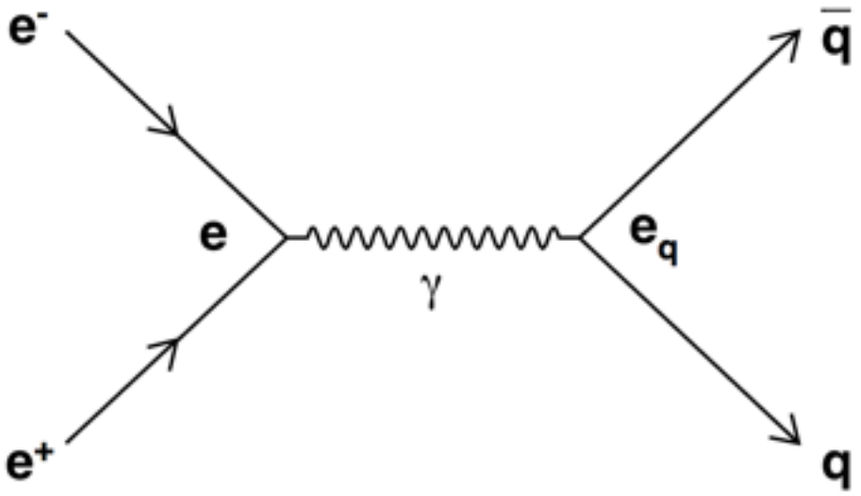
Vector Resonances in e^+e^- annihilation

resonance width $\mathbf{\Gamma}$ and lifetime $\boldsymbol{\tau}$ of resonant state

$$\Gamma\tau = \hbar$$

time-energy uncertainty relation

$$R = \frac{\sigma\,(\text{hadronic})}{\sigma\,(\mu\text{pair})} = \frac{\sigma\,(e^+e^- \to q\bar{q})}{\sigma\,(e^+e^- \to \mu^+\mu^-)} = (3colors)\Sigma_i q_i^2$$



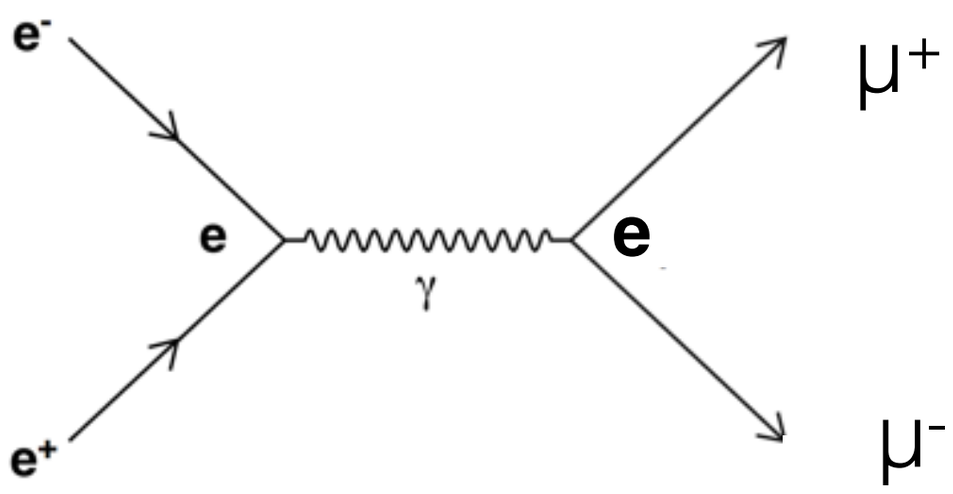
q_i = quark charge in units of e

jump in R when $E_{cm} > 2m_q$

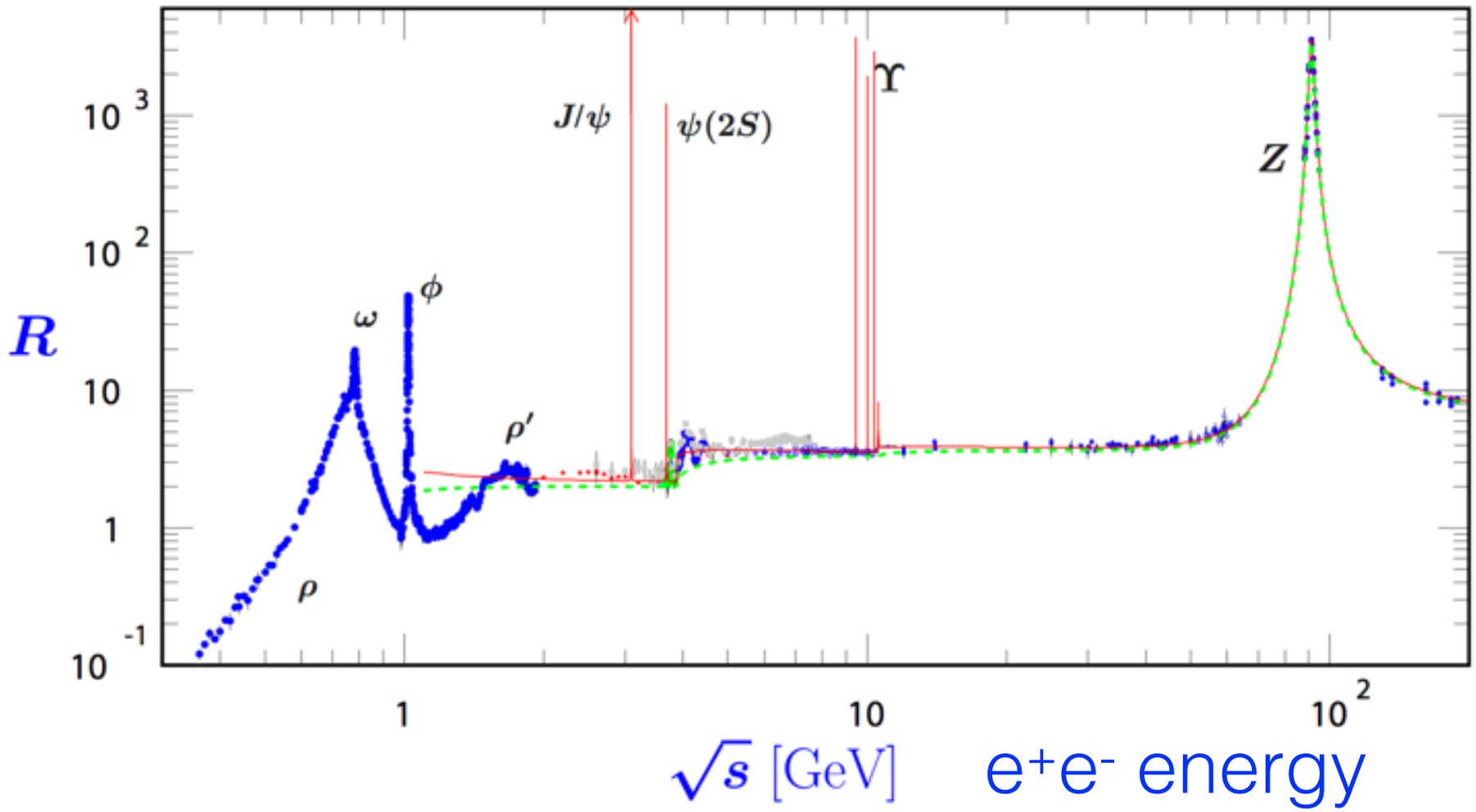
R(u+d+s) = 3(4+1+1)/9=2

R(u+d+s+c) =3(6+4)/9=10/3

R(u+d+s+c+b) =3(10+1)/9=11/3



very narrow vector resonances, Φ,J/Ψ ,Ψ(2s), ϒ



line shape is Breit-Wigner, ~long tailed Gaussian

FWHM $\boldsymbol{\Gamma} = \hbar/\boldsymbol{\tau}$ where $\boldsymbol{\tau}$ is resonance lifetime

J/Ψ surprisingly narrow.

Discovery of a Narrow Resonance in $e^+ e^-$ Annihilation*

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We have observed a very sharp peak in the cross section for $e^+e^- \to$ hadrons, e^+e^-, and possibly $\mu^+\mu^-$ at a center-of-mass energy of 3.105 ± 0.003 GeV. The upper limit to the full width at half-maximum is 1.3 MeV.

https://archive.org/details/CahnGoldhaberExperimentalFoundationsOfParticlePhysics

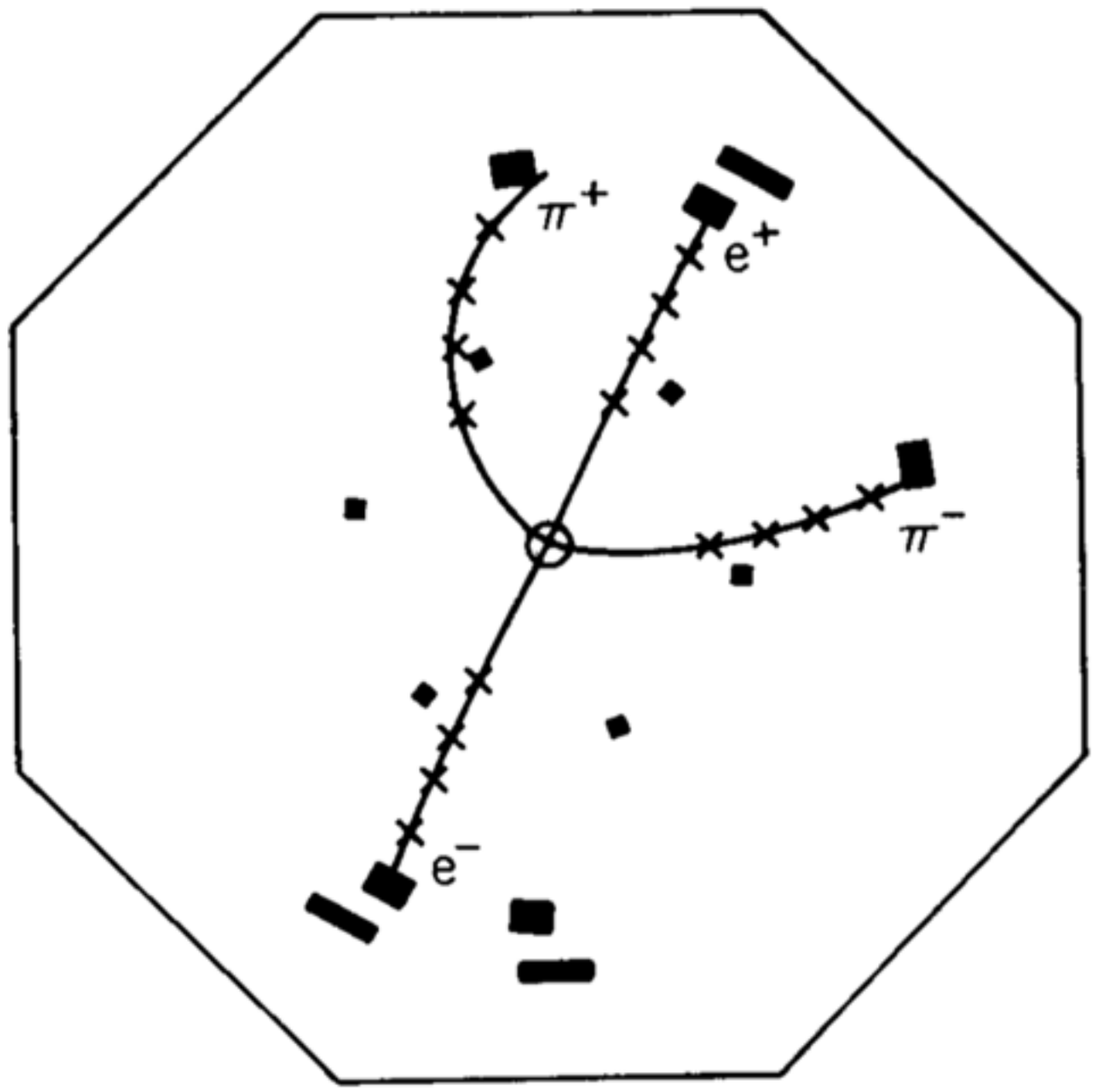
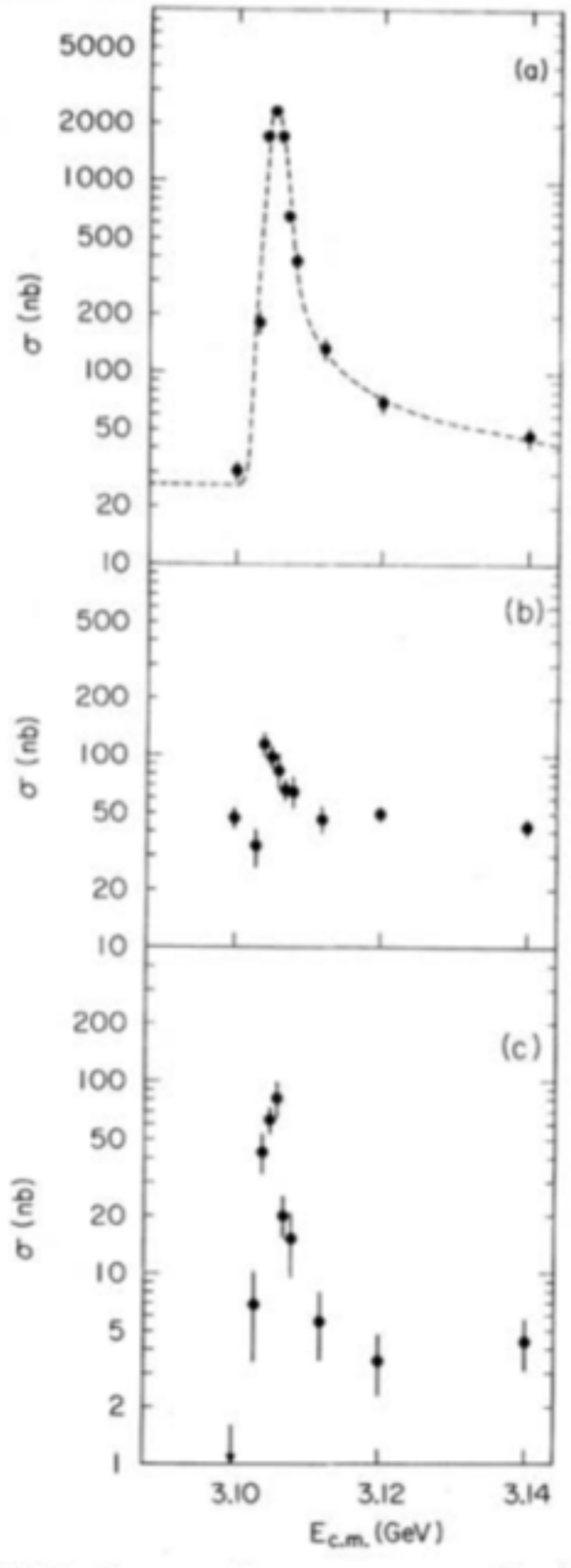


Figure 9.1. An example of the decay $\psi' \to \psi\pi^+\pi^-$ observed by the SLAC–LBL Mark I Collaboration. The crosses indicate spark chamber hits. The outer dark rectangles show hits in the time-of-flight counters. Ref. 9.5.



$E_{c.m.}$ (GeV)

FIG. 1. Cross section versus energy for (a) multihadron final states, (b) e^+e^- final states, and (c) $\mu^+\mu^-$, $\pi^+\pi^-$, and K^+K^- final states. The curve in (a) is the expected shape of a δ-function resonance folded with the Gaussian energy spread of the beams and including radiative processes. The cross sections shown in (b) and (c) are integrated over the detector acceptance. The total hadron cross section, (a), has been corrected for detection efficiency.

hadrons

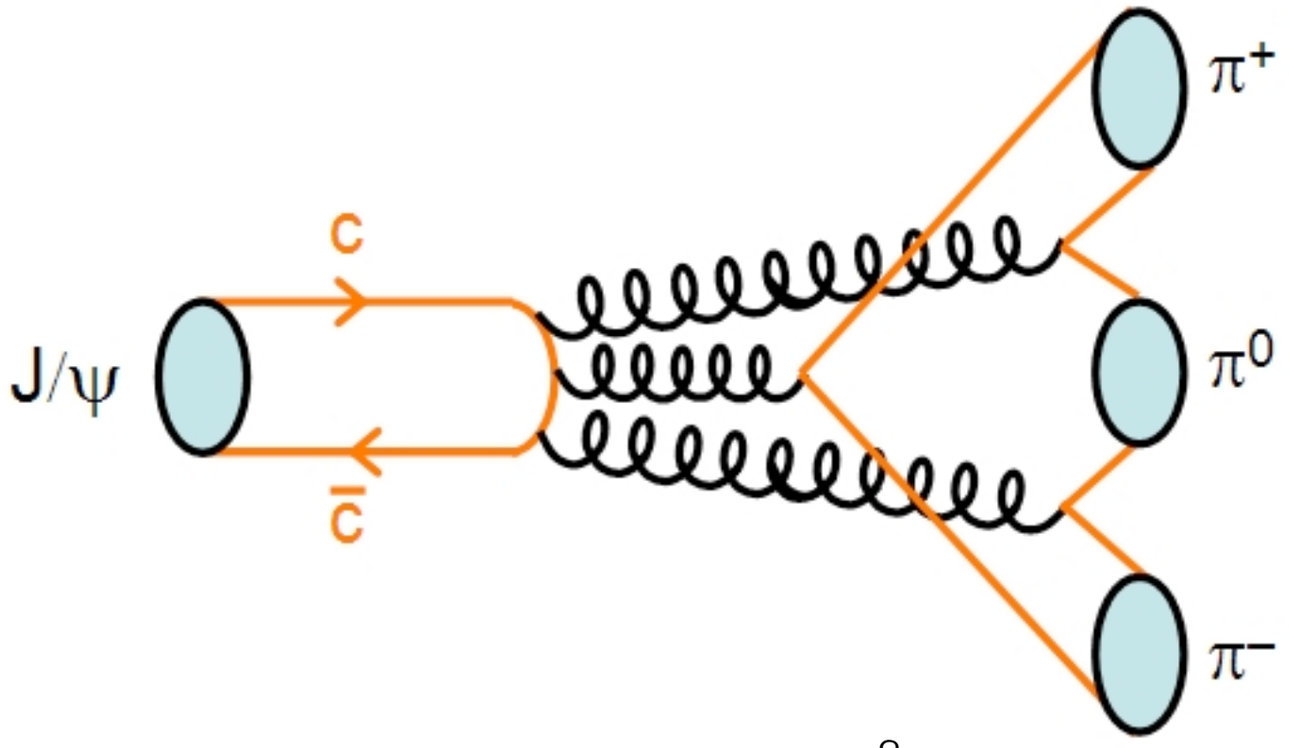
electron-positron

mostly muon-antimuon pairs

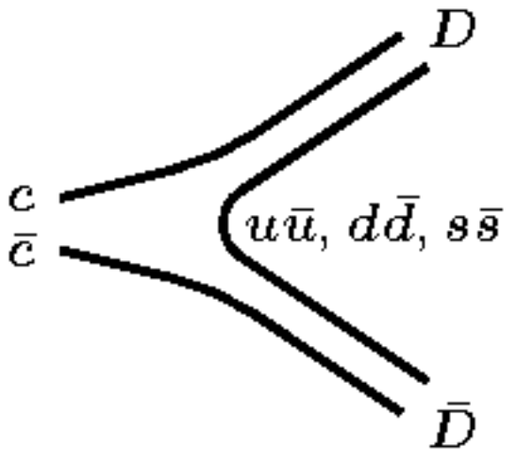
J/Ψ is lowest M charm-anti-charm bound state

Mass of resonance below “open charm” threshold decay to D mesons (u,c)

Strong decay through single gluon prevented by color conservation. Angular momentum conservation prevents vector resonances from decaying to two massless spin-one particles (gluons). Decay through 3 “hard gluon” suppressed (Zweig rule).



upper limit Γ <1.3 MeV on width due to resolution
best measured width now 93 keV or
$\tau = 6.6\times10^{-16}$ eV-s/$0.93\text{x}10^{5}$ eV=$6.7\text{x}10^{-21}$s
(typical strong resonance width ~ 100 MeV)



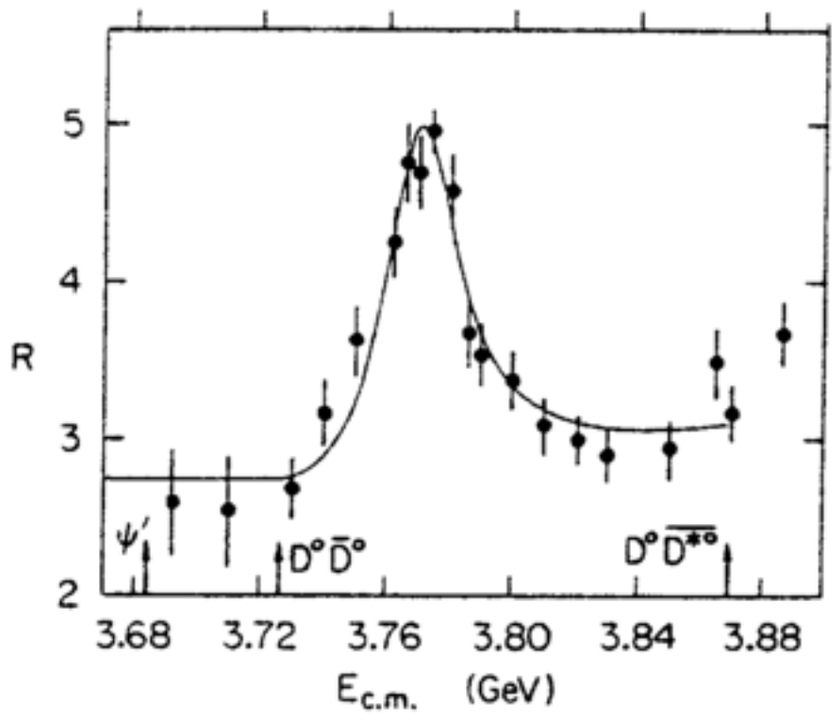
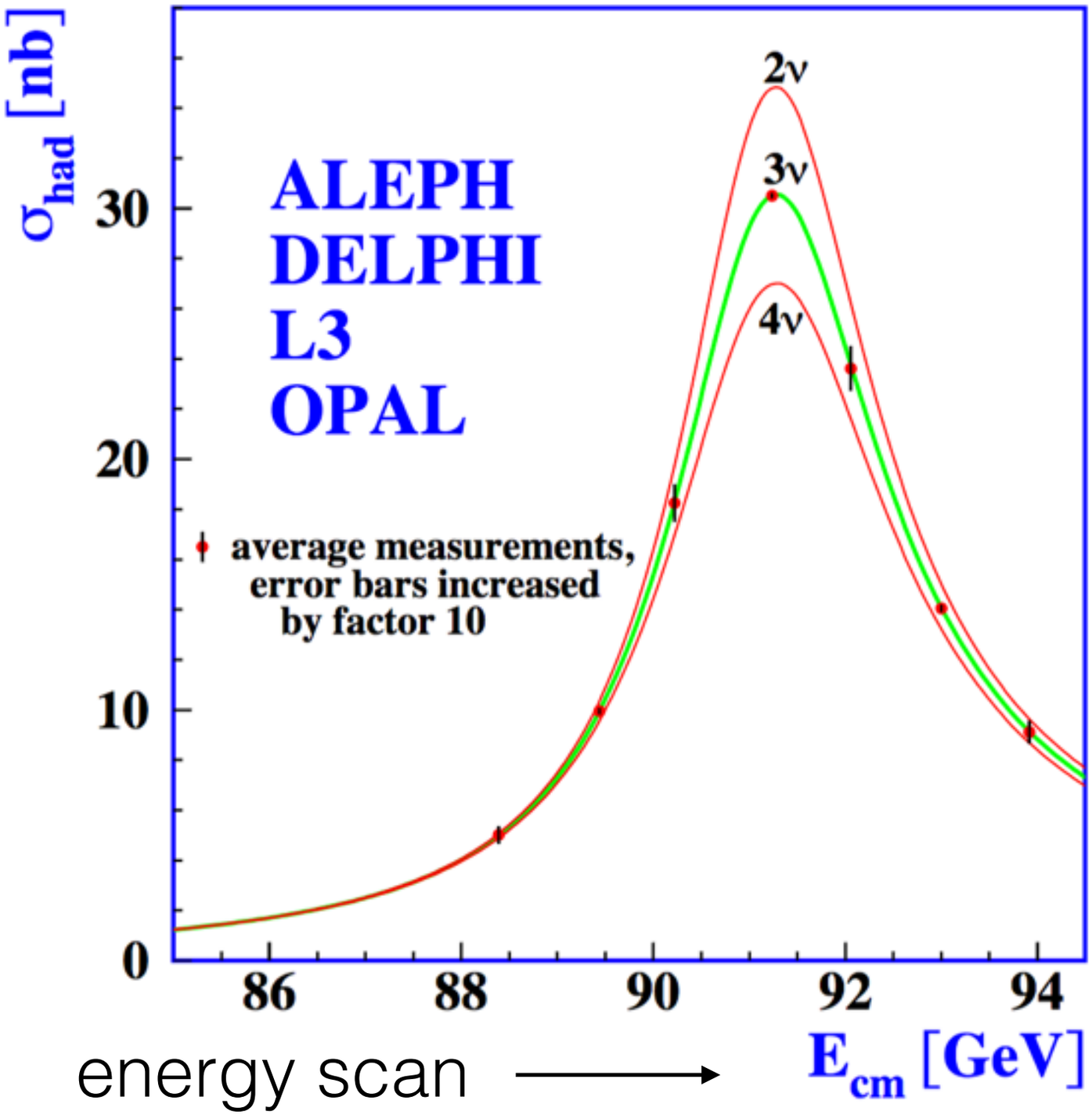


Figure 9.10. The $\psi(3772)$ resonance is broader than the $\psi(3096)$ and $\psi(3684)$ because it can decay into $D\overline{D}$. P. A. Rapidis *et al.*, (Ref. 9.14).

Z width and number of light neutrino species

https://arxiv.org/pdf/hep-ex/0509008.pdf



energy scan ⟶

$N_\nu = 2.984 \pm 0.008$

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