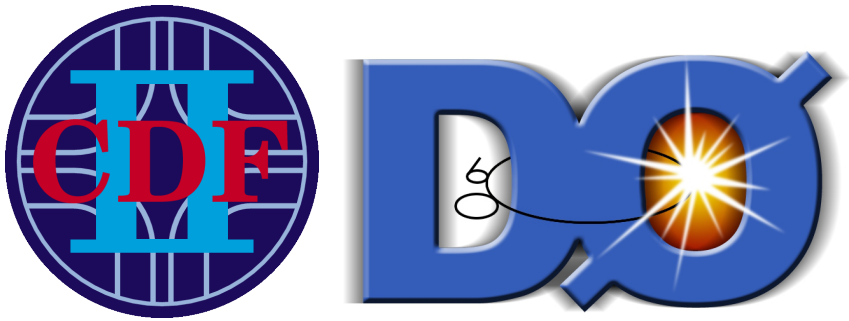


Single Top at Tevatron

Matteo Cremonesi

Single Top Quark Production

The top quark can be produced:

- in $t\bar{t}$ pairs through strong interaction;
- as **single top via EW interaction**.

Observed by CDF and DØ in 2009:

- T. Aaltonen, et al. [CDF collaboration], Phys. Rev. Lett. 103, 092002 (2009)
- V.M. Abazov et al. [DØ Collaboration], Phys. Rev. Lett. 103, 092001 (2009)

Two dominant processes:

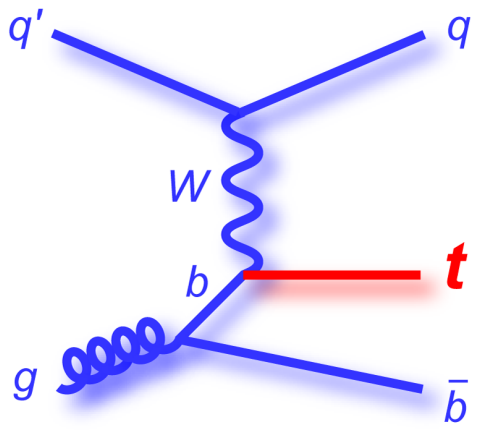
- t-channel;
- s-channel.
  - Wt-channel has a small cross section at the Tevatron.

	σ(pb)
s-ch	1.05 ± 0.05 [a]
t-ch	2.08 ± 0.08 [b]
Wt-ch	0.25 ± 0.03 [c]
$t\bar{t}$	7.08 ± 0.49 [d]

Theoretical cross sections at Tevatron considering $m_t = 173\text{GeV/c}^2$

[a] N. Kidonakis, arXiv:1001.5034
[b] N. Kidonakis, arXiv:1103.2792
[c] N. Kidonakis, arXiv:1005.4451
[d] N. Kidonakis, arXiv:1205.3453

Single Top t-channel

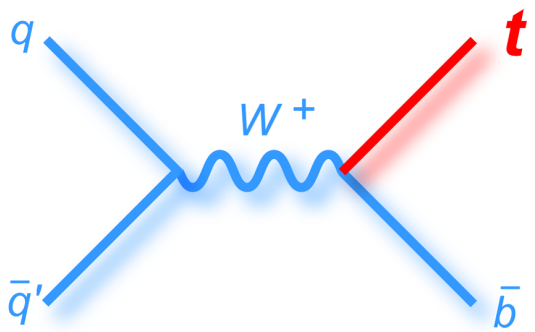


- It has already been established by the LHC experiments[1] [2];
- The light-flavor jet is more forward:
  - For a precise measurement, a good η coverage is required;

[1] ATLAS Collaboration, Measurement of the t-channel Single Top-Quark Production Cross Section in 0.70 fb^{-1} pp Collisions $\sqrt{s} = 7$ TeV with the ATLAS detector, ATLAS-CONF-2011-101(2011)

[2] CMS Collaboration, Measurement of the t-channel single top quark production cross sec tion in pp collisions at $\sqrt{s} = 7$ TeV, CMS-TOP-10-008 (2011)

Single Top s-channel



.

- It has not been observed yet;
- Difficult at LHC;
  - $\sigma^{SM}_{s-ch} \cong$ 5 pb ($\cong$ 5 $\times$ σ^{SM}_{s-ch} at Tevatron), $\sigma^{SM}_{t-ch} \cong$ 65 pb ($\cong$ 30 $\times$ σ^{SM}_{s-ch} at Tevatron) at LHC 7 TeV.
- Deviations from SM prediction may indicate new physics, like the existence of a W' or of a charged Higgs boson[3].

[3] T. M. P. Tait and C. P. Yuan, Single top quark production as a window to physics beyond the standard model, Phys. Rev. D 63 (2000) 014018.

Single Top at Tevatron

DØ :

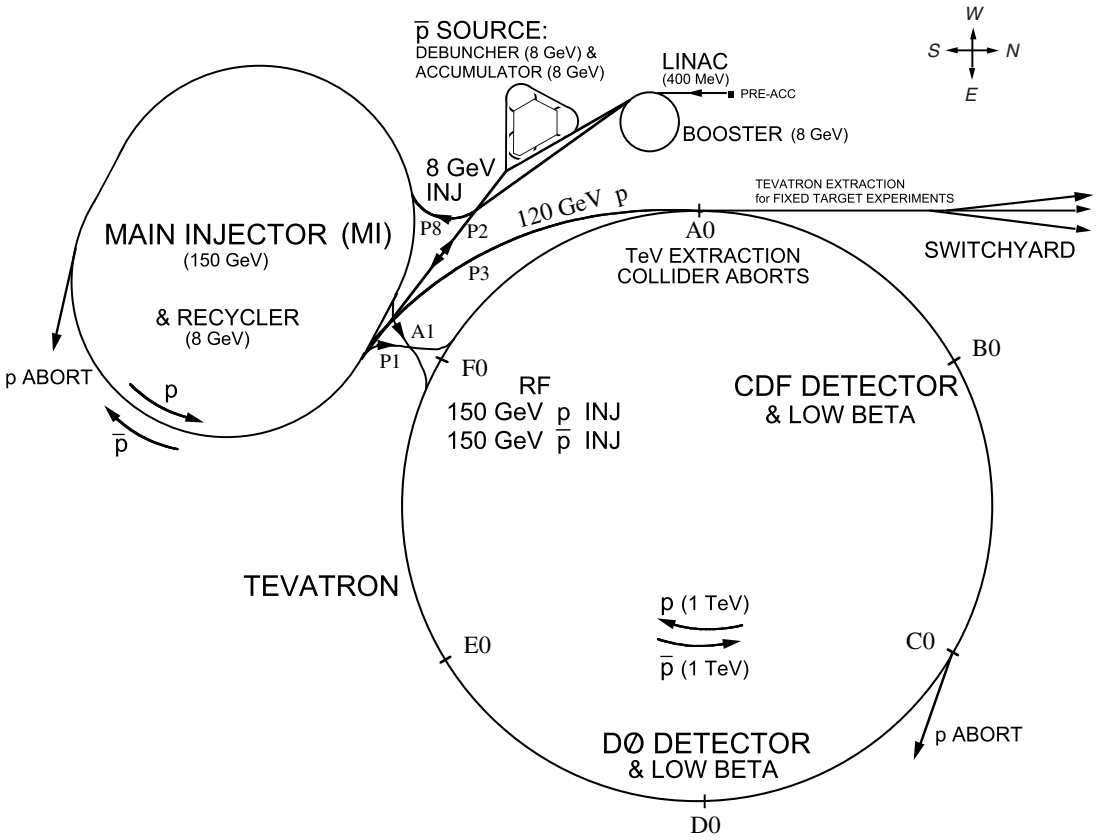
- Basically one analysis that does everything:
  - $s + t$ cross section measurement;
  - t-channel measurement;
  - **First s-channel evidence**[4].

CDF:

- Two statistically independent samples are analyzed:
  - The $l\nu b\bar{b}$ sample:
    - One isolated lepton, missing transverse energy $\not\!\!E_T$ and jets are required.
  - The $\not\!\!E_T b\bar{b}$ sample:
    - Only large $\not\!\!E_T$ and jets are required.
- $s + t$ cross section measurements;
- Qptimzed s-channel searches:
  - **Evidence of s-channel in the $l\nu b\bar{b}$ analysis**.

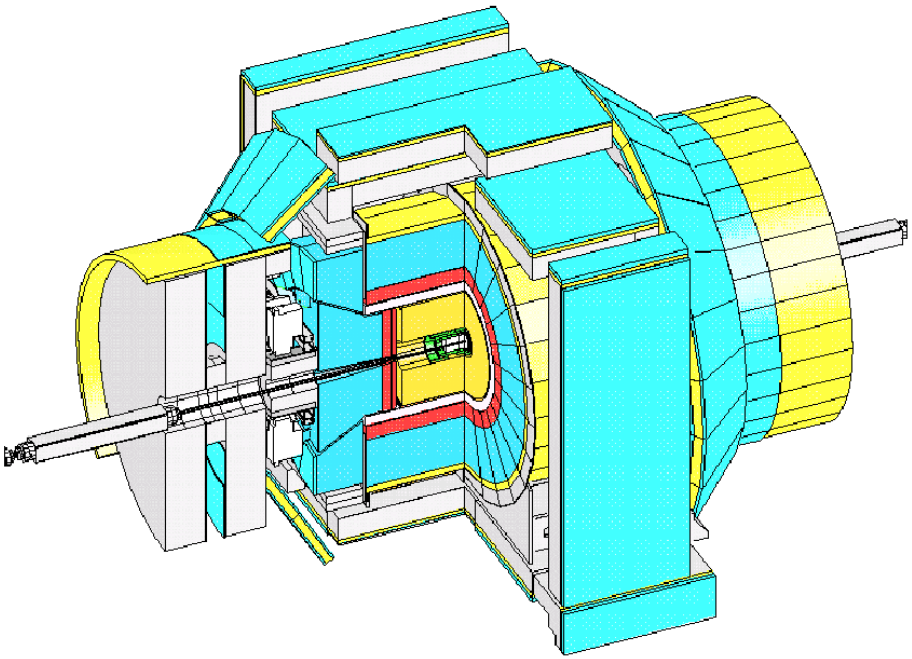
[4] arXiv: 1307.0731 (submitted to PLB)

The Tevatron



- Collider $p\bar{p}$ $\sqrt{s} = 1.96$ TeV
- Radius $R = 1$ km
- Two experiments: CDF and DØ
- Run II (2001–2011):
  ~ 12 fb^{-1} of $p\bar{p}$ collisions, ~ 10 fb^{-1} recorded by CDF.

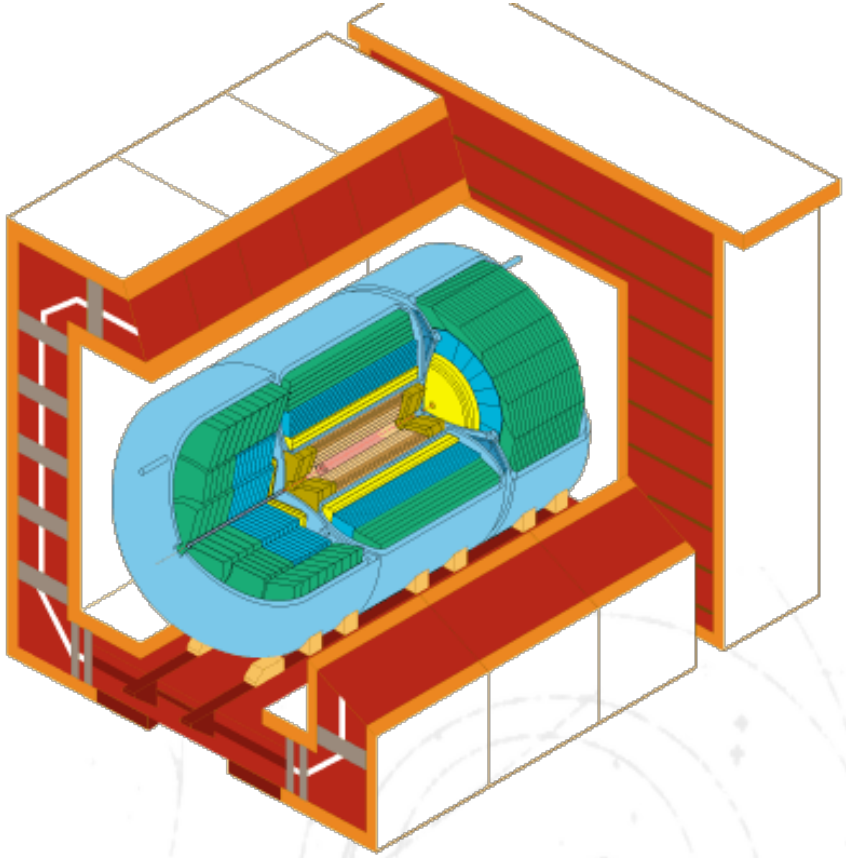
The CDF Detector



- Multipurpose detector, BØ interaction point at Tevatron
- Tracking system in magnetic field at 1.4 T
- Calorimeters
  - Electromagnetic and hadronic
  - Sampling
  - Projective towers
- Muon chambers
  - 4 layers of drift chambers
- Trigger system
  - Three levels of online selection

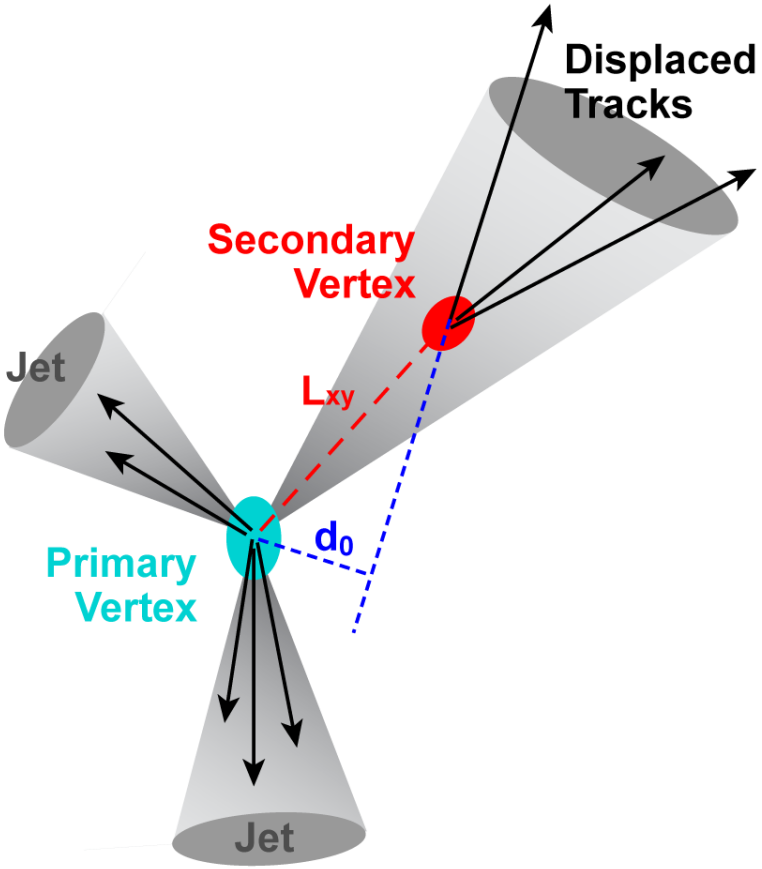
The DØ Detector

- Multipurpose detector, DØ interaction point at Tevatron
- Tracking system
  - Silicon Microstrip Tracker
  - Central Fiber Tracker
- Calorimeters: Uranium/Liquid Argon
- Muon detectors
  - Drift chambers
  - Scintillation counters
- Trigger system
  - Three levels of online selection



Main Analysis Features/1

b-jet Identification



- Identify b-jet from u,d,s,c, and g jets;
  - reduces a lot of backgrounds.
- Features of *b*-hadron in *b*-jets:
  - Long lifetime
  - Large invariant mass
- Reconstruct a secondary vertex;
- Make use of the displaced tracks with large impact parameter;

DØ

- Multivariate *b*-ID.

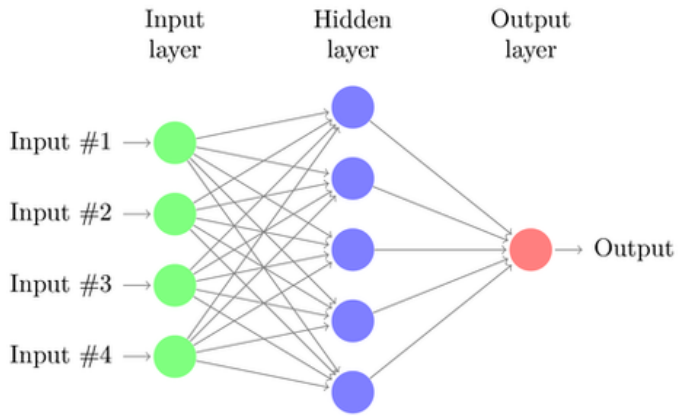
CDF:

- *SecVtx*, `HOBIT`[a].

[a] J. Freeman, T. Junk, M. Kirby, Y. Oksuzian, T. J. Phillips, F. D. Snider, M. Trovato, J. Vizan, and W. M. Yao, Nucl. Instrum. Methods Phys. Res., Sect. A **697**, 64 (2013).

Main Analysis Features/2

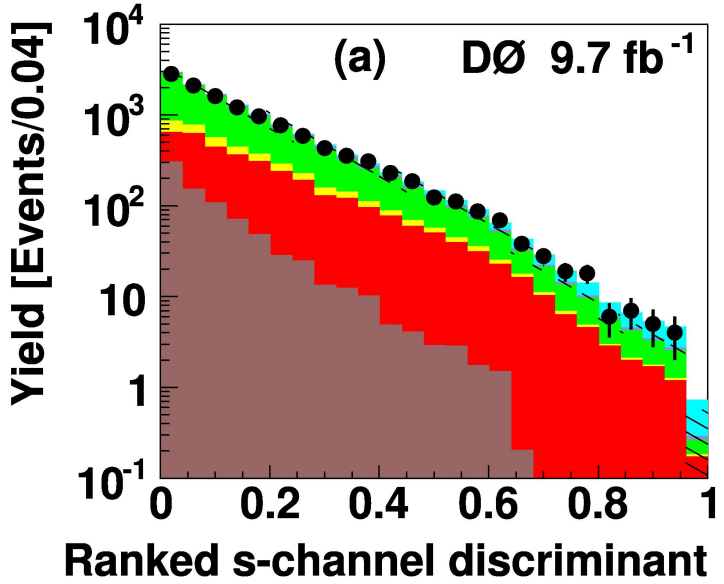
Multivariate Analysis



Since we are looking for a small signal in a very large background, we need to use **Multivariate Techniques**. Several Neural Networks (NN) with different purpose are employed in these analyses:

- QCD rejection, final discrimination between signal and backgrounds.

DØ analysis



Event selection:

- Only one high p_T isolated electron or muon: $p_T >$ 20 GeV
  - electron: $|\eta| < 1.1$
  - muon: $|\eta| < 2.0$
- Two or three jets
  - $p_T >$ 20 GeV, $|\eta| < 2.5$
  - The leading jet $p_T >$ 25 GeV
- Missing transverse energy $>$ 25 GeV
- $H_T >$ 120 GeV
  - H_T all jet p_T + lepton p_T + missing transverse energy

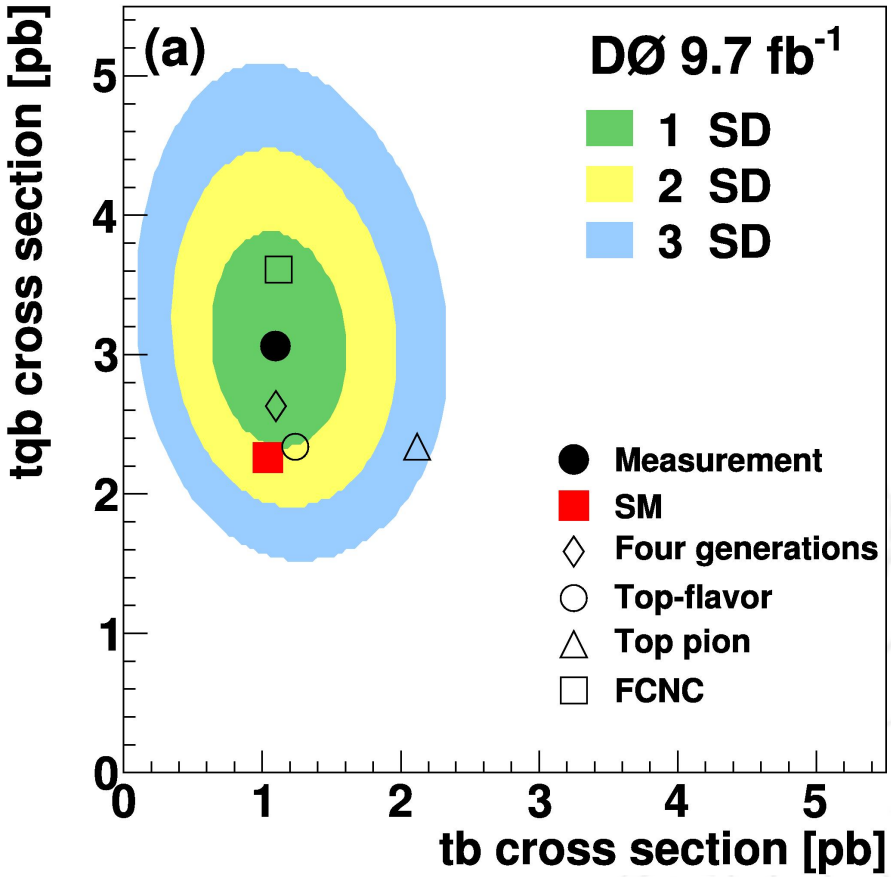
Signal & Background Simulation:

- Signals: CompHEP (NLO) + PYTHIA
- W + jets & top pair: ALPGEN + PYTHIA
  - Correct ALPGEN (LL) to NLO
    - e.g. a factor 1.9 for $W + bb$
- Multijet: Data with non-isolated lepton

Strategy

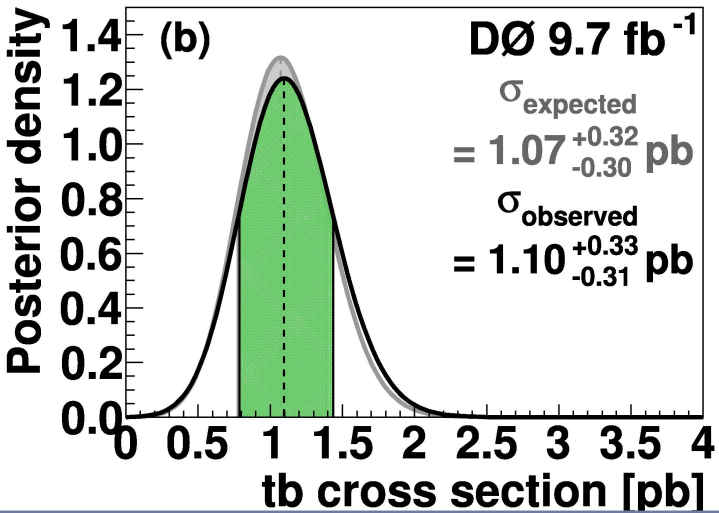
Measure simultaneously tb and tqb signals without assuming the SM prediction for either. Then, integrate over σ_{tbq} and obtain a ID posterior p.d.f. of σ_{tb+tbq}

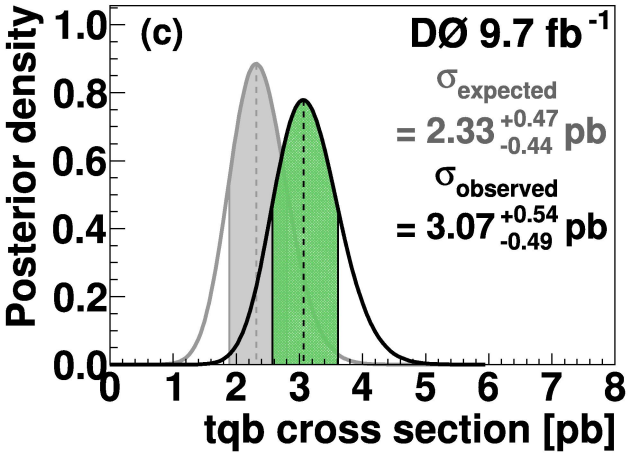
- Measure σ_{tb+tbq} without assuming the SM σ_{tb}/σ_{tbq}
- Use 2D posterior p.d.f.

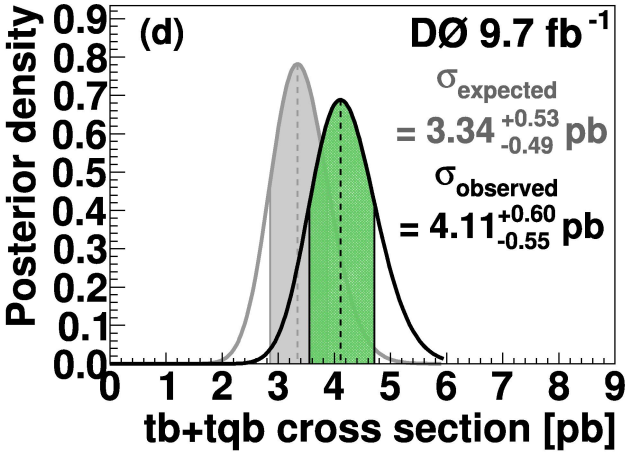


Results

- $\sigma_{tb} = 1.10^{+0.33}_{-0.31}$ (stat+syst) pb
- $\sigma_{tbq} = 3.07^{+0.53}_{-0.49}$ (stat+syst) pb
- $\sigma_{tb+tbq} = 4.11^{+0.59}_{-0.55}$ (stat+syst) pb
- Expected p-values:
  - tb: 1.0 $\times 10^{-4}$ (3.7 SD)
  - tbq: 9.9 $\times 10^{-10}$ (6.0 SD)
- Observed p-values:
  - **tb: 1.0 $\times 10^{-4}$ (3.7 SD)**
    - **First evidence of single top s-channel.**
  - tbq: 6.1 $\times 10^{-15}$ (7.7 SD)
- $0.92 < |V_{tb}| \leq 1$ at 95% CL







CDF Measurements

Main features:

- $s + t$ cross section measurement:
  - Employment of the *SecVtx* tagger;
- s-channel search:
  - All the tools developed for the VH analyses were migrated to the s-channel searches
    - The multivariate `HOBIT` tagger is used.
  - t-channel and WH/ZH are included as backgrounds.
- Multivariate analysis.

Model:

- s-/t-channel: POWHEG
- W/Z+jets: ALPGEN, normalization from data
- $t\bar{t}$, WW/WZ/ZZ, WH/ZH: PYTHIA

The parton showering is performed by PYTHIA.

QCD multijet is data-derived in both the analyses and validated in several control regions:

- $l\nu b\bar{b}$: data with no isolated leptons;
- $\not\!\!E_T b\bar{b}$: tag rate matrix.

$s+t$ Cross Section Measurement in $l\nu b\bar{b}$

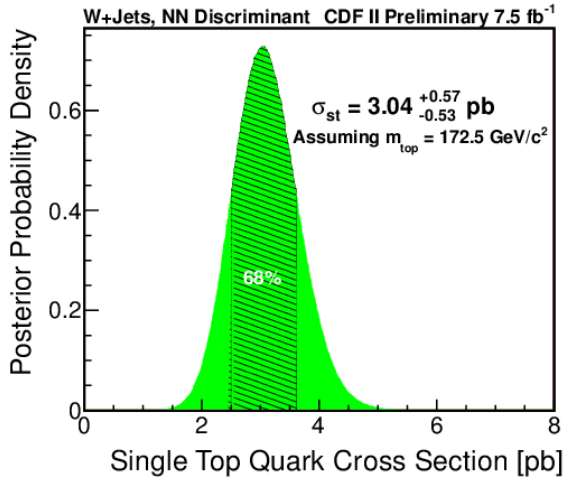
Last result (Moriond 2012 - CDF Conference Note 10793) with 7.5 fb^{-1} of CDF data.

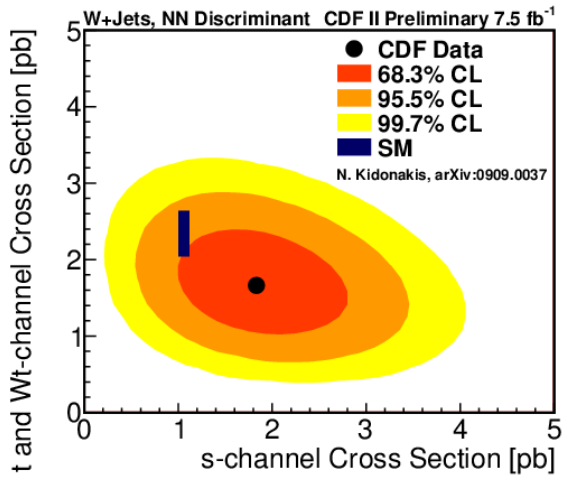
Event Selection:

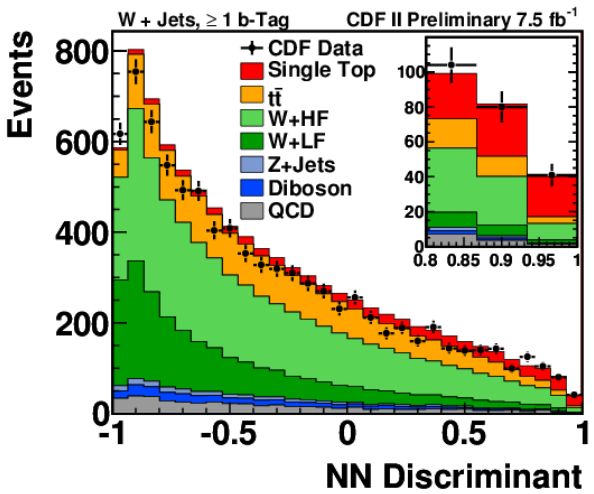
- 1 High-p_T lepton ($p_T > 20$ GeV/c);
- Large $\not\!\!E_T$ ($\not\!\!E_T > 25$ GeV/c^2);
- 2-3 jets with $E_T > 20$ GeV/c^2 & $|\eta_{\rm det}| < 2.8$;
- At least one SecVtx b-tagged jet.

Results:

- $\sigma_{s+t} = 3.04^{+0.57}_{-0.53}$ (stat+syst) pb;
- $|V_{tb}| = 0.96 \pm 0.09$ (stat+syst)$\pm$0.05 (th);
- Limit: $|V_{tb}| > 0.78$ at 95% C.L.;
- Measured c.s. from 2D fit s-ch Vs t-ch:
  - $\sigma_s = 1.81^{+0.63}_{-0.58}$ pb; $\sigma_t = 1.49^{+0.47}_{-0.42}$ pb.







$s+t$ Cross Section Measurement in $\not\!\!E_T b\bar{b}$

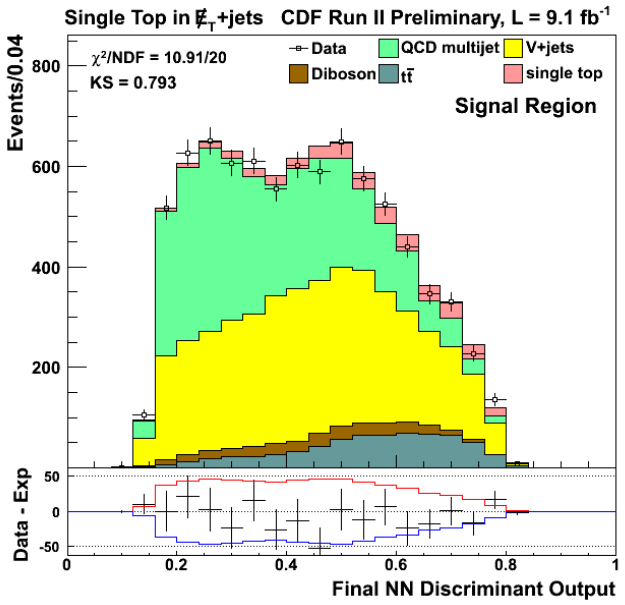
Last result (Moriond 2013 - CDF Conference Note 10979) with the full CDF dataset.

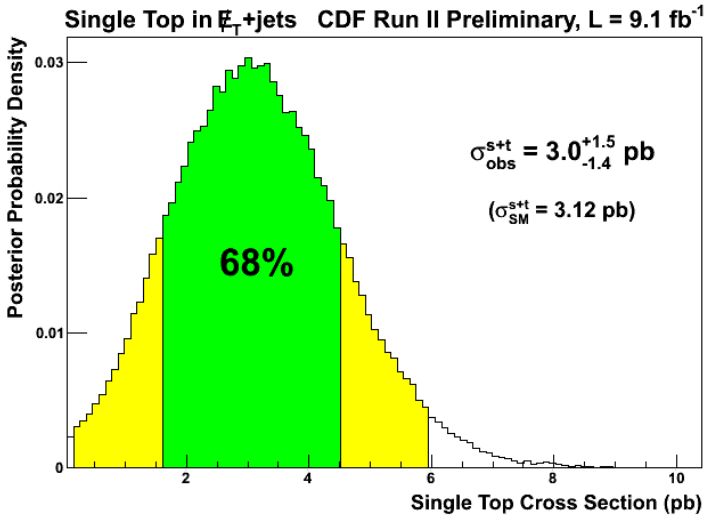
Event Selection:

- $\not\!\!E_T > 50$ GeV;
- 2-3 jets with $\mathrm{E_T^{j1}} > 35$ GeV, $\mathrm{E_T^{j2}} > 25$ GeV, $|\eta_{j_1/j_2}| < 0.9$ central;
- 3 tagging categories:
- At least one SecVtx b-tagged jet.
- NN QCD multijet and $t\bar{t}$ vetos.

Result:

- $\sigma_{s+t} = 3.15^{+1.41}_{-1.43}$ (stat+syst) pb.





s-channel Search in $l\nu b\bar{b}$

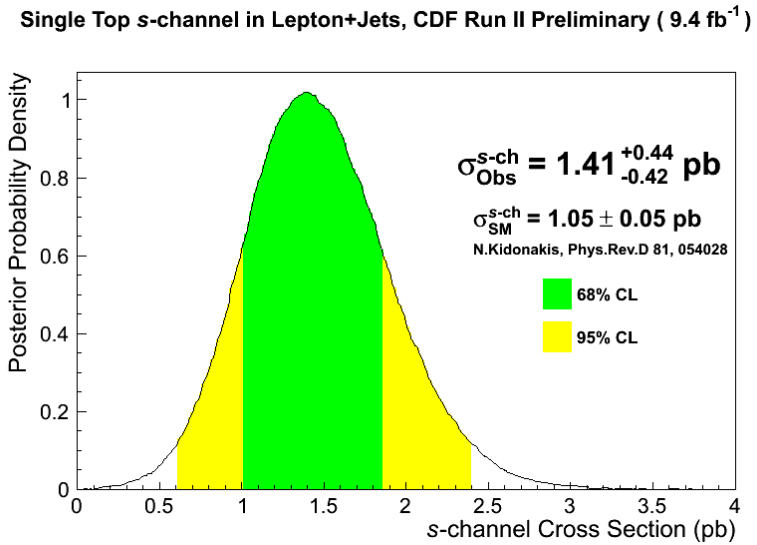
Last result (DPF 2013 - CDF Conference Note 11025) with the full CDF dataset.

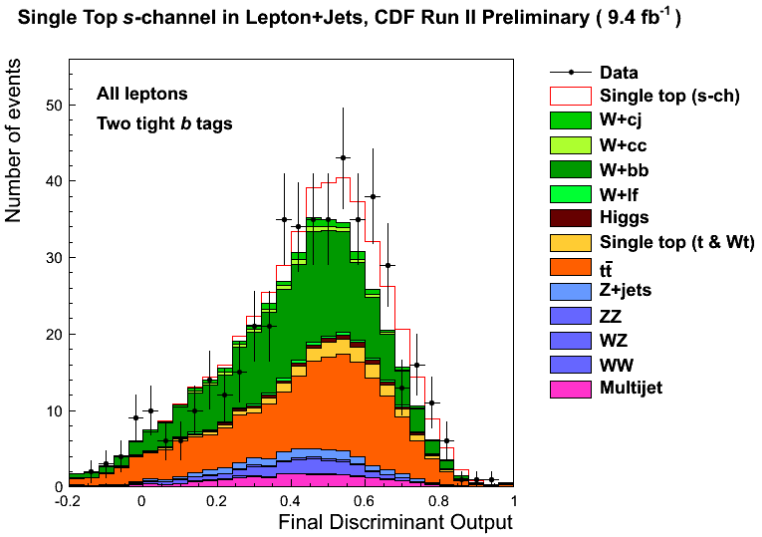
Event Selection:

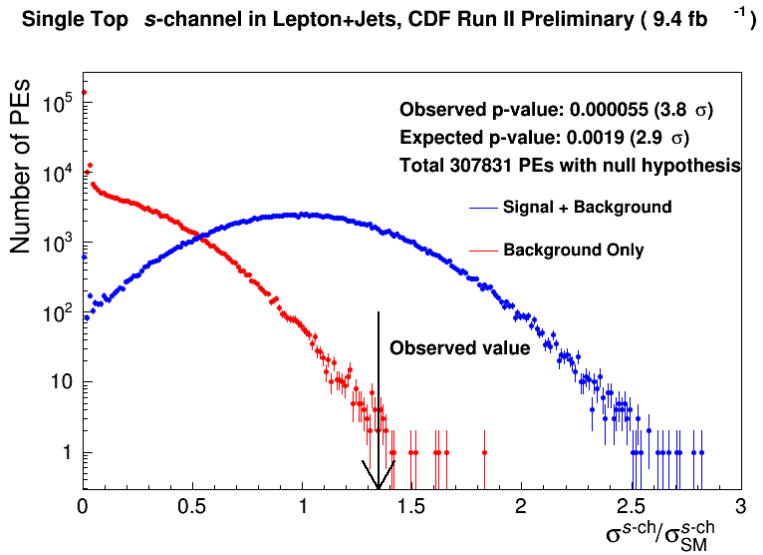
- 1 High-p_T lepton ($p_T > 20$ GeV/c);
- Large $\not\!\!E_T$;
- 2 jets, $|\eta_{\rm jet}| < 2.0$;
- At least one HOBIT b-tagged jet.
- Multivariate QCD filter.

Results:

- $\sigma^{\rm obs}_{\rm s-ch} = 1.41^{+0.44}_{-0.42}$ (stat+syst) pb
- **Observed p-value = 3.7 SD**







s-channel Search in $\not\!\!E_T b\bar{b}$

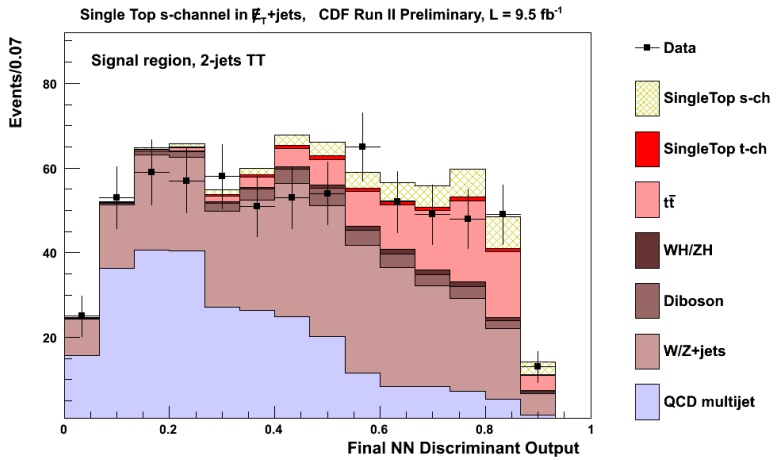
Last result (DPF 2013 - CDF Conference Note 11015) with the full CDF dataset.

Event Selection:

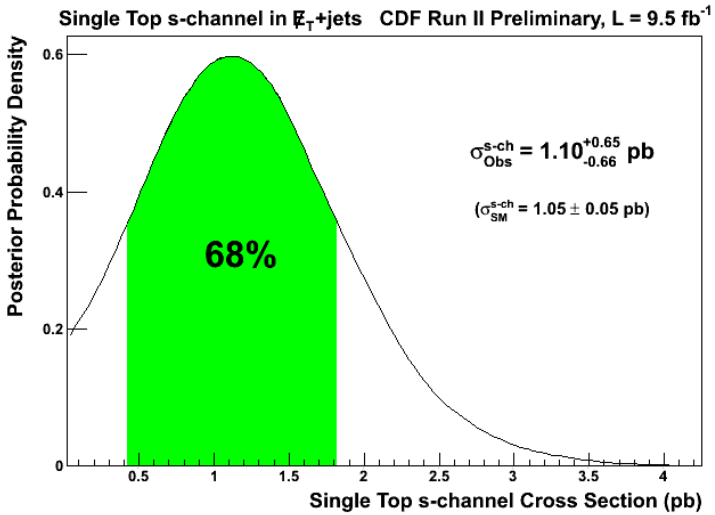
- $\not\!\!E_T > 35$ GeV;
- 2-3 jets with $\mathrm{E_T^{j1}} > 25$ GeV, $\mathrm{E_T^{j2}} > 20$ GeV, $|\eta_{j_1/j_2}| < 0.9$ central;
- At least one HOBIT b-tagged jet.
- Multivariate QCD filter.

Result:

- $\sigma^{obs}_{s-ch} = 1.10^{+0.65}_{-0.66}$ (stat+syst) pb.



TT: double tight b-tag region.



Summary

- All the DØ and CDF single top measurements are approved by the two collaboration;
- Ready to combine, high priority for the *s*-channel:
  - Both CDF and DØ showed and evidence for the *s*-channel;
  - The CDF *s*-channel combination is ready to be approved;
- The discussion between CDF and DØ for the Tevatron combination is on-going:
  - There is the possibility to have a combined *s*-channel result by October.
- The *s*-channel combination would be a legacy measurement from Tevatron.