"Measurements of the $t\bar{t}$ Production Cross-Section at the Tevatron Run II CDF Experiment Using B-Tagging"

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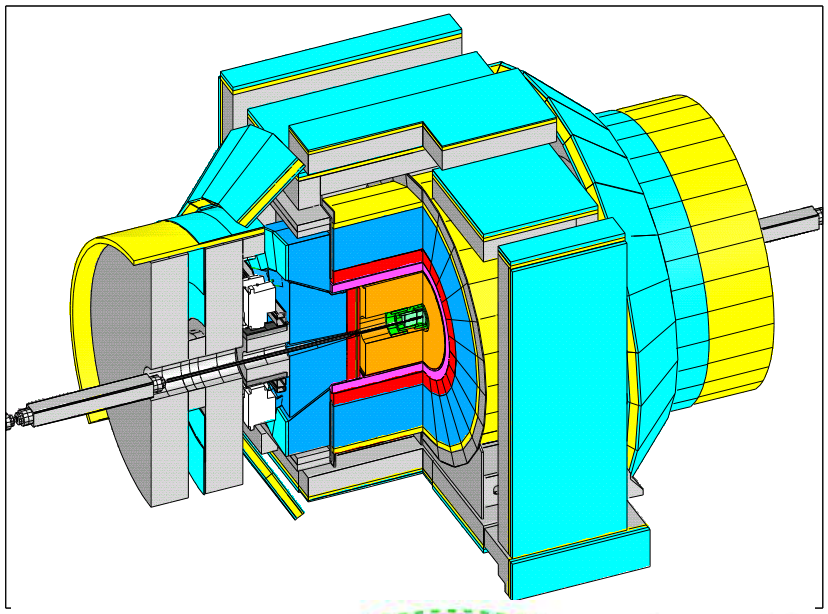
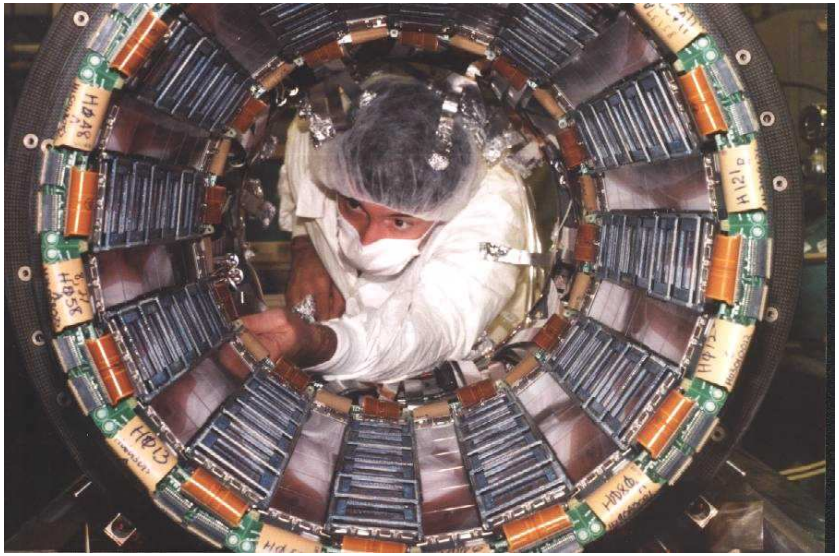
The CDF Detector Upgrade

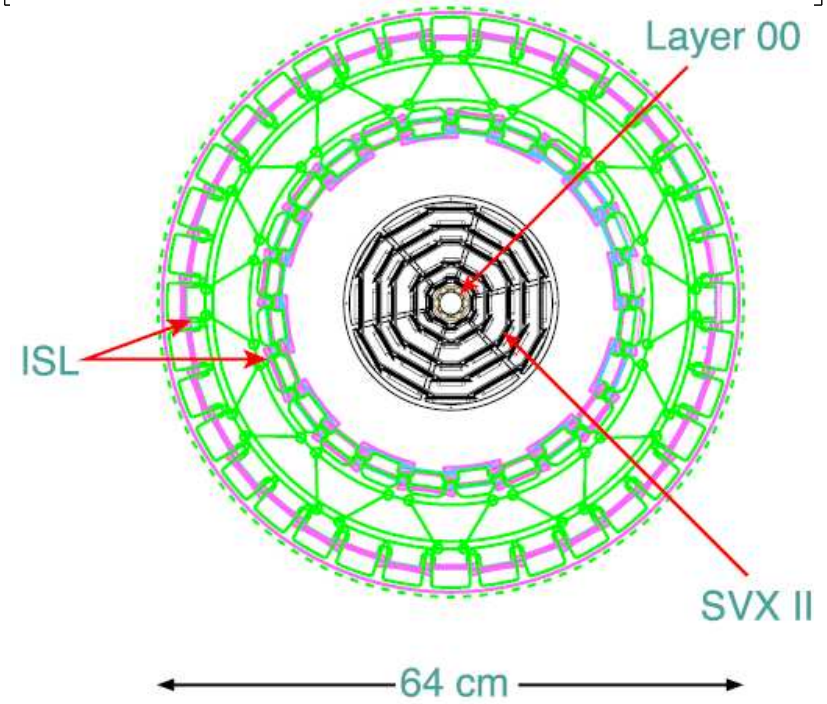
- Most of the detector has been upgraded.
- Main upgrade:

  new Silicon Vertex Detector (larger coverage)
- 7 double-sided layers.
- 1 single-sided layer on beam pipe (not used here).
- 90 cm long.

  (instead of 4 layers of 50 cm in Run I)

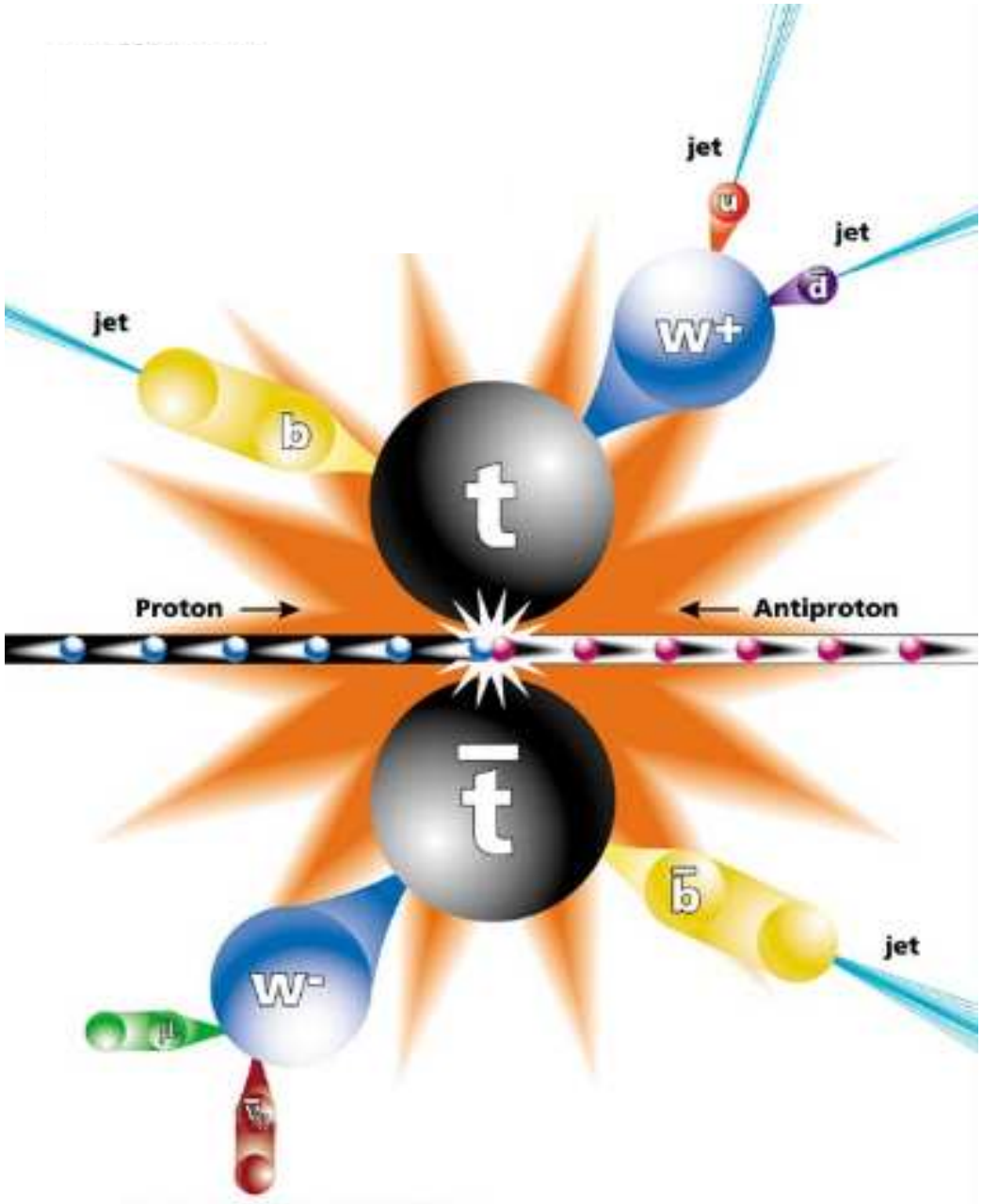






Topology and Selection of "Lepton+Jets" $t\bar{t}$ Events

- **Decay chain:**
  - Both top quarks decay to W+b.
  - W $\rightarrow q\bar{q}$.
  - W $\rightarrow l\nu_l$ (l=e or μ).
- **Branching ratio** ≈30%:
  large B.R., and reasonable background
- **Signature and selection:**
  - 1 High p_T lepton: > 20 GeV
    Isolated: $I^{0.4} < 10\%$
  - High Missing E_T: > 20 GeV
  - 4 jets:
    require ≥ 3 jets of $E_T > 15$ GeV
  - 2 B-jets, can be tagged by reconstructing secondary vertices, or identifying soft muons:
    require ≥ 1 tagged jet



Overview of the Analyses

- I will show results from 4 similar analyses.
- All analyses share the same lepton ID, jet and missing E_T selection.
- Differ in b-tagger and signal extraction technique.
- 2 B-Taggers:

Secondary Vertex Tagger:

1) Evaluation of background and event counting.

2) Using the double-tag sub-sample.

3) Kinematic fit to extract the signal fraction.

Soft Muon Tagger:

4) Evaluation of background and event counting.

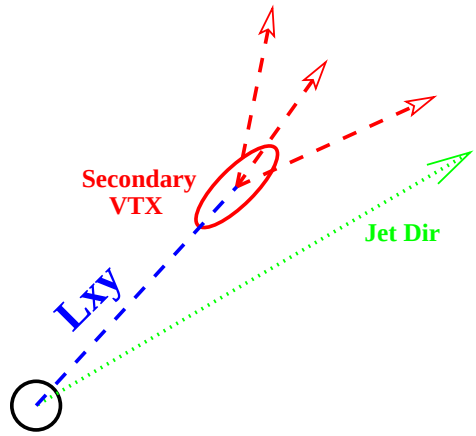
Secondary Vertex B-Tagging Algorithm

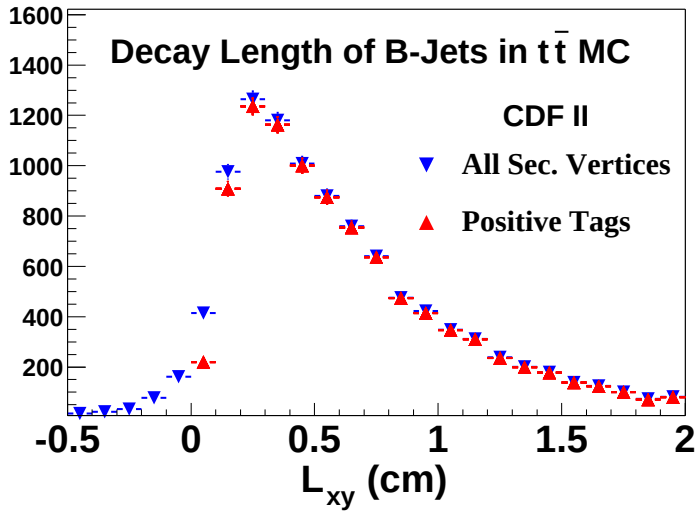
- Take advantage of the long life-time of B hadrons:

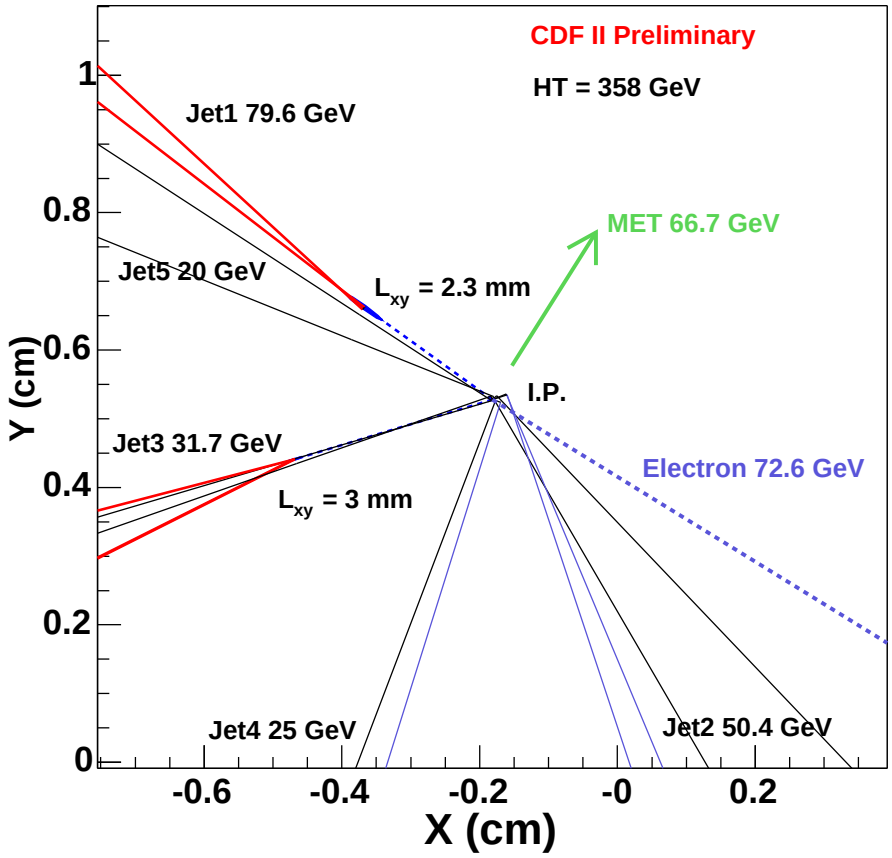
  $c\tau \approx 450\ \mu m$

- Secondary Vertex algorithm.
- Select good quality tracks with large impact parameter.
- Try to reconstruct a vertex.
- Tag vertices with large (transverse) decay length significance:

$$\frac{L_{xy}}{\sigma_{L_{xy}}} > 3$$







Secondary Vertex B-Tagging Efficiency

- Use sample of semi-leptonic decay b-jets as a control sample to normalize the MC to data:

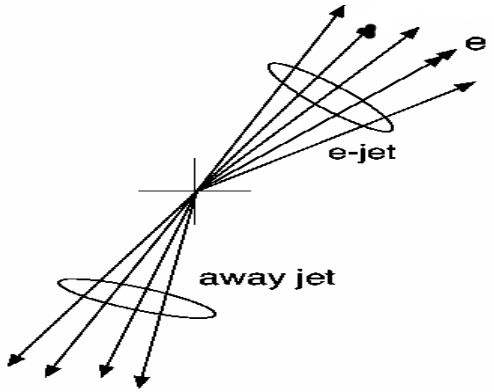
$$\frac{\epsilon_B^{\text{data}}}{\epsilon_B^{\text{MC}}} = 81 \pm 7\ \%$$

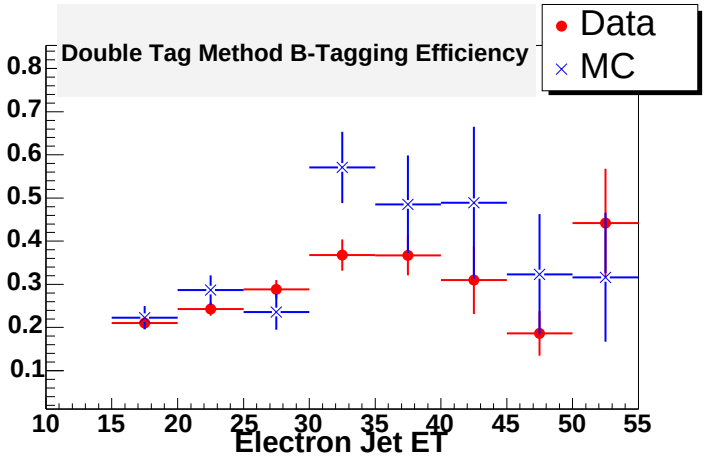
- Error dominated by statistics, and understanding of control sample Heavy Flavor content.

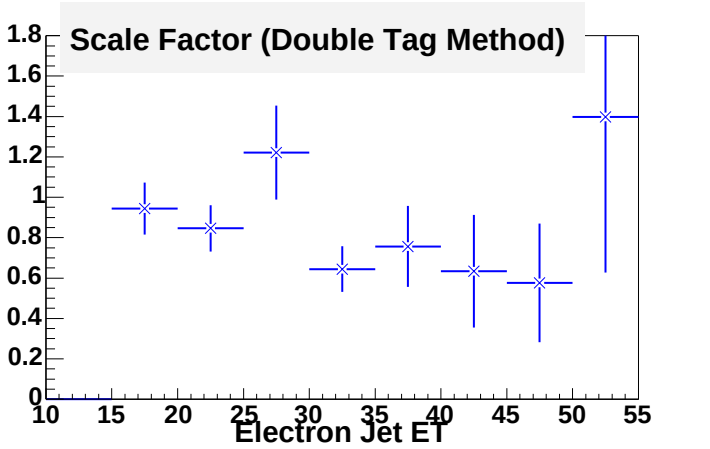
- Check in multi-jet events the E_T dependence of the b-tagging efficiency, as well as the mistag rate of the algorithm.

- Efficiency for tagging at least one jet in a $t\bar{t}$ event (l+$\geq$3 jets, incl. data-MC scaling):

$$\epsilon^{t\bar{t}}_{\geq 1\, tag} = 53 \pm 4\%$$







Measurement with Secondary Vertex B-Tagging (I)

Method:

- Simple counting analysis:

  $$\sigma_{t\bar{t}} = \frac{N_{t\bar{t}}}{\mathcal{L}} = \frac{N_{obs} - N_{bkd}}{A_{t\bar{t}} \epsilon_{t\bar{t}}^{tag} \mathcal{L}}$$

- N_{obs} : Number of observed events
- N_{bkd} : Number of expected background events
- $A_{t\bar{t}} \cdot \epsilon_{t\bar{t}}^{tag}$: Acceptance x b-tag efficiency = fraction of produced $t\bar{t}$ events that are actually detected
- $\mathcal{L}$: Integrated Luminosity

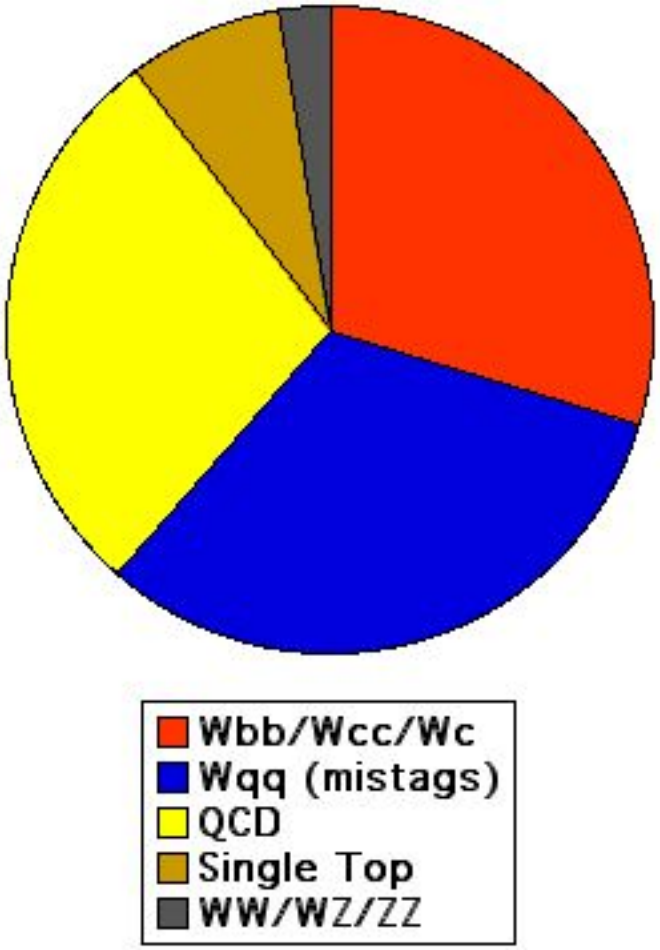
- In order to increase sensitivity, reject background by using the total (transverse) energy in the event:

  H_T = Scalar Sum of Jets E_T, Lepton p_T, Missing E_T

- Requiring $H_T > 200$ GeV rejects $> 1/3$ of background, keeping 96% of $t\bar{t}$ signal.

Backgrounds

- Key issue of this analysis: Understanding the W+jets sample composition
- We use both data and MC to evaluate the backgrounds.



- $Wb\bar{b}$,$Wc\bar{c}$,Wc:

  Monte Carlo provides Heavy Flavor fraction of W+jets, normalization from data

- $Wq\bar{q}$ (mistag):

  Mistag rates measured in multi-jet control sample

- QCD (multi-jets): W faked either by fake lepton, or semileptonic B decay

  Use non-isolated lepton sample

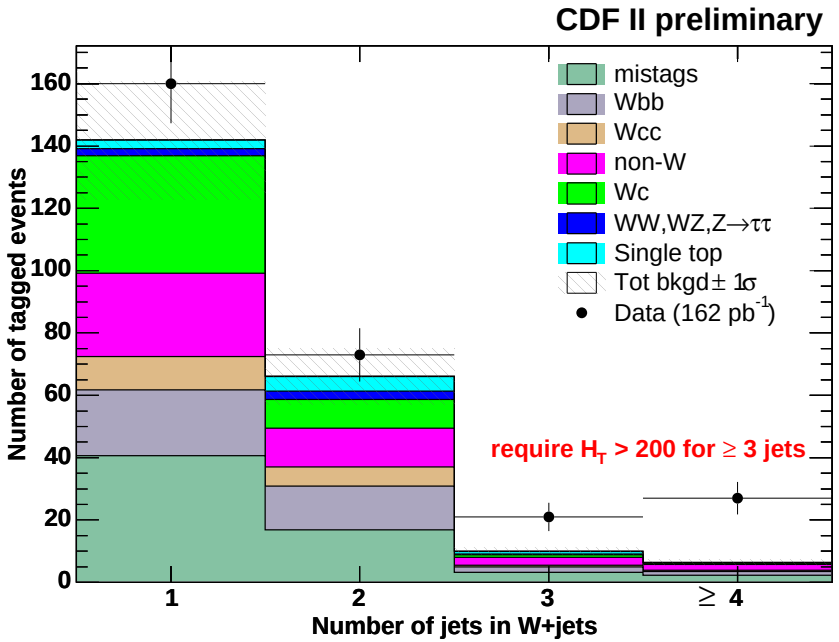
- Single Top, WW, WZ, ZZ: from MC

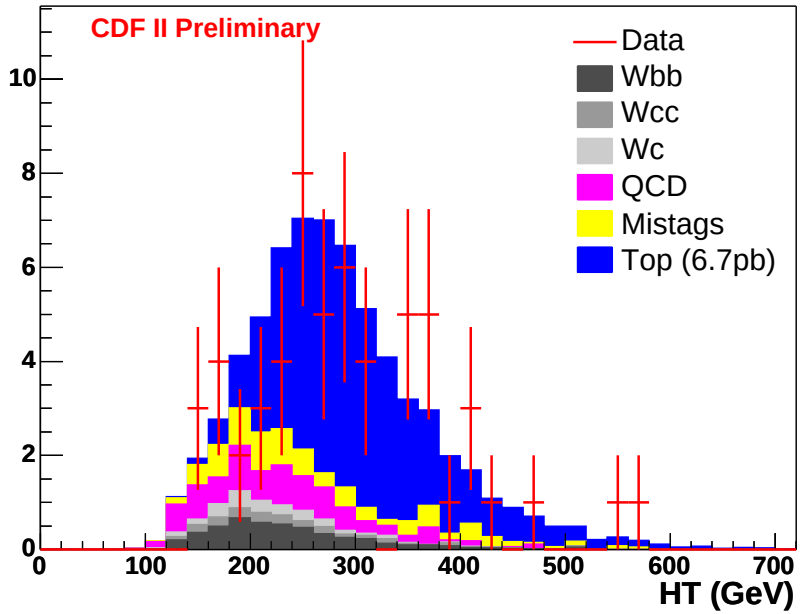
Measurement with Secondary Vertex B-Tagging:

- Analysis based on 162 pb^{-1} accumulated between Feb. 2002 and Sep. 2003.
- 48 tagged events with 3 or more jets and $H_T > 200$GeV (57 without H_T cut).

$$\sigma_{t\bar{t}} = 5.6^{+1.2}_{-1.0}(\text{stat.})^{+1.0}_{-0.7}(\text{syst.}) \quad \text{pb}$$

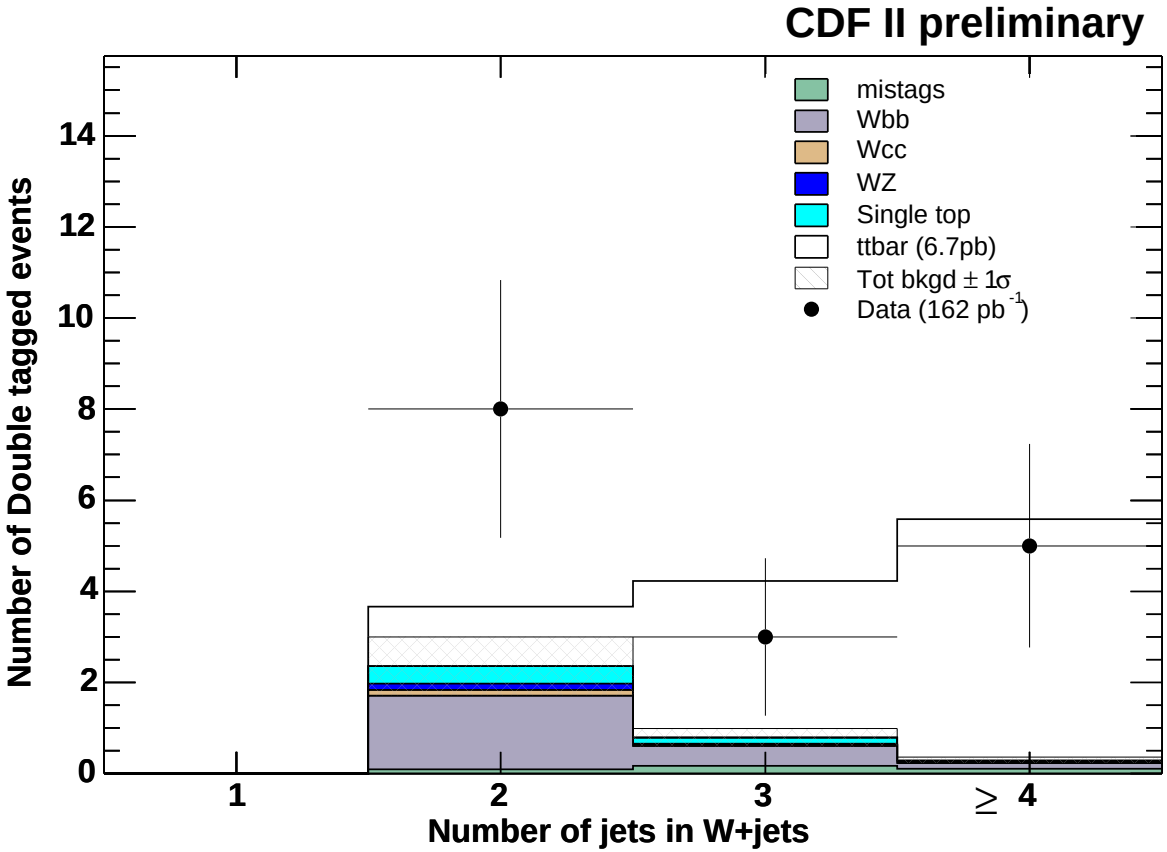
Syst.	Err on $\sigma_{t\bar{t}}$
Acceptance	10%
B-tagging	8.6%
Luminosity	6%
Bgd	4.4%





Measurement of $\sigma_{t\bar{t}}$ with double-tag events

- Look at the sub-sample of events with 2 tagged jets.
- Very pure signal: S/B=9
- Interesting check of the B content of W+jets sample.
- 8 candidates $\longrightarrow$ dominated by statistics.



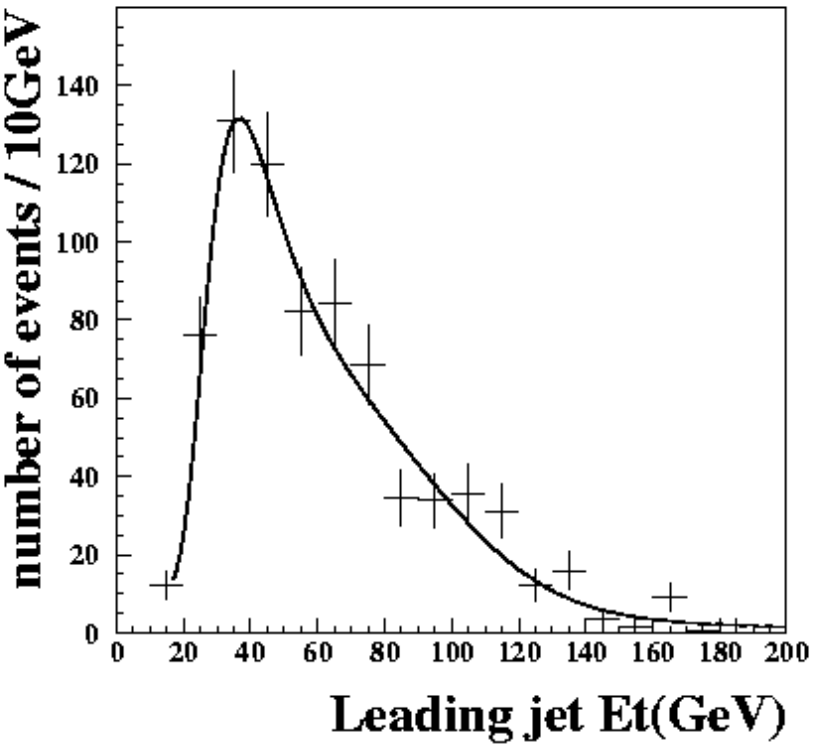
$$\sigma_{t\bar{t}} = 5.4 \pm 2.2 \pm 1.1 \text{ pb}$$

- 2-jet events: $\leq 2\sigma$ excess
- But not seen in the single-tag sample

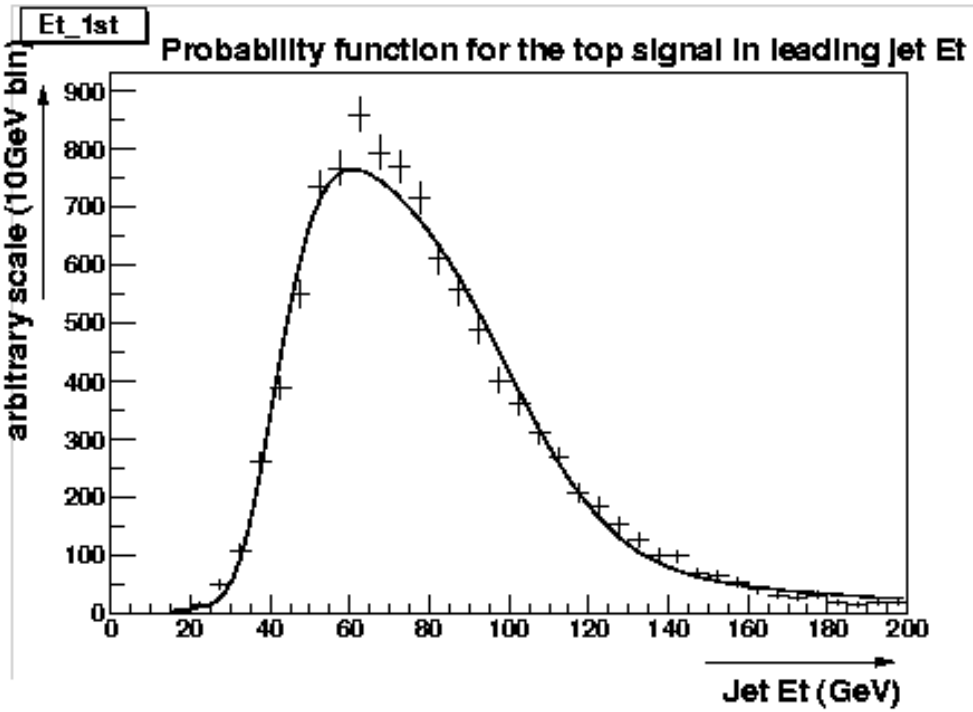
Measurement with Secondary Vertex B-Tagging, Using a Kinematic Fit

- Uses the same secondary vertex tagger, and same sample (but no H_T cut).
- Fit the E_T distribution of the leading jet to extract the fraction of $t\bar{t}$ events.
- This variable is both sensisitive and well-understood.
- Avoids evaluating the background contributions. Background shape from 0-tag data
  $\longrightarrow$ does not rely on Monte Carlo (complementary method)

Background template:



Signal template (Herwig):

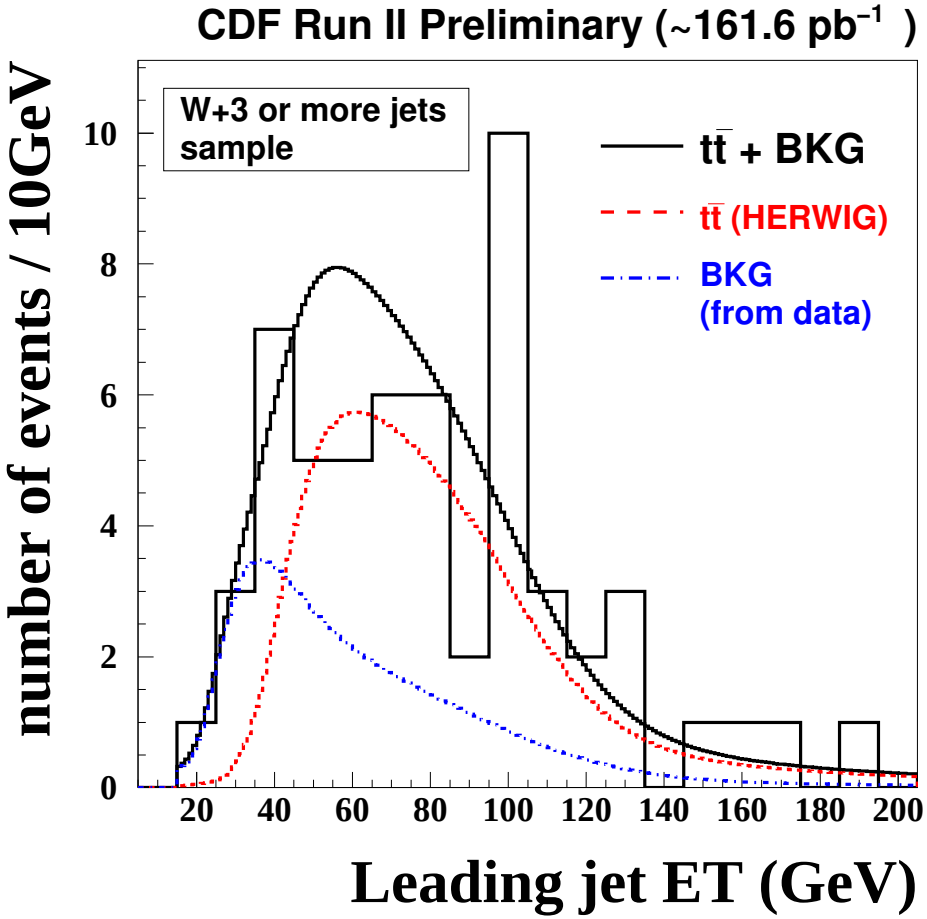


Measurement with Secondary Vertex B-Tagging, Using a Kinematic Fit

- Result based on 162 pb^{-1}.
- 57 candidates.
- The fit gives a $t\bar{t}$ fraction of:
  $0.67^{+0.13}_{-0.16}$
  consistent with previous analysis.
- Cross-section:

$$\sigma_{t\bar{t}} = 6.0^{+1.5}_{-1.8}(\text{stat.}) \pm 0.8(\text{syst.}) \quad \text{pb}$$

- Cross-check: measurements with other kinematic variables, such as second leading jet, or sum of two leading jets E_T give consistent results.



Soft Muon B-Tagging Algorithm

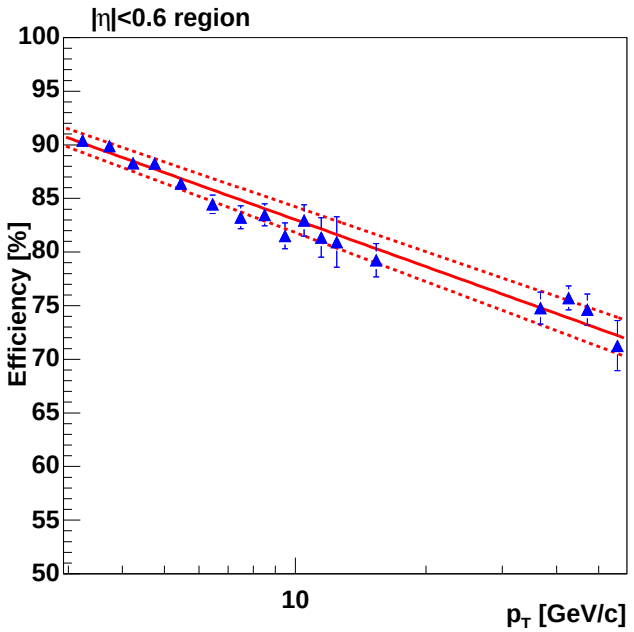
- Identify muons coming from B hadron semi-leptonic decays.
- Match tracks in drift chamber with segments in muon chambers.
- Likelihood fit based on muon system information only.
- Efficiency measured from J/ψ, Z^0 samples.

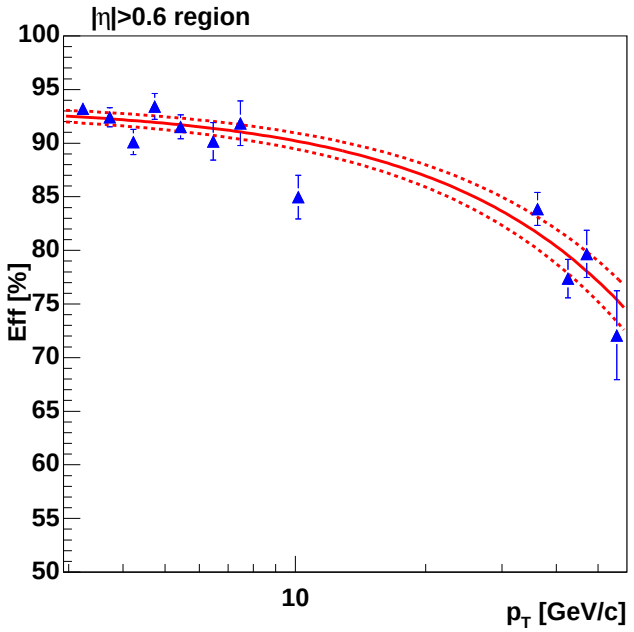
  Main uncertainty due to higher track occupancy in $t\bar{t}$ events than in control sample.
- Fake rate determined from γ+jets control sample, parametrized in η, ϕ, and p_T:

  Average fake rate = 0.7%
- Actual efficiency is lowered by the semi-leptonic decay branching ratio:
- Efficiency to tag at least one jet in a $t\bar{t}$ event:

  $\epsilon = (14 \pm 0.3^{+0}_{-1.1})$ % for 3-jet events

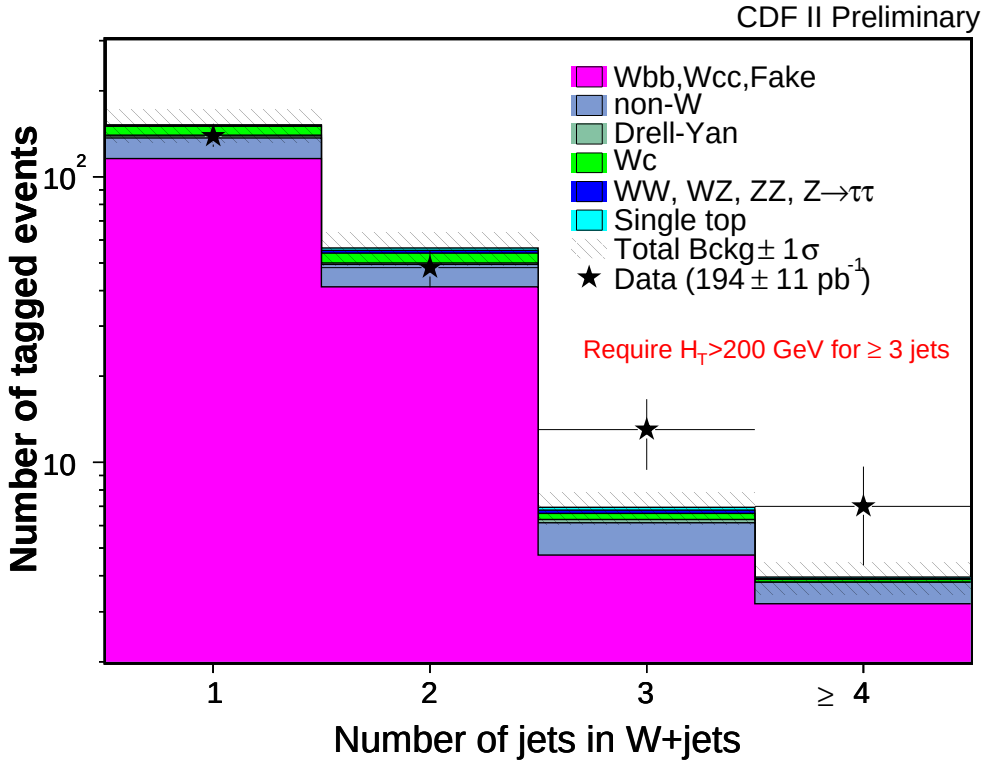
  $\epsilon = (16 \pm 0.3^{+0}_{-1.3})$% for $\geq$4-jet events





Measurement with Soft Muon Tagger

- Test of the Heavy Flavor properties of the $t\bar{t}$ sample.
- Same counting method as shown before with Sec. Vec algorithm.
- Lower efficiency $\longrightarrow$ poorer statistics, but larger data sample (no silicon detector required)
- Backgrounds are evaluated with same methods: dominated by mistags and QCD
- 20 candidates in 194 pb^{-1} of data.

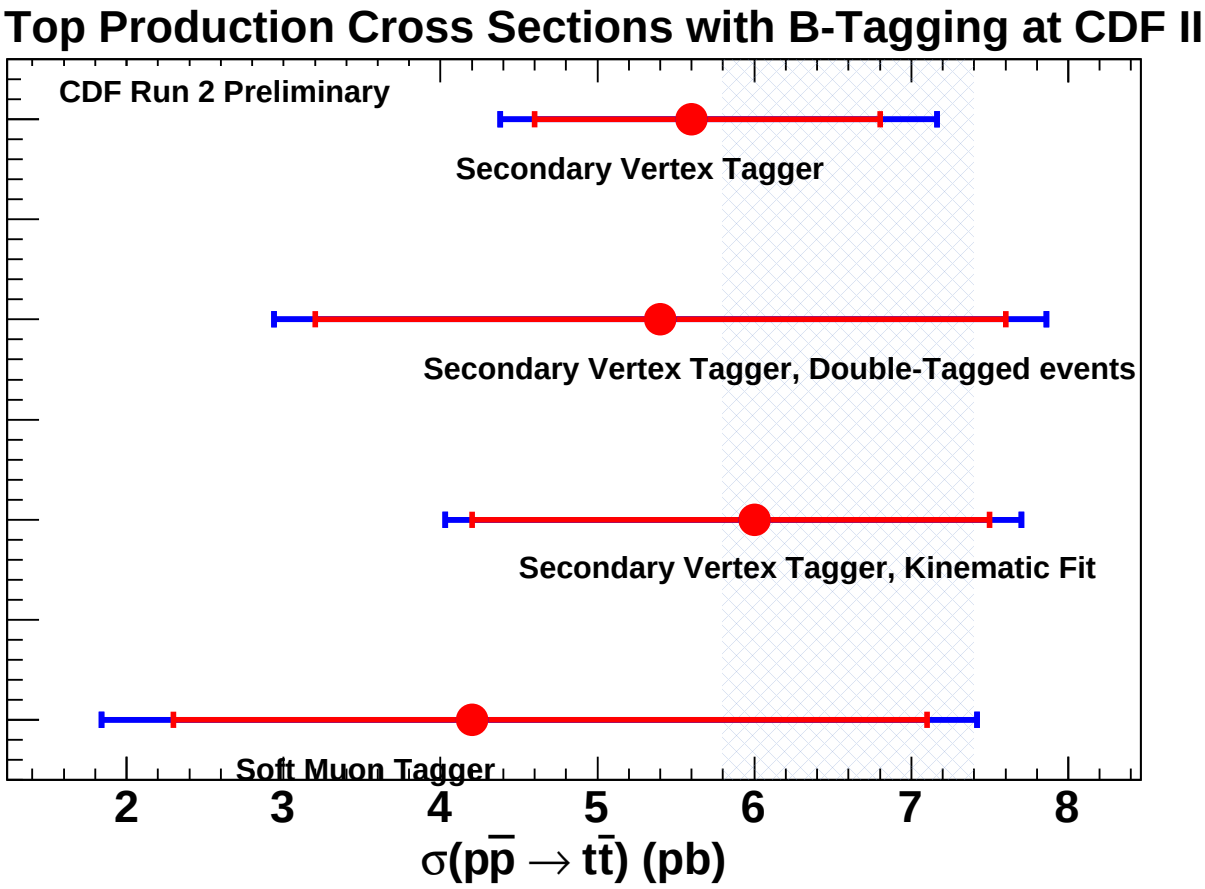


$$\sigma_{t\bar{t}} = \frac{N_{obs} - N_{bkd}}{\epsilon_{t\bar{t}}\mathcal{L}} = 4.2^{+2.9}_{-1.9}(\text{stat.}) \pm 1.4(\text{syst.}) \quad \text{pb}$$

Conclusion

- $\sigma_{t\bar{t}}$ has been measured with significantly larger statistics than in Run I, at a new center-of-mass energy ($\sqrt{s} = 1.96$ TeV):
- So far, results are consistent with a Standard Model $t\bar{t}$ signal with $m_t \approx 175$GeV ($\sigma_{t\bar{t}}^{SM} = 6.7^{+0.7}_{-0.9}$ pb):

- Publication in preparation.
- Looking forward to more data...



Background Summary Sec. Vertex (backup)

Background	W + 1 jet	W + 2 jets	W + 3 jets	$W + \geq$ 4jets
Events before tagging	15314	2448	179	91
mistags	40.6 ± 4.9	16.8 ± 2.2	3.2 ± 0.5	2.3 ± 0.4
$Wb\bar{b}$	21.2 ± 7.6	14.1 ± 4.7	1.7 ± 0.6	1.2 ± 0.5
$Wc\bar{c}$	10.7 ± 4.7	6.1 ± 2.4	0.6 ± 0.3	0.4 ± 0.2
$Wb\bar{b}$, $Wc\bar{c}$, mistags (Method 2)	72.5 ± 13.2	37.0 ± 7.5	5.6 ± 1.0	3.8 ± 0.8
Wc	37.7 ± 12.3	9.2 ± 3.4	0.8 ± 0.3	0.3 ± 0.1
$WW/WZ/ZZ$, $Z \rightarrow \tau\tau$	2.3 ± 0.5	2.6 ± 0.5	0.3 ± 0.1	0.08 ± 0.06
non-W	26.7 ± 2.8	12.5 ± 1.9	2.5 ± 0.5	11.9 ± 0.4
single top	2.7 ± 0.4	4.7 ± 0.7	0.8 ± 0.1	0.2 ± 0.03
Total	141.8 ± 18.9	66.0 ± 8.9	10.0 ± 1.2	6.3 ± 0.9
Corrected Total	141.8 ± 18.9	66.0 ± 8.9	13.8 ± 2.0	
Observed positive tags	160	73	21	27

Soft Muon Tagger results (backup)

Results

Background	W + 1 jet	W + 2 jets	W + 3 jets	W +≥ 4 jets	W+≥ 3 jets
Events before tagging	18314	2889	226	111	337
Fake, $Wb\bar{b}$, $Wc\bar{c}$	115.9 ± 11.6	41.2 ± 4.1	6.4 ± 0.6	4.3 ± 0.4	10.7 ±1.1
Wc	10.4 ± 2.9	4.1 ± 1.3	0.4 ± 0.1	0.12 ± 0.05	0.55 ± 0.18
WW, WZ, ZZ, Z→ $\tau^+\tau^-$	1.13± 0.17	1.36 ± 0.07	0.18 ± 0.03	0.04 ± 0.01	0.20 ± 0.02
non-W	21.1 ± 9.9	8.1 ± 3.9	1.5 ± 0.8	0.7 ± 0.5	2.4 ± 1.2
Drell-Yan	3.1 ± 0.6	0.64 ± 0.27	0.18 ± 0.14	0.0 ± 0.0	0.18 ± 0.14
Single-Top	0.51 ± 0.04	0.95 ± 0.06	0.15 ± 0.01	0.036 ± 0.003	0.19 ± 0.01
Total Background	152.2 ± 15.5	56.3 ± 5.9	8.9 ± 1.0	5.2 ± 0.7	14.2 ± 1.6
Corrected Background			11.59±1.5		11.59±1.5
$t\bar{t}$ expectation	0.36 ± 0.09	3.0 ± 0.5	5.6 ± 0.9	8.1 ± 1.8	13.7 ± 2.7
Total Background plus $t\bar{t}$	152.5 ± 15.5	59.3 ± 5.9	25.3±3.1		25.3 ± 3.1
Tagged Events	139	48	13	7	20

>=3 jets bin

$$\sigma_{t\bar{t}} = 4.2^{+2.9}_{-1.9}\ (\text{stat.})\ \pm 1.4\ (\text{sys.})\text{pb}$$