# Recent Results and Prospects for High $p_T$ Physics at DØ

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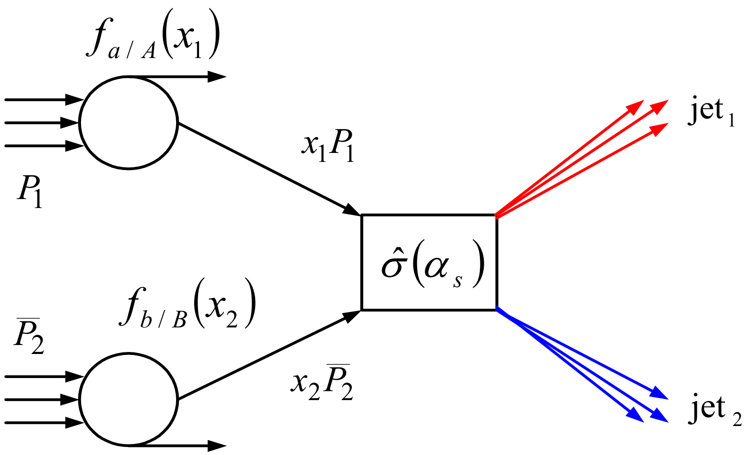
# Outline

- New results and prospects for
  - QCD
  - Electroweak
  - Top
  - Higgs
  - New Phenomena (a sample)
    - Accelerator and detector performance, as well as B physics topics, are covered in separate talks

# Jet Production




$$\sigma(p_1\overline{p}_2 \to 2 \text{ jets}) = \sum_{abcd} \int dx_1 dx_2 f_{a/A}(x_1) f_{b/B}(x_2) \hat{\sigma}(ab \to cd)$$

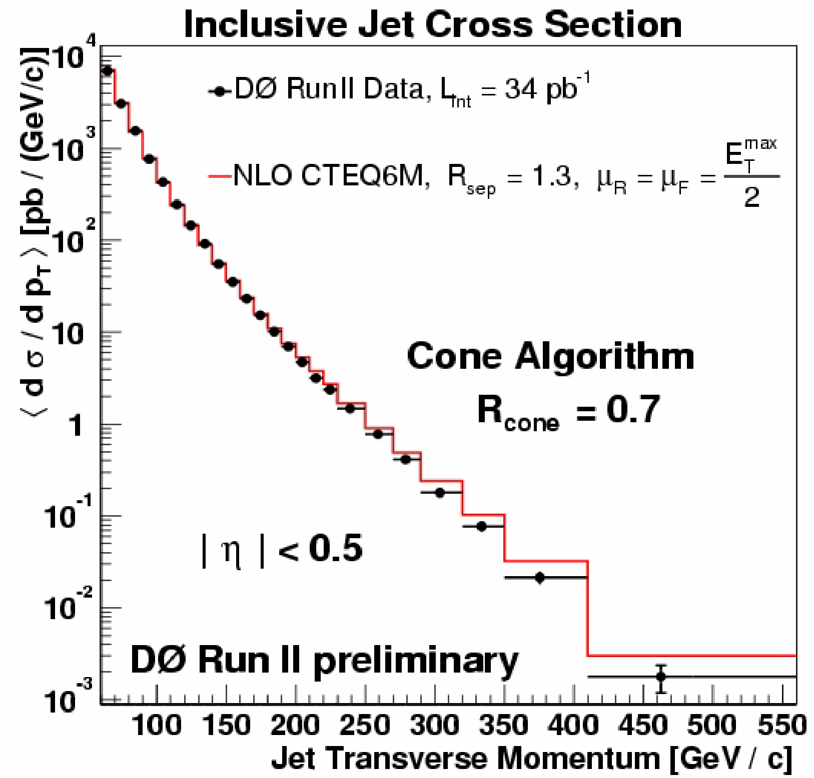
- What is the value of $\alpha_s$ ?
- How well do we know the proton structure ? PDFs: f( x)
- Is NLO ( $\alpha_s^3$ ) sufficient?
- Are quarks composite structures?

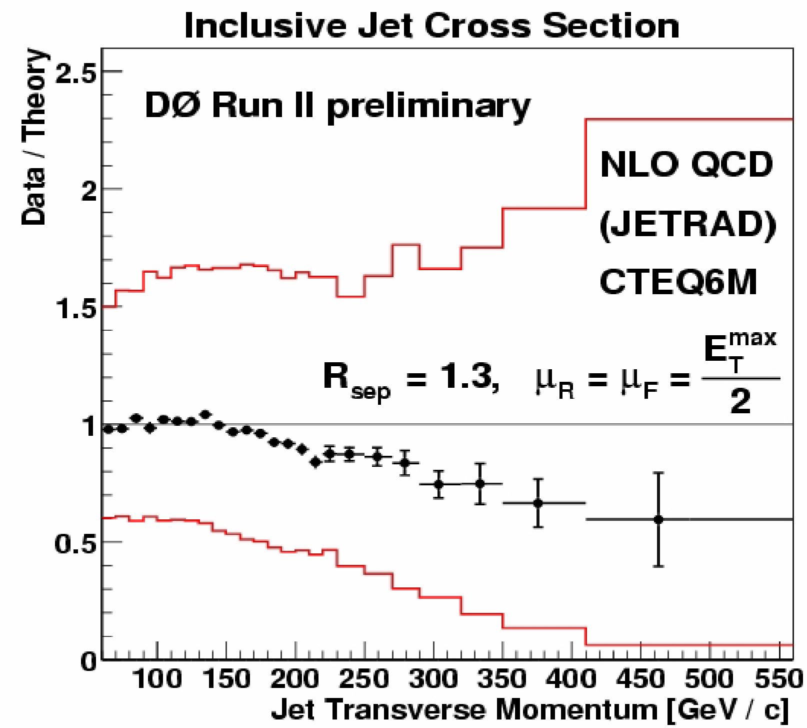
- Inclusive Jet Cross Section in the central rapidity region
  - Most basic test of QCD
  - Extraction of $\alpha_s$
  - PDFs at high $Q^2$
  - proton structure at large x
  - test of compositeness
- Dijet Mass Spectrum
  - Search for resonances

# Inclusive Jet Cross Section

$\sqrt{s}$ = 1.96 TeV, |η| < 0.5

$$\frac{N_{jet}}{\varepsilon \Delta E_T \Delta\eta \int L dt} \text{ vs. } E_T$$



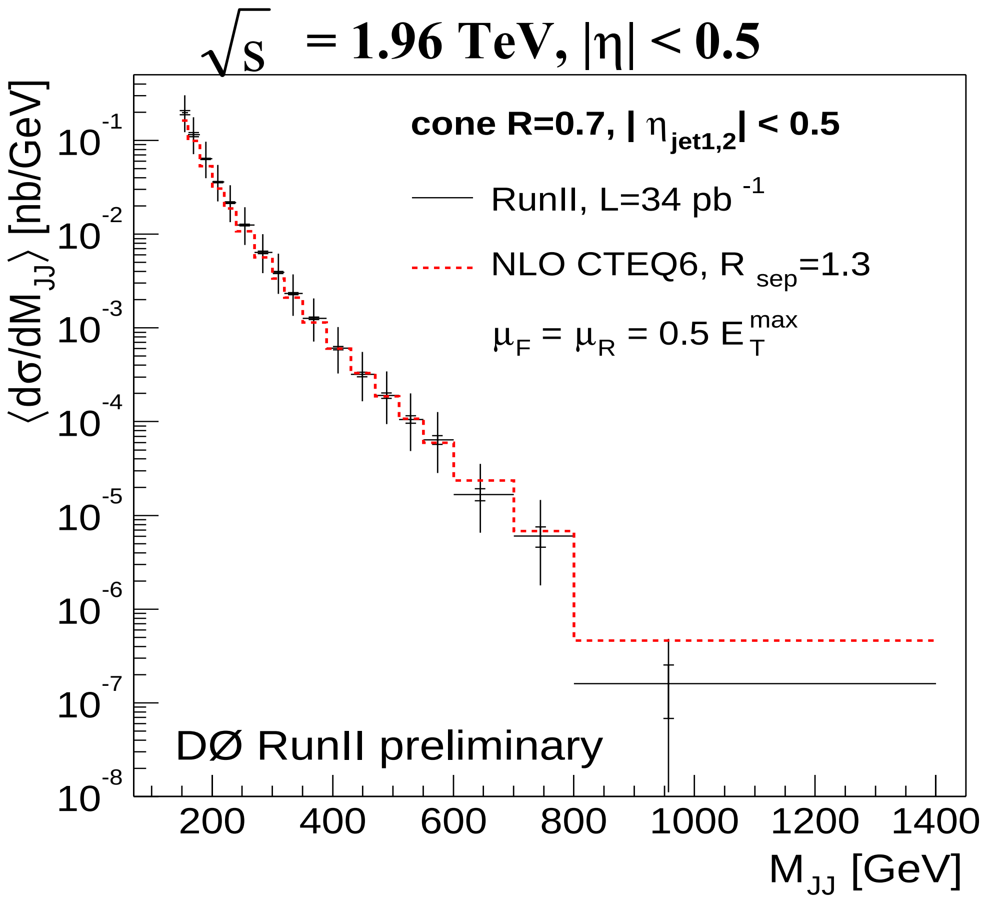




JES error (9% at $p_T$ < 200 GeV) and Luminosity error (10%) not shown

JES error shown as a band. Luminosity error (10%) not shown

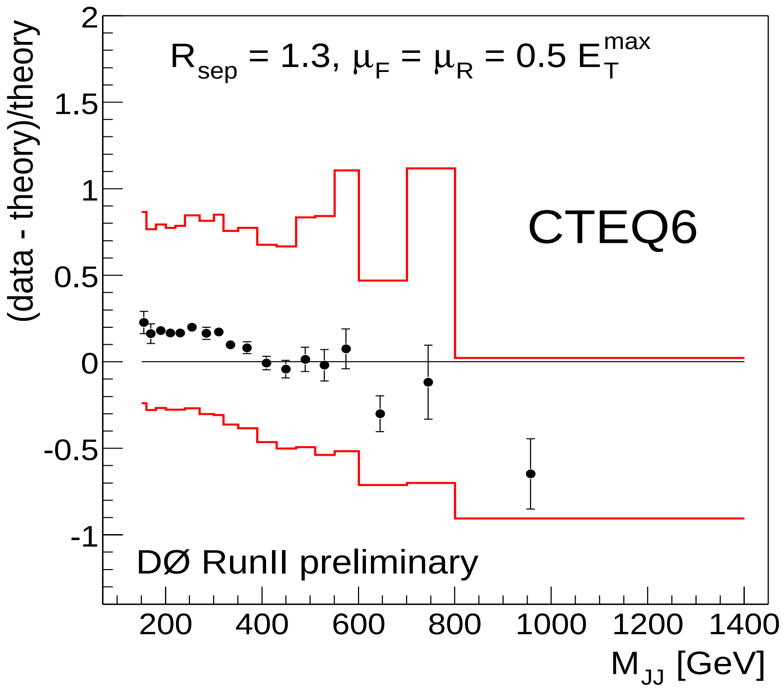
Good agreement between data and NLO QCD

# Dijet Mass Cross Section




Total error (except luminosity) shown

$$\frac{N_{jet}}{\varepsilon \Delta M_{jj} \Delta \eta \int L dt} \text{ vs. } M_{jj}$$



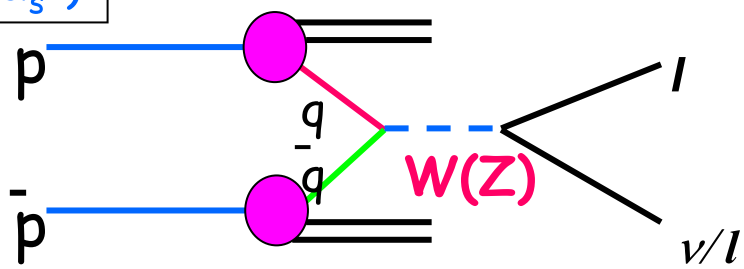

JES error shown as a band

Luminosity error of 10% not shown

Good agreement between data and NLO QCD

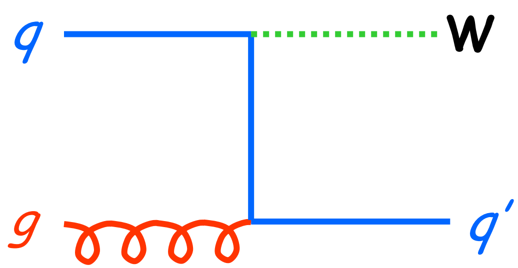
# W/Z production

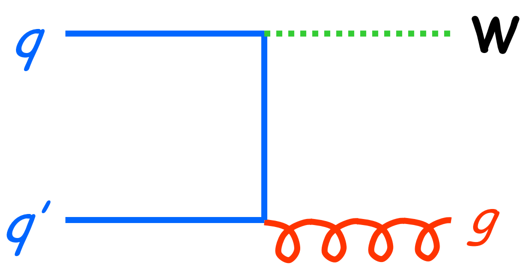
$O(\alpha_s^0)$




- Production dominated by $q\bar{q}$ annihilation
- Due to very large $p\bar{p} \rightarrow jj$ production, need to use leptonic decays
  - (BR ~ 11% (W), ~3% (Z) per mode)

$O(\alpha_s)$



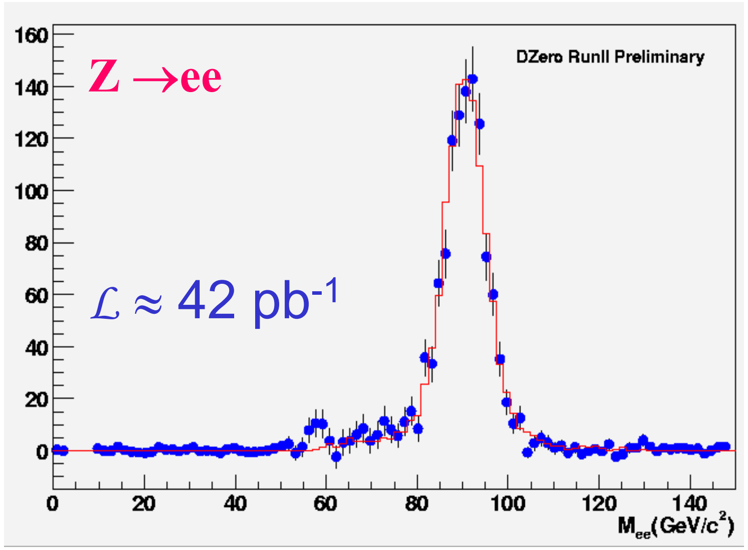

## Modifications due to QCD corrections:

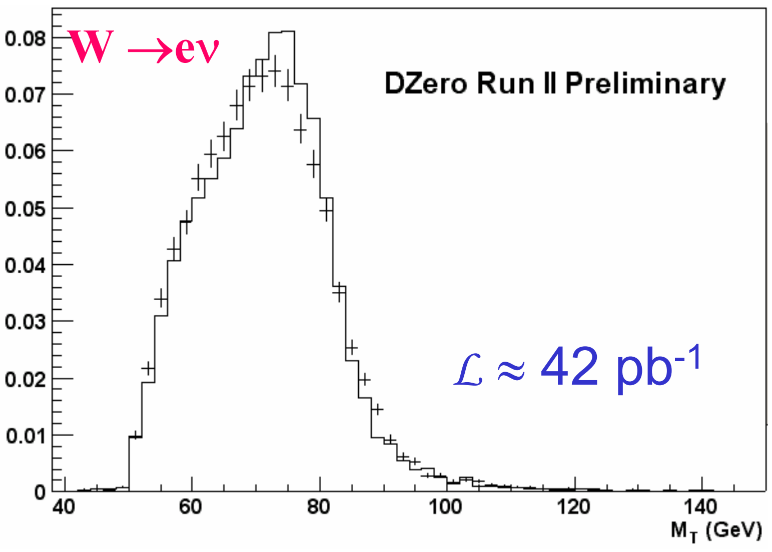
- Boson produced with transverse momentum ( $\langle P_T \rangle \sim 10$ GeV )
- Boson + jet events possible ( W + 1 jet ~ 7%, $E_T^{jet} > 25$ GeV )
- Inclusive cross sections larger (K factor ~ 18%)
- Boson decay angular distribution modified

## Benefits of studying QCD with W&Z bosons:

- Distinctive event signatures
- Low backgrounds
- Large $Q^2$ ($Q^2 \sim Mass^2 \sim 6500$ GeV$^2$)
- Well understood Electroweak Vertex

# W/Z in the electron channel



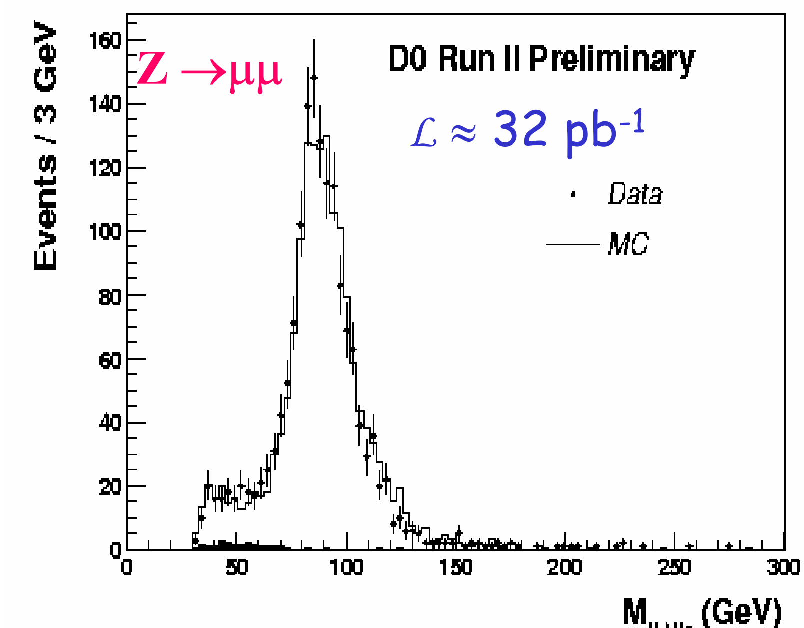

- 1139 Z→ee candidates
  - $|\eta^e|<1.1$, $E_T>25$ GeV, no track match required
- $\varepsilon(Z)\approx 8\%$, bkgd ~ 18%

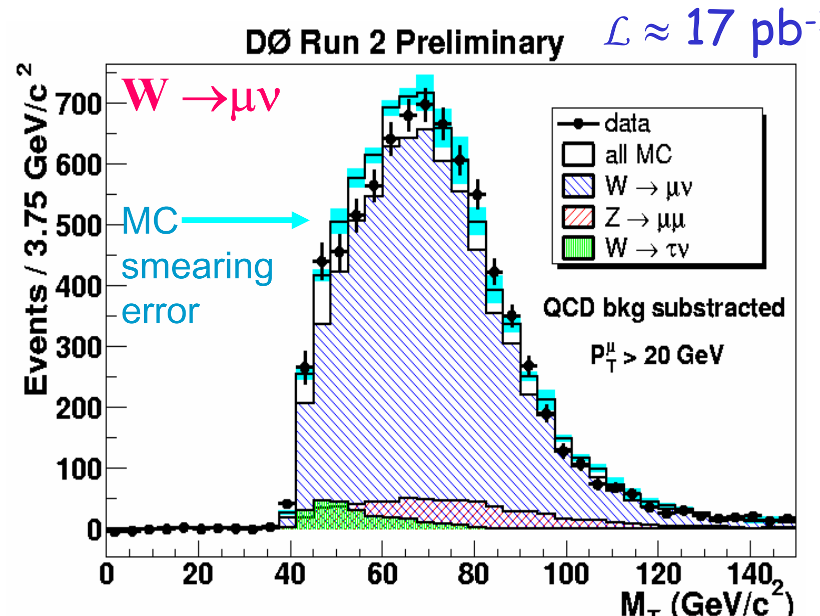
- 27370 W→eν candidates
  - $|\eta^e|<1.1$, $E_T$ & $\not{E}_T$ >25 GeV
- $\varepsilon(W)\approx 16\%$
- bkgd ~ 3% QCD, ~1.5% τ

$$\sigma(W)Br(W \rightarrow e\nu) = 3054 \pm 100(N_W) \pm 86(sys) \pm 305(lumi)\ \ pb$$

$$\sigma(Z)Br(Z \rightarrow ee) = 294 \pm 11(N_Z) \pm 8(sys) \pm 29(lumi)\ \ pb$$

# W/Z in the muon channel



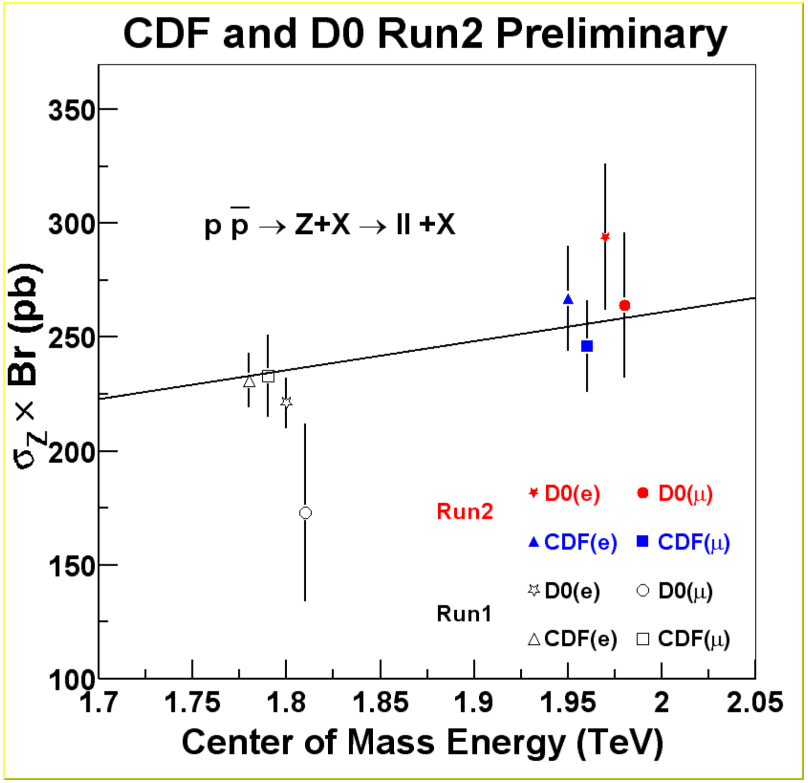

- 1585 $Z \to \mu\mu$ candidates
  - $|\eta^{\mu}|<1.6$, $p_T>15$ GeV
- $\varepsilon(Z)\approx 16\%$, background ~ 1.5%
- Corrected for $Z/\gamma$ interference

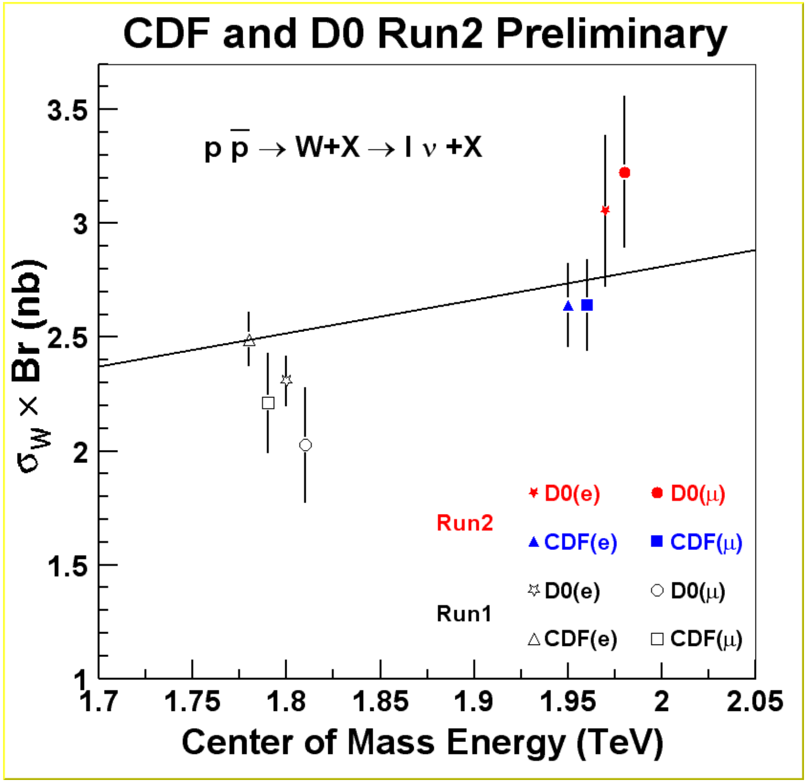
- 7352 $W \to \mu\nu$ candidates
  - $|\eta^{\mu}|<1.6$, $p_T$ & $\not{E}_T > 20$ GeV
- $\varepsilon(W)\approx 13\%$
- bkgd ~6% $b\bar{b}$, 9% Z, 4% $\tau$

$$\sigma(W)Br(W \to \mu\nu) = 3226 \pm 128(stat) \pm 100(sys) \pm 323(lumi)\ \ pb$$

$$\sigma(Z)Br(Z \to \mu\mu) = 264 \pm 7(stat) \pm 17(sys) \pm 26(lumi)\ pb$$

# W/Z Cross Section results



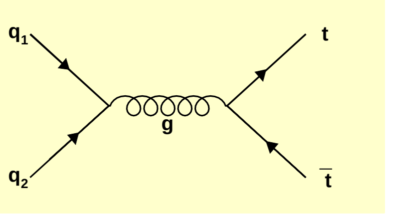



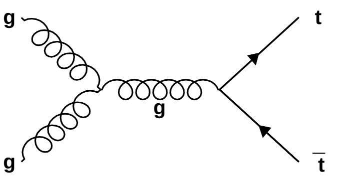

theoretical prediction: C. R. Hamberg, W.L. van Neerven and T. Matsuura, Nucl. Phys. B359 (1991) 343, CTEQ4M PDF

uncertainties dominated by the 10% error on the luminosity

# Top Production and Decay

- Top quarks are produced predominantly in pairs via the strong interaction (EW single top prod. not observed yet)
  - x-sec ~7pb (30% increase w.r.t. RunI)




- Decay BR($t \to Wb$) 100%
- Both W's decay via $W \to l\nu$ (l=e or $\mu$; 5%) "dilepton"
- One W decays via $W \to l\nu$ (l=e or $\mu$; 30%) "lepton+jets"
- Both W's decay via $W \to qq$ (44%) "all hadronic"

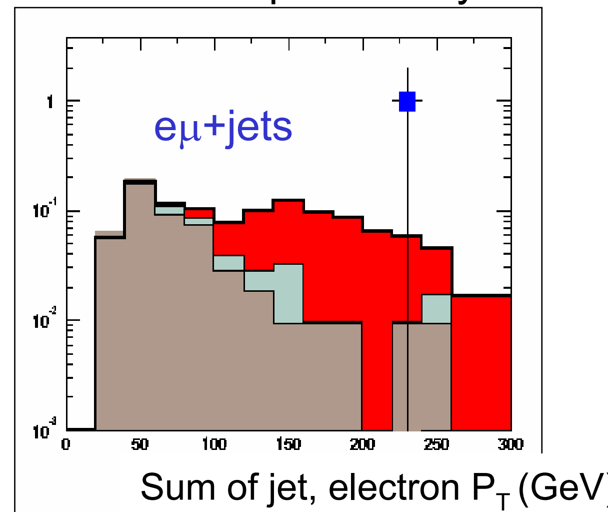
- Seven cross section measurements presented: ee, $\mu\mu$, e$\mu$ (dilepton) e+j and $\mu$+j (topo & SLT) (lepton+jets)
- Work in progress for lifetime tags and mass measurements.

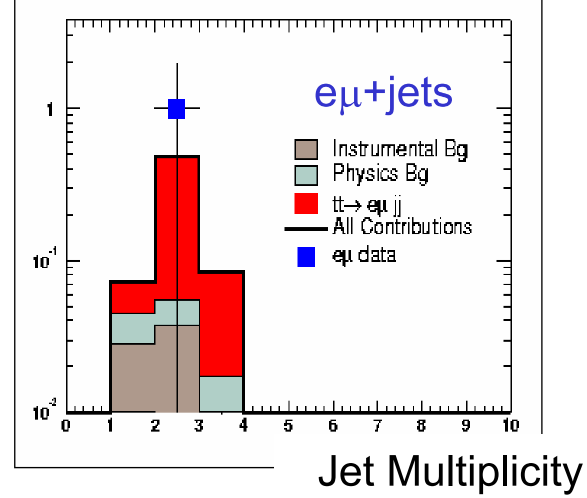
# Dilepton (ee,μμ,eμ) Channels

- Event Selection
  - Two isolated leptons
  - $\not{E}_T$
  - ≥ 2 jets
  - $H_T = \Sigma(E^l_T, E^{jet}_T)$ cut
- Backgrounds
  - WW, $Z \rightarrow \tau\tau$ (from MC)
  - $Z/\gamma^*$, W+jets (from data)

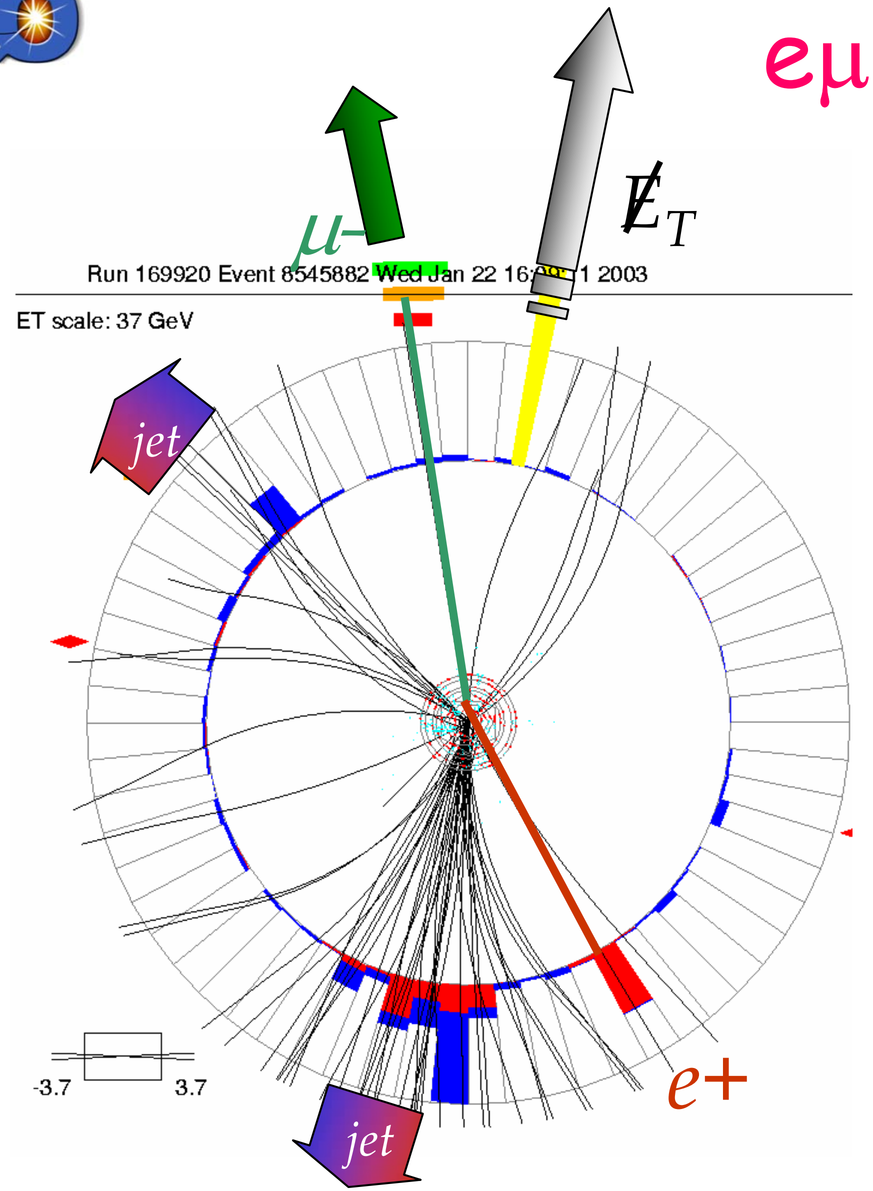
| | ee | eμ | μμ |
|---|---|---|---|
| $\mathscr{L}$ ($pb^{-1}$) | 48 | 33 | 43 |
| Total Background | $1.00 \pm 0.49$ | $0.07 \pm 0.01$ | $0.60 \pm 0.30$ |
| Expected $t\bar{t}$ signal | $0.25 \pm 0.02$ | $0.50 \pm 0.01$ | $0.3 \pm 0.04$ |
| Observed events | 4 | 1 | 2 |

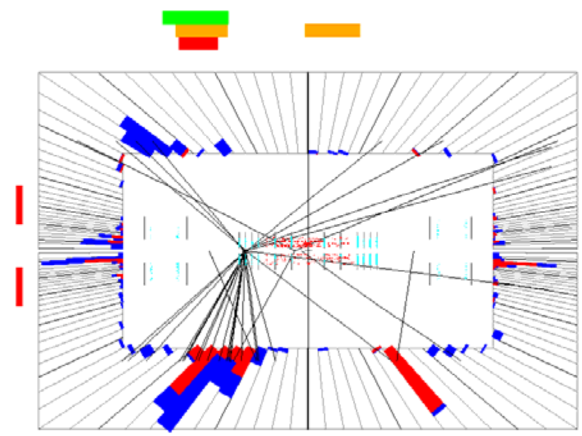
DØ Run II preliminary



# eμ Top candidate

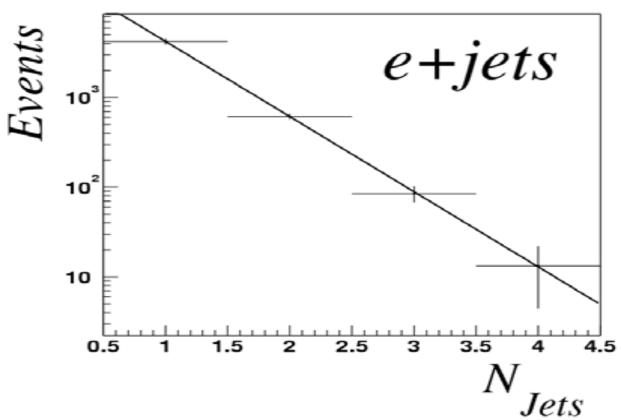


| | |
|---|---|
| e+ | $P_T$= 20.3 |
| μ− | $P_T$= 58.1 |
| j | $P_T$= 141.0 |
| j | $P_T$= 55.2 |
| $\not{E}_T$ | 91 GeV |

# Lepton + Jets (topological)

- Select samples with isolated high $p_T$ leptons and large $\not{E}_T$
- Veto on soft $\mu$ in sample
- QCD background estimated from data
  - Jets ($\pi^0$, $\gamma$) faking electrons
  - HF b's appear isolated
- W+jets background in the 4 jet bin estimated from data by Berends scaling law before topological cuts

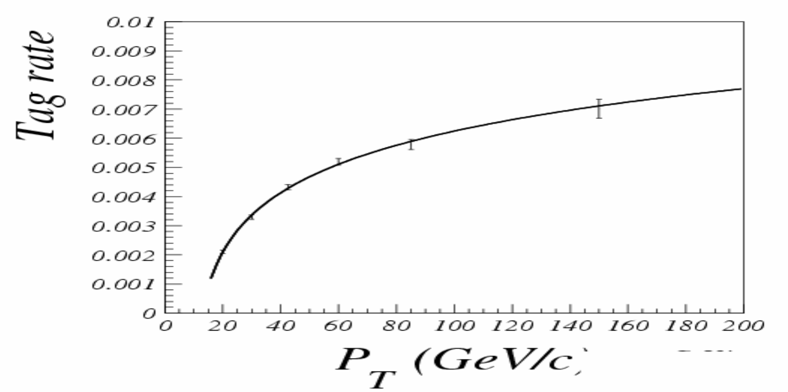



- Topological Cuts
  - $\geq$ 4 jets
  - Aplanarity > 0.06
  - $H_T$(jets) > 180 GeV (e)
  - $H_T$(jets+W$p_T$) > 220 GeV ($\mu$)

| | e+jets | $\mu$+jets |
|---|---|---|
| $\mathscr{L}$ (pb$^{-1}$) | 50 | 40 |
| Total Background | $2.7 \pm 0.6$ | $2.7 \pm 1.1$ |
| Expected $t\bar{t}$ signal | 1.8 | 2.4 |
| Observed events | 4 | 4 |

# Lepton+Jets (soft $\mu$ tag)

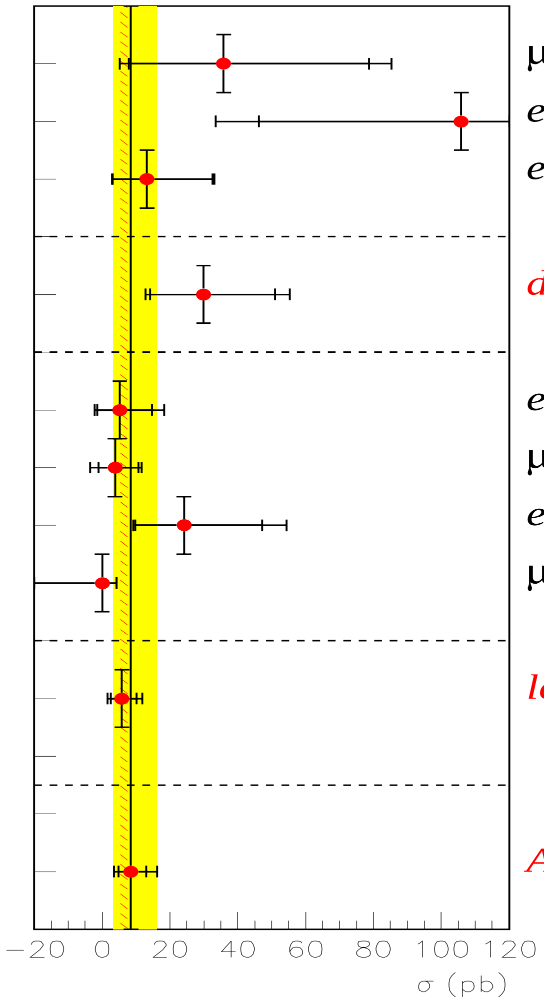
- Select samples with isolated high $p_T$ leptons and large $\not{E}_T$
- Soft $\mu$ within jet
  - $b \rightarrow \mu$, $b \rightarrow c \rightarrow \mu$
- Backgrounds estimated from data




- Softer Topological Cuts
  - $\geq 3$ jets
  - Aplanarity > 0.04
  - $H_T$(jets) > 110 GeV (e and $\mu$)

| | e+jets | $\mu$+jets |
|---|---|---|
| $\mathscr{L}$ ($pb^{-1}$) | 50 | 40 |
| Total Background | $0.2 \pm 0.1$ | $0.7 \pm 0.4$ |
| Expected $t\bar{t}$ signal | 0.5 | 0.8 |
| **Observed events** | **2** | **0** |

# Summary of $t\bar{t}$ x-sec measurements




## Dilepton channels combined

$$29.9 \, {}^{+21.0}_{-15.7} \, (\text{stat}) \, {}^{+14.1}_{-6.1} \, (\text{sys}) \pm 3.0 \, (\text{lumi}) \, \text{pb}$$

## Lepton + Jets channels combined

$$5.8 \, {}^{+4.3}_{-3.4} \, (\text{stat}) \, {}^{+4.1}_{-2.6} \, (\text{sys}) \pm 0.6 \, (\text{lumi}) \, \text{pb}$$

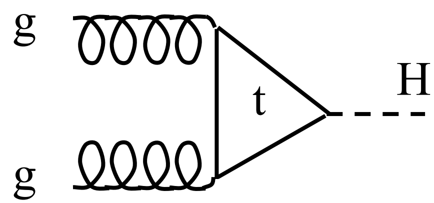
## all 7 analyses combined:

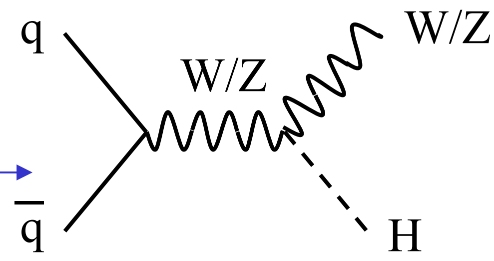
$$8.5 \, {}^{+4.5}_{-3.6} \, (\text{stat}) \, {}^{+6.3}_{-3.5} \, (\text{sys}) \pm 0.8 \, (\text{lumi}) \, \text{pb}$$

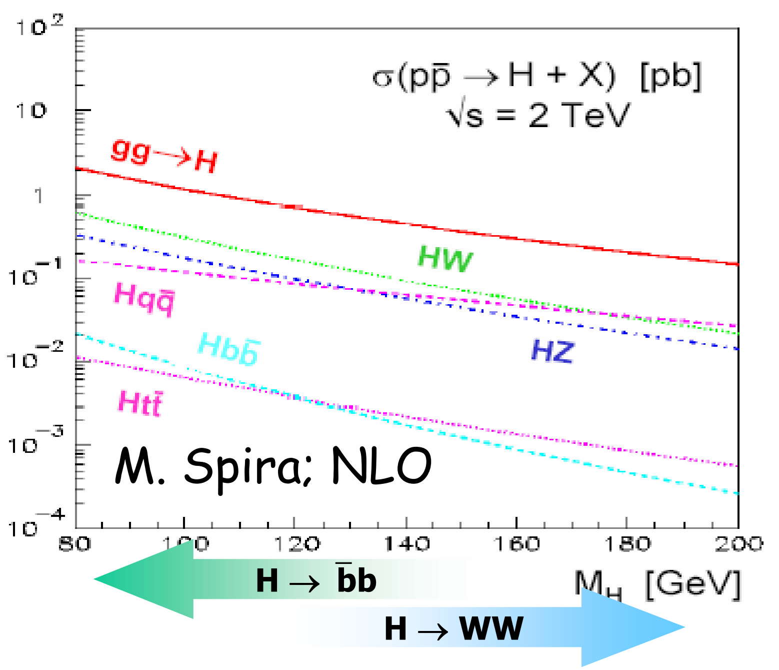
theoretical prediction at 1.96 TeV
$\sigma(t\bar{t}) \approx 6.7$ to $7.5$ pb
shown as red dashed line

# Higgs Searches

- Gluon Fusion
  - Overwhelmed by QCD at low mass
  - Good at high mass
- Associated production
  - Good at low mass



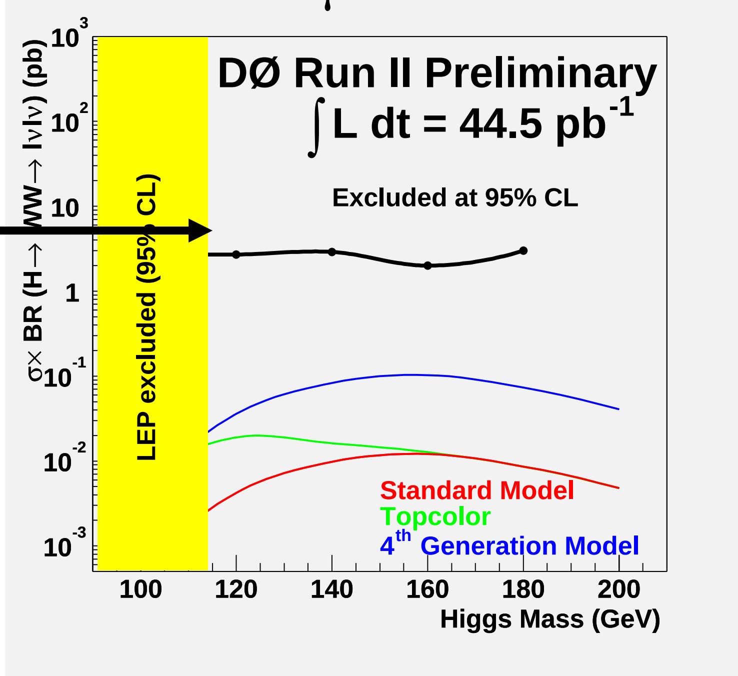

- Higgs searches with limited luminosity
  - Backgrounds to the SM Higgs W/Z H associated production:
  - Study properties of jets in W/Z events
  - Develop b-tagging techniques
- Search for non SM Higgs
  - $H \rightarrow WW^* \rightarrow \ell^+ \ell^- \nu\ \nu$
  - $H \rightarrow \gamma\ \gamma$

# $H \to WW^* \to \ell^+ \ell^- \nu \nu$

- Interesting physics in WW prod. from SM Higgs & extensions that enhance the production x-sec
- Signal: dileptons + $\not{E}_T$
- Bkgd: $Z/\gamma^*$, WW, $t\bar{t}$, W/Z + j, QCD
- Opening angle between leptons is useful discriminating variable
  - Two leptons tend to move in parallel due to spin correlation of Higgs boson decay products
- Excluded x-sec together with expectations from SM Higgs production and alternative models.
- Limit will improve with more luminosity and improved object ID

| | ee | eμ | μμ |
|---|---|---|---|
| $\mathcal{L}$ ($pb^{-1}$) | 44 | 34 | 48 |
| Total Background | 0.7 ± 1.4 | 0.9 ± 1.5 | 0.3 ± 0.1 (stat) |
| **Observed events** | 0 | 1 | 1 |

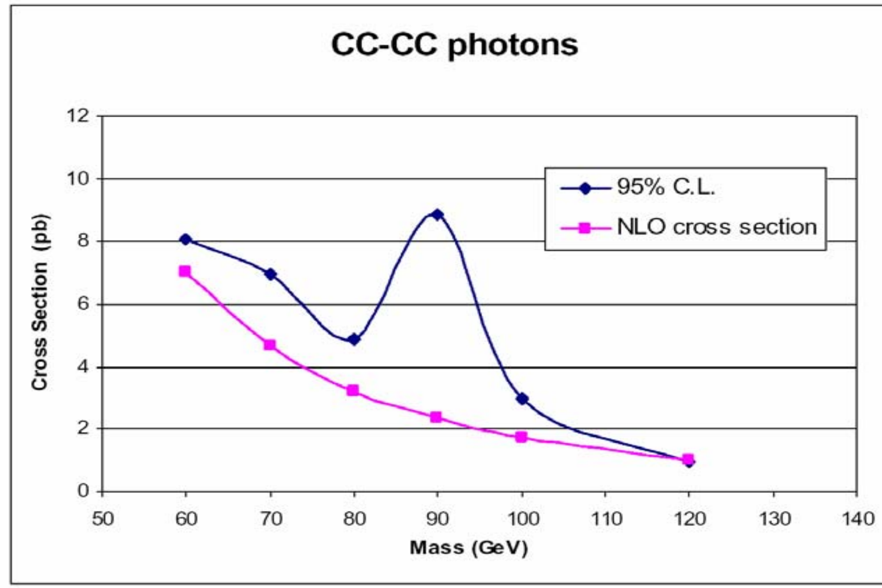
ee & eμ combined



# $H \rightarrow \gamma\ \gamma$

- Look for non-SM processes giving $H \rightarrow \gamma\gamma$
  - Use the SM $p\bar{p} \rightarrow$ H x-sec, but the BR($H \rightarrow \gamma\gamma$) is assumed 100%
- $\mathscr{L}$ = 52 $pb^{-1}$
- Selection requires
  - 2 isolated EM objects ($E_T$>25 GeV) with no track match
  - $\gamma\gamma$ mass window cut which selects a region about a hypothesized Higgs mass.
- SM Backgrounds
  - $Z/\gamma^*$, QCD

Experimental cross section limits and Theory cross sections as a function of $\gamma\gamma$ mass



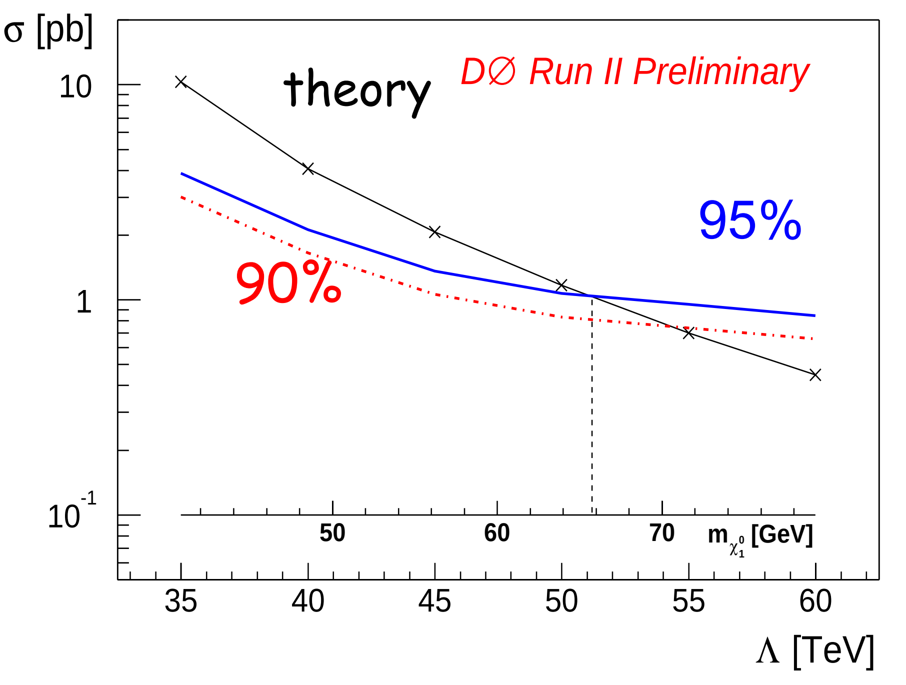

Additional statistics will probe High mass region.

Analysis currently being optimized for lower Higgs mass values.

# $\gamma\,\gamma + \not{E}_T$ SUSY Search

- Motivated by Gauge Mediating SUSY Breaking
- Model has one dimensional parameter $\Lambda$, which determines the scale of SUSY breaking
- Selection requires ($\mathscr{L}$ = 42 $pb^{-1}$)
  - 2 central EM objects ($p_T$>20 GeV) without a track match
  - Clean jets to ensure $\not{E}_T$ determination
  - Opening angle ($\not{E}_T$,leading Jet)<2.5 rad
  - $\not{E}_T$>30 GeV
- QCD background (dominant) estimated from data

GMSB $\sigma$ vs $\Lambda$ CL limits

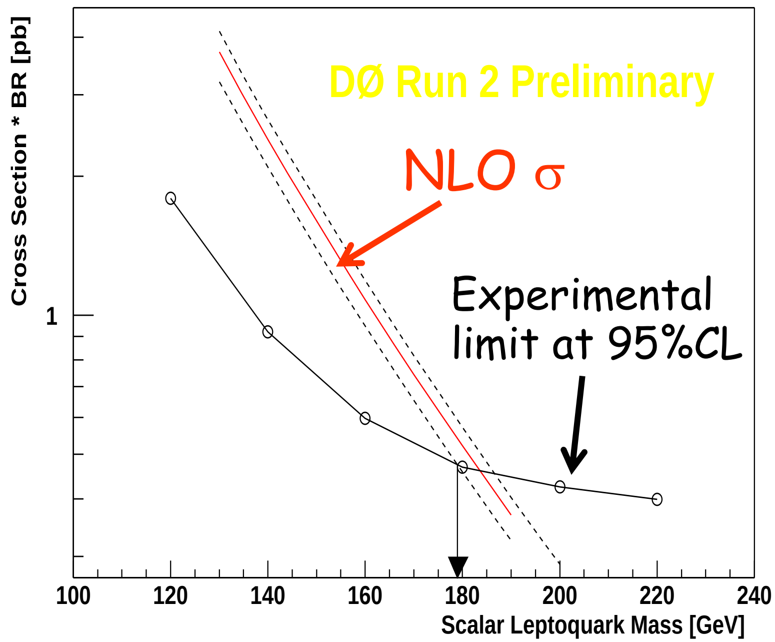


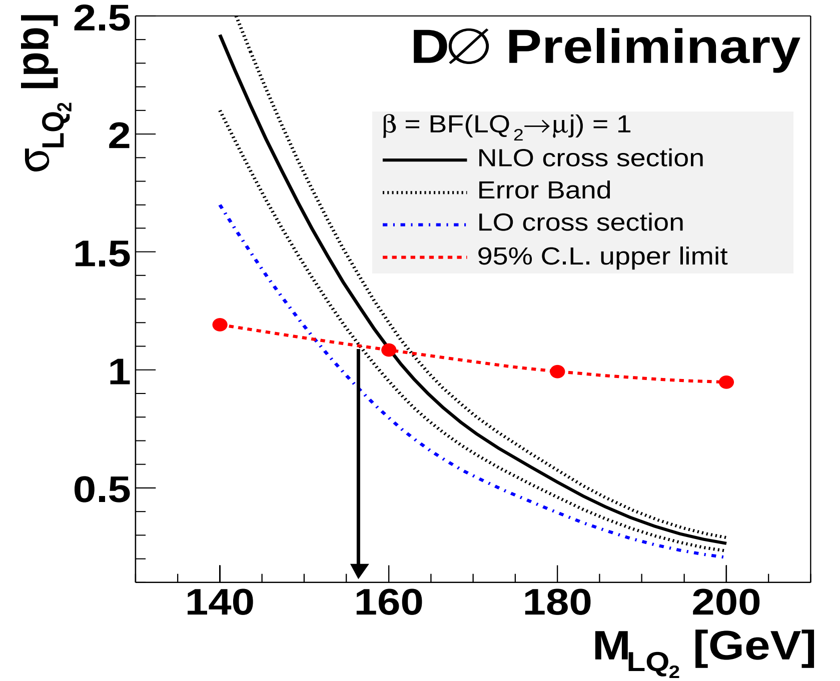

95% CL limit on lightest neutralino mass >66 GeV, $\Lambda$>52TeV

Run I limit $m(\chi_1^0)$ >75 GeV (DØ)

# Scalar Leptoquark Searches

- $1^{st}$ generation search in the eejj final state ($\mathscr{L}$ = 43 $pb^{-1}$)
- $2^{nd}$ generation search in the μμjj channel ($\mathscr{L}$ = 40 $pb^{-1}$)




Data is consistent with SM

σ(LQ) < 0.47pb @ 95% CL

$m_{LQ1}$ > 179 GeV for Br($LQ_1 \to eq$) = 1

(Run I limit m > 225 GeV)

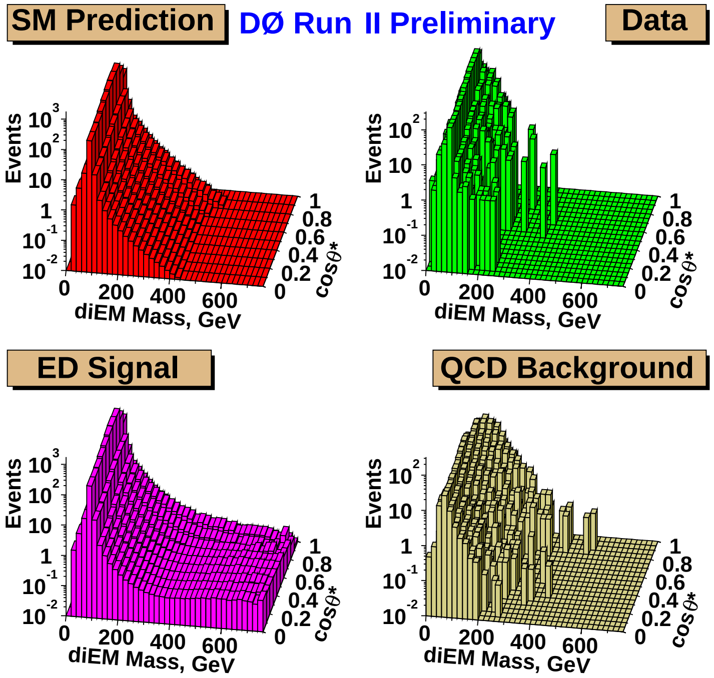
Data is consistent with SM

for Br($LQ_1 \to eq$) = 1 $m_{LQ1}$ > 157 GeV

(Run I limit m > 200 GeV)

# Search for Large Extra Spatial Dimensions

- String theory with SM restricted to D3-brane, gravity propagating in extra dimensions.
  - Signature arises from virtual graviton diagrams contributing to dilepton and diboson production
- Signatures:
  - $ee/\gamma\gamma$ (combined) and $\mu\mu$, low $\not\!\!E_T$
- Fit to 2-D distributions in the (M(ll), $|\cos\theta^*|$) space to extract limit on $\eta_G$ (strength of gravity in the presence of large extra dimensions)



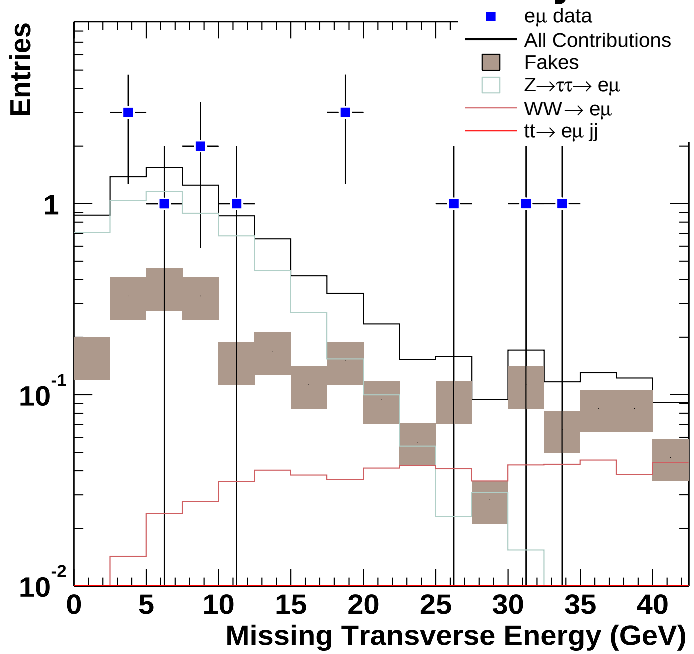

Translated into 95% CL upper limits for the Planck Scale Ms of 1.12 (diEM) & 0.79 TeV ($\mu\mu$) for the HLZ formalism (n=4)

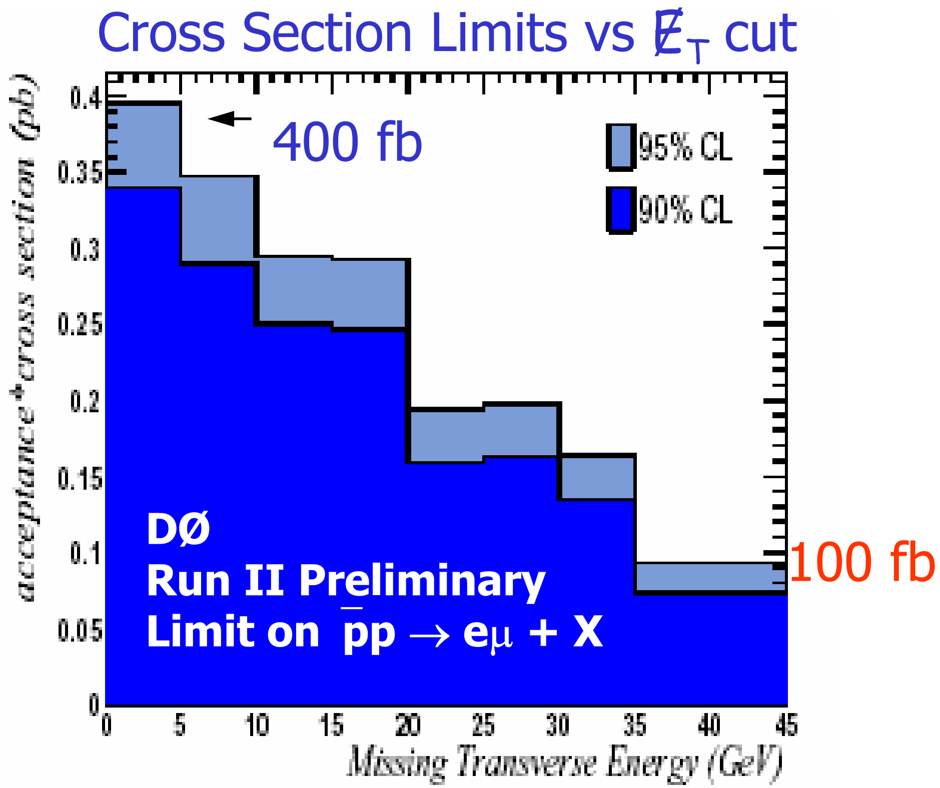
- Results for best fits:
  - di-EM analysis: $\eta_G = 0.0 \pm 0.27$ TeV$^{-4}$
    di-$\mu$ analysis: $\eta_G = 0.02 \pm 1.35$ TeV$^{-4}$
- Gives 95% CL upper limit on $\eta_G$ of 0.63 TeV$^{-4}$ (diEM) & 2.5 TeV$^{-4}$ ($\mu\mu$)

Di-EM limit close to RunI. Di-$\mu$ limit new channel, same as LEP2

# eμ inclusive final state

- Channel rich in discovery potential and low in backgrounds provides model independent limit on NP x-sec
- $\mathscr{L}$ = 33 $pb^{-1}$
- 1 central electron ($p_T$>15 GeV),
- 1 isolated muon ($p_T$>15 GeV)
- No jets with $E_T$ > 15 GeV

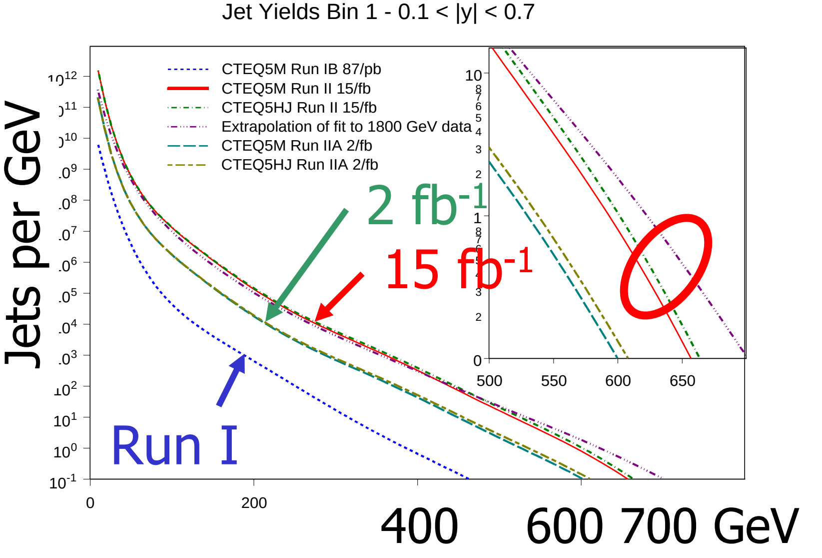


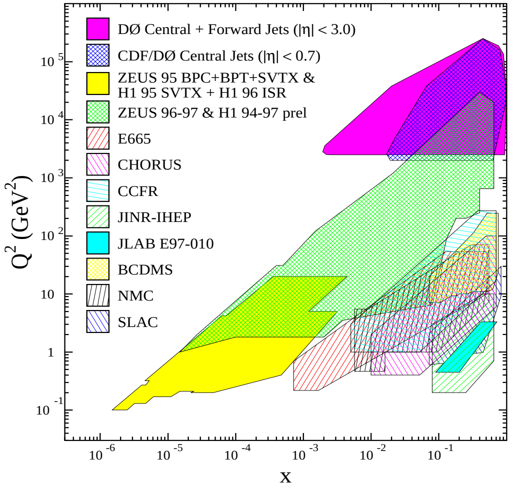




95% CL upper limits on the production x-sec of new physics in the eμ final state range from 400 fb (no $\not{E}_T$ cut) to 90 fb ($\not{E}_T$>40 GeV)

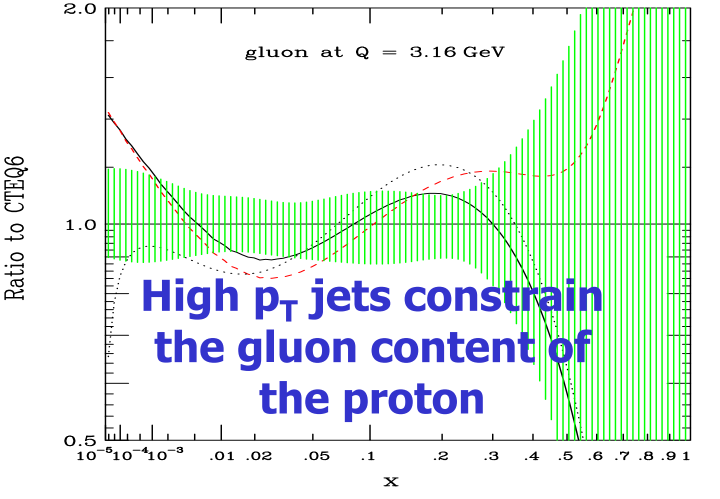
# Prospects for QCD

- Test QCD at higher precision
- Input to PDF fits
- Reliable calculation of backgrounds to new physics
- Excellent interaction between experimentalists and phenomenologists




**Run I jet data already used in CTEQ6 and MRST2001 parton distribution fits; complements HERA's kinematic range**



# EW Physics Prospects

- Improved top mass
- Expect ~ 500 b-tagged lepton+jets events per experiment per $fb^{-1}$
- Improved techniques (equivalent to a factor of 2.4 in statistics)
- Expectations per experiment using "traditional" methods

| $\Delta m_t$ | $l$ + jets | dilepton |
|---|---|---|
| 2 $fb^{-1}$ | ± 2.7 GeV | ± 2.8 GeV |
| 10 $fb^{-1}$ | ± 1.6 GeV | ± 1.6 GeV |

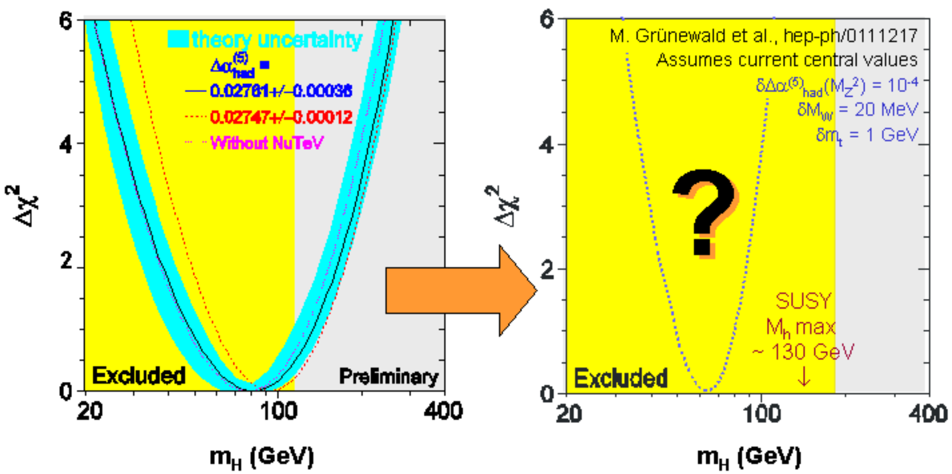
- Improved W mass
- Expectations per experiment

| | $\Delta m_W$ |
|---|---|
| 2 $fb^{-1}$ | ±27 MeV |
| 10 $fb^{-1}$ | ±18 MeV |

- Constraint on Higgs

$dm_H/dm_t$ ~ 50 GeV/4 GeV

$dm_H/dm_W$ ~ 50 GeV/25 MeV

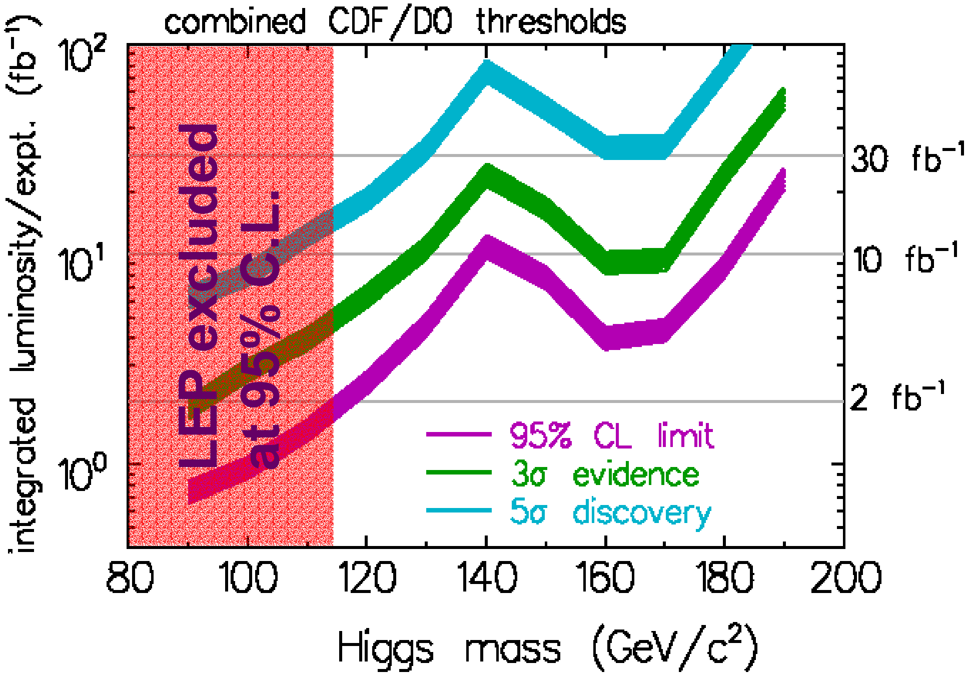



Current Central Values with $\Delta m_W$ = 20 MeV & $\Delta m_t$ = 1 GeV

Can exclude SM Higgs with mass below 185 GeV at 95% CL

# Direct Searches for Higgs

- Higgs discovery potential at the Tevatron has been evaluated
  (hep-ph/0010338)
- Joint effort by theorists and both experiments, using a parameterized detector simulation




- To make this a reality, we need
  - Two detectors
  - Good Resolutions
  - Good b-jet and lepton identification
  - Triggers efficient at high luminosities
  - Good understanding of all the backgrounds

CDF and DØ have a joint effort underway to re-evaluate some key channels in this Higgs reach plot. Results by ~ June.

# Top physics program

- Single top production
  - So far unobserved
  - Measure $|V_{tb}|$
  - With ~ 1 $fb^{-1}$ should be able to see signals for both s and t-channel production

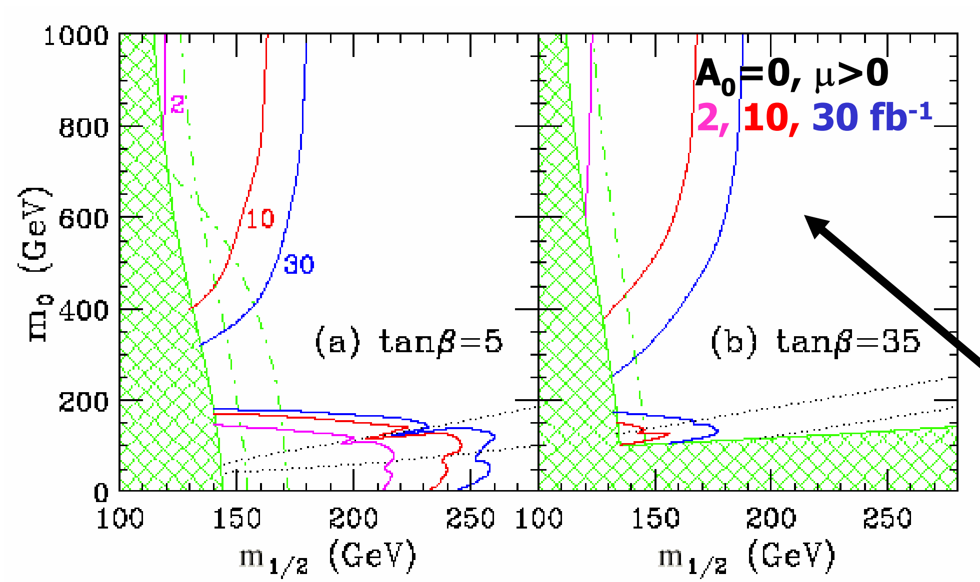
| | $\Delta\sigma$ (s) | $\Delta|V_{tb}|$(s) | $\Delta\sigma$ (t) | $\Delta|V_{tb}|$(t) |
|---|---|---|---|---|
| 2 $fb^{-1}$ | 21% | 12% | 12% | 10% |
| 10 $fb^{-1}$ | 9% | 6% | 5% | 8% |

- Top-antitop spin correlations
  - With 2$fb^{-1}$, distinguish spin-½ from spin-0 (at the 2$\sigma$) level
- New physics
  - $t\bar{t}$ mass, top $p_T$, rare decays and nonstandard decays, anomalous single top …

# Beyond the SM

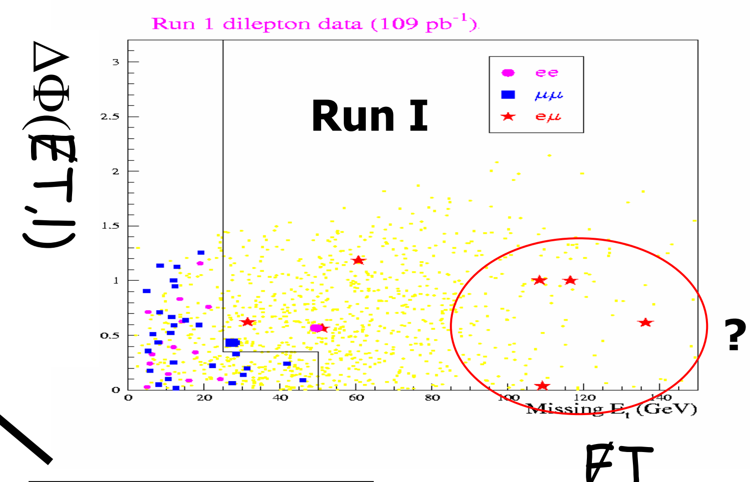
- SUSY
  - most popular extension
- Squark/Gluino searches
  - Jets + $\not\!\!E_T$
- Chargino/Neutralino searches
  - 3 leptons (very low SM bkgd)

- Many more theories
  - Look for deviations to the SM in specific signatures
  - Follow up anomalies in Run I data, and set model-independent limits ("Sleuth")




**Big gain from 2 to 10 fb$^{-1}$**

CDF dilepton top events



# Conclusions

- Many analyses in progress
  - Re-establishing benchmark signals
  - searches already approach Run I limits and will break new grounds soon
- Many more results still to come
  - improved detector understanding
  - improved object ID efficiencies
  - increased statistics
- Tevatron program is rich and promising
- We are enthusiastic about the physics through the end of the decade