Evidence of single top s-channel in lepton+jets channel at CDF

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(on behalf of CDF collaboration)
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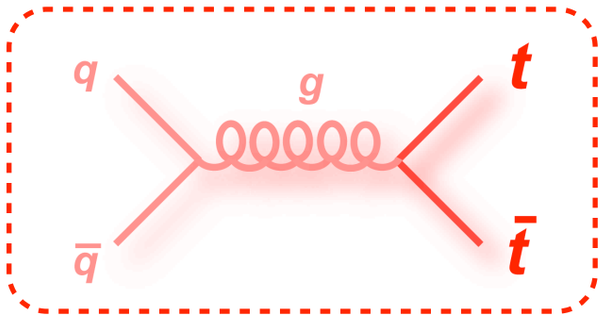
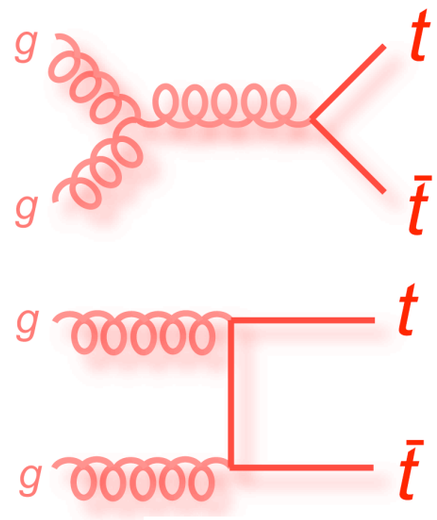
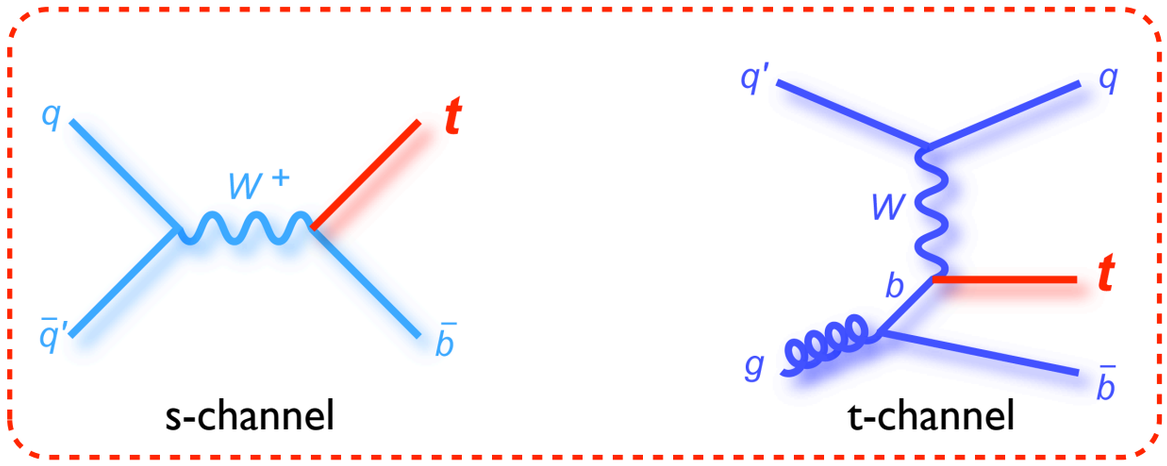
Top quark

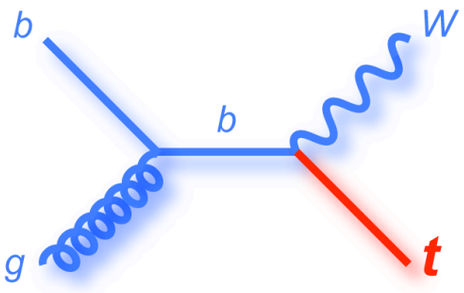
- Top quark: the heaviest know particle, couples strongly to Higgs, decays as a free quark.
- Top quark pair production process was first observed at Tevatron in 1995. Single top production process was first observed at Tevatron again in 2009.
- Strong production



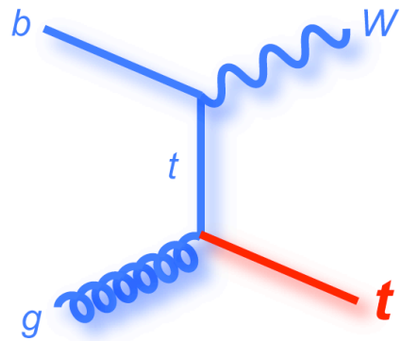


- Electroweak production





tW-channel



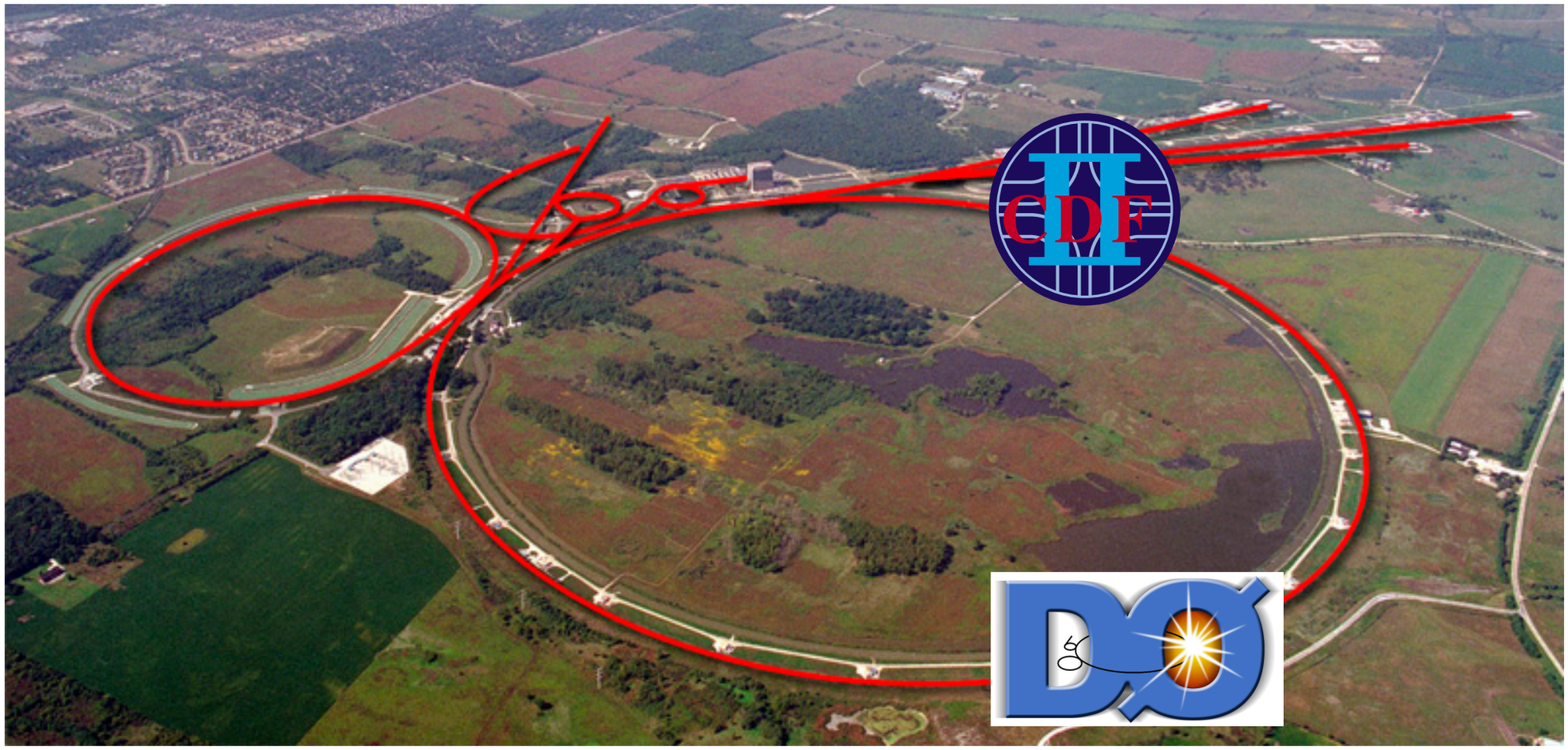
Production Cross Section

Cross section(pb)	$t\bar{t}$	s-channel	t-channel	tW-channel
Tevatron(1.96 TeV)	7.08	1.05	2.08	0.25
	×33	×5.3	×42	×88
LHC(8 TeV)	234	5.55	87.2	22.2

N. Kidonakis, Phys. Rev. D 83, 091503 (2011)
N. Kidonakis, Phys. Rev. D 81, 054028 (2010)
N. Kidonakis, Phys. Rev. D 82, 054018 (2010)
N. Kidonakis, arxiv:1210.7813.

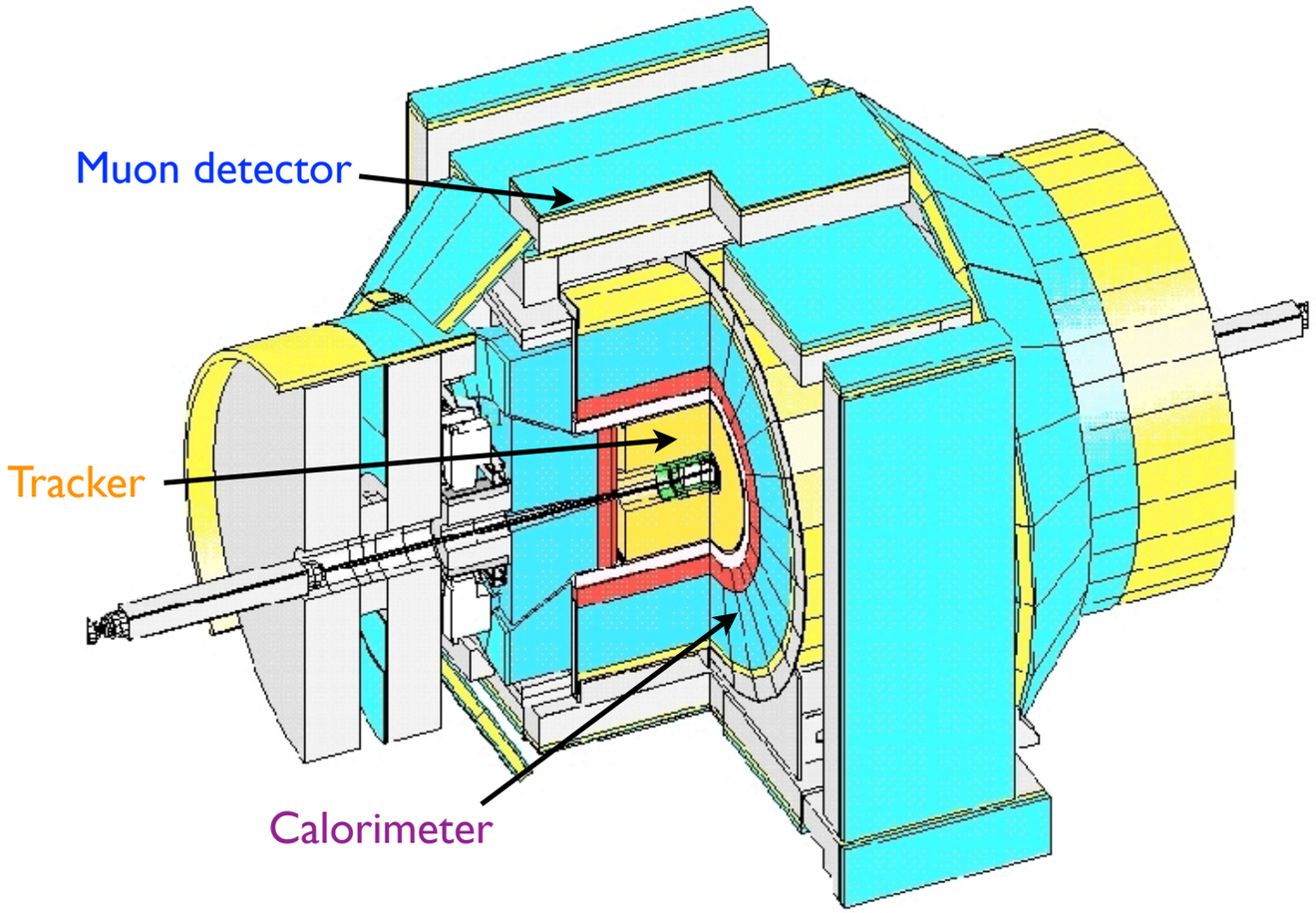
- The cross section of s-channel single top process at 8 TeV LHC only increased a little compare to Tevatron 1.96 TeV $p\bar{p}$ collision. Thus, the signal to background ratio is lower for s-channel process at LHC.
- Single top process
  - Direct probe to the $|V_{tb}|$ element of CKM matrix.
  - Able to measure the quark decay width.
  - Sensitive to several new physics models, such new bosons.

Fermilab Tevatron



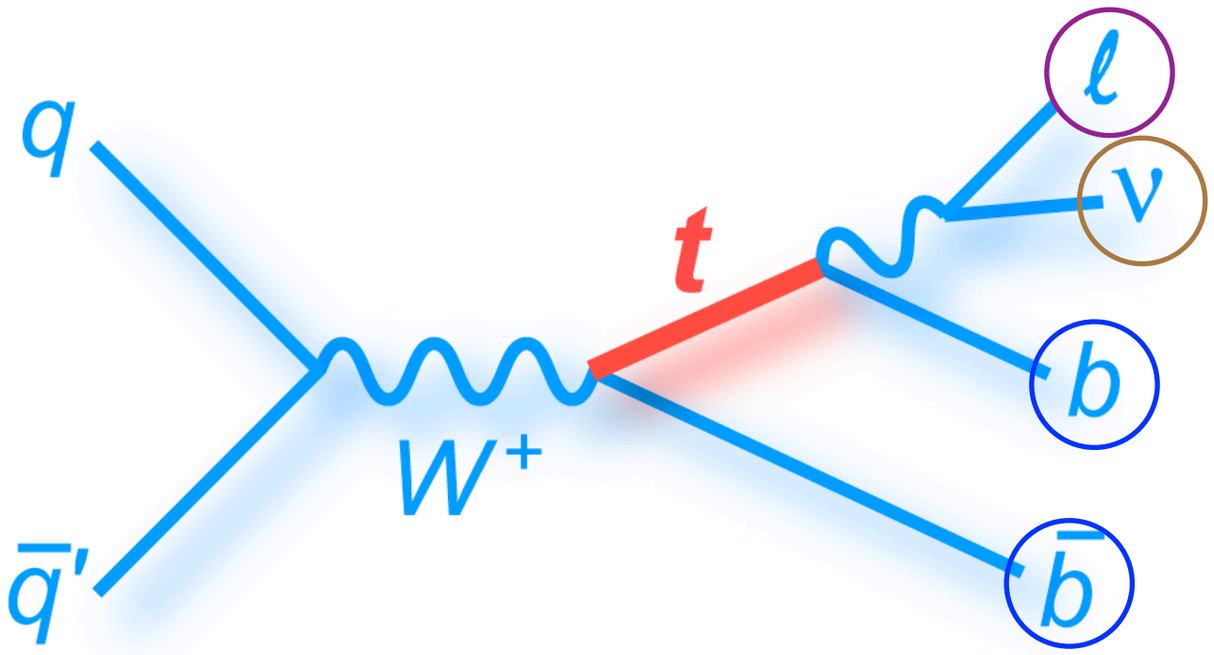
- Proton-antiproton collider, with circumference of 4 mile, center of mass energy 1.96 TeV.
- Run II starts since 2001, ends in 2011. More than 10 fb^{-1} total luminosity delivered. At CDF, after data quality requirement, 9.4 fb^{-1} used in this analysis.

CDF Detector



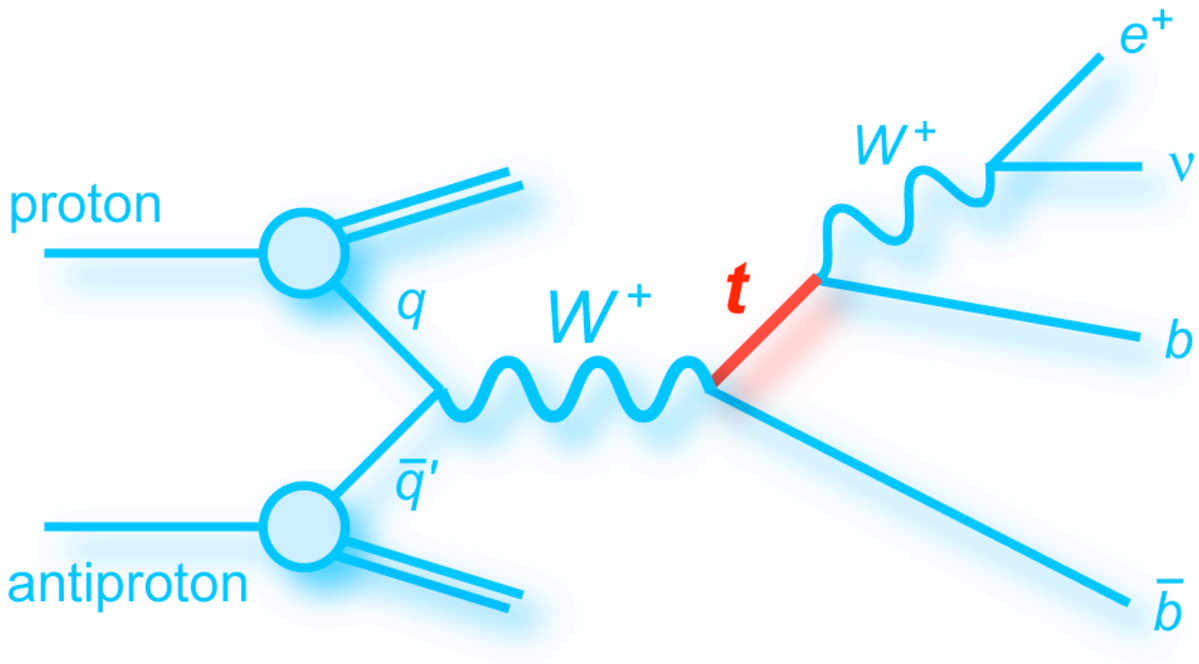
- CDF is a general purpose particle detector.
- From inside to outside:
  - Tracker
  - Calorimeter
  - Muon detector

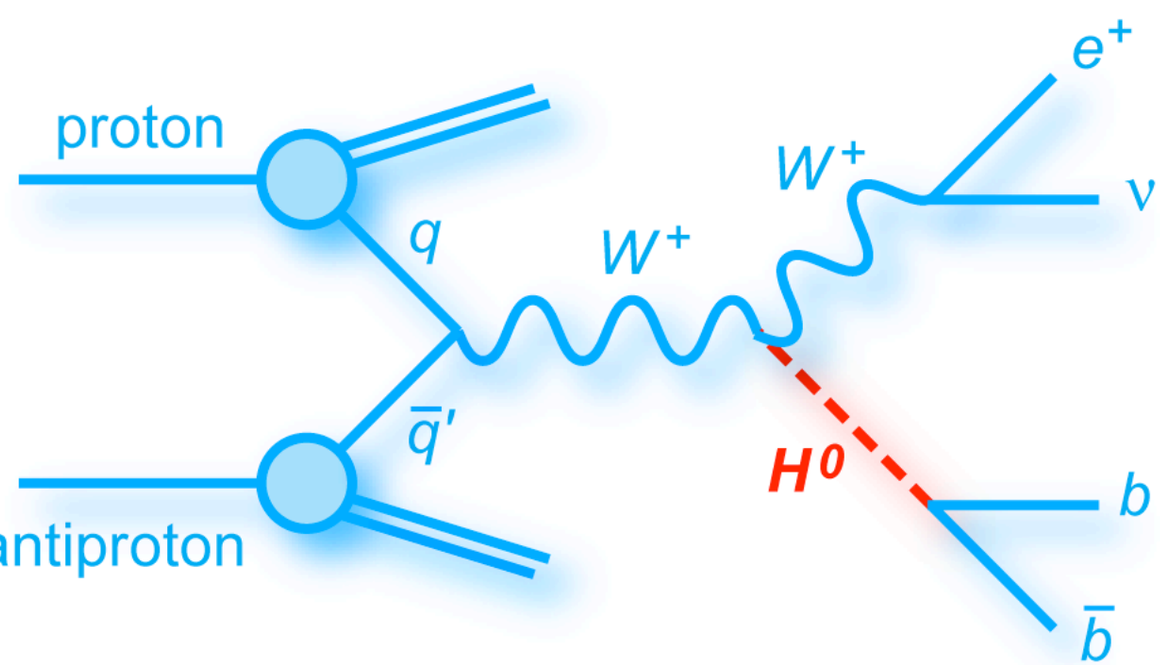
Event Selection



- High p_T isolated lepton (e/μ):
  - $p_T > 20$ GeV.
- Missing transverse energy:
  - > 10 GeV(for central muons)
  - > 20 GeV(other leptons)
- Two jets:
  - $E_T > 20$ GeV, $|\eta| < 2.0$,
  - leading jet: $E_T > 30$ GeV.
- $H_T > 125$ GeV, $M_{jj} > 30$ GeV.
  - H_T = Jets E_T + Lepton p_T + Missing E_T

Higgs Search at CDF

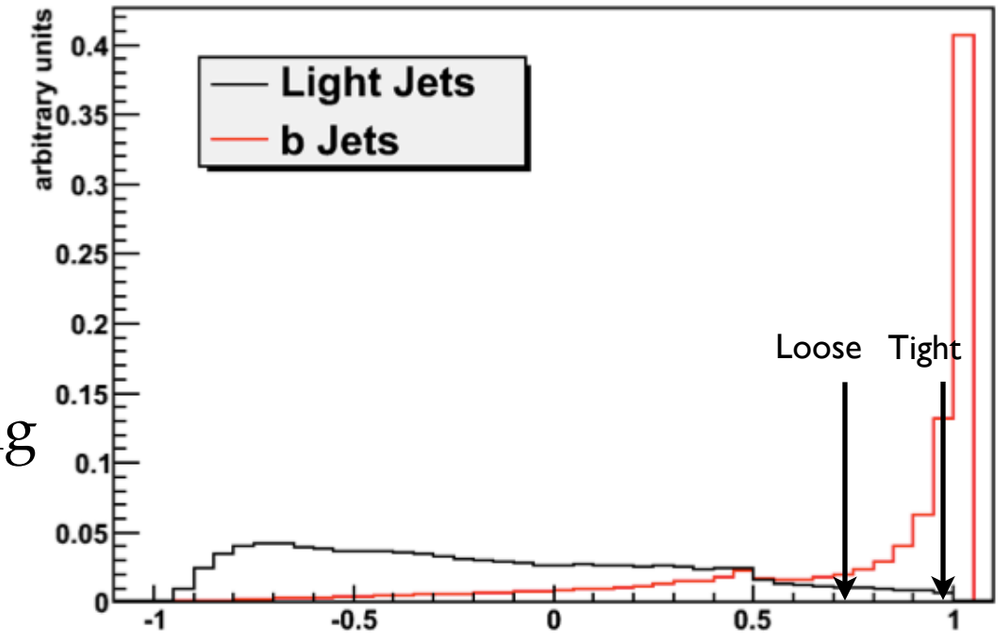


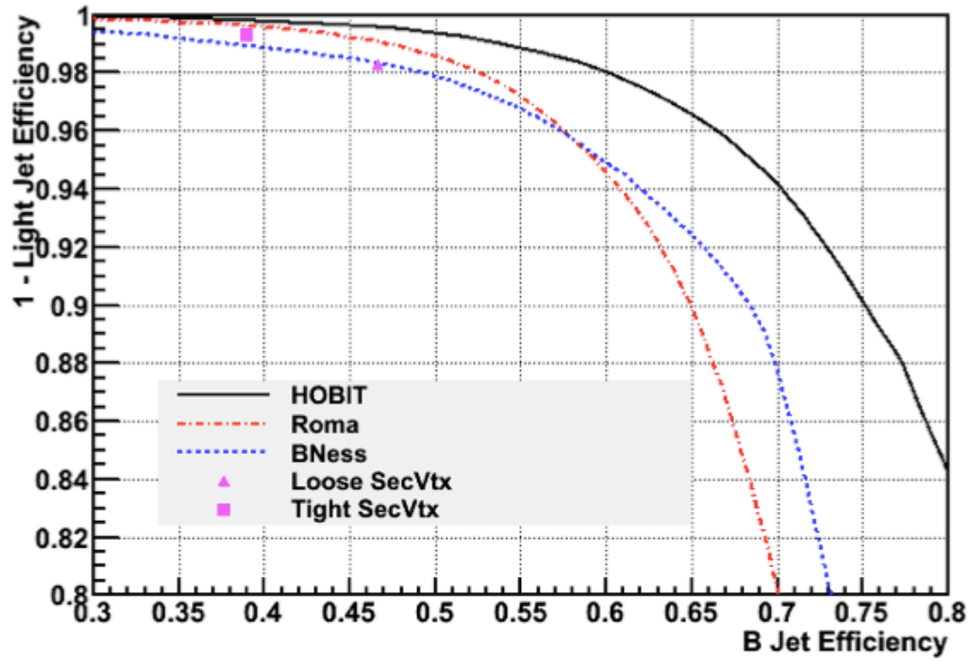


- CDF published the final Higgs search results with CDF full dataset in 2012.
- In our analysis, we applied most improvements we made in Higgs search, in order to increase the signal acceptance.

b-Jet Identification

- We applied *b*-tagging algorithm to identify the *b*-jets in this analysis.
- HOBIT (**H**iggs **O**ptimized ***b***-**I**dentification **T**agger) was developed for Higgs analysis, but has been validated for *b*-jet in other processes.
- We defined two different tagged jets by applying different requirements on the HOBIT output value
  - Tight tag (**T**): tagging efficiency 0.42
  - Loose tag (**L**): tagging efficiency 0.70
- From these two tag requirements, we defined four tagging categories:
  - TT: two tight *b* tags
  - TL: one tight + one loose *b* tags
  - T: exclusive one tight *b* tag
  - LL: two loose *b* tags

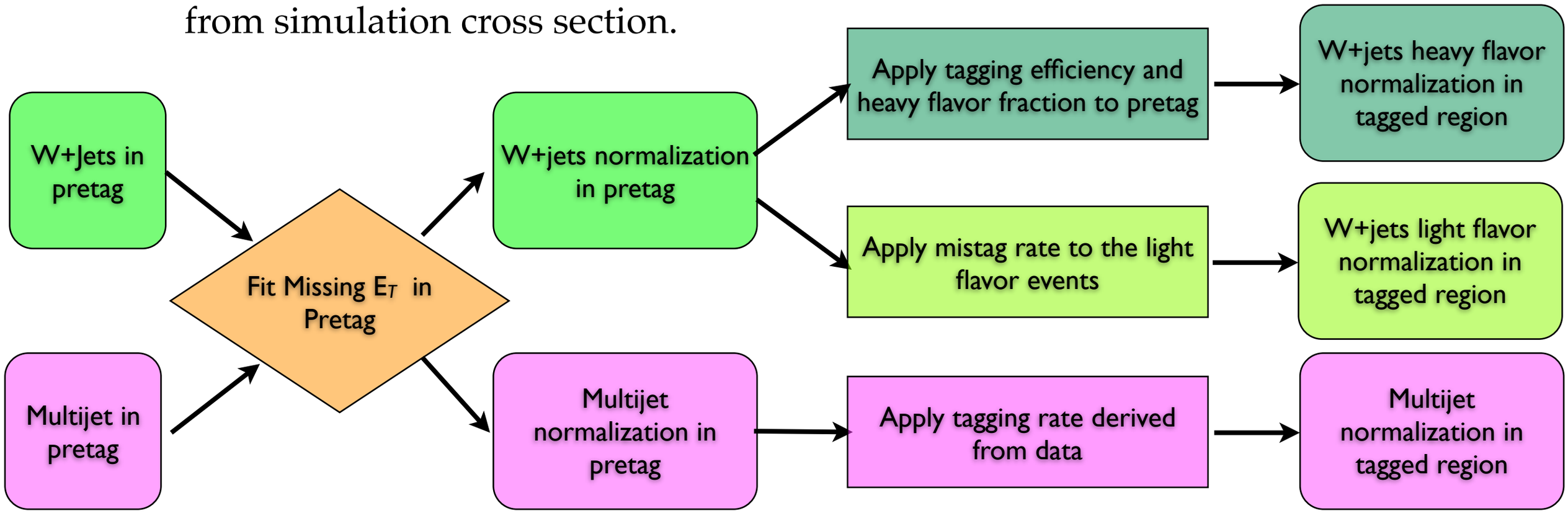




J.Freeman, *et al*. Nucl.Instrum.Meth. A697 (2013) 64-76

Signal & Background Modeling

- Backgrounds are simulated by each of the following simulator, and all been showered by PYTHIA
  - Single top: POWHEG
  - $t\bar{t}$, diboson, Higgs: PYTHIA
  - W/Z+jets: ALPGEN
- Multijet is a data driven background.
- The normalization of single top, $t\bar{t}$, diboson, Higgs and Z+jets are determined from simulation cross section.



Number of Events Prediction

- The table shows the prediction of all processes and with systematic uncertainty of normalization included.

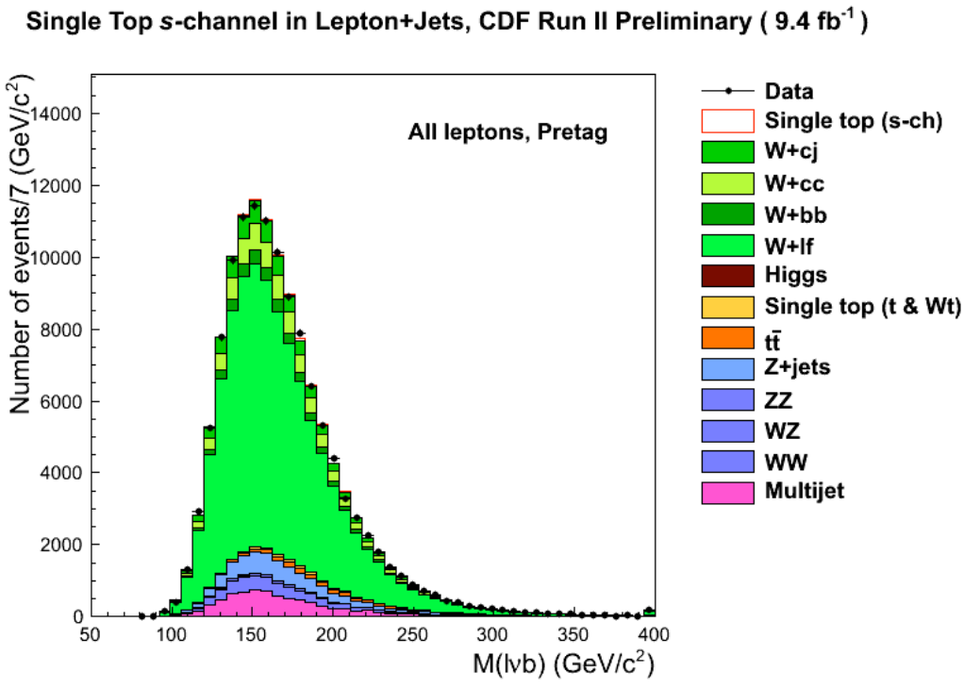
Category	TT	TL	T	LL
WW	1.7±0.4	13.2±2.7	184±23	24.8±3.9
WZ	17.8±2.2	21.2±2.0	52.7±5.4	9.9±0.9
ZZ	2.4±0.3	2.4±0.2	7.1±0.7	0.96±0.08
Z + jets	10.9±1.2	20.7±2.3	163±18	27.1±3.1
$t\bar{t}$	163±21	194±19	502±50	58.1±6.6
Higgs	6.1±0.6	6.4±0.4	10.3±0.7	1.7±0.2
Wbb	246±99	327±130	1166±468	109±44
Wcc	19.0±7.8	120±49	1158±467	164±67
W + Mistag	4.3±1.3	62±13	978±141	242±34
Multijet	29±12	47±19	281±112	45±18
t and Wt-channel	18.1±2.5	35.3±4.2	251±28	13.6±1.5
s-channel	54.5±6.7	61.2±5.6	109±10	17.8±2.1
Total Prediction	573±155	911±248	4860±1320	714±181
Observed	466	765	4620	718
Significance	2.52	2.21	1.60	0.66

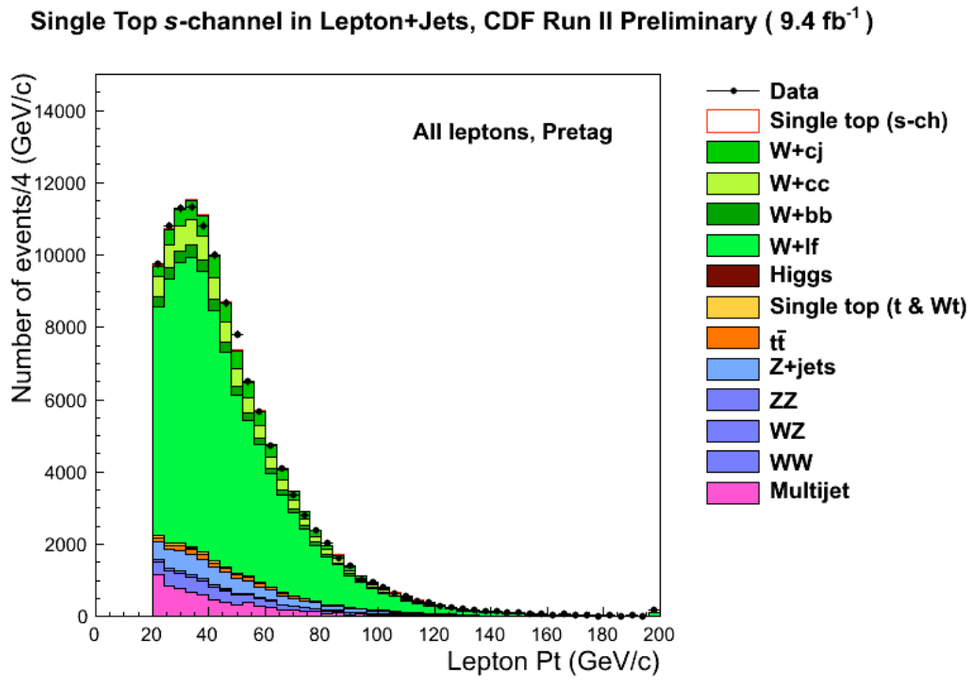
Final Discriminants

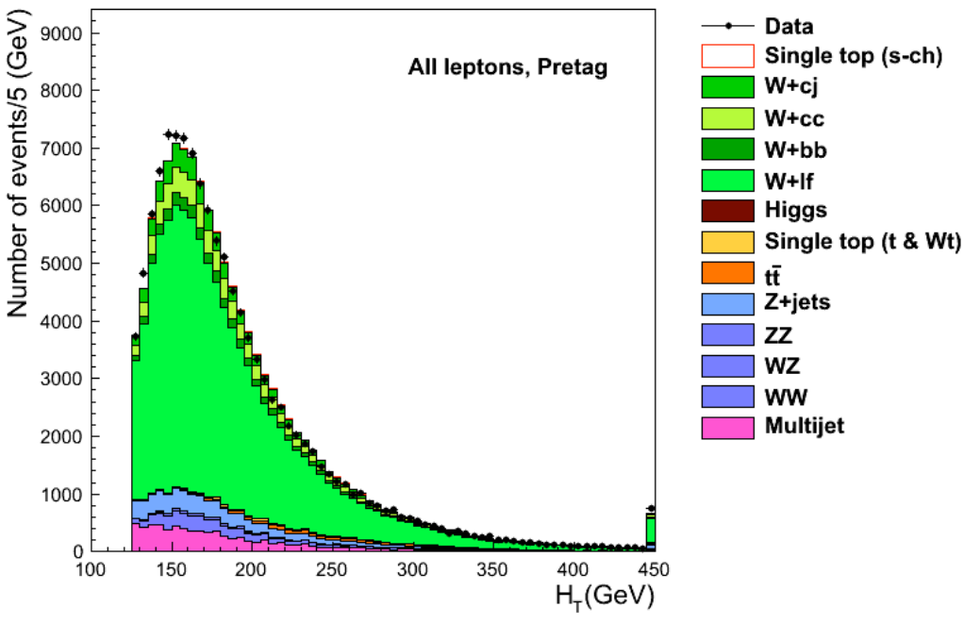
- To increase the sensitivity, we need a multivariate technique to separate signal from backgrounds.
- We used TMVA trained neural network to work as the final discriminant of this analysis.
- Input variables used in the analysis are listed in the table.
- We trained separate neural networks for central leptons and loose muons, also separately for each tagging category.

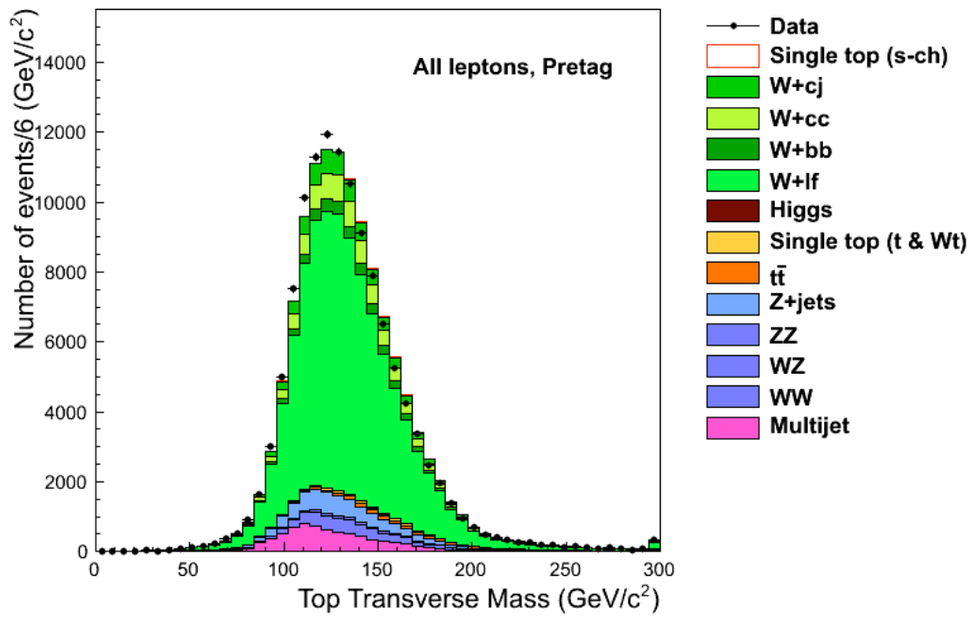
variable	Central Leptons	Loose Muons
$M_{l\nu b}$	$\surd$	$\surd$
$M_{l\nu bb}$	$\surd$	$\surd$
Lep p_T	$\surd$	$\surd$
M_{jj}	$\surd$	$\surd$
$\cos\theta_{lj}$	$\surd$	$\surd$
H_t	$\surd$	$\surd$
$M^T_{l\nu b}$		$\surd$
b jet selector output	$\surd$	

Data Simulation Comparison



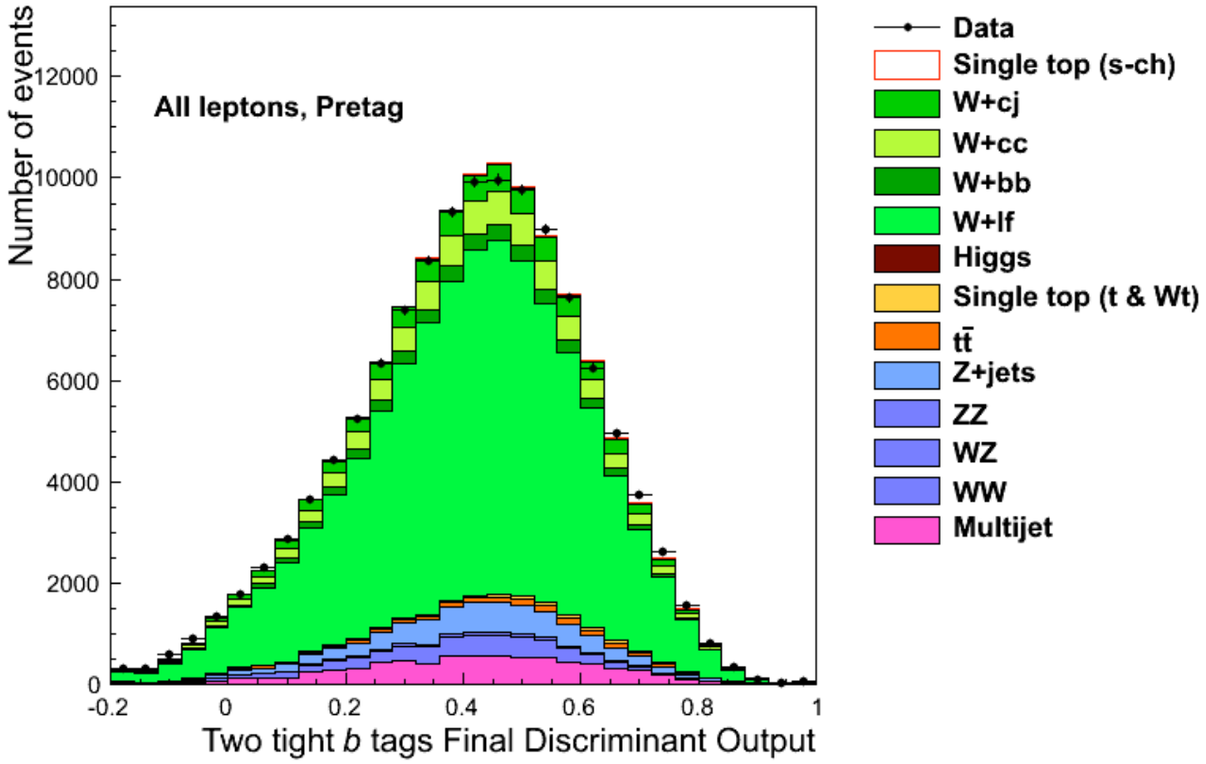


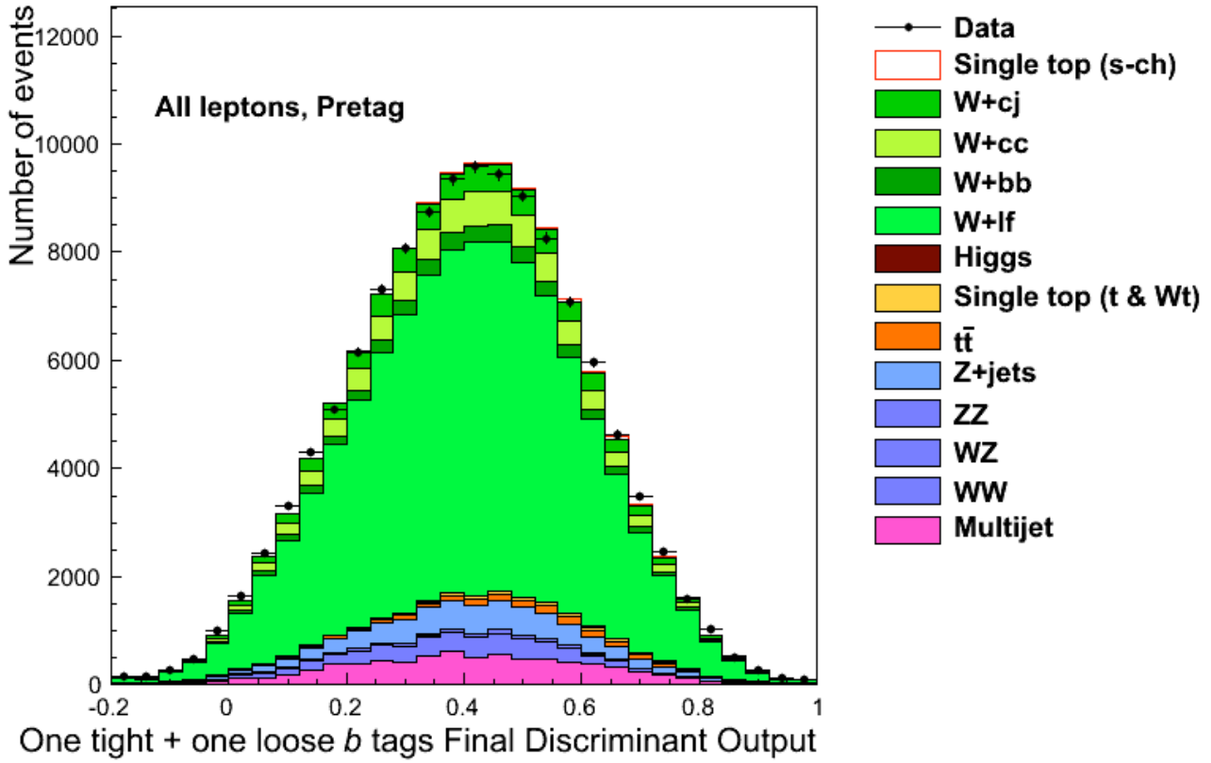




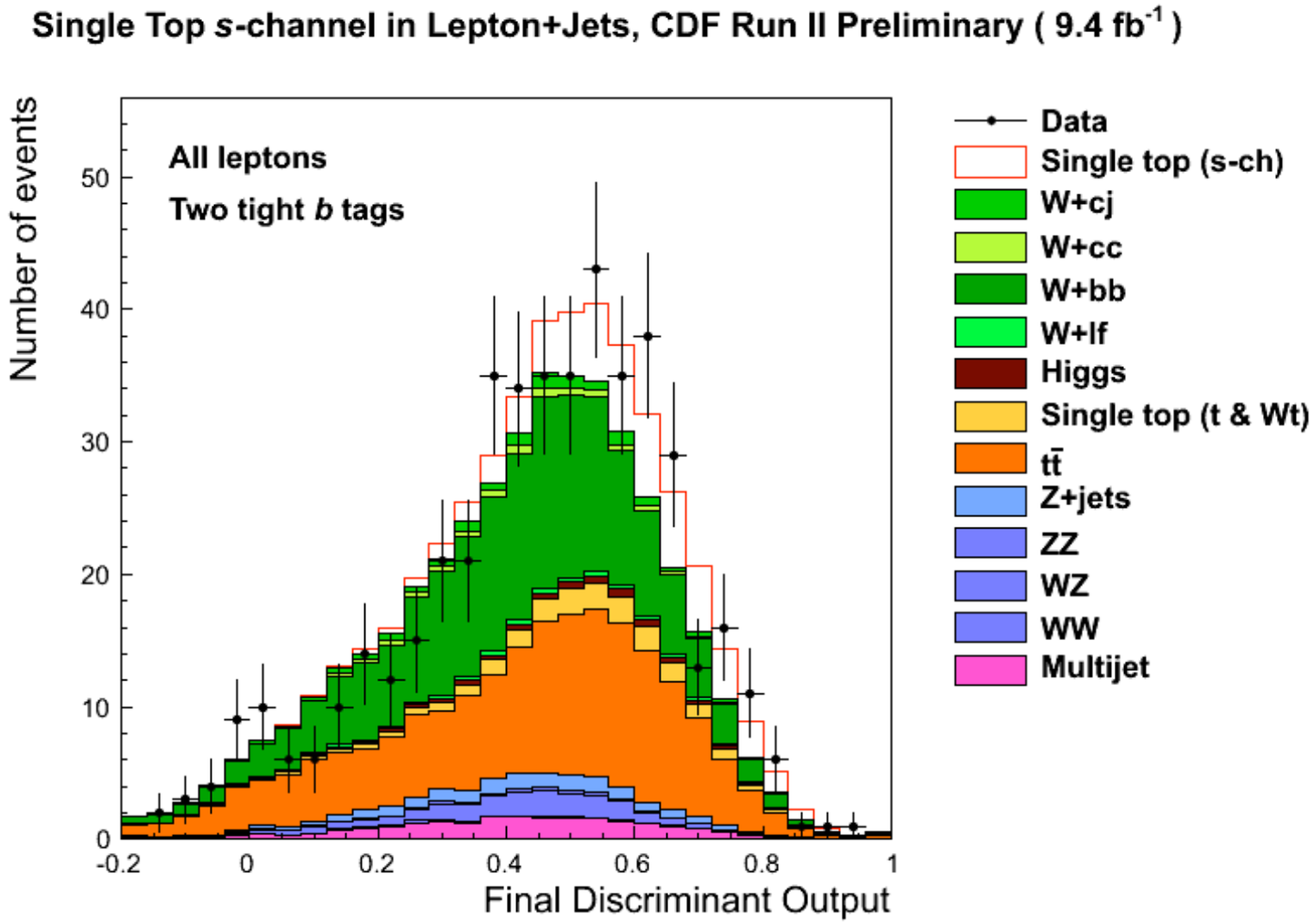
Final Discriminants

- The modeling of final discriminants was checked in the pretag control region for each neural networks.
- These plots validates the modeling of the correlations between input variables we used in this analysis.



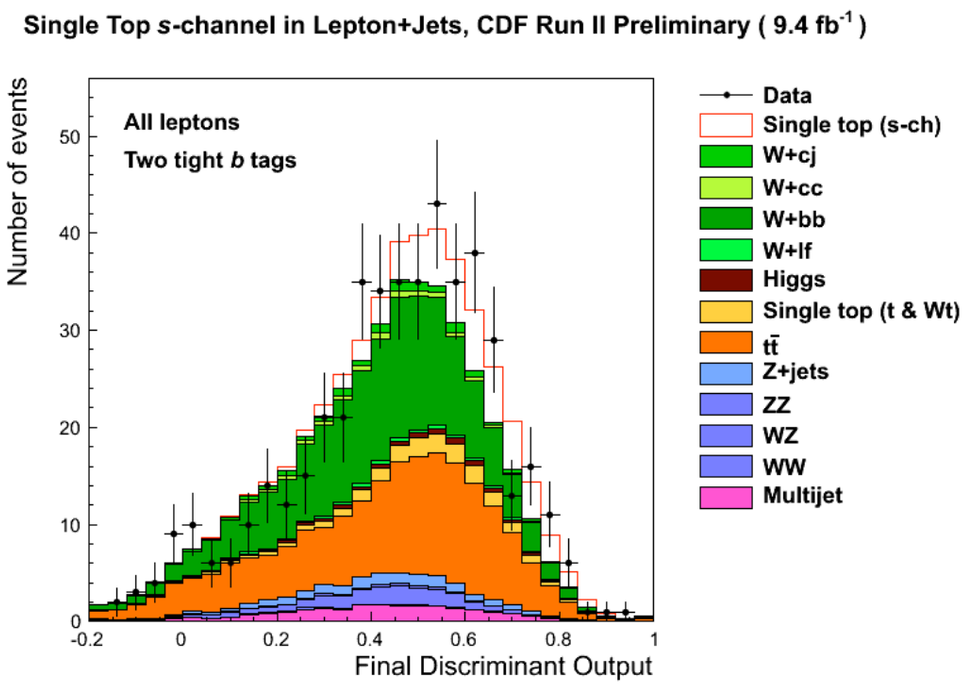


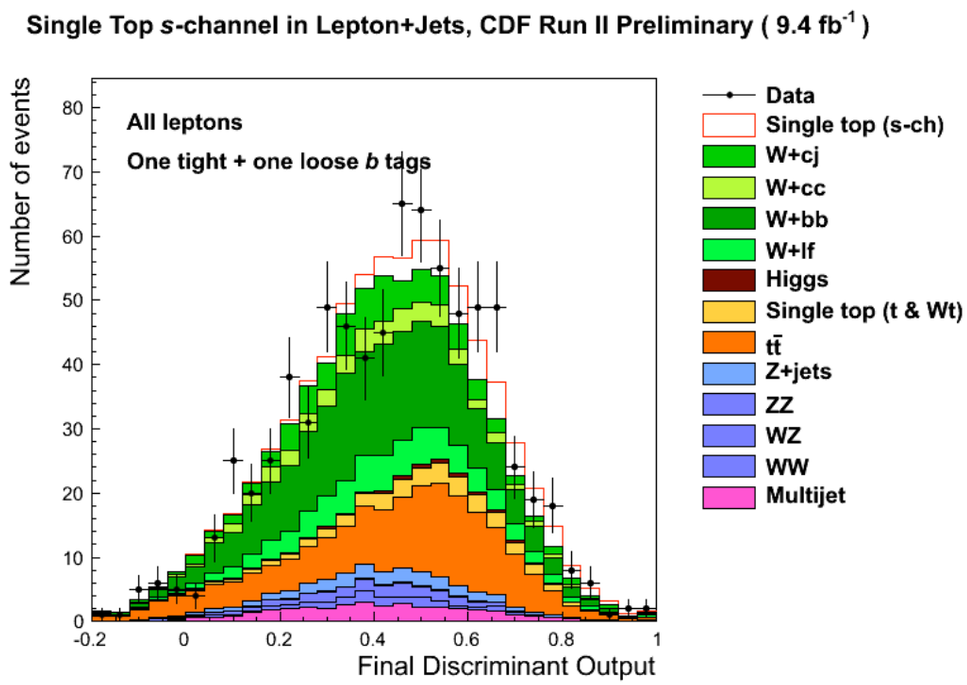
Discriminants Output

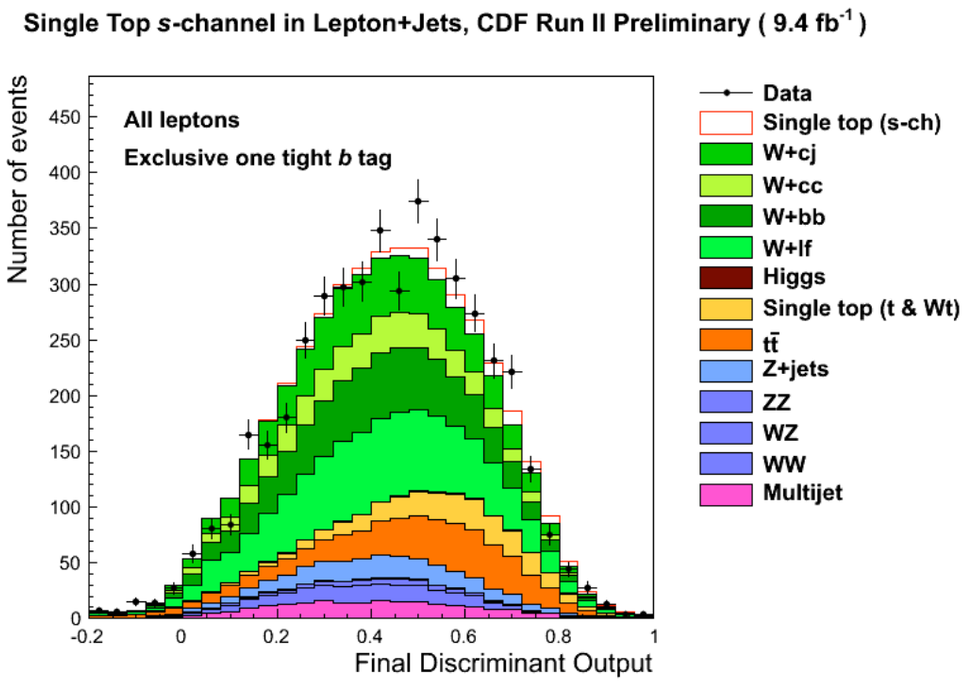


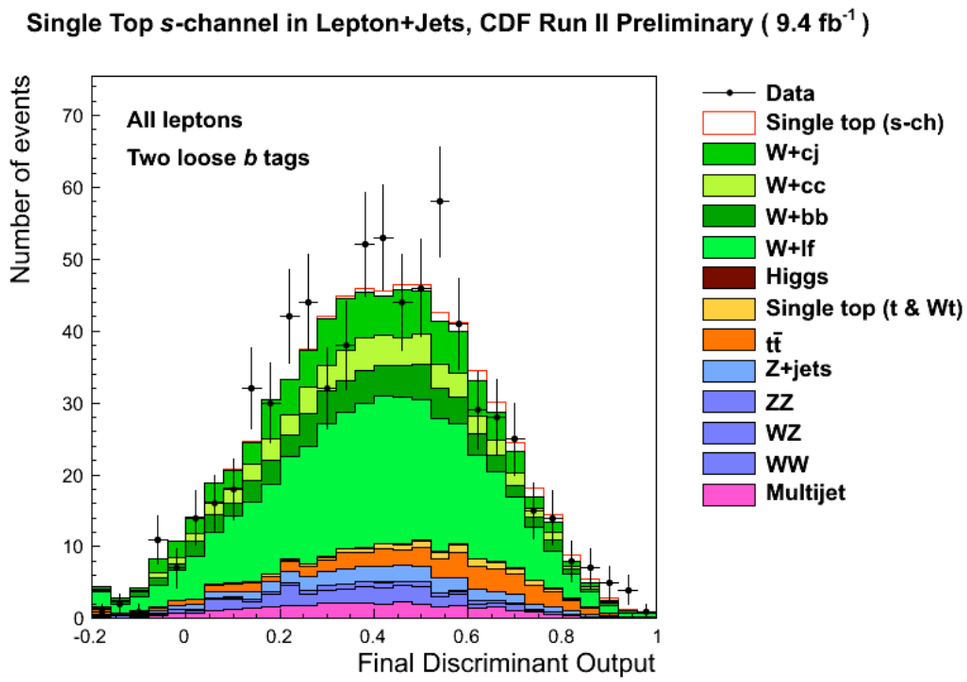
- Shows a good agreement between data and background prediction.
- This is the most sensitive channel, single top s-channel is obvious there.

Discriminants Output









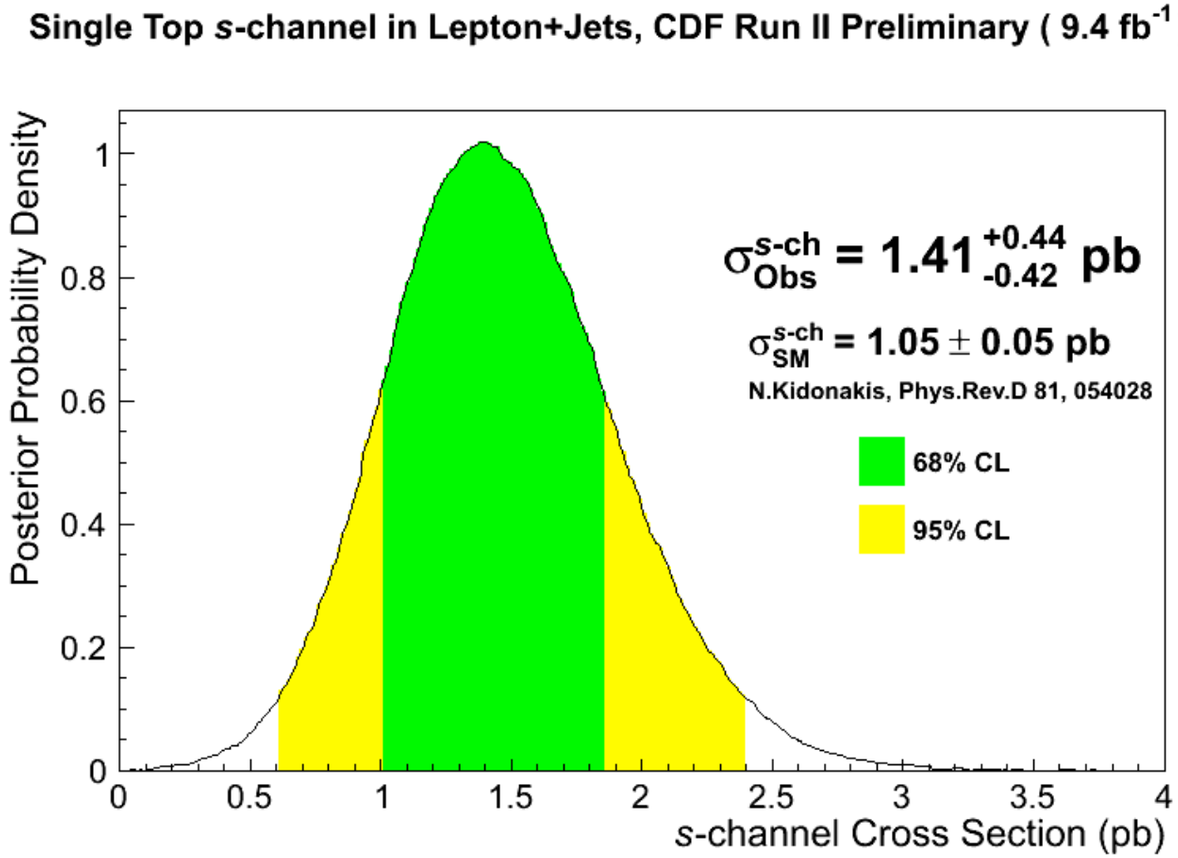
Systematic Uncertainties

- We considered two types of systematic uncertainties. Rate uncertainty only affects the overall scale, while shape uncertainty changes the discriminant output bin by bin (shape changing).
- Uncertainties considered in this analysis are listed below.

Source of uncertainty	Rate	Shape	Affected samples
b tagging scale factor uncertainty	4%-18%		$t\bar{t}$, single top, WZ, ZZ, Higgs
Charm mistag rate	7%-37%		WW
W+jets mistag rate	4%-37%		W + Mistag jets
Luminosity uncertainty	6%		$t\bar{t}$, single top, diboson, Higgs
Lepton acceptance uncertainty	2%-4%		$t\bar{t}$, single top, diboson, Higgs
Cross section uncertainty	6%-10%		$t\bar{t}$, single top, diboson, Higgs
Initial/Final state radiation	0%-10%	√	$t\bar{t}$, single top
Multijet normalization	40%		Multijet
Z+jets normalization	45%		Z+jets
Wbb and Wcc normalization	30%		Wbb, Wcc
Wc normalization	30%		Wc
Jet energy scale	0%-10%	√	All
Normalization and factorization scale		√	W+jets
Electron multijet background		√	Electron multijet

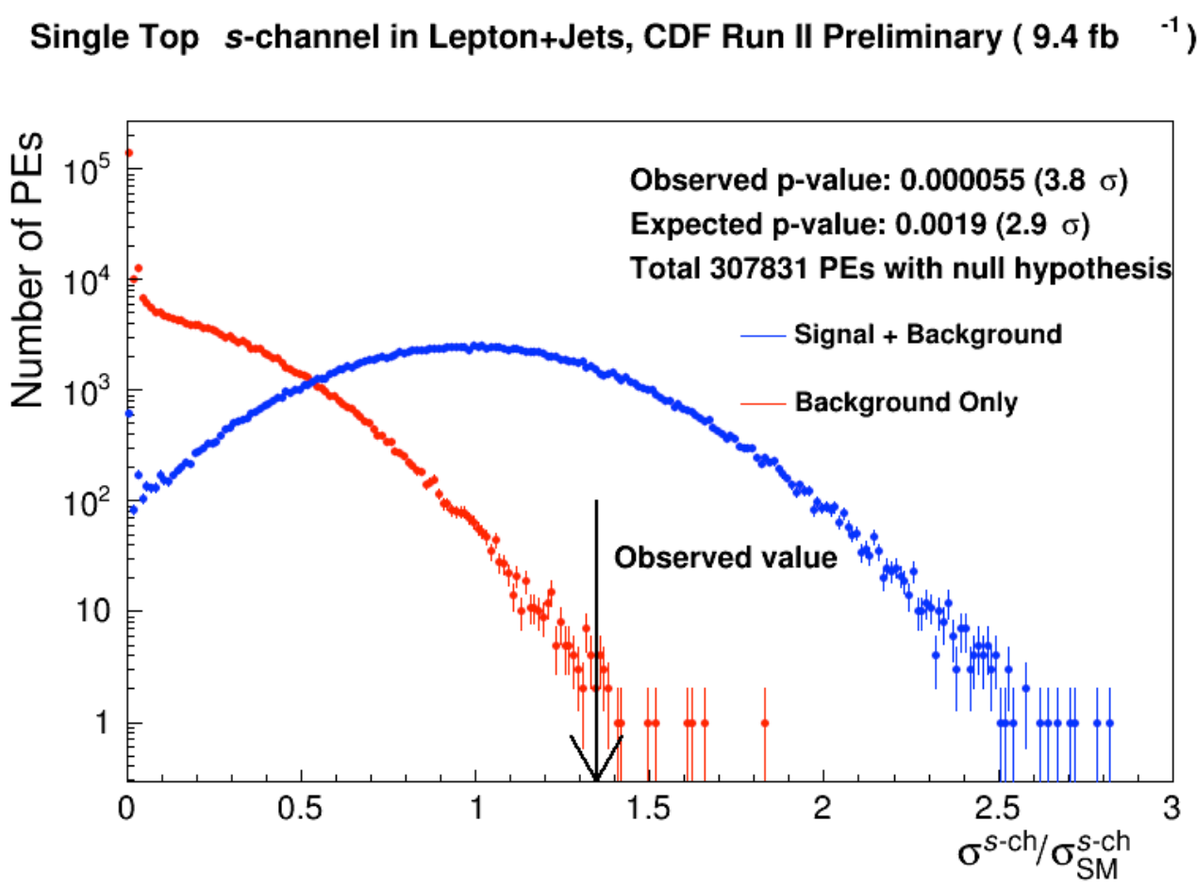
Observed Cross Section

- We measured the single top *s*-channel cross section using a Bayesian binned likelihood technique assuming a flat prior in the cross section and integrating the posterior over all sources of systematic uncertainty.
- The final measured cross section are extracted from the posterior probability density distribution. The cross section for t-channel are set to standard model prediction in the calculation.

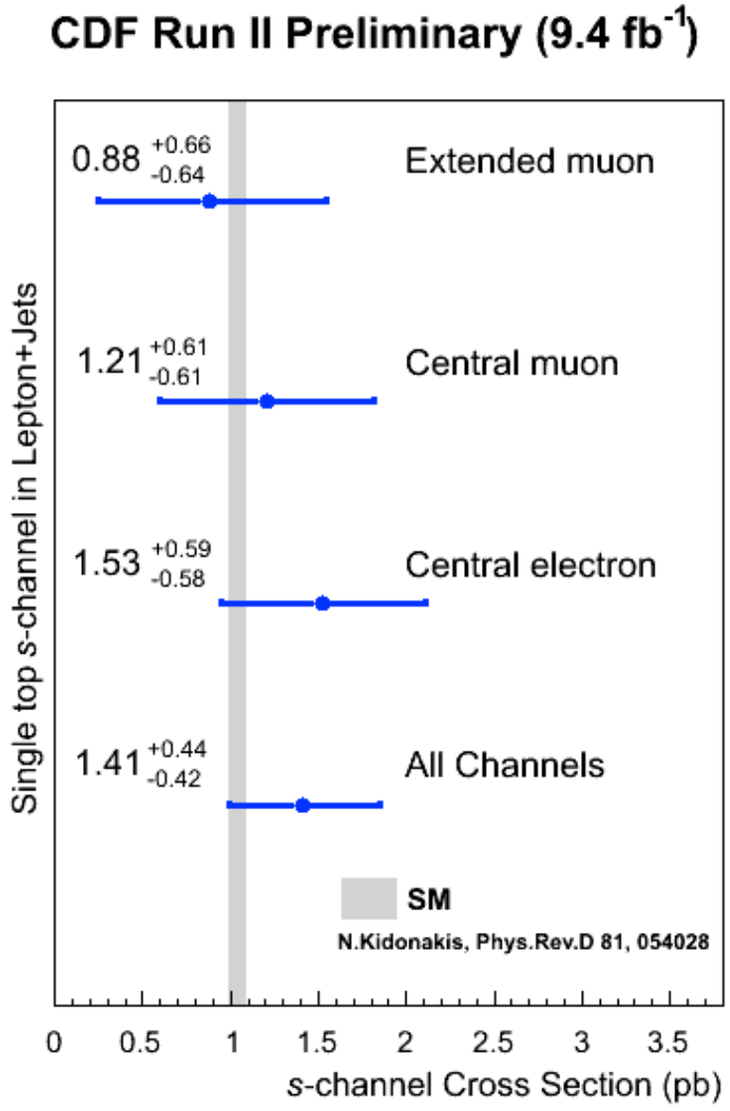


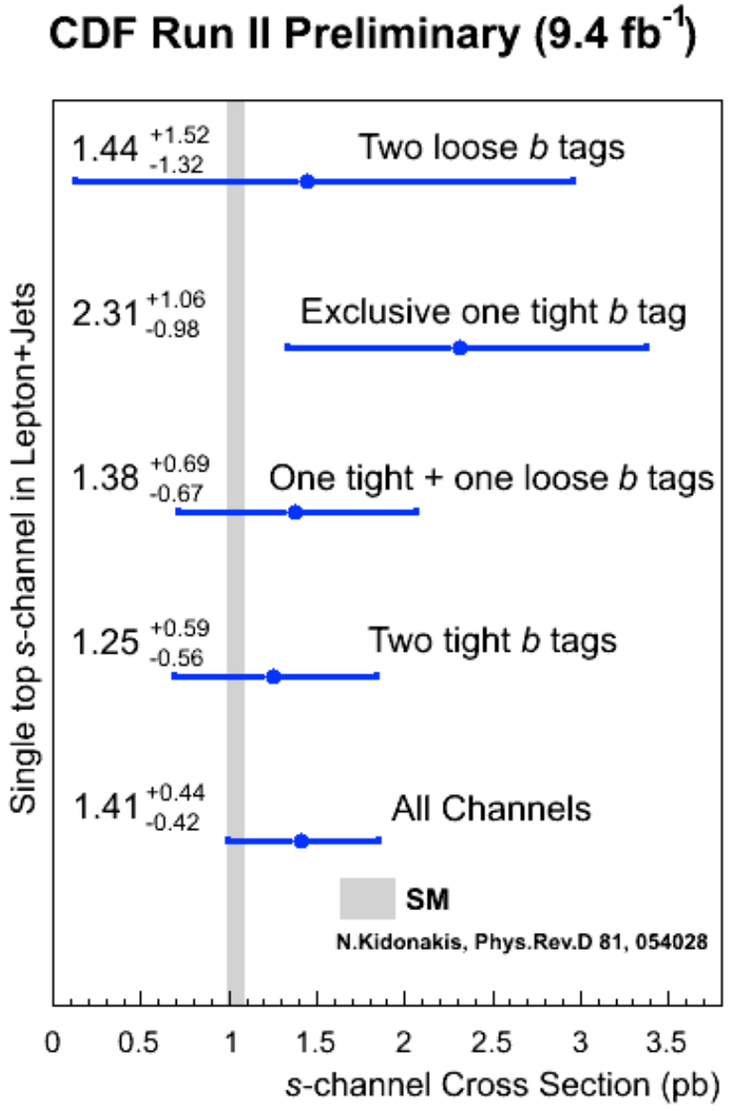
Significance

- To calculate p-value, we ran pseudo-experiments with background only hypothesis.
- P-value is a test how likely the data would fluctuate to the observed cross section when there is no signal.
  - Expected significance: 2.9 sigma
  - Observed significance: 3.8 sigma



Consistency Check





- We also measured the *s*-channel cross section in each lepton and tagging category.
- This shows our measurement results are consistent with each other in each subset of data.

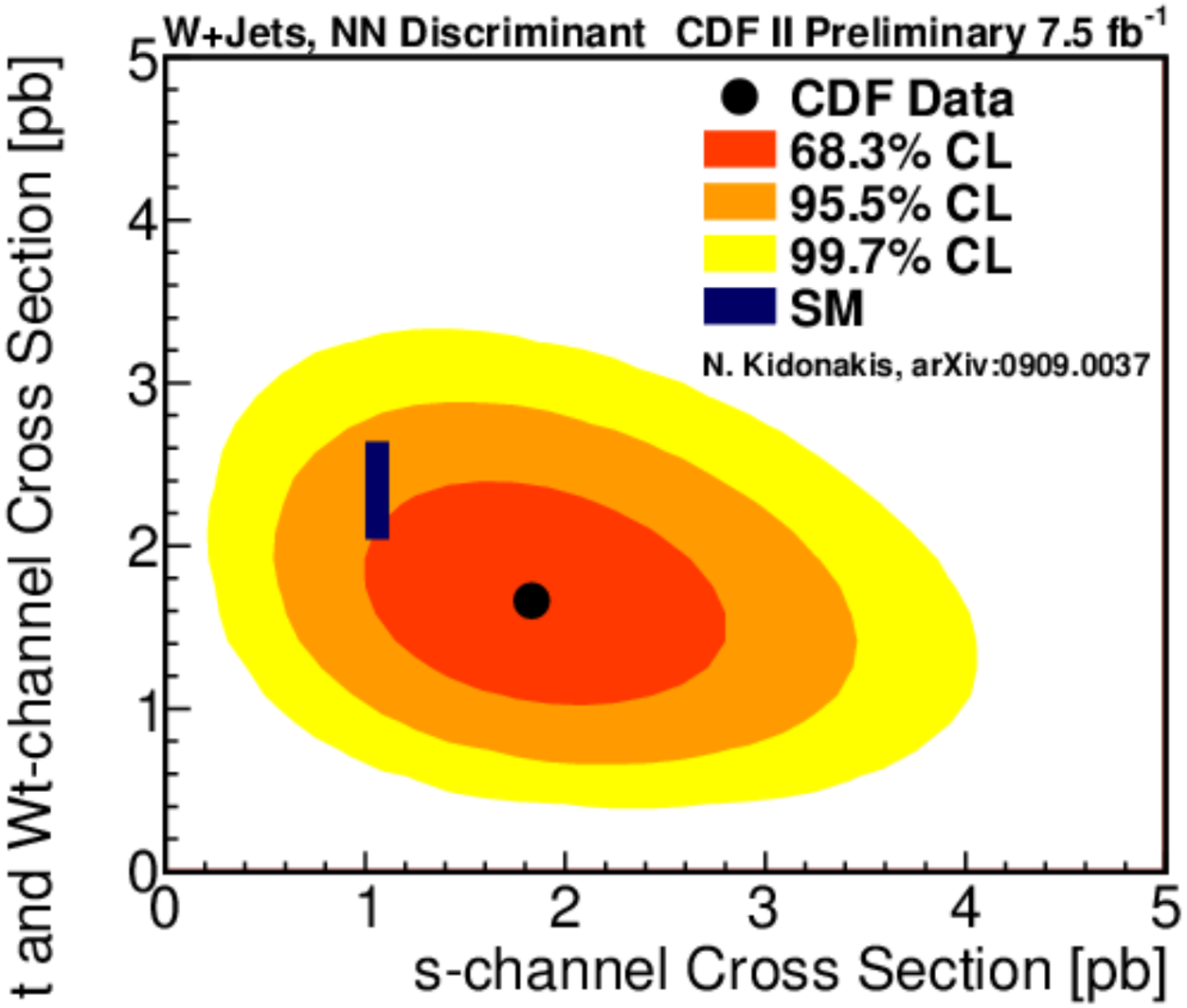
Summary

- We measured the cross section of single top s-channel cross section in lepton + jets channel.
- The observed cross section is $\sigma_{\mathrm{Obs}}^{s-\mathrm{ch}} = 1.41^{+0.44}_{-0.42}\ \mathrm{pb}$, corresponds to a significance of 3.8 sigma.
- Compatible with standard prediction.
- This results, when combined with other measurements, will be a legacy measurement at Tevatron.

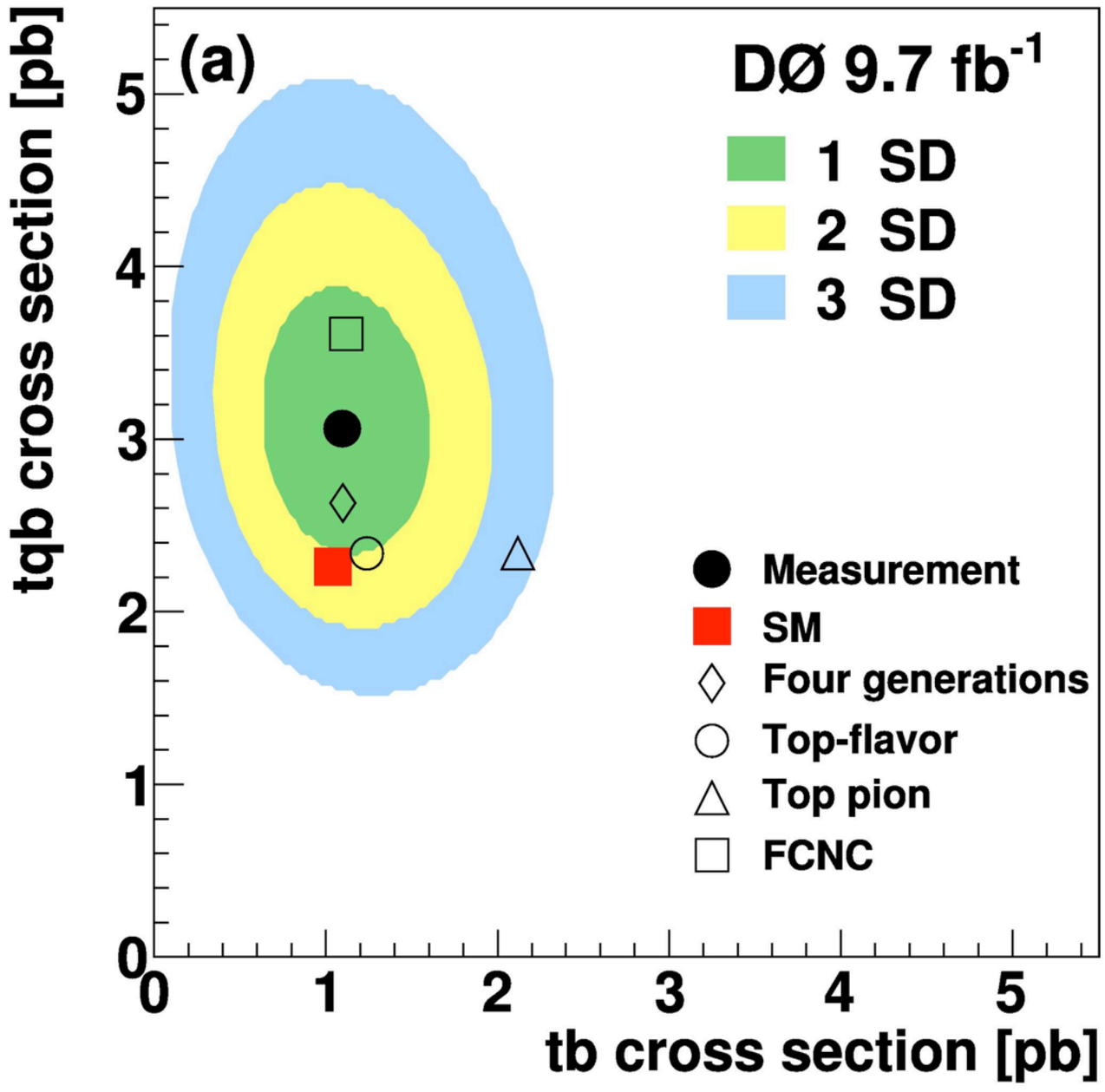
Thank you for your attention!

Backup

CDF Previous Results



D0 Results


(a)
DØ 9.7 fb-1
1 SD
2 SD
3 SD
Measurement
SM
Four generations
Top-flavor
Top pion
FCNC
tqb cross section [pb]
tb cross section [pb]
0
1
2
3
4
5