Top Quark Production at Tevatron

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(On behalf of the CDF and D0 Collaborations)
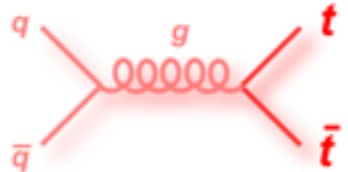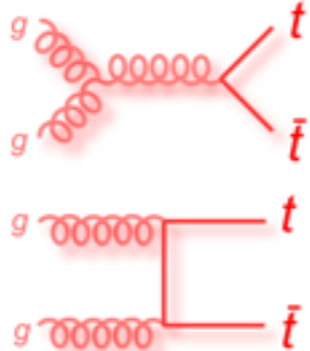
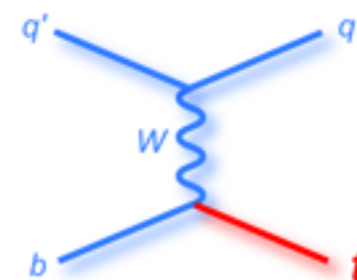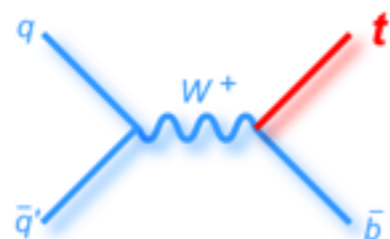# Outline

- Top Quark
  - Heaviest know particle, $m_{top} = 173.34 \pm 0.76$ GeV/c^2;
  - No hadronization;
  - Almost 100% decaying into a *W* boson and a *b* quark.

- Pair Production (strong interaction)

  85%   15%

- Single Production (electroweak interaction)

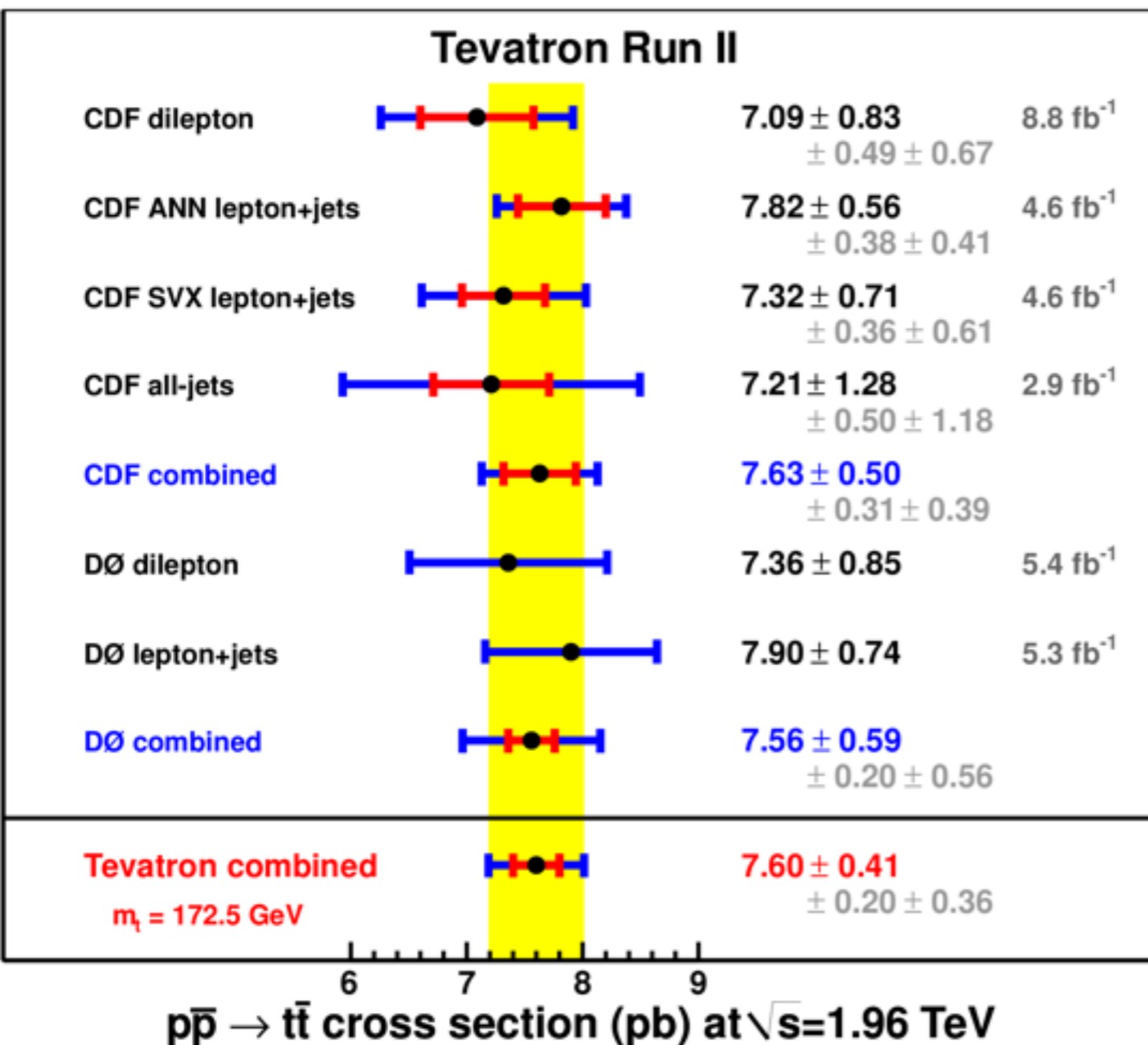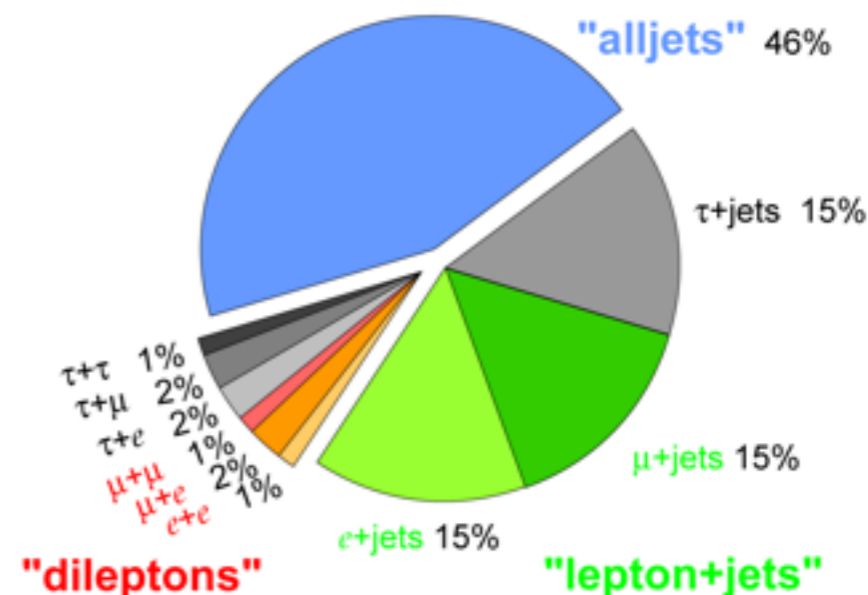- *Top quark properties at Tevatron* is covered by Gianluca Petrillo in Top 2 session

Pair Production Cross Section
——Tevatron Combination

Tevatron Run II

CDF dilepton	7.09 ± 0.83 $\pm 0.49 \pm 0.67$	8.8 fb^{-1}
CDF ANN lepton+jets	7.82 ± 0.56 $\pm 0.38 \pm 0.41$	4.6 fb^{-1}
CDF SVX lepton+jets	7.32 ± 0.71 $\pm 0.36 \pm 0.61$	4.6 fb^{-1}
CDF all-jets	7.21 ± 1.28 $\pm 0.50 \pm 1.18$	2.9 fb^{-1}
CDF combined	7.63 ± 0.50 $\pm 0.31 \pm 0.39$	
DØ dilepton	7.36 ± 0.85	5.4 fb^{-1}
DØ lepton+jets	7.90 ± 0.74	5.3 fb^{-1}
DØ combined	7.56 ± 0.59 $\pm 0.20 \pm 0.56$	
Tevatron combined m_t = 172.5 GeV	7.60 ± 0.41 $\pm 0.20 \pm 0.36$	

$p\bar{p} \to t\bar{t}$ cross section (pb) at $\sqrt{s}$=1.96 TeV

Top Pair Branching Fractions

"alljets" 46%
τ+jets 15%
μ+jets 15%
e+jets 15%
$\tau+\tau$ 1%
$\tau+\mu$ 2%
$\tau+e$ 2%
$\mu+\mu$ 1%
$\mu+e$ 2%
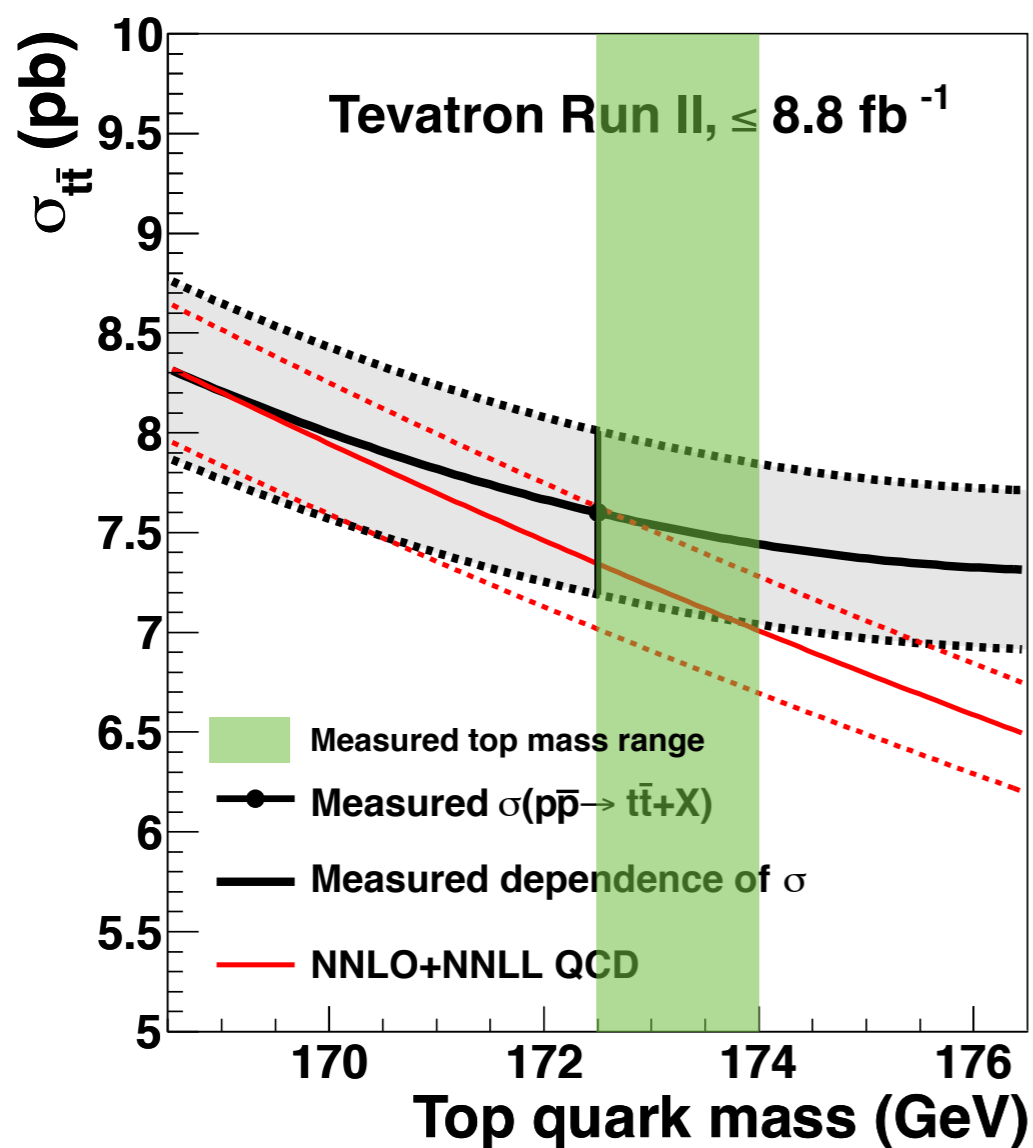$e+e$ 1%
"dileptons"
"lepton+jets"

- Both experiments contributes similarly (CDF 60%, D0 40%).
- All systematics and correlations between them are considered.

- Top quark mass assumed to be 172.5 GeV

- Combination results published:
  - Phys. Rev. D **89**, (2014) 072001

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Pair Production Cross Section
——Tevatron Combination

Tevatron Run II, $\leq$ 8.8 fb^{-1}

$\sigma_{t\bar{t}}$ (pb)

Top quark mass (GeV)

- Measured top mass range
- Measured $\sigma(p\bar{p} \to t\bar{t}+X)$
- Measured dependence of σ
- NNLO+NNLL QCD

Phys. Rev. Lett. **110**, (2013) 252004

- Measured Cross section at 172.5 GeV

$$\sigma_{tt} = 7.60 \pm 0.41 \text{ pb}$$

- Standard model prediction:

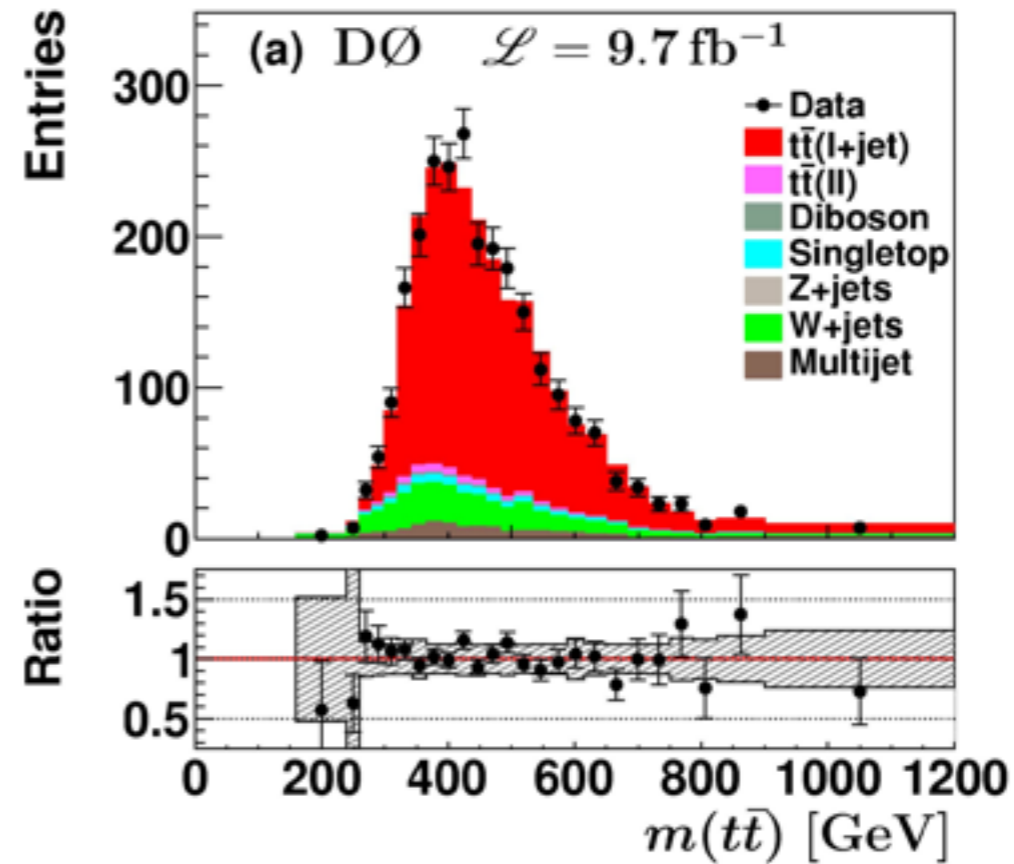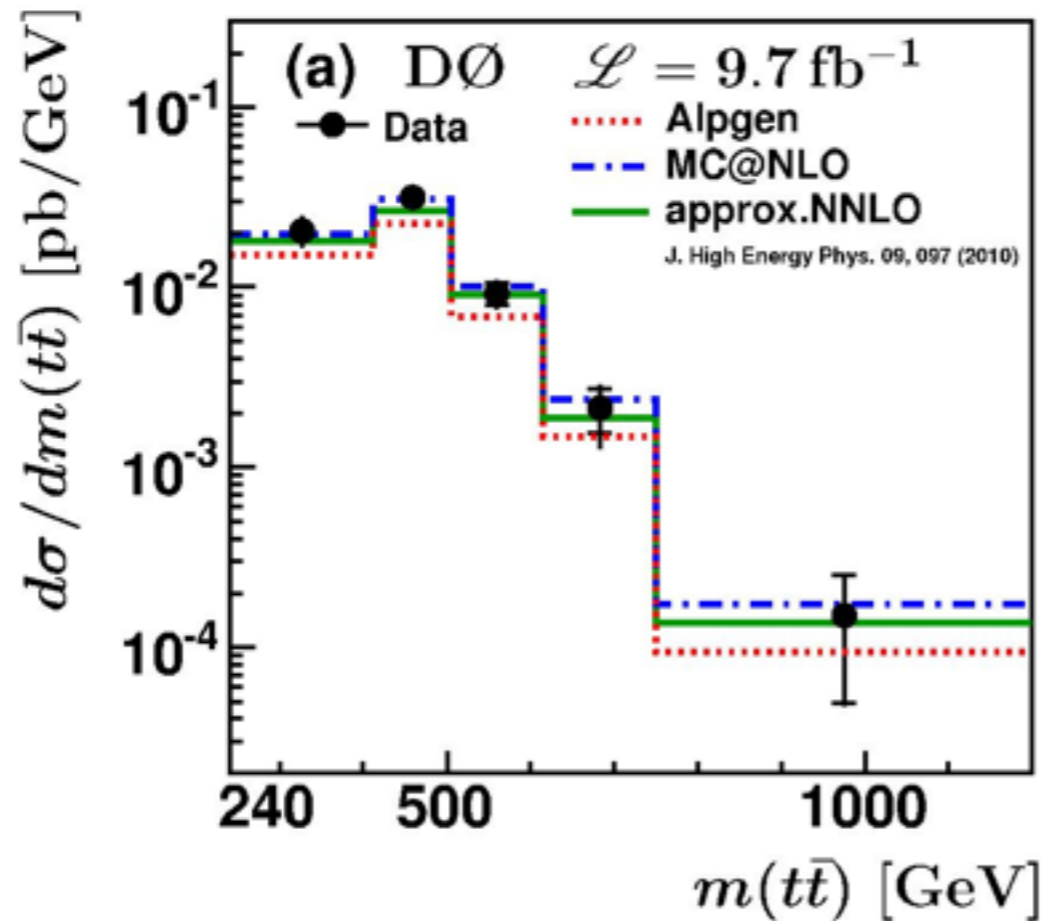$$\sigma_{t\bar{t}} = 7.35^{+0.11}_{-0.21}(\text{scales})^{+0.17}_{-0.12}(\text{PDF})$$

- Within the measured mass range, the measured cross section is in good agreement with theory calculation.
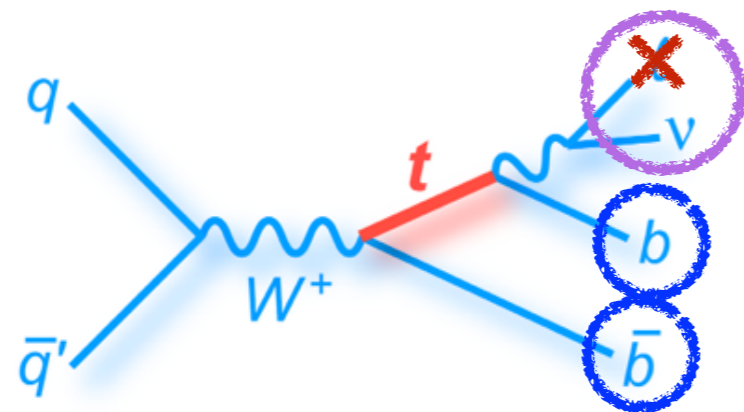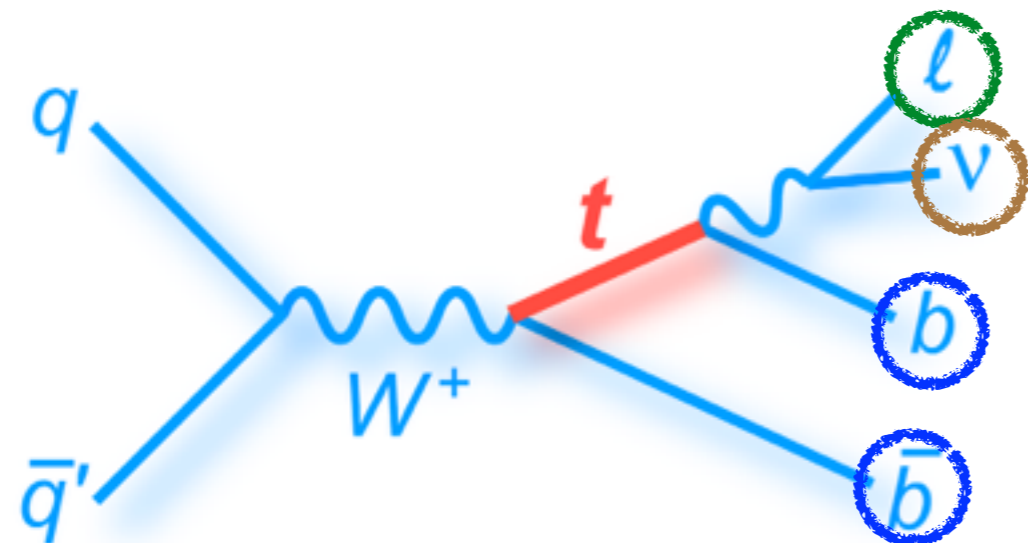
Differential $t\bar{t}$ Cross Section
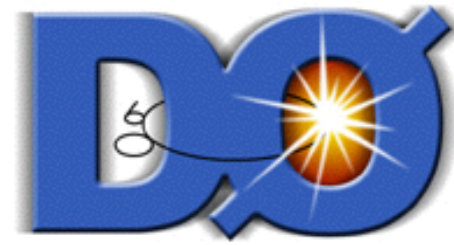
- Final state is obtained by kinematic reconstruction.
- Cross section as a function of m_{tt}, $p_T(t)$, $|y(t)|$.
- Measured with typical precision ~ 9%.
- General agreement with predictions by QCD generators and NNLO.

Single Top Quark Production

Independently observed by CDF and D0 in 2009
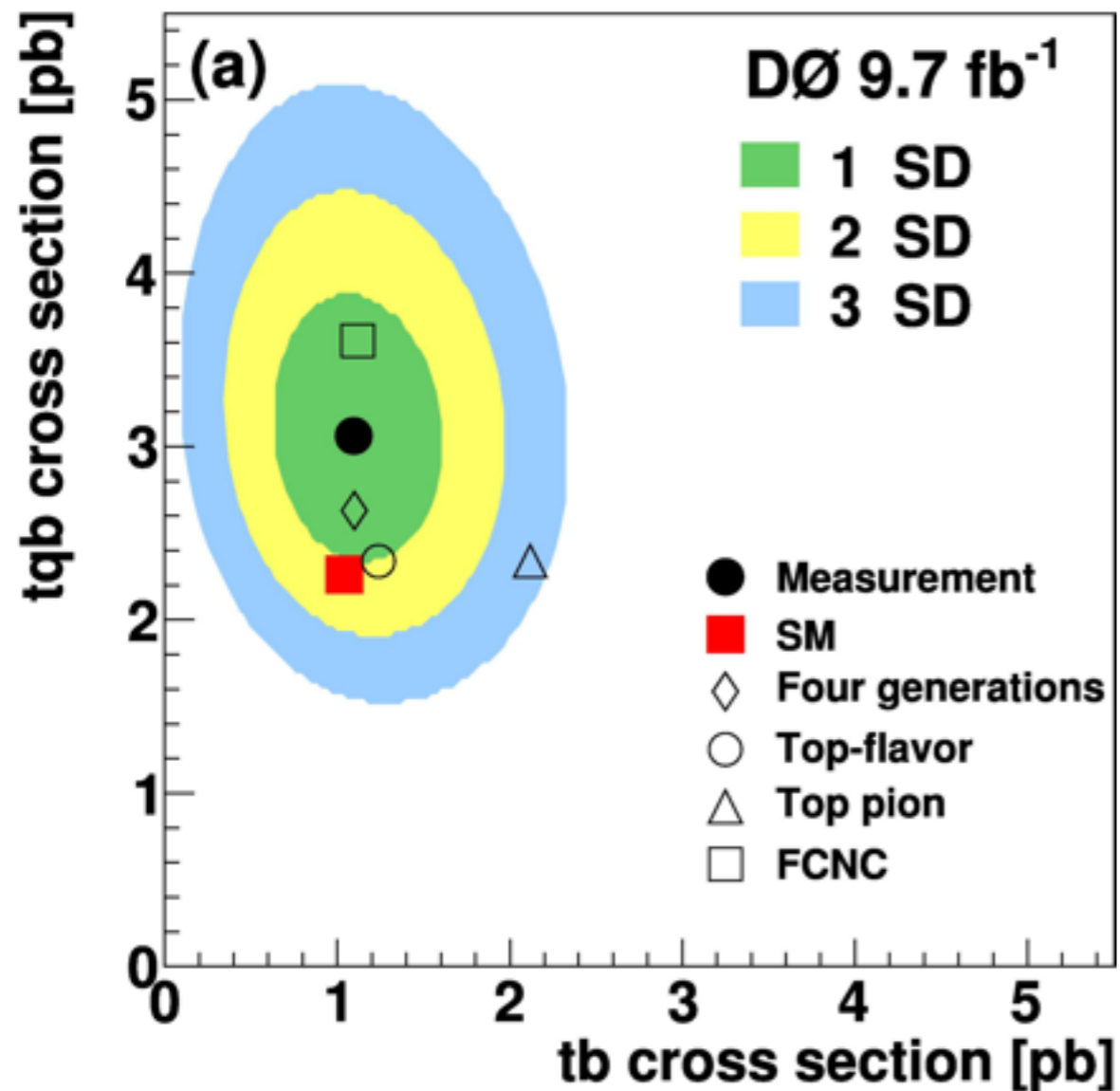
- **Event Selection**

- Lepton + Jets (both CDF and D0)
  - one lepton
  - large missing E_T
  - two or three jets
  - ≥ 1 b jet

- Missing E_T + Jets (only CDF)
  - large missing E_T
  - two or three jets
  - ≥ 1 b jet

Single Top Quark Measurements
Lepton + jets

(a) DØ 9.7 fb^{-1}

- 1 SD
- 2 SD
- 3 SD

- ● Measurement
- ■ SM
- ◇ Four generations
- ○ Top-flavor
- △ Top pion
- □ FCNC

$$\sigma_s = 1.10^{+0.33}_{-0.31} \text{ pb}$$

**s-channel Significance 3.7 σ**

- 2-jets and 3-jets events included
- 3 MVA techniques used
  - Boosted decision tree
  - Neural network
  - Matrix element
- Outputs from 3 MVAs are combined into one BNN.
- Final discriminant is sensitive to both *s*- and *t*-channel.
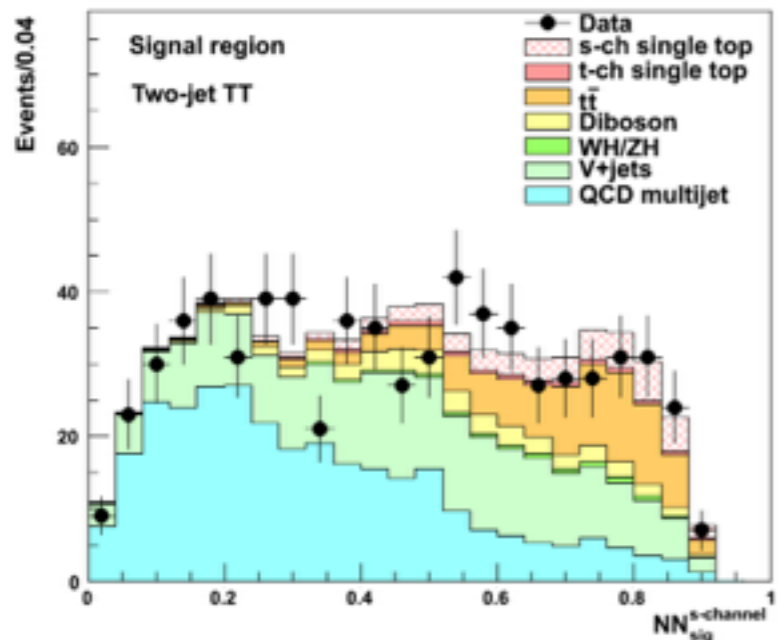- Integrate over the 2D plot to calculate σ_{s+t}

|V_{tb}|>0.92 @ 95% CL

s-channel Measurements
——————two final states

Single Top *s*-channel in Lepton+Jets, CDF Run II Preliminary (9.4 fb⁻¹)
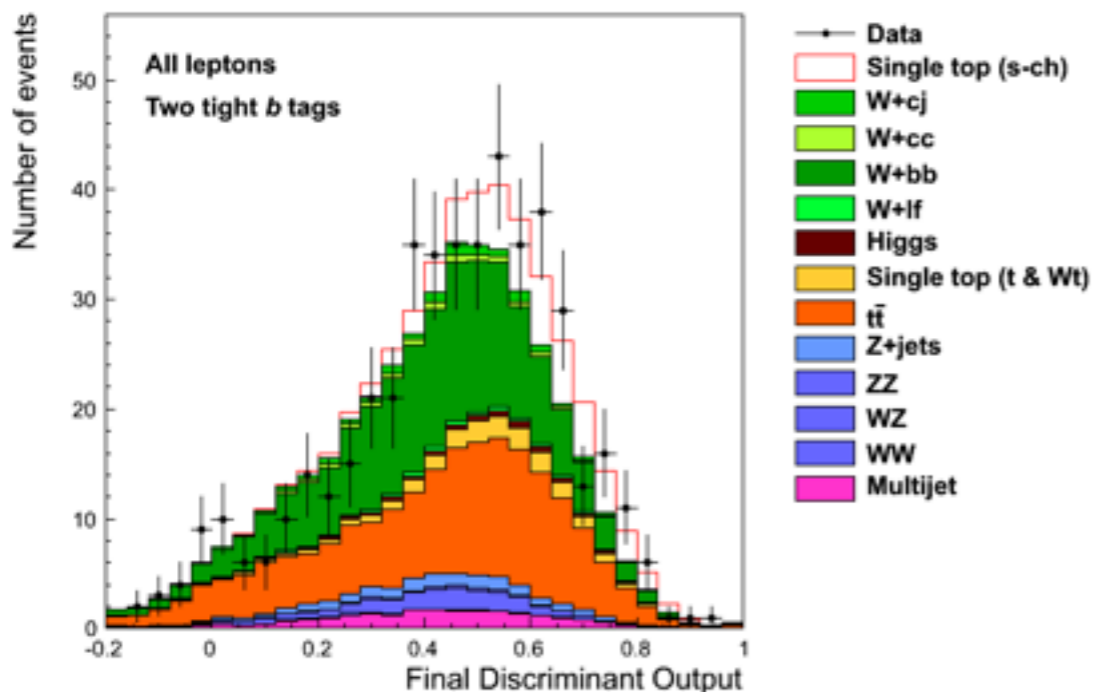
arxiv:1402.0484 accepted by PRL

arxiv:1402.3756 accepted by PRL

- lepton+jets & met+jets
  - CDF full data set used
  - Improved *b*-jet tagger used
  - Top reconstruction algorithm optimized for *s*-channel
  - Final discriminant is optimized for *s*-channel only
- lepton+jets
  - Only 2-jet events used
  $$\sigma_s = 1.41^{+0.44}_{-0.42} \text{ pb}$$
- met+jets
  - Both 2-jet and 3-jet events used
  $$\sigma_s = 1.12^{+0.61}_{-0.57} \text{ pb}$$

Combined Significance 4.2 σ

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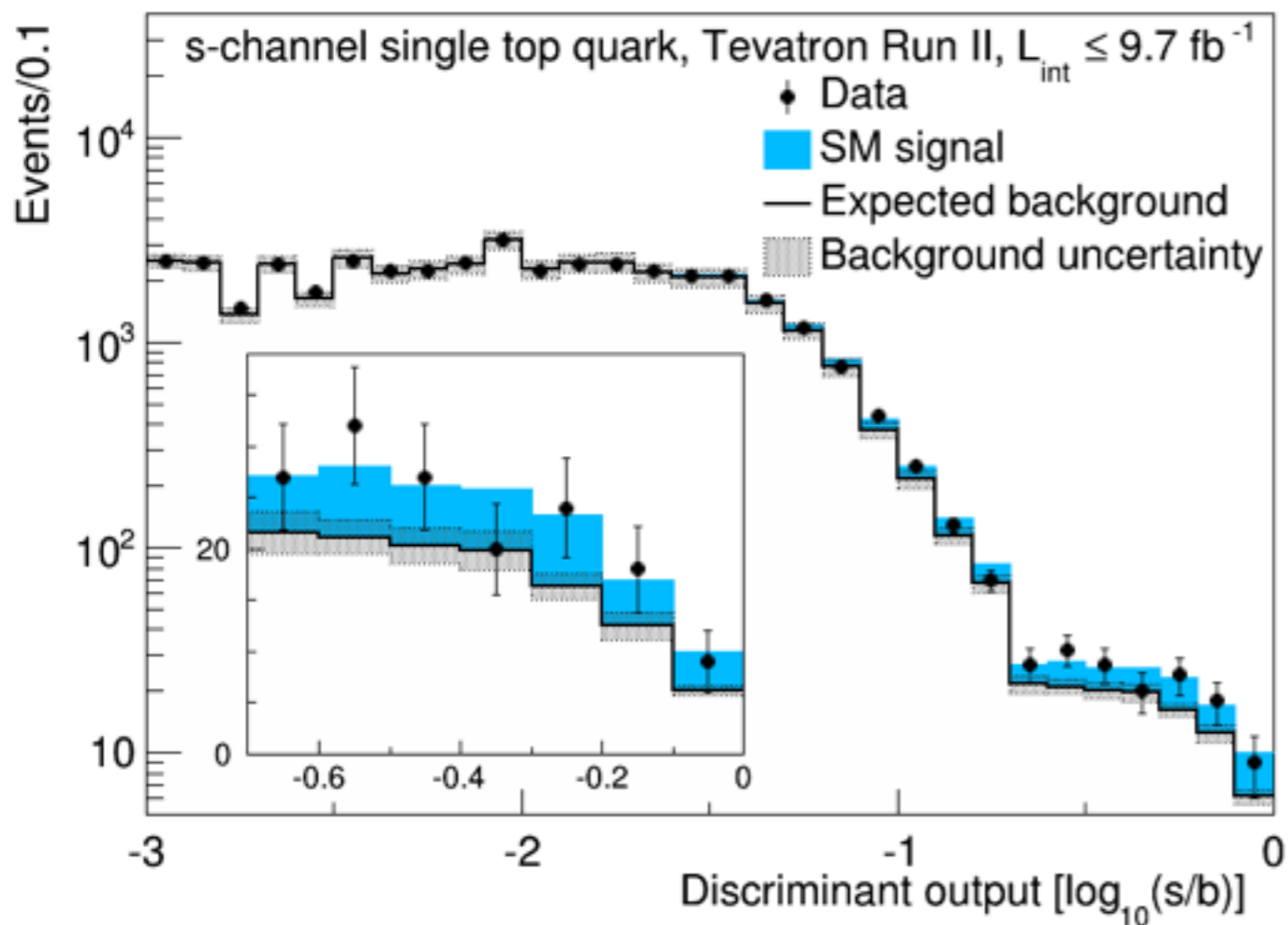# Tevatron Combination

First *s*-channel observation

- Include two CDF s-channel and one D0 measurements.
- Include all systematics and their correlations.

Tevatron Combination
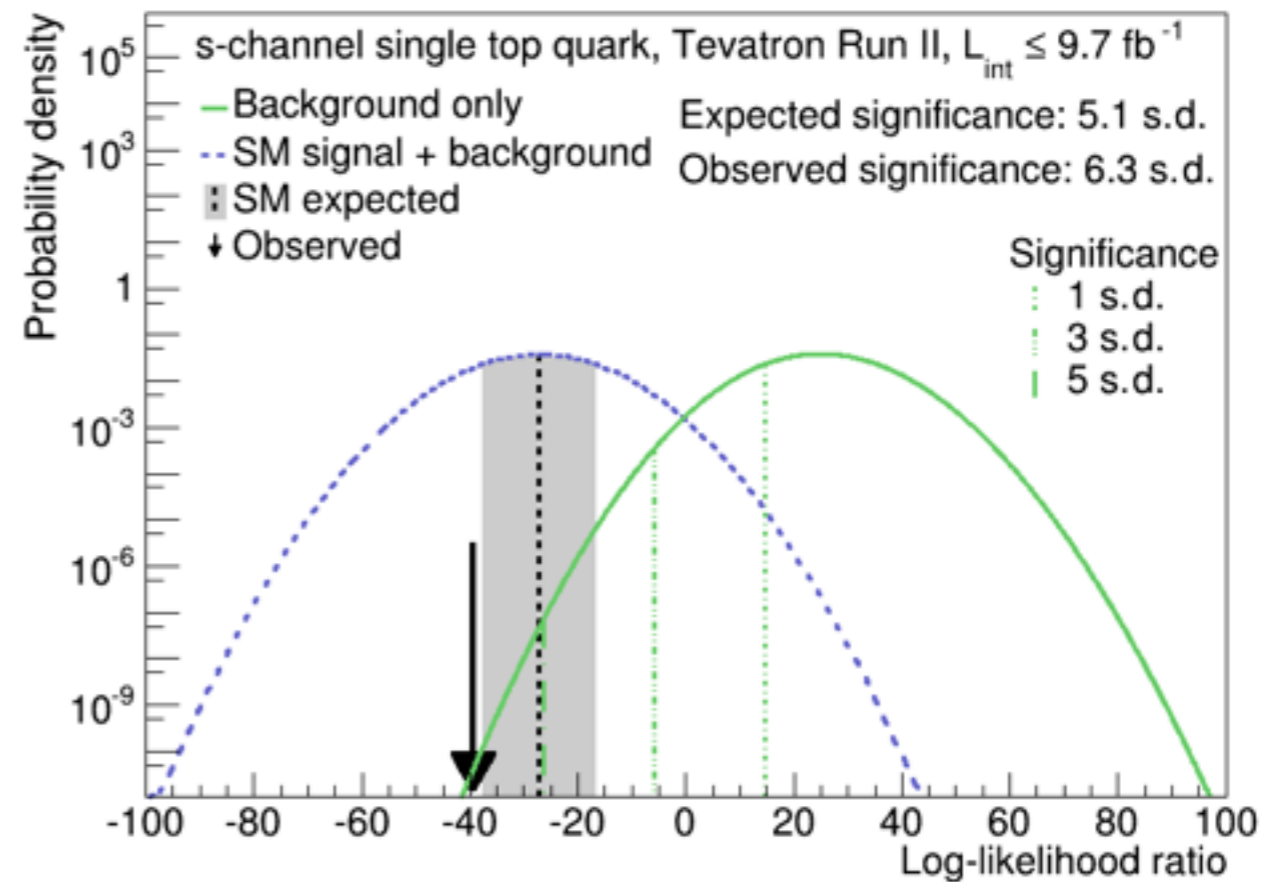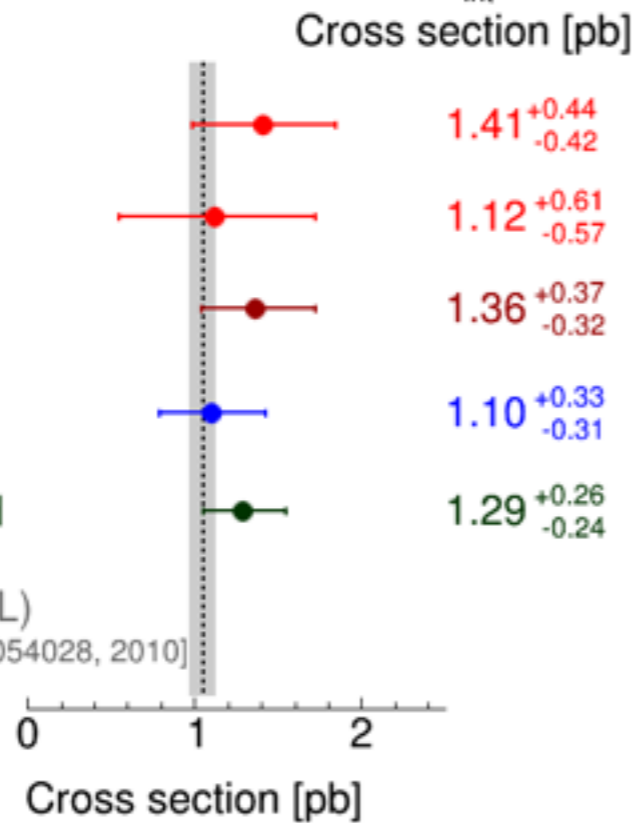
$$\sigma_s = 1.29^{+0.26}_{-0.24} \text{ pb}$$

- **Observed *p*-value: 1.8x10⁻¹⁰**
- **Observed significance: 6.3 σ**

Conclusion

- Tevatron continues providing valuable top physics results.

- Differential cross section.

- Single top quark results is Tevatron legacy
    - Single top quark observation (2009)

    - *t*-channel observation (2011)

    - *s*-channel observation (2014)

- Future
    - σ_{s+t} Tevatron combination is underway.

Backup Slides

Systematics

Systematic uncertainty	CDF		D0		Corre-
	Norm	Dist	Norm	Dist	lated
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

Top Quark Production Cross Section

Theory prediction

Cross section(pb)	$t\bar{t}$	s-channel	t-channel	tW-channel
Tevatron(1.96 TeV)	7.08	1.05	2.08	0.25
	x33	x5.3	x42	x88
LHC(8 TeV)	234	5.55	87.2	22.2

- The unique opportunity of *s*-channel for Tevatron.

- Because of the difference between *p-p* and *p-pbar* collision, the relative signal-to-background ratio for *s*-channel is higher at Tevatron than LHC.

- The production mode for $t\bar{t}$ is also different for Tevatron and LHC.

Single Top Quark Measurement
————————Lepton + jets
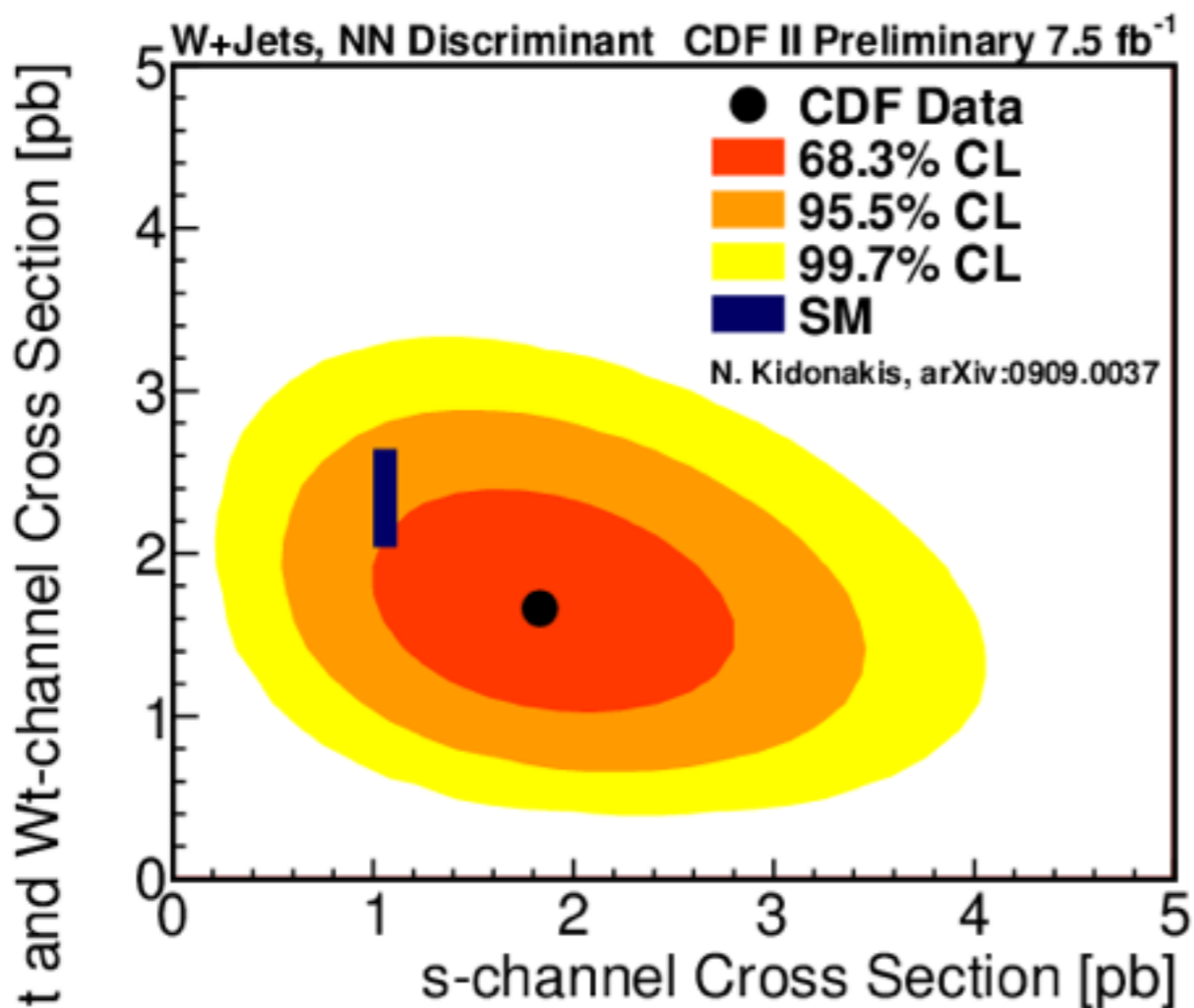
- Up to 7.5 fb^{-1}
- SVX *b*-jet tagger used
- Four jet categories used
  - 2J1T, 2J2T, 3J1T, 3J2T
- 1D neural network used for each jet category
- NN for 2J2T is optimized for *s*-channel, other NNs are optimized for *t*-channel.
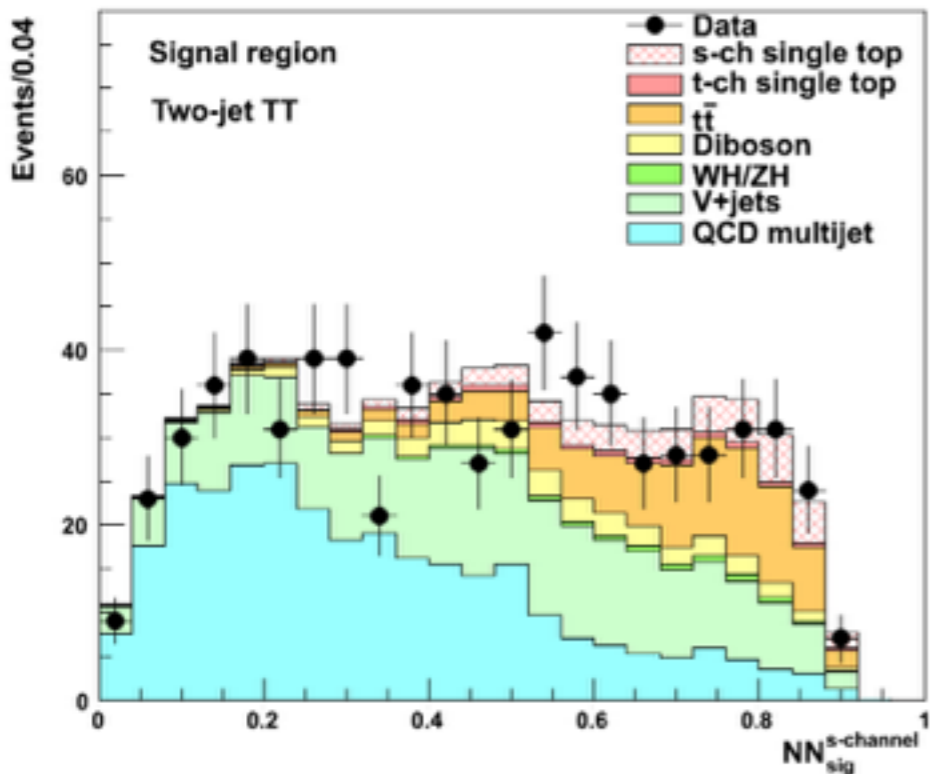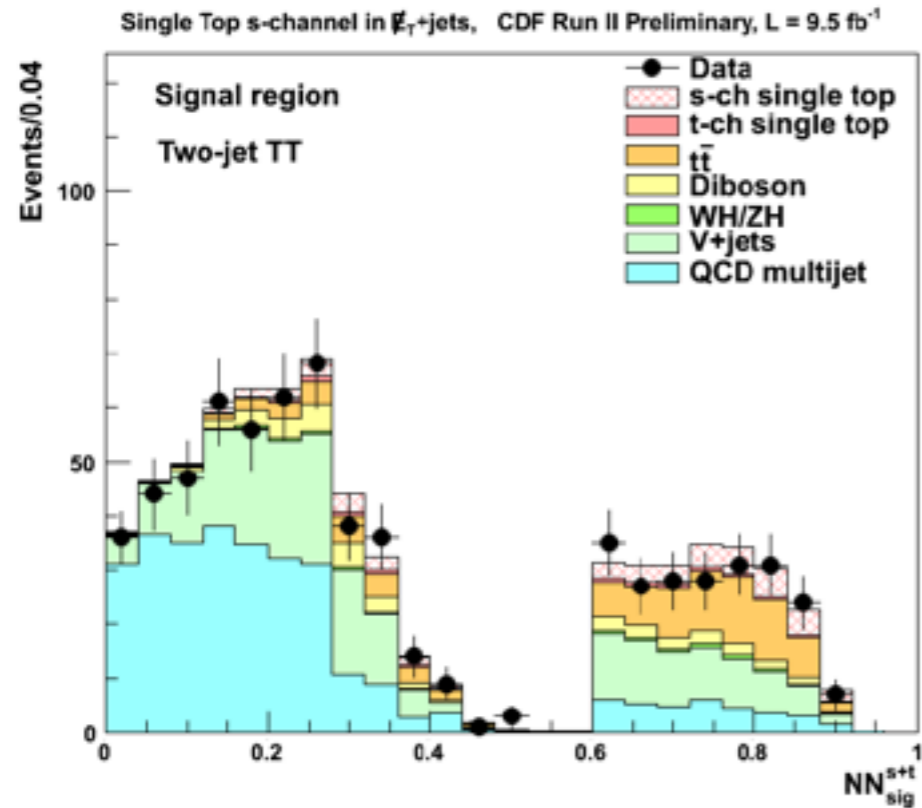- σ_{s+t} is extract by assuming SM ratio of σ_s/σ_t

- **Results**

$$\sigma_{s+t} = 3.04^{+0.57}_{-0.53} \text{ pb}$$

$$\sigma^{SM}_{s+t} = 3.13 \text{ pb}$$

Single Top Quark Measurements
————Missing E_T+jets

- Both 2-jet and 3-jet events used.
- Final discriminants optimized for s- and t-channel separately
- σ_{s+t} is calculated by assuming SM ratio of σ_s/σ_t

- **Results**

$$\sigma_{s+t} = 3.53^{+1.25}_{-1.16} \text{ pb} \qquad \sigma_{s+t}^{SM} = 3.13 \text{ pb}$$

$$\sigma_s = 1.12^{+0.61}_{-0.57} \text{ pb} \qquad \sigma_s^{SM} = 1.05 \text{ pb}$$