

## New phenomena searches at Tevatron Run I

G.-S. Muanza

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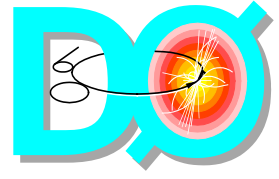
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# New Phenomena Searches at TEVATRON Run I



Steve Muanza, IPN Lyon

On behalf of CDF and D0 collaborations

## Outline

- Run I at the TEVATRON
- Search for SUGRA:
  - dilepton channel at CDF
  - electron channel at D0
- Search for large ED:
  - monojet channel at D0
  - diphoton channel at CDF
- Conclusions

# Collider in Run I



Proton-Antiproton  
Collisions

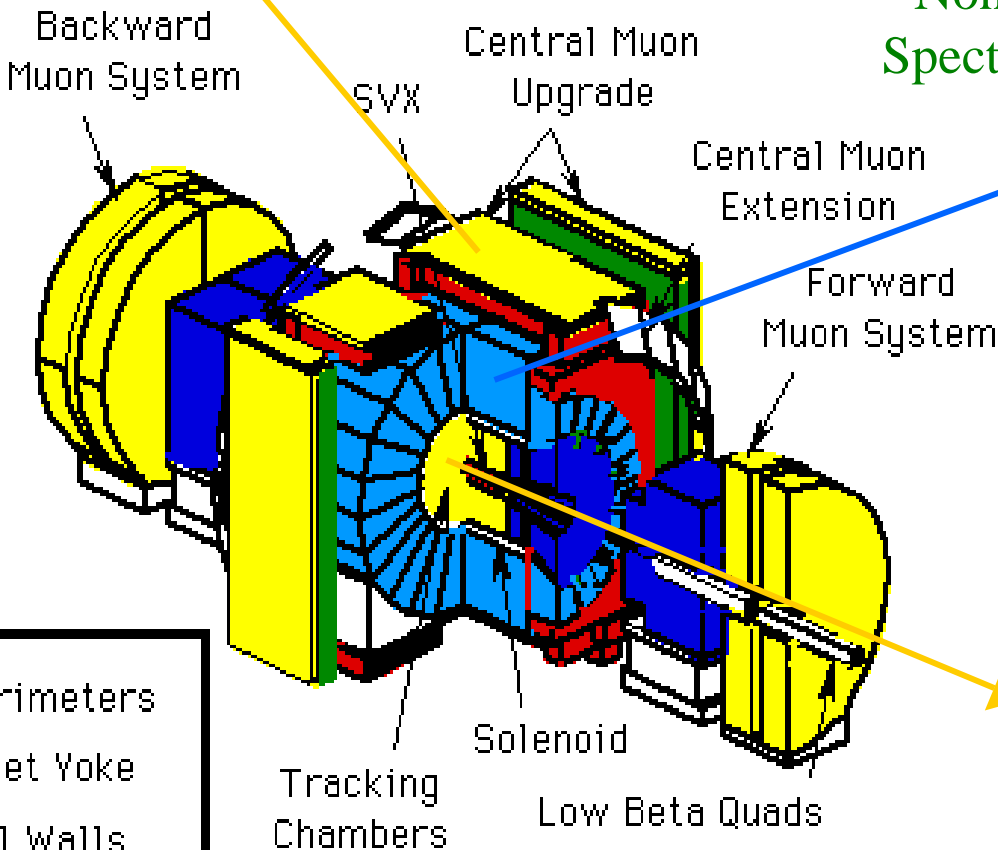
$\sqrt{s}$	$L$	$\Delta t_x$	Period
$1.8\text{TeV}$	$2 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$	$3.5 \mu\text{s}$	1992-1996

# Detectors in Run I

Muon:  
 $\sigma(r\phi) = 250 \mu\text{m} (\text{CMU})$

## CDF Detector

- Silicon Vertex Detector
- Large Magnetic Tracking Volume
- Non-Magnetic Central Muon Spectrometer (Forward Toroid)



### Calorimeter:

$$\frac{\sigma_{EM}}{E} = \sqrt{\left(\frac{13.5\%}{\sqrt{E_T}}\right)^2 + (2\%)^2}$$

$$\frac{\sigma_{HAD}}{E} = \sqrt{\left(\frac{75\%}{\sqrt{E_T}}\right)^2 + (3\%)^2}$$

### Tracking:

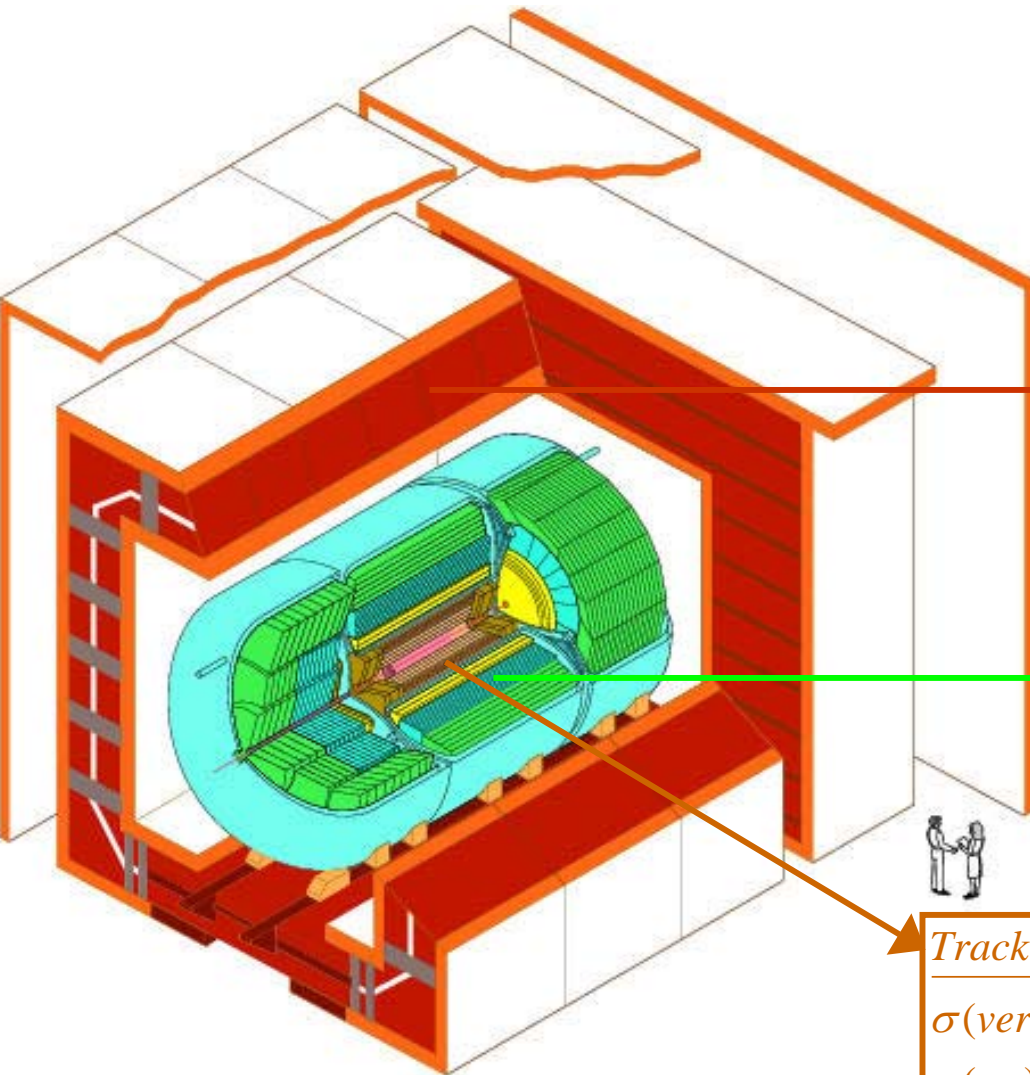
$$\sigma(r\phi) = 17 \mu\text{m} (\text{SVX})$$

$$\sigma(z) = 1 \text{ mm} (\text{VTX})$$

$$\frac{\Delta p_T}{p_T} \approx (0.1\%) \times p_T (\text{SVX} + \text{CTC})$$

# Detectors in Run I

- Good Calorimetry: hermeticity, resolution
- Iron Toroid Muon Spectrometer, Large Acceptance



**DØ Detector**

Muon :

$$|\eta| < 3.3$$

$$\frac{\Delta p}{p} = 0.2 \oplus 0.003 p$$

Calorimeter :

$$\frac{\sigma_{EM}}{E} = \frac{15\%}{\sqrt{E}} + 0.3\%$$

$$\frac{\sigma_{HAD}}{E} = \frac{45\%}{\sqrt{E}} + 4\%$$

Tracking :

$$\sigma(\text{vertex}) = 6 \text{ mm}$$

$$\sigma(r\phi) = 60 \mu\text{m (VTX)}$$

$$= 180 \mu\text{m (CDC)}$$

$$\sigma(r\phi) = 200 \mu\text{m (FDC)}$$

# SUGRA Models

## RPC Gravity Mediated SUSY Breaking (MSSM, mSUGRA)

### MSSM Particle Content:

S=1	S=1/2	S=0
	$l$	$\tilde{l}$
	$q$	$\tilde{q}$
$g$	$\tilde{g}$	
$W^\pm$	$\tilde{\chi}_1^\pm$ $\tilde{\chi}_2^\pm$	$\phi_1^+$ $\phi_2^-$
$\gamma$	$\tilde{\chi}_3^0$ $\tilde{\chi}_4^0$	$\phi_1^0$ $\phi_2^0$
$Z$	$\underline{\tilde{\chi}_1^0}$ $\tilde{\chi}_2^0$	

$$M_{\tilde{t}}^2 = \begin{pmatrix} m_{\tilde{t}_L}^2 + m_t^2 & m_t (A_t - \mu/\tan\beta) \\ m_t (A_t - \mu/\tan\beta) & m_{\tilde{t}_R}^2 + m_t^2 \end{pmatrix}$$

### MSSM Phenomenology:

Parameters:

- $m_{1/2}$  : universal gaugino mass
- $A_0$  : universal trilinear coupling
- $\mu$  : higgsino mass parameter
- $\tan\beta$  : ratio of 2 Higgs doublets vev
- $m_0$  : universal scalar mass

R Parity:  $R_P = (-1)^{L+2S+3B}$

Conservation:

- Sparticles pair production
- LSP  $\tilde{\chi}_1^0$  stable  $\Rightarrow E_T^{miss}$  signature

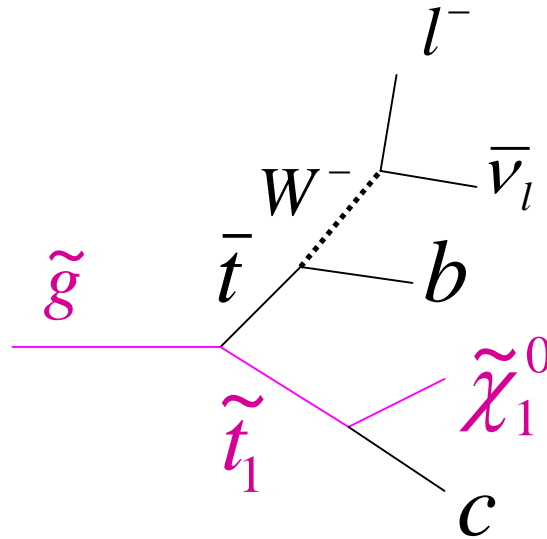
# SUGRA in dileptons at CDF

## Glino Pair Production

LO contributions:

$$gg \rightarrow \tilde{g}\tilde{g}$$

$$q\bar{q} \rightarrow \tilde{g}\tilde{g}$$



## Glino and Stop Decays

$$\tilde{g} \rightarrow t\bar{t}_1 / \bar{t}\tilde{t}_1$$

$$\tilde{g} \rightarrow t\bar{t}_1 / \bar{t}\tilde{t}_1$$

- gluino: Majorana sparticle

$$\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0 \quad (\text{stop NLSP})$$

$$t \rightarrow W^\pm b \rightarrow l^\pm \nu b$$

## Final State Topology

Top dilepton events

Like-sign:  $l^\pm l^\pm + jets + E_T^{miss}$

(Opp-sign:  $l^\mp l^\pm + jets + E_T^{miss}$ )

## Main SM Backgrounds

- **Very low**
- Fake lepton ( $W^\pm + \geq 3 jets$ )
- SM Top pair production
- Diboson production

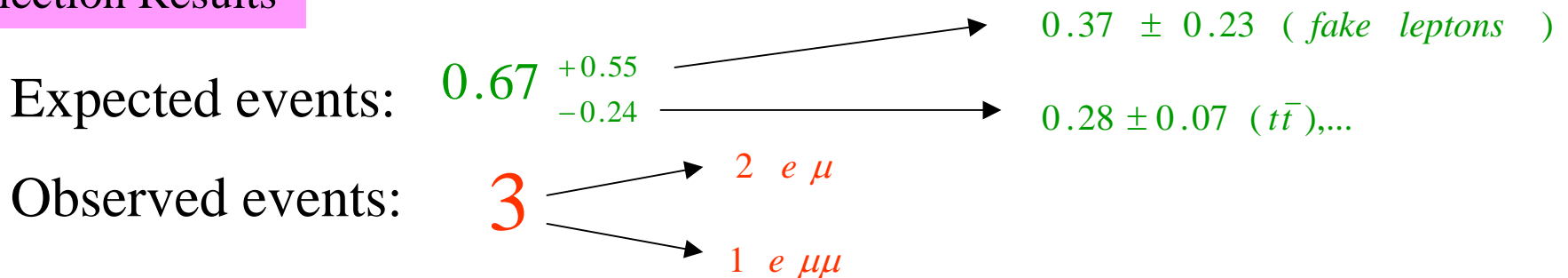
# SUGRA in dileptons at CDF

## Analysis

$$\int L dt = 106.1 \text{ pb}^{-1}$$

- **Trigger:** L3 inclusive electron or muon (isolation,  $p_T > 13-15 \text{ GeV}, \dots$ )
- **Lepton ID:** track matching (e), shower shape (e), track-calo. isol. (both),
- **Remove:** conversions (e), cosmics (mu), Z peak (both), radiative Z
- **Etmis:**  $E_T^{miss} > 25 \text{ GeV}$  (isolated)
- **Jets:** at least 2 central jets with  $p_T > 10 \text{ GeV}$

## Selection Results





# SUGRA in dileptons at CDF

## Interpretation of Run I Result

- Limit on cross section:

$$\sigma_{\tilde{g}\tilde{g}} < 15.1 - 18.0 \text{ pb}$$
$$(200 \leq m_{\tilde{g}} \leq 320 \text{ GeV})$$

$$(BR(\tilde{g} \rightarrow t\tilde{t}) = 1)$$

## Preliminary 95% CL Limits

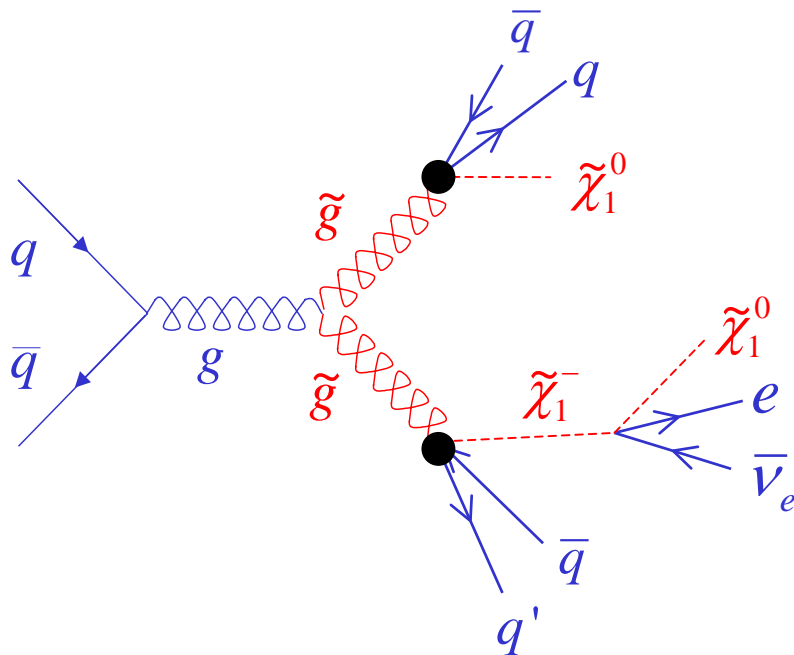
- Mass limit:

$$m_{\tilde{g}} > 180 \text{ GeV}$$

# mSUGRA in electrons at D0

## Glino Pair Production/Decay

$$gg \rightarrow \tilde{g}\tilde{g}$$
$$q\bar{q} \rightarrow \tilde{g}\tilde{g}$$



## Final State Topology

$$e^\pm + (\geq 4 \text{ jets}) + E_T^{\text{miss}}$$

## Motivation

- Signal sensitive to high and moderate  $m_0$  region: complement to (dilepton and jets)+ $E_T^{\text{miss}}$

## Main SM Backgrounds

$$W^\pm + \text{jets}, t\bar{t}, QCD$$

# mSUGRA in electrons at D0

Selection: NN (9-18-1)

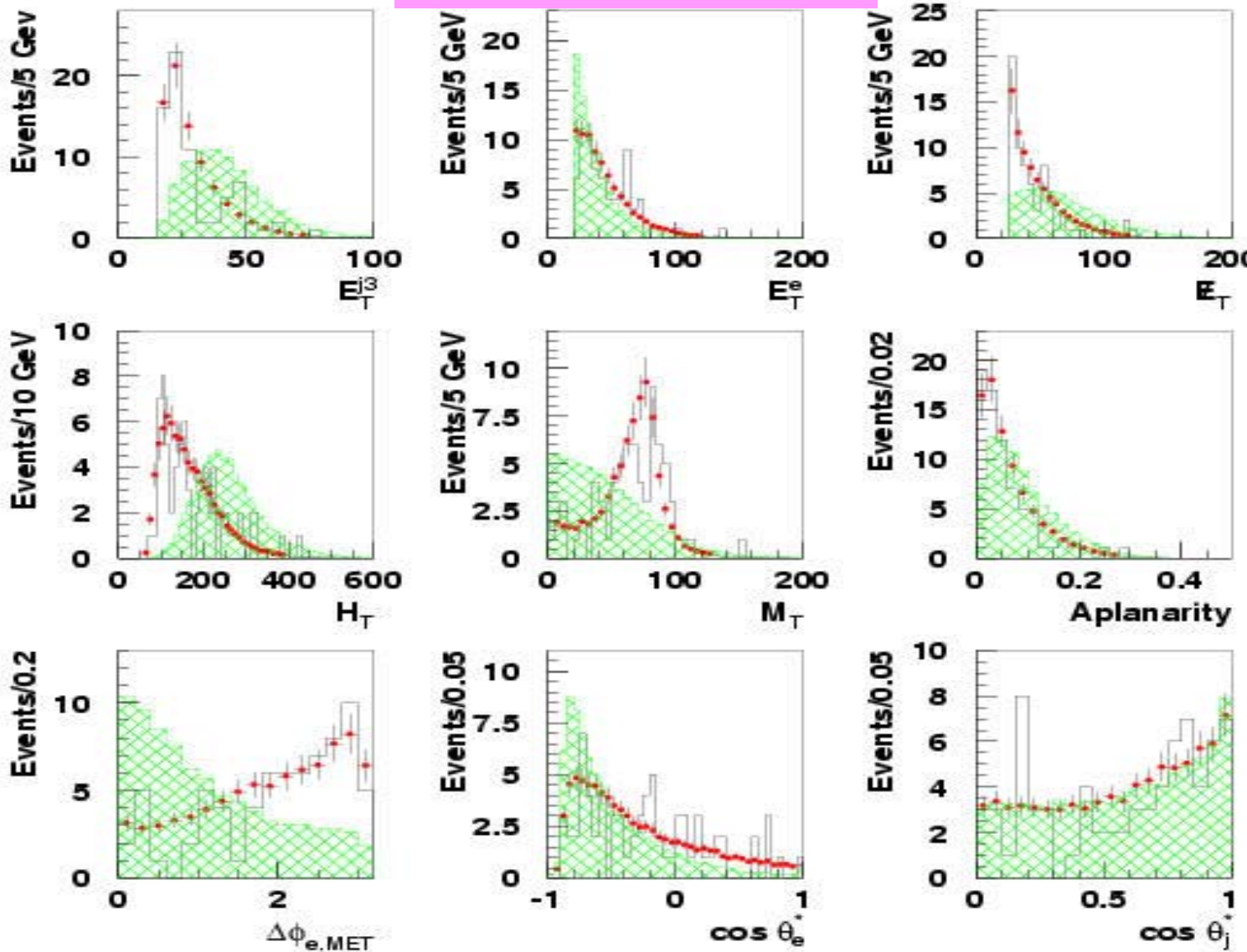
$$\int L dt = 94 \text{ pb}^{-1}$$

Preselection

$$E_T(e^\pm) > 20 \text{ GeV}$$

$$E_T(\text{jets}) > 15 \text{ GeV}$$

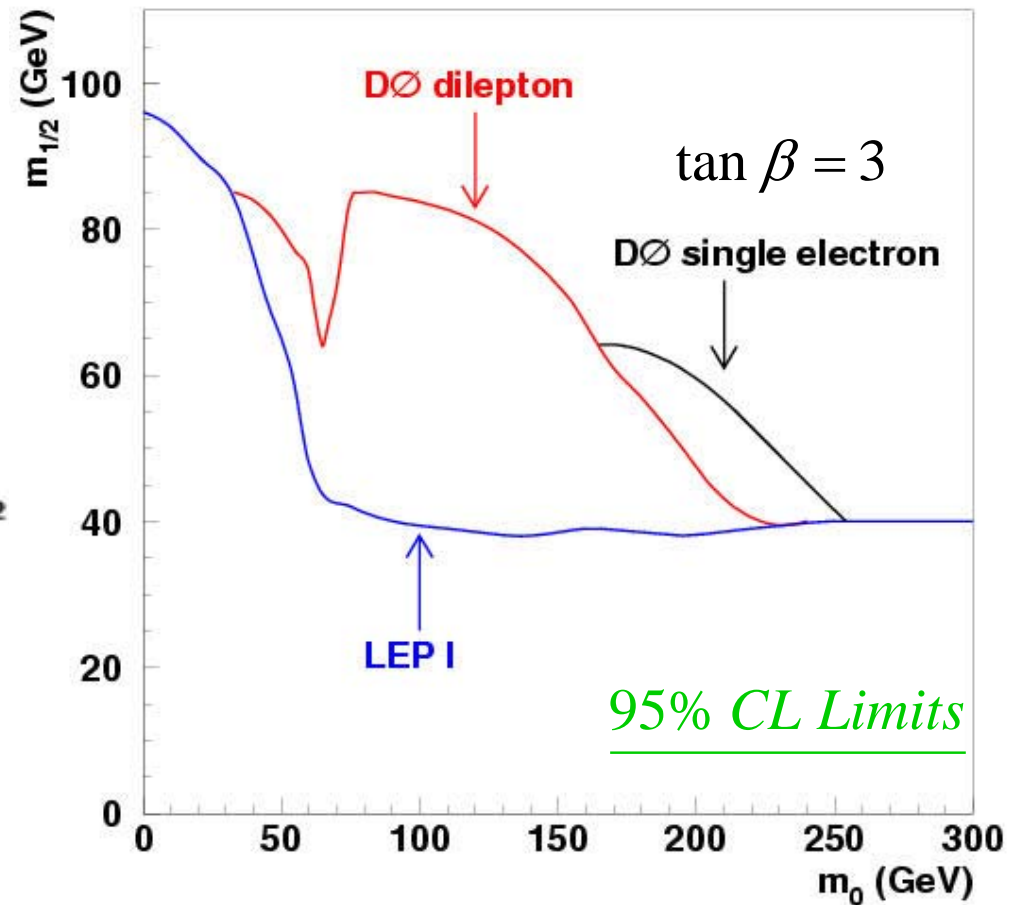
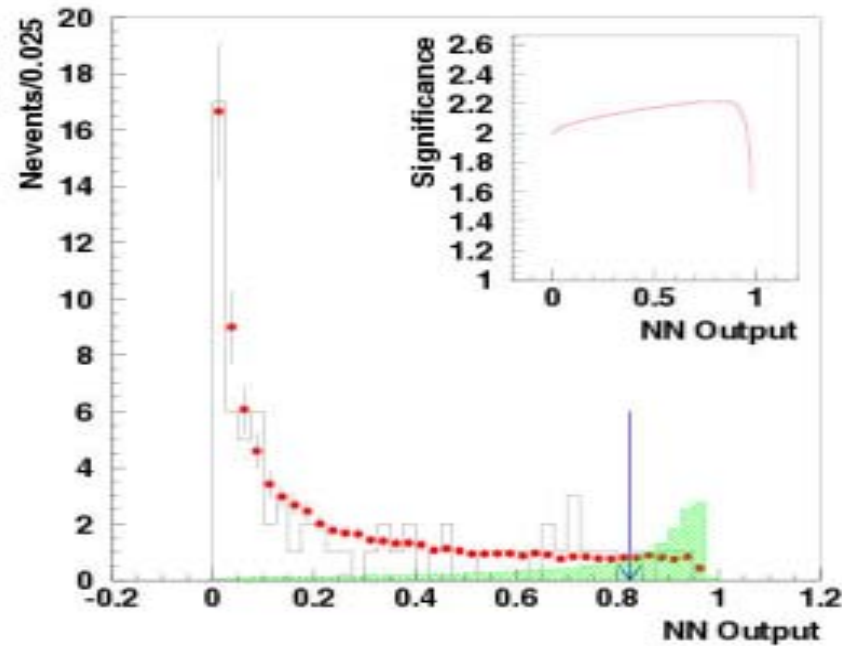
$$E_T^{\text{miss}} > 25 \text{ GeV}$$



# mSUGRA in electrons at D0

## Results

## mSUGRA Limit



- $t \bar{t}$  :  $16.8 \pm 5.2$
- $WW + \geq 2$  jets :  $1.4 \pm 0.3$
- QCD Multijet:  $19.1 \pm 4.7$
- $W + \geq 4$  jets :  $43.0 \pm 7.6$
- **Expected Events:  $80.3 \pm 10.4$**
- **Observed Events: 72**

# Large Extra Dimensions

Theoretical Foundation:

- Quantum gravity scale  $M_D$  can be  $O(1 \text{ TeV})$ , solution to hierarchy problem

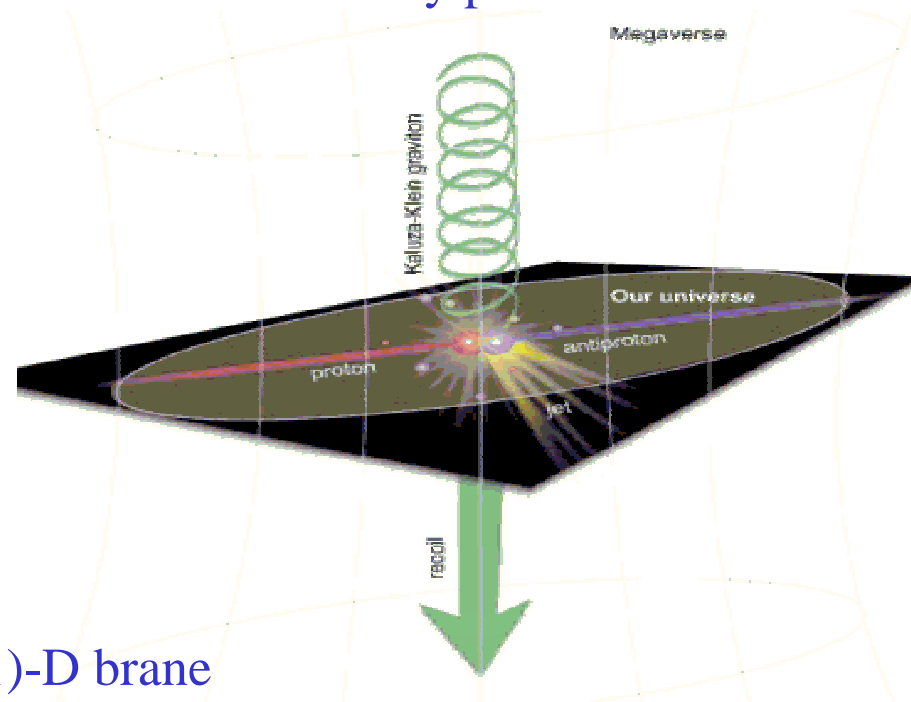
“Modified” Gravity:

$$\frac{4-D}{G_N^{-1} \sim M_{Pl}^2} \longrightarrow \frac{(4+n)-D}{G_N^{-1} \sim R^n M_D^{2+n}}$$

R: compactification (torus) radius

Phenomenology:

- SM particles (open strings): confined to (3+1)-D brane
- Graviton (closed strings): can propagate in the bulk (“weakness of gravity”)
- Equivalence: massive gravitons (KK) in 4-D and massless gravitons (4+n)-D
- Ref: Giudice, Rattazzi, Wells, NPB 544 (1999)
- Ref: Arkani-Hamed, Dimopoulos, Dvali, PLB 429 (1998)
- Ref: Antoniadis, PLB 246 (1990)



# Large ED Searches at Colliders

## ED Nbers and Radii

$$M_D \approx 1 \text{ TeV}$$

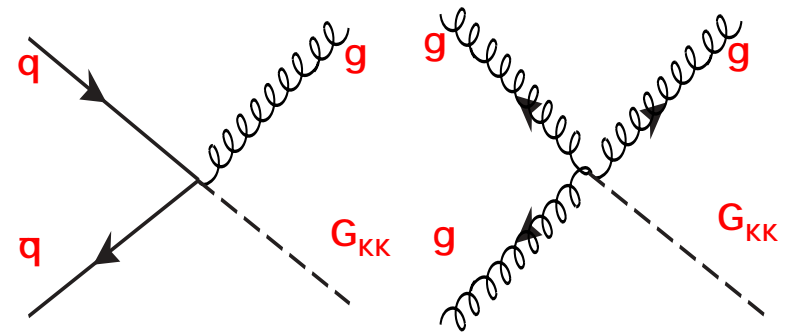
$$R = \begin{cases} 1.2 \times 10^{12} \text{ m} & n = 1 \\ 0.48 \text{ mm} & n = 2 \\ 3.6 \text{ nm} & n = 3 \\ 9.7 \times 10^{-12} \text{ m} & n = 4 \end{cases}$$

Eöt-Wash Experiment  
 Test Newton's Law down to  
 $O(200 \mu\text{m})$   
 Ref: Adelberger et al, PRL 86 (2001)

## Production Mechanisms

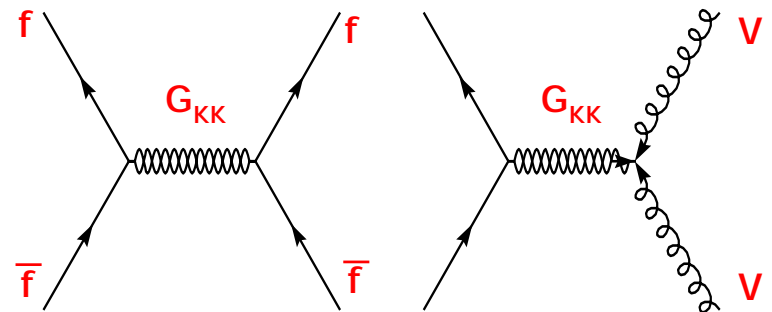
### Real Gravitons

Monojets at hadron colliders



### Virtual Gravitons

Fermion or VB pairs at hadron or  $e^+e^-$  colliders



# LED in monojets at D0

## Selection

- $N_{\text{jets}} = 1$  or  $2$
- $E_T(j_1) > 150$  GeV,  $E_T(j_2) < 50$  GeV
- $j_1$  central (good quality)
- $E_T^{\text{miss}} > 150$  GeV
- Reject events with isol. muons,
- Reject cosmics

## Results

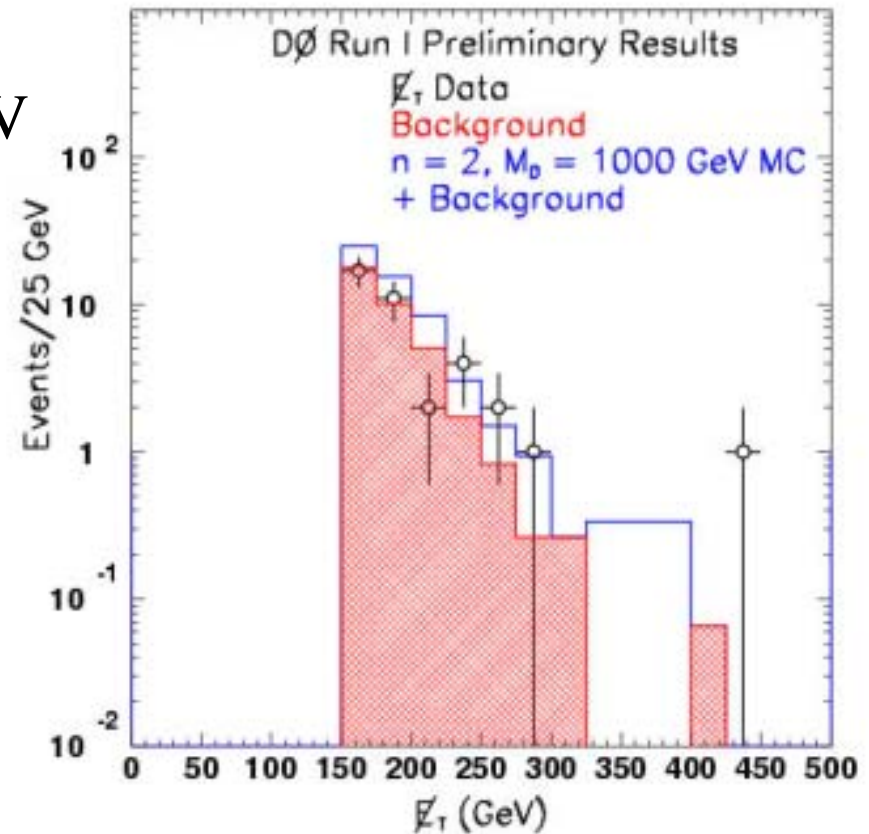
WZ background =  $30.2 \pm 4.0$

QCD background =  $7.9 \pm 7.1$

Expected Events =  $38.0 \pm 8.2$

Observed Events = 38

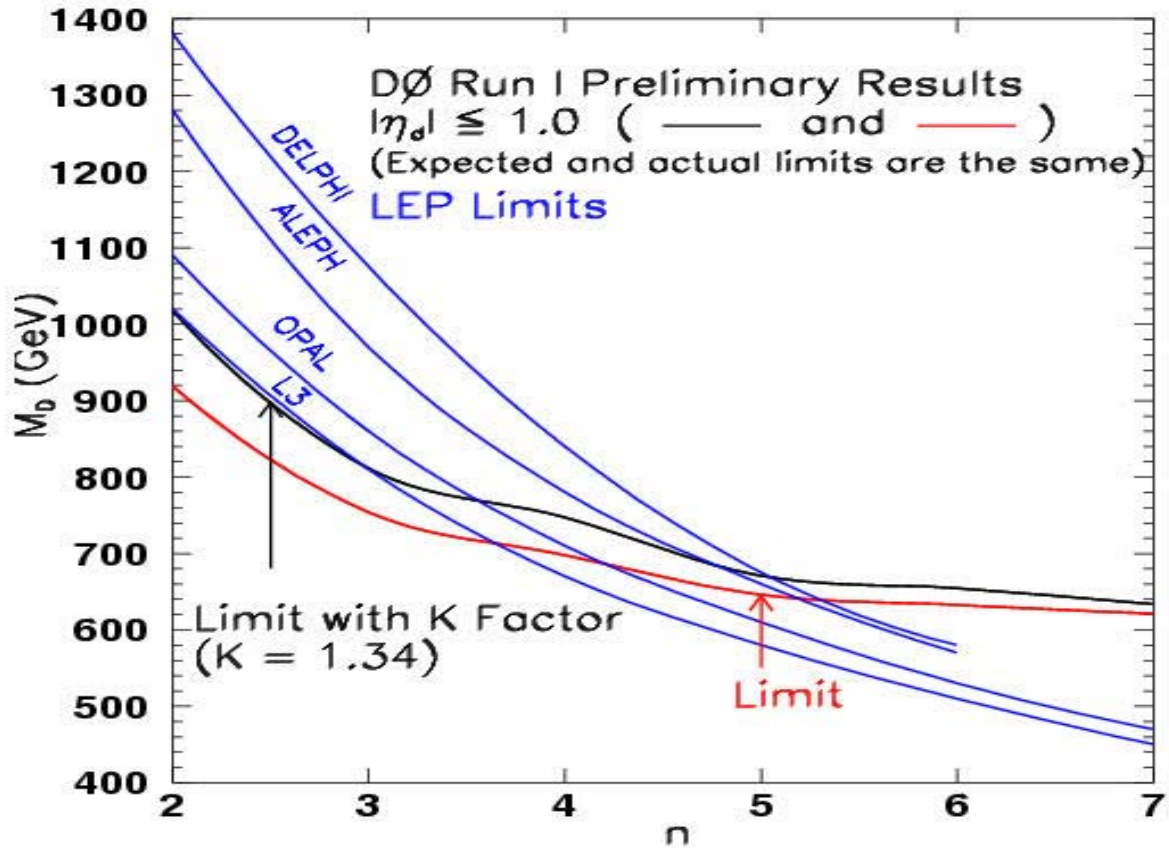
$$\int L dt = 78.8 \text{ pb}^{-1}$$



# LED in monojets at D0

Limits

95% CL Limits



$n=4$

$M_D > 698$  (840) GeV

D0 DELPHI

Conservative Limit  
(no K-factor)

$n=6$

$M_D > 632$  (580) GeV

D0 DELPHI



# LED in diphotons at CDF

## Signal

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

## Backgrounds

$\gamma$ +jets

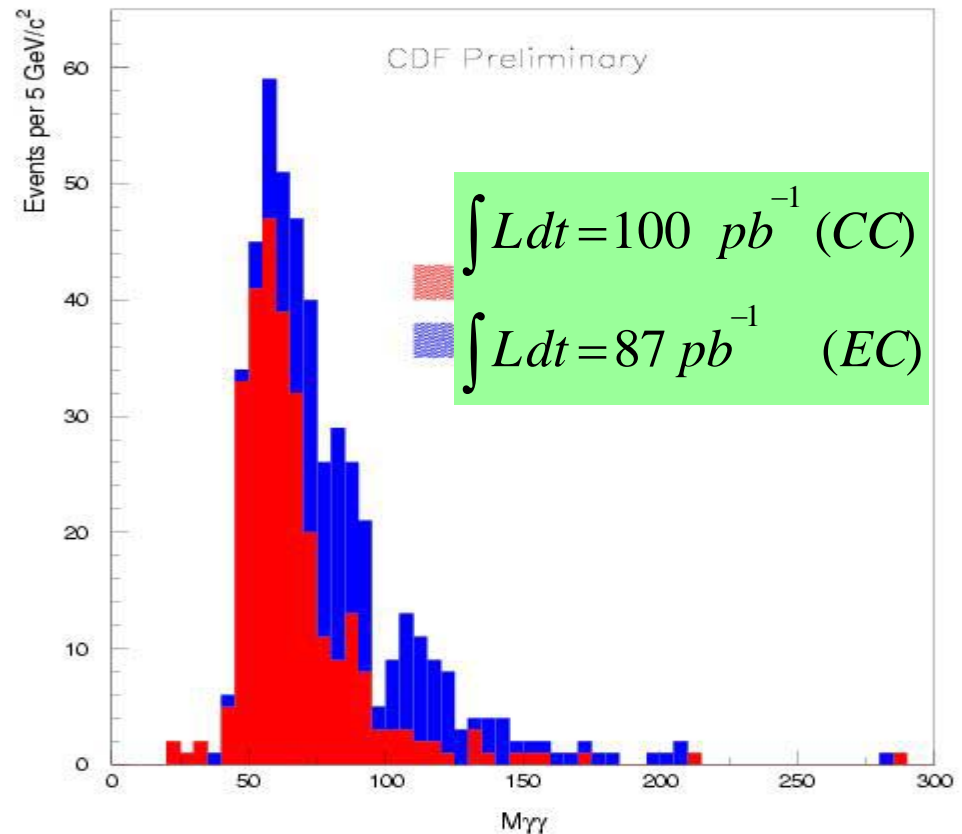
QCD dijets

## Selection

- Isolated photons
- $E_T(\gamma) > 22 \text{ GeV}$ ,  $|\eta(\gamma_1)| < 1.0$

## Results

	Central	EndCap
Observed	287	192
Expected	$280 \pm 70$	$208 \pm 42$
SM diphotons	$96 \pm 31$	$76 \pm 31$
Bkgd from fakes	$184 \pm 63$	$132 \pm 28$



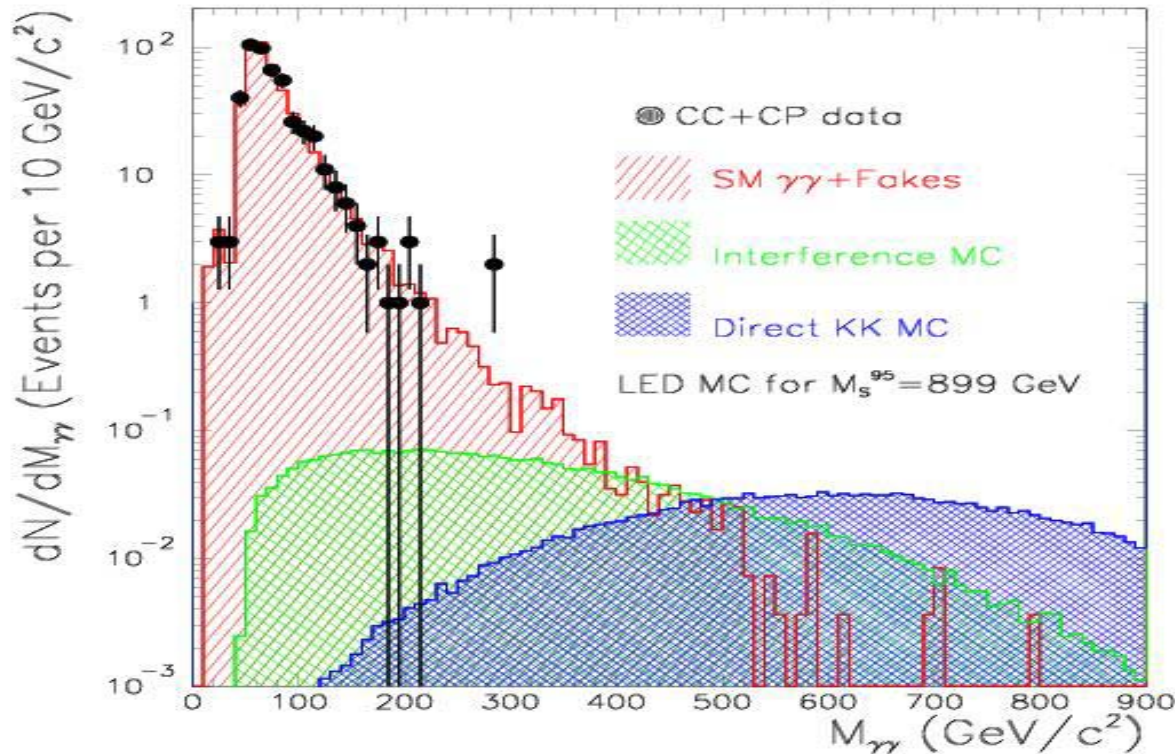
# LED in diphotons at CDF

- Cross section of:

$$p\bar{p} \rightarrow q\bar{q} / gg \rightarrow \gamma\gamma + X$$

$$\frac{d\sigma}{dM_{\gamma\gamma}} = \left. \frac{d\sigma}{dM_{\gamma\gamma}} \right|_{SM} + \eta \left. \frac{d\sigma}{dM_{\gamma\gamma}} \right|_{INT} + \eta^2 \left. \frac{d\sigma}{dM_{\gamma\gamma}} \right|_{KK}$$

CDF Preliminary



- Free parameter to fit:

$$\eta = \frac{\lambda}{M_D^4}$$

Limits

*CDF*

$$M_D > 1.01 \text{ TeV}$$

(This analysis)

*D0*

$$M_D > 1.21 \text{ TeV}$$

- Add  $\cos\theta^*$  to fit,  $127 \text{ pb}^{-1}$
- Ref: PRL 86 (2001)

95% CL Limits

# Conclusions

- New Analyses of Run I Data
- Better sensitivity:
  - Improved Selection Techniques
  - Use of Full Calorimeter Acceptance
- Resulting in:
  - Improved Limits
  - Complementary and Competitive wrt LEP II
- Next Moves Have Just Started in Run II:
  - Slightly Higher Energy
  - Higher Luminosity
  - Upgraded Detectors
  - Improved Trigger Designs ... News Soon

# Large ED Searches

Different theoretical notations

$$\lambda_{GRW} = \frac{-2}{\pi} \lambda_{Hew.}$$

$\lambda_{Hew.} = O(\pm 1)$       Dimensionless parameter  
Sign: destructive or constructive interference

# Prospects for Run II

## mSUGRA search in dileptons at CDF

- Estimated limit:  $m_{\tilde{g}} > 181 - 182 \text{ GeV}$   $\rightarrow$   $m_{\tilde{g}} > 280 - 295 \text{ GeV}$   
(same observed and expected events than Run I analysis, with  $2 \text{ fb}^{-1}$ )

## LED search in monojets at D0

- $n=2$ : sensitive to  $M_D=920 \rightarrow 1400 \text{ GeV}$
- $n=5$ : sensitive to  $M_D=700 \rightarrow 900 \text{ GeV}$   
(with  $2 \text{ TeV}$  and  $300 \text{ pb}^{-1}$ )