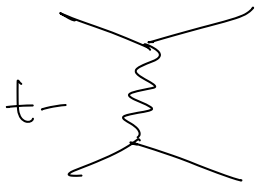
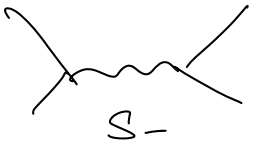
QED test and production of quark and Color



t-

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

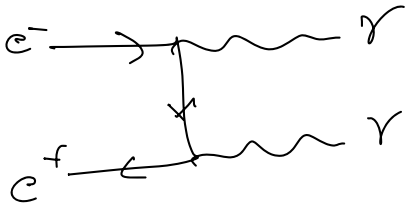
$e^+e^+ \to e^+e^+$



s-

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

$\mu^+\mu^-$



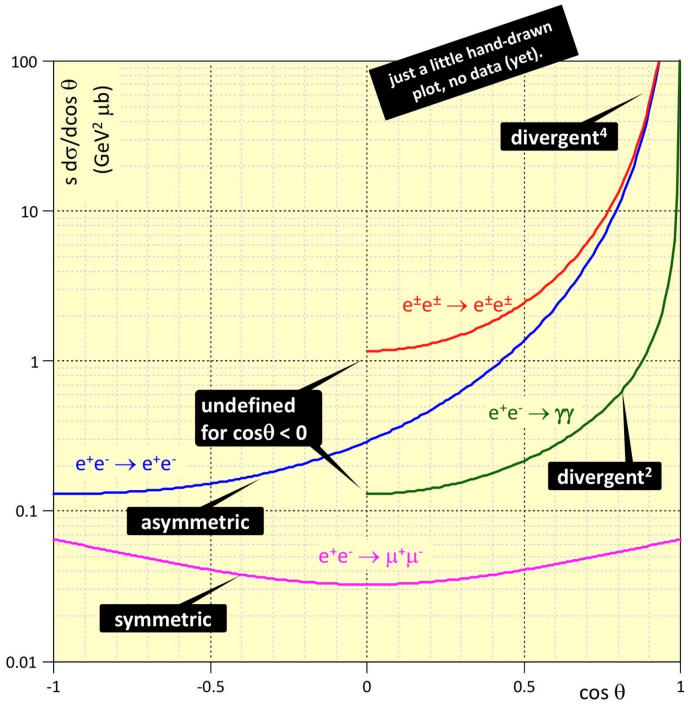
$e^+e^- \to \gamma\gamma$

$$\frac{d\sigma(e^\pm e^\pm \to e^\pm e^\pm)}{d\cos\theta} = \frac{2\pi\alpha^2}{s} \times \left(\frac{3+\cos^2\theta}{1-\cos^2\theta}\right)^2;$$

$$\frac{d\sigma(e^+e^- \to \gamma\gamma)}{d\cos\theta} = \frac{2\pi\alpha^2}{s} \times \frac{1+\cos^2\theta}{1-\cos^2\theta};$$

$$\frac{d\sigma(e^+e^- \to e^+e^-)}{d\cos\theta} = \frac{\pi\alpha^2}{2s} \times \left(\frac{3+\cos^2\theta}{1-\cos\theta}\right)^2;$$

$$\frac{d\sigma(e^+e^- \to \mu^+\mu^-)}{d\cos\theta} = \frac{\pi\alpha^2}{2s} \times (1+\cos^2\theta);$$



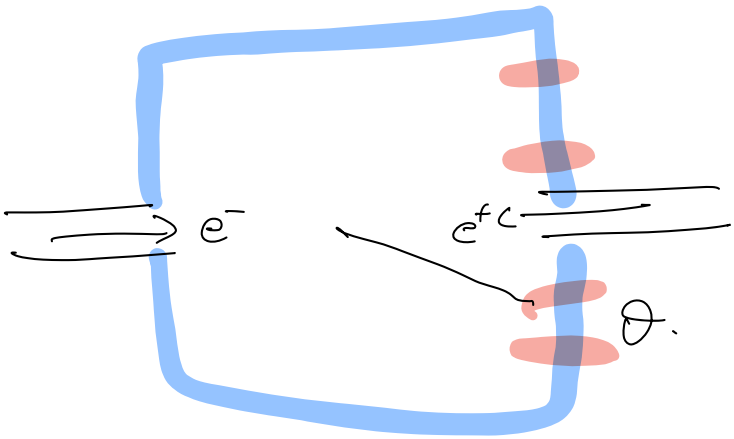
- limits of $d\sigma/d\cos\theta$ for $\cos\theta \to 1$ (i.e. $\theta \to 0$):

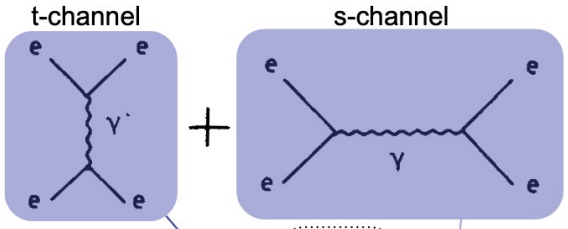
$e^\pm e^\pm \to e^\pm e^\pm$: $\frac{2\pi\alpha^2}{s}\left(\frac{3+1}{\sin^2\theta}\right)^2 = \left(\frac{2\pi\alpha^2}{s}\right)\left(\frac{16}{\theta^4}\right)$;

$e^\pm e^\pm \to \gamma\gamma$: $\frac{2\pi\alpha^2}{s}\frac{1+1}{\sin^2\theta} = \left(\frac{2\pi\alpha^2}{s}\right)\left(\frac{2}{\theta^2}\right)$;

$e^+e^- \to e^+e^-$: $\frac{\pi\alpha^2}{2s}\left(\frac{3+1}{2\sin^2(\theta/2)}\right)^2 = \left(\frac{2\pi\alpha^2}{s}\right)\left(\frac{16}{\theta^4}\right)$;

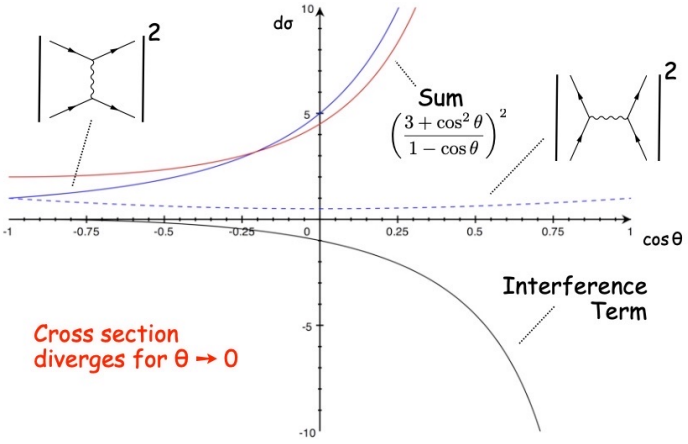
$e^+e^- \to \mu^+\mu^-$: $\frac{\pi\alpha^2}{2s}(1+1) = \left(\frac{2\pi\alpha^2}{s}\right)\left(\frac{1}{2}\right)$.

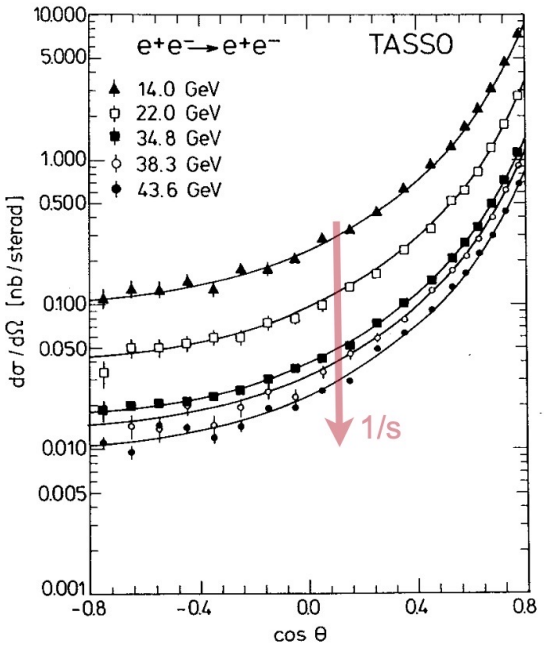


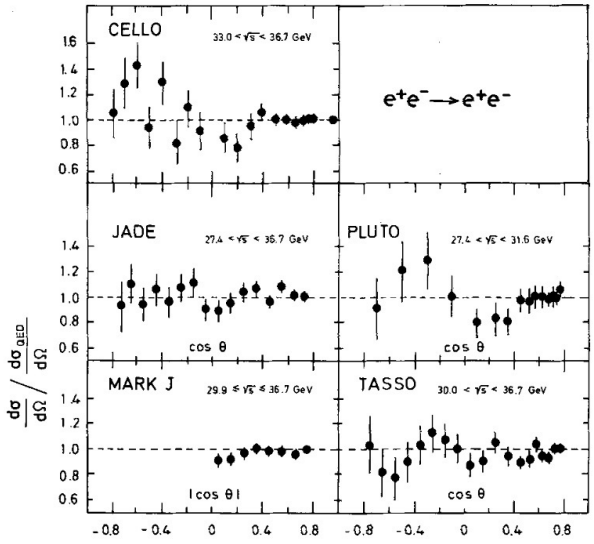


interference term

$$\frac{d\sigma_0}{d\Omega} = \frac{\alpha^2}{2s}\left(\frac{q'^4+s^2}{q^4} + \frac{2q'^4}{q^2 s} + \frac{q'^4+q^4}{s^2}\right) = \frac{\alpha^2}{4s}\left(\frac{3+\cos^2\theta}{1-\cos\theta}\right)^2$$







Ratio between measured cross section and QED calculation

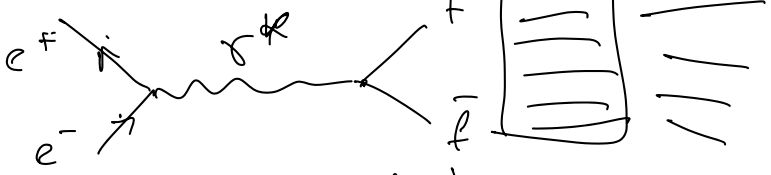
Ratio plot

$\frac{\text{Meas.}}{\text{TH}}$

$$\mathcal{M}_{Bh} = \mathcal{M}_u + \mathcal{M}_s + \mathcal{M}_x$$

$$\sigma_{Bh} \propto \underbrace{|\mathcal{M}_u|^2 + |\mathcal{M}_s|^2 + 2\mathcal{M}_u^{\not}\mathcal{M}_s}_{\text{QED}} + \underbrace{|\mathcal{M}_x|^2 + 2\mathcal{M}_x^{\not}\mathcal{M}_u + 2\mathcal{M}_x^{\not}\mathcal{M}_s}_{\text{NEW}}$$

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



Hadronization.

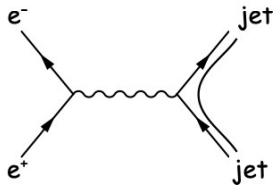
mesons.

Baryons.

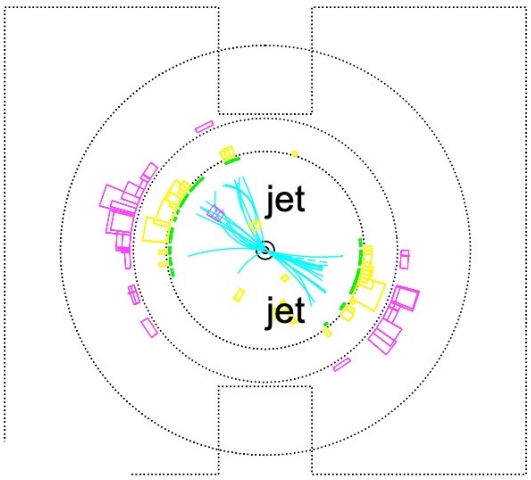
production of quarks.

Hadronic decays: $\tau \sim 10^{-23}$ sec.

$$\Gamma = \frac{1}{\tau}$$

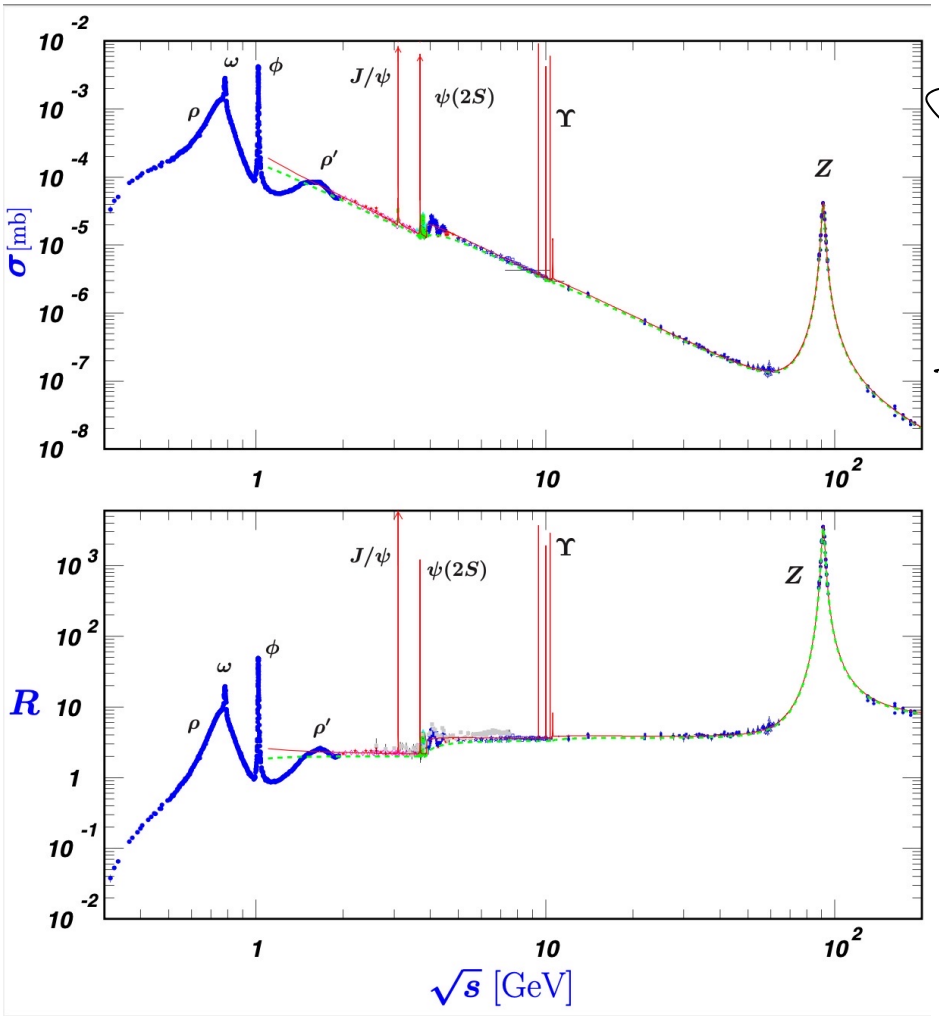


$$R = \frac{\sigma(e^+e^- \to \text{had})}{\sigma(e^+e^- \to \mu^+\mu^-)} = \sum_f Q_f^2 N_c$$



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

$\sqrt{s} \leq 2m_f$ flavor.



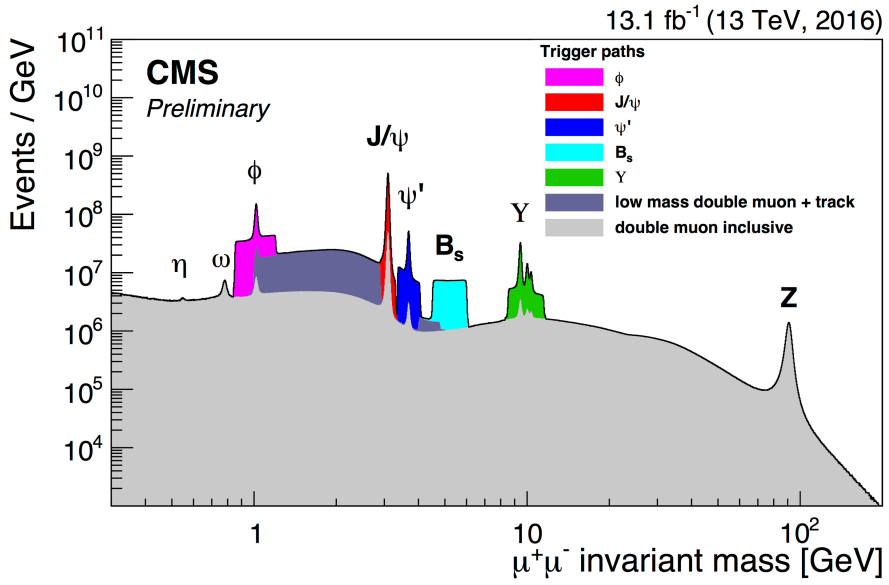
$$\sigma = \frac{86.8\ \text{nb}}{s\ [\text{GeV}^2]}$$

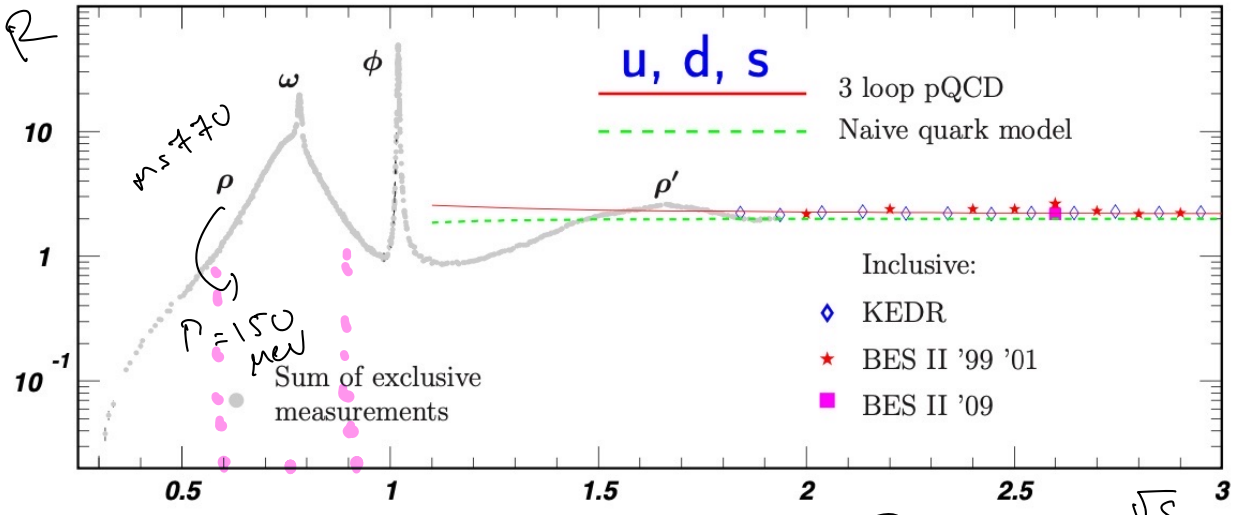
$\sqrt{s} = 1$ GeV.

$\Rightarrow \sigma = 86.8$ nb. $\simeq 10^{-7}$ b.

$= 10^{-4}$ mb.

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





BW: Γ Γ 70%

$\sqrt{s} > 2m_u, 2m_d, 2m_s$

$$R = \left[\left(\frac{2}{3}\right)^2 + \left(-\frac{1}{3}\right)^2 + \left(-\frac{1}{3}\right)^2\right] \times 3 = \frac{6}{9} \times 3 = 2.$$

ω(782) : Γ = 8.7 MeV

φ(1020) : Γ = 4 MeV

ρ(1570) Γ = 145 MeV

ρ(770) DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_1	$\pi\pi$	~ 100 %	
Γ_2	$K\overline{K}$		

ω(782) DECAY MODES

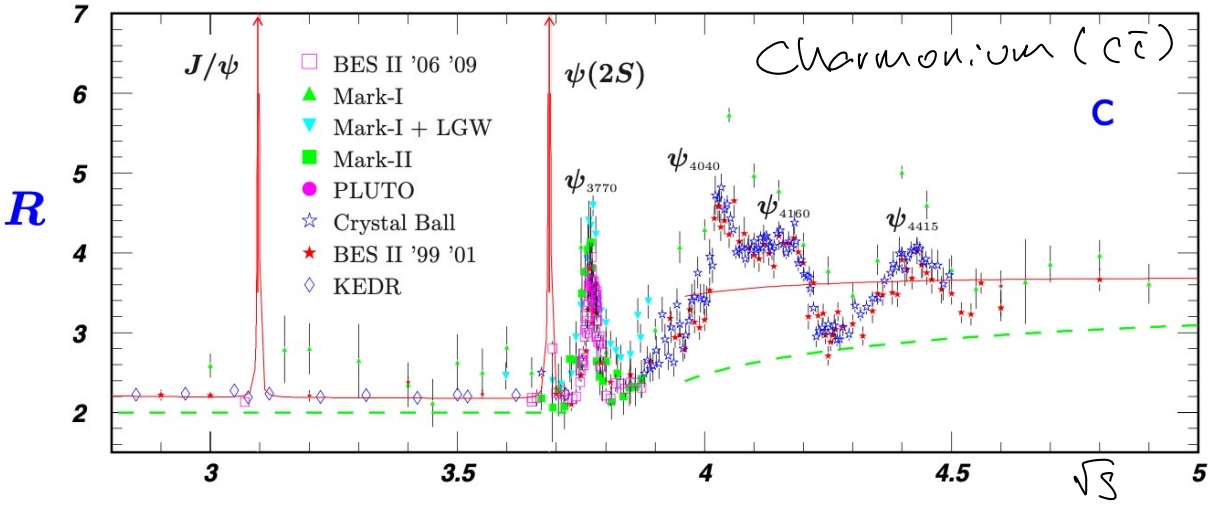
	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_1	$\pi^+\pi^-\pi^0$	(89.2 ±0.7) %	
Γ_2	$\pi^0\gamma$	(8.35±0.27) %	S=2.2
Γ_3	$\pi^+\pi^-$	($1.53^{+0.11}_{-0.13}$) %	S=1.2

$\phi(1020)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_1	K^+K^-	(49.1 ±0.5) %	S=1.3
Γ_2	$K^0_L K^0_S$	(33.9 ±0.4) %	S=1.2
Γ_3	$\rho\pi + \pi^+\pi^-\pi^0$	(15.4 ±0.4) %	S=1.2
Γ_4	$\rho\pi$		
Γ_5	$\pi^+\pi^-\pi^0$		
Γ_6	$\eta\gamma$	(1.301±0.025) %	S=1.2
Γ_7	$\pi^0\gamma$	(1.32 ±0.05) $\times 10^{-3}$	
Γ_8	$\ell^+\ell^-$	—	
Γ_9	e^+e^-	(2.979±0.033) $\times 10^{-4}$	S=1.3
Γ_{10}	$\mu^+\mu^-$	(2.85 ±0.19) $\times 10^{-4}$	

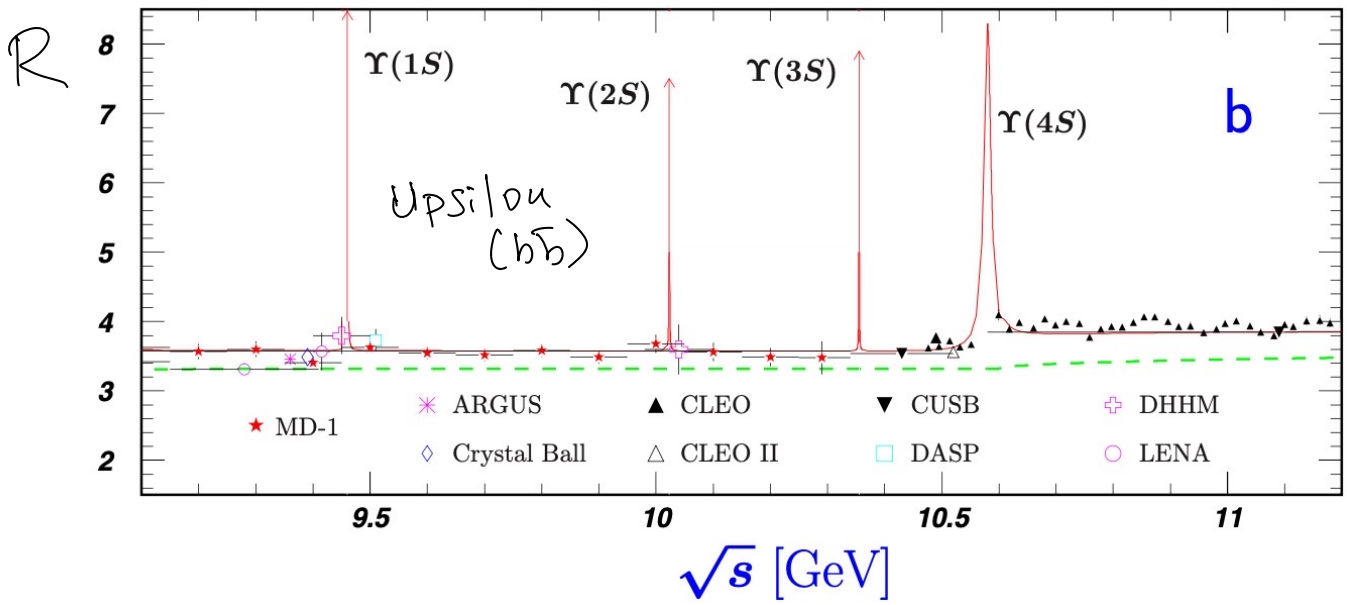
$\phi = (s\bar{s})$

$s\bar{u}\,s\bar{u}$



$R_{uds} = 2$

$R_{udsc} = R_{uds} + \left(\frac{2}{3}\right)^2 \times 3 = 2 + \frac{4}{9} \times 3 = 3 + \frac{1}{3}$

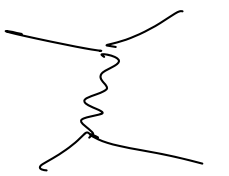


$R_{udsc} = 3$

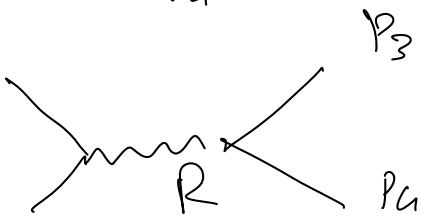
$R_{udscb} = R_{udsc} + \left(\frac{1}{3}\right)^2 \times 3 = 3 + \frac{2}{3}$

$$R = \frac{\#(e^+e^- \to \text{hadrons})}{\#(e^+e^- \to \mu^+\mu^-)}$$

$N = \sigma \cdot \mathcal{L}\,dt$

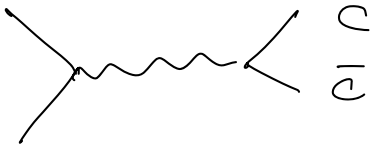


$(p_3+p_4)^2$ cannot be a resonance



$(p_3+p_4)^2 = M_R = \sqrt{s}$

Charmonium J/ψ $c\bar{c}$ 1974

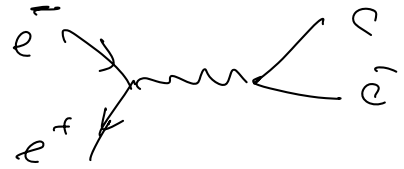


November 1974

1970: possibility of 4th quark charm.

GIM mechanism: Glashow-Iliopoulour-Maiani:

suppression $K^0 \to \mu^+\mu^-$

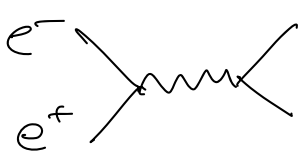
1) 

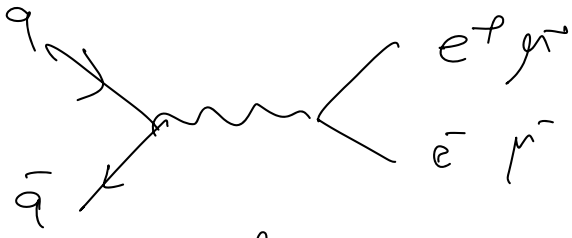
$e^\pm$ beams.

Richter @ SLAC
Stanford.

SPEAR: Stanford positron electron asym. ring

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

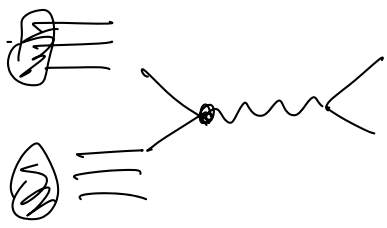


2) 

proton + fixed target

Ting @ Brookhaven
AGS.
Alternating gradient synchrotron.

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



Richter: ψ

Today J/ψ

Ting: J

$m = 3097$ MeV

$\Gamma = 0.087$ MeV

$\frac{\Gamma}{m} = 10^{-5}$

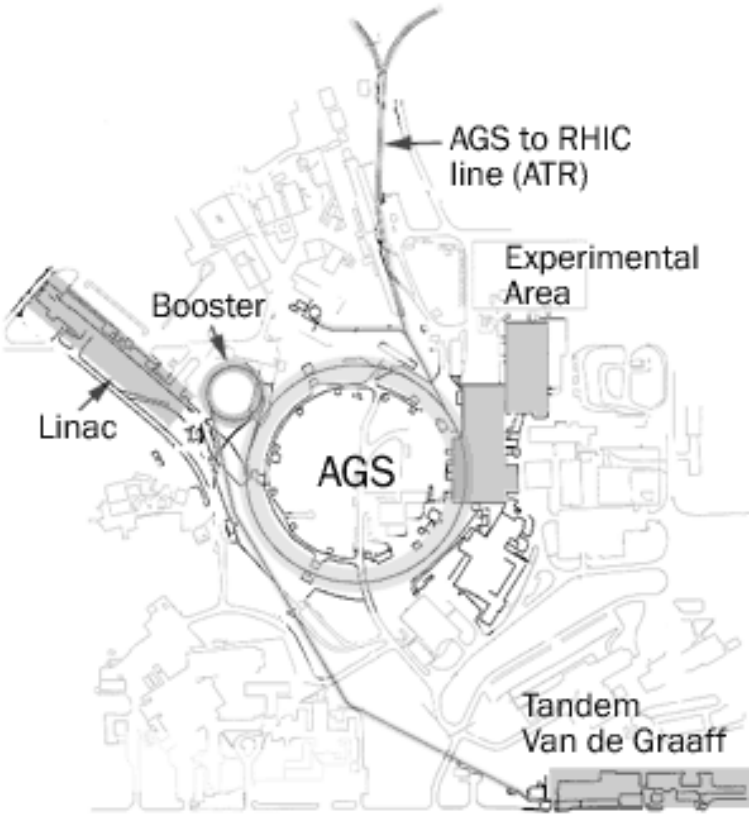
Ting J

$p + Be \rightarrow e^+e^- + X$

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

invariant mass $m(e^+e^-)$.

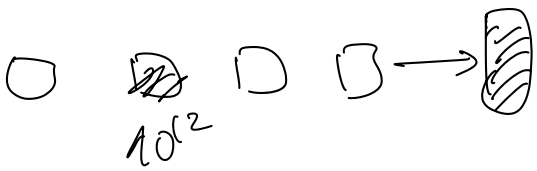
$m(\mu^+\mu^-)$



Fixed target

pulses of particles.

10^{12} particles per pulse.



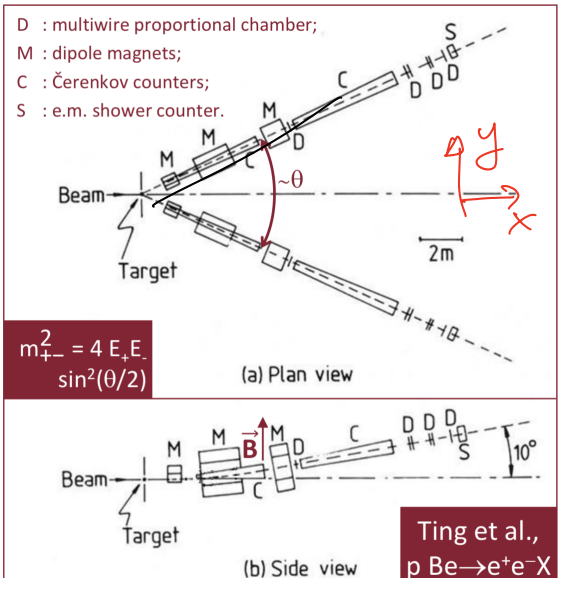
2-arm spectrometer

Rare events e^+e^- in final state

$p^+ = \underline{P}(e^+) = (E^+,\ p^+\cos\frac{\vartheta}{2},\ -p^+\sin\frac{\vartheta}{2})$

$p^- = \underline{P}(e^-) = (E^-,\ p^-\cos\frac{\vartheta}{2},\ +p^-\sin\frac{\vartheta}{2})$

$p \gg m_e \Rightarrow p^\pm \simeq E^\pm$



$$(p^+ + p^-)^2 = p^{+2} + p^{-2} + 2\,\underline{p}^+ \cdot \underline{p}^- = \sum m_e^2 + 2\left(E^+E^- - \vec{p}^+ \cdot \vec{p}^-\right)$$

$$\approx 2E^+E^- - 2E^+E^-\left(\cos^2\tfrac{\theta}{2} - \sin^2\tfrac{\theta}{2}\right)$$

$$= 2E^+E^-\left(1 - \cos^2\tfrac{\theta}{2} + \sin^2\tfrac{\theta}{2}\right)$$

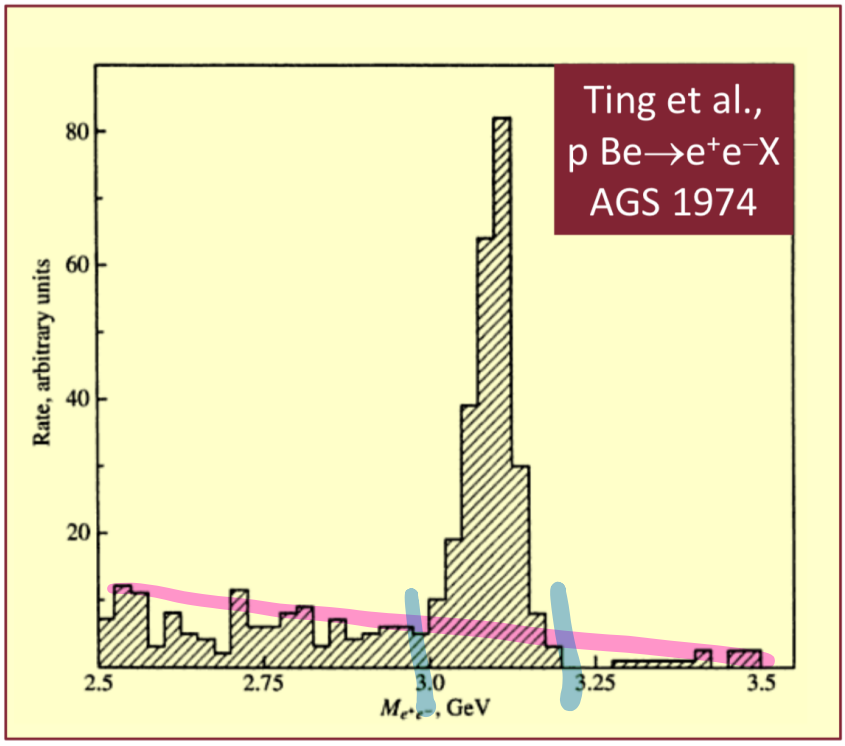
$$\cos^2\tfrac{\theta}{2} = 1 - \sin^2\tfrac{\theta}{2}.$$

$$= 4E^+E^-\sin^2\tfrac{\theta}{2} = M(e^+e^-)$$

$m_e^2 = (0.5\ \text{MeV})^2 = 0.25\ \text{MeV}^2$

$E \simeq 1$ GeV. $\quad E^+E^- \simeq (1000\ \text{MeV})^2 = 10^6\ \text{MeV}^2$

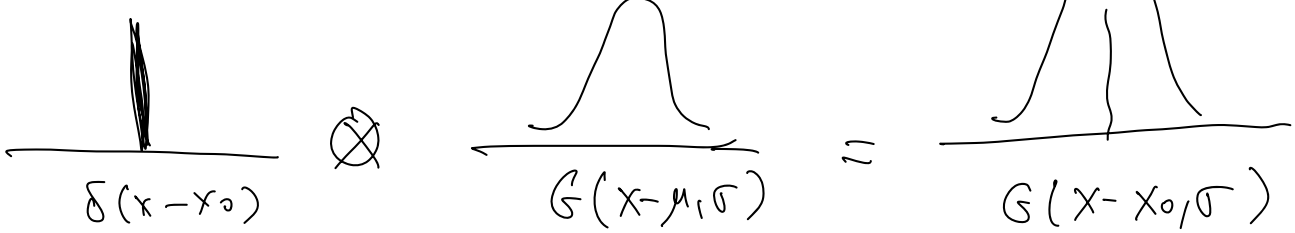
$\mu^+\mu^-$ 의 worse $M(\mu^+\mu^-)$ resolution because of multiple scattering.



$M = 3.1$ GeV

$3.0 \rightarrow 3.2$ GeV

$\Gamma_{Res} \simeq 30$ MeV



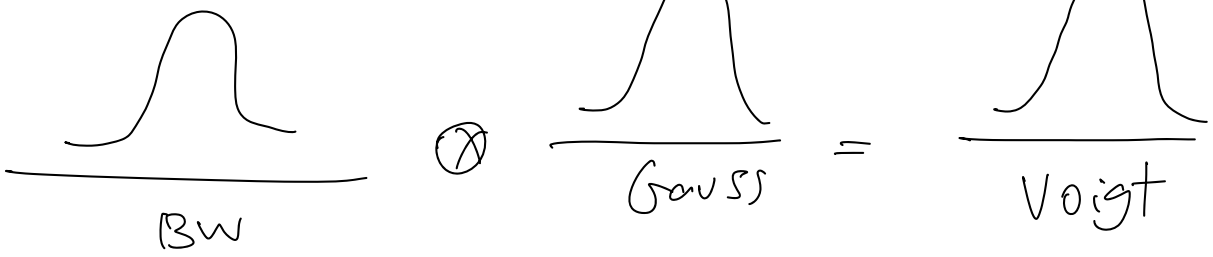
Theory physics.

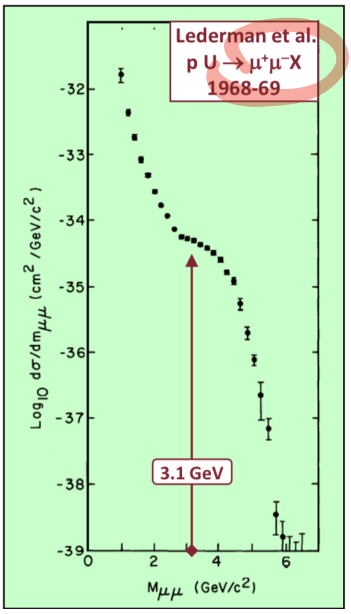
Experim. Resolution.

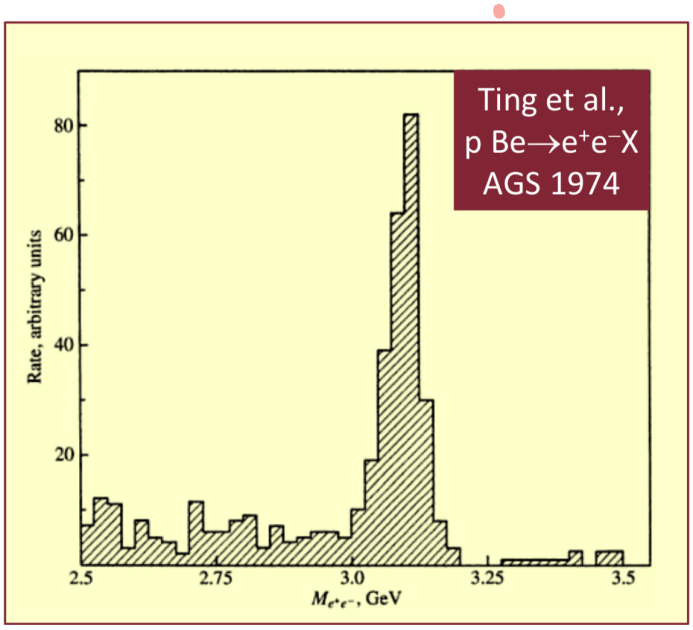
σ: exp. resolution.

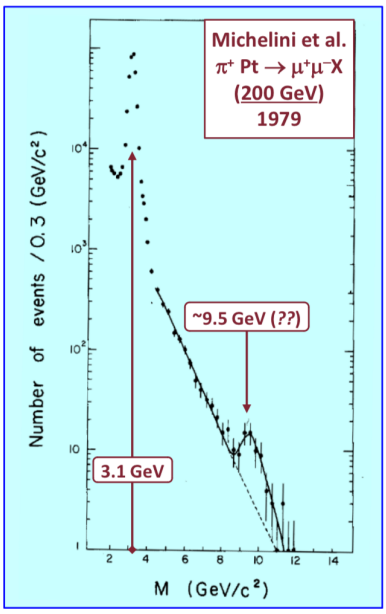
Good detec. : $\mu = 0$.

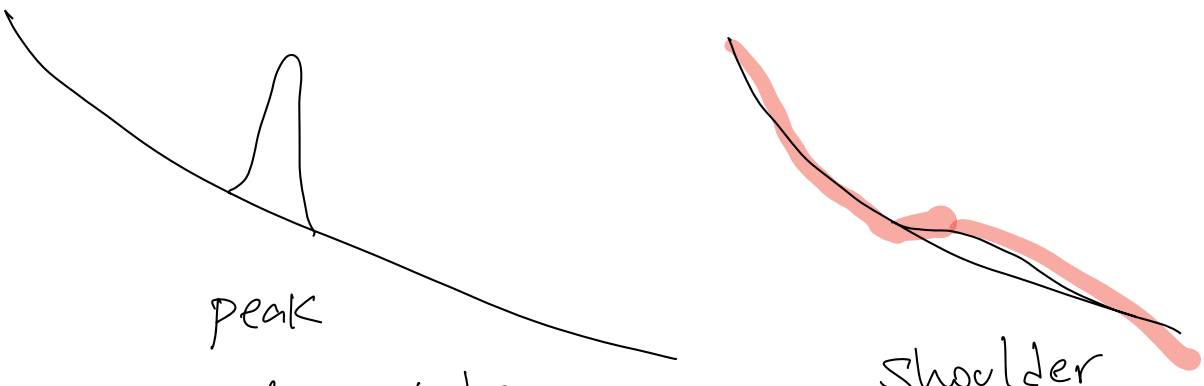
wide resonance.











$J^P = 1^-$