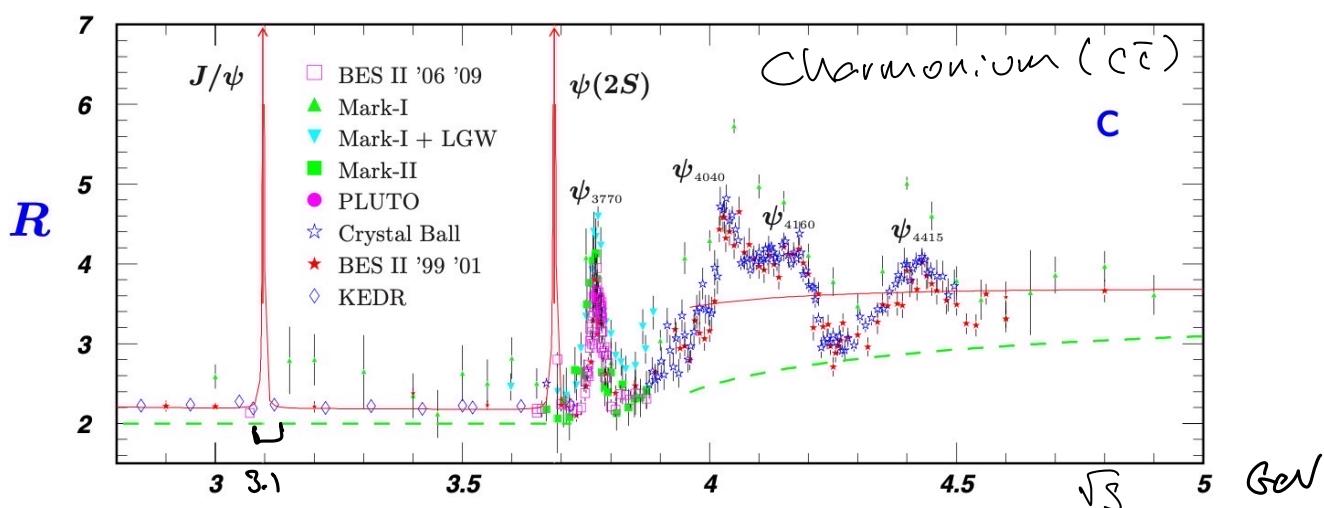


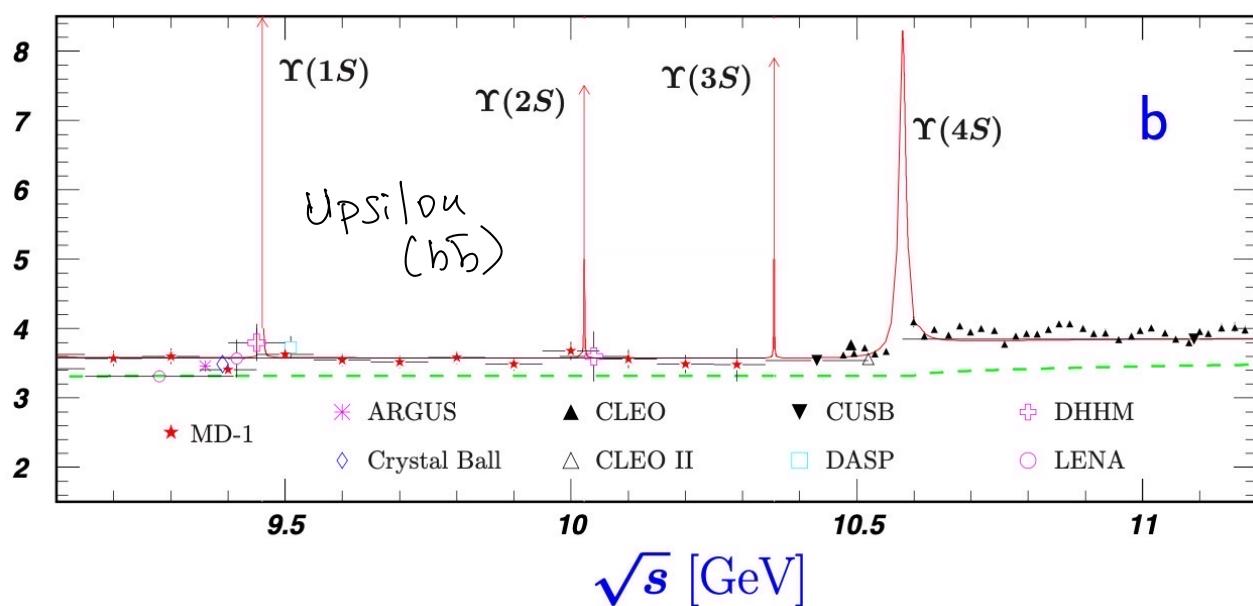
$Z \Rightarrow$ indirect indication
of 3 quarks.
and $N_C = 3$

resonances of u, d, s quarks.

$$R = R(\sqrt{s})$$



$$R = N_C \times \sum_i Z_i^q$$

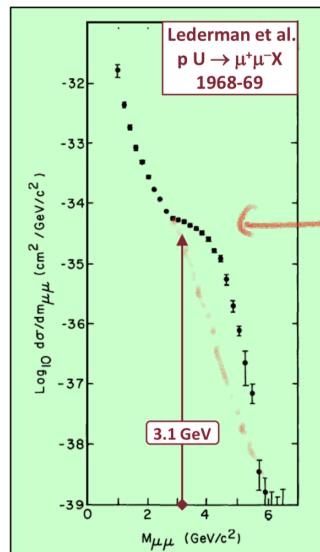


Between $s \rightarrow 9$ GeV of \sqrt{s}

$$R = N_C \times \left[\frac{(\frac{2}{3})^2}{u} + \frac{(\frac{1}{3})^2}{d} + \frac{(\frac{1}{3})^2}{s} + Z_C^2 \right]$$

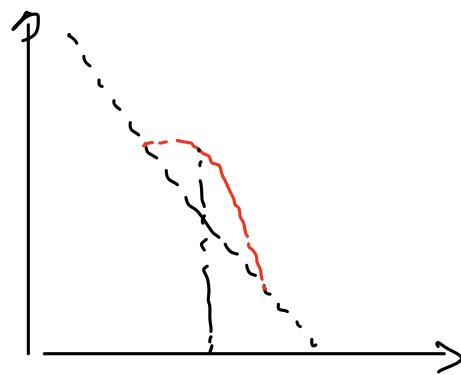
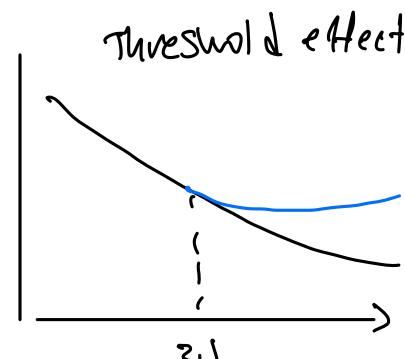
From measurement of $R \Rightarrow$ a 4th quark with charge $Z = +\frac{2}{3}$

End of 1960's indication of c quark



$p + \text{target} \rightarrow (\mu^+\mu^-) + X$
look at invariant mass of $\mu^+\mu^-$.

8 possibilities
 $\log N$



or wide peak.
on top of
background

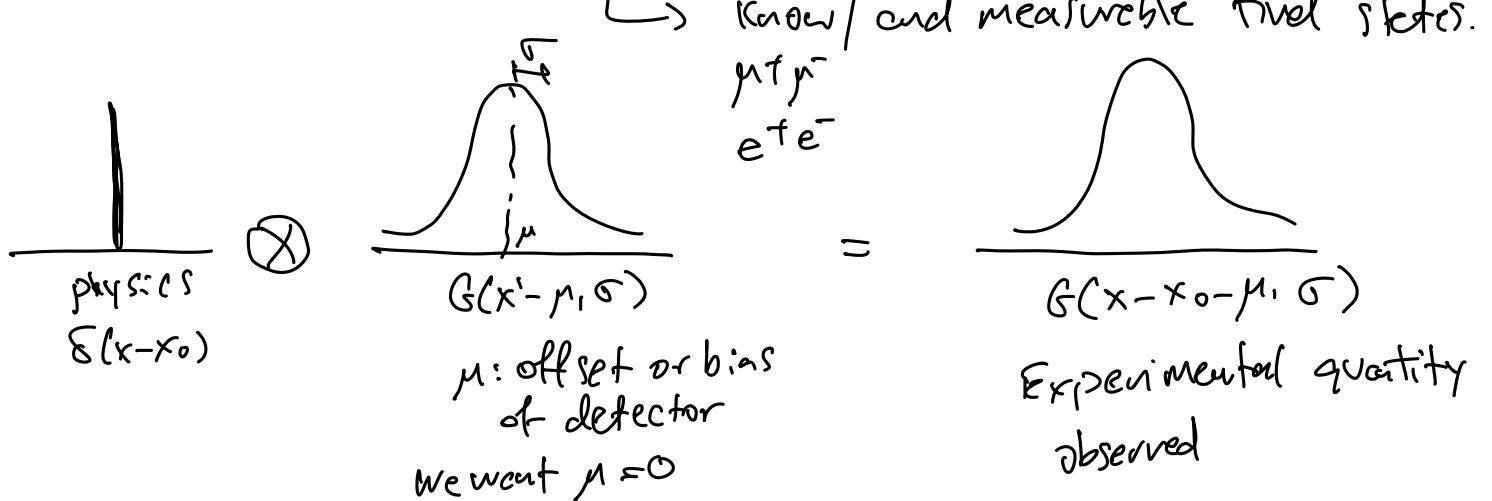
1970's GIM mechanism (Glashow-Iliopoulos-Maiani)
in $K^0 \rightarrow \mu^+\mu^-$ (weak decay)

To discover new quarks \Rightarrow 2 ways.

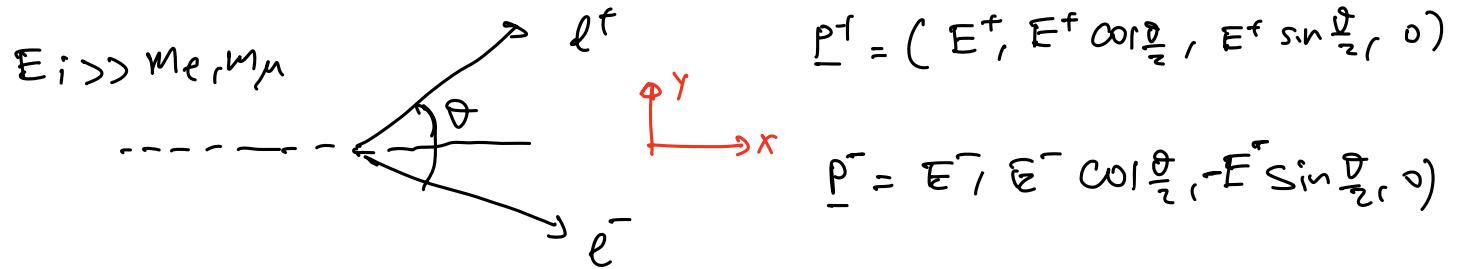
$$1) e^+e^- \rightarrow x\bar{x}$$

$$2) p + \text{target} \rightarrow (x\bar{x}) + \gamma$$

↳ know / and measurable final states.



Better resolution in e^+e^- or $\mu^+\mu^-$



$$m_{ll}^2 = (E^f + E^-)^2 - (\underline{p}^f + \underline{p}^-)^2 = 4E^f E^- \sin^2\frac{\theta}{2}$$

$$2 \sin^2\frac{\theta}{2} = 1 - \cos\theta$$

$$\sigma_m^2 = \sigma_E^2 \oplus \sigma_\theta^2 \quad \text{Experimental resolution}$$

Need both energy and angle for good M_{ll} peak.

p_T target $\rightarrow X + Y$ $Y = P, \pi^+, \pi^-, \eta^0, \dots$

$\hookrightarrow \mu^+ \mu^-$

$$m_\pi = 140 \text{ MeV}$$

$$P = 1 \text{ GeV}$$

$$m_\mu = 106 \text{ MeV}$$

$$\Rightarrow E_{\pi, \mu} \approx \text{are the same.}$$

Thick material to stop hadrons: cement, concrete, metal
hadronic interaction & ionization

decay length: $= \beta \gamma C \tau$.

$$\beta \gamma = \frac{P}{v} = \frac{1 \text{ GeV}}{100 \text{ MeV}} = 10$$

$$\tau \approx 10^{-6} \text{ s}$$

$$C = 3 \times 10^8 \text{ m/s.}$$

$$\beta \gamma C \tau = 2 \times 10^5 \times 3 \times 10^8 \text{ m}$$

muon under/over muon scattering \Rightarrow Bad angular resolution

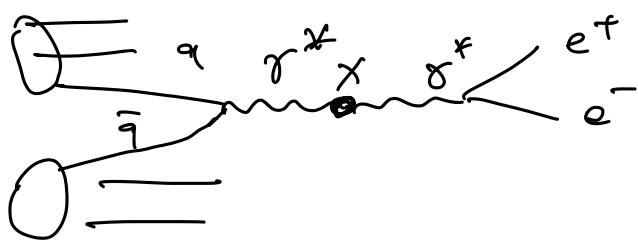


November Revolution 1974:

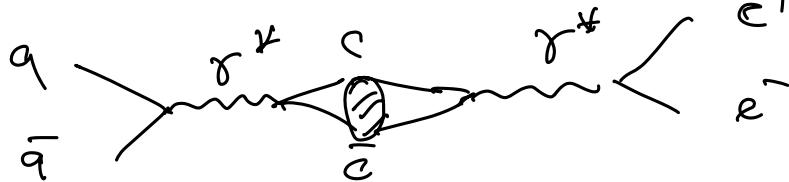
1) $p_T Be \rightarrow (e^+ e^-) + X$

\hookrightarrow Resonance.

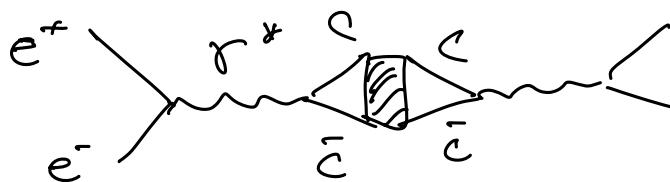
Sam Ting: Brookhaven
Alternating Gradient Synch.



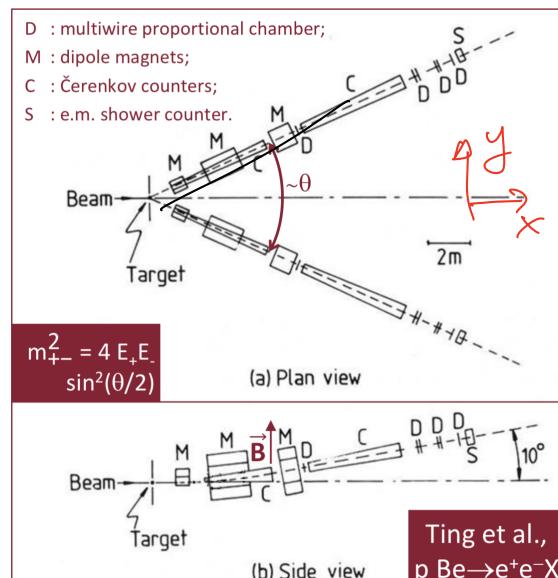
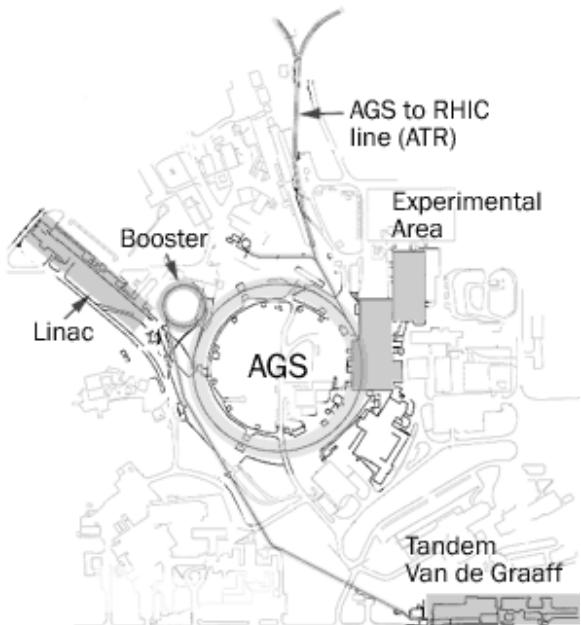
Burton Richter: SLAC.
SPEAR
Stanford Positron Electron Asym. Ring



$$\text{e)} \quad e^+ e^- \rightarrow \tau/\psi \rightarrow e^+ e^-, \mu^+ \mu^-, \text{ hadrons.}$$



Brookhaven

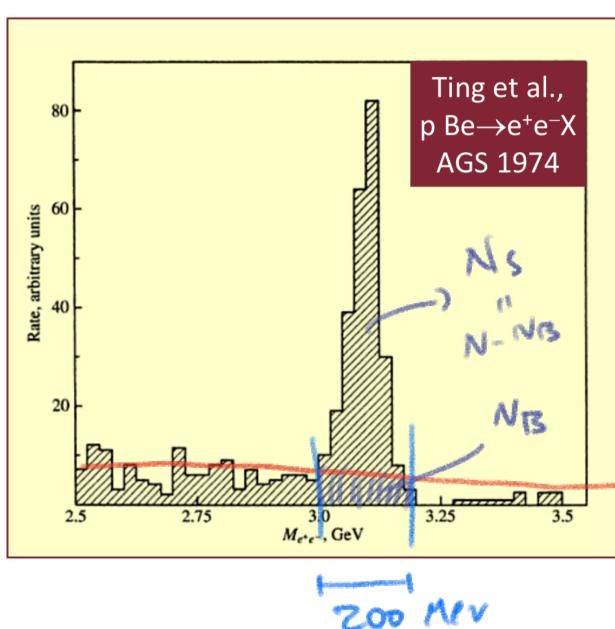


$$m_{e^+ e^-} = G E^+ E^- \sin^2 \frac{\theta}{2}$$

observed with damped by experimental resolution.

$$m \approx 3.1 \text{ GeV}$$

$$\sigma_{\text{Gauff}} \approx 30 \text{ MeV}$$

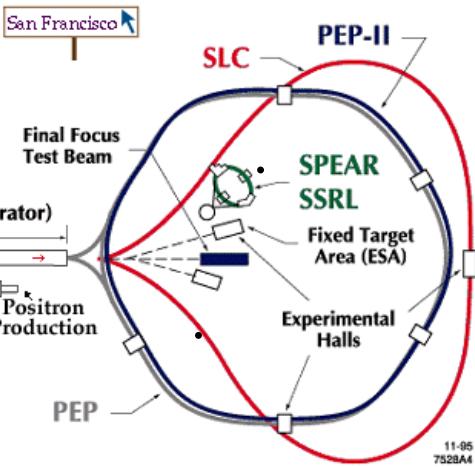


$$N_S \approx \frac{N_{\text{tot}} - N_B}{\sqrt{N_B}}$$

SLAC experiment

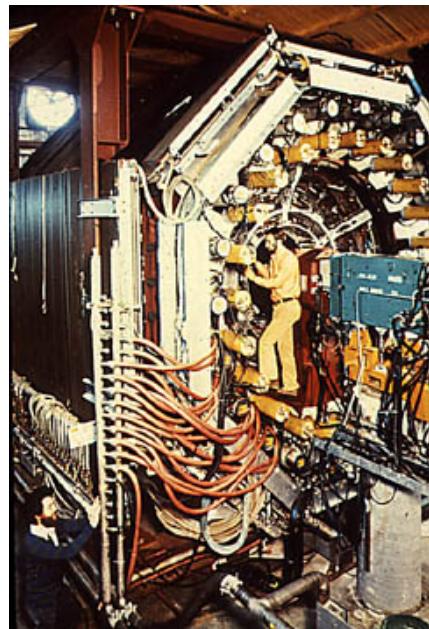
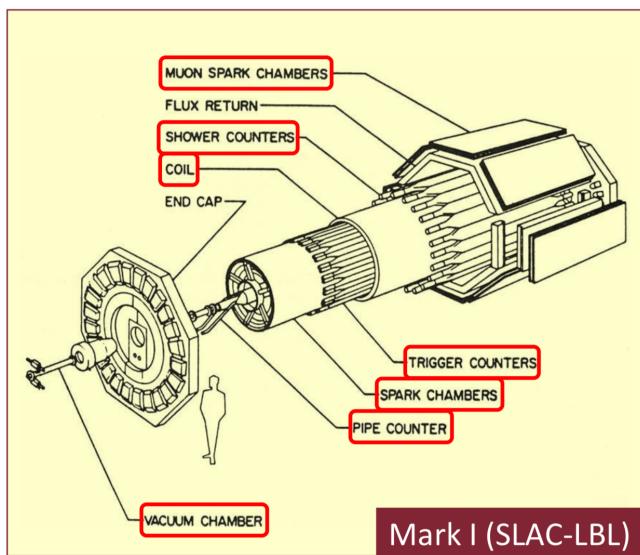
Experimental Areas at SLAC

Linac 50 GeV
SPEAR 4 x 4 (1/2 SSRL)
PEP 20 x 20
PEP-II 9 x 3.1
SLC 50 x 50



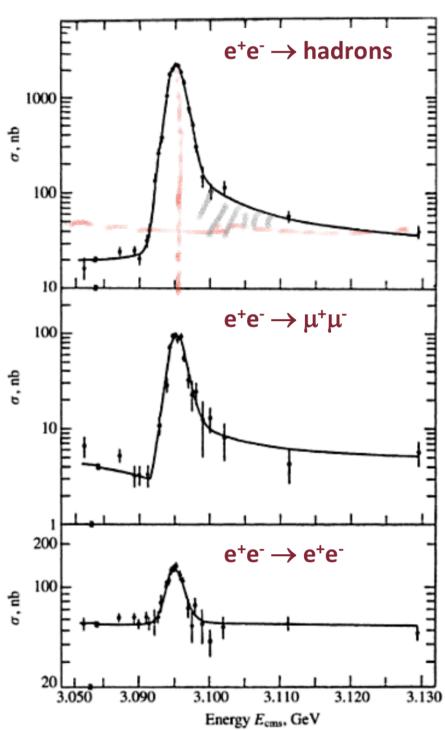
$e^+e^- \rightarrow e^+e^-, \mu^+\mu^-, \text{had.}$

$\sqrt{s} : 2.5 \rightarrow 7.5 \text{ GeV}$



Scan $2.5 \rightarrow 7.5$ in steps of 200 MeV

in 1974 Nov \rightarrow 2.5 MeV steps



Scan near 3.1 GeV
production cross section of a new resonance:

Tip: decay of a new resonance.

why right shoulder $>$ left shoulder

$$\Gamma(e^+e^- \rightarrow X)$$

$$\sqrt{s} = \sqrt{s_{\text{nom}}} \text{ normal } \sqrt{s'}$$

$\sqrt{s_{\text{eff}}} \leq \sqrt{s_{\text{nom}}}$, because of Bremsstrahlung

$$\sigma(e^+e^- \rightarrow x) \propto \frac{16\pi}{S} \frac{2J+1}{(2S_{\text{tot}}+1)(2S_{\text{tot}}+1)} \frac{\Gamma_{ee}}{\Gamma_{\text{tot}}} \frac{\Gamma_{\bar{q}\bar{q}}}{\Gamma_{\text{tot}}} \frac{\Gamma_{\text{tot}}^2}{(x - x_0)^2 + \Gamma_{\text{tot}}^2/4}$$

$\sqrt{s} > m_x$ (right shoulder)
now.

$$\Gamma_{\text{eff}} = \sqrt{S_{\text{beam}}} - \sum_C \text{Brems.}$$

properties of new resonance:

$$\text{mass} = 3.1 \text{ GeV} \quad \Gamma_{\text{tot}} = 0.087 \text{ MeV}$$

hypothesis: $X = c\bar{c}$ bound state C: the new charm quark.

$$e^+e^- \rightarrow \gamma^* \rightarrow X \rightarrow e^+e^-$$

Tiny: J

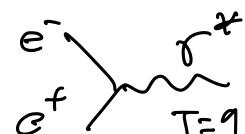
Richter: ψ

Today: J/ψ

$$J_X^{PC} = 1^{--} \text{ same as photon.}$$

if X is ground state $\Rightarrow L=0$.

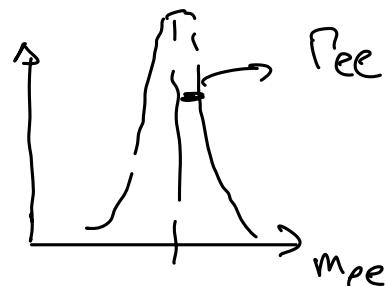
$$\gamma \rightarrow e^+e^-$$



What is total width Γ ?

$$p + p_{\text{jet}} \rightarrow (X) + \gamma$$

$\hookdownarrow e^+e^-$



\Rightarrow Cannot determine Γ_{tot}

In e^+e^- experiment:

$$\sigma(e^+e^- \rightarrow \text{hadrons}) \propto \frac{\Gamma_{ee}}{\Gamma_{\text{tot}}} \frac{\Gamma_{\text{had}}}{\Gamma_{\text{tot}}}$$

$$\sigma(e^+e^- \rightarrow \mu^+\mu^-) \propto \frac{\Gamma_{ee}}{\Gamma_{\text{tot}}} \frac{\Gamma_{\mu\mu}}{\Gamma_{\text{tot}}}$$

$$\sigma(e^+e^- \rightarrow e^+e^-) \propto \frac{\Gamma_{ee}^2}{\Gamma_{\text{tot}}^2}$$

4 unknowns: Γ_{ee} , $\Gamma_{\mu\mu}$, Γ_{had} , Γ_{tot}

3 observables: Γ_{ee} , $\Gamma_{\mu\mu}$, Γ_{had} .

$$\Rightarrow \Gamma_{\text{tot}} = 0.087 \text{ MeV}$$

1 constraint: $\Gamma_{\text{tot}} = \Gamma_{ee} + \Gamma_{\mu\mu} + \Gamma_{\text{had}}$.

10 days later new resonance

