

# Search for MMSM/mSUGRA at DØ

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- **Why SUSY?**
- **Tevatron and the DØ-Experiment**
- **Four Analyses:**
  - **Stop search in the di-jet+ME<sub>T</sub> channel**
  - **MSSM search in the 3 leptons + ME<sub>T</sub> channel**
  - **Tau identification**
  - **Model independent: Search for  $e\mu$**
- **Conclusion**

# What is so attractive about SUSY?



- We know that the Standard Model can't be everything: **Somewhere between  $10^2$  and  $10^{19}$  GeV there has to be “new physics”** .
- A supersymmetrical extension of the SM is not necessary
- **But:**
  - SUSY yields explanations for open questions of the SM
  - SUSY makes a Grand Unified Theory easier
  - String theories imply SUSY

# Supersymmetry: What's the idea?



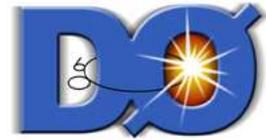
- “Minimal solution” (MSSM):
  - Every fermion (boson) has a bosonic (fermionic) “super-partner”.
  - A second Higgs-doublet is necessary

SM Particle		SUSY Partner	
Quarks	$(u_L, d_L)$	Squarks	$(\tilde{u}_L, \tilde{d}_L)$
	$u_R$		$\tilde{u}_R$
	$d_R$		$\tilde{d}_R$
Fermions	$(\nu, e_L)$	Sfermions	$(\tilde{\nu}, \tilde{e}_L)$
	$e_R$		$\tilde{e}_R$
Higgs	$(H^+_u, H^0_u)$	Higgsinos	$(\tilde{H}^+_u, \tilde{H}^0_u)$
	$(H^0_d, H^-_d)$		$(\tilde{H}^0_d, \tilde{H}^-_d)$
Gluon	$g$	Gluino	$\tilde{g}$
W-Boson	$W^\pm, W^0$	Wino	$\tilde{W}^\pm, \tilde{W}^0$
B-Boson	$B^0$	Bino	$\tilde{B}^0$

# Is SUSY an exact Symmetry?

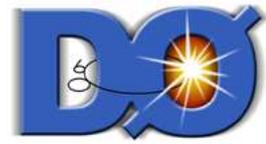
- Obviously Supersymmetry is broken; otherwise SUSY particles had the same masses as their SM-partners.  
 $\Rightarrow$  SUSY gauge-eigenstates mix into mass-eigenstates different from SM mass-eigenstates.
- **Mass-Eigenstates:**
  - The super-partners of the gauge bosons and Higgs-particles mix to form 2 charged „Charginos“  $\chi_{1,2}^{\pm}$  and four „Neutralinos“  $\chi_{1,2,3,4}^0$  (sorted by mass)
  - The left- and right-handed heavy quarks  $\tilde{b}_L, \tilde{b}_R, \tilde{t}_L, \tilde{t}_R$  mix to  $\tilde{b}_1, \tilde{b}_2, \tilde{t}_1, \tilde{t}_2$   
 $\tilde{\tau}_L$  and  $\tilde{\tau}_R$  mix to  $\tilde{\tau}_1$  and  $\tilde{\tau}_2$

# mSUGRA



- It is attractive to assume a spontaneous symmetry breaking
- One possible model: **SuperGravity**:
  - The symmetry breaking takes place in a “hidden sector” and is transmitted to the “visible sector” by gravitons
  - Side effect: The number of free parameters is reduced from 105 (MSSM) to 5:
    - Universal squark and chargino masses at the GUT scale:  $m_0, m_{1/2}$
    - Universal trilinear coupling:  $A_0$
    - Ratio of Higgs VEVs:  $\tan \beta$
    - Sign of the Higgs parameter:  $|\mu|$

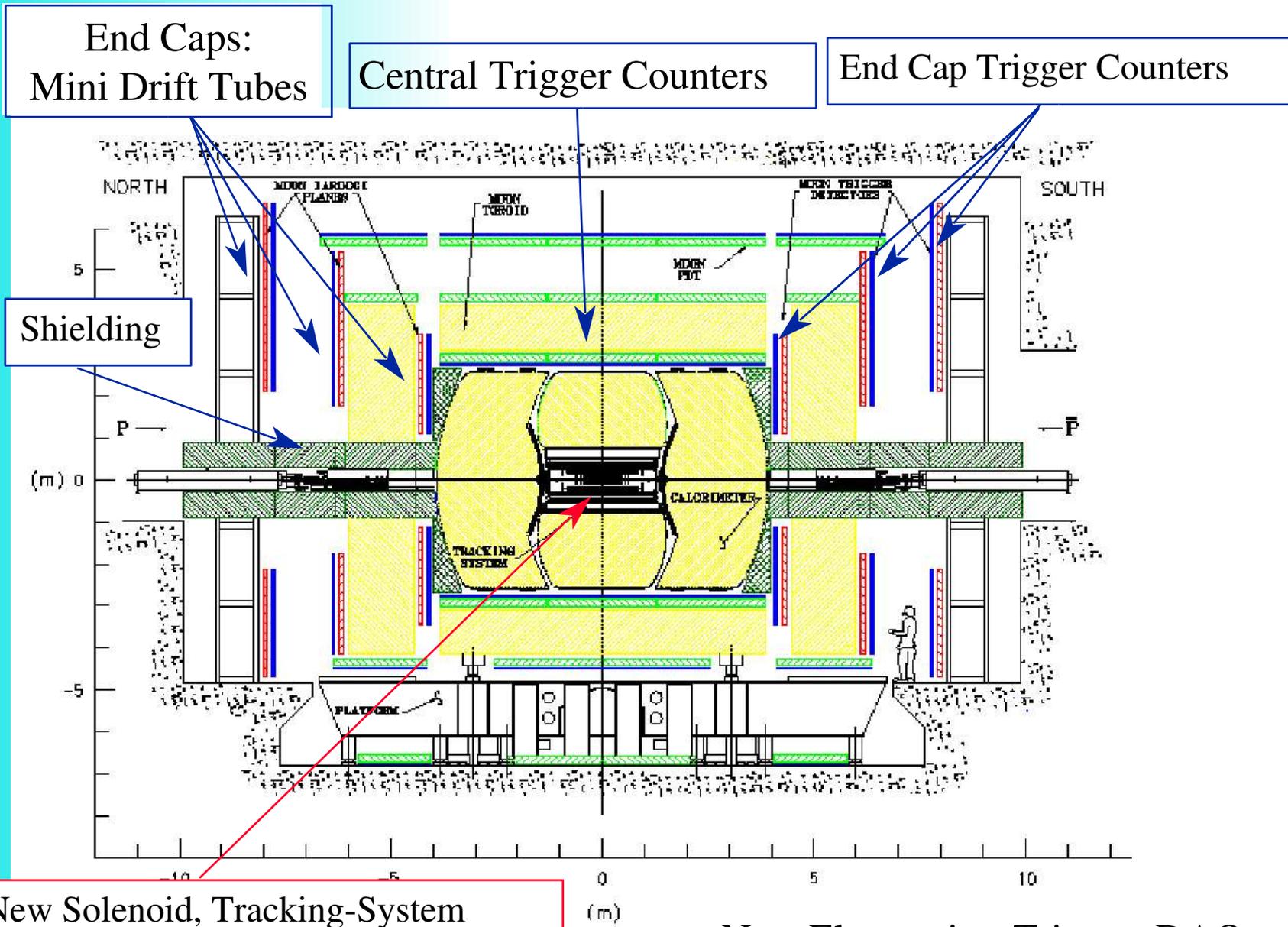
# What does the accelerator look like?



- **Run II** (since 2001):
- **CM energy**  
1.96 TeV vs.  
1.8 TeV in Run I
- **Luminosity**
  - So far delivered:  
258 pb<sup>-1</sup>
  - Goal for Run IIa:  
 $\mathcal{L}$  fb<sup>-1</sup>
  - For comparison:  
Run I:  $\mathcal{L} = 0.1$  fb<sup>-1</sup>



# The DØ Detector: What's new?



New Solenoid, Tracking-System  
(Silicon, Scint. Fibers, Preshowers)

+ New Electronics, Trigger, DAQ

# Stop search with Run I data



- **What signal are we looking for?**

- Assume  $m_{\text{stop}} > m_{\text{LSP}} + m_c$ ,  $m_{\text{stop}} < m_W + m_b + m_{\text{LSP}}$   
and  $m_{\text{stop}} < m_{\text{slepton}}, m_{\text{sneutrino}}$   
 $\Rightarrow \text{BR}(\tilde{t} \rightarrow c + \text{LSP}) = 100\%$

➔ **Search for two jets and large missing energy**

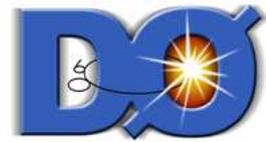
- **What are the backgrounds?**

1 Standard-Model background (large!):

- $W \rightarrow l\nu + \text{jets}$
- $W \rightarrow l\nu, W \rightarrow qq$
- $W \rightarrow l \rightarrow \text{anything}$
- $Z \rightarrow \nu\nu$
- $Z \rightarrow \tau\tau$
- $t\bar{t}$  decays

➔ **A lepton may be mis-identified as a jet!**

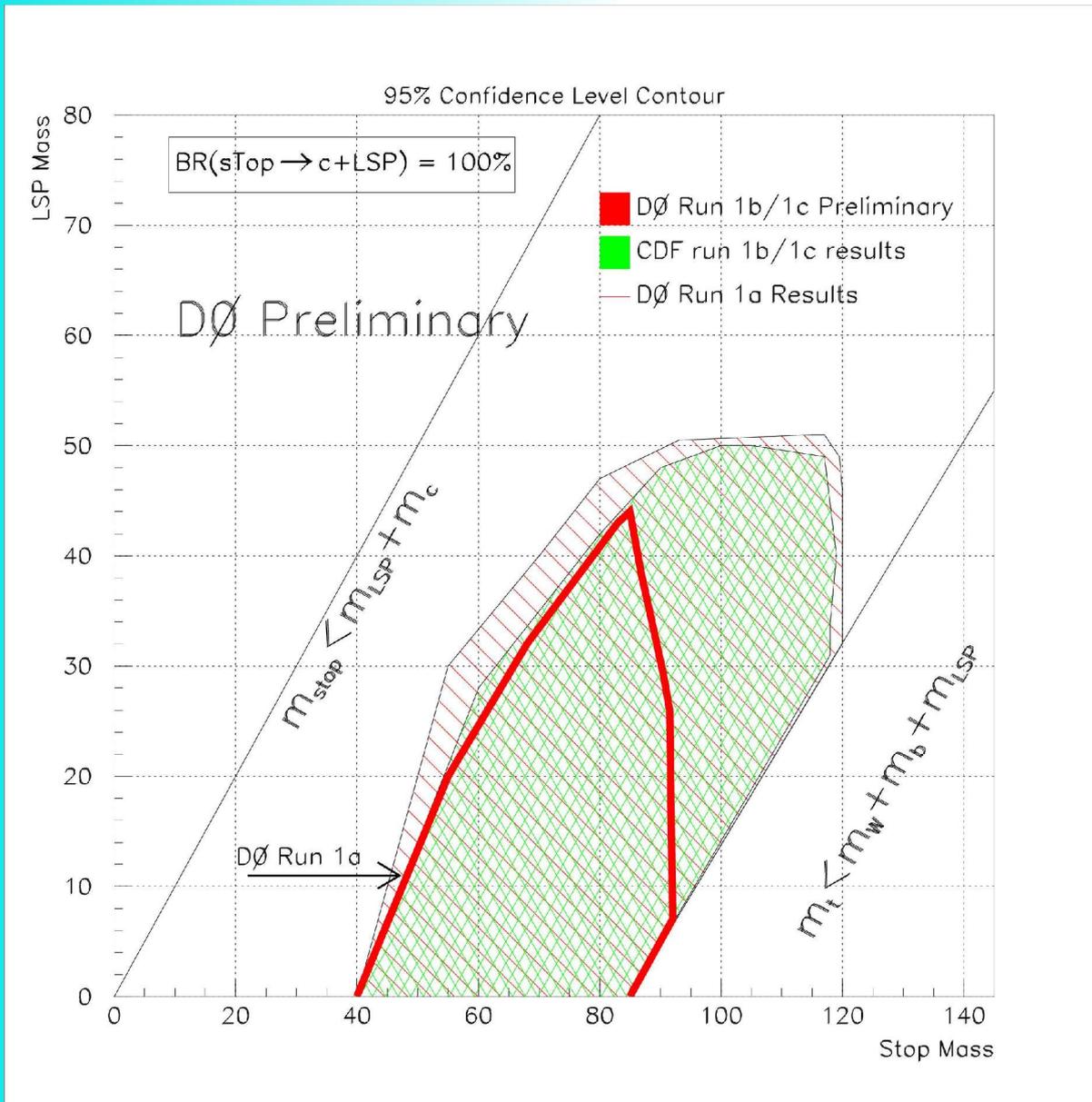
2 Detector mis-measurements, leading to fake  $ME_T$



# Stop search (2)

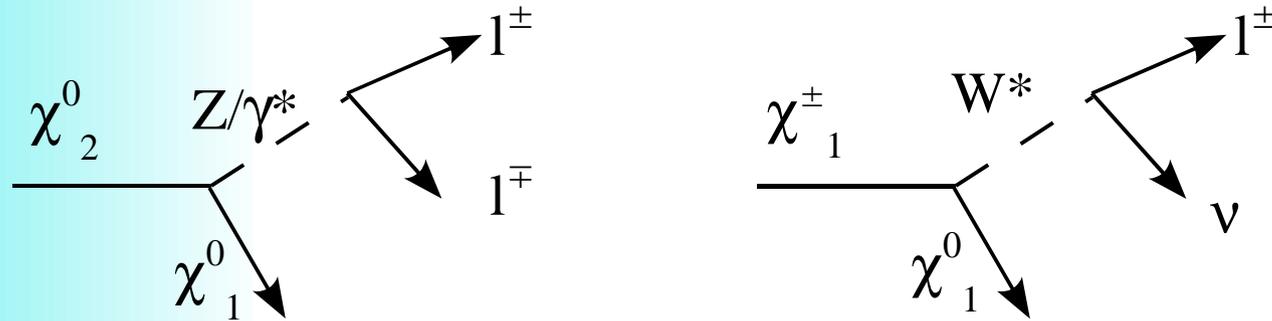
- **What data set has been used?**
  - **85.2 pb<sup>-1</sup>** of data, taken with a di-jet+MET trigger
- **Which cuts were applied?**
  - Leading Jet  $E_T > 100$  GeV
  - Second Jet  $E_T > 60$  GeV
  - $ME_T > 40$  GeV
  - Angle between any jet and  $ME_T > 30^\circ$
  - $\eta$  of leading jet  $< 0.8$  (central calorimeter only)
  - $\eta$  of any jet: NOT  $0.8 < |\eta| < 1.2$  (overlap region of central and forward cal.)

# Stop search: What do we find?



- After all cuts  $12.81 \pm 1.77$  events were expected and 12 events were found
- This translates to an excluded region in the  $m_{\text{LSP}} - m_{\text{stop}}$  plane

# How do we get 3 leptons?

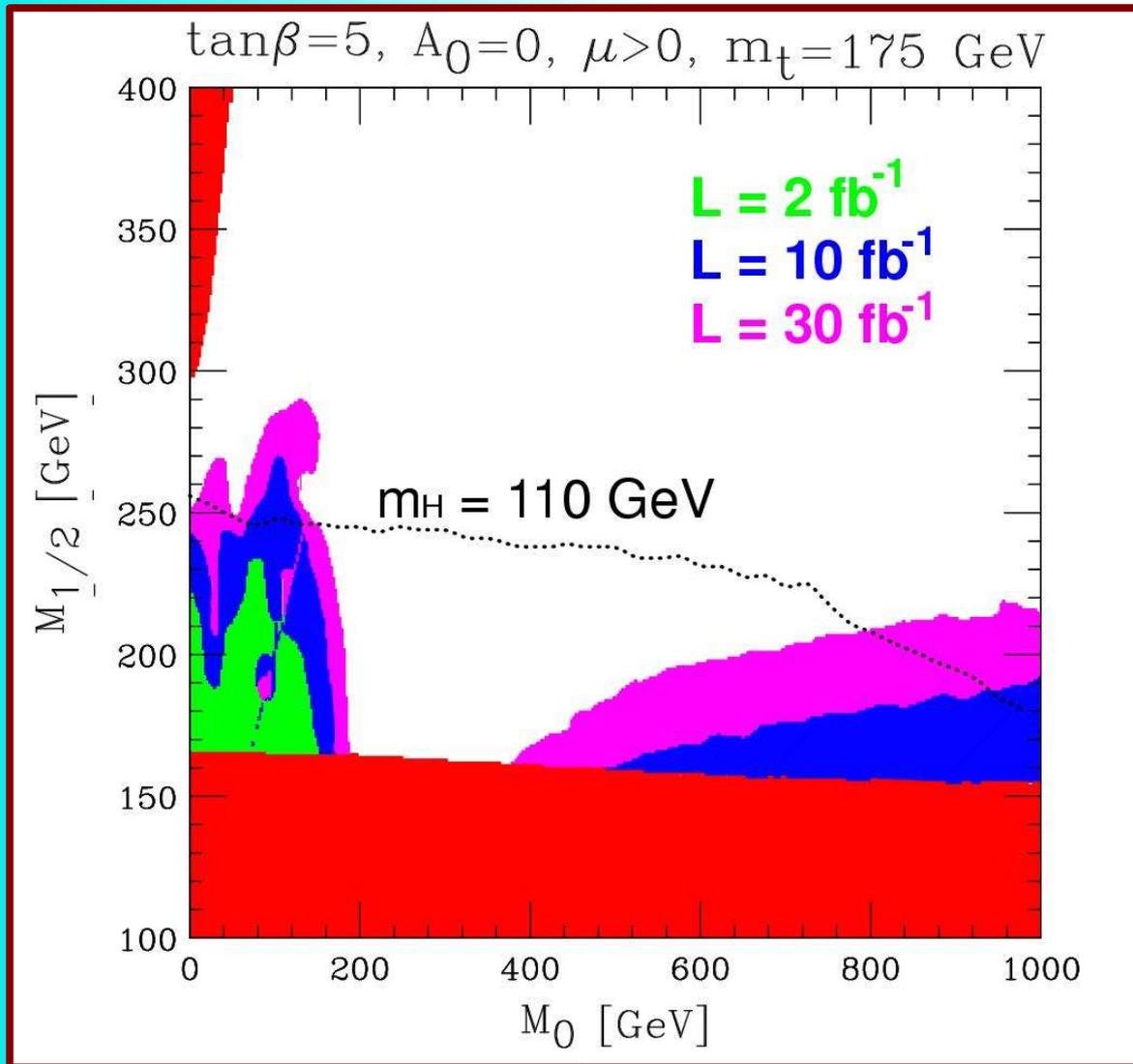


- Chargino and second-lightest neutralino are produced associated and decay into  
3 charged leptons + neutrino + 2 LSPs
- Advantage of this channel:
  - Little Standard Model Background
  - Relatively high X-section, compared to other SUSY channels

➔ **Analysis:**

**Search for 2 identified electrons and an isolated third track**

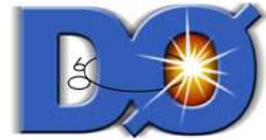
# 3l: Where can we find New Physics?



Dedes et al., hep-ph/0207026

- $\chi_{1\pm}^{\pm}\chi_{20}^0 \rightarrow 3l$  is one of the most promising channels for SUSY discovery at Tevatron
- Run 2a and Run 2b will be able to cover new regions of the  $m_0$ - $m_{1/2}$  parameter space.
- The potential is greatest for low  $\tan\beta$
- Limits by direct Higgs search at LEP are highly model-dependent.

# 2e+l: What does the signal look like?



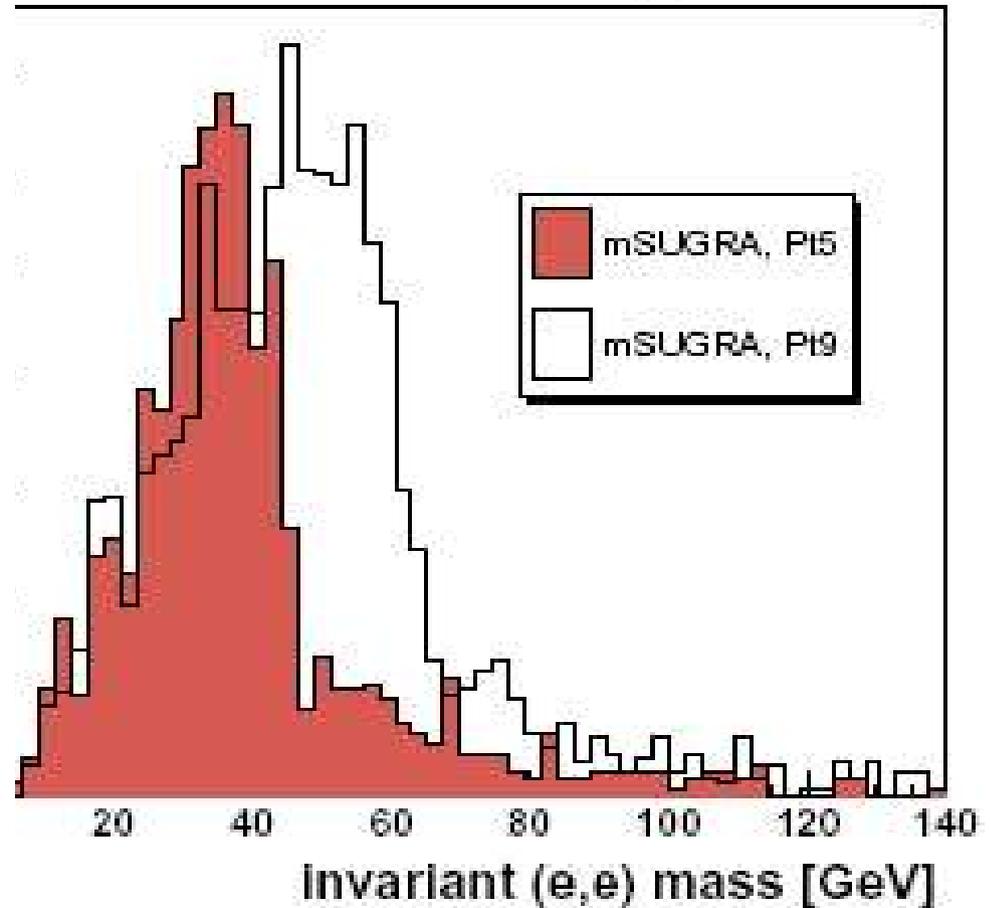
- Generate Monte-Carlo data sets for two mSUGRA points

1  $m_0 = 500$  GeV  
 $m_{1/2} = 100$  GeV  
 $\tan \beta = 2, \mu > 0$

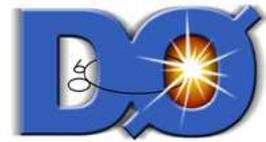
2  $m_0 = 150$  GeV  
 $m_{1/2} = 150$  GeV  
 $\tan \beta = 2, \mu > 0$

- The invariant ee-mass peaks between 30 and 60 GeV

DØ Run II Preliminary



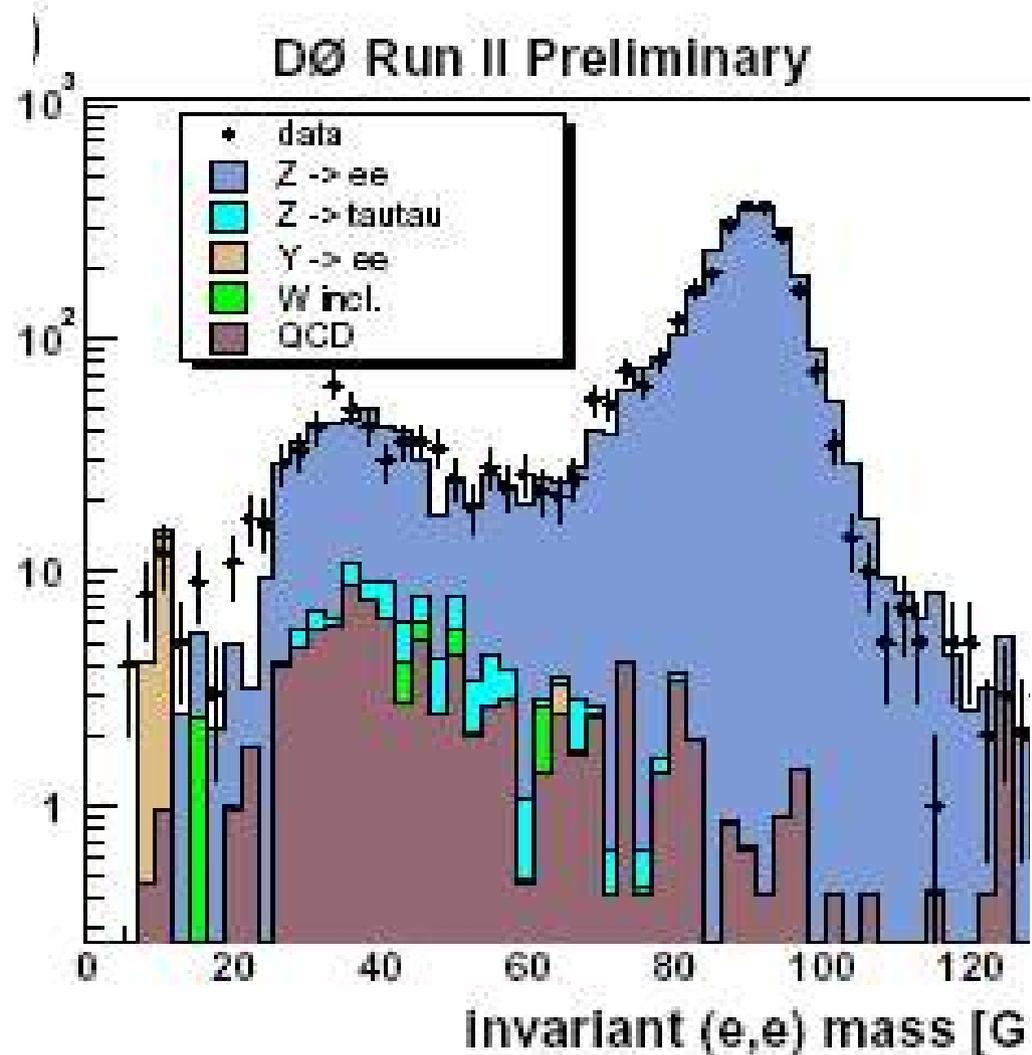
# 2e+1: What does the BG look like?



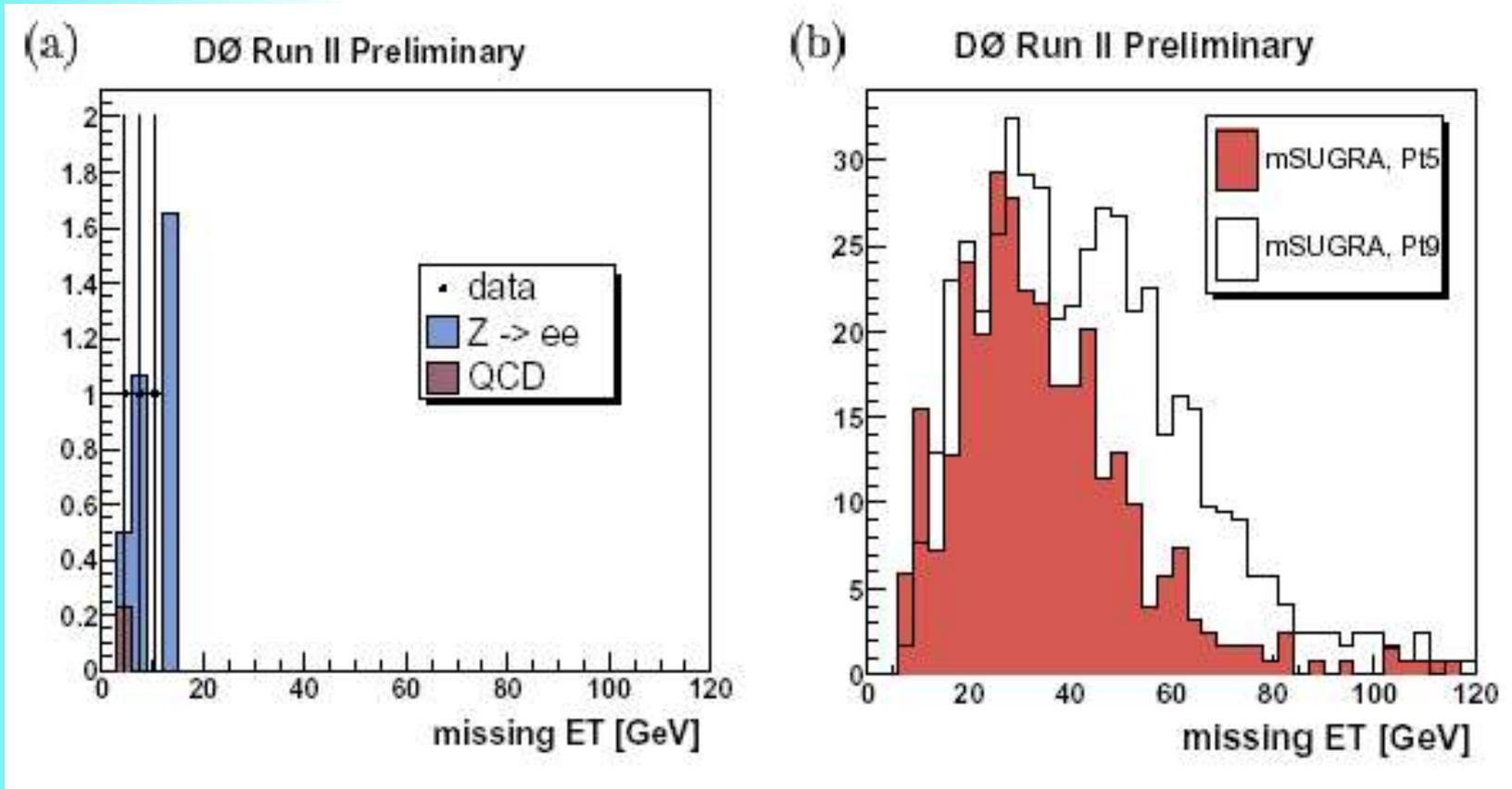
→ Deal with the **two-electron background** first:

- **Potential background:** All SM-processes with at least 1 electron in the final state (The second e can be faked by a jet or Photon)

→ **QCD Background:**  
Extracted from **data**  
by inverting the  
Hmatrix- $\chi^2$  cut



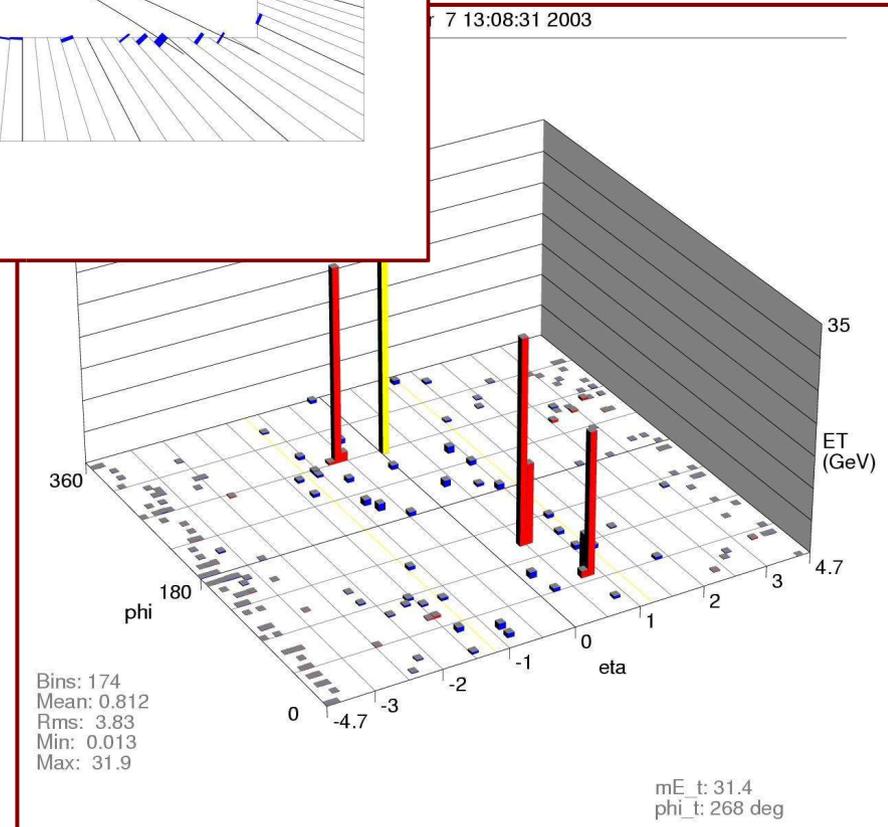
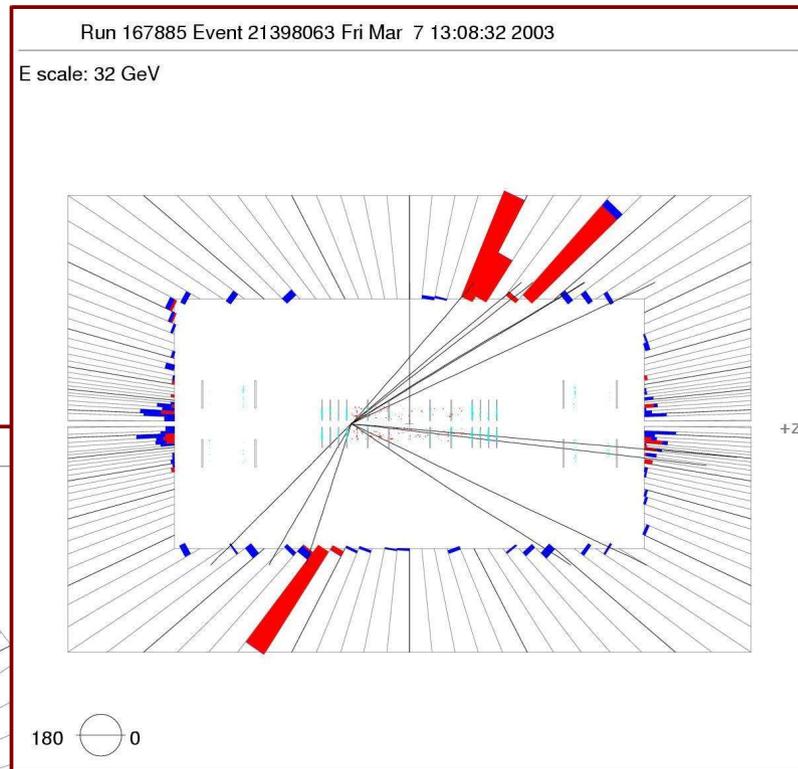
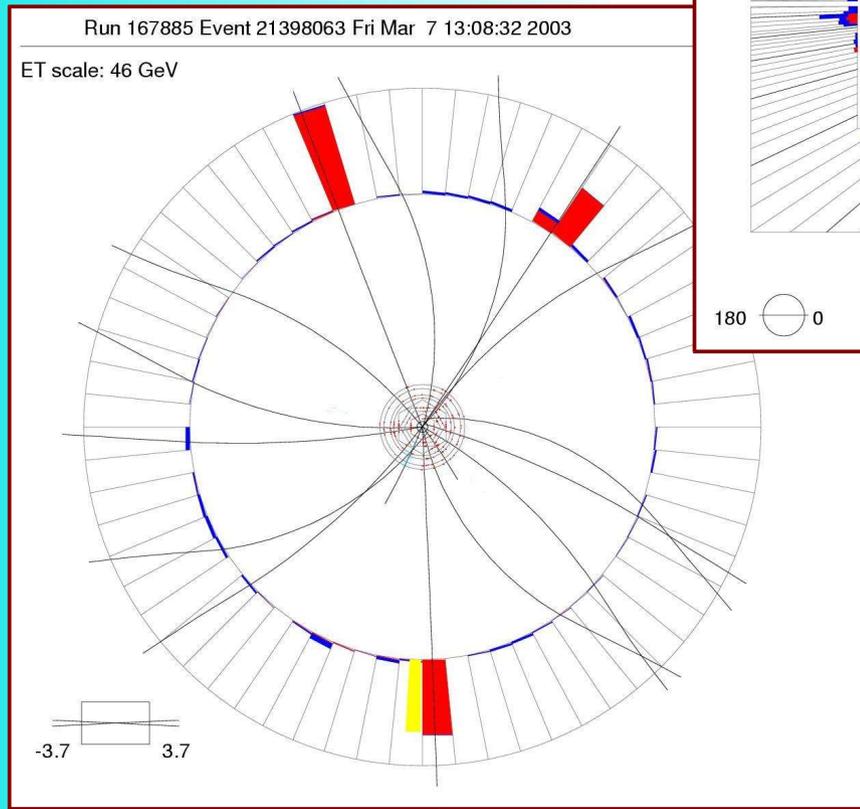
# 3I: What's left after the cuts?



- After cutting on the invariant ee-mass ( $10\text{GeV} < m < 70\text{GeV}$ ) and the transversal e-MET-mass, one loses nearly the complete background (but only 50% of the signal) by requiring a third isolated track.
- Finally we require  $ME_T > 15\text{ GeV}$

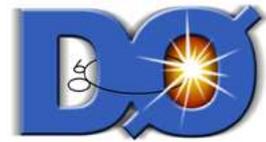
# A “wannabe candidate”

- The event only fails the last MET cut



# 3 leptons: Results

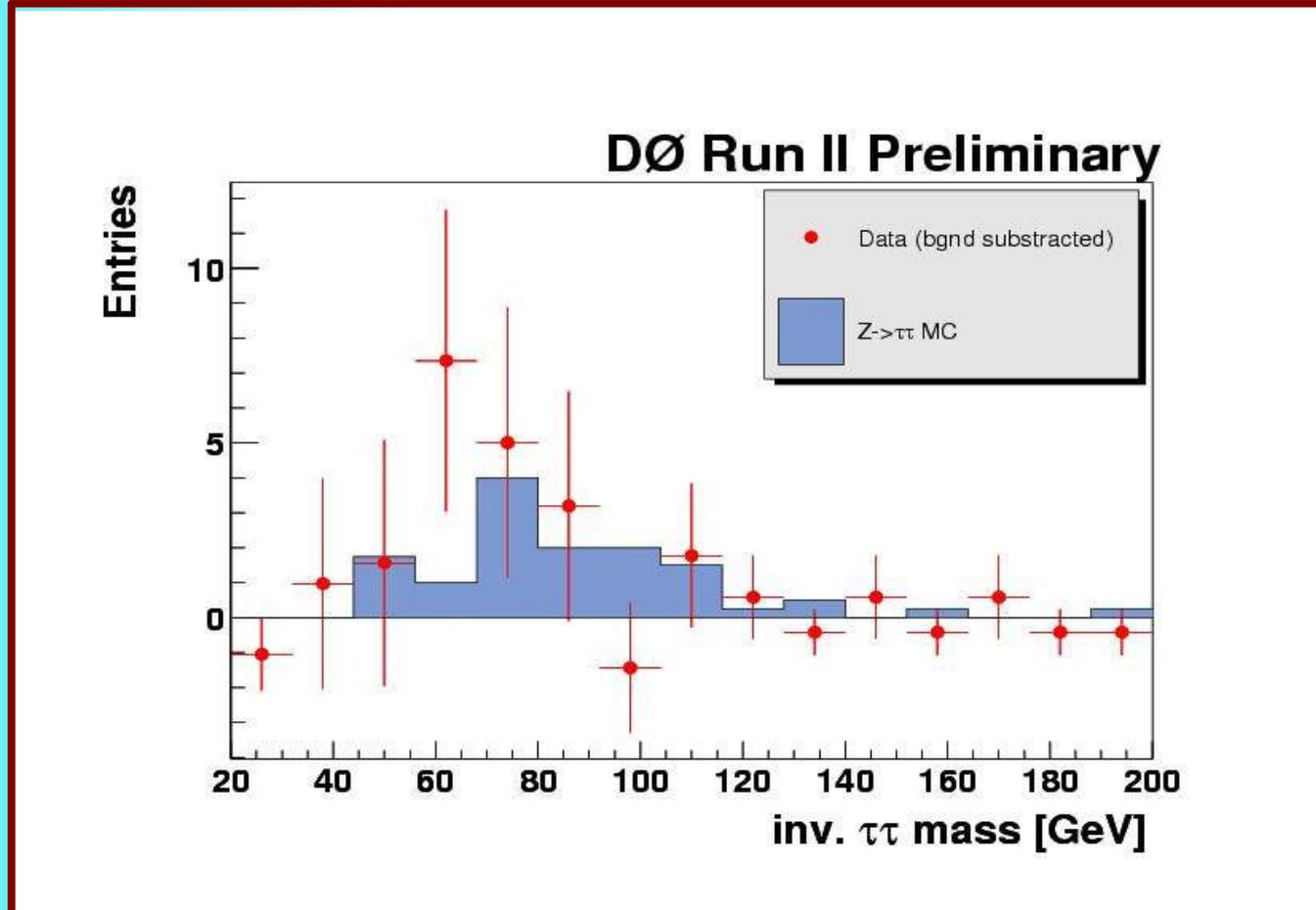
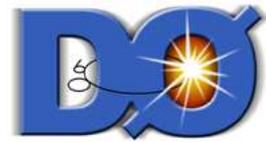
- After all cuts one expects  $0 \pm 2$  events and finds 0 events
- For the mSUGRA-point  
 $m_0 = 500, m_{1/2} = 100, \tan \beta = 2, \mu < 0$   
this corresponds to a 95% C.L. limit of  
 $\sigma_{\text{prod}} \times \text{BR} = 3.54 \text{ pb.}$
- For the mSUGRA-point  
 $m_0 = 150, m_{1/2} = 150, \tan \beta = 2, \mu < 0$   
this corresponds to a 95% C.L. limit of  
 $\sigma_{\text{prod}} \times \text{BR} = 2.20 \text{ pb.}$



# What about Taus?

- The identification of  $\tau$ s is crucial for high  $\tan \beta$
- Strategy:
  - Search for  $Z \rightarrow \tau\tau \rightarrow e + \text{hadrons}$
  - Electron is identified using standard cuts
  - Use a **Neural Network** to identify  $\tau$ -jet
  - Apply the following **extra cuts**:
    - Exactly one track matching the  $\tau$ -cluster
    - $p_T(\tau) > 7 \text{ GeV}$  (remove low  $p_T$  QCD jets)
    - Transverse mass of electron and  $ME_T < 60 \text{ GeV}$  (remove Ws)
    - Transverse mass of e and  $\tau < 60 \text{ GeV}$  (remove Zs)
    - $(ME_{T,\tau}) < 0.5$  (remove evts w/ poorly measured e energy)

# Do we find $Z \rightarrow \tau\tau$ ?



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

- The invariant-mass distribution shows a peak with a clear excess of unlike-sign events
- ➔ **Evidence for  $\tau$  at DØ!**

# What's the charm of the $e\mu$ -channel?

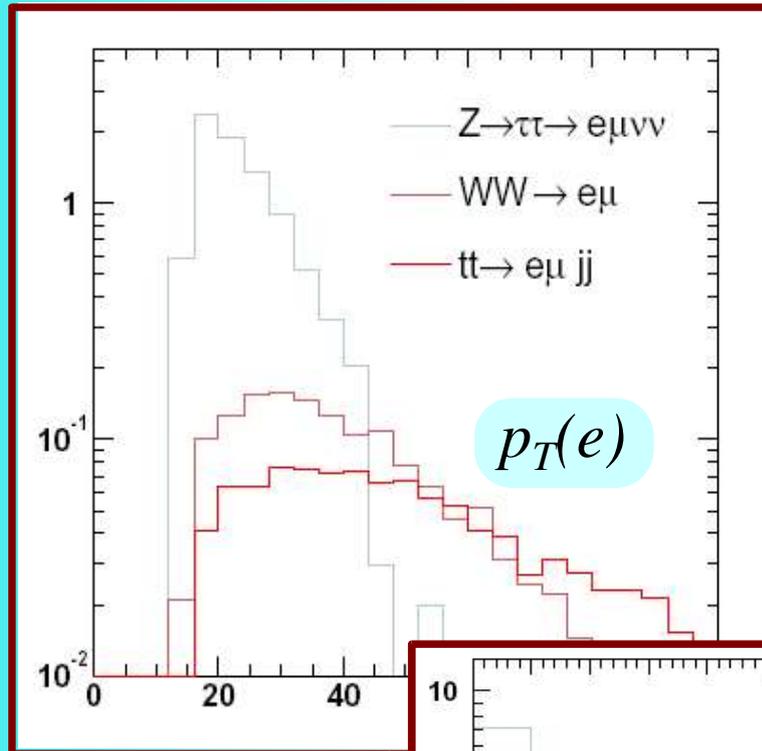


- Very low Standard Model background
- Especially in comparison with other multi-lepton analyses:  
No Z-Resonance
- Discovery potential in several physics scenarios

→ Idea:

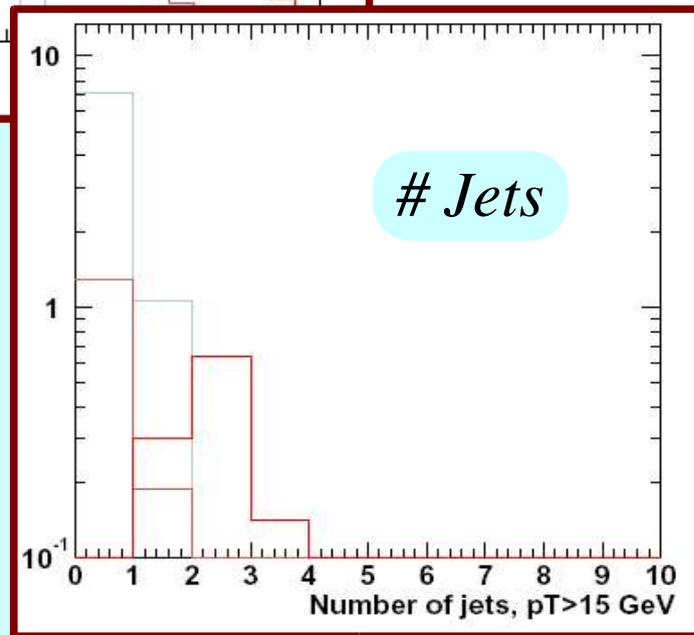
**Model-independent search for „New Physics“**

# $e\mu$ : Which physics backgrounds do exist?

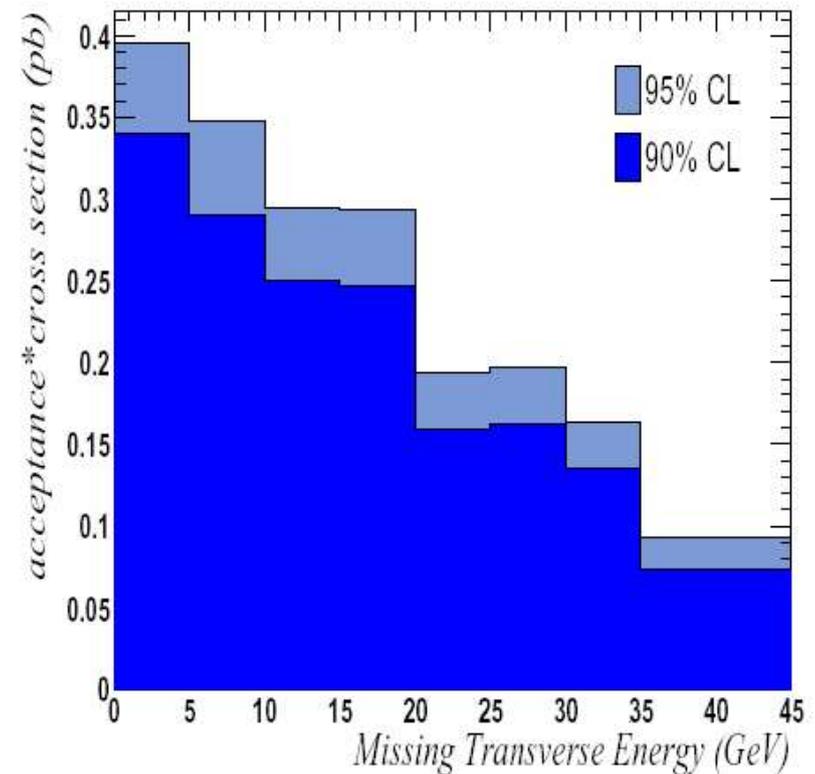
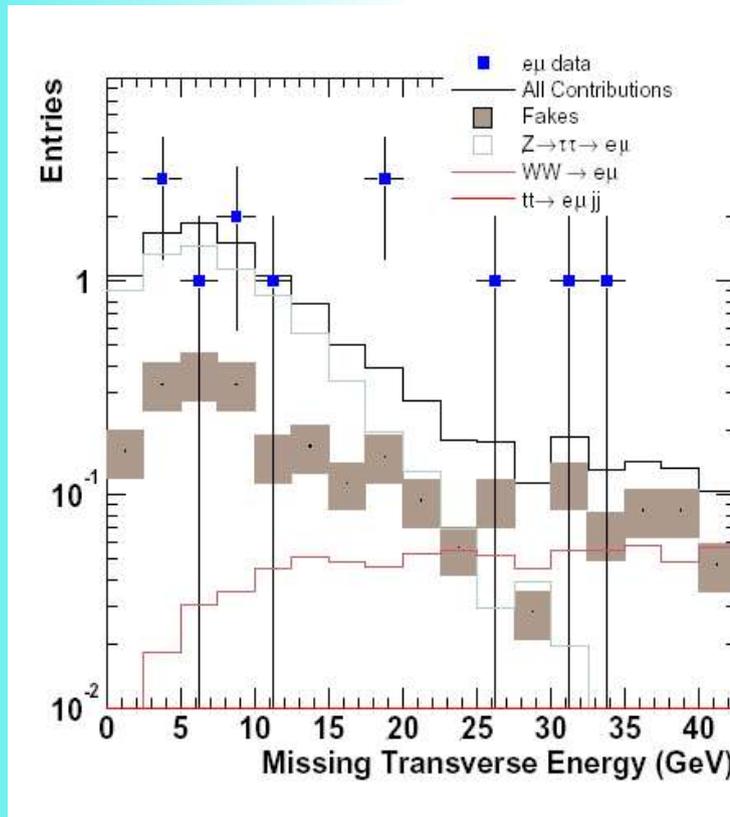
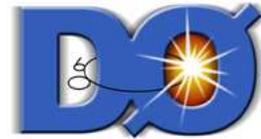


- „True“ backgrounds are mostly:
- $Z/\gamma^* \rightarrow \tau\tau \rightarrow e\mu\nu\nu$
- $WW \rightarrow e\mu\nu\nu$
- $tt \rightarrow e\mu\nu\nu jj$

- Z-background differs from the rest in lepton- $p_T$  and  $ME_T$
- WW and tt differ in the number of jets



# $e\mu$ : What does this mean for New Physics?



- Within error bounds the data is compatible with the known background.
- Limits for the product of cross section and acceptance for new physics can be quoted as a function of  $ME_T$ .
- For comparison: Acceptance for  $WW \rightarrow e\mu$ : 16.9%

# Conclusions



- Run II at Tevatron will cover new regions in the MSSM parameter space
- New limits were set for the existence of a stop-particle (Run I data).
- A search for 3 leptons + MET is proceeding
- Taus can be identified at DØ
- A model independent search for  $e + \mu$  is setting limits for “new physics”
- Challenging times are ahead of us.