Results from Run I of the Tevatron

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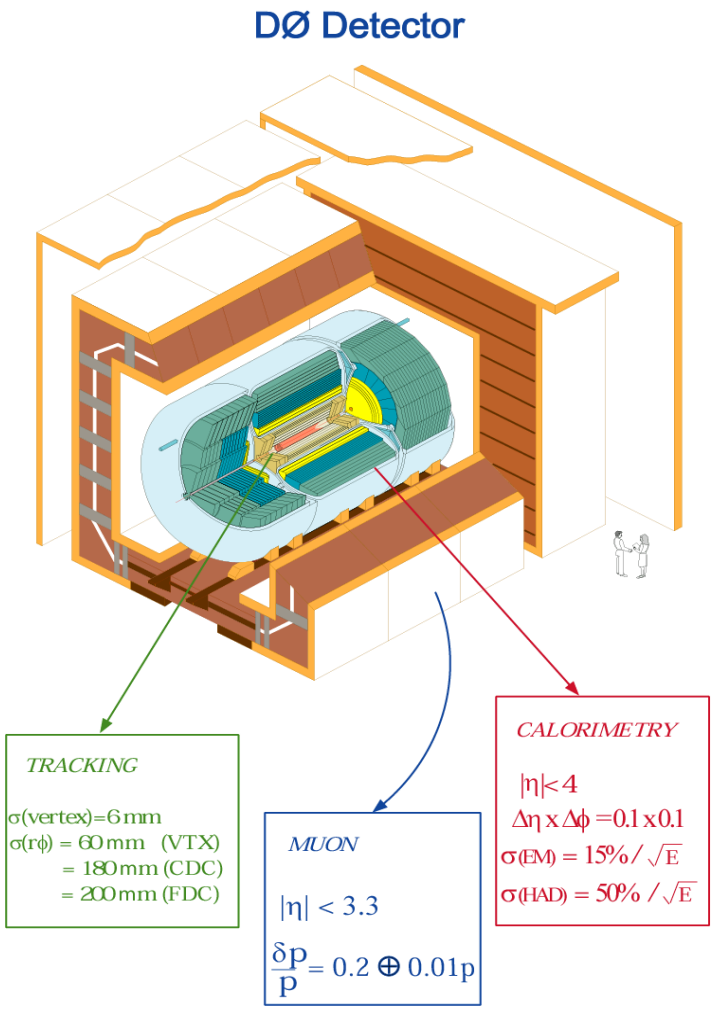
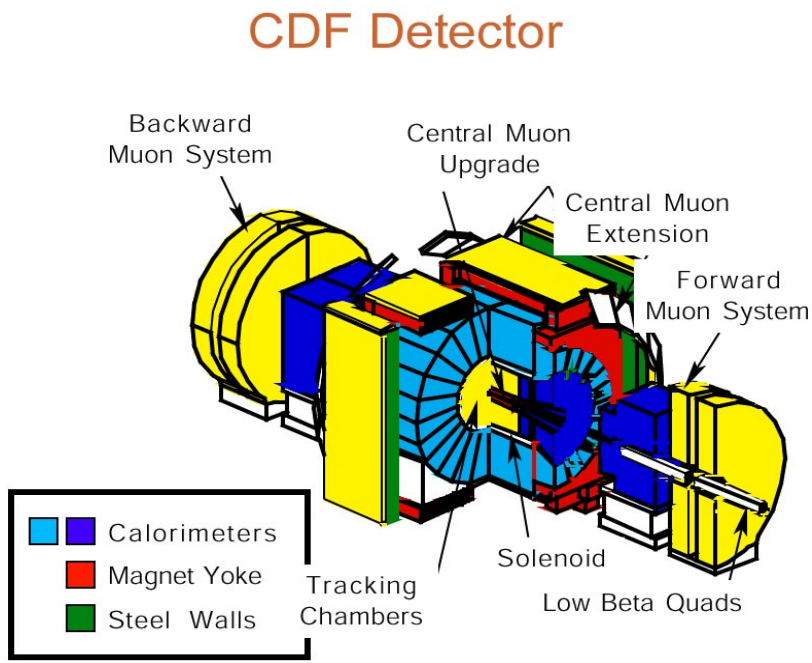
Overview of Talk

- Overview of Tevatron Run I
- Rich Program of Physics at the Tevatron
  - Top Quark Physics
  - Bottom Quark Physics
  - Electroweak Studies
  - QCD Studies
  - Searches for New Phenomena
- Concentrate on Recent Results on QCD and Searches
- Summary

Thanks to my DØ and CDF colleagues
All errors and misrepresentations are mine

Cast of Characters





DØ NIM A338, 185 (1994)

CDF NIM A271, 387 (1988)

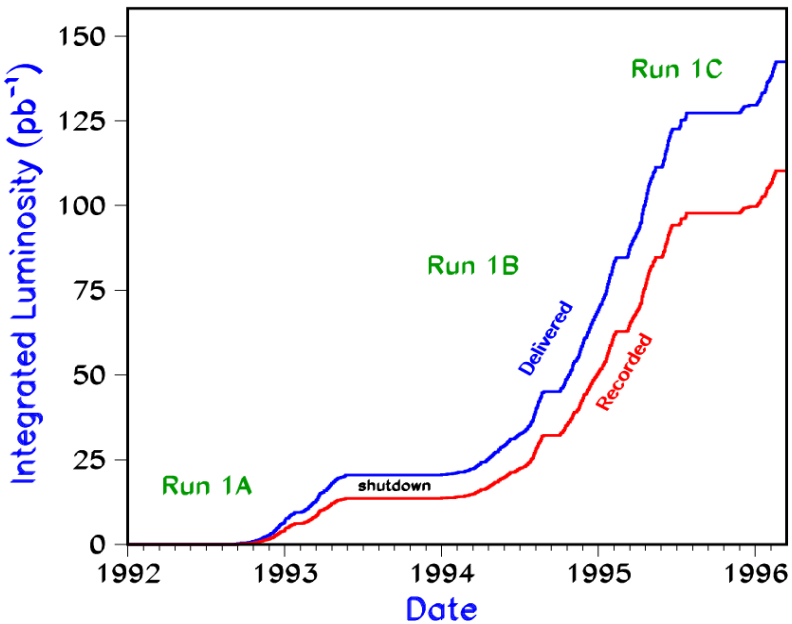
Run I Summary

Run I data taking from 1992-96

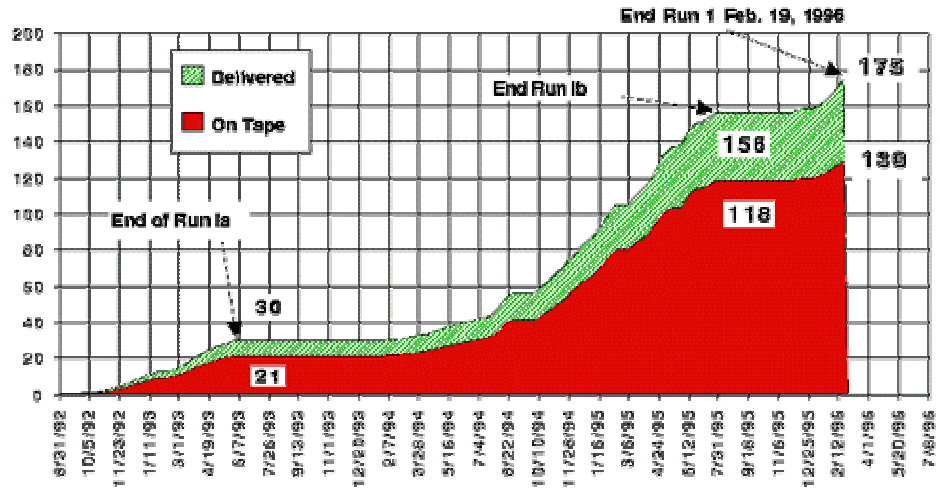
$p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV and 630 GeV

$\int \mathcal{L}\ dt \sim 0.1\ fb^{-1}$ per experiment

DØ Run I Integrated Luminosity

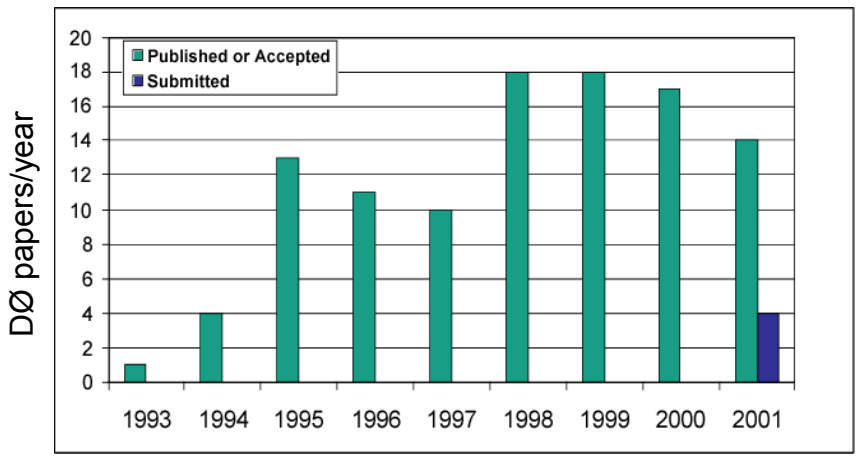


CDF Run I Integrated Luminosity



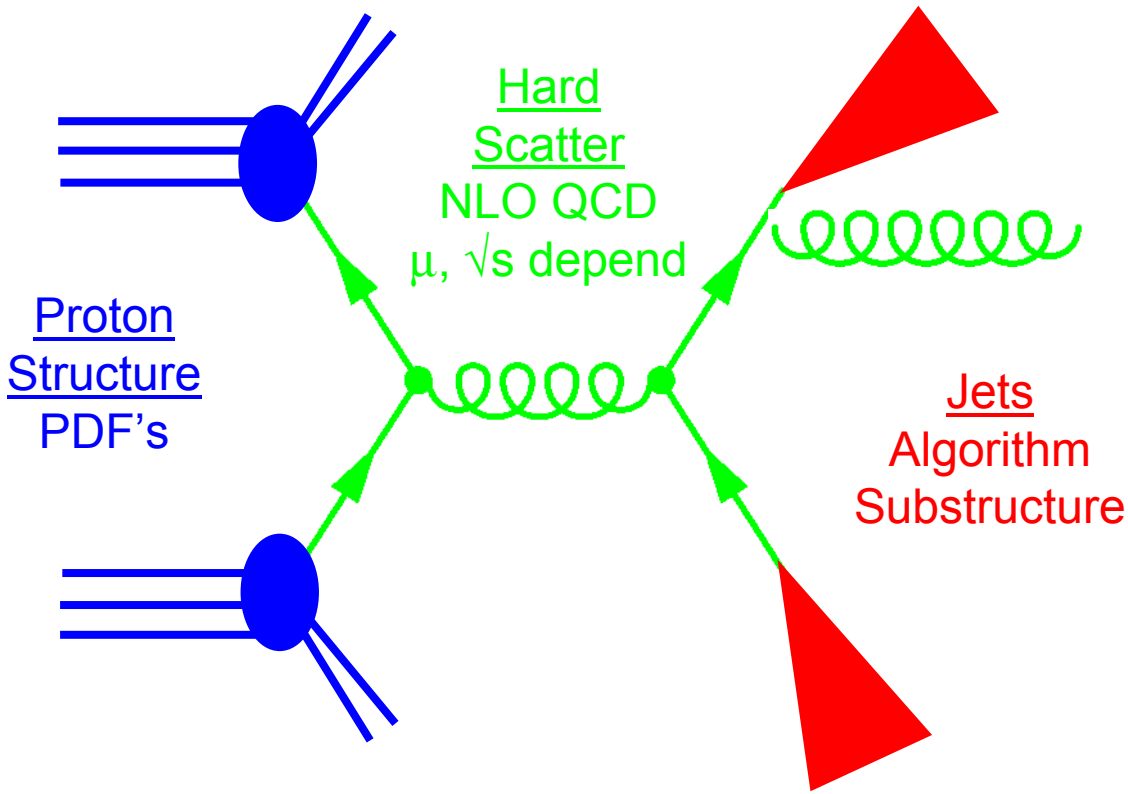
Run I Results Just Keep On Comin'

- Run I has been extremely productive
  - ~300 Run I publications so far from CDF and DØ
  - ~300 PhD's so far from CDF and DØ
- 5 years after the run, the rate is not decreasing!



- In addition to papers on new physics topics, latest results feature mix of
  - Detailed documentation of analyses (PRD's)
  - Innovative analysis techniques
  - Development of analyses for Run II

Studying Strong Interactions at the Tevatron



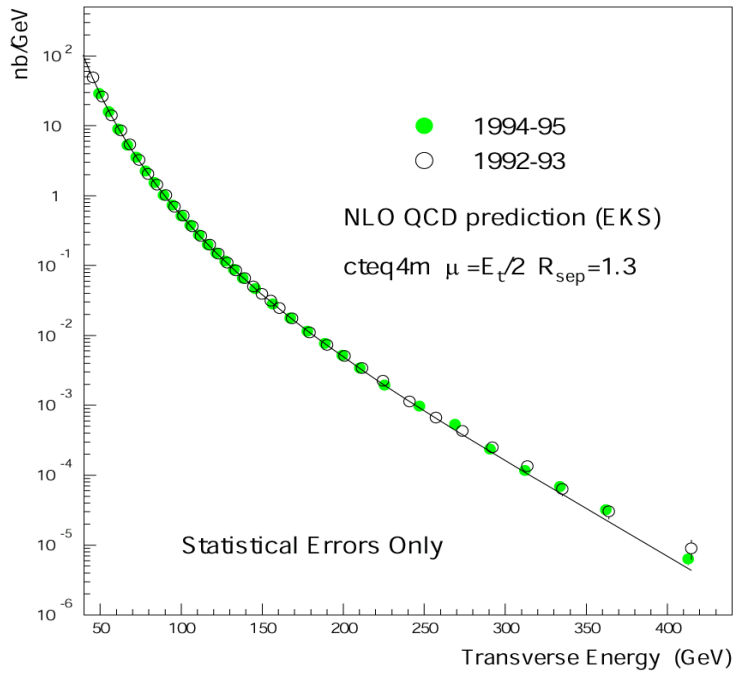
Recent QCD Results From the Tevatron

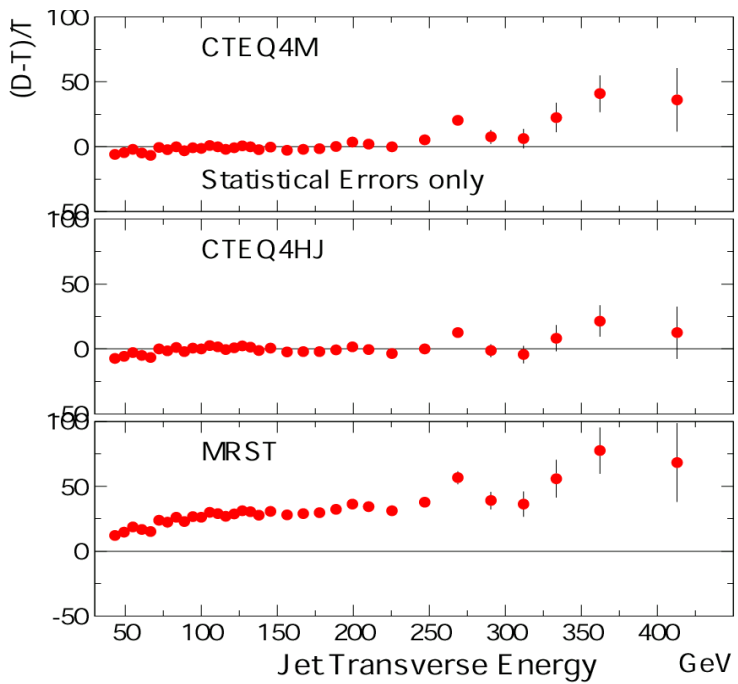
- Inclusive Jet Production (CDF,DØ)
- Dijet Triple Differential Cross Section (CDF)
- Run 1b and 630 GeV Photon Cross Sections (CDF,DØ)
- The Inclusive Jet Cross Section using the k_T Algorithm (DØ)
- The Ratio of Jet Cross Sections at $\sqrt{s}$ = 630 GeV and 1800 GeV (DØ)
- Study of the multiple jet production in the low E_T region (DØ)
- Measurement of Dijet Transverse Thrust Distributions (DØ)
- Ratios of Multijet Cross Sections in pbarp Collisions at $\sqrt{s}$ = 1.8 TeV (DØ)
- Subjet Multiplicity in Quark and Gluon Jets (DØ)
- Photon + Muon Cross Section (CDF)
- A Study of Diffractive Dijets with a Leading Antiproton (CDF)
- The Underlying Event in Hard Scattering Processes (CDF)

For more details, visit
http://www-cdf.fnal.gov/
http://www-d0.fnal.gov/

Inclusive Jets at CDF

- Inclusive jet production tests QCD and structure of the proton through PDF's
- Highest $E_T = E \sin\theta$ jets probe distance scale of order 10^{-17} cm
- Sensitive to new physics, e.g. quark compositeness
- Statistical precision much better than uncertainty in systematics and theory
- CDF Run Ib result
  - $\int L\, dt = 87$ pb-1
  - $0.1 < |\eta| < 0.7$ where $\eta = -\ln(\tan(\theta/2))$
- **Good agreement with NLO QCD**
- **Results favor CTEQ4HJ**
  - Uses Tevatron high E_T jet data
  - Higher gluon content at high x

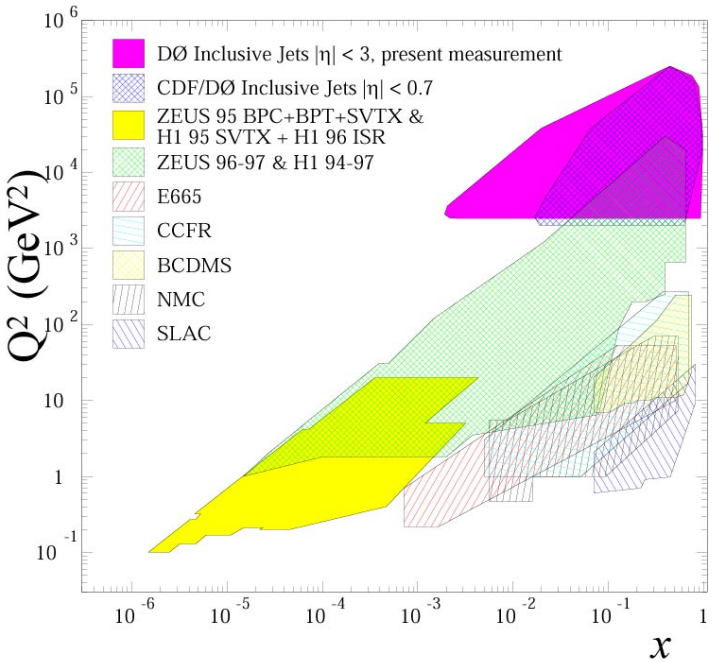


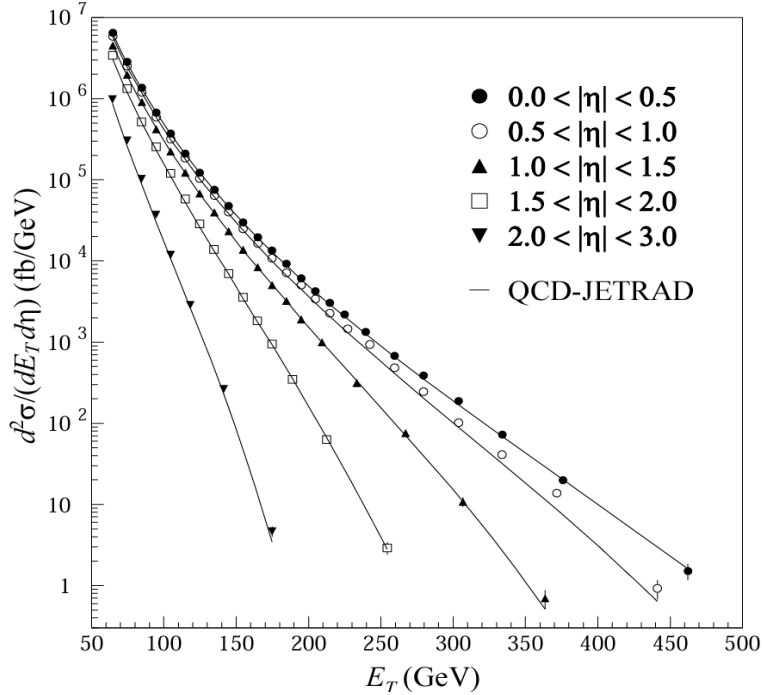


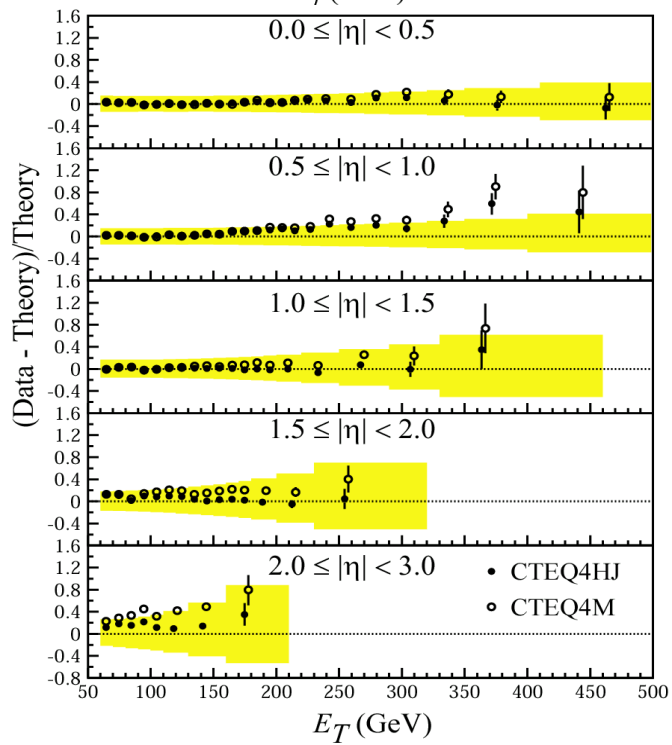
CDF FERMILAB-PUB-01/008-E
Accepted for pub by PRD

Inclusive Jets at DØ

- DØ Run Ib result
  - $\int L\,dt = 95\ pb^{-1}$
  - $|\eta| < 3.0$
- Significantly extends the kinematic reach in Q^2 vs. x
- **Good agreement with NLO QCD**
- **Data prefer CTEQ4HJ, MRSTg↑, and CTEQ4M PDF's**







DØ PRL 86, 1707 (2001)

Dijet Triple Differential Cross Section at CDF

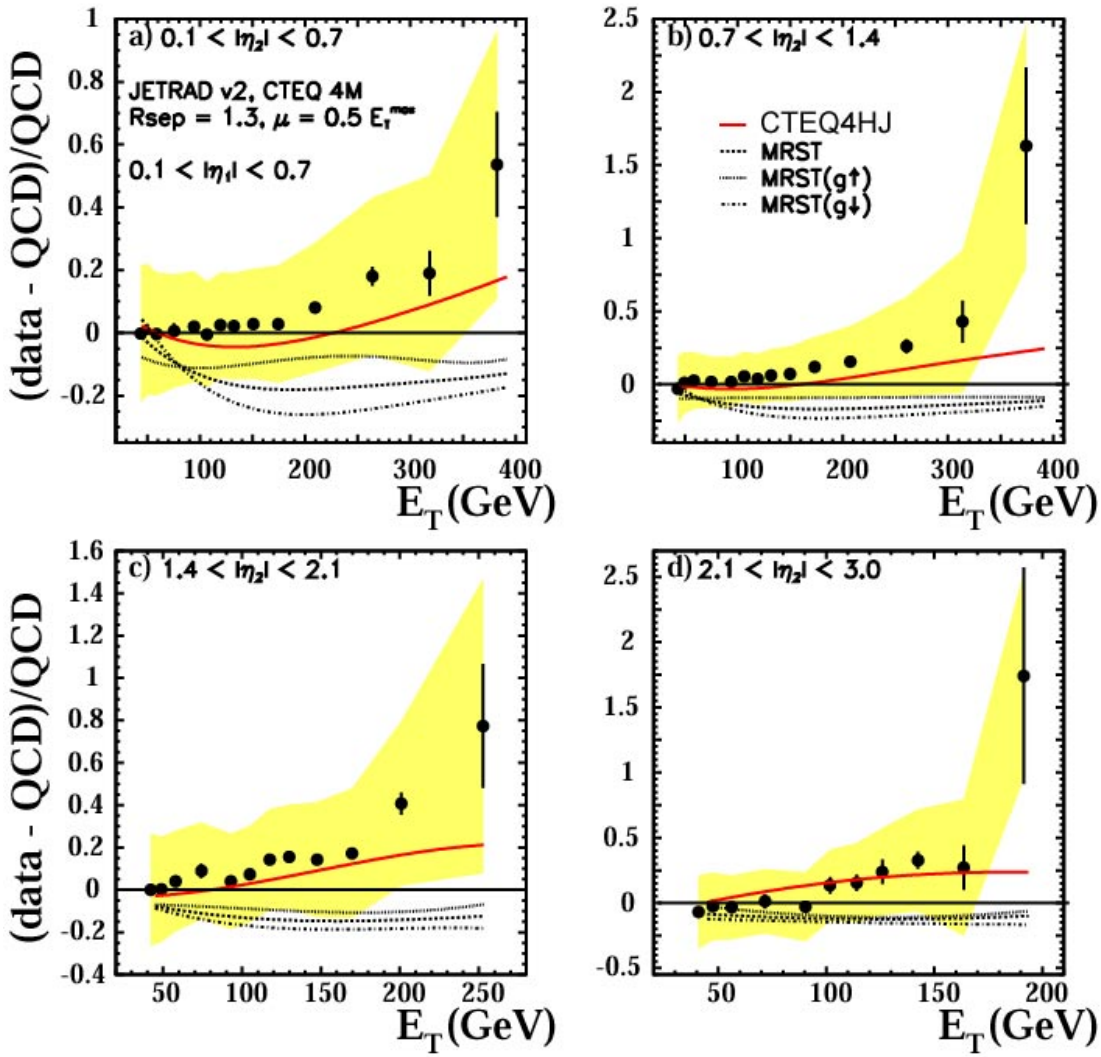
CDF Preliminary

- Large data sets allow a more detailed analysis of data
- Using L = 86 pb^{-1} collected at 1800 GeV, CDF measures the 2-jet differential cross section

$$d^3\sigma / dE_T d\eta_1 d\eta_2$$

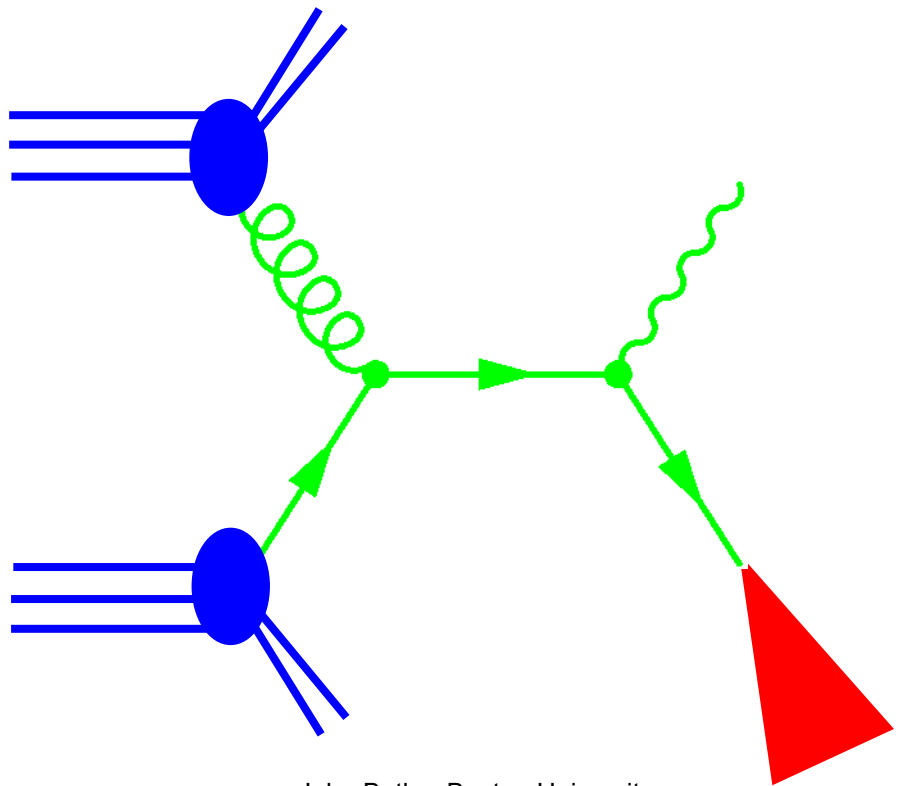
as a function of the E_T of jet 1 in $0.1 < |\eta_1| < 0.7$ for 4 different η bins of a 2nd jet restricted to $0.1 < |\eta_2| < 3.0$

- Data is compared with NLO QCD using the CTEQ4 and MRST PDF's
- **None of the PDF's examined in this analysis provides a good description of the data**



Direct Photons at the Tevatron

- Primary production mechanism is gluon Compton scattering $qg \rightarrow \gamma q$
- Sensitive to gluon distribution in proton
- Clean probe without fragmentation and ID problems of jets
- Earlier experiments observed excess at low E_T
  - Limitations of NLO QCD and/or PDF's



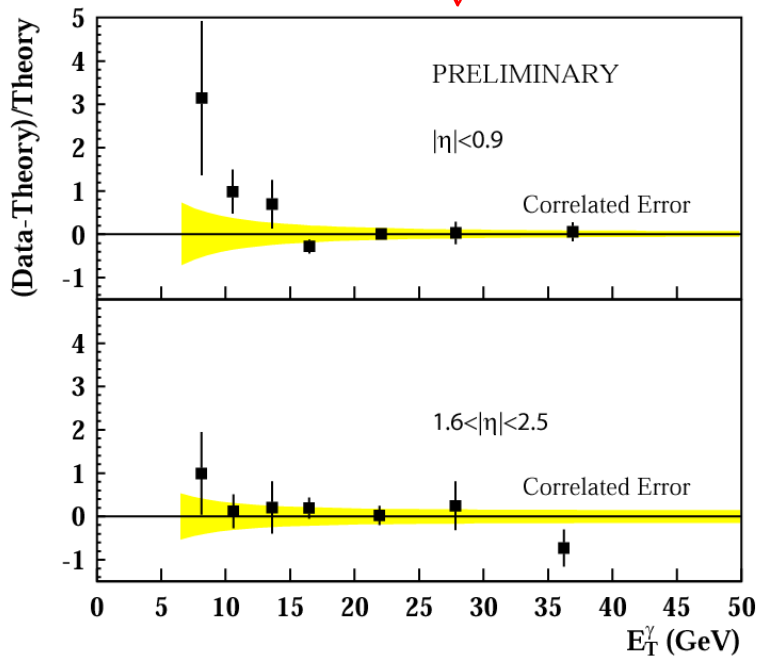
Photon Cross Sections at √s = 630 GeV at DØ

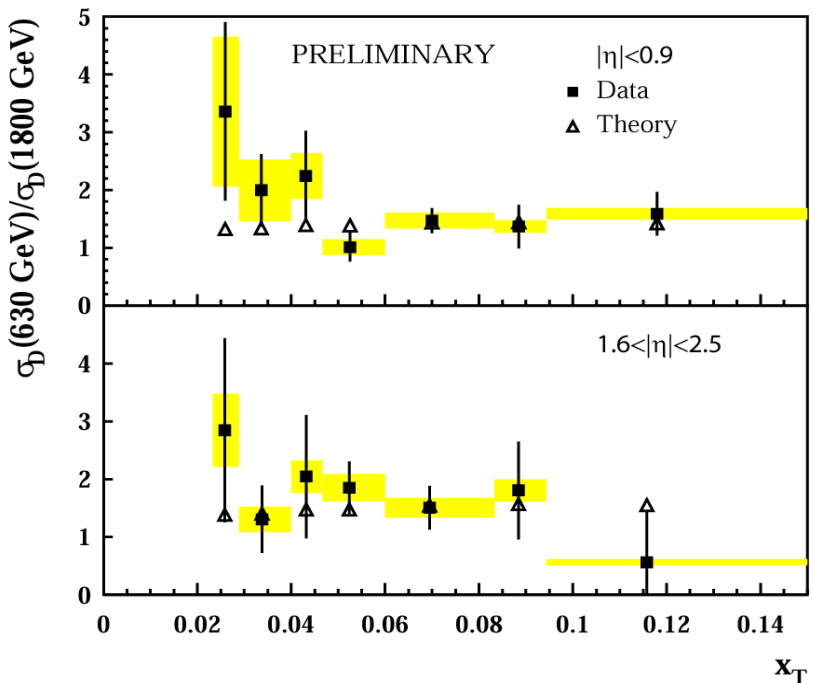
$\sqrt{s} = 630 GeV$

- L = 520 nb^{-1} collected at 630 GeV
- Data agrees with QCD although low E_T excess is observed
- Dimensionless cross section

$$\sigma_D = \frac{E_T^3}{2\pi} \frac{d^2\sigma}{dE_T d\eta}$$

  as a function of $x_T = 2E_T/\sqrt{s}$ does not naively depend on √s
- Many uncertainties cancel in $\sigma_D(630)/\sigma_D(1800)$: test of QCD
- **Good agreement between ratio and theory**

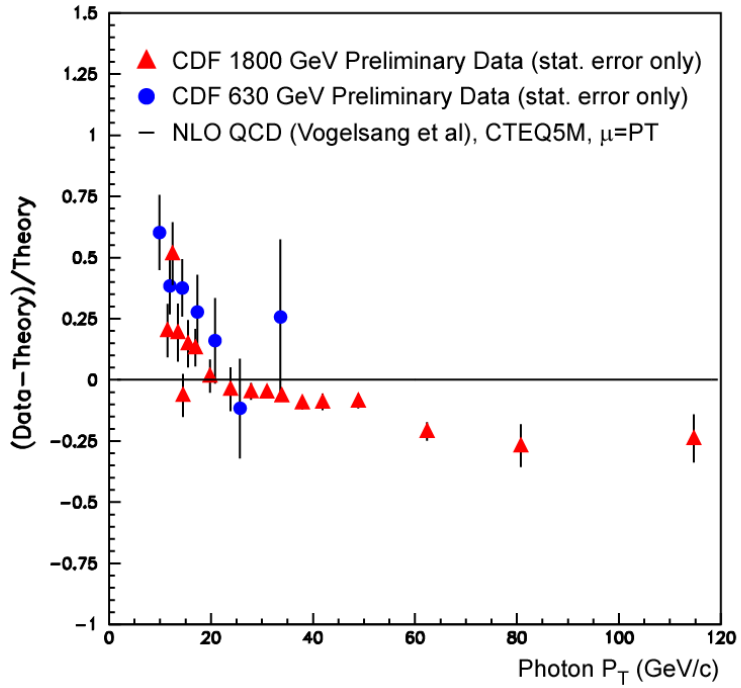


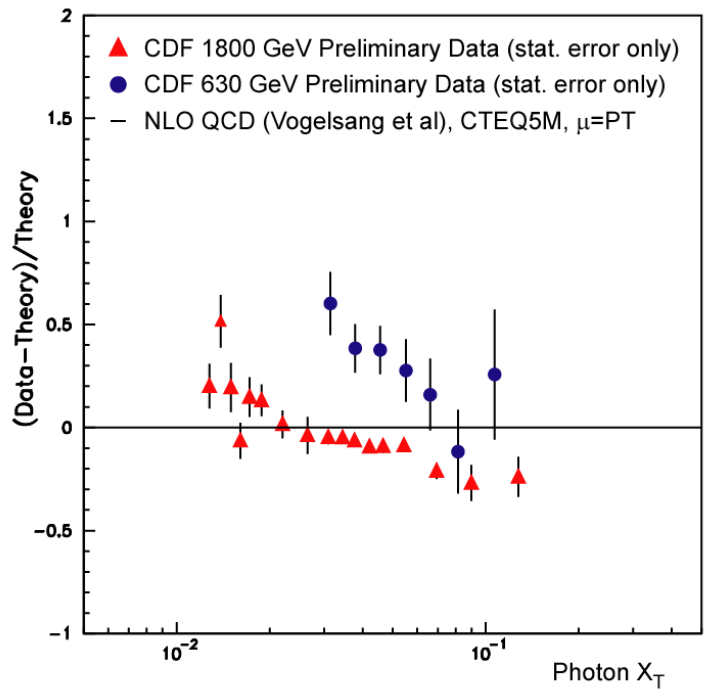


DØ hep-ex/0106026

Photon Cross Sections at √s = 1800 & 630 GeV at CDF

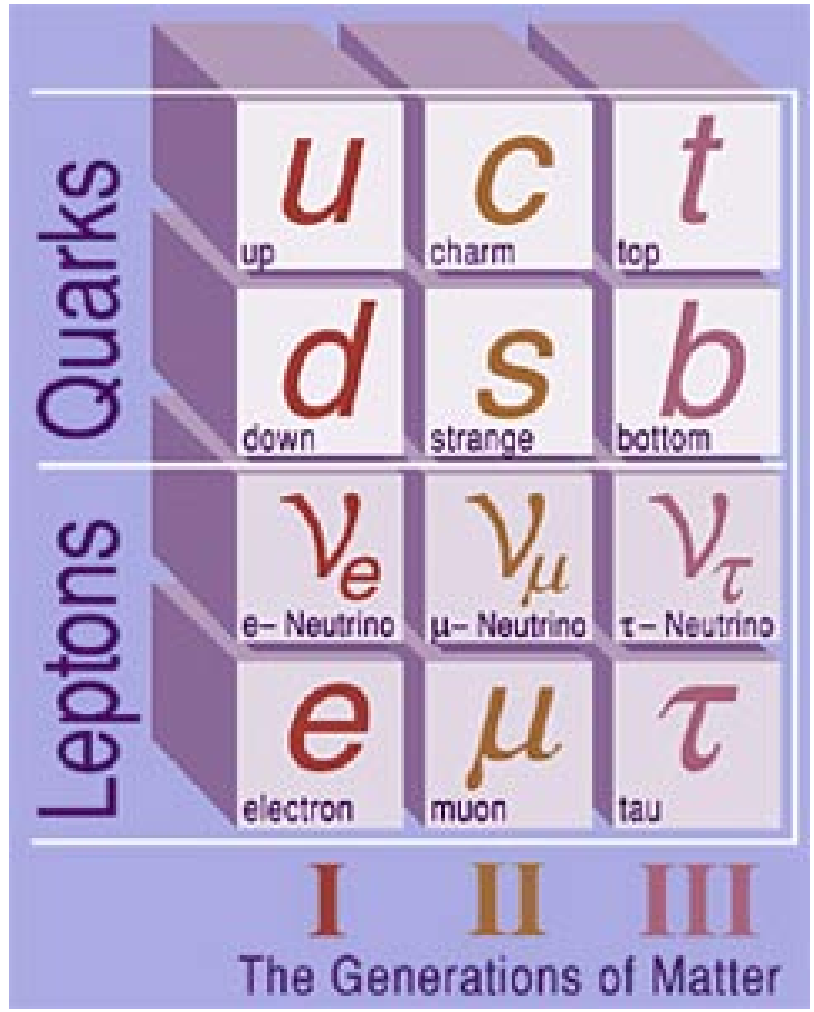
- Run Ia and Ib results at 1800 GeV are consistent with each other
- **Systematic differences in shape between data and theory**
- **Run Ib and 630 GeV cross sections are consistent with each other when plotted as a function of photon P_T**
- **Large discrepancy when the two cross sections are plotted as a function of photon $x_T = 2P_T/\sqrt{s}$**





Searches for New Phenomena

- The Standard Model provides an excellent description of nature
- No significant deviation from the SM has been observed and yet…
- Nobody believes the SM is the complete picture!
- Many extensions and alternatives to the SM have been proposed
- At the energy frontier, the Tevatron is a sensitive probe of new physics



Recent Searches for New Phenomena at the Tevatron

- Wide range of new results have appeared in the last year. Topics include searches for
  - SUSY - gluinos and squarks, scalar top quark, ...
  - RPV SUSY
  - Strong Dynamics: Technihadrons
  - New Heavy Gauge Bosons: W' & Z'
  - Leptoquarks
  - Quark Lepton Compositeness
  - Large Extra Dimensions (LED)
  - Charged Higgs
  - ...
- Many new models and ideas have emerged since the end of Run I, for example, LED. As a result, exotics groups remain very active.

Search for Scalar Top Quark at DØ

- Consider SUSY models where stop is the lightest squark
- In MSSM where the LSP is the sneutrino, the following decay is dominant

$$\tilde{t} \to b\ \tilde{\chi}_1^+ \to b\ \ell\ \tilde{\nu}$$

- Signal at the Tevatron

Generally: $p\bar{p} \to 2\ell\ 2b \not{E}_T$

Use only: $p\bar{p} \to e\mu \not{E}_T$

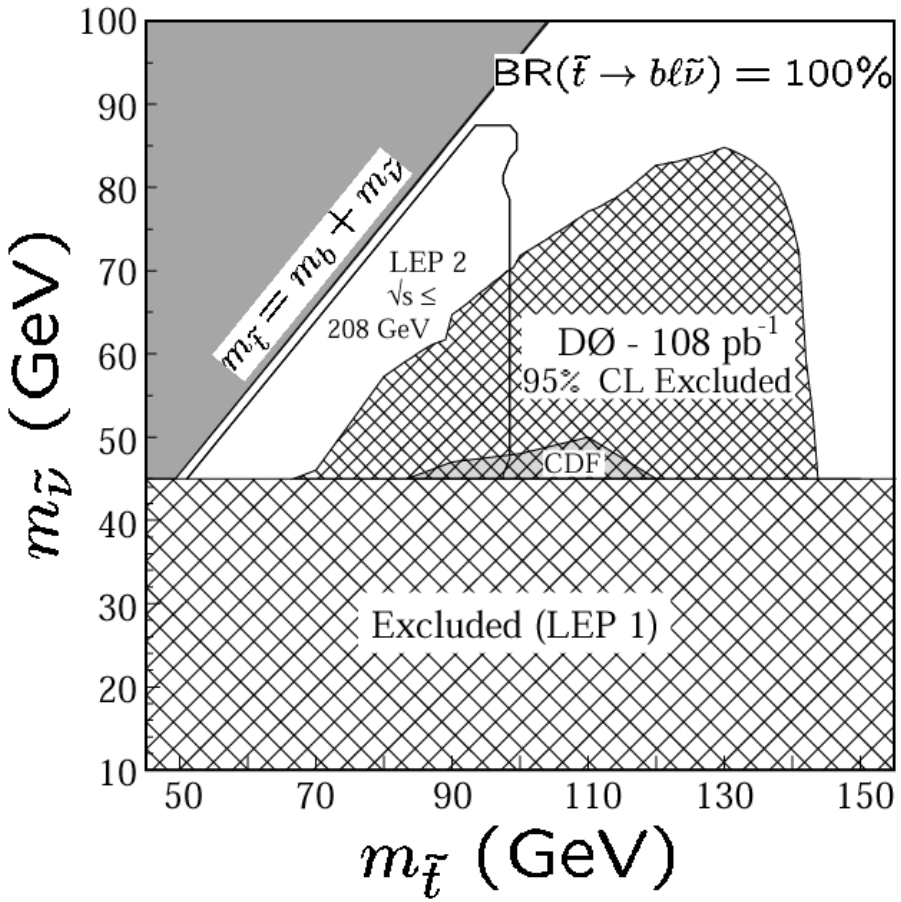
- Backgrounds

Multijet with fake $e, \not{E}_T$,

$Z \to \tau^+\tau^-,\ WW \to e\mu\nu\nu$

$t\bar{t} \to e\mu\nu\bar{\nu}jj,\ DY \to \tau^+\tau^-$

- Observe 10 events, expect 13.7 from SM, 13.2 for stop mass of 120 GeV
- **Exclude stop with mass up to 144 (130) GeV for sneutrino mass of 45 (85) GeV**



DØ hep-ex/0108018

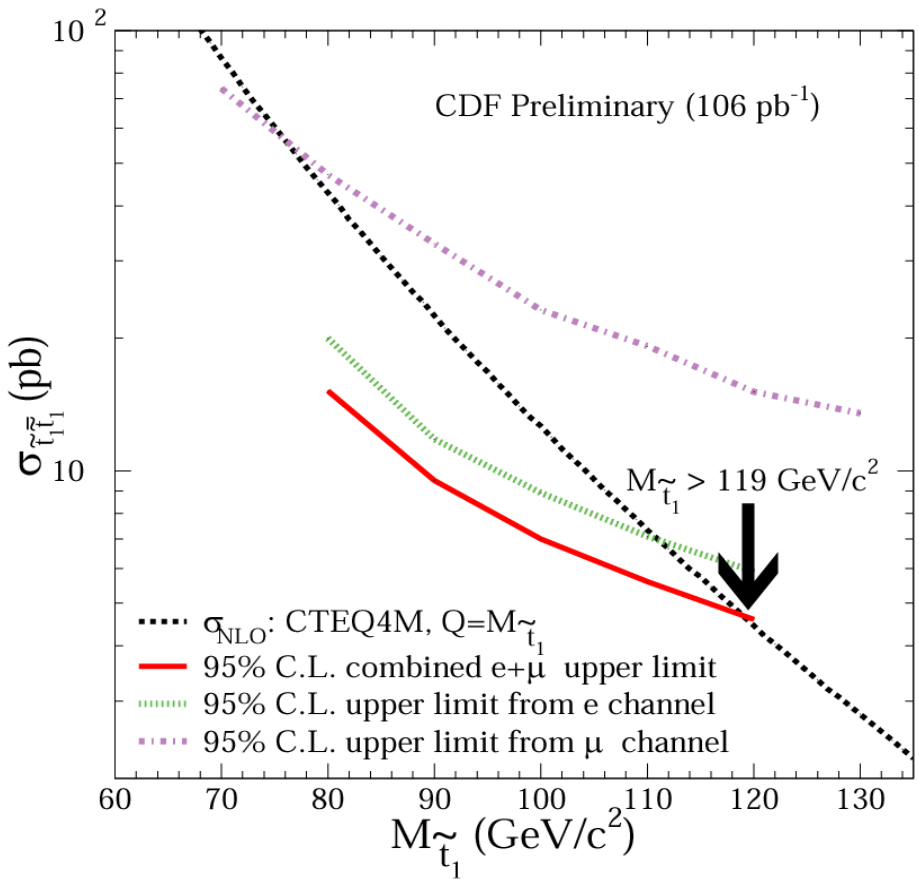
Search for RPV Stop at CDF

- In SUSY there is new quantum number, R parity
  - $R_p \equiv (-1)^{3B+L+2S}$
  - R_p = +1 for particles
    = -1 for sparticles
- If R_p conserved, sparticles are pair produced and LSP stable
  - classic large missing ET signature
- If R_p violated (RPV), new signatures
- Assuming RPV in 3rd generation and LSP is stop, the decay

  $\tilde{t}_1 \rightarrow \tau^+ b$

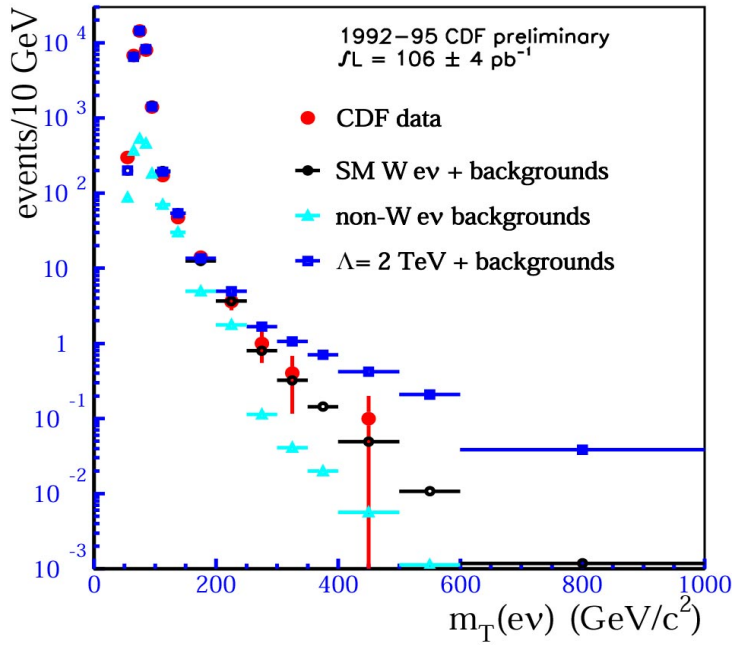
  dominates
- CDF looks for one τ decaying leptonically and the other hadronically (τ_h)
- No candidate events observed
- **CDF sets a 95% CL lower limit on stop mass of 119 GeV**

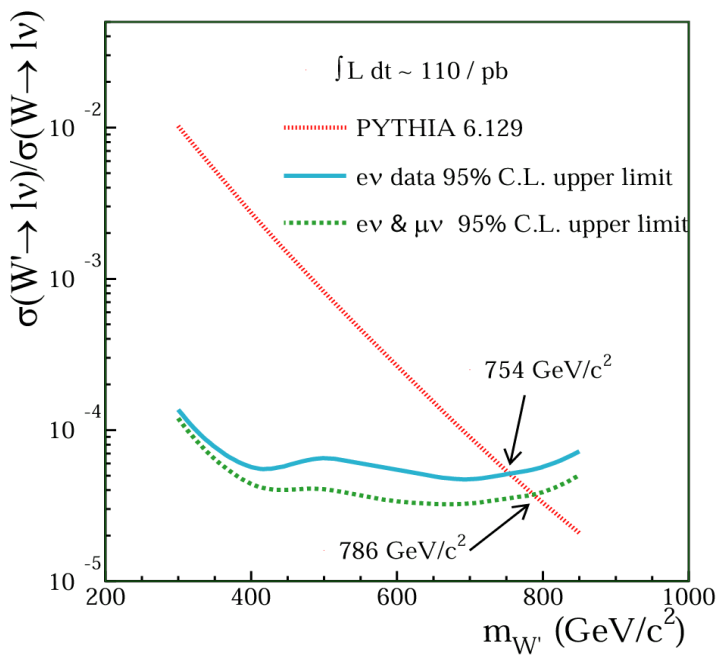
$\tilde{t}_1\bar{\tilde{t}}_1 \rightarrow \tau^+ b \tau^- \bar{b} \rightarrow \ell\ \tau_h\ 2j\ X$
where $\ell = e, \mu$
$BR(\tilde{t}_1 \rightarrow \tau^+ b) = 100\%$



Search for Quark-Lepton Compositeness & W' at CDF

- Use the eν final state
  - Normalize MC to inclusive W's
  - Analyze shape of $m_T(e\nu)$ distribution
- Probe extensions to SM
  - Models where SM fermions are composite, bound by new strong dynamics. Looks like 4 fermion contact interaction with scale Λ.
  - Models with larger gauge groups predict new gauge bosons W', Z'.
- Physics backgrounds dominate at high $m_T(e\nu)$
- **Good agreement of data and SM allows exclusion at 95% CL**
  - **Λ < 2.81 TeV**
  - **W' masses below 786 GeV**





Search for Technihadrons at DØ

- Lepton pair production has been an important discovery channel in HEP
- In topcolor-assisted technicolor, lightest technihadrons π_T, ρ_T, ω_T have substantial rate at Tevatron
- The decays are

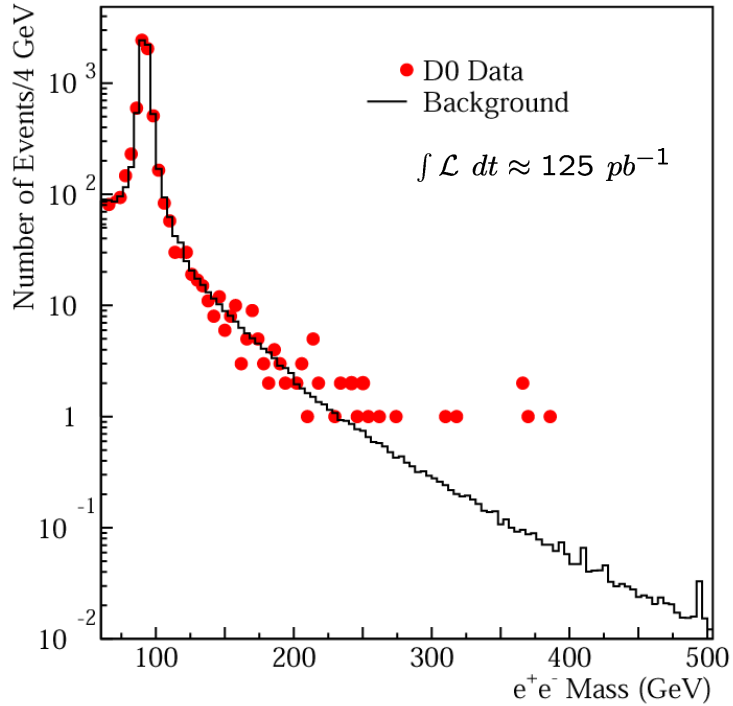
$$\rho_T, \omega_T \rightarrow \gamma\pi_T, \quad W\pi_T, \quad f\bar{f}$$

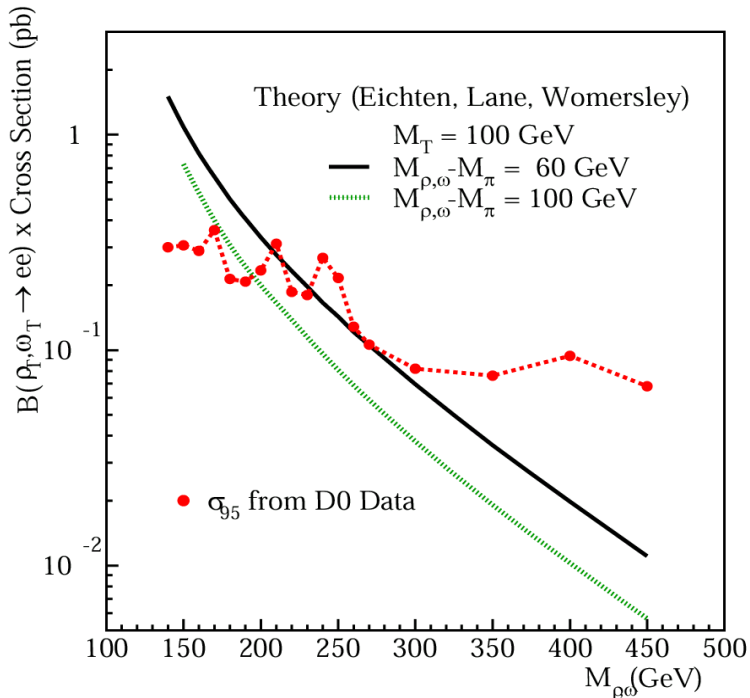
- Assume $M_\rho = M_\omega$
- Analyze the dielectron final state

$$p\bar{p} \rightarrow \rho_T, \omega_T \rightarrow e^+e^-$$

- Cross section and BR depend on technihadron masses and mass parameter M_T
- **Good agreement of data with SM, set 95% CL limits**

$$M_{\rho_T,\omega_T} > 207 \text{ GeV if } M_{\rho_T} - M_{\pi_T} < M_W$$
$$M_{\rho_T,\omega_T} > 203 \text{ GeV if } M_T > 200 \text{ GeV}$$





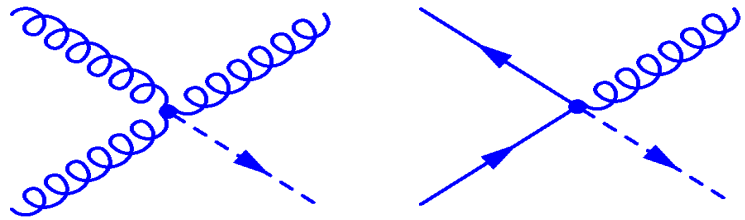
DØ PRL 87, 61802 (2001)

Search for Large Extra Dimensions at the Tevatron

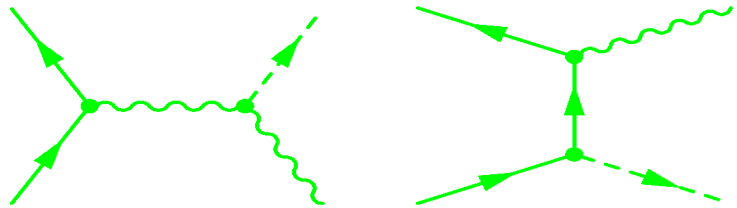
- Much recent interest in large extra dimensions (LED)
  [Arkani-Hamed, Dimopoulos, Dvali]
- Solve hierarchy problem by effectively lowering Planck scale to EW scale
- Size R of ED depends on # of ED n

$$R \sim \frac{1}{M_S}\left(\frac{M_{Pl}}{M_S}\right)^{2/n}$$

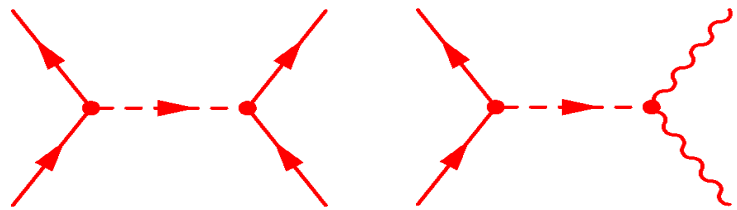
  where M_S is the effective Planck scale
- Cavendish-style expt's and cosmological constraints likely rule out n = 2
- For n > 2, ED microscopic and new technique needed
- Best signature at the Tevatron is from virtual graviton exchange



Monojets



Single vector bosons



Virtual graviton effects

Tevatron Search

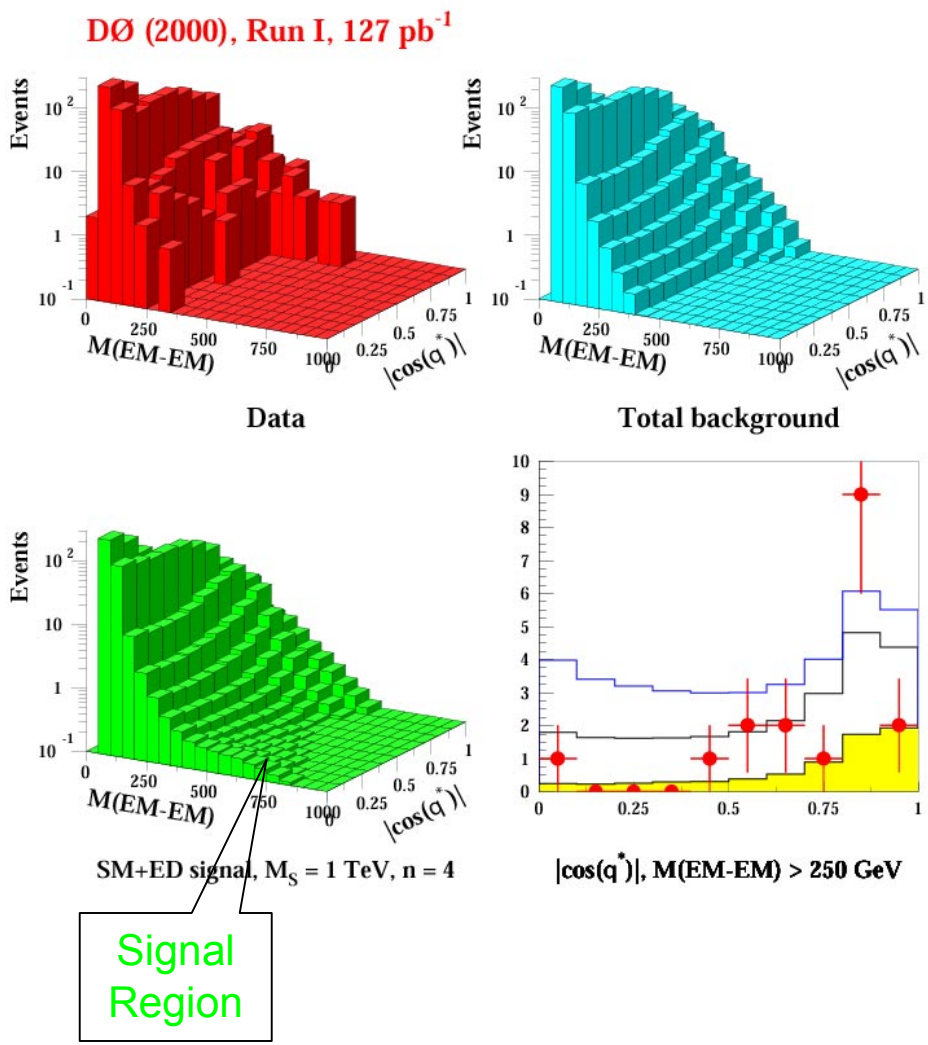
Search for Large Extra Dimensions at DØ

- Search for virtual graviton effects in dielectron and diphoton final states

$$p\bar{p} \rightarrow e^+e^- \text{ or } \gamma\gamma$$

- Maximize ε by relaxing track requirement: "di-EM" final states
- Signal shows up as excess at high $M_{EM\text{-}EM}$ and low $|\cos\theta^*|$
- Lower limits are placed on the effective Planck scale M_S for several models

Giudice, Rattazzi, Wells	Han, Lykken, Zhang		Hewett
	n = 2	n = 7	Λ = +1 (-1)
1.2 TeV	1.4 TeV	1.0 TeV	1.1 (1.0) TeV



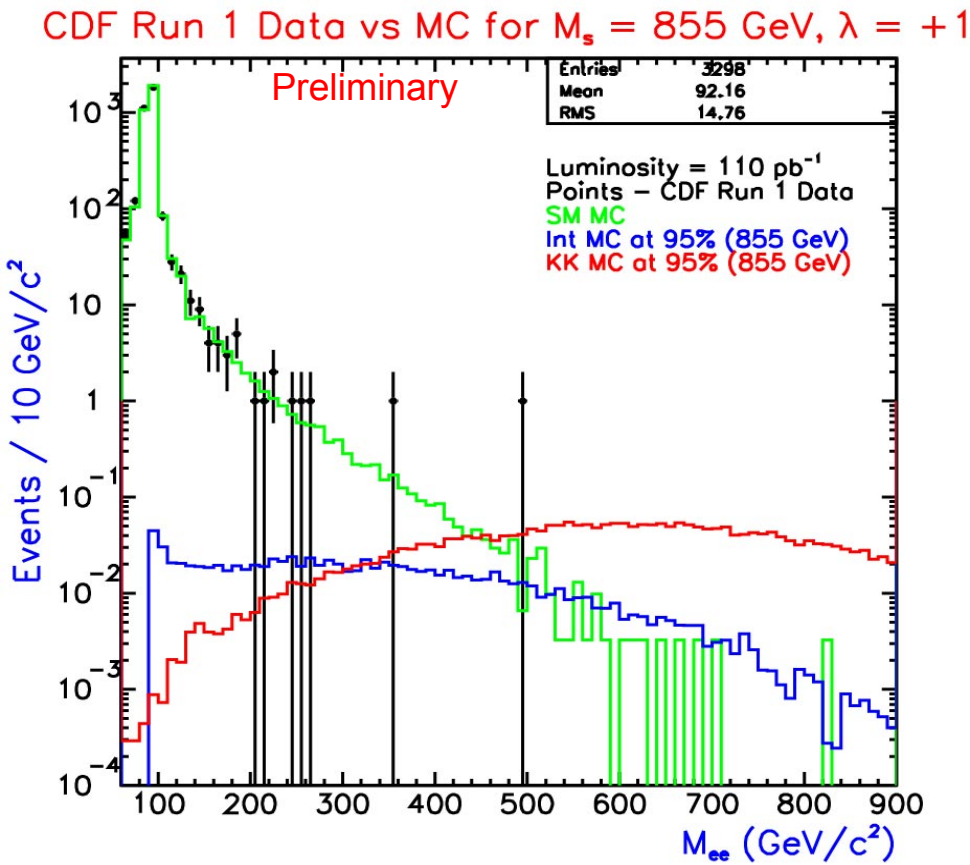
DØ PRL 86, 1156 (2001)

Search for Large Extra Dimensions at CDF

- CDF searches in the dielectron final state

  $p\bar{p} \rightarrow e^+e^-$

- Event selection based on Z' search. Require 2 electrons
  - $|\eta|<1.0$
  - $E_T > 25$ GeV
- Normalize to the Z region
- Limits are placed on the effective Planck scale M_S for Hewett model
  - **$M_S > 0.855$ TeV for $\Lambda = +1$**
  - **$M_S > 0.840$ TeV for $\Lambda = -1$**
- Analysis of diphoton final state in progress



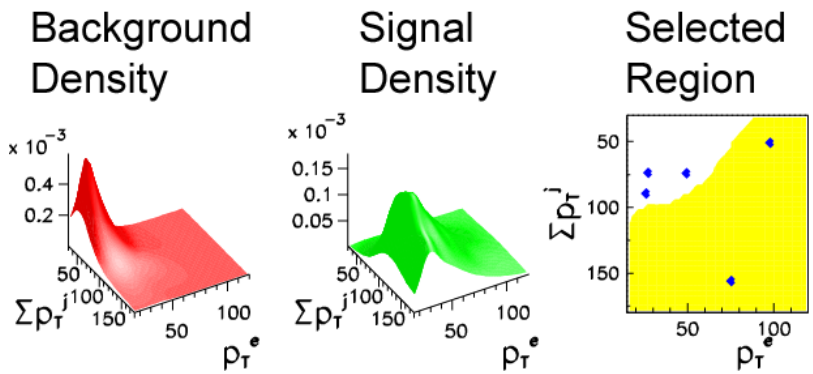
QUAERO

- Have a new model? Check it yourself against DØ data!
- QUAERO is a tool to make HEP data publicly available.
- Inclusive final states (may have additional jets)

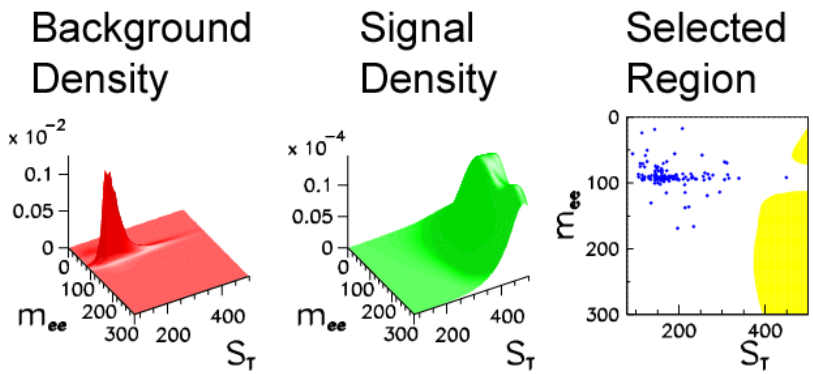
  $e\mu, \quad e \not\!\!E_T \; 2j, \quad ee \; 2j$

- Through a web interface
  [http://quaero.fnal.gov/quaero]
  user specifies signal and variables
- QUAERO automatically calculates selected region, compares to DØ data, and returns $\sigma^{95\%}$, the 95% CL cross section upper limit
- Tested on many processes
  - Slight excess in eμ final state consistent with top σBR
  - Reproduces DØ LQ limit in *ee* 2j final state

Signal: $t\bar{t} \rightarrow e \; \mu \not\!\!E_T \; 2j$



Signal: $LQ_{225}\overline{LQ}_{225} \rightarrow e \; e \; 2j$



DØ hep-ex/0106039

Geek Chic

Secrets of the Atom Revealed

By Jeffrey Benner

2:00 a.m. July 27, 2001 PDT

You can find a lot of information on the Web, but you just couldn't find a decent picture of the subatomic universe online.

Until now.

Scientists at the Fermilab in Illinois, home to the world's most powerful atom smasher, announced Wednesday that data collected during the last big round of experiments into the depths of the atom is now available online.

Using a Web interface called Quaero, particle physicists around the world can go online to test their own theories against Fermilab's data. The system is not quite the same as an automated database, but it's close. Scientists can request a search for signs of a particular particle -- generally in the form of a mathematical formula only a physicist could appreciate -- and the next day they'll hear, yea or nay, whether their hunch was correct.

The information was gathered during a series of experiments conducted from 1992 to 1996 with Fermilab's Tevatron, the world's most powerful particle accelerator. About 500 scientists worked on the project. It's known as the DZero collaboration in honor of the five-story, 5,000-ton DZero microscope used to spot particles after an atom gets smashed.

Nineteen-ninety-six might sound like old news, but this is the first time results like this have been made freely accessible.

"In our field, it's always been that if you wanted to look at the data, you had to join the collaboration," said Ann Heinson, a physics professor at the University of California, Riverside. She's an experimental particle physicist who's worked with the DZero detector before.

Summary

- Analysis of the data from Run I of the Tevatron continues to be very active
- DØ and CDF are still producing world class results from the many ongoing analyses on a wide range of topics
- The emphasis is now shifting to Run II data taking
- Very excited about the prospects for Run II physics
  - Higher energy – 1.8 TeV $\rightarrow$ 2.0 TeV
  - Large data sets – L = 15 fb^{-1} planned for Run IIb
  - Upgraded detectors with improved capabilities