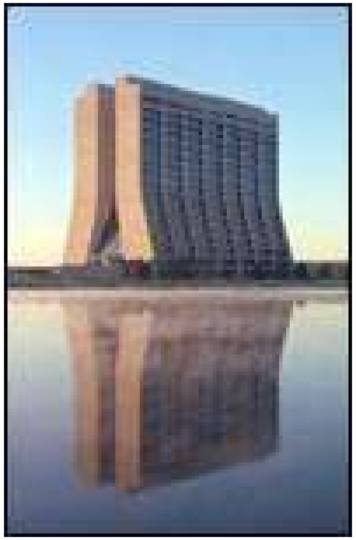
Measurements of the Top Quark Pair Production Cross Section using Lifetime b-Tagging



with the DØ Detector
in ppbar collisions
at the Fermilab Tevatron
at a center of mass energy
of $\sqrt{s}$ = 1.96 TeV

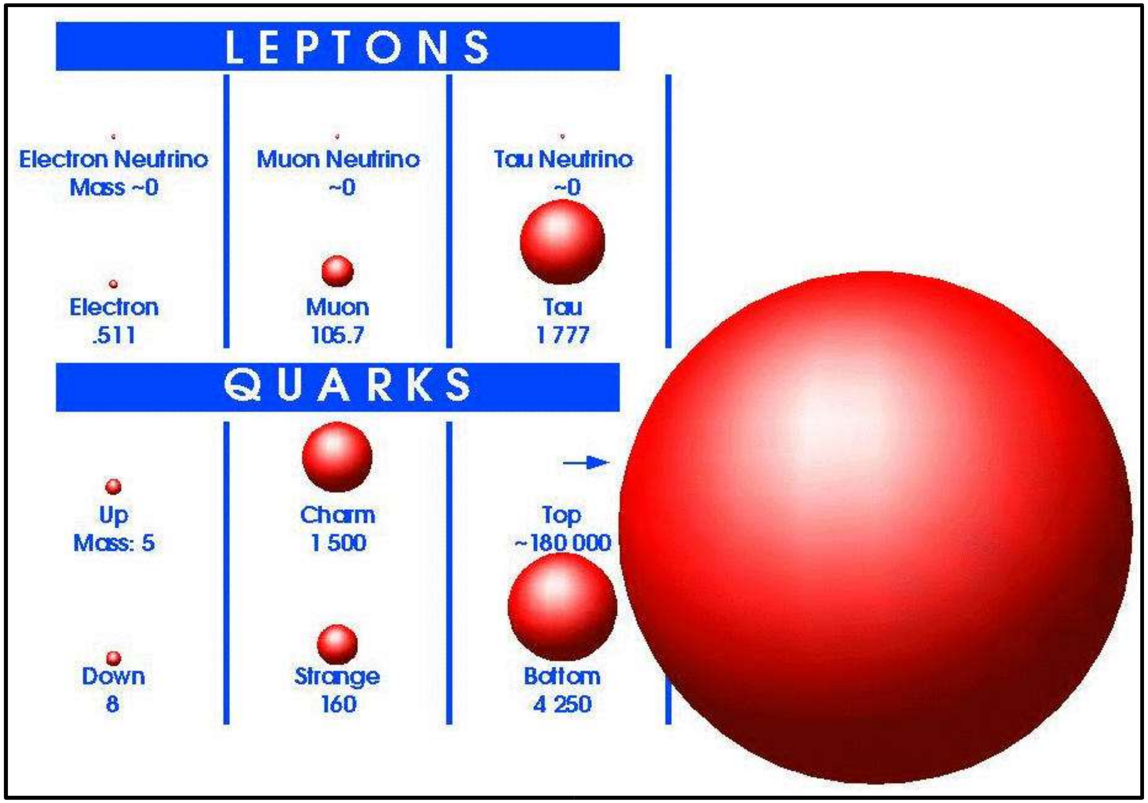
Tobias Golling – FCP – Vanderbilt/Nashville – 05/23/05

The Top Quark in the Standard Model

Why is the Top Quark so interesting ?

- **Completes the quark sector**
- **Large mass: m_{top} ~ 178 GeV / c^2**
- **Short lifetime: τ ~ 5 · 10^{-25} s**
  - **No bound states or hadronization**
  - **Spin information conserved**
- **Higgs-Boson coupling to fermions:**
  $\lambda_f \sim m_f \;\Rightarrow\; \lambda_t \sim 1$

Discovery of the top quark in 1995 by the CDF and DØ collaborations.

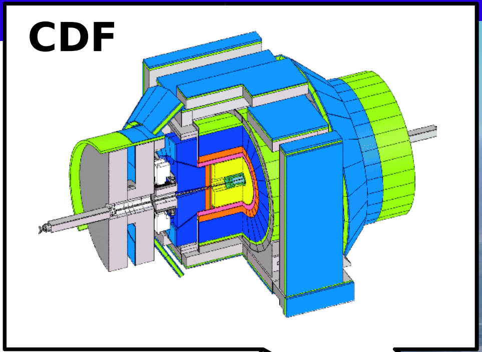


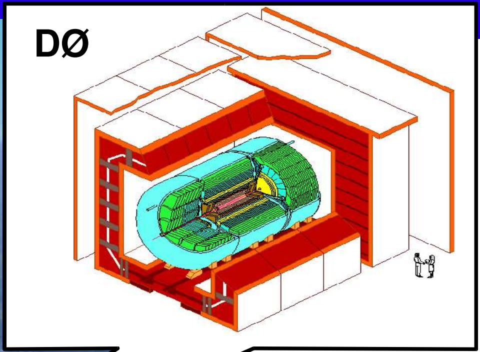
Top-antitop production cross section

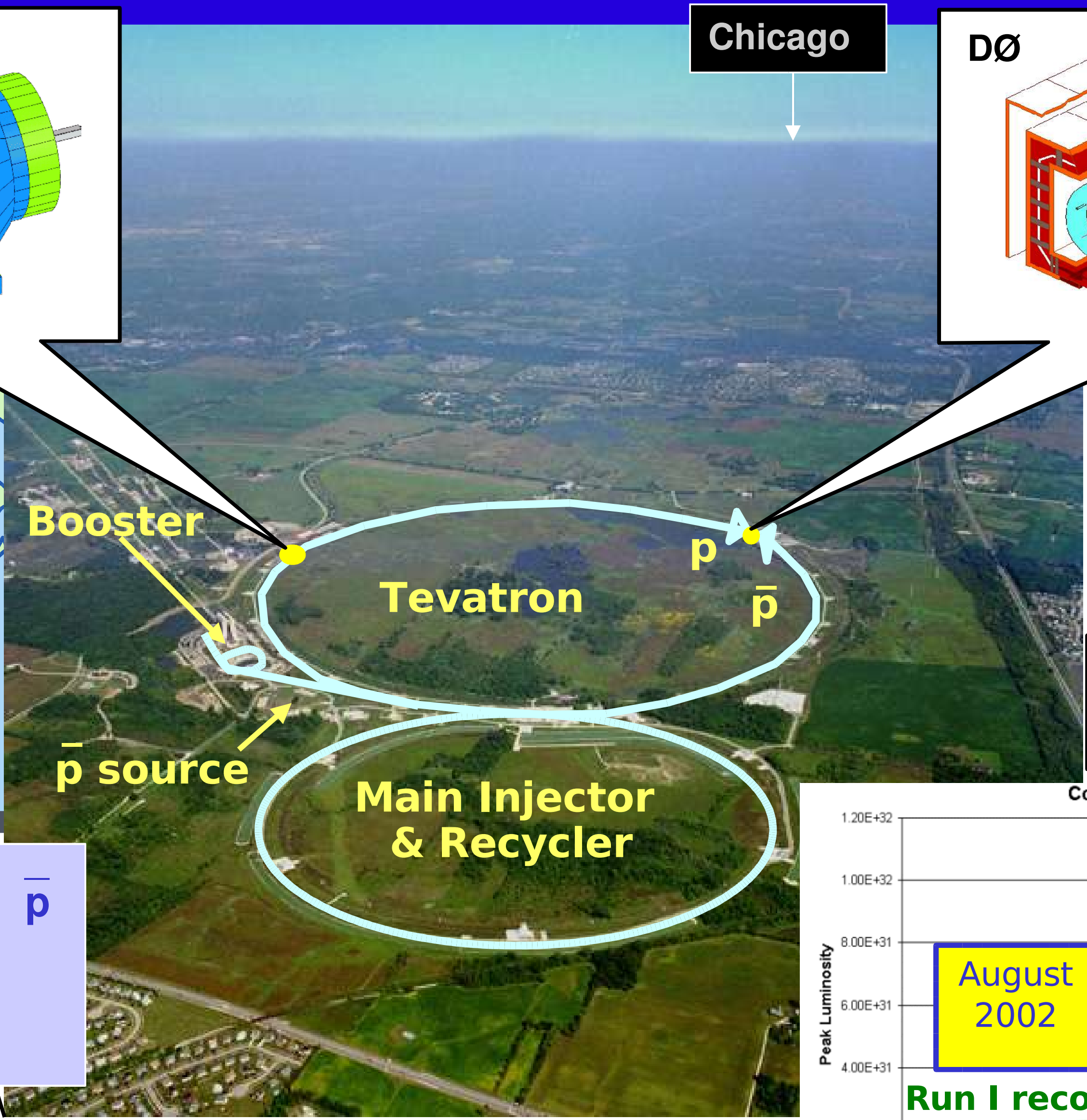
- **Study of the high-p_T data set**
- **Test of the SM / perturbative QCD**
- **Background to many New Physics signals**

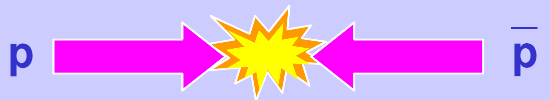
Fermilab is only place to study the top quark before the LHC era

The Tevatron at Fermilab



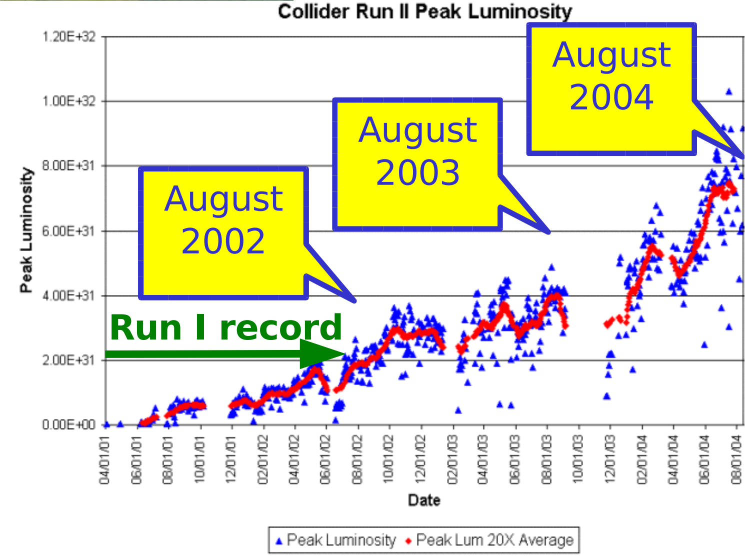






$\sqrt{s}$ =1.96 TeV
Δt = 396 ns

Peak Luminosity
x2 increase per year
Exceeded $L=10^{32}cm^{-2}s^{-1}$

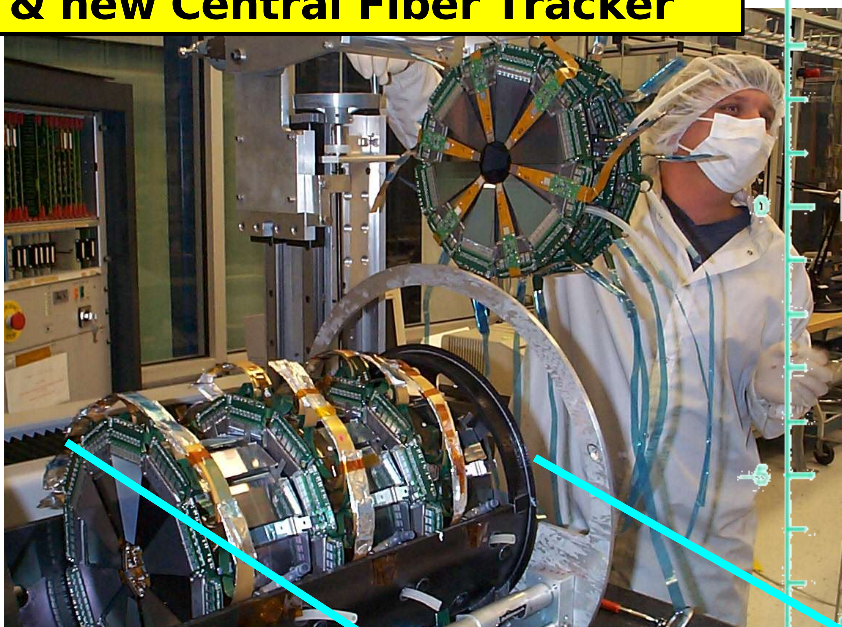


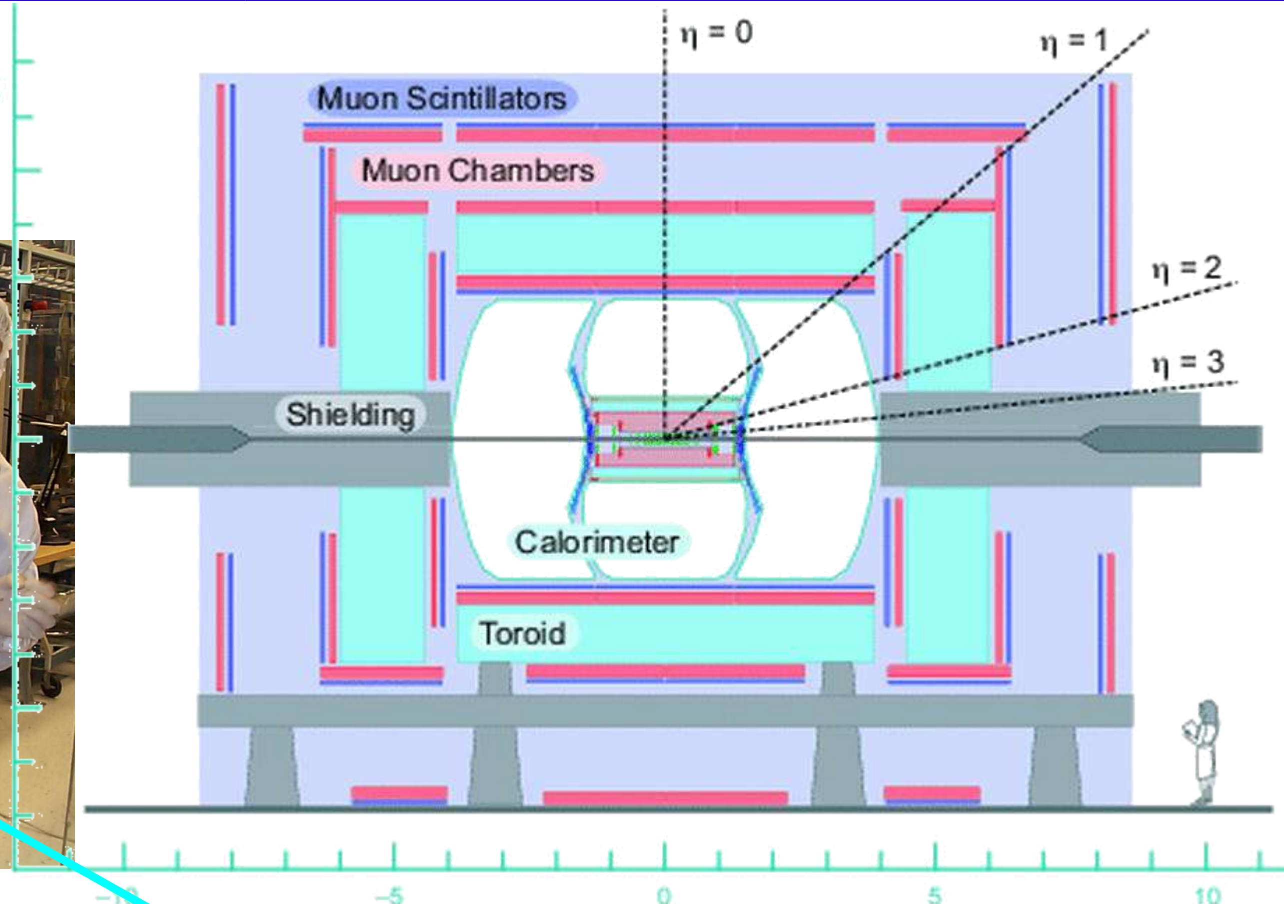
Run I 1992-95 — L_{int} ~ 125 pb^{-1}

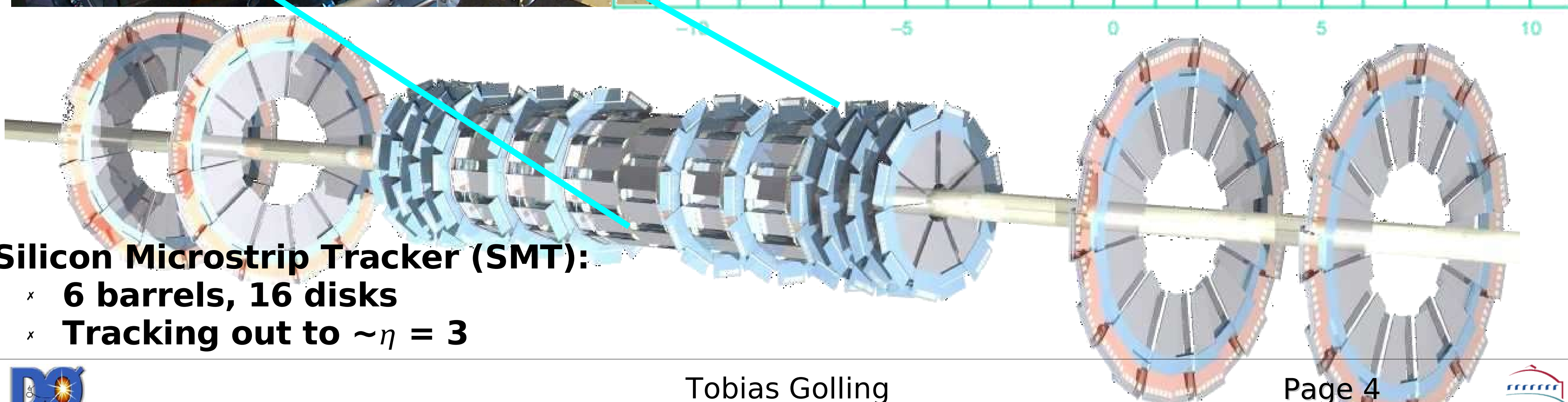
Run II 2001-09 — 40 × larger dataset at increased energy

DØ Detector at Fermilab

- **Improved muon system**
- **Improved Trigger/DAQ**
- **New ~2 T Solenoid**
- **New Silicon Microstrip Tracker & new Central Fiber Tracker**





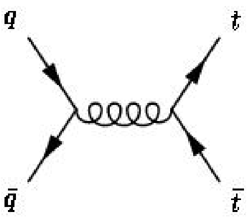


Silicon Microstrip Tracker (SMT):
- **6 barrels, 16 disks**
- **Tracking out to ~η = 3**

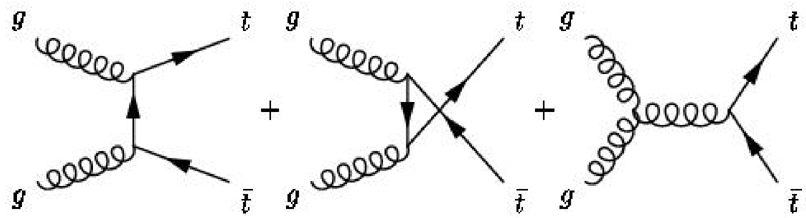
Top-Quark Production

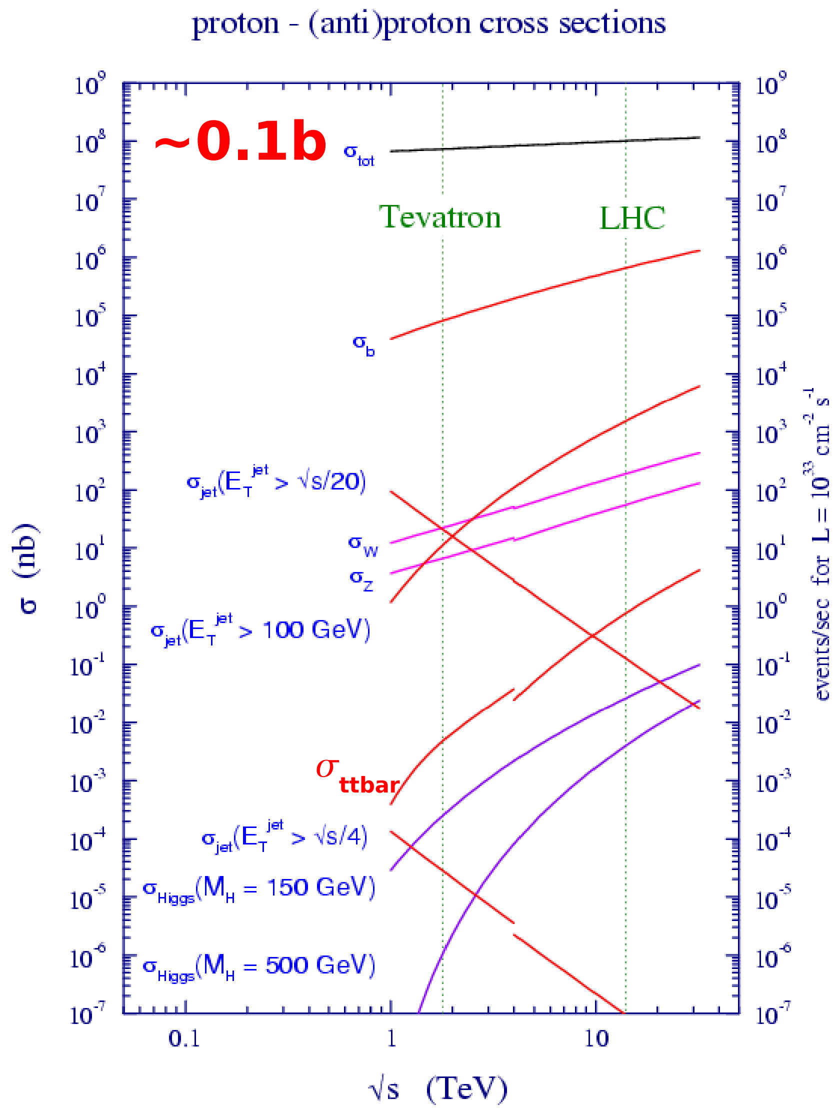
Top quarks mainly produced in pairs at Tevatron and LHC

$q\bar{q}$



gg



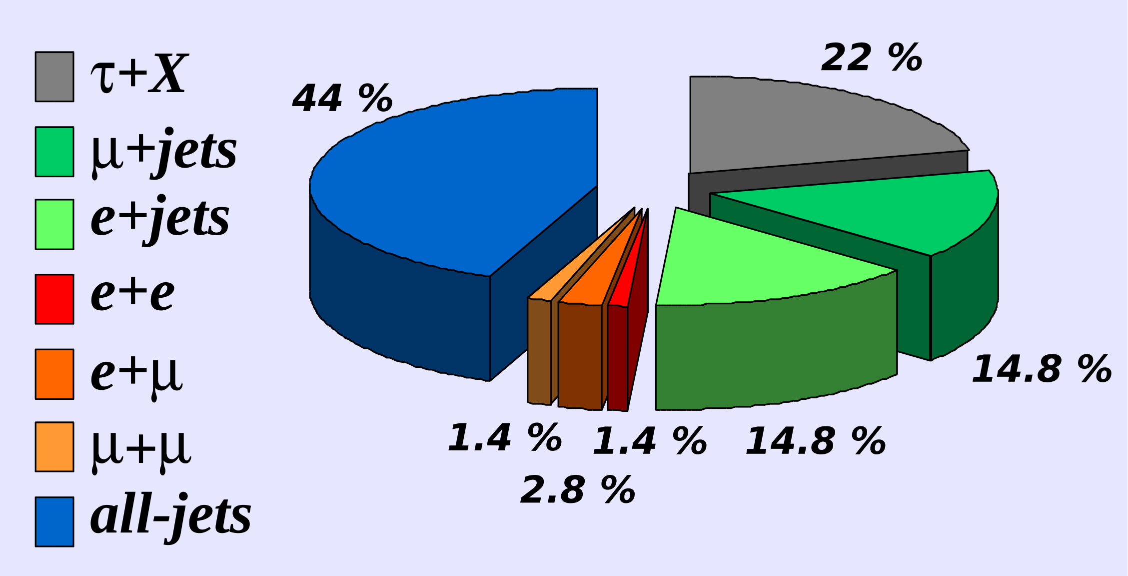


	σ_{ttbar}^{NLO} (pb)	qq->tt	gg->tt
Run I (1.8 TeV)	**4.87±10%**	**90%**	**10%**
Run II (2.0 TeV)	**6.70±10%**	**85%**	**15%**
LHC (14 TeV)	**803±15%**	**10%**	**90%**

$$\sigma^{D0\ RunI}_{p\bar{p}\to t\bar{t}+X} = 5.7 \pm 1.6\ pb$$

(limited by statistics)

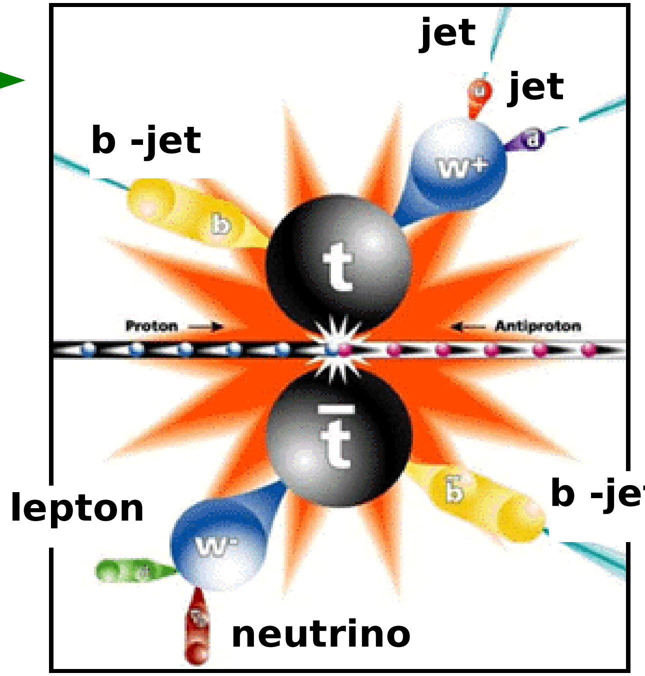
Top Quark Decay



Top quarks decay predominantly (~100%) to a W-Boson and a b-quark

Top-Antitop Signatures determined by the W decay modes:

`Lepton+jets channel'
~30%: 4 jets, 1 charged lepton, 1 neutrino
- Large statistics compared to dilepton channel
- Clear signature compared to all-jets channel



`Dilepton channel'
~5% : 2 jets, 2 charged leptons, 2 neutrinos

`All-jets channel'
~44%: 6 jets

always 2 jets are b-jets !

Overview of the Three Analyses

Counting Experiments

$$N_{bkg}^{tag} = \sum_{bkg} N_{bkg}^{untag} \times P_{bkg}^{tag}$$

$$\sigma_{p\bar{p} \to t\bar{t}+X} = \frac{N_{observed}^{tag} - N_{bkg}^{tag}}{BR \cdot L \cdot \epsilon_{sel} \cdot P_{t\bar{t}}^{tag}}$$

Number of observed events with b-tag

$t\bar{t}$ event probability for one or more jets being identified as b-jets (b-tag)

Branching ratio

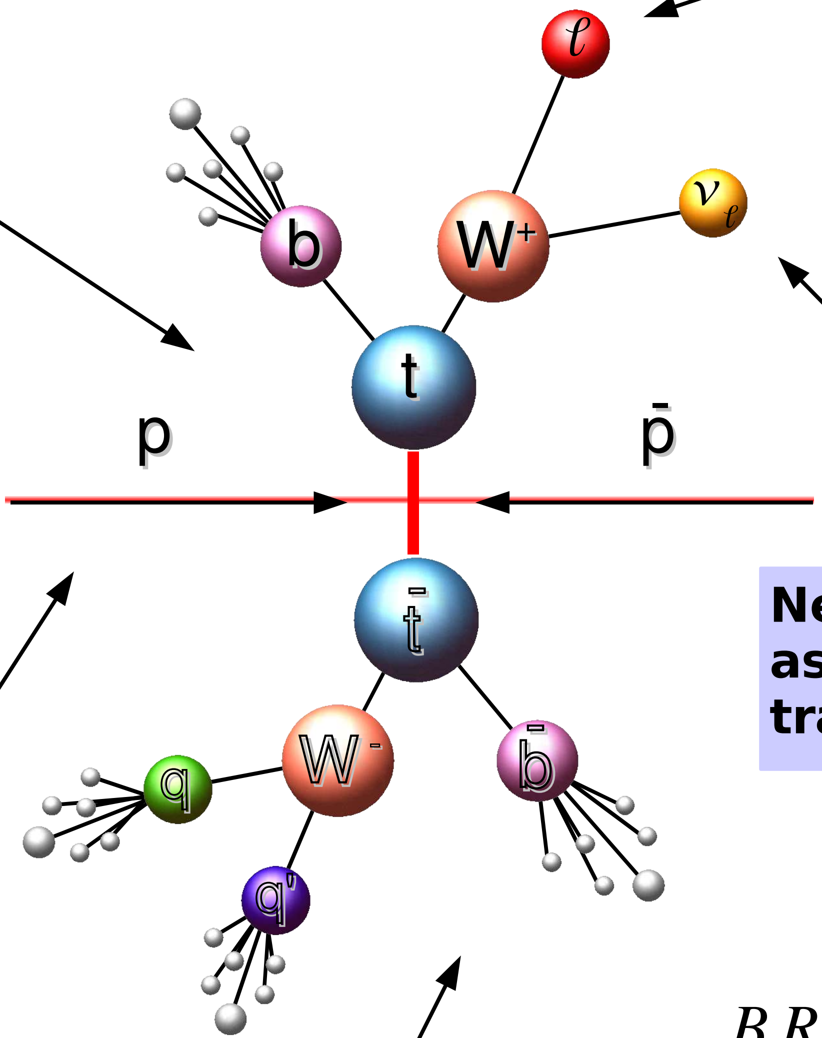
Luminosity

Preselection efficiency comprises:
- **Trigger**
- **Acceptance**
- **ID- & selection efficiencies**
- **MC correction factors using Z->l^+l^- data and MC**

L+Jets Signature - W+Jets Preselection

Hard scatter primary vertex

Isolated high p_T lepton (e or μ)



Neutrino reconstructed as missing transverse energy

≥ 3 jets with p_T > 15 GeV and $|\eta|$ < 2.5

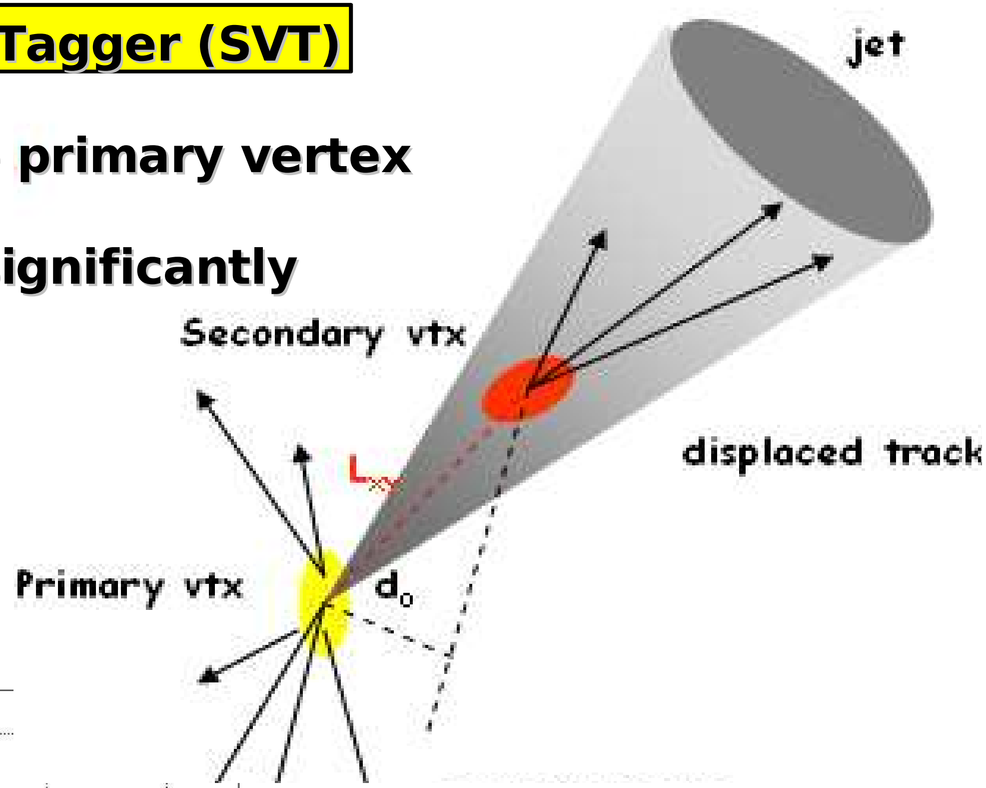
$BR = 30\%$

$\epsilon_{sel}^{3\,jets} = 10\%,\ \epsilon_{sel}^{\geq 4\,jets} = 14\%$

B-Tagging @ DØ

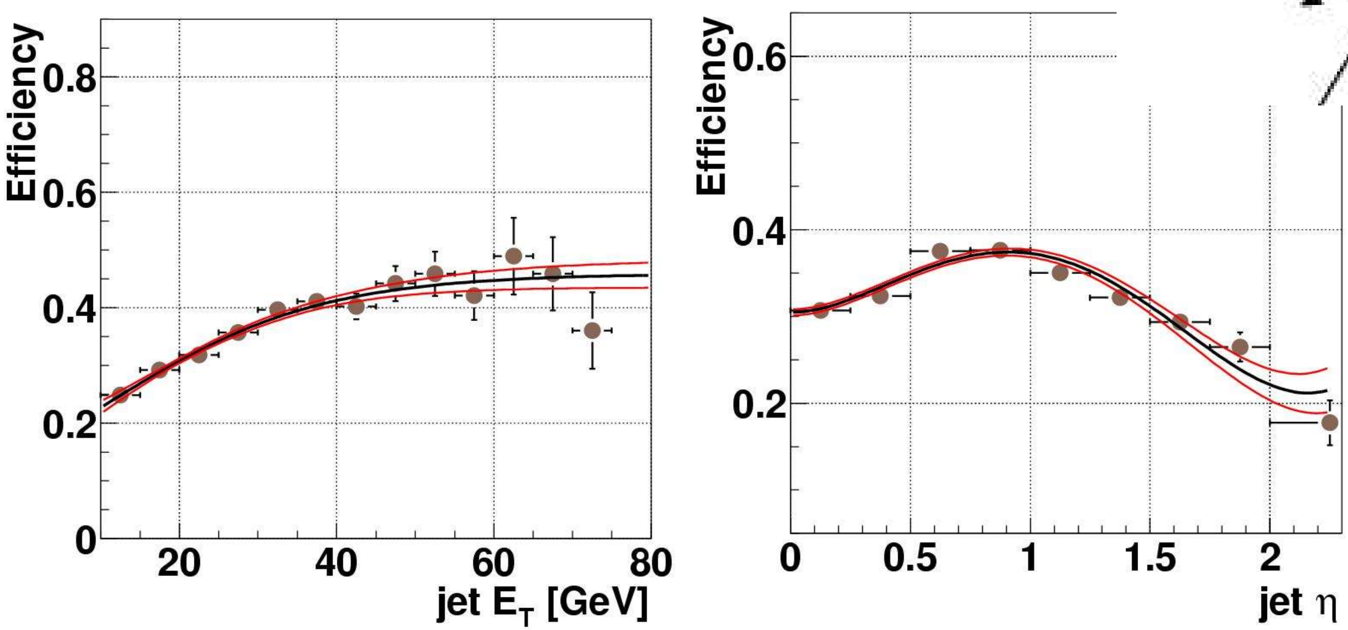
Secondary Vertex Tagger (SVT)

- **Tracks, significantly displaced from the primary vertex**
- **Reconstruction of secondary vertices, significantly displaced from the primary vertex**



L_{xy} = 500µm – several mm

Probability to identify a b-jet ≙ Tagging efficiency



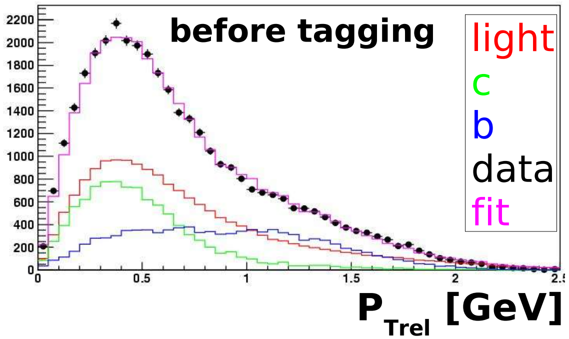
B-Tagging Efficiency in the Data

Challenge: **Selection of pure and unbiased sample of jets of one flavors (b, c, light)**

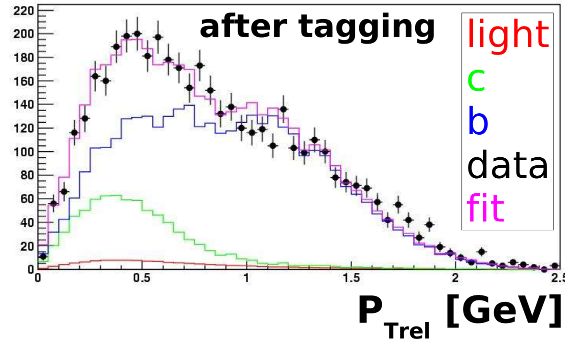
Dijet events (QCD $b\bar{b}$ production)
→ Semileptonic decay of b-quarks ≙ jets with muons

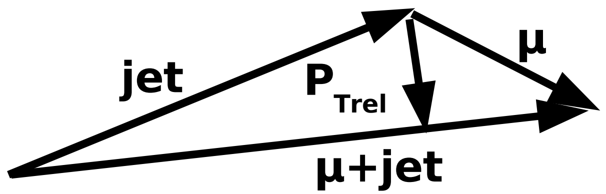
Method 1 (purely from data):
- **2 taggers (lifetime, soft-muon)**
- **2 data samples with different b-jet fraction**

→ Solve system of 8 equations with 8 unknowns
→ B-tagging efficiency



Method 2 (cross check):
- **Shape of the P_{Trel} distribution different for b-jets and light-flavor jets**



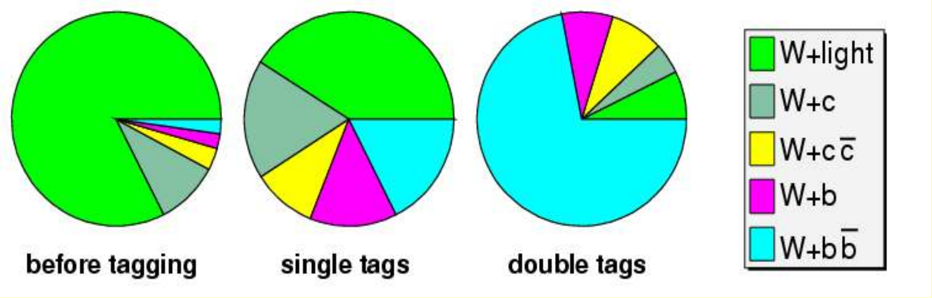


P_{Trel} = Transverse momentum of muon relative to (μ+jet) axis

Backgrounds

Dominant background:
Electroweak W production in association with jets with leptonic W decay

- **Exclusive generation of W+jets MC flavor-subprocesses (ALPGEN+PYTHIA)**
  - **W+light (light=u, d, s, gluon)**
  - **W+c**
  - **W+c$\bar{c}$**
  - **W+b**
  - **W+b$\bar{b}$**



- **Relative fractions of flavor-subprocesses from MC simulation**
- **Absolute normalization of W+jets from the data**

Subtract small backgrounds using known NLO cross sections:

- **Diboson production: WW → l+jets, WZ → l+jets, WZ → jjll, ZZ → lljj**
- **Single top production in s- and t-channel**
- **Z → $\tau\tau$ → l+jets**

Instrumental QCD multijet background determined purely from data

Philosophy of this B-Tagging Analysis

- **Measure the jet tagging efficiencies in data (*b, c, light*)**
- **Parametrize as a function of jet E_T and η : $\epsilon_{jet(flavor)}(E_T,\eta)$**
- **Weight the MC according to the data parameterizations $\epsilon_{jet(flavor)}(E_T,\eta)$**
  - **Determine the event tagging probability: P^{tag}_{event}**

$$P^{tag}_{event}(n \geq 1 tag) = 1 - \prod_{jets}(1 - \epsilon_{jet(flavor)}(E_T, \eta))$$

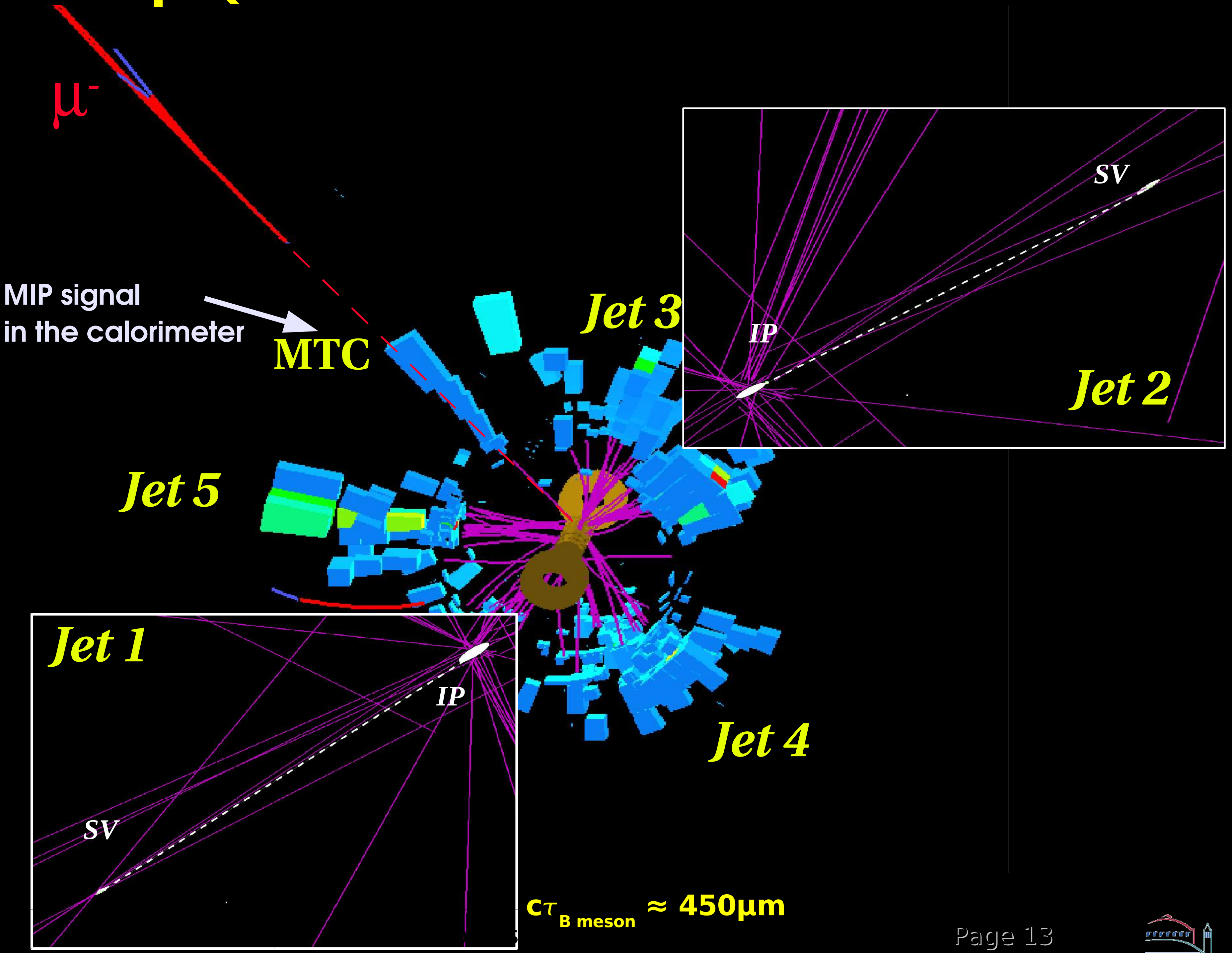
- **Determine the number of expected events with b-tag in the MC: N^{tag}**

$$N^{tag} = N^{untag} \times P^{tag}_{event}$$

$P^{singletag}_{W+jets} = 4\%$	$\Leftrightarrow$	$P^{singletag}_{t\bar{t}} = 45\%$
$P^{doubletag}_{W+jets} = 0.3\%$		$P^{doubletag}_{t\bar{t}} = 14\%$

⇒ B-tagging: Keep ~60% $t\bar{t}$, eliminate ~95% background!

Top Quark Pair Candidate Event



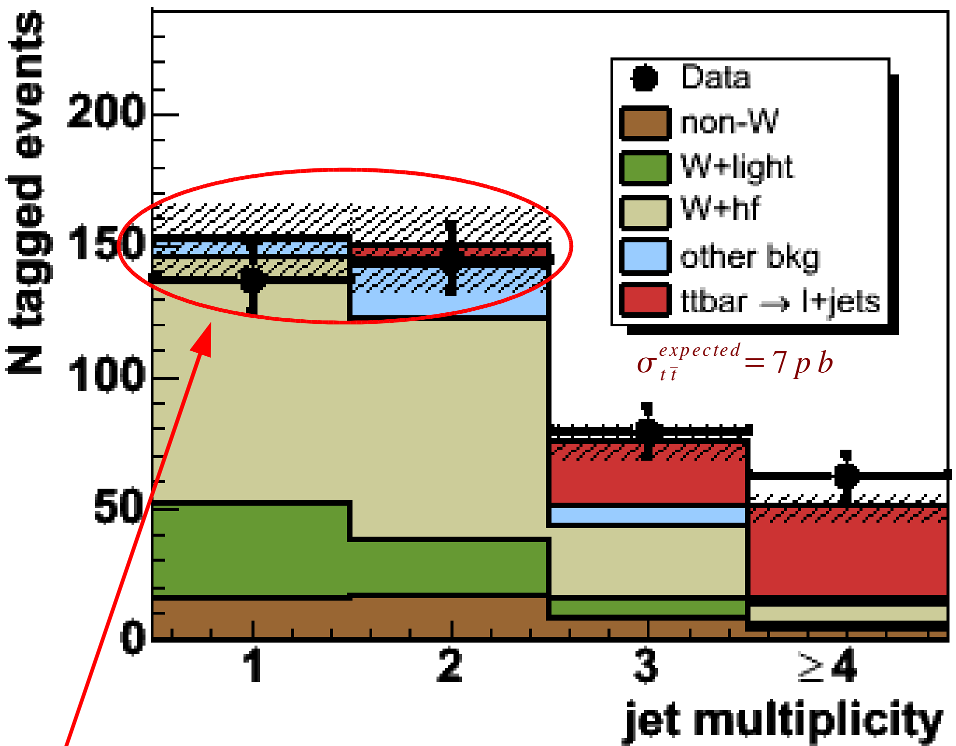
$c\tau_{B\ meson} \approx 450\mu m$

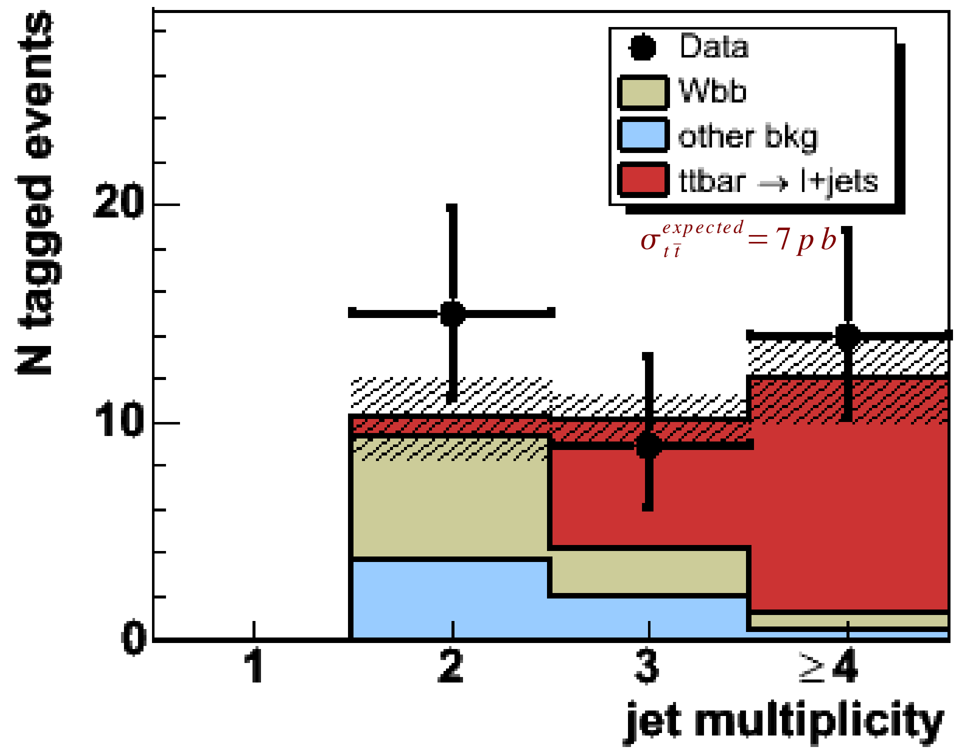
Result

$$\sigma = \frac{N^{tag}_{observed} - N^{tag}_{bkg}}{BR \cdot L \cdot \epsilon_{sel} \cdot P^{tag}_{t\bar{t}}}$$

Single Tags: **Double Tags:**

Each bin is a separate counting experiment





Control bins

Cross section extraction from events with 3, ≥4 jets, single & double tags:

$$\sigma_{p\bar{p} \to t\bar{t}+X} = 8.6^{+1.2}_{-1.1}(stat)^{+1.1}_{-1.0}(syst) \pm 0.6(lumi)\,pb$$

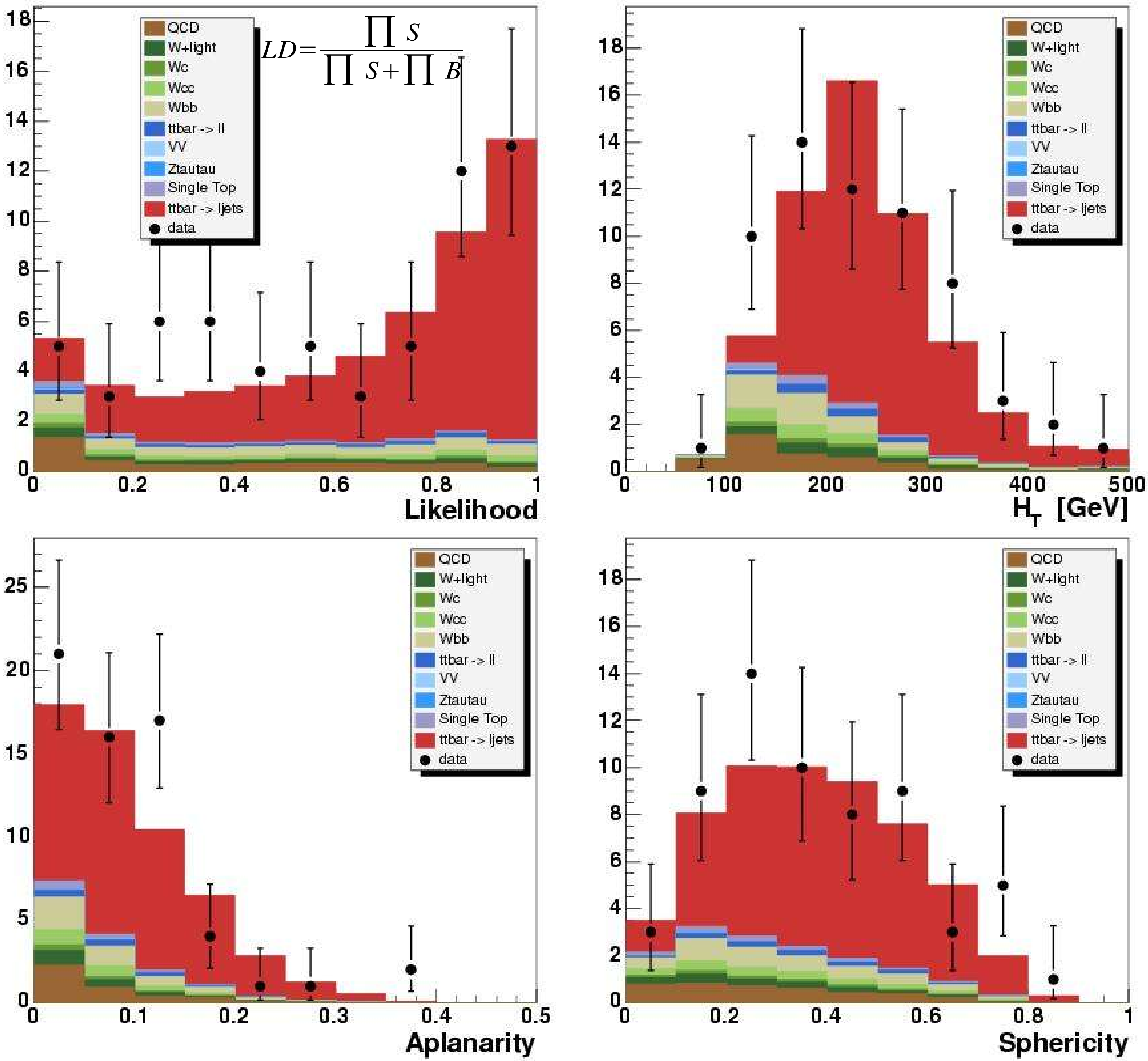
submitted to PRL:
hep-ex/0504058
FERMILAB-PUB-05-087-E

$L_{lepton+jets} \approx 230\ pb^{-1}$

Dominant systematic uncertainties:

- **Jet energy calibration (≈0.5pb)**
- **Background flavor composition (≈0.5pb)**
- **b-tagging efficiency (≈0.6pb)**

Kinematic Characteristics



Top cross section measurement based on kinematics

submitted to PRL:
hep-ex/0504043
FERMILAB-PUB-05-079-E

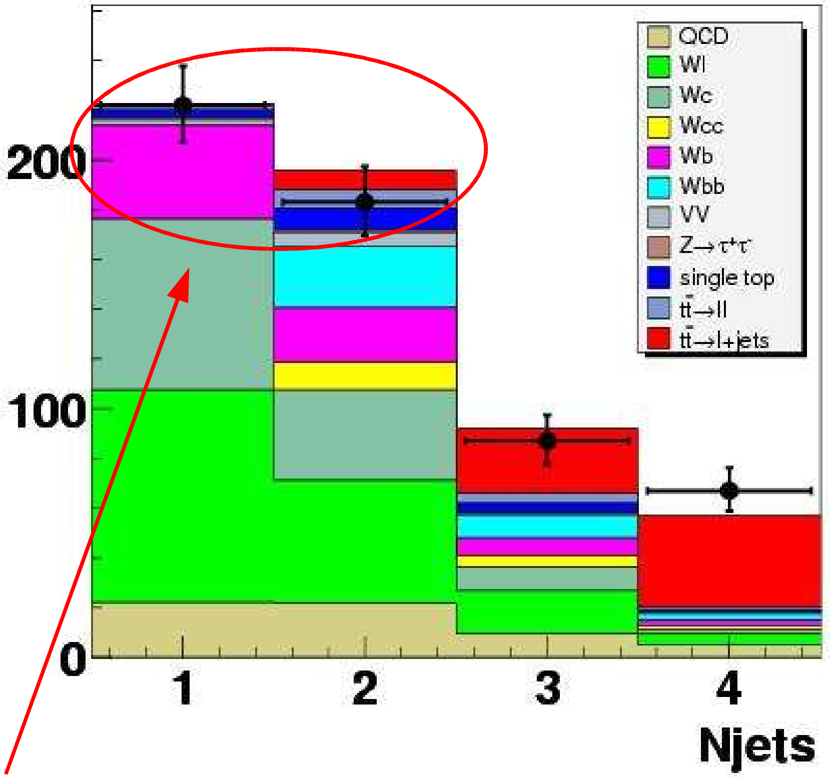
Single-tagged events with ≥4 jets look very "top-like"

Cross Check with CSIP Tagger

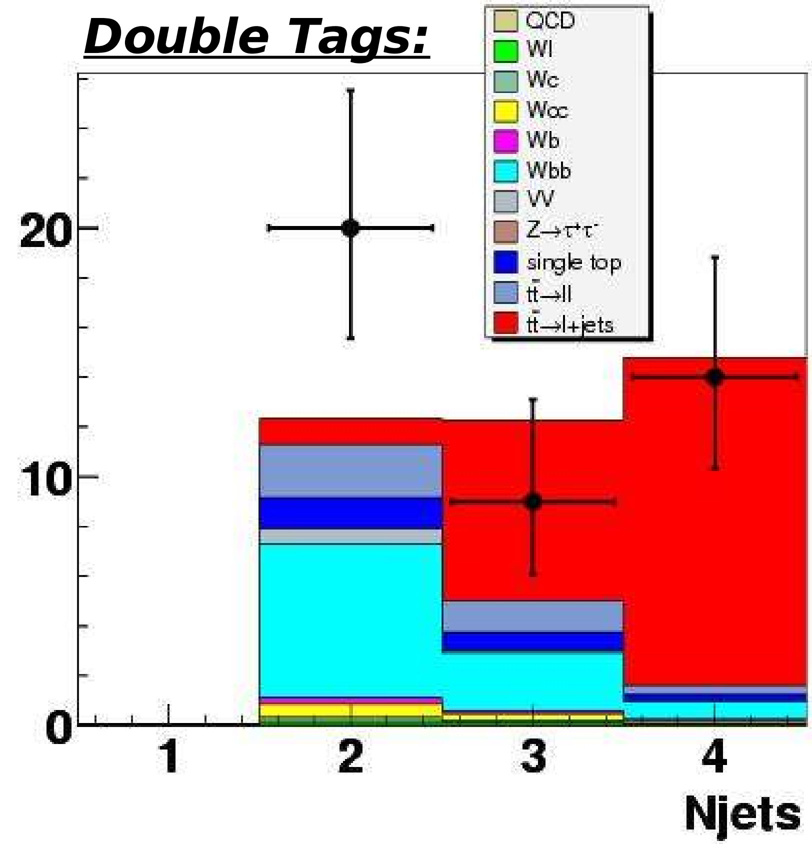
CSIP algorithm: counting tracks with significant impact parameter

- Slightly higher b-tagging efficiency
- Factor 2 higher mistagging rate
- Conditional probability P(CSIP | SVT) =85%

Single Tags:



Double Tags:



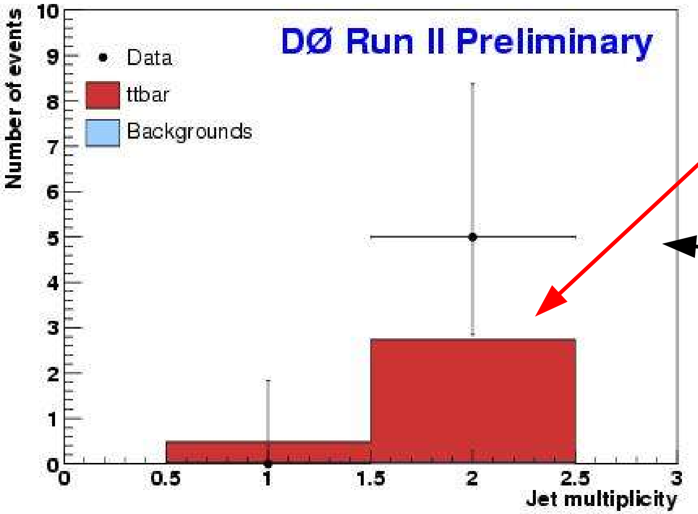
$L_{lepton+jets} \approx 230\ pb^{-1}$

$$\sigma_{p\bar{p}\rightarrow t\bar{t}+X} = 7.6^{+1.1}_{-1.0}(stat)^{+1.2}_{-1.0}(syst) \pm 0.6(lumi)\ pb$$

1.8σ agreement between SVT and CSIP measurements

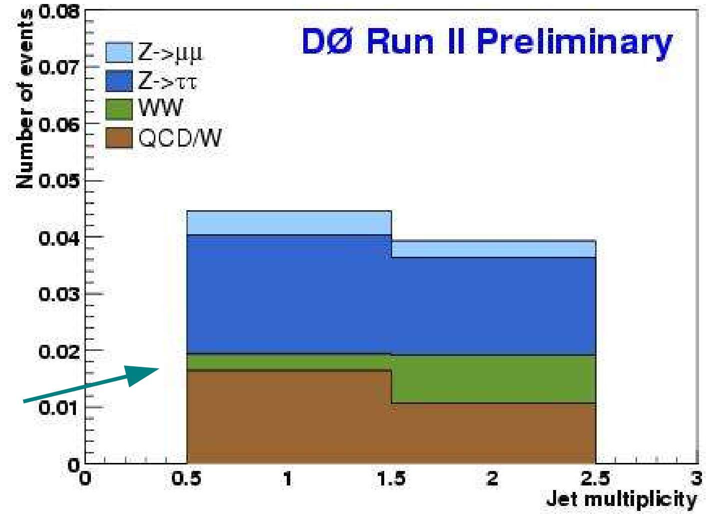
eμ Channel

Ultra-pure sample

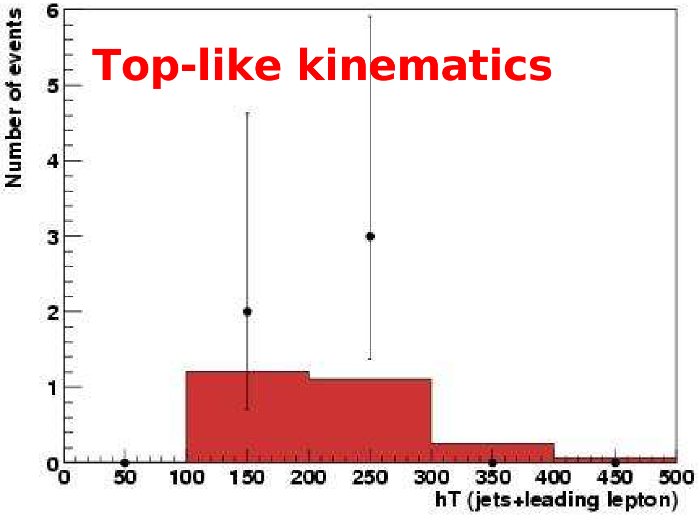


Signal+background:
> 3 ttbar events expected

5 events observed



Total background:
< 0.1 events!



This analysis is:

- **"too pure" for a precision cross section measurement**
- **excellent for the study of top properties in a pure sample**

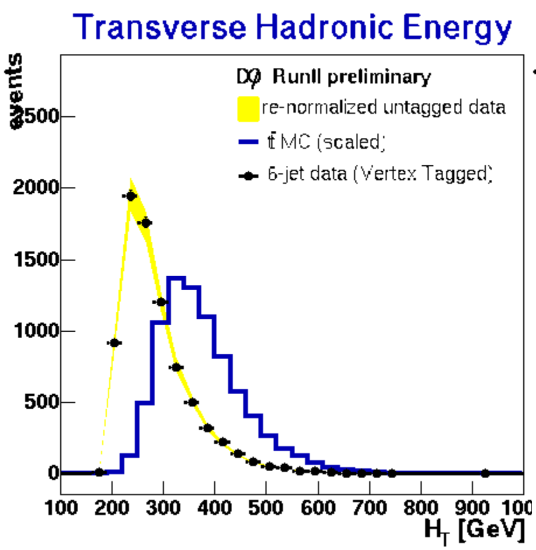
→ **Work in progress:** **recover efficiency**

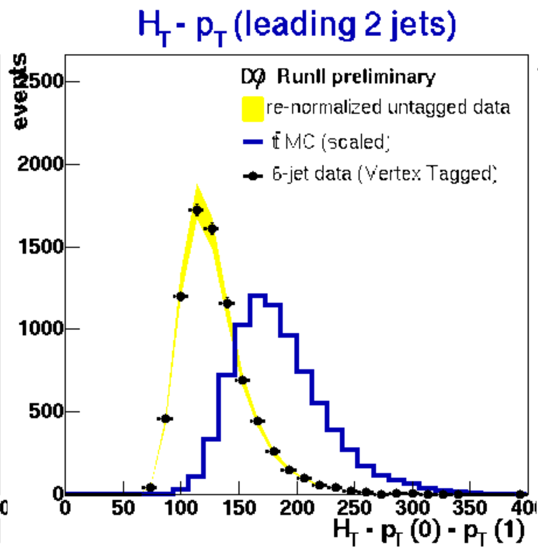
$L_{e\mu} = 158\ pb^{-1}$

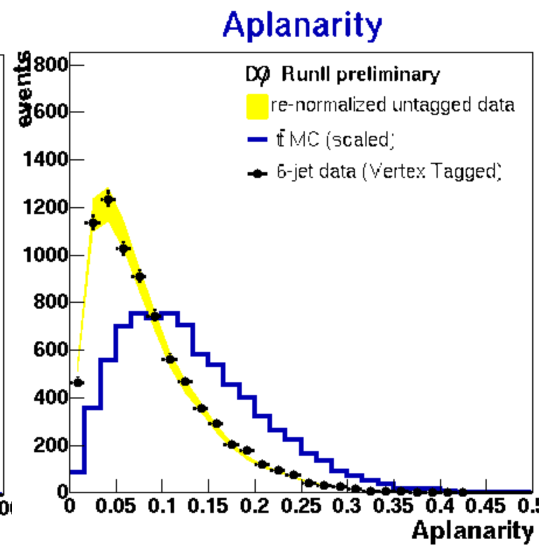
$$\sigma^{e\mu}_{p\bar{p}\rightarrow t\bar{t}+X} = 11.1^{+5.8}_{-4.3}(stat) \pm 1.4(syst) \pm 0.7(lumi)\ pb$$

All-Jets Channel

QCD multijet background-swamped sample

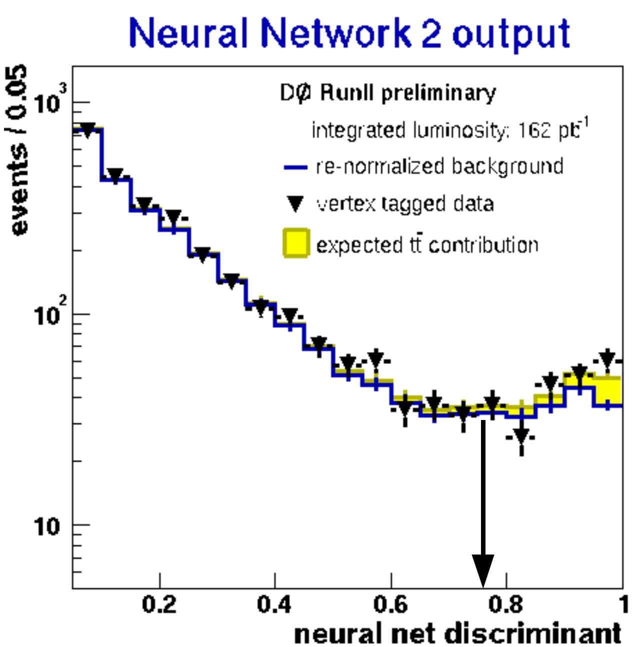






Chain of 3 NN's to exploit the ttbar topology:

- **energy in event**
- **hard non-leading jets**
- **event-shape**
- **top properties (mass)**



Untagged and tagged sample dominated by background
→ Use to determine average background jet tagging probability P(p_T,η,H_T)

1. **Cut on NN0**
2. **NN1 as input for NN2**
3. **NN2 > 0.75**

- **$N_{background}$ = 186**
- **$N_{expected\ ttbar}$ = 31**
- **$N_{observed}$ = 220**

$$\sigma^{all-jets}_{p\bar{p}\to t\bar{t}+X} = 7.7^{+3.4}_{-3.3}(stat)^{+4.7}_{-3.8}(syst) \pm 0.5(lumi)\,pb$$

$L_{all-jets}$ = 162 pb^{-1} **Dominant systematics: Jet energy calibration**

Summary

- **Entering the precision era of Tevatron's top measurements**

- **The measured cross sections:**

$$\sigma^{lepton+jets}_{p\bar{p}\to t\bar{t}+X} = 8.6^{+1.2}_{-1.1}(stat)^{+1.1}_{-1.0}(syst) \pm 0.6(lumi)\,pb$$

$$\sigma^{e\mu}_{p\bar{p}\to t\bar{t}+X} = 11.1^{+5.8}_{-4.3}(stat) \pm 1.4(syst) \pm 0.7(lumi)\,pb$$

$$\sigma^{all-jets}_{p\bar{p}\to t\bar{t}+X} = 7.7^{+3.4}_{-3.3}(stat)^{+4.7}_{-3.8}(syst) \pm 0.5(lumi)\,pb$$

are in good agreement with NLO theoretical predictions of 6.8pb

- **Work in progress:**
  - **Improve all measurements using more luminosity**
  - **Better control the dominant systematic uncertainties**
  - **Better exploit the statistics available**
  - **Combine results**

Stay tuned for DØ's summer results !

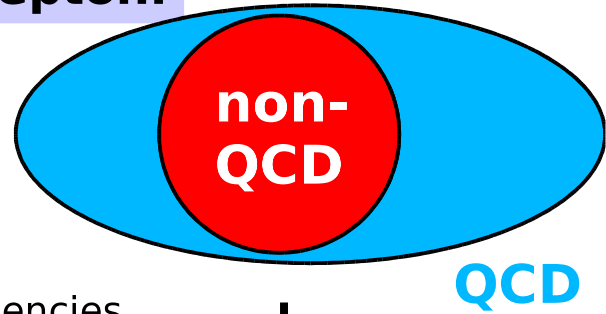
Backup Slides

Determination of QCD Background

- **Determine instrumental QCD multijet background <u>purely from data</u>**

<u>e:</u> electromagnetic jets
<u>μ:</u> fake isolation of muons in jets
<u>MET:</u> Calorimeter resolution, muon momentum resolution

loose lepton:



$$N^{tag}_{loose} = N^{tag}_{loose,QCD} + N^{tag}_{loose,non-QCD}$$

ϵ $\epsilon_{QCD} = 8\,\%$ $\epsilon_{non-QCD} = 82\,\%$

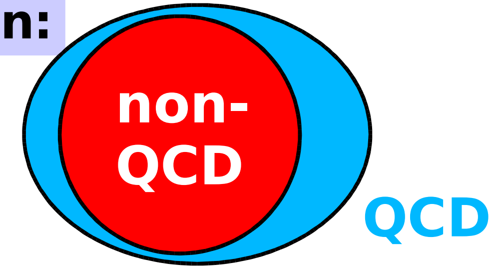
$$N^{tag}_{tight} = \epsilon_{QCD}\, N^{tag}_{loose,QCD} + \epsilon_{non-QCD}\, N^{tag}_{loose,non-QCD}$$

the efficiencies are determined on reference data sets

ϵ

tight lepton:

(final selection)

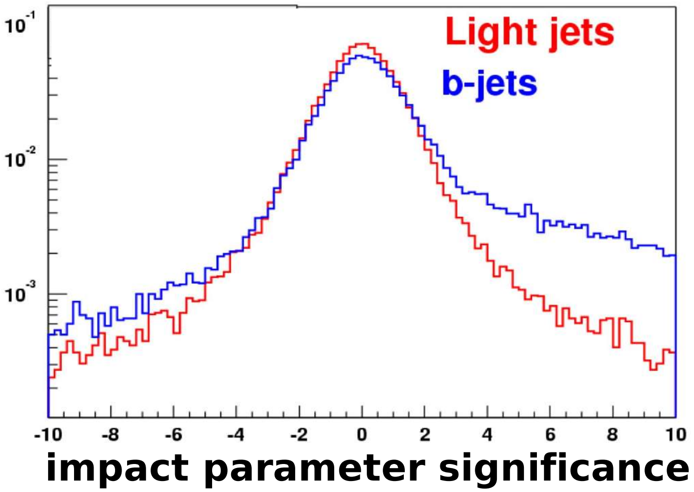


- **Solve linear system of equations for $N^{tag}_{loose,QCD}$ and $N^{tag}_{loose,non-QCD}$**

Misidentification Rate of b-Jets

Misidentification = Tagging of light-flavor jets

- **Dominant reason: Finite impact parameter resolution / decay length resolution**



Measure negative tagging rate in data
=
Measure of the misidentification rate