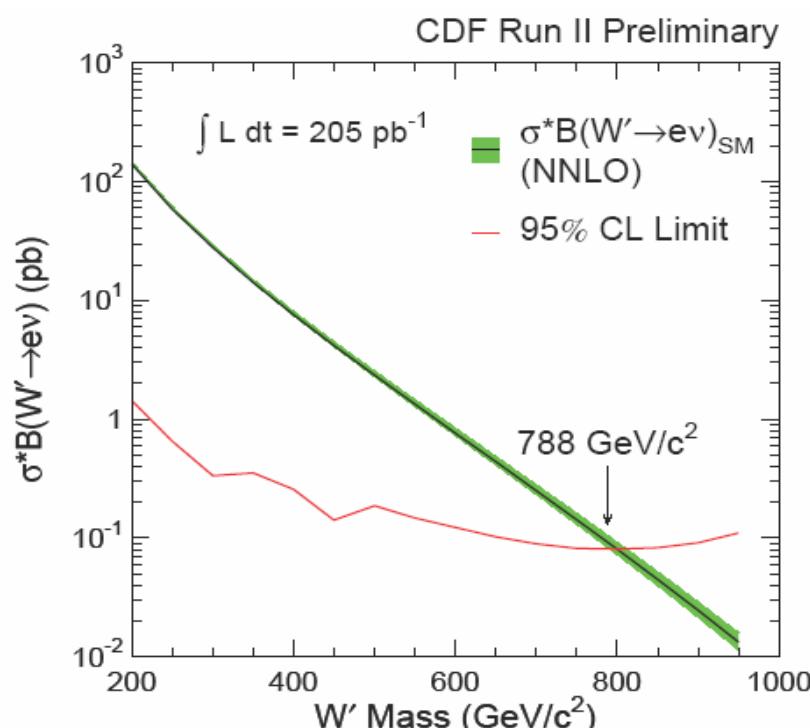
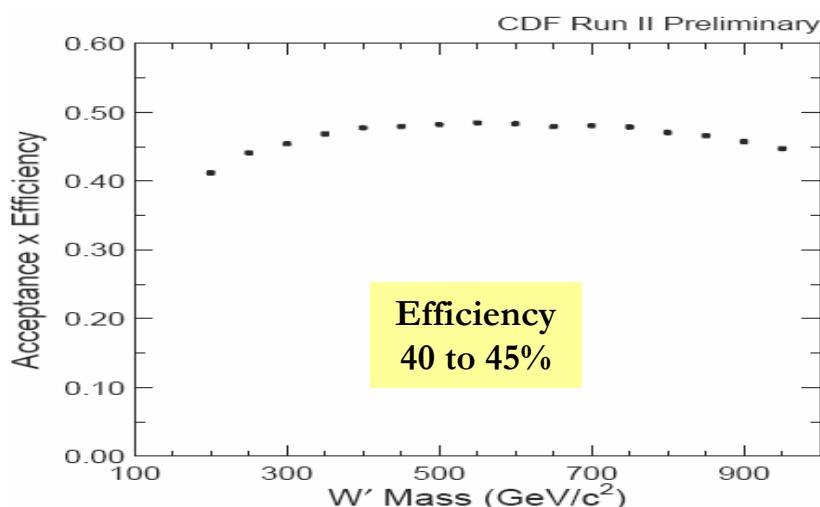
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Trigger: inclusive electron $E_T > 18$ GeV

Selection

- One isolated electron $E_T > 25$ GeV
- $ME_T > 25$ GeV
- $0.4 < E_T / ME_T < 2.5$

Background:
 $W \rightarrow e\nu$, $W \rightarrow \tau\nu$,
 Multijet (fakes)



	Events in Each M_T Bin (GeV/c^2)				
	200 - 250	250 - 350	350 - 500	500 - 700	700 - 1000
$W \rightarrow e\nu$	30.8 ± 5.7	17.0 ± 4.0	3.52 ± 1.70	0.27 ± 0.45	0.00 ± 0.00
Multijet	2.7 ± 6.1	0.0 ± 3.3	0.00 ± 0.29	0.00 ± 0.01	0.00 ± 0.00
Other Backgrounds	5.2 ± 1.0	3.0 ± 0.9	0.51 ± 0.22	0.06 ± 0.08	0.00 ± 0.03
Total Background	38.7 ± 8.9	20.0 ± 5.9	4.03 ± 1.97	0.33 ± 0.53	0.01 ± 0.03
Data	41	21	9	1	0

Systematics:

- JES
- PDF
- EM scale, ISR

$M_W > 788 \text{ GeV} @ 95\% \text{ CL}$

World Best Limit



Non-SUSY searches at the TeVatron

Final state: Leptons+jets+(\cancel{ME}_T)

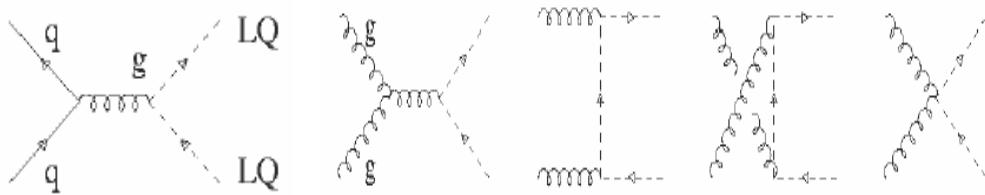
*leptoquarks
technicolor
excited quarks*

Leptoquarks

LQ: bosons carrying the quantum numbers of a quark-lepton system

2nd generation: LQ 2 LQ $2 \rightarrow \mu\mu jj$ (CDF+D0)
 LQ 2 LQ $2 \rightarrow \mu\nu jj$ (CDF)

} 2 isolated energetic jets + one (two) isolated high pT muons



Background:
 DY: $Z/\gamma^*(\mu\mu) + \text{jets}$

D0
 $L \sim 294 \text{ pb}^{-1}$

CDF
 $L \sim 200 \text{ pb}^{-1}$

2 isolated muons $p_T > 15 \text{ GeV}$

$\mu\mu jj$
 $p_T > 25 \text{ GeV}$

$\mu\nu jj$
 $p_T > 25 \text{ GeV}$

2 isolated jets $E_T > 25 \text{ GeV}$

$E_T (\text{jet1}) > 30 \text{ GeV}$

$E_T (\text{jet2}) > 15 \text{ GeV}$

$M(\mu\mu) > 105 \text{ GeV}$

$15 \text{ GeV} < < 75 \text{ GeV}$

> 105

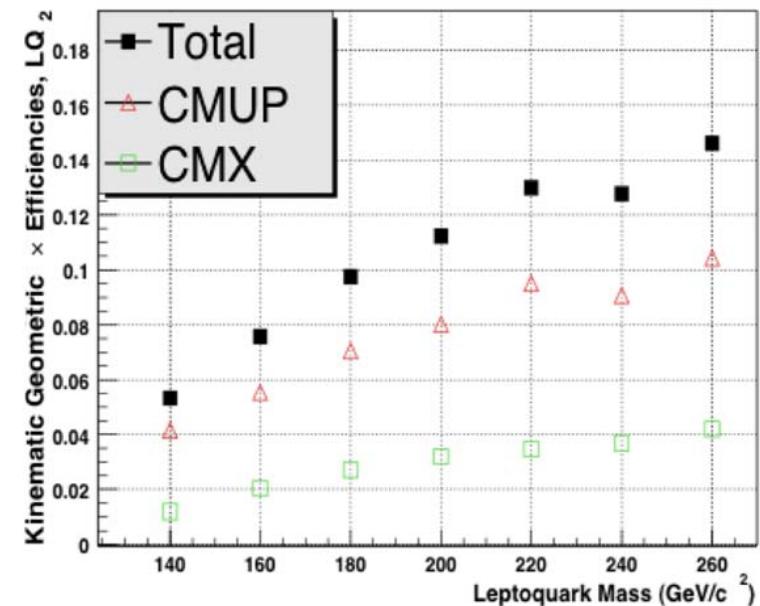
$ME_T > 60 \text{ GeV}$

+additional cuts: scalar sum of transverse energies of objects ($\mu\mu jj$), angular selections and mass cut around M_{LQ} ($\mu\nu jj$)

Systematics:

- CDF: lumi, PDF
- D0: JES, lumi, PDF

Combined Total Acceptances

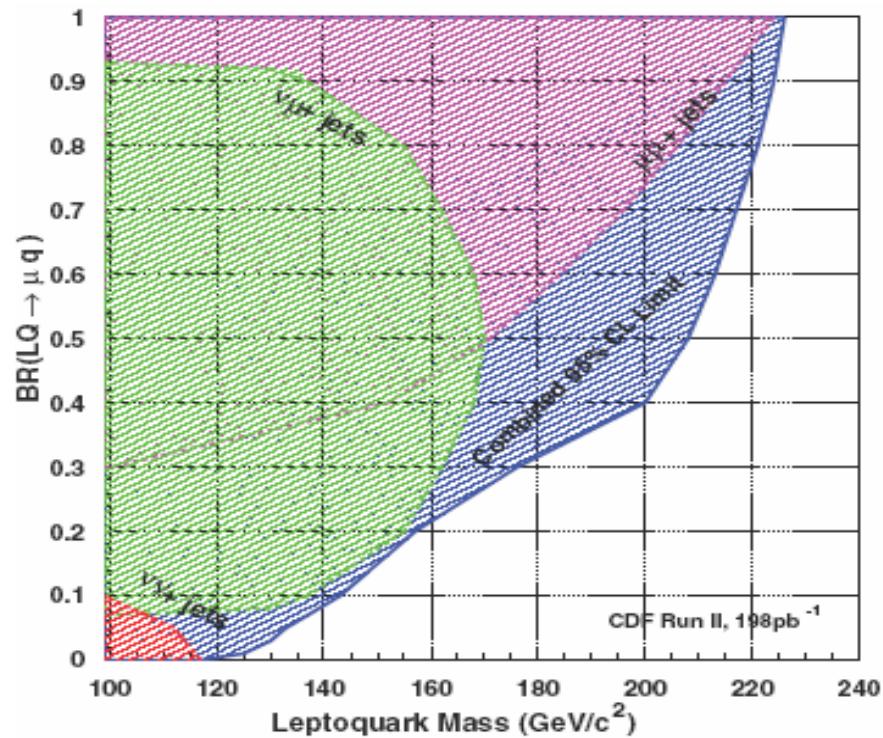


$\mu\mu jj$

 $\mathcal{L} \sim 200 \text{ pb}^{-1}$ $\mathcal{L} \sim 294 \text{ pb}^{-1}$

Data 2 6
MC 1.87 ± 1 6.8 ± 2

	140	160	180	200	220	240	260	$\mu\mu jj$
W	0.92 ± 0.06	1.44 ± 0.10	1.44 ± 0.10	1.67 ± 0.11	1.65 ± 0.11	0.93 ± 0.06	0.44 ± 0.03	
Top	1.69 ± 0.21	1.84 ± 0.23	1.35 ± 0.17	1.00 ± 0.39	0.80 ± 0.29	0.67 ± 0.08	0.52 ± 0.06	
Z	0.18 ± 0.01	0.22 ± 0.02	0.19 ± 0.01	0.18 ± 0.01	0.14 ± 0.01	0.05 ± 0.00	0.04 ± 0.00	
QCD	0.29 ± 0.29	0.29 ± 0.00						
Total	3.09 ± 0.57	3.74 ± 0.62	3.22 ± 0.56	3.08 ± 0.53	2.83 ± 0.51	1.94 ± 0.44	1.30 ± 0.39	
Data	3	3	2	0	0	0	0	$\mu\mu jj$

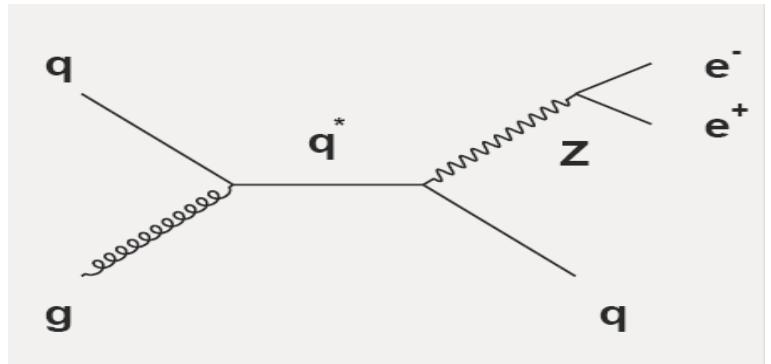
 $\mu\nu jj$


2 parameters:
 $\beta: BR(LQ \rightarrow l^\pm q)$
 M_{LQ}

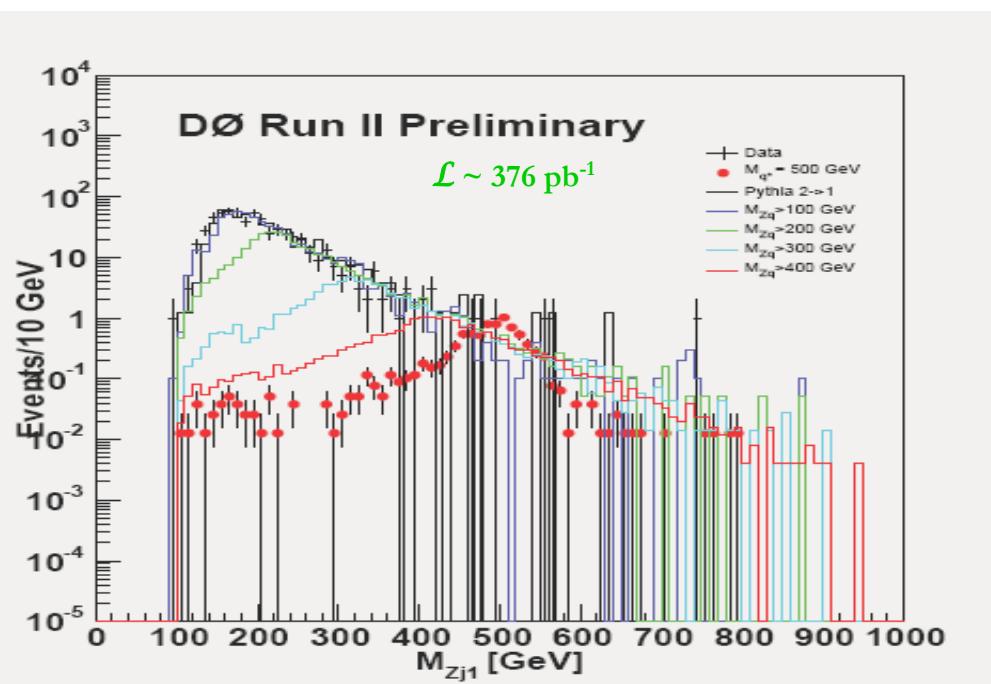
$\beta = 1$ $M_{LQ2} > 251 \text{ GeV}$ @95% CL

World Best Limit

Excited quarks



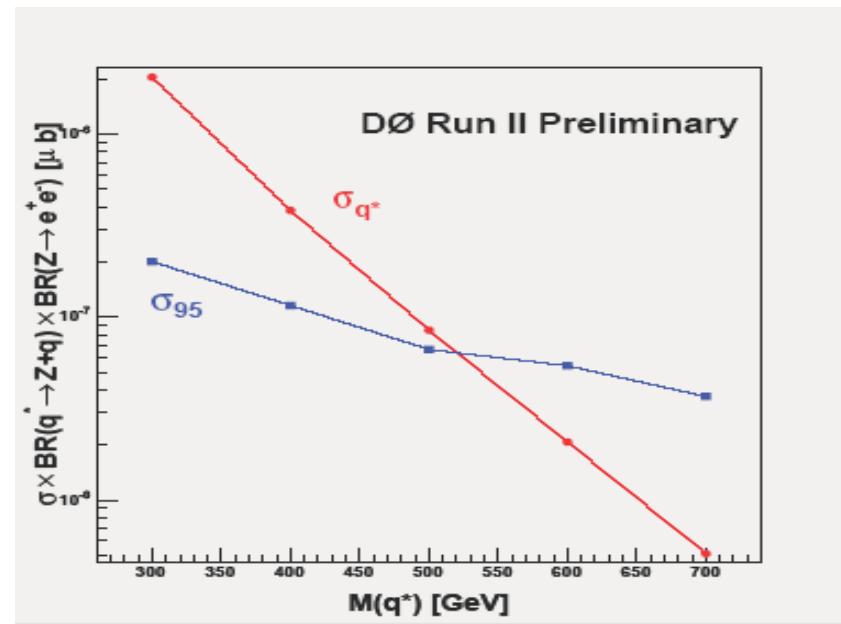
Signature: $Z(ee) + \text{jet}$
 M_{Zq} resonant



Event selection:

- 2 electrons ($E_T > 30, 25 \text{ GeV}$): usual criteria
- $81 < M_{ee} < 101 \text{ GeV}$
- 1 jet $p_T > 10 \text{ GeV}$
- no matching jet – EM object

Main background: DY $Z(ee) + \text{jets}$



$M_{q^*} > 520 \text{ GeV} @ 95\% \text{ CL}$



Non-SUSY searches at the TeVatron

Final state: jets+ \cancel{M}_T

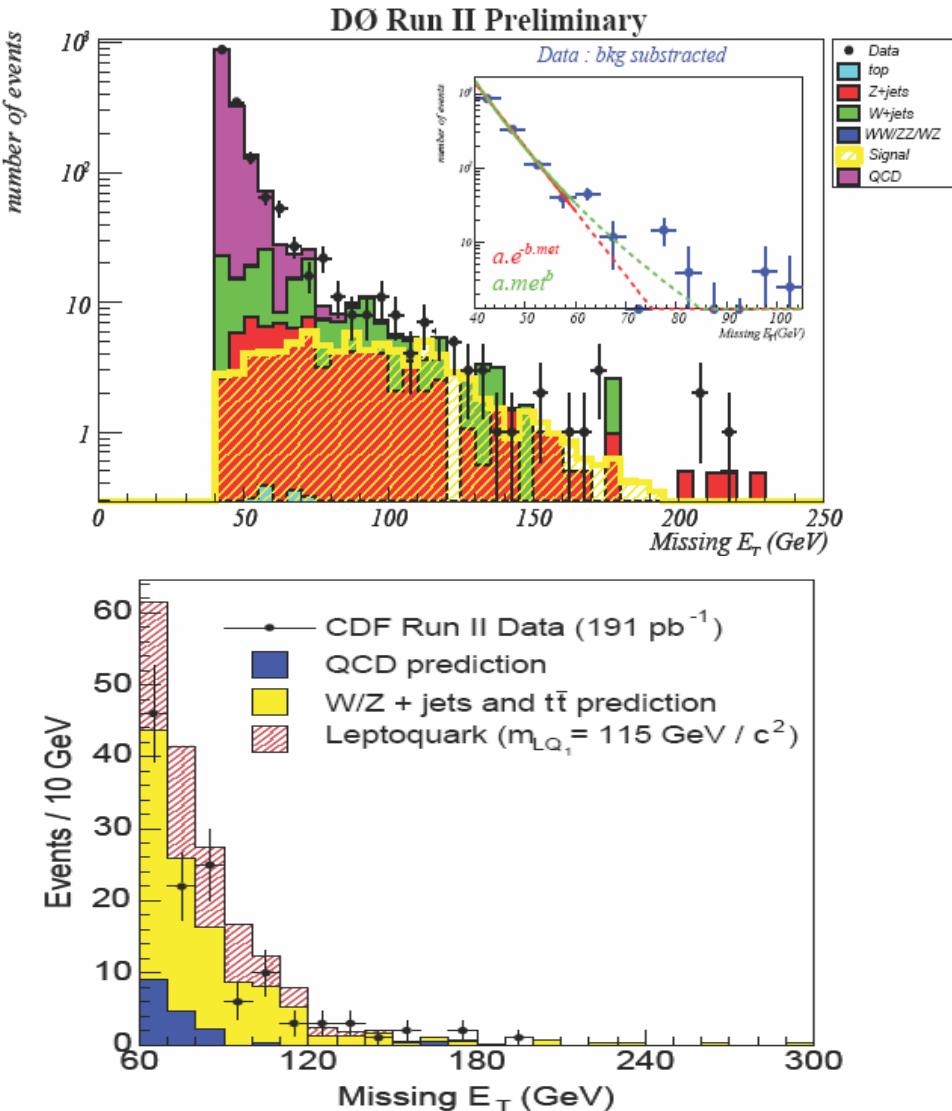
*ADD LED (monojet)
leptoquarks*

$p\bar{p} \rightarrow LQLQ \rightarrow vvjj : 2$ acoplanar (light) jets + ME_T

Main background:

- $Z(vv)+\text{jets}$
- $W(lv)+\text{jets}$
- QCD multijets (instrumental) \rightarrow from data

	CDF	DØ
$\mathcal{L} \sim 191 \text{ pb}^{-1}$	$\mathcal{L} \sim 310 \text{ pb}^{-1}$	
Triggers	MET	jets+MET
2 central jets	$p_T > 40, 25 \text{ GeV}$	$p_T > 60, 50 \text{ GeV}$
MET	$> 60 \text{ GeV}$	$> 80 \text{ GeV}$
	no isolated track, no electron or muon	
	cuts on $\Delta\Phi(\text{MET}, \text{jet})$ to remove SM and QCD background	



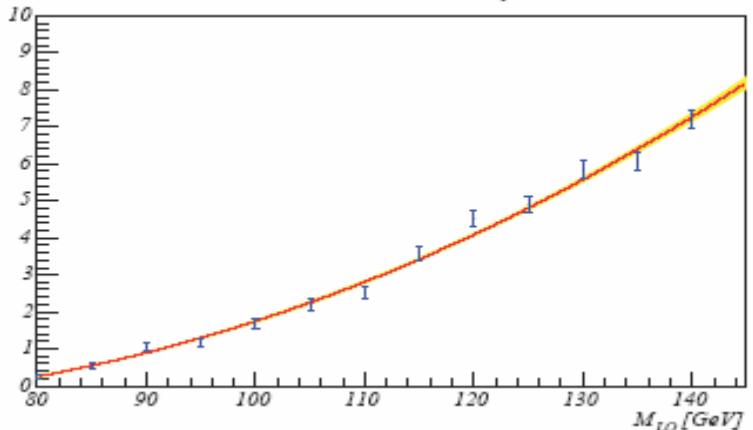


Scalar Leptoquarks



$p\bar{p} \rightarrow LQLQ \rightarrow vvjj : 2$ acoplanar (light) jets + ME_T

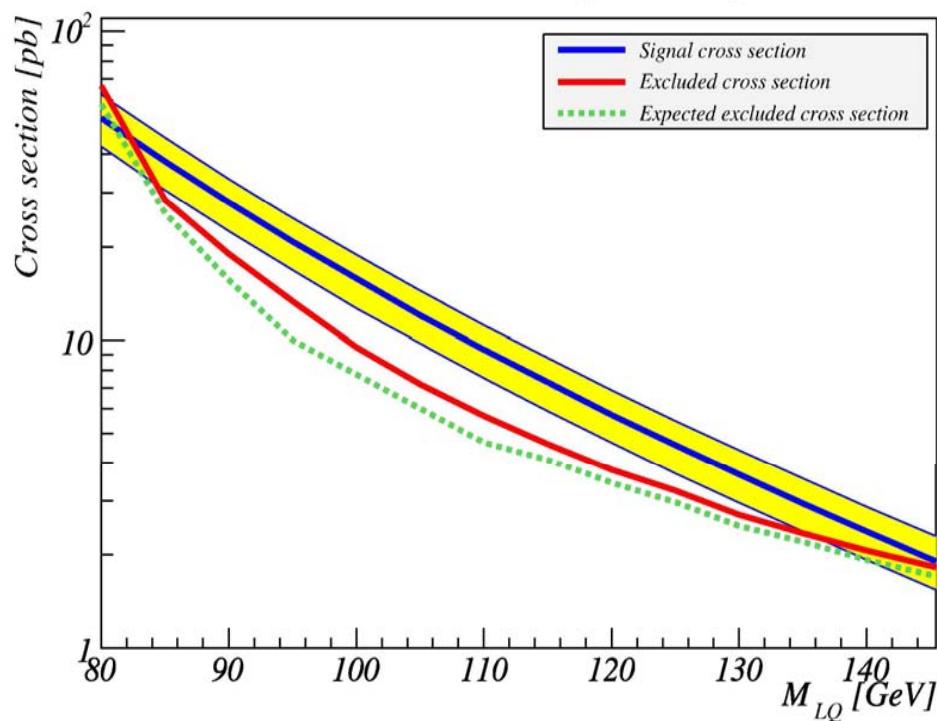
DØ Run II Preliminary



DATA	124	86
SM	118.3 ± 14.5	$75.2^{+10.1}_{-9.7} {}^{+10.7}_{-12.2}$

Systematics: 14 to 16%
(luminosity, JES, Jet energy reso, PDFs)

DØ Run II Preliminary, $L = 310 \text{ pb}^{-1}$



$\beta = 0$ $M_{LQ} > 117 \text{ GeV}$ @95% CL



$\beta = 0$ $M_{LQ} > 136 \text{ GeV}$ @95% CL

World Best Limit

Extra Dimensions

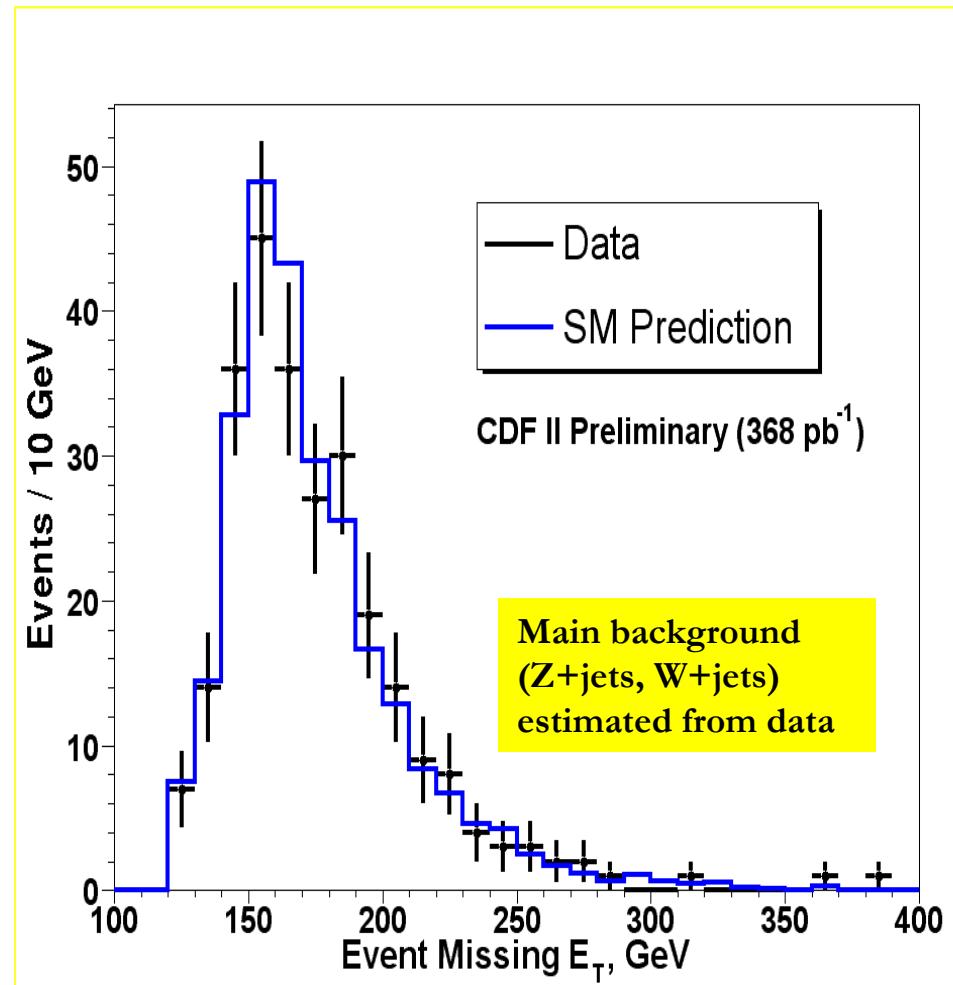
$qq, qg, gg \rightarrow gG, qG$: a single energetic jet + large ME_T

Main background:

- $Z(vv) + \text{jets}$
- $W(lv) + \text{jets}$
- QCD multijets -> from data

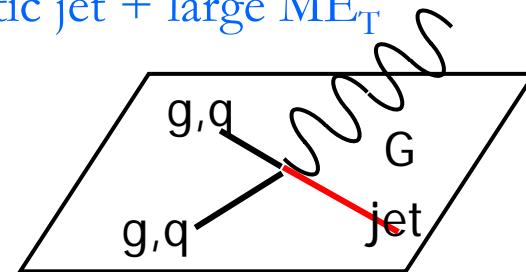
High sensitivity to
Jet Energy Scale

	 $\mathcal{L} \sim 368 \text{ pb}^{-1}$
Triggers	High E_T single jet
1 central jet (quality criteria)	$p_T > 150 \text{ GeV}$
ME_T	$> 120 \text{ GeV}$
2 nd leading jet	$p_T < 60 \text{ GeV}$
	no isolated track, no electron or muon
cuts on $\Delta\Phi(MET, \text{jet})$	to remove SM and QCD background



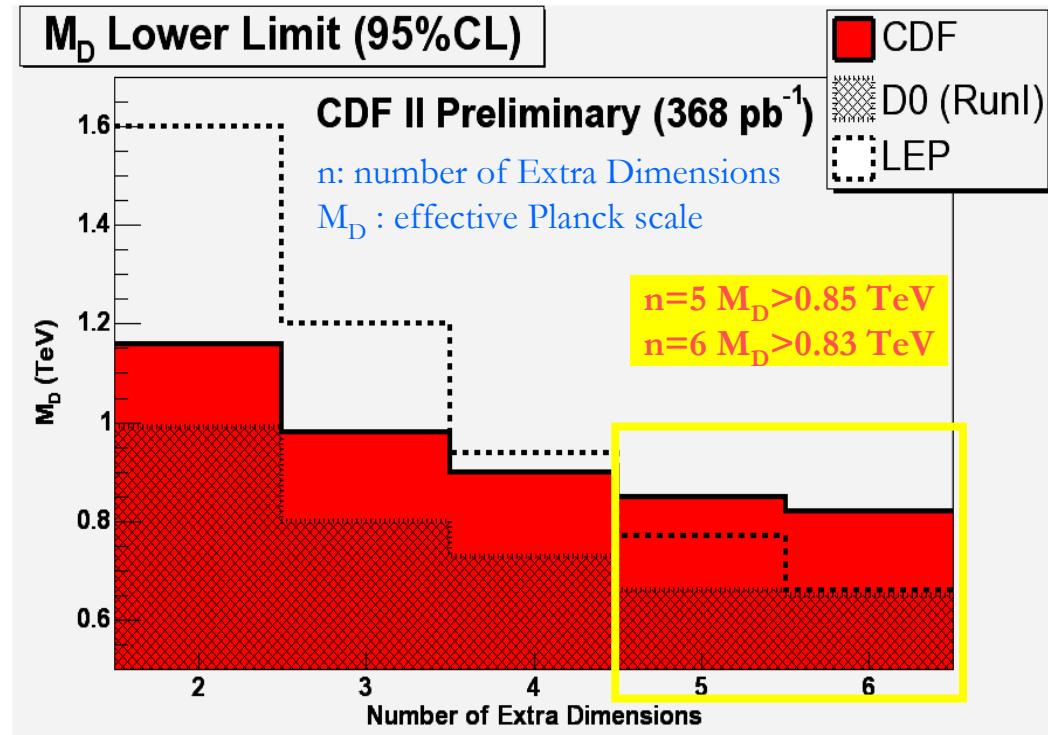
Extra Dimensions

$qq, qg, gg \rightarrow gG, qG$: a single energetic jet + large ME_T



Background	
$Z \rightarrow \nu\bar{\nu}$	130 ± 14
$W \rightarrow \tau\nu$	60 ± 7
$W \rightarrow \mu\nu$	36 ± 4
$W \rightarrow e\nu$	17 ± 2
$Z \rightarrow \ell\ell$	3 ± 1
QCD	15 ± 10
Non-collision	4 ± 4
Total predicted	265 ± 30
Data observed	263

Uncertainties:
 - stat+syst: 11%
 (bckgd from data)



World Best Limit

- CDF and D0 are probing unexplored areas
- Signatures: leptons/photons, leptons+jets, jets+ ME_T
- Good understanding of the detectors is requested to have systematic (dominant) uncertainties under control.
- No excess wrt the Standard Model observed
 - > limits (95% CL) on non-SUSY models: extra dimensions, Z' , W , leptoquarks, excited fermions, compositeness
- Not covered in this talk: $LQ \rightarrow ej, vb$; $Z' \rightarrow \tau\tau$, technicolor in dielectron, magnetic monopoles, ... Information available on these topics:
 - <http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm>
 - <http://www-cdf.fnal.gov/physics/exotic/exotic.html>
- The TeVatron is performing well: 1.2 fb^{-1} recorded per experiment (10x RunI) . First results with 1 fb^{-1} !
new exciting results are in the pipeline and we hope that soon...

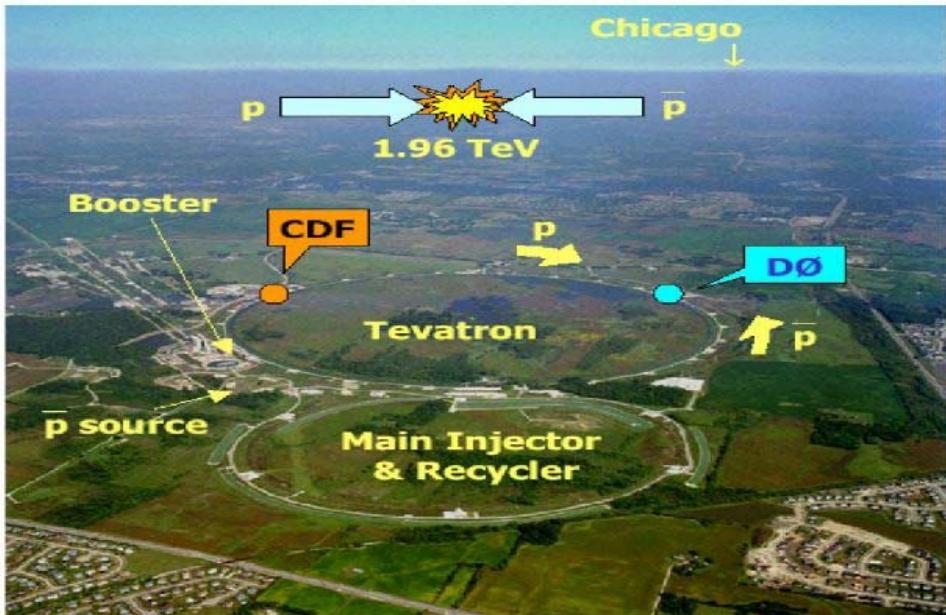
~~World Best Limit~~

Discovery

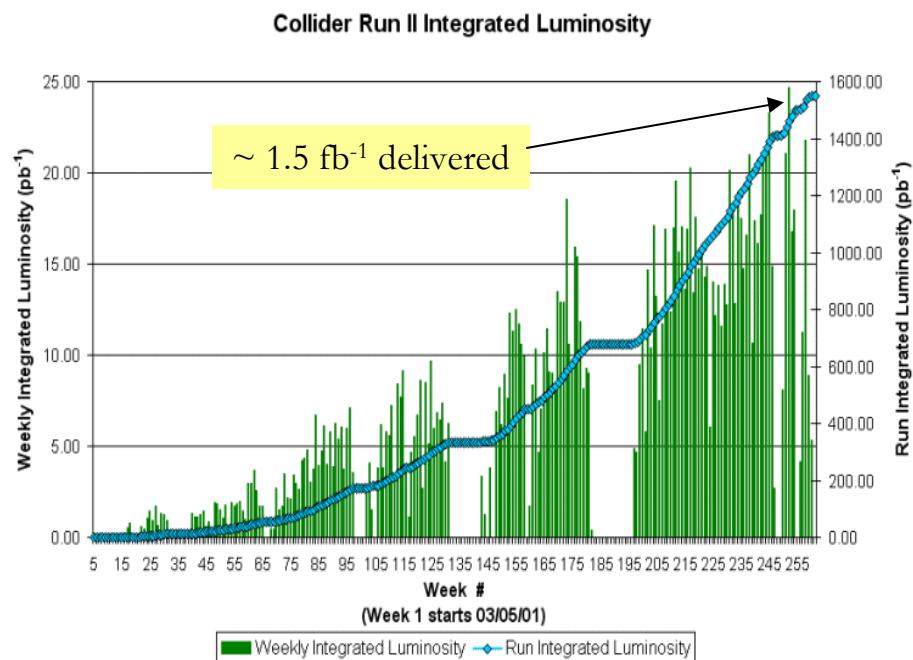
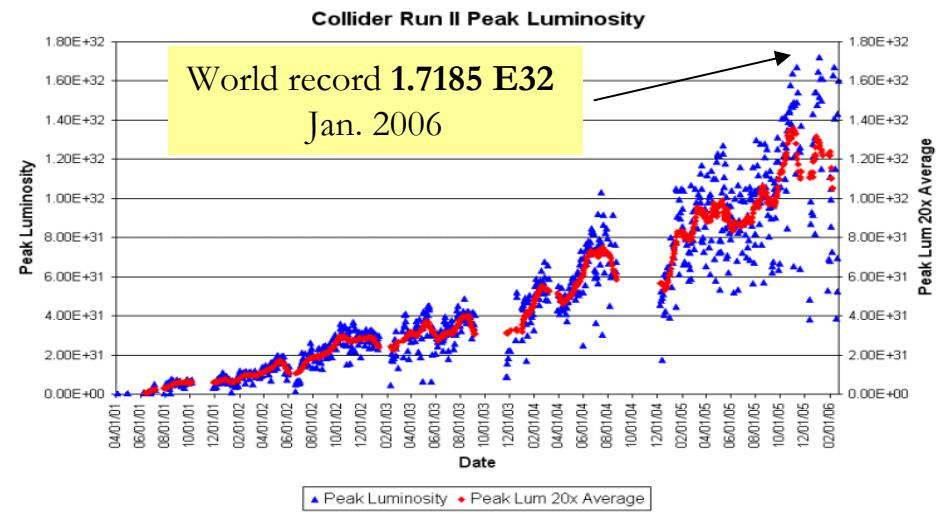


Backup

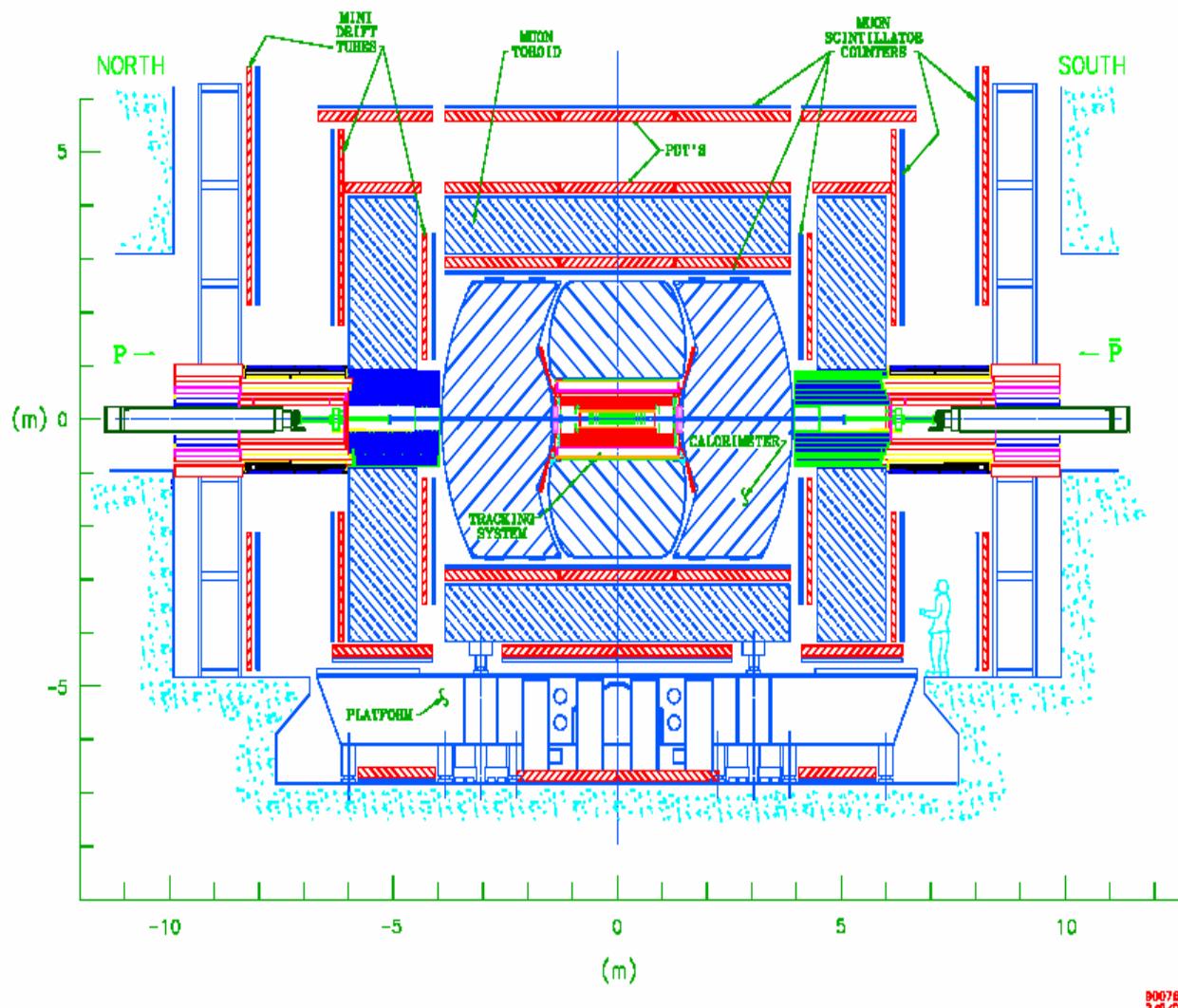
TeVatron



Typical « recorded » to « delivered »
luminosity ratio: 80 to 90%
 $\sim 1.2 \text{ fb}^{-1}$ on tape for each experiment
 0.2 to 0.4 fb^{-1} for results presented here
 4 to 8 fb^{-1} expected in 2009

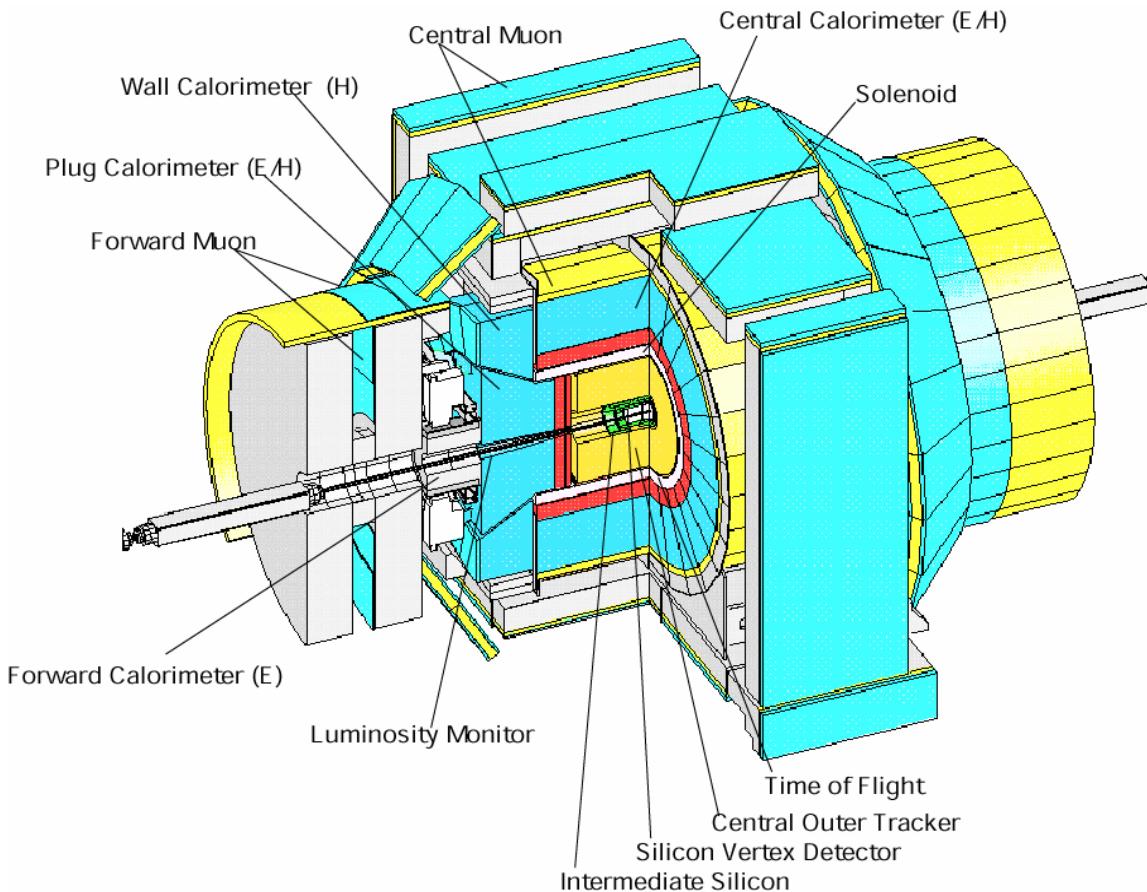


Do detector



- New silicon and fiber tracker
- Solenoid (2 Tesla)
- Upgrade of muon system
- Upgrade of Trigger/DAQ

CDF detector



- New silicon and drift chamber
- Upgrade of calorimeter and muon system
- Upgrade of Trigger/DAQ

Extra Dimensions

Hierarchy problem: Why $\mathcal{M}_{PL} \sim 10^{16} \text{ TeV} >> \mathcal{M}_{EW} \sim 1 \text{ TeV}$?

Arkani-Hamed, Dimopoulos Dvali (ADD)

- SM particles confined to a three-dimensional « brane »
- Gauge interactions: embedded in a « multiverse »: the three standard plus additional compact dimension
- Graviton can propagate in the multiverse
- Gravitons propagating in compact extra dimensions appear as a tower of Kaluza-Klein (KK) excited modes (point of view of the SM brane)
- Radius of compactification can be as large as 1 mm
- Gravitons are free to propagate in extra dimensions
 - > gravitational appears suppressed on the SM brane
 - > the apparent Planck scale is $\sim 10^{19} \text{ GeV}$ with respect to the $3+n$ dimensional space but the fundamental Planck scale M_s can be as low as 1 TeV
 - > no more hierarchy problem in the SM

Excited states with masses n/R^{δ}
(n =number of extra dimensions, R : compactification radius)
Coupling to matter $\propto 1/M_{PL}$
Continuum of KK states -> cross section $\sim \text{pb}$

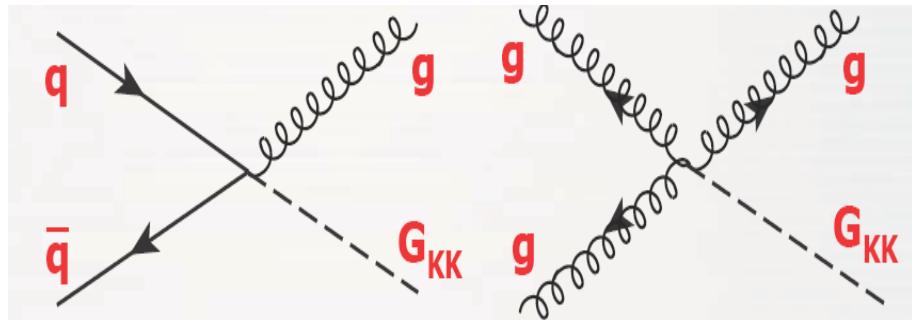
Randall-Sundrum (RS)

- two branes (Planck and SM) in a slice of Anti de Sitter space-time (AdS_5)
- gravity originates on the Planck brane and the graviton wave function is exponentially suppressed away from the brane along the extra dimension due to a warp factor (metric)
 - > low energy effects on the SM brane with a typical scale: $\Lambda_\pi \sim M_{PL} \exp(-k\pi R) / M_{PL} = M_{PL} / \sqrt{8\pi}$
 - > hierarchy problem solved if $\Lambda_\pi \sim 1 \text{ TeV}$ ie $kR \sim 10$

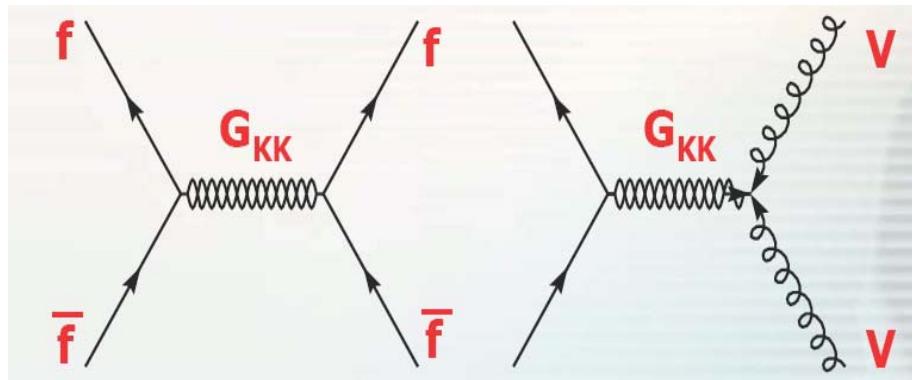
Only one dimension
Massive resonances not equidistant in mass
First excited state: cross section $\sim \text{pb}$

Extra Dimensions

Signatures at the TeVatron



Real graviton emission
-> monojets



LED: Virtual graviton effect
RS: real graviton
-> fermion or vector boson pairs
(resonance in RS)

Jet Energy Scale in Do

- Jets are reconstructed from energy deposits in the calorimeter using a cone algorithm
- Jets are made of different kinds of particles (γ, π, K, p, n) for which calorimeter responses are different.
- Moreover: there are energy depositions in the calorimeter from spectator interactions, additionnal $p\bar{p}$ interactions, electronic noise, and noise due to radioactive decay of uranium.
- Furthermore: not always all particles in a jet deposit energy within algorithm cone.
-> all these effects produce a distortion in the jet energy and the particle level jet energy can be obtained from the measured jet energy through:

$$E_{jet}^{ptcl} = \frac{E_{jet}^{meas} - E_0(R, \eta, \mathcal{L})}{R_{jet}(E_{jet}^{meas}, \eta) * R_{cone}(R, E_{jet}^{meas}, \eta)}$$

Offset energy(multiple interaction, underlying event energy, electronic noise, uranium noise and pile-up)

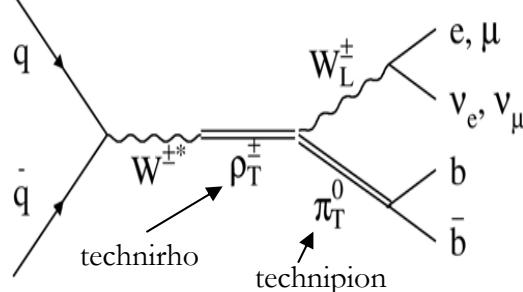
Zero Bias (ZB) and Minimum Bias (MB) events

dijet events

Fraction of particle jet energy contained within the algorithm cone

Calorimeter response to the hadronic jet

$\gamma + \text{jet events } (p_T \text{ imbalance})$



$\text{evbQ } (Q=b,c) \mathcal{L} \sim 238 \text{ pb}^{-1}$

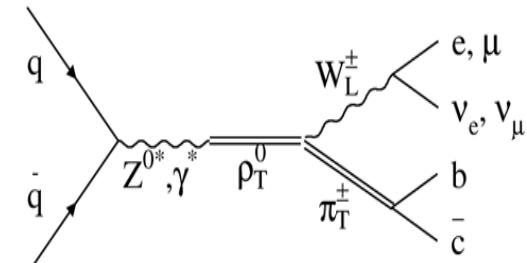


1 electron $p_T > 20 \text{ GeV}$
 $M_{T(W)} > 30 \text{ GeV}$
 2 jets $p_T > 20 \text{ GeV}$
 1 jet b-tagged ($\epsilon_b \sim 35\%$; mistg $\sim 0.25\%$)
 $\Delta\Phi(jj) > 2.2$, $p_T(jj) < 75 \text{ GeV}$
 $HT = p_T^e + p_T^j + p_T^j < 200 \text{ GeV}$
 Invariant masses: $m(jj)$, $m(Wjj)$
 Main background: Wbb, W+light (mistag)
Data: 4 MC: 6.6

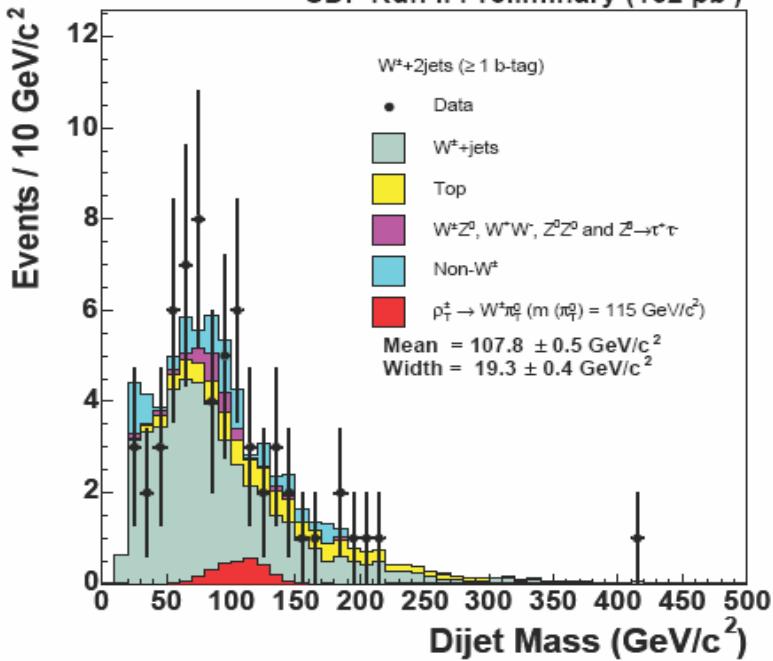
Systematics:

- D0: JES, Jet reso, btag
- CDF: FSR, btag, ISR, JES

1 isolated lepton
 2 jets flavoured tagged
 (similar to HW for bblv)



CDF Run II Preliminary (162 pb $^{-1}$)



$$m(\rho_T, \pi_T) = (200, 105) \text{ GeV} \quad \sigma < 0.681 \text{ pb} @ 95\% \text{ CL}$$

Projection $Z' \rightarrow ee$

