Top quark and W/Z results from the Tevatron

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Recontres de Moriond

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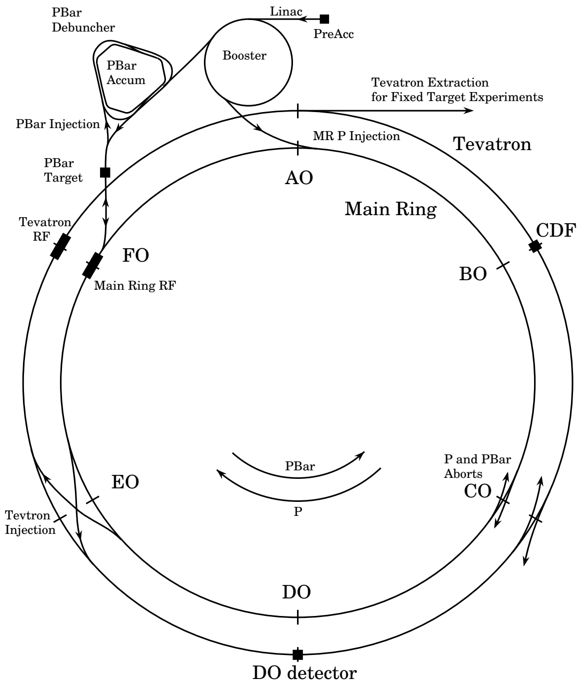
The Tevatron

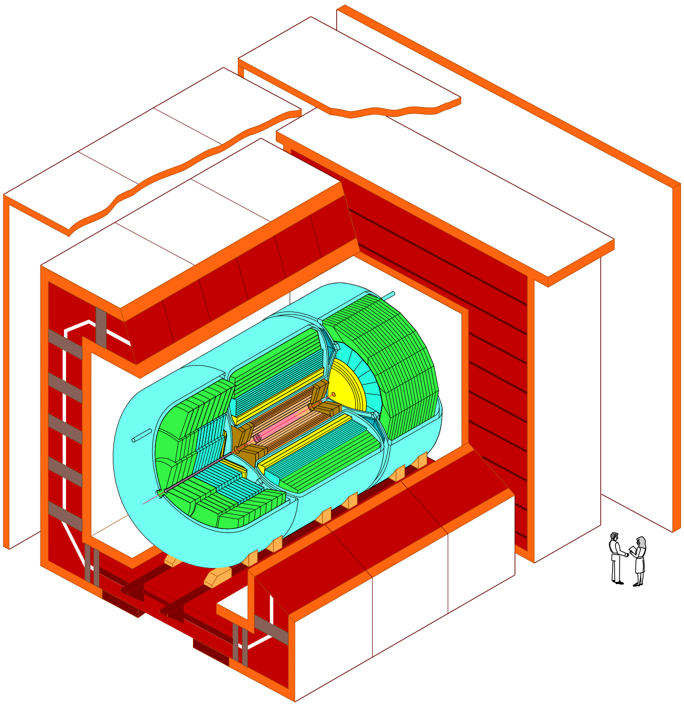


Instantaneous Luminosity: $\mathcal{L} = \dfrac{N_p N_{\bar{p}} B f_0}{4\pi\sigma^2}$

Parameter	Run 1	Run 2
CM energy ($\sqrt{s}$, TeV)	1.80	1.96
N_p (protons/bunch)	2×10^{11}	3×10^{11}
$N_{\bar{p}}$ (antiprotons/bunch)	6×10^{10}	6×10^{10}
B (# bunches in ring)	6	36
f_0 (frequency, KHz)	50	50
Bunch spacing (ns)	3500	396
σ^2 (beam "area", cm^2)	3×10^{-5}	2×10^{-5}
$\langle\mathcal{L}\rangle$ (cm^{-2}s^{-1})	1.6×10^{31}	2×10^{32}
$\int \mathcal{L}dt$ (fb^{-1})	0.125 ± 0.006	2 (2a), 15 (2b)

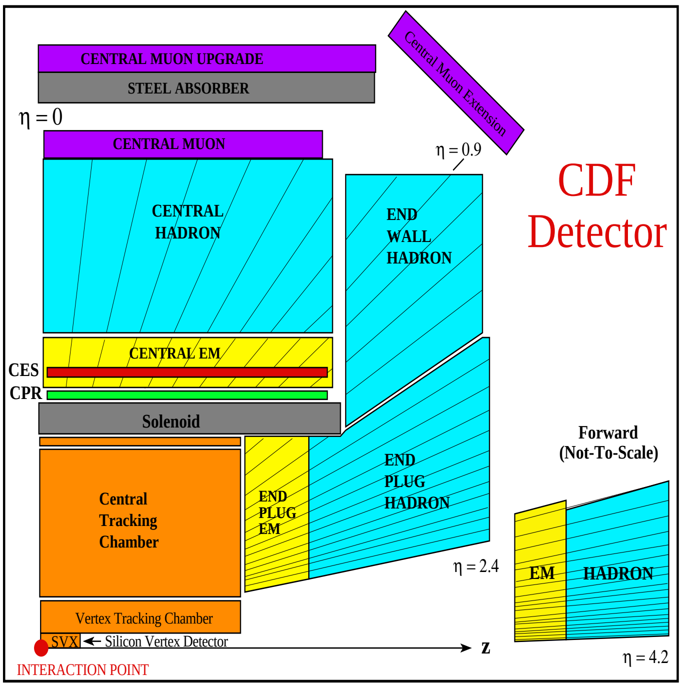
The detectors at the Tevatron

DØ



DØ Detector

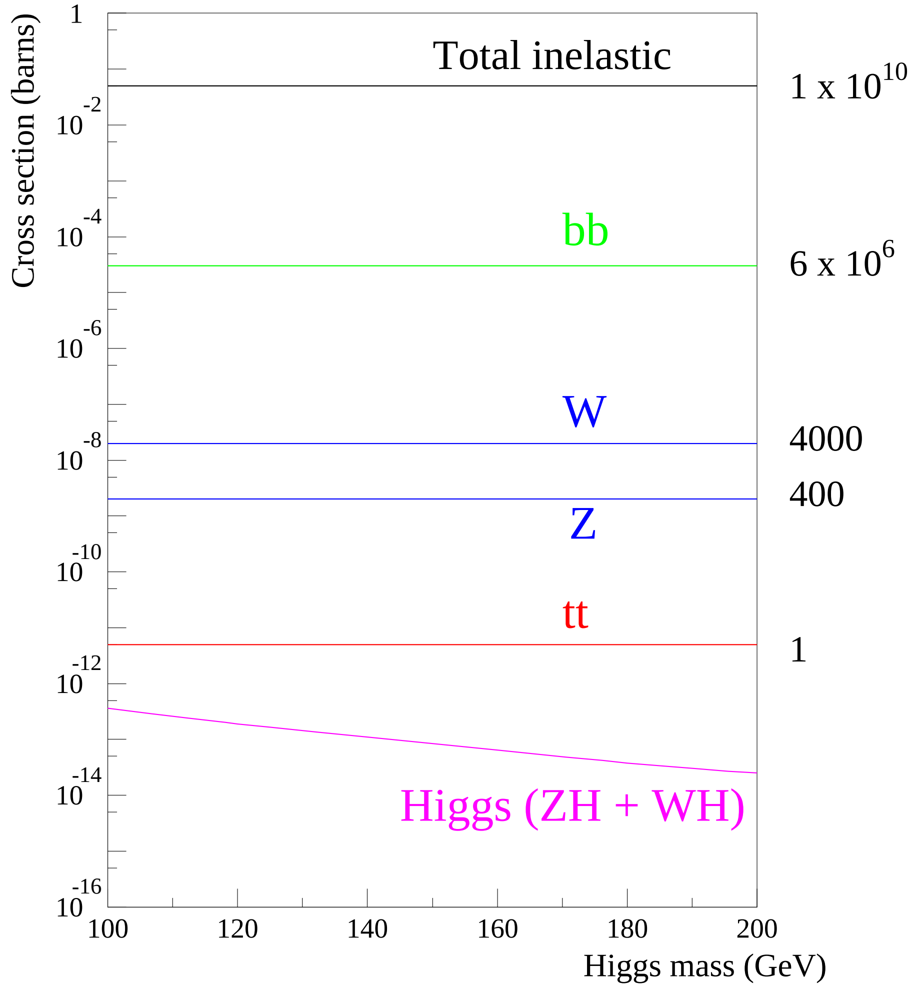
CDF



Motivations to study the top and W/Z

1. Many important tests and calibrations of the SM (EW, QCD) at large mass scales through production rates, kinematic distributions, and decay characteristics.
2. In the SM, m_t and m_W constrain m_H. Hence, precision measurements of these help guide the search for the SM Higgs boson.
3. $\tau_t \sim 10^{-24}$ s $\Rightarrow$ top decays before hadronization $\Rightarrow$ opportunity to study a bare quark, free from long-range effects of the strong interaction.
4. Likely to shed light on the mechanism of mass generation; searches for mass-dependent couplings.
5. Deviations from SM prediction in mass, width, decay characteristics, and kinematical distributions could lead to new physics. Top decay is an excellent place to look for certain particles beyond the SM (e.g., $\tilde{t}$, $H^{\pm}$, ...) believed to be heavier than other SM particles.

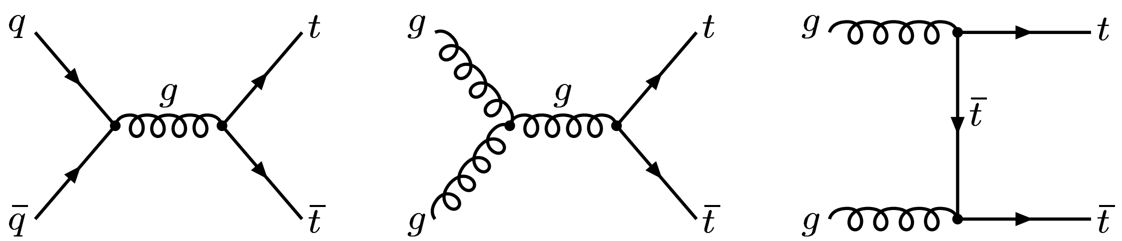
$\sigma(p\bar{p} \rightarrow X)$ at $\sqrt{s} = 1.8$ TeV



- In Run 1, over 5×10^{12} total collisions, one in every 10^{10} producing a $t\bar{t}$ event, one in every 2.5×10^{6} producing a W event.
- When running at maximum luminosity, a $t\bar{t}$ event was produced about every 3 hours, and a W event every 3 seconds.
- But these events must be detected and filtered out from the huge number of other processes.

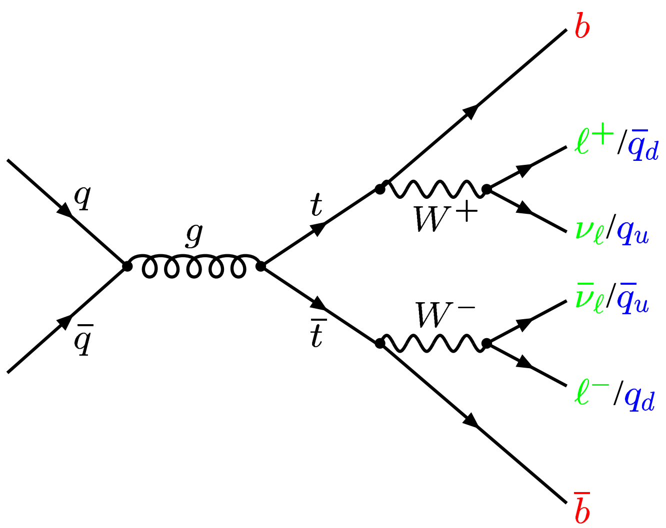
Production and decay of top quarks

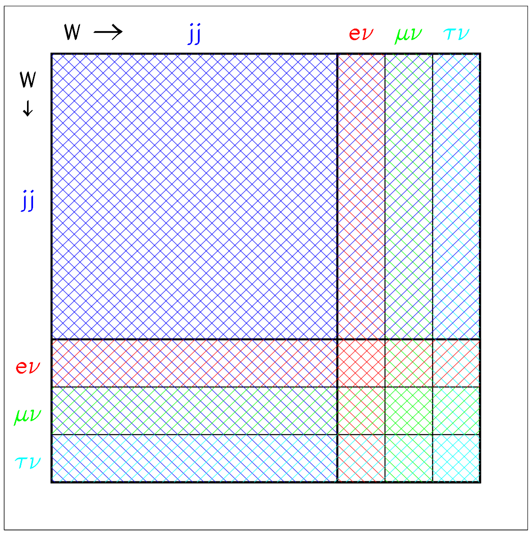
- At the tevatron, top quarks are produced most often in pairs via strong interactions.
  $\sigma(p\bar{p} \to t\bar{t}X) \approx 5.5$ pb @ $\sqrt{s} = 1.8$ TeV.



  Such events have been used in measuring the the mass of the top quark (m_t).

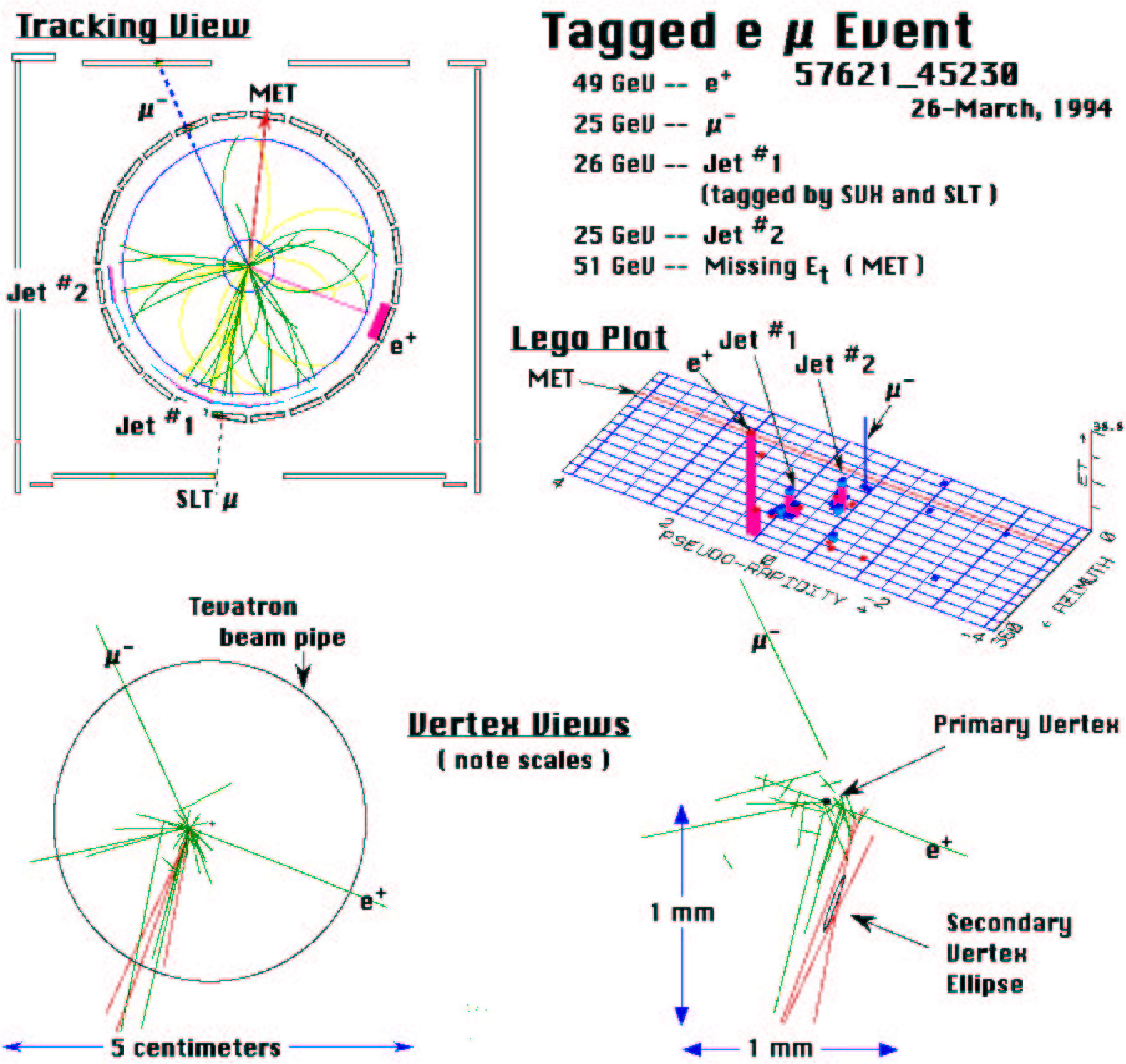
- In the SM, $B(t \to W^+b) \approx 1 \Rightarrow$ final state classified by the decays of the two Ws:



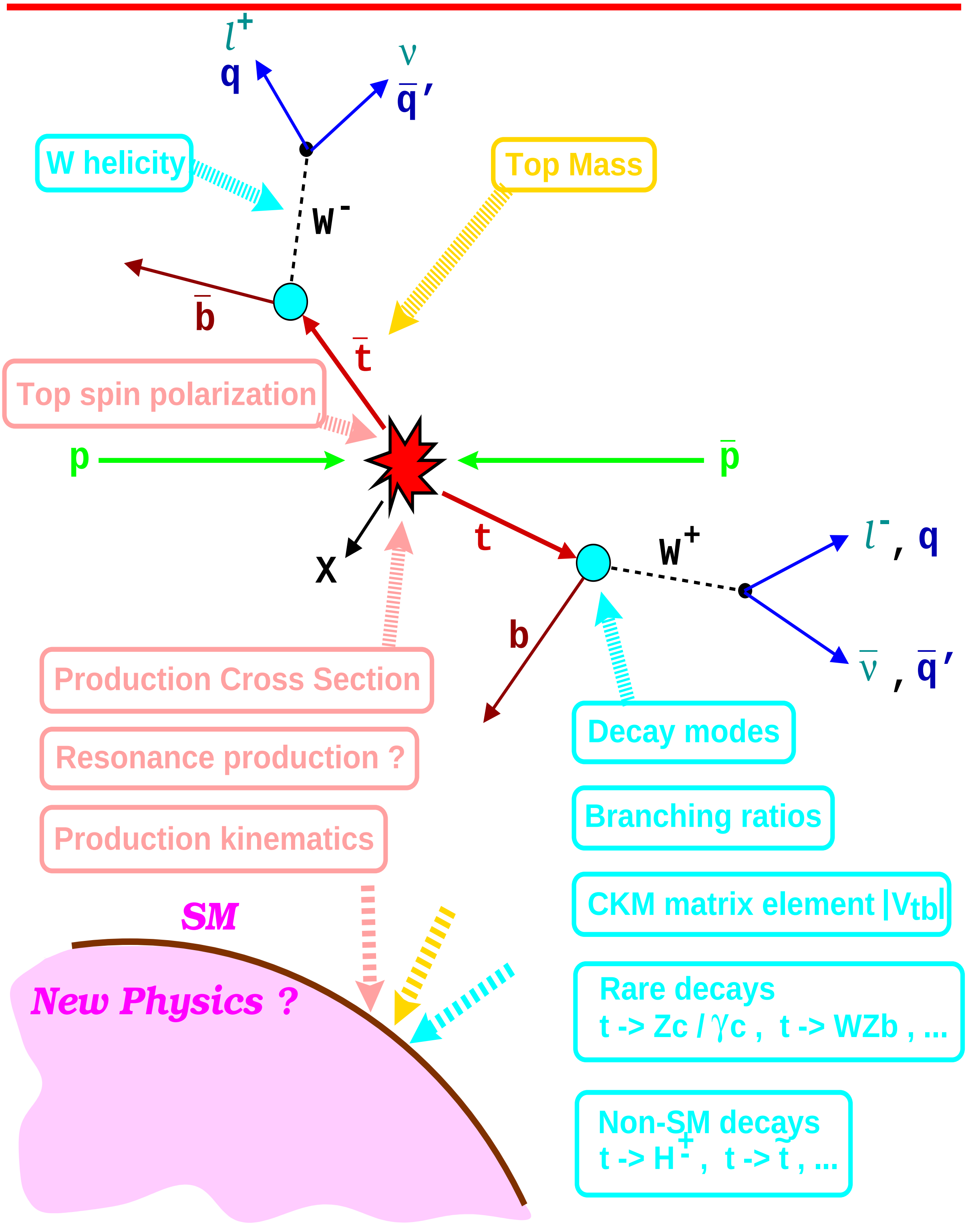


- Identification of b jets improves background suppression.

A dilepton candidate (CDF)



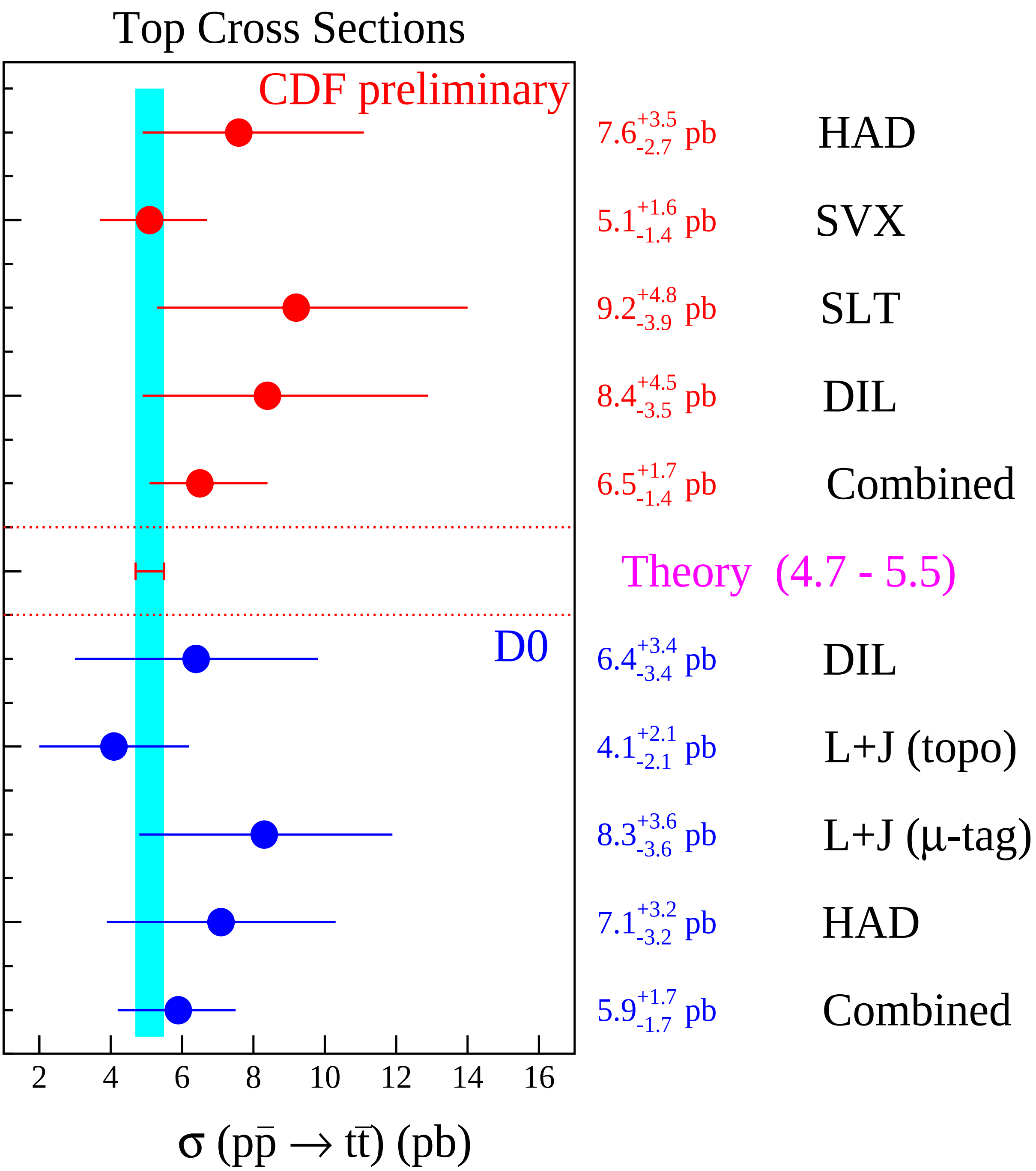
Physics of the top quark



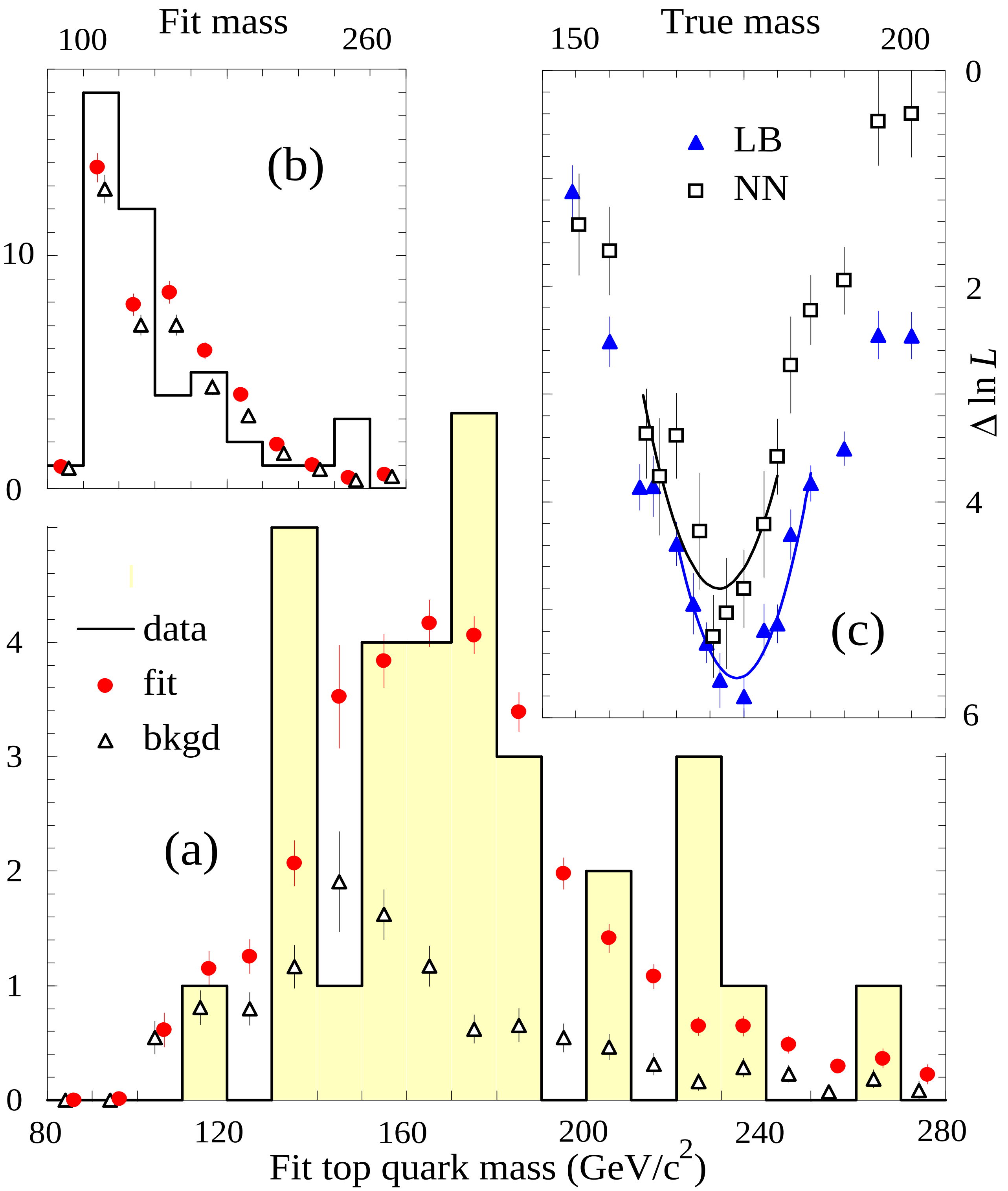
$\sigma(p\bar{p} \rightarrow t\bar{t})$ from Tevatron Run 1

	DØ		CDF	
Channel	N_{obs}	$\langle N_B \rangle$	N_{obs}	$\langle N_B \rangle$
Dilepton	5	1.4 ± 0.4	9	2.4 ± 0.5
Single lepton (SVX b-tag)	-	-	34	9.2 ± 1.5
Single lepton (Lepton b-tag)	11	2.4 ± 0.5	40	22.6 ± 2.8
Single lepton (Topological)	19	8.7 ± 1.7	-	-
All-hadronic	41	24.8 ± 2.4	187	142 ± 12
$e\tau$, $\mu\tau$	-	-	4	~ 2
$e\nu$	4	1.2 ± 0.4	-	-

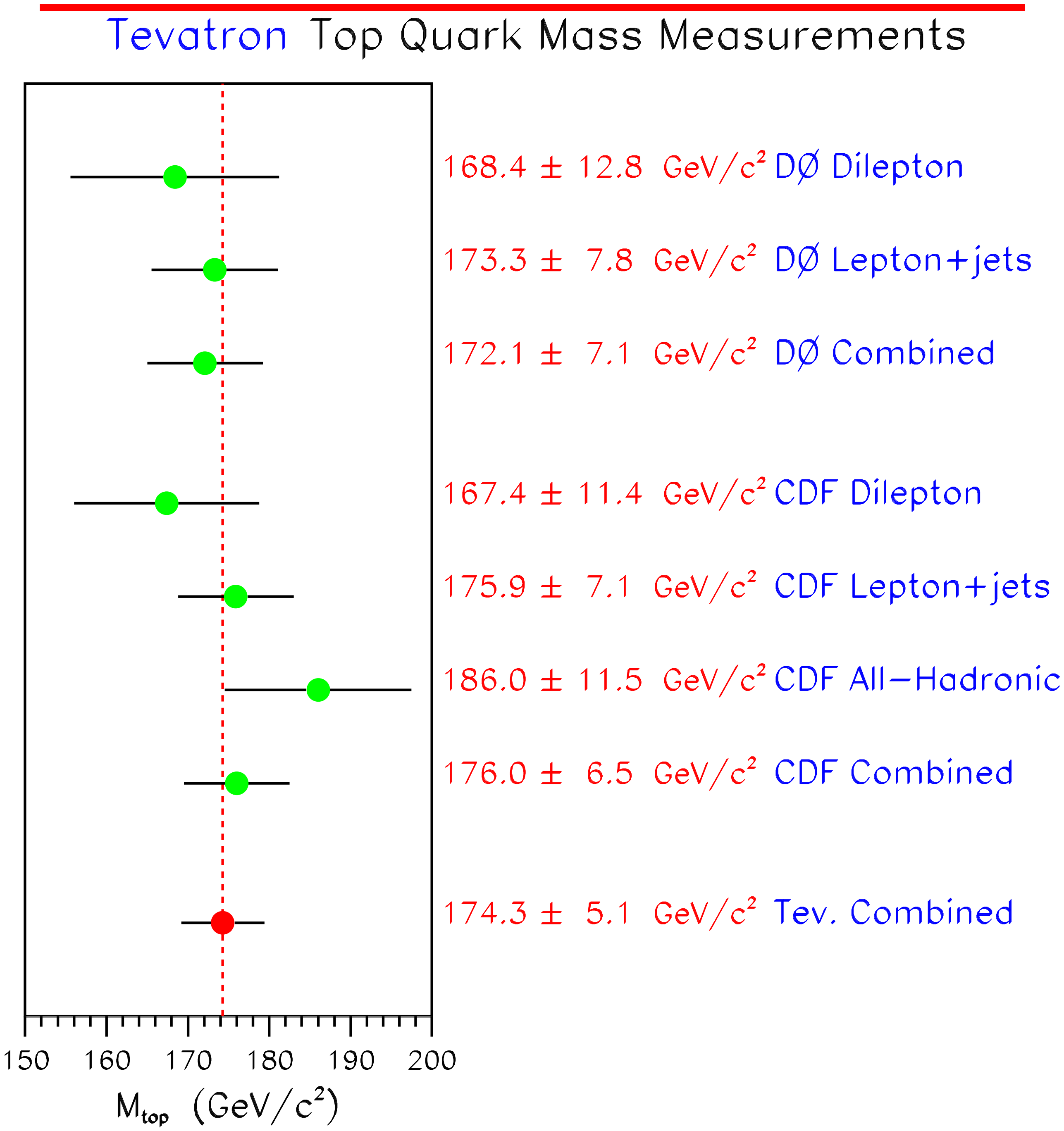
$\sigma(p\bar{p} \rightarrow t\bar{t})$ from Tevatron Run 1



m_t from single lepton events at DØ

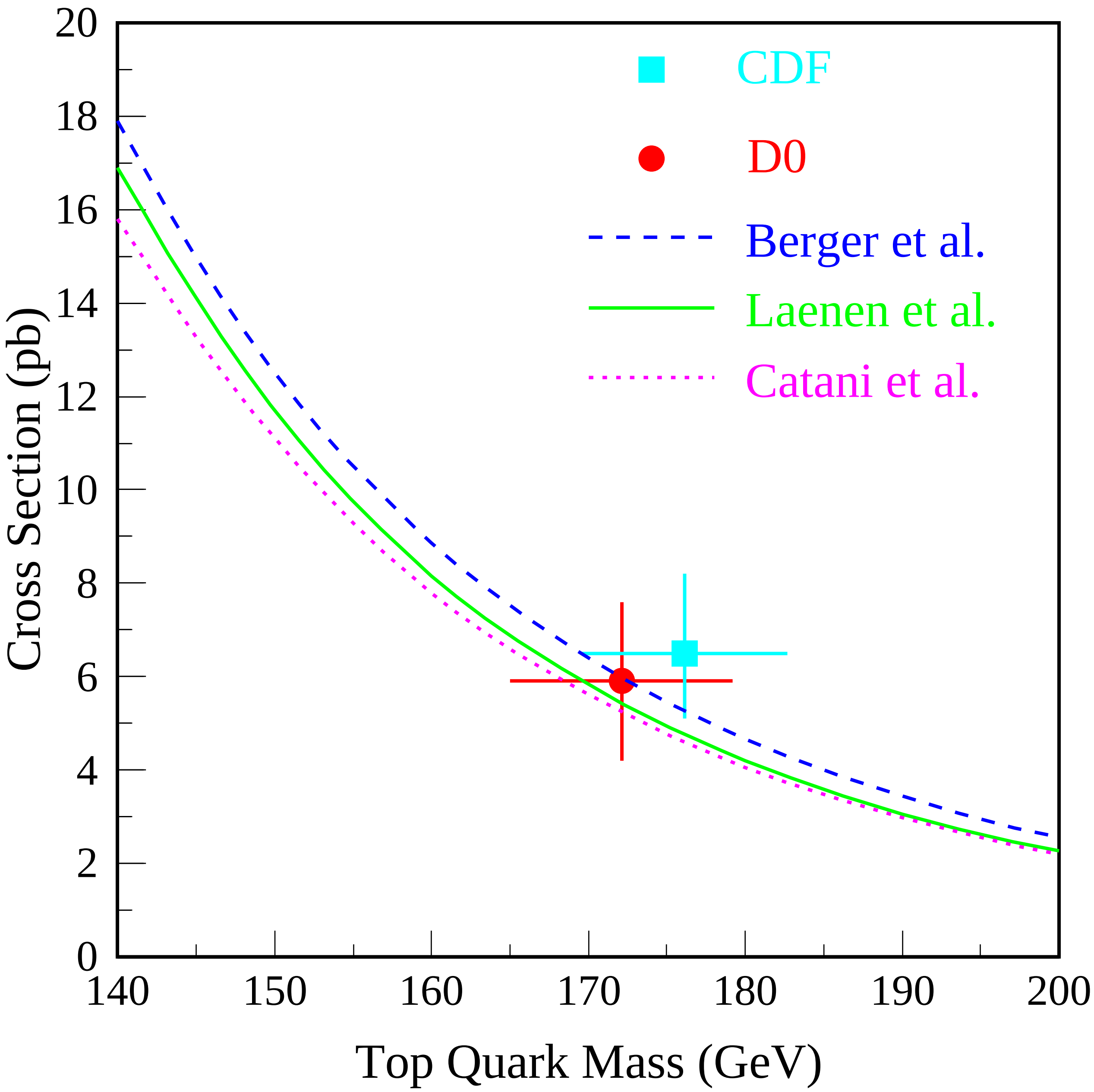


Measurement of m_t from Tevatron Run 1

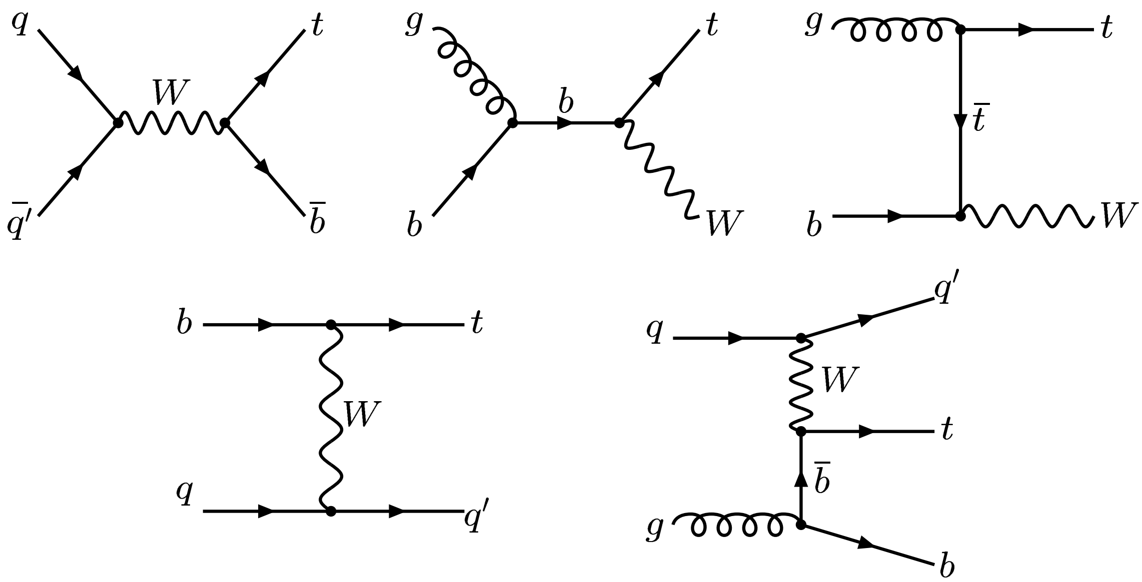


The top quark has the best measured mass of all quarks ($\sim$ 3% precision)

m_t and $\sigma(t\bar{t})$ from Tevatron Run 1



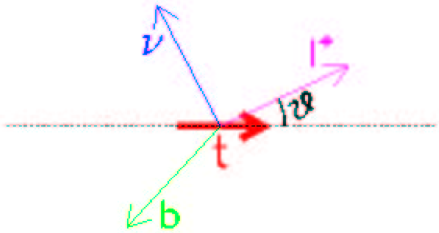
Single top production



- Study of electroweak interactions at a mass scale of m_t.
- Direct measurement of $|V_{tb}|$.
- Significant background for SM Higgs ($p\bar{p} \to VH^0X; V = W^\pm/Z^0, H^0 \to b\bar{b}$).
- SM: $0.73(s) + 1.73(t) \approx 2.4$ pb.
- $\sigma < 13.5$ pb ($s + t$) at 95% CL (CDF)
- $\sigma < 17$ pb (s), $\sigma < 22$ pb (t) at 95% CL (DØ)
- Will be able to observe in Run 2.

Top-antitop spin correlation

- SM $\Rightarrow$ $\tau_t \ll$ top hadronization timescale $\ll t\bar{t}$ spin decorrelation timescale $\Rightarrow$spin correlation information should reflect in angular correlation of decay products.



$$\frac{1}{\Gamma}\frac{d\Gamma}{d(\cos\theta_i)} = \frac{1+\alpha_i\cos\theta_i}{2}$$

particle (i)	α_i for m_t = 175 GeV
e^+ or d	1
ν or u	-0.31
W^+	0.41
b	-0.41

- For $t\bar{t} \to l^+l^-X$ events,

$$\frac{1}{\sigma}\frac{d^2\sigma}{d(\cos\theta_+)d(\cos\theta_-)} = \frac{1+\kappa\cos\theta_+\cos\theta_-}{4}; \quad -1 < \kappa < 1.$$

- SM: $\kappa \approx 0.9$.
- DØ: $\kappa > -0.25$ at 68% C.L.

W helicity in top decay

- SM at leading order:

$$\mathcal{F}_0 \equiv \frac{\Gamma(h_W = 0)}{\Gamma(h_W = 0) + \Gamma(h_W = -1)} = \frac{m_t^2/(2m_W^2)}{1 + m_t^2/(2m_W^2)} \approx 0.70$$

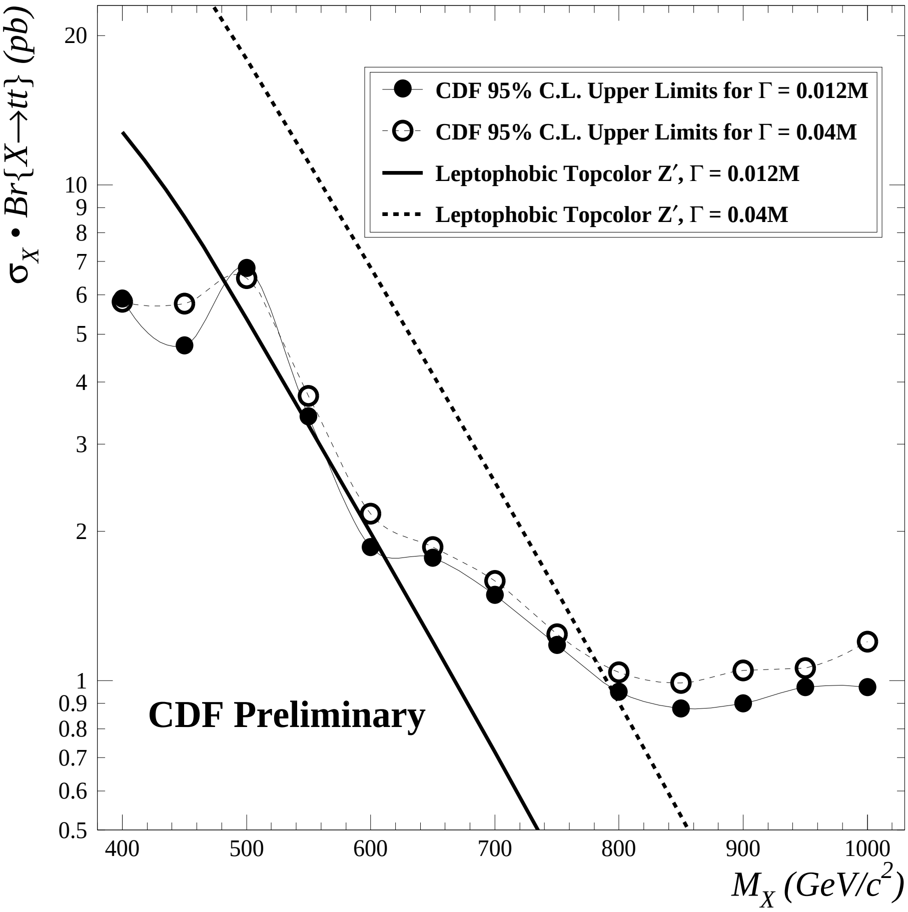
- The massive top quark exposes the longitudinal mode of W: a window to EWSB?
- Charged lepton from a W_- (W_0) tends to move opposite (perpendicular) to the W direction of motion $\Rightarrow W$ polarization is reflected in $p_T(l)$.
- Fits of $h_W = 0$, $h_W = -1$, and $h_W = +1$ Monte Carlo to CDF dilepton and lepton+jets data $\Rightarrow$

$$\mathcal{F}_0(W) = 0.91 \pm 0.37 \pm 0.13$$

$$\mathcal{F}_+(W) = 0.11 \pm 0.15 \pm 0.06$$

$t\bar{t}$ invariant mass and kinematics

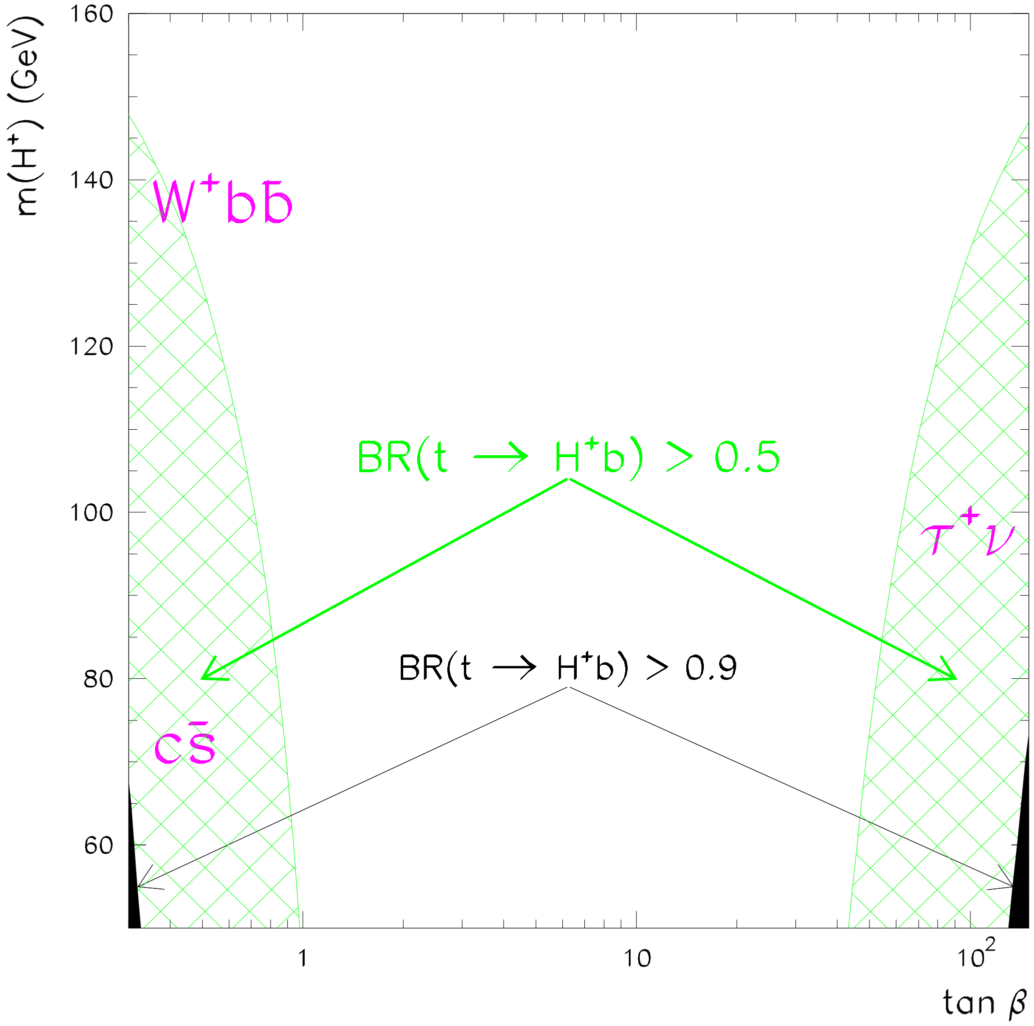
- Important test for the SM (QCD, EW).
- Search for non-SM top quark condensates.



- CDF: $M_{Z'(\to t\bar{t})} > 610$ GeV.
  DØ: results coming soon.
- Both CDF and DØ have examined various kinematic distributions and find all to be in excellent agreement with SM predictions.

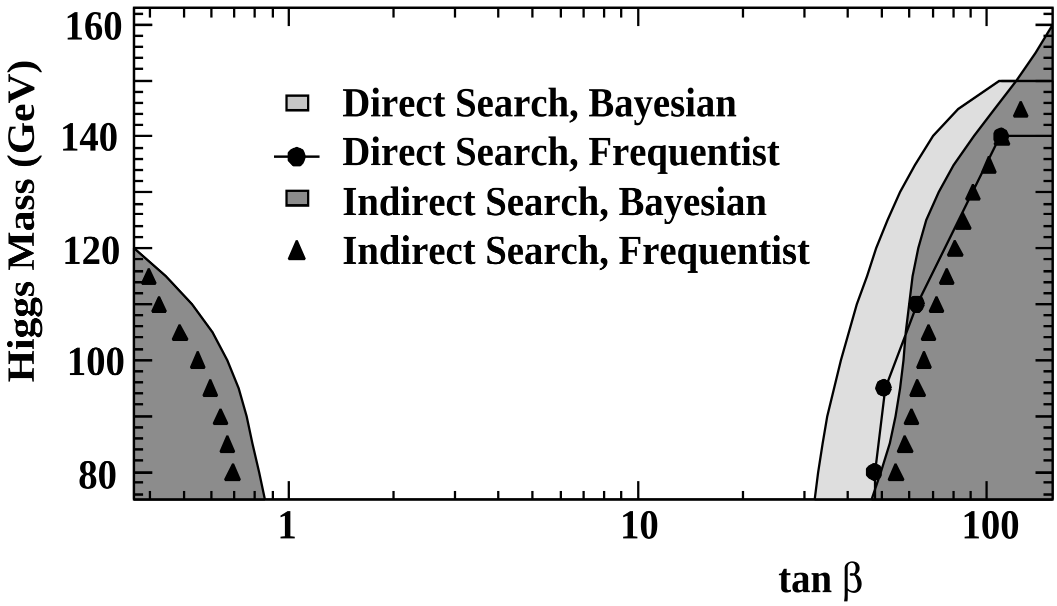
Search for $t \to H^+ b$

- Charged Higgs arise in the simplest extension of the SM Higgs sector to a two-Higgs-doublet model.
- If $m_{H^+} < m_t - m_b$, then $t \to H^+ b$ could compete with $t \to W^+ b$ depending on $[m_{H^+}, \tan\beta]$ (where $\tan\beta$ = ratio of VEV's of the two scalar doublets)

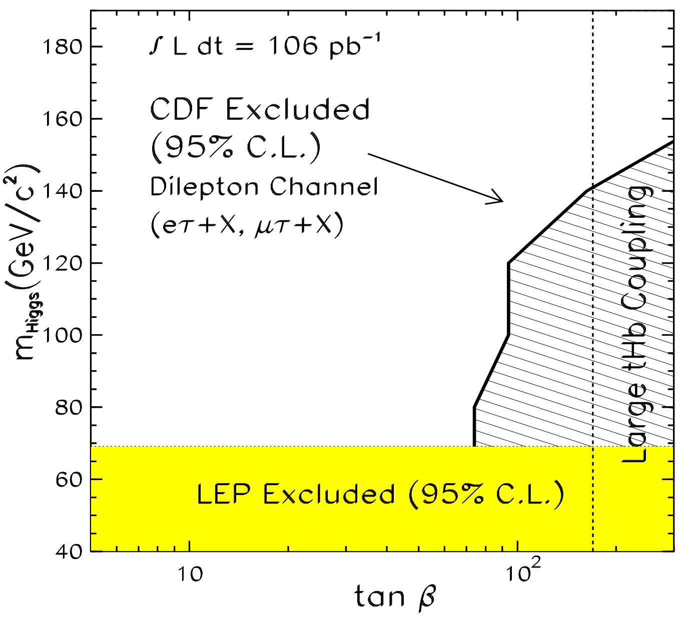


Search for $t \to H^{+}b$: results

Both DØ and CDF have searched for $t \to H^{+}b$ and excluded a significant portion of the previously unexplored region of the $[m_{H^+}, \tan\beta]$ pram-eter space.

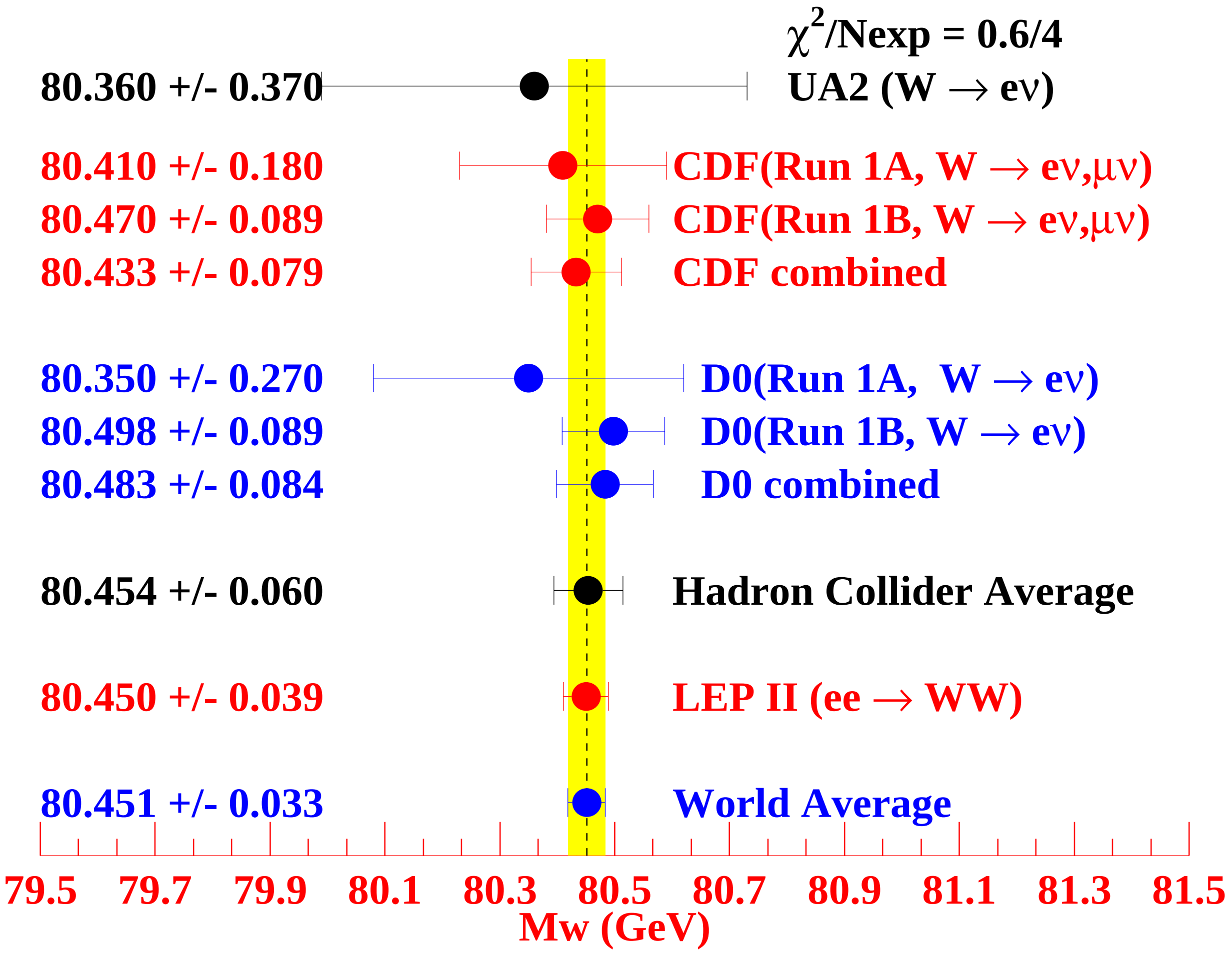


DØ

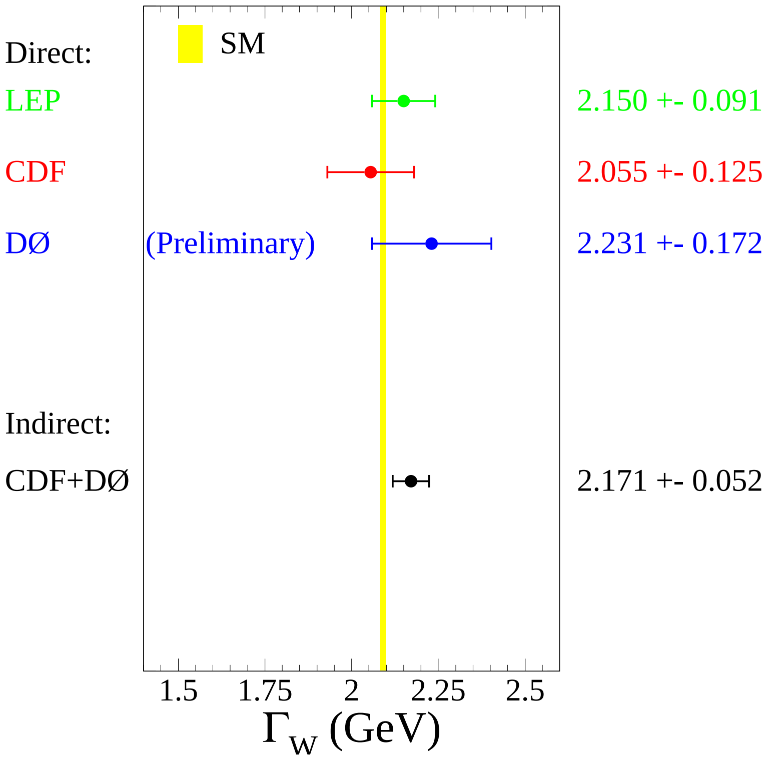


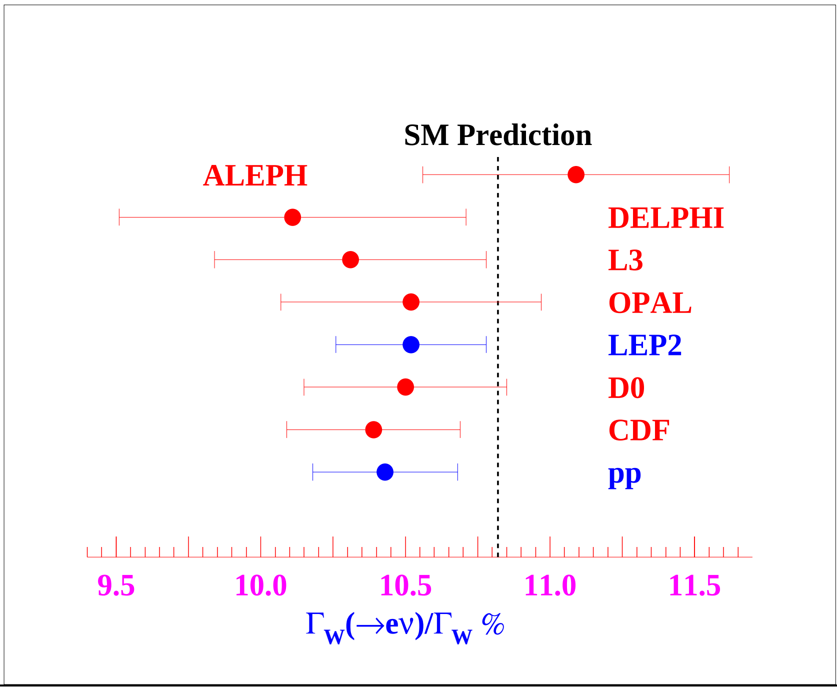
CDF

Measurement of m_W from Tevatron Run 1

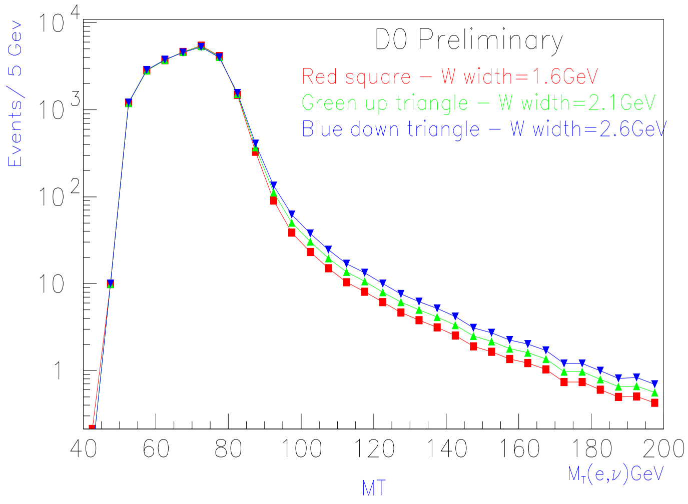


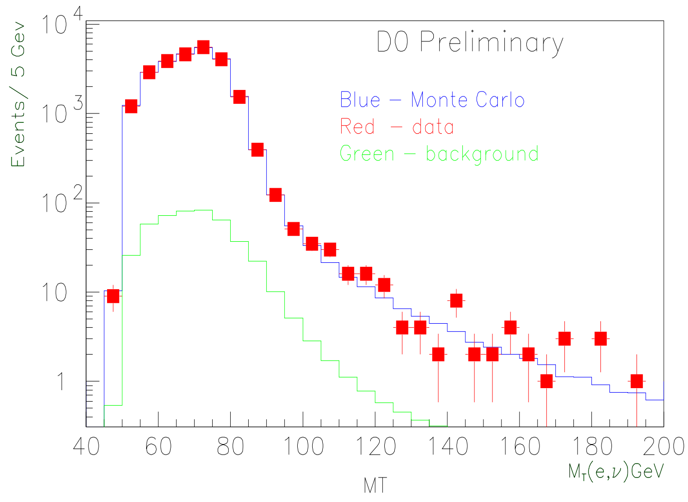
Measurements of $\Gamma(W)$ and $B(W \to e\nu)$

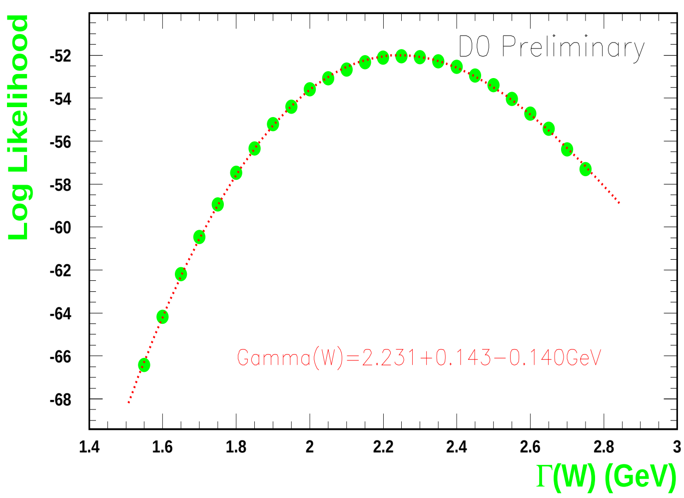




Direct measurement of $\Gamma(W)$ by DØ





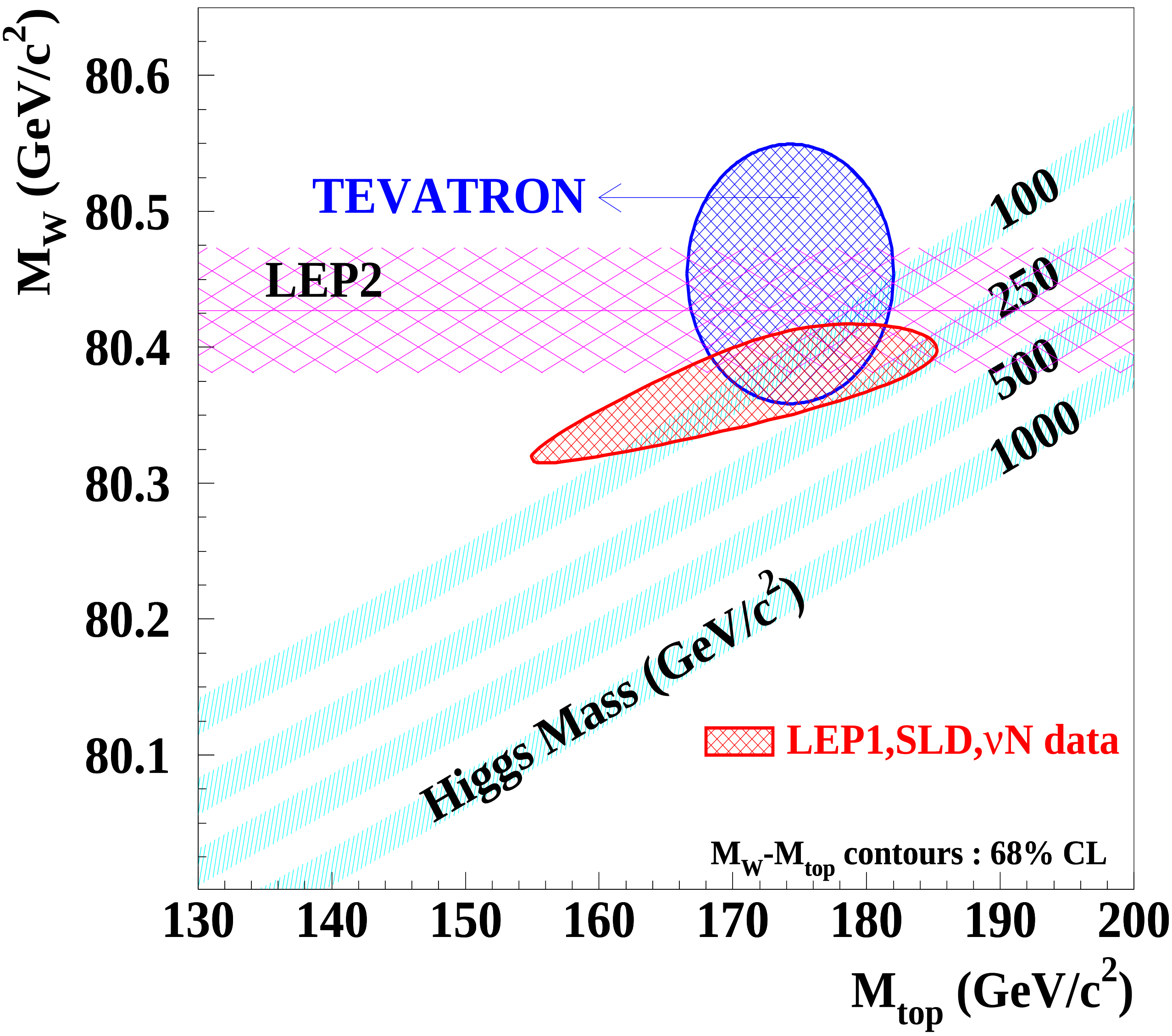


Constraint on m_H from m_t and m_W

Top quark and Higgs boson contribute to the radiative (loop) corrections to m_W:

$$\Delta m_W \propto m_t^2; \qquad \Delta m_W \propto \ln m_H.$$

Thus, m_W and m_t together constrain m_{H^0}.



Summary

- Using $\sim$ 110 pb^{-1} of data collected from Run 1 of the Fermilab Tevatron, both DØ and CDF have studied many aspects of top quark and W/Z physics including measurements of production cross sections and masses, several tests of the SM, and some searches for physics beyond the SM.
- $m_t = 174.3 \pm 5.1$ GeV (3% uncertainty: best of all quarks).
- $m_W = 80.454 \pm 0.060$ GeV (competitive with LEP2).
  $\Gamma_W = 2.171 \pm 0.052$ GeV (best yet).

Summary (contd.)

- All results are consistent with the SM predictions:
  - various top, W/Z kinematic distributions and ratios,
  - single top production,
  - top-antitop spin correlation,
  - W helicity in top decay,
  - $B(t \to W^+b)$, $|V_{tb}|$.
- Searches for rare and non-SM decays of top have revealed no signal, leading to exclusion of previously unexplored regions of parameter space.
  - $t \to H^+b$
  - $Z' \to t\bar{t}$
  - $t \to \gamma q, t \to Zq$

Future Outlook

- Run 2 of the Tevatron, presently in an early stage, holds much potential.
  - Accelerator upgrade $\Rightarrow$

Quantity	Run 1	Run 2 (a+b)
$\sigma(t\bar{t})$	5.5 pb	$\sim$ 7.0 pb
$\int \mathcal{L}dt$	110 pb^{-1}	$\sim$ 15 fb^{-1}

  - Detector upgrades $\Rightarrow$
    - Improved signal acceptance.
    - Superior background rejection.
- Signal enhancement of $\sim$300$\times$ for $t\bar{t}$ and $\sim$1000$\times$ for single top.
- Better background rejection.
- $\Rightarrow$2-3$\times$ reduction in Δm_t, Δm_W.
- All other studies (including those on which first results have been obtained) are dominated by statistical uncertainties. These will benefit greatly from Run 2.

Future Outlook (contd.)

Top quark property	Run 1 measurement	Precision Run 1	Precision Run 2a	Precision Run2b	Precision LHC
Mass	$174.3 \pm 3.3 \pm 3.9$ GeV	2.9%	1.2%	1.0%	
$\sigma(t\bar{t})$ $\sigma(t\bar{t})$	$6.5^{+1.7}_{-1.4}$ pb (CDF) 5.9 ± 1.7 pb (DØ)	25%	10%	5%	5%
$F_0(W)$ $F_+(W)$	$0.91 \pm 0.37 \pm 0.13$ $0.11 \pm 0.15 \pm 0.06$	0.4 0.15	0.09 0.03	0.04 0.01	0.01 0.003
$R \equiv \frac{B(t \to W^+ b)}{B(t \to W q)}$	$0.94^{+0.31}_{-0.24}$ (3-gen.) > 0.61 at 90% C.L.	30%	4.5%	0.8 %	0.2%
$\|V_{tb}\|$	$0.96^{+0.16}_{-0.12}$ (3-gen.) > 0.051 at 90% C.L.	> 0.05	> 0.25	> 0.50	> 0.90
σ(single top) $\Gamma(tWb)$ $\|V_{tb}\|$	< 13.5 pb – –	– – –	20% 25% 12%	8 % 10 % 5 %	5% 10 % 5 %
$B(t \to \gamma q)$ $B(t \to Zq)$	< 0.03 (95% C.L.) < 0.32 (95% C.L.)	< 0.03 < 0.3	? < 0.02	? ?	? ?