Theoretical study of light vector mesons around 2.0 GeV

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2025 年超级陶粲装置研讨会， 湘潭
2025 年 7 月 2-6 日

主要内容

- 研究背景
- 在谱学支撑下对ρ介子产生过程的分析
- 总结

1

研究背景

为什么要研究轻介子态

Photo from the Nobel Foundation archive.

Hideki Yukawa
The Nobel Prize in Physics 1949

Born: 23 January 1907, Tokyo, Japan

Died: 8 September 1981, Kyoto, Japan

Affiliation at the time of the award: Columbia University, New York, NY, USA; Kyoto University, Kyoto, Japan

Prize motivation: "for his prediction of the existence of mesons on the basis of theoretical work on nuclear forces"

Prize share: 1/1

Photo from the Nobel Foundation archive.

Cecil Frank Powell
The Nobel Prize in Physics 1950

Born: 5 December 1903, Tonbridge, United Kingdom

Died: 9 August 1969, Italy

Affiliation at the time of the award: Bristol University, Bristol, United Kingdom

Prize motivation: "for his development of the photographic method of studying nuclear processes and his discoveries regarding mesons made with this method"

Prize share: 1/1

Rev.Mod.Phys.71:1411-1462,1999

"Meson physics and the strong interactions have been intimately connected since pions were first introduced by Yukawa to explain the inter-nucleon force ."
——**S. Godfrey and J. Napolitano: Light-meson spectroscopy**

为什么要研究轻介子

一些奇特强子态与传统介子的量子数是相同的，对轻味介子的研究是寻找和鉴别一些奇特强子态的基础

A Structure at 2175-MeV in $e^+e^- \to \phi$ f0(980) Observed via Initial-State Radiation #2

BaBar Collaboration • Bernard Aubert (Barcelona U., ECM) et al. (Oct, 2006)

Published in: *Phys.Rev.D* 74 (2006) 091103 • e-Print: hep-ex/0610018 [hep-ex]

pdf links DOI cite claim reference search 216 citations

Determination of Spin-Parity Quantum Numbers of $X(2370)$ as 0^{-+} from $J/\psi \to \gamma K_S^0 K_S^0 \eta'$ #1

BESIII Collaboration • Medina Ablikim (Beijing, Inst. High Energy Phys.) et al. (Dec 8, 2023)

Published in: *Phys.Rev.Lett.* 132 (2024) 18, 181901 • e-Print: 2312.05324 [hep-ex]

pdf DOI cite claim reference search 40 citations

CERN-EP-2021-025
LHCb-PAPER-2020-044
March 2, 2021

Observation of new resonances decaying to $J/\psi K^+$ and $J/\psi\phi$

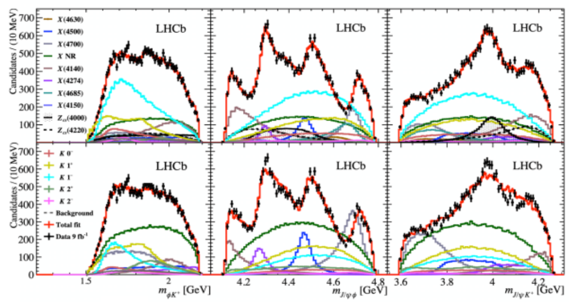
LHCb collaboration†

Abstract

The first observation of exotic states with a new quark content $c\bar{c}u\bar{s}$ decaying to the $J/\psi K^+$ final state is reported with high significance from an amplitude analysis of the $B^+ \to J/\psi\phi K^+$ decay. The analysis is carried out using proton-proton collision data corresponding to a total integrated luminosity of $9\,\text{fb}^{-1}$ collected by the LHCb experiment at centre-of-mass energies of 7, 8 and 13 TeV. The most significant state, $Z_{cs}(4000)^+$, has a mass of $4003 \pm 6\,^{+\,4}_{-14}$ MeV, a width of $131 \pm 15 \pm 26$ MeV, and spin-parity $J^P = 1^+$, where the quoted uncertainties are statistical and systematic, respectively. A new 1^+ $X(4685)$ state decaying to the $J/\psi\phi$ final state is also observed with high significance. In addition, the four previously reported $J/\psi\phi$ states are confirmed and two more exotic states, $Z_{cs}(4220)^+$ and $X(4630)$, are observed with significance exceeding five standard deviations.

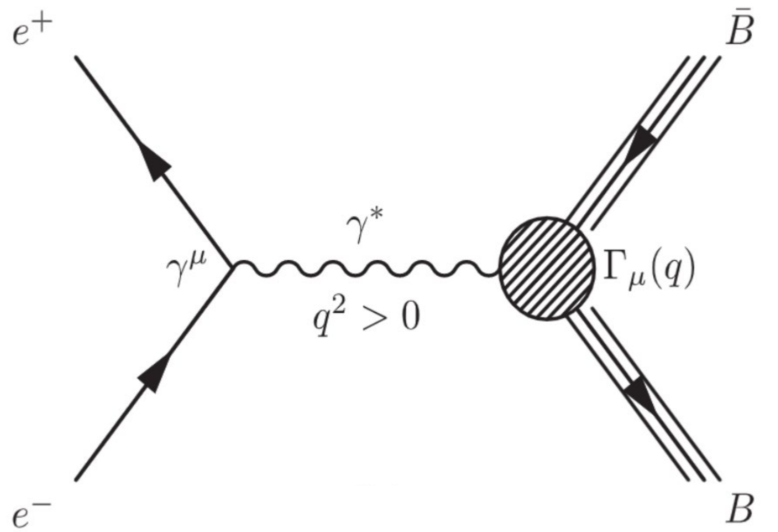
Submitted to Phys. Rev. Lett.

†Authors are listed at the end of this paper.



K介子家族

为什么要研究轻介子



e^+e^-湮灭过程研究

重子**类时电磁形状因子**

以及一些**阈值增强现象**

与**矢量介子的性质**

紧密相关

Timelike nucleon electromagnetic form factors: All about interference of isospin amplitudes #7

Xu Cao (Lanzhou, Inst. Modern Phys. and Beijing, GUCAS), Jian-Ping Dai (Yunnan U.), Horst Lenske (Giessen U.) (Sep 30, 2021)

Published in: *Phys.Rev.D* 105 (2022) 7, L071503 • e-Print: 2109.15132 [hep-ph]

pdf DOI cite claim reference search 10 citations

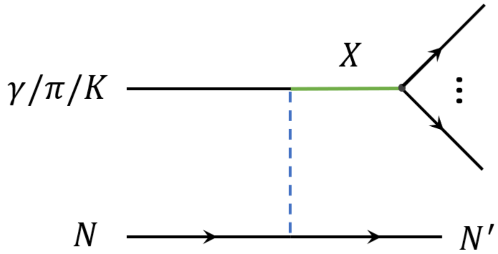
Electromagnetic Form Factors of Λ Hyperon in the Vector Meson Dominance Model and a Possible Explanation of the Near-Threshold Enhancement of the Reaction #1

Zhong-Yi Li (Lanzhou, Inst. Modern Phys. and Beijing, GUCAS), An-Xin Dai (Lanzhou, Inst. Modern Phys. and Beijing, GUCAS), Ju-Jun Xie (Lanzhou, Inst. Modern Phys. and Beijing, GUCAS and Zhengzhou U. and Lanzhou U.) (Jul 22, 2021)

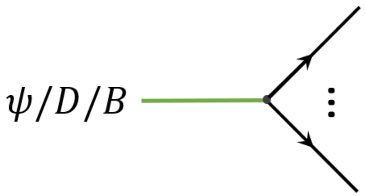
Published in: *Chin.Phys.Lett.* 39 (2022) 1, 011201, *Chin.Phys.Lett.* 39 (2022) 011201 • e-Print: 2107.10499 [hep-ph]

pdf DOI cite claim reference search 11 citations

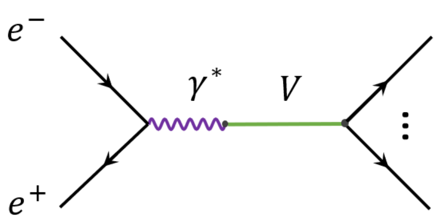
高能物理实验发现了丰富的轻介子态



COMPASS, J-PARC, GlueX



BESIII, Belle, LHCb



BESIII, BaBar, Belle

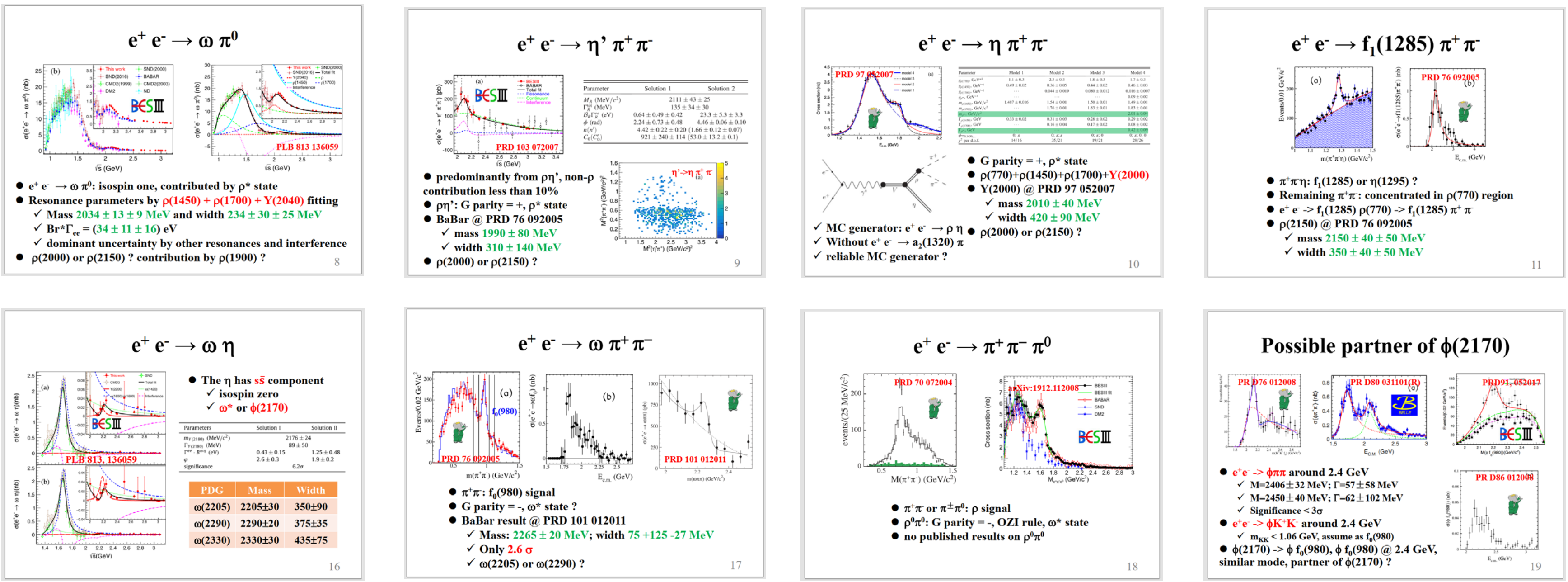
研究**矢量介子态**的天然平台！

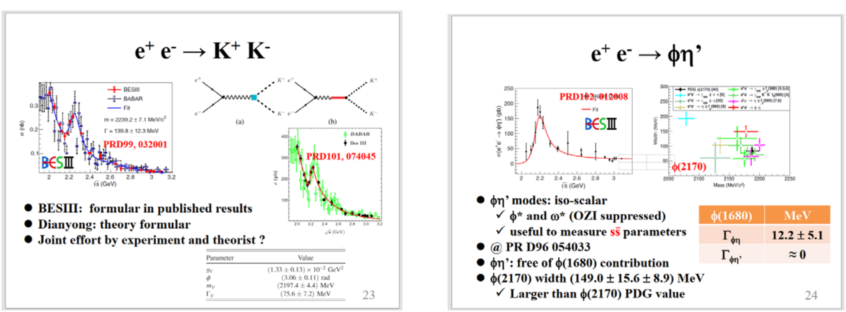
PDG 2022

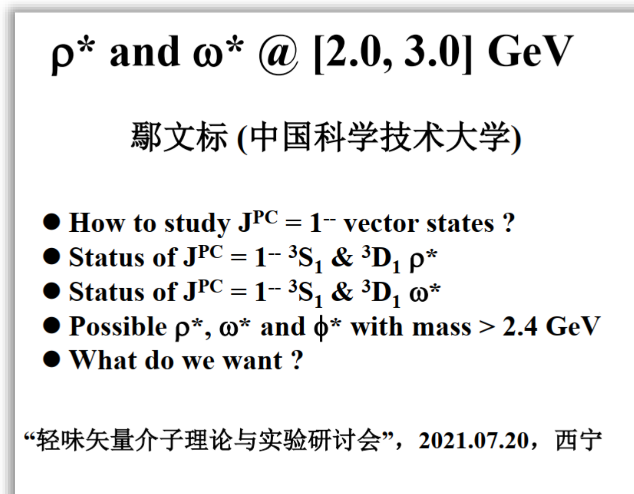
$n^{2s+1}\ell_J$	J^{PC}	$I=1$ $u\bar{d}$, $\bar{u}d$, $\frac{1}{\sqrt{2}}(d\bar{d}-u\bar{u})$	$I=\frac{1}{2}$ $u\bar{s}$, $d\bar{s}$; $\bar{d}s$, $\bar{u}s$	$I=0$ f'	$I=0$ f
1^1S_0	0^{-+}	π	K	η	$\eta'(958)$
1^3S_1	1^{--}	$\rho(770)$	$K^*(892)$	$\phi(1020)$	$\omega(782)$
1^1P_1	1^{+-}	$b_1(1235)$	$K_{1B}{}^{a}$	$h_1(1415)$	$h_1(1170)$
1^3P_0	0^{++}	$a_0(1450)$	$K_0^*(1430)$	$f_0(1710)$	$f_0(1370)$
1^3P_1	1^{++}	$a_1(1260)$	$K_{1A}{}^{a}$	$f_1(1420)$	$f_1(1285)$
1^3P_2	2^{++}	$a_2(1320)$	$K_2^*(1430)$	$f_2'(1525)$	$f_2(1270)$
1^1D_2	2^{-+}	$\pi_2(1670)$	$K_2(1770)^{a}$	$\eta_2(1870)$	$\eta_2(1645)$
1^3D_1	1^{--}	$\rho(1700)$	$K^*(1680)^{b}$	$\phi(2170)^{d}$	$\omega(1650)$
1^3D_2	2^{--}		$K_2(1820)^{a}$		
1^3D_3	3^{--}	$\rho_3(1690)$	$K_3^*(1780)$	$\phi_3(1850)$	$\omega_3(1670)$
1^3F_4	4^{++}	$a_4(1970)$	$K_4^*(2045)$	$f_4(2300)$	$f_4(2050)$
1^3G_5	5^{--}	$\rho_5(2350)$	$K_5^*(2380)$		
2^1S_0	0^{-+}	$\pi(1300)$	$K(1460)$	$\eta(1475)^{c}$	$\eta(1295)$
2^3S_1	1^{--}	$\rho(1450)$	$K^*(1410)^{b}$	$\phi(1680)$	$\omega(1420)$
2^3P_1	1^{++}	$a_1(1640)$			
2^3P_2	2^{++}	$a_2(1700)$	$K_2^*(1980)$	$f_2(1950)$	$f_2(1640)$

2 GeV附近的轻介子态
还没有被建立起来

e^+e^-湮灭实验在2GeV能区积累了丰富的数据

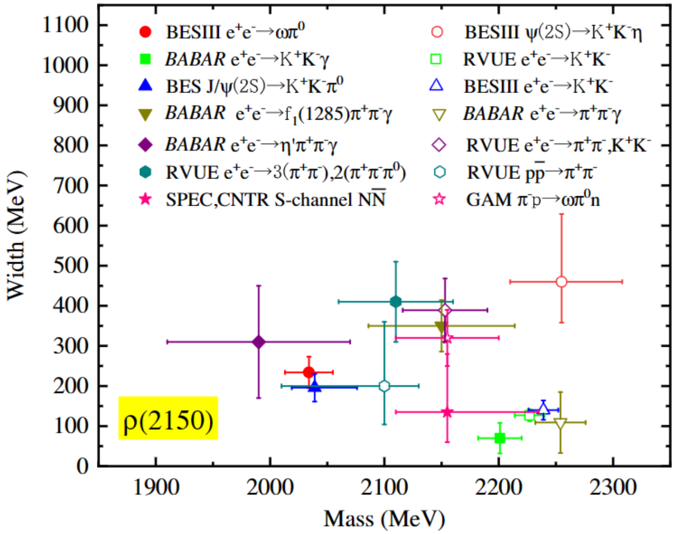


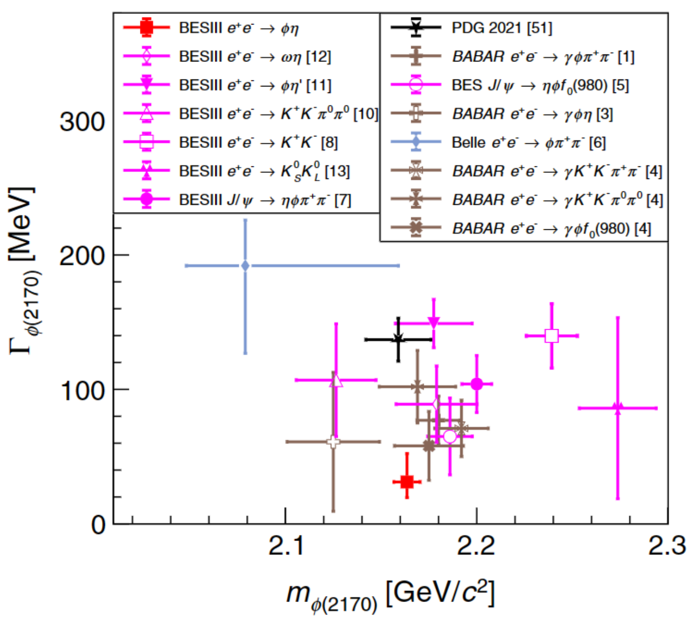




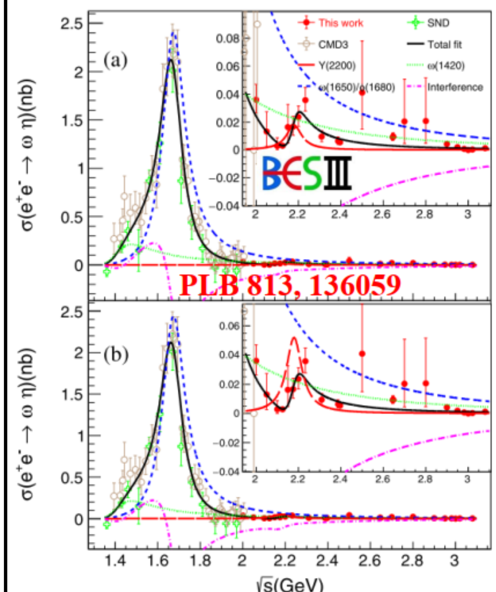
共振态参数存在很大差异，
难以统一解释！

2 GeV附近矢量轻介子的态共振态参数测量结果





$e^+ e^- \to \omega\,\eta$



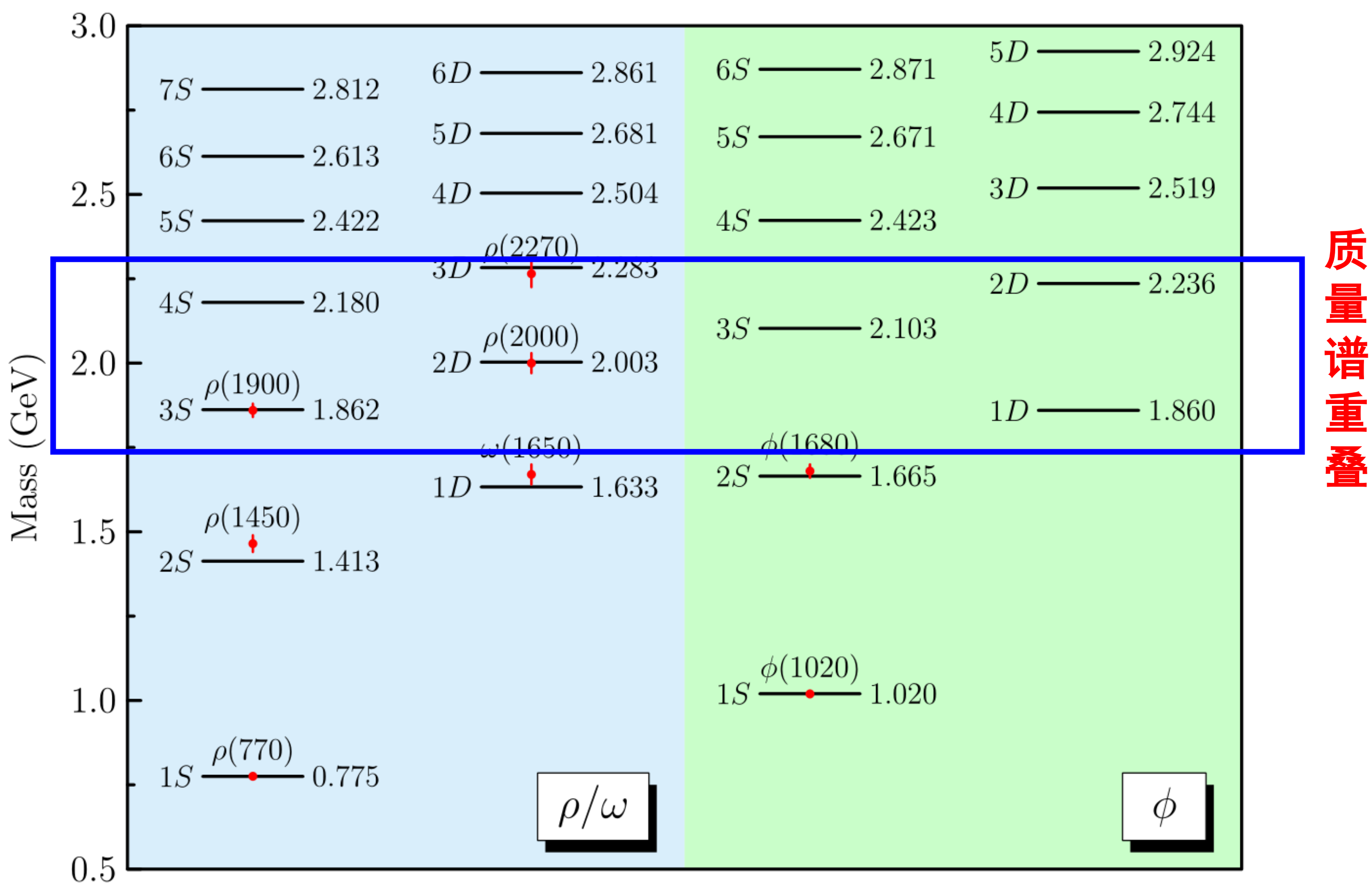
- The η has $s\bar{s}$ component
  - ✓ isospin zero
  - ✓ ω* or φ(2170)

Parameters	Solution I	Solution II
$m_{Y(2180)}$ (MeV/c^2)	2176 ± 24	
$\Gamma_{Y(2180)}$ (MeV)	89 ± 50	
$\Gamma^{ee} \cdot B^{\omega\eta}$ (eV)	0.43 ± 0.15	1.25 ± 0.48
φ	2.6 ± 0.3	1.9 ± 0.2
significance	6.2σ	

PDG	Mass	Width
ω(2205)	2205±30	350±90
ω(2290)	2290±20	375±35
ω(2330)	2330±30	435±75

通过对比共振态参数的实验和理论结果的方法来建立2 GeV能区的矢量介子态失效了。

矢量轻介子质量谱（MGI）



随着能级的增加质量间隔逐渐变小，干涉效应凸显出来，这给实验测量和理论计算的精度都提出了更高的要求。

$\rho(1450)$ 和 $\rho(1700)$ 的建立

Nuclear Physics B58 (1973) 31-44

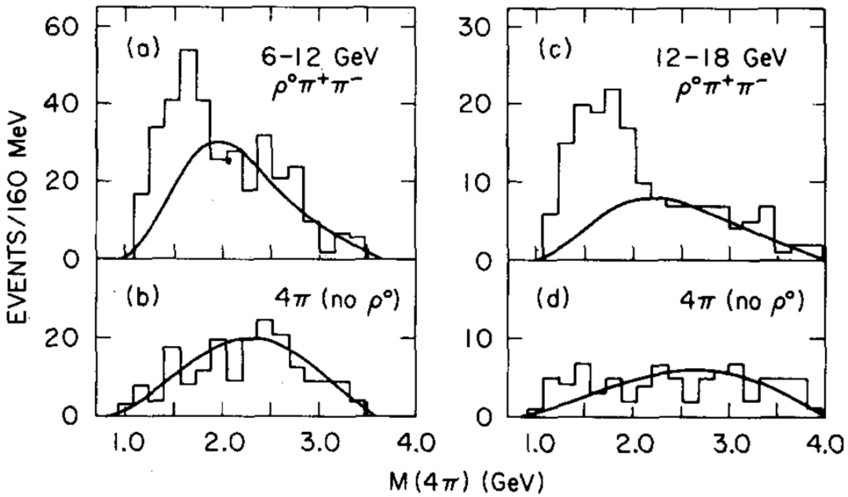


Fig. 7. $\gamma p \to \pi^+\pi^-\pi^+\pi^- p$. Four-pion invariant mass distributions with Δ^{++} excluded.

Photon energy (GeV)	6–12	12–18
Mass (MeV)	1622 ± 20	1624 ± 50
Width (MeV)	265 ± 90	433 ± 100

PDG 1976

Data Card Listings

For notation, see key at front of Listings.

$\rho'(1600)$ $\to 4\pi$

65 RHO PRIME(1600,JPG=1-+) I=1

The ρ' was first seen in

γ (real or virtual) $\to \rho'^0 \to \rho^0\pi^+\pi^-$

with the $\pi^+\pi^-$ pair apparently in an S wave

(BINGHAM 72, DAVIER 73, SCHACHT 74, ALEXANDER 75).

PDG 1988

$\rho(1450)$ $I^G(J^{PC}) = 1^+(1^{--})$

OMITTED FROM SUMMARY TABLE

This entry contains claims for vector mesons in the 1250–1500 MeV range. Needs confirmation. See the mini-review under the $\rho(1700)$.

$\rho(1700)$ $I^G(J^{PC}) = 1^+(1^{--})$

NOTE ON $\rho(1450)$ AND $\rho(1700)$

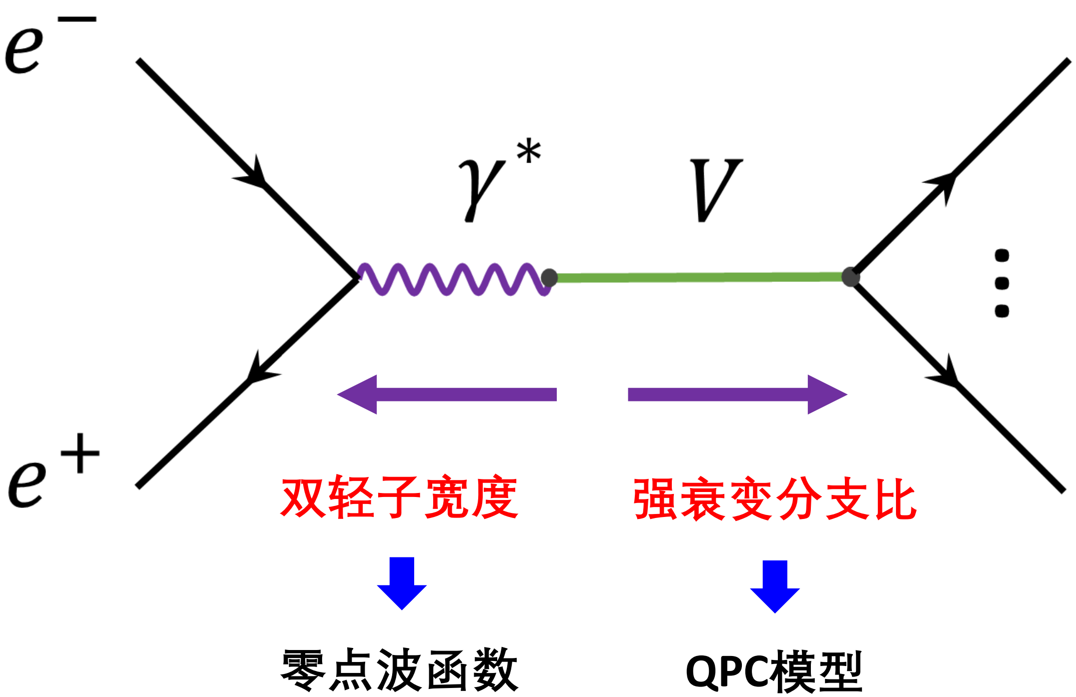
Early indications that the 1600 MeV mass region may contain two 1^{--} resonances were given by COSME 79, BARBER 80, DIBIANCA 81.

干涉效应给实验准确抽取共振参数带来很大的影响，

谨慎对待实验的共振态参数测量结果，关注数据点！

质量谱和衰变性质支撑下对截面数据的研究

在质量谱和衰变性质的支撑下，中间态贡献大小被确定



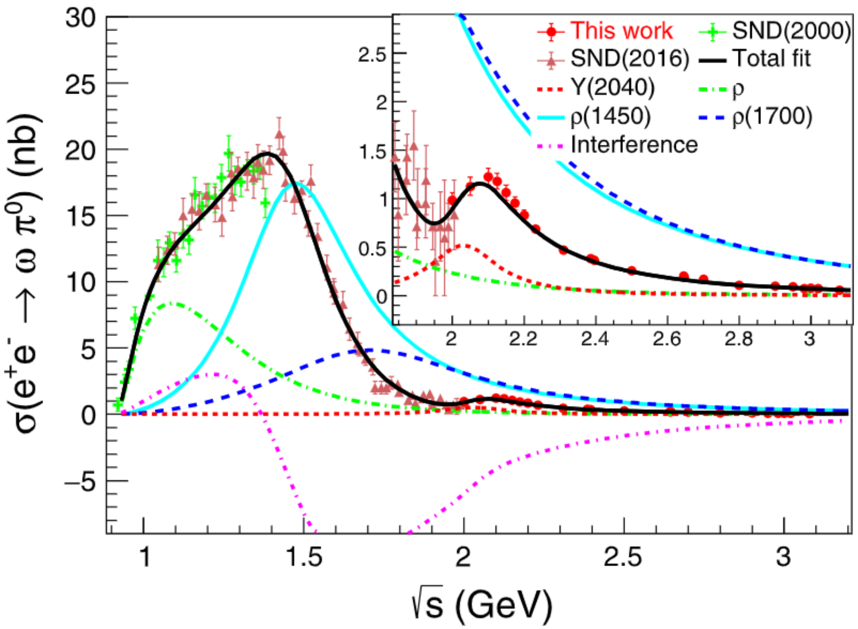
从质量谱、衰变性质和产生过程全方位地认识，
避免盲人摸象带来的理解偏差！

2

谱学支撑下对ρ介子产生过程的分析

$e^+e^- \to \omega\pi^0$和$a_2(1320)\pi$的截面测量结果

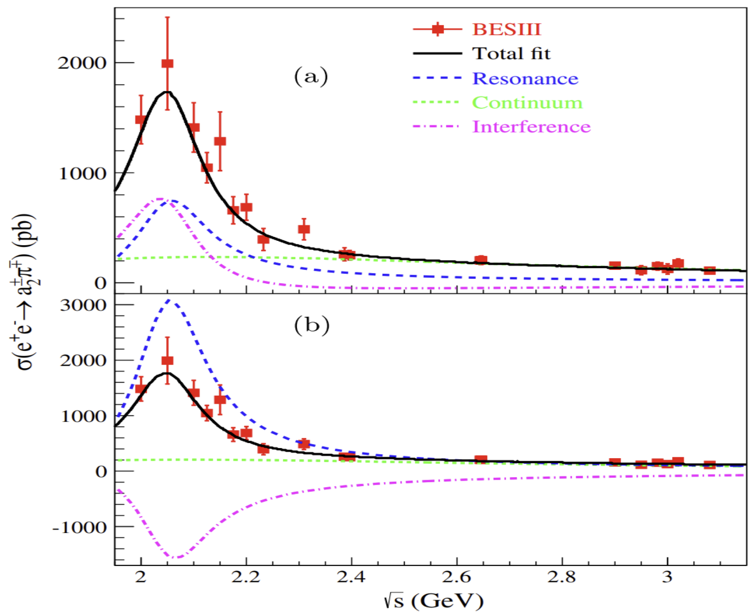
BESIII: Physics Letters B 813 (2021) 136059



$$M = 2034 \pm 13\ \text{MeV},$$
$$\Gamma = 234 \pm 30\ \text{MeV},$$
$$\Gamma_{ee}B(\omega\pi^0) = 34 \pm 11\ \text{eV}$$

Another structure is observed in the $\omega\pi^0$ cross section with a significance of more than 10σ and with a mass of $m = (2034 \pm 13 \pm 9)\,\text{MeV}/c^2$, width of $\Gamma = (234 \pm 30 \pm 25)\,\text{MeV}$ and $\Gamma^{ee} \cdot B^{\omega\pi^0}$ of $(34 \pm 11 \pm 16)$ eV. This structure could either be the $\rho(2000)$ or the $\rho(2150)$ state. However, the mass and width of the observed resonance is closer to the $\rho(2000)$ resonance, which is suggested to be the 2^3D_1 state [41].

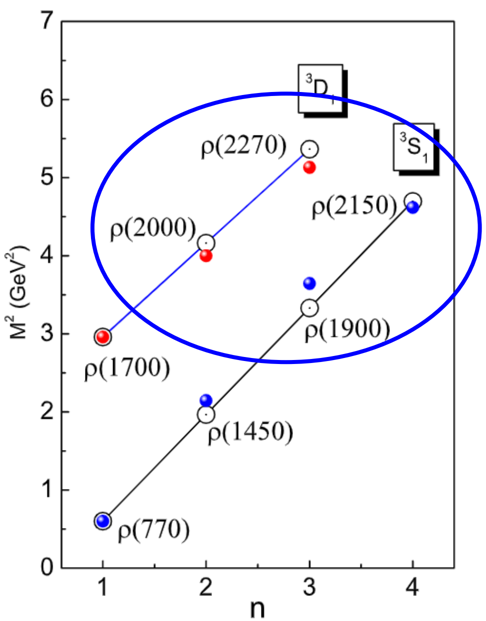
BESIII: Phys. Rev. D 108, L111101 (2023)

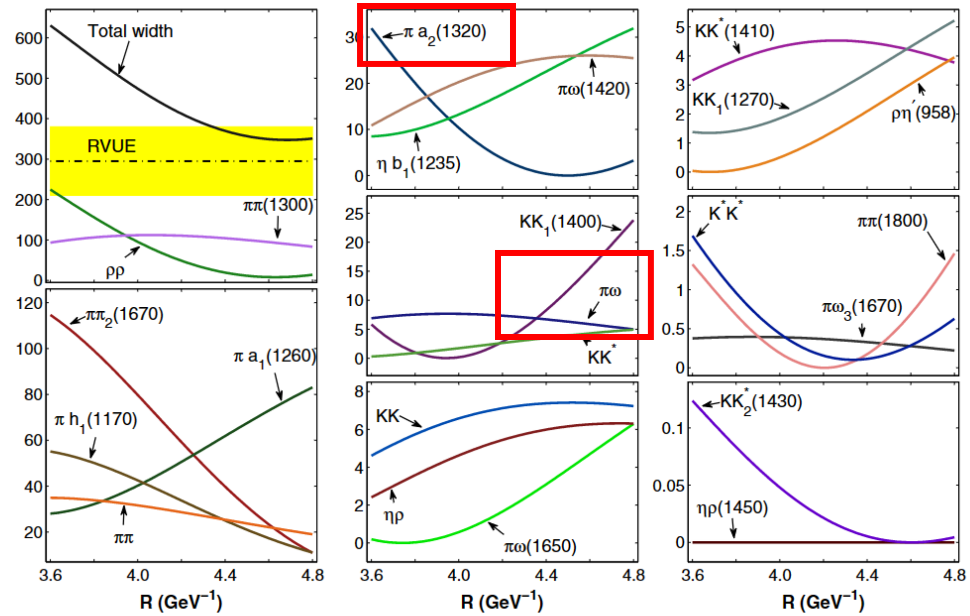


$$M = 2044 \pm 31 \pm 4\ \text{MeV},$$
$$\Gamma = 163 \pm 69 \pm 24\ \text{MeV},$$
$$\Gamma_{ee}B(a_2\pi) = 34.6 \pm 17.1 \pm 6.0$$
$$(137.1 \pm 73.3 \pm 2.1)\ \text{eV}$$

$(137.1 \pm 73.3 \pm 2.1)$ eV, respectively. The observed structure agrees with the properties of the $\rho(2000)$ resonance observed in $e^+e^- \to \omega\pi^0$ [49], which indicates the first observation of the decay $\rho(2000) \to a_2(1320)\pi$. To further

$Y(2040)$作为$\rho(2^3D_1)$态的困难





PHYS. REV. D 102, 034037

State	M_{exp} (MeV)	R (GeV^{-1}) [6]	$\Gamma_{e^+e^-}$ (keV)
$\rho(1900)$	$1909 \pm 17 \pm 25$ [16]	$3.85 \sim 4.28$	$0.1958 \sim 0.1578$
$\rho(2150)$	2150 ± 17 [6]	$4.74 \sim 4.98$	$0.0888 \sim 0.0806$
$\rho(2000)$	2000 ± 30 [38]	$4.34 \sim 4.80$	$0.0204 \sim 0.0160$
$\rho(2270)$	2265 ± 40 [31]	$4.40 \sim 4.80$	$0.0163 \sim 0.0129$

$\rho(2^3D_1)$态的双轻子宽度约为20 eV，且远小于$\rho(4^3S_1)$的双轻子宽度

如果$Y(2034) \equiv Y(2044) \equiv \rho(2D) \Rightarrow Br\big(\rho(2D) \to \omega\pi^0/a_2(1320)\pi\big) > 100\%$！

两个问题：

1. 为什么联合分支比存在量级上的差异？
2. 为什么没有观测到$\rho(2150)$的信号？

The ground states and the first radially excited states of D-wave vector ρ and ϕ mesons #27

Guo-Liang Yu (North China Electric Power U., Baoding), Zhi-Gang Wang (North China Electric Power U., Baoding), Xiu-Wu Wang (North China Electric Power U., Baoding), Hui-Juan Wang (North China Electric Power U., Baoding) (Feb 22, 2021)

Published in: *Int.J.Mod.Phys.A* 36 (2021) 27, 2150197, *Int.J.Mod.Phys.A* 36 (2021) 2150197 • e-Print: 2102.11078 [hep-ph]

pdf DOI cite claim reference search 2 citations

Assignments of the Y(2040), ρ(1900), and ρ(2150) in the quark model #28

Zheng-Ya Li (Zhengzhou U.), De-Min Li (Zhengzhou U.), En Wang (Zhengzhou U.), Wen-Cheng Yan (Zhengzhou U.), Qin-Tao Song (Zhengzhou U.) (Feb 10, 2021)

Published in: *Phys.Rev.D* 104 (2021) 3, 034013 • e-Print: 2102.05356 [hep-ph]

pdf DOI cite claim reference search 13 citations

$Y(2034) \equiv \rho(2^3D_1)$

TABLE IV. Decay widths of $Y(2040)$ as the $\rho(2^3D_1)$ (in MeV), the initial mass is set to be 2034 MeV and the masses of all the final states are taken from PDG [2].

Channel	Mode	$\rho(2^3D_1)$	Mode	$\rho(2^3D_1)$
$1^- \to 0^-0^-$	$\pi\pi$	19.77	KK	0.32
	$\pi\pi(1300)$	14.81	$KK(1460)$	0.30
	$\pi\pi(1800)$	1.28		
$1^- \to 0^-1^-$	$\boxed{\pi\omega}$	$\boxed{6.31}$	$\rho\eta'$	0.013
	$\rho\eta$	2.17	KK^*	0.015
	$\omega(1420)\pi$	6.68	$\omega(1650)\pi$	0.14
	$KK^*(1410)$	0.57	$\rho(1450)\eta$	0.51
$1^- \to 1^-1^-$	$\rho\rho$	36.38	K^*K^*	0.13
$1^- \to 0^-1^+$	$a_1(1260)\pi$	26.60	$h_1(1170)\pi$	35.20
	$KK_1(1400)$	0.098	$b_1(1235)\eta$	6.23
	$KK_1(1270)$	0.19		
$1^- \to 0^-2^+$	$\boxed{a_2(1320)\pi}$	$\boxed{9.76}$	$KK_2^*(1430)$	0.027
$1^- \to 0^-2^-$	$\pi\pi_2(1670)$	39.15		
$1^- \to 0^-3^-$	$\pi\omega_3(1670)$	0.19		
$1^- \to 1^-1^+$	$b_1(1235)\rho$	15.86	$a_1(1260)\omega$	5.20
Total width		227.91		
Experiment		$234 \pm 30 \pm 25$ [1]		

(1) The screening effects play an important role in studying the masses of $Y(2040)$, $\rho(1900)$, $\rho(2150)$, and $\rho(3^3D_1)$, and mass gaps around 100 MeV appear when we compare the MGI model predictions with the ones of the GI model.

(2) The newly observed state $Y(2040)$ should be the same state as $\rho(2000)$ which is omitted in the summary table of PDG [2], since they share the similar resonance parameters [1,16,30].

(3) The $Y(2040)$, $\rho(1900)$, and $\rho(2150)$ can be interpreted as the $\rho(2^3D_1)$, $\rho(3^3S_1)$, and $\rho(4^3S_1)$ states, respectively.

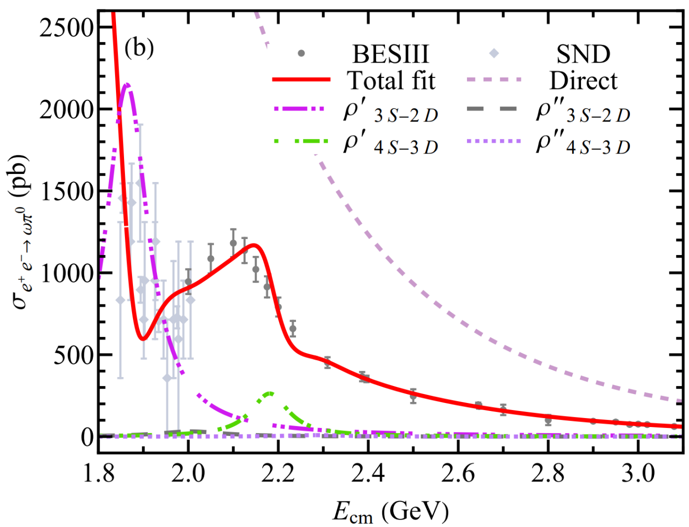
在Fano干涉的框架下理解$Y(2044)$

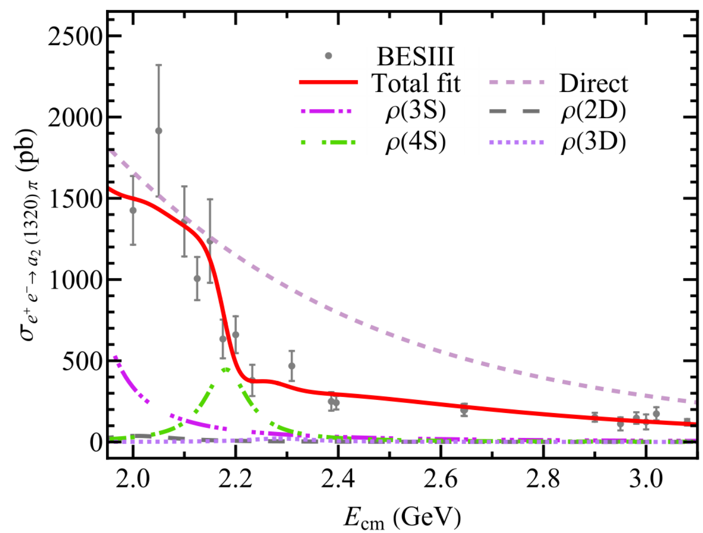
$$\sigma(s)=|\mathcal{M}^{\mathrm{Dir}}+\sum_{k}e^{i\phi_k}\mathcal{M}_k^{\rho^*}|^2$$

$$\mathcal{M}^{\mathrm{Dir}}=C_0\cdot s^{-n}\sqrt{\Phi_2(s)}$$

$$\mathcal{M}^{\rho^*}=\frac{\sqrt{12\pi\Gamma^{\rho^*}_{e^+e^-}\mathcal{B}^{\rho^*}_{a_2(1320)\pi}\Gamma^{\mathrm{tot}}_{\rho^*}}}{s-M^2_{\rho^*}+iM_{\rho^*}\Gamma^{\mathrm{tot}}_{\rho^*}}\sqrt{\frac{\Phi_2(s)}{\Phi_2(M^2_{\rho^*})}}$$

Parameters	$\rho(3S)$	$\rho(2D)$	$\rho(4S)$	$\rho(3D)$
M_{ρ^*} (MeV)	1862	2003	2180	2283
$\Gamma^{\mathrm{tot}}_{\rho^*}$ (MeV)	115	179	102	158
$\Gamma^{e^+e^-}_{\rho^*}$ (eV)	156	20	63	16
$\mathcal{B}^{\omega\pi^0}_{\rho^*}$ (10^{-2})	19.75	0.34	3.31	0.12
$\mathcal{B}^{a_2(1320)\pi}_{\rho^*}$ (10^{-2})	18.1	0.40	5.52	0.29

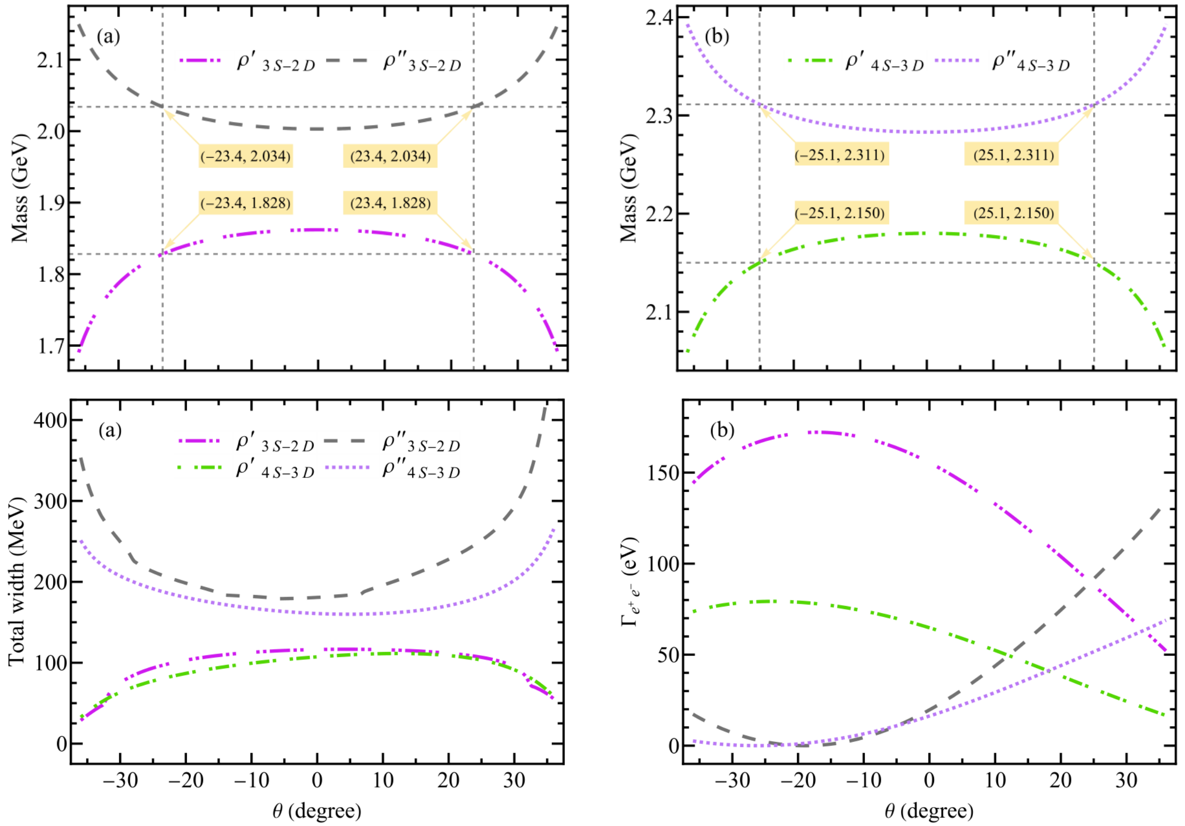




需要存在一个质量在2044 MeV左右，且在该过程有较大贡献的ρ-like态。

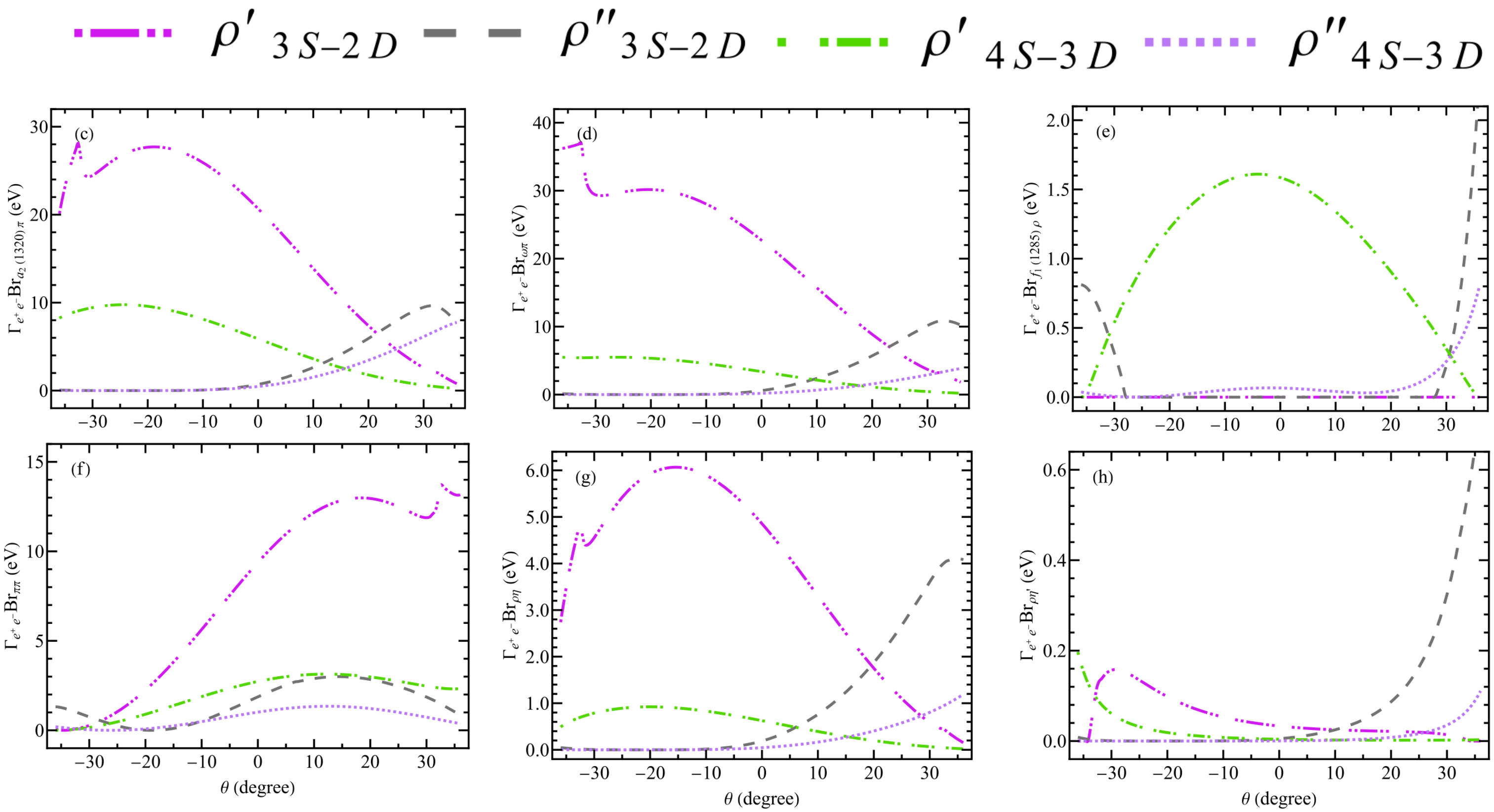
S–D混合框架下ρ介子态的质量谱和衰变性质

$$\begin{pmatrix} |\rho'_{nS-(n-1)D}\rangle \\ |\rho''_{nS-(n-1)D}\rangle \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} |\rho(nS)\rangle \\ |\rho((n-1)D)\rangle \end{pmatrix}$$



- $Y(2044)$有可能是来自ρ''_{3S-2D}的贡献；
- $\rho''_{nS-(n-1)D}$的$\Gamma_{e^+e^-}$相较于纯的$\rho((n-1)D)$可能会显著增大。

S–D混合框架下ρ介子态的质量谱和衰变性质



- $e^+e^- \to a_2(1320)\pi$： ρ''_{3S-2D}在该过程有较大贡献$\Rightarrow$ $\theta_{3S-2D} > 0$；
- $e^+e^- \to \omega\pi^0$: $Y(2034) \equiv \rho''_{3S-2D} \Rightarrow \theta_{3S-2D} = +23.4°$；
- $e^+e^- \to f_1(1285)\pi^+\pi^-$: $\rho(2150) \equiv \rho'_{4S-3D} \Rightarrow \theta_{4S-3D} = \pm 25.1°$。

S–D混合框架下ρ介子态的质量谱和衰变性质

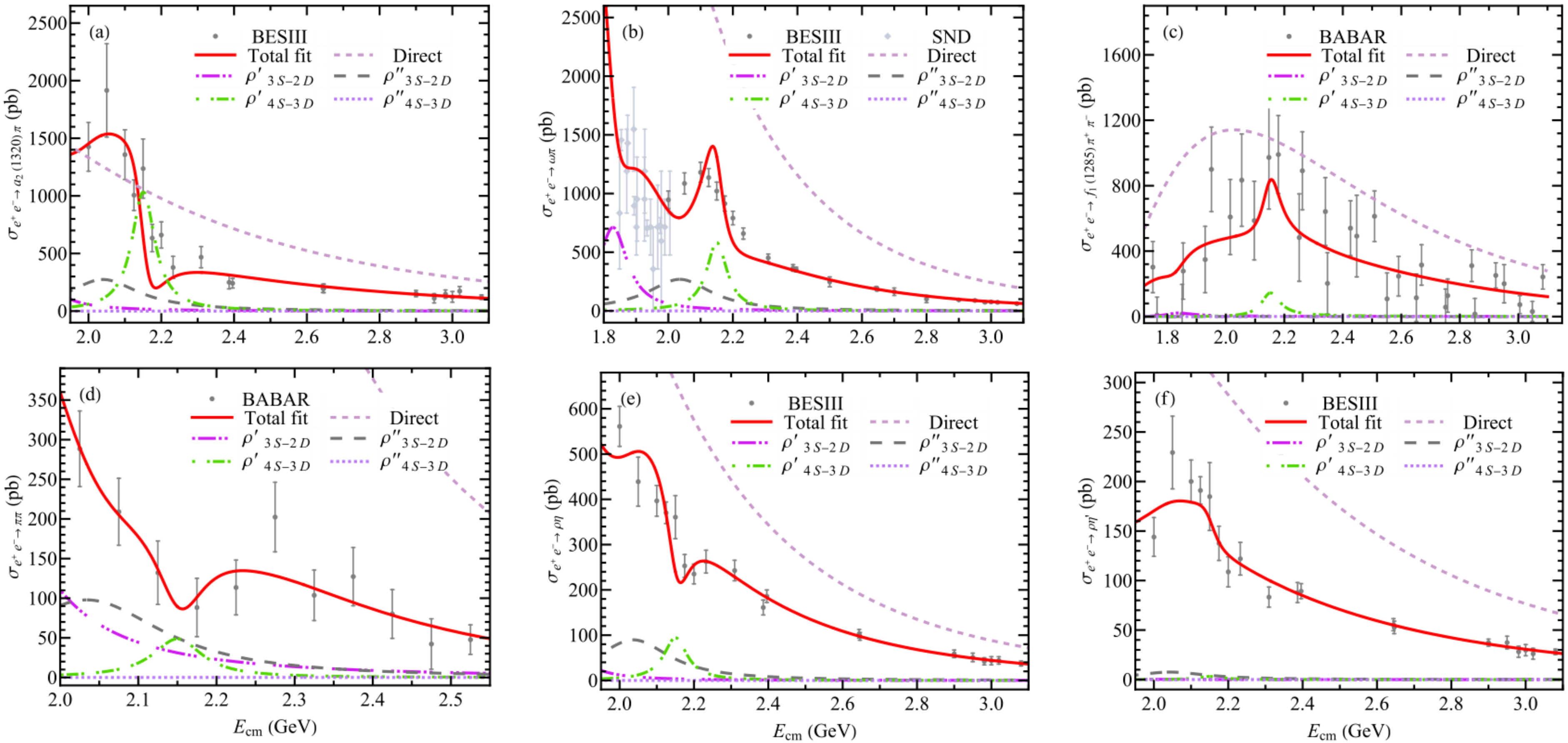
TABLE III: Masses and decay properties of ρ'_{3S-2D}, ρ''_{3S-2D}, ρ'_{4S-3D}, and ρ''_{4S-3D}. Here, mixing angles for $3S$-$2D$ wave and $4S$-$3D$ wave admixtures are taken as $\pm 23.4°$ and $\pm 25.1°$, respectively.

Parameters	Positive angle ρ'_{3S-2D}	Positive angle ρ''_{3S-2D}	Positive angle ρ'_{4S-3D}	Positive angle ρ''_{4S-3D}	Negative angle ρ'_{3S-2D}	Negative angle ρ''_{3S-2D}	Negative angle ρ'_{4S-3D}	Negative angle ρ''_{4S-3D}
Mass (MeV)	1828	2034	2150	2311	1828	2034	2150	2311
$\Gamma_{\rm tot}$ (MeV)	109	243	103	182	97	207	77	192
$\Gamma_{e^+e^-}$ (eV)	93.35	85.94	31.03	51.81	169.59	1.14	79.21	0.02
$\Gamma_{e^+e^-}\mathcal{B}_{a_2(1320)\pi}$ (eV)	5.51	7.25	1.11	4.75	27.15	3.67×10^{-4}	9.76	5.52×10^{-7}
$\Gamma_{e^+e^-}\mathcal{B}_{\omega\pi^0}$ (eV)	6.87	7.17	0.72	2.20	30.01	5.96×10^{-7}	5.49	2.90×10^{-6}
$\Gamma_{e^+e^-}\mathcal{B}_{f_1(1285)\rho}$ (eV)	$\cdots$	$\cdots$	0.63	0.11	$\cdots$	$\cdots$	0.92	3.28×10^{-4}
$\Gamma_{e^+e^-}\mathcal{B}_{\pi\pi}$ (eV)	12.70	2.61	2.74	1.00	1.38	0.14	0.46	2.01×10^{-3}
$\Gamma_{e^+e^-}\mathcal{B}_{\rho\eta}$ (eV)	1.29	2.39	0.12	0.58	5.63	1.01×10^{-6}	0.89	7.35×10^{-7}
$\Gamma_{e^+e^-}\mathcal{B}_{\rho\eta'}$ (eV)	0.02	0.13	0.02	0.02	0.12	1.76×10^{-6}	0.03	2.62×10^{-7}

Parameters	$\Gamma_{e^+e^-}\mathcal{B}_{f_1(1285)\pi^+\pi^-}$ (eV)	$\Gamma_{e^+e^-}\mathcal{B}_{\eta'\pi^+\pi^-}$ (eV)
ρ'_{3S-2D}	0.20 (0.21)	0.03 (0.19)
ρ''_{3S-2D}	0.02 (0.04)	0.18 (2.52×10^{-6})
ρ'_{4S-3D}	0.93 (1.38)	0.03 (0.04)
ρ''_{4S-3D}	0.20 (0.0006)	0.03 (4.3×10^{-7})

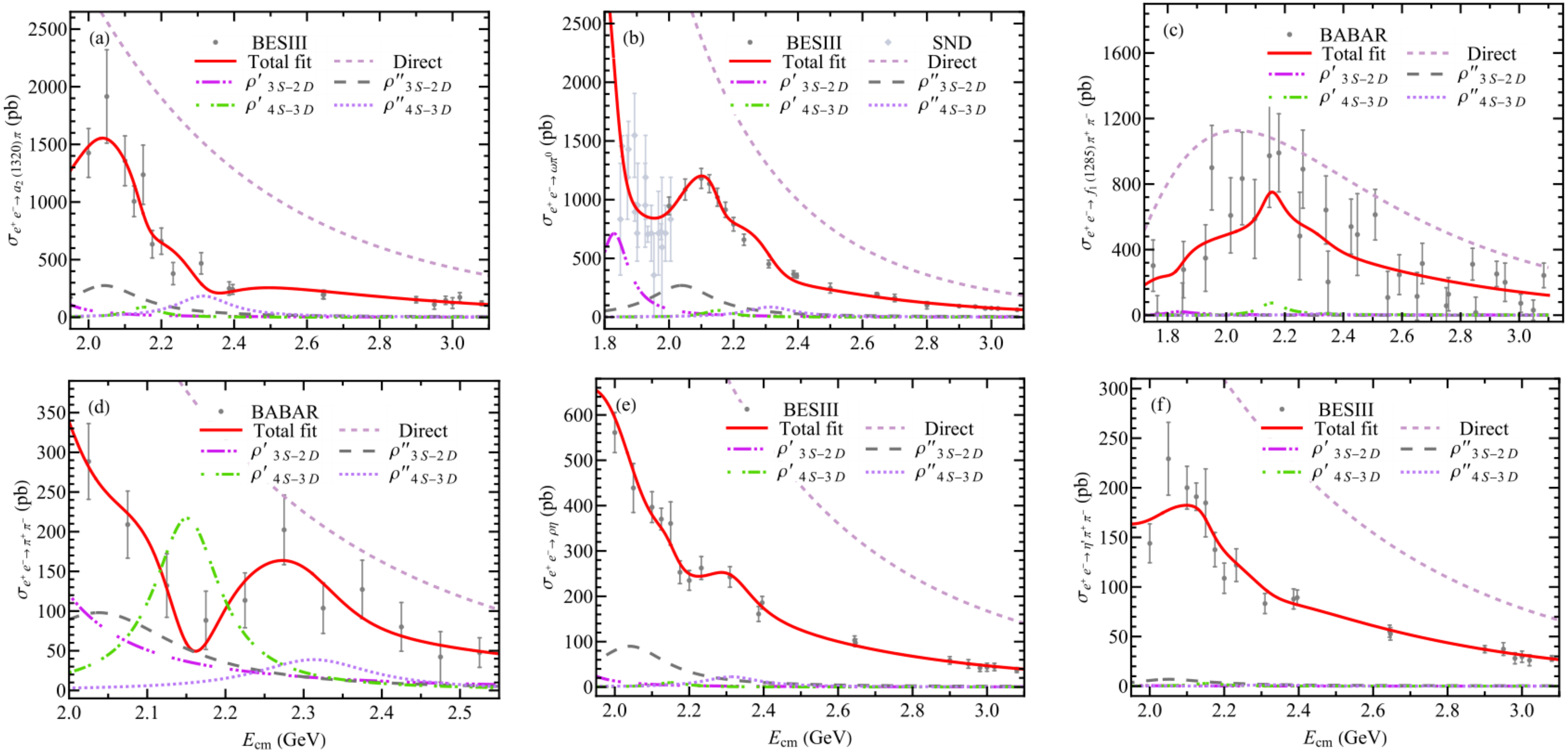
在$e^+e^-\to f_1(1285)\pi^+\pi^-$过程中，$\rho'_{3S-2D}$和$\rho''_{3S-2D}$是压低的。

$\theta_{4S-3D} = -25.1°$的拟合结果



$\theta_{4S-3D} = -25.1°$不能描述好截面数据

$\theta_{4S-3D} = +25.1^\circ$的拟合结果



- $\theta_{4S-3D} = +25.1^\circ$可以较好地描述截面数据；
- $Y(2034)$是ρ''_{3S-2D}的一个很好的候选态， $Y(2044)$主要来自ρ''_{3S-2D}，在误差范围内可认为$Y(2044)$与$Y(2034)$是同一个态。

总结

- 2 GeV能区矢量轻介子的质量谱间隔变小，在产生过程中，不同中间态之间的干涉效应会变得尤为明显，从而导致实验在不同过程中观测到的共振态参数出现很大的差异，截面数据可能会给我们提供更丰富的信息；
- S-D混合效应在理解2 GeV能区矢量轻介子态的性质时可能是需要考虑的；
- 我们也给出了研究2 GeV附近各个ρ介子态的特征道，希望未来在STCF被关注。

谢谢大家！