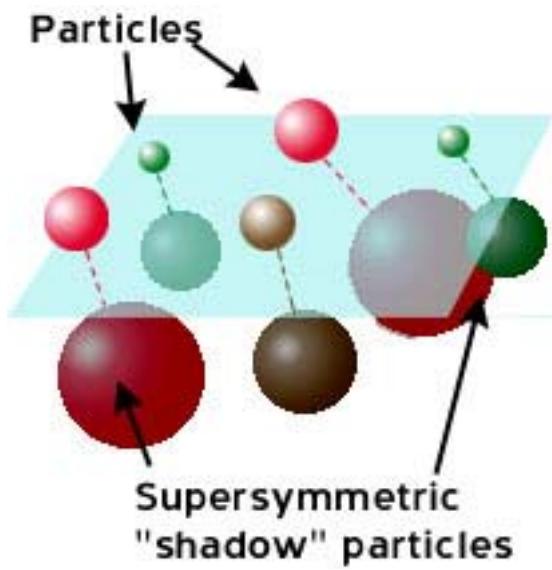
Searches for New Phenomena at DØ

Intensive search for New Phenomena is a reflection of the general consensus that Standard Model is incomplete. For the moment and for the near future the Tevatron is the highest energy machine and hence a natural place to look for deviations from SM …..

- **evidence of new particles: SUSY, leptoquarks**
- **identification of new gauge interactions (technicolor) and complexities beyond the SM (compositeness)**
- **evidence of the X-tra dimensions**



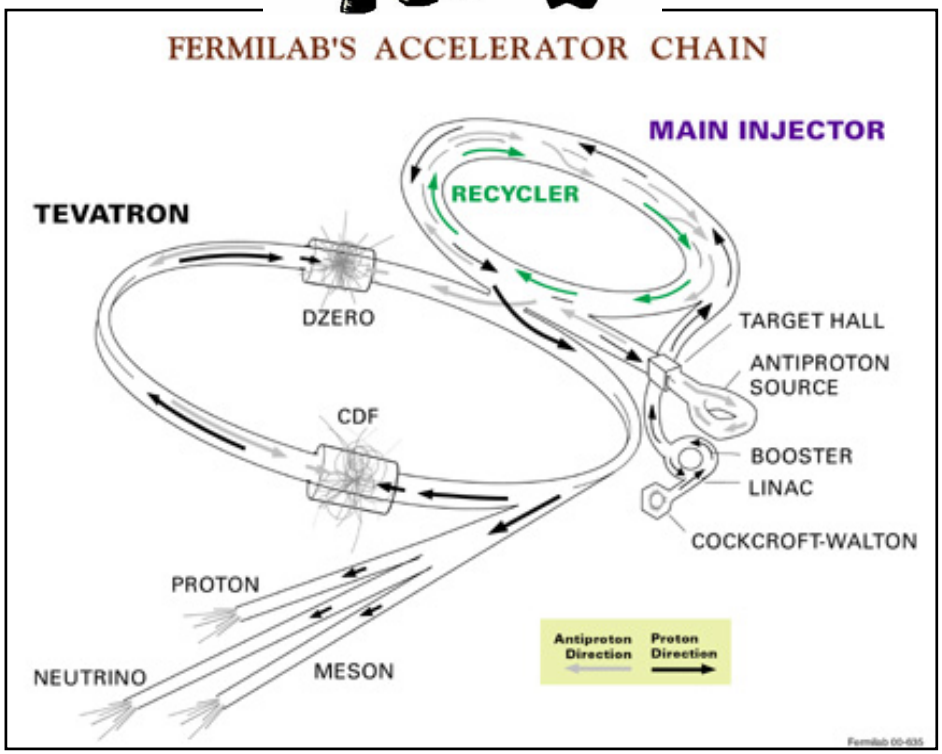
❖Hunting for the New Phenomena

… does nature hide any surprises?

- ❖SUGRA Search : Jets + mE_T
- ❖Limits on New Physics in eμ Search
- ❖Chargino/Neutralino Search : Trilepton mode
- ❖GMSB SUSY Search : $2\gamma + mE_T$
- ❖Search for LQ : (2 e + 2 jets) and (2 μ + 2 jets)
- ❖Extra Dimensions : di-EM and di-μ channel

Search for New Phenomena, in other words, means the detailed understanding of the Standard Model background

The Fermilab Tevatron Collider and



TEVATRON

–Increase in CM energy
1.8 TeV -> 1.96 TeV

–Increase in Luminosity

2×10^{31} -> $(4\text{-}8) \times 10^{31}$ cm^{-2} s^{-1}
4×10^{32} cm^{-2} s^{-1} (future)

-Bunch spacing

3.5 μs -> 396 ns

Dzero

-Silicon & fiber trackers, preshowers
- Upgraded μ detectors
- Upgraded trigger, DAQ..
- New inner tracking in 2T

Typical Delivered, Recorded Luminosity and Operating Efficiency/week: Del ~6 pb^{-1} Rec ~ 5 pb^{-1} Eff. ~82-85%

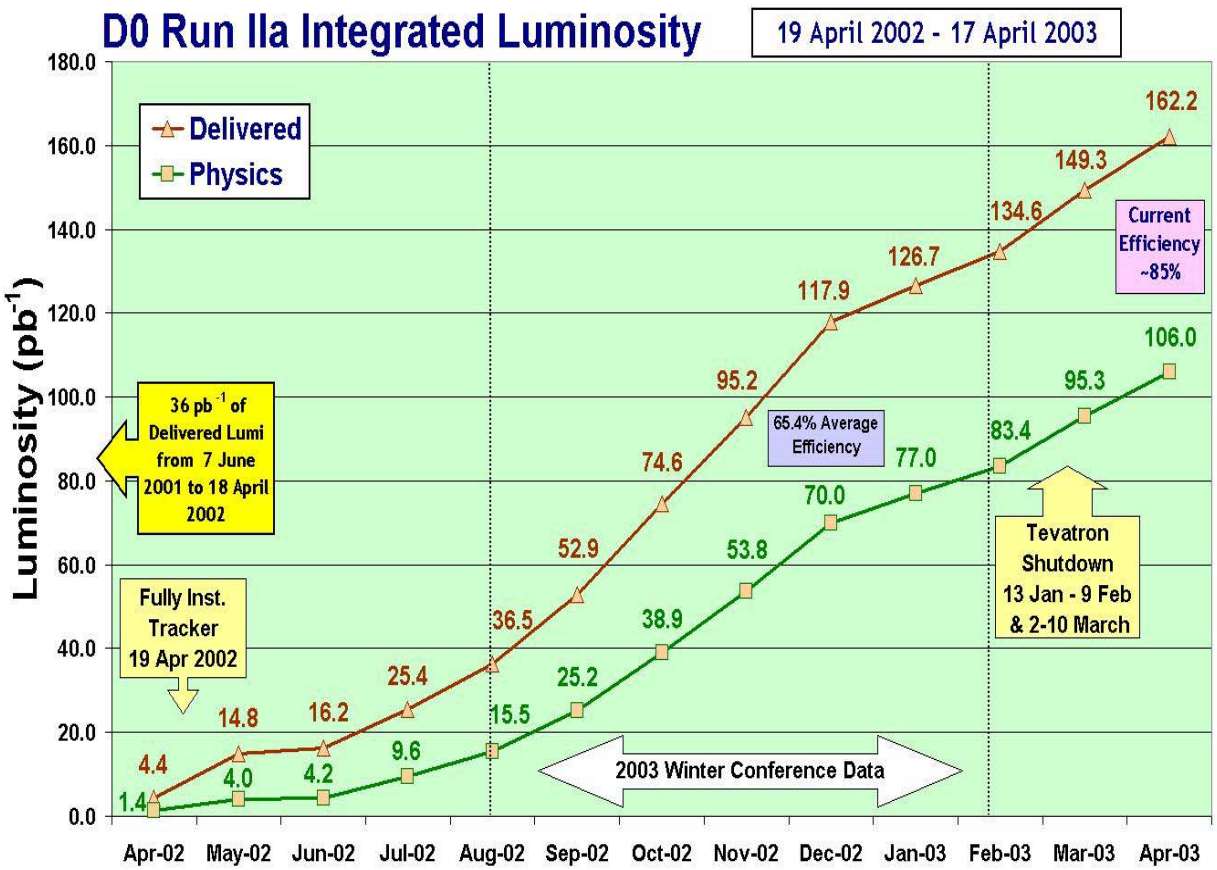
We record about10 million Physics Quality Events per week

Reasonably smooth data taking

~5% front-end busy at ~1.1kHz Level 1 accept rate

~5-7% hard/soft are failures during beam time

~5% necessary overhead: begin/end store, change prescales, etc.



Searches for Supersymmetry at DØ

SUSY production

$$p\bar{p} \to \tilde{\chi}_i^{\pm}\tilde{\chi}_j^{\mp},\ \tilde{\chi}_i^{0}\tilde{\chi}_j^{\pm},\ \tilde{\chi}_i^{0}\tilde{\chi}_j^{0},\ \tilde{q}\bar{\tilde{q}},\ \tilde{q}\tilde{g},\ \tilde{g}\tilde{g},\ \tilde{l}\bar{\tilde{l}}$$

- **Neutralinos/charginos**
  - trilepton channel
  - dilepton channel

$$p\bar{p} \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0} \Rightarrow \ell^{1,2,3} + \not{E}_T + X$$
$$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm} \Rightarrow \ell^{1,2} + \not{E}_T + X$$

- **squarks/gluinos**
  - jets + mE$_T$

$$p\bar{p} \to \tilde{q}\bar{\tilde{q}}, \tilde{q}\tilde{g}, \tilde{g}\tilde{g} \Rightarrow jj\not{E}_T + X$$

stop and sbottom

$$\tilde{t}_1 \to b + \tilde{\chi}_1^{\pm} \to Wb + \tilde{\chi}_1^{0}$$
$$\tilde{t}_1 \to b + \tilde{\chi}_1^{\pm} \to b\ell + \tilde{\nu}$$
$$\tilde{t}_1 \to \tilde{\chi}_1^{0} + c$$
$$\tilde{t}_1 \to t + \tilde{\chi}_1^{0}$$

$$\tilde{b}_1 \to b\tilde{\chi}_1^{0}$$

$\tilde{b}_1 \to b\ \tilde{\chi}_2^{0}$
$\hookrightarrow \tilde{\chi}_1^{0}\ e^+\ e^-$

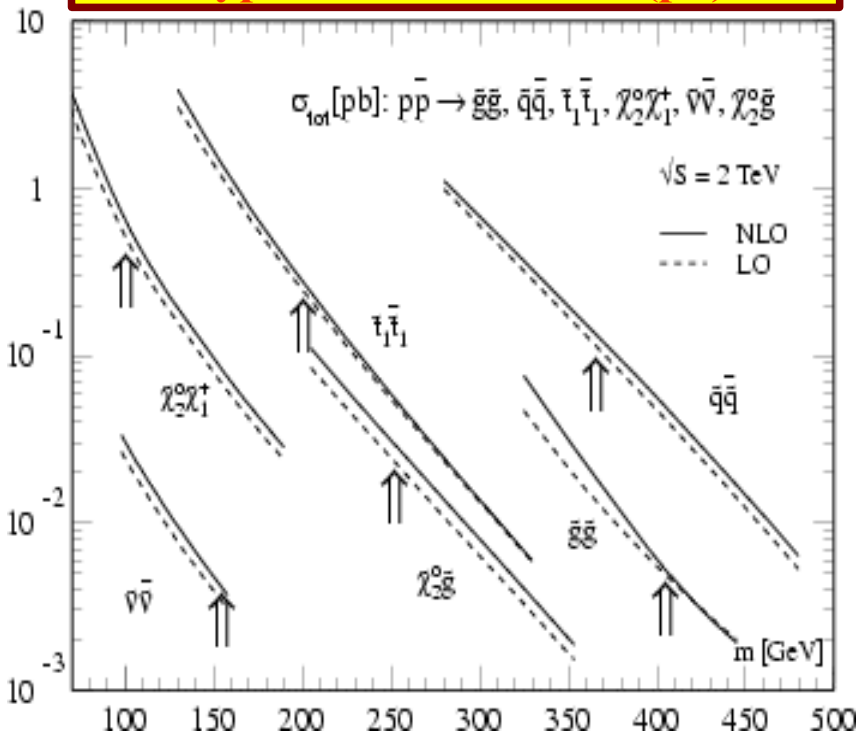
SUGRA search: Jets + mE_T

Favoured channel to look for squarks and gluinos …their decay chains produce jets (quarks & gluons), leptons and missing energy because LSP - neutralino – escapes the detection

$\mathcal{L} = 4.1 pb^{-1}$ 2-3 jets/event
P_T leading jet > 100 GeV

- **Quality cuts : reduce instrumental Bkg**
- **Topological cuts: increase Sig/Bkg ratio** $\tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$
- **Physics Bkg from simulation**
- **QCD background from data**

Typical cross-sections (pb)

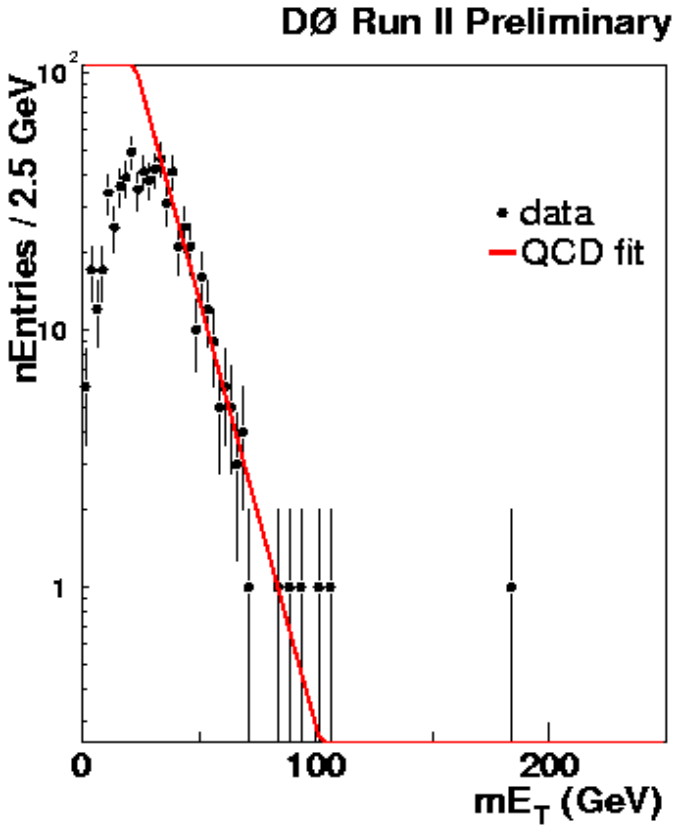


SUGRA search: Jets + mE_T

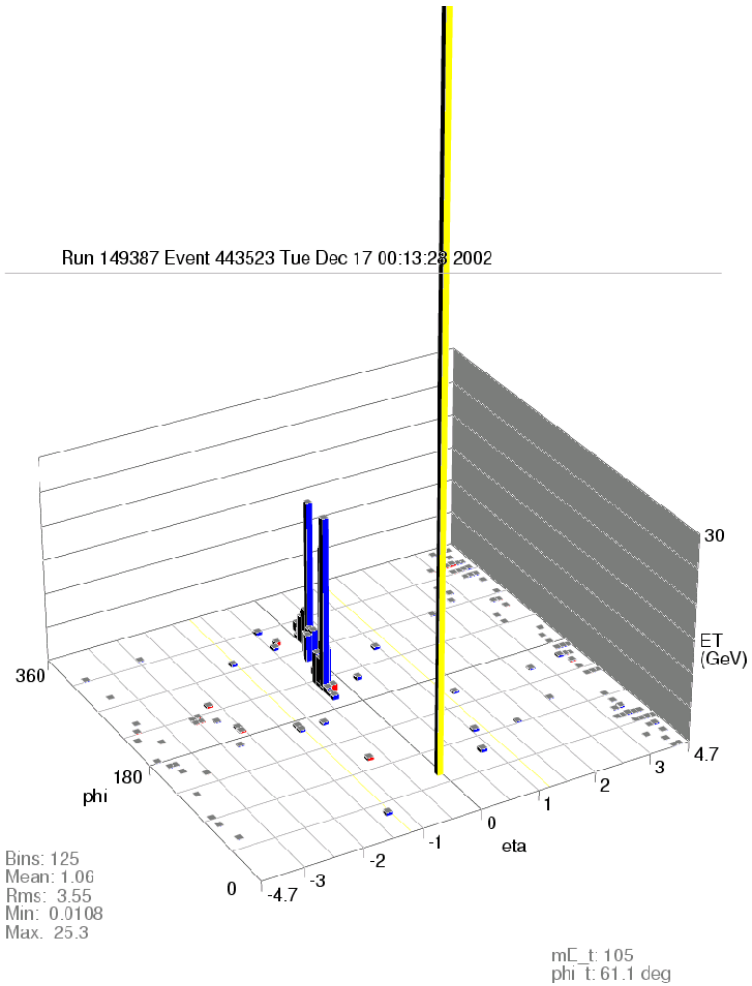
QCD background is dominant: 95% (mE_T>70 GeV) and 76% (mE_T>100 GeV) of the Total Background

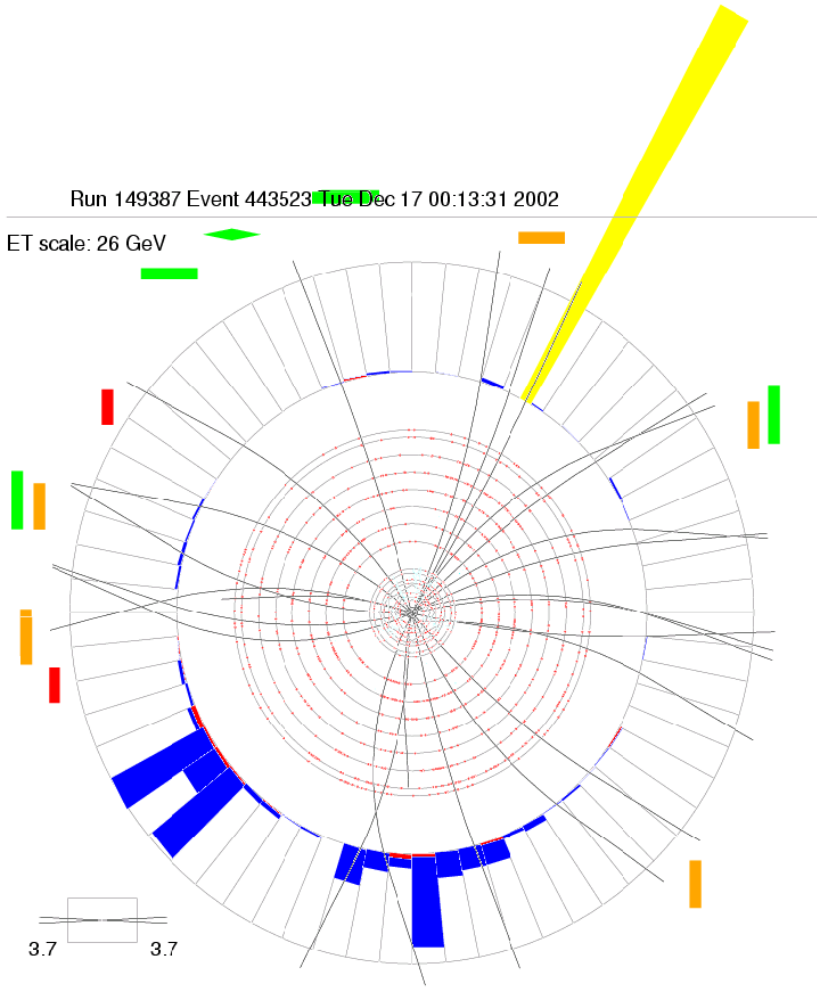
mE_T	Total Bkg	Data	95% CL $\varepsilon\,\sigma$ (pb)
> 70 GeV	18.4 ± 8.4	7	4.2
> 80 GeV	9.5 ± 5.3	6	3.8
> 90 GeV	5.1 ± 3.2	4	3.1
> 100 GeV	2.7 ± 1.8	3	2.7

Fit the interval 40-65 GeV
$f(mE_T)=a*\exp(-b*mE_T)$



SUGRA search: Jets + mE_T
--- highest mE_T (184 GeV) event---

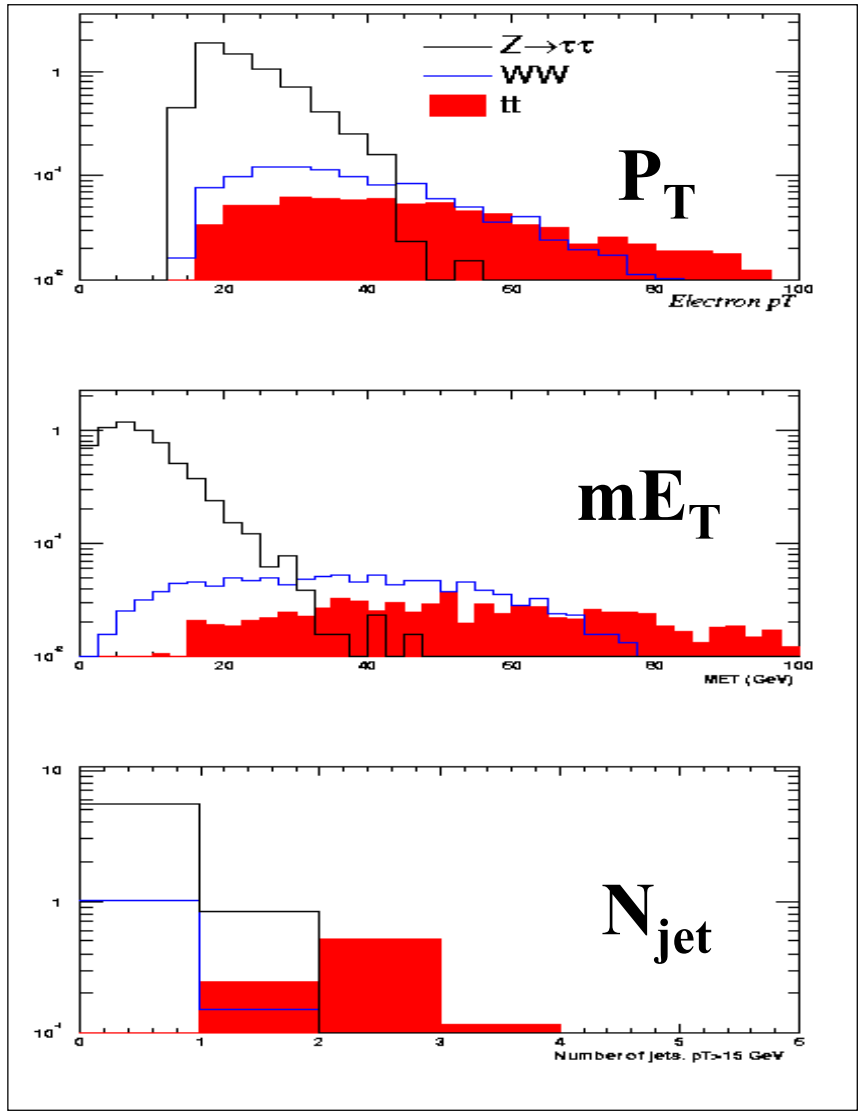




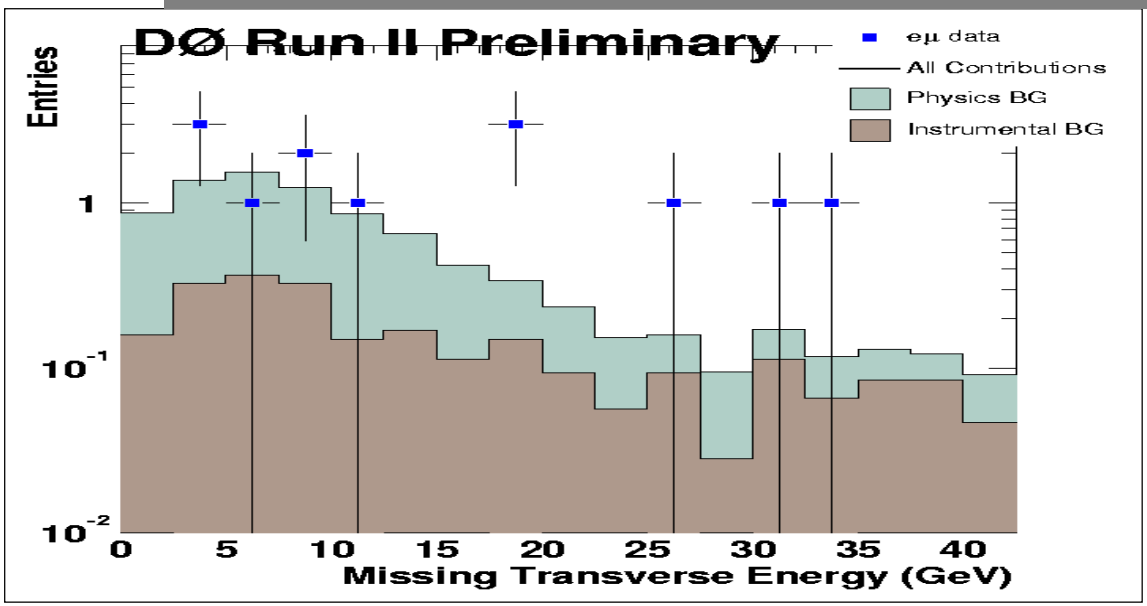
Limits on New Physics in an eμ Search

- ❖ Channel with low SM background
- ❖ has high discovery potential
- ❖ provides model-independent limit on NP cross section

- require p_T >15 GeV (e/μ)
- no jets with p_T >15 GeV
- estimate fake rates from data
- physics background from Monte Carlo



Limits on New Physics in the eμ Search



$\mathcal{L} = 33.0\ pb^{-1}$

Process	Size
$Z \rightarrow \tau\tau \rightarrow e\mu$	5.6 ± 0.4
$WW \rightarrow e\mu$	1.0 ± 0.1
$tt \rightarrow e\mu\, jj$	0.02 ± 0.01
QCD + W+jets	3.01 ± 2.7
All	9.6 ± 2.7
Data	*13*

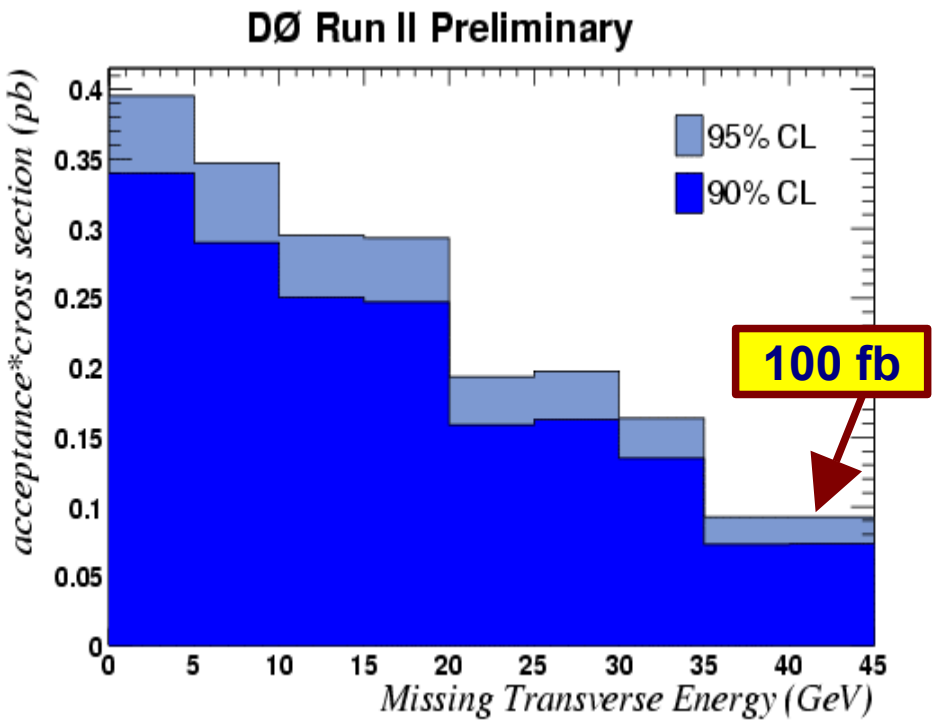
Limits on New Physics in an eμ Search

at low mE_T physics background dominates
at high mE_T the instrumental one dominates

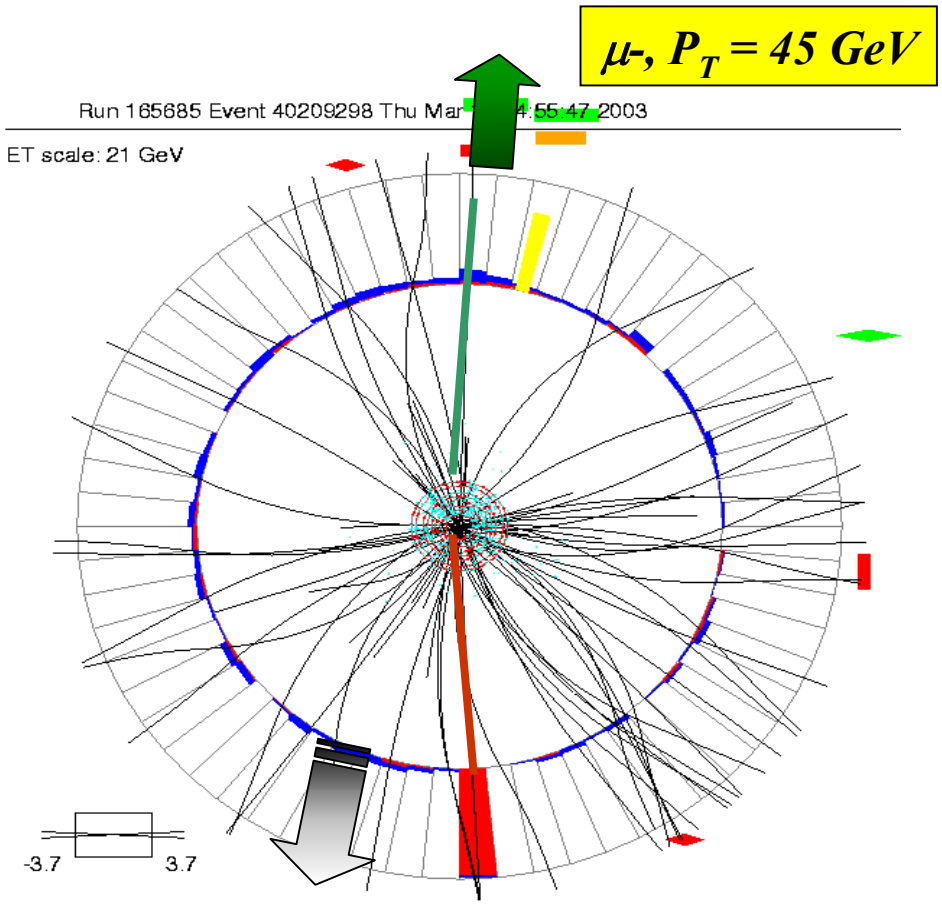
mE_T	DATA	TOT BKG
> 0	13	9.6 ± 2.7
> 5	10	7.4 ± 2.2
> 10	7	4.6 ± 1.6
> 15	6	3.0 ± 1.3
> 20	3	2.3 ± 1.1
> 25	3	1.9 ± 1.0
> 30	2	1.6 ± 0.8
> 40	0	1.4 ± 0.7
> 45	0	1.1 ± 0.5

$A^* \sigma_{new\ physics}$

(f.e acceptance for WW→eμ –> 17%)



Highest mE_T eμ event



Missing E_T = 33.5 GeV

e+, P_T = 21 GeV

Chargino/Neutralino Search : Trilepton mode

$\mathcal{L} = 42.0\ pb^{-1}$

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

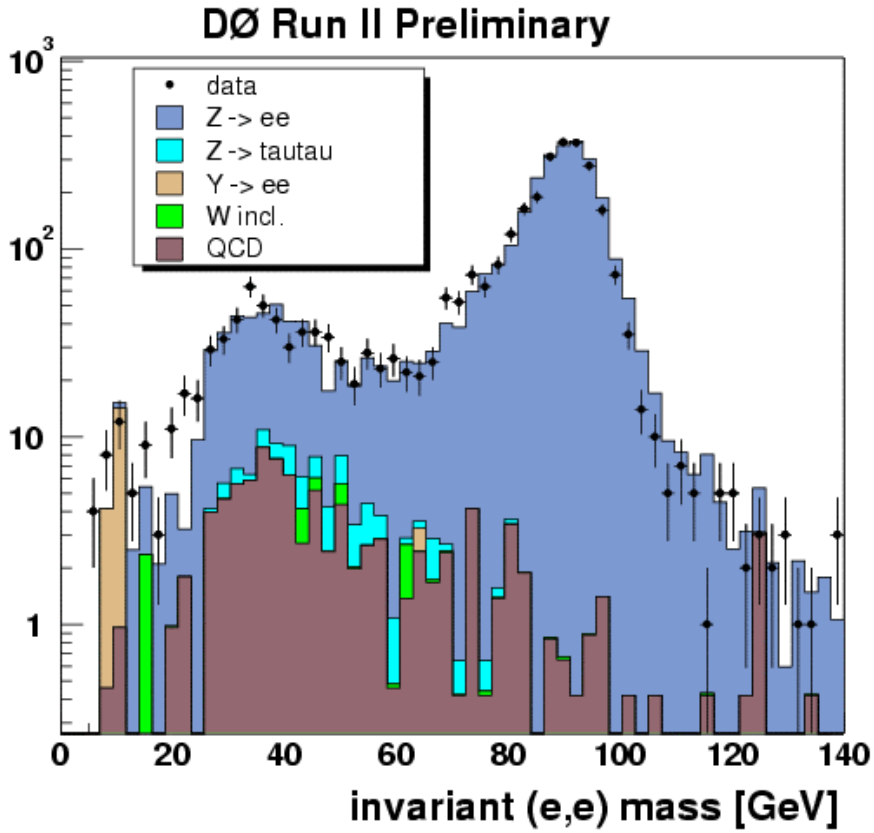
Selection:

$E_T(e_1) > 15$ GeV,
$E_T(e_2) > 10$ GeV

Background:

SM processes $Z \rightarrow ee$, $Z \rightarrow \tau^+\tau^-$ and $W \rightarrow e\nu$ are the dominant Bkg;

- QCD background estimated from data with inverted ID cuts



Chargino/Neutralino Search : Trilepton mode

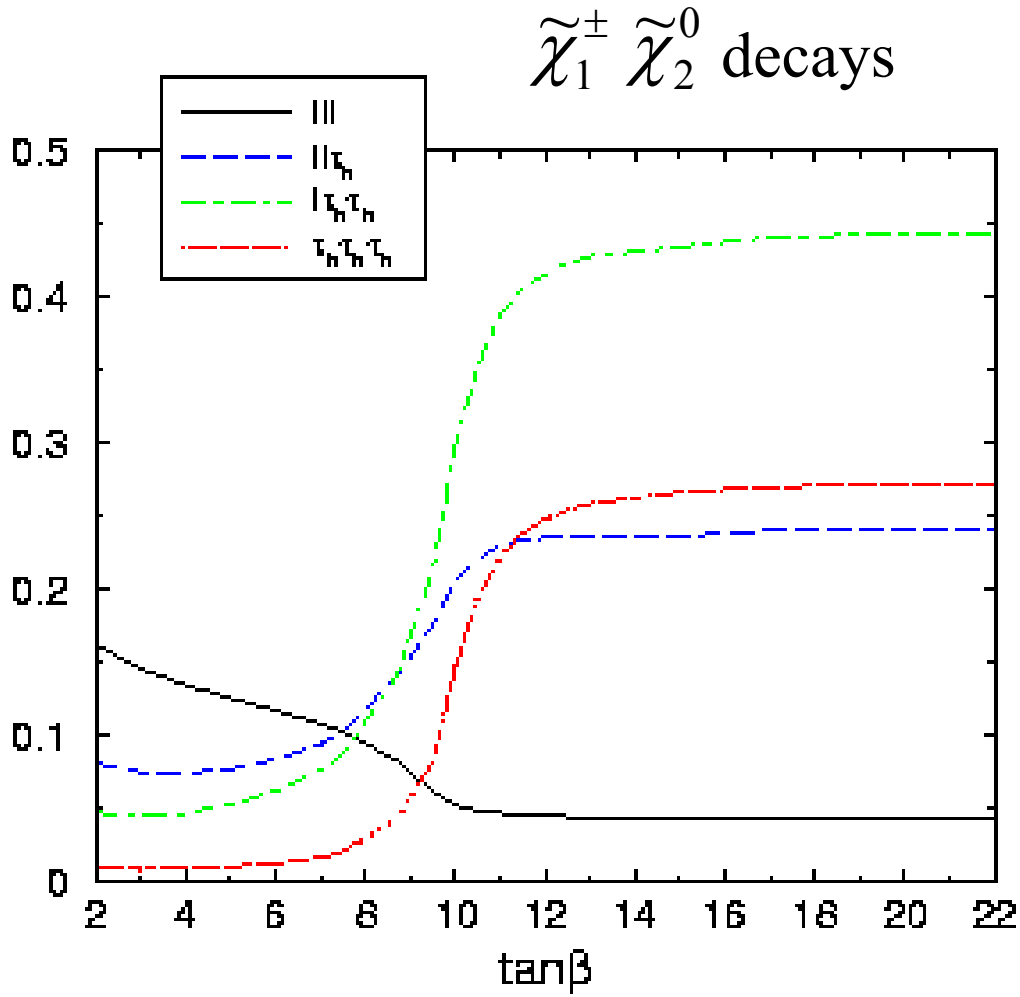
Cuts	Sum Bkg	Data
ID + kinem + trk	3216 ± 43	3132
$10 < M_{ee} < 70$ GeV	660 ± 19	721
$M_T > 15$ GeV	96 ± 8	123
3rd trk	3.2 ± 2.3	3
$mE_T > 15$ GeV	0.0 ± 1.4	0

σ x BR(3lepton) < 3.5 pb (95% CL) ……typical selection efficiency for SUGRA 2-4% ……sensitivity still about factor of 7 away from extending excluded area in the parameter space → working on improving efficiency, adding channels

Chargino/Neutralino Search : τ channels

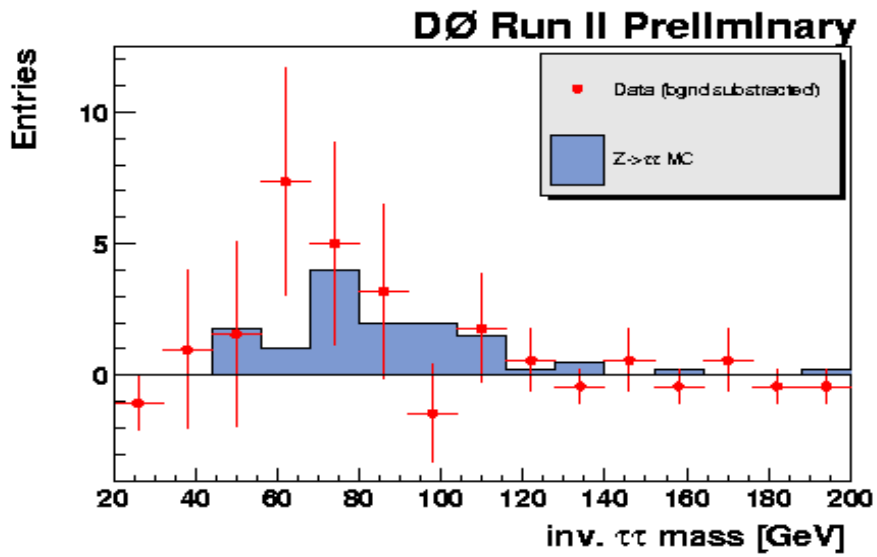
Branching fraction of the chargino/neutralino pairs into the final states with e, μ or hadronic τ

Also…..Higgs searches , third generation leptoquarks



A New Capability for D0 in Run II : $Z \to \tau^+\tau^-$ decays

$Z \to \tau^+\tau^- \to ehX$



Distribution in invariant ττ mass, calculated using collinear approximation, (opp sign - like sign)

Data: 14 ± 9 evt

Signal MC norm to 50 pb-1: 13 ± 4 evt

$\mathcal{L} = 50\ pb^{-1}$

$Z \to \tau^+\tau^- \to \mu hX$ decays were also observed

GMSB SUSY search

An alternative to gravity mediated SUSY: introduce new gauge fields ("messengers") which propagate SUSY-breaking interactions and couple to ordinary and SUSY particles

Phenomenology:

- **Gravitino is very light (<<MeV) and is LSP**
- **NLSP can be a neutralino or a slepton**
- **In case of the neutralino NLSP:**
  final state always has two photons

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

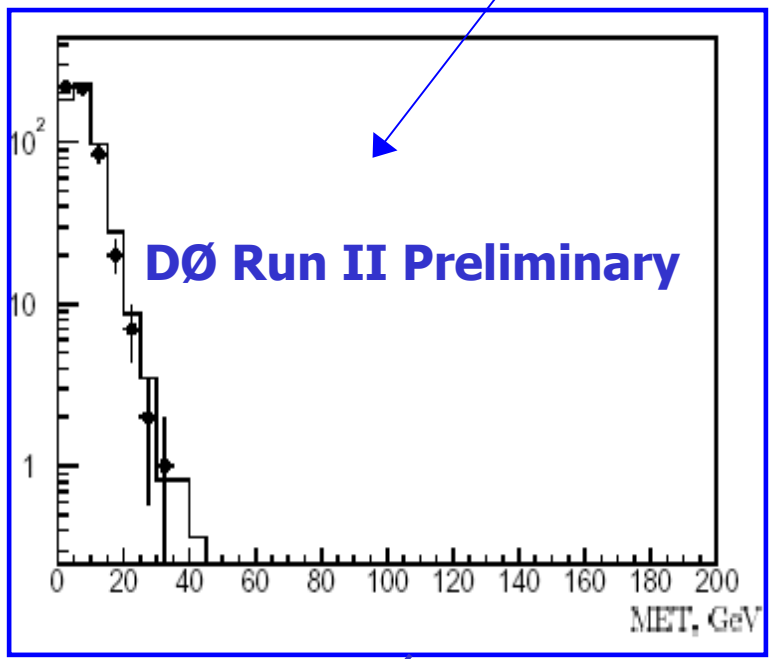
$$p\bar{p} \rightarrow \text{gauginos} \rightarrow W, Z, \gamma + \chi_1^0 \chi_1^0 \rightarrow$$
$$\rightarrow \gamma\gamma + \tilde{G}\tilde{G} + X$$

GMSB SUSY search

Require two photons with $p_T > 20$ GeV, apply quality and topological cuts, determine QCD background from data

Sample / MET bin	QCD - dominated Data Sample	2 γ data	QCD Data Sample Normalized
< 20 GeV	5841	535	Normalized to be equal
> 25 GeV	65	3	6.0 ± 0.8
> 30 GeV	27	1	2.5 ± 0.5
> 35 GeV	18	0	1.6 ± 0.4

Missing E_T distribution of 2 γ data (points) compared with normalized QCD background (hist)

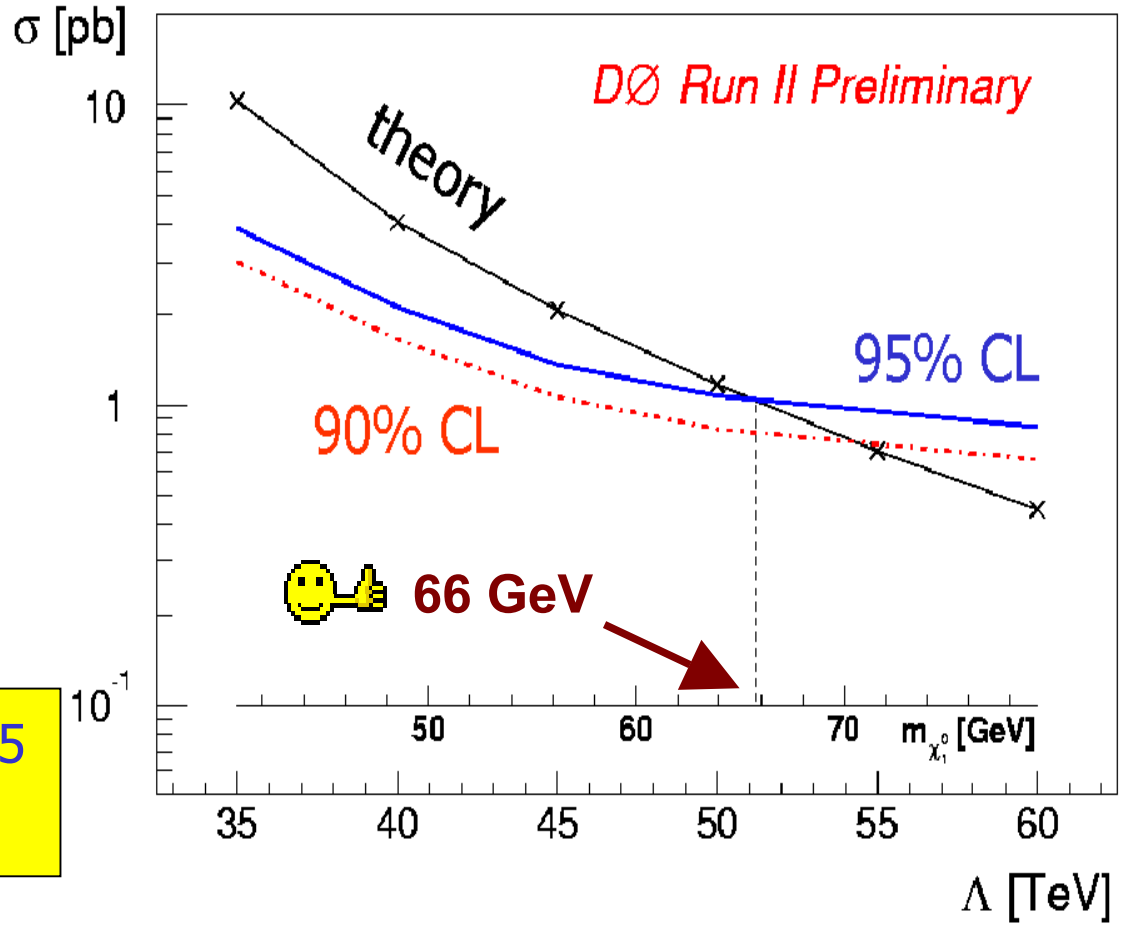


QCD background sample obtained by inverting EM quality cuts

GMSB SUSY search

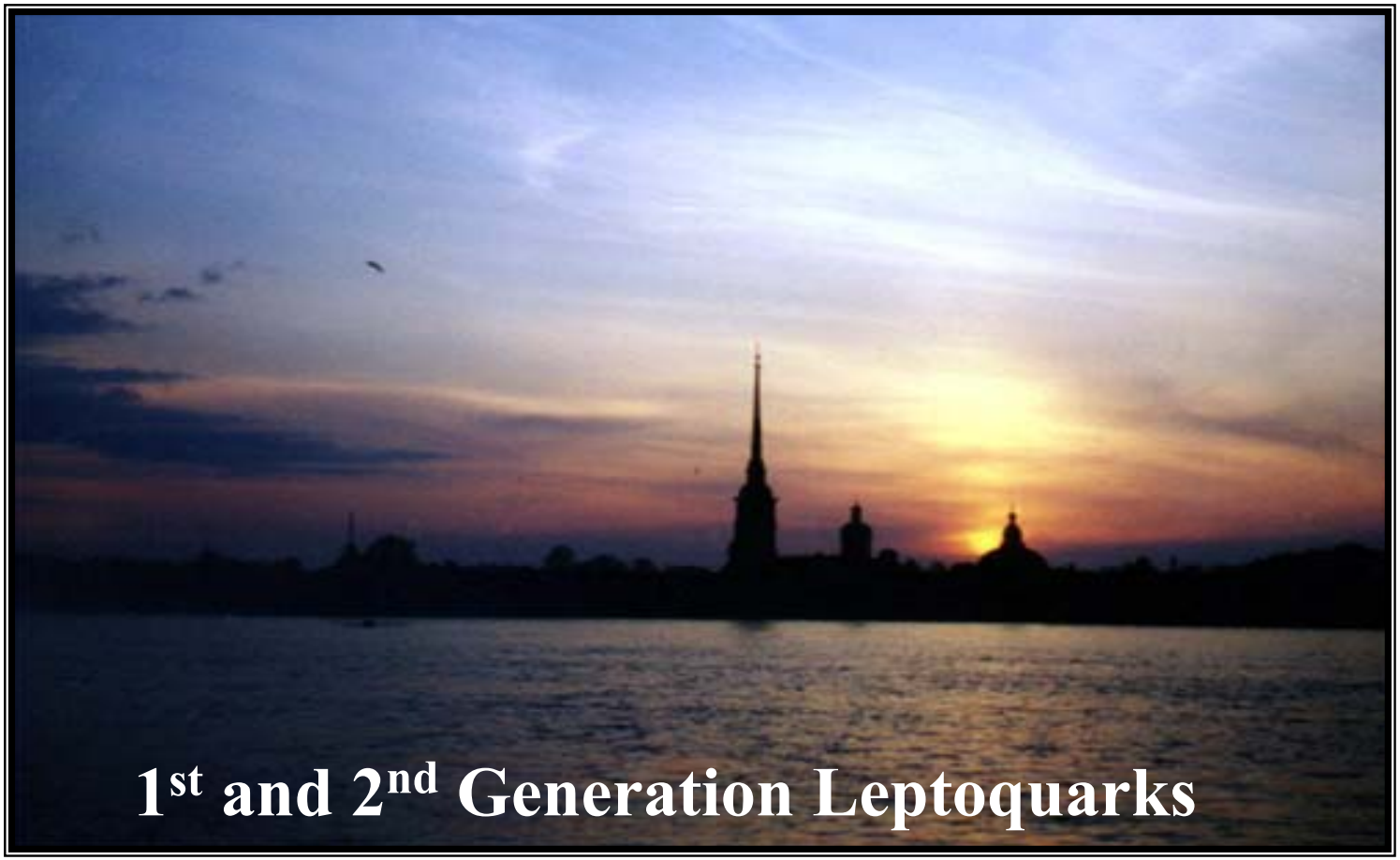
$\mathcal{L} = 40.0\ pb^{-1}$

Theory = "Snowmass" slope:
$M = 2\Lambda$,
$N_5 = 1$,
$\tan\beta = 15$,
$\mu > 0$



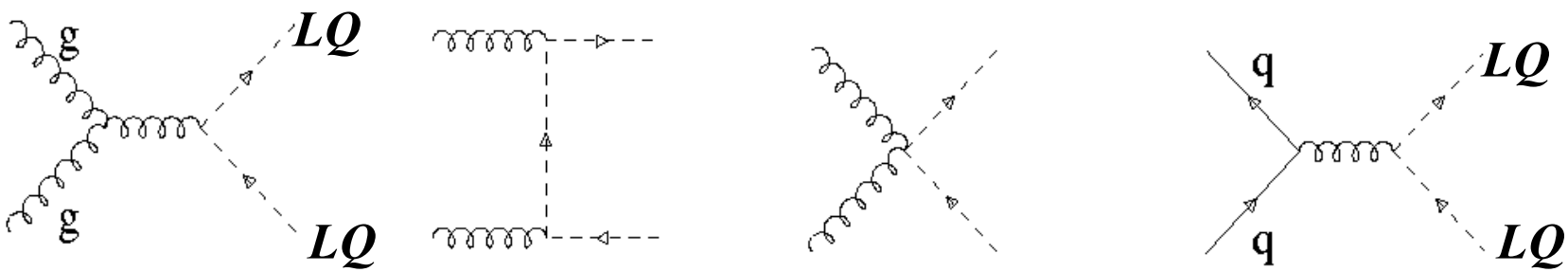
Run I result: $M(\chi^0) > 75$ GeV ($\mathcal{L} = 120\ pb^{-1}$)

Searches for Exotics at 



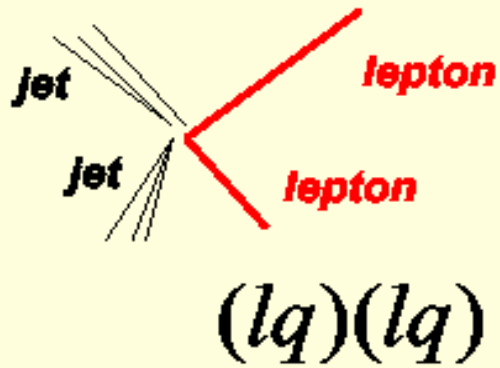
Search for Leptoquarks

- **Leptoquarks (LQ) appear in extended gauge sectors and composite models**
  - directly couple to Leptons and Quarks
  - carry color, fractional electric charge, lepton and baryon number
  - scalar (spin 0) or vector (spin 1)
- **LQ would be pair produced at the Tevatron**
  - Gluon fusion (dominant), quark anti-quark annihilation



Search for Leptoquarks

- **Leptoquark Decay**
  - $LQ \rightarrow l^{\pm}q$ or νq
  - $\beta \equiv$ Branching Ratio ($LQ \rightarrow l^{\pm}q$)
  - LQ could have 3 generations, but no cross-generational decay



- **LQ search was performed in 2e + 2jets and 2μ +2jets channels assuming $\beta \equiv 1$**

- **Background**
  - --Drell-Yan/Z … $Z/\gamma^* + jets \rightarrow l^+l^- + jets$ (dominant)
  - --Top and W pair production
  - --Multi-jet QCD, 2 jets fake EM objects

Search for 1st Gen LQ : 2 e + 2 jets

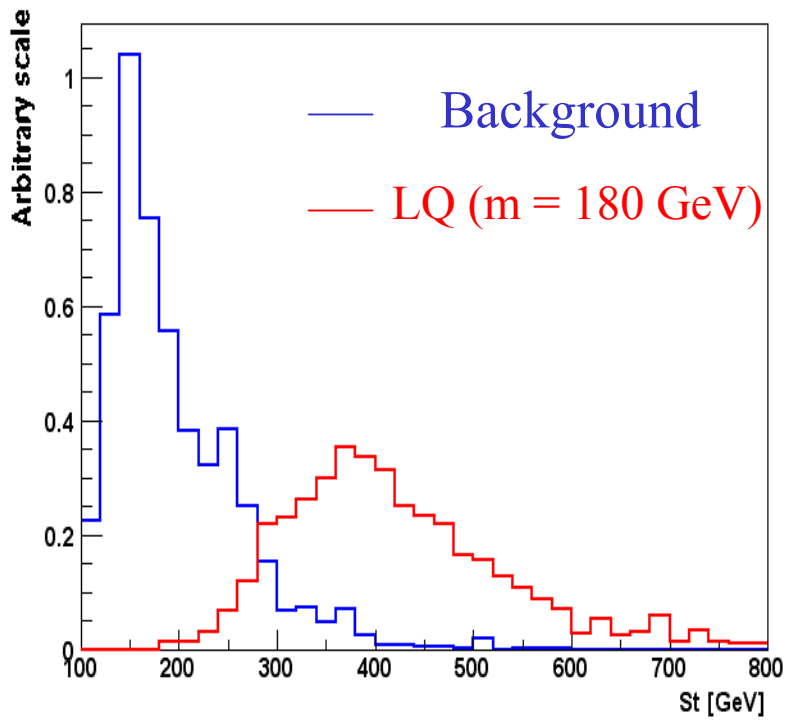
$\mathcal{L} = 43.0\ pb^{-1}$

Event selection

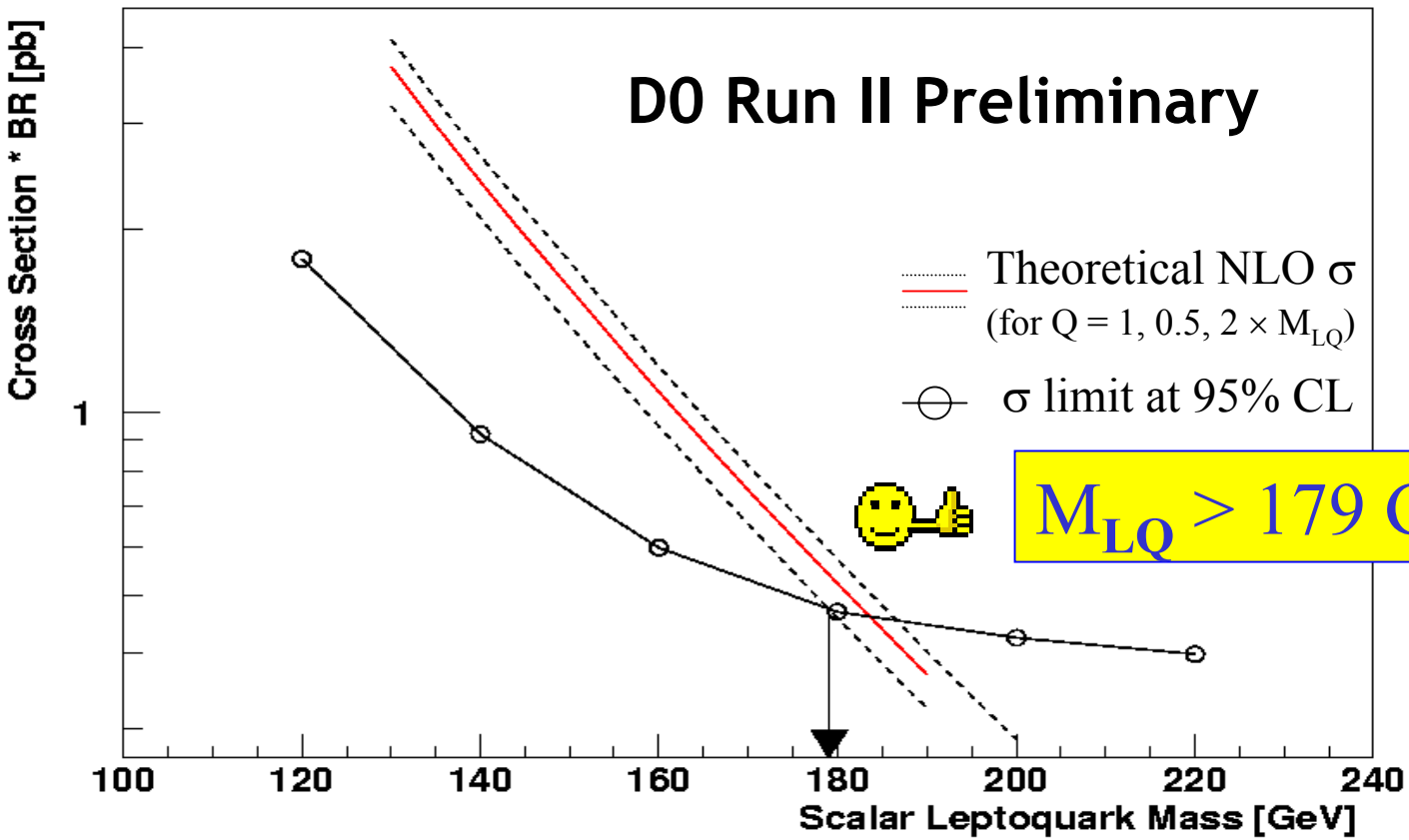
- 2 electrons with $p_T > 25$ GeV
- 2 jets or more with $p_T > 20$ GeV
- $M_{ee} < 75$ GeV or $M_{ee} > 105$ GeV

S_T CUT : $S_T \equiv \sum E_T$(of 2e2j)
S_T >300 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



Search for 1st Gen LQ : 2 e + 2 jets



$M_{LQ} > 179$ GeV

Run I result: $M_{LQ} > 225$ GeV ($\mathcal{L} = 115\ pb^{-1}$)

Search for 2nd Gen LQ : 2 μ + 2 jets

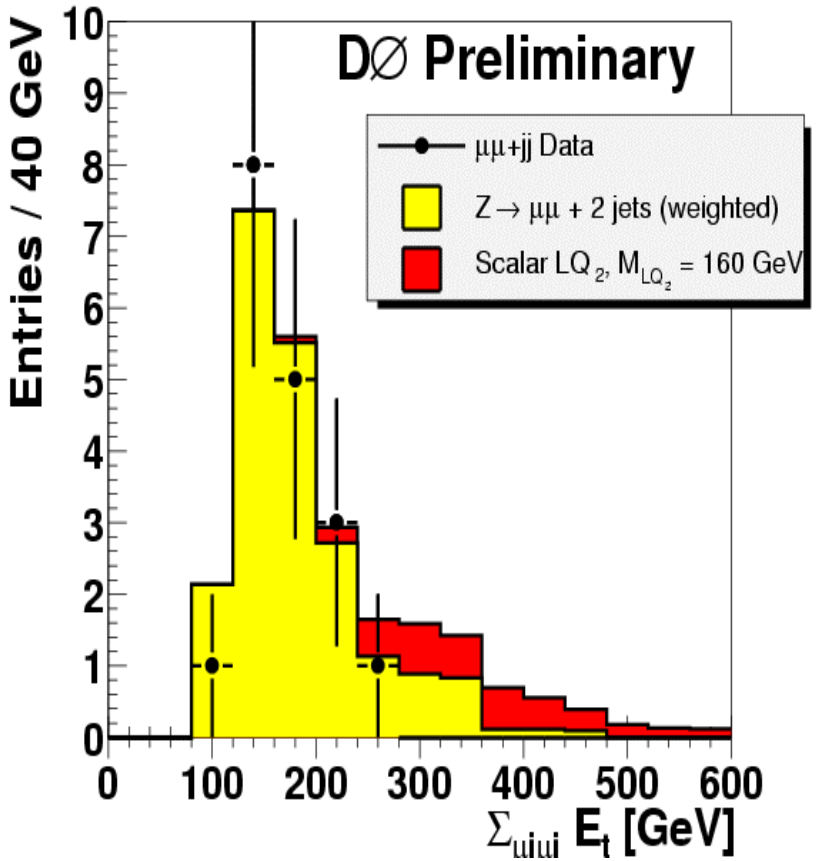
$\mathcal{L} = 30.0\ pb^{-1}$

$S_T \equiv \sum E_T$(of 2μ2j)

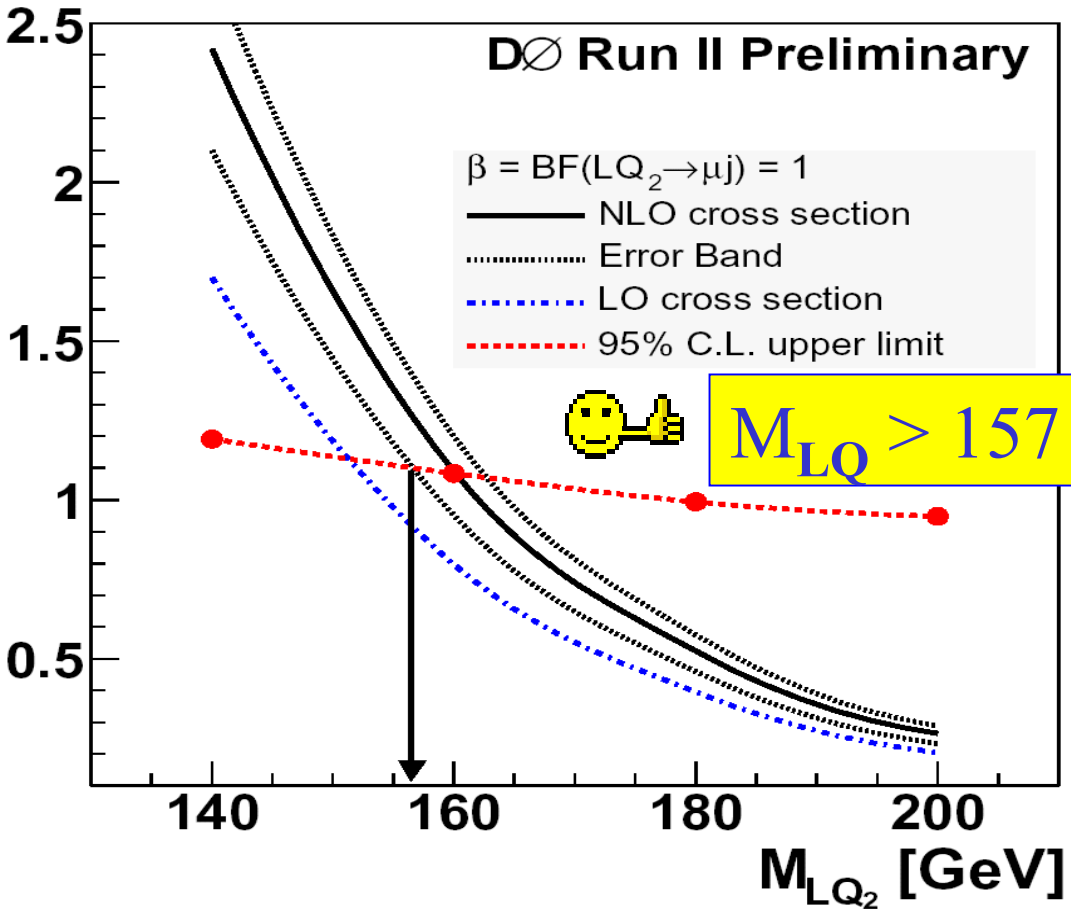
Event selection

- 2 opposite sign muons with $p_T > 15$ GeV
- 2 jets with $p_T > 20$ GeV
- $M_{\mu\mu} > 110$ GeV

	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



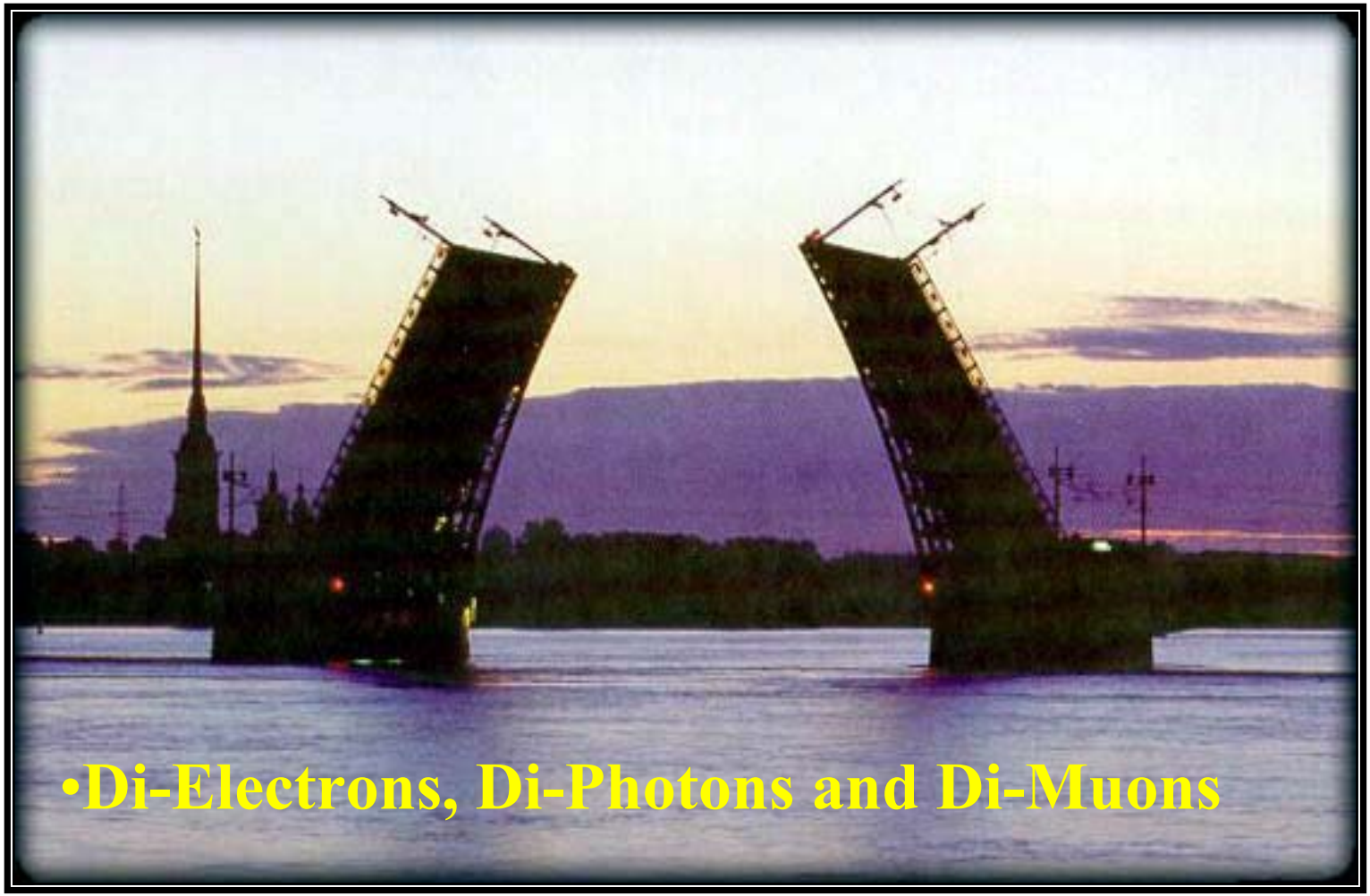
Search for 2nd Gen LQ : 2 μ + 2 jets



$M_{LQ} > 157$ GeV

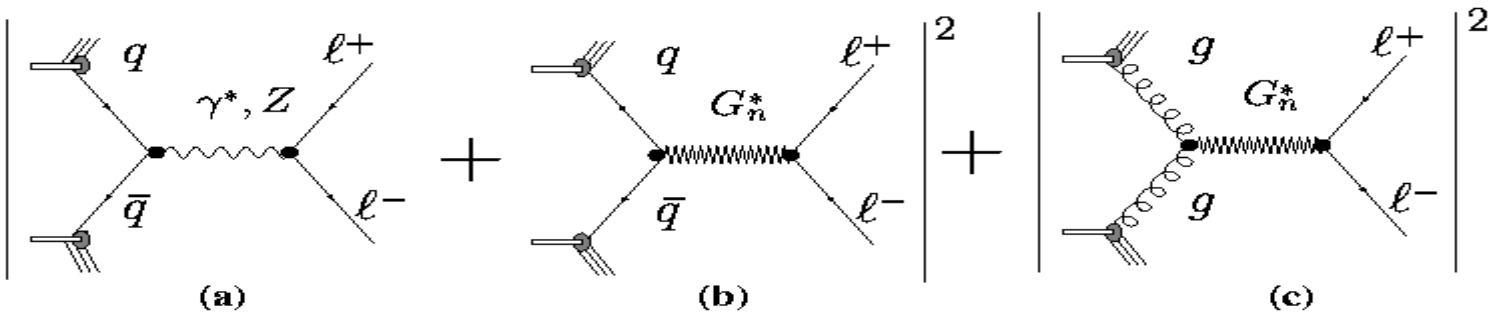
Run I result: $M_{LQ} > 200$ GeV ($\mathcal{L} = 120\ pb^{-1}$)

Searches for Large Extra Dimensions at DØ



Large Extra Dimensions Search

String theory attempting to unify gravity to other interactions require extra dimensions, which can be probed by fermion or boson pair production via virtual gravitons. Signature-> high-mass dileptons and diphotons

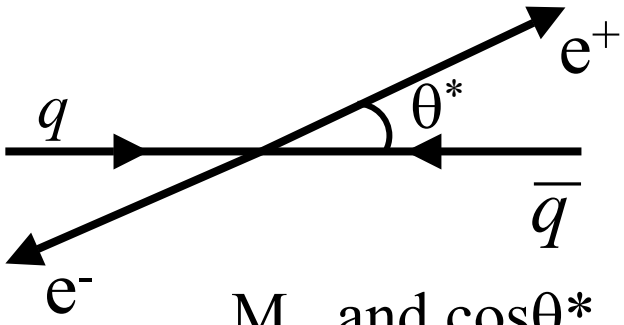


$$\frac{d^2\sigma}{d\mathrm{M}\,d\cos\vartheta} = f_{SM} + f_{\mathrm{int}}\,\eta_G + f_{KK}\,\eta_G^2 \qquad \text{where} \quad \eta_G = \mathrm{F}/M_S^{-4}$$

M_s is the fundamental Planck scale. To solve the hierarchy problem, one can have M_s in the TeV scale for "n"of extra dimensions at least equal to 3. n=1 is ruled-out and n=2 is tightly constrained.

LED Search: Di-EM channel

$\mathcal{L} = 50\ pb^{-1}$

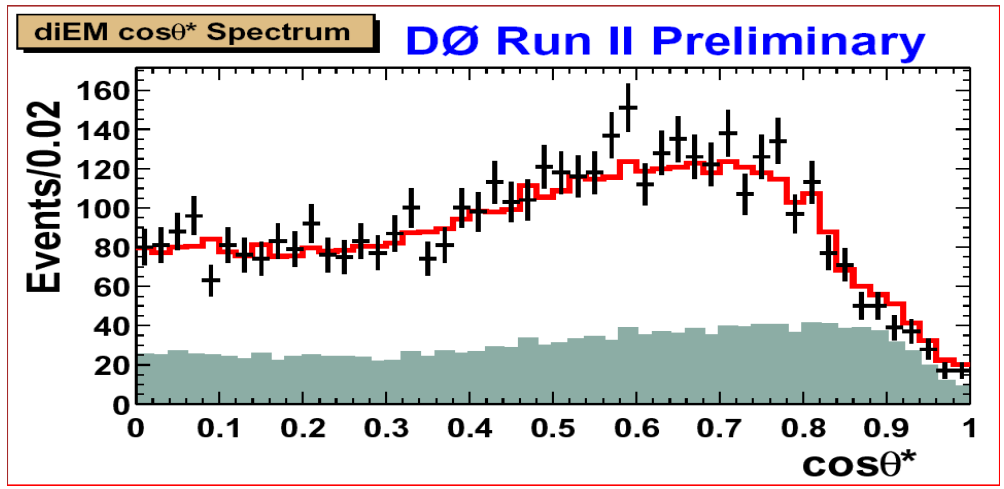


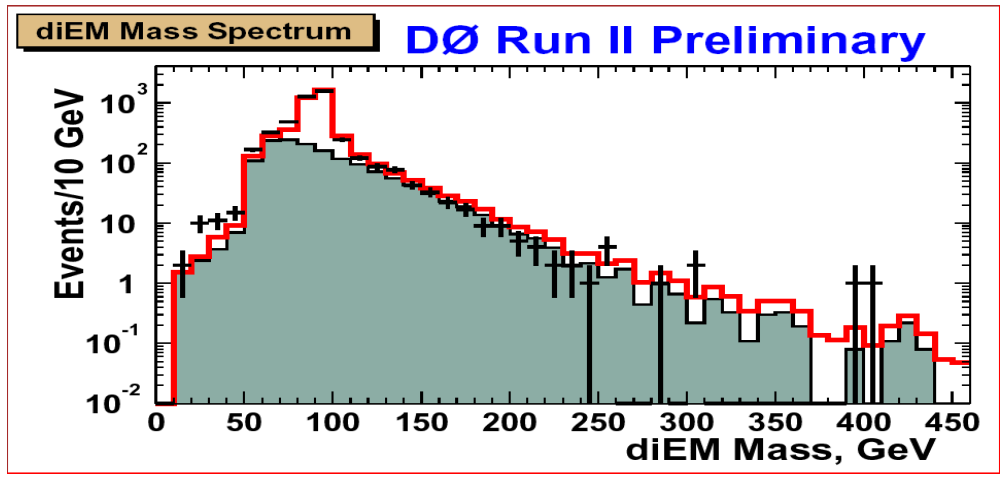
M_{ee} and cosθ*

Require 2 electromagnetic objects with $p_T > 25$ GeV, missing $E_T < 25$ GeV

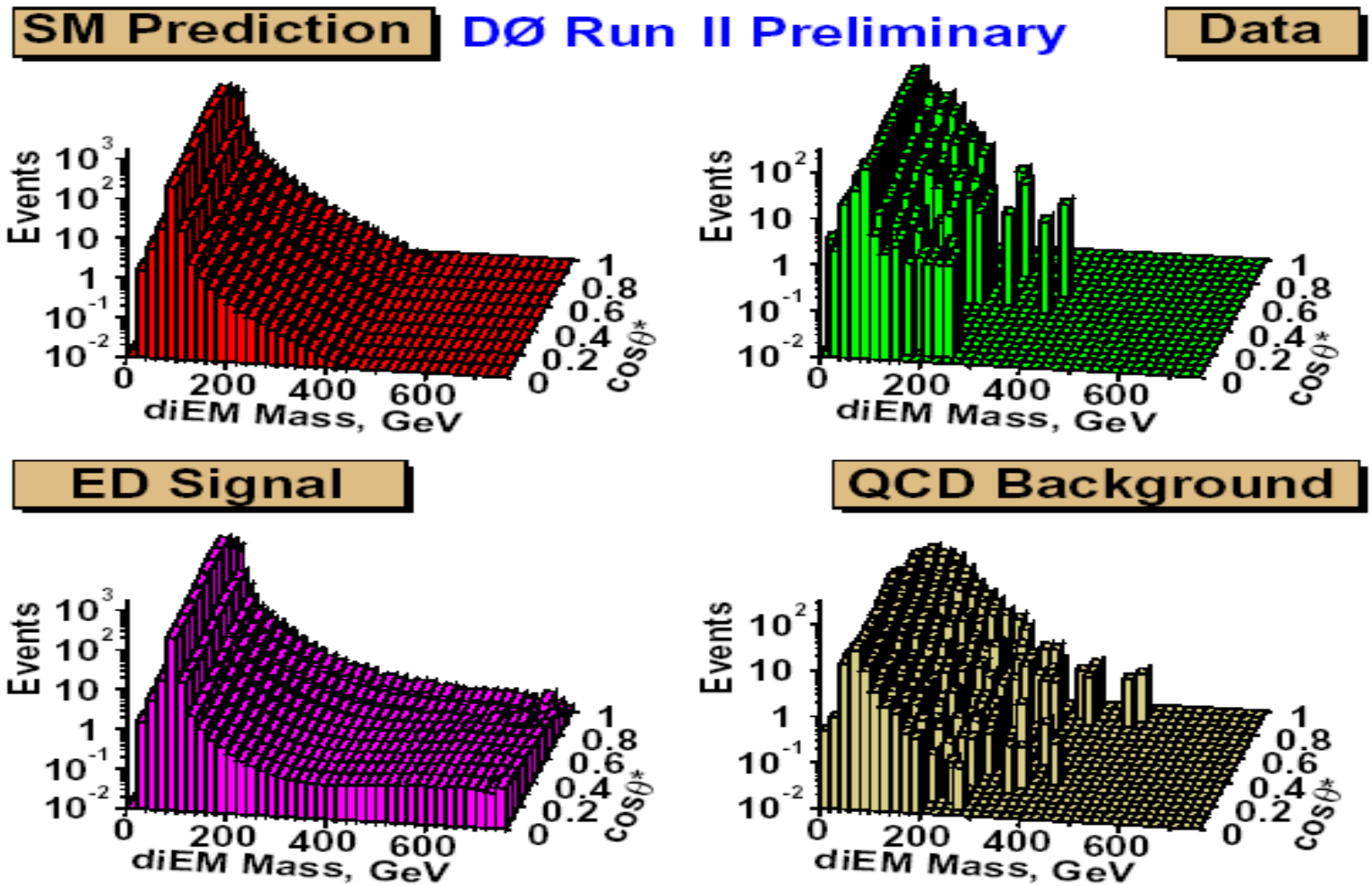
Background

Drell-Yan/Z , direct di-photon, QCD fake EM





LED Search: Di-EM channel

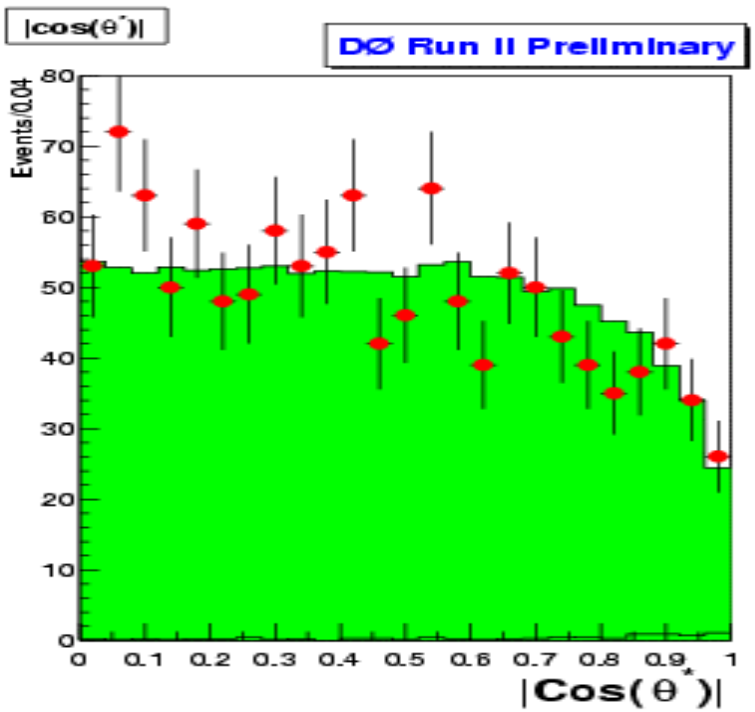


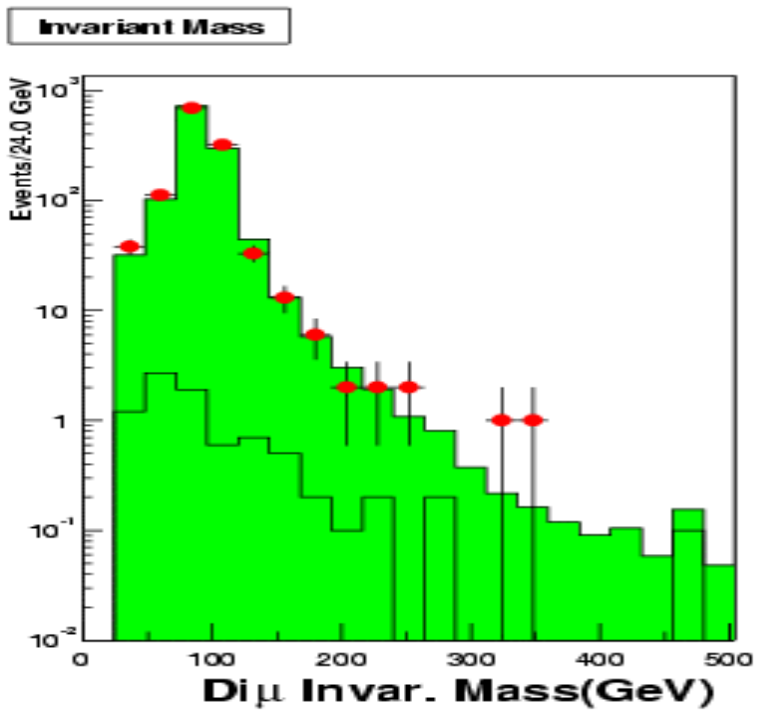
LED Search: Di-Muon channel

$\mathcal{L} = 30\ pb^{-1}$

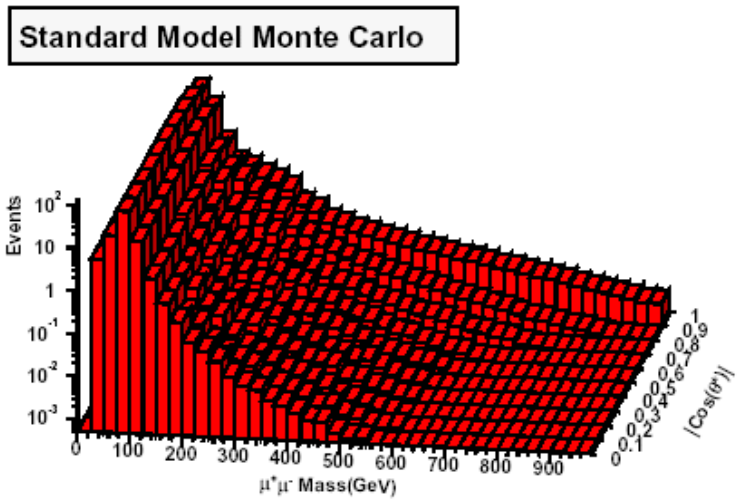
Require two muons with $p_T > 15$ GeV, impose $M\mu\mu > 40$ GeV

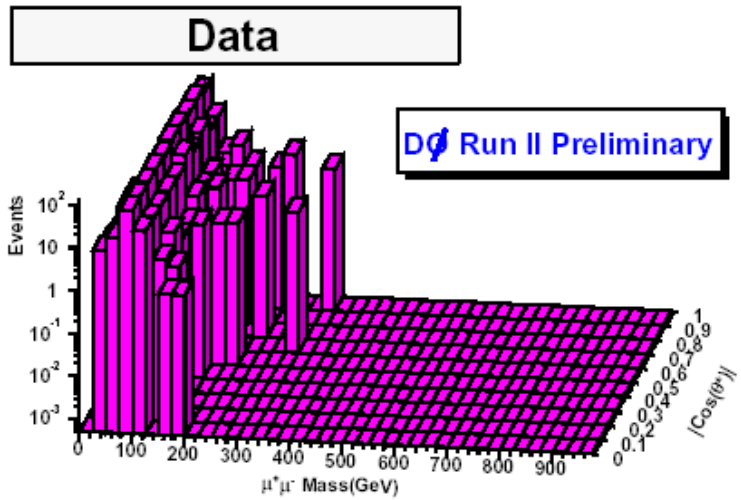
Bkg: DY/Z , heavy quark decays, charge mis-measurement

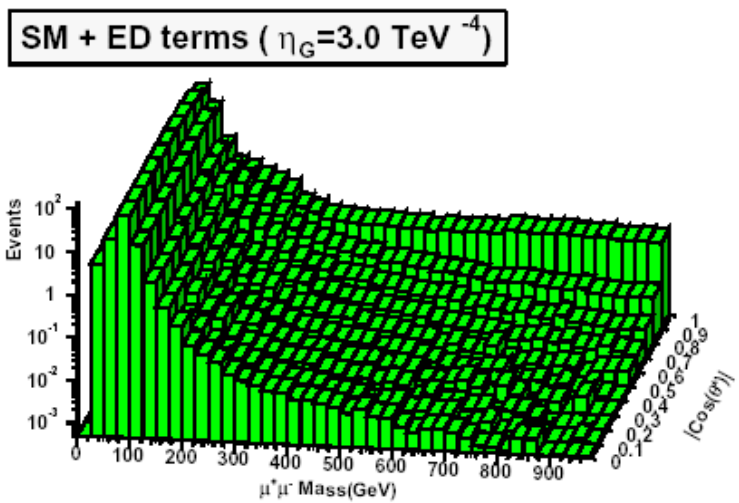


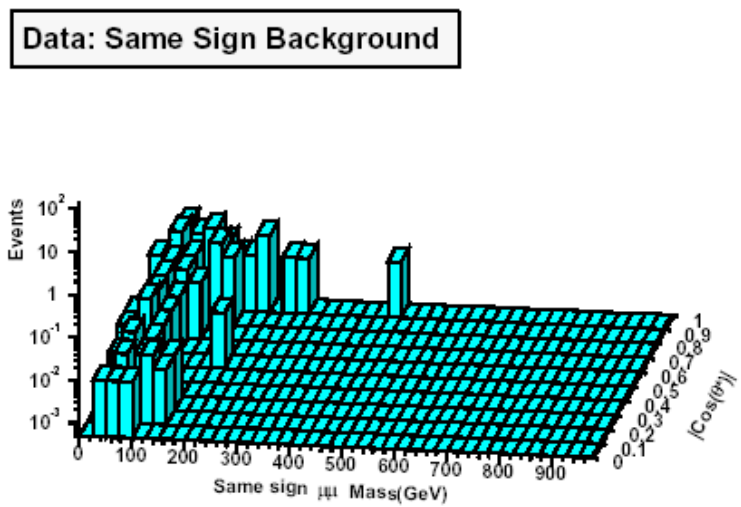


LED Search: Di-Muon channel







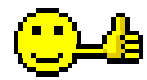


Large Extra Dimensions Search: Results

- **Fit the distributions in the M_{ll} - cosθ* plane to determine the value of η_G ($\eta_G = 0$ 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}
- **Extract 95% CL upper limits on η_G**
- **Translate to 95% CL *lower* limits on Planck scale M_S, in TeV, using different formalisms for F**

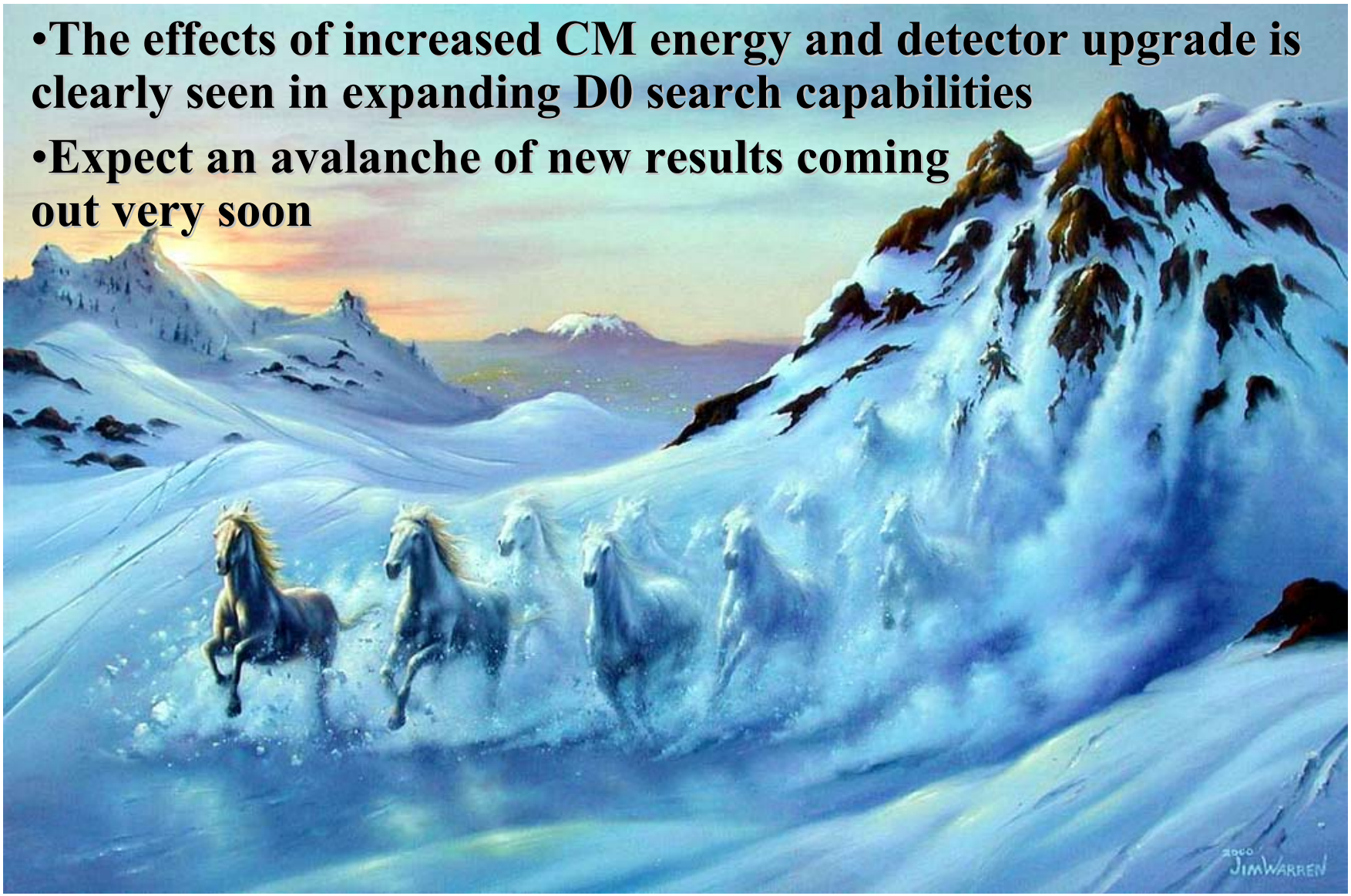
Formalism	GRW	HLZ for n=: 2	7	Hewett λ= 1
di-EM (~50 pb^{-1})	1.12	1.16	0.89	1.00
di-MU (~30 pb^{-1})	0.79	0.68	0.63	0.71

Di-EM limit close to Run I



Di-Muon (new)

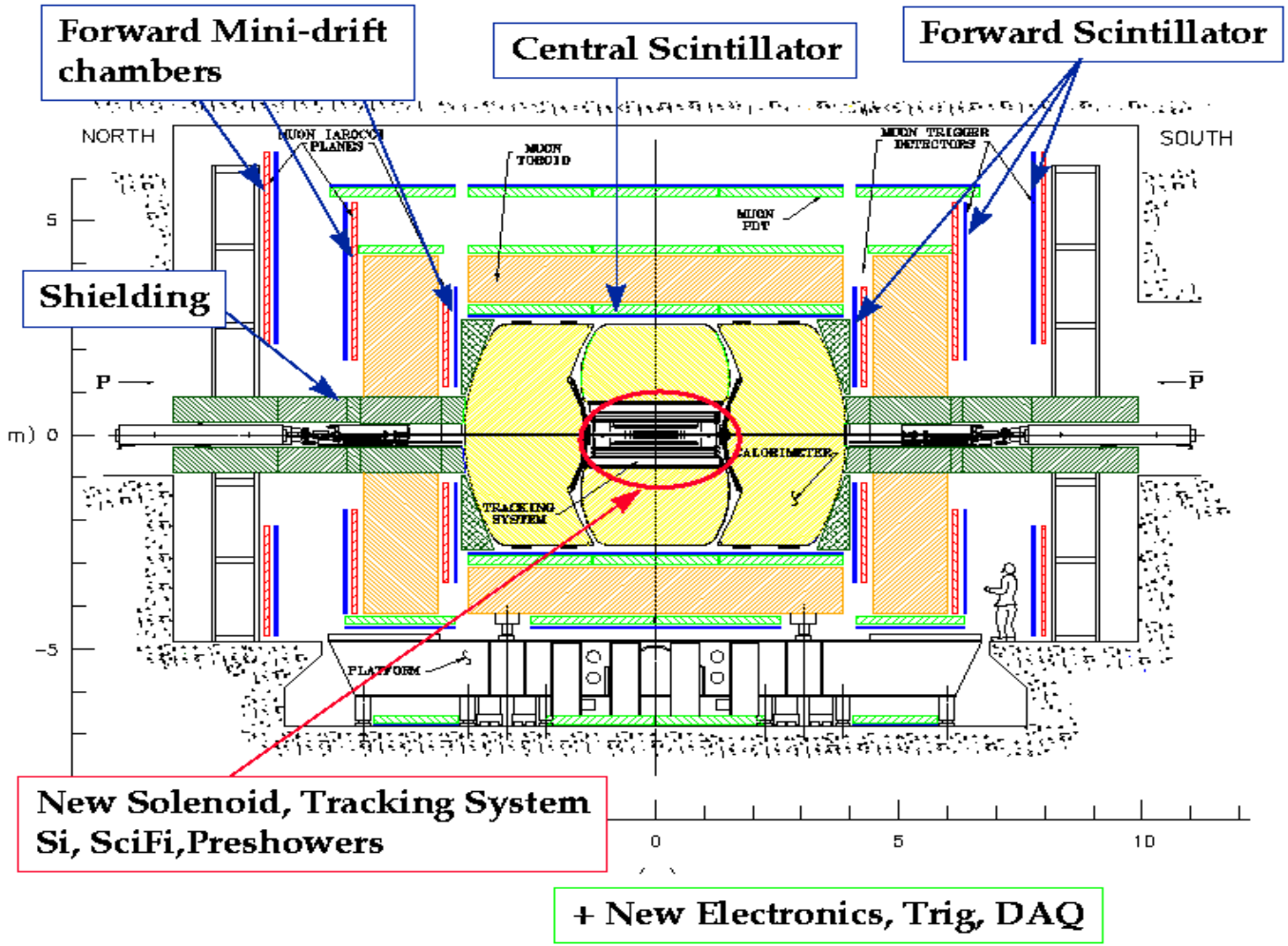
Conclusion


•The effects of increased CM energy and detector upgrade is clearly seen in expanding D0 search capabilities
•Expect an avalanche of new results coming out very soon
JIM WARREN

DØ upgrade/status

D0 upgrade
- tracking
  - Silicon vertex
  - Fiber tracker
- solenoid
  - 2 T magnetic field
- Preshower
- Muons detector
- Electronics
- Trigger system

D0 still commissioning central track and displaced vertex trigger



SUSY Particle Zoo

$$p\bar{p} \rightarrow \tilde{\chi}_i^{\pm}\tilde{\chi}_j^{\mp},\ \tilde{\chi}_i^{\ 0}\tilde{\chi}_j^{\pm},\ \tilde{\chi}_i^{\ 0}\tilde{\chi}_j^{0},\ \tilde{q}\bar{\tilde{q}},\ \tilde{q}\tilde{g},\ \tilde{g}\bar{\tilde{g}},\ \tilde{l}\bar{\tilde{l}}$$

SM Particles		SUSY Particles				
		interaction eigenstates			mass eigenstates	
Name	Spin	Name	Spin	Symbol	Name	Symbol
q = u, d, s, c	1/2	squark	0	$\tilde{q}_L, \tilde{q}_R$	squark	$\tilde{q}_L, \tilde{q}_R$
q = b, t	1/2	squark	0	$\tilde{q}_L, \tilde{q}_R$	squark	$\tilde{q}_1, \tilde{q}_2$
$l = e, \mu, \tau$	1/2	slepton	0	$\tilde{l}_L, \tilde{l}_R$	slepton	$\tilde{l}_1, \tilde{l}_2$
$\nu = \nu_e, \nu_\mu, \nu_\tau$	1/2	sneutrino	0	$\tilde{\nu}$	sneutrino	$\tilde{\nu}$
gluons g	1	gluino	1/2	$\tilde{g}$	gluino	$\tilde{g}$
$W^{\pm}$	1	wino	1/2	$\tilde{W}^{\pm}$	2 charginos of each sign	$\tilde{\chi}^{\pm}_{1,2}$
$H^{\pm}$	1	higgsino	1/2	$\tilde{H}^{\pm}$		
photon γ	1	photino	1/2	$\tilde{\gamma}$	4 neutralinos	$\tilde{\chi}^{0}_{1,2,3,4}$
Z^0	1	zino	1/2	$\tilde{Z}^0$		
h,H,A	1	higgsino	1/2	$\tilde{H}^0_{1,2}$		
graviton G	2	gravitino	3/2	$\tilde{G}$	gravitino	$\tilde{G}$

Where we are standing: Run I vs Run II

SUSY search	Run I ($120\ pb^{-1}$)	Run II
Jets $+mE_T$ (new)	--------	$\varepsilon \times \sigma < 4.2$ pb ($4.1\ pb^{-1}$) $mE_T > 70$ GeV
$e\mu + mE_T$	?	$A \times \sigma$ <0.1 pb ($33\ pb^{-1}$) $mE_T > 45$ GeV
$lll + mE_T$ (Run I) $eel + mE_T$ (Run II)	$\sigma \times BR < 0.3$ pb $M(\chi^0) \approx 60$ GeV $mE_T > 10$-15 GeV	$\sigma \times BR < 2.2$ pb ($42\ pb^{-1}$) $M(\chi^0) = 62$ GeV $mE_T > 15$ GeV

Where we are standing: Run I vs Run II

Analysis	Run I (120 pb^{-1})	Run II
SUSY $2\gamma + mE_T$	$M(\chi^0) > 75$ GeV	$M(\chi^0) > 66$ (40 pb^{-1})
1st LQ 2 e + 2 jets	$M_{LQ} > 225$ GeV	$M_{LQ} > 179$ (43 pb^{-1})
2nd LQ 2 μ + 2 jets	$M_{LQ} > 200$ GeV	$M_{LQ} > 157$ (30 pb^{-1})
LED 2em	$M_S > 1.1$ TeV	$M_S > 1.0$ (50 pb^{-1})
LED 2 μ (new)	-------	$M_S > 0.71$ (30 pb^{-1})

A lot of another analyses are going on: gauge interactions search, SUGRA particles search with the different jets & leptons & mE_T signatures … etc