Searches for BSM Physics at the Tevatron (non SUSY)

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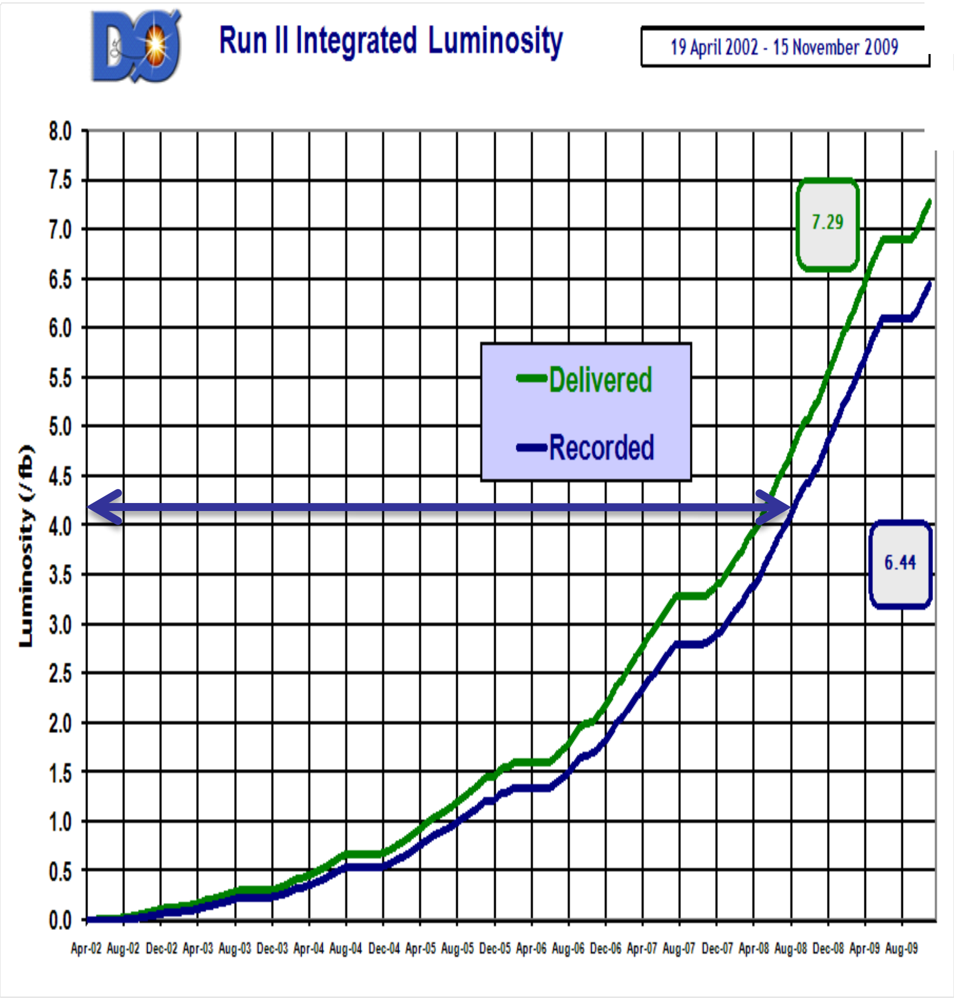
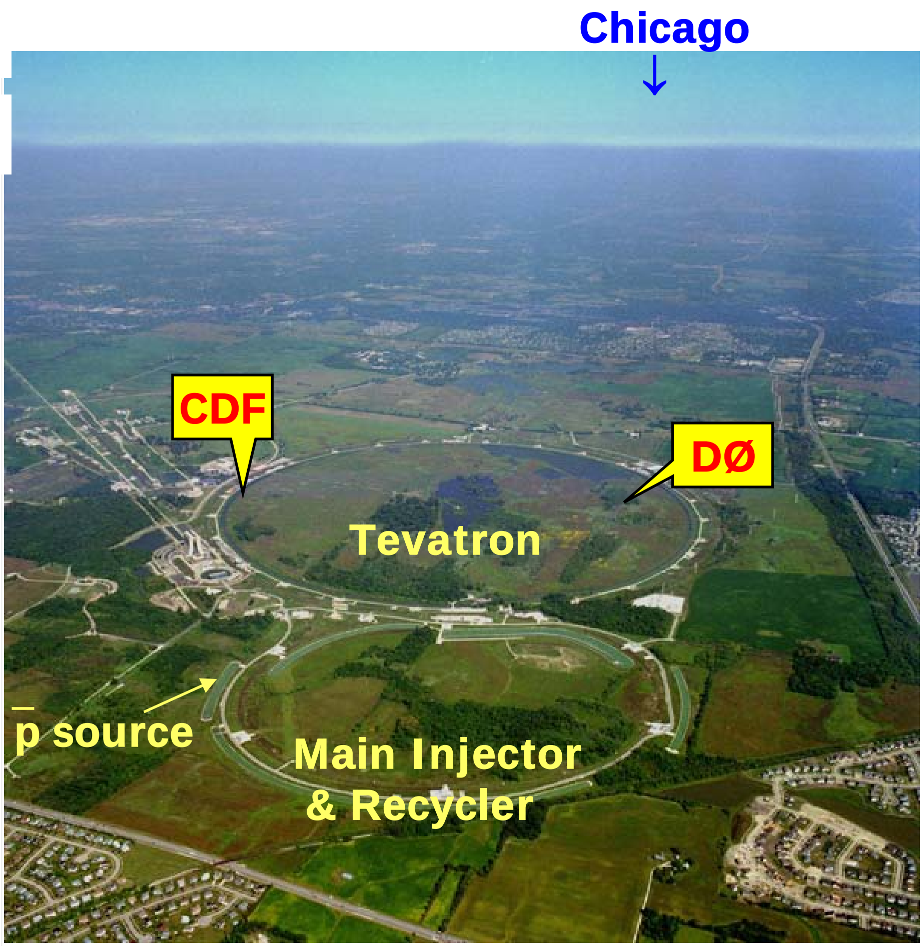
On behalf of the CDF and D0 collaborations

- *Searches for new high mass resonances decaying in $\ell\bar{\ell}$ and VV*
- *Search for quark compositeness*
- *Searches for Leptoquarks*
- *Search for a heavy fourth generation down-type quark b'*
- *Search for Neutral Long-Lived Particles (NLLP)*
- *Conclusion*

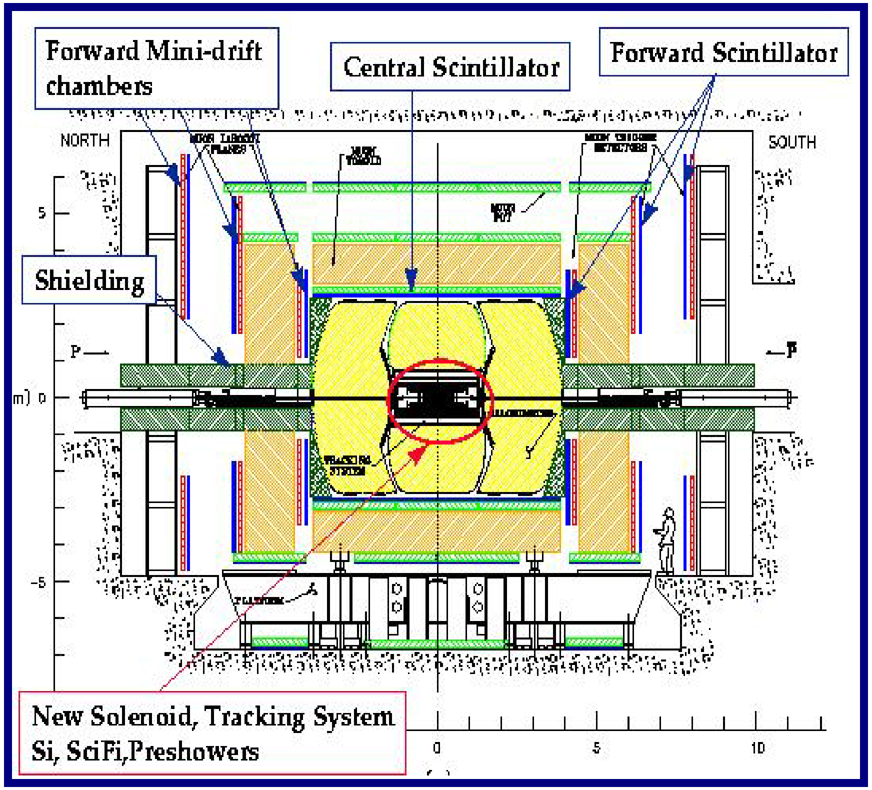
Tevatron experiments – Run II

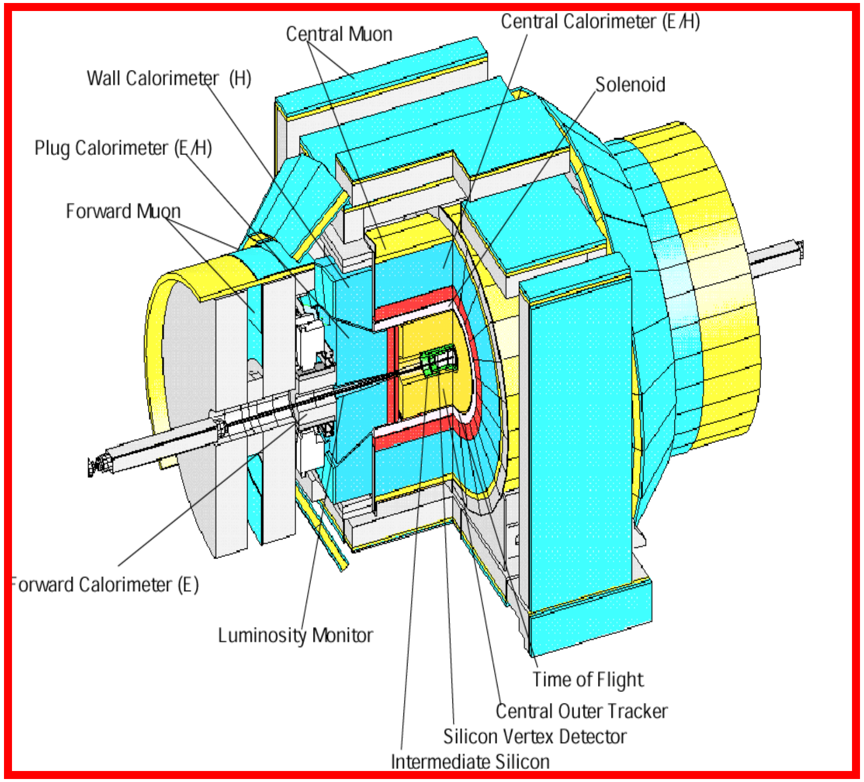




Analyses presented here use up to ~4.1 fb^{-1}

D0 CDF





Both general purpose detectors well understood and highly efficient with:

Excellent calorimeters and muon chambers coverage

Precision tracking (Silicon Vertex Detector)

Data taking efficiency ~90 %

New high mass resonances decaying in $f\bar{f}$ or VV

Many extensions of the SM model predict new heavy particles X decaying in $f\bar{f}$, VV (Z' , W' , Graviton) such as Supersymmetry , Extra Dimensions , Little Higgs or Technicolor.

W' and Z' are generated using a Sequential Standard Model (SSM) parametrization . Results on Z' are also given in the scheme of E_6 models . In these models 2 additional neutral massive spin1 gauge bosons that can mix with an arbitrary mixing angle are predicted . The different Z' studied in the following analyses correspond to specific values of the mixing angle.

In extra spatial dimensions models such as the Randall-Sundrum (RS) model used here, the gravitons G propagate in the extra dimension and the parameters of the RS model are the M_G mass of the first excited mode of the graviton and the dimensionless coupling to the SM fields k/M_{pl} , where k^2 is the space time curvature in extra dimension and M_{pl} the reduced Planck mass. k/M_{pl} is expected to be between 0.01 and 0.1.

In extra dimension models , the cross sections for jets production are modified due to virtual exchanges of Kaluza-Klein excitations:

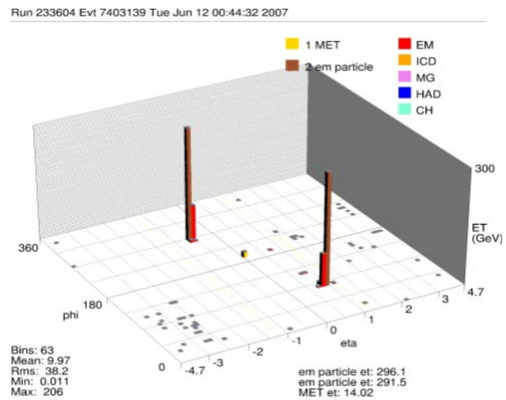
- *KK excitations of the graviton in the Large Extra Dimension model ADD . Different formalisms are used : GRW and HLZ . The parameters are the effective Planck scale M_S and , in the case of the HLZ model , the number of extra dimensions n_d.*
- *KK excitations of the SM gauge bosons in the TeV^{-1} ED model. In this model the parameter is the compactification scale M_C*

Search for High Mass *ee* resonances

3.6 fb^{-1}

2.5 fb^{-1}

PRL 102, 031801(2009)



2 central ($|\eta| <1.1$) EM clusters with track match

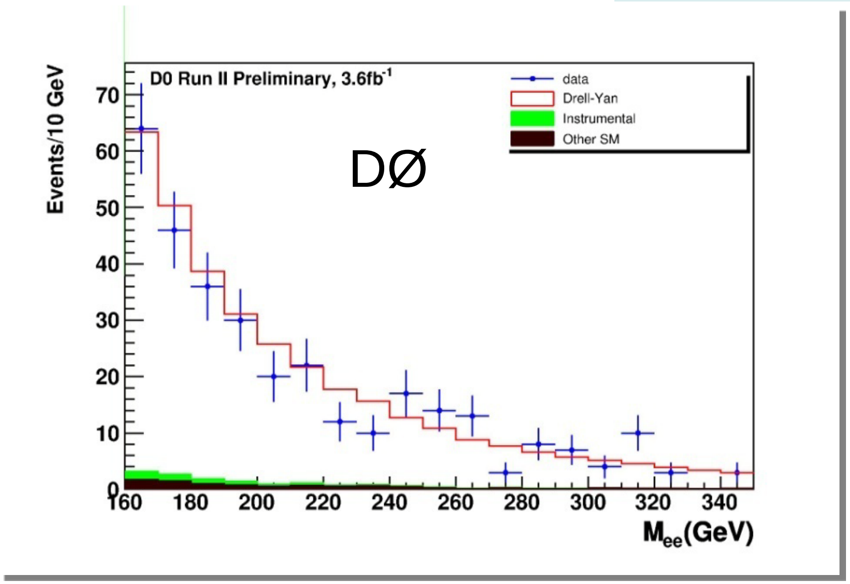
(E_T > 25 GeV)

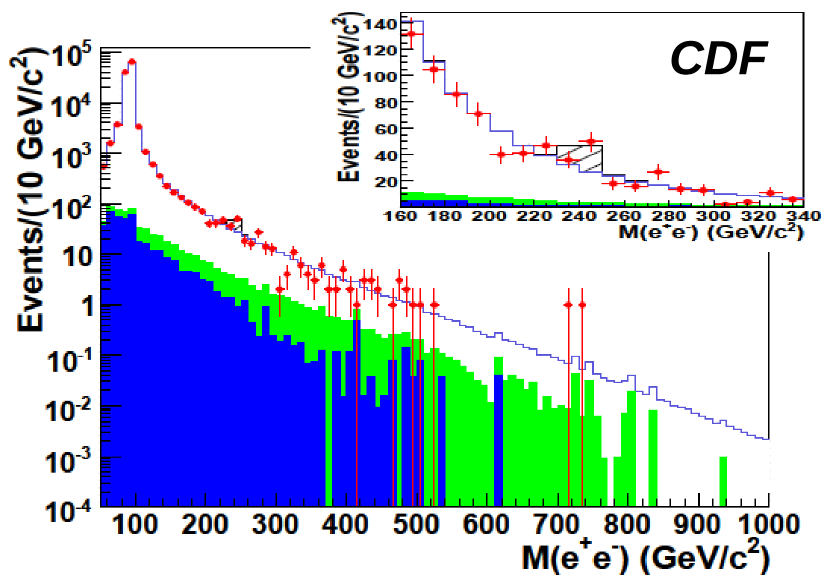
1 electron in central ($|\eta| <1.1$), 2nd either central or forward

(E_T>25 GeV)

If both central : opposite charge

Main BG $Z/\gamma^* \rightarrow ee$





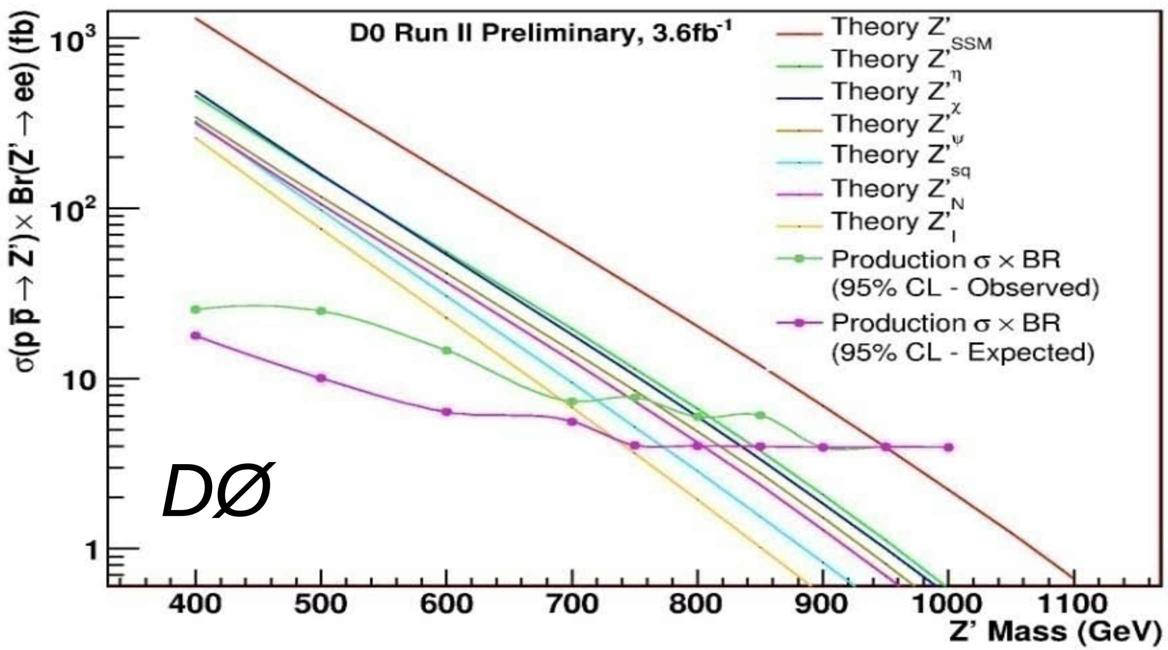
the 2.5σ excess observed by CDF around 240 GeV not confirmed by D0

Limits on $q\bar{q} \to Z' \to e\,e$

3.6 fb^{-1}

2.5 fb^{-1}

PRL 102,031801(2009)



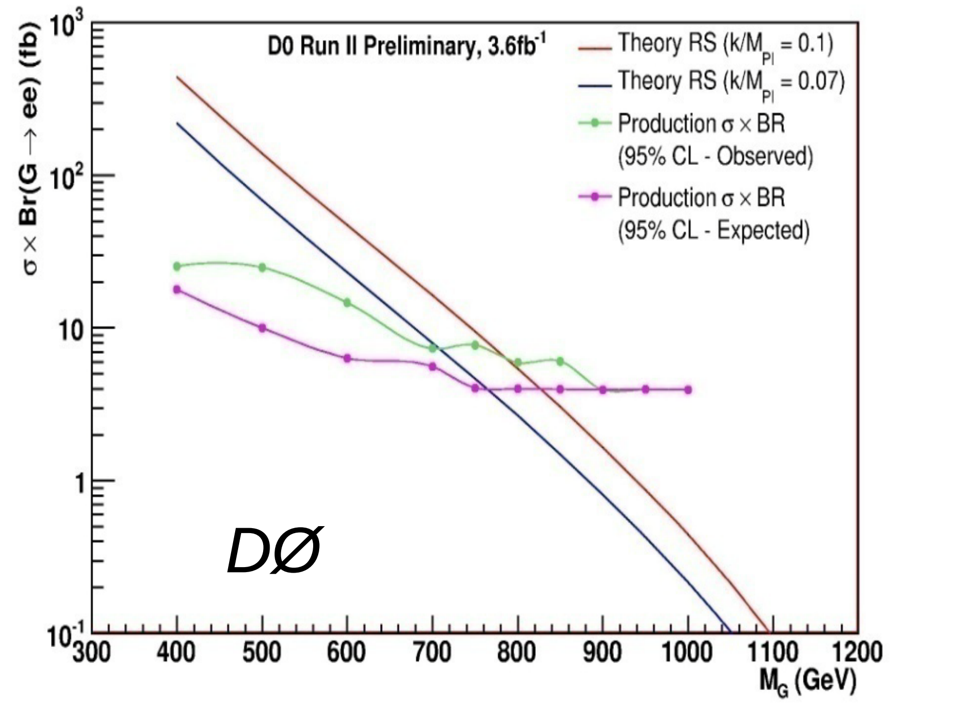
	Obs. 95% C.L lower limits on Z' masses (GeV)						
Z' model	Z'_{SM}	Z'_{Ψ}	Z'_{χ}	Z'_{η}	Z'_{I}	$Z'_{seq.}$	Z'_{N}
CDF	963	851	862	930	735	792	837
D0	950	763	800	810	692	719	744

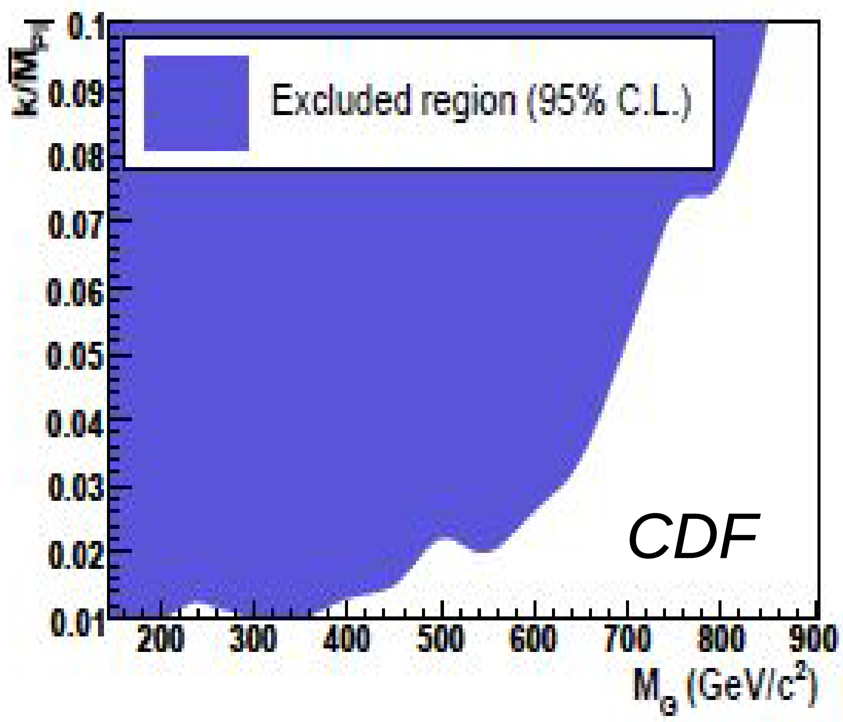
Limits on Graviton $q\bar{q} \rightarrow G_{RS} \rightarrow ee$

$3.6\ fb^{-1}$

$2.5\ fb^{-1}$

PRL 102, 031801(2009)





95%C.L. RS $(k/M_{pl}) = 0.1$

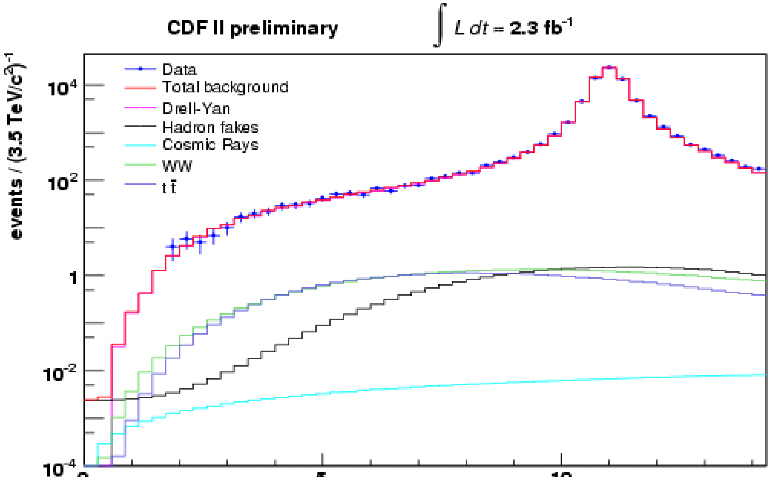
CDF obs. = exp. $M(G_{RS}) > 848$ GeV

D0 obs. (exp.) $M(G_{RS}) > 786\ (826)$ GeV

Search for High-Mass μμ resonances

$2.3\ fb^{-1}$

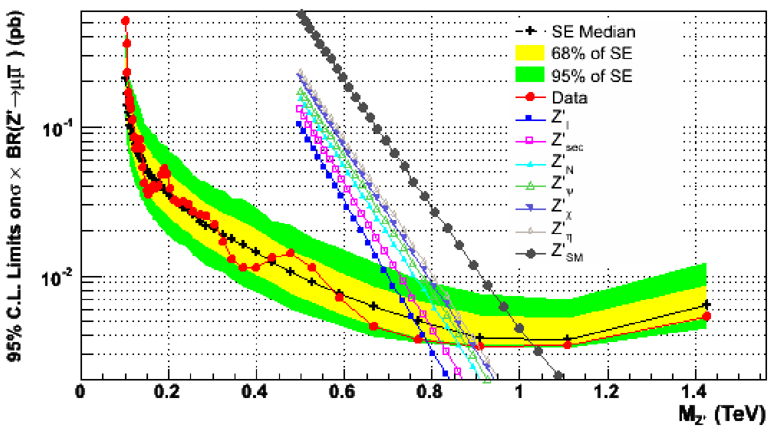
PRL 102, 091805(2009)

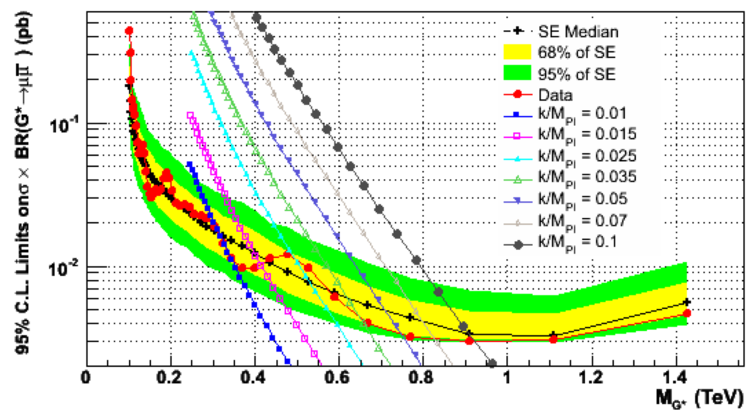


Pair of oppositely-charged muons with P_T>30 GeV

Inverse mass $m_{\mu\mu}^{-1}$ used because the detector resolution is approximatively constant ($\approx 0.17\ TeV^{-1}$) over the whole plot range

Narrow resonance would appear as an excess of events in 3 adjacent bins





	Obs. 95% C.L lower limits on Z' masses						
Z' model	Z'_{SM}	Z'_{Ψ}	Z'_{χ}	Z'_{η}	Z'_{I}	$Z'_{seq.}$	Z'_{N}
M_{lim} (GeV)	1030	878	892	904	789	821	861

k/M_{pl}	0.1	0.05	0.025	0.01
M_{lim} (GeV)	921	746	493	293

Search for WW or WZ resonances
final state: electron , missing E_T and 2 jets

2.9 fb^{-1}

- $e + E_T^{miss}$ → W (both >30 GeV)
- 2 or 3 jets (E_T>30 GeV) used to form the other W or the Z with:

  $M_{jj} \in$ [65-95 GeV] (W) and $M_{jj} \in$ [70-105 GeV] (Z)
- H_T (=sum of all E_T) > 150 GeV

WW 3577 events total BG: 3349±20.9±513.7 W (e ν) + jets :58.5%

WZ 3735 events total BG: 3354±20.4±535.3 W (e ν) + jets :59.0%

For each of the mass of the G, Z' and W', higher E_T cuts are tuned to find the best expected cross section limit :*

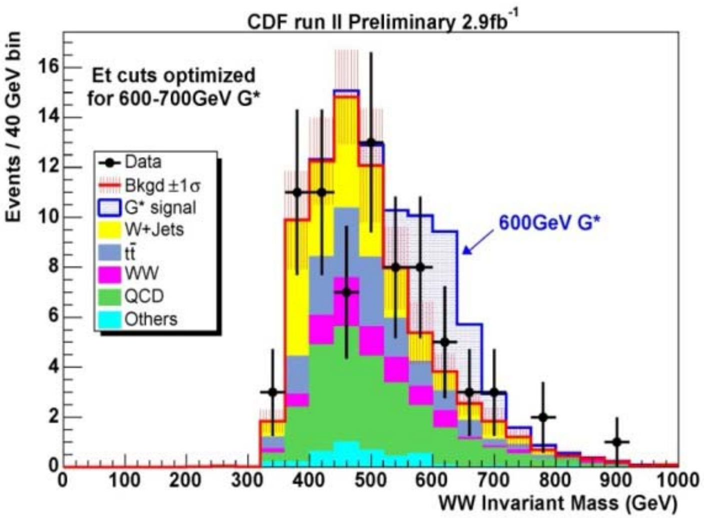
As an example:

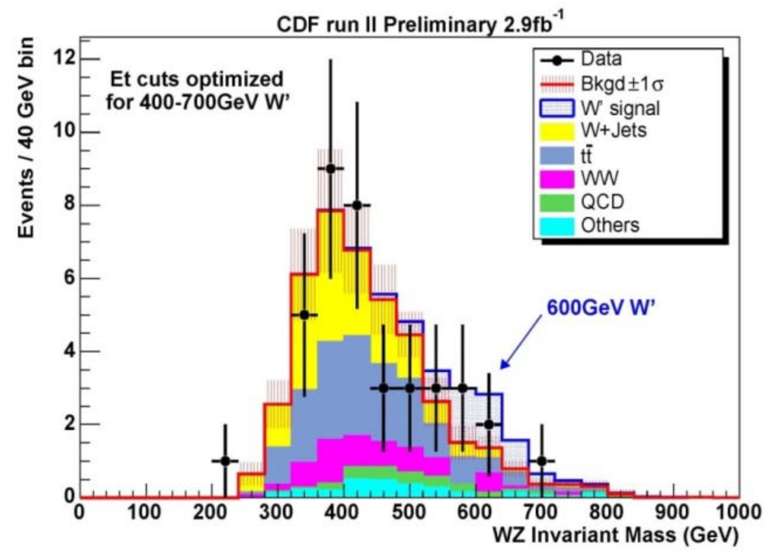
❖ *G* (M=600 GeV) one of the decay products of each W should have E_T>120 GeV*

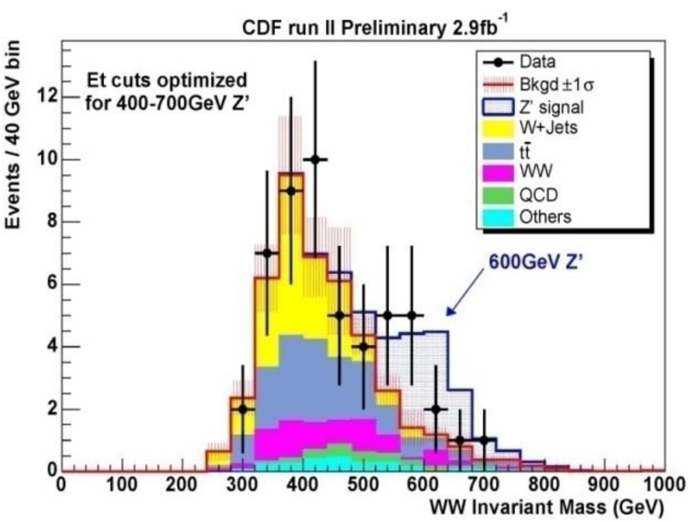
❖ *Z' or W' (M=600 GeV) the 4 decay products of the WW or WZ have E_T>60 GeV*

Search for WW or WZ resonances

2.9 fb^{-1}



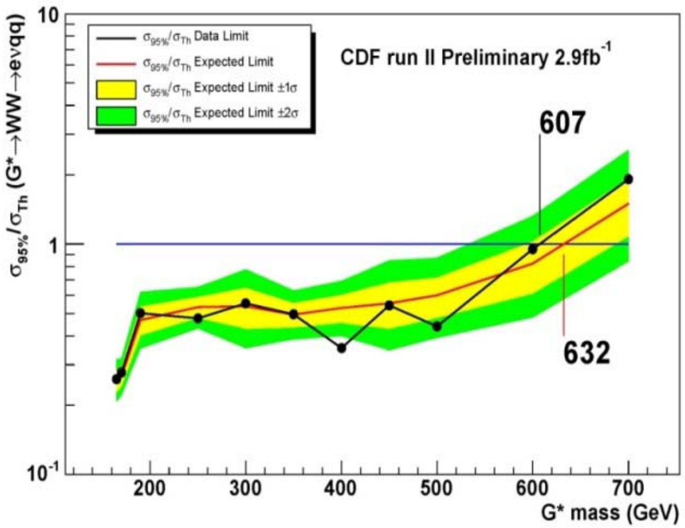


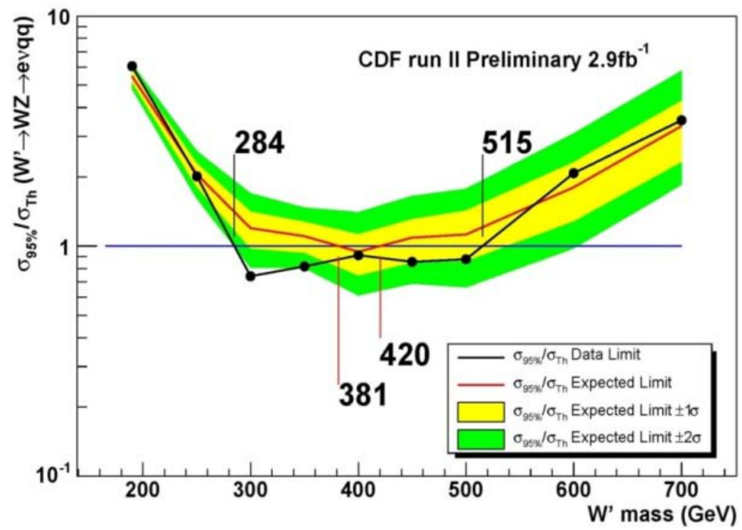


	G*→ WW	Z' → WW	W' → WZ
Data (events)	75	51	38
Total BG	75.6±2.5±11.2	43.2 ±2.3±5.7	41.3±1.5±6.9
t tbar	20%	35%	37%
W(eν)+jets	28%	33%	37%
WW	11%	15%	13%
MJ	33%	5%	6%

Search for WW or WZ resonances

2.9 fb^{-1}





95% C.L.	G*	Z'	W'
Expected Exclusion	< 632 GeV	257 – 630 GeV	381 – 420 GeV
Observed Exclusion	< 600 GeV	247 – 545 GeV	284 – 515 GeV

Search for a WZ resonance

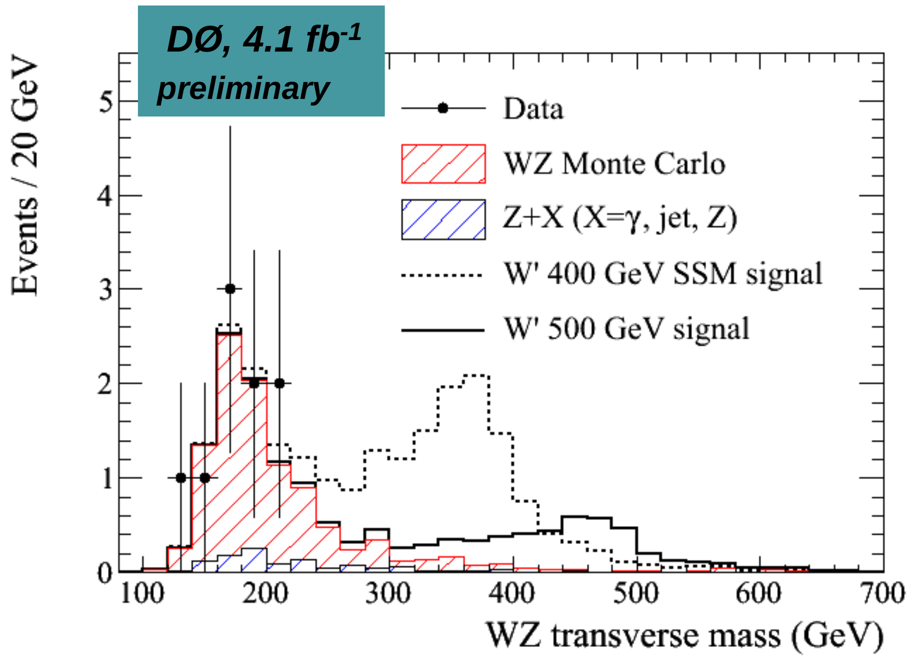
4.1fb^{-1}

Fully leptonic decay of the bosons: $\ell^\pm \ell^\pm \ell^\pm \nu$:

E_T^{miss} > 30 GeV + ≥ 3 $\ell^\pm$ (e or μ)

1. Selection of the decay products of the Z: M(ee) or M($\mu^+\mu^-$) nearest to the Z mass
   80 < M(ee) < 102 GeV or 70 < M($\mu^+\mu^-$) < 110 GeV
2. Then the highest P_T $\ell^\pm$ is used to form the W with the E_T^{miss}
3. $\Delta R(\ell_W, \ell_Z^1)$ and $\Delta R(\ell_W, \ell_Z^2)$ >1.2
   (because W and Z are higly boosted)

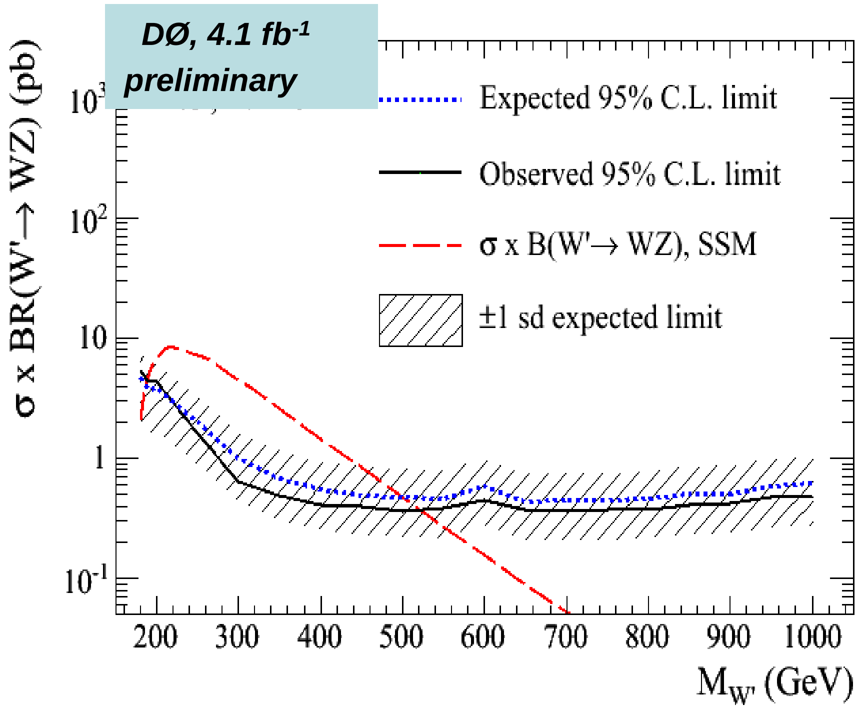
Mode	Data	Total BG	WZ
eeeν	3	1.52 ± 0.33	1.4 ± 0.3
eeμν	2	2.31 ± 0.49	2.0 ± 0.4
eνμμ	2	2.21 ± 0.46	2.0 ± 0.4
μμμν	2	4.19 ± 0.89	3.6 ± 0.8

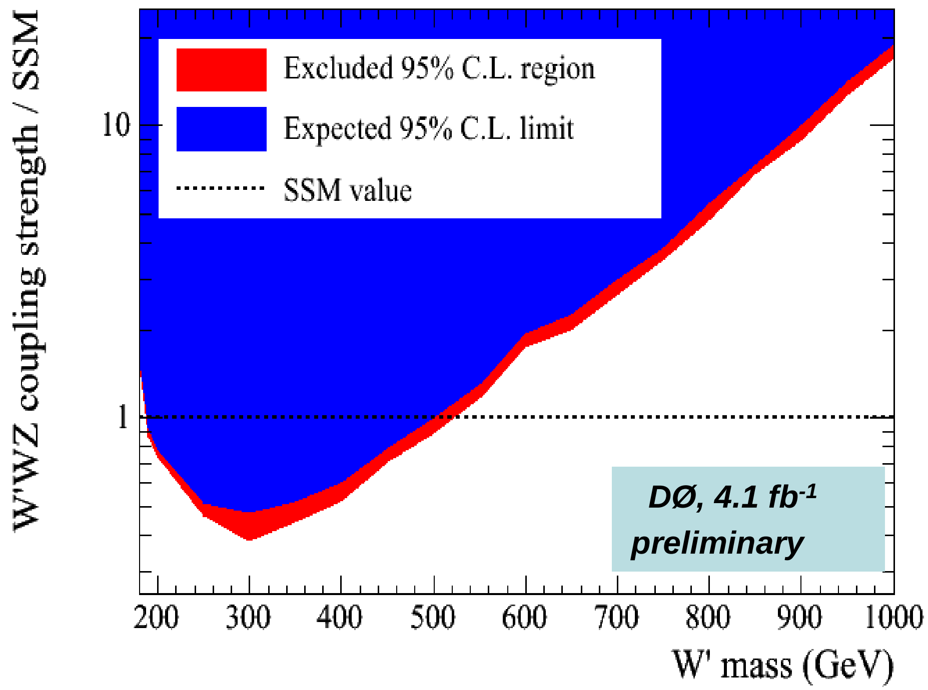


$M_T = ((E_T^Z + E_T^W)^2 - (P_x^Z + P_x^W)^2 - (P_y^Z + P_y^W)^2)^{1/2}$

Search for a WZ resonance

4.1fb[-1]





Assuming SSM production

188 < M(W') < 520 GeV is excluded (obs. lim)

188 < M(W') < 497 GeV expected exclusion region

Exclusion in the plane :

W'WZ trilinear coupling normalized to the SSM value as function of the W' mass

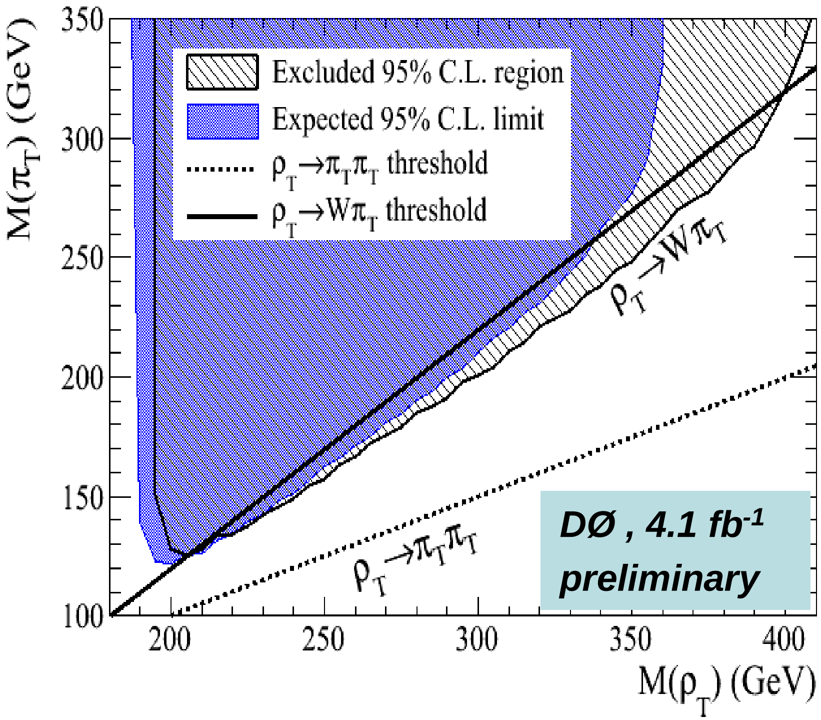
Search for a WZ resonance

$4.1 fb^{-1}$

In the low scaleTechnicolor model (LSTC), the particle ρ_T is predicted to be below 500 GeV .

The branching fraction BR($\rho_T \rightarrow WZ$) depends strongly of the relative masses of the technipion π_T and technirho ρ_T

If M(π_T) is smaller or of the order of M(ρ_T) ρ_T decays predominantly to a pair WZ



For M(ρ_T) < M(π_T) + M(W)

208 < M(ρ_T)<408 GeV is excluded (95%C.L.)

Most of the allowed phase space where $\rho_T \rightarrow WZ$ is dominant is excluded

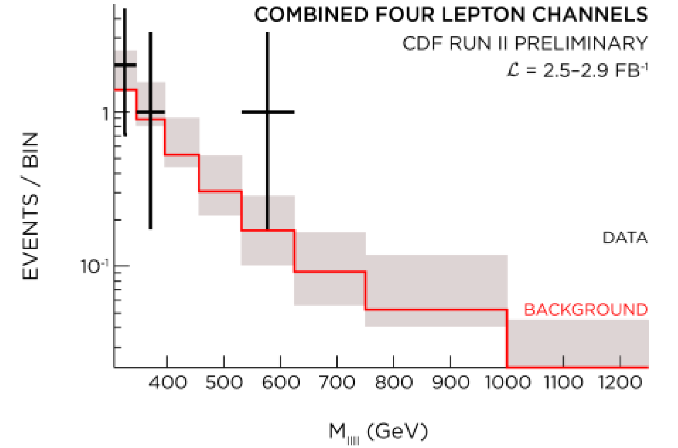
Search for ZZ resonance
final states: eeee ,μμμμ, eeμμ, eejj ,μμjj

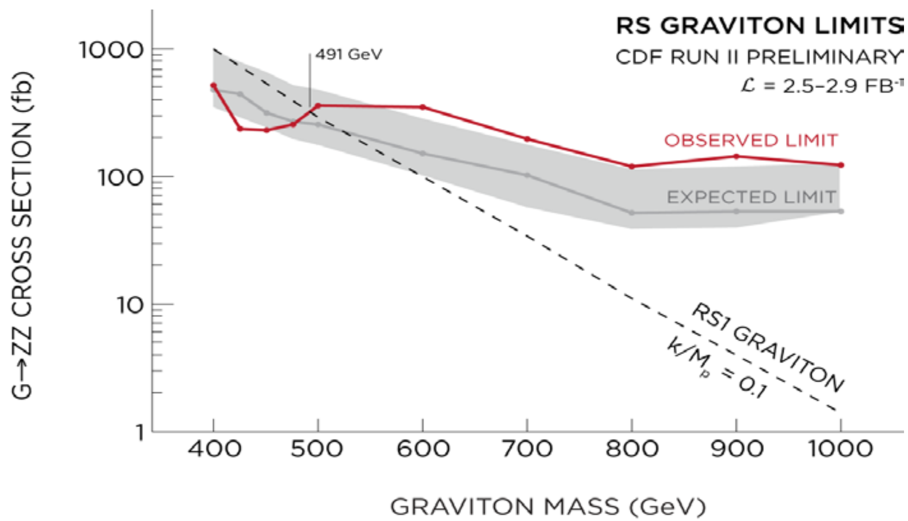
2.5 -2.9 fb^{-1}

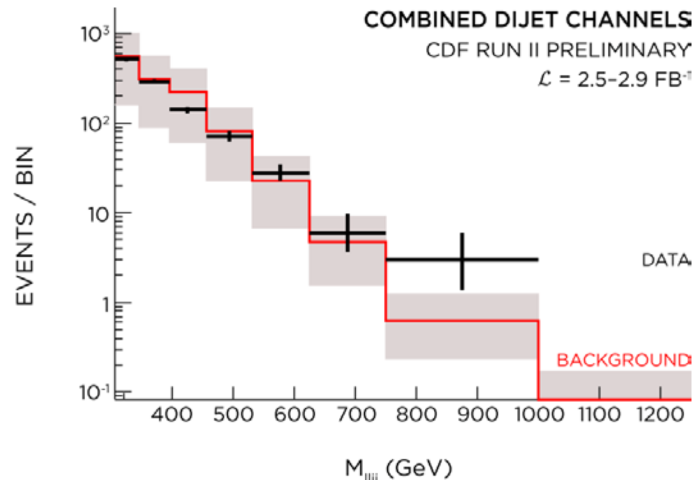
ℓℓℓℓ channels : minimization of χ_{ZZ}^2 → ℓℓ pair association

$$\chi_{ZZ}^2 = (M_{\ell\ell}^1 - M_Z)^2/(\sigma_M^2+\sigma_Z^2) + (M_{\ell\ell}^2 - M_Z)^2/(\sigma_M^2+\sigma_Z^2)$$

ℓℓjj channels : 2 highest E_T jets and ℓℓ pair which minimizes : $\chi_{ZZ}^2 = (M_{\ell\ell} - M_Z)^2/(\sigma_M^2+\sigma_Z^2)$







No evidence for a ZZ resonance: M_G> 491 GeV

(spin 2 Kaluza-Klein graviton with $k/M_p = 0.1$)

Searches for quark compositeness and extra spatial dimensions

Measurement of dijet angular distributions

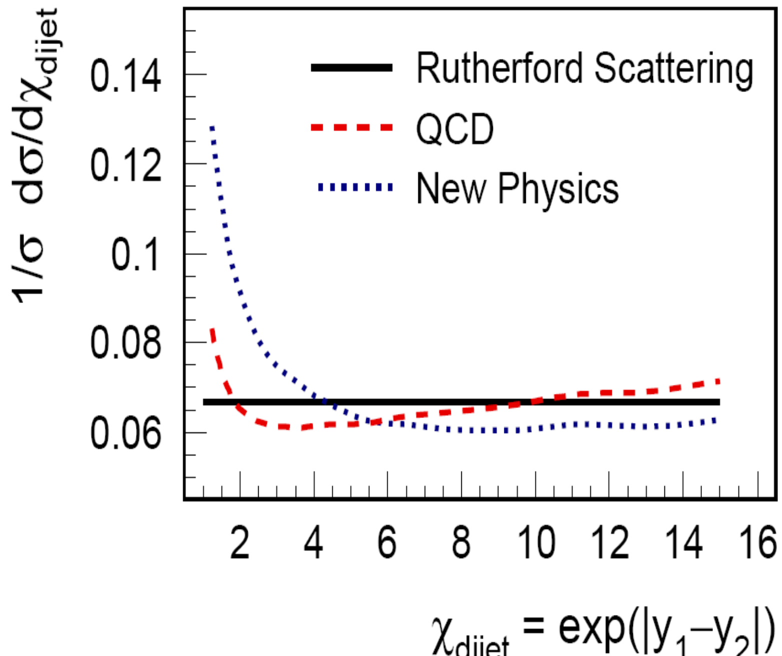
Measurement of $\chi_{dijet} = exp(|y_1 - y_2|)$ in bins of M_{jj}

where the y_i (i=1,2) are the rapidities of the 2 leading jets .

For massless 2 -> 2 scattering , χ_{dijet} is related to the polar scattering angle in the partonic center-of-mass frame .

Rutherford scattering is independent of χ_{dijet} .
In QCD the distribution shows small deviations from Rutherford scattering.

An excess at large M_{jj} and small χ_{dijet} would be a sign of new physics processes such as substructure of quarks or the existence of extra dimensions



from N. Parua EPS2009

Searches for quark compositeness and extra spatial dimensions

0.7 fb^{-1}

PRL 103, 191803(2009)

1.1 fb^{-1}

Quark compositeness

CDF Λ > 2.4 TeV

D0 Λ > 2.9 TeV

Large extra dimensions (D0)

2 models:

1. *ADD LED*

Ms effective Planck mass

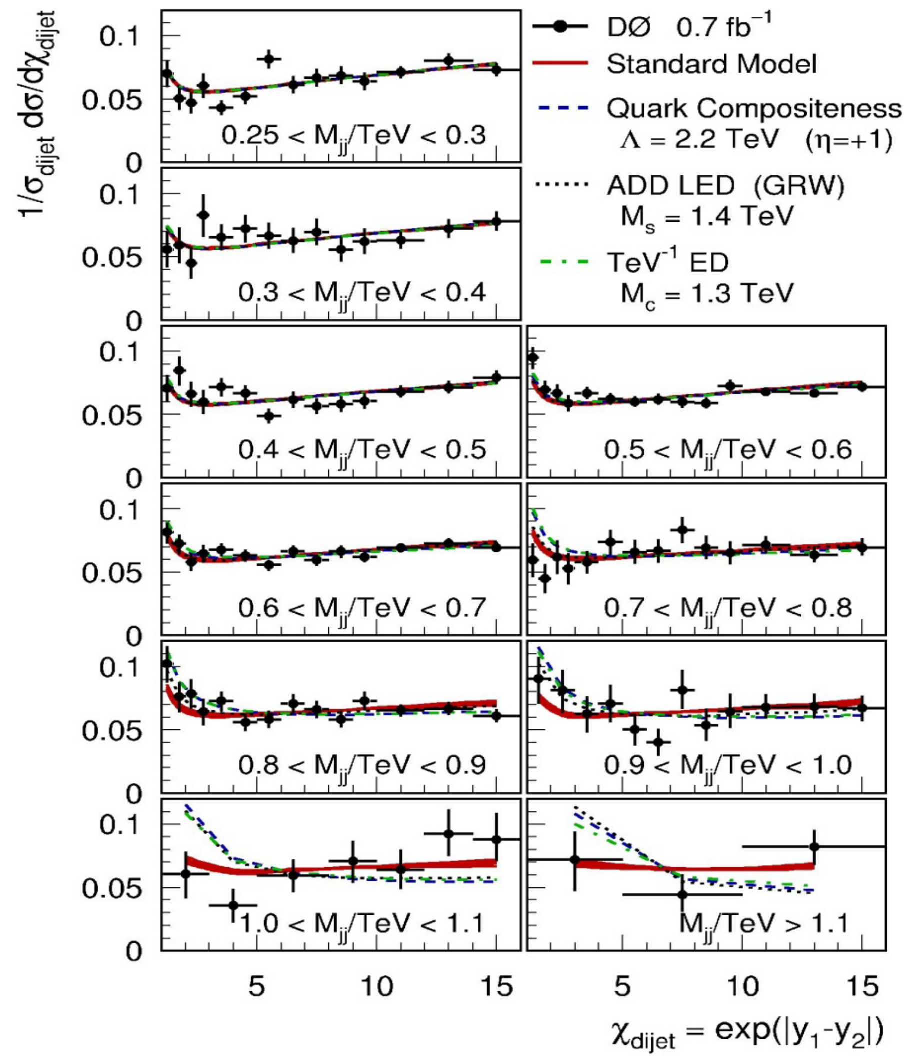
GRW Ms > 1.66 TeV

HLZ M_S > 1.97 TeV (n_d=3)

2. *TeV^{-1} ED parameter:*

M_C compactification scale

M_C > 1.59 TeV



Distributions normalized to their integrals

Some aspects of Leptoquark phenomenology

Predicted by many extensions of the SM connecting the quark and lepton sectors (GUTs, compositeness, extended Technicolor…).

Leptoquarks are color-triplet bosons which carry:

- non-zero lepton *L* and baryon *B* numbers
- fractional electrical charge Q=1/3, 2/3, 4/3, 5/3

LQ states = scalar or vector

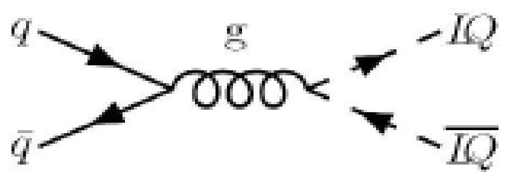
for scalar LQ, Lagrangian and production cross section only depend on M_{LQ} (and α_s)

but for vector LQs, they also depend on anomalous couplings λ_G and κ_G.

Pair production of LQs:

Dominant LO diagram, at Tevatron

for M_{LQ}>100 GeV/c^2



3 generations of leptoquarks are predicted

Leptoquarks couple directly to leptons ($l^\pm$, ν) and quarks : β=Br(LQ $\rightarrow$ lq)

3 types of final states

lljj $\sigma\times$Br(l^+l^-qq) $\propto \beta^2$ $\nu\nu$jj $\sigma\times$Br($\nu\nu$qq) $\propto (1-\beta)^2$ lνjj $\sigma\times$Br($l^\pm\nu$qq) $\propto 2\beta(1-\beta)$

Search for pair production of scalar LQ in the final state 2 jets + E_T^{miss}

2.5 fb^{-1}

PLB 668, 357(2008)

2 fb^{-1}

2 jets (E_T>30 GeV) no third jet (E_T>15 GeV) , no charged lepton

1. Low mass region:

$H_T=E_T(j1)+E_T(j2)$ > 125 GeV E_T^{miss}> 80 GeV

2506 events total BG: 2533±151

2. High mass region:

H_T > 225 GeV E_T^{miss} > 100 GeV

186 events total BG: 216.1±29.8

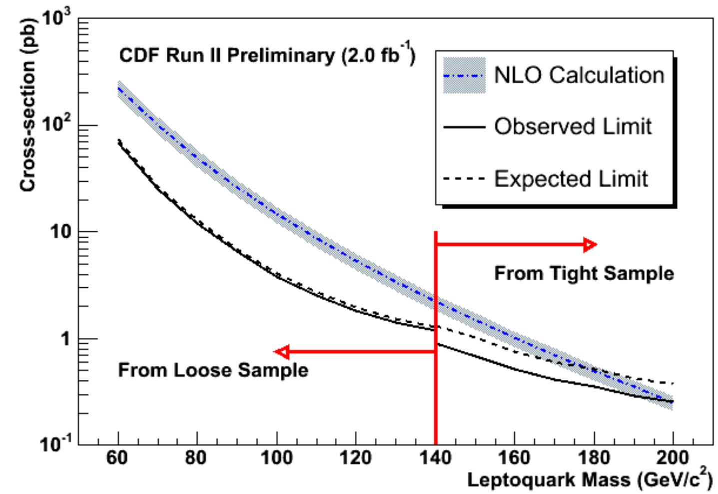
2 acoplanar jets (P_T>35 GeV) no charged lepton

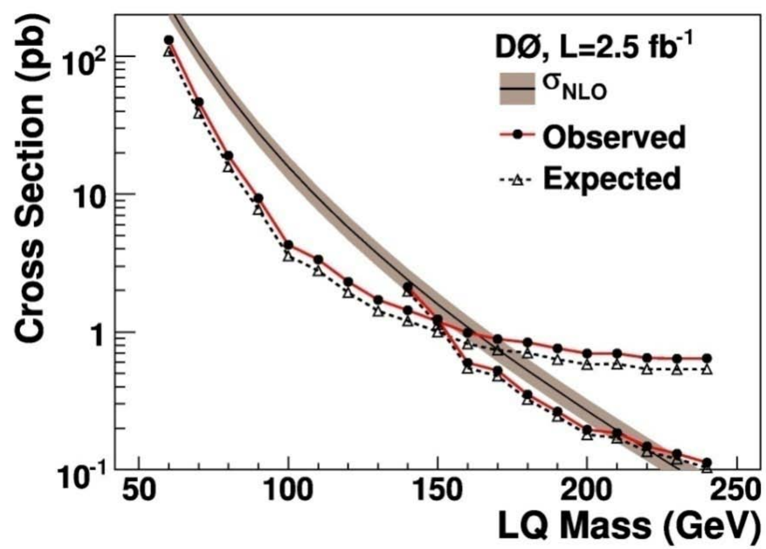
$\Delta\phi$ (jet1,jet2)<165 degrees

E_T^{miss} and H_T cuts optimized by minimizing the expected limit on the cross section:

1. *H_T>150 GeV E_T^{miss}>75 GeV low mass region*
2. *H_T>300 GeV ET^{miss}>125 GeV high mass region*

β = BR(LQ→$l^\pm$ q)=0	95% C.L.
LQ_1 or LQ_2	Lower Mass limit (GeV)
CDF	190
D0	205





Search for pair production of First-Generation Leptoquark

$1fb^{-1}$

PLB 681, 224(2009)

2 final states analysed:

- *2 e + 2 jets*

main BG: Z/γ^* + jets , $t\bar{t}$

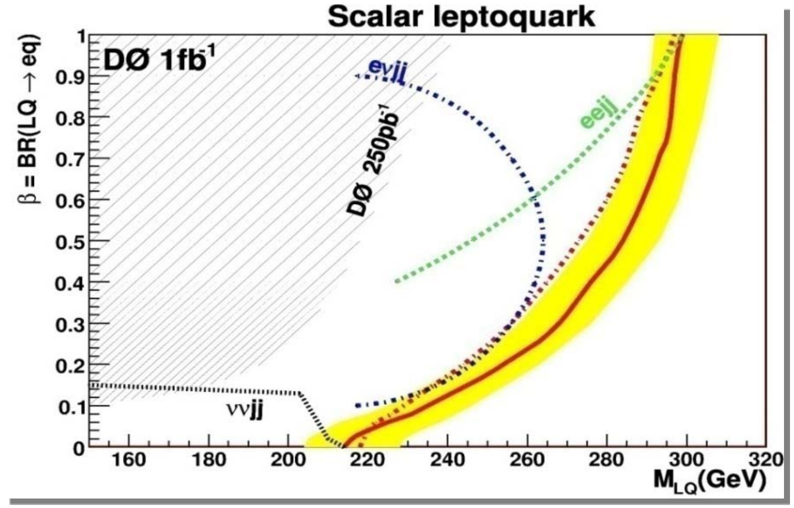
- *e + E_T^{miss} + 2 jets*

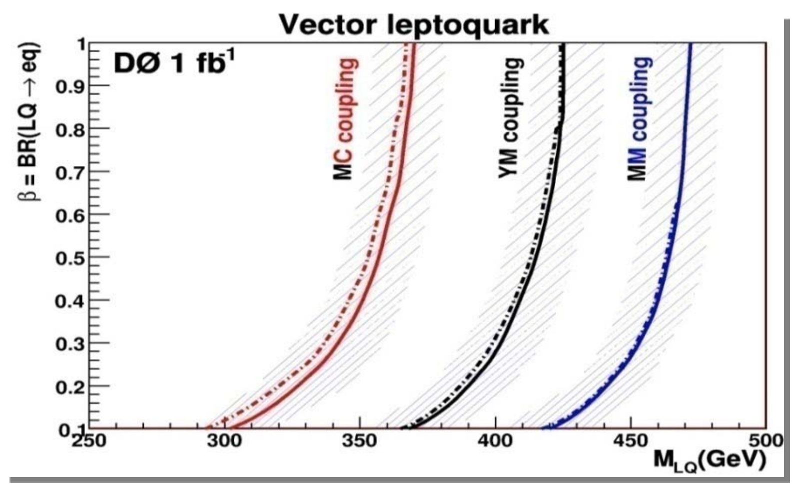
main BG: W + jets $t\bar{t}$

Variables used for signal discrimination:

- **eejj** M(e,e) , $S_T = E_T(e1)+E_T(e2)+E_T(jet_1)+E_T(jet_2)$
  limit from average M(e,jet) distribution
- **e j E_T^{miss}** $E_T(e)$, $E_T(jet1)$, $E_T(jet2)$, E_t^{miss}
  limit from S_T distribution

	lower LQ mass limit GeV			
β	Scalar LQ	$\kappa_G = 1$ $\lambda_G = 0$	$\kappa_G = 0$ $\lambda_G = 0$	$\kappa_G = -1$ $\lambda_G = -1$
0.1	235	302	368	420
0.5	284	357	415	464
1	299	370	425	472





Search for pair production of Second-Generation Leptoquark

1 fb^{-1}

PLB 671, 224(2009)

2 final states analysed:

- 2 μ + 2 jets

main BG: Z/γ^* + jets , $t\bar{t}$

- μ + E_T^{miss} + 2 jets

main BG: W + jets $t\bar{t}$

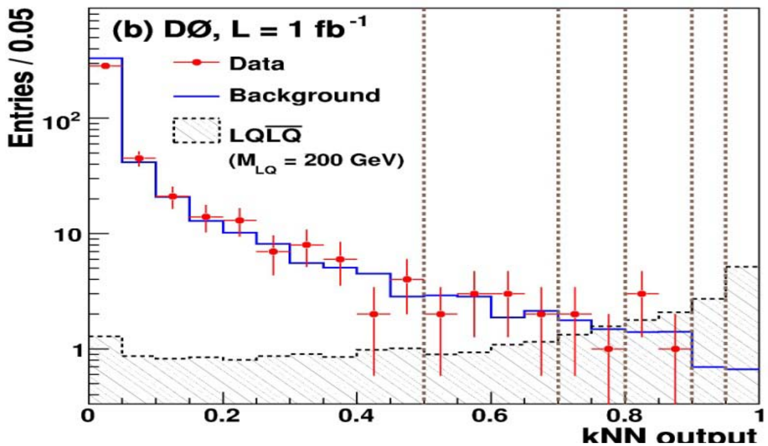
Multivariate discrimination using 6 input variables for each channel:

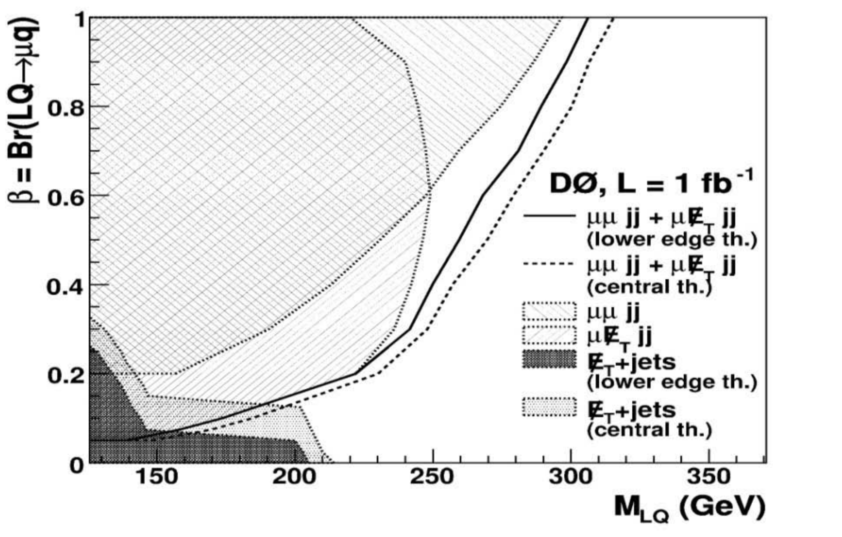
(kNN : k-Nearest-Neighbors algorithm)

$\mu\mu jj$: $M(\mu,\mu)^{min}$, S_T , $M_T(\mu_{1,2}, jet_{1,2})$

$\mu j E_T^{miss}$: $M_T(\mu, E_T^{miss})$, S_T , $M_T(jet_{1,2}, E_T^{miss})$, $M_T(\mu, jet_{1,2})$

β=BR($LQ_2 \rightarrow \mu$ q)	M_{LQ2}^{obs} GeV
0.1	185
0.5	270
1.0	316





Search for pair production of Third-Generation Leptoquark

4 fb^{-1}

Pair production of LQ_3 both decaying in b quark and ν_τ

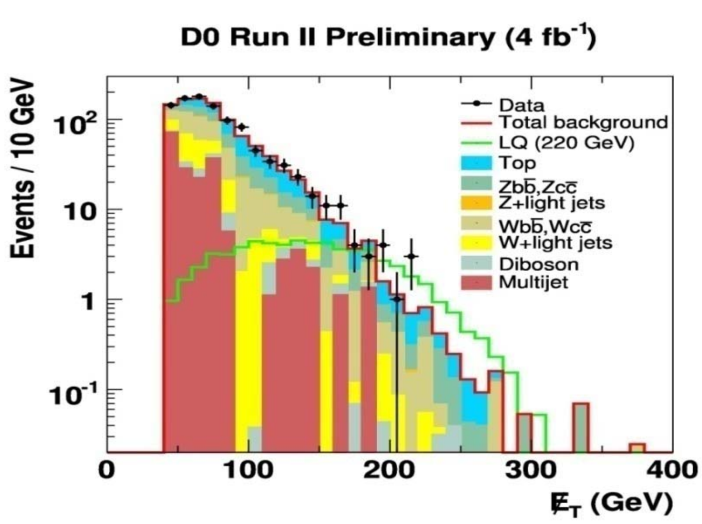
Events with exactly 2 or 3 jets (E_T>20GeV) and E_T^{miss}>40GeV

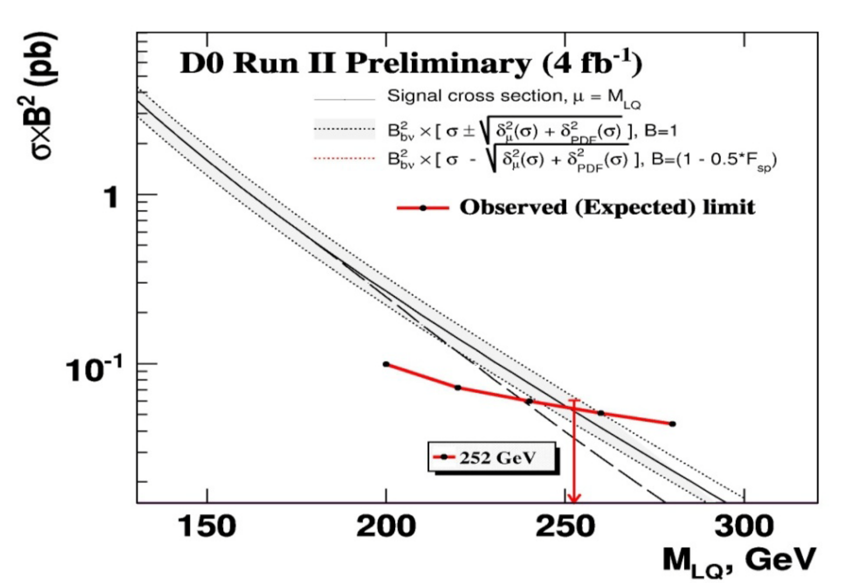
E_T^{miss} quality cuts applied

NN based b-tagging : 2 jets b-tagged (70% and 45% efficiencies)

BG: largest contribution from W/Z +b $\bar{b}$ production and Top

3 events selected (SM+MJ) expected: 3.2±0.3 ±0.6 events





Assuming B(LQ→ν b)=1

a third-generation scalar LQ with M_{LQ} < 252 GeV is excluded

Search for a heavy fourth-generation down-type quark (**b'**)

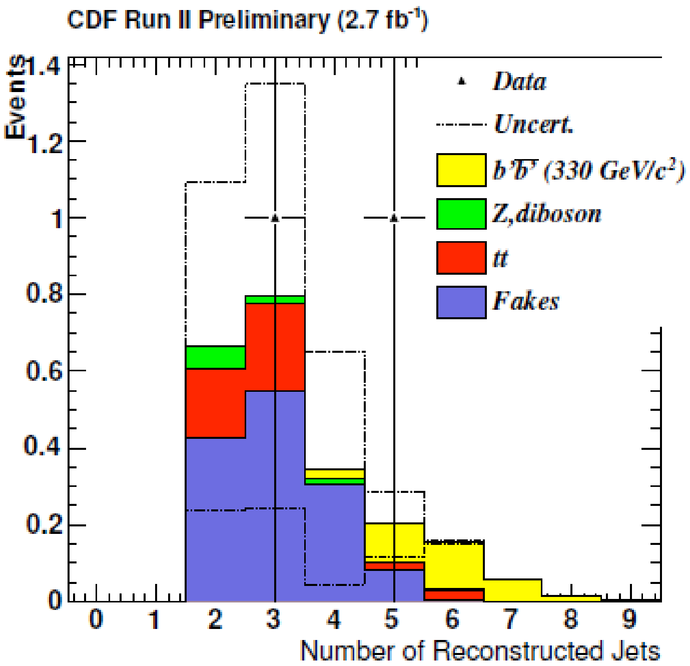
2.7 fb^{-1}

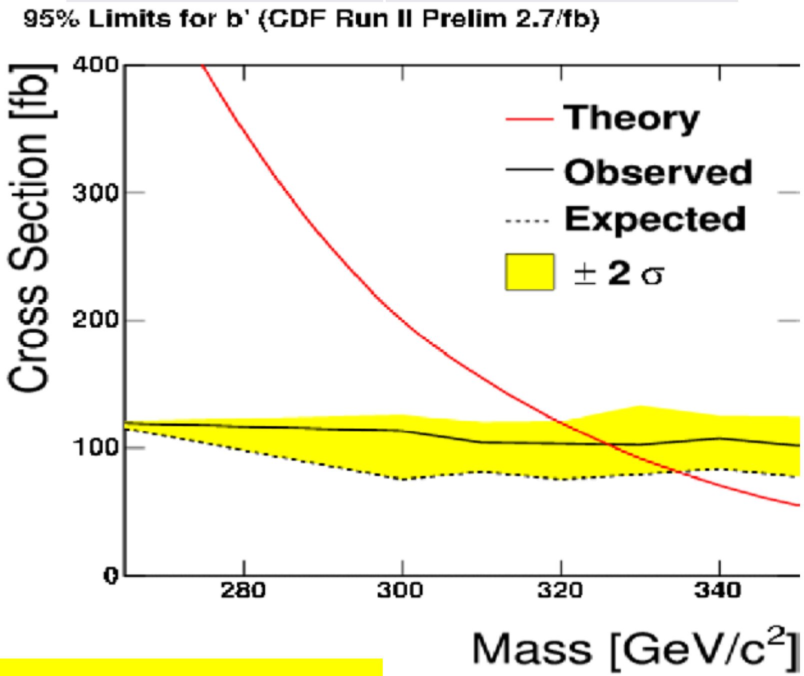
Pair production of b' decaying in W t

- *2 same-charge leptons l (P_T > 20 GeV)*
- *> 1 b-tag jet + ≥ 2 jets (P_T > 15 GeV)*
- *E_T^{miss} > 20 GeV*

Bined likelihood fit in the number of jets of the ratio of the measured to the theoretical σ

Data	2 (1μμ,1μe)
Total BG	1.9± 1.4
W + jets	1.4 ± 1.4
$t\bar{t}$	0.5 ± 0.05
Z + dibosons	0.1 ± 0.05





$M_{b'}$ < 325 GeV is excluded

Search for pair production of Neutral Long-Lived Particles decaying to $b\bar{b}$

3.6 fb^{-1}

PRL 103 071801 (2009)

Hidden-valley HV models predict production of HV particles which hadronize producing « v-hadrons » which could be long-lived.

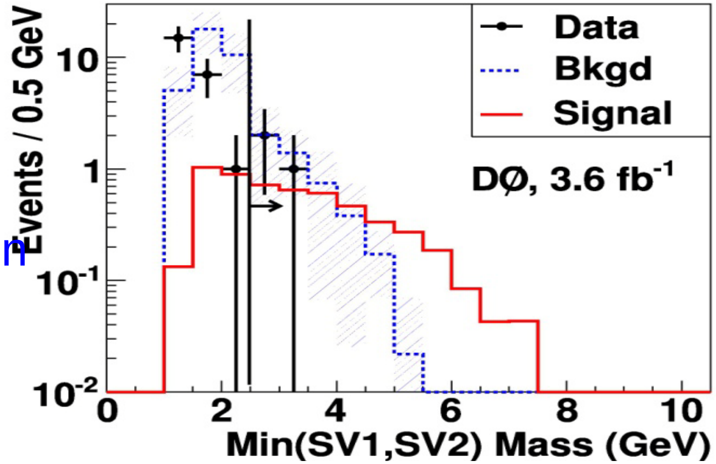
model used as benchmark : $gg \rightarrow H \rightarrow$ v-hadron + v-hadron $\rightarrow (b\bar{b})(b\bar{b})$

Search for pair of displaced vertices

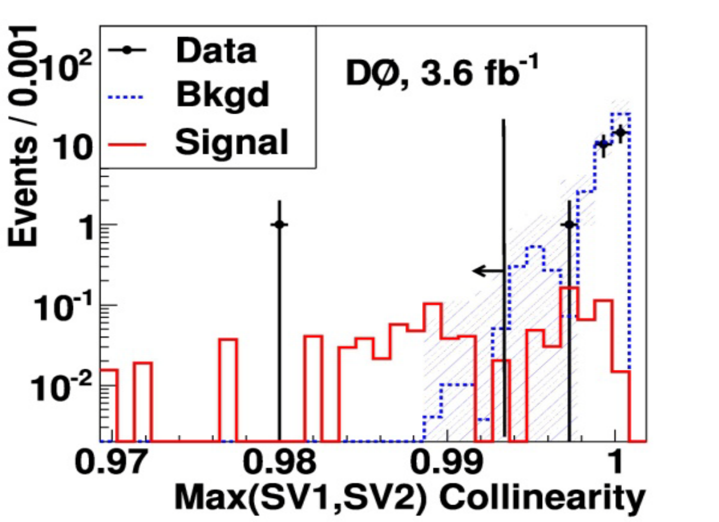
M_{SV}: 4-momenta of the tracks (π mass)

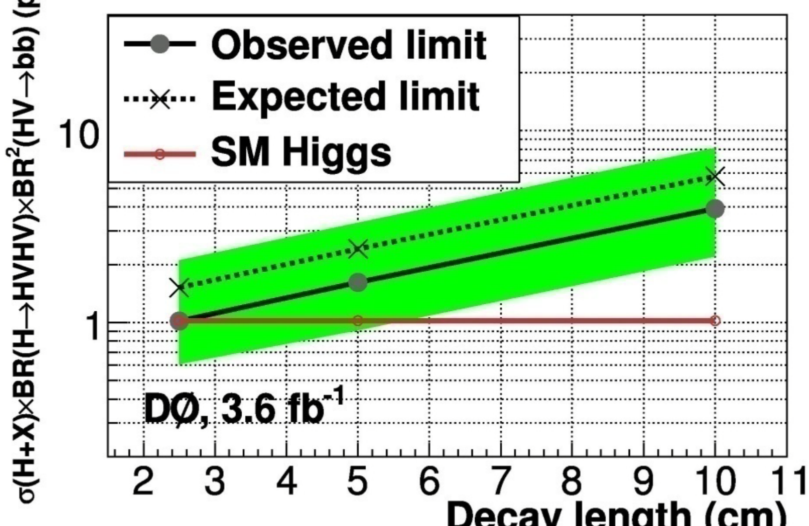
Collinearity : $\cos(\theta)$ between the PV-SV direction

And the sum of the momenta of the tracks



M_H=120 GeV, m_{HV}=15 GeV





Conclusions

CDF and D0 have both covered many BSM searches using an integrated luminosity of up to 4.1 fb^{-1}

No significant excess of events over SM expectations ! The Standard model is still in good shape.

Both collaborations are now working on the > 6.5 fb^{-1} data already recorded per experiment .

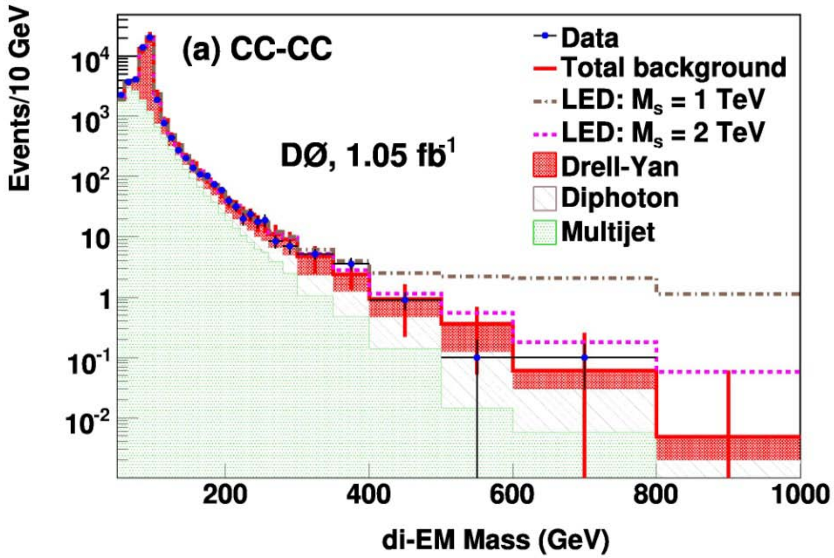
Tevatron is performing better then ever. We could hope to collect up to 12 fb^{-1} by 2011....

BACK-UP SLIDES

Search for LED in the ee and $\gamma\gamma$ channel

1 fb^{-1}

PRL 102, 051601 (2009)



2 EM clusters (E_T > 25 GeV) with at least one in the central part of the calorimeter ($|\eta|$ > 1.1)

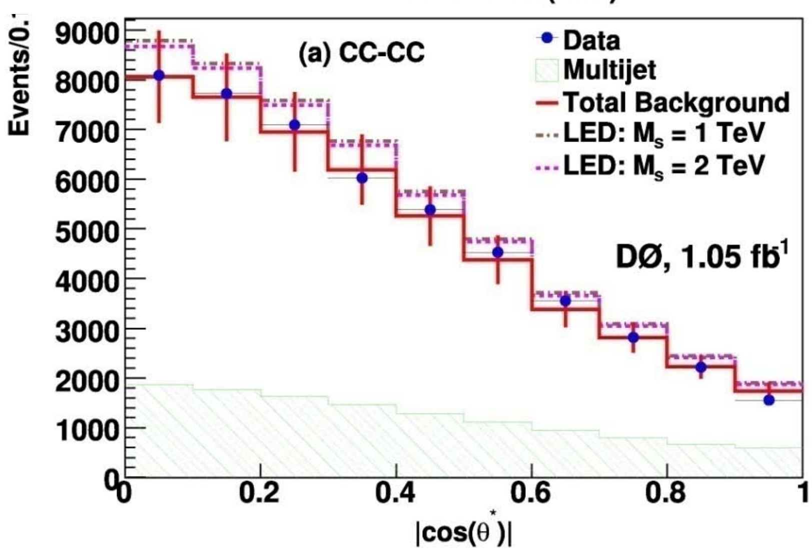
Look for deviations in the di-EM mass and the $|\cos(\theta^*)|$ distributions

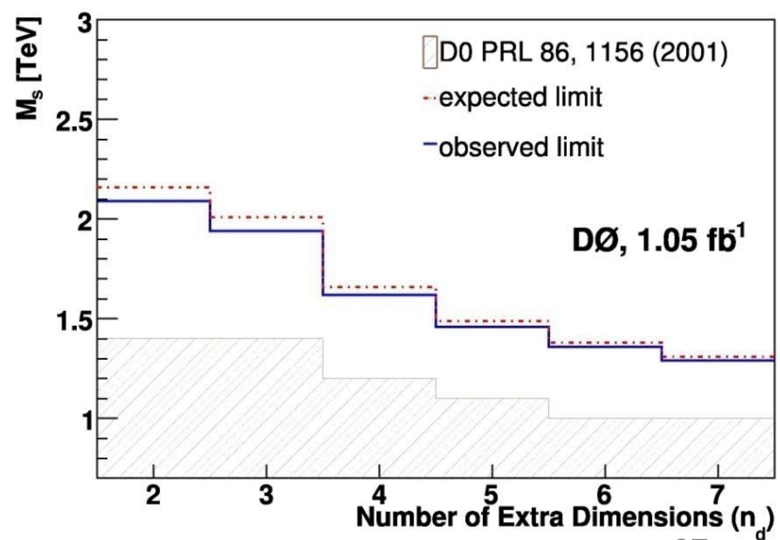
95% C.L. limit on the effective Planck scale M_s

GRW model (n_d independent) ***M_S >1.62 TeV***

HLZ model (n_d dependent)

M_S>2.09 (1.29) TeV for n_d=2 (7)





W'-like resonances in the ($t\ \bar{b}$) decay channel

Final state: ($l\ \nu\ b$) $\bar{b}$

- *Only one $l^{\pm}$ (e or μ) (P_T>20 GeV)*
- *E_T^{miss} > 25 GeV*
- *2 or 3 jets E_T>20 GeV at least one b-tag*

$M_{t\bar{b}}$ from the 4-momenta of $l^{\pm}$, ν,2jets
(constrained by $M_{l\nu} = M_W$ to get $p_{\nu z}$)

Main BGs: W + jets and top

1.9 fb^{-1}

PRL 103,041801(2009)

Extension of the SM model which adds a narrow rigth-handed W' with SM-like couplings

No excess compared to SM expectation:

$M_{W'}$ > 825 GeV (if $M_{W'} < M\nu_R$) *leptonic decay forbidden*

$M_{W'}$ > 800 GeV (if $M_{W'} > M\nu_R$)