Recent results on Extra Dimensions and Exotics from the DØ Experiment.

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on behalf of the DØ collaboration

Exotic Signals at Hadron Colliders
Durham, March 31 – April 2, 2004.

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

OUTLINE

INTRODUCTION :

- Presentation of the TeVatron collider and performance
- The D∅ detector for RunII.

RECENT RESULTS :

⇒ LEPTOQUARKS : First Generation searches.

⇒ SUSY: mSugra, GMSB

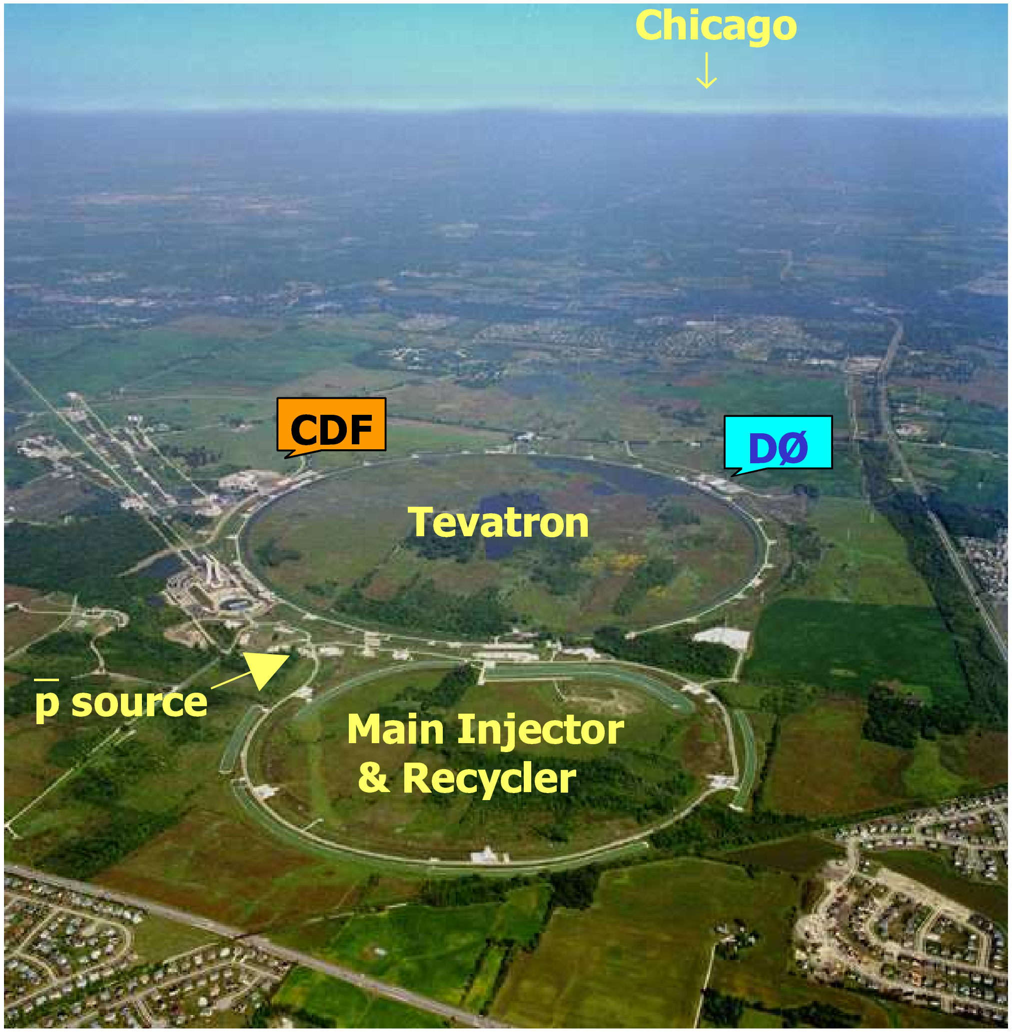
⇒ EXTRA-DIMENSIONS:
- LED in the Monojet topology
- LED in the Dielectron & Diphoton channels
- TeV^{-1} Extra Dimensions in Dielectrons

⇒ Z' : search in the Dielectron channel

CONCLUSIONS

The TeVatron Collider

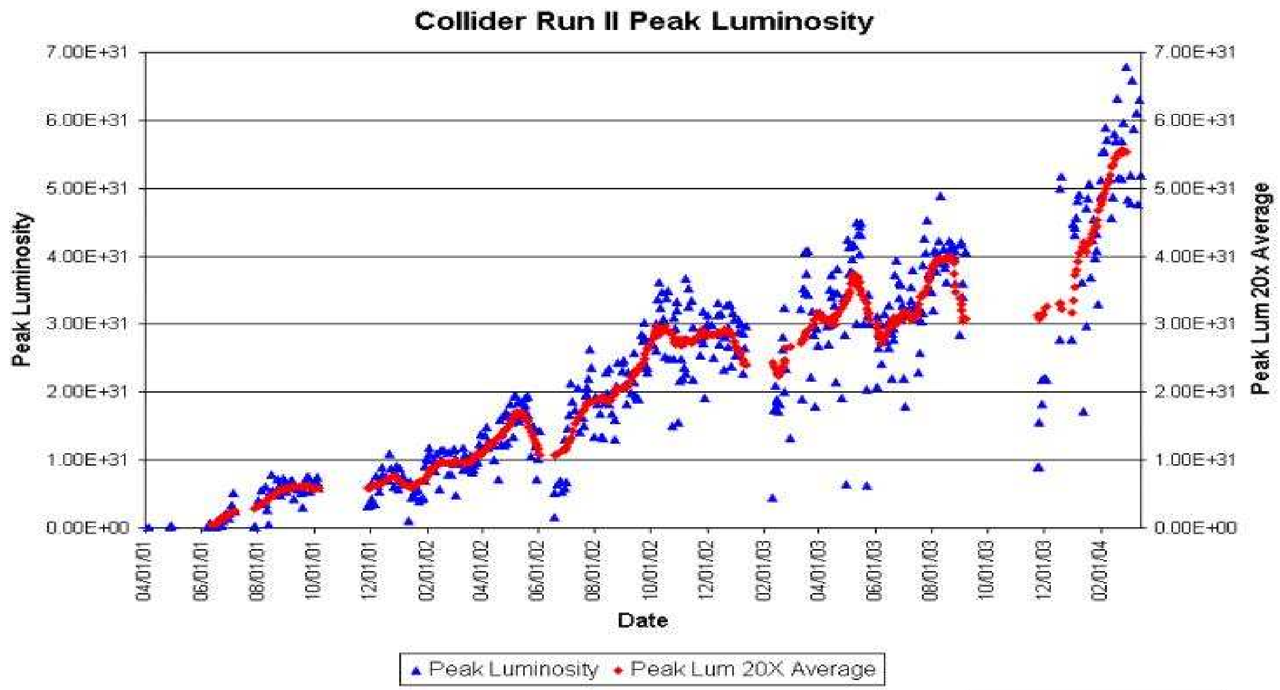
- **New Main Injector : 150 GeV**
  - Store protons, shoot to target for anti-proton production
- **New recycler :**
  - Storage ring for anti- protons
- **Higher energy:**
  - 1.96 TeV vs 1.8 TeV
  - Higher cross-sections for heavy objects (+40% for top)
- **Higher antiproton intensity:**
  - 6x6 → 36x36 bunches (3.5 μs → 396 ns)
  - Higher luminosity
    - ✓ Run I : 2×10^{31} cm^{-2}s^{-1}
    - ✓ Run II : 2×10^{32} cm^{-2}s^{-1}



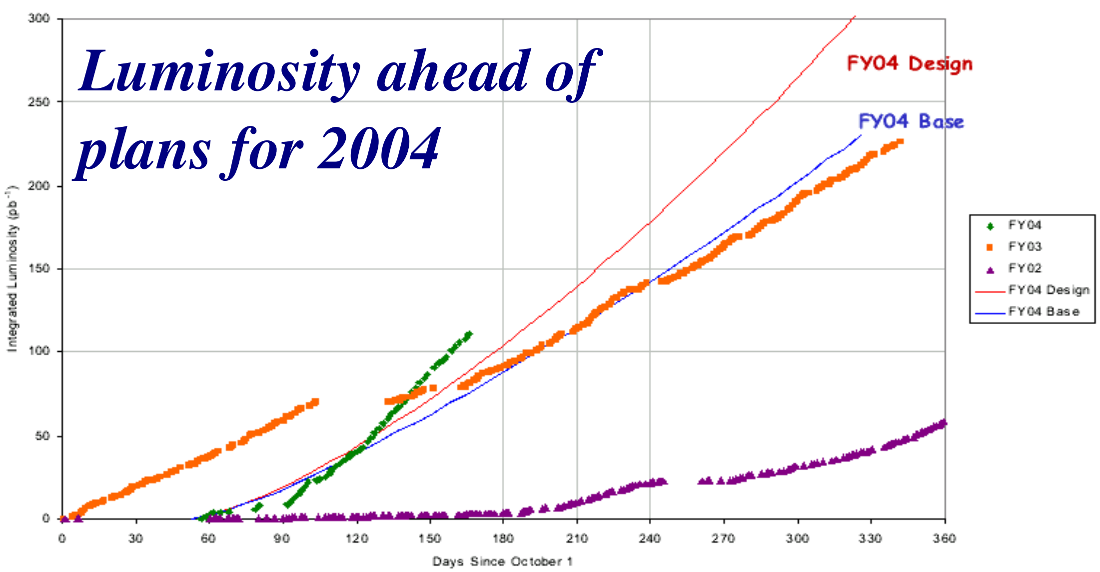
The Recycler has been used recently as a second antiproton storage ring.

The TeVatron Collider

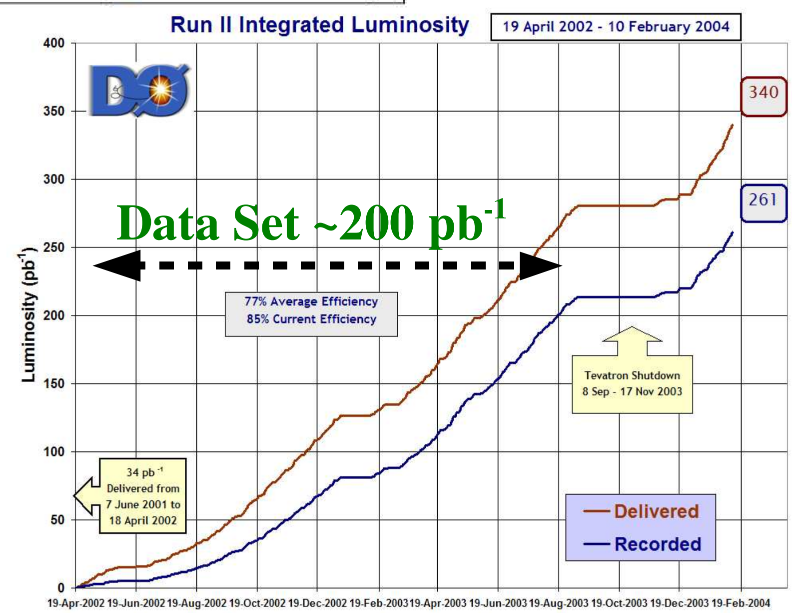
- **Peak Luminosity:**
  - $6 - 7\ 10^{31}\ cm^{-2}\ s^{-1}$
- **Weekly delivered :**
  - Reached $\sim 10\ pb^{-1}$
- **Data taking Efficiency :**
  - 85-90 %
- **Initial goals :**
  - Run II a : $9 \times 10^{31}\ cm^{-2}s^{-1}$
  - Run II b : $2 \times 10^{32}\ cm^{-2}s^{-1}$



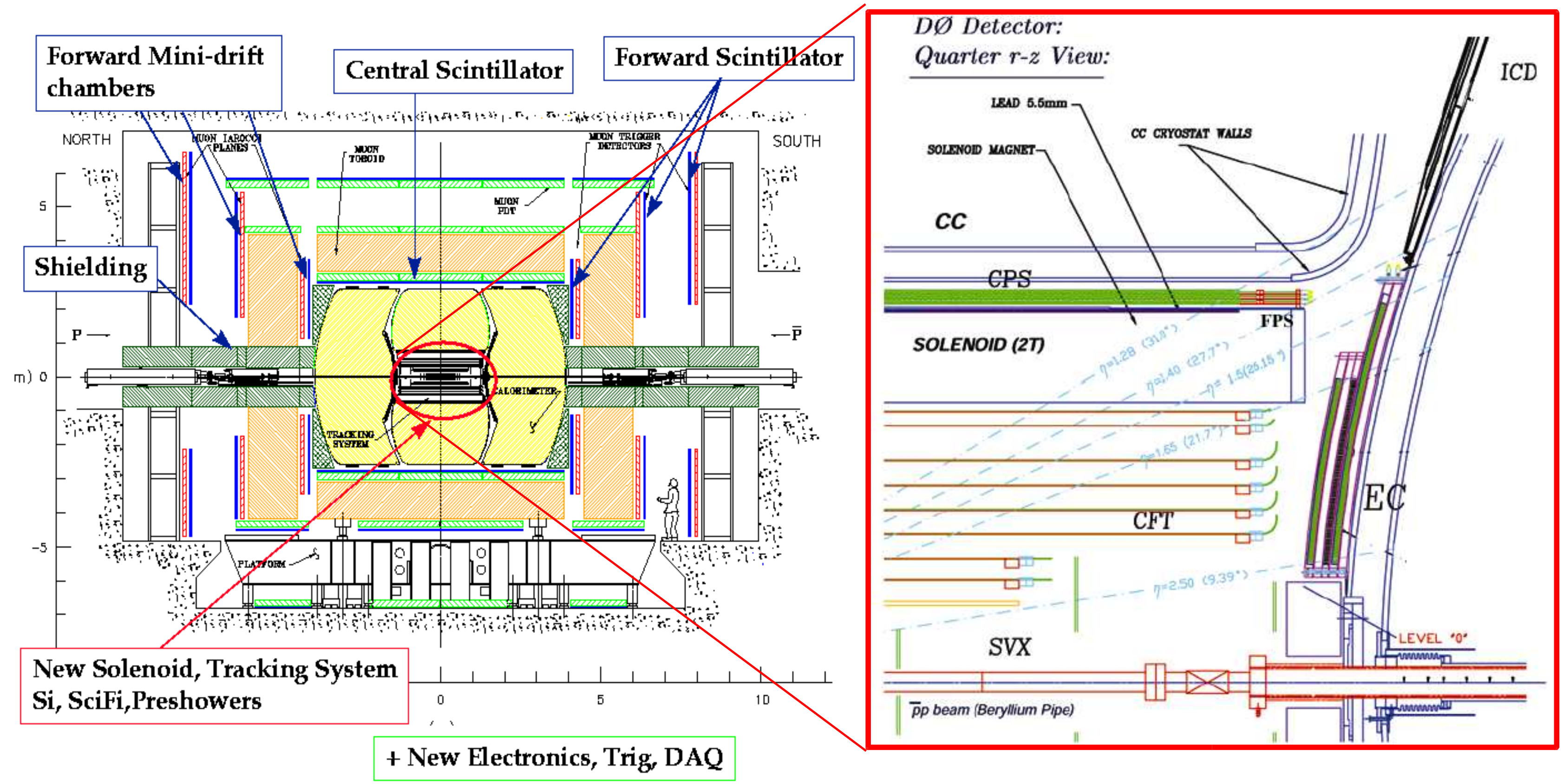
Luminosity ahead of plans for 2004



Data Set ~200 pb^{-1}



The upgraded D∅ Detector



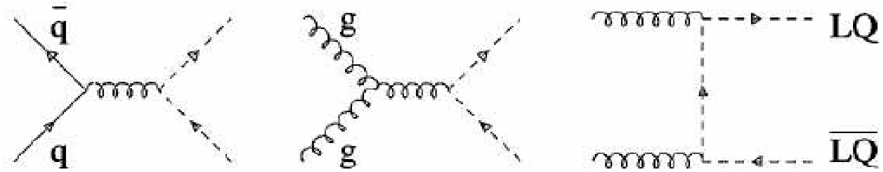
- Solenoid (2T)
- Central tracker
- Silicon vertex detector
- Preshower

- Muon forward chamber (benefits from increased shielding in forward region)
- Calorimeter electronic
- Trigger system
- DAQ system

First Generation Leptoquarks

Leptoquarks of GUT ⇒ Connect the Lepton and Quark Sectors.

Production at the Tevatron :



- *First Generation couples to e (ν_e) and u (d) quarks*
- *β is the Branching ratio of LQ→eq*

⇒ Looking for eνjj and eejj final states in 175 pb^{-1} of RunII Data.

eejj Final State

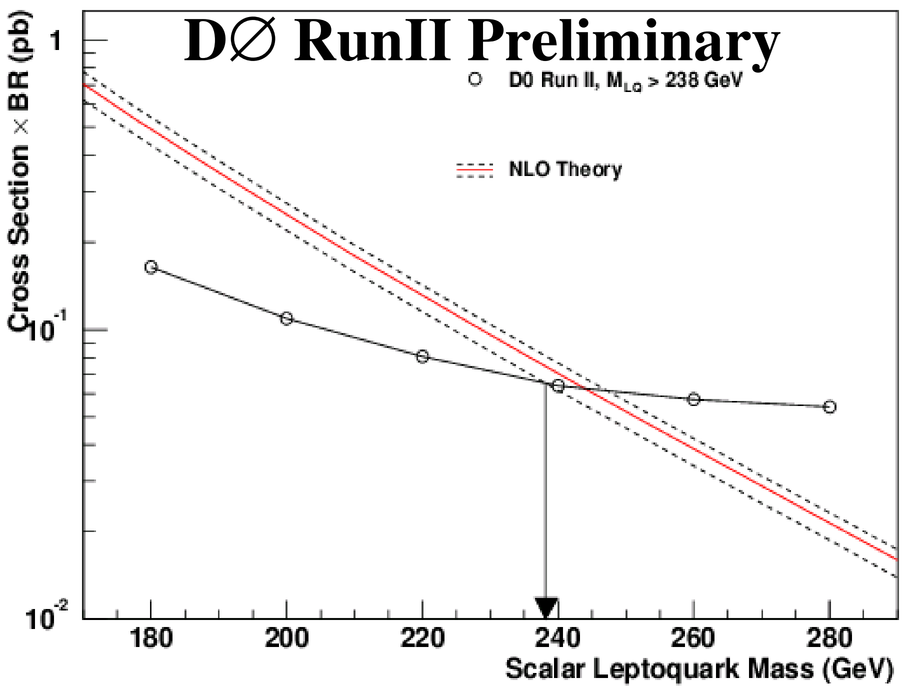
Backgrounds:

- QCD multijet where 2jets fake 2EM
- Drell-Yan/Z
- top

⇒ Optimized cut on ST (scalar sum of PT of all objects): ST > 450 GeV

Data = 0, Total bkg=0.4±0.1

Signal = 3.3±0.4 (for M_{LQ}= 240 GeV)



Limit : M_{LQ} > 238 GeV for β= 1

First Generation Leptoquarks

eνjj Final State

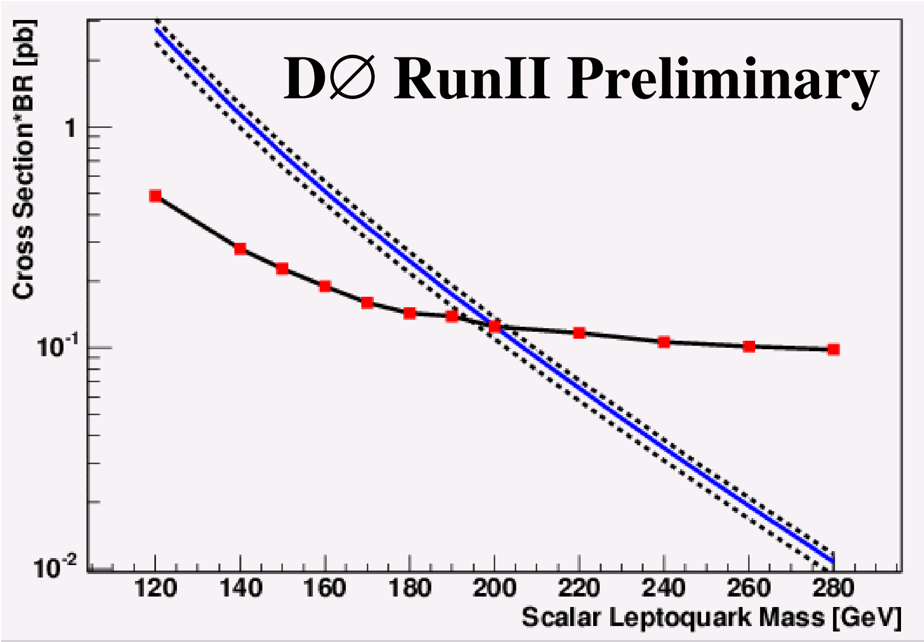
Backgrounds:

- QCD : γ + 2 or 3 jets (jets fake EM)
- SM : W→ eν + 2jets and top.

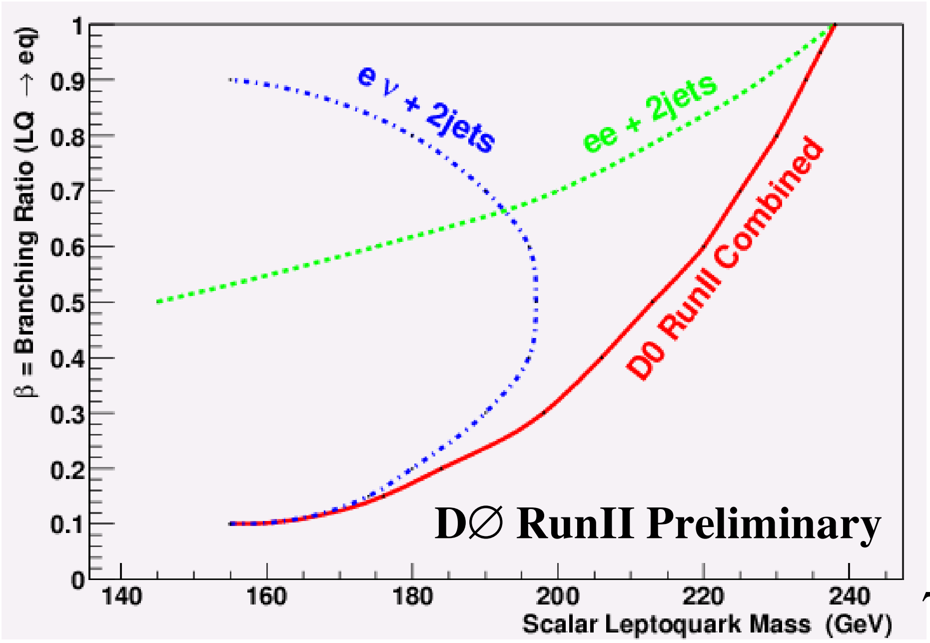
⇒ *Optimized cut : ST > 330 GeV (including Missing ET in the sum)*

Data = 2, Total bkg=4.7±0.9

Limit : M_{LQ} > 194 GeV for β= 0.5



Combined Results ⇒



Searches for SUSY signals

Supersymmetry is a symmetry which transforms bosons ⇔ fermions

It has been introduced to address several problems of the standard model: hierarchy, fine-tuning, gauge unification,...

SUSY:

⇒ Every particle of SM has a corresponding SUSY partner.

R-Parity: R=+1 for SM particles and R=-1 for SUSY particles.

If R-Parity is conserved ⇒ The lightest SUSY particle (LSP) is stable

Breaking of SUSY: As we do not observe SUSY particles, this symmetry must be broken at some point:

- Via gravity e.g. Minimal SUGRA model (LSP is the neutralino).

- Via gauge interactions : GMSB SUSY (Gravitino is the LSP).

SUSY mSUGRA: Chargino & Neutralino

Susy Search in the Tri-Lepton final state:

⇒ *"Golden Channel" → tri-lepton or 2 same sign leptons & very clean final state*

⇒ *mSUGRA :* $M\chi_1^+ \sim M\chi_2^o \sim 2\ M_{LSP}$

→ Low slepton mass (Good leptonic BR)

⇒ *But - Low Chargino Mass → soft leptons*

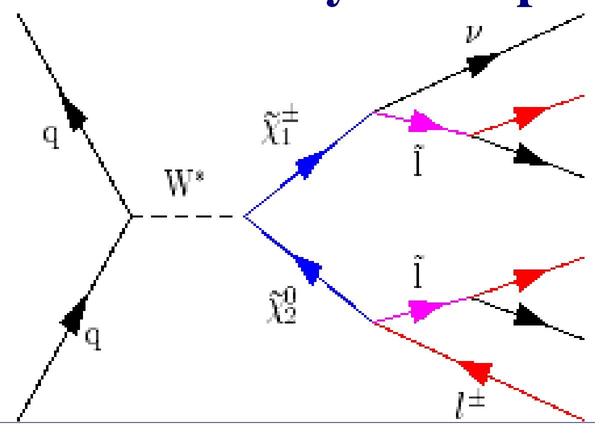
- small cross-section.

Points for mSUGRA:

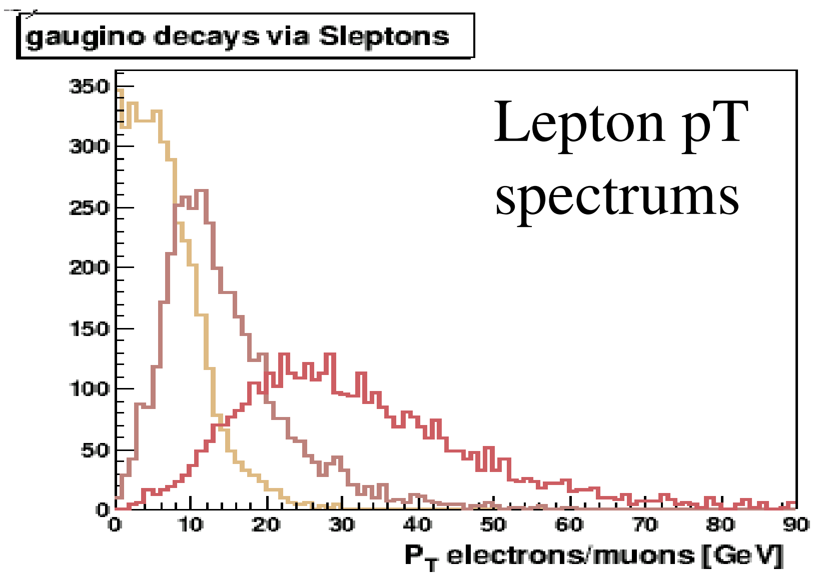
Around LEP limit

- **m_o(72-88)**
- **$m_{1/2}$ (165-185)**
- **tanβ = 3**
- **μ >0**
- **Ao=0**

Cascades decay via sleptons:



ν and χ_1^o escape detections → Missing ET

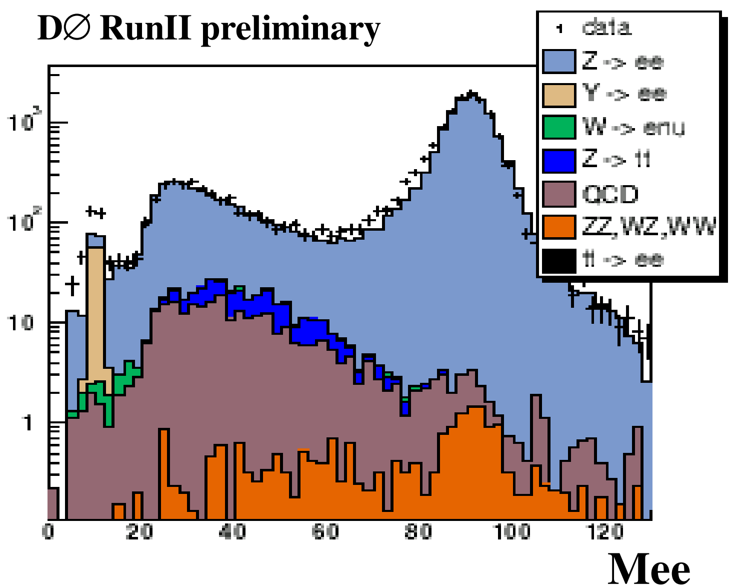


Strategy : Combine the eel, μel and same sign μμ analyses

SUSY mSUGRA: Chargino & Neutralino

⇒ ***eel final state*** **:** ***Using 174 pb^{-1} of RunII data***

Backgrounds : Z⟶ ee and Drell-Yan
And multijet QCD (from data)



On top of Anti-QCD, Anti-DY/Z cuts

⇒ Requiring a the 3rd track

- pT > 3 GeV
- ΔR (electron-track) > 0.4

+ Optimized cut on
track-pT x Missing ET > 250 GeV

Data	⇒ 1 Event
Bkg	⇒ 0.3 Events (mostly Z→ee,WW→eνeν)
Signal	⇒ Between 1-2 events expected

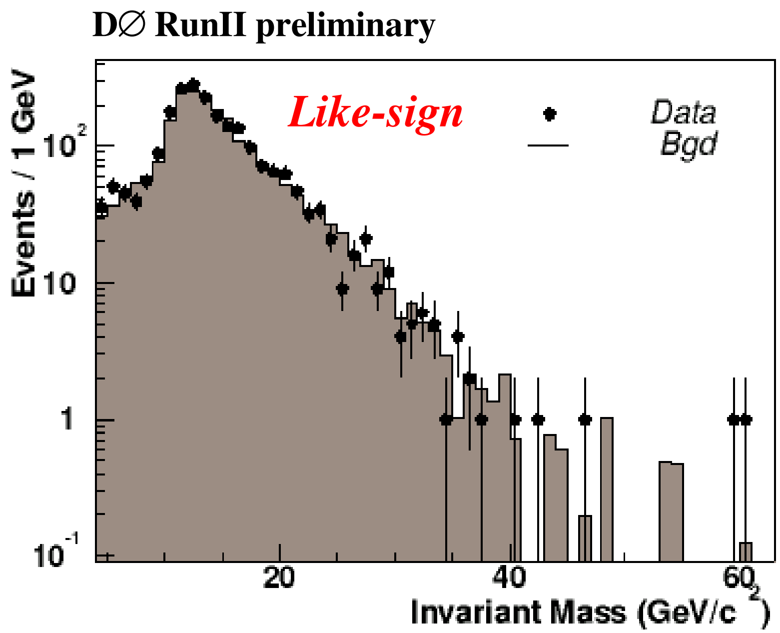
SUSY mSUGRA: Chargino & Neutralino

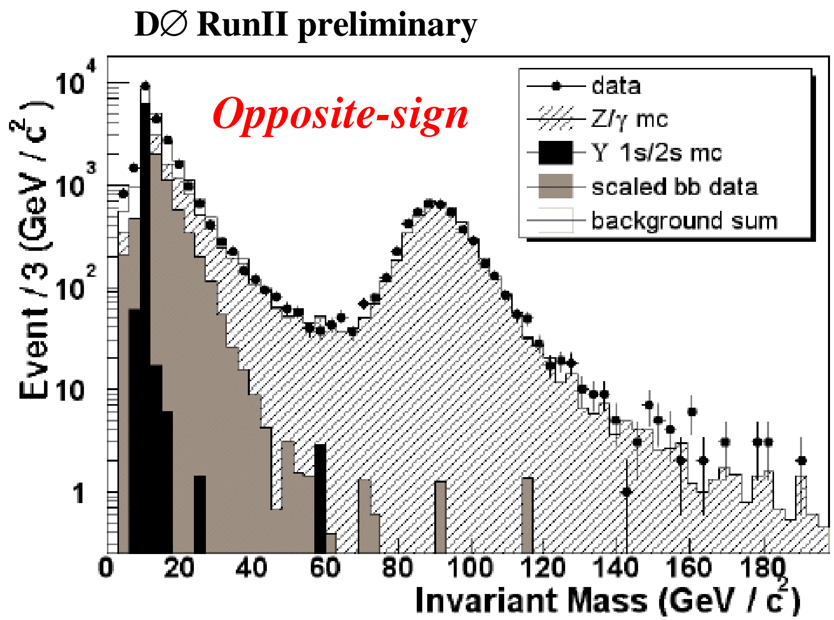
⇒ ***2 like-sign Muons*: *Using 147 pb^{-1} of RunII data***

→ Improved Signal acceptance w.r.t. requiring 3 muons.

→ Same Sign Muons reduces dimuon DY and resonances.

Physics backgrounds : bb/cc dominant





Data ⇒ 1 event

Bkg ⇒ *WZ(0.07)+bb(0.04)+ZZ(0.02) = 0.13±0.04*

Signal ⇒ *Between 0.2 and 0.4 events expected.*

SUSY mSUGRA: Chargino & Neutralino

⇒ ***eμ+l final State:*** ***Using 158 pb^{-1} of RunII data***

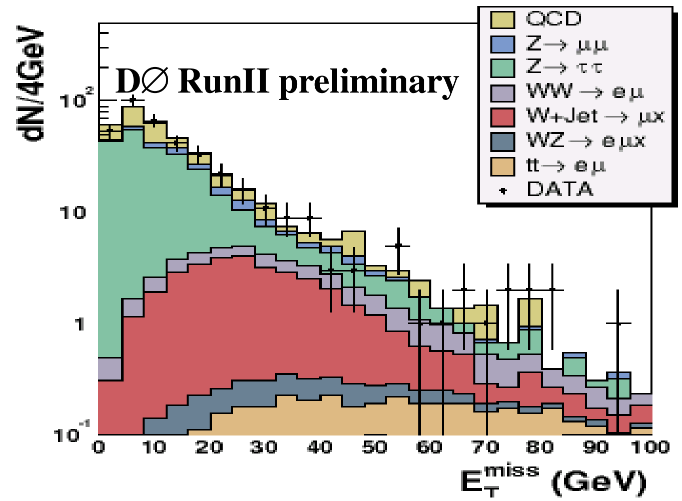
Requiring a 3rd Track : pT > 3GeV & isolated

→ further reduce the bkg.

Data ⇒ *0 event*

Bkg ⇒ 0.54±0.24

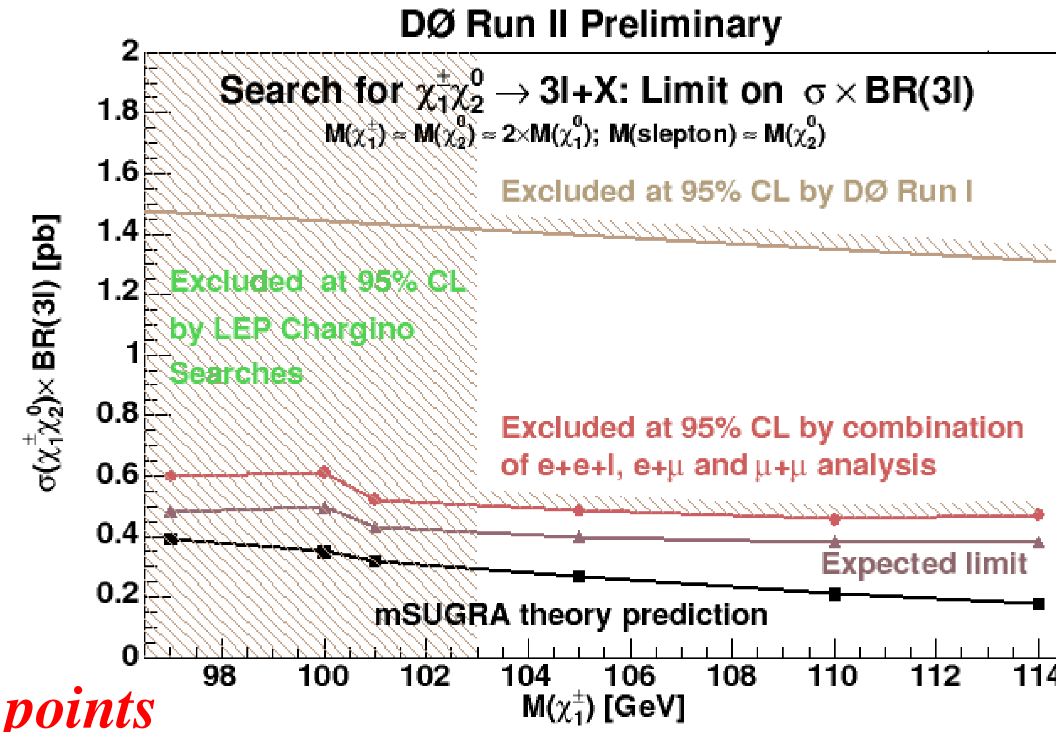
Signal ⇒ *0.6 to 0.9 events expected.*



Combining results (3 analyses)

⇒ **No evidence of SUSY**

⇒ Cross section limit.



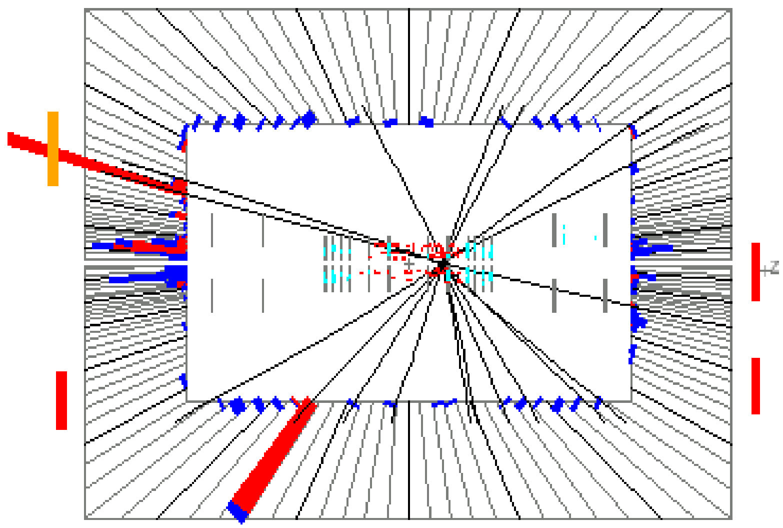
Chargino masses probed beyond LEP reach

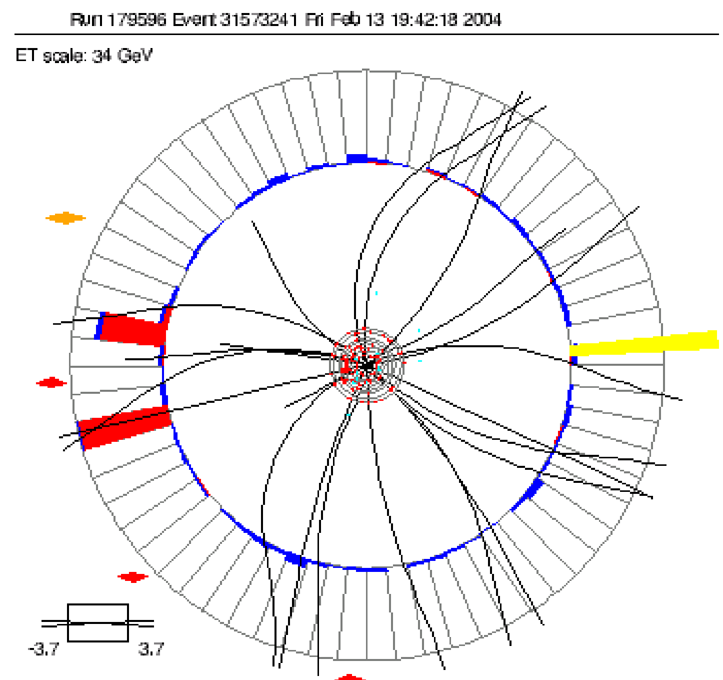
New limit more stringent than the D∅ RunI result.

We're about to exclude mSUGRA points

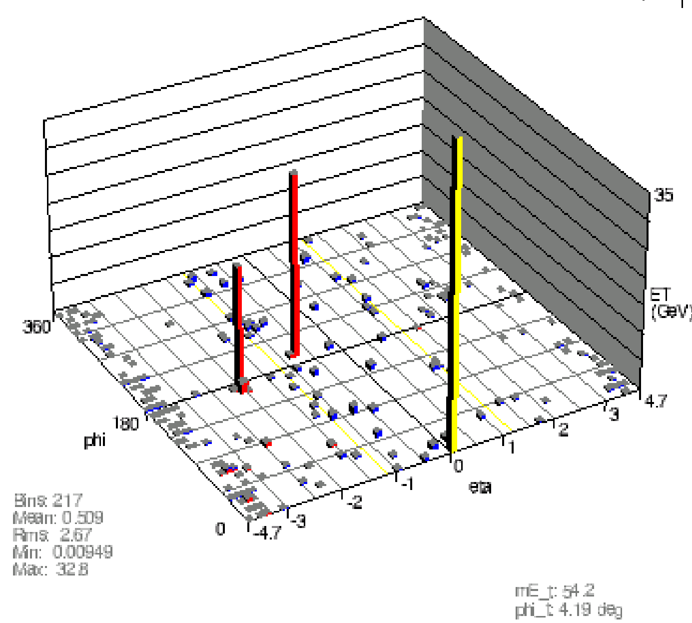
SUSY mSUGRA: Chargino & Neutralino

The selected candidate in eel final state





2 same sign electrons
E1=33GeV
E2=26GeV
Inv mass = 39.5 GeV
3rd Track Pt = 9 GeV
Missing ET = 52 GeV



SUSY mSUGRA: Squarks and Gluinos

⇒ **Acoplanar jet topology:**

⇒ ***Analysis using 85^{-1}pb of data recorded with a trigger specifically designed for Jets + Missing Et topologies.***

→ 1: ***Msquarks < Mgluinos : squarks*** $\rightarrow q\chi_1^o$ ***(Acoplanar jets + Missing ET)***

→ 2: ***Msquarks > Mgluinos : gluino*** $\rightarrow qq\chi_1^o$ ***(Multijets + Missing ET)***

⇒ ***1 is considered here*** → ***Within mSUGRA*** $m_0 \ll m_{1/2}$

Production processes: qq or gg → q̃q̃ or g̃g̃; qq → q̃q̃ and qg → q̃g̃

Investigating in Jets + Missing ET topologies :

⇒ It is a very challenging channel to look for new physics at hadron colliders:

→ QCD background is overwhelming **(mismeasured jet ET and σ many order of magnitude)**

→ Any intrumental problem in the calorimeter ultimately ends up creating fake missing ET.

→ Cosmic muon showering in the calorimeter.

→ Fake Missing ET from misvertexing.

⇒ *A well controlled sample has to be put together prior to perform the analysis.*

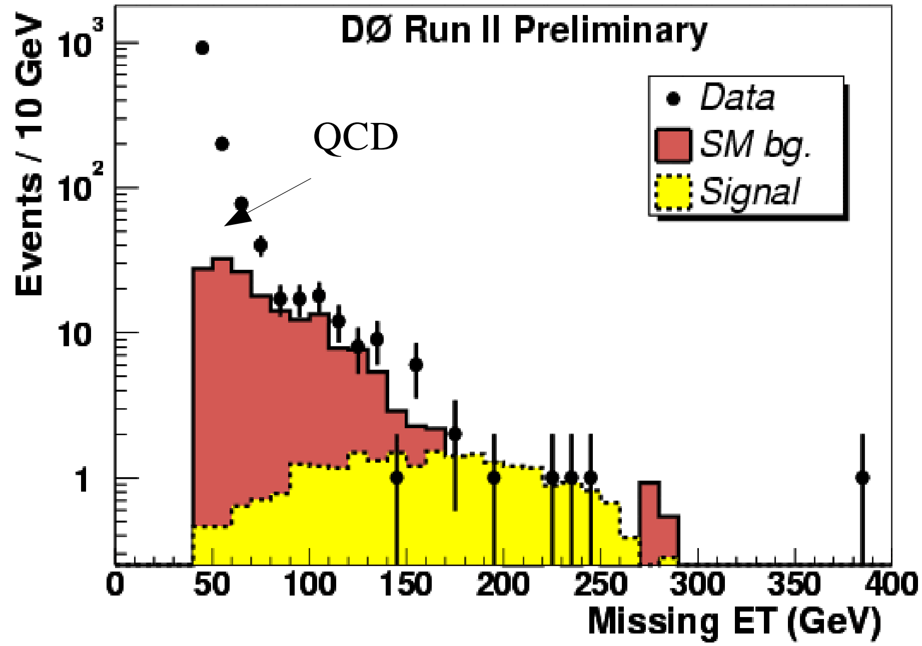
SUSY mSUGRA: Squarks and Gluinos

⇒ *improved tracking in RunII largely reduces QCD and cosmic backgrounds.*

<u>SM Backgrounds:</u> Z/W + jets

Z* $\rightarrow \nu\nu$ + *jets is dominant.

<u>Signal :</u> ***efficiency 2%-7%***



⇒ **for m_0=25 and $m_{1/2}$ = 130**

Optimized cuts on Missing ET and HT=Σ|PTjet| :

MET > 175 GeV and HT > 275 GeV: QCD background is negligible here

⇒ **Data = 4 events, Bkg = 2.7 ± 0.95, Signal = 8.4±0.5**

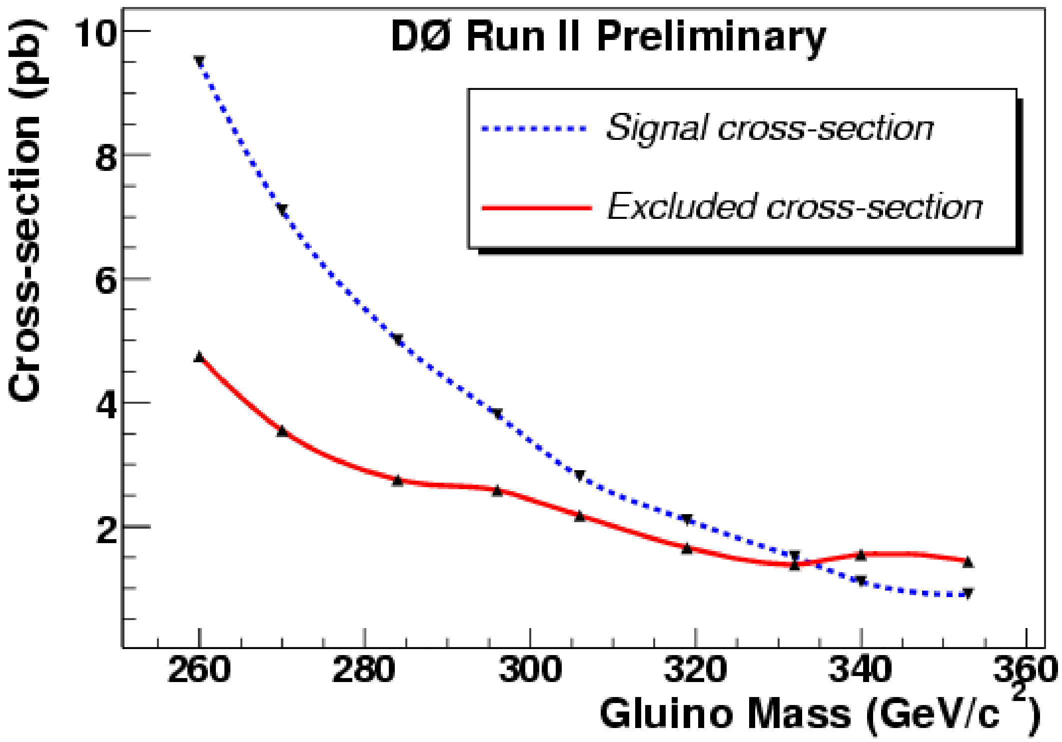
SUSY mSUGRA: Squarks and Gluinos

⇒ Limit on the gluino mass (at low m0) :

Scan in mSUGRA:

m_0=25, tanβ =3, A_0=0, μ<0

→ $m_{1/2}$ = 100-140



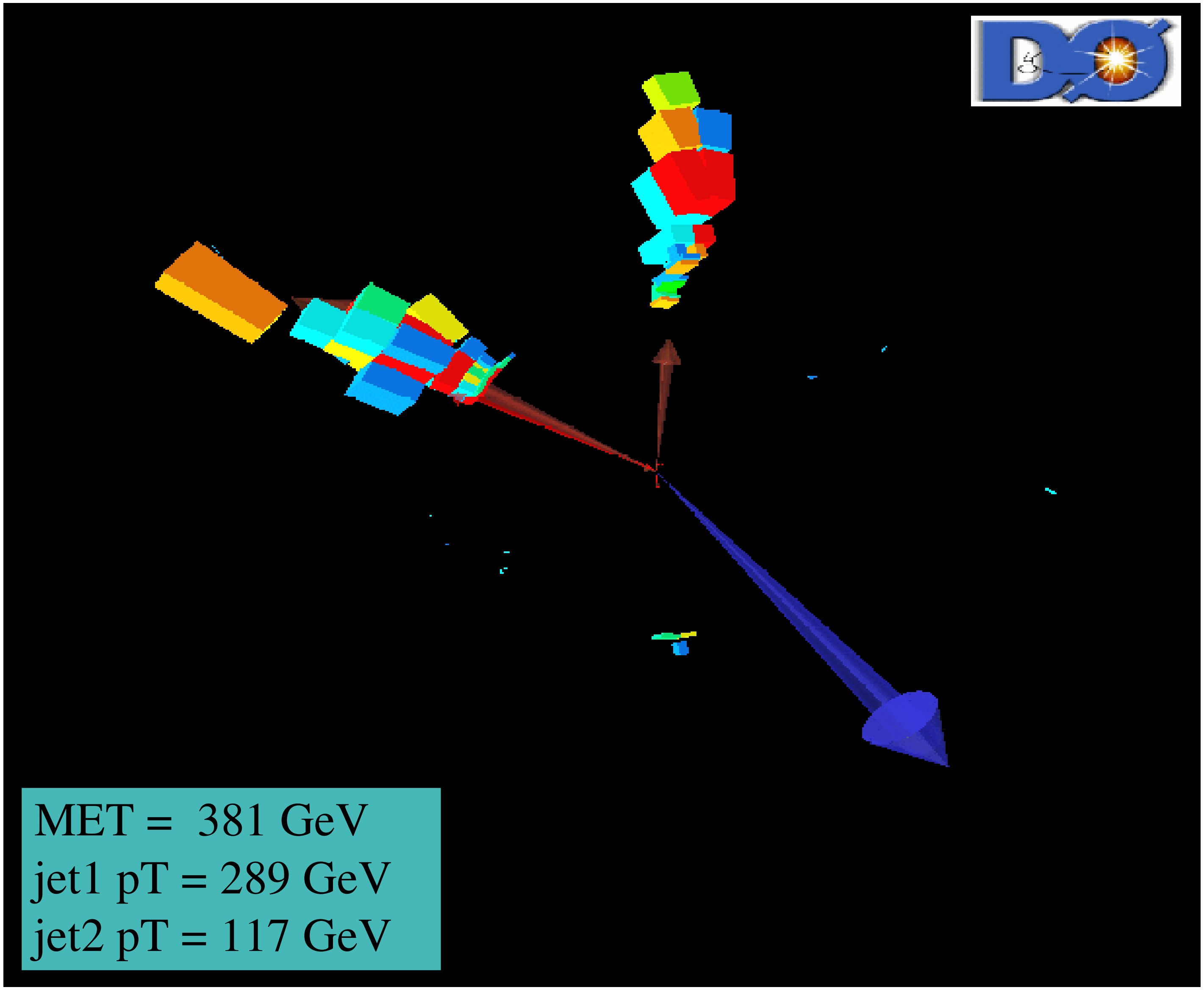
For Msquark = 292 GeV: Mgluino > 333 GeV @95% CL

(For the same Msquark, the RunI limit was ~ 310GeV)

This is the most constraining limit on gluino mass to date

SUSY mSUGRA: Squarks and Gluinos

Largest Missing ET candidate



SUSY GMSB

GMSB Models with gravitino LSP, neutralino NLSP

Phenomenology : $\chi \rightarrow \gamma + G$

$\Rightarrow$ ***Topology : 2 γ and Missing ET in 185pb^{-1} of RunII data***

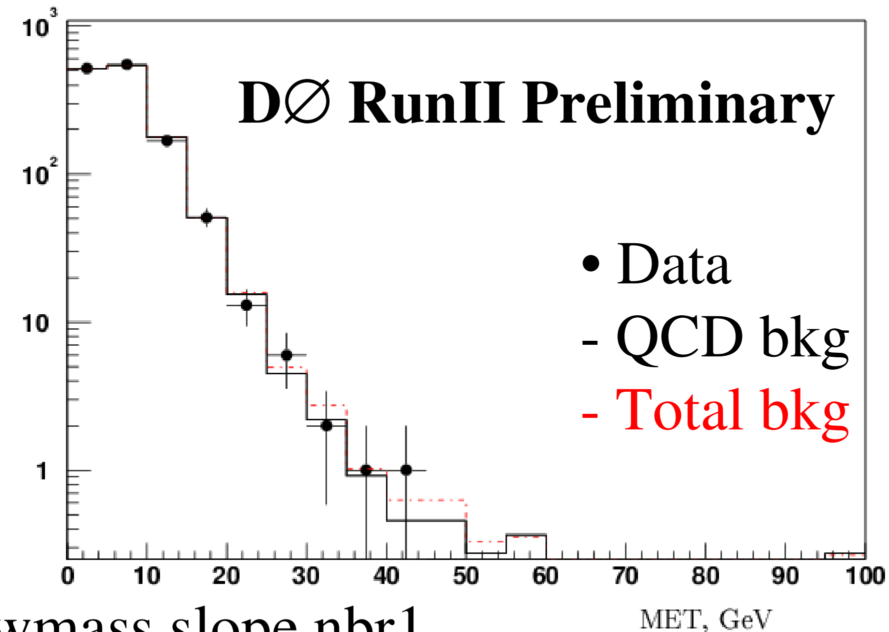
Backgrounds :

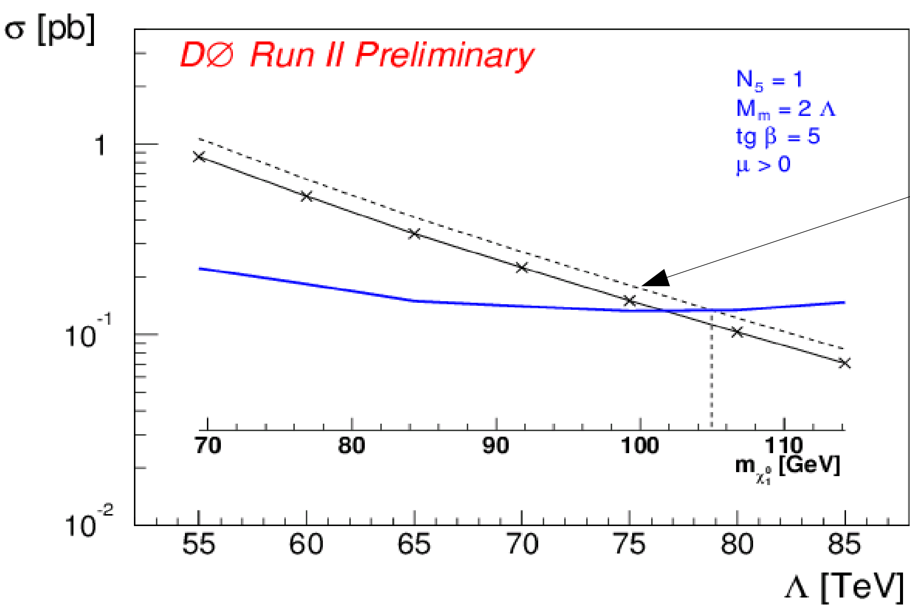
$\rightarrow$ ***QCD w/ direct γ or misidentified jets***

$\rightarrow$ ***DY w/ both e misidentified as γ***

$\Rightarrow$ Optimal cut on Missing ET at 40 GeV

Data = 1 Bkg = 2.5±0.5





Snowmass slope nbr1

--- is with K-factor

$\Rightarrow$ $M\chi_1^0$ > 105 GeV and $M\chi_1^+$ > 180 GeV

Most constraining limits to date

Extra Dimensions

One outcome of introducing Extra Dimensions (ED)

⇒ It can cure the hierarchy problem of the Standard Model:

2 fundamental scales, Mw~100GeV (electroweak) and

$Mpl = G_N^{-1/2} \sim 10^{19}$ GeV where gravity becomes as strong as other forces.

Tow models are considered:

- **Arkani-Hamed, Dimopoulos and Dvali (ADD)**
- **Diedes, Dudas and Gergetha (DDG)**

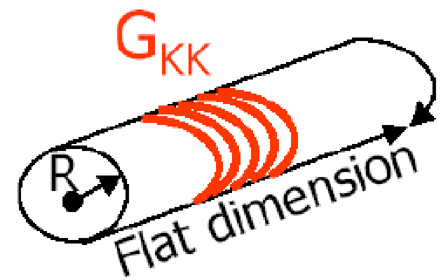
Large Extra Dimensions searches

ADD model:

The SM is confined on a 3-brane and gravity propagates in the ED.

By introducing Large Extra Dimensions, ***Mpl*** is brought to the TeV range.

In a (3+n)-dimentional space with n extra dimensions compactified on a n-torus with radii R:



The expression of the Gravitational potential using the a (3+n)-dim Gauss' law gives :

$$V = \frac{m}{(M_{\rm Pl}^{[3+n]})^{n+2} r^{n+1}}, \quad \text{If r << R}$$

$$V = \frac{m}{(M_{\rm Pl}^{[3+n]})^{n+2} R^n\, r}, \quad \text{If r >> R}$$

$\Rightarrow$

$$M_{\rm Pl}^2 = (M_{\rm Pl}^{[3+n]})^{n+2} R^n \equiv M_S^{n+2} R^n,$$

Where

$$R \sim \frac{1}{M_S} (M_{\rm Pl}/M_S)^{2/n}.$$

$\Rightarrow$ with M_s being the Fundamental Planck Scale

For M_s ~ TeV, n=1 $\rightarrow$ R ~ 10^8 km (size of solar system!) $\Rightarrow$ Ruled out.

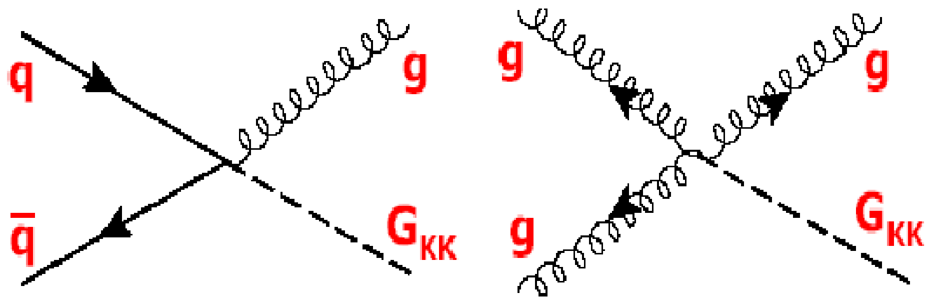
$\Rightarrow$ The minimum number of Large Extra Dimension is 2.

The high-energy colliders are the only sensitive probe for n≥3

Large Extra Dimensions searches

<u>DIRECT SEARCH for LED :</u>

→ ***Production of a graviton recoiling against a gauge boson or a quark:***



The Graviton escapes in the ED and is not detected.

⇒ ***Produces monojet/monophoton final states***

A Graviton in the extra dimensions is equivalent to an infinite tower of KK modes ⇒ gives sizeable cross sections in spite of the small coupling

Extra Dimensions : Monojet

DØ RunI studies: ⇒ **for n_D=7, M_D > 0.62 TeV** (~80 pb^{-1}) PRL. **90** (2003) 251802

RunII Analysis :

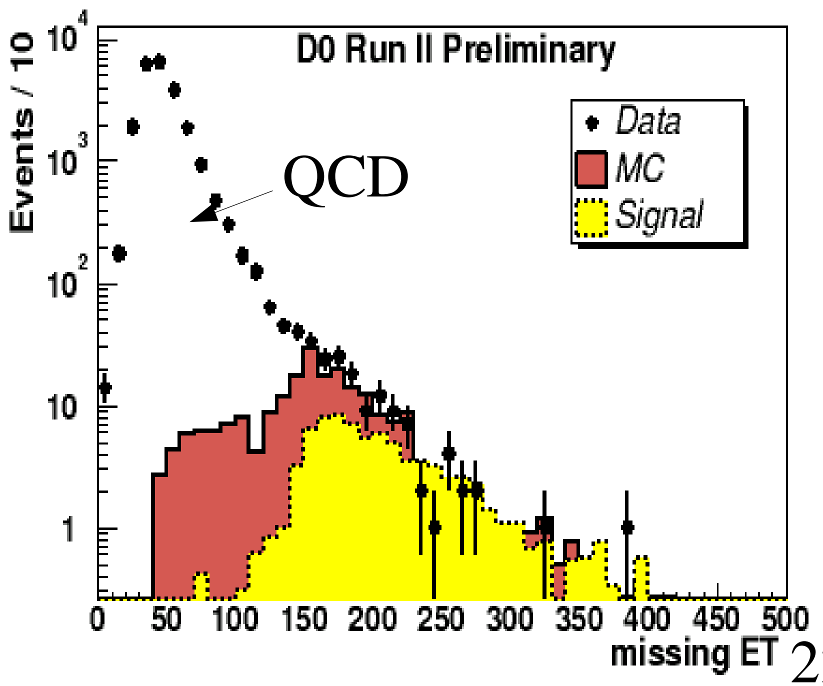
⇒ ***follows the same line as the search for squarks and gluinos in the Jets + Missing Et topologies :***

The same data set and backgrounds are used.

Signal : qq→Gg, qg→Gq and gg→Gg

⇒ ***Typical Signal Efficiency*** ~ 5%

for n_D=4-7 and M_D=0.6-0.8



Extra Dimensions : Monojet

⇒ ***Background*** ⇒ 100.2 ± 9.7 +/– ***syst***

⇒ ***DATA*** ⇒ 63 (5.2% ***efficiency***)

Jet Energy Scale uncertainties:

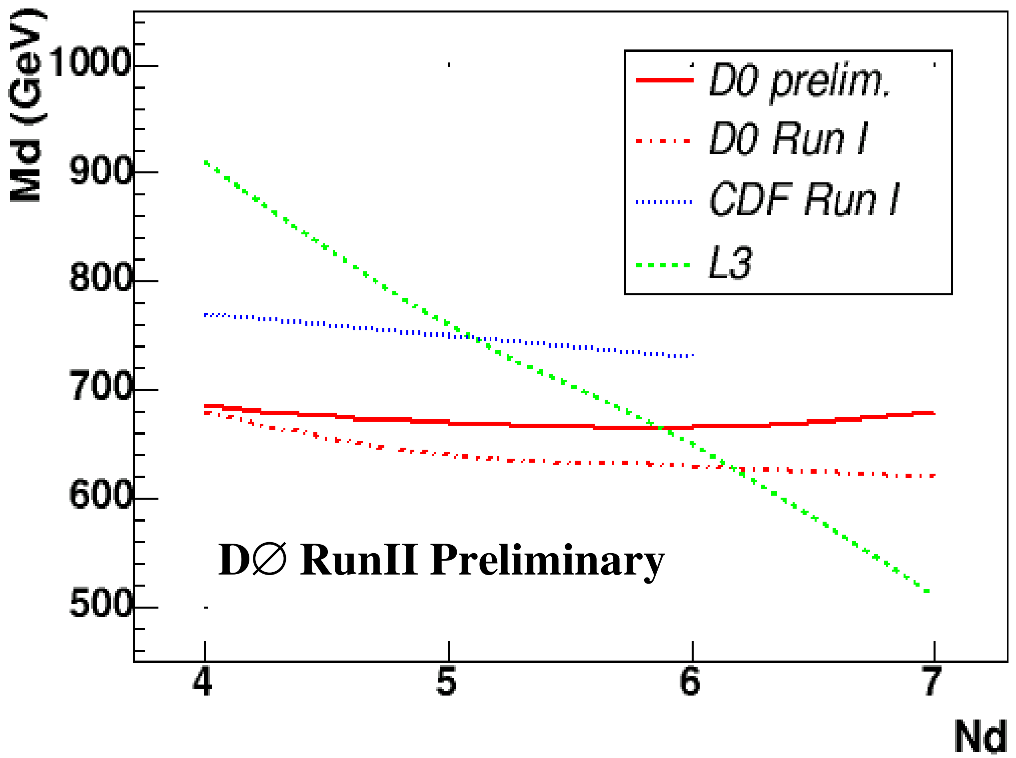
Background = +50% -30%.

Signal Efficiency = 20%

Expected and predicted agree within syst errors.

Lower Limits on M_D :

n_D	DØ RII	CDF RI	LEP
4	0.68	0.77	0.91
5	0.67		0.76
6	0.66	0.73	0.65
7	0.68		0.51

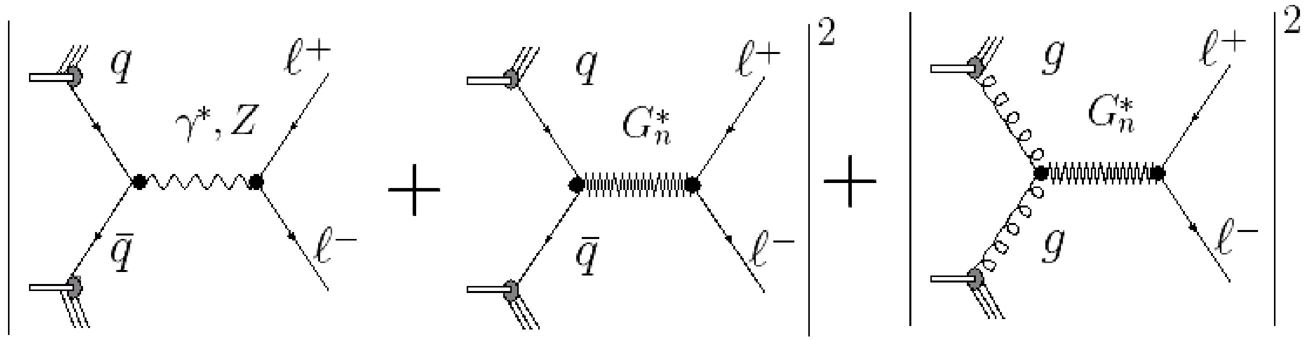


⇒ ***The JES uncertainties are very conservative. Once settled, this analysis will be competitive.***

Large Extra Dimensions searches

INDIRECT SEARCH for LED :

→ *Look for the effects of virtual gravitons in the fermion or boson pair production:*



Formalisms :

$$\frac{d^2\sigma}{dM\,d\cos\theta^*} = f_{\rm SM} + f_{\rm int}\eta_G + f_{\rm KK}\eta_G^2$$

With $\eta_G = \mathcal{F}/M_S^4$

Dimension of TeV^{-4}

- $f_{\rm SM}$ → SM term
- $f_{\rm int}\eta_G$ → Interference terms
- $f_{\rm KK}\eta_G^2$ → G_{KK} Terms

$$\mathcal{F} = 1, \text{ (GRW [7]);}$$

$$\mathcal{F} = \begin{cases} \log\left(\frac{M_S^2}{M^2}\right), & n = 2 \\ \frac{2}{n-2}, & n > 2 \end{cases}, \text{ (HLZ [8]);}$$

$$\mathcal{F} = \frac{2\lambda}{\pi} = \pm\frac{2}{\pi}, \text{ (Hewett [9]).}$$

Note : - M invariant mass of diEM system.
- cosθ* cosine of scattering angle in c.o.m

Extra Dimensions : dielectron & diphoton channels

⇒ Search for LED in Dielectron & Diphoton Channel :

⇒ ***It is a very powerful way to search for LED at colliders since it is a very clean final state considering the hadronic environment.***

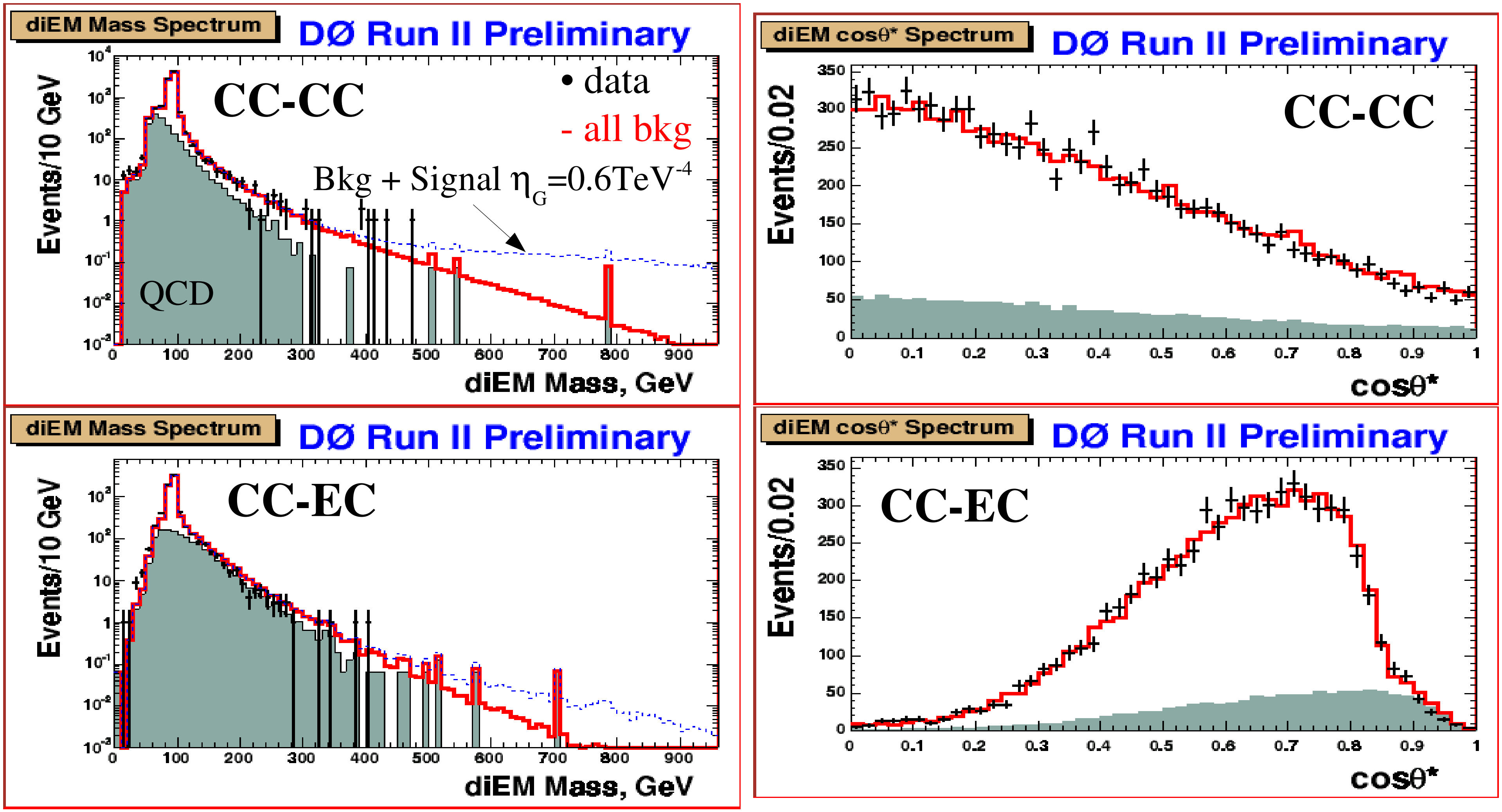
→ Looking for DiEM objects in the calorimeter

→ ***Analysis performed with ~200pb^{-1} of RunII data.***

Combining di-ele and di-γ ⇒ Increase the sensitivity.
(di-photon dominates the sensitivity)

Backgrounds : → ***Drell-Yan*** production and direct diphoton production
→ ***Instrumental background*** : dijet and direct photon events where jets misidentified as EM objects.

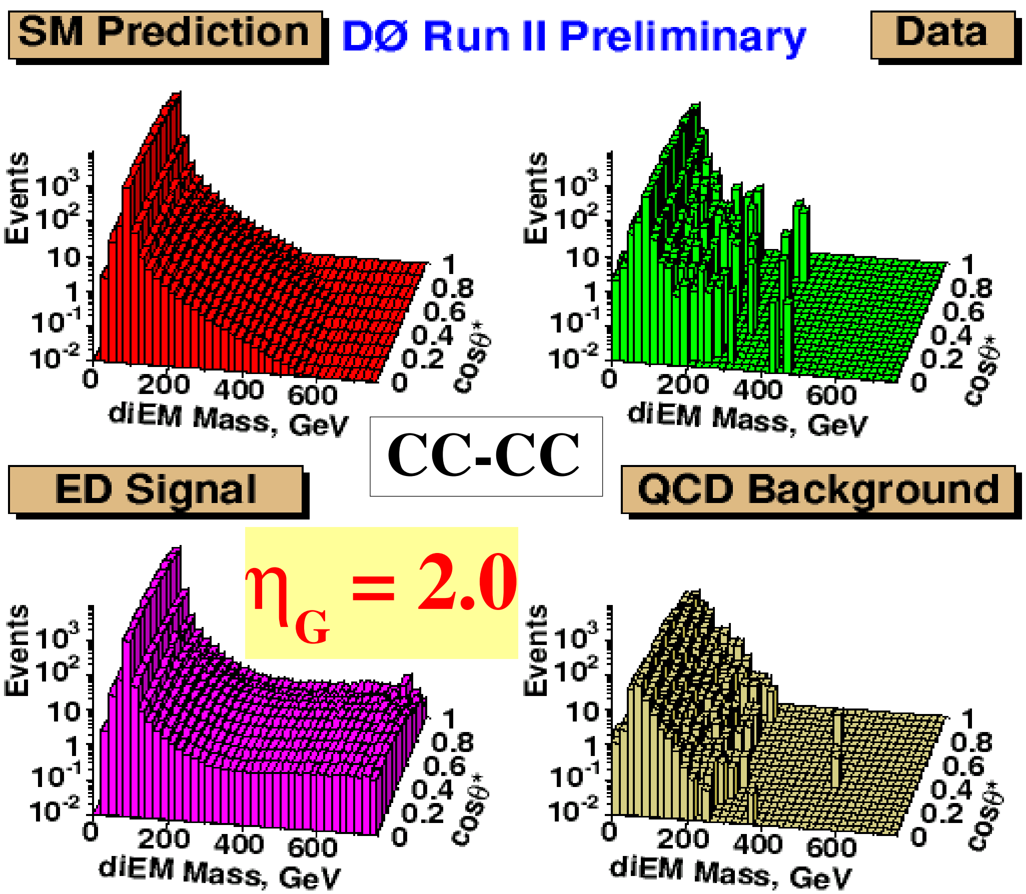
Extra Dimensions : dielectron & diphoton channels



⇒ Agreement between the data and the background.

Extra Dimensions : dielectron & diphoton channels

Extracting Limits :



The data agree well with the sum of DY & Bkg sources:

→ ***No Extra Dimension contribution***

⇒ ***Setting Limits on*** η_G

Systematics :

→ Background = 20% for high mass (stat+sys on intrumental bkg)

→ Signal : (K-Factor = 1.3)

Source of Systematics	Uncertainty
K-Factor	10.00%
Choice of pdf	5.00%
Luminosity x Efficiency	2.00%
ET dependence of Eff	5.00%
Total	12.00%

Extra Dimensions : dielectron & diphoton channels

⇒ By combining CC-CC and CC-EC topologies :

η_G < 0.292 TeV^{-4} (GRW convention) ⇒ M_s > 1.36 TeV @95%CL

(cf 0.46 TeV^{-4} @ Run I)

⇒ ***Limits on η_G → Limits on the fundamental Planck Scale M_S***

RunI and Run II combined limits on Ms :

GRW [7]	HLZ [8]						Hewett [9]
	n=2	n=3	n=4	n=5	n=6	n=7	$\lambda = +1$
1.43	1.67	1.70	1.43	1.29	1.20	1.14	1.28

η_G < 0.24 TeV^{-4} (GRW convention)

M_s > 1.43 TeV @95%CL

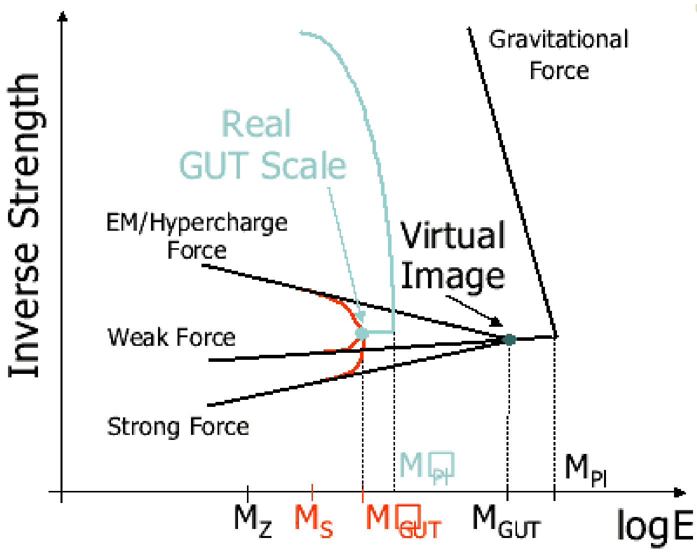
→ Most stringent limit to date

TeV^{-1} Extra Dimensions : Dielectron Channel

Longitudinal Extra Dimensions :

The same dataset is used to test the TeV^{-1} longitudinal Extra Dimensions suggested by Dienes, Dudas and Gherghetta.

With this model ⇒ Low energy unification of gauge forces could be achieved.



Dienes, Dudas, Ghergetta
[Nucl. Phys. **B537**, 47 (1999)]

Phenomenology: SM gauge bosons can propagate in these extra dimensions.

⇒ introduces γ_{KK} W_{KK} Z_{KK} g_{KK} resonances.

Direct Probes → *High Energy machine capable of exciting g/Z/W/γ KK modes.*

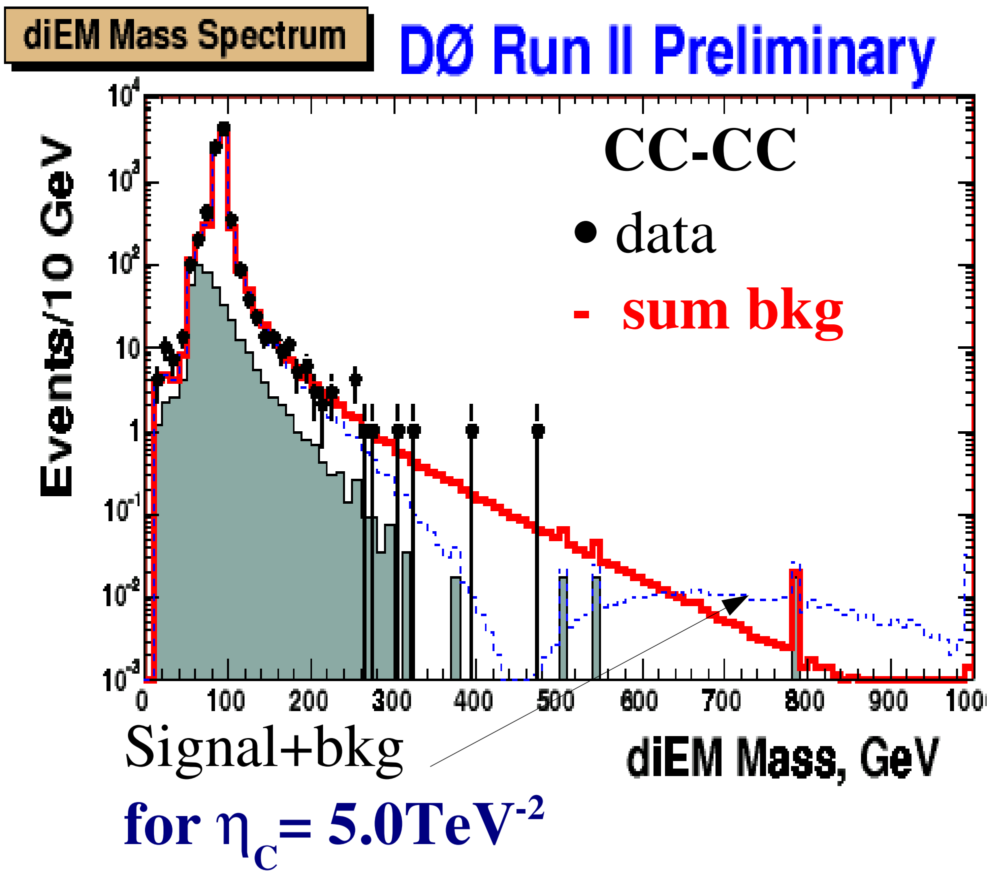
Indirect Probes → *Virtual exchange of KK modes.*

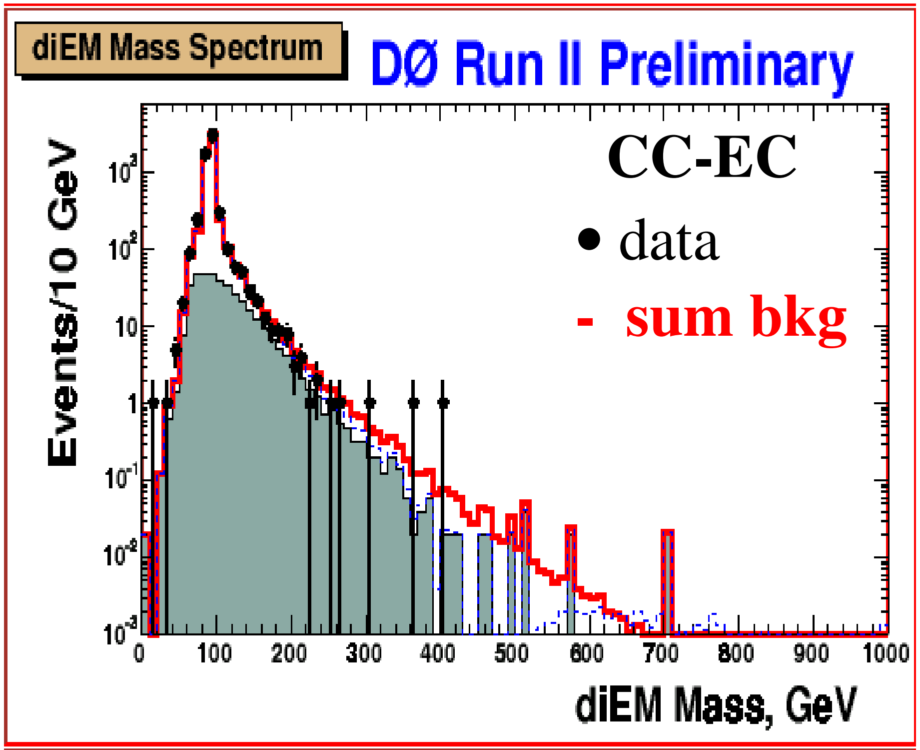
Lepton pair production cross-section depends on $\eta_C = \pi^2/3M_C^{\ 2}$ where M_C is the compactification scale of TeV^{-1} extra dimensions.

⇒ In the following, we study the effects of virtual exchanges of the KK excitations of the Z and γ

TeV^{-1} Extra Dimensions : Dielectron Channel

Analysis : ⇒ **Selecting only Dielectron final state** (requiring a track-match)





⇒ η_C< 2.63 TeV^{-2} → lower limit on the compactification scale of the longitudinal ED : M_C > 1.12 TeV @95% CL

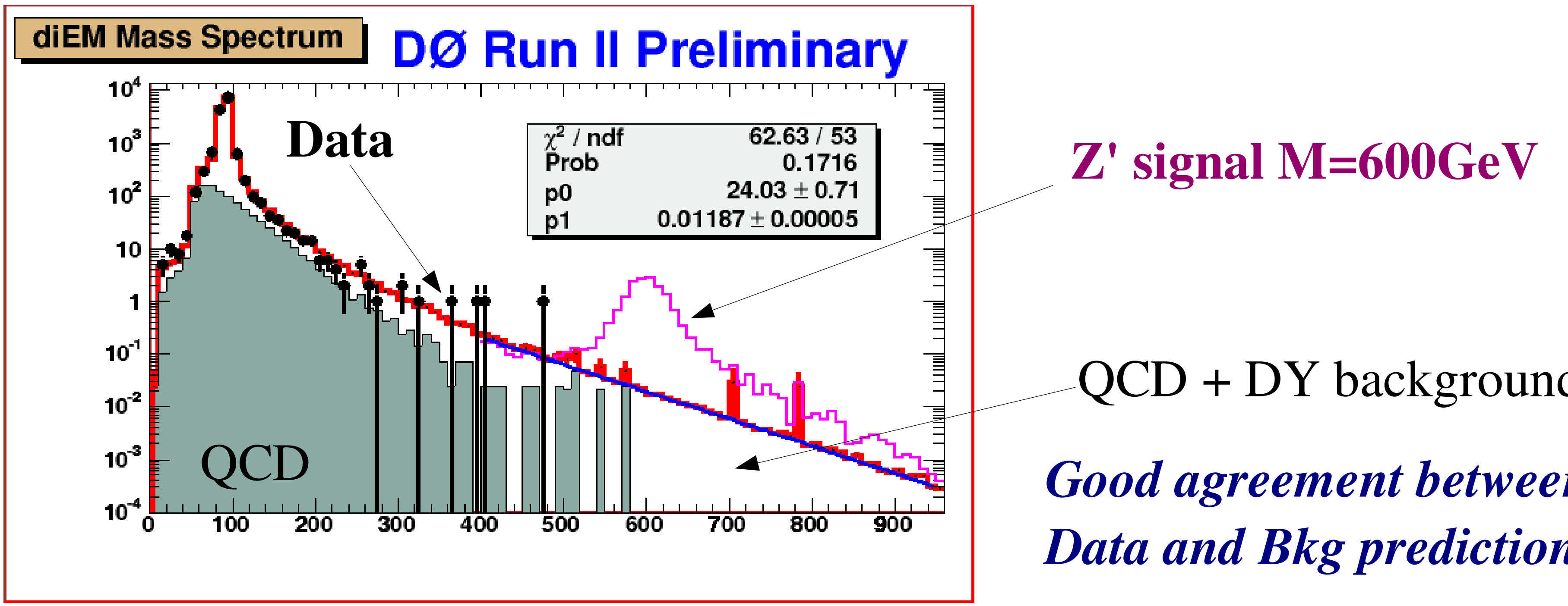
Z' : Dielectron Channel

In many extensions of the Standard Model (SM) the Z' boson is a heavy partner of the Z boson: Extended technicolor, GUT, ED and little Higgs.

$\Rightarrow$ ***<u>We consider here</u> :*** $\rightarrow$ ***Z' resonance with SM-like couplings.***

$\rightarrow$ ***Z' of E6 models: Zψ ,Z χ,Zη and*** Z_I ***.***

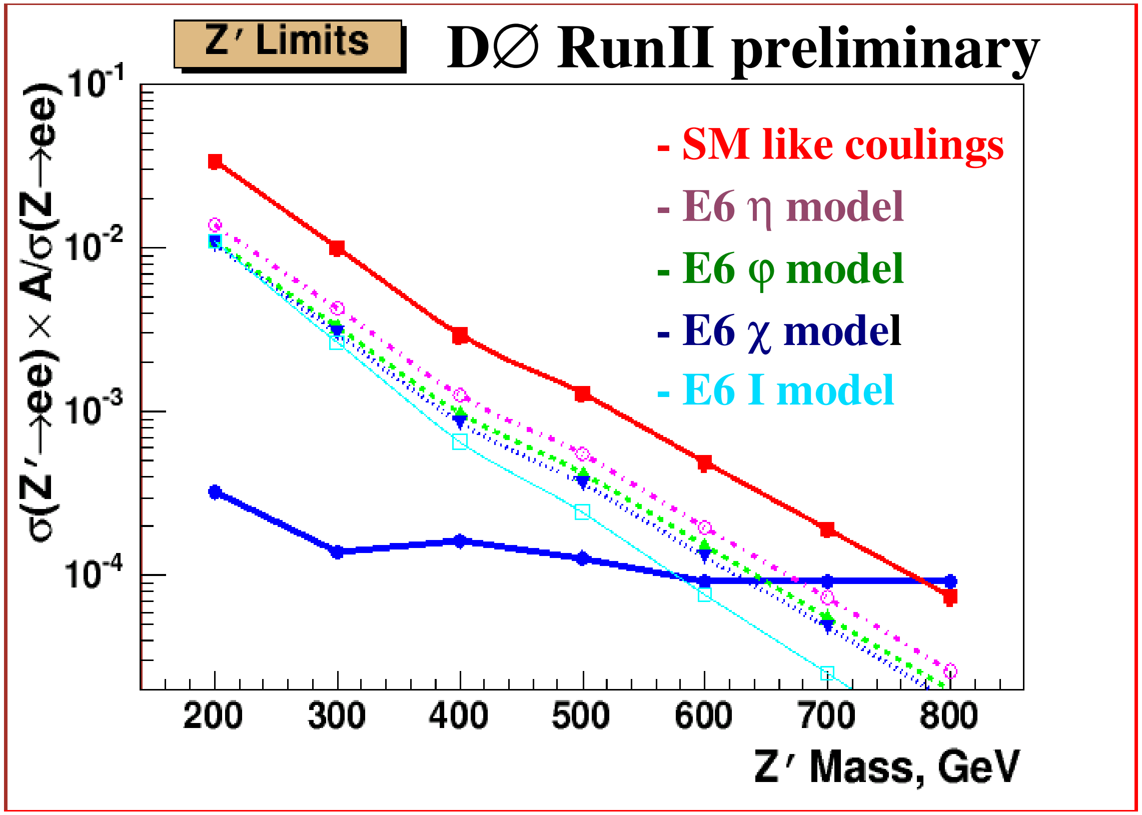
$\Rightarrow$ ***Searches for Z' resonance in the Dielectron channel using the same Date Set as for LED searches.***



Good agreement between Data and Bkg prediction.

Z' : Dielectron Channel

⇒ *Setting limits on the Z' mass :*



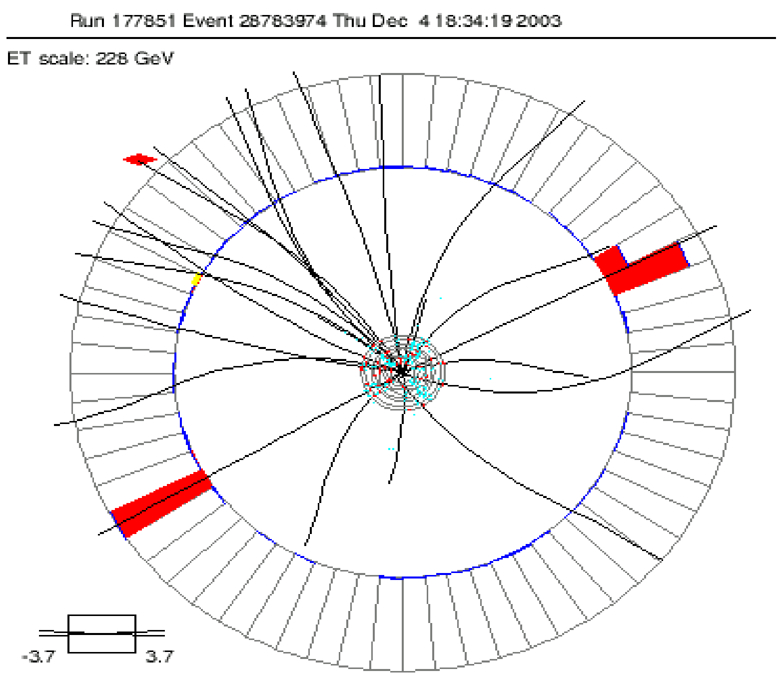
Model	Mass limit
SM-like couplings	780 GeV
ψ model	650 GeV
χ model	640 GeV
η model	680 GeV
I model	575 GeV

D∅ RunII :MZ' > 780 GeV

Most Strigent Limit to date.

Extra Dimensions : dielectron & diphoton channels

Interesting high mass dielectron event :



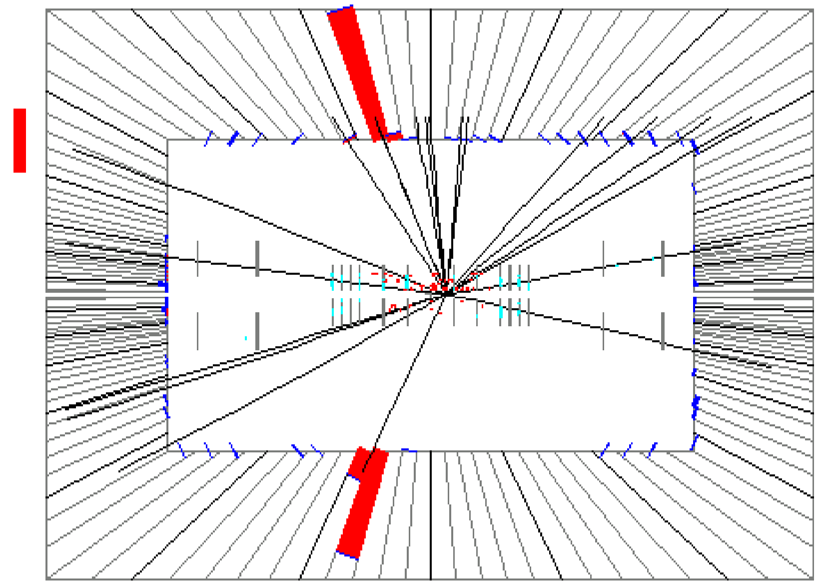


Table:

Run	Event	$\not{E}_T$	Type	E_T^1 (p_T^1)	E_T^2 (p_T^2)	η_1	η_2	ϕ_1	ϕ_2	M	$\cos\theta^*$	N_{jet}
177851	28783974	8.8	e^+/e^-	239.2 (190.8)	226.9 (234.4)	-0.45	-0.50	0.48	3.68	475	0.01	1

CONCLUSION

Searches for physics beyond the standard model at the Tevatron are entering a mode were we explore regions beyond the reach of previous experiments.

→ **Improved leptoquark and Z' limits**

MLQ > 238 GeV (1^{st} gen) and MZ' > 780 GeV (SM-like in e^+e^-)

→ **Searches for SUSY:**

- In tri-lepton channel: Already close to excluding SUGRA points beyond LEP chargino/neutralino reach. Limit : σx BR(3l) < 0.5 pb
- New territory for Squarks and Gluinos. Limit : Mgluino > 333 GeV
- GMSB Limit : $M\chi_1^0 > 105$ GeV and $M\chi_1^+ > 180$ GeV

→ **Searches for Large Extra dimensions:**

- Different types of models have been explored.
- Improved limits on the fundamental Plank Scale in LED: $M_S > 1.43$ TeV in the GRW convention.

⇒ **All these limits are the most constraining to date.**

This is just the beginning ... twice the data set is expected for next summer.