Searches for Sbottom & Stop in D-Zero at the Tevatron (Run 2)

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R-parity conserving searches for the pair-production and decay of *stop* or *sbottom* in proton-antiproton collisions at the Tevatron

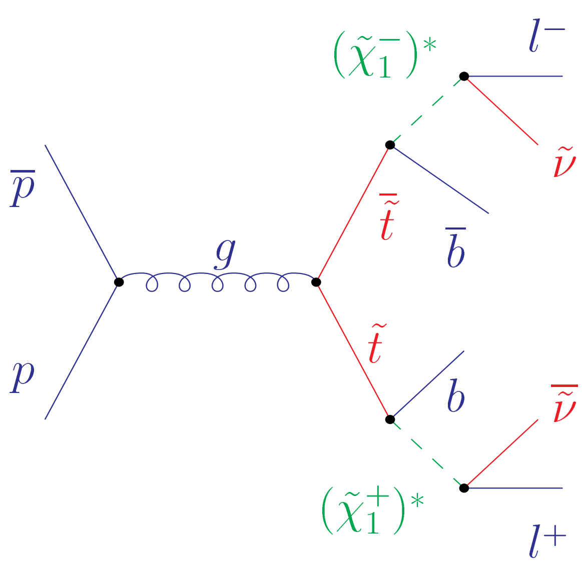
large m_{top} => substantial mixing between SUSY scalar partners of the L- and R-handed top quarks; lightest stop t_1 could be the lightest squark

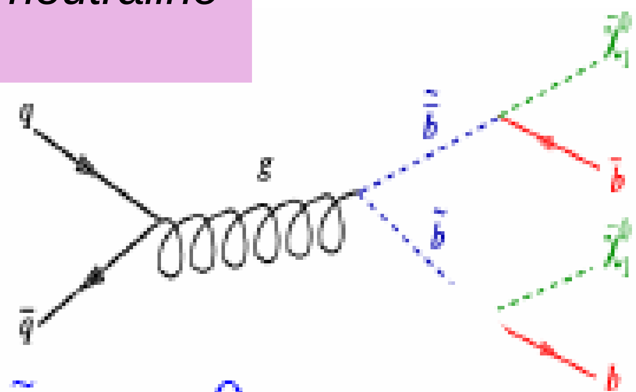
… sbottom may also be quite light …

3-body decays of t_1 favoured at Tevatron over 2-body (e.g. c+χ_1^0); $t_1 \rightarrow$ b+l+snu dominates if $m_\nu \approx M_W$; χ_1^0 is the LSP $\therefore$ snu $\rightarrow$ nu + χ_1^0

dominant decay mode expected: $b_1 \rightarrow b + \chi_1^0$

assume lightest *neutralino* χ_1^0 is the LSP





$$BR(\tilde{b} \rightarrow b\chi_1^0) = 100\ \%$$

Final state: 2 leptons+(b-)jets+ME_T

Final state: (b-)jets+ME_T

Event Reconstruction Requirements

stop & sbottom

- efficient trigger → 2 muons (stop); acoplanar jets + ME_T (sbottom)
- jet reconstruction → cone algorithm $\Delta R=0.5$
- b-tagging of these jets → JLIP algorithm
- missing E_T measurement

- charged lepton reconstruction & identification

sbottom: lepton veto

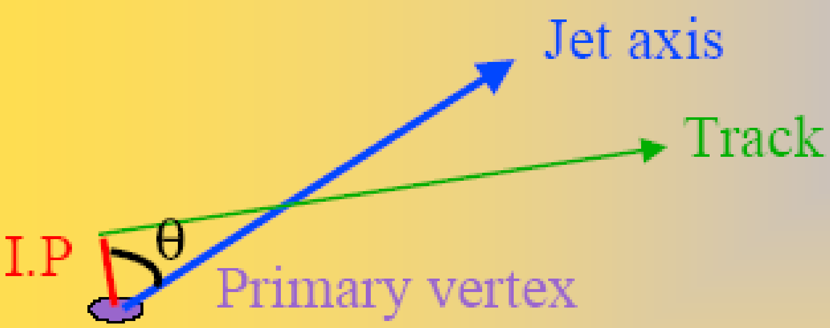
stop:

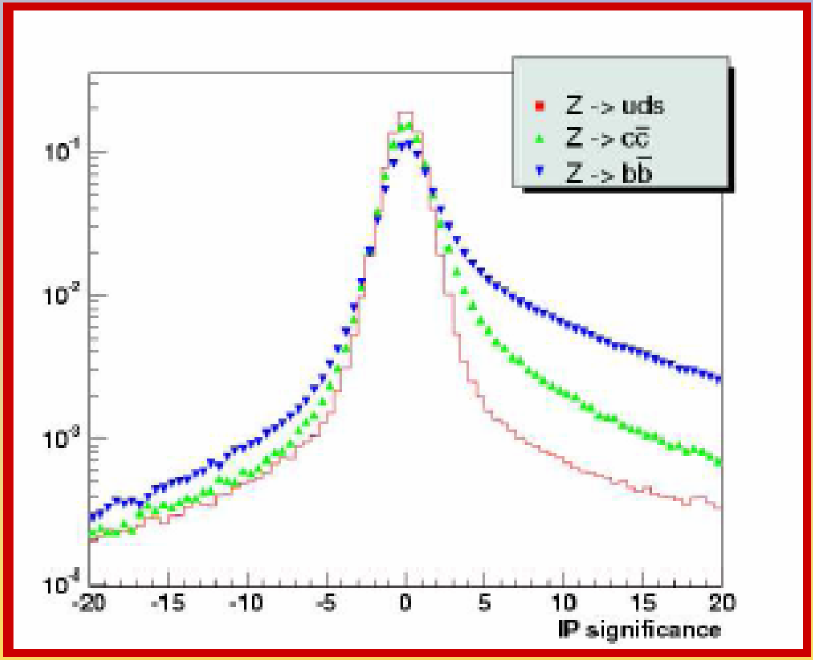
only *muons* are used in the *stop* analysis:
- e + μ analysis is still in progress
- expected to give greater sensitivity due to larger BR (x2) and much smaller SM background

Data samples (after trigger/data quality selection): **339 pb^{-1} (stop)**
310 pb^{-1} (sbottom)

Jet LifeTime Probability (JLIP)

Use the signed impact parameter significance of tracks associated to a jet (dR<0.5 cone matching) to identify jets with long lived particles (mostly b-jets).





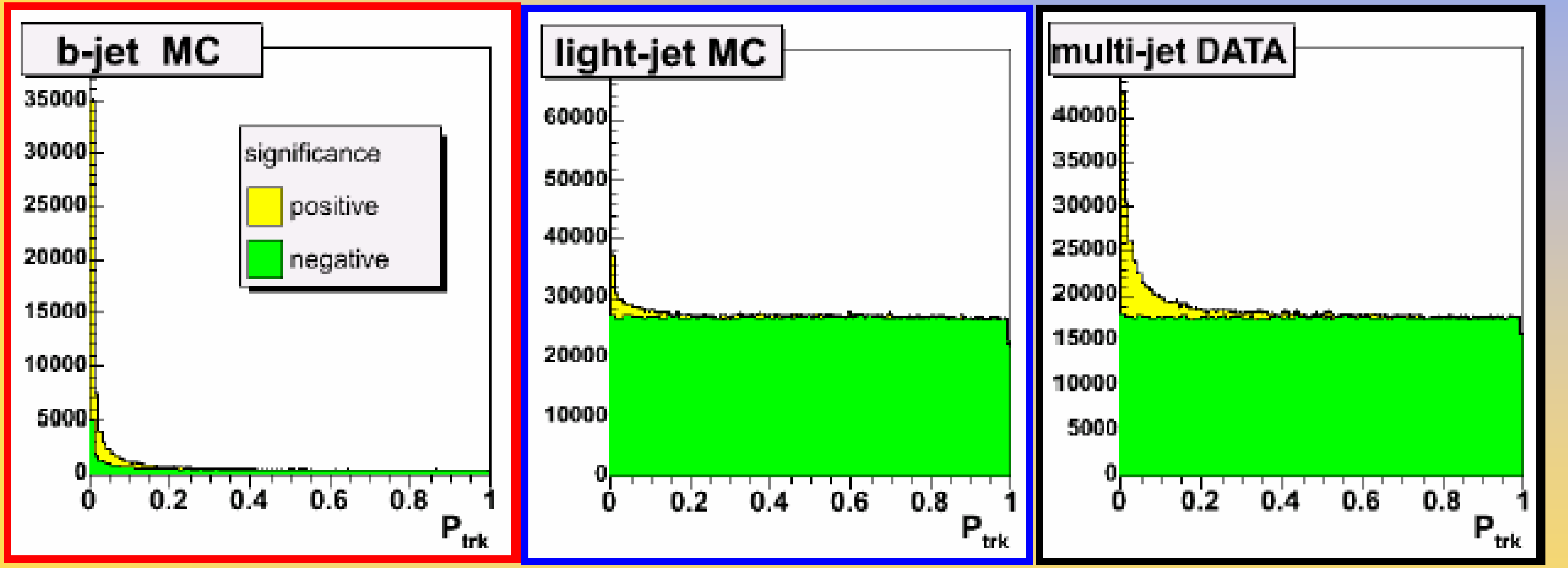
Impact parameter (IP) sign :

- positive for $\theta < \pi/2$
- negative for $\theta > \pi/2$

JLIP : Track probability

For each track :
- Determine its category.
- Compute track probability.

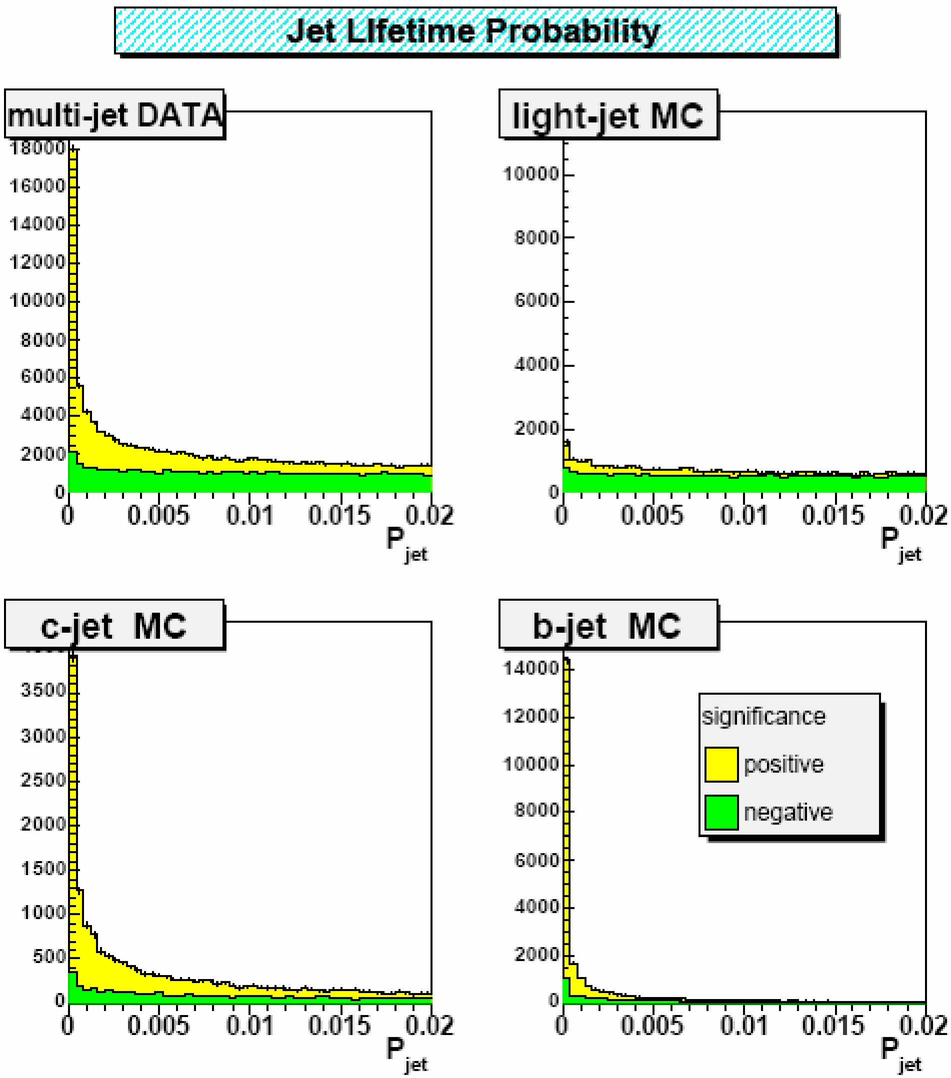
$$P_{Trk}^{cat}(S_{IP}) = \frac{\int_{S_{IP}}^{+\infty} R_{cat}(s)ds}{\int_{0}^{+\infty} R_{cat}(s)ds}$$



Track probabilities for tracks with positive and negative IP significance

JLIP : Jet Probability

Combine track probabilities for tracks with positive (P^{+}_{Jet}) or negative (P^{-}_{Jet}) significance.

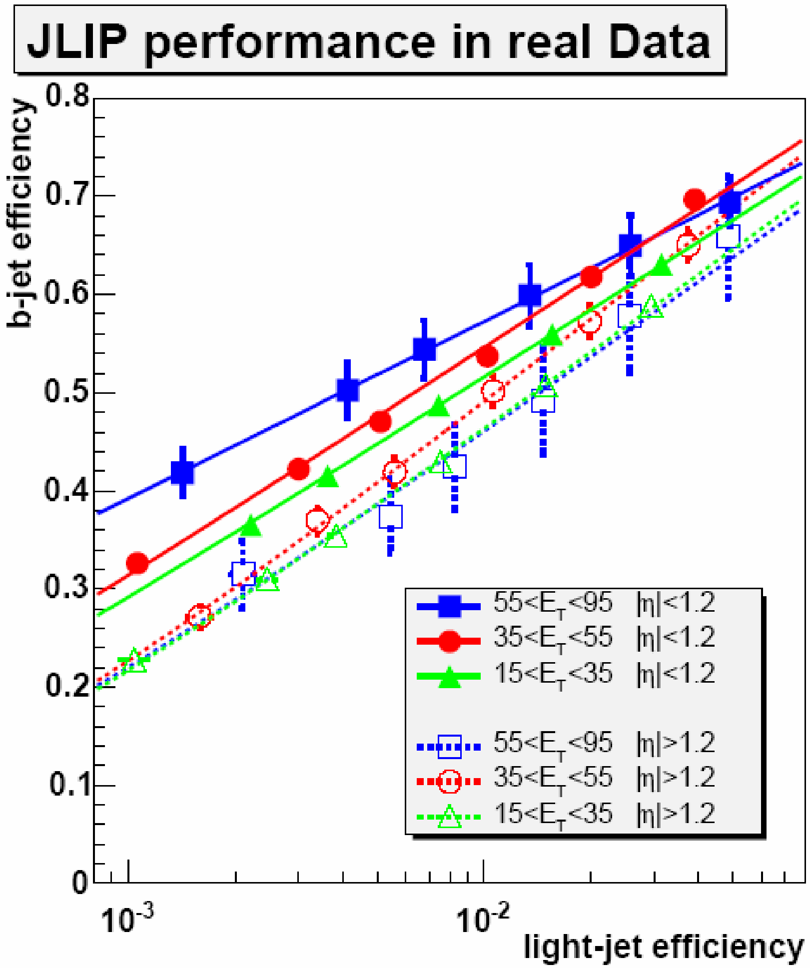


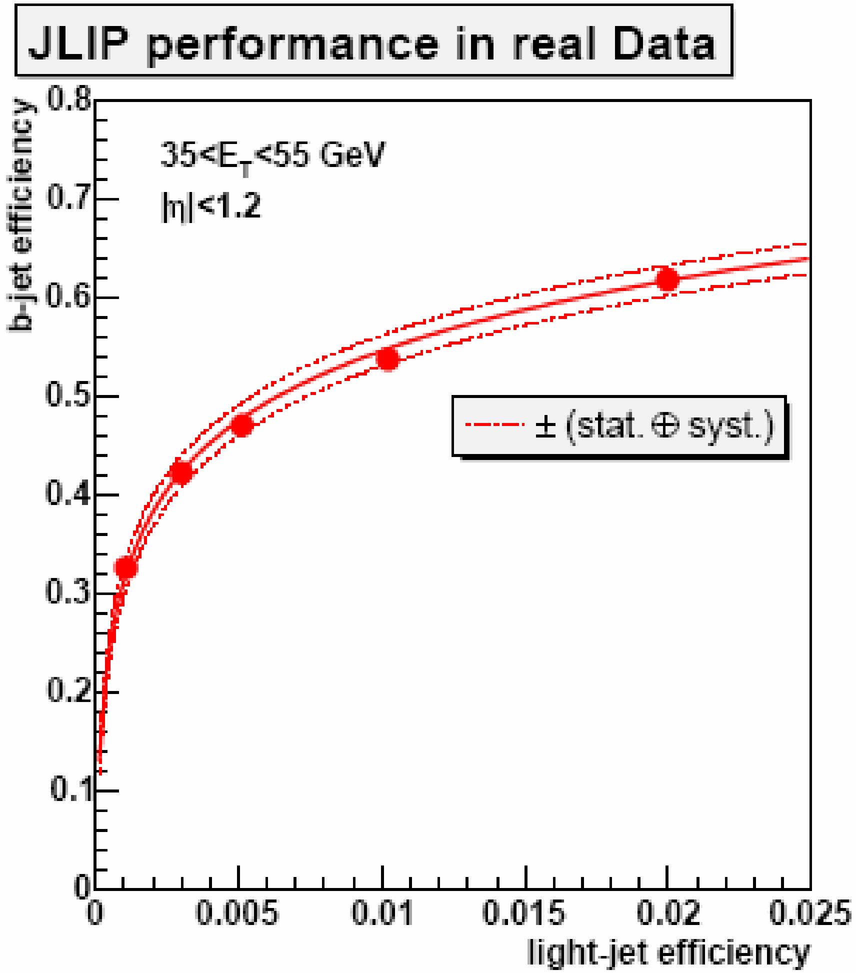
$$P^{\pm}_{Jet} = \Pi^{\pm} \cdot \sum_{j=0}^{N^{\pm}_{Trk}-1} \frac{(-\log \Pi^{\pm})^{j}}{j!}, \quad \text{with}\ \Pi^{\pm} = \prod_{i=0}^{N^{\pm}_{Trk}} P_{Trk}\left(\begin{smallmatrix} S_{IP}>0 \\ S_{IP}<0 \end{smallmatrix}\right)$$

P^{+}_{Jet} is the jet probability. Tagging a jet is done by cutting on this value.

P^{-}_{Jet} is used to determine mistg rate on QCD data

b-jet tagging efficiency





stop search: signal & background simulation

3-body t_1 decays: CompHEP & PYTHIA 6.202

BR ($\chi_1^\pm \rightarrow$ sneutrino + ch. lepton) = 100% (lepton flavour universality imposed)

MSSM parameters varied to obtain a set of SUSY signal points (m_{t1}, m_{snu})

- slepton parameters set to give equal BRs for $\chi_1^\pm$ into all lepton flavours
- tanβ = 20 – favours 3-body decays of t_1
- μ = +225 GeV, M_{gluino} = 500 GeV, M_{HA} = 800 GeV
- trilinear stop mixing A_T varied to obtain required $t_1$masses
- 1st/2nd generation L-handed sleptons masses varied to obtain e/μ m_{snu}
- Bino mass M_1 set to ensure that χ_1^0 is the LSP
- Wino mass M_2 set to ensure that $\chi_1^\pm$ is virtual

NLO *stop* pair production cross-section ~ PROSPINO

Background samples ~ PYTHIA 6.202
QCD multi-jet background deduced from data

SUSY signal points

stop mass

snu mass

TABLE I: Overview of the different SUSY signal points ($M(\tilde{t}_1)$,$M(\tilde{\nu})$) as simulated by CompHEP for $\tan\beta = 20$, $\mu = +225$ GeV, $M(\tilde{g}) = 500$ GeV$/c^2$, $M(H_A) = 800$ GeV$/c^2$, and the corresponding MSSM parameters and the total cross section as obtained from PROSPINO [5].

Signal points	A_T [GeV]	$M_{L\,1,2}$ [GeV$/c^2$]	M_1 [GeV$/c^2$]	M_2 [GeV$/c^2$]	$M(\tilde{t}_1)$ [GeV$/c^2$]	$M(\tilde{\nu})$ [GeV$/c^2$]	$\sigma \cdot Br$ [pb]
A1	510	82	53.5	215	70.63	50.86	10.83
A2	501.5	82	53.5	215	80.06	50.86	5.56
A3	480	82	53.5	210	100.03	50.86	1.65
A4	453	82	53.5	225	120.50	50.86	0.58
A5	438	82	53.5	225	130.49	50.86	0.37
A6	422.5	82	53.5	230	140.07	50.86	0.25
A7	413	82	53.5	230	145.63	50.86	0.20
A8	405	82	53.5	250	150.16	50.86	0.16
A9	386	82	53.5	275	160.39	50.86	0.11
B1	501.5	88.5	63	215	80.06	60.80	5.56
B2	491.2	88.5	63	215	90.18	60.80	2.92
B3	480	88.5	63	210	100.03	60.80	1.65
B4	453	88.5	63.7	225	120.50	60.80	0.58
B5	422.5	88.5	63.7	230	140.07	60.80	0.25
B6	405	88.5	63.7	250	150.16	60.80	0.16
C1	491.2	95.5	74	215	90.18	70.60	2.92
C2	480	95.5	74	210	100.03	70.60	1.65
C3	467	95.5	74	210	110.36	70.60	0.96
C4	438	95.5	74	225	130.49	70.60	0.37
C5	422.5	95.5	74	230	140.07	70.60	0.25
C6	405	95.5	74	250	150.16	70.60	0.16
D1	480	103	85	210	100.03	80.45	1.65
D2	467	103	85	210	110.36	80.45	0.96
D3	453	103	85	225	120.50	80.45	0.58
D4	438	103	85	225	130.49	80.45	0.37
D5	422.5	103	85	230	140.07	80.45	0.25
D6	405	103	85	250	150.16	80.45	0.16

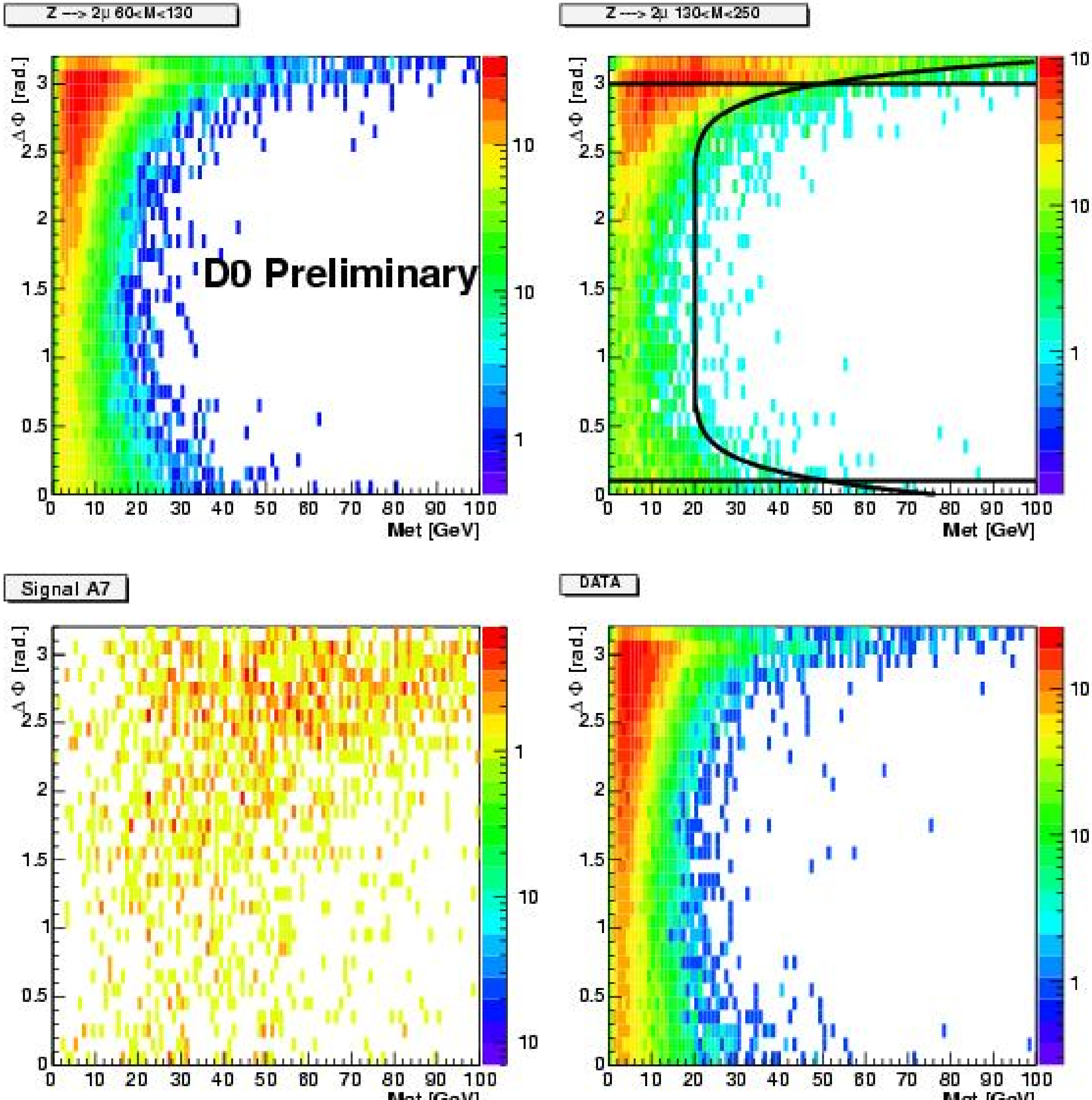
Backgrounds & Signal Pre-selection

Main background sources:

- $Z \to \mu\mu$ / $\tau\tau$
- QCD multijets
- $\Upsilon(1S) \to \mu\mu$
- WW
- tt

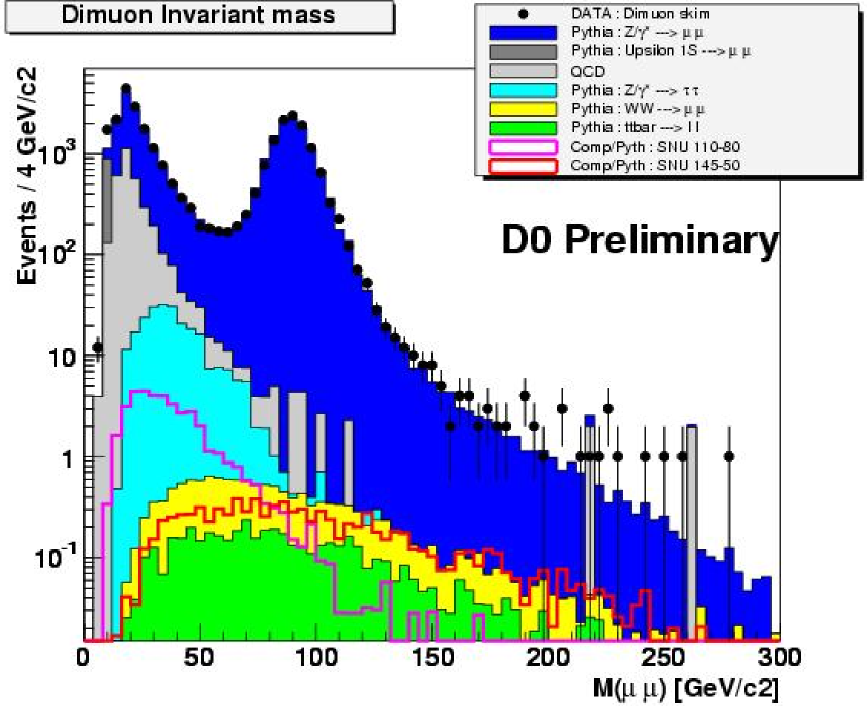
Pre-selection ('Quality') cuts:

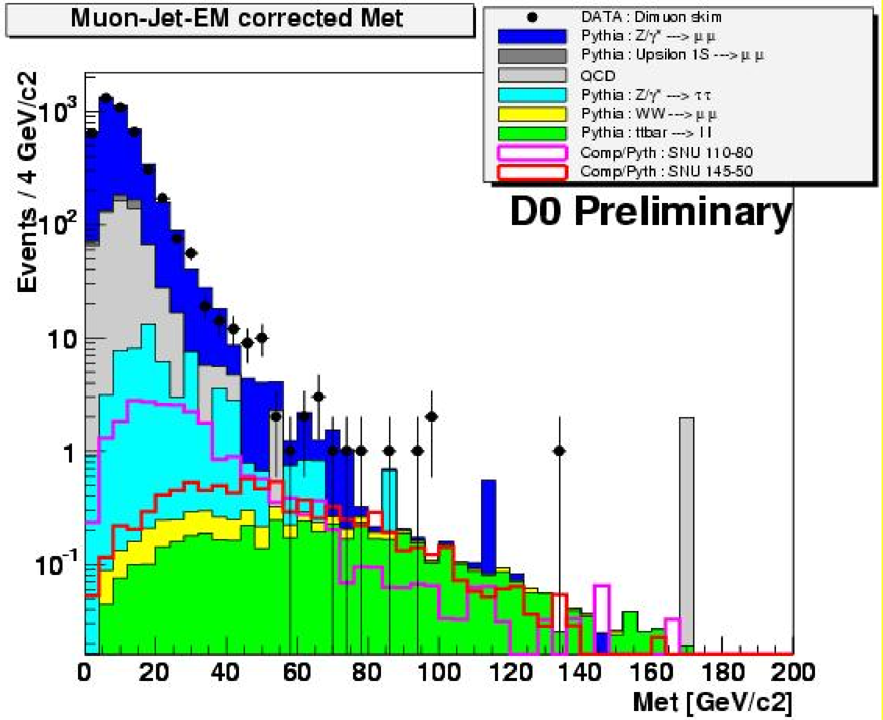
- 2 *isolated* oppositely charged muons
- $p_T(\mu_1) > 8$ GeV/c; $p_T(\mu_2) > 6$ GeV/c → reduces QCD multijets but retains 'soft' signals ($m_{stop} \approx m_{snu}$)
- 0.1 rad $< \Delta\phi(\mu, ME_T) <$ 3 rad → poorly reconstructed muon direction mistaken as ME_T direction

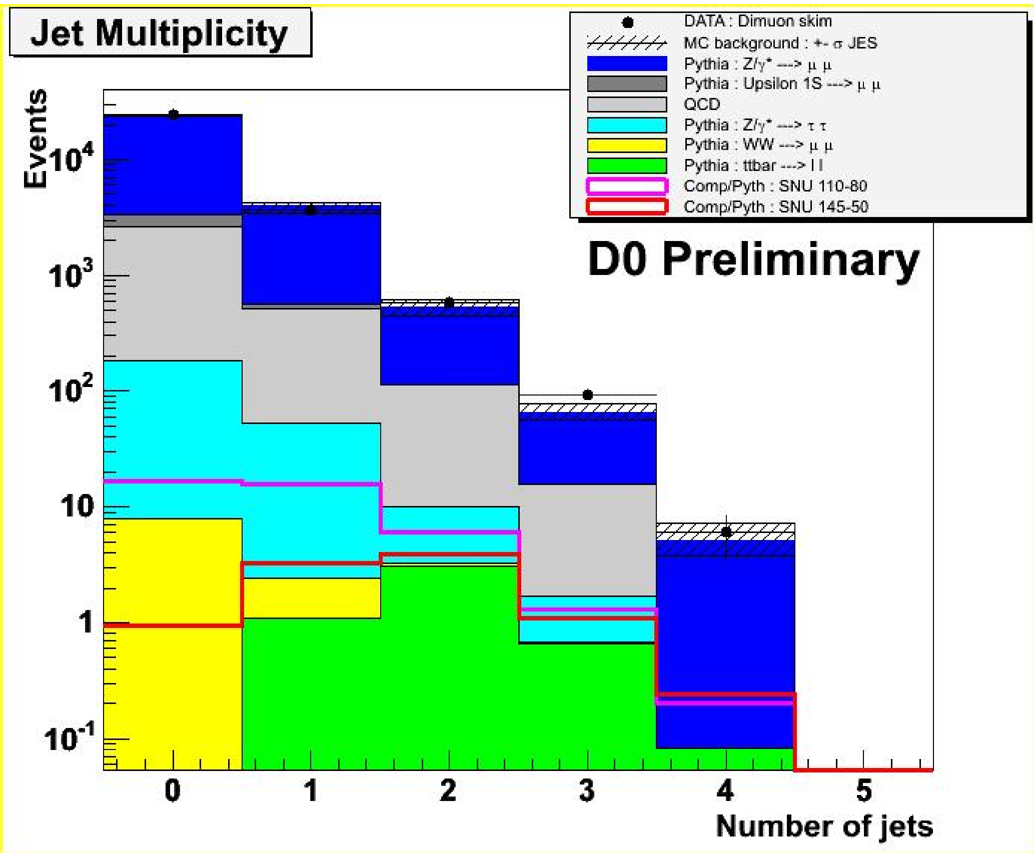

Z ---> 2μ 60<M<130
Z ---> 2μ 130<M<250
D0 Preliminary
Signal A7
DATA
ΔΦ [rad.]
Met [GeV]

Signal selection

Cut1	$N_{jet} \geq 1$ ($p_T > 15$ GeV)
Cut2	$ME_T > 20\text{-}50$ GeV
Cut3	$JLIP_{jet1} < 1\%$ (b-tag)
Cut4	$m_{\mu\mu} \notin [75,120]$ GeV (for $ME_T < 50$ GeV)







Results

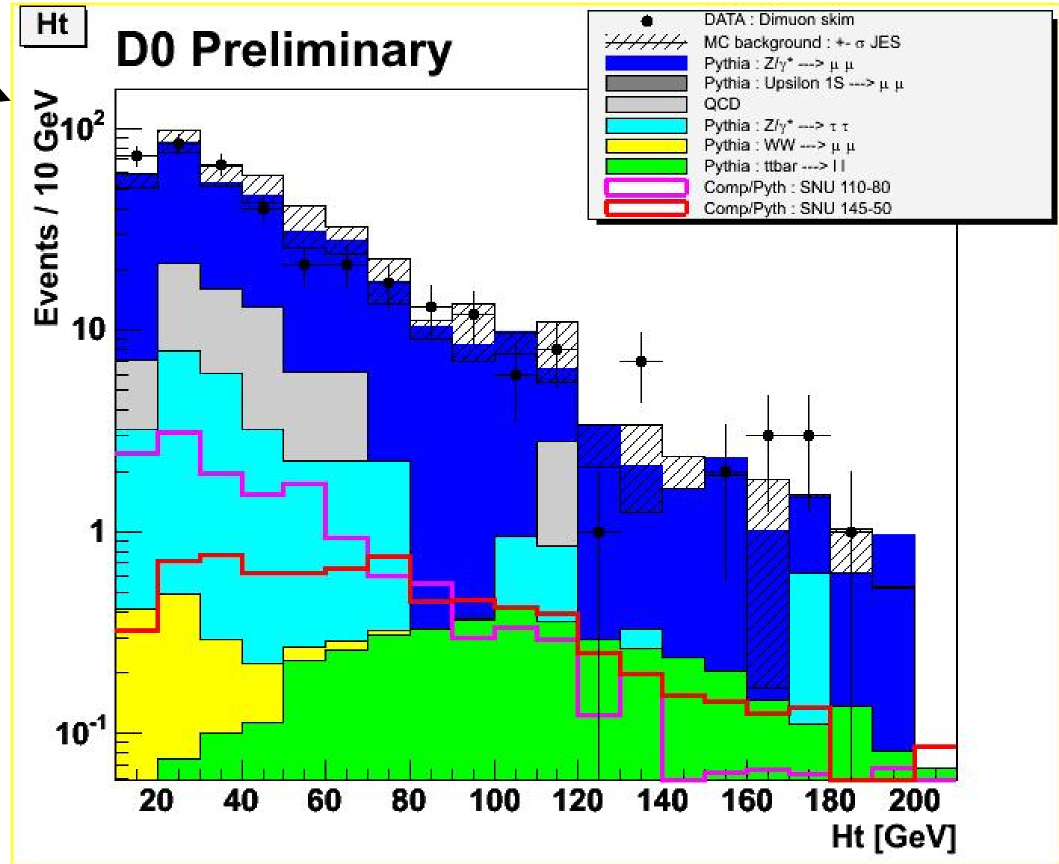
TABLE II: Expected number of events in various background and signal channels, and number of observed events in data, at various levels of the analysis. "QC" refers to the quality cuts mentioned in Sec. III. The two last columns represent the signal points D2 ($M(\tilde{t}_1) = 110$ GeV$/c^2$,$M(\tilde{\nu}) = 80$ GeV$/c^2$) and A7 ($M(\tilde{t}_1) = 145$ GeV$/c^2$,$M(\tilde{\nu}) = 50$ GeV$/c^2$). The uncertainties are statistic and JES systematics for the total predicted background and signal events.

Cut	$\Upsilon(1S)$	QCD	$Z \to \mu^+\mu^-$	$Z \to \tau^+\tau^-$	WW	$t\bar{t}$	Background	Data	$A7$	$D2$
QC	788	3053	23549	233	9.6	5.1	27637 ± 348	28733	9.8	41.1
Cut 1	61	577	3836	59	1.5	5.1	$4539 \pm 97^{+452}_{-883}$	4337	$8.81^{+0.11}_{-0.10}$	$24.14^{+1.46}_{-1.90}$
Cut 2	0	35	136	20	1.1	4.7	$197 \pm 8^{+82}_{-22}$	213	$7.49^{+0.17}_{-0.12}$	$12.92^{+1.21}_{-1.28}$
Cut 3	0	0	5.7	0.44	0.03	2.6	$8.7 \pm 1.6^{+1.3}_{-0.1}$	4	$3.49^{+0.21}$	$3.37^{+0.37}_{-0.27}$
Cut 4	0	0	0.10	0.44	0.03	2.3	$2.88 \pm 0.43^{+0.10}_{-0.04}$	1	$3.06^{+0.15}$	$3.30^{+0.35}_{-0.27}$

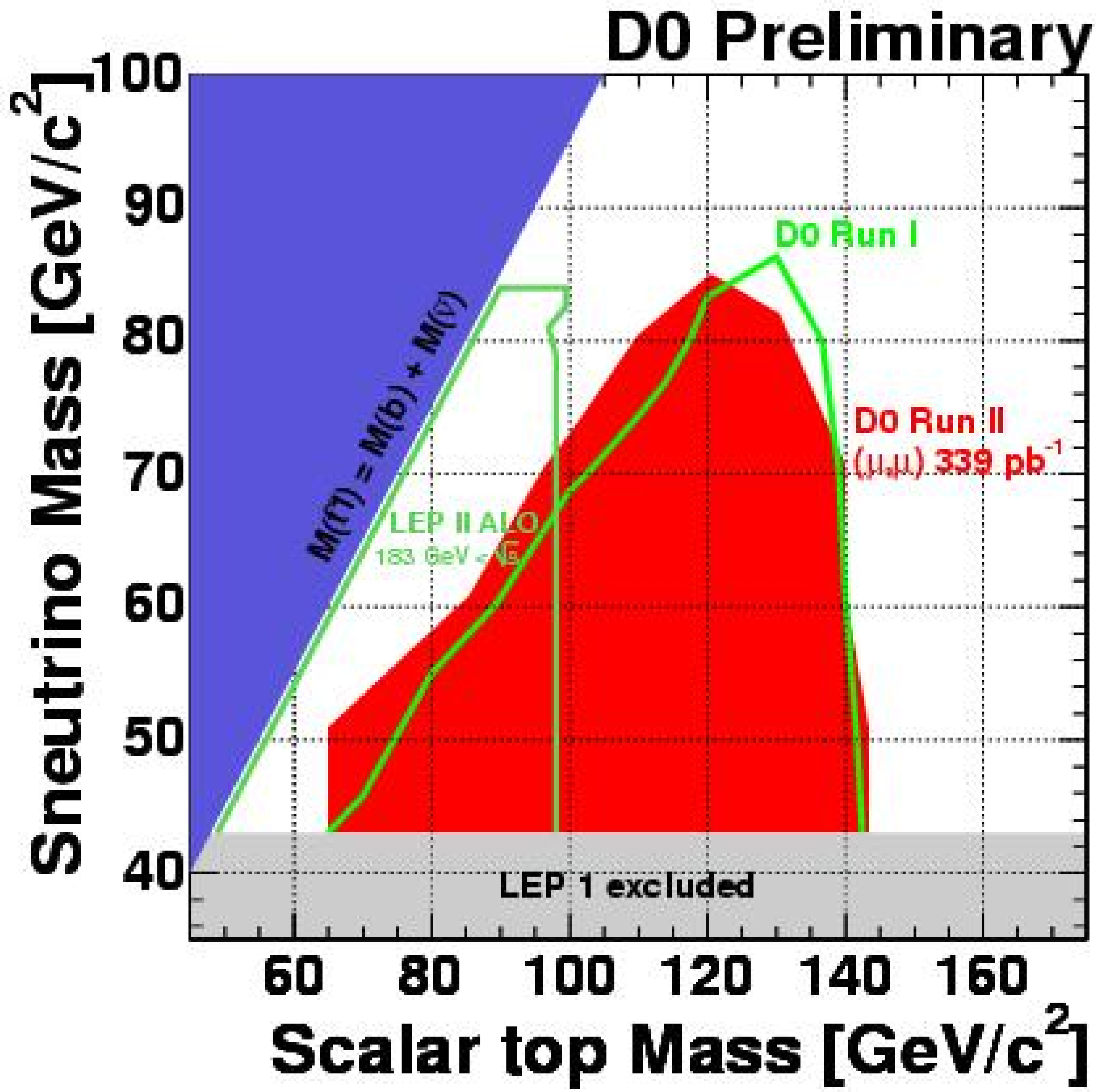
QC & ME_T > 20 GeV

$H_t = \Sigma_{jets} |\mathbf{p}_t|$

H_t bin (GeV)	Background	Data
0-40	0.11 ± 0.03	0
40-80	0.89 ± 0.43	0
80-120	0.75 ± 0.11	0
120-160	0.56 ± 0.07	1
> 160	0.57 ± 0.08	0



95% CL limits obtained using a *modified frequentist* (CL_S) approach

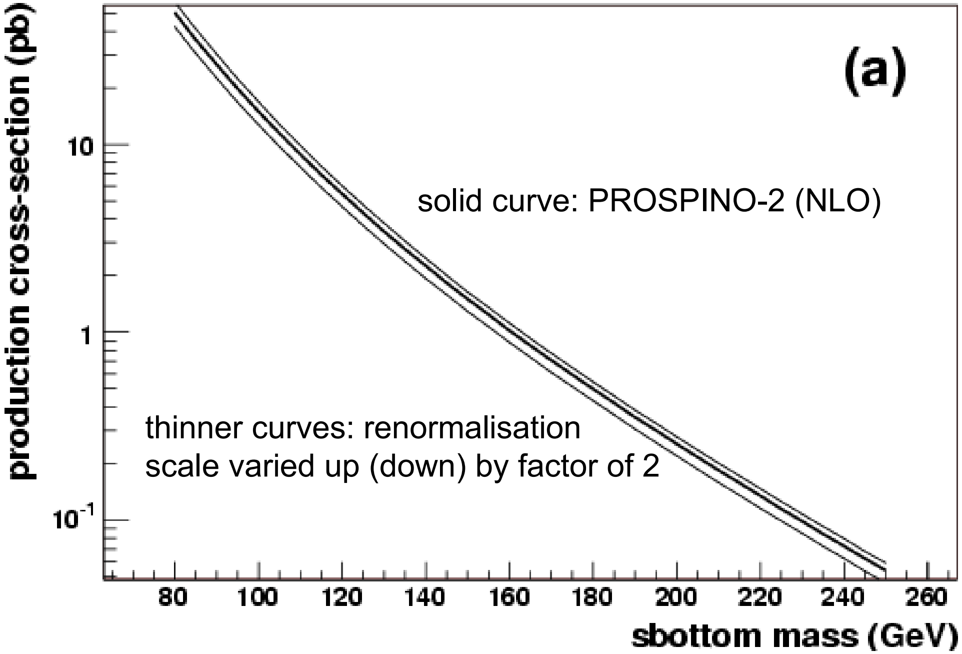


n.b. D0 Run I result based on e+μ channel

main systematics:

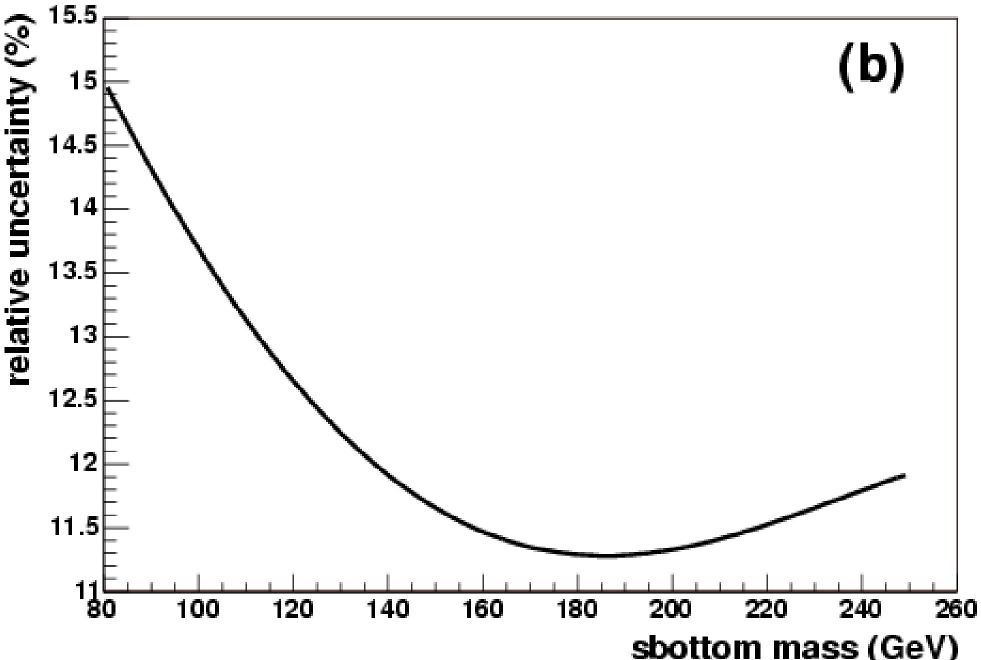
- Jet Energy Scale (4-22%)
- b-tagging (0-10%)
- muon id (3-7%)
- luminosity (6.5%)

Simulation of Sbottom Signal & NLO cross-section



- MSSM framework
- PYTHIA 6.202 / CTEQ5L pdf
- only vary masses of scalar b_1 and χ_1^0
- < min bias overlay > = 0.8 events

NLO cross-section derived from PROSPINO-2 (sbottom and stop have same production cross-section)



For m_{b1} ~ 100 GeV, $<ME_T>$ & $<\text{jet } p_T>$ are similar for signal & background, but at high b_1 mass (and large b_1-χ_1^0 mass difference) they are much higher for signal events

⇒*optimization* of selections cuts for high b_1 mass (& high mass difference)

-low b_1 mass suffers from SM background
-high b_1 mass suffers from low x-section

Standard Model Backgrounds

W/Z + jets, dibosons & top pairs

TABLE I: Standard-model (SM) processes, number of events generated, LO cross sections in pb from the generator, K-factors and NLO cross sections in pb (from Ref. [8], except for $t\bar{t}$ which is computed using the NLO cross section from Ref. [9]).

SM process	# evts	σ(LO)	K-factor	σ(NLO)
$W(e\nu)+jj$	53500	225	1.28	288
$W(\mu\nu)+jj$	51750	225	1.28	288
$W(\tau\nu)+j$	97750	714	1.18	840
$Z(\tau\tau)+j$	96500	70	1.17	81
$Z(\nu\nu)+jj$	33500	133	1.31	174
$W(\tau\nu)+b\bar{b}$	27250	2.1	2	4.2
$Z(\nu\nu)+b\bar{b}$	98000	1.4	2.3	3.3
$t\bar{t}\to bbl\nu jj$	191300			2.98
$t\bar{t}\to b\bar{b}l\nu l\nu$	57500			0.74
WW inclusive	50000	8.6	1.31	11.3
WZ inclusive	53000	2.6	1.35	3.5
ZZ inclusive	53500	1.2	1.28	1.5
$WZ\to e\nu b\bar{b}$	73000	0.043	1.35	0.058
$WZ\to\mu\nu b\bar{b}$	39500	0.043	1.35	0.058
$ZZ\to\nu\nu b\bar{b}$	52024	0.064	1.28	0.082

ALPGEN interfaced to PYTHIA/CTEQ5L
K-factors for W/Z+jets from MCFM
uncertainty on NLO SM σ = 15%

Event Selection

C1-12	reduce instrumental & QCD multi-jets background
C4-5	reduce SM backgrounds
C13-15	reduce SM backgrounds (isolated e, μ & τ)
C16	reduce top pair background

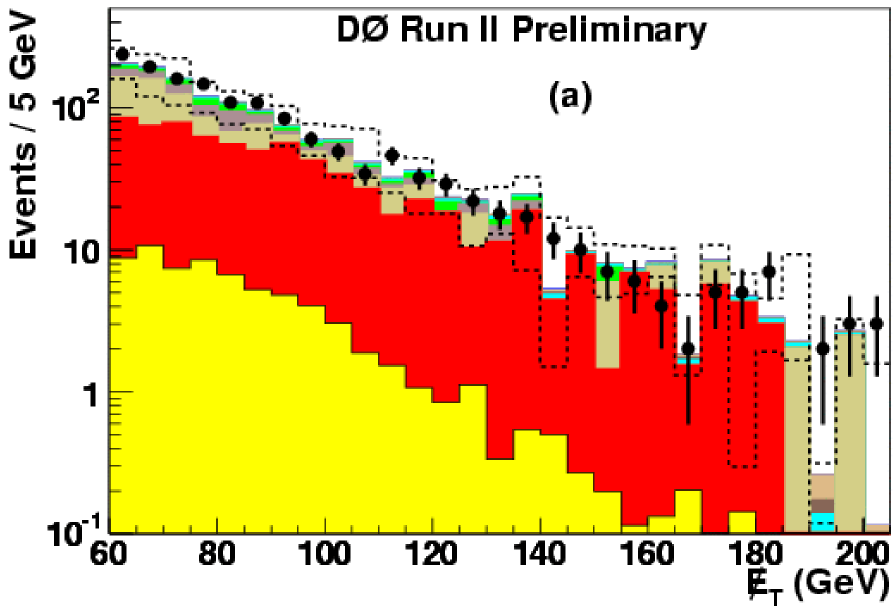
no jet b-tagging at this stage

mb_1 = 140, $m\chi$ = 80 GeV

TABLE II: Sequence of criteria applied for the selection, with the corresponding remaining events, together with the signal efficiency, for a signal corresponding to ($m_{\tilde{b}}$,$m_{\tilde{\chi}_1^0}$) = (140,80).

		events remaining			
	Criterion	Data	SM (no QCD)	Signal	ϵ_{Signal}
Preselection:		827517	61100 ± 350	362 ± 6	59%
C1 :	$\not{E}_T > 60$ GeV	154452	16300 ± 170	204 ± 4	33%
C2 :	Vertex $\|z\| < 60$ cm	126974	16020 ± 170	201 ± 4	33%
C3 :	*Acoplanarity* $< 165°$	82693	15160 ± 160	189 ± 4	31%
C4 :	1st leading jet $p_T > 40$ GeV	80196	13190 ± 150	178 ± 4	29%
C5 :	2nd leading jet $p_T > 15$ GeV	70893	11870 ± 140	168 ± 4	27%
C6 :	$\|\eta^{det}_{jet1}\| < 0.9$	45174	7200 ± 110	132 ± 3	21%
C7_8 :	jet1,2 CPF> 0.05	23994	6250 ± 100	125 ± 3	20%
C9_10 :	jet1,2 EMF< 0.95	22254	5170 ± 90	124 ± 3	20%
C11 :	Bad jet veto ($p_T > 15$ GeV)	9672	5070 ± 90	123 ± 3	20%
C12 :	$\Delta_{min}(\not{E}_T, any\ good\ jet) > 35°$	5151	4270 ± 85	105 ± 3	17%
C13 :	Isolated EM veto $p_T > 5$ GeV	4355	3660 ± 80	104 ± 3	17%
C14 :	Isolated muon veto $p_T > 5$ GeV	3745	3110 ± 75	103 ± 3	17%
C15 :	Isolated track veto $p_T > 5$ GeV	1642	1480 ± 50	78 ± 2	13%
C16 :	$Nj = 2, 3$	1433	1335 ± 48	69 ± 2	11%

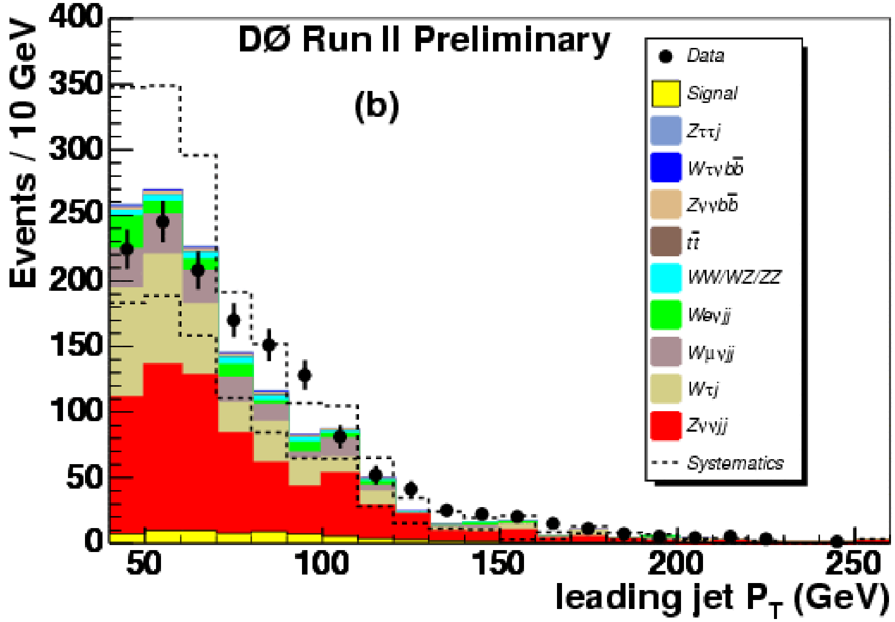
Event Selection

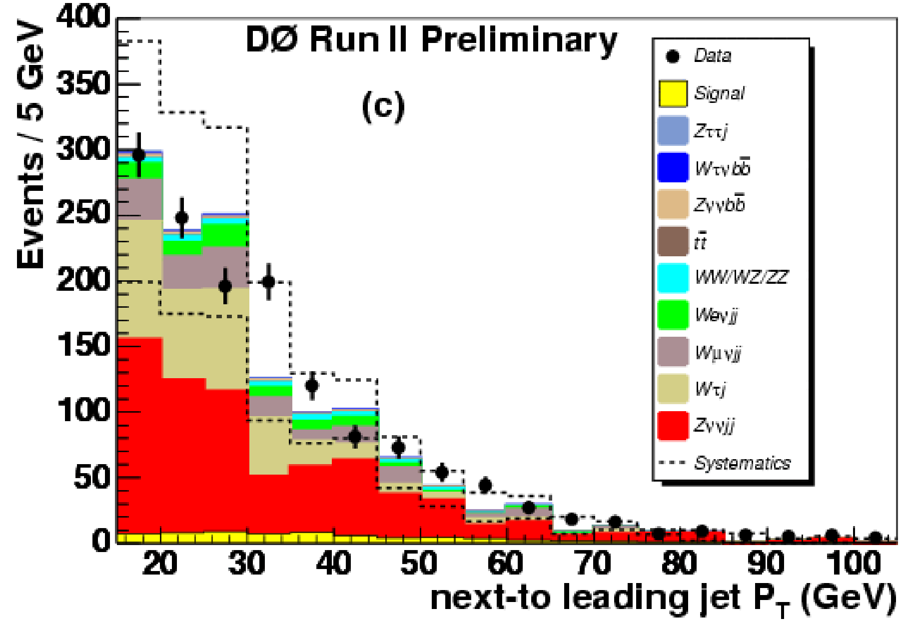


--- correlated systematic uncertainties (~ ±20%)

signal << background

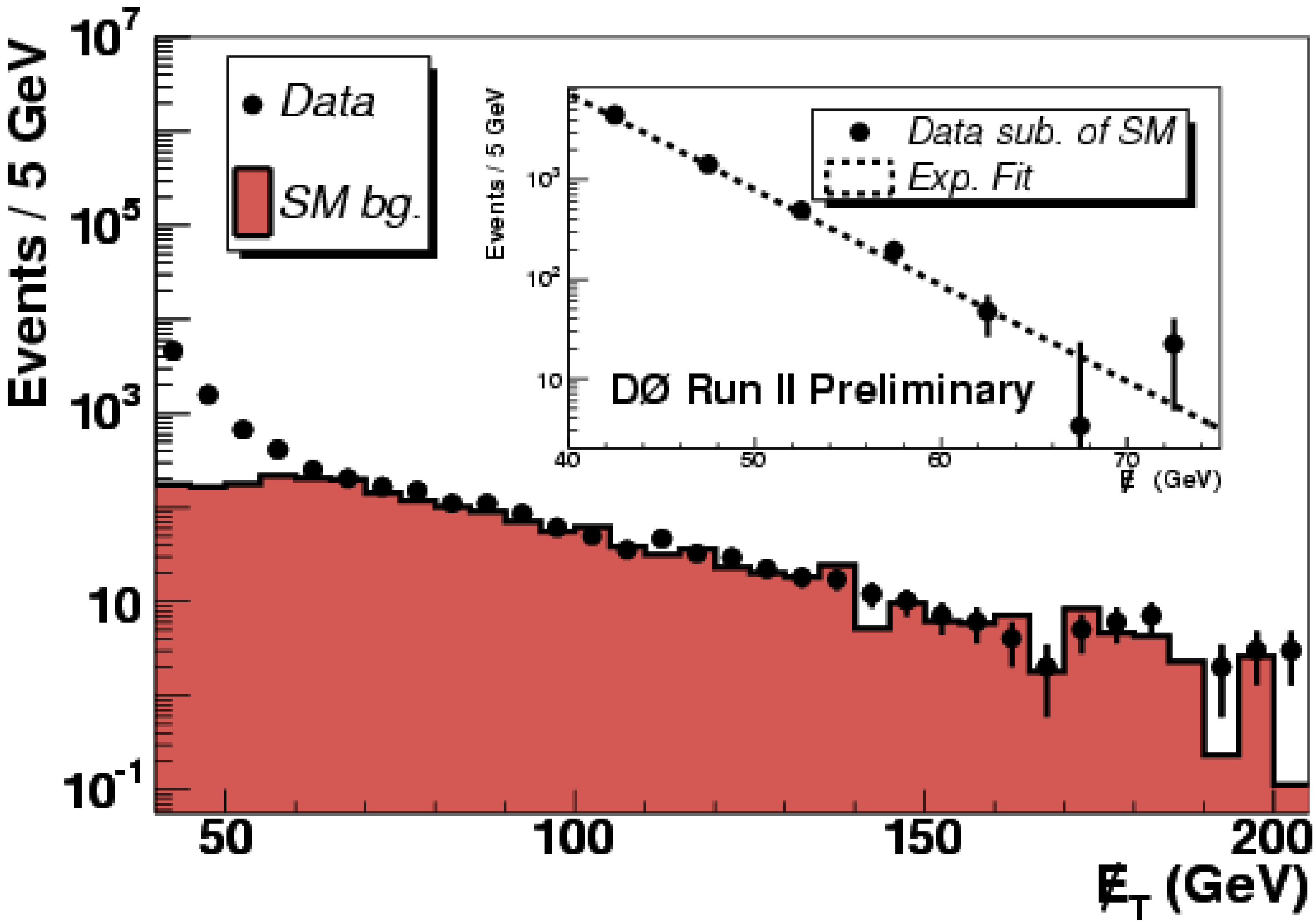
no jet b-tagging at this stage



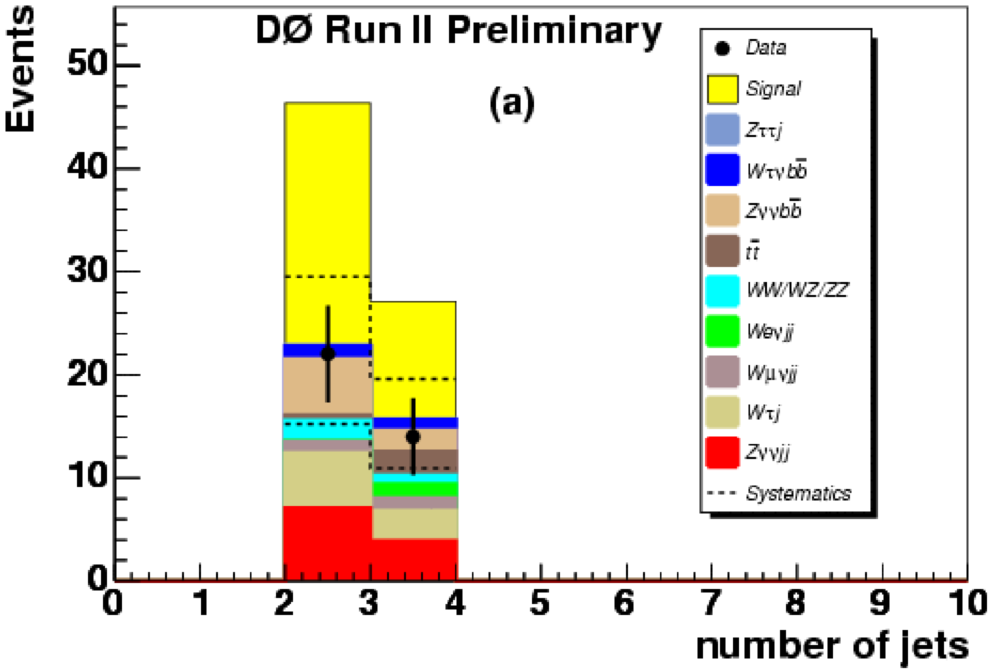


QCD Background

Remove cut on ME_T (C1) and attribute excess at low ME_T to QCD
Extrapolate low ME_T fit to ME_T > 60 GeV region: ~ 80 events
=> After b-tagging QCD background is small (& conservatively neglected)



jet b-tagging



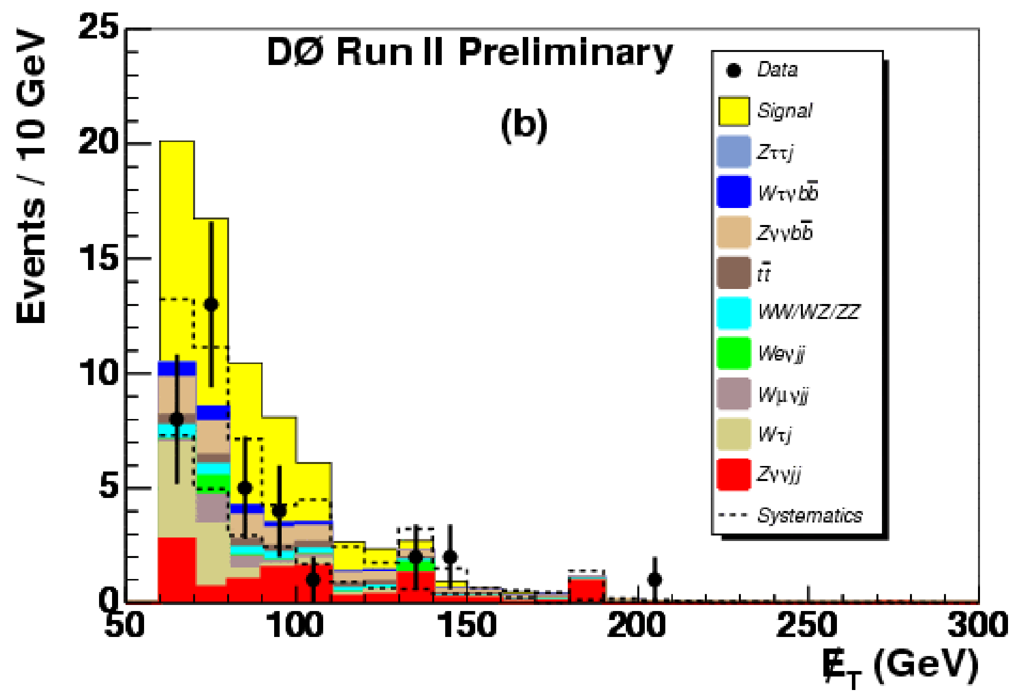
require ≥ 1 JLIP b-tag per event

- use JLIP certified working point with smallest mistag rate (~0.1% for jets with E_T < 95 GeV)

mb1 = 140, mχ = 80 GeV

expected signal ≈ SM background

no excess of events after all cuts



Optimization for higher sbottom masses

$M(\tilde{b})$	Low val.	Med.val.	High val.
$E_T(j1,j2)$ (GeV)	>(40,15)	>(40,15)	>(70,40)
E_T^{miss} (GeV)	>60	>80	>100
Data	36	15	2
SM exp.	38.6±2.8	19.6±1.7	4.4±0.4

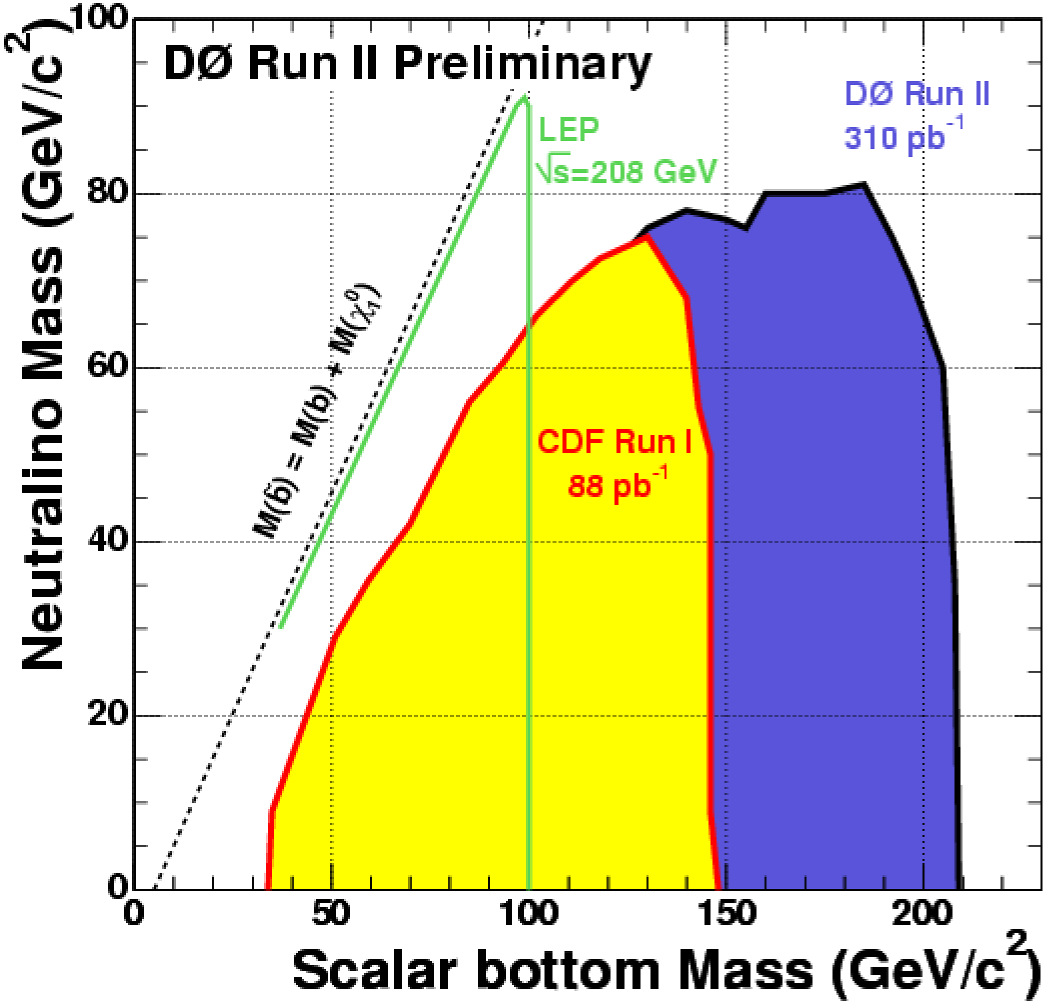
no excess observed in data relative to SM expectations

Main Systematics: NLO Signal & SM background cross-sections (11-15%)
Jet Energy Scale corrections (12-22%)
b-tagging efficiency (7-8%)
luminosity (6.5%)

Overall ~ ± 30% → *this can be reduced, leading to a substantial improvement in the search sensitivity in the future …*

95% CL limits obtained using a *modified frequentist* (CL_S) approach

- correlations among systematic uncertainties included



Future improvements: double b-tag, better Jet Energy Scale & optimization of ME_T & jet-p_T cut-offs

Summary

- Run II Tevatron data providing enhanced sensitivity to SUSY parameters
- These two searches are the first of their kind performed with Run II data
- Improvement in D0 *stop* exclusion, despite large background, especially for *small stop-snu mass difference*

– limits will significantly improve with inclusion of **e** - μ channel
- Substantial improvement in D0 *sbottom* exclusion
- Current D0 dataset ~ 3 x samples used → greater sensitivity in near future