Line shape of states in e^+e^- annihilation and the role of below-threshold resonance

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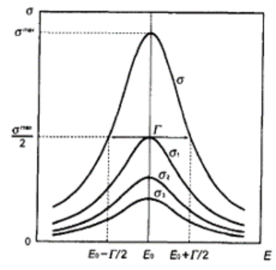
Introduction

Hadron spectrum

1. Hadron in ground state: objects with internal components
2. Hadron spectrum: excitation of internal freedom



Breit-Wigner resonances $\frac{M\Gamma}{s-M^2+iM\Gamma}$

$\Gamma \Longrightarrow$ decaying more or less to other hadrons ....

3. however, Reality is much more complicated because of background:

non-resonant contribution

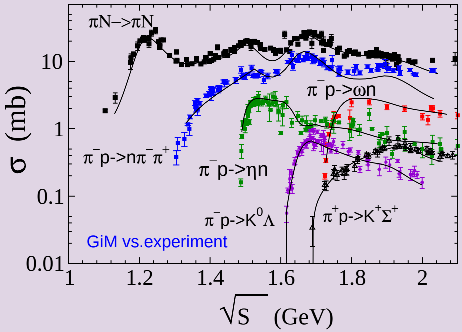
near-by resonances & thresholds

Introduction

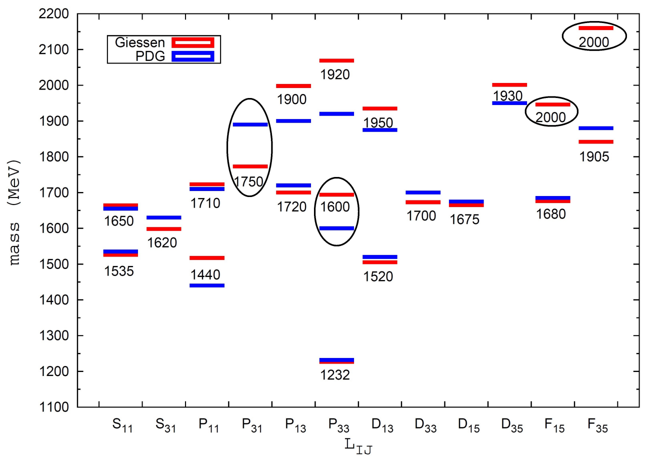
e.g. Baryon spectrum - N^* and Δ^*

1. Nucleon: objects with internal components and structure.
2. Baryon spectrum: excitation of internal freedom
   $\Longrightarrow$ must be wide > 100 MeV (coupled strongly to πN, ηN ....)

Reaction in Reality: X.C.& H.Lenske,PRC88(2013)055204;PLB772(2017)274



Introduction



Baryon spectrum in a coupled-channel model

H. Lenske, M. Dhar, T. Gaitanos, X.C., PPNP98(2018)119

Formula: Beyond Breit-Wigner resonance

$$\frac{M\sqrt{\Gamma_{tot}\Gamma_{i(s)}}}{s - M^2 + \mathrm{i}\sqrt{s}\sum_i \Gamma_{i(s)}}$$

1. the Flatté formula Flatté,PLB63(1976)224

$$\Gamma_{i(s)} = \Gamma_0 \left(\frac{p_{(s)}}{p_{(M^2)}}\right)^{2L+1} \frac{M}{\sqrt{s}} \left(\frac{F_L(p_0, p_{(s)})}{F_L(p_0, p_{(M^2)})}\right)^2$$

with $F_L(p_0, p_{(M^2)})$ being (Blatt-Weisskopf) form factor.

2. E.G. energy dependent width in p-wave: $\Gamma_{i(s)} = g_i \frac{p^3}{s(1+r^2p^2)}$

$p_{(s)}$: c.m. momenta of final particles
pure imaginary below threshold

Formula: Fano resonance

$$|F_{bg}|^2 \frac{|q+\varepsilon|^2}{1+\varepsilon^2} \qquad \text{with} \qquad \varepsilon = \frac{-s+M^2}{M\Gamma}$$

1. interplay of discrete states with continua Fano,PhysRev124(1961)1866

$$|\Psi\rangle = z_r|r\rangle + \sum_c \int_0^\infty dk_c z_c(k_c)|c\rangle$$

   is the wave function of the system.

2. After solving the coupled Schödinger equations Z.Y.Zhou session 3@Aug.17:

$$q = \frac{\langle b'|T|i\rangle}{\langle r'|T|i\rangle}$$

   determined by the wave functions of resonance and continuum.

3. producing a dip in line shape at the position of $q = -\varepsilon|_{s=s_0}$

Formula: Fano resonance

F_{bg}?   AND q?

1. We can construct models to calculate them!
2. q: energy dependent, but can be regraded as a constant in limited energy range of interest.
3. The form of background:

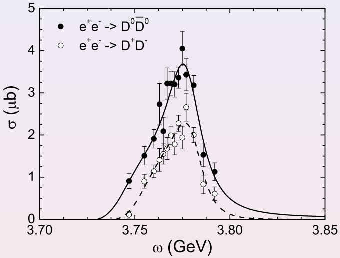
$$F_{bg} = \begin{cases} \text{Breit Wigner of } \psi(3686) & \text{for } \psi(3770) \\ \frac{A_B}{\tau^2 \ln^2(s/\Lambda^2_{QCD})} & \text{for } \Lambda \text{ EFF} \end{cases}$$

which is the main uncertainties!

Results: $\psi(3770)$

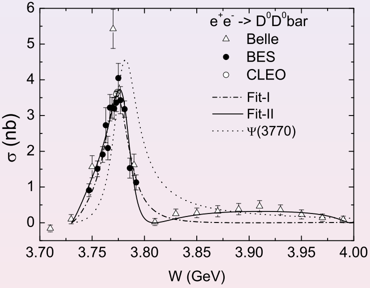
- non-resonant background:
$$\psi(2S) = \psi(3686)$$
- main difference is from q, $\psi(3770)$ is the same in both channels.

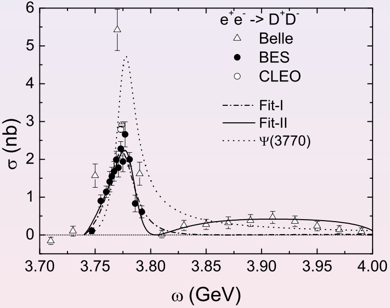
X. C., H. Lenske, arXiv:1410.1375; 1408.5600.



	$D^0\bar{D}^0$	D^+D^-
$m_{\psi'}$ (MeV)	3782.1 ± 1.6	3784.0 ± 2.0
$g_{\psi' D\bar{D}}$	11.8 ± 0.9	10.7 ± 1.3
q	-2.1 ± 0.3	-1.6 ± 0.3
m_{bg} (MeV)	3743.0 ± 5.4	3753.3 ± 3.9
Γ_{bg} (MeV)	34.1 ± 5.2	33.3 ± 5.6
$\chi^2/d.o.f$	0.83	0.90

Results: $\psi(3770)$

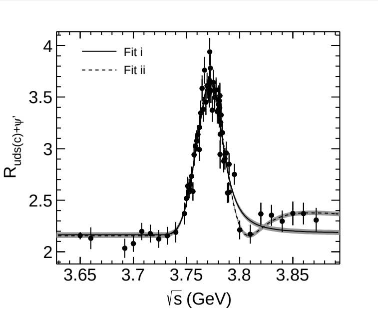


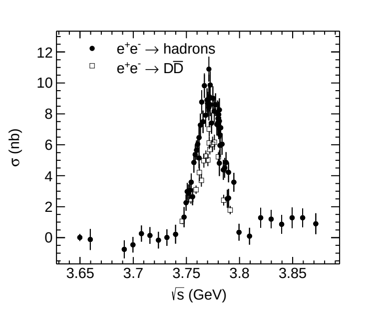


- in a parameterized coupled-channel formalism
- Fit-I: $\psi(3686)$ and $D\bar{D}$ channel
- Fit-II: $\psi(4040)$ and $D^*\bar{D} + h.c.$ channel also added

X. C., H. Lenske, arXiv:1410.1375; 1408.5600.

Results: $\psi(3770)$





- R_{uds} value in the vicinity of $\psi(3770)$ state
- $R_{uds} = 2.156 \pm 0.022$ after correction of line shape
- Fit-I: $g_{\psi(3770)\gamma}$ fixed
- Fit-II: $g_{\psi(3770)\gamma}$ non-fixed

- Extracted $e^+e^- \to hadrons$ Versus $e^+e^- \to D\bar{D}$
- non-$D\bar{D}$ decay of $\psi(3770)$?

Rong Wang, X. C., Xurong Chen, PLB747(2015)321

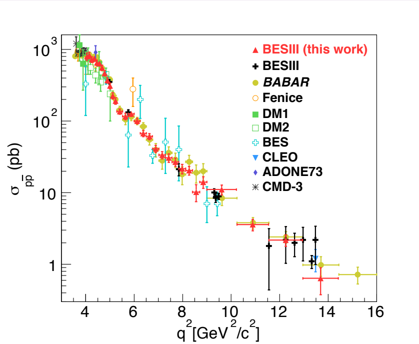
Results: Λ electromagnetic form factor (EFF)

- proton EFF: follows pQCD expectation:

$$\frac{A_B}{\tau^2 \ln^2(s/\Lambda^2_{QCD})}$$

BESIII, PRD99(2019)092002

- Some small structures:
  resonances?
  thresholds opening?
- threshold enhancement



Results: Λ electromagnetic form factor (EFF)

- non-resonant background:
  $\phi(2170)$ and pQCD
- The second errors are obtained by varying the mass and width of $\phi(2170)$

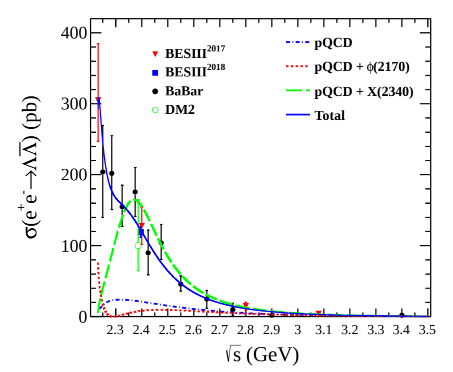
X. C., Jian-Ping Dai, Ya-Ping Xie, PRD98(2018)094006

- A vector meson as in $p\bar{p} \to \Lambda\bar{\Lambda}$?

D. V. Bugg, EPJC 36(2004)161

$\mathrm{M} = 2.338 \pm 0.046 \pm 0.030$

$\Gamma = 257 \pm 159 \pm 41$



q_1^0	q_2^0	A_Λ
$6.32 \pm 2.22 \pm 2.95$	$-2.53 \pm 0.93 \pm 0.35$	$1.19 \pm 0.46 \pm 0.09$

Conclusion

- A parameterization originated from Fano resonance is discussed
  - easy to use for both theoretical and experimental purposes
  - directly connected to underlying nature of resonance
- We use it to study line shape of states in e^+e^- annihilation
- The role of below threshold resonance
- Other interesting cases?
- Thanks for the attention!!!

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  - close-to-threshold enahncement of Λ EFF: $\phi(2170)$?
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Spares: Abstract for HADRON2019

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We give a parameterizztion of the anomalous line shape of resonances based on a Fano-type formula, which can be widely used to extract properties of resonances from data. We employ it to explain the anomalous line shape of the $e^+e^- \to D\bar{D}$ and $e^+e^- \to \Lambda\bar{\Lambda}$. In both reactions, a below-threshold state is found to play significant role in the measured cross sections.

1. Xu Cao, Jian-Ping Dai, Ya-Ping Xie, Phys. Rev. D98 (2018) 094006;
2. Rong Wang, Xu Cao, Xurong Chen, Phys. Lett. B747 (2015) 321-324;
3. Xu Cao, H. Lenske, arXiv:1410.1375;1408.5600 [nucl-th].