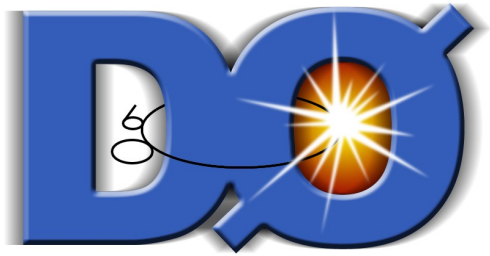
Search for New Phenomena at the DØ Experiment

Carsten Noeding
University of Freiburg
on behalf of the DØ Collaboration

Lake Louise Winter Institute 2006



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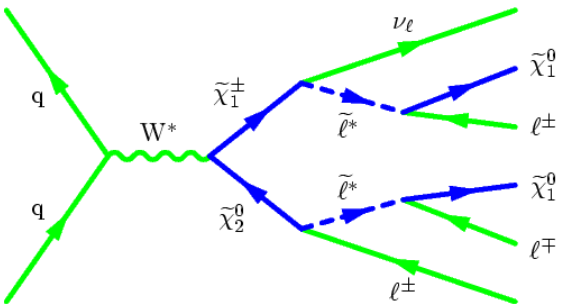
Outline/Motivation

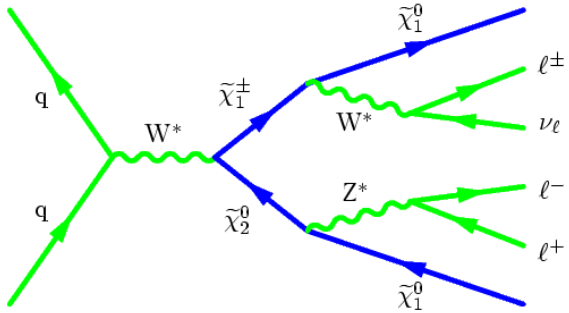
- Reasons for extending the Standard Model:
  - Gravity? Hierarchy problem? Unification of coupling constants?
- Consider Standard Model as a low-energy approximation of a more fundamental theory:
  - Superysmmetry
    ⇨ symmetry between bosons and fermions: each Standard Model particle has supersymmetric partner that differs by ½ in spin
    ⇨ new quantum number: $R=(1)^{3B+L+2S}$ (B/L: baryon/lepton number; S: Spin)
    - Search for Associated Chargino/Neutralino Production in Final States with Three Leptons
    - Search for Squarks and Gluinos in Jets+MET Topology
    - Search for Direct Production of Scalar Top/Bottom Quarks
    - Search for Charged Massive Scalar Particles
    - Search for Neutral Long-Lived Particles
  - Leptoquarks
    ⇨ colored bosons which carry both lepton and quark quantum numbers, motivated by the symmetry between quark and lepton generations
    - Search for 1st and 2nd Generation Leptoquarks
  - Large Extra Dimensions
  - Technicolor
- Only a small subset of DØ results are presented; more at:
  - http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm

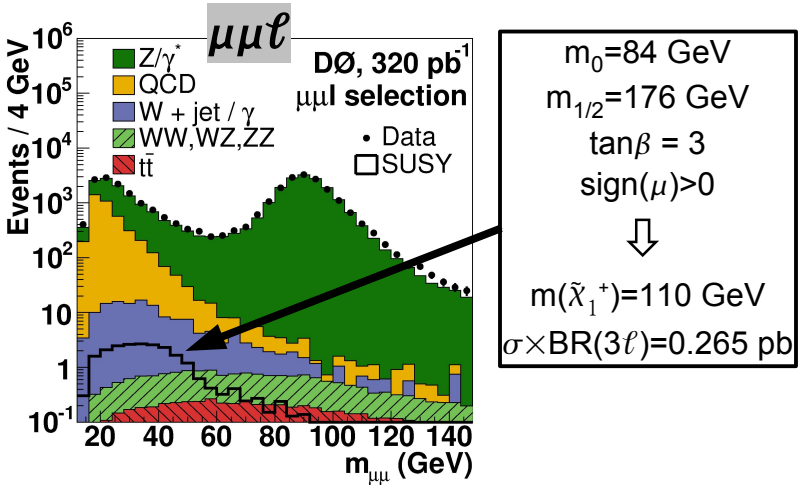
Search for Associated Chargino/Neutralino Production

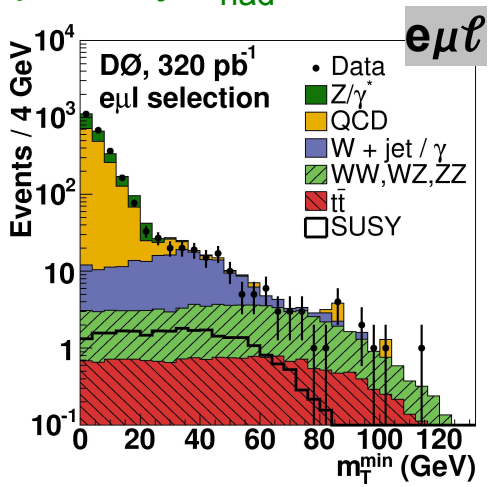
- Final state: 3 leptons + MET
  - "Golden Channel" for SUSY discovery at the TeVatron
    - Background from Standard Model processes is small
    - But: σ × BR(3 leptons) ~ 0.5 pb
    - R parity is conserved ⇒ $\tilde{\chi}_1^0$ is stable + escapes detection
- Combine different analysis channels:
  - eeℓ, $\mu\mu\ell$, e$\mu\ell$, like-sign $\mu\mu$
- Event selection ($\mathscr{L}$=320 pb^{-1}):
  - Identify 2 leading leptons
  - Require large MET>22 GeV
  - Mass selection: Z-veto
  - 3rd isolated track: covers e, μ and partially τ_{had}

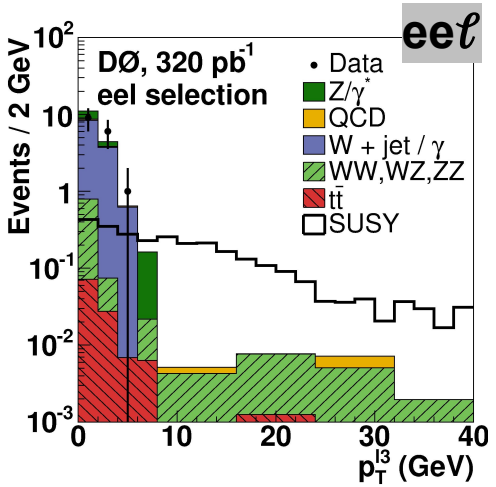


(destructive t-channel interference not shown)





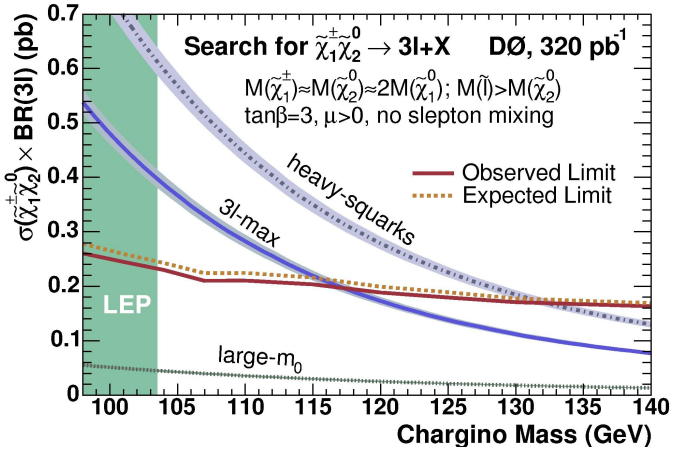


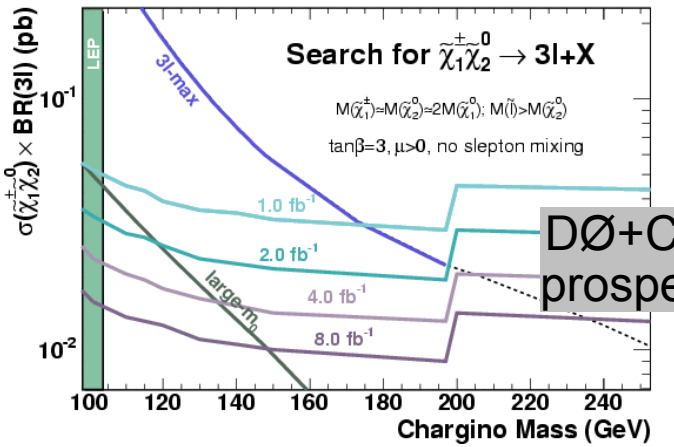


Search for Associated Chargino/Neutralino Production

- No excess found
  ⇒ calculate cross section limit at 95% CL
- Assume mSUGRA mass relation:
  $M(\tilde{\chi}_1^{\pm}) \approx M(\tilde{\chi}_2^0) \approx 2M(\tilde{\chi}_1^0)$
  - nearly model independent cross section limits
- "3l-max" ⇒ $M(\tilde{\chi}_1^{\pm}) > 117$ GeV
  - maximal leptonic BR
  - no slepton mixing assumed
  - $M(\text{slepton}) \approx M(\tilde{\chi}_2^0)$
- "large-m_0" ⇒ no sensitivity
  - small leptonic BR
  - $\tilde{\chi}_2^0$ decay mainly via W*/Z*
- "heavy squarks" ⇒ $M(\tilde{\chi}_1^{\pm}) > 132$ GeV
  - enhanced σ due to relaxed mass unification and suppressed t-channel interference
- Sensitivity extends LEP limits: $M(\tilde{\chi}_1^{\pm}) > 103$ GeV
- Published: PRL 95, 151805 (2005)
- Preliminary tau analyses (e+τ_h+ℓ and μ+τ_h+ℓ) improve cross section limit by 10%

	N_{DATA}	N_{BGND}	Signal
e+e+ℓ	0	0.21 ± 0.11 ± 0.05	1.87 ± 0.16
e+μ+ℓ	0	0.31 ± 0.13 ± 0.03	1.21 ± 0.14
μ+μ+ℓ	2	1.75 ± 0.34 ± 0.46	1.63 ± 0.14
like-sign μ+μ	1	0.64 ± 0.37 ± 0.10	0.62 ± 0.13
Total	**3**	**2.93 ± 0.54 ± 0.64**	**5.33 ± 0.16**



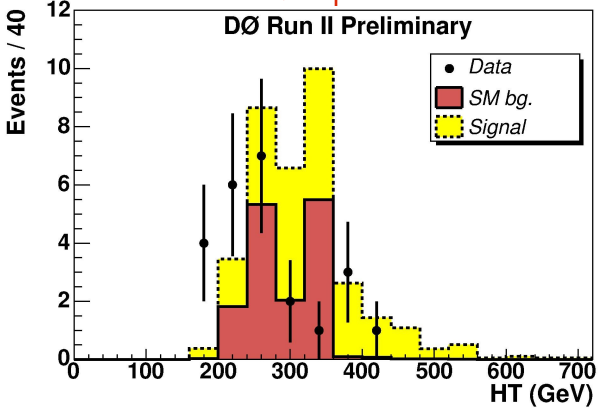


DØ+CDF prospects

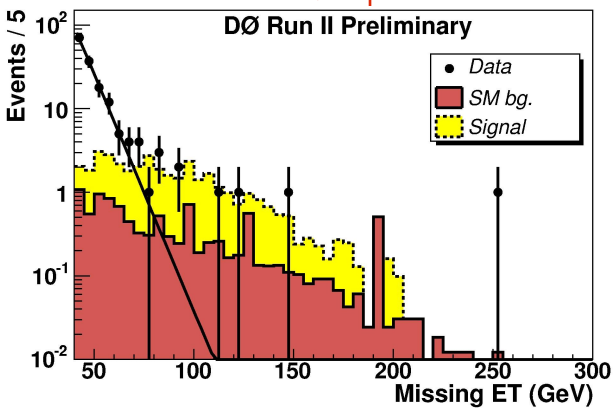
Search for Squarks and Gluinos in Jets + MET Topology

- Large production cross section for squarks and gluinos at hadron colliders
- Three different parameter regions (tanβ=3, A_0=0, μ<0):
  - low $m_0 \Rightarrow m_{squark} < m_{gluino}$: "dijet" $\quad \tilde{q}\bar{\tilde{q}} \rightarrow q\tilde{\chi}^0 + \bar{q}\tilde{\chi}^0$
    - m_0=25 GeV, 100 GeV<$m_{1/2}$<160 GeV
  - high $m_0 \Rightarrow m_{squark} > m_{gluino}$: "gluino" $\quad \tilde{g}\,\tilde{g} \rightarrow q\bar{q}\tilde{\chi}^0 + q\bar{q}\tilde{\chi}^0$
    - m_0=500 GeV, 65 GeV<$m_{1/2}$<90 GeV
  - intermediate region: "3 jets" $\quad \tilde{q}\,\tilde{g} \rightarrow q\tilde{\chi}^0 + q\bar{q}\tilde{\chi}^0$
    - 290 GeV<$M_{\tilde{q}}=M_{\tilde{g}}$<340 GeV

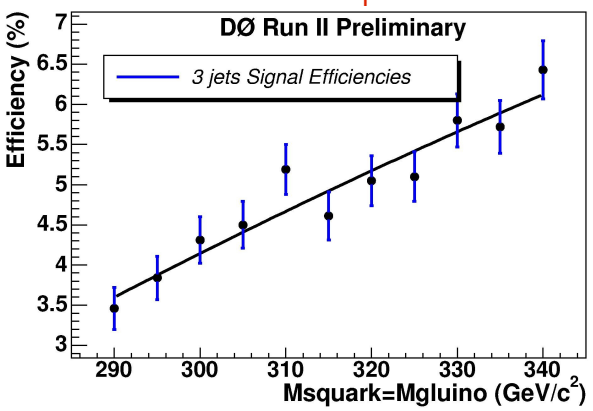
"dijet" event selection
- $p_T(j_1/j_2)$>60/50 GeV
- Veto on isolated e/μ
- $\Delta\phi$(MET,j_i/j_2)>30°/50°
- MET>175 GeV, H_T>250 GeV



"gluino" event selection
- ≥4 jets with p_T>60/40/30/20 GeV
- Veto on isolated e/μ
- $\Delta\phi$(MET,j_1/j_2)>90°/50°
- MET>75 GeV, H_T>250 GeV



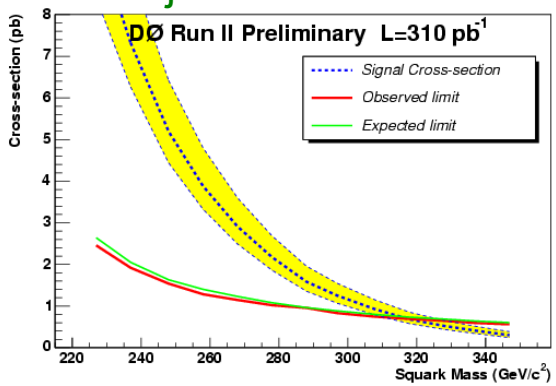
"3 jets" event selection
- ≥3 jets with p_T>60/50/25 GeV
- Veto on isolated e/μ
- $\Delta\phi$(MET,j_1/j_2)>90°/50°
- MET>100 GeV, H_T>325 GeV



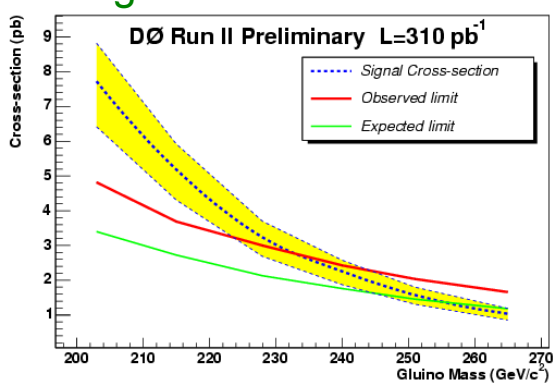
Search for Squarks and Gluinos in Jets + MET Topology

- Results ($\tan\beta$=3, A_0=0, μ<0):

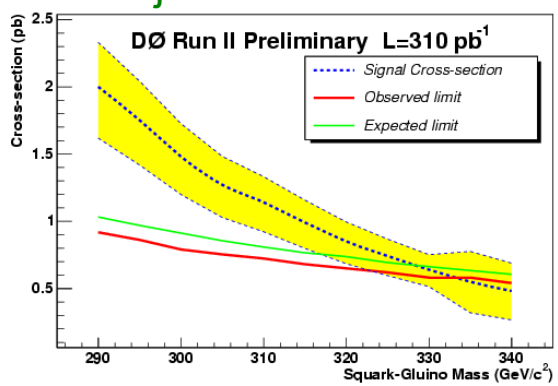
"dijet": Limit on σ^{Prod}



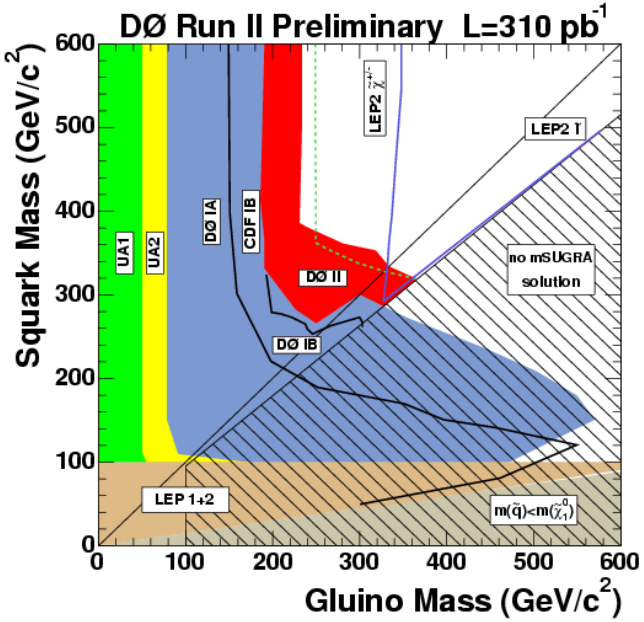
"gluino": Limit on σ^{Prod}

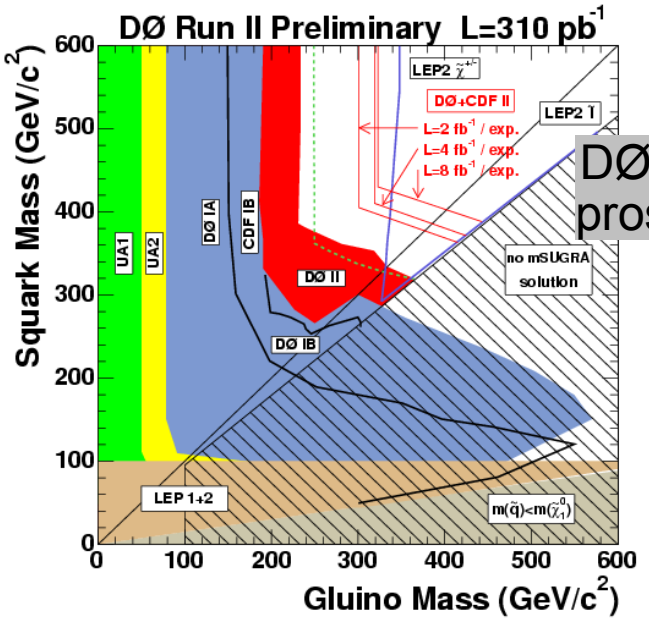


"3 jets": Limit on σ^{Prod}



$M(\tilde{q})>318$ GeV (m_0=25 GeV) $M(\tilde{g})>233$ GeV (m_0=500 GeV) $M(\tilde{q},\tilde{g})>333$ GeV for $M_{\tilde{q}}=M_{\tilde{g}}$

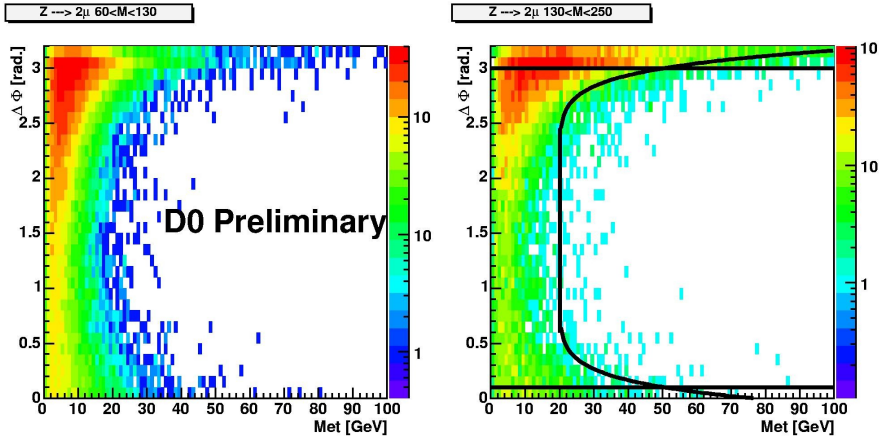


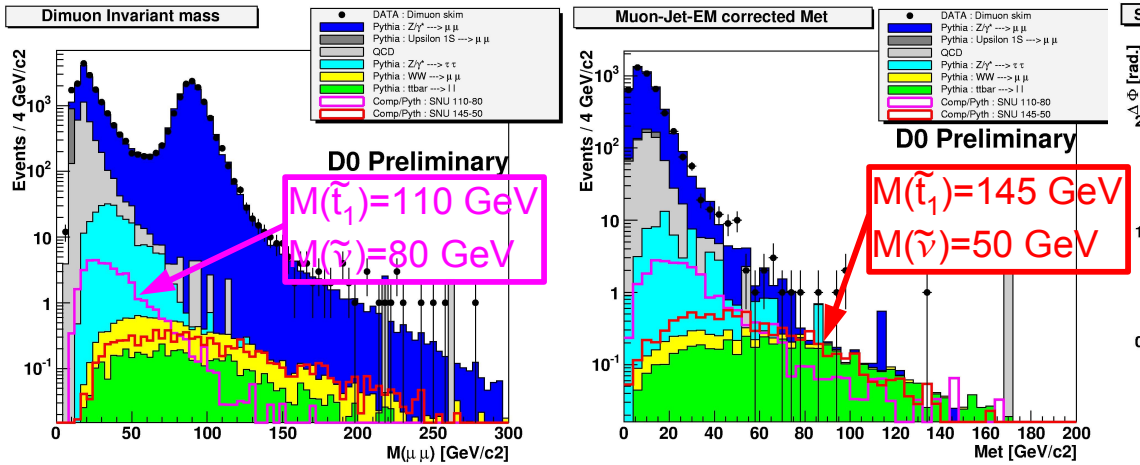


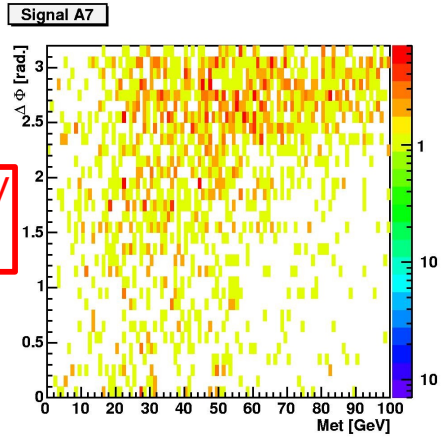
DØ+CDF prospects

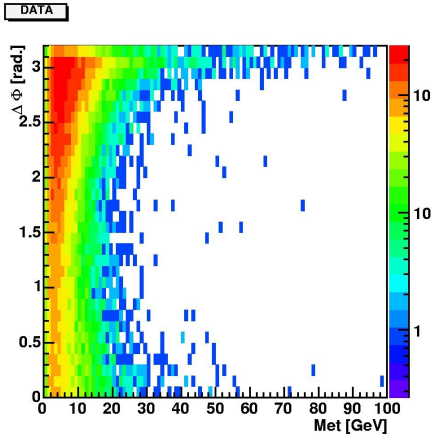
Search for Direct Production of Scalar Top Quarks

- Squark mixing ~ m_q ⇒ stop might be the lightest squark
- Pair production of lightest stop quark with subsequent three body decays via virtual charginos into $bW\tilde{\chi}_1^0$ and/or $b\ell\tilde{\nu}$:
  - decay via $\tilde{\nu}$ dominant if $m_{\tilde{\nu}}<m_W$
- Process: $\tilde{t}_1\bar{\tilde{t}}_1 \to b\bar{b}\mu\mu\nu\bar{\nu}\tilde{\chi}_1^0\tilde{\chi}_1^0$
- Event selection ($\mathscr{L}$=339 pb^{-1}):
  - 2 opposite sign μ
  - ≥1 jet; 1 jet with b-tag
  - Require significant MET
    - Anti $Z\to\mu\mu$
    - $\Delta\phi$(leading μ,MET)





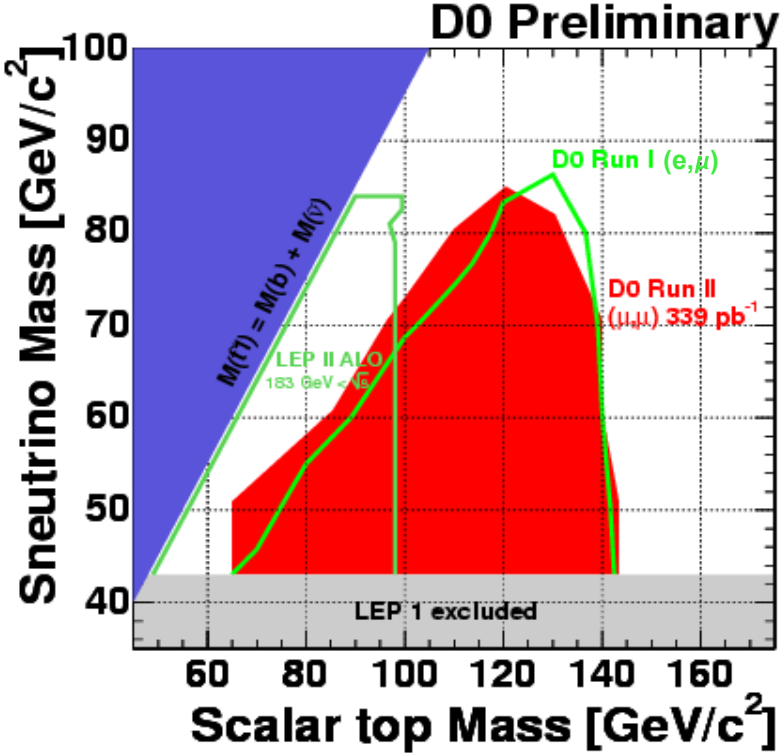


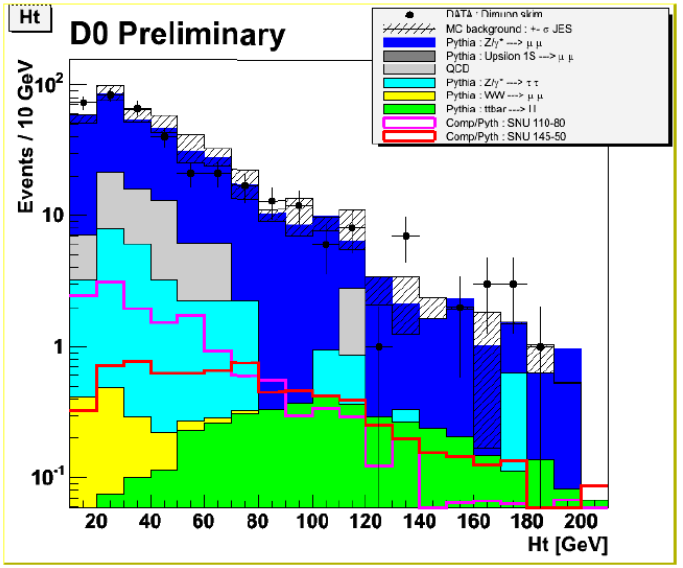


Search for Direction Production of Scalar Top Quarks

- After application of all selection criteria:
  - Data and Monte Carlo are in agreement
  - Main background stems from $t\bar{t}$
    - Divide scalar sum of all jets (H_T) in different bins and calculate cross section limit at 95% CL

H_T Bin	N_{BGND}	N_{DATA}
[0,40] GeV	0.11 ± 0.03	0
[40,80] GeV	0.89 ± 0.44	0
[80,120] GeV	0.75 ± 0.13	0
[120,160] GeV	0.56 ± 0.06	1
>160 GeV	0.57 ± 0.08	0





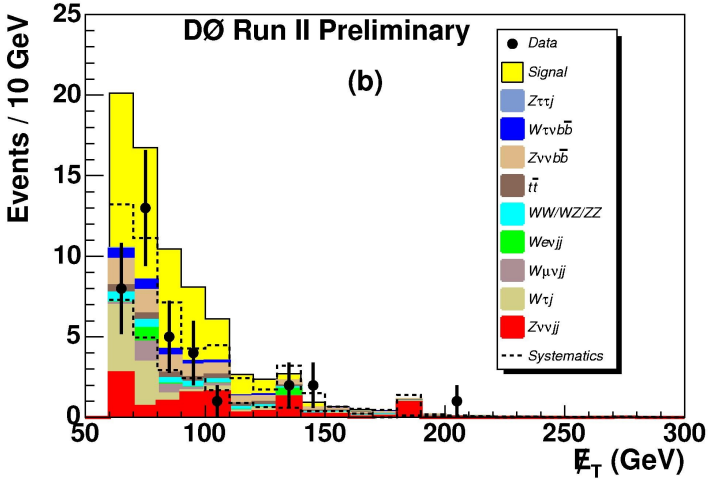
- e+e and e+μ final states are in progress

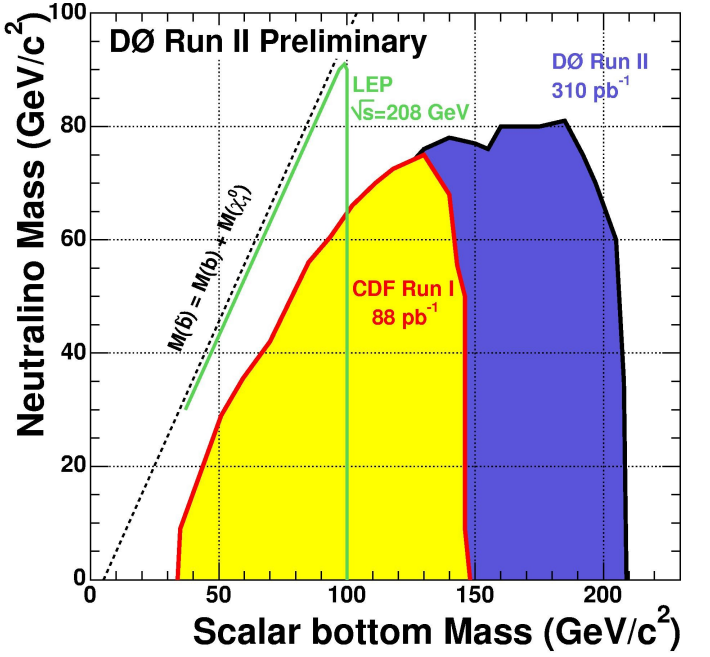
Search for Direct Production of Scalar Bottom Quarks

- Process: $\tilde{b}\bar{\tilde{b}} \rightarrow b\tilde{\chi}_1^0 + b\tilde{\chi}_1^0$
  - Two acoplanar b jets
  - Significant MET from LSP
- Event selection ($\mathscr{L}$=310 pb^{-1}):
  - 2 jets; 1 jet with b-tag
  - Acoplanarity < 165°
  - $\Delta\phi$(MET,any good jet) > 35°
  - Mass dependent cuts for ($m_{sbottom}$,$m_{neutralino}$) = (140,80) GeV, (160,75) GeV, (205,60) GeV
    - MET > 60/80/100 GeV
    - $p_T(j_1)$ > 40/40/70 GeV
    - $p_T(j_2)$ > 15/15/40 GeV
- Results:

	(140,80) GeV	(160,75) GeV	(205,60) GeV
N_{DATA}	36	15	2
N_{BGND}	38.6 ± 2.8	19.6 ± 1.7	4.40 ± 0.44
Signal	35.0 ± 1.2	21.6 ± 0.7	6.10 ± 0.17

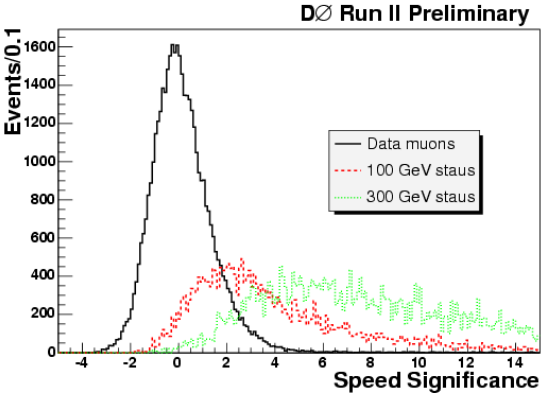
⇒ No excess in data, calculate limit at 95% CL

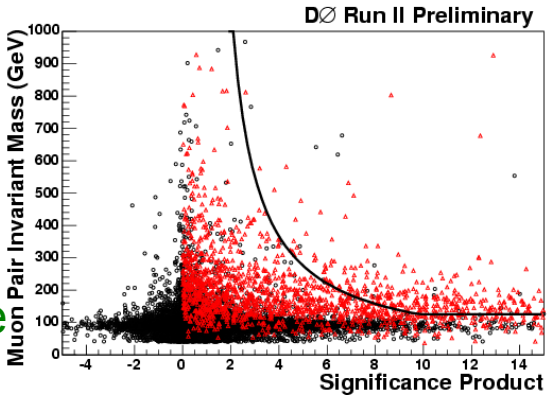


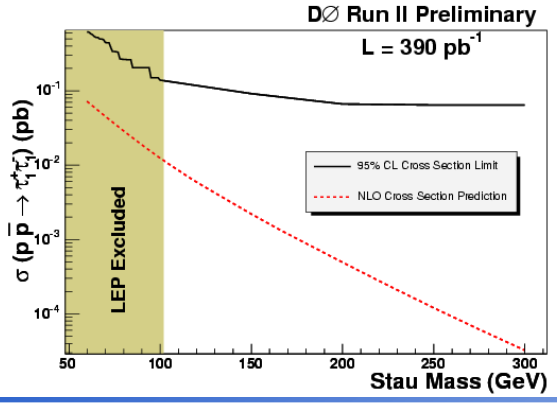


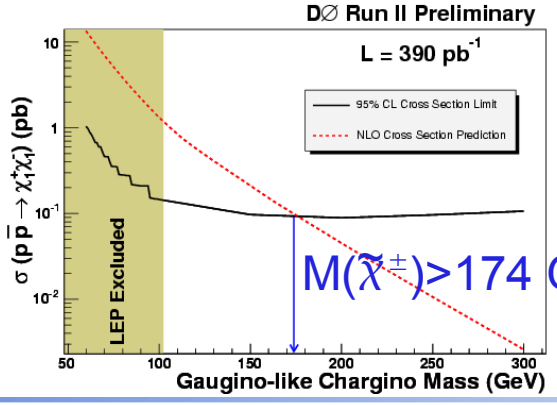
Search for Charged Massive Stable Particles (CMSP)

- Pair production of CMSPs
  - $M_{CMSP} \geq 100$ GeV
  - CMSP escape detector before decaying
  - CMSP signature resembles μ signal
- Theoretical Models
  - GMSB: stau is NLSP and decays to gravitino/goldstino are suppressed
  - AMSB/no gaugino mass unification: $\tilde{\chi}^{\pm}$ can be CMSP
- Event Selection ($\mathscr{L}$=390 pb^{-1}):
  - 2 μ with p_T>15 GeV, $\Delta\phi$>1.0
  - Speed significance: CMSPs move slower than c
  - Use correlation between inv. mass & speed significance
- Results

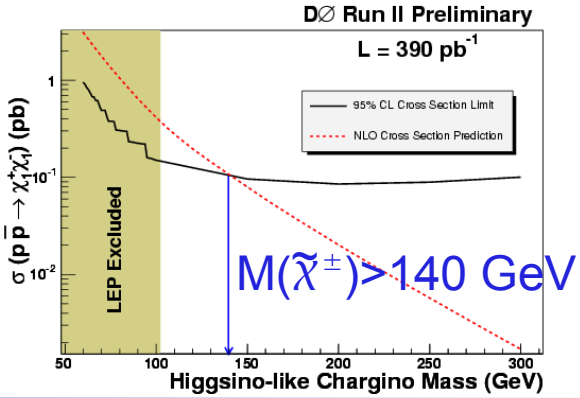








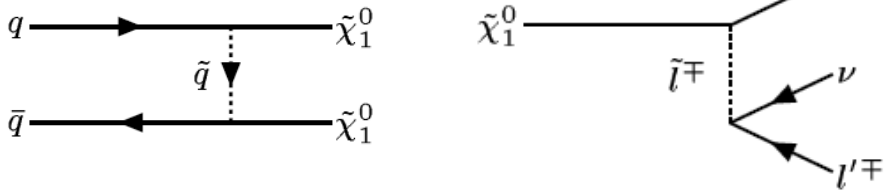
$M(\tilde{\chi}^{\pm})$>174 GeV



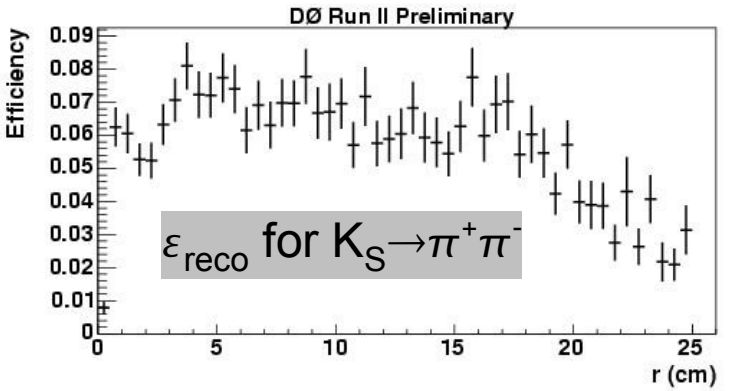
$M(\tilde{\chi}^{\pm})$>140 GeV

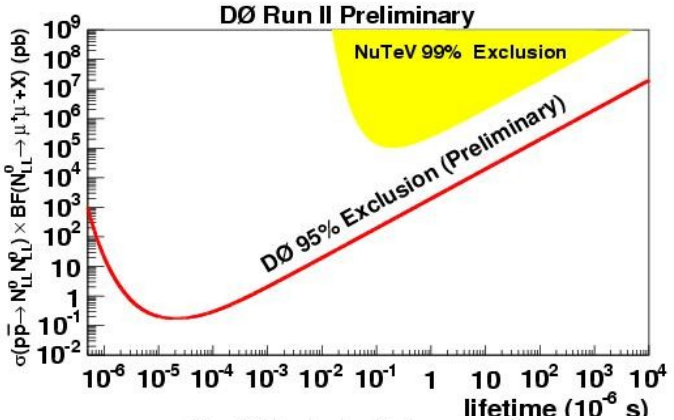
Search for Neutral Long-Lived Particles

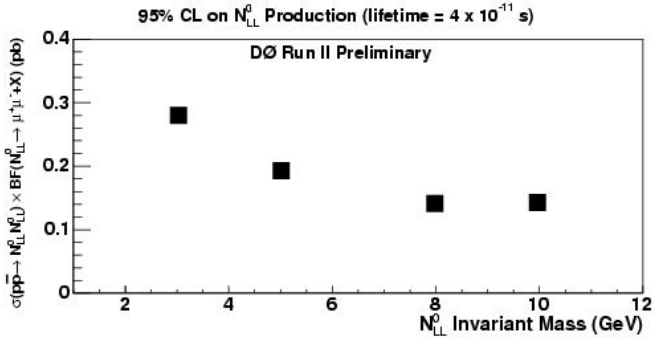
- Brand new result for Lake Louise!
- Pair production of neutral particles
  - mass ~ GeV
  - $c\tau$ ~ cm



- MSSM with relaxed GUT constraints and RPV:
  - M_1= 3,5,8,10 GeV, M_2=200 GeV, M_3=400 GeV
  - tanβ=10, μ=-5000
  - λ_{122}<1.0, $M_{\tilde{b},\tilde{t}}$=1500 GeV, $M_{\tilde{q}}$=300 GeV
- Event Selection ($\mathscr{L}$=383 pb^{-1}):
  - 2 isolated μ, p_T>10 GeV
  - displaced vertex: r= 5-20cm in transverse plane
  - DCA(x,y) > 0.01cm, DCA(z) > 0.1 cm
- Results:
  - N_{DATA}: 0
  - N_{BGND}: 0.75±1.1±1.1

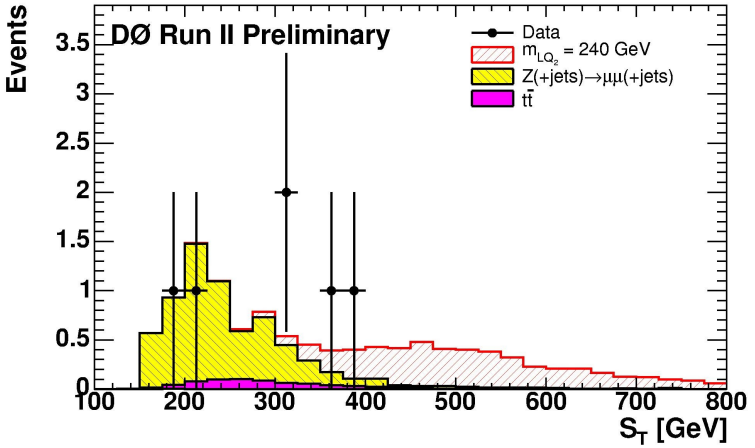


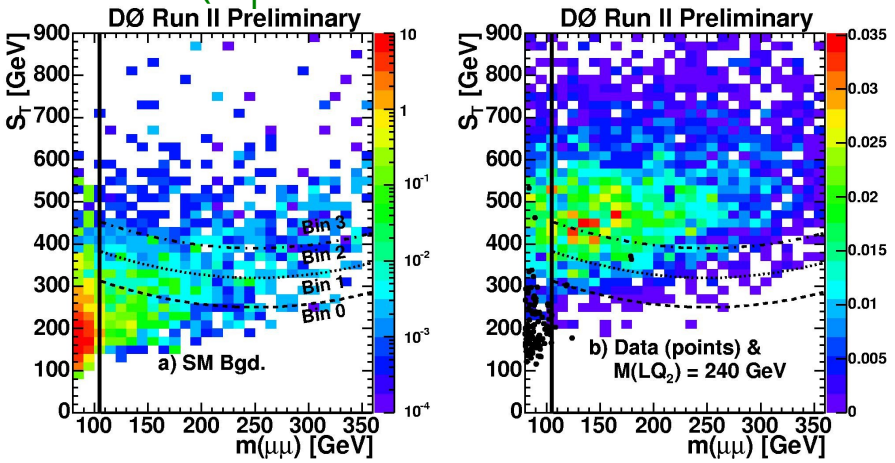


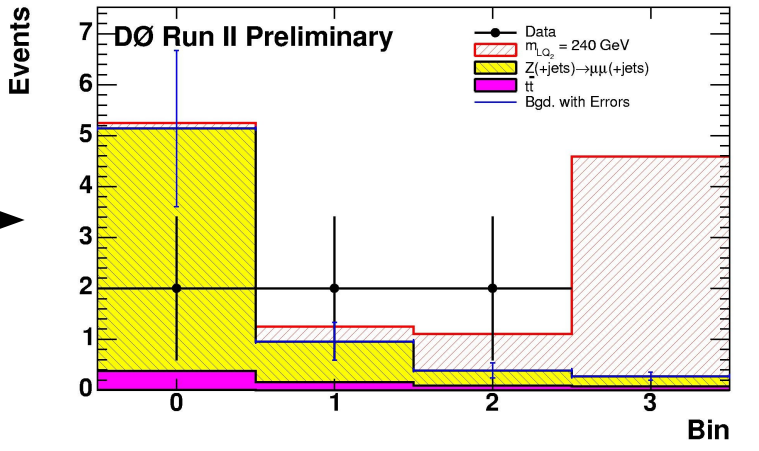


Search for 1st and 2nd Generation Leptoquarks

- Experimental results on lepton number violation, FCNC, proton decay:
  - Three different generations of Leptoquarks (LQ)
  - Each LQ generation couples to one quark and one lepton generation only
- Pair production of leptoquarks: $LQ_i\,\overline{LQ_i}$
- 2nd generation Leptoquarks:
  - Decay: β=BR($LQ_2 \rightarrow \mu$+j)=1 $\Rightarrow$ final state: μj+μj
  - Event Selection ($\mathscr{L}$=294 pb^{-1}):
    - p_T (μ_1/μ_2)>15 GeV
    - E_T(j_1/j_2)>25 GeV
    - m(μ_1,μ_2)>105 GeV
  - Analyze remaining events in different S_T bins (S_T: scalar sum of transverse energies)







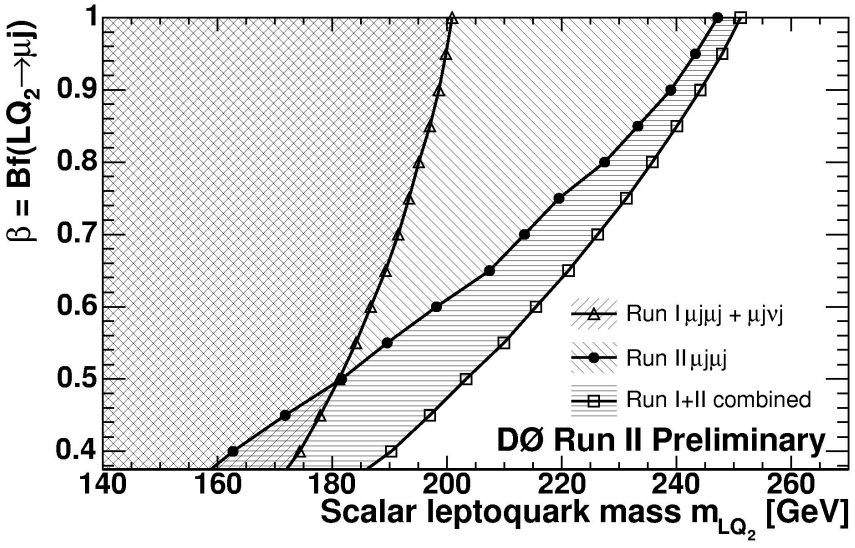
Search for 1st and 2nd Generation Leptoquarks

- Results for LQ_2 ($\mathscr{L}$=294 pb^{-1}): (submitted to PLB)

	N_{DATA}	N_{BGND}	$\epsilon(m_{LQ2}$=200 GeV)
$\mu j \mu j$	6	6.67 ± 0.73 ± 1.86	0.216 ± 0.006 ± 0.0128

⇒ combine results with Run I ($\mu j \mu j + \mu j \nu j$)

- β=1: $m_{LQ2} > 251$ GeV
- β=0.5: $m_{LQ2} > 204$ GeV

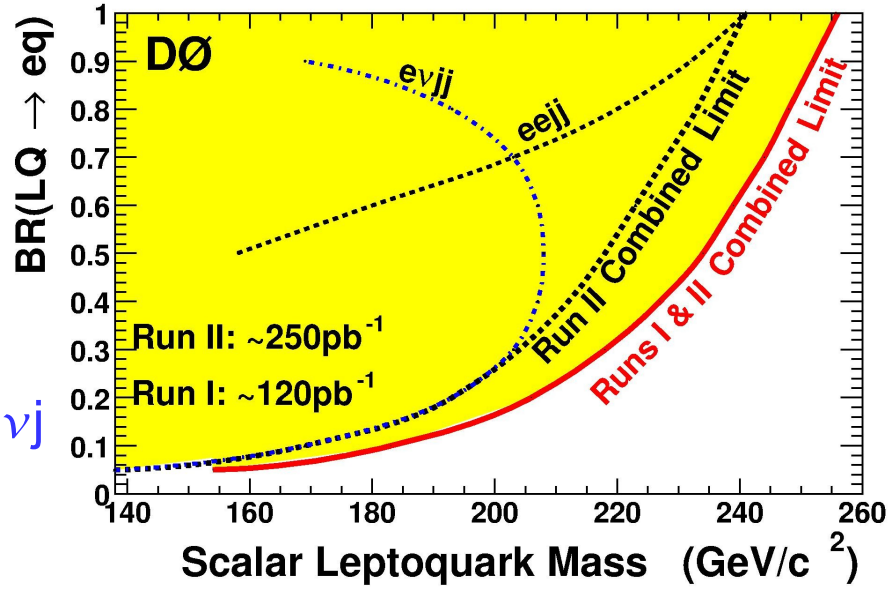


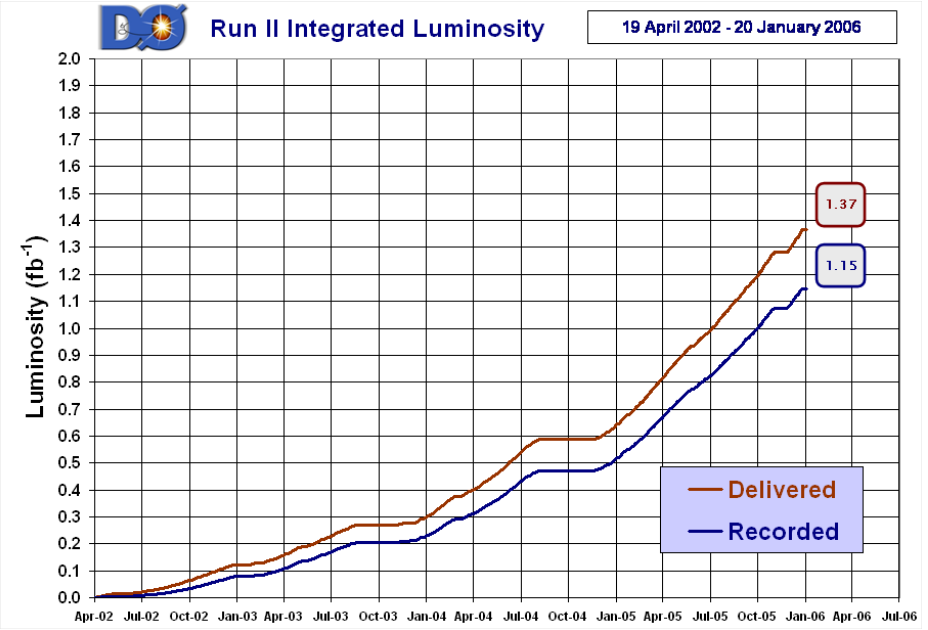
- Results for LQ_1 ($\mathscr{L}$=252 pb^{-1}): (PRD 71, 071104 (2005))

	N_{DATA}	N_{BGND}	$\epsilon(m_{LQ1}$=240 GeV)
ejej	1	0.54 ± 0.11	0.303 ± 0.039
ejνj	1	3.6 ± 1.2	0.209 ± 0.075

⇒ combine results with Run I: ejej, ejνj, $\nu j \nu j$

- β=1: $m_{LQ1} > 256$ GeV
- β=0.5: $m_{LQ1} > 234$ GeV



Summary

- Run II of the TeVatron is performing well
  - DØ is collecting a large amount of high quality data
- No discoveries yet with $\mathscr{L} \sim 350\ pb^{-1}$
  - Vast amount of restrictive upper limits on new physics
  - Most limits are well beyond LEP limits
  - Several publications:
    - Search for Supersymmetry with Gauge-Mediated Breaking in Diphoton Events
    - Search for Randall-Sundrum Gravitons in Dilepton and Diphoton Events
    - Search for LED in the Dimuon Channel
    - ...
- Currently 1 fb^{-1} of data is being analyzed
  - Hope to find deviation from Standard Model expectation
  - No discovery: expect substantial improvements of the current limits
- More data is coming...