Heavy resonances search at Tevatron

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On behalf of the

And

collaborations

Outline

- Tevatron Collider, CDF and D0 detectors
- Spin 0 resonances searches
  - High mass RPV sneutrino : $q\bar{q} \rightarrow \tilde{\nu}_\tau \rightarrow e\mu$
- Spin 1/2 resonances searches
  - Excited quarks (q*) : $q + g \rightarrow q^* \rightarrow Z^0(e^+e^-) + q$
- Spin 1 resonances searches
  - W' : $t\bar{b}\ (\bar{t}b),\ e\upsilon$
  - Z' : $e^+e^-, t\bar{t}$
- Spin 2 resonances searches
  - RS graviton : $\gamma\gamma, e^+e^-, e^+e^- + \gamma\gamma, Z^0Z^0$

Tevatron - CDF - D0

→ *Tevatron in Fermilab near Chicago (USA) :*

The most powerfull collider running

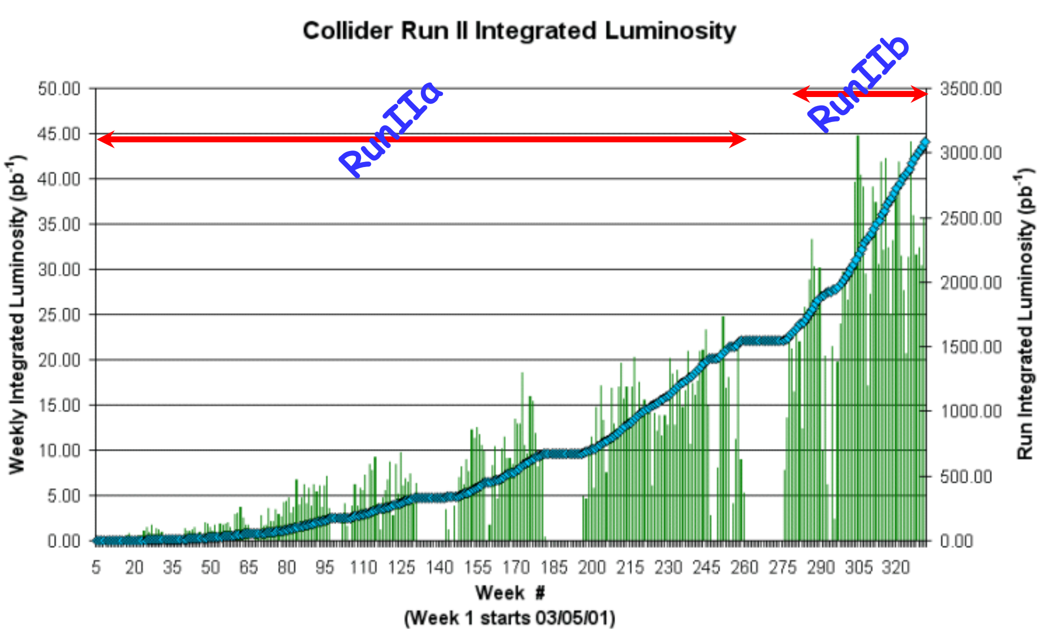
→ *Circumference : 6.4 Km*

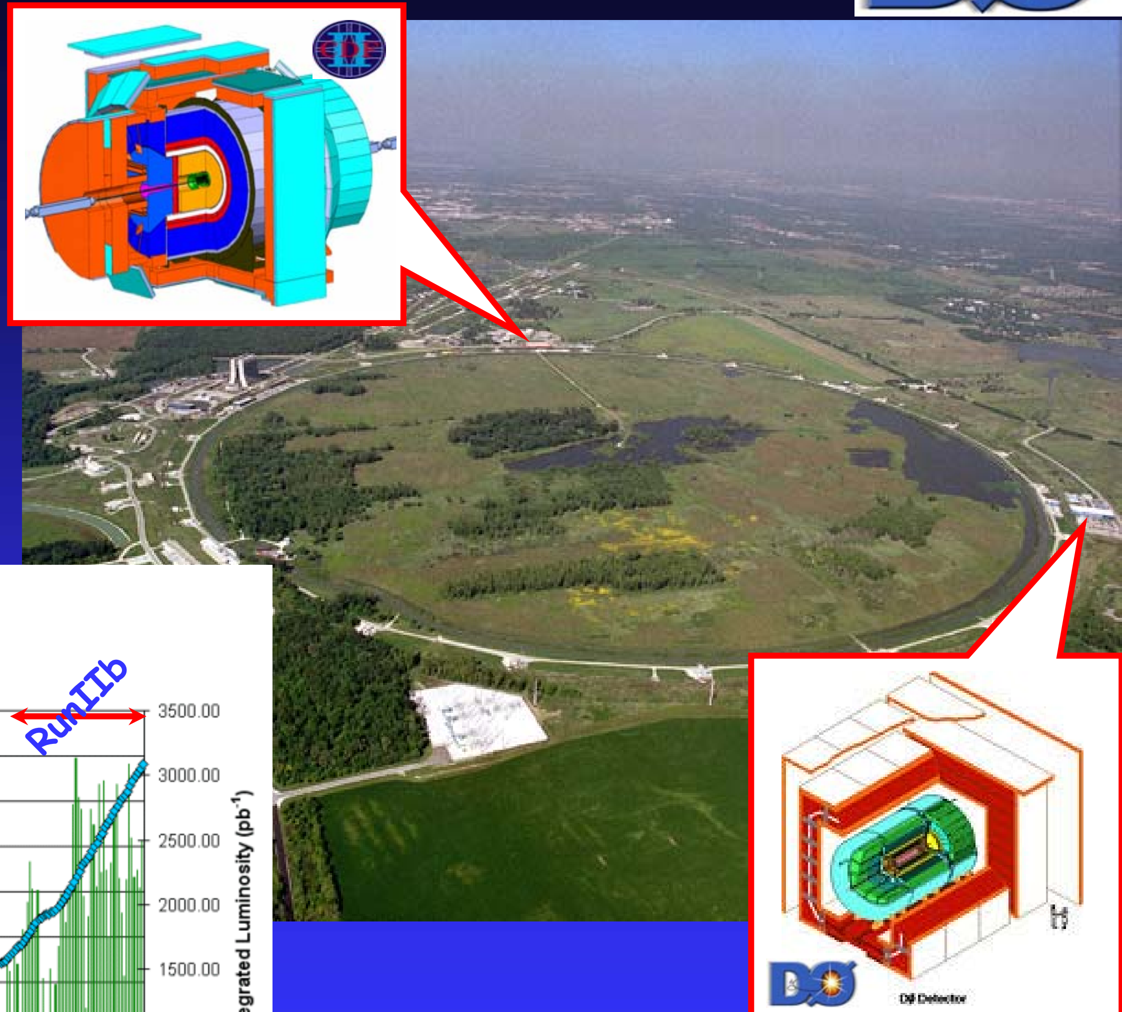
→ *$p\bar{p}$ collisons - $\sqrt{s}$ = 1.96 TeV*

→ *Run I (1992 - 96) : 0.1 fb^{-1} /exp*

→ *Run IIa (2002 - 06) : 1.3 fb^{-1} /exp.*

→ *Run IIb (untill 2009) : ~ 8 fb^{-1} /exp.*





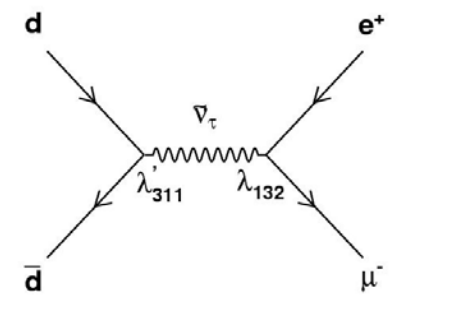
CDF and D0 : Typical multipurpose collider detectors with (starting from the interaction point) : Trackers, Calorimters (EM, Had), Muon detectors.

Spin 0 resonances : Susy RPV $\tilde{\nu}_\tau$

Search of SUSY RPV $\tilde{\nu}_\tau$

$d\bar{d} \to \tilde{\nu}_\tau \to e\mu$

Scanned mass : 50 GeV – 800 GeV



Data : $\mathcal{L}$ = 0.35 fb $^{-1}$

Selection :

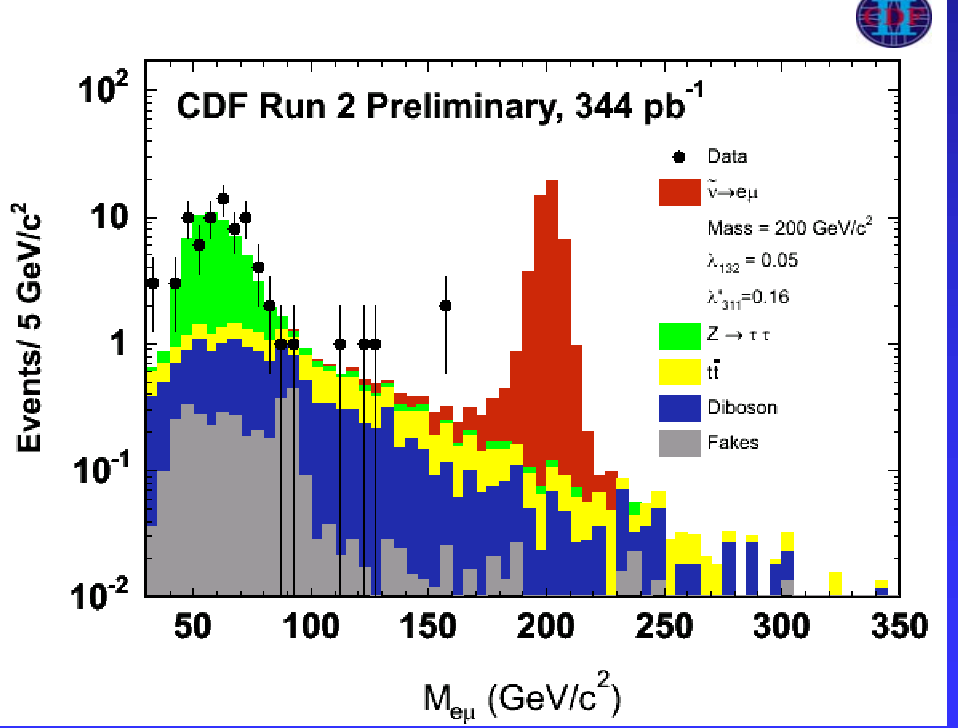
- 2 hight E_T isolated leptons, with
  - 1 electron : E_T > 20 GeV
  - 1 oppositely charged muon : P_T > 20 GeV
- 1 common vertex for electron and muon

SM backgrounds :

- Main : $Z \to \tau^+\tau^-$
- Other : WW and $t\bar{t}$

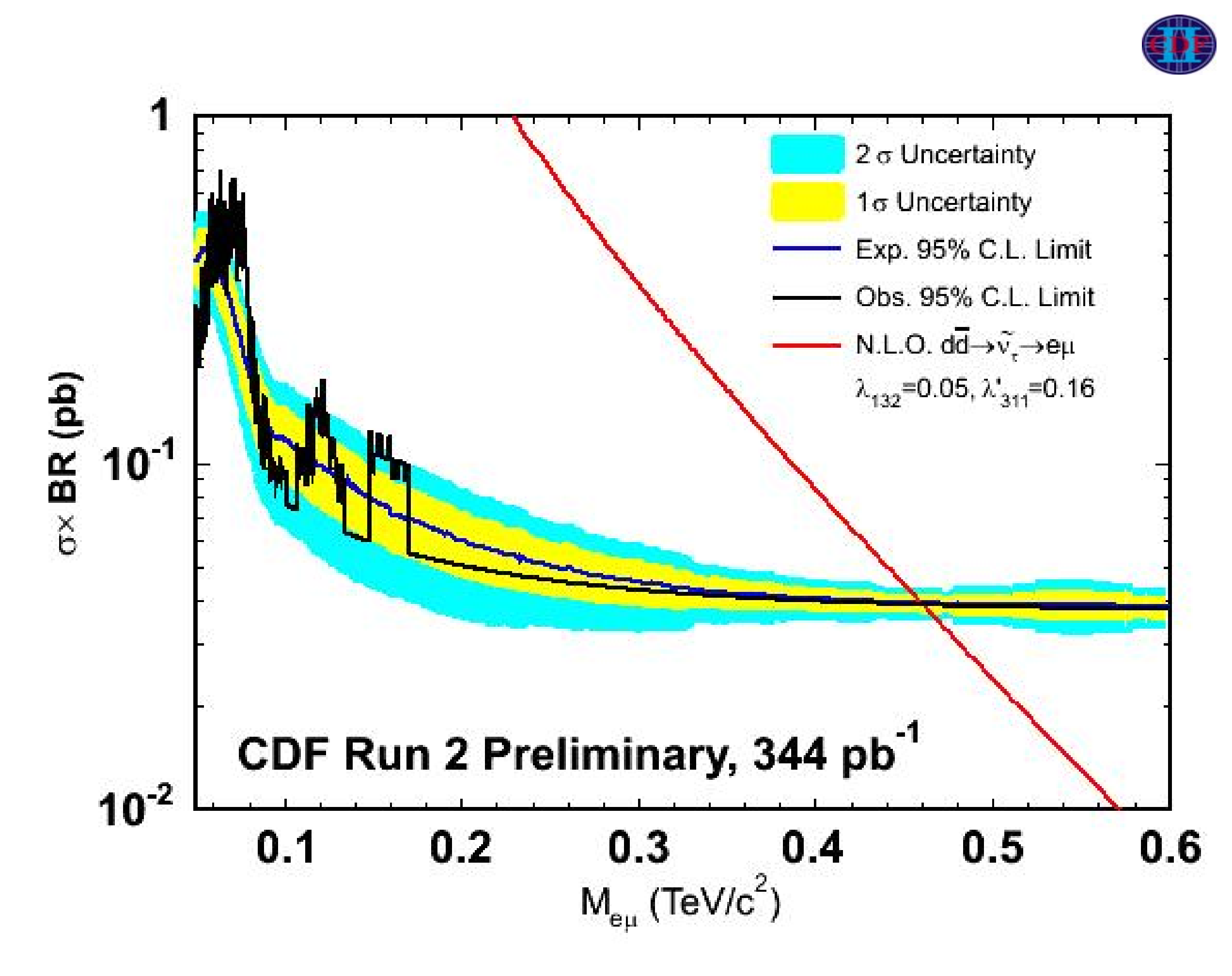
+ QCD (Instrumental) background

MC : Pythia



Spin 0 resonances : Susy RPV $\tilde{\nu}_\tau$

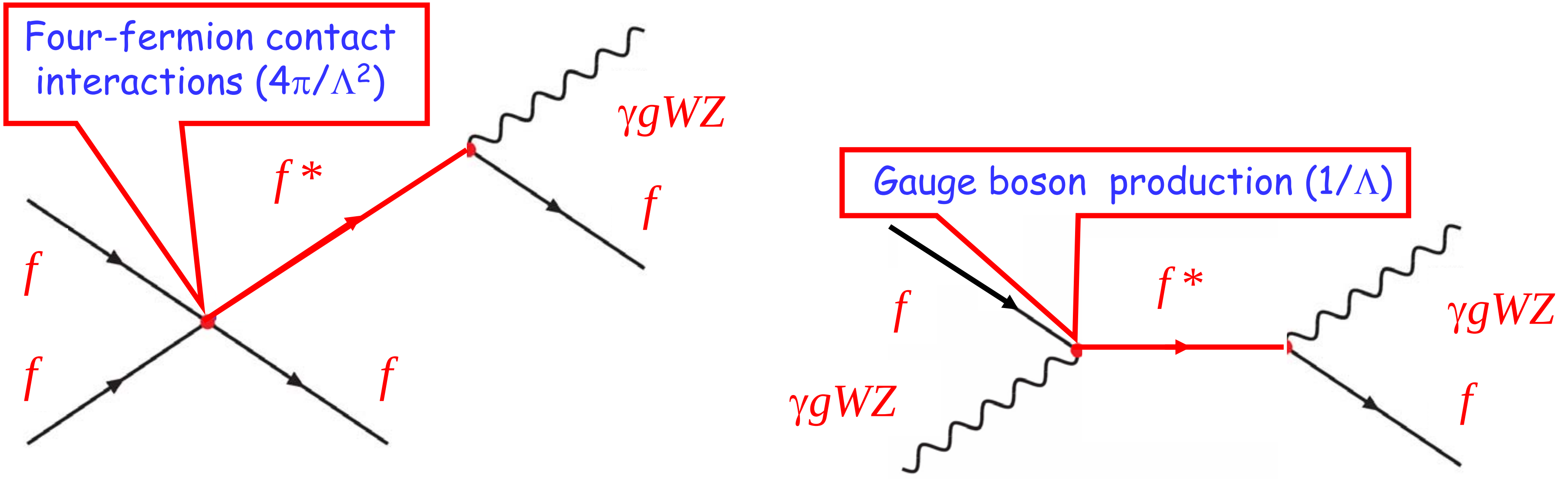
No excess -> Upper limits (95% CL)



For the current best limits values of λ_{132} = 0.05 and λ'_{311} = 0.16
$M_{\tilde{\nu}_\tau} > 460$ GeV at 95% CL

Spin 1/2 resonances : Excited Fermions

- Excited fermions occur in compositeness models where the known fermions are bound states of more fundamental particles which are bound together by a new strong interaction.
- Relevant parameters :
  - M_{f*} : excited fermion mass
  - Λ : Compositeness scale



Excited quarks : q*

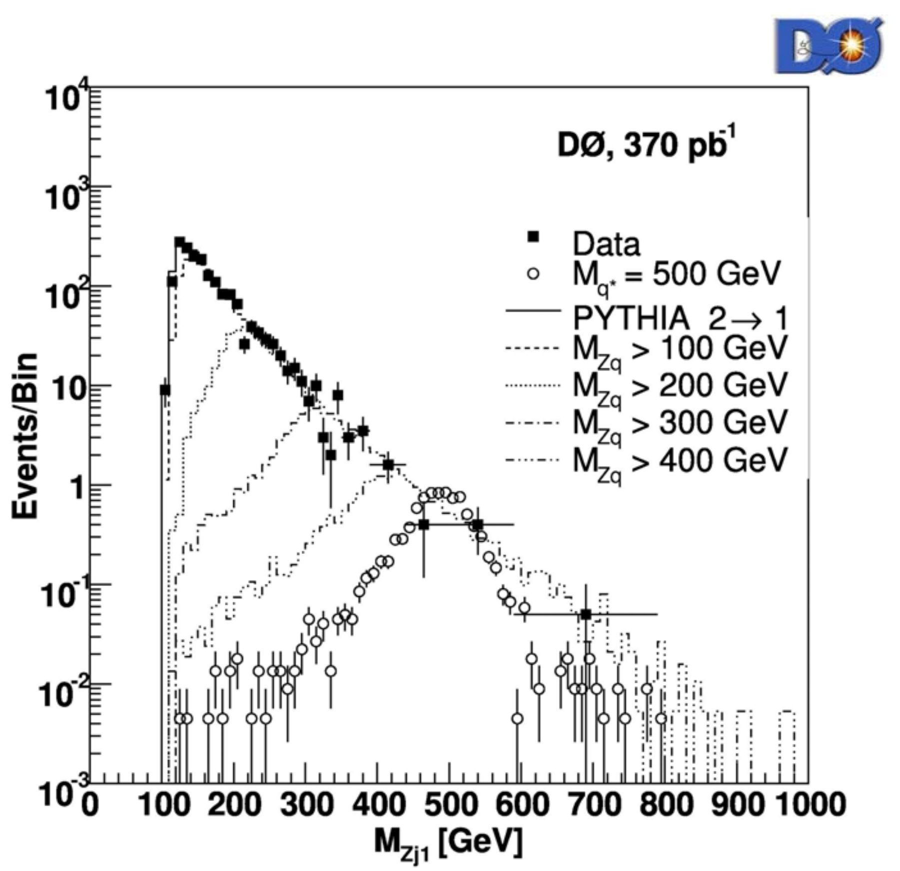
Search of q* produced by a gluon-quark fusion :

$$q + g \rightarrow q^* \rightarrow Z^0(e^+e^-) + q$$

Data : $\mathcal{L} = 0.37\ fb^{-1}$

Selection :

- 2 hight pT isolated electrons, with
  - $p_T^1 > 30$ GeV
  - $p_T^2 > 25$ GeV
- Cut around Z mass : 80 GeV < M_{e+e-} < 120 GeV
- At least 1 hight p_T jet : $p_T > 20$ GeV



SM backgrounds :

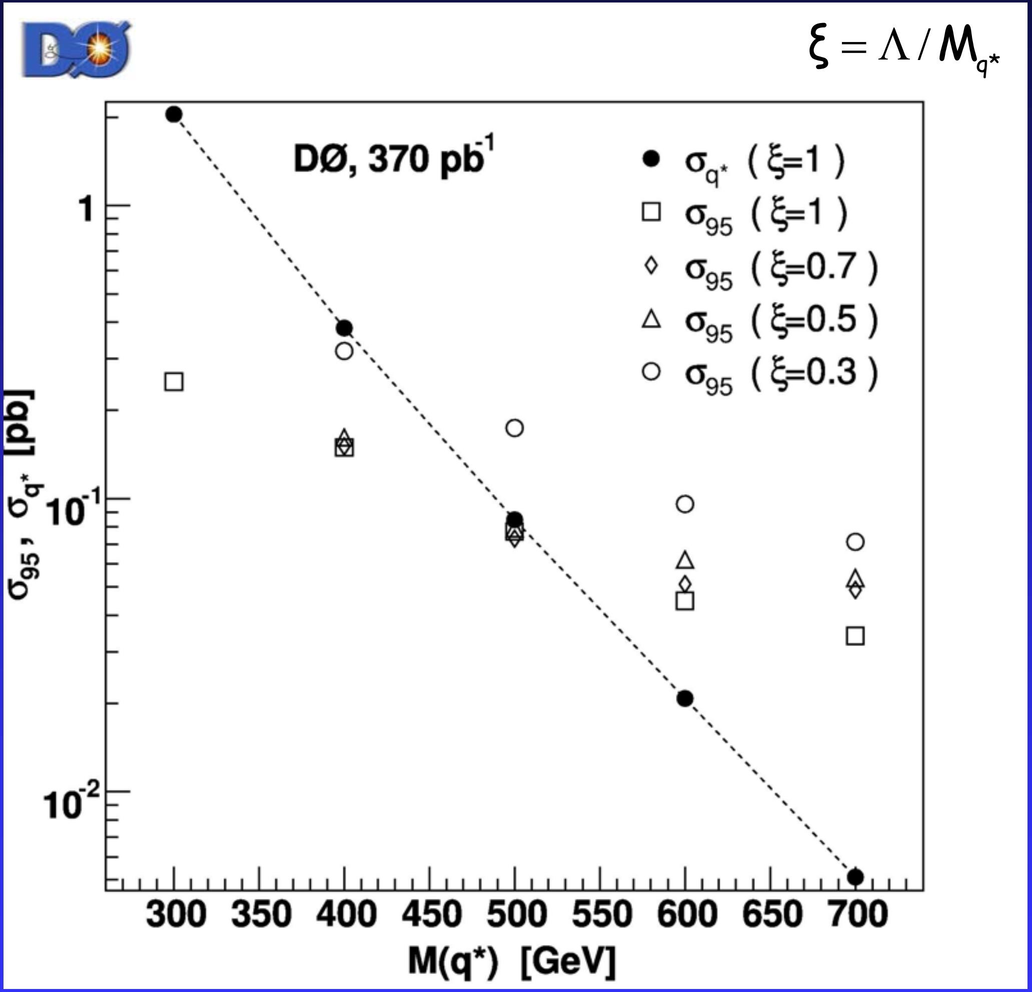
- Main :
  - Drell-Yann ($Z/\gamma^* \rightarrow e^+e^-$)
- Other (small):
  - $W \rightarrow e\upsilon + jet$

+ QCD (Instrumental) background

MC : Pythia 6.2, PDF CTEQ5L + ALPGEN

Excited quarks : q*

No excess -> Upper limits in the q* gauge model (95% CL)



For $\Lambda = M_{q^*}\ (\xi = 1)$:

M_{q^*} > 510 GeV at 95% CL

Spin 1 resonances

- Some models propose SM extensions with additional symmetry groups (to explain hierarchy problems, fundamental forces unification, etc …)
    - Left-Right symmetric models ($SU(2)_L X SU(2)_R$) : W', Z'
    - E(6) Guts : Z'_I, Z'_ψ, Z'_χ, Z'_η

W' search in $t\bar{b}\,(\bar{t}b)$

Search for a massive W-like boson, SM-like couplig to fermions :

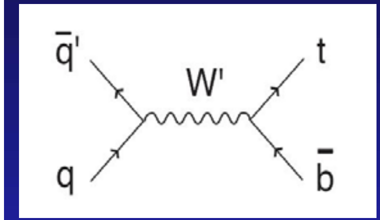
$$q\bar{q}\,' \rightarrow W' \rightarrow t\bar{b} \rightarrow Wb\bar{b} \rightarrow l\upsilon jj$$

Masse range : 300 GeV – 950 GeV

Data : $\mathcal{L} = 1\ fb^{-1}$

Selection (a la single top) :

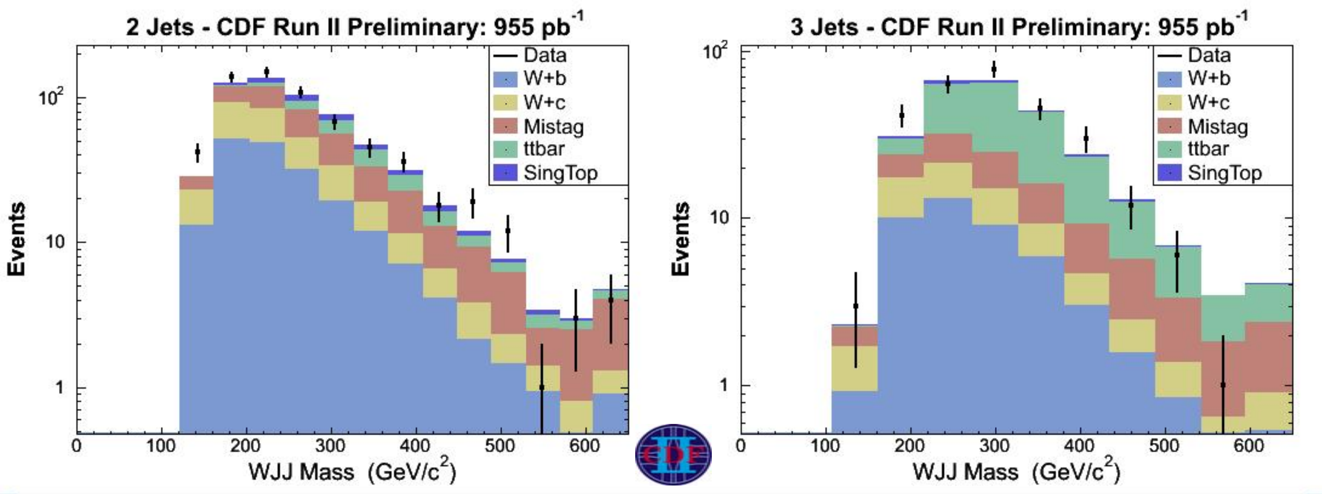
- 1 hight E_T isolated lepton : E_T>30 GeV
- Large missing E_T : E_T > 25 GeV
- 2 or 3 energetic jets : E_T > 15 GeV
- At least one displaced secondary vertex



Backgrounds :

- W : $Wb\bar{b}, c\bar{c}, Wcj$
- Dibosons : WW, WZ
- $Z + jets$
- Single top and $t\bar{t}$
- QCD (Instrumental) background

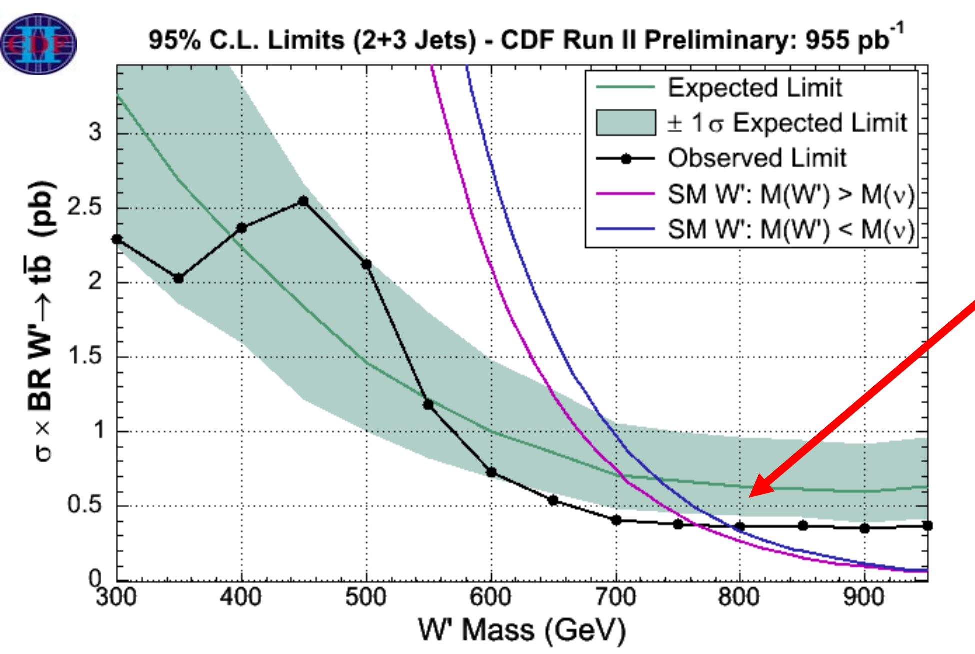
MC : ALPGEN, HERWIG, and PYTHIA



Background scaled up by 10% for visual comparison

W' search in $t\bar{b}\,(\bar{t}b)$

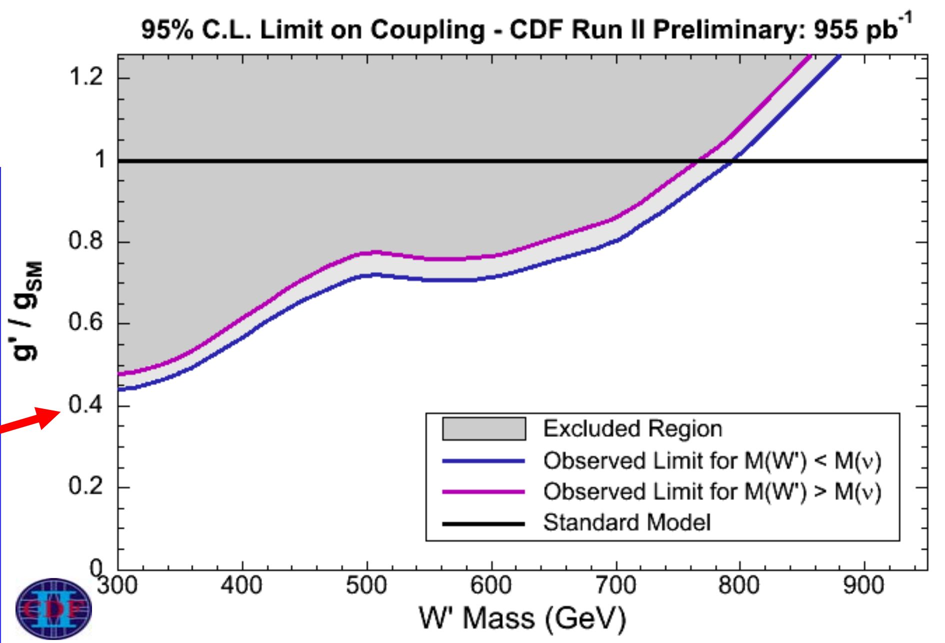
No excess -> Upper limits (95% CL)



W' with SM couplings :

$M_{W'}$ > 760 GeV if $M_{W'} > M(\nu_R)$

$M_{W'}$ > 790 GeV if $M_{W'} < M(\nu_R)$



If g' not equal to g : g' > 0.45g

W' search in eν

Search for a massive W-like boson, SM-like coupling to fermions :

$$q\bar{q}' \to W' \to e\upsilon$$

Data : $\mathcal{L} = 0.9\ fb^{-1}$

Selection :

- 1 hight E_T isolated electron : $E_T > 30$ GeV
- Large missing E_T : $\not{E}_T > 30$ GeV
- $\not{E}_T$ opposite to electron : $0.7 < E_T / \not{E}_T < 1.3$
- Jets not back-to-back to electron or $\not{E}_T$

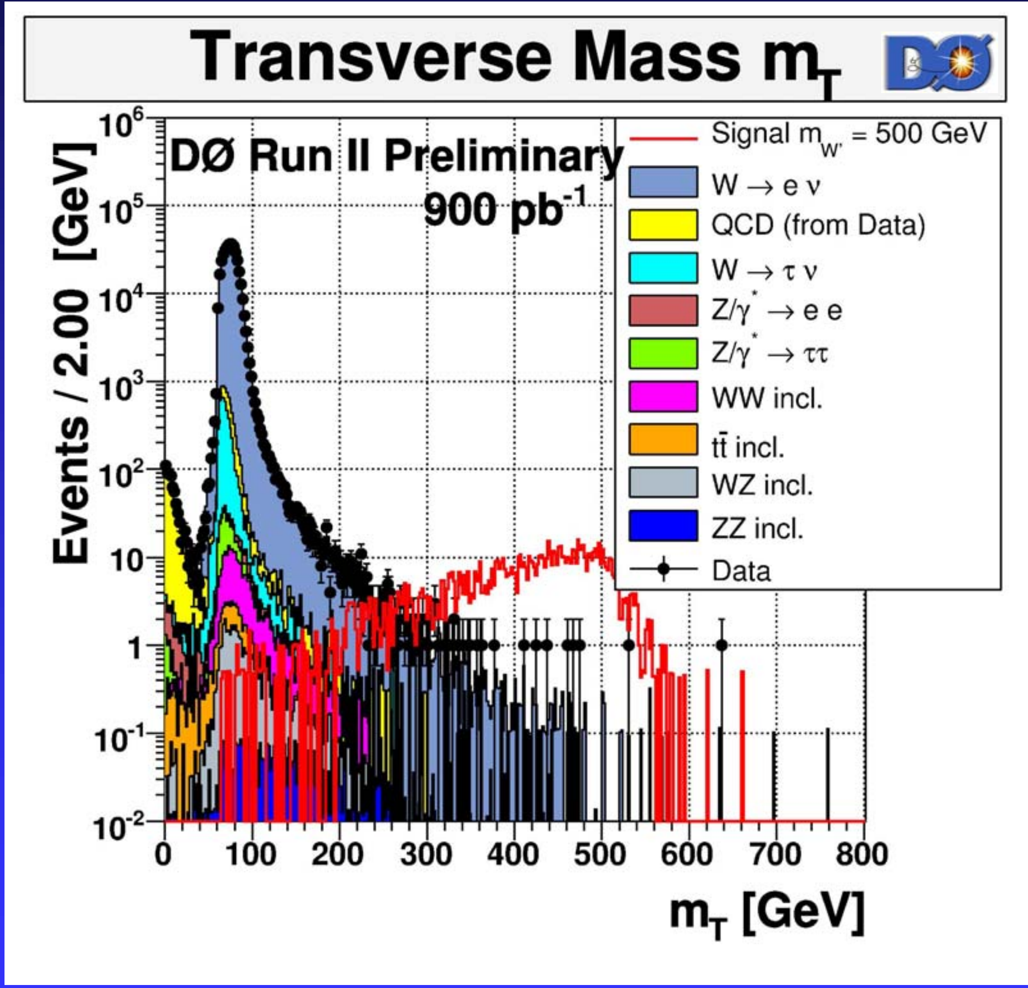
Backgrounds :

- SM : electron + Missing E_T

  $Z^0/\gamma^* \to e^+e^-$

- QCD (Instrumental) background

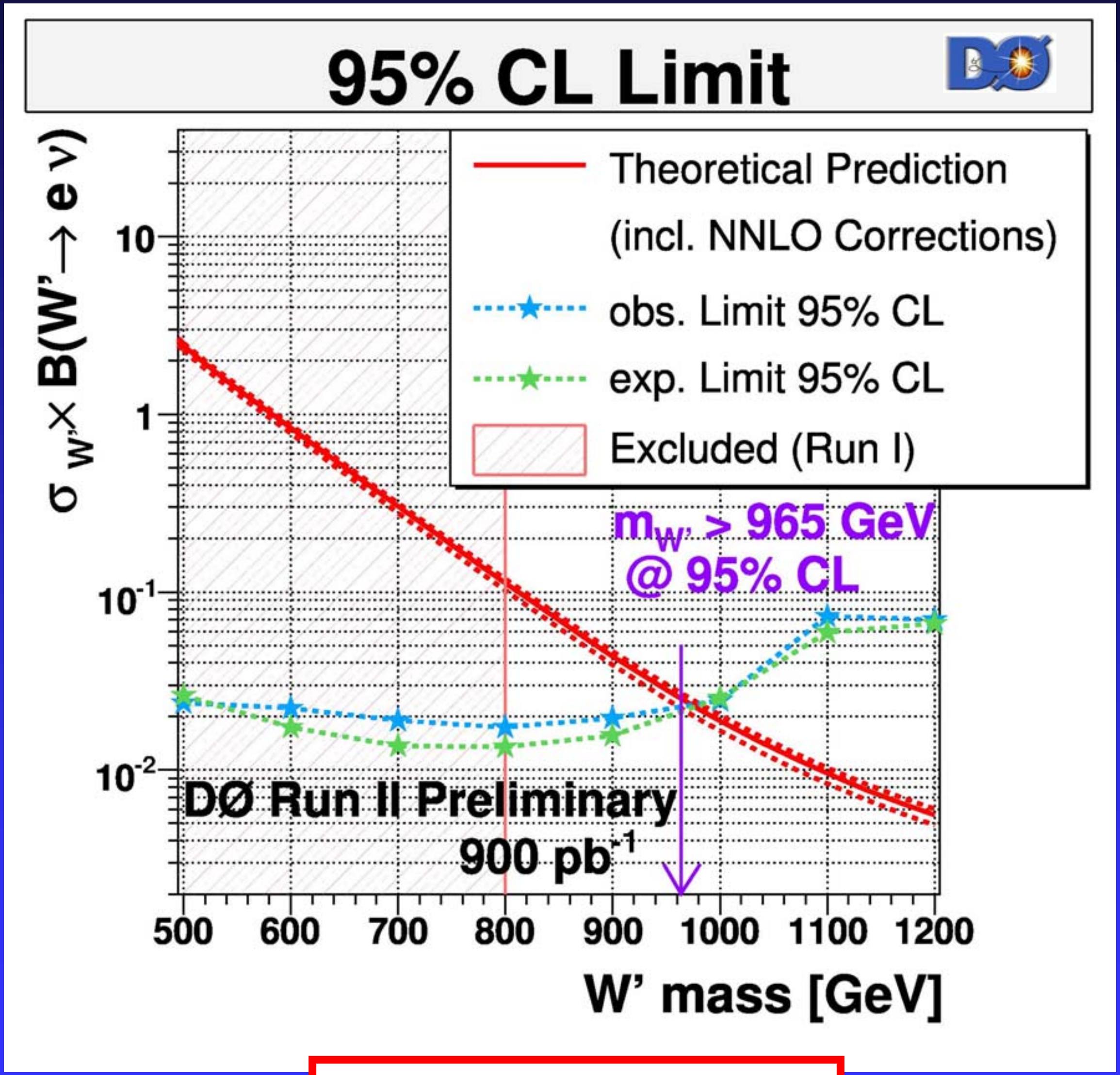
MC : PYTHIA 6.323, PDF CTEQ6L



$$m_T = \sqrt{2E_T \not{E}_T (1 - \cos\Delta\phi(\text{electron, MET}))}$$

W' search in eν

No excess -> Upper limits (95% CL)



$M_{W'} > 965$ GeV at 95% CL

Z' search in e^+e^- events

Search for a narrow resonance decaying into e^+e^-

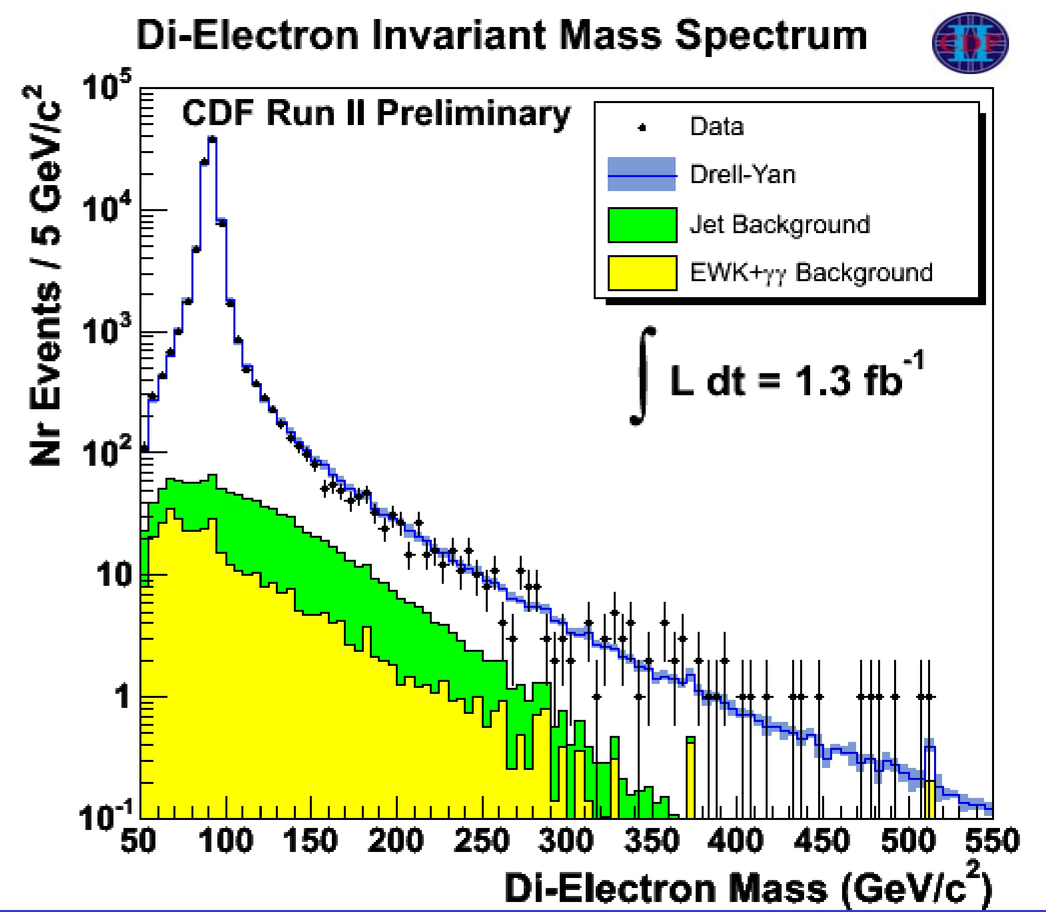
$$q\bar{q} \rightarrow Z' \rightarrow e^+e^-$$

The search mass range : 150 GeV -950 GeV

Data : $\mathcal{L} = 1.3\ fb^{-1}$

Selection :

- 1 hight E_T isolated electron :
  - $E_T > 25$ GeV
  - |eta| < 1.1, Central Calorimeter(CC)
- 1 hight E_T electron :
  - $E_T > 25$ GeV
  - $|\eta| < 1.1$ or $1.2 < |\eta| < 3.0$ (CC or plug Calorimeter)
- 1 track matching in CC
- 1 photon conversion veto



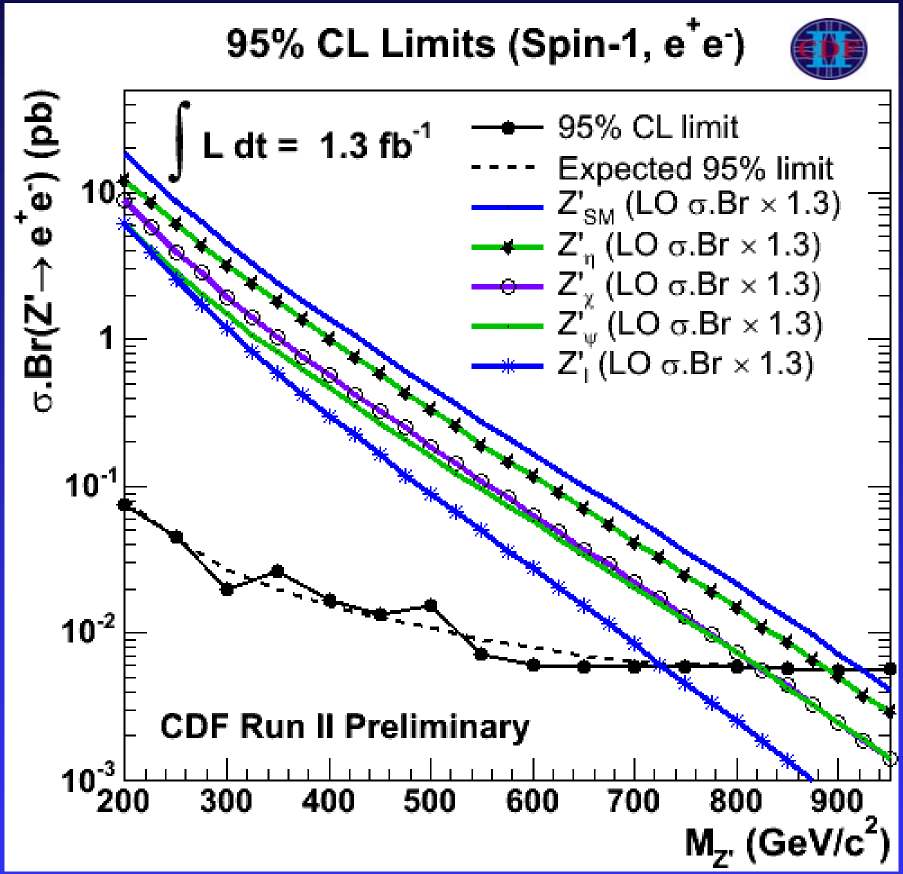
Backgrounds :

- Drell-Yann : $Z^0/\gamma^* \rightarrow e^+e^-$
- $jet + jet, W \rightarrow e + \upsilon + \gamma/jet, \gamma + \gamma$

MC : PYTHIA, PDF CTEQ5L

Z' search in e⁺e⁻ events

No excess -> Upper limits (95% CL)



Mass Limits Z':

Z' Model	Z'_{SM}	Z'_{ETA}	Z'_{CHI}	Z'_{PSI}	Z'_{IOTA}
Mass Limit (GeV/c^2)	923	891	822	822	729

Z' search in $t\bar{t}$ events

Study the invariant mass of the $t\bar{t}$ system.

Set model independent limits on a new resonant $t\bar{t}$ production

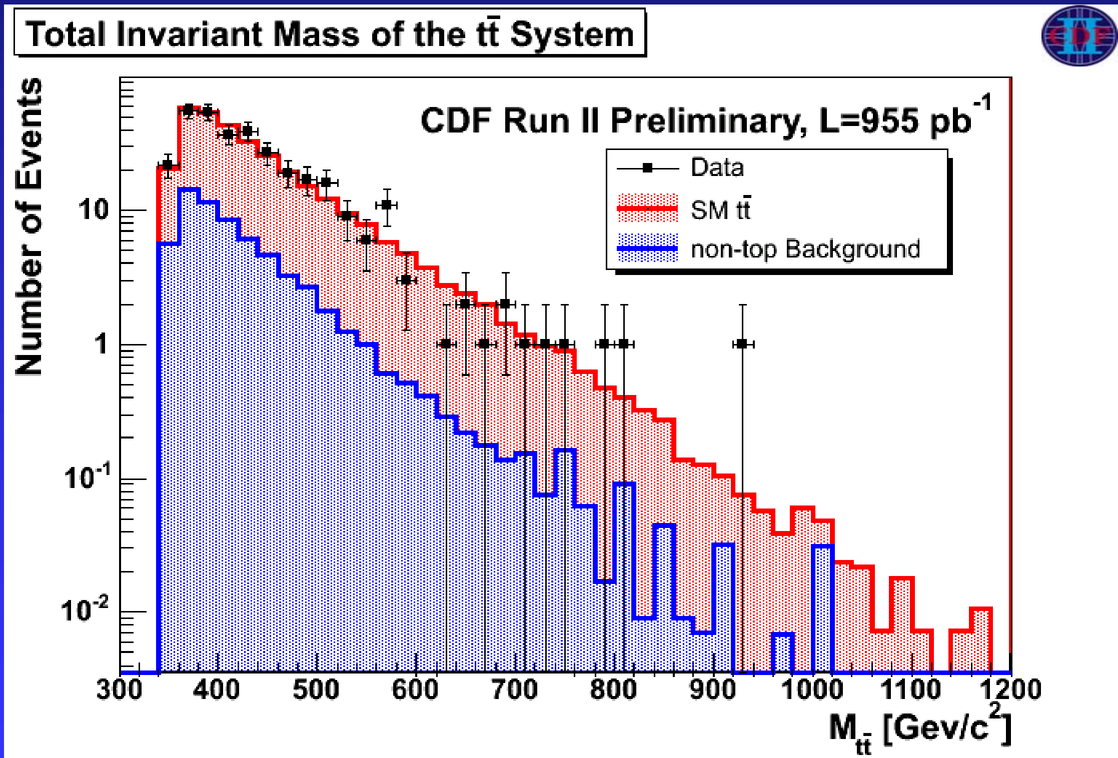
Interpreted it as a Z' :

$$q\bar{q} \rightarrow Z' \rightarrow t\bar{t}$$

Data : $\mathcal{L} = 1\ fb^{-1}$

Selection : (Standard b-tagged top mass selection)

- 1 central high E_T lepton : $E_T > 20$ GeV
- High missing E_T : $E_T > 20$ GeV
- 4 jets with $|\eta| < 2.0$:
  - 3 jets with $E_T > 15$ GeV
  - the 4th jet with $E_T > 8$ GeV
- At least 1 jet with a secondary vertex.



Backgrounds :

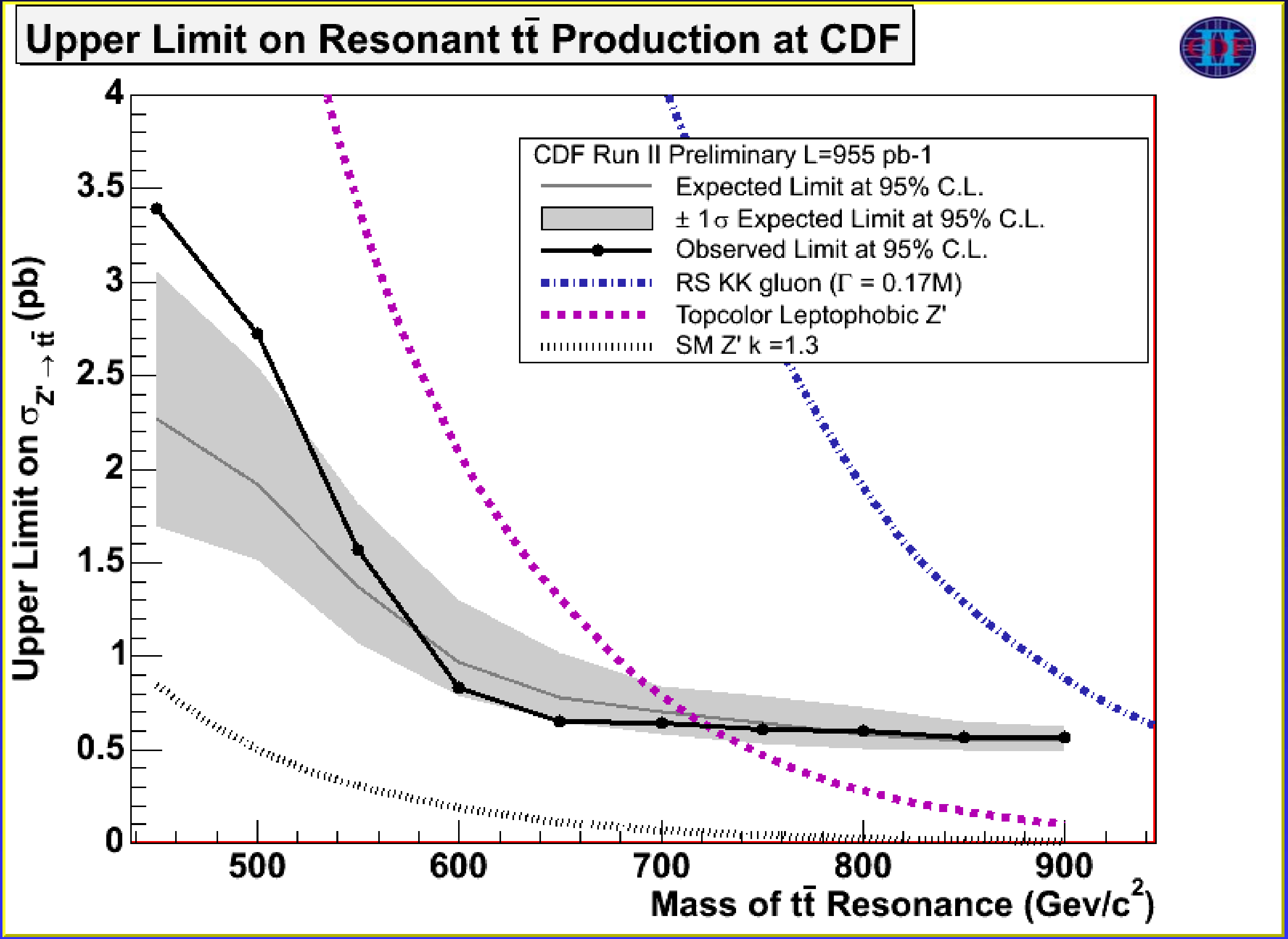
- SM $t\bar{t}$

MC :

- HERWIG
- Signal : PYTHIA heavy Z^0-like neutral boson (mass : 450-900 GeV every 50 GeV, width =1.2%*mass)

Z' search in $t\bar{t}$ events

No excess -> Upper limits (95%CL)



- Massive Z' SM-like couplings : out of range of our sensitivity
- With more lumi we can exclude a RS KK gluon
- For a leptophobic topcolor Z' : $M_{Z'}$ > 720 GeV (95% CL).

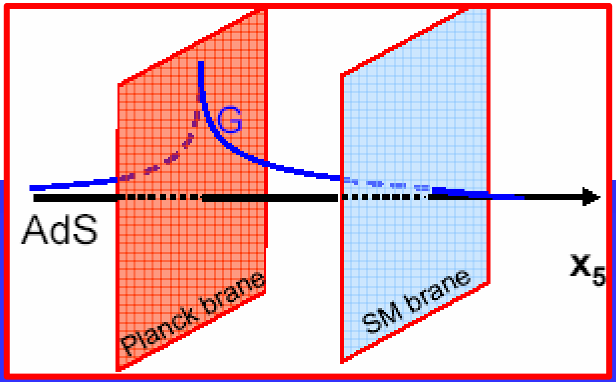
Spin 2 resonances

- Additional models to explain the hierarchy scale between EW symmetry breaking scale (~ 1 TeV) and Planck scale (M_{pl} ~ 10^{16} TeV) where gravity becomes strong.
- Randall-Sundrum (RS) model : Gravity on a (3+1)-dimentional brane, the Plank brane.
- Separated from SM brane by a 5th extra-dimension with a warped metric.
- Gravitons are the only (spin 2) particles propagating in the extra-dimension.
- Graviton wave function suppressed exponentially from Planck brane to SM brane : Gravity weak in SM.
- RS gravitons towers of Kaluza-Klein excitations, with different modes.
- Zero mode RS graviton decays in the SM brane into di-photons or dileptons :

$$Br(G \to \gamma\gamma) = 2 \times Br(G \to l^+l^-)$$

- Characterized by its masse M_1 and the coupling to the SM fields $k/\overline{M}_{pl}$, where :
  - k: the warp factor giving the extra dimension curvature
  - $\overline{M}_{pl} = M_{pl} / \sqrt{8\pi}$
- EW data constraints + perturbative model :

$k/\overline{M}_{pl}$ values between 0.01 and 0.1



Search for RS Graviton in $\gamma\gamma$ events

Search for high mass di-photon states :

$q\bar{q}\ (gg) \rightarrow G \rightarrow \gamma\gamma$

Data : $\mathcal{L} = 1.2\ fb^{-1}$

Selection :

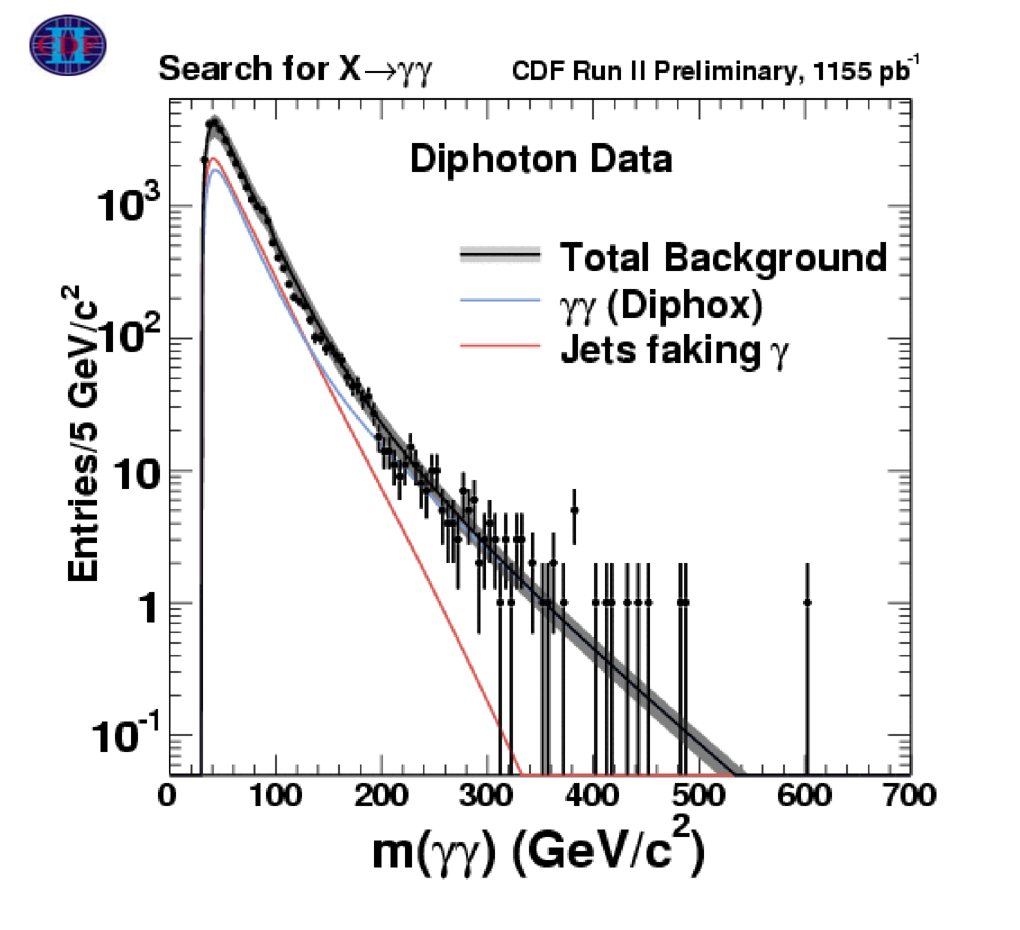
- 2 hight E_T isolated photons :
  $E_T > 15$ GeV
- $M_{\gamma\gamma} > 30$ GeV

Backgrounds :

- SM : Di-photons production
- $Jets \rightarrow \pi^0$

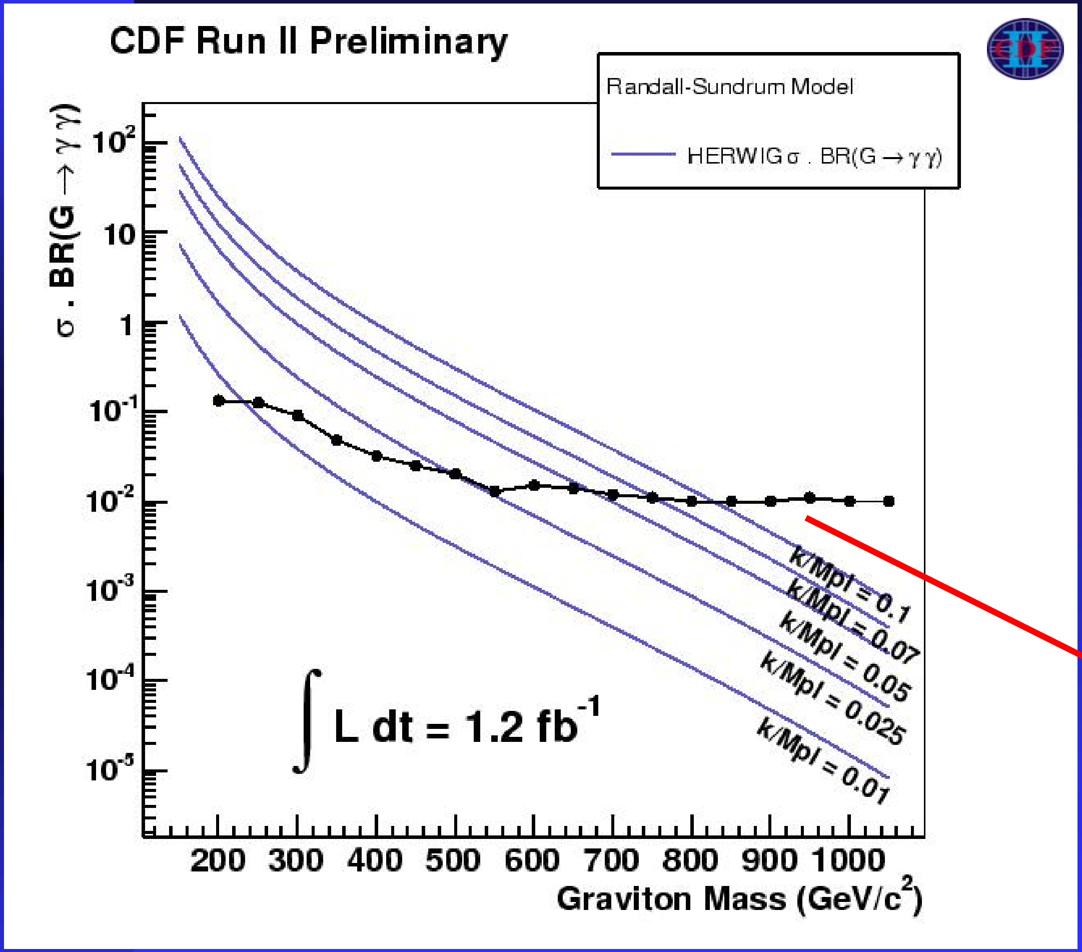
MC :

- Background ($\gamma\gamma$) :
  Diphox NLO+PYTHIA
- Signal (RS graviton) :
  HERWIG, PDF CTEQ5L



Search for RS Graviton in $\gamma\gamma$ events

No excess -> Upper limits (95% CL)



k/M_{Pl}	Lower Mass Limit (GeV/c^2)
0.1	850
0.07	784
0.05	694
0.025	500
0.01	230

Search for RS Graviton in $\gamma\gamma$+e^+e^- events

Search for high mass di-photon or di-electron final states :

$$q\bar{q}\ (gg) \rightarrow G \rightarrow \gamma\gamma \text{ or } e^+e^-$$

<u>Data :</u> $\mathcal{L}$ = 1.1 fb^{-1}

<u>Selection :</u>

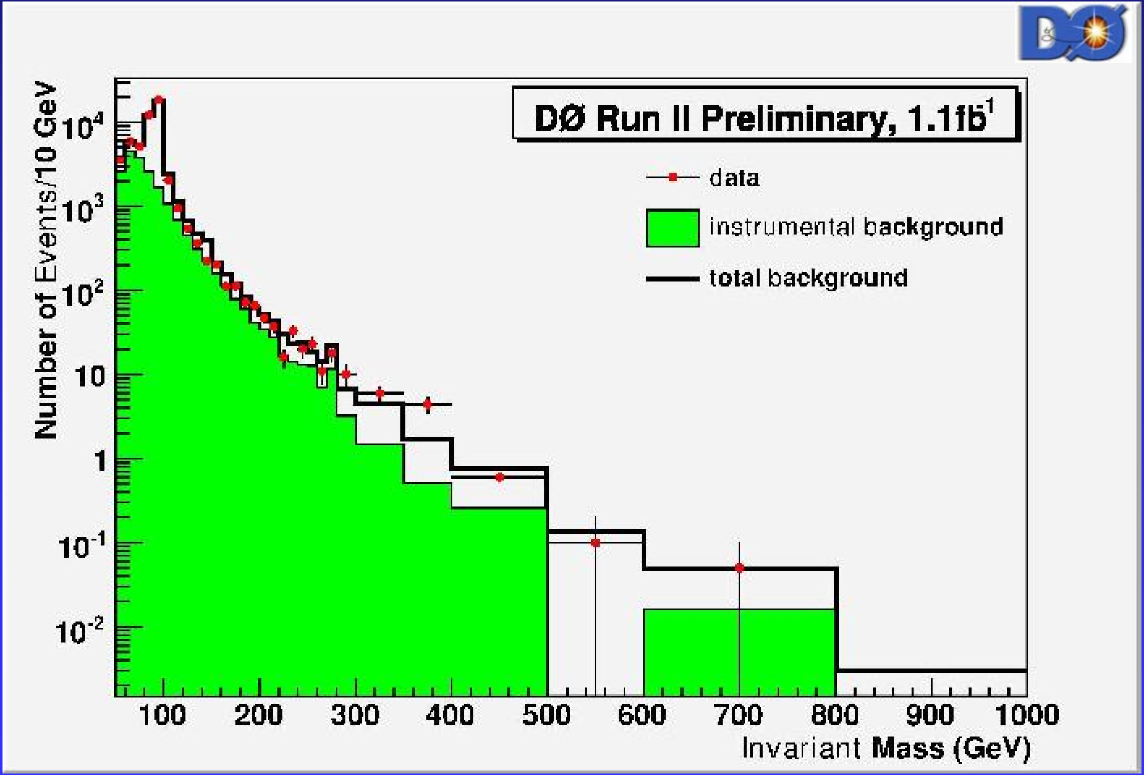
- 2 hight p_T isolated EM objects :
  - p_T > 25 GeV
  - $|\eta|$ < 1.1 (Central Calorimeter)
- M_{EM-EM} > 50 GeV

<u>Backgrounds :</u>

- SM :
  - Drell-Yann : $Z^0/\gamma^* \rightarrow e^+e^-$
  - Direct $\gamma\gamma$ production
- Instrumental :

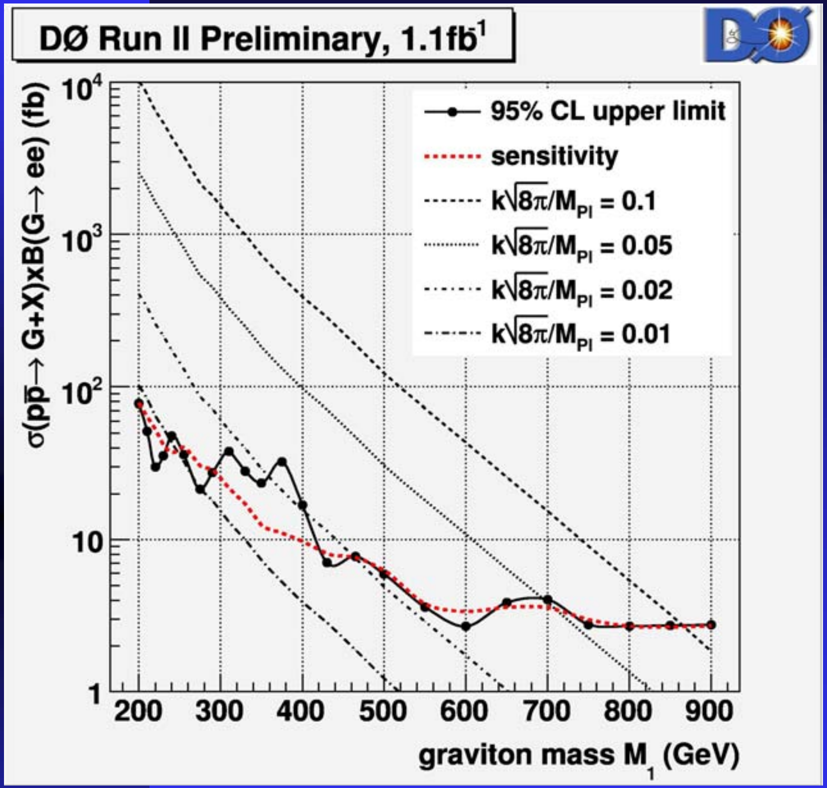
$jet + jet, W \rightarrow e + \upsilon + \gamma/jet, \gamma + \gamma$

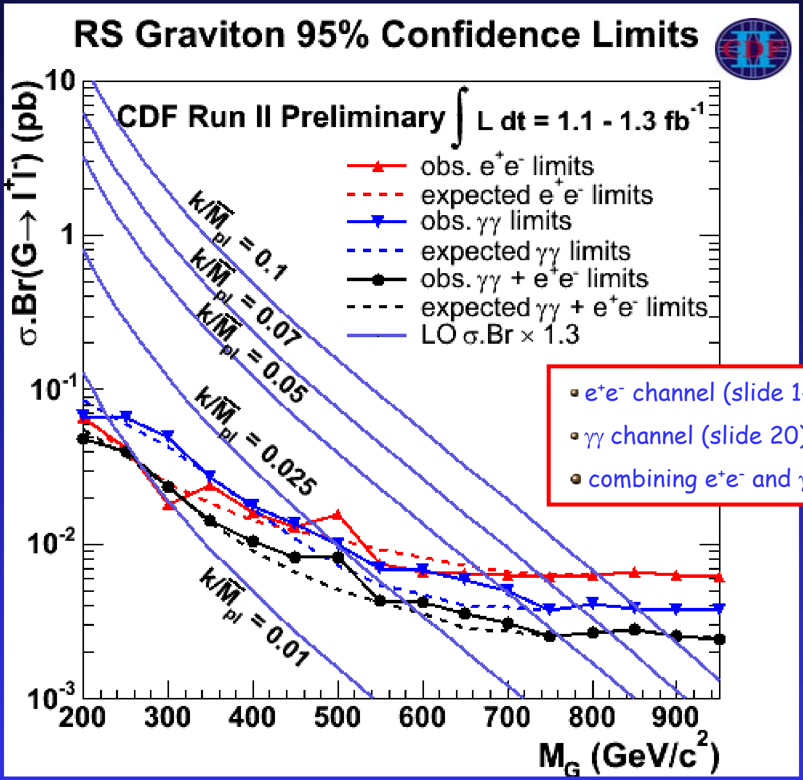
<u>MC :</u> PYTHIA



Search for RS Graviton in $\gamma\gamma$+e^+e^- events

No excess -> Upper limits (95% CL)





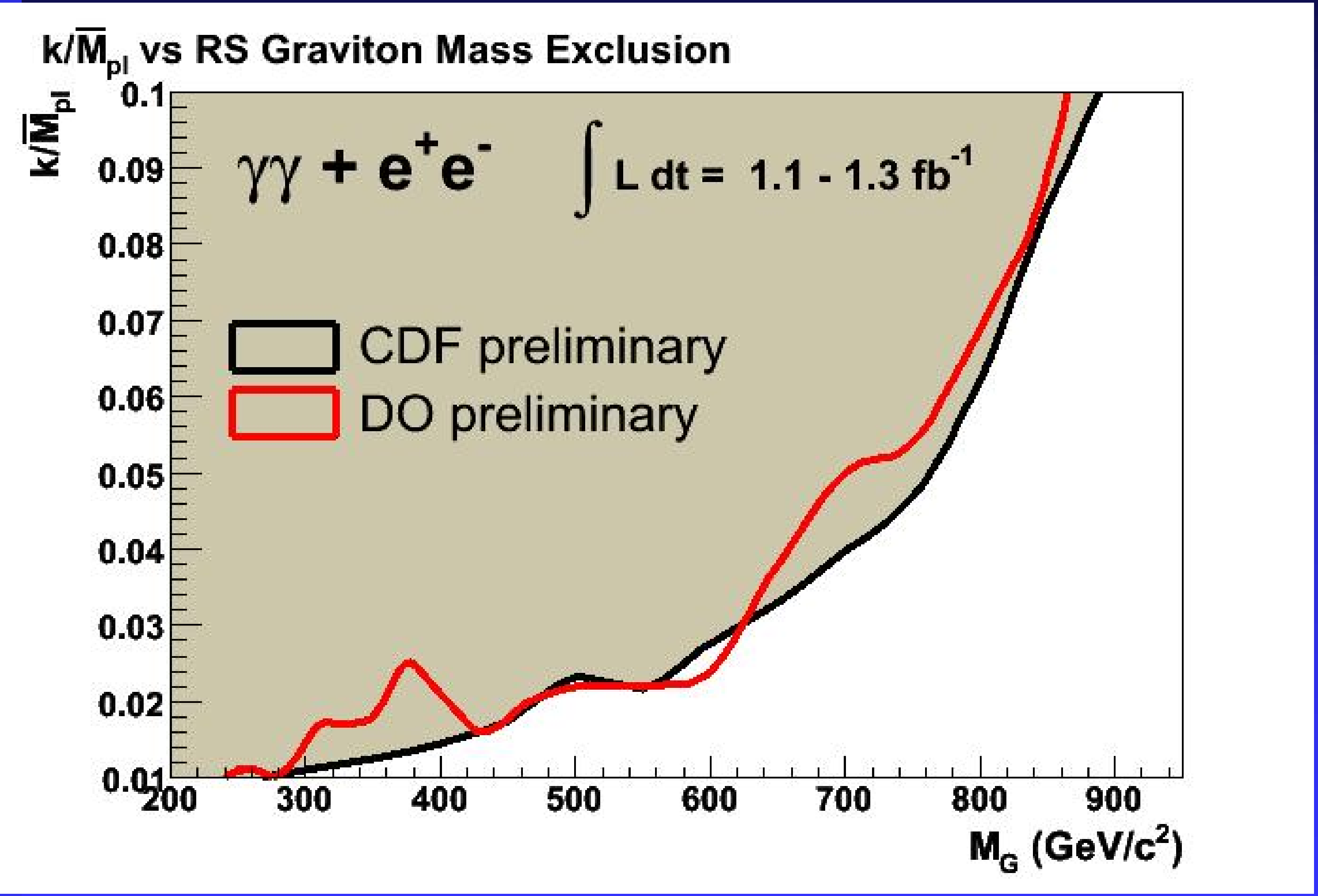
- e^+e^- channel (slide 14)
- $\gamma\gamma$ channel (slide 20)
- combining e^+e^- and $\gamma\gamma$

- Mass limit at 95% CL of RS graviton decaying into e^+e^- or $\gamma\gamma$:
  - M_1 > 865 GeV for $k/\overline{M}_{pl} = 0.1$
  - M_1 > 240 GeV for $k/\overline{M}_{pl} = 0.01$

Mass Limits RS Graviton (GeV/c^2):

k/Mpl	0.01	0.025	0.05	0.07	0.10
e+e-	302	469	674	741	807
gamma gamma	230	500	694	782	850
e+e- + gamma gamma	267	580	761	820	889

Search for RS Graviton in $\gamma\gamma+e^+e^-$ events



Search for RS Graviton in eeee events

Search a massive resonance : m > 500 GeV

Decaying into Z^0Z^0 in the final state

$$q\bar{q}\ (gg) \rightarrow G \rightarrow Z^0 Z^0 \rightarrow e^+ e^- e^+ e^-$$

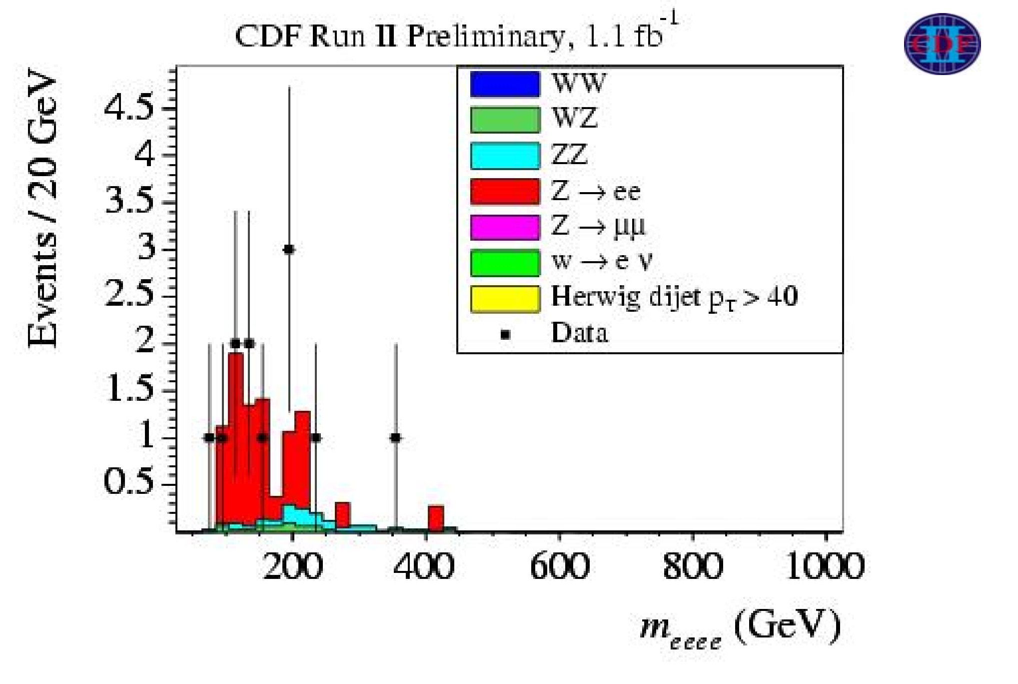
Data : $\mathcal{L} = 1.1\ fb^{-1}$

Selection :

- 1 hight E_T isolated electron : E_T > 20 GeV
- At least 3 electron with
  - Isolated CC energy : E_T > 5 GeV

    Or
  - Isolated track p_T > 10 GeV
- Select ZZ-> eeee events with a χ^2 cut :

$$\chi^2 = \sum \left(\frac{m_{ee} - m_{Z^0}}{\sigma} \right)^2$$



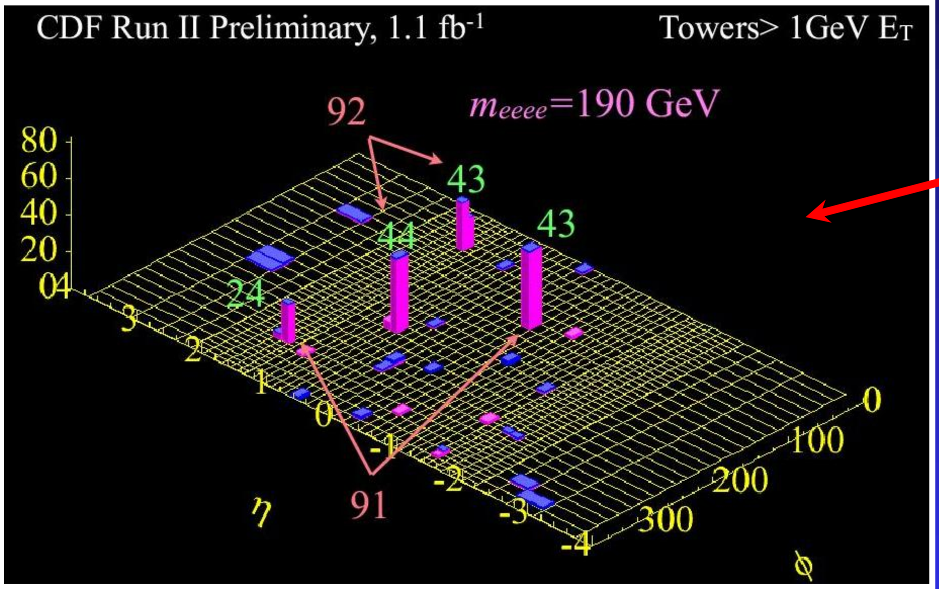
Backgrounds :

- SM : Z + jets, W+jets
- + QCD

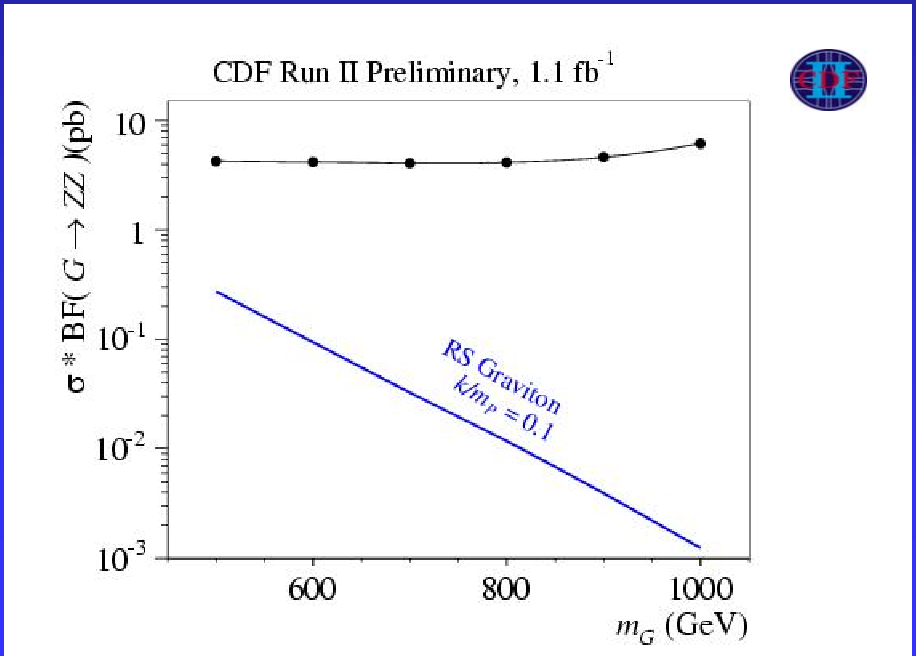
MC : HERWIG

Search for RS Graviton in eeee events

No event found in the signal region



Lowest χ^2 event !



- Assuming zero background
- Using background prediction as uncertainty
- Set 95% CL limits

Summary

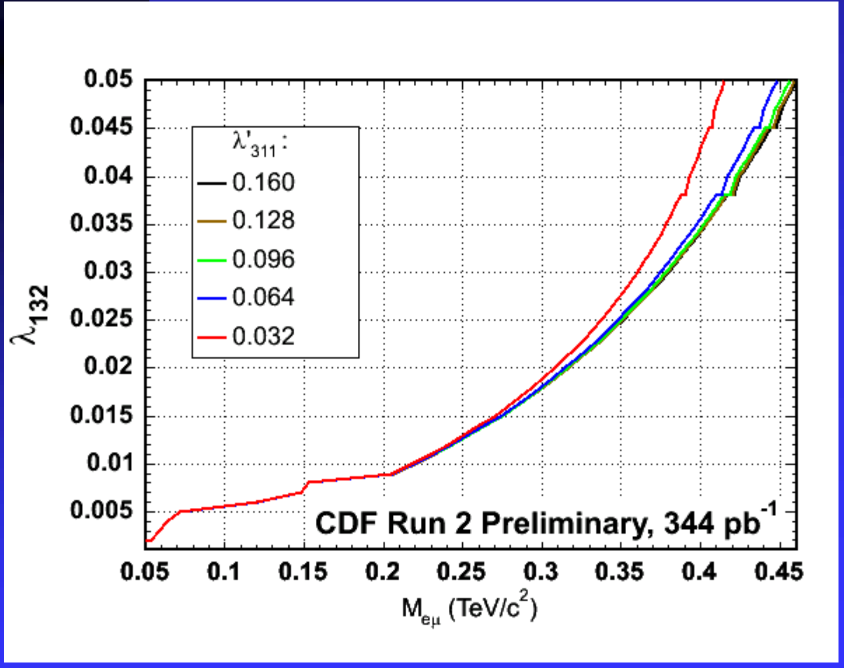
- In this talk, we presented the Tevatron CDF and D0 searches of heavy resonances.
- Those searches were based on RunIIa data giving more than *1 fb-1* data per experiment.
- No evidence of new physics or deviations from the SM observed.
- We set model independent σxBr of the production of such resonances, and also interpreted them using different models and extracted limits on their masses as :
  - sneutrinos
  - Excited quarks (q*)
  - W'
  - Z'
  - RS graviton
- Too many other results not presented here, apologize …
- Tevatron delivered more than 3 fb-1 per experiment, data are being analyzed, more exciting results are coming soon. Expect *8* fb^{-1} per experiment by 2009 !

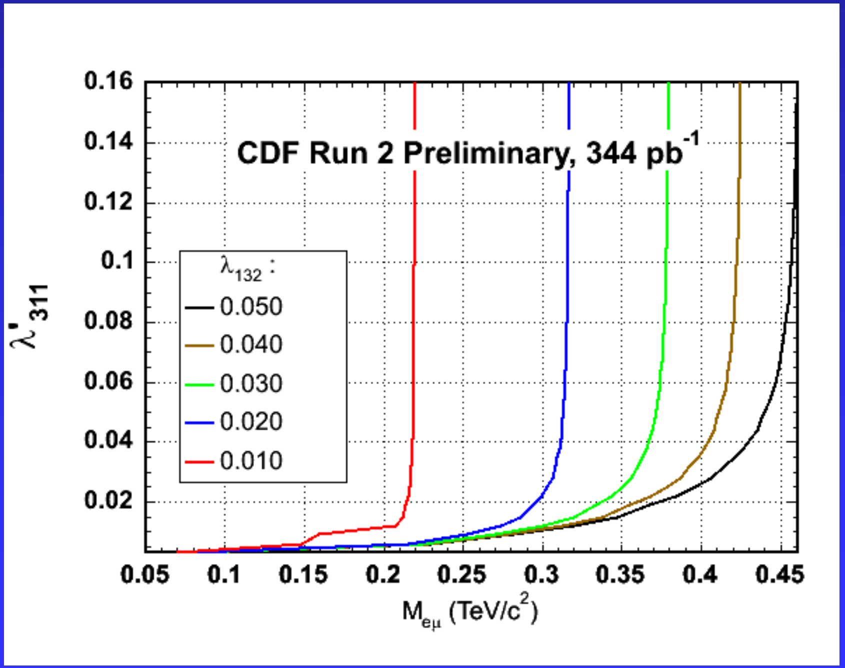
Backup slides

Spin 0 resonances : Susy RPV $\tilde{\nu}_\tau$

Channel	Control Region	Signal Region
$Z \to \tau\tau$	$38.77 \pm 0.63 \pm 2.33$	$0.57 \pm 0.01 \pm 0.03$
diboson	$6.63 \pm 0.18 \pm 0.37$	$3.48 \pm 0.10 \pm 0.19$
$t\bar{t}$	$3.57 \pm 0.05 \pm 0.21$	$3.16 \pm 0.05 \pm 0.19$
fake lepton	$2.90 \pm 1.10 \pm 1.33$	$0.44 \pm 0.40 \pm 0.40$
Prediction	$51.87 \pm 1.11 \pm 2.72$	$7.66 \pm 0.41 \pm 0.48$
Observation	56	5

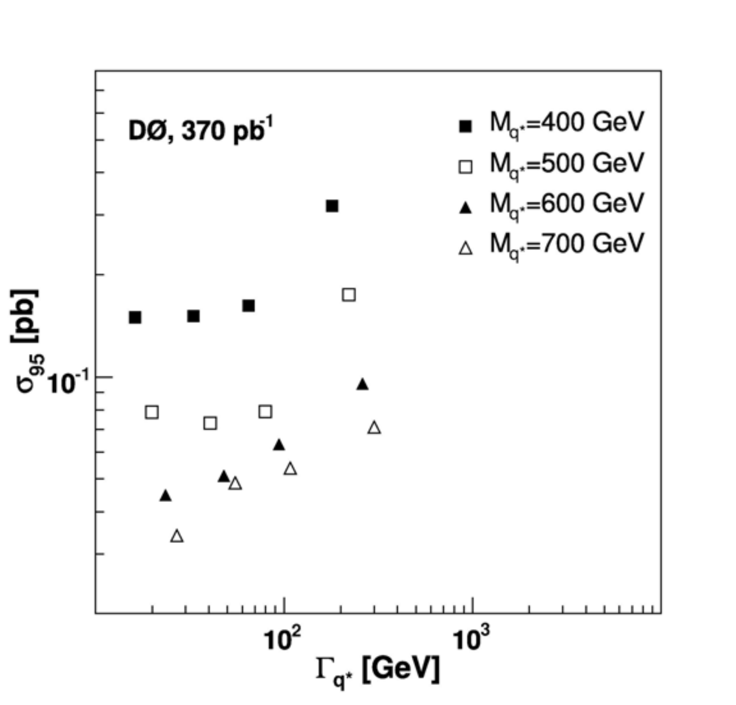
$\alpha_t \times L$ Uncertainty Source	Fractional Sys. Uncert.
E & P Resolution	3.2%
PDF's	2.4%
Scale Factors	1.6%
Luminosity	6%
N_{BG} Uncertainty Source	Fractional Sys. Uncert.
Luminosity	5.6%
Fake Probabilities	3.1%





Excited quarks : q*

M_{q^*} (GeV)	k	σ_{95} (pb)	σ_{95}^{ave} (pb)	Acceptance $\times$ efficiency	SM background	Data (events)
300	1.1	0.25	0.290	0.140 ± 0.009	32.8 ± 2.9	31
400	1.2	0.15	0.129	0.164 ± 0.010	7.5 ± 0.8	9
500	1.3	0.08	0.079	0.195 ± 0.012	2.9 ± 0.8	3
600	1.8	0.05	0.053	0.244 ± 0.014	1.6 ± 0.6	1
700	1.7	0.03	0.044	0.243 ± 0.014	0.64 ± 0.06	0



W' search in $t\bar{b}\,(\bar{t}b)$

Background	2 Jets	3 Jets
$Wb\bar{b}$	170.9 ± 50.7	38.2 ± 10.2
$Wc\bar{c}$	63.4 ± 19.9	15.2 ± 4.8
Wcj	68.6 ± 19.0	12.3 ± 3.4
Mistags	136.1 ± 19.7	42.9 ± 7.0
Non-W	26.2 ± 15.9	26.2 ± 15.9
$t\bar{t}$	58.35 ± 13.46	129.03 ± 29.62
Singtop (s+t)	37.8 ± 5.87	8.83 ± 1.37
WW	5.5 ± 0.96	1.69 ± 0.32
WZ	7.96 ± 0.83	2.05 ± 0.28
Z+Jets	11.92 ± 4.42	4.47 ± 2.79
Total BG	587.8 ± 96.5	257.5 ± 39.7
Data	644	279

W' search in $t\bar{b}$ ($\bar{t}b$)

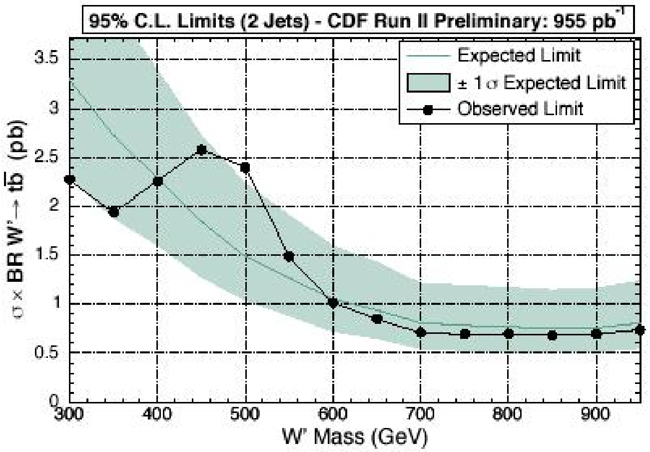


FIG. 6: Observed limits and expect limits in the 2-jet bin.

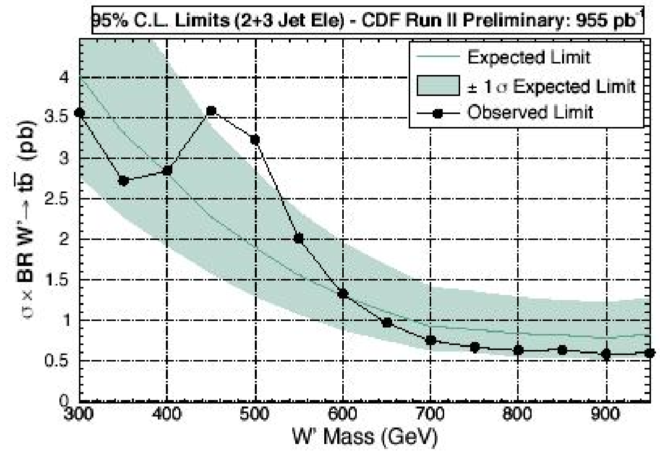


FIG. 8: Observed limits and expect limits in 2+3 jets for electrons.

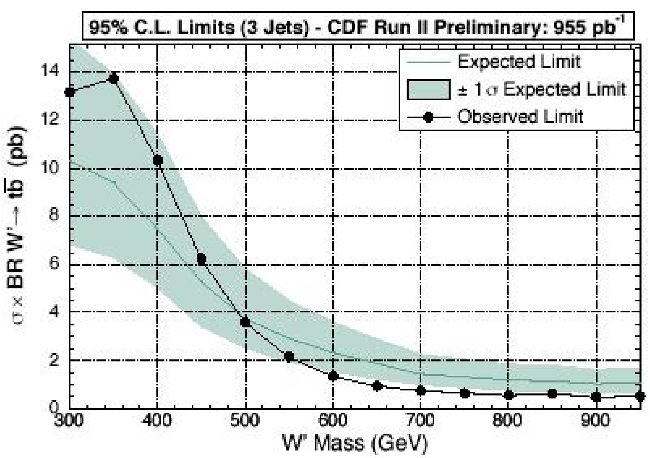


FIG. 7: Observed limits and expected limits in the 3-jet bin.

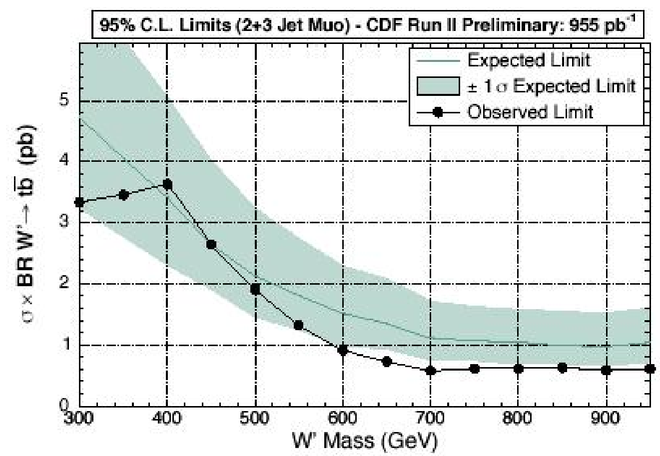


FIG. 9: Observed limits and expected limits in 2+3 jets for muons.

W' search in eν

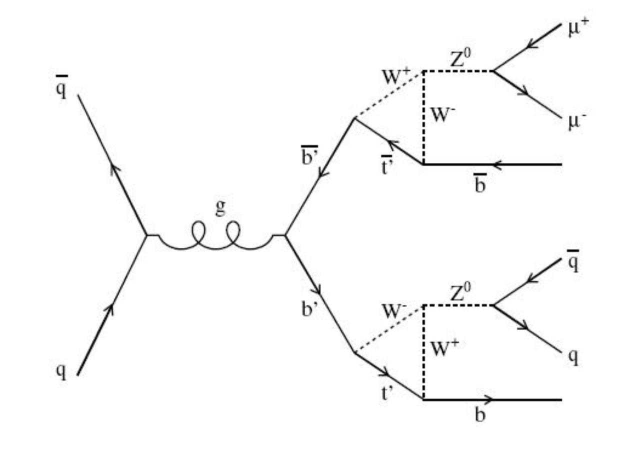
Process	Events	Statistical error	Systematical error (+)	Systematical error (−)
Data	**630**			
Sum Backgrounds	622.93	17.91	82.65	75.25
$W \to e\nu$	572.73	17.49	77.42	71.19
$W \to \tau\nu$	10.10	2.26	3.37	1.86
$Z \to ee$	0.07	0.03	0.01	0.01
$Z \to \tau\tau$	1.11	0.08	0.32	0.18
$WW, WZ, ZZ, t\bar{t}$ (incl.)	15.47	1.08	2.57	2.75
QCD (from data)	23.46	2.97	0.94	0.94
$W' \to e\nu$ (500 GeV)	1032.16	22.45	164.19	164.00
$W' \to e\nu$ (600 GeV)	349.91	7.39	61.42	61.87
$W' \to e\nu$ (700 GeV)	131.02	2.93	30.92	29.93
$W' \to e\nu$ (800 GeV)	46.16	1.05	13.68	13.07
$W' \to e\nu$ (900 GeV)	16.64	0.39	6.86	6.06
$W' \to e\nu$ (1000 GeV)	6.56	0.16	3.54	2.95
$W' \to e\nu$ (1100 GeV)	3.01	0.07	1.76	1.36
$W' \to e\nu$ (1200 GeV)	1.51	0.04	0.78	0.58

Heavy quark : b'

Search for 4th quark generation

In the final state : Z + jets

"blind" analysis



Data : $\mathcal{L}$ = 1.1 fb^{-1}

Selection :

- 2 hight P_T isolated electrons or muons, with
  - p_T > 20 GeV , $|\eta|$ < 2
- 81 GeV < M_{ll} < 101 GeV
- 2 variables to reject background :
  - $N_{jet}^{30} \geq 3$: N jets with E_T> 30 GeV
  - J_{Jet}^{30} large : Scalar sum of all jets with E_T> 30 GeV

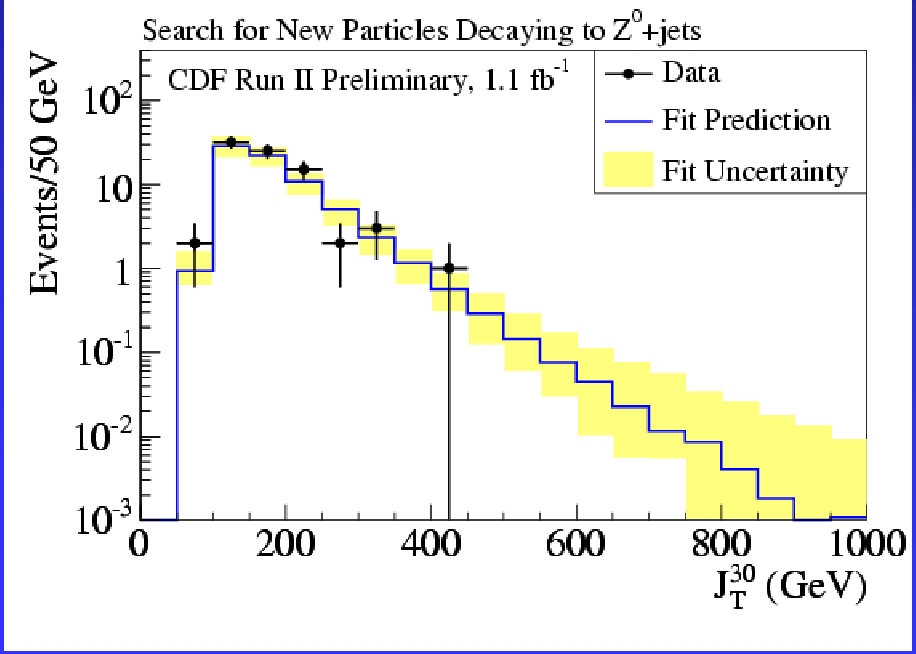
SM backgrounds :

- $Z^0 + jets$
- $WW + jets,\ ZZ + jets,\ t\bar{t} + jets$

+ QCD (Instrumental) background

All background predicted from data by fitting E_T spectrum and modeling J_T

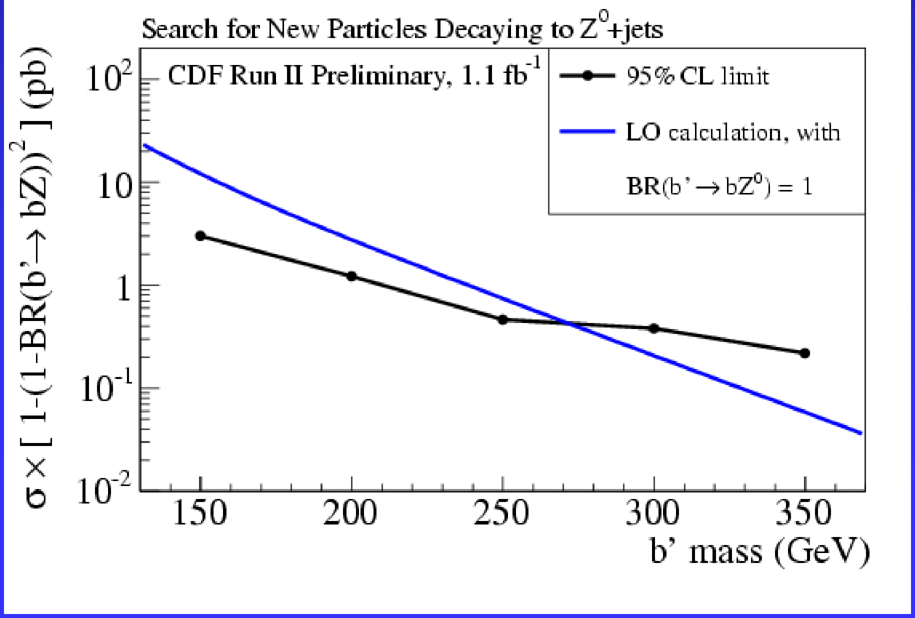
MC : Pythia



Heavy quark : b'

Minimum J_T^{30}	Total Bkg. (stat.+syst. errors)	Data
50	$72.1\,^{+17.7}_{-22.6}$	80
100	$71.2\,^{+17}_{-22.3}$	78
150	$42.7\,^{+9.48}_{-14}$	46
200	$20.5\,^{+5.64}_{-7.77}$	21
250	$9.67\,^{+3.48}_{-4.04}$	6
300	$4.67\,^{+2.17}_{-2.13}$	4
350	$2.31\,^{+1.4}_{-1.16}$	1
400	$1.17\,^{+0.925}_{-0.642}$	1
450	$0.605\,^{+0.655}_{-0.378}$	0

No excess -> Upper limits (95%CL)



For $Br(b' \to Z^0) = 100\%$

$M_{b'} > 270$ GeV at 95% CL

Z' search in $\tau^+\tau^-$ events

Study resonance production in $\tau^+\tau^-$

"blind" analysis optimser on conrol region at m_{vis} < 120 GeV

Data : $\mathcal{L}$ = 0.2 fb^{-1}

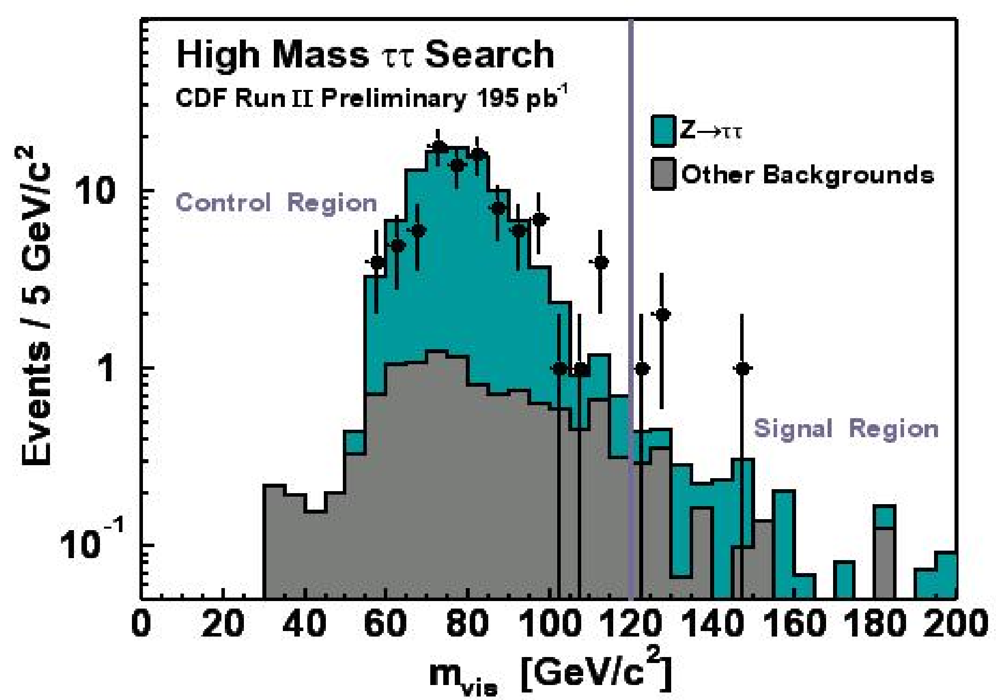
Selection :

$\tau_e\tau_h, \tau_\mu\tau_h$

- 1 isolated electron : E_T > 10 GeV or
- 1 isolated muon : p_T > 10 GeV and
- 1 isolated reconstructed τ :
  - p_T (seed) > 6 GeV and
  - p_T (tracks + π^0's) > 25 GeV and
- $\not{E}_T$ > 15 GeV

$\tau_h\tau_h$

- τ candidate : E_T > 20 GeV
- $\not{E}_T$ > 25 GeV
- 2 isolated τ with :
  - p_T (seed) > 6 GeV and
  - p_T (tracks + π^0's) > 25 GeV and 10 GeV



Backgrounds :

- SM : $Z^0/\gamma^* \rightarrow ee, \mu\mu, \tau\tau$
- $jet \rightarrow \tau$ fakes

MC :

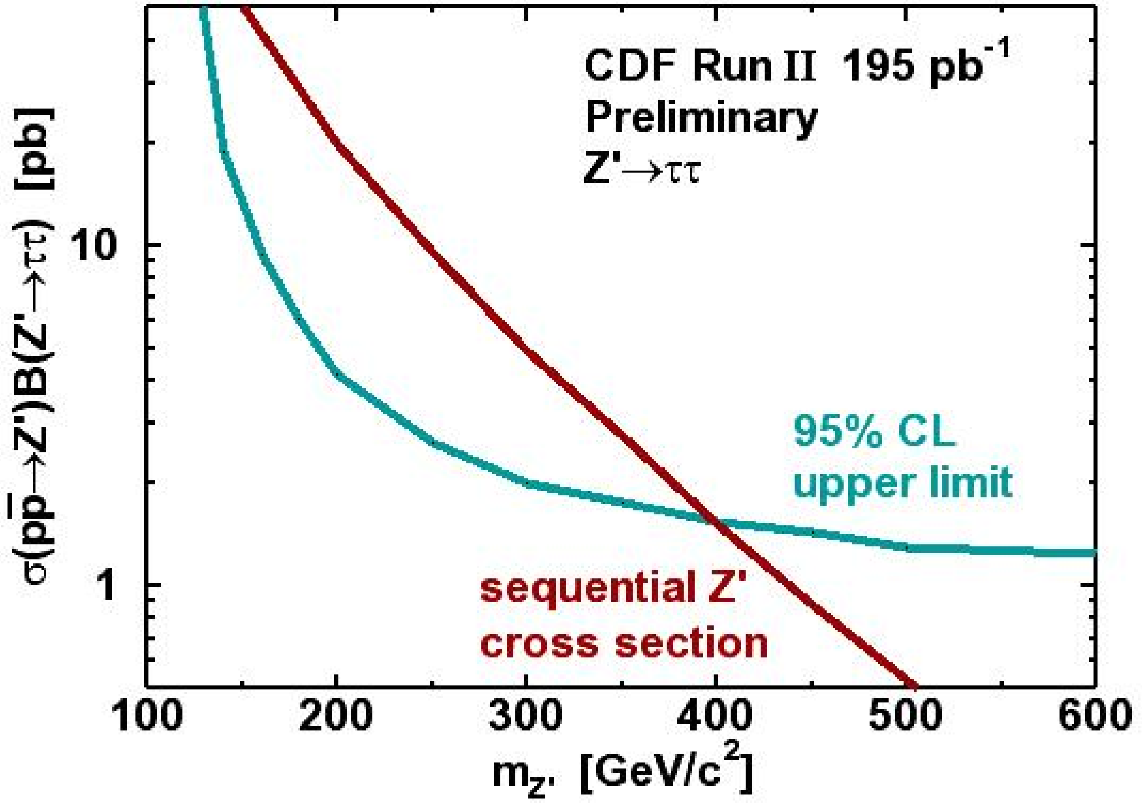
- PYTHIA

Z' search in $\tau^+\tau^-$ events

Source	$\tau_e\tau_h$	$\tau_\mu\tau_h$	$\tau_h\tau_h$	Total
$Z/\gamma^* \to \tau\tau$	45.36±6.84	38.39±5.72	4.19±0.77	87.94±12.38
$Z/\gamma^* \to ee$	0.14±0.14	0	0	0.14± 0.14
$Z/\gamma^* \to \mu\mu$	0	0.48±0.25	0	0.48± 0.25
Jet$\to \tau$	3.83±1.03	3.72±0.88	3.16±0.55	10.71± 1.46
Total	49.32±6.94	42.59±5.85	7.35±0.95	99.27±12.55
Observed	46	36	8	90

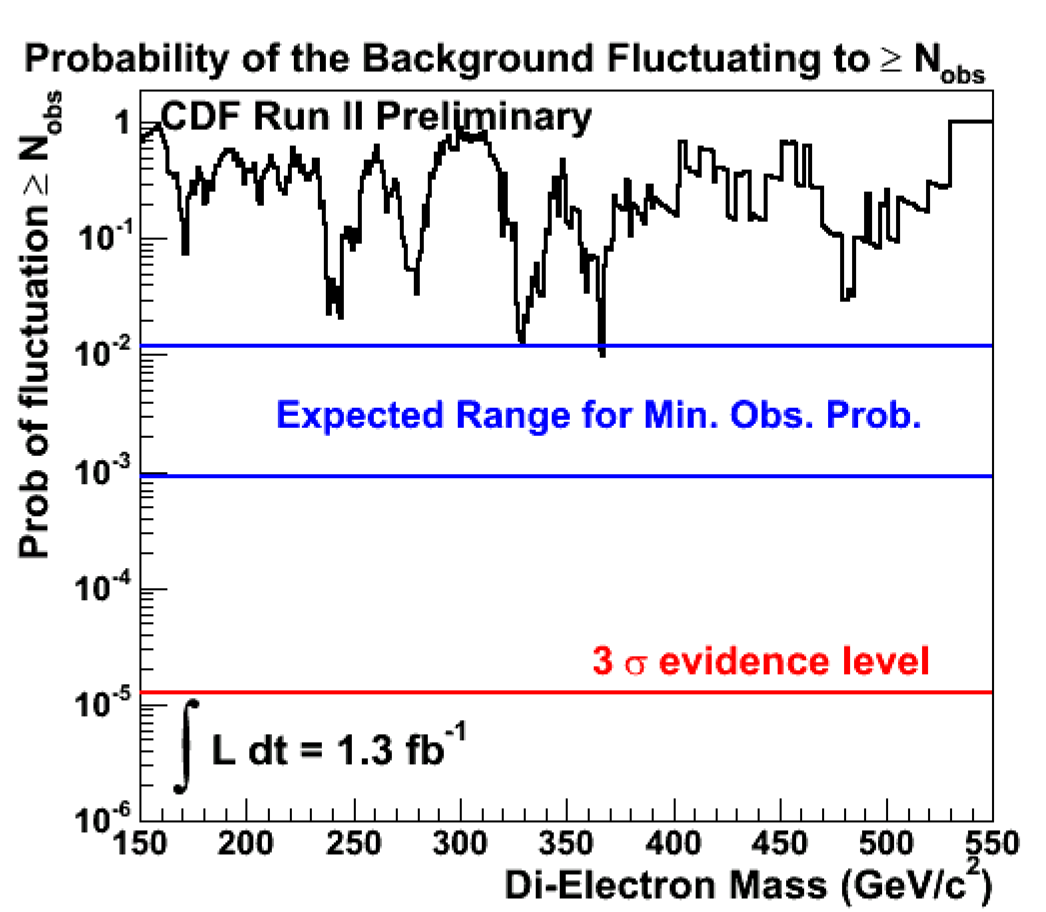
No excess -> Upper limits (95%CL)

$M_{Z'}$ >~ 400 GeV at 95% CL

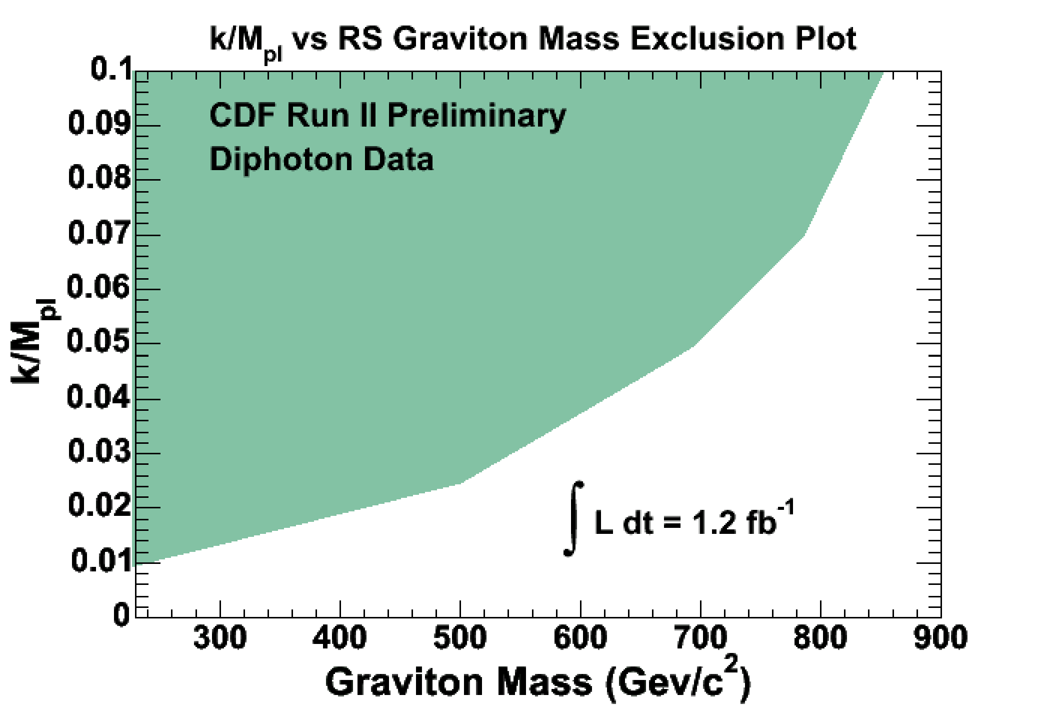


Resonance search in e^+e^- events

- Frequentist model search of excess over SM performed in mass intervall 150-950 GeV.
- Calculate in 1 GeV intervals the probability that the background fluctuates at the observed data level.
- Mass windows : $4.8+0.044*M_{ee}$
- Lowest value $9.7\ 10^{-3}$: M_{ee} ~ 367 GeV : consistent with statistical fluctuation
- Data compatible with SM -> set limits



Search for RS Graviton in $\gamma\gamma$ events



Search for RS Graviton in e^+e^- events

Search for a narrow resonance decaying into 2 electrons in the mass range : 150-950 :

$$q\bar{q}\ (gg) \rightarrow G \rightarrow e^+e^-$$

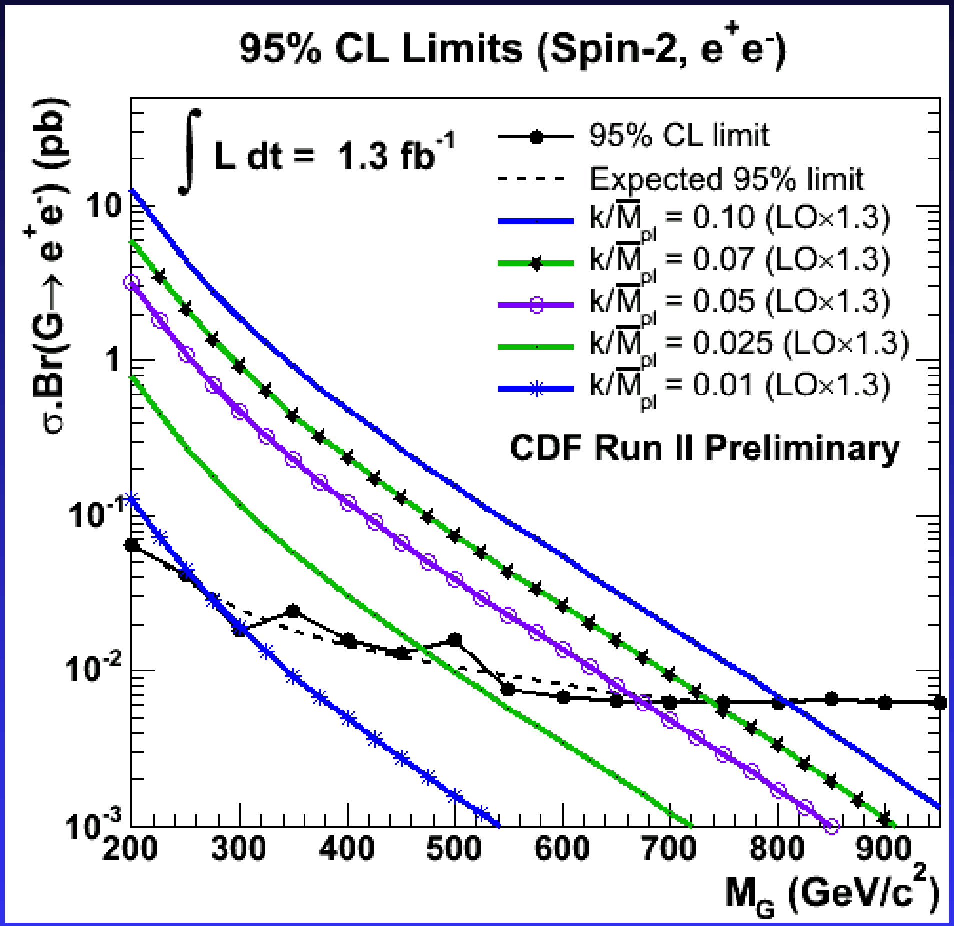
- Same analysis as slides 18-19 interpreted in terms of RS model.
- See slide 30 for final mass limits on M_1 in combined channels with di-photons

(reminder data and cuts)

Data : $\mathcal{L} = 1.3\ fb^{-1}$

Selection :

- 1 hight E_T isolated lepton, with $E_T > 25$ GeV and |eta| < 1.1 (Central Calorimeter)
- 1 hight Et electron pt > 25 GeV with |eta| < 1.1 or 1.2 < |eta| < 3.0 (Central + plug Calorimeter)
- 1 track matching in CC
- 1 photon conversion veto



Backgrounds :

- Drell-Yann : $Z^0/\gamma^* \rightarrow e^+e^-$
- $jet + jet, W \rightarrow e + \upsilon + \gamma/jet, \gamma + \gamma$

MC : PYTHIA, PDF CTEQ5L + HERWIG

Search for RS Graviton in $\gamma\gamma$+e^+e^- events