Top Quark Production Cross Section at E_{cm} = 2 TeV

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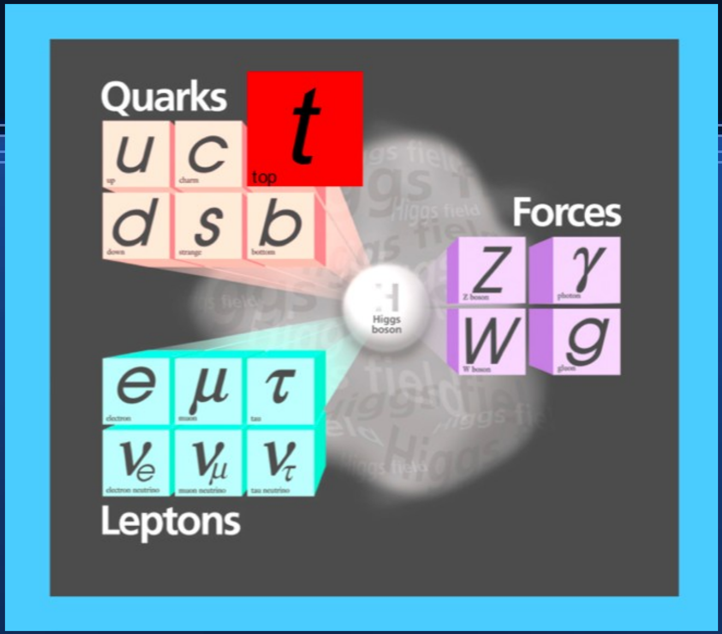
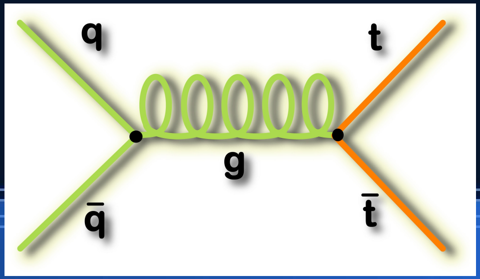
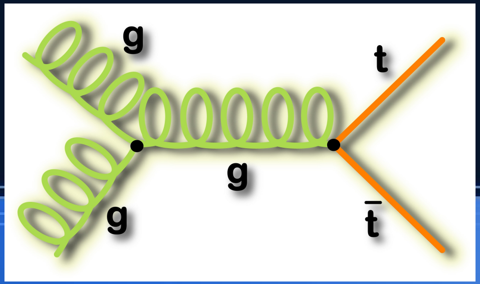
on behalf of

Rencontres de Moriond
La Thuile, 20-27 March 2011

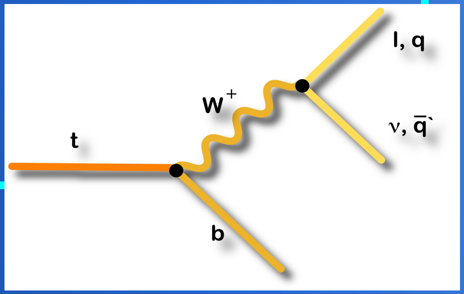
The top quark: from theory....







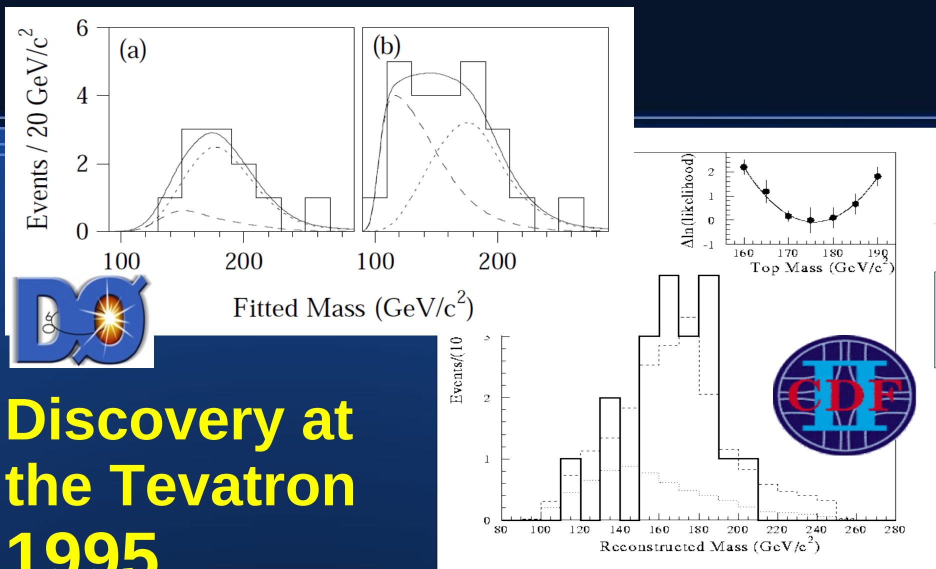
- Weak isospin partner of b quark
- Spin ½ fermion, Charge 2/3
- Produced in pairs via *qq annihilation or gg fusion*
- Lifetime ~ 5 10^{-25} s
- Decays (BR ~ 100%) in **Wb**



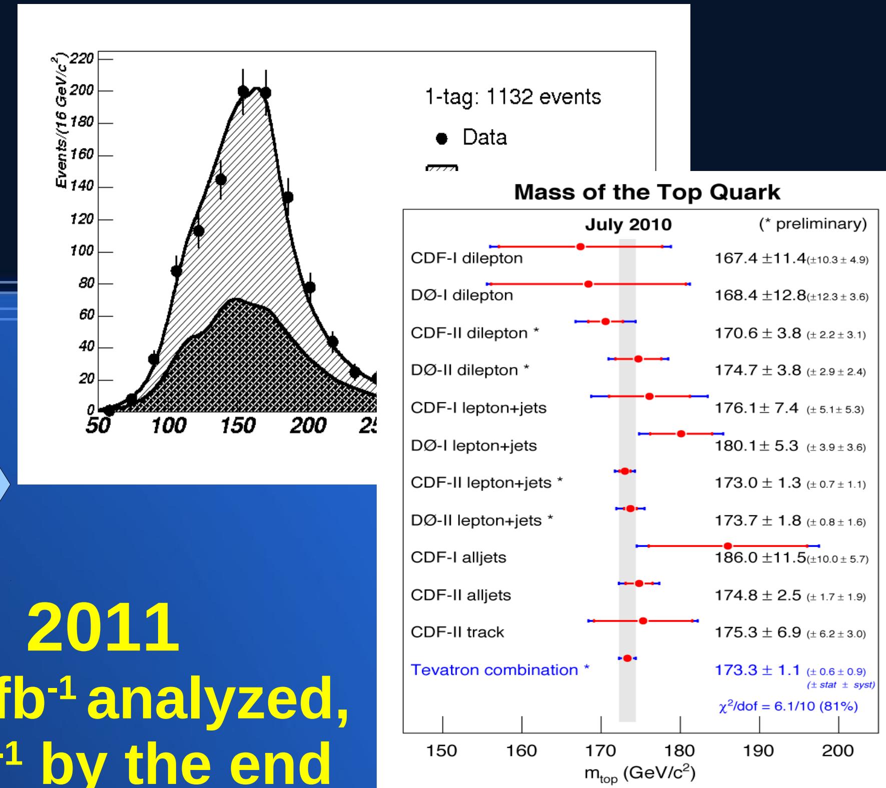
Most precise predictions of the production cross section are given by *approximate NNLO calculations,* with a **precision of 6% to 9%.**

For M_t = 172.5 GeV/c^2, $\sigma_{t\bar{t}}$ ~7.5 pb.

… to experiment



Discovery at the Tevatron 1995 (67 pb^{-1})



2011 (> 5 fb^{-1} analyzed, 10 fb^{-1} by the end of RunII)

- Mass known with a precision < 1% → ***see next talk by Zhenyu Ye***
- Top properties (charge, width, …) deeply investigated → ***see Oleg Brandt's talk***
- Single top → ***see Victor Batzerra's talk***
- Top samples now land for searches for new physics → ***see Dookee Cho's talk (Last Monday)***

Measuring the top cross section

Why?

- Test of pQCD at high energy
- Probe for *new physics*
    - Does a charged Higgs H^{+-} exist? If $t \rightarrow H^{+-} b$, we would see a change in the relative ratio of the various cross sections.
    - Is A_{fb} due to a new production mechanism? If so it could modify the top cross section.
- Extract *top quark mass from cross section*
- *Background to Higgs searches*

Measuring the top cross section

How?

Event counting or fit of discriminating variable shape

Expected background events

$$\sigma_{t\bar{t}} = \frac{N_{observed} - N_{background}}{\varepsilon_{t\bar{t}} L}$$

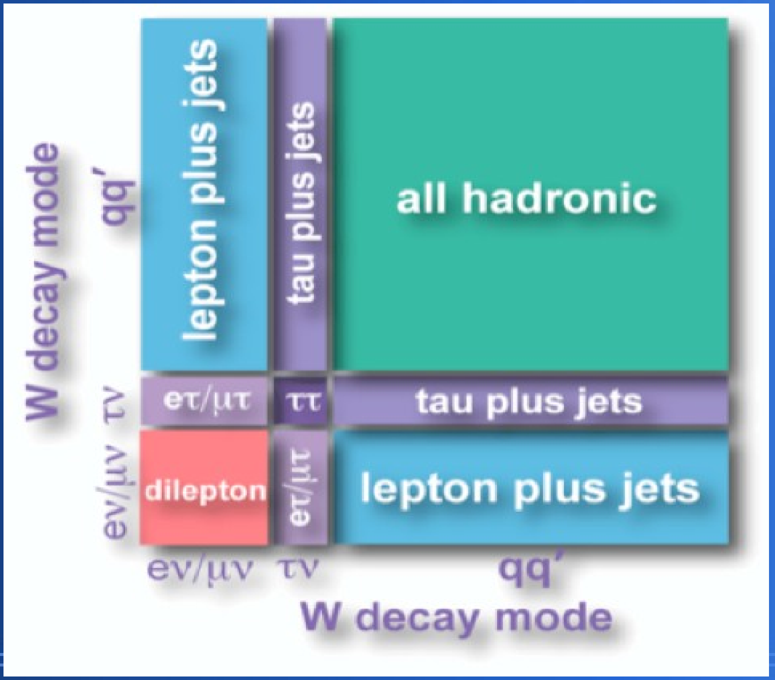
Efficiency on signal selection

Recorded data

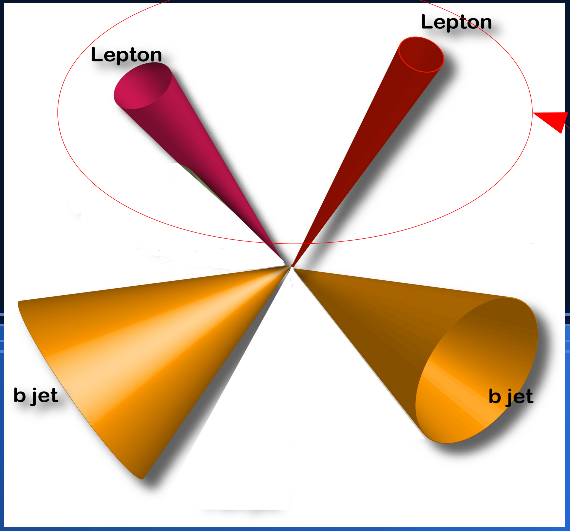
Investigate all possible decay channels

Different channels sensitive to different new physics, for example:

- If $\tan\beta > 1$, $H^+ \rightarrow \tau^+\nu_\tau$, tau modes enhanced
- If $\tan\beta < 1$ and H^+ is light, $H^+ \rightarrow c\bar{s}$, all hadronic modes enhanced.

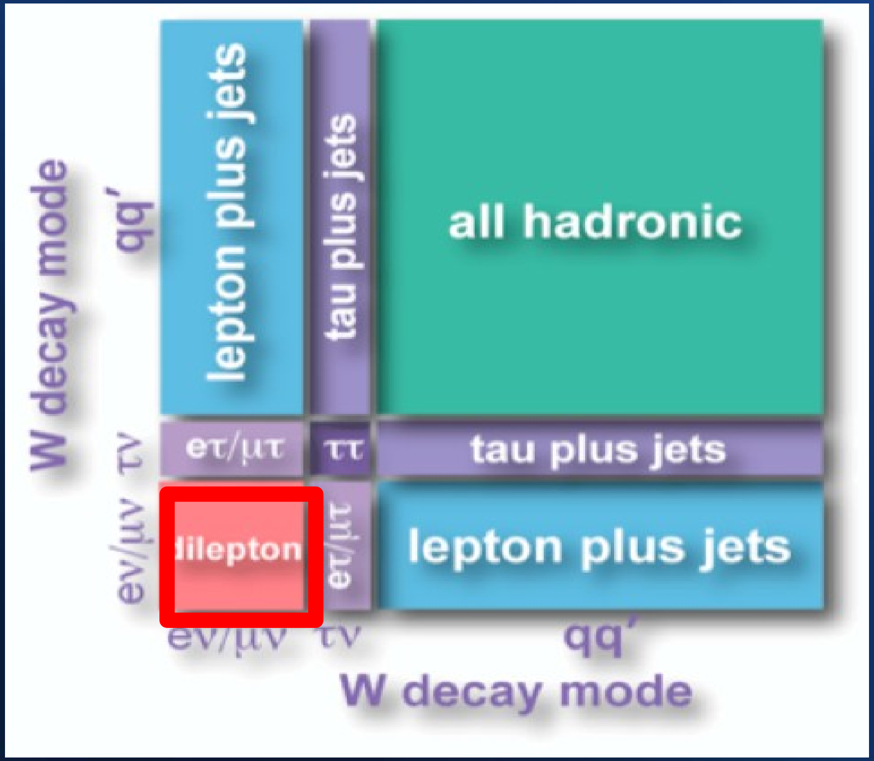


The dilepton channel



Key element: Lepton ID

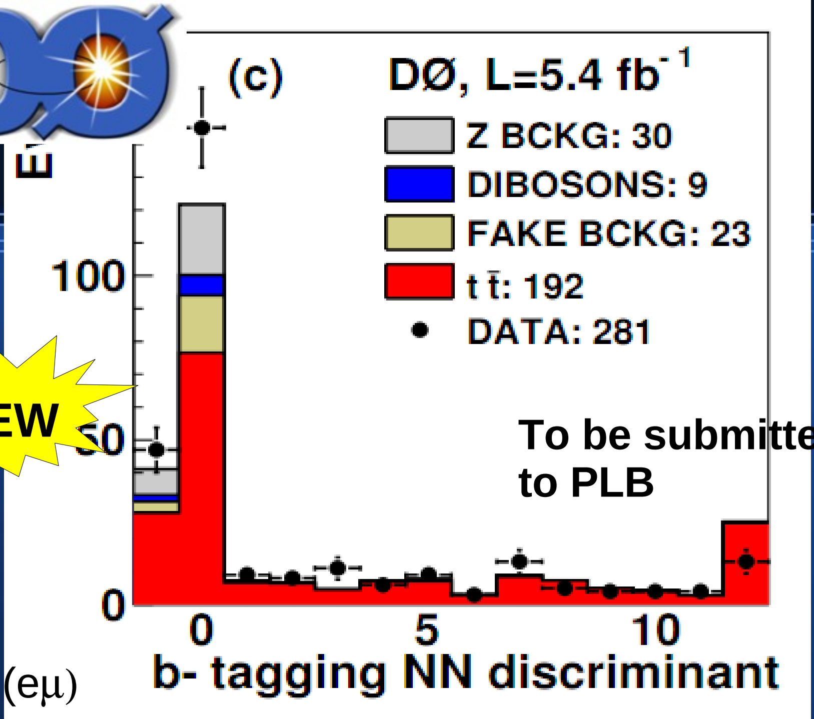
Low BR (5%)
Cleanest signature → 2 e/μ

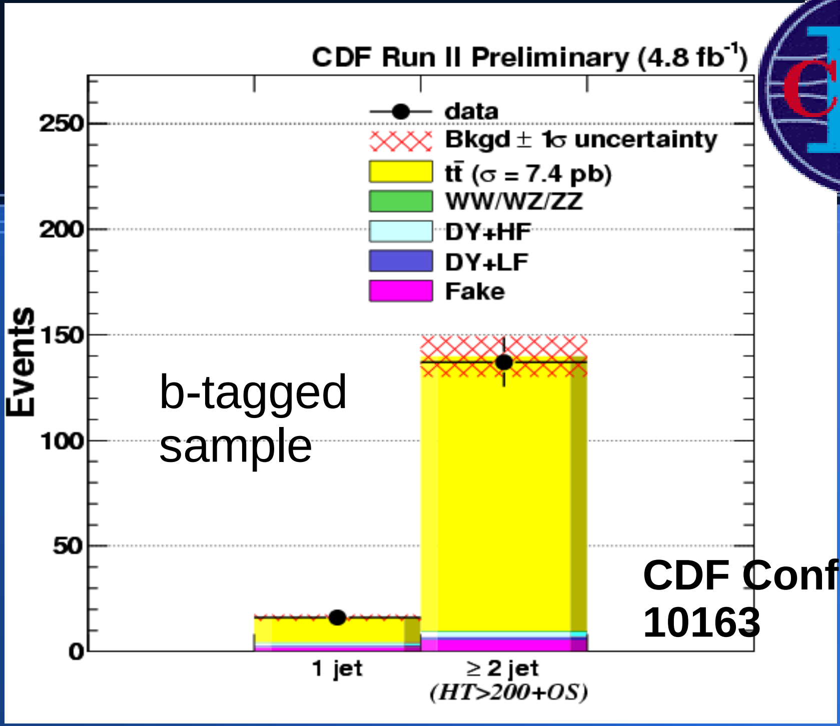


Selection:
- 2 high-Pt leptons, opposite sign
- Missing Et
- At least 2 jets

Background:
- Physics
  - DY (MC or Data), WW/ZZ/WZ (MC)
- Instrumental
  - W+jets, Wγ (Data)

Inclusive $t\bar{t}$ xsec in dilepton channel





- 4 channels (ee, μμ, eμ, eμ+1jet)
- Cross section from simultaneous fit of the b-tagging NN discriminant outputs
- Systematic uncertainties included in the fit (**20% improvement**)

Systematic dominated

Most precise result in dilepton channel! $\Delta\sigma/\sigma \sim 11\%$

- All leptonic modes together
- Counting method

$\Delta\sigma/\sigma \sim 13\%$

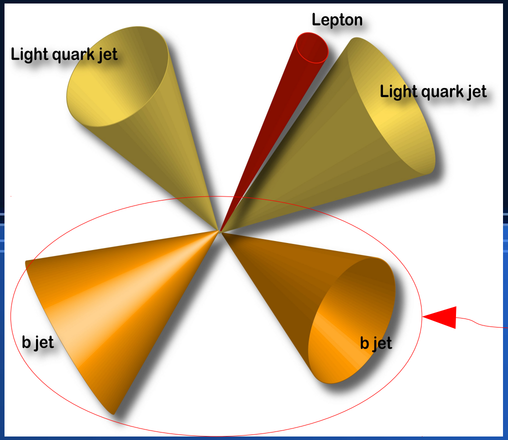
$M_t = 172.5$ GeV/c^2

D0 → $\sigma_{t\bar{t}} = 7.4^{+0.9}_{-0.8}$ (stat + syst) pb

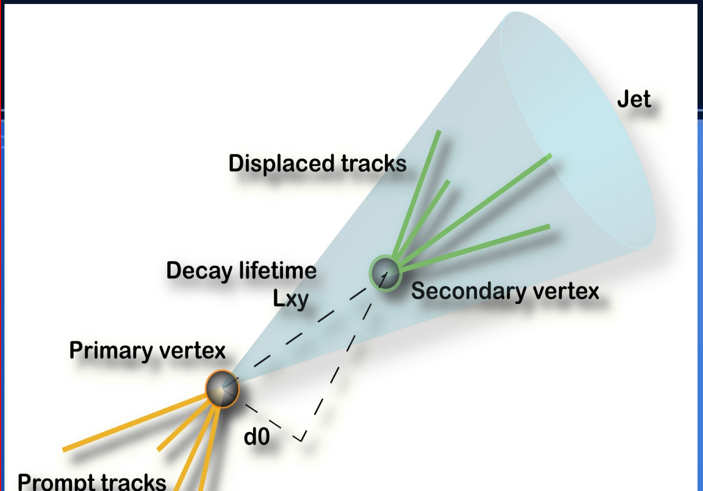
CDF → $\sigma_{t\bar{t}} = 7.25 \pm 0.66$ (stat) ± 0.47 (syst) ± 0.44 (lumi) pb (b-tagged sample)

The lepton+jets channel

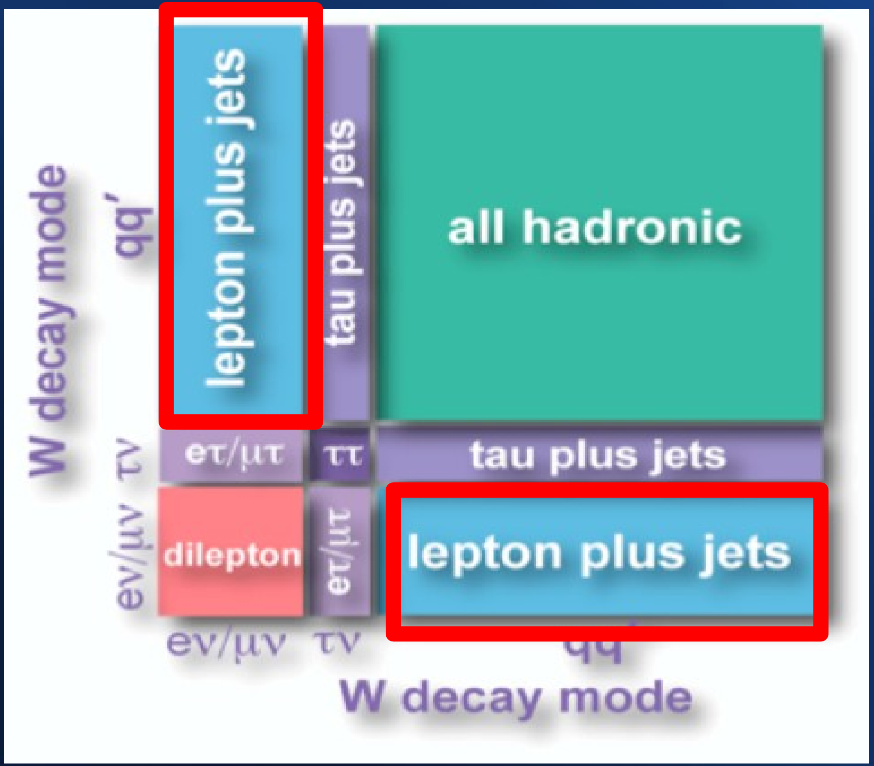
Best compromise between BR (30%) and clean signature



Key element: b-jet identification



- **Eff ~ 50%**
- **Mistag rate ~ 0.5%**

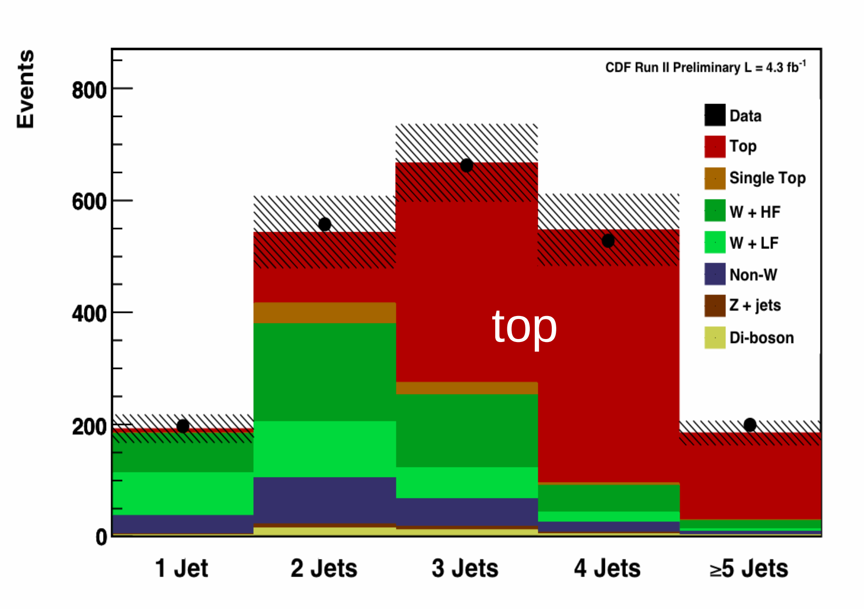


Selection:
- 1 high-Pt isolated e/μ
- Missing E_T
- ≥ 1 jet

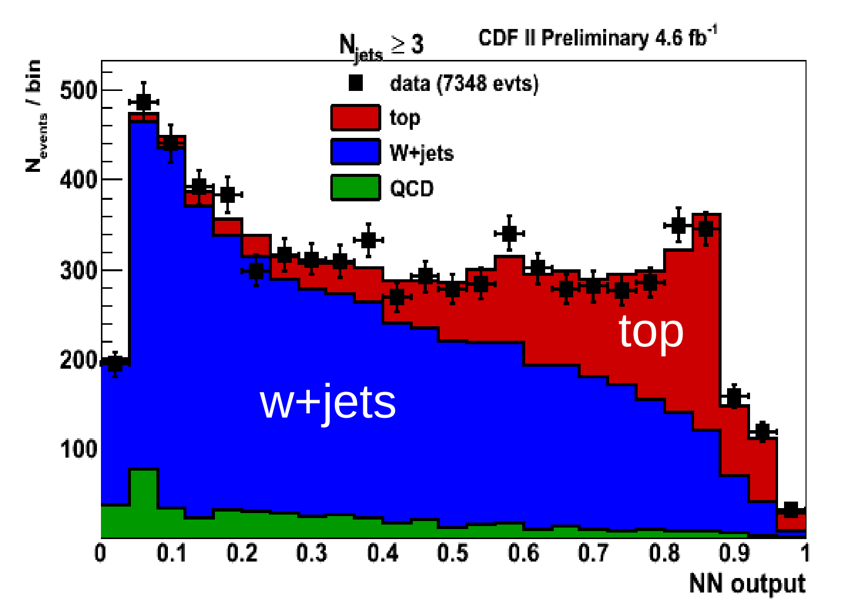
Background:
- Physics
  - W+jets (Data + MC)
- Instrumental
  - QCD (Data)

Inclusive tt xsec with ratio over Z xsec

1^{st} application to $t\bar{t}$ xsec!



B-tagging to reduce background. Xsec from likelihood fit.



NN to separate $t\bar{t}$ from background exploting kinematic differences. Xsec from NN output fit.

Results dominated by systematics. Dominant uncertainty from *integrated luminosity* ***(6%)***

$$R = \frac{\sigma_{t\bar{t}}}{\sigma_Z}$$

Measured on the same sample

$$\sigma_{t\bar{t}} = R \cdot \sigma_Z^{theory}$$

2% uncertainty

$\Delta\sigma/\sigma \sim 7\%$

$\sigma_{t\bar{t}}$ = 7.70 ± 0.52 (stat + syst + theory) pb (combined)

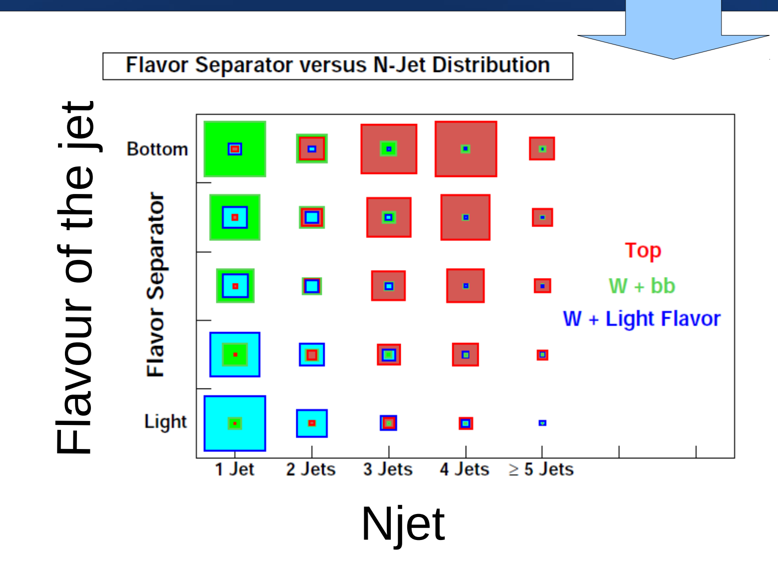
M_t = 172.5 GeV/c^2

arXiv:1004.3224v2 [hep-ex]

Inclusive $t\bar{t}$ xsec with simultaneous kinematic fits

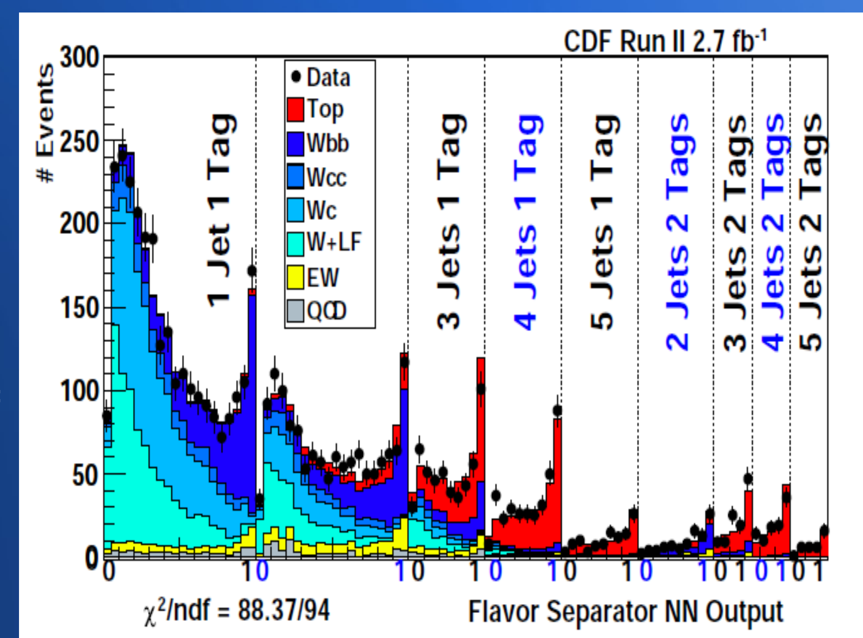
After b-tagging, W+HF MC simulation source of large systematic uncertainty → can we constrain the W+HF fraction to the data?

We need variables to discriminate W+HF from $t\bar{t}$ and W+LF: **flavor** from NN flavour separator + **N_{jet}**



Template = flavor distribution for (N_{jet}, N_{tags})

Simultaneous fit of **$\sigma_{t\bar{t}}$, W+HF**, W+LF **and systematic uncertainties**



21% improvement!

$\sigma_{t\bar{t}}$ = 7.64 ± 0.57 (stat + syst) ± 0.45 (lumi) pb

$\Delta\sigma/\sigma \sim 9\%$

M_t = 175 GeV/c^2

CDF Public Note 10427 (to be submitted to PRL)

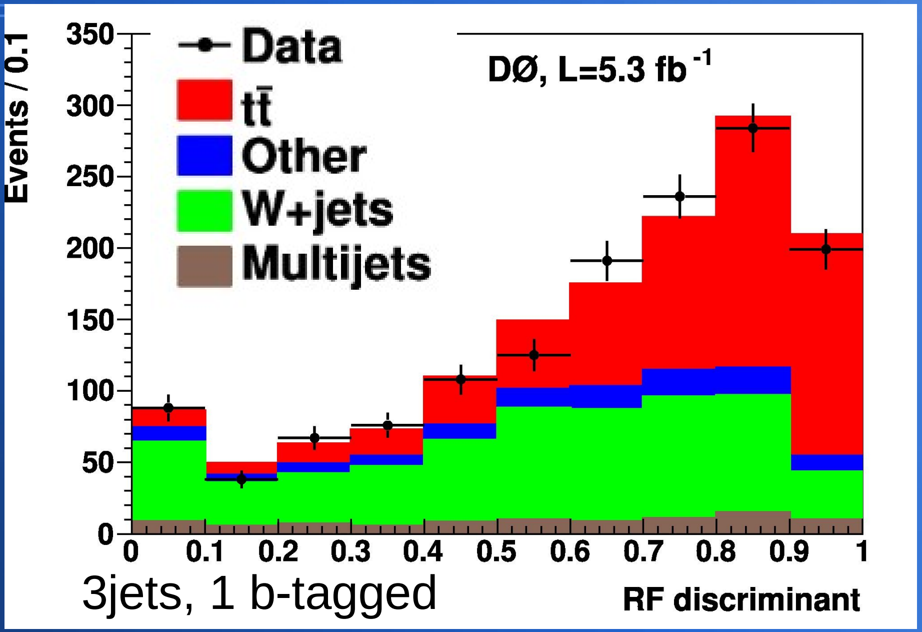
Inclusive $t\bar{t}$ xsec with kinematic + b-tagging methods

Split samples according to $\mathbf{N_{jet}}$ **and** $\mathbf{N_{btag}}$

- **> 2 jets**, **0-1 b-tag** → Discriminant (BDT) based on kinematic variables.

- **> 2 jets, 2 b-tags** → High S/B. b-tagged event distribution.

- **2 jets, ≥ 1 b-tag** → Low S/B. Used to measure W+HF scale factor



Xsec from binned likelihood fit considering all channels and *incorporating systematic uncertainties.*

M_t = 172.5 GeV/c^2

$\boldsymbol{\sigma_{t\bar{t}} = 7.78\,^{+0.77}_{-0.64}}$ **(stat + syst + lumi) pb**

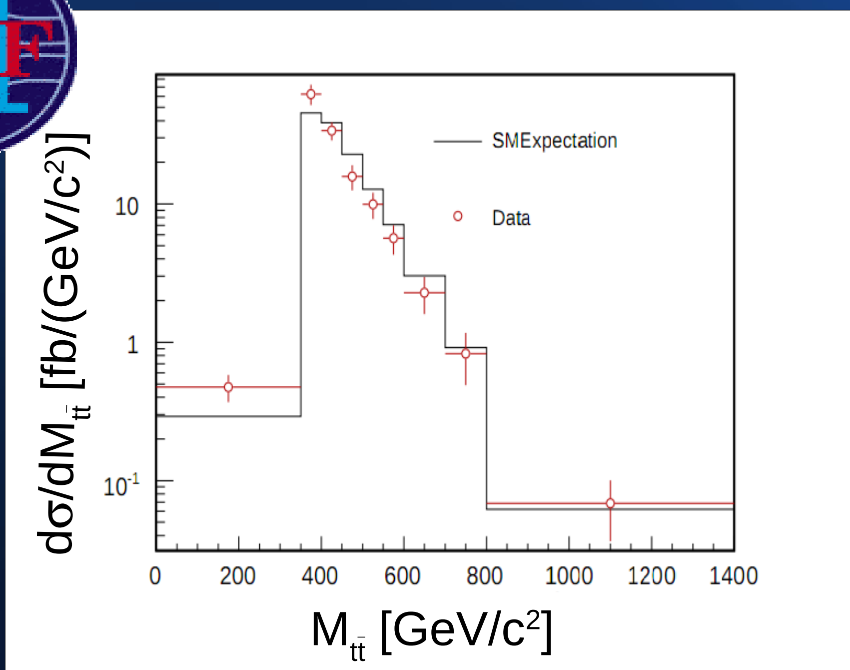
$\Delta\sigma/\sigma \sim 9\%$

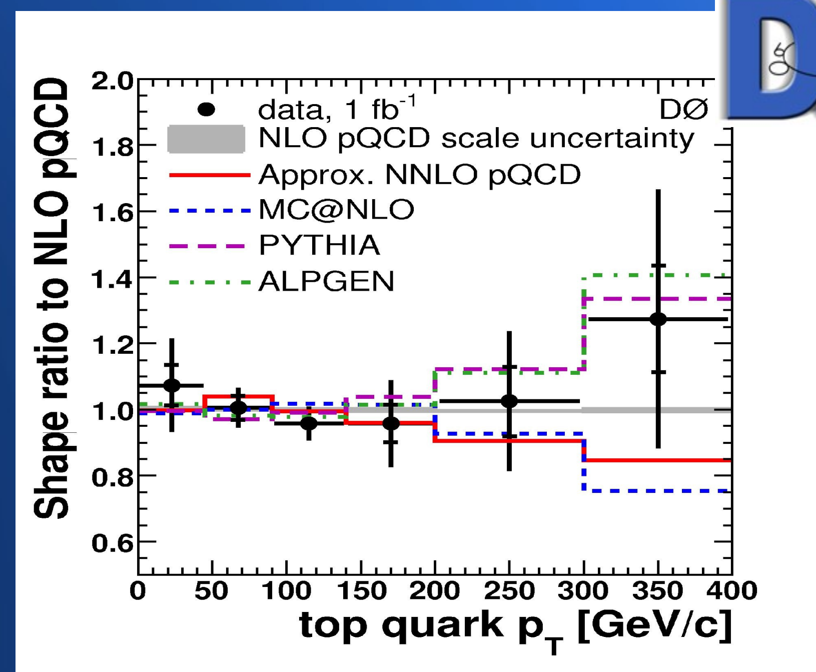
Differential cross section

Differential cross section measurements
- precision test of pQCD calculations
- can probe non-SM production mechanisms

Dependence on top mass:
- 1-2 b-tags, $W \rightarrow q\bar{q}$ to constrain JES
- Reconstruct $t\bar{t}$ invariant mass
- Correct for detector effects

Dependence on p_T:
- Associate leptons and jets with individual tops quarks by means of a constrained kinematic fit to the tt final state
- Correct for detector effects





M_t = 175 GeV/c^2

arXiv:0903.2850v1 [hep-ex]

M_t = 170 GeV/c^2

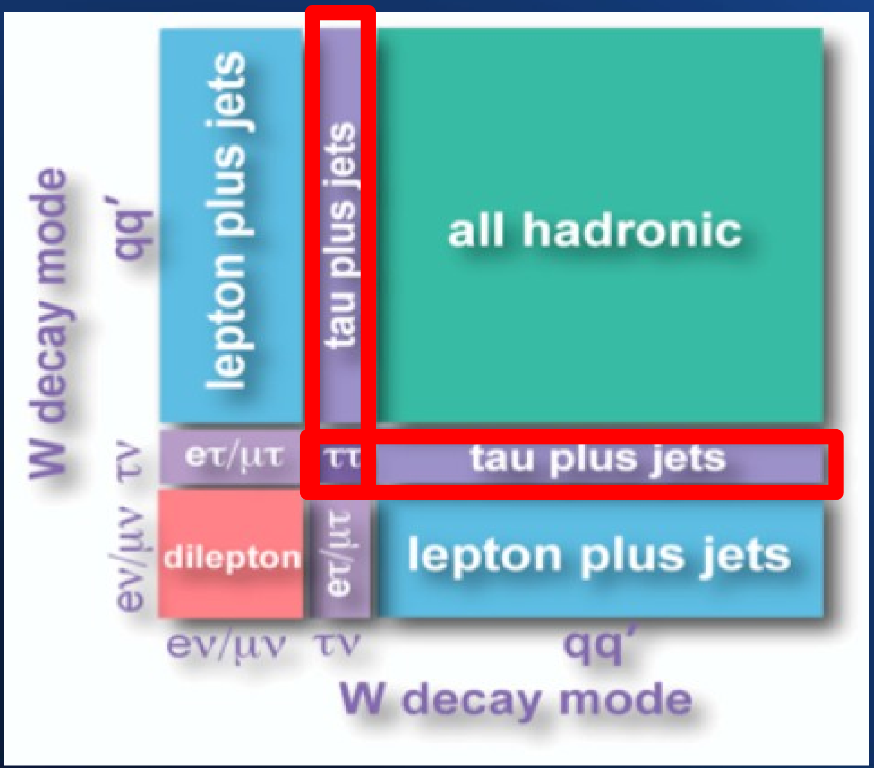
arXiv:1001.1900v2 [hep-ex]

Final states with τ

BR ($tt \rightarrow \tau$ + jets) ~ 15 %

- $\tau \rightarrow \nu_\tau \nu_e e$ (B.R.~17%)
- $\tau \rightarrow \nu_\tau \nu_\mu \mu$ (B.R.~17%)
- $\tau \rightarrow \nu_\tau X_h$ (B.R.~65%)

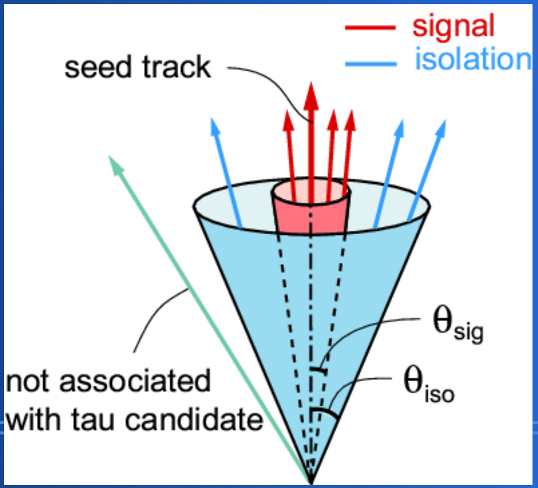
l+jets analysis (the first two decays)



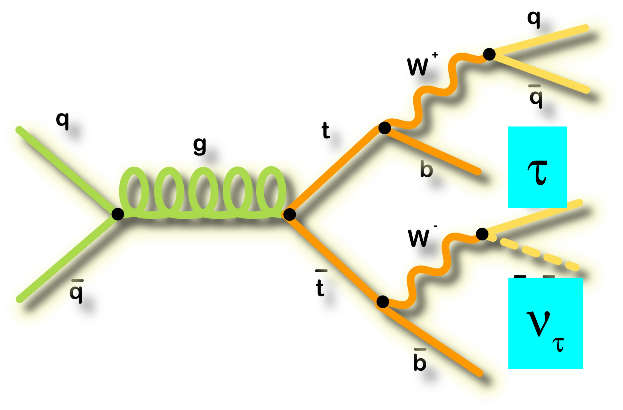
Hadronic tau difficult to identify. Look for a low track multiplicity jet, exploit calorimeter and tracking isolation

Background:

- Physics
  - W/Z+jets (Data + MC)
- Instrumental
  - QCD (Data)

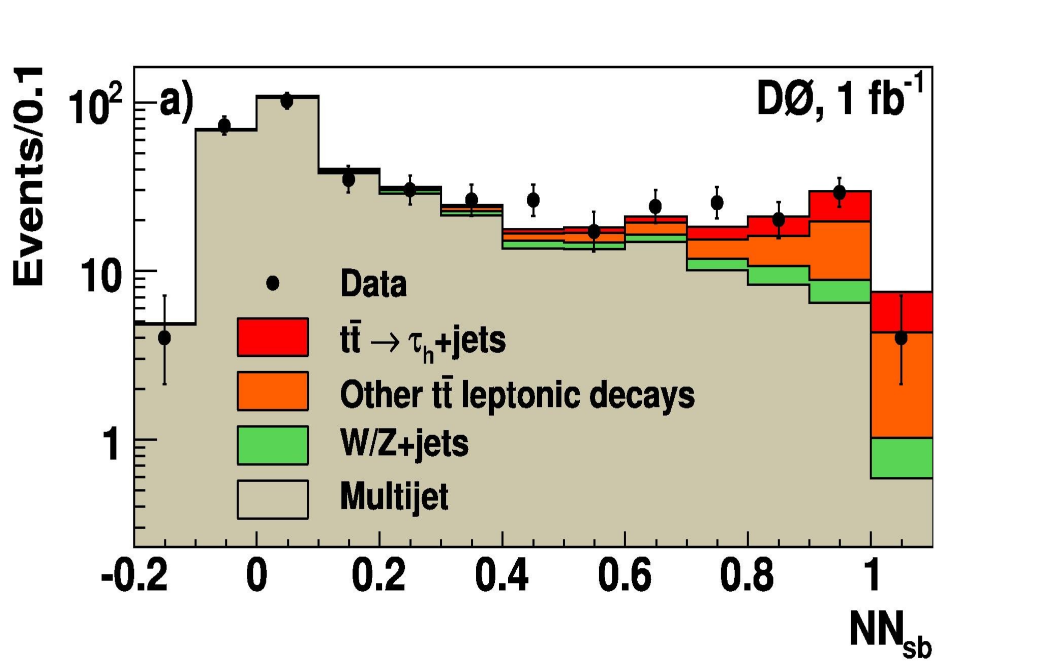


τ + jets



Sensitive to new physics (t → **H**$^{+-}$ b → $\boldsymbol{\tau\nu_\tau}$ b)

- Hadronic tau τ_h , ≥ 4 jets, ≥ 1 b-tag
- Neural network based analysis:
  - τ_h from fakes
  - Signal events from bgnd (W+jets, QCD)
- NN output fit



$$\sigma_{t\bar{t}} BR_{\tau h+j} = 0.60^{+0.23}_{-0.22} \text{(stat)}\ ^{+0.15}_{-0.14} \text{(syst)} \pm 0.04 \text{ (lumi) pb}$$

M_t = 170 GeV/c^2

$$BR_{\tau h+j} = 0.074^{+0.029}_{-0.027}$$

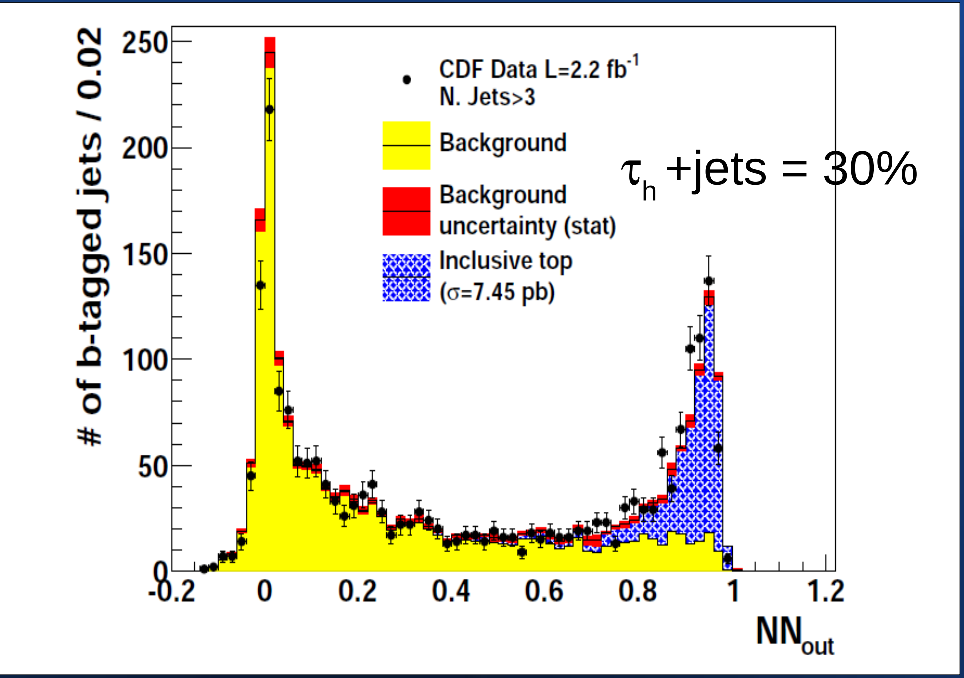
In agreement w/ SM

arXiv:1008.4284v2 [hep-ex]

Missing E_T + jets

Analysis focus on Met from neutrino instead of lepton ID
Sensitive to leptonic W decays regardless of lepton type
Veto on leptons: statistically independent samples wrt to l+jets

Met + ≥ **4 jets, ≥ 1 b-tag, NN, counting method**



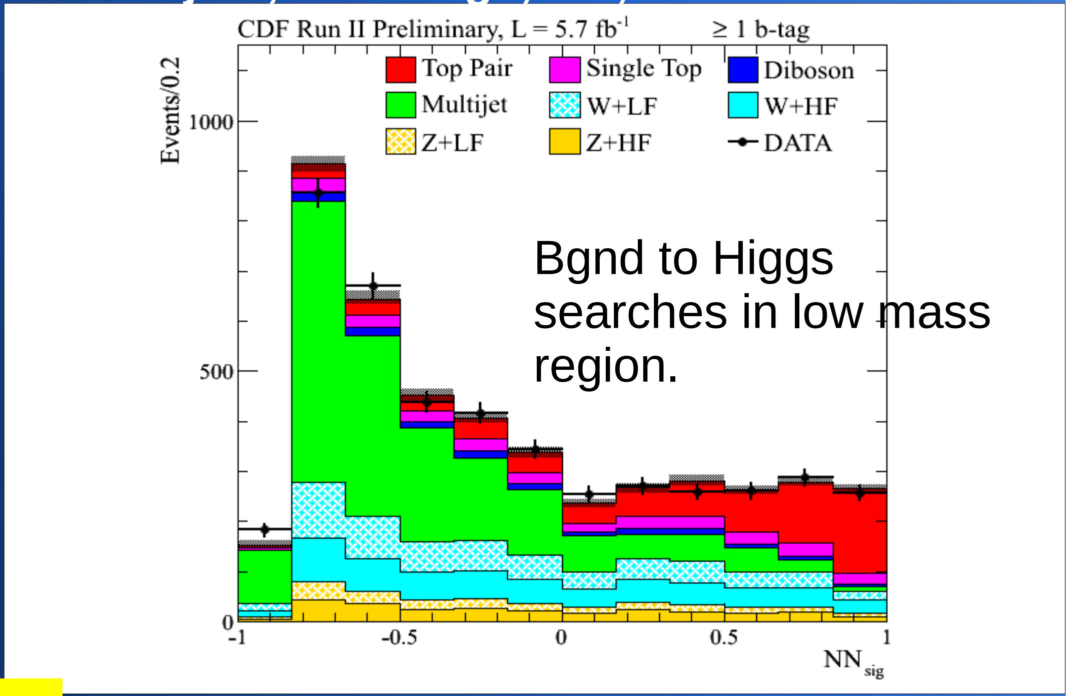
$\sigma_{t\bar{t}}$ = 7.99±0.55 (stat)±0.76 (syst)±0.46 (lumi) pb

M_t = 172.5 GeV/c^2

$\Delta\sigma/\sigma \sim 13\%$

CDF conference note 9988
To be submitted to PRD

Met + **2-3 jets, 1-2 b-tags, NN, binned likelihood**



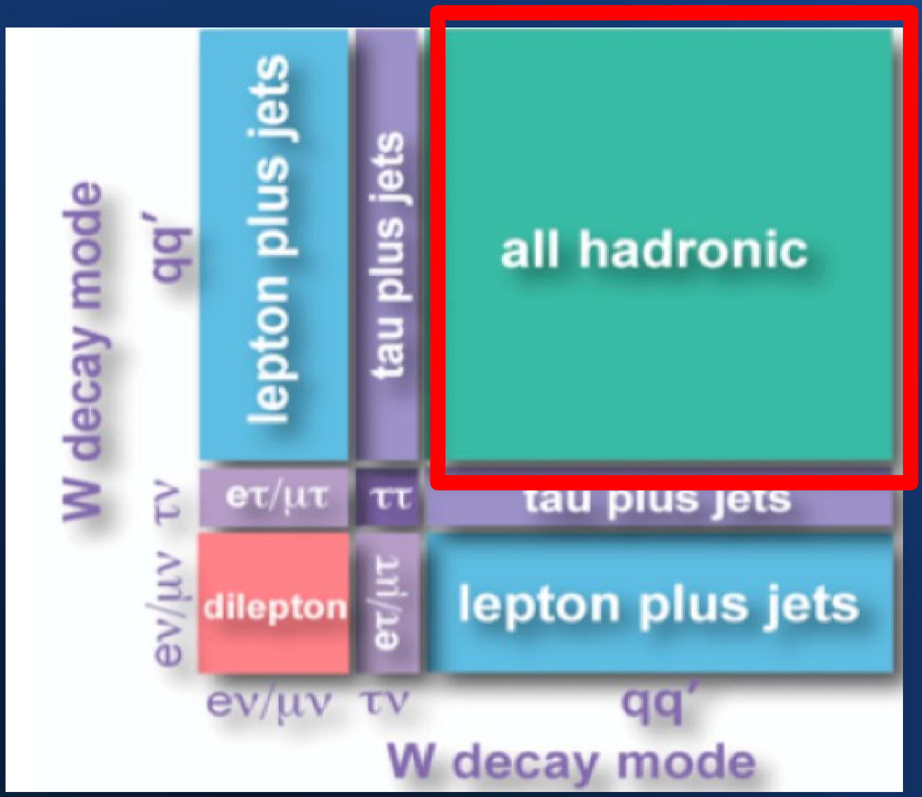
$\sigma_{t\bar{t}} = 7.12^{+1.20}_{-1.12}$ (stat + syst) pb

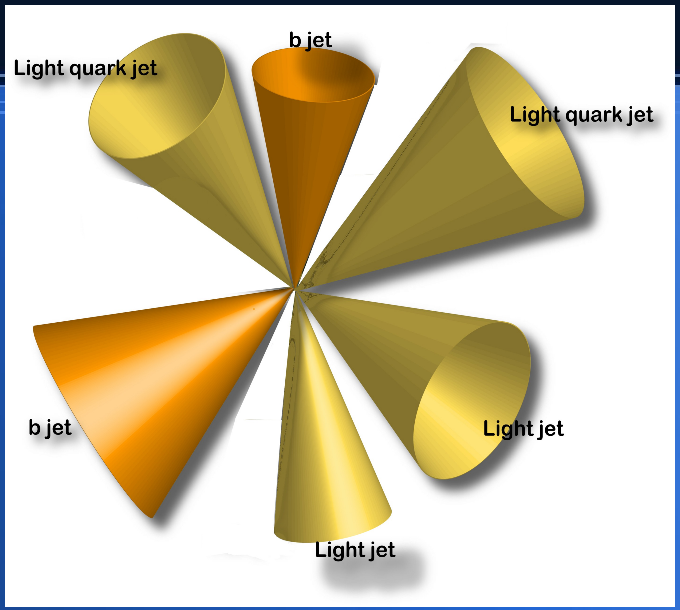
CDF conference note 10237

$\Delta\sigma/\sigma \sim 16\%$

All-hadronic final states

Highest BR (46%), no neutrinos in the final state
Huge background from QCD multijet events



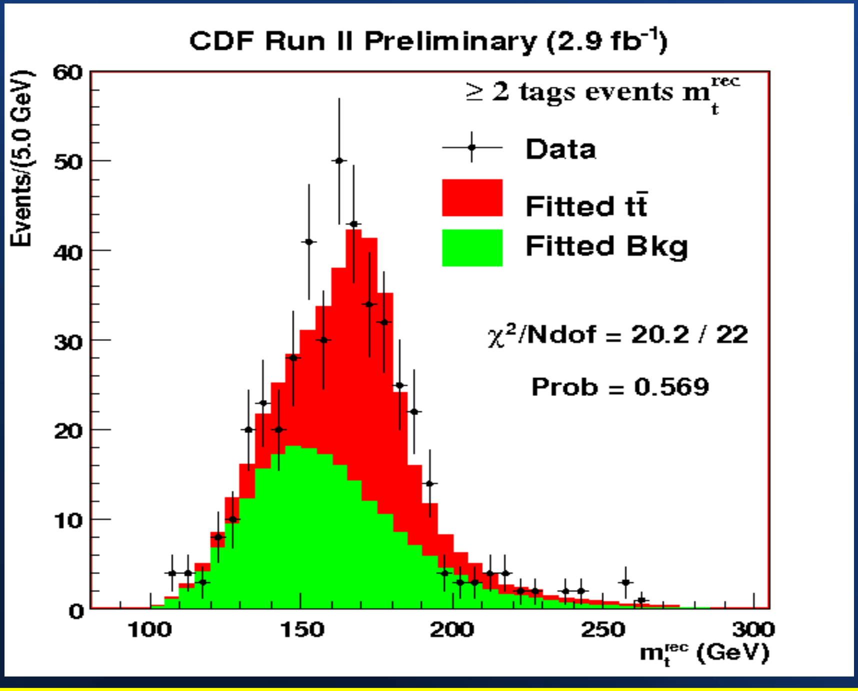


Selection:
- At least 6 jets of which 1-2 b-tagged

Background:
- Physics
  - QCD (Data)

All-hadronic final states

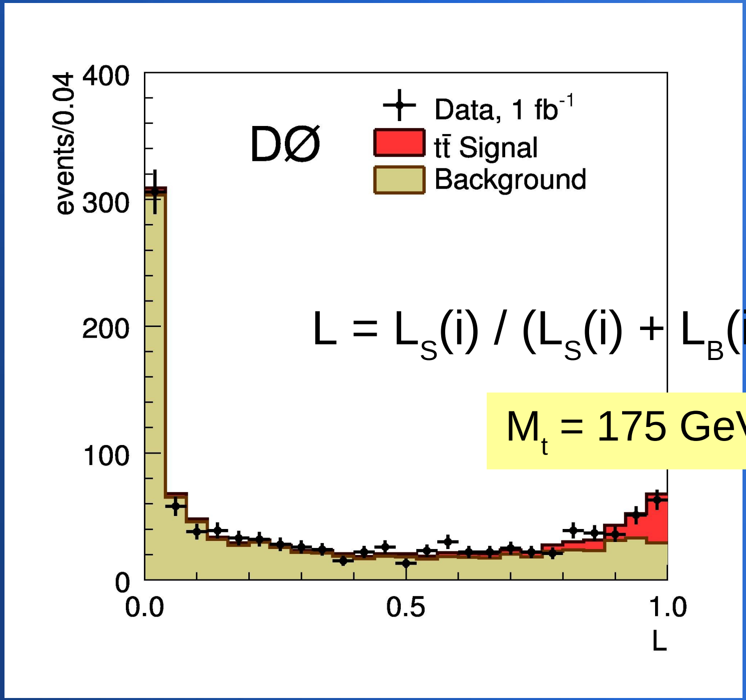
➔ NN based kinematical selection
➔ Likelihood fit for M_t, JES and $\mathbf{N_s, N_b}$
➔ W → qq decays to constrain JES



$\sigma_{t\bar{t}}$ = 7.2 ± 0.5 (stat) ± 1.0 (syst) ± 0.4 (lumi) pb

Most precise result in all-hadronic channel!

➔ Likelihood discriminant based on topological observables
➔ N_s from a fit to the likelihood output



$L = L_S(i) / (L_S(i) + L_B(i))$

M_t = 175 GeV/c^2

$\sigma_{t\bar{t}}$ = 6.9 ± 1.3 (stat) ± 1.4 (syst) ± 0.4 (lumi) pb

PRD 81, 052011 (2010) $\Delta\sigma/\sigma \sim 18\%$

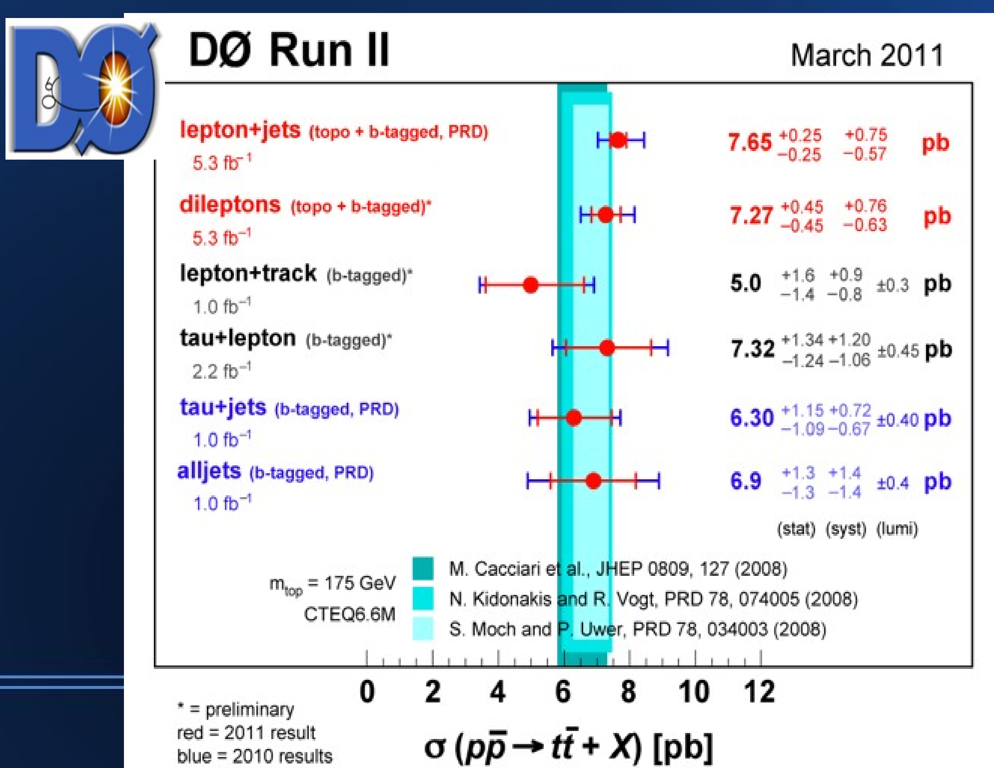
PRD 82, 032002 (2010) $\Delta\sigma/\sigma \sim 28\%$

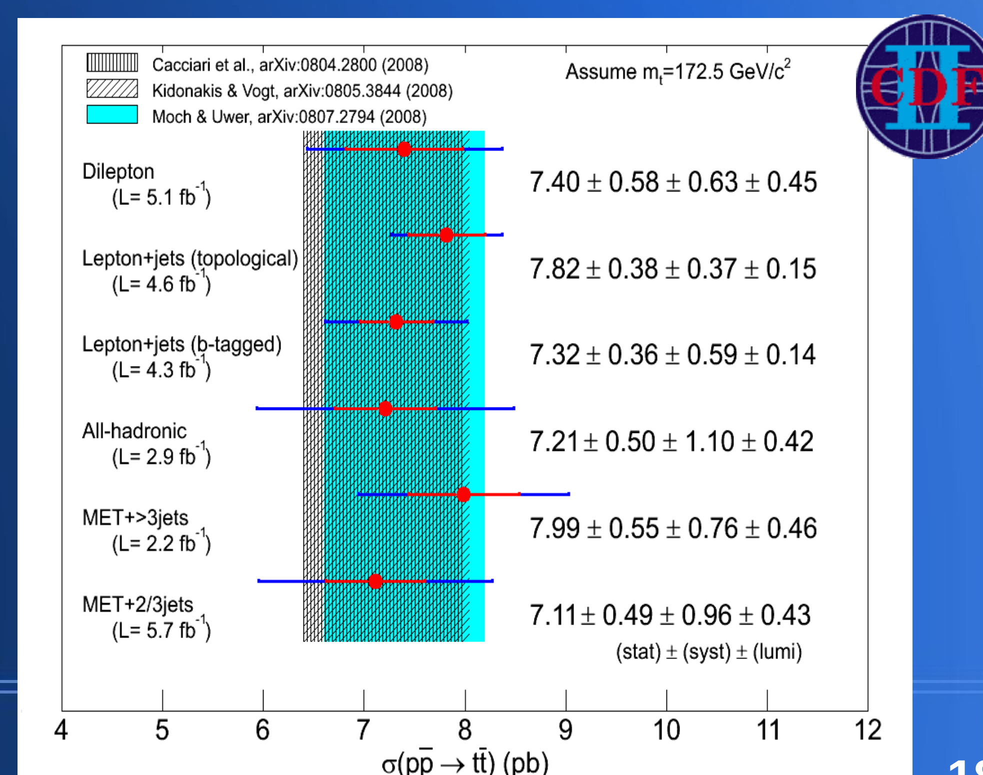
Summary

At Tevatron, $t\bar{t}$ production cross section measured **in all possible final states**, with **precision comparable to the theoretical one (7-9%)**

Precise knowledge of tt cross section important to **test pQCD**, for **NP searches** and to determine **background to NP searches .**

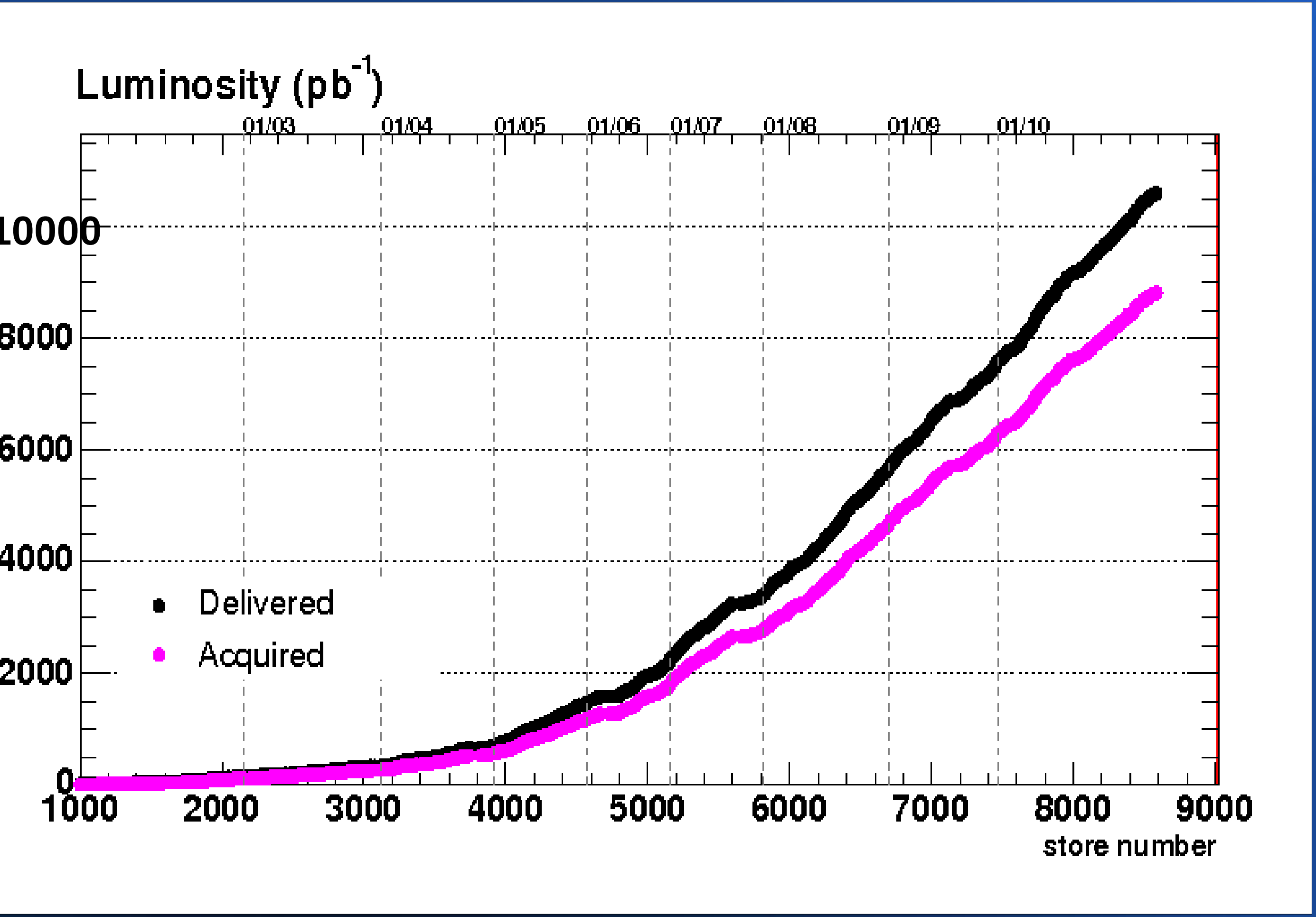
Results **dominated by the systematic uncertainty** → Important to understand them better and constrain them to data.





BACKUP

Integrated luminosity



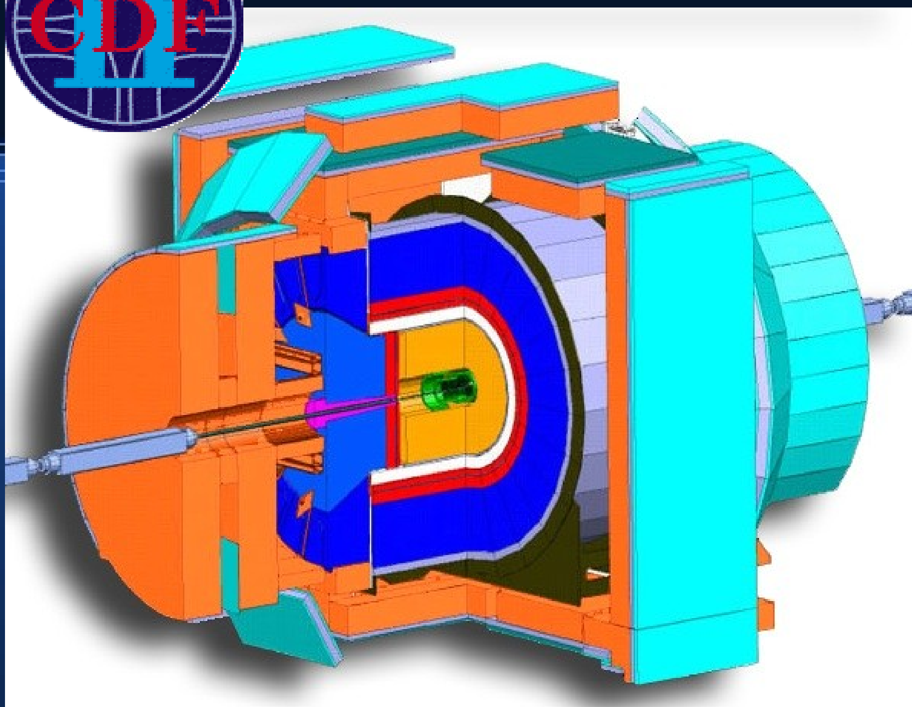
Very good Tevatron performance!

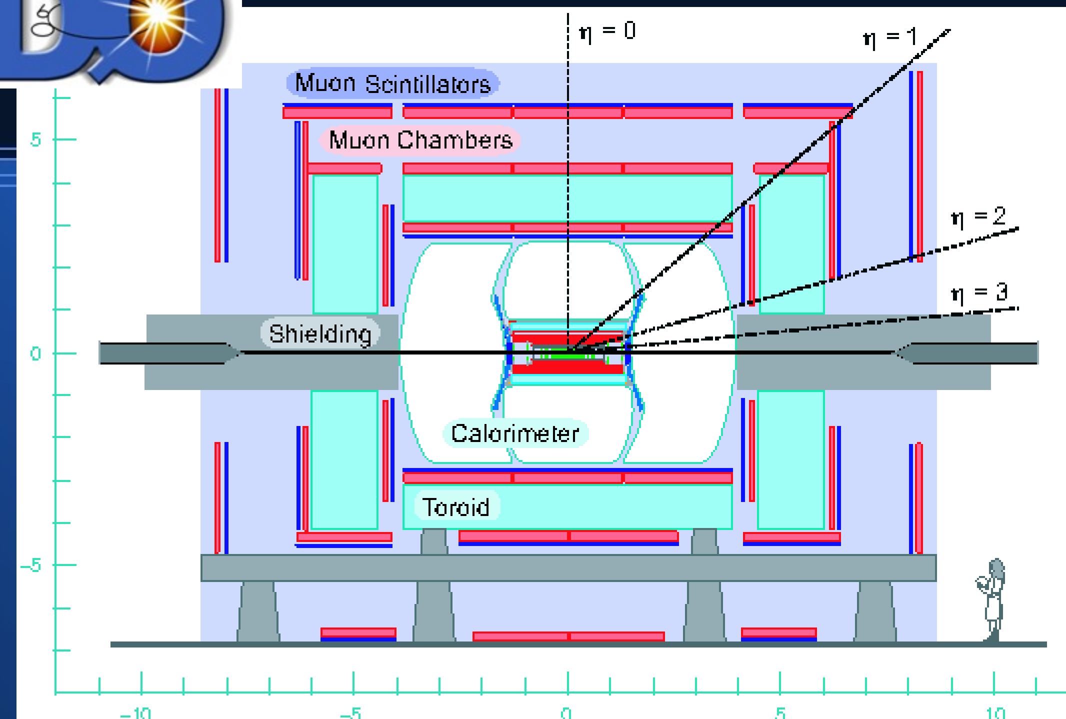
10 fb^{-1} delivered/experiment
> 8 fb^{-1} for data analysis

60 pb^{-1}/ week on average

Plan to reach 10 fb^{-1} for data analysis by the end of RunII

CDF and D0 detectors





Silicon microstrip detector (|η| < 2, |η| < 3)

Open cell drift chamber (|η| < 1)

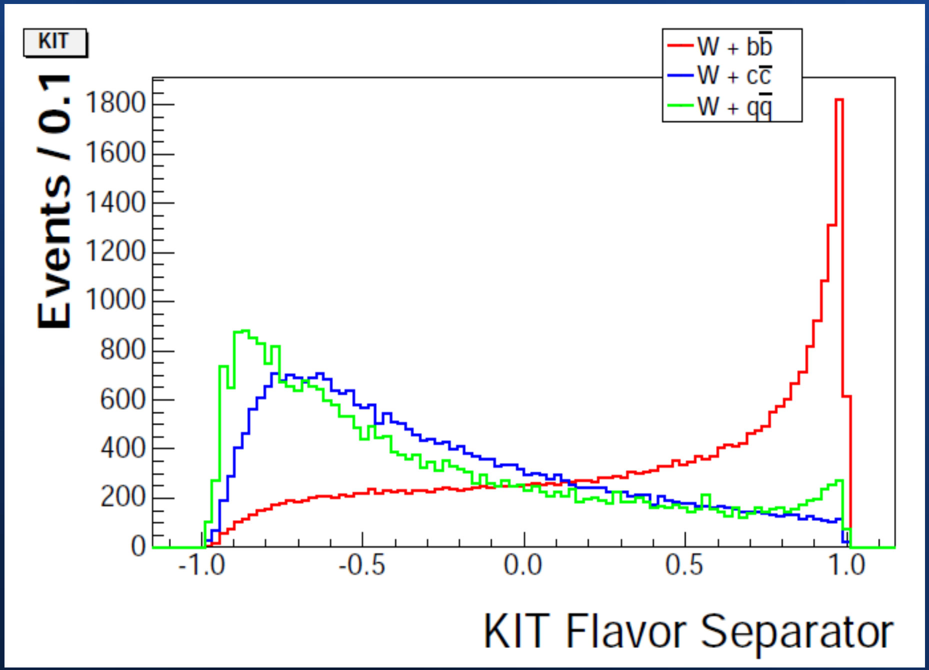
Scintillating fiber tracker (|η| < 1.7)

Lead/iron-scintillator calorimeters (|η| < 3.6)

Uranium-liquid argon calorimeters (|η| < 4.2)

Scintillator and drift tubes for muon detection (|η| < 1.5, |η| < 2)

Inclusive $t\bar{t}$ xsec with simultaneous kinematic fits



Standard lepton+jets selection +

Variable	Selection Criteria
$\not{E}_T$	$\geq$ 20 GeV
n_{tag}	1 or 2
Run	Good silicon
m_T^W	> 10 GeV$/c^2$ for muons
m_T^W	> 20 GeV$/c^2$ for electrons
$MetSig$	$> (-0.05 m_T^W + 3.5)$ for electrons

QCD veto

Inclusive $t\bar{t}$ xsec with simultaneous kinematic fits

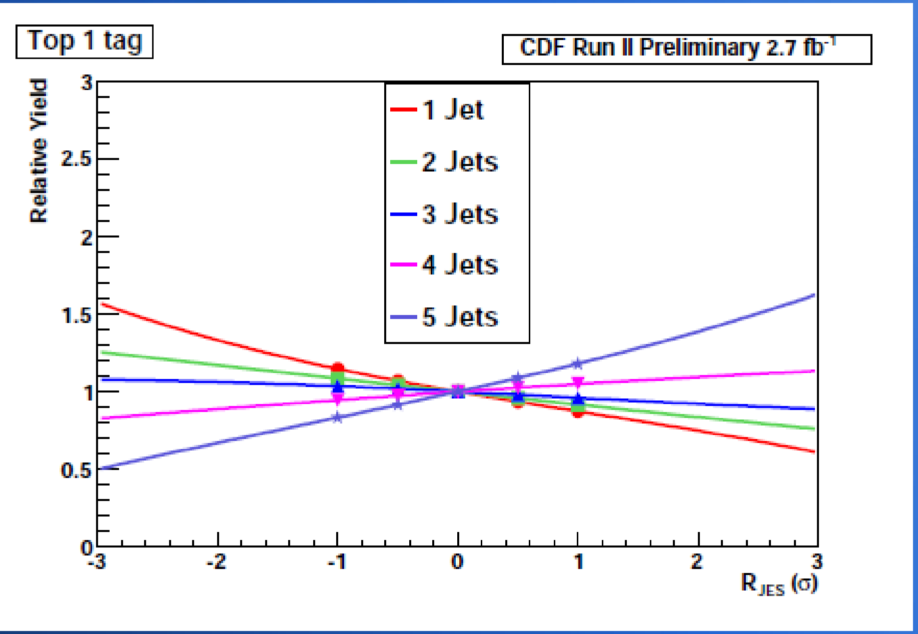
How do we put systematic uncertainties in the fit?
- Create shifted templates
- Compare shifted and nominal templates
- Fit relative shifts for each jet/tag bin

The functional form for each uncertainty is

$$P_N^{Syst}(i, j, \xi_{Syst})$$

i = jets
j = tags

Relative shift of the uncertainty



It parametrize the effect of Syst in the subsample with i jets and j tags as a function of the relative shift ξ_{Syst} of Syst

Applied as multiplicative factor:

$$N_{t\bar{t}}^{pred}(i,j) = \sigma_{t\bar{t}} \cdot L \cdot F_{t\bar{t}}^{MC}(i,j) \cdot P_N^{ISR/FSR}(i,j,\xi_{ISR/FSR}) \cdot P_N^{Btag}(i,j,\xi_{Btag}) \cdot P_N^{Mistag}(i,j,\xi_{Mistag}) \cdot P_N^{JES}(i,j,\xi_{JES})$$

Output of the fit:
- normalization factors for the templates (ttbar xsec and W+jets fractions)
- Relative shifts for the systematic uncertainties

Inclusive $t\bar{t}$ xsec with kinematic + b-tagging methods

Systematic uncertainties

$$\mathcal{L} = \prod_{j=1}^{12}\left[\prod_i \mathcal{P}^j(n_i^o,\mu_i)\right]\mathcal{P}^j(N_{LT}^o,N_{LT})\prod_{k=1}^{K}\mathcal{G}(\nu_k;0,\mathrm{SD})\,, \quad (1)$$

Poisson probability densities

$$\mu_i(N_T^{t\bar{t}},N_T^W,N_T^{MC},N_T^{\mathrm{MJ}}) = \quad (2)$$
$$\left(f_i^{t\bar{t}}N_T^{t\bar{t}} + f_i^W N_T^W + \sum_m (f_i^{\mathrm{MC}_m}N_T^{\mathrm{MC}_m})\right)\times$$
$$\times\left(1-\frac{\varepsilon_b}{1-\varepsilon_b}\,\frac{1-\varepsilon_s}{\varepsilon_s}\right)+$$
$$+\ f_i^{\mathrm{MJ}}\left(N_T^{\mathrm{MJ}}+\frac{\varepsilon_b}{1-\varepsilon_b}\,\frac{1-\varepsilon_s}{\varepsilon_s}\left(N_T^{t\bar{t}}+N_T^W+N_T^{\mathrm{MC}}\right)\right)\,,$$

N(W) = N(H+LF) + f_H N(W+HF) + f_{Wc} N(W+)