DØ Top Quark Properties

from the 1992-1995 Tevatron Run

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by

Jeffrey Bantly

Brown **U**niversity

for

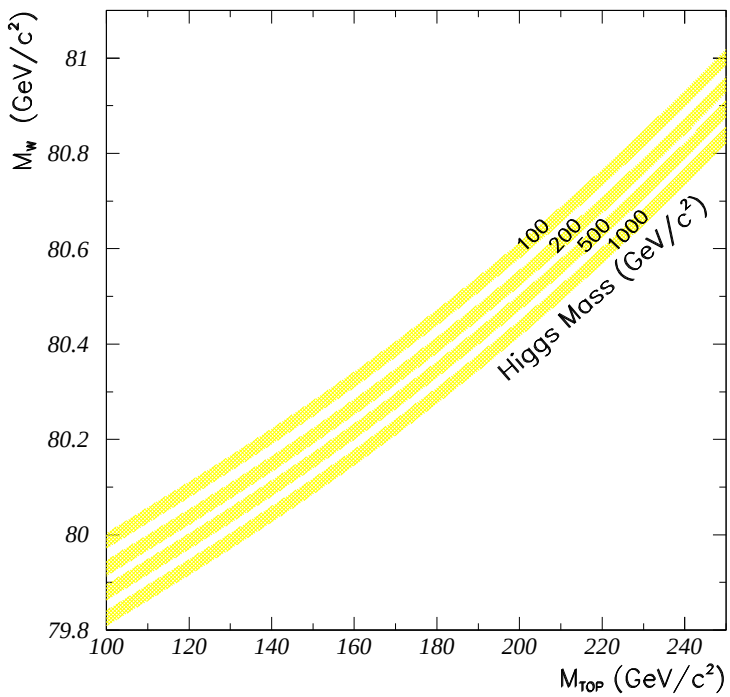
The **DØ C**ollaboration

Outline

- Introduction
- DØ Detector
- Search in 7 top quark decay modes
  - Dileptons
    - $e\,\mu$, $e\,e$, $\mu\,\mu$
    - $e\,\nu$ - new channel
  - Lepton + Jets
    - e/μ + jets + event shape
    - e/μ + jets + b tag
- Cross Section
- Kinematic Properties
- Conclusions

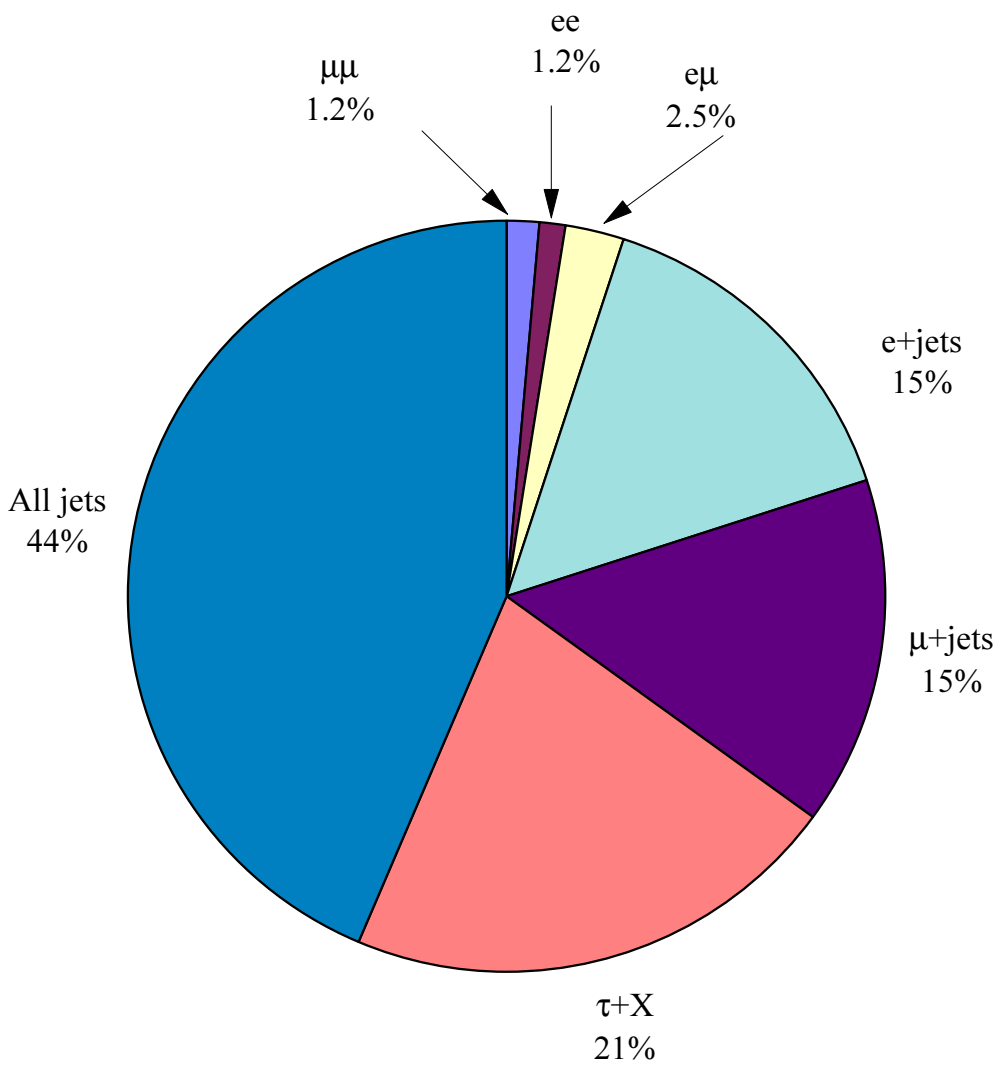
Top Quark Overview

- Knowledge of M_t allows many SM tests with sensitivity to new physics
- Top, W, Higgs masses related in SM



Top Production and Decay

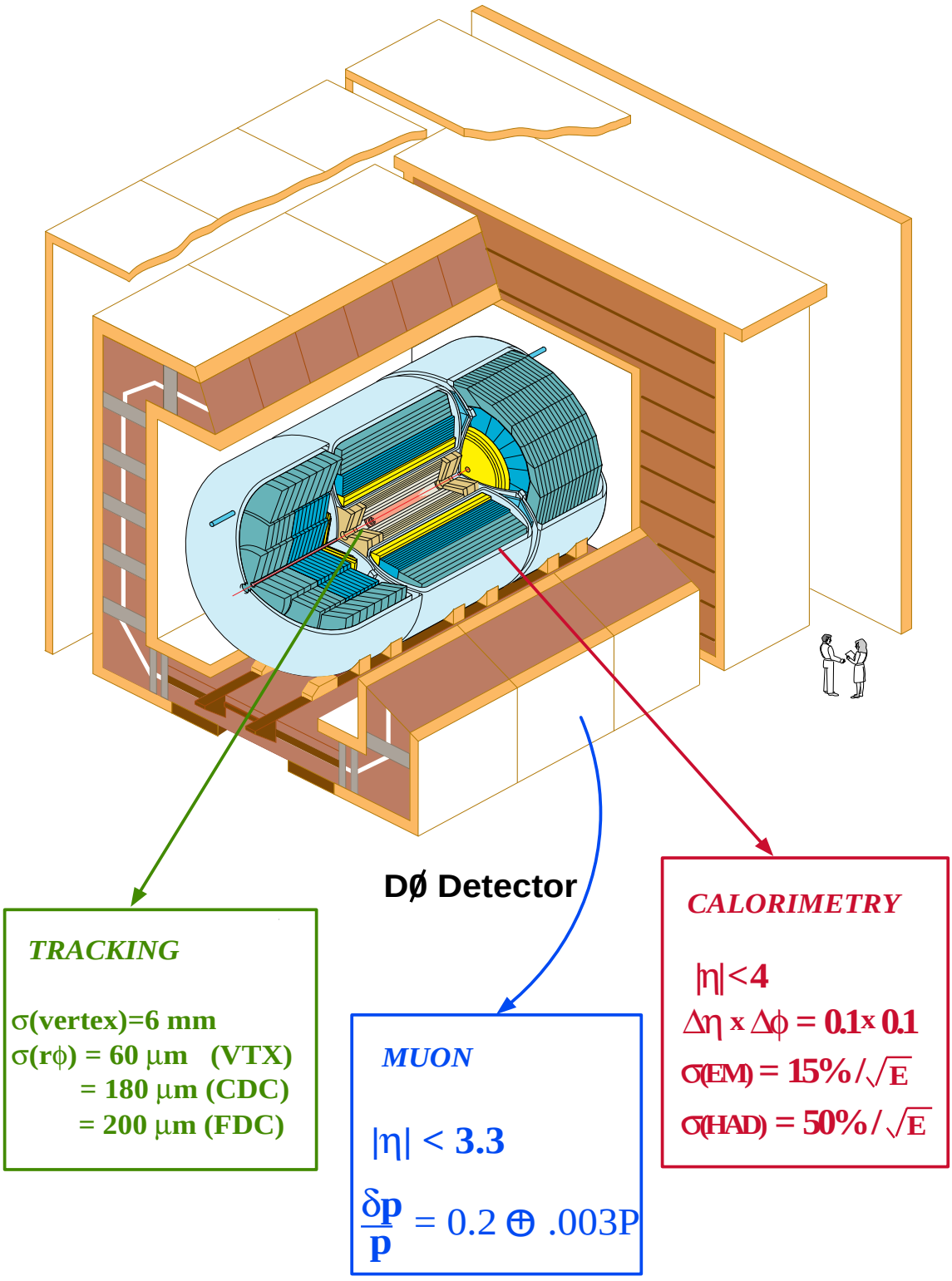
* At the Tevatron top quarks are pair-produced via the reactions: $qq \rightarrow t\bar{t}$ (~90%) and $gg \rightarrow t\bar{t}$ (~10%)
* Standard Model top decays $t \rightarrow Wb$ with branching fraction ~100%
* Each W decays via either $W \rightarrow l\bar{\nu}$ or $W \rightarrow q\bar{q}$
* Classify channels as dilepton, l + jets, or all jets



Top Quark

- Top quark discovery: March 1995 by DØ and CDF
- Updates in the DØ analysis:
  - Doubled integrated luminosity from 50 => 100 pb^{-1}
  - Improved particle identification and jet energy corrections.
  - Cross section analysis optimized on Monte Carlo to minimize expected cross section error
  - New channels: *all jets* and $e\nu$
  - Mass and kinematic analyses of lepton + jet events. (see also parallel talk by Serban Protopopescu)

The DØ Detector



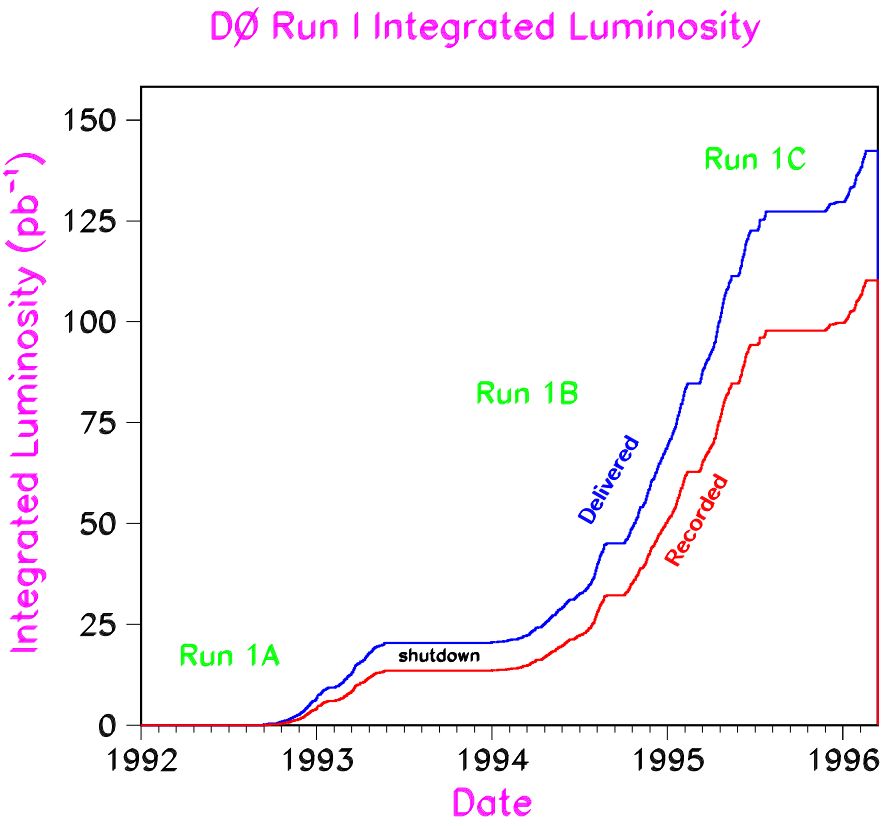
Particle Identification

- Electrons
  - Longitudinal and transverse shower shapes
  - Isolation
  - Track match
  - dE/dx
  - $|\eta| < 2.5$ for Dileptons, 2.0 for Lepton + Jets
- Jets
  - R = 0.5 cone for search
  - $|\eta| < 2.5$ for Dileptons, 2.0 for Lepton + Jets
- Neutrinos
  - Calorimeter missing E_T
- Muons
  - Track quality
  - MIP in calorimeter
  - $|\eta| < 1.0$ (1.7 in Run Ia, latter Run 1b)

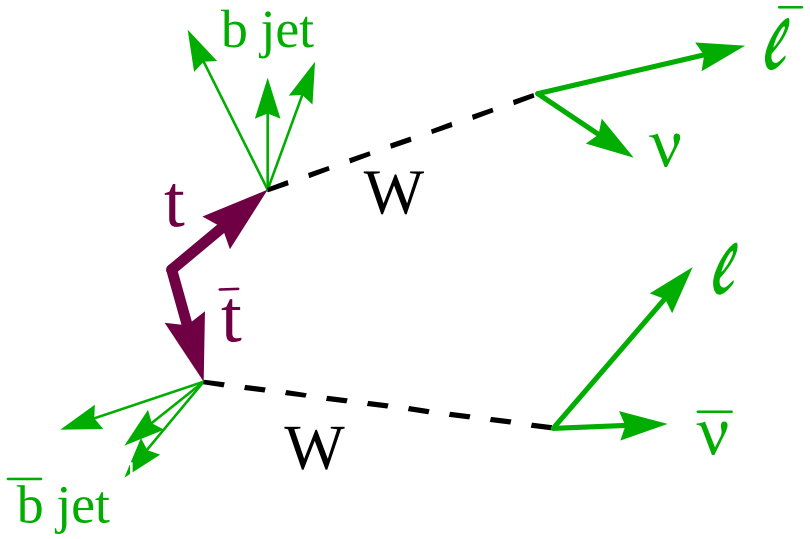
Data Set

- "Run I" - 1992-96 Tevatron run
- Total integrated luminosity of

$$\int L\, dt \approx 100\ \mathrm{pb}^{-1}$$



Dilepton Channels



- Final state:
  - Two isolated, high p_T leptons (e or μ)
  - Significant $\not{E}_T$
  - Jets from b quarks
- Total branching fraction: ~ 5%
- Backgrounds
  - QCD: $b\bar{b}$, $c\bar{c} \rightarrow \ell^+\ell^-$
  - Drell-Yan: $Z/\gamma \rightarrow \ell^+\ell^-$
  - W- Pair: $W^+W^- \rightarrow \ell^+\ell^-$
  - multi-jet events: jets misidentified as electrons

Dilepton Event Selection

($e\nu$ in a moment)

Selection Cut	$e\,\mu$	$e\,e$	$\mu\,\mu$
Lepton p_T	> 15/15 GeV	> 20/20 GeV	> 15/15 GeV
Missing E_T	> 20 GeV	> 25 GeV	...
# of Jets	≥ 2	≥ 2	≥ 2
Jet E_T	> 20 GeV	> 20 GeV	> 20 GeV
H_T	> 120 GeV	> 120 GeV	> 100 GeV

- For $e\mu$ and ee , $H_T^e = p_T^e + \Sigma\, E_T^{jets}$
- For $\mu\mu$, Z kinematic fit cut applied.

e-μ *Analysis*

Event Selection:

$p_T^e > 15$ GeV

$p_T^\mu > 15$ GeV ($\Delta R_{(\mu,jet)} > 0.5$)

$\not{E}_T > 20$ GeV

≥ 2 jets, $E_T > 20$ GeV ($|\eta| < 2.5$)

$H_T^e > 120$ GeV ($H_T^e = p_T^e + \Sigma E_T^{jets}$)

Expected Event Yield (90 pb^{-1})

Top (160 GeV)	2.5 ± 0.5
Top (180 GeV)	1.7 ± 0.3
Top (200 GeV)	1.0 ± 0.2
Total Bkg.	0.36 ± 0.09
Data	3

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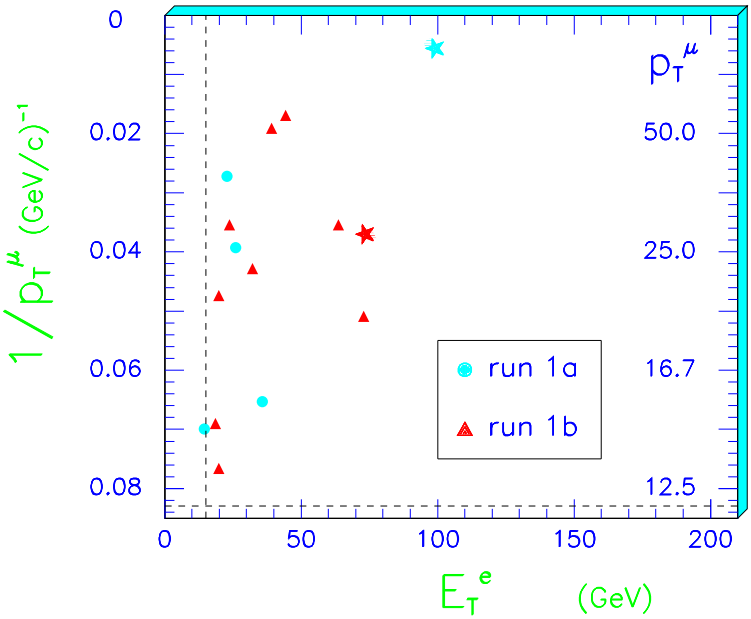
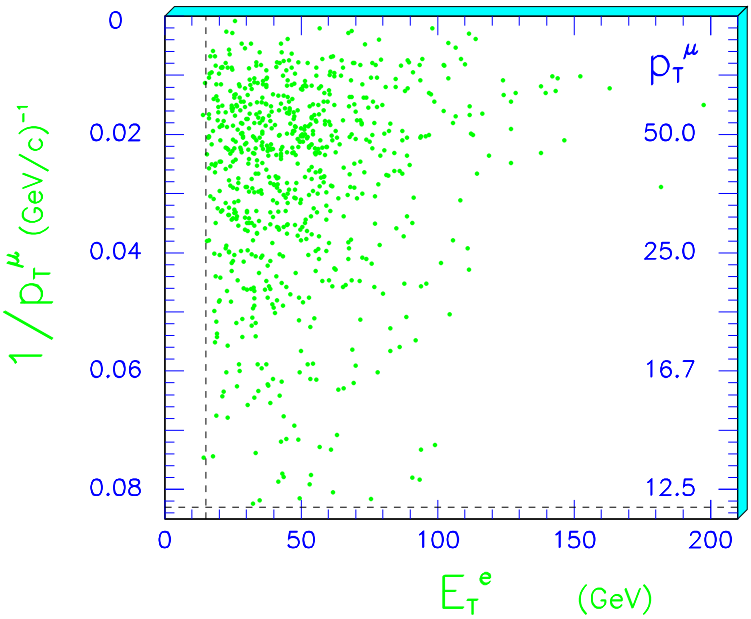
e-μ *Analysis*

- Before $\not{E}_T$, jet, and H_T cuts



E_T^e vs $1/p_T^{\mu}$

Collider Data
$\int Ldt = 47.9\ pb^{-1}$



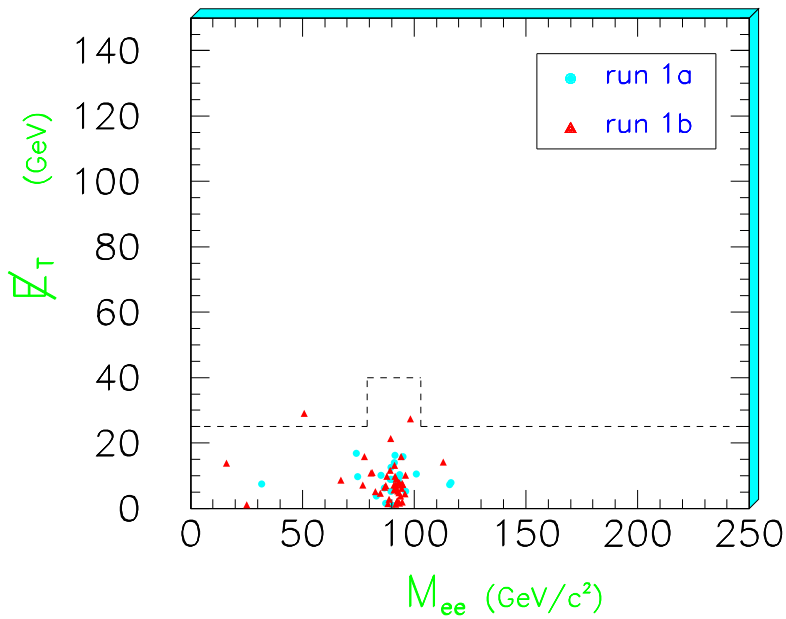
E_T^e vs $1/p_T^{\mu}$

$tt \rightarrow e\mu$ (m_t=170)
monte carlo
$\int Ldt = 21\ fb^{-1}$

- After all cuts, see 3 events

e-e Analysis

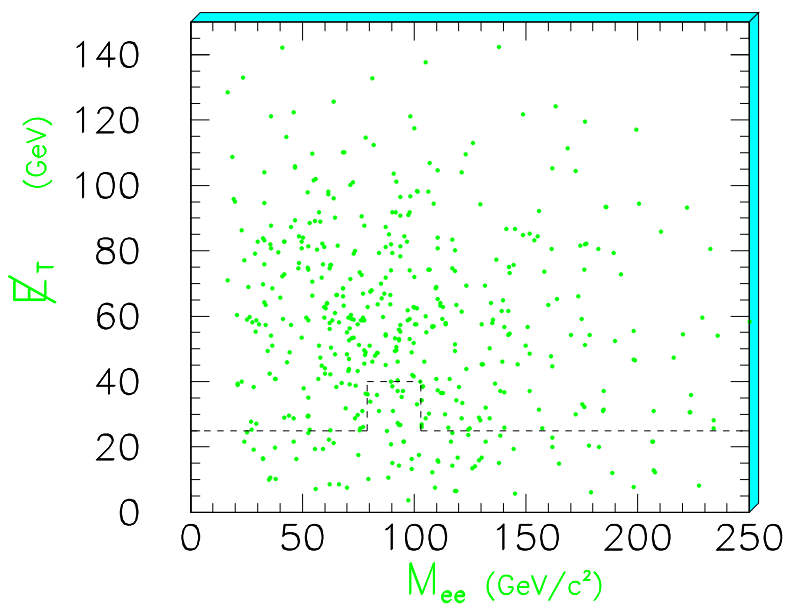
- After electron E_T and jet cuts, before H_T cut



M_{ee} vs $\not{E}_T$

Collider Data

$\int Ldt = 55.7\ pb^{-1}$



M_{ee} vs $\not{E}_T$

$tt \rightarrow ee$ (m_t=160)

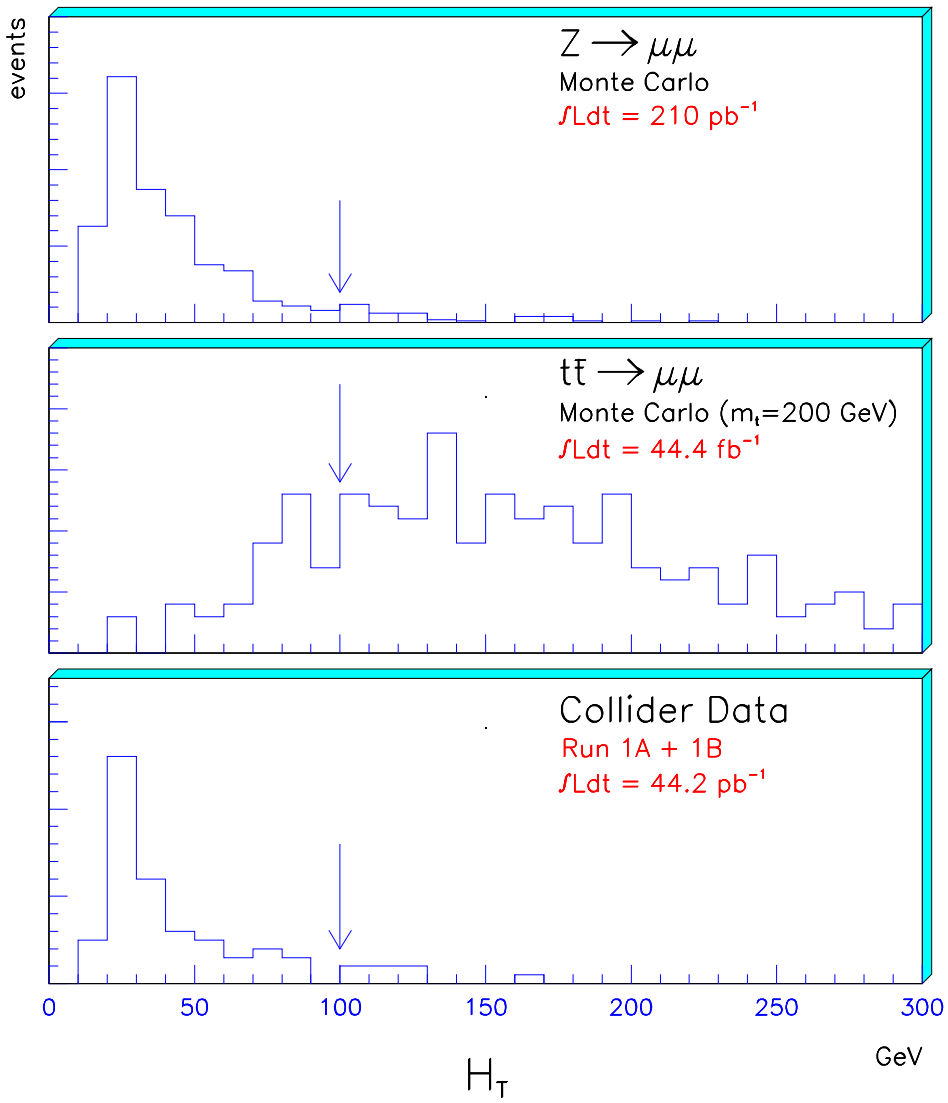
monte carlo

$\int Ldt = 19\ fb^{-1}$

- After all cuts, 1event survives

μ –μ *Analysis*

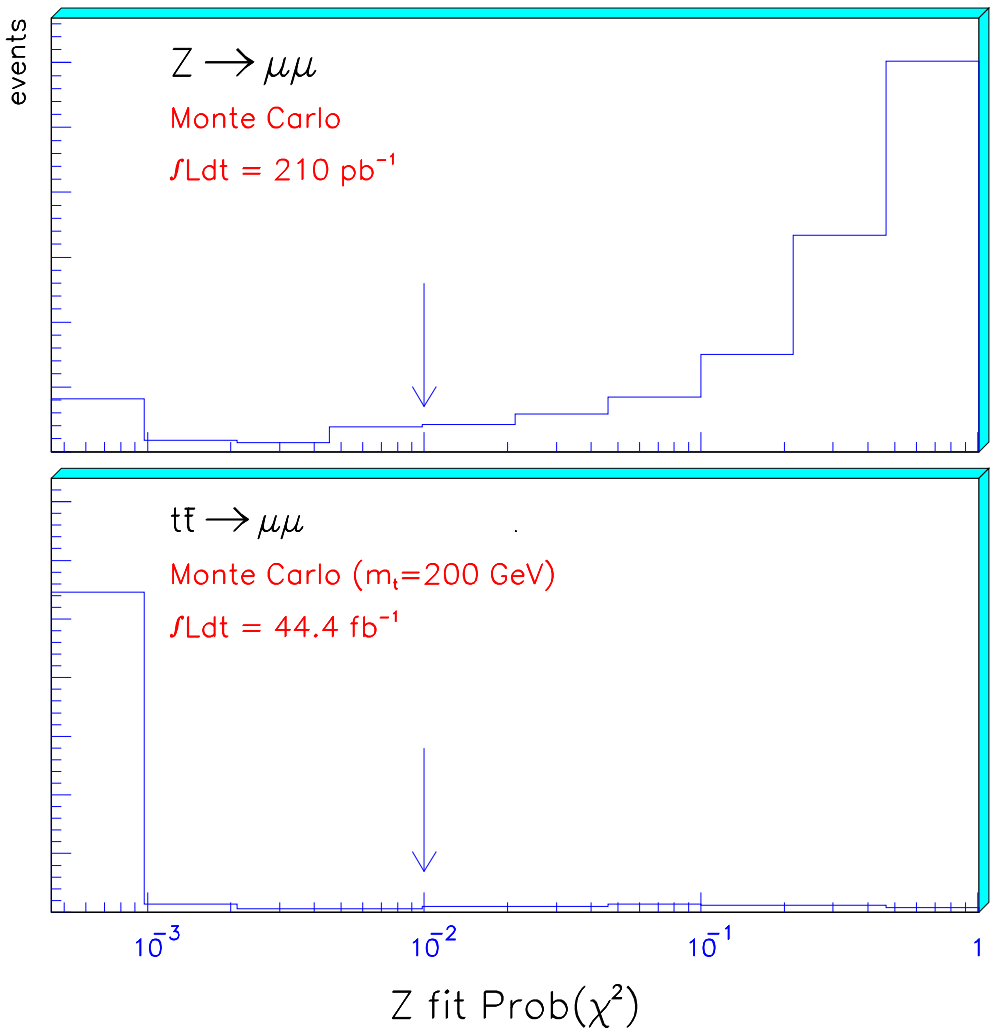
- Before 2nd jet, H_T, and Z fit cuts



- After all cuts, see 1 event

μ –μ *Analysis*

- Use of Kinematic Fitting to reject $Z \rightarrow \mu\mu$

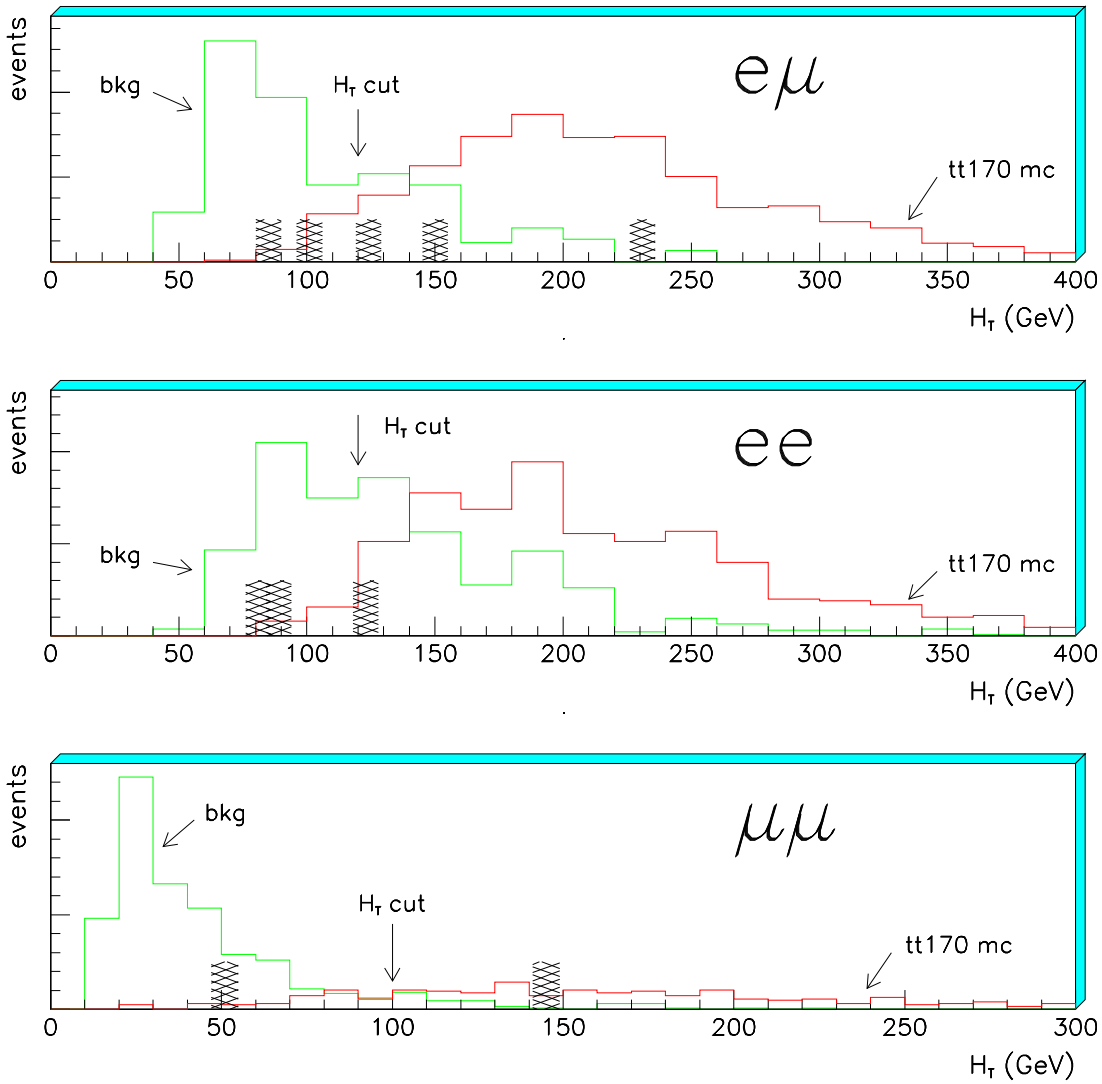


H_T for Dilepton Channels

After all cuts except H_T

Background

MC *tt* signal (170 GeV/c^2)

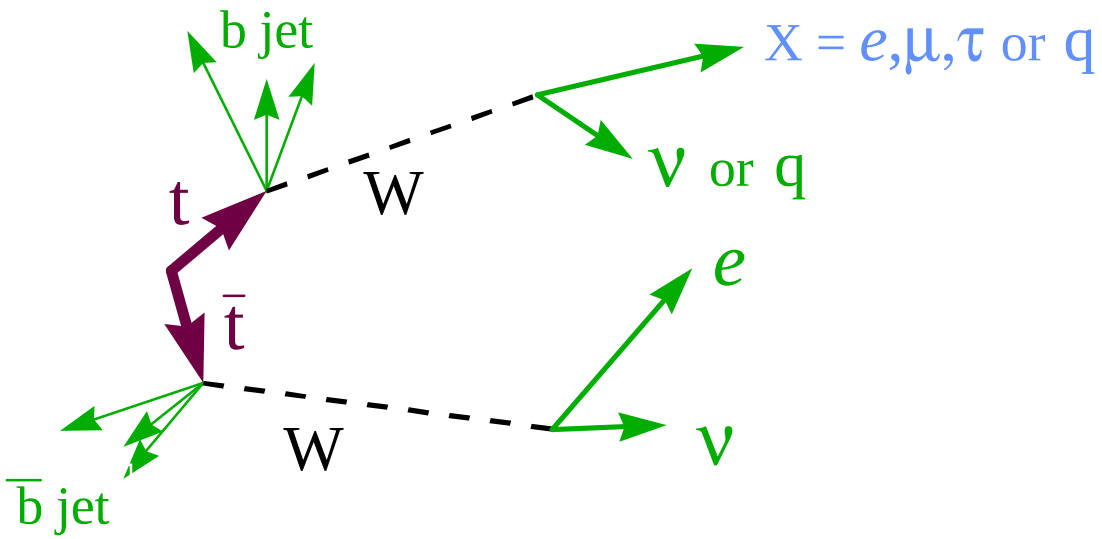


H_T (GeV)

Backgrounds

- Physics Backgrounds
  - Real physics processes which have the same signature as top
  - Example: $W\,W \rightarrow e\,\mu\,X$
  - Estimated using Monte Carlo and data
- Fake Backgrounds
  - Estimated using data
  - Jet faking a lepton
    - Fake probability from independent jet data $P(\text{jet}\rightarrow\text{lepton}) \equiv$ # of "leptons"/# of jets
    - $N_{fake} = N_{jet} \times P(\text{jet}\rightarrow\text{lepton})$
  - Large missing E_T from resolution & fluctuations
  - Example: $W(\rightarrow \mu\nu)$ + jets $\rightarrow$ "e" $\mu\,X$
  - Cosmics, punchthrough, π/K decays negligible

New Analysis: e-ν Channel



- Extend search with W → leptons where background is small to include:
  - τ decay channels
  - restricted phase space of charge leptons
- Requires single lepton, and $\not{E}_T > 50$ GeV
- Orthogonal to other channels by construction
- Background:
  - W+jets production
  - Multi-jet events

e-ν *Analysis*

- Selection:

	$e\nu$
Lepton	$E_T(e) > 20$ GeV $\lvert\eta\rvert < 1.1$
Missing Et rejects multi-jet with miss-ID *e*	$\not{E}_T > 50$ GeV $\Delta\phi(\not{E}_T, E_T^{\text{2nd object}}) > 30^o$
Jets	≥ 2 jets with $E_T > 30$ GeV and $\lvert\eta\rvert < 2$
Transverse mass rejects W+jets	$m_T(e, \not{E}_T) > 115$ GeV
	reject *ee*, *e*μ, *e*+jets and *e*+jets/μ

- Early results for $\int \mathcal{L}\, dt = 88\ \text{pb}^{-1}$

Background (events)	
W + jets	0.6 ± 0.3
QCD (fake lepton)	0.8 ± 0.2
Total	1.4 ± 0.5

2 events observed

Expected top (events)	
$m_t = 170\ \text{GeV}/c^2$	1.4 ± 0.1

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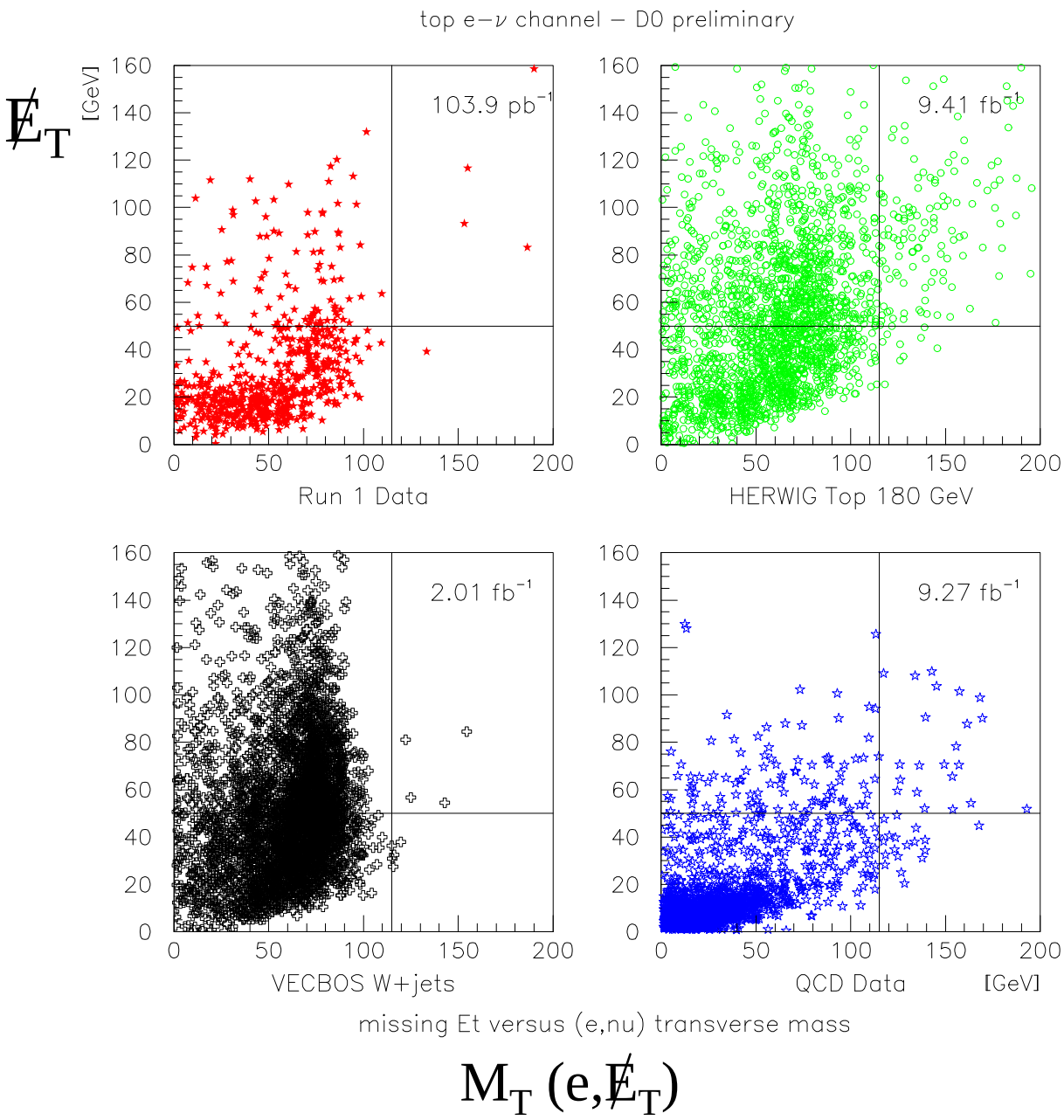
$\not{E}_T$ vs. Transverse Mass of $(e,\not{E}_T)$



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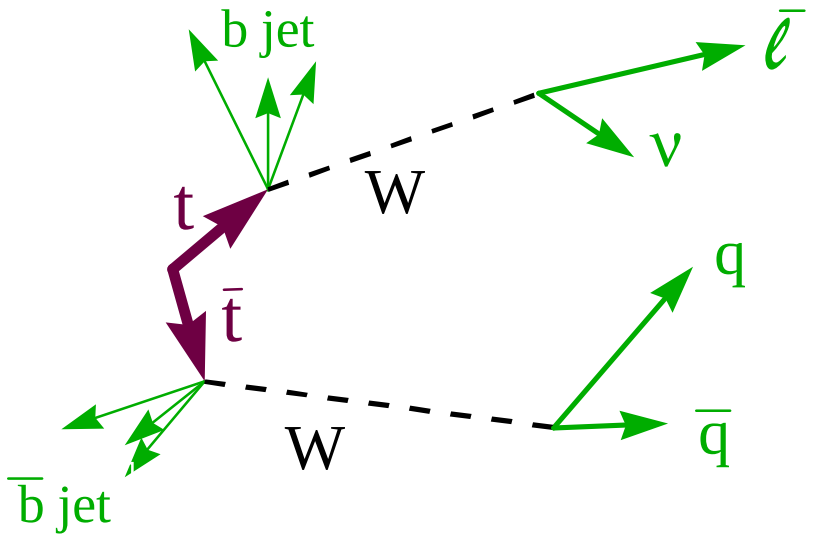
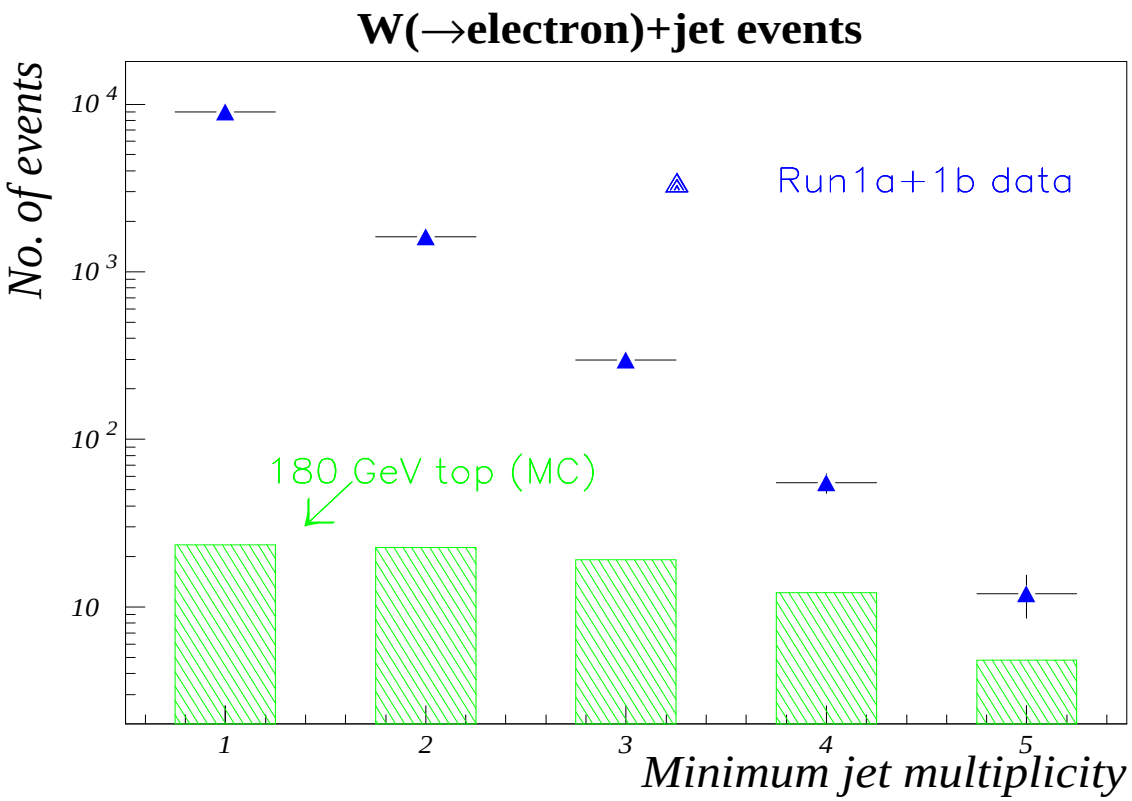
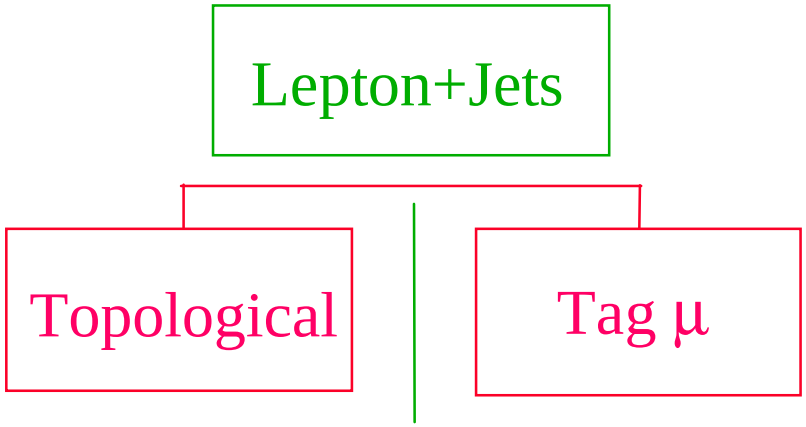
Lepton+Jets Channels



- Final State
  - One high-p_T isolated lepton
  - Missing E_T
  - Four or more jets (2 ***b***, 2 ***q***)
- Backgrounds
  - Physics
    - $W \rightarrow \ell\nu$ + jets
    - $Z \rightarrow \ell\ell$ + jets (1/10 W+jets)
  - Instrumental: Multi-jet production
    - jet misidentified as electron
    - μ+jet misidentified as isolated μ

Lepton+Jets


W(→electron)+jet events
No. of events
10 4
10 3
10 2
10
Run1a+1b data
180 GeV top (MC)
1
2
3
4
5
Minimum jet multiplicity


Lepton+Jets
Topological
Tag μ

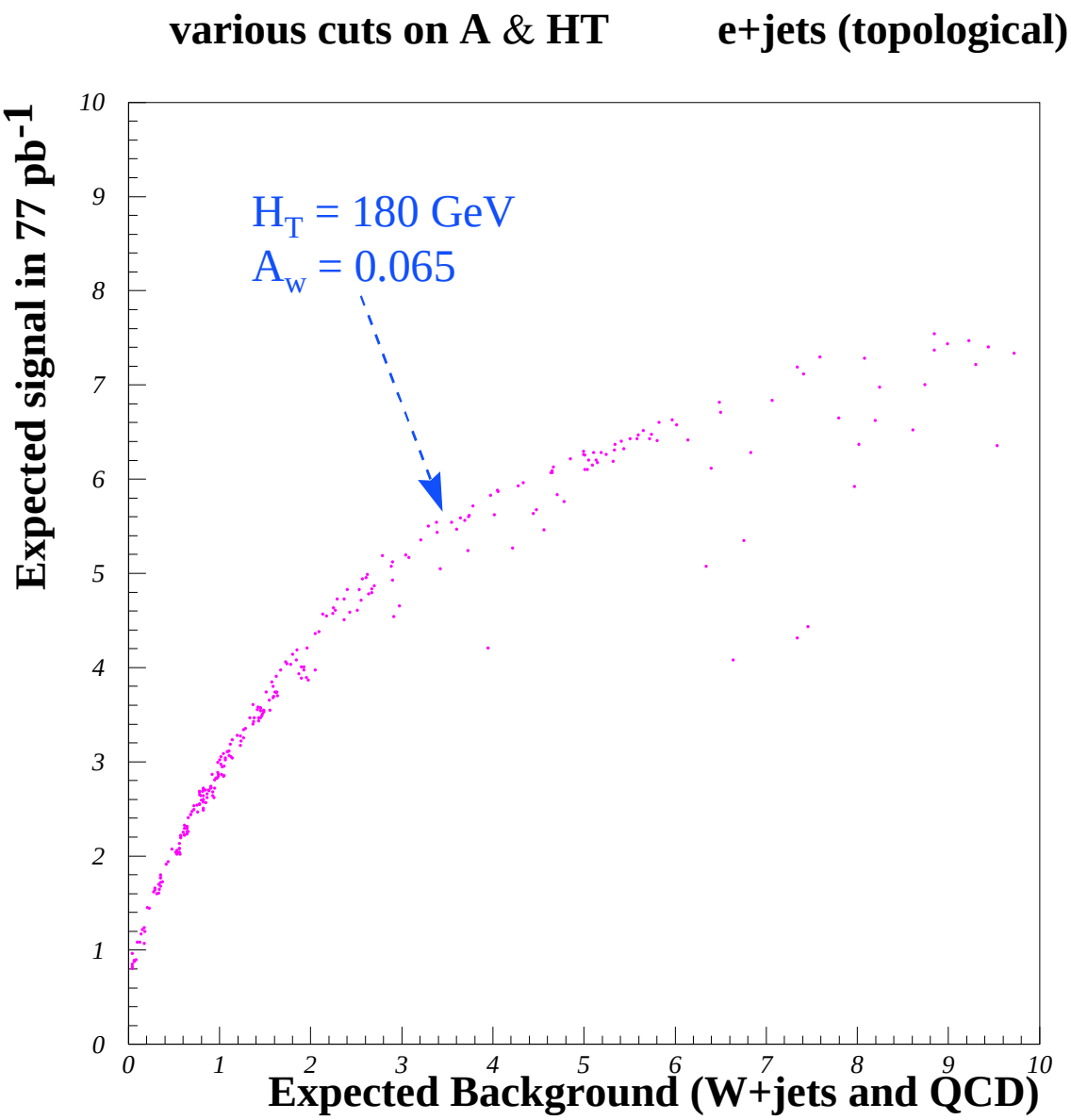
Lepton+Jets Topological

- Event shape variables:
  - Total leptonic E_T: $E_T^{\ell} = p_T^{\ell} + \not{E}_T$
  - Hadronic Activity: $H_T = \sum E_T^{jets}$
    - Large H_T signifies the decay of a massive object
  - Aplanarity: $A_W = 3/2$ of the smallest eigenvalue of the momentum tensor for the W and jets
    - A_W =1/2 for spherical events, 0 for planar events
    - Top events are expected to be more spherical than those from radiative QCD processes
- Selection cuts:

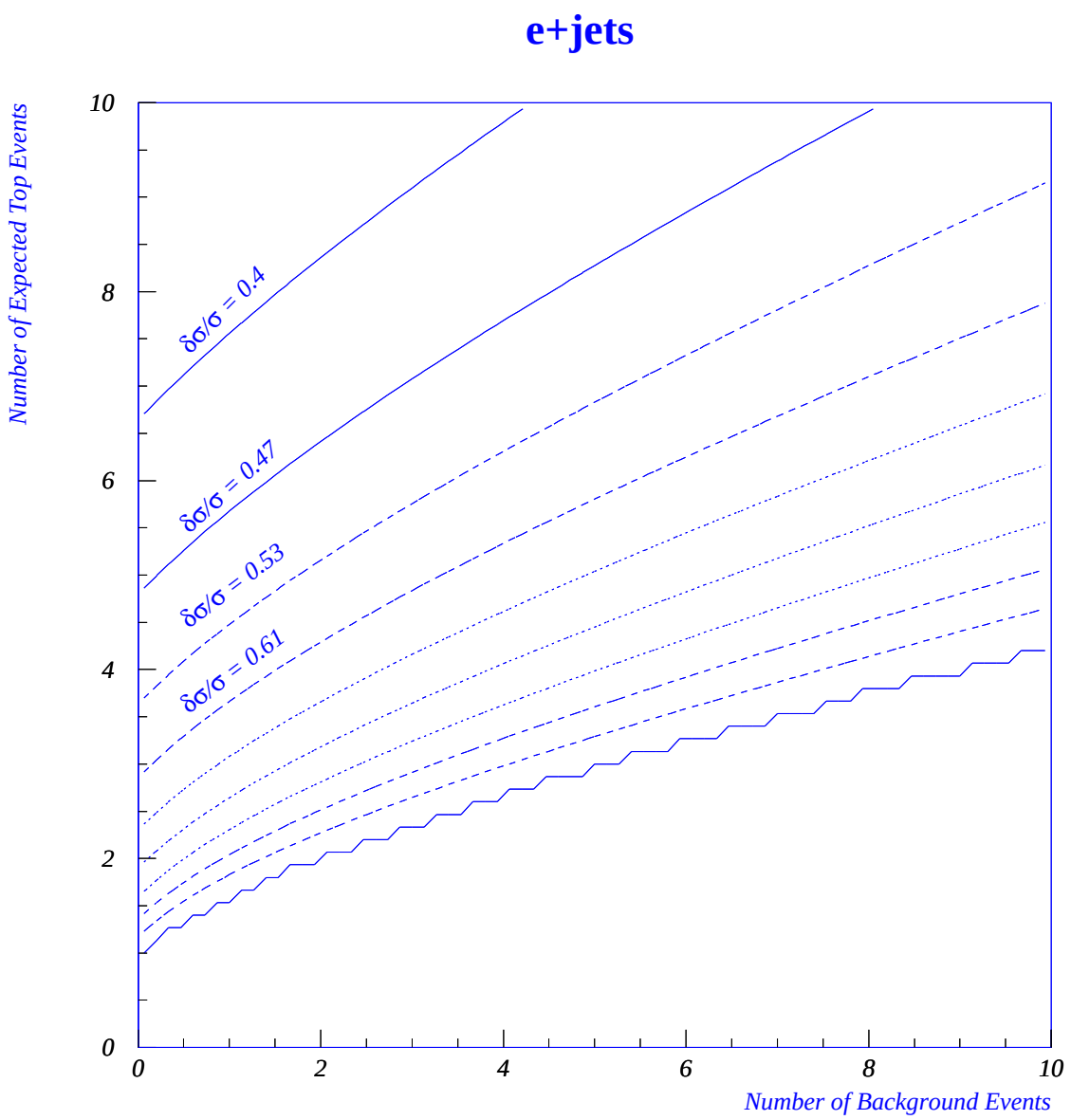
	e + jets	μ + jets
Lepton	$E_T(e) > 20$ GeV $\lvert\eta\rvert < 2$	$p_T(\mu) > 20$ GeV/c $\lvert\eta\rvert < 1.7$
Missing Et	$\not{E}_T > 25$ GeV	$\not{E}_T > 20$ GeV
Jets	≥ 4 jets with $E_t > 15$ GeV and $\lvert\eta\rvert < 2$	
Shape cuts	$E_T^{\ell} > 60$ GeV $A_W > 0.065$ $H_T > 180$ GeV	
	No soft μ tag	

Monte Carlo Optimization using Grid Search

Choose shape cuts to Minimize cross section error



Contours of constant cross section error



Lepton+Jets μ-*tag*

- Two *b*-quark jets in each $t\bar{t}$ event
- Background has minimal heavy flavor
- Tag *b* by signature $b \rightarrow \mu$
  - ~ 20% of $t\bar{t}$ events have a detectable tag μ
  - background: ~ 2% of W + ≥ 3 jet events
- Relax event shape cuts and require only 3 jets
- Selection cuts:

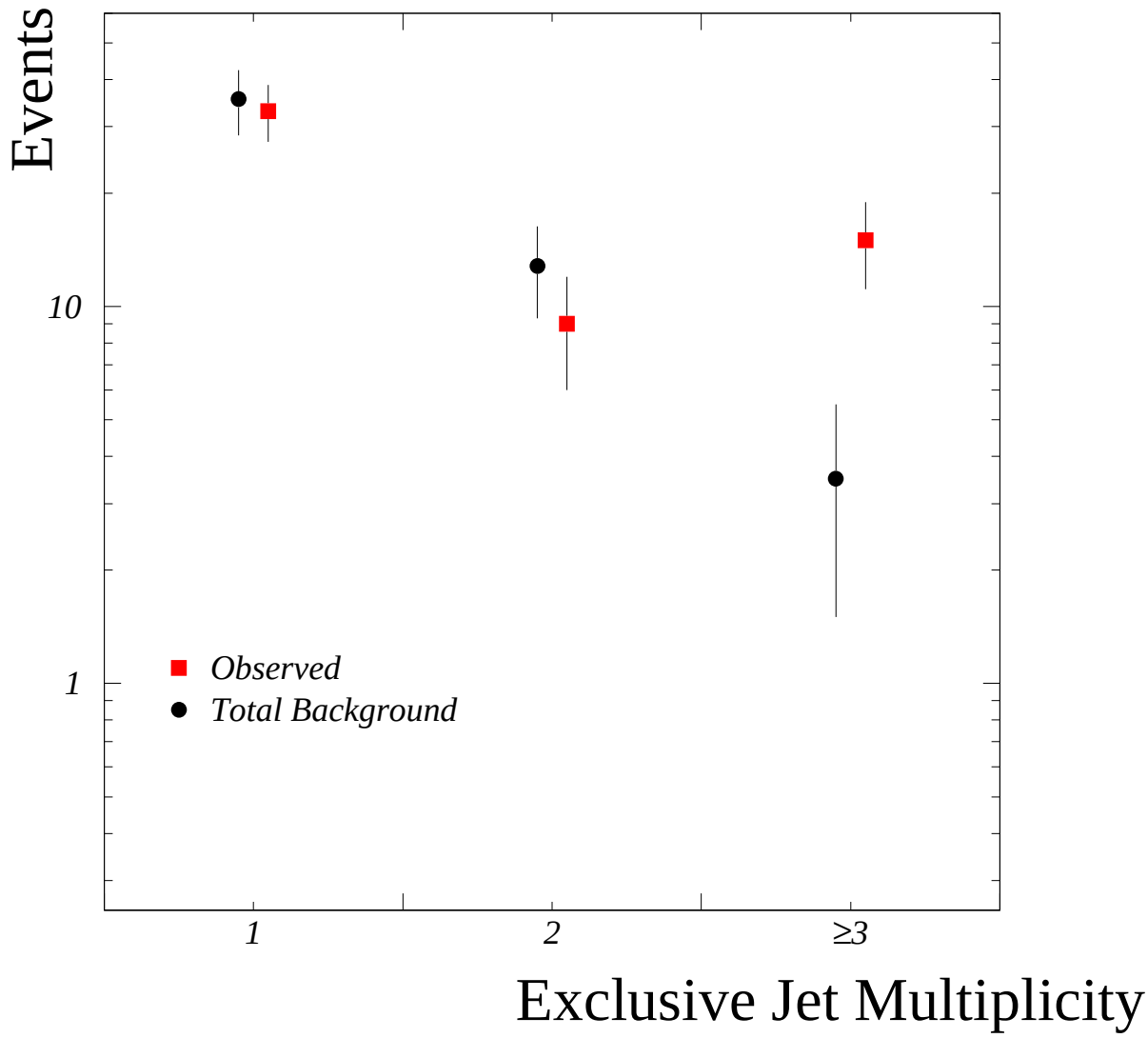
	e + jets/μ	μ + jets/μ
Lepton	$E_T(e) > 20$ GeV $\lvert\eta(e)\rvert < 2$	$p_T(\mu) > 20$ GeV/c $\lvert\eta(\mu)\rvert < 1.7$
Missing E_T	$\not{E}_T > 20$ GeV $\not{E}_T > 35$ GeV if $\Delta\phi(\not{E}_T,\mu) < 25°$	$\not{E}_T > 20$ GeV $\Delta\phi(\not{E}_T,\mu) < 170°$
$Z \rightarrow \mu\mu$ fit	–	$\mathrm{Prob}(\chi^2) < 0.01$
Tag μ	$p_T > 4$ GeV/c and $\Delta R(\mu,\mathrm{jet}) < 0.5$	
Jets	≥ 3 jets with $E_T > 20$ GeV and $\lvert\eta\rvert < 2$	
Shape cuts	$A_W > 0.04$ $H_T > 110$ GeV	

μ-*tags top signal*

Exclusive jet multiplicity distribution for lepton+jets+μ-tag events

Before A_w and H_T cuts

$\int \mathcal{L}\, dt = 90\ \mathrm{pb}^{-1}$



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Event Yields for Cross Section

- ~100 pb^{-1} (full 1992 - 1995 statistics)

Channel	Top*	Bkg	Data
eμ	1.7±0.3	0.4±0.1	3
ee	0.9±0.1	0.7±0.2	1
μμ	0.5±0.1	0.5±0.3	1
e+jets	6.5±1.4	3.8±1.4	10
μ+jets	6.4±1.5	5.4±2.0	11
e+jets/tag	2.4±0.4	1.4±0.4	5
μ+jets/tag	2.8±0.9	1.1±0.2	6
Total	21.2 ± 3.8	13.4±3.0	37

*m_t =180 GeV/c^2.

Top cross section from Laenen, *et. al.*, Phys. Lett. **321B**, 254 (1994)

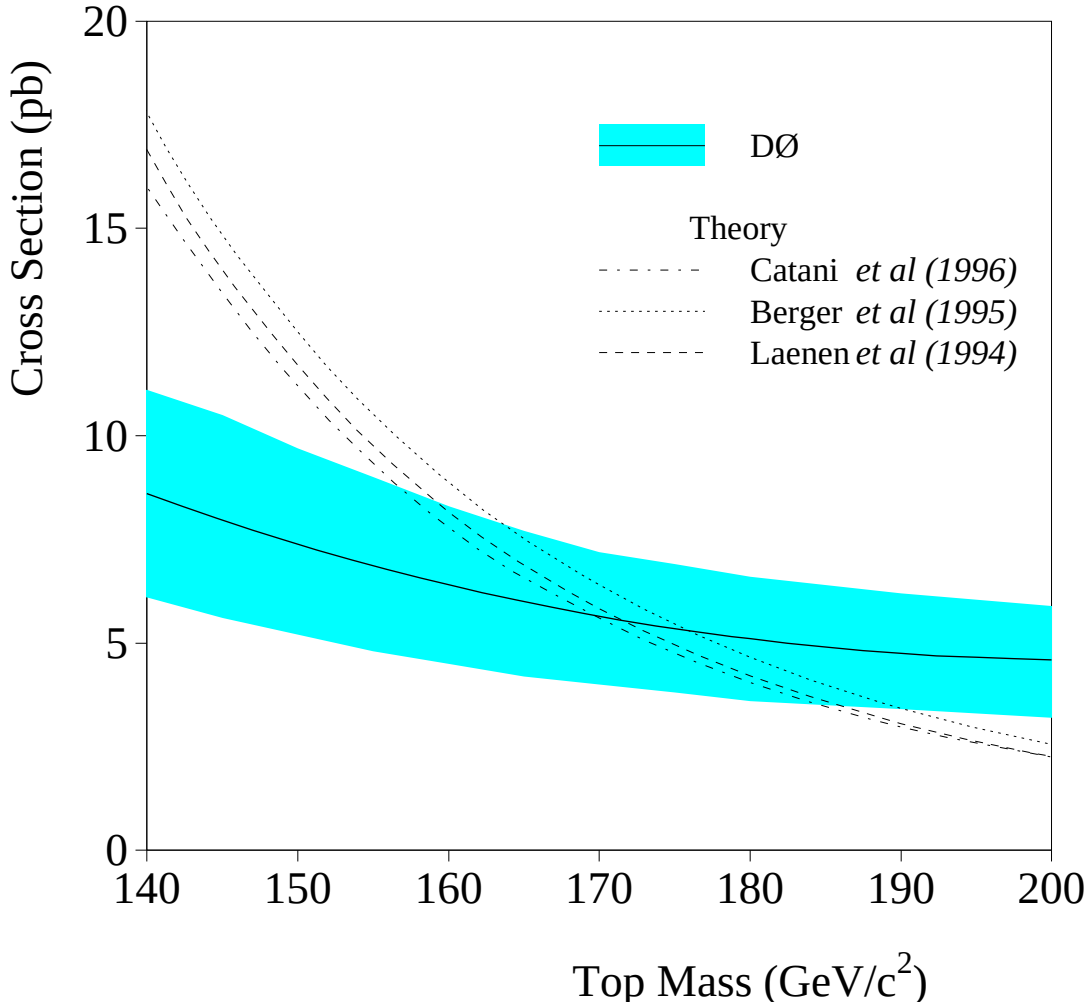
DØ preliminary

DØ top cross section

Preliminary

$\int \mathcal{L}\, dt \approx 100\ \mathrm{pb}^{-1}$

37 events observed (7 channels) over background of 13.4 ± 3.0



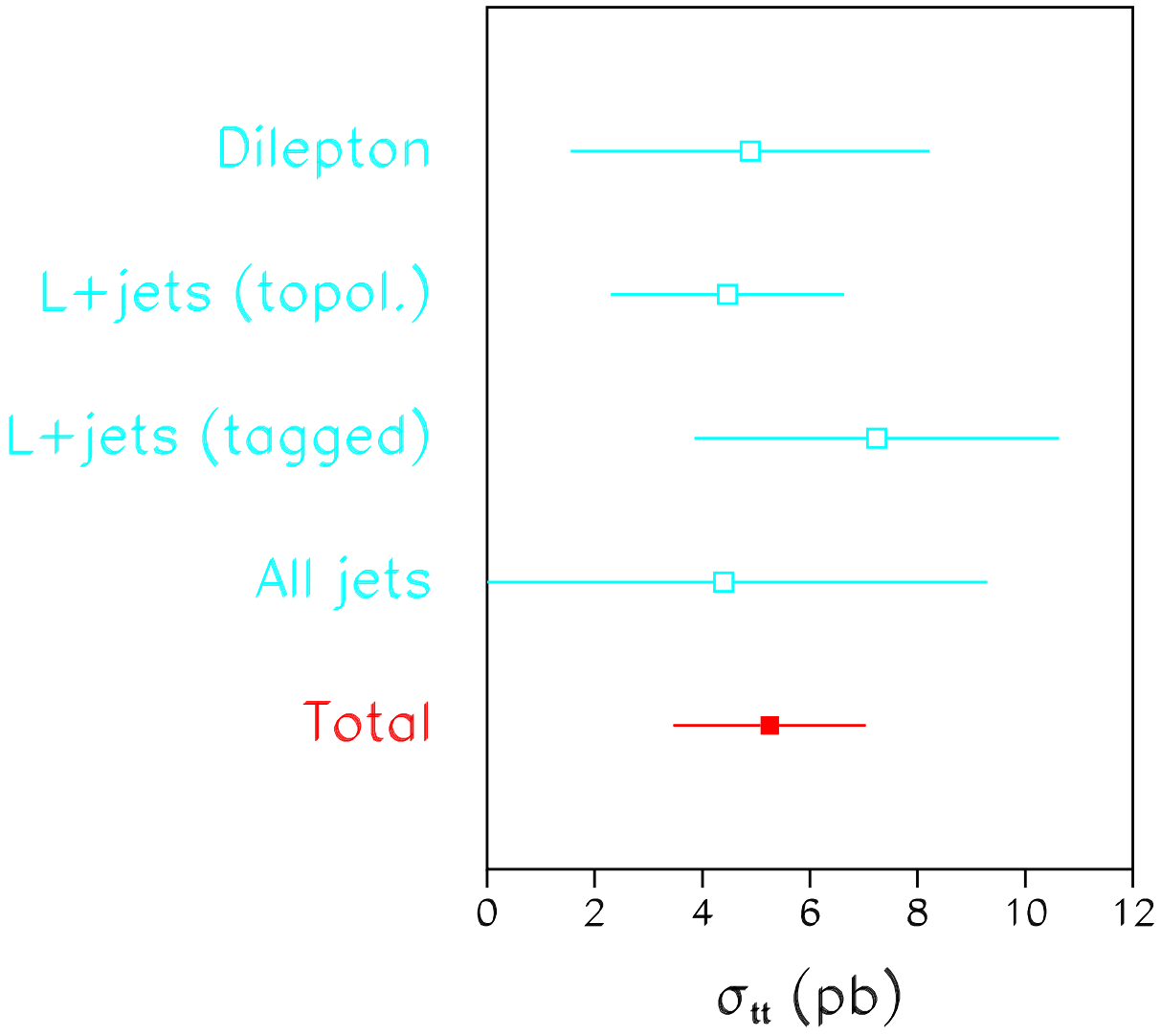
$\sigma = 5.8 \pm 2.0$ pb (m_t = 160 GeV/c^2)

$\sigma = 5.2 \pm 1.8$ pb (m_t = 170 GeV/c^2)

$\sigma = 4.7 \pm 1.6$ pb (m_t = 180 GeV/c^2)

Cross Section by Channel

m_t = 170 GeV



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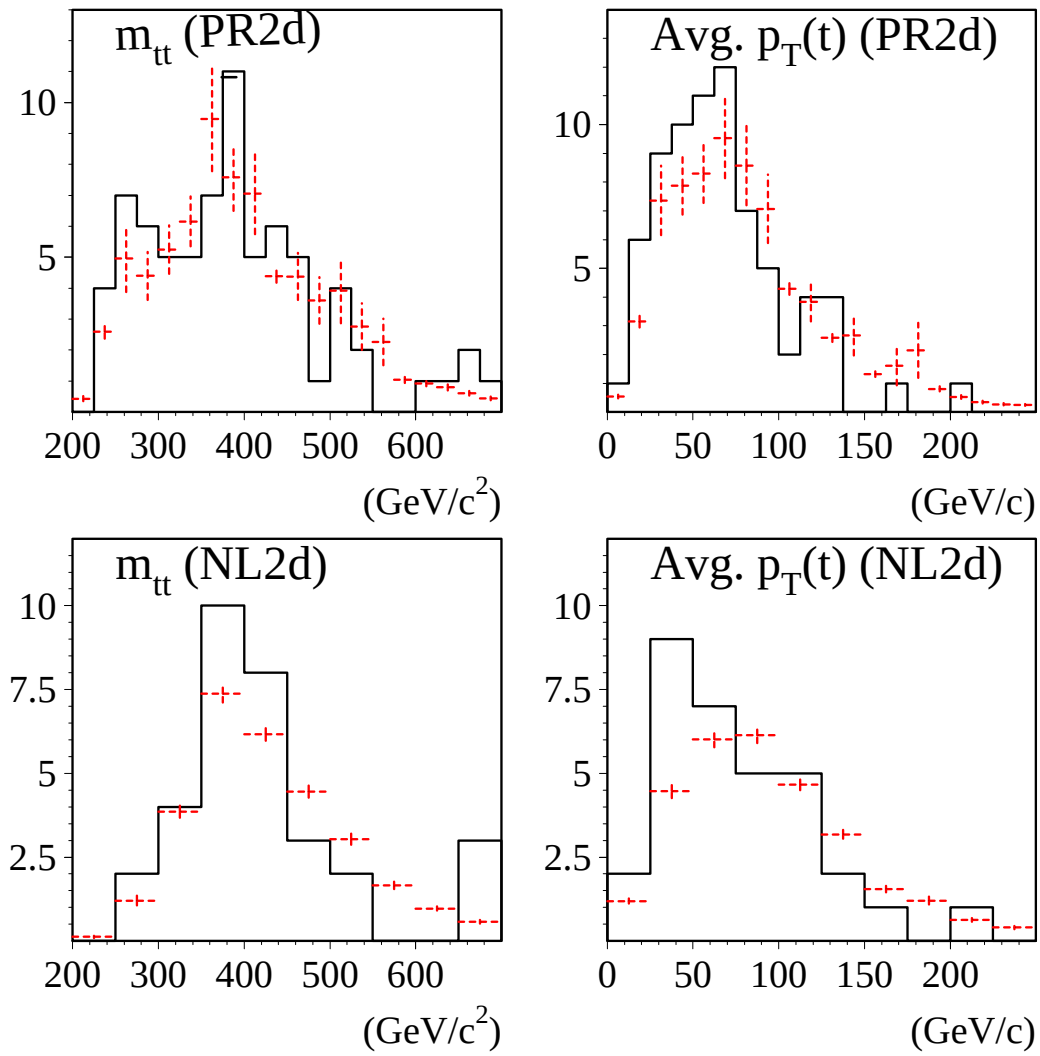
Lepton+Jets:
studies of production kinematics

- mass of $t\bar{t}$ system
- transverse momentum spectrum of top

—— Data

- - - - - MC: HERWIG (m_t=170 GeV/$c^{2)}$ + background



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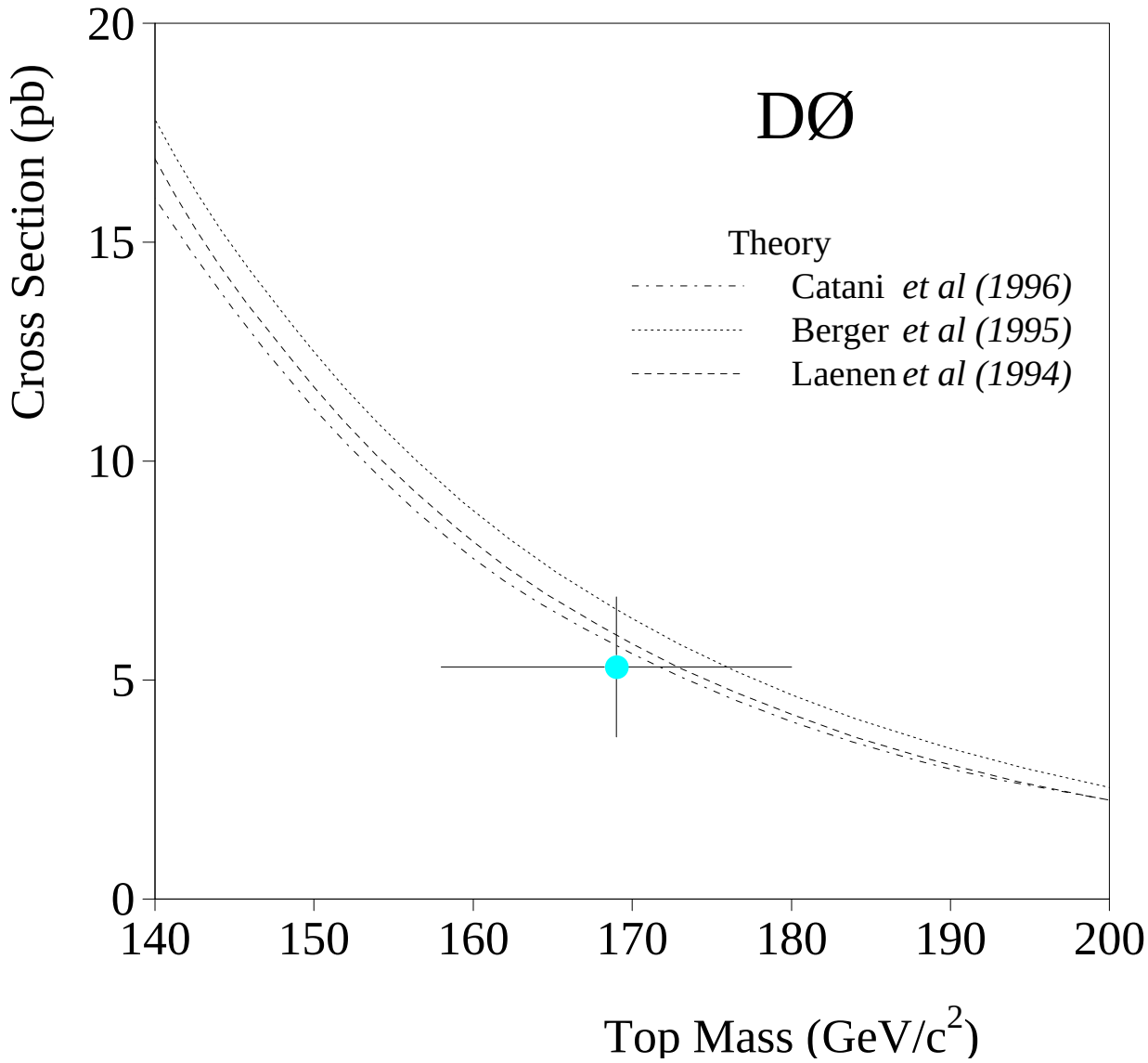
Top Mass and Cross Section

Preliminary

$\int \mathcal{L}\, dt \approx 100\ \mathrm{pb}^{-1}$



$m_{top} = 169 \pm 8 \pm 8\ \mathrm{GeV}/c^2$

$\sigma_{t\bar{t}} = 5.2 \pm 1.8\ \mathrm{pb}$

Standard Model m_W vs. m_{top}

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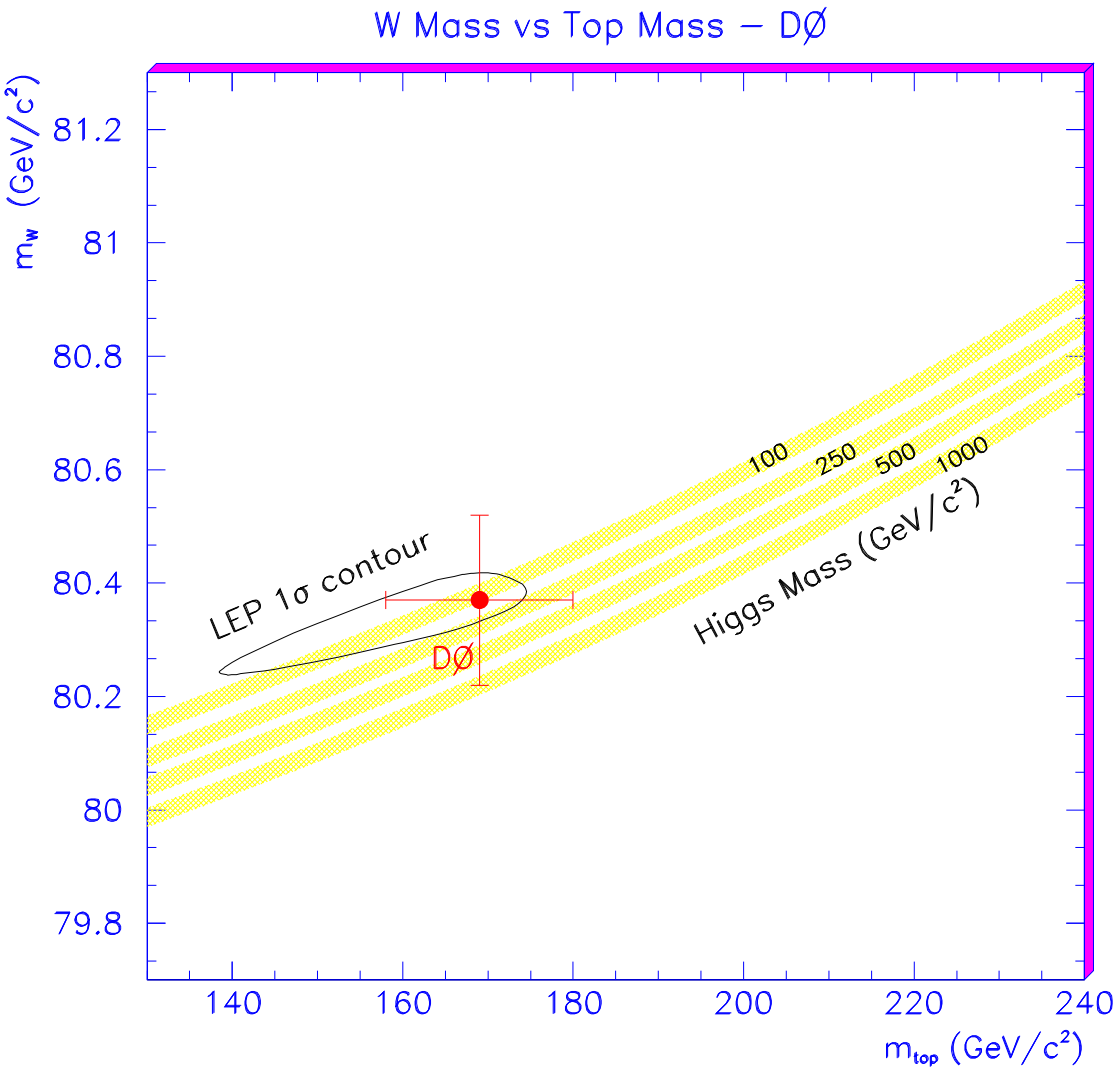


$m_{top} = 169 \pm 8 \pm 8$ GeV/c^2

$m_W = 80.331 \pm 0.140 \pm 0.165 \pm 0.160$ GeV/c^2

DØ Top Analyses: Summary

$\int \mathcal{L}\, dt \approx 100\ \mathrm{pb}^{-1}$

- Mass measurement, using lepton + jets channels:

$$m_{top} = 169 \pm 8 \pm 8\ \mathrm{GeV}/c^2$$

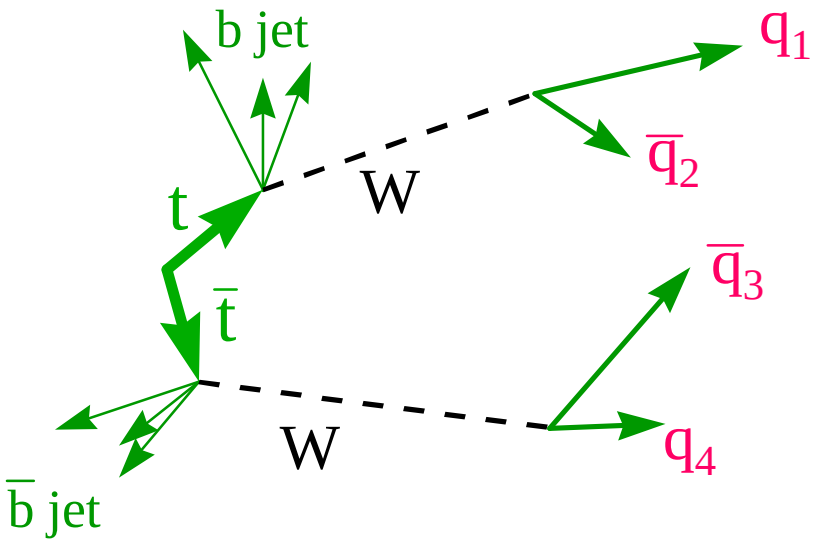
(preliminary)

- $t\bar{t}$ production cross section measurement:
  - 37 events from 7 channels
  - Background: 13.4 ± 3.0 events
  - Cross section: $\sigma = 5.2 \pm 1.8\ \mathrm{pb}$

(preliminary)

- New channels:
  - $e\nu$ - S/B and acceptance comparable to ee and $\mu\mu$
  - *all jets* - σ_{tt} in agreement with above

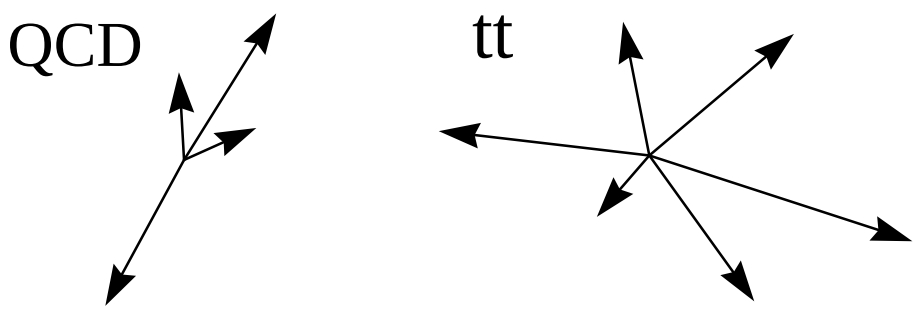
All Jets Channel



- Largest single channel decay mode
  - Branching ratio: ~ 44%
- Large Background: Multi-jet
  - 6 jets $\Rightarrow$ S/B ~ 1/1000
  - use μ-tagging and event shape cuts to reject background
- Two subchannels
  - Single μ-tag
  - Double μ-tag

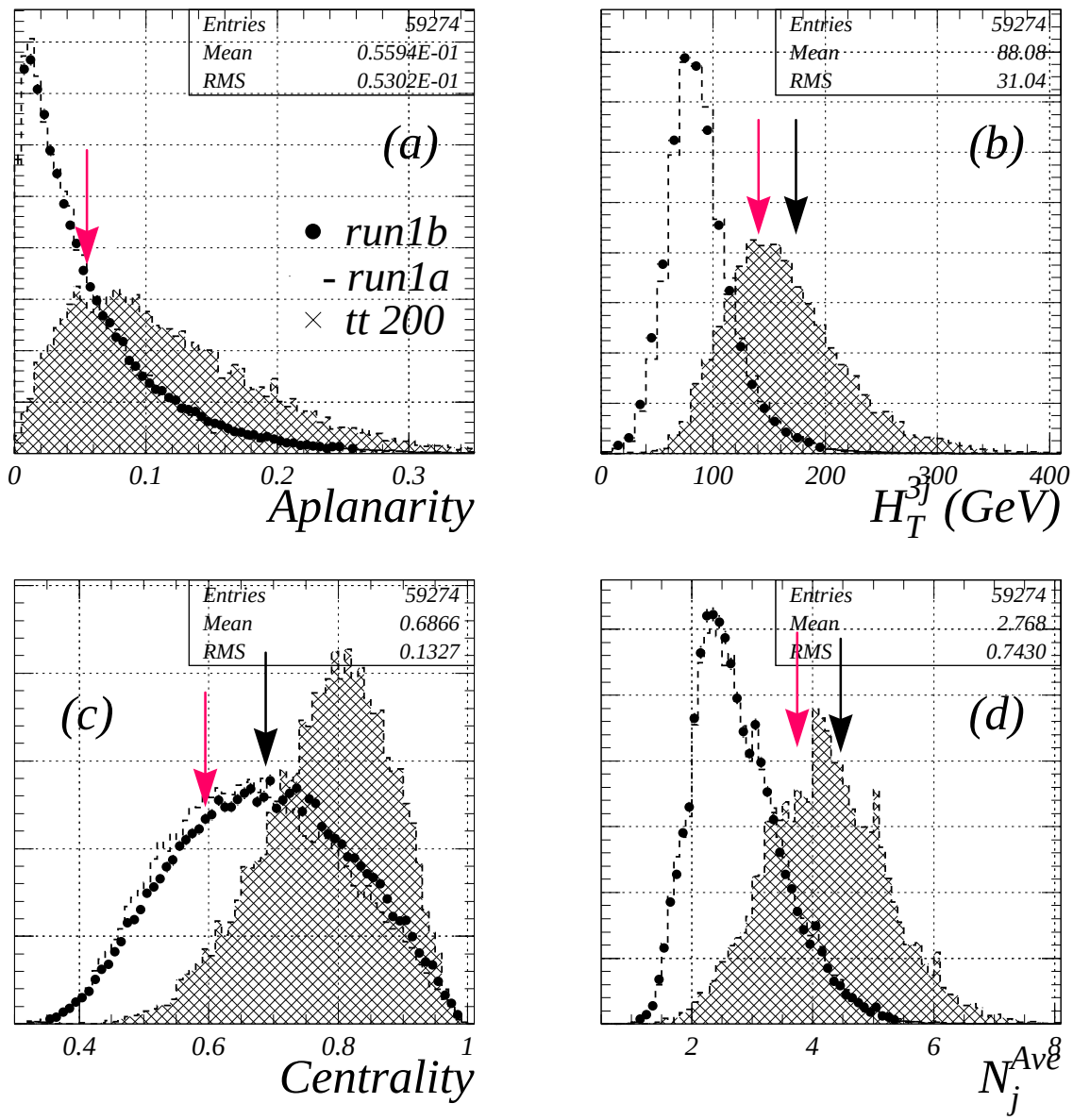
Selection

- ≥ 6 jets
- Kinematic Variables
  - $H_T^{3j} = \Sigma_{\text{Jets } i=3,N} E_T^i$: H_T without two leading jets



  - $\langle N_J \rangle$: Energy weighted jet multiplicity
  - Centrality: $C = \Sigma E_T^{jet} / \Sigma E^{jet}$
  - Aplanarity: use all jets with $|\eta| < 2$
- μ–tag: 1 or 2 tags, as defined in lepton+jets

All jets: Kinematic Variables



double μ cut ↓

↓ single μ cut

All jets: Summary

- Single μ-Tag
  - Data: 15 events
  - Background: 11 ± 2 events
  - Cross section

    4.4 ± 4.9 pb

- Double μ-Tag
  - Data: 2 events
  - Background: 1.4 ± 0.4 events
  - Cross section

    3.9 ± 9.8 pb

DØ preliminary