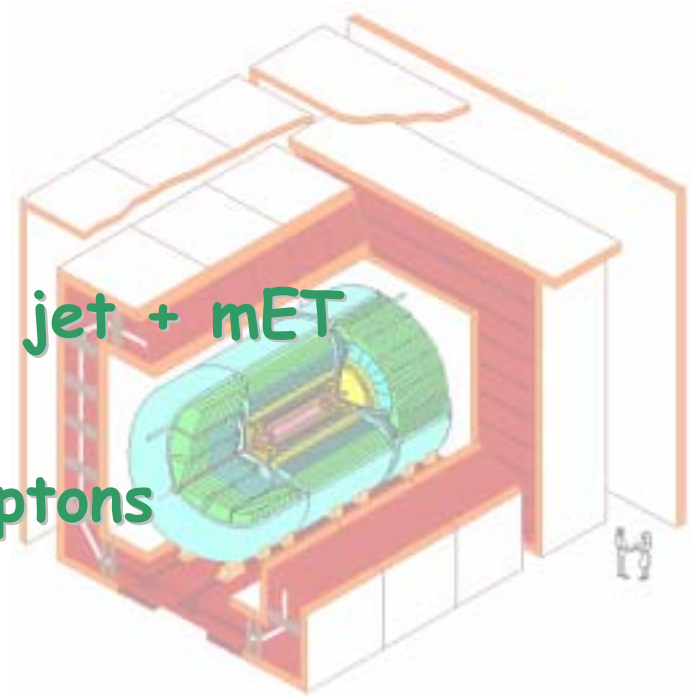
PASCOS 2003

Supersymmetry at DØ

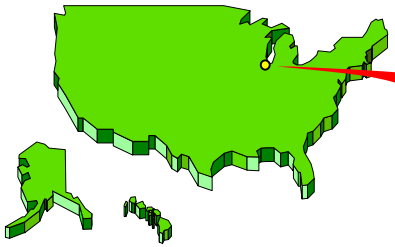
and other new phenomena searches in Run II

- TeVatron and DØ upgrade
- Run II preliminary studies
  - mSUGRA : squarks and gluinos jet + mET
  - GMSB : diphotons
  - RPV : trileptons / likesign dileptons
  - Extra-dimensions

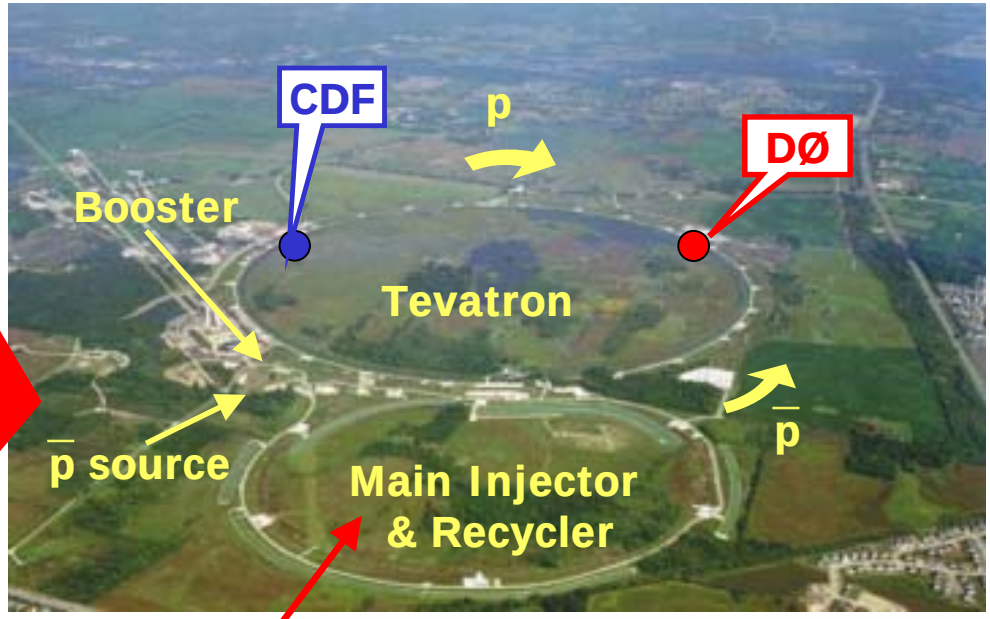


Auguste BESSON for the D0 collaboration

TeVatron upgrade

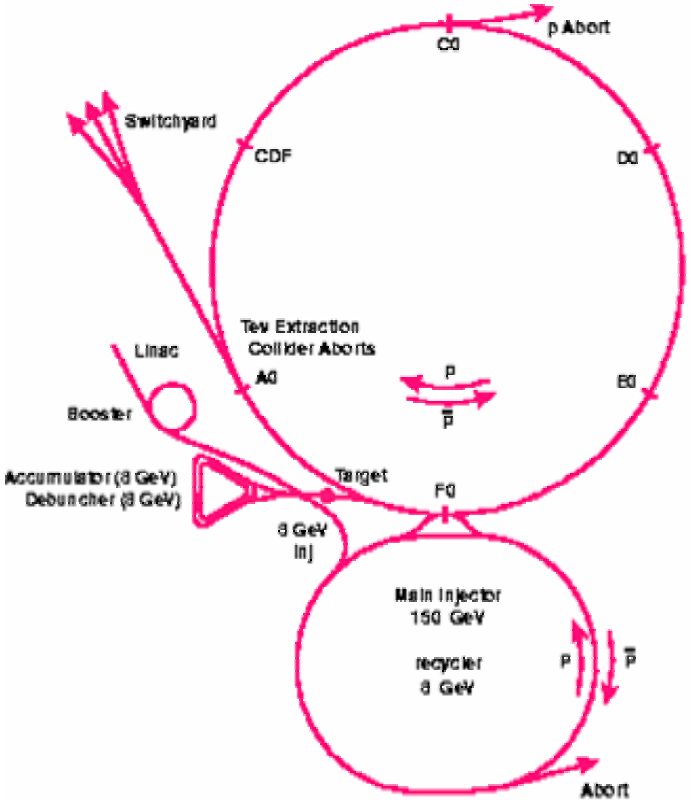


Fermilab



- p-pbar collider
- Run IIa : march 2001
- Energy: 1.8 → 1.96 TeV
- Luminosity
  - new injector : main injector
  - # bunches : 6 x 6 → 36 x 36
  - pbar production ↗
  - pbar recycling :

  Recycler (Run IIb)

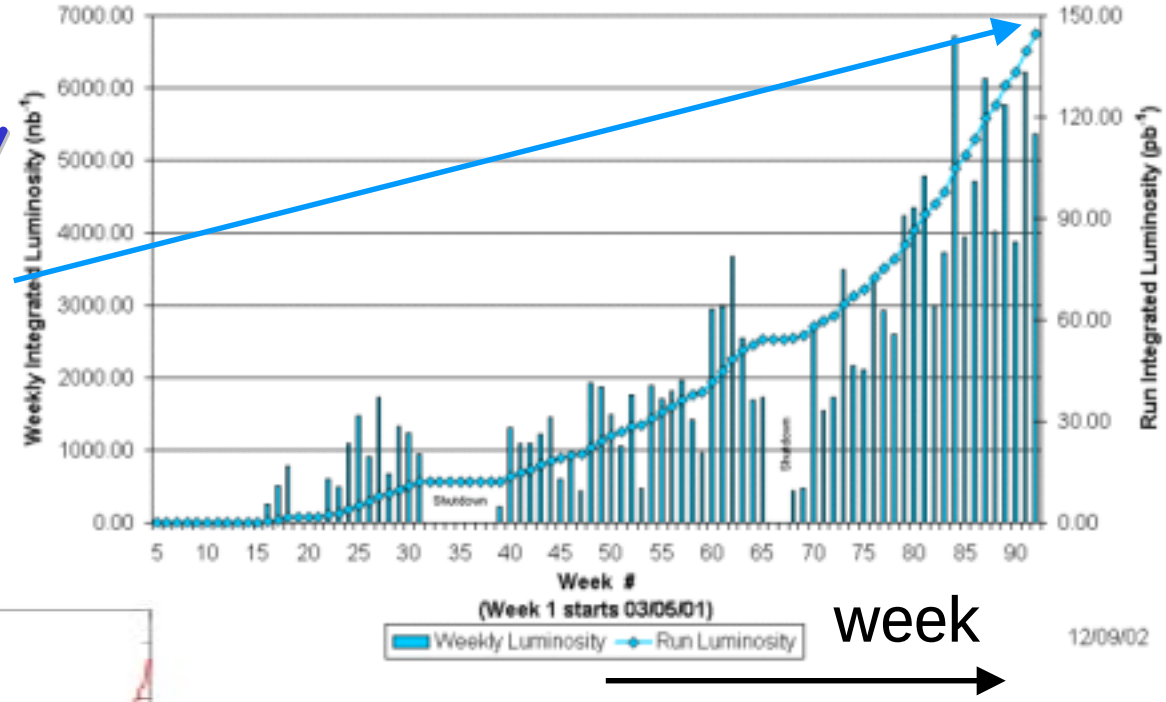


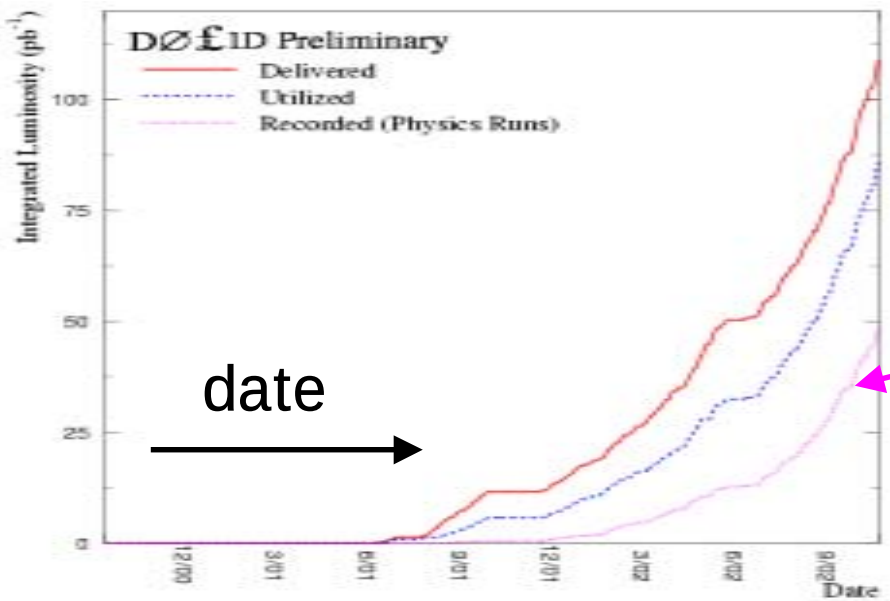
TeVatron upgrade (2)

	Run 1b	Run 2a	Run 2 upgrade
time	1990-96	2001-2005	start 2005-06
p/bunch (10^{11})	2.3	2.7	2.7
pbar/bunch (10^{10})	5.5	3.0	10
# bunches	6 x 6	36 x 36	140 x 103
bunch length (cm)	60	37	37
time between bunch (ns)	~ 3500	396	132
# interactions/crossing	2.5	2.3	4.8
crossing angle (μrad)	0	0	136
p/p emittance (mm mrad)	$23\pi/13\pi$	$20\pi/15\pi$	$20\pi/15\pi$
$\sqrt{s}$ (TeV)	1.8	1.96	1.96
Instantaneous L ($10^{31}cm^{-2}s^{-1}$)	0.16	8.6	52
$\int Ldt$ (pb^{-1}/week)	3.2	17.3	105
integrated $\int Ldt$ (fb^{-1})	~ 0.13	~ 2	10-15

Run IIa : current luminosity

- Maximum Luminosity
  = 3.6 x 10^{31} $cm^{-2}s^{-1}$
- Delivered luminosity
  ~ 150 pb^{-1}
  (9 december 2002)





∫L.dt on tape

~ 50 pb^{-1} (october 2002)

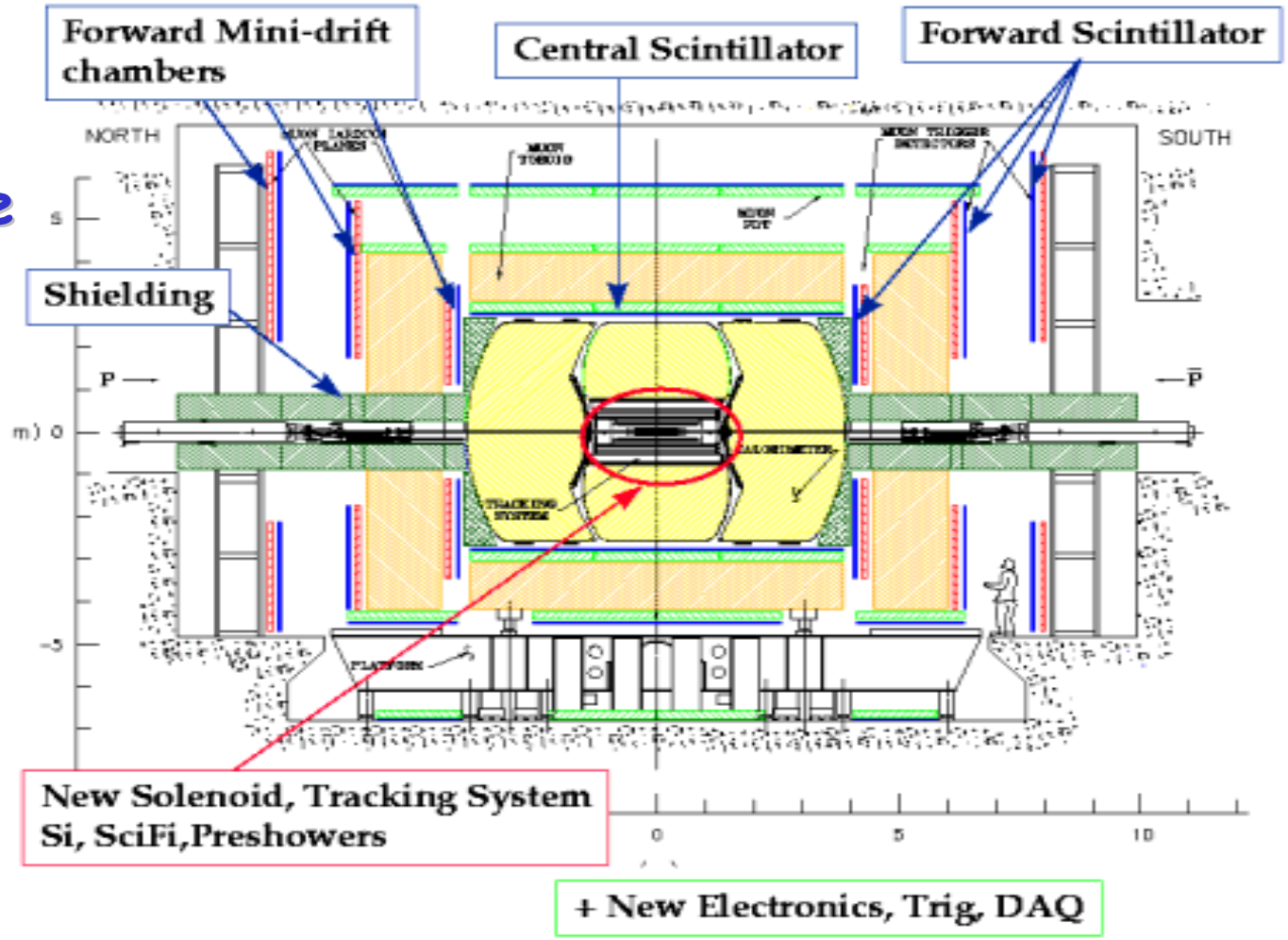
~ 75 pb^{-1} (mid-december 2002)

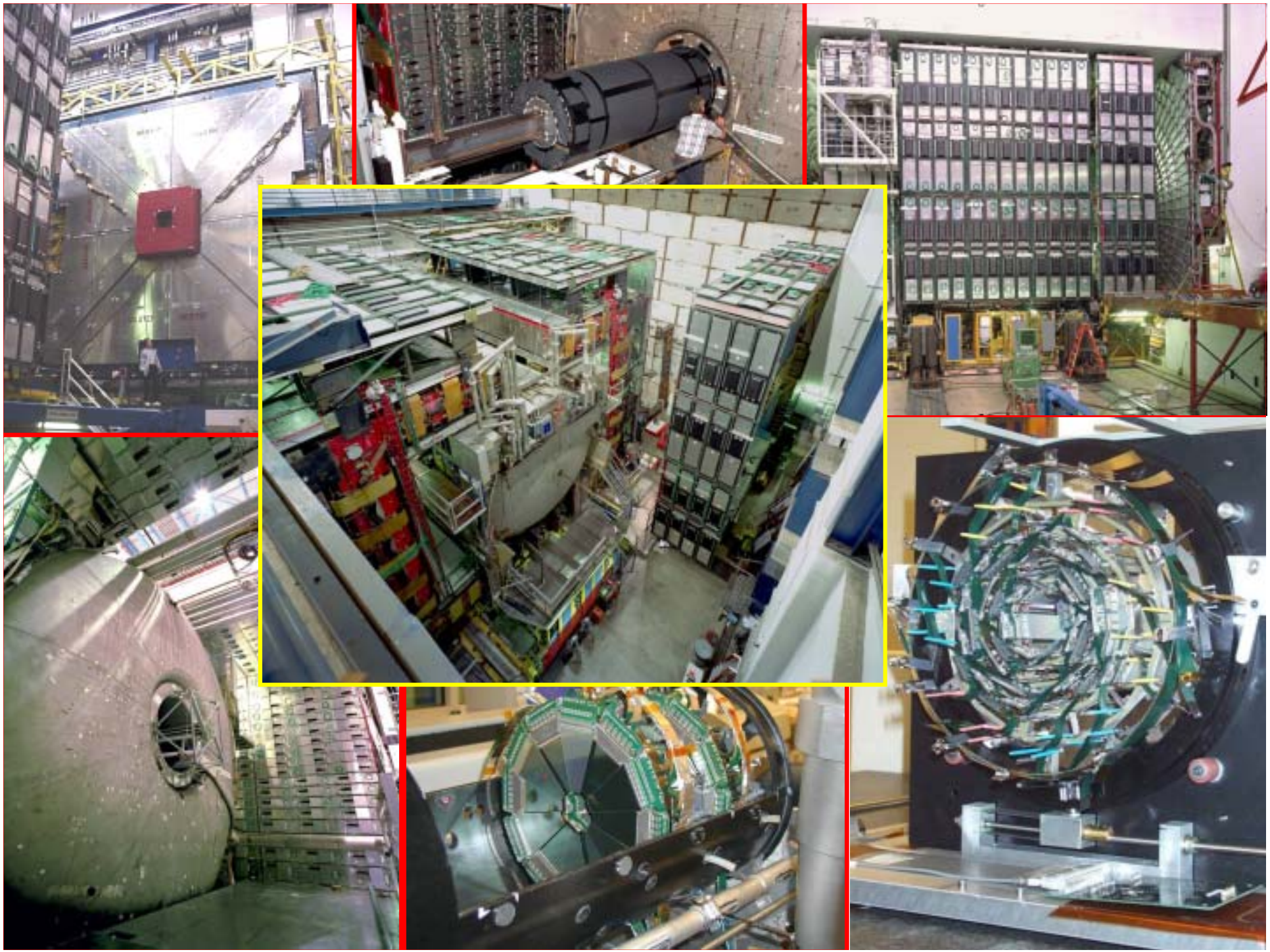
The DØ collaboration

~ 650 physicists; 76 institutions; 18 countries

DØ upgrade

- **Run I**
- Calorimeter
  - LAr/U, compensate
- **Run II upgrade**
- tracking
  - Silicon vertex
  - Fiber tracker
- solenoid
  - 2 T magnetic field
- Preshower
- Muons detector
- Electronics
- Trigger system





MSSM / mSUGRA

production

Cross-sections

Run II preliminary study: squarks/gluinos

Susy production

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

- **Neutralinos/charginos**
  - trilepton channel $p\bar{p} \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0} \Rightarrow \ell^{1,2,3} + \not{E}_T + X$
  - dilepton channel $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm} \Rightarrow \ell^{1,2} + \not{E}_T + X$
- **sleptons** cross-section small.
- **squarks/gluinos**
  - jet + mET $p\bar{p} \to \tilde{q}\bar{\tilde{q}}, \tilde{q}\tilde{g}, \tilde{g}\tilde{g} \Rightarrow jj\not{E}_T + X$
  - single γ + jets + mET $p\bar{p} \to \tilde{q}/\tilde{g} \Rightarrow \tilde{\chi}_2^0 + X \Rightarrow \gamma jj\not{E}_T + X$
    $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 + \gamma$
- **stops and sbottom**

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

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

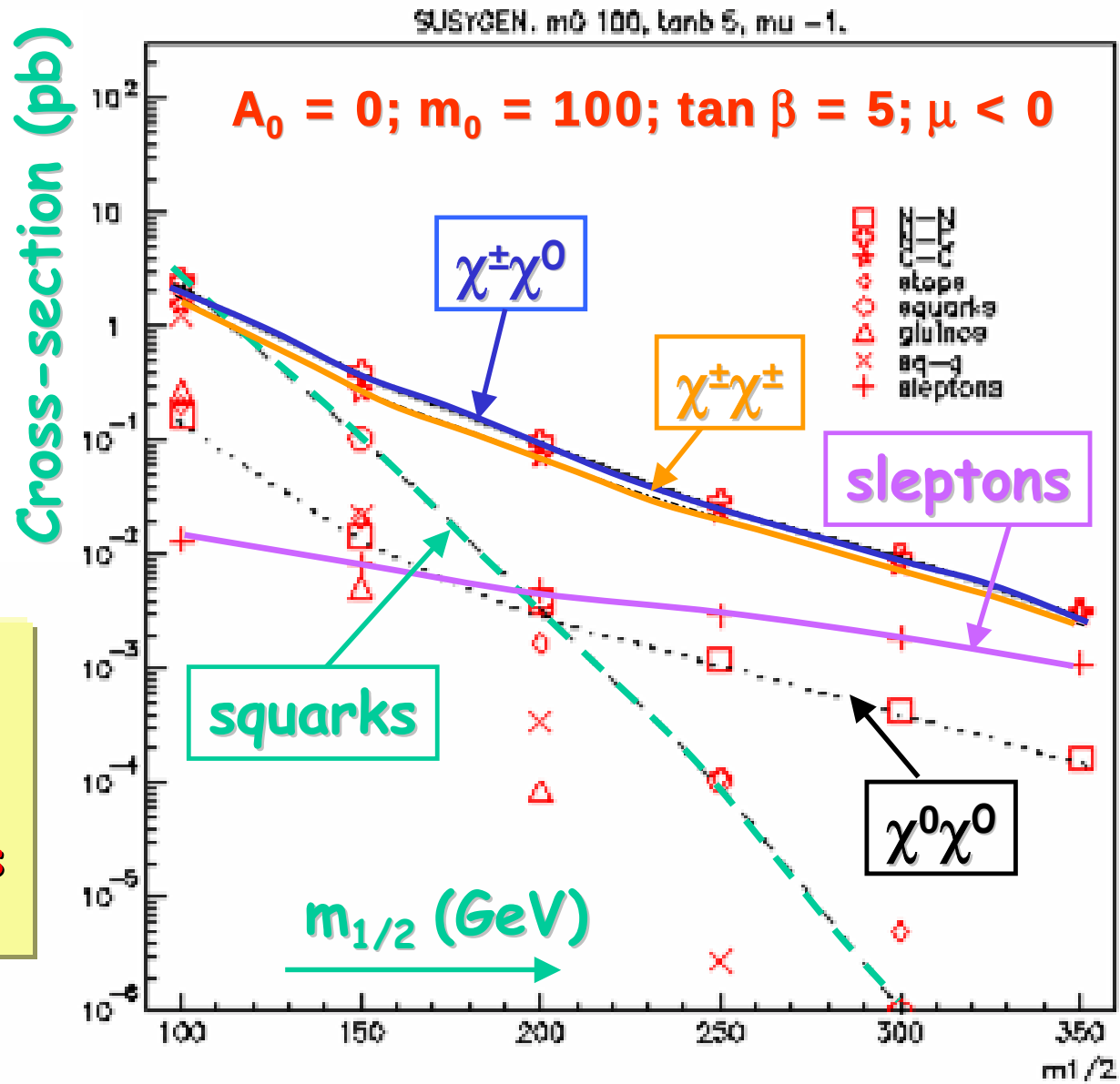
$\tilde{b}_1 \to b\,\tilde{\chi}_2^0$
$\hookrightarrow \tilde{\chi}_1^0\, e^+ e^-$

cross-section (mSUGRA)

$m_{1/2}$ is the crucial parameter

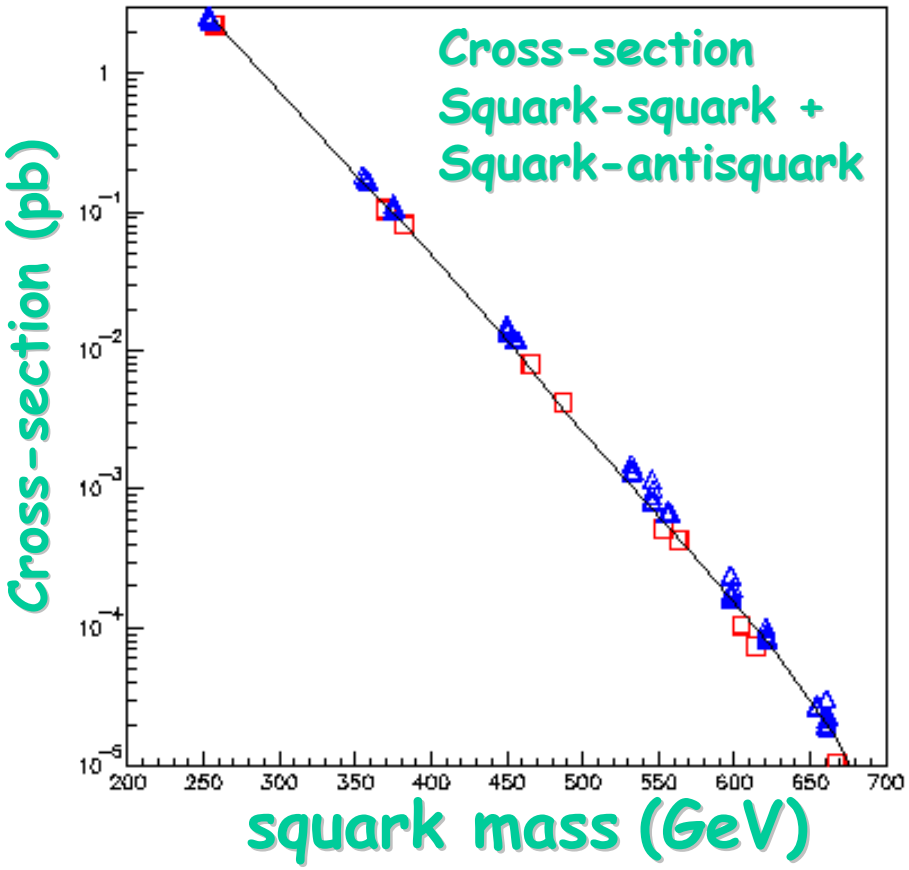
$m_0 = 100$
$\tan\beta = 5$
$\mu < 0$

For $m_{1/2} > 100$ GeV and $m_0 > 100$ GeV pair production of Charginos/Neutralinos dominates

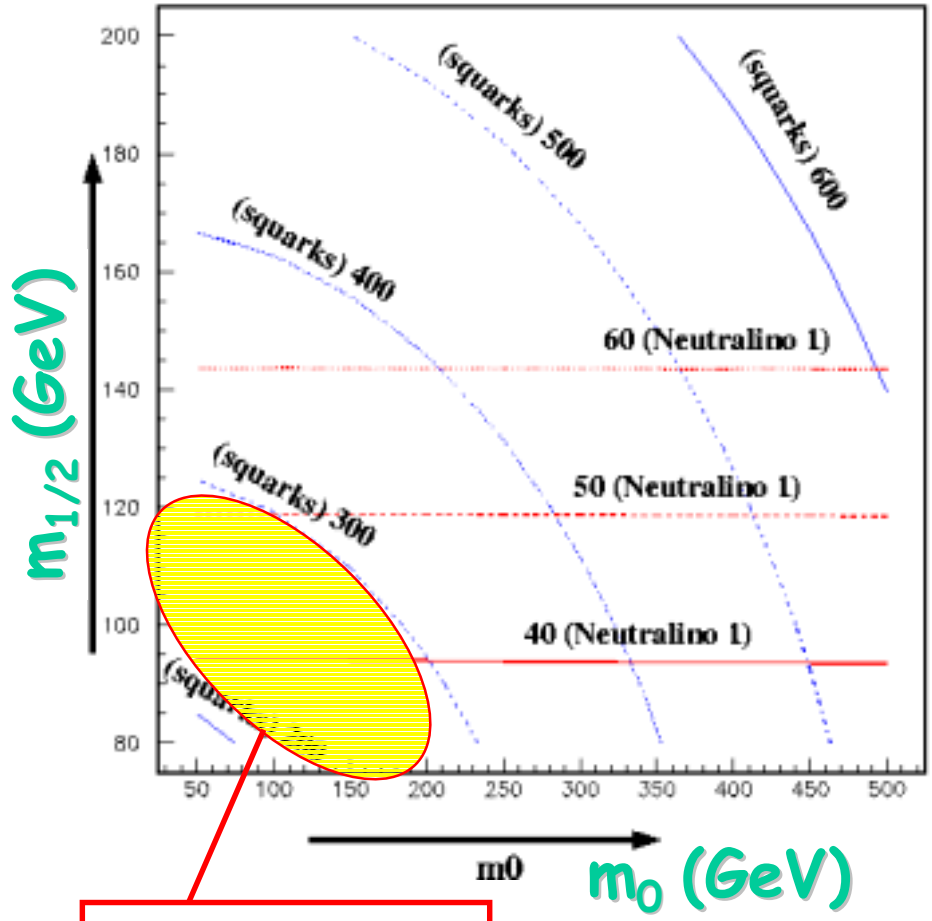


Cross-section (squarks)

- squark productions depend "only" on their mass

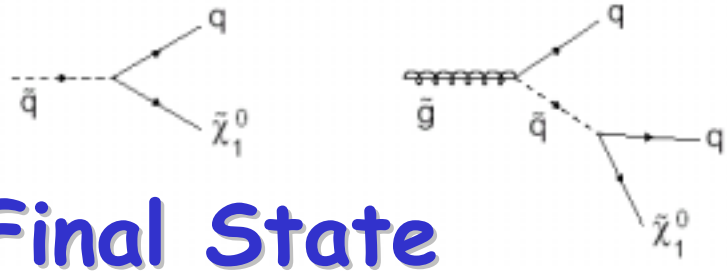


tan β = 5; μ < 0; A_0 = 0

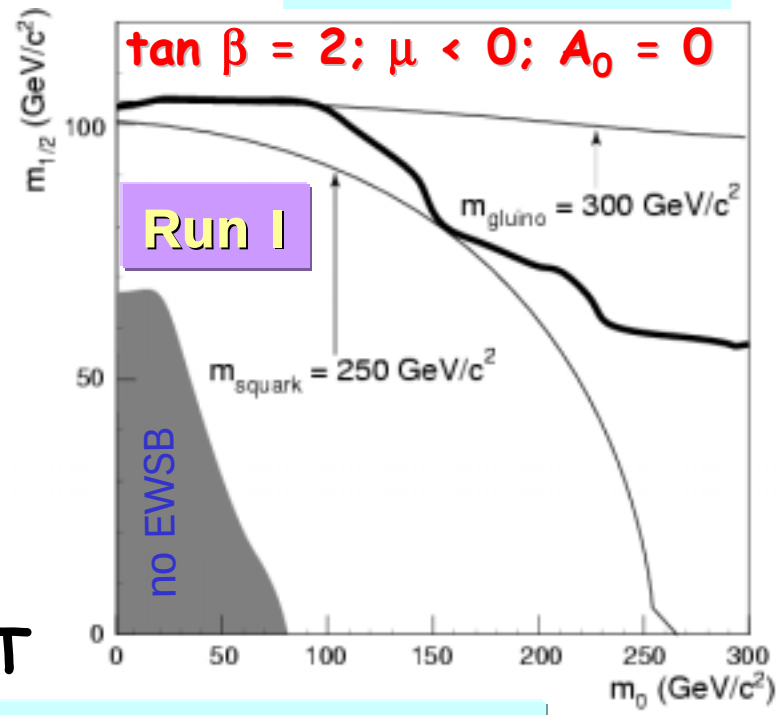


Squarks dominate

squarks and gluinos



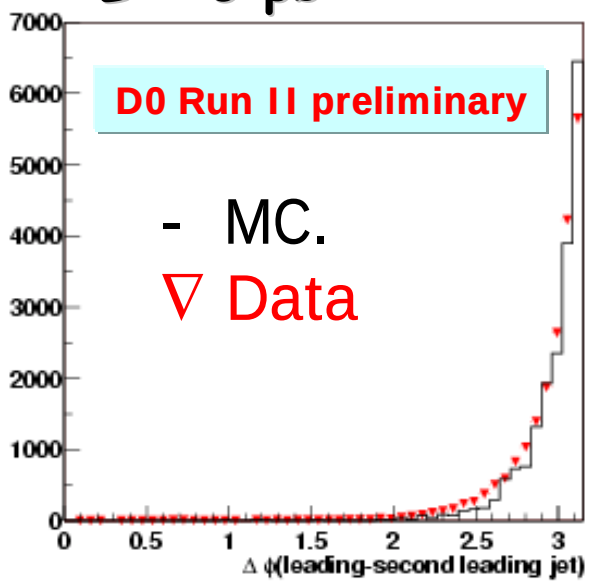
PRL 83, 4937 (1999)



- **Final State**

  >=2 jets + mET

L ~ 6 pb^{-1}



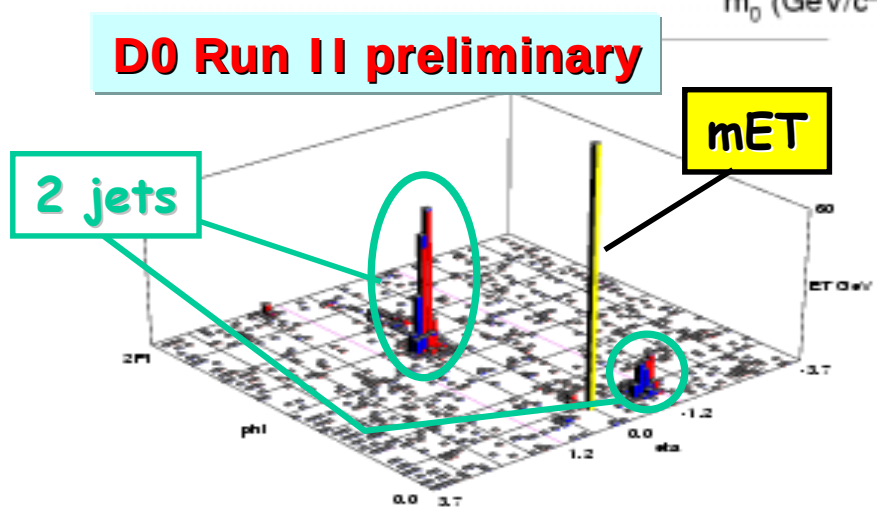
Δφ(jet1-jet2)

significant cuts:

mET, pTjets

scalar sum of ET

acoplanarity



GMSB

framework

Run II preliminary study: di-photons + mET

GMSB

Fermilab Run II workshop:
Baer et al. hep-ph/0008070
Baer et al. hep-ph/9903333

- **Minimal Model of Gauge Mediation (MGM) 6 parameters :**

Λ effective visible sector SUSY breaking parameter
N number of messenger
M_m mass scale of messengers
tan β ratio of v.e.v. of the 2 higgs doublets
sign(μ) sign of mixing parameter of higgsinos
C_G ratio of the messenger sector SUSY breaking order parameter to the intrinsic SUSY breaking parameter

- NLSP nature. either:

χ^0_1, stau, slepton, squark, etc.

- lifetime of NLSP
- signature:

$\gamma\gamma$+mET; $l^\pm l^\pm$+mET ; $\tau^\pm\tau^\pm$+mET, monojet

$$\tilde{\chi}^0_1 \to \gamma\tilde{G},\ Z\tilde{G},\ h\tilde{G}$$
$$\tilde{\ell} \to \ell G$$

$$p\bar{p} \to SUSY \Rightarrow 2\,NLSP + \ell^n + j^m$$
$$\Rightarrow (\not{E}_T + \ell^n + j^m) + \gamma\gamma$$
$$\Rightarrow (\not{E}_T + \ell^n + j^m) + \ell\ell$$
$$\Rightarrow (\not{E}_T + \ell^n + j^m) + \gamma h$$
$$\ldots\ldots$$

di-photons + mET

- **Neutralino NLSP**

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

- **Final state:**

$\gamma\gamma$ + mET + X

Run II preliminary:

$N = 1;\ M_m = 2 \times \Lambda;\ \tan\beta = 15;\ \mu > 0$

- **Background**

Wγ,Wj,Zee,tt,WW,WZ,etc.

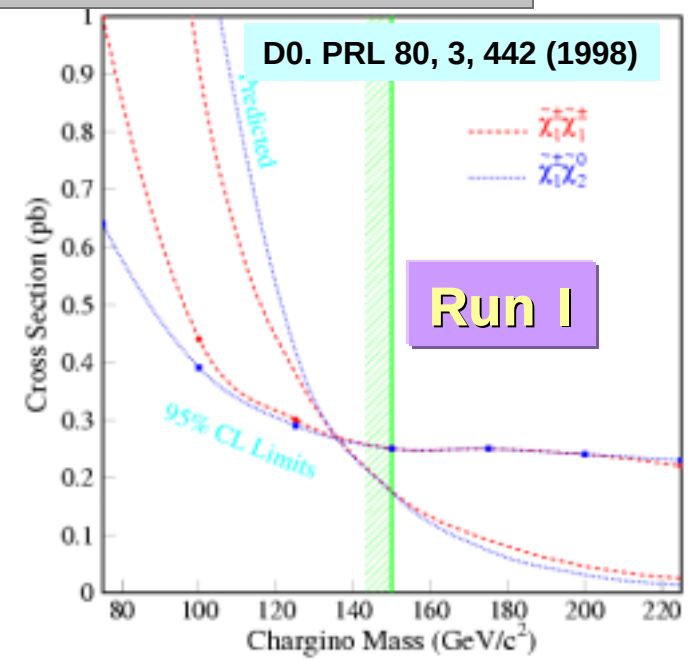
- **Cuts:** pT_γ > 20 GeV, track veto

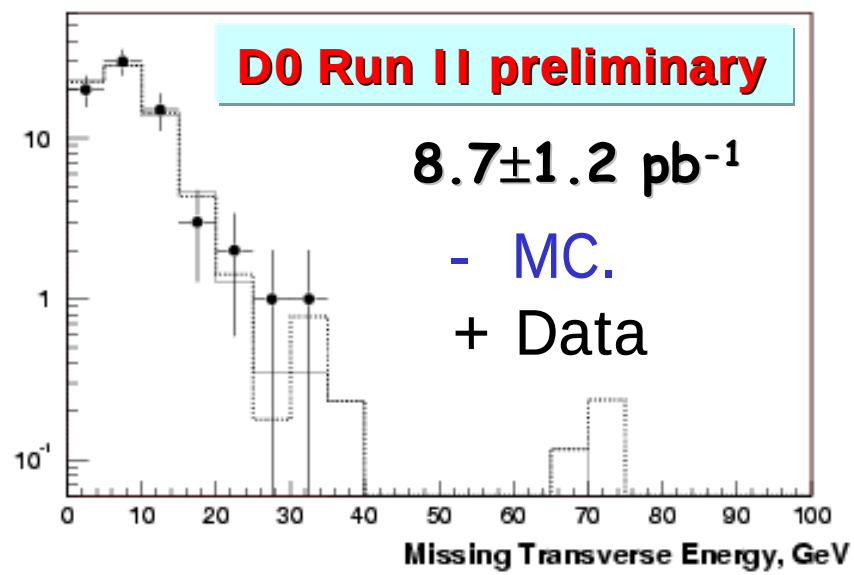
$\Delta\varphi$(Jet,mET)>0.5

$M_{\gamma\gamma} \not\subset$ 80-102 GeV, vertex

mET > 25 GeV

Expected Bkd	1.0 ± 0.3
Data	2





R-Parity violated (RPV)

consequences

LSP decay

Run II preliminary study:

like sign dileptons

trileptons

R-parity

- SUSY potential: $W_{SUSY} = W_{MSSM} + W_{RpV}$

With $W_{RpV} = \lambda_{ijk} L_i L_j \overline{E}_k + \lambda'_{ijk} L_i Q_j \overline{D}_k + \lambda''_{ijk} \overline{U}_i \overline{D}_j \overline{D}_k$

⇨ i,j,k = 1,2,3 (family indices)

⇨ 9 + 27 + 9 = 45 new Yukawa couplings.

⇨ Lepton (λ and λ') or Baryon (λ'') number not conserved

⇨ define R-parity : discrete quantum number

$R_p = (-1)^{3B+2S+L}$

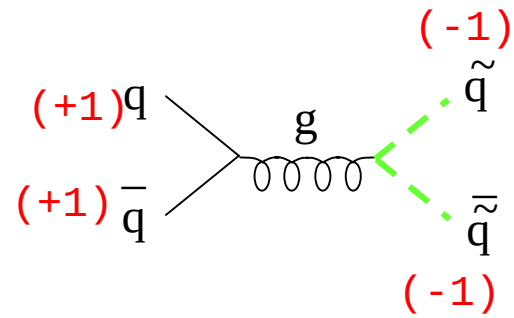
B= Baryon #, L=Lepton #, S=spin

R_p= +1 ⇨ SM particle

R_p= -1 ⇨ SUSY particle

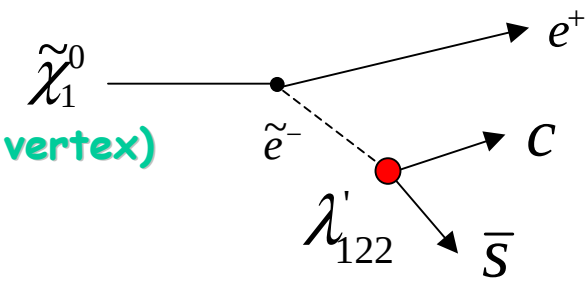
R-parity: consequences

- **R-p conserved:**
  - LSP stable and candidate for dark matter
  - Susy particles pair produced

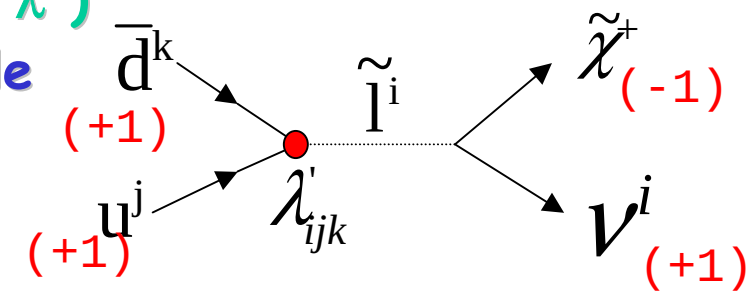


$$p\bar{p} \rightarrow \tilde{\chi}_i^{\pm}\tilde{\chi}_j^{\pm}, \tilde{\chi}_i^0\tilde{\chi}_j^{\pm}, \tilde{\chi}_i^0\tilde{\chi}_j^0, \tilde{q}\tilde{q}, \tilde{q}\tilde{g}, \tilde{g}\tilde{g}, \tilde{l}\tilde{l}$$

- **R-p violated:** B or L not conserved
- Lightest Susy Particle (LSP) decays either
  - inside the detector (with or without a displaced vertex)
  - outside the detector



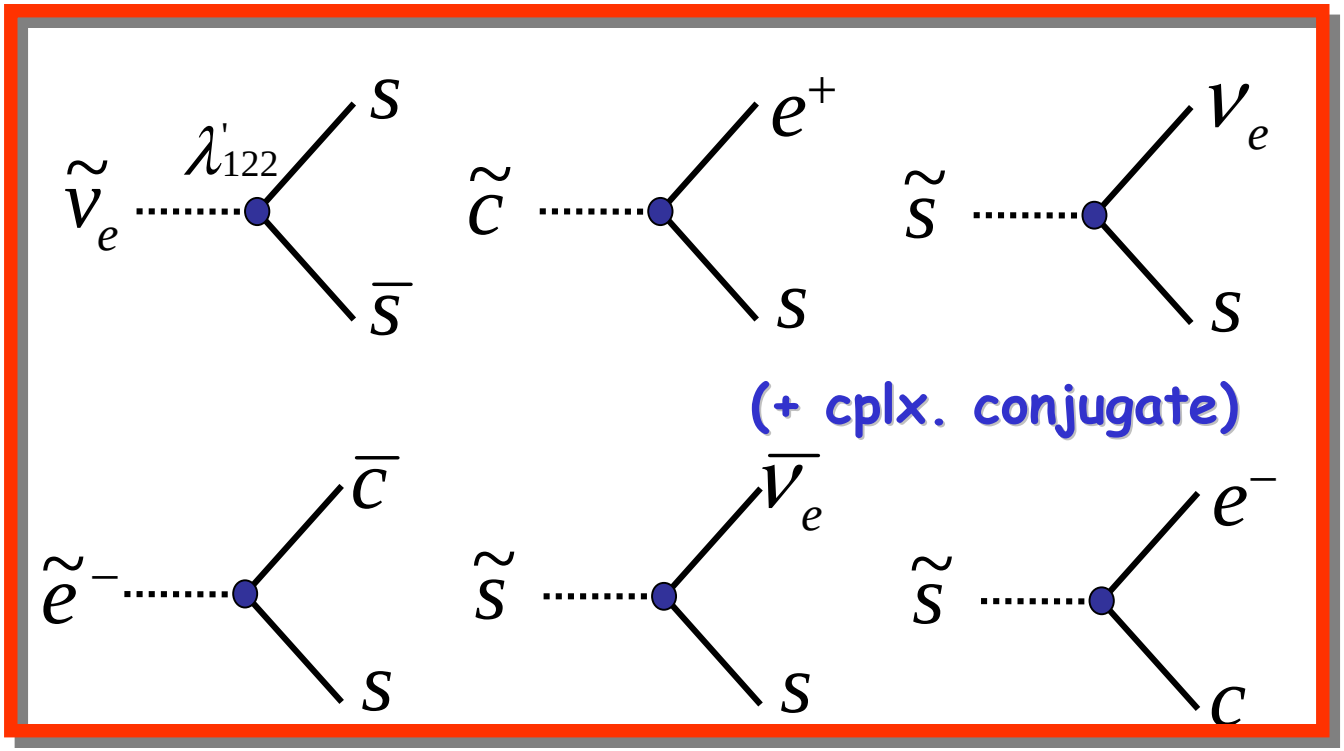
- Susy signature can be very different
  - Less missing Et
  - More leptons (λ or λ') and jets (λ' or λ'')
- Single Susy particle production is possible
  - via λ' or λ'' @ TeVatron
  - cross-section ∝ $(\lambda'_{ijk})^2$

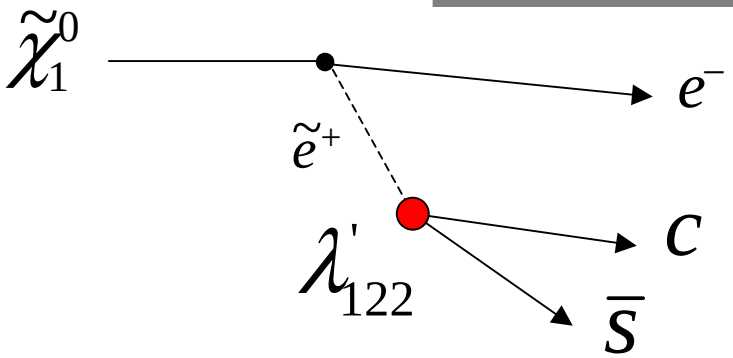


RPV example: λ'_{122} couplings

$\lambda'_{122} L_1 Q_2 \bar{D}_2$

- Via λ'_{122}





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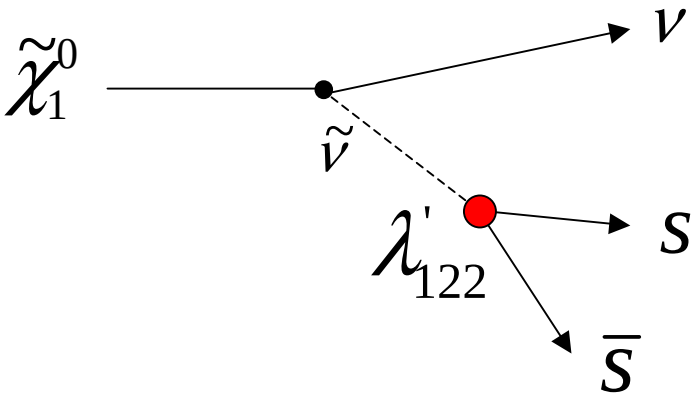


λ'_{122} : like sign dileptons

- **Final state**
  2 likesign $e^{\pm}$ + 4 jets
- **Backgd:** Drell-Yan, Zee, tt, e+efake, wrong sign assignment
- pT el > 15 GeV

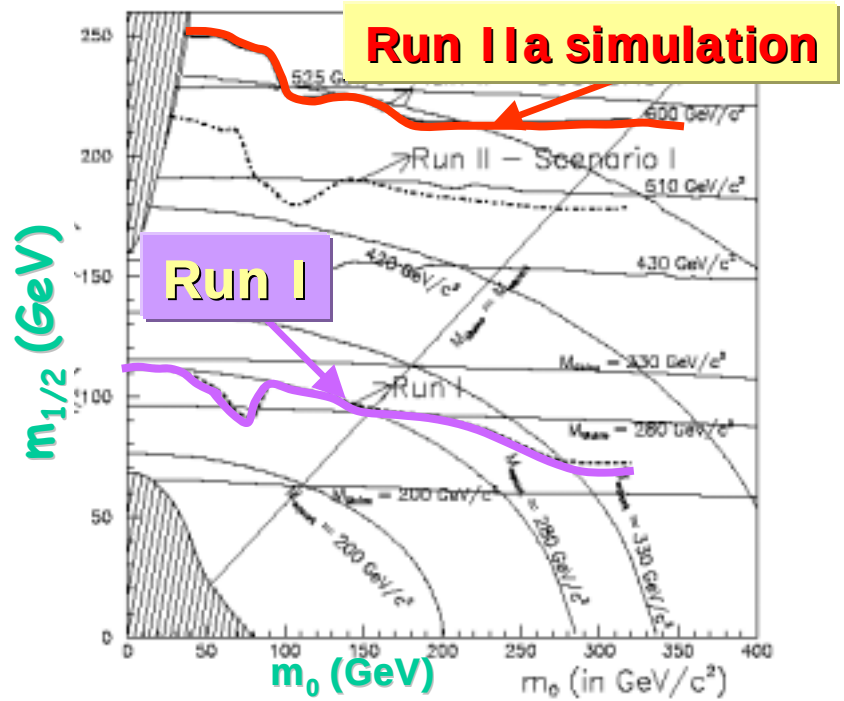
D0 Run II preliminary

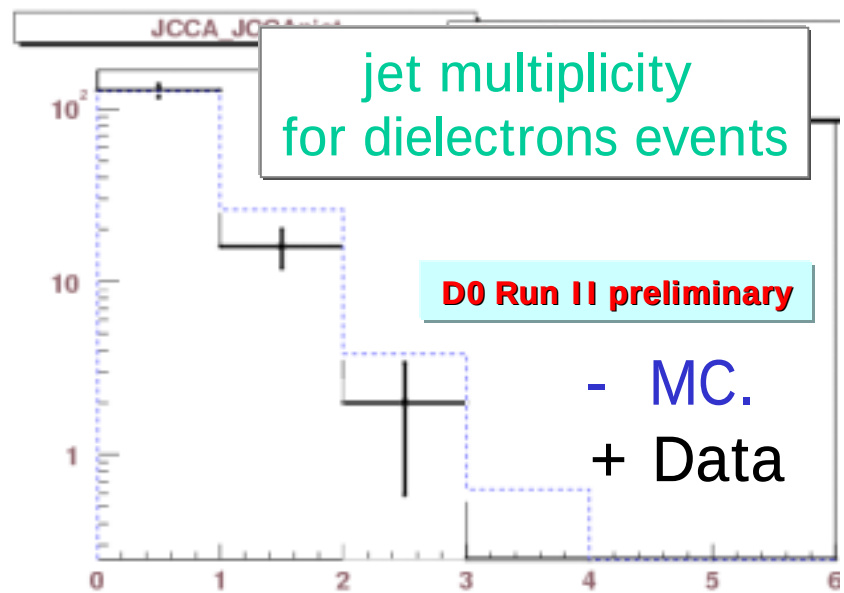
L = 9.7 ± 1.4 pb^{-1}

2 like sign leptons + >= 1 jets	
SM backgd	0.1 ±0.1
Instrumental	2.8 ± 1.3
Data	2

D0, Phys. Rev. Lett. 83, 4476 (99)

$A_0 = 0 : \mu < 0 : \tan\beta = 2$

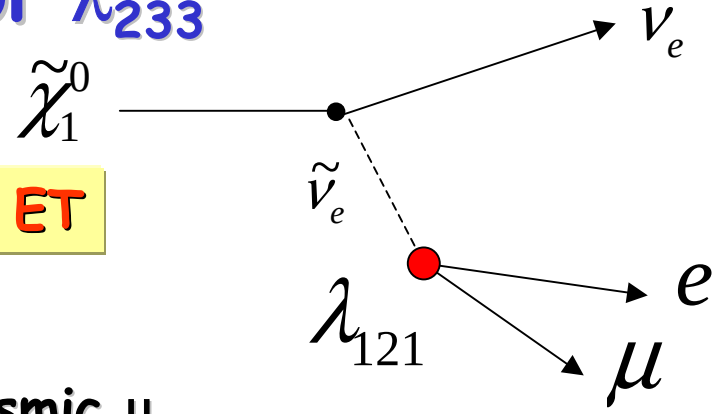




λ coupling: trilepton channel

- Dominant coupling λ_{121}, λ_{122} or λ_{233}

LSP $\rightarrow$ 2 charged leptons + 1 ν



Final State : $\geq$ eee,eeμ,e$\mu\mu$,$\mu\mu\mu$ + missing ET

- **Backgd:** Drell-Yan, tt, $Z \rightarrow \tau\tau \rightarrow \mu\mu$, misidentification of jets as electrons, cosmic μ

D0 Run II preliminary

L = 5.2 $\pm$0.8 pb^{-1}

e e e	
SM backgd	0.9 $\pm$0.2
Instrumental	1 $\pm$ 0.3
Data	2

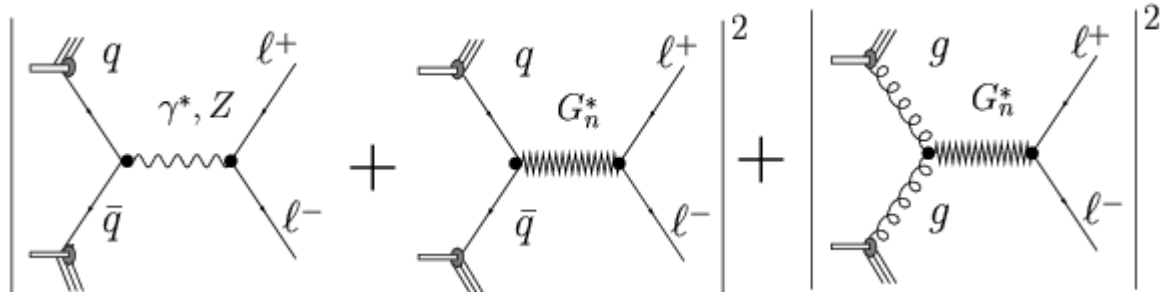
e e μ	
SM backgd	0.13 $\pm$ 0.08
e + μ + e fake	0.6 $\pm$ 0.2
e + e + cosmic μ	0.145 $\pm$ 0.014
Data	1

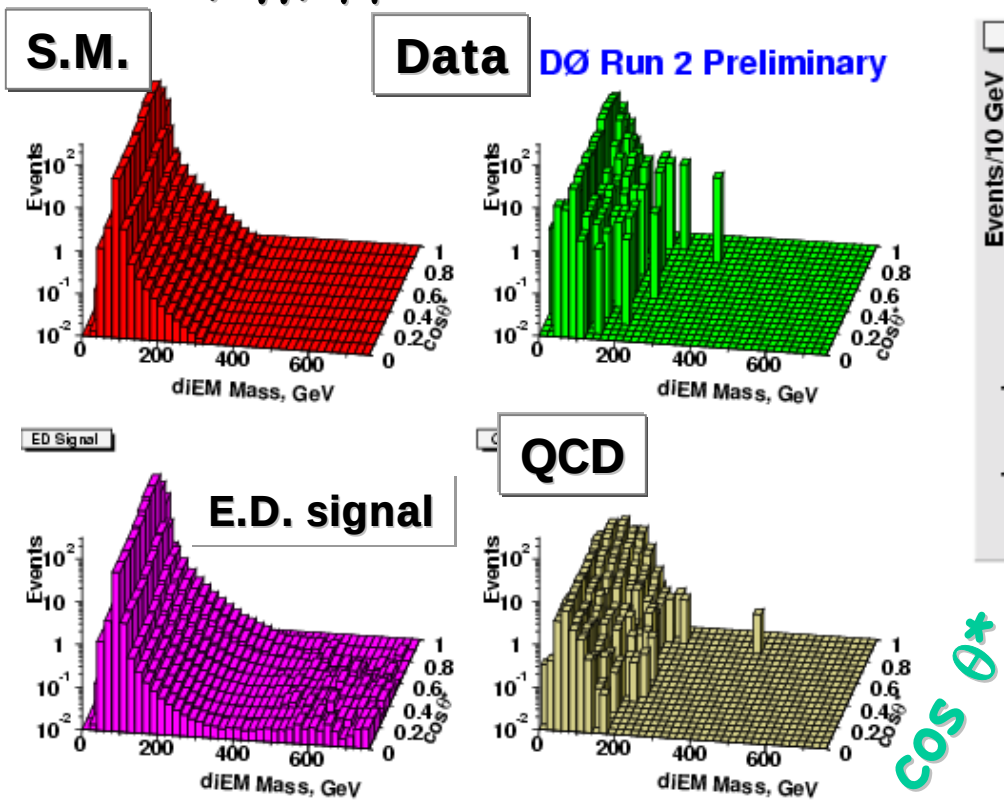
Large Extra Dimensions

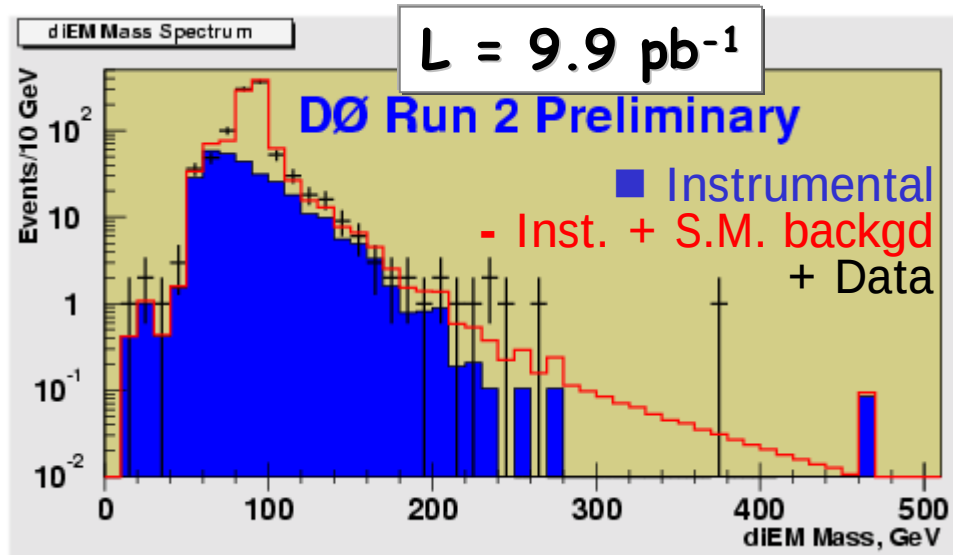
Large extra dimensions

- Virtual graviton
  - Planck scale Ms
- final state

  ee, γγ, μμ







Run I Limit: (95% C.L.)

Ms(GRW) > 1.2 TeV

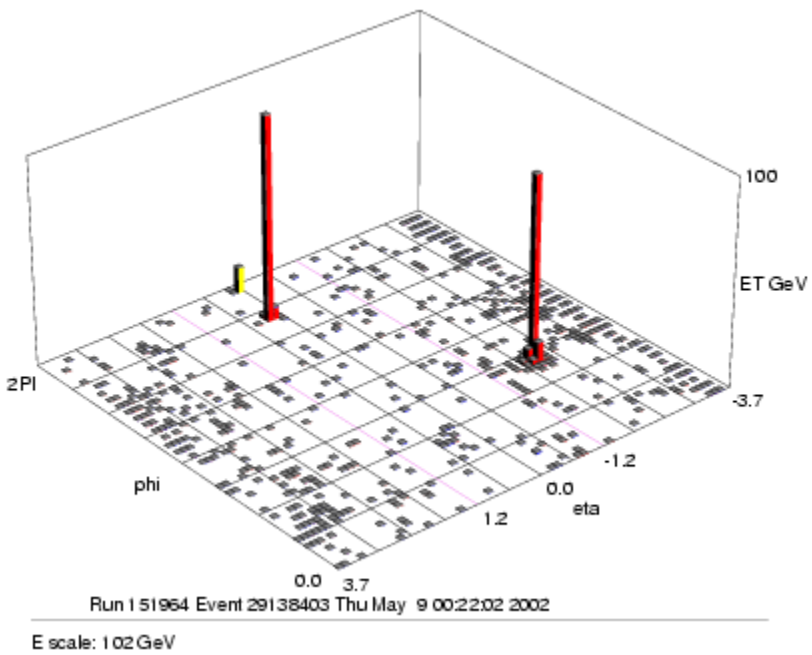
Run II preliminary:

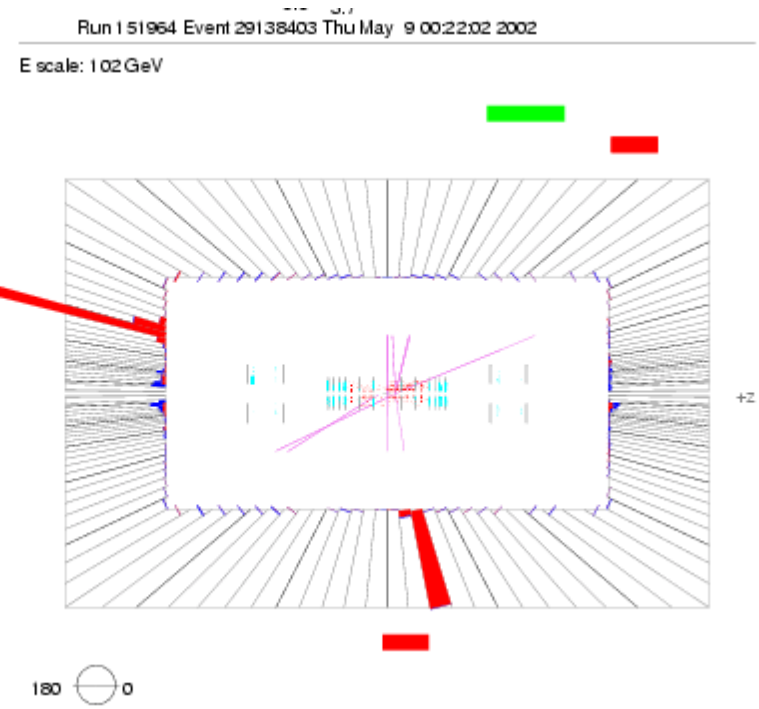
Ms(GRW) > 0.92 TeV

di-photon candidate

ET_1(GeV)	ET_2	η_1	η_2	cos θ*	$M_{\gamma\gamma}$	mET
120.3	106.2	0.10	-2.10	0.77	377	12.6

D0 Run II preliminary





Conclusion

- **D0 detector:** upgrade is a success

  tremendous effort on calibration, comissioning, instrumental backgd, particle ID, etc.
- **first new phenomena analysis underway**
  - many exciting channels
- **Luminosity** large progress during the last months
  - now: ~ 50 pb^{-1} on tape
  - ~ 200 pb^{-1} in summer 2003
  - First Run II limits in the coming months.

  (better than the Run I results) **Stay tuned !**

Back up

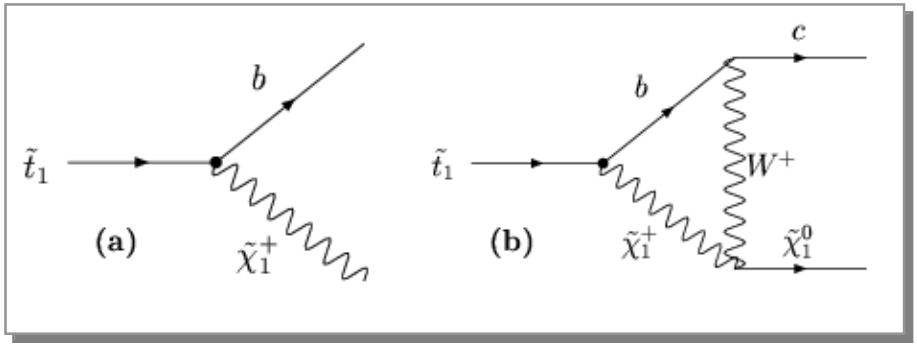
SUSY framework

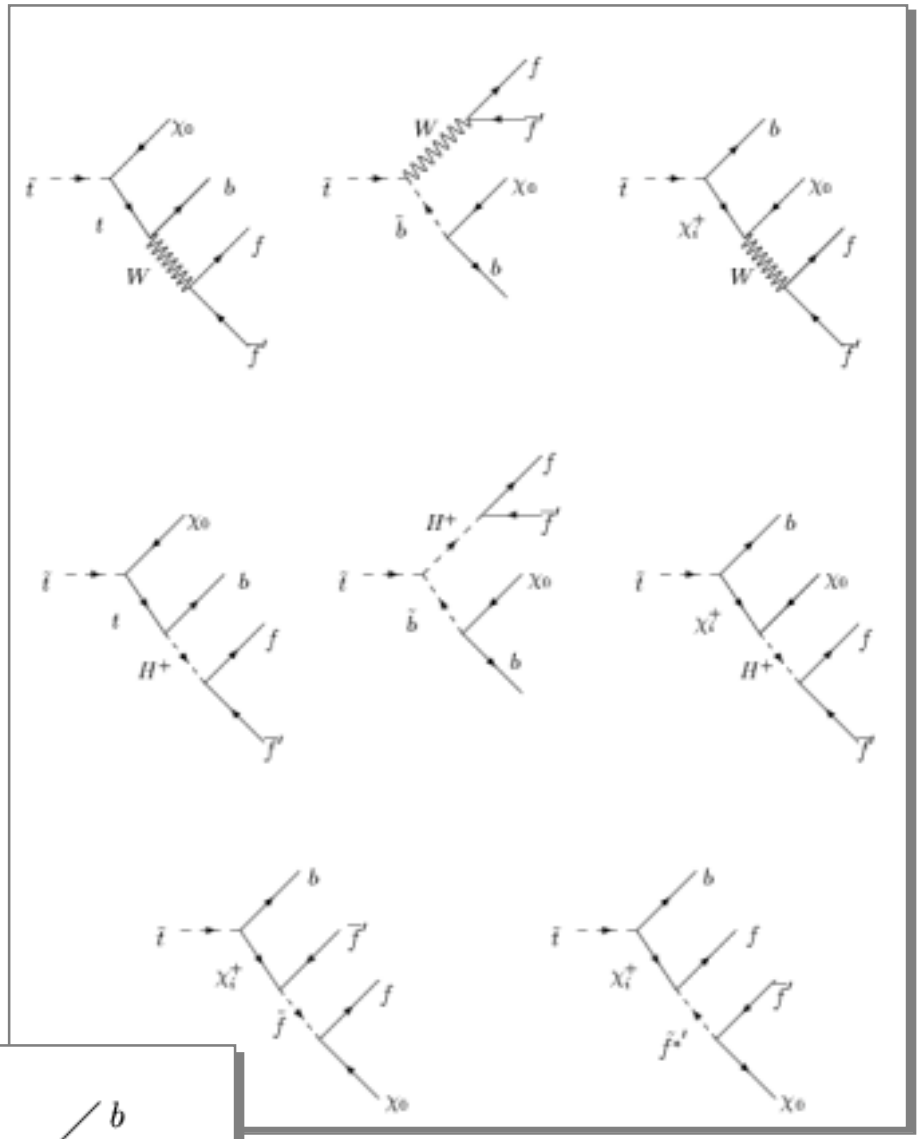
- **SUSY** $Q \mid Boson >= \mid Fermion >$; $Q \mid Fermion >= \mid Boson >$
  - New symmetry between fermions and bosons
  - Solves hierarchy problem
  - allows convergence of coupling constants at GUT scale
  - complete new spectrum of susy particles.
- **In most of the models**
  - SUSY particles are pair produced

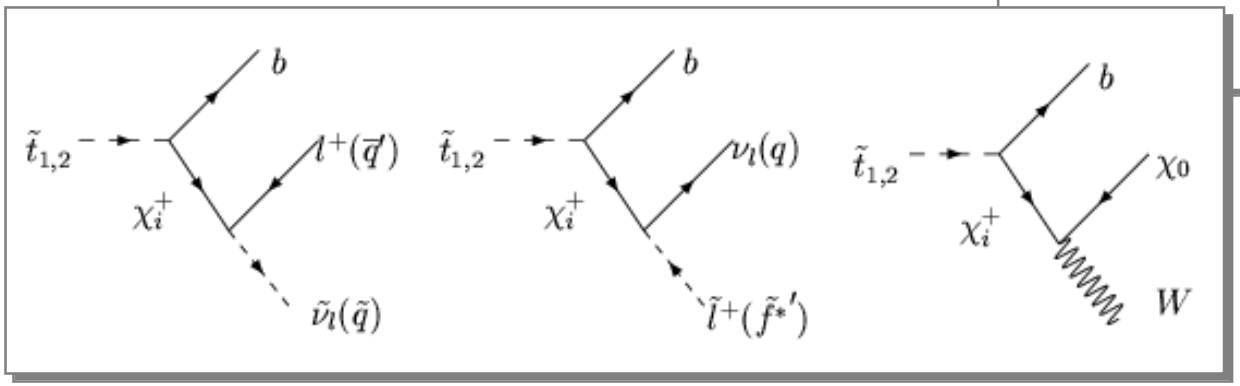
$$p\bar{p} \rightarrow \tilde{\chi}_i^{\pm}\tilde{\chi}_j^{\pm}, \tilde{\chi}_i^{0}\tilde{\chi}_j^{\pm}, \tilde{\chi}_i^{0}\tilde{\chi}_j^{0}, \tilde{q}\tilde{q}, \tilde{q}\tilde{g}, \tilde{g}\tilde{g}, \tilde{l}\tilde{l}$$

  - The lightest SUSY particle (LSP) is stable and escape from detector.

2,3 and 4 body decays of stop







RPV Experimental constraints

- **Indirect limits via low energy processes**

- e-μ-τ universality
- Charged current universality
- Atomic parity violation
- Neutrinoless double-beta decay
- Top decay
- etc.

- **2σ limits for $\tilde{m}$ = 100 GeV**

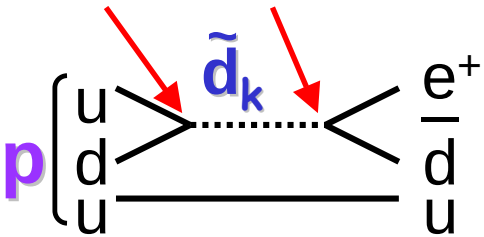
(limits often linear in mass)

Barger et al. Phys.Rev. D40 (89)
Ledroit, Sajot GDR-S-008 (98)
Allanach et al., PRD 60 (99)

- **Stronger limits on products of coupling**

- proton decay :

$\lambda''_{11k} \cdot \lambda'_{11k} < 10^{-22}$



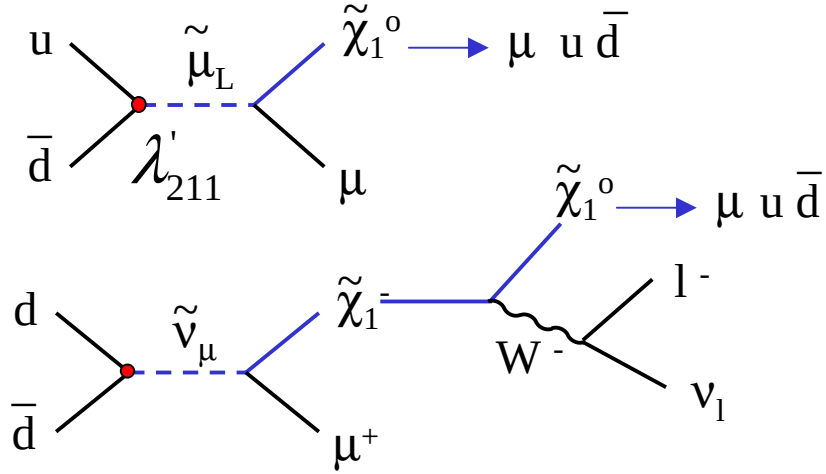
ijk	λ_{ijk}	ijk	λ'_{ijk}	ijk	λ'_{ijk}	ijk	λ'_{ijk}	ijk	λ''_{ijk}
121	0.05	111	$5.2\ 10^{-4}$	211	0.06	311	0.12	112	10^{-6}
122	0.05	112	0.02	212	0.06	312	0.12	113	10^{-5}
123	0.05	113	0.02	213	0.06	313	0.12	123	1.25^*
131	0.062	121	0.04	221	0.18	321	0.52	212	1.25^*
132	0.062	122	0.04	222	0.18	322	0.52	213	1.25^*
133	0.006	123	0.04	223	0.18	323	0.52	223	1.25^*
231	0.07	131	0.02	231	0.18	331	0.45	312	0.50
232	0.07	132	0.28	232	0.45	332	0.45	313	0.50
233	0.07	133	$1.4\ 10^{-3}$	233	0.15	333	0.45	323	0.50

Resonant production : dimuons channel

- **Dominant coupling λ'_{211}**

→ resonant prod via RPV

→ Decay of LSP via RPV



Final State : ≥ 2 μ + 2 jets

- **Backgd : tt, Z+2jets, WW+jets**
- **Cuts : $pT_\mu \geq 20$ GeV ; $pT_{jets} \geq 20$ GeV**

Scalar ET ≥ 50 GeV ; $\Delta R_{\mu jets} \geq 0.5$

Dimuons in m_0-$m_{1/2}$ plane

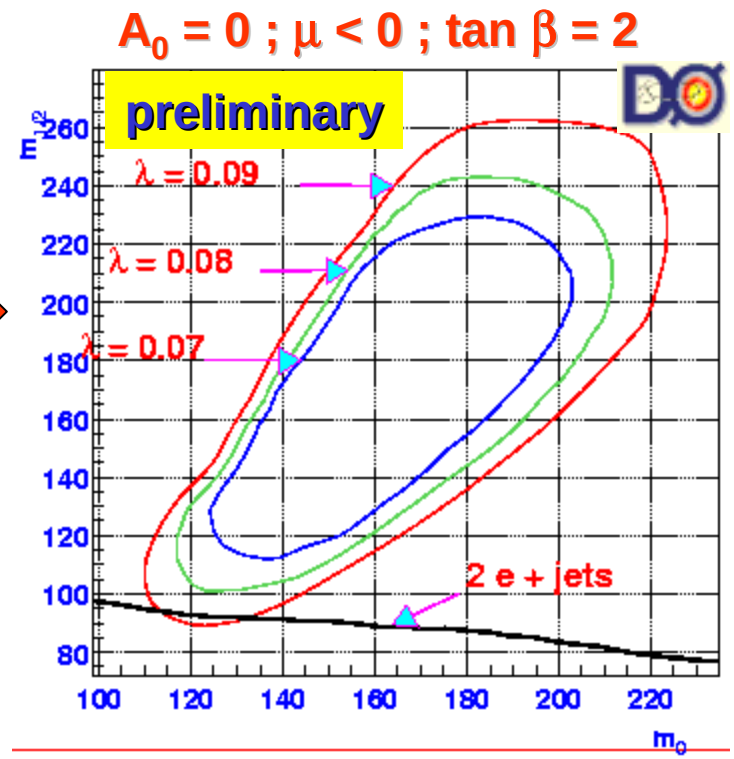
- **Run I:**

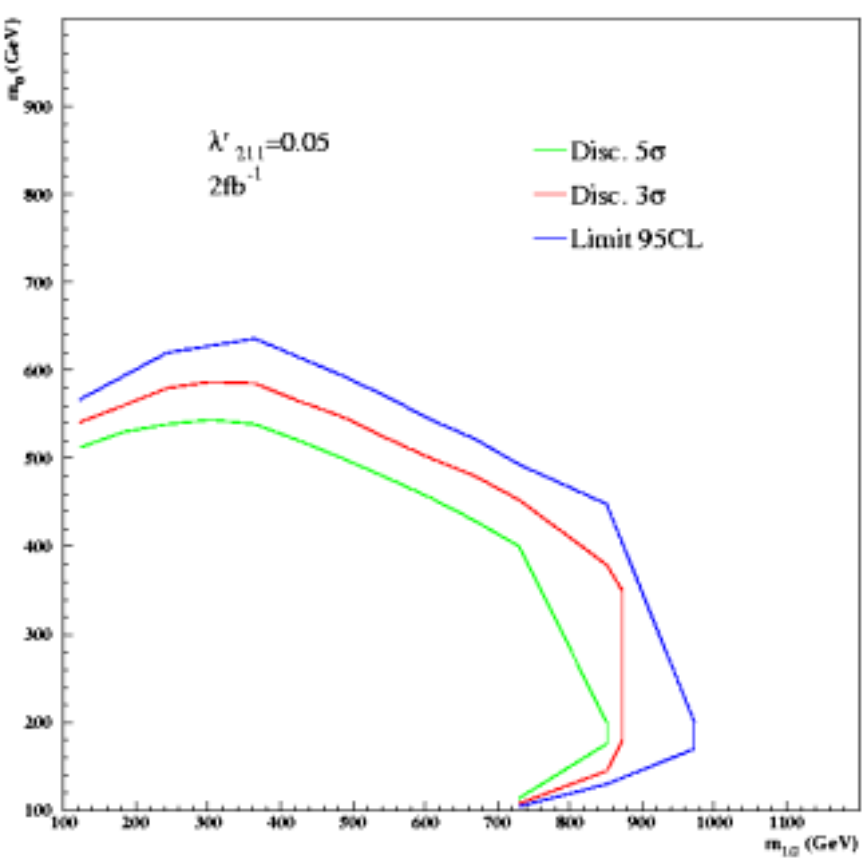
L = 94 ± 5 pb^{-1}

Events observed = 5

Expected Background = 5.34 ± 0.07

95% conf. level





- **Run II:**

(Fast simulation)

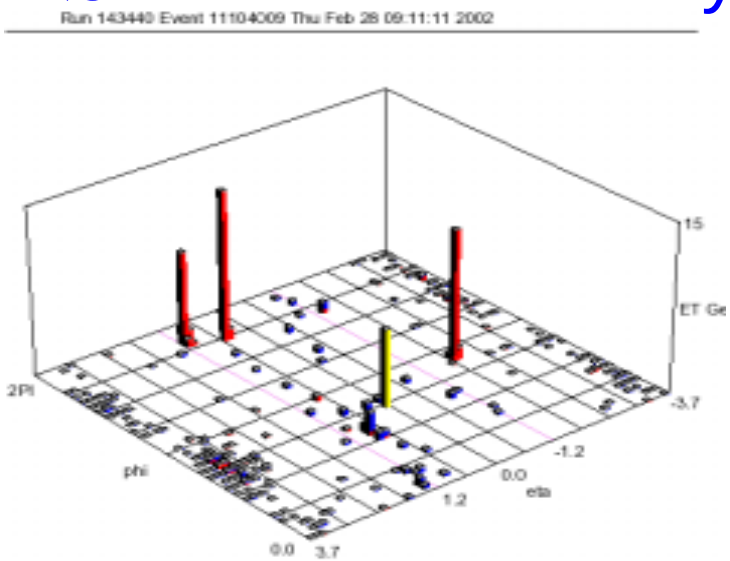
λ'_{211}=0.05

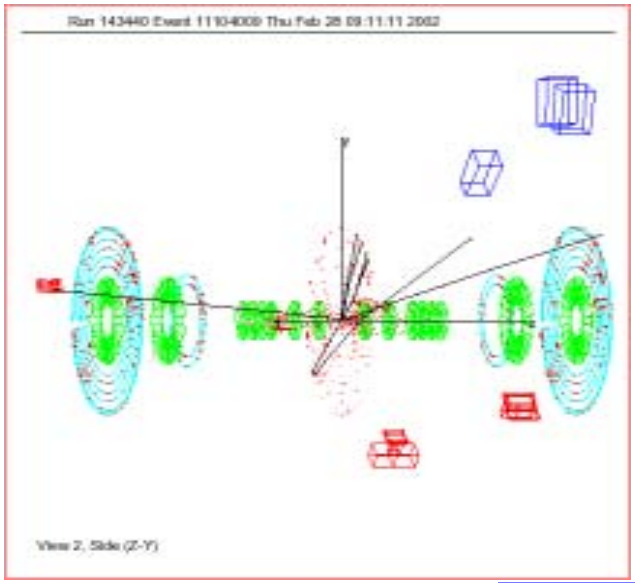
$A_0 = 0$; $\mu < 0$; $\tan\beta = 1.5$

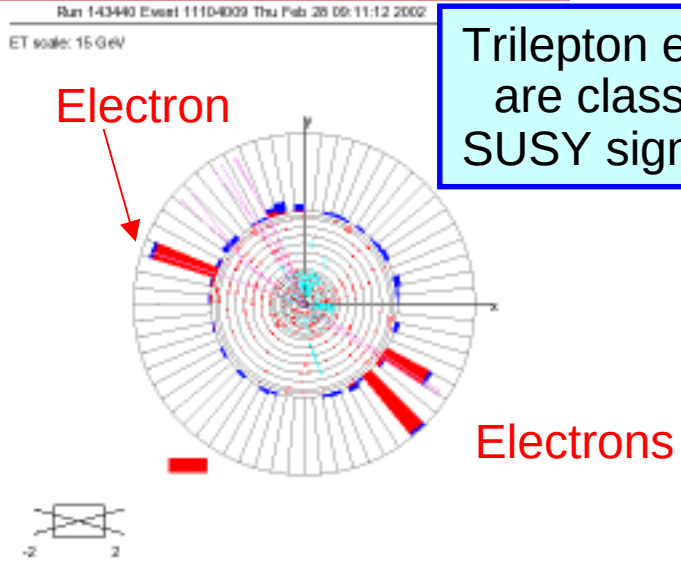
Déliot et al., EPJ C 19 (01) 155

eee candidate event

DØ Run 2 Preliminary





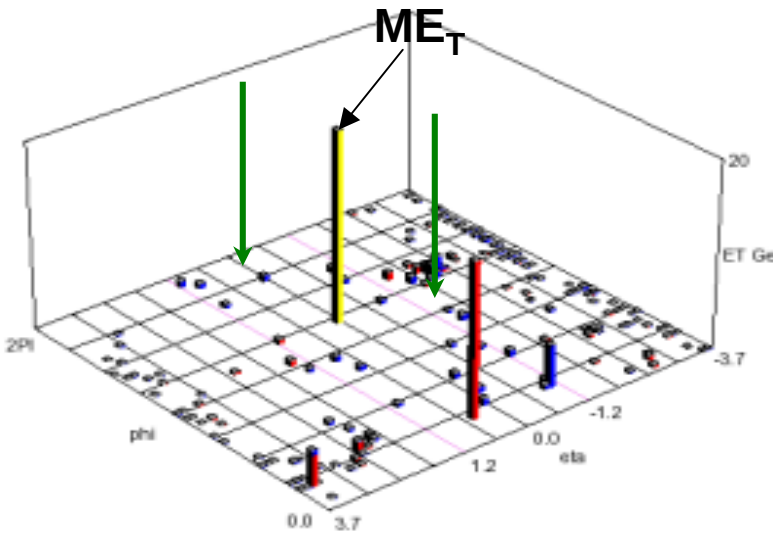


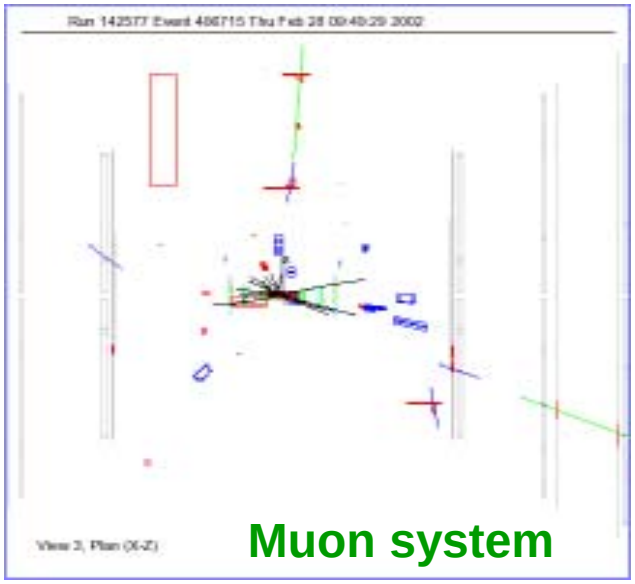
Trilepton events are classical SUSY signature

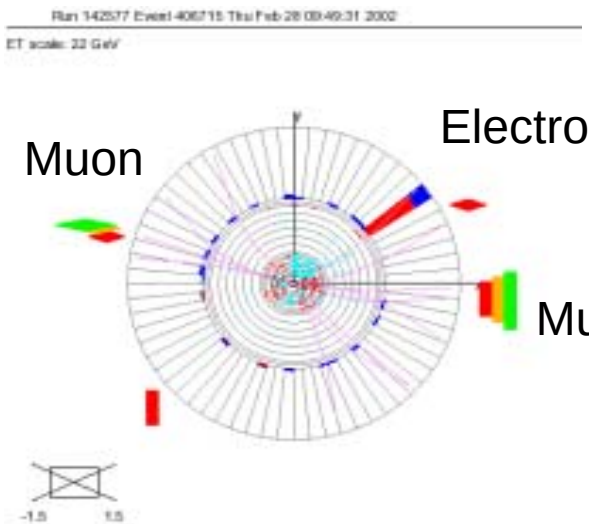
e1	e2	e3
E_T = 17.9 GeV p_T = 0.52 GeV η = 0.43 φ = 5.42 Charge = +1	E_T = 13.9 GeV p_T = 10.9 GeV η = -1.94 φ = 2.80 Charge = +1	E_T = 13.2 GeV p_T = 15.1 GeV η = 1.06 φ = 5.72 Charge = -1
m_{e1e2} = 55.7	m_{e1e3} = 10.8	m_{e2e3} = 63.5
m_{e1e2e3} = 85.2 GeV/c^2		ME_T =10.7 GeV

eμμ candidate event

D0 Run II preliminary



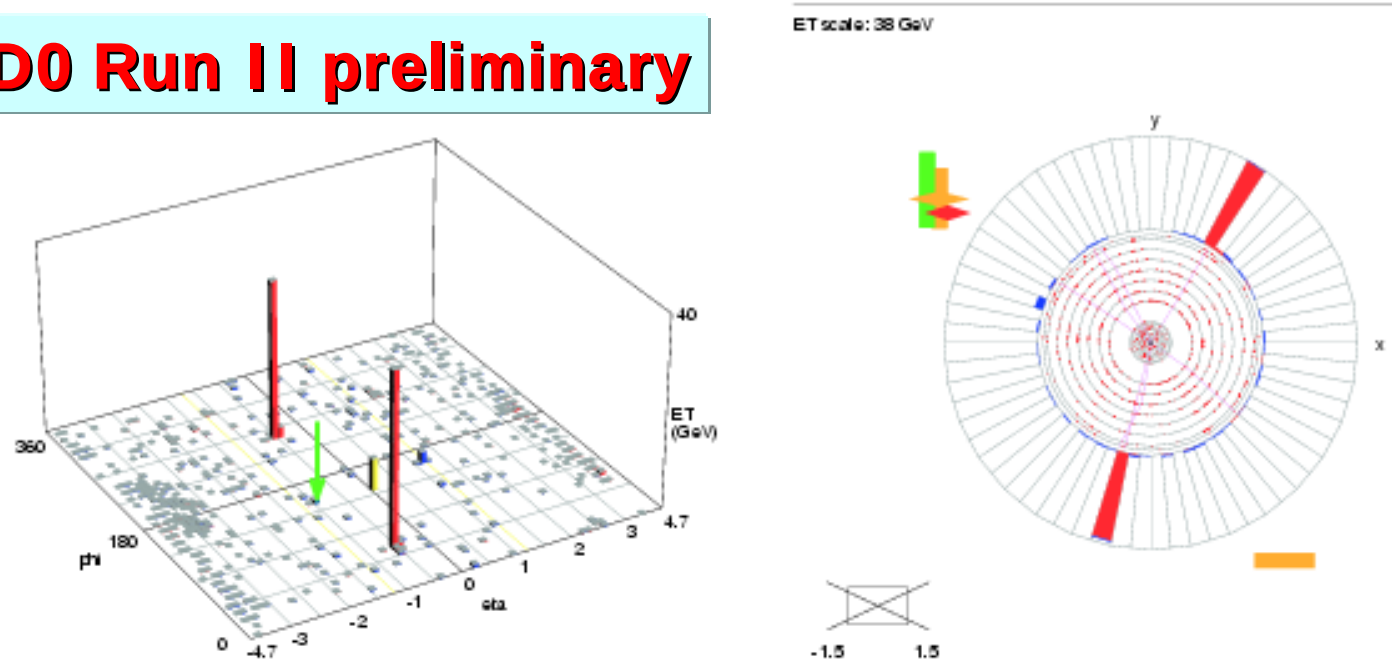




e	μ1	μ2
E_T = 19.2 GeV η = 0.40 φ = 0.63 No track match	p_T = 28.2 GeV η = -0.10 φ = 6.20 Charge = -1	p_T = 9.82 GeV η = -1.48 φ = 2.88 Charge = 1
	$m_{\mu\mu}$ = 41.5 GeV/c^2	
ME_T =31.8 GeV		

eeμ candidate event

D0 Run II preliminary



(a) (b)

e_1	e_2	μ
$p_T(\mathrm{cal}) = 46.5$ GeV/c	$p_T(\mathrm{cal}) = 43.5$ GeV/c	$p_T = 12.9$ GeV/c
$\eta = -0.36$	$\eta = -0.33$	$\eta = -0.92$
$\varphi = 1.02$	$\varphi = 4.47$	$\varphi = 2.59$
no track match	no track match	charge = -1
$m_{e_1e_2} = 88.9$ GeV/c^2		$\mathrm{ME_T} = 11.9$ GeV

FIG. 7: VERY PRELIMINARY: $\eta - \varphi$ lego plot (a), $x - y$ view (b) and properties of an example $e + e + \mu$ candidate.