Missing ET+jets signatures at the Tevatron

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on behalf of the CDF and DØ collaborations

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Overview

Monojet :

Large Extra Dimensions (LED)	CDF 1.1 fb^{-1}	Preliminary [PRL 97 (2006) 171802 with 368 pb^{-1}]	

Acoplanar dijet to multijet :

Squarks and Gluinos in mSUGRA	DØ 1 fb^{-1}	Preliminary [PLB 638 (2006) 119 with 310 pb^{-1}]	
Squarks and Gluinos in mSUGRA	CDF 371 pb^{-1}	Preliminary	

Multijet :

Gluino to sbottom b	CDF 156 pb^{-1}	PRL 96 (2006) 171802	

Acoplanar dijet :

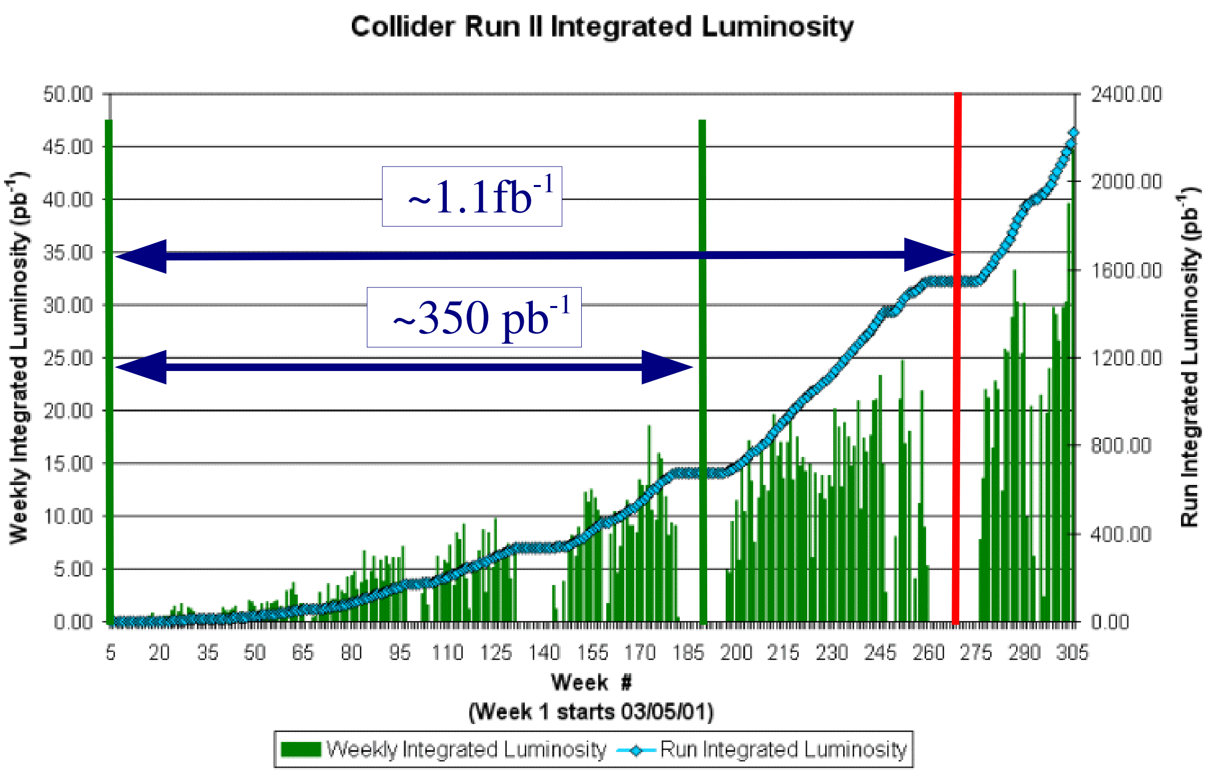
1st gen. LQ	DØ 310pb^{-1}	PLB 640 (2006) 230-237	
1st gen. LQ	CDF 191pb^{-1}	PRD 71 (2005) 112001	

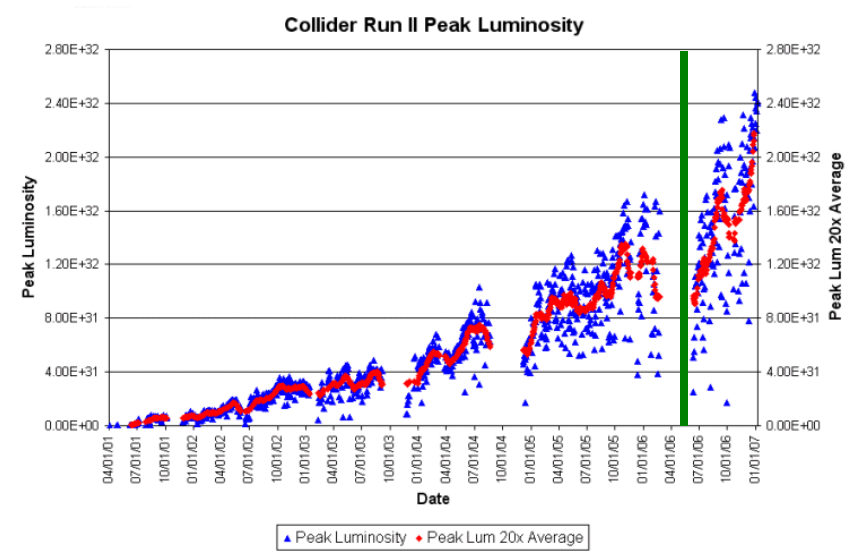
with heavy flavor tagging

stop/sbottom	CDF 295 pb^{-1}	Preliminary	
sbottom	DØ 310 pb^{-1}	PRL 97 (2006) 171806	
stop	DØ 360 pb^{-1}	Accepted by PLB	
3rd gen. LQ	DØ 310 pb^{-1}	Preliminary	=> Maxwell Chertok Friday

All limits at the 95% CL

Data samples and Luminosity



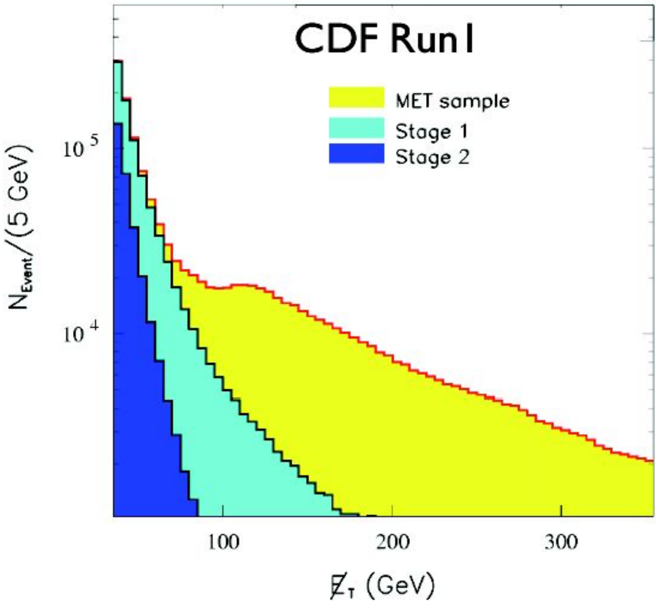


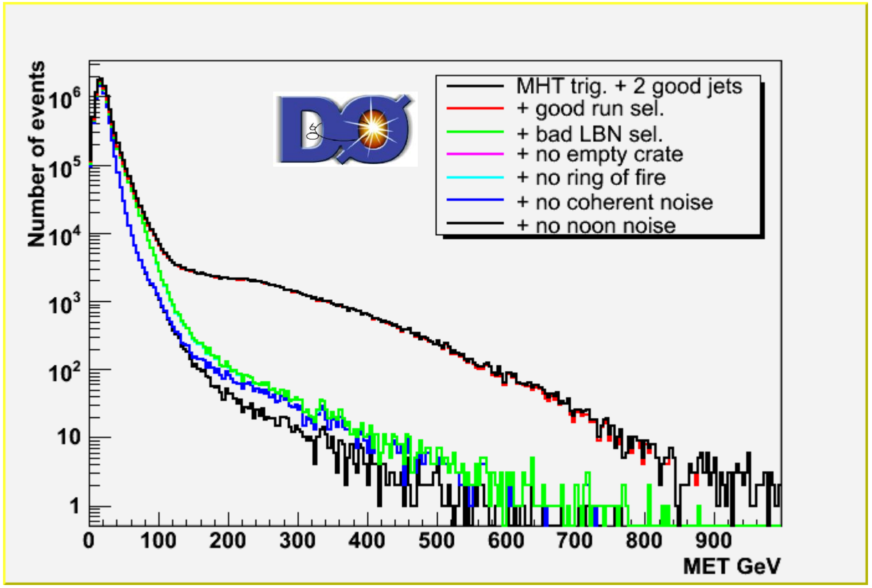
RunIIa RunIIb

- <u>Triggers:</u>
  - CDF :
    - one trigger for jets+MET analyses MET>25 GeV at L1, 2 jets @ L2 and MET>35 GeV @ L3
    - use also single jet trigger (monojet analysis)
  - DØ :
    - a trigger for acoplanar dijet+MET MET>30 GeV + acop. and MET isolation cuts @ L3
    - a trigger for multijet+MET MET>25 GeV + at least 3 jets @ L3

Data Quality

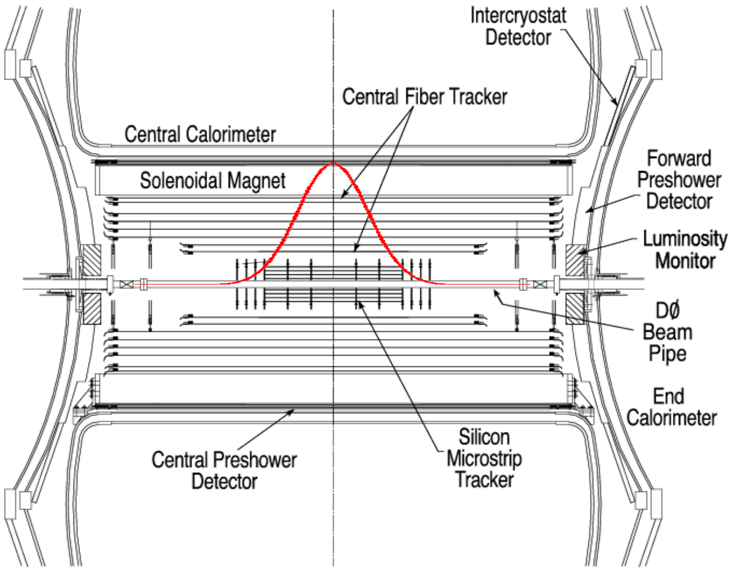
- Most of the time, a problem in online data taking will generate fake MET
  - Excellent detector operations are required to trigger on MET
  - A perfect understanding of the calorimeter is required to control the MET tail
  - A huge amount of work is done prior to the physics analysis to clean the data. And there are redundancies between online and offline data quality monitoring



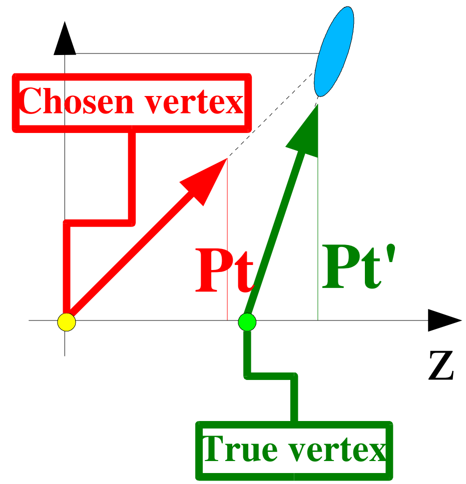


- Reject runs with detector problems
- CDF clean up procedure based on Run I experience:
  - use event EM and charged energy fraction
  - exclude events with activity in poorly instrumented regions
- New electronic of the DØ calorimeter at RunII:
  - flag events with well known and identified noise pattern (mainly based on calorimeter occupancy per layer, per crates, in phi rings ...)
- But, some data quality problems are as rare as the new physics we are searching for !

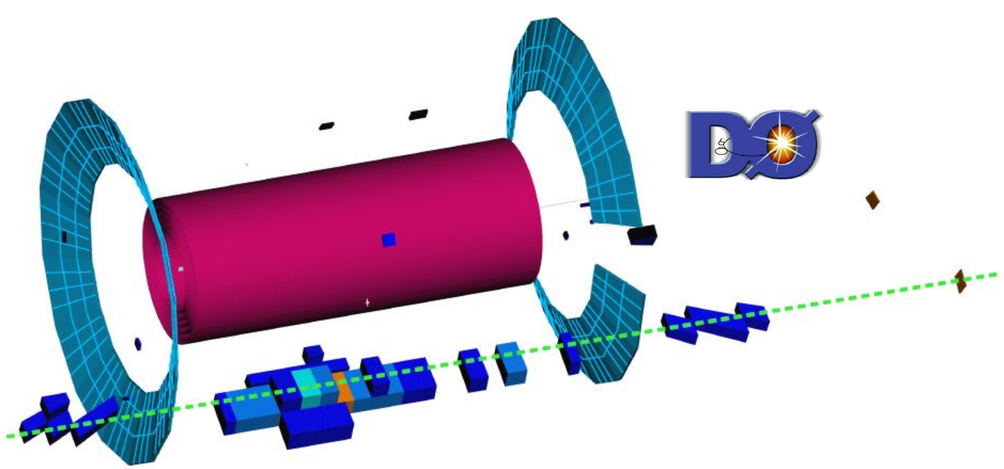
Tracking

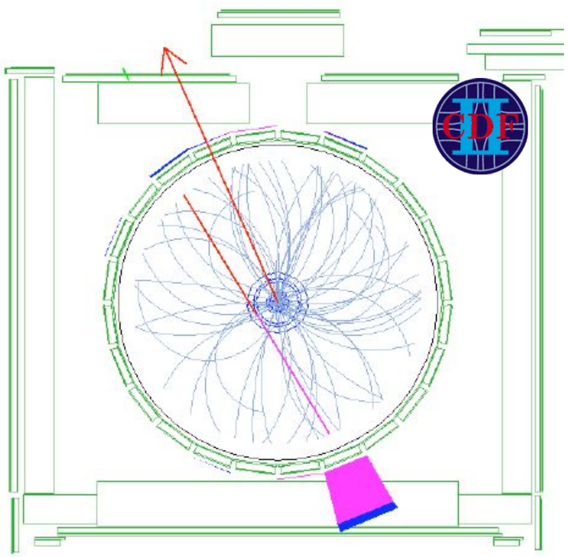


At the Tevatron, the gaussian width of the interaction region is ~23 cm. Jets, electrons, missing ET reconstruction is done with respect to THE best primary vertex. If the wrong vertex is chosen, the bias can be very large. This effect is often the main source of QCD background in physics analyses.



- <u>Develop "Jet track confirmation" algorithms : Strategy adopted both by CDF and DØ:</u>
  - Require tracks associated to the jets
  - Require that the tracks from those jets come from the primary vertex
  - Those algorithms allow also to reject cosmic and beam related noise



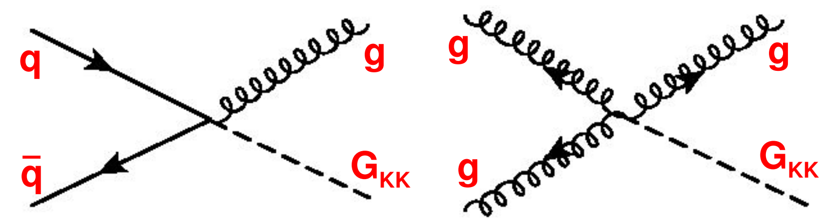


Large Extra Dimensions (I)

- ADD model with Large extra dimensions (LED):
- n extra dimensions compactified at radius R

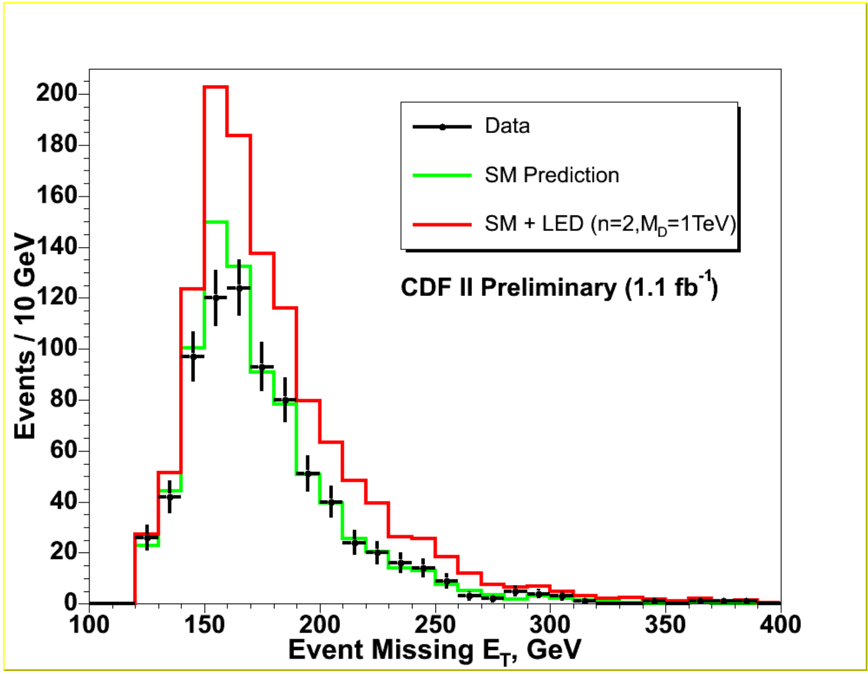
$$M_{Pl}^2 \sim R^n M_D^{2+n}$$

- Only gravity can access the extra dimension



Direct sensitivity to the fundamental Planck scale M_D

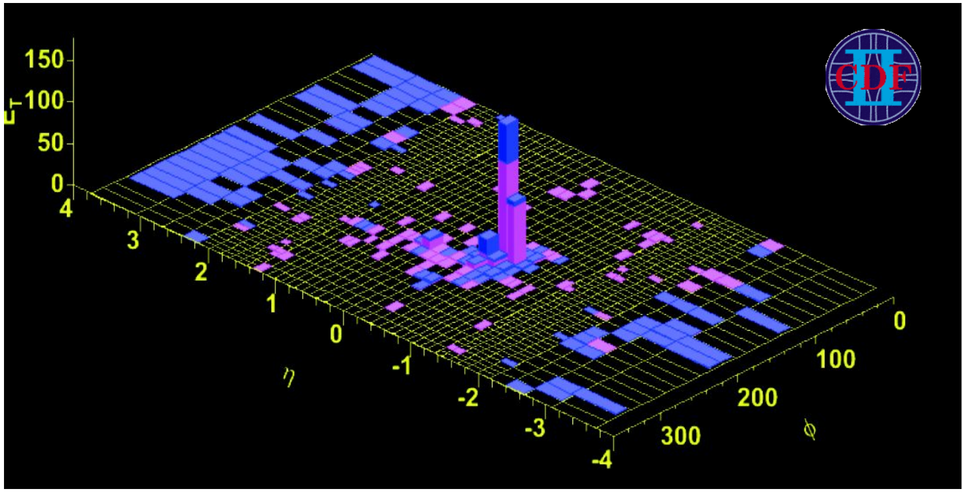
- <u>Direct production of graviton:</u>
  - qqbar -> gG
  - qg -> qG
  - gg -> gG
- Graviton escapes in the bulk
- => monojet signature
- Z(->νν)+jet : irreducible background



- <u>Main selection cuts:</u>
  - jet pT > 150 GeV and MET > 120 GeV
  - 2nd jet pT below 60 GeV
  - jets far away from the MET direction
  - lepton veto
- Calibrate SM backgrounds with Z->ll and W->lν to reduce systematic uncertainties on the SM background expectations

Large Extra Dimensions (II)

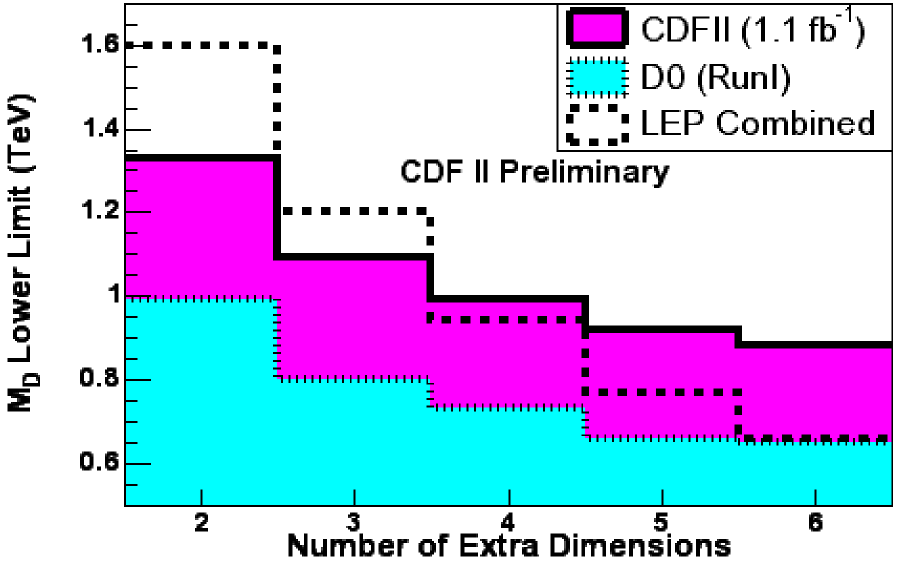
Back.	# events
Z -> νν	398 ± 30
W -> τν	192 ± 20
W -> μν	119 ± 12
W -> eν	58 ± 6
Z -> ll	7 ± 1
QCD	39 ± 14
non collision	6 ± 6
Total back.	819 ± 71
data	779



jet pT = 419 GeV, MET= 417 GeV

$$R^n = \frac{1}{8\pi} \left(\frac{M_{PL}}{M_D}\right)^2 \frac{1}{M_D^n}$$

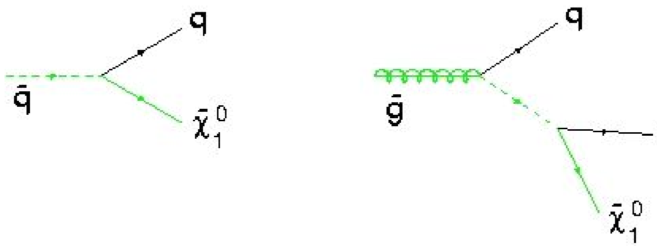
n	MD (TeV) K=1.3	R (mm)
2	> 1.33	< 0.27
3	> 1.09	$< 3.1 \times 10^{-6}$
4	> 0.99	$< 9.9 \times 10^{-9}$
5	> 0.92	$< 3.2 \times 10^{-10}$
6	> 0.88	$< 3.1 \times 10^{-11}$



Best world limits for n>3

Squarks and Gluinos (I)

- Pair production of squarks and gluino in mSUGRA:
  - R-parity is conserved
  - lightest neutralino LSP
  - tan(β)=3, A=0, μ<0
  - jets+MET topology : largest branching ratio



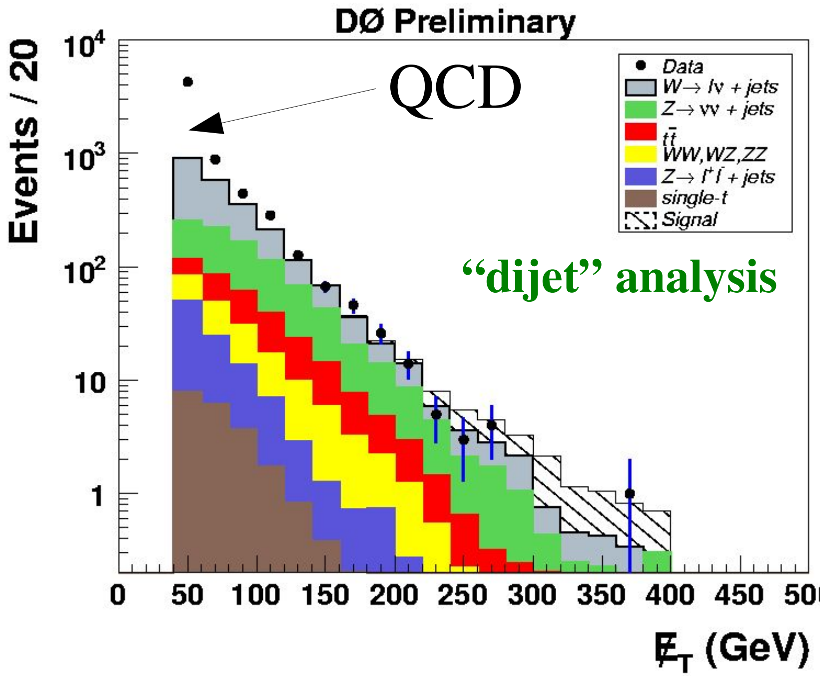
+ all possible cascade decays

- All RunIIa data, L=0.96 fb^{-1}
- Main backgrounds: Z->νν+jets, ttbar, W+jets (ALPGEN)
- QCD negligible at the end of the selections
- Common pre-selection:
  - 2 acoplanar jets with Et >35 GeV and |η|<0.8 confirmed by the tracks
  - MET>40 GeV
- 3 analyses for 3 different signal benchmarks:
  - Low m0 : m(squark) < m(gluino) => "dijet" analysis
    - m0=25
    - at least 2 jets

    $$\tilde{q}\bar{\tilde{q}} \rightarrow q\tilde{\chi}_1^0 \bar{q}\tilde{\chi}_1^0$$
  - Intermediate m0 : m(squark) = m(gluino) => "3-jets" analysis
    - at least 3 jets

    $$\tilde{q}\tilde{g} \rightarrow q\tilde{\chi}_1^0 q\bar{q}\tilde{\chi}_1^0$$
  - High m0: m(squark) > m(gluino) => "gluino" analysis
    - m0=500
    - at least 4 jets

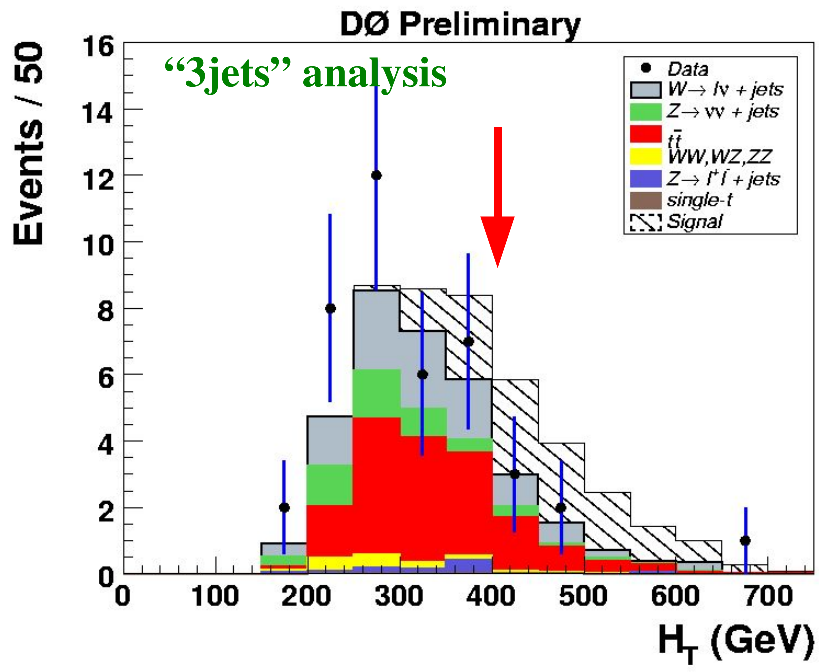
    $$\tilde{g}\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0 q\bar{q}\tilde{\chi}_1^0$$
- For the three analyses :
  - MET vs jets isolation cuts
  - electron and muon veto
  - optimization of the 2 final cuts on HT and MET



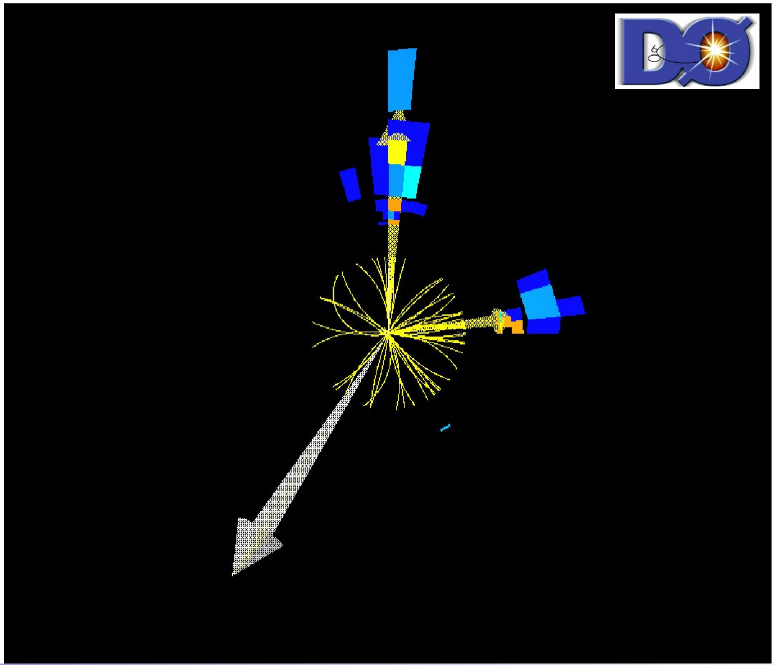
Squarks and Gluinos (II)

- Final MET/HT cuts :
  - "dijet" : MET > 225 GeV, HT > 300 GeV
  - "3-jets" : MET > 150 GeV, HT > 400 GeV
  - "gluino" : MET > 100 GeV, HT > 300 GeV

	Data	Total background
"Dijet"	5	7.5 ±1.1 (stat) +1.3 -1.0 (syst)
"3 jets"	6	6.1 ±0.4 (stat) +1.3 -1.2 (syst)
"Gluino"	34	33.4 ±0.8 (stat) +5.6 -4.9 (syst)

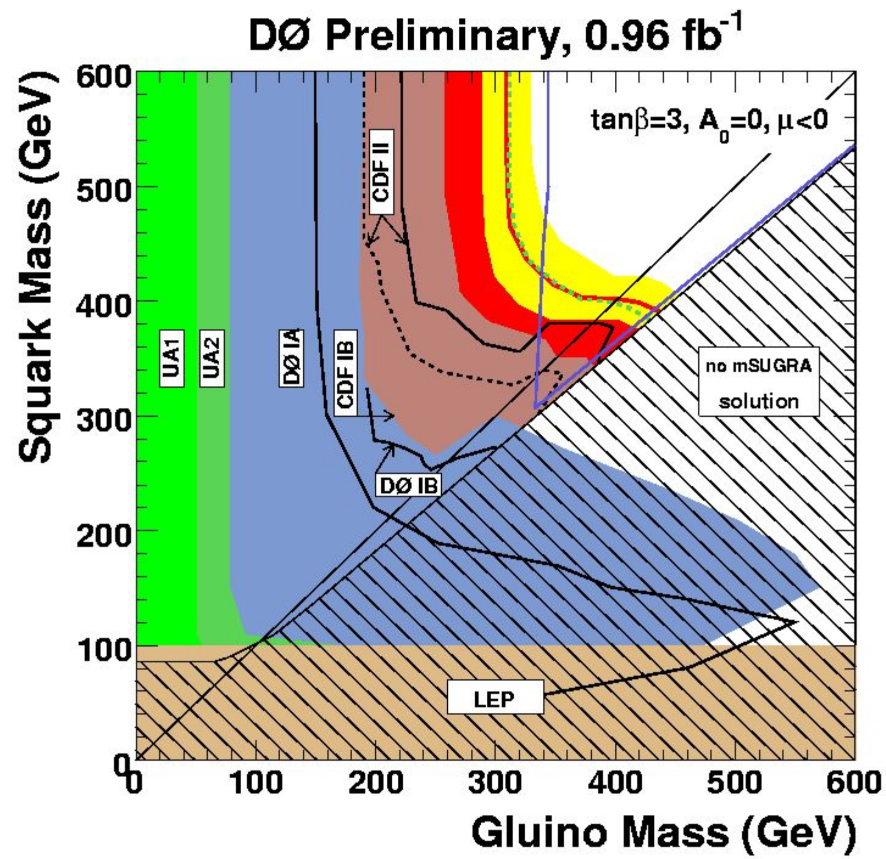


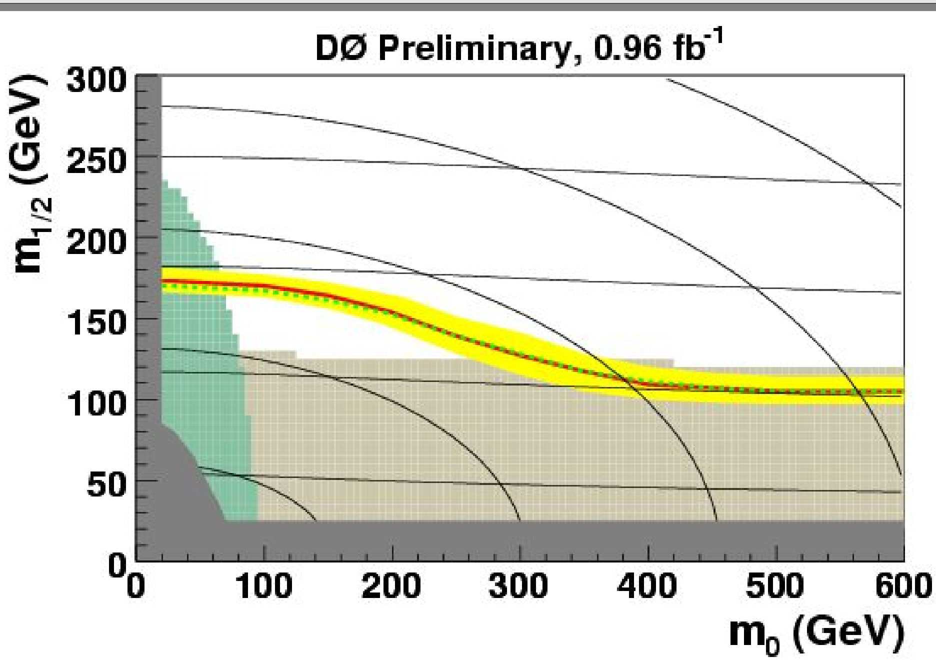
- No excess
- Systematic uncertainties :
  - mainly JES (6 to 17%) and background cross sections (15%)
  - jet reco*ID, resolution, track confirmation : 5 to 7%
  - luminosity 6.1%
  - PDF on the signal acceptance : 6%
- Signal efficiencies:
  - up to 10%, and higher at large squark-gluino masses
- Acoplanar dijet event with the largest MET : 368 GeV



Squarks and Gluinos (III)

- Signal cross sections:
  - using the 40 CTEQ6.1M PDF sets
  - large PDF uncertainty comes from the very poor knowledge of the gluon at high-x
  - Combine quadratically with the effect of the renormalization/factorization scale (μ=Q,Q/2,2Q) => 3 cross section hypotheses:
    - nominal : CTEQ6.1M and μ=Q
    - minimal
    - maximal
  - Very large effect: +75 -45% for intermediate m0
- Cross section and mass limits :
  - for the 3 cross section hypotheses
  - Combine the 3 analyses in the limit computation (removing the small overlap between them)



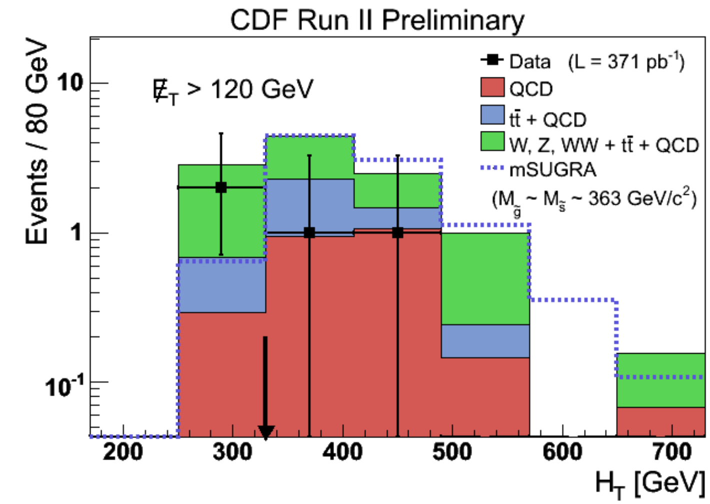


$(M\tilde{g}, M\tilde{q})$	observed	expected
σ min	(289,375)	(290,366)
σ nom	(309,311)	(311,384)
σ max	(329,405)	(332,397)

Previous Limits are improved by ~50 GeV

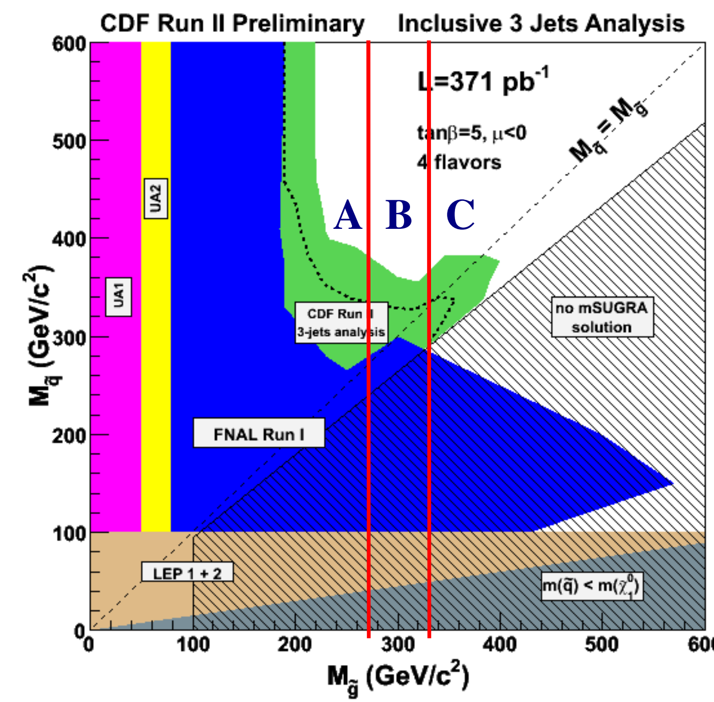
Squarks and Gluinos (IV)

- Preliminary result with 378 pb^{-1} optimized for M(squark)=M(gluino): at least 3 jets
  - tan(b)=5 (=3 for DØ) : small effect
  - only 1st and 2nd gen. squarks (+sbottom for DØ) : small effect
  - CDF treats the effect of the PDF/Scale on the signal cross section as a systematic uncertainty on the number of signal events expected, in the limit computation : DØ result for the minimal cross section is much more conservative



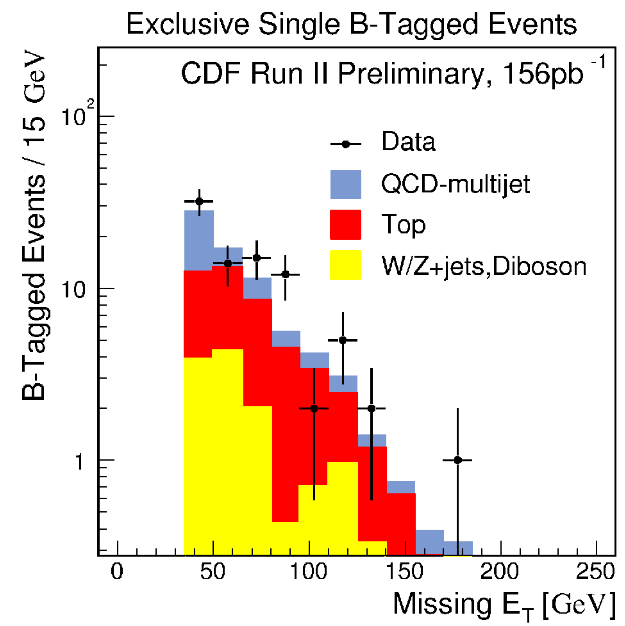
	A	B	C
MET	75	90	120
HT	230	280	330
Et jet 1	95	120	140
Et jet 2	55	70	100
Et jet 3	25	25	25
Data	185	40	2
SM back.	211 ±7 ±44	56 ±3 ±14	8.2 ±1.2 ±2.6

Use PYTHIA MC to estimate the QCD back. contribution



Gluino to sbottom b

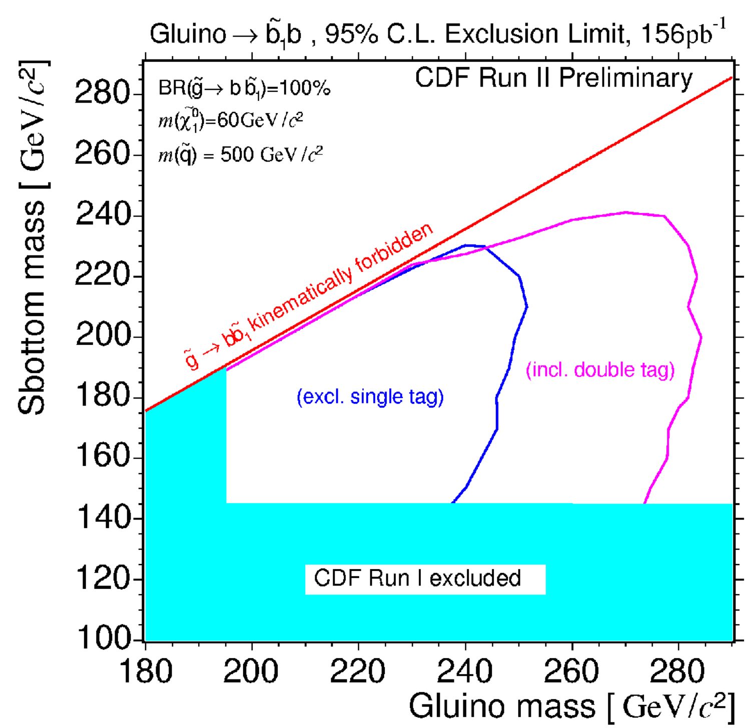
- Large sbottom mixing
- In this scenario, a sbottom squark significantly lighter than the other squarks
- Sbottom decays to a b-quark and the neutralino1 (100% BR assumed)
- The LSP mass is fixed at 60 GeV
- => 4 b-quarks + MET



- 156 pb^{-1} of RunIIa data
- Main preselection cuts :
  - at least 3 jets
  - MET > 80 GeV
  - MET isolated vs jets
  - lepton veto
  - b-tagging : secondary vertex tagging:
    - a single b-tagged jet
    - at least 2 b-tagged jets

Process	Exclusive Single B-Tag	Inclusive Double B-Tag
EWK	$5.66 \pm 0.76(stat) \pm 1.72(sys)$	$0.61 \pm 0.21(stat) \pm 0.19(sys)$
TOP	$6.18 \pm 0.12(stat) \pm 1.42(sys)$	$1.84 \pm 0.06(stat) \pm 0.46(sys)$
QCD	$4.57 \pm 1.64(stat) \pm 0.57(sys)$	$0.18 \pm 0.08(stat) \pm 0.05(sys)$
Total Predicted	$16.41 \pm 1.81(stat) \pm 3.15(sys)$	$2.63 \pm 0.23(stat) \pm 0.66(sys)$
Observed	21	4

Table 24: Number of expected and observed events in signal region.

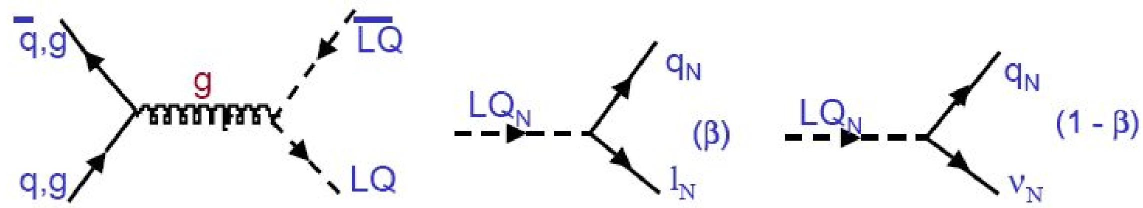


M(gluino) > 280 GeV for M(sbottom1)=200 GeV

1^{st} gen. Leptoquarks

- Leptoquarks carry both Lepton and quark quantum number
- Predicted by many extensions of the SM
- Scalar and Vector LQ

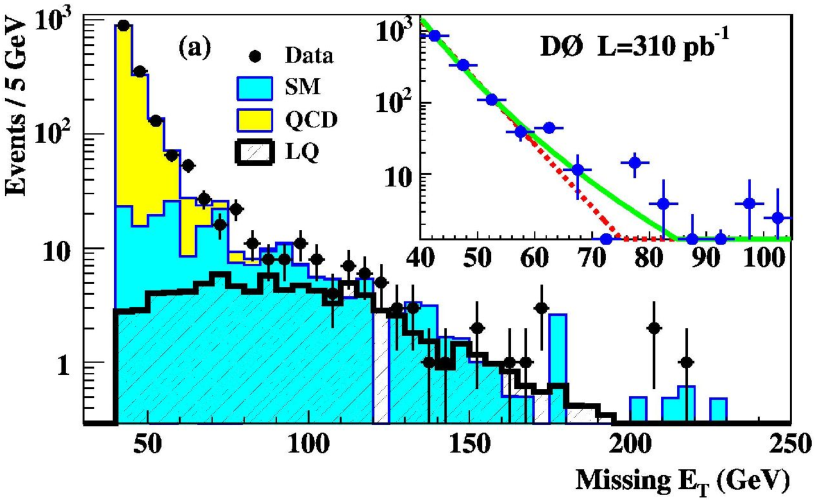
- Here, only scalar LQ
- Assume BR(LQ -> qν) = 100%

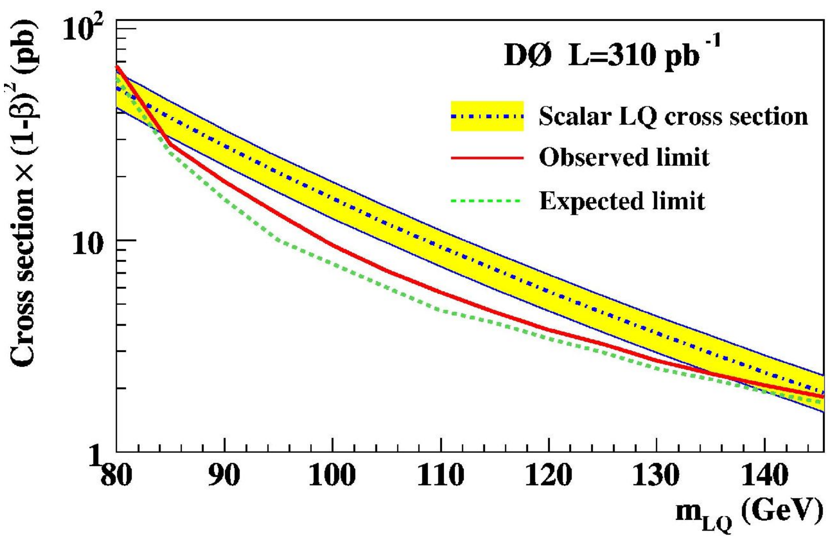


- 310 pb^{-1} of RunIIa data
- Selection cuts :
  - exactly 2 jets (pt1>60 and pt2>50), |eta|<1.5, confirmed by the tracks
  - acoplanarity < 165 degrees
  - isolated electron/muon/track veto
  - MET vs jets isolation cuts
  - MET > 80 GeV
- Systematic uncertainties: JES between 5 and 8%
  - SM background cross section: 12%

Back.	# events
SM back. tot.	72.9 +10.1 -9.7 (stat.) +10.6 -12.1 (syst.)
Instrumental back.	2.3 ± 1.2
Total back.	75.2 +10.1 -9.7 (stat.) +10.7 -12.2 (syst.)
data	86

- Limit : M(LQ) > 136 GeV





- CDF results with 191 pb^{-1} :
  - M(LQ) > 117 GeV

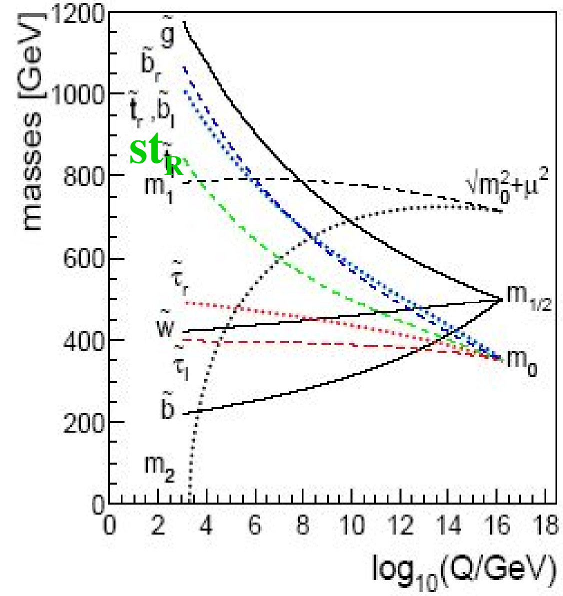
Sbottom/Stop

$$M^2_{\tilde{f}_{1,2}} = \frac{1}{2}\left[(M^2_{\tilde{f}_L} + M^2_{\tilde{f}_R}) \mp \sqrt{(M^2_{\tilde{f}_L} - M^2_{\tilde{f}_R})^2 + a^2_{\tilde{f}} m^2_f}\right]$$

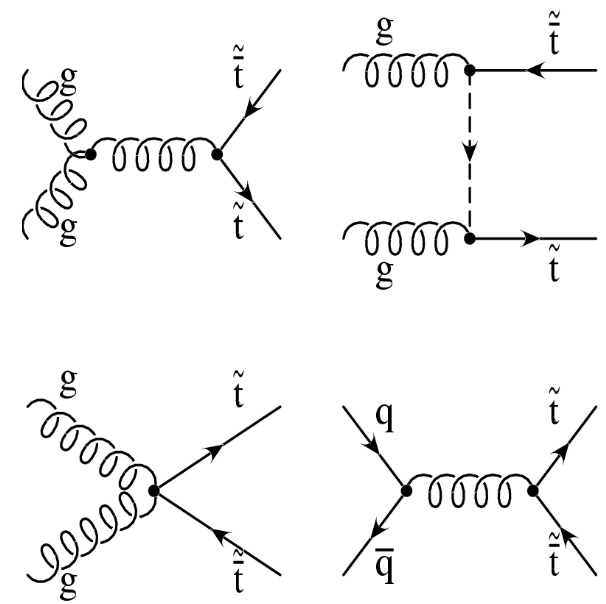
$$a_{\tilde{t}} = A_U - \mu / \tan\beta$$

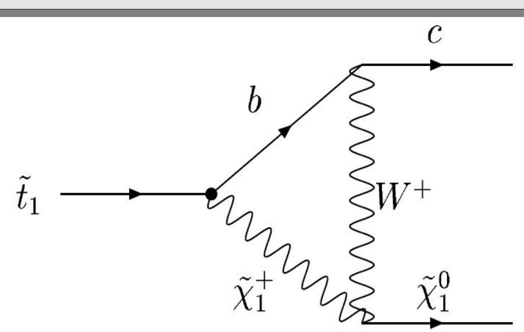
$$a_{\tilde{b}} = A_D - \mu * \tan\beta$$

- Large top-yukawa impact in RGE
- large mixing in the 3rd generation squark sector:
  - the lightest stop or lightest sbottom is expected to be the NLSP

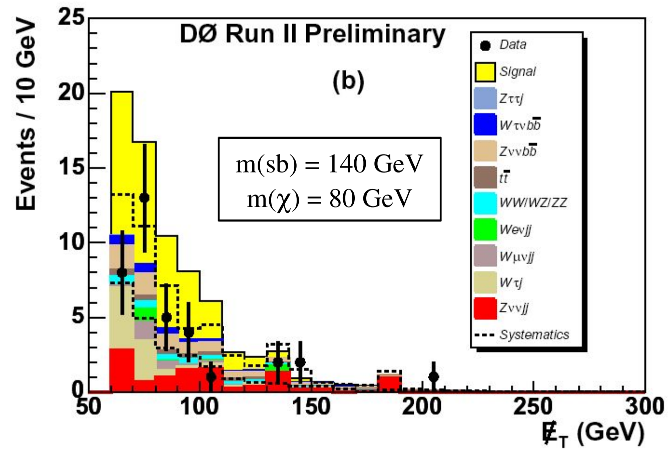


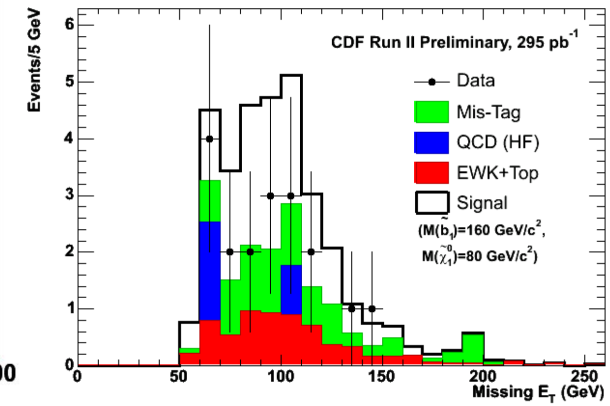
- Pair production of stop and sbottom squarks
- R-parity conservation
- sbottom:
  - assume BR(sbottom1 -> b χ^0_1) = 100%
- stop decay via FCNC :
  - assume BR(stop1 -> c χ^0_1) = 100%
  - if m(stop1) < m(b)+m(W)+m(χ^0_1)
- 2 acoplanar jets with b or c jet tagging





Sbottom

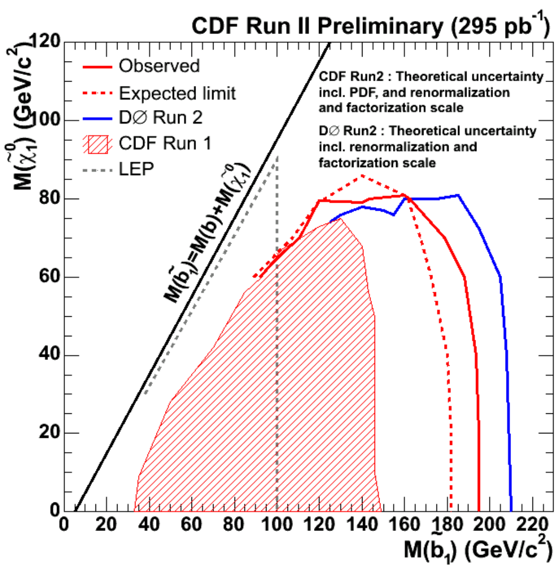


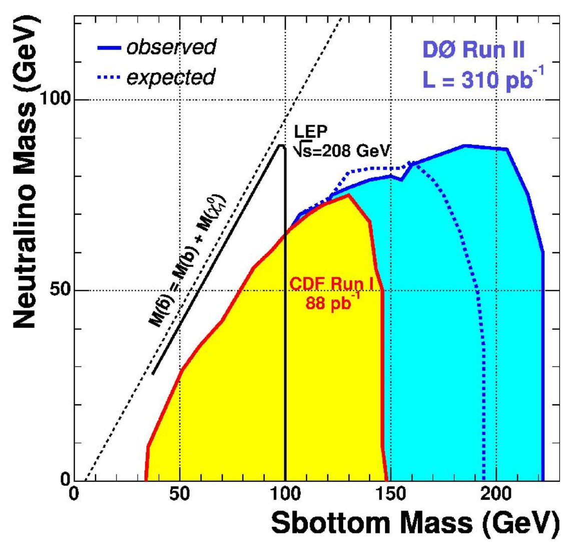


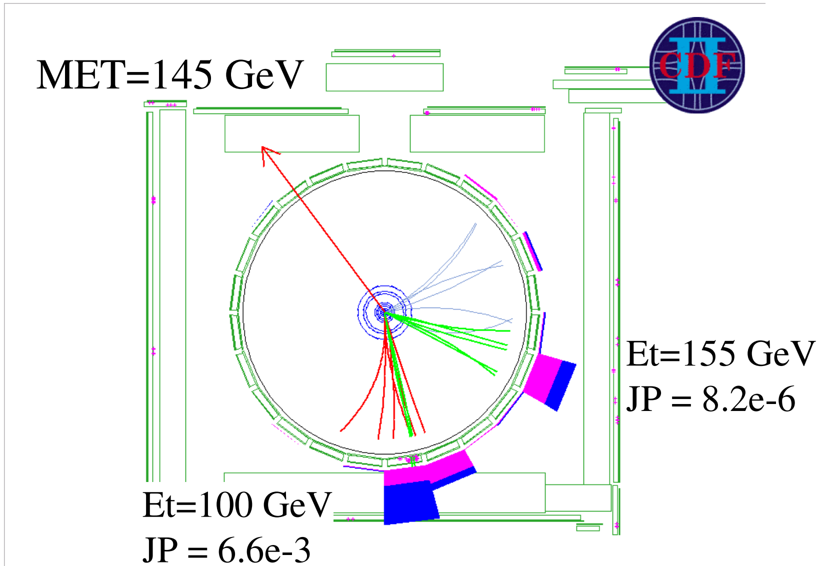
- <u>Integrated luminosity:</u>
  - DØ : 310 pb^{-1}
  - CDF : 295 pb^{-1}

- b-tagging using Jet Lifetime Probability Algorithm
- at least 1 b-jet tagged
- Various optimization on jets pT and MET cuts as a function of the sbottom and neutralino1 masses

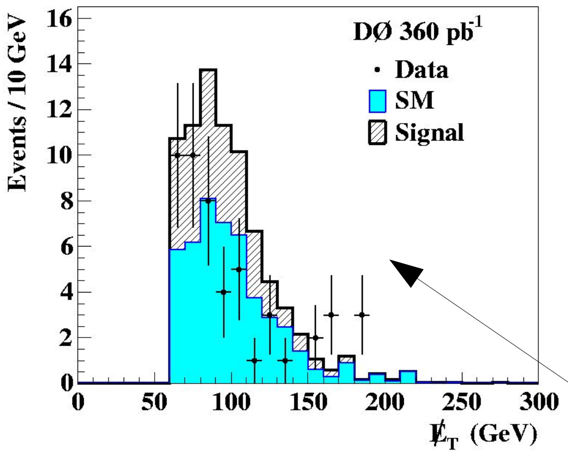
Need to cut as low as possible on jet pT and MET to be sensitive to low mass differences between the sbottom and the neutralino1 mass



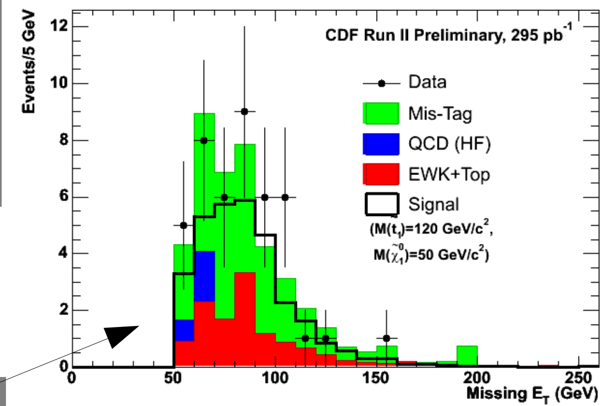




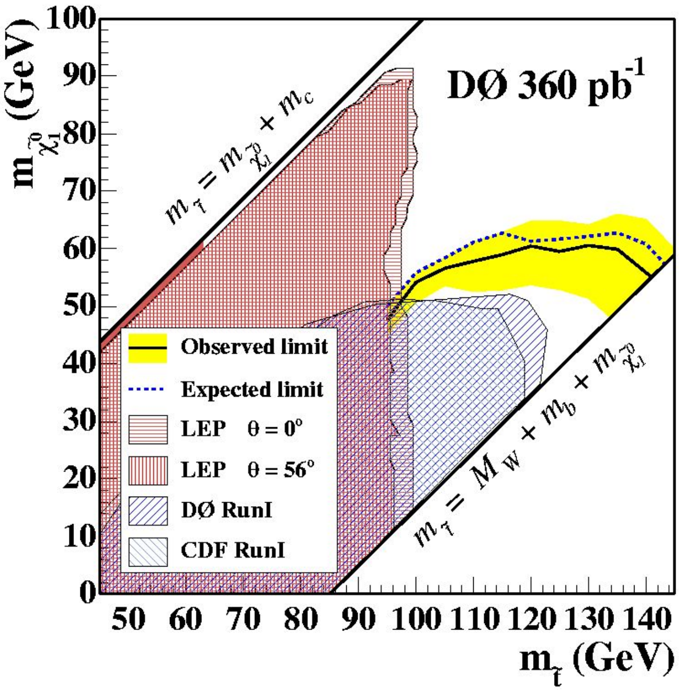
Stop

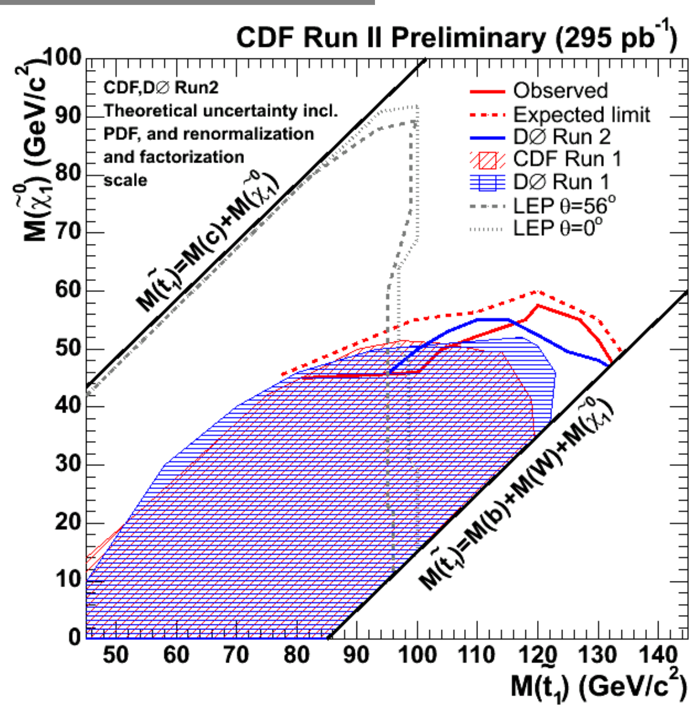


- soft Jet Lifetime Probability tag used
- at least 1 c-jet tagged
- Various optimization on jets pT and MET cuts as a function of the stop and neutralino1 masses



- Small excess of events at large MET in the D0 analysis : 8 for 3.2 ± 1.4 expected for MET>150 GeV
- Not seen by CDF





Summary

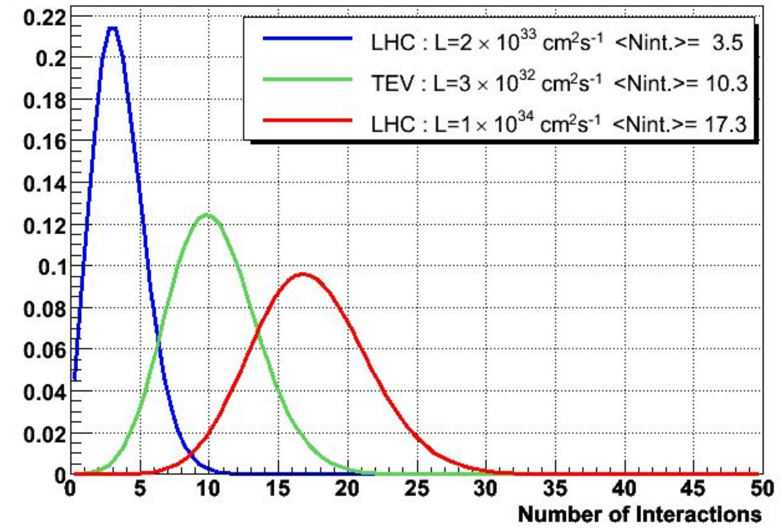
Analysis	Exp.	Model	Lumi. (pb^{-1})	Mass Limits (GeV)	Conditions
monojet	CDF	ADD LED	1100.	M_D > 0.99 TeV for n=4	limits on M_D as a function of n
squark-gluino	DØ	mSUGRA	960	Msquark>375, Mgluino>289	tan(β)=3, A=0,mu<0.
	CDF	mSUGRA	371	Msquark>340, Mgluino>220	tan(β)=5, A=0,mu<0.
gluino-> sbottom1 b	CDF	MSSM	191	Mgluino>280	at Msbottom1=200 (see 2D plot)
sbottom->b-chi01	DØ	MSSM	310	Msbottom1>220 GeV	BR(b chi01)=100% M(chi01)=60
	CDF	MSSM	295	Msbottom1>188 GeV	BR(b chi01)=100% M(chi01)=60
stop->c-chi01	DØ	MSSM	360	Mstop1>134 GeV	BR(c chi01)=100% M(chi01)=48
	CDF	MSSM	295	Mstop1>132 GeV	BR(c chi01)=100% M(chi01)=47
1st gen. LQ	DØ		310	M(LQ)>136 GeV	BR(LQ->qν)=100%
	CDF		191	M(LQ)>117 GeV	BR(LQ->qν)=100%
3rd gen. LQ	DØ		310	M(LQ)>219 GeV	BR(LQ->bν)=100%

- A large variety of topology is covered:
  - from monojet to multijet
  - without and with heavy flavor tagging
- No new physics seen so far
- 2 analyses with all RunIIa data
  - Stay tuned : new results should be available soon with more luminosity

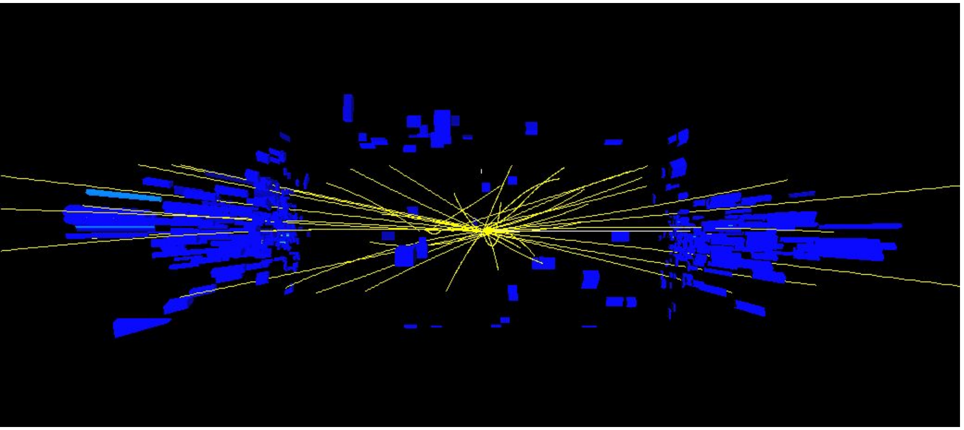
CDF: http://www-cdf.fnal.gov/physics/exotic/exotic.html
DØ: http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm

RunIIb

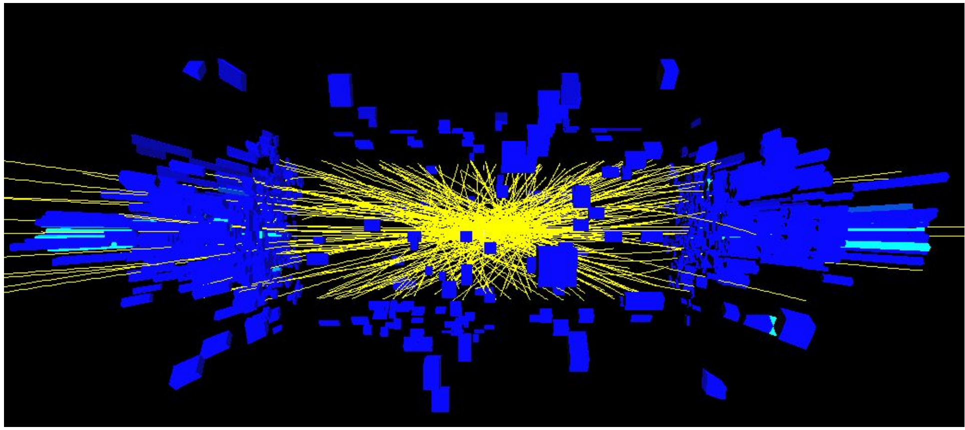
- The Tevatron is already running at very high luminosity :
  - The RunIIb goal is to reach 300E30 cm^2s^{-1}
  - at this instantaneous luminosity, the average number of interaction per beam crossing is ~10 (beam crossing time = 396 ns)



A zero bias event @ 60E30 cm^2s^{-1}

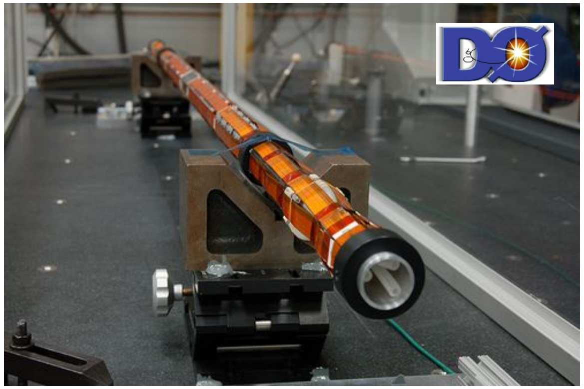


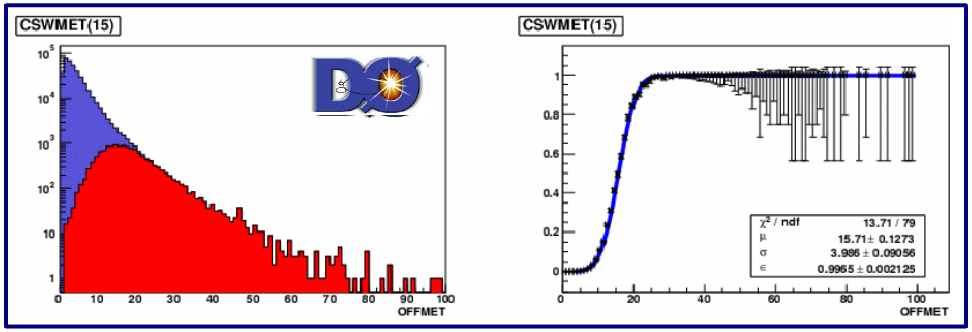
... and @ 240E30 cm^2s^{-1}



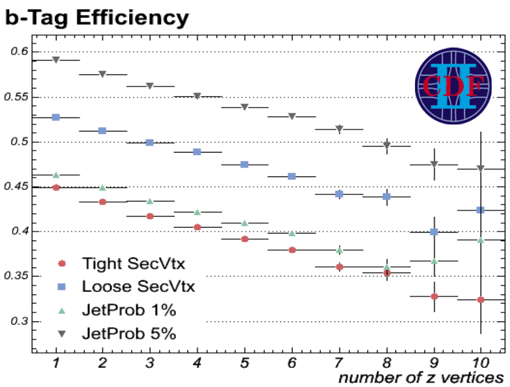
Very challenging environment for RunIIb physics...

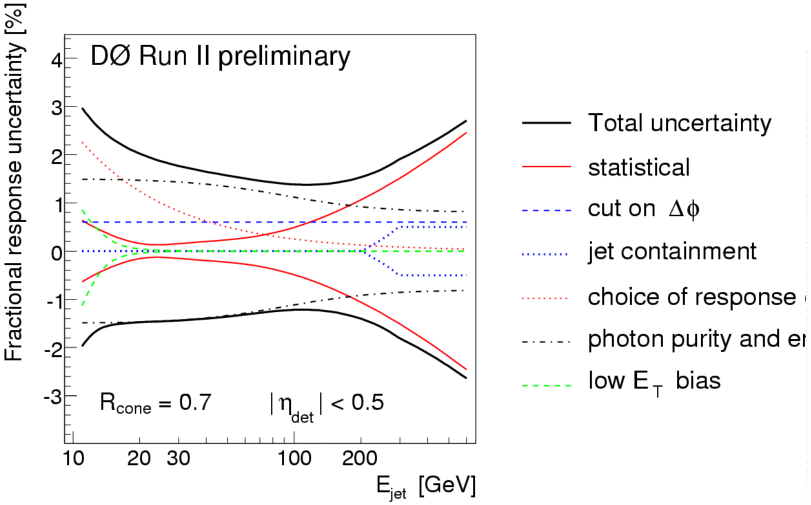
RunIIb

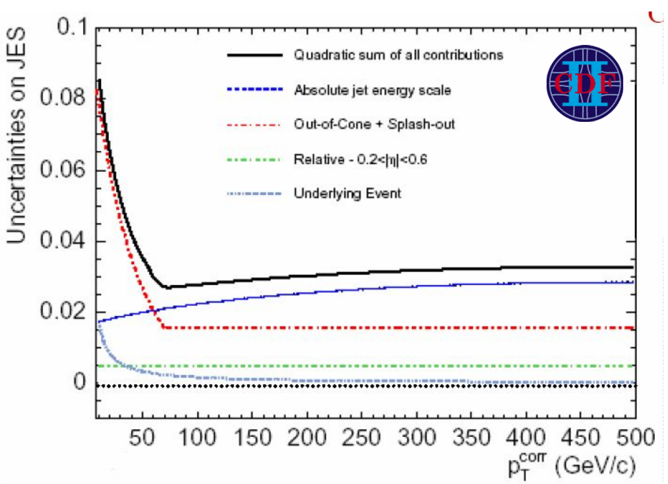


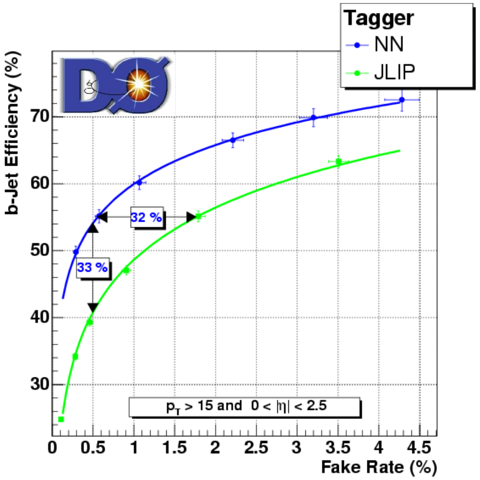


- Very high instantaneous luminosity @ the peak since the beginning of RunIIb in June 2006. Current record is ~240E30 cm^2s^{-1}
- New L1Cal system in DØ which allows to trigger on MET @ L1
- New layer0 for the DØ micro-vertex detector installed and commissioned
- Working trigger menus for high luminosity running
- Improved JES and b-tagging understanding underway









... but, we are ready

Backup Slides

Supersymmetry

- Beyond the SM ?
  - radiative corrections to the Higgs mass
  - Unification of the coupling constants
  - include gravitation
  - hierarchy problem
- Supersymmetry: each SM particle has a SUSY partner which differ by ½ in spin :
  - SM fermion ⇔ SUSY boson
  - SM boson ⇔ SUSY fermion

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

- No scalar electron with the same mass as the electron:
  - SUSY must be broken
- R-parity conservation:
  - SUSY particles are pair produced
  - the LSP is stable : dark matter candidate
- R-parity violation:
  - new terms which violate the conservation of the lepton and baryon number can be added in the lagrangian
  - the LSP is no longer stable

$$W_{RPV}=\lambda_{ijk}L_iL_j\bar{E}_k+\lambda'_{ijk}L_iQ_j\bar{D}_k+\lambda''_{ijk}\bar{U}_i\bar{D}_j\bar{D}_k$$

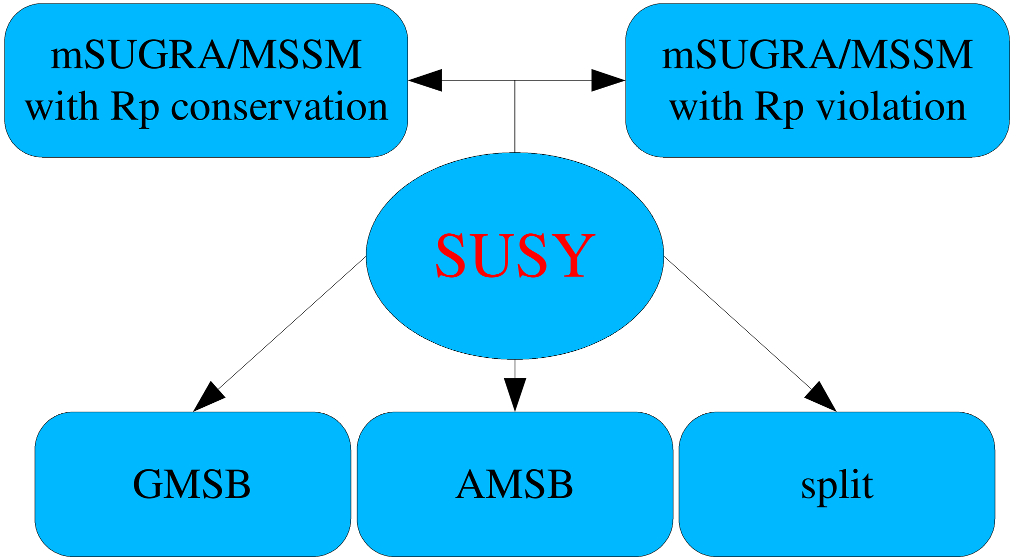
SM	Supersymmetric particles: R-parity = -1			
R-parity=+1	Interaction		Mass	
$q=u,d,c,s,t,b$	$\tilde{q}_L,\tilde{q}_R$	squarks	$\tilde{q}_1,\tilde{q}_2$	squarks
$l=e,\mu,\tau$	$\tilde{l}_L,\tilde{l}_R$	sleptons	$\tilde{l}_1,\tilde{l}_2$	sleptons
$\nu=\nu_e,\nu_\mu,\nu_\tau$	$\tilde{\nu}$	sneutrino	$\tilde{\nu}$	sneutrino
g	$\tilde{g}$	gluino	$\tilde{g}$	gluino
W^{+-}	$\tilde{W}^{+-}$	wino	$\tilde{\chi}^{+-}_{1,2}$	charginos
H_1^-	$\tilde{H}_1^-$	higgsino		
H_2^+	$\tilde{H}_2^+$	higgsino		
γ	$\tilde{\gamma}$	photino	$\tilde{\chi}^0_{1,2,3,4}$	neutralinos
Z	$\tilde{Z}$	zino		
H_1^0	$\tilde{H}_1^0$	higgsino		
H_2^0	$\tilde{H}_2^0$	neutralino		

Supersymmetry

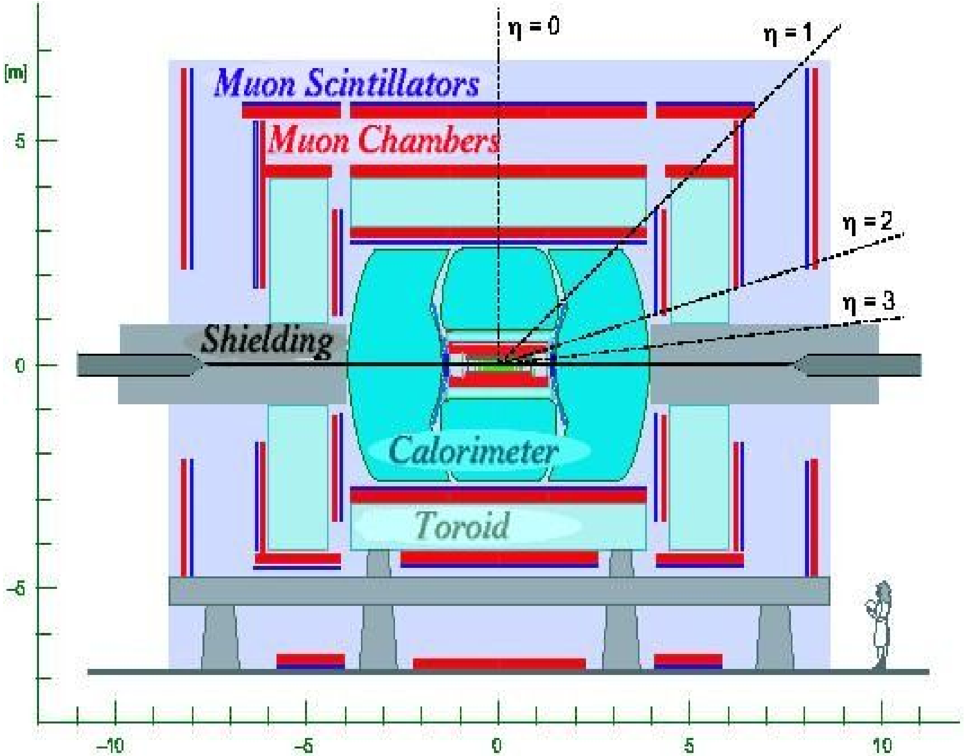
- Why is it so interesting for experimentalists ?
  - It doubles the particle spectrum: large variety of new particles and of final states
  - Large number of SUSY models which can be tuned to predict new particles at ~any masses
  - SUSY can be searched for in all topologies: missing ET, multijets, multileptons, photons, with b quarks or taus, long lived particles...

- Large numbers of new parameter
- mSUGRA: 5 parameters:

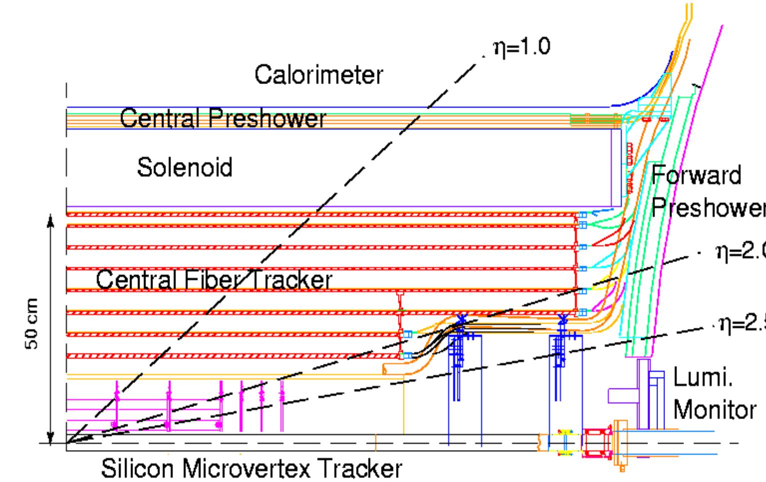
  tan(β) : v.e.v. ratio of the 2 Higgs Fields
  m_0 : scalar mass @ GUT scale
  $m_{½}$: gaugino mass @ GUT scale
  sign(μ) : Higgs mixing mass parameter
  A_0 : trilinear coupling @ GUT scale



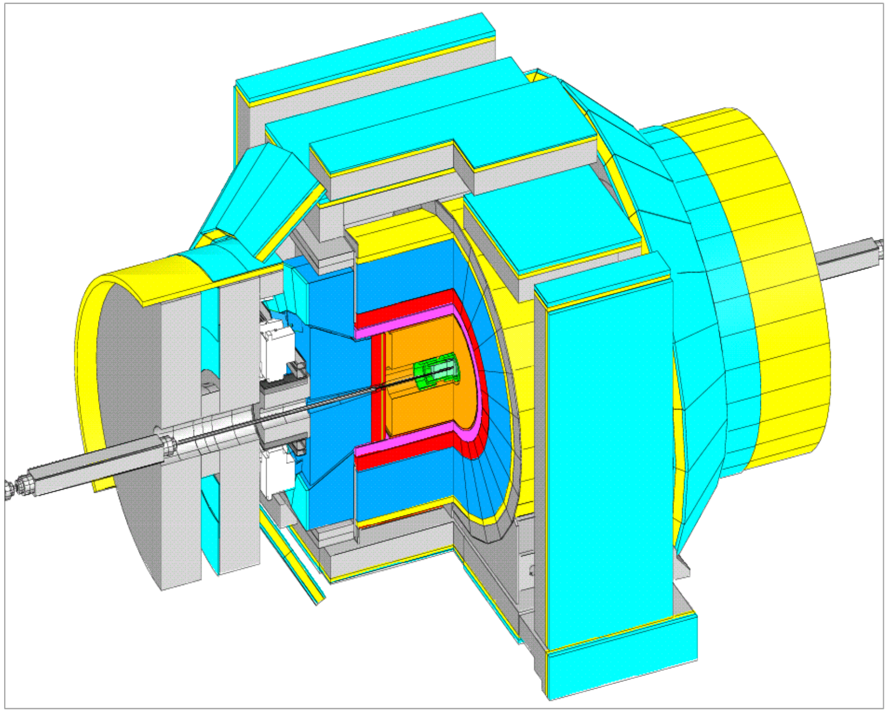
Detectors



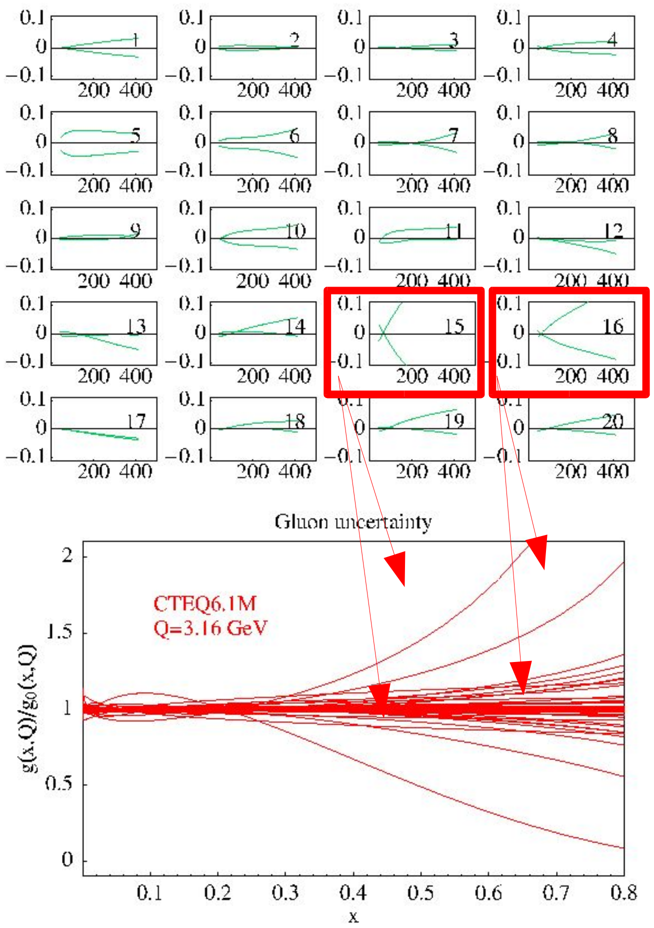
η = 0
η = 1
η = 2
η = 3
[m]
Muon Scintillators
Muon Chambers
Shielding
Calorimeter
Toroid
5
0
-5
-10
-5
0
5
10



Calorimeter
η=1.0
Central Preshower
Solenoid
Forward Preshower
η=2.0
Central Fiber Tracker
η=2.5
50 cm
Lumi. Monitor
Silicon Microvertex Tracker

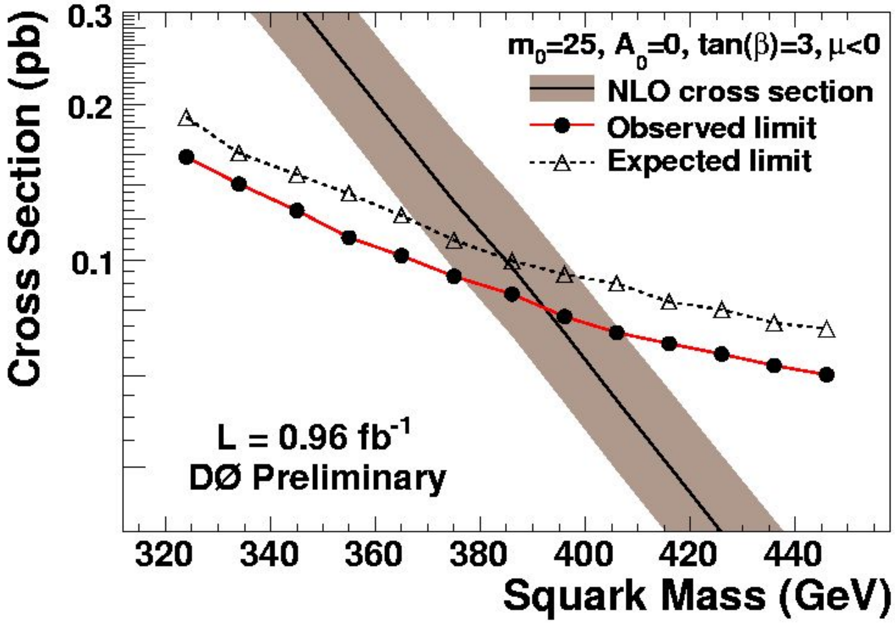


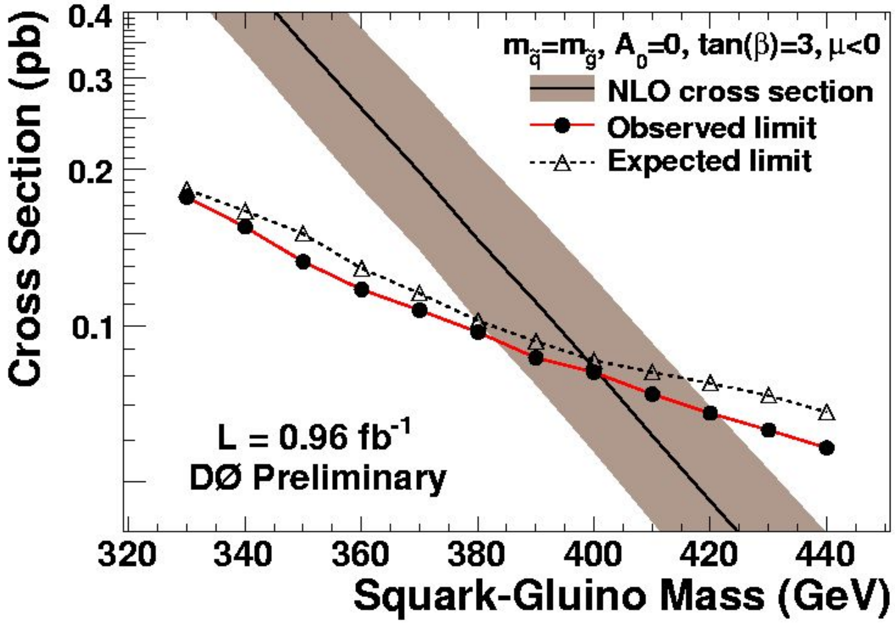
Squarks/Gluinos

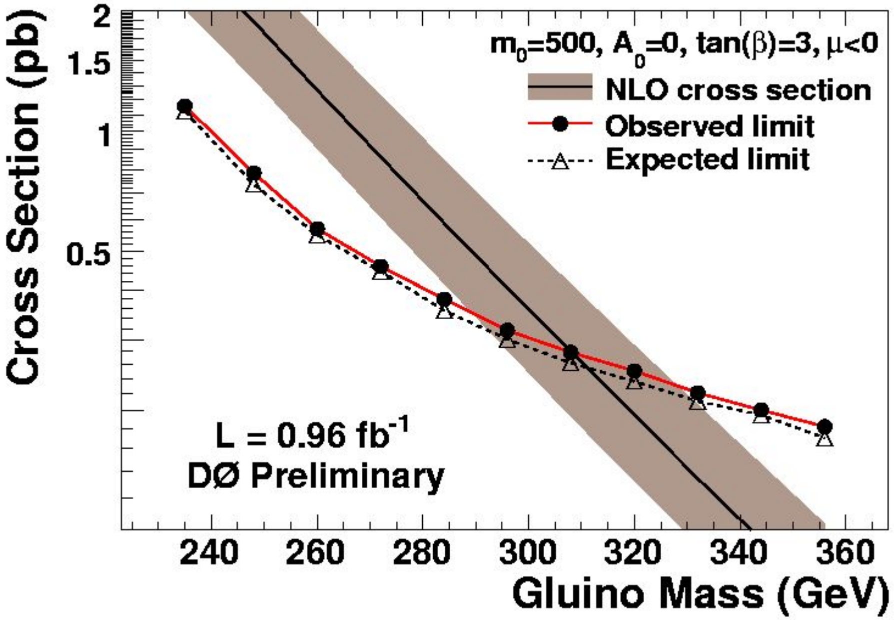


- Signal cross sections:
  - Signal cross sections using the 40 CTEQ6.1M PDF sets
  - The large uncertainty using eigenvector 15 (PDF sets 29 and 30) comes from the very poor knowledge of the gluon at high-x
  - Combine quadratically the effect of the 20 eigenvectors
  - Combine quadratically with the effect of the renormalization/factorization scale (μ=Q,Q/2,2Q) => 3 cross section hypotheses:
    - nominal : CTEQ6.1M and μ=Q
    - minimal
    - maximal
  - Very large effect: +75 -45% for intermediate m0
- Cross section and mass limits :
  - They are therefore obtained for the 3 cross section hypotheses
  - Combine the 3 analyses in the limit computation (removing the small overlap between them)

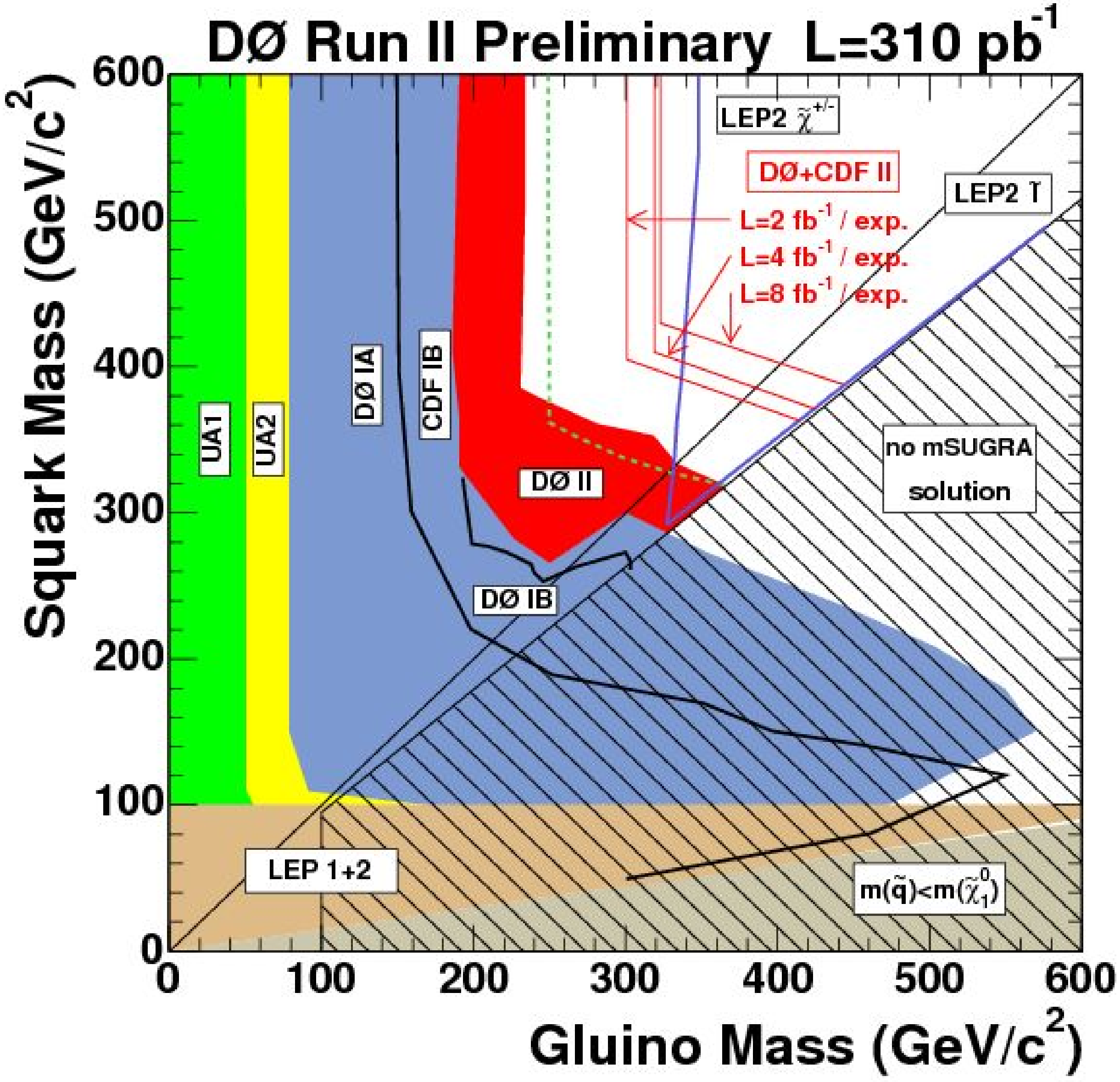
Squarks/Gluinos



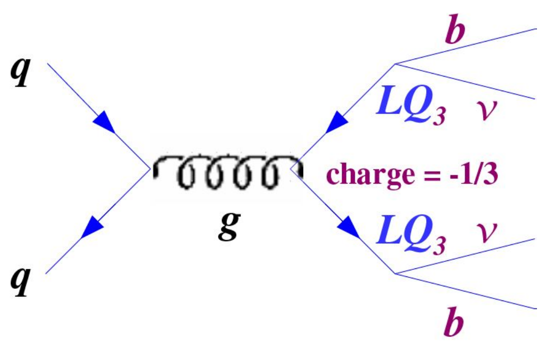


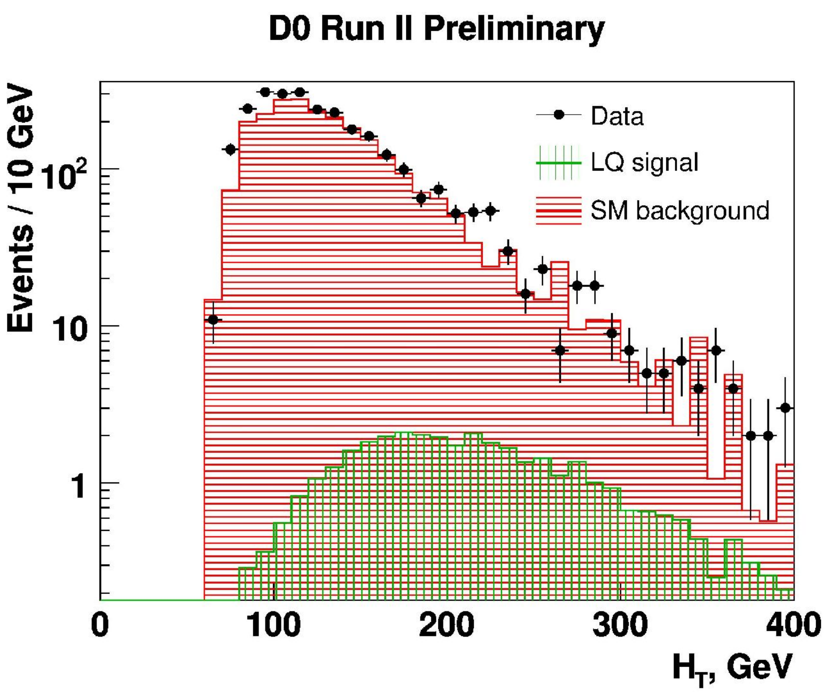


Squarks/Gluinos



3rd gen. LQ





- L=310 pb^{-1}
- Event selection:
  - at least 2 jets with $|\eta|<0.9$ and Pt1>40 and Pt2>20 GeV confirmed by the tracks
  - b-tagging using a Jet Lifetime Probaility (JLIP) and muon tagging:
    - 2 jets b-tagged
  - MET > 70 GeV
- BR(LQ->bν)=100% : M(LQ) > 219 GeV
- Taking into account LQ-> tτ : M(LQ)>213 GeV