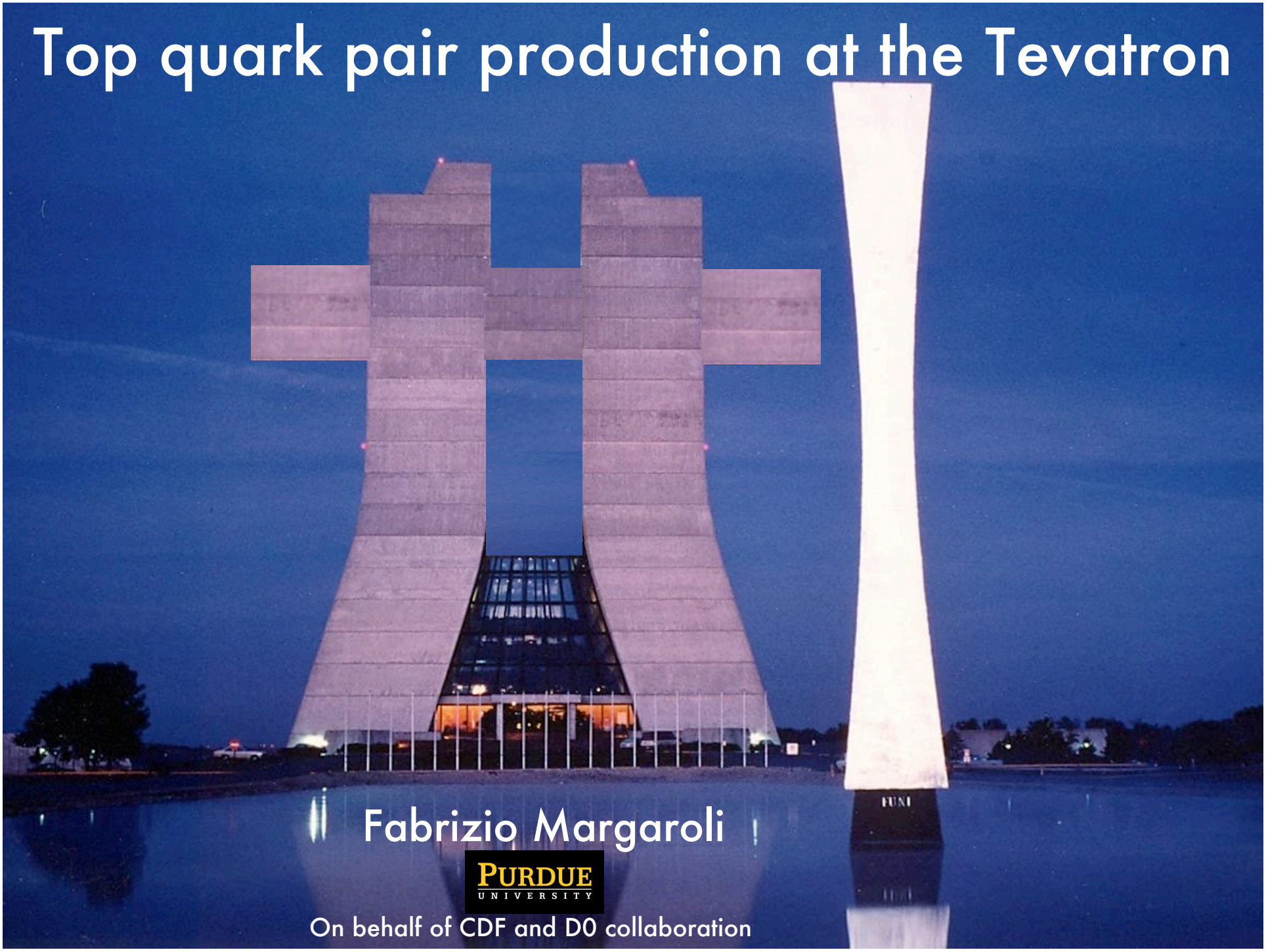
Top quark pair production at the Tevatron



Fabrizio Margaroli

PURDUE UNIVERSITY

On behalf of CDF and D0 collaboration

What?

Top was discovered at Fermilab in 1995

Its mass much larger than any other fermion

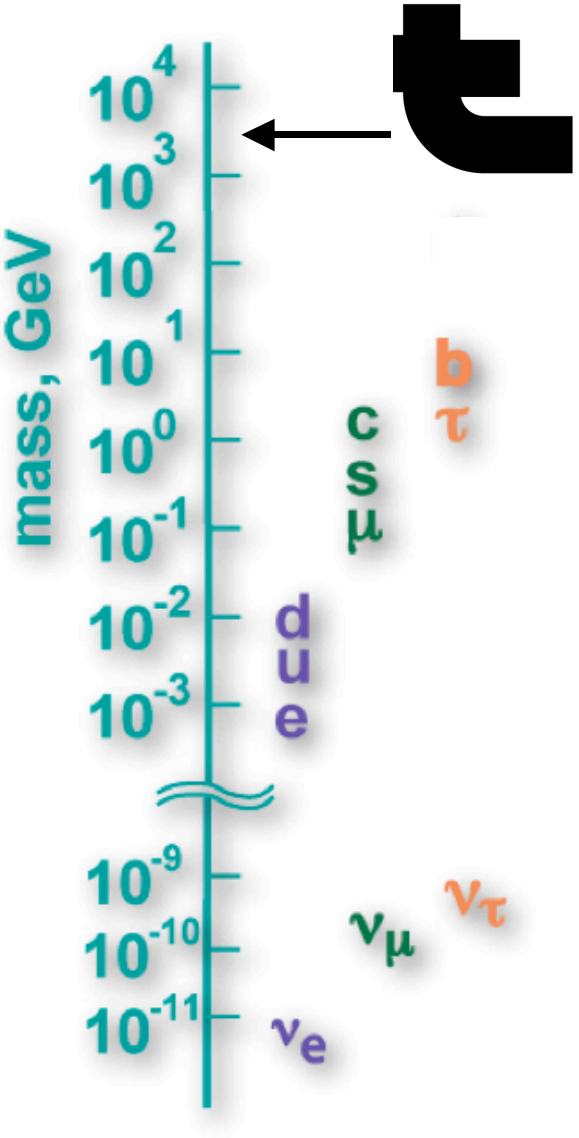
Using the latest Tevatron-averaged M_{top},

$$L_{Yukawa} = - \quad L \quad R$$

Yukawa coupling = 0.996±0.006

- What role does it play in EW symmetry breaking?
- Several authors point to a special role for the top quark

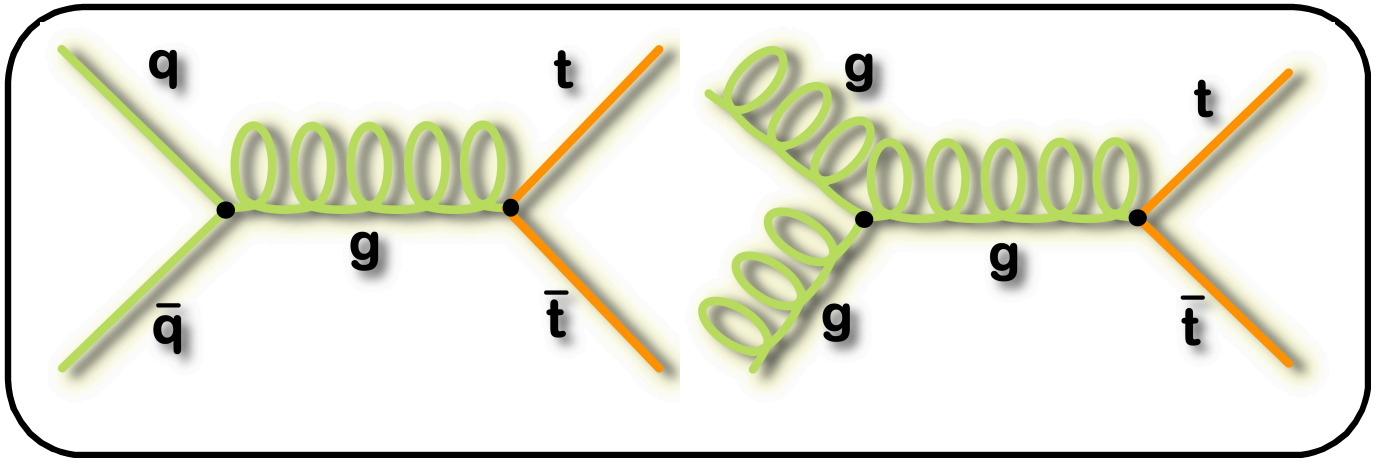
Lifetime shorter than hadronization time → only quark that decays before hadronizing



How?

Top was discovered at Fermilab in 1995

Top - antitop production is the dominant mode at a pp collider



$\sigma_{t\bar{t}}$=7.5pb*:

QCD process: test pQCD NLO calculation

First step in understanding selected top quark sample

Exotic top quark decays would lead to different observed values of the inclusive ttbar production cross section in the different channels.

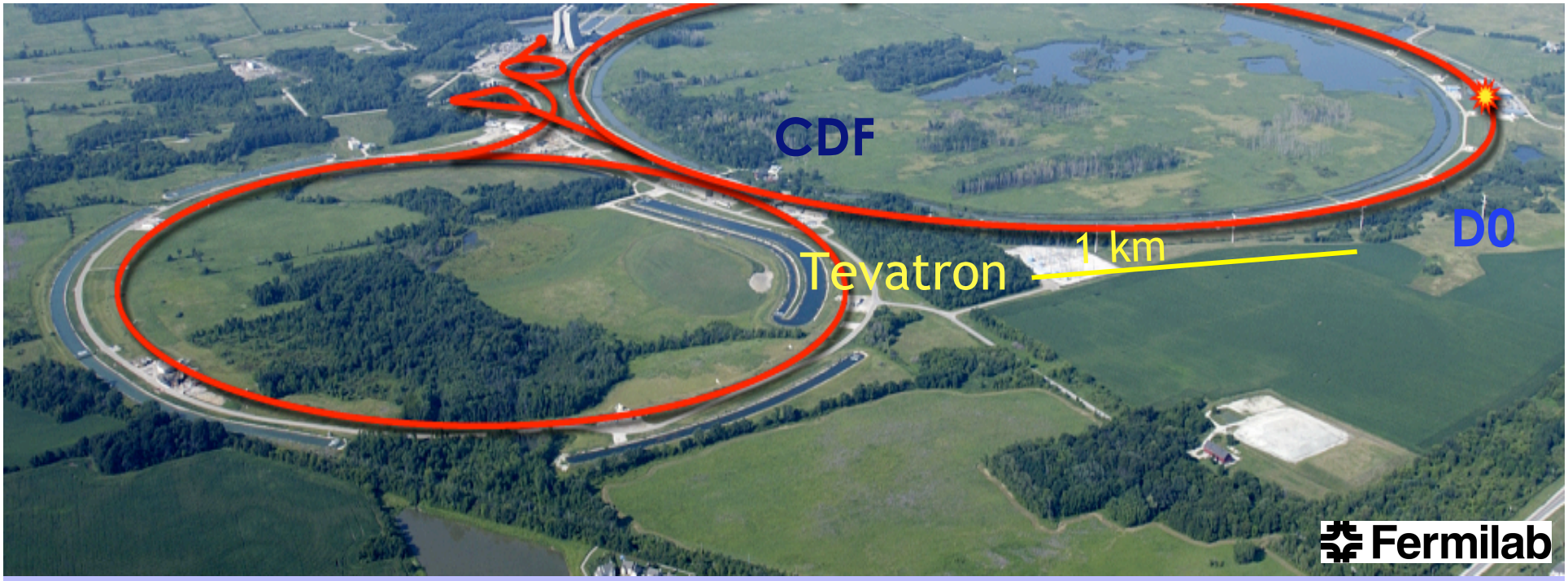
*assuming M_{top}=175GeV

Where?

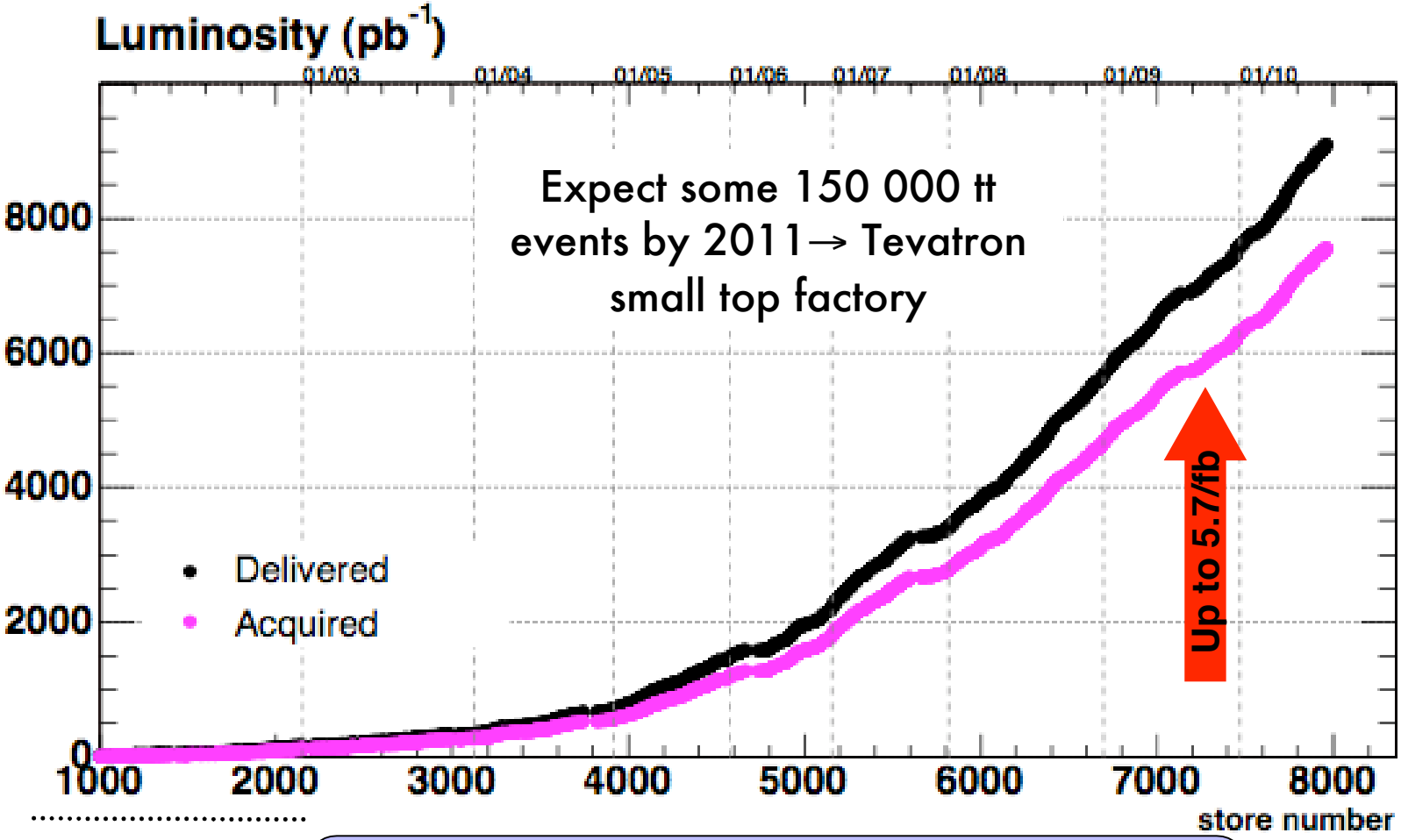
Fermilab's Tevatron Run II pp collider at 1.96 TeV, running since year '01. Currently performing very well:

- New record in instantaneous luminosity $4 \cdot 10^{32}$ cm^{-2} s^{-1}
- New record in delivered luminosity: >$2fb^{-1}$ per year
- Two multi-purpose, well-understood detectors CDF and D0

Top created in1 in O(10) billion collisions at the Tevatron



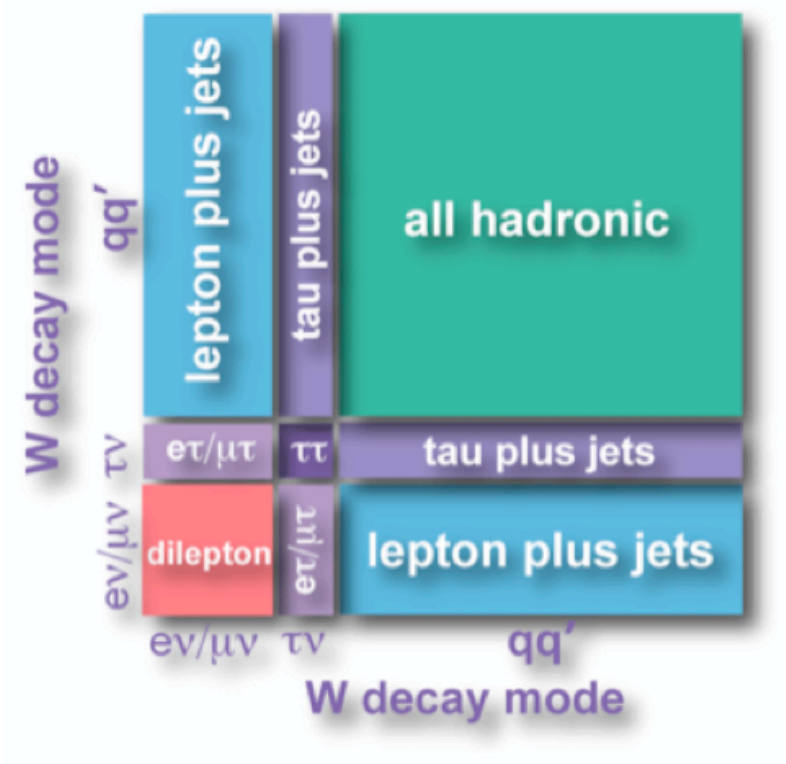
How many



Delivered 9.0 fb^{-1}
Acquired 7.6 fb^{-1}* (slightly less w/ silicon)
Almost 6fb^{-1}* analyzed

*CDF shown here
Similar numbers for D0

Pair production decay signature



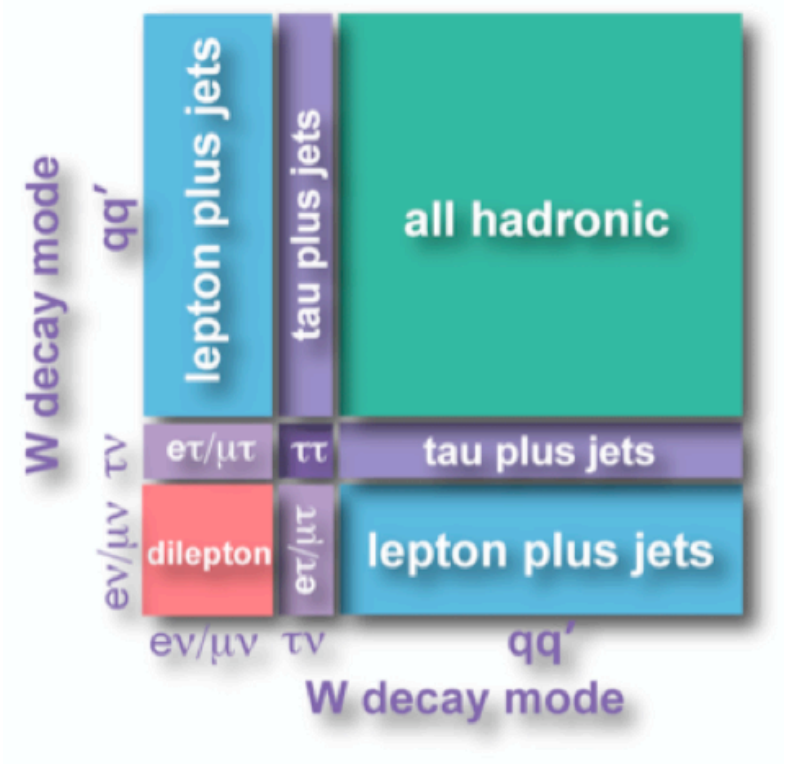
Integrated acceptance 9%

Dileptonic
- Highest S/B
- lowest BR(5%)

Lepton+Jets
- large BR(30%)
- good S/B ratio.

All hadronic
- highest BR(44%)
- Overwhelming QCD background

Pair production decay signature



Integrated acceptance 13%

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- Highest S/B
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MET + ≥ 4jets
- Lepton+jets decays where lep not id'ed (many taus)

MET + 2/3jets
- Dileptonic and semileptonic decays where the leptons are not identified

Pair production decay signature

Expect to analize more than 30 000 top quarks by 2011

Integrated acceptance 13%

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MET + 2/3jets
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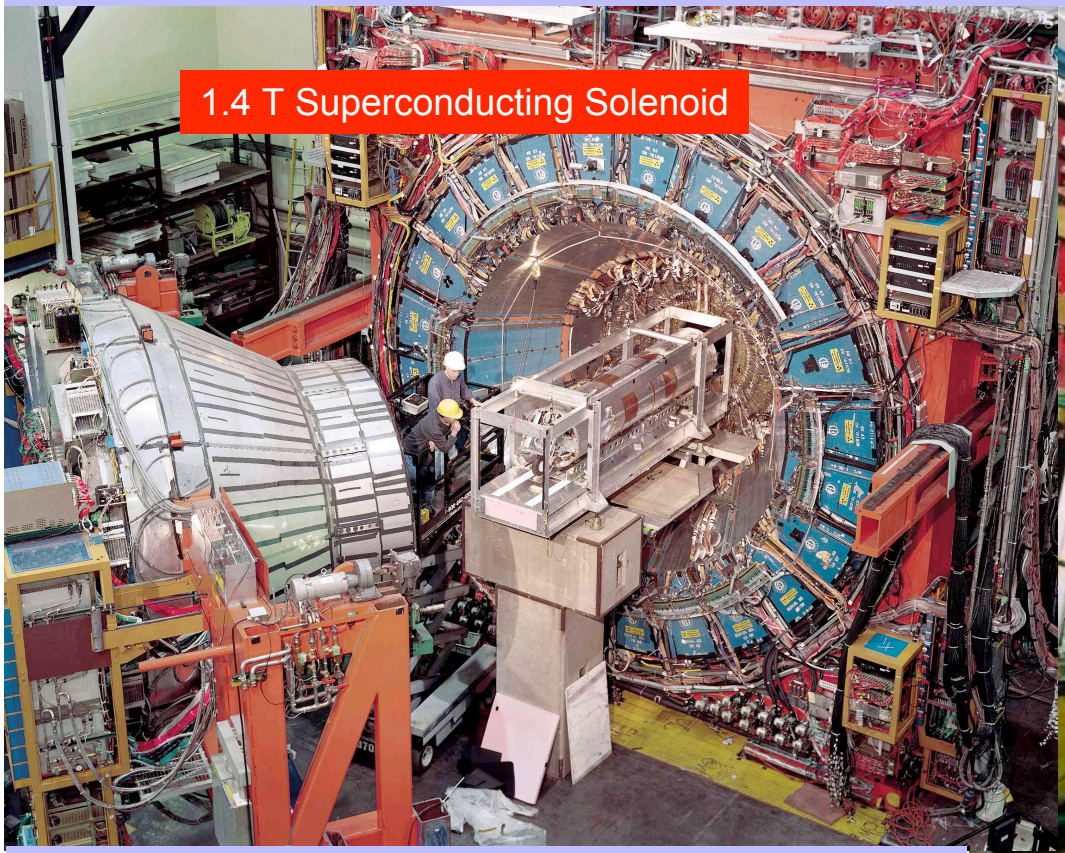
How they are recorded: CDF II



Tracking:

- Silicon tracker allows precision vertex detection $|\eta|<2$
- Drift chamber measures charged particle P_T

Calorimeter split in EM and HAD devices

- Muon chamber outside calorimeter

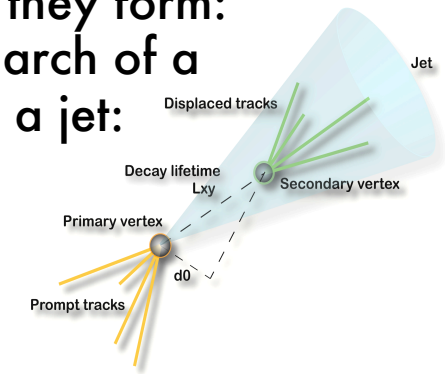
Jets at CDF

Quark/gluons hadronize and produce particle jets. CDF uses cone based jet reconstruction algorithm. Loops over calorimetric towers

Seconday vertex: b-quark id'ed w long lifetime of the B mesons they form: identification through search of a secondary vertex within a jet:

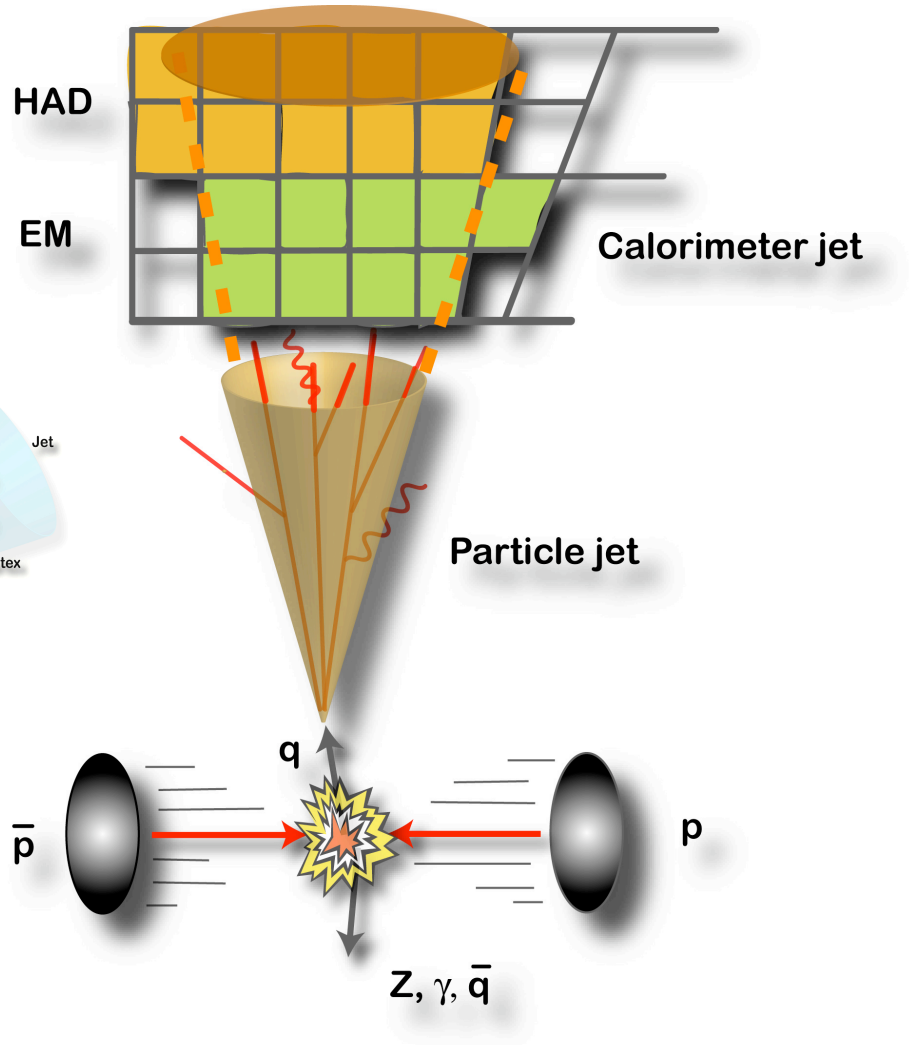
b-tag eff: ~ 40%

fake rate ~ 0.5%

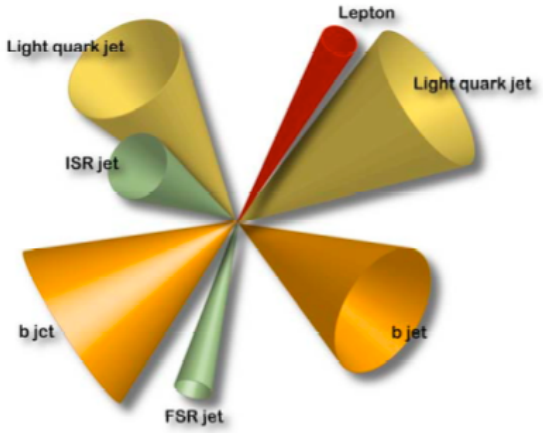


Neural Network for flavor separation

- L_{xy}, vertex mass, track multiplicity, impact parameter, semi-leptonic decay information, etc...

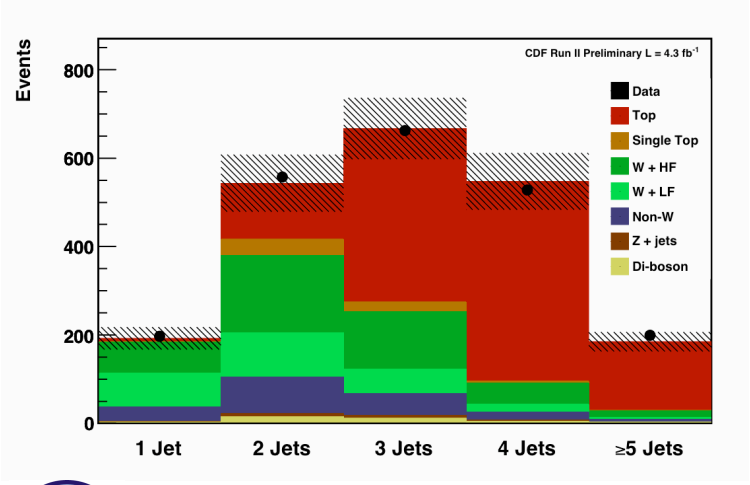


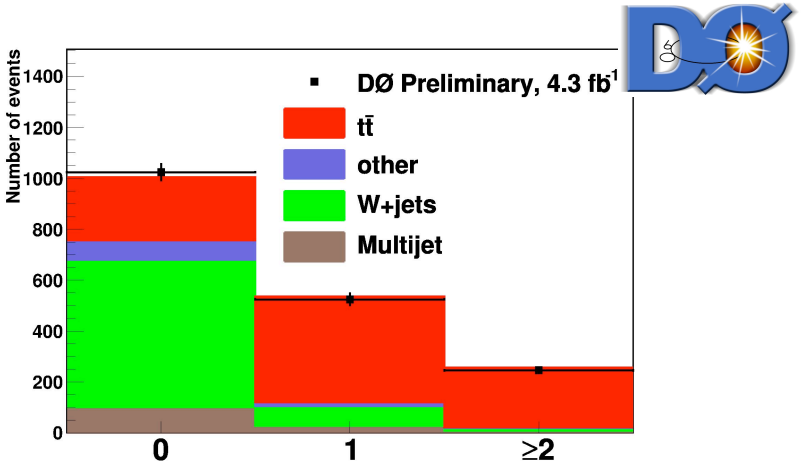
Lepton+jets b-tagged



counting by number of jets and b-tag jets:

- W+HF cross section underestimated in the MC: W+HF content measured in data in the 1 or 2 jet event sample
- b-tagging mistag rate measured in data, parametrization applied to W+jets
- CDF measures ratio of ttbar/Z→ll with the same trigger and use the theoretical Z cross section to remove the uncertainty due to luminosity measurement

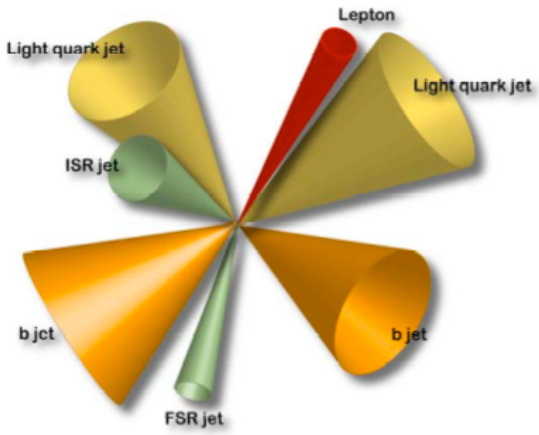




arXiv:1004.3224

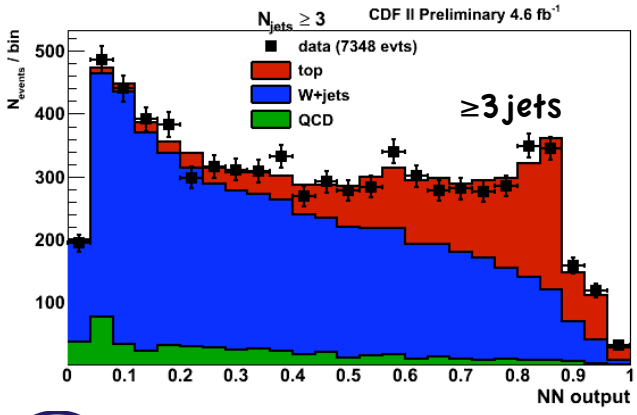
D0 (L=5.3fb^{-1}): σ_{tt} = 7.70 ± 0.75 (stat+syst+lumi) pb
CDF(L=4.6fb^{-1}): σ_{tt} = 7.32 ± 0.71 (stat+syst+theory) pb

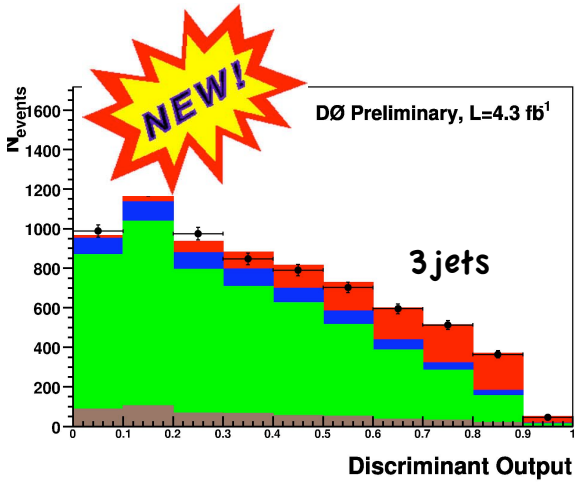
Lepton+jets topological

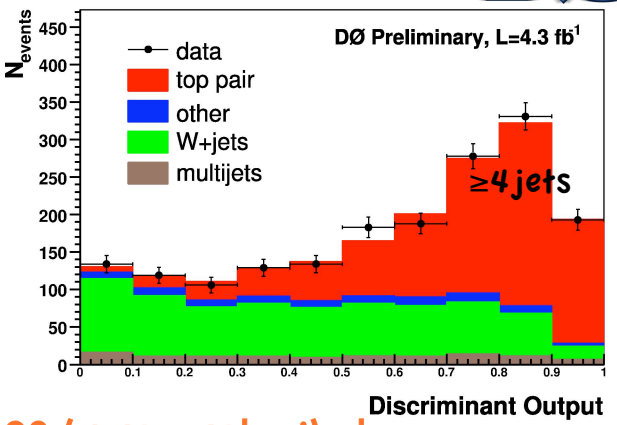


Signal/background discrimination:

- ttbar more energetic, central and isotropic than W+jets
- NN (CDF) or BDT (D0) input variables: Ht, aplanarity, sphericity, etc.
- cross section measurement: template fit of ttbar and W+jets to the discriminant output
- CDF measures ratio of ttbar/Z→ll with the same trigger and use the theoretical Z cross section to remove the uncertainty due to luminosity measurement





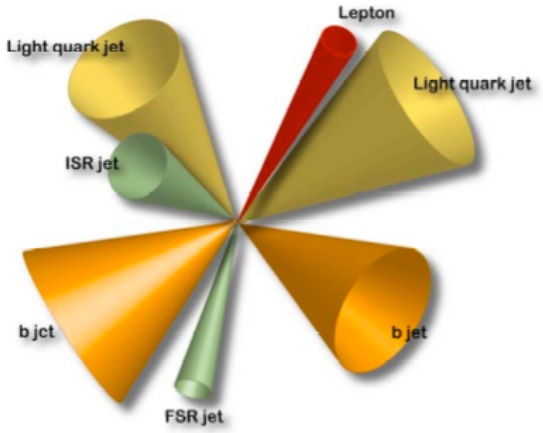


arXiv:1004.3224

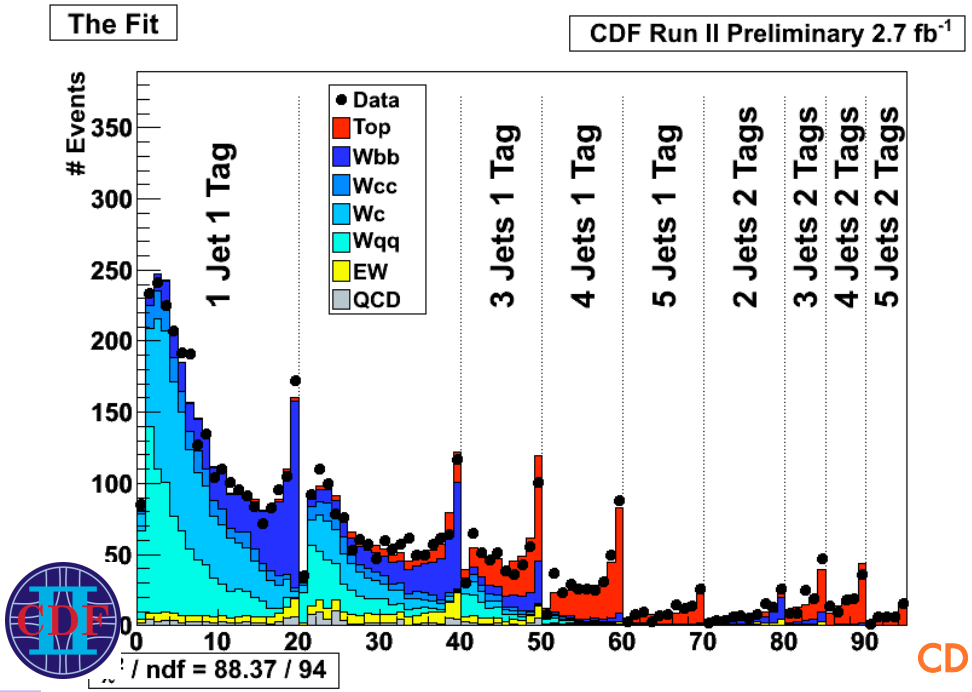
D0 (L=4.3fb^{-1}): σ_{tt} = 7.93 ± 0.98 (stat+syst+lumi) pb

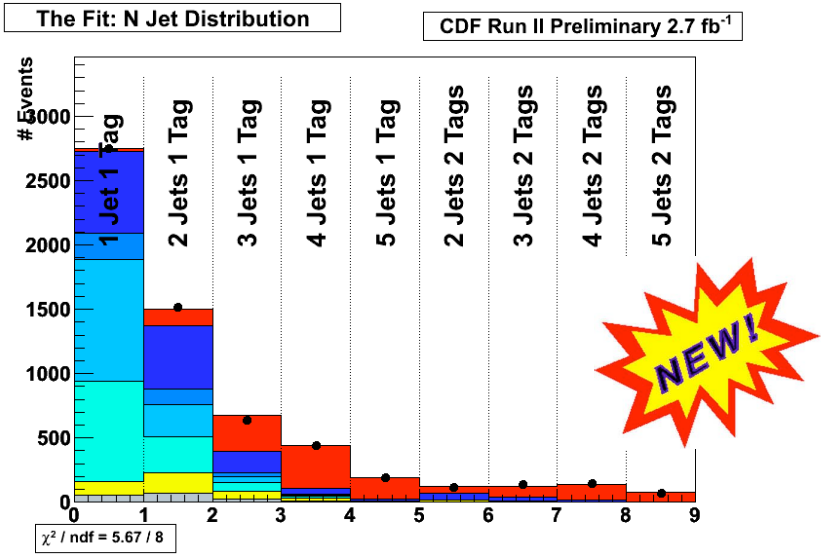
CDF(L=4.6fb^{-1}): σ_{tt} = 7.82. ± 0.55 (stat+syst+theory) pb

Simultaneous S and B kinematic fit



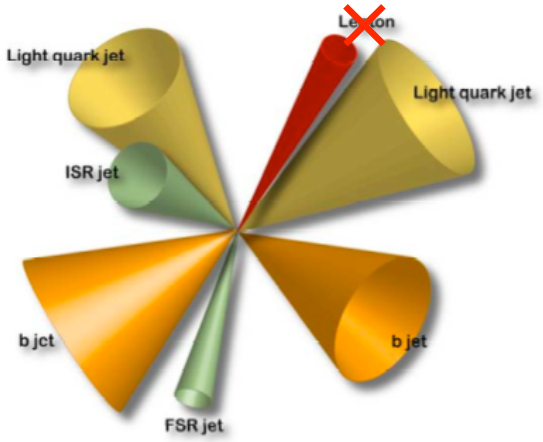
- Use events with 1lepton, ≥1jet, ≥1b-tag to measure signal cross section and background contributions.
- Templates: NN based flavor separator, Njets, Nbtags
- Fit simultaneously for signal Nevts, backgrounds Nevts, nuisance parameters (JES, data-MC scale factors, extra radiation, etc)
- Potentially very sensitive as more data is added





CDF(L=2.7fb^{-1}): σ_{tt} = 7.64± 0.57(stat+syst)+0.45(lumi) pb

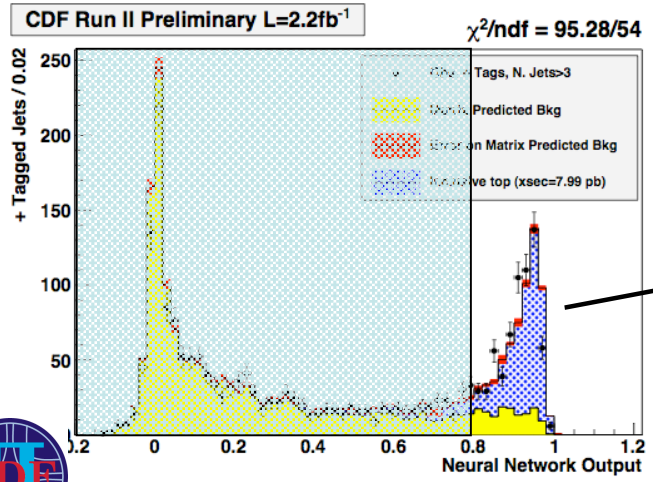
Missing transverse energy plus jets

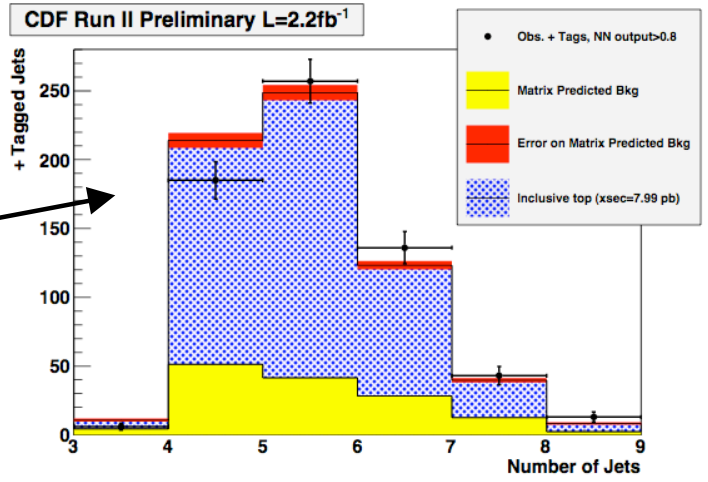


MET + jets: -alternative way to select tau channels, and recover unidentified e/mu (1/3tau, 1/3e, 1/3mu)

Independent from "lepton+jets" channel

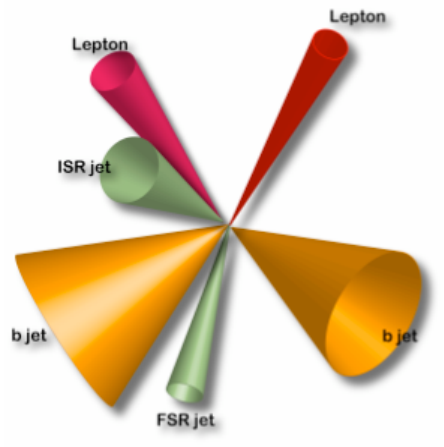
- at least 3 strict identified jets, at least one b-tagged jet
- NN trained against background, NN > 0.8 background estimation:
- -b-tag rate/misrate evaluated from data in a 3 jet sample (small signal contamination)sample composition
- Counting experiment - count number of b-tagged jet





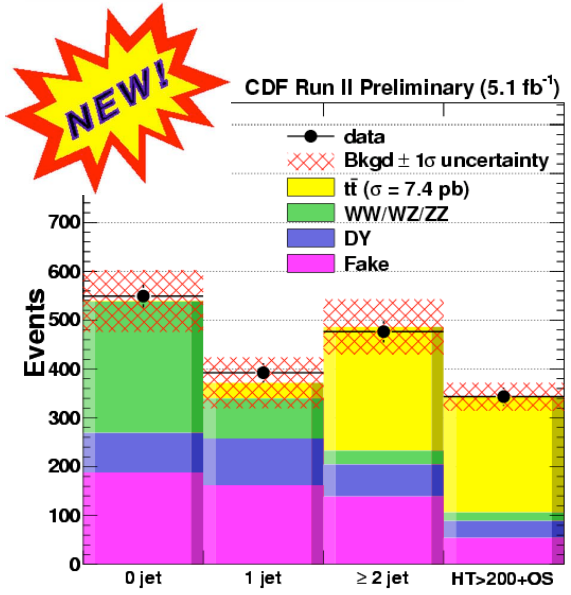
CDF(L=2.2fb^{-1}): σ_{tt} = 7.99± 0.55(stat)+0.76(syst)+0.46(lumi) pb

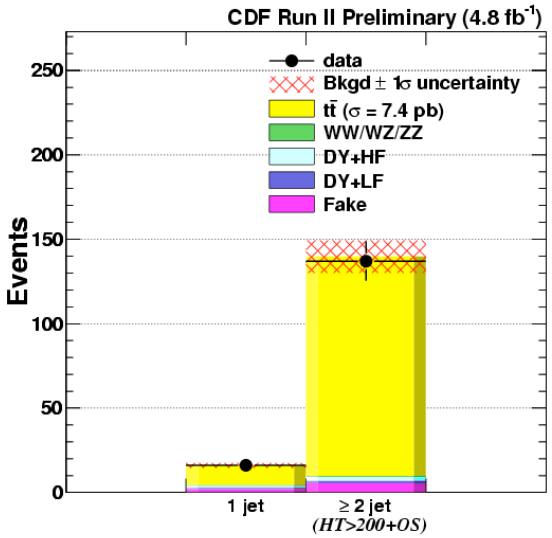
Dileptonic channel

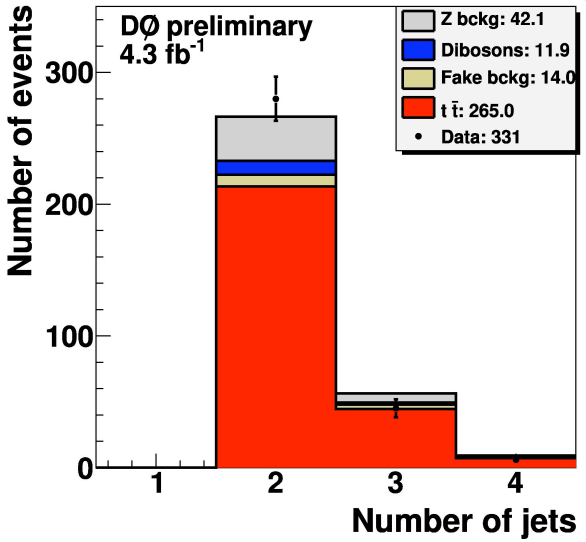


Signal/background discrimination

- CDF: Ht and MET significance cuts, or b-tagging
- D0: Ht cut and BDT trained against Z+jets and diboson







D0 (L=4.3fb^{-1}): σ_{tt} = 8.4 ± 0.5(stat) ± 0.9(syst) ± 0.7 (lumi) pb

Pretag CDF (L=5.1fb^{-1}): σ_{tt} = 7.4 ± 0.6(stat) ± 0.6 (syst) ± 0.5 (lumi) pb

ttbar background to new physics

Many new particles can appear in the MET+2 b-jets channel:

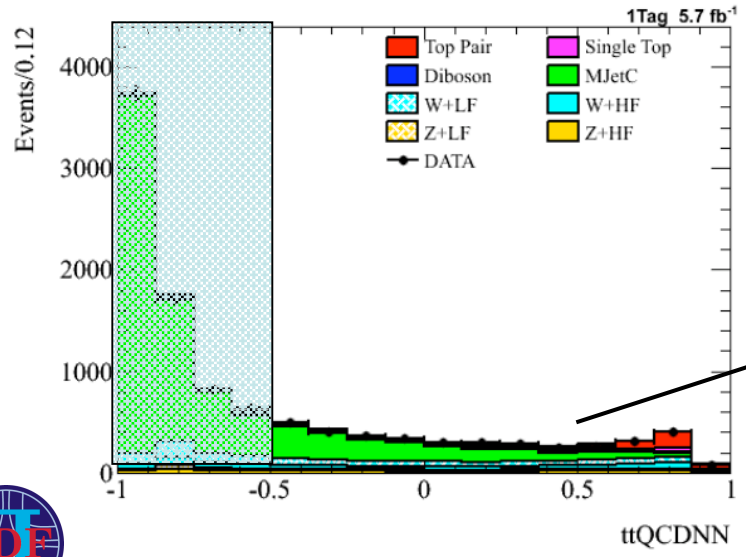
- Lowmass Higgs (ZH→νν̄bb̄)
- $\tilde{b}\tilde{b} \rightarrow bb\chi^0\chi^0$
- 3rd gen leptoquarks
- technicolor etc.etc.

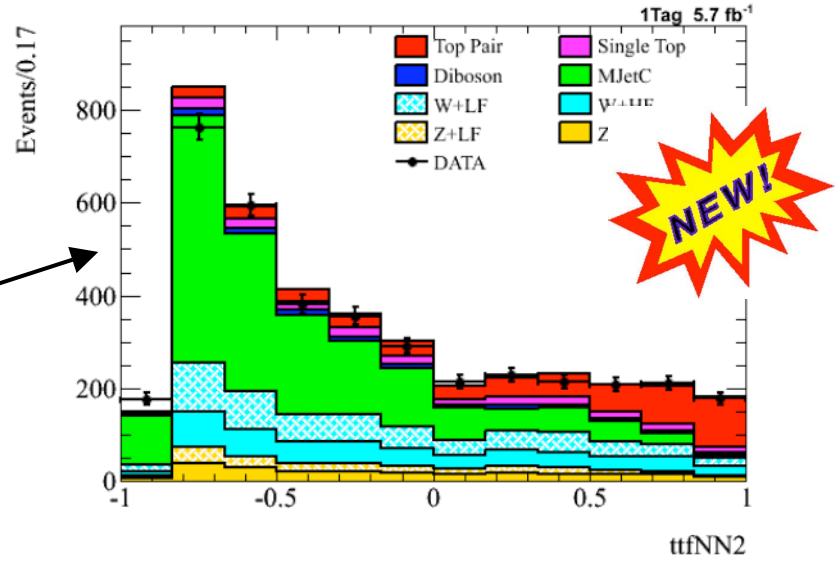
ttbar is a much larger background: test of the backgrounds and tools

Measurement here independent from others

Using same strategy as in search for ZH→νν̄bb̄:

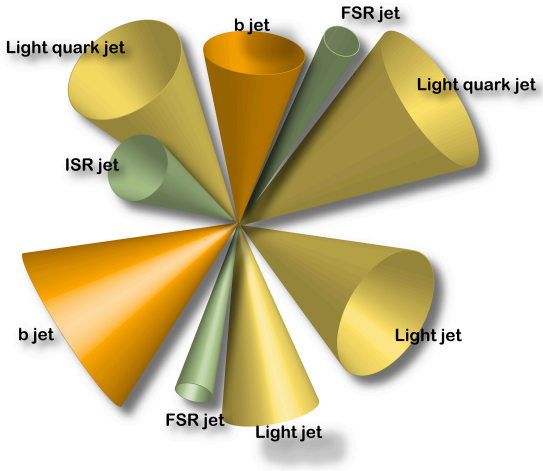
- Suppress overwhelming QCD background using multivariate technique (NN)
- Isolate the signal from remaining backgrounds, likelihood scan of NN output





CDF(L=5.7fb^{-1}): σ_{tt} = 7.1 ± 1.1 (stat+syst+lumi) pb

All-hadronic channel

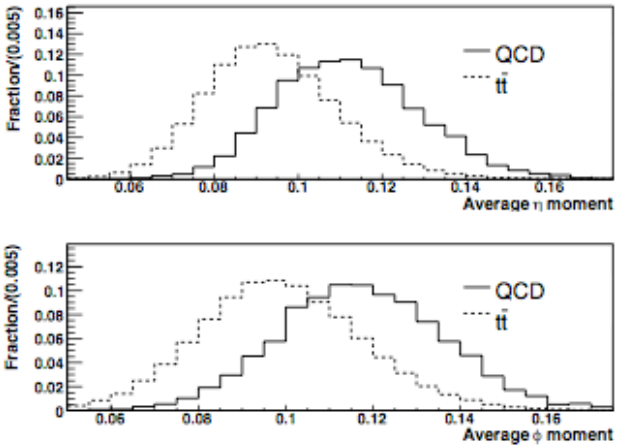


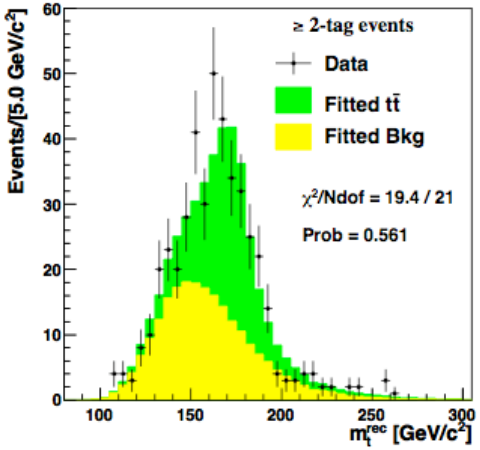
Both collaborations use b-tagging and multivariate techniques to isolate the signal from the overwhelming QCD background

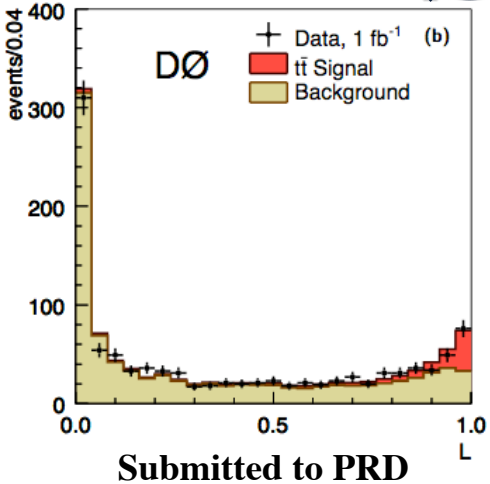
To measure the cross section:

- CDF cuts on NN output, scans the reconstructed M_{top}
- D0 scans the likelihood output

JES largest syst: CDF uses W→qq decays to constrain it







Submitted to PRD

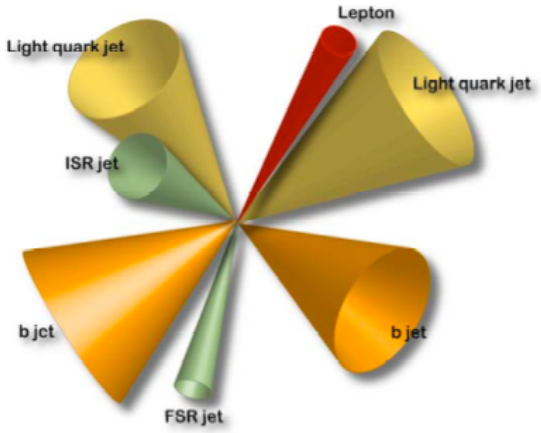
Exploiting distinctive quark-jet vs gluon-jet features

PRD 81 052011 (2010)

D0 (L=1.0fb^{-1}): σ_{tt} = 6.9 ± 1.3 (stat) ± 1.4 (syst) ± 0.4(lumi) pb

CDF(L=2.9fb^{-1}): σ_{tt} = 7.2 ± 0.5 (stat) ± 1.0 (syst) ± 0.4(lumi) pb

ttbar+jets

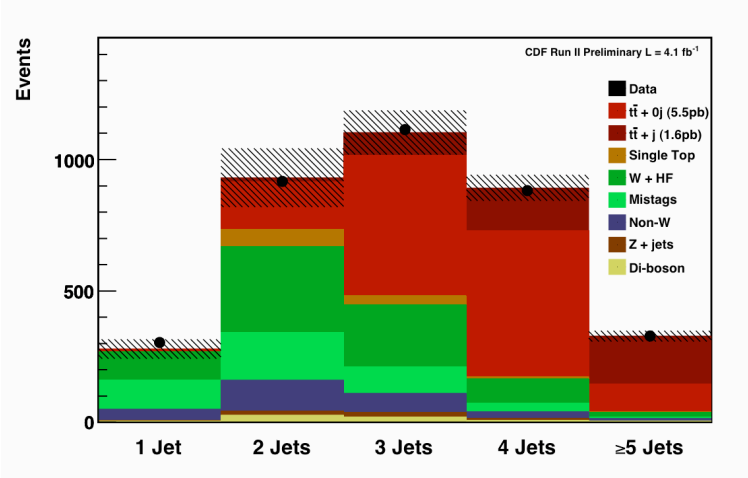


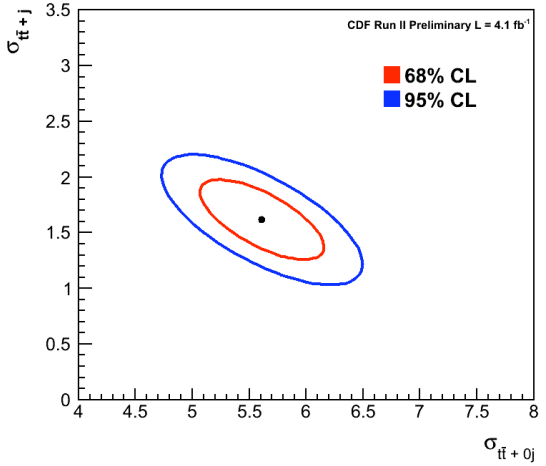
Test of QCD prediction, sensitive to NLO effects

Most top events at the LHC will be produced with additional jets → substantial background for many new physics signals

Strategy: simultaneous fit of tt+0jet and tt+1jet

SM cross section is $\sigma_{tt} = 1.79^{+0.16}_{-0.31}$pb EPJ C59 625 (2009)



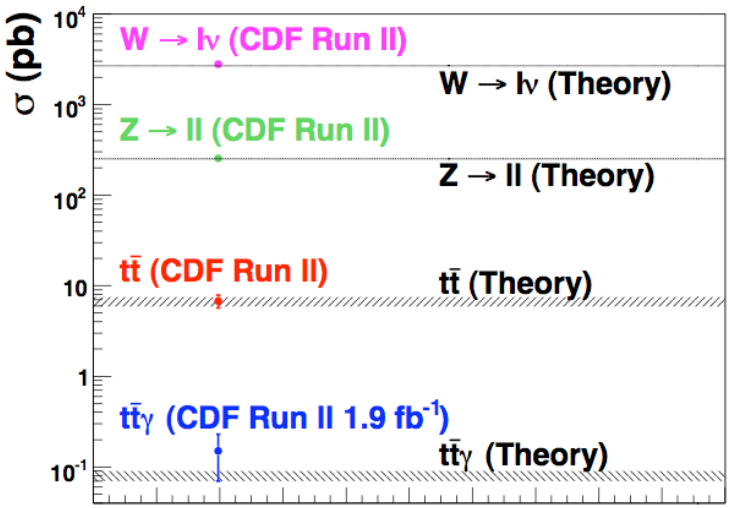


CDF(L=4.1fb^{-1}): σ_{tt} = 1.6 ± 0.2 (stat)+0.5(syst) pb

ttbar+γ

Search for new physics/measure ttbar +gamma signature in the >=1lepton, >=3jets, MET, gamma

?Do I want it?



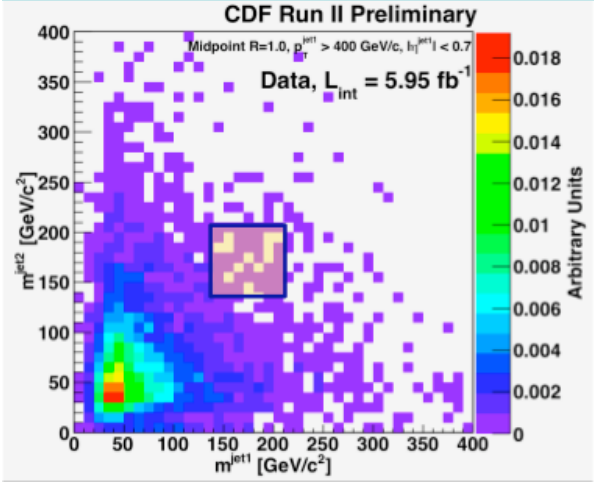
Search for boosted top quarks

Decays fully contained in jet cone happen with high top Pt (>=400GeV here)

- identification of the W decay and the b quark unfeasible
- jet has mass~Mtop - thus very different from jets from other quarks or gluons

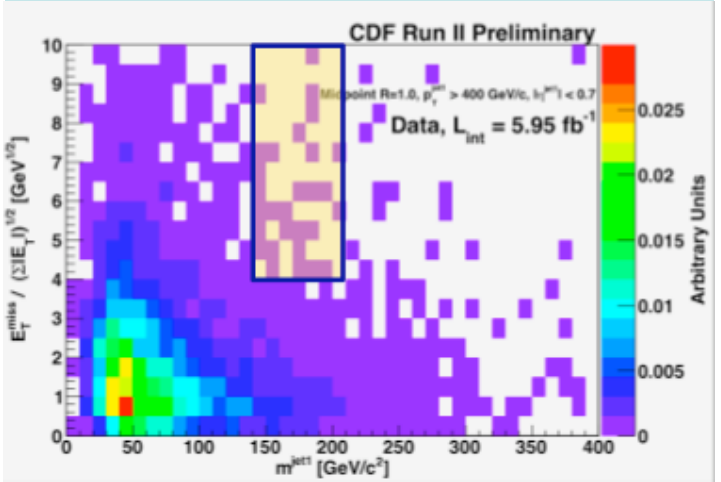
Cross section for events with Pt(top/antitop)>400GeV is a handful of fb - analysis strategy splits into

all-hadronic decays:
two tops with mass~175



(jet1 mass vs jet2 mass)

Lepton+jets decays:
one jet with mass~175, large MET



(jet1 mass vs $\not\!\!E_T/\sum E_T$)

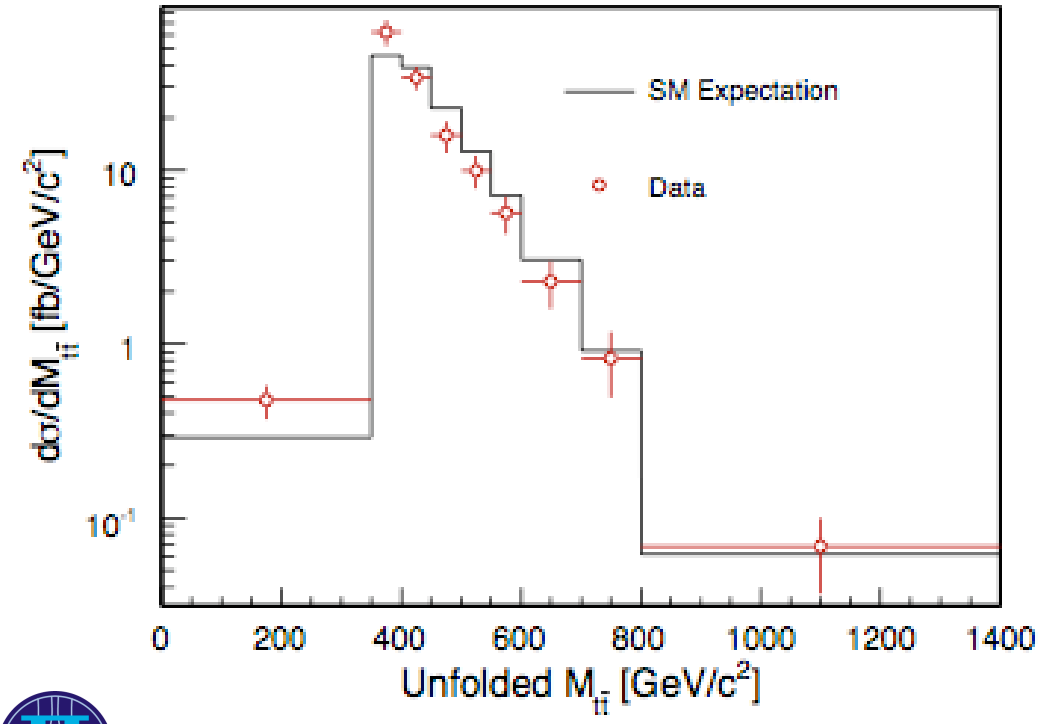
Set limits on ttbar xsec <55fb@95CL (expected <39fb)

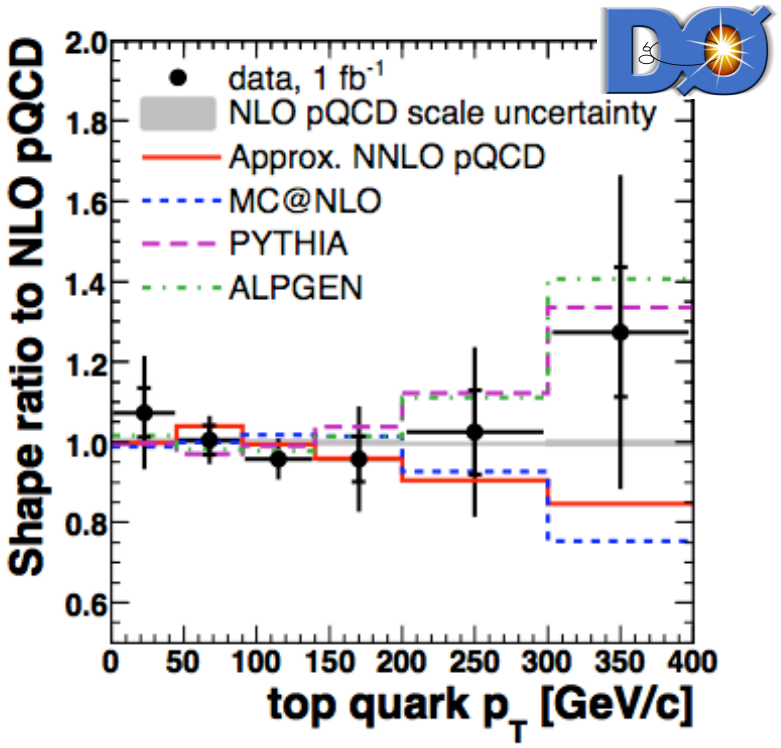
Best strategy for probing exotic Z'→ttbar models

Differential cross sections

Measuring differential cross sections is important:

- test for pQCD in finer details
- probes non-SM production mechanisms





Conclusions

Large integrated datasets allowed both CDF and D0 collaboration to probe finely the production of top quarks through strong interactions.

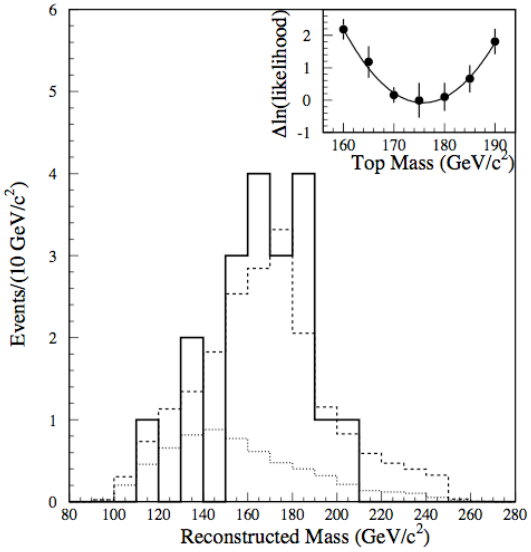
- Precison in integral ttbar xsection higher than theoretical NLO+NNLL
- Studies of differential ttbar xsections probe finely NNLO QCD and resonant production
- Comparison among channels allows exclusion of exotic decays (H+)
- Studyied ttbar + X production as background to new physics
- Measured the ttbar background to low mass Higgs search

All results consistent with the Standard Model so far!

backup

Top in 1995

Top quark discovered in pair production at CDF

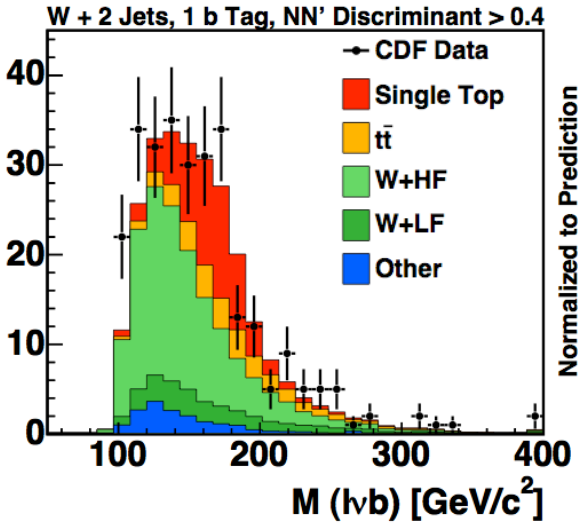


For many years, the only place where to study the top quark

Top in 2010

Single top challenges

- half the cross section as ttbar production
- about 100 times worse S/B ratio



Single top pocketed as well. Now exploring the energy frontier up to the TeV scale

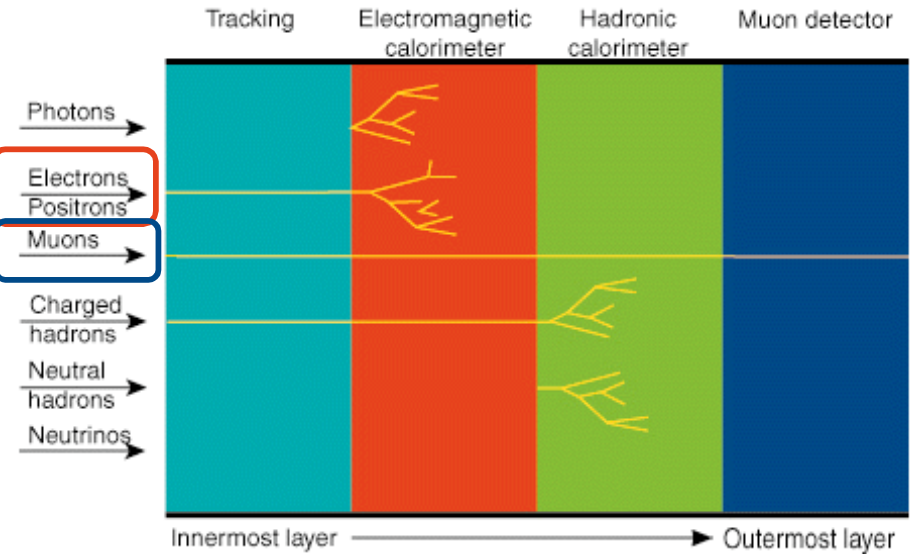
Charged leptons

Electrons:

- Track in central tracker *MATCHING* to em calo deposit *AND* shower max (reject π^0s) *AND* isolation (reject showers from quark)

Muons:

- track in central tracker *MATCHING* to stubs in muon chambers (if $|\eta|<1.3$)



Taus:

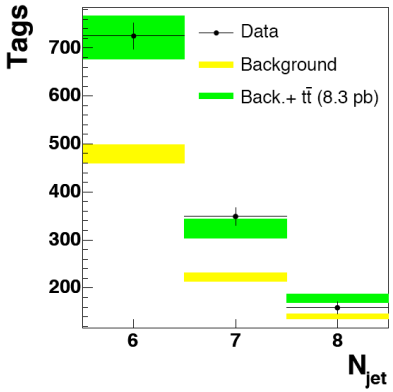
- No <u>explicit</u> τ ID here.
  Accept $\tau \rightarrow$ *leptons* through μ,e and $\tau \rightarrow$ *hadrons* through jets

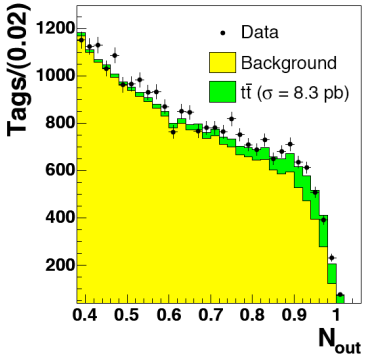
Strict requirement to ID a lepton and limited tracking coverage-> often you don't identify them!
Missing leptons can appear as jets(e,τ) or MET(e,μ,τ)!

Previously published results

Cross section measurement is first step as it requires background - done with 1fb^{-1}

Phys.Rev.D76:072009,2007



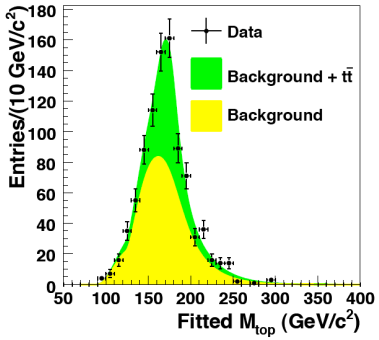


Biggest syst source

Source	Uncertainty (%)
Energy Scale	16.3
Parton Distribution Functions	1.4
Initial/Final State Radiation	2.9
Monte Carlo Modeling	1.1
Multiple interactions	2.5
Average number of tags	7.4
Estimated background	2.5
Integrated luminosity	6.0

clean sample of ttbar events, and background understanding, measure the top

$$\sigma_{t\bar{t}} = 8.3 \pm 1.0(\text{stat.})^{+2.0}_{-1.5}(\text{syst.}) \pm 0.5(\text{lumi.})\ \text{pb}$$



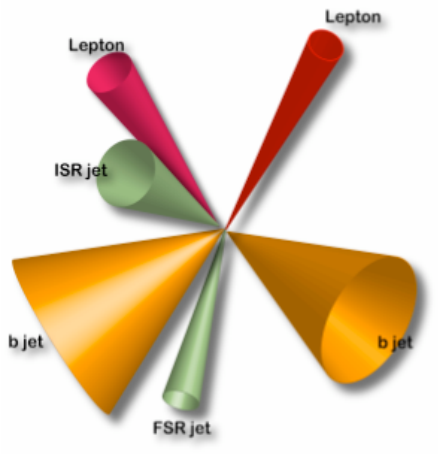
Source	Uncertainty (GeV/c^2)
Jet energy scale	4.5
Generator	1.0
b-jet energy scale	0.5
Parton Distribution Function	0.5
Background shape	0.5
Background fraction	0.5
ISR	0.5
FSR	0.5
b-tag	0.5
MC statistics	0.1
Template parametrization	0.1
Total	4.8

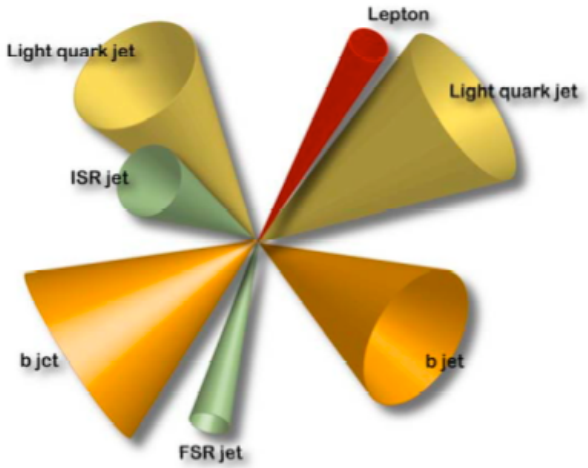
Biggest syst source

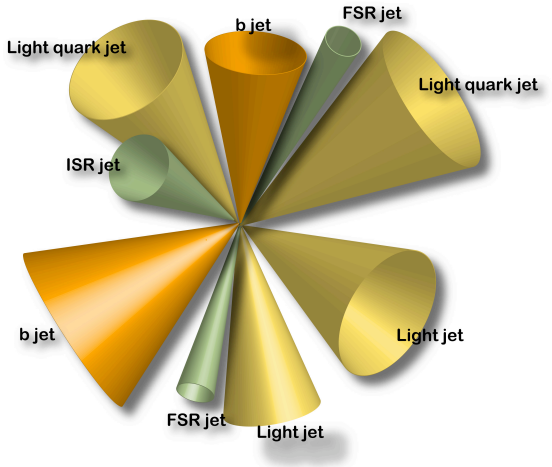
$$M_{\text{top}} = 174.0 \pm 2.2(\text{stat.}) \pm 4.8(\text{syst.})\ \text{GeV}/c^2$$

Good statistical power, BUT large uncertainty due to JES

A case example







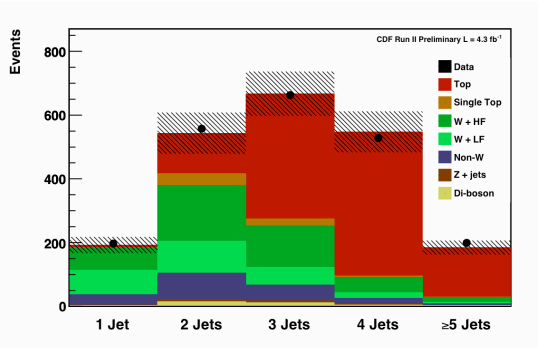
Are multivariate techniques safe?

Look at top pair production x-sec measurements in different *samples*, with different *techniques*

Semileptonic, Counting experiment

S/B~3/1

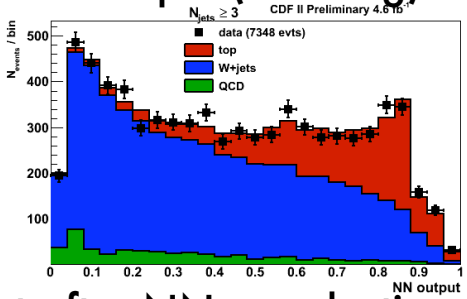
Conf. Note 9462



Semileptonic, Likelihood fit to NN output (no b-tag)

S/B~1/5

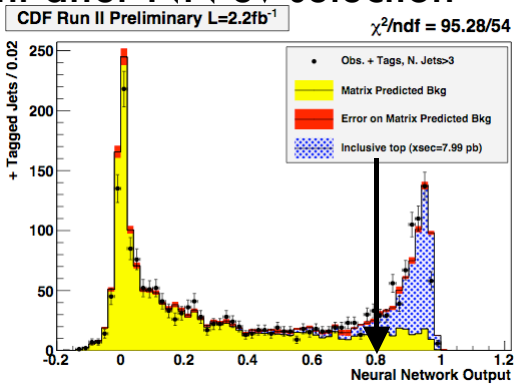
Conf. Note 9474



MET+jets, counting experiment after NN ev selection

S/B ~1/3 before NN cut

S/B ~4/1 after NN cut



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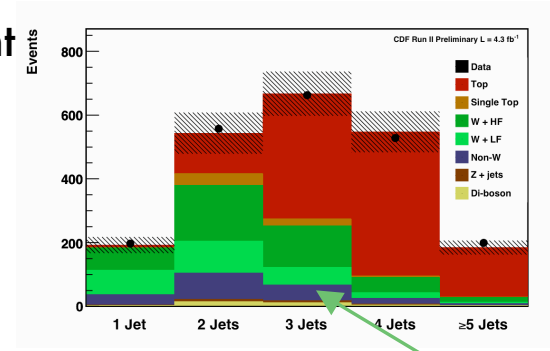

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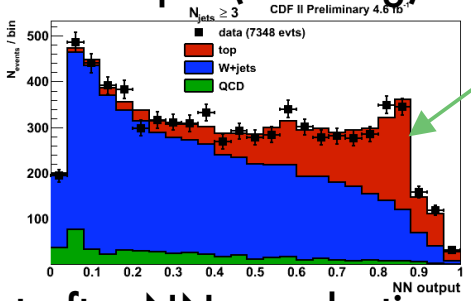

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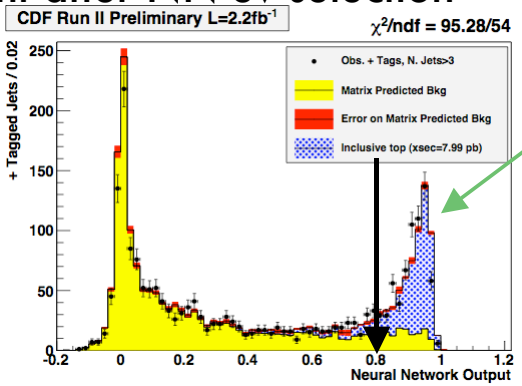
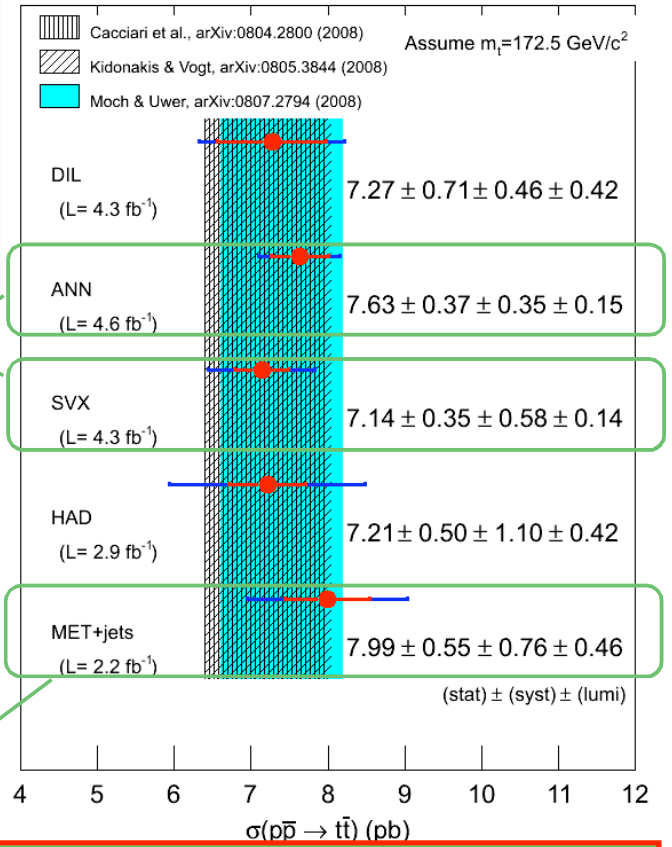
YES!





They all agree with each other and SM prediction: bad S/B ratio can be handled