Top Cross Section Measurement at CDF

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on behalf of the CDF Collaboration

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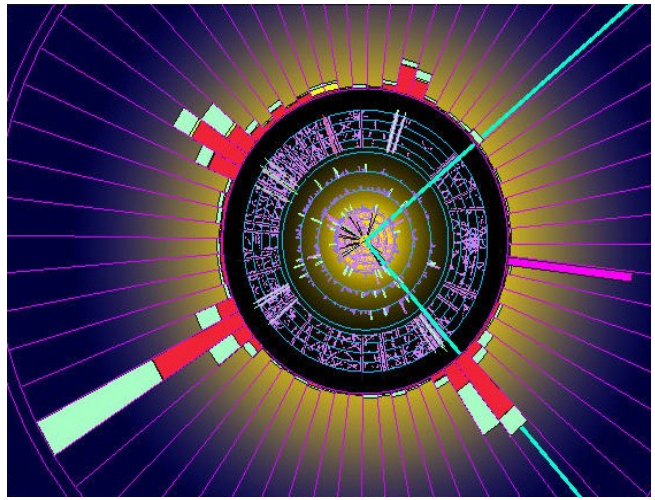
Top Quark Physics

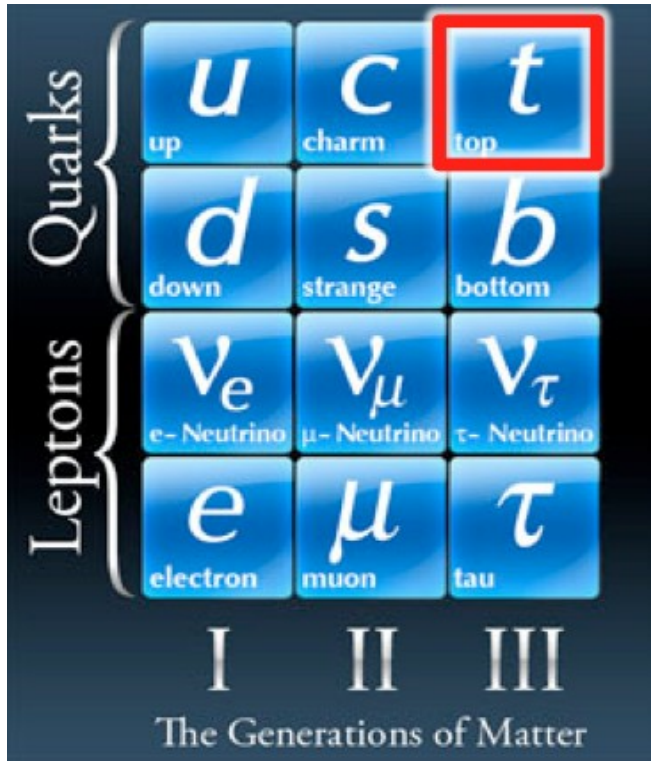
- *Top quark first observation at Tevatron in 1995*

- *Existence Required by the SM: Spin 1/2 fermion, charge +2/3, weak-isospin partner of the b quark*



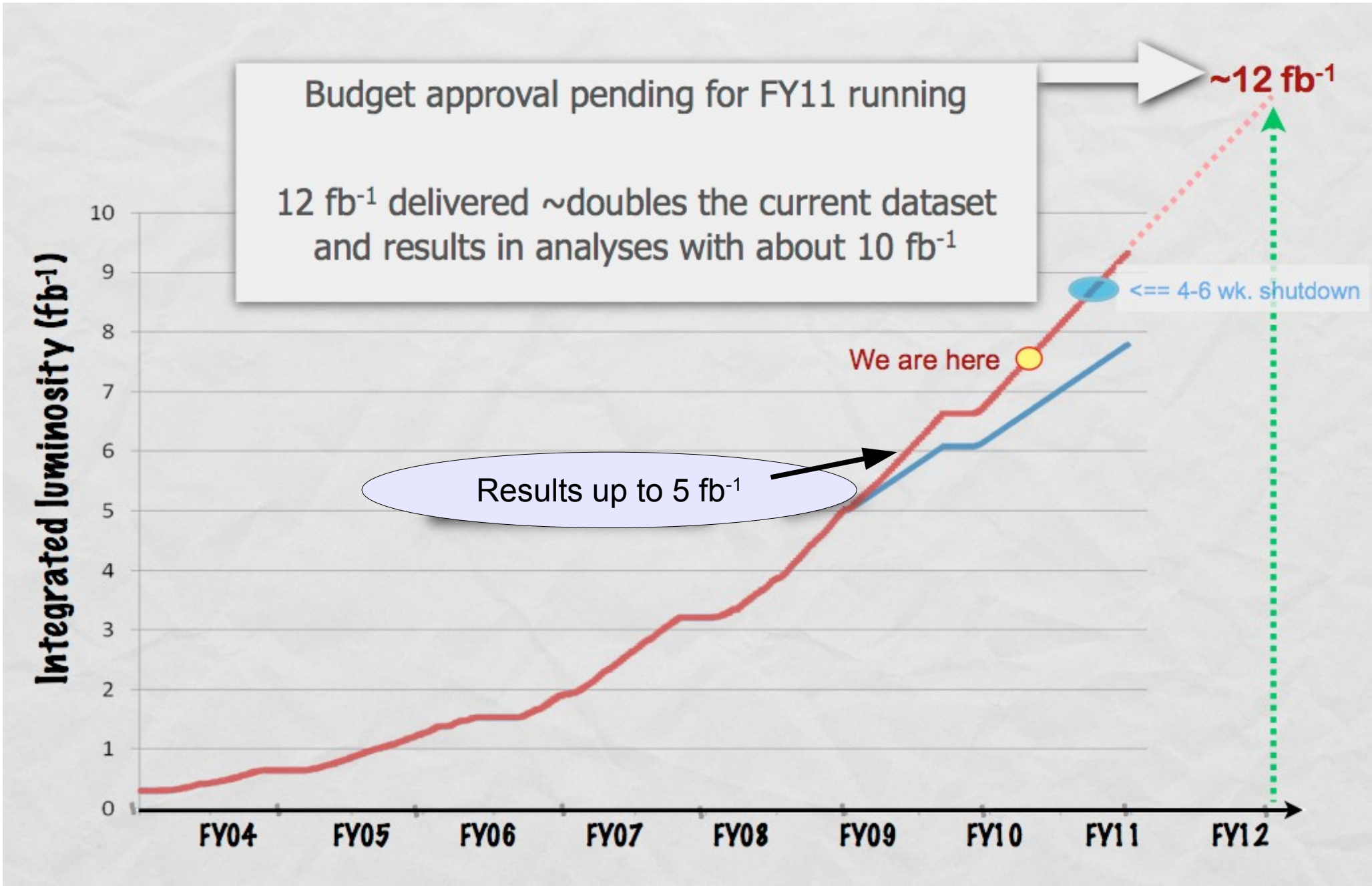
- *Mass: top is ~40x heavier than the bottom quark: only SM fermion with mass at the EW scale*
  Large contribution in virtual fermionic loops

- *Top decays before hadronization: $\Gamma \sim 1.4$ GeV $>> \Lambda_{QCD}$*
  Provide an unique opportunity to study a "bare" quark



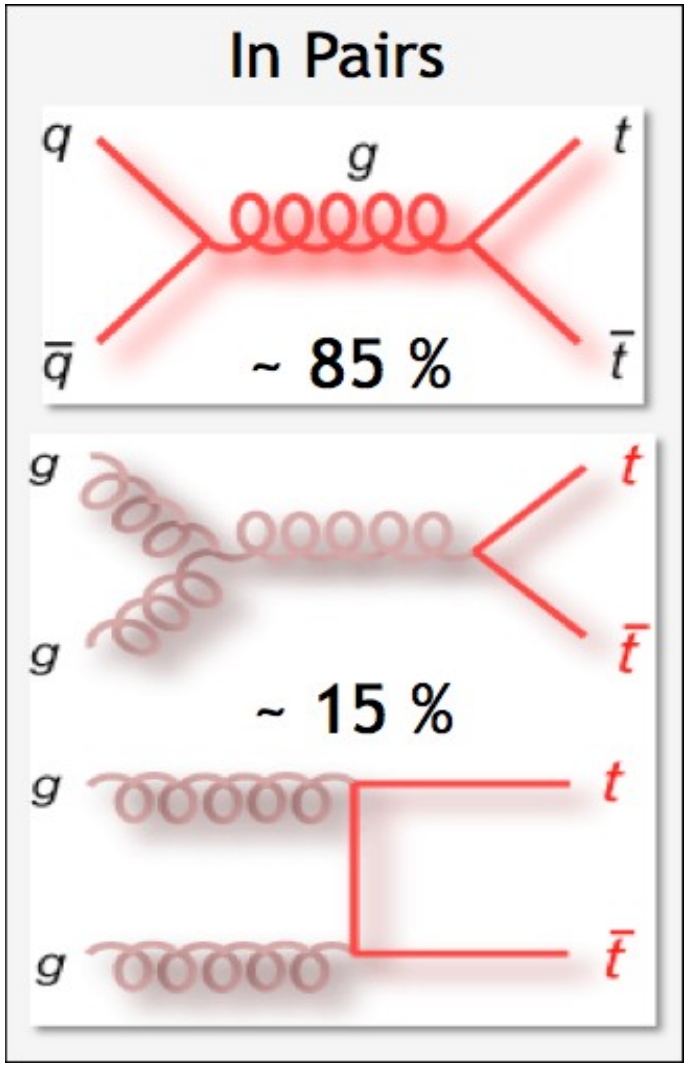
Is it the SM top?

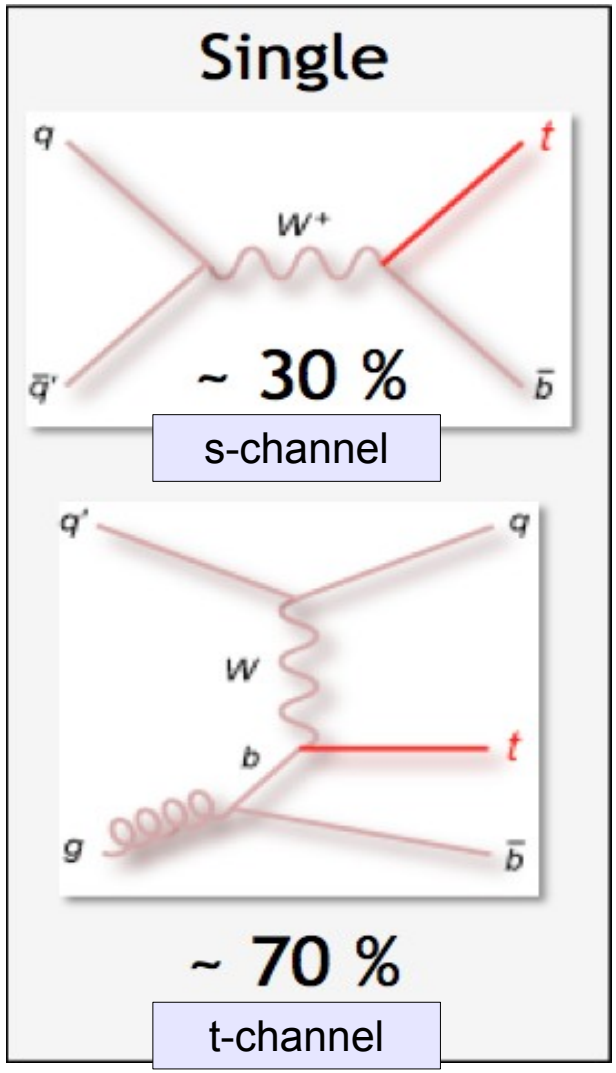
Tevatron Performance



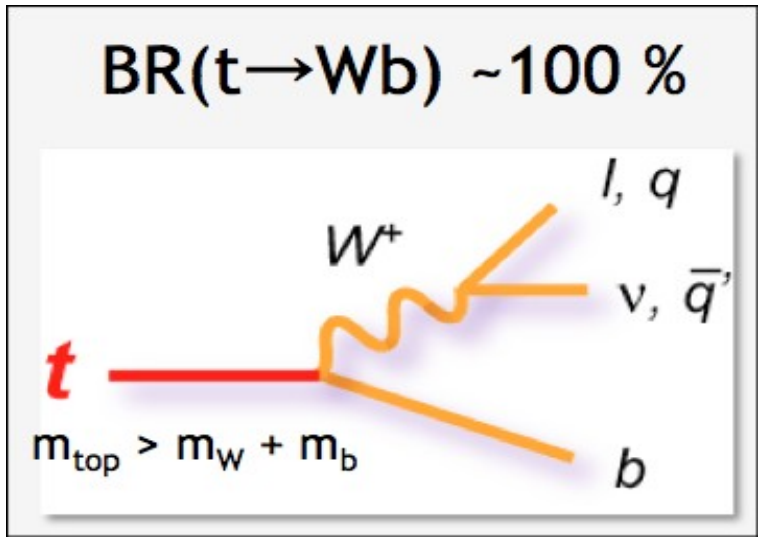
Top Quark Production at Tevatron

Top Quark Production





Top Quark Decay



$\sigma_{NLO} = 7.4\ ^{+0.5}_{-0.7}$ pb
JHEP 0809, 127 (2008)

$\sigma_{NLO} = 3.4 \pm 0.4$ pb
PRD 74, 114012 (2006)

(m_{top} = 172.5 GeV)

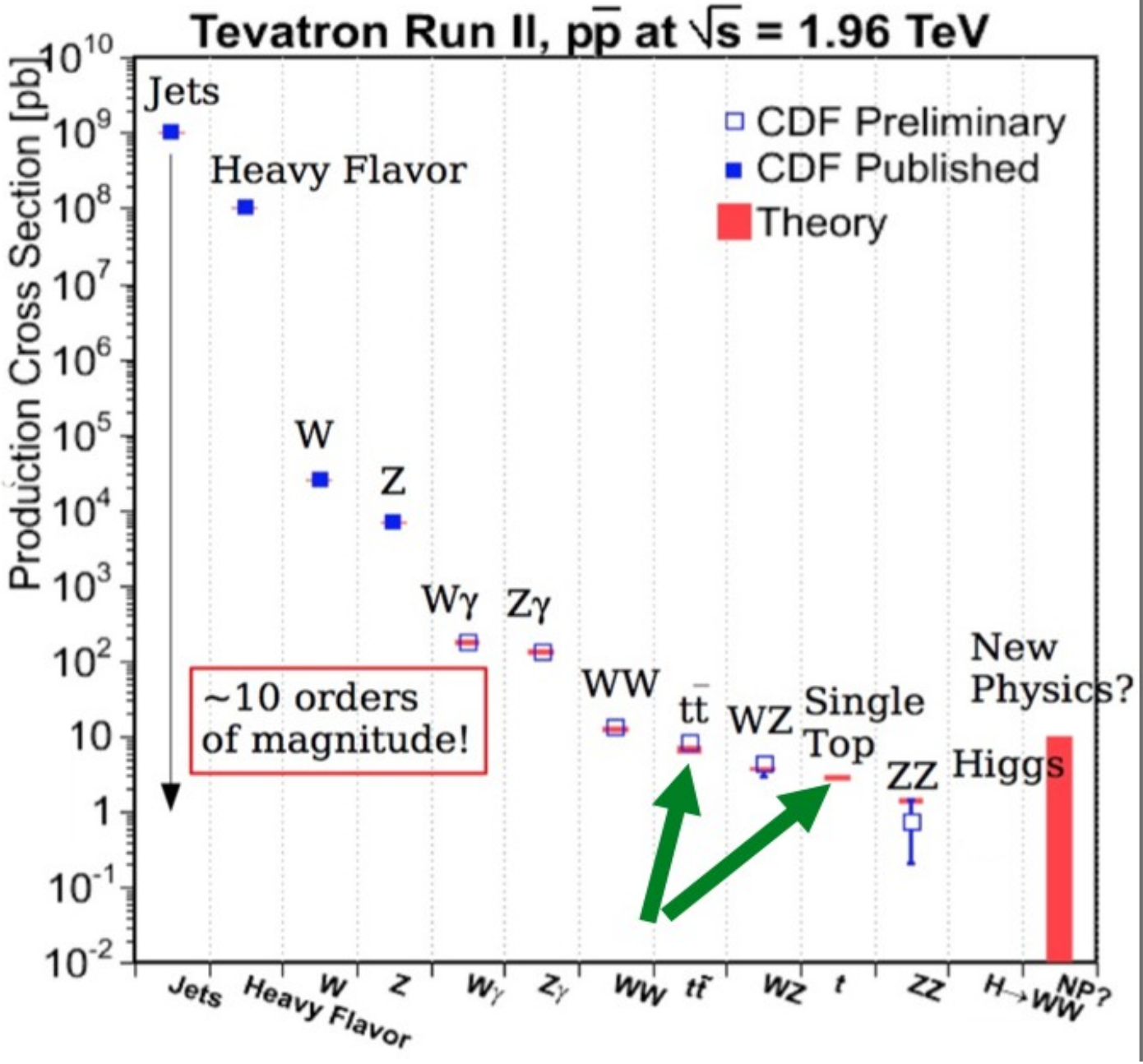
Top Quark Production at Tevatron

Top quarks are rare!

Small cross section:
only 1 top pair in 10 billion inelastic collisions
→ for an integrated luminosity of ~1 fb^{-1}
around 7000 top pairs and 3500 single tops are expected

Other processes appear as background...

...makes Single top especially difficult



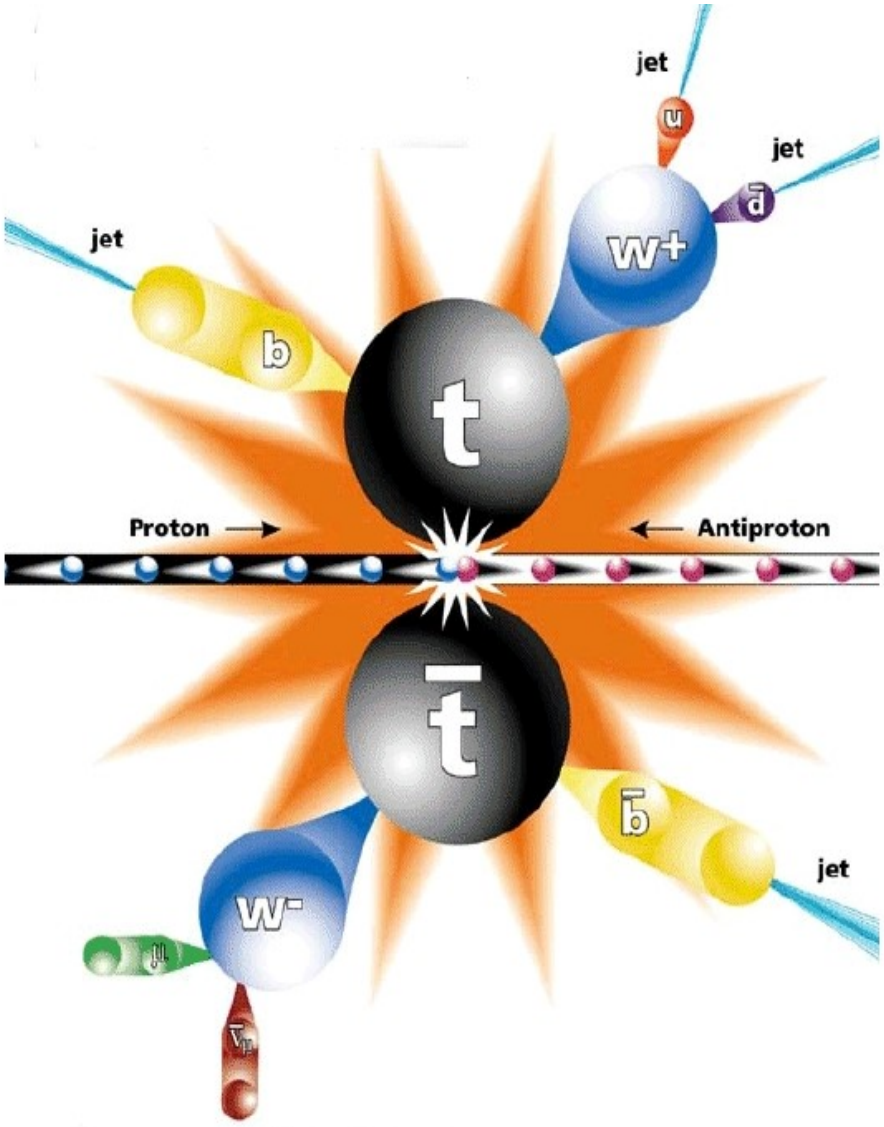
σ_{ttbar} is an inclusive quantity that allows:

- test the SM : compare the experimental measurement with the QCD NLO prediction
- measuring σ_{ttbar} is first thing you have to do before studying other top properties
- study clean top samples

Is also a probe to new physics (Massive gluons, Z', ...):

- anomalous ttbar production rate
- compare cross-sections in different top decay channels

Allows careful evaluation of background for Higgs and new phenomena searches



Event counting or
fit of discriminating
variable shape

Number of expected
background events
Using Monte Carlo or data

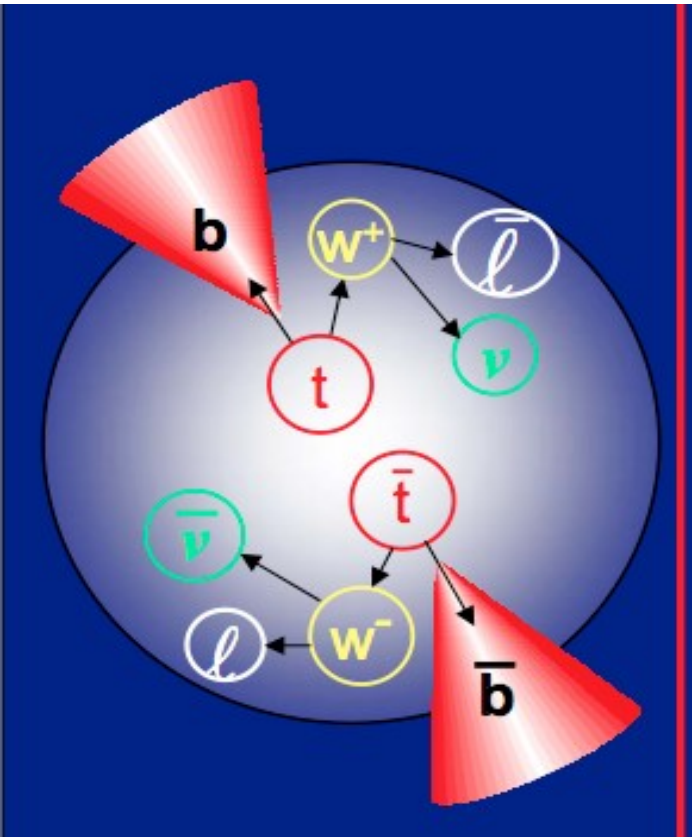
$$\sigma_{ttbar} = \frac{N_{observed} - N_{background}}{\varepsilon_{ttbar}(m_{top}) \cdot L}$$

Signal selection efficiency
using ttbar Monte Carlo samples
Pythia or Alpgen

Recorded luminosity
Channel dependent

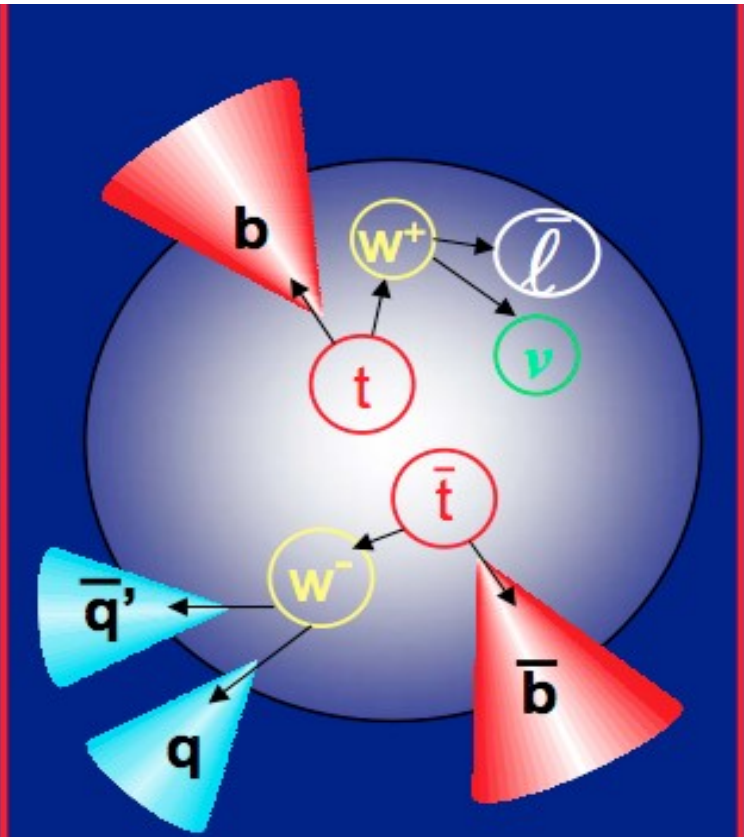
Top Pair Production Signatures

Dilepton (e or μ) 5%



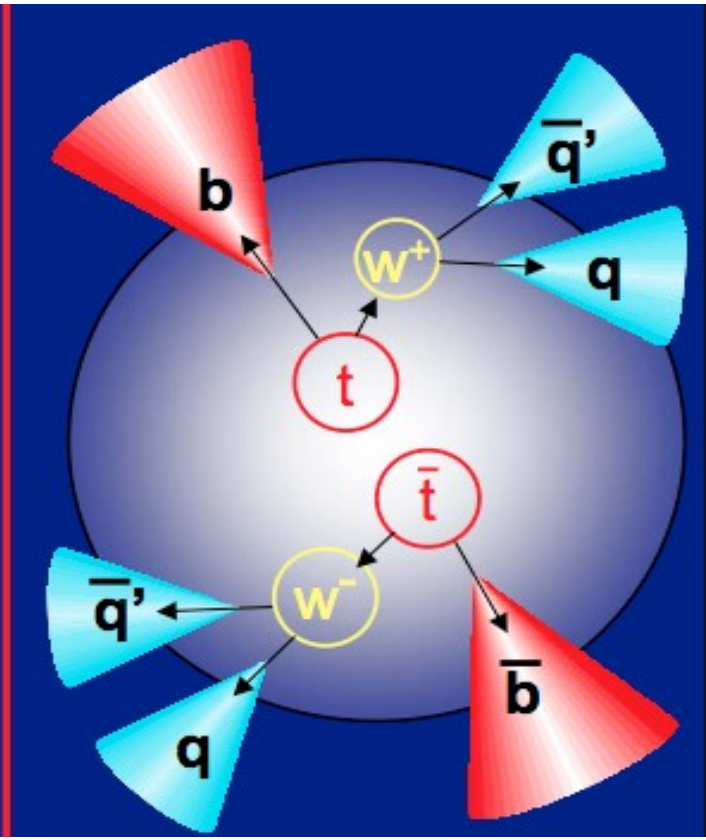
low rate, low background (mainly Drell-Yan)
High purity

Lepton (e or μ) +jets 30%



higher rate, manageable background (mainly W+jets)
Golden Channel

All hadronic 44%



large rate, large background (mainly QCD)
Lowest purity

Hadronic Taus (tau+lepton, tau+jets) (14%):
small rate and large background (mainly Multijets, W+jets)
Challenging purity

MET+jets ("hybrid channel"):
Focus on MET from ν, catches what other channels miss (bkg mainly QCD, EWK+HF)
Large acceptance to taus in the final state

Selection:

2 OS isolated leptons (e, μ) with ET ≥ 20 GeV

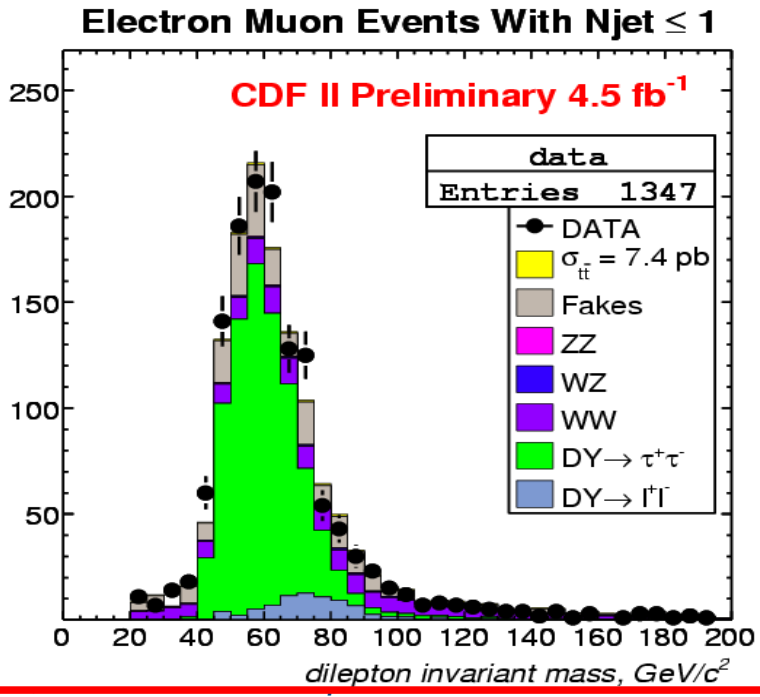
jets with |η| < 2.5 and ET ≥ 15 GeV,
at least one jet with ET ≥ 30 GeV

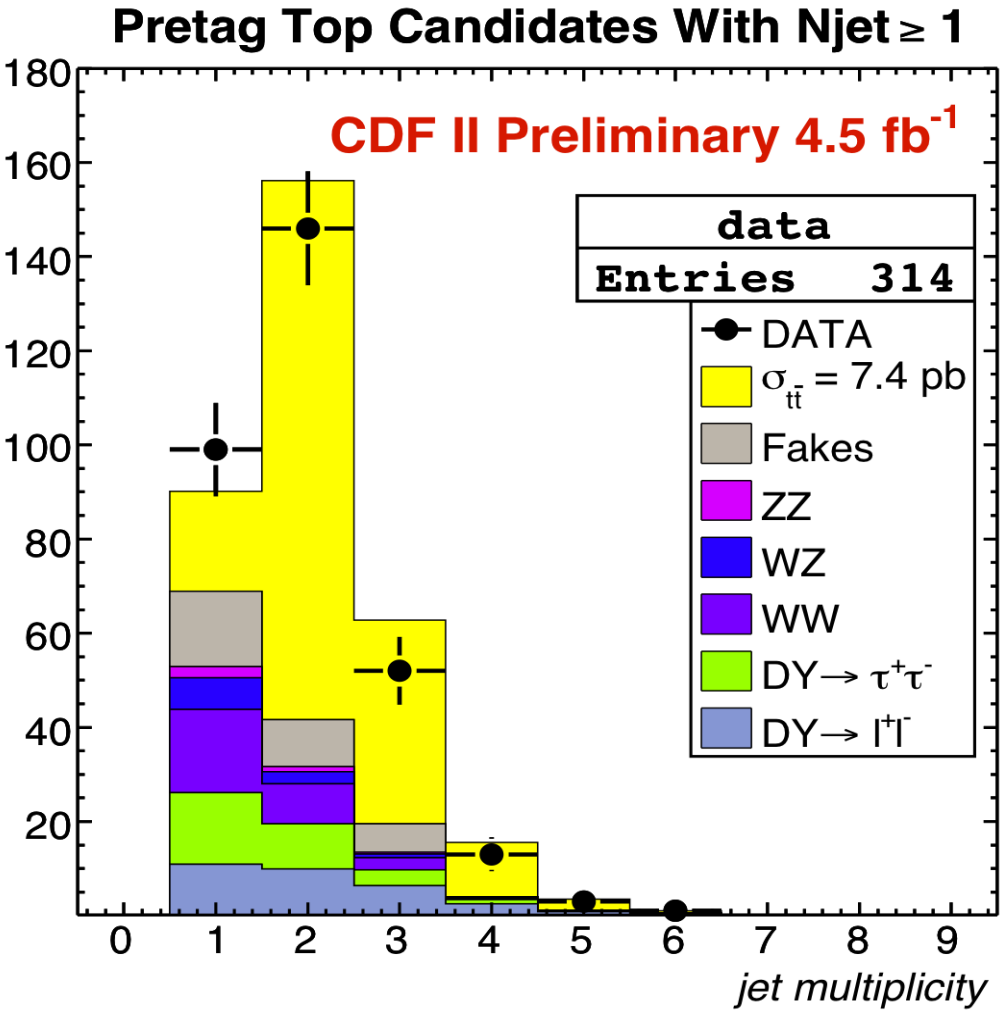
Drell Yan veto

MET ≥ 25 GeV

Background Modeling:

Drell Yan, diboson → use Monte Carlo
Fakes, QCD → use data with same charge leptons





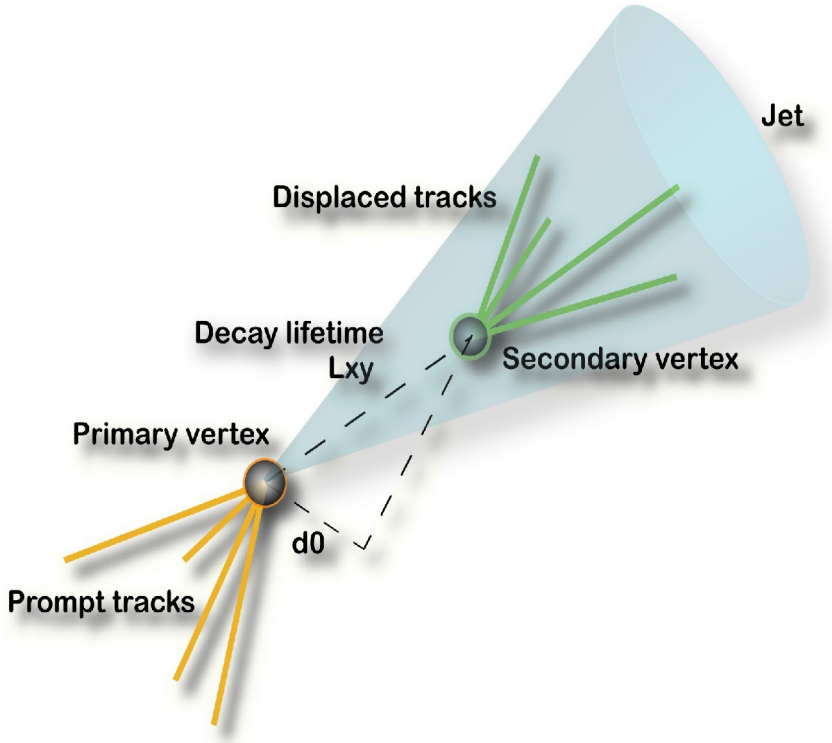
Very clean ttbar sample!

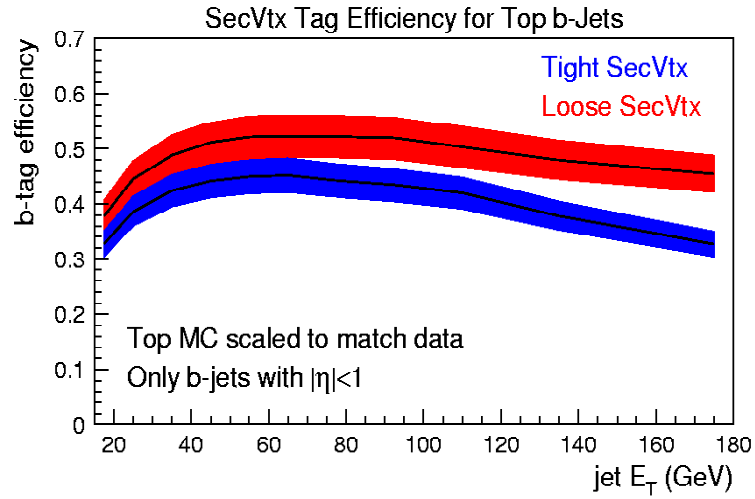
CDF dilepton (4.5 fb^{-1}):
σ_{ttbar} = 6.56 ± 0.65 (stat) ± 0.41 (syst)
± 0.38 (lumi) pb

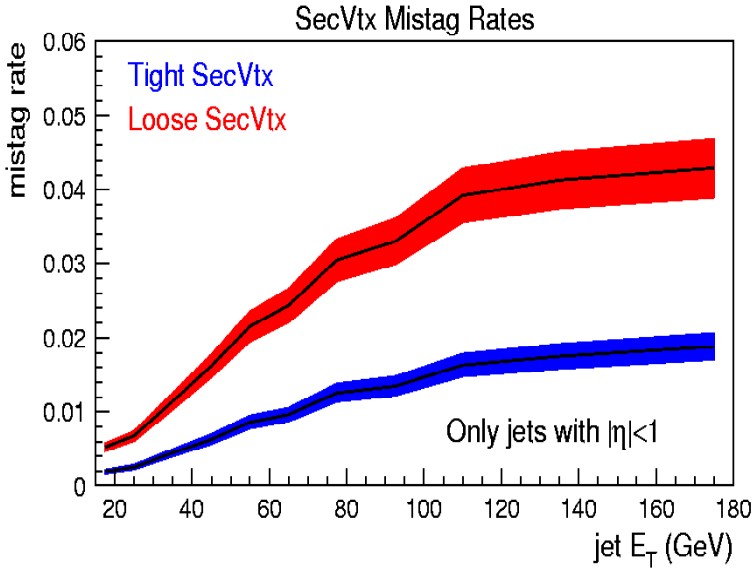
$\Delta\sigma/\sigma$ = 13%

b-jets identification

For the other channels, ttbar signature is not as clean as in the dilepton, need additional tools to identify top pairs decay products → ***b-tagging***







SECondary VerTeX tagging:
search a displaced secondary vertex among high impact parameter tracks using an iterative fit.

Efficiency is tuned on data:
- ➔ is around 50% for ttbar central b-jets
- ➔ mistag rate kept under 2% for tight SecVtX

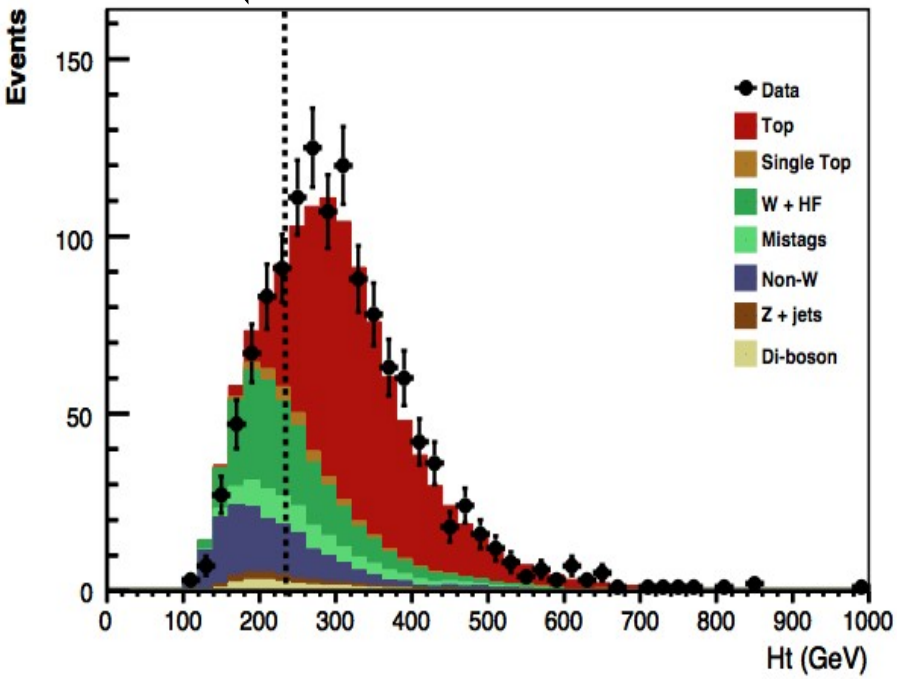
Lepton + jets channel with b-tag

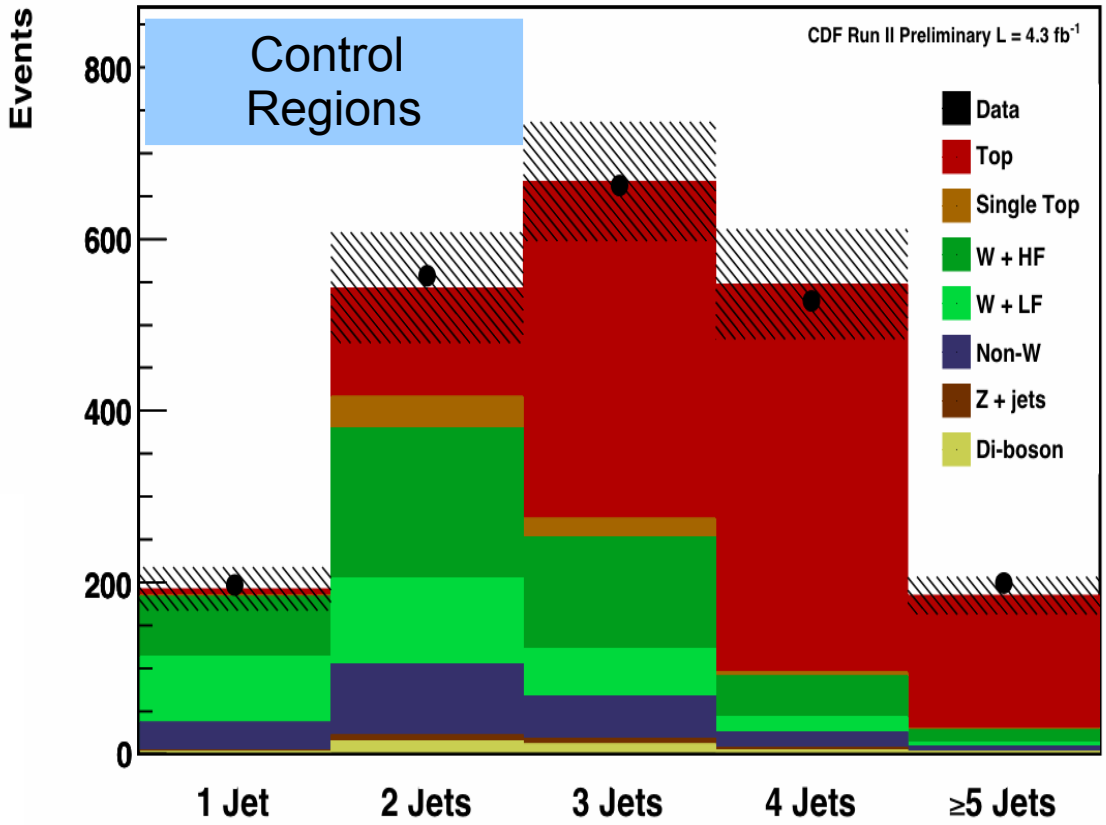
Selection:

1 isolated lepton (e, μ) with ET>20 GeV
≥3 jets with |η|<2.0, ET>20 GeV
MET>25 GeV

≥1 SecVtx b-tagged jet

H_T > 250 GeV (Sum of the transverse energy of jets, lepton, and MET)





CDF lepton+jets b-tag (4.3 fb^{-1}):

σ_{ttbar} = 7.22 ± 0.35 (stat) ± 0.56 (syst) ± 0.44 (lumi)

$\Delta\sigma/\sigma$ = 10.3%

Lepton + jets channel with b-tag

Selection:

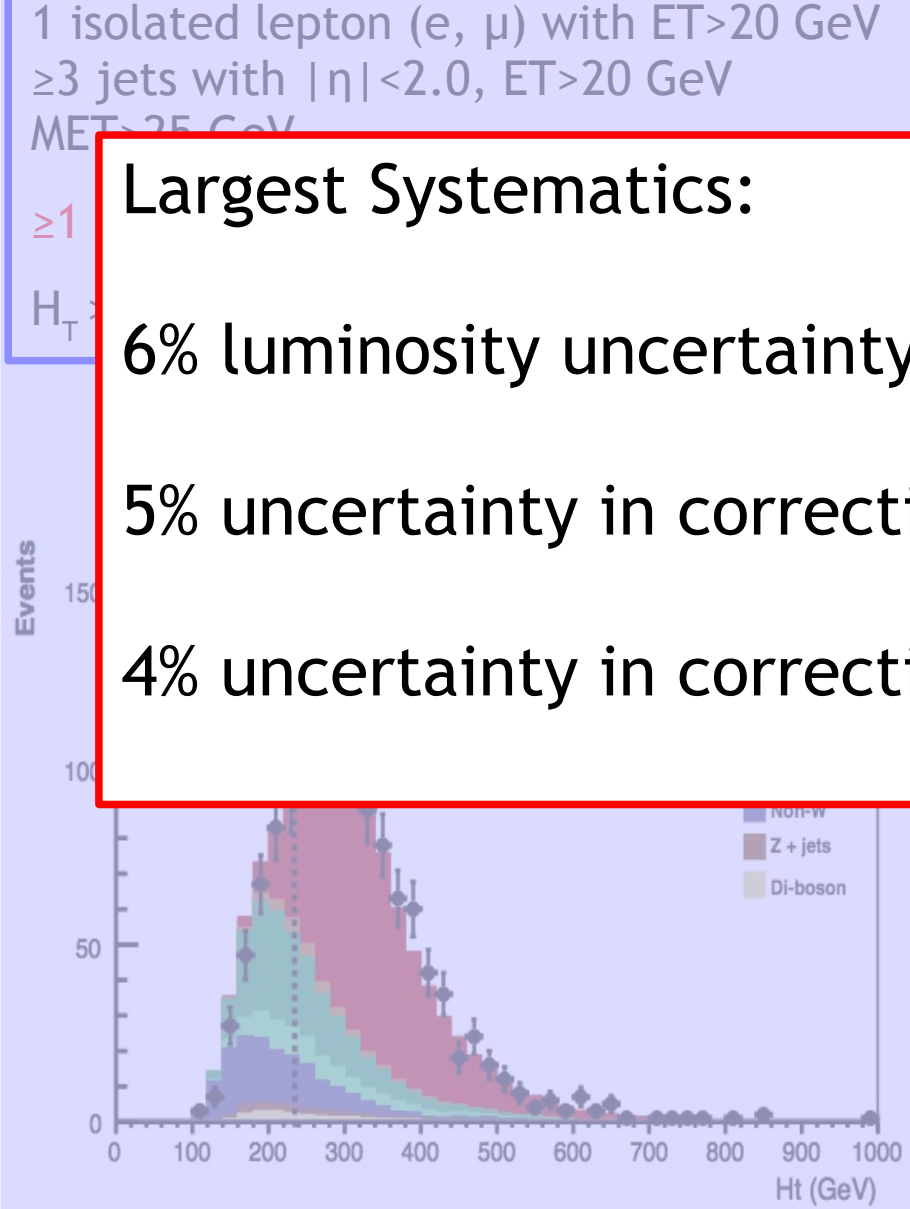
1 isolated lepton (e, μ) with ET>20 GeV
≥3 jets with |η|<2.0, ET>20 GeV
MET>25 GeV
≥1
H_T >

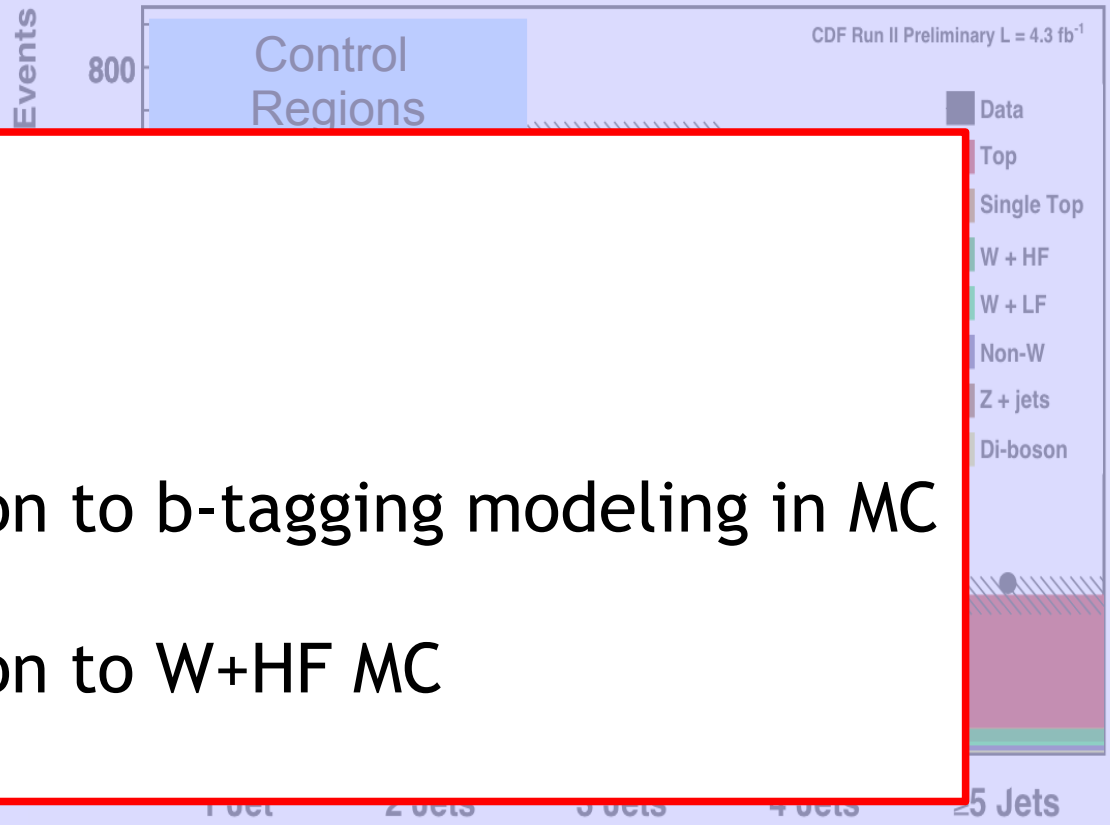
Largest Systematics:

6% luminosity uncertainty

5% uncertainty in correction to b-tagging modeling in MC

4% uncertainty in correction to W+HF MC





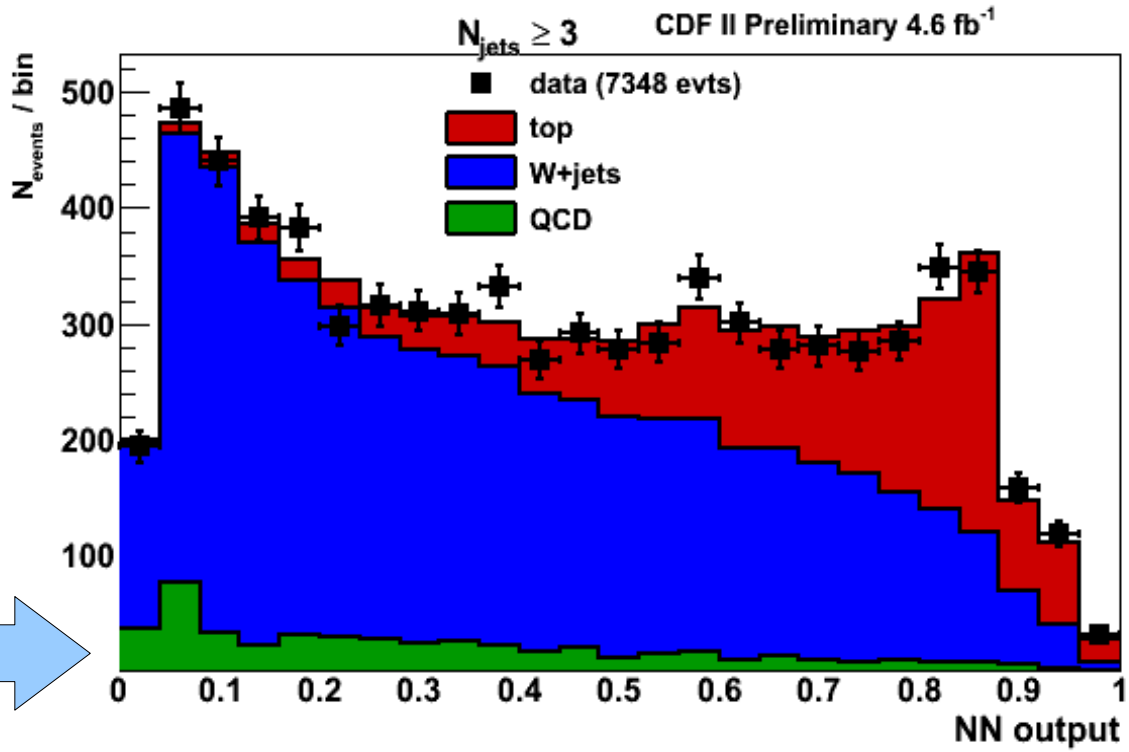
CDF lepton+jets b-tag (4.3 fb^{-1}):
σ_{ttbar} = 7.22 ± 0.35 (stat) ± 0.56 (syst)
± 0.44 (lumi)

Lepton + jets channel with NN

Try a different, topological, approach using Neural Networks:
Rely on identifying top events through kinematics as opposed to b-jet identification
→ no b-tag, same selection with no H_T cut

Kinematic Variables:

- *Total Sum Transverse Energy*
- *Aplanarity*
- *Sum Pz / Sum Et of Jets*
- *Sum Jet Et Excluding Two Highest*
- *Minimum Di-Jet Mass*
- *Minimum Angle Between Two Jets*
- *Maximum Angle of a Jet*



train NN to distinguish signal from background and fit templates to data

CDF lepton+jets NN (4.6 fb^{-1}):
σ_{ttbar} = 7.71 ± 0.37 (stat) ± 0.36 (syst) ± 0.45 (lumi) pb

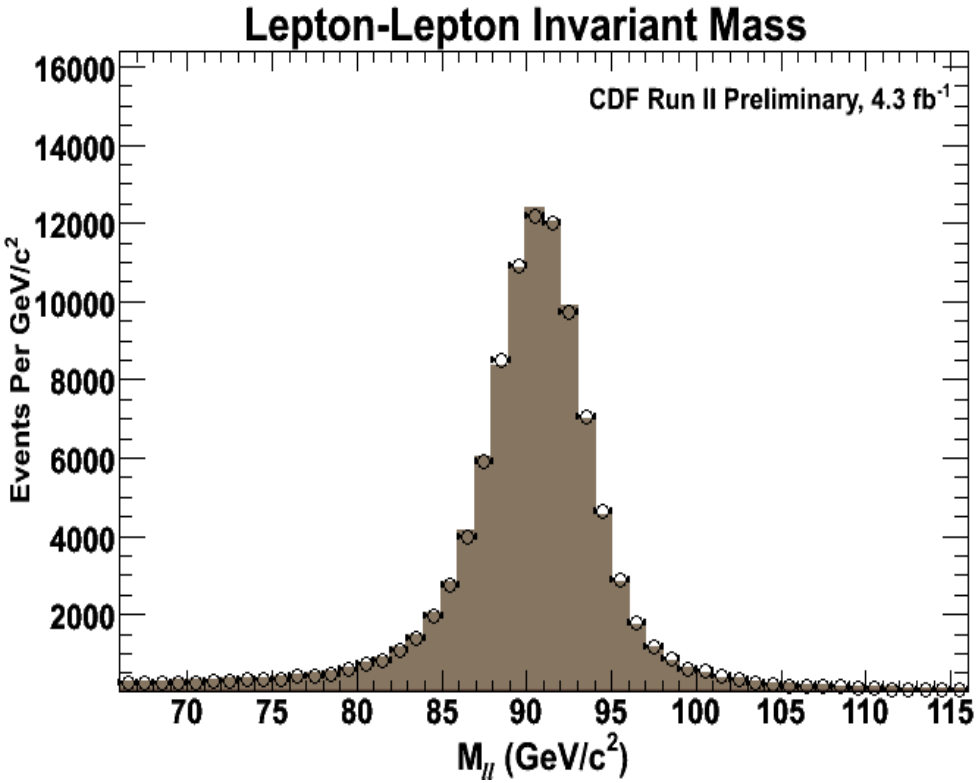
$\Delta\sigma/\sigma$ = 8.8%

Largest systematics:
6% Luminosity
3% Jet Energy Scale

Luminosity Uncertainty

Optimizing the analysis:
reducing the largest systematics

- σ_Z well known theoretically
- Z well modeled in MC
- Z small background
- Luminosity uncertainty can be **cancelled out** in ratio if we use the same triggers and data periods



measure:
$R = \sigma_{ttbar}^{measured} / \sigma_{Z->ll}^{measured}$ ratio

Get $\sigma_{ttbar} = R\, \sigma_{Z-> ll}(th)$

σ_Z measured in OS dileptons with
66 GeV > m_{ll} > 116 GeV

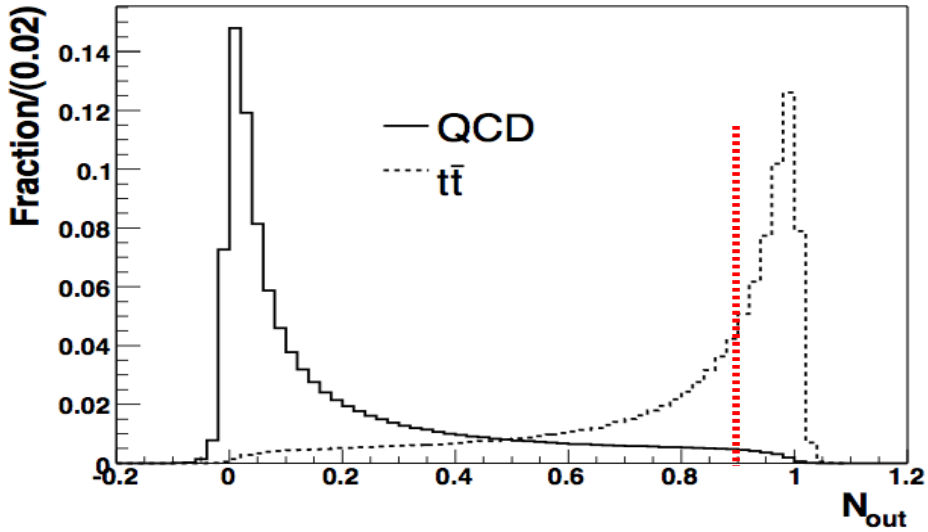
lepton+jets with b-tag and Z ratio (4.3 fb^{-1}):
σ_{ttbar} = 7.32 ± 0.36 (stat) ± 0.59 (syst) ± 0.14 (Z theory)
$\Delta\sigma/\sigma$ = 9.6%

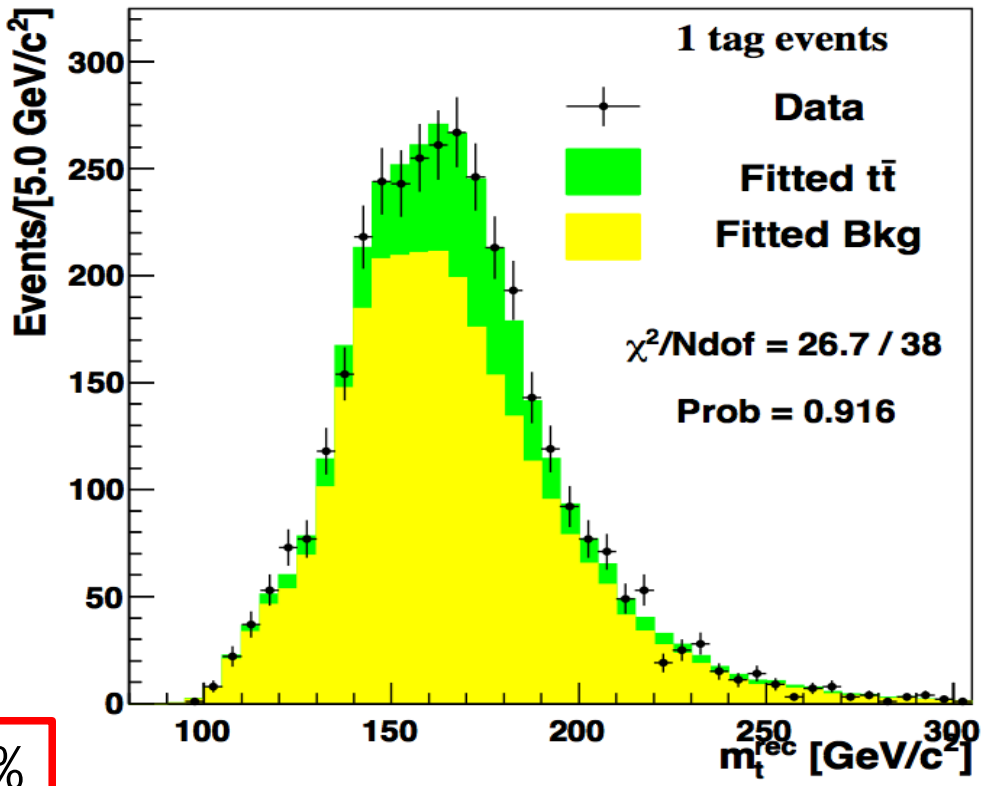
lepton+jets with NN and Z ratio (4.6 fb^{-1}):
σ_{ttbar} = 7.82 ± 0.38 (stat) ± 0.37 (syst) ± 0.15 (Z theory)
$\Delta\sigma/\sigma$ = 7.0%

All hadronic channel

Selection:
- Veto leptons and require low MET
- Require 6 <= Njets <= 8 in the signal region
- Use a NN (jet invariant masses, sphericity, aplanarity, ...) to separate S/N
- Jet shapes variables allow to separate quark jets from gluon jets, big impact in the NN
- ≥1 SecVtx b-tagged jets

Technique:
- Parameterize background b-tags from 4 Jet data, QCD dominated, using b-tag rates
- Use a kinematic fitter to reconstruct M_{top} for each event
- From MC get M_{top}^{reco} distribution for different values of the input top mass (templates)
- By fitting data to templates of Signal+Background get the number of ttbar events and measure cross section



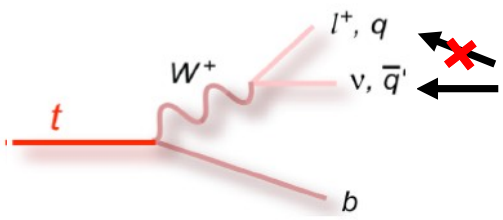


CDF all hadronic (2.9 fb^{-1}):

σ_{ttbar} = 7.21 ± 0.50 (stat) ± 1.10 (syst) ± 0.42 (lumi) pb

$\Delta\sigma/\sigma$ = 17.7%

MET+Jets channel



Analysis focuses on MET from neutrino rather than on lepton identification, requires large Jet multiplicity, at least one btagged jet

Selection

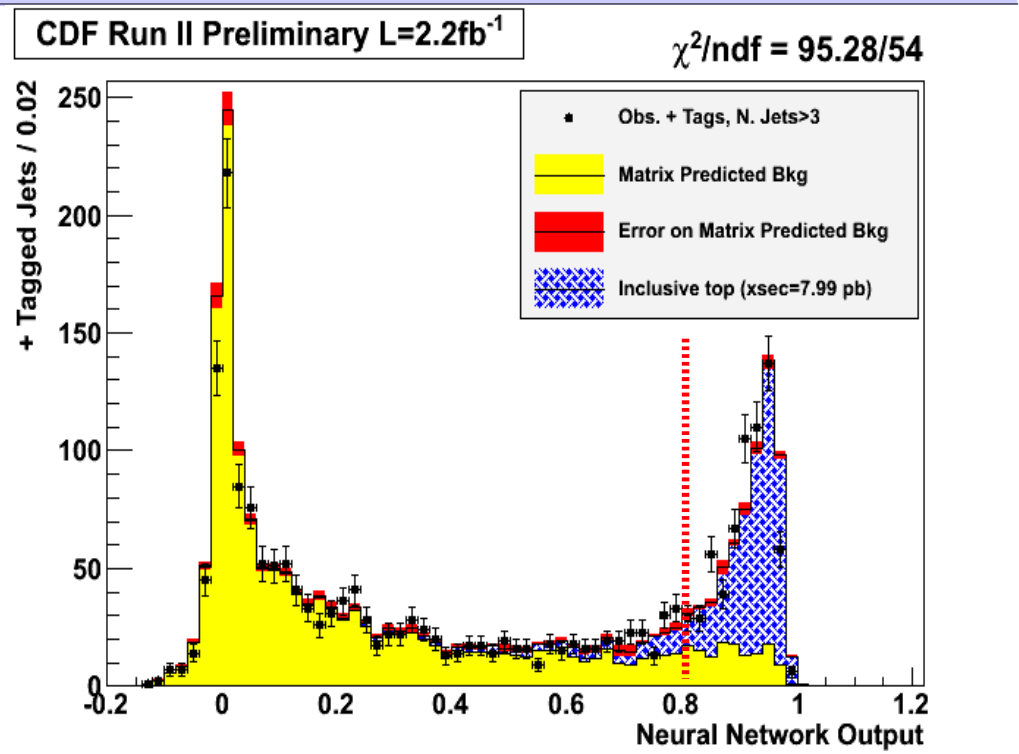
- Require significant MET, MET_{Sigf} > 3 $GeV^{1/2}$
- Veto well reconstructed leptons
- Require 4 or more jets
- Use a NN to discriminate S/N
- Paremeterize background b-tags from 3 Jet data, QCD dominated
- Perform counting experiment on b-tags for events with NNout>0.8

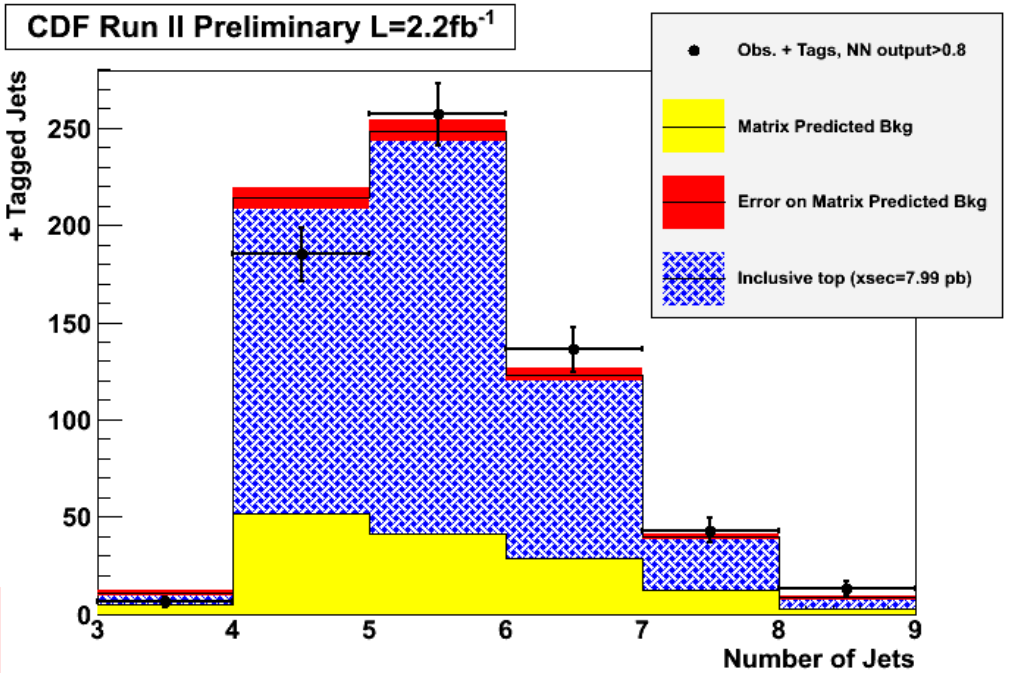
Large acceptance to tau+jets events!
Orthogonal and complementary results with respect to other channels

CDF MET+jets ($2.2\ fb^{-1}$):

σ_{ttbar} = 7.99 ± 0.55 (stat) ± 0.76 (syst) ± 0.46 (lumi) pb

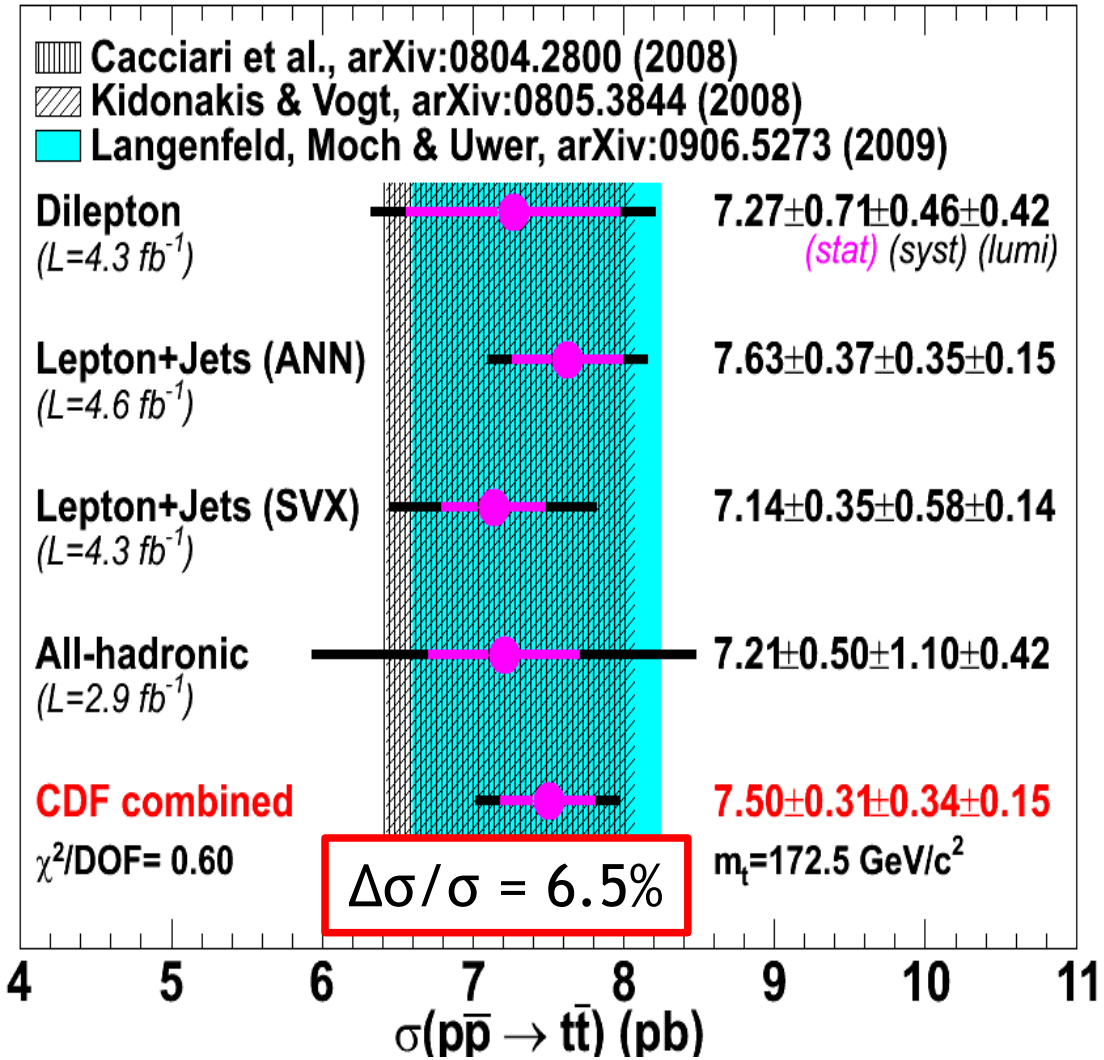
$\Delta\sigma/\sigma$ = 13%

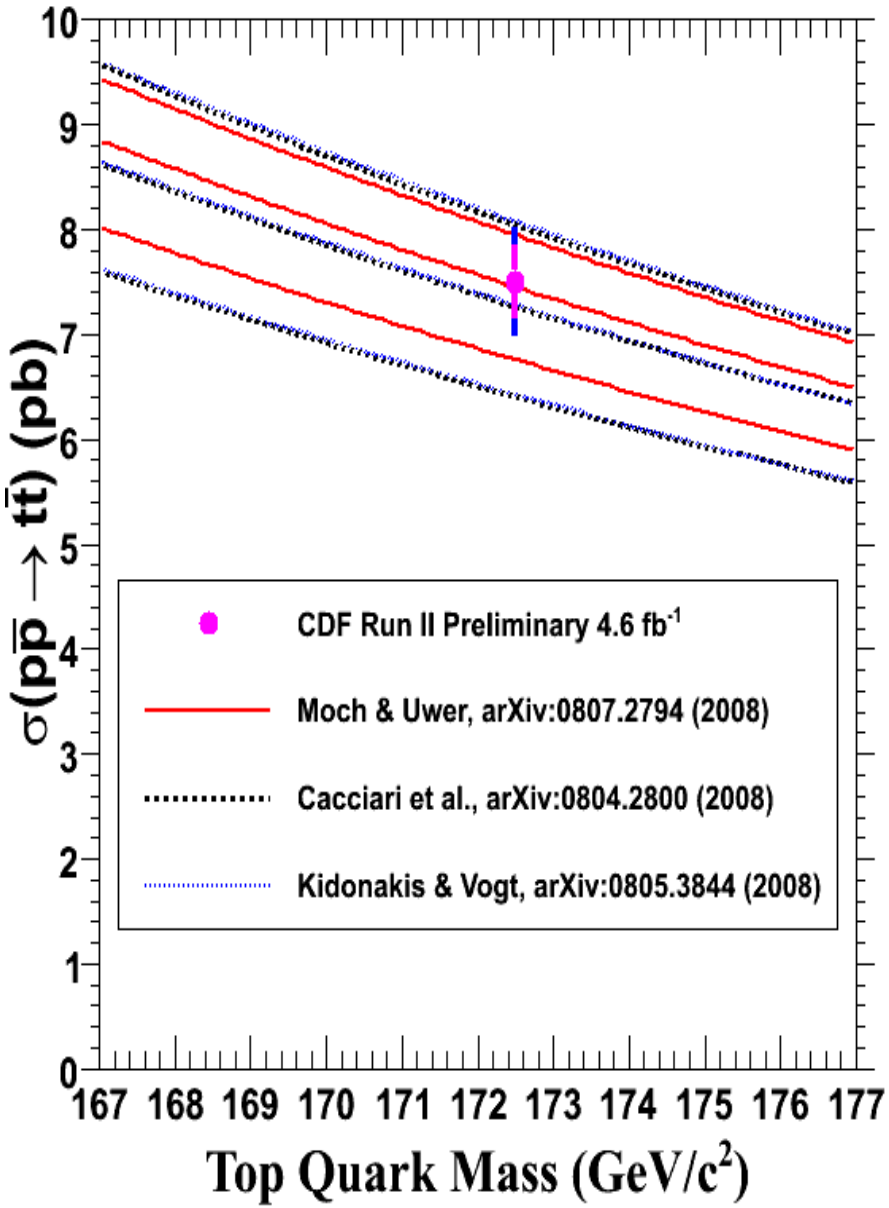




Overview and combination

Good agreement:
- among different channels
- with theoretical prediction

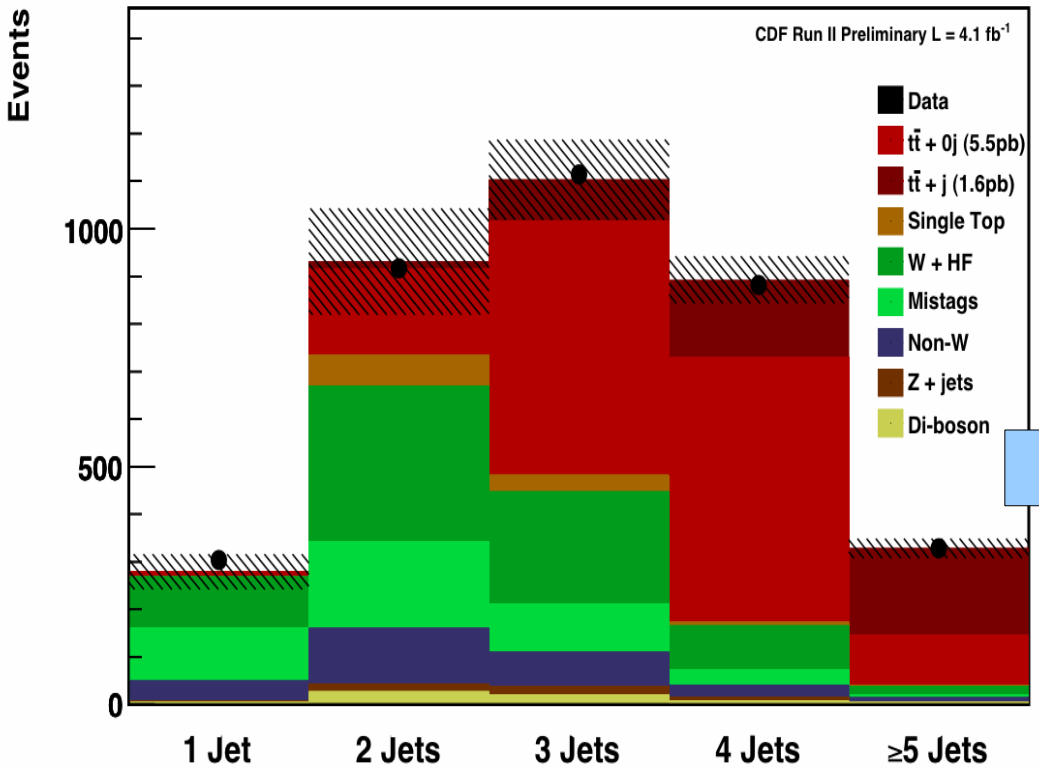


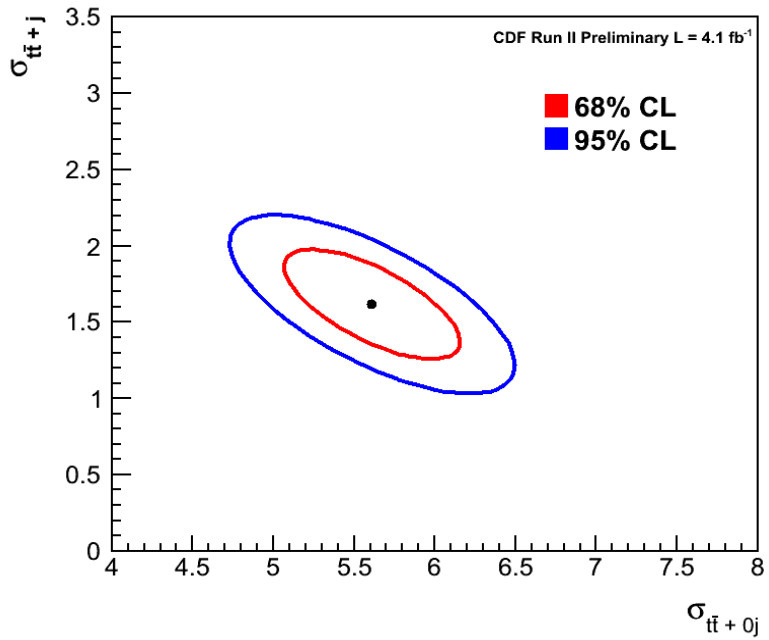


*(not yet updated with the latest results)

One more thing: ttbar+jet cross section

- Important test of perturbative QCD, NLO effects
- at the LHC ttbar will be produced with additional jets
  → background for many new physics signals
- use b-tagged events in the lepton+jets channel
- data-driven background
- 2D likelihood to simultaneously measure ttbar+jet and ttbar without jet cross sections





CDF result (4.1 fb^{-1}):
$\sigma_{ttbar+jet}$ = 1.6 ± 0.2 (stat) ± 0.5 (syst) pb

Theory:
$\sigma_{ttbar+jet} = 1.79\ ^{+0.16}_{-0.31}$ pb

Conclusions

- *Reviewed CDF measurements of the top pair production cross section in different channels*

- *Experimental uncertainties in the various channels are comparable to the theoretical*
- *Uncertainty of the CDF combination is even better than the theoretical*

- *Cross sections are consistent with SM, but still plenty of room for new physics!*

- Backup -

Dilepton channel with b-tag

Selection:

2 OS isolated leptons (e, μ) with ET ≥ 20 GeV

jets with |η| < 2.5 and ET ≥ 15 GeV,
at least one jet with ET ≥ 30 GeV

Drell Yan veto

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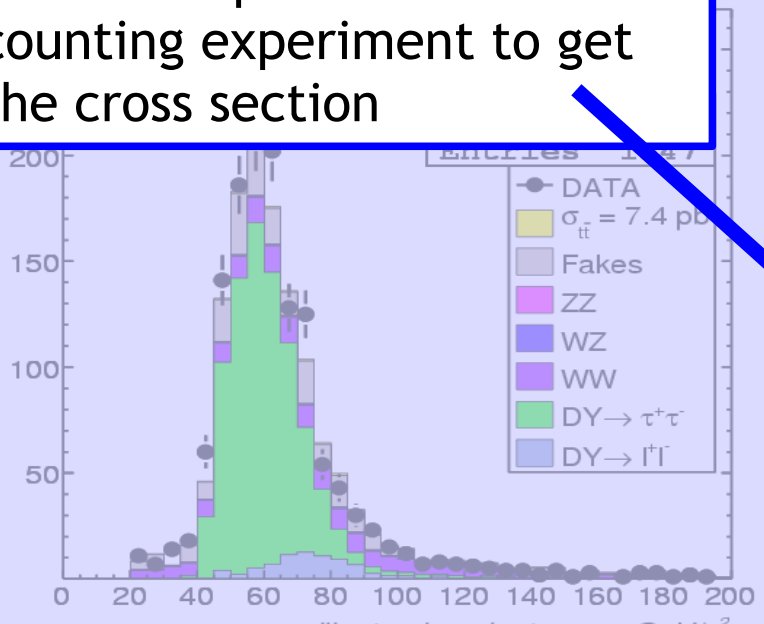
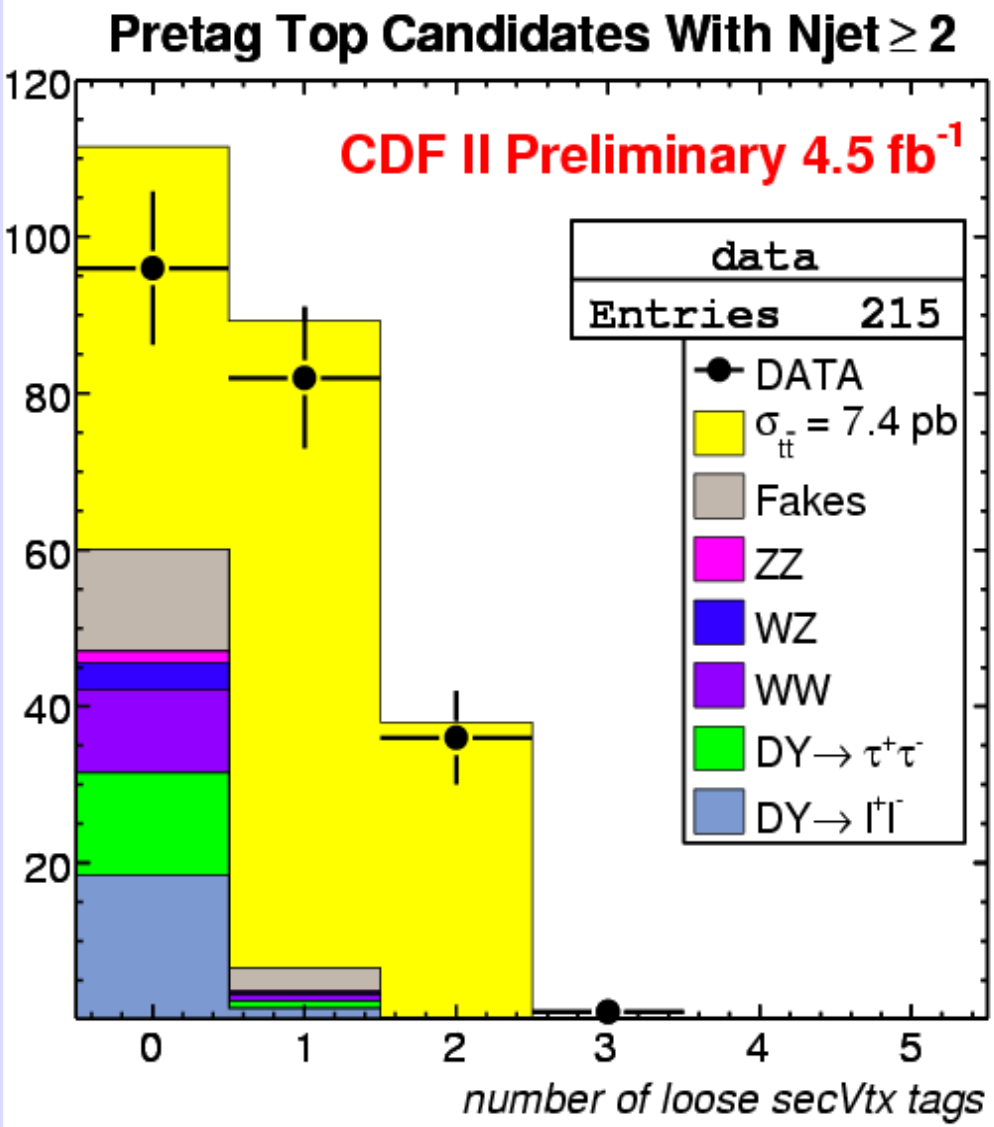
Can apply b-tagging to the dilepton channel

In addition to standard dilepton selection, require at least one SecVtX tag in the event and perform a counting experiment to get the cross section



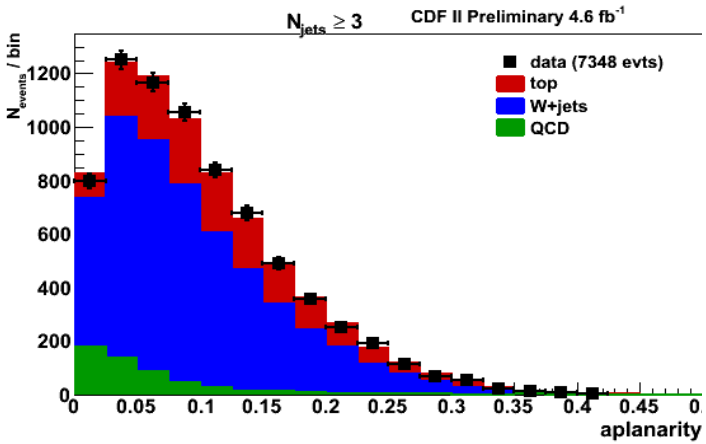


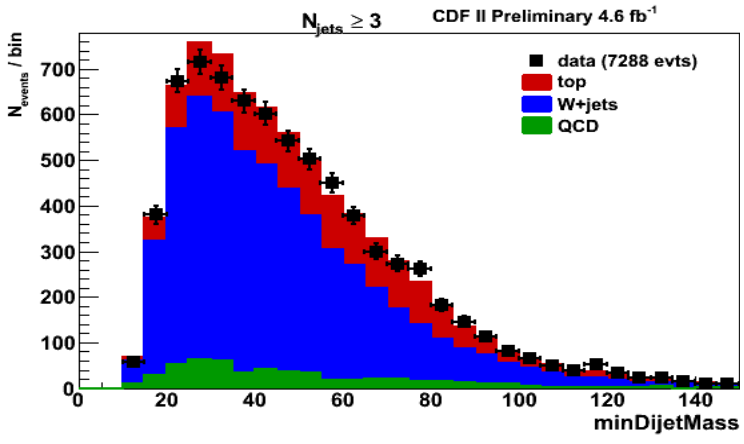
CDF dilepton with b-tag (4.5 fb^{-1}):

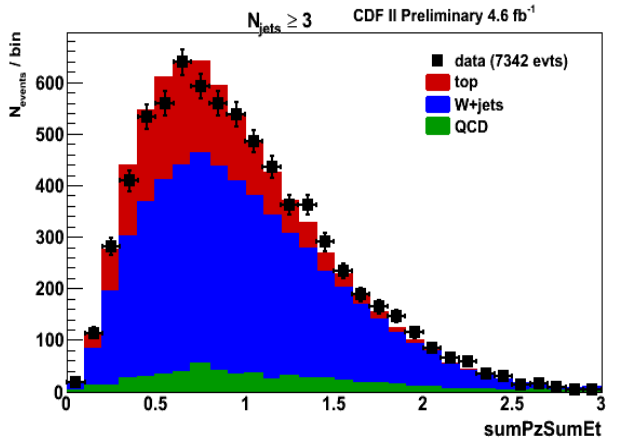
σ_{ttbar} = 7.27 ± 0.71 (stat) ± 0.46 (syst) ± 0.42 (lumi) pb

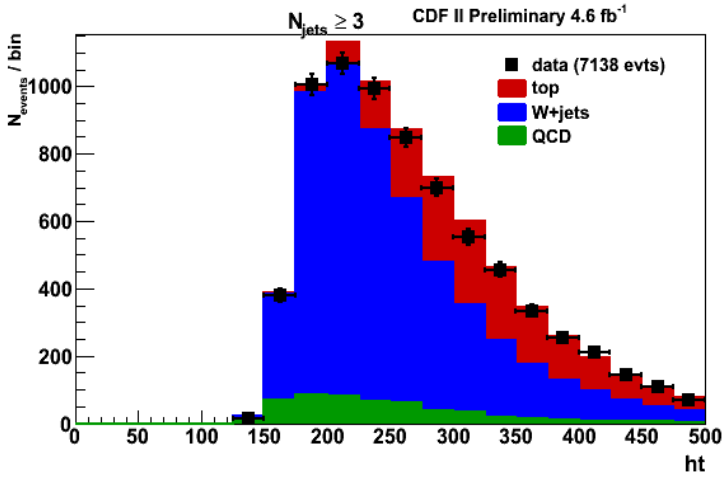
$\Delta\sigma/\sigma$ = 13%

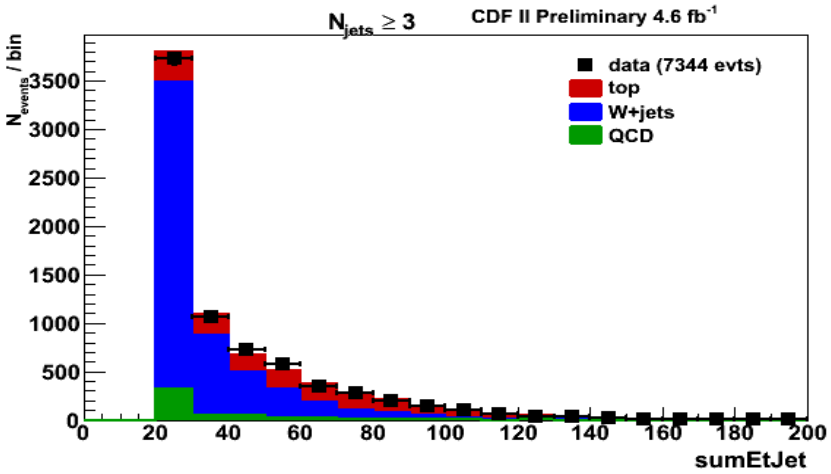
Lepton+Jets NN variables

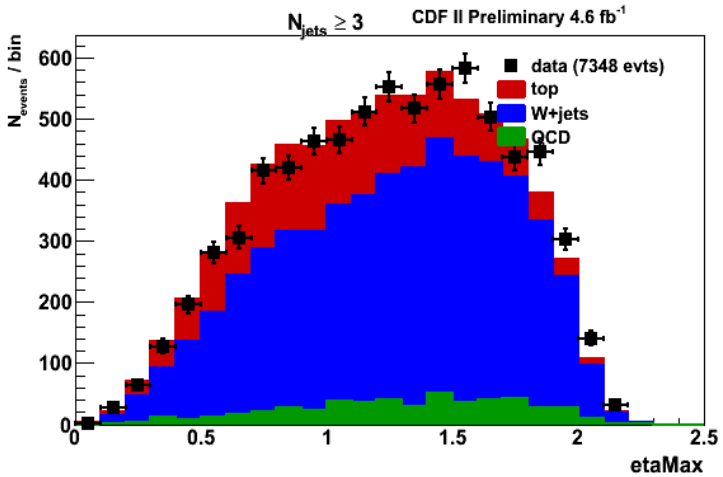


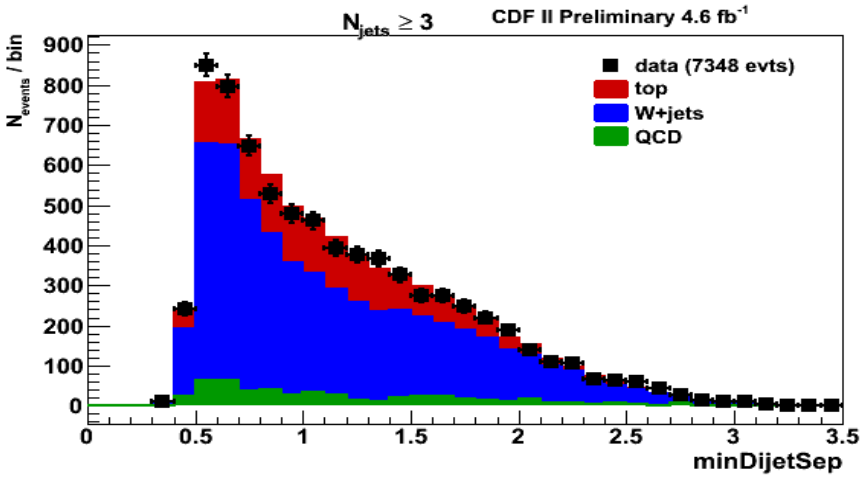












Jet Shapes in the all hadronic analysis

$$M_\eta = \sqrt{\left[\sum_{\text{tow}} \frac{E_T^{\text{tow}}}{E_T}\eta_{\text{tow}}^2\right] - \eta^2}$$

$$M_\phi = \sqrt{\left[\sum_{\text{tow}} \frac{E_T^{\text{tow}}}{E_T}\phi_{\text{tow}}^2\right] - \phi^2}$$

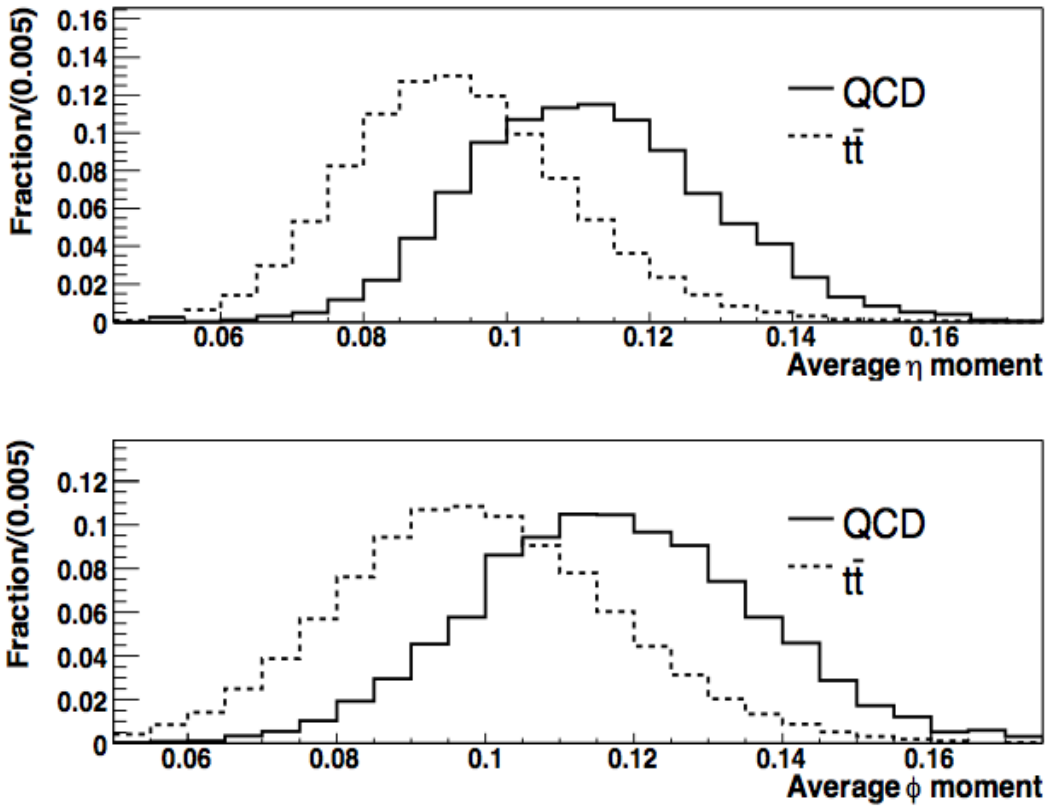
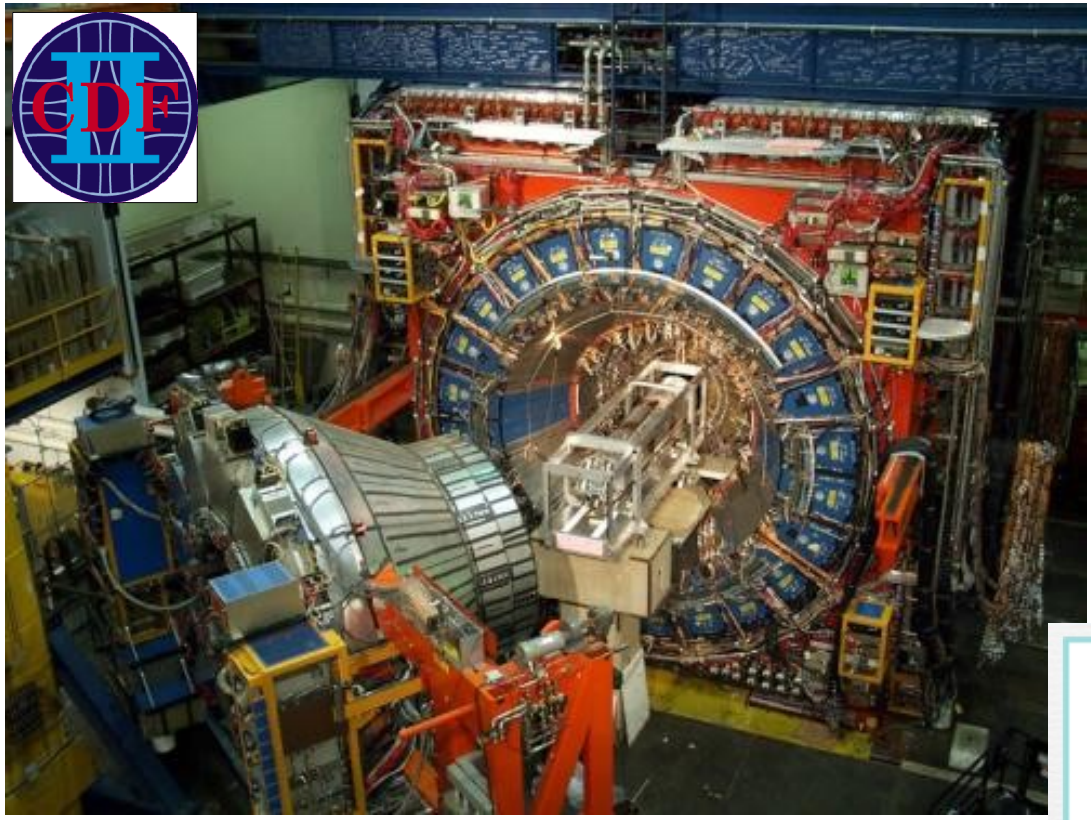


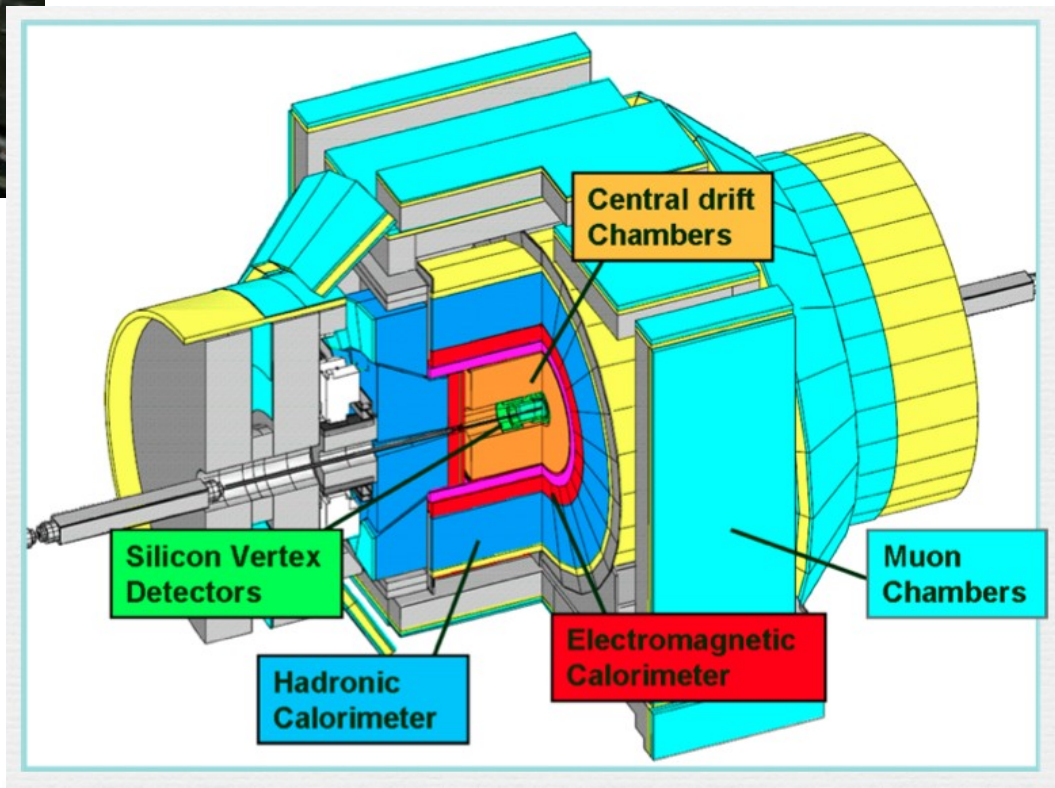
FIG. 1: Geometric average of the η scaled moments ($\langle M_\eta^s \rangle$, upper plot) and of the ϕ scaled moments ($\langle M_\phi^s \rangle$, lower plot) for QCD multijet (solid histogram) and simulated $t\bar{t}$ (dashed histogram) events with $6 \leq N_{\text{jets}} \leq 8$.

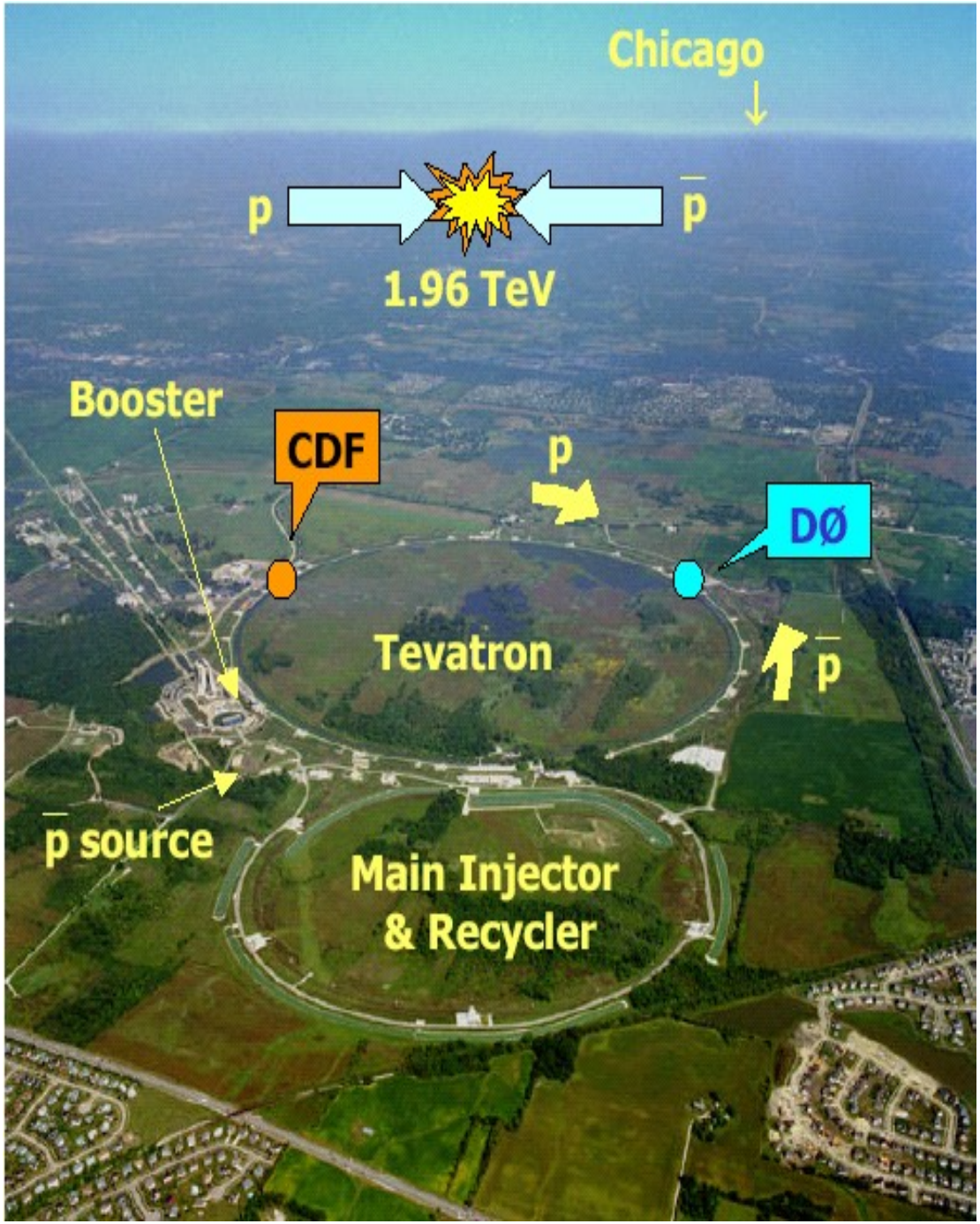


Multipurpose collider detector
Large international collaboration,
600+ members

- Silicon tracking
- Large radius drift chamber (r=1.4m)
- 1.4 T solenoid
- Projective calorimetry ($|\eta| < 3.5$)
- Muon chambers ($|\eta| < 1.0$)

- Silicon Vertex Trigger





The Tevatron Collider

- *Circumference 6.8 km*
- *ppbar collisions at 1.96 TeV*
- *Run I (1987-1995)*
- *Run II (since 2001)*
- *Surpassed design luminosity*

Peak Luminosity