

# Overview of recent BESIII results and prospects

王大勇

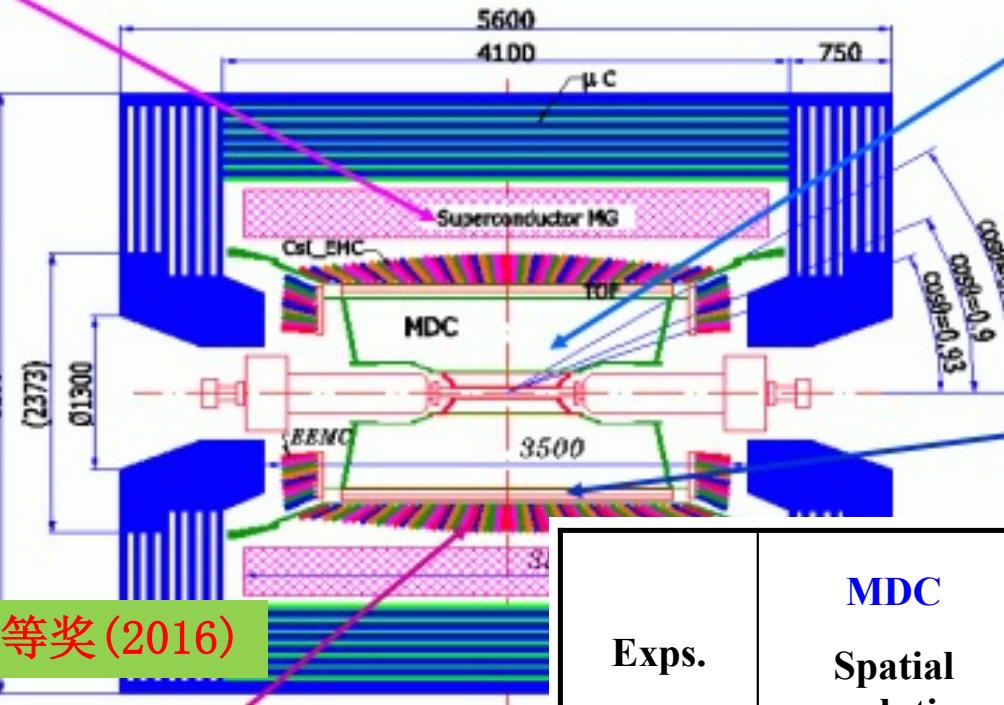
北京大学物理学院

第五届重味物理与量子色动力学研讨会

武汉，2023年4月21日



Magnet: 1 T Super conducting



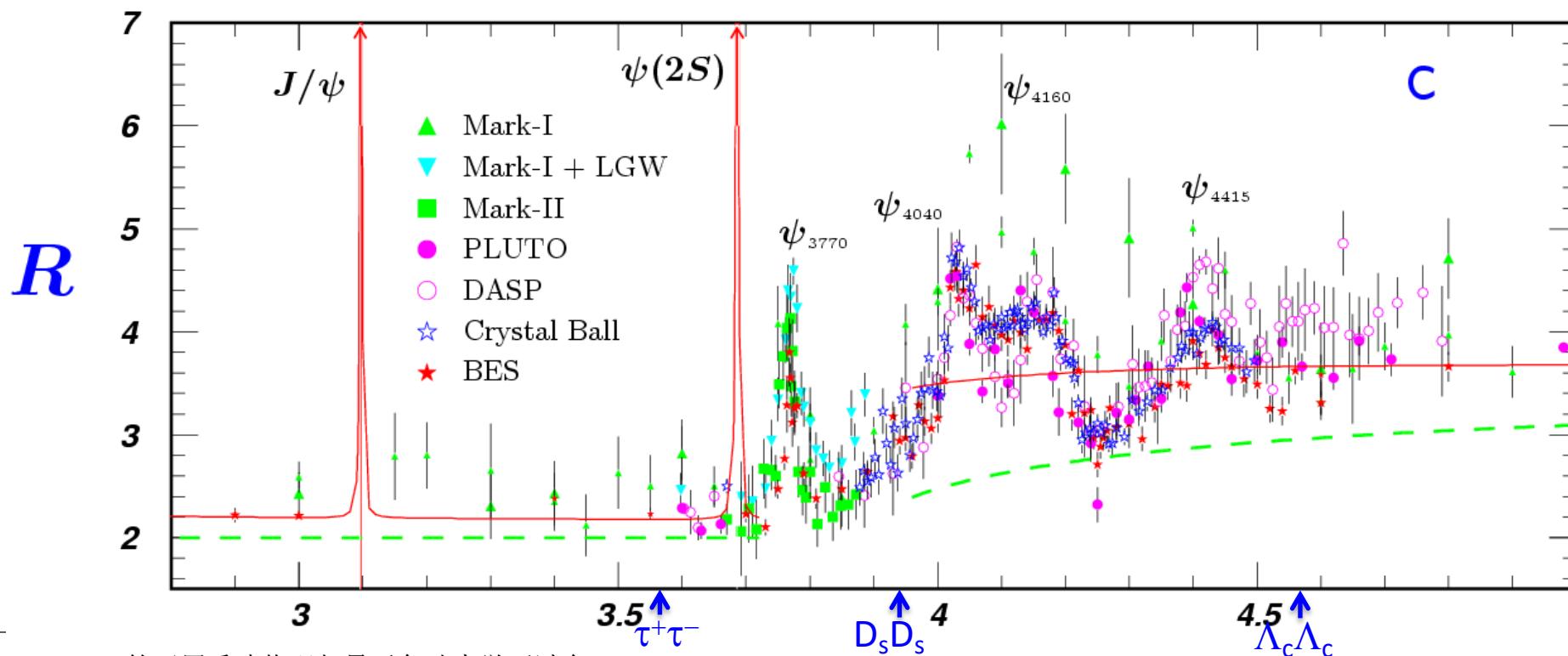
国家科技进步一等奖(2016)

high lumi, large datasets, hermetic detector with good performance and clean environment

- First collision in 2008, physics run started in 2009
- Operation c.m. energy: 2.0-4.95 GeV
- BEPCII reached peak lumi of  $1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$  @ 1.89 GeV in April 2016, this round data-taking:  $1.1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$
- 2020: energy upgrade & top-up mode
- Secured the running for another 5-10 years, with small(but critical) energy increase and lumi upgrade

Exps.	MDC Spatial resolution	MDC $dE/dx$ resolution	EMC Energy resolution
CLEO-c	110 $\mu\text{m}$	5%	2.2-2.4 %
BaBar	125 $\mu\text{m}$	7%	2.67 %
Belle	130 $\mu\text{m}$	5.6%	2.2 %
<b>BESIII</b>	<b>115 <math>\mu\text{m}</math></b>	<5% (Bhabha)	<b>2.4%</b>

- Rich of **resonances**, charmonia and charmed mesons.
- **Threshold characteristics** (pairs of  $\tau$ , D,  $D_s$ , charmed baryons...).
- **Transition** between perturbative and non-perturbative **QCD**.
- New **hadrons**: glueballs, hybrids, multi-quark states
- New **Physics**: large datasets, hermetic detector, good performance



2009: 106M  $\psi(2S)$ 225M  $J/\psi$ 2010:  $0.98 \text{ fb}^{-1}$   $\psi(3770)$  (for  $D^{0(+)}$ )2011:  $2.93 \text{ fb}^{-1}$   $\psi(3770)$  (for  $D^{0(+)}$ , total)  
 $0.48 \text{ fb}^{-1}$  @4.01 GeV2012:  $0.45\text{B}$   $\psi(2S)$  (total)  
 $1.30\text{B}$   $J/\psi$  (total)2013:  $1.09 \text{ fb}^{-1}$  @4.23 GeV  
 $0.83 \text{ fb}^{-1}$  @4.26 GeV  
 $0.54 \text{ fb}^{-1}$  @4.36 GeV  
 $10 \times 0.05 \text{ fb}^{-1}$  XYZ scan@3.81-4.42 GeV2014:  $1.03 \text{ fb}^{-1}$  @4.42 GeV  
 $0.11 \text{ fb}^{-1}$  @4.47 GeV  
 $0.11 \text{ fb}^{-1}$  @4.53 GeV  
 $0.05 \text{ fb}^{-1}$  @4.575 GeV  
 $0.57 \text{ fb}^{-1}$  @4.60 GeV (for  $\Lambda_c^+$ )  
 $0.80 \text{ fb}^{-1}$  R scan @3.85-4.59 GeV

# Data samples collected by BESIII so far



- 2015: R-scan  $2\text{-}3 \text{ GeV+}2.175 \text{ GeV}$
- 2016:  $3.20 \text{ fb}^{-1}$  @4.178 GeV (for  $D_s^+$ )
- 2017:  $7 \times 0.50 \text{ fb}^{-1}$  XYZ scan@4.19-4.27 GeV
- 2018: More  $J/\psi$ +tuning new RF cavity
- 2019:  $10\text{B}$   $J/\psi$  (total)  
 $8 \times 0.50 \text{ fb}^{-1}$  XYZ scan@4.13, 4.16, 4.29-4.44 GeV
- 2020:  $3.8 \text{ fb}^{-1}$  @ 4.61-4.7 GeV (XYZ& $\Lambda_c^+$ )
- 2021:  $2.0 \text{ fb}^{-1}$  @ 4.74-4.946 GeV
- 2021:  $2.7\text{B}$   $\psi(2S)$  (total)
- 2022:  $2 \times 0.4 \text{ fb}^{-1}$ @3.65, 3.682 GeV,  
 $5.1 \text{ fb}^{-1}$   $\psi(3770)$  (for  $D^{0(+)}$ , total)
- 2023:  $\sim 8 \text{ fb}^{-1}$  at  $\psi(3770)$

More than  $40 \text{ fb}^{-1}$  of data taken between 2 and 4.95 GeV

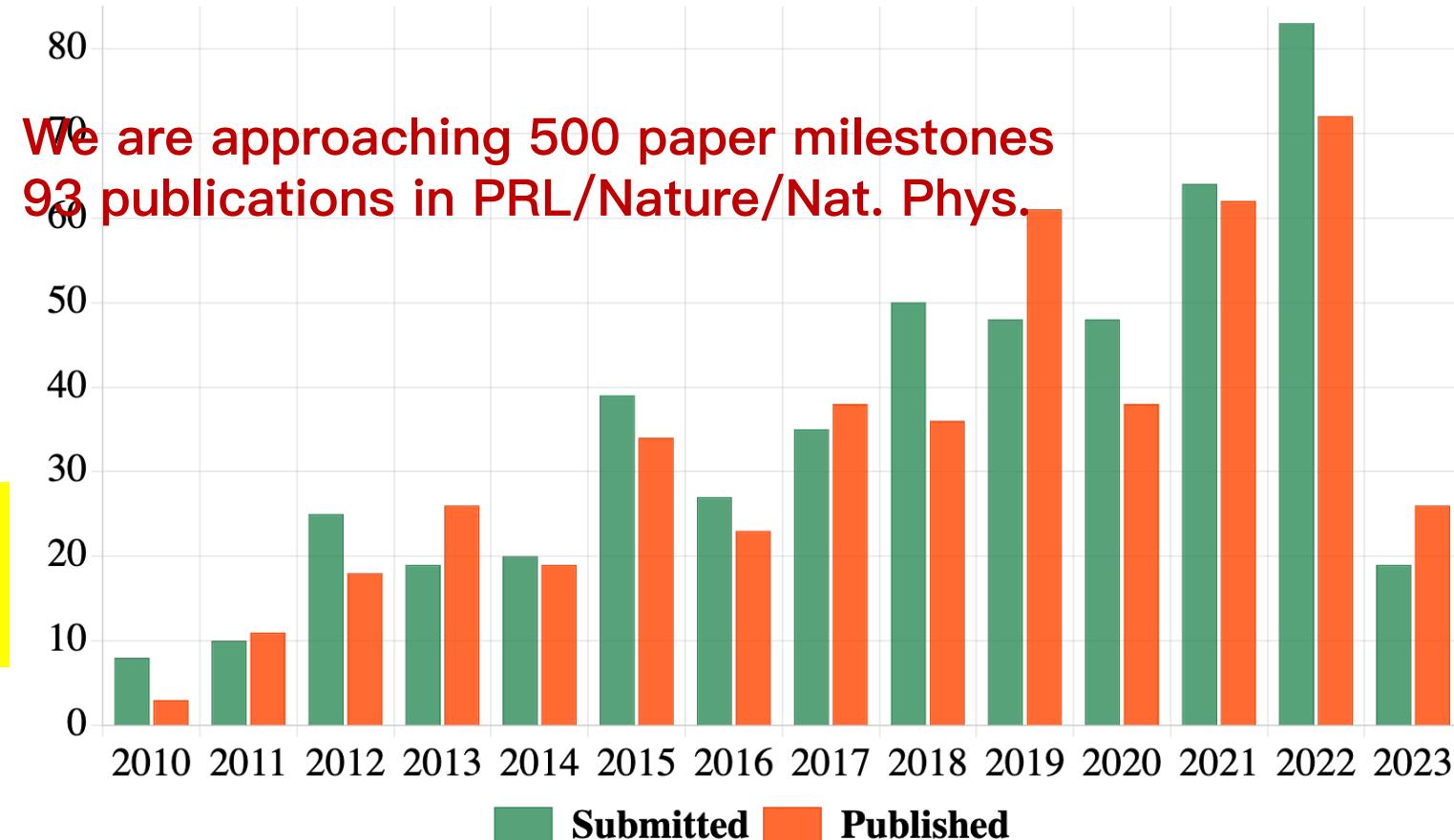
/home21/home/zhaozhuo/setup/BES\_llferate.edl

2023/01/07 18:18:47

Luminosity	10.50 E32/cm^2/s
e+	1.8935
Energy [GeV]	1.8935
Current [mA]	885.64
Lifetime [hr]	1.61
Inj.Rate [mA/min]	0.00
e-	843.00
	1.94
	0.00

New lumi record  
Very stable data-taking  
Good detector performance  
Aging effects under control

### BESIII Publication

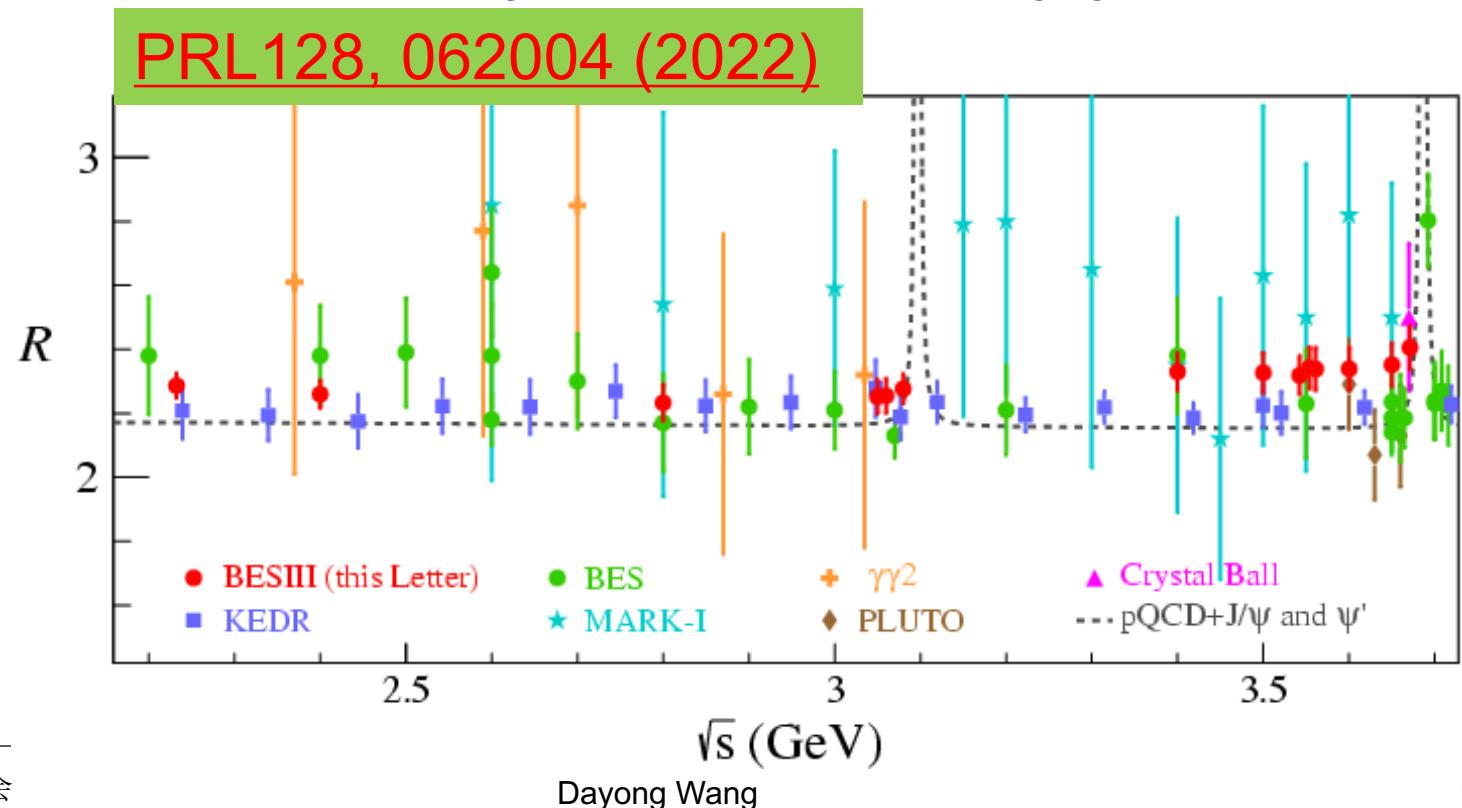
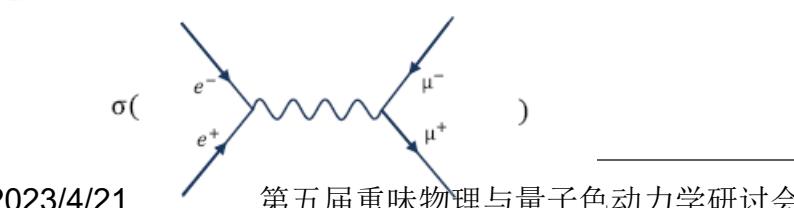
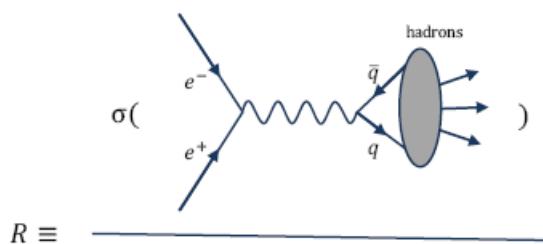


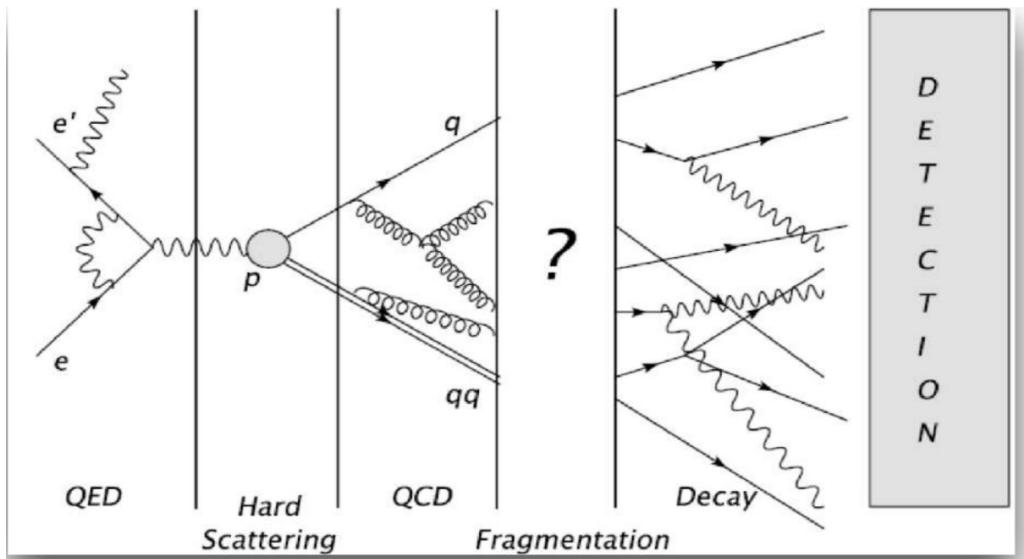
The collaboration size still growing: ~600 members from 85 institutions in 17 countries.

- Measurement of R values in 14 energy points of 2.23-3.67 GeV
- Precision is < 2.6%(<3.0GeV)/3% and twofold better than previous best measurement
- Crucial input parameters to calculate the running coupling constant
- Help to constrain the muon g-2

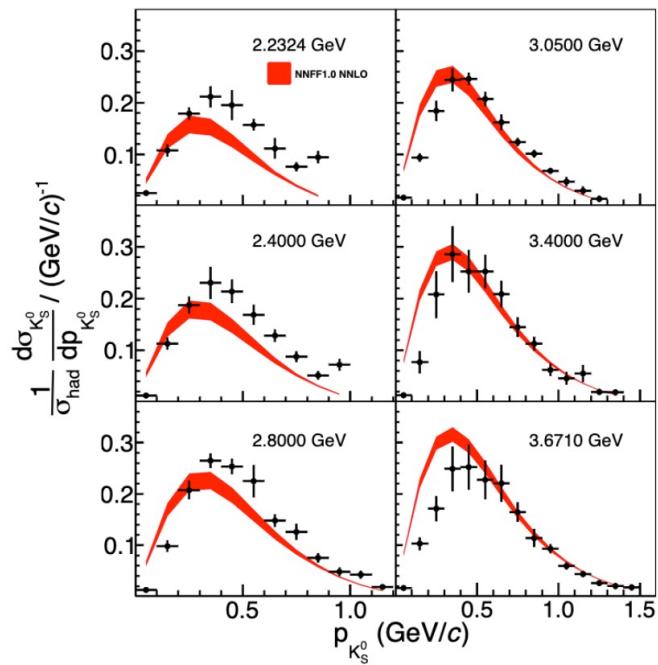
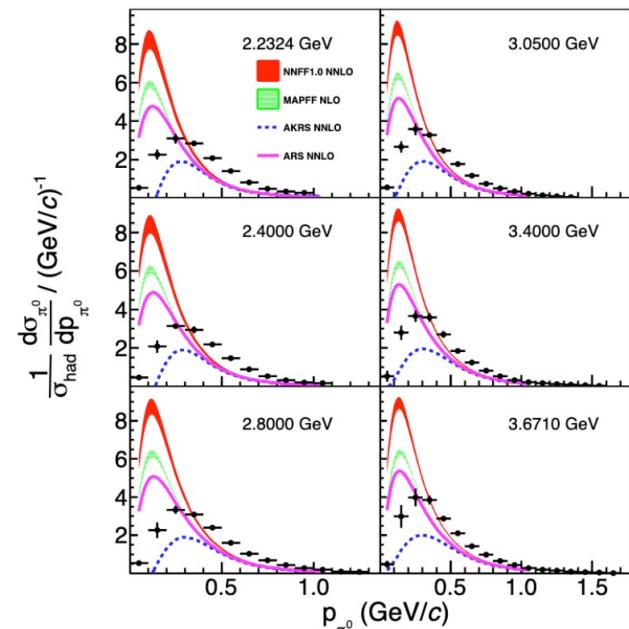
Milestone achievement from efforts of many people in many years

$$R \equiv \frac{\sigma^0(e^+e^- \rightarrow \text{hadrons})}{\sigma^0(e^+e^- \rightarrow \mu^+\mu^-)} \equiv \frac{\sigma_{\text{had}}^0}{\sigma_{\mu\mu}^0}$$



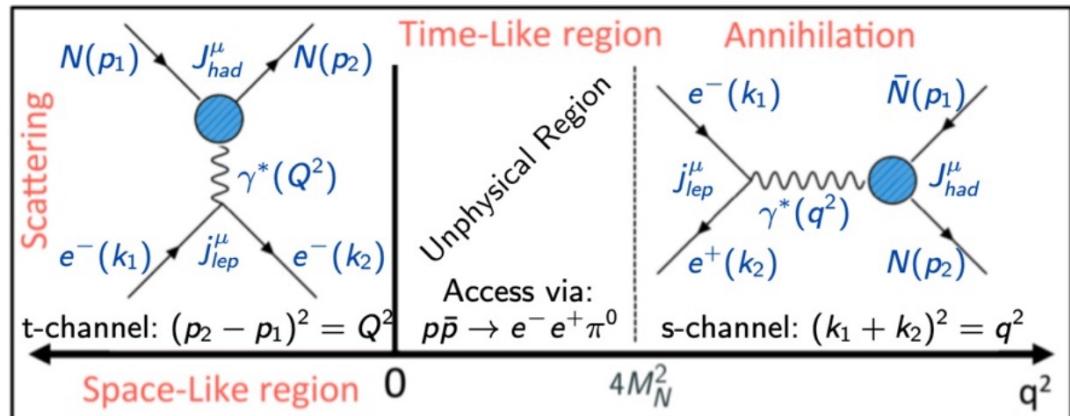


$$\frac{1}{\sigma_{\text{tot}}} \frac{d\sigma(h+x)}{dx} = \sum_i \int_x^1 \frac{dz}{z} C_i(z, \alpha_s(s), \frac{s}{\mu^2}) D_i^h(\frac{x}{z}, \mu^2)$$



- Inclusive  $\pi^0$  and  $K_s$  production in  $e^+ e^-$  collision at 2.2324, 2.400, 2.800, 3.050, 3.400, 3.671 GeV.
  - broad  $z_h$  coverage from 0.1 to 0.9, best precision
  - provide brand new inputs in low-energy region to global fits of fragmentation function
  - Studies of eta, charged K/pi is in progress

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



Near-threshold measurements

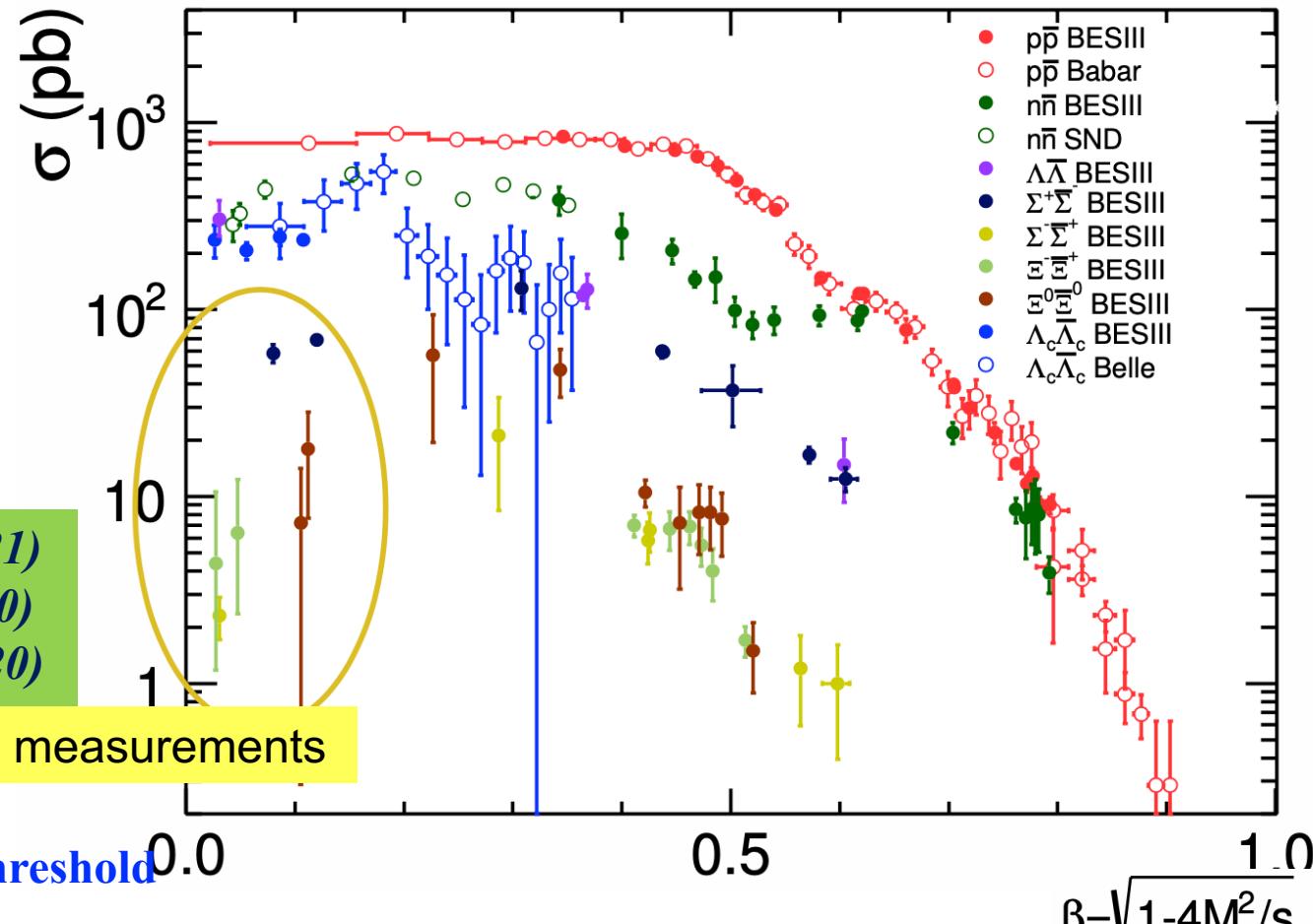
*PRD 97, 032013 (2018)*  
*PLB814 (2021) 136059,*  
*PLB831 (2022) 136187*  
*PRD103, 012005(2021),*  
*PLB820,(2021)136557*  
*PRL 124, 042001 (2020)*  
*PRD 99, 092002 (2019)*  
*PRD 91, 112004 (2015)*  
*Nat. Phys. 17, 1200 (2021)*

*PRD104, L091104(2021)*  
*PRL124, 032002, (2020)*  
*PRL 124, 032002, (2020)*

Above open-charm threshold measurements

$e^+e^- \rightarrow \Omega^+\Omega^-$  : **No obvious threshold enhancement (limited data samples), EFF agree with theory**

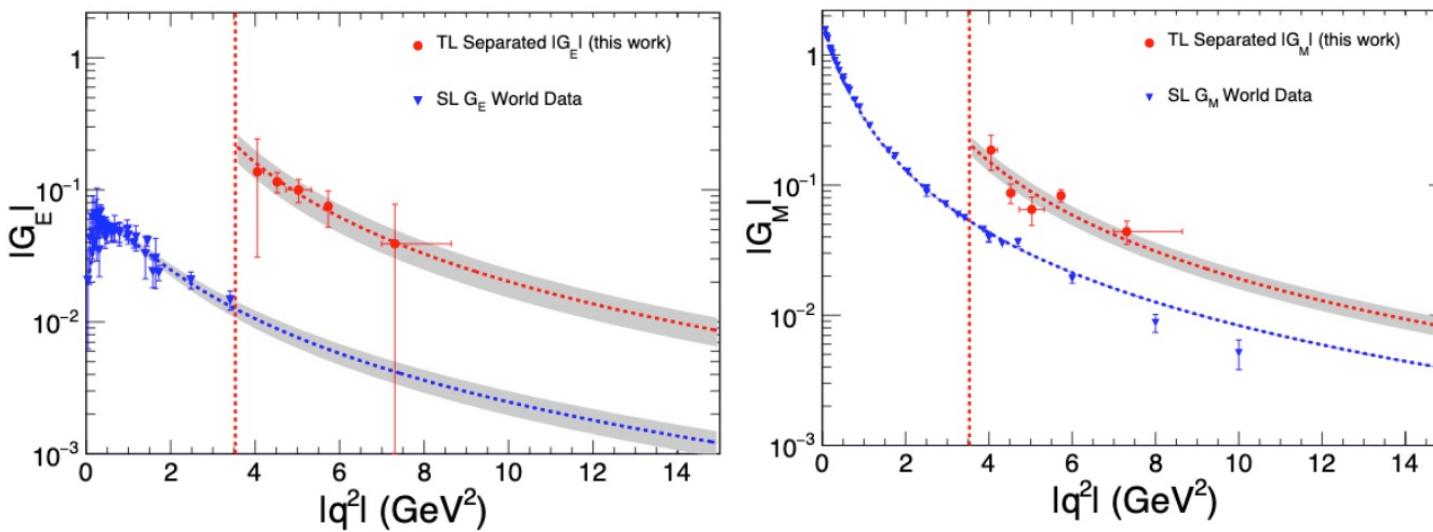
*Phys.Rev.D 107 (2023) , 052003*



Threshold enhancement is observed for nucleon/ $\Lambda$  / $\Lambda_c$  pairs, while not for  $\Sigma/\Xi$  pairs

## Separated E/M FFs of the neutron in time-like region

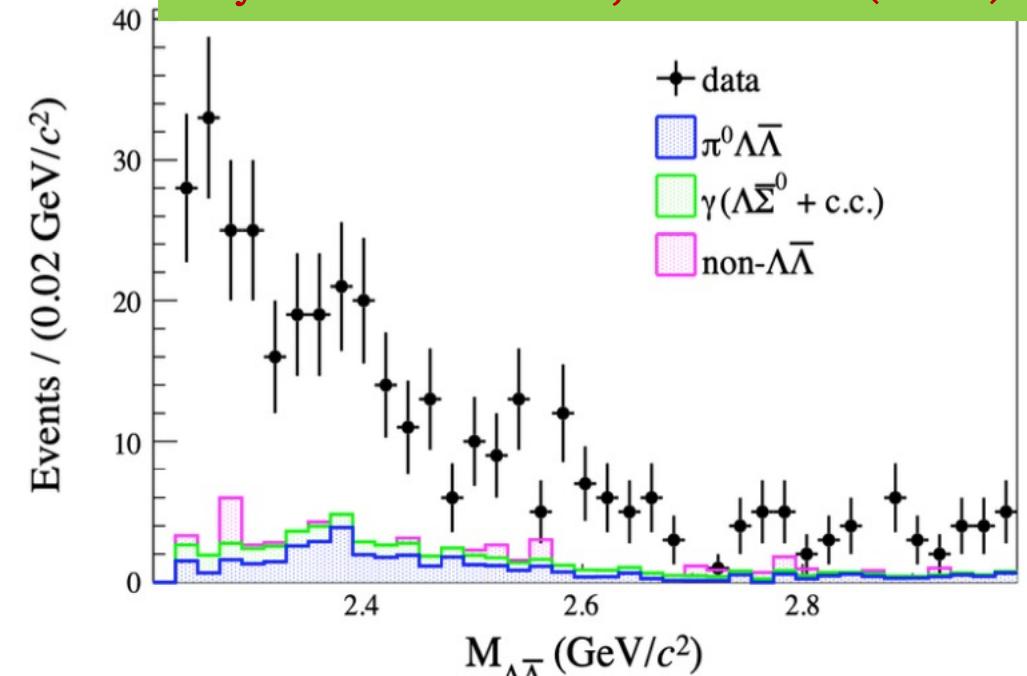
arXiv:2212.07071, PRL in press



- $G_M$ : lower than FENICE results
- $G_E$  and  $G_M$ : agree more with Dispersion Relations (DR)
- TL vs SL: no sign of  $R \rightarrow 1$  ( $|q^2| \rightarrow \infty$ )

$e^+e^- \rightarrow \Lambda\Lambda\bar{\Lambda}$  via Initial State Radiation

Phys. Rev. D 107, 072005 (2023)

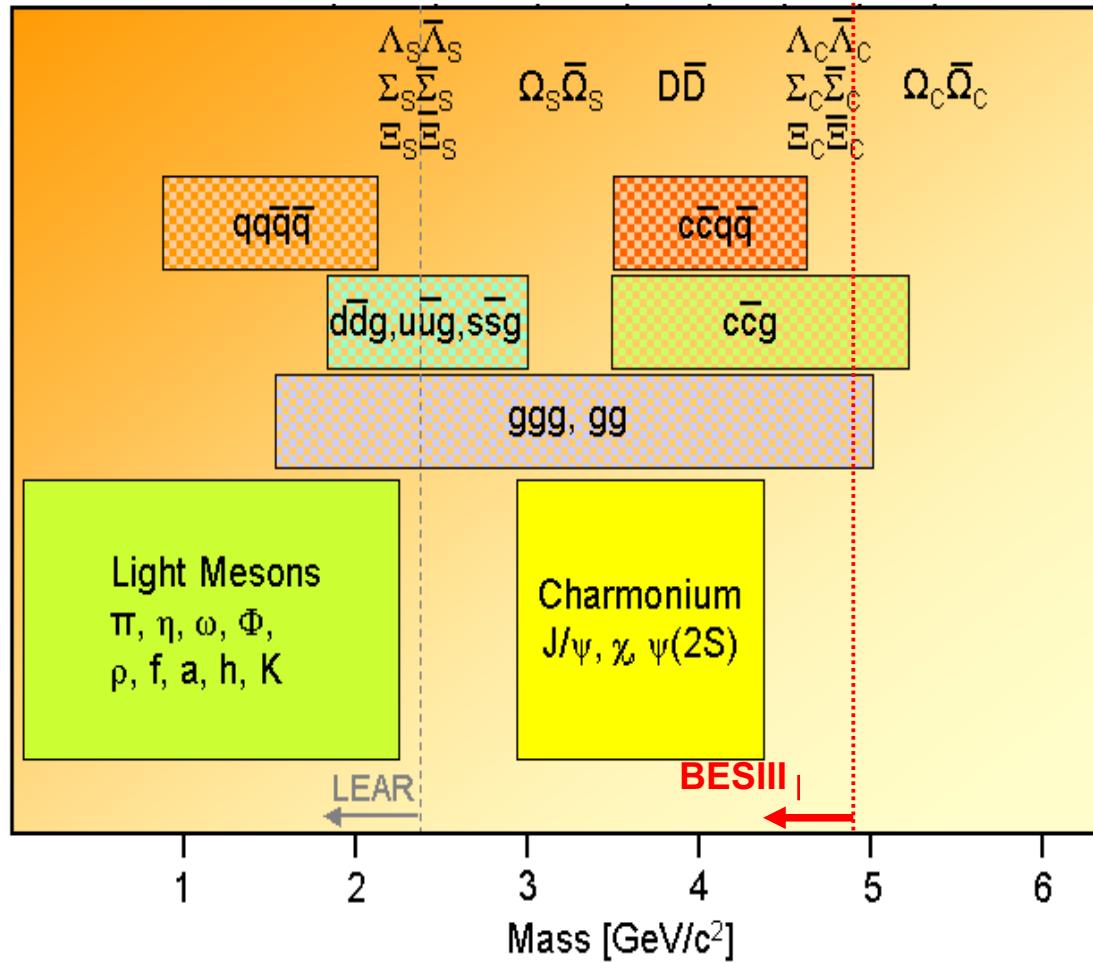


$$\sigma_B(\Lambda\bar{\Lambda}) = \frac{(dN_{sig}/dM(\Lambda\bar{\Lambda}))_{corr}}{\varepsilon \cdot Br^2(\Lambda \rightarrow p\pi) \cdot d\mathcal{L}_{int}/dM(\Lambda\bar{\Lambda})}$$

$$\frac{d\mathcal{L}_{int}}{dM(\Lambda\bar{\Lambda})} = W(s, x) \cdot \mathcal{L}_{int}$$

Two-body  
Thresholds

Molecules

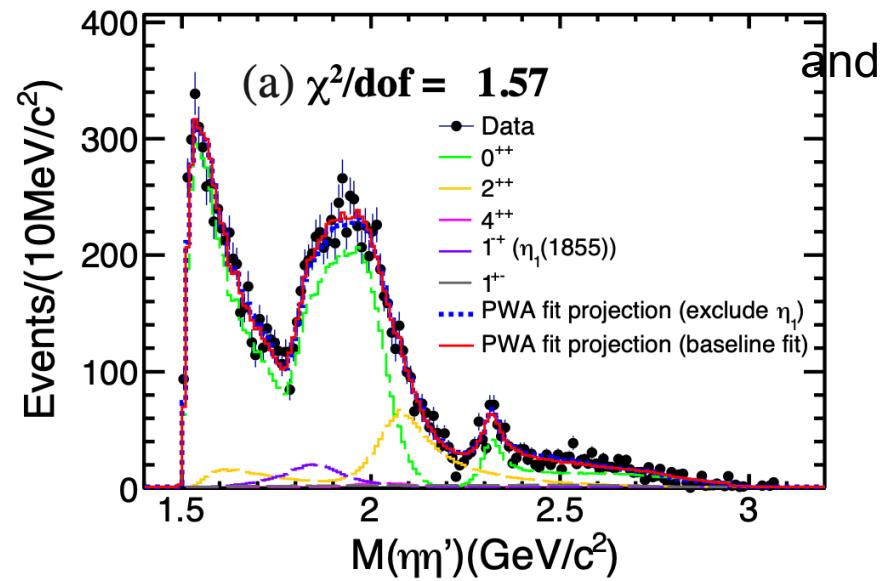
Gluonic  
Excitationq<sup>-</sup>  
Mesons

## Hadron physics opportunities:

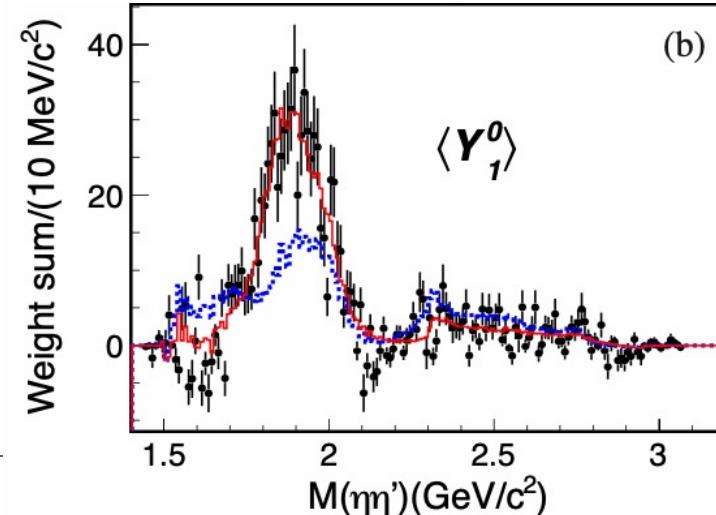
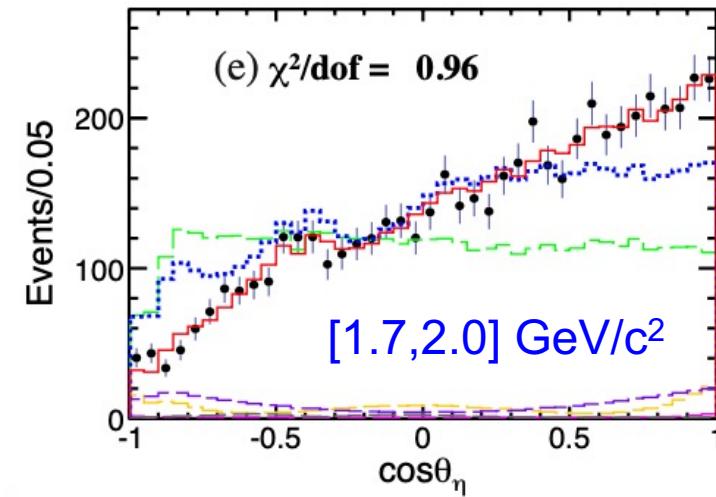
- Precision hadron spectroscopy → understand the established hadron states
- Search for the unexpected hadron states and spectroscopy study → explore nature of exotic hadron states

Partial wave analysis of  $J/\psi \rightarrow \gamma\eta\eta'$ 

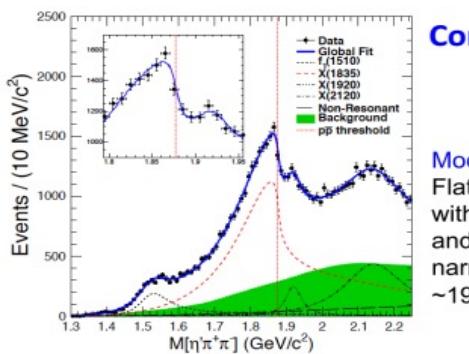
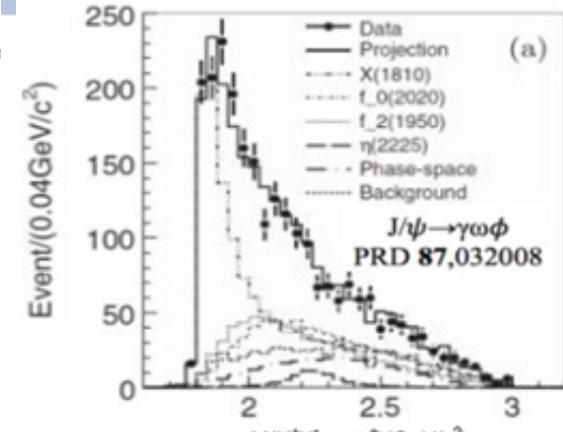
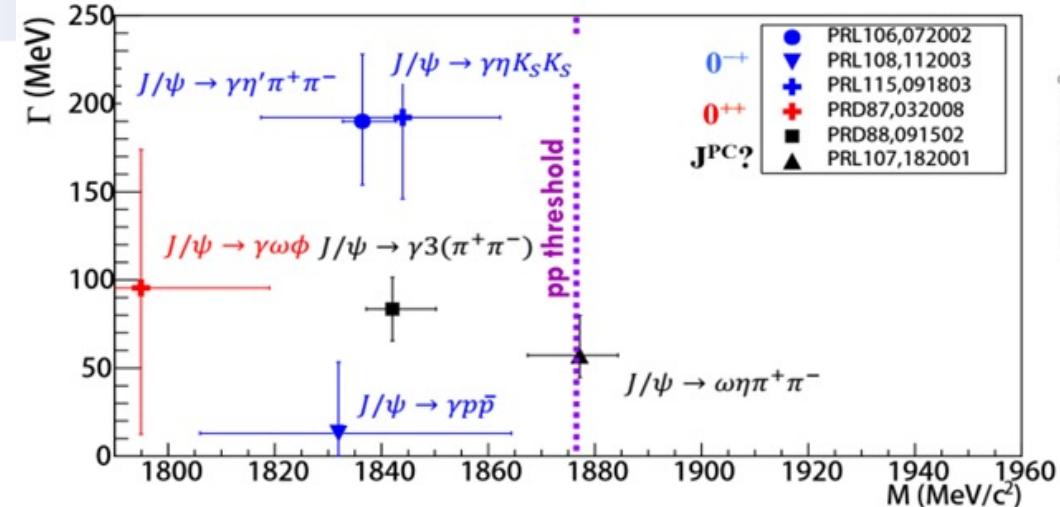
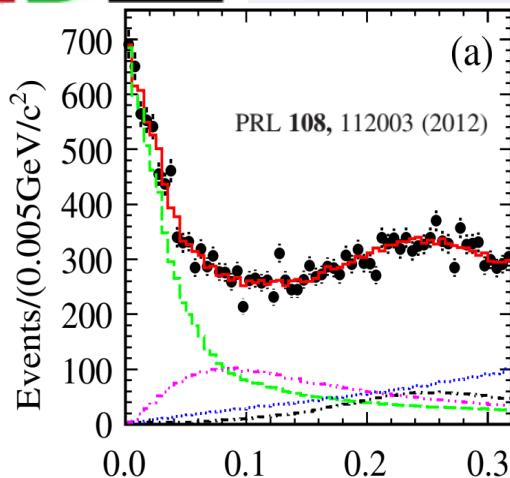
Phys. Rev. Lett. 129, 192002 (2022), Phys. Rev. Lett. 130, 159901(2023)  
 Phys. Rev. D 106, 072012 (2022), Phys. Rev. D 107, 079901(2023)



and



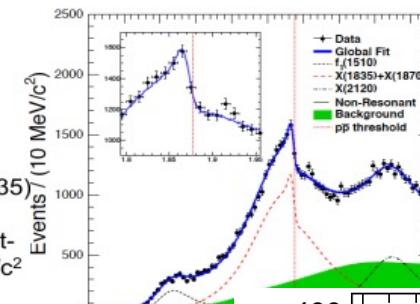
- critical to establish the  $1^{-+}$  hybrid nonet.
- supporting  $f_0(1710)$  overlap with glueball



**Connection is emerging**  
PRL 117, 042002 (2016)

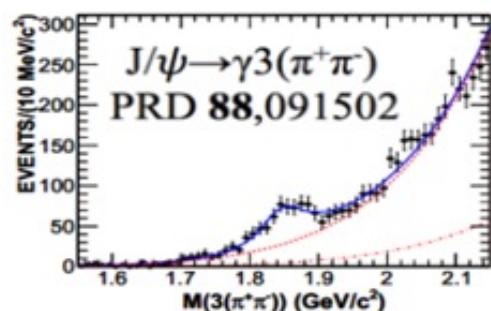
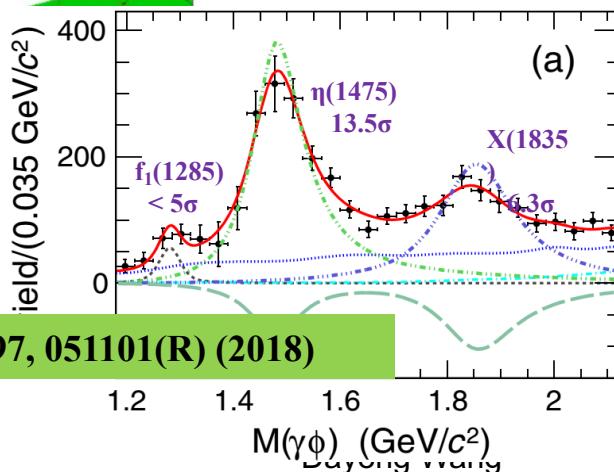
**Model 1:**  
Flatte lineshape  
with strong coupling to  $p\bar{p}$   
and one additional,  
narrow Breit-Wigner at  
 $\sim 1920$  MeV/ $c^2$

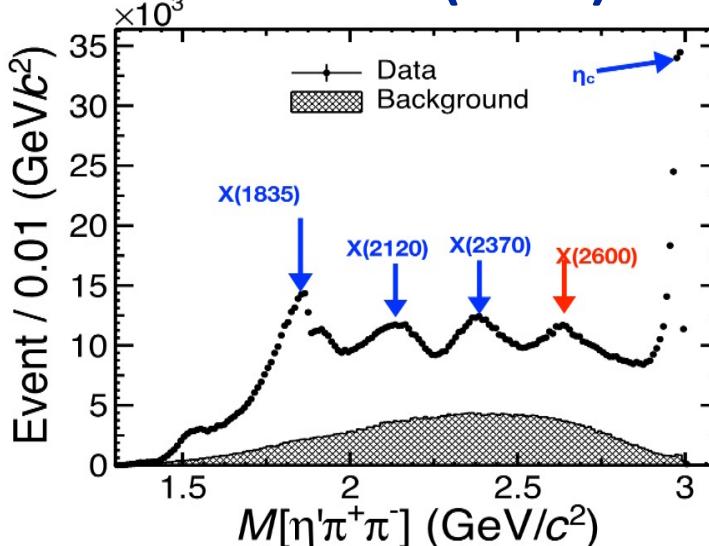
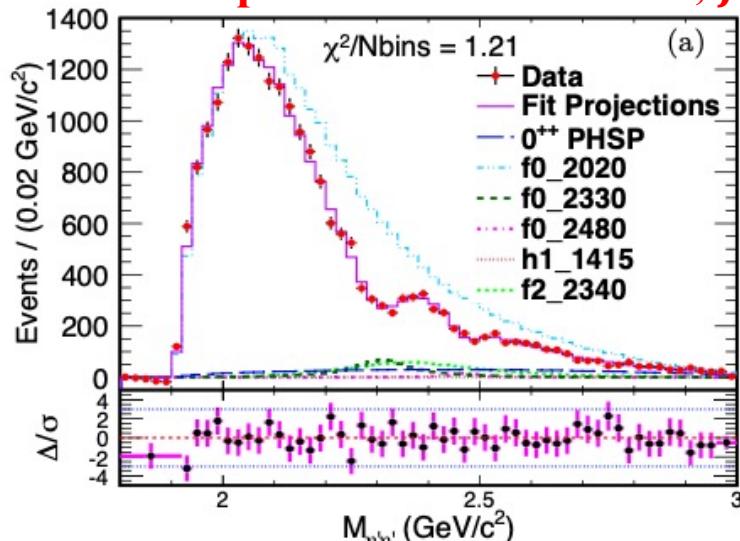
**Model 2:**  
Coherent sum of  $X(1835)$   
Breit-Wigner and one  
additional, narrow Breit-  
Wigner at  $\sim 1870$  MeV/ $c^2$



- Suggest the existence of a state, either a broad one with couplings to  $p\bar{p}$ , or a narrow state just below the  $p\bar{p}$  mass
- Support the existence of a  $p\bar{p}$  molecule-like state or bound state
- Any relations?
- What is the role of the  $p\bar{p}$  threshold (and other thresholds)?
- Patterns in the production and decay modes

Phys. Rev. D 97, 051101(R) (2018)



Observation of  $X(2600)$  in  $J/\psi \rightarrow \gamma \eta' \pi^+ \pi^-$ Observed a possible new  $0^{++}$  state,  $f_0(2480)$  $J/\psi \rightarrow \gamma \eta' \eta'$ 

PRL129(2022)042001

 $J^{PC}$ : unknown $M = 2618.3 \pm 2.0^{+16.3}_{-1.4} \text{ MeV}/c^2$  $\Gamma = 195 \pm 5^{+26}_{-17} \text{ MeV}$  $\eta$  radial excitation or exotic hadron?

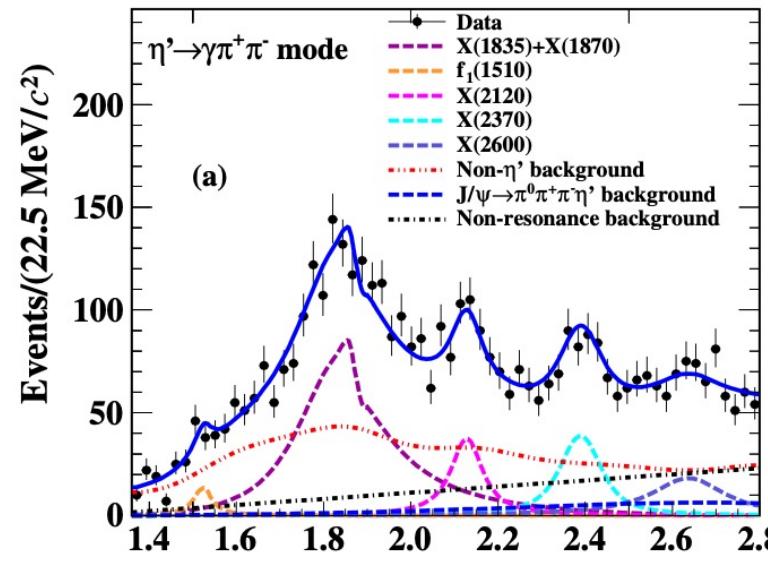
PRD105(2022)072002

Resonance	$M(\text{MeV}/c^2)$	$\Gamma(\text{MeV})$	B.F.	Sig.( $\sigma$ )
$f_0(2020)$	$1982 \pm 3^{+54}_{-0}$	$436 \pm 4^{+46}_{-49}$	$(2.63 \pm 0.06^{+0.31}_{-0.46}) \times 10^{-4}$	$\gg 25$
$f_0(2330)$	$2312 \pm 2^{+10}_{-0}$	$134 \pm 5^{+30}_{-9}$	$(6.09 \pm 0.64^{+4.00}_{-1.68}) \times 10^{-6}$	16.3
$f_0(2480)$	$2470 \pm 4^{+4}_{-6}$	$75 \pm 9^{+11}_{-8}$	$(8.18 \pm 1.77^{+3.73}_{-2.23}) \times 10^{-7}$	5.2
$h_1(1415)$	$1384 \pm 6^{+9}_{-0}$	$66 \pm 10^{+12}_{-10}$	$(4.69 \pm 0.80^{+0.74}_{-1.82}) \times 10^{-7}$	5.3
$f_2(2340)$	$2346 \pm 8^{+22}_{-6}$	$332 \pm 14^{+26}_{-12}$	$(8.67 \pm 0.70^{+0.61}_{-1.67}) \times 10^{-6}$	16.1
$0^{++}$ PHSP	...	...	$(1.17 \pm 0.23^{+4.09}_{-0.70}) \times 10^{-5}$	15.7

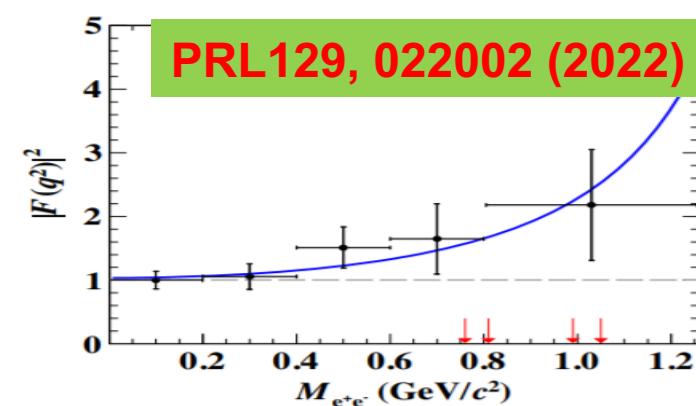
The large production rate of  $f_0(2020)$  in radiative  $J/\psi$  decay suggests that it has a large overlap with scalar glueball. But, its mass is lower than LQCD calculation

# EM Dalitz decay studies

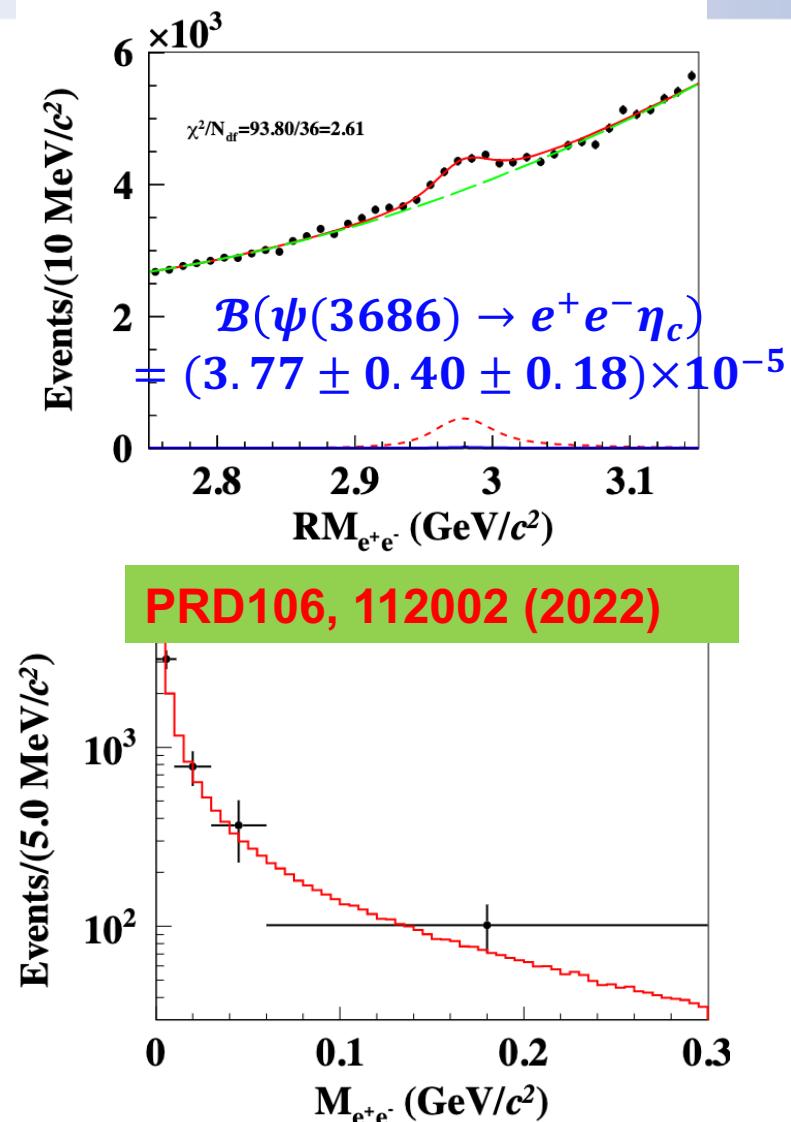
- X(1835) in  $J/\psi \rightarrow e^+e^- \eta'\pi^+\pi^-$



PRL129, 022002 (2022)

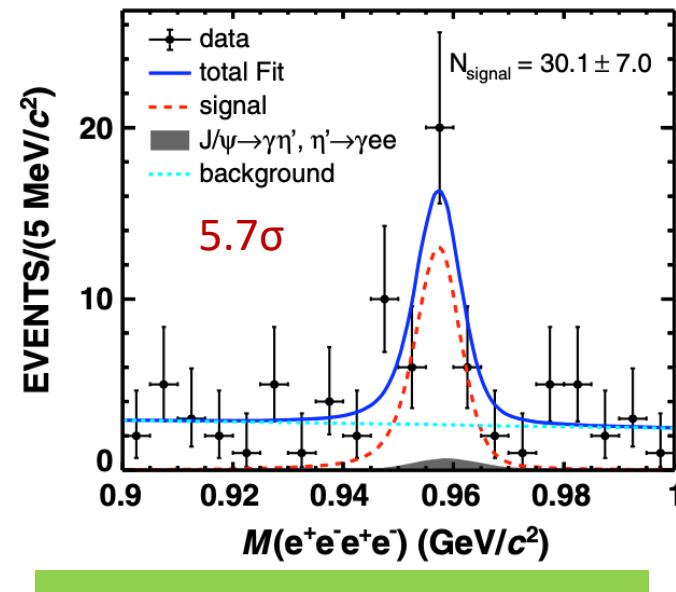


$$\Lambda = [1.75 \pm 0.29(\text{stat}) \pm 0.05(\text{syst})] \text{ GeV}/c^2$$

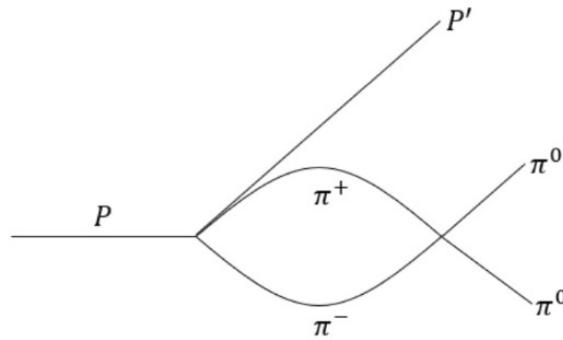


consistent with the theoretical prediction from the VMD model

- Observation of double Dalitz decay



$$B(\eta' \rightarrow e^+e^-e^+e^-) = (4.5 \pm 1.0 \pm 0.5) \times 10^{-6}$$

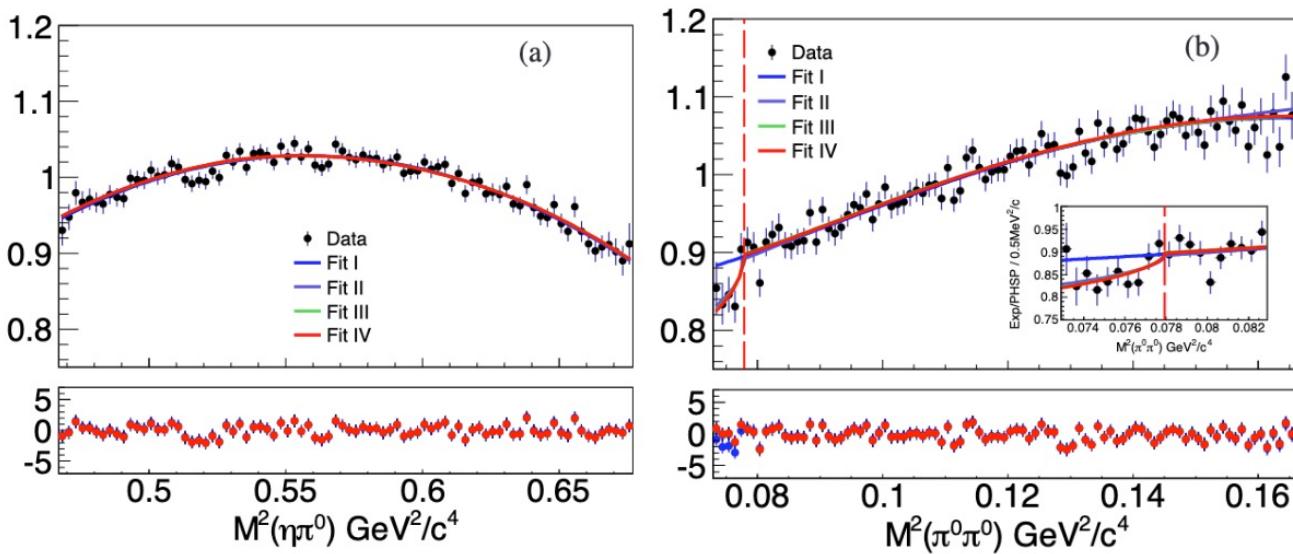


$$C_{00} = \frac{16\pi}{3}(a_0 + 2a_2)(1 - \xi),$$

$$C_x = \frac{16\pi}{3}(a_2 - a_0)\left(1 + \frac{\xi}{3}\right),$$

$$C_{+-} = \frac{8\pi}{3}(2a_0 + a_2)(1 + \xi),$$

$$\xi = \frac{M_{\pi^\pm}^2 - M_{\pi^0}^2}{M_{\pi^\pm}^2}.$$



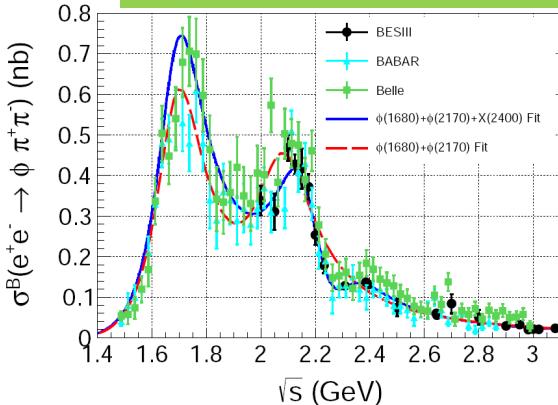
PRL130, 081901 (2023)

- Evidence for a structure at  $\pi^+ \pi^-$  mass threshold in the  $\pi^0 \pi^0$  mass spectrum with significance  $3.5\sigma$ , consistent with the cusp effect predicted by NREFT
- Scattering length combination  $a_0 - a_2 = 0.226 \pm 0.060 \pm 0.012$  in good agreement with theoretical calculation of  $0.2644 \pm 0.0051$

# Results on Y(2175)/phi(2170)

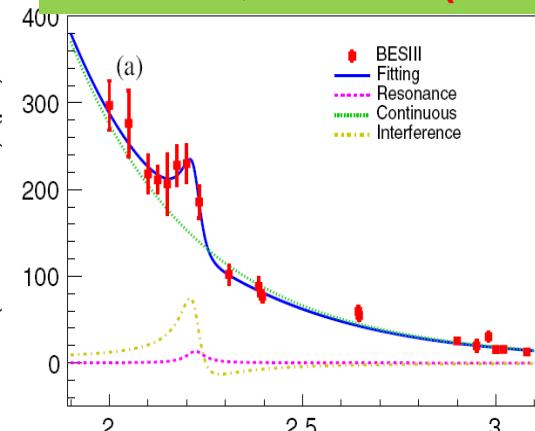
$$e^+e^- \rightarrow \phi\pi^+\pi^-$$

arXiv:2112.23219



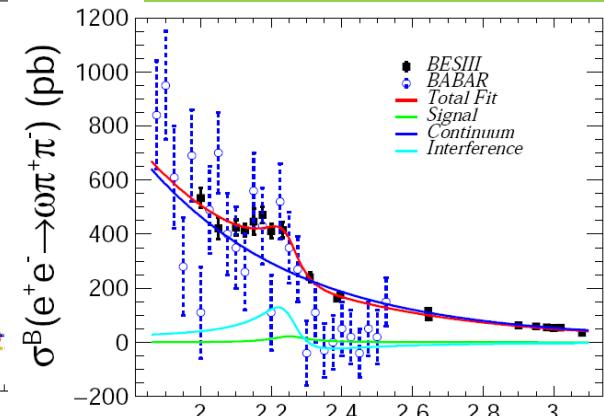
$$e^+e^- \rightarrow \omega\pi^0\pi^0$$

PRD105, 032005 (2022)



$$e^+e^- \rightarrow \omega\pi^+\pi^-$$

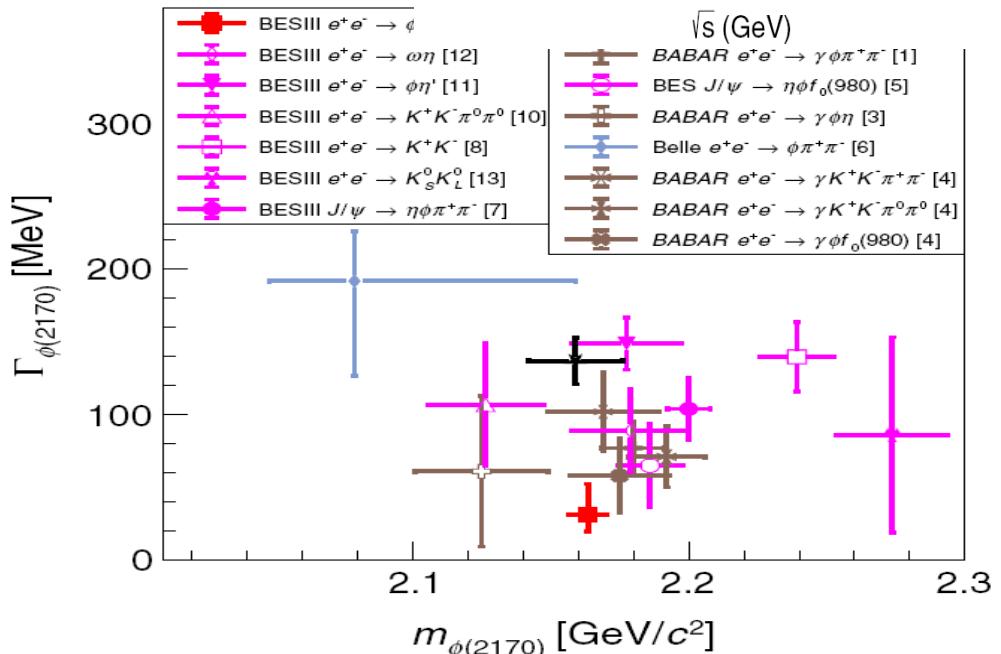
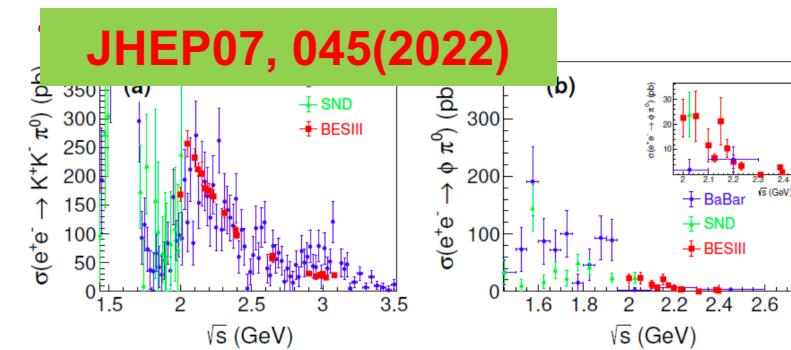
JHEP 01 (2023) 111



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

- M=2190±19±37 MeV/c<sup>2</sup>, Γ=191±28±60 MeV from PWA of K\*(892)K and K<sub>2</sub>\*(1430)K;

JHEP07, 045(2022)

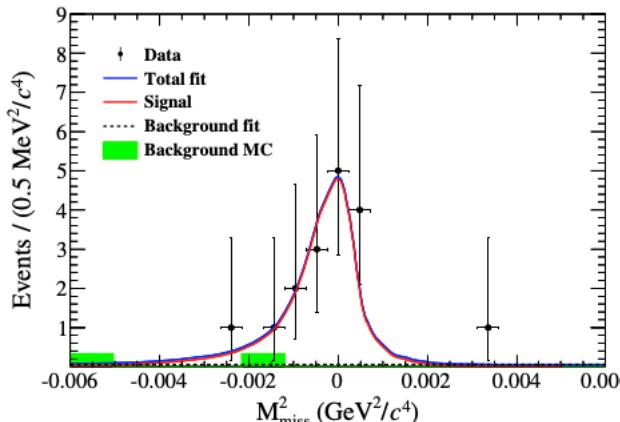


- Different masses and widths
- Limited decay modes
- Nature is mysterious
- More studies are desirable

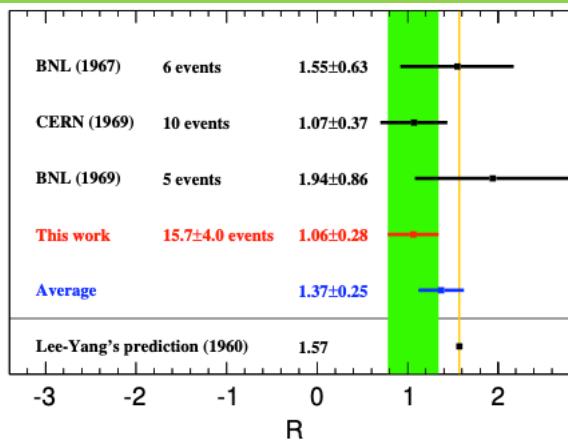
# Decay properties of hyperons

With world largest  $J/\psi$  sample , BESIII is also a hyperon factory!

$\Sigma^+ \rightarrow \Lambda e^- \bar{\nu}$  via  $J/\psi \rightarrow \Sigma^+ \bar{\Sigma}^-$

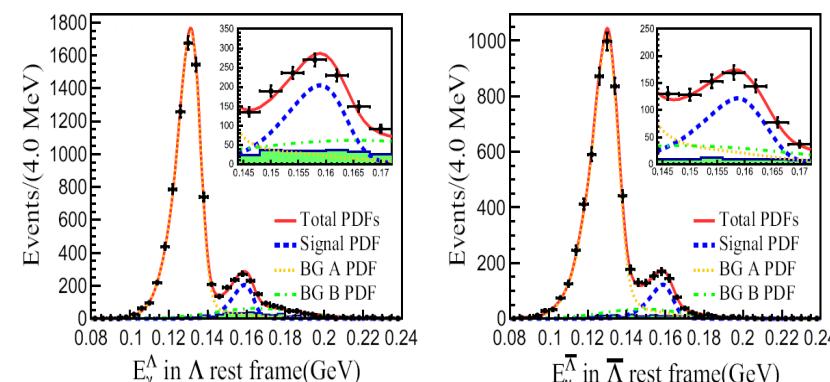


Arxiv:2212.05296, PRD in press



$\Lambda \rightarrow n\gamma$  via  $J/\psi \rightarrow \Lambda \bar{\Lambda}$

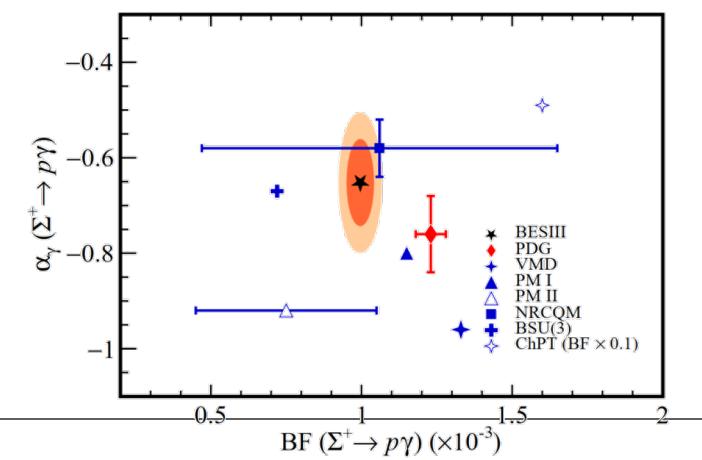
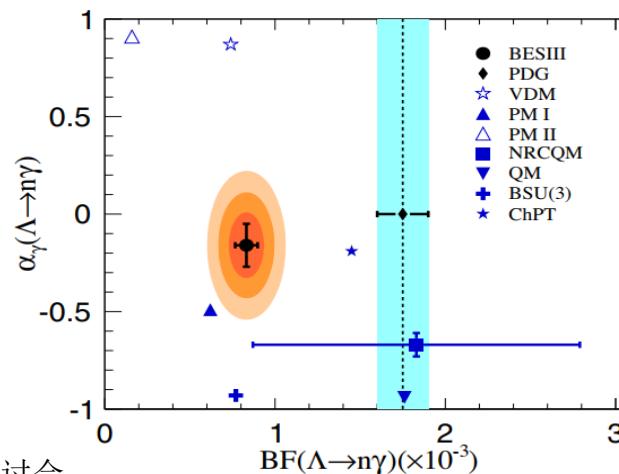
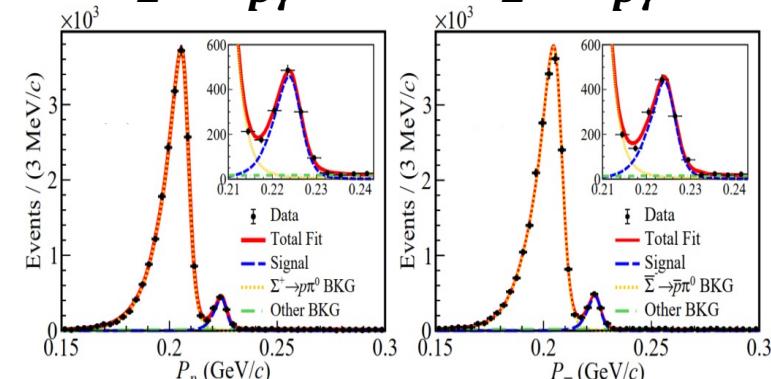
PRL129(2022)122002

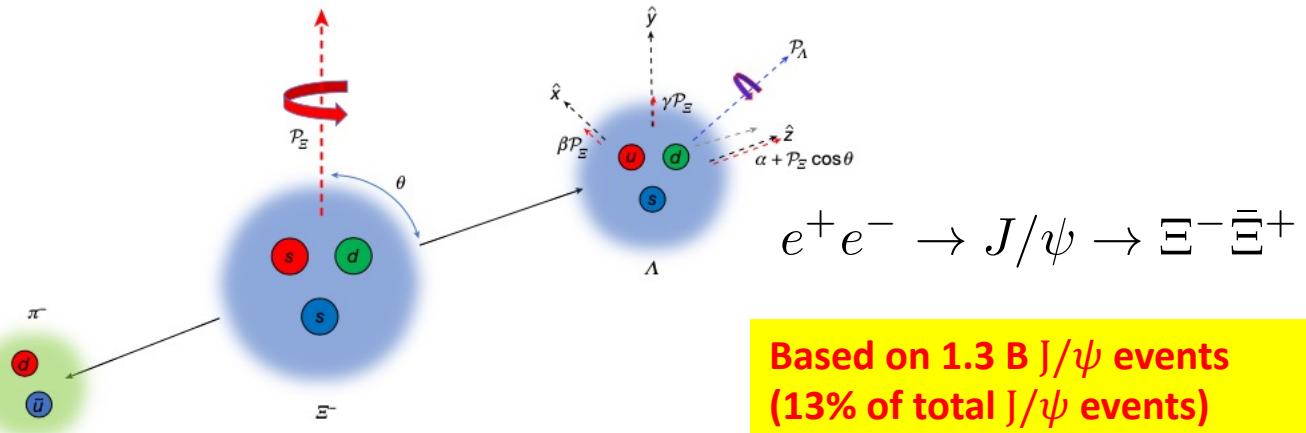


$\Sigma^+ \rightarrow p\gamma$  via  $J/\psi \rightarrow \Sigma^+ \bar{\Sigma}^-$

$\Sigma^+ \rightarrow p\gamma$

$\bar{\Sigma}^- \rightarrow \bar{p}\gamma$





- ✓ First measurement of polarization
- ✓ First direct determination of all  $\Xi$  decay parameters
- ✓ First extraction of weak phase difference from baryon weak decays
- ✓ Three CP tests

[Nature 606, 64 \(2022\)](#)

Parameter	This work	Previous result
$a_\psi$	$0.586 \pm 0.012 \pm 0.010$	$0.58 \pm 0.04 \pm 0.08$
$\Delta\phi$	$1.213 \pm 0.046 \pm 0.016$ rad	-
$a_\Xi$	$-0.376 \pm 0.007 \pm 0.003$	$-0.401 \pm 0.010$
$\phi_\Xi$	$0.011 \pm 0.019 \pm 0.009$ rad	$-0.037 \pm 0.014$ rad
$\bar{a}_\Xi$	$0.371 \pm 0.007 \pm 0.002$	-
$\bar{\phi}_\Xi$	$-0.021 \pm 0.019 \pm 0.007$ rad	-
$a_\Lambda$	$0.757 \pm 0.011 \pm 0.008$	$0.750 \pm 0.009 \pm 0.004$
$\bar{a}_\Lambda$	$-0.763 \pm 0.011 \pm 0.007$	$-0.758 \pm 0.010 \pm 0.007$
$\xi_p - \xi_s$	$(1.2 \pm 3.4 \pm 0.8) \times 10^{-2}$ rad	-
$\delta_p - \delta_s$	$(-4.0 \pm 3.3 \pm 1.7) \times 10^{-2}$ rad	$(10.2 \pm 3.9) \times 10^{-2}$ rad
$A_{CP}^\Xi$	$(6 \pm 13 \pm 6) \times 10^{-3}$	-
$\Delta\phi_{CP}^\Xi$	$(-5 \pm 14 \pm 3) \times 10^{-3}$ rad	-
$A_{CP}^\Lambda$	$(-4 \pm 12 \pm 9) \times 10^{-3}$	$(-6 \pm 12 \pm 7) \times 10^{-3}$
$\langle\phi_\Xi\rangle$	$0.016 \pm 0.014 \pm 0.007$ rad	

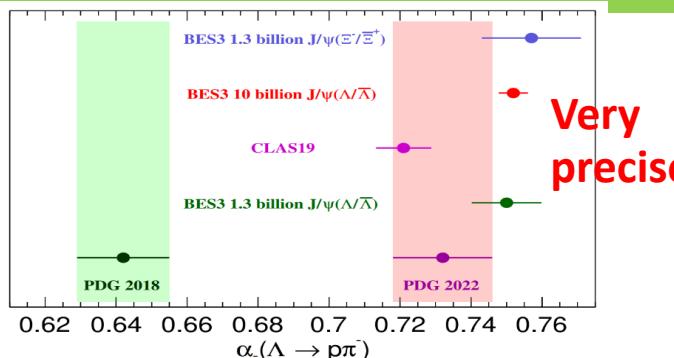
HyperCP(2004):  $\phi_{\Xi, \text{HyperCP}} = -0.042 \pm 0.011 \pm 0.011$

the same precision for  $\phi$  as HyperCP with **three orders of magnitude** smaller data sample!

- Relative phase between electronic and magnetic form factors:  $\Delta\Phi$
- Decay asymmetry parameter:  $\alpha$
- New window to test CP violation of hyperons:  $A_{CP} = (\alpha_+ + \alpha_-) / (\alpha_+ - \alpha_-)$



Nat. Phys. 15, 631(2019) → PRL129, 131801(2022)

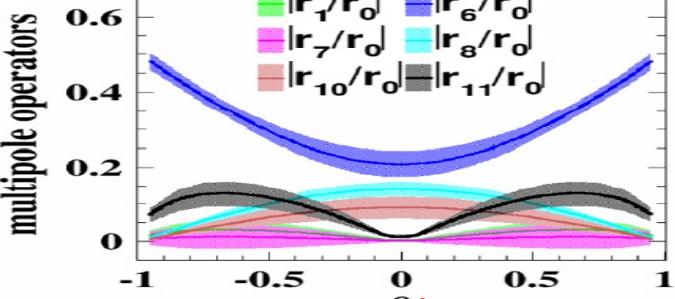


$$\Delta\Phi = (0.7521 \pm 0.0042 \pm 0.0066) rad$$

$$A_{CP} = (-0.25 \pm 0.46 \pm 0.12)\%$$

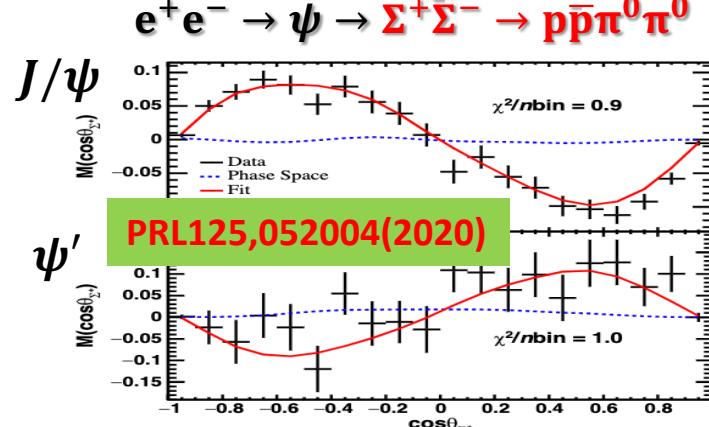


PRL126, 092002(2021)



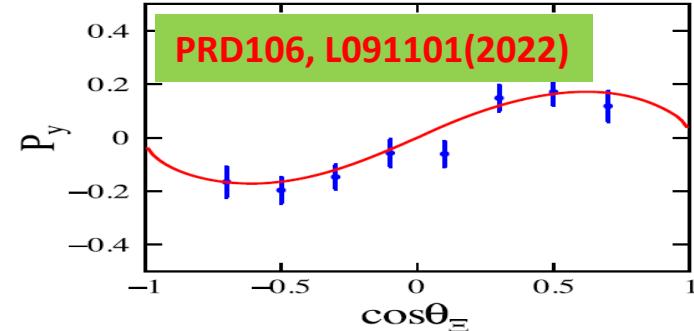
Spin of  $\Omega^-$  is set to be 3/2 for the first time

### $e^+e^- \rightarrow \psi' \rightarrow \Sigma^+\bar{\Sigma}^- \rightarrow p\bar{p}\pi^0\pi^0$



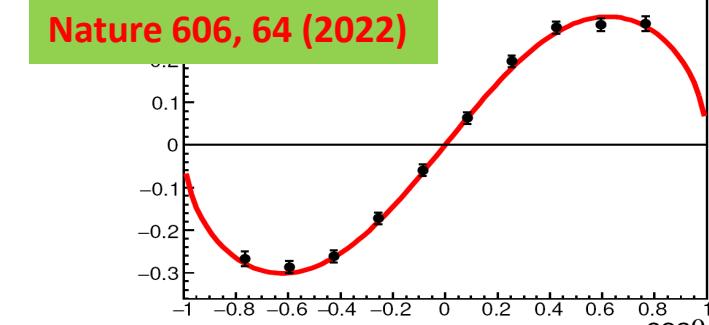
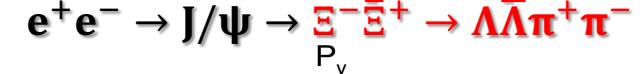
$$\Delta\Phi[J/\psi] = 15.5^\circ \pm 0.7^\circ \pm 0.5^\circ \quad \Delta\Phi[\psi'] = 21.7^\circ \pm 4.0^\circ \pm 0.8^\circ$$

$$A_{CP} = (-0.4 \pm 3.7 \pm 1.0)\%$$



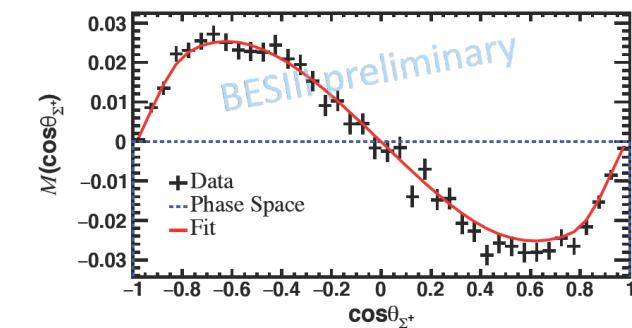
$$\Delta\Phi = (0.667 \pm 0.111 \pm 0.058) rad$$

$$A_{CP} = (1.5 \pm 5.1 \pm 1.0)\%$$



$$\Delta\Phi = (1.213 \pm 0.046 \pm 0.016) rad$$

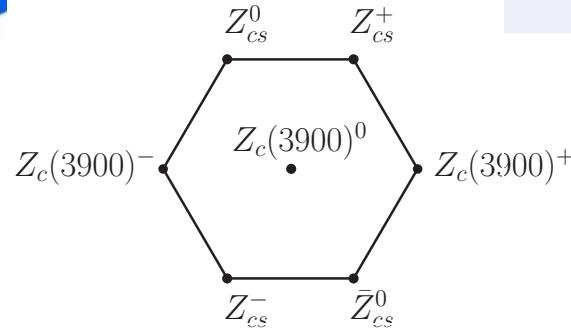
$$A_{CP} = (0.60 \pm 1.34 \pm 0.56)\%$$



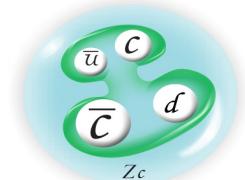
$$\Delta\Phi = (-0.277 \pm 0.004 \pm 0.0xx) rad$$

$$A_{CP} = (8.0 \pm 5.2 \pm x.x)\%$$

# Observation of $Z_{cs}(3985)$ and search for $Z'_{cs}$

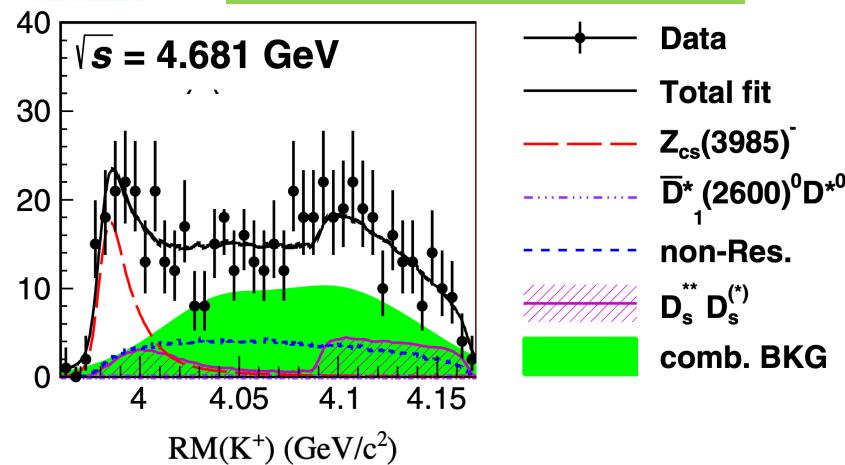


"Tetra"-Octet?



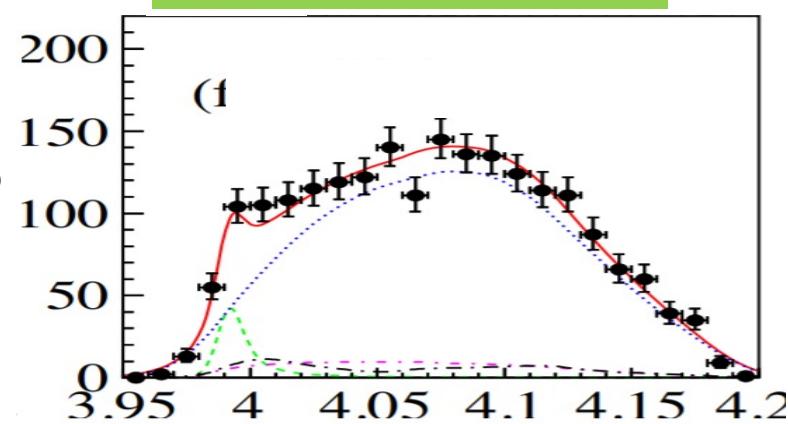
$$e^+e^- \rightarrow K^+ (D_s^- D^{*0} + D_s^{*-} D^0)$$

BESIII PRL126(2021)102001



$$e^+e^- \rightarrow K_s^0 (D_s^+ D^{*-} + D_s^{*+} D^-)$$

PRL129(2022)112003

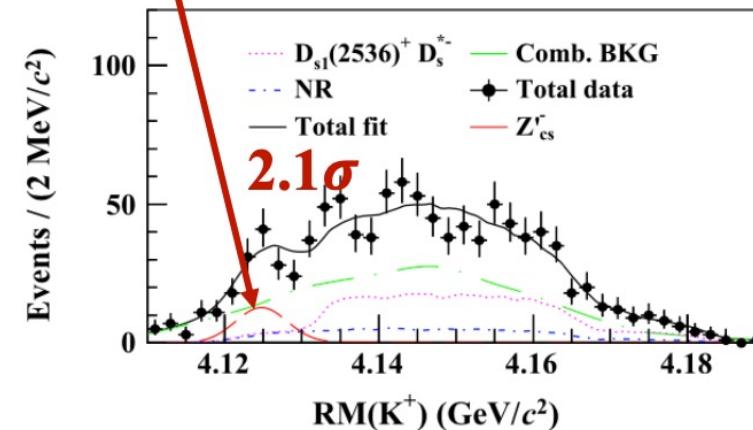


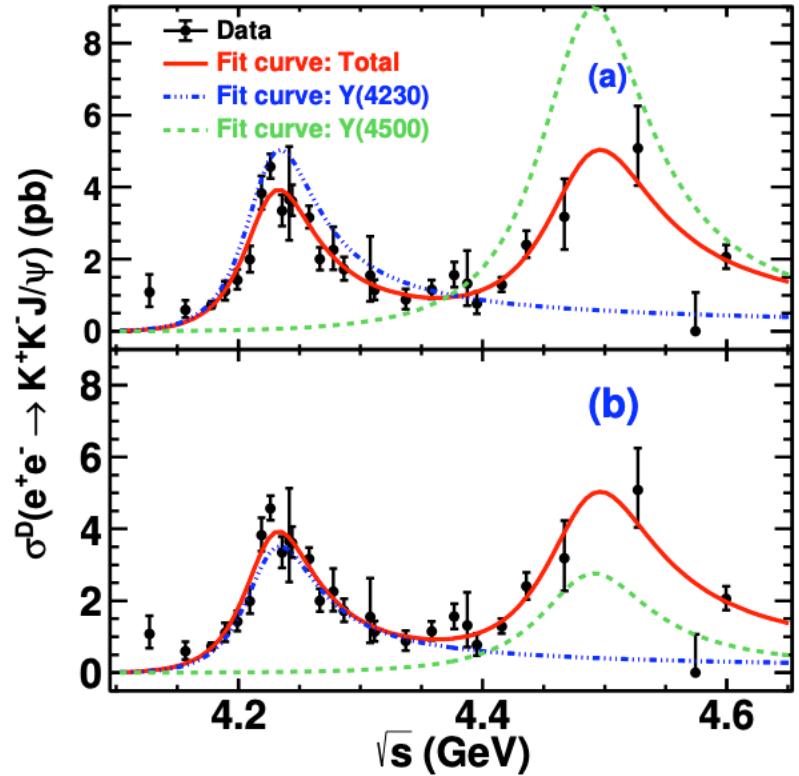
- M = (3985.2<sup>+2.1</sup><sub>-2.0</sub><sup>+1.7</sup>) MeV/c<sup>2</sup>
- Γ = (13.8<sup>+8.1</sup><sub>-5.2</sub><sup>+4.9</sup>) MeV
- Open charm final state

- M = 3992.2 ± 1.7 ± 1.6 MeV/c<sup>2</sup>
- Γ = (7.7<sup>+4.1</sup><sub>-3.8</sub><sup>+4.3</sup>) MeV
- Open charm final state

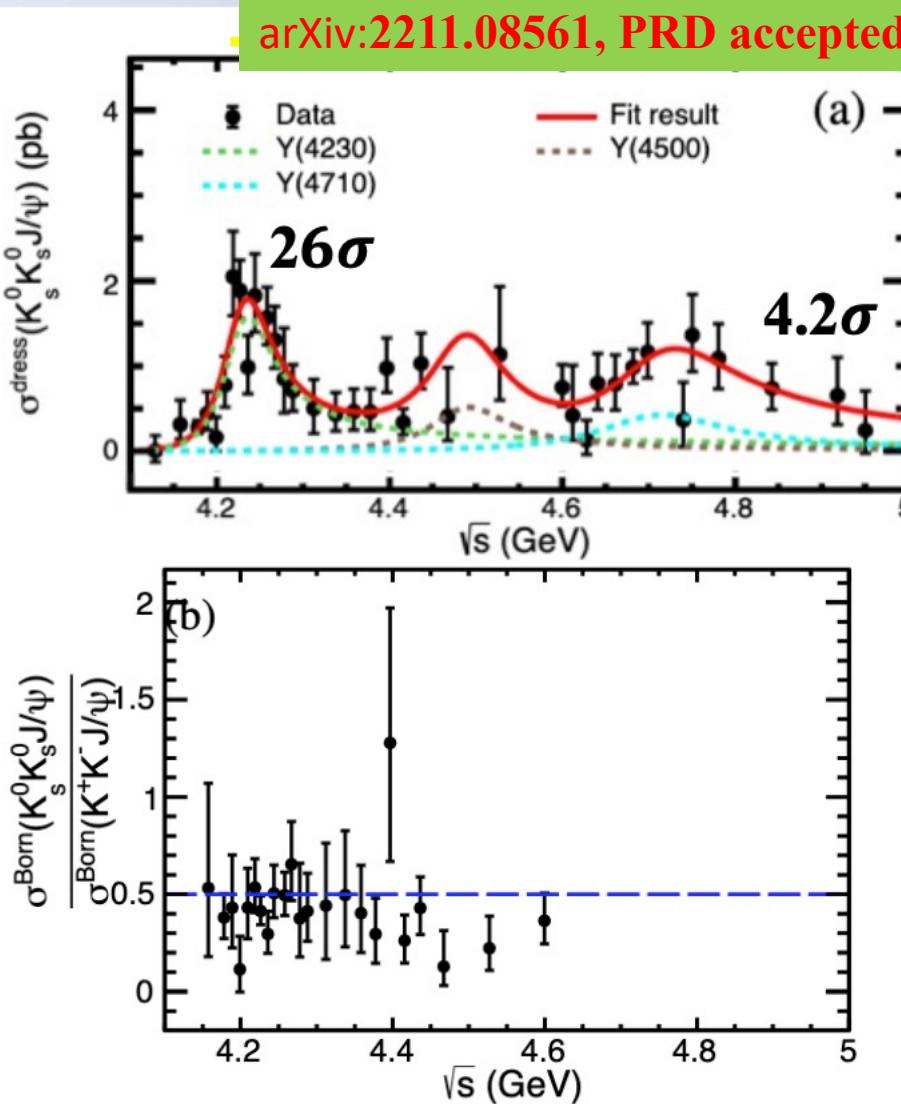
Given tetraquark state assumption, there should exist SU(3) partner **Z<sub>cs</sub> state with strangeness**

$$(4123.5 \pm 0.7_{\text{stat.}} \pm 4.7_{\text{syst.}}) \text{ MeV}/c^2$$



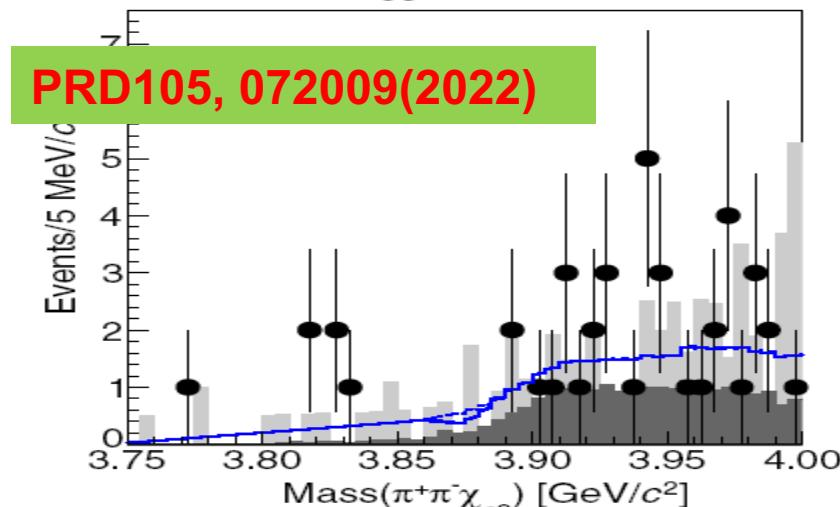


CPC 46, 111002(2022)

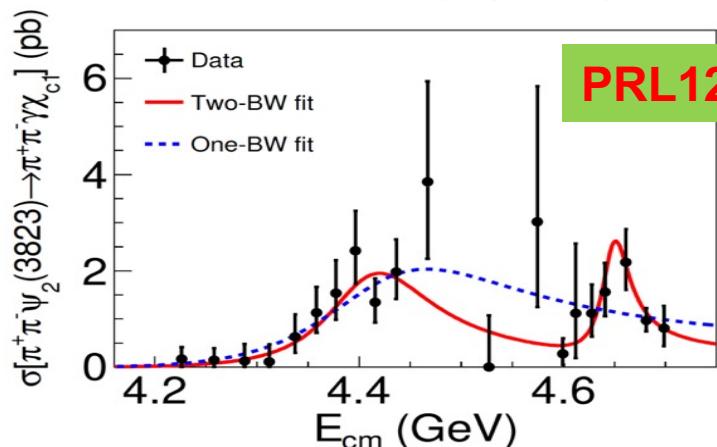


■ X(3872) Main production channel:  $e^+e^- \rightarrow \gamma X(3872)$

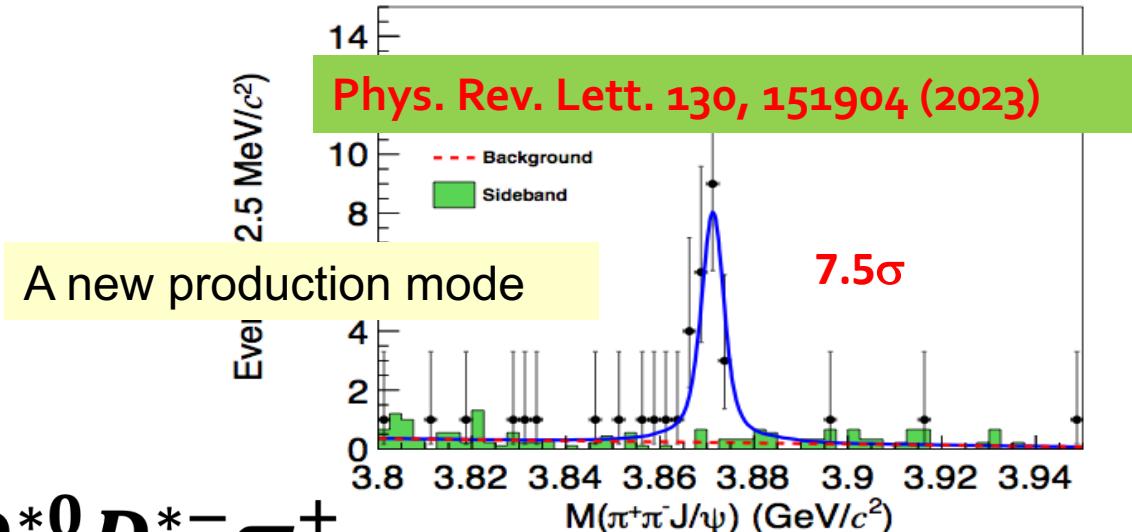
$X(3872) \rightarrow \pi^0 \chi_{c0}$  and  $\pi\pi\chi_{c0}$   
 $\chi_{c0} \rightarrow \pi^+\pi^-$



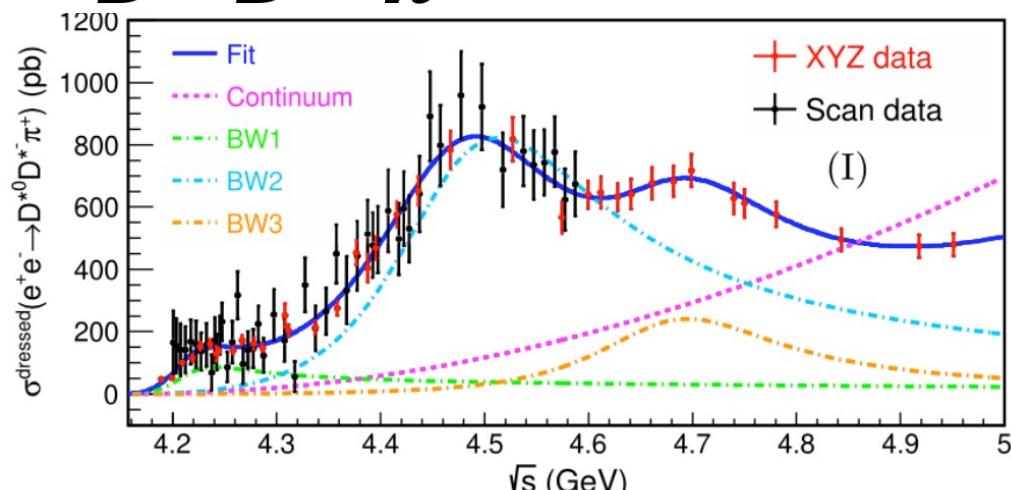
$e^+e^- \rightarrow \pi^+\pi^-\psi_2(3823)$



$e^+e^- \rightarrow \omega X(3872) \rightarrow \omega\pi^+\pi^-J/\psi$

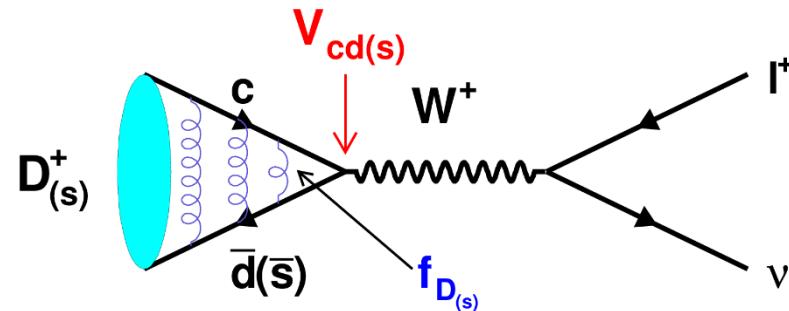


$e^+e^- \rightarrow D^{*0}D^{*-}\pi^+$



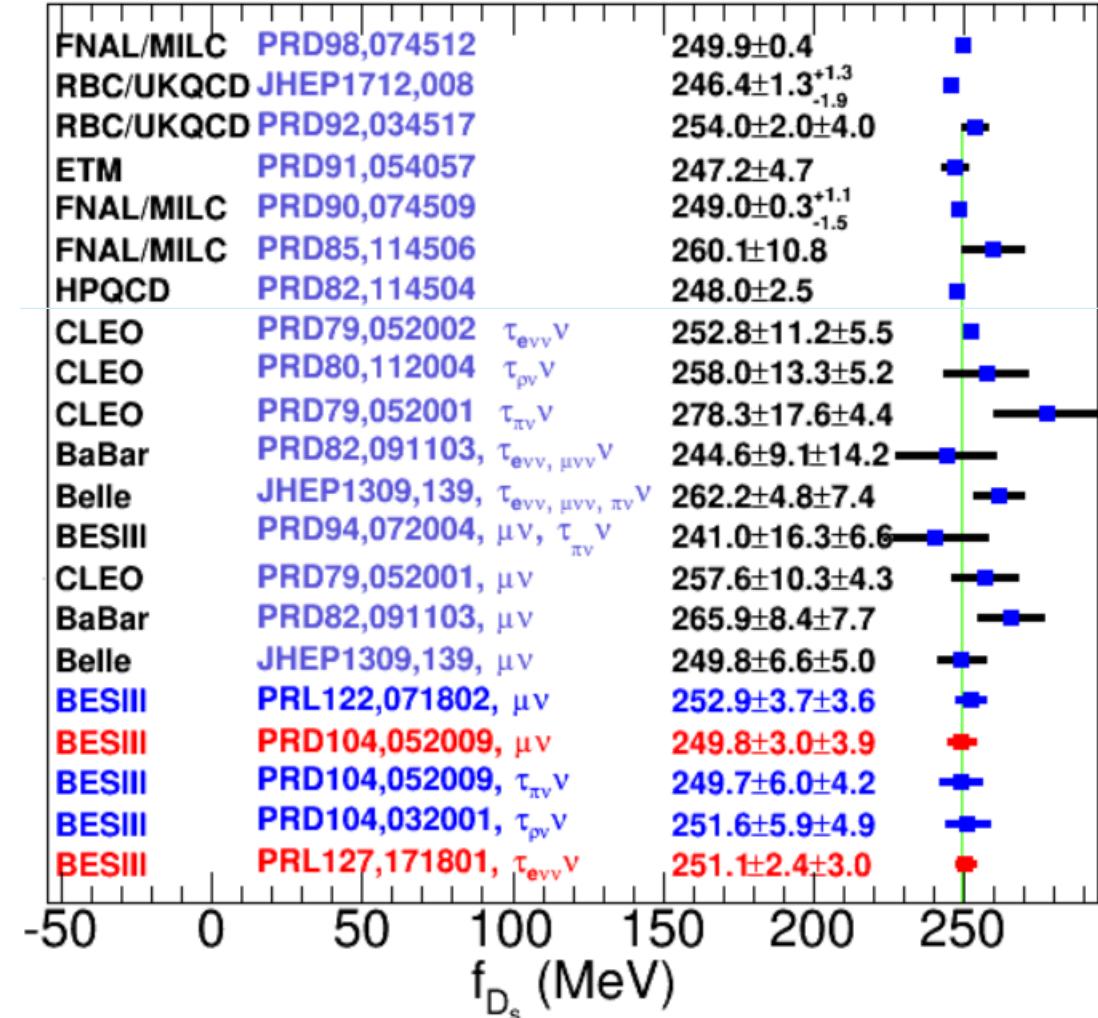
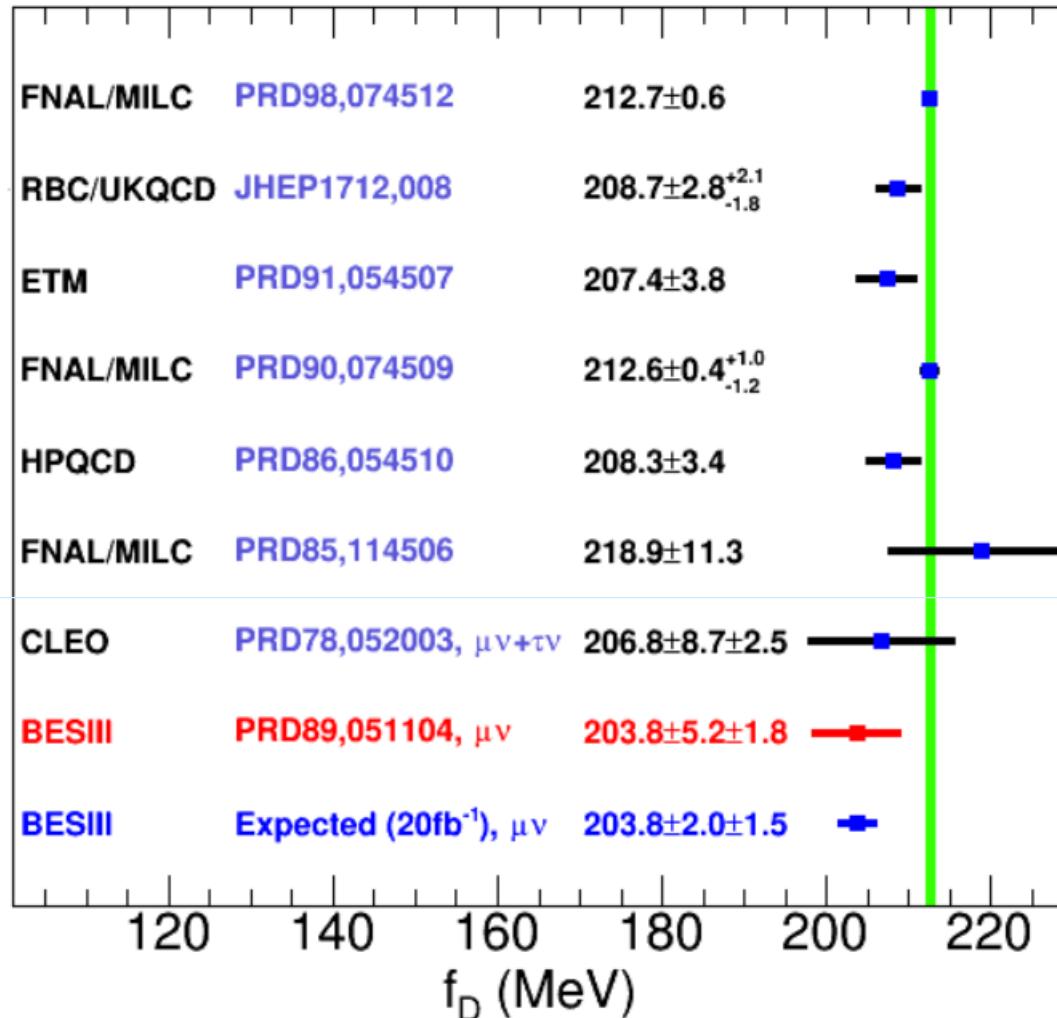
PRL130, 121901 (2023)

- Extract decay constant  $f_{D(s)}$  incorporates the strong interaction effects (wave function at the origin)
- To validate Lattice QCD calculation of  $f_{B(s)}$  and provide constraint of CKM- unitarity



Decay rate (Exp.)  $\Gamma(D_{(s)} \rightarrow \ell \nu) = |V_{cd(s)}|^2 \times f_{D_{(s)}}^2 \times \frac{G_F^2}{8\pi} m_\ell^2 m_{D_{(s)}} (1 - m_\ell^2/m_{D_{(s)}}^2)^2$

Decay constant (LQCD)  
CKM matrix element



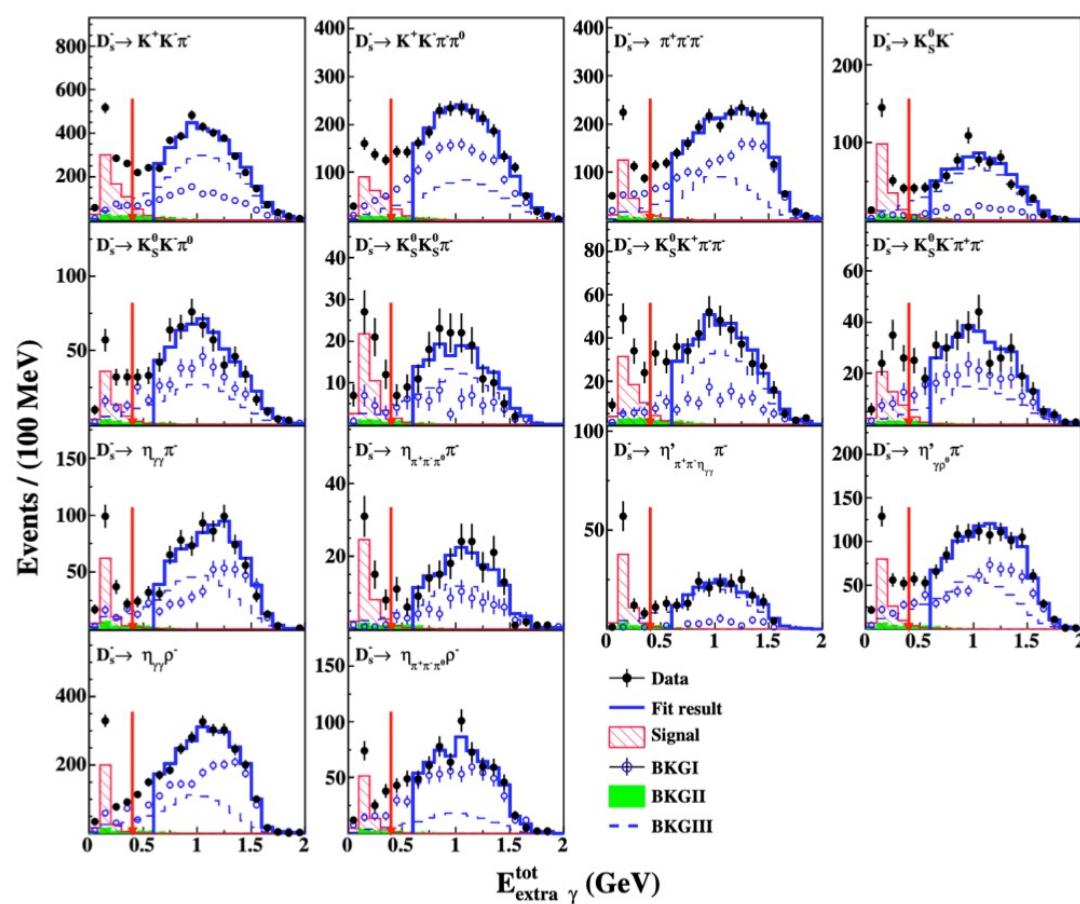
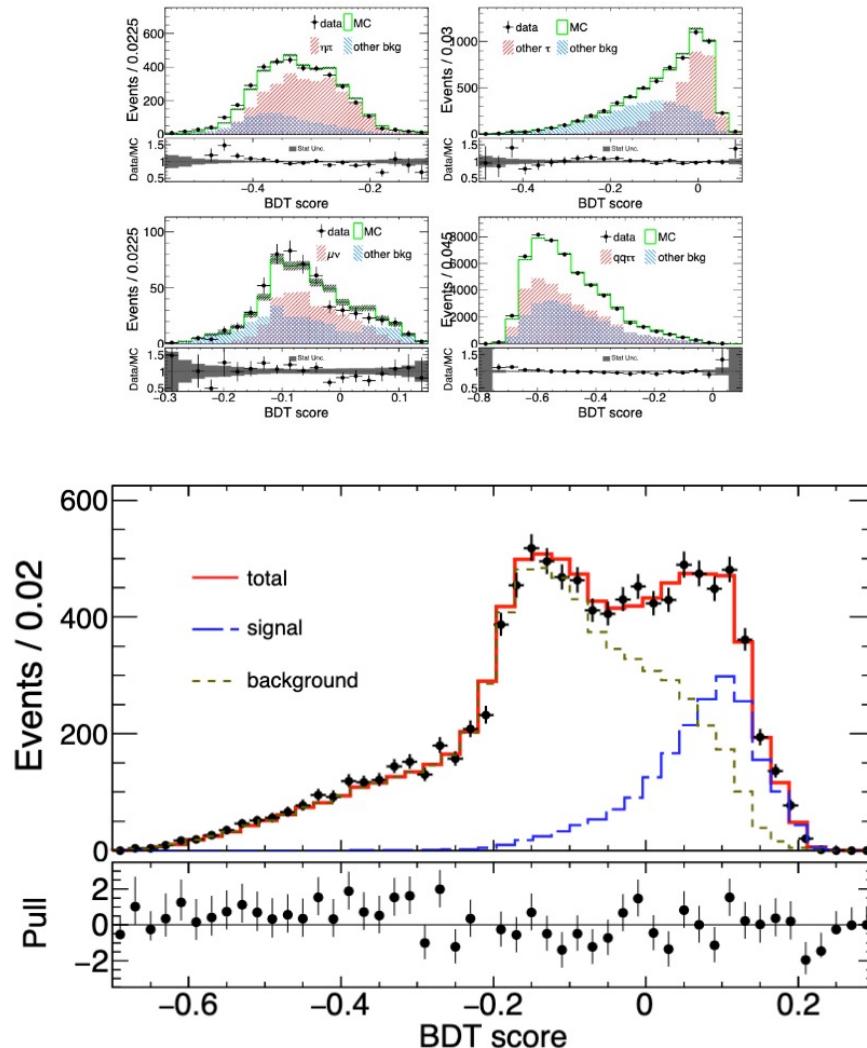
# Latest updates of $D_s \rightarrow \tau \nu$

7.33 fb<sup>-1</sup> data from 4.128 GeV to 4.226 GeV

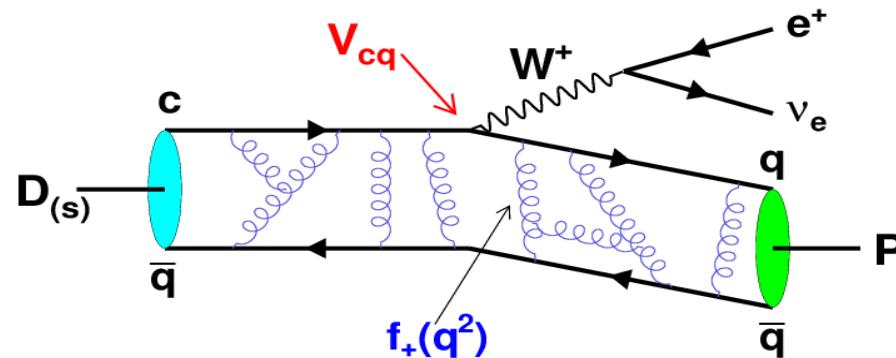
$$D_s^+ \rightarrow \tau^+ \nu_\tau, \tau^+ \rightarrow \mu^+ \nu_\mu \bar{\nu}_\tau$$

$D_s^+ \rightarrow \tau^+ \nu_\tau$ ,  $\tau^+ \rightarrow \pi^+ \bar{\nu}_\tau$  arXiv:2303.12600

arXiv:2303.12468



- form factor (FF)
  - ◆ Measure  $|V_{cx}| \times \text{FF}$
  - ◆ CKM-unitarity  $\Rightarrow |V_{cx}|$ , extract FF, test LQCD
  - ◆ Input LQCD FF to test CKM-unitarity



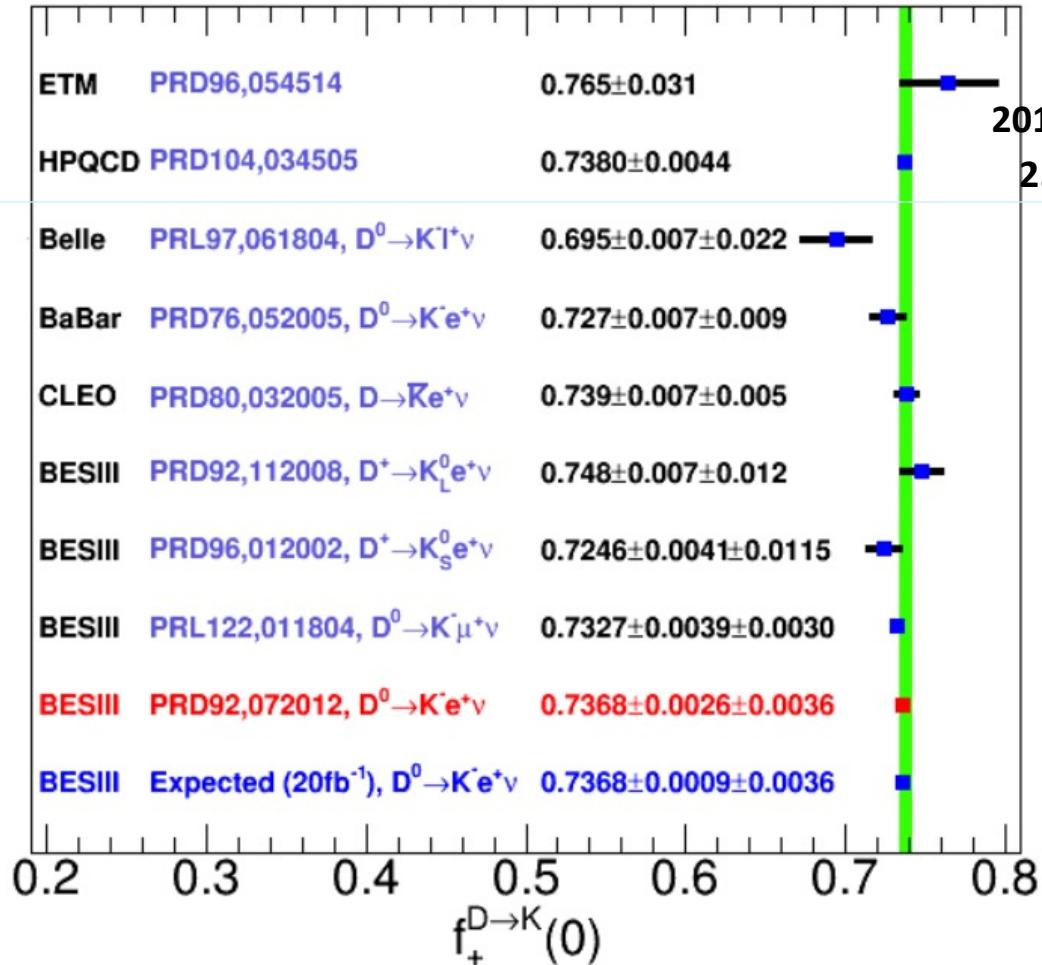
At zero positron mass limit:

Differential rate (Exp.)

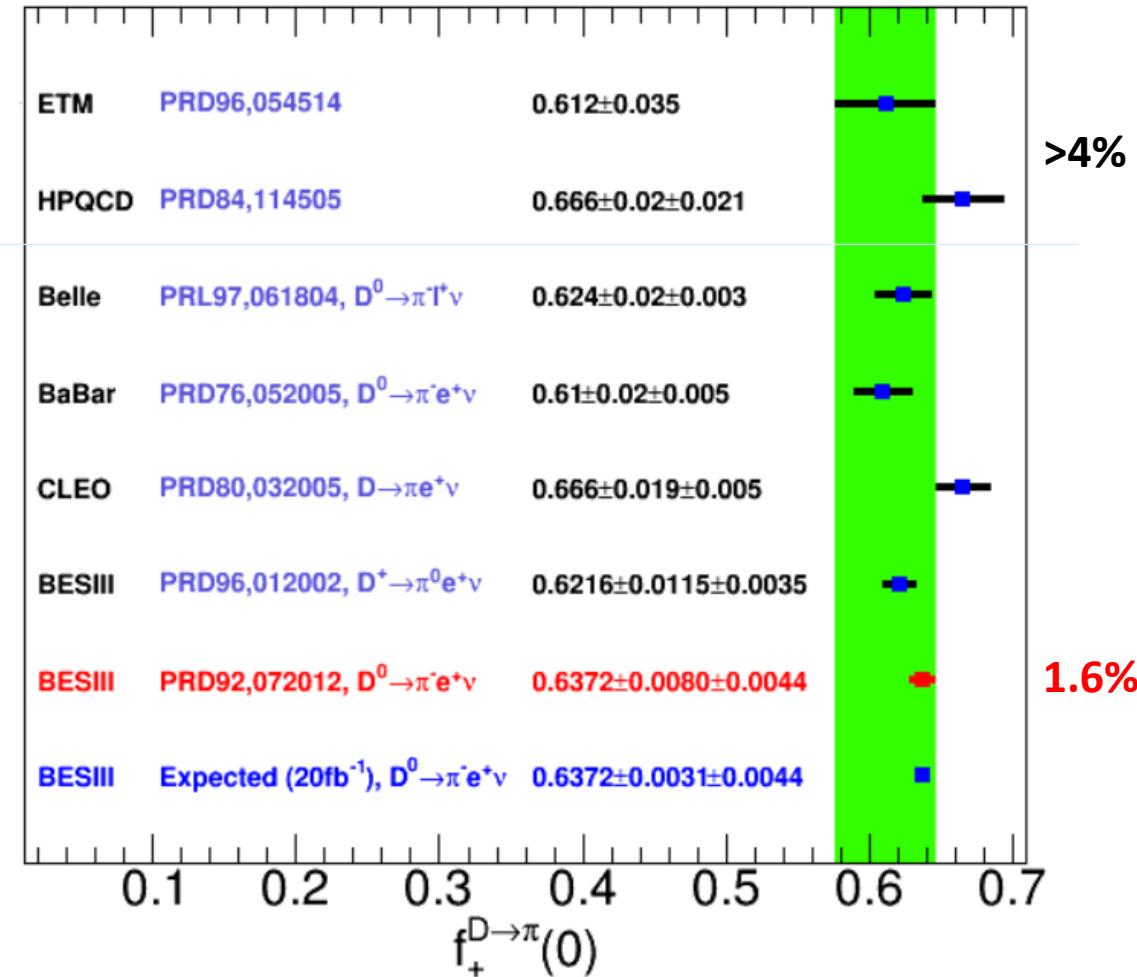
$$\frac{d\Gamma(D_{(s)} \rightarrow K(\pi) l\nu)}{dq^2} = \frac{G_F^2}{24\pi^3} \left| V_{cs(d)} \right|^2 P_{K(\pi)}^3 \left| f_+(q^2) \right|^2$$

CKM matrix element

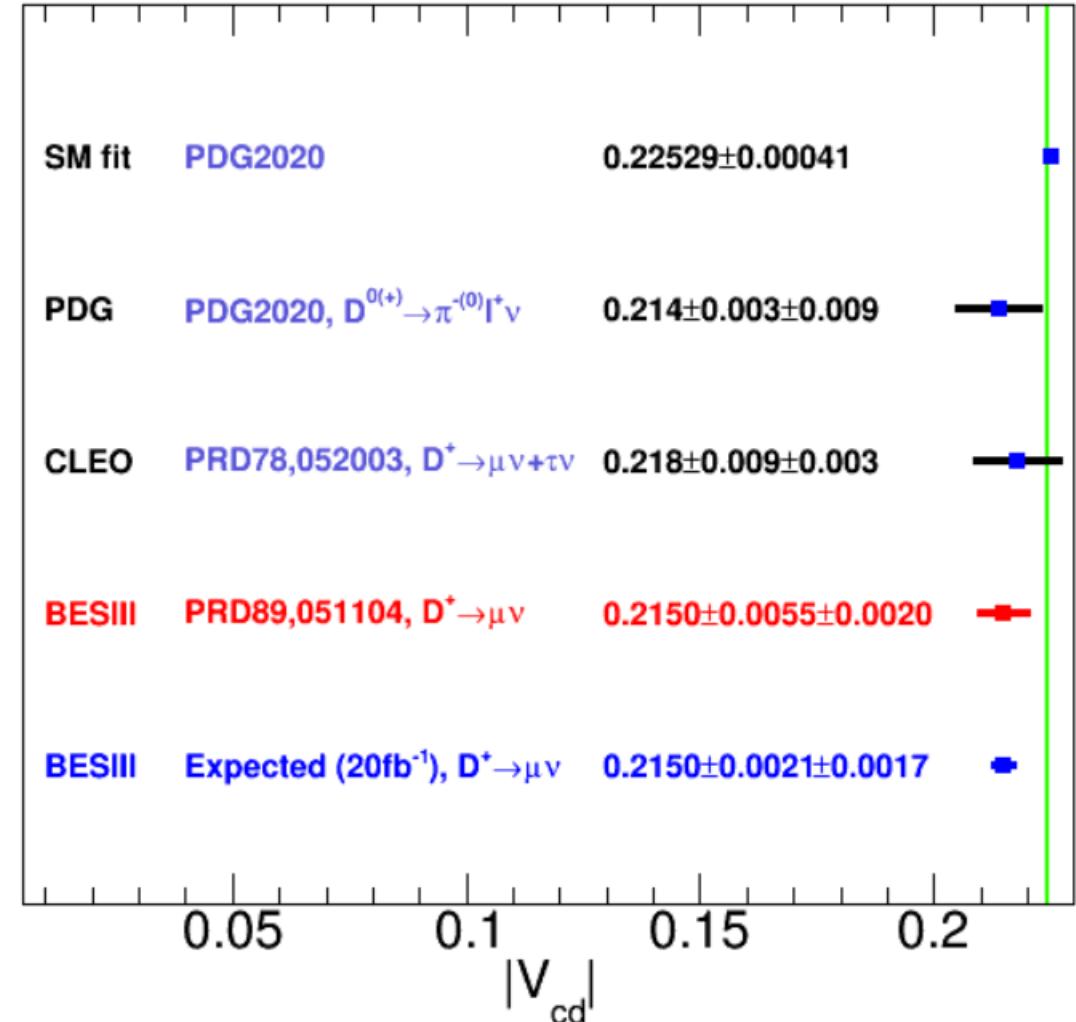
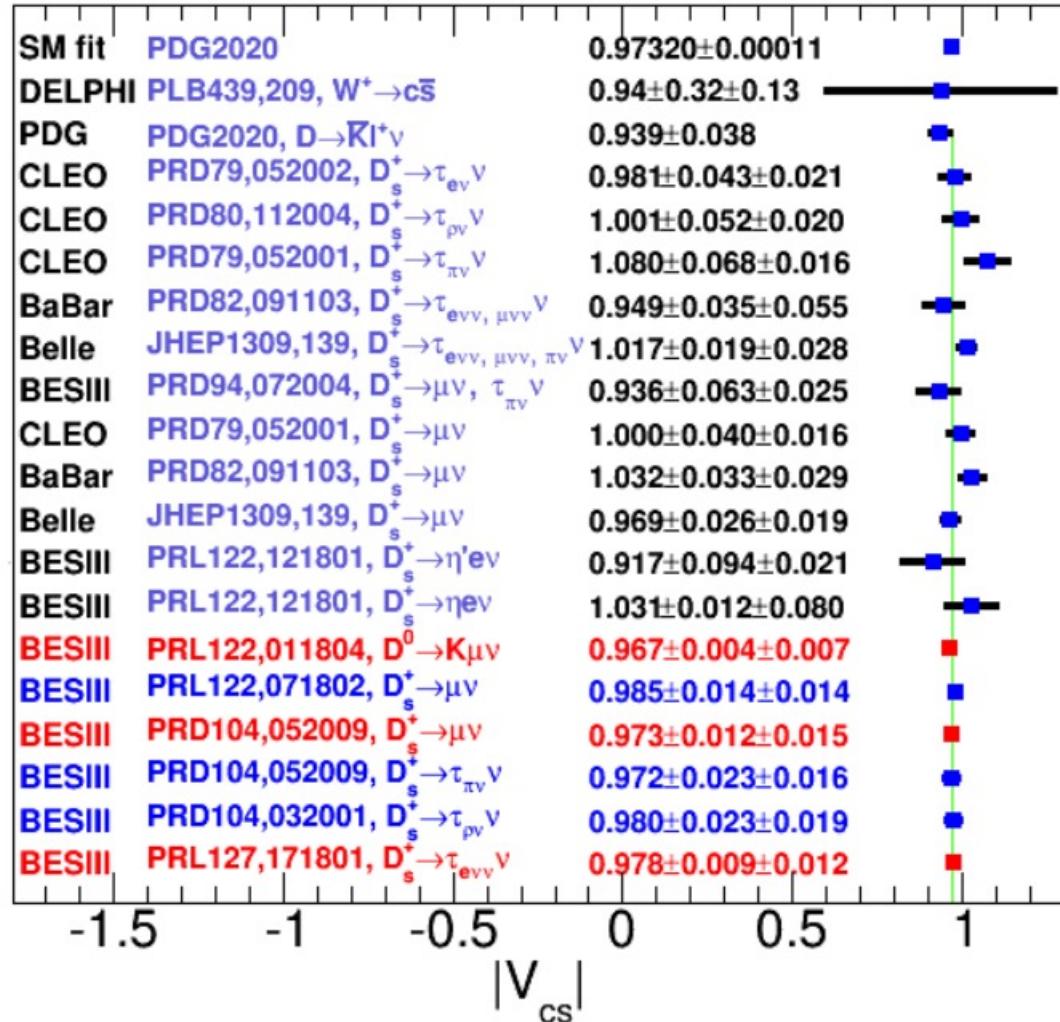
Form factor (LQCD)



Experimental precision of  $f_+^{D \rightarrow K}(0)$  is comparable to the latest LQCD precision



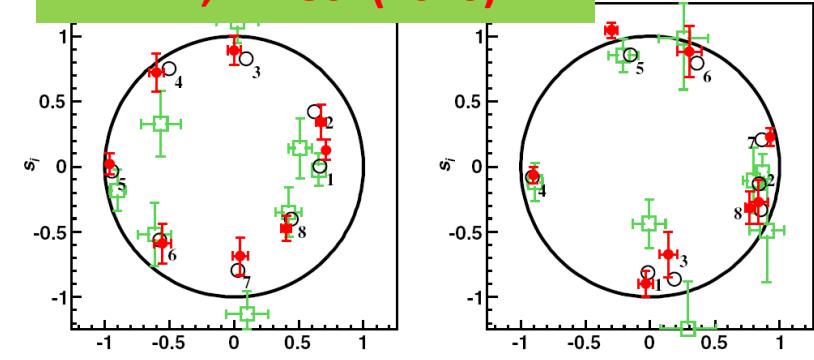
Experimental precision of  $f_+^{D \rightarrow \pi}(0)$  is still dominated by statistical uncertainties



# Strong phases in hadronic $D^0 / \bar{D}^0$ decays

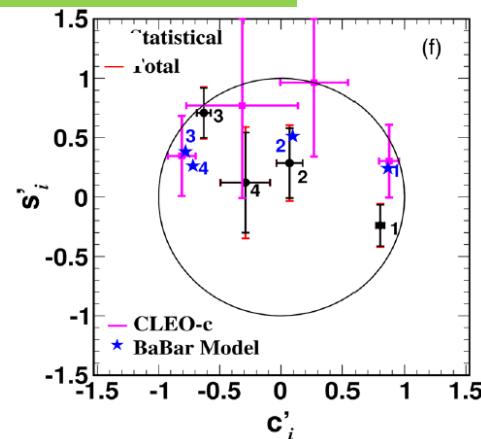
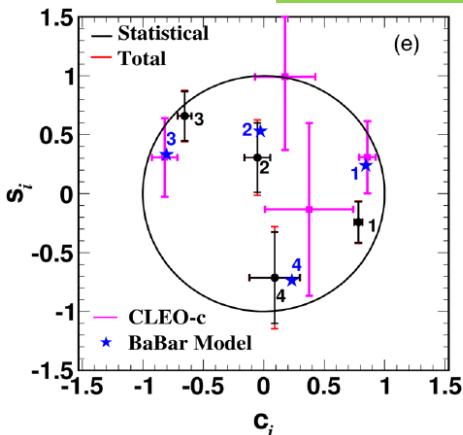
$D \rightarrow K_{S/L}^0 \pi^+ \pi^-$

PRL124, 241802(2020)

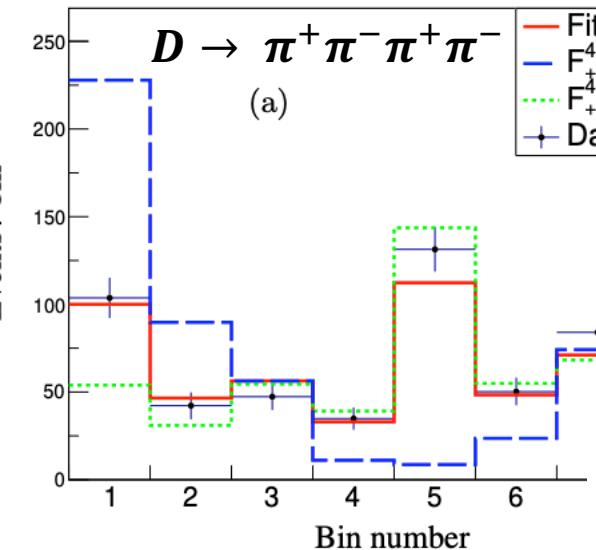


$D \rightarrow K_{S/L}^0 K^+ K^-$

PRD102, 052008(2020)



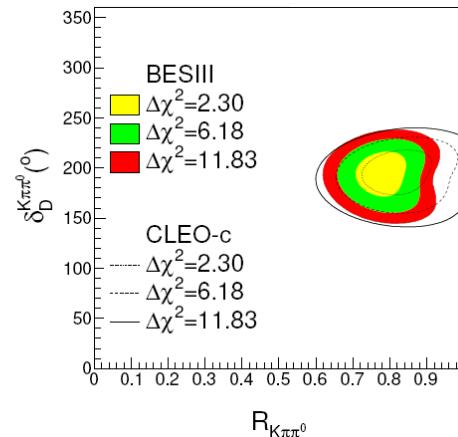
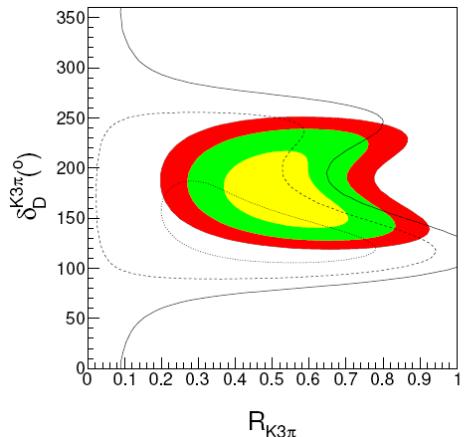
Constraint on  $\gamma$  measurement



PRD106, 092004(2022)

Tag modes	$F_+^{4\pi}$
$CP$ eigenstates	$0.721 \pm 0.019 \pm 0.007$
$D \rightarrow \pi^+ \pi^- \pi^0$	$0.753 \pm 0.028 \pm 0.010$
$D \rightarrow K_{S,L}^0 \pi^+ \pi^-$	$0.754 \pm 0.031 \pm 0.009$
Combination	$0.735 \pm 0.015 \pm 0.005$

$D \rightarrow K^- \pi^+ \pi^+ \pi^-$  and  $K^- \pi^+ \pi^0$



Analysis	Resonance	
$D_s^+ \rightarrow K^+ K^- \pi^+ \pi^- \pi^+$	$a_1(1260)^+$	JHEP07(2022)051
$D_s^+ \rightarrow K_S^0 K_S^0 \pi^+$	$a_0(1710)^0, f_0(1710)$	PRD105(2022) L051103
$D_s^+ \rightarrow K_S^0 K^+ \pi^0$	$a_0(1817)^+$	<u>PRL129, 182001 (2022)</u>
$D_s^+ \rightarrow K^+ \pi^+ \pi^-$	$f_0(500), f_0(980), f_0(1370)$	JHEP08(2022)196
$D_s^+ \rightarrow \pi^+ \pi^0 \pi^0$	$f_0(980), f_0(1370), f_2(1270)$	JHEP01(2022)052

Charge conjugate channels are included.

- Amplitude analysis,  $N_{\text{tot}} = 1050$  with a signal purity of  $(94.7 \pm 0.7)\%$
- Observed  $a_0(1817)^+(\rightarrow K_S^0 K^+)$ : isovector partner of  $f_0(1710)$ ?

$$M = (1.817 \pm 0.008_{\text{stat.}} \pm 0.020_{\text{syst.}}) \text{GeV}/c^2$$

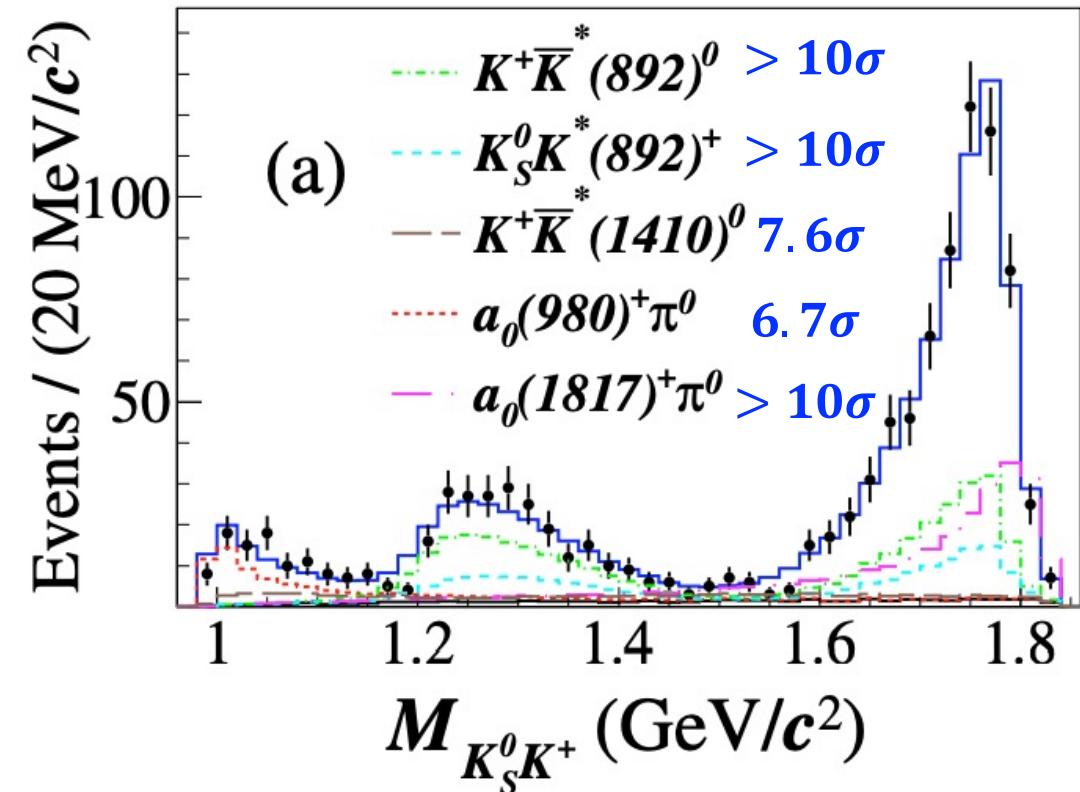
$$\Gamma = (0.097 \pm 0.022_{\text{stat.}} \pm 0.015_{\text{syst.}}) \text{GeV}$$

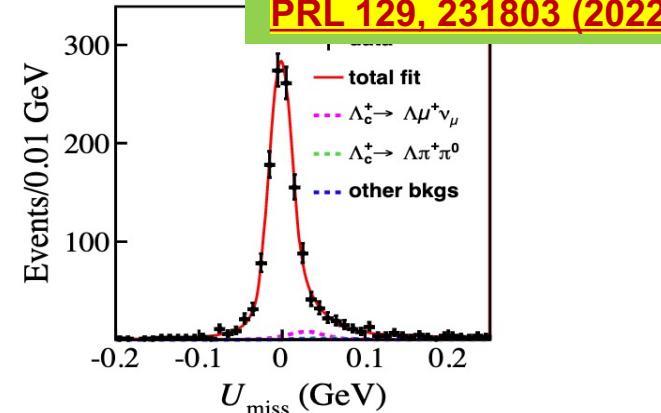
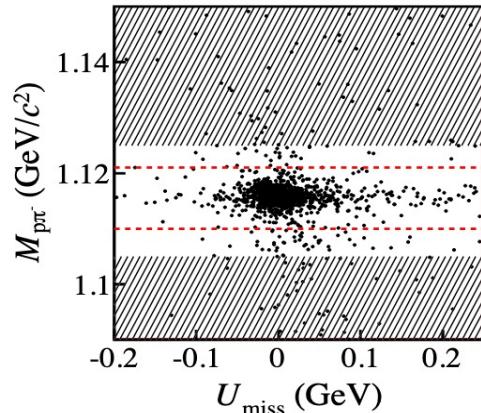
- The measured ratio for  $a_0(980)^+$ :

$$\frac{B[a_0(980)^+ \rightarrow \bar{K}^0 K^+]}{B[a_0(980)^+ \rightarrow \pi^+ \eta]} = (13.7 \pm 3.6_{\text{stat.}} \pm 4.2_{\text{syst.}})\%$$

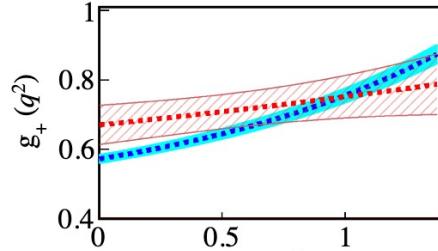
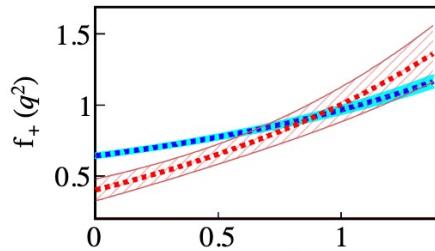
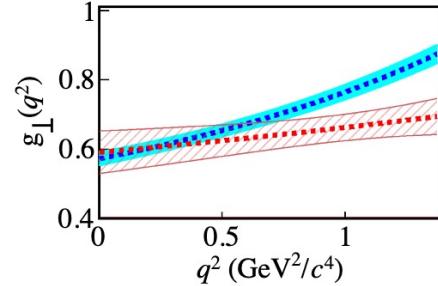
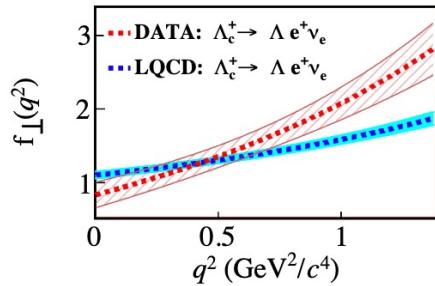
A key experimental input for the calculation of the coupling constants of the  $a_0(980)$ , and helps to determine its quark composition

[PRL129, 182001 \(2022\)](#)

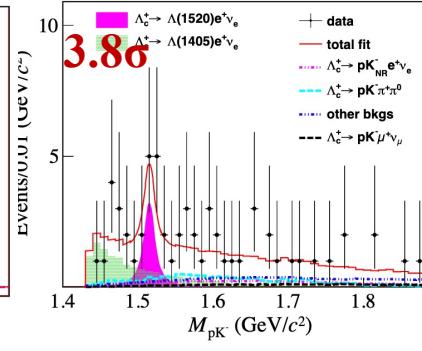
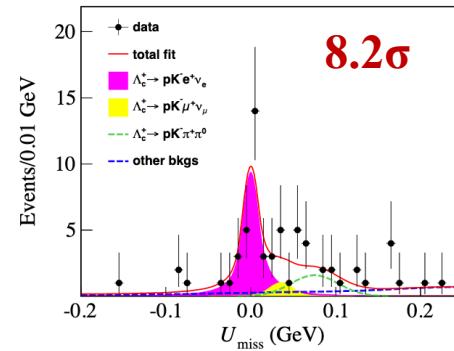


Determination of form factors of  $\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e$ 

$$B(\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e) = (3.56 \pm 0.11 \pm 0.07)\%$$



First direct comparisons on differential decay rates and form factors with LQCD

Observation of  $\Lambda_c^+ \rightarrow p K^- e^+ \nu$ 

$$B(\Lambda_c^+ \rightarrow p K^- e^+ \nu) = (0.88 \pm 0.17 \pm 0.07) \times 10^{-3}$$

$$B(\Lambda_c^+ \rightarrow \Lambda(1405)e^+ \nu) = (1.69 \pm 0.76 \pm 0.16) \times 10^{-3}$$

$$B(\Lambda_c^+ \rightarrow \Lambda(1520)e^+ \nu) = (0.99 \pm 0.51 \pm 0.10) \times 10^{-3}$$

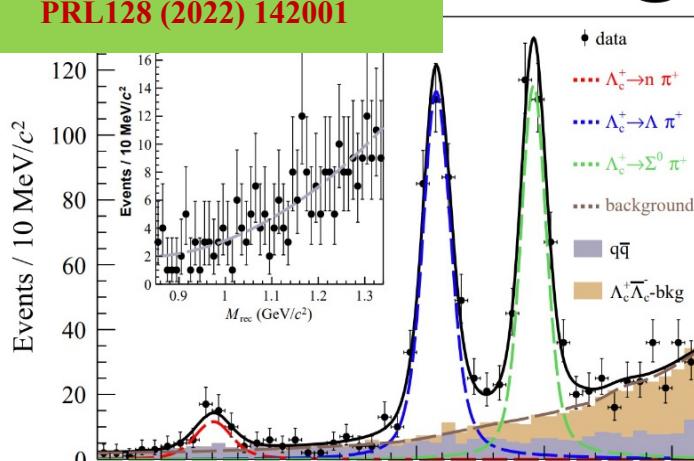
- Second leptonic decay of  $\Lambda_c^+$  is observed!
- Good channel to study  $\Lambda$  excited states, such as  $\Lambda(1405)$ ,  $\Lambda(1520)$

# Recent results on $\Lambda_c^+$ hadronic decays

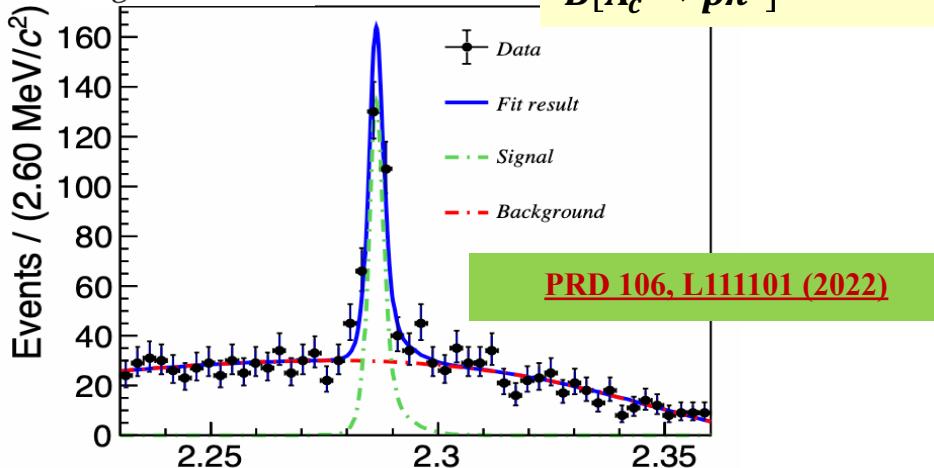


Observation of  $\Lambda_c^+ \rightarrow n\pi^+$

PRL128 (2022) 142001

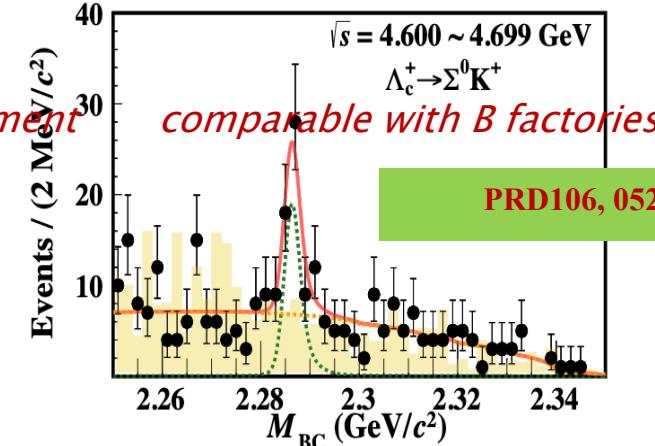
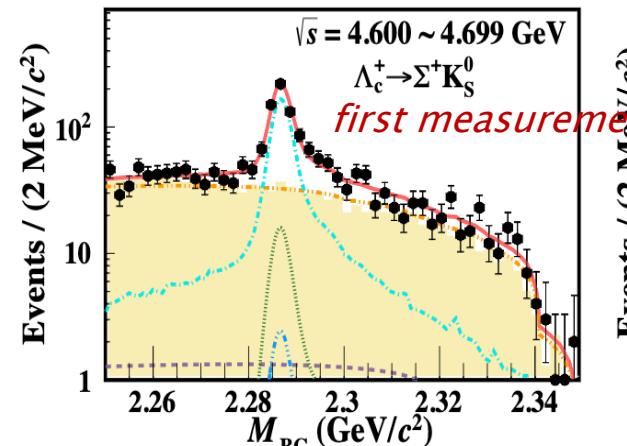


$$\frac{B[\Lambda_c^+ \rightarrow n\pi^+]}{B[\Lambda_c^+ \rightarrow p\pi^0]} > 7.2$$



Many CS modes are explored.

Determination of the BF for  $\Lambda_c^+ \rightarrow \Sigma^+ K_S$  and  $\Sigma^0 K^+$

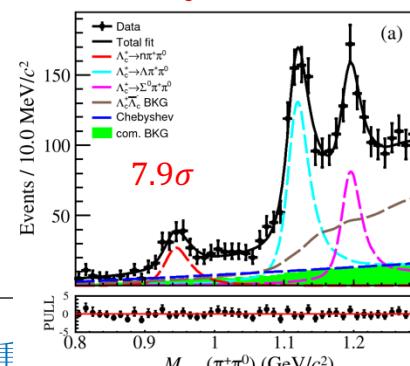


PRD106, 052003 (2022)

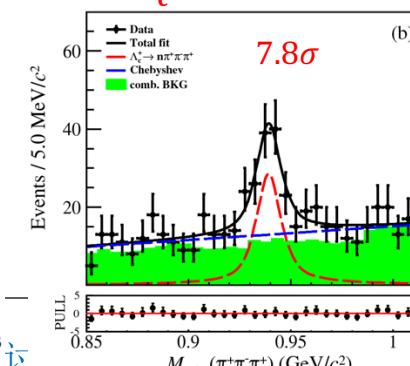
Arxiv:2304.09405

Decay mode	RBF (This work)	RBF (Belle)	BF (This work)	BF (PDG)
$\Sigma^+ K^+ K^-$	$8.38 \pm 0.93 \pm 0.41$	$7.6 \pm 0.7 \pm 0.9$	$0.377 \pm 0.042 \pm 0.018 \pm 0.021$	$0.35 \pm 0.04$
$\Sigma^+ K^+ \pi^-$	$4.44 \pm 0.52 \pm 0.23$	$4.7 \pm 1.1 \pm 0.8$	$0.200 \pm 0.023 \pm 0.010 \pm 0.011$	$0.21 \pm 0.06$
$\Sigma^+ K^+ \pi^- \pi^0$	$< 2.4$	-	$< 0.11$	-
$\Sigma^+ \phi$	$9.2 \pm 1.8 \pm 0.6$	$8.5 \pm 1.2 \pm 1.2$	$0.414 \pm 0.080 \pm 0.029 \pm 0.023$	$0.39 \pm 0.06$
$\Sigma^+ K^+ K^-$ (non- $\phi$ )	$4.38 \pm 0.79 \pm 0.19$	-	$0.197 \pm 0.036 \pm 0.008 \pm 0.011$	-

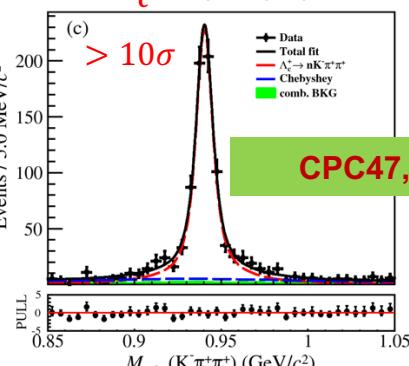
$\Lambda_c^+ \rightarrow n\pi^+\pi^0$



$\Lambda_c^+ \rightarrow n\pi^+\pi^-\pi^+$

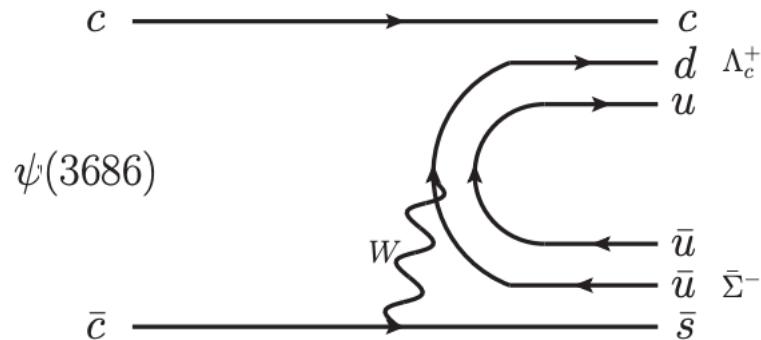


$\Lambda_c^+ \rightarrow nK^-\pi^+\pi^+\pi^+$



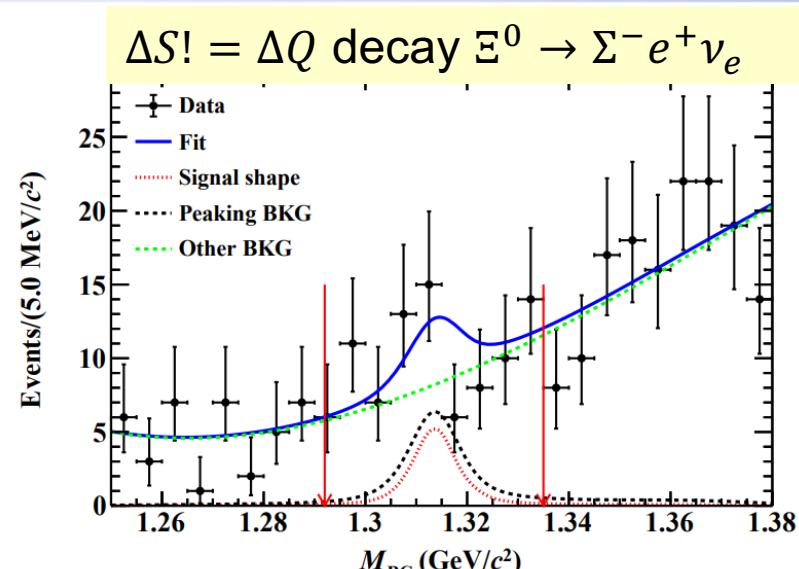
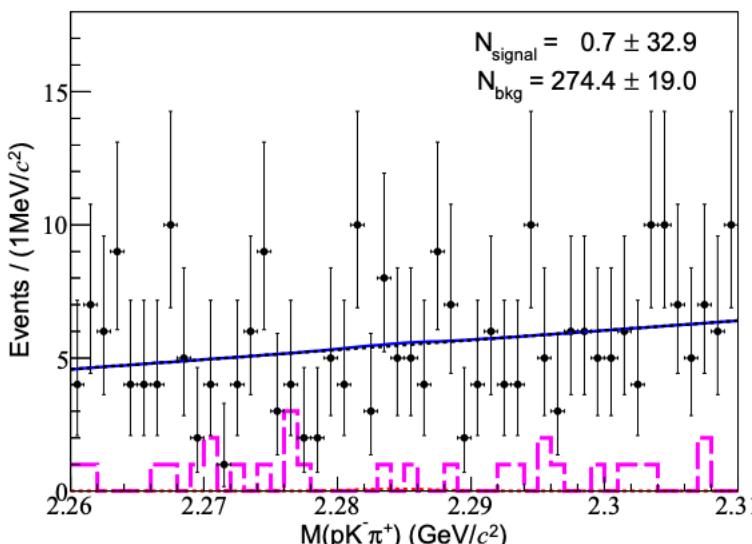
CPC47, 023001(2023)

# Search for rare decays



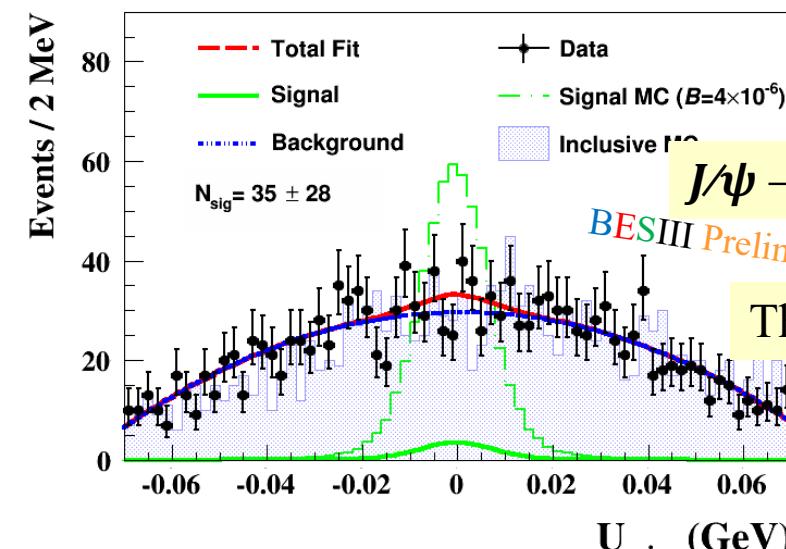
$$B(\psi(3686) \rightarrow \Lambda_c^+ \text{ anti-}\Sigma^-) < 1.4 \times 10^{-5} .$$

Chin. Phys. C 47, 013002 (2022)



Phys. Rev. D 107, 012002 (2023)

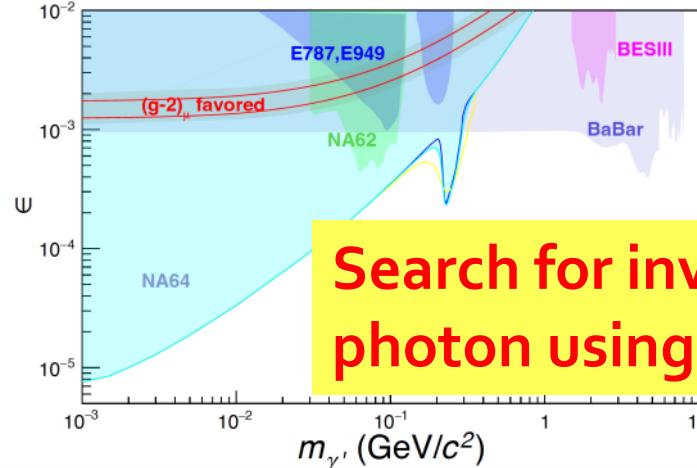
$BF < 1.6 \times 10^{-4}$  @ 90% C. L.  
One order of magnitude improvement over PDG



The 1<sup>st</sup> search for semi-muonic decay

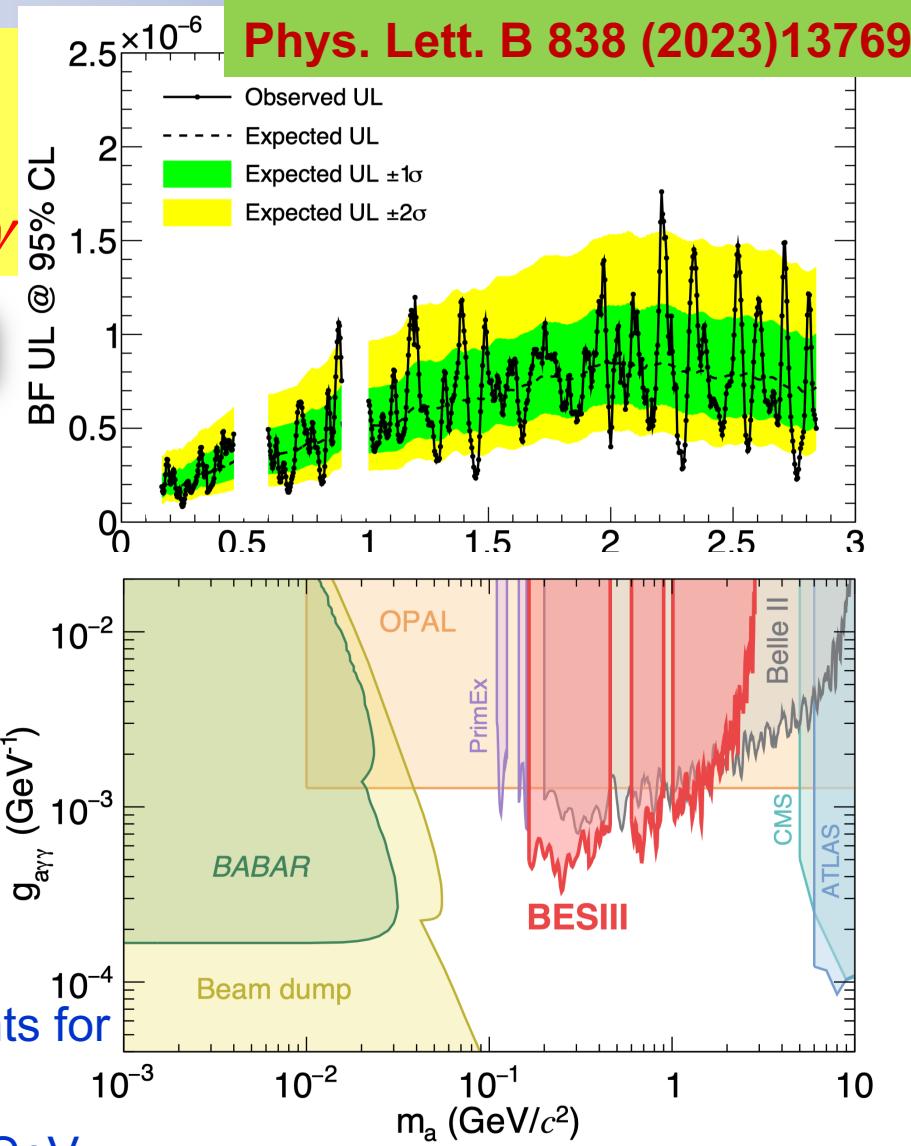
# BSM particle searches

Phys. Lett. B 839 (2023) 137785



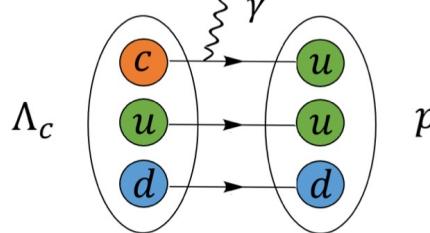
Search for a ALP in  
 $\psi(2s) \rightarrow J/\psi\pi\pi$   
 $J/\psi \rightarrow \gamma a, \quad a \rightarrow \gamma\gamma$

2.7 billion  $\psi(2S)$  events



## ■ Search for massless dark photon in $\Lambda_c$ decay

$$\mathcal{B}(\Lambda_c^+ \rightarrow p\gamma') < 8.0 \times 10^{-5} \text{ @ 90\% C.L.}$$



- Most stringent constraints for  $0.165 \leq m_a \leq 1.468 \text{ GeV}$
- $g_{a\gamma\gamma} > 3 \times 10^{-4}$  at  $0.25 \text{ GeV}$

Phys. Rev. D 106, 072008 (2022)

Table 7.1: List of data samples collected by BESIII/BEPCII up to 2019, and the proposed samples for the remainder of the physics program. The most right column shows the number of required data taking days in current ( $T_C$ ) or upgraded ( $T_U$ ) machine. The machine upgrades include top-up implementation and beam current increase.

Energy	Physics motivations	Current data	Expected final data	$T_C / T_U$
1.8 - 2.0 GeV	$R$ values Nucleon cross-sections	N/A	$0.1 \text{ fb}^{-1}$ (fine scan)	60/50 days
2.0 - 3.1 GeV	$R$ values Cross-sections	Fine scan (20 energy points)	Complete scan (additional points)	250/180 days
✓ $J/\psi$ peak	Light hadron & Glueball $J/\psi$ decays	$3.2 \text{ fb}^{-1}$ (10 billion)	$3.2 \text{ fb}^{-1}$ (10 billion)	N/A
✓ $\psi(3686)$ peak	Light hadron & Glueball Charmonium decays	$0.67 \text{ fb}^{-1}$ (0.45 billion)	$4.5 \text{ fb}^{-1}$ (3.0 billion)	150/90 days
✓ $\psi(3770)$ peak	$D^0/D^\pm$ decays	$2.9 \text{ fb}^{-1}$	$20.0 \text{ fb}^{-1}$	610/360 days
3.8 - 4.6 GeV	$R$ values $XYZ$ /Open charm	Fine scan (105 energy points)	No requirement	N/A
4.180 GeV	$D_s$ decay $XYZ$ /Open charm	$3.2 \text{ fb}^{-1}$	$6 \text{ fb}^{-1}$	140/50 days
4.0 - 4.6 GeV	$XYZ$ /Open charm Higher charmonia cross-sections	$16.0 \text{ fb}^{-1}$ at different $\sqrt{s}$	$30 \text{ fb}^{-1}$ at different $\sqrt{s}$	770/310 days
4.6 - 4.9 GeV	Charmed baryon/ $XYZ$ cross-sections	$0.56 \text{ fb}^{-1}$ at 4.6 GeV	$15 \text{ fb}^{-1}$ at different $\sqrt{s}$	1490/600 days
4.74 GeV	$\Sigma_c^+ \Lambda_c^-$ cross-section	N/A	$1.0 \text{ fb}^{-1}$	100/40 days
4.91 GeV	$\Sigma_c \bar{\Sigma}_c$ cross-section	N/A	$1.0 \text{ fb}^{-1}$	120/50 days
4.95 GeV	$\Xi_c$ decays	N/A	$1.0 \text{ fb}^{-1}$	130/50 days

Future Physics Programme of  
BESIII (white book)

Chin. Phys. C 44, 040001 (2020)  
arXiv:1912.05983

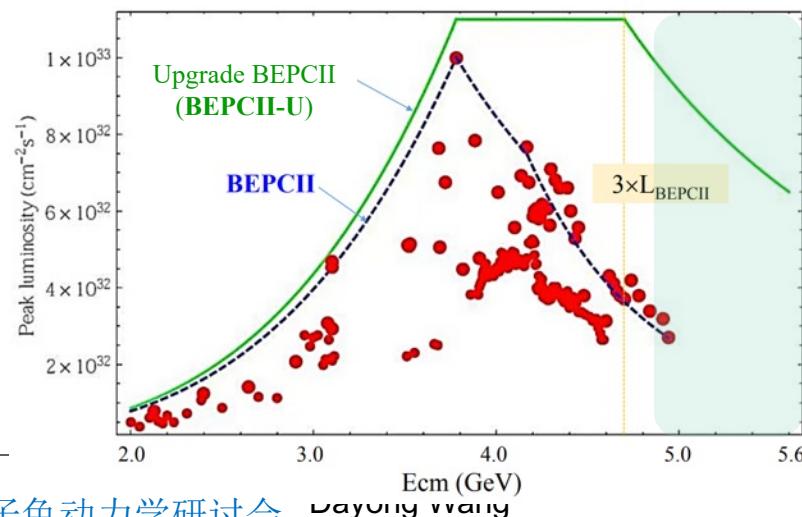
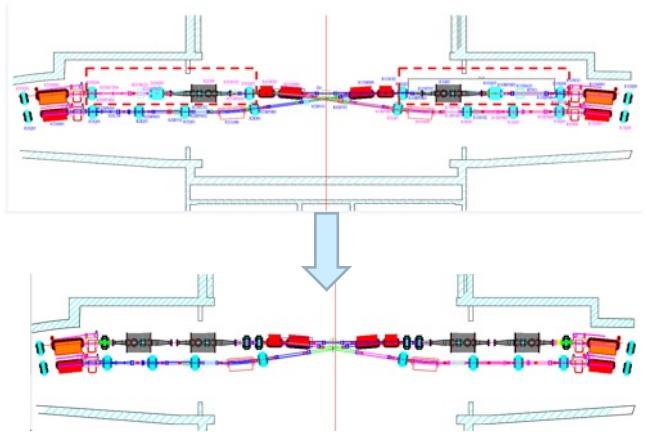
ongoing, finish in 2024

~55  $\text{fb}^{-1}$

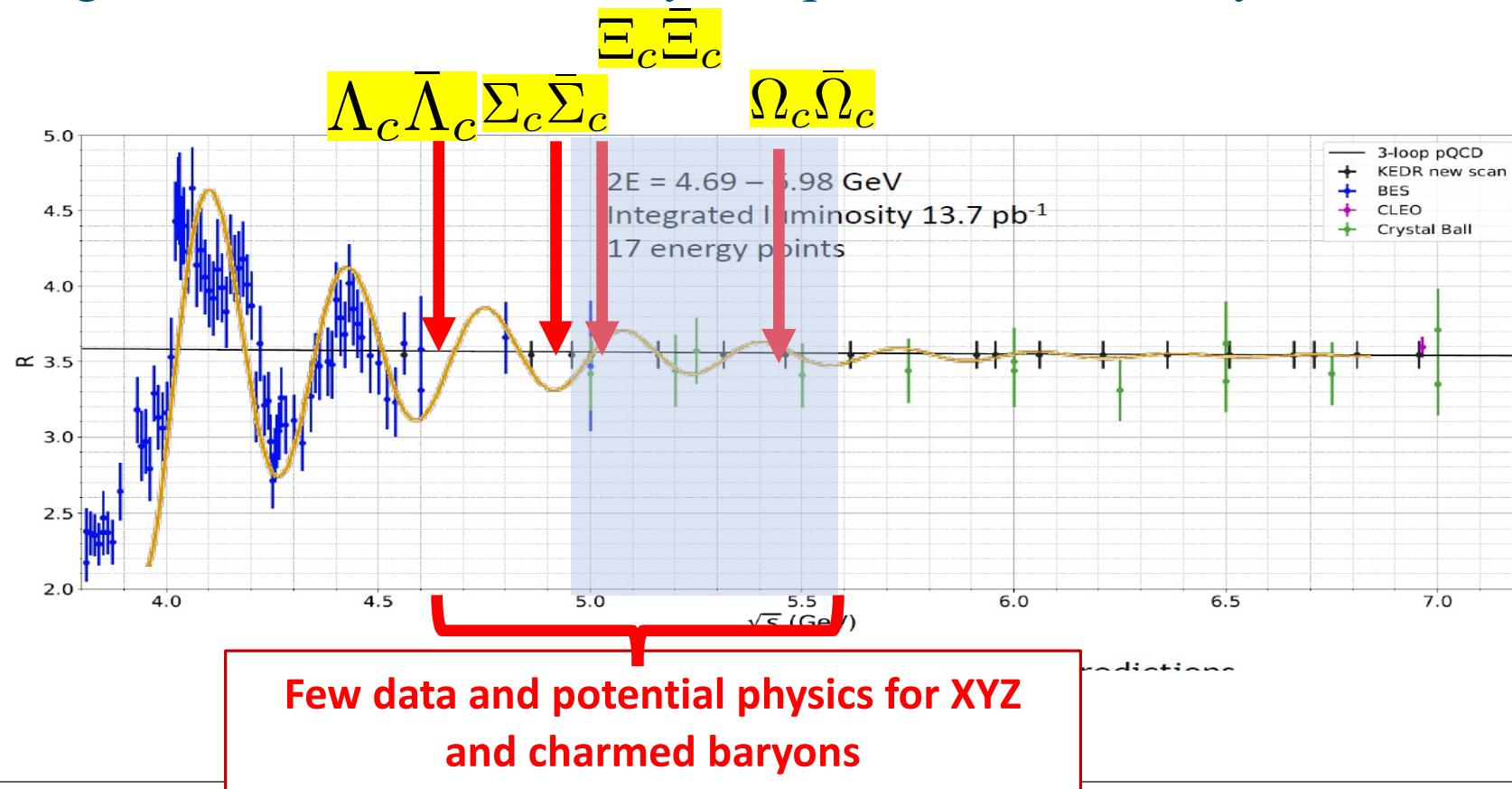
- ✓ An upgrade of BEPCII (**BEPCII-U**) has been approved in July 2021:  
**the optimized energy is 2.35 GeV with luminosity 3 times higher than current BEPCII and extend the maximum energy to 5.6 GeV**

- Add another cavity per beam to improve the RF power
- Change optics slightly, increase number of bunches
- Challenges: high beam intensities, backgrounds and aging effect in the detector
- Small risk: can continue running with better performance than BEPCII
- Timescale: 2.5 years construction + 0.5 year installation
- Installation: July – December 2024 and the upgraded machine ready

in Jan. 2025



- ✓ Detailed studies of the known  $Z_c(s)$  states and search for more exotic states in the higher energy region within a considerable amount of data sets.
- ✓ Cover all the ground-state charmed baryons: production & decays, CPV search



- **BESIII is operating with good performance of the machine and the detector**
  - collect large data samples in the energy range 2.0~5.6 GeV
- **BESIII has performed wide range of physics studies**
  - ◆ Light hadron spectroscopy and decays
  - ◆ Charmonia transitions and XYZ
  - ◆ R value and QCD studies
  - ◆ Charmed meson and charmed baryon
  - ◆ Rare decays and new physics search
- **BESIII has great potential with unique datasets and analysis techniques. Operation for another 5-10 years foreseen**
  - BEPCII-U: 3x upgrade on luminosity, with energy to 5.6GeV
  - ...More to come!

粲介子半轻衰变到轻标介子 张书磊  
BESIII粲强子衰变研究 许威  
R值与QCD实验研究 周小蓉