Searches for New Particles at the Energy Frontier at Tevatron

Patrice Verdier
Laboratoire de l'accélérateur Linéaire (France)

On behalf of the CDF and DØ Collaborations

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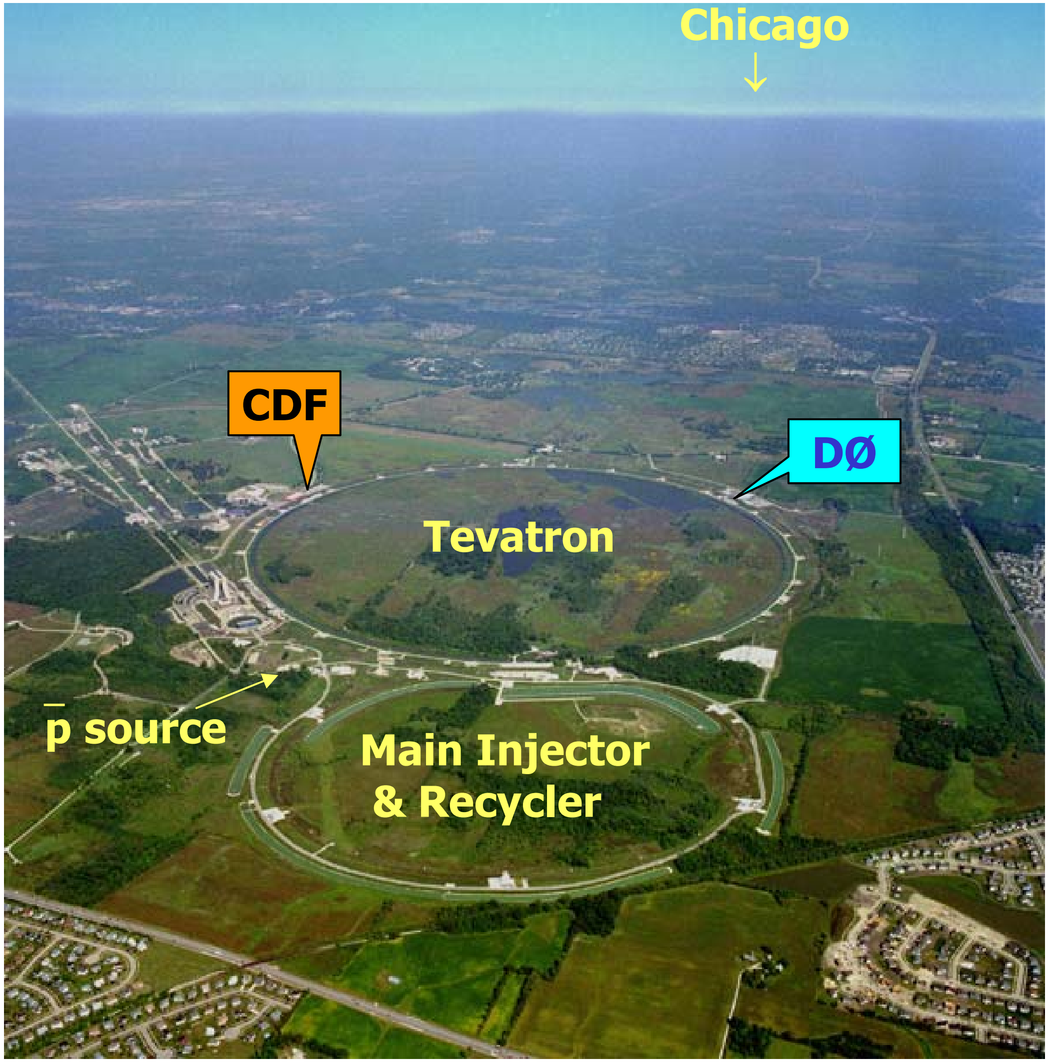
Introduction

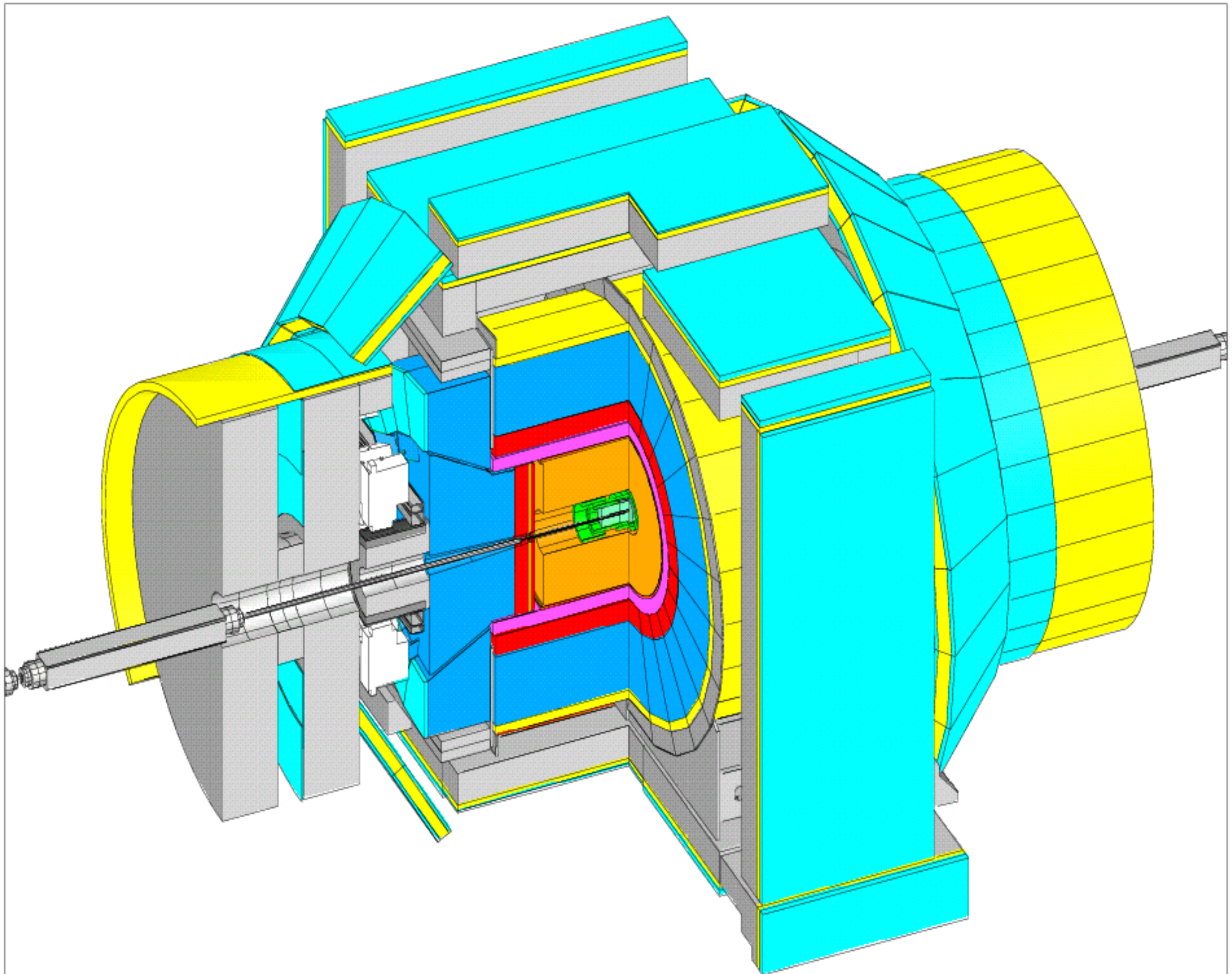
- TEVATRON/CDF/DØ upgrades
- Lepton/Photon Final states :
  - Z' boson
  - Large Extra Dimensions (ED)
  - Small Extra Dimensions
  - Excited Leptons
  - eμ Inclusive Final States
  - SUSY Trilepton "Golden Channel"
  - GMSB SUSY
- Jets/missing Et Final States :
  - SUSY Squarks and Gluinos
  - Jets Inclusive Final States
  - Small Extra Dimensions
- Jets + Leptons Final states :
  - Leptoquarks 1st generation
  - Leptoquarks 2nd generation
- Massive Stable Particles
- Summer 2003 perspectives

TEVATRON Run II Upgrade

- **New Main Injector : 150 GeV**
  - •Store protons, shoot to target for anti-proton production
- **New recycler :**
  - •Magnet storage ring for anti-proton
- **Higher energy:**
  - • 1.96 TeV vs 1.8 TeV
  - • Higher cross sections
    (30 % for the SUSY)
- **Higher antiproton intensity:**
  - •6x6 $\rightarrow$ 36x36 bunches
    (3.5 μs $\rightarrow$ 396 ns)
  - • Higher luminosity
    - ✓ Run I : $2\times10^{31}\ cm^{-2}s^{-1}$
    - ✓ Run II : $2\times10^{32}\ cm^{-2}s^{-1}$

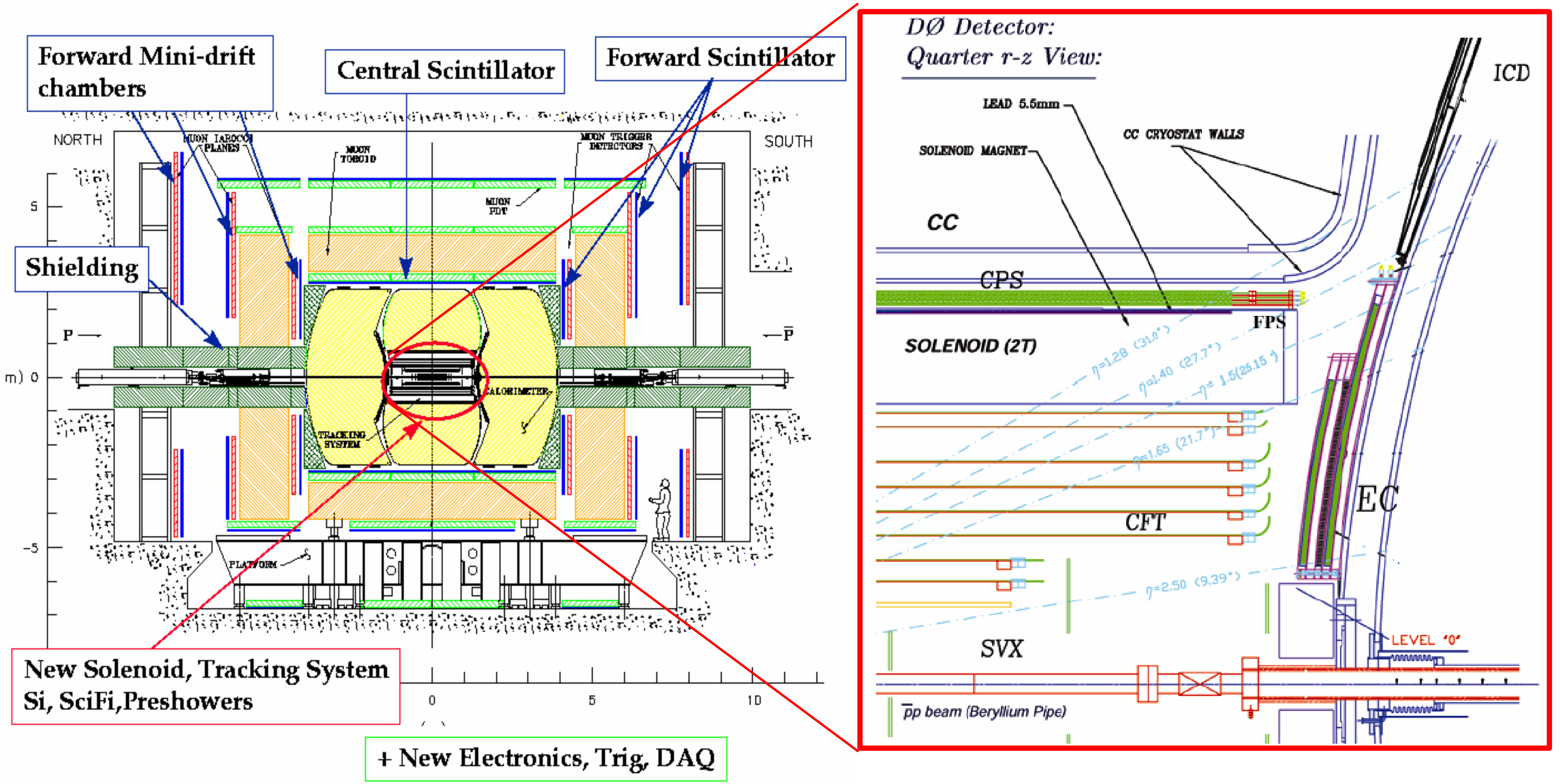


CDF Upgrade



- Improved Si coverage:
  - $|\eta| < 2$
  - 8 layers
- Central Drift Chamber:
  - 96 layers
- Time of Flight
- Expanded μ coverage
- Forward Calorimeter
- Trigger :
  - COT tracks at L1
  - Silicon tracks at L2
- DAQ

DØ Upgrade



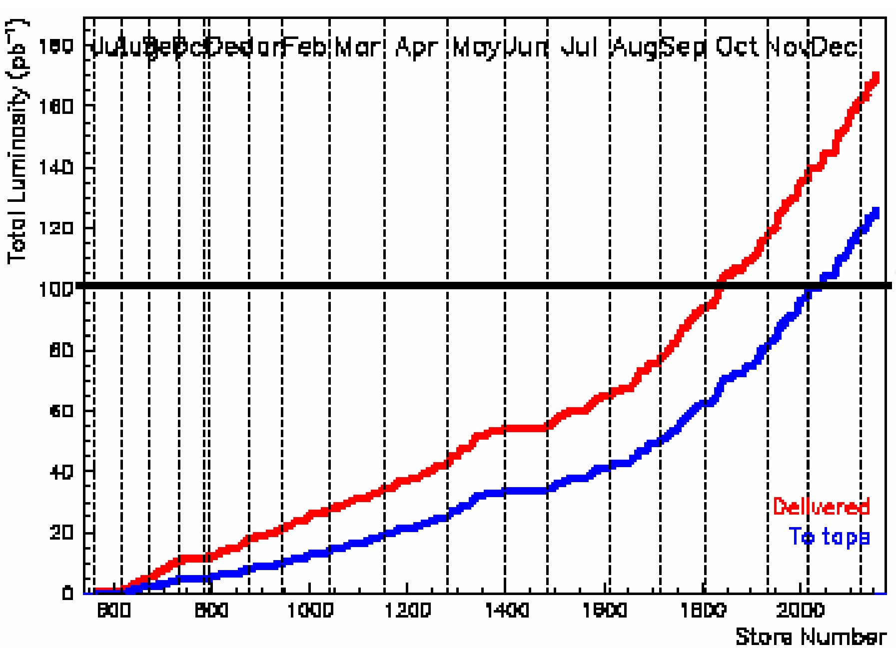
- Solenoid (2T)
- Central tracker
- Silicon vertex detector
- Preshower
- Muon forward chamber
- Calorimeter electronic
- Trigger system
- DAQ system

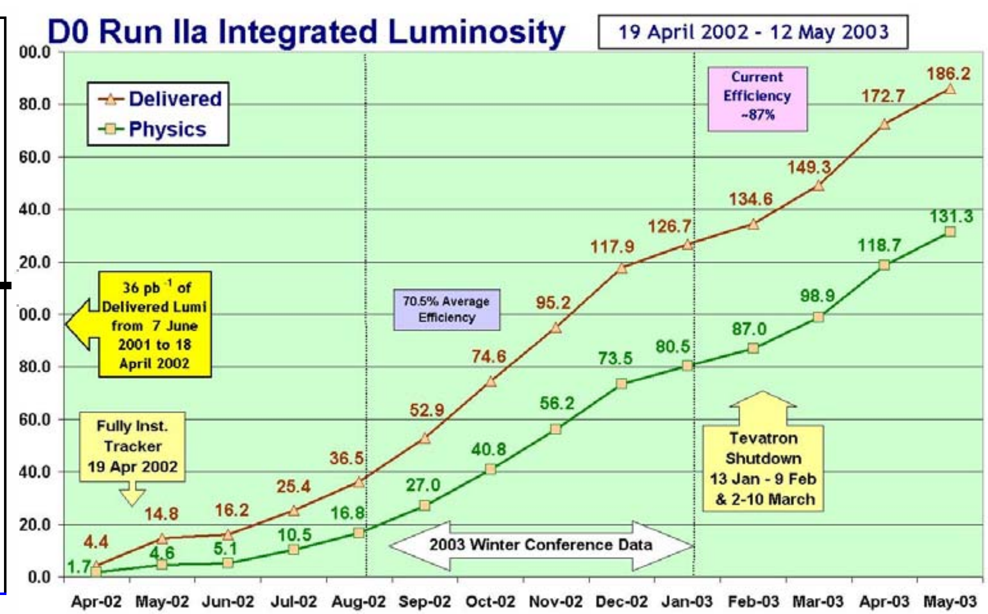
Luminosity and Performance

2003 Winter Conferences data samples

Delivered Lumi	180 pb^{-1}	
Physics Lumi	CDF	DØ
	130 pb^{-1}	84 pb^{-1} (since April 02)

- **Run IIa goal** 9×10^{31} cm^{-2}s^{-1}
- **Now** 4×10^{31} cm^{-2}s^{-1}
- **Run IIb goal** 2×10^{32} cm^{-2}s^{-1}

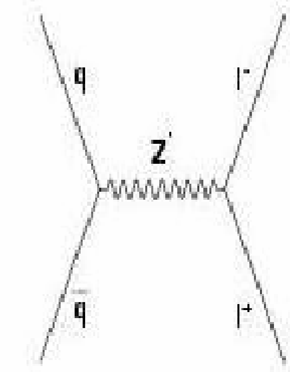




High Mass Dileptons

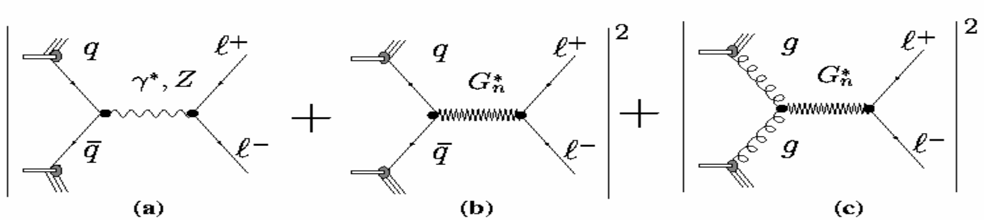
- **New neutral gauge boson :**
  various extensions of the SM - M(Z')

Resonance in dilepton channels



- **Extra Dimensions (ED) :**
  - ADD models (Large ED)
  - Randall-Sundrum model (Small ED)

- Search for LED assuming SM particles are confined to a 3-brane, but gravity propagates in the ED.
- Signatures is excess of high-mass dielectron, diphoton or dimuon events over SM expectation, from coupling to Kaluza-Klein gravitons

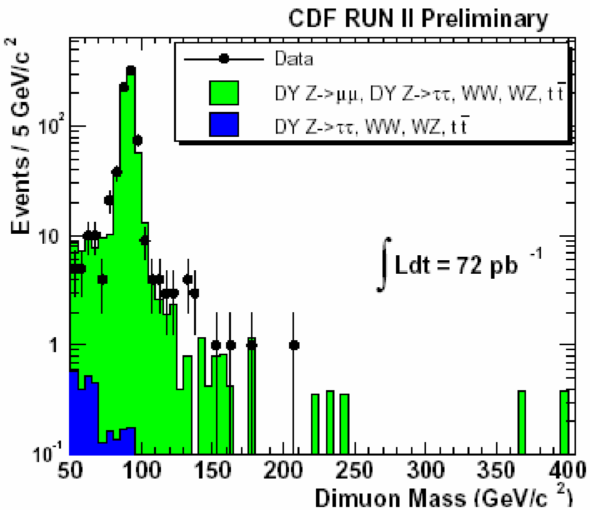


$$\frac{d^2\sigma}{dM d\cos\vartheta} = f_{SM} + f_{\text{int}}\eta_G + f_{KK}\eta_G^2 \qquad \eta_G = F / M_S^4$$

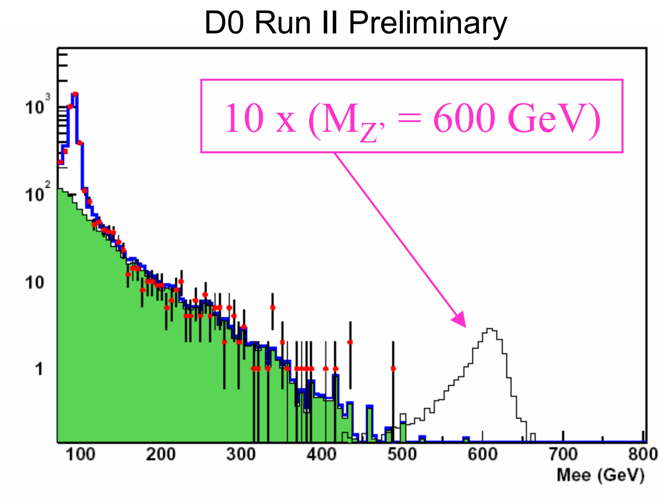
- 4 dimensional metric multiplied by warp factor exponentially changing with the additional dimension.
- KK states can be observed as spin 2 resonances
- Two parameters :
  - M_G
  - k/M_{Planck} determines the coupling and resonance width

Z' boson

CDF μμ channel : 72 pb^{-1}



DØ ee channel : ~50 pb^{-1}



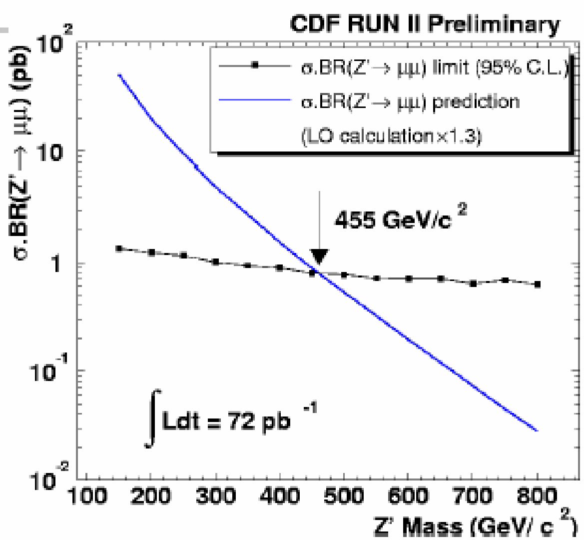
✘ **Main backgrounds :**

- Drell-Yan
- EW dileptons
- QCD misidentified (ee channel)

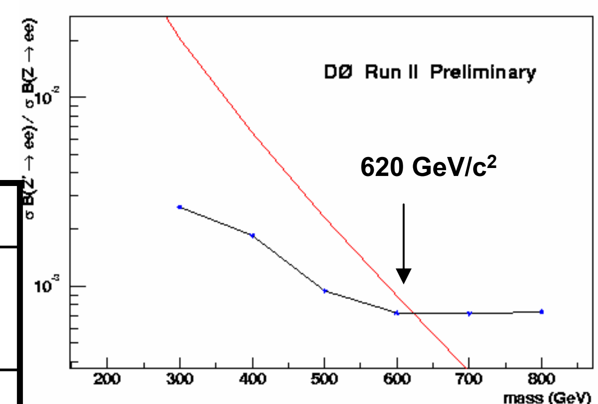
Data consistent with SM background

Z' mass limit

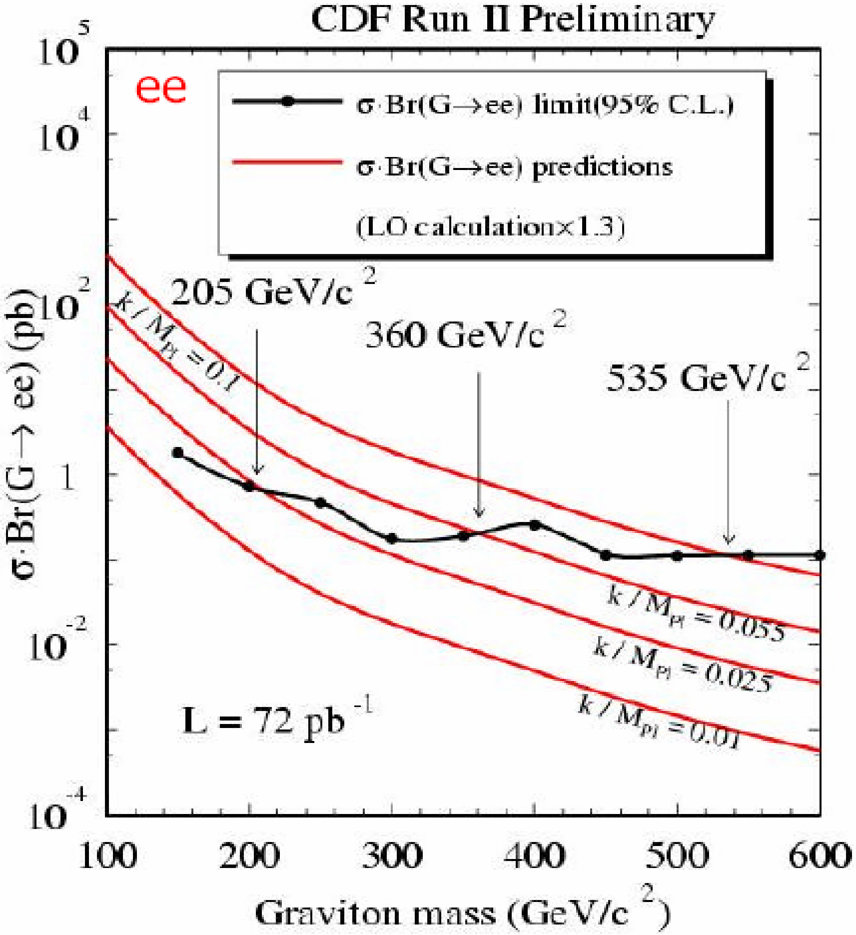
Assuming SM couplings (95 % CL)

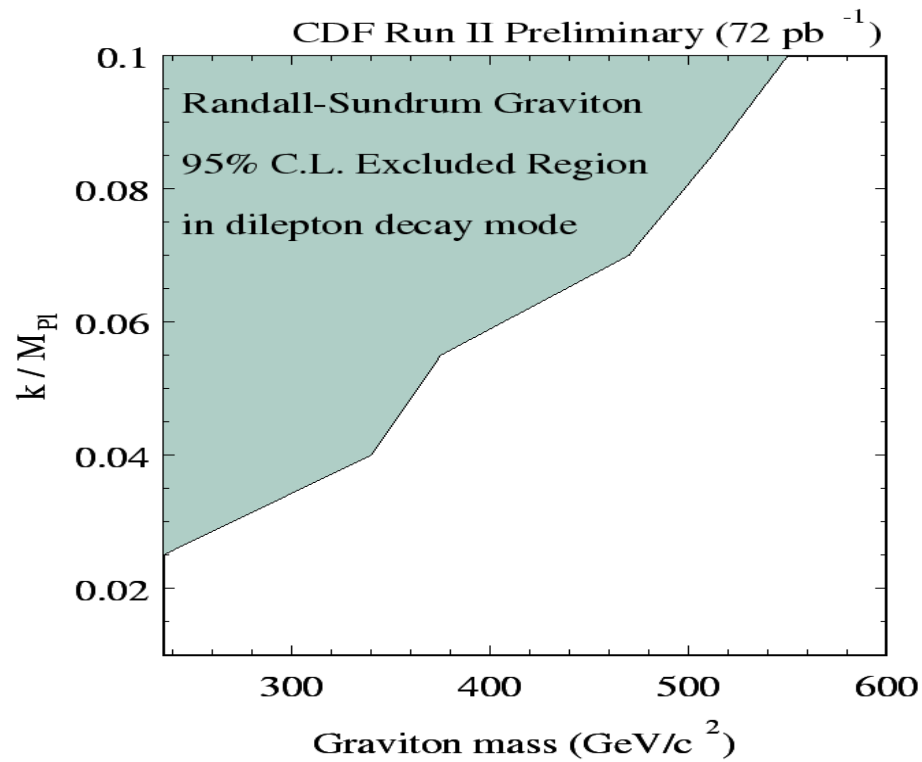


Channel	CDF	D0
ee	> 650 GeV (640 RunI)	> 620 GeV (690 RunI)
μμ	> 455 GeV (575 RunI)	-



Small Extra Dimensions





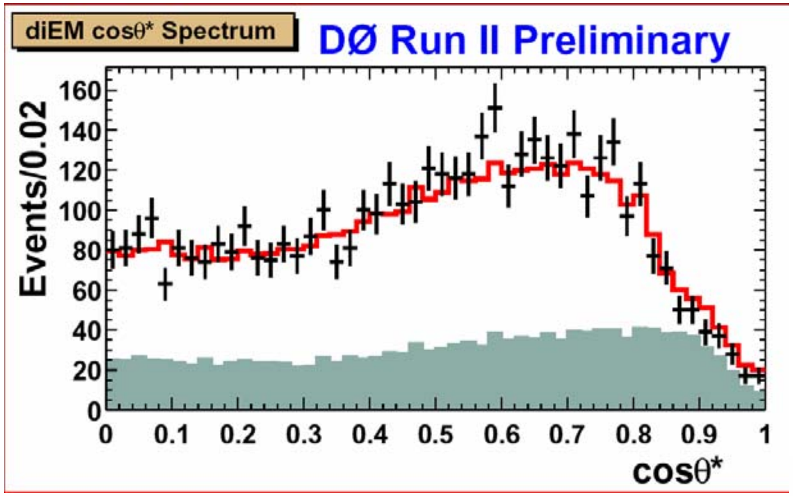
Exclusion plot also for the muon channel

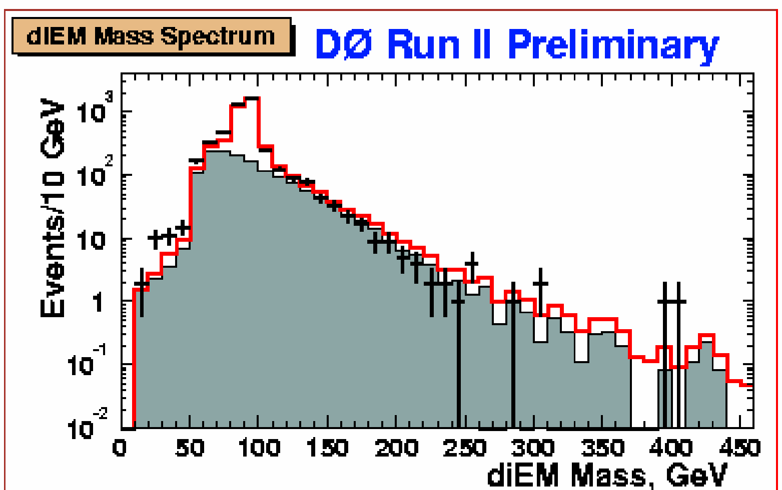
CDF graviton mass limit

Channel	CDF
ee	> 535 GeV
μμ	> 370 GeV
combined	> 550 GeV

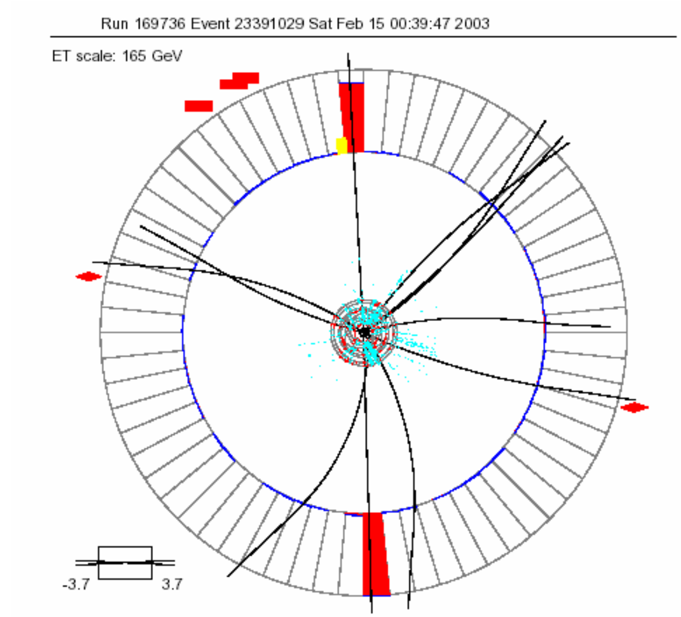
Large Extra Dimensions : EM Channel

- **Two variables :**
  - Di-EM Invariant mass
  - cos θ* (scattering angle in the rest frame)



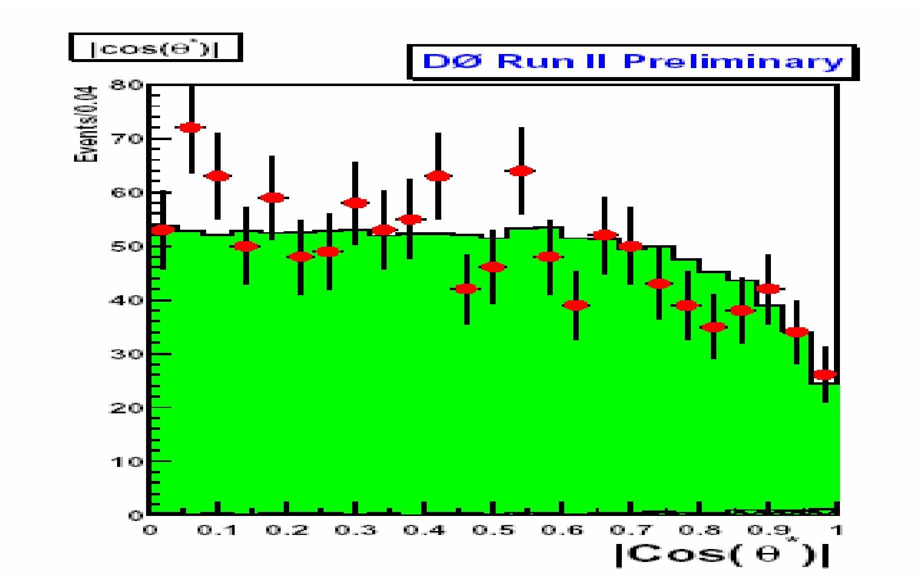


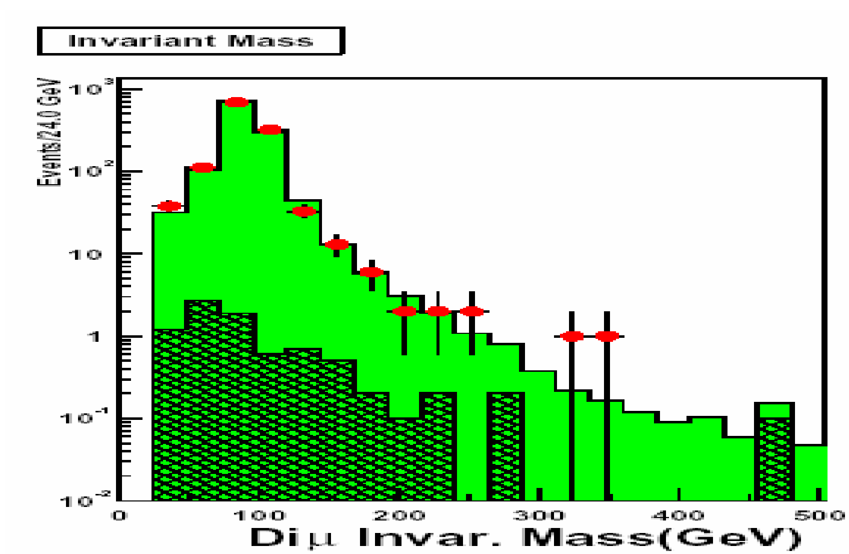
- **Event selection : (~50 pb^{-1})**
  - 2 EM objects Pt > 25 GeV
  - Missing Et < 25 GeV
- **Backgrounds :**
  - Drell-Yan, Direct γ γ production (from MC)
  - EM mis-identification (from data)



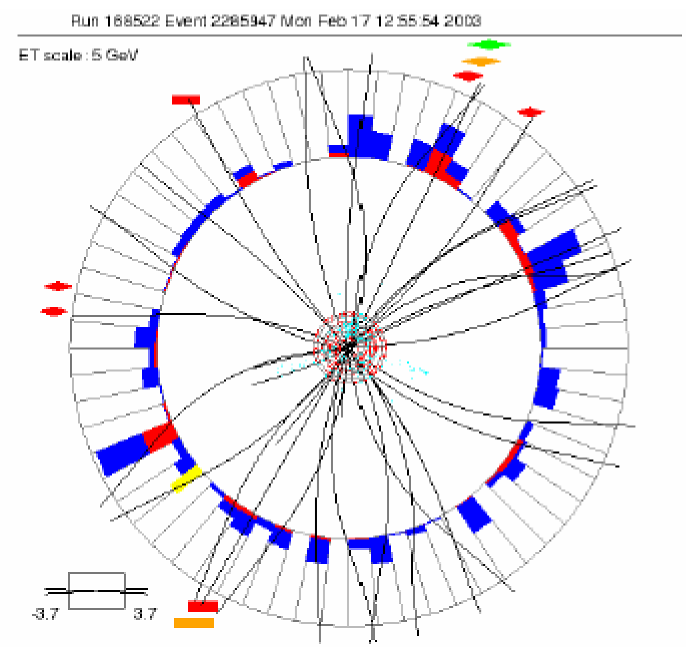
$M_{EM\text{-}EM}$ = 394 GeV
cos θ* = 0.49

Large Extra Dimensions : Muon Channel





- **Event selection : (~30 pb^{-1})**
  - 2 opposite signs muons Pt > 15 GeV
  - Mμμ > 40 GeV
- **Backgrounds :**
  - Drell-Yan, Heavy quark decay



Mμμ = 347 GeV

Large Extra Dimensions : Results

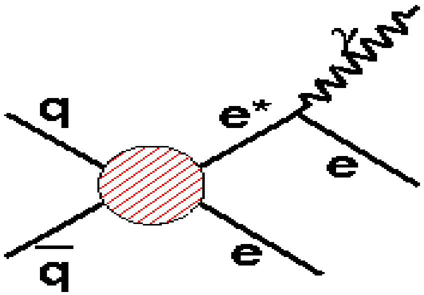
- Fit the distributions in the (M_{inv} , $\cos\theta^*$) plane to determine the value of η_G
  - (expected to be zero in SM)
  - Di-EM analysis : $\eta_G = 0.0 \pm 0.27\ TeV^{-4}$
  - Di-Muon analysis: $\eta_G = 0.02 \pm 1.35\ TeV^{-4}$
- Translate 95% CL upper limits on η_G to 95% CL *lower* limits on M_S, the fundamental Planck scale (in TeV)

$$\eta_G = F/M_s^{-4}$$

Formalism	GRW	HLZ for n= 2	7	Hewlett λ = 1
di-EM (~50 pb^{-1})	> 1.12	> 1.16	> 8.89	> 1.00
di-Mu (~30 pb^{-1})	> 0.79	> 0.68	> 0.63	> 0.71

Di-EM limit close to Run I (1.1 TeV)
Di-Muon analysis is new

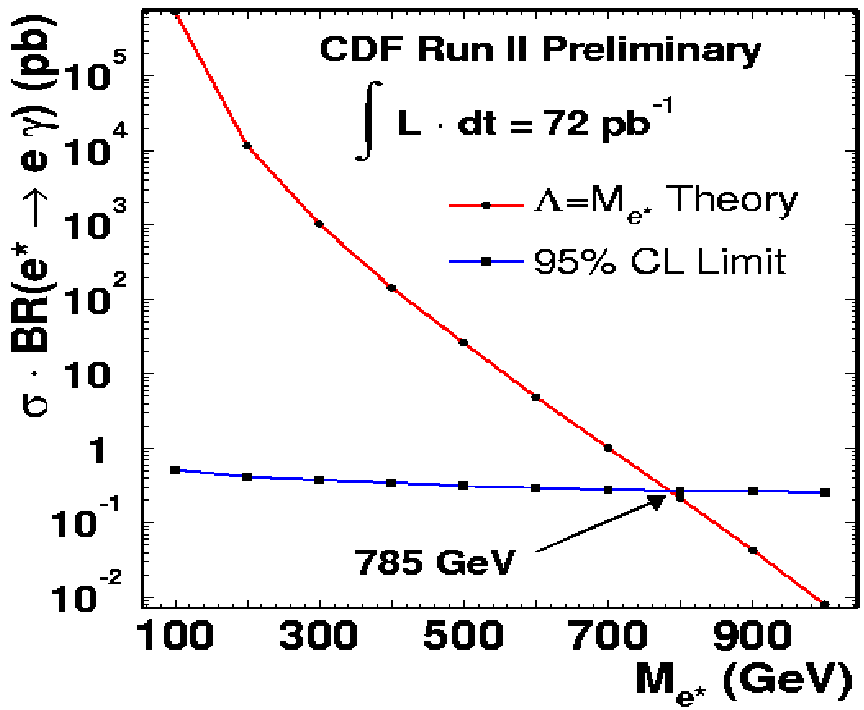
Excited Leptons

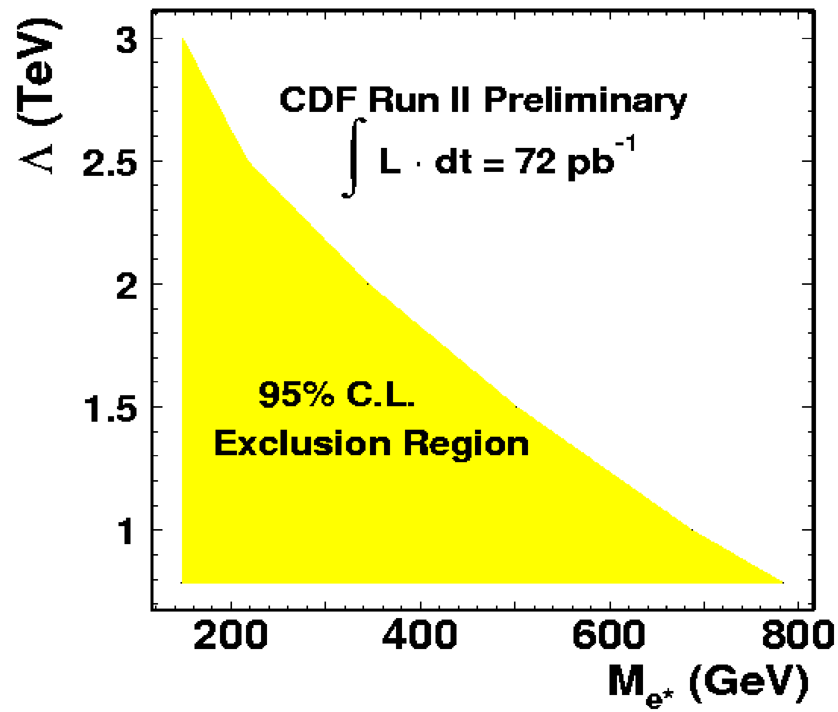


- Compositeness models
- Clear signature
- Two parameters:
  - Λ(comp. scale) and M(e*)

- 2 electrons + 1 photon : Et > 25
- Reject M(ee) around the Z

No event observed



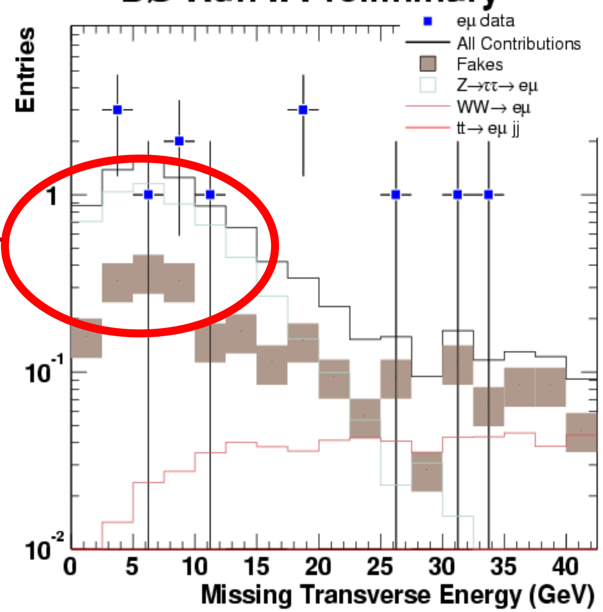


M(e*) = Λ , M(e*) > 785 GeV

eμ Inclusive Search

- Very low backgrounds
- Model Independent analysis
- Very simple cuts :
  - 1 electron and 1 muon with Pt > 15 GeV
  - Jet veto
- Backgrounds :
  - Instrumental from data
  - Physics from simulation

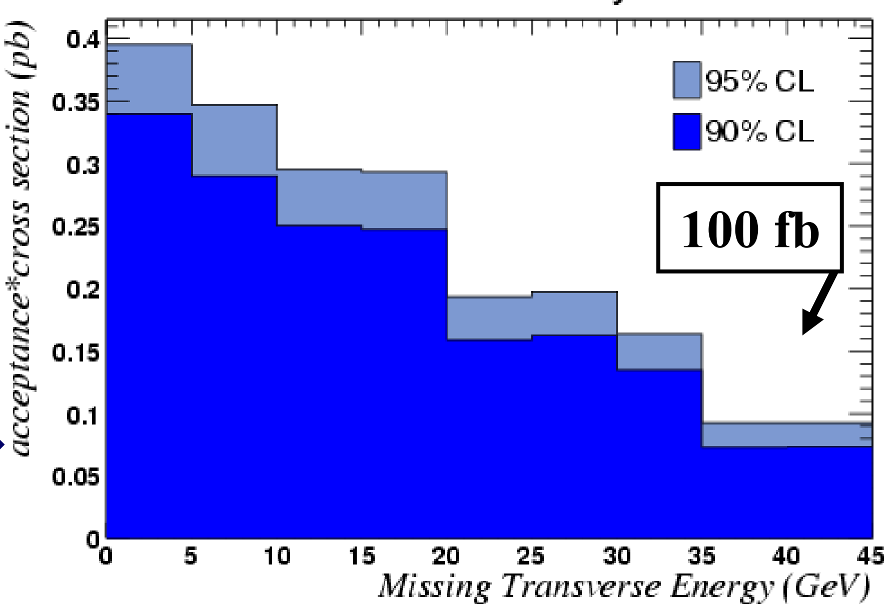
mE_T Cut	DATA	TOT BKG
> 0	13	$9.6 \pm 0.6 \pm 2.6$
> 10	7	$4.6 \pm 0.6 \pm 2.6$
> 20	3	$2.3 \pm 0.6 \pm 2.6$
> 30	2	$1.6 \pm 0.6 \pm 2.6$
> 40	0	$1.4 \pm 0.6 \pm 2.6$



Z→ ττ → eμ

Cross section limit vs Missing Et cut

e.g., 17% for WW→eμ



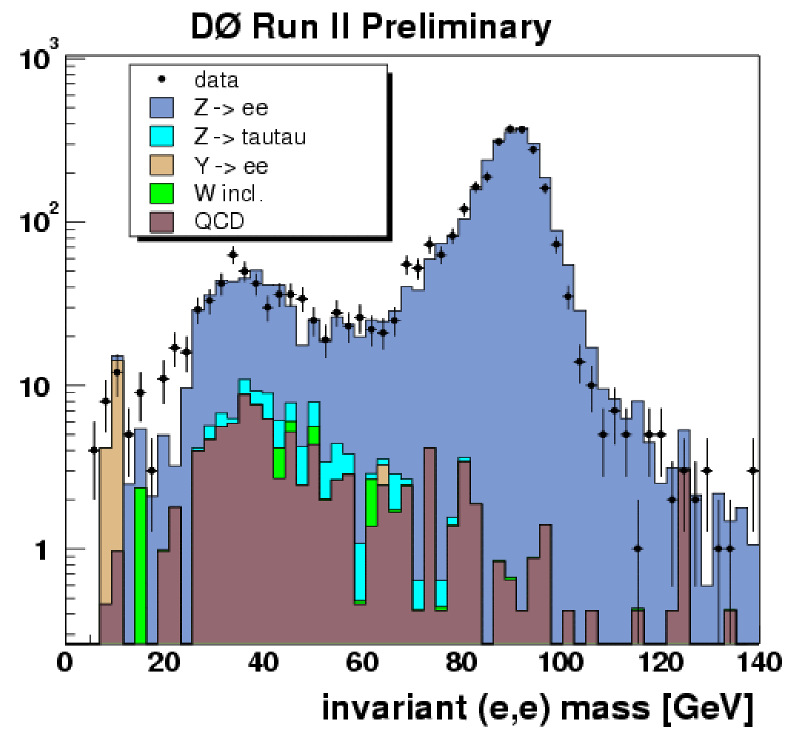
Trilepton : eel + X

$$p\bar{p} \longrightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \longrightarrow lee\,\nu\tilde{\chi}_1^0\tilde{\chi}_1^0$$

Similar analysis in the eμl channel

- Start from dielectron sample (~40 pb-1)

	back.	data
Pt(e1)>15,Pt(e2) > 10	3216±43	3132
10 < M(ee) < 70	660±19	721
M_T > 15	96.4±8.1	123
Add. Iso. Track Pt > 5	3.2±2.3	3
missing Et > 15 GeV	0.0±2.0	0



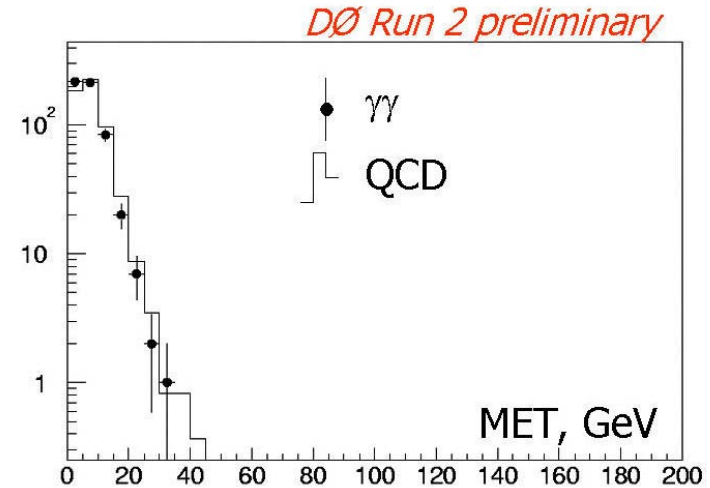
- Typical mSUGRA selection efficiency:
  3 to 4 % at the edge of the excluded region
- Sensitivity still a factor 7 away from extending the excluded domain

"Golden channel" : very low backgrounds, but large statistics will be needed

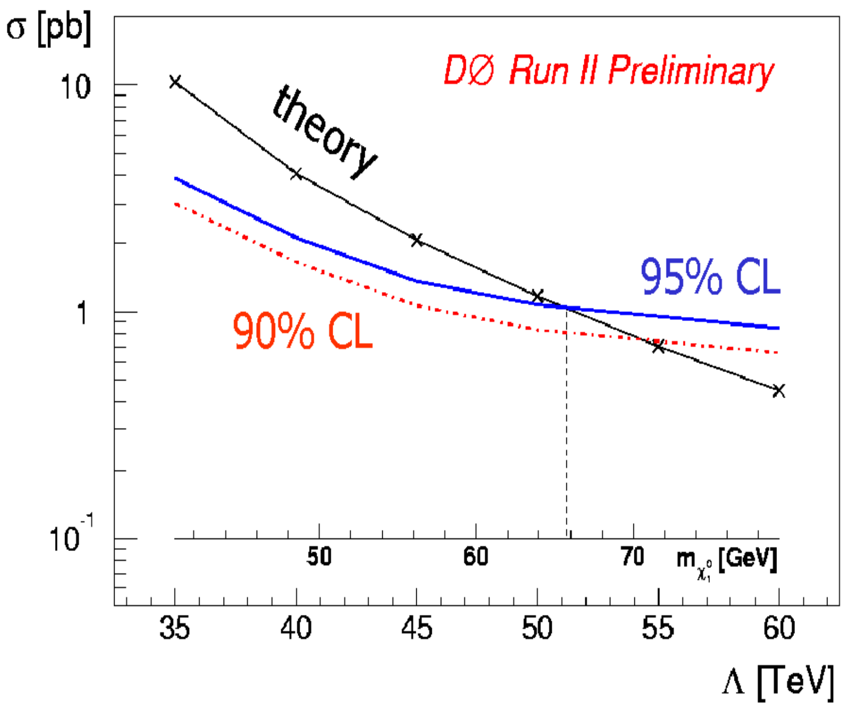
GMSB Search (DØ)

- In GMSB, the LSP is a light gravitino
- With a "bino" NLSP, the signature is therefore two photons with missing Et.
- L = 40 pb^{-1}

$$\tilde{\chi}_1^0 \rightarrow \gamma \tilde{G}$$



•Require 2 isolated photons with Pt > 20 GeV
•Apply topological cuts
•Determine the instrumental QCD background from the data (inversion of the quality cuts)



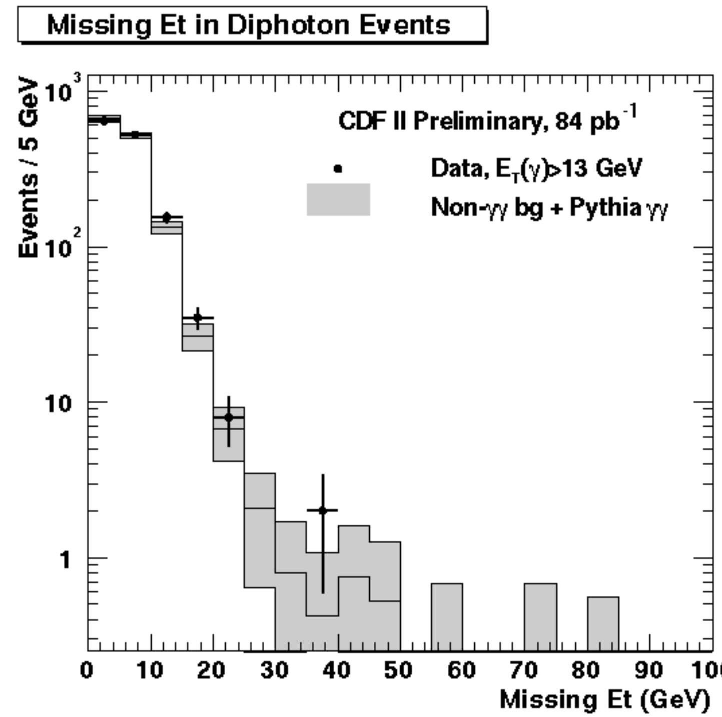
Theory = "Snowmass" slope:
M = 2Λ,
N_5 = 1,
tan β = 15,
μ > 0

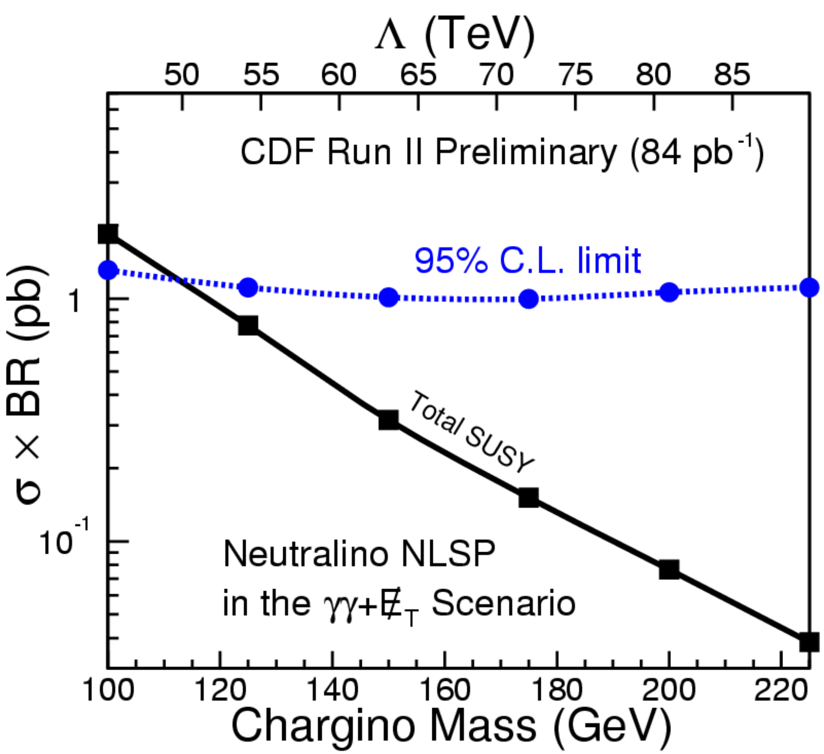
- Photon pointing will be used for long lifetime

With ~50 pb^{-1}, the Run I limit is approached

GMSB SUSY Search (CDF)

- **Event selection :**
  - Two central photons sample
  - Reject cosmics
  - Use missing Et
- **In 84 pb^{-1} :**
  - Expect 2 ± 2 events from background
  - 2 events observed



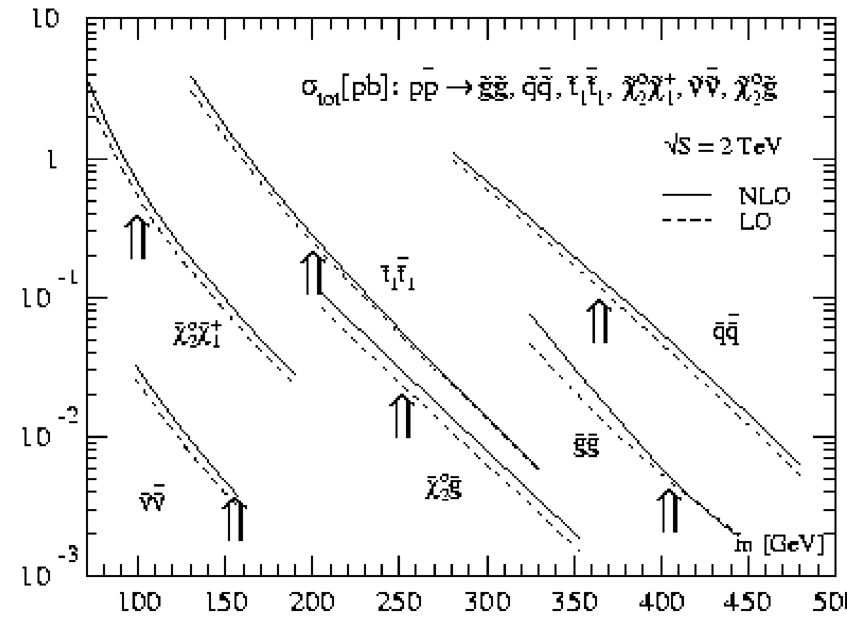


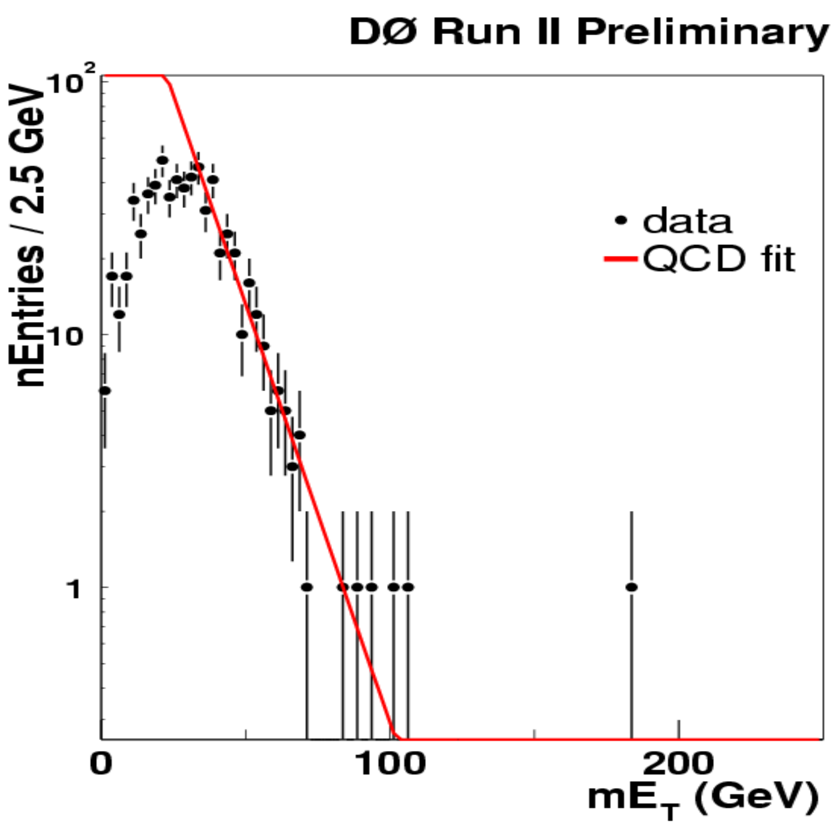
Theory = "Snowmass" slope

M(Chargino) > 113 GeV

SUGRA search : Jets + mEt

- Squarks and gluinos cross section high
- Their decay chains produce jets, leptons, and missing energy because the neutralino LSP escapes detection.
- First look with 4 pb^{-1}

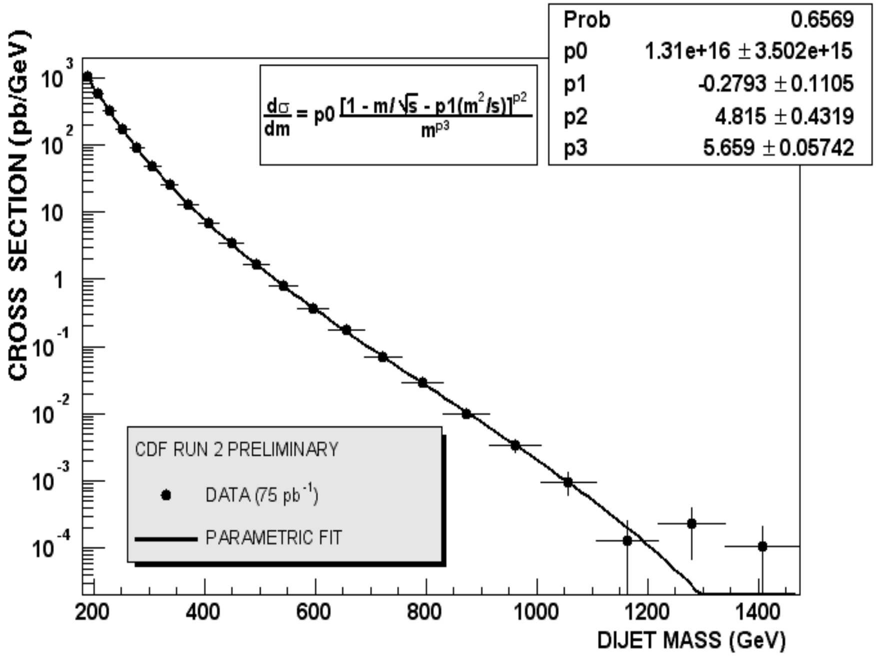




- Select events with at least one jet with Pt > 100 GeV
- Apply topological cuts
- Simulate physics background
- Estimate the large instrumental QCD background from the data

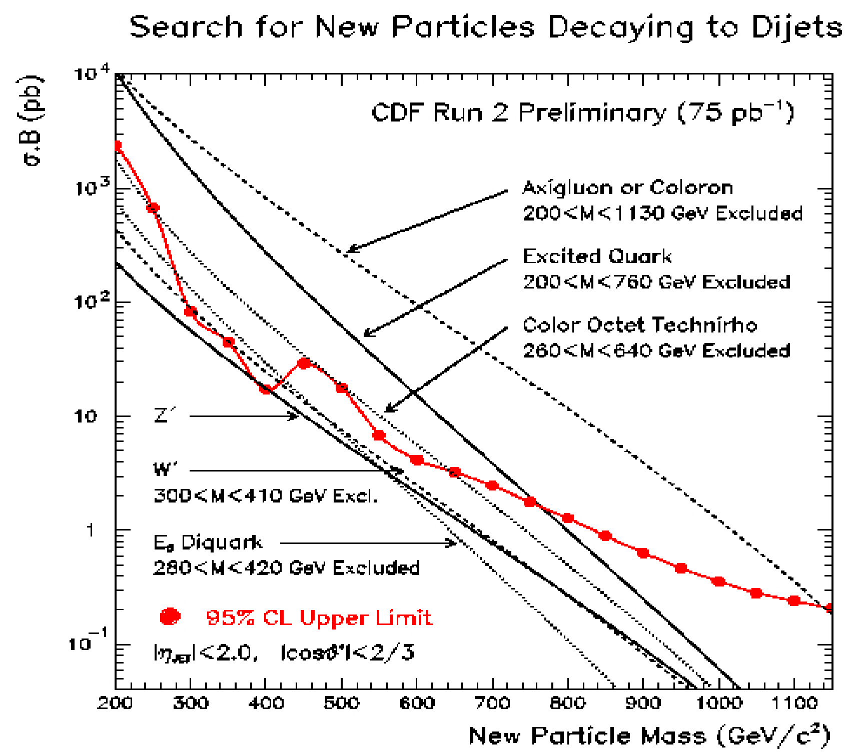
No surprise. For mEt > 100 :
3 events observed , 2.7 $\pm$ 1.8 expected

Search for Resonance in Dijets



- Inclusive jet sample
- 2 highest Et jets selected
- Fit the mass spectrum

No significant evidence

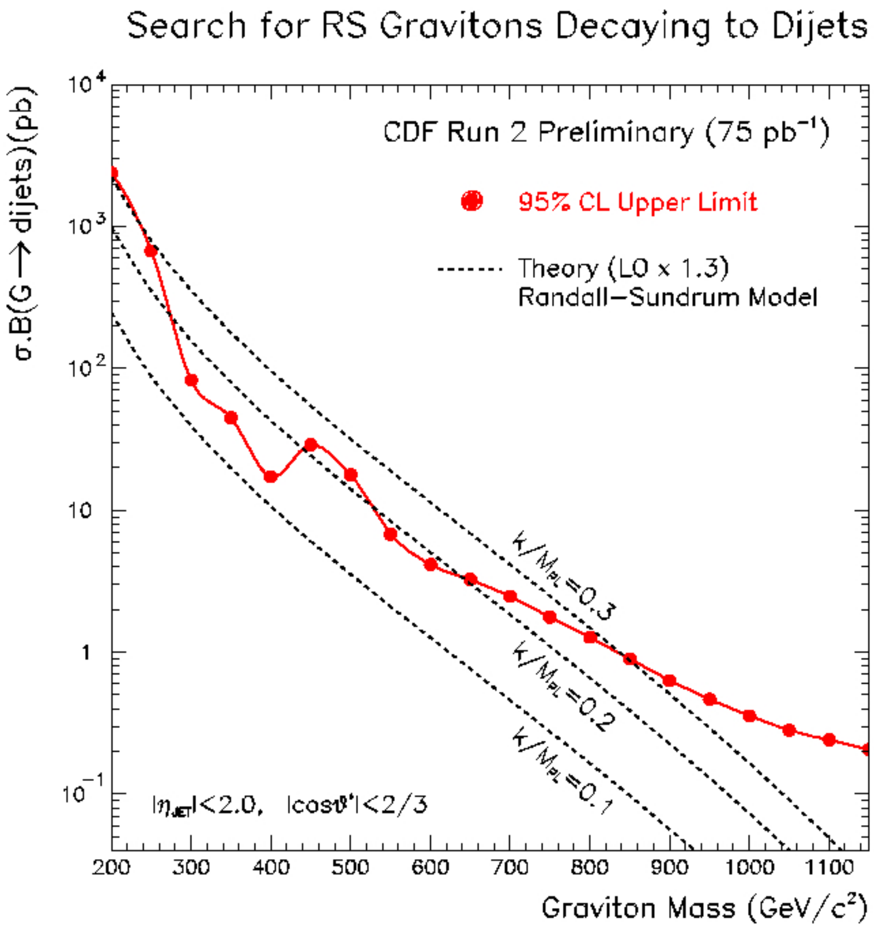


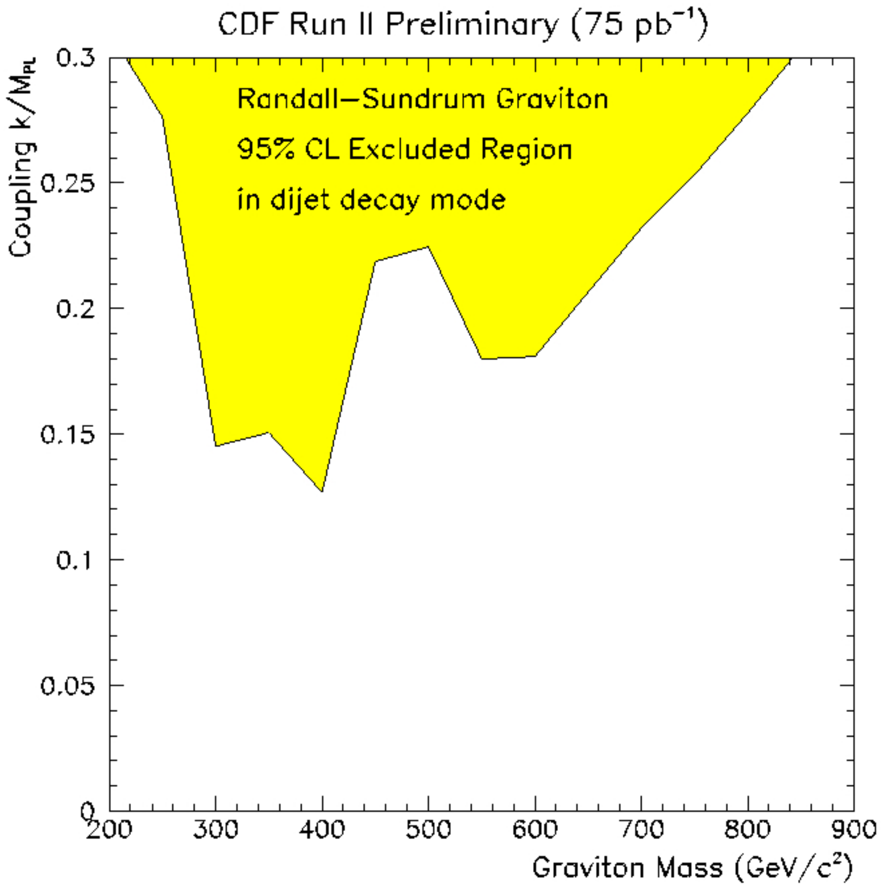
New Particle	Limit (GeV)
Axigluons/Colorons	200< M <1130
Excited quarks	200< M <760
Color octet techni-ρ's	260< M < 640
E6 diquarks	280 < M < 420
Z'/W'	300 < M < 410

Results improved with respect to CDF run I

Small Extra Dimensions in dijets

Randall-Sundrum Limits from Dijets



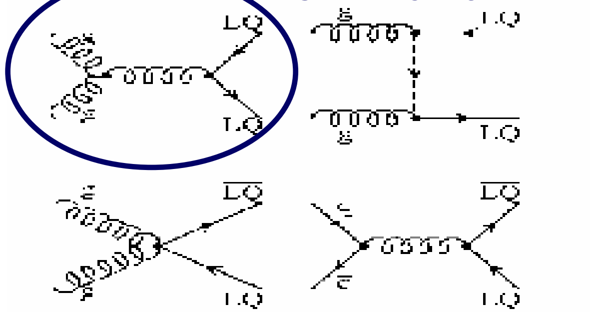


Dijet channel excludes region :
$k/M_{Planck} \sim 0.3$, $200 < M_{dijets} < 800$

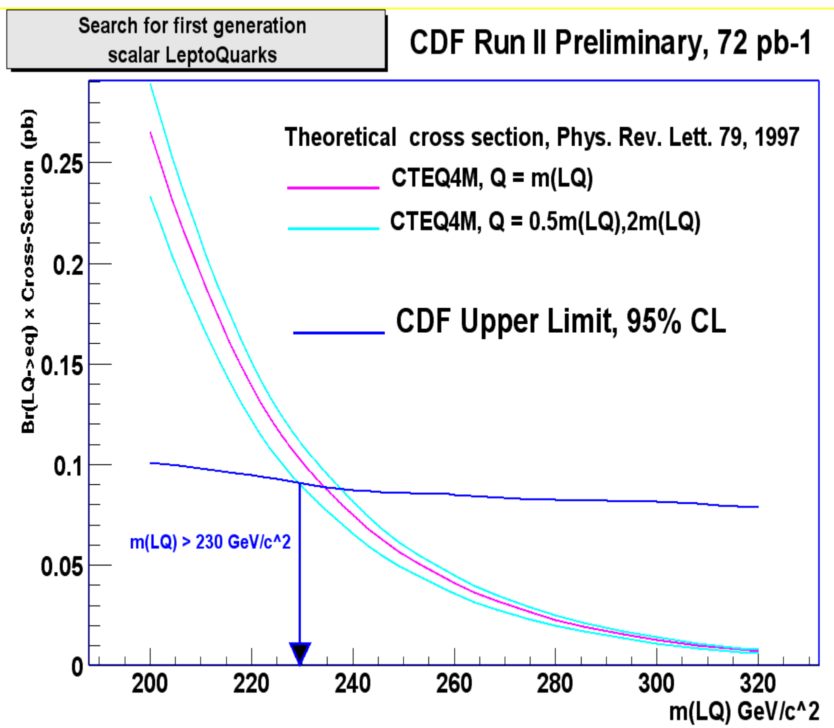
1st Generation Leptoquarks (CDF)

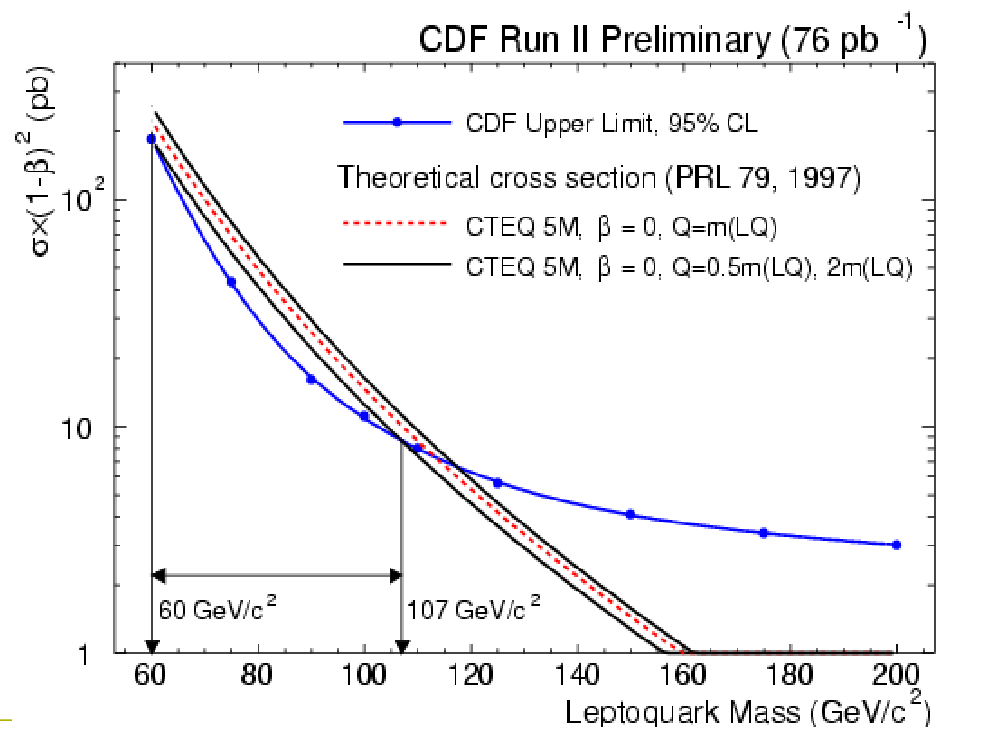
- **LQ1LQ1 → e^+e^-qq**
  - 2 high Et electrons
  - 2 jets
- **Selection :**
  - 0 events observed
  - 3.4 ± 3 events expected

Dominant



- **LQ1LQ1 → ννqq**
  - 2 high Et jets
  - Large Et
- **Selection :**
  - 42 events observed
  - 43 ± 11 events expected





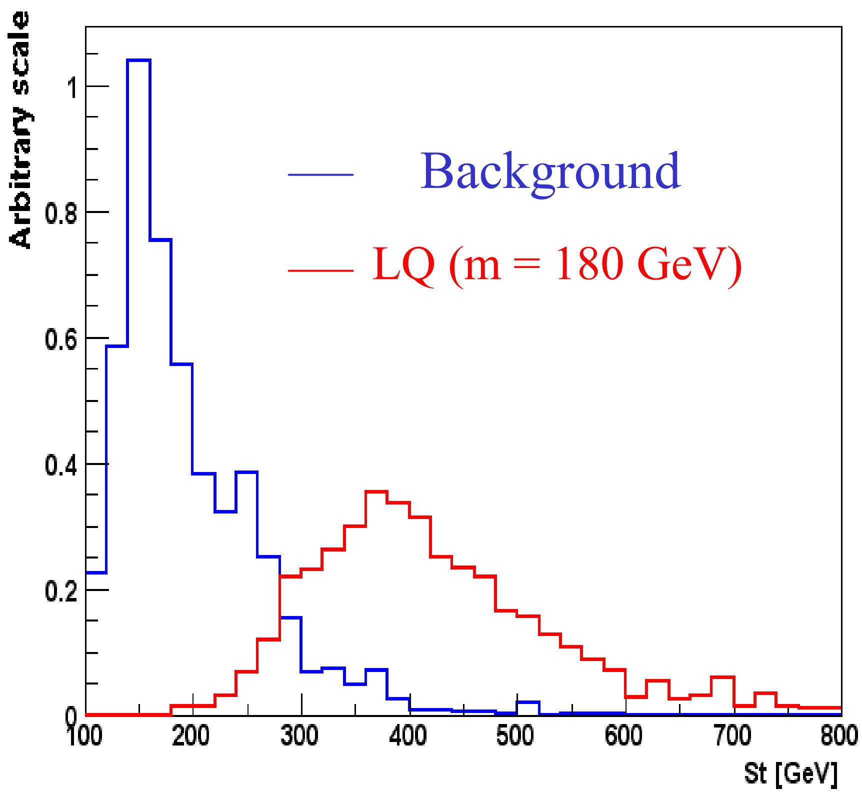
Limit : M(LQ1) > 230 GeV

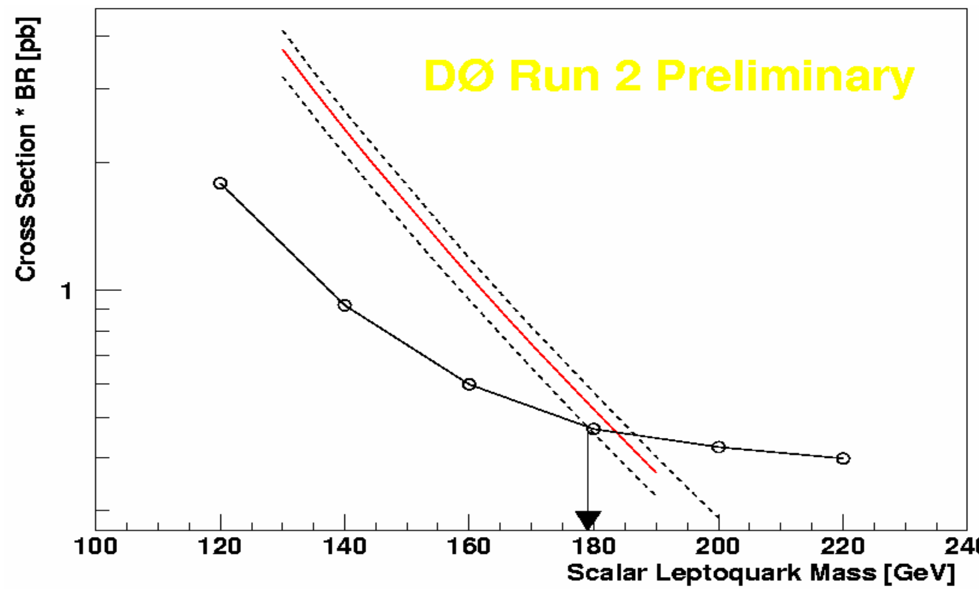
Exclusion : 60 < M(LQ1) < 107 GeV

1st Generation Leptoquarks (DØ)

- Lum = 43 pb^{-1}
- 2 electrons with p_T > 25 GeV
- 2 jets or more with p_T > 20 GeV
- M_{ee} < 75 GeV or M_{ee} > 105 GeV

	no S_T cut	S_T cut
Data	6	0
Total BKG	5.1 ± 1.1	0.34 ± 0.06
Drell-Yan	3.1 ± 0.9	0.17 ± 0.05
QCD	1.6 ± 0.6	0.09 ± 0.03
Top	0.37 ± 0.10	0.08 ± 0.02
LQ 200 GeV	2.09 ± 0.24	1.98 ± 0.22



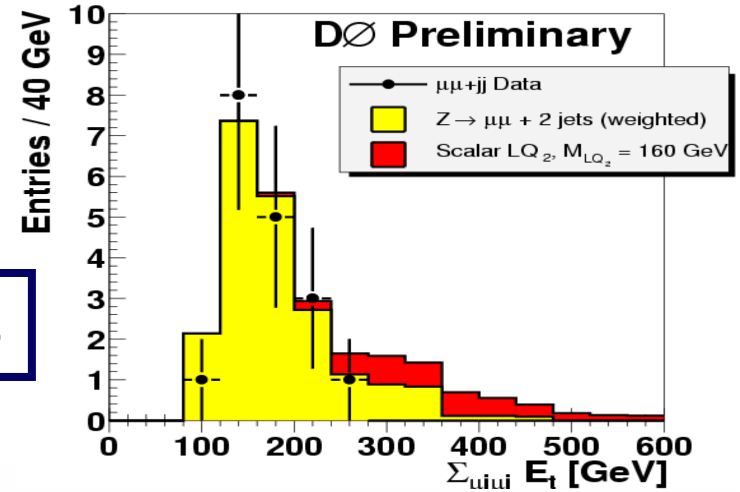


M(LQ1) > 179 GeV , Run I : 225 GeV

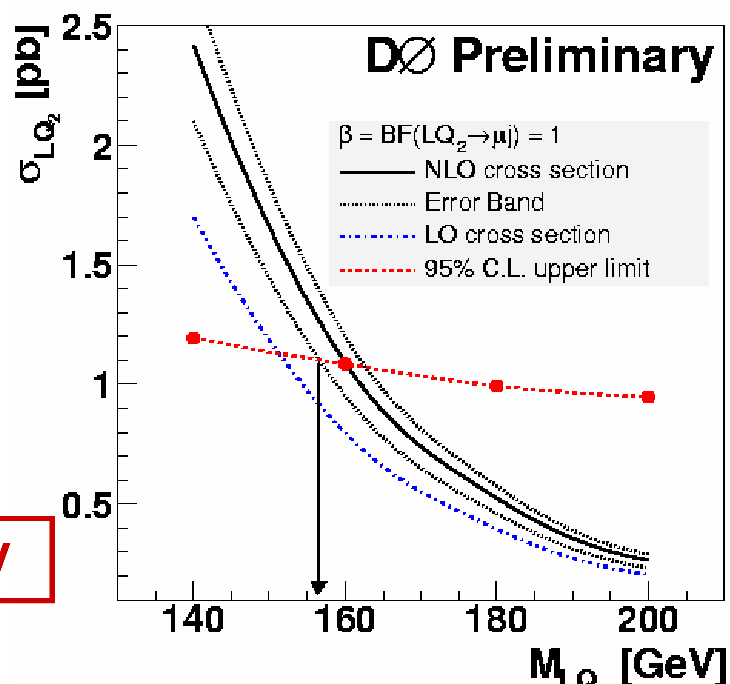
2nd Generation Leptoquarks

- Lum = 30 pb^{-1}
- LQ2LQ2 $\rightarrow \mu^+\mu^- qq$
  - 2 opposite sign muons with Pt > 15 GeV
  - 2 jets with Pt > 20 GeV
  - ST > 300 GeV
  - Mμμ > 110 GeV

$$S_T \equiv \sum E_T(\text{of } 2\mu 2j)$$



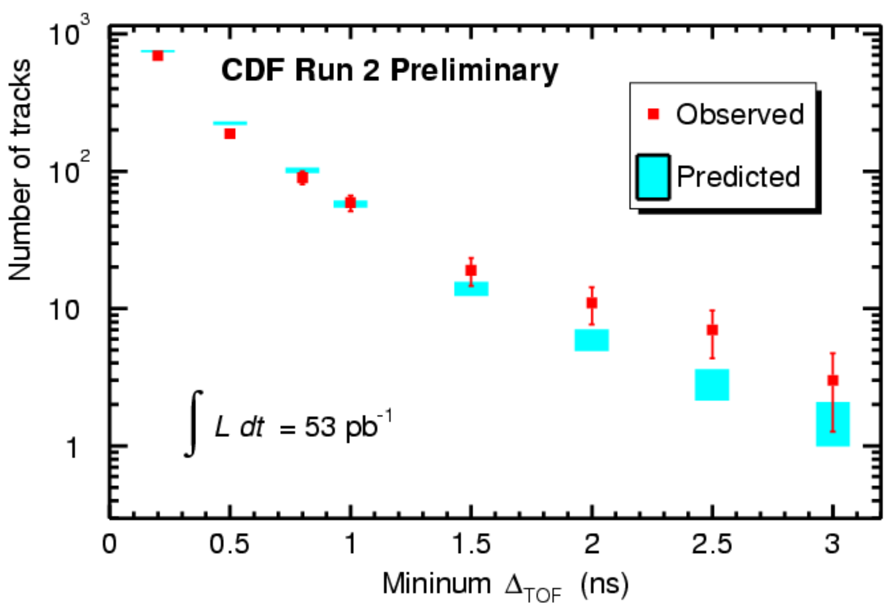
	no $M_{\mu\mu}$ cut	$M_{\mu\mu}$ > 110 GeV
Data	18	0
Drell-Yan	21.5 ± 1.4	4.0 ± 0.6
WW	0.002 ± 0.001	0.001 ± 0.001
Top	0.193 ± 0.004	0.081 ± 0.003
LQ 160 GeV	4.8 ± 0.1	3.5 ± 0.1



M(LQ2) > 157 GeV (30 pb^{-1}) , Run I : 200 GeV

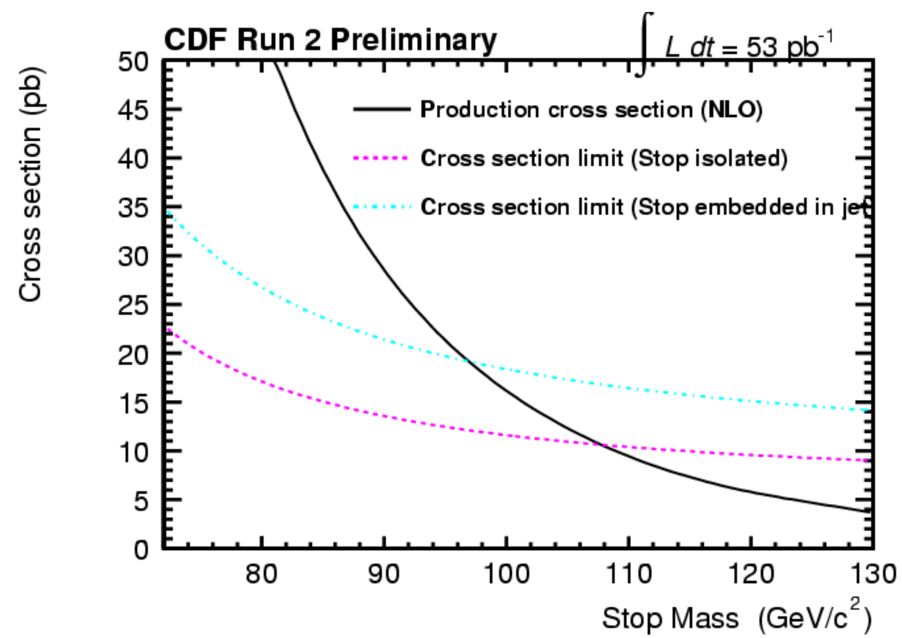
Charged Massive Stable Particles

- **Long lived stable particles escaping the detector ("heavy muon")**
- **Isolated, slow moving :**
  - **use the Time Of Flight detector**



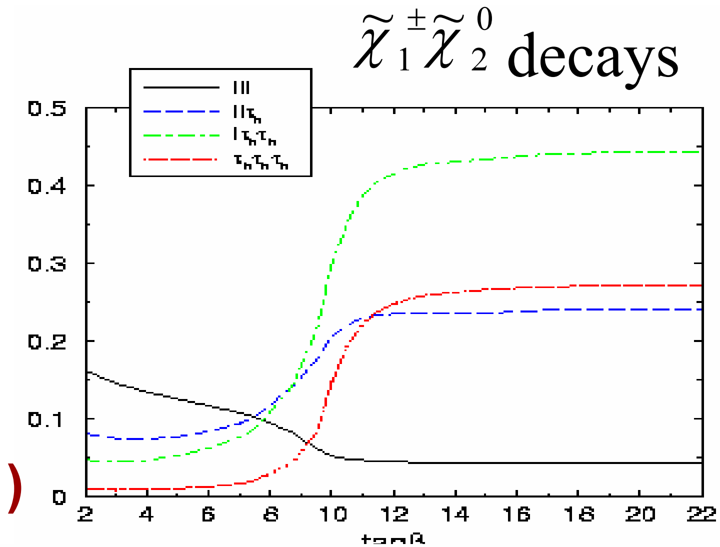
- **Data sample : 53 pb^{-1}**
  - **2.9 ± 0.7 ± 3.1 background events**
  - **7 events observed**

Stable stop scenario :
M(stop) > 107 GeV

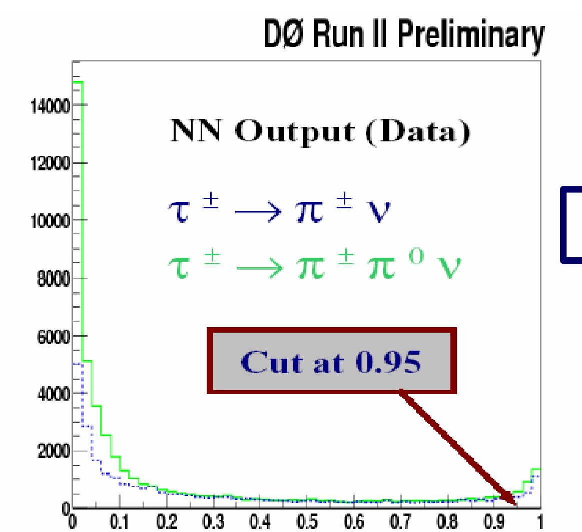


Of the importance of the tau lepton

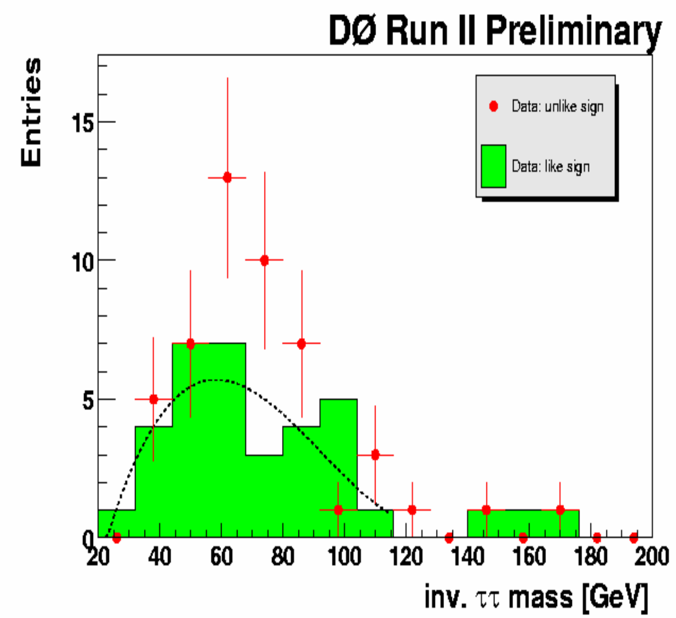
- **SUSY :**
  - Include tau's to improve leptonic channels
  - Anyway, tau dominates at large tan β
- **Higgs :**
  - investigate tau channels to extend sensitivity



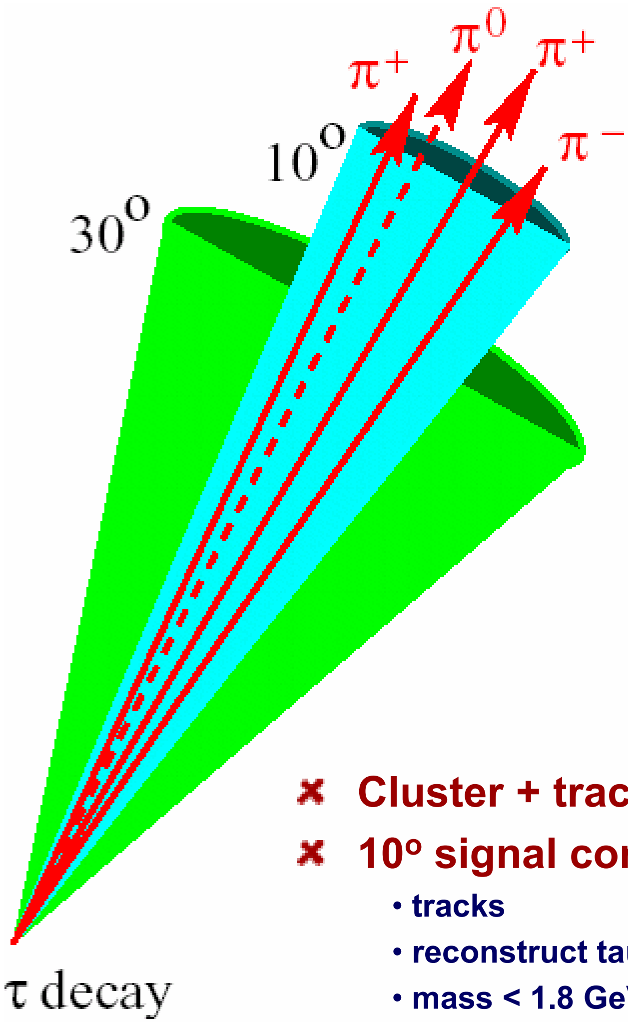
- **Two analysis in DØ seeing Z →τ⁺τ⁻ (50 pb-1)**
  - electron and hadronic tau decays
  - muon and hadronic tau decays

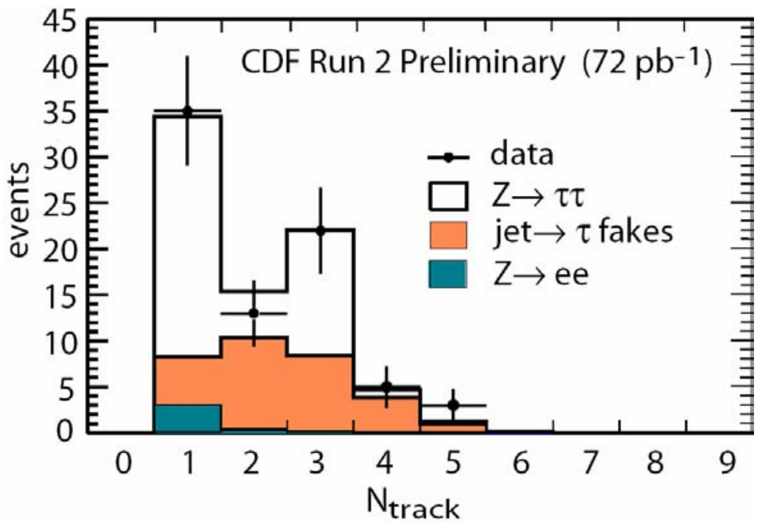


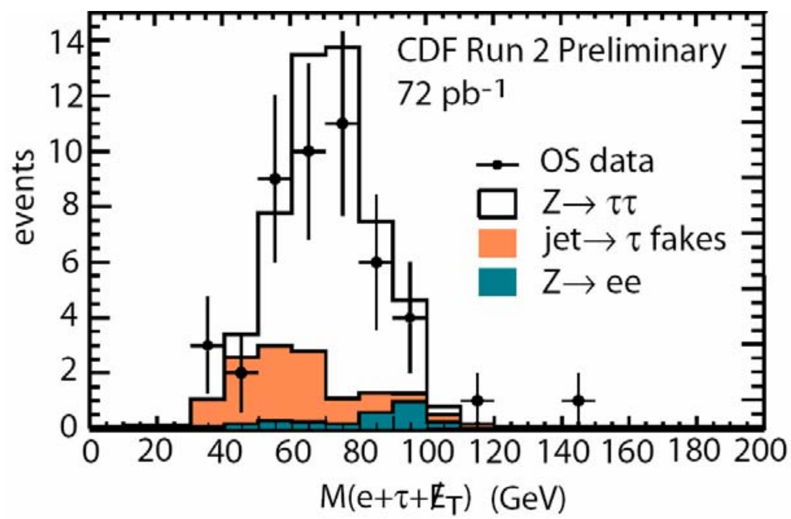
Use NN for tau ID



Of the importance of the tau lepton (2)





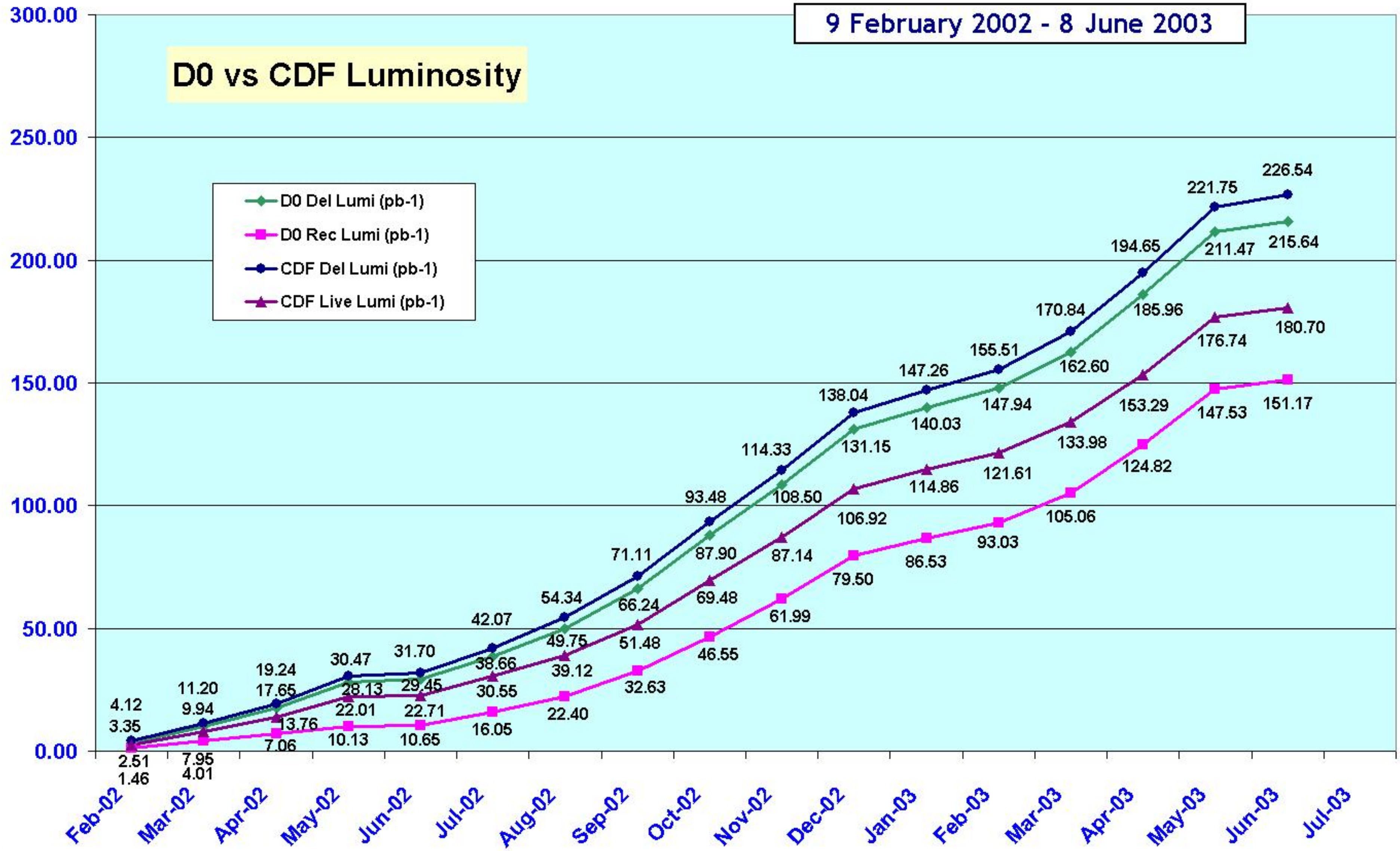


- **Cluster + track seed**
- **10° signal cone:**
  - **tracks**
  - **reconstruct tau**
  - **mass < 1.8 GeV**
- **30° track isolation cone:**
  - **compare Ecal and sum E tracks and taus**

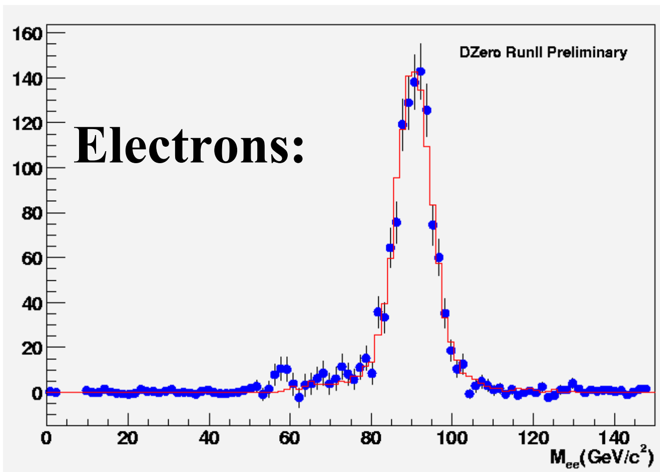
Conclusion

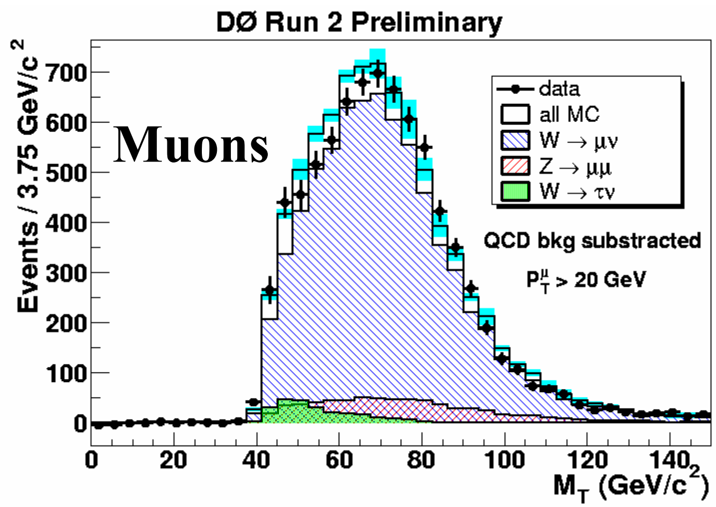
- CDF/DØ results based on 50-80 pb^{-1} have been presented
- The effects of the higher collider energy and of improved detector capabilities can already be seen in an increased sensitivity with respect to Run I.
- A lot of analyses are in progress and new results are expected in a near future :
  - as the accumulated luminosity increases
    - ✓ This summer : Luminosity Run II > Luminosity Run I
  - as the understanding of the detectors improves
    - ✓ Tau ID
    - ✓ B-tagging
    - ✓ …
  - as the trigerring capabilities get extended
- With the basics now firmly established, we can look forward with confidence to the many inverse femtobarns to come, and – why not? - to exciting discoveries

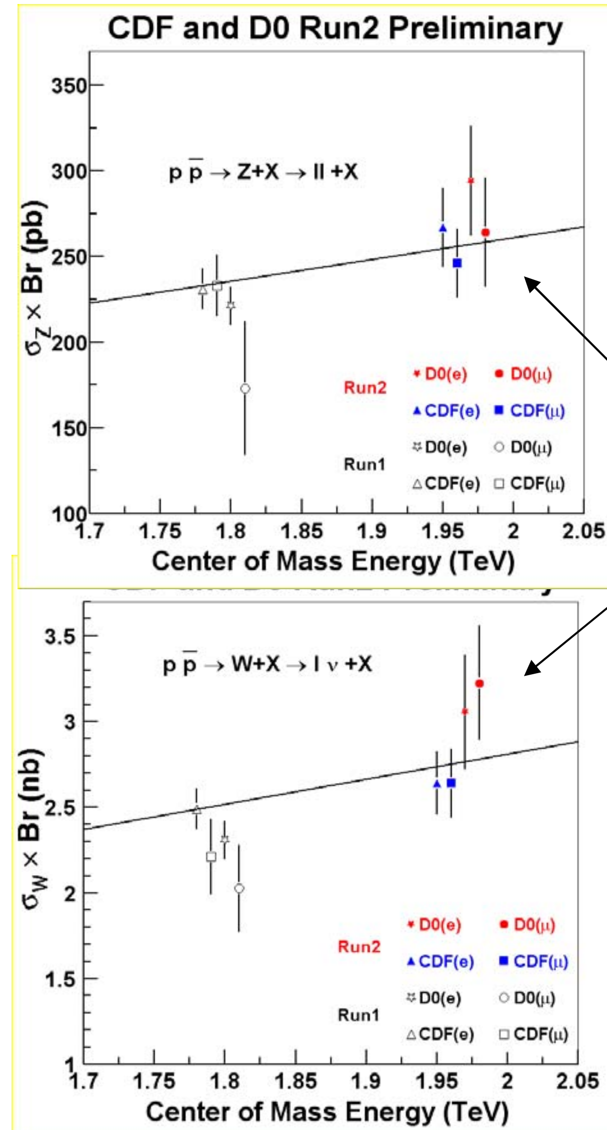
Lumi


9 February 2002 - 8 June 2003
D0 vs CDF Luminosity
D0 Del Lumi (pb-1)
D0 Rec Lumi (pb-1)
CDF Del Lumi (pb-1)
CDF Live Lumi (pb-1)
300.00
250.00
200.00
150.00
100.00
50.00
0.00
4.12
3.35
2.51
1.46
11.20
9.94
7.95
4.01
19.24
17.65
13.76
7.06
30.47
28.13
22.01
10.13
31.70
29.45
22.71
10.65
42.07
38.66
30.55
16.05
54.34
49.75
39.12
22.40
71.11
66.24
51.48
32.63
93.48
87.90
69.48
46.55
114.33
108.50
87.14
61.99
138.04
131.15
106.92
79.50
147.26
140.03
114.86
86.53
155.51
147.94
121.61
93.03
170.84
162.60
133.98
105.06
194.65
185.96
153.29
124.82
221.75
211.47
176.74
147.53
226.54
215.64
180.70
151.17
Feb-02
Mar-02
Apr-02
May-02
Jun-02
Jul-02
Aug-02
Sep-02
Oct-02
Nov-02
Dec-02
Jan-03
Feb-03
Mar-03
Apr-03
May-03
Jun-03
Jul-03

DØ : Electron and Muon ID

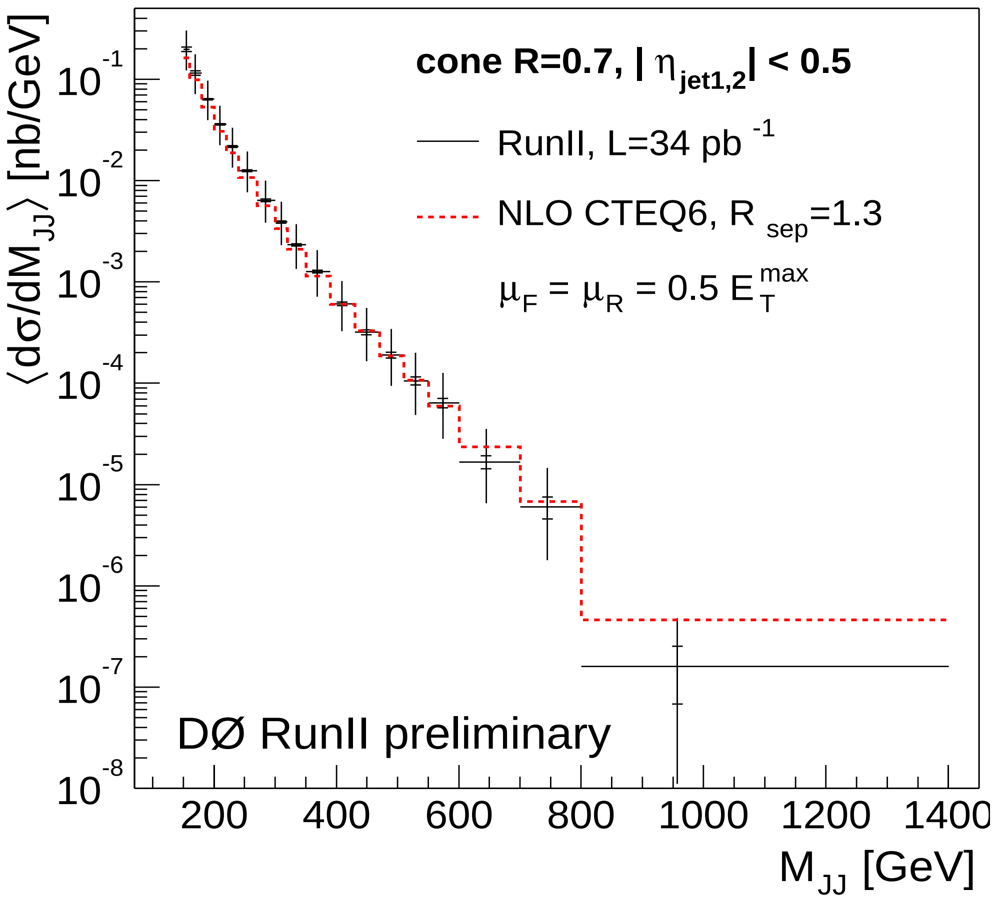


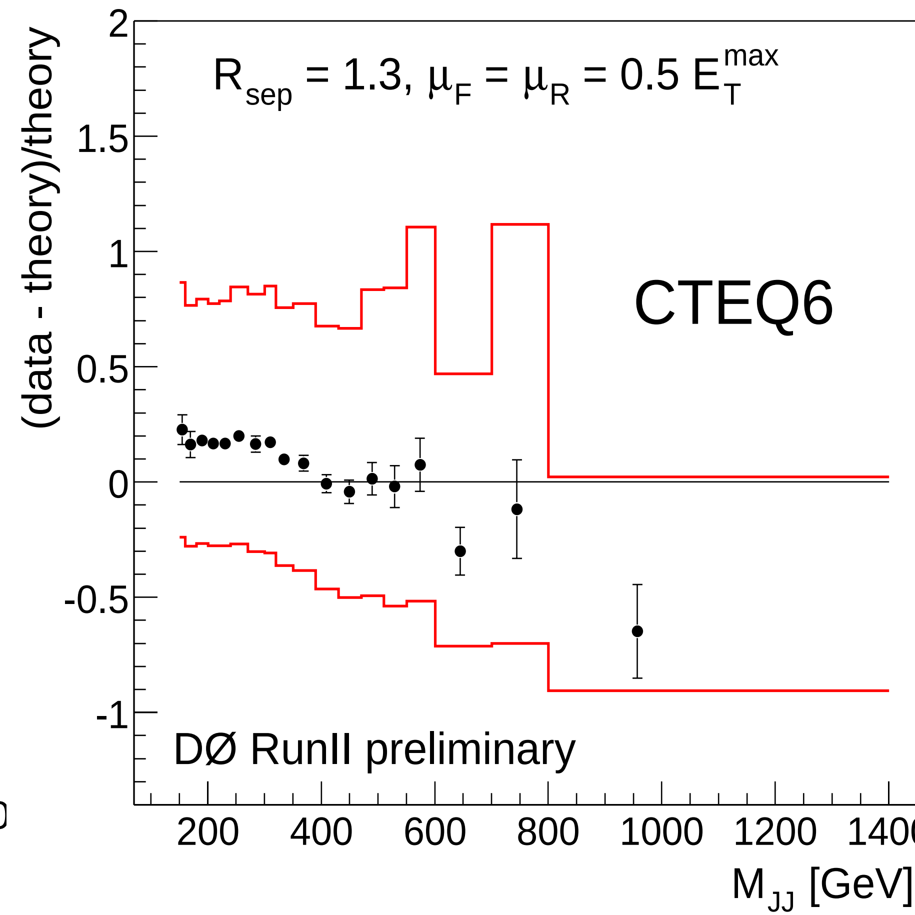




10% Lumi error will decrease to 6% by LP2003

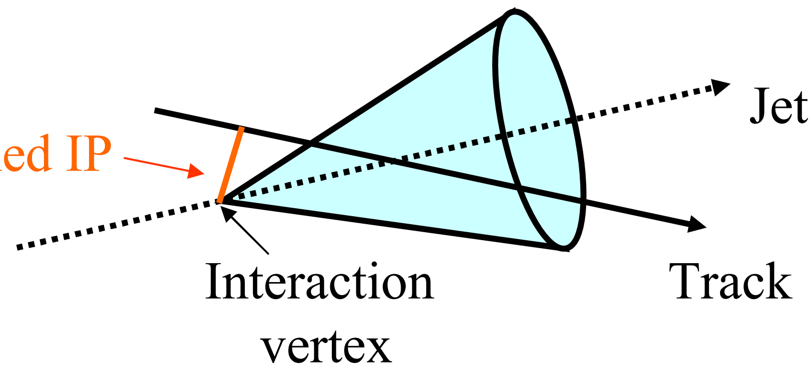
DØ : Jets



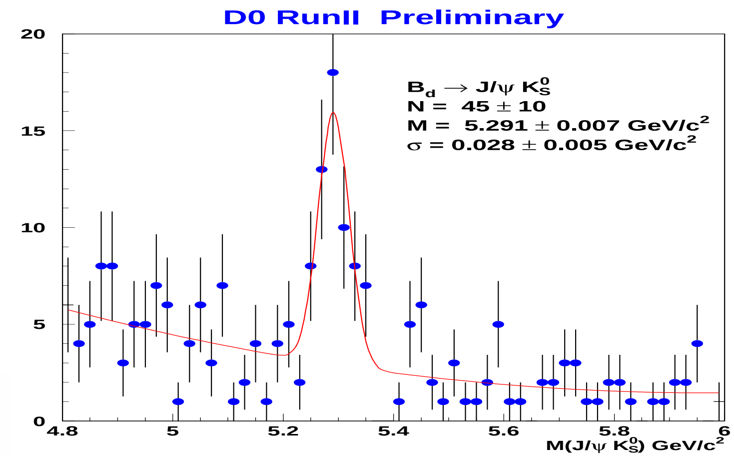


Dominant systematic error: Jet energy scale (will improve with statistics)

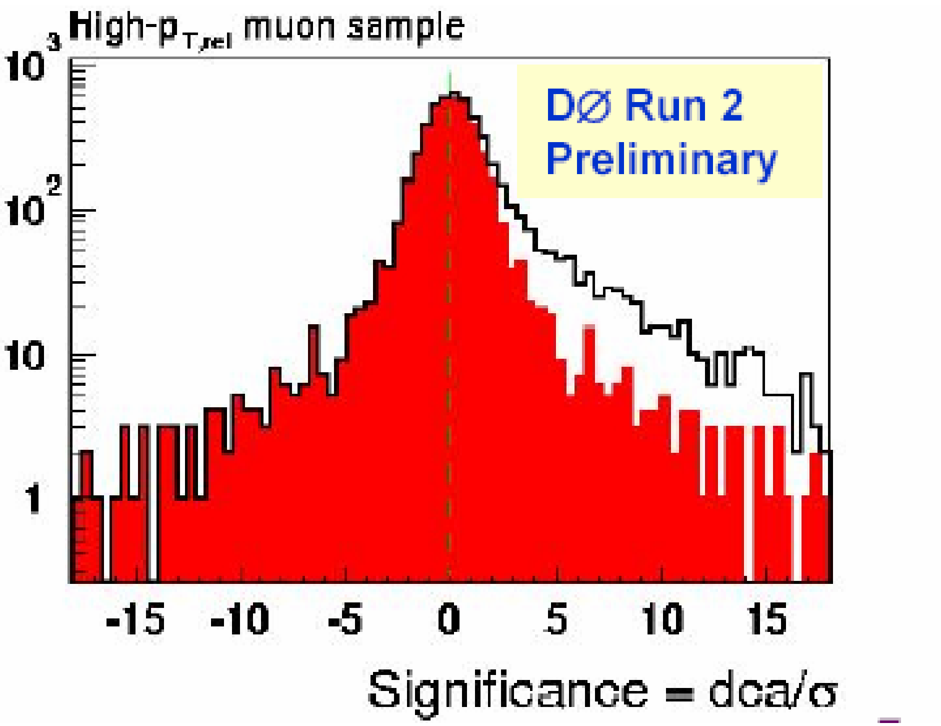
DØ : b-tagging



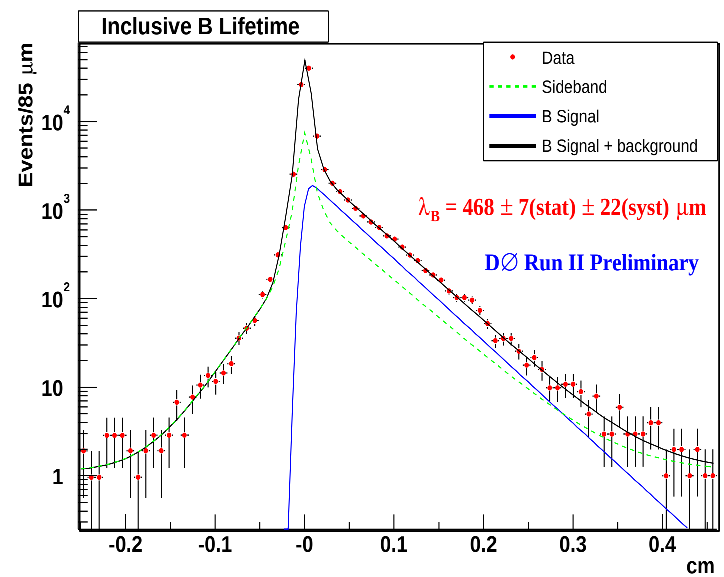
Signed IP
Jet
Interaction vertex
Track



D0 RunII Preliminary
$B_d \to J/\psi K^0_S$
N = 45 ± 10
M = 5.291 ± 0.007 GeV/c^2
σ = 0.028 ± 0.005 GeV/c^2
M(J/ψ K^0_S) GeV/c^2



High-$p_{T,rel}$ muon sample
DØ Run 2 Preliminary
Significance = dca/σ



Inclusive B Lifetime
Data
Sideband
B Signal
B Signal + background
λ_B = 468 ± 7(stat) ± 22(syst) μm
DØ Run II Preliminary
Events/85 μm
cm