# $t\bar{t}$ cross section at CDF

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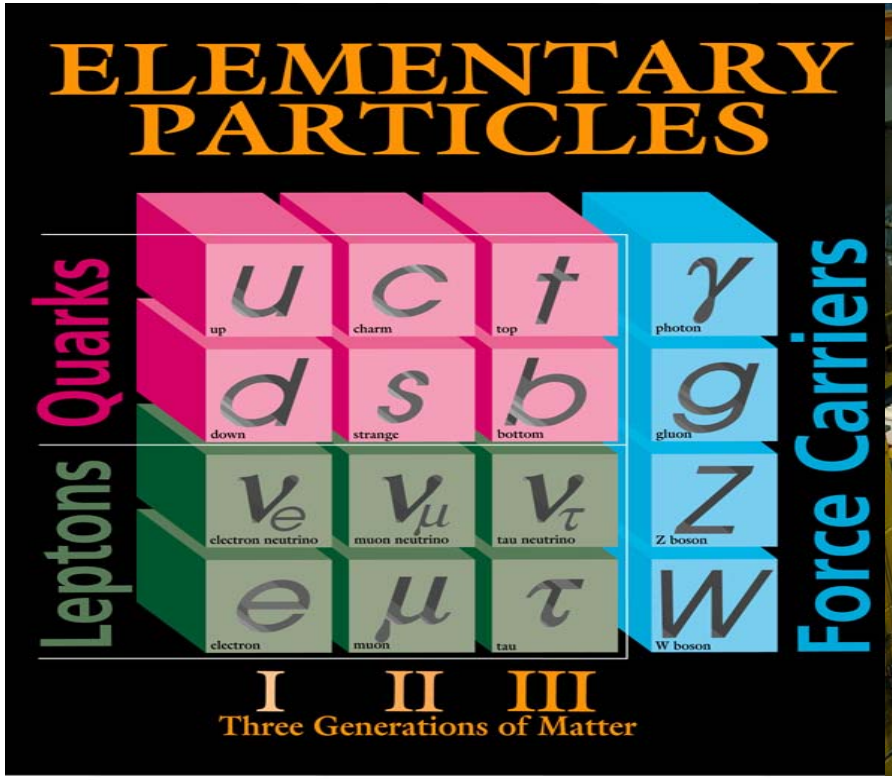
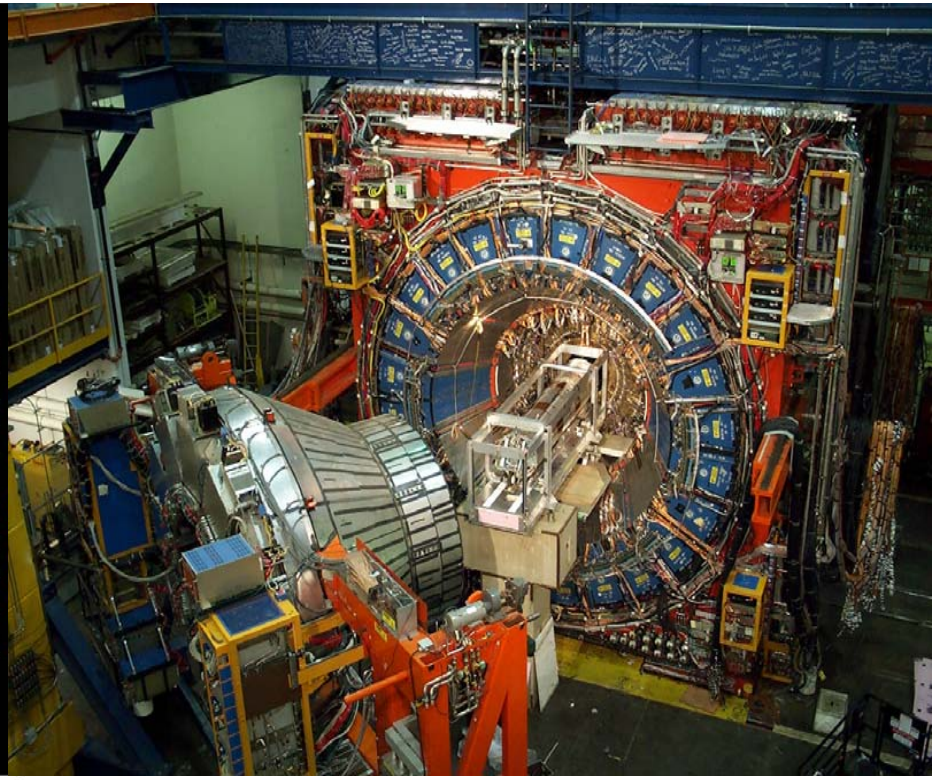


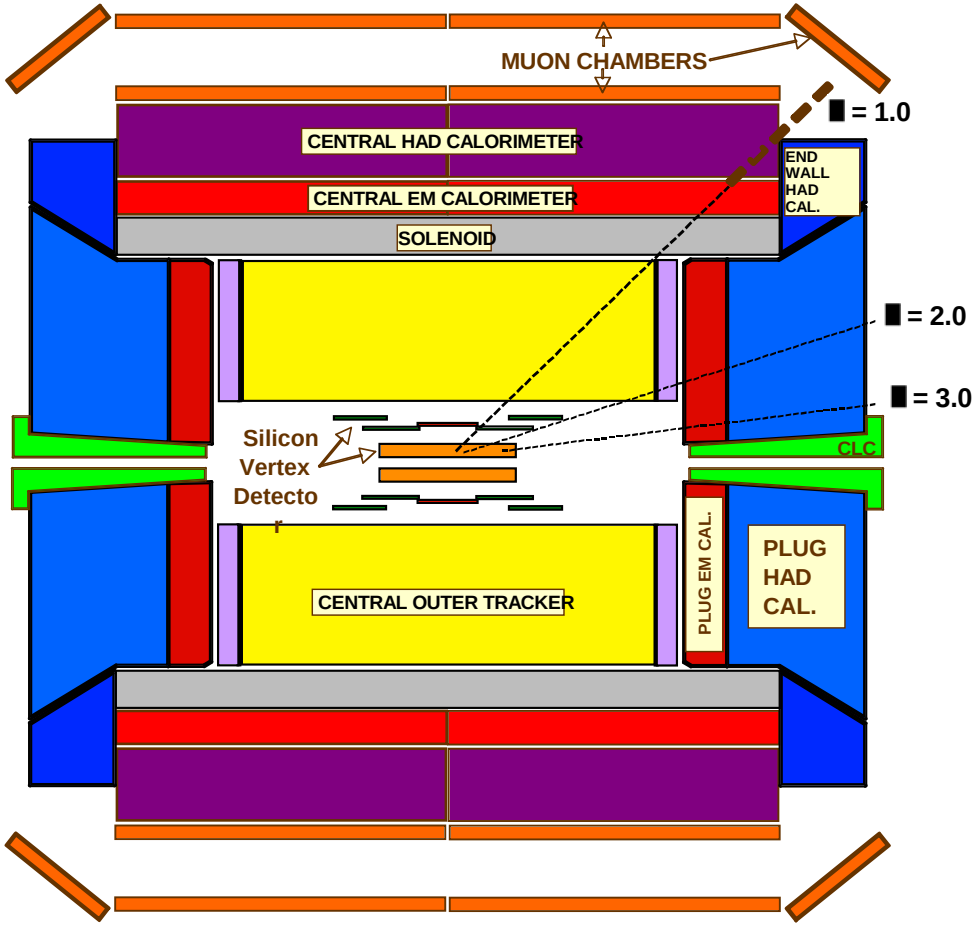



# Outline

- **WHY** it is important to measure $\sigma(t\bar{t})$
- **HOW** we perform the measurements
- **WHAT** are the measurements
- **WHICH** conclusions can be drawn

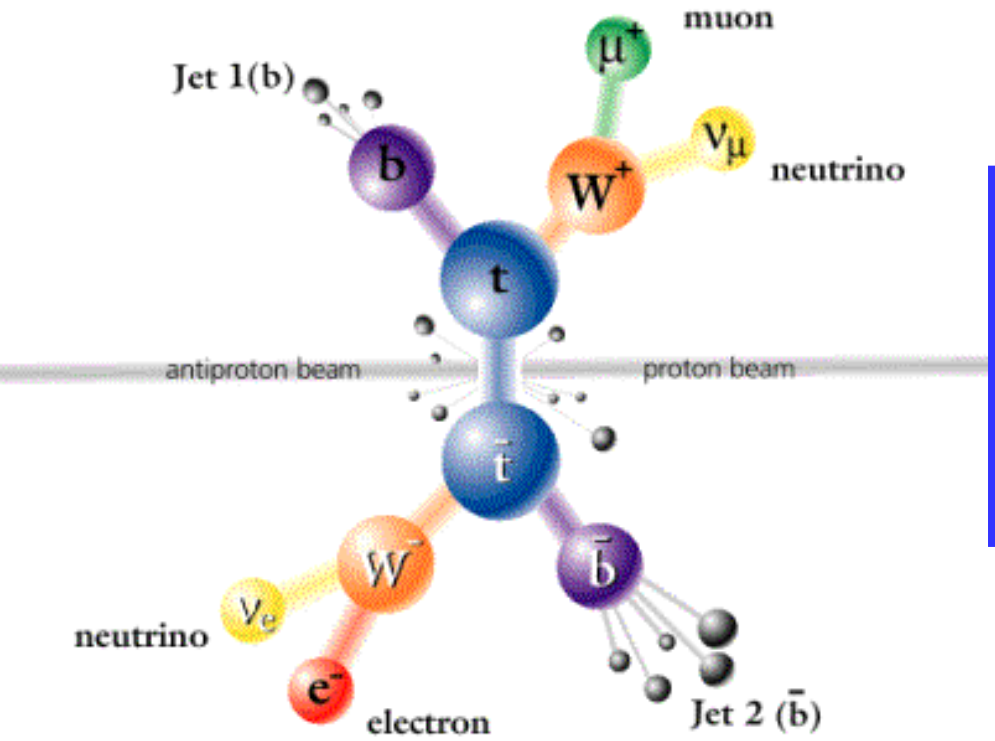
# CDF detector

- Classic multipurpose
  - Silicon Vertex Detector
  - Wire tracker
  - Solenoid
  - Pre-shower detector & TOF
  - EM Calorimeter
  - HAD Calorimeter
  - Muon chambers



# Quick look at $t\bar{t}$ production

## The experimental starting point:




Leptons, jets and missing $E_T$ in the final state

# ***Why*** *we measure* $\sigma$

1) The comparison between observed production properties and the expected SM ones is a test of SM and probe of New Physics

2) $\sigma(tt)$ is the most inclusive property and the least sensitive to higher order corrections

# ***Why*** *we measure* $\sigma$

- The recent $\sigma$ calculations are based on parton-level $\sigma$ evaluated in pQCD with NLO matrix elements
- This matches the PDF which are extracted comparing data to NLO calculations
- Top is very heavy and might couple to New Physics at high energy scales

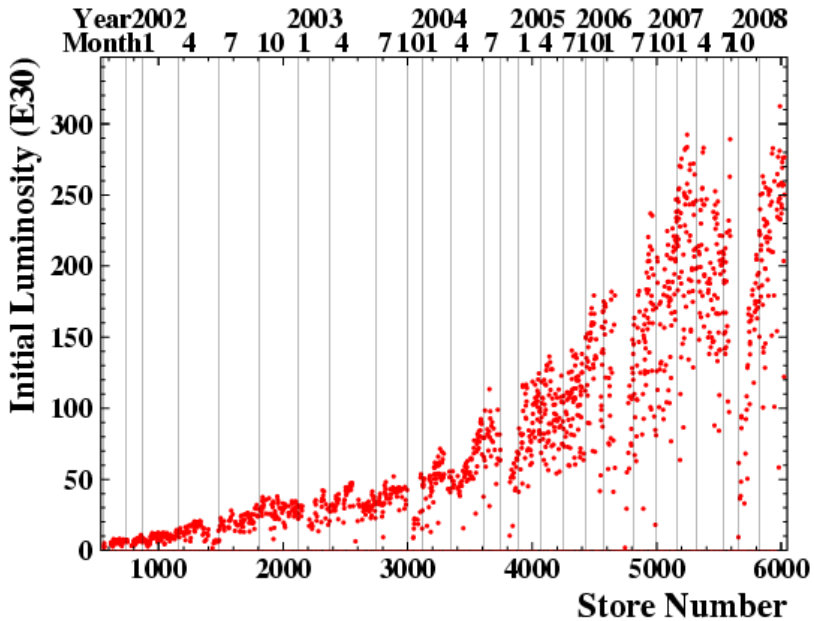
# ***Why*** *we measure* $\sigma$

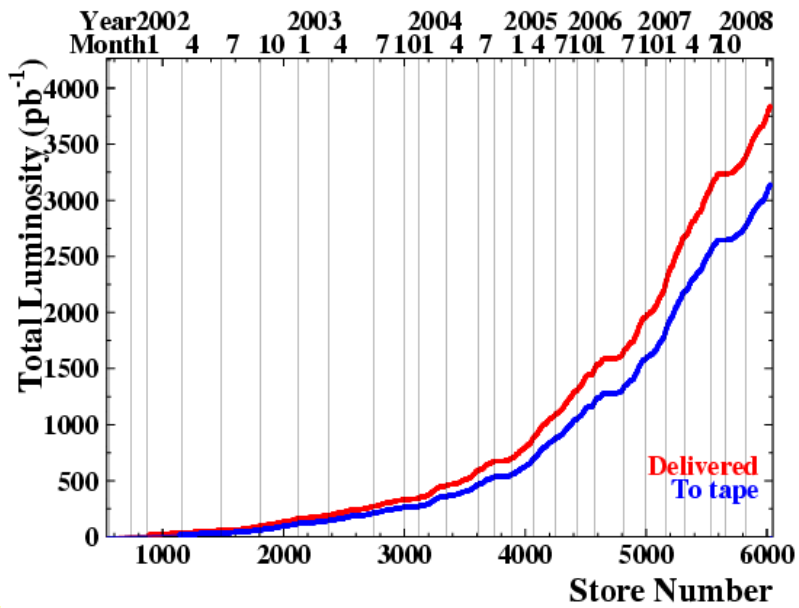
- An anomalous tt rate can be indication of new physics (e.g. production of resonant state $X \rightarrow tt$)
- Compare $\sigma$ for different final states:

- $\sigma_{\ell+jet}/\sigma_{\ell\ell}$ sensitive to non-W decays

- different channels have different sensitivity

# *The Tevatron* (Run2 at √s = 1.96 TeV)

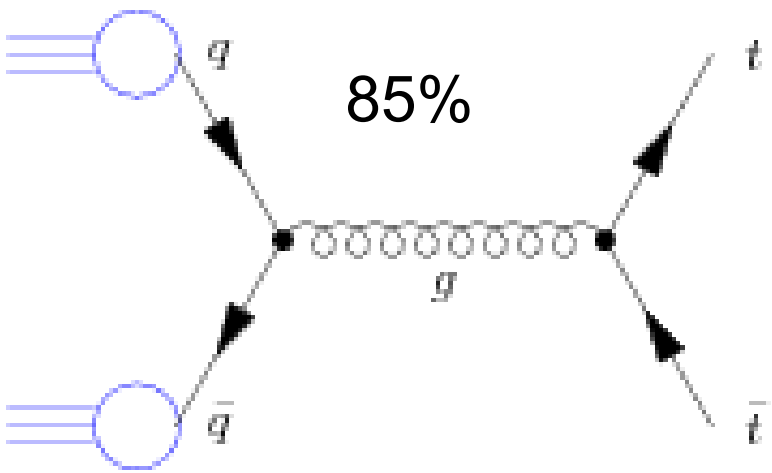


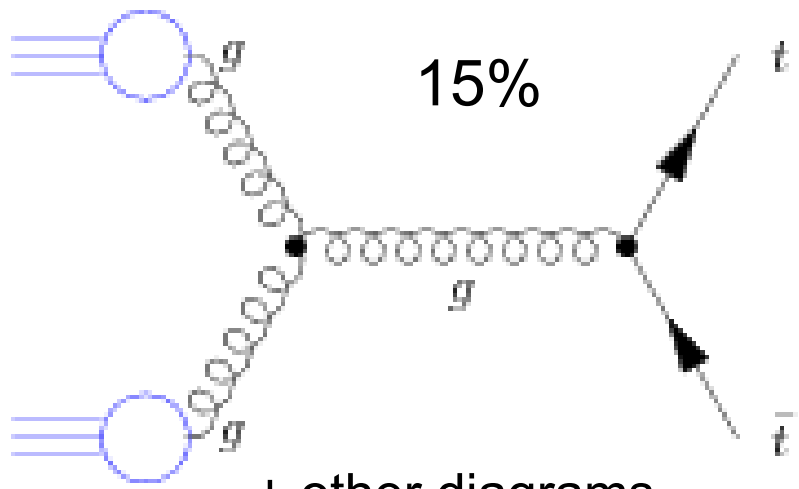




- Record inst. Luminosity = $3.15 \times 10^{32}$ $cm^{-2}s^{-1}$
- Both experiments have now ~ 3.5 $fb^{-1}$ on tape
- The goal is 6-8 $fb^{-1}$ by 2009 (or 2010?)

~ 20000 top pairs produced. Not a top factory but still …

# $t\bar{t}$ Production …



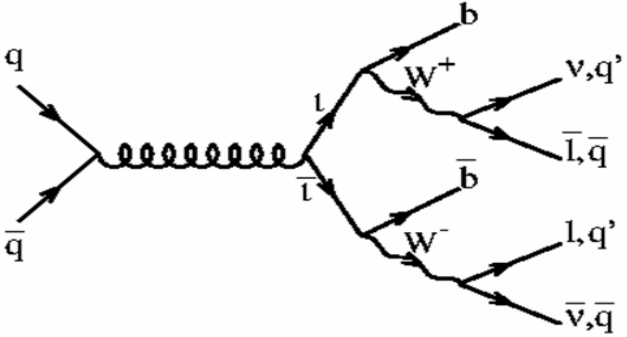




+ other diagrams

At the Tevatron top quarks are mainly produced in pairs:

$\sigma$(single top)~1/2 of $\sigma$(tt)

# … and decay



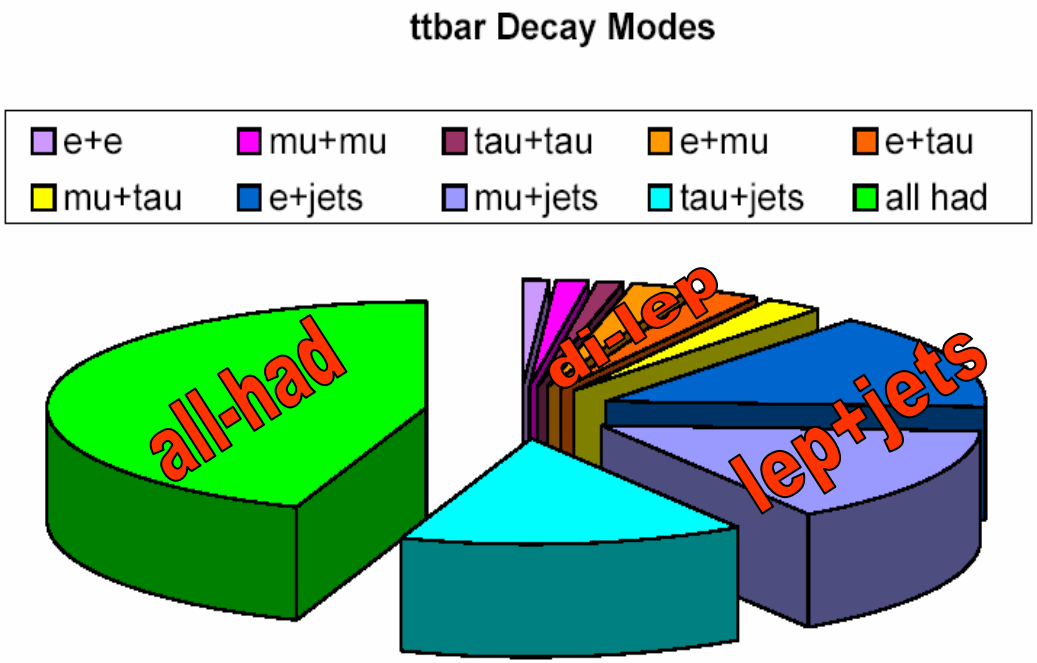

The final states are classified according to the way the W's decay:

1) Di-lepton (5%)

2) Lepton+jets (30%)

3) All-hadronic (44%)

4) (others, including $\tau$)



# $t\bar{t}$ Final states

Each final state/topology has specific characteristics and requires a specific approach:

1) Di-lepton: low yield, low bckgd, well defined leptonic signature

2) Lepton+jets: higher yield, moderate bckgd, lepton signature + MET + jets

3) All-hadronic: highest yield, huge background, only jets

4) Others

# How we measure $\sigma$

- The $\sigma$ measurements are based on counting candidates (n) and subtracting an estimated background (b)
- All in one formula:

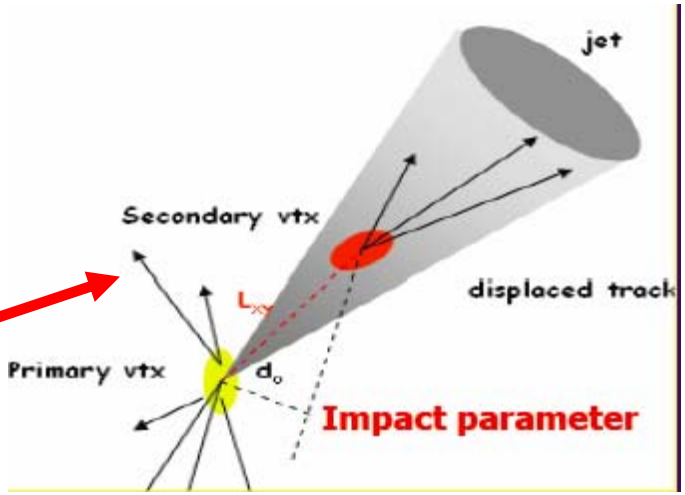
$$\sigma = \frac{n - b}{\varepsilon a L}$$

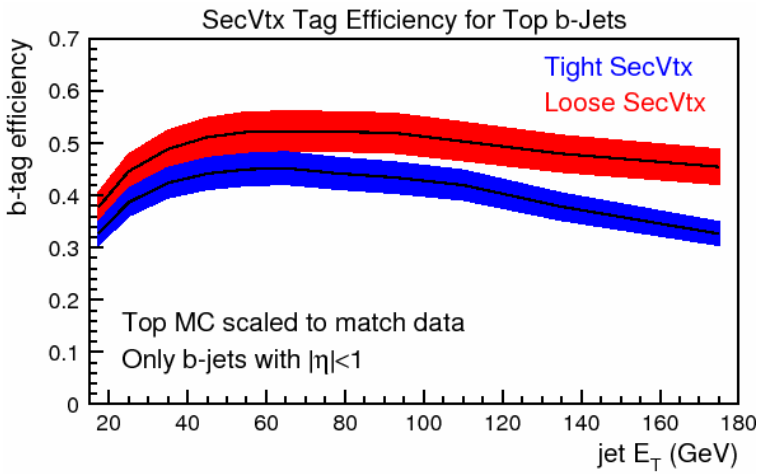
Usually the background estimate is the most delicate part (simulations and data-driven)

For the all-hadronic channel a tough thing is to reach a good S/B

# SecVertex b-tagging

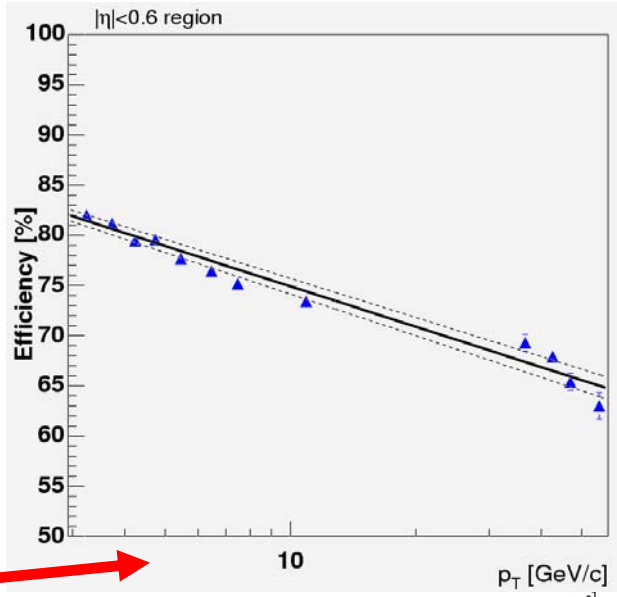
- The b-tagging is important, in some channels is essential
- A displaced secondary vertex is searched among high impact parameter tracks
- The efficiency is tuned on data

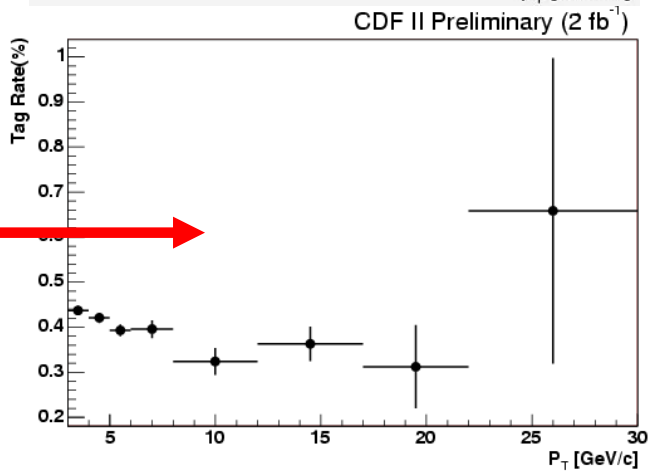


# Soft $\mu$ b-tagging

- HF enrichment can be done tagging soft-leptons from semileptonic B decays
- A well identified $\mu$ is searched matching tracks to muon chamber segments (likelihood)
- The efficiency is tuned on data (convol. $\varepsilon(p_T)$ to $p_T^{MC}$)
- Mistag parametrization from data ($\pi$,k,p samples)



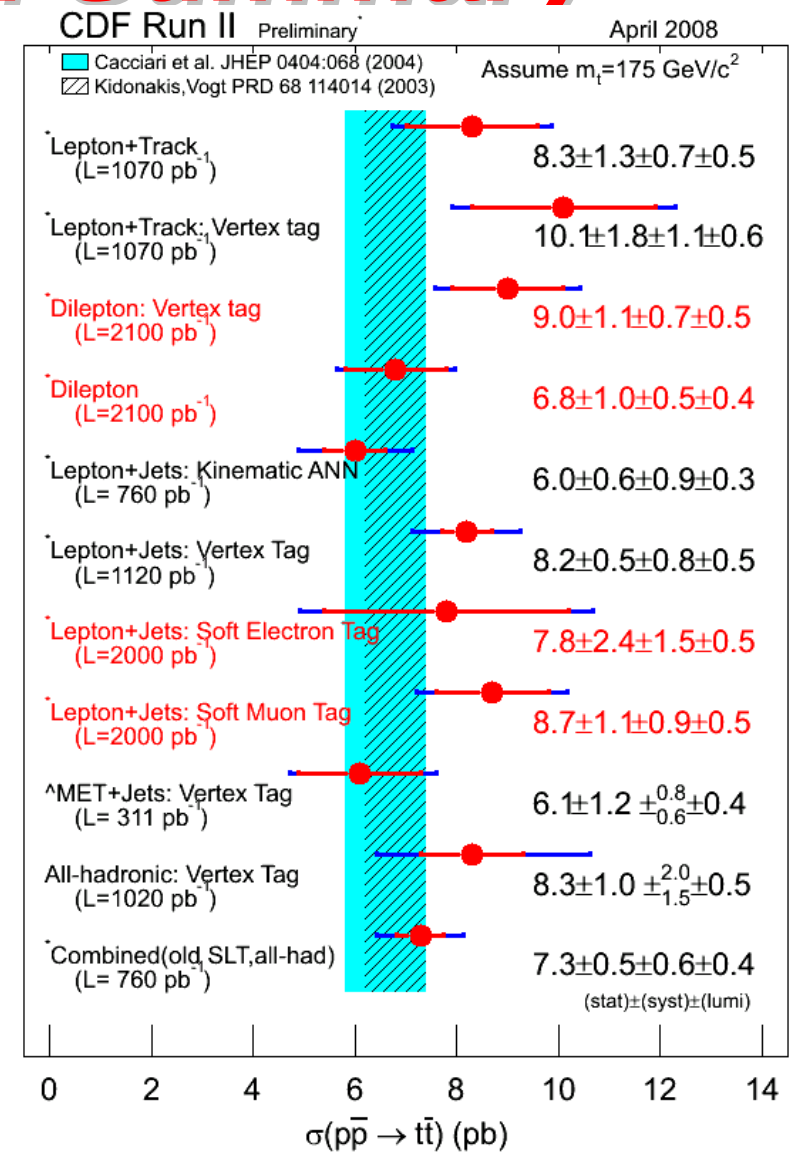



# ***What we measure***

- We measure individual cross section for different final states and with different selections
- We verify the consistency among individual $\sigma$
- We combine them into a CDF $\sigma$
- Eventually combine it with D0
- Shown here only 2 latest + most accurate measurements

# Cross-section Summary

- All channels are consistent
- Lepton+jets is the most accurate
- Systematics dominated by JES and b-tagging uncertainties
- Combined σ with ~10% accuracy, close to the theoretical one (<15%)



# *Dilepton+b-tag ($2fb^{-1}$)*

## *Selection:*

- Require two opposite charge isolated lepton ($e/\mu$) with $P_T$>20 GeV/c
- ≥ 2 jets ($E_T$>15 GeV, $|\eta|$<2.5)
- MET>20 GeV
- Require at least one sec-vertex b-tag

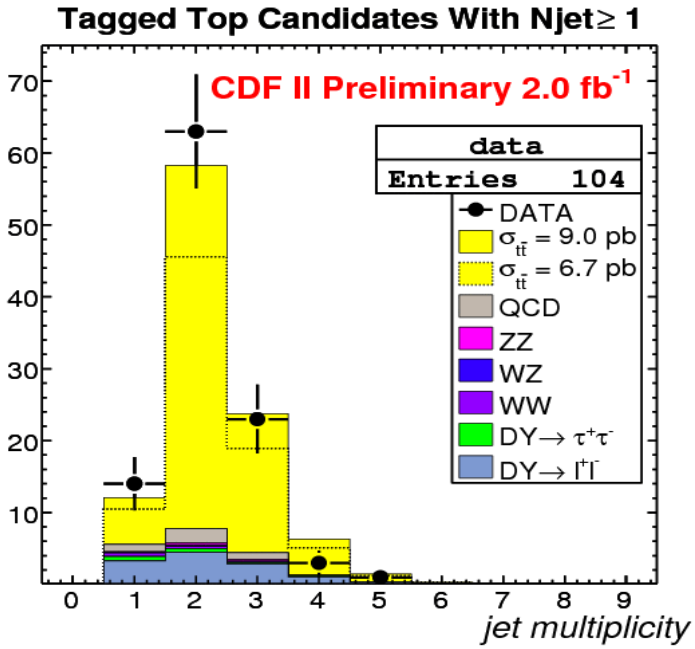
# Dilepton+b-tag ($2fb^{-1}$)

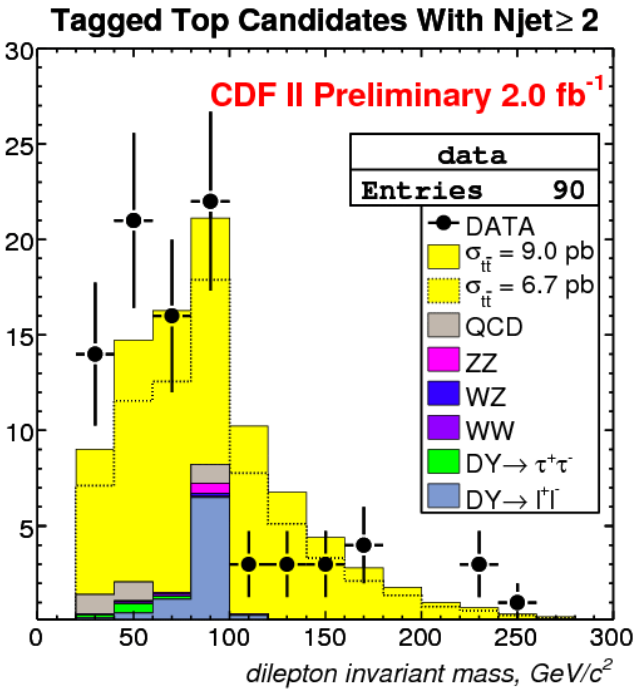
## Background:

1. Dominating bckgd: Drell-Yan $Z/\gamma^*$ events extrapolating from Z region + simulations
2. Diboson: WW,WZ,ZZ predicted from simulations
3. QCD (fake leptons): from data with 2 same-charge leptons

Then, for ZZ we count the tags, while for the others we apply a tag rate parametrization

# Dilepton+b-tag ($2fb^{-1}$)




Signal region: n=90, b=13±2

**$\sigma(tt) = 9.0 \pm 1.1\ (stat) \pm 0.7\ (sys) \pm 0.5\ (lum)$ pb**

Dominant systematics: uncertainty on JES (3%) and background (2%)

# Lepton+jets+soft $\mu$ ($2fb^{-1}$)

## *Selection:*

- Require one isolated lepton ($e/\mu$) with $P_T$>20 GeV/c
- $\geq$ 3 jets ($E_T$>20 GeV)
- MET>30 GeV
- $H_T=\Sigma E_T^{jet}+P_T^{lep}+MET>200$ GeV
- Require at least one soft $\mu$ b-tag

# Lepton+jets+soft $\mu$ ($2fb^{-1}$)

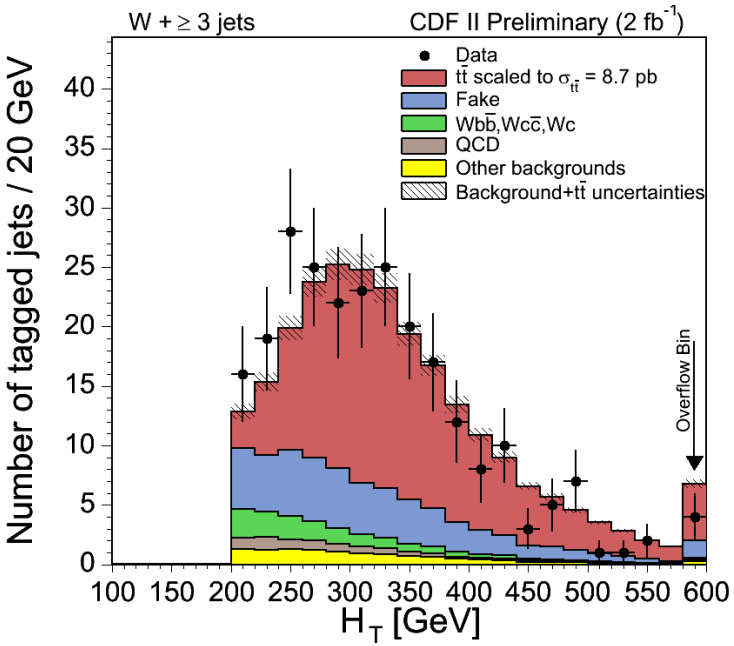
## *Background:*

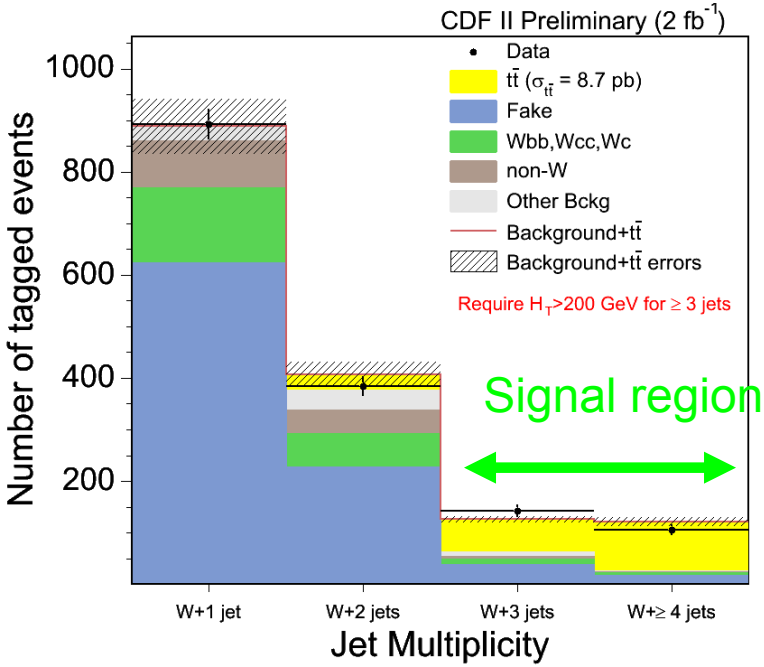
- Estimated with a combination of MC and data-driven methods
- W+jets is the dominant bckgd:

- HF fraction from MC
- light flavor from parametrized tag rate
- real HF from simulation but corrected $\varepsilon_{\mu tag}$

- Contributions from non-W events, diboson, and other channels are considered

# Lepton+jets+soft $\mu$ ($2fb^{-1}$)




Signal region: n=248 evts, b=87±6

**$\sigma(tt) = 8.7 \pm 1.1\ (stat) \pm 0.9\ (sys) \pm 0.6\ (lum)$ pb**

Dominant systematics: soft $\mu$-tagging acceptance (8%) and fakes (4%), W+HF fractions (4%)

# *Lepton+jets+b-tag (1.1fb$^{-1}$)*

## *Selection:*

- Require one isolated lepton (e/$\mu$) with $P_T$>20 GeV/c
- $\geq$ 3 jets ($E_T$>20 GeV)
- MET>30 GeV
- $H_T=\Sigma E_T^{jet}+P_T^{lep}+MET>250$ GeV
- Require at least one sec-vertex b-tag

# Lepton+jets+b-tag (1.1fb$^{-1}$)

## Background:

- Estimated with a combination of MC and data-driven methods
- W+jets is the dominant bckgd:

- normalization from data (pretag) subtracting non-W evts, tt, VV
- HF fraction from MC (Alpgen+Pythia)
- light flavor from parametrized tag rate
- real HF from simulation but corrected $\varepsilon_{btag}$

# *Lepton+jets+b-tag (1.1fb$^{-1}$)*

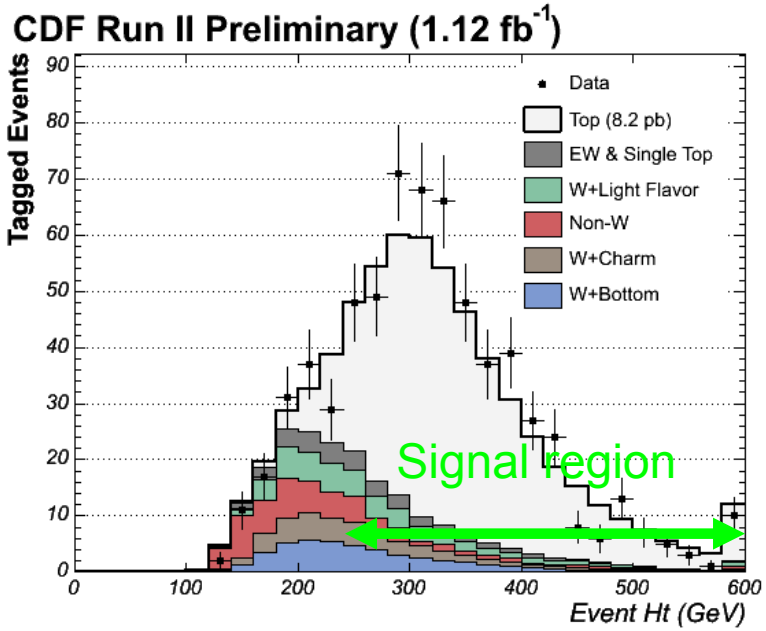
## *Background:*

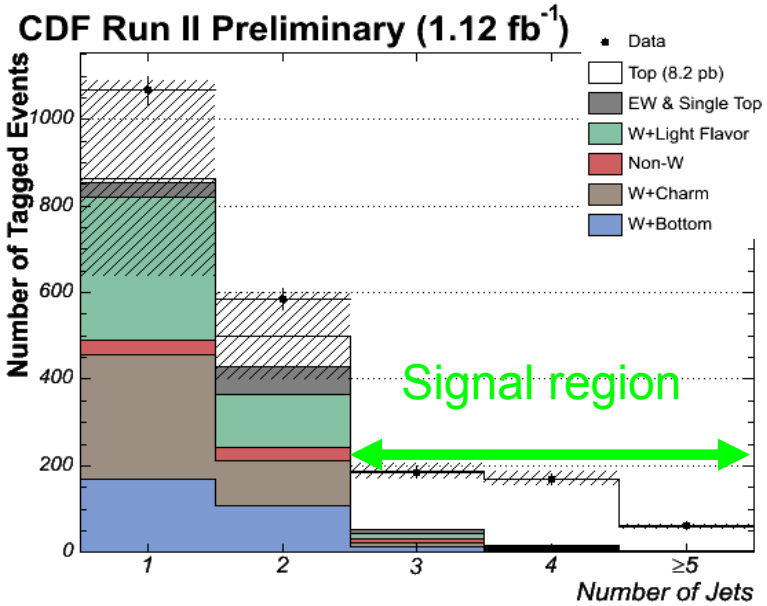
- Non-W (generic QCD with fake W):

 - extrapolated from MET distributions in pretag sample

- Contributions from single top, diboson are derived from MC

# Lepton+jets+b-tag (1.1fb$^{-1}$)




Signal region: n=416 tags, b=75 ±15

**$\sigma(tt) = 8.2 \pm 0.5\ (stat) \pm 0.8\ (sys) \pm 0.5\ (lum)$ pb**

Best CDF individual measurement !

# Lepton+jets+b-tag (1.1fb$^{-1}$)

Major systematics on the cross section:

- JES: the uncertainty on the jet energy correction translates into an uncertainty on the efficiency (6.1%)

- b-tagging: the MC efficiency is scaled to agree with data. The scale factor has an uncertainty which affects the efficiency (5.8%). Similar thing for c-tagging (1.1%)

- W+HF fraction: changed by 1$\sigma$ (3.3%)

- non-W fraction: changed by 1$\sigma$ (1.7%)

- mistag rate uncertainty: (1.0%)

# Lepton+jets+b-tag (1.1fb$^{-1}$)

- lepton ID: the MC efficiency is scaled to agree with data. The scale factor has an uncertainty which affects the ID efficiency (1.8%).

- ISR/FSR: compare samples with more/less (0.5/0.6%)

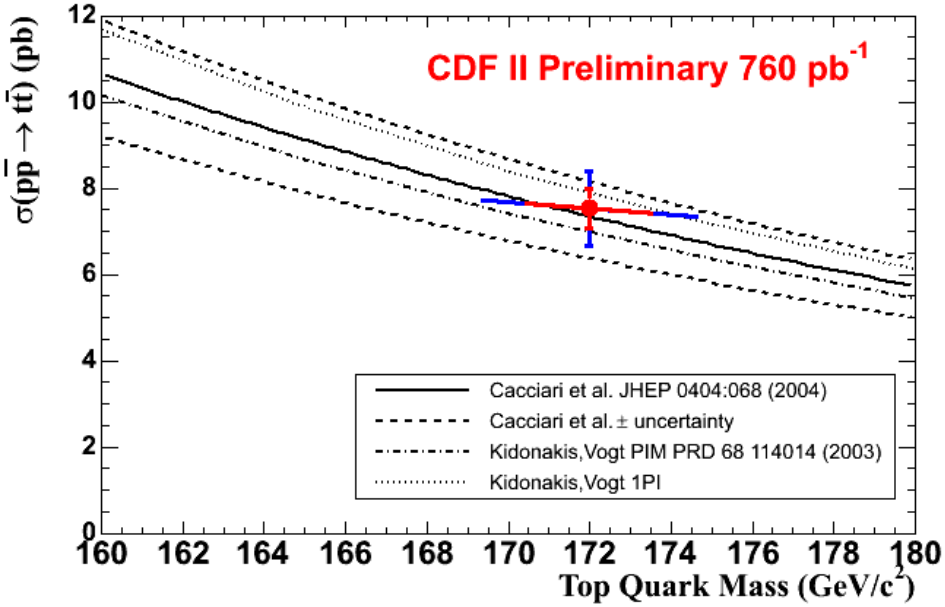
- generation/fragmentation modeling: comparing Pythia/Herwig (2.2%)

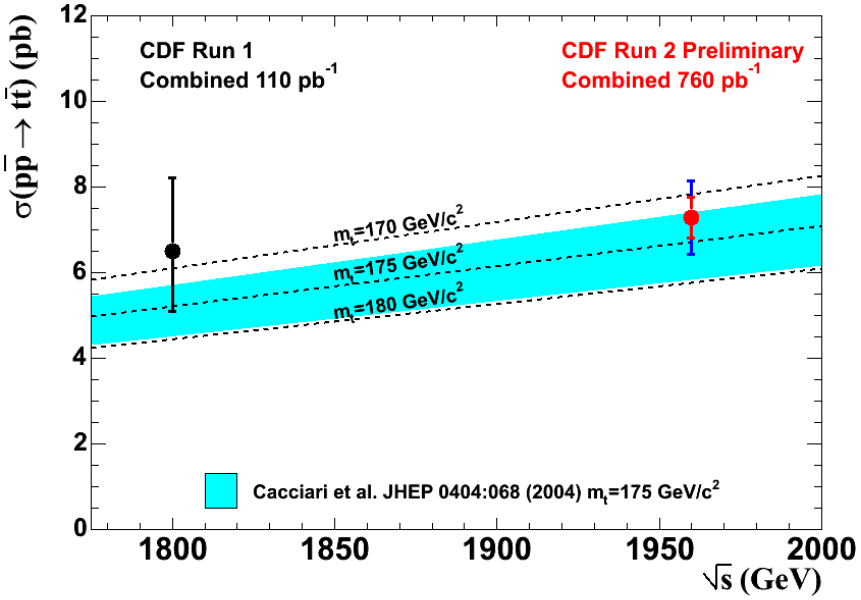
- PDF: deviations in different sets (MRST72, MRST75, CTEQ6M) (1.0%)

- luminosity: due to the uncertainty on inelastic $\sigma$ and precision of the luminosity counter (6.2%)

# Combined $\sigma$ vs theory

- The measured $\sigma$ is consistent with theory
- Combined CDF $\sigma$ (760 $pb^{-1}$) = **7.3 ± 0.5±0.6 ±0.4 pb**




Latest $M_{top}$=172.6 ± 1.4 GeV/$c^2$

# Conclusions

- CDF has measured $t\bar{t}$ production cross section in several complementary channels and with different selection techniques
- The accuracy of the measurements is comparable to the theoretical uncertainty
- Confirmation of the SM with no hints (so far) of New Physics

# Backup slides

# Lepton+jets+ANN

## Selection:

- Require one isolated lepton (e/m) with $P_T$>20 GeV/c
- ≥ 3 jets ($E_T$>15 GeV)
- MET>20 GeV + $0.5 \leq \Delta\phi \leq 2.5$ w.r.t. leading jet

## Background:

- W+jets: Alpgen ME generator + Herwig to evolve the partons to hadrons)
- QCD multi-jet: inferred from data passing all cuts but the lepton isolation (few % of bckgd)

# *Lepton+jets+ANN*

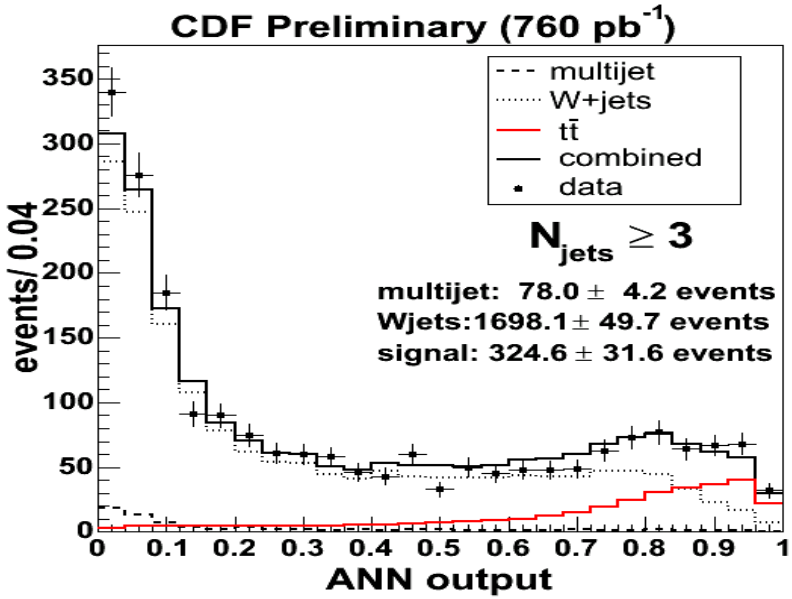
Then develop a NN based on 20 event variables.

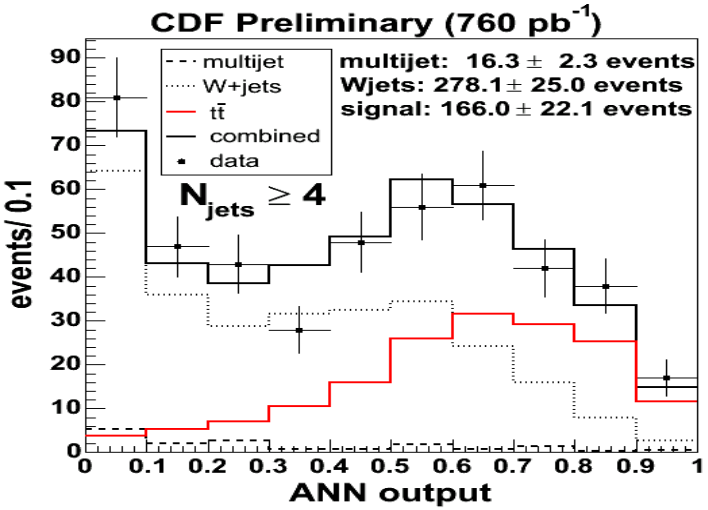
- NN training on S=tt and B=W+jets
- Define a binned likelihood in terms of $NN_{out}$
- Perform a likelihood fit on 3 populations

$$L(n_{tt}, n_W, n_{mj})$$

to extract the amount of signal

# Lepton+jets+ANN




Likelihood fit: n=2102, s=324.6 ±31.6, b=1776 ±54

**$\sigma(tt)$ = 6.0 ± 0.6 (stat) ± 0.9 (sys) ± 0.3 (lum) pb**

Dominant systematics: hard scattering scale used in MC, uncertainty on JES

# *Dilepton w. iso.track*

## *Selection:*

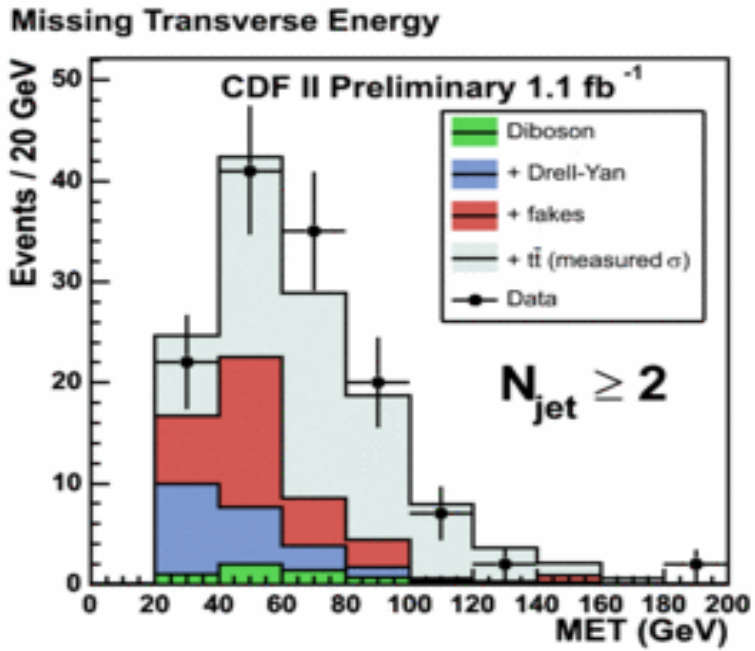
- Require one isolated lepton ($e/\mu$) + one isolated track with $P_T$>20 GeV/c
- ≥ 2 jets ($E_T$>20 GeV, $|\eta|$<2)
- MET>25 GeV + no jets/leptons in MET direction + MET>40 at Z resonance

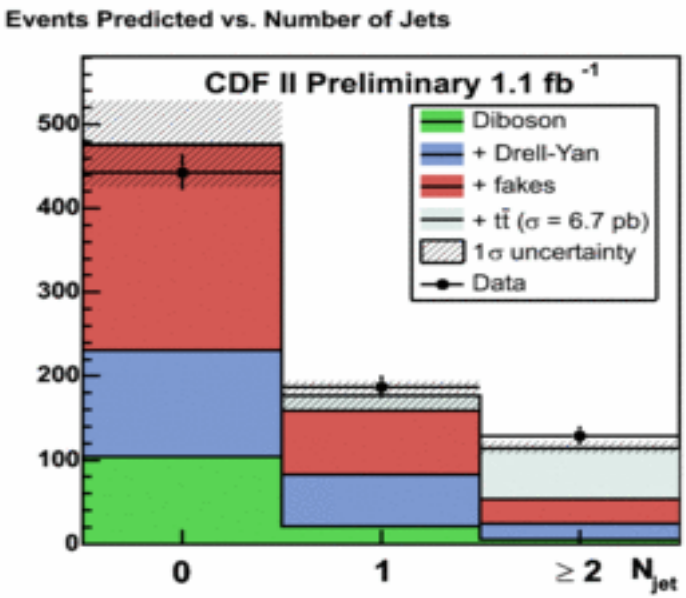
# Dilepton w. iso.track

## Background:

- Dominating bckgd: Drell-Yan $Z/\gamma^*$ events from simulations (normalization from data with no Z-veto)
- Diboson: WW,WZ,ZZ (and $Z/\gamma^* \rightarrow \tau\tau$) predicted from simulations
- QCD (fake leptons): from $\gamma$+jets data (analog to W+jets) + simulations

# Dilepton w. iso.track




Signal region: n=129, b=54.0±6.6

**$\sigma(tt)$ = 8.3 ± 1.3 (stat) ± 0.7 (sys) ± 0.5 (lum) pb**

Dominant systematics: (signal) JES +ISR/FSR; (bck) uncertainty on DY normalization and fake leptons

# *Allhad+b-tag*

## *Selection:*

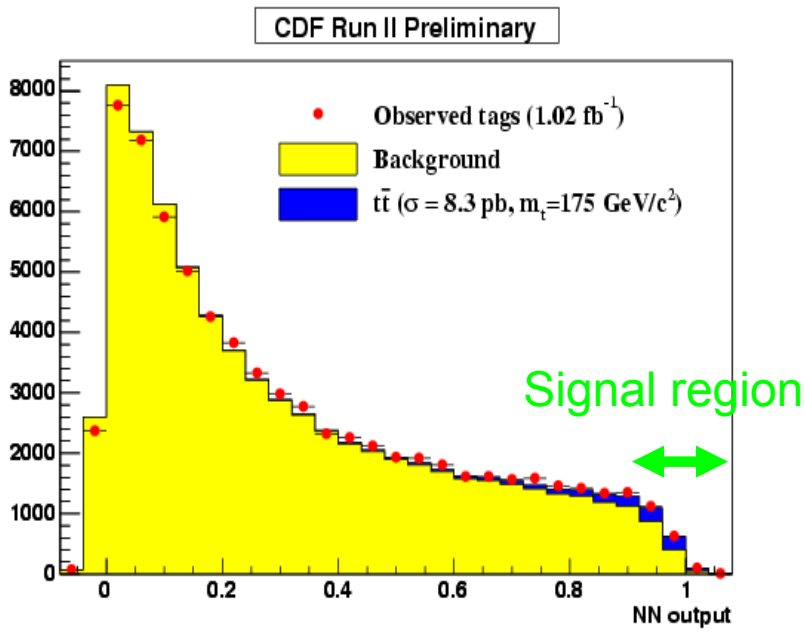
- After a dedicated multijet trigger S/B is still low (1/1100)
- Preselection: $6<=N_{jet}<=8$ ($E_T>15$ GeV, $|\eta|<2$
- A NN selection is needed (11 event variables): NN>=0.94 ($\varepsilon$=4.8%)
- We require also at least one tag ($n_{ave}^{tag}$=0.95)

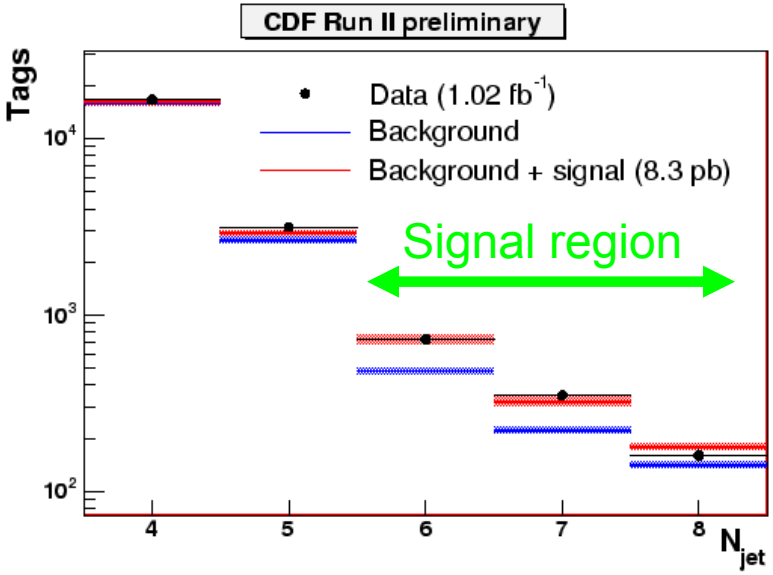
# *Allhad+b-tag*

## *Background:*

- Impossible to derive QCD background from MC simulations (too many events needed, large uncertainty on $\sigma_{QCD}$)
- Data driven background: tag rate parametrization evaluated in a control sample (4-jet events) and applied to the signal sample
- Background estimate is accurate within 2.5%

# Allhad+b-tag




Signal region:

n=1233 tags, b=846 ±37

$$\sigma(tt) = 8.3 \pm 1.0\ (stat)\ ^{+2.0}_{-1.5}\ (sys) \pm 0.5\ (lum)\ pb$$

Dominant systematics: JES, b-tagging, bck normalization