Evidence for Top Quark Production in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8\,\text{TeV}$

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28.07.2014

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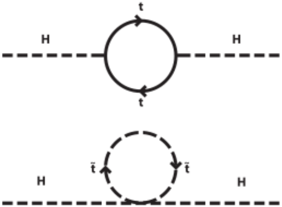
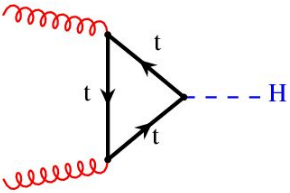
Introduction - Top quark

Why is the top quark important?

1. completes quark model of three generations
2. has the highest mass of all known particles, $m_{\text{top}} \approx 173\,\text{GeV}$
3. decays before it hadronizes
4. has a strong coupling to Higgs boson (loops) $\rightarrow$ **Higgs search**
5. searches beyond the SM

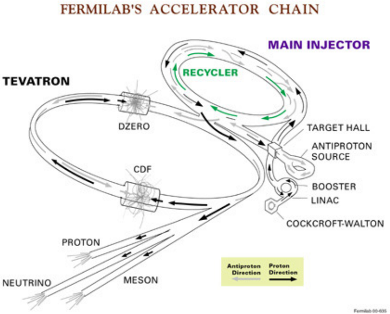


(a) Higgs loop diagrams

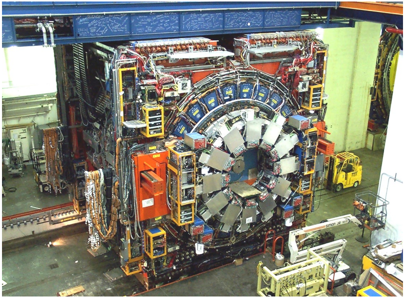


(b) Gluon-Gluon fusion

CDF experiment at Tevatron



(c) Tevatron

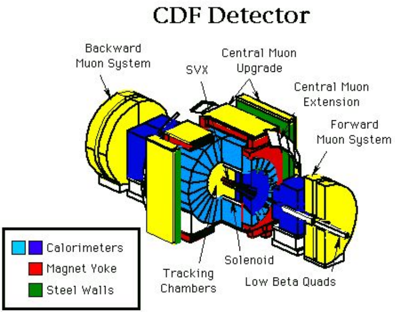


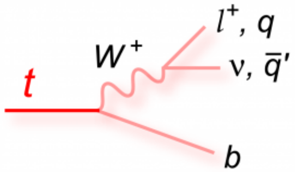
(d) CDF detector

- CDF experiment at Tevatron at Fermilab, Illinois (USA)
- Hadron collider: $p\bar{p}$ collisions at $\sqrt{s} = 1.8\,\text{TeV}$
- Data sample size for this top search: $19.3\,\text{pb}^{-1}$ (1992-1993)

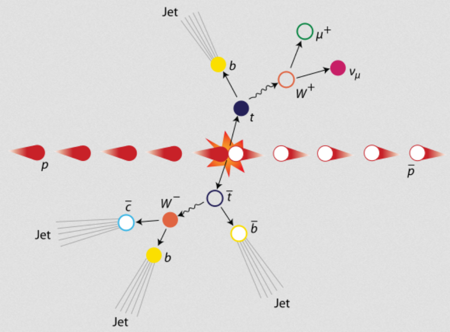
CDF detector

1. central tracking chamber (CTC)
   $\rightarrow$ momenta of charged particles
2. EM and hadronic calorimeter covering $|\eta| < 3.6$
   $\rightarrow \not\!\!E_{\mathrm{T}}$, electrons and jets
3. drift chambers in $|\eta| < 1.0$
   $\rightarrow$ muons
4. silicon vertex detector (SVX)
   $\rightarrow$ secondary vertices from b and c quark decays





Decay channels

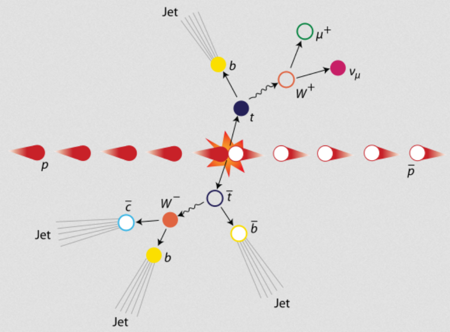


'Always' two b jets, ignore τ

$\rightarrow$ Three decay channels from W boson decay:

1. All jets: 6 jets in the final state (45%) $\rightarrow$ ignore
2. l+jets: 4 jets, 1 charged lepton (30%)
3. Dilepton: 2 jets, 2 charged leptons (5%)

Kinematics



- Expect one isolated lepton with high P_T
- neutrinos $\rightarrow$ huge $\not{E}_\mathrm{T}$
- Dilepton: two leptons with high P_T and opposite charge

still have too much background $\rightarrow$ need additional criteria!

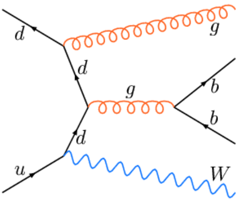
Background events

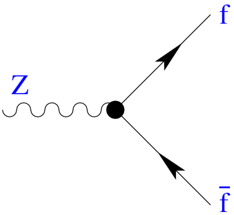
Dominant background in dilepton channel:

- $Z \rightarrow l^+ l^-$
  $\rightarrow$ exclude $M_{ll} \approx M_Z$ region
- induced $\not{E}_T$ by jet mismeasurement
  $\rightarrow$ require large ϕ between $\not{E}_T$ and nearest lepton

Dominant background in l+jets channel:

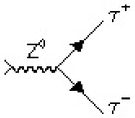
- $W +$ jets (direct $b\bar{b}$, Z, W^+W^-, fake leptons, ...)
  $\rightarrow$ require high number of jets (≥ 3) and **b-tag**!





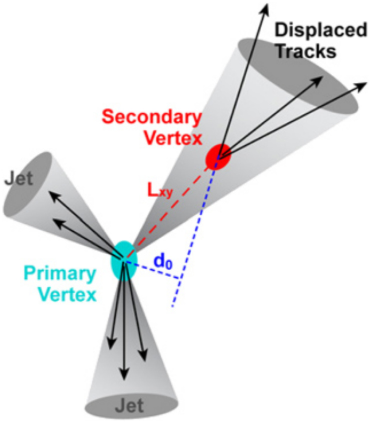
Event selection

1. Dilepton channel
   - Require a high energy isolated lepton
   - Only the $e\mu$ channel survive the kinematic cuts
2. Z rejection
   - Remove Z events by restricting the $\mu\mu, ee$ invariant masses
   - Additional rejection against $Z \to \tau\tau$ require cuts on $\not{E}_T$

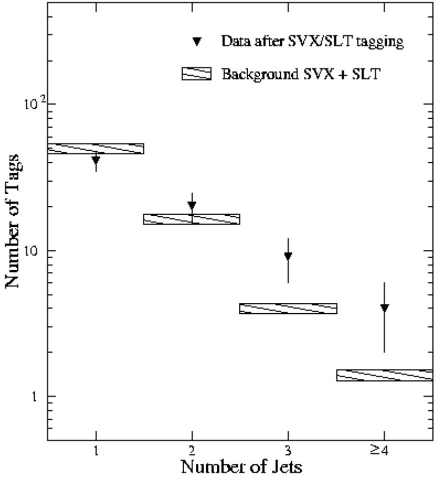


B-tagging

1. SLT: Use the $b \to l\nu X$ decay
   - Low energy leptons $\to$ Easy to distinguish from W decays
   - But: Possibly misidentify hadron jets as soft-leptons
2. SVX: Use vertex-finding algorithm

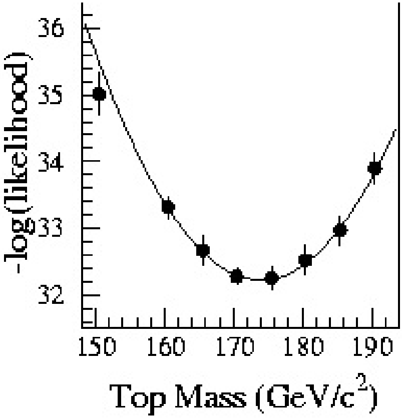


Background discrimiation



Kinematic fits

- Likelihood fit → Estimate M_t
- χ^2 fit → Estimate σ



Uncertainty

Estimation:

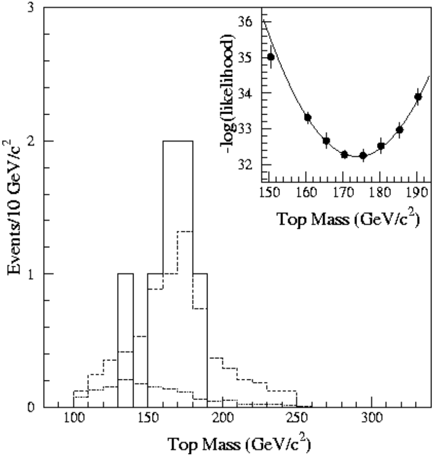
- Monte-Carlo simulations
- Z decay data $Z \to \mu^+\mu^-$

M_{top}	120 GeV/c^2	140 GeV/c^2	160 GeV/c^2	180 GeV/c^2
ϵ_{DIL}	$0.49 \pm .07\%$	$0.66 \pm .07\%$	$0.78 \pm .07\%$	$0.86 \pm .07\%$
ϵ_{SVX}	$1.0 \pm 0.3\%$	$1.5 \pm 0.4\%$	$1.7 \pm 0.5\%$	$1.8 \pm 0.6\%$
ϵ_{SLT}	$0.84 \pm 0.17\%$	$1.1 \pm 0.2\%$	$1.2 \pm 0.2\%$	$1.3 \pm 0.2\%$
$\sigma_{t\bar{t}}^{Theor}$ (pb)	$38.9^{+10.8}_{-5.2}$	$16.9^{+3.6}_{-1.8}$	$8.2^{+1.4}_{-0.8}$	$4.2^{+0.6}_{-0.4}$
$\sigma_{t\bar{t}}^{Expt}$(pb)	$22.7^{+10.0}_{-7.9}$	$16.8^{+7.4}_{-5.9}$	$14.7^{+6.5}_{-5.1}$	$13.7^{+6.0}_{-4.7}$

Expectation and Observation

Channel:	Dilepton	SVX	SLT
$N_{expected}$, $M_{top} = 120$ GeV/c^2	3.7 ± 0.6	7.7 ± 2.5	6.3 ± 1.3
$N_{expected}$, $M_{top} = 140$ GeV/c^2	2.2 ± 0.2	4.8 ± 1.7	3.5 ± 0.7
$N_{expected}$, $M_{top} = 160$ GeV/c^2	1.3 ± 0.1	2.7 ± 0.9	1.9 ± 0.3
$N_{expected}$, $M_{top} = 180$ GeV/c^2	0.68 ± 0.06	1.4 ± 0.4	1.1 ± 0.2
Total Background	$0.56^{+0.25}_{-0.13}$	2.3 ± 0.3	3.1 ± 0.3
Observed Events	2	6	7

Result



$$M_{\text{top}} = 174 \pm 10^{+13}_{-12}\ \text{GeV}$$

$$\sigma_{t\bar{t}}(M_{\text{top}}) = 13.9^{+6.1}_{-4.8}\ \text{pb}$$

$$\text{significance} = 2.8\sigma$$