



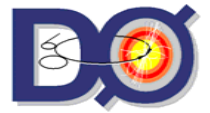
# Recent Results on New Phenomena and Higgs Searches at DZERO

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Ruston, Louisiana  
U.S.A.



# Outline




- **Motivation for DØ Run II Detector at Fermilab**
- **The Fermilab Tevatron Collider**
- **Recent New Phenomena Results**
- **Prospects for Higgs Search at the Tevatron**

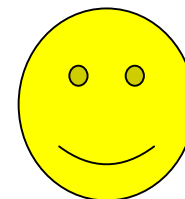


# Motivation



➤ **Run I DØ** (1992-96)  **Run II DØ**  
Began 1 March, 2001

**Top Quark discovered in Run I**



- **Search for Higgs**
- **New Phenomena Searches**
- **Detailed Top quark Physics**
- **Electroweak Physics**
- **B Physics**
- **QCD**



# The DØ Collaboration



**The DØ Collaboration**

 U. of Arizona U. of California, Berkeley U. of California, Irvine U. of California, Riverside Cal State U., Fresno Lawrence Berkeley Nat. Lab. Florida State U. Fermilab U. of Illinois, Chicago Northern Illinois U. Northwestern U. Indiana U. U. of Notre Dame Iowa State U. U. of Kansas Kansas State U. Louisiana Tech U. U. of Maryland Boston U. Northwestern U. U. of Michigan Michigan State U. U. of Nebraska Columbia U. U. of Rochester SUNY, Stony Brook Brookhaven Nat. Lab. Langston U. U. of Oklahoma Brown U. U. of Texas, Arlington Texas A&M U. Rice U. U. of Virginia U. of Washington	 U. de Buenos Aires	 LAFEX, CBPF, Rio de Janeiro State U. do Rio de Janeiro State U. Paulista, São Paulo	 IHEP, Beijing	 U. de los Andes, Bogotá
 Charles U., Prague Czech Tech. U., Prague Academy of Sciences, Prague	 U. San Francisco de Quito	 ISN, IN2P3, Grenoble CPPM, IN2P3, Marseille LAL, IN2P3, Orsay LPNHE, IN2P3, Paris DAPNIA/SPS, CEA, Saclay IRIS, Strasbourg IPN, IN2P3, Villeurbanne	 U. of Aachen Bonn U. IOP, U. Mainz Ludwig-Maximilians U. Munich U. of Wuppertal	
 Panjab U., Chandigarh Delhi U., Delhi Tata Institute, Mumbai	 KDL, Korea U., Seoul	 CINVESTAV, Mexico City	 FOM-NIKHEF, Amsterdam U. of Amsterdam/NIKHEF U. of Nijmegen/NIKHEF	
 INP, Kraków	 JINR, Dubna ITEP, Moscow Moscow State U. IHEP, Protvino PNPI, St Petersburg	 Lund U. RIT, Stockholm Stockholm U. Uppsala U.	 Lancaster U. Imperial College, London U. of Manchester	 HCIP, Hochiminh City

Ann Heinson, UC Riverside

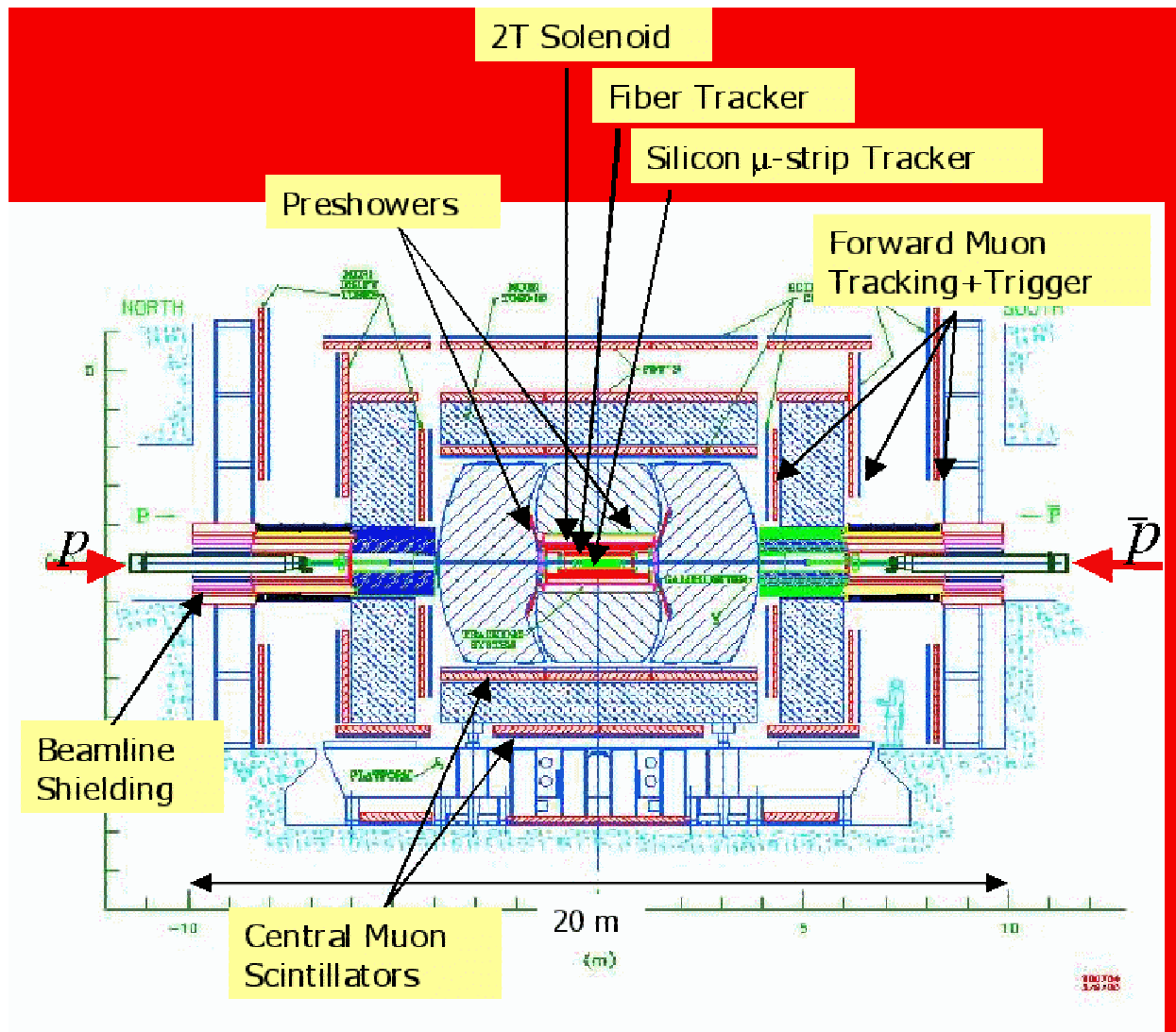
**~ 650 physicists**  
**76 institutions**  
**18 countries**

**> 50% non-USA**  
**~ 120 graduate students**





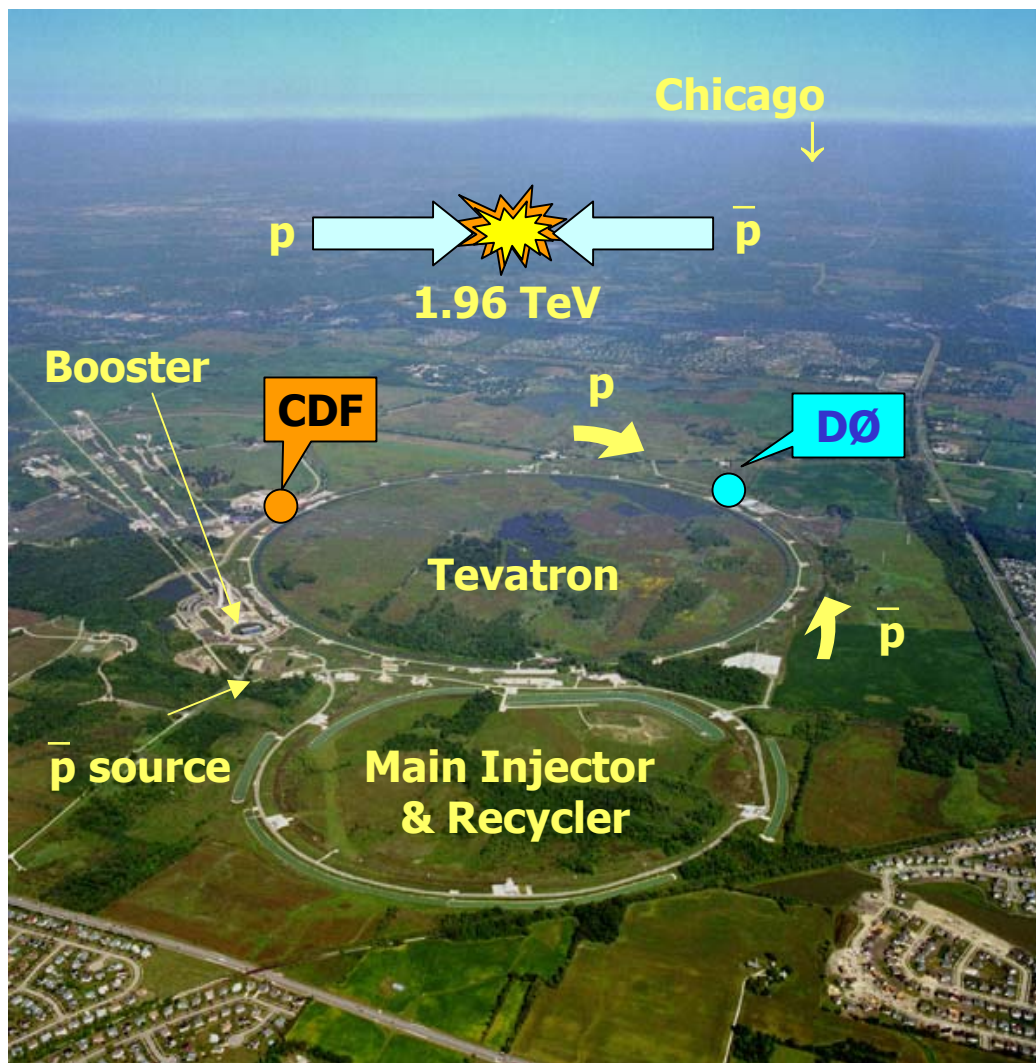
# The DØ Run II Detector







# The Fermilab Tevatron Collider



## Tevatron Upgrades

- Increase in Luminosity
  - $2 \times 10^{31} \rightarrow 5 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$
- Bunch spacing
  - $3.5 \mu\text{s} \rightarrow 396 \text{ ns}$
- Increase in CM energy
  - $1.8 \text{ TeV} \rightarrow 1.96 \text{ TeV}$

## Detector challenges

- Large occupancies and event pile-up
- Radiation damage



## Different forms

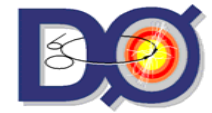
- Observation of unseen particles predicted by SM
  - Higgs
- Discovery of particles not in the SM
  - SUSY, leptoquarks
- Identification of new gauge interactions
  - W'/Z', technicolor
- Unexpected complexities beyond the SM
  - Compositeness
- Fundamental changes to modern physics
  - Extra dimensions

## Current DØ searches

- **Supersymmetry**
  - Jets + missing  $E_T$
  - Di- and Tri-leptons
  - GMSB:  $\gamma\gamma$  + missing  $E_T$
- **Exotics**
  - 2<sup>nd</sup> Generation Leptoquarks
- **Large Extra Dimensions**
  - Dielectrons and diphotons
  - Dimuons



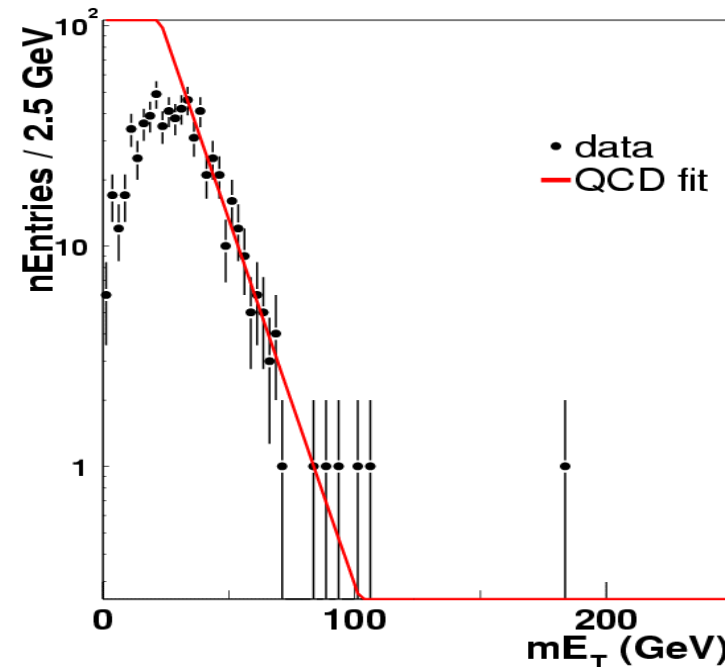
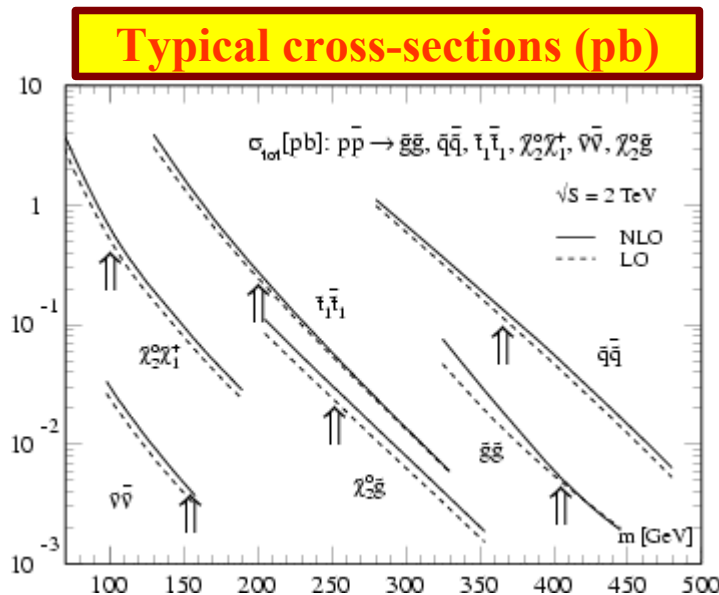
# Jets + Missing $E_T$



- Cascade decays end in quarks and/or gluons and missing transverse energy (Lightest Supersymmetric Particle escaping detector)
- Generic signature for production of squarks and/or gluinos in SUGRA

Cut: Missing $E_T >$	70 GeV	80 GeV	90 GeV	100 GeV
Expected (events)	$18.4 \pm 8.4$	$9.5 \pm 5.3$	$5.1 \pm 3.2$	$2.7 \pm 1.8$
Data	7	6	4	3
Cross-section Limit (pb)	4.2	3.8	3.1	2.7

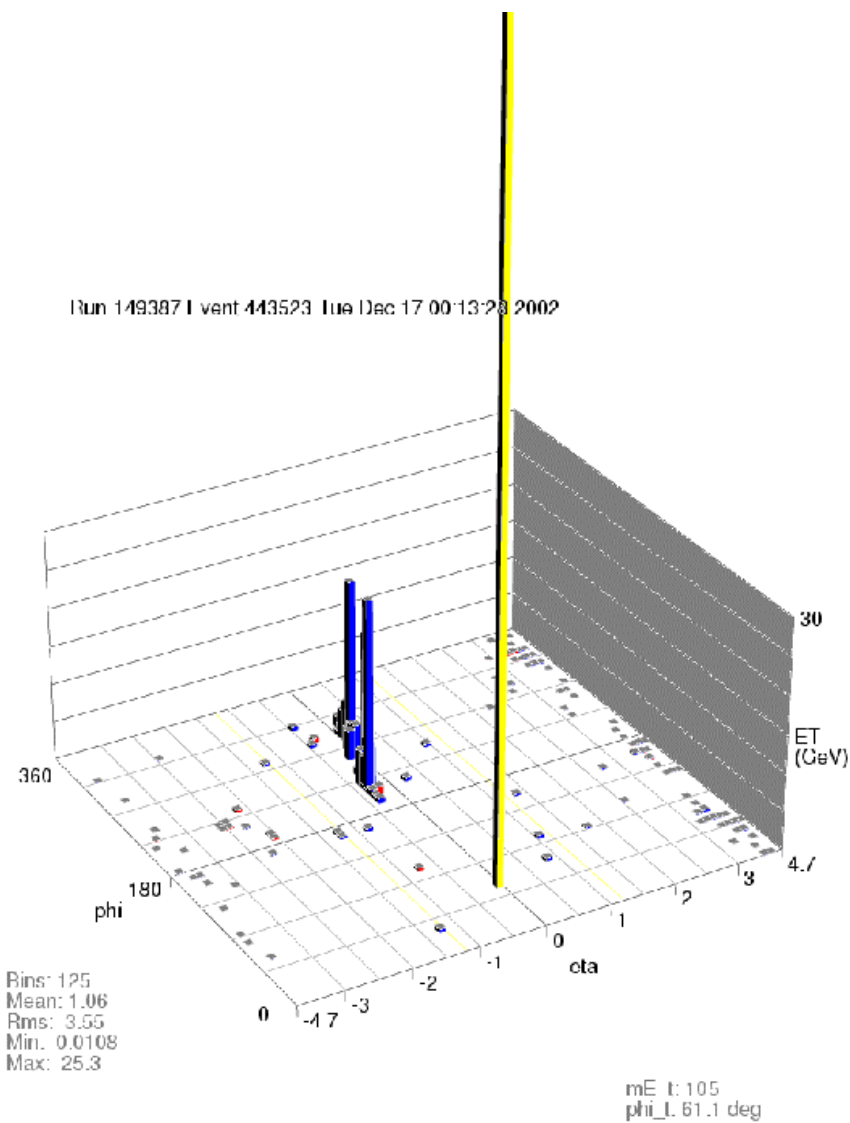
DØ Run II Preliminary





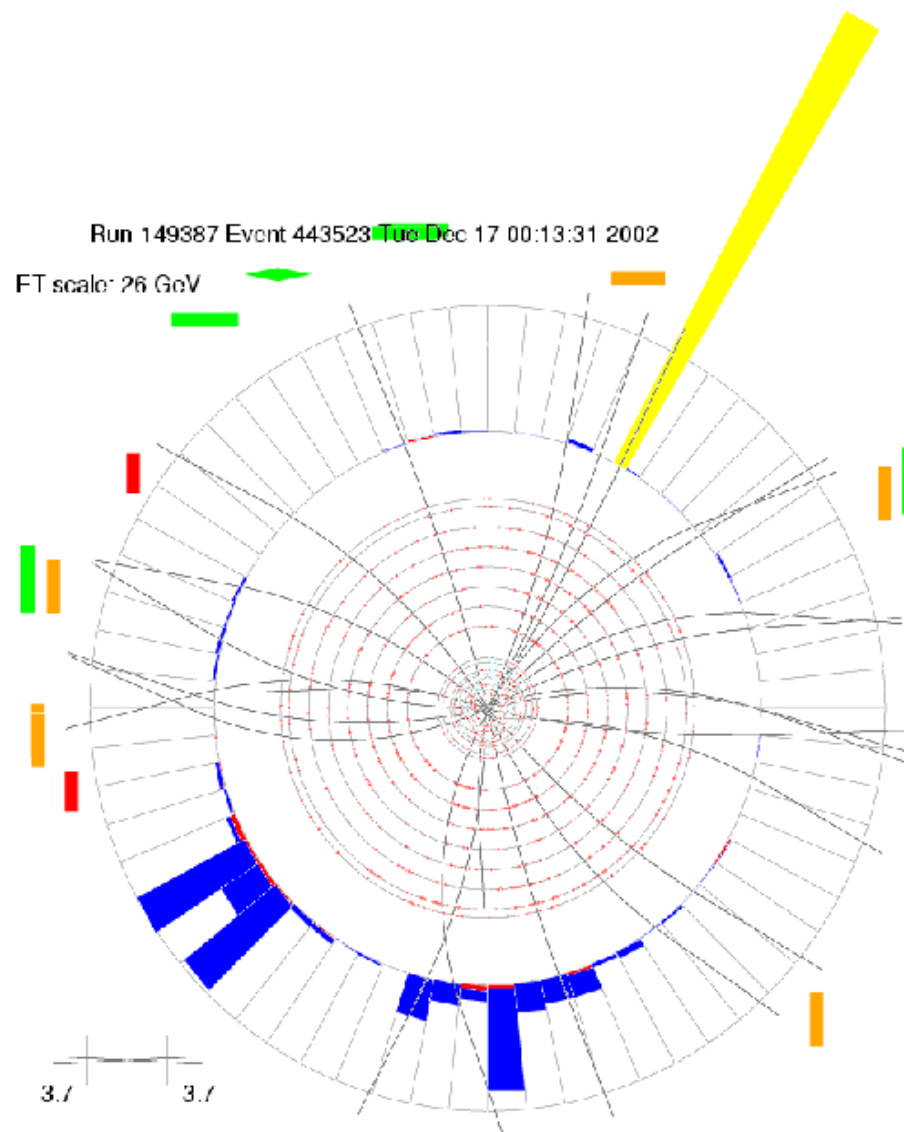


# Jets + Missing $E_T$ Event



Run 149387 Event 443523 Tue Dec 17 00:13:31 2002

FT scale: 26 GeV



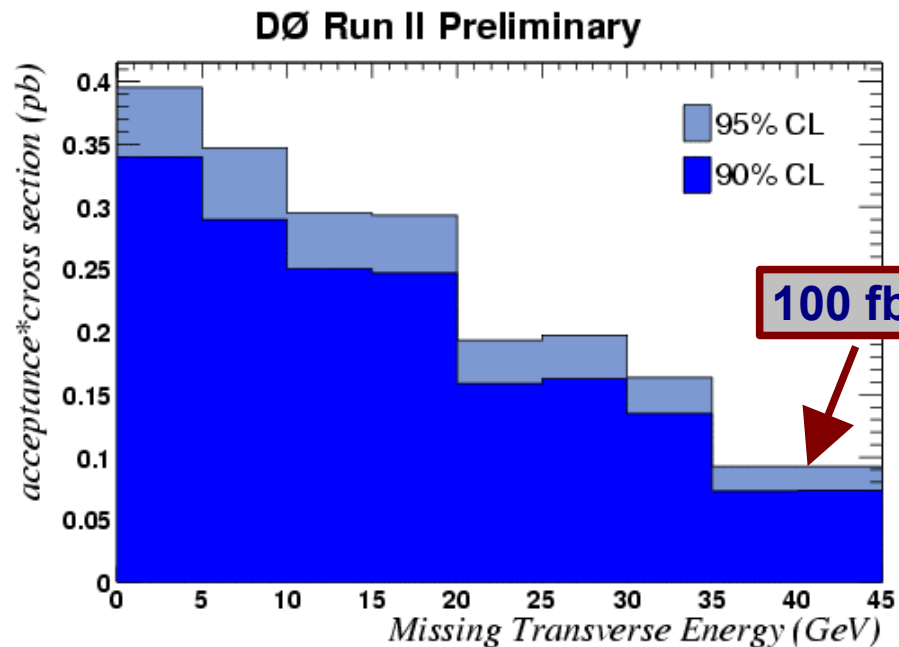
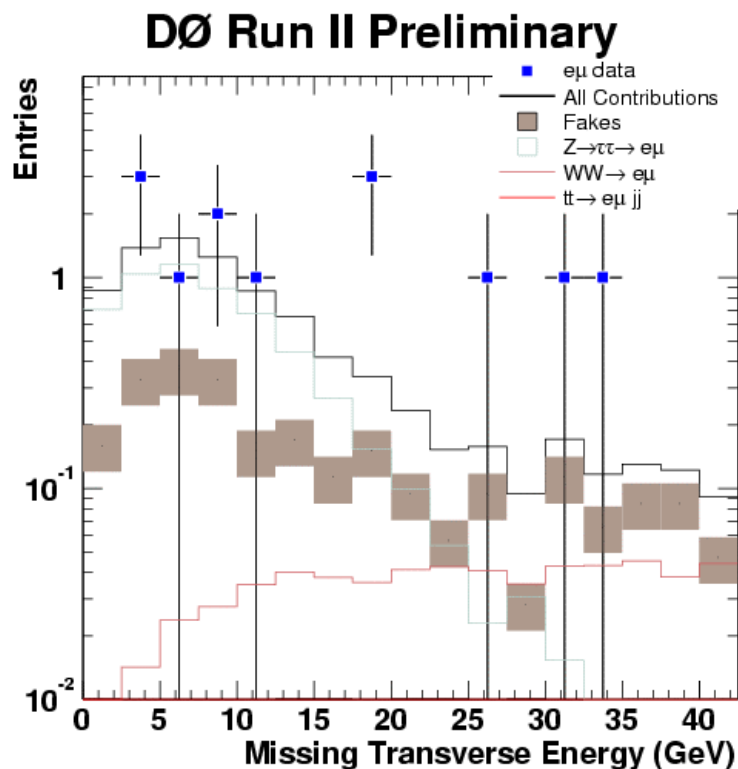


# $e \mu + X$



- **Very low backgrounds → pursue analysis in a model-independent way**
- **Require  $e, \mu p_T > 15$  GeV, estimate fake rates from data, physics backgrounds from simulation**
- **$\sim 30 \text{ pb}^{-1}$**

## Cross-section Limit as a function of missing $E_T$





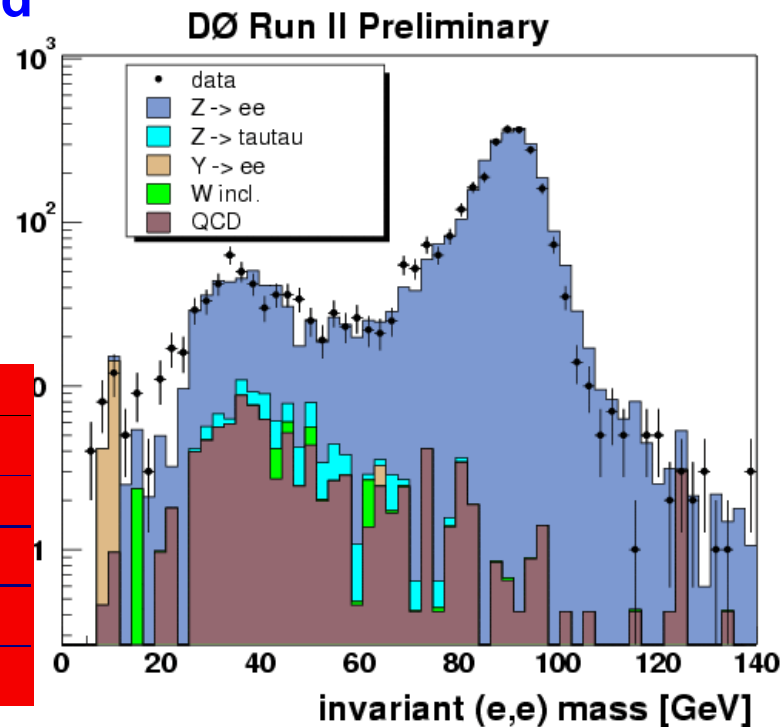
# eel + X



- Start from dielectron sample: understand trigger, reconstruction, simulation
- Also verify determination of QCD fake background (from data)

~40 pb<sup>-1</sup>

	Backgrounds	Data
$p_T(e_1) > 15 \text{ GeV}, p_T(e_2) > 10 \text{ GeV}$	$3216 \pm 43.2$	3132
$10 \text{ GeV} < M(ee) < 70 \text{ GeV}$	$660.2 \pm 19.1$	721
$M_T > 15 \text{ GeV}$	$96.4 \pm 8.1$	123
Add. Isolated Track, $p_T > 5 \text{ GeV}$	$3.2 \pm 2.3$	3
Missing $E_T > 15 \text{ GeV}$	$0.0 \pm 2.0$	0



- Typical selection efficiency for SUGRA 2-4%
- Sensitivity still about factor 7 away from extending excluded area in parameter space → working on improving efficiency, adding channels



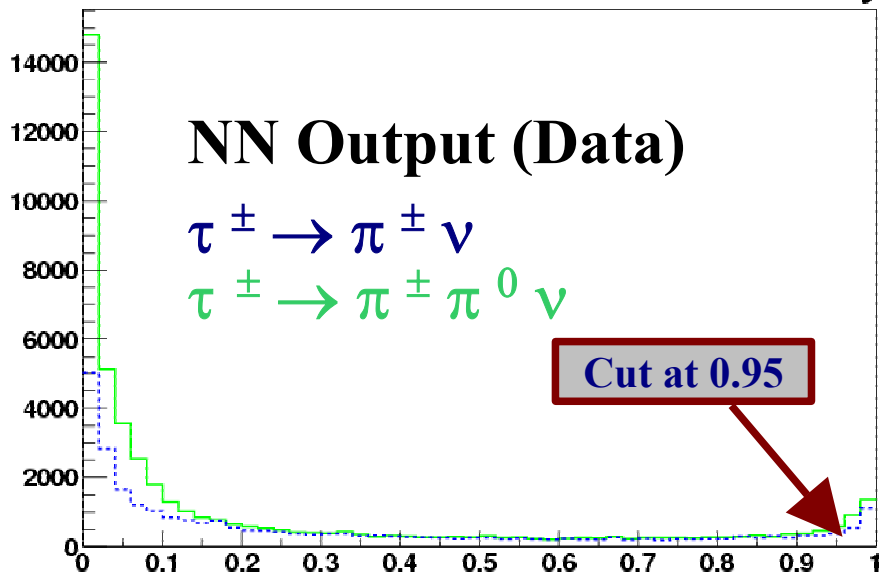
# $Z \rightarrow \tau \tau \rightarrow e h X$



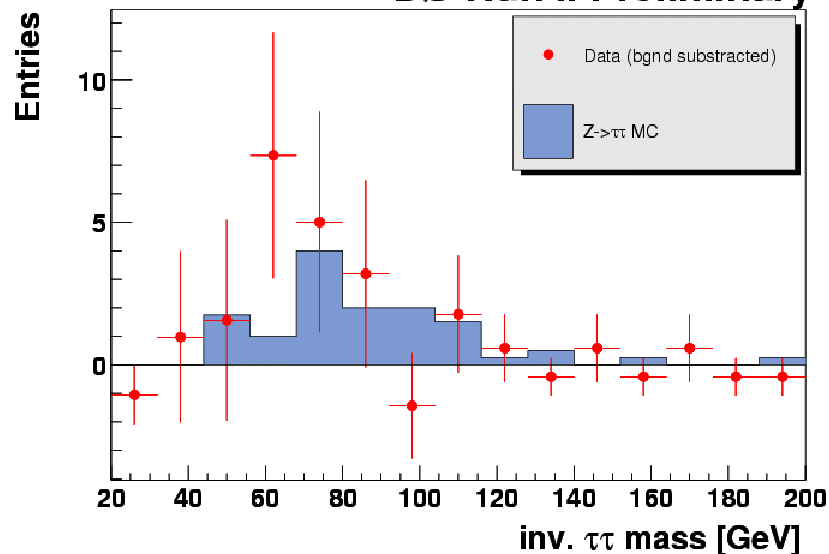
- In  $\sim 50 \text{ pb}^{-1}$ , select events with an electron ( $p_T(e) > 12 \text{ GeV}$ ) and a narrow jet of  $p_T > 7 \text{ GeV}$  with a single track of  $p_T > 1.5 \text{ GeV}$
- Use neural net to further discriminate between QCD and tau jets

- Reconstruct di-tau invariant mass using the assumption that the tau direction = visible tau daughter direction
- Finally, subtract same-sign  $e-\tau$  events from opposite sign

DØ Run II Preliminary



DØ Run II Preliminary





# Gauge Mediated SUSY Breaking

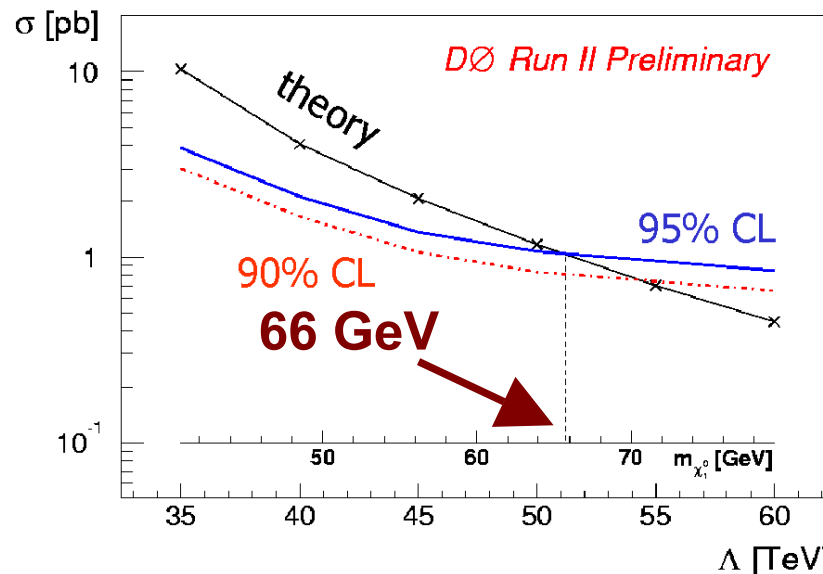
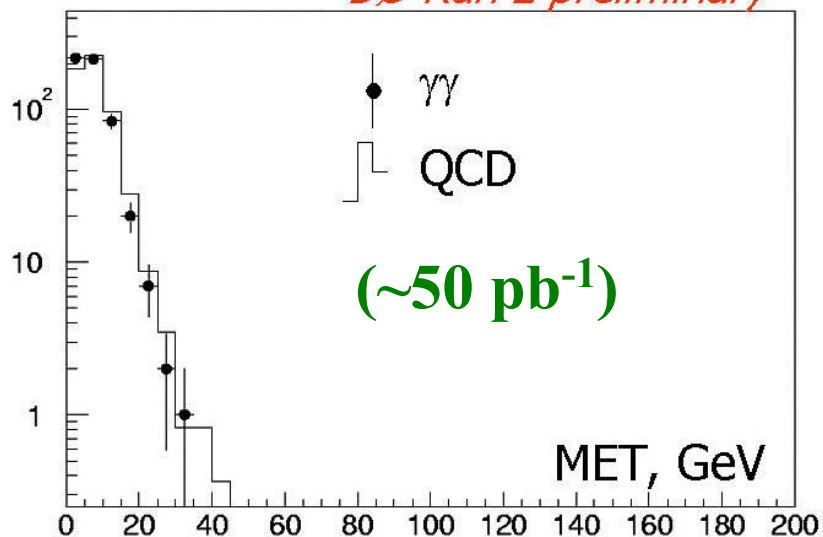


- LSP is a light ( $\ll 1$  eV) gravitino, phenomenology driven by nature of the NLSP
- "Bino" NLSP will lead to signatures with 2 photons and missing  $E_T$

➤  $\sim 50 \text{ pb}^{-1}$ , close to Run I limit!

Theory =  
 "Snowmass"  
 slope:  
 $M = 2\Lambda$ ,  
 $N_5 = 1$ ,  
 $\tan \beta = 15$ ,  
 $\mu > 0$

*DØ Run 2 preliminary*

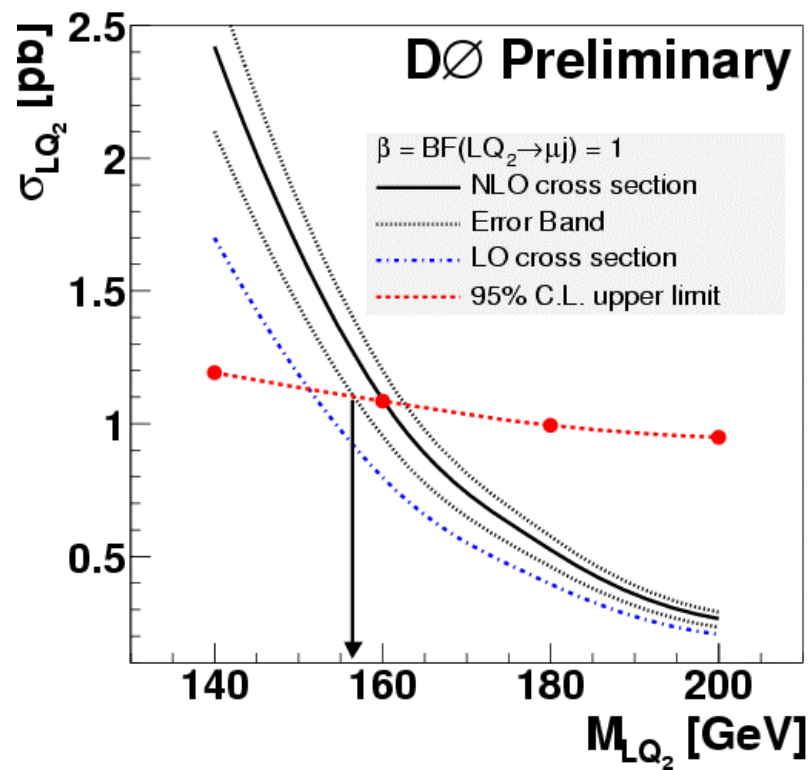
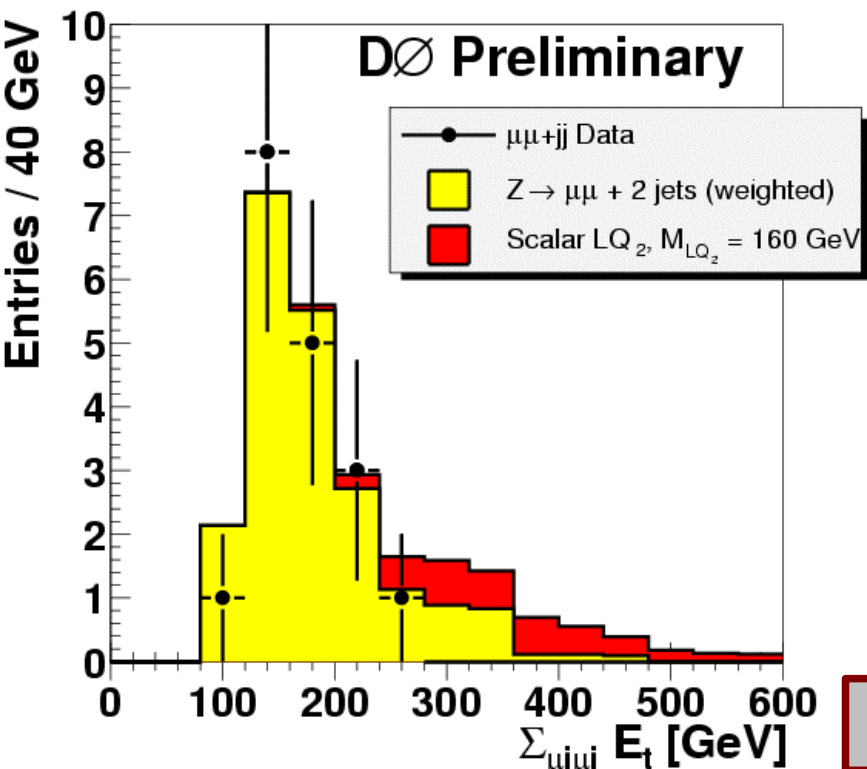




# Second Generation Leptoquarks



- In this analysis, assume  $\beta = 1$ , i.e. leptoquarks decay to  $\mu + c$  or  $s$
- Pair production  $\rightarrow$  2 muons + 2 jets



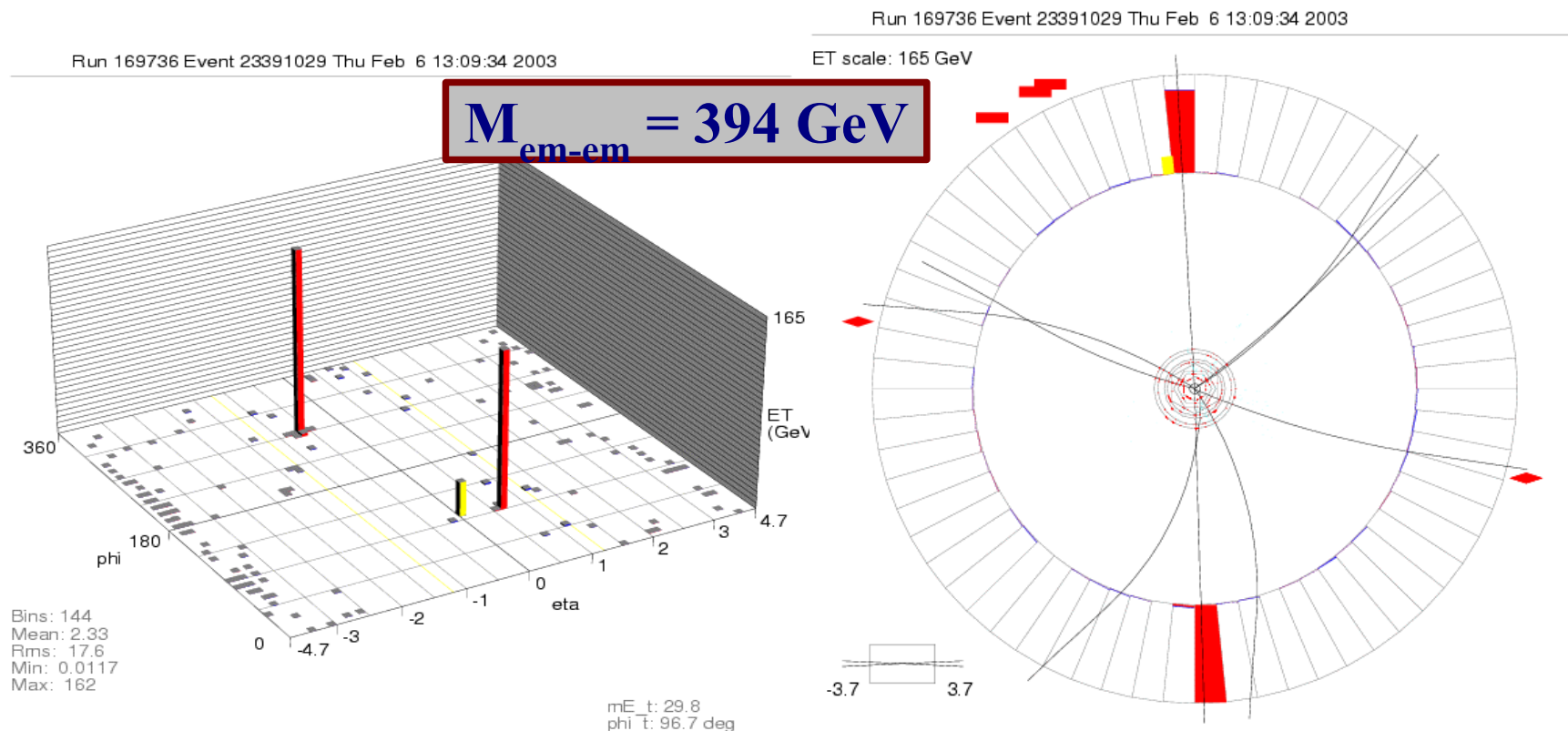
$M_{LQ_2} > 157$  GeV ( $\sim 30$  pb $^{-1}$ ) (Run I: 200 GeV)





## Dielectrons and diphotons

- Require 2 electromagnetic objects with  $p_T > 25$  GeV, missing  $E_T < 25$  GeV
- Estimate physics backgrounds from MC, fake rates from data





# Large Extra Dimensions

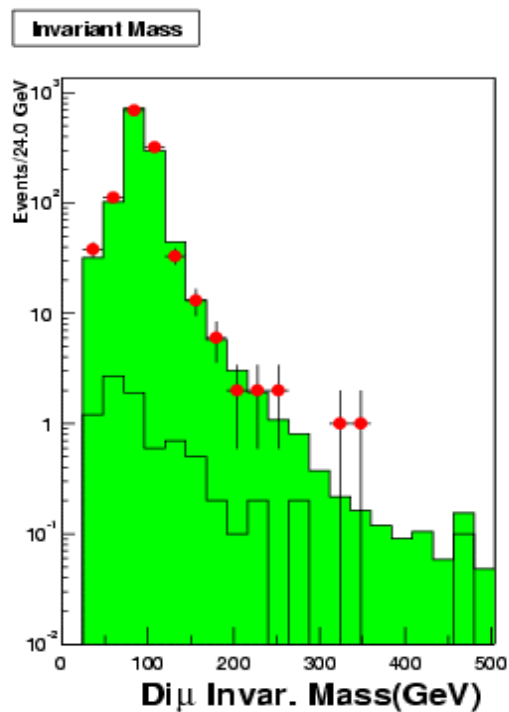
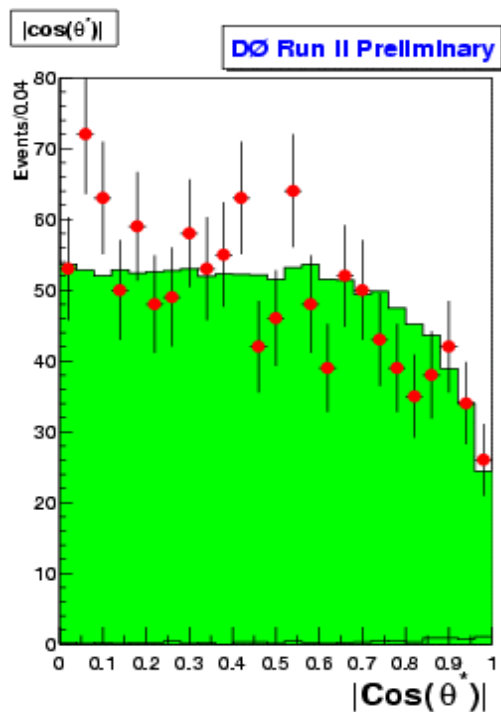


## Dimuons

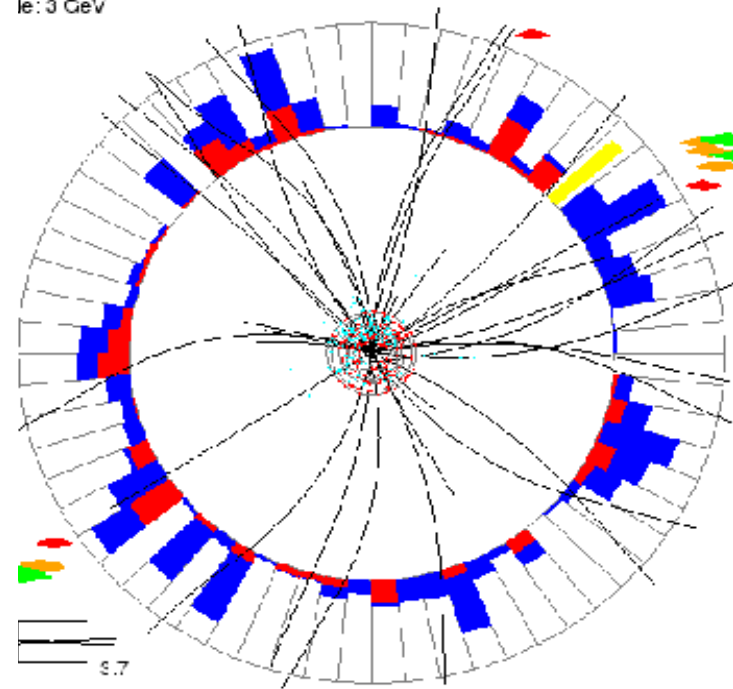
- Require two muons with  $p_T > 15$  GeV, impose  $M_{\mu\mu} > 40$  GeV

$M_{\mu\mu} = 460$  GeV

700 16649 Even. 441 1544 Mon Feb 17 13:00:47 2000



le: 3 GeV



0 500 GeV



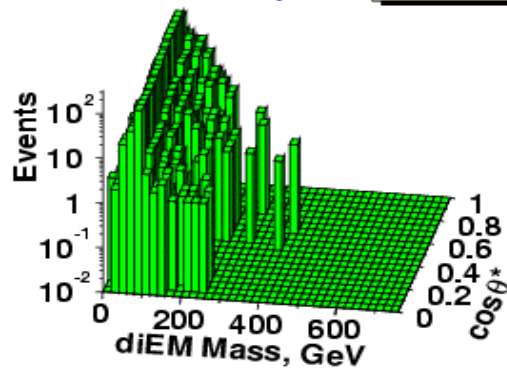
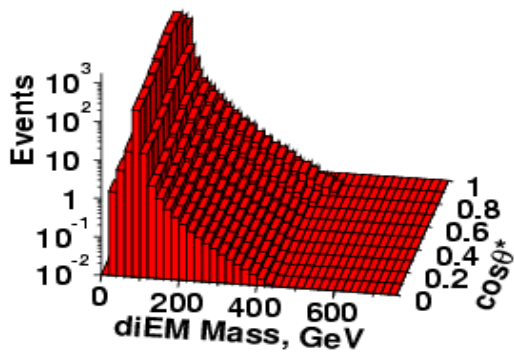
# Large Extra Dimensions



SM Prediction

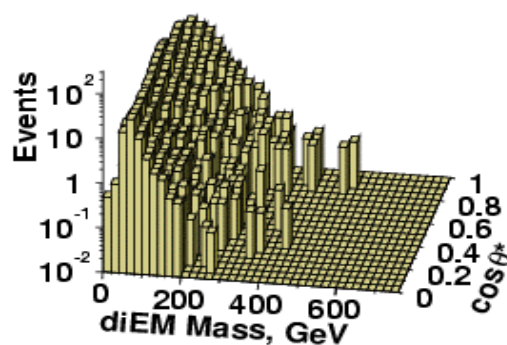
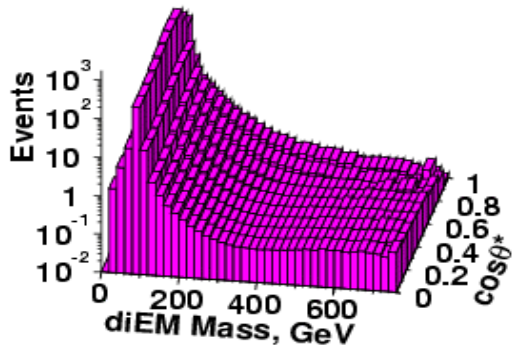
DØ Run II Preliminary

Data



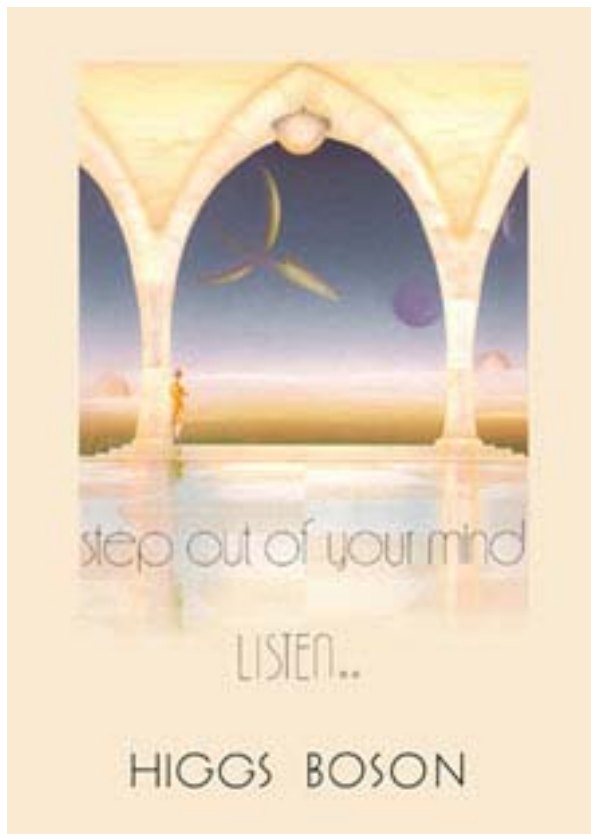
ED Signal

QCD Background



**Di-em result is close to Run 1**  
**Dimuon is a new channel**  
**Both similar to individual LEP limits**

Formalism	GRW	HLZ, n=2	HLZ, n=7	Hewett, $\lambda = +1$
di-EM ( $\sim 50 \text{ pb}^{-1}$ )	1.12	1.16	0.89	1
dimuon ( $\sim 30 \text{ pb}^{-1}$ )	0.79	0.68	0.63	0.71



## Higgs Boson Keyboards

HOME FHP Records

Close this window

Here are some of my favourite albums.

- [Pat Metheny](#)  
[Pat Metheny Group](#)  
[As Falls Wichita, So Falls Wichita Falls](#)  
[American Garage](#)  
[First Circle](#)
- [Yellow Jackets](#)  
[Blue Hats](#)
- [Bill Bruford](#)  
[Master Strokes 1978-1985](#)
- [Frank Zappa](#)  
[Apostrophe](#)  
[Rozz & Elsewhere](#)
- [Steely Dan](#)  
[Royal Scam](#)  
[Aja](#)
- [Brand X](#)  
[Masques](#)  
[Do They Hurt?](#)

I am basically a classically trained pianist who started playing at the age of eight. Prominent influences as a child were Chopin and Rachmaninov although my step father being a Hi Fi fanatic during the 60s and 70s meant that I was occasionally subjected to the odd Hammond A Go Go record, I think I'm just about getting over that now.

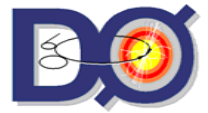
My life started to change from about the age of twelve when I first encountered progressive rock. It seems unbelievable now but that encounter was actually Led Zeppelin II. A friend of mine bought it out the desire to become fashionable and I strung along through fear of being left out. I remember thinking it was the biggest load of bollocks I'd ever heard, however I did at a later date recognise it's originality and it was out of this desire for originality that would be the driving force of my life.

to be continued...

## Higgs Boson is the name of a British musician

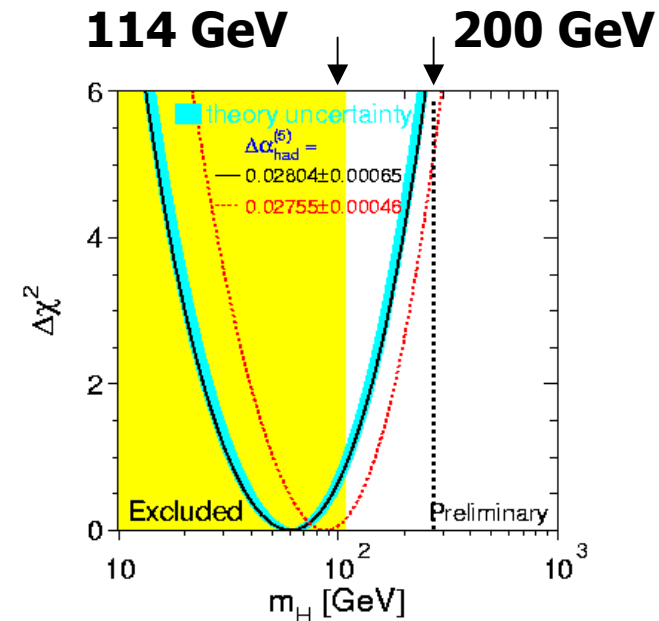


# Searching for the Higgs



➤ Focus has been on experiments at the LEP  $e^+e^-$  collider at CERN

- precision measurements of parameters of the W and Z bosons, combined with Fermilab's top quark mass measurements, set an upper limit of  $m_H \sim 200$  GeV
- direct searches for Higgs production exclude  $m_H < 114$  GeV





# Higgs Production and Decay

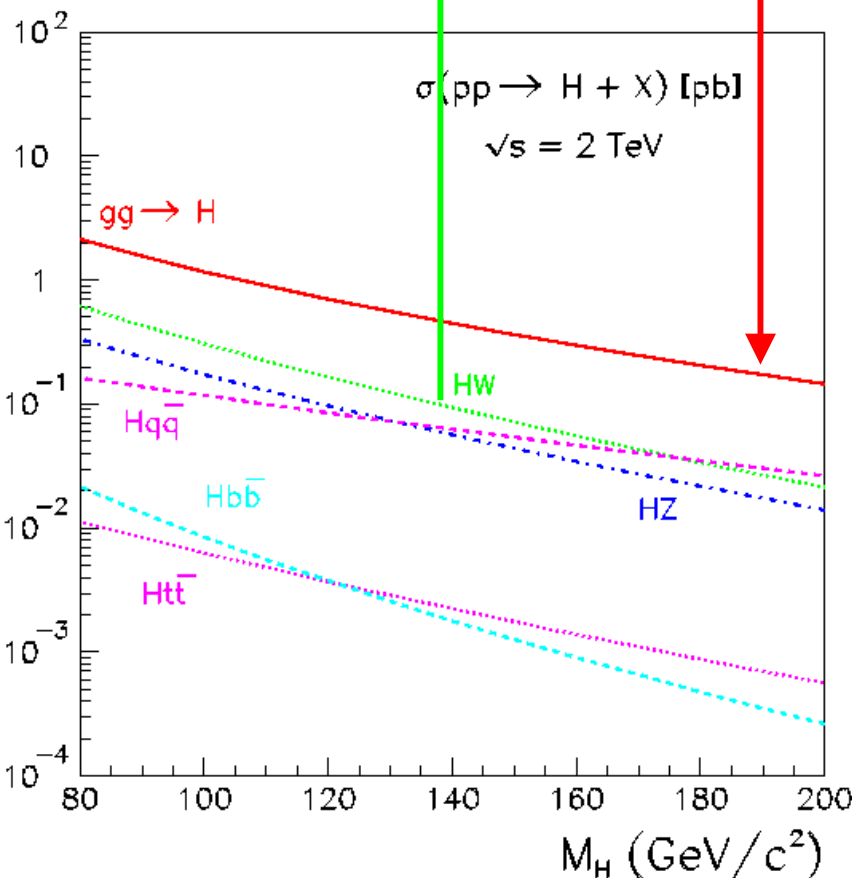


**Gluon Fusion: high background**

➤ For  $M_H < 135$  GeV,  $H \rightarrow bb$  dominates

**Associated Production: better rejection**

- $WH \rightarrow l\nu bb$ 
  - backgrounds:  $Wbb$ ,  $WZ$ ,  $tt$ , single  $t$
- $WH \rightarrow qqbb$ 
  - overwhelmed by QCD background
- $ZH \rightarrow ll bb$ 
  - backgrounds  $Zbb$ ,  $ZZ$ ,  $tt$
- $ZH \rightarrow \nu\nu bb$ 
  - backgrounds QCD,  $Zbb$ ,  $ZZ$ ,  $tt$



➤ For  $M_H > 135$  GeV,  $H \rightarrow WW$  dominates

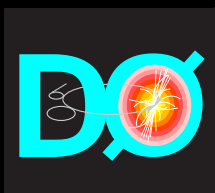
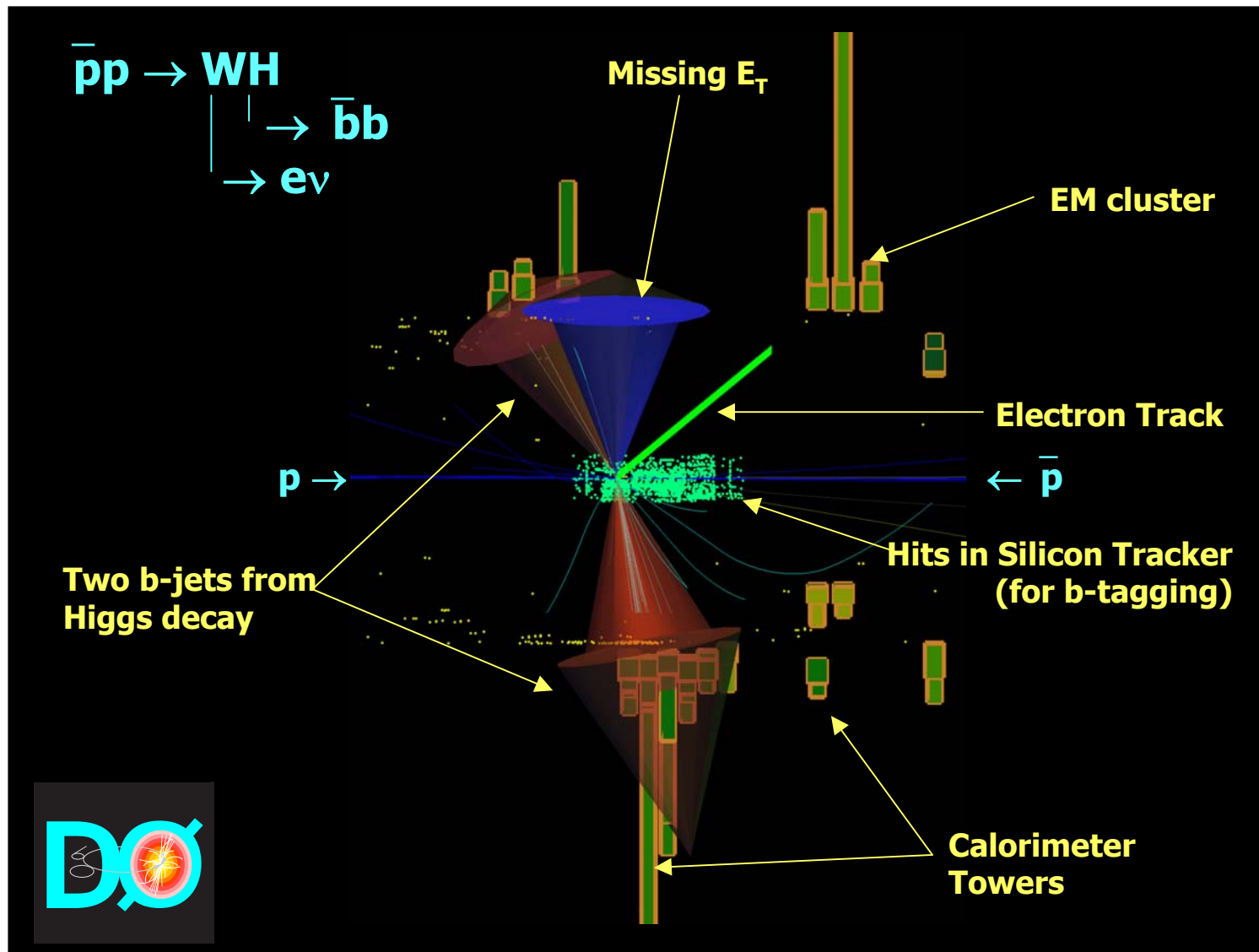
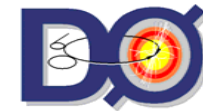
- $gg \rightarrow H \rightarrow WW^*$ 
  - backgrounds: Drell-Yan,  $WW$ ,  $WZ$ ,  $ZZ$ ,  $tt$ ,  $tW$ ,  $\tau\tau$

**Tools:** **b-tagging efficiency**  
**Di-jet mass resolution**





# SM Decay Higgs Signature





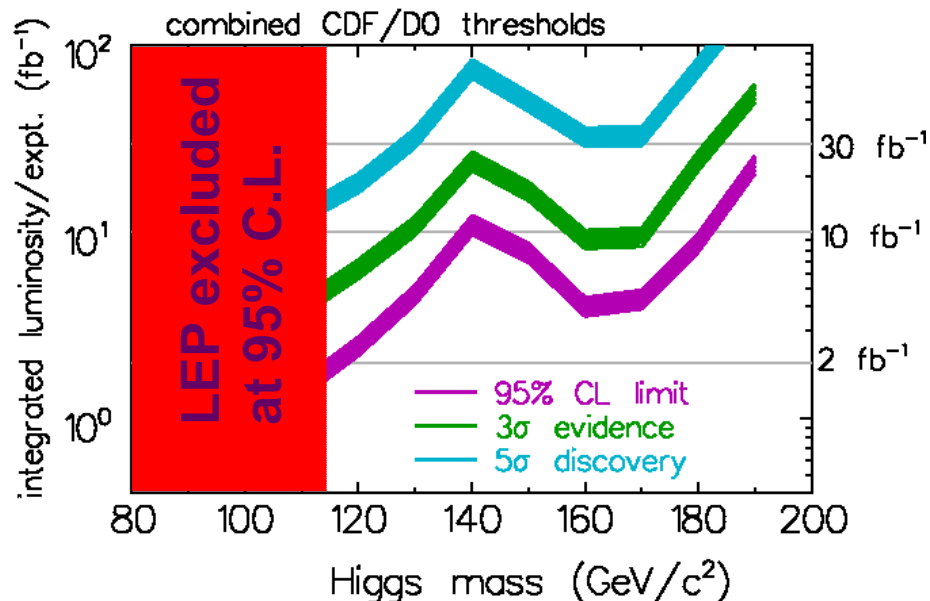
➤ The Higgs discovery potential for Run II has been evaluated (hep-ph/0010338, using a parameterized fast detector simulation)

➤ **Discovery at  $3\text{-}5\sigma$  can be made**

➤ **Combine all channels, data from both D0 and CDF**

➤ **Improve understanding of signal and background processes**

➤ **b-tagging, resolution of  $M_{bb}$**



➤ **Advanced analysis techniques are vital**

➤ **Largest luminosity required to discover Higgs**

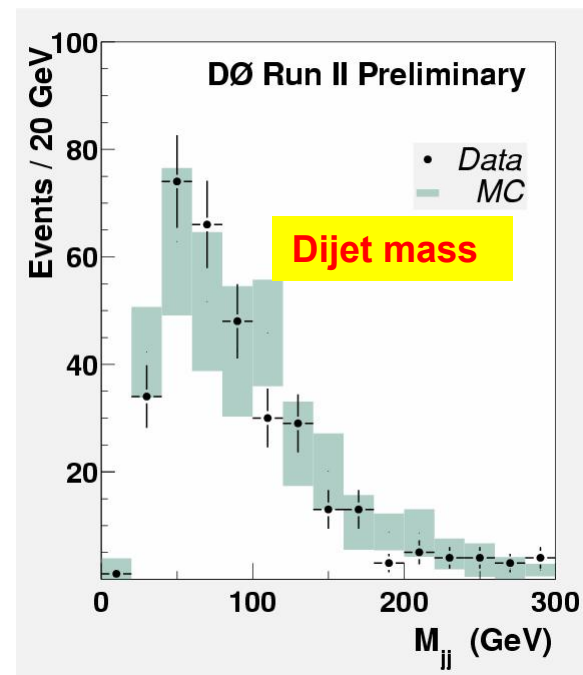
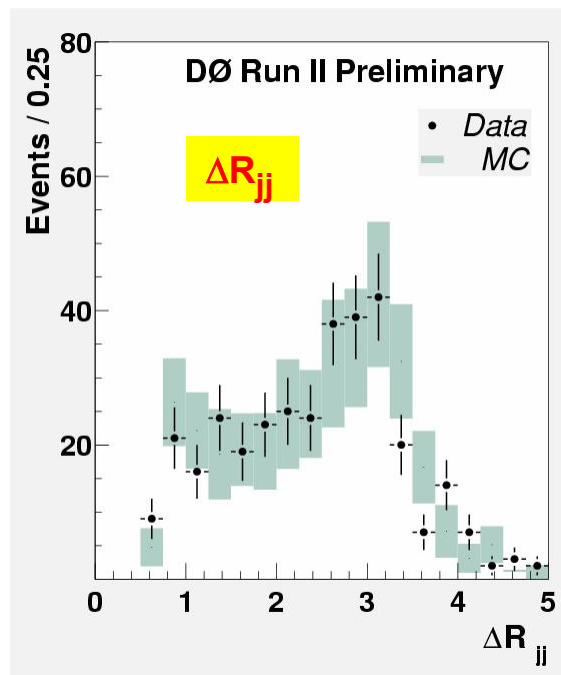
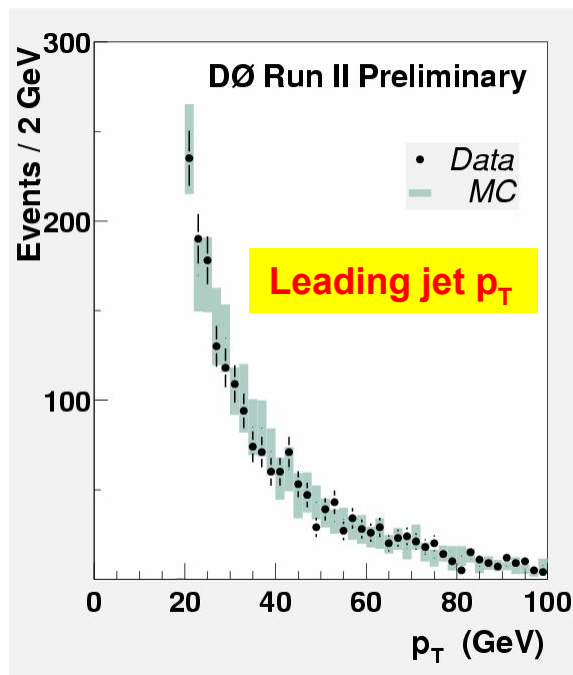
➤ **Results of simulations consistent with SHWG expectations**



# W + jets

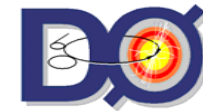


- First step towards  $W(\rightarrow \ell\nu) + H(\rightarrow bb)$  measurement
- Major background source from  $W + \text{di-jets}$
- Basic selection, based on  $35 \text{ pb}^{-1}$ 
  - Isolated high  $p_T$  lepton (e or  $\mu$ ) with large missing  $E_T$
  - Jets  $p_T > 20 \text{ GeV}$  in  $|\eta| < 2.5$

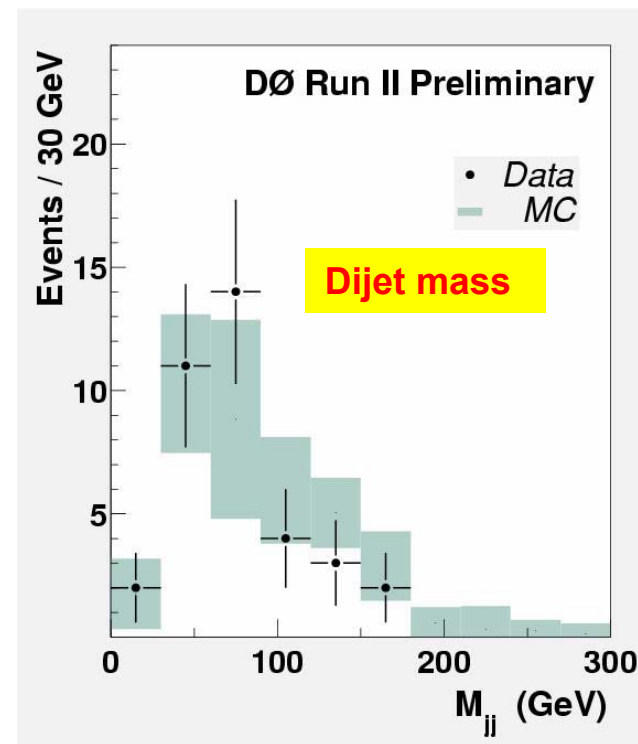
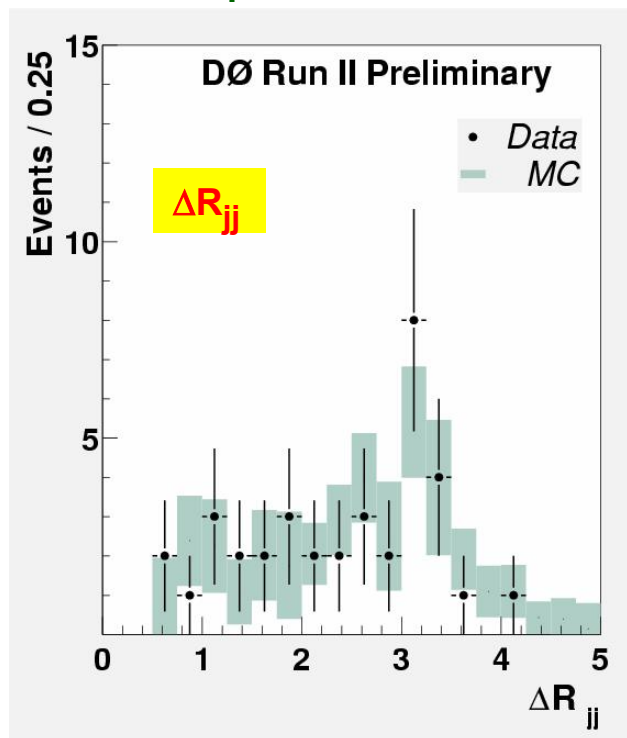




# Z + jets

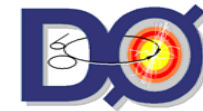


- First step towards  $Z(\rightarrow \text{leptons}) + H(\rightarrow \text{bb})$  measurement
- Major background source from  $Z + \text{di-jets}$
- Basic selection, based on  $35 \text{ pb}^{-1}$ 
  - 2 high  $p_T$  leptons ( $ee$  or  $\mu\mu$ )
  - Mass of dileptons consistent with Z mass
  - Jets  $p_T > 20 \text{ GeV}$  in  $|\eta| < 2.5$



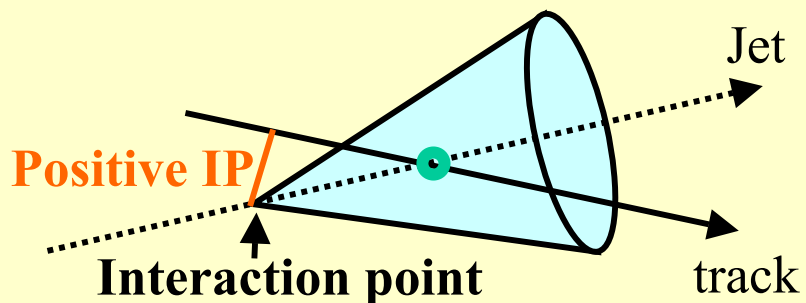


# b-tagging

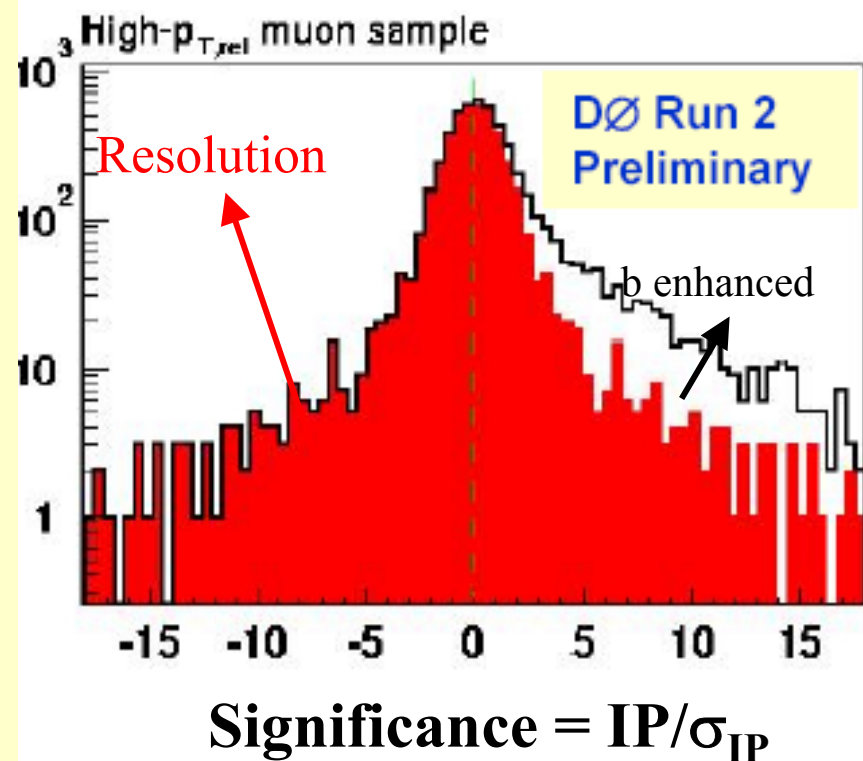
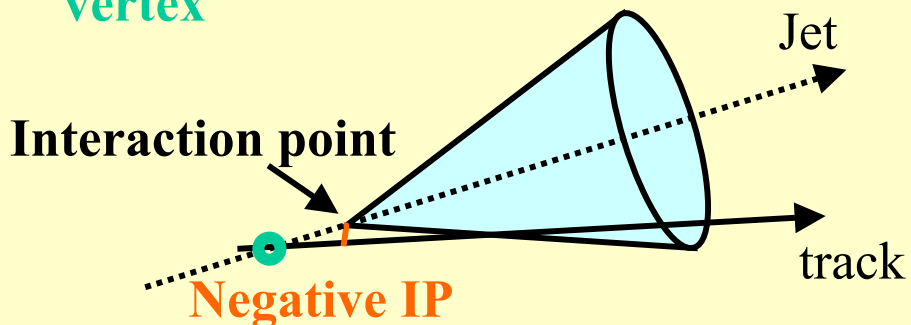


- b-tagging explores IP significance method
- Lepton from semileptonic decay of b is very useful

- Impact Parameter  $> 0$   
→ track crosses jet axis after primary vertex



- Impact Parameter  $< 0$   
→ track crosses jet axis before primary vertex





# $H \rightarrow WW^{(*)} \rightarrow e^+e^- \nu \nu$ final states

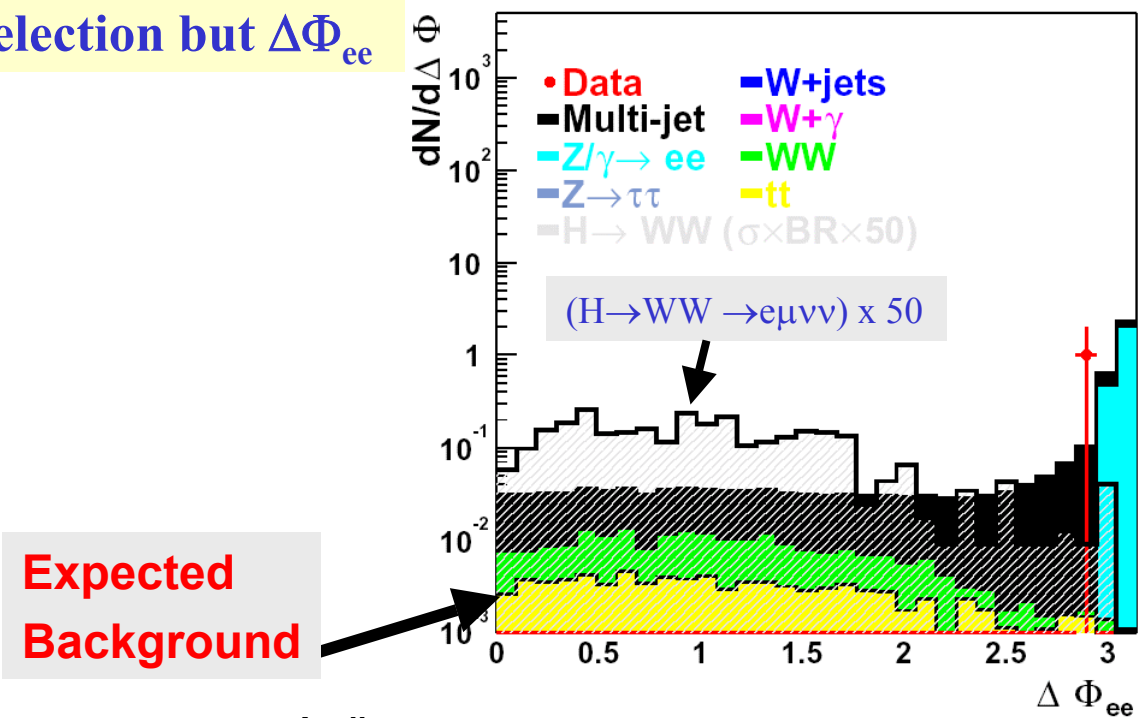


$L=44.5 \text{ pb}^{-1}$   
 Selection optimized  
 for  $m_H = 120 \text{ GeV}$

Efficiency =  $\sim 8\%$

Event selection	Expected background	DATA
Lepton ID, $p_T > 10, 20 \text{ GeV}$	$2748 \pm 42 \pm 245$	2753
$m_{ee} < m_H / 2$	$264 \pm 18.6 \pm 4.3$	262
$E_T > 20 \text{ GeV}$	$12.3 \pm 2.5 \pm 0.7$	11
$m_T < m_H + 20 \text{ GeV}$	$3.6 \pm 1.4 \pm 0.2$	1
$\Delta\Phi_{ee} < 2.0$	$0.7 \pm 1.4 \pm 0.1$	0

After all selection but  $\Delta\Phi_{ee}$







# Candidate of $H \rightarrow WW^{(*)} \rightarrow e^+e^- \nu \nu$

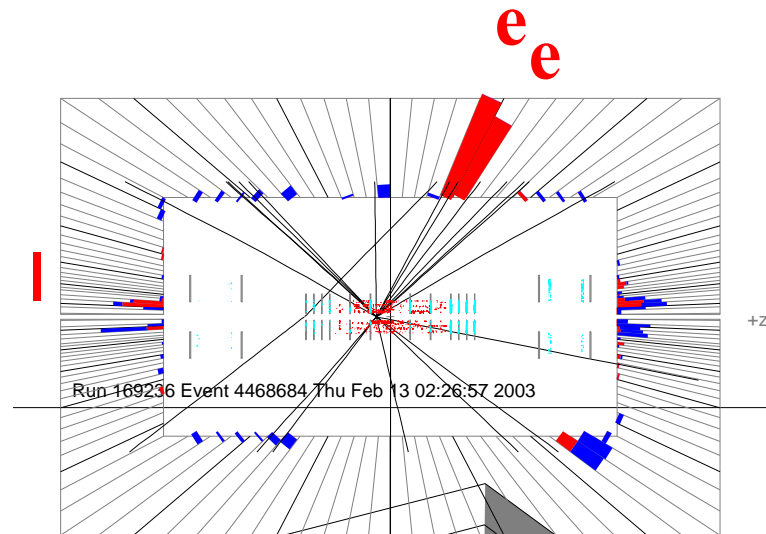
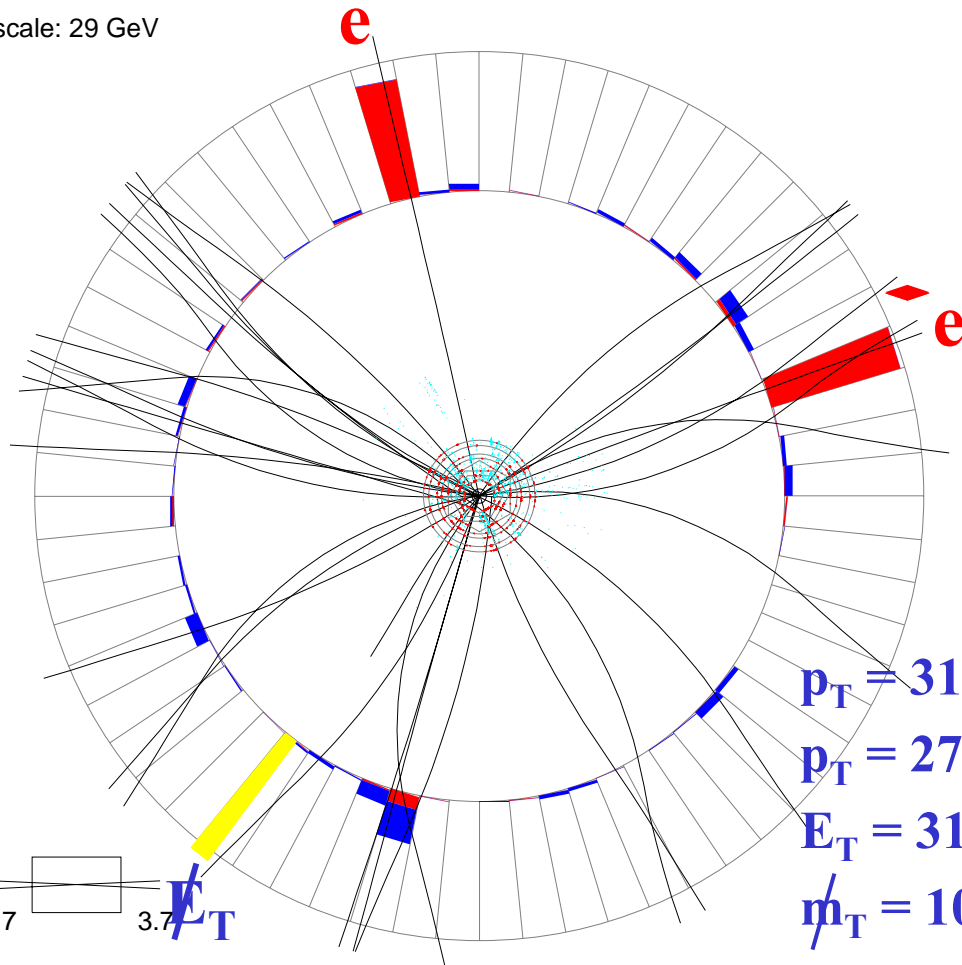


Run 169236 Event 4468684 Thu Feb 13 02:26:58 2003

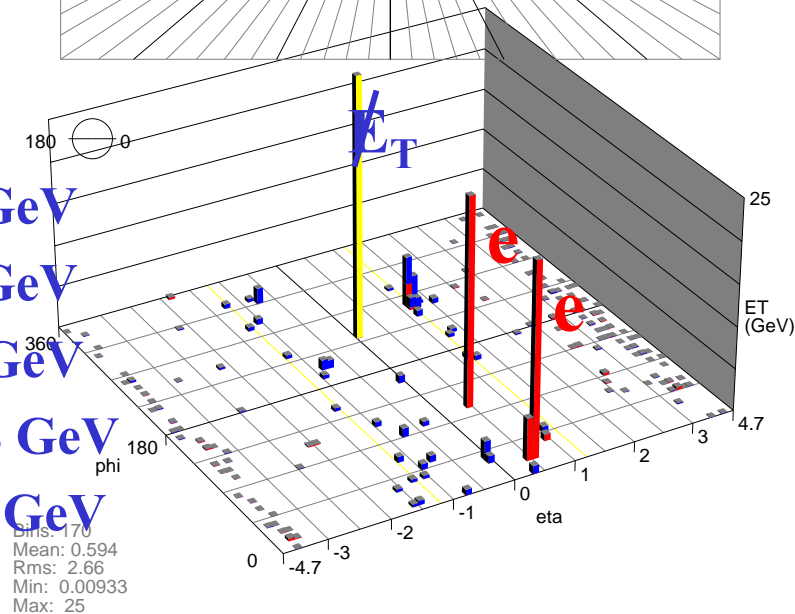
Run 169236 Event 4468684 Thu Feb 13 02:26:57 2003

E scale: 30 GeV

ET scale: 29 GeV



$p_T = 31.1 \text{ GeV}$   
 $p_T = 27.3 \text{ GeV}$   
 $E_T = 31.2 \text{ GeV}$   
 $m_T = 106.8 \text{ GeV}$   
 $M_{ee} = 36.1 \text{ GeV}$   
 $\Delta\Phi_{ee} = 1.43$

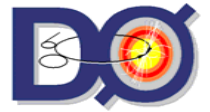


Bins: 170  
 Mean: 0.594  
 Rms: 2.66  
 Min: 0.00933  
 Max: 25

$mE_t: 31.2$   
 $\phi_t: 232 \text{ deg}$



# Summary



- **DØ has been taking data since March 1, 2001**
- **The effects of increased center-of-mass energy and an improved detector can now be seen in improved sensitivity**
- **DØ continues to search for New Physics and Higgs**