Search for Large Extra Dimensions at the Tevatron

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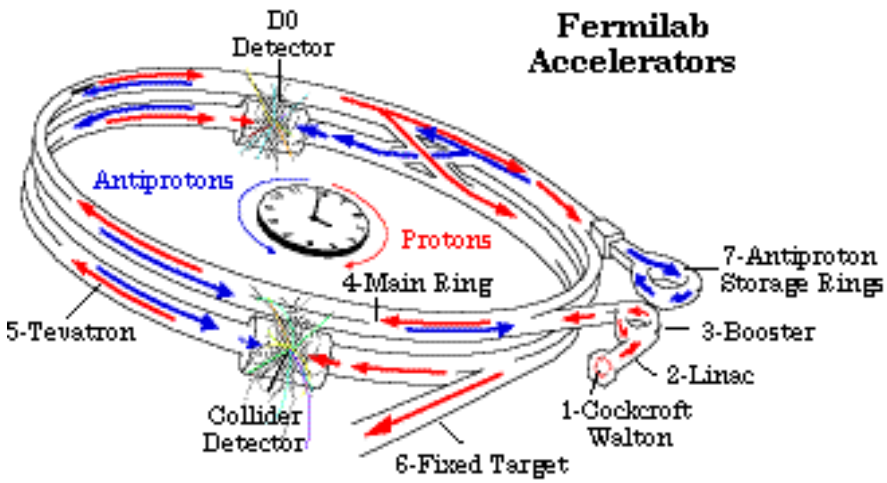
on behalf of the CDF and D0 collaborations

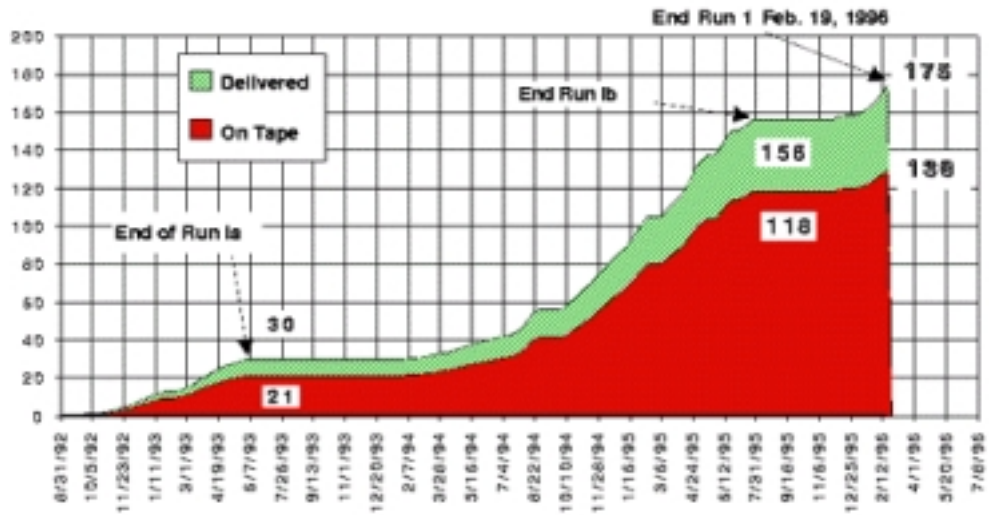
Outline:

- Tevatron in Run I – CDF, D0 detectors
- Signatures of Extra Dimensions
- Results of Searches for Graviton Exchange
- Results of Searches for Graviton Emission
- First Look at Run II

Tevatron Performance in Run I



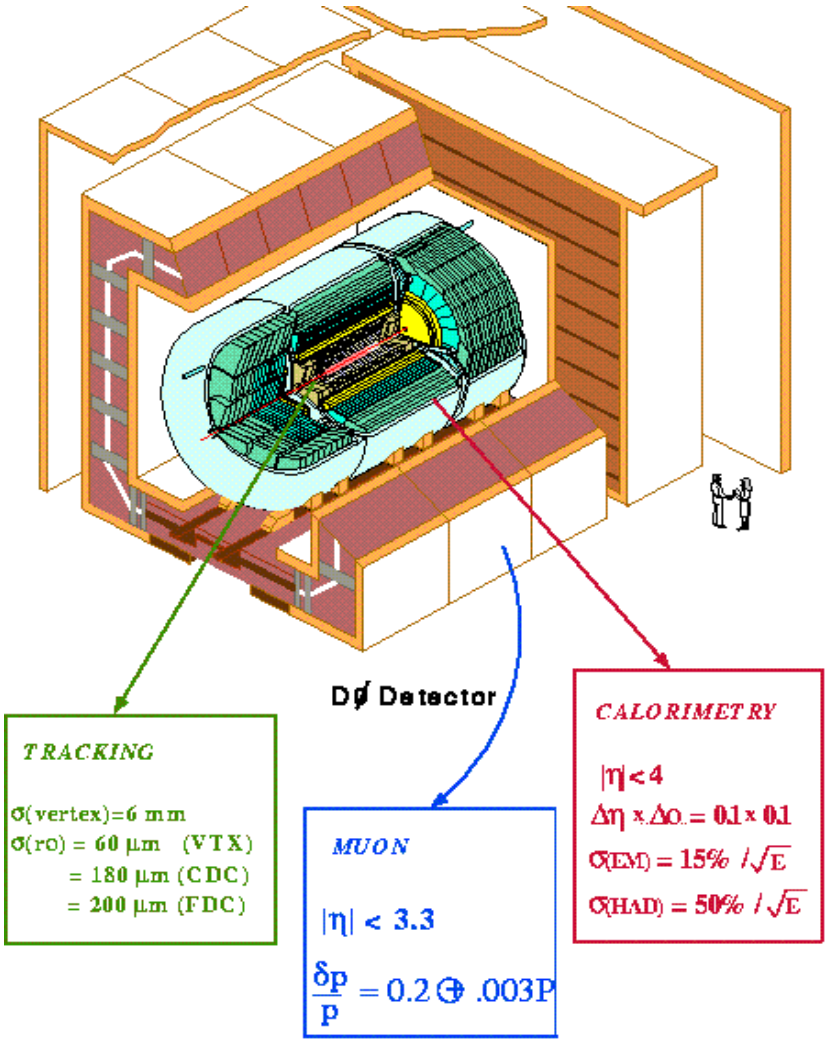
Luminosity

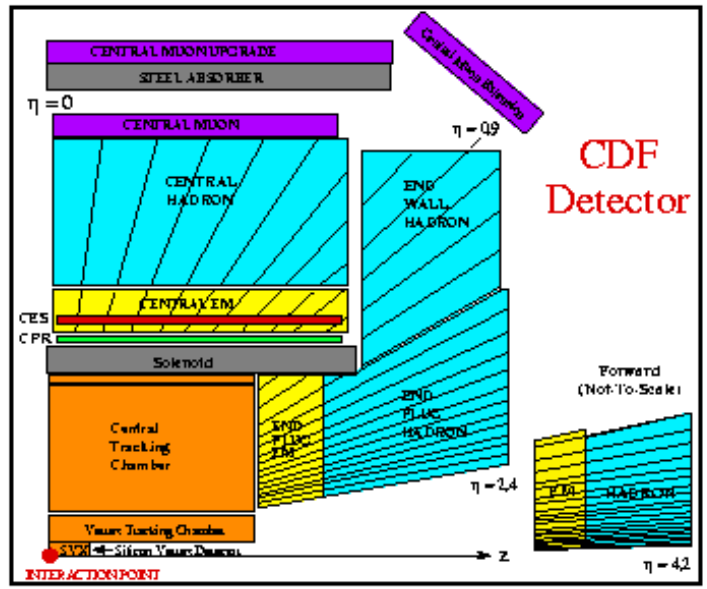


- proton-antiproton collider
- $\sqrt{s}$ = 1.8 TeV

- Run I: Oct 92 – Feb 96
- Integrated Luminosity ~120 pb^{-1}/expt.

CDF and D0 Detectors in Run I





- Silicon Vertex Detector

  impact resolution $\sigma_{d_0} \sim (13 \oplus 40/P_T)\mu m$

- Central Tracking Chamber

  $(\delta P_T/P_T)^2 = (0.0066)^2 \oplus (0.0009 \times P_T)^2$

- Muon and Calorimeter Systems

  high efficiency for e and μ trigger and offline ID

Collider Signatures for Large Extra Dimensions

Collider Searches for LED have focused on models of Arkani-Hamed, Dimopoulos, and Dvali (ADD)

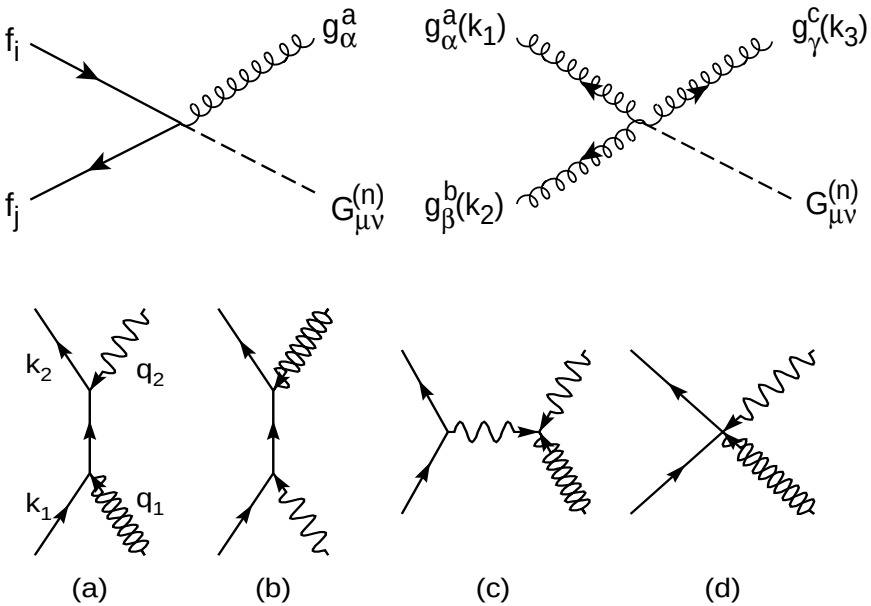
- n Extra Dimensions are compactified
- SM world constrained to 4D brane, gravity can propagate in bulk
- (4+n)D Planck scale related to 4D Planck scale

$$M_{Pl}^2 \sim R^n \; M_S^{2+n}$$

- Signatures:
  - Direct Graviton Emission
  - Virtual Graviton Exchange

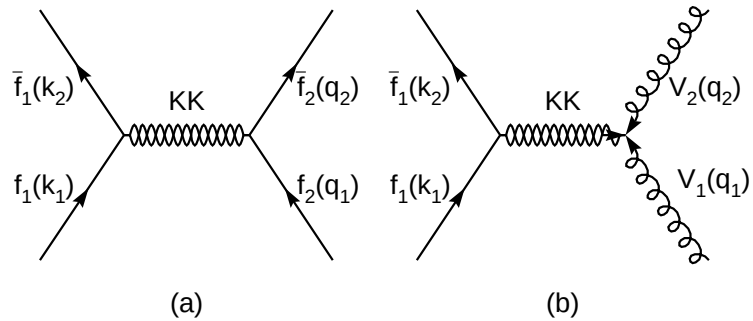
Collider Signatures for Large Extra Dimensions

Direct Graviton Emission



- Jets + Missing E_T
- Photon + Missing E_T

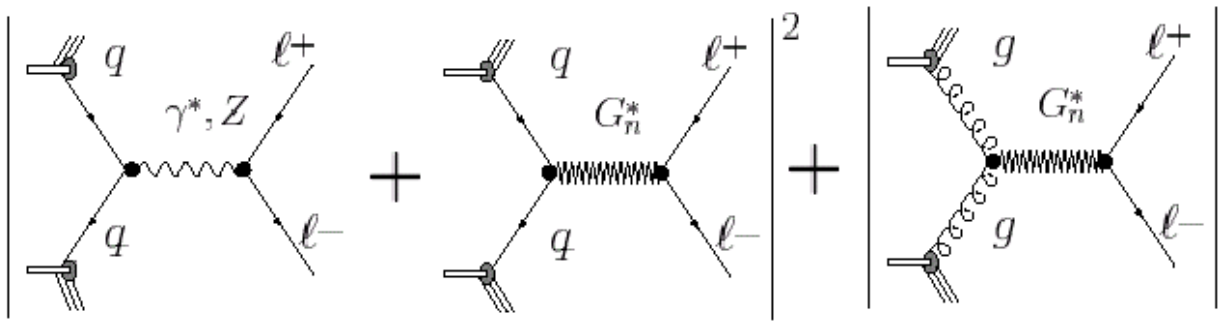
Virtual Graviton Exchange



- Dileptons
- Diphotons

Virtual Graviton Searches

- Pair production in virtual graviton exchange
- Interference between SM and Graviton exchange



- Three terms in cross section: SM, interference, graviton

$$\sigma = \sigma_{SM} + \eta\sigma_{INT} + \eta^2\sigma_{KK} \quad \text{where } \eta = F/M_s^4$$

Definitions of F :

1		(GRW)
$\log(M_S^2/M)$	n=2	(HLZ)
(2/n-2)	n>2	(HLZ)
$2\lambda/\pi$		(Hewett)

D0 Search in Diphotons and Dielectrons

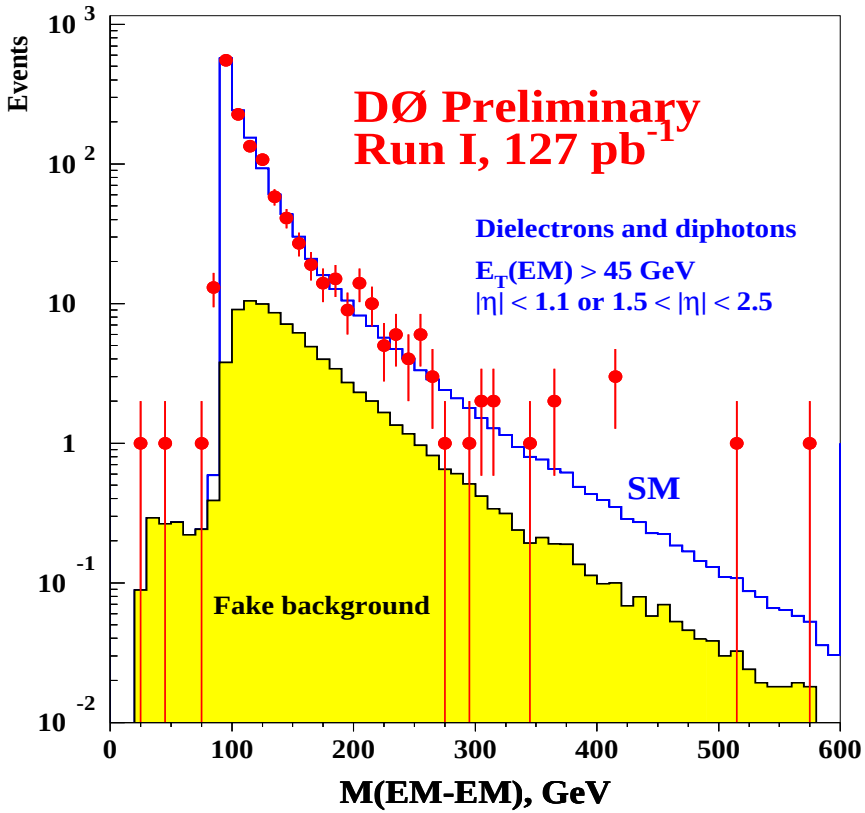
Combine Diphotons and Dielectrons by dropping track requirements on electrons

- Require 2 EM Objects
  - E_T > 45 GeV
  - $|\eta_d|$<1.1 or 1.5< $|\eta_d|$<2.5
  - $\not\!\!E_T$ < 25 GeV
- All Run I data: 127 pb^{-1}
- 1282 events in final sample
  - Main backgrounds: Drell-Yan and $\gamma\gamma$
- Use both invariant mass and $|\cos\theta^*|$ in fit for η

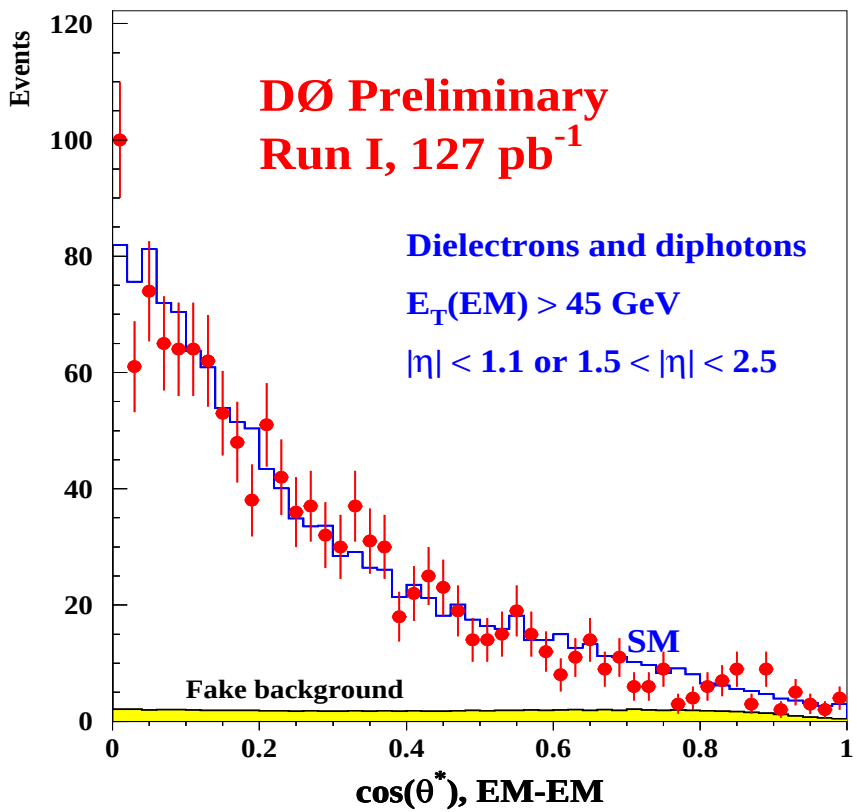
D0 Search in Di-photons and Di-electrons

Using M(EM-EM) and $|\cos\theta^*|$ separately

Comparison of the data with the SM predictions



Comparison of the data with the SM predictions

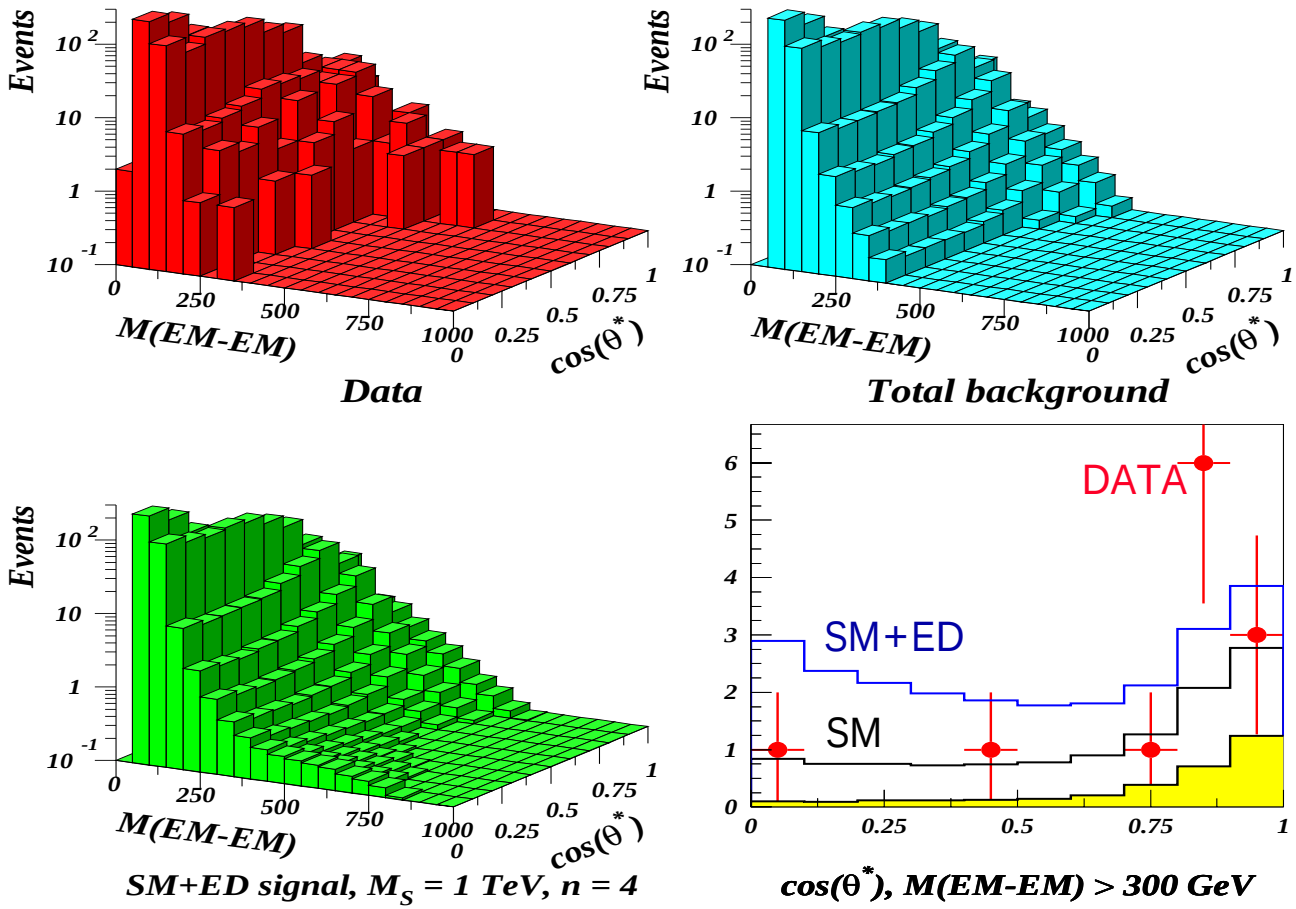


D0 Search in Diphotons and Dielectrons

Comparison of the data and the SM predictions

Combine M(EM-EM) and $|\cos\theta^*|$ in final fit

DØ Preliminary, Run I, 127 pb^{-1}



D0 Search in Diphotons and Dielectrons

- Data agrees well with SM

- No excess of events at large M(EM-EM) and small $|\cos\theta^*|$ where signal would dominate

- Set limits on M_S

Limits (95%CL):

M_S > 1.2 TeV (GRW)

> 1.1 TeV (Hewett λ=+1)

> 1.0 TeV (Hewett λ=-1)

HLZ:

n	M_S(TeV)
2	1.4
3	1.4
4	1.2
5	1.1
6	1.0
7	1.0

CDF Search in Diphotons

Cross-Section for $p\bar{p} \to \gamma\gamma + X$

$$\frac{d\sigma}{dM_{\gamma\gamma}} = \frac{d\sigma}{dM_{\gamma\gamma}}\bigg|_{SM} + \eta\frac{d\sigma}{dM_{\gamma\gamma}}\bigg|_{INT} + \eta^2\frac{d\sigma}{dM_{\gamma\gamma}}\bigg|_{KK} \qquad \eta = \frac{\lambda}{M_S^4}$$

Event Selection:

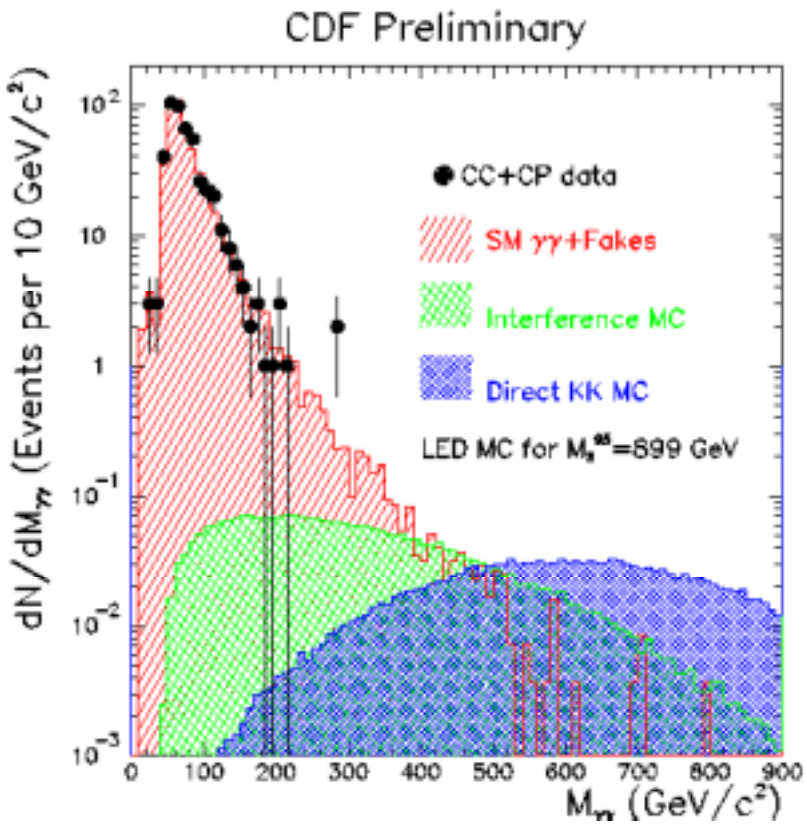
- $E_T(\gamma)$>22 GeV, $|\eta|$<1
- Use central-central (CC) and central-plug (CP)

Results:

	CC	CP
Data	287	192
SM	96±63	76±31
Fakes	184±63	132±28

M_s Limits (95%CL):

- 899 GeV (λ=-1 Hewett)
- 797 GeV (λ=+1 Hewett)



CDF Search in Dielectrons

Similar to Diphoton Analysis

$$\frac{d\sigma}{dM_{ll}} = \frac{d\sigma}{dM_{ll}}\bigg|_{SM} + \eta\frac{d\sigma}{dM_{ll}}\bigg|_{INT} + \eta^2\frac{d\sigma}{dM_{ll}}\bigg|_{KK} \qquad \eta = \frac{\lambda}{M_S^4}$$

Data: 3319(CC), 3825(CP) evts

Perform Simultaneous Fit for:

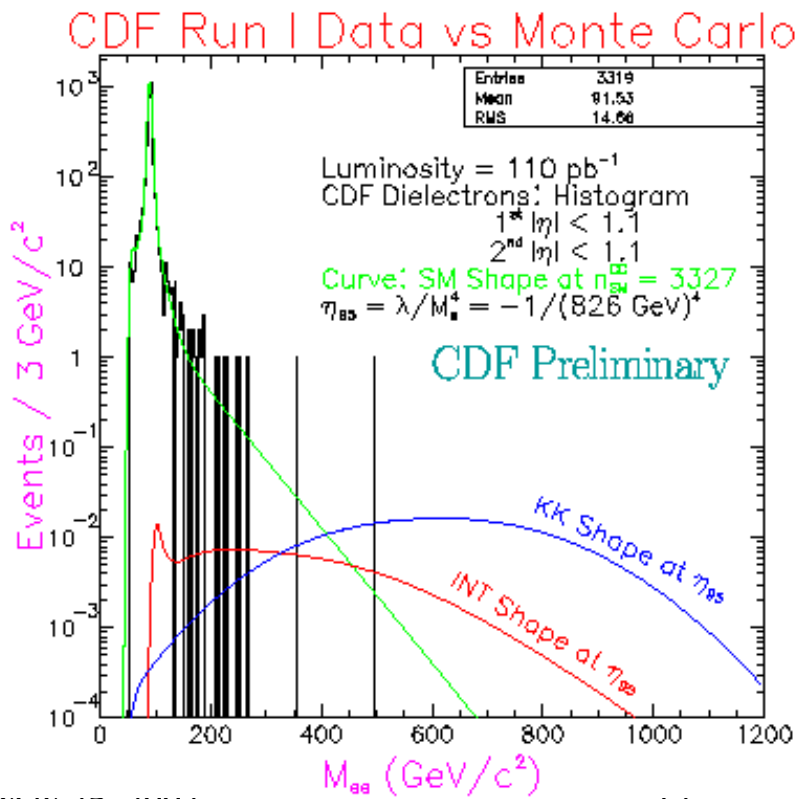
$n_{SM}(CC)$, $n_{SM}(CP)$, $n_{BKG}(CP)$, η

Results:

	Expected	Fit
$n_{SM}(CC)$	3463±223	3327±56
$n_{SM}(CP)$	3883±292	3687±63
$n_{BKG}(CP)$	224±71	151±24

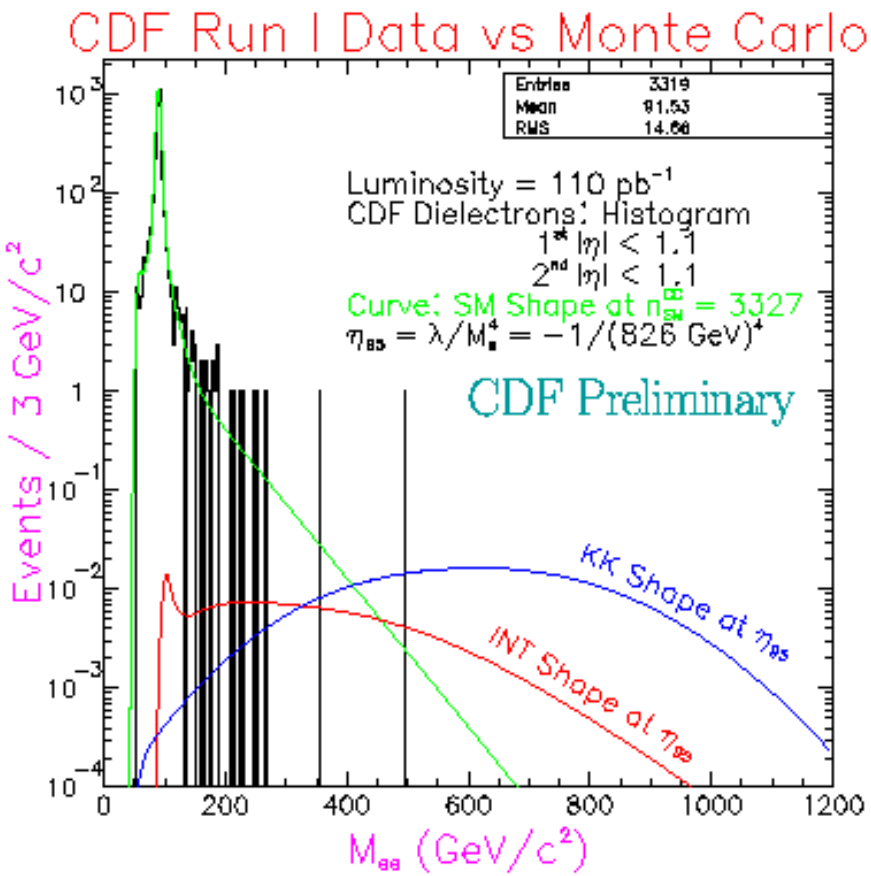
M_s Limits (with K=1.3):

- 826 GeV (λ=-1 Hewett)
- 808 GeV (λ=+1 Hewett)

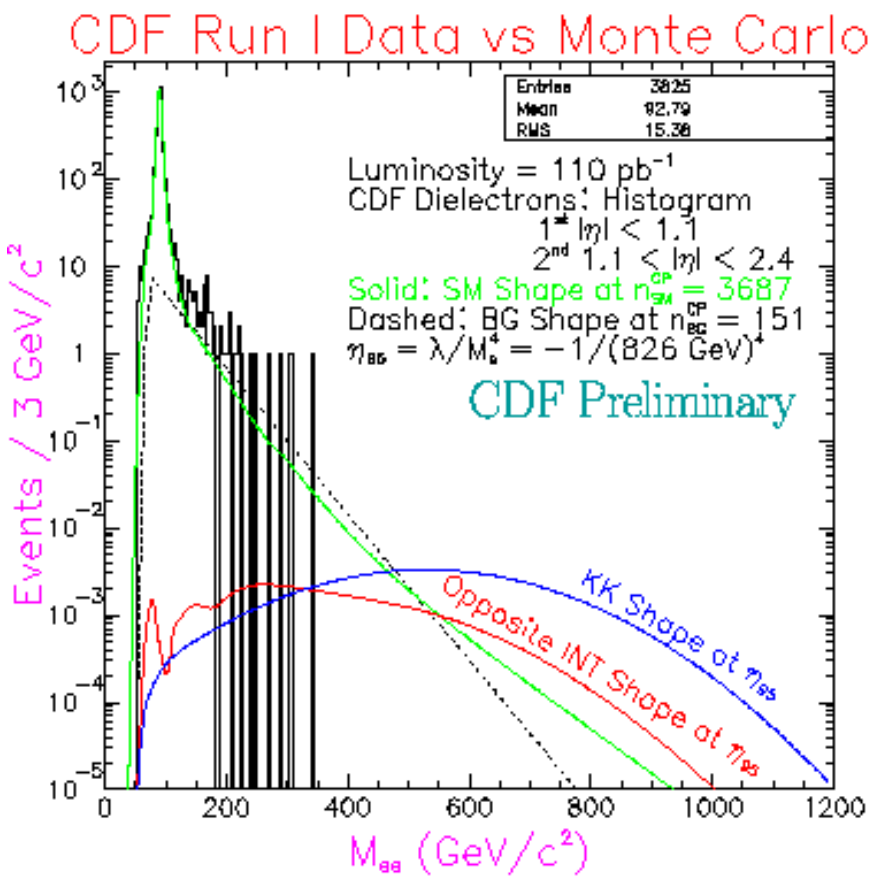


CDF Search in Dielectrons

Central-Central Dielectrons



Central-Plug Dielectrons



CDF Search in Diphotons and Dielectrons

Combine M_S Limits(GeV) from Dileptons and Diphotons

	Dilepton	Dilepton+ Diphoton
GRW	925	1051
Hewett $\lambda=+1$	808	853
Hewett $\lambda=-1$	826	939
n=3 (HLZ)	1100	1250
n=4 (HLZ)	925	1051
n=5 (HLZ)	836	950
n=6 (HLZ)	778	884
n=7 (HLZ)	735	836

CDF and D0 Results for Diphotons and Dielectrons

Run I M_S Lower Limits from Graviton Exchange (GeV)

Model	CDF	D0
GRW	1051	1200
Hewett $\lambda=+1$	853	1100
Hewett $\lambda=-1$	939	1000
n=3 (HLZ)	1250	1400
n=4 (HLZ)	1051	1200
n=5 (HLZ)	950	1100
n=6 (HLZ)	884	1000
n=7 (HLZ)	836	1000

LEP:

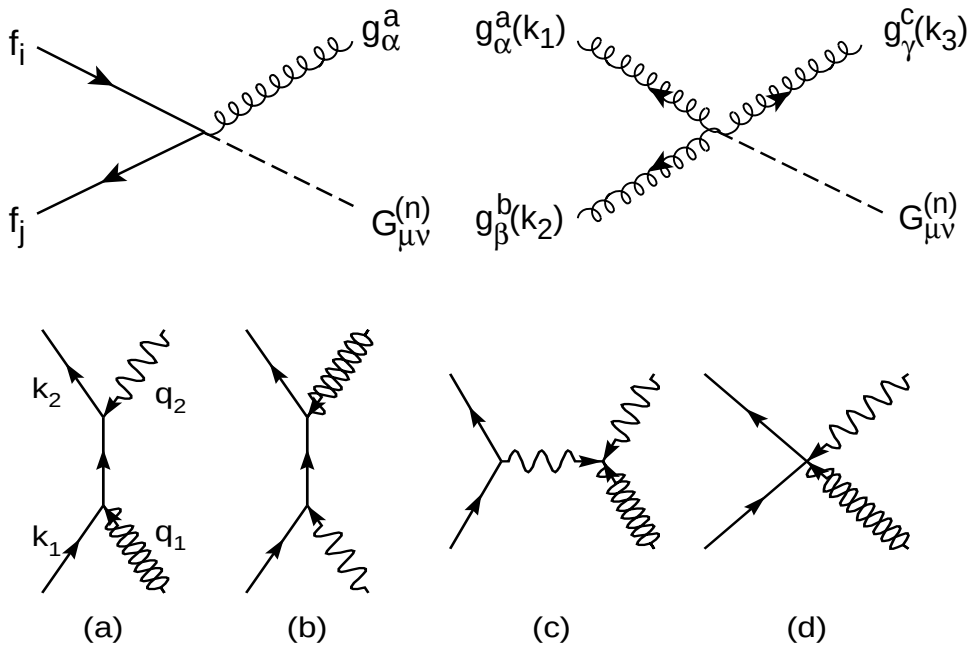
Dileptons(OPAL) $M_S > 1180, 1170$ ($\lambda=+1,-1$)

Diphotons(Comb.) $M_S >$ 970, 940 ($\lambda=+1,-1$)

Graviton Emission Searches

- Graviton produced along with photon or jet

$$q\bar{q} \to G_{kk}g \qquad gg \to G_{kk}g \qquad q\bar{q} \to G_{kk}\gamma$$



- Additional jets possible from ISR, FSR
- Signature is jets or photon + $\not{E}_T$

D0 Search in Jets+$\not\!\!E_T$

Event Selection:

- E_T(jet1)>150 GeV, $|\eta|$<1
- E_T(jet2)<50 GeV
- $\not\!\!E_T$ > 150 GeV
- $|\Delta\phi(\text{Jet2},\not\!\!E_T)|$ > 15^o to reduce QCD background
- Reject events with isolated muons
- Reject cosmic ray events

Background	Expected # Evt
Z → νν+jets	21.0 ± 5.1
W → eν+jets	3.1 ± 0.7
W → μν+jets	0.8 ± 0.3
W → τν+jets	5.3 ± 2.3
QCD/Cosmics	7.8 ± 7.1
Total	38.0 ± 9.6

D0 Search in Jets+$\not\!\!E_T$

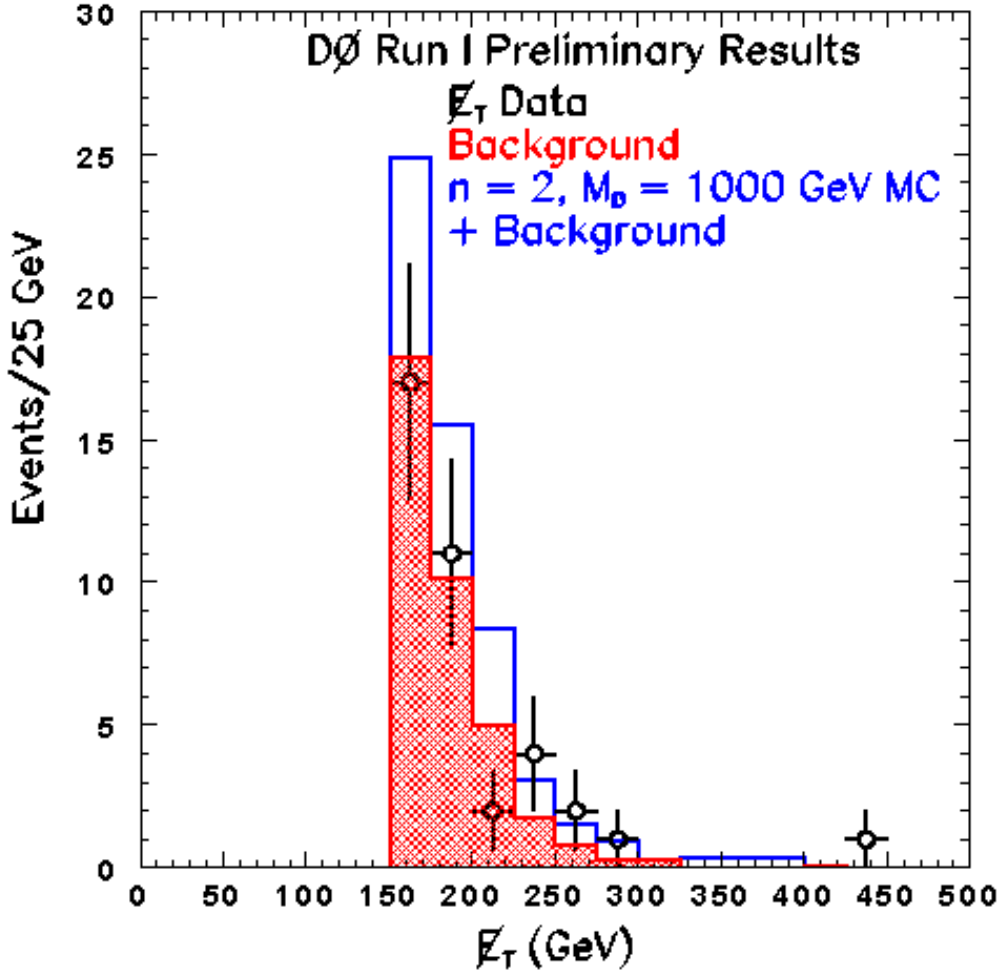
Results in 78 pb^{-1}:

- N(data) = 38
- N(bkgd) = 38.0 ± 9.6

Expected Signal

(n=2, M_S=1TeV)

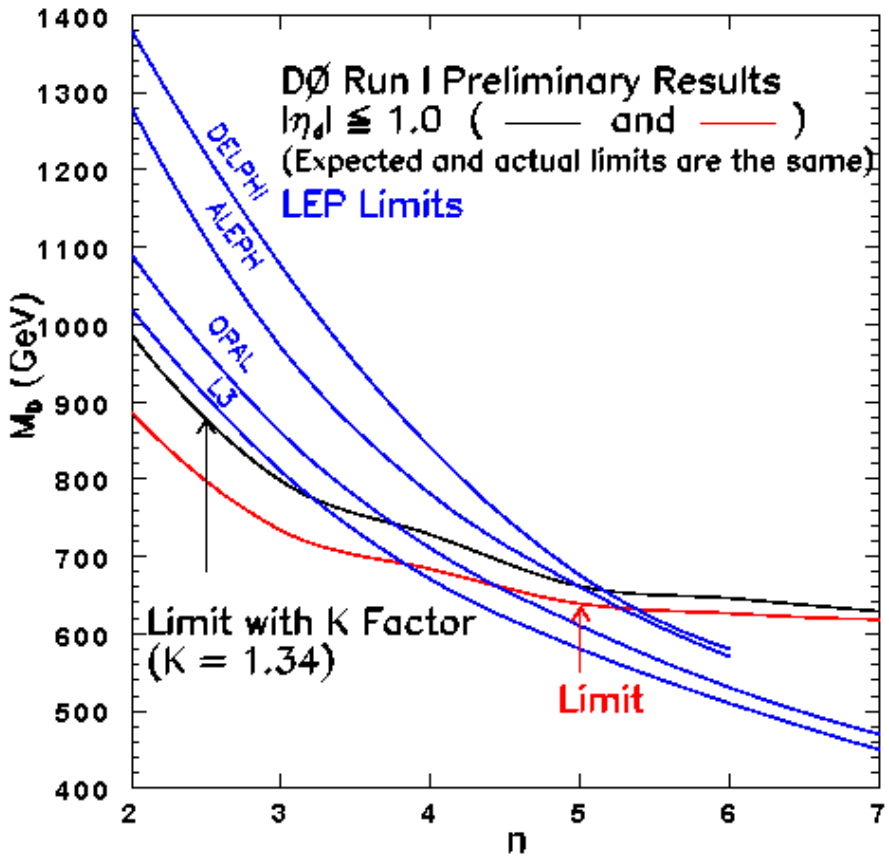
- N(signal)= 19.5 ± 3.9



D0 Search in Jets+$\not{E}_T$

Limits on M_S(GeV) at 95%CL

n	M_S(GeV) K=1.0	M_S(GeV) K=1.34
2	886	987
3	734	797
4	683	728
5	639	661
6	626	646
7	617	629



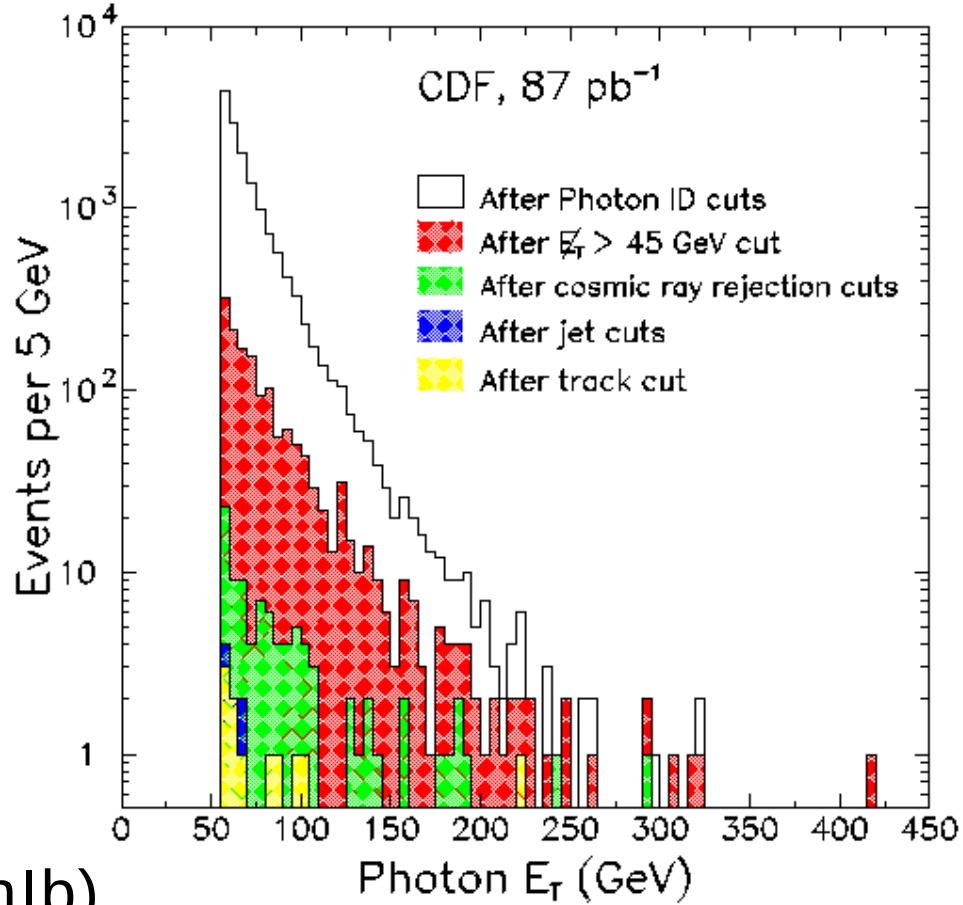
CDF Search in $\gamma + \not\!\!E_T$

Look for graviton emission

$$q\bar{q} \rightarrow G_{kk}\gamma$$

Event Selection:

- $E_T(\gamma)$ >55 GeV, $|\eta(\gamma)|$<1.1
- $\not\!\!E_T$ > 45 GeV
- Remove cosmic ray events
- No jets w/ E_T>15 GeV
- No tracks w/ p_T>5 GeV/c



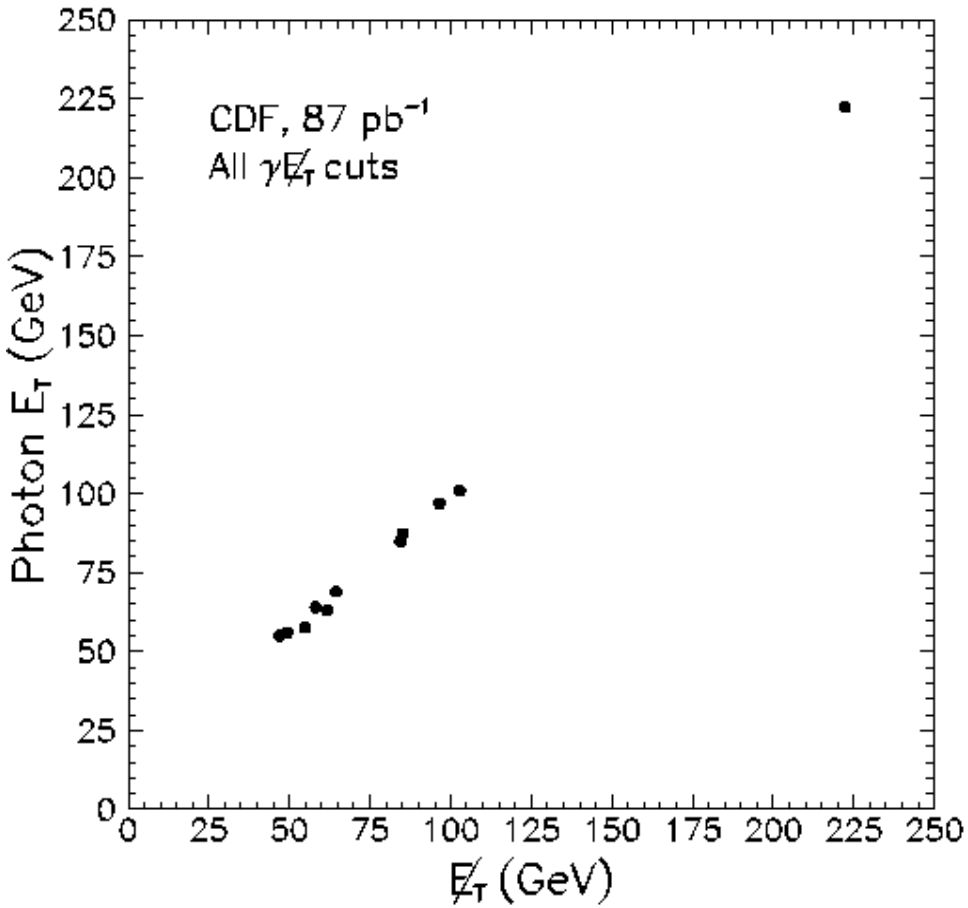
11 events found in 87 pb^{-1} (RunIb)

CDF Search in $\gamma + \not{E}_T$

Backgrounds:

Cosmics	6.3 ± 2.0
$Z\gamma \rightarrow \nu\nu\gamma$	3.2 ± 1.0
$W \rightarrow e\nu$	0.9 ± 0.1
Prompt $\gamma\gamma$	0.4 ± 0.1
$W\gamma$	0.3 ± 0.1
Total	11.0 ± 2.2

Observed in Data 11



Limits (95% CL):

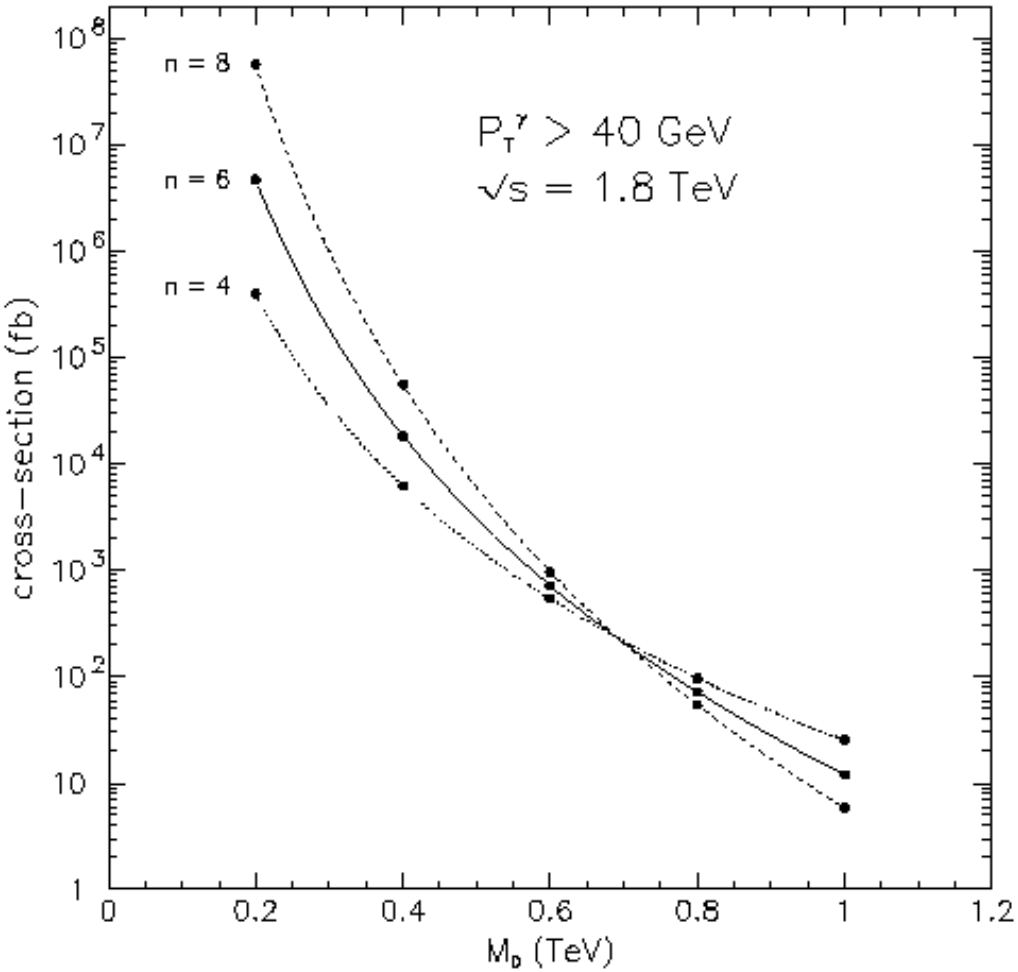
n=4	$M_S > 549$ GeV
n=6	$M_S > 581$ GeV
n=8	$M_S > 602$ GeV

CDF Search in $\gamma + \not{E}_T$

For a given value of n, cross-section falls like $1/M_S^{2+n}$

For low values of M_S cross-section in MC is higher for increasing values of n

At low M_S, limits higher for larger values of n

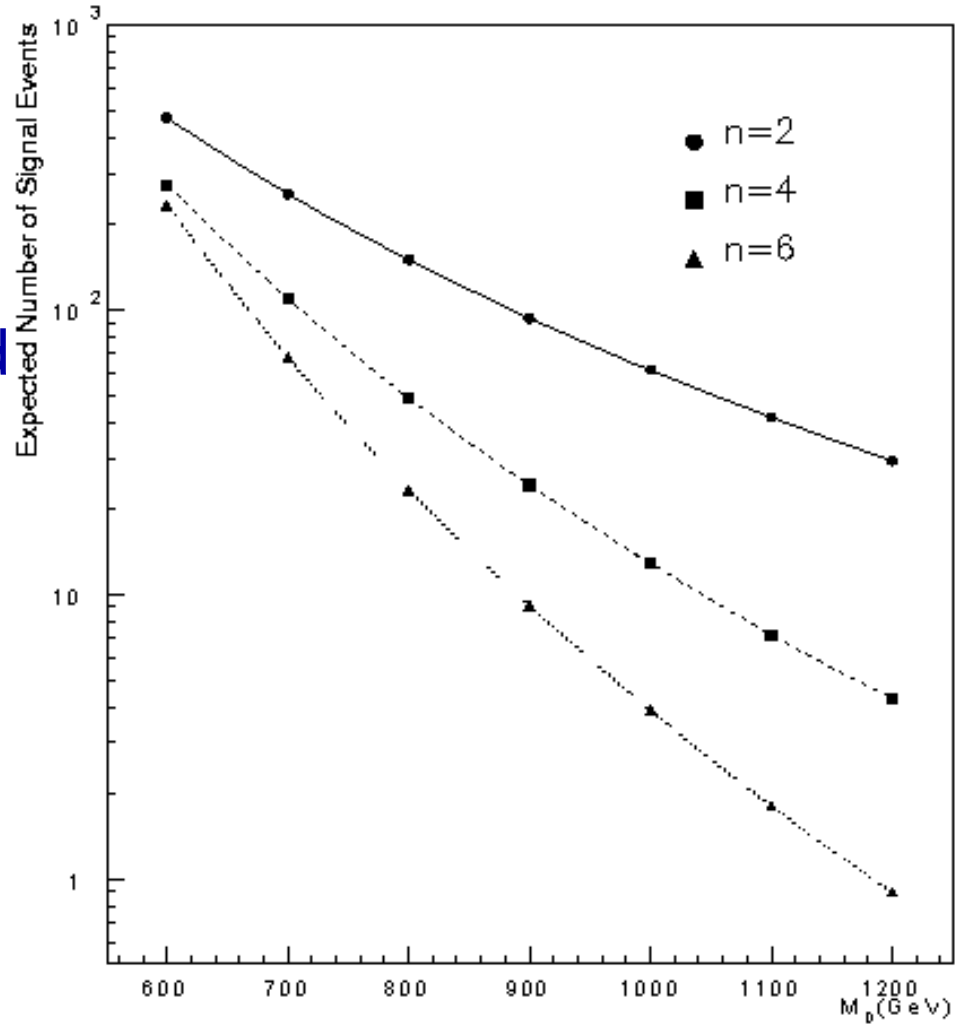


CDF Search in Jets+$\not\!\!E_T$

No limits yet

Preliminary result expected by end of summer

Expected sensitivity for M_S ~900 GeV (n=2)



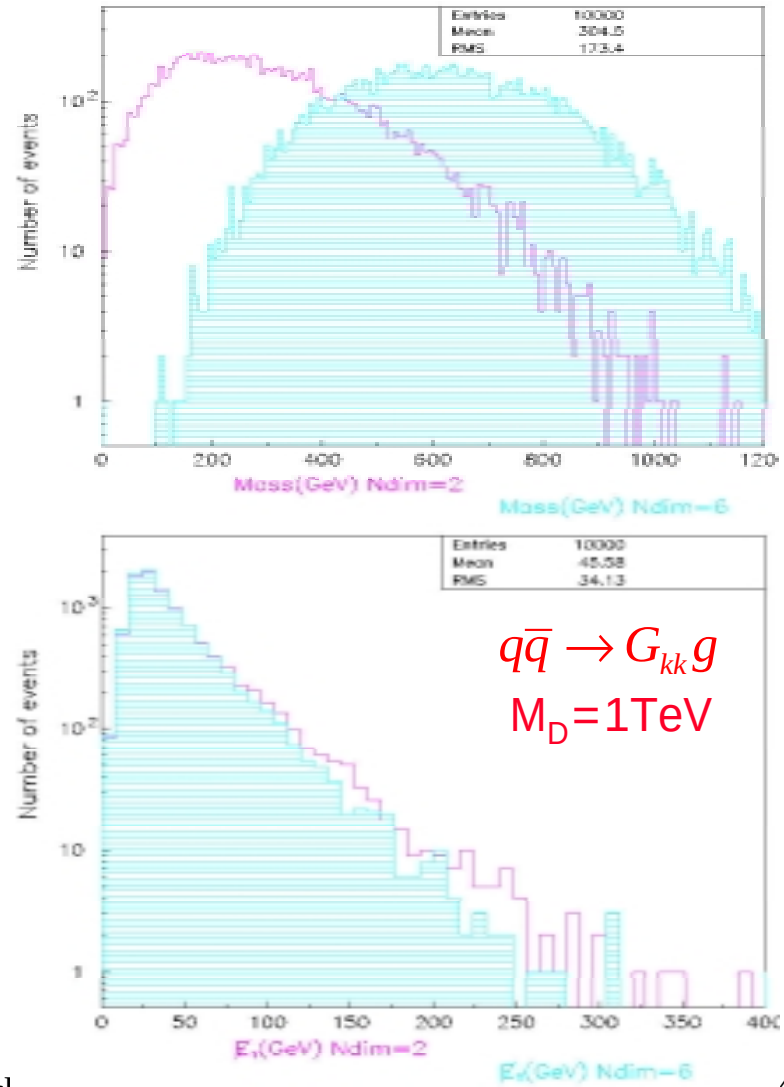
Can We Determine n from $\not{E}_T$?

Graviton mass distribution peaks higher for n=6

No difference seen in $\not{E}_T$

2 competing effects

- Heavier gravitons in n=6 case will have larger E_T
- Heavier gravitons produced closer to threshold due to falling PDFs



Tevatron, Detector Upgrades for Run II

Tevatron Upgrades for Run II

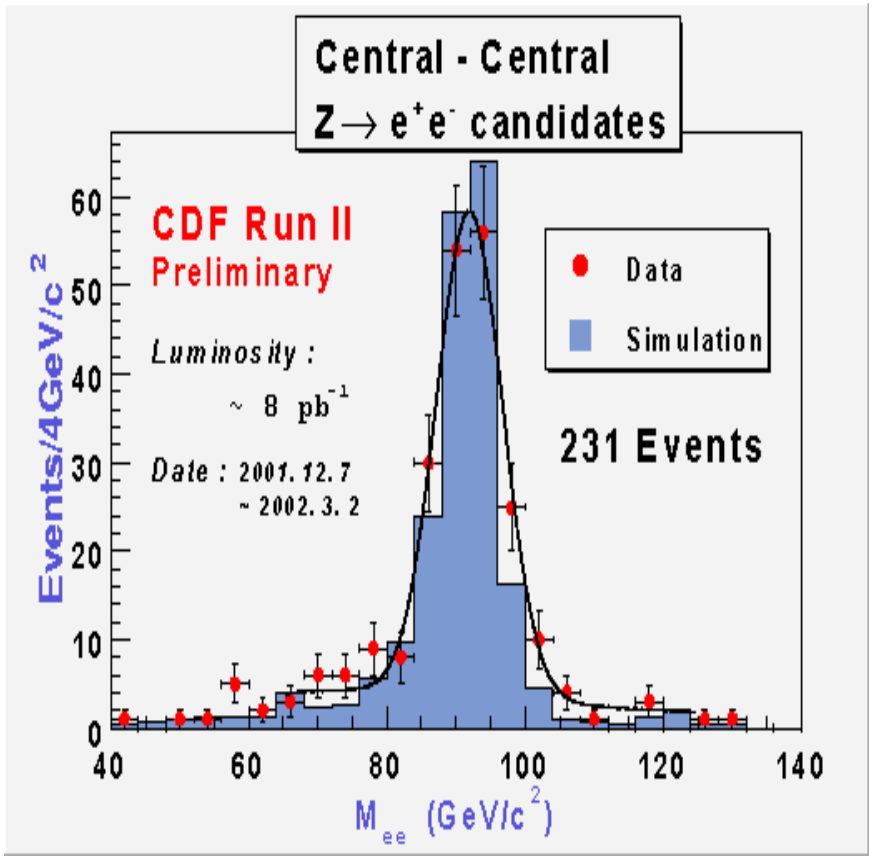
- $\sqrt{s}$ = 1.8 TeV →1.96 TeV
- Crossing rate 3.5 μsec → 396 nsec
- Expect ~200 pb^{-1} by end of year

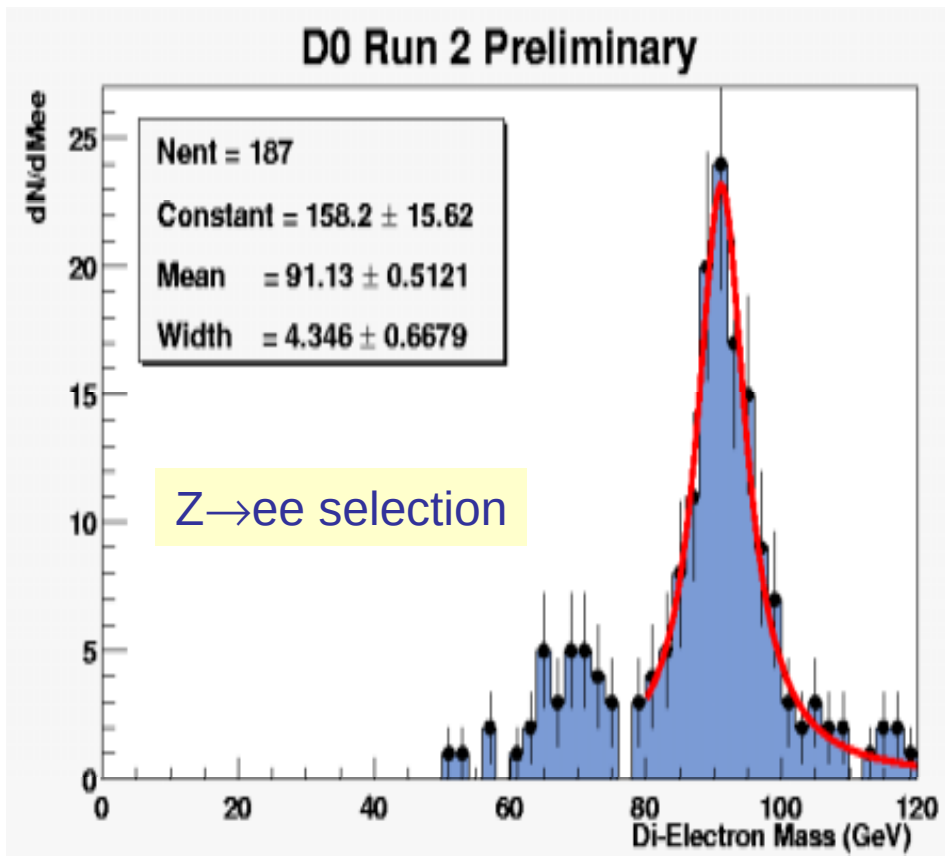
Detector Upgrades for Run II

- D0
  - New 2T solenoid
  - New silicon, fiber tracker
    - Silicon to $|\eta|=3$
  - Retain calorimeter, but faster readout
- CDF
  - New silicon, drift chamber, TOF
  - New secondary vertex trigger
  - New scintillating tile plug cal.
    - Extends to $|\eta|=3.6$

First Look at Run II Data

Z→ee Candidates from CDF and D0





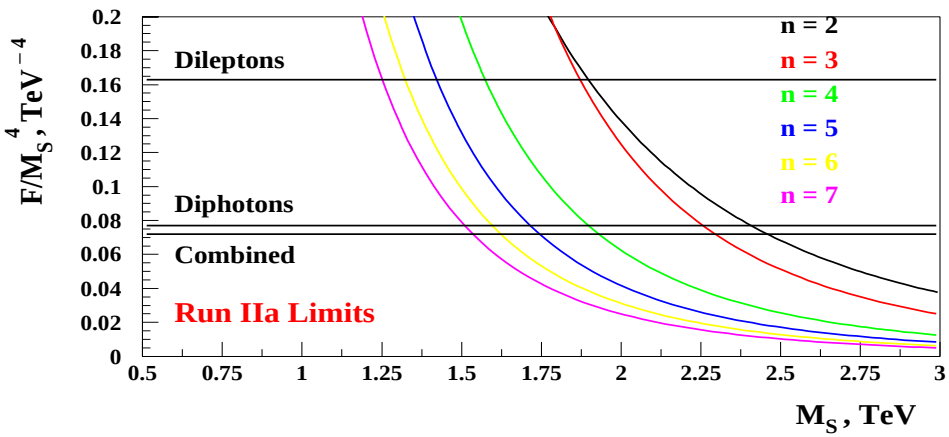
D0 Expected Run II M_S Sensitivity (TeV)

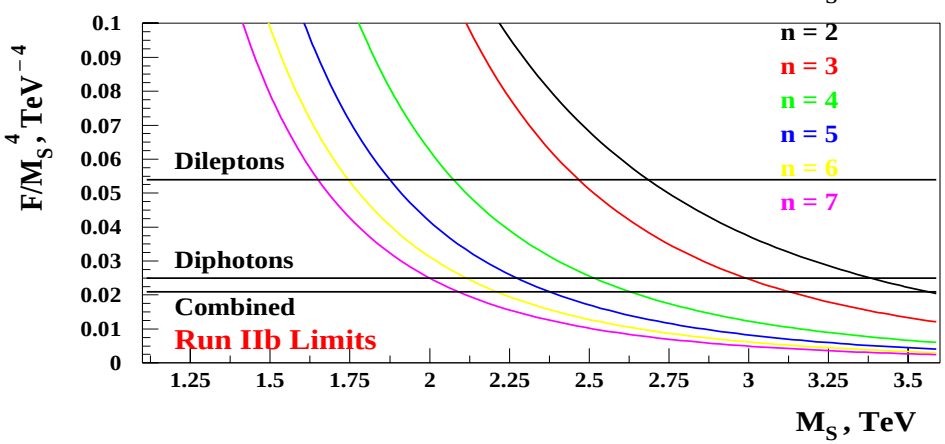
Jets+$\not{E}_T$ Search

n	Early Run II (300 pb^{-1})
2	1.40
3	1.15
4	1.00
5	0.90

Dilepton, Diphoton Search

	Run IIa (2 fb^{-1})	Run IIb (20 fb^{-1})
Dileptons	1.3-1.9	1.7-2.7
Diphotons	1.5-2.4	2.0-3.4
Combined	1.5-2.5	2.1-3.5





First D0 Plots in Virtual Graviton Search in RunII

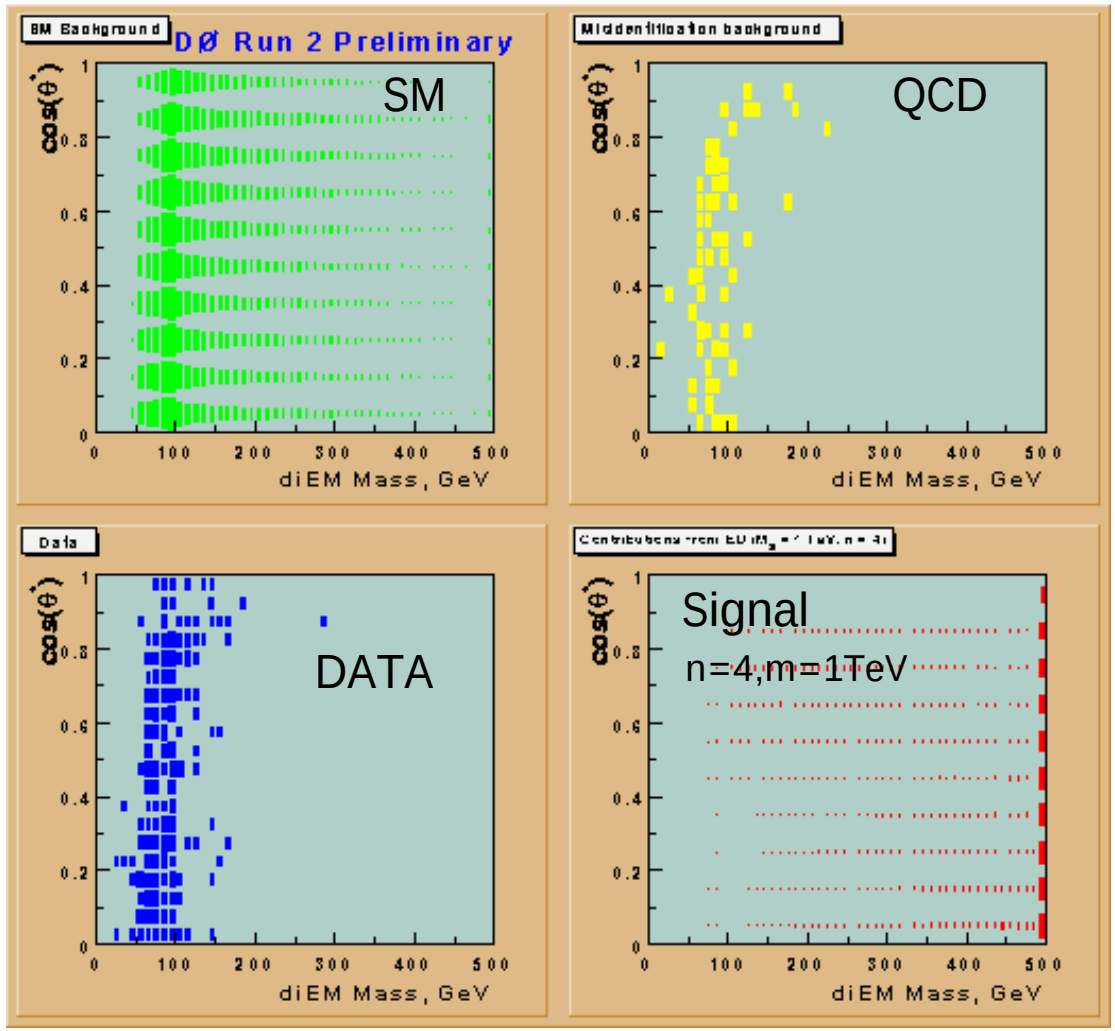
Follows Run I analysis

- Both ee and $\gamma\gamma$
- Use mass, $\cos\theta^*$
- $E_T(EM) > 25$ GeV

First data agrees qualitatively with background prediction

Highest mass candidate consistent with background topology

No limits yet



Conclusion

- Results from Run I analyses nearly complete
  - ➤All should be out by end of summer
  - ➤No evidence yet for Large Extra Dimensions
- Run II has begun at the Tevatron
  - ➤Upgraded D0 and CDF detectors are operating well
  - ➤Expect 100-200 pb^{-1} of data by end of the year
  - ➤First Run II results at next winter conferences