Top pair production cross-section measurement in the dilepton channel at CDF

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for

The CDF II Collaboration

Outline

- Motivation
- Top quark signal
- Dilepton analyses
- Cross section results
- Conclusion

Motivation

Measurement of σ(t-tbar) is important:

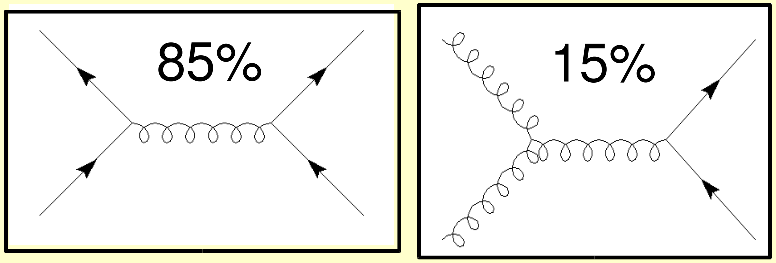
- **For testing the SM in the top quark sector:**
  - top discovery is relatively new (EST 1995)
  - characterize production/decay mechanisms & kinematics
- **Probe for physics beyond SM**
  - non-SM production, X → t-tbar
  - non-SM decay, t → Xb
- **t-tbar event topology is a background for exotics searches**
- **Theoretical cross-section:** NLO @ $\sqrt{s}$ =1.96 TeV for M_{top} = 175 GeV:

$$\boxed{\sigma_{t\bar{t}} = 6.7^{+0.7}_{-0.9}\ \mathrm{pb}}$$

(Bonciani *et al.* hep-ph/0303085)

Top quark signal

Pair production dominant:



In SM $BR(t \rightarrow Wb) \approx 100\%$

t-tbar final states (topologies):

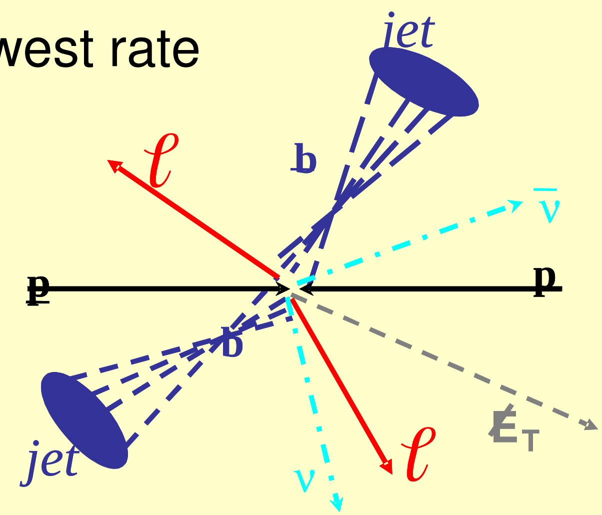
Dilepton (BR = 11%)
2 leptons + 2 b-jets + missing-E_T

Lepton + jets (BR = 44%)
1 lepton + 4 jets (2 b-jets) + missing-E_T

All-hadronic (BR = 45%)
6 jets (2 b-jets), no missing-E_T

Dilepton channel (our signal):

- cleanest
- smallest background
- lowest rate



Search motivated by intriguing Run I dilepton sample:

- 7 eμ events out of 9 total
- several events have larger E_T^{miss} than expected

Measurement strategy for Run II

Two independent / complementary analyses:

"DIL" analysis (Run I-like)

- Second lepton uses traditional lepton ID in calorimeter, muon chambers
- Two well-identified leptons
- **Higher purity, lower statistical significance**

"LTRK" analysis (new)

- Second lepton is just track isolated in drift chamber ("**tl**")
- Increase acceptance at expense of purity
  - Get ~hadronic τ & holes in lepton ID coverage
- **Lower purity, higher statistical significance**

Perform counting experiment for each:

$$\sigma_{t-tbar} = \frac{\left(N_{\text{obs}} - N_{\text{bgnd}}\right)}{A \times \epsilon \int L\, dt}$$

Combine cross sections

Event Selection

Baseline selection: *(dilepton + E_T^{miss} + jets)*

- **first lepton:** a high-pT electron or muon (trigger)
- **second lepton:** looser ID (DIL) or an isolated track with P_T > 20 GeV(LTRK)
- **opposite charge**
- **$E_T^{miss} > 25$ GeV**
- **$\geq$2 jets :** E_T>15 GeV, $|\eta|$<2.5 (DIL) or E_T >20 GeV, $|\eta|$<2.0 (LTRK)

Further background supression:

- **if E_T^{miss} co-linear with jet or lepton [|| or anti-|| with isolated track]**
- **Z region :** ratio of E_T^{miss} to sum of jet E_T's projected on E_T^{miss}< 8 (DIL)

  E_T^{miss}>40 GeV (LTRK)
- **$H_T \equiv$ (scalar sum of event energy) > 200 GeV (DIL)**

Backgrounds

Instrumental backgrounds

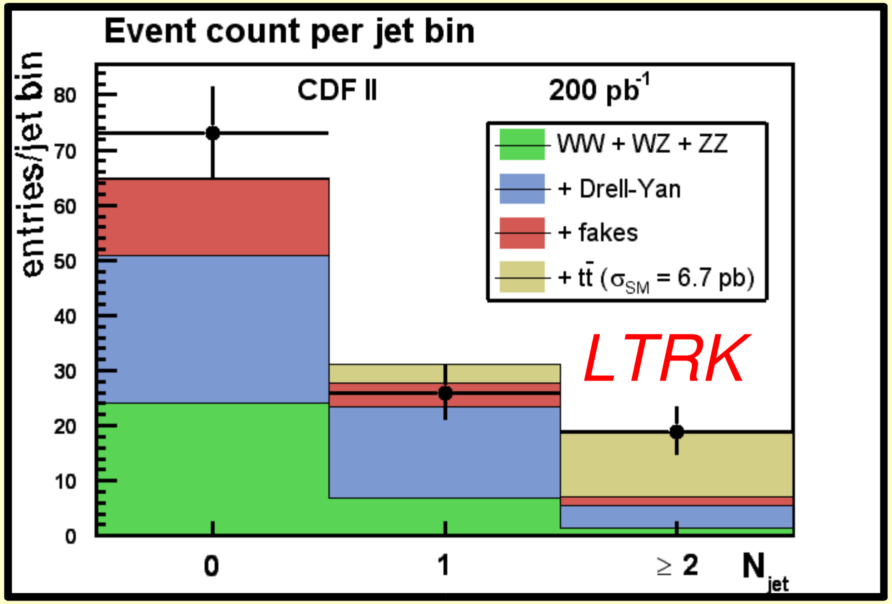
- **Drell-Yan** ($Z/\gamma^* \rightarrow ee, \mu\mu$)
  - False E_T^{miss} from mismeasured leptons, jets
- **Fake leptons**
  - W+jets with jet misidentified as a lepton
- Use data wherever possible

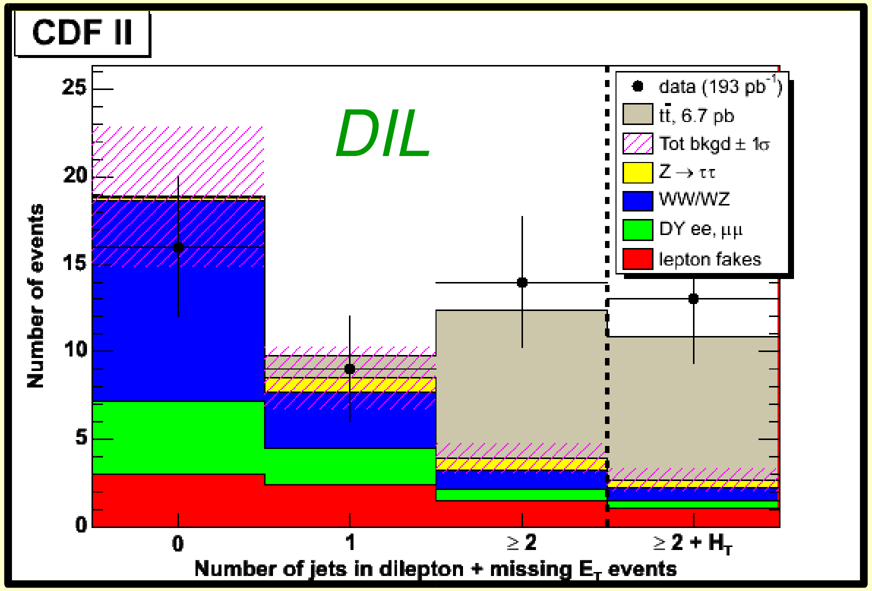
Physics backgrounds

- **Diboson** (WW/WZ/ZZ) and $Z/\gamma^* \rightarrow \tau\tau$
  - Real leptons, E_T^{miss}, jets
  - Evaluated using MC

Understanding background composition in 0 jet & 1 jet gives confidence in the signal region ($\geq$2 jets)

Events expected, observed





	LTRK			DIL			
	$N_{\rm jet} = 0$	$N_{\rm jet} = 1$	$N_{\rm jet} \geq 2$	$N_{\rm jet} = 0$	$N_{\rm jet} = 1$	$N_{\rm jet} \geq 2$	$H_T > 200$ GeV
WW, WZ, ZZ	21.8 ± 5.5	6.3 ± 1.6	1.2 ± 0.3	11.4 ± 3.3	3.2 ± 0.9	1.1 ± 0.3	0.74 ± 0.21
Drell-Yan	26.5 ± 9.8	16.4 ± 6.0	4.2 ± 1.6	4.4 ± 1.9	2.9 ± 1.1	1.3 ± 0.5	0.85 ± 0.48
Fakes	16.5 ± 2.4	5.0 ± 1.0	1.5 ± 0.5	3.0 ± 1.2	2.4 ± 1.0	1.5 ± 0.6	1.1 ± 0.5
Total Bkgd	64.8 ± 11.5	27.7 ± 6.3	6.9 ± 1.7	18.8 ± 4.0	8.5 ± 1.8	3.9 ± 0.9	2.7 ± 0.7
Expected $t\bar{t}$	0.3 ± 0.2	3.4 ± 0.6	11.5 ± 1.8	0.1 ± 0.0	1.3 ± 0.2	8.5 ± 1.2	8.2 ± 1.1
Total	65.1 ± 11.5	31.1 ± 6.3	18.4 ± 2.5	18.9 ± 4.0	9.8 ± 1.9	12.4 ± 1.6	10.9 ± 1.4
Observed	73	26	19	16	9	14	13

Good agreement in 0j, 1j bins (control region)

signal region

Signal and Background Uncertainties

	LTRK	DIL
Lepton (track) ID	5%(6%)	5%
Jet energy scale – signal	6%	5%
Jet energy scale – background	10%	18-29%
Initial / final state radiation	7%	2%
Parton distribution functions	6%	6%
Monte Carlo Generators	5%	6%
WW,WZ,ZZ estimate	20%	20%
Drell-Yan estimate	30%	51%
Fake estimate	12%	41%

Cross section results

Effective luminosity of 197 pb^{-1}

DIL: A * ε = (0.62 ± 0.09)%

$$\sigma_{t\bar{t}} = 8.4^{+3.2}_{-2.7}(\mathrm{stat.})^{+1.5}_{-1.1}(\mathrm{syst.}) \pm 0.5(\mathrm{lum.})\ \mathrm{pb}$$

LTRK: A * ε = (0.88 ± 0.14)%

$$\sigma_{t\bar{t}} = 7.0^{+2.7}_{-2.3}(\mathrm{stat.})^{+1.5}_{-1.3}(\mathrm{syst.}) \pm 0.4(\mathrm{lum.})\ \mathrm{pb}$$

(assuming BR(W→lν)=10.8%)

- Both measurements are consistent with SM calculation
- Error is statistics-dominated → results to be combined

Cross checks

Various cross / sanity checks were performed:

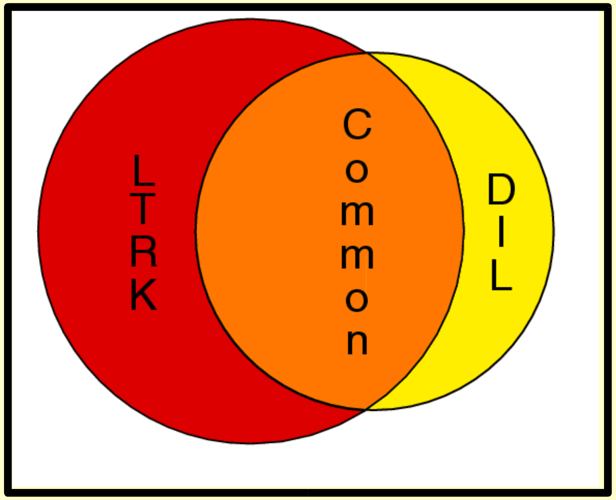
- ✔ Identical analysis techniques reproduce the expected W and Z cross sections
- ✔ Number of like-sign events (fakes-dominated sample) observed agrees with prediction in all jet bins
- ✔ Number of b-tagged events (DIL: 7, LTRK: 10) consistent w/ that expected from top
- ✔ Cross section stable over a wide range of jet, lepton E_T thresholds
- ✔ Measured cross section with a "lepton-lepton" subset of LTRK:

$$\sigma(t\bar{t}) = 8.5^{+4.5}_{-3.5}(stat)^{+1.8}_{-1.4}(syst) \pm 0.5(lum)\ \mathrm{pb}$$

⟶ Good agreement with DIL and LTRK

Combining the cross sections

- Combining two measurement reduces the largest uncertainty (**statistics**)
- Strategy: divide signal, background expectation and data into **three** disjoint regions:



LTRK-only, DIL-only and Common (overlap)

	Acceptance
Common	0.464%
DIL-Only	0.156%
LTRK-Only	0.411%
Total	1.031%

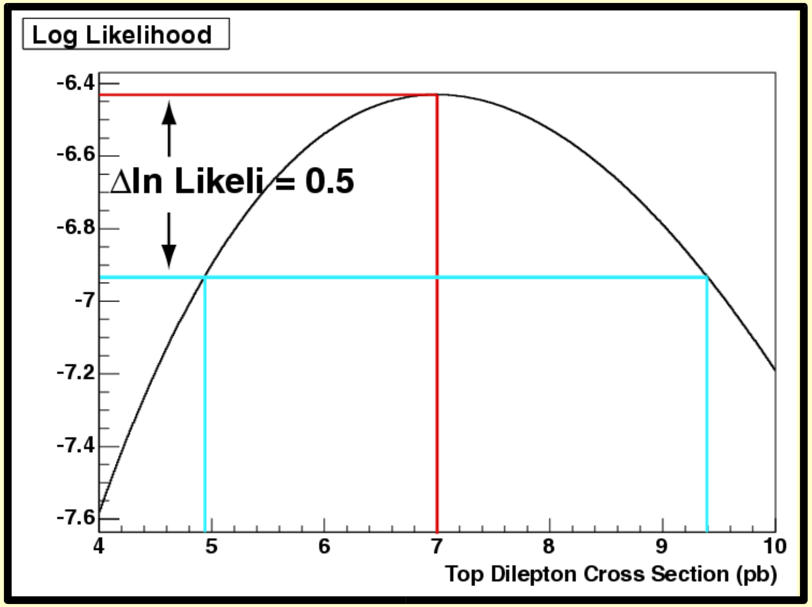
	Background Events
Common	1.8
DIL-Only	0.9
LTRK-Only	5.1
Total	7.8

	Events
Common	11
DIL-Only	2
LTRK-Only	8
Total	21

Combination technique

$$L = \prod_{\alpha}^{subgroup} P(n^{\alpha}_{obs} \mid n^{\alpha}_{pred}(\sigma_{t\bar{t}}))$$

α = product over DIL-only, LTRK-only, overlap



- Maximize combined Poisson likelihood for three regions
- Be conservative w/ systematics between regions
  - Treated as 100% correlated, distributed to give largest total systematic

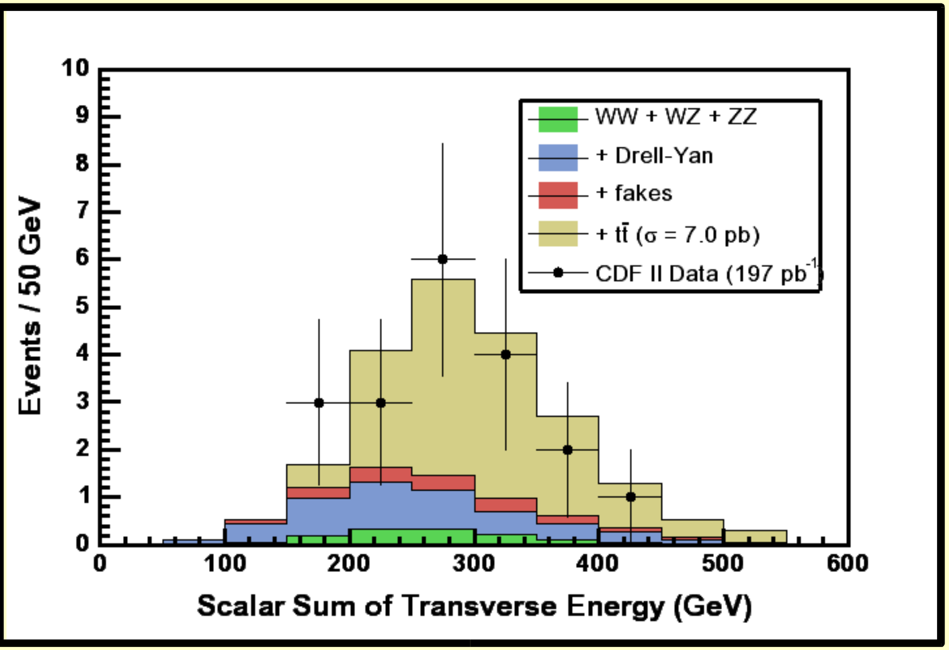
$$\sigma_{t\bar{t}} = 7.0^{+2.4}_{-2.1}(\mathrm{stat.})^{+1.6}_{-1.1}(\mathrm{syst.}) \pm 0.4(\mathrm{lum.})\ \mathrm{pb}$$

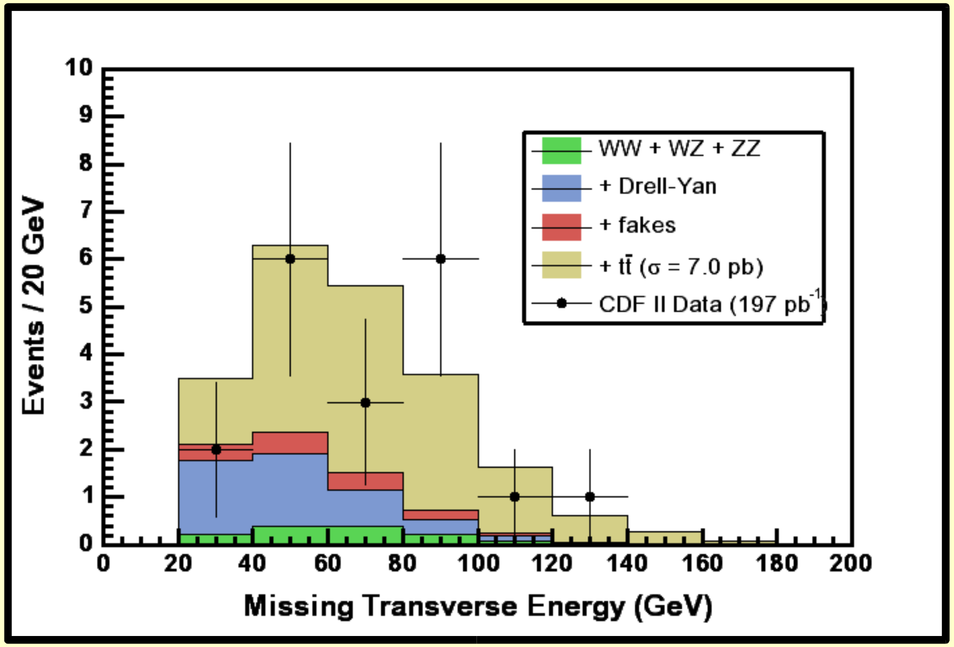
→ **12% reduction in statistical error**

Kinematic distributions

With larger statistics, we can start going beyond counting experiments to do shape tests on our selected sample.

Use larger statistics of **LTRK** to examine sample kinematics

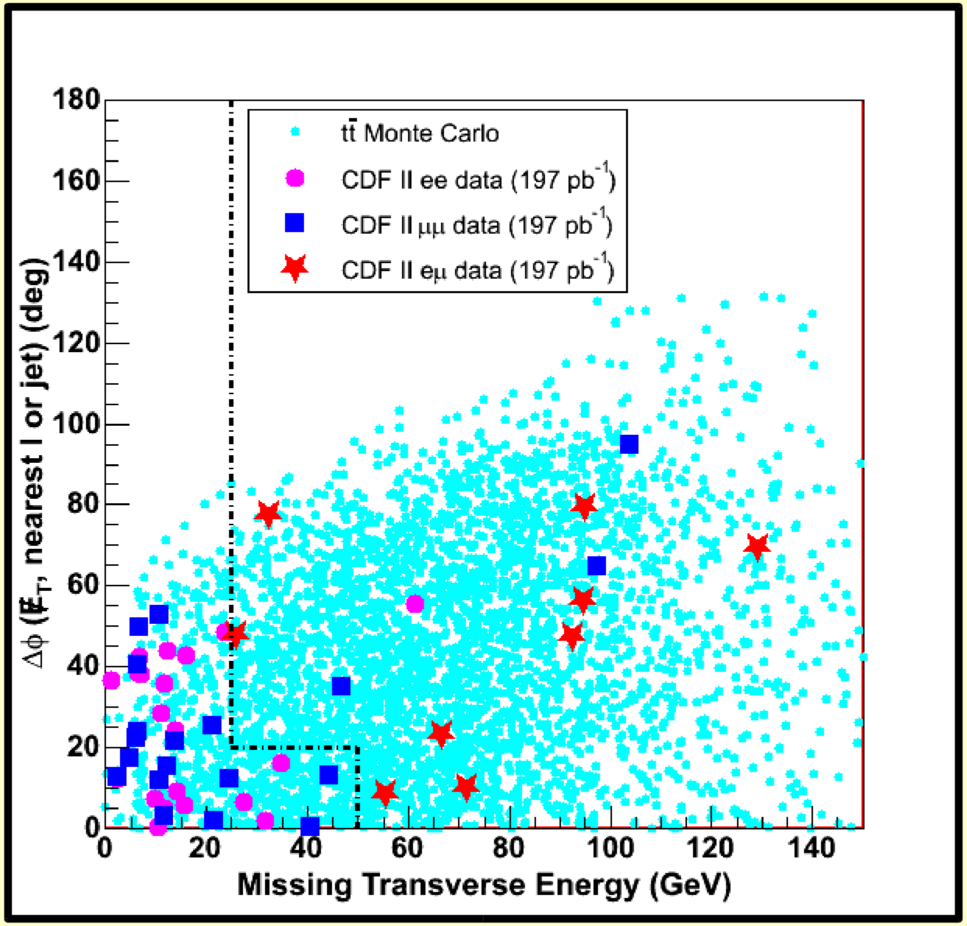




KS = 75% KS = 66%

Data follow expected distribution of top + background

Flavor distribution



Use **DIL** sample with two identified lepton

channel	Expected (scaled to 13 total obsv'd)	Observed
ee	*3.3 ± 0.5*	*1*
μμ	*2.8 ± 0.5*	*3*
*e*μ	*6.8 ± 0.8*	*9*

(# of events)

Consistent with expectation

Conclusions

- We have measured the $t\bar{t}$ production cross section in the dilepton decay channel using 197 pb^{-1} of Run II data
- Our result is (m_t = 175 GeV/c^2, BR($W \rightarrow l\nu$)=10.8%):

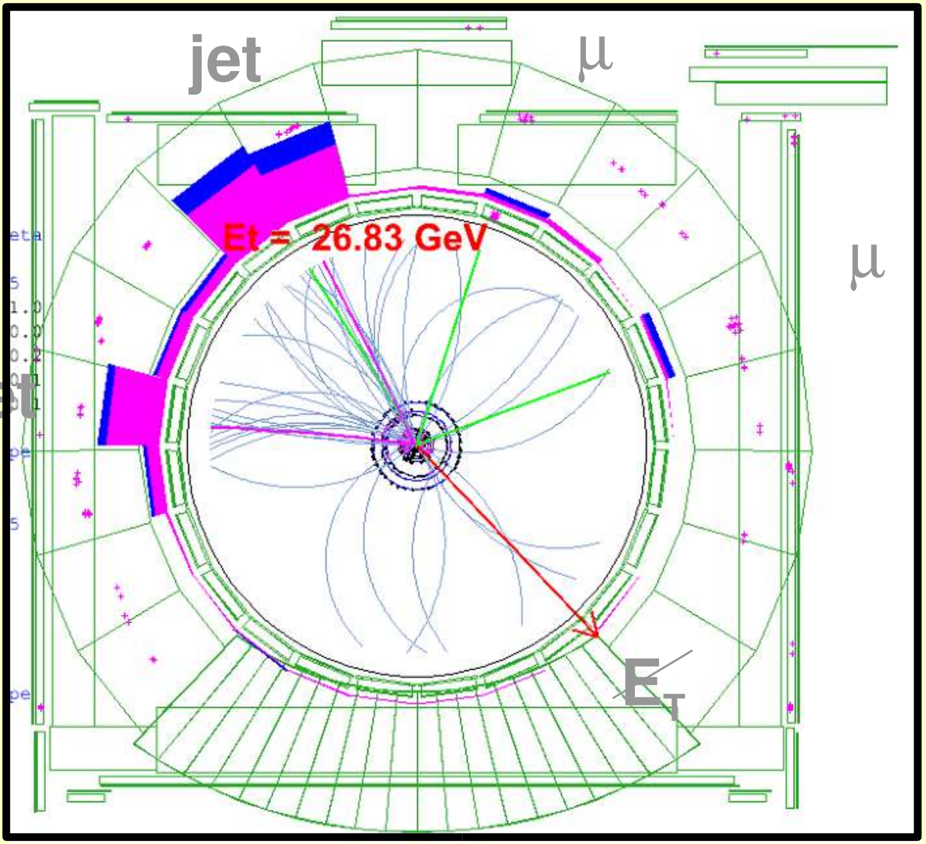
$$\sigma_{t\bar{t}} = 7.0^{+2.4}_{-2.1}(\mathrm{stat.})^{+1.6}_{-1.1}(\mathrm{syst.}) \pm 0.4(\mathrm{lum.})\ \mathrm{pb}$$

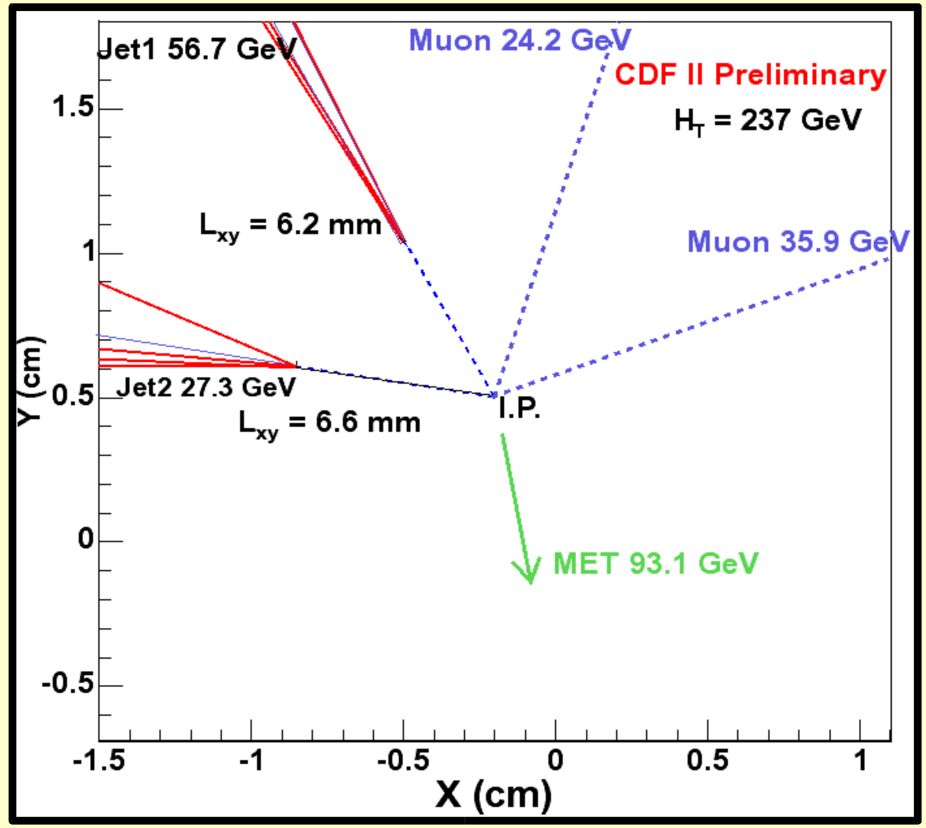
consistent with NLO SM calculation of $\sigma = 6.7^{+0.7}_{-0.9}$ pb

- Kinematics, flavor distribution of data also consistent with Standard Model expectation
- Paper (arXiv:hep-ex/0404036) accepted by PRL.

Double-tagged top dilepton candidate

- An event with 2 jets and 2 muons



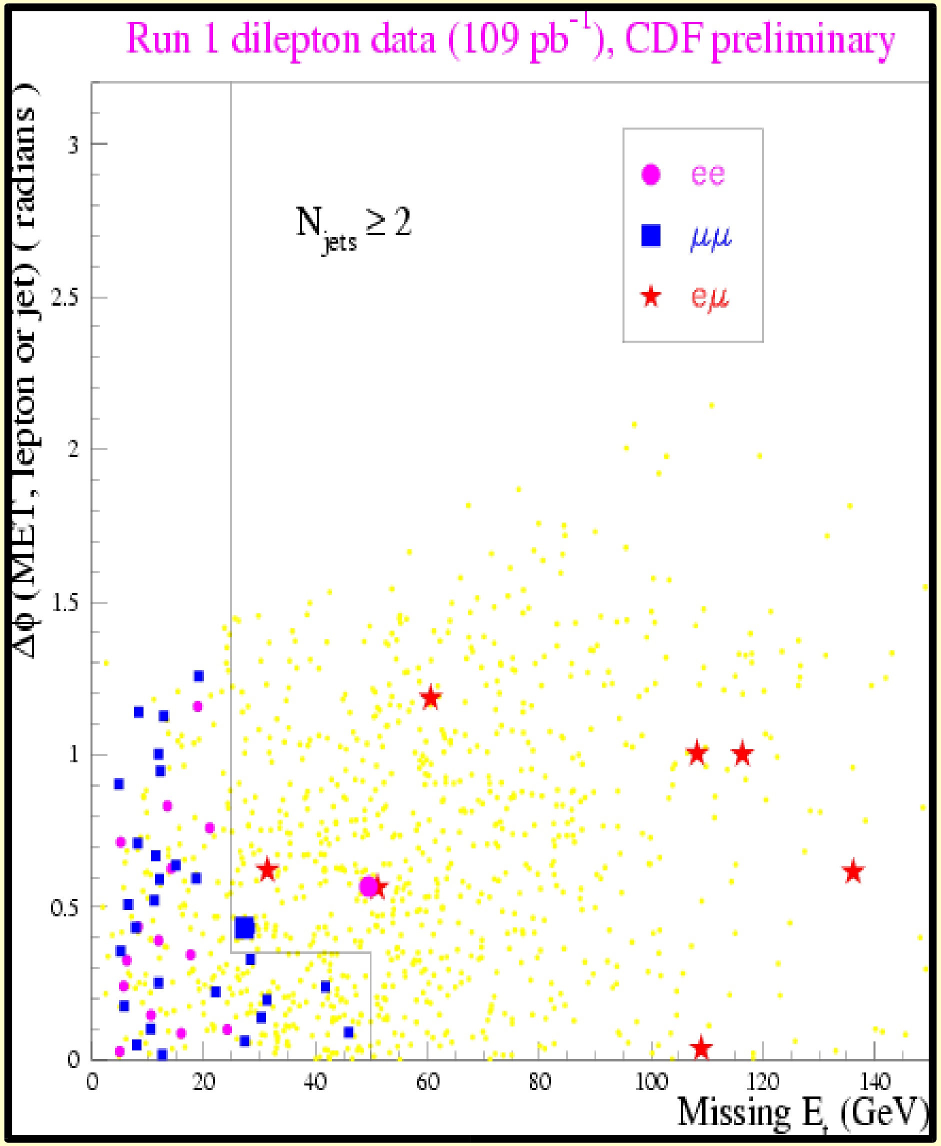


- Both jets show displaced secondary vertices from the interaction point: b jet candidates

Backup slides

Dileptons in Run I

- Run I dilepton sample had some interesting features
  - 7 eμ events out of 9 total
  - Several events with large E_T^{Miss}.
  - Measured $\sigma = 8.2^{+4.4}_{-3.4}$ pb (to be compared with 5.2 pb theoretical)
- Something to watch in Run II!



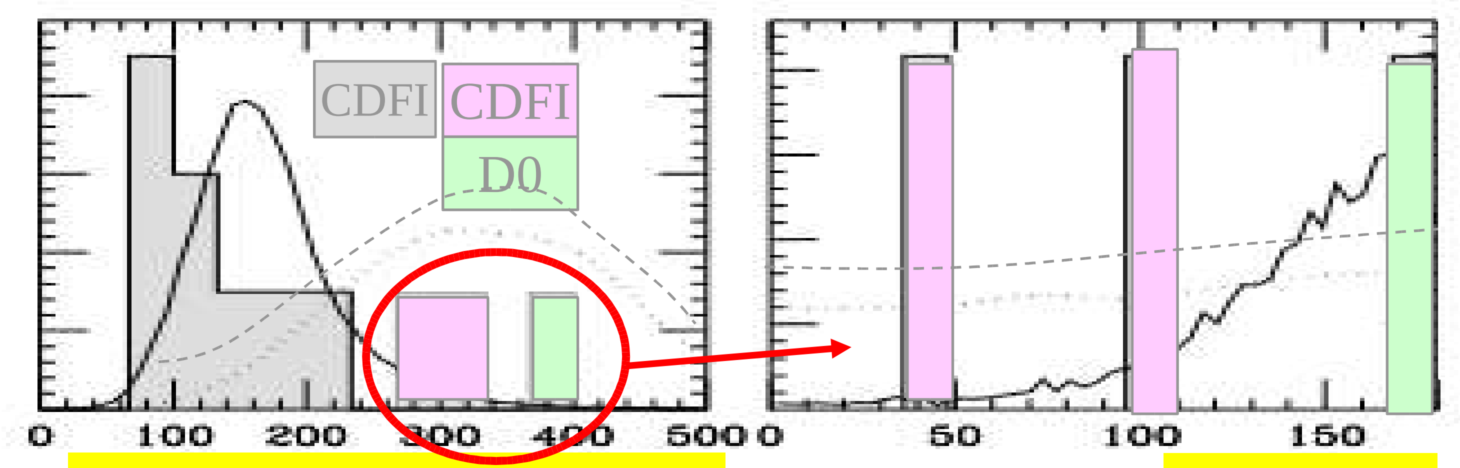
Run I Dileptons: new physics?

$t\bar{t}$

$\tilde{l} \rightarrow l\nu\tilde{\chi}_1^0$

SM top or SUSY?

Theory interest from hep-ph/9609313



$E_t^{MISS}+E_t(l_1)+E_t(l_2)$ [GeV]

θ_l [deg]

ttbar or cascade decay of squarks with masses around 300 GeV?

Kinematics in Dilepton Events

Run II Data sample

- **We have 4 lepton/detection categories (triggers): each have different "good-run" requirements and luminosities**
    - 202 pb^{-1} central electrons
    - 197 pb^{-1} central muons
    - 179 pb^{-1} central muon (extension region)
    - 180 pb^{-1} plug electrons (SVXII+ISL required)
- **Effective luminosity is 197 pb^{-1}**

What about m_{top} = 178 GeV?

- CDF & D0 released a new Run 1 combined top mass result (arXiv:hep-ex/0404010)

$$m_{top} = 178 \pm 2.7(stat) \pm 3.3(syst)\,\mathrm{GeV}/c^2$$

- Top acceptances changes by ~0.5%/GeV/c^2.
- Top cross section would go from 7.0 $\longrightarrow$ 7.1 pb