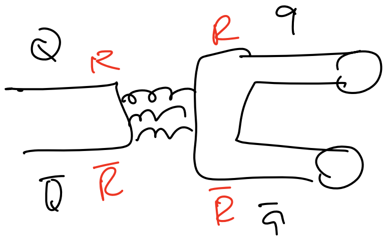
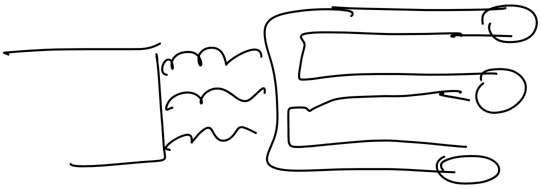




$q = S$ $\qquad$ $m_S >> m_u, m_d \Rightarrow$ final states with u, d. have more phase space

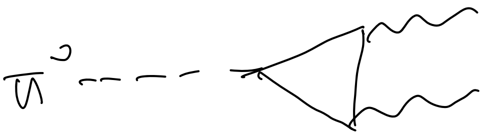
$$\begin{pmatrix} e^- \\ \nu_e \end{pmatrix} \quad \begin{pmatrix} \mu^- \\ \nu_\mu \end{pmatrix}$$

$$\begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} c \\ s \end{pmatrix}$$

N_f: free $\qquad$ # families/ flavor

N_c: fixed by experiments.

$$R = \frac{\sigma(e^+e^- \to had)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$



$\pi^0 \to \gamma\gamma$.

$\tau_{\pi^0} \neq \tau_{\pi^\pm}$

$\tau = 10^{-17}s$ $\qquad$ $\tau = 10^{-8}s$

EM $\qquad$ weak.

$\Gamma(\pi^0 \to \gamma\gamma) \propto N_c$.

Experimentally from decay $Z^0 \to$ 3 light families. leptons, quarks.

~~CP~~ requires at least 3 families in the SM.

Anomaly in gauge theories:

Gauge Symm. valid classically but broken in QM.

(anomalous symm. breaking).

SM gauge theory $\qquad$ EM, weak, QCD.

$$\underbrace{SU(3)_C}_{QCD} \times \underbrace{SU(2) \times U(1)}_{\text{Electro-weak.}}$$

color, isospin. $Q_{EM} = I_3 + Y$

q_L ($Q_{color} = 3$, $Q_{isospin} = 2$) $\qquad Y = Q_{EM} - I_3$

$I_3 \begin{matrix} = +\frac{1}{2} \\ -\frac{1}{2} \end{matrix} \begin{pmatrix} u \\ d \end{pmatrix}_L \quad \Leftrightarrow$ $\qquad$ up: $Y = \frac{2}{3} - \frac{1}{2} = \frac{4-3}{6} = \frac{1}{6}$

down: $Y = -\frac{1}{3} - (-\frac{1}{2}) = \frac{-2+3}{6} = \frac{1}{6}$

$q_L = (3, 2)_{1/6}$ $\quad (Q_{color}, Q_{Isos})_Y$

$q_R = (3, 1)_{-1/3}$ $\quad I_3 = 0, I = 0.$ $\quad Y = Q_{EM} - I_3 = -1/3.$

$\ell_L = \begin{pmatrix} \nu_e \\ e^- \end{pmatrix}_L = (1, 2)_{-1/2}$ $\quad Y = Q - I_3 \begin{cases} -1 - (-\frac{1}{2}) = -1/2 \\ 0 - (\frac{1}{2}) = -1/2. \end{cases}$

$\ell_R = (1, 1)_{-1}$ $\qquad Y = -1 - 0 = -1.$

$U(1)^3 = \sum_{left} Y^3 - \sum_{right} Y^3 = 1$ anomaly in SM.

anomaly $= 0$ if # quark fam $\equiv$ # lepton fam.

$q_L = \begin{pmatrix} u \\ d \end{pmatrix}_L \begin{pmatrix} c \\ s \end{pmatrix}_L \begin{pmatrix} t \\ b \end{pmatrix}_L$

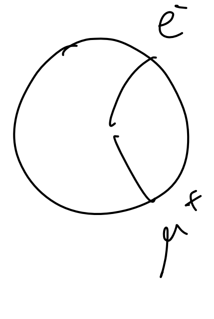
$u_R, d_R, c_R, s_R, t_R, b_R$

$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix} \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix} \begin{pmatrix} \; \\ \; \end{pmatrix}$

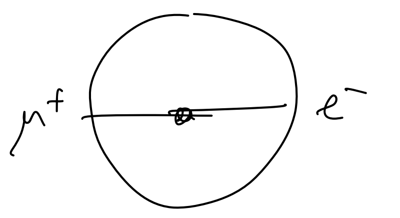
$\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ c \end{pmatrix} \begin{pmatrix} \; \\ \; \end{pmatrix}$ $\qquad$ Nobel 1995

1976: Martin Perl @ SLAC, Merk I

$e^+e^- \to e^+\mu^-$ unbalanced.



Balanced



violating flavor #

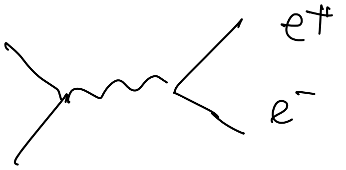
$e^+e^- \longrightarrow X^+ \; X^-$

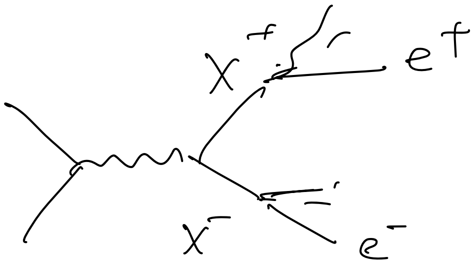
$X^- \to e^- + X$

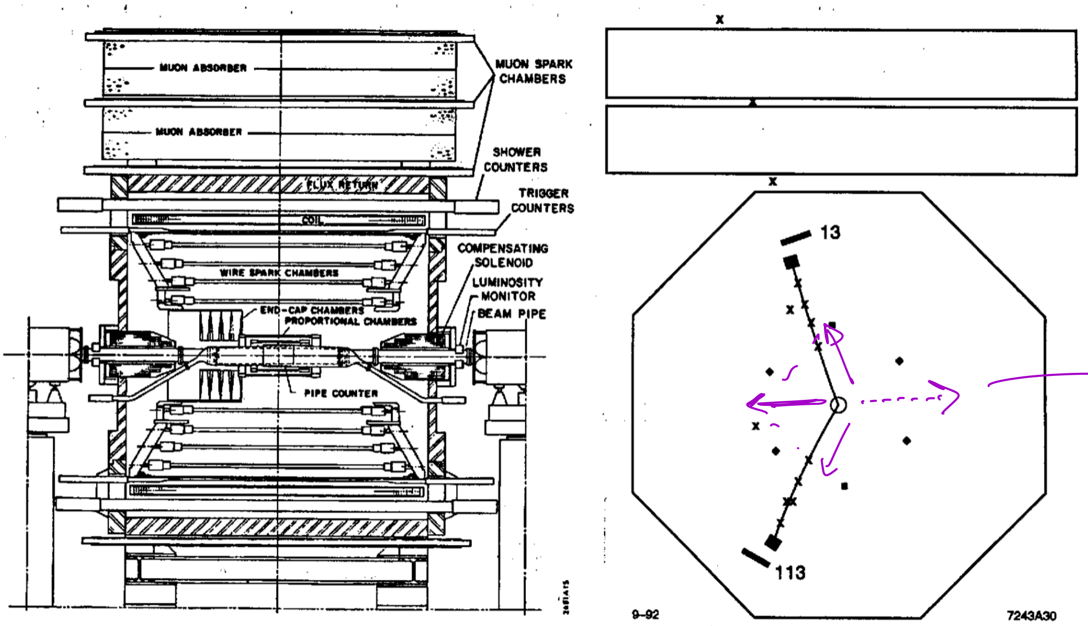
$X^+ \to \mu^+ + X$

$e^+e^- \to e^+e^-$ unb.

$\mu^+\mu^-$ unb.







(a) (b)

not observed.

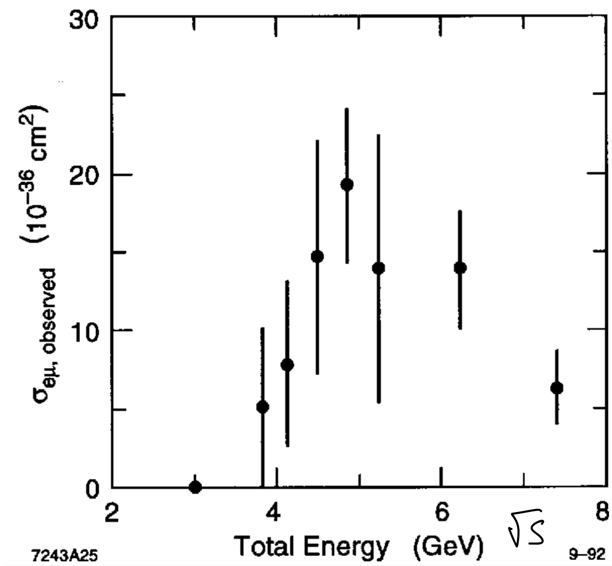
$e^+e^- \xrightarrow{\sqrt{s}} \tau^- \; \tau^+$

$\tau^+ \to \mu^+ \nu_\mu \bar{\nu}_\tau$

$\tau^- \to e^- \bar{\nu}_e \nu_\tau$

$\sqrt{s} \geq 2m_\tau \Rightarrow$

production of unbalanced $e^+\mu^-$



Threshold production.

$\Rightarrow m_\tau \simeq 1.8$ GeV

m_τ large $\Rightarrow$ hadronic decays of τ.

but LEP and other exp. $\Rightarrow$ τ behaves like a lepton

$\Rightarrow$ find ν_τ

$$e^+e^- \longrightarrow \tau^+ \tau^-$$

$\tau^- \to e^- + \nu$

$\quad\;\; \mu^- + \nu$

$\tau^+ \to e^+ + \nu_e$

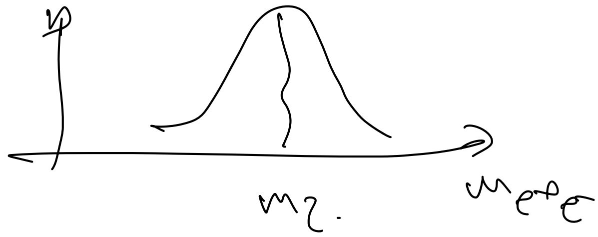
$\quad\;\; \mu^+ + \nu_\mu$

$$N(e^+e^- \to e^+\mu^- \nu\bar{\nu}) + N(e^+e^- \to e^+e^- \nu\bar{\nu})$$

$$= N(e^+e^- \to \mu^+\mu^- \nu\bar{\nu})$$

$$= N(e^+e^- \to \mu^+ e^-)$$

$$Z^0 \to e^+e^-$$



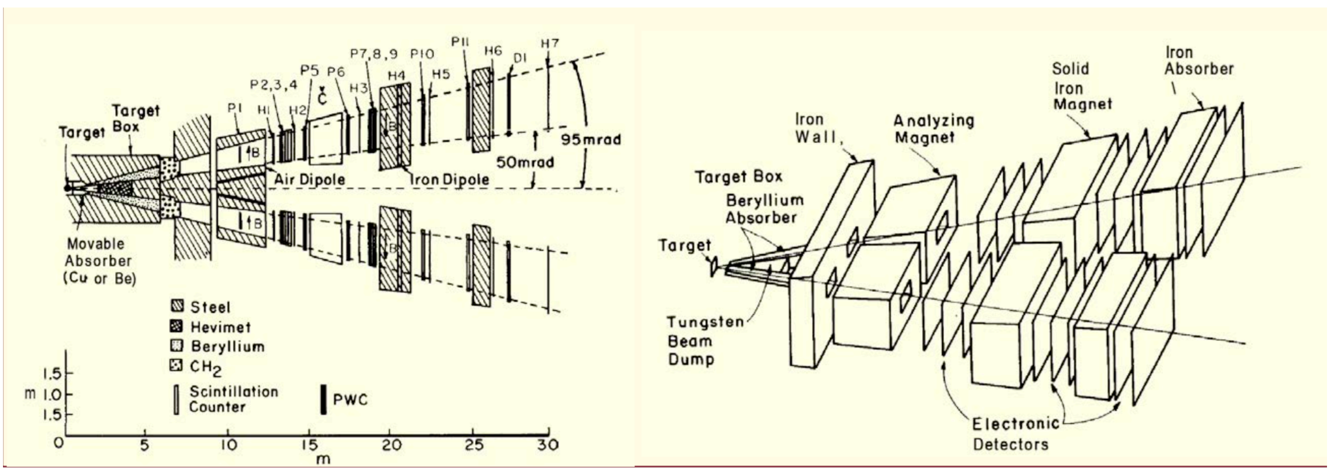
$$Z^0 \to \tau^+\tau^-$$

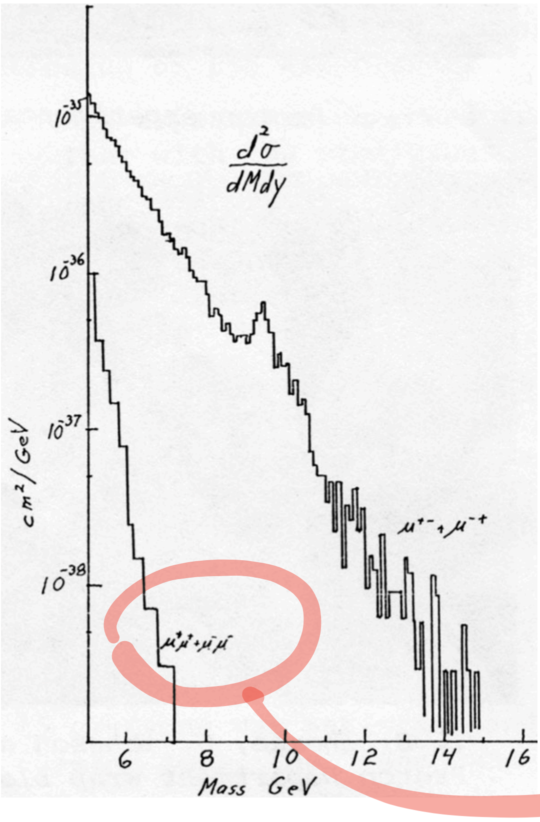
@ Fermilab.

1977: Leon Ledderman. Nobel 1988

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

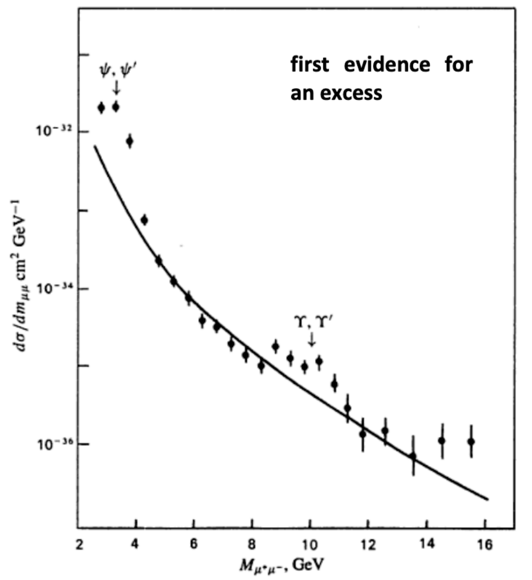
10^4 particles per pulse with 2-arm spectrometer

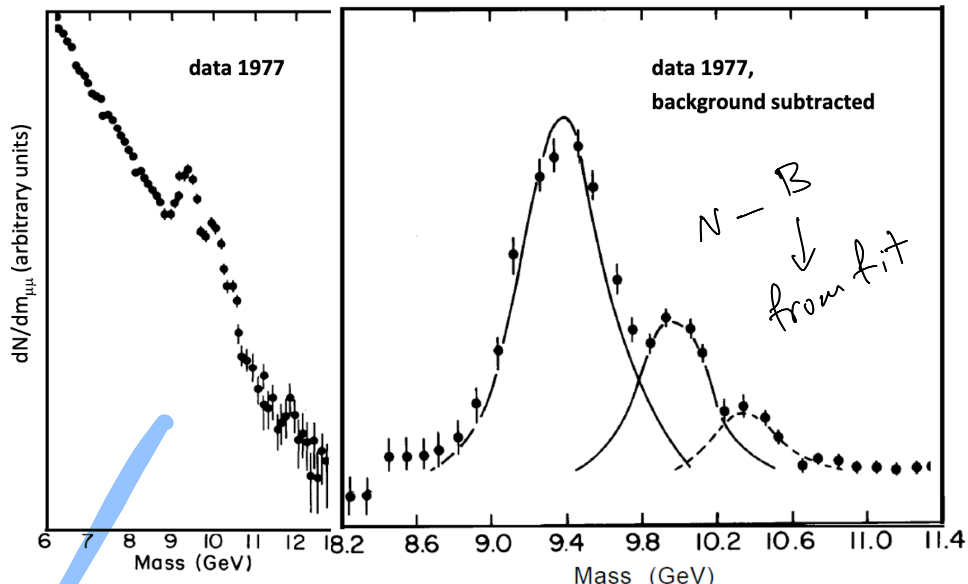




$X^{++} \longrightarrow \mu^+\mu^+$

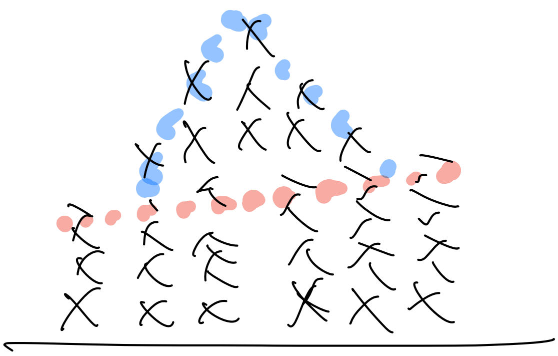
bottomonium $b\bar{b}$



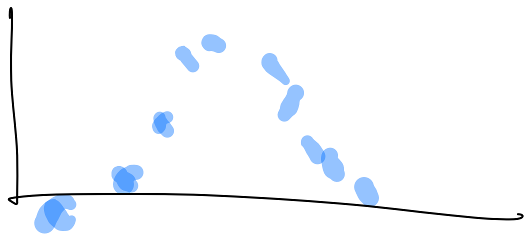


signal = B + Gaussian.

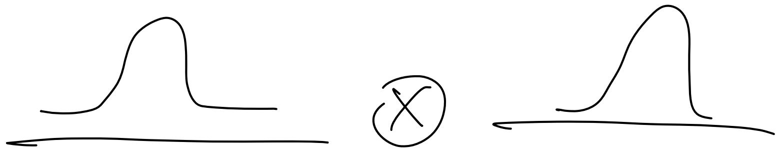
$$\hookrightarrow A e^{-\alpha x} + B\,G(x_0,\sigma_1) + C\,G(x_1,\sigma_2) + D\,G(x_3,\sigma_3)$$



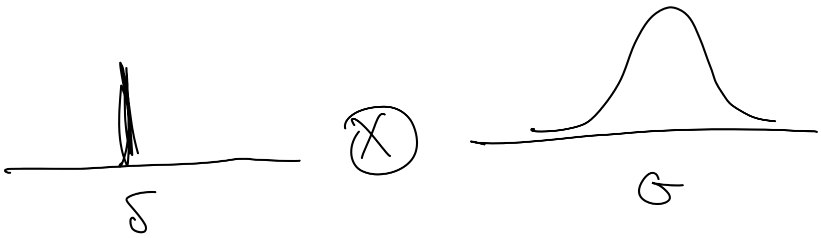
$\longrightarrow$



Experimental width = BW width ⊗ Gaussian Resol.

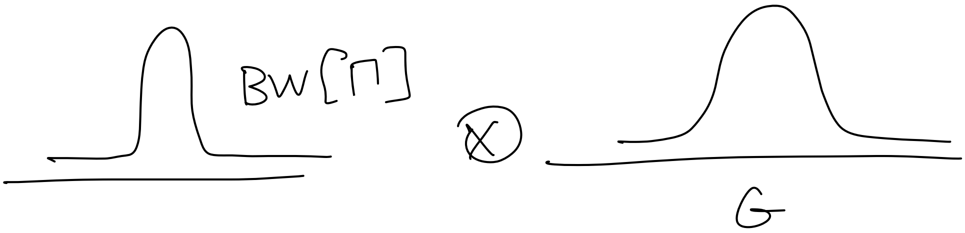


plots show $\frac{d\sigma}{dm_{\mu\mu}} \equiv \frac{\#\text{events}}{\text{bin width}}$

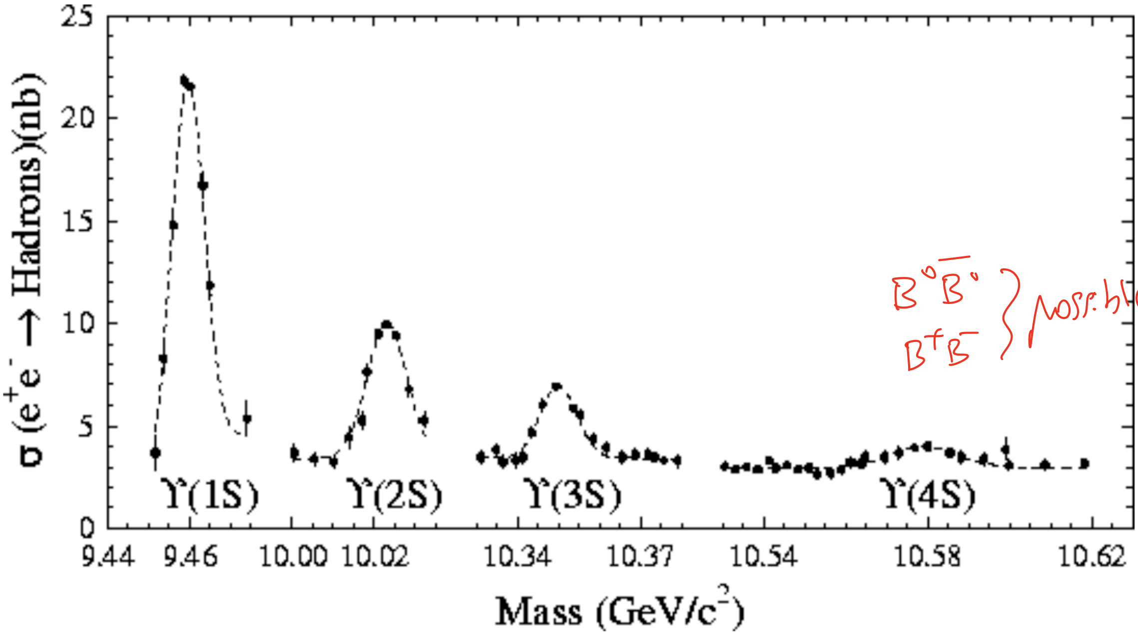


$\delta \otimes G = G$

$$\int \delta(x-x_0)\, e^{-(x_1-x)/2\sigma^2}\, dx$$



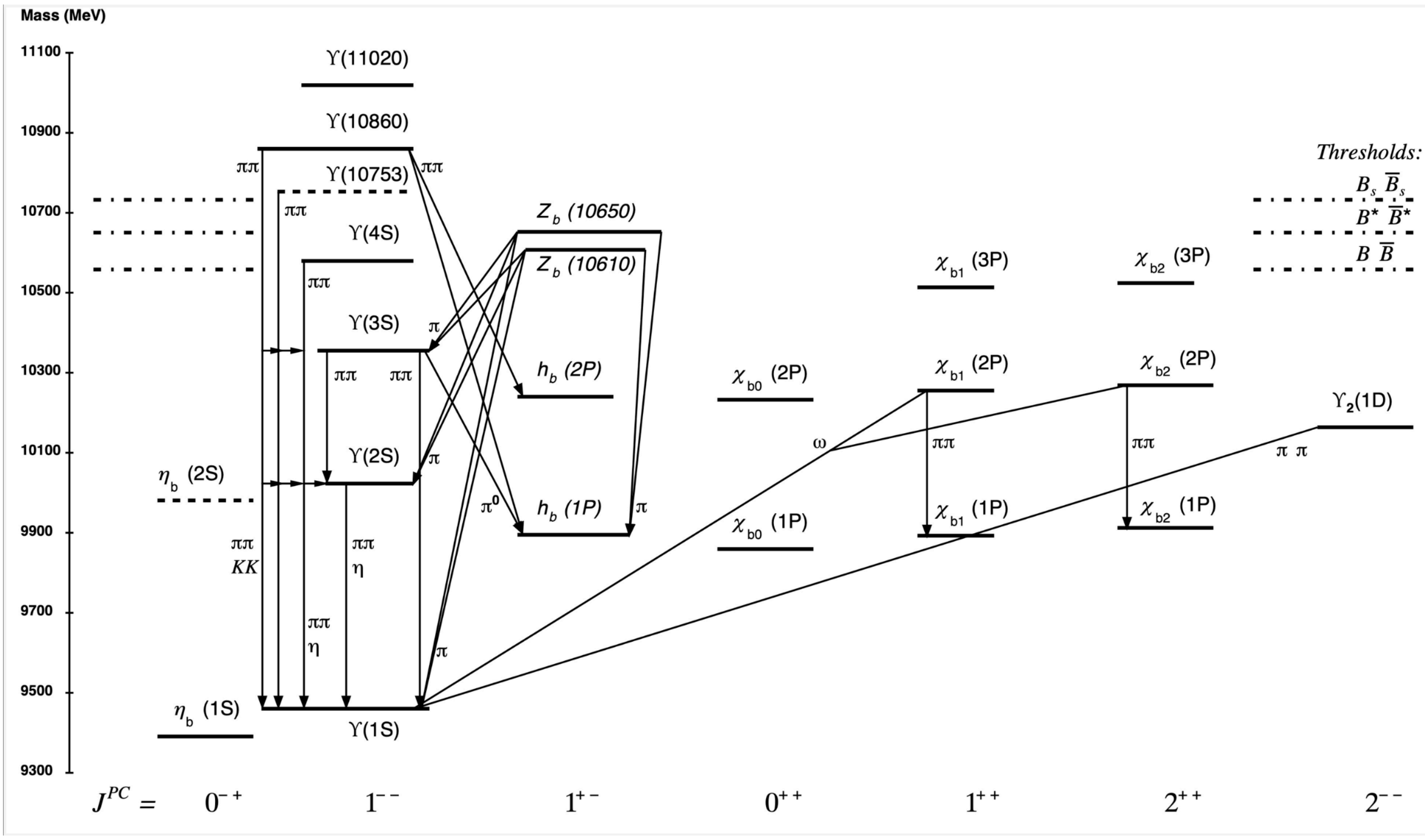
BW[Γ] ⊗ G



$B^0\bar{B}^0$
B^+B^- } possible

CESR.
@ Cornell.
PEP-II
KEK.

scan of $\Upsilon \equiv b\bar{b}$ Upsilon.



$b\bar{b} \longrightarrow b\bar{u} \quad \bar{b}u \quad B^0 \bar{B}^0$

$b\bar{d} \quad \bar{b}d \quad B^- B^+$

$m\,\Upsilon(4S) = 10.580$ GeV

$m\,B^0 = 5.279$ GeV.

$m_\Upsilon > 2 \times m_B$

$\Upsilon(4S) \longrightarrow B^0 \bar{B}^0 +$ some energy.

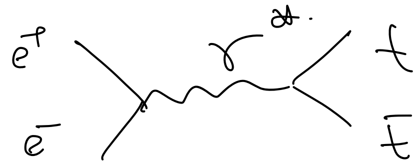
B_ factory: e^+e^- colliders $\sqrt{s} = m\,\Upsilon(4S)$

$\begin{pmatrix} \\ b \end{pmatrix}$

$\begin{pmatrix} \\ \tau^- \end{pmatrix}$

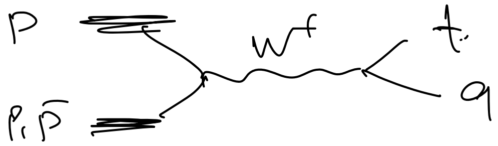
Top Quark

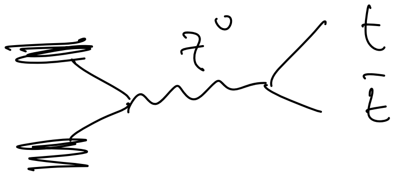
$e^+e^- \to t\bar{t}$ $\quad \sqrt{s} \gtrsim 2m_{top}.$



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

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





LEP: $1989 \to 2001$

$\sqrt{s} \simeq 90\,\text{GeV} \to 200-$

Search for top @ hadron colliders $\quad$ Fermilab.

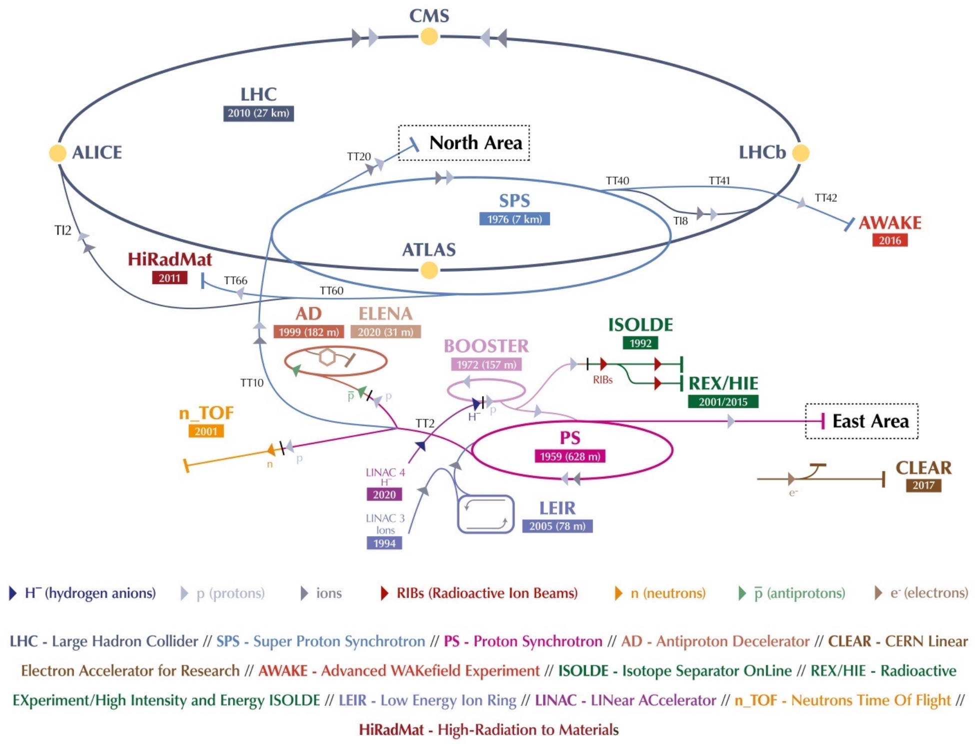
$Sp\bar{p}S \quad$ CERN.

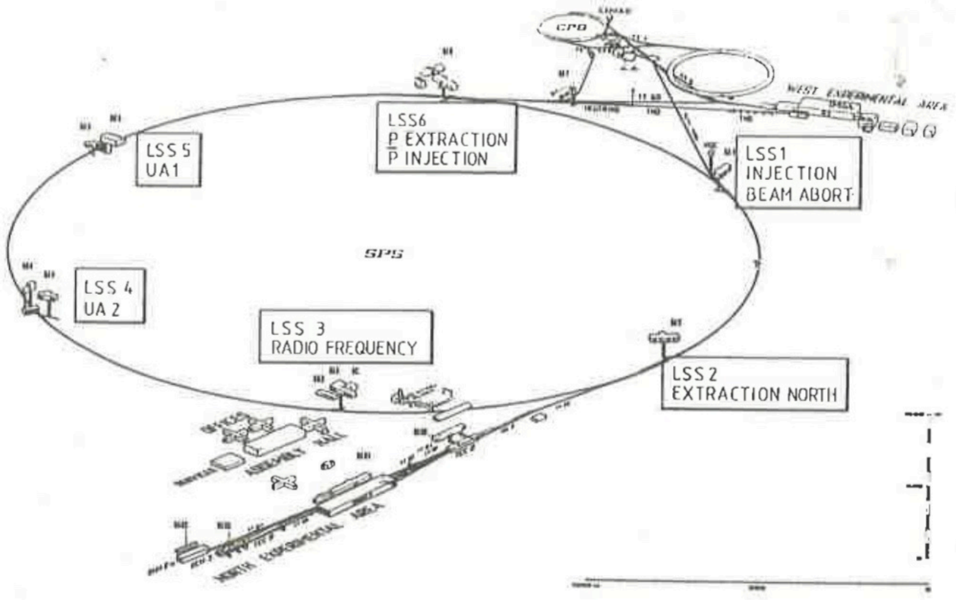
@ e^+e^- Colliders. $\quad$ Tristan, CERN.

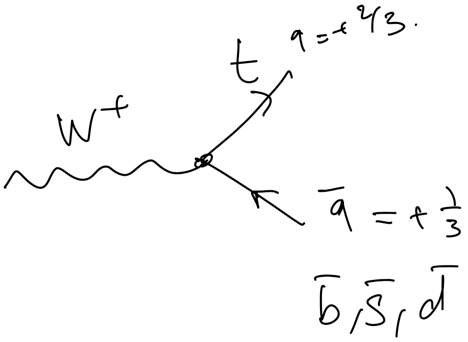
if $m_t \approx 90$ GeV.

The CERN accelerator complex

Complexe des accélérateurs du CERN







$\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix}$

most likely process $W^+ \rightarrow t\bar{b}$

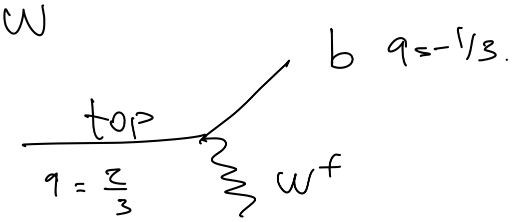
$m_W > M_t + m_b$.

$m_b \simeq 5$ GeV.

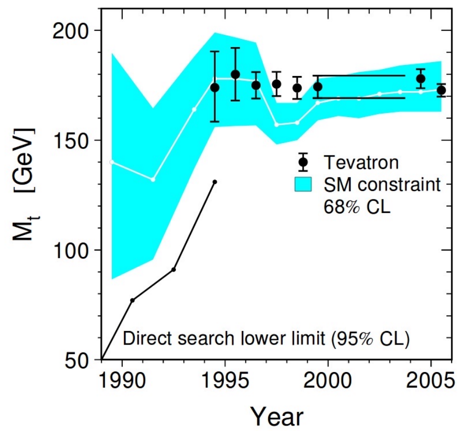
1983 discovery. $m_W \simeq 80$ GeV. $\Rightarrow$ limit on top mass.

$\Rightarrow$ top $> W$

if $m_{top} > m_W \Rightarrow$



LEP + Calculations based on m_Z, m_W.



$\Rightarrow$ hadron colliders.