Search for New Particles or Gauge Bosons Decaying into Dileptons/Dijets at the Tevatron

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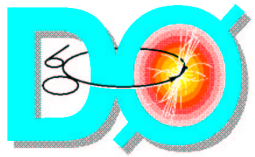
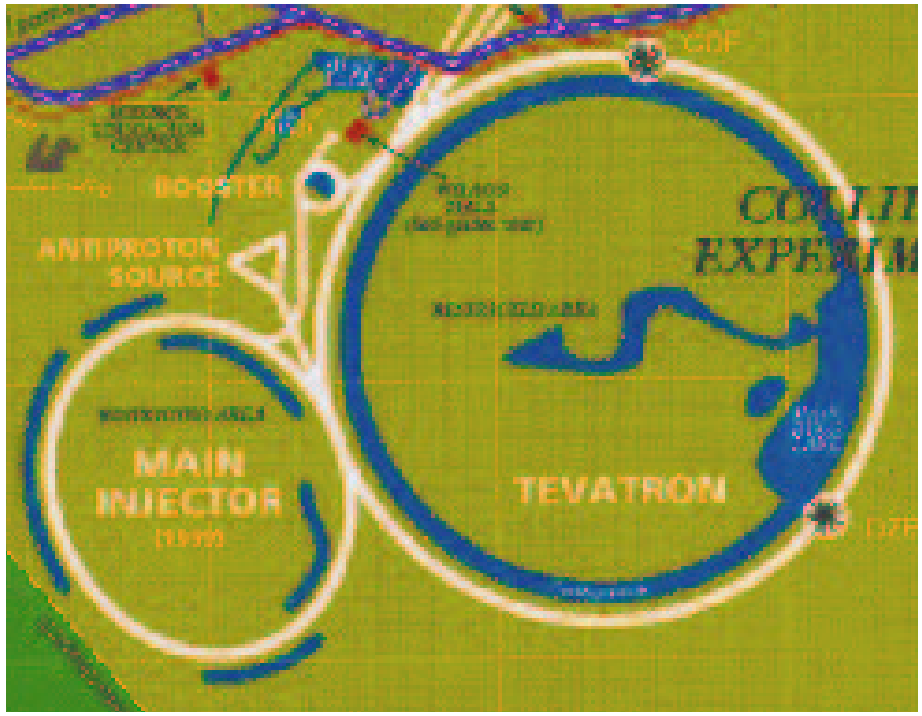


on behalf of the CDF and DO Collaborations

EUROPEAN PHYSICAL SOCIETY – AACHEN, GERMANY – JULY 17-23, 2003
International Europhysics Conference on High Energy Physics

Outline

- Accelerator Performance
- Detectors
- Dijet Resonances
  - axigluons
  - flavour universal colorons
  - excited quarks
  - color octet techni-ρ
  - E_6 diquarks
  - Z', W' gauge bosons
  - randall-sundrum gravitons
- Dilepton Resonances
  - Z' gauge bosons
  - randall-sundrum gravitons
- Concluding Remarks

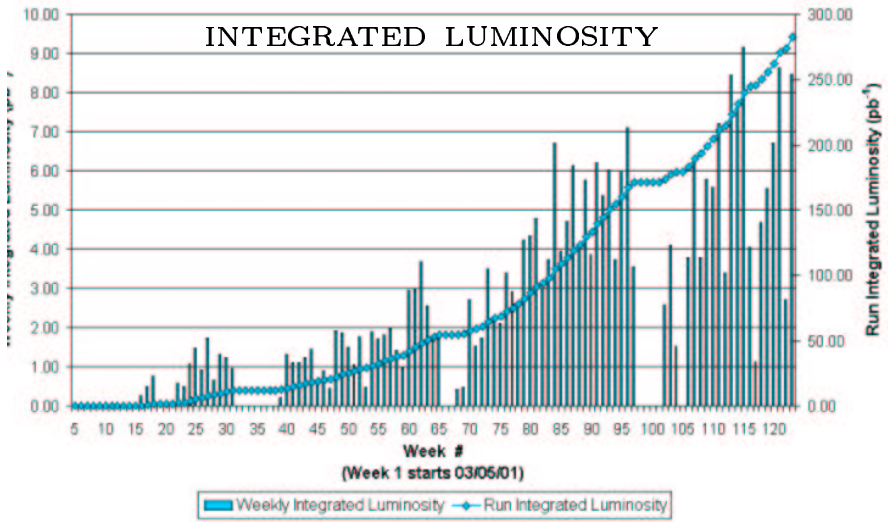


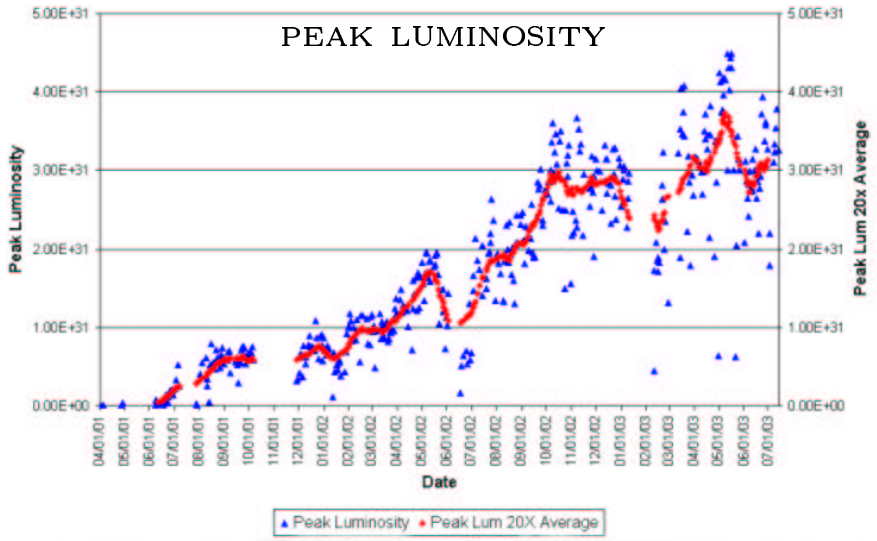
The Tevatron II Accelerator Complex

☑ Accelerator Performance

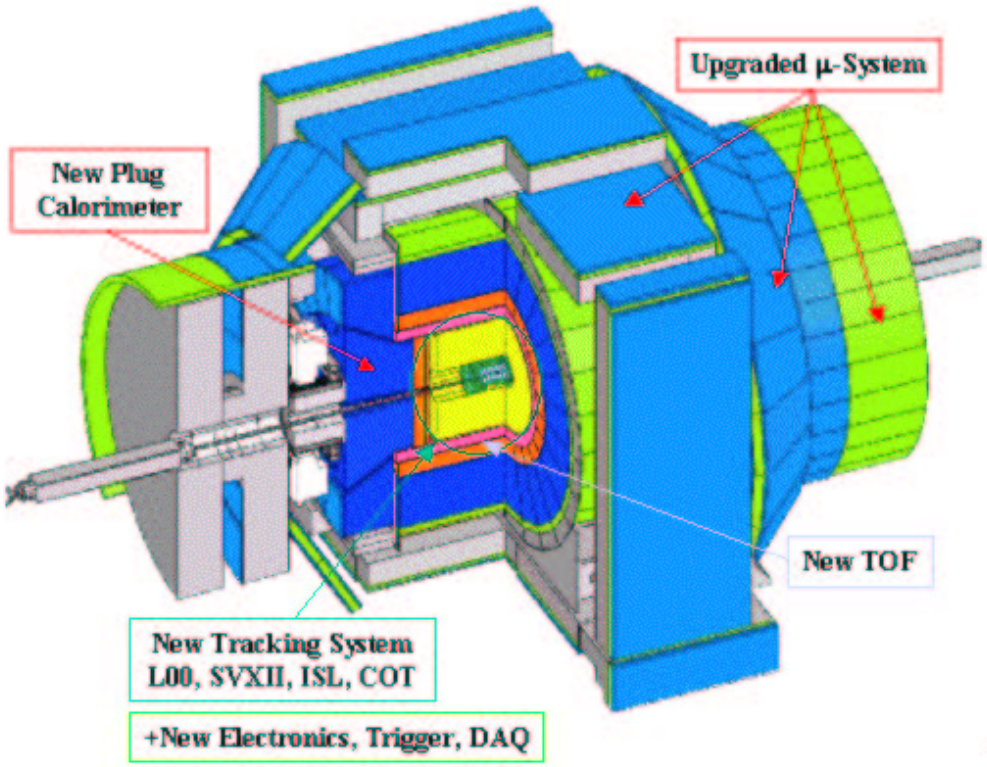
- ACHIEVED:
  - $\int \mathcal{L} dt/\text{week} \simeq 9\,\text{pb}^{-1}$
  - $\mathcal{L} \simeq 4.9\text{e}31\,\text{cm}^{-2}\text{s}^{-1} \Rightarrow \bar{N}(\textit{interactions/beam-cross}) \simeq 1.5$
- BY END SUMMER 2003: $\int \mathcal{L} dt \simeq 280\,\text{pb}^{-1}$
- LONG(ER)-TERM PLAN: MAJOR EFFORT TO IMPROVE $\bar{\text{p}}$ CHAIN
  - INTEGRATE RECYCLER
  - ENABLE ELECTRON COOLING

$\Rightarrow$ $\mathcal{L} \longrightarrow 3\text{e}32\,\text{cm}^{-2}\text{s}^{-1}$, $\bar{N}(\textit{interactions/beam-cross}) \longrightarrow 10$



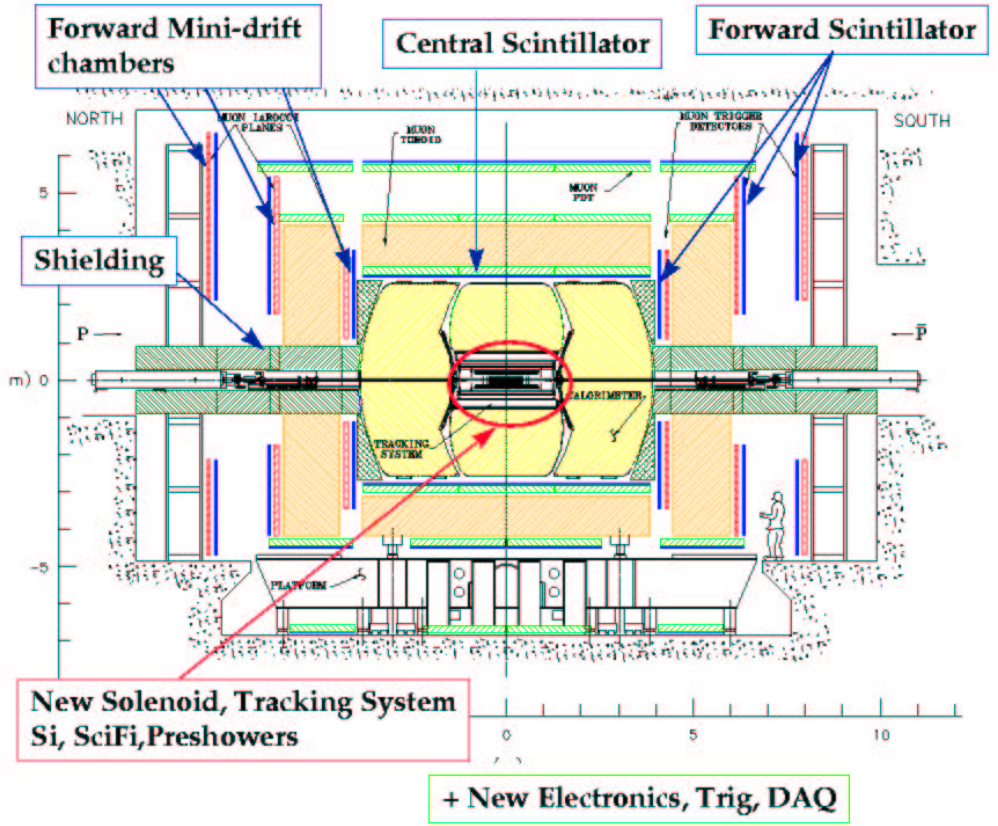


☑ Tevatron Detectors



CDF

- μ coverage up to $|\eta| \simeq 1.5$
- electron coverage up to $|\eta| \simeq 2.5$
- jet reconstruction up to $|\eta| \simeq 3.0$



DO

- μ coverage up to $|\eta| \simeq 2$
- electron coverage up to $|\eta| \simeq 3.0$
- jet reconstruction up to $|\eta| \simeq 3.0$

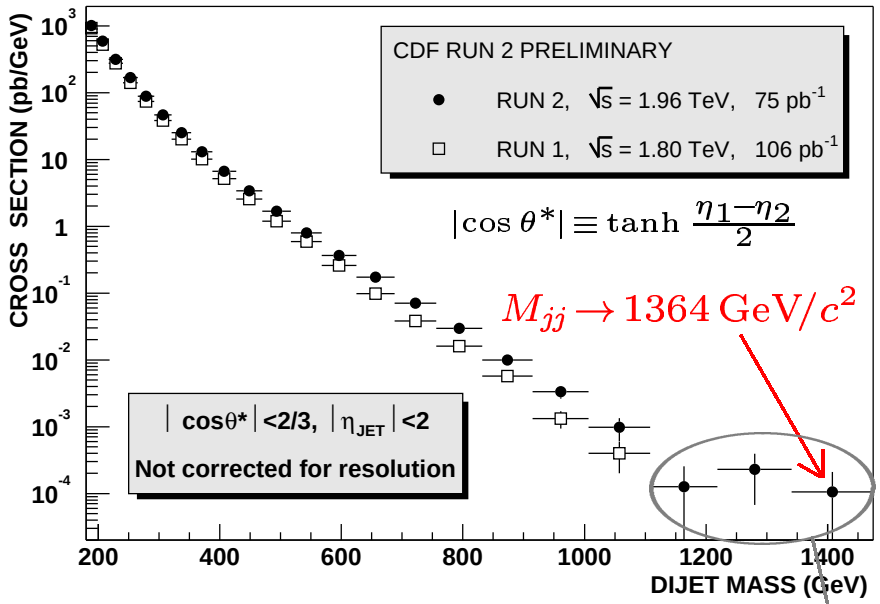
☑ New Particles Decaying to Dijets – 1

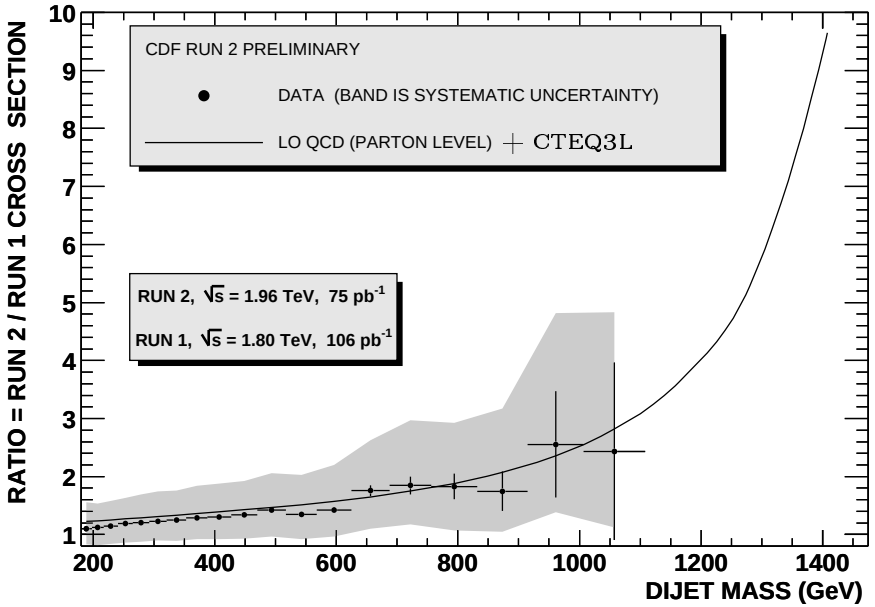
- for many classes of new particles $\mathrm{B.R.}(\mathrm{X}\to jj)$ is large
- QCD background is huge...
- ...however, all particles narrower than $\sigma_{jj}^{\mathrm{CDF}}$ $(\sim 0.1\cdot M_{jj})$
  - ⊛ will be reconstructed equally wide
- same lineshape (sculpted by σ_{jj}) fits all
- general procedure to set limits on $\sigma(\mathrm{p\bar{p}}\to\mathrm{X})\cdot\mathrm{B.R.}(\mathrm{X}\to jj)$ for:

axigluons	$\mathrm{A}\to\mathrm{q\bar{q}}$	$\Gamma_{\mathrm{A}}/2\sim 0.05\cdot M_{\mathrm{A}}$	(chiral colour)
colorons	$\mathrm{C}\to\mathrm{q\bar{q}}$	$\Gamma_{\mathrm{C}}/2\sim 0.05\cdot M_{\mathrm{C}}$	(etc – technicolor)
excited quarks	$\mathrm{q}^*\to\mathrm{qg}$	$\Gamma_{\mathrm{q}^*}/2\sim 0.02\cdot M_{\mathrm{q}^*}$	(compositeness)
color octet techni-ρ	$\rho_{\mathrm{T}}\to\mathrm{g}\to\mathrm{q\bar{q}},\mathrm{g\bar{g}}$	$\Gamma_{\rho_{\mathrm{T}}}/2\sim 0.01\cdot M_{\rho_{\mathrm{T}}}$	(technicolor)
E_6 diquarks	$\mathrm{D}\to\mathrm{u\bar{d}}$	$\Gamma_{\mathrm{D}}/2\sim 0.004\cdot M_{\mathrm{D}}$	(string theory)
new gauge bosons	$\mathrm{Z}'(\mathrm{W}')\to\mathrm{q\bar{q}}^{(\prime)}$	$\Gamma_{\mathrm{V}'}/2\sim 0.014\cdot M_{\mathrm{V}'}$	(various)
RS graviton	$\mathrm{G}\to\mathrm{q\bar{q}},\mathrm{g\bar{g}}$	$\Gamma_{\mathrm{G}}/2\sim 0.06\cdot M_{\mathrm{G}}$	(randall-sundrum)

☑ New Particles Decaying to Dijets – 2

- starting point: inclusive jet samples ($E_T > 20, 50, 70, 100\,\mathrm{GeV}$)
- cosmic clean-up requires $\not\!\!E_T/\sqrt{\Sigma E_T} < 6$
- two leading jets (cone 0.7, E_T-corrected) with: $|\eta_{jet}| < 2$
- reduction of QCD t-channel contribution: $|\cos\theta^*| < 2/3$





HIGHEST MASS EVENTS ($M_{jj} \sim 0.7\sqrt{s}$) PROBES x UP TO 0.7

☑ New Particles Decaying to Dijets – 3

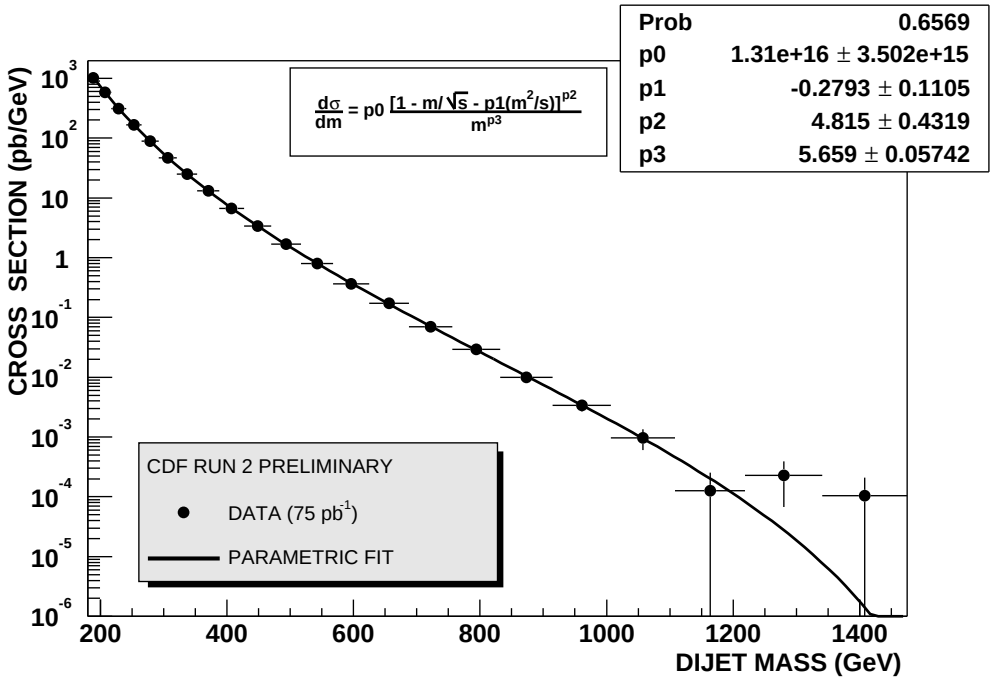
- (LO) QCD-inspired background parametrization:

$$\left.\frac{\mathrm{d}\sigma}{\mathrm{d}M}\right|_{dijet} = \frac{p_0(1 - M/\sqrt{s} - p_1 M^2/s)^{p_2}}{M^{p_3}}$$

→ $\sim(1-x)^n$ PDF behaviour

→ mimics QCD ME

- Background parametrization fits well on data



NO EVIDENCE OF NEW PHYSICS

☑ New Particles Decaying to Dijets – 4

- ADD NARROW RESONANCE TO BACKGROUND PARAMETRIZATION:
  - CDF DIJET MASS RESOLUTION DOMINATES THE LINESHAPE
  - SHAPE PARAMETRIZED BY $q^* \to qg$ THROUGH DETECTOR SIMULATION
  - WELL REPRESENTED BY A 10%-CORE GAUSSIAN + LOW-M_{jj} RADIATIVE TAIL
- BINNED MAXIMUM LIKELIHOOD FIT:

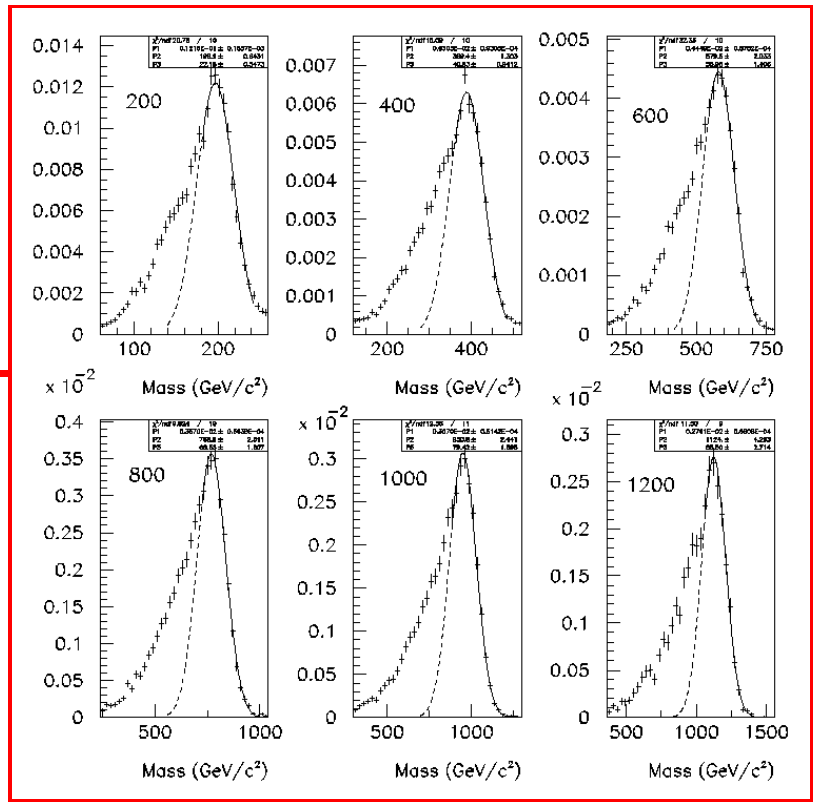
$$\mathcal{L} = \prod_i P_i = \prod_i \frac{\mu_i^{n_i} e^{-\mu_i}}{n_i!}$$

n_i: OBSERVED EVENTS } IN i-TH M_{jj} BIN

$\mu_i = N_i^B + \alpha N_i^S$

NORMALIZED TO SIGNAL X-SECTION

BACKGROUND PARAMETRIZATION



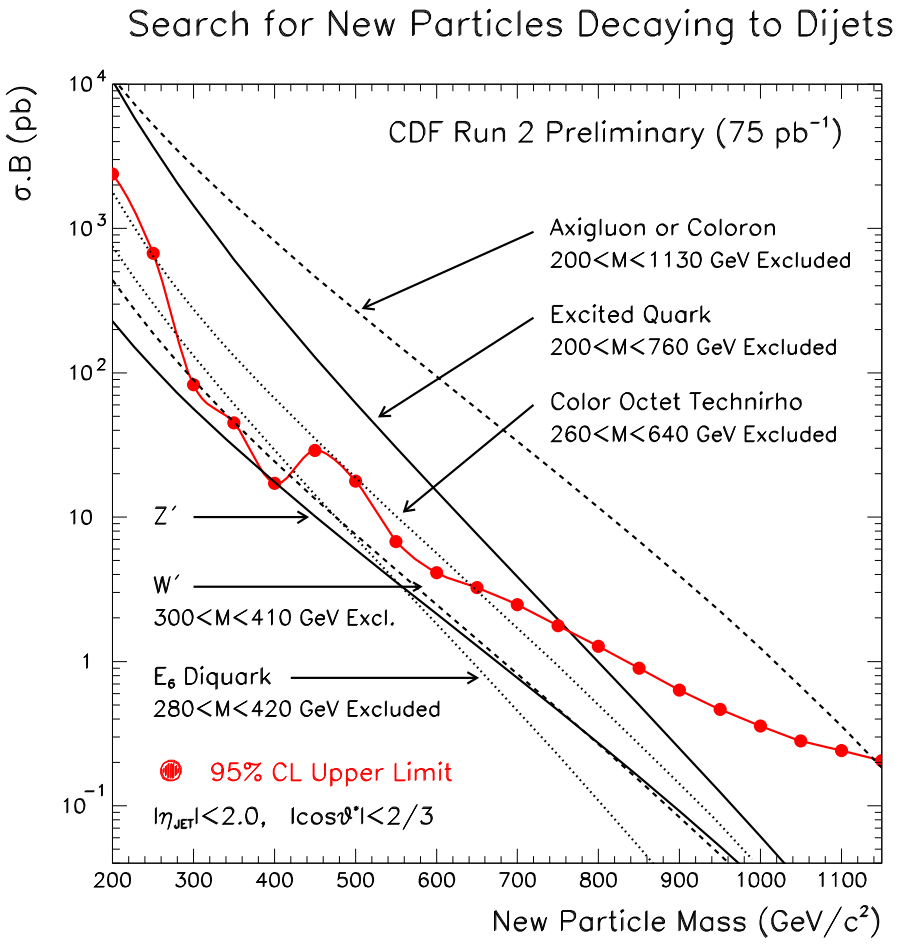
- ESTIMATE $\bar{p}_i(\bar{\alpha})$
- α_{95} FROM $\int_0^{\alpha_{95}} \mathcal{L}(\bar{p}_i,\alpha)\mathrm{d}\alpha \Big/ \int_0^{\infty} \mathcal{L}(\bar{p}_i,\alpha)\mathrm{d}\alpha = 0.95$

- SET 95% *C.L.* LIMITS AS $\sigma_{95} = \alpha_{95} \cdot \sigma_{signal}$

☑ New Particles Decaying to Dijets – 5

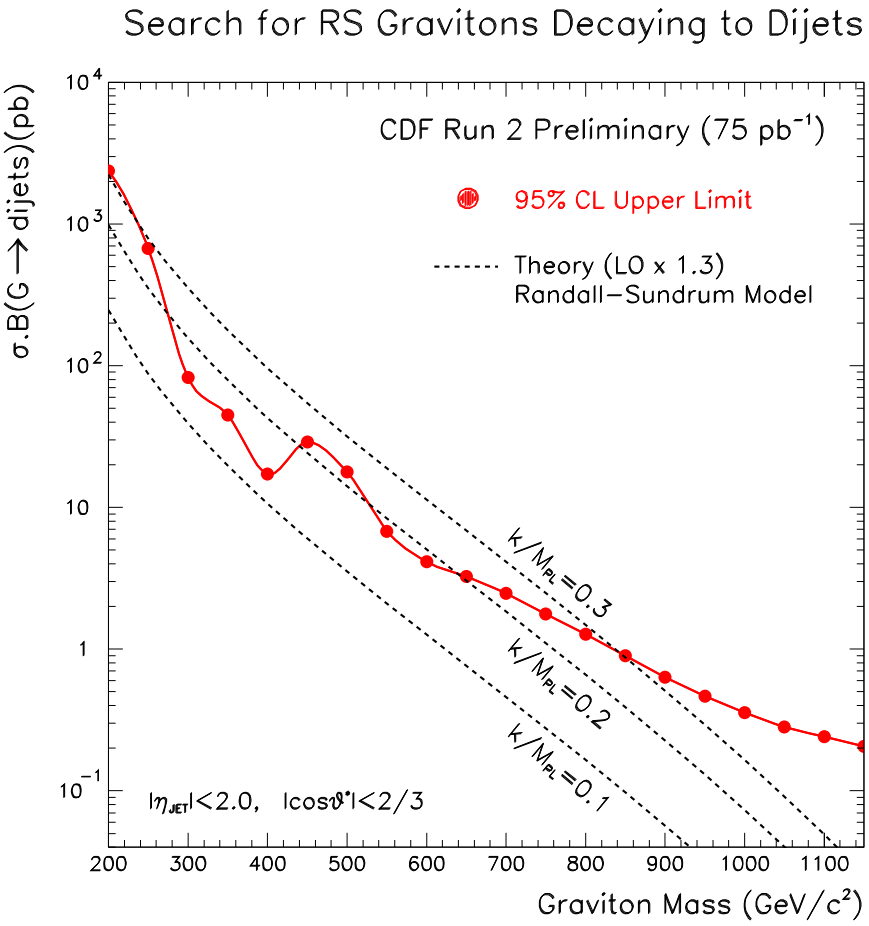
NEW PARTICLE	95% *C.L.* EXCLUDED MASS [GeV/c^2]
AXIGLUON†	$200 < M_{\mathrm{A}} < 1130$
COLORON	$200 < M_{\mathrm{C}} < 1130$
EXCITED QUARK	$200 < M_{\mathrm{q}^*} < 760$
TECHNI-ρ	$260 < M_{\rho_{\mathrm{T}}} < 640$
E_6 DIQUARK	$280 < M_{\mathrm{D}} < 420$
GAUGE BOSONS	$300 < M_{\mathrm{W}'} < 410$

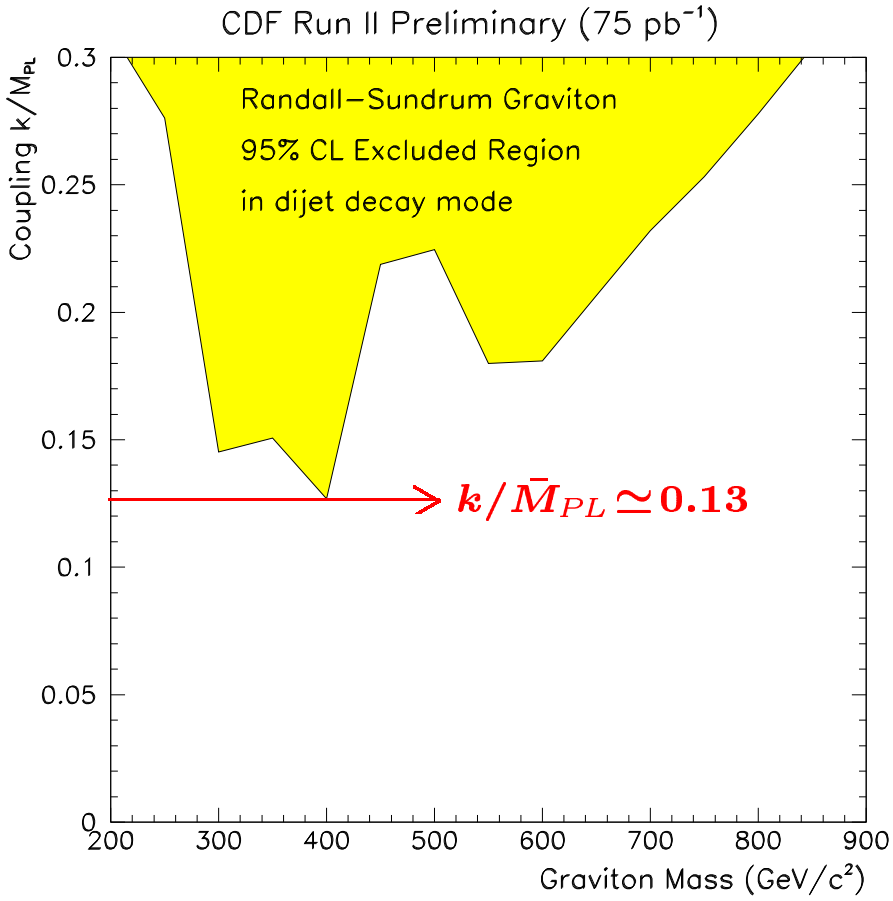
† PREVIOUS CDF MEASUREMENT
$120\,\mathrm{GeV}/c^2 < M_{\mathrm{A}}$ (@ 95% *C.L.*)



LEADING ORDER MC (CTEQ2L) + 1-LOOP α_S – RENORMALIZATION SCALE @ $\mu = M$
K-FACTOR APPLIED FOR NEW GAUGE BOSONS

☑ New Particles Decaying to Dijets – 6





$220\,\mathrm{GeV}/c^2 < M_\mathrm{G} < 840\,\mathrm{GeV}/c^2$ EXCLUDED @ 95% *C.L.* FOR $k/\bar{M}_{PL} = 0.3$

NEXT-TO-LEADING ORDER MC (CTEQ6L) – RENORMALIZATION SCALE @ $\mu = M_\mathrm{G}$

☑ New Particles Decaying to Dileptons

- signalled by anomalous high-$M_{\ell\ell}$ resonances
- models predicts $\mathrm{B.R.}(\mathrm{X} \to \ell^+\ell^-)$ as a function of M_{X}
- drell-yan, qcd and ewk processes contribute to background
- general search for dilepton bumps interpreted in terms of:

new gauge bosons	$\mathrm{Z}' \to \ell^+\ell^-$	(various models)
RS graviton	$\mathrm{G} \to \ell^+\ell^-$	(randall-sundrum)

- set limits on $\sigma(\mathrm{p\bar{p}} \to \mathrm{X}) \cdot \mathrm{B.R.}(\mathrm{X} \to \ell^+\ell^-)$
- searches performed in $\ell = \mathrm{e}, \mu$ channels

☑ New Particles Decaying to Dielectrons – 1

- STARTING POINT: INCLUSIVE HIGH-P_T ELECTRON SAMPLES

CDF	$E_T > 18\,\text{GeV},\ \|\eta\| < 1.1$	← TRACK @ L1 & L2
	$E_T > 70\,\text{GeV},\ \|\eta\| < 1.1$	$\int \mathcal{L} dt = 72\,\text{pb}^{-1}$
DO	$E_T > 20\,\text{GeV},\ \|\eta\| < 3.0$	$\int \mathcal{L} dt = 50\,\text{pb}^{-1}$

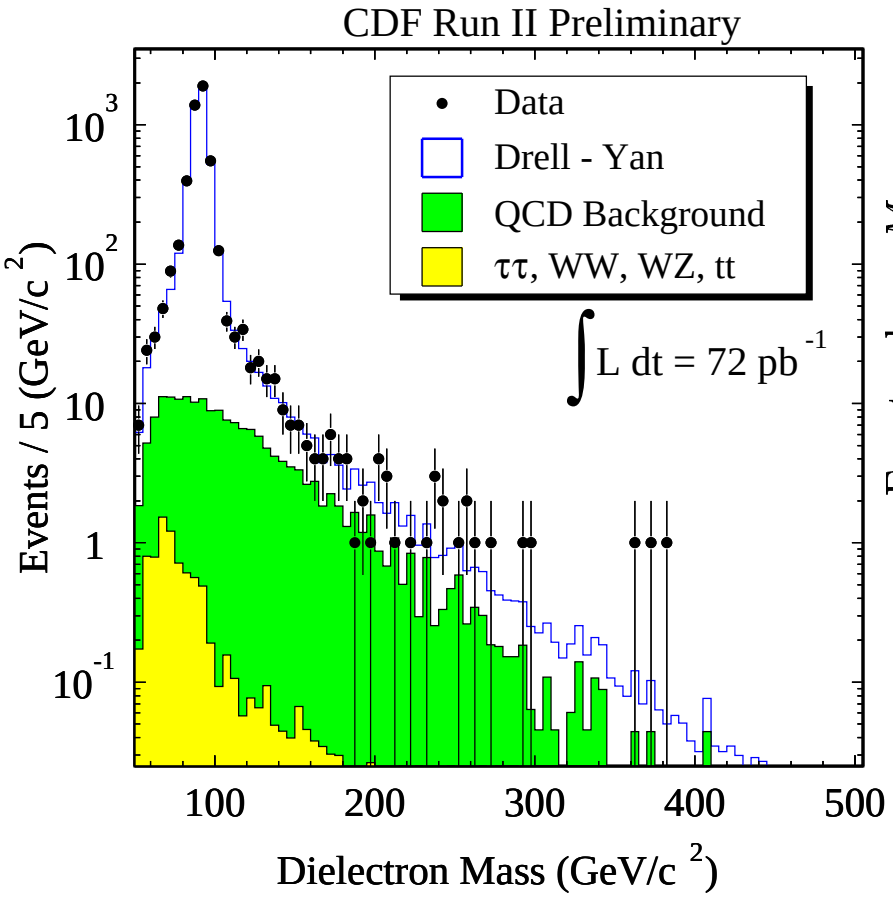
- OFFLINE DIELECTRON SELECTION

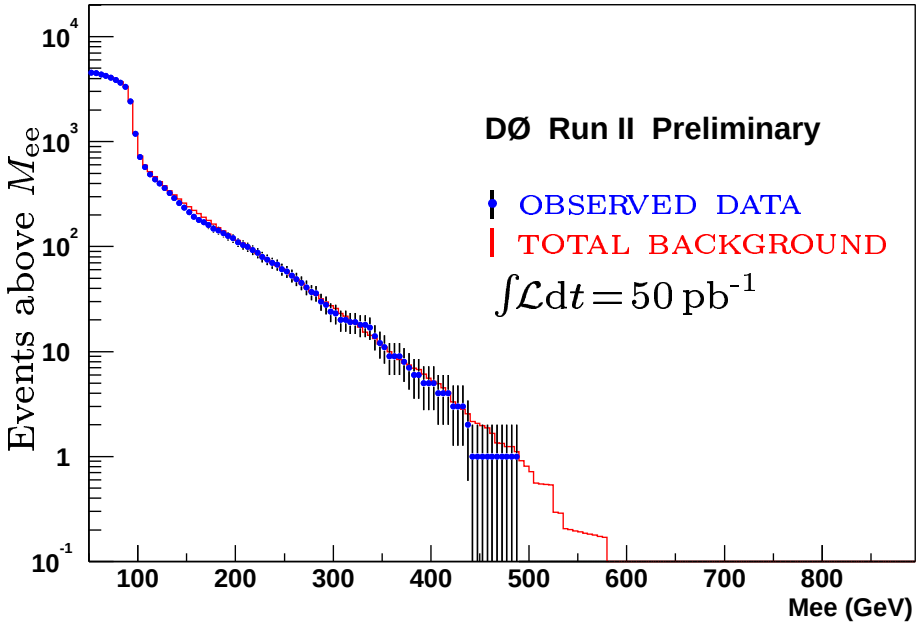
CDF	$E_T(\text{e}_1) > 25\,\text{GeV},\quad \|\eta\| < 1.1$	← BC TRACK W/ $P_T > 13\,\text{GeV}/c$
	$E_T(\text{e}_2) > 25\,\text{GeV},\quad \|\eta\| < 1.1$ OR $1 < \|\eta\| < 3$	
DO	$E_T(\text{e}_1, \text{e}_2) > 25\,\text{GeV},\ \|\eta\| < 1.1$ OR $1.5 < \|\eta\| < 2.5$	

  - ID SELECTION INCLUDES E_{had}/E_{em}, E/P, ISOLATION, SHOWER PROFILE χ^2

- BACKGROUND TREATMENT:
  - $\not\!\!E_T/\sqrt{\Sigma E_T} < 2.5$ REDUCES W+*jets* } **CDF**
  - QCD CONTAMINATION ESTIMATED BY REVERSING e_1, e_2 ISOLATION CUTS } **CDF**
  - QCD BACKGROUND FROM DIJET EVENTS ⊗ ELECTRON FAKE-RATE → **DO**

☑ New Particles Decaying to Dielectrons – 2

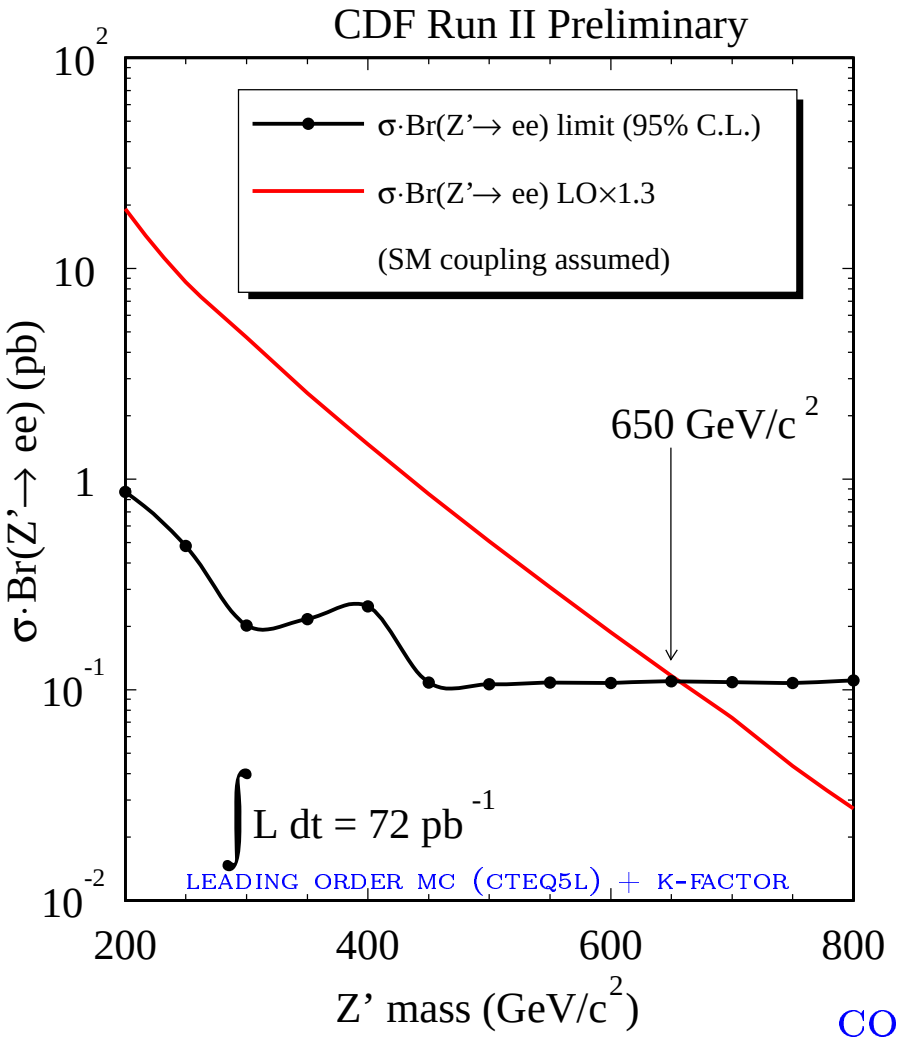


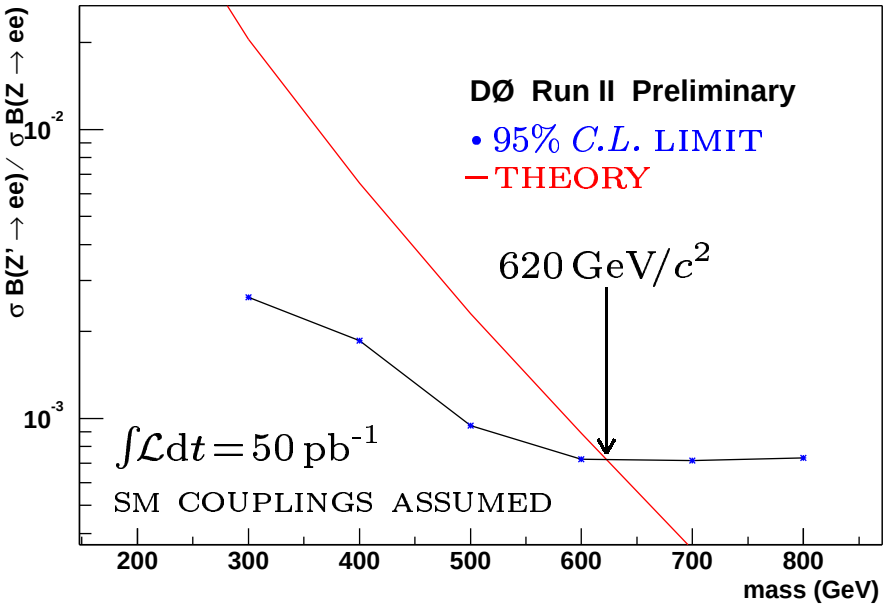


	M_{ee} [GeV/c^2]	N_{exp}	N_{obs}
CDF	> 150	63.8	63
DO		239	213

NO SIGNIFICANT EXCESS OBSERVED

☑ New Particles Decaying to Dielectrons – 3





95% *C.L.* LIMITS ON POISSON PROCESS

$Z'_{SM-like} \to e^+e^-$

CROSS-CHECK: $\sigma \cdot B.R.(Z \to e^+e^-)$

COMPATIBLE WITH CDF & DO MEASUREMENTS

☑ New Particles Decaying to Dimuons – 1

- Starting point: inclusive high-P_T muon samples

CDF	$P_T > 18\,\mathrm{GeV}/c^2,\ \lvert\eta\rvert < 0.6$	$\int \mathcal{L}\mathrm{d}t = 72\,\mathrm{pb}^{-1}$
	$P_T > 18\,\mathrm{GeV}/c^2,\ 0.6 < \lvert\eta\rvert < 1$	$\int \mathcal{L}\mathrm{d}t = 56\,\mathrm{pb}^{-1}$

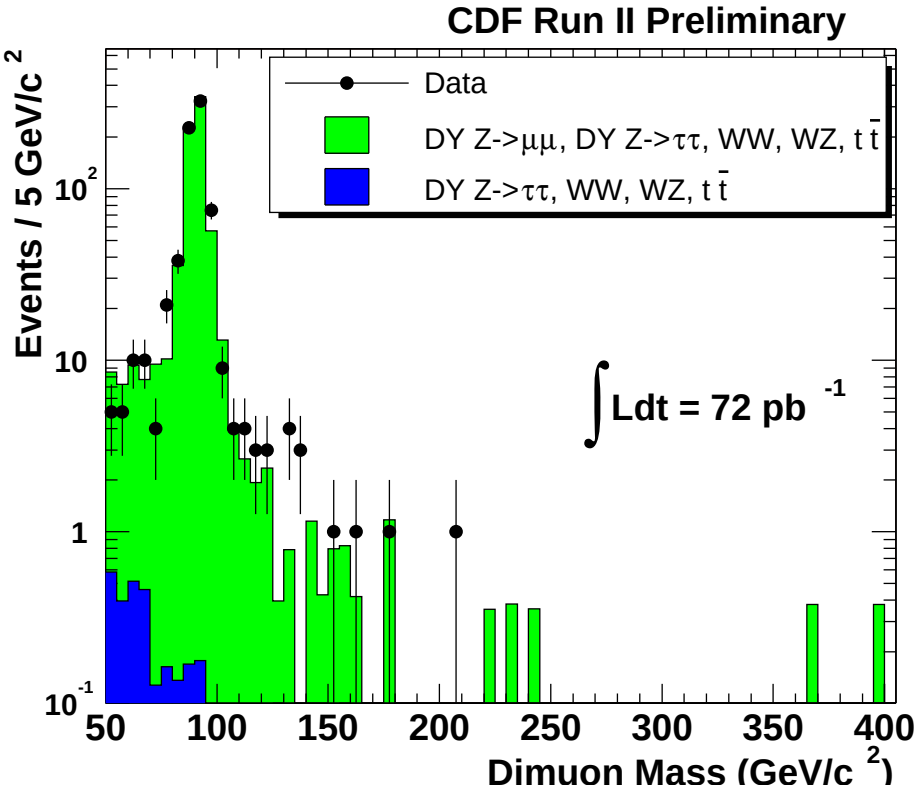
- Offline dimuon selection

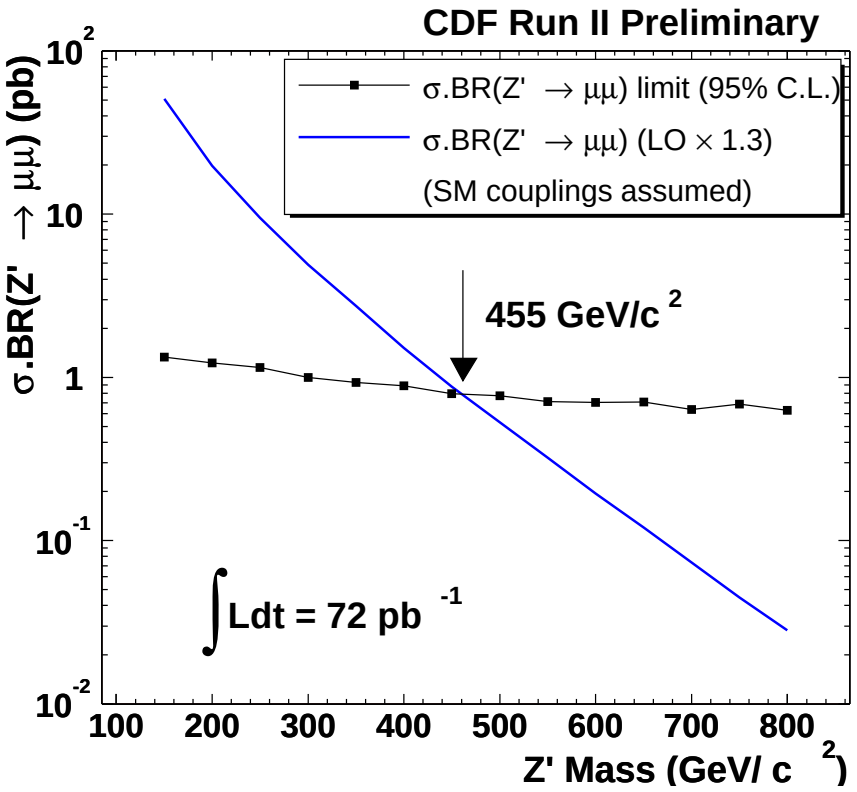
CDF	$P_T(\mu_1, \mu_2) > 20\,\mathrm{GeV}/c^2,\ \lvert\eta\rvert < 0.6$ or $0.6 < \lvert\eta\rvert < 1$

  - ID selection includes → track-stub matching quality
  - ID selection includes → E_{em}, E_{had} compatible w/ MIP
- Cosmic background removal:
  - track-based: "attach" muons to beamline/vertex (d_0, z_0)
  - timing-based: rely on TOF and hadron TDC information
- Other backgrounds: essentially DY (QCD negligible)

  only background @ high-$M_{\mu\mu}$

☑ New Particles Decaying to Dimuons – 2





	$M_{\mu\mu}$ [GeV/c^2]	N_{exp}	N_{obs}
CDF	> 150	5.2	4

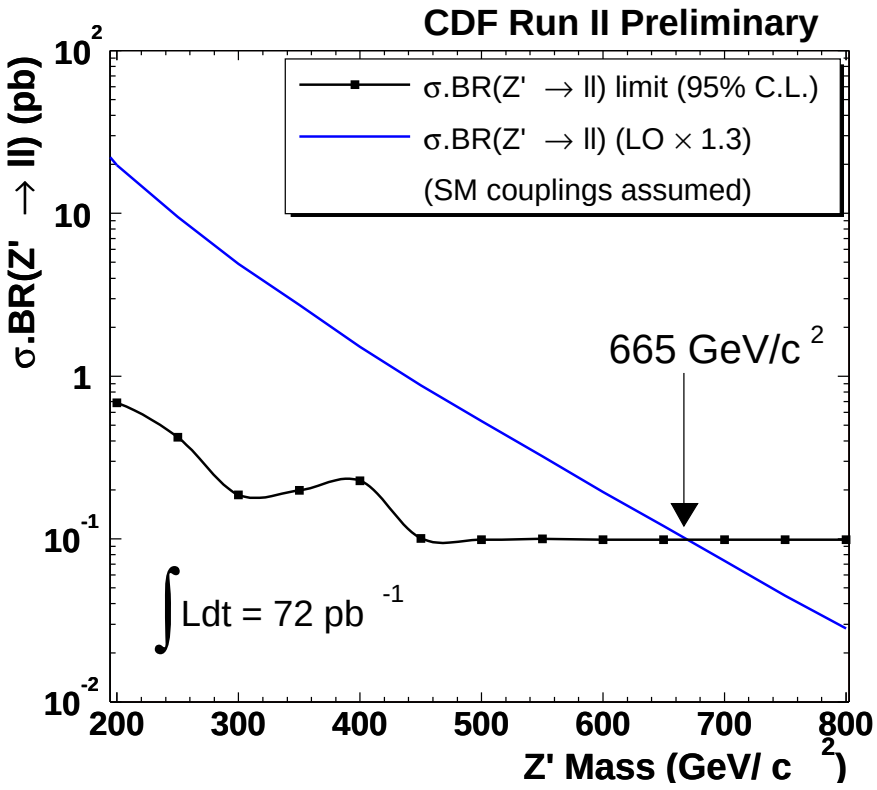
CROSS-CHECK: $\sigma \cdot B.R.(Z \to \mu^+\mu^-)$
COMPATIBLE WITH CDF MEASUREMENTS

95% *C.L.* LIMITS ON POISSON PROCESS
$Z'_{\mathrm{SM}-like} \to \mu^+\mu^-$

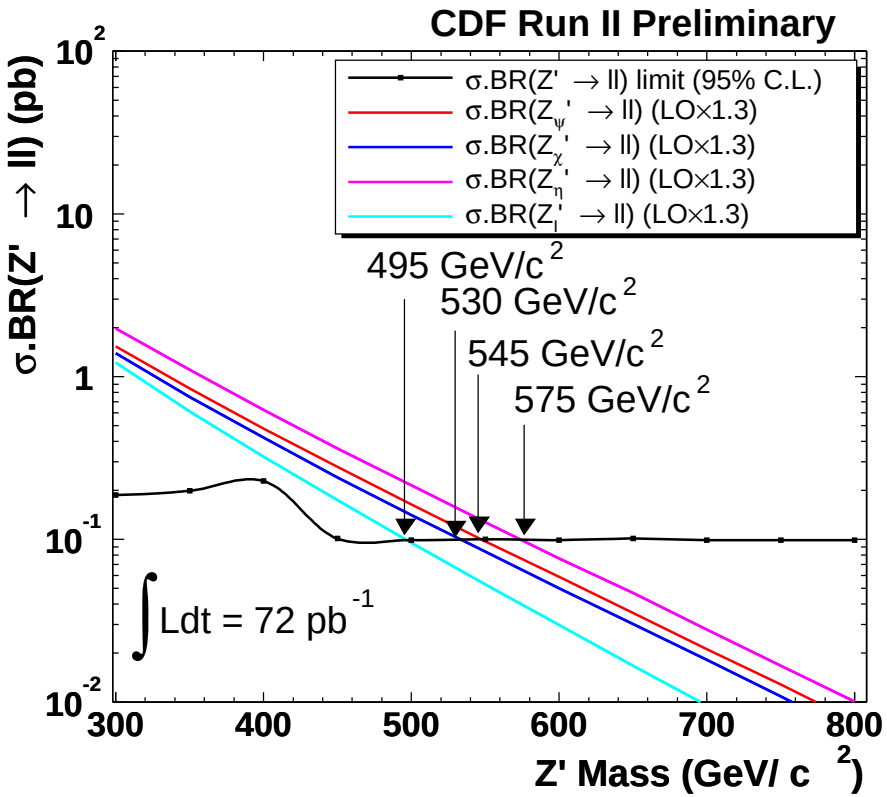
NO EXCESS OBSERVED

☑ New Particles Decaying to Dileptons – 1

⊡ combined dielectron + dimuon channel Z′ sensitivity



SM-coupling Z′

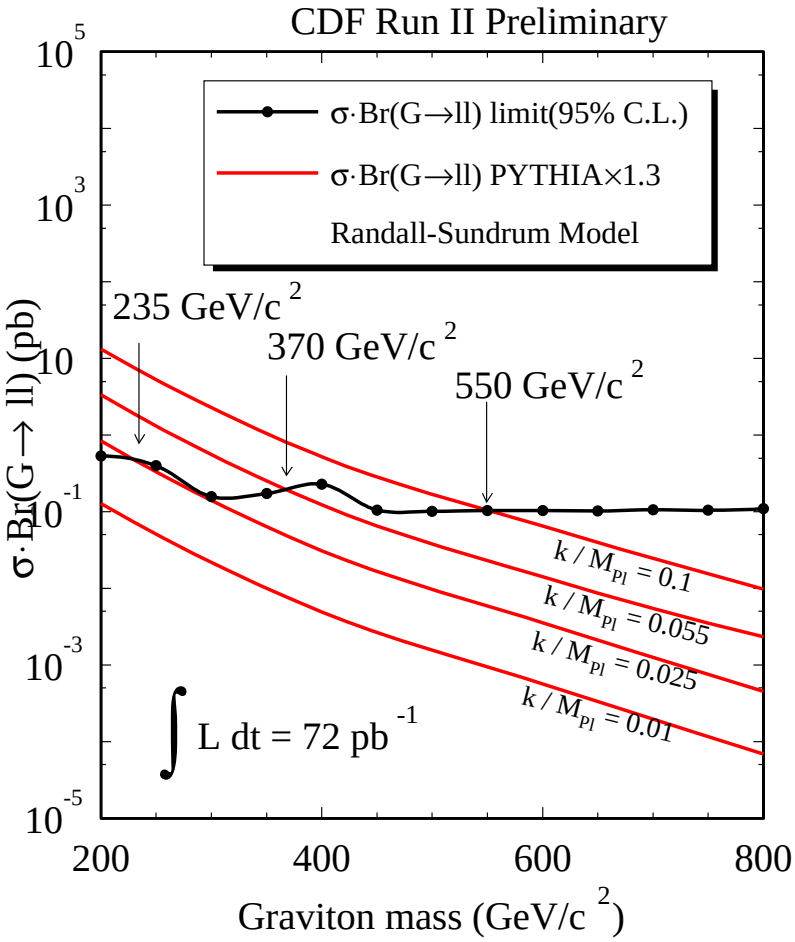


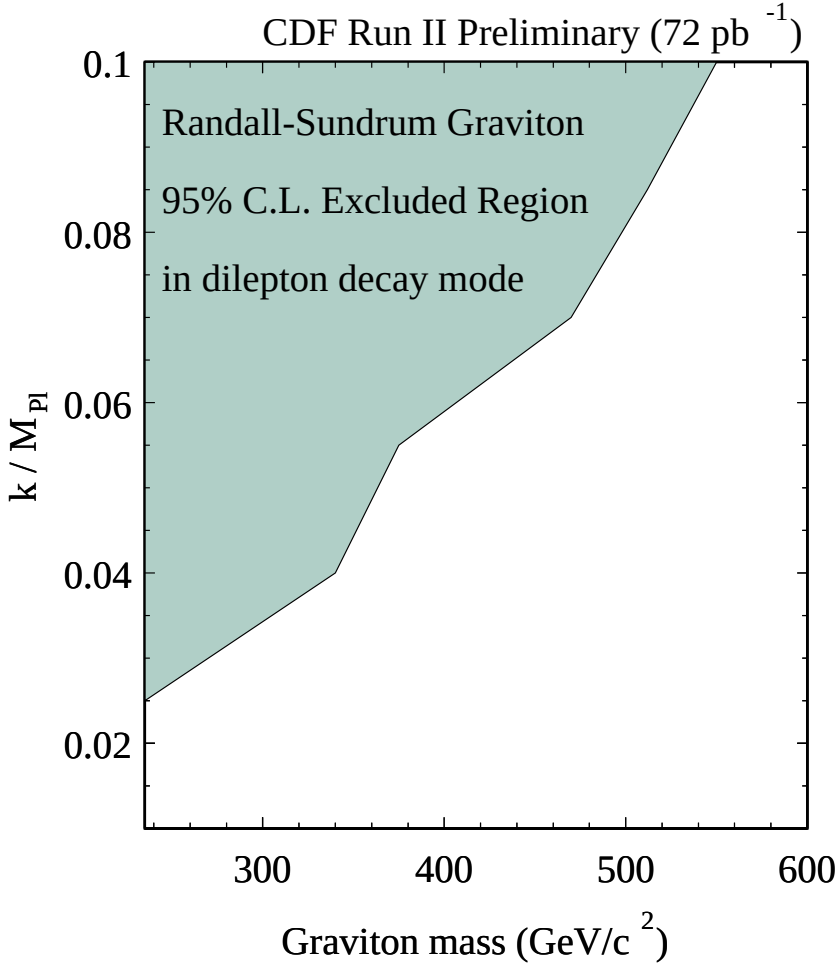
E_6 model Z′

leading order mc (cteq5l) + k-factor

☑ New Particles Decaying to Dileptons – 2

⊡ Combined dielectron + dimuon channel RS-graviton sensitivity





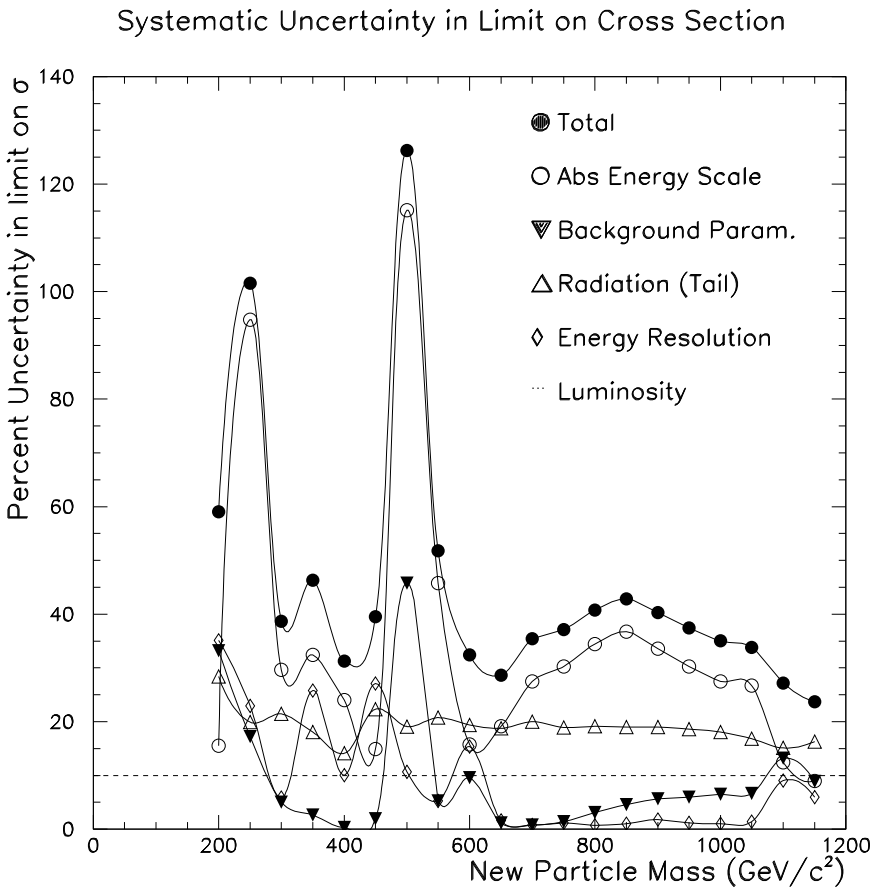
leading order mc (cteq5l) + k-factor

☑ Conclusions

- ⊡ searches in the dijet channel
  - ⊛ provided the first exclusion beyond the TeV limit
  - ⊛ all limits have improved wrt run I searches...
  - ⊛ ...already with $75\,\mathrm{pb}^{-1}$
- ⊡ searches in the dilepton channel
  - ⊛ dielectron channel as sensitive as run I
    - ⇝ increased cross-section compensates for lower luminosity
  - ⊛ dimuon channel penalized by temporary lower acceptance
    - ⇝ extended μ-chambers activated almost one year ago
- ⊡ CDF & DO actively probing beyond the SM horizons

☑ Searches for New Particles – Systematics

NEW PARTICLES → DIJETS



NEW PARTICLES → DIELECTRONS

⊡ LUMINOSITY	6%
⊡ ENERGY RESOLUTION	1.9% ÷ 3.5%
⊡ ENERGY SCALE	0.9% ÷ 1.7%
TOTAL CDF	∼9%
⊡ K-FACTOR	5%
⊡ $A_{Z'}/A_Z$ & PDF	2% ÷ 3%
TOTAL DO	∼6%

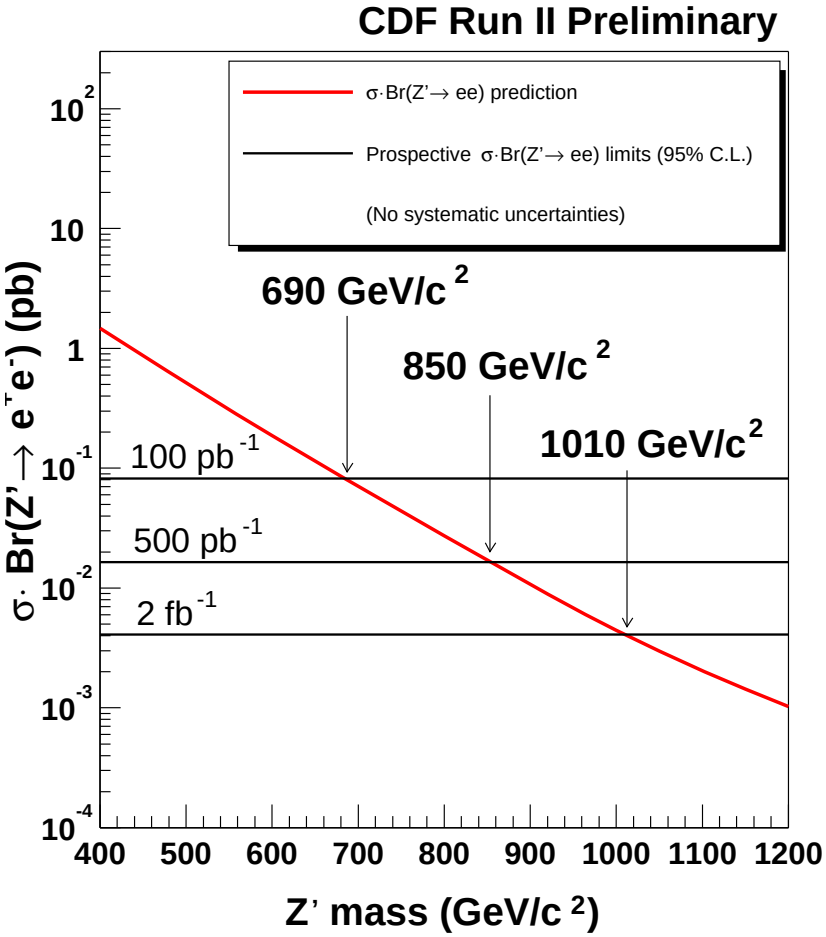
NEW PARTICLES → DIMUONS

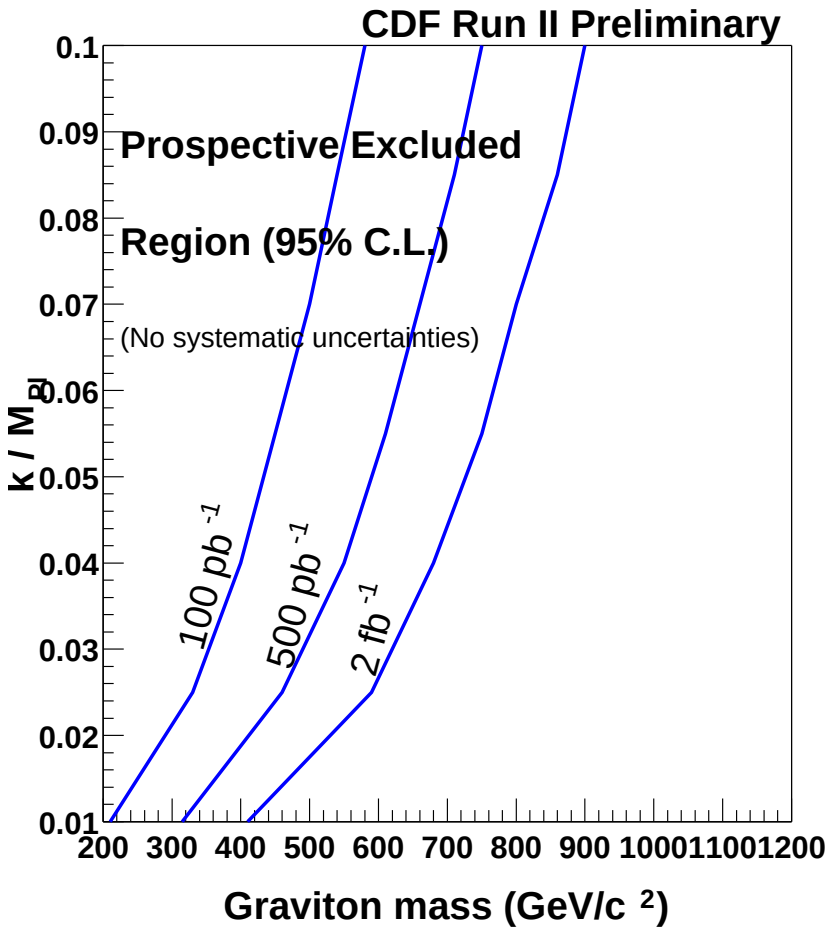
⊡ LUMINOSITY	6%
⊡ EFFICIENCY	6%
TOTAL	∼9%

☑ Searches for New Particles – RUN I vs RUN II

NEW PARTICLE	DECAY	CDF EXCLUDED MASS [GeV/c^2] RUN I	RUN II
AXIGLUON		$120 < M_{\mathrm{A}} < 870$	$200 < M_{\mathrm{A}} < 1130$
COLORON		–	$200 < M_{\mathrm{C}} < 1130$
EXCITED QUARK	$\mathrm{X} \to jj$	$200 < M_{\mathrm{q}^*} < 560$	$200 < M_{\mathrm{q}^*} < 760$
TECHNI-ρ		$320 < M_{\rho_{\mathrm{T}}} < 480$	$260 < M_{\rho_{\mathrm{T}}} < 640$
E_6 DIQUARK		–	$280 < M_{\mathrm{D}} < 420$
GAUGE BOSONS			
$\mathrm{W}'_{\mathrm{SM-like}}$	$\mathrm{W}' \to jj$	–	$300 < M_{\mathrm{W}'} < 410$
$\mathrm{Z}'_{\mathrm{SM-like}}$		$M_{\mathrm{Z}'} < 690\ ^{655}_{590}$	$M_{\mathrm{Z}'} < 665\ ^{650}_{455}$
Z'_{χ}		$M_{\mathrm{Z}'} < 595\ ^{530}_{500}$	$M_{\mathrm{Z}'} < 530\ ^{525}_{330}$
Z'_{ψ}		$M_{\mathrm{Z}'} < 590\ ^{520}_{495}$	$M_{\mathrm{Z}'} < 545\ ^{540}_{340}$
Z'_{η}	$\mathrm{Z}' \to \ell\ell\ ^{\mathrm{ee}}_{\mu\mu}$	$M_{\mathrm{Z}'} < 620\ ^{550}_{520}$	$M_{\mathrm{Z}'} < 575\ ^{565}_{340}$
Z'_{I}		$M_{\mathrm{Z}'} < 565\ ^{505}_{480}$	$M_{\mathrm{Z}'} < 495\ ^{565}_{365}$
$\mathrm{Z}'_{\mathrm{LR}}$		$M_{\mathrm{Z}'} < 630\ ^{565}_{530}$	–
$\mathrm{Z}'_{\mathrm{ALRM}}$		$M_{\mathrm{Z}'} < 600\ ^{525}_{500}$	–

☑ Searches for New Particles – Prospects





☑ Searches for New Particles – E_6 Model Z′

$$E_6 \to SO(10) \times U(1) \to SU(5) \times U(1)_\chi \times U(1)_\psi \to \underbrace{SU(3)_C \times SU(2)_L \times U(1)_Y}_{SM} \times U(1)_\chi \times U(1)_\psi$$

$U(1)_\chi$, $U(1)_\psi$ $\longleftrightarrow$ two additional neutral vector bosons (Z_χ, Z_ψ)

mass eigenstates: $Z'(\theta) = Z_\psi \cos\theta + Z_\chi \sin\theta$

$Z'(\theta)$	θ
Z'_χ	0
Z'_ψ	$-\pi/2$
Z'_η	$\sin^{-1}\sqrt{3/8}$
Z'_I	$\sin^{-1}\sqrt{5/8}$