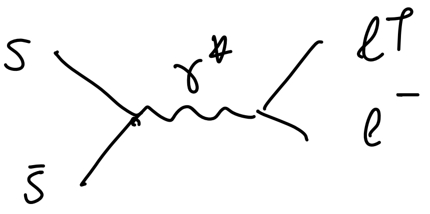


$P_\phi = 0$ ϕ rest frame.

$e^+ \longleftarrow \bullet \longrightarrow e^-$

$\Gamma_\phi = 4$ MeV $\qquad \Gamma(\phi \to ee) \sim 1$ keV

$\Gamma_{tot} = \Sigma_i \Gamma_i \qquad \Gamma_\phi = \underbrace{\Gamma_{had}}_{999} + \underbrace{\Gamma_{e^+e^-}}_{1} + \underbrace{\Gamma_{\mu^+\mu^-}}_{1}$

1000

inspirehep.net database of particle physics papers

DAΦNE e^+e^- machine @ Frascati

$e^+e^- \longrightarrow \phi \longrightarrow$

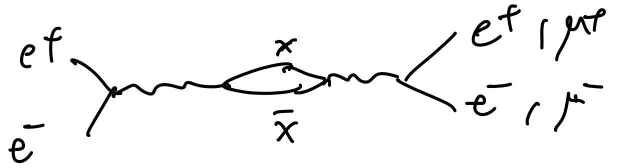
$\sqrt{s} = m_\phi$

---

u, d, s, c quarks. $\qquad e, \mu, \tau, \nu$ leptons.

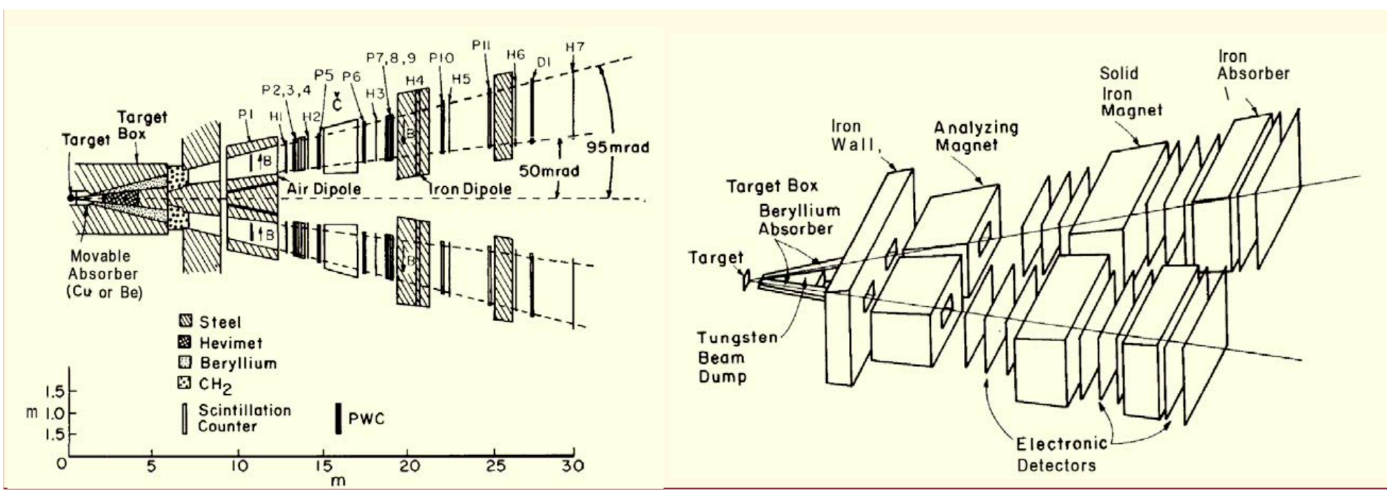
1977 @ Fermilab. Leon Ledderman Nobel Prize 1988

proton + Cu(Pt) $\longrightarrow (\mu^+\mu^+) + X$



look for resonances in $m_{\mu\mu}$

$Y = (x\bar{x})$ resonance $\Rightarrow \sqrt{s} \geq m_Y$



$p +$ target $\rightarrow \mu^+\mu^- + X(\pi^\pm, \pi^0, K^\pm, K^0, p, \bar{p} - -)$

$P \simeq 3$ GeV $\Rightarrow$ $E_\pi, E_\mu = (m^2 + p^2)$

↳ exp. meas.

↳ make hypothesis

P measured through Lorentz: $p = q\,B\,R$

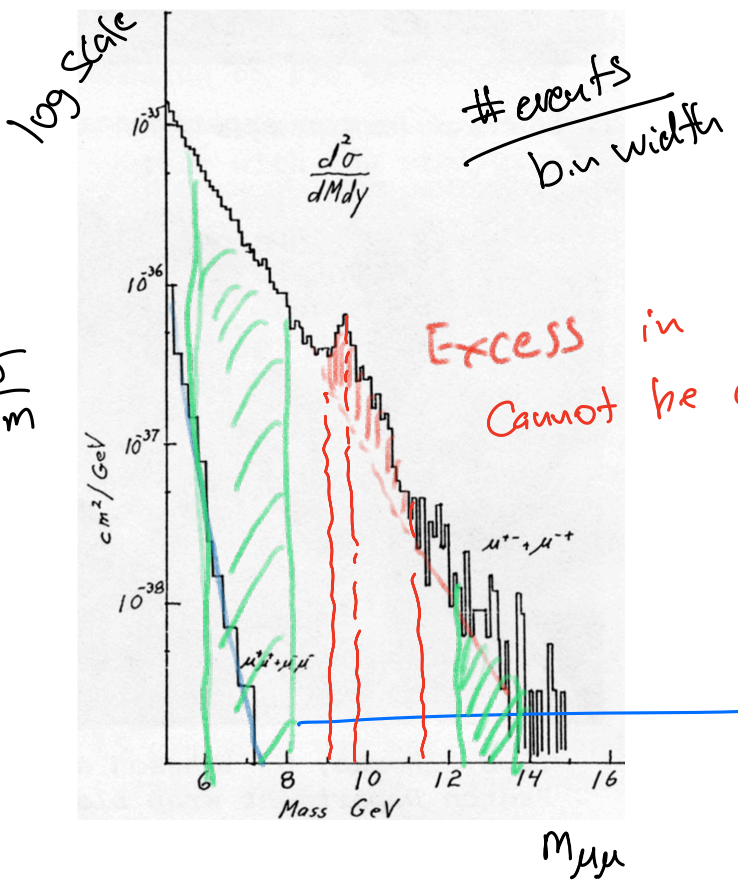
[GeV] [T] [m]

↳ q/e

$m_\pi = 140$ MeV

$m_\mu = 106$ MeV $\Rightarrow$ $v_\pi \simeq v_\mu$

Absorbers $\Rightarrow$ remove most of hadrons/pions



Excess in $\mu^+\mu^-$

Cannot be explained by known particles.

proton + target $\rightarrow$ $\mu^+\mu^+ + X$

$\mu^-\mu^- + X$

In absence of a real particle $\gamma^{*} \xrightarrow{++} \mu^+\mu^+$

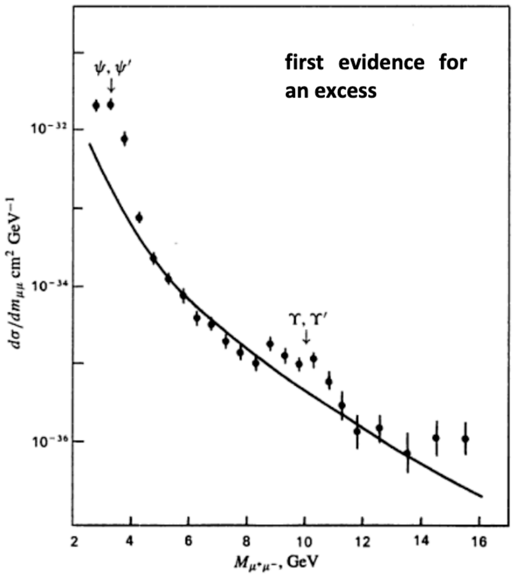
$\Rightarrow$ estimate of background.

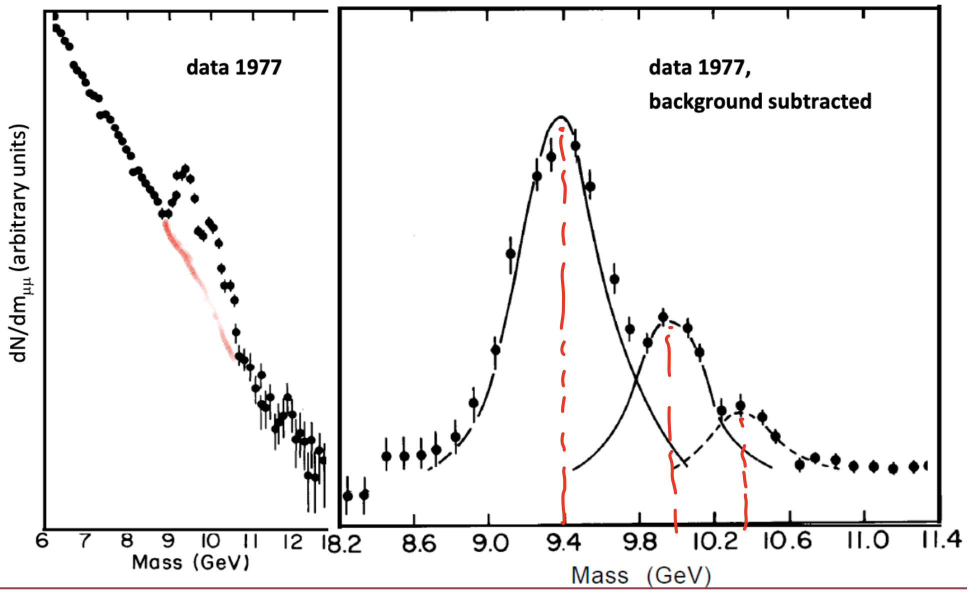
$A\,e^{-\alpha m}$ + Signal hypothesis.

↳ can be determined outside the excess.

$\Rightarrow$ produce Background-subtracted distribution

$\hat{N}_s = N_{obs} - N_B^{est}$



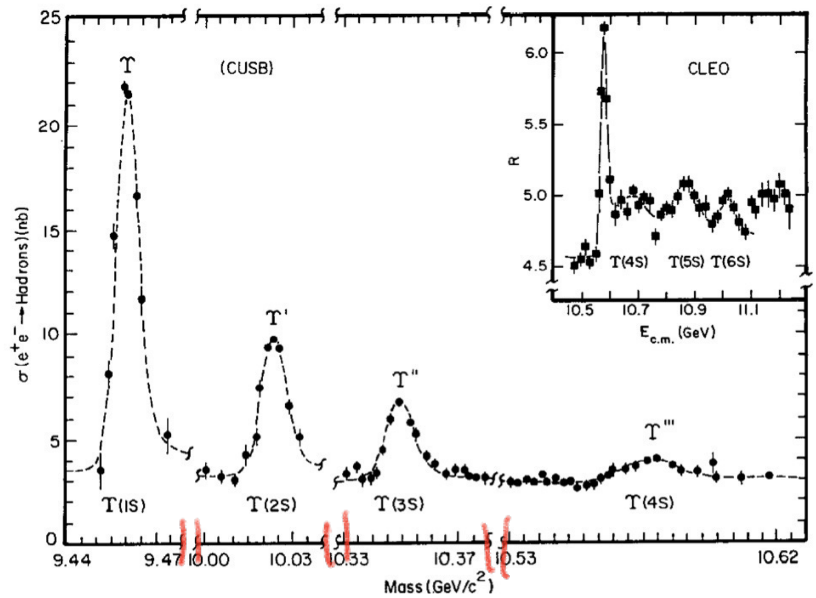


$$F(x) = A e^{-\alpha x} + B e^{-(x-x_0)^2/2\sigma_1^2} + C e^{-(x-x_1)^2/2\sigma_2^2} + D e^{-(x-x_2)^2/2\sigma_3^2}$$

Bottomonium ($b\bar{b}$) bound state Υ Upsilon

To study this resonance $\Rightarrow$ $e^+e^- \longrightarrow$ had, $\mu^+\mu^-$, e^+e^-

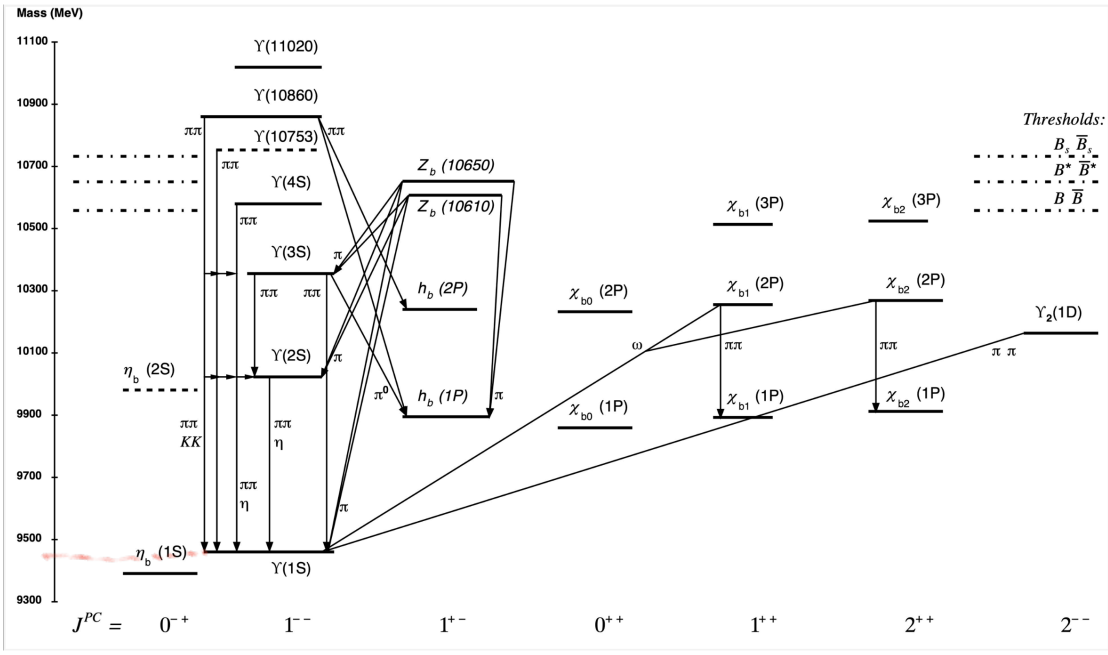
$\sqrt{s} = 9.4$ GeV



e^+e^- machine at Cornell university CLEO exp.

PEP-II machine at SLAC BaBar Detector.

KEK machine Japan. BELLE- experiment



$b\bar{b}$ Spectroscopy

(PDG)

Γ $\Upsilon(1S)$: 52 keV

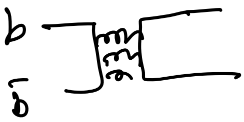
$\Upsilon(4S)$: 20.5 MeV

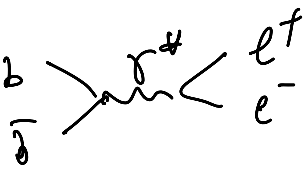
Υ(1S) DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_1	$\tau^+\tau^-$	(2.60 ±0.10) %	
Γ_2	e^+e^-	(2.39 ±0.08) %	
Γ_3	$\mu^+\mu^-$	(2.48 ±0.04) %	
	Hadronic decays		
Γ_4	ggg	(81.7 ±0.7) %	
Γ_5	γgg	(2.2 ±0.6) %	
Γ_6	$\eta'(958)$ anything	(2.94 ±0.24) %	
Γ_7	$J/\psi(1S)$ anything	(5.4 ±0.4) $\times 10^{-4}$	S=1.4
Γ_8	$J/\psi(1S)\eta_c$	< 2.2 $\times 10^{-6}$	CL=90%
Γ_9	$J/\psi(1S)\chi_{c0}$	< 3.4 $\times 10^{-6}$	CL=90%
Γ_{10}	$J/\psi(1S)\chi_{c1}$	(3.9 ±1.2) $\times 10^{-6}$	
Γ_{11}	$J/\psi(1S)\chi_{c2}$	< 1.4 $\times 10^{-6}$	CL=90%

Υ(4S) DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Confidence level
Γ_1	$B\bar{B}$	> 96 %	95%
Γ_2	B^+B^-	(51.4 ±0.6) %	
Γ_3	D_s^+ anything + c.c.	(17.8 ±2.6) %	
Γ_4	$B^0\bar{B}^0$	(48.6 ±0.6) %	
Γ_5	$J/\psi K_S^0 + (J/\psi,\ \eta_c)K_S^0$	< 4 $\times 10^{-7}$	90%
Γ_6	non-$B\bar{B}$	< 4 %	95%
Γ_7	e^+e^-	(1.57±0.08) $\times 10^{-5}$	
Γ_8	$\rho^+\rho^-$	< 5.7 $\times 10^{-6}$	90%
Γ_9	$K^*(892)^0\bar{K}^0$	< 2.0 $\times 10^{-6}$	90%
Γ_{10}	$J/\psi(1S)$ anything	< 1.9 $\times 10^{-4}$	95%
Γ_{11}	D^{*+} anything + c.c.	< 7.4 %	90%
Γ_{12}	ϕ anything	(7.1 ±0.6) %	
Γ_{13}	$\phi\eta$	< 1.8 $\times 10^{-6}$	90%
Γ_{14}	$\phi\eta'$	< 4.3 $\times 10^{-6}$	90%
Γ_{15}	$\rho\eta$	< 1.3 $\times 10^{-6}$	90%





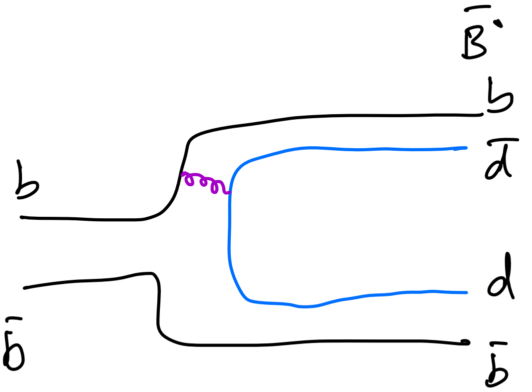
B mesons: $b\bar{q}$ $q = u, d$ B^0, B^+ Discovered 1979

B_s mesons $b\bar{s}$

B_c mesons $b\bar{c}$

$m_B = 5.279$ GeV

$m_{\Upsilon(1S)} = 9.4$ GeV $< 2 \times m_B$



Not possible kinematically.

$\Rightarrow$ only $\Upsilon(1S) \to ggg$ $\Rightarrow$ small decay width.

m $\Upsilon(2S), \Upsilon(3S) < 2m_B \Rightarrow \Gamma \sim 20-30$ keV.

$m(\Upsilon(4S)) = 10.580$ GeV $\gtrsim 2B_D$.

$$\Rightarrow \Upsilon(4S) \to B^+B^-$$
$$\qquad\quad \to B^0\bar{B}^0$$

$e^+e^- \to \Upsilon(4S) \to B\bar{B}$ B-Factory

$2 \times m_B = 10.558$

$$\overset{\Upsilon(4S)}{B \leftarrow \bullet \rightarrow \bar{B}}$$

$Q = m(\Upsilon(4S)) - 2m_B = 242$ MeV

$\Upsilon(4S) \to B^+B^- / B^0\bar{B}^0 \Rightarrow$ Q value $\Rightarrow$ momentum of B mesons in $\Upsilon(4S)$ frame

$\Rightarrow P \simeq 200$ MeV.

$m = 5.279$ GeV. $\beta\gamma = \frac{P}{m} = \frac{200}{5279} \ll 1$.

$\beta = \frac{P}{E} = \frac{200 \text{ MeV}}{\sqrt{200^2 + 5279^2}}$ B mesons almost at rest.

Top Quark

$e^+e^- \to t\bar{t} \to$ final states $\sqrt{s} \geqslant 2m_t$

$p + \bar{p} \to t + \bar{t} + X$
$p + p \to t + \bar{t} + X$ } hadronic machines.

no sign of top in $p\bar{p}$ collisions. ($Sp\bar{p}S$ and Fermilab)

LEP: Large Electron Positron Collider (CERN).

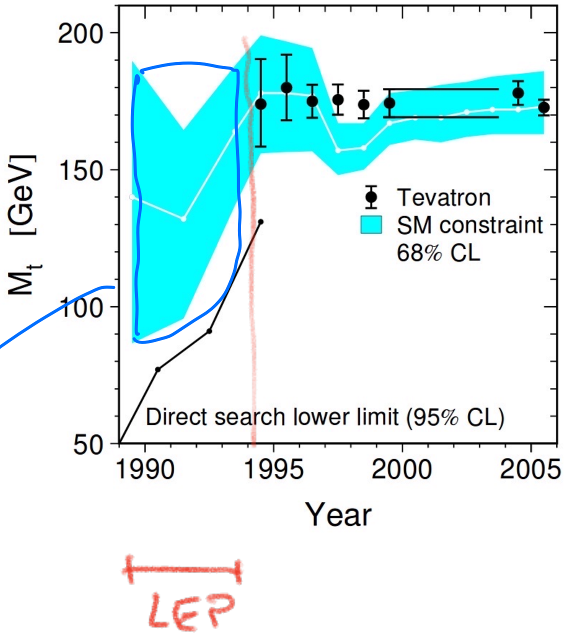
1989 → 2001 $\sqrt{s}$: 90 → 100 GeV

no sign of top.

Best way to discover top through hadronic machines.

In weak interactions: m_{top}, m_W, m_Z are related.

Study of W, Z bosons $\Rightarrow$ provide constraints on m_t



indirect constraint on top mass from LEP (e^+e^- machine)

top discovery at Tevatron at Fermilab 1994

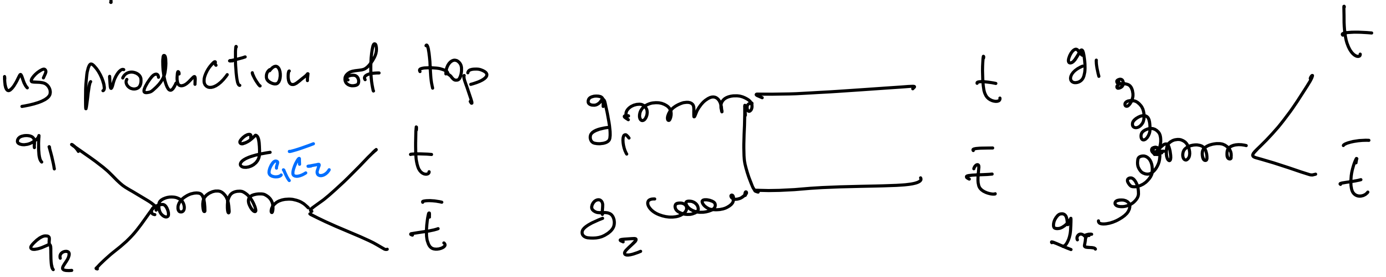
$p\bar{p}$ collider $\sqrt{s} = 1.96$ TeV

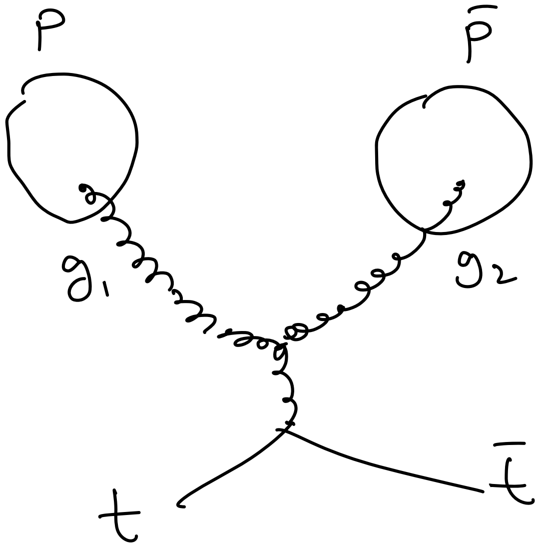
$P_1 = x_1 P$ $\qquad$ $P_2 = -x_2 P$

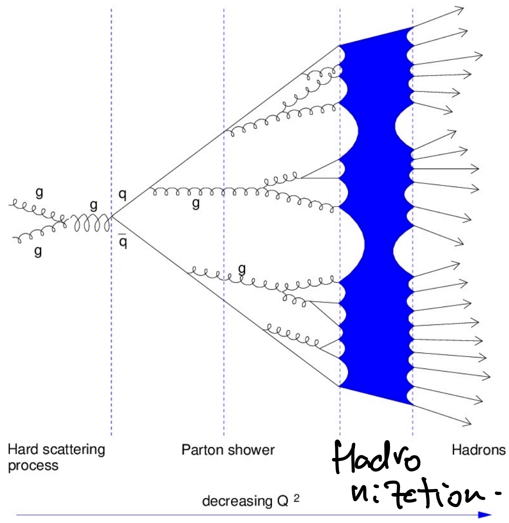
x_1, x_2 come from Parton density functions.

$$p + \bar{p} \longrightarrow t + \bar{t} + X$$

Strong production of top







No $t\bar{t}$ bound state (toponium)

top mass : 170 GeV $\qquad t \longrightarrow a\,b.$

width Γ : 2 GeV

Decay width for $t \to a+b \quad \alpha \quad G_F^2\, m_t^3$ (weak decay)

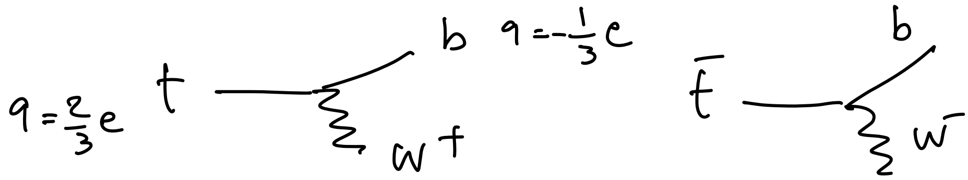
$G_F = 1.16 \times 10^{-5}\ \text{GeV}^{-2}$

$\tau = \frac{1}{\Gamma} = 10^{-25}$ sec. from weak decay.

weak decay faster than strong interaction.

$\Rightarrow$ not enough time to form $t\bar{t}$ bound state

$M_W = 80$ GeV $\quad m_Z = 90$ GeV $\qquad t = q = +\frac{2}{3}$



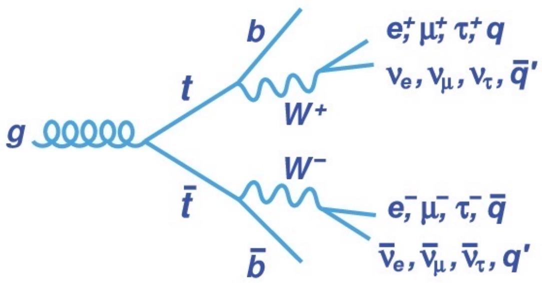
$p + \bar{p} \longrightarrow t + \bar{t}$

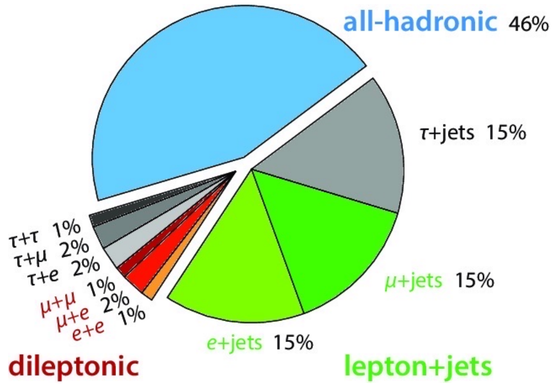
$t \longrightarrow b + W^+$

$\bar{t} \longrightarrow b + W^-$

W^+ DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\ell^+\nu$	[b]	(10.86 ± 0.09) %		–
$e^+\nu$		(10.71 ± 0.16) %		40189
$\mu^+\nu$		(10.63 ± 0.15) %		40189
$\tau^+\nu$		(11.38 ± 0.21) %		40170
hadrons		(67.41 ± 0.27) %		–

$p + \bar{p} \to t + \bar{t} \longrightarrow b\,\bar{b}\,e^+ e^-\,\nu_e\,\bar{\nu}_e$



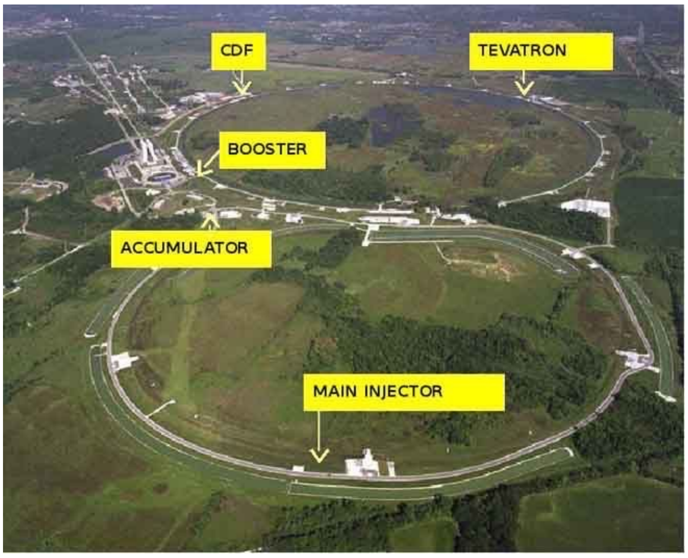


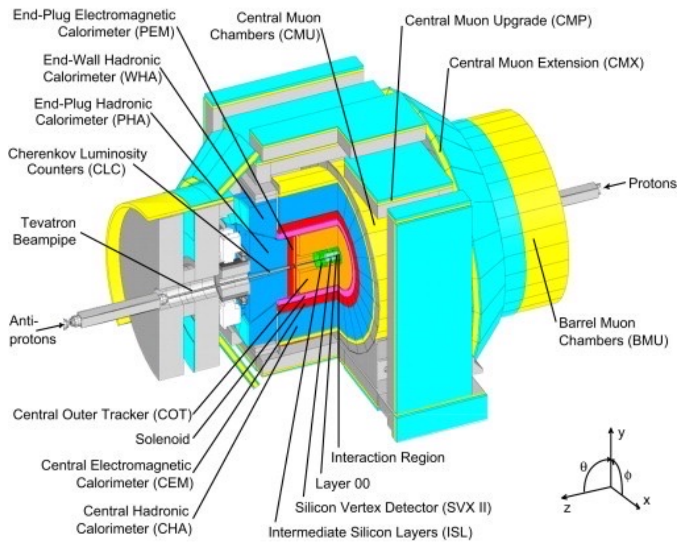
$BF(t \to bW) \simeq 1$

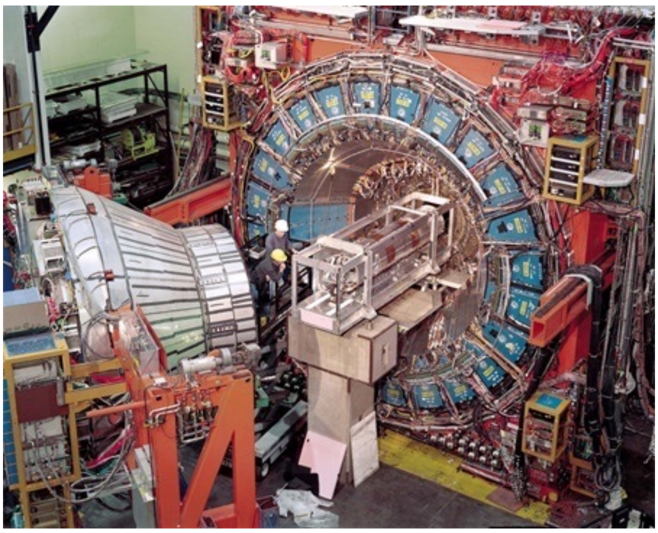
$$\#\text{events} = \mathcal{L}_{int}\,\Delta t\,\sigma_{t\bar{t}} \times BF(W^+ \to fin) \times BF(W^- \to fin).$$

all hadronic: $t + \bar{t} \longrightarrow b + W^+ + \bar{b} + W^-$, $W^+ \to q_1 \bar{q}_2$, $W^- \to q_3 \bar{q}_4$

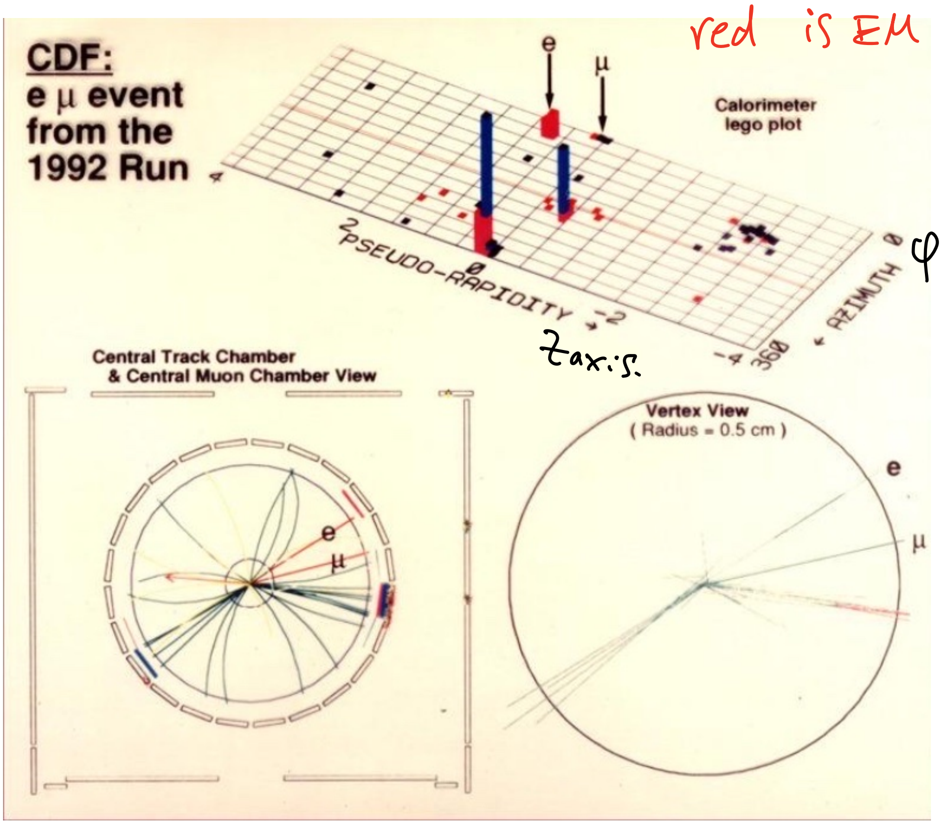
Golden modes: $b + \bar{b} + e^+ + e^- +$ missing energy.

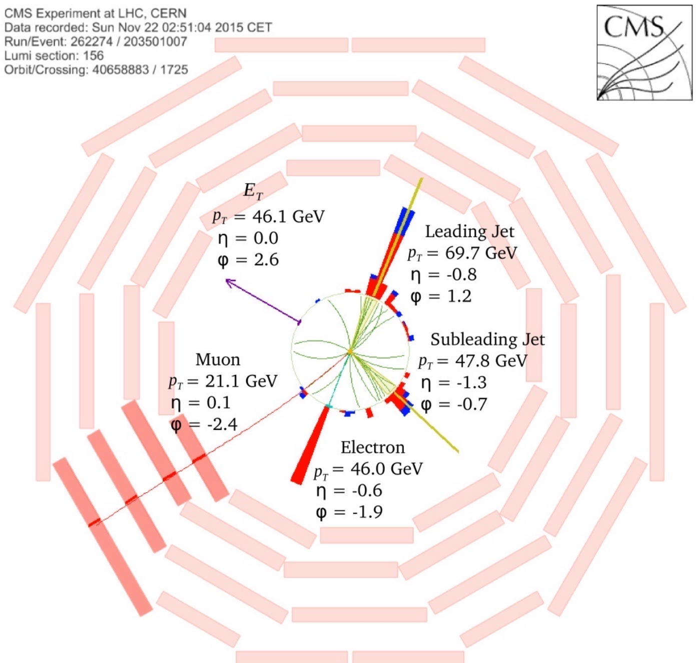


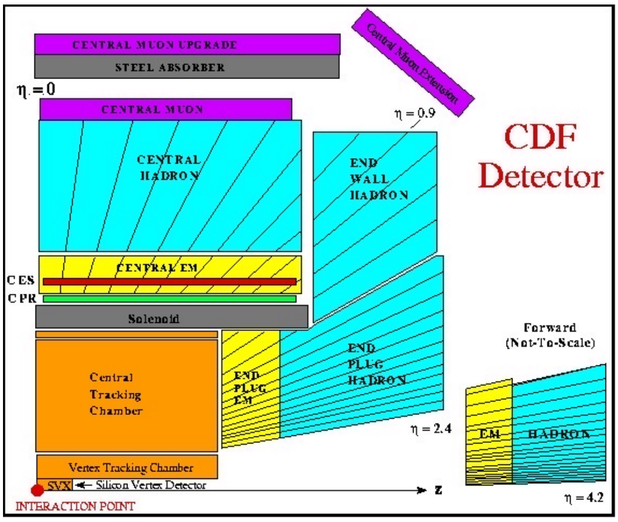


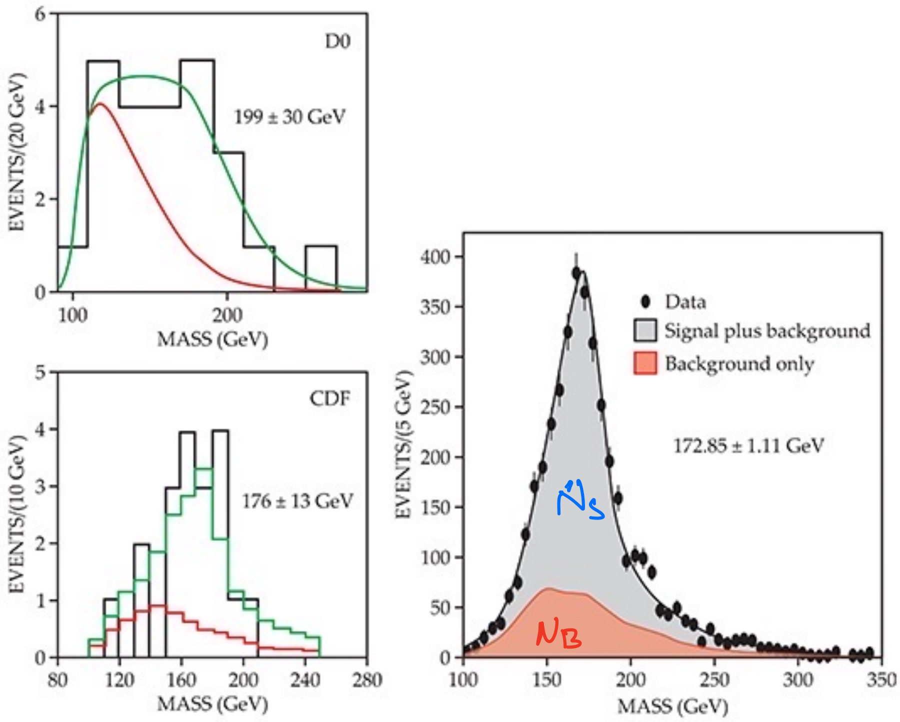


red is EM deposit









invariant mass

$$(P_b + P_{\bar{b}} + P_{\ell^+} + P_{\ell^-} + \hat{P}_\nu)^2$$

$$\hat{N}_S = N_{tot} - N_B$$

$$\frac{\hat{N}_S}{\sqrt{N_B}}$$