Exclusive measurement of hadronic channels between 2 and 3 GeV from BESIII

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BEPCII/BESIII: a τ-charm factory

E_{cm}= 2.0-4.6 GeV (2.0-4.95 GeV since 2019)

Energy spread: $\Delta E \approx 5 \times 10^{-4}$

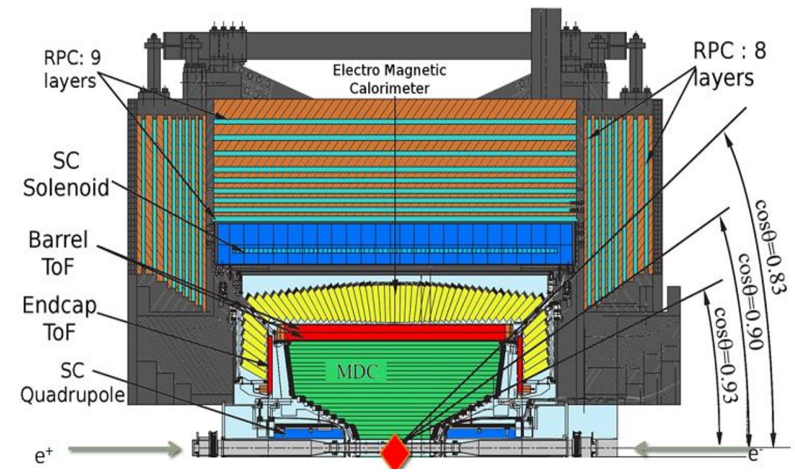
Peak lumi. @3.77 GeV: 1.0×10^{33} $cm^{-2}s^{-1}$

~30 fb^{-1} integrated luminosity collected

Wishlist comprises about 40 fb^{-1} (including 20fb^{-1} on $\psi(3770)$) CPC 44,040001(2020)

Electromagnetic Calorimeter
CsI(Tl): L=28 cm
Barrel σ_E=2.5%
Endcap σ_E=5.0%

Muon Counter
RPC
Barrel: 9 layers
Endcap: 8 layers
$\sigma_{spatial}$: 1.48 cm

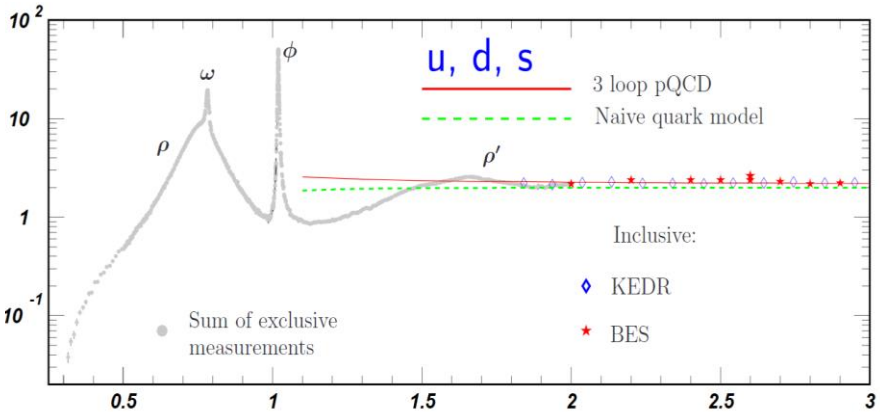


Main Drift Chamber
Small cell, 43 layer
σ_{xy}=130 μm
dE/dx~6%
σ_p/p= 0.5% at 1 GeV

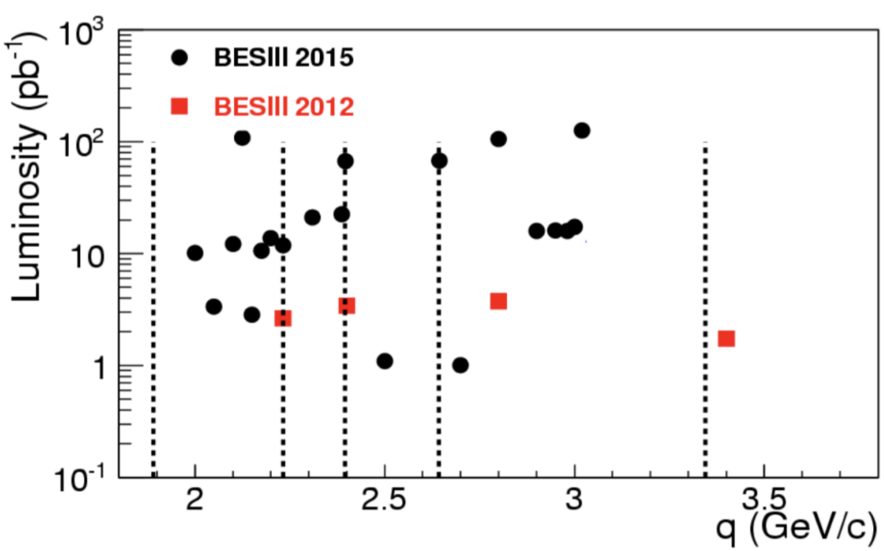
Time Of Flight
Plastic scintillator
σ_T(barrel): 80 ps
σ_T(endcap): 110 ps
(update to 65 ps with MRPC)

Topics to be presented

R($\frac{\sigma(e^+e^-\to hadrons)}{\sigma(e^+e^-\to\mu^+\mu^-)}$)≈2.25 in $\sqrt{s}$ =2.0-3.0 GeV



Data set: >650 pb^{-1} collected



□Baryon Form Factor

- $e^+e^- \to p\bar{p}$
- $e^+e^- \to n\bar{n}$
- $e^+e^- \to \Lambda\bar{\Lambda}$
- $e^+e^- \to \Sigma\bar{\Sigma}$
- $e^+e^- \to \Xi\bar{\Xi}$

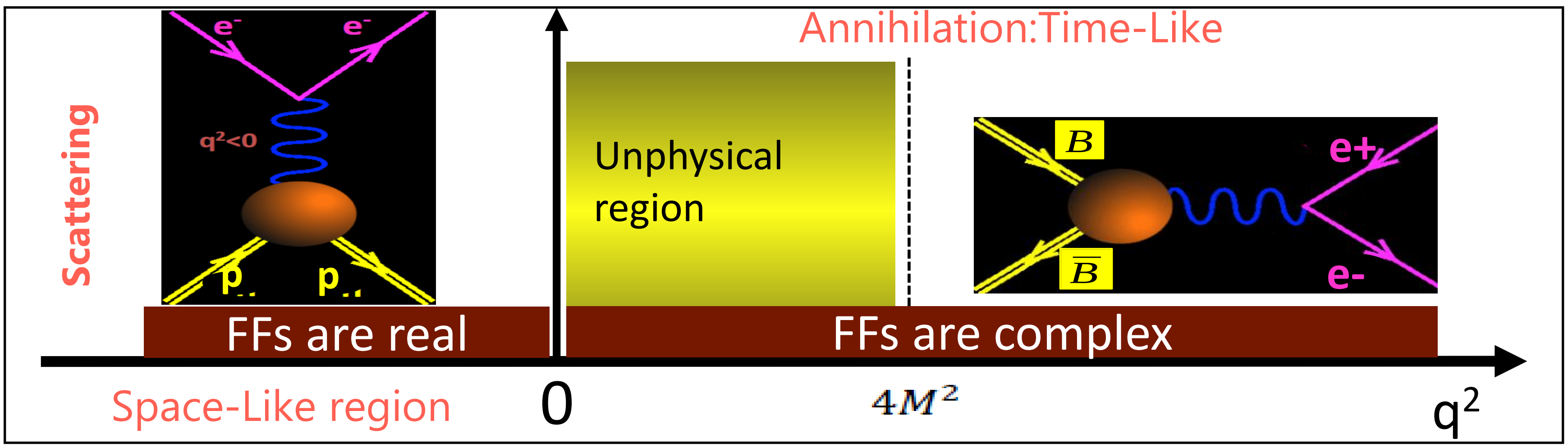
□Light Flavor Mesons

- $e^+e^- \to \phi\eta, \phi\eta'$
- $e^+e^- \to K\bar{K}$
- $e^+e^- \to K^+K^-\pi^0\pi^0$
- $e^+e^- \to \omega\pi^0, \eta'\pi^+\pi^-$

Baryon form factor

Electromagnetic Form Factors

- Fundamental properties of the baryon
  - Connected to charge, magnetization distribution
  - Crucial testing ground for models of the baryon internal structure



- The Born cross section for $e^+e^- \to B\bar{B}$ (one-photon-exchange):

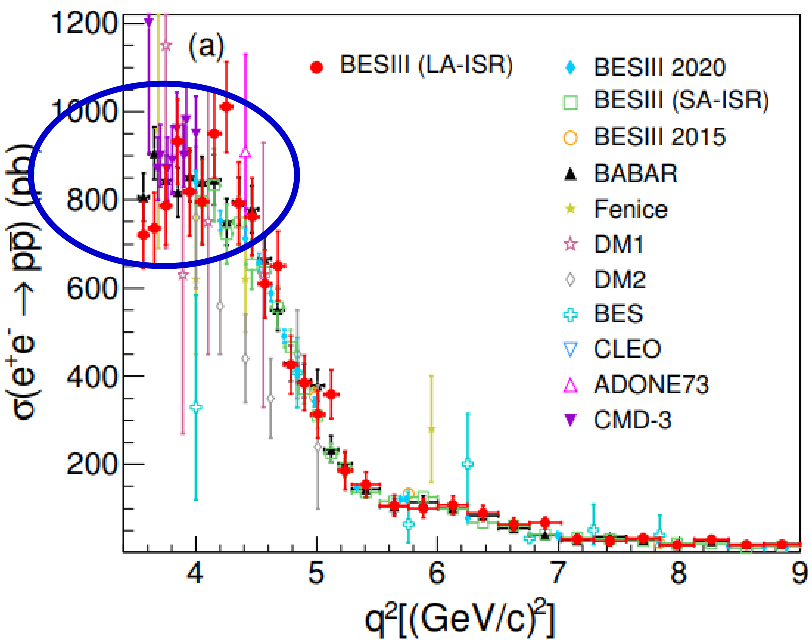
$$\sigma_{B\bar{B}}(q) = \frac{4\pi\alpha^2 C\beta}{3q^2}\left[|G_M(q)|^2 + \frac{1}{2\tau}|G_E(q)|^2\right]$$

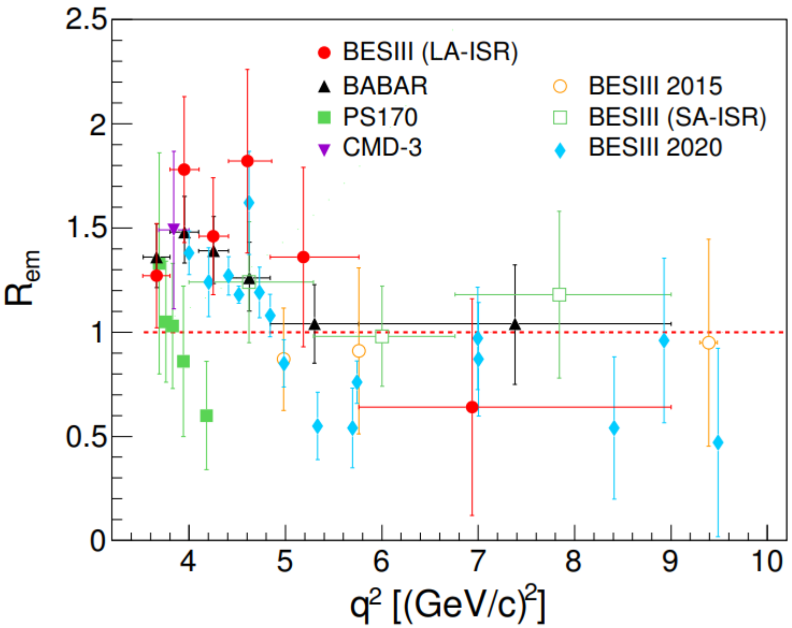
Coulomb factor: Charged: $C=\frac{\pi\alpha}{\beta}\frac{1}{1-exp\,(-\frac{\pi\alpha}{\beta})}$, Neutral: $C=1$

Proton Form Factors

SA-ISR: PRD 99, 092002 (2019)
LA-ISR: PLB 817, 136328 (2021)

- ISR method with detected photon and undetected using 7.5 fb^{-1} data with $\sqrt{s} \geq 3.773$ GeV.



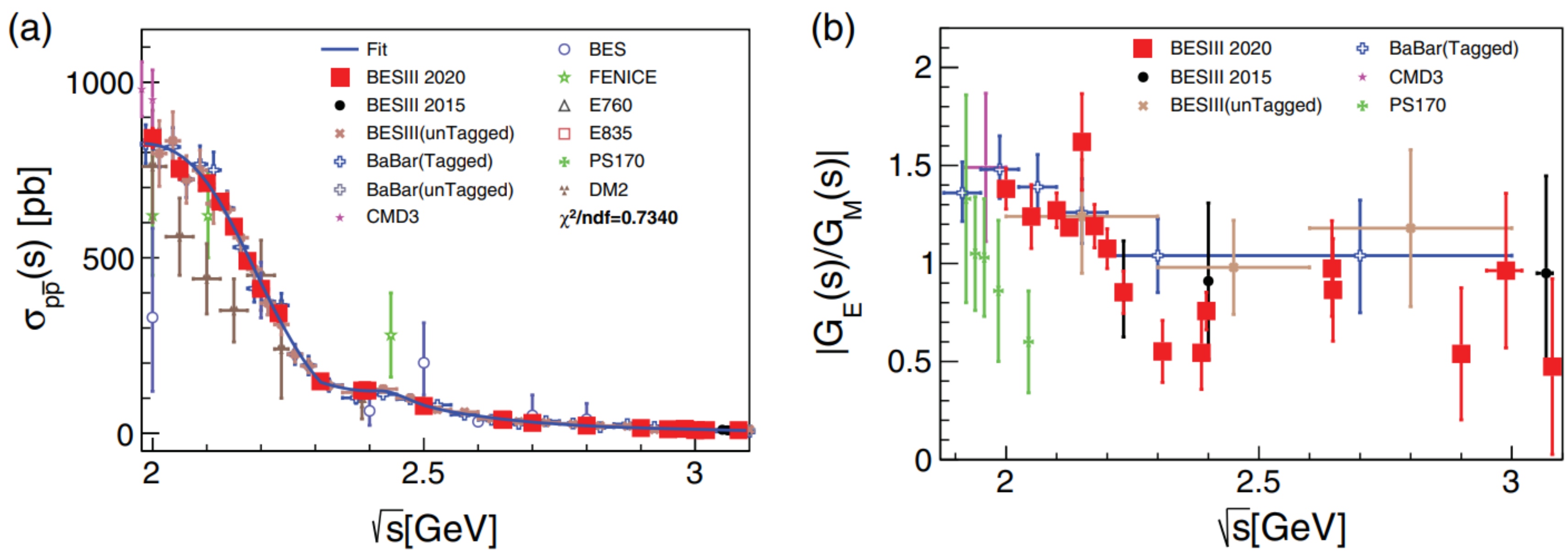


- From threshold to q^2=4.0 GeV^2, average cross section 840 pb
- $|G_E/G_M|$ measured, consistent with BaBar

Proton Form Factors

PRL 124, 042001 (2020)
PRD 91, 112004 (2015)

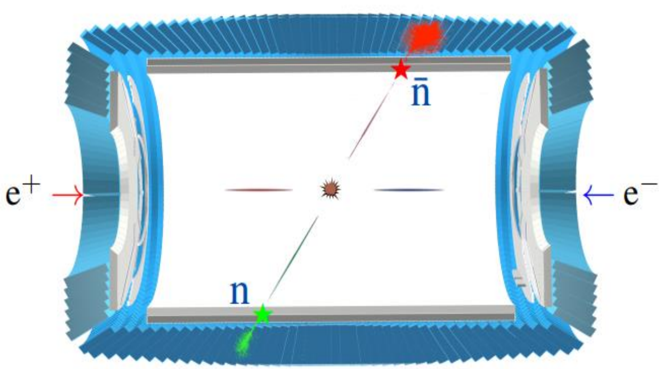
- Scan technique from 2.0 to 3.08 GeV, using 688.5 pb^{-1} integrated luminosity.
- $|G_E/G_M|$, $|G_M|$ are determined with **high accuracy**, comparable to data in SL.
- $|G_E|$ is measured for the first time.

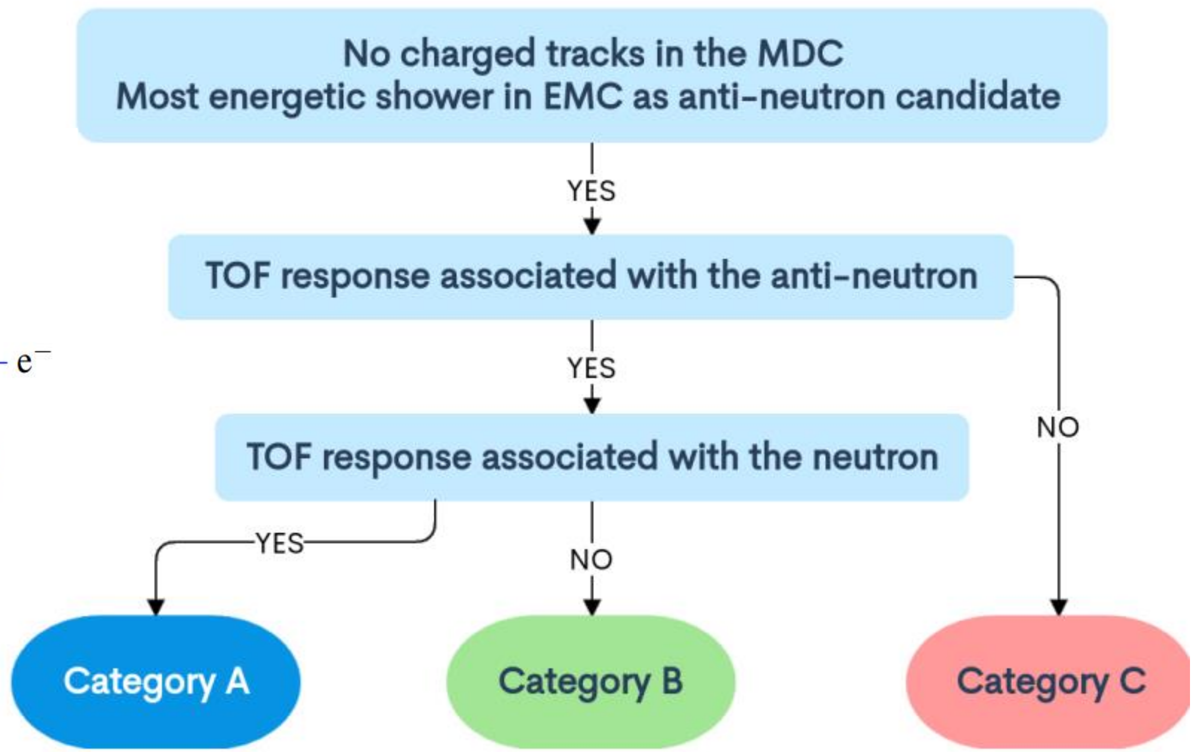


Neutron Form Factors

Nat. Phys. 17, 1200–1204 (2021)

- High luminosity 18 data sets at center-of-mass energies between 2.0 and 3.08 GeV, 647.9 pb^{-1}
- Pure neutral channel $e^+e^- \to n\bar{n}$, only EMC and/or TOF information
- Sophisticated background suppression: $e^+e^- \to \gamma\gamma$, beam-associated

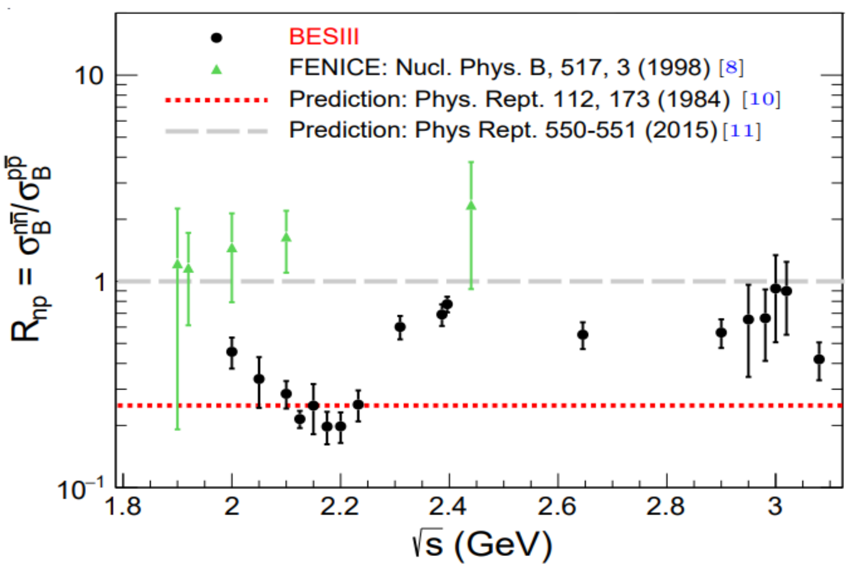


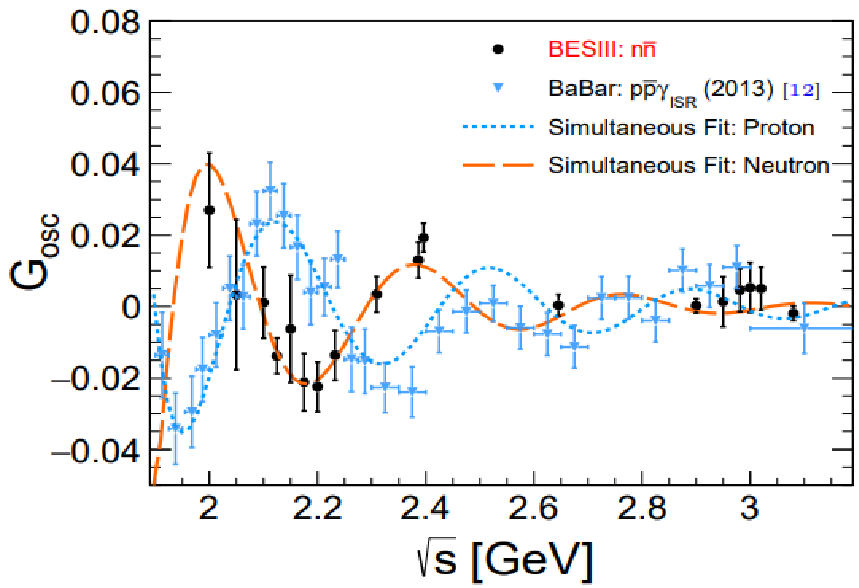


Neutron Form Factors

Nat. Phys. 17, 1200–1204 (2021)

- Discrepancy observed with FENICE results: the photon-neutron coupling smaller than photon-proton coupling.
- Oscillation of FF observed in residual form factor lineshape, same frequency, but orthogonal phase

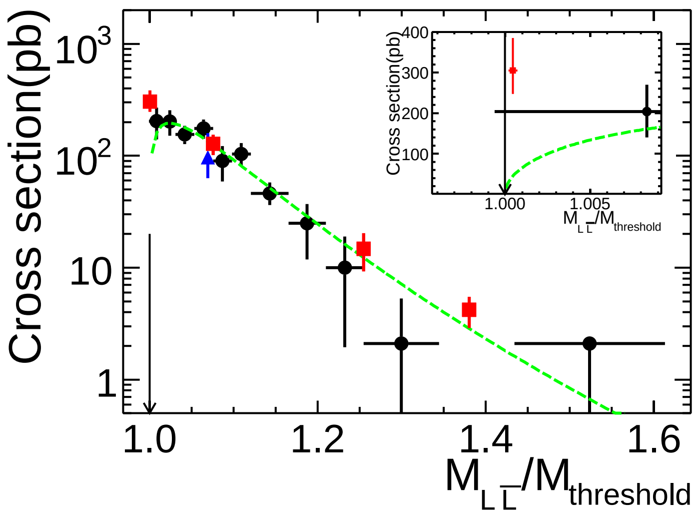


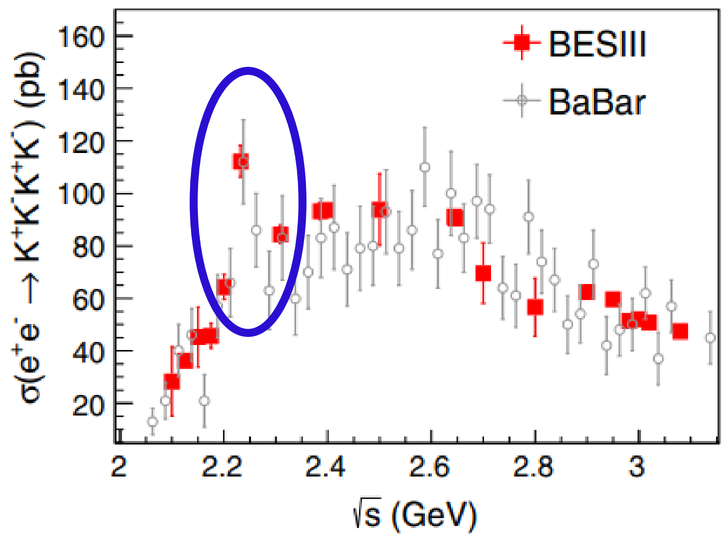


Cross section of $e^+e^- \to \Lambda\bar{\Lambda}$

$\Lambda\bar{\Lambda}$:PRD 97, 032013 (2018)
$KKKK$:PRD 100, 032009 (2019)

- Cross section of $e^+e^- \to \Lambda\bar{\Lambda}$ measured from threshold to 3.08 GeV
- The **anomalous behavior** differing from the pQCD prediction at threshold is observed.





- A hint for resonance around $\Lambda\bar{\Lambda}$ threshold in $e^+e^- \to KKKK$ cross section
  - Mass=2232$\pm$3.5 MeV， width<20 MeV

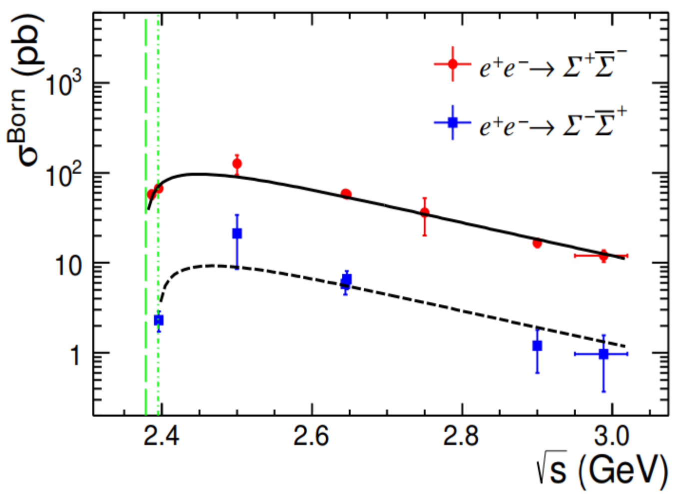
Cross sections of $e^+e^- \rightarrow \Sigma\bar{\Sigma}$

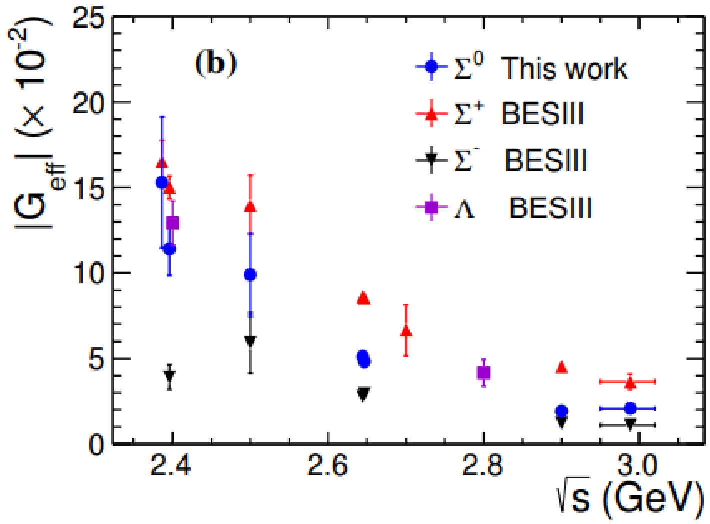
$\Sigma^{\pm}\bar{\Sigma}^{\mp}$:PLB 814, 136110 (2021)
$\Sigma^0\bar{\Sigma}^0$:arXiv:2110.04510

- Born cross sections of $e^+e^- \rightarrow \Sigma^+\bar{\Sigma}^-, \Sigma^-\bar{\Sigma}^+, \Sigma^0\bar{\Sigma}^0$ are measured from threshold to 3.02 GeV
- The cross sections can be well described by pQCD-motivated functions

$$\sigma^{\mathrm{B}}(s) = \frac{\beta C}{s}\left(1+\frac{2m_B^2}{s}\right)\frac{c_0}{(s-c_1)^4(\pi^2+\ln^2(s/\Lambda_{\mathrm{QCD}}^2))^2}$$

- An asymmetry in cross sections/FFs is observed for Σ isospin triplets

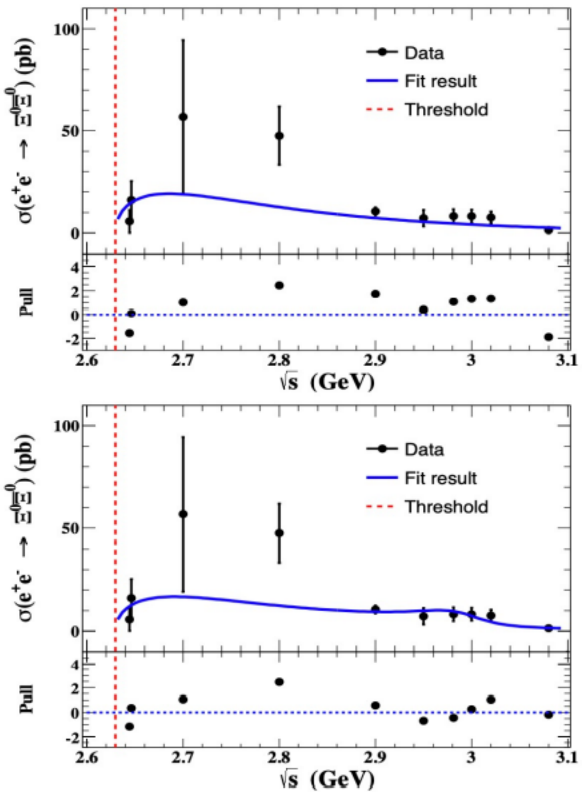


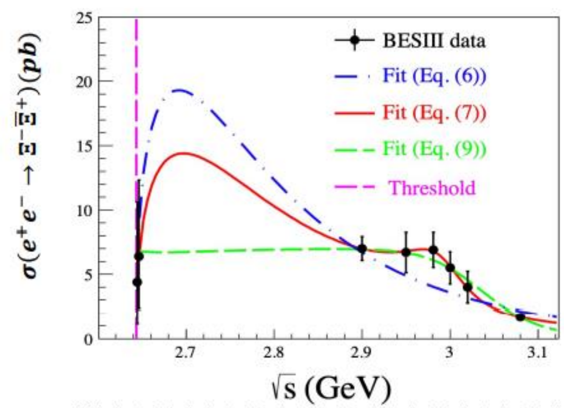


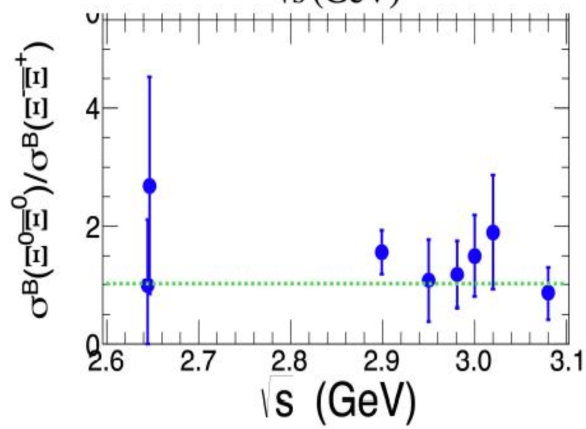
Cross sections of $e^+e^- \to \Xi\bar{\Xi}$

$\Xi^0\bar{\Xi}^0$:PLB. 820, 136557 (2021)
$\Xi^-\bar{\Xi}^+$:PRD103, 012005(2021)

- Born cross sections of $e^+e^- \to \Xi^0\bar{\Xi}^0$ and $\Xi^-\bar{\Xi}^+$ are measured from threshold to 3.08 GeV
- No obvious threshold enhancement observed.
- The ratio of Born cross sections for both modes agrees with the expectation of isospin symmetry.







Light flavor mesons

Light vector mesons around 2.0 GeV

- Experimental information of $\phi(2170)$
  - Limited decay modes
  - Inconsistence on Mass & Width

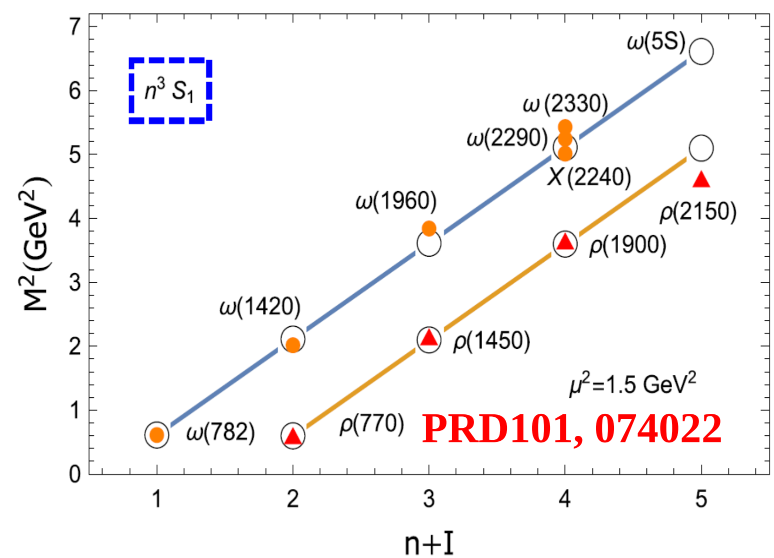
- Theoretical explain of $\phi(2170)$
  - $s\bar{s}g$ hybrid
  - 2^3D_1 or 3^3S_1 $s\bar{s}$
  - Tetraquark
  - Molecular state $\Lambda\bar{\Lambda}$
  - …

- Rich vector resonances around 2.0 GeV for excited ρ^*, ω^*, but are controversial

PDG2021

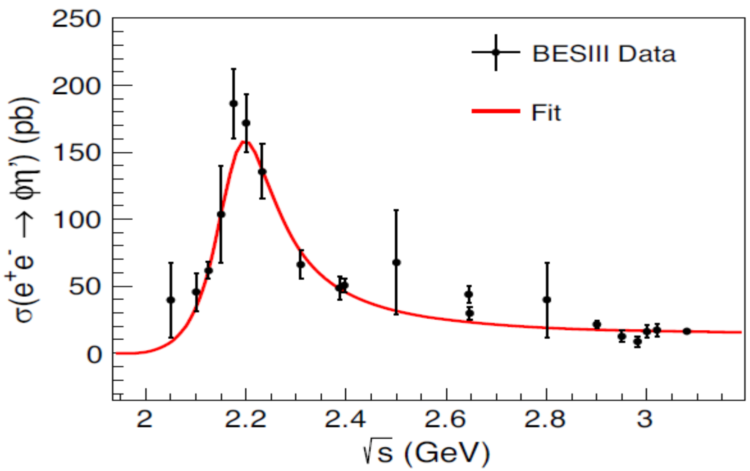
$\phi(2170)$ DECAY MODES

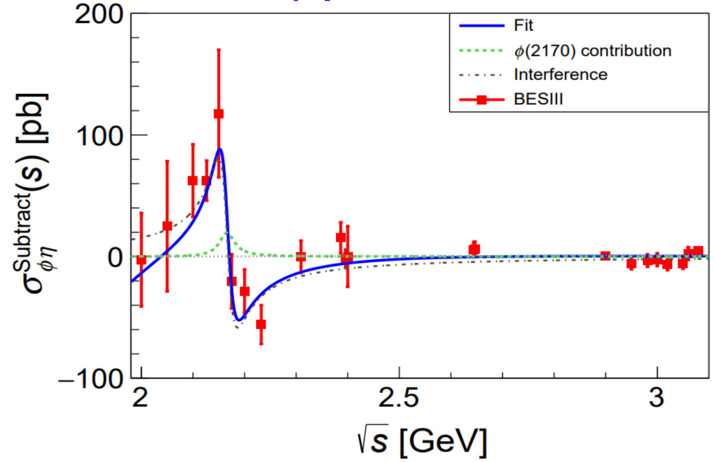
	Mode	Fraction (Γ_i/Γ)
Γ_1	e^+e^-	seen
Γ_2	$\phi\eta$	
Γ_3	$\phi\pi\pi$	
Γ_4	$\phi f_0(980)$	seen
Γ_5	$K^+K^-\pi^+\pi^-$	
Γ_6	$K^+K^-f_0(980) \to K^+K^-\pi^+\pi^-$	seen
Γ_7	$K^+K^-\pi^0\pi^0$	
Γ_8	$K^+K^-f_0(980) \to K^+K^-\pi^0\pi^0$	seen
Γ_9	$K^{*0}K^\pm\pi^\mp$	not seen
Γ_{10}	$K^*(892)^0\bar{K}^*(892)^0$	not seen



$e^+e^- \to \phi\eta'$ and $\phi\eta$

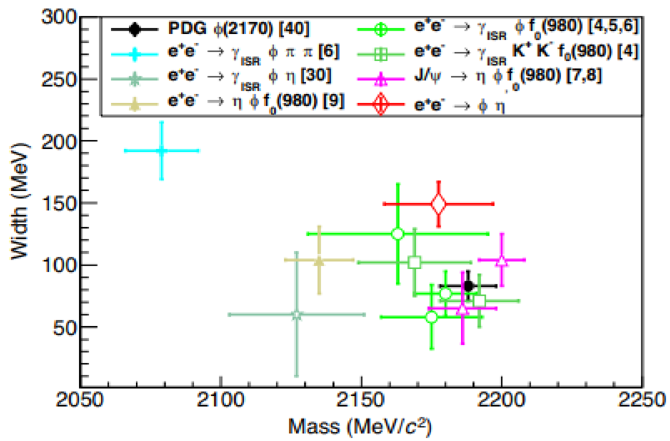
$\phi\eta'$:PRD 102, 012008 (2019)
$\phi\eta$: PRD 104, 3, 032007 (2021)





$M = 2177.5 \pm 4.8 \pm 19.5\ \mathrm{MeV}/c^2$
$\Gamma = 149.0 \pm 15.6 \pm 8.9\ \mathrm{MeV}$
$\mathcal{B}_{\phi\eta'}\Gamma_{ee} = 7.1 \pm 0.7 \pm 0.7\ \mathrm{eV}$

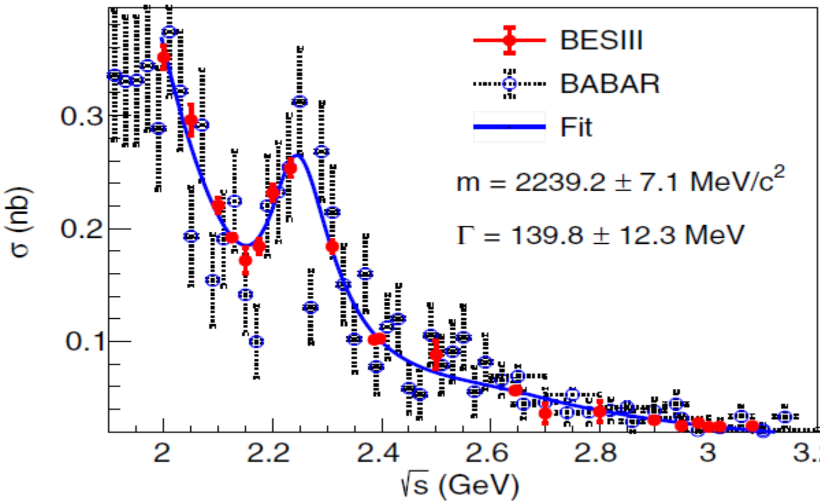
$M = 2165.5 \pm 5.8 \pm 1.5\ \mathrm{MeV}/c^2$
$\Gamma = 36.4^{+31.4}_{-15.3} \pm 2.1\ \mathrm{MeV}$
$\mathcal{B}_{\phi\eta}\Gamma_{ee} = 0.23^{+0.37}_{-0.06}\ \mathrm{eV}$



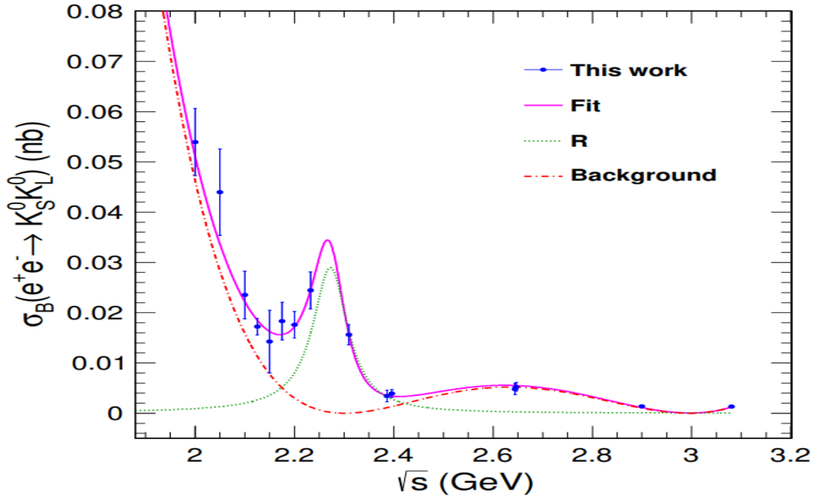
- 1^{--} resonances observed in $\phi\eta$ and $\phi\eta'$
  - Rich $s\bar{s}$ component, ω^* OZI suppressed
  - Partial width in $\phi\eta$ is much smaller than $\phi\eta'$

$e^+e^- \to K\bar{K}$

K^+K^- : PRD 99, 032001 (2019)
K_sK_L: arXiv:2105.13597



M =2239.2 ± 7.1 ± 11.3 MeV/c²
Γ =139.8 ± 12.3 ± 20.6 MeV

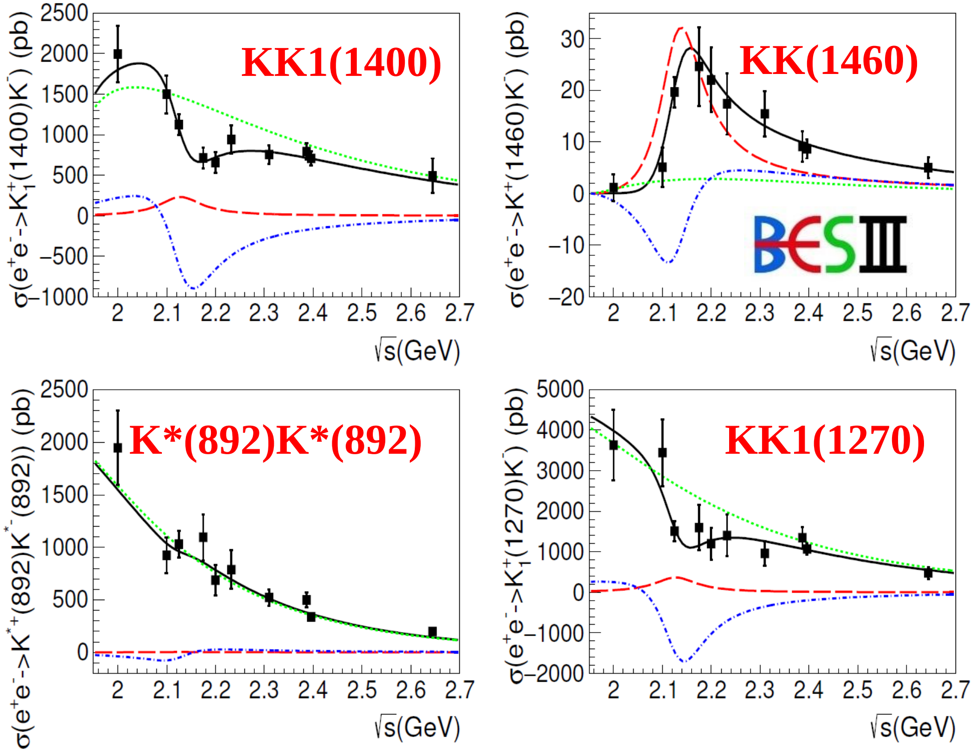


M =2273.7 ± 5.7 ± 19.3 MeV/c²
Γ =86 ± 44 ± 51 MeV

- 1^{--} resonance observed in K^+K^- and K_sK_L lineshapes:
  - PDG average of $\phi(2170)$: M=2159 $\pm$ 17 MeV/c^2, $\Gamma = 137 \pm 16$
  - Interpreted as isoscalar : $\omega^*, \phi(2170)$ or isovector : $\rho(2150)$

$e^+e^- \to K^+K^-\pi^0\pi^0$

PRL 124, 012001 (2020)



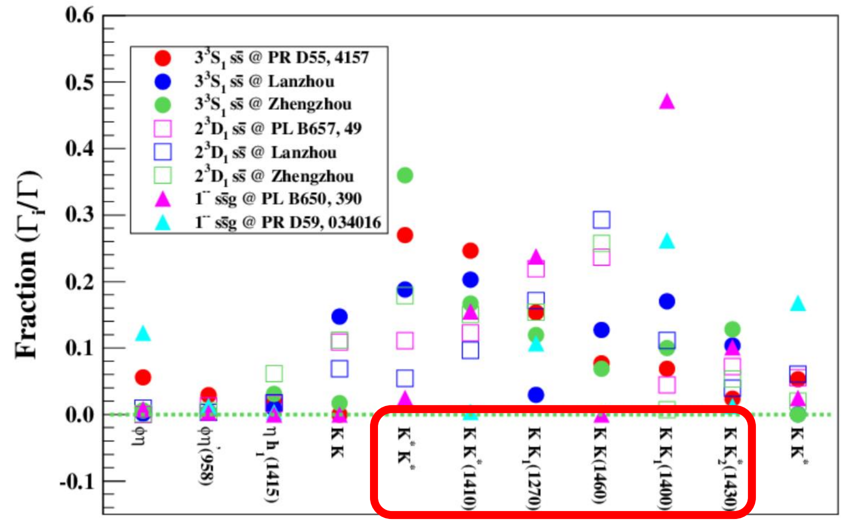


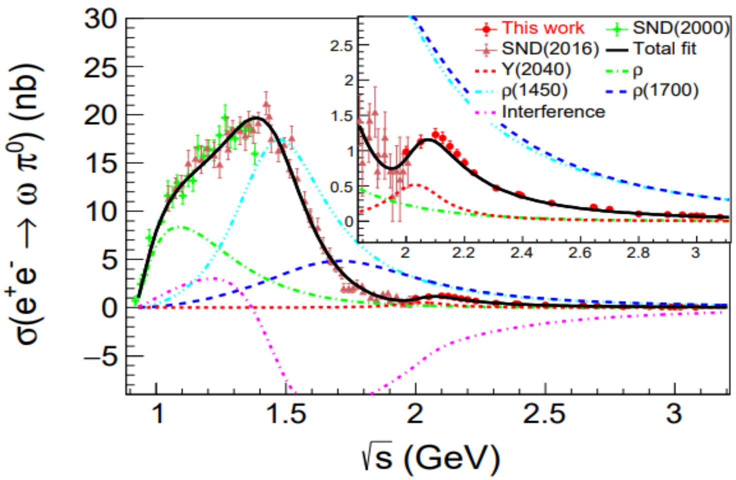
Table 22: Fitting parameters.

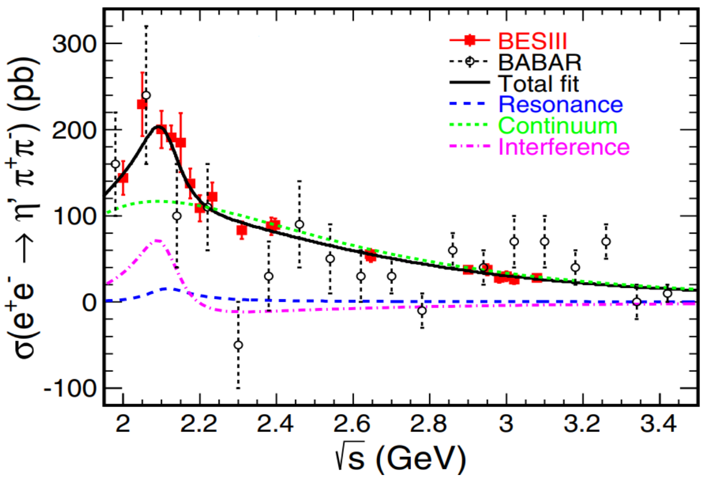
channel	$e^+e^- \to K_1^+(1400)K^-$		$e^+e^- \to K^+(1460)K^-$	$e^+e^- \to K_1^+(1270)K^-$		$e^+e^- \to K^{*+}K^{*-}$
Mass (MeV/c^2)	2126.5 ± 16.8					
Width (MeV)	106.9 ± 32.1					
	Solution1	Solution2		Solution1	Solution2	
$\mathcal{B}_R\Gamma^{e^+e^-}$ (eV)	7.6 ± 3.7	152.6 ± 14.2	1.0 ± 1.3	4.7 ± 3.3	98.8 ± 7.8	0.04 ± 0.2
ϕ (rad)	3.7 ± 0.4	4.5 ± 0.3	5.6 ± 1.5	4.0 ± 0.2	4.5 ± 0.1	5.8 ± 1.9
Significance(σ)	4.8		4.5	1.4		1.2

- PWA for $e^+e^- \to K^+K^-\pi^0\pi^0$ at multiple energy points
- Cross section lineshapes for intermediate states => **essential input to clarify the nature of $\phi(2170)$**

$e^+e^- \to \omega\pi^0$ and $\eta'\pi^+\pi^-$

$\omega\pi^0$: PLB 813, 136059 (2021)
$\eta'\pi^+\pi^-$: PRD 103, 072007 (2021)





$$M = 2034 \pm 14 \pm 9\ \mathrm{MeV}/c^2$$
$$\Gamma = 234 \pm 30 \pm 25\ \mathrm{MeV}$$
$$\mathcal{B}_{\omega\pi^0}\Gamma_{ee} = 34 \pm 11 \pm 16\ \mathrm{eV}$$

$$M = 2111 \pm 43 \pm 25\ \mathrm{MeV}/c^2$$
$$\Gamma = 135 \pm 34 \pm 30\ \mathrm{MeV}$$
$$\mathcal{B}_{\eta'\pi^+\pi^-}\Gamma_{ee} = 0.64 \pm 0.49 \pm 0.42$$
or $23.3 \pm 5.3 \pm 3.3$ eV

- Resonances in $\omega\pi^0$ and $\eta'\pi^+\pi^-$ lineshapes
- Could be excited ρ mesons: $\rho(2000)$ or $\rho(2150)$

Summary and Prospect

- **Fruitful physics results of exclusive hadronic channels in $\sqrt{s}$=2.0 to 3.0 GeV at BESIII**
  - SU(3) octet baryon: cross section near threshold, electromagnetic form factor
  - Light flavor vectors: improved knowledge for $\phi(2170)$, hints of ρ^*, ω^* states
- **More results are expected**
  - Production of SU(3) decuplet baryons
  - Properties of excited vector states with PWA
  - 20 fb^{-1} $\psi(3770)$ to be collected: exclusive hadronic studies with ISR approach

Thank you!