Single Top Quark Production at Tevatron

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on behalf of the CDF and DØ Collaborations

Top2014 Cannes, September 29th, 2014

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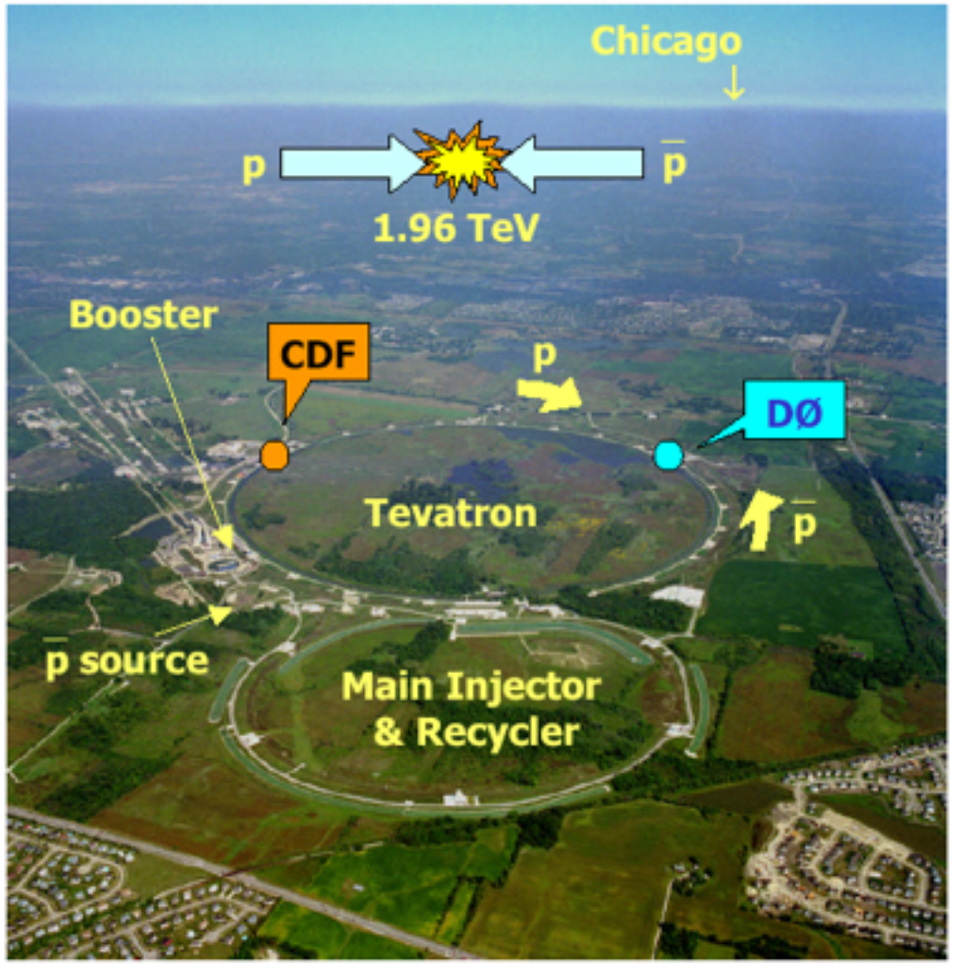
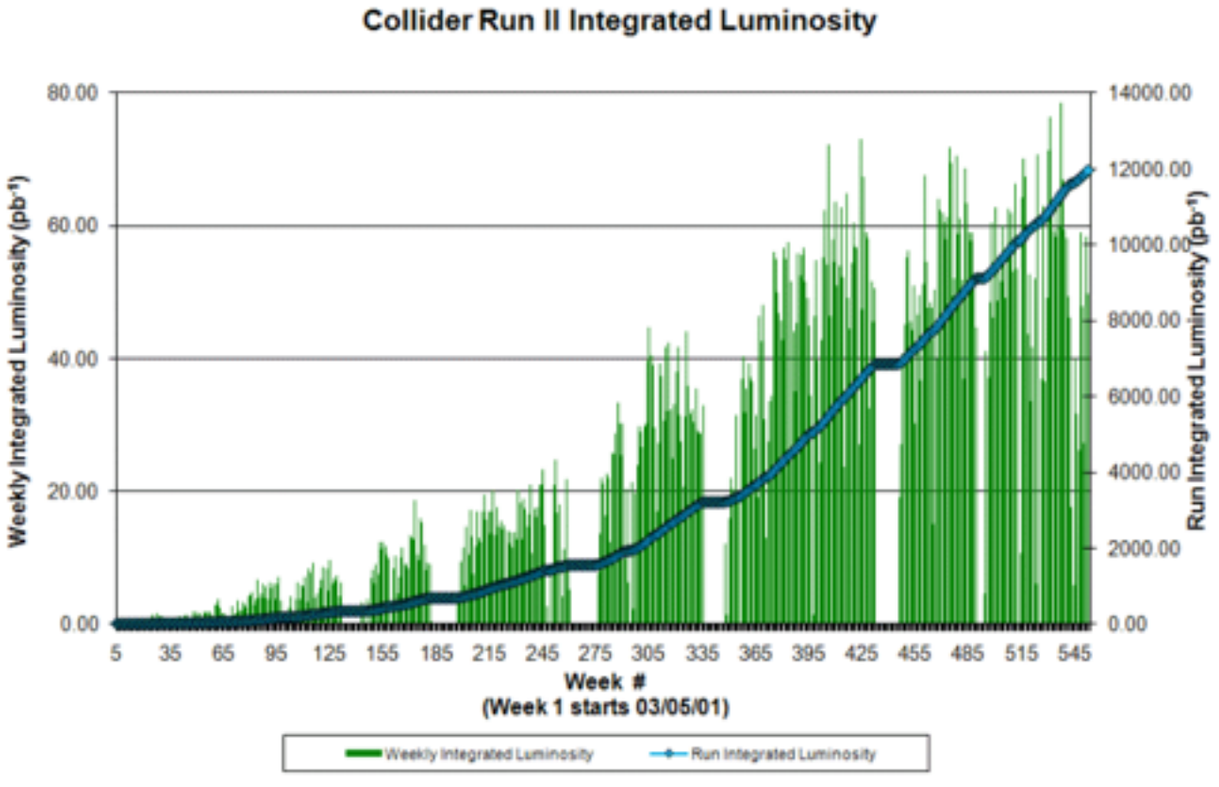
  - DØ s+t 9.7 fb^{-1}
  - Tevatron Combination 

- s-channel Production
  - DØ s-ch
  - CDF s-ch (l+jets & Met+jets)
  - Tevatron Combination -> First Observation!
- Summary

The Tevatron, CDF and DØ



- Run II: $\sqrt{s}$ = 1.96 TeV
- In operation from 2002 to September 30th, 2011 (Shutdown)
- Total integrated Luminosity delivered by Tevatron: ~12 fb^{-1}
- CDF & DØ luminosity acquired ~10 fb^{-1} (full dataset)
- Instantenous luminosity record: $\approx 4.03 \cdot 10^{32}\ cm^{-2}s^{-1}$

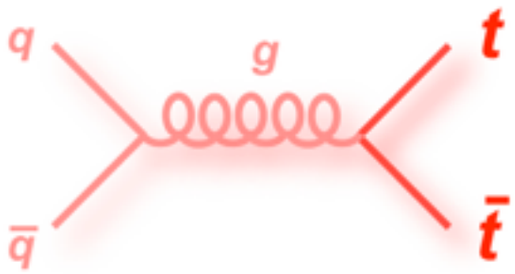


Top quark observed at Tevatron in 1995, by CDF & DØ

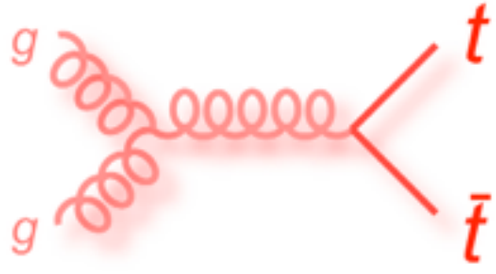
Top Production at Tevatron

- Mostly via QCD pair production
- M ≃ 173 GeV
- $\tau \simeq 5 \cdot 10^{-25}$ s: no top-flavoured hadrons!
  - ➡ Nearly 100% decay to Wb
  - ➡ Opportunity to study a “bare” quark!
- Coupling to Higgs boson ~ 1
- First evidence by CDF in 1994; Observation in 1995 by CDF/D0;

Tevatron production rate: ~85% ~15%



Dominant process at Tevatron



Dominant process at LHC

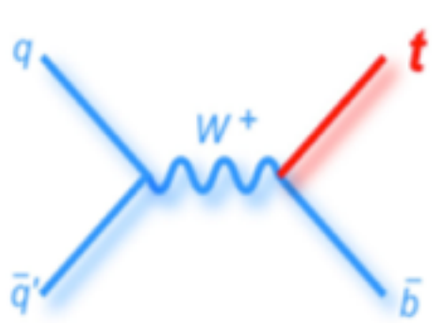
Single Top Production at Tevatron

- Production via EW in 3 channels: s, t, Wt;
- First Observation by CDF & D0 in 2009;

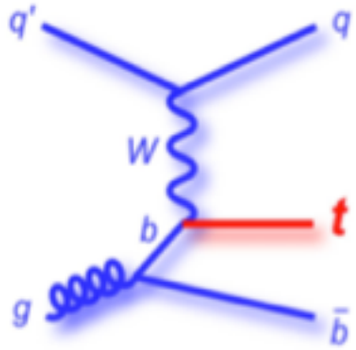
  Phys.Rev. Lett., 103:092002, 2009;

- Tevatron and LHC both sensitive to t-ch; Tevatron not sensitive to Wt-ch but advantage on s-ch!

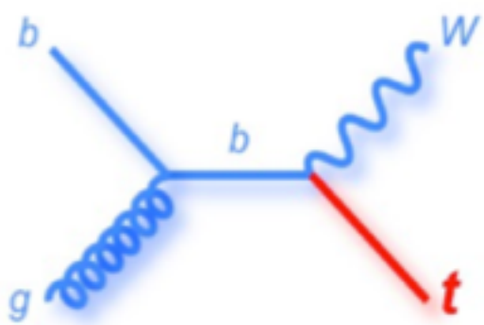
  at LHC 5 times more signal but 15 times more background….
  will be very challenging also at RunII since processes like ttbar increase more than s-ch production!



s-ch

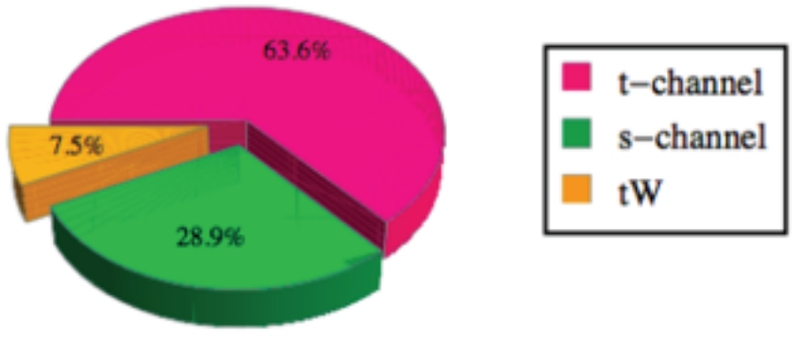


t-ch

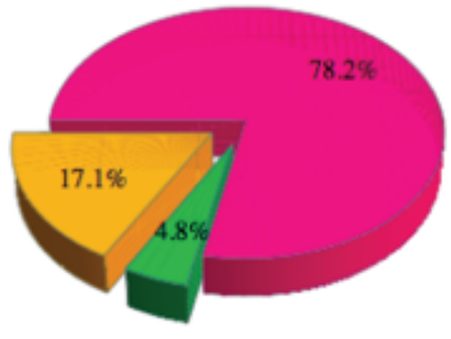


Wt-ch

Tevatron: σ_{tot} = 3 pb



LHC: σ_{tot} = 114 pb @ 8 TeV



Detector/σ(pb)	s-ch	t-ch	Wt-ch
Tevatron	1.05	2.08	0.25
LHC (8Tev)	5.55	87.2	11.1

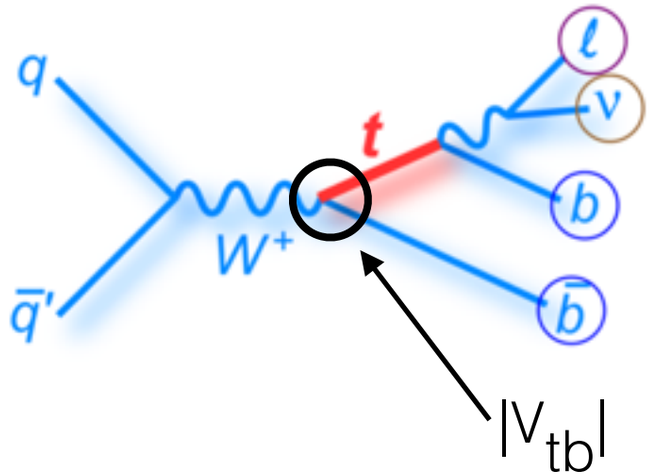
arXiv:1311.0283

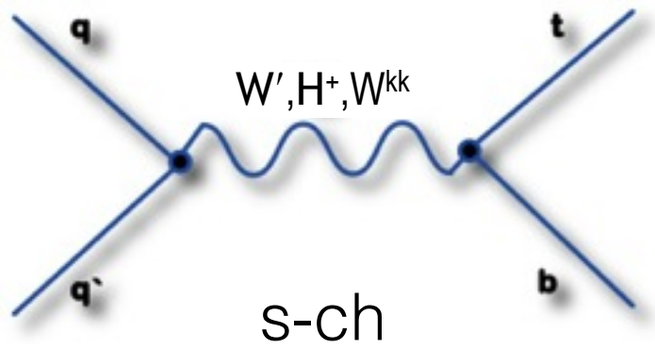
Motivations

$\sigma_{\text{single top}} \propto |V_{tb}|^2$

- Direct measurement of $|V_{tb}|$ CKM matrix element;
- Does unitarity holds? $|V_{ub}|^2 + |V_{cb}|^2 + |V_{tb}|^2 = 1$

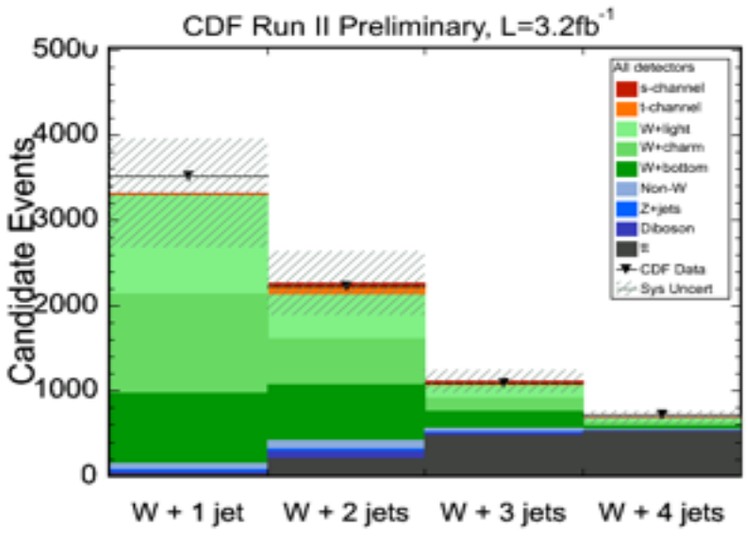
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} & V_{uX}? \\ V_{cd} & V_{cs} & V_{cb} & V_{cX}? \\ V_{td} & V_{ts} & V_{tb} & V_{tX}? \\ V_{Yd}? & V_{Ys}? & V_{Yt}? & V_{YX}? \end{pmatrix}$$





Sensitivity to new physics

- t-ch: FCNC
- s-ch: heavy W', Top pion



The Challenge

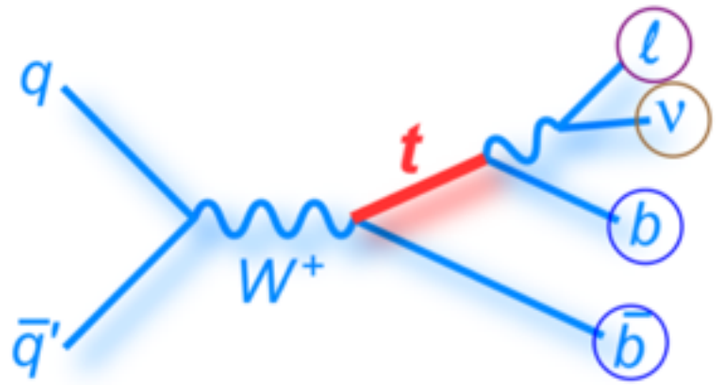
Single top quark production with decay into W + 2 Jets (dominated by W+jets):
final state hidden behind large backgrounds with large uncertainties (i.e. W+HF uncertainty ~ 30%)

➡ MVA using Multiple variables combined into a single more powerful discriminant to separate S from B

Event Selection

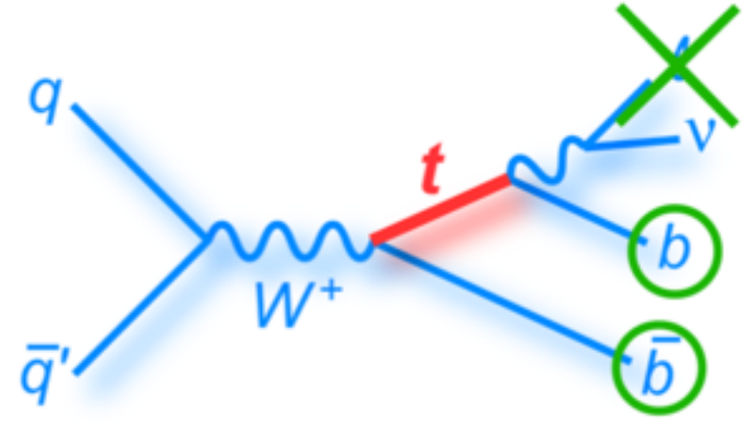
1) l+jets

- One high-p_T isolated lepton (e,mu)
- Missing transverse energy $\not\!\!E_T$
- 2 or 3 jets
- At least one b-tag



2) Met+jets (CDF only!)

- No isolated lepton (e,mu)
  - ➡ Leptons vetoed, orthogonal to l+jets
- Large MET > 35 GeV
- 2 or 3 jets
- At least one b-tag

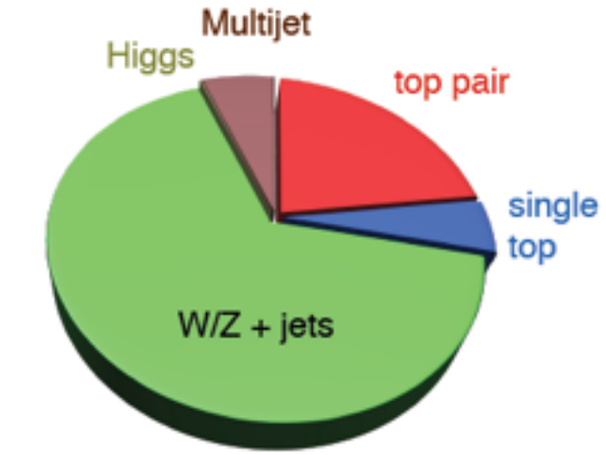


Orthogonal Event Selections: (2) adds 33% acceptance to (1)

Signal and Background Model

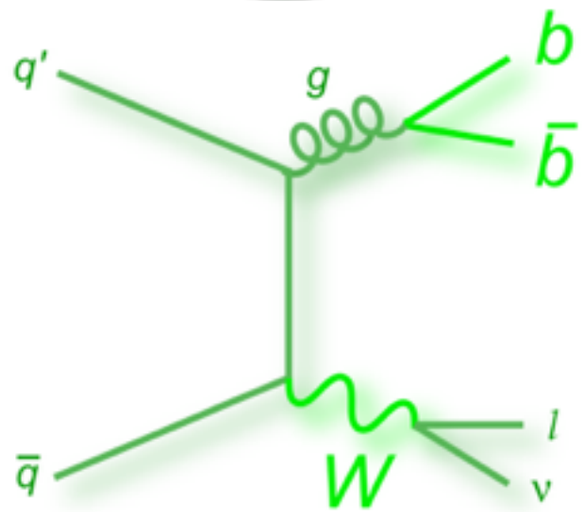
Electroweak/Top: Single Top, ttbar, diboson

- modeled by Monte Carlo (MC)
  - single top: POWHEG (CDF), COMPHEP (DØ)
  - ttbar: PYTHIA (CDF), ALPGEN (DØ)
  - diboson, WH: PYTHIA
- normalized to theoretical cross section



W+jets:

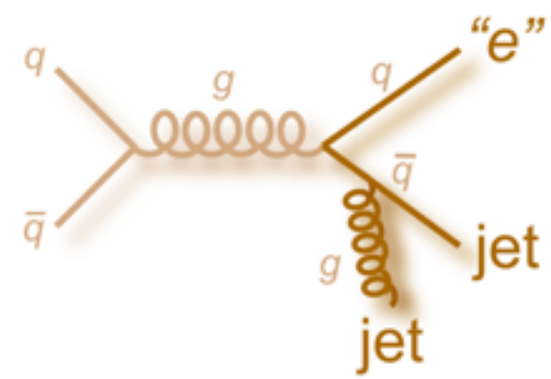
- modeled by ALPGEN+PYTHIA Monte Carlo (MC)
- normalisation and flavour composition from data



Mistags:

- falsely tagged light quark or gluon jet
- mistag probability from data

Z+jets: modeled by ALPGEN+PYTHIA MC



Multijet:

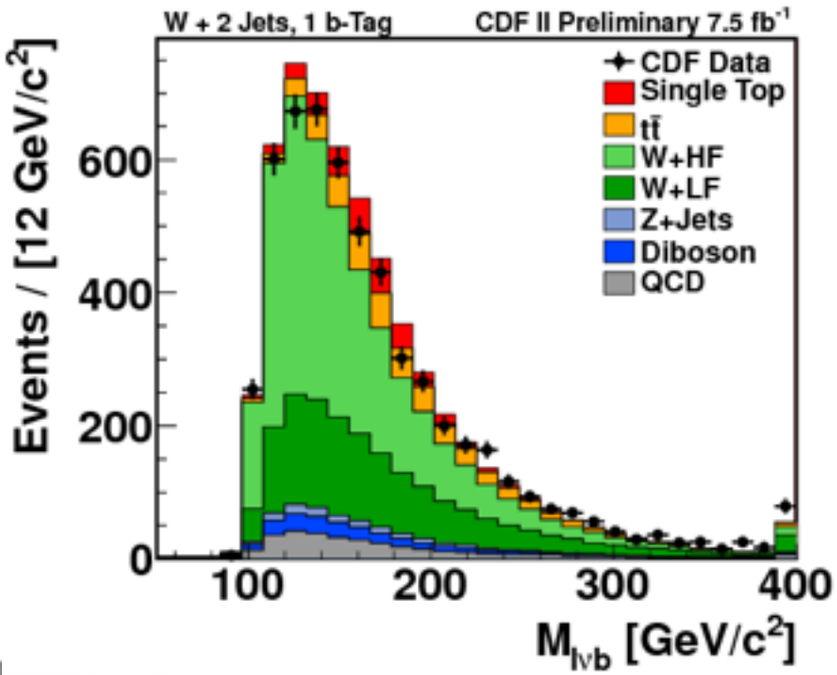
- Normalisation and shape from data-driven model

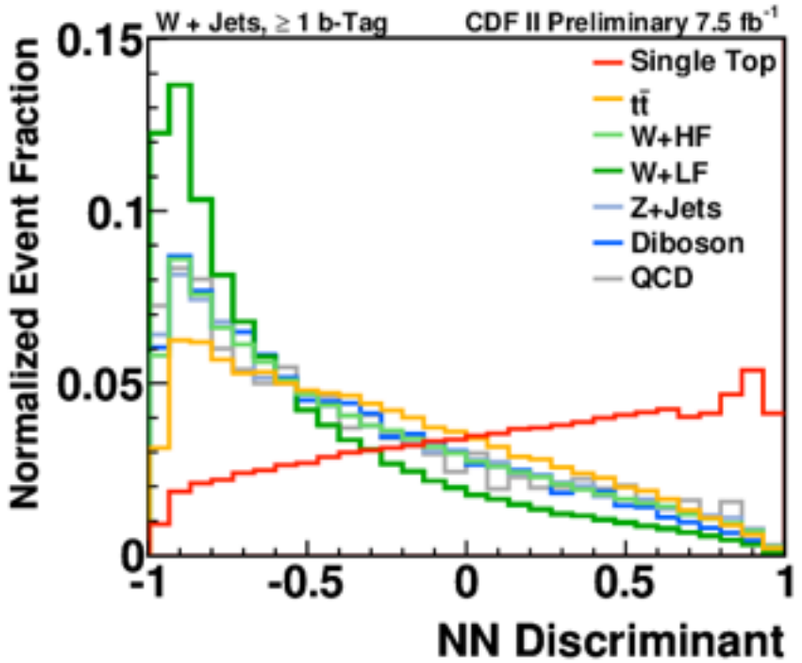
s+t Inclusive Production and Measurement at Tevatron

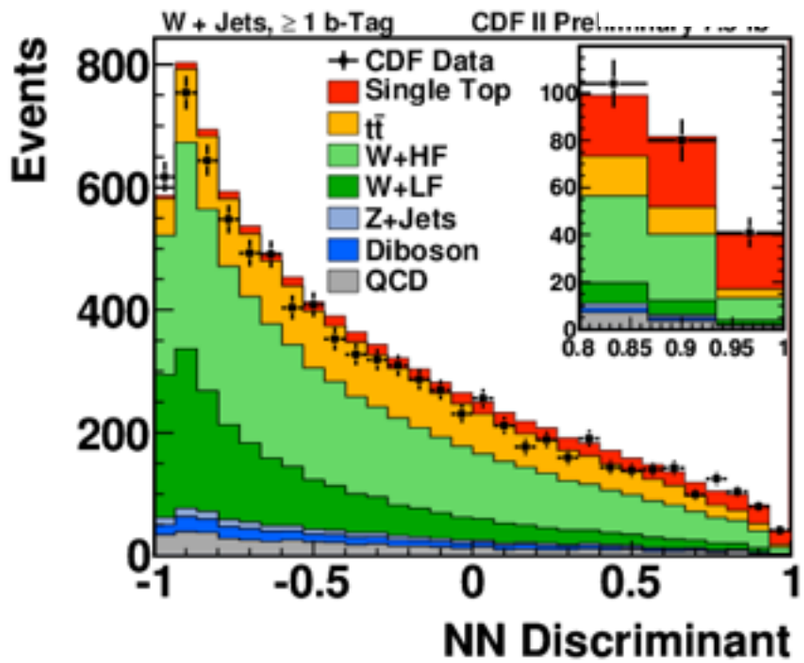
CDF lvbb̄ s+t Analysis

Strategy

- Lepton+jets with **7.5 fb⁻¹** of CDF data
- Subsamples wrt #jets and #b-tags (2J1T…3J2T)
- NNs trained with 11-14 variables
  - Use s-ch as signal in only 2J2T and t-ch for the rest
- Validate data-bg agreement in 0T Control Region
- Use admixture of systematics shifted samples
  - ➡ 3% improvement





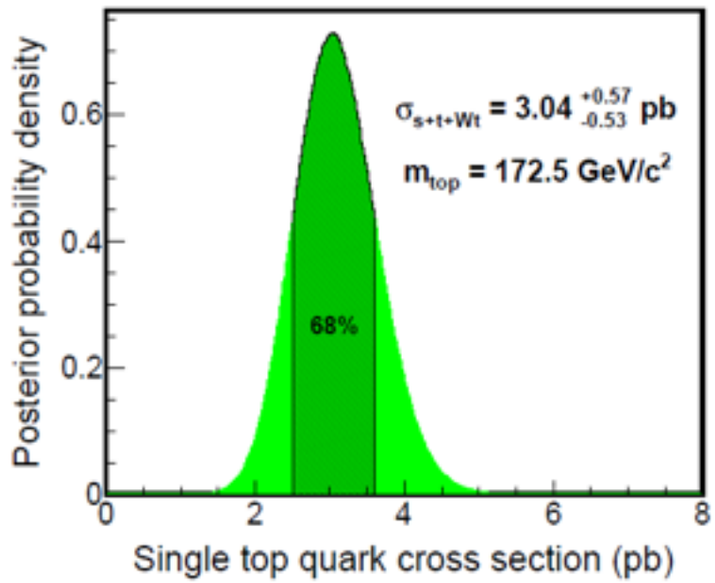


arXiv:1407.4031 [hep-ex]

CDF lvbb̄ s+t Analysis

Single Top s+t+Wt Cross Section

- Measure cross section using maximum likelihood fit to the binned NN output distributions
- Integrate the posterior probability density over the parameters associated with all sources of systematic uncertainties
- First inclusive measurement with Wt-ch at CDF!

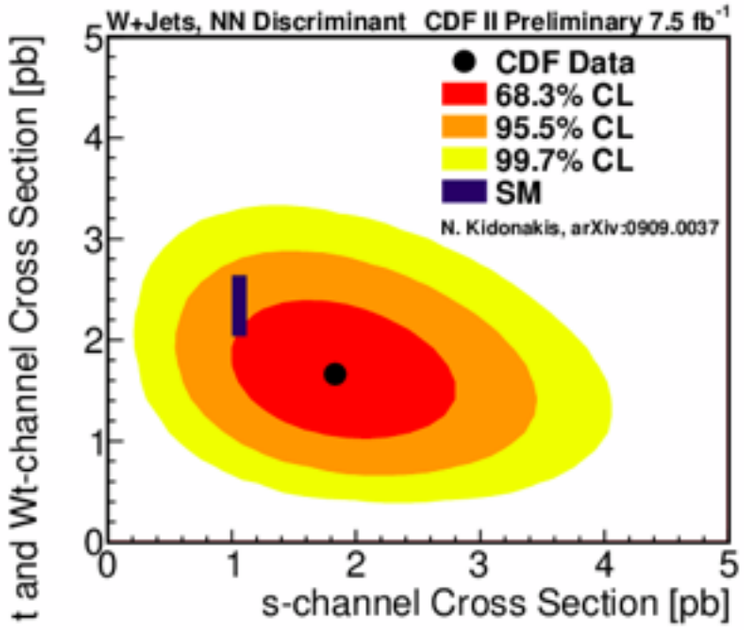


σ_{s+t+Wt} = 3.04 $^{+0.57}_{-0.53}$ (stat+syst) pb (± 19%)

Single Top t-channel VS s-channel 2D fit

- 2D plane (σ_s , $\sigma_{(t+Wt)}$)
- The t-channel and Wt processes are combined as they share the same final-state topology.

σ_s = 1.81 $^{+0.63}_{-0.58}$ pb
$\sigma_{(t+Wt)}$ = 1.66 $^{+0.53}_{-0.47}$ pb

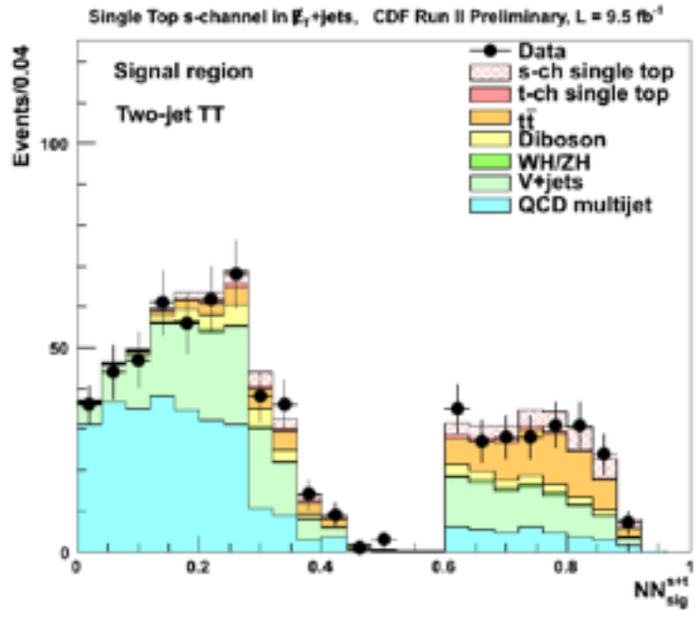


arXiv:1407.4031 [hep-ex]

CDF $\not\!\!E_T b\bar{b}$ s+t Analysis

Strategy

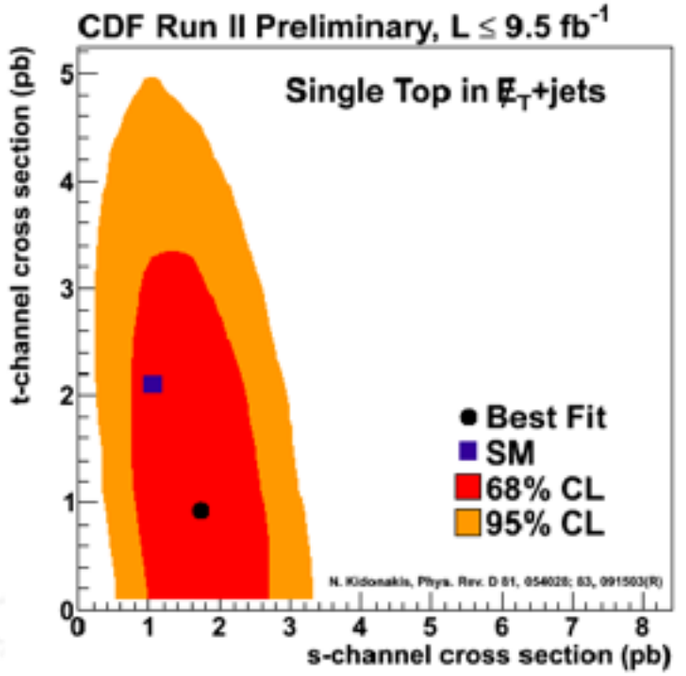
- MET+jets with full CDF dataset **9.5 fb^{-1}**
- Completely orthogonal dataset to ℓ+jets selection
- Subsamples wrt #jets and #b-tags (2J1T…3J2T)
  - Latest CDF HOBIT multiavariate tagger used
- Dedicated NN used to discriminate QCD, V+jets and ttbar for s-ch and t-ch
- 1D posterior obtained for σ_{s+t} assuming constant SM σ_s/σ_t



Results

σ_{s+t} = 3.53 $^{+1.25}_{-1.16}$ pb (stat+syst) (± 34%)

$|V_{tb}| > 0.63$ at 95% CL

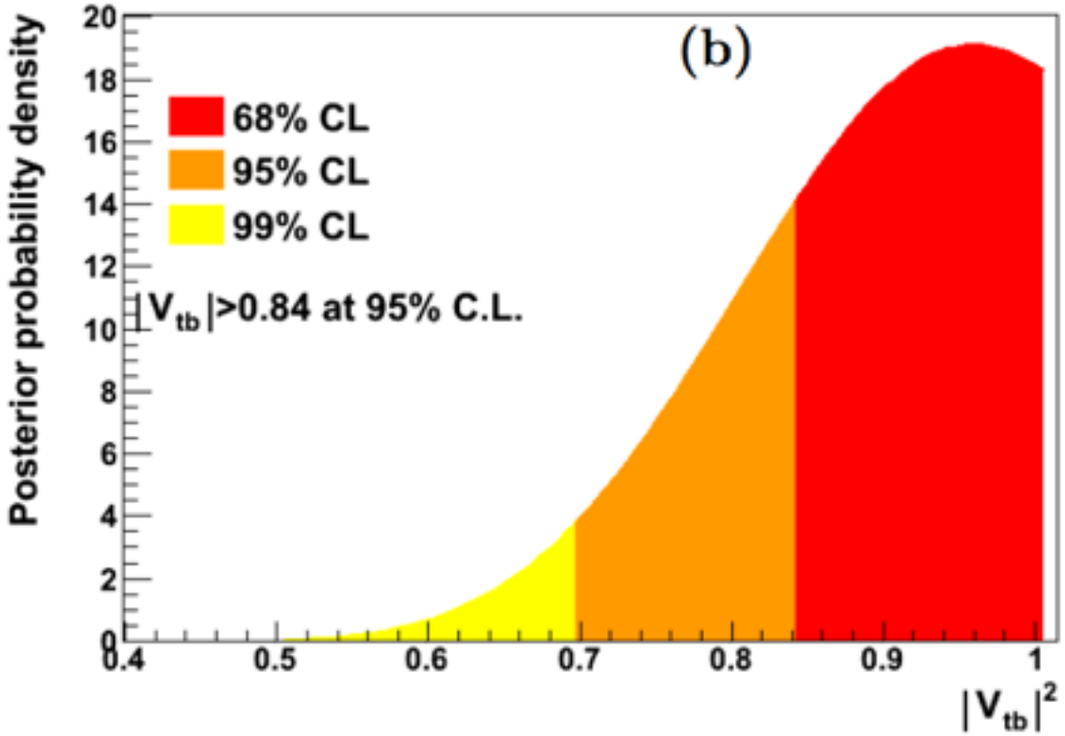


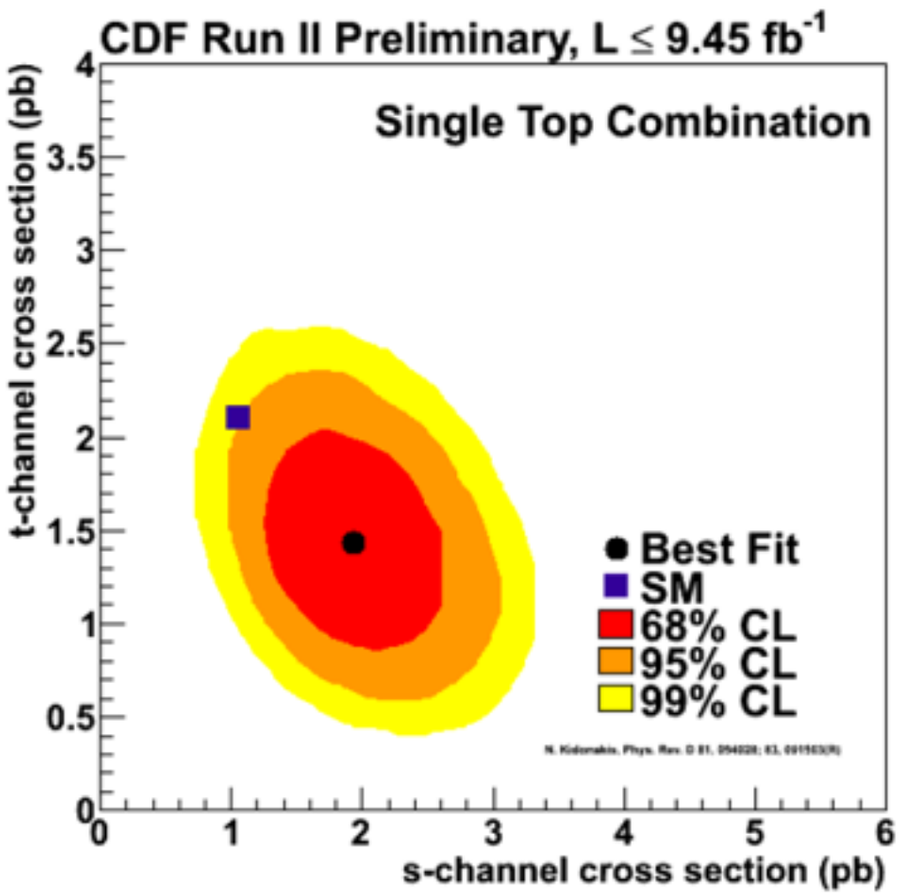
CDF note 11033

CDF s+t Combination

The results of the two s+t analyses (l+jets and MET +jets) are combined by taking the product of their likelihoods and simultaneously varying correlated uncertainties

$$\sigma_{s+t} = 3.02\ ^{+0.49}_{-0.48}\ \text{pb}\ (\pm 16\%)$$





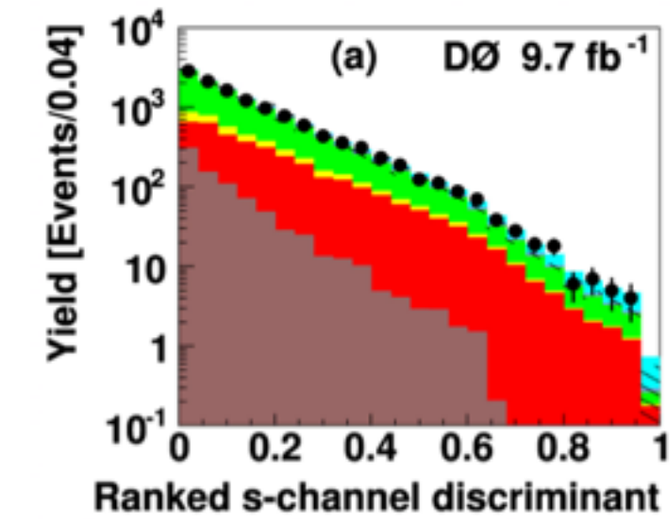
$|V_{tb}| > 0.84$ at 95% C.L.

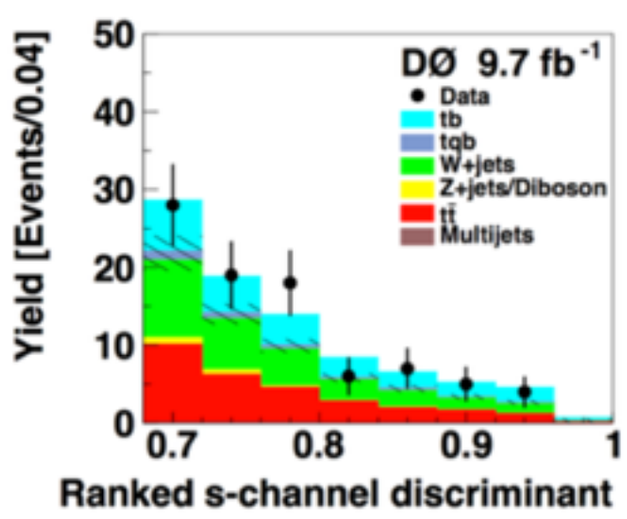
CDF note 11033

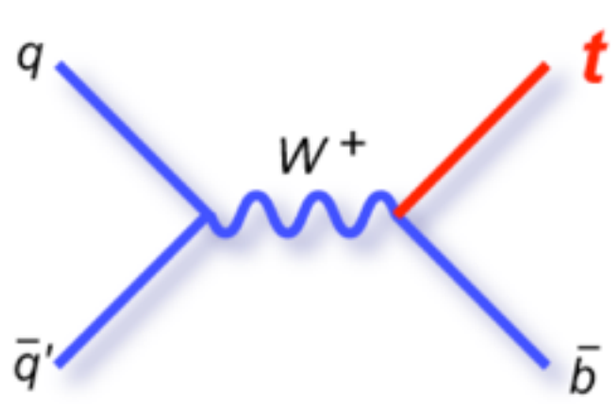
DØ Single Top Analysis

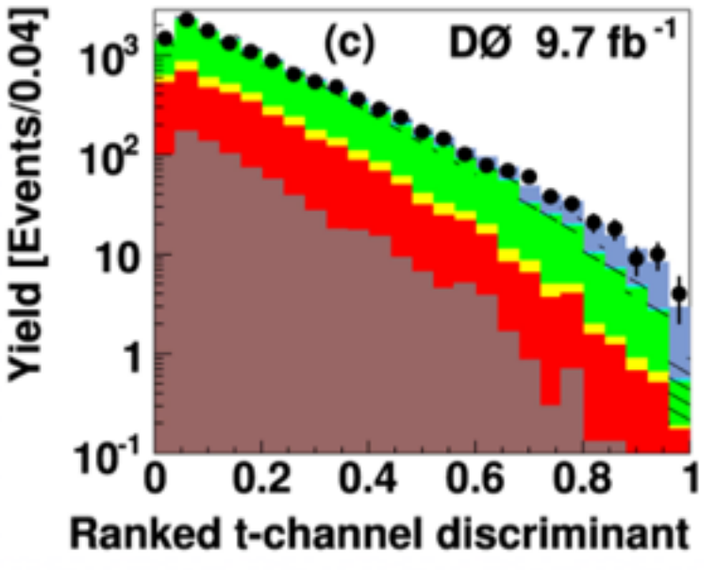
Strategy

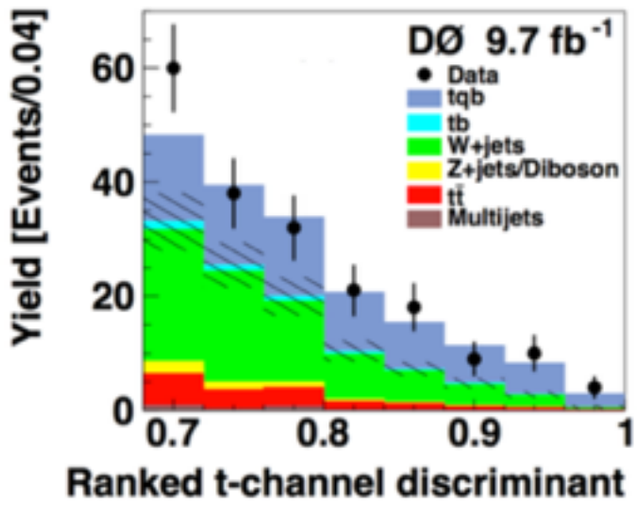
- Basically one analysis doing everything with **9.7 fb^{-1}** of DØ data
  - ➡ s-channel, t-channel, s+t channel measurements
- DØ used three different techniques: BDT, BNN, ME
  - Each method selects different event kinematics ➡ Around 75% correlation

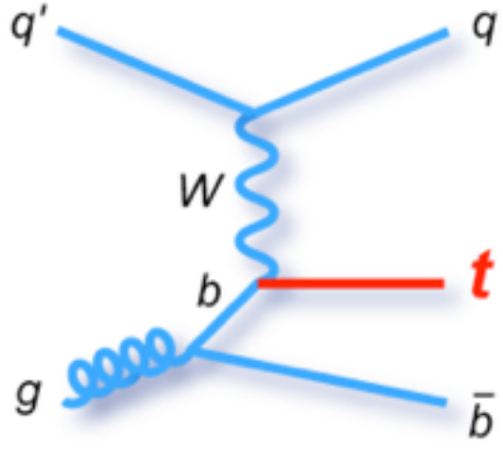












PLB 726, 656 (2013)

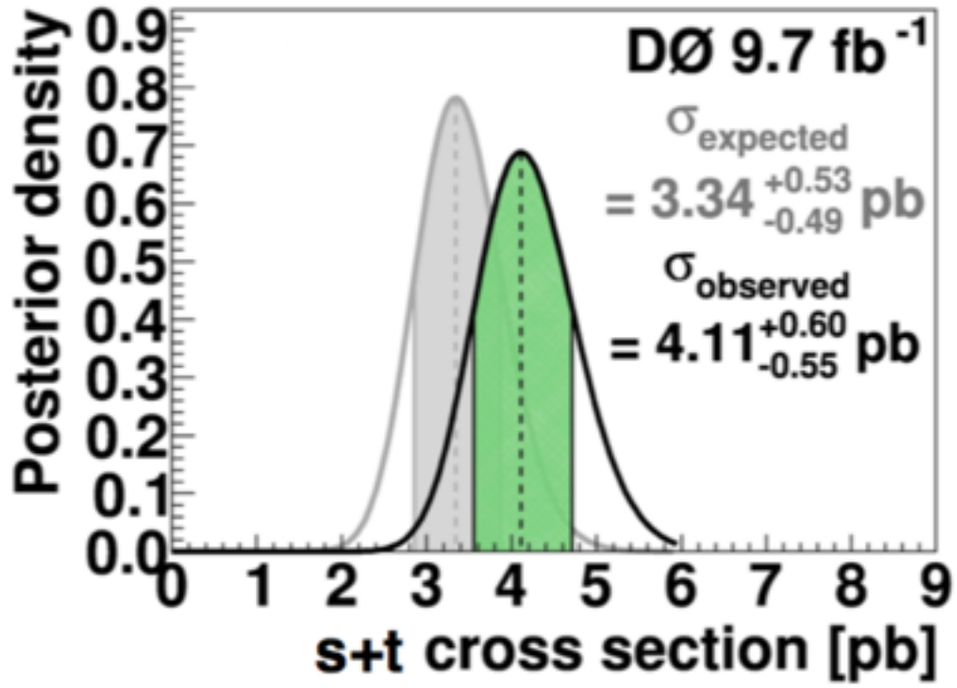
DØ Single Top Analysis

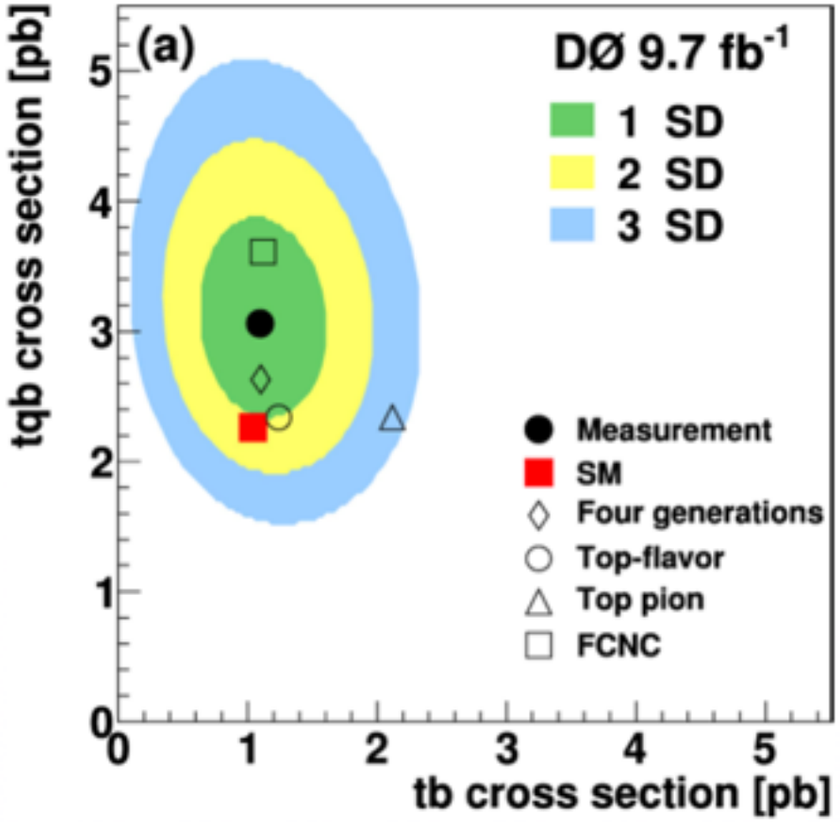
s+t cross section

- Combination of the 3 MVAs in a BayesianNN
- 1D posterior obtained for σ_{s+t} integrating over σ_t with no assumption on SM σ_s/σ_t

$\sigma_{s+t} = 4.11\ ^{+0.60}_{-0.55}$ pb (±14%)

$|V_{tb}| > 0.92$ at 95% CL





s-ch VS t-ch cross section

- 2D final discriminant sensitive to s-, t-ch
- Integrating over σ_t and extract σ_s and vice-versa

$\sigma_s = 1.10\ ^{+0.33}_{-0.31}$ pb (±29%)

$\sigma_t = 3.07\ ^{+0.54}_{-0.49}$ pb (±17%)

first evidence with 3.7σ significance

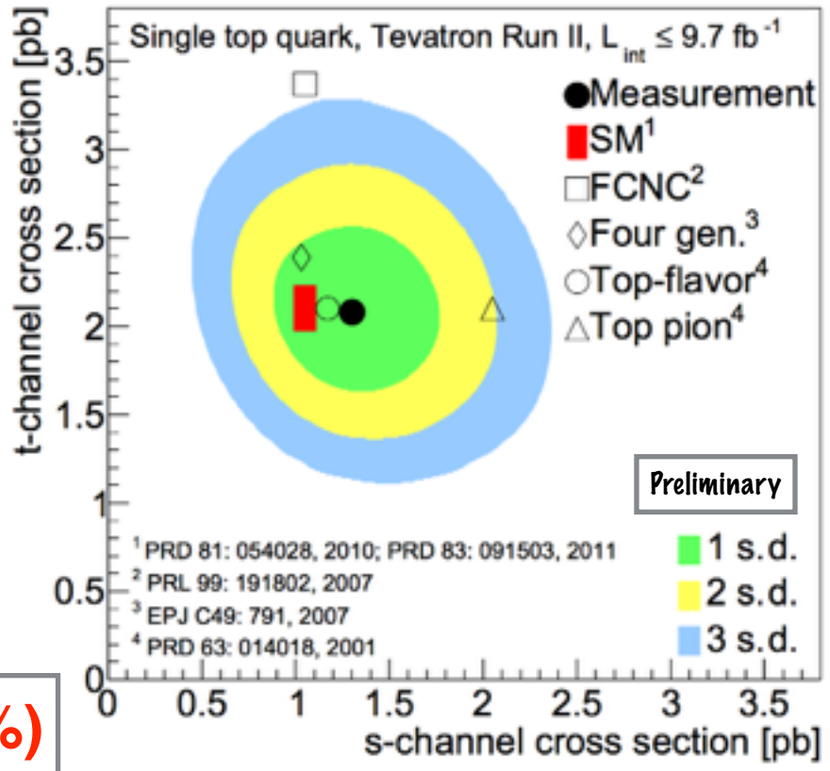
PLB 726, 656 (2013)

Tevatron s+t Combination

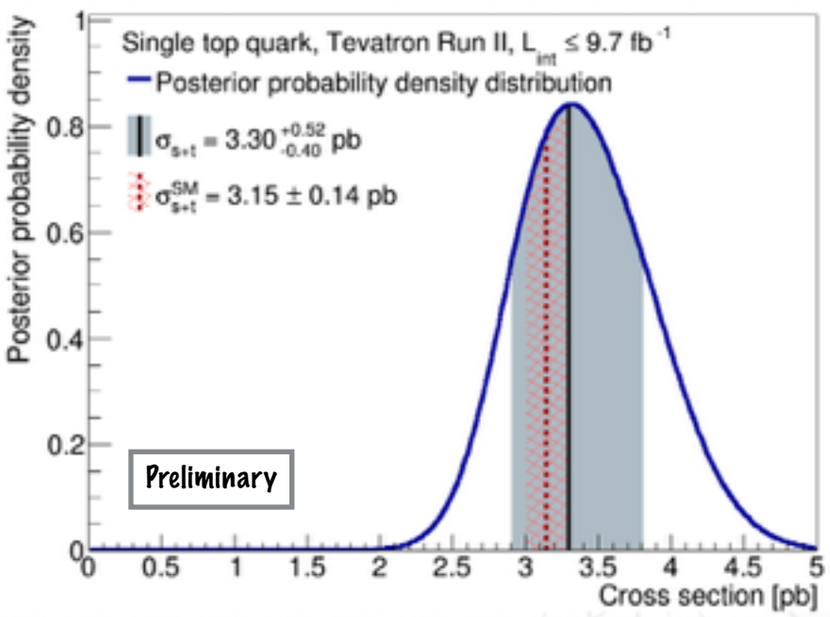
NEW!

Last Single Top legacy measurements from Tevatron!

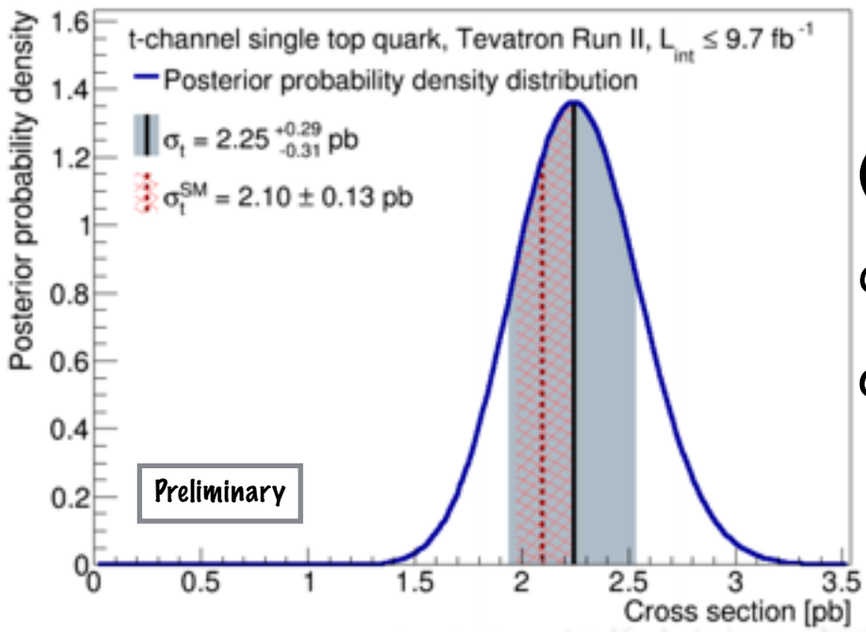
- σ_{s+t} VS σ_t with **L<9.7 fb^{-1}**
- Vtb
- Combines CDF and D0 analysis, fitting simultaneously D0 and CDF combined inputs (discriminants)
- 1D posterior on σ_{s+t} obtained by integrating 2D posterior over σ_t with no assumption on SM σ_s /σ_t



σ_{s+t} = 3.30 $^{+0.52}_{-0.40}$ pb (±13%)



σ_t = 2.25 $^{+0.29}_{-0.31}$ pb (±13%)



(More on combination method in dedicated talk by Yvonne Peters on Wednesday - Stay tuned!)

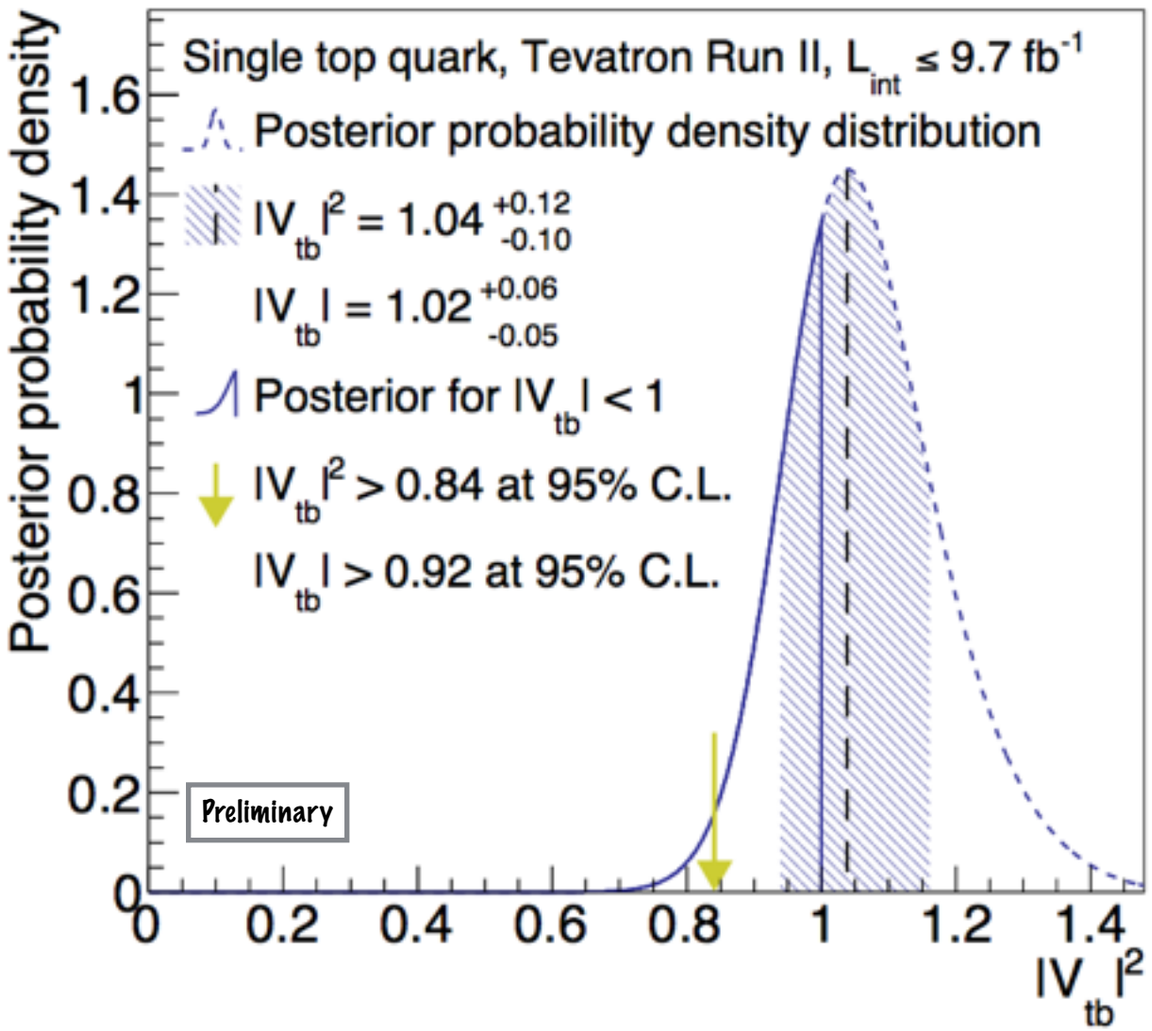
Fermilab-CONF-14-370-E

Tevatron s+t Combination

NEW!

$|V_{tb}|$ Matrix Element Extraction

- V_{tb}: same MVA discriminants as for s- and t-channel cross sections
- form a Bayesian posterior p.d. for $|V_{tb}|^2$ assuming a "flat" prior with no assumption on SM σ_s/σ_t



$|V_{tb}| > 0.92$ at 95% C.L.

Fermilab-CONF-14-370-E

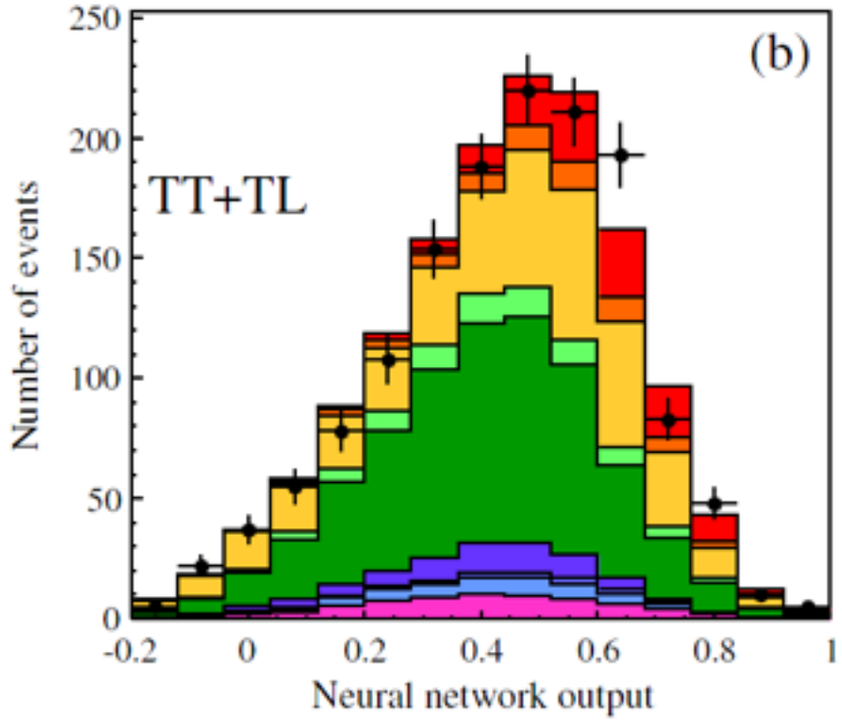
s-channel Production and Observation at Tevatron

CDF s-channel Analyses

s-channel l+jets & MET+jets with full CDF dataset 9.5 fb^{-1}

- New l+jets and MET+jets s-channel optimized analyses based on Higgs search techniques and selection
- Use CDF full Run II data set, new HOBIT tagger, extra lepton trigger adds 10% more leptons
- Both use MVA discriminant sensitive to s-channel only

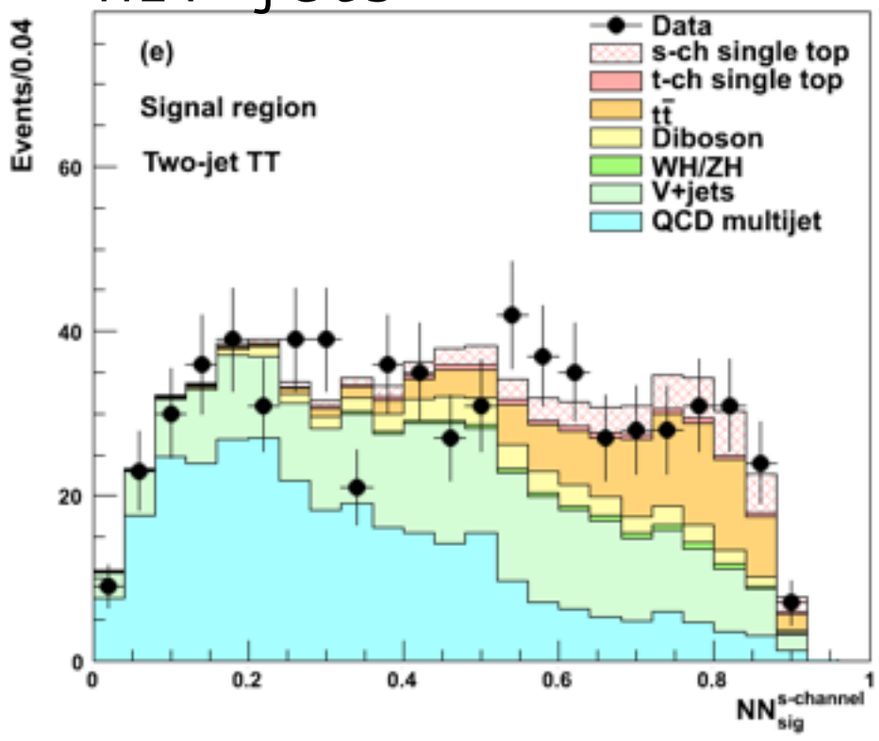
l+jets



$\sigma_s = 1.41^{+0.44}_{-0.42}$ (stat+syst) pb
p-value = 3.8σ (2.9σ expected)

PRL 112 231804 (2014)

MET+jets

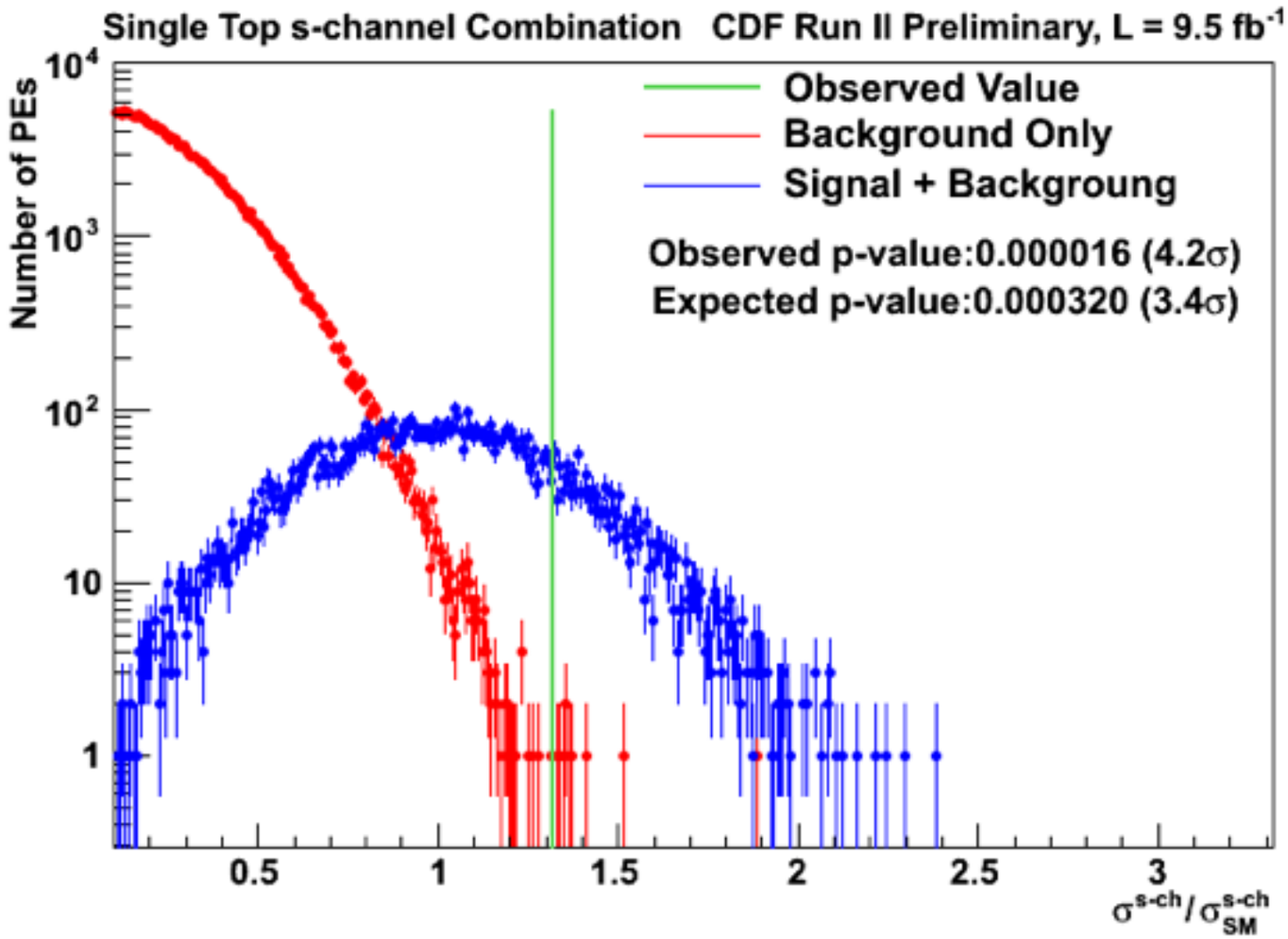


$\sigma_s = 1.12^{+0.61}_{-0.57}$ (stat+syst) pb
p-value = 1.9σ (1.8σ expected)

PRL 112 231805 (2014)

CDF s-channel Combination

$\sigma_s = 1.36^{+0.37}_{-0.32}$ (stat+syst) pb
(±27%)

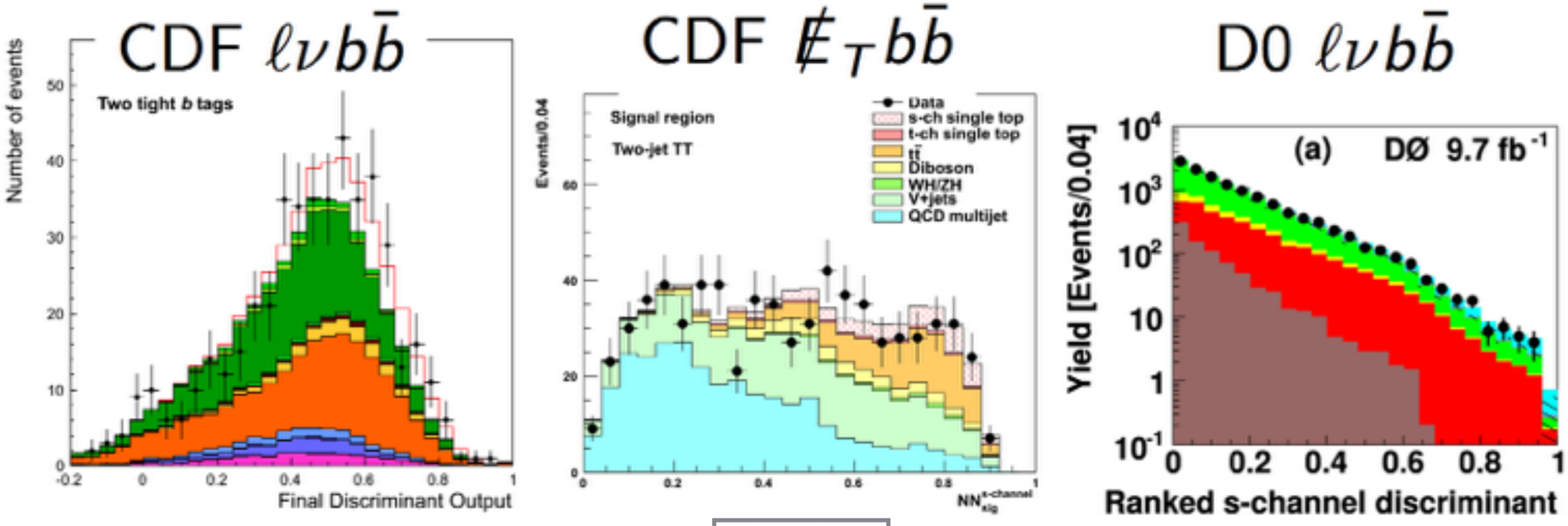


4.2σ significance

PRL 112 231805 (2014)

Tevatron s-channel Combination

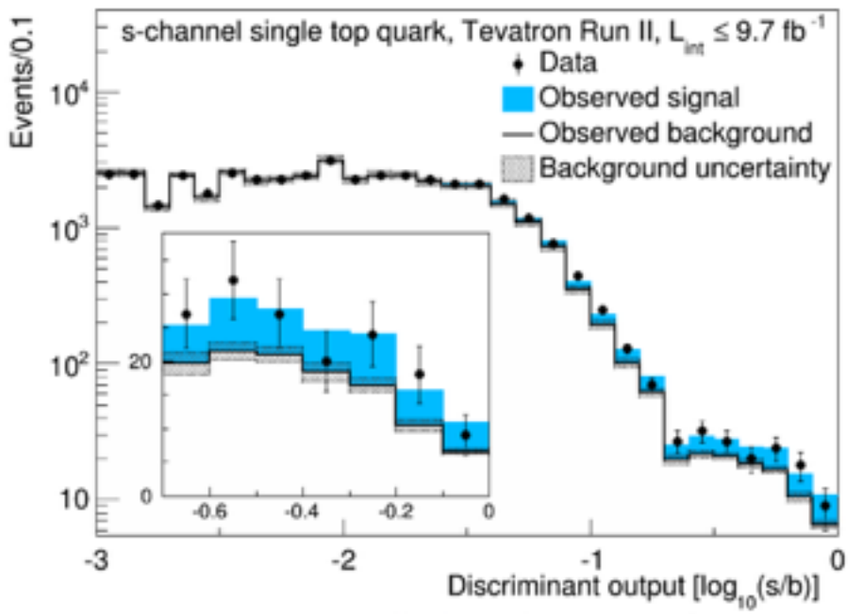
Inputs



Output

combine individual discriminants

including all correlations

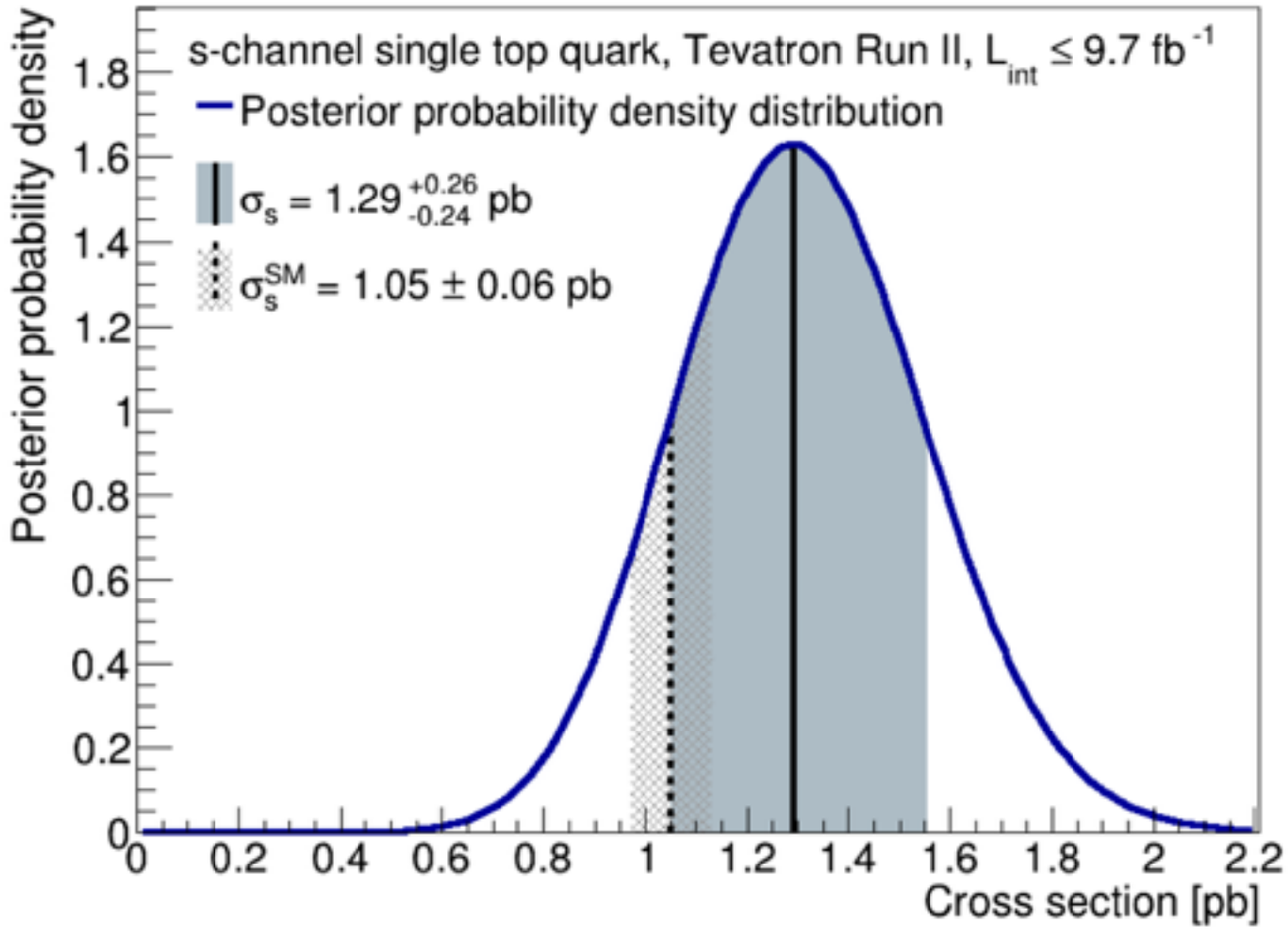


(More on combination method in dedicated talk by Yvonne Peters on Wednesday - Stay tuned!)

PRL 112 231803 (2014)

Tevatron s-channel Observation

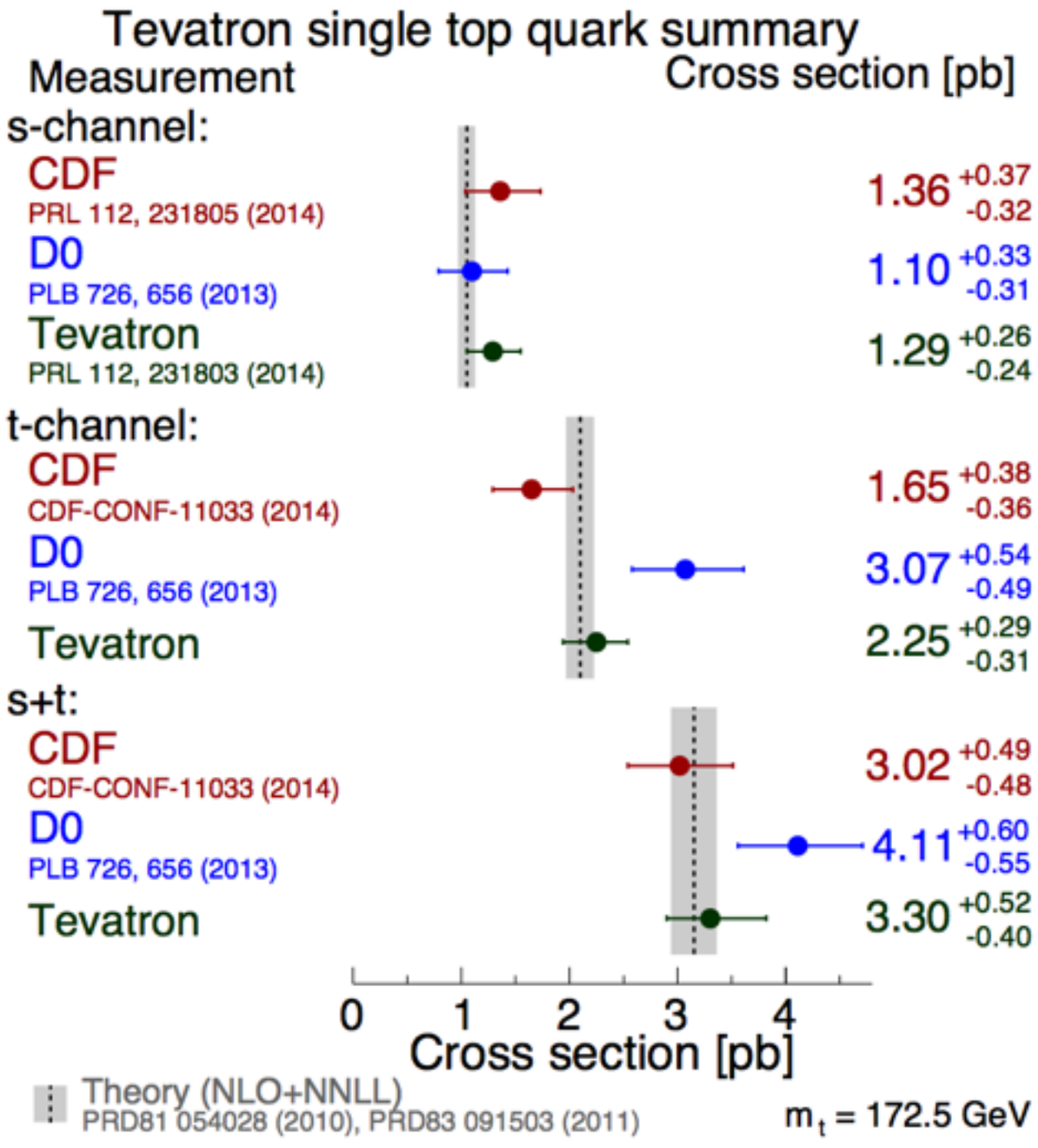
$\sigma_s = 1.29^{+0.26}_{-0.24}$ (stat+syst) pb
(±19%)
6.3σ (5.1σ expected)



First observation of s-channel single top production!

PRL 112 231803 (2014)

Tevatron Single Top Summary



Full Tevatron dataset

up to 9.7 fb^{-1}

29% first evidence: 3.7σ

19% first Observation: 6.1σ

13% ; $|V_{tb}|$: 5.3% precision

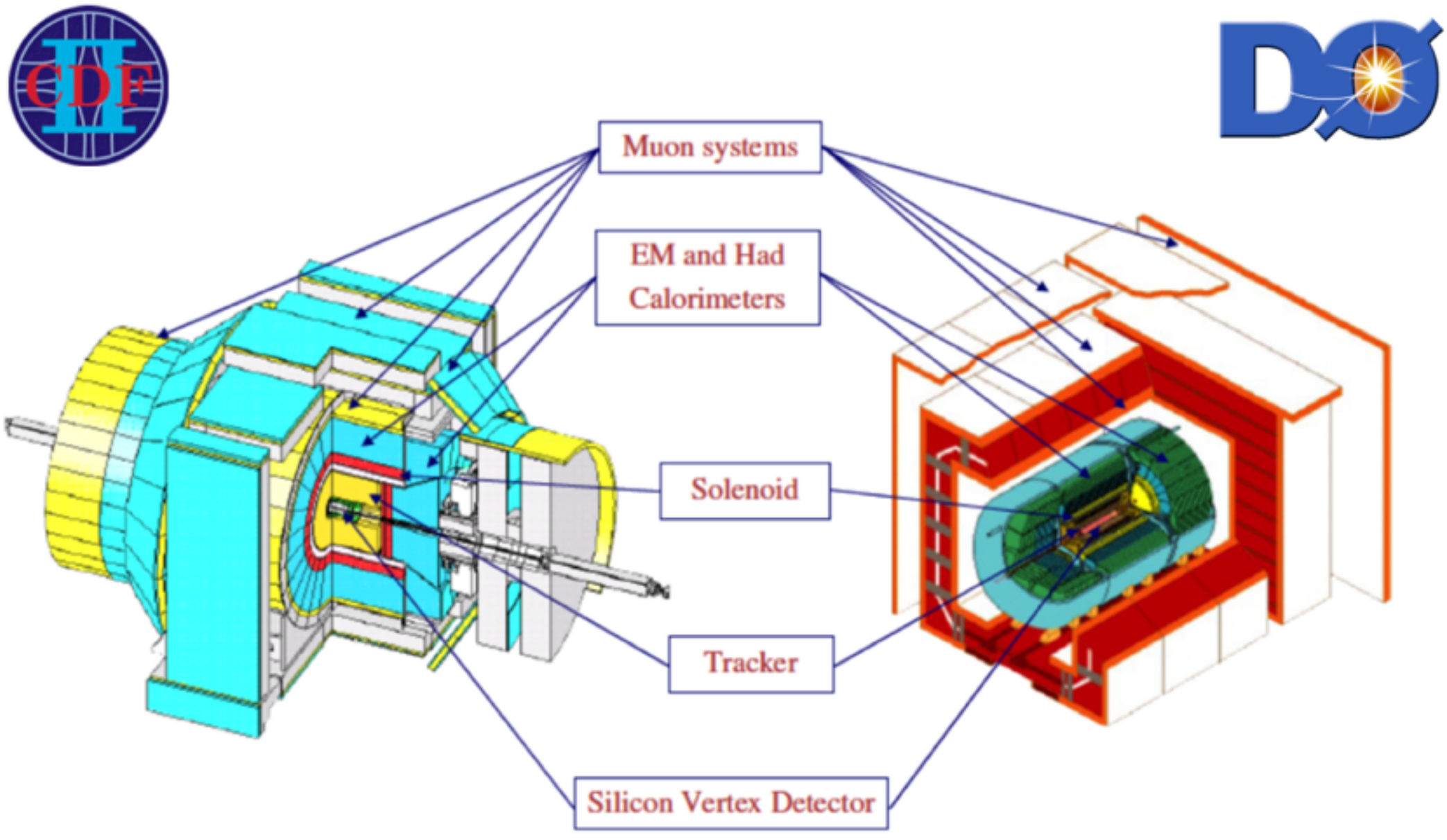
Summary

- Single Top was observed at CDF&D0 in 2009
- Now, Single Top program at Tevatron is (almost) complete!
  - ✓ All measurements in agreement with SM prediction!
  - ✓ At least for single top cross section, this is the final measurement by Tevatron!
- New s+t Tevatron combination has been performed
- s-channel was the last missing block in ST **-> Observed!**

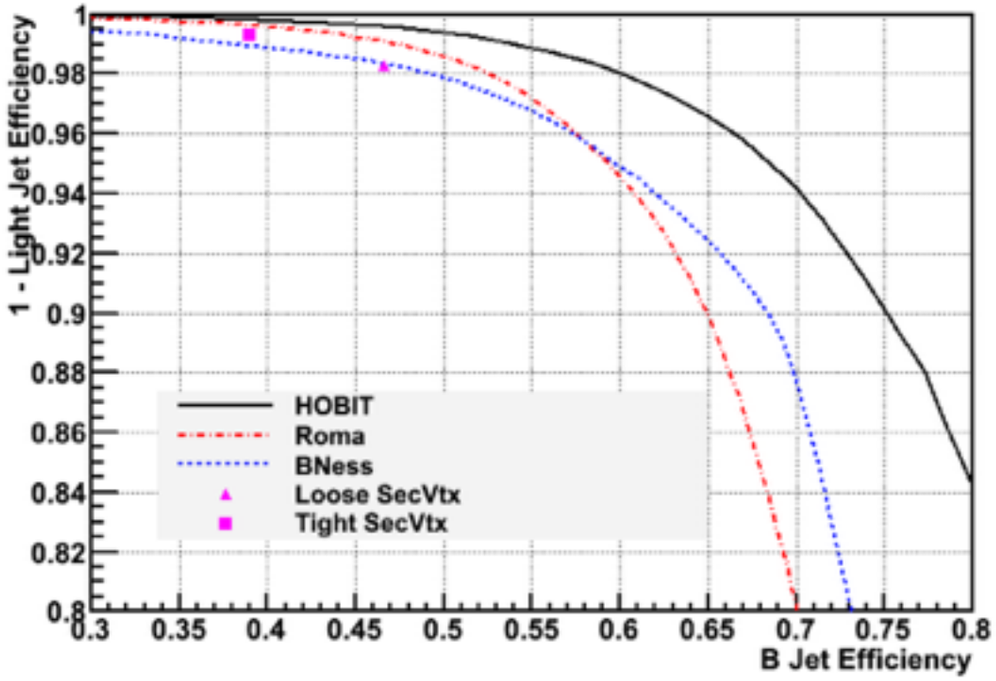
Thanks for the attention!

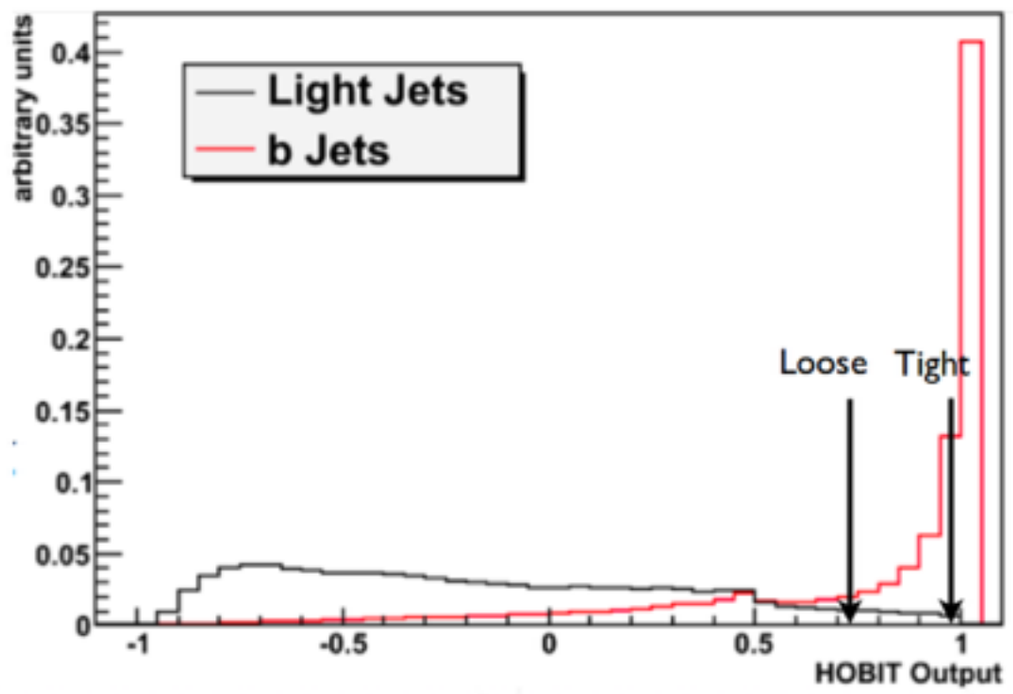
BACKUP

CDF & DØ detectors



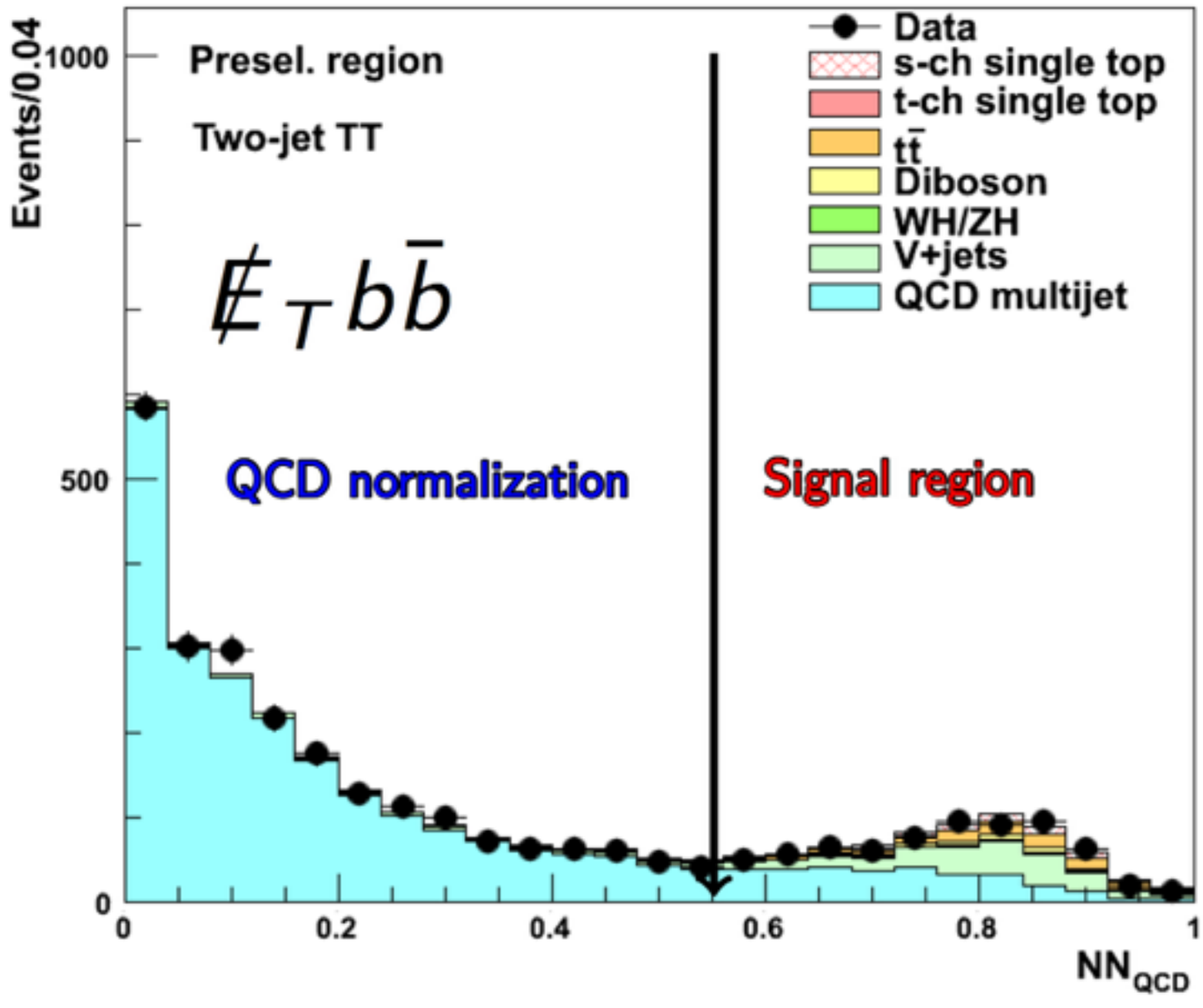
HOBIT b-tagger at CDF





- A new b-jet identification algorithm optimized for H → bb searches: HOBIT
- Two different HOBIT cuts are used: tight b-tag (T), loose b-tag (L)

MET+jets QCD rejection (CDF)



Uncertainties

Systematic uncertainty	CDF		D0		Correlated
	Norm	Dist	Norm	Dist	
Lumi from detector	4.5%		4.5%		No
Lumi from cross section	4.0%		4.0%		Yes
Signal modeling	2–10%	•	3–8%		Yes
Background (simulation)	2–12%	•	2–11%	•	Yes
Background (data)	15–40%	•	19–50%	•	No
Detector modeling	2–10%	•	1–5%	•	No
b-jet-tagging	10–30%		15–40%	•	No
JES	0–20%	•	9–40%	•	No

s-ch Observation

total expected uncertainty: 20%

expected uncertainty w/o systematics: 14%

s+t Tevatron

total expected uncertainty: 13%

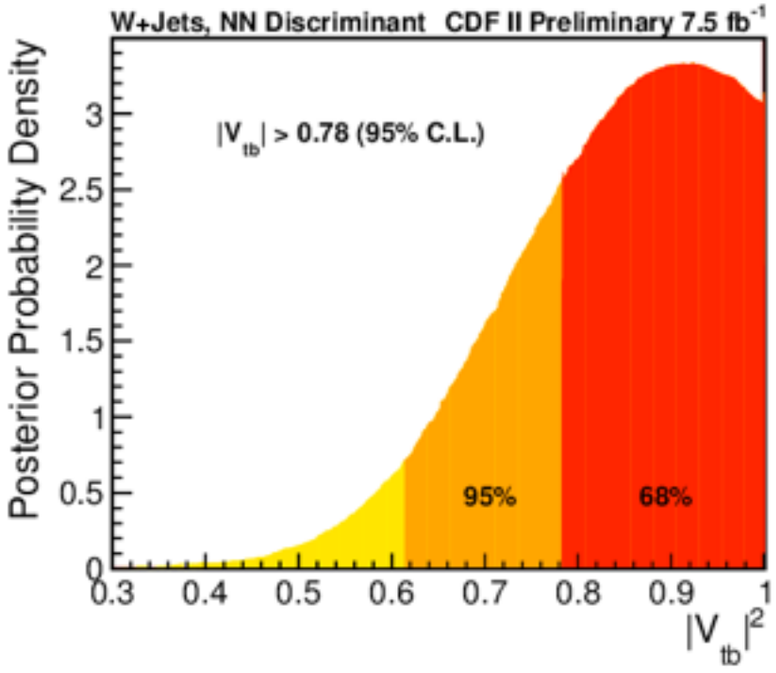
expected uncertainty w/o systematics: 8%

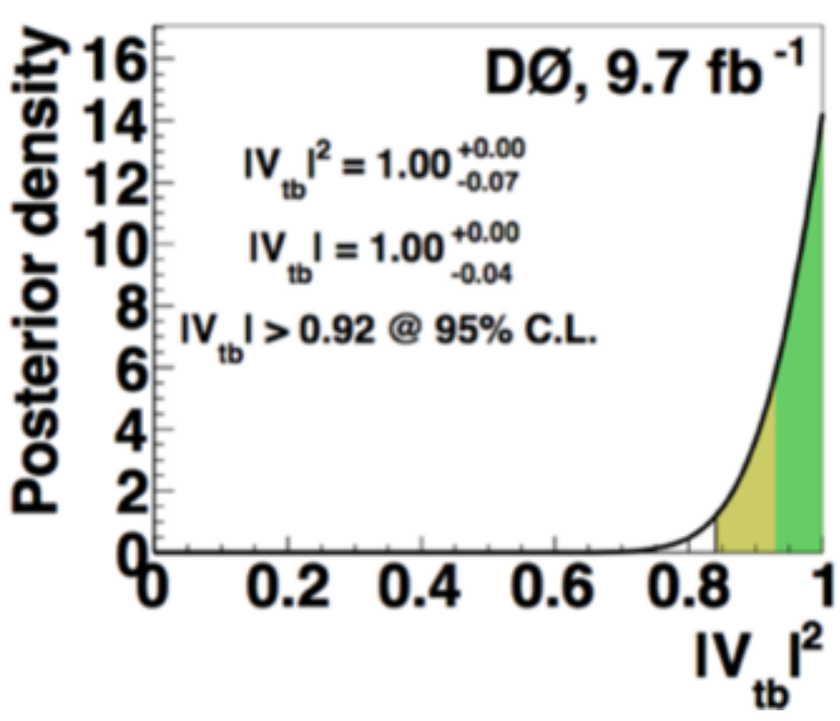
$|V_{tb}|$ measurement

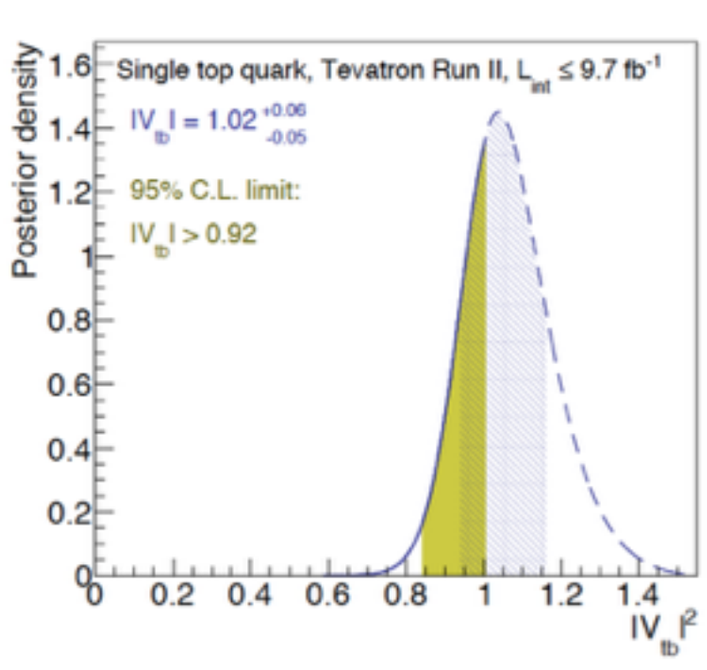
- $\sigma(s+t+Wt) \propto |V_{tb}|^2$ so we can extract the matrix element, assuming:
  - SM top quark decay: $|V_{td}|^2+|V_{ts}|^2 \ll |V_{tb}|^2$
  - V-A and CP conserving Wtb vertex
  - No assumption on # of families or CKM unitarity

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

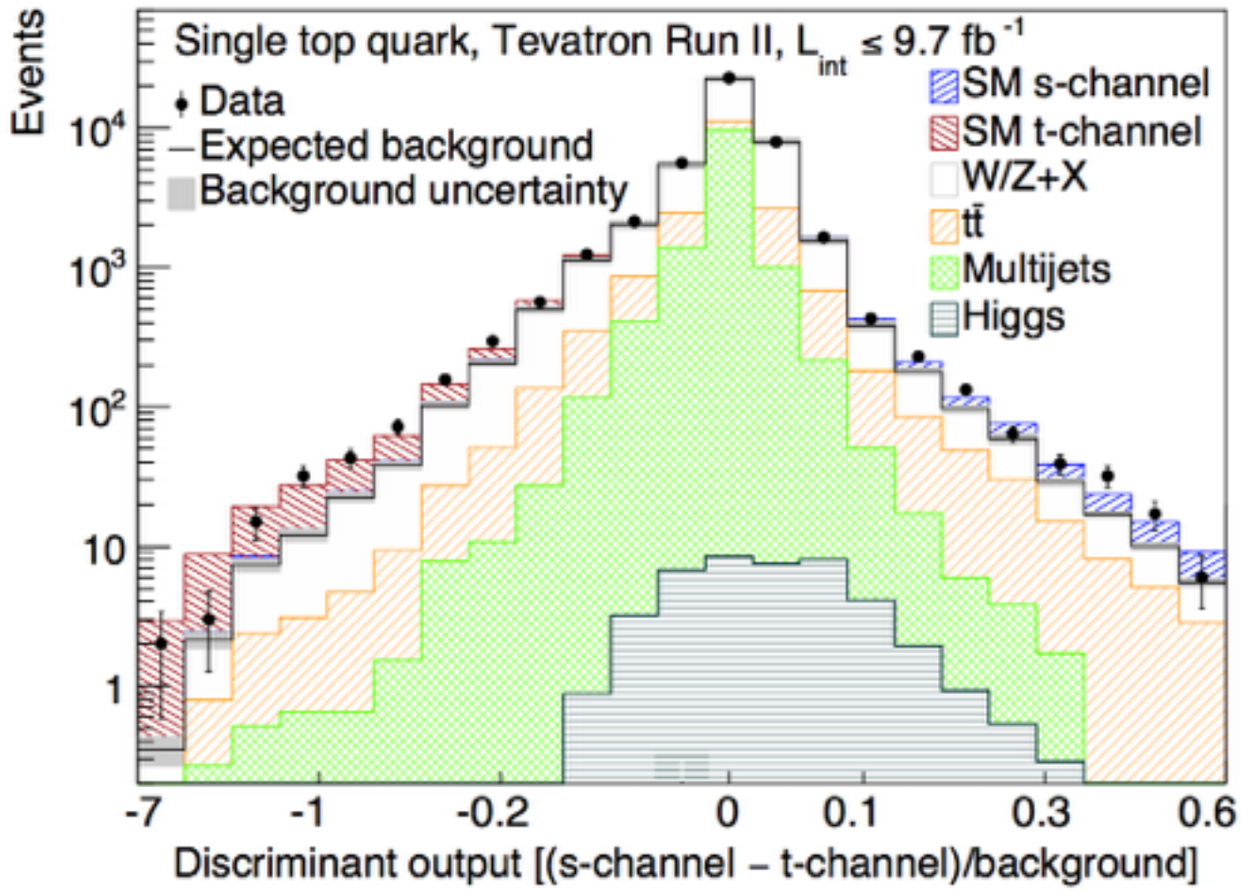
- additional systematic uncertainties: theoretical uncertainty on single top cross section







Tevatron s+t Discriminant



without background subtraction:

➡ t-channel SR at the left, the s-channel SR at the right.

Tevatron s+t Combination & BSM