The top search

1970s B-quark discovery

e+ e-	PETRA	12-47 GeV
	TRISTAN	61.4 GeV
	LEP	≈Mz

Mt > 45.8 GeV

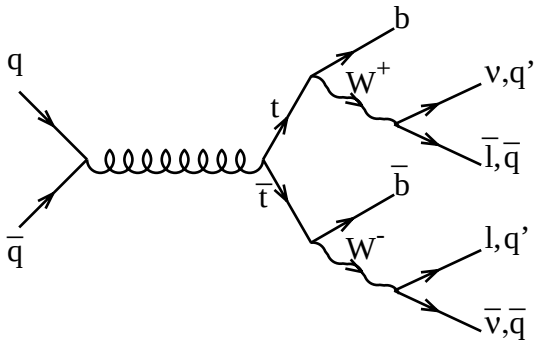
p+p-	ISR	60 GeV
	SppS	630 GeV
	Tevatron	1800 GeV

1984	UA1	Mt = 40 ± 10
1989	UA1	Mt > 60 GeV
	UA2	Mt > 69 GeV

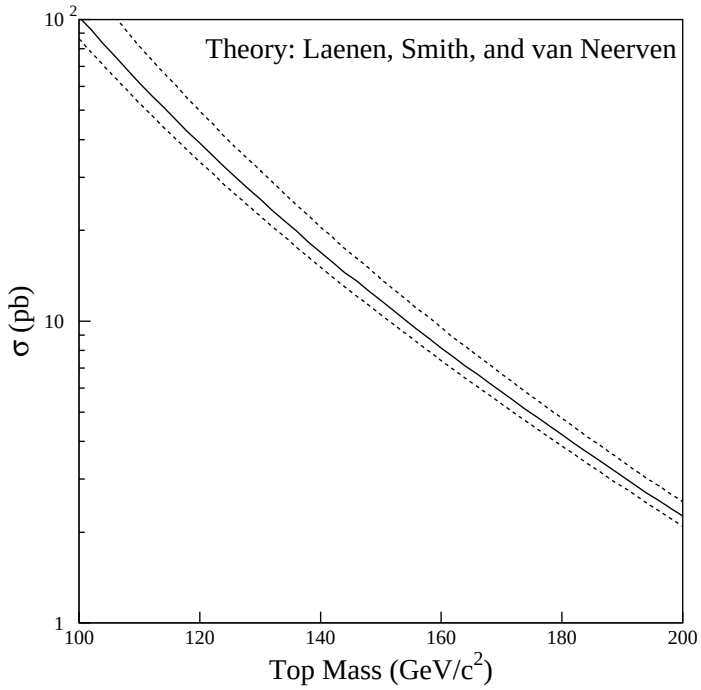
1989	CDF	Mt > 91 GeV
1993	D0	Mt > 131 GeV
1994	CDF	Mt = 174 ± 10 ± 12
	first evidence	

Top Production and Decay

- Production:



- Theory production cross section versus mass:



- In the Standard Model, top decays via

$$t \rightarrow W + b$$

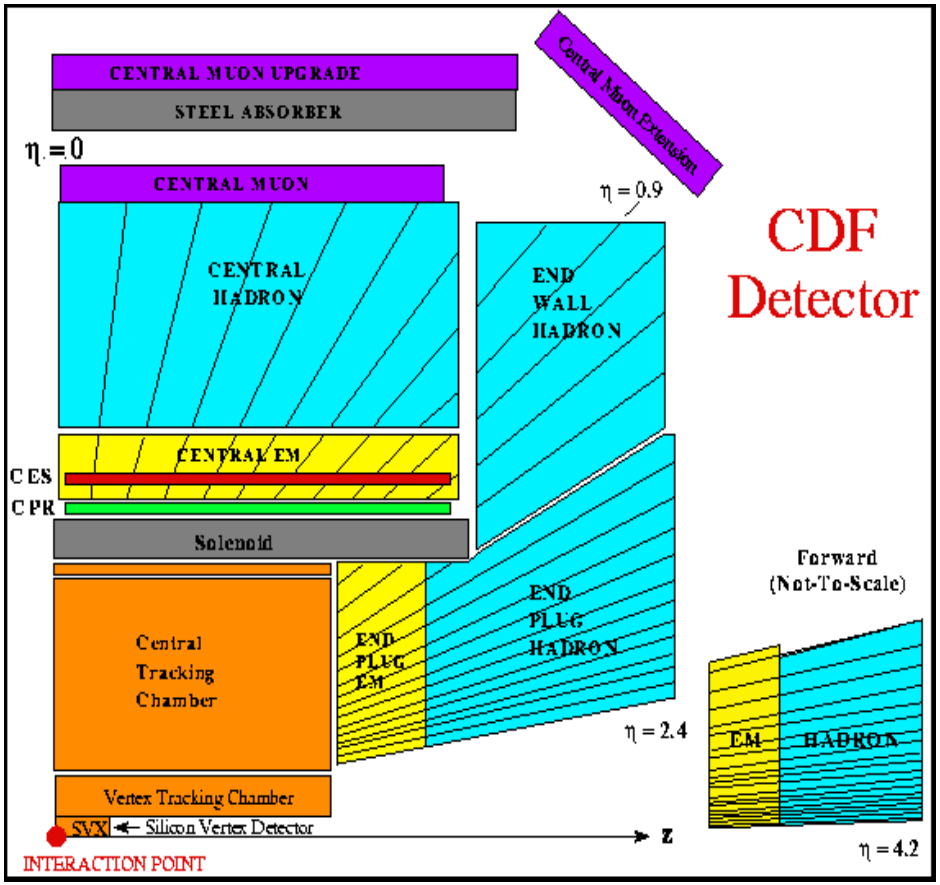
Top Decay Signature

- Both W's Decay $W \to \ell\nu$
  - Final State: $\ell^+\nu\ell^-\nu b\bar{b}$ (ℓ: e or μ)
  - Dilepton Channel, Branching Ratio $\sim 5\%$
  - Require jet activity to reduce the background.

- One W Decays $W \to \ell\nu$
  - Final State: $\ell^+\nu\ q\bar{q}'\ \ b\bar{b}$ (ℓ: e or μ)
  - Lepton+Jets Channel, Branching Ratio $\sim 30\%$
  - Identify b-quarks to reduce the background.

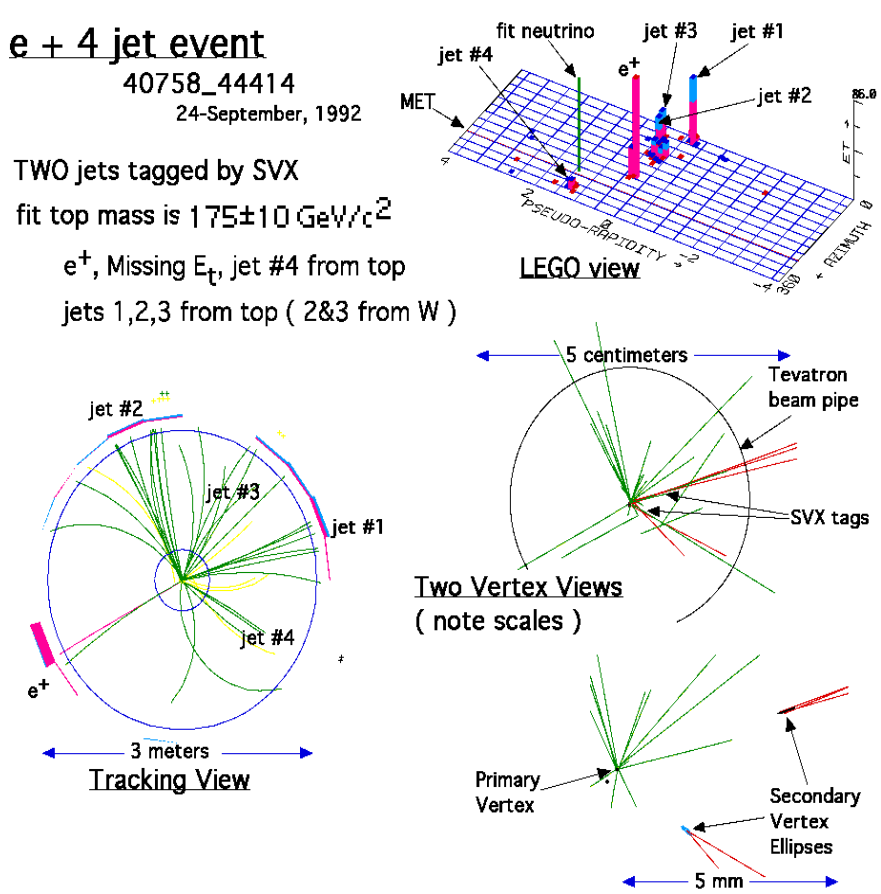
- Both W's decay $W \to q\bar{q}'$
  - Final State: $q\bar{q}'\ q\bar{q}'\ \ b\bar{b}$
  - All Hadronic Channel, Branching Ratio $\sim 44\%$
  - Identify b-quarks, use mass information, to reduce the background.

Top and CDF



SVX with average Impact parameter resolution ~ 40 μm

Magnetic field ~ 1.4 Tesla



Lepton Plus Jets Channel

$$t \to W^+ b \to \ell^+ \nu b$$
$$\bar{t} \to W^- \bar{b} \to q\bar{q}' \bar{b}$$

Event Selection

- A primary lepton with $E_T > 20$ GeV.
- $\not{E}_T > 20$ GeV
- Require $N_{jet} \geq 3$, $E_T > 15$ GeV, $|\eta| < 2.0$
- Remove Z's: $75 < M_{\ell\ell} < 105$ GeV/c^2
- Dilepton Events Removed

After Selection:

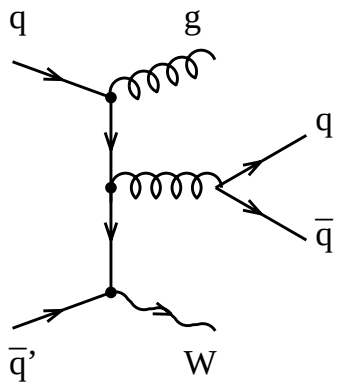
- Total Number of W+$\geq$ 3 jets: 324 Events

- For $\sigma_{t\bar{t}} = 4.8$ pb $\longrightarrow$ expect ≈ 44 $t\bar{t}$ Events satisfying selection criteria.

Need Background Rejection!

Backgrounds:

- Dominant Background in lepton+jets search is non-top QCD W+multijet production.



- Background rejected using b tagging:
  - Every $t\bar{t}$ event contains 2 b quarks
  - Only $\sim$ 2% of QCD W+jets events are expected to contain b quarks.

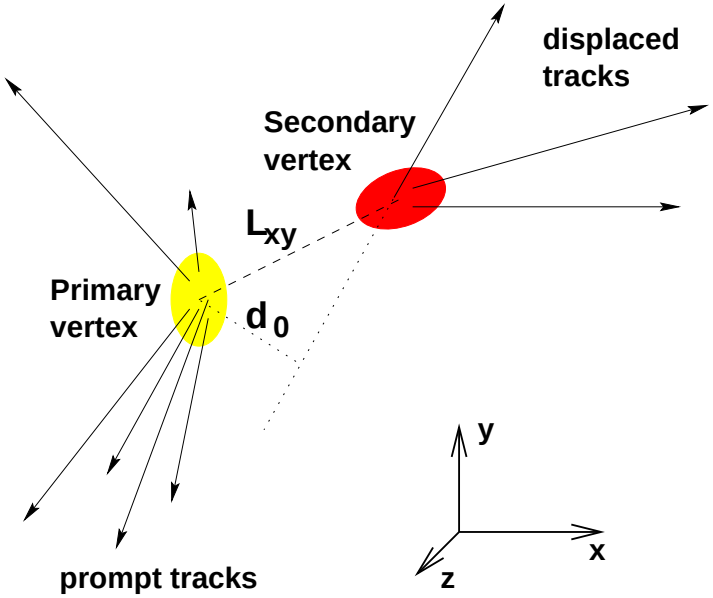
Two b tagging Algorithms:

- Location of displaced vertex using SVX.
- Soft Lepton (e or μ) from b-quark decay.

b tagging

- b-quarks have a long lifetime : $\tau(\mathrm{b}) \sim 1.5\,\mathrm{ps}$ ($c\tau \sim 450\,\mu\mathrm{m}$)
  $\Longrightarrow$ B hadrons travel $\mathrm{L_{xy}} \sim 3\,\mathrm{mm}$ before decay.

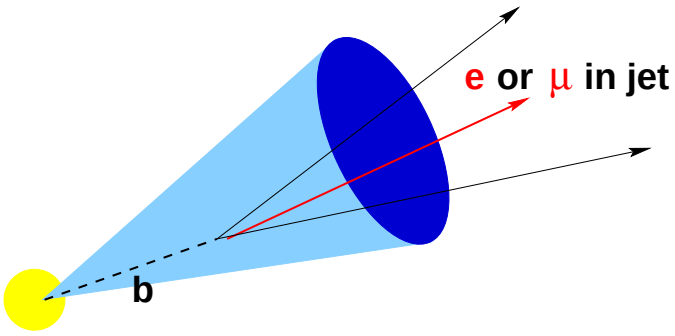
- b-tagging using displaced vertices (SVX) (CDF)



- Uses SVX tracking
- Secondary vertex ≥ 2 tracks
- Tagged if $\mathrm{L_{xy}}/\sigma_{\mathrm{L_{xy}}} > 3.0$
  (typically $\sigma_{\mathrm{L_{xy}}} \sim 150\,\mu\mathrm{m}$)

$\epsilon_b \sim 25\%$
$\epsilon(\text{top event}) \sim 50\%$
$\epsilon_c \sim 4\%$
$\epsilon_{fake} \sim 0.2\%$ per jet

- Soft lepton tagging (SLT) of b quarks (DØ and CDF)

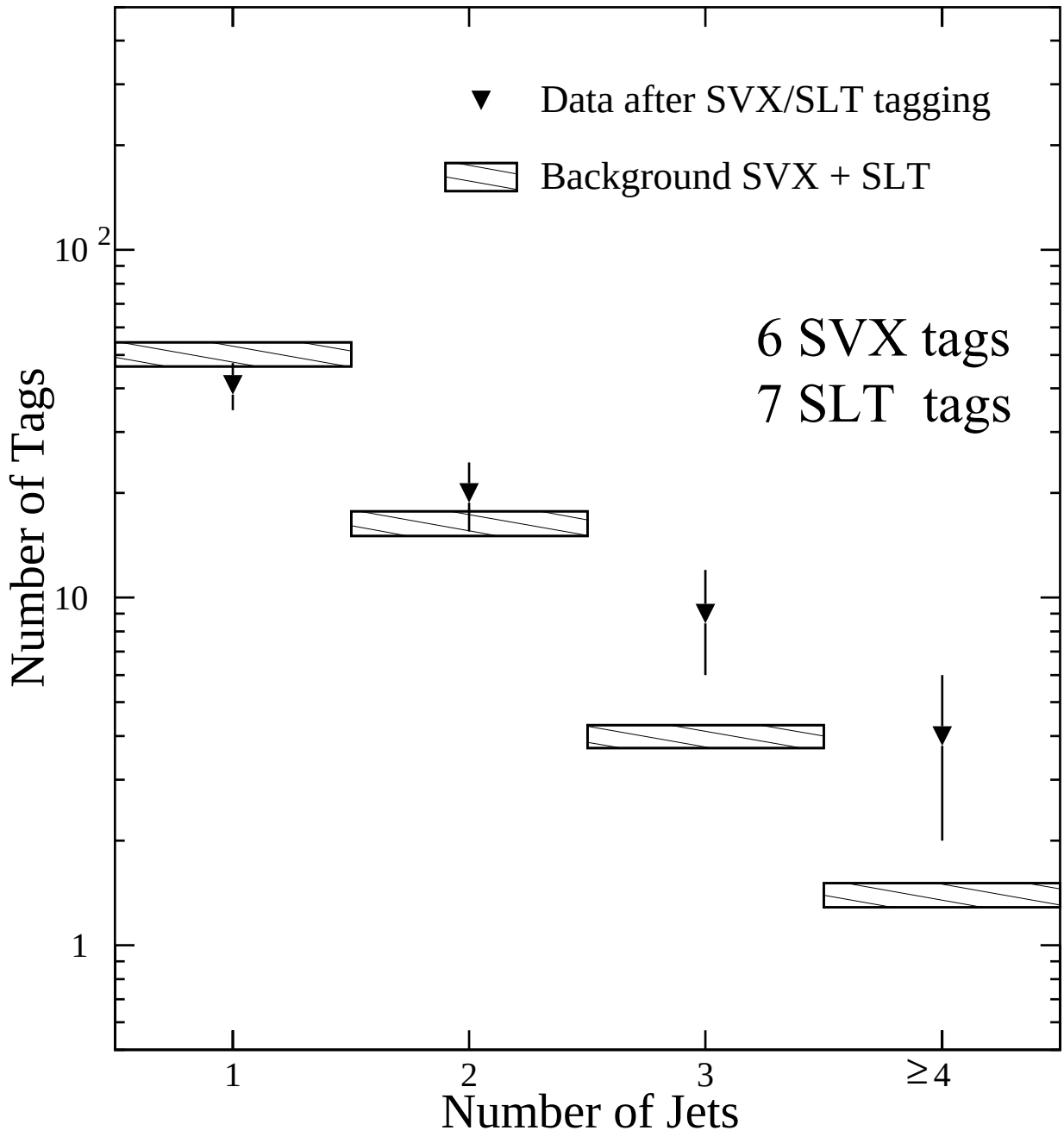


- $b \to \ell\nu c$ (BR $\sim 20\%$)
- $b \to c \to \ell\nu s$ (BR $\sim 20\%$)

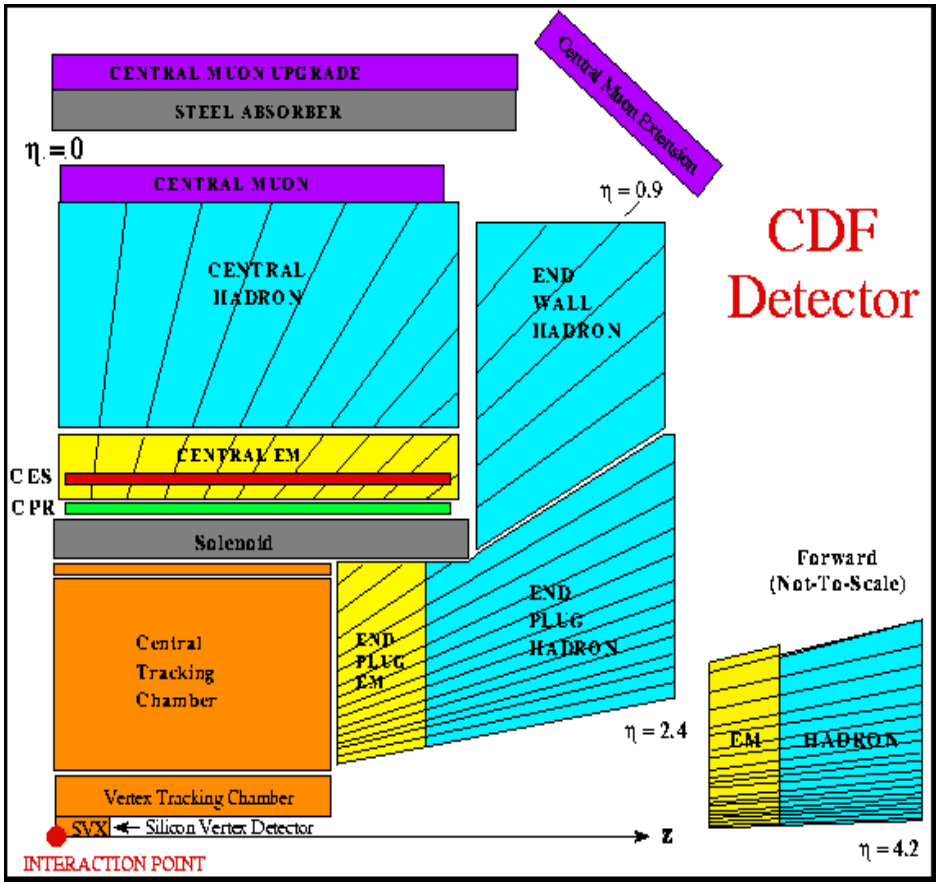
- Identifies lepton in semi-leptonic b (or c) decays
- Lepton softer, less isolated than from W/Z decay

$\epsilon_b \sim 7\%$
$\epsilon(\text{top event}) \sim 16\%$
$\epsilon_c \sim 4\%$
$\epsilon_{fake} \sim 1\%$ per jet

The first "Evidence"



Top and CDF



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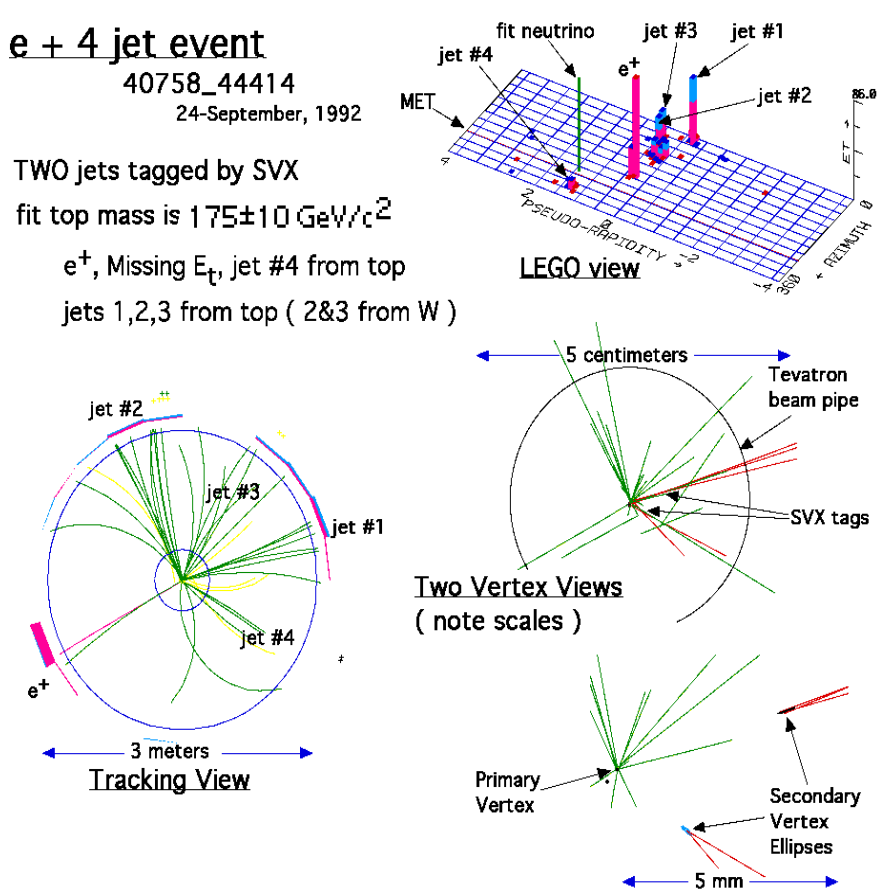


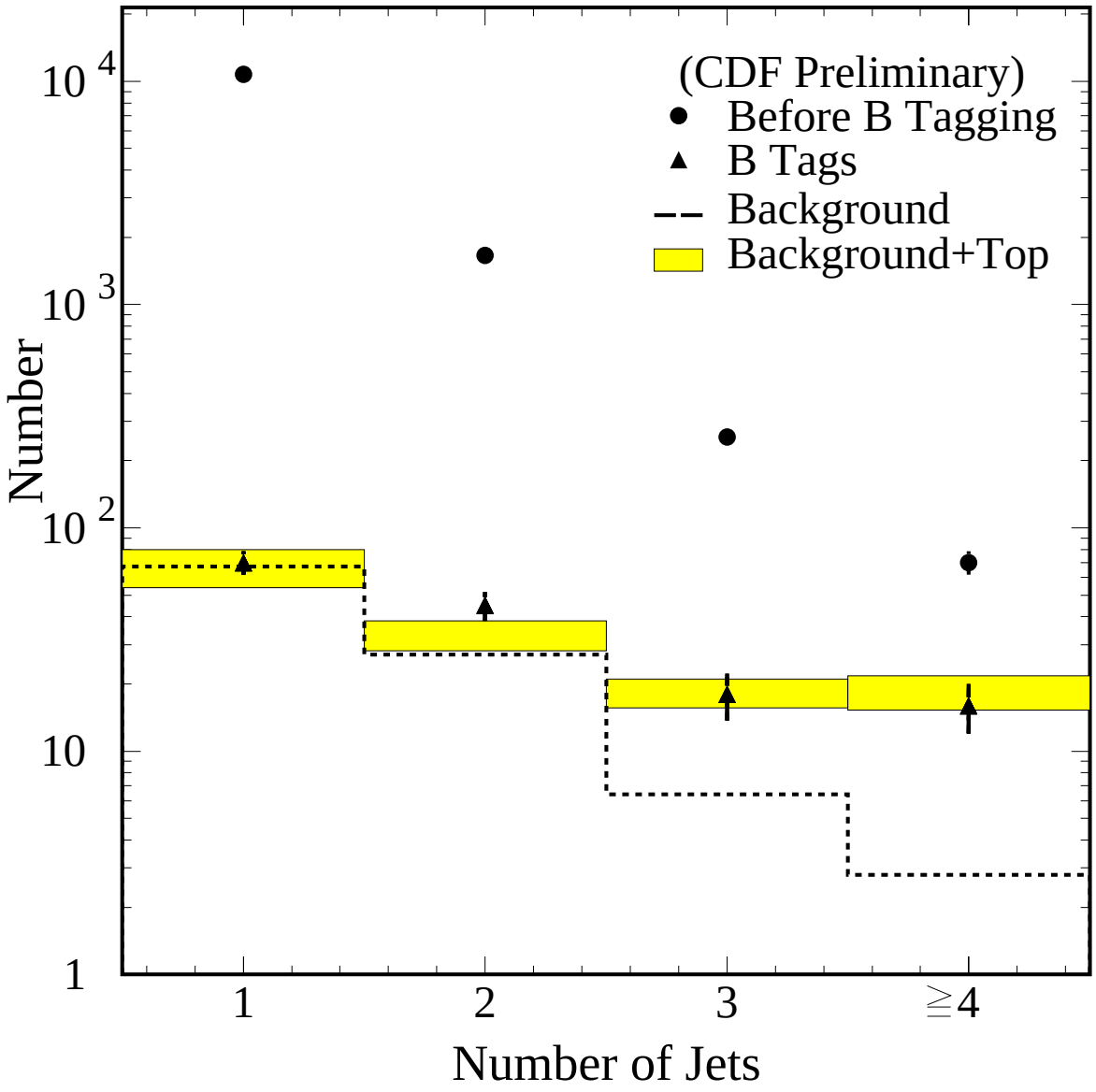
Background Determination:

- The fake background is parametrized from "generic" jet data.
- $Wb\bar{b}, Wc\bar{c}, Wc$ rates determined from Monte Carlo and scaled to the observed number of W events in a given jet multiplicity bin.
- The additional backgrounds are derived from a combination of data and monte carlo.

SVX b-tagging Results

	Before Tag	Exp Tags	Obs Tags (Evts)
W+1 Jet	10716	69 ± 10.9	70 (70)
W+2 Jet	1663	29 ± 3.9	51 (45)
W+3 Jet	254	6.8 ± 0.9	24 (18)
W+$\geq$4 Jet	69	2.6 ± 0.5	18 (16)

N_{jet} Plot for SVX



Signal Region (3 or More Jets):

Background: 9.47 ± 1.4 Tags
Observed Tags: 42
Tagged Events: 34

Soft Lepton b-tagging Results

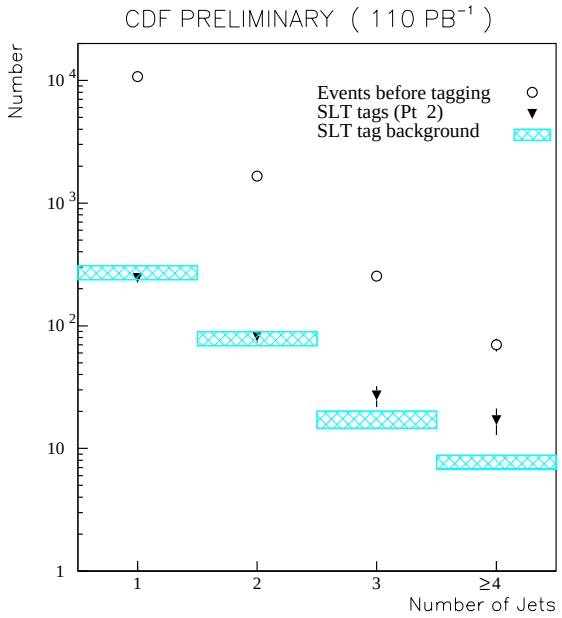
	Before Tag	Exp Tags	Obs Tags (Evts)
W+1 Jet	10716	273±35	245 (245)
W+2 Jet	1663	79±10	82 (80)
W+3 Jet	254	17.4±2.8	27 (25)
W+≥4 Jet	69	7.8±1.0	17 (15)

Signal Region:

Background: 25.2 ± 3.8 Tags

Observed Tags: 44

Tagged Events: 40



Dilepton Channel

$$t \rightarrow W^+ b \rightarrow \ell^+ \nu b$$
$$\bar{t} \rightarrow W^- \bar{b} \rightarrow \ell^- \bar{\nu} \bar{b}$$

Primary Lepton Selection:

- E_T (P_T) $\geq$ 20 GeV (GeV/c)
- Tight set of identification cuts

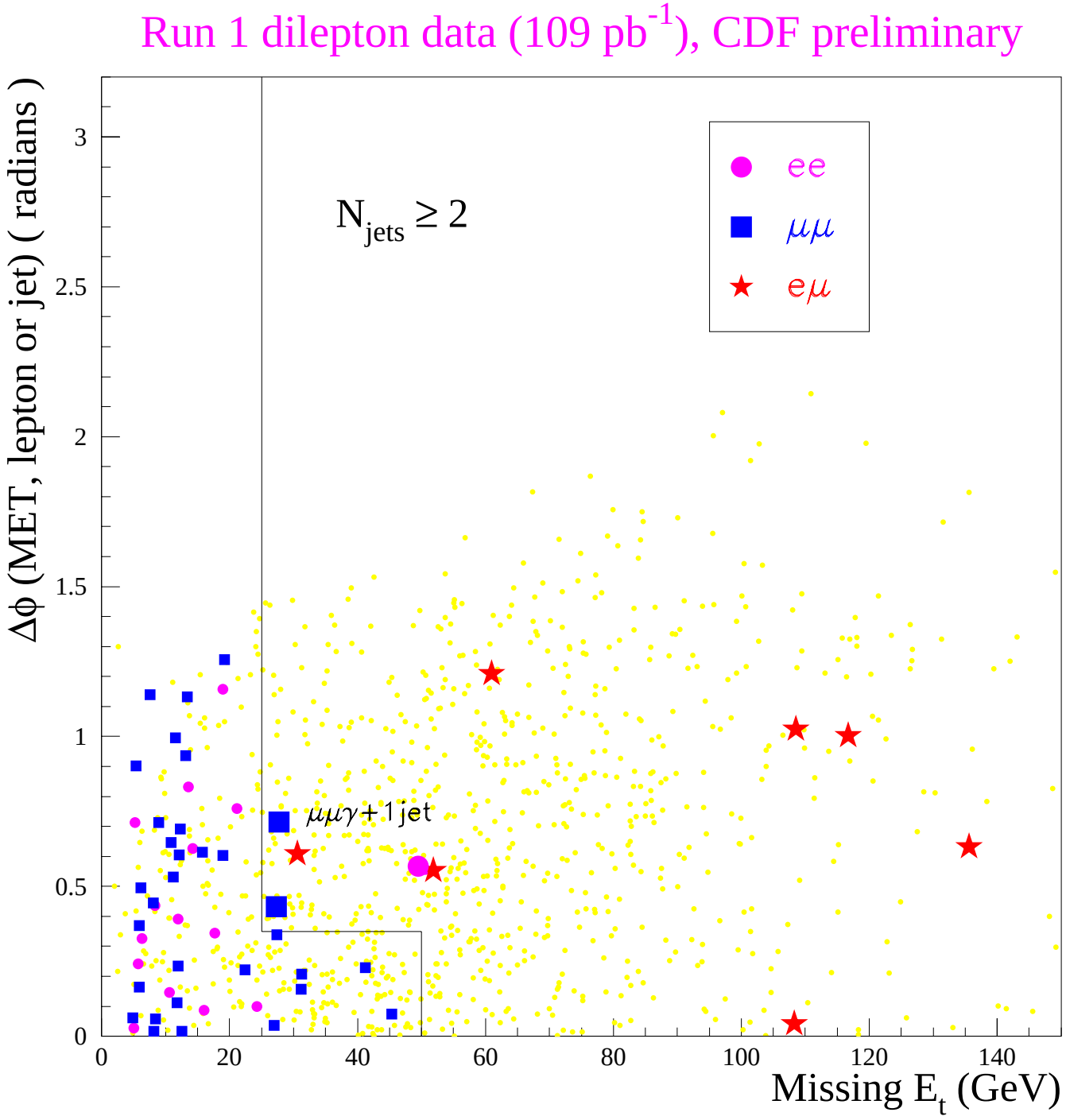
Second Lepton Selection:

- E_T (P_T) $\geq$ 20 GeV (GeV/c)
- Loose set of identification cuts
- opposite charge

Kinematic Selection:

- $\not\!\!E_{\rm T} \geq$ 25 GeV (From two ν's)
- Two Jets with $E_T \geq$ 10 GeV and $|\eta| < 2.0$
- Remove $Z \rightarrow ee$ ($\mu\mu$), $75 < M_{\ell\ell} < 105$ GeV/c^2.
- $\Delta\phi(l, \not\!\!E_{\rm T}) > 20^\circ$ and $\Delta\phi(jet, \not\!\!E_{\rm T}) > 20^\circ$ when $\not\!\!E_{\rm T} < 50$ GeV (Removes $Z \rightarrow \tau\tau$)

Summary of Dilepton Data

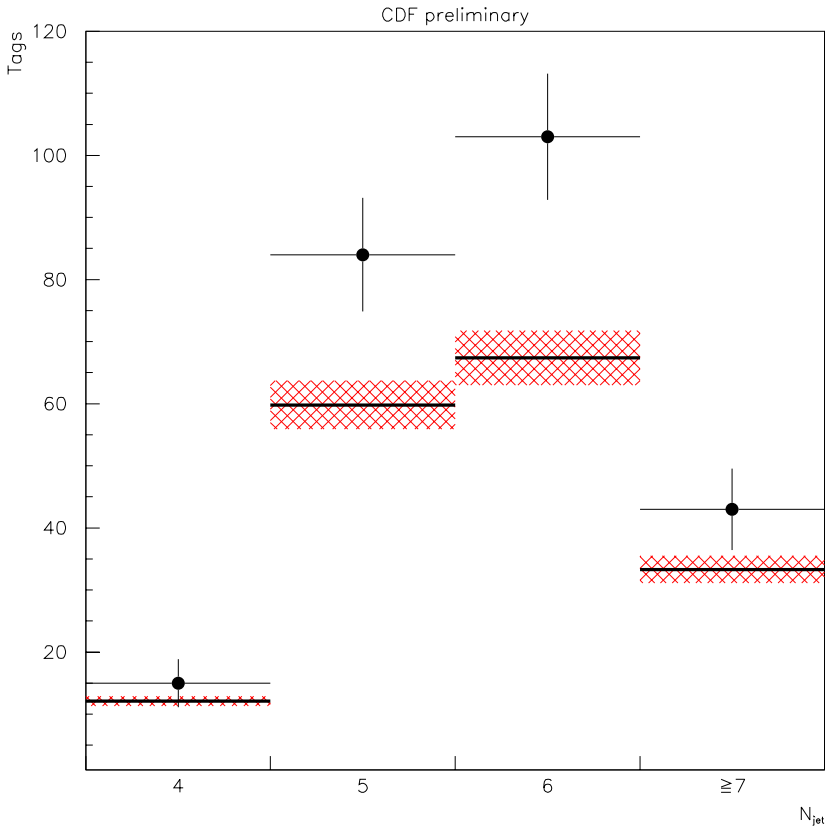


All Hadronic Channel

$$t \rightarrow W^{+}b \rightarrow q\bar{q}'b$$
$$\bar{t} \rightarrow W^{-}\bar{b} \rightarrow q\bar{q}'\bar{b}$$

Kinematical Selection:

- $5 \geq N_{jet} \geq 8$ ($E_T > 15\ GeV, |\eta| < 2.0$, $\Delta R_{min} \geq 0.5$)
- $\Sigma\, E_T \geq 300\ GeV$, $\Sigma\, E_T/\sqrt{s} \geq 0.75$, Aplanarity
- Require $\geq$ 1 SVX b-tag.



$t\bar{t}$ Production Cross Section

Method:

- We calculate the cross section implied by the excess of events observed in the 3 counting experiments: W+jets with an SVX B-tag, W+jets with an SLT B-tag, and Dileptons.
- The cross section is calculated using the relation:

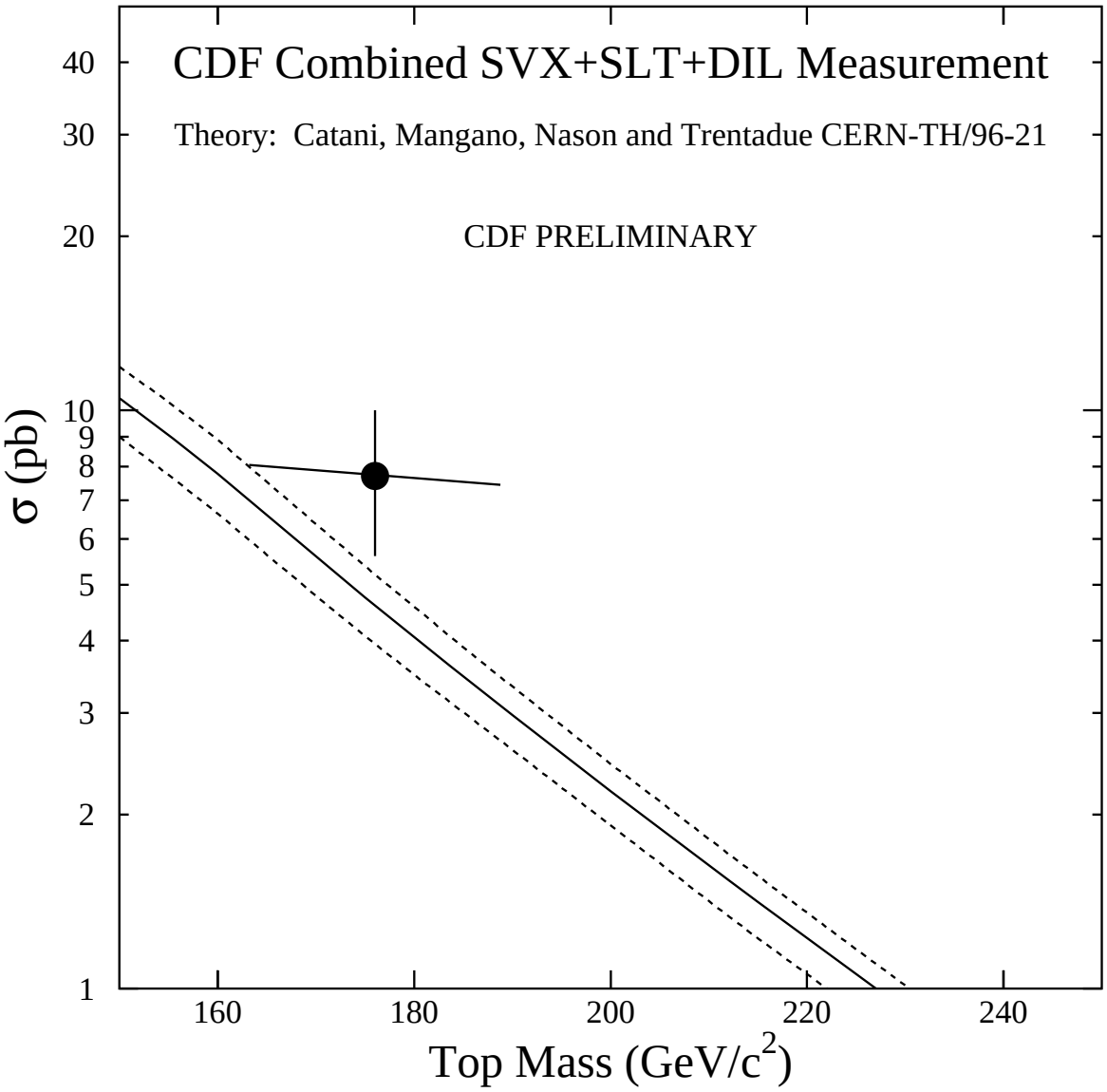
$$\sigma = \frac{n - b}{\epsilon^{tot} \cdot \int \mathcal{L} dt}$$

Item	SVX	SLT	Dilepton
N_{events}^{tagged}	34	40	10
ϵ_{total} (in %)	3.5 ± 0.6	1.7 ± 0.3	0.78 ± 0.08
Background	8.0 ± 1.4	24.3 ± 3.5	2.1 ± 0.4
Luminosity	$109.4 \pm 7\ pb^{-1}$	$109.4 \pm 7\ pb^{-1}$	$109.4 \pm 7\ pb^{-1}$
X-Section	$6.8 \pm 2.1\ pb$	$8.0 \pm 4.0\ pb$	$9.3 \pm 3.9\ pb^{-1}$

Combined $\sigma(t\bar{t}) = 7.5\ ^{+1.9}_{-1.6}\ pb$

Uncertainty from systematics: $\sim 16\%$
Uncertainty from statistics: $\sim 24\%$

Comparison with Theory Cross Section



Mass Analysis

We fit the tagged lepton+jets events to the $t\bar{t}$ hypothesis using constrained fitting techniques.

Sample: Lepton + Jet events with a 4th jet with
$E_T > 8$ GeV, $|\eta| < 2.4$
162 events remain, 34 events with a b-tag

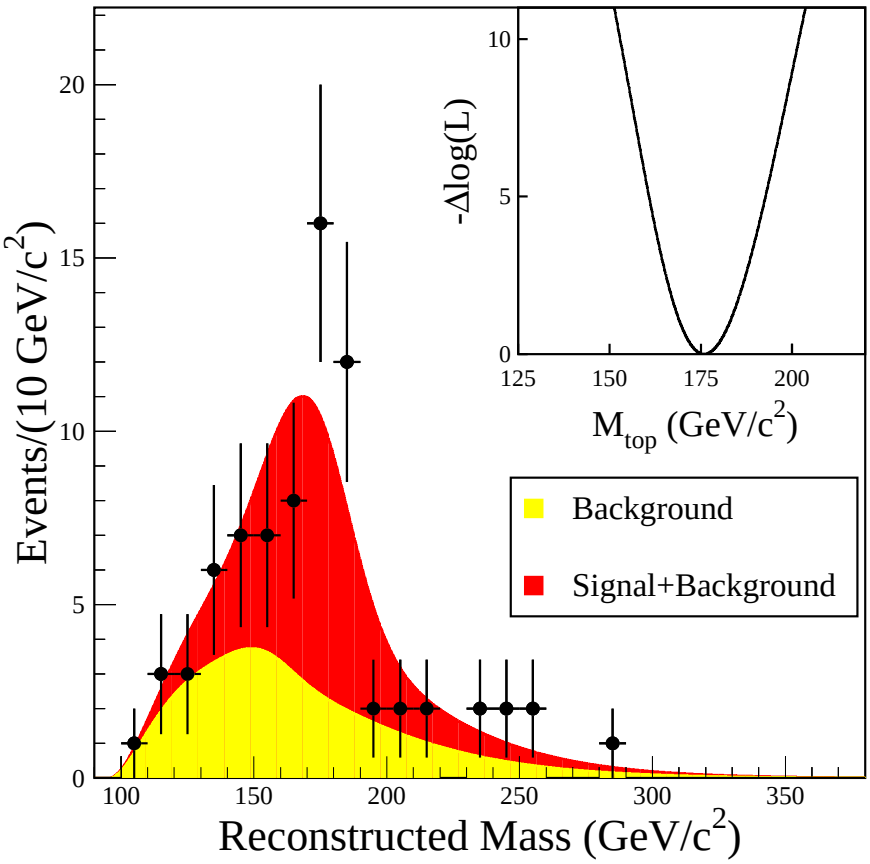
$$p\bar{p} \rightarrow t_1 + t_2 + X$$
$$t_1 \rightarrow W_1 + b_1$$
$$t_2 \rightarrow W_2 + b_2$$
$$W_1 \rightarrow l + \nu$$
$$W_2 \rightarrow j_1 + j_2$$

- All jet assignments are attempted.
- Both solutions for $P_z(\nu)$ are tried.
- b-tag required to be one of the b jets.
- The solution with the lowest χ^2 is kept.

Constraints:

$$M_{l\nu} = M_W$$
$$M_{j_1 j_2} = M_W$$
$$M_{t_1} = M_{t_2}$$

Top Mass measurement in the $\ell + j$ channel: CDF

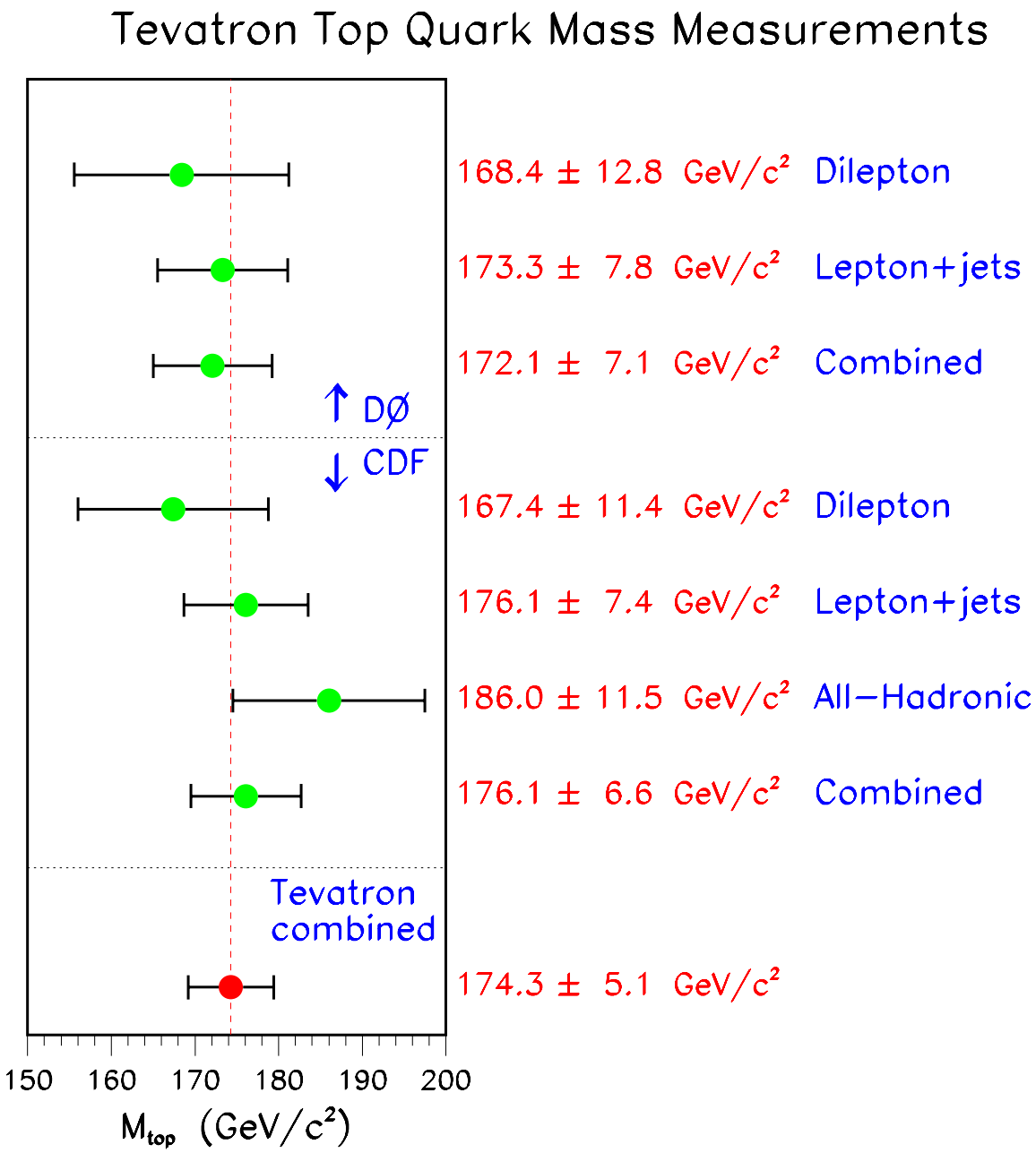


76 events total

$$M_{top} = 176.1 \pm 5.1(stat.) \pm 5.3(syst.)\ \mathrm{GeV}/c^2)$$

Systematic	Δm(GeV/c^2)
Jet energy scale	4.4
Initial and Final state radiation	2.6
Shape of background spectrum	1.3
b-tagging bias	0.4
Parton distribution functions	0.3
Monte Carlo generators	0.1
TOTAL	5.3

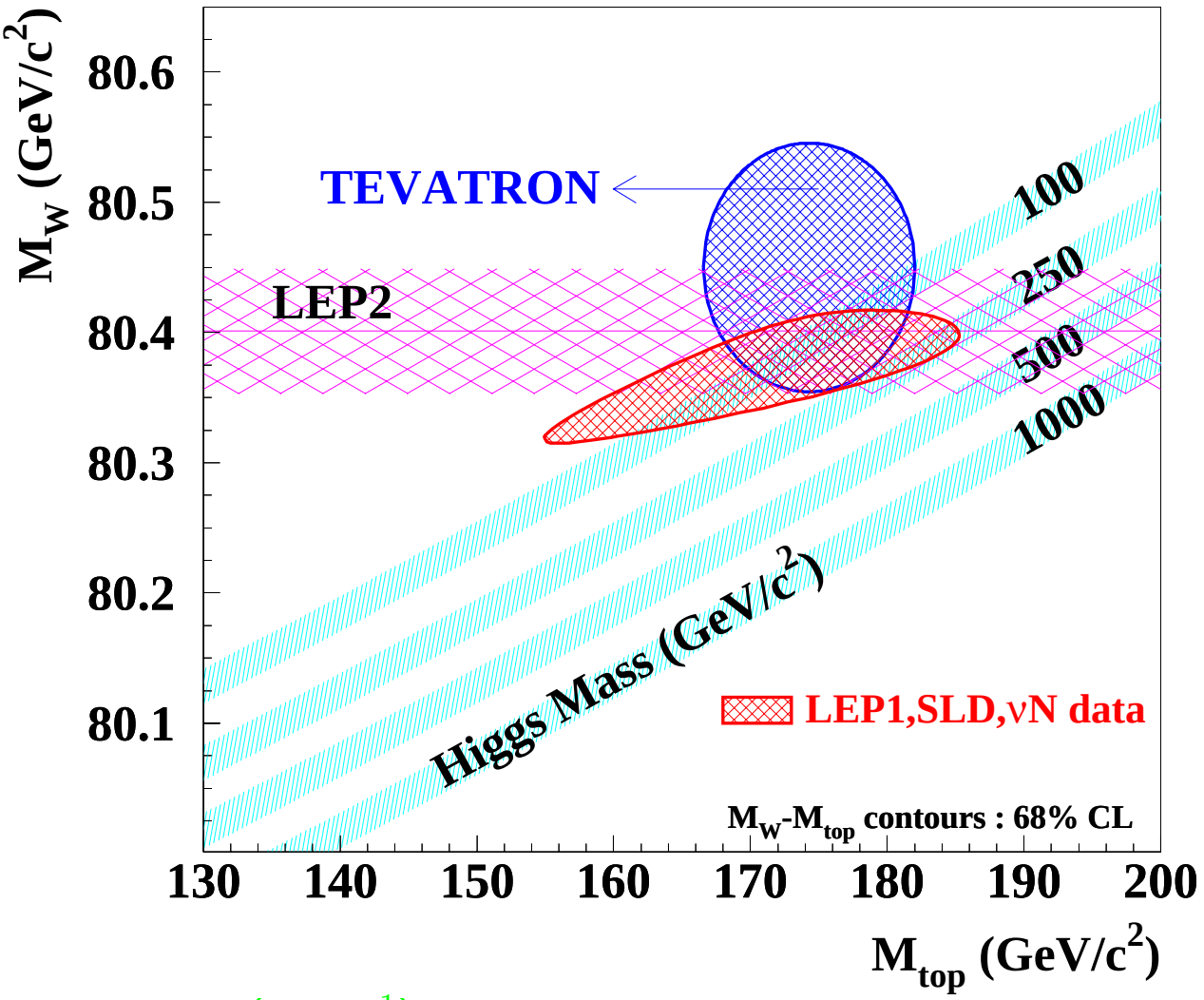
Summary of Run 1 top mass measurements



The top quark has the best measured mass of all quarks ($\sim 3\%$ precision)

Top, W and the Higgs sector

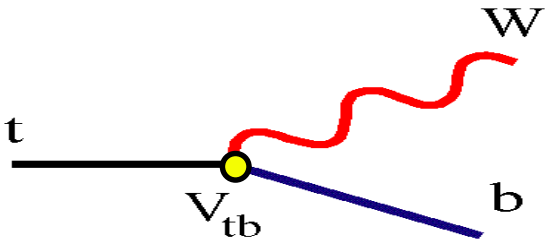
- Measurements of M_W and M_{top} constrain M_H.



- In Run II ($2\ fb^{-1}$) should be able to infer $\delta M_H/M_H \approx 40\%$ at the Tevatron.
- These indirect probes into the Higgs sector, together with the limits from direct searches (currently $M_H <\sim 108$ GeV from LEP), are narrowing the window available to the SM Higgs. (See also CDF combined Higgs limits in session V14)

CDF Measurement of Vtb

- Unitarity (within a 3-generation SM) $V_{tb} \sim 1$.
- CDF has analyzed the *l* + jets and dilepton samples to:
  - measure the ratios of the event numbers with 0,1, and 2 b-tags
  - use them to extract the ratio: $$R_b = \frac{\Gamma(t \to Wb)}{\Gamma(t \to Wq)}$$
- The result is independent of top cross section and W branching ratio.
- Maximum likelihood fit to the data yields:
  $R_b = 0.99 \pm 0.29$ or $R_b > 0.64$ at 95% C.L.
- Assuming three-generations unitarity:



$$R_b = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{td}|^2 + |V_{ts}|^2}$$

CDF preliminary

$|V_{tb}| = 0.99 \pm 0.15$ and $|V_{tb}| > 0.76$ at 95% C.L.

Run 2 Data Sample Sizes

- **Tevatron Upgrade, 1.8 -> 2.0 TeV, 20X more lum.**
- **At 2 TeV, the top cross section is ~40% higher than Run 1**
- **Primary lepton (W->lnu) acceptance increases**
  - ~33% for electrons , ~15% for muons
- **We expect: ~60% more sgl tags, ~200% more dbl tags**
- **Impact on Physics Data Samples ($2fb^{-1}$, 6.8pb ttbar XS)**
  - ~1000 SVX tagged W+>3 Jet Events (34 in Run 1)
  - ~300 SVX double tagged events (8 in Run 1)
  - ~150 Dilepton Events (9 in Run 1)
  - Lepton+jets Mass Sample
    - ~750 events with at least 1 SVX b-tag (15 in Run 1)
    - ~250 events with 2 SVX b-tags (5 in Run 1)
- **For lepton+jet events in the SVX channel our total acceptance will do ble**

Top Physics @ LHC

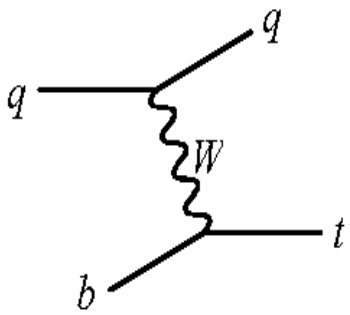
LHC $\sqrt{S}$ = 14 TeV L = 10^34 cm^-2

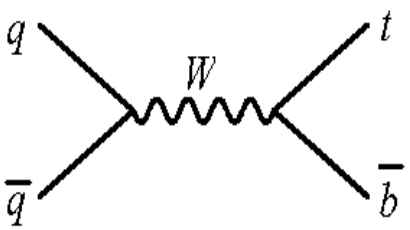
$\sigma(t\bar{t}) \approx$ 800pb $\approx$ 10^8 $t\bar{t}$ pairs/year

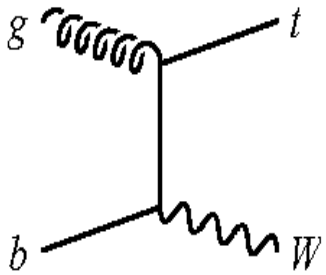
7pb @ $\sqrt{S}$ = 1.8 TeV

- **Single top:** $\sigma \approx 300$ pb (40% of $t\bar{t}$)

Never observed so far!!







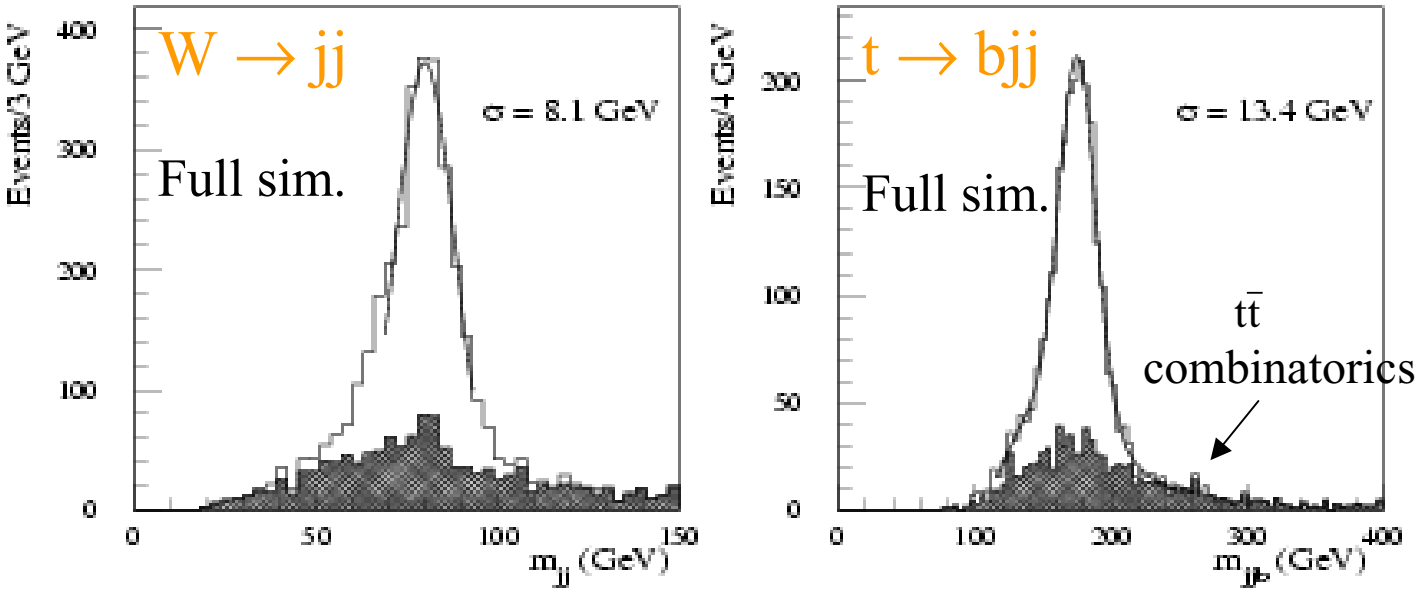
1/3 of $t\bar{t}$

- $t\bar{t}$ production is main background to New Physics (Higgs, SUSY, …)

Measurement of m_{top}

- Year 2005 : $\Delta m_{top} \approx 3$ GeV (Tevatron)
- Best channel: $t\bar{t} \rightarrow Wb \rightarrow l\nu b$; $\rightarrow Wb \rightarrow jjb$ ≈29.6% of all tt evts

top mass determined from hadronic part of decay $m_t = m_{jjb}$
leptonic top used to tag event: hight p_T lepton
large E_T^{miss}



Contribution	Δm_{top} (GeV)
statistics	< 0.07
background	0.2
light-jet scale	0.3
b-jet scale	0.7
b-fragmentation	0.3
ISR	0.3
FSR	1.2
Total	≈1.5 GeV

dominated by knowledge of physics