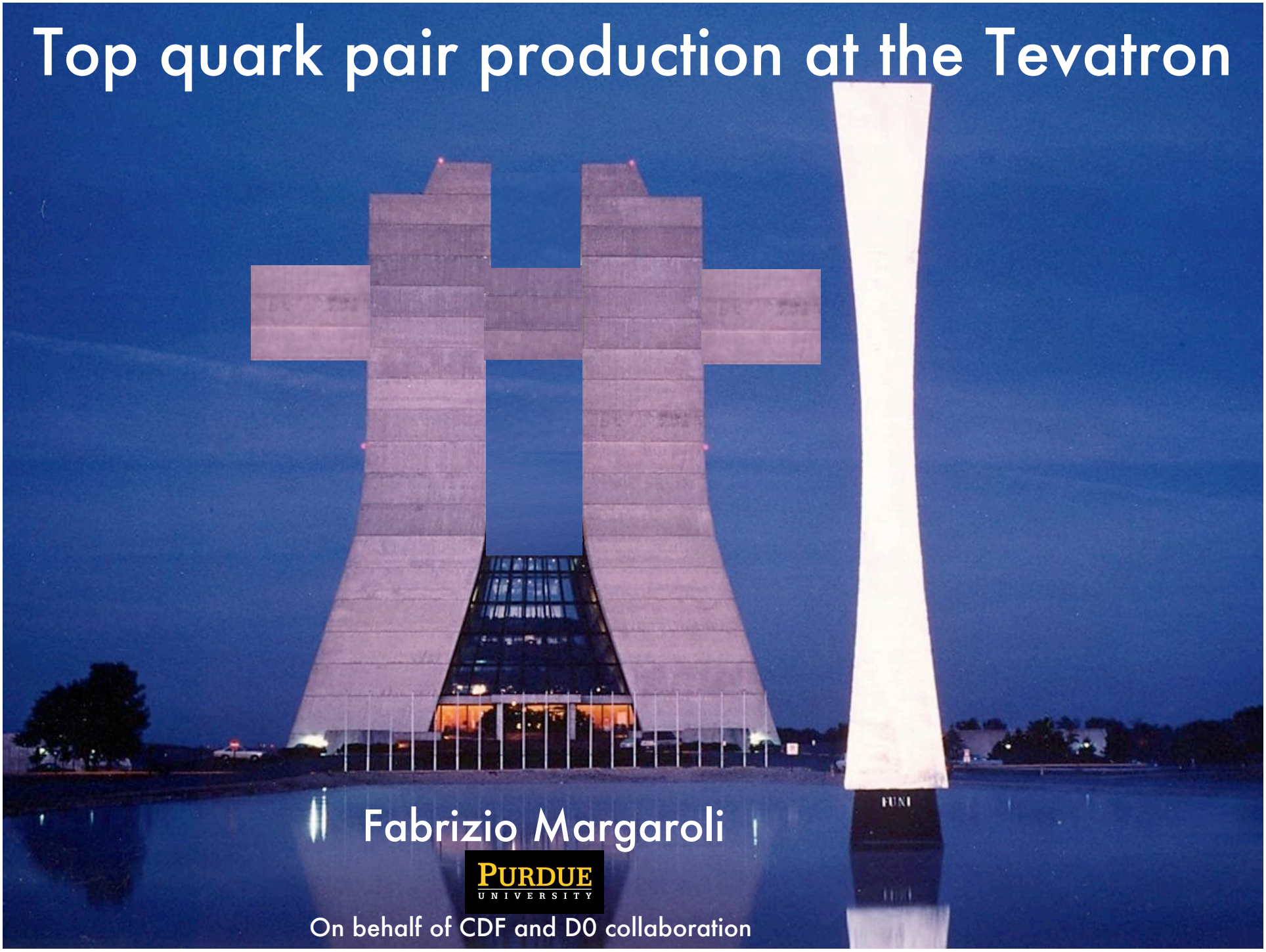
Top quark pair production at the Tevatron



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} arXiv:1007.3178

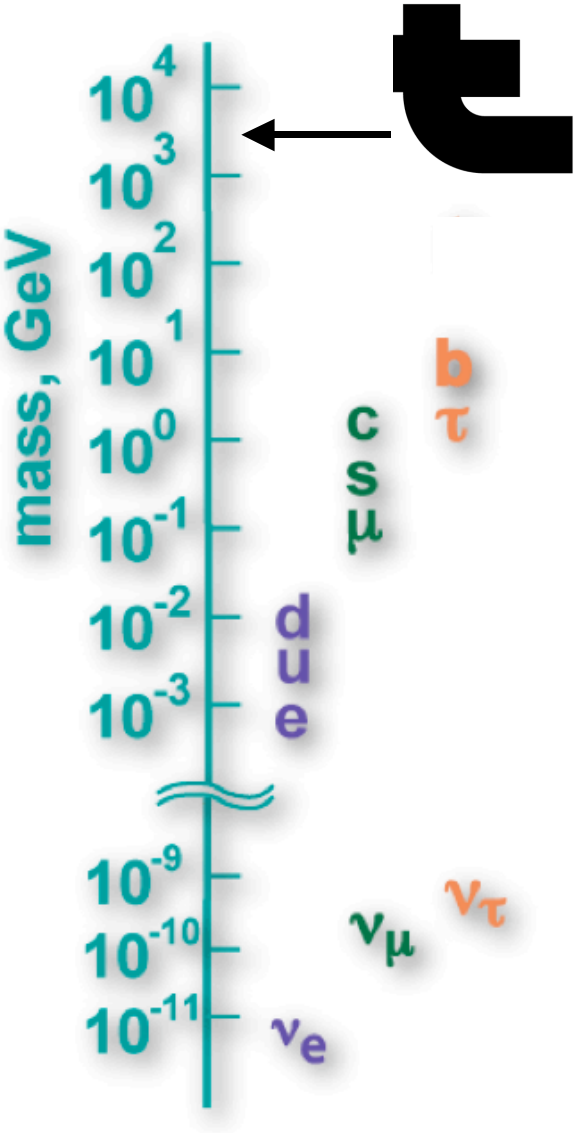
$$L_{\text{Yukawa}} = -\lambda \bar{\psi}_L \Phi \psi_R$$

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

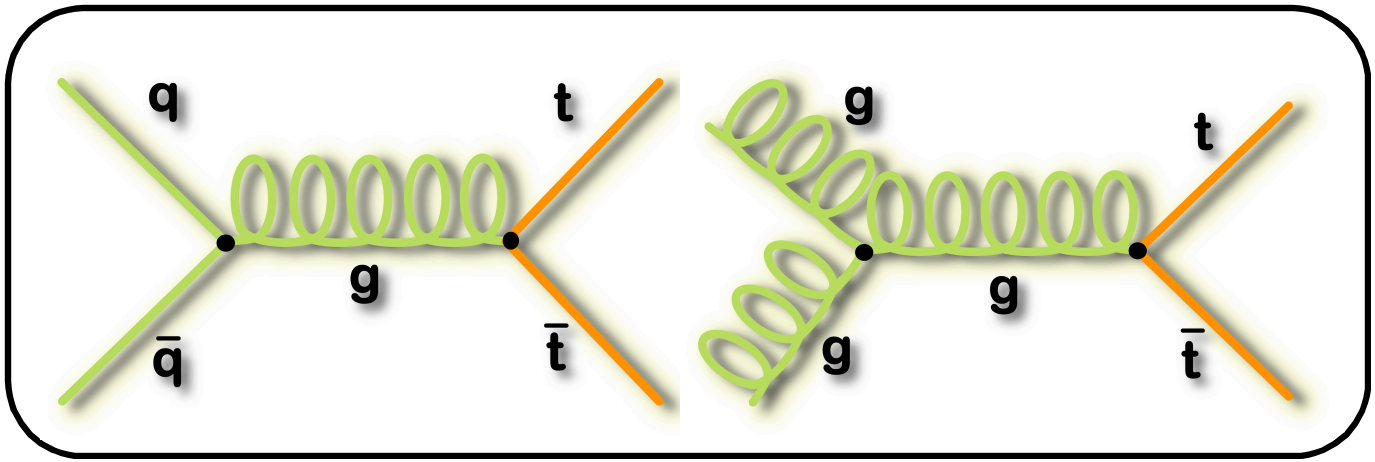
Lifetime shorter than hadronization time

→ only quark that decays before hadronizing



How?

Top anti-top production is the dominant mode at a hadron collider



σ_{tt}=7.5pb*

- QCD process: test pQCD NLO calculation
- First step in understanding selected top quark sample
- New physics in ttbar production or decays could appear as larger/lower σ_{tt}, or in different measured σ_{tt} in different channels

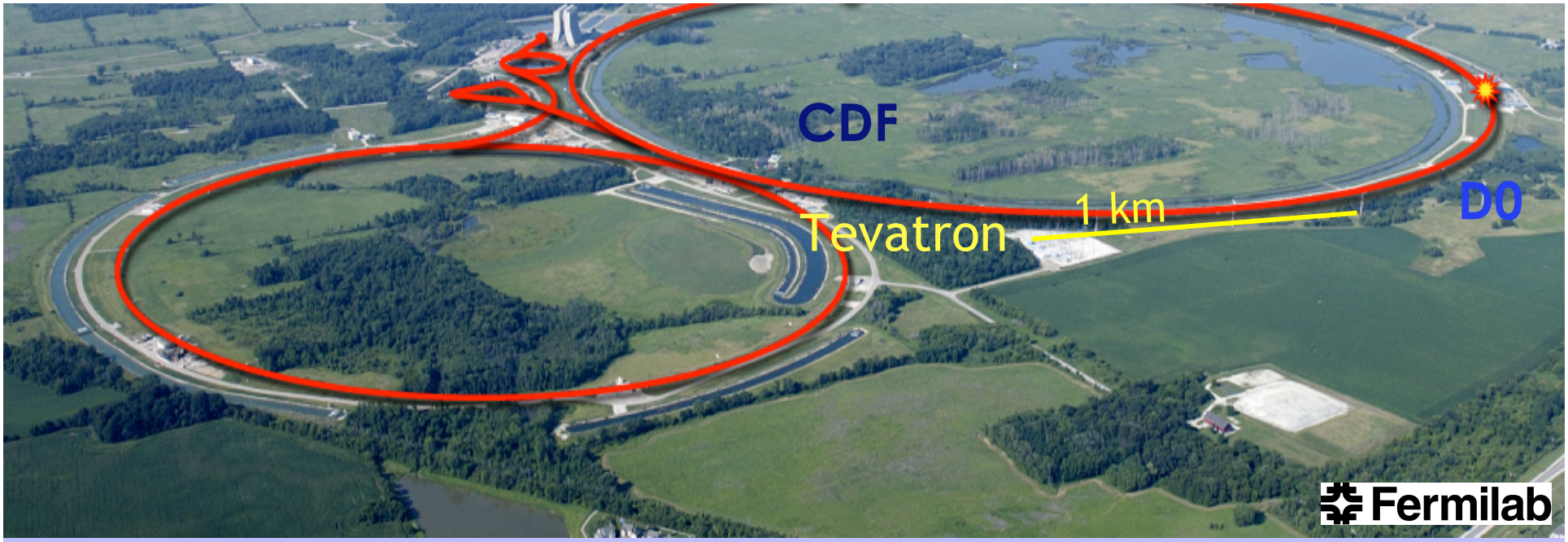
*M_{top}=172.5GeV, E_{cdm}=1.96TeV

Where?

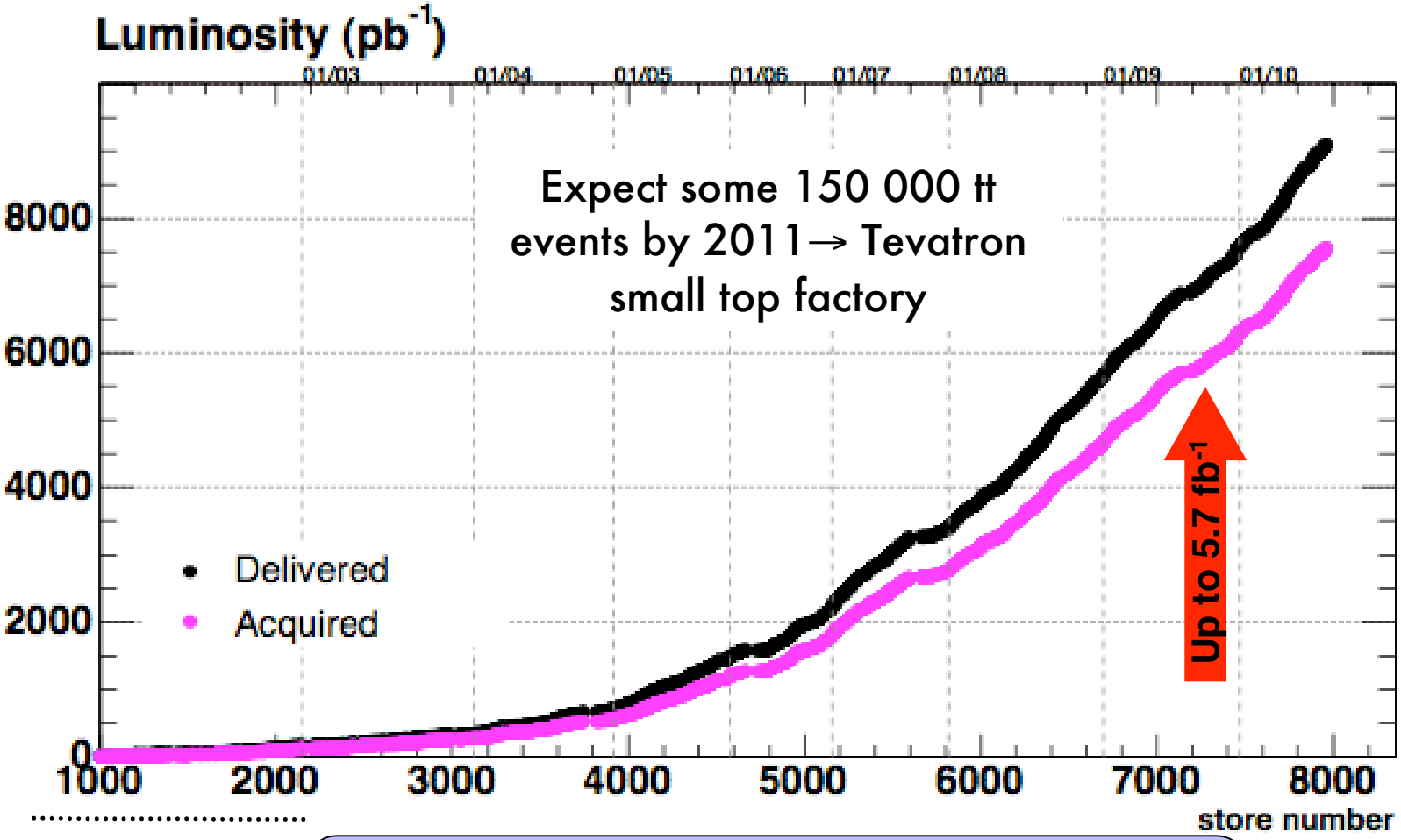
Fermilab's Tevatron Run II $p\bar{p}$ collider at 1.96 TeV, running since year '01. Currently performing very well:

- 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 in 1 in O(10^{10}) collisions at the Tevatron



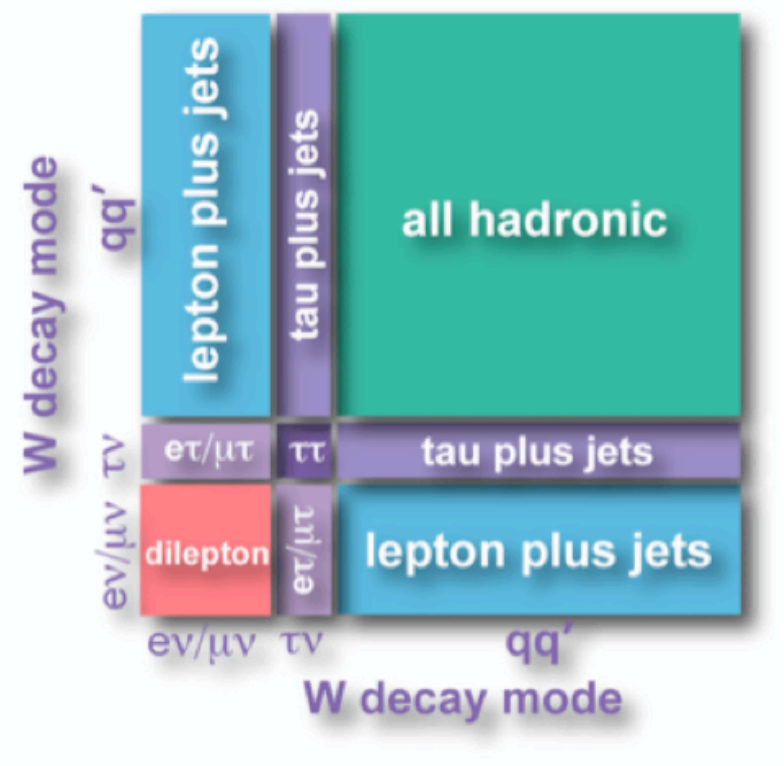
How many?



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

*CDF shown here
Similar numbers for D0

Pair production decay signatures



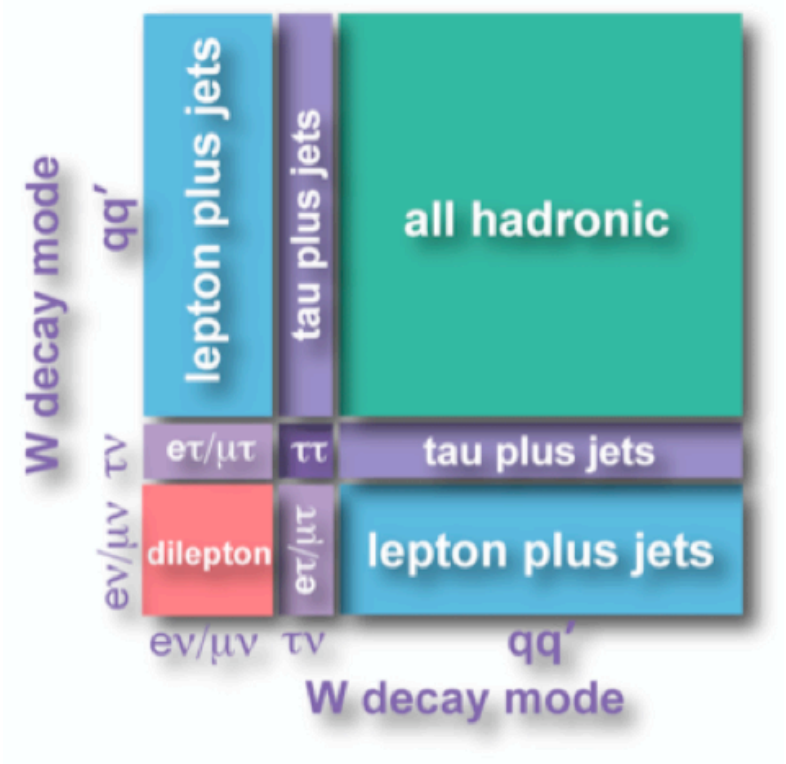
Total acceptance 9%

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

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

All hadronic
- highest BR(44%)
- Very large QCD background

Pair production decay signatures



Total acceptance 13%

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

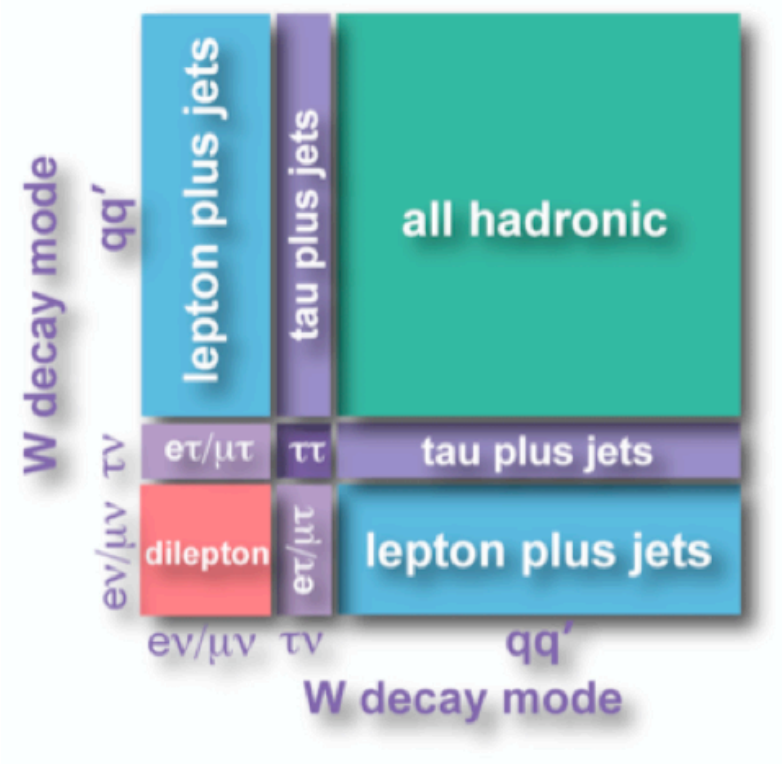
Dileptonic
- Highest S/B
- lowest BR(5%)

All hadronic
- highest BR(44%)
- Very large QCD background

Tau modes DØ
- explicit tau identification

MET + jets CDF
- Lepton+jets and dileptonic decays where electron/muon is not id'ed. Large acceptance to taus

Pair production decay signatures



Expect to analize more than 30 000 top quarks by 2011

Total acceptance 13%

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

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

All hadronic
- highest BR(44%)
- Very large QCD background

Tau modes DØ
- explicit tau identification

MET + jets CDF
- Lepton+jets and dileptonic decays where electron/muon is not id'ed. Large acceptance to taus

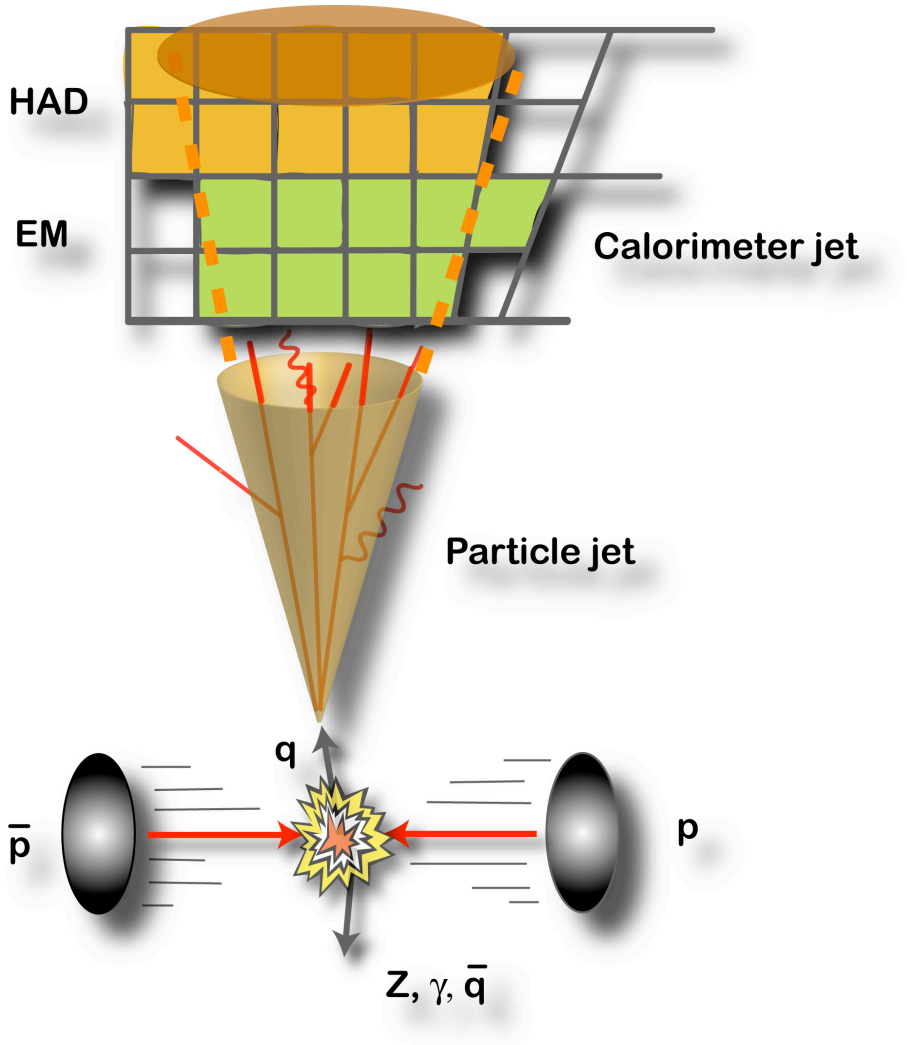
Jets

Quark/gluons hadronize and produce particle jets. B-jets identification very important for top phyiscs

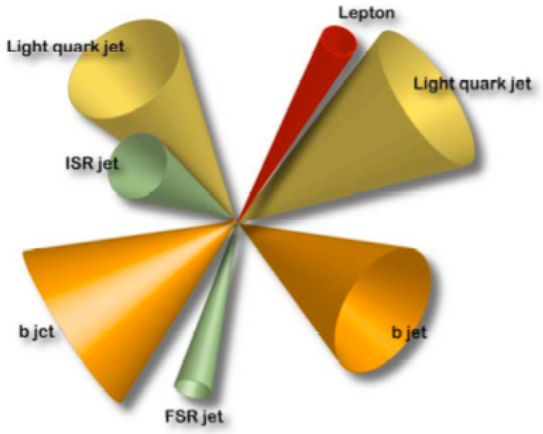
Seconday vertex: b-quark id'ed w long lifetime of the B mesons they form: identification through search of a secondary vertex within a jet:
b-tag eff: ~ 40%
fake rate ~ 0.5%

Neural Network for flavor separation

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

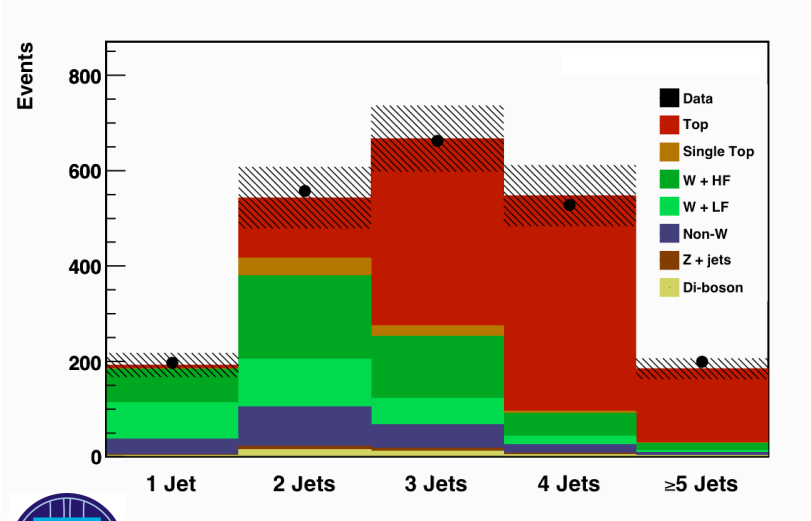


Lepton+jets b-tagged

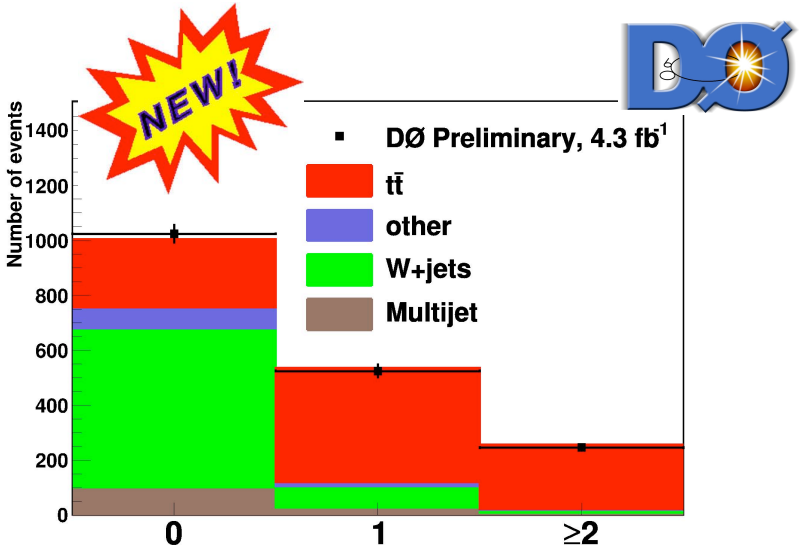


Counting experiment after background understanding:

- 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



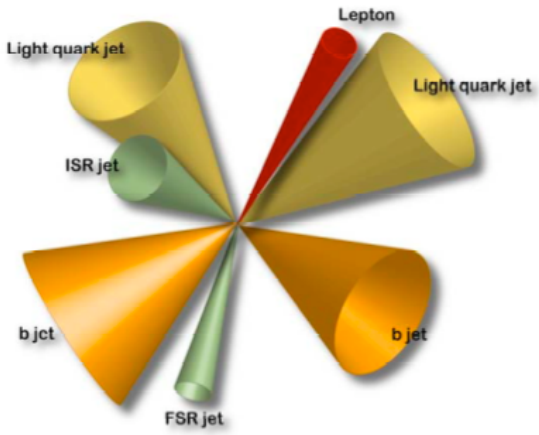
PRL 105 012001 (2010)



D0 (L=4.3fb^{-1}): $\sigma_{t\bar{t}}$ = 7.93 ± 0.98 (stat+syst+lumi) pb

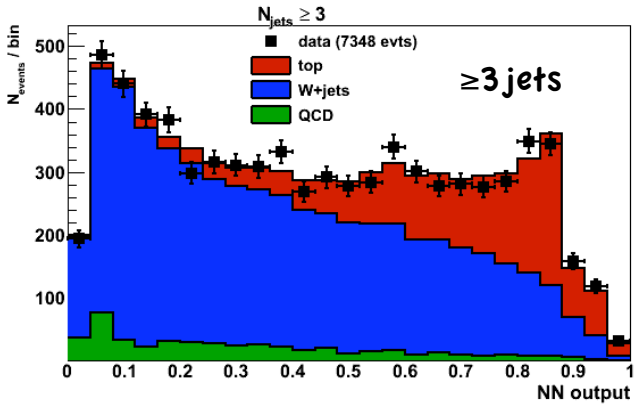
CDF(L=4.3fb^{-1}): $\sigma_{t\bar{t}}$ = 7.32 ± 0.71 (stat+syst+theory) pb

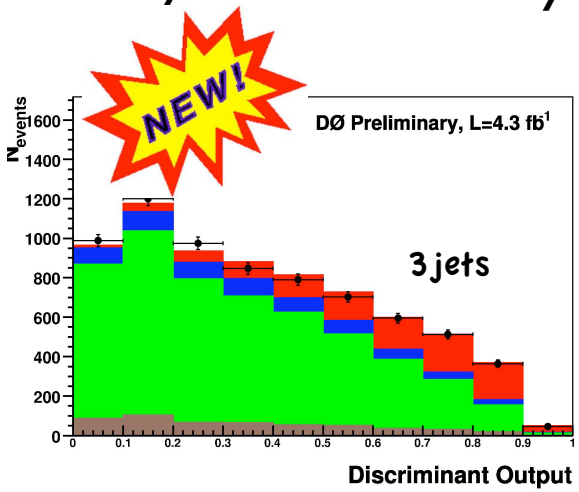
Lepton+jets topological

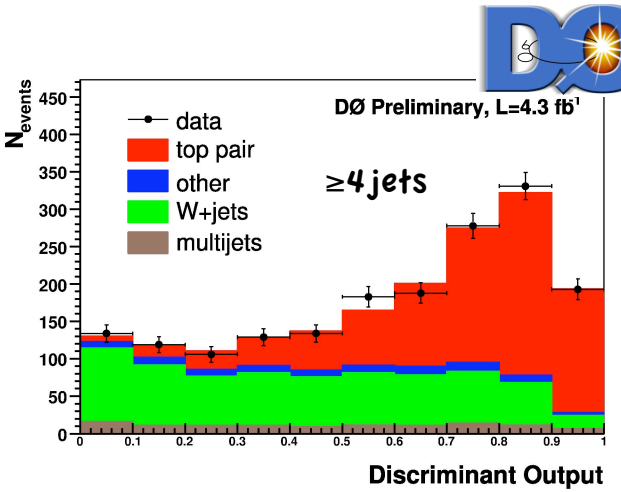


One step further: signal/background discrimination:

- 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





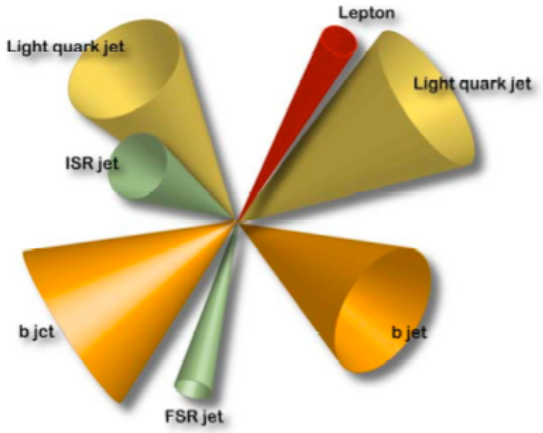


PRL 105 012001 (2010)

D0 (L=4.3fb^{-1}): σ_{tt} = 7.70 ± 0.75 (stat+syst+lumi) pb

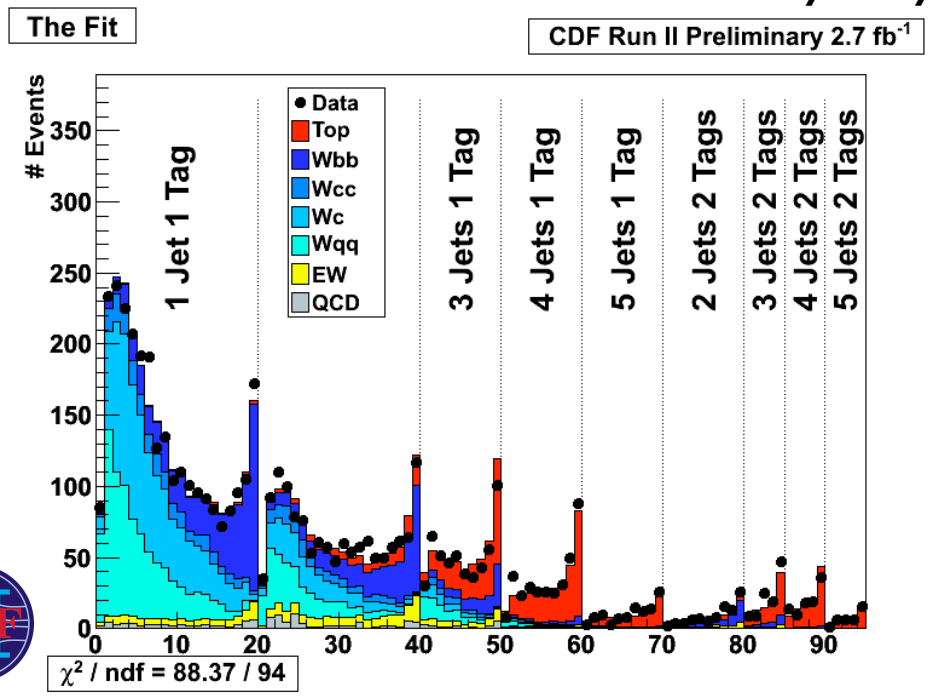
CDF(L=4.6fb^{-1}): σ_{tt} = 7.82 ± 0.55 (stat+syst+theory) pb

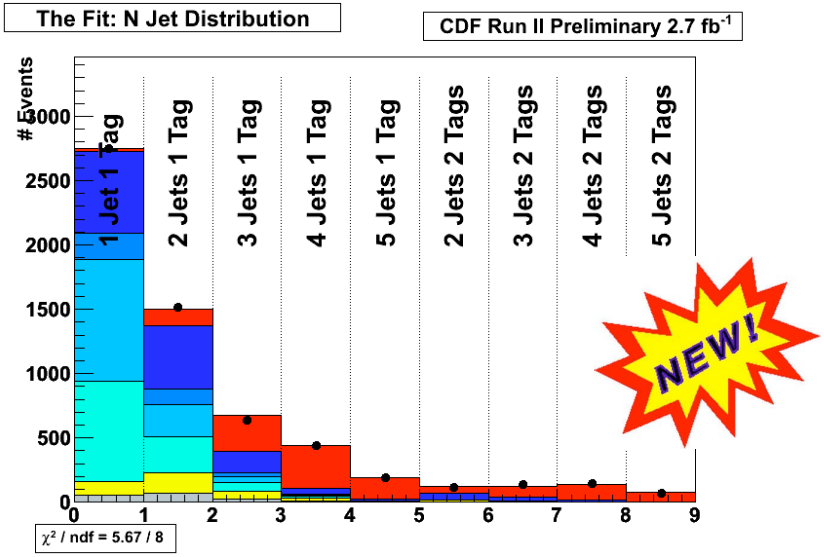
Simultaneous S and B kinematic fit



Looser event selection, better constraint on backgrounds

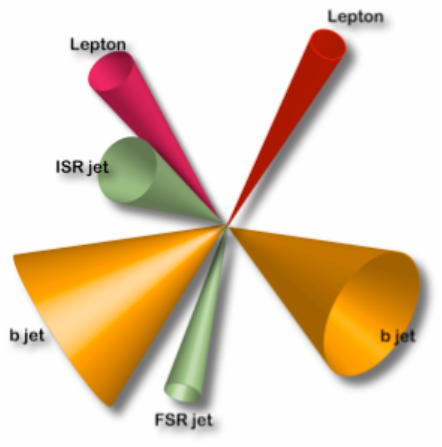
- Use events with 1lepton, ≥1jet, ≥1b-tag to measure signal cross section and background contributions.
- Templates: NN based flavor separator, N_{jets}, N_{btags}
- Fit simultaneously for σ_{tt} , W+heavy flavor fractions and systematics sources *in situ*
- Potentially very sensitive as more data is added





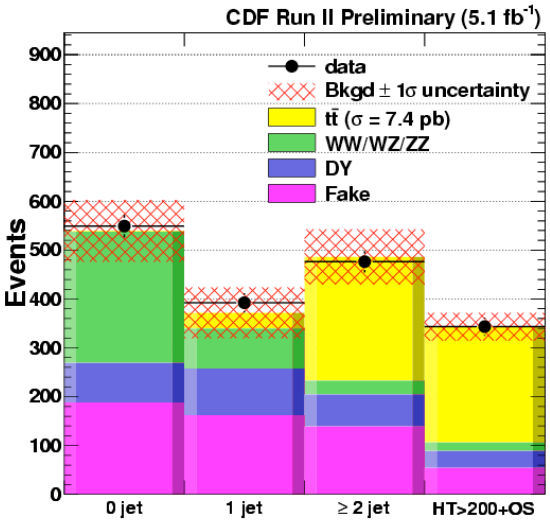
σ_{tt} = 7.64± 0.57(stat+syst)+0.45(lumi) pb

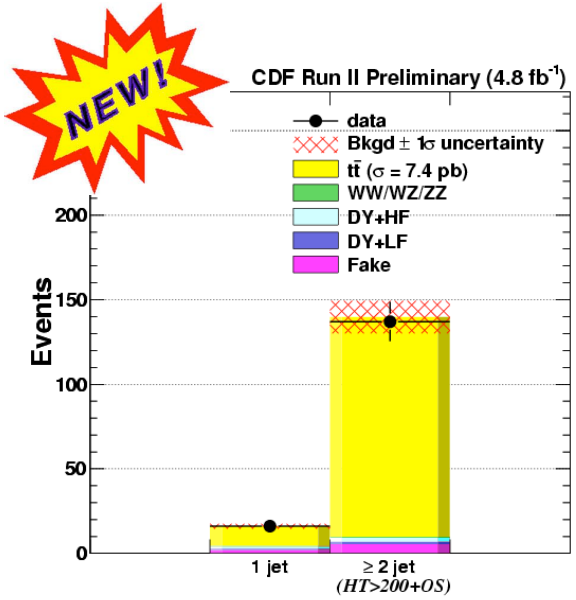
Dileptonic channel

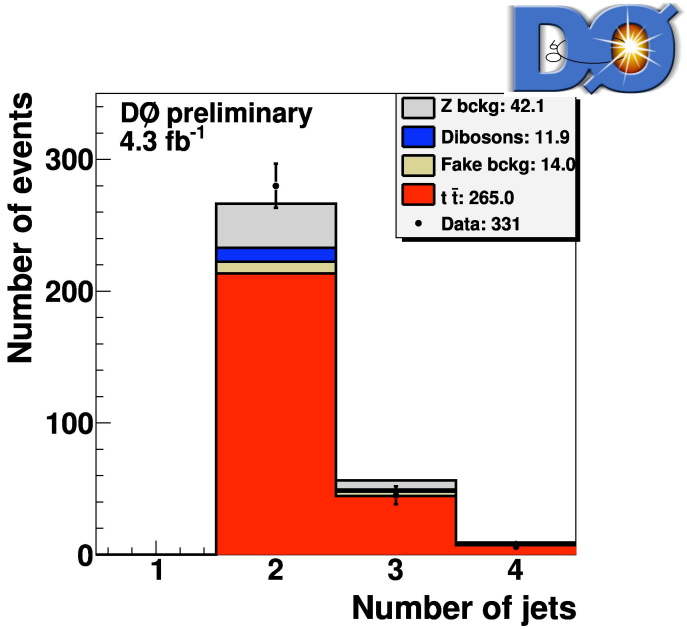


Signal/background discrimination

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



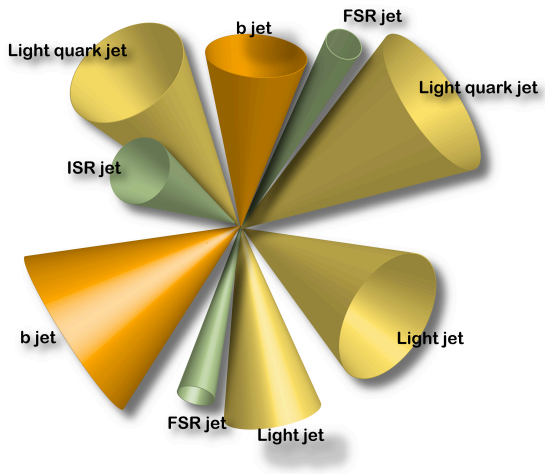




D0 (L=5.3fb^{-1}): σ_{tt} = 8.4 ± 0.5(stat) ± 0.9(syst) ± 0.7 (lumi) pb

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

All-hadronic channel

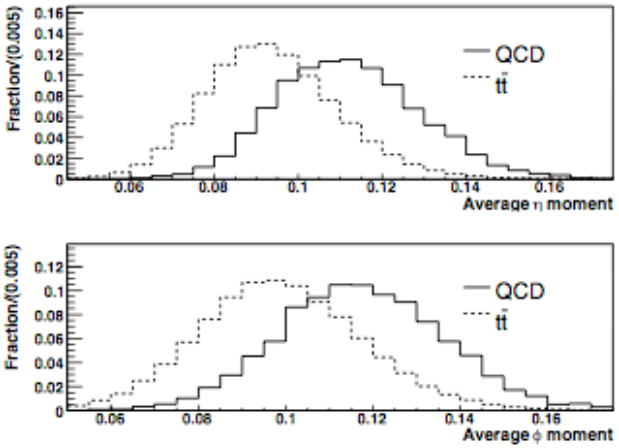


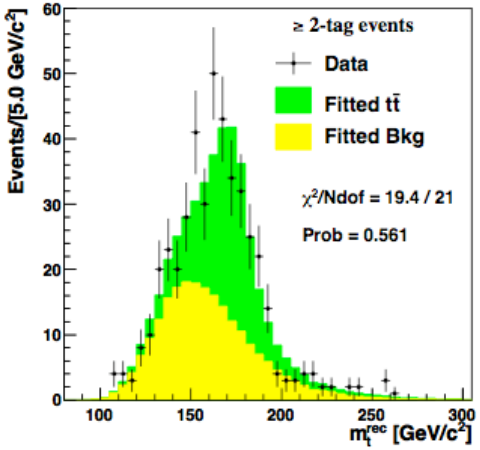
Both collaborations use b-tagging and multivariate techniques to isolate the signal from the overwhelming QCD background

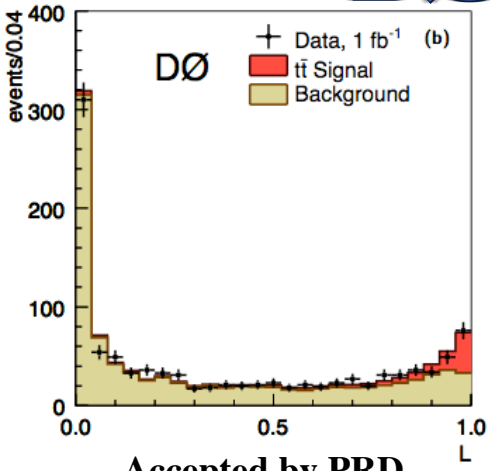
To measure the cross section:

- 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







Accepted by PRD

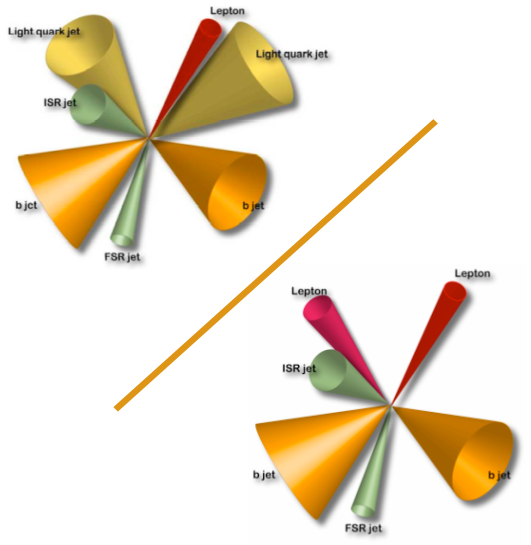
Exploiting distinctive quark-jet vs gluon-jet features

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

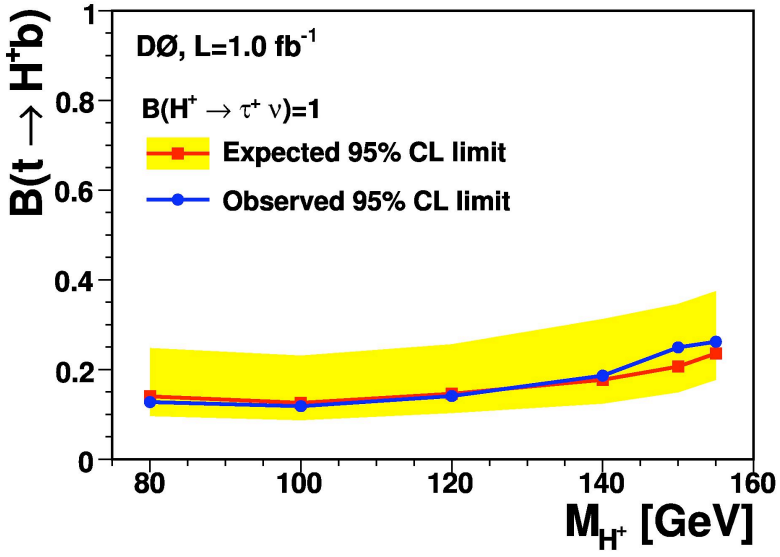
Charged Higgs search

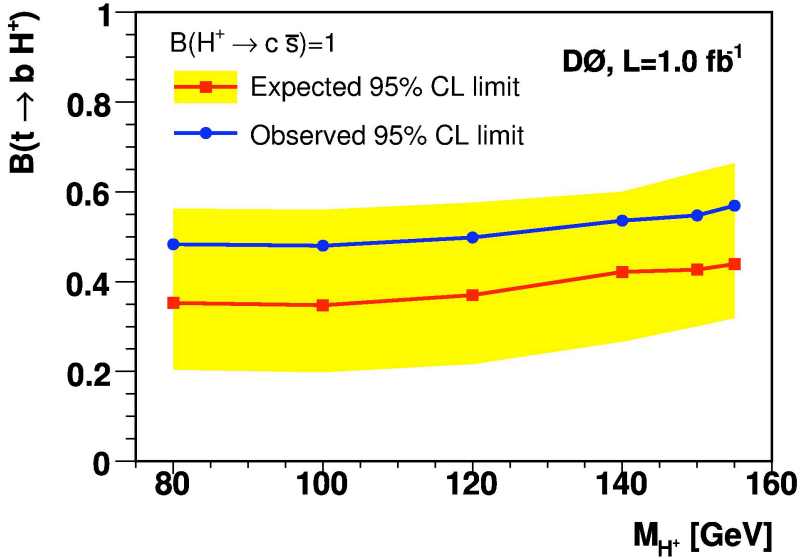


Cross section in different channels sensitive to new physics:

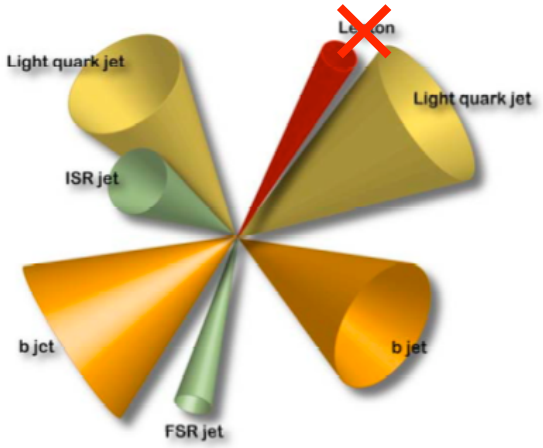
in SM extension with extended Higgs sector (like MSSM or HDM) $t \to H^+b$ can compete with $t \to Wb$. Strategy: compare number of events in ljets, ll and l+tau:

- $H^+ \to$ tau nu would increase ttbar events identified through taus
- $H^+ \to$ cs would give larger than expected lepton+jets events





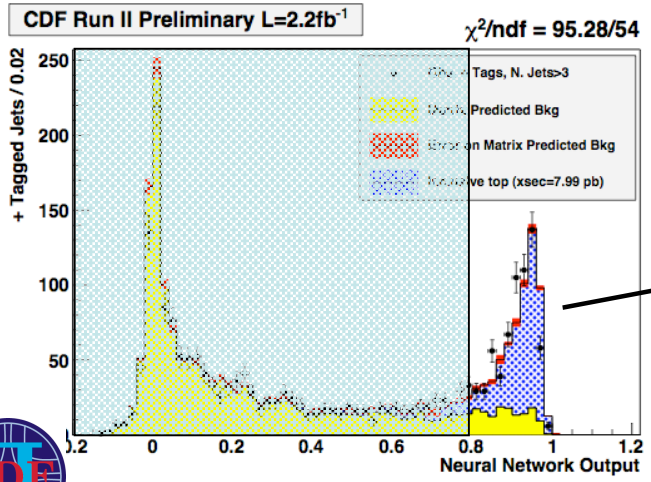
Missing energy plus many jets

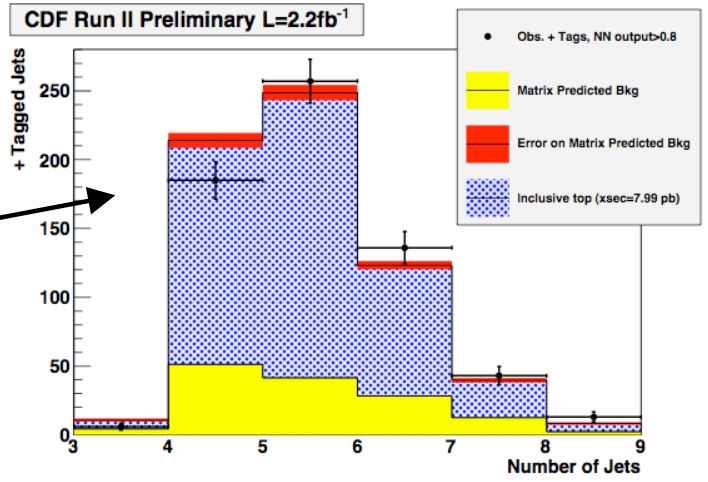


MET + jets: -alternative way to select tau channels, and recover unidentified e/mu (1/3tau, 1/3e, 1/3mu)

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





$\sigma_{t\bar{t}}$ = 7.99± 0.55(stat)+0.76(syst)+0.46(lumi) pb

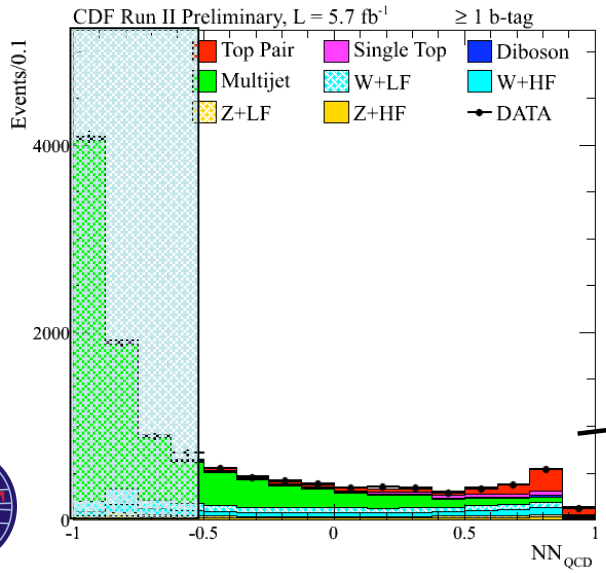
ttbar in MET+2b-jets

Many new particles can appear here

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

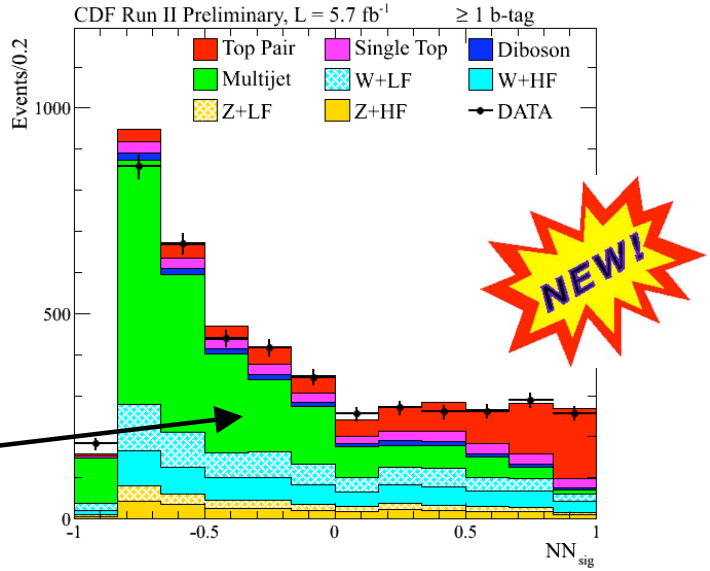
ttbar cross section measurement here is

- a test of the backgrounds for Higgs and NP
- independent from other measurements → can be combined



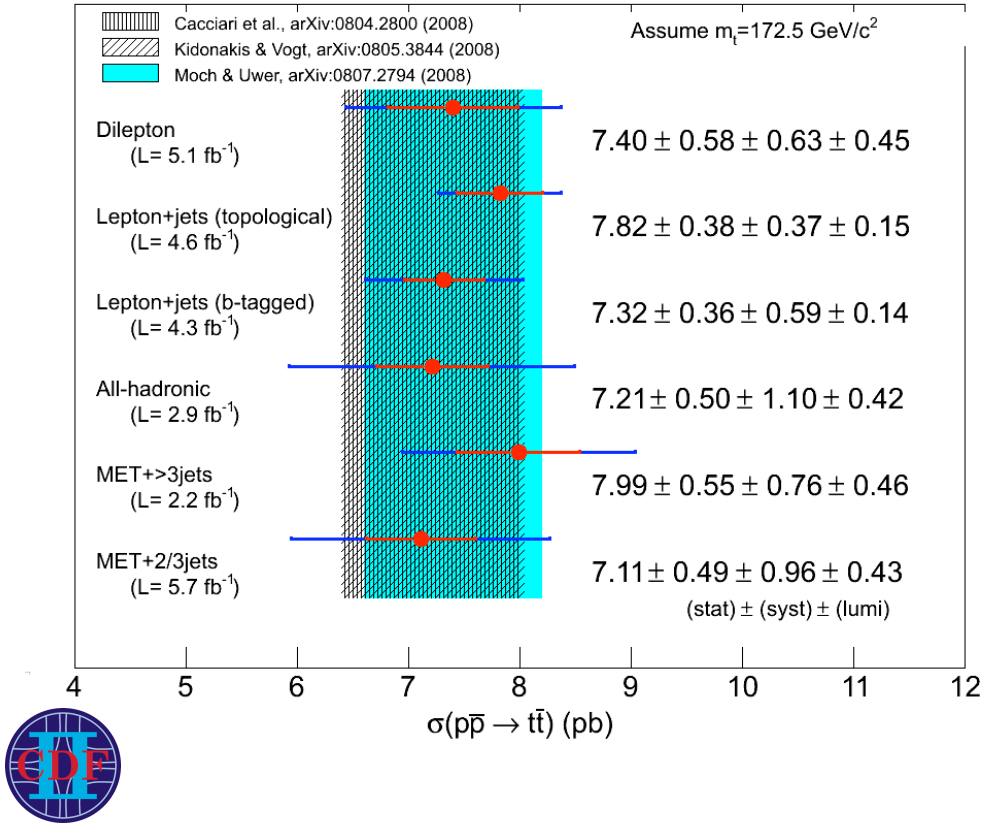
Using same strategy as in search for ZH→ννbb:

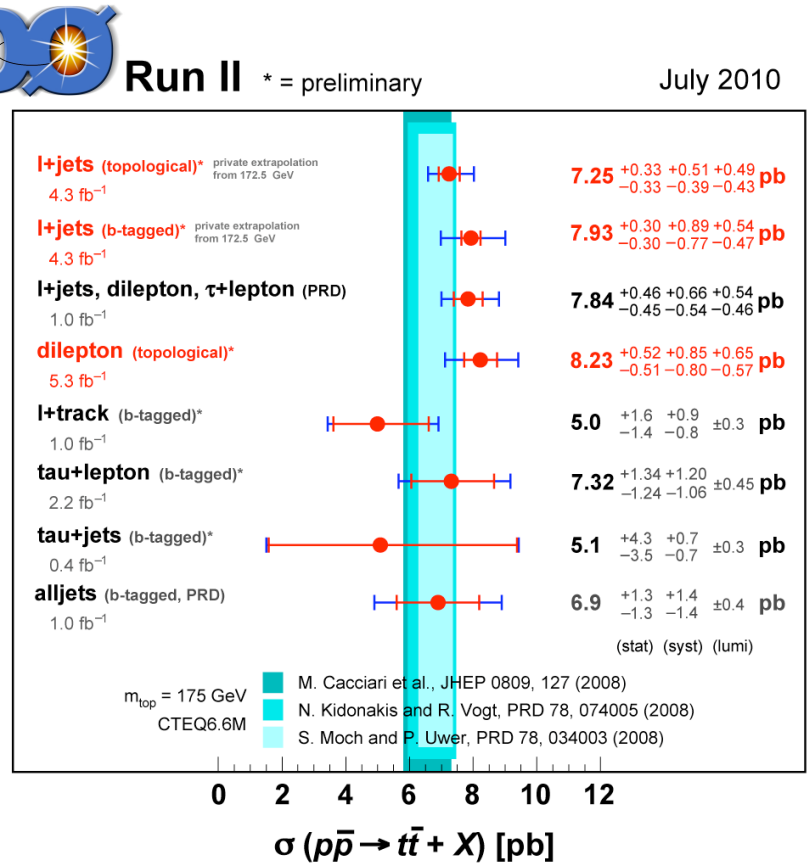
- Suppress overwhelming QCD background using multivariate technique (NN)
- Isolate the signal from remaining backgrounds, likelihood scan of NN output



$\sigma_{tt} = 7.1 \pm 1.1$ (stat+syst+lumi) pb

Total cross section: summary

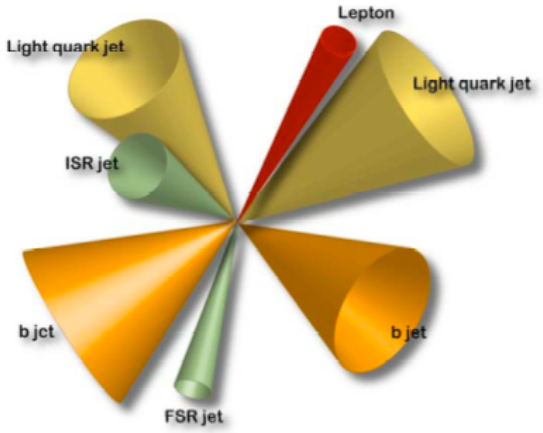




Good consistency among channels/experiments

Planning to combine CDF and D0 measurements to increase precision

ttbar+jets

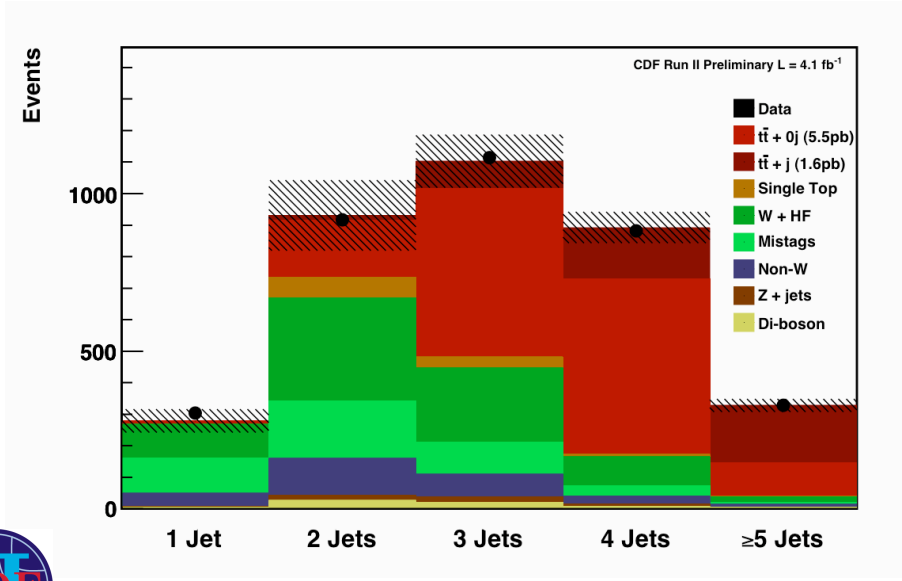


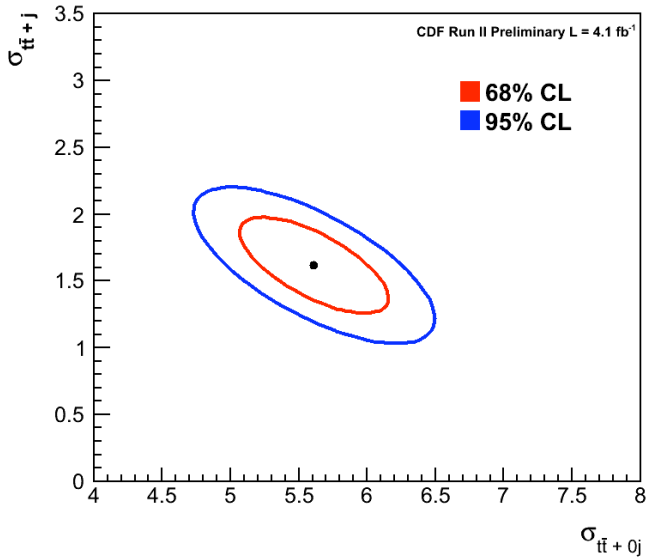
Test of QCD prediction, sensitive to NLO effects

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)



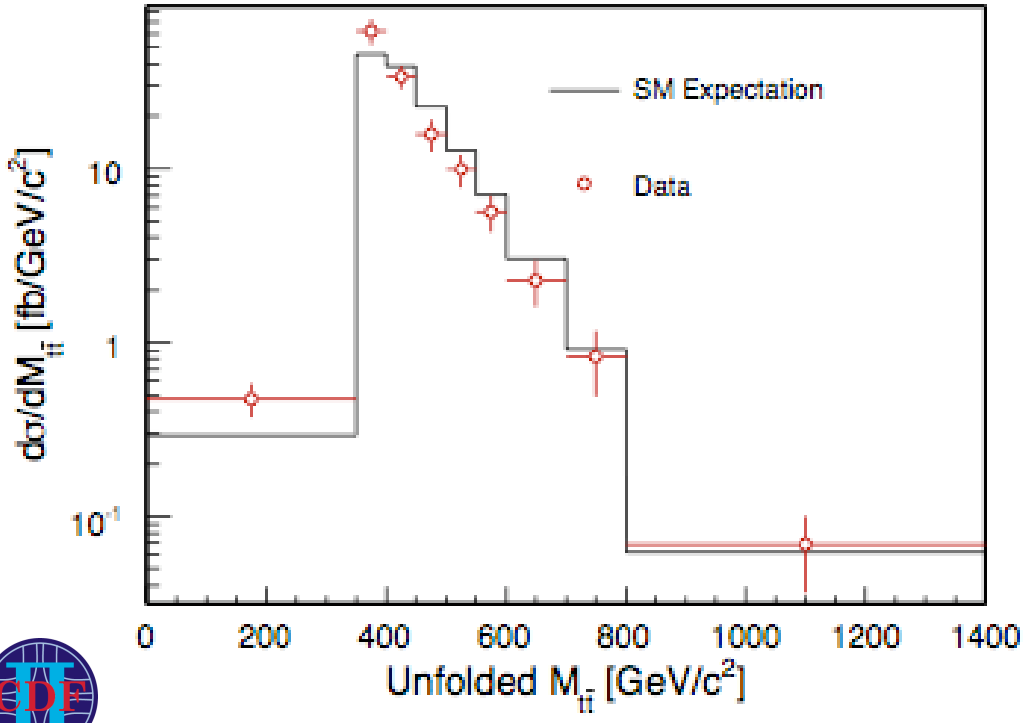


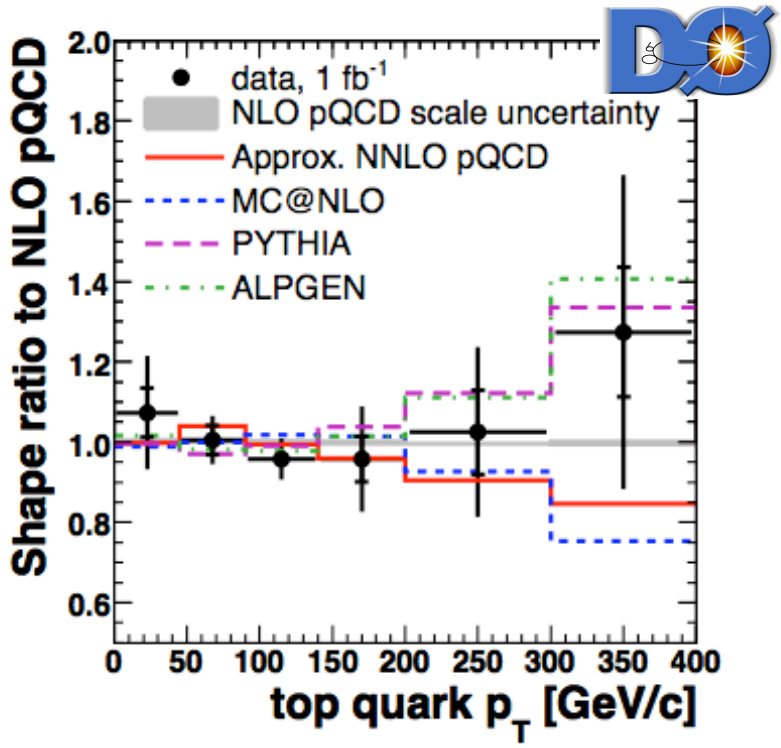
σ_{tt+jet} = 1.6 ± 0.2 (stat)+0.5(syst) pb

Differential cross sections

After measuring total cross sections, measuring differential cross sections is an important step:

- test perturbative QCD in finer details
- probes non-SM production mechanisms
- Lepton+jets mode best here for high purity and large statistics





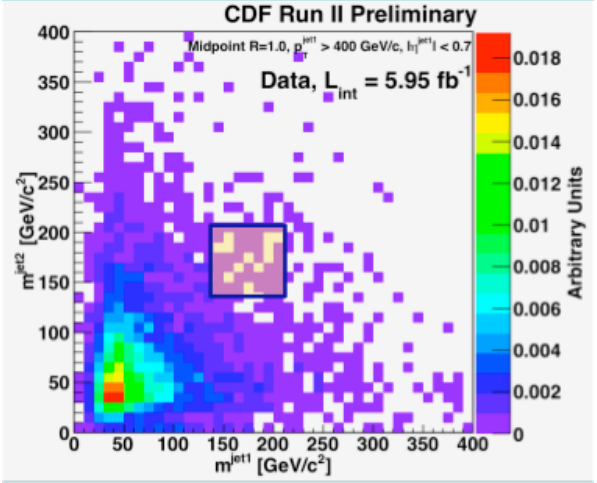
Search for boosted top quarks

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 → very different from jets from lighter quarks or gluons

Cross section for events with Pt(top) ≥ 400GeV is a handful of fb

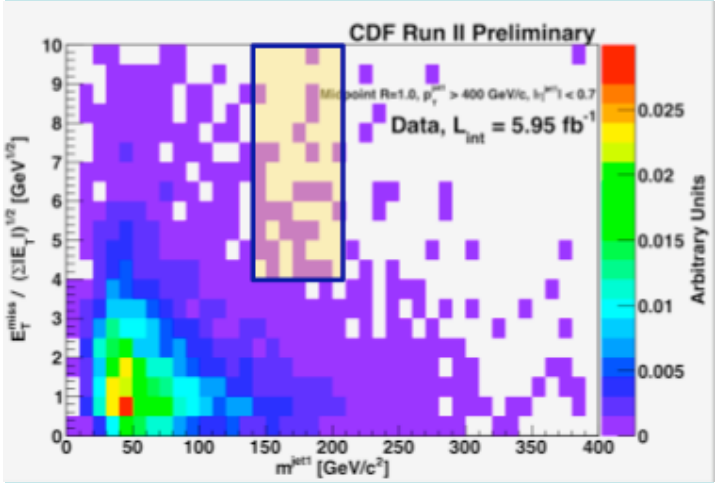
all-hadronic decays:
two tops with mass~175



(jet1 mass vs jet2 mass)

NEW!

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



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

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

Summary

- Measurement of the *total* cross section with the Tevatron large dataset allowed
  - understanding of the sample composition fundamental to perform top properties measurements *(mass, spin, charge, etc.)*
  - precision in xsection measurement *higher than (N)NLO*
  - comparison among channels to probe exotic decays *(H^+)*
  - estabilishing the ttbar background to new physics searches *(ttbar+X, resonant production through Z', low mass Higgs, etc.)*

- Studies of *differential* ttbar xsections probe in a finer way (N)NLO QCD and resonant production

- Searching *boosted* top quarks allows studies of jets substructure and estabilish tools for searching Higgs and New Physics at the Tevatron/LHC

Summary

- Measurement of the *total* cross section with the Tevatron large dataset allowed
  - understanding of the sample composition fundamental to perform top properties measurements *(mass, spin, charge, etc.)*
  - precision in xsection measurement *higher than (N)NLO*
  - comparison among channels to probe exotic decays *(H^+)*
  - estabilishing the ttbar background to new physics searches *(ttbar+X, resonant production through Z', low mass Higgs, etc.)*

- Studies of *differential* ttbar xsections probe in a finer way (N)NLO QCD and resonant production

- Searching *boosted* top quarks allows studies of jets substructure and estabilish tools for searching Higgs and New Physics at the Tevatron/LHC

Thank you!